

Test of lepton flavour universality using $B^0 \rightarrow D^{*-} e^+ \nu_e$ and $B^0 \rightarrow D^{*-} \tau^+ \nu_\tau$ decays in LHCb

Ching-Hua LI

Jury members

Francesco POLCI
LPNHE, CNRS, Paris

Rapporteur

Jérôme BAUDOT
IPHC, Université de Strasbourg

Rapporteur

Simon AKAR
LPCA, Université Clermont Auvergne

Examineur

Éric KAJFASZ
CPPM, CNRS, Marseille

Président du jury

Supervisors

Olivier LEROY
CPPM, CNRS, Marseille

Directeur de thèse

Dorothea VOM BRUCH
CPPM, CNRS, Marseille

Co-directrice de thèse

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Outline

Introduction

- Theoretical framework
- LHCb detector in Run 3

Test of lepton flavour universality using $B^0 \rightarrow D^{*-} e^+ \nu_e$ and $B^0 \rightarrow D^{*-} \tau^+ \nu_\tau$ decays

- Methodology
- Background suppression
- $R(D^*)_{\tau/e}$ extraction
- Conclusions

Secondary Vertex Reconstruction in LHCb

- Vertex reconstruction in HLT1 & HLT2
- Comparison study
- Conclusions

Prospects

Introduction

The Standard Model of particle physics

The Standard Model (SM) describes

All known particles

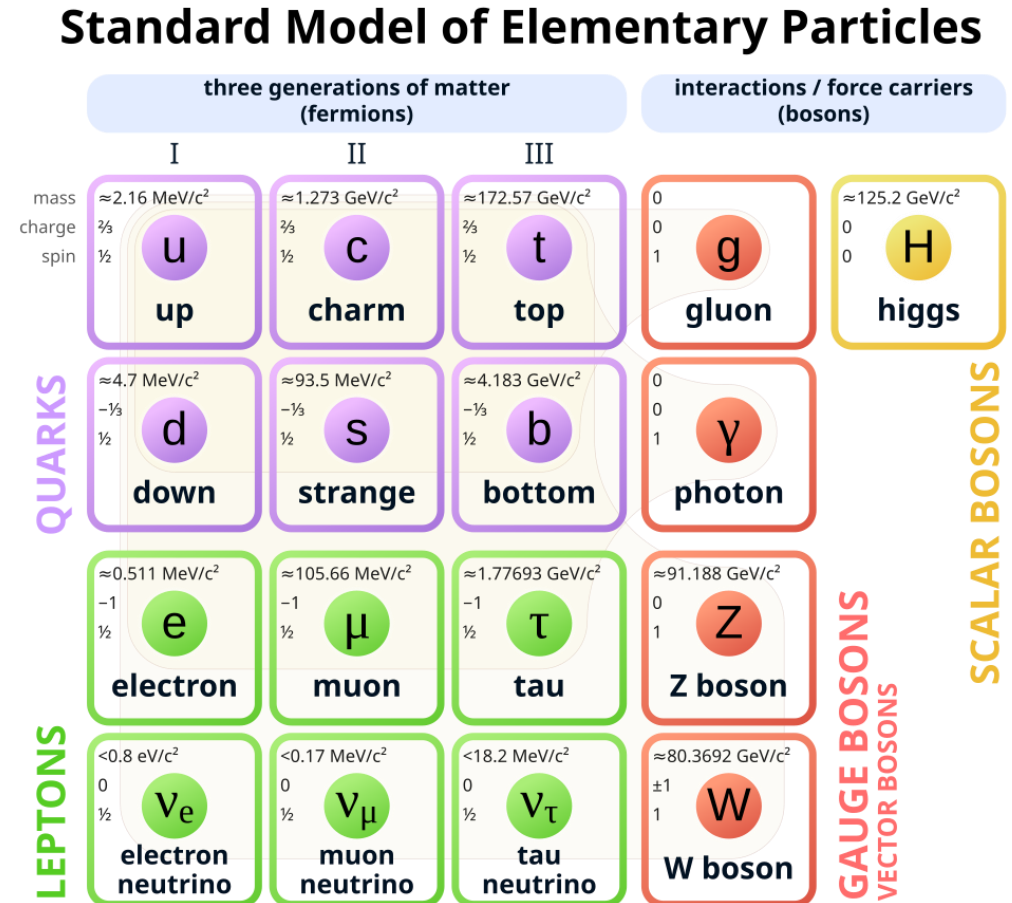
- 12 fermions form all visible matter

Three fundamental forces

- Mediated by gluons (strong), photon (EM) and W/Z bosons (weak)

Mass of elementary particles

- Given by Higgs boson through Higgs mechanism



The Standard Model of particle physics

The SM couldn't describe

Dark matter

- No viable particle candidate

Matter & anti-matter asymmetry

- Known CP violation mechanism is not sufficient

Mass of neutrino

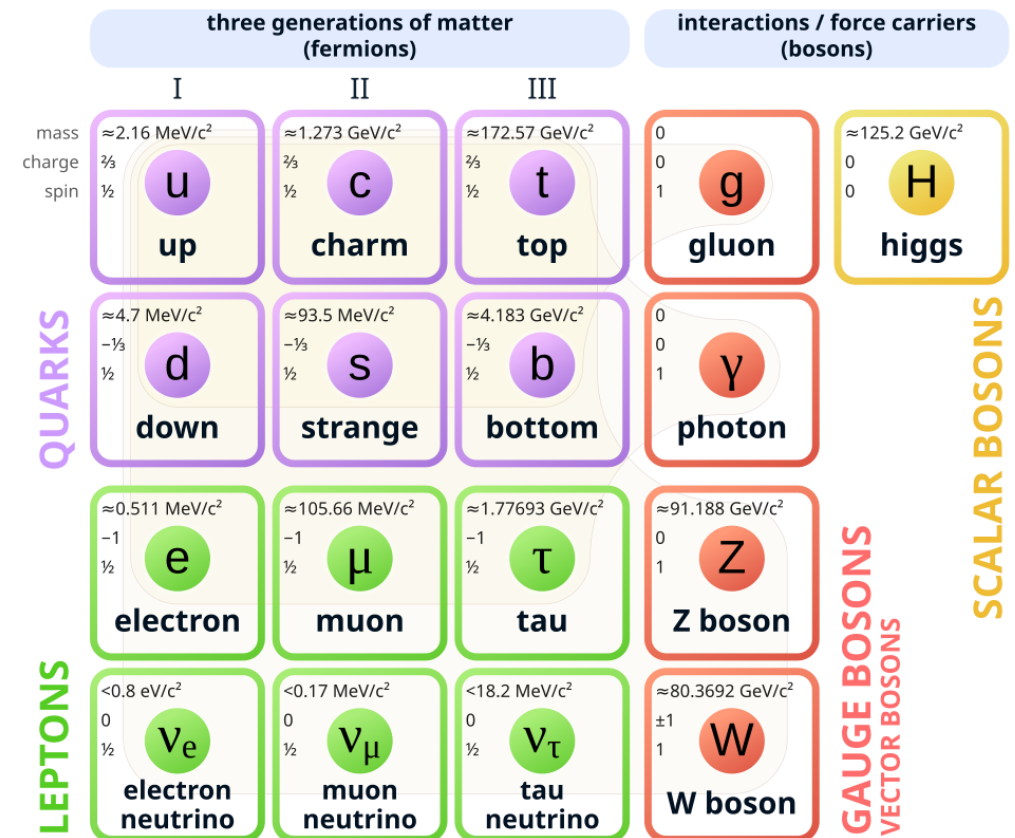
- Not accommodated in the SM

Gravitational force

- Different scales (micro vs macro)

And more ...

Standard Model of Elementary Particles



Lepton Flavour Universality (LFU) in the SM

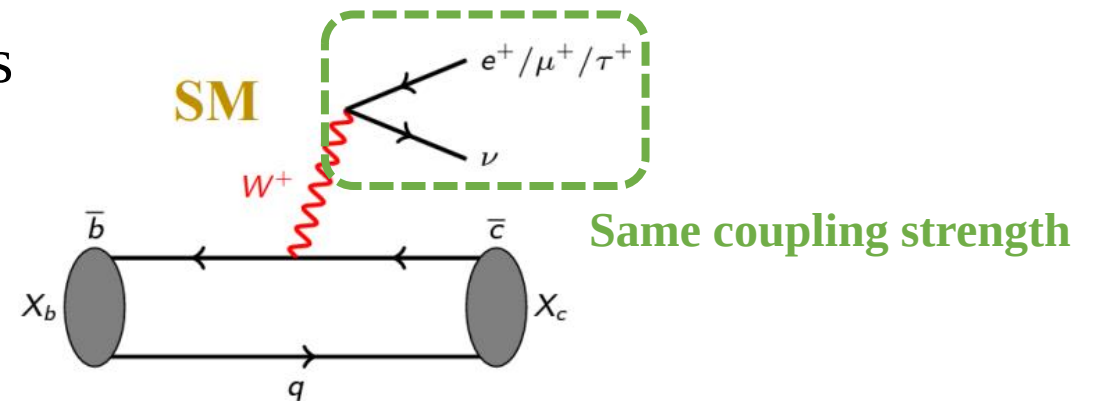
What is LFU ?

All three leptons have the same representation in $SU(2)_L$

$$L_e = \begin{pmatrix} \nu_e \\ e \end{pmatrix}_L, \quad L_\mu = \begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix}_L, \quad L_\tau = \begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix}_L$$

with the same quantum number

→ **Equal electroweak coupling** to all charged leptons



Validate LFU

How do people test LFU ?

LFU can be tested by measuring the ratio of decay rates with different leptonic final states,

e.g. measuring $R(H_c) = \frac{\mathcal{B}(H_b \rightarrow H_c \ell \nu)}{\mathcal{B}(H_b \rightarrow H_c \ell' \nu)}$, $H_{b(c)}$ is a meson or baryon containing a b or c quark
 ℓ and ℓ' denote leptons of different generations

Validate LFU

How do people test LFU ?

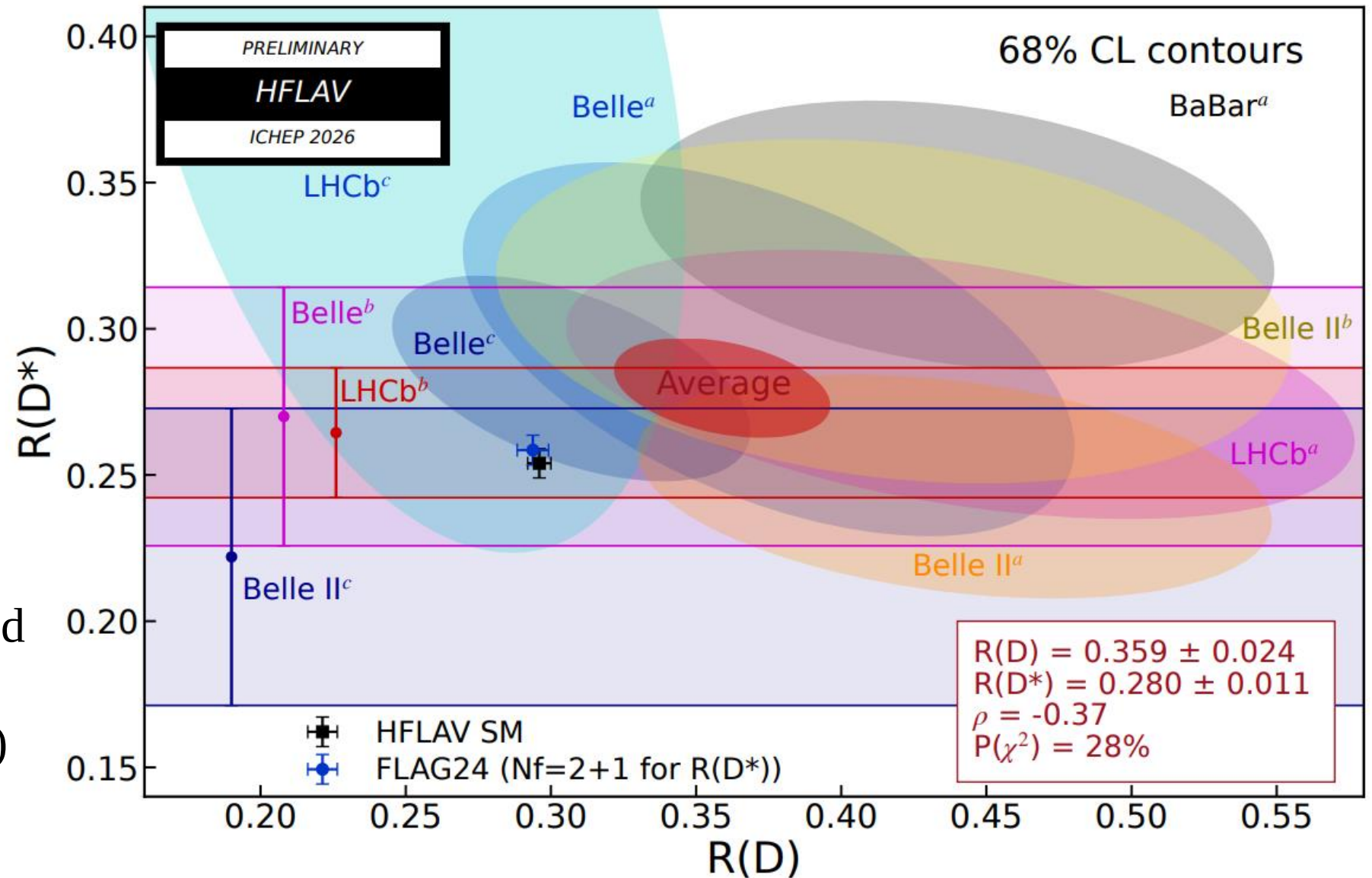
LFU can be tested by measuring the ratio of decay rates with different leptonic final states,

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 ℓ and ℓ' denote leptons of different generations

$$R(D^{(*)}) \equiv \frac{\mathcal{B}(B \rightarrow D^{(*)} \tau \nu_\tau)}{\mathcal{B}(B \rightarrow D^{(*)} \ell \nu_\ell)}, \ell = e, \mu$$

- Serves an excellent choice to test LFU (large statistics due to $b \rightarrow c$ transition)
- Several results are published by BaBar, Belle, Belle II and LHCb

$R(D^{(*)})$ measurements and predictions



3.7 σ tension in combined
 $R(D) - R(D^*)$ value

- 2.2 σ tension in $R(D^*)$
- 2.6 σ tension in $R(D)$

LFU Beyond the Standard Model

How can LFU be violated ?

Effective Field Theory (EFT): describes the low-energy effects of heavy New Physics (NP) without specifying the full underlying theory

In EFT framework, the $b \rightarrow c\ell\nu$ transition can be described by

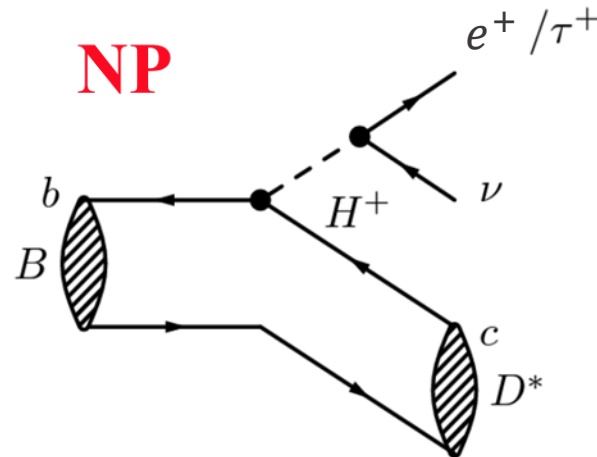
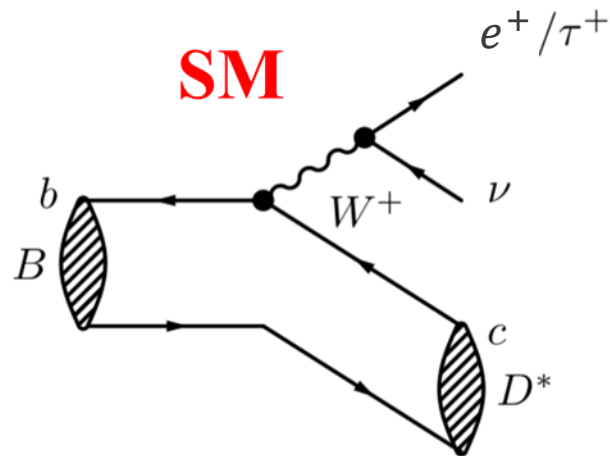
$$\mathcal{H}_{\text{eff}} = \mathcal{H}_{\text{SM}} + \sum_i C_i \mathcal{O}_i$$

- $\mathcal{O}_i$: Effective operator
- C_i : Wilson coefficient encoding possible NP contributions

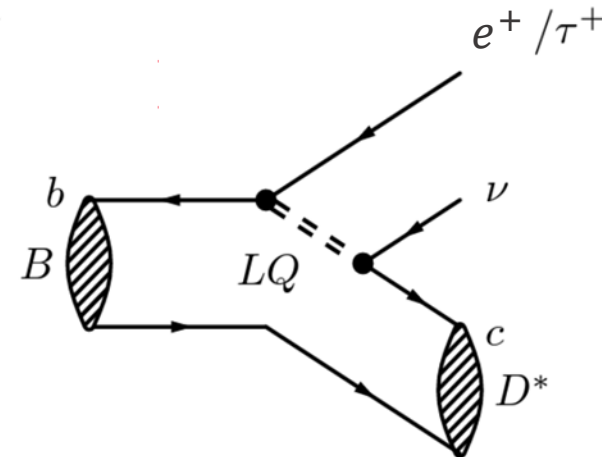
LFU Beyond the Standard Model

How can LFU be violated ?

NP contributions such as Leptoquarks or additional Higgs bosons can generate non-zero C_i



[PRD 85,094025 \(2012\)](#)



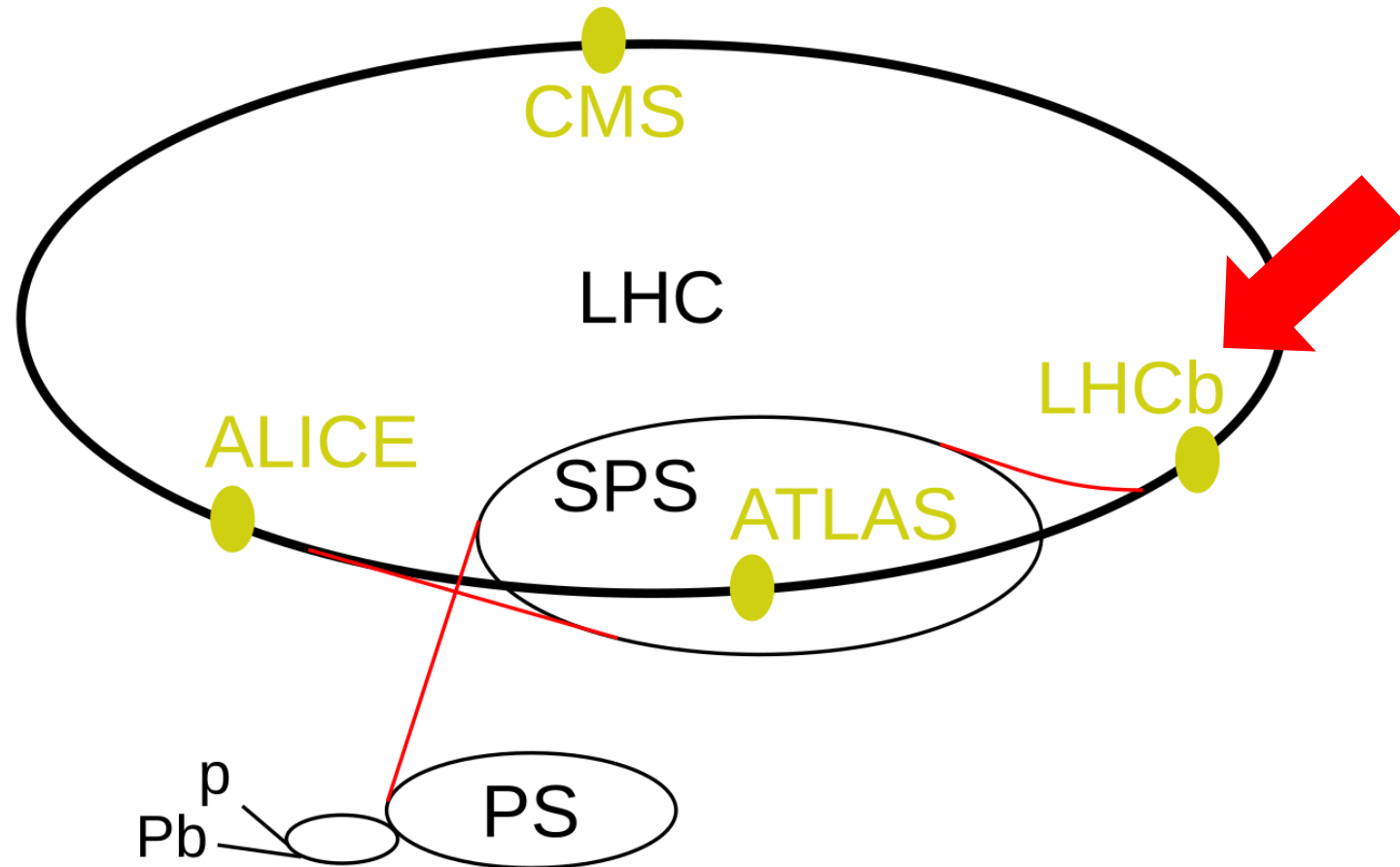
[PRD 110, 055023 \(2024\)](#)

With unequal strength to different lepton flavors

→ lepton flavor universality is violated

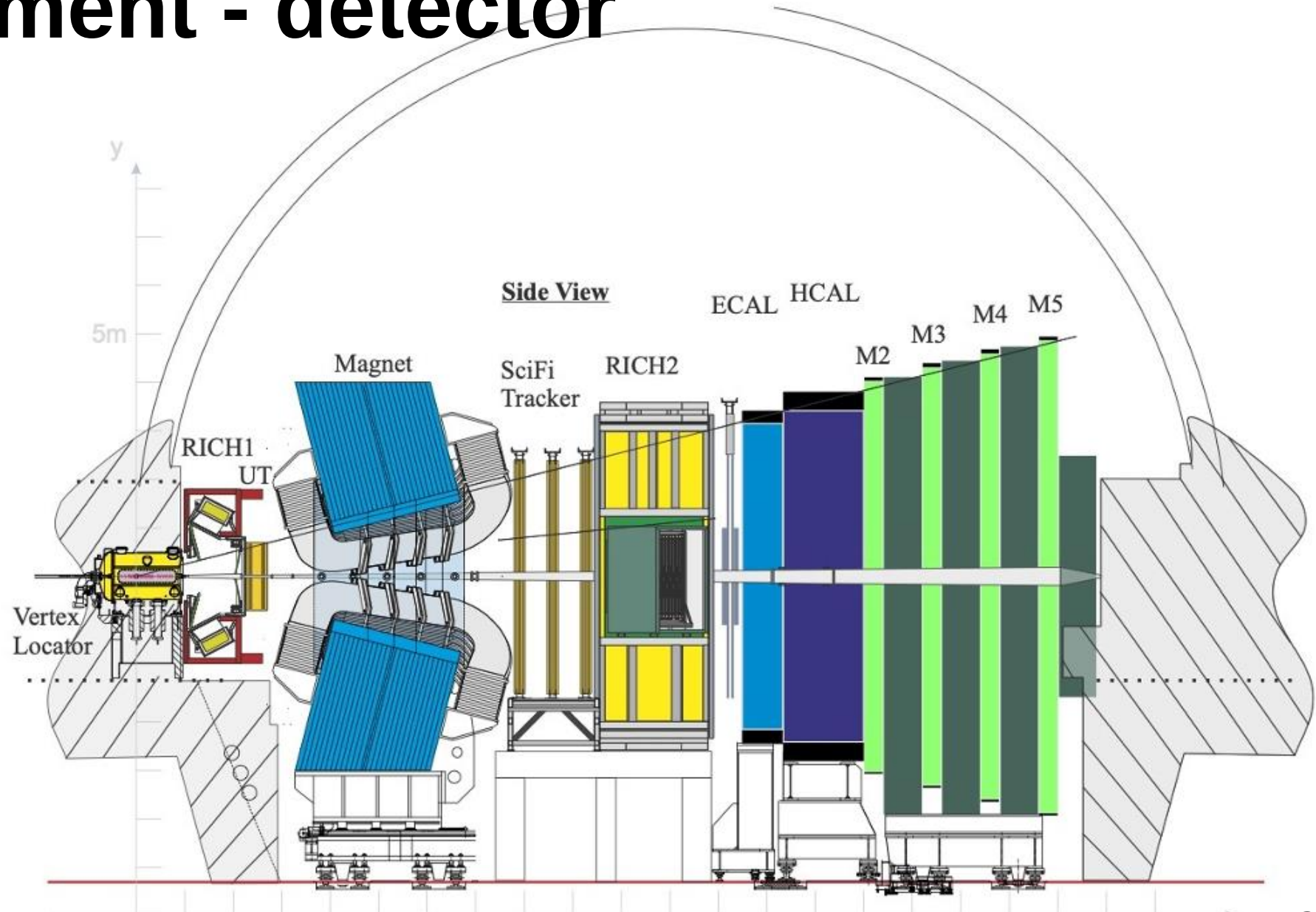
LHCb experiment

- One of the experiments in Large Hadron Collider (LHC)
- Collect the pp collision data at a center-of-mass of 13.6 TeV



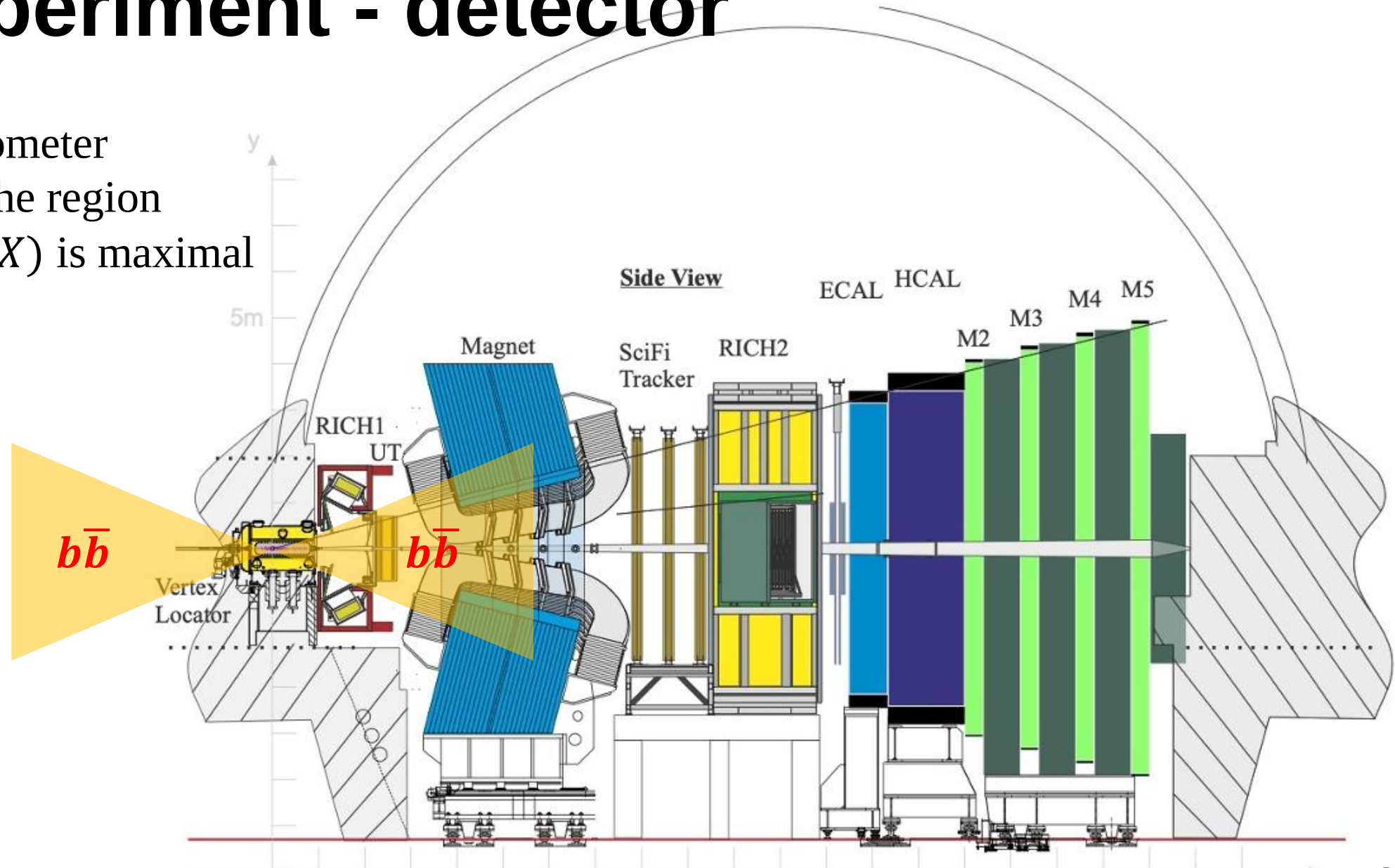
LHCb experiment - detector

Single-arm spectrometer

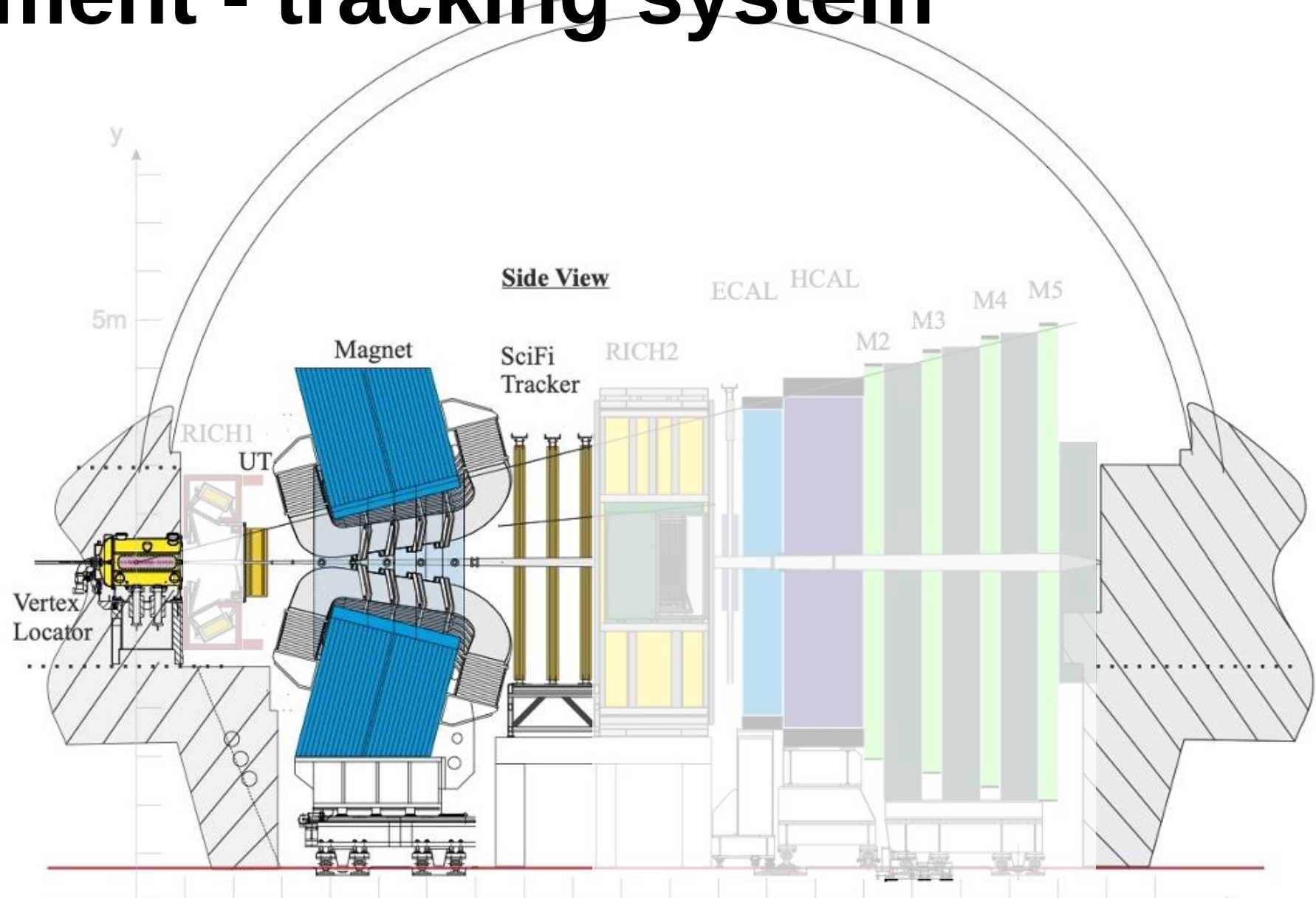


LHCb experiment - detector

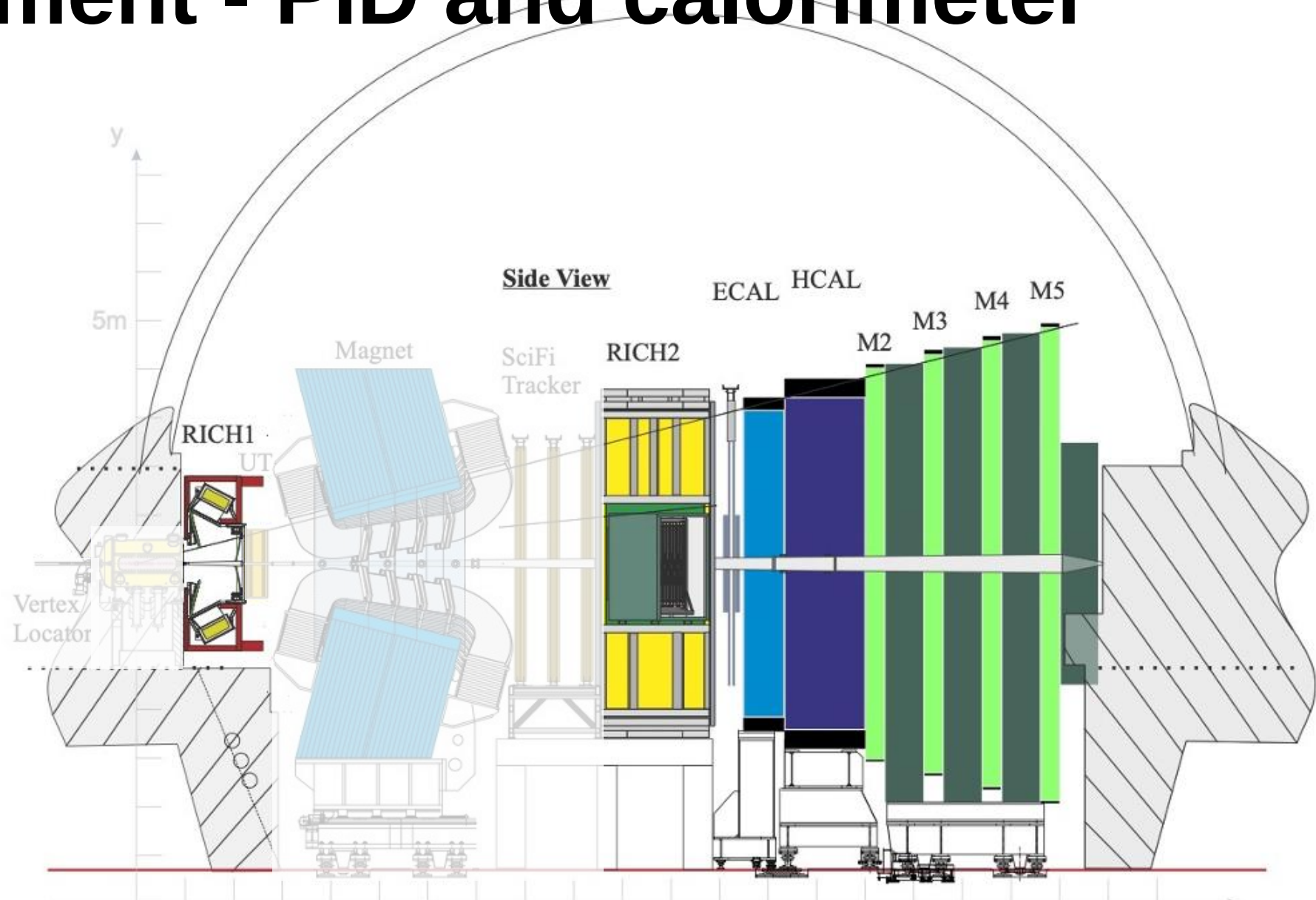
Single-arm spectrometer
covering most of the region
where $\sigma(pp \rightarrow b\bar{b}X)$ is maximal



LHCb experiment - tracking system

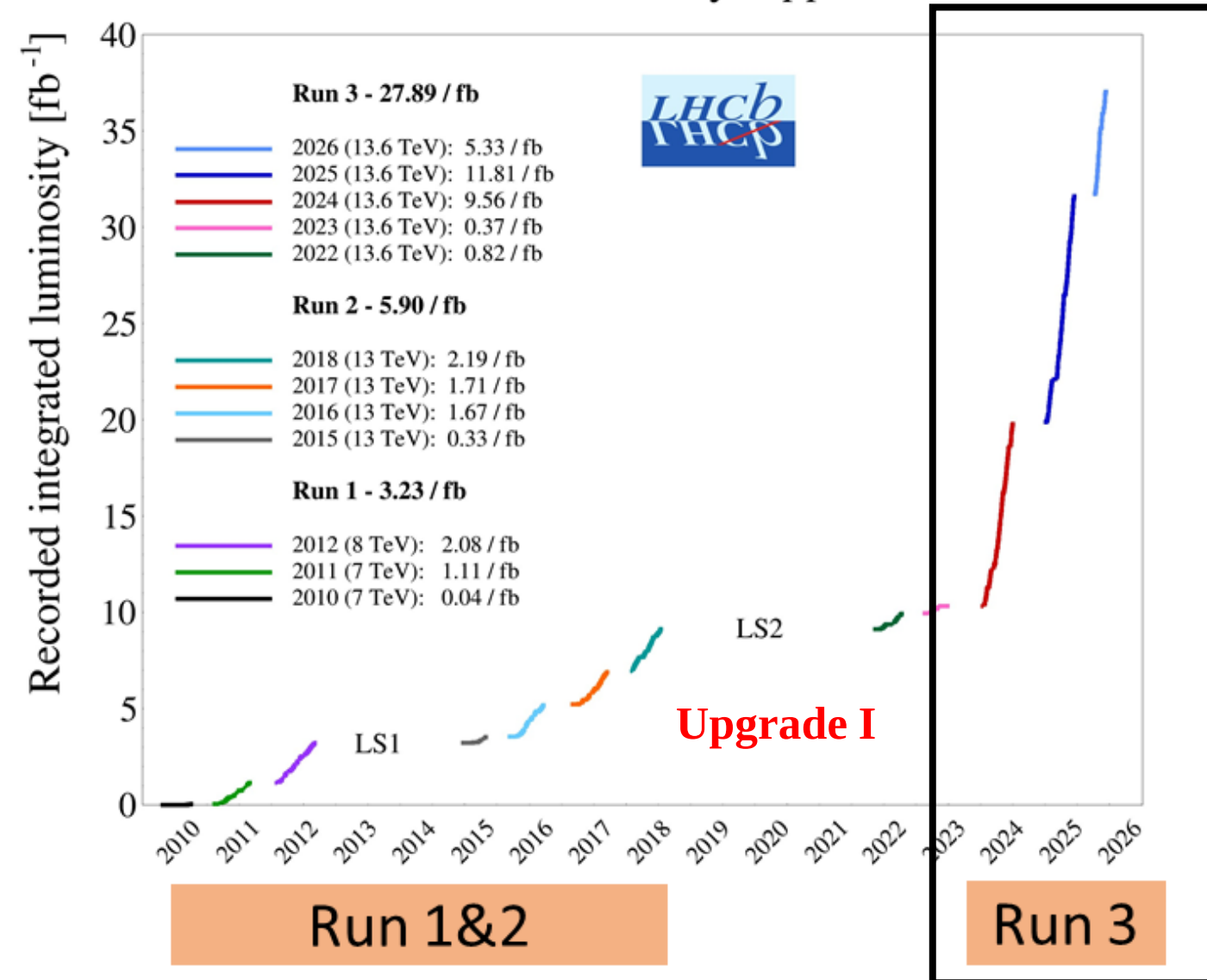


LHCb experiment - PID and calorimeter



LHCb experiment – integrated luminosity

Total recorded luminosity – pp – 37.0 fb^{-1}



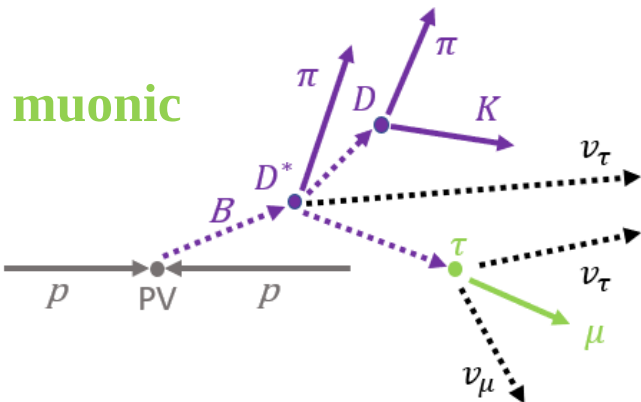
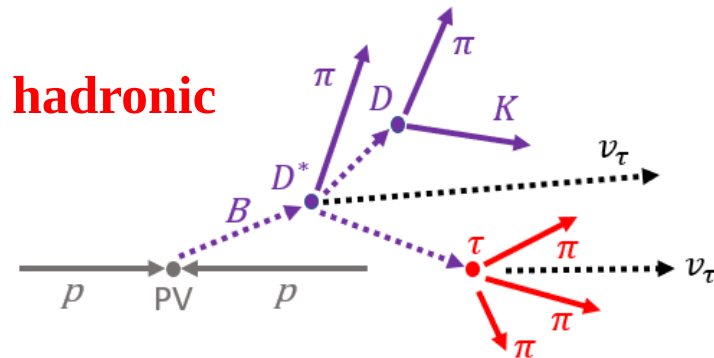
With five-fold increase in inst. luminosity

LHCb has collected **28 fb^{-1}** data
~ 3 times of data size in Run 1 & 2

**Test of lepton flavour universality
using $B^0 \rightarrow D^{*-} e^+ \nu_e$ and
 $B^0 \rightarrow D^{*-} \tau^+ \nu_\tau$ decays**

$R(D^*)$ - motivation

Currently, several $R(D^*)_{\tau/\mu}$ measurements using **hadronic** and **muonic** τ decays in LHCb are published



LHCb results

Muonic Run 1 (2023)

Hadronic Run 2 (2023)

Muonic Run 2 (2024)

Reference

[PhysRevLett.131.111802](#)

[PhysRevD.108.012018](#)

[PhysRevLett.134.061801](#)

$R(D^*)$ value

$0.281 \pm 0.018 \pm 0.024$

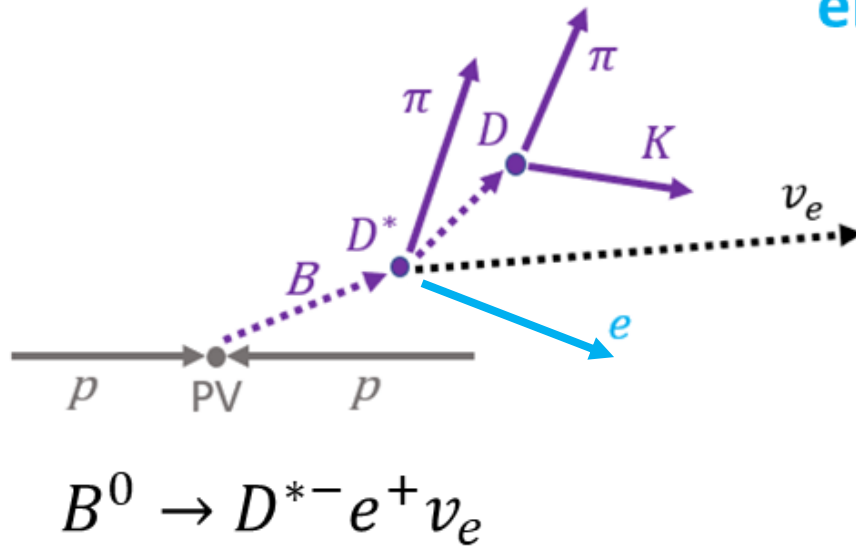
$0.260 \pm 0.015 \pm 0.016 \pm 0.012$

$0.402 \pm 0.081 \pm 0.085$

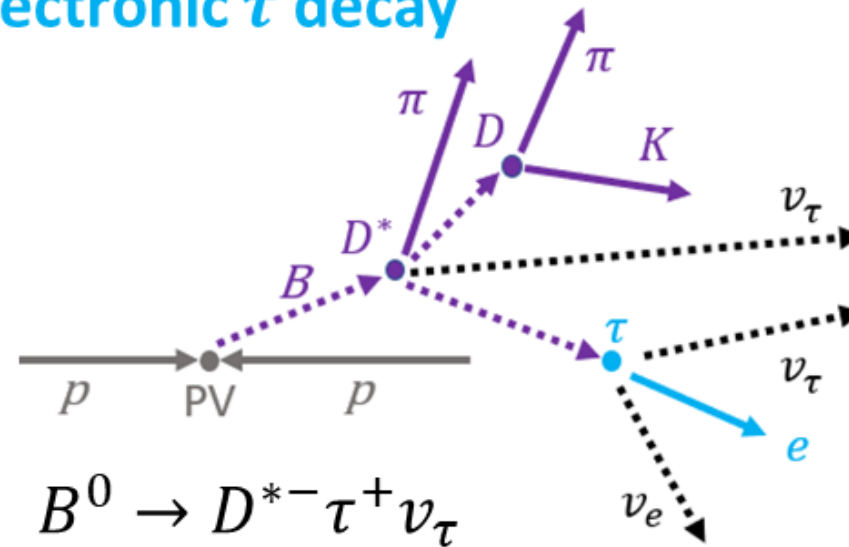
stat. syst. ext.

$R(D^*)$ - motivation

We test LFU by measuring the **electronic** modes



electronic τ decay

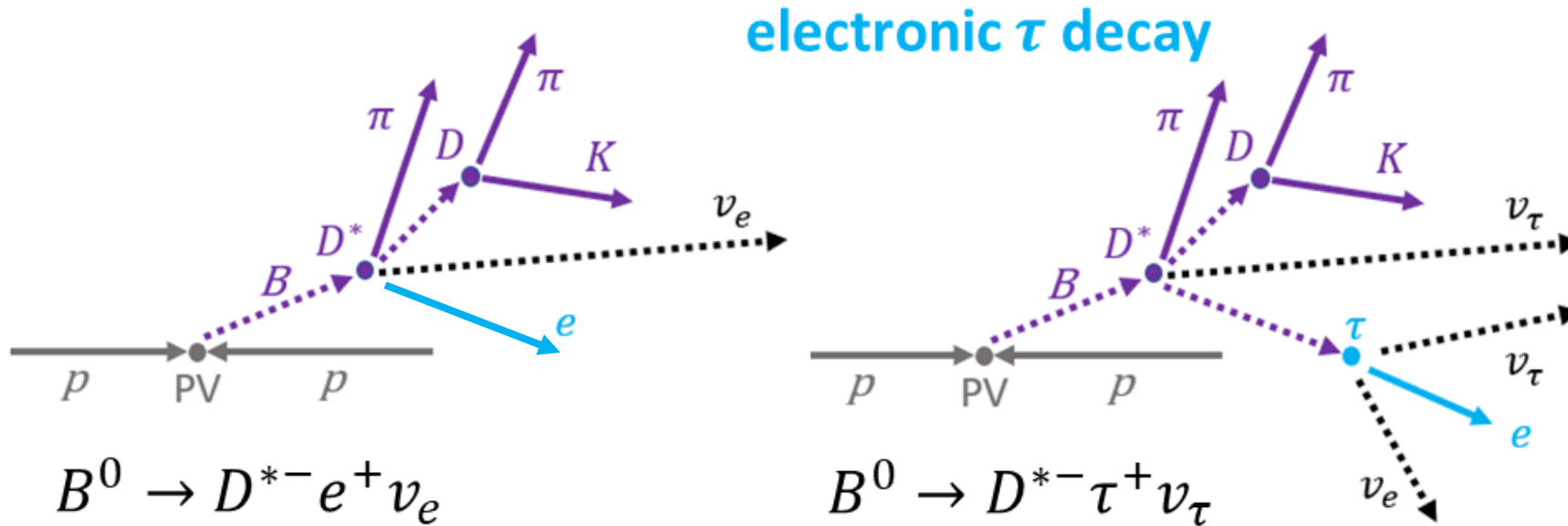


Both decays have the same visible final state

→ Measuring the ratio cancels many sources of systematic uncertainties

$R(D^*)$ - motivation

We test LFU by measuring the **electronic** modes



Both decays have the same visible final state

→ Measuring the ratio cancels many sources of systematic uncertainties

In Run 3, we have better trigger efficiency for low-momentum hadronic decays

→ It's the first time $\tau - e$ universality is being tested at LHCb !

Methodology

$R(D^*)_{\tau/e}$ determination

$$R(D^*)_{\tau/e} \equiv \frac{BR(B^0 \rightarrow D^{*-} \tau^+ \nu_\tau)}{BR(B^0 \rightarrow D^{*-} e^+ \nu_e)} \quad , \text{where } \tau^+ \rightarrow e^+ \nu_e \bar{\nu}_\tau$$

$$= \frac{N(B^0 \rightarrow D^{*-} \tau^+ \nu_\tau)}{N(B^0 \rightarrow D^{*-} e^+ \nu_e)} \times \frac{\epsilon(B^0 \rightarrow D^{*-} e^+ \nu_e)}{\epsilon(B^0 \rightarrow D^{*-} \tau^+ \nu_\tau)}$$

$R(D^*)_{\tau/e}$ determination

$$R(D^*)_{\tau/e} \equiv \frac{BR(B^0 \rightarrow D^{*-} \tau^+ \nu_\tau)}{BR(B^0 \rightarrow D^{*-} e^+ \nu_e)}, \text{ where } \tau^+ \rightarrow e^+ \nu_e \bar{\nu}_\tau$$

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$R(D^*)_{\tau/e}$ determination

$$R(D^*)_{\tau/e} \equiv \frac{BR(B^0 \rightarrow D^{*-} \tau^+ \nu_\tau)}{BR(B^0 \rightarrow D^{*-} e^+ \nu_e)}, \text{ where } \tau^+ \rightarrow e^+ \nu_e \bar{\nu}_\tau$$

$$= \left[\frac{N(B^0 \rightarrow D^{*-} \tau^+ \nu_\tau)}{N(B^0 \rightarrow D^{*-} e^+ \nu_e)} \right] \times \left[\frac{\epsilon(B^0 \rightarrow D^{*-} e^+ \nu_e)}{\epsilon(B^0 \rightarrow D^{*-} \tau^+ \nu_\tau)} \right]$$

Extracted from simulated samples

Extracted from a fit

$R(D^*)_{\tau/e}$ determination

$$R(D^*)_{\tau/e} \equiv \frac{BR(B^0 \rightarrow D^{*-} \tau^+ \nu_\tau)}{BR(B^0 \rightarrow D^{*-} e^+ \nu_e)}, \text{ where } \tau^+ \rightarrow e^+ \nu_e \bar{\nu}_\tau$$

$$= \underbrace{\frac{N(B^0 \rightarrow D^{*-} \tau^+ \nu_\tau)}{N(B^0 \rightarrow D^{*-} e^+ \nu_e)}}_{\text{Extracted from a fit}} \times \underbrace{\frac{\epsilon(B^0 \rightarrow D^{*-} e^+ \nu_e)}{\epsilon(B^0 \rightarrow D^{*-} \tau^+ \nu_\tau)}}_{\text{Extracted from simulated samples}}$$

Extracted from a fit

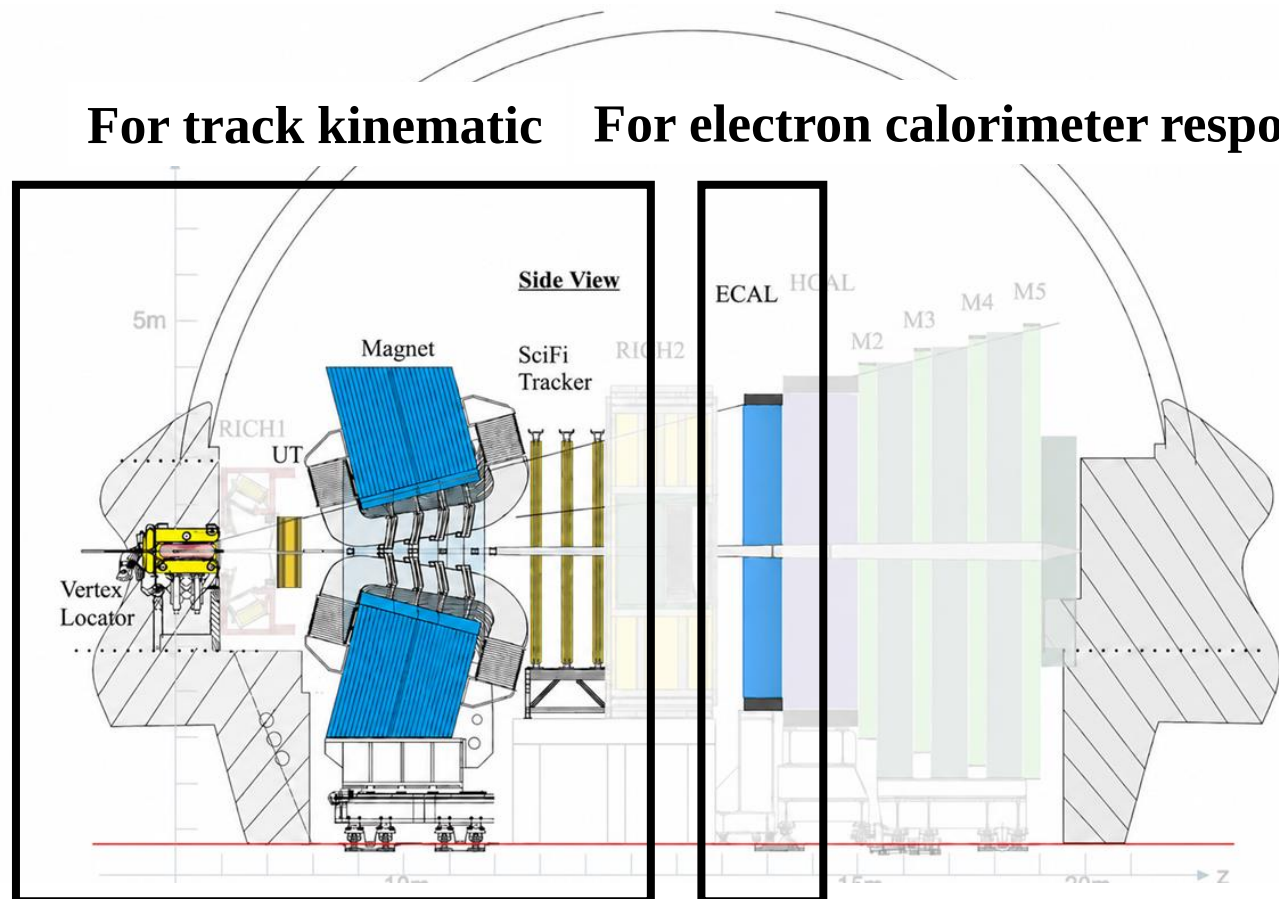
Extracted from simulated samples

Both rely on large simulation samples

Samples

Simulation

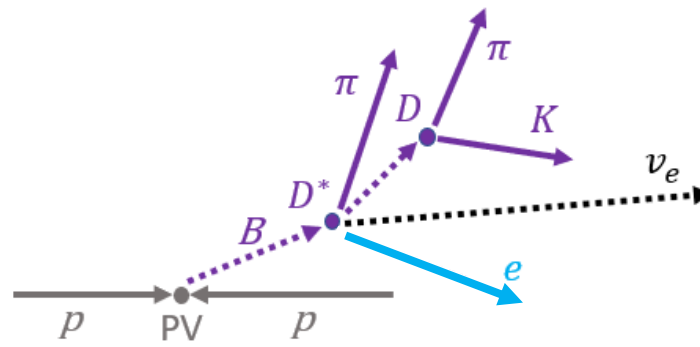
Only tracking detector and ECAL are simulated to reduce the **time consumption of detector simulation** and the **size of file**



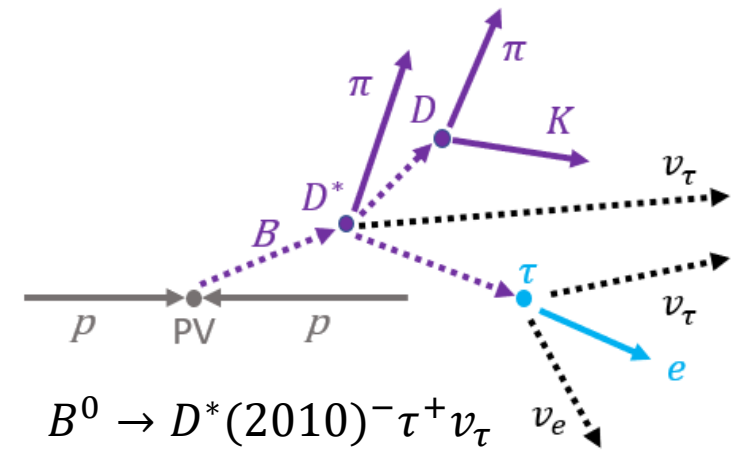
Samples

Simulation

Samples include **signal modes**



$$B^0 \rightarrow D^{*}(2010)^- e^+ \nu_e$$



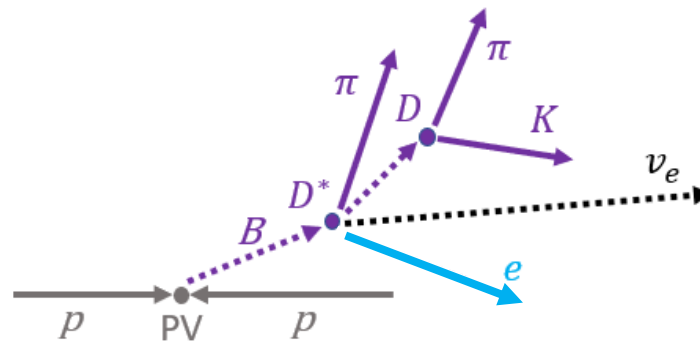
$$B^0 \rightarrow D^{*}(2010)^- \tau^+ \nu_\tau$$

Samples

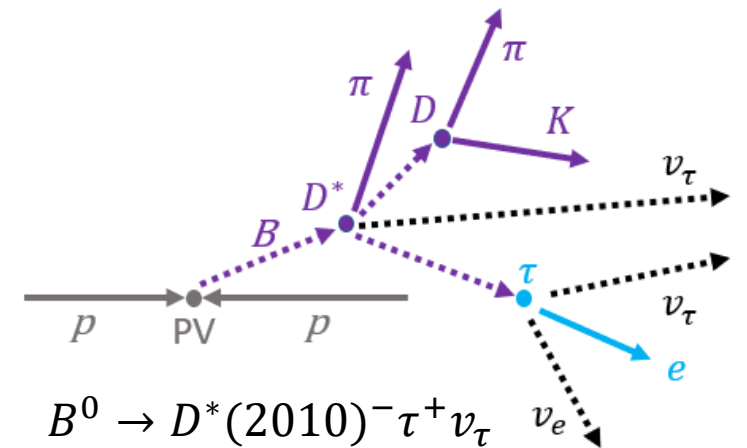
Simulation

Samples include **signal modes** and backgrounds coming from other semi-leptonic modes - **physics backgrounds**

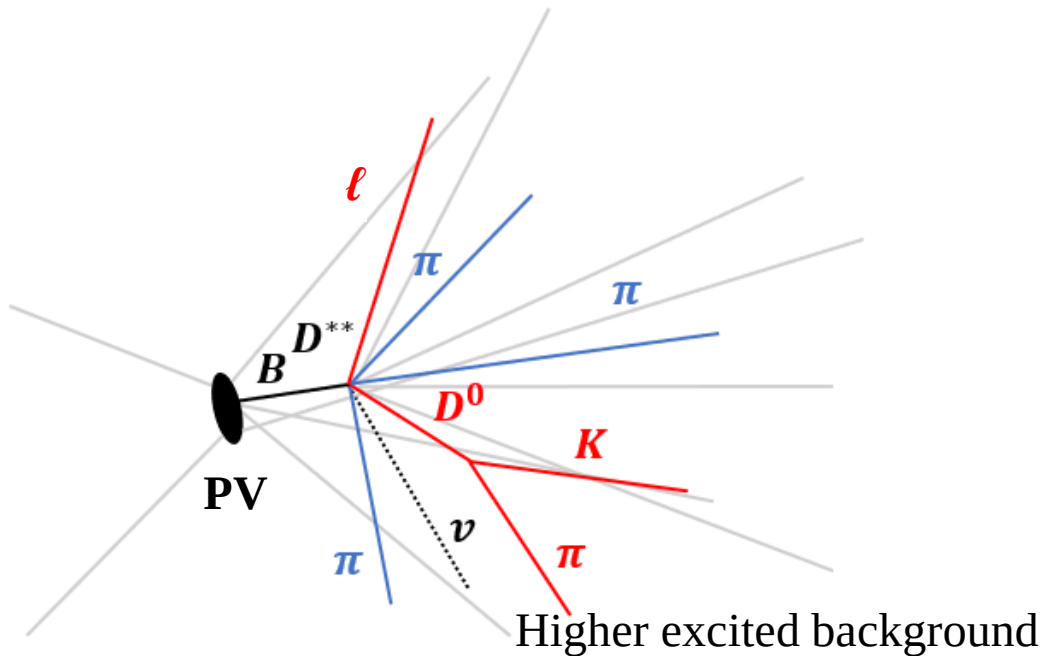
- Higher excited background : $\bar{B} \rightarrow D^{**}(\rightarrow D^* n\pi)\ell v$, ($n \geq 1$)
 - D^{**} is higher excited charmed state, such as $D_0^*(2300)$, $D_1(2420)$, $D_2^*(2460)$, etc.



$$B^0 \rightarrow D^{*}(2010)^- e^+ \nu_e$$



$$B^0 \rightarrow D^{*}(2010)^- \tau^+ \nu_\tau$$



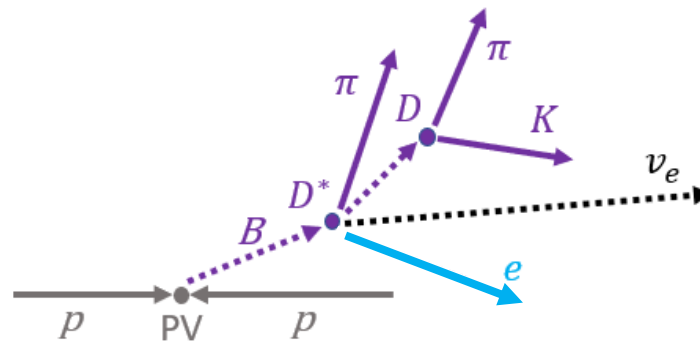
ℓ denotes e or τ

Samples

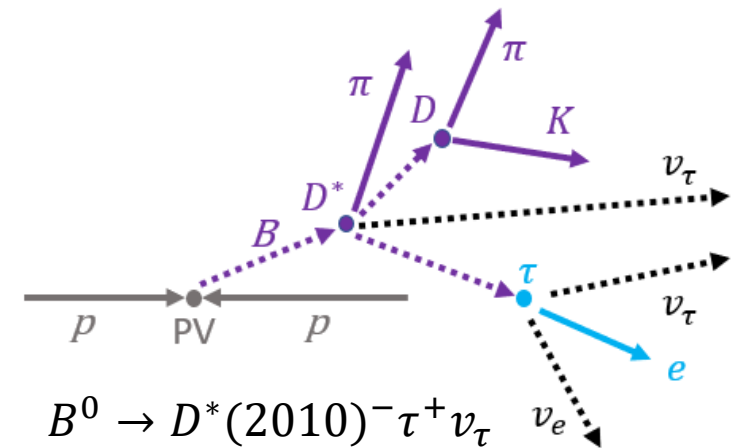
Simulation

Samples include **signal modes** and backgrounds coming from other semi-leptonic modes - **physics backgrounds**

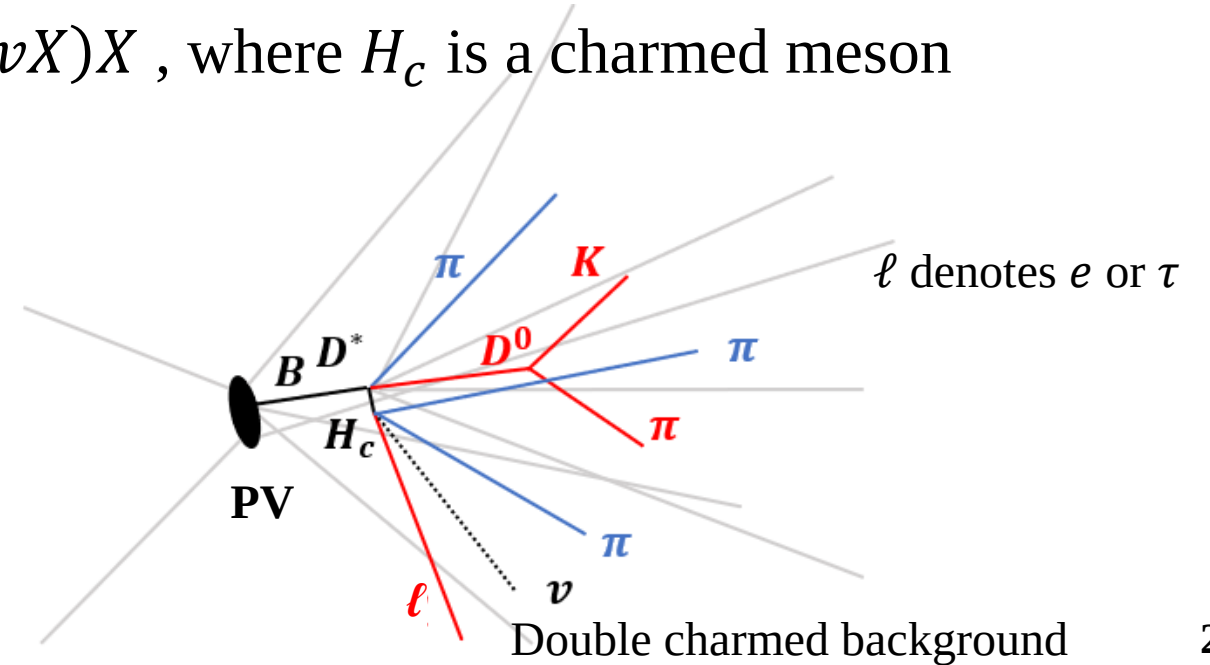
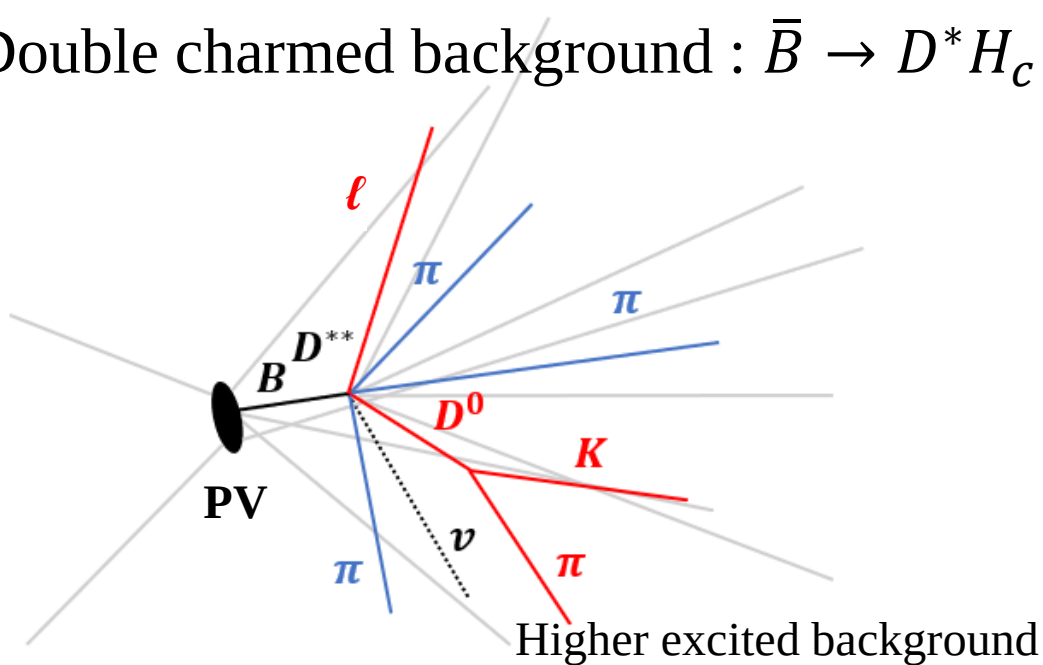
- Higher excited background : $\bar{B} \rightarrow D^{**}(\rightarrow D^* n\pi)\ell v, (n \geq 1)$
 - D^{**} is higher excited charmed state, such as $D_0^*(2300), D_1(2420), D_2^*(2460)$, etc.
- Double charmed background : $\bar{B} \rightarrow D^* H_c(\rightarrow \ell v X)X$, where H_c is a charmed meson



$$B^0 \rightarrow D^*(2010)^- e^+ v_e$$



$$B^0 \rightarrow D^*(2010)^- \tau^+ v_\tau$$



Samples

Simulation

100 M events for $B^0 \rightarrow D^{*-} e^+ \nu_e$ and 10 M $B^0 \rightarrow D^{*-} \tau^+ \nu_\tau$ are prepared

1~5 M events are generated for various physics background modes

Samples

Simulation

100 M events for $B^0 \rightarrow D^{*-} e^+ \nu_e$ and 10 M $B^0 \rightarrow D^{*-} \tau^+ \nu_\tau$ are prepared

1~5 M events are generated for various physics background modes

Data

Subset (16%) of good-quality Run 3 data are used in this thesis

Block indexes, polarities and luminosities of 2024 data

Block	Polarity	Luminosity (fb^{-1})
1	Up	1.215 (1.178 with UT)
2	Up	0.614 (0.604 with UT)
3	Up	0.900 (0.681 with UT)
4	Down	1.392 (1.147 with UT)
5	Up	1.160
6	Down	0.998
7	Down	0.737
8	Up	0.435

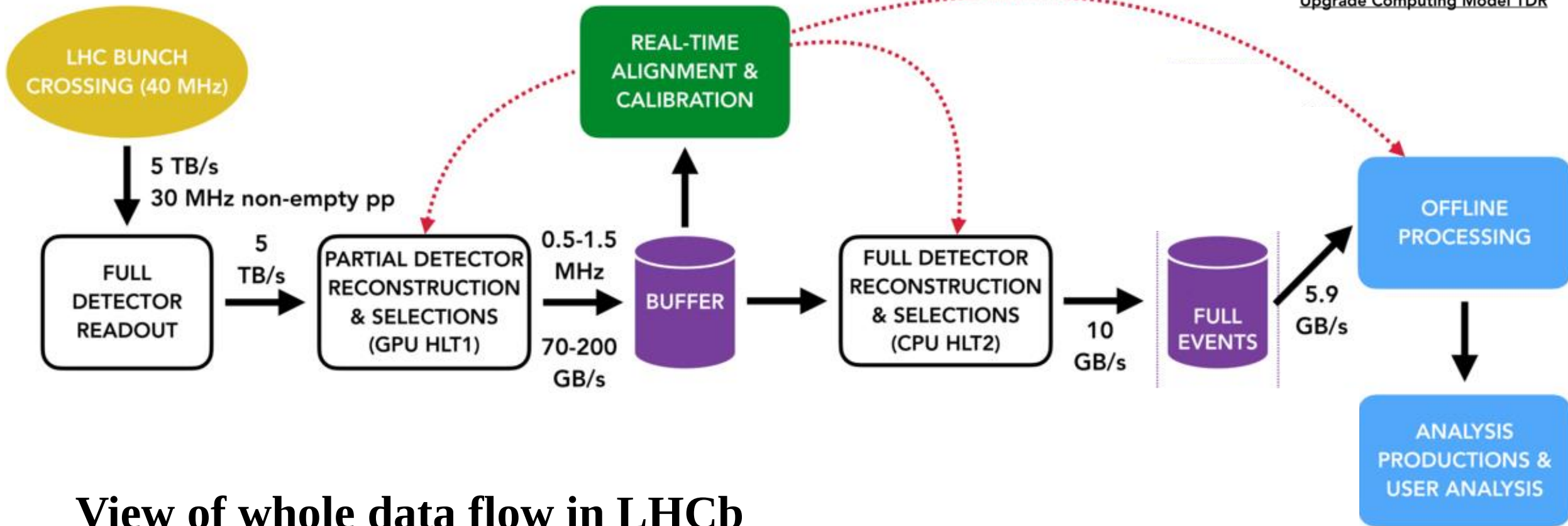
3.3 fb^{-1} data are used in this work

Data flow of $B^0 \rightarrow D^{*-} e^+ \nu$ reconstruction

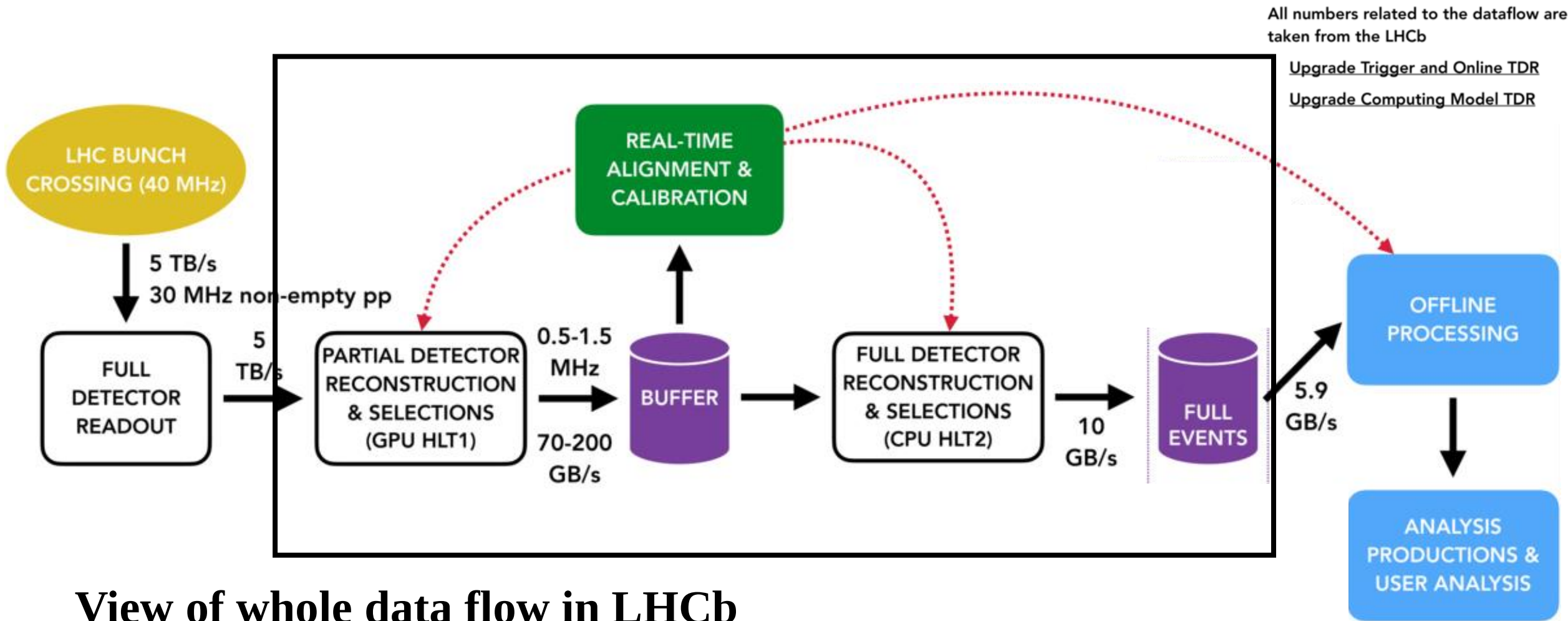
All numbers related to the dataflow are taken from the LHCb

[Upgrade Trigger and Online TDR](#)

[Upgrade Computing Model TDR](#)



Data flow of $B^0 \rightarrow D^{*-} e^+ \nu$ reconstruction

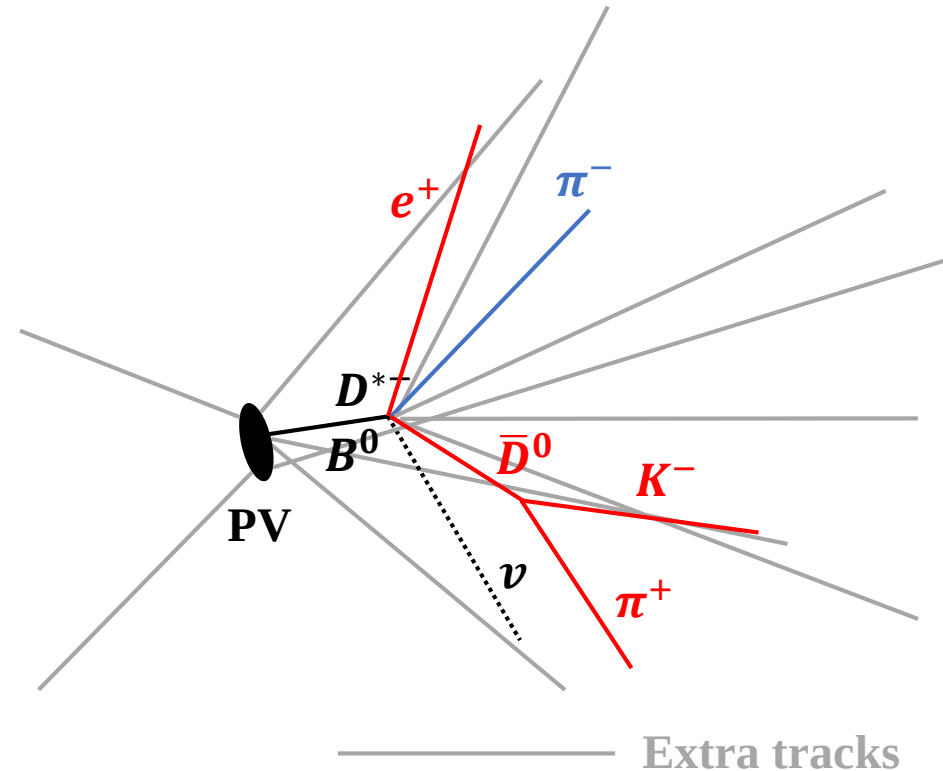
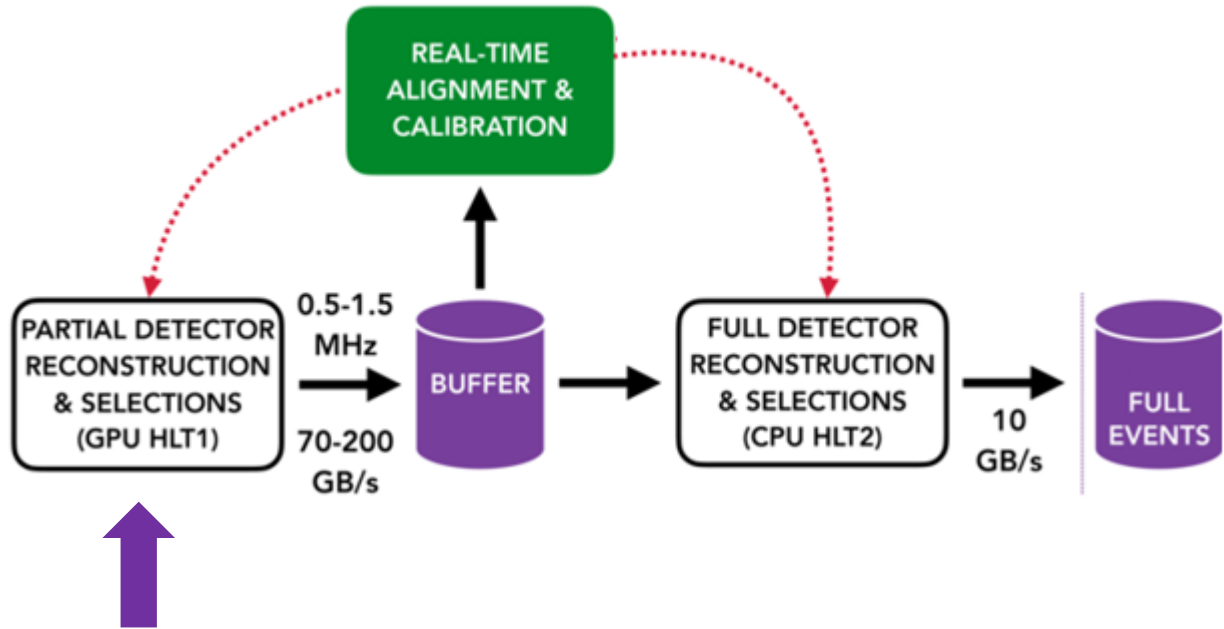


View of whole data flow in LHCb

We start from the online reconstruction

HLT reconstruction

During online reconstruction

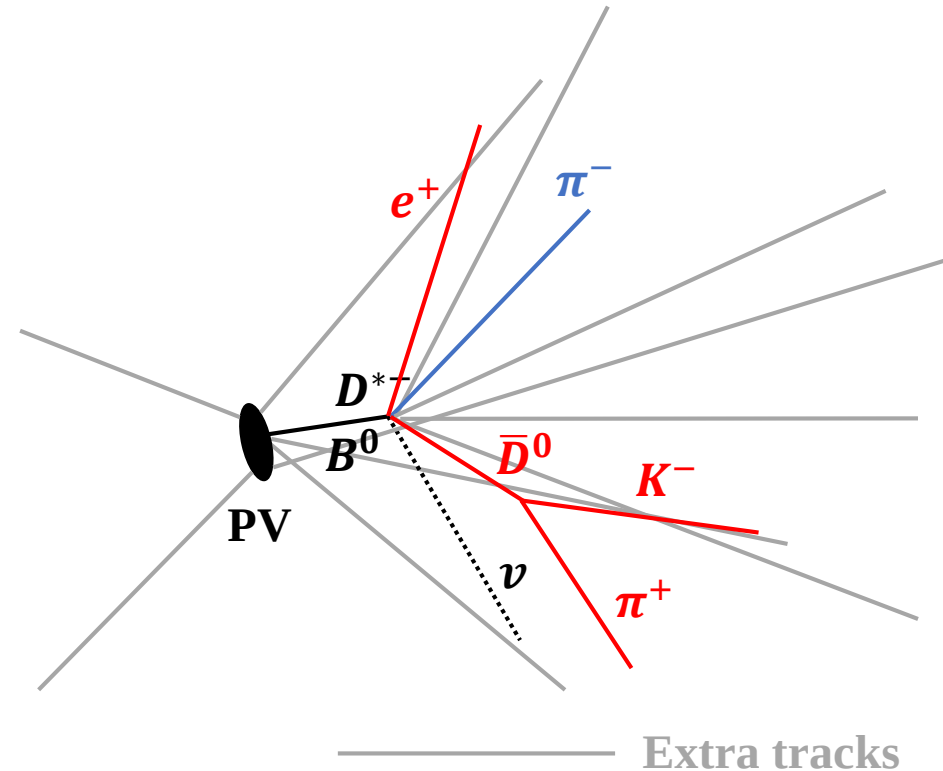
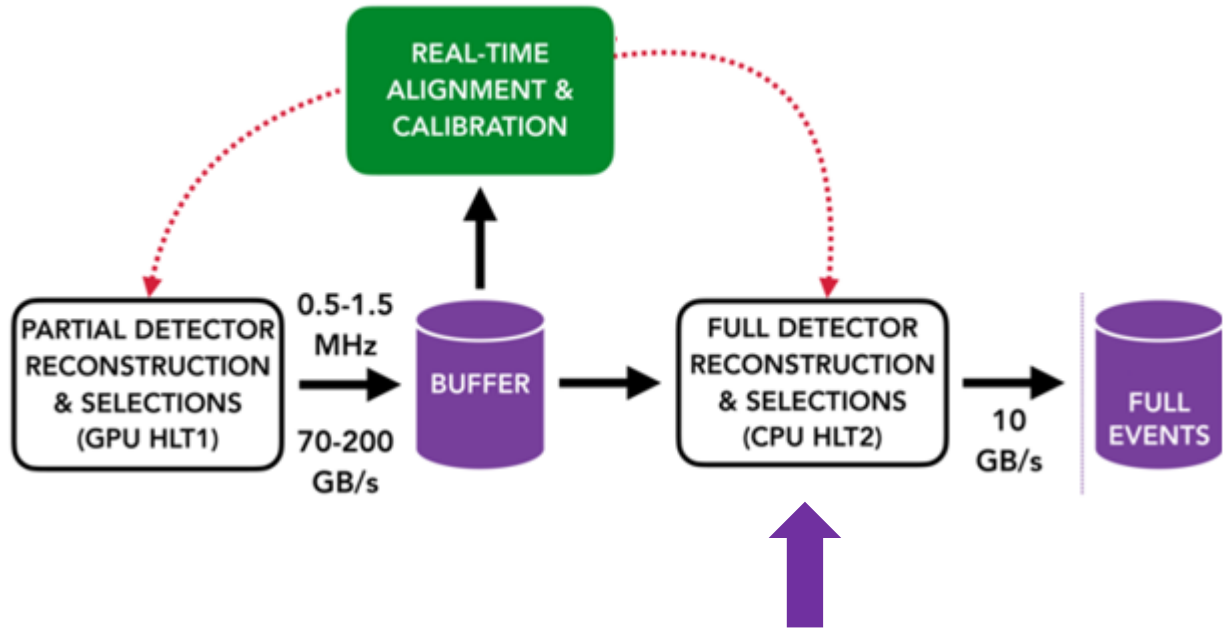


In HLT 1, the events are triggered

- Based on the hadronic tracks from D^0 candidates
- Filtered data are stored in buffer

HLT reconstruction

During online reconstruction

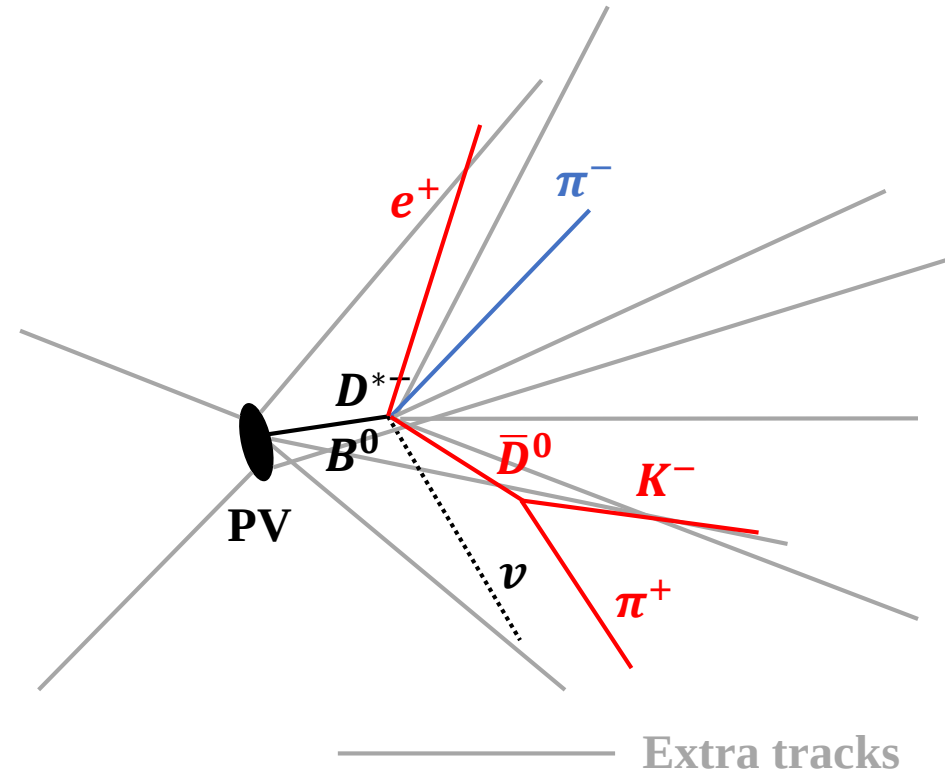
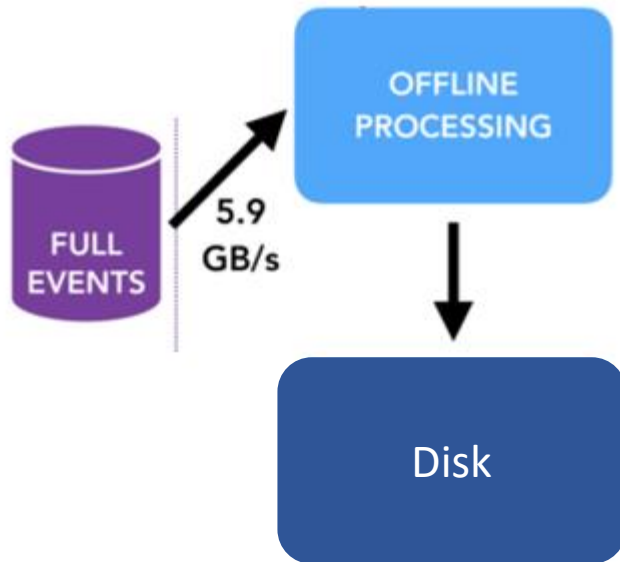


In HLT 2, we store the following candidates on tape

- Ground-state particles $\bar{D}^0 e$ are reconstructed & selected
- All **extra tracks** including π from $D^{*-} (\rightarrow \bar{D}^0 \pi^-)$

Offline processing

During offline processing



Due to the limit on data rate, storing all extra tracks is not viable

→ An ML-based Inclusive Multivariate Isolation (IMI) tool was developed to select the track candidates

Inclusive Multivariate Isolation tool

An **inclusive** and **multivariate** tool has been developed using

Inclusive Multivariate Isolation tool

An **inclusive** and **multivariate** tool has been developed using

- **Inclusive** simulation containing various semi-leptonic decays (4×10^4 signal particles)

Base particles	Non-isolated particles	Decay chain
$\bar{D}^0 \ell^+$	π^-	$B^0 \rightarrow D^{*-} \ell^+ \nu_\ell, D^{*-} \rightarrow \bar{D}^0 \pi^-$
$\bar{D}^0 \ell^+$	π^-	$B^0 \rightarrow D^{*-} \tau^+ \nu_\tau, D^{*-} \rightarrow \bar{D}^0 \pi^-, \tau^+ \rightarrow \ell^+ \nu_\ell \bar{\nu}_\tau$
$\bar{D}^0 \tau^+$	π^-	$B^0 \rightarrow D^{*-} \tau^+ \nu_\tau, D^{*-} \rightarrow \bar{D}^0 \pi^-, \tau^+ \rightarrow \pi^+ \pi^- \pi^+ (\pi^0) \bar{\nu}_\tau$
$D^0 \ell^+$	π^-, π^+	$B^+ \rightarrow D^{*0} \ell^+ \nu_\ell, D^{*0} \rightarrow D^{*+} \pi^- \pi^0, D^{*+} \rightarrow D^0 \pi^+$
$D^0 \ell^+$	π^-, π^+	$B^+ \rightarrow D^{*0} \tau^+ \nu_\tau, D^{*0} \rightarrow D^{*+} \pi^- \pi^0, D^{*+} \rightarrow D^0 \pi^+, \tau^+ \rightarrow \ell^+ \nu_\ell \bar{\nu}_\tau$
$\bar{D}^0 \ell^+$	π^+, π^-, π^-	$B^0 \rightarrow D^{*-} \ell^+ \nu_\ell, D^{*-} \rightarrow D^{*-} \pi^+ \pi^-, D^{*-} \rightarrow \bar{D}^0 \pi^-$
$\bar{D}^0 \ell^+$	π^+, π^-, π^-	$B^0 \rightarrow D^{*-} \tau^+ \nu_\tau, D^{*-} \rightarrow D^{*-} \pi^+ \pi^-, D^{*-} \rightarrow \bar{D}^0 \pi^-, \tau^+ \rightarrow \ell^+ \nu_\ell \bar{\nu}_\tau$
$D^0 \ell^+$	π^+, π^-, π^-	$B^+ \rightarrow D^{(*)} D_{(s)}^{(*)}, D^{(*)} \rightarrow D^0 \pi^- (\pi^+ \pi^-), D_{(s)}^{(*)} \rightarrow \ell^+ X$
$D^0 \ell^+$	$K^-, 2\pi^-, 2\pi^+$	$B^+ \rightarrow D^{(*)} D_{(s)}^{(*)} K^- \pi^+, D^{(*)} \rightarrow D^0 \pi^- (\pi^+ \pi^-), D_{(s)}^{(*)} \rightarrow \ell^+ X$
$K^+ \ell^-$	ℓ^+	$B^+ \rightarrow K^+ J/\psi, J/\psi \rightarrow \ell^+ \ell^-$
$K^+ \ell^-$	K^+, π^-	$B_s^0 \rightarrow D_s^- \ell^+ \nu_\ell, D_s^- \rightarrow K^+ \pi^- K^-$
$K^+ \ell^-$	K^+, π^-	$B_s^0 \rightarrow D_s^- \tau^+ \nu_\tau, D_s^- \rightarrow K^+ \pi^- K^-, \tau^+ \rightarrow \ell^+ \nu_\ell \bar{\nu}_\tau$
$K^+ \ell^-$	$K^+, 2\pi^-, \pi^+$	$B_s^0 \rightarrow D_s^{*-} \ell^+ \nu_\ell, D_s^{*-} \rightarrow D_s^+ \pi^+ \pi^-, D_s^+ \rightarrow K^+ \pi^- K^-$
$\Lambda_c^+ \ell^-$	$\pi^+ \pi^-$	$\Lambda_b^0 \rightarrow \Lambda_c^{*+} \ell^- \bar{\nu}_\ell, \Lambda_c^{*+} \rightarrow \Lambda_c^+ \pi^+ \pi^-$
$p \ell^-$	$K^- \pi^+$	$\Lambda_b^0 \rightarrow \Lambda_c^+ \ell^- \bar{\nu}_\ell, \Lambda_c^+ \rightarrow p K^- \pi^+$

Inclusive Multivariate Isolation tool

An **inclusive** and **multivariate** tool has been developed using

- **Inclusive** simulation containing various semi-leptonic decays (4×10^4 signal particles)
- **Multivariate** features include
 - Track Impact Parameters,
 - Spatial & angular properties of extra tracks and base-particles
 - Vertex dynamics and extra-track kinematics

Inclusive Multivariate Isolation tool

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- **Inclusive** simulation containing various semi-leptonic decays (4×10^4 signal particles)
 - **Multivariate** features include
 - Track Impact Parameters,
 - Spatial & angular properties of extra tracks and base-particles
 - Vertex dynamics and extra-track kinematics
 - Trained using XGBoost, and hyperparameters are tuned using Optuna
 - With a loose cut on MVA score
- **Reduce 45 % data size** while **keep ~ 99 % of signal tracks** in offline processing

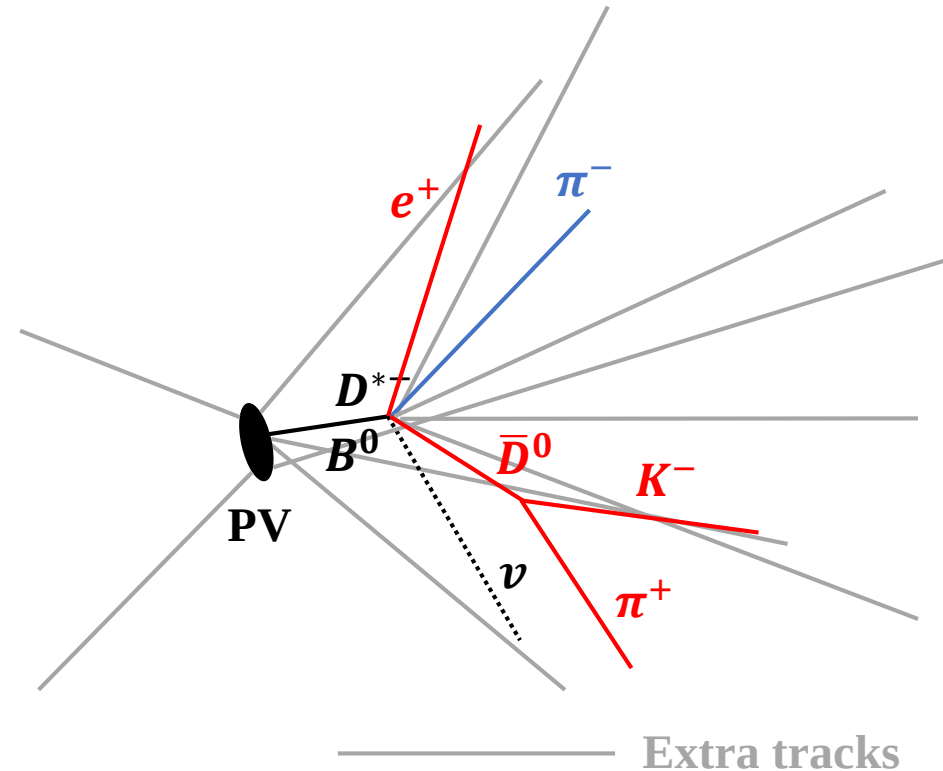
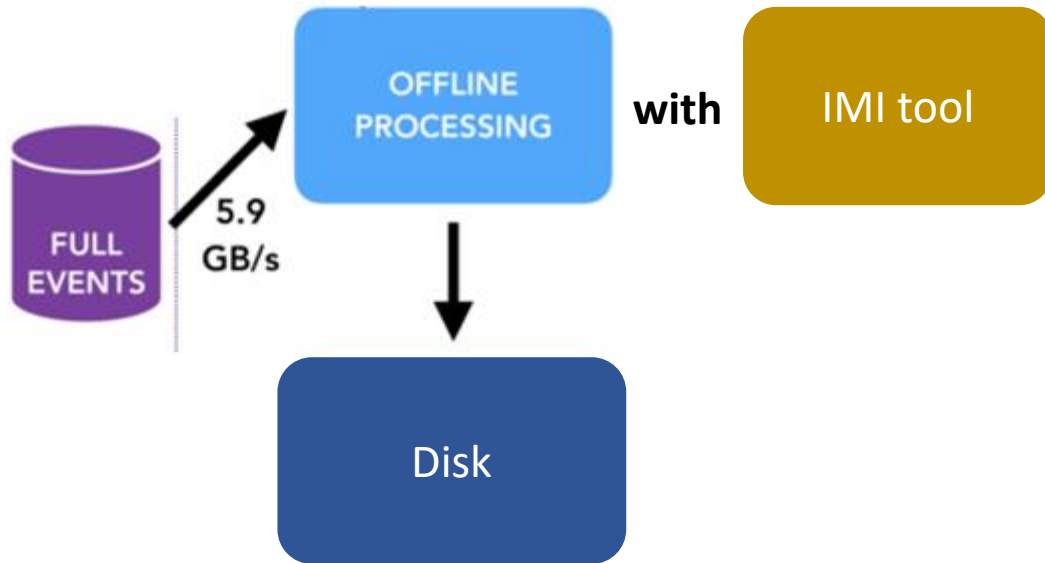
Inclusive Multivariate Isolation tool

An **inclusive** and **multivariate** tool has been developed using

- **Inclusive** simulation containing various semi-leptonic decays (4×10^4 signal particles)
 - **Multivariate** features include
 - Track Impact Parameters,
 - Spatial & angular properties of extra tracks and base-particles
 - Vertex dynamics and extra-track kinematics
 - Trained on a large sample of signal and background events
 - With a cut on the multivariate score, the study & result of this inclusive multivariate isolation tool has been published on [Eur. Phys. J. C 86 \(2026\) 241](#)
- **Reduce 45 % data size while keep ~ 99 % of signal tracks** in offline processing

Offline processing with IMI tool

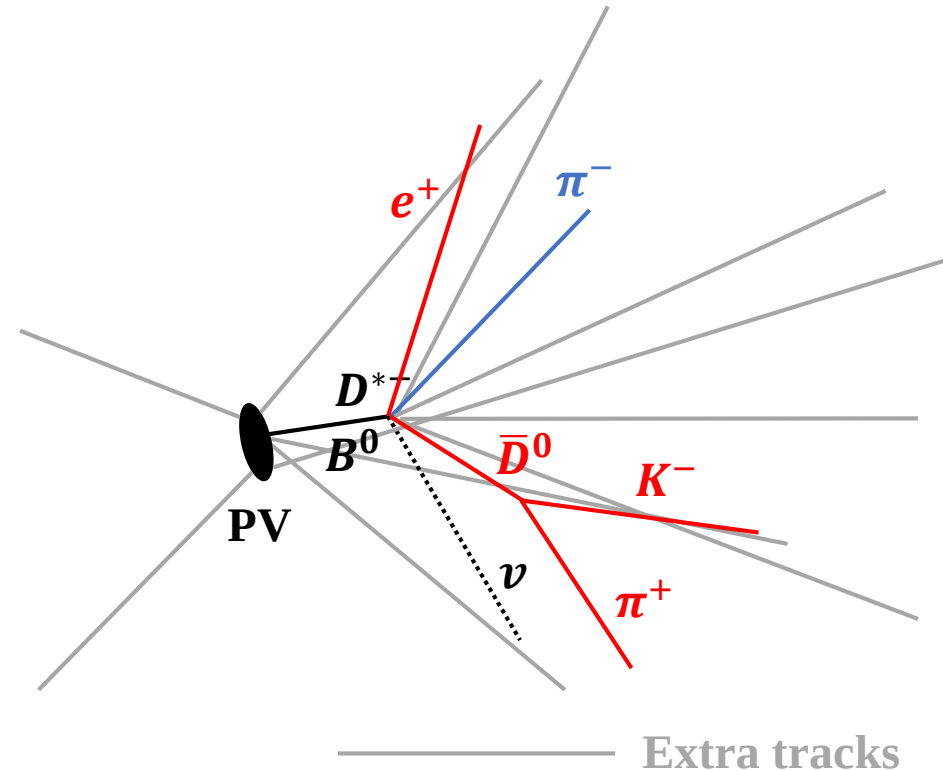
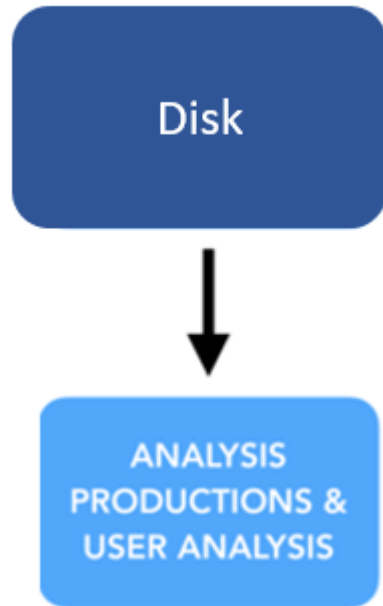
During offline processing



- We pair **ground-state particles** and **extra tracks** (including π^-) to get the B^0 candidates
- Select and store the **extra tracks** based on IMI score to the disks

$B^0 \rightarrow D^{*-} e^+ \nu$ reconstruction in tuple making

At the tuple making stage

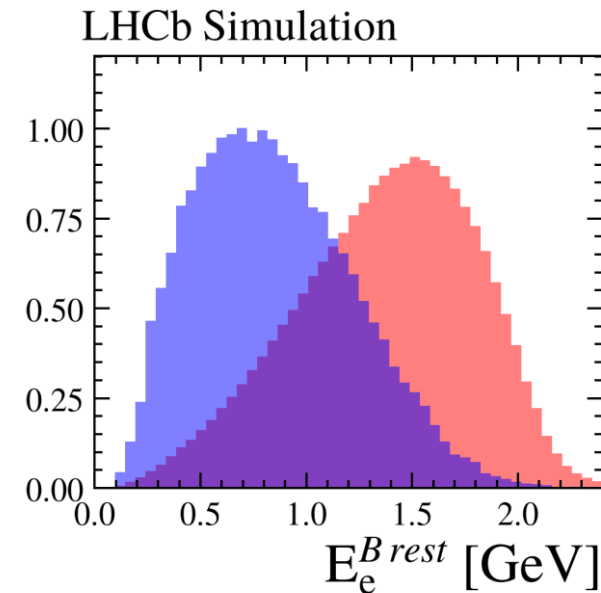
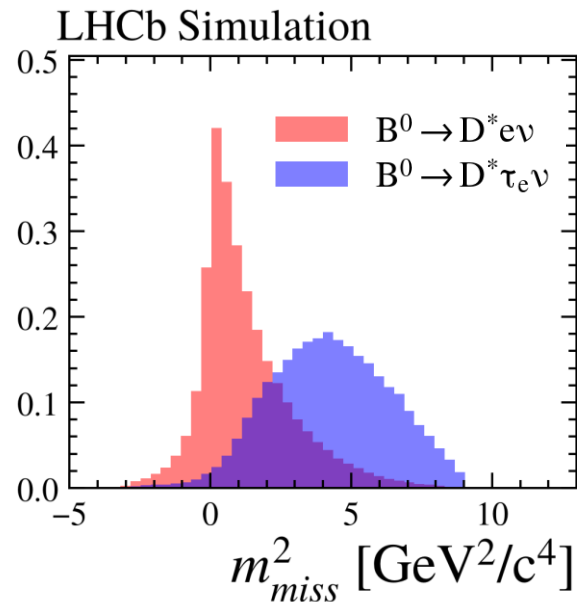
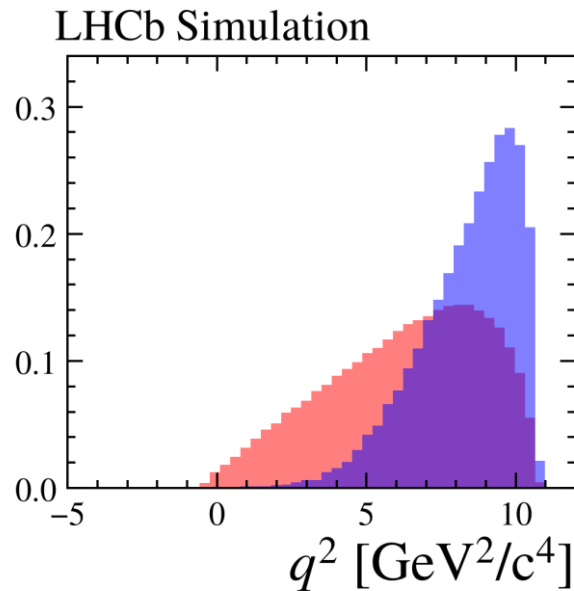


- At the final stage, we reconstruct the B^0 candidates with filtered $\bar{D}^0 e^+$ and **extra tracks** to make tuples which includes various physics quantities
- The B^0 is the **signal** candidate if it is reconstructed with $\bar{D}^0 e^+$ and π^- , otherwise **background**

Fitting variables

We use the following fitting variables to distinguish different decays

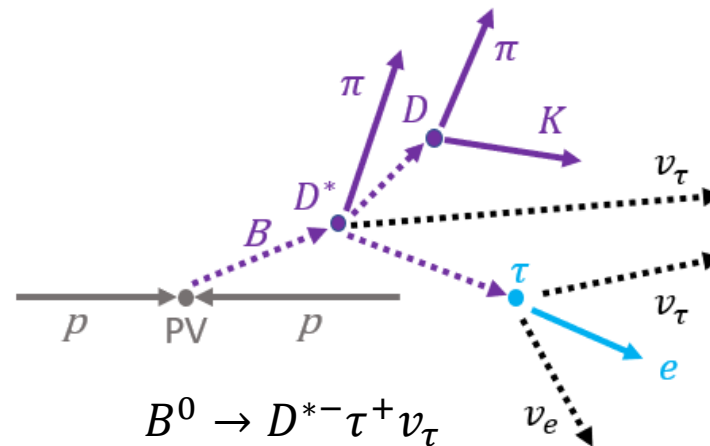
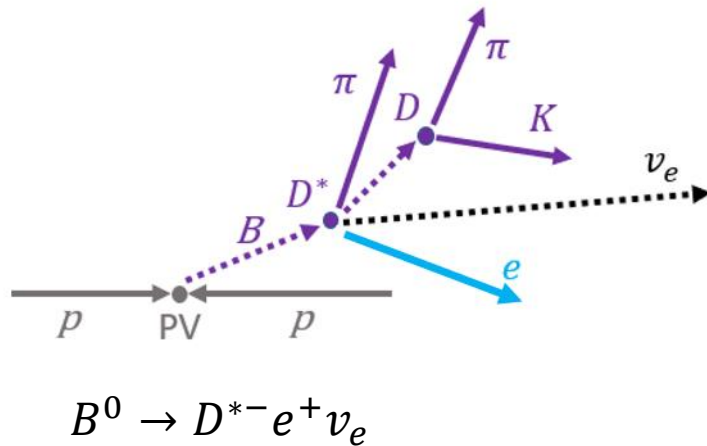
- $M_{\text{miss}}^2 = (p_{B^0} - p_{D^{*-}} - p_{e^+})^2$
- $q^2 = (p_{B^0} - p_{D^{*-}})^2$
- E_e^* : Electron energy in B^0 rest frame, which are derived from reconstructed $\vec{p}_{B^0}$



D^*e and $D^*\tau$ sample are well separated !

B^0 kinematic reconstruction

Due to the presence of neutrino(s) ,



The reconstruct B^0 kinematics are not accurate and need to be corrected

B^0 kinematic reconstruction

We reconstruct B^0 kinematics in the following procedure :

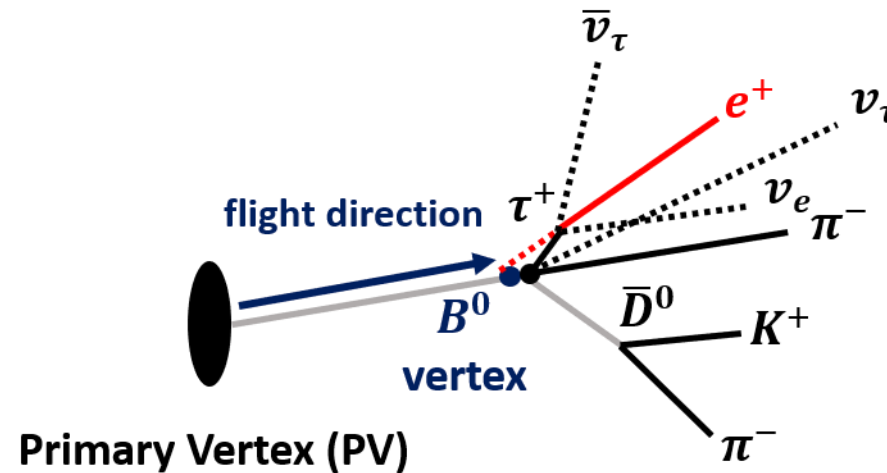
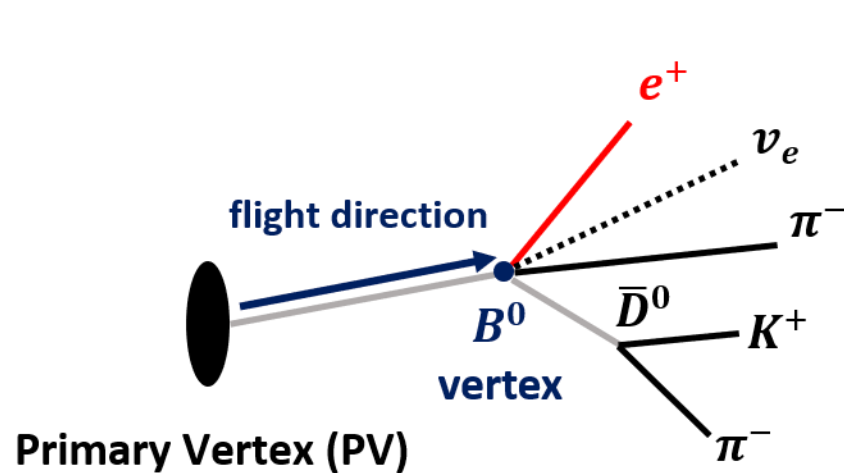
- **Correct reconstructed $(p_{B^0})_z$ with true m_{B^0}**

$$(p_{B^0})_z \approx \frac{m_{B^0}^{\text{PDG}}}{m_{B^0}^{\text{Rec}}} \times (p_{B^0})_z^{\text{Rec}}$$

B^0 kinematic reconstruction

We reconstruct B^0 kinematics in the following procedure :

- **Correct reconstructed $(p_{B^0})_z$ with true m_{B^0}**
- **Correct the B^0 flight direction with the positions of PV and B^0 vertex**

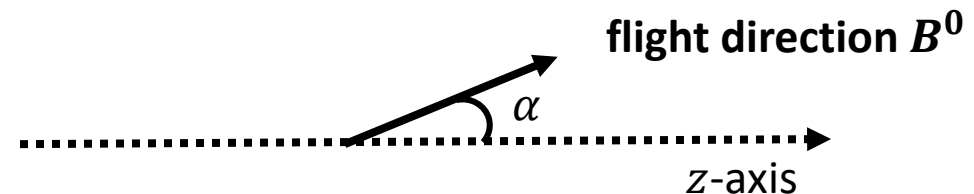


B^0 kinematic reconstruction

We reconstruct B^0 kinematics in the following procedure :

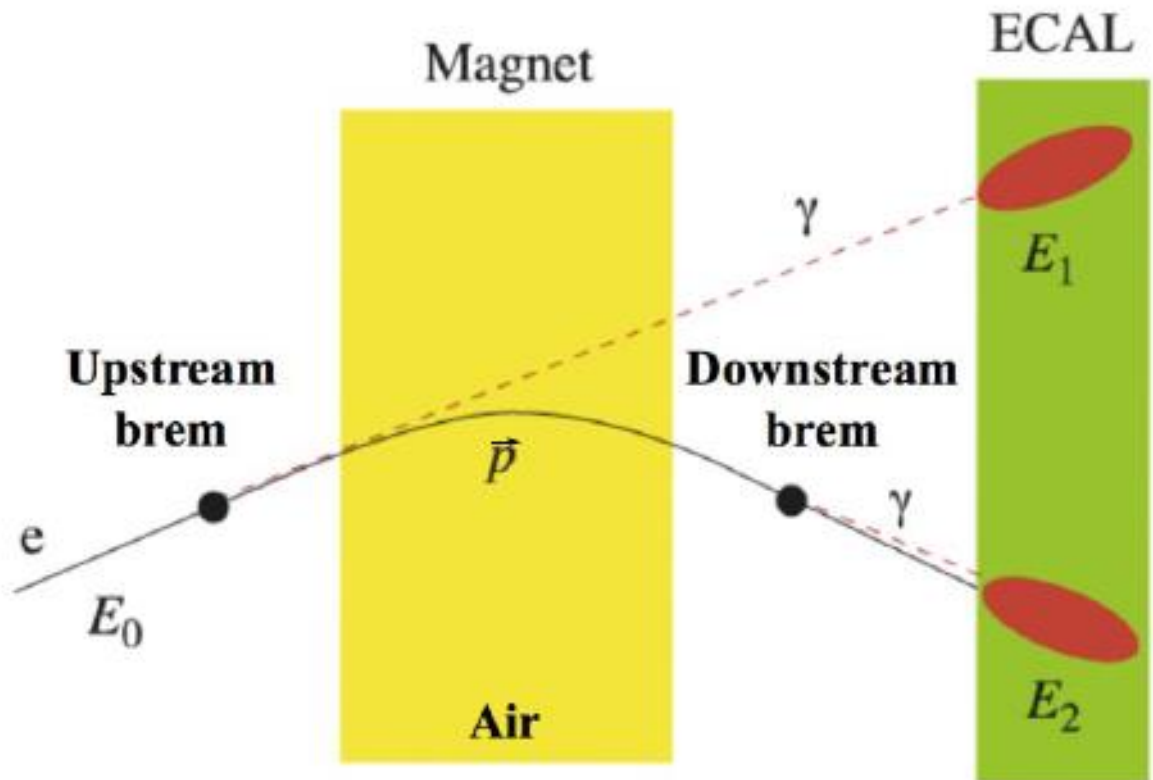
- **Correct reconstructed $(p_{B^0})_z$ with true m_{B^0}**
- **Correct the B^0 flight direction with the positions of PV and B^0 vertex**
- **Derive $|\vec{p}_{B^0}|$ using the flight direction and corrected $(p_{B^0})_z$**

$|\vec{p}_{B^0}| = (p_{B^0})_z / \cos \alpha$, where α is angle between flight direction and the z-axis



Bremsstrahlung of electrons

$$B^0 \rightarrow D^{*-} e^+ \nu_e \quad B^0 \rightarrow D^{*-} \tau^+ \nu_\tau, \tau^+ \rightarrow e^+ \nu_e \bar{\nu}_\tau$$

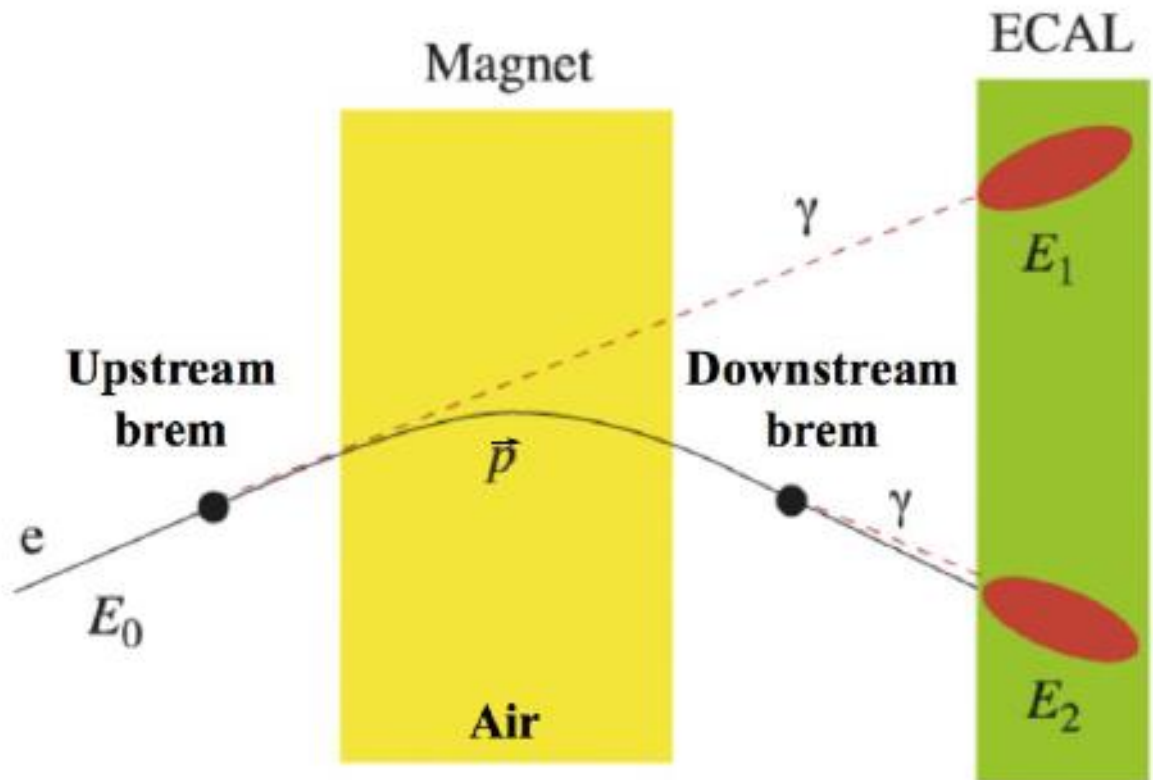


Bremsstrahlung recovery

- Extrapolate the electron track to the ECAL
- Associate compatible ECAL photon clusters
- Add the recovered photon energy to the electron momentum

Bremsstrahlung of electrons

$$B^0 \rightarrow D^{*-} e^+ \nu_e \quad B^0 \rightarrow D^{*-} \tau^+ \nu_\tau, \tau^+ \rightarrow e^+ \nu_e \bar{\nu}_\tau$$



Bremsstrahlung recovery

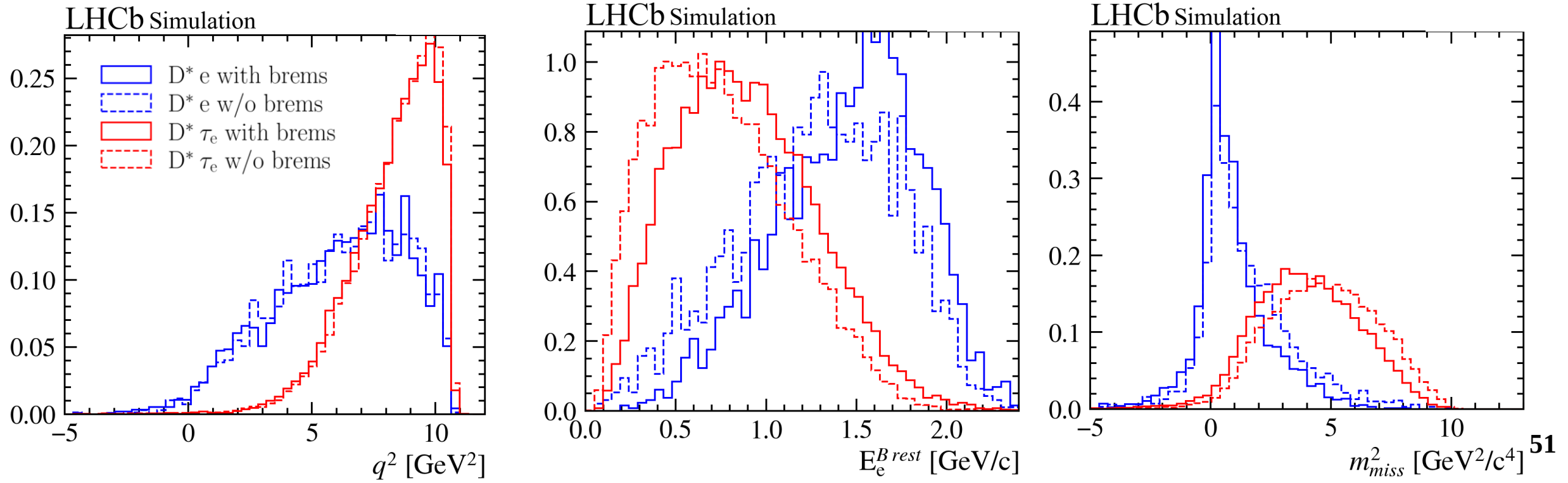
- Extrapolate the electron track to the ECAL
- Associate compatible ECAL photon clusters
- Add the recovered photon energy to the electron momentum

Bremsstrahlung is successfully recovered for ~60% of electrons

Bremsstrahlung recovery in fitting variables

We split the data samples into two categories: **with and w/o bremsstrahlung recovery**

These datasets are be fitted simultaneously



MC correction

PID

The simulation samples are simulated without RICH

→ **Generate data-driven PID response using PID resampling**

MC correction

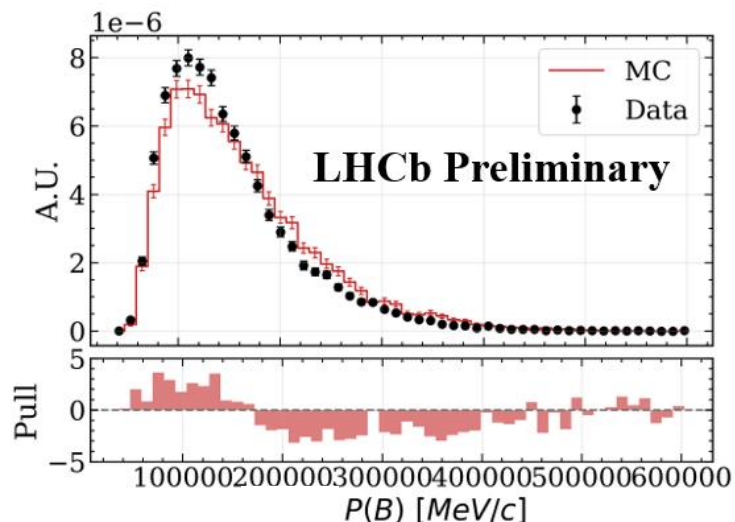
PID

The simulation samples are simulated without RICH

→ **Generate data-driven PID response using PID resampling**

Kinematics & multiplicity

The simulation is not perfect, leading to discrepancies between data and MC



**Control mode
before re-weight**

MC correction

PID

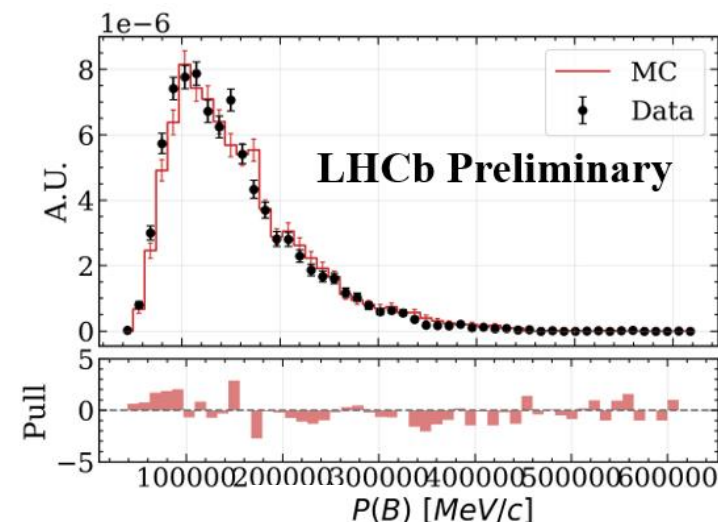
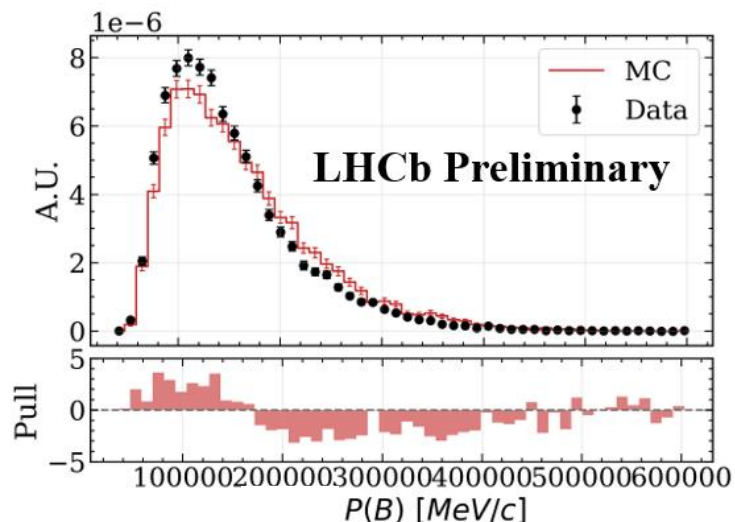
The simulation samples are simulated without RICH

→ **Generate data-driven PID response using PID resampling**

Kinematics & multiplicity

The simulation is not perfect, leading to discrepancies between data and MC

→ **Train a NN reweighter on the control sample and apply the resulting weights to simulation**



Background suppression

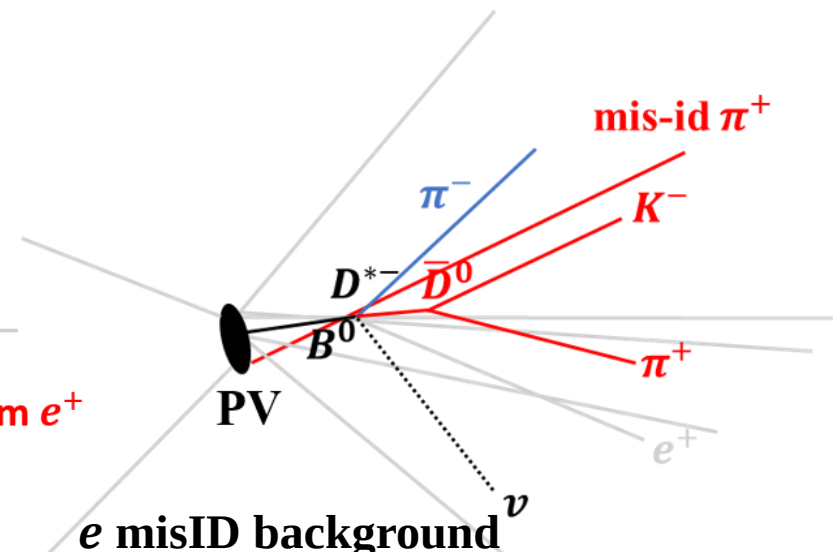
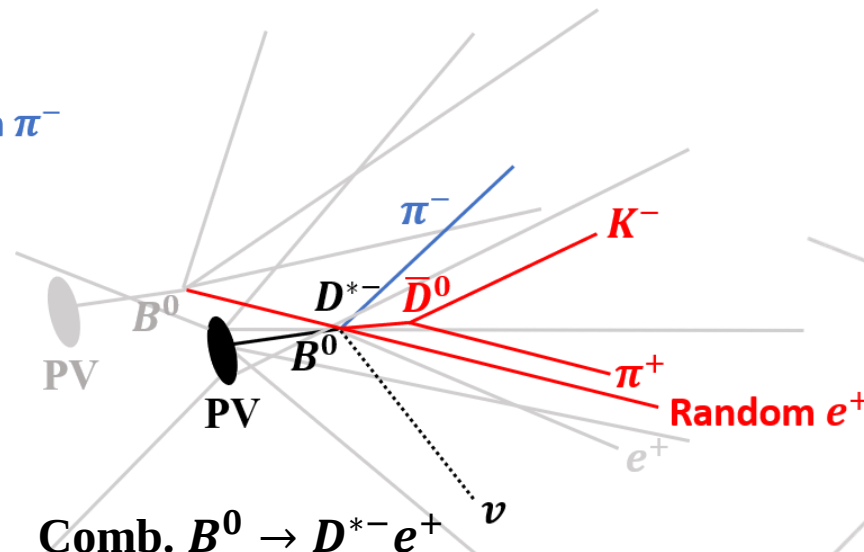
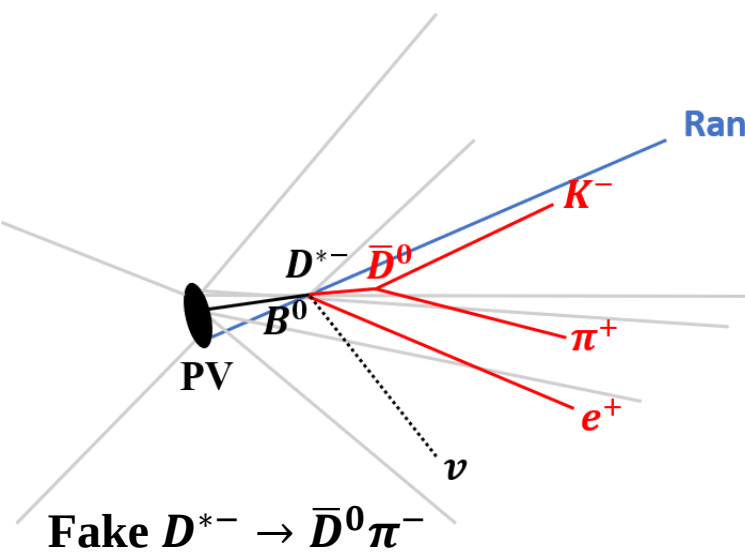
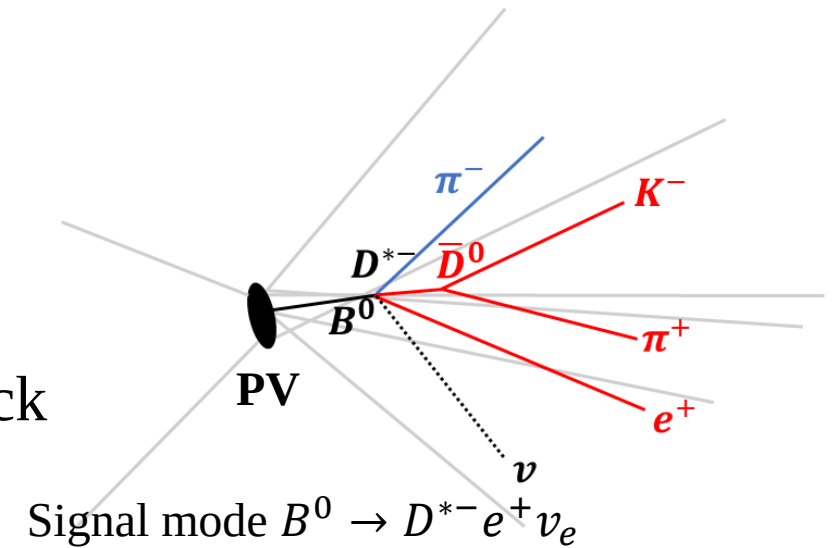
Combinatorial and mis-ID backgrounds

Combinatorial backgrounds: random track combinations

- Fake D^{*-} ($\rightarrow \bar{D}^0 \pi^-$) : fake $\bar{D}^0$ or true $\bar{D}^0$ + random π^-
- Combinatorial $B^0 \rightarrow D^{*-} + \text{random } e^+$

e mis-ID background:

- hadron / muon / ghost track reconstructed as the electron track



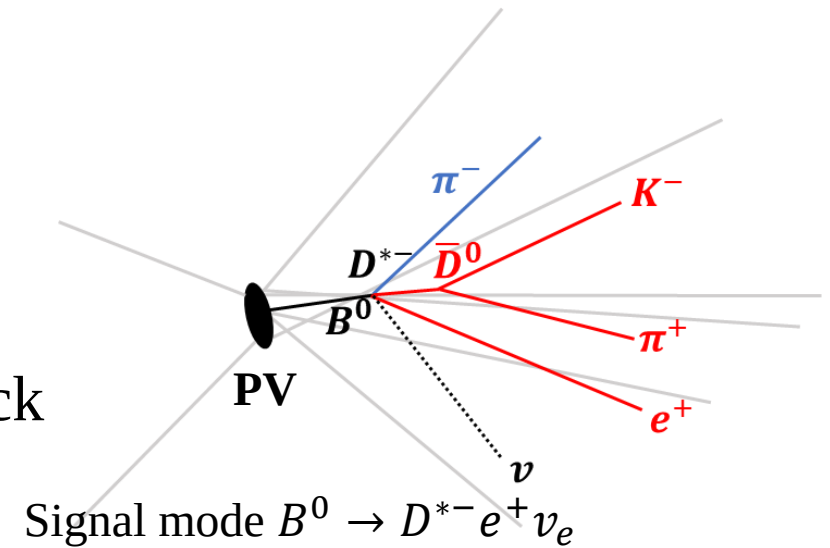
Combinatorial and mis-ID backgrounds

Combinatorial backgrounds: random track combinations

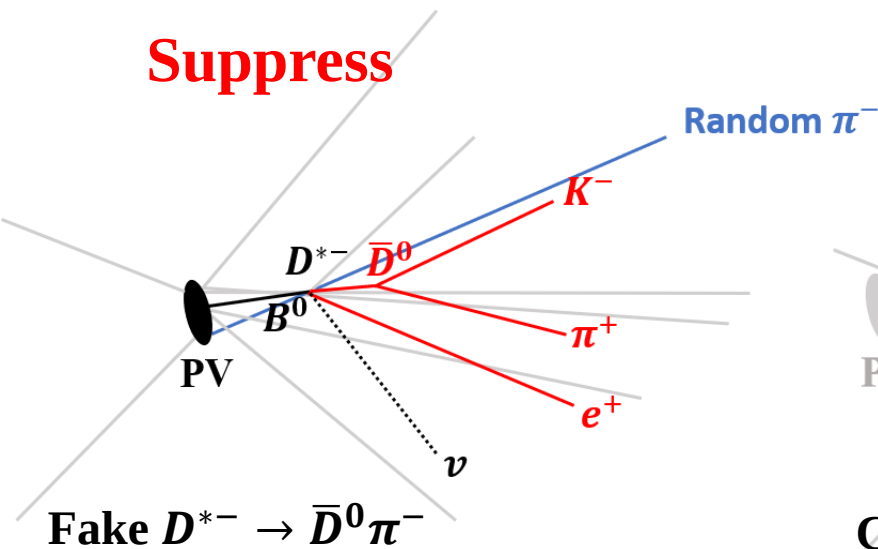
- Fake $D^{*-} (\rightarrow \bar{D}^0 \pi^-)$: fake $\bar{D}^0$ or true $\bar{D}^0$ + random π^-
- Combinatorial $B^0 \rightarrow D^{*-} + \text{random } e^+$

e mis-ID background:

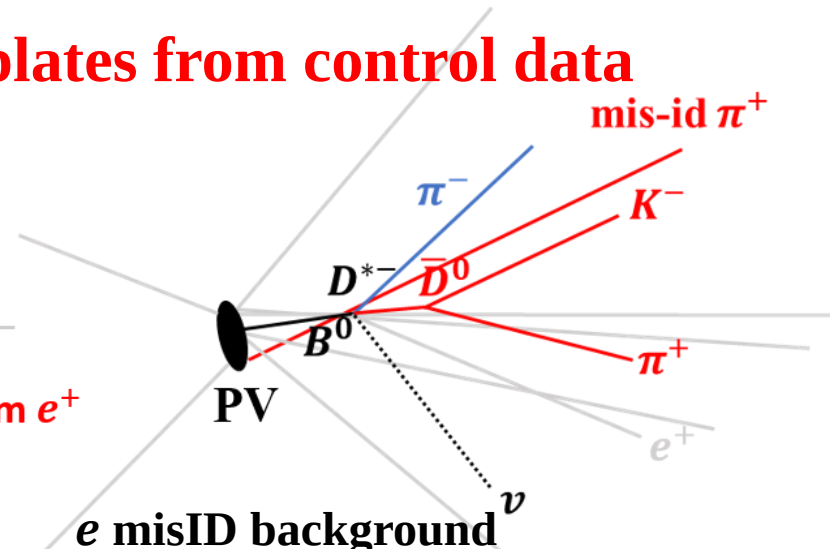
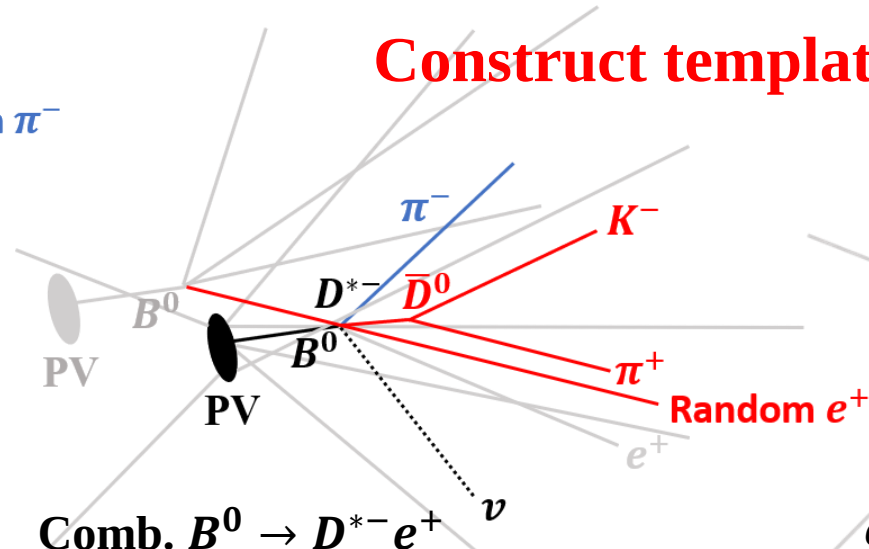
- hadron / muon / ghost track reconstructed as the electron track



Suppress

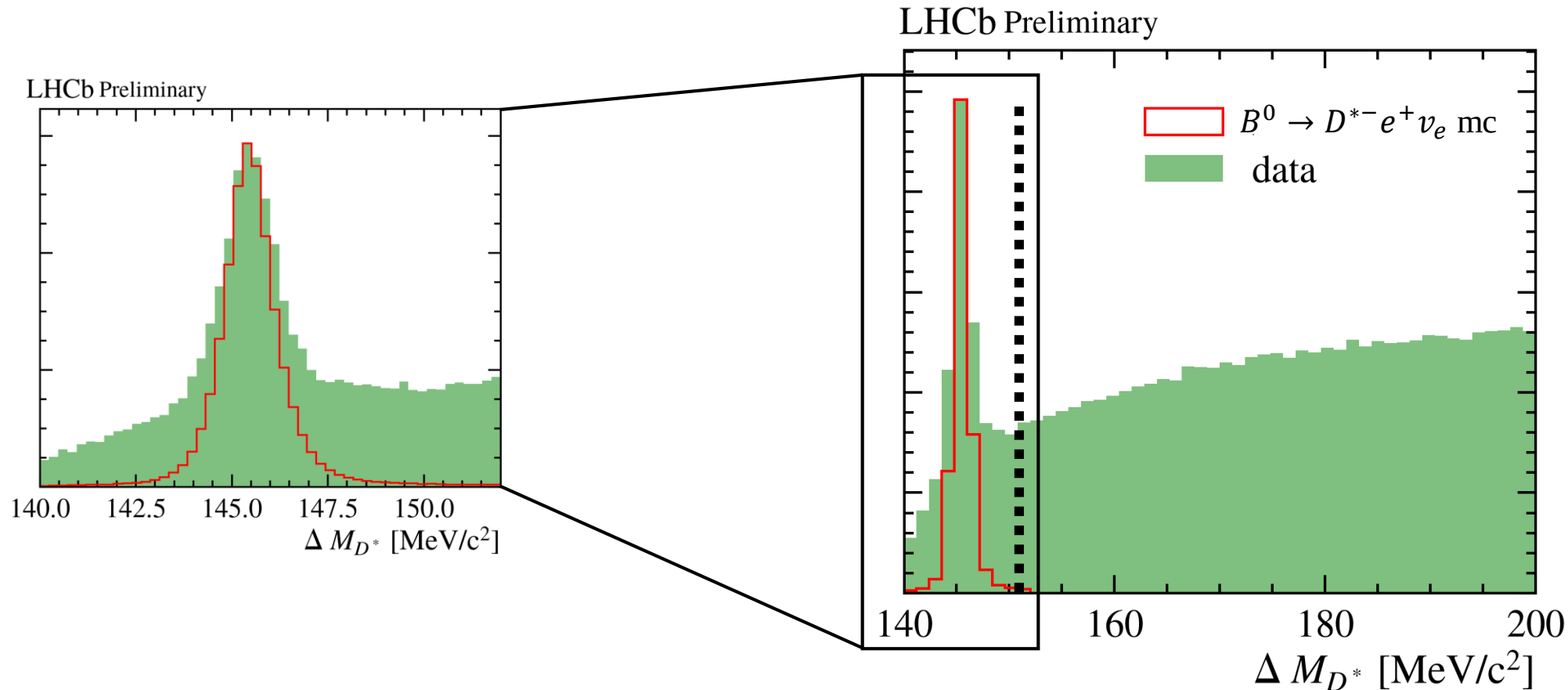


Construct templates from control data



Fake $D^{*-}(\bar{D}^0 + \text{random } \pi^-)$ suppression

Selection on $\Delta M_{D^*} \equiv |M_{D^*} - M_{D^0}|$ rejects backgrounds from random pion



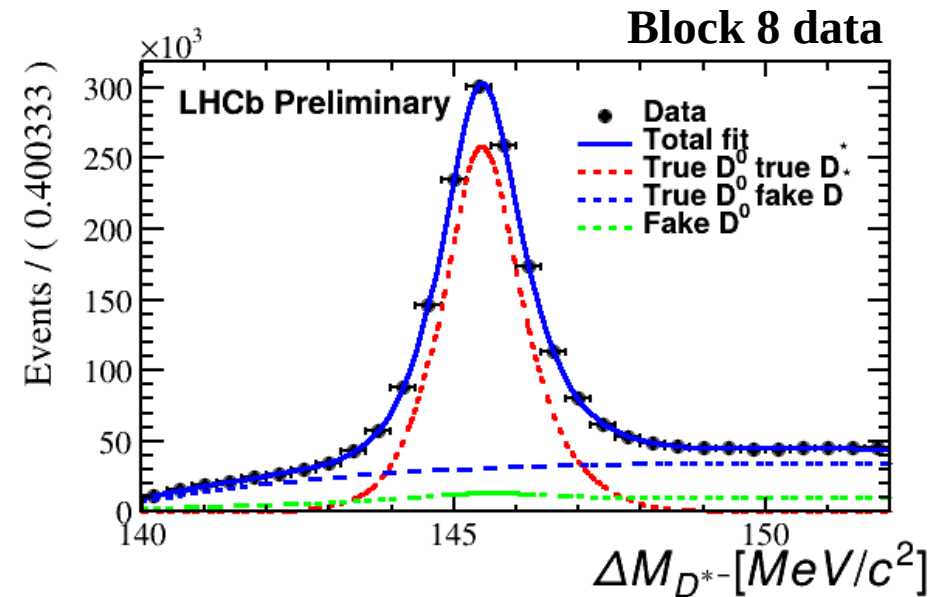
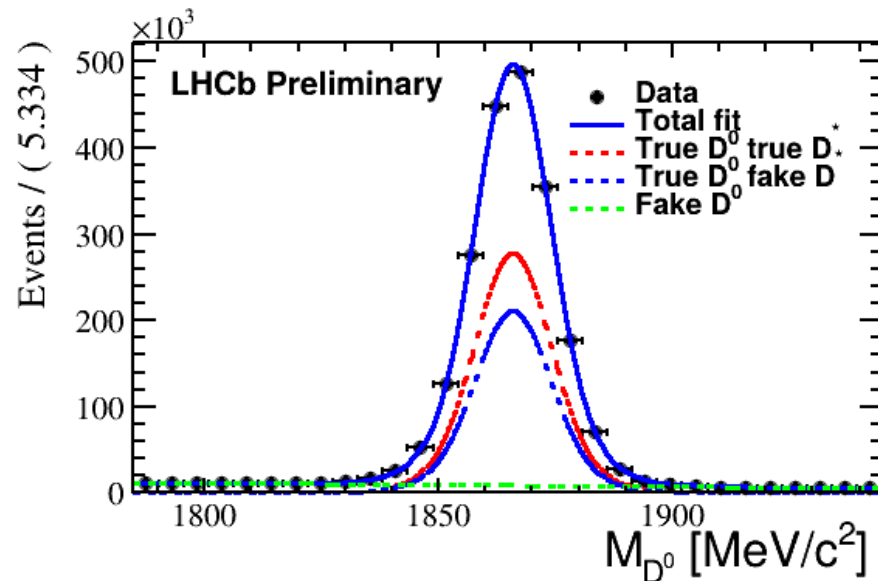
Still combinatorial background remaining

Fake D^{*-} and $\bar{D}^0$ suppression

To project out the remaining backgrounds from

- $D^{*-}(\bar{D}^0 + \text{random } \pi^-)$ combinations (True D^0 Fake D^*)
- Fake $\bar{D}^0$ candidates (Fake D^0)

$sWeight$ technique is used and the weight is computed by performing 2D $M_{D^0} \times \Delta M_{D^*}$ binned-fit on data.

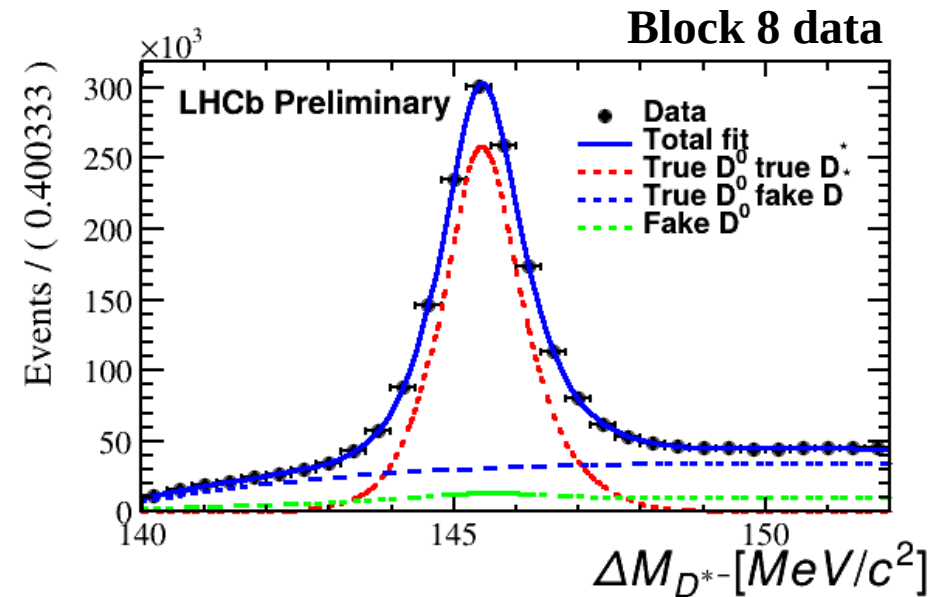
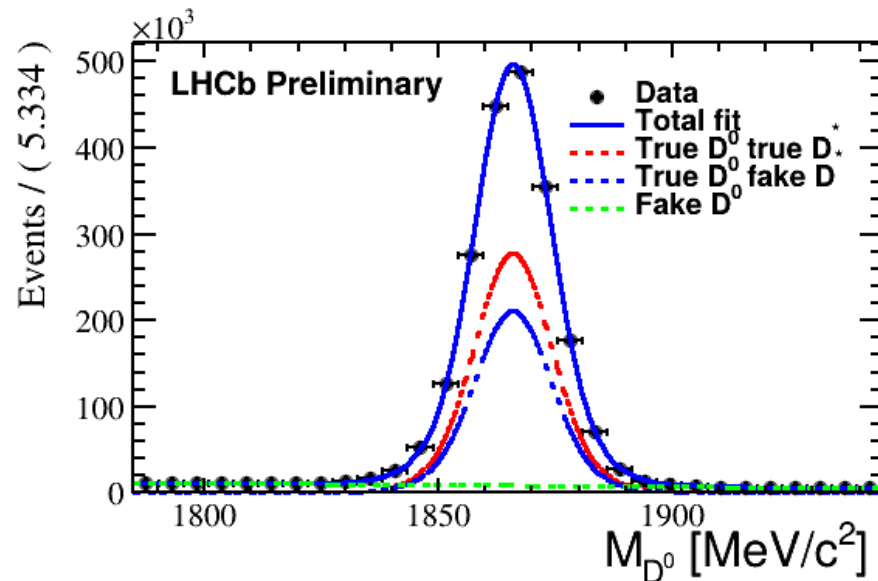


Fake D^{*-} and $\bar{D}^0$ suppression

To project out the remaining backgrounds from

- $D^{*-}(\bar{D}^0 + \text{random } \pi^-)$ combinations (True D^0 Fake D^*)
- Fake $\bar{D}^0$ candidates (Fake D^0)

$sWeight$ technique is used and the weight is computed by performing 2D $M_{D^0} \times \Delta M_{D^*}$ binned-fit on data.



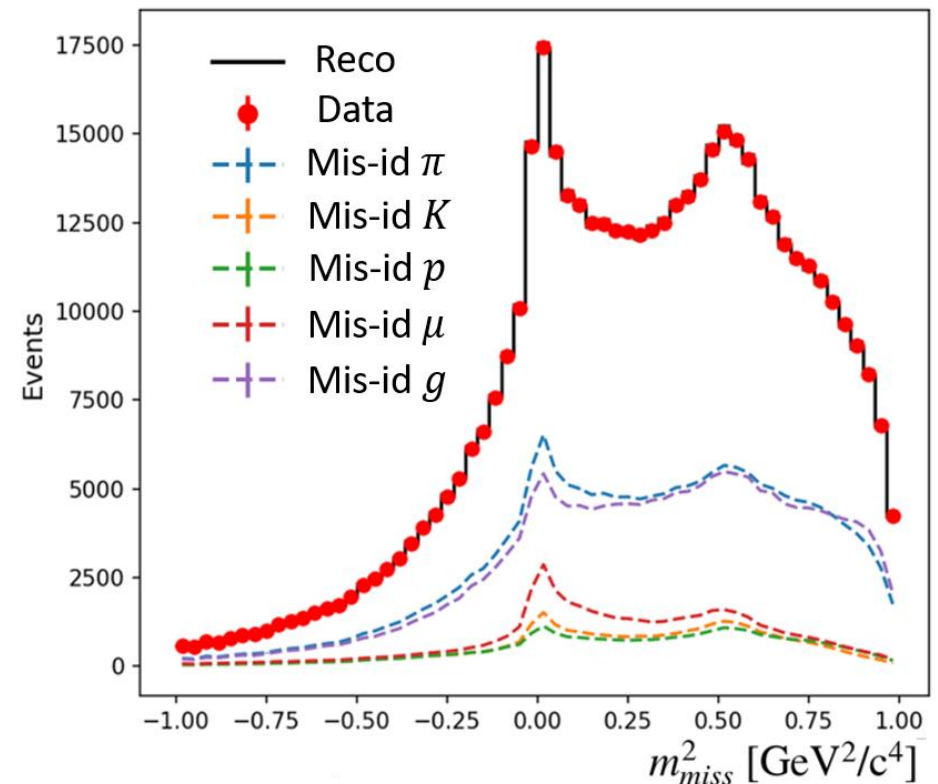
Apply the weight on data to suppress background

Mis-identification background

π, K, p, μ and ghost tracks are mis-identified as signal electrons

A **mis-ID-enriched data control sample** is selected by reversing the electron-ID requirement

Templates are **constructed from this control sample** and used to model the mis-ID background in the fit

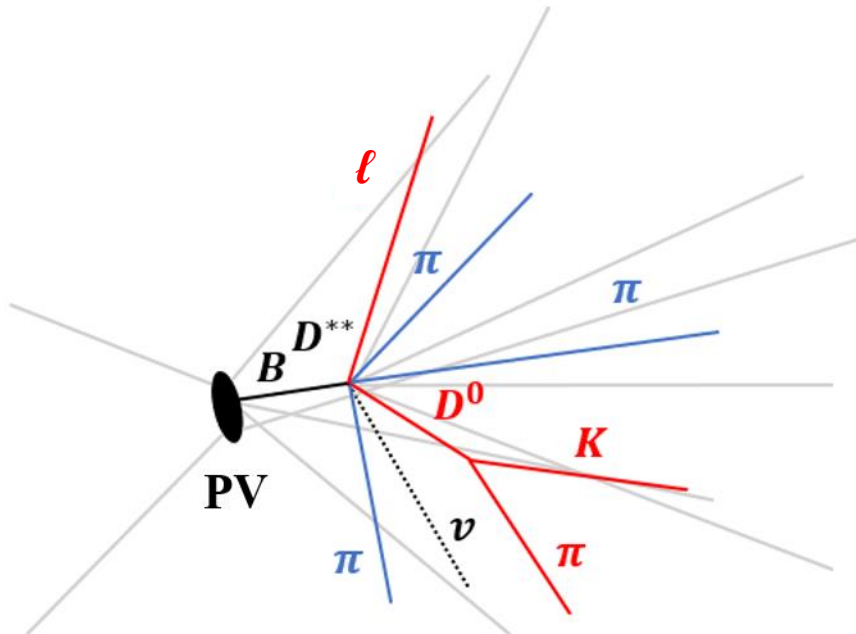
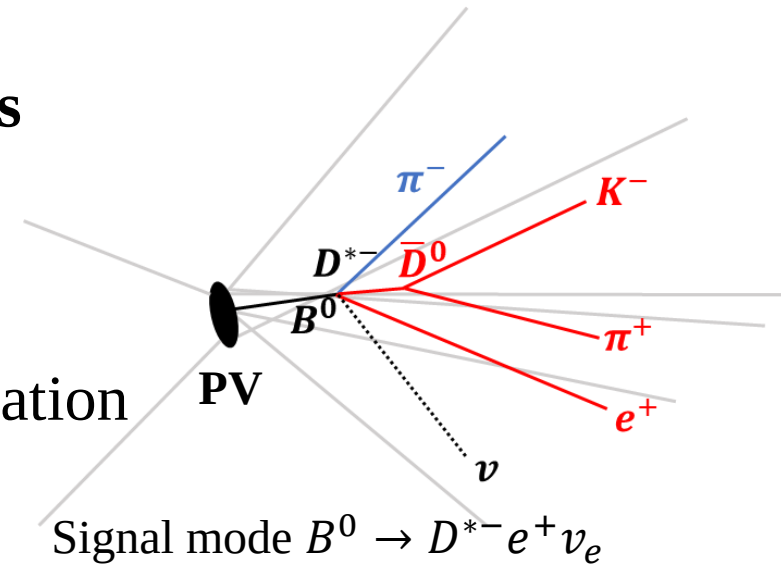


Physics background

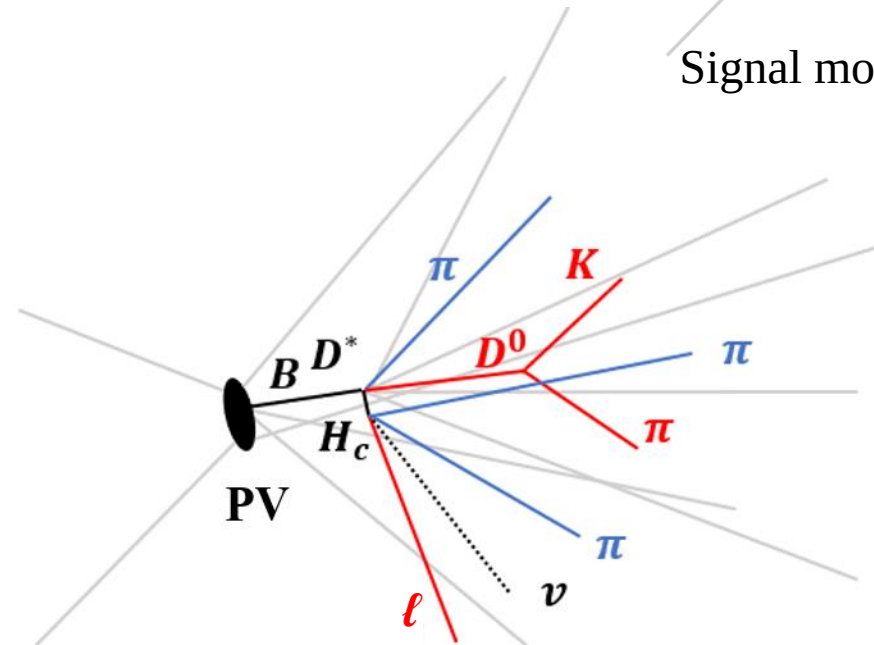
Dominant background in the previous LHCb $R(D^*)_{\tau/\mu}$ analyses

Background treatment :

- Suppressed using vertex isolation
- In the fit, model with dedicated templates constructed from simulation



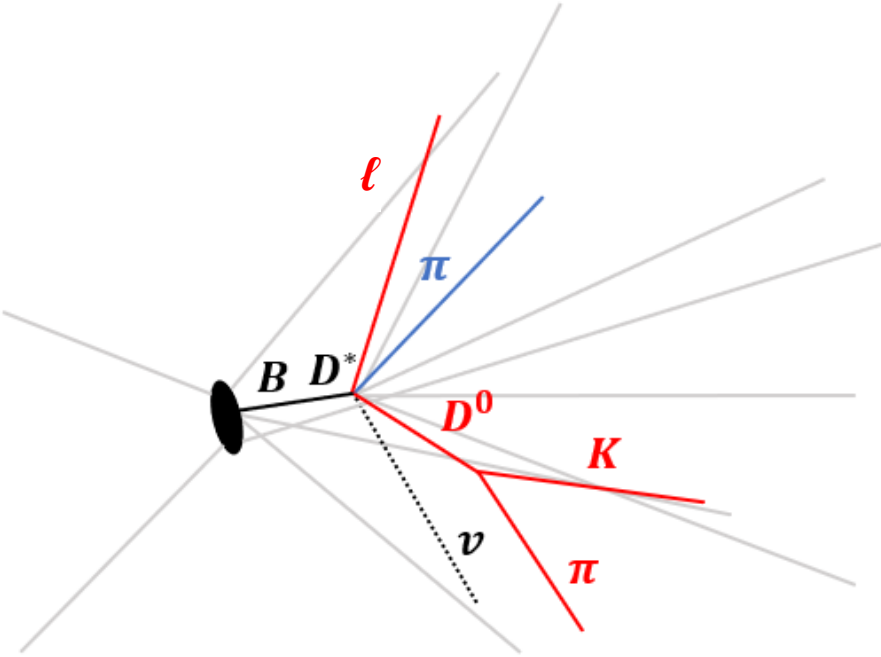
Higher excited background



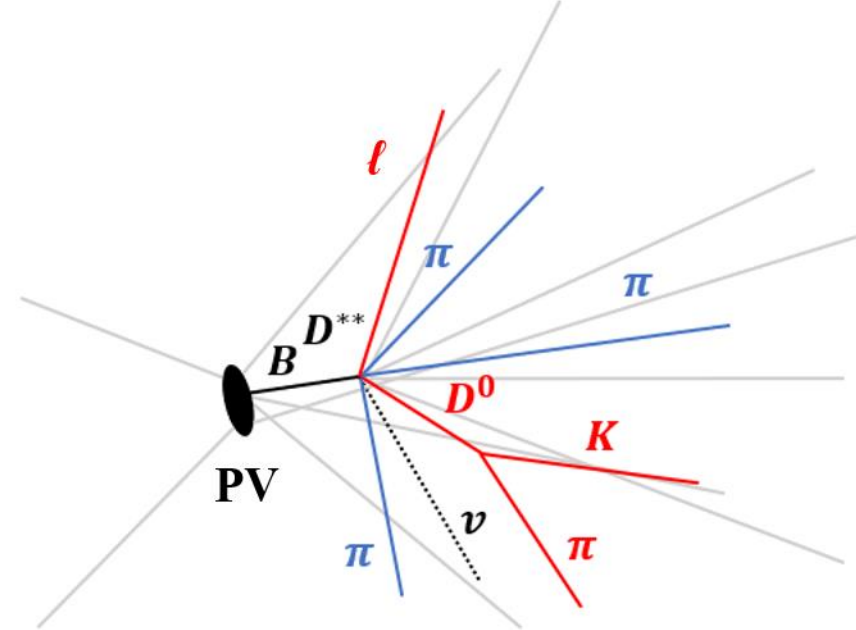
Double charmed background

Noted : ℓ denotes e or τ

Vertex isolation



$B^0 \rightarrow D^{*-} \ell^+ \nu_\ell$ signal : only single high MVA π

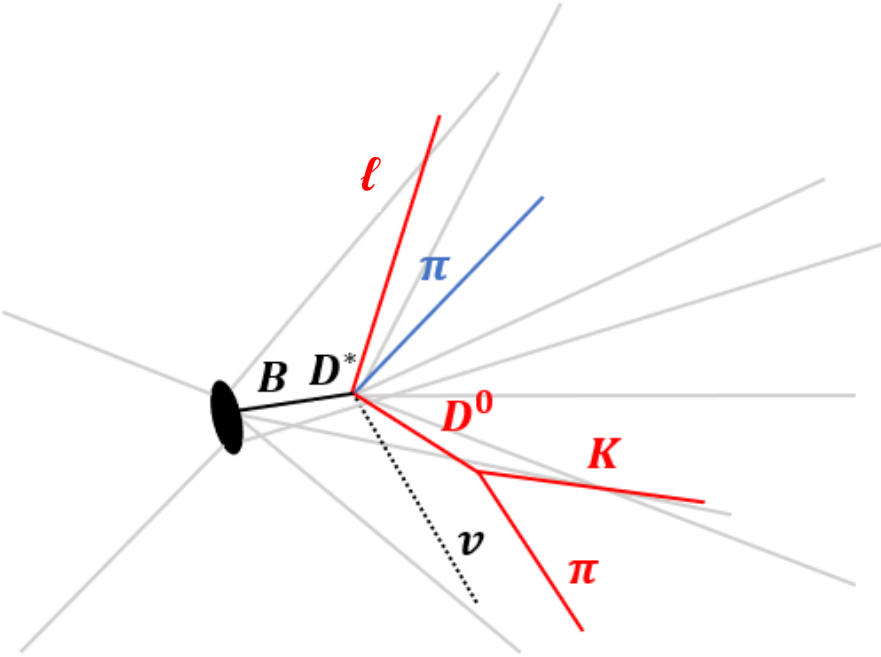


$B^0 \rightarrow D^{*-} (\rightarrow D^* n\pi) \ell^+ \nu_\ell$ bkg : multiple high MVA π 's

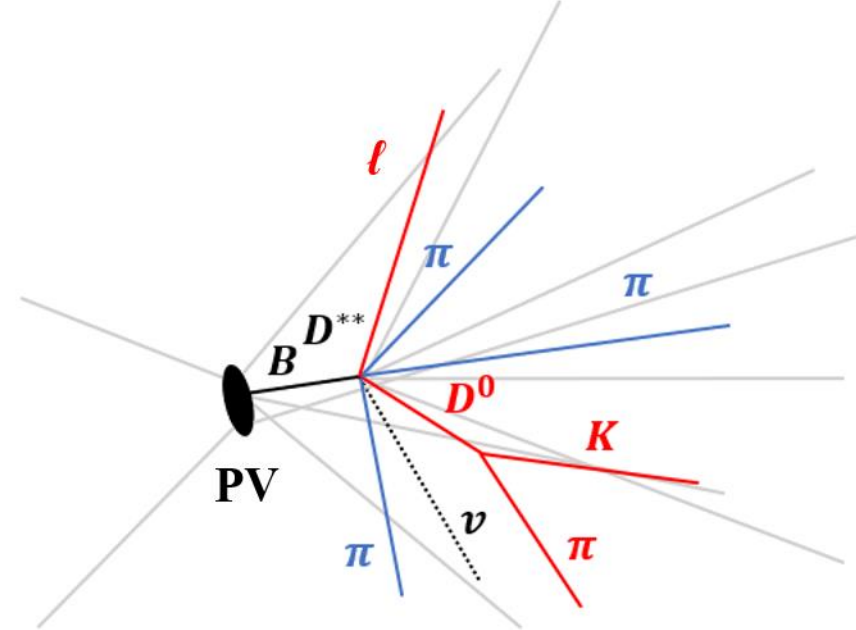
The IMI MVA is used to reject this background

We remove the events containing multiple extra pions with high IMI scores

Vertex isolation



$B^0 \rightarrow D^{*-} \ell^+ \nu_\ell$ signal : only single high MVA π



$B^0 \rightarrow D^{*-} (\rightarrow D^* n\pi) \ell^+ \nu_\ell$ bkg : multiple high MVA π 's

After vertex-isolation,

- The retention rate is around **(10-80) %** across different background channels
- Retain more than **85 %** signal candidates

$R(D^*)_{\tau/e}$ extraction

$R(D^*)_{\tau/e}$ determination

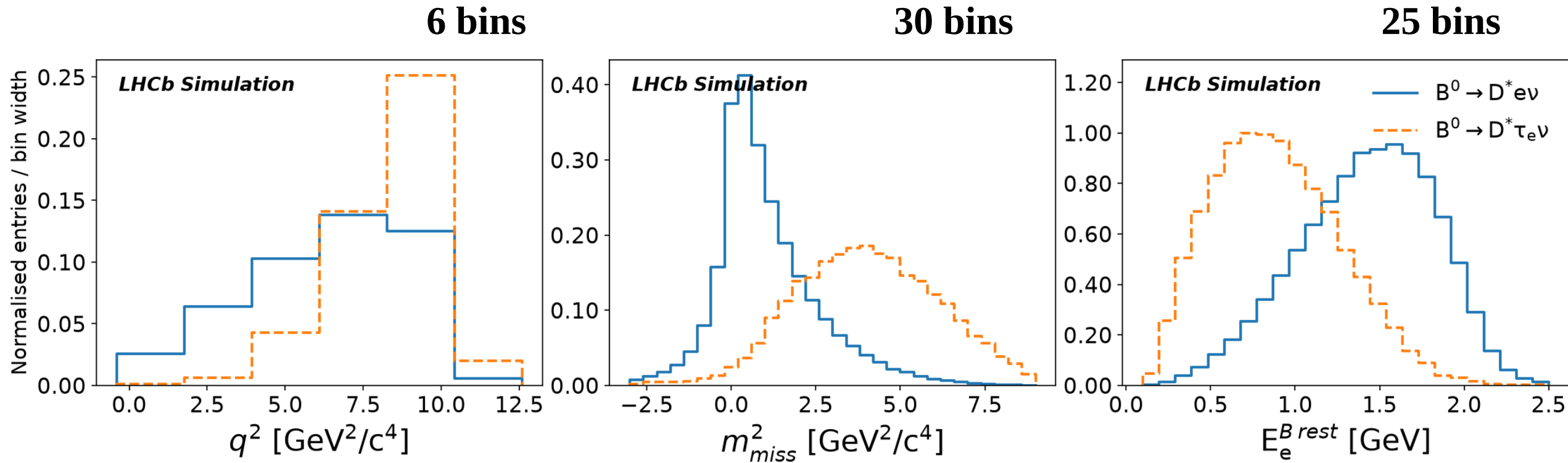
$$R(D^*)_{\tau/e} \equiv \frac{BR(B^0 \rightarrow D^{*-} \tau^+ \nu_\tau)}{BR(B^0 \rightarrow D^{*-} e^+ \nu_e)}, \text{ where } \tau^+ \rightarrow e^+ \nu_e \bar{\nu}_\tau$$

$$= \left[\frac{N(B^0 \rightarrow D^{*-} \tau^+ \nu_\tau)}{N(B^0 \rightarrow D^{*-} e^+ \nu_e)} \right] \times \left[\frac{\epsilon(B^0 \rightarrow D^{*-} e^+ \nu_e)}{\epsilon(B^0 \rightarrow D^{*-} \tau^+ \nu_\tau)} \right] \quad \text{Evaluated in MC}$$

Extracted from a 3D ($q^2 \times M_{miss}^2 \times E_e^*$) binned template fit

Template preparation - binning scheme

The templates are constructed based on the following binning scheme



Template preparation

Signal modes and physics backgrounds

- Templates are constructed using simulation samples
- 13 (decay modes) $\times$ 2 (brems category) $\times$ 4 (blocks) templates

Combinatorial $B^0 \rightarrow D^{*-} e^+$ and mis-identified electron backgrounds

- Templates are constructed using control data
- 2 (comb., mis ID) $\times$ 2 (brems category) $\times$ 4 (blocks) templates

Bremsstrahlung fraction in fitter

The bremsstrahlung fractions serve as bridge to connect datasets with and w/o bremsstrahlung recovery,

$$N_{\text{with brem}}^{\text{data}} = \sum_{t \in \text{template}} N_t \cdot f_t$$

$$N_{\text{w/o brem}}^{\text{data}} = \sum_{t \in \text{template}} N_t \cdot (1 - f_t)$$

N_t : yield of template t

f_t : bremsstrahlung fraction of template t

The fractions are extracted from MC samples, and treated differently due to the difference in the electron kinematic across different decays

Bremsstrahlung fraction

Calibrated Bremsstrahlung correction fractions in simulation samples.

Decay Channel	Block 5	Block 6	Block 7	Block 8
$B^0 \rightarrow D^{*-} e^+ \nu_e$	0.60 ± 0.03	0.59 ± 0.03	0.59 ± 0.03	0.62 ± 0.05
$B^0 \rightarrow D^{*-} \tau^+ \nu_\tau$	0.57 ± 0.03	0.56 ± 0.03	0.54 ± 0.03	0.56 ± 0.04
$B^0 \rightarrow D_{0,1,2}^{*-} e^+ \nu_e$	0.59 ± 0.03	0.58 ± 0.03	0.56 ± 0.03	0.59 ± 0.05
$B^0 \rightarrow D_{0,1,2}^{*-} \tau^+ \nu_\tau$	0.57 ± 0.03	0.57 ± 0.03	0.52 ± 0.03	0.59 ± 0.05
$B^+ \rightarrow D_{0,1,2}^{*0} e^+ \nu_e$	0.58 ± 0.03	0.58 ± 0.03	0.56 ± 0.03	0.59 ± 0.05
$B^+ \rightarrow D_{0,1,2}^{*0} \tau^+ \nu_\tau$	0.57 ± 0.03	0.55 ± 0.03	0.53 ± 0.03	0.56 ± 0.04
$B^0 \rightarrow (D_{1,2}^{*-} / D^{(*)}(2S)^-) e^+ \nu_e$	0.58 ± 0.03	0.57 ± 0.03	0.56 ± 0.04	0.57 ± 0.05
$B^+ \rightarrow (D_{1,2}^{*0} / D^{(*)}(2S)^0) e^+ \nu_e$	0.58 ± 0.03	0.57 ± 0.03	0.57 ± 0.04	0.58 ± 0.05
$B_s^0 \rightarrow (D_{s1}^- (2536) / D_{s2}^- (2573)) e^+ \nu_e$	0.59 ± 0.03	0.59 ± 0.03	0.56 ± 0.03	0.60 ± 0.05
$B^0 \rightarrow D^0 (X_c \rightarrow e^+ \nu_e X') X$	0.55 ± 0.03	0.53 ± 0.03	0.50 ± 0.03	0.53 ± 0.05
$B^+ \rightarrow D^0 (X_c \rightarrow e^+ \nu_e X') X$	0.54 ± 0.03	0.53 ± 0.03	0.51 ± 0.04	0.52 ± 0.05
$B^0 \rightarrow D^0 (D_s^- \rightarrow \tau^+ \nu_\tau) X$	0.59 ± 0.03	0.56 ± 0.03	0.54 ± 0.04	0.56 ± 0.05
$B^+ \rightarrow D^0 (D_s^- \rightarrow \tau^+ \nu_\tau) X$	0.58 ± 0.03	0.57 ± 0.03	0.54 ± 0.04	0.57 ± 0.05

* X_c denotes an inclusive charm-hadron state.

* X and X' denote a system of any additional final-state particles.

Bremsstrahlung fraction

Re-evaluate common f across all blocks based on the lumi to reduce the # of fitting variables

Decay Channel	Block 5	Block 6	Block 7	Block 8	
$B^0 \rightarrow D^{*-} e^+ \nu_e$	0.60 ± 0.03	0.59 ± 0.03	0.59 ± 0.03	0.62 ± 0.05	— $f_{D^{*}ev}$
$B^0 \rightarrow D^{*-} \tau^+ \nu_\tau$	0.57 ± 0.03	0.56 ± 0.03	0.54 ± 0.03	0.56 ± 0.04	— $f_{D^{*}\tau\nu}$
$B^0 \rightarrow D_{0,1,2}^{*-} e^+ \nu_e$	0.59 ± 0.03	0.58 ± 0.03	0.56 ± 0.03	0.59 ± 0.05	} $f_{D^{**}\tau\nu}$
$B^0 \rightarrow D_{0,1,2}^{*-} \tau^+ \nu_\tau$	0.57 ± 0.03	0.57 ± 0.03	0.52 ± 0.03	0.59 ± 0.05	
$B^+ \rightarrow D_{0,1,2}^{*0} e^+ \nu_e$	0.58 ± 0.03	0.58 ± 0.03	0.56 ± 0.03	0.59 ± 0.05	
$B^+ \rightarrow D_{0,1,2}^{*0} \tau^+ \nu_\tau$	0.57 ± 0.03	0.55 ± 0.03	0.53 ± 0.03	0.56 ± 0.04	
$B^0 \rightarrow (D_{1,2}^{*-} / D^{(*)} (2S)^-) e^+ \nu_e$	0.58 ± 0.03	0.57 ± 0.03	0.56 ± 0.04	0.57 ± 0.05	} $f_{D^{**}ev}$
$B^+ \rightarrow (D_{1,2}^{*0} / D^{(*)} (2S)^0) e^+ \nu_e$	0.58 ± 0.03	0.57 ± 0.03	0.57 ± 0.04	0.58 ± 0.05	
$B_s^0 \rightarrow (D_{s1}^- (2536) / D_{s2}^- (2573)) e^+ \nu_e$	0.59 ± 0.03	0.59 ± 0.03	0.56 ± 0.03	0.60 ± 0.05	— $f_{D_s ev}$
$B^0 \rightarrow D^0 (X_c \rightarrow e^+ \nu_e X') X$	0.55 ± 0.03	0.53 ± 0.03	0.50 ± 0.03	0.53 ± 0.05	} $f_{D^0 X_c e}$
$B^+ \rightarrow D^0 (X_c \rightarrow e^+ \nu_e X') X$	0.54 ± 0.03	0.53 ± 0.03	0.51 ± 0.04	0.52 ± 0.05	
$B^0 \rightarrow D^0 (D_s^- \rightarrow \tau^+ \nu_\tau) X$	0.59 ± 0.03	0.56 ± 0.03	0.54 ± 0.04	0.56 ± 0.05	} $f_{D^0 D_s^- \tau}$
$B^+ \rightarrow D^0 (D_s^- \rightarrow \tau^+ \nu_\tau) X$	0.58 ± 0.03	0.57 ± 0.03	0.54 ± 0.04	0.57 ± 0.05	

Some decays are grouped to share common f to reduce the # of fitting variables

Bremsstrahlung fraction after grouping

Decay category	Combined blocks
$B^0 \rightarrow D^{*-} e^+ \nu_e$	0.598 ± 0.016
$B^0 \rightarrow D^{*-} \tau^+ \nu_\tau$	0.561 ± 0.016
$D^{**} e \nu$	0.574 ± 0.009
$D^{**} \tau \nu$	0.565 ± 0.014
$B_s^0 \rightarrow (D_{s1}^-(2536) / D_{s2}^-(2573)) e^+ \nu_e$	0.588 ± 0.016
Double charm (e)	0.529 ± 0.013
Double charm ($\tau \rightarrow e$)	0.566 ± 0.013

Serve as initial values in the fitter

Overview of the fitter

To extract $R(D^*)_{\tau/e}$, the blocks 5-8 data are **fitted simultaneously**.

BRs, $R(D^*)_{\tau/e}$ and f are common variables across blocks 5-8 data.

Overview of the fitter

In block b and brems category c,

$$R(D^*)_{\tau/e} \equiv \frac{BR(B^0 \rightarrow D^{*-} \tau^+ \nu_\tau)}{BR(B^0 \rightarrow D^{*-} e^+ \nu_e)}$$

Component

Yields in bremsstrahlung category c

Signal

$$B^0 \rightarrow D^{*-} e^+ \nu_e$$

$$\mathcal{B}(B^0 \rightarrow D^{*-} e \nu) \times N_B^{b\ddagger} \times \epsilon_{B^0 \rightarrow D^{*-} e \nu}^{b\ddagger} \times \alpha_c(f_{B^0 \rightarrow D^{*-} e \nu})$$

$$B^0 \rightarrow D^{*-} \tau^+ \nu_\tau$$

$$\mathcal{B}(B^0 \rightarrow D^{*-} e \nu) \times R(D^*) \times N_B^{b\ddagger} \times \epsilon_{B^0 \rightarrow D^{*-} \tau \nu}^{b\ddagger} \times \alpha_c(f_{B^0 \rightarrow D^{*-} \tau \nu})$$

 : Floated parameter

$$\alpha_c(f) = \begin{cases} f, & \text{when } c = \text{with brem} \\ 1 - f, & \text{when } c = \text{without brem} \end{cases}$$

Overview of the fitter

In block b and brems category c,

$$R(D^{**}) \equiv \frac{BR(B \rightarrow D^{**}\tau\nu)}{BR(B \rightarrow D^{**}\mu\nu)} \quad \text{LHCb } R(D^{**}) \text{ result}$$

D^{**} & B_s^0 Backgrounds

$$B^{(0,+)} \rightarrow D_{0,1,2}^{**} e^+ \nu_e$$

$$\mathcal{B}(B^{(0,+)} \rightarrow D_{0,1,2}^{**} e^+ \nu_e) \times N_B^{b\ddagger} \times \epsilon_{B^{(0,+)} \rightarrow D_{0,1,2}^{**} e^+ \nu_e}^{b\ddagger} \times \alpha_c(f_{D^{**}e\nu})$$

$$B^{(0,+)} \rightarrow D_{0,1,2}^{**} \tau^+ \nu_\tau$$

$$\mathcal{B}(B^{(0,+)} \rightarrow D_{0,1,2}^{**} e^+ \nu_e) \times R(D^{**})^\dagger \times N_B^{b\ddagger} \times \epsilon_{B^{(0,+)} \rightarrow D_{0,1,2}^{**} \tau^+ \nu_\tau}^{b\ddagger} \times \alpha_c(f_{D^{**}\tau\nu}^\dagger)$$

$$B^{(0,+)} \rightarrow (D_{1,2}^{**}/D(2S)) e^+ \nu_e$$

$$\mathcal{B}(B^{(0,+)} \rightarrow (D_{1,2}^{**}/D(2S)) e^+ \nu_e) \times N_B^{b\ddagger} \times \epsilon_{B^{(0,+)} \rightarrow (D_{1,2}^{**}/D(2S)) e^+ \nu_e}^{b\ddagger} \times \alpha_c(f_{D^{**}e\nu})$$

$$B_s^0 \rightarrow D_{s1,s2} e^+ \nu_e$$

$$\mathcal{B}^\dagger(B_s^0 \rightarrow D_{s1,s2} e^+ \nu_e) \times N_{B_s}^{b\ddagger} \times \epsilon_{B_s^0 \rightarrow D_{s1,s2} e^+ \nu_e}^{b\ddagger} \times \alpha_c(f_{B_s^0 \rightarrow D_s^- e^+ \nu_e}^\dagger)$$

 : Floated parameter

 : Gaussian constrained parameter

$$\alpha_c(f) = \begin{cases} f, & \text{when } c = \text{with brem} \\ 1 - f, & \text{when } c = \text{without brem} \end{cases}$$

Overview of the fitter

In block b and brems category c,

Double charm Backgrounds

$$B^{(0,+)} \rightarrow D^0(X_c \rightarrow e^+ \nu_e X') X \quad \mathcal{B}(B^{(0,+)} \rightarrow D^0(X_c \rightarrow e^+ \nu_e X') X) \times N_B^{b\ddagger} \times \epsilon_{B^{(0,+)} \rightarrow D^0(X_c \rightarrow e^+ \nu_e X') X}^{b\ddagger} \times \alpha_c(f_{B^{(0,+)} \rightarrow D^0 X_c e}^\ddagger)$$

$$B^{(0,+)} \rightarrow D^0(D_s^- \rightarrow \tau^+ \nu_\tau) X \quad \mathcal{B}^\dagger(B^{(0,+)} \rightarrow D^0(D_s^- \rightarrow \tau^+ \nu_\tau) X) \times N_B^{b\ddagger} \times \epsilon_{B^{(0,+)} \rightarrow D^0(D_s^- \rightarrow \tau^+ \nu_\tau) X}^{b\ddagger} \times \alpha_c(f_{B^{(0,+)} \rightarrow D^0 D_s \tau}^\ddagger)$$

WS $D^{*-} e^-$ and mis-ID Backgrounds

$$\text{WS } D^{*-} e^- \quad \mu_{\text{WS } D^{*-} e^-}^b \times \alpha_c^b(f_{\text{WS } D^{*-} e^-}^\ddagger)$$

$$\text{mis-ID} \quad \mu_{\text{mis-ID}}^b \times \alpha_c^b(f_{\text{mis-ID}}^\ddagger)$$

Brems fractions obtained from data-driven templates are fixed

 : Floated parameter

 : Gaussian constrained parameter

$$\alpha_c(f) = \begin{cases} f, & \text{when } c = \text{with brem} \\ 1 - f, & \text{when } c = \text{without brem} \end{cases}$$

Overview of the fitter

In block b and brems category c,

Double charm Backgrounds

$B^{(0,+)} \rightarrow D^0(X_c \rightarrow e^+ \nu_e X') X$
 $\mathcal{B}(B^{(0,+)} \rightarrow D^0(X_c \rightarrow e^+ \nu_e X') X) \times N_B^{b\ddagger} \times \epsilon_{B^{(0,+)} \rightarrow D^0(X_c \rightarrow e^+ \nu_e X') X}^{b\ddagger} \times \alpha_c(f_{B^{(0,+)} \rightarrow D^0 X_c e}^\ddagger)$

$B^{(0,+)} \rightarrow D^0(D_s^- \rightarrow \tau^+ \nu_\tau) X$
 $\mathcal{B}^\dagger(B^{(0,+)} \rightarrow D^0(D_s^- \rightarrow \tau^+ \nu_\tau) X) \times N_B^{b\ddagger} \times \epsilon_{B^{(0,+)} \rightarrow D^0(D_s^- \rightarrow \tau^+ \nu_\tau) X}^{b\ddagger} \times \alpha_c(f_{B^{(0,+)} \rightarrow D^0 D_s \tau}^\ddagger)$

WS $D^{*-} e^-$ and mis-ID Backgrounds

$WS D^{*-} e^-$
 $\mu_{WS D^{*-} e^-}^b \times \alpha_c^b(f_{WS D^{*-} e^-}^\ddagger)$

mis-ID

- 19 free parameters
8 Gaussian constrained parameters
23 fixed parameters (including efficiencies, number of produced B mesons and brems ratio for mis-ID and comb. $D^{*-} e^+$ components)

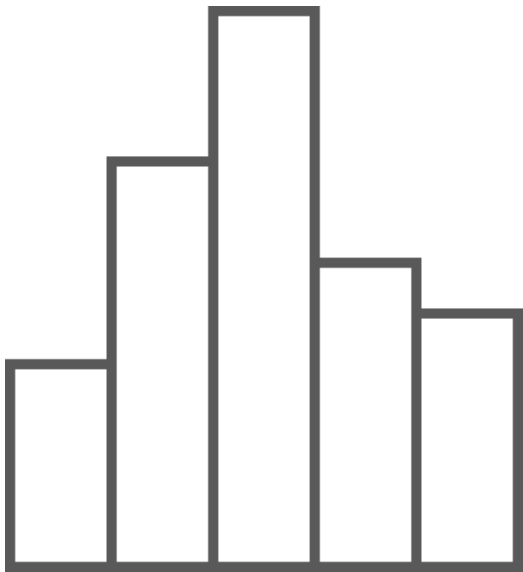
from fixed

: Fld

 $\alpha_c(f) = \begin{cases} f, \\ 1 - \end{cases}$

Blinded fit setup & procedure

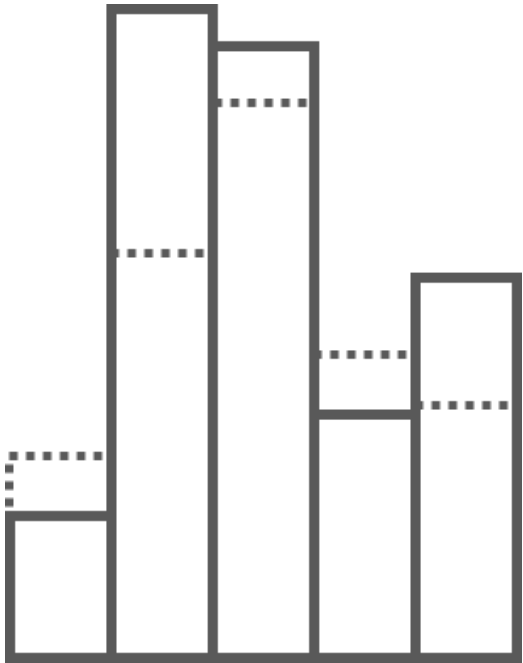
Setup :
Simultaneous fit to **blocks 5 - 8** in **two bremsstrahlung categories** with **Beeston Barlow (BB) lite method**



Default template



Allows each bin scaling factor to vary during minimization



Template varied with BB lite

Bin index	1	2	3	4	5
Fitted scaled factor	0.7	1.6	1.1	0.8	1.5

Blinded fit setup & procedure

Setup :

Simultaneous fit to **blocks 5 - 8** in **two bremsstrahlung categories** with **Beeston Barlow (BB) lite method**

$R(D^*)$ and $B^0 \rightarrow D^{*-} e^+ \nu_e$ branching fraction are **blinded by hidden scale factors**

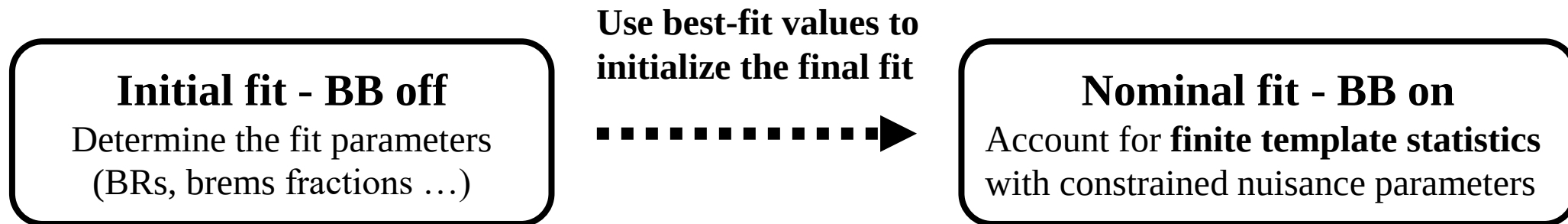
Blinded fit setup & procedure

Setup :

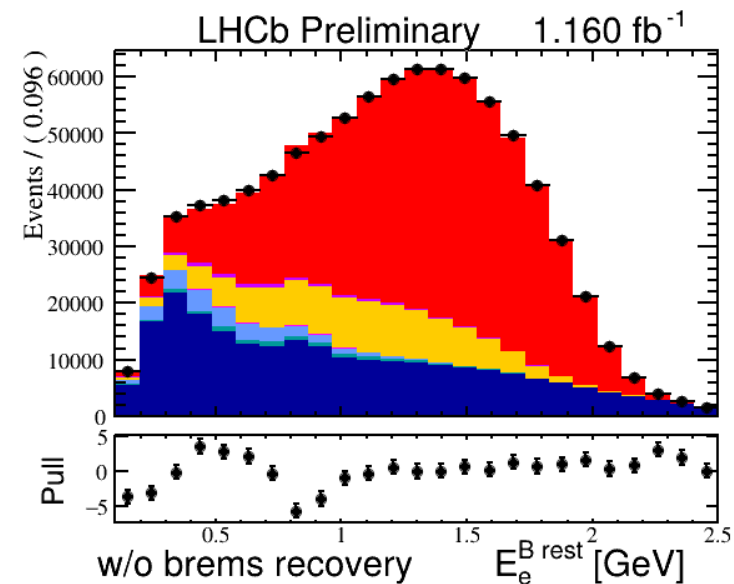
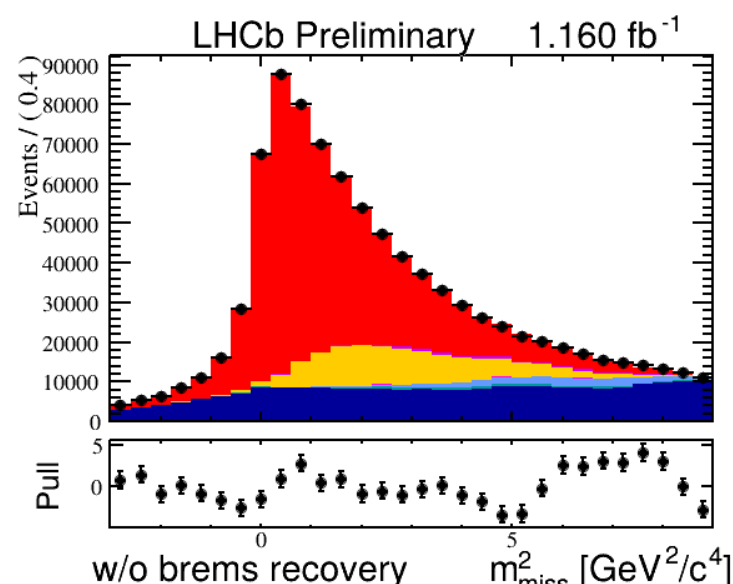
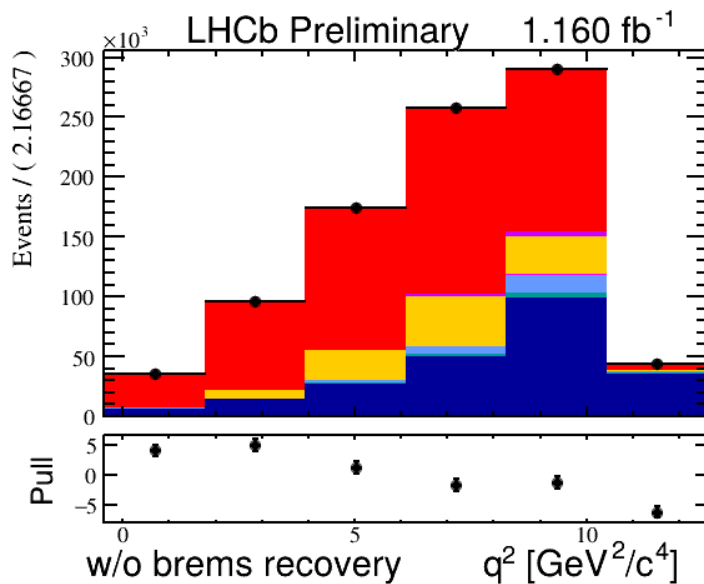
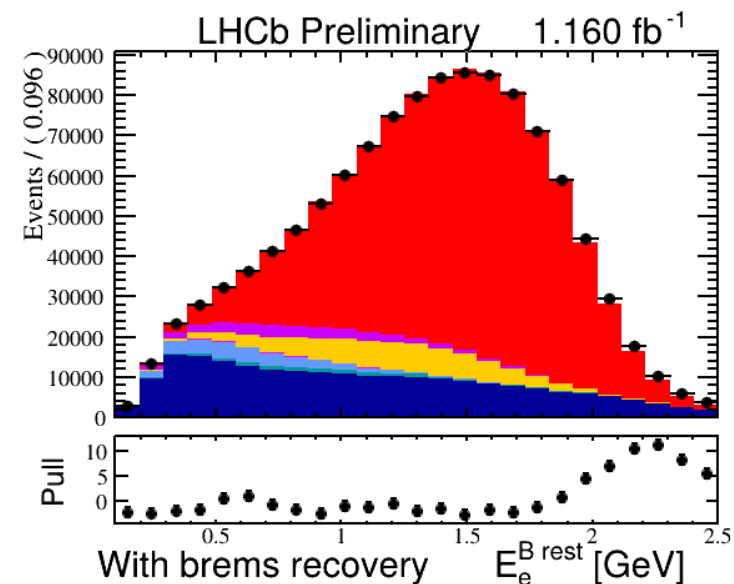
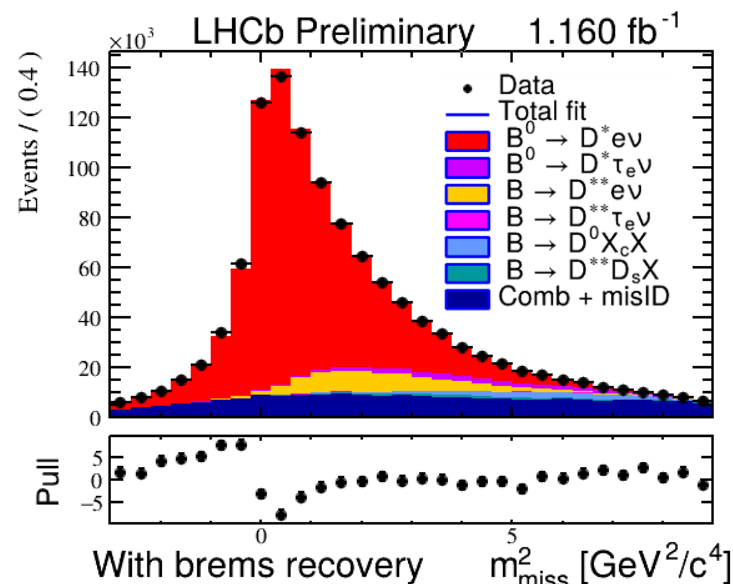
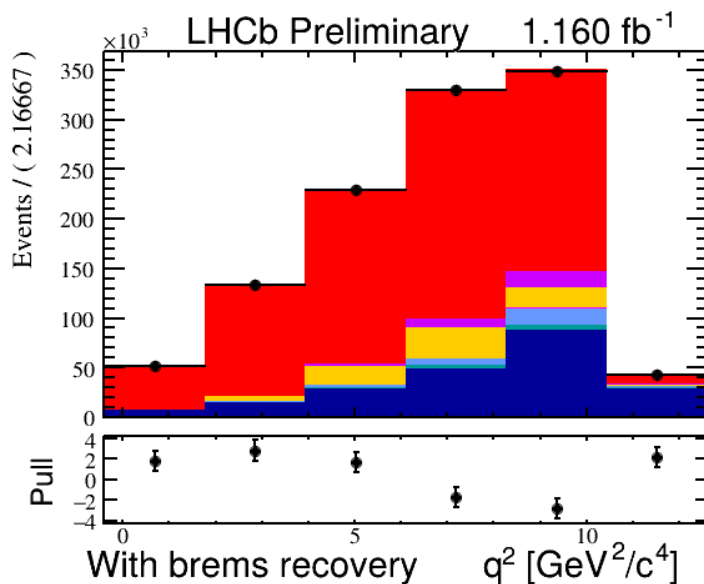
Simultaneous fit to **blocks 5 - 8** in **two bremsstrahlung categories** with **Beeston Barlow (BB) lite method**

$R(D^*)$ and $B^0 \rightarrow D^{*-} e^+ \nu_e$ branching fraction are **blinded by hidden scale factors**

Procedure :



Fit result - block 5 data



Preliminary blinded result : $R(D^*)_{\tau/e}$ and $B^0 \rightarrow D^{*-} e^+ \nu_e$ branching fraction

Free parameters	
$\mathcal{B}(B^0 \rightarrow D^{*-} e^+ \nu_e)$	$(1.776 \pm 0.003) \times 10^{-4}$
$R(D^*)$	0.027 ± 0.002

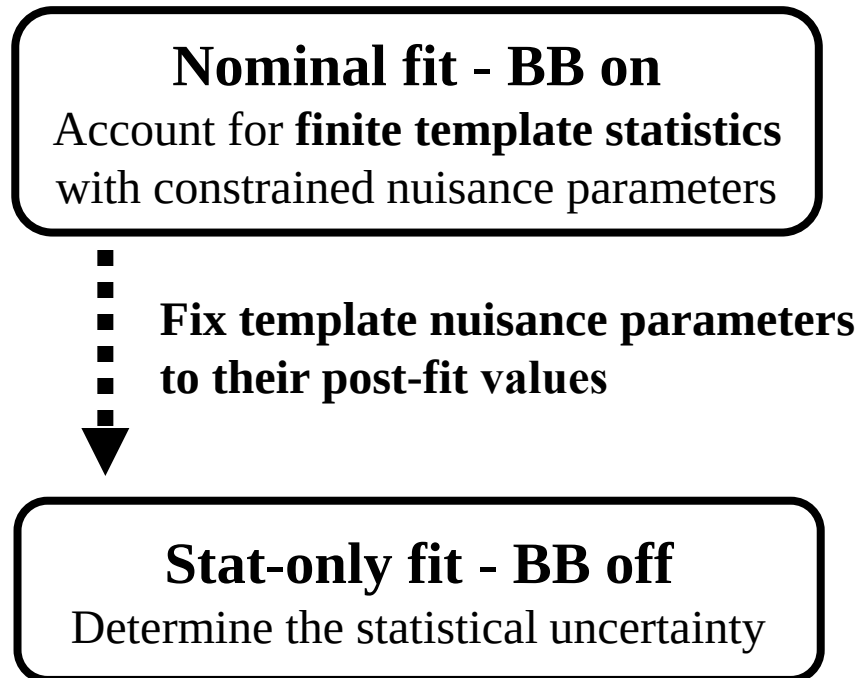
Blinded results including template size uncertainty

Preliminary blinded result : $R(D^*)_{\tau/e}$ and $B^0 \rightarrow D^{*-} e^+ \nu_e$ branching fraction

Free parameters	
$\mathcal{B}(B^0 \rightarrow D^{*-} e^+ \nu_e)$	$(1.776 \pm 0.003) \times 10^{-4}$
$R(D^*)$	0.027 ± 0.002

Blinded results including template size uncertainty

To evaluate the **pure statistical uncertainty**,

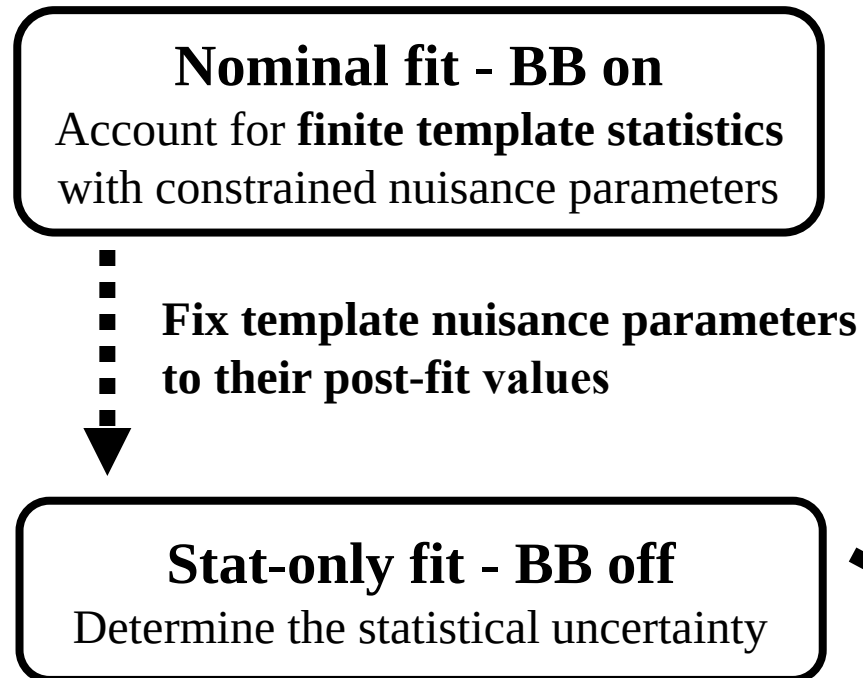


Preliminary blinded result : $R(D^*)_{\tau/e}$ and $B^0 \rightarrow D^{*-} e^+ \nu_e$ branching fraction

Free parameters	
$\mathcal{B}(B^0 \rightarrow D^{*-} e^+ \nu_e)$	$(1.776 \pm 0.003) \times 10^{-4}$
$R(D^*)$	0.027 ± 0.002

Blinded results including template size uncertainty

To evaluate the **pure statistical uncertainty**,



Updated since thesis submission

$$R(D^*) \quad 0.027 \pm 0.001(\text{stat}) \pm 0.002(\text{temp. size})$$

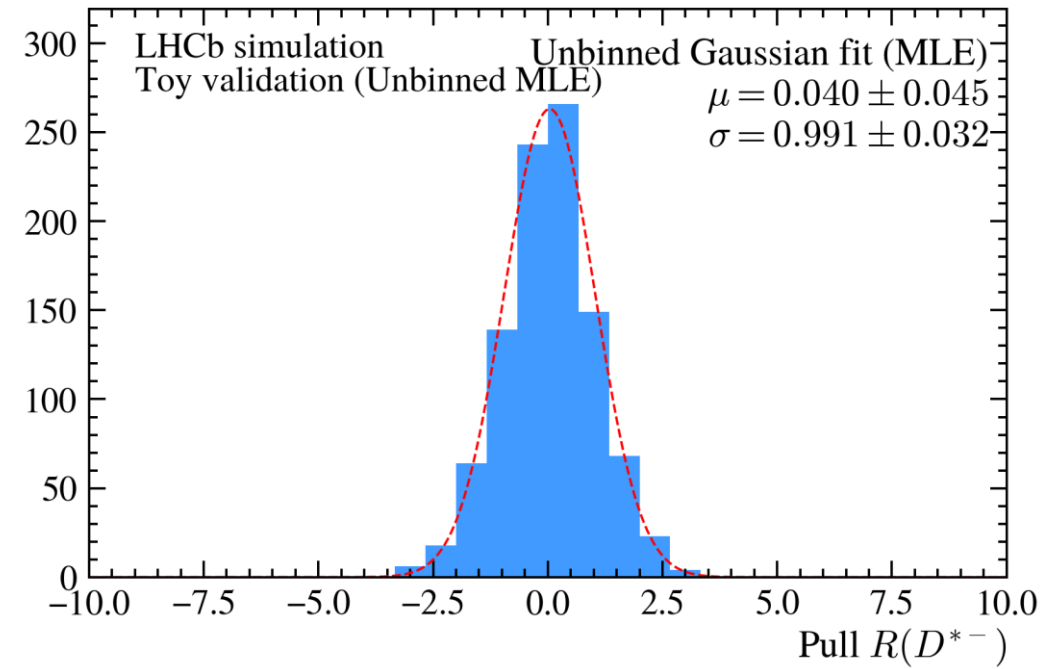
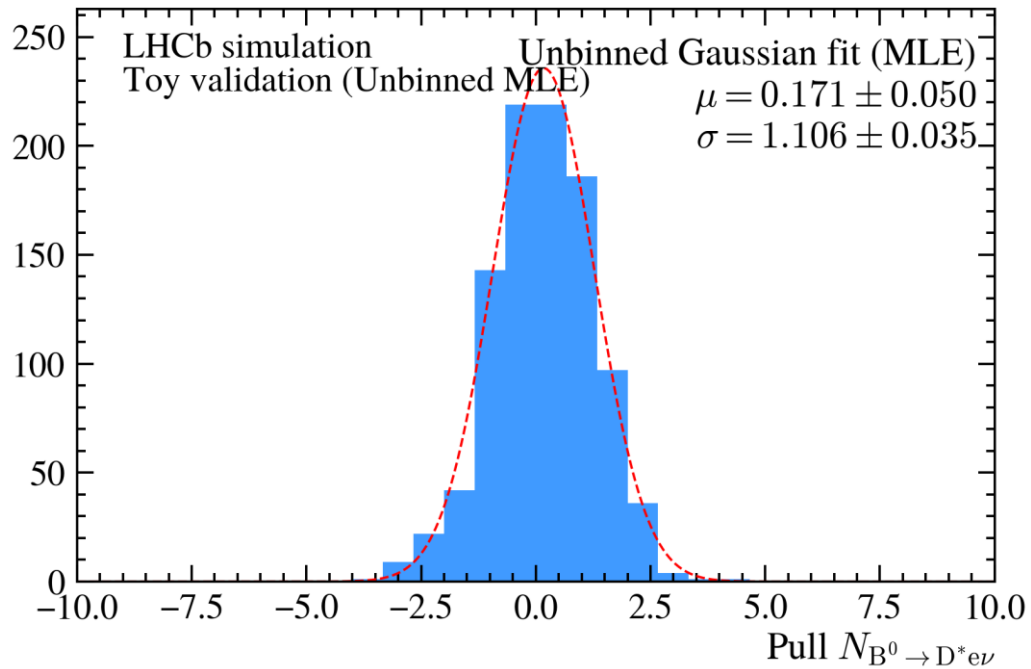
Measurement	Relative stat. σ	Luminosity
Run 1 muonic $R(D^*)_{\tau/\mu}$	6.4 % (ref)	3 fb ⁻¹
Run 2 hadronic $R(D^*)_{\tau/\mu}$	5.8 % (ref)	2 fb ⁻¹
Run 2 muonic $R(D^*)_{\tau/\mu}$	20 % (ref)	2 fb ⁻¹
This measurement	4.7 %	3.3 fb⁻¹

Comparable with the LHCb $R(D^*)_{\tau/\mu}$ measurements !

Fitter validation

Perform fits on **1000 pseudo-experiments**

$$\text{Pull} = (N_{\text{fit}} - N_{\text{expect}}) / \sigma_{\text{fit}}$$



Bias on $\text{BR}(B^0 \rightarrow D^{*-} e^+ \nu_e)$ but $R(D^*)$ looks fine

Conclusions - $R(D^*)_{\tau/e}$ analysis

Achievements

- Run 3 analysis framework established for the $R(D^*)_{\tau/e}$ measurement
- **First blinded $R(D^*)_{\tau/e}$ fit performed** using 3D binned-template fit on a subset of 2024 data
- Preliminary stat. precision is **comparable to LHCb $R(D^*)_{\tau/\mu}$ measurements in Run 1 & 2**

Next steps

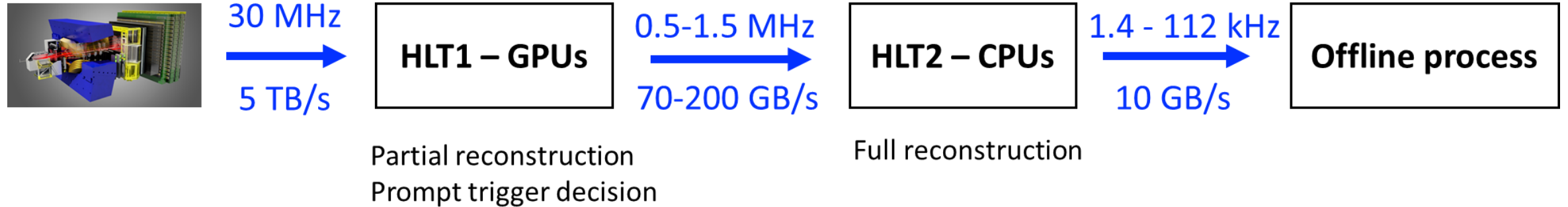
- Evaluation of systematic uncertainties
- Fit-model validation and investigation of background-component behaviour
- Fit of background enriched control sample for better modelling of physics backgrounds
- Extension to the **full Run 3 data**

Secondary Vertex Reconstruction in LHCb

High level triggers in Run 3 LHCb

Run 3 operates at ~ 5 times the Run 2 instantaneous luminosity

→ The software-only high-level-trigger (HLT) heavily reduces the data rates



Towards full reconstruction on GPUs

After Upgrade II, Run 5 (2034 - 2036) will operate at $4 \times$ higher inst. luminosity

→ The number of interaction per bunch is increased **from 5 to 20**

Much more demanding real-time event reconstruction in LHCb ([arxiv.2511.03883](https://arxiv.org/abs/2511.03883))

→ R&D is underway to run the **full HLT2 reconstruction on GPUs**

→ Motivates HLT1–HLT2 reconstruction comparisons

This work :

GPU

CPU

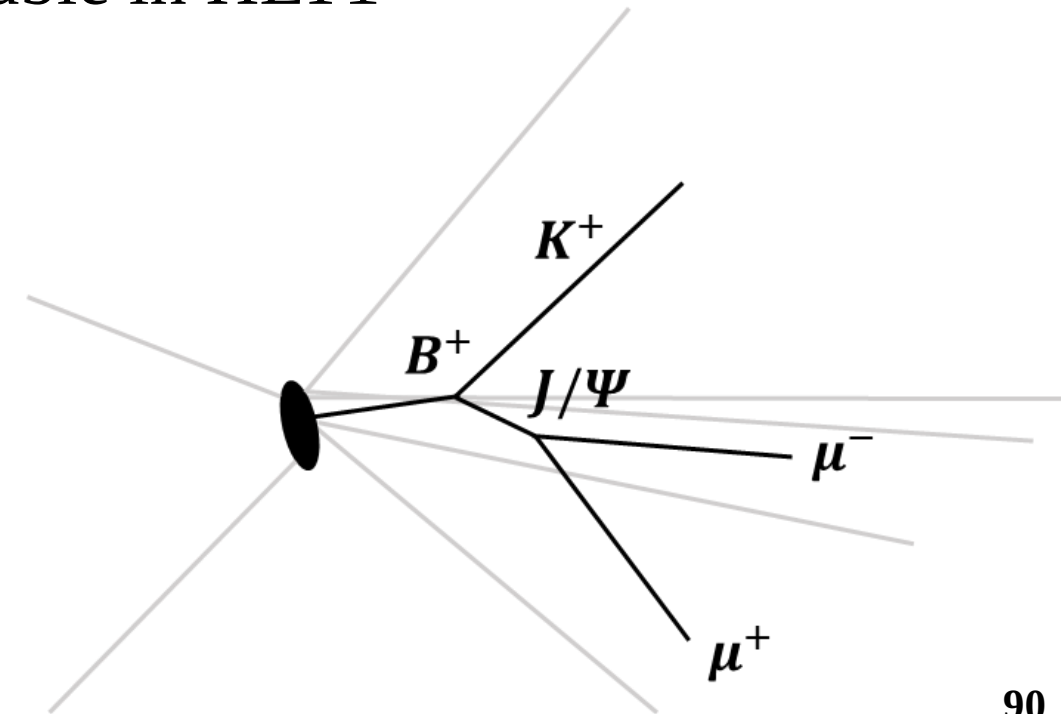
Compares the secondary-vertex reconstruction in HLT1 and HLT2

Sample

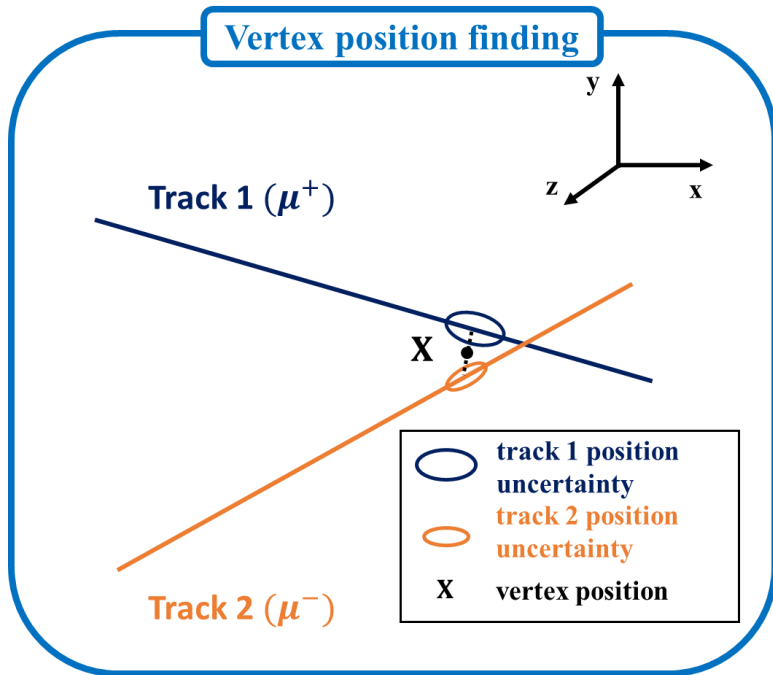
$B^+ \rightarrow J/\Psi K^+$ MC sample, with $J/\Psi \rightarrow \mu^+ \mu^-$ as the secondary vertex

Served as an ideal choice

- Only lepton-identification information is available in HLT1
- Compared with electrons,
 - Muons are more robustly identified
 - Do not require bremsstrahlung recovery

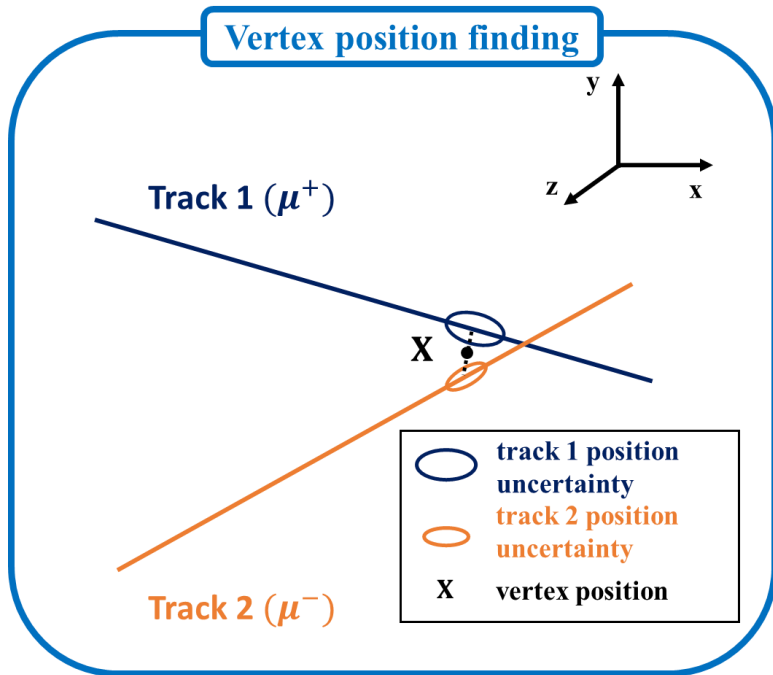


Vertex reconstruction in HLT2



The initial vertex position (**X**) is determined by the midpoint of POCA (point of closest approach) between the two tracks

Vertex reconstruction in HLT2



The initial vertex position (X) is determined by the midpoint of POCA (point of closest approach) between the two tracks

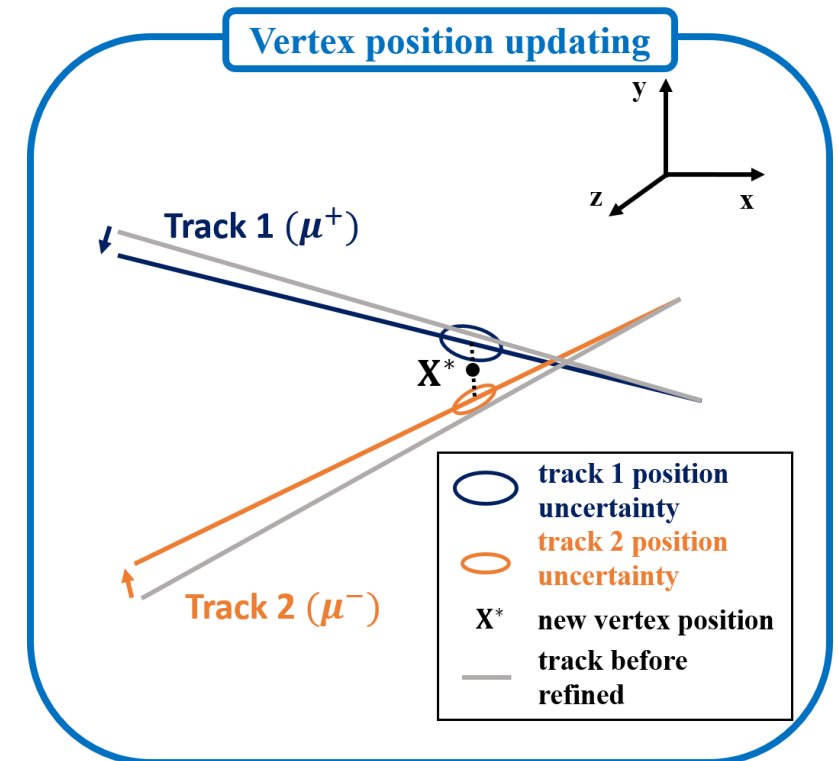
In each vertex-fit iteration :

Update the vertex position to X^* based on POS_{trk} and σ_{trk}

↓
Update the track slope & momentum

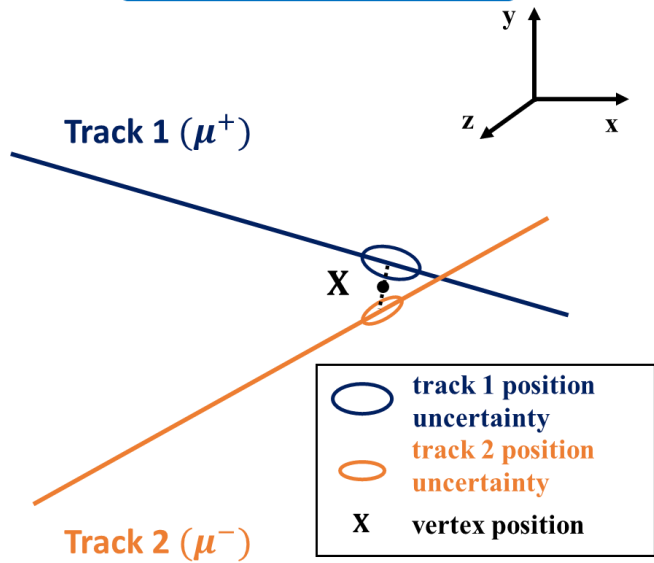
↓
Check vertex-fit convergence

If not converge



Vertex reconstruction in HLT2

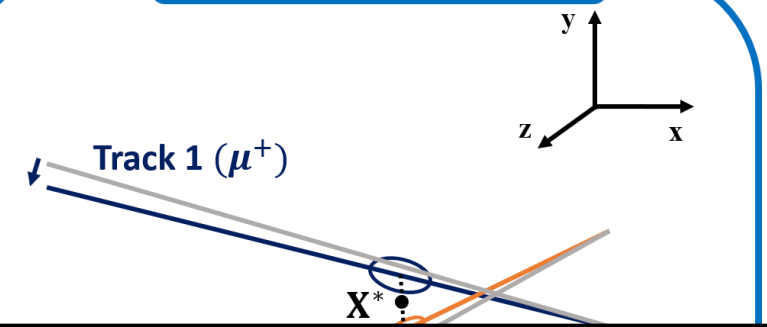
Vertex position finding



The initial vertex position (**X**) is determined by the midpoint of POCA (point of closest approach) between the two tracks

In each vertex-fit iteration :

Vertex position updating



In this stage, both the vertex position and the corresponding uncertainty are determined

Check vertex-fit convergence

If no

track before refined

Vertex reconstruction in HLT1

Unlike HLT2, HLT1 reconstructs vertex candidates in GPU threads in parallel to achieve **high-throughput GPU execution**

Main differences :

The track position weight matrix is diagonal

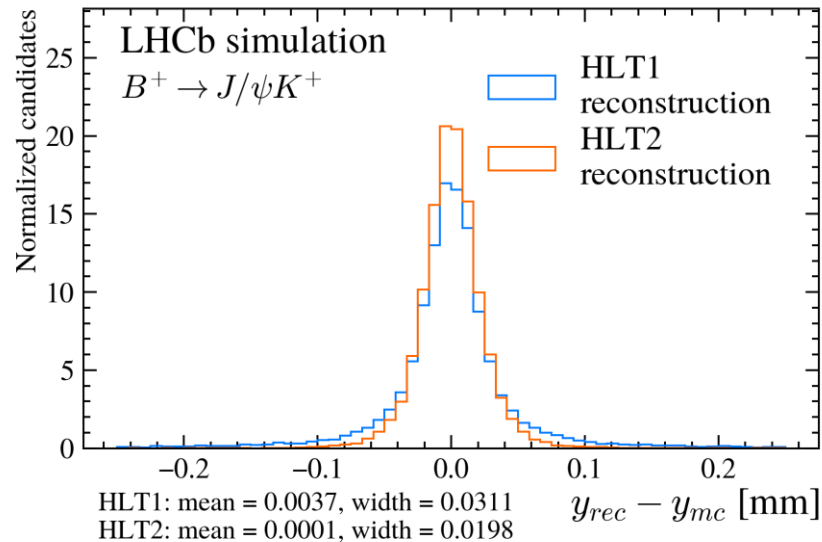
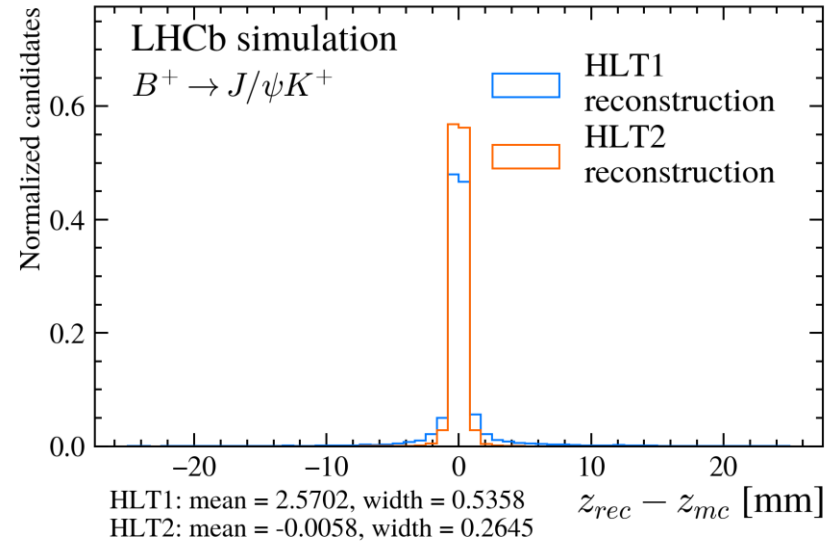
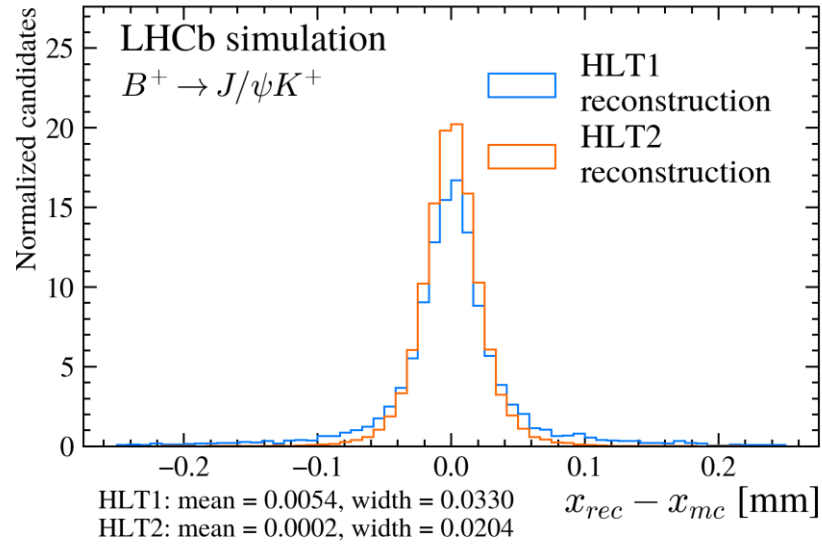
→ neglect the correlation between x and y

Vertex position is updated using a **single step** from POCA

→ ensure all threads perform the same sequence of operations

Simpler vertex-fit algorithm but optimized in real-time event processing

Vertex position in HLT1 and HLT2



Resolution of vertex position is worse in HLT1 (blue) due to simpler reconstruction procedure, but the results in different triggers are comparable

Conclusions - SV reconstruction

Achievements

- **Extended and validated a framework** for evaluating HLT2 secondary-vertex reconstruction performance
- Co-developed a **conversion framework** to represent HLT1 objects as HLT2-compatible particle objects, enabling direct performance comparisons
- **Performed a direct comparison** of HLT1 and HLT2 secondary-vertex reconstruction

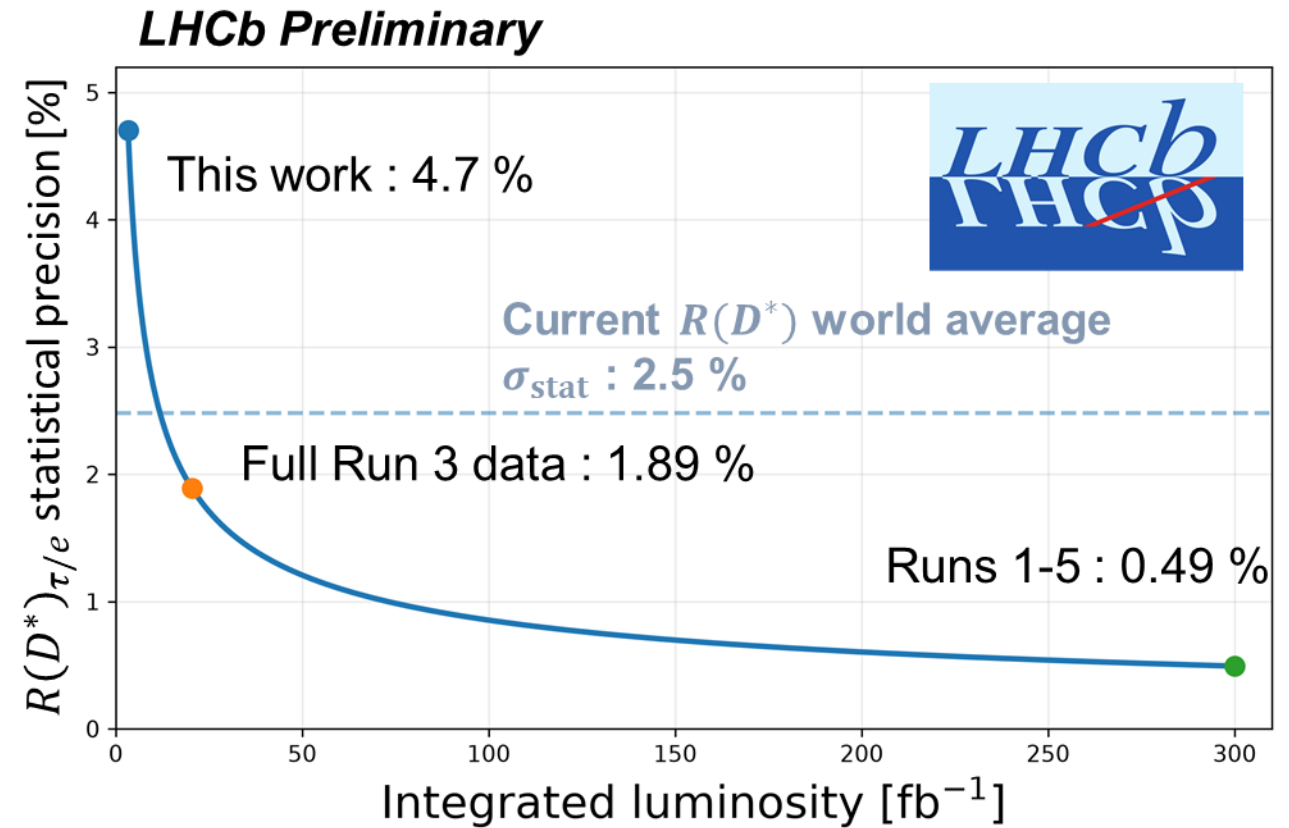
Next step

- Integrate the developed tools into the **central LHCb software framework**

Prospects

Run 3 $R(D^*)_{\tau/e}$ analysis

- The statistical precision could reach $\sim 0.5\%$ by the end of Run 5
- Controlling systematic uncertainty will be the biggest challenge
- With Upgrade II, the NP searches will continue through other observables (angular analysis) and other decay modes (B_s, B_c, Λ_b , etc.)



Secondary vertex reconstruction in HLT1 and HLT2

- Developed tools fit into the broader effort of HLT1-HLT2 comparison studies
- Provides a step toward HLT2 reconstruction on GPUs for Upgrade II

Thanks for listening

Backup

Hamiltonian : $b \rightarrow cl\nu$

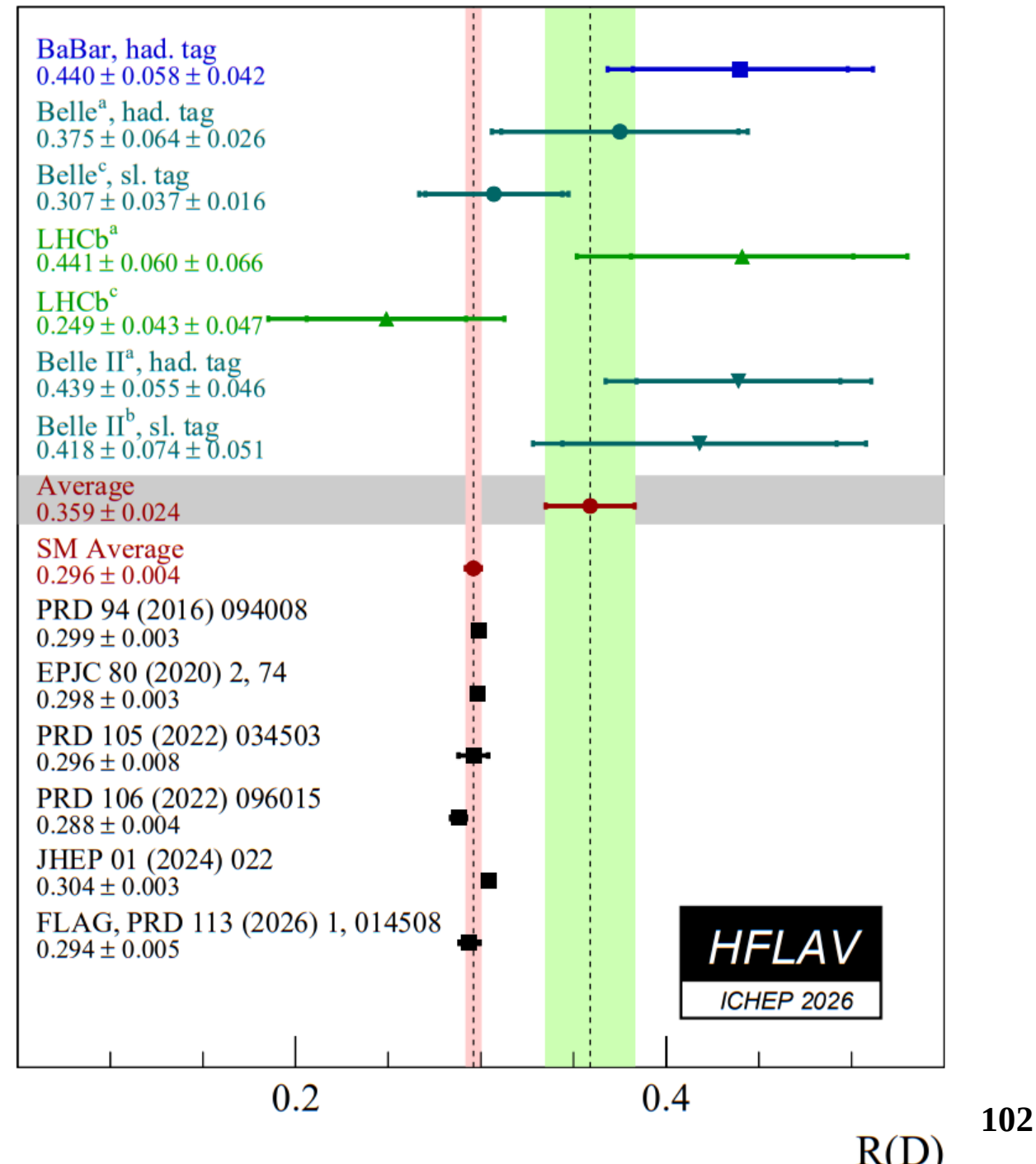
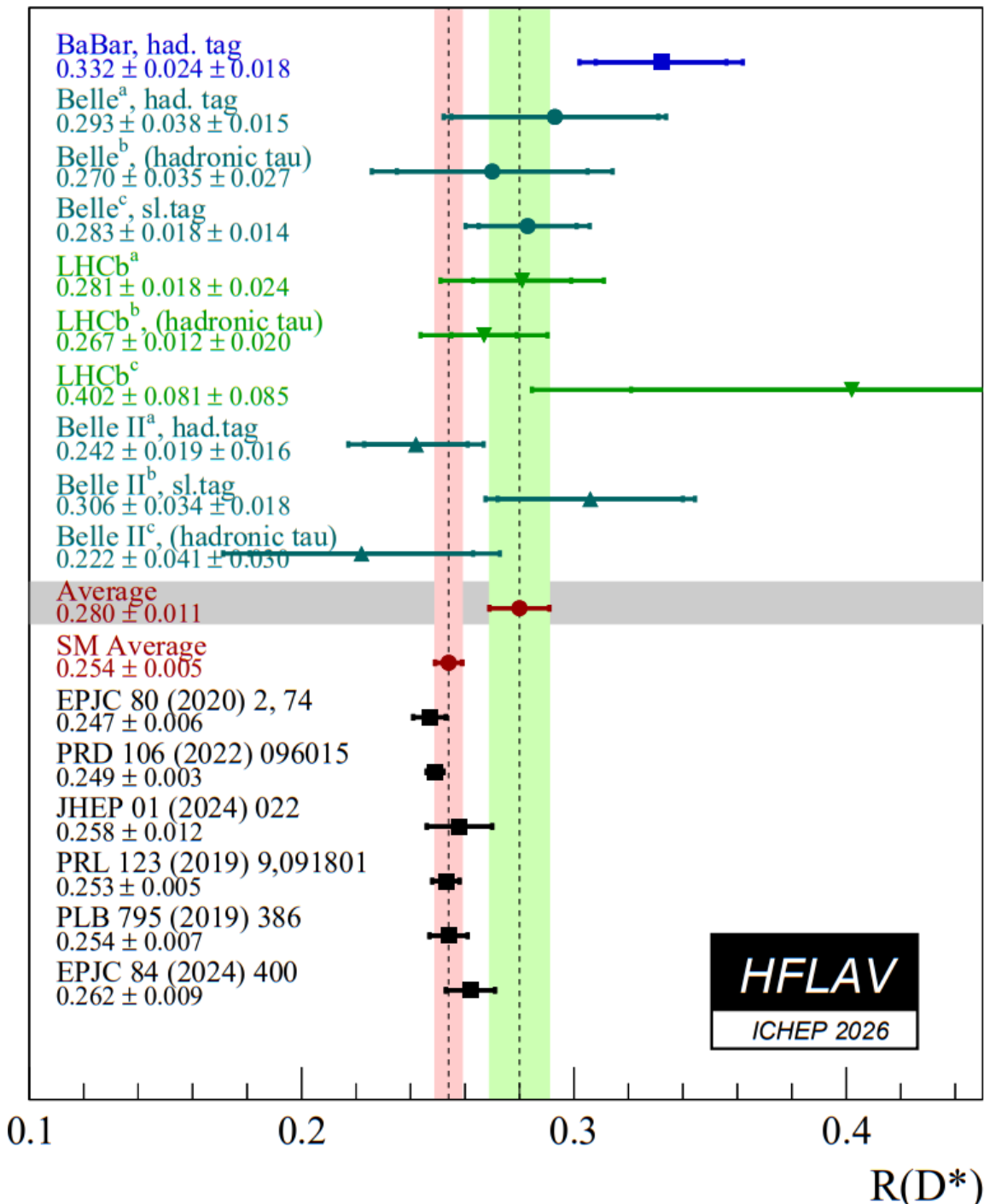
How can LFU be violated ?

Effective Field Theory (EFT): describes the low-energy effects of heavy new physics (NP) without specifying the full underlying theory

In EFT framework, the $b \rightarrow cl\nu$ transition can be described by

$$\mathcal{H}_{\text{eff}} = \frac{4G_F V_{cb}}{\sqrt{2}} (\mathcal{O}_{\text{SM}} + \sum_i C_i \mathcal{O}_i) , \quad \mathcal{O}_{\text{SM}} = (\bar{c}\gamma^\mu P_L b)(\bar{\ell}\gamma^\mu P_L \nu_\ell)$$

- $\mathcal{O}_i$: Effective operator
- C_i : Wilson coefficient encoding possible NP contributions



Generator cuts used in simulation sample

TABLE 4.3. – Generator cuts used in the generation of simulation samples.

K^+/π^- selections
$\theta > 0.01$
$p_x/p_z < 0.34$ and $p_y/p_z < 0.34$
$p_x/p_z > -0.34$ and $p_y/p_z > -0.34$
$p_T > 250 \text{ MeV}/c$
$4.5 < p < 300 \text{ GeV}/c$
e^- selections
$\theta > 0.01$
$p_x/p_z < 0.34$ and $p_y/p_z < 0.34$
$p_x/p_z > -0.34$ and $p_y/p_z > -0.34$
$2.05 < \eta < 4.25$
$p > 2 \text{ GeV}/c$
D^0 selections
$p > 1.5 \text{ GeV}/c$

Sample

Simulation

100 M events for $B^0 \rightarrow D^{*-} e^+ \nu_e$ and 10 M $B^0 \rightarrow D^{*-} \tau^+ \nu_\tau$ are prepared

1~5 M events are generated for various physics background modes

	Decay	Number of generated events (M)
Signal modes	$B^0 \rightarrow (D^*(2010)^- \rightarrow (\bar{D}^0 \rightarrow K^+ \pi^-) \pi^-) e^+ \nu_e$	100
	$B^0 \rightarrow (D^*(2010)^- \rightarrow (\bar{D}^0 \rightarrow K^+ \pi^-) \pi^-) (\tau^+ \rightarrow e^+ \nu_e \nu_\tau) \nu_\tau$	10
Higher excited bkg	$B^0 \rightarrow (D_0^*(2400)^- / D_1(2420)^- / D_1'(2430)^- / D_2^*(2460)^-) e^+ \nu_e$	3
	$B^0 \rightarrow (D_0^*(2300)^- / D_1(2420)^- / D_1'(2430)^- / D_2^*(2460)^-) \tau^+ \nu_\tau$	1
	$B^+ \rightarrow (D_0^*(2400)^0 / D_1'(2430)^0 / D_1(2420)^0 / D_2^*(2460)^0) e^+ \nu_e$	3
	$B^+ \rightarrow (D_0^*(2300)^0 / D_1'(2430)^0 / D_1(2420)^0 / D_2^*(2460)^0) \tau^+ \nu_\tau$	1
	$B^0 \rightarrow (D^*(2S)^- / D(2S)^- / D_1(2420)^- / D_2^*(2460)^-) e^+ \nu_e$	3
	$B^+ \rightarrow (D^*(2S)^0 / D(2S)^0 / D_1(2420)^0 / D_2^*(2460)^0) e^+ \nu_e$	3
	$B_s^0 \rightarrow (D_{s1}(2536) / D_{s2}(2573)) e^+ \nu_e$	2
	$B^0 \rightarrow D^0 (X_c \rightarrow e^+ \nu_e X') X$	5
Double charmed bkg	$B^+ \rightarrow D^0 (X_c \rightarrow e^+ \nu_e X') X$	2
	$B^0 \rightarrow D^0 (D_s^- \rightarrow \tau^+ \nu_\tau) X$	3
	$B^+ \rightarrow D^0 (D_s^- \rightarrow \tau^+ \nu_\tau) X$	1

* X_c denotes an inclusive charm-hadron state.

* X and X' denote a system of any additional final-state particles.

Expected yields in data

Produced beauty mesons within LHCb acceptance, from [Ref](#)

Experiment	LHCb			
	Run 1	Run 2	Runs 3–4	Run 5
Completion date	2012	2018	2032	2041
Center-of-mass energy	7/8 TeV	13 TeV	14 TeV	14 TeV
$b\bar{b}$ cross section [nb]	$(3.0/3.4)\times 10^5$	5.6×10^5	6.0×10^5	6.0×10^5
Integrated luminosity [fb^{-1}]	3	6	50	250
B^0 mesons [10^9]	100	350	3,200	16,000
B^+ mesons [10^9]	100	350	3,200	16,000
B_s^0 mesons [10^9]	24	84	760	3,800
Λ_b^0 baryons [10^9]	51	180	1,600	8,100
B_c^+ mesons [10^9]	0.8	4.4	24	120

[Upgrade I](#) [Upgrade II](#)

We shall have $18.56 \times 10^{10} B^{0/+}$ ($6.7 \times 10^9 B_s^0$) mesons produced in block 8 data

With the formula
$$N_{channel} = N_B \times \mathcal{B}_{channel} \times \epsilon_{gen} \times \epsilon_{trg} \times \epsilon_{off}$$
We can derive the expected yields in data for each decay

Block	Polarity	Luminosity (fb^{-1})	Fraction (%)
1	Up	1.215 (1.178 with UT)	16.3
2	Up	0.614 (0.604 with UT)	8.2
3	Up	0.900 (0.681 with UT)	12.1
4	Down	1.392 (1.147 with UT)	18.7
5	Up	1.160	15.6
6	Down	0.998	13.4
7	Down	0.737	9.9
8	Up	0.435	5.8

Reconstructed statistics vs expected yields

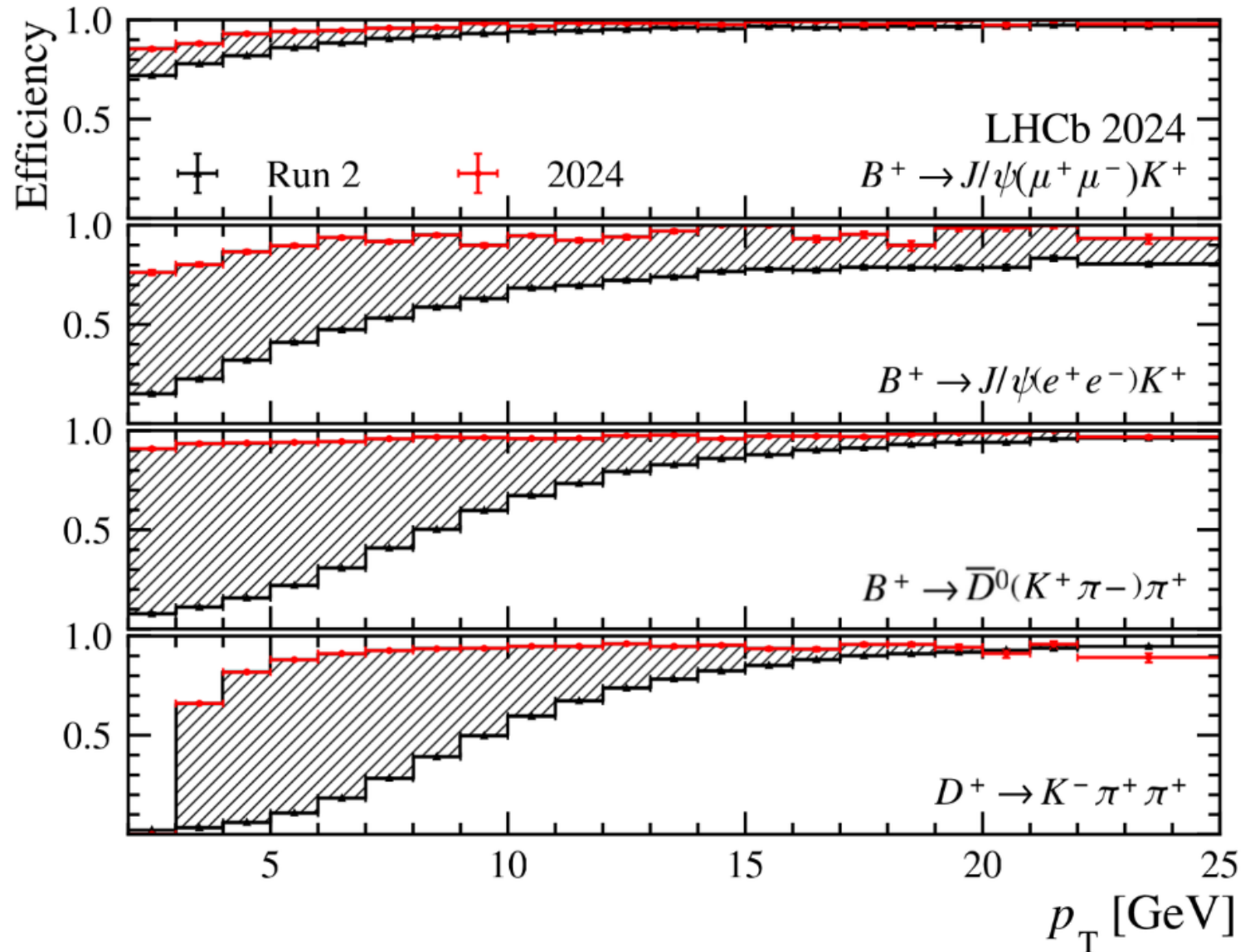
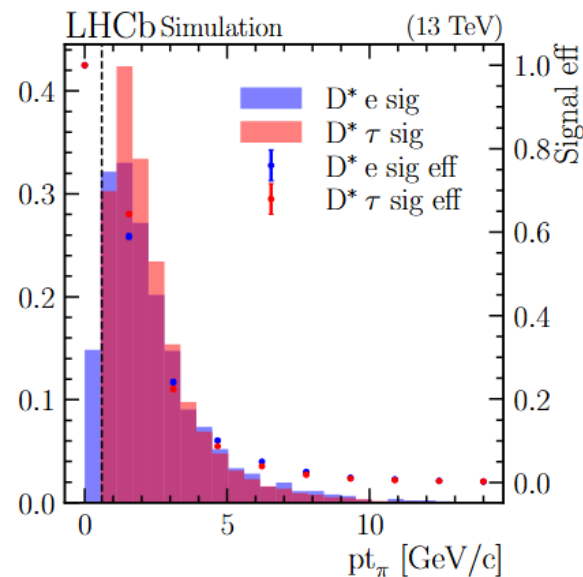
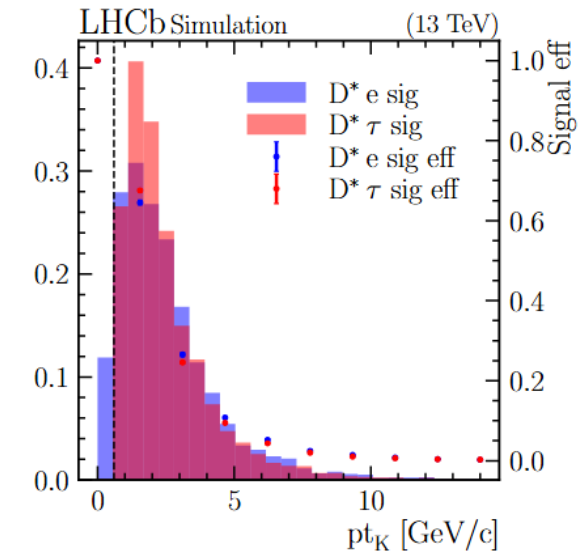
TABLE 3.1. – Statistics of current MC sample and the expected yields **Block 8**.

Decay	EventType	Expected entries	MC statistics
$B^0 \rightarrow D^{*-} e^+ \nu_e$	11584035	436,539.35	293,833.54
$B^0 \rightarrow D^{*-} \tau^+ \nu_\tau$	11584036	16,017.20	26,926.70
$B^0 \rightarrow D_{0,1,2}^{*-} e^+ \nu_e$	11584052	7,194.42	2,239.77
$B^0 \rightarrow D_{0,1,2}^{*-} \tau^+ \nu_\tau$	11883002	59.91	387.60
$B^+ \rightarrow D_{0,1,2}^{*0} e^+ \nu_e$	12885001	40,245.82	4,775.59
$B^+ \rightarrow D_{0,1,2}^{*0} \tau^+ \nu_\tau$	12883001	716.49	1,564.36
$B^0 \rightarrow (D_{1,2}^{*-} / D^{(*)} (2S)^-) e^+ \nu_e$	11686001	12,236.33	3,309.15
$B^+ \rightarrow (D_{1,2}^{*0} / D^{(*)} (2S)^0) e^+ \nu_e$	12685401	21,517.78	5,419.79
$B_s^0 \rightarrow (D_{s1}^- (2536) / D_{s2}^- (2573)) e^+ \nu_e$	13884001	23.05	5,866.93
$B^0 \rightarrow D^0 (X_c \rightarrow e^+ \nu_e X') X$	11884651	13,611.52	3,285.42
$B^+ \rightarrow D^0 (X_c \rightarrow e^+ \nu_e X') X$	12685412	4,780.06	1,598.52
$B^0 \rightarrow D^0 (D_s^- \rightarrow \tau^+ \nu_\tau) X$	11884272	1,199.30	2,411.84
$B^+ \rightarrow D^0 (D_s^- \rightarrow \tau^+ \nu_\tau) X$	12885032	388.52	864.93

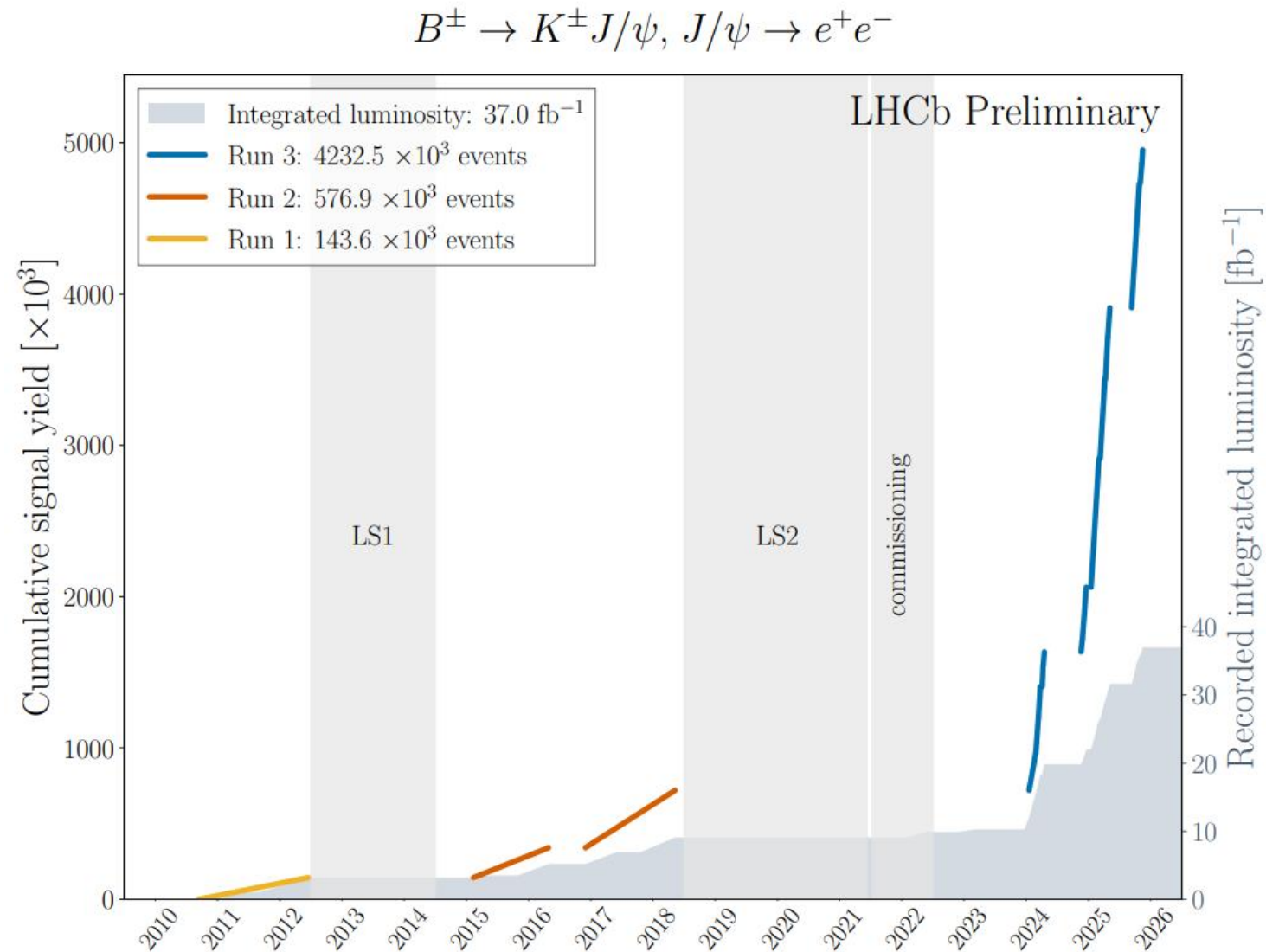
* X_c denotes an inclusive charm-hadron state.

* X and X' denote a system of any additional final-state particles.

Trigger efficiency Run 2 vs Run 3



Electron yields in Run 1-3



Trigger selections used in HLT2

B^+ selections	
Mass (MeV/c^2)	$1500 < M < 10000$
$\chi^2_{\text{vertex}}/\text{n.d.f.}$	< 9
χ^2_{FD}	> 20
DIRA	> 0.9995
DOCA(mm)	< 0.3
$z_{\text{end vtx}}^{D^0} - z_{\text{end vtx}}^{B^{*+}}$ (mm)	> -5
D^0 selections	
Mass (MeV/c^2)	$1784.84 < M < 1944.84$
p (GeV/c)	> 15
χ^2_{DOCA}	< 5
χ^2_{FD}	> 25
$\chi^2_{\text{vertex}}/\text{n.d.f.}$	< 5
DIRA	> 0.9998

$K^\pm, \pi^\pm$ selections	
p (GeV/c)	> 5
p_T (MeV/c)	> 300
PID $_K$ for $K(\pi)$	> 4 (< 2)
min. χ^2_{IP}	> 45
<i>GhostProb</i>	< 0.35
$e^\pm$ selections	
p (GeV/c)	> 3
p_T (MeV/c)	> 300
min. χ^2_{IP}	> 15
PID $_e$	> 2.0
η	$2.2 < \eta < 4.2$

Replicate the re-sprucing selections

The 2024 re-sprucing campaign uses HLT2 selections before re-tunning and Sprucing line with tuned HLT2 selections

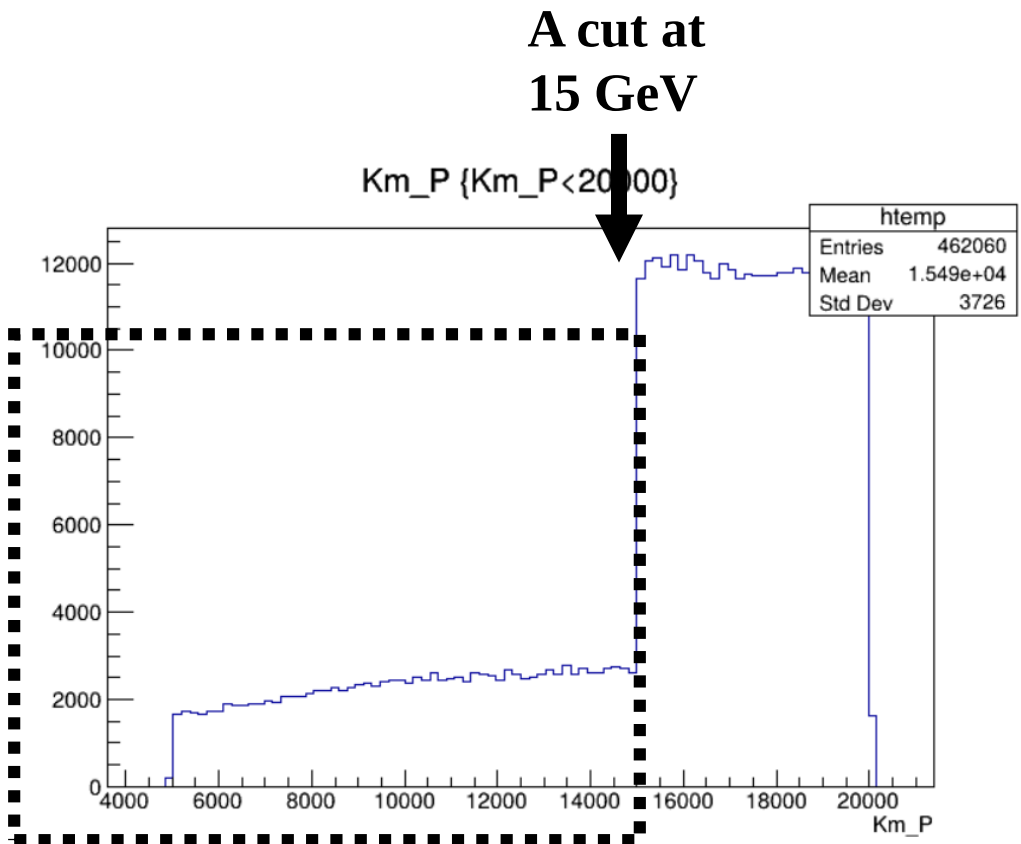
$K^\pm, \pi^\pm$ selections	
p (GeV/c)	> 15
p_T (MeV/c)	> 600
PID K for $K(\pi)$	> 0 (< 2)
$min. \chi^2_{IP}$	> 10

Old cuts

$K^\pm, \pi^\pm$ selections	
p (GeV/c)	> 5
p_T (MeV/c)	> 300
PID K for $K(\pi)$	> 4 (< 2)
$min. \chi^2_{IP}$	> 45
$GhostProb$	< 0.35

New cuts

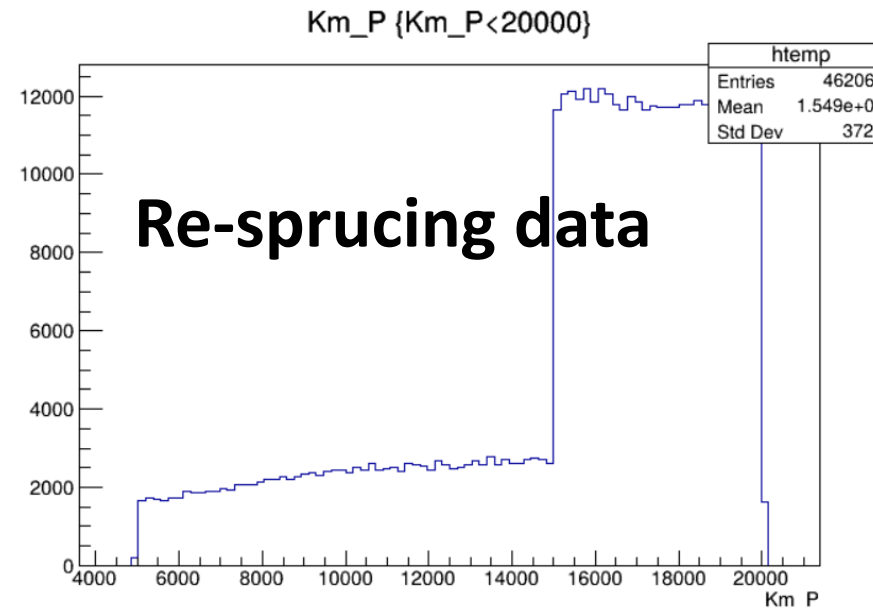
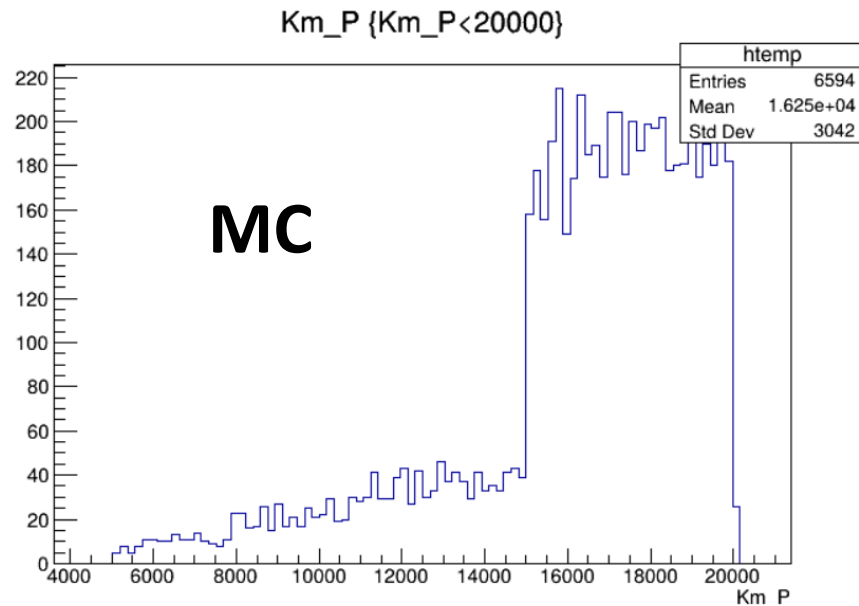
Leads discontinuous variable distributions



Replicate the re-sprucing selections

With MC flag and dedicated selections,

```
((Km_P>15000 && pip_P>15000 && Km_PT>600 && pip_PT>600) ||  
((Hlt2Topo2BodyDecision==1 || Hlt2Topo3BodyDecision==1) && (Km_P<15000 || pip_P<15000 || Km_PT<600 || pip_PT<600))))"
```



We reproduce discontinuous selection

Training sample

Inclusive simulation contains 4×10^4 signal particles and $50\text{-}100 \times$ more bkg per channel across various semileptonic decays in simulation.

Data split :
70 % training, 15 % validation
15 % evaluation

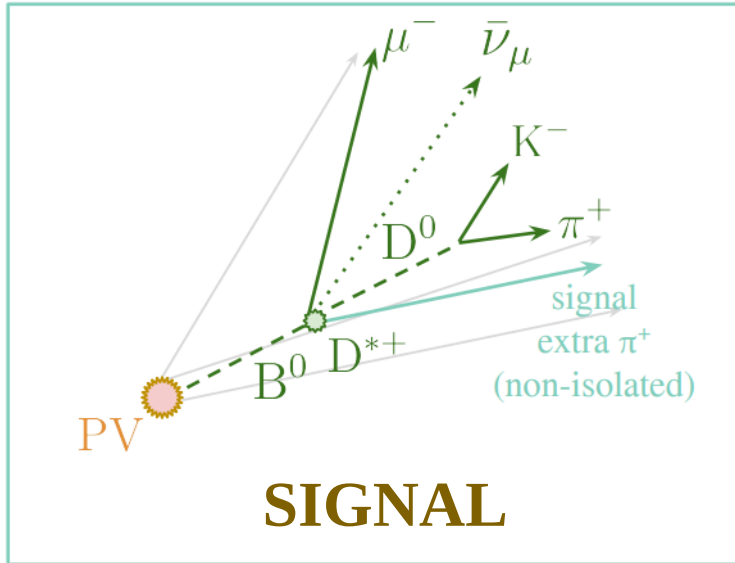
Train/valid : bkg down-sampled to match signal.
Eval : full imbalance ($\geq 50:1$) kept for realistic Run-3 conditions.

Base particles	Non-isolated particles	Decay chain
$\bar{D}^0 \ell^+$	π^-	$B^0 \rightarrow D^{*-} \ell^+ \nu_\ell, D^{*-} \rightarrow \bar{D}^0 \pi^-$
$\bar{D}^0 \ell^+$	π^-	$B^0 \rightarrow D^{*-} \tau^+ \nu_\tau, D^{*-} \rightarrow \bar{D}^0 \pi^-, \tau^+ \rightarrow \ell^+ \nu_\ell \bar{\nu}_\tau$
$\bar{D}^0 \tau^+$	π^-	$B^0 \rightarrow D^{*-} \tau^+ \nu_\tau, D^{*-} \rightarrow \bar{D}^0 \pi^-, \tau^+ \rightarrow \pi^+ \pi^- \pi^+ (\pi^0) \bar{\nu}_\tau$
$D^0 \ell^+$	π^-, π^+	$B^+ \rightarrow D^{*0} \ell^+ \nu_\ell, D^{*0} \rightarrow D^{*+} \pi^- \pi^0, D^{*+} \rightarrow D^0 \pi^+$
$D^0 \ell^+$	π^-, π^+	$B^+ \rightarrow D^{*0} \tau^+ \nu_\tau, D^{*0} \rightarrow D^{*+} \pi^- \pi^0, D^{*+} \rightarrow D^0 \pi^+, \tau^+ \rightarrow \ell^+ \nu_\ell \bar{\nu}_\tau$
$\bar{D}^0 \ell^+$	π^+, π^-, π^-	$B^0 \rightarrow D^{*-} \ell^+ \nu_\ell, D^{*-} \rightarrow D^{*-} \pi^+ \pi^-, D^{*-} \rightarrow \bar{D}^0 \pi^-$
$\bar{D}^0 \ell^+$	π^+, π^-, π^-	$B^0 \rightarrow D^{*-} \tau^+ \nu_\tau, D^{*-} \rightarrow D^{*-} \pi^+ \pi^-, D^{*-} \rightarrow \bar{D}^0 \pi^-, \tau^+ \rightarrow \ell^+ \nu_\ell \bar{\nu}_\tau$
$D^0 \ell^+$	π^+, π^-, π^-	$B^+ \rightarrow D^{(*)} D_{(s)}^{(*)}, D^{(*)} \rightarrow D^0 \pi^- (\pi^+ \pi^-), D_{(s)}^{(*)} \rightarrow \ell^+ X$
$D^0 \ell^+$	$K^-, 2\pi^-, 2\pi^+$	$B^+ \rightarrow D^{(*)} D_{(s)}^{(*)} K^- \pi^+, D^{(*)} \rightarrow D^0 \pi^- (\pi^+ \pi^-), D_{(s)}^{(*)} \rightarrow \ell^+ X$
$K^+ \ell^-$	ℓ^+	$B^+ \rightarrow K^+ J/\psi, J/\psi \rightarrow \ell^+ \ell^-$
$K^+ \ell^-$	K^+, π^-	$B_s^0 \rightarrow D_s^- \ell^+ \nu_\ell, D_s^- \rightarrow K^+ \pi^- K^-$
$K^+ \ell^-$	K^+, π^-	$B_s^0 \rightarrow D_s^- \tau^+ \nu_\tau, D_s^- \rightarrow K^+ \pi^- K^-, \tau^+ \rightarrow \ell^+ \nu_\ell \bar{\nu}_\tau$
$K^+ \ell^-$	$K^+, 2\pi^-, \pi^+$	$B_s^0 \rightarrow D_s^{*-} \ell^+ \nu_\ell, D_s^{*-} \rightarrow D_s^+ \pi^+ \pi^-, D_s^+ \rightarrow K^+ \pi^- K^-$
$\Lambda_c^+ \ell^-$	$\pi^+ \pi^-$	$\Lambda_b^0 \rightarrow \Lambda_c^{*+} \ell^- \bar{\nu}_\ell, \Lambda_c^{*+} \rightarrow \Lambda_c^+ \pi^+ \pi^-$
$p \ell^-$	$K^- \pi^+$	$\Lambda_b^0 \rightarrow \Lambda_c^+ \ell^- \bar{\nu}_\ell, \Lambda_c^+ \rightarrow p K^- \pi^+$

*Label ℓ represents either an electron (e) or a muon (μ)

Signal and Background definition

[Eur. Phys. J. C 86 \(2026\) 241](#)

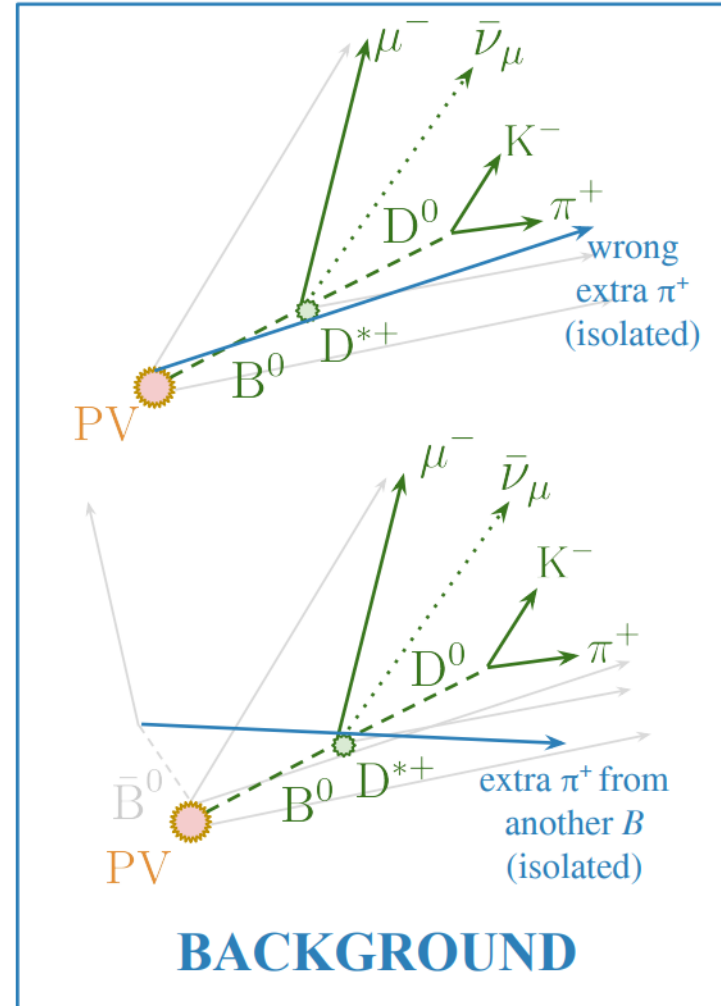
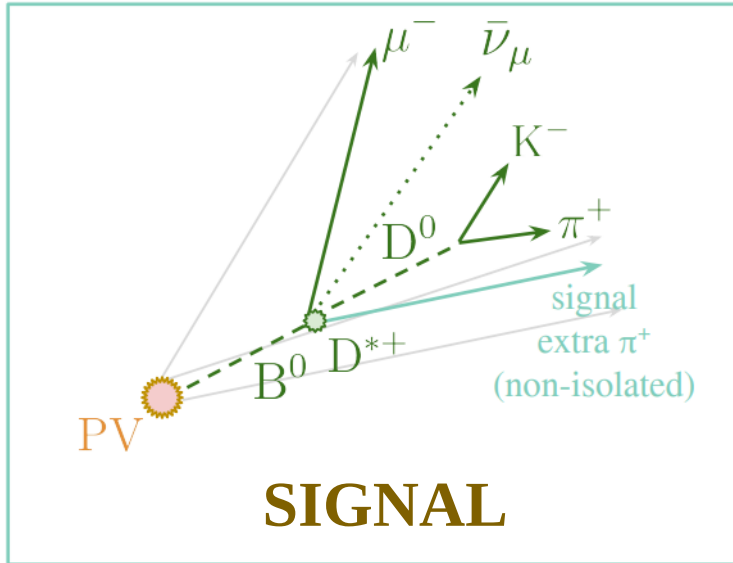


Produced at the
displaced secondary
and tertiary vertex of
the b-hadron decay

Referred to as **non-isolated tracks**

Signal and Background definition

[Eur. Phys. J. C 86 \(2026\) 241](#)

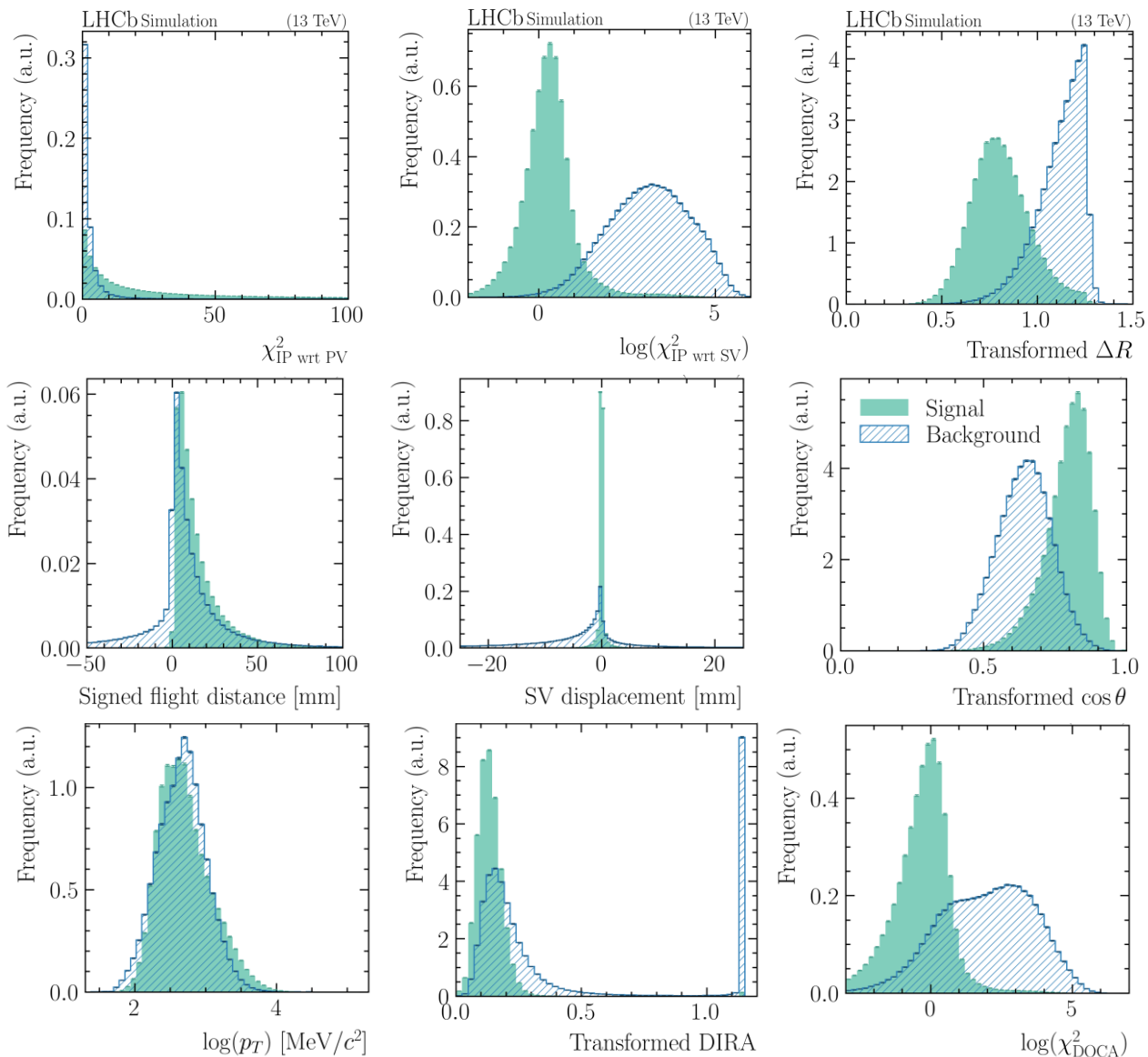


Produced at or near the PV

Originating from the decay of the other b-hadron in the event

Referred to as **isolated tracks**

Input Features



Features involve

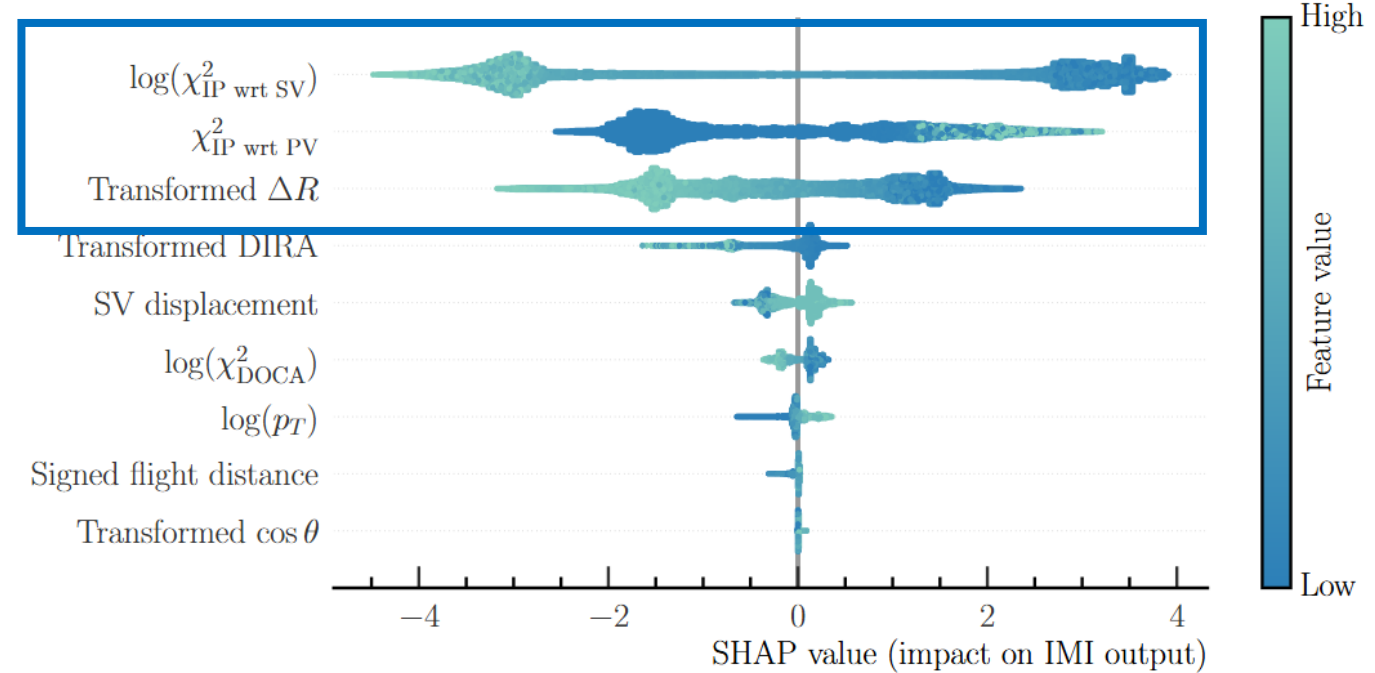
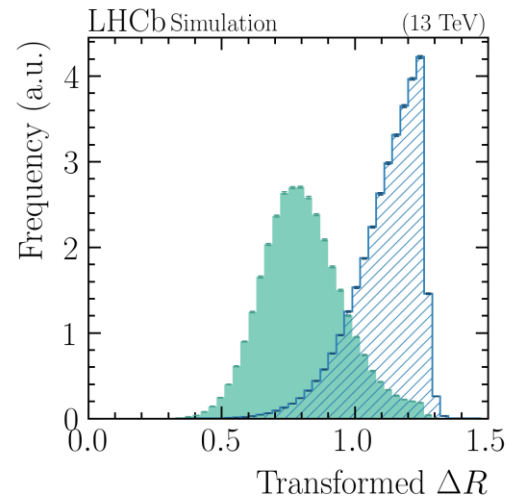
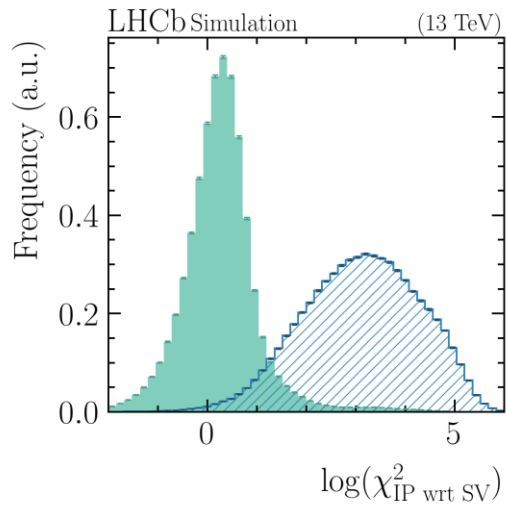
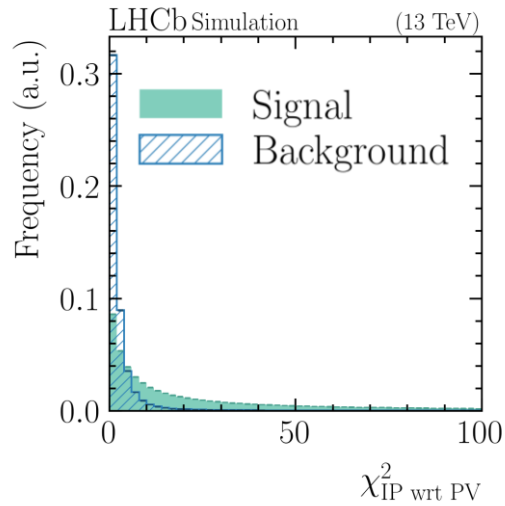
Track Impact Parameters

Spatial & angular properties of extra tracks and base-particles

Vertex dynamics and extra tracks kinematics

[Eur. Phys. J. C 86 \(2026\) 241](#)

SHAP value



The [SHapley Additive exPlanations](#) quantifies the contribution of each feature to the model.

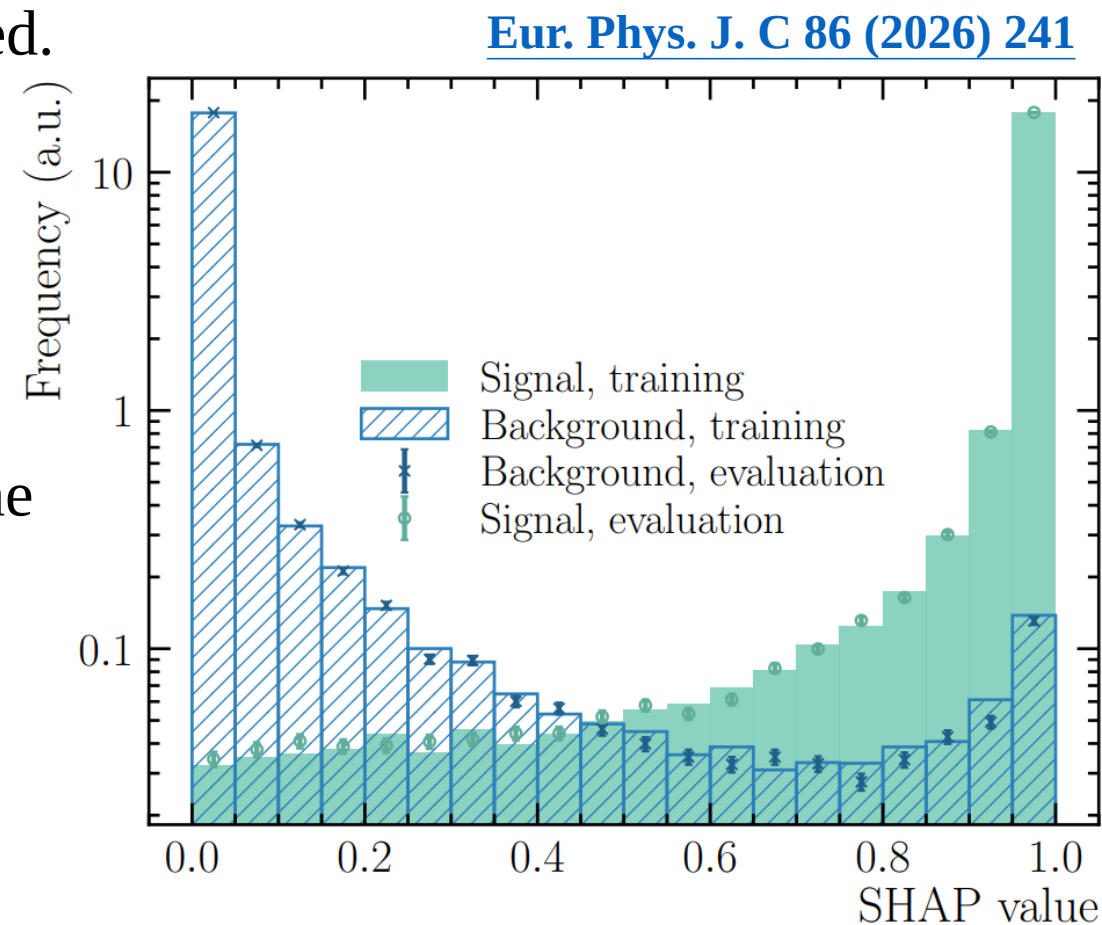
Training configuration and result

The [Extreme Gradient Boosting](#) algorithm is selected.

Hyperparameters are optimized using the Bayesian optimization framework [Optuna](#).

The objective is to minimize the **Kolmogorov-Smirnov statistic** between the classifier outputs on the training and validation sets.

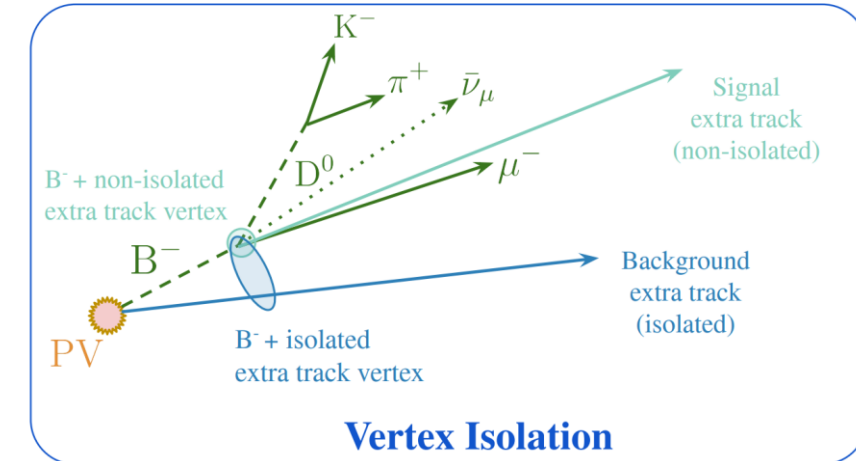
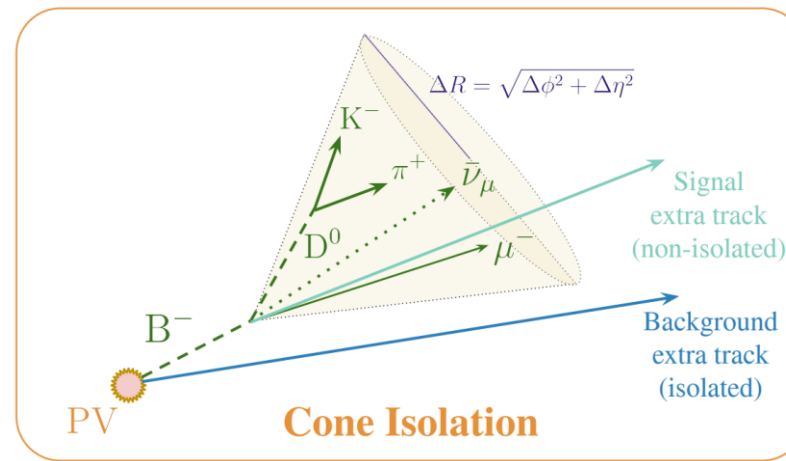
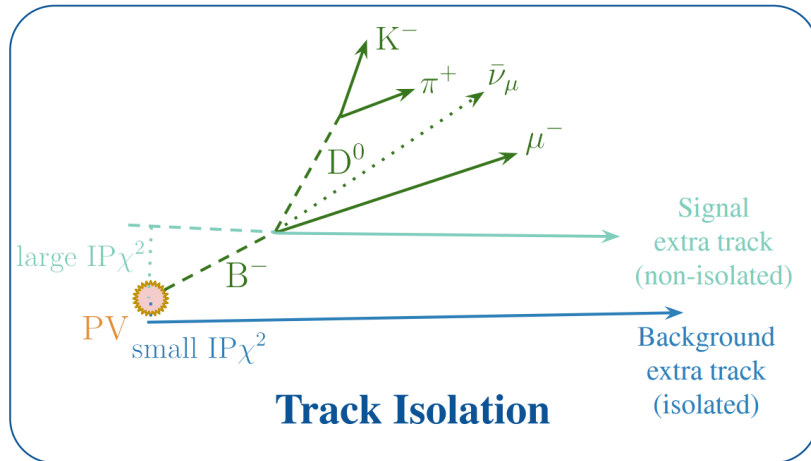
→ Suppress overfitting



No evidence of overtraining observed

Classical isolation algorithms

[Eur. Phys. J. C 86 \(2026\) 241](#)



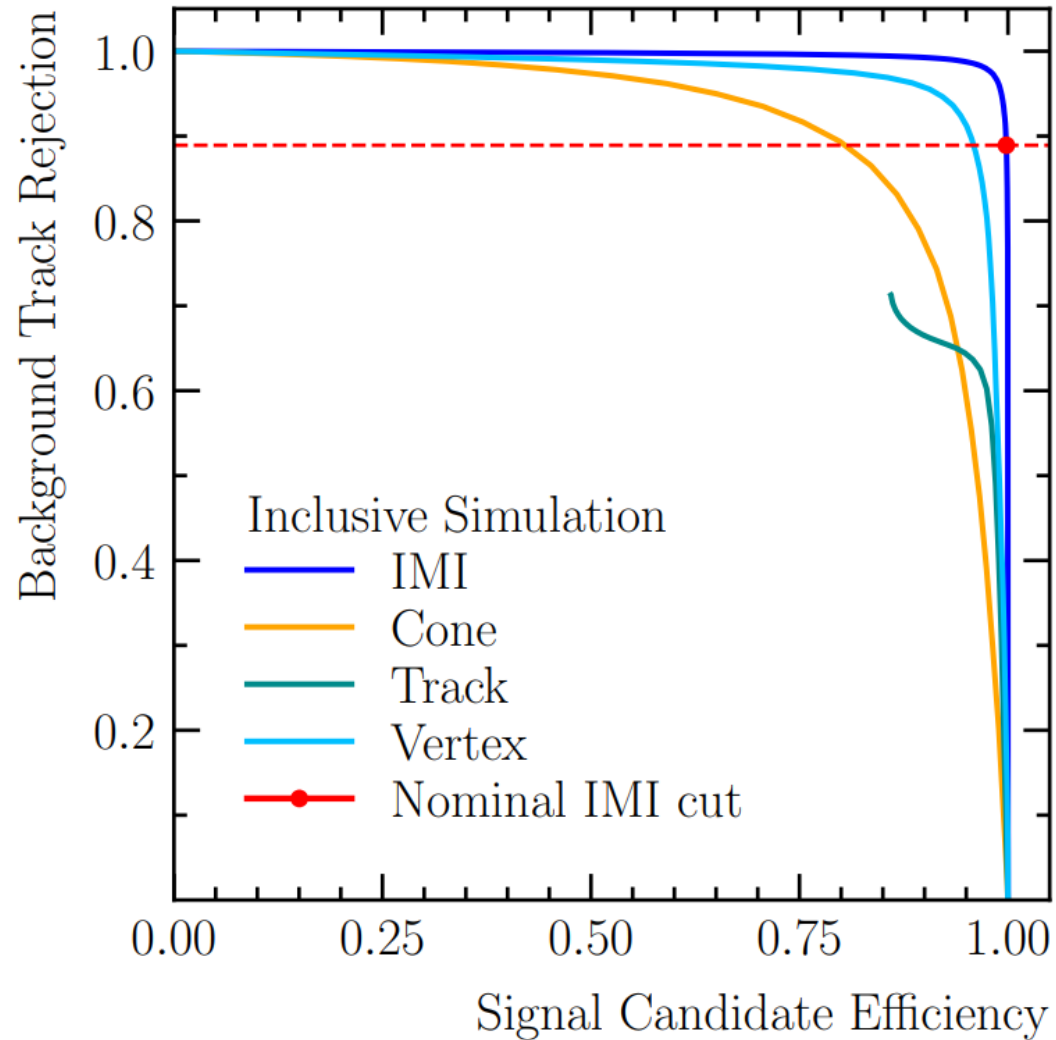
How displaced are signal candidates or signal tracks with respect to the given primary vertex (PV) ?

What are the properties of particles within a given cone radius ($\eta - \phi$ plane) relative to the signal ?

How compatible is the signal candidate/track with the given secondary vertex (SV)?

Performance : signal efficiency vs bkg rejection

[Eur. Phys. J. C 86 \(2026\) 241](#)



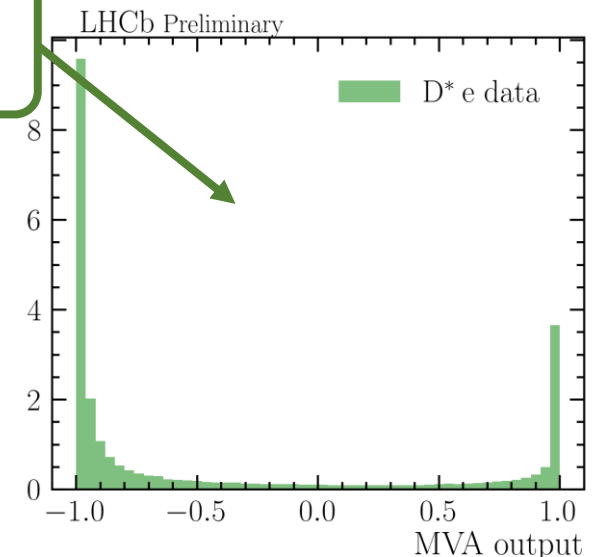
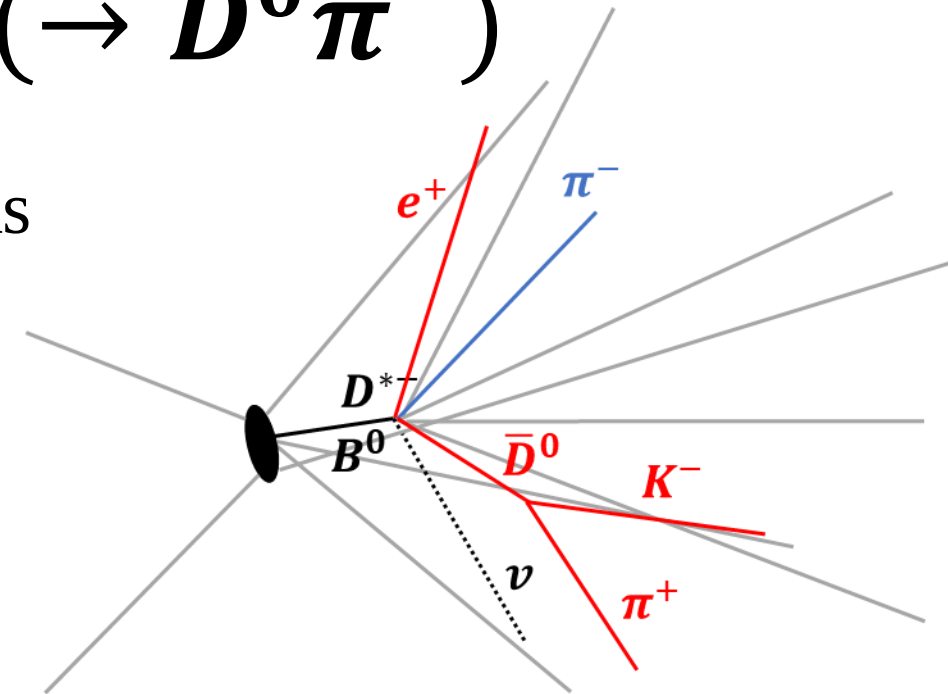
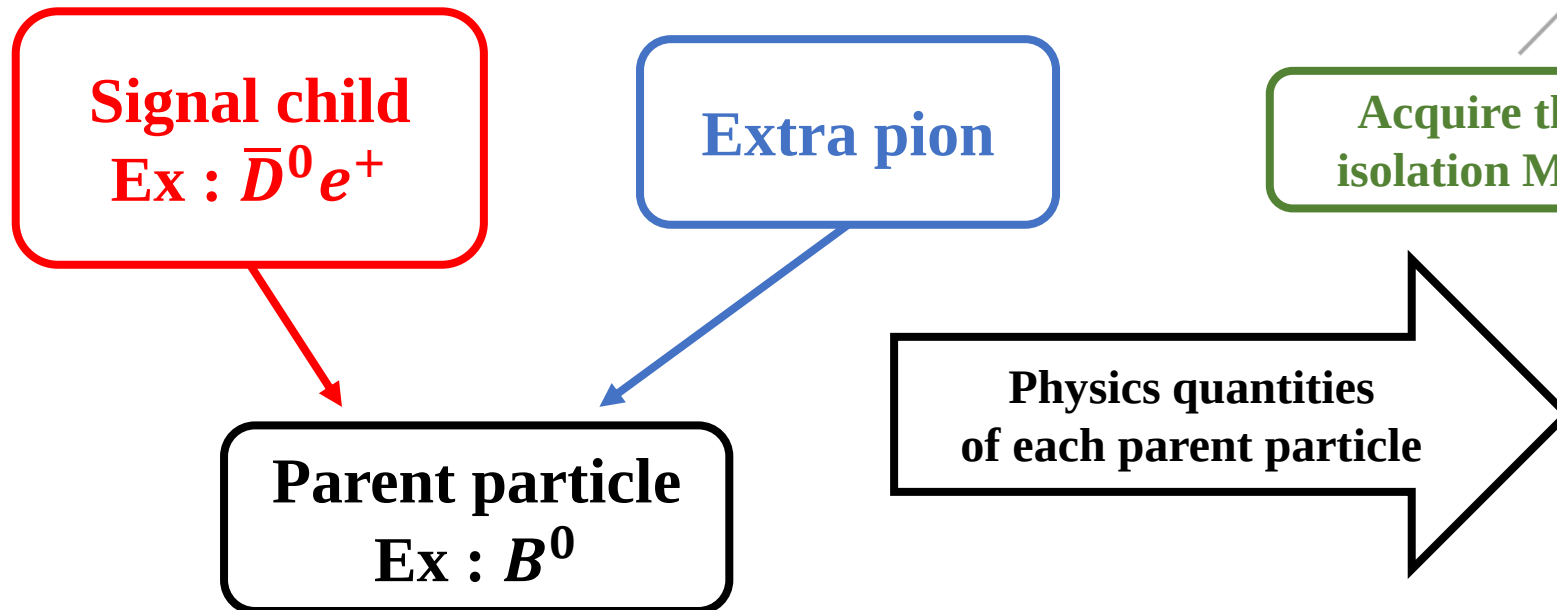
Compared with the classical isolation algorithm, **IMI algorithm** demonstrates a clear advantage.

With 99 % signal efficiency, 90–95 % background is rejected.

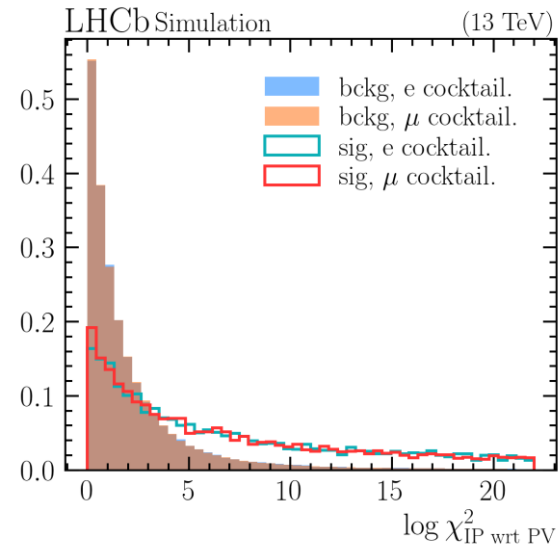
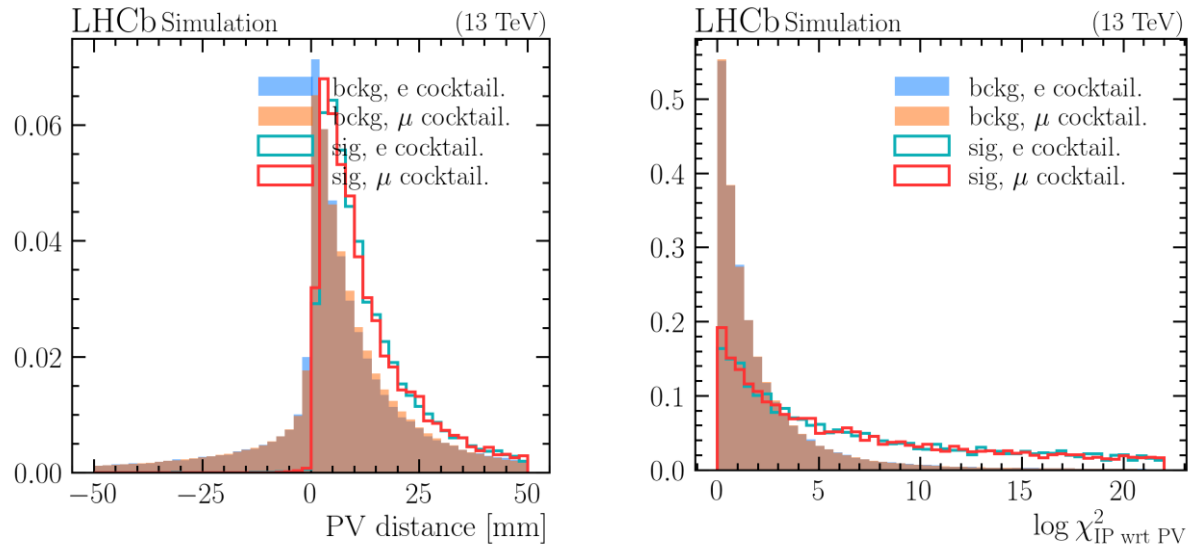
Finding charged π from $D^{*-} (\rightarrow \bar{D}^0 \pi^-)$

We trained a model using **XGBoost** to identify tracks that likely originate from the B hadron decay.

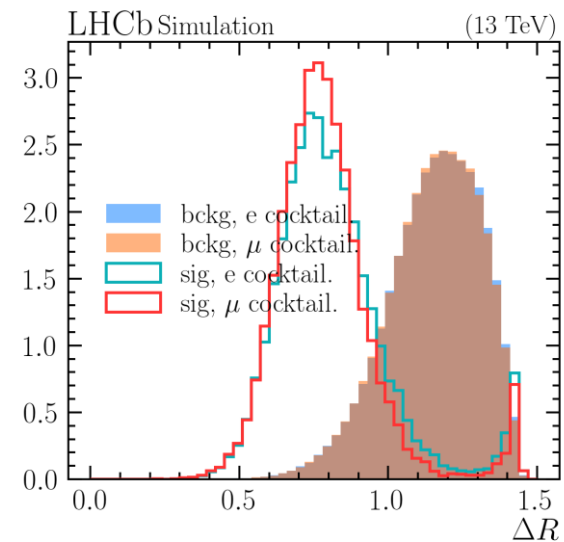
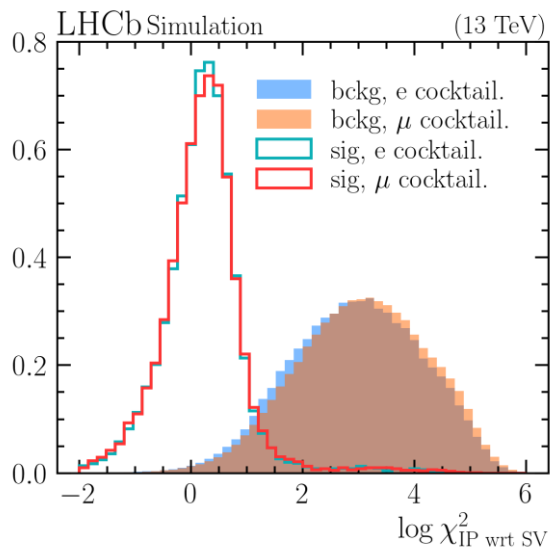
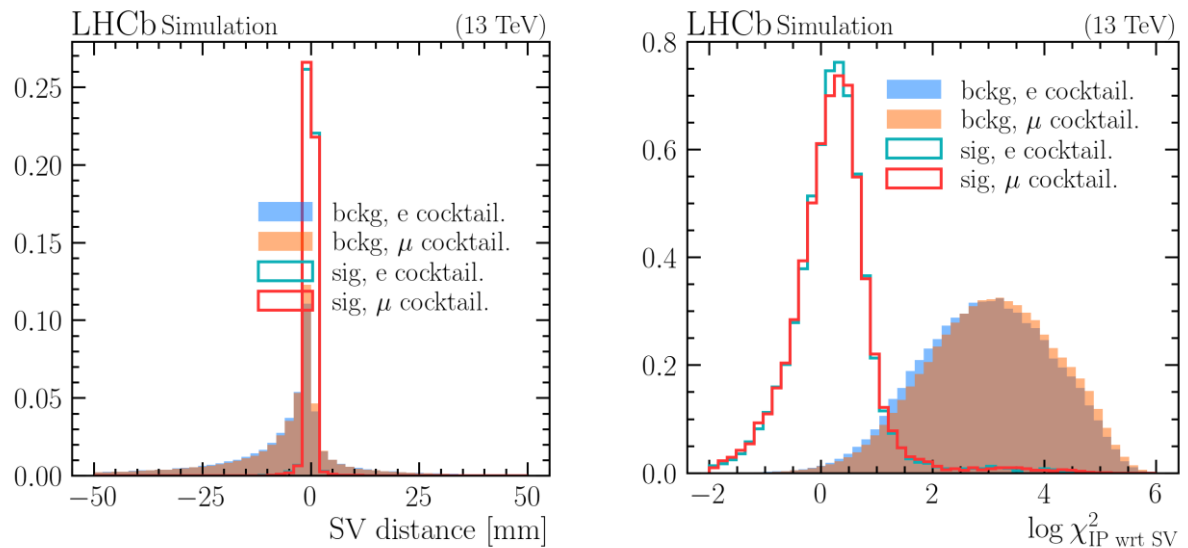
After the online trigger reconstruction



Training variables - e and μ cocktails



Variables of e / μ samples look identical



Performance - e cocktail track isolation

Table 1: Number of remaining tracks and corresponding BDT cuts

Decay	BDT>0.05	BDT>0.08	BDT>0.1	BDT>0.2	BDT>0.5
$B^0 \rightarrow D^{*-} e^+ \nu_e$	11.8	9.9	9.0	6.5	3.6
$B^0 \rightarrow D^{*-} \tau^+ \nu_\tau, \tau^+ \rightarrow e^+ \nu_e \bar{\nu}_\tau$	11.0	9.1	8.2	5.8	3.2
$B^0 \rightarrow D^{*-} e^+ \nu_e$	13.1	11.2	10.3	7.9	5.0
$B^0 \rightarrow D^{*-} \tau^+ \nu_\tau, \tau^+ \rightarrow e^+ \nu_e \bar{\nu}_\tau$	11.2	9.2	8.4	6.0	3.3
$B^+ \rightarrow D^{*0} e^+ \nu_e$	12.4	10.5	9.6	7.2	4.4
$B^+ \rightarrow D^{*0} \tau^+ \nu_\tau, \tau^+ \rightarrow e^+ \nu_e \bar{\nu}_\tau$	11.7	9.8	9.0	6.7	4.1



With cut > 0.08 :

Table 2: Signal efficiency and corresponding BDT cuts.

Decay	BDT>0.05	BDT>0.08	BDT>0.1	BDT>0.2	BDT>0.5
$B^0 \rightarrow D^{*-} e^+ \nu_e$	0.999	0.999	0.998	0.997	0.987
$B^0 \rightarrow D^{*-} \tau^+ \nu_\tau, \tau^+ \rightarrow e^+ \nu_e \bar{\nu}_\tau$	1.0	1.0	1.0	0.999	0.995
$B^0 \rightarrow D^{*-} e^+ \nu_e$	0.996	0.993	0.992	0.985	0.957
$B^0 \rightarrow D^{*-} \tau^+ \nu_\tau, \tau^+ \rightarrow e^+ \nu_e \bar{\nu}_\tau$	0.995	0.992	0.991	0.984	0.962
$B^+ \rightarrow D^{*0} e^+ \nu_e$	0.997	0.995	0.994	0.988	0.971
$B^+ \rightarrow D^{*0} \tau^+ \nu_\tau, \tau^+ \rightarrow e^+ \nu_e \bar{\nu}_\tau$	0.996	0.994	0.992	0.985	0.966



Around **10 tracks** per event remain, preserving **almost all of the events** we are interested in !

In terms of file size, it reduces the number of tracks by approximately a **factor of 10**

Performance - μ cocktail track isolation

Table 1: Number of remaining tracks and corresponding BDT cuts

Decay	BDT>0.05	BDT>0.08	BDT>0.1	BDT>0.2	BDT>0.5
$B^0 \rightarrow D^{*-} \mu^+ \nu_\mu$	10.3	8.6	7.8	5.6	3.2
$B^0 \rightarrow D^{*-} \tau^+ \nu_\tau, \tau^+ \rightarrow \mu^+ \nu_\mu \bar{\nu}_\tau$	9.7	8.0	7.3	5.2	2.8
$B^0 \rightarrow D^{*-} \mu^+ \nu_\mu$	10.2	8.6	7.8	5.7	3.3
$B^0 \rightarrow D^{*-} \tau^+ \nu_\tau, \tau^+ \rightarrow \mu^+ \nu_\mu \bar{\nu}_\tau$	9.7	8.1	7.3	5.2	2.9
$B^+ \rightarrow D^{*0} \mu^+ \nu_\mu$	10.8	9.1	8.4	6.3	4.0
$B^+ \rightarrow D^{*0} \tau^+ \nu_\tau, \tau^+ \rightarrow \mu^+ \nu_\mu \bar{\nu}_\tau$	10.5	8.9	8.1	6.0	3.7

Table 2: Signal efficiency and corresponding BDT cuts.

Decay	BDT>0.05	BDT>0.08	BDT>0.1	BDT>0.2	BDT>0.5
$B^0 \rightarrow D^{*-} \mu^+ \nu_\mu$	1.0	1.0	0.999	0.998	0.991
$B^0 \rightarrow D^{*-} \tau^+ \nu_\tau, \tau^+ \rightarrow \mu^+ \nu_\mu \bar{\nu}_\tau$	1.0	1.0	1.0	0.999	0.995
$B^0 \rightarrow D^{*-} \mu^+ \nu_\mu$	0.999	0.998	0.998	0.995	0.988
$B^0 \rightarrow D^{*-} \tau^+ \nu_\tau, \tau^+ \rightarrow \mu^+ \nu_\mu \bar{\nu}_\tau$	0.993	0.99	0.989	0.981	0.96
$B^+ \rightarrow D^{*0} \mu^+ \nu_\mu$	0.997	0.995	0.995	0.991	0.976
$B^+ \rightarrow D^{*0} \tau^+ \nu_\tau, \tau^+ \rightarrow \mu^+ \nu_\mu \bar{\nu}_\tau$	0.994	0.992	0.991	0.985	0.963

We evaluate e training model on μ cocktail samples. The performance still good

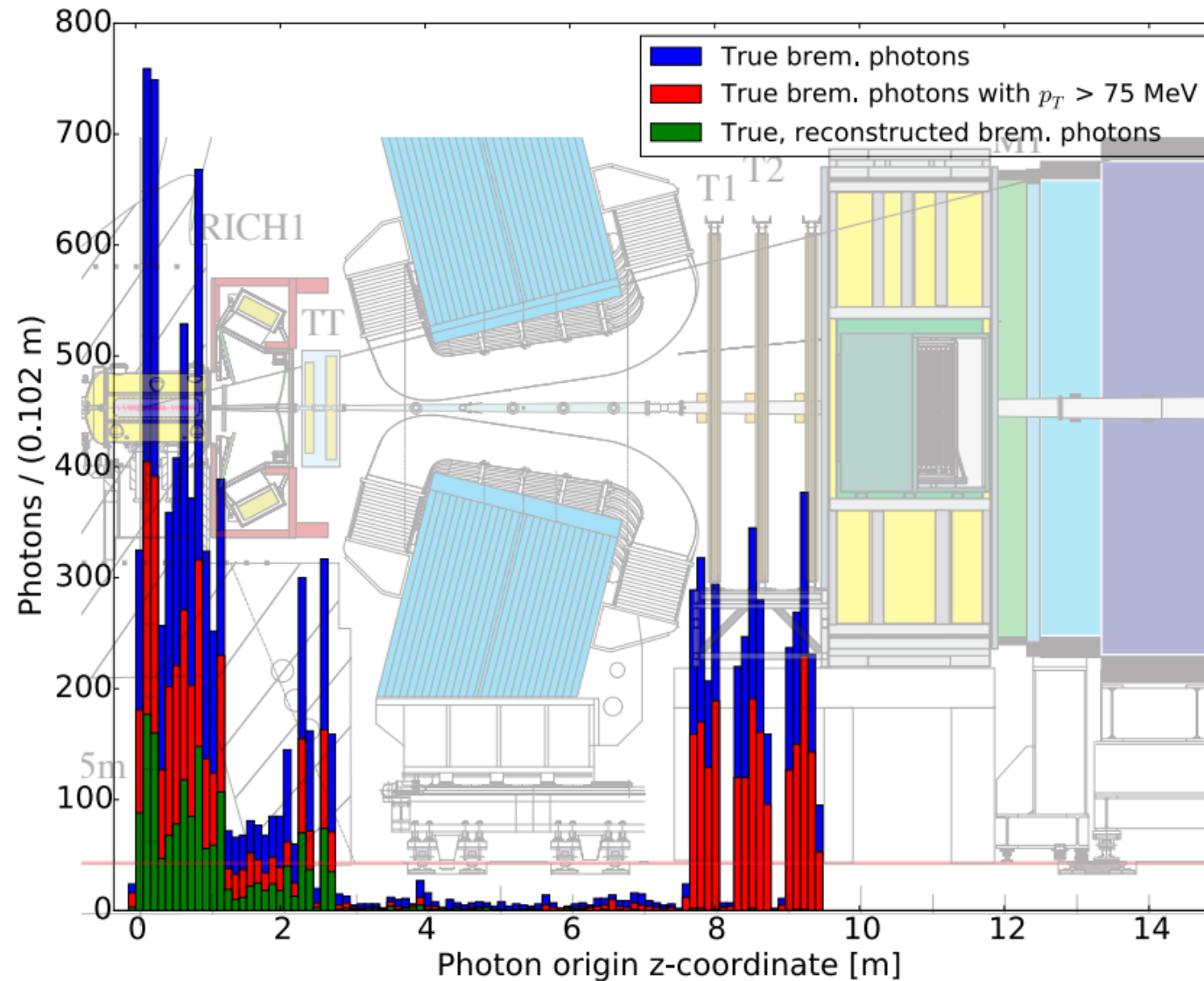
TABLE 5.12. – Decay name and the corresponding sub decays

Decay name	Decay composite
$B^0 \rightarrow D^{*-} e^+ \nu_e$	$B^0 \rightarrow (D^*(2010)^- \rightarrow (\bar{D}^0 \rightarrow K^+ \pi^-) \pi^-) e^+ \nu_e$
$B^0 \rightarrow D^{*-} \tau^+ \nu_\tau$	$B^0 \rightarrow (D^*(2010)^- \rightarrow (\bar{D}^0 \rightarrow K^+ \pi^-) \pi^-) (\tau^+ \rightarrow e^+ \nu_e \nu_\tau) \nu_\tau$
$B^0 \rightarrow D_{0,1,2}^{*-} e^+ \nu_e$	$B^0 \rightarrow (D_0^*(2400)^- / D_1(2420)^- / D_1'(2430)^- / D_2^*(2460)^-) e^+ \nu_e$
$B^0 \rightarrow D_{0,1,2}^{*-} \tau^+ \nu_\tau$	$B^0 \rightarrow (D_0^*(2300)^- / D_1(2420)^- / D_1'(2430)^- / D_2^*(2460)^-) \tau^+ \nu_\tau$
$B^+ \rightarrow D_{0,1,2}^{*0} e^+ \nu_e$	$B^+ \rightarrow (D_0^*(2400)^0 / D_1'(2430)^0 / D_1(2420)^0 / D_2^*(2460)^0) e^+ \nu_e$
$B^+ \rightarrow D_{0,1,2}^{*0} \tau^+ \nu_\tau$	$B^+ \rightarrow (D_0^*(2300)^0 / D_1'(2430)^0 / D_1(2420)^0 / D_2^*(2460)^0) \tau^+ \nu_\tau$
$B^0 \rightarrow (D_{1,2}^{*-} / D^{(*)}(2S)^-) e^+ \nu_e$	$B^0 \rightarrow (D^*(2S)^- / D(2S)^- / D_1(2420)^- / D_2^*(2460)^-) e^+ \nu_e$
$B^+ \rightarrow (D_{1,2}^{*0} / D^{(*)}(2S)^0) e^+ \nu_e$	$B^+ \rightarrow (D^*(2S)^0 / D(2S)^0 / D_1(2420)^0 / D_2^*(2460)^0) e^+ \nu_e$
$B_s^0 \rightarrow (D_{s1}(2536) / D_{s2}(2573)) e^+ \nu_e$	$B_s^0 \rightarrow (D_{s1}(2536) / D_{s2}(2573)) e^+ \nu_e$
$B^0 \rightarrow D^0(X_c \rightarrow e^+ \nu_e X') X$	$B^0 \rightarrow D^0(X_c \rightarrow e^+ \nu_e X') X$
$B^+ \rightarrow D^0(X_c \rightarrow e^+ \nu_e X') X$	$B^+ \rightarrow D^0(X_c \rightarrow e^+ \nu_e X') X$
$B^0 \rightarrow D^0(D_s^- \rightarrow \tau^+ \nu_\tau) X$	$B^0 \rightarrow D^0(D_s^- \rightarrow \tau^+ \nu_\tau) X$
$B^+ \rightarrow D^0(D_s^- \rightarrow \tau^+ \nu_\tau) X$	$B^+ \rightarrow D^0(D_s^- \rightarrow \tau^+ \nu_\tau) X$

* X_c denotes an inclusive charm-hadron state.

* X and X' denote a system of any additional final-state particles.

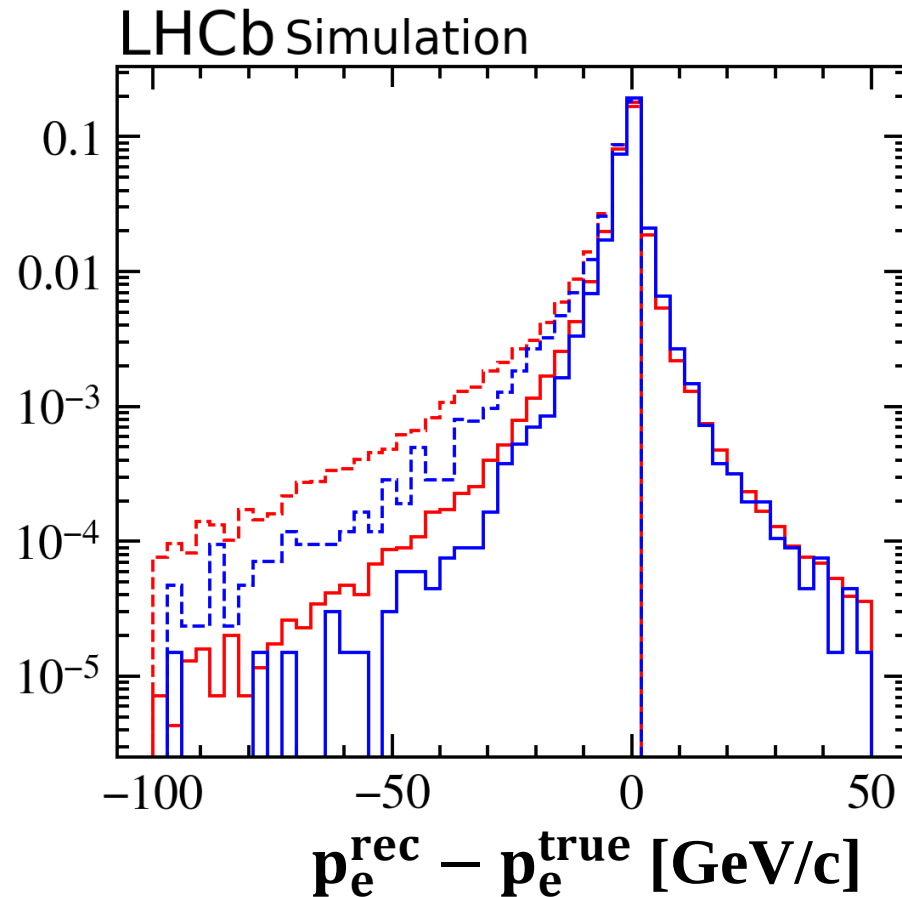
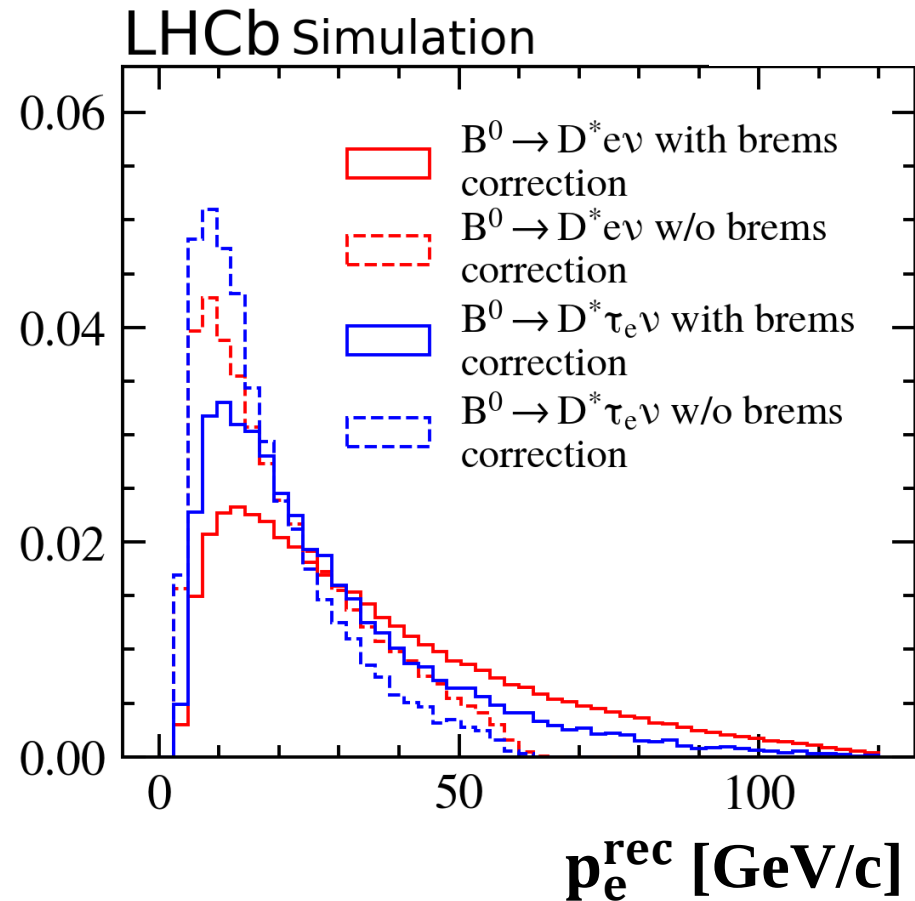
Bremsstrahlung emission in LHCb



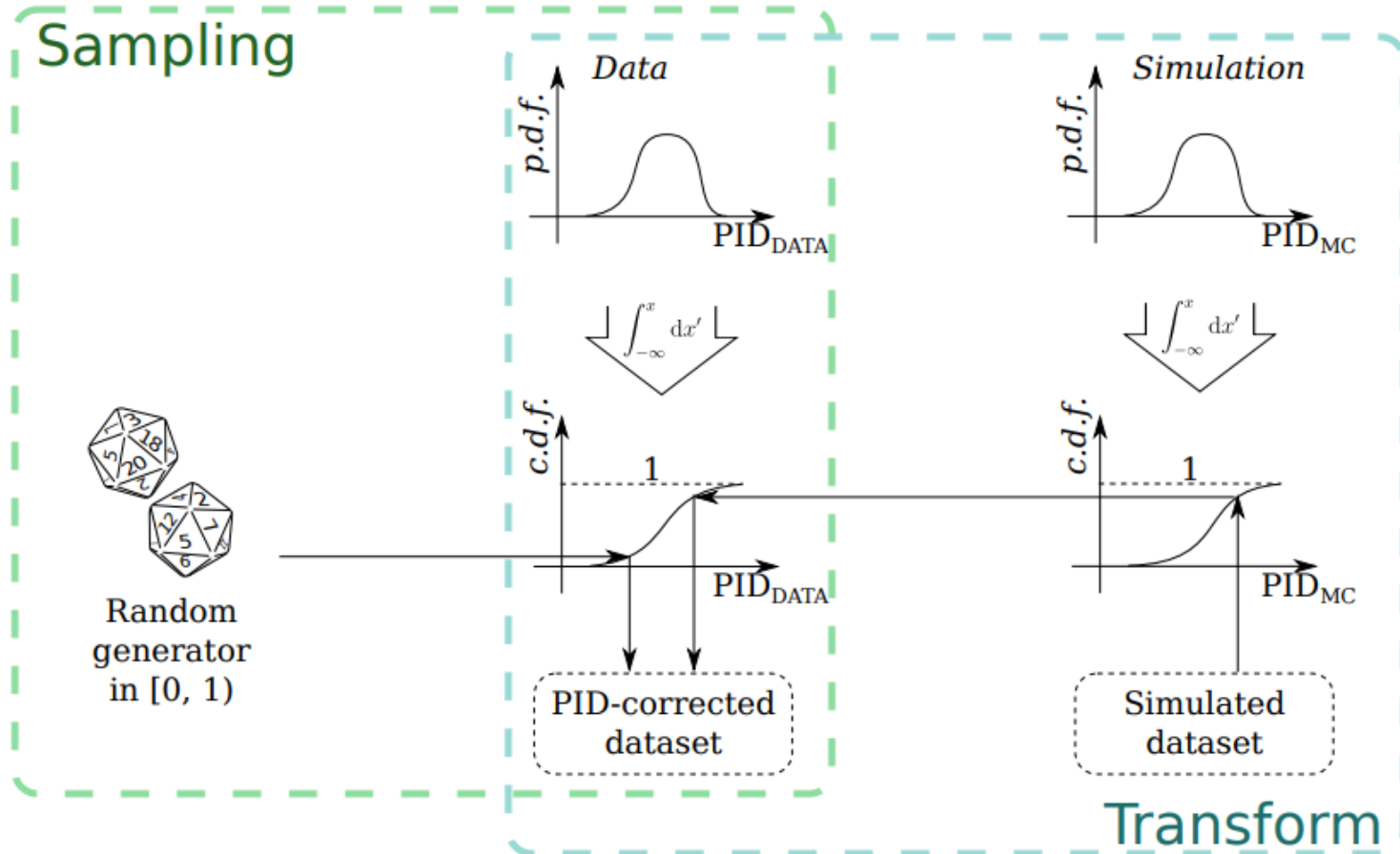
Bremsstrahlung recovery in kinematics

$$B^0 \rightarrow D^{*-} e^+ \nu_e$$

$$B^0 \rightarrow D^{*-} \tau^+ \nu_\tau, \tau^+ \rightarrow e^+ \nu_e \bar{\nu}_\tau$$



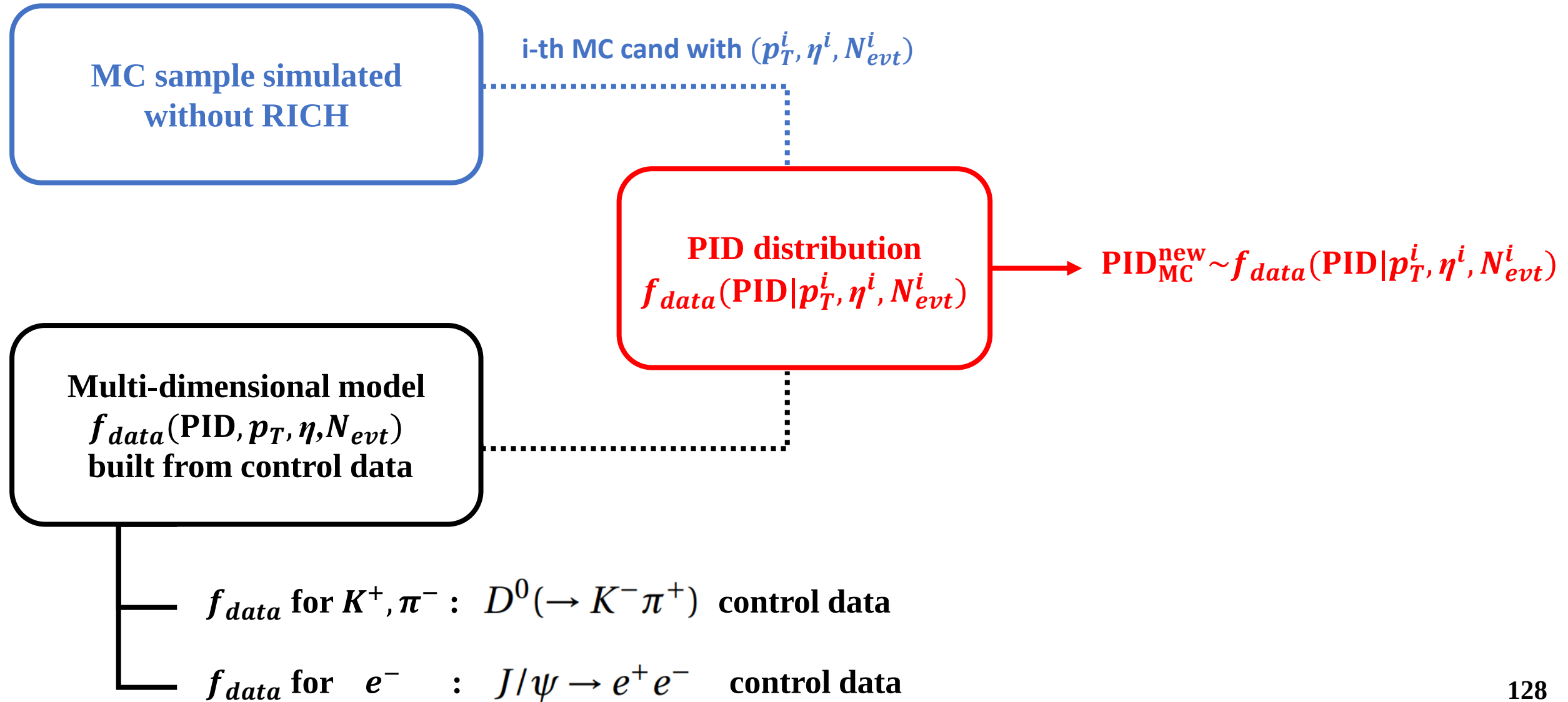
Schematic representation of PID resampling



[Plot reference](#)

Figure 2: Schematic representation of the PID resampling and variable transformation techniques.

MC corrections - PID resampling



HLT2 selections of $B^0 \rightarrow J/\psi K^{*0}$ control sample

B^0 selections	
Mass (MeV/c^2)	$4000 < M < 6500$
$\chi^2_{\text{vertex}}/\text{n.d.f.}$	< 9
χ^2_{FD}	> 1000
DIRA	> 0.995
χ^2_{IP}	< 25
J/ψ selections	
Mass (MeV/c^2)	< 5500
$\chi^2_{\text{vertex}}/\text{n.d.f.}$	< 10
χ^2_{FD}	> 30
min. χ^2_{IP} of $e^\pm$	> 9

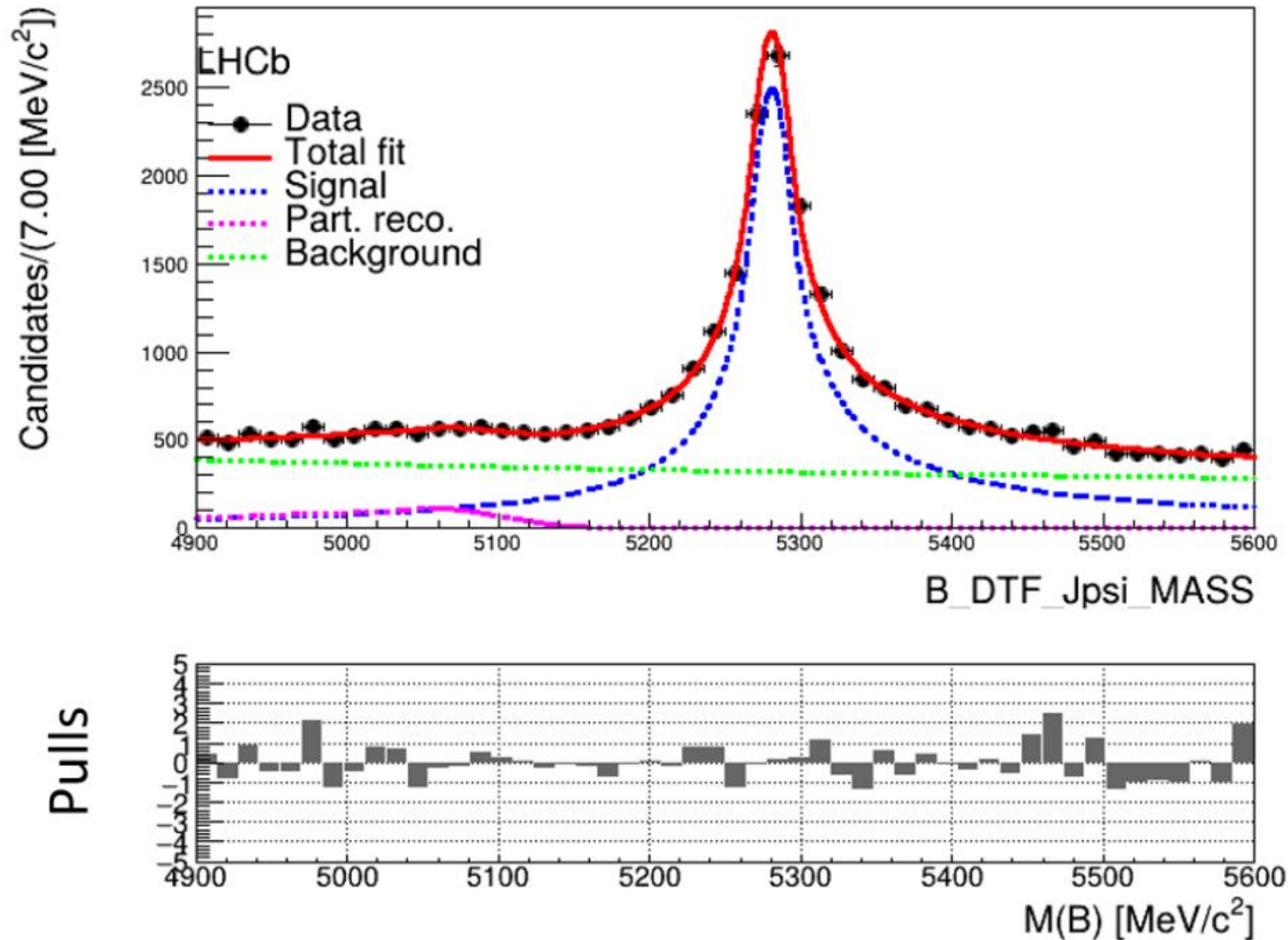
K^{*0} selections	
DOCA (mm)	< 30
Mass (MeV/c^2)	$592 < M < 1192$
p_T (MeV/c)	> 500
χ^2	< 25
p (MeV/c) of K, π	> 2000
p_T (MeV/c) of K, π	> 250
min. χ^2_{IP} of K, π	> 9
PID _K of K, π	> 2 ($< 10^{-5}$)

Offline selections of $B^0 \rightarrow J/\psi K^{*0}$ control sample

B^0 selections	
DIRA	> 0.9995
J/ψ selections	
Mass (MeV/c^2)	< 3139.9
$\chi^2_{\text{vertex}}/ndf$	< 6
χ^2_{DOCA}	< 30
K^{*0} selections	
Mass (MeV/c^2)	$792 < M < 992$
$\chi^2_{\text{vertex}}/ndf$	< 9
χ^2_{DOCA}	< 30

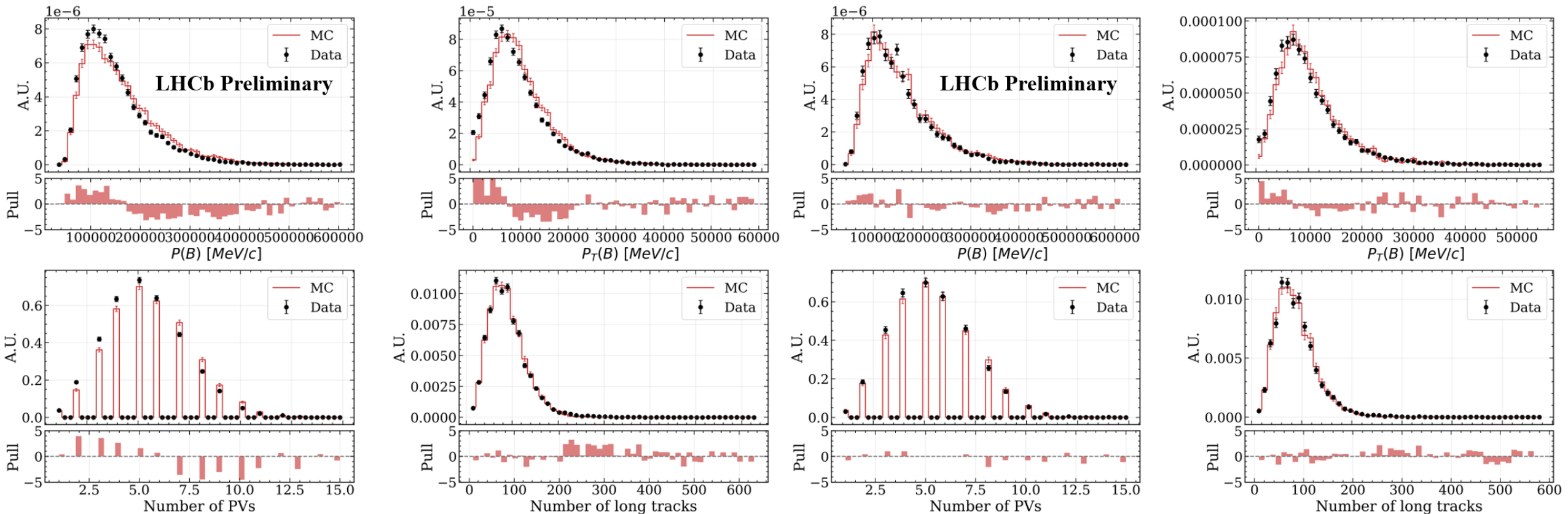
$e^\pm$ selections	
PID _e	> 2.0
p (GeV/c)	$3 < p < 200$
p_T (MeV/c)	> 300
min. χ^2_{IP}	> 15
η	$2.2 < \eta < 4.2$
$K^\pm, \pi^\pm$ selections	
p (GeV/c)	$5 < p < 200$
p_T (MeV/c)	> 300
min. χ^2_{IP}	> 45
η	$1.5 < \eta < 5$

$B^0 \rightarrow J/\psi K^{*0}$ control sample bkg subtraction fit



MC corrections - kinematics & multiplicity

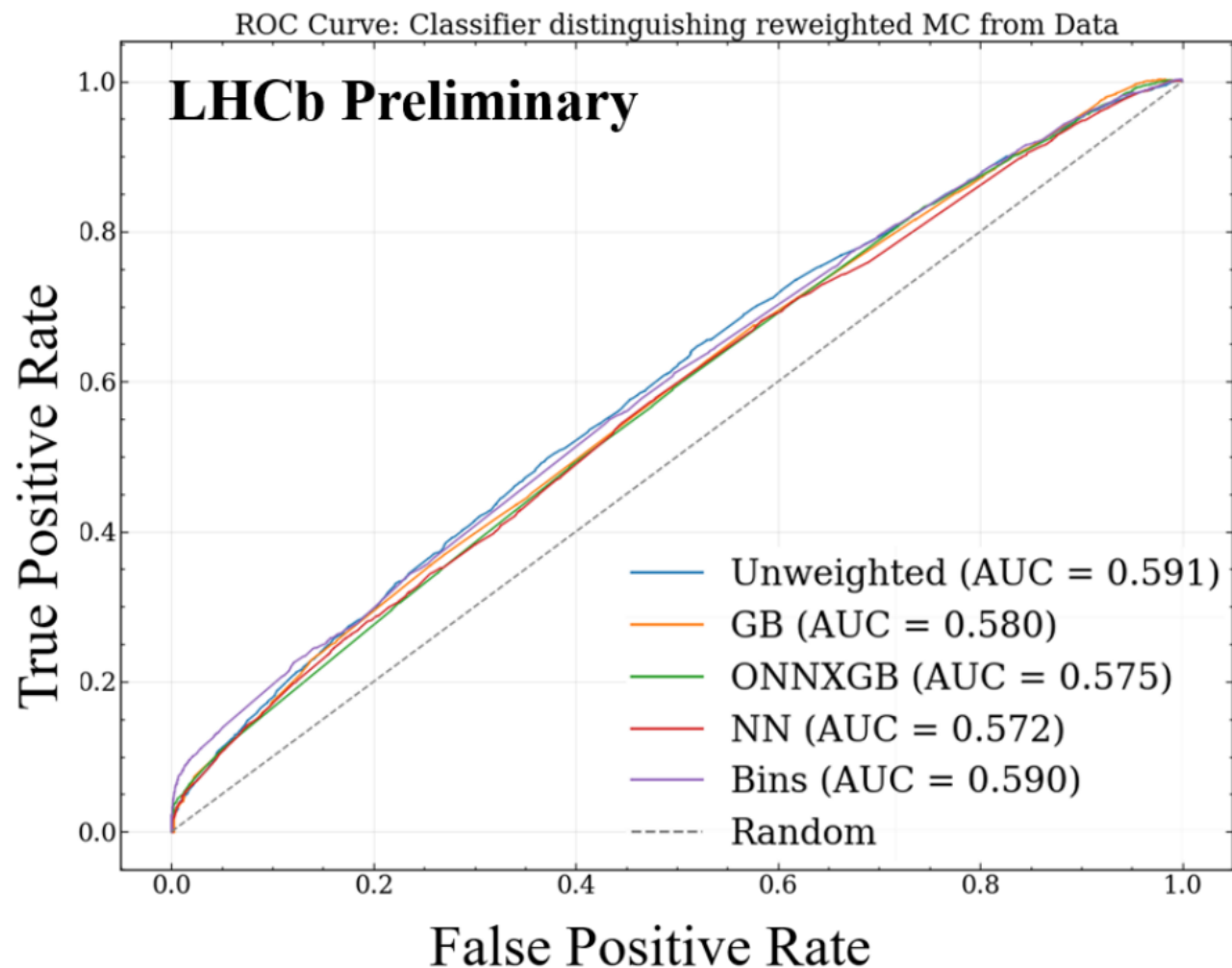
$B^0 \rightarrow J/\psi K^{*0}$, with $J/\psi \rightarrow e^+e^-$ and $K^{*0} \rightarrow K^+\pi^-$ control sample



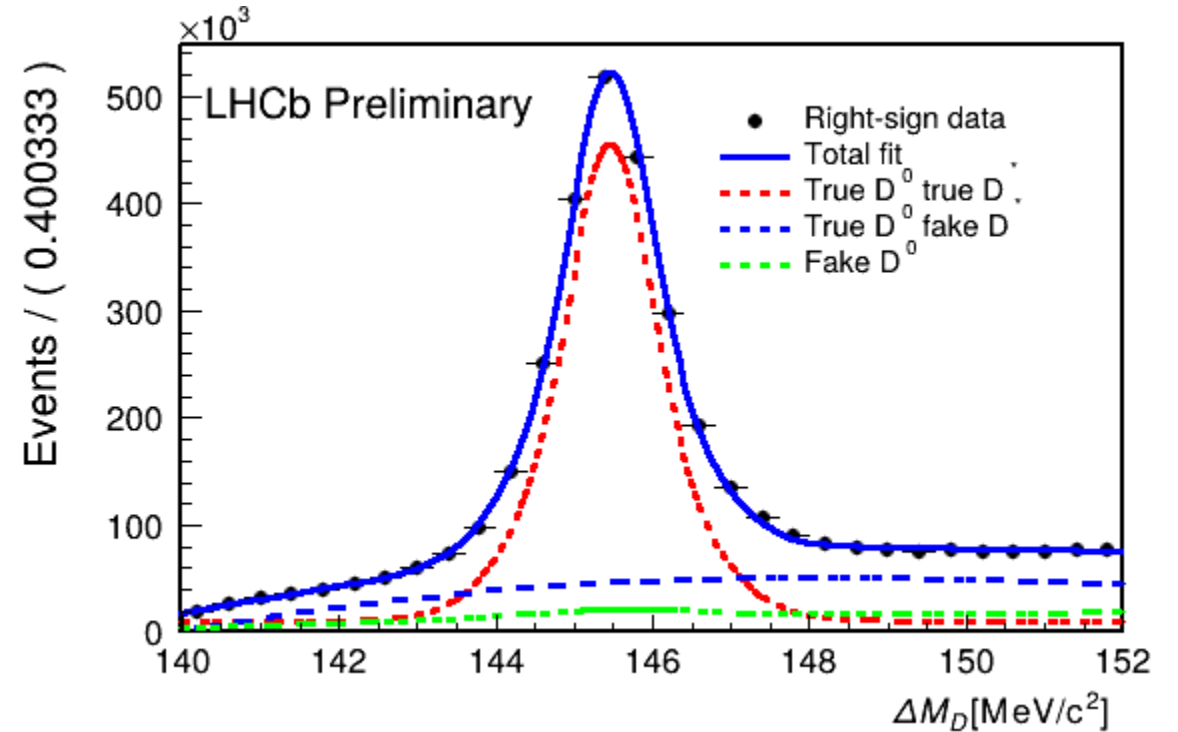
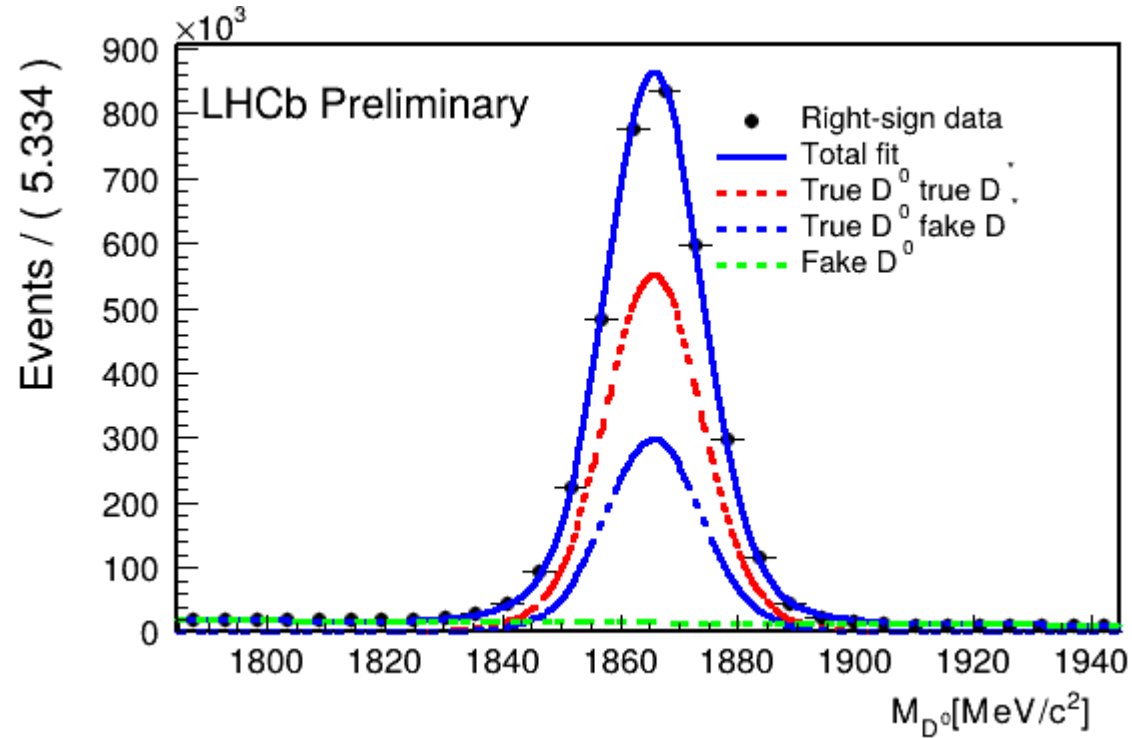
Without weight

With weight

Comparison of different methods for mcreweight



$M_{D^0} \times \Delta M_{D^*}$ fit on block 7 data

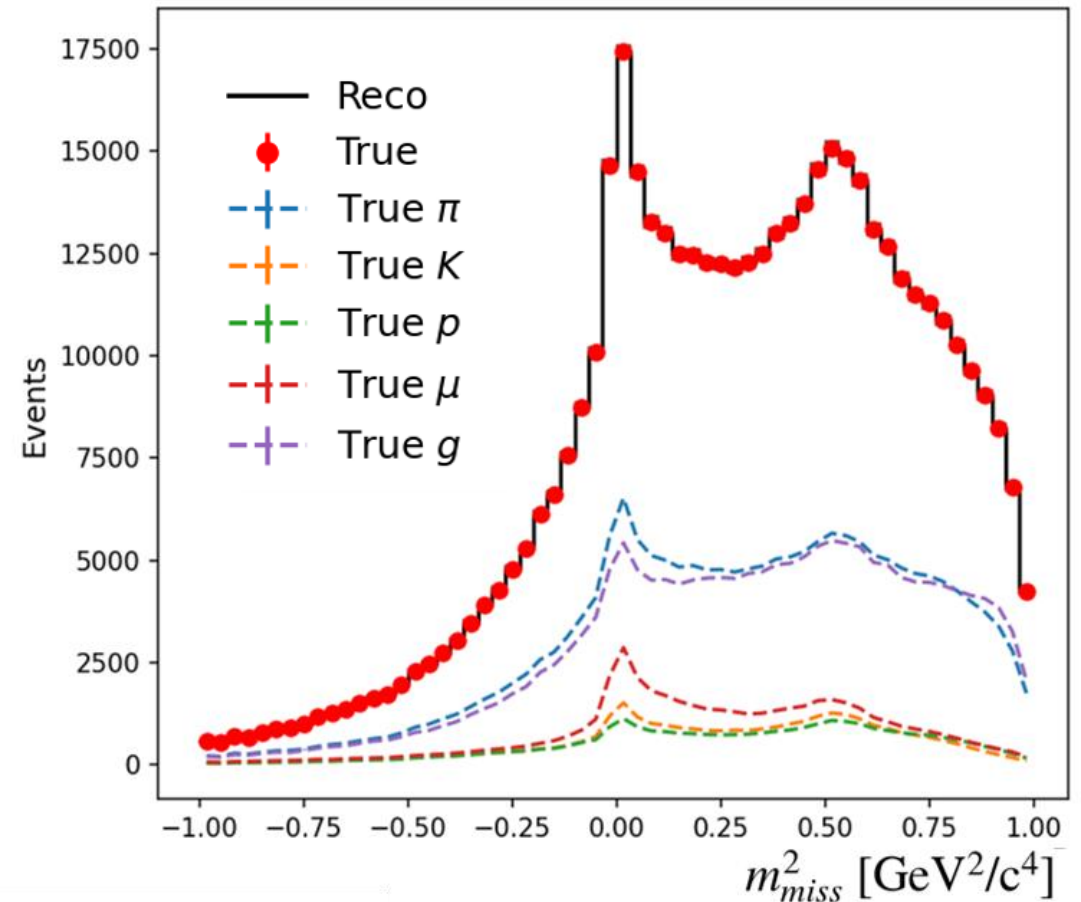


	True D^0 True D^*	True D^0 Fake D^*	Fake D^0
Number of yields in data	2.2 M	1.2 M	0.5 M

Mis-identification background

Mis-ID backgrounds are distinguished in the fit

→ Need to quantify the **true yields** $\vec{n}_{true}$ of each misidentified track category



Mis-identification background

Mis-ID backgrounds are distinguished in the fit

→ Need to quantify the **true yields** $\vec{n}_{true}$ of each misidentified track category

The true yields $\vec{n}_{true}$ can be unfolded using

- **Reconstructed yields** $\vec{n}_{rec}$

→ Determined using bkg-enriched control sample : data with reversed electron ID cut (PIDE < 2)

- **Mis-ID matrix**

→ Obtained from calibration group and MC study

$$\begin{pmatrix} \epsilon_{\pi \rightarrow \pi} & \epsilon_{K \rightarrow \pi} & \epsilon_{p \rightarrow \pi} & \epsilon_{\mu \rightarrow \pi} & \epsilon_{g \rightarrow \pi} & \epsilon_{e \rightarrow \pi} \\ \epsilon_{\pi \rightarrow K} & \epsilon_{K \rightarrow K} & \epsilon_{p \rightarrow K} & \epsilon_{\mu \rightarrow K} & \epsilon_{g \rightarrow K} & \epsilon_{e \rightarrow K} \\ \epsilon_{\pi \rightarrow p} & \epsilon_{K \rightarrow p} & \epsilon_{p \rightarrow p} & \epsilon_{\mu \rightarrow p} & \epsilon_{g \rightarrow p} & \epsilon_{e \rightarrow p} \\ \epsilon_{\pi \rightarrow \mu} & \epsilon_{K \rightarrow \mu} & \epsilon_{p \rightarrow \mu} & \epsilon_{\mu \rightarrow \mu} & \epsilon_{g \rightarrow \mu} & \epsilon_{e \rightarrow \mu} \\ \epsilon_{\pi \rightarrow g} & \epsilon_{K \rightarrow g} & \epsilon_{p \rightarrow g} & \epsilon_{\mu \rightarrow g} & \epsilon_{g \rightarrow g} & \epsilon_{e \rightarrow g} \\ \epsilon_{\pi \rightarrow e} & \epsilon_{K \rightarrow e} & \epsilon_{p \rightarrow e} & \epsilon_{\mu \rightarrow e} & \epsilon_{g \rightarrow e} & \epsilon_{e \rightarrow e} \end{pmatrix}$$

Vertex isolation procedure

Step 1 : rank the B^0 candidates in each event

		BDT
Event 1	B_1^-	π_1^+ 0.998
	B_1^-	π_2^+ 0.969
	B_1^-	π_3^+ 0.903
	B_2^-	π_1^+ 0.856
	B_1^-	π_4^+ 0.821
	B_2^-	π_3^+ 0.411
Event 2	B_1^-	π_1^+ 0.995
	B_1^-	π_2^+ 0.992
	B_2^-	π_1^+ 0.956
	B_2^-	π_2^+ 0.827
	B_1^-	π_3^+ 0.733
	B_2^-	π_3^+ 0.591

Step 2 : Remove the event if the second candidate has BDT > 0.99

		BDT
Event 1	B_1^-	π_1^+ 0.998
	B_1^-	π_2^+ 0.969
	B_1^-	π_3^+ 0.903
	B_2^-	π_1^+ 0.856
	B_1^-	π_4^+ 0.821
	B_2^-	π_3^+ 0.411
Event 2	B_1^-	π_1^+ 0.995
	B_1^-	π_2^+ 0.992
	B_2^-	π_1^+ 0.956
	B_2^-	π_2^+ 0.827
	B_1^-	π_3^+ 0.733
	B_2^-	π_3^+ 0.591

Passed

Remove
event2

Vertex isolation procedure

Step 1 : rank the B^0 candidates in each event

Step 2 : Remove the event if the second candidate has $\text{BDT} > 0.99$

BDT

$B^- \pi^+$ 0.999

BDT

$B^- \pi^+$ 0.999

Why check the second and third one ?

Ideally, in $D^* \tau$ or e decays, there is only one extra π originate from B meson, if other high mva extra π 's exists, that decay might involve a higher excited D-meson

Why remove the whole event ?

In each collision, multiple B decays occur, but consider the branching ratio of our signal channel (10^{-2}) and the signal efficiency (selection and detection), it's unlikely that D^{**} and $D^* l$ decays would be reconstructed in the same event.

$B_1^- \pi_3^+$ 0.733

$B_2^- \pi_3^+$ 0.591

$B_1^- \pi_3^+$ 0.733

$B_2^- \pi_3^+$ 0.591

	2 nd highest MVA ΔM_{D^*} sideband < 0.995	Sum of top 3 MVA < 2.995
$B^0 \rightarrow D^* e \nu$	82.8(78.1)	84.7(79.4)
$B^0 \rightarrow D^* \tau \nu$	85.7(80.9)	86.9(81.5)
$B^0 \rightarrow D^{**} e \nu$	21.5(12.4)	34.4(14.2)
$B^0 \rightarrow D^{**} \tau \nu$	68.3(58.6)	68.2(56.7)
$B^+ \rightarrow D^{**} e \nu$	57.7(53.8)	58.6(53.5)
$B^+ \rightarrow D^{**} \tau \nu$	66.6(61.7)	66.7(60.9)
$B^+ \rightarrow D^0(X_c \rightarrow e \nu X') X$	44.9(28.7)	50.2(29.5)
$B^+ \rightarrow D^{**}(D_s \rightarrow \tau \nu) X$	66.4(61.3)	69.1(62.8)
$B^0 \rightarrow D^{**}(D_s \rightarrow \tau \nu) X$	82.0(76.7)	84.0(77.8)
$B^0 \rightarrow D^0(X_c \rightarrow e \nu X') X$	45.5(31.3)	50.9(32.7)
$B^0 \rightarrow D_{0,1,2}^{*-} e \nu$	64.5(56.8)	64.4(55.3)
$B^+ \rightarrow D_{0,1,2}^{*0} e \nu$	62.2(57.8)	62.5(57.2)
$B_s^0 \rightarrow D_s^{**} e \nu$	81.6(60.4)	84.8(61.7)

Efficiency [%] Vertex isolation (offline selection)

Background MC investigation

	Estimated BR	Generator cuts [%]	Trigger selection [%]	Vertex isolation and offline selection [%]	Overall efficiency [%]
$B^0 \rightarrow D^{**}(D_s \rightarrow \tau \nu) X$	1.3×10^{-5}	8.5	12.6	80.3	0.86

```
# -----
# DECAY OF THE B0
# -----
Decay anti-B0sig
0.0177000000 MyD*+      MyD_s*-      SVV_HELAMP 0.4904 0.0 0.7204 0.0 0.4904 0.0;
0.0080000000 MyD*+      MyD_s-       SVS;
0.0006  MyD'_1+  MyD_s-       SVS;
0.0012  MyD'_1+  MyD_s*-      SVV_HELAMP 0.48 0.0 0.734 0.0 0.48 0.0;
0.0012  MyD_1+   MyD_s-       SVS;
0.0024  MyD_1+   MyD_s*-      SVV_HELAMP 0.48 0.0 0.734 0.0 0.48 0.0;
0.0042  MyD_2*+  MyD_s-       STS;
0.0040  MyD_2*+  MyD_s*-      PHSP;

0.0015  MyD*+    MyD_s0*-      SVS;
#dubious HELAMP values
0.0093  MyD*+    MyD_s1-       SVV_HELAMP 0.4904 0.0 0.7204 0.0 0.4904 0.0;

#0.0005  MyD*+    MyD'_s1-      SVV_HELAMP 0.4904 0.0 0.7204 0.0 0.4904 0.0;
```

Main source of this cocktail sample

```
Decay MyD_s+
  1 Mytau+      nu_tau
Enddecay
CDecay MyD_s-

Decay MyD_s*+
0.9420000000 MyD_s+      gamma
0.0580000000 MyD_s+      pi0
Enddecay
CDecay MyD_s*-
```

The only extra particle is γ

Branching ratio estimation

	Estimated BR	Generator cuts [%]	Trigger selection [%]	Vertex isolation and offline selection [%]	Overall efficiency [%]
$B^+ \rightarrow D^* e \nu$	1.3×10^{-3}	8.8	28.4	82.4	2.06
$B^+ \rightarrow D^* \tau \nu$	6.9×10^{-5}	8.9	24.8	84.0	1.85
$B^0 \rightarrow D^{**} e \nu$	1.0×10^{-4}	8.6	51.4	15.3	0.68

Signal modes are determined with the PDG value, for cocktail background MC:

1. Search the PDG value of the sub-decays in dec file

```
Decay B0sig
  0.05  MyD*(2S)-      e+  nu_e      PHOTOS  ISGW2;
  0.45  MyD(2S)-       e+  nu_e      PHOTOS  ISGW2;
  0.45  MyD(2750)-     e+  nu_e      PHOTOS  ISGW2;
  0.05  MyD(3000)-     e+  nu_e      PHOTOS  ISGW2;
Enddecay
CDecay anti-B0sig
```

The sub-decays
B0 -> MyD(2750)- e+ nu_e and B0 -> MyD(3000)- e+ nu_e
are found in PDG

```
PDG value for B0 --> D_2^(2460)- e+ nu_e : ratio 0.45 and decays in decfile B0 -> MyD(2750)- e+ nu_e
Found data : B0 --> D_2^(2460)- lepton+ nu_lepton , D_2^()- --> Dbar0 pi- with pdg_values (1.41+-0.20)E-3
Found data : B0 --> D_2^(2460)- lepton+ nu_lepton , D_2^()- --> Dbar^()0 pi- with pdg_values (6.6+-1.1)E-4
PDG value for B0 --> D_1(2420)- e+ nu_e : ratio 0.05 and decays in decfile B0 -> MyD(3000)- e+ nu_e
Found data : B0 --> D_1(2420)- lepton+ nu_lepton , D_1()- --> Dbar^()0 pi- with pdg_values (2.85+-0.25)E-3
Found data : B0 --> D_1(2420)- lepton+ nu_lepton , D_1()- --> D- pi+ pi- with pdg_values (1.02+-0.16)E-3
```

Branching ratio estimation

	Estimated BR	Generator cuts [%]	Trigger selection [%]	Vertex isolation and offline selection [%]	Overall efficiency [%]
$B^+ \rightarrow D^* e \nu$	1.3×10^{-3}	8.8	28.4	82.4	2.06
$B^+ \rightarrow D^* \tau \nu$	6.9×10^{-5}	8.9	24.8	84.0	1.85
$B^0 \rightarrow D^{**} e \nu$	1.0×10^{-4}	8.6	51.4	15.3	0.68

Signal modes are determined with the PDG value, for cocktail background MC:

2. Estimate the branching ratios of this dec file

```
Decay B0sig
  0.05  MyD*(2S)-      e+  nu_e      PHOTOS  ISGW2;
  0.45  MyD(2S)-       e+  nu_e      PHOTOS  ISGW2;
  0.45  MyD(2750)-     e+  nu_e      PHOTOS  ISGW2;
  0.05  MyD(3000)-     e+  nu_e      PHOTOS  ISGW2;
Enddecay
CDecay anti-B0sig
```

```
PDG value for B0 --> D_2^*(2460)- e+ nu_e : ratio 0.45 and decays in decfile B0 -> MyD(2750)- e+ nu_e
Found data : B0 --> D_2^*(2460)- lepton+ nu_lepton , D_2^*()- --> Dbar0 pi- with pdg_values (1.41+-0.20)E-3
Found data : B0 --> D_2^*(2460)- lepton+ nu_lepton , D_2^*()- --> Dbar^*()0 pi- with pdg_values (6.6+-1.1)E-4
PDG value for B0 --> D_1(2420)- e+ nu_e : ratio 0.05 and decays in decfile B0 -> MyD(3000)- e+ nu_e
Found data : B0 --> D_1(2420)- lepton+ nu_lepton , D_1()- --> Dbar^*()0 pi- with pdg_values (2.85+-0.25)E-3
Found data : B0 --> D_1(2420)- lepton+ nu_lepton , D_1()- --> D- pi+ pi- with pdg_values (1.02+-0.16)E-3
```

The summed BR of sub-decays
 B0 -> MyD(2750)- e+ nu_e and B0 -> MyD(3000)- e+ nu_e
 are around 2×10^{-3} and the ratio in decfile is $0.45 + 0.05 = 0.5$
 the estimated BR is $(2 \times 10^{-3}) / (0.5 / 1.0) = 4 \times 10^{-3}$
 Consider the BR for $D^{*-}(\rightarrow D^0 \pi^-)$ and $D^0(\rightarrow K \pi)$
 We get $BR \sim 1.0 \times 10^{-4}$

Efficiency determination

	Estimated BR	Generator cuts [%]	Trigger selection [%]	Vertex isolation and offline selection [%]	Overall efficiency [%]
$B^+ \rightarrow D^* e \nu$	1.3×10^{-3}	8.8	28.4	82.4	2.06
$B^0 \rightarrow D^{**} e \nu$	1.0×10^{-4}	8.6	51.4	15.3	0.68

Step 1 : [Prepare MC tuples](#) which only contain generator level information

```
tuple_Bst_MC = FuntupleMC(  
    name="Bstar_MCTuple",  
    tuple_name="DecayTree",  
    fields=fields,  
    variables=variables_mc,  
    event_variables=mc_evt_vars,  
    inputs=all_mc_particles,  
)
```

Using FuntupleMC and
decay descriptors

Step 2 :
Get the number of truth-matched candidates after trigger cuts
Divide this number by number of entries in the MC tuple

```
"b0_dstp_e": {  
    "B": "[[B0]CC => (D*(2010)- => D~0 pi-) e+ nu_e]CC",  
    "Dst": "[[B0]CC => ^(D*(2010)- => D~0 pi-) e+ nu_e]CC",  
    "D0": "[[B0]CC => (D*(2010)- => ^D~0 pi-) e+ nu_e]CC",  
    "pi": "[[B0]CC => (D*(2010)- => D~0 ^pi-) e+ nu_e]CC",  
    "lep": "[[B0]CC => (D*(2010)- => D~0 pi-) ^e+ nu_e]CC",  
    "nu": "[[B0]CC => (D*(2010)- => D~0 pi-) e+ ^nu_e]CC"  
},
```

Descriptor for signal mode

```
"b0_dststp_e": {  
    "B": "([([B0]CC => D*(2640)- e+ nu_e]CC) ||  
    ([B0]CC => D(2S)- e+ nu_e]CC) ||  
    ([B0]CC => D*_2(2460)- e+ nu_e]CC) ||  
    ([B0]CC => D_1(2420)- e+ nu_e]CC))"  
},
```

Descriptor for cocktail sample

Efficiency determination

	Estimated BR	Generator cuts [%]	Trigger selection [%]	Vertex isolation and offline selection [%]	Overall efficiency [%]
$B^+ \rightarrow D^* e \nu$	1.3×10^{-3}	8.8	28.4	82.4	2.06
$B^+ \rightarrow D^* \tau \nu$	6.9×10^{-5}	8.9	24.8	84.0	1.85
$B^0 \rightarrow D^{**} e \nu$	1.0×10^{-4}	8.6	51.4	15.3	0.68

Defined as

Number of truth-matched candidates after trigger selections, vertex isolation and ΔM_{D^*} cut

Number of truth-matched candidates after trigger selections

Cumulative selection efficiencies in block 8

Decay	Generator cuts [10^{-2}]	Trigger selections [10^{-2}]	Offline selections [10^{-2}]	Overall efficiency [10^{-4}]
$B^0 \rightarrow D^{*-} e^+ \nu_e$	8.80 ± 0.02	3.16 ± 0.00	82.23 ± 0.06	22.90 ± 0.06
$B^0 \rightarrow D^{*-} \tau^+ \nu_\tau$	8.90 ± 0.02	2.30 ± 0.01	85.38 ± 0.17	17.47 ± 0.10
$B^0 \rightarrow D_{0,1,2}^{*-} e^+ \nu_e$	8.60 ± 0.02	4.03 ± 0.03	18.28 ± 0.30	6.33 ± 0.12
$B^0 \rightarrow D_{0,1,2}^{*-} \tau^+ \nu_\tau$	8.40 ± 0.02	2.52 ± 0.04	11.67 ± 0.46	2.47 ± 0.10
$B^+ \rightarrow D_{0,1,2}^{*0} e^+ \nu_e$	8.70 ± 0.02	2.36 ± 0.02	65.82 ± 0.49	13.51 ± 0.17
$B^+ \rightarrow D_{0,1,2}^{*0} \tau^+ \nu_\tau$	8.30 ± 0.02	1.88 ± 0.03	69.49 ± 0.82	10.85 ± 0.23
$B^0 \rightarrow (D_{1,2}^{*-} / D^{(*)} (2S)^-) e^+ \nu_e$	8.60 ± 0.02	6.00 ± 0.04	16.84 ± 0.23	8.69 ± 0.13
$B^+ \rightarrow (D_{1,2}^{*0} / D^{(*)} (2S)^0) e^+ \nu_e$	8.50 ± 0.02	2.98 ± 0.03	60.53 ± 0.45	15.31 ± 0.18
$B_s^0 \rightarrow (D_{s1}(2536) / D_{s2}(2573)) e^+ \nu_e$	8.60 ± 0.02	3.85 ± 0.04	67.56 ± 0.44	22.39 ± 0.26
$B^0 \rightarrow D^0 (X_c \rightarrow e^+ \nu_e X') X$	7.90 ± 0.02	2.03 ± 0.02	34.12 ± 0.39	5.48 ± 0.08
$B^+ \rightarrow D^0 (X_c \rightarrow e^+ \nu_e X') X$	7.90 ± 0.02	2.37 ± 0.03	35.65 ± 0.58	6.67 ± 0.13
$B^0 \rightarrow D^0 (D_s^- \rightarrow \tau^+ \nu_\tau) X$	8.50 ± 0.02	1.04 ± 0.02	80.90 ± 0.60	7.17 ± 0.12
$B^+ \rightarrow D^0 (D_s^- \rightarrow \tau^+ \nu_\tau) X$	8.40 ± 0.02	1.28 ± 0.03	68.17 ± 1.11	7.31 ± 0.21

* X_c denotes an inclusive charm-hadron state.

* X and X' denote a system of any additional final-state particles.

Offline selections includes vertex isolation and $\Delta M_{D^{-}}, e p_T$ cuts introduced in Sec. 4.2.3

Generator cuts :

Cuts used in event generation

Trigger selections :

Selections in trigger line

Offline selection :

ΔM_{D^*} selection & physics background suppression

Cumulative selection efficiencies in block 5

Decay	Generator cuts [10^{-2}]	Trigger selections [10^{-2}]	Offline selections [10^{-2}]	Overall efficiency [10^{-4}]
$B^0 \rightarrow D^{*-} e^+ \nu_e$	8.80 ± 0.02	3.66 ± 0.00	78.08 ± 0.04	25.14 ± 0.06
$B^0 \rightarrow D^{*-} \tau^+ \nu_\tau$	8.90 ± 0.02	2.57 ± 0.01	76.42 ± 0.13	17.47 ± 0.07
$B^0 \rightarrow D_{0,1,2}^{*-} e^+ \nu_e$	8.60 ± 0.02	4.55 ± 0.02	17.67 ± 0.17	6.91 ± 0.07
$B^0 \rightarrow D_{0,1,2}^{*-} \tau^+ \nu_\tau$	8.40 ± 0.02	2.75 ± 0.02	11.04 ± 0.26	2.55 ± 0.06
$B^+ \rightarrow D_{0,1,2}^{*0} e^+ \nu_e$	8.70 ± 0.02	2.67 ± 0.02	60.01 ± 0.28	13.92 ± 0.11
$B^+ \rightarrow D_{0,1,2}^{*0} \tau^+ \nu_\tau$	8.30 ± 0.02	2.05 ± 0.02	61.73 ± 0.56	10.52 ± 0.15
$B^0 \rightarrow (D_{1,2}^{*-} / D^{(*)}(2S)^-) e^+ \nu_e$	8.60 ± 0.02	6.84 ± 0.02	15.65 ± 0.13	9.20 ± 0.09
$B^+ \rightarrow (D_{1,2}^{*0} / D^{(*)}(2S)^0) e^+ \nu_e$	8.50 ± 0.02	3.37 ± 0.02	56.11 ± 0.25	16.07 ± 0.12
$B_s^0 \rightarrow (D_{s1}(2536) / D_{s2}(2573)) e^+ \nu_e$	8.60 ± 0.02	4.39 ± 0.02	63.32 ± 0.27	23.90 ± 0.17
$B^0 \rightarrow D^0(X_c \rightarrow e^+ \nu_e X') X$	7.90 ± 0.02	2.24 ± 0.01	28.33 ± 0.21	5.02 ± 0.05
$B^+ \rightarrow D^0(X_c \rightarrow e^+ \nu_e X') X$	7.90 ± 0.02	2.56 ± 0.02	29.71 ± 0.34	6.00 ± 0.08
$B^0 \rightarrow D^0(D_s^- \rightarrow \tau^+ \nu_\tau) X$	8.50 ± 0.02	1.19 ± 0.01	69.15 ± 0.40	7.02 ± 0.07
$B^+ \rightarrow D^0(D_s^- \rightarrow \tau^+ \nu_\tau) X$	8.40 ± 0.02	1.49 ± 0.02	58.62 ± 0.64	7.36 ± 0.12

* $D_{0,1,2}^{**}$ and $D_{1,2}^{**} / D^{(*)}(2S)$ denote $D_0^*(2300) / D_1'(2430) / D_1(2420) / D_2^*(2460)$ and $D^*(2S) / D(2S) / D_1(2420) / D_2^*(2460)$ states, respectively.

* X_c denotes an inclusive charm-hadron state.

* X and X' denote a system of any additional final-state particles.

* Offline selections includes vertex isolation and $\Delta M_{D^{*-}}, e p_T$ cuts introduced in Sec. 4.2.3

Cumulative selection efficiencies in block 6

Decay	Generator cuts [10^{-2}]	Trigger selections [10^{-2}]	Offline selections [10^{-2}]	Overall efficiency [10^{-4}]
$B^0 \rightarrow D^{*-} e^+ \nu_e$	8.80 ± 0.02	3.64 ± 0.00	77.40 ± 0.04	24.78 ± 0.06
$B^0 \rightarrow D^{*-} \tau^+ \nu_\tau$	8.90 ± 0.02	2.55 ± 0.01	75.69 ± 0.15	17.17 ± 0.08
$B^0 \rightarrow D_{0,1,2}^{*-} e^+ \nu_e$	8.60 ± 0.02	4.54 ± 0.02	16.99 ± 0.18	6.63 ± 0.08
$B^0 \rightarrow D_{0,1,2}^{*-} \tau^+ \nu_\tau$	8.40 ± 0.02	2.73 ± 0.02	10.06 ± 0.26	2.31 ± 0.06
$B^+ \rightarrow D_{0,1,2}^{*0} e^+ \nu_e$	8.70 ± 0.02	2.63 ± 0.02	59.05 ± 0.31	13.53 ± 0.11
$B^+ \rightarrow D_{0,1,2}^{*0} \tau^+ \nu_\tau$	8.30 ± 0.02	2.08 ± 0.03	61.61 ± 0.60	10.64 ± 0.17
$B^0 \rightarrow (D_{1,2}^{*-} / D^{(*)}(2S)^-) e^+ \nu_e$	8.60 ± 0.02	6.78 ± 0.03	14.85 ± 0.14	8.66 ± 0.09
$B^+ \rightarrow (D_{1,2}^{*0} / D^{(*)}(2S)^0) e^+ \nu_e$	8.50 ± 0.02	3.37 ± 0.02	55.93 ± 0.28	16.03 ± 0.13
$B_s^0 \rightarrow (D_{s1}(2536) / D_{s2}(2573)) e^+ \nu_e$	8.60 ± 0.02	4.29 ± 0.03	62.30 ± 0.29	23.00 ± 0.18
$B^0 \rightarrow D^0(X_c \rightarrow e^+ \nu_e X') X$	7.90 ± 0.02	2.21 ± 0.01	28.23 ± 0.23	4.94 ± 0.05
$B^+ \rightarrow D^0(X_c \rightarrow e^+ \nu_e X') X$	7.90 ± 0.02	2.54 ± 0.02	29.17 ± 0.36	5.86 ± 0.09
$B^0 \rightarrow D^0(D_s^- \rightarrow \tau^+ \nu_\tau) X$	8.50 ± 0.02	1.17 ± 0.01	68.39 ± 0.44	6.81 ± 0.08
$B^+ \rightarrow D^0(D_s^- \rightarrow \tau^+ \nu_\tau) X$	8.40 ± 0.02	1.47 ± 0.02	57.09 ± 0.57	7.05 ± 0.11

* $D_{0,1,2}^{**}$ and $D_{1,2}^{**} / D^{(*)}(2S)$ denote $D_0^*(2300) / D_1'(2430) / D_1(2420) / D_2^*(2460)$ and $D^*(2S) / D(2S) / D_1(2420) / D_2^*(2460)$ states, respectively.

* X_c denotes an inclusive charm-hadron state.

* X and X' denote a system of any additional final-state particles.

* Offline selections includes vertex isolation and $\Delta M_{D^{*-}}, e p_T$ cuts introduced in Sec. 4.2.3

Cumulative selection efficiencies in block 7

Decay	Generator cuts [10^{-2}]	Trigger selections [10^{-2}]	Offline selections [10^{-2}]	Overall efficiency [10^{-4}]
$B^0 \rightarrow D^{*-} e^+ \nu_e$	8.80 ± 0.02	3.37 ± 0.00	77.88 ± 0.05	23.08 ± 0.06
$B^0 \rightarrow D^{*-} \tau^+ \nu_\tau$	8.90 ± 0.02	2.42 ± 0.01	76.41 ± 0.15	16.45 ± 0.08
$B^0 \rightarrow D_{0,1,2}^{*-} e^+ \nu_e$	8.60 ± 0.02	4.17 ± 0.02	17.91 ± 0.23	6.43 ± 0.09
$B^0 \rightarrow D_{0,1,2}^{*-} \tau^+ \nu_\tau$	8.40 ± 0.02	2.63 ± 0.03	11.07 ± 0.33	2.45 ± 0.08
$B^+ \rightarrow D_{0,1,2}^{*0} e^+ \nu_e$	8.70 ± 0.02	2.49 ± 0.02	59.89 ± 0.38	12.97 ± 0.13
$B^+ \rightarrow D_{0,1,2}^{*0} \tau^+ \nu_\tau$	8.30 ± 0.02	1.96 ± 0.02	61.37 ± 0.62	9.99 ± 0.16
$B^0 \rightarrow (D_{1,2}^{*-} / D^{(*)}(2S)^-) e^+ \nu_e$	8.60 ± 0.02	6.37 ± 0.03	16.09 ± 0.18	8.82 ± 0.11
$B^+ \rightarrow (D_{1,2}^{*0} / D^{(*)}(2S)^0) e^+ \nu_e$	8.50 ± 0.02	3.15 ± 0.02	57.20 ± 0.34	15.33 ± 0.14
$B_s^0 \rightarrow (D_{s1}(2536) / D_{s2}(2573)) e^+ \nu_e$	8.60 ± 0.02	4.00 ± 0.03	63.23 ± 0.36	21.76 ± 0.21
$B^0 \rightarrow D^0(X_c \rightarrow e^+ \nu_e X') X$	7.90 ± 0.02	2.11 ± 0.01	28.56 ± 0.28	4.76 ± 0.06
$B^+ \rightarrow D^0(X_c \rightarrow e^+ \nu_e X') X$	7.90 ± 0.02	2.40 ± 0.02	29.08 ± 0.42	5.52 ± 0.10
$B^0 \rightarrow D^0(D_s^- \rightarrow \tau^+ \nu_\tau) X$	8.50 ± 0.02	1.12 ± 0.01	69.12 ± 0.52	6.57 ± 0.09
$B^+ \rightarrow D^0(D_s^- \rightarrow \tau^+ \nu_\tau) X$	8.40 ± 0.02	1.38 ± 0.02	57.94 ± 0.86	6.70 ± 0.15

* $D_{0,1,2}^{**}$ and $D_{1,2}^{**} / D^{(*)}(2S)$ denote $D_0^*(2300) / D_1'(2430) / D_1(2420) / D_2^*(2460)$ and $D^*(2S) / D(2S) / D_1(2420) / D_2^*(2460)$ states, respectively.

* X_c denotes an inclusive charm-hadron state.

* X and X' denote a system of any additional final-state particles.

* Offline selections includes vertex isolation and $\Delta M_{D^{*-}}, e p_T$ cuts introduced in Sec. 4.2.3

What does Barlow-Beeston lite do ?

When turn on Barlow-Beeston lite, fitter vary the bin scaling factors γ to include the uncertainty of the template statistics.

And γ is constrained by the Poisson function with τ as the mean value

$$\underbrace{\text{Pois} \left(n_b | \gamma_b \nu_b^{\text{MC}}(\alpha) \right)}_{\text{data model}} \cdot \underbrace{\text{Pois} \left(\tau_b | \gamma_b \tau_b \right)}_{\text{constraint}}, \text{where } b \text{ is the index of bin}$$

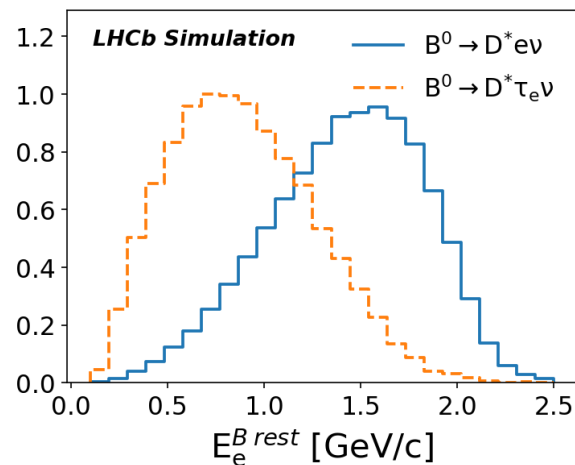
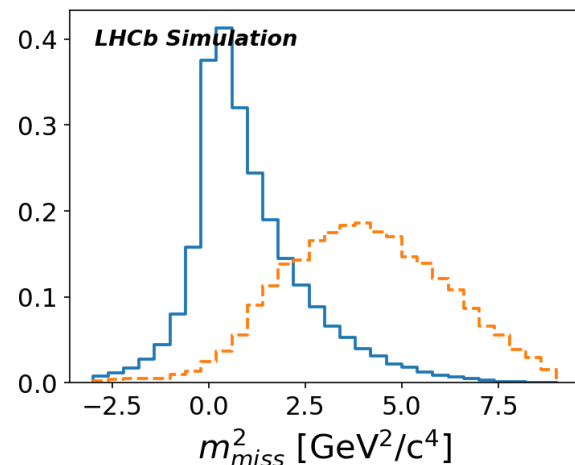
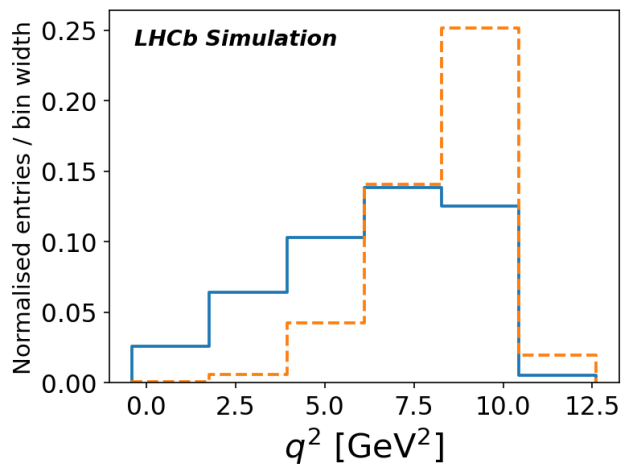
And the effective bin count - τ is defined as

$$\tau_b = \left(\frac{\nu_b^{\text{MC}}(\alpha_{\text{prefit}})}{\sigma_b^{\text{MC}}(\alpha_{\text{prefit}})} \right)^2, \text{where } \nu \text{ and } \sigma \text{ are sum of weight and uncertainty}_{149}$$

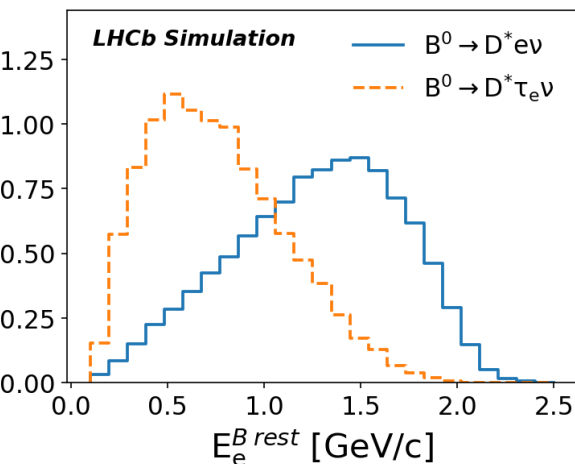
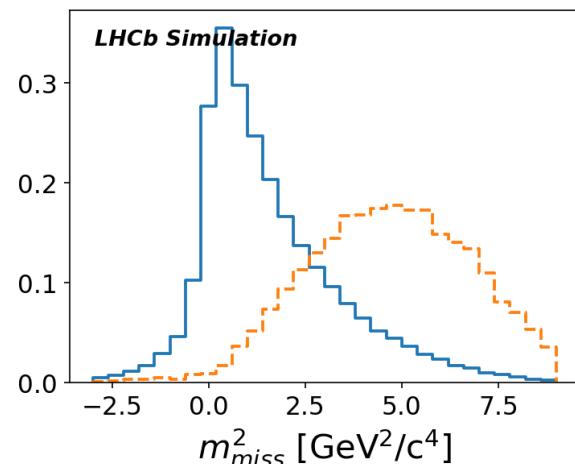
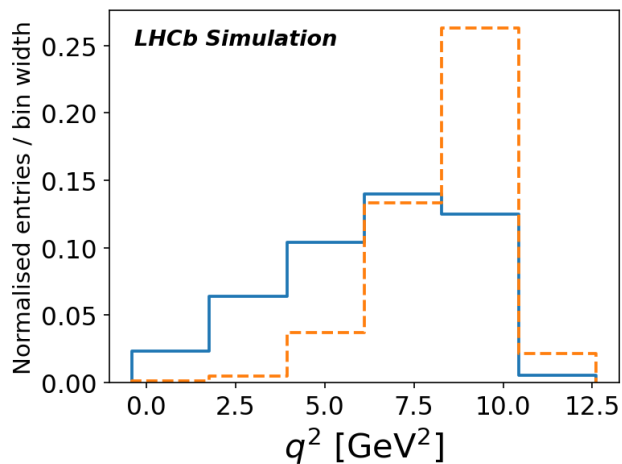
Template preparation - simulation

Construct templates of signal channels and physics background using MC samples

Signal modes



With brems correction

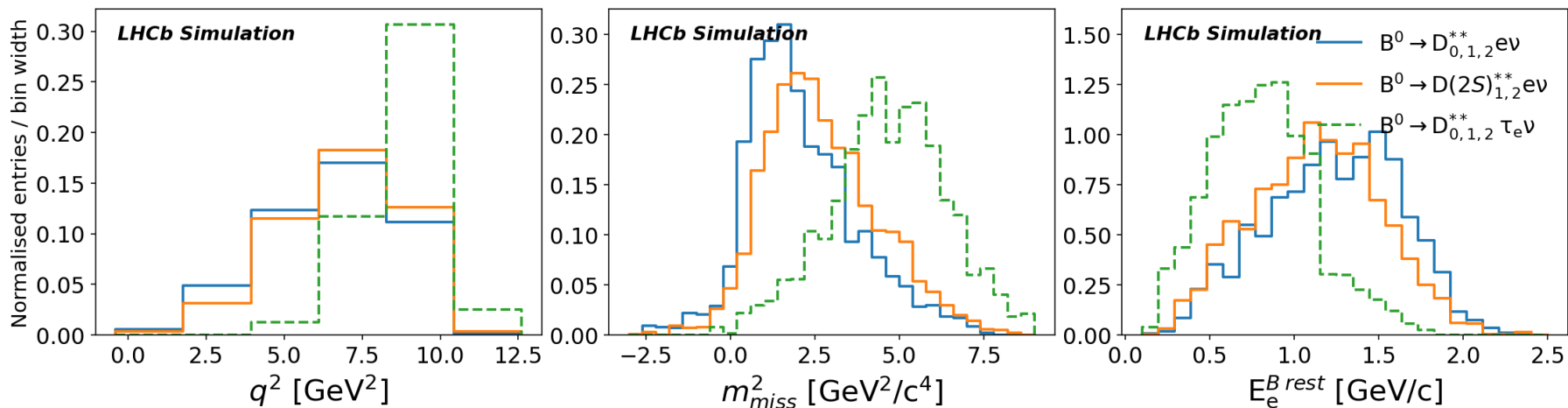


Without brems correction

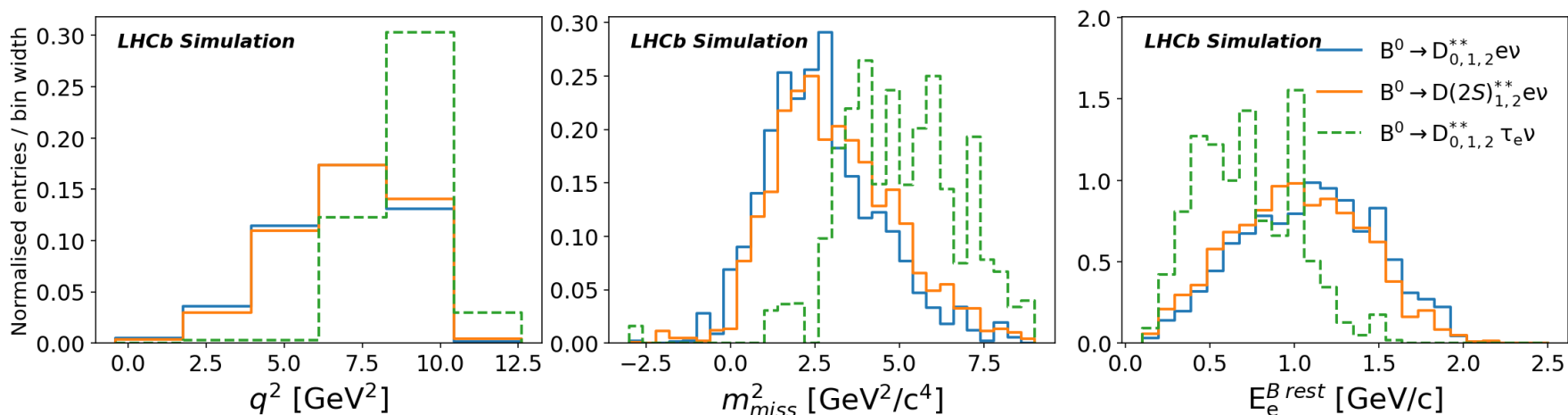
Template preparation - simulation

Construct templates of signal channels and physics background using MC samples

$B^0 \rightarrow D^{**} e(\tau) \nu$ background



With brems correction

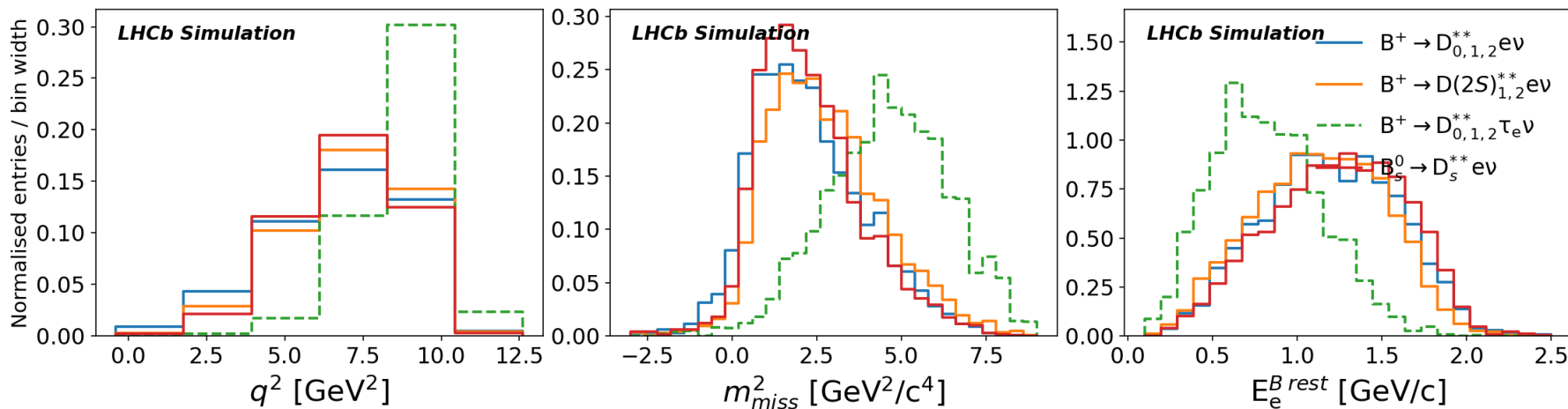


Without brems correction

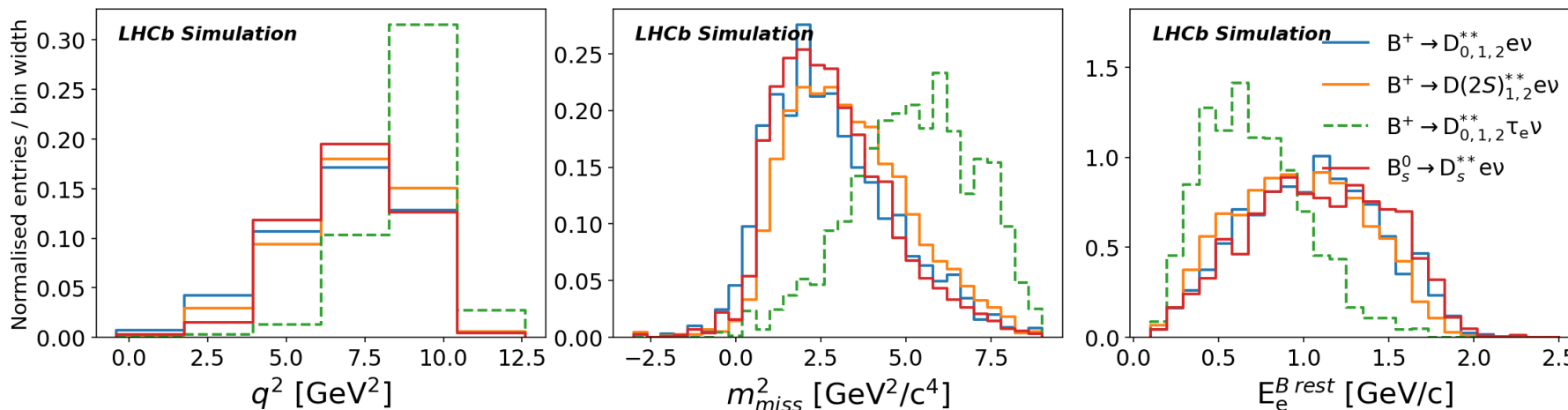
Template preparation - simulation

Construct templates of signal channels and physics background using MC samples

$B^+ \rightarrow D^{**} e(\tau) \nu$ and $B_s^0 \rightarrow D_s^{**} e \nu$ background



With brems correction

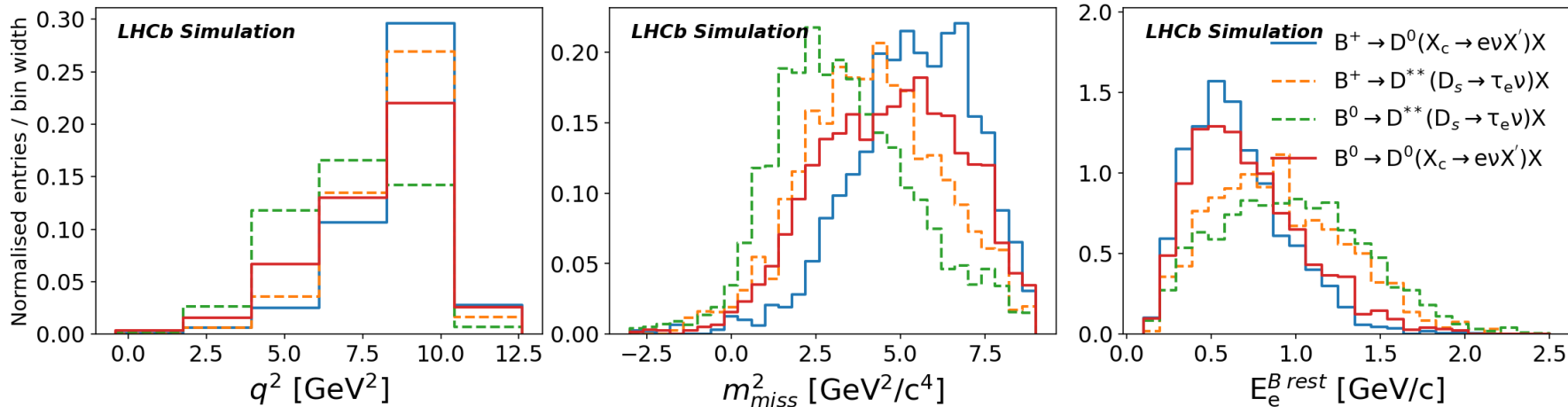


Without brems correction

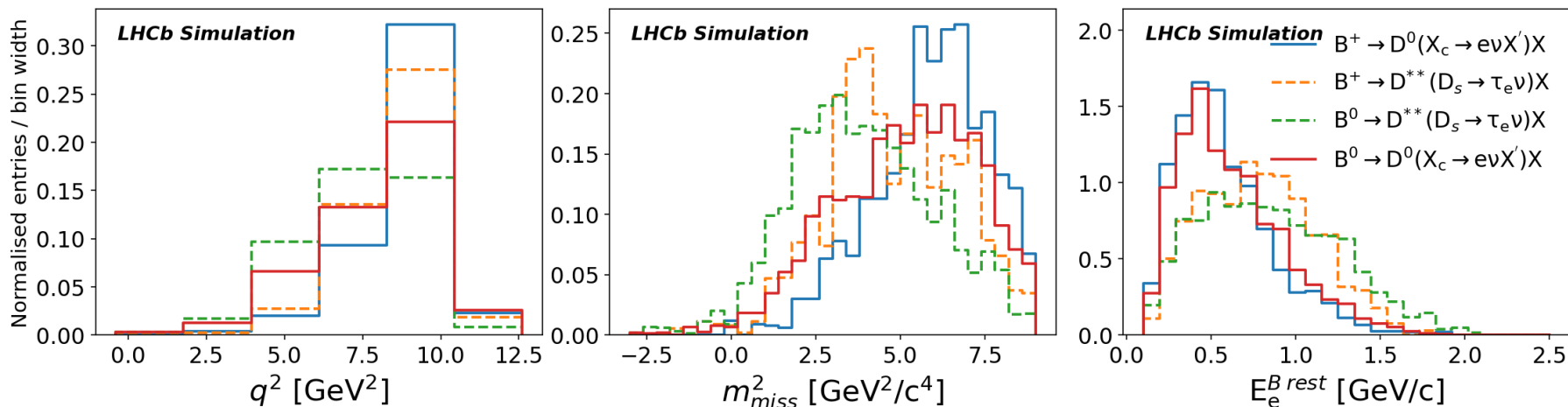
Template preparation - simulation

Construct templates of signal channels and physics background using MC samples

Double charmed background



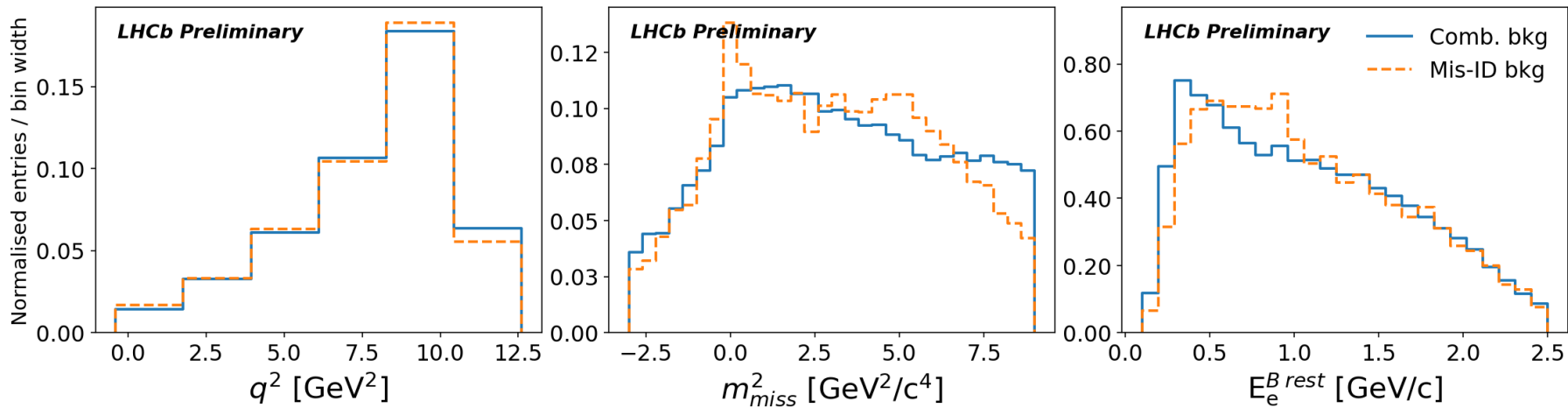
With brems correction



Without brems correction

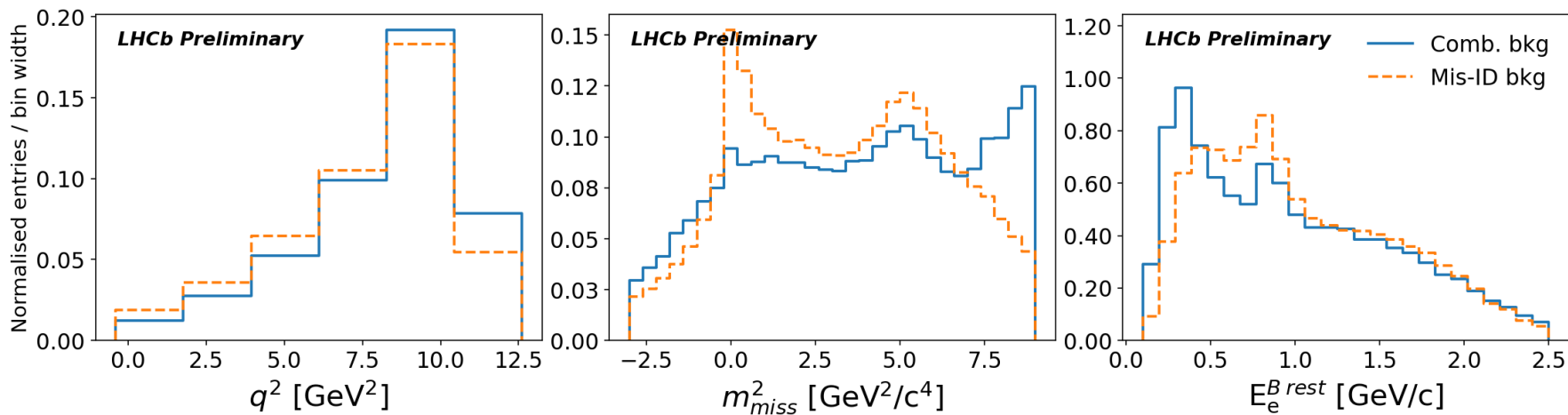
Template preparation – data driven

Construct combinatorial and mis-identified electron background from
Wrong-signed $D^{*-}e^{-}$ data and data with reverse PIDE requirement



*See [Tommaso's talk](#) for details of mis-ID preparation

With brems correction

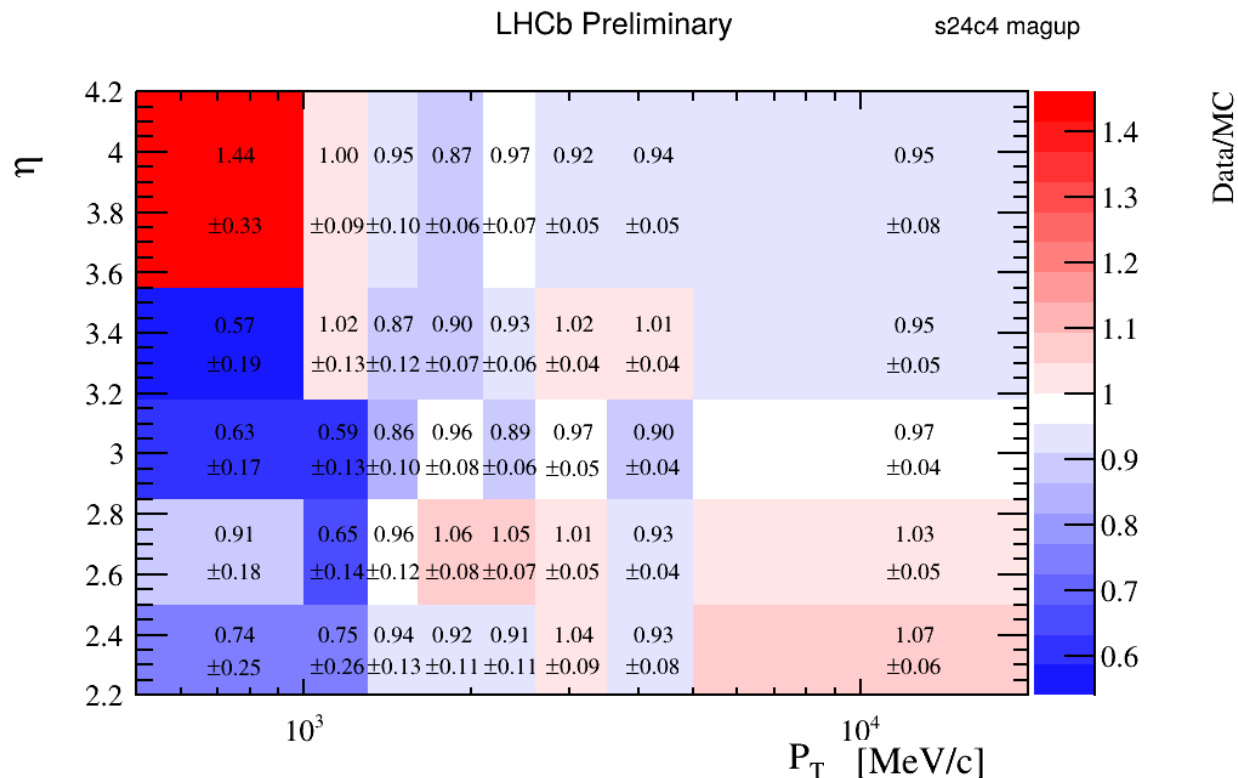


Without brems correction

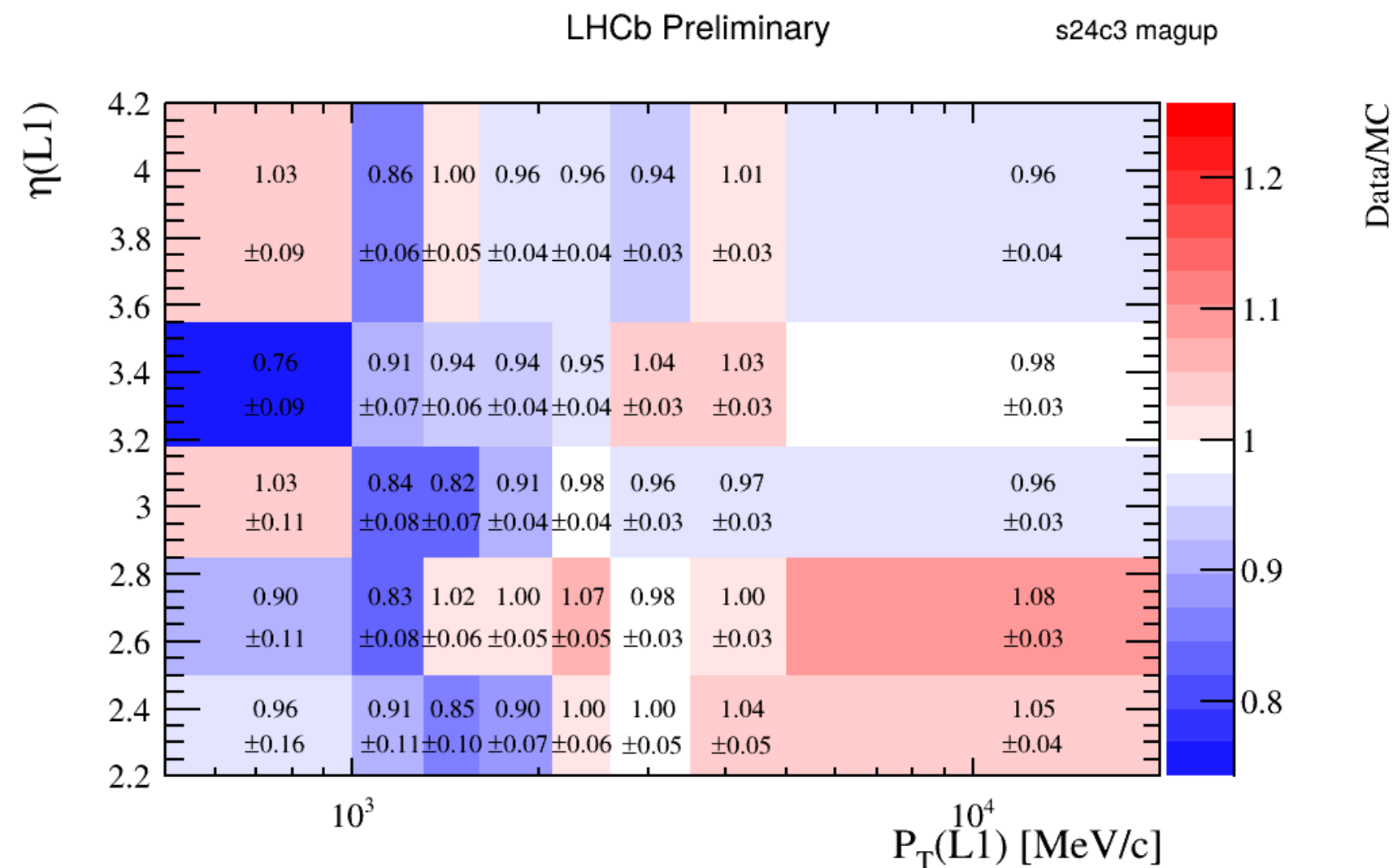
Calibration of Bremsstrahlung fraction

To calibrate the MC brems fractions in MC, a 2D data/MC ratio map in electron p_T and η , derived from the control channel is prepared.

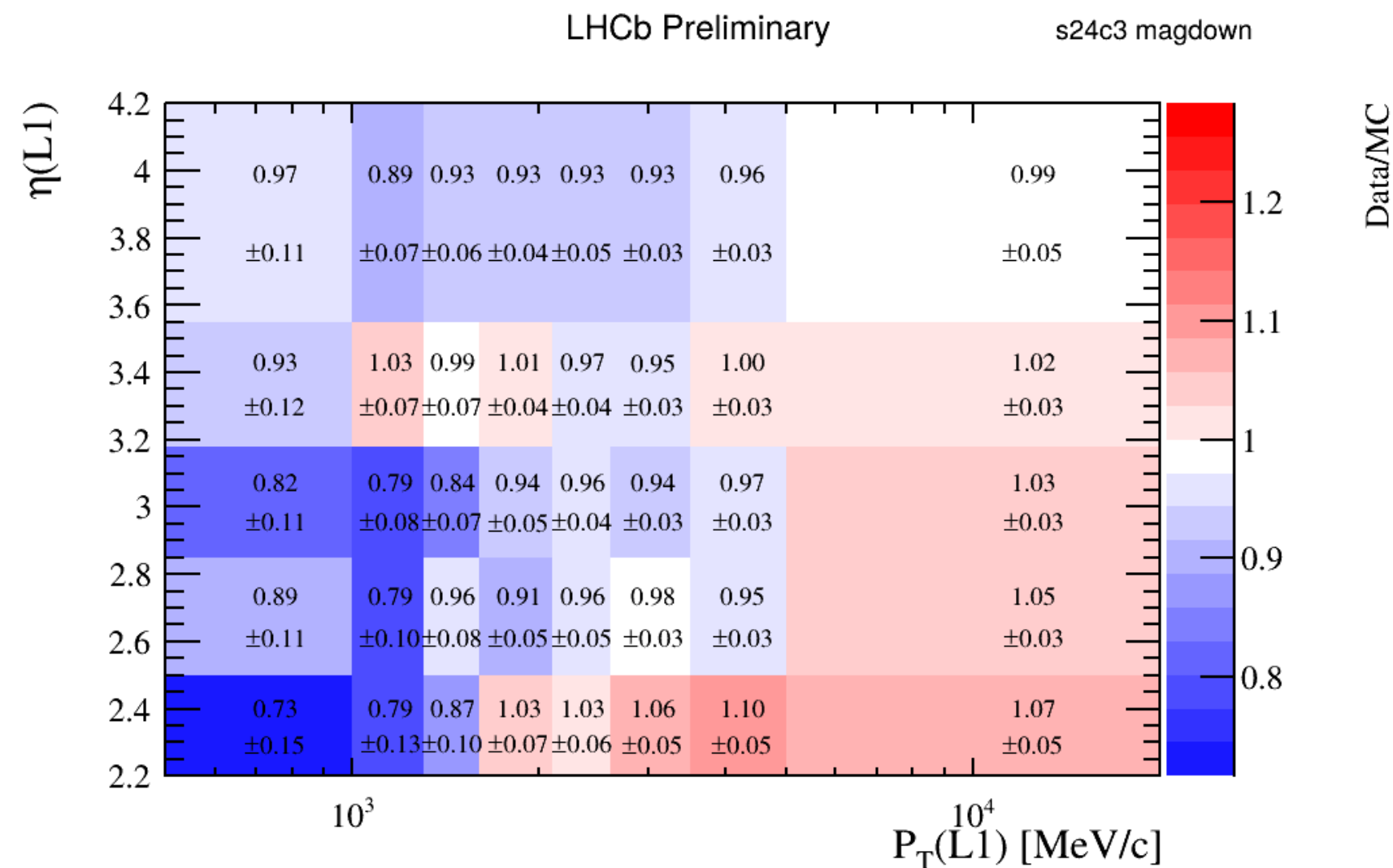
$$B^0 \rightarrow J/\psi K^{*0}, \text{ with } J/\psi \rightarrow e^+e^- \text{ and } K^{*0} \rightarrow K^+\pi^-$$



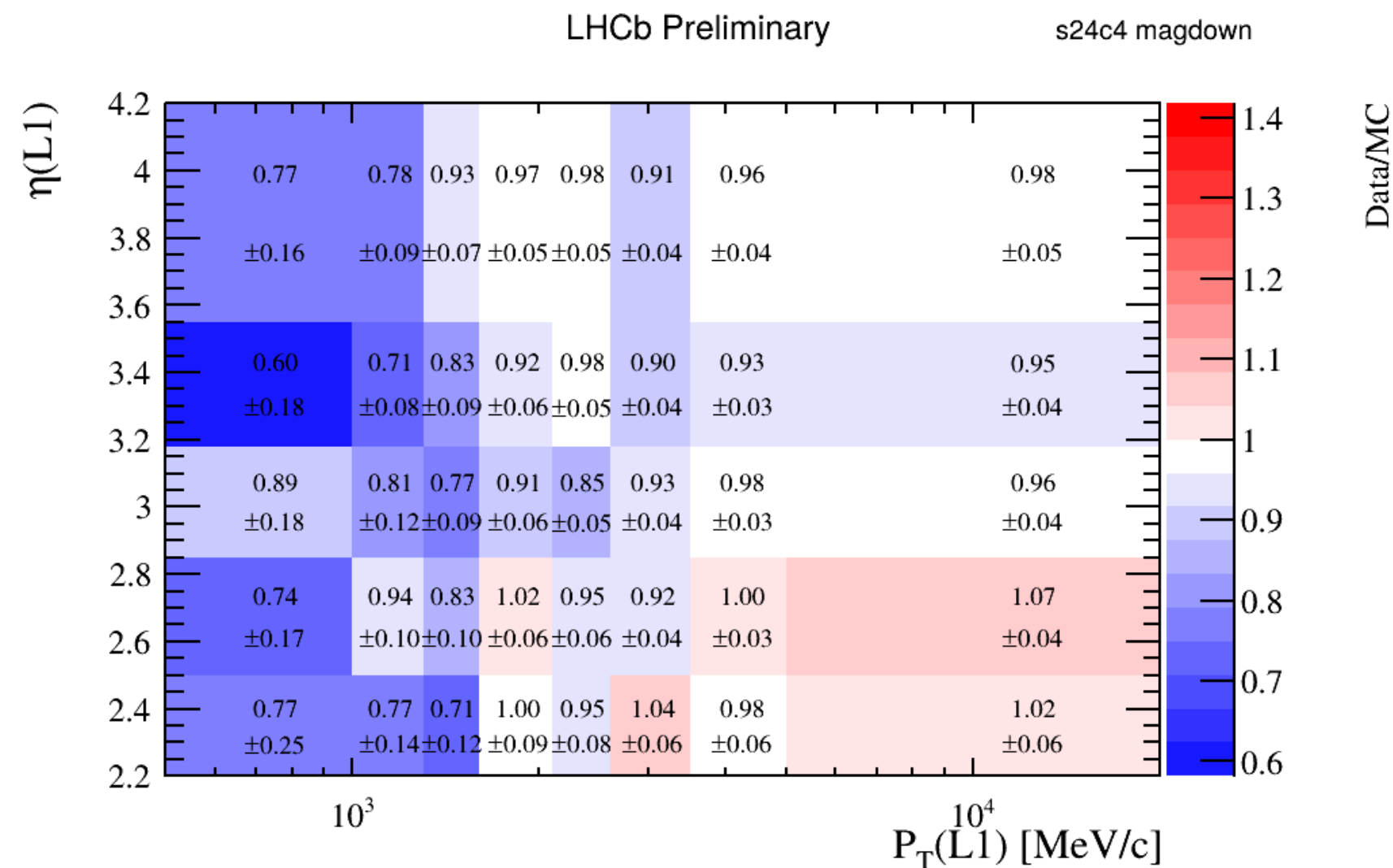
Calibration map of bremsstrahlung fraction - block5



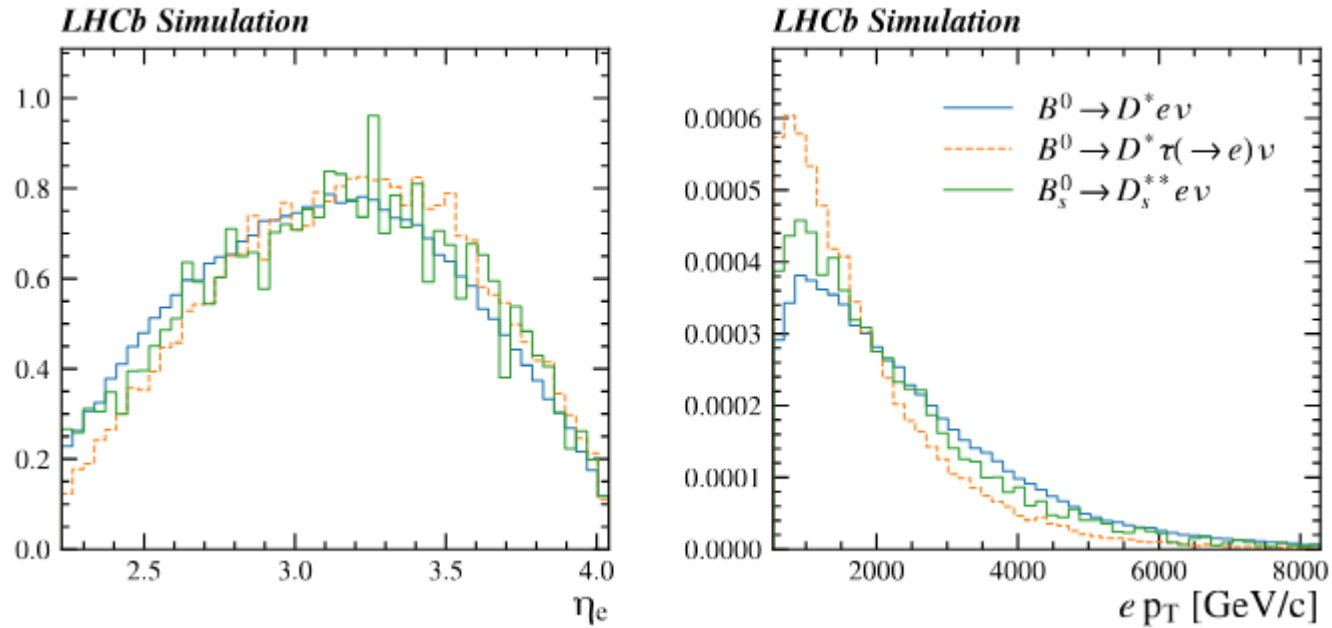
Calibration map of bremsstrahlung fraction - block6



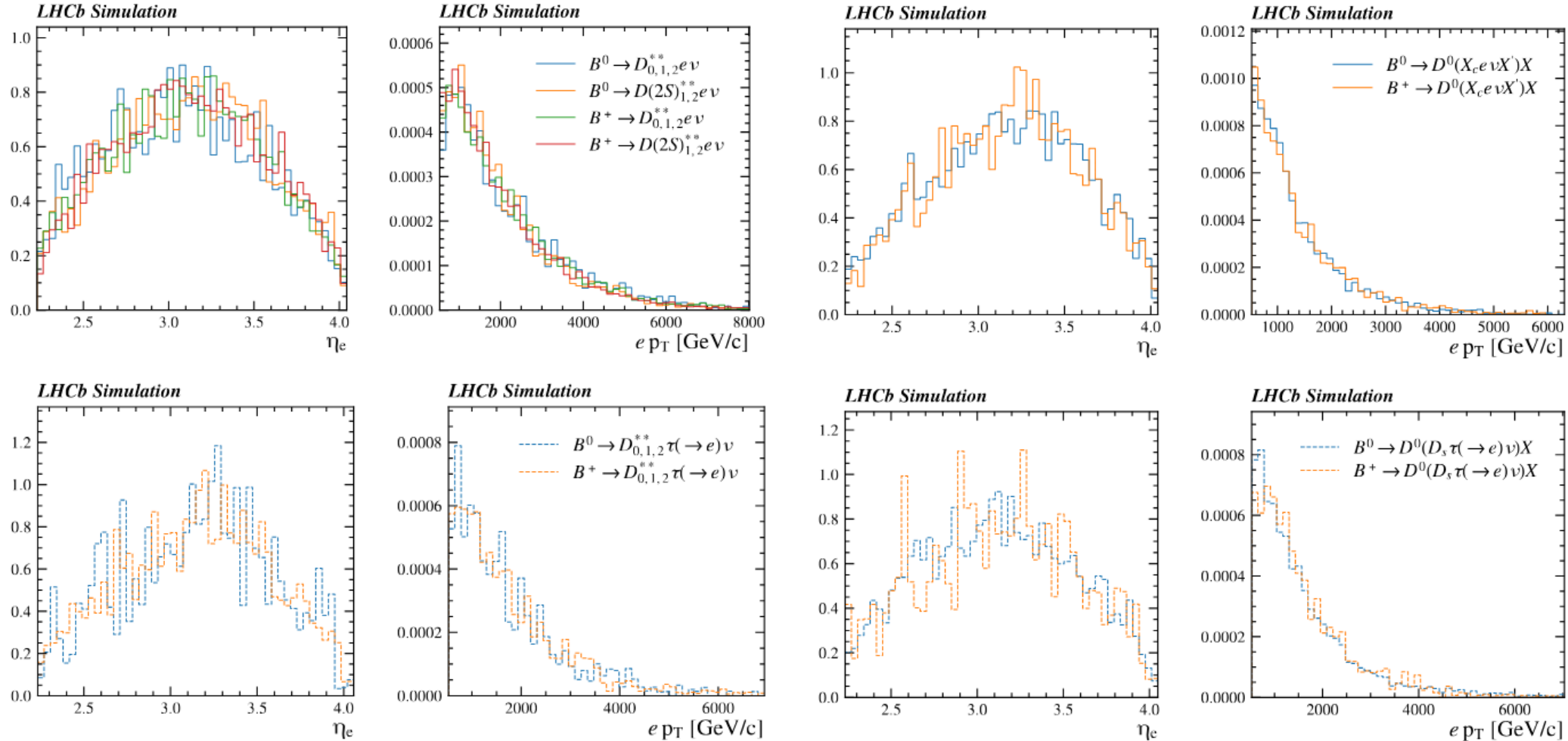
Calibration map of bremsstrahlung fraction - block7



Electron kinematic - signal and B_s^0 decays



Electron kinematic - physics background



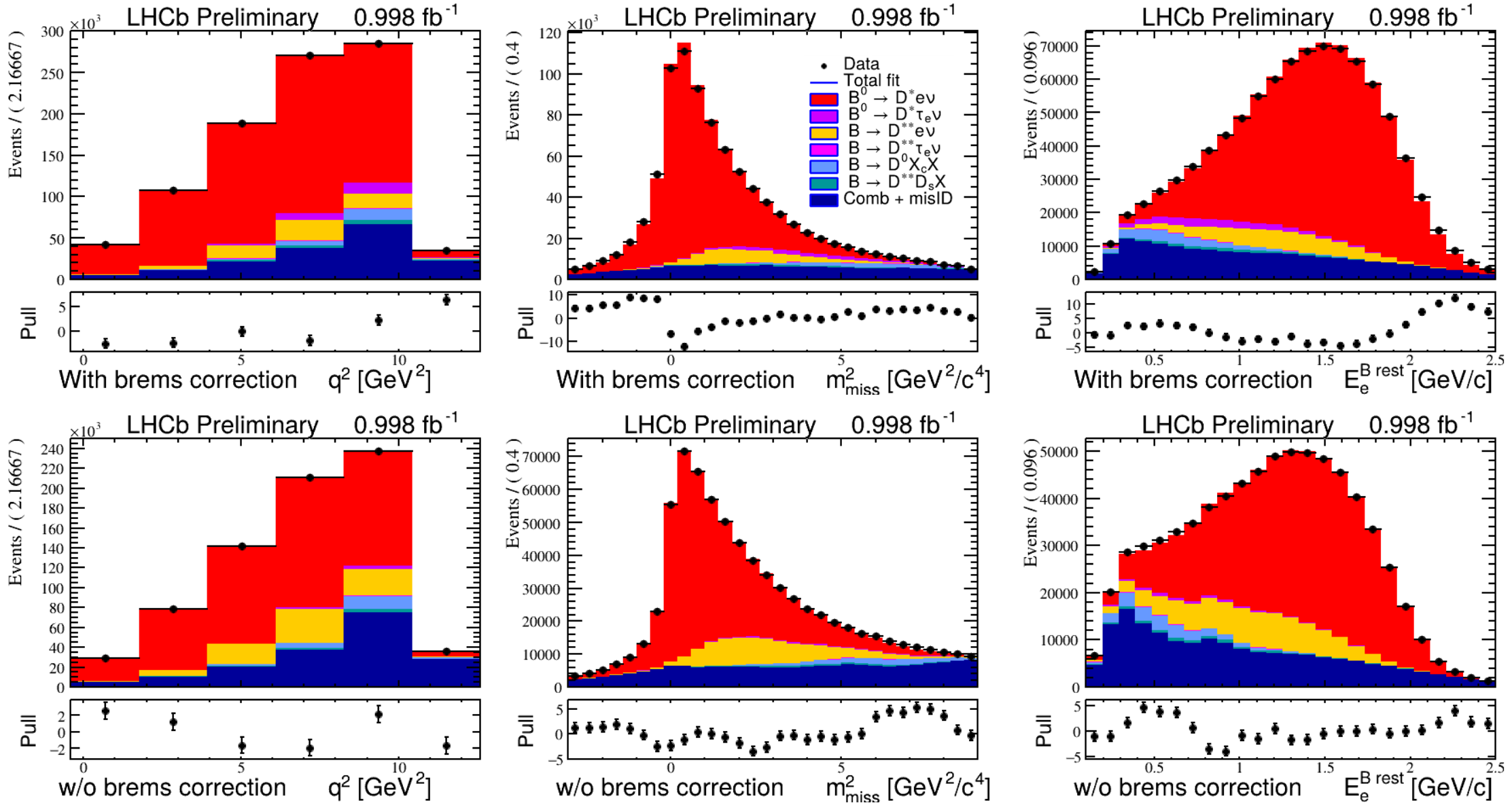
Component	Yields in bremsstrahlung category c
Signal	
$B^0 \rightarrow D^{*-} e^+ \nu_e$	$\mathcal{B}(B^0 \rightarrow D^{*-} e \nu) \times N_B^{b\ddagger} \times \epsilon_{B^0 \rightarrow D^{*-} e \nu}^{b\ddagger} \times \alpha_c(f_{B^0 \rightarrow D^{*-} e \nu})$
$B^0 \rightarrow D^{*-} \tau^+ \nu_\tau$	$\mathcal{B}(B^0 \rightarrow D^{*-} e \nu) \times R(D^*) \times N_B^{b\ddagger} \times \epsilon_{B^0 \rightarrow D^{*-} \tau \nu}^{b\ddagger} \times \alpha_c(f_{B^0 \rightarrow D^{*-} \tau \nu})$
D^{**} & B_s^0 Backgrounds	
$B^{(0,+)} \rightarrow D_{0,1,2}^{**} e^+ \nu_e$	$\mathcal{B}(B^{(0,+)} \rightarrow D_{0,1,2}^{**} e^+ \nu_e) \times N_B^{b\ddagger} \times \epsilon_{B^{(0,+)} \rightarrow D_{0,1,2}^{**} e^+ \nu_e}^{b\ddagger} \times \alpha_c(f_{D^{**} e \nu})$
$B^{(0,+)} \rightarrow D_{0,1,2}^{**} \tau^+ \nu_\tau$	$\mathcal{B}(B^{(0,+)} \rightarrow D_{0,1,2}^{**} e^+ \nu_e) \times R(D^{**})^\dagger \times N_B^{b\ddagger} \times \epsilon_{B^{(0,+)} \rightarrow D_{0,1,2}^{**} \tau^+ \nu_\tau}^{b\ddagger} \times \alpha_c(f_{D^{**} \tau \nu}^\dagger)$
$B^{(0,+)} \rightarrow (D_{1,2}^{**}/D(2S)) e^+ \nu_e$	$\mathcal{B}(B^{(0,+)} \rightarrow (D_{1,2}^{**}/D(2S)) e^+ \nu_e) \times N_B^{b\ddagger} \times \epsilon_{B^{(0,+)} \rightarrow (D_{1,2}^{**}/D(2S)) e^+ \nu_e}^{b\ddagger} \times \alpha_c(f_{D^{**} e \nu})$
$B_s^0 \rightarrow D_{s1,s2} e^+ \nu_e$	$\mathcal{B}^\dagger(B_s^0 \rightarrow D_{s1,s2} e^+ \nu_e) \times N_{B_s}^{b\ddagger} \times \epsilon_{B_s^0 \rightarrow D_{s1,s2} e^+ \nu_e}^{b\ddagger} \times \alpha_c(f_{B_s^0 \rightarrow D_s^- e^+ \nu_e}^\dagger)$
Double charm Backgrounds	
$B^{(0,+)} \rightarrow D^0(X_c \rightarrow e^+ \nu_e X') X$	$\mathcal{B}(B^{(0,+)} \rightarrow D^0(X_c \rightarrow e^+ \nu_e X') X) \times N_B^{b\ddagger} \times \epsilon_{B^{(0,+)} \rightarrow D^0(X_c \rightarrow e^+ \nu_e X') X}^{b\ddagger} \times \alpha_c(f_{B^{(0,+)} \rightarrow D^0 X_c e}^\dagger)$
$B^{(0,+)} \rightarrow D^0(D_s^- \rightarrow \tau^+ \nu_\tau) X$	$\mathcal{B}^\dagger(B^{(0,+)} \rightarrow D^0(D_s^- \rightarrow \tau^+ \nu_\tau) X) \times N_B^{b\ddagger} \times \epsilon_{B^{(0,+)} \rightarrow D^0(D_s^- \rightarrow \tau^+ \nu_\tau) X}^{b\ddagger} \times \alpha_c(f_{B^{(0,+)} \rightarrow D^0 D_s \tau}^\dagger)$
WS $D^{*-} e^-$ and mis-ID Backgrounds	
WS $D^{*-} e^-$	$\mu_{\text{WS } D^{*-} e^-}^b \times \alpha_c^b(f_{\text{WS } D^{*-} e^-}^\dagger)$
mis-ID	$\mu_{\text{mis-ID}}^b \times \alpha_c^b(f_{\text{mis-ID}}^\dagger)$

Constraint on physics backgrounds

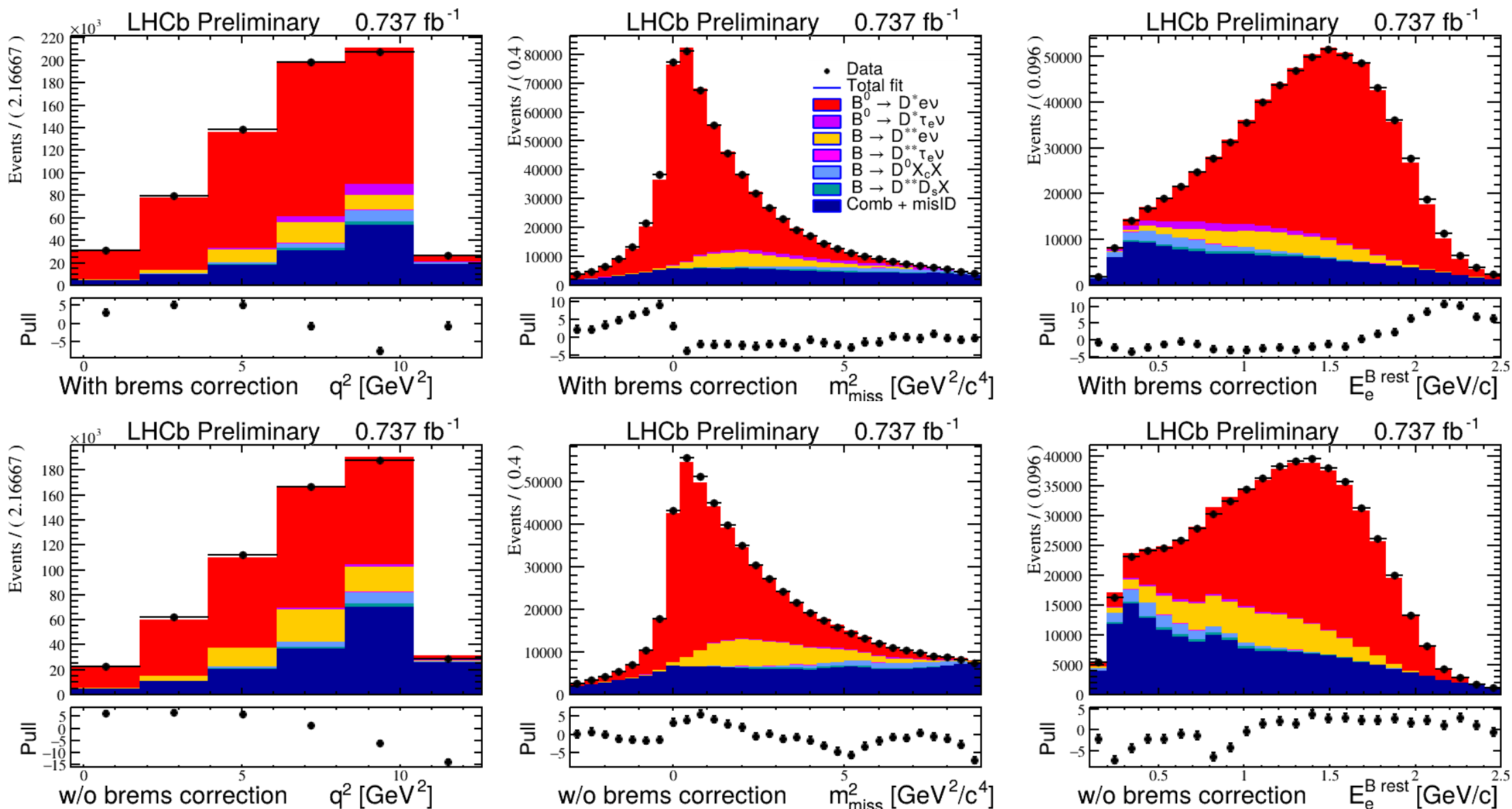
The ratio between $B \rightarrow D^{**}\tau\nu$ and $D^{**}e\nu$ with the $R(D^{**})$ [measurement](#) (37 %)

The BRs of $B^0 \rightarrow D^{**}(D_s \rightarrow \tau\nu)X$ and $B^+ \rightarrow D^{**}(D_s \rightarrow \tau\nu)X$ are constrained (25 % and 50 %) based on the measured BR in PDG, for the decays not measured, assign 50 % uncertainty.

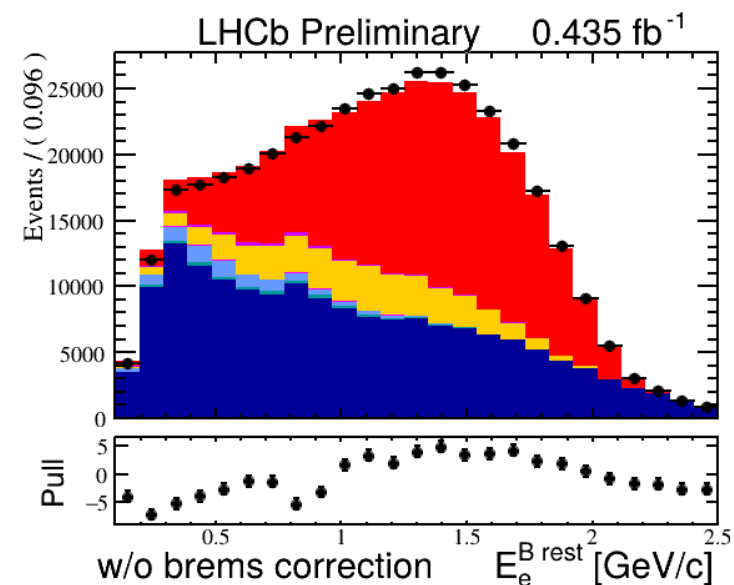
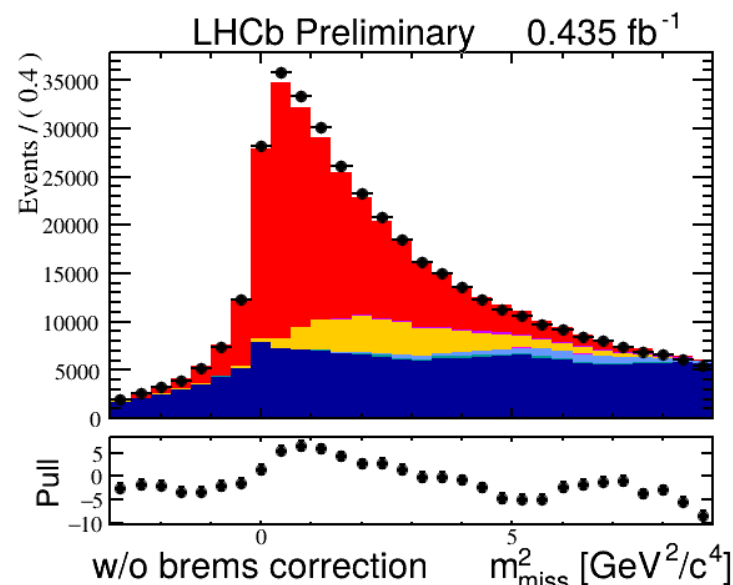
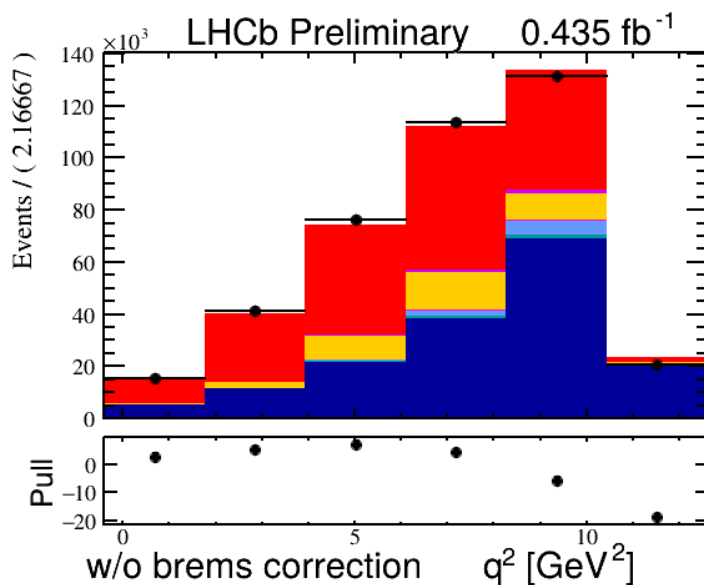
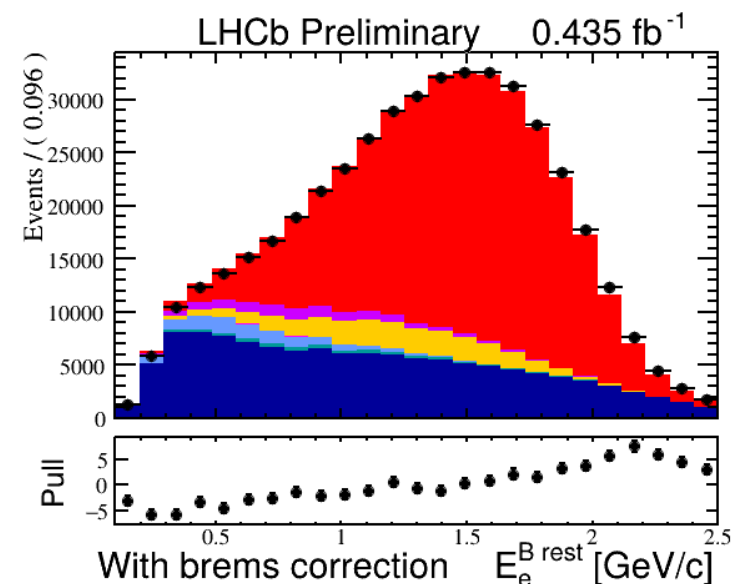
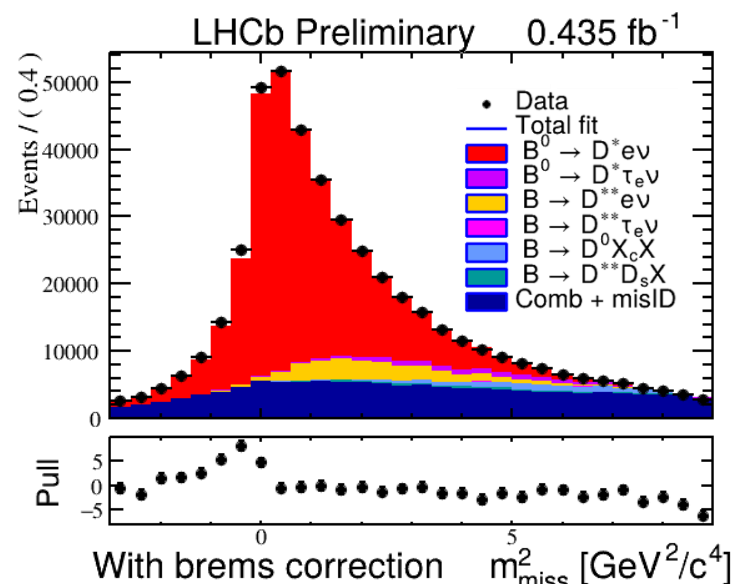
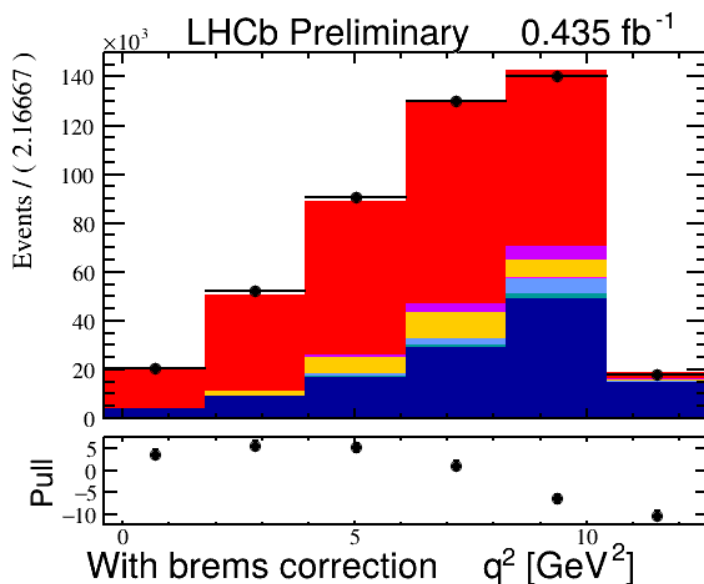
Fit result - block 6



Fit result - block 7



Fit result - block 8



Preliminary blinded result : physics backgrounds

Free parameters		
$\mathcal{B}(B^0 \rightarrow D_{0,1,2}^{*-} e^+ \nu_e)$	$(4.62 \pm 0.52) \times 10^{-5}$	
$\mathcal{B}(B^+ \rightarrow D_{0,1,2}^{*0} e^+ \nu_e)$	$(5.01 \pm 0.34) \times 10^{-5}$	
$\mathcal{B}(B^0 \rightarrow (D_{1,2}^{*-} / D(2S)^-) e^+ \nu_e)$	$(5.87 \pm 0.48) \times 10^{-5}$	
$\mathcal{B}(B^+ \rightarrow (D_{1,2}^{*0} / D(2S)^0) e^+ \nu_e)$	$(5.16 \pm 0.32) \times 10^{-5}$	
$\mathcal{B}(B^0 \rightarrow D^0(X_c \rightarrow e^+ \nu_e X') X)$	$(5.03 \pm 0.59) \times 10^{-5}$	
$\mathcal{B}(B^+ \rightarrow D^0(X_c \rightarrow e^+ \nu_e X') X)$	$(10.47 \pm 0.46) \times 10^{-5}$	
Gaussian constrained parameters		
	Fit value	Constrained value
$R(D^{**})$	0.315 ± 0.014	0.13 ± 0.037
$\mathcal{B}(B_s^0 \rightarrow D_{s1,s2} e^+ \nu_e)$	$(2.013 \pm 0.040) \times 10^{-4}$	$(2.1 \pm 0.5) \times 10^{-4}$
$\mathcal{B}(B^0 \rightarrow D^0(D_s^- \rightarrow \tau^+ \nu_\tau) X)$	$(1.75 \pm 0.23) \times 10^{-5}$	$(1.3 \pm 0.3) \times 10^{-5}$
$\mathcal{B}(B^+ \rightarrow D^0(D_s^- \rightarrow \tau^+ \nu_\tau) X)$	$(13.70 \pm 0.63) \times 10^{-6}$	$(4 \pm 2) \times 10^{-6}$

Validation of physics background yields

- **Direct validation is limited:** many exclusive branching fractions are poorly measured
- Some Gaussian-constrained parameters **shift significantly from their prior values**

Preliminary blinded result : combinatorial and mis-ID backgrounds

Free parameters	
$N_{\text{WS } D^{*-}e^{-}}$ in block 5	$(4.330 \pm 0.023) \times 10^5$
$N_{\text{mis-ID}}$ in block 5	$(1.74 \pm 0.17) \times 10^4$
$N_{\text{WS } D^{*-}e^{-}}$ in block 6	$(3.370 \pm 0.020) \times 10^5$
$N_{\text{mis-ID}}$ in block 6	$(0.98 \pm 0.12) \times 10^4$
$N_{\text{WS } D^{*-}e^{-}}$ in block 7	$(2.852 \pm 0.019) \times 10^5$
$N_{\text{mis-ID}}$ in block 7	$(1.84 \pm 0.14) \times 10^4$
$N_{\text{WS } D^{*-}e^{-}}$ in block 8	$(2.382 \pm 0.018) \times 10^5$
$N_{\text{mis-ID}}$ in block 8	$(5.00 \pm 0.15) \times 10^4$

Background yields checks

- Combinatorial $D^{*-} + \text{random } e^{+}$ enhanced in block 8 data
- Mis-ID yields / fb fluctuate across data blocks
- Further investigation is ongoing

Preliminary blinded result : Bremsstrahlung fractions

Free parameters		
$f_{B^0 \rightarrow D^{*-} e \nu}$	0.596 ± 0.001	
$f_{B^0 \rightarrow D^{*-} \tau \nu}$	0.805 ± 0.034	
$f_{D^{**} e \nu}$	0.362 ± 0.010	
Gaussian constrained parameters		
	Fit value	Constrained value
$f_{D^{**} \tau \nu}$	0.575 ± 0.010	0.565 ± 0.014
$f_{B_s^0 \rightarrow D_s^- e^+ \nu_e}$	0.557 ± 0.013	0.588 ± 0.016
$f_{B^{(0,+)} \rightarrow D^0 X_c e}$	0.532 ± 0.010	0.529 ± 0.013
$f_{B^{(0,+)} \rightarrow D^0 D_s \tau}$	0.572 ± 0.013	0.566 ± 0.013

Calibrated values	
Decay category	Combined blocks
$B^0 \rightarrow D^{*-} e^+ \nu_e$	0.598 ± 0.016
$B^0 \rightarrow D^{*-} \tau^+ \nu_\tau$	0.561 ± 0.016
$D^{**} e \nu$	0.574 ± 0.009
$D^{**} \tau \nu$	0.565 ± 0.014
$B_s^0 \rightarrow (D_{s1}^- (2536) / D_{s2}^- (2573)) e^+ \nu_e$	0.588 ± 0.016
Double charm (e)	0.529 ± 0.013
Double charm ($\tau \rightarrow e$)	0.566 ± 0.013

Bremsstrahlung fraction checks

- $f_{D^* e \nu}$ is consistent with the estimated value
- $f_{D^* \tau \nu}$ and $f_{D^{**} \tau \nu}$ show deviations from the table of calibrated values

Toy validation - setup

Generate the pseudo-experiment data histogram from the fitting template

- Expected yields estimated using efficiencies and number of estimated B mesons in each blocks
- The statistics in each bin follows Poisson distribution
- To account for effect of BB method, we applied generated binning scaling factors to include the shape variations
 - Extract τ of the template for each bin
 - Generate new random τ , defined as τ' using gamma function
 - Evaluate new scaling factor for each bin $\gamma_b = \tau'_b / \tau_b$ and apply it to change the sum of weight for the bin b , which changes the template shape
 - Generate toy data with the varied template

Effective bin count - τ is defined as

$$\tau_b = \left(\frac{\nu_b^{\text{MC}}(\alpha_{\text{prefit}})}{\sigma_b^{\text{MC}}(\alpha_{\text{prefit}})} \right)^2$$

,where ν and σ are sum of weight and uncertainty

Preliminary blinded result for $R(D^*)_{\tau/e}$ extraction

Free parameters

$\mathcal{B}(B^0 \rightarrow D^{*-} e^+ \nu_e)$	$(1.776 \pm 0.003) \times 10^{-4}$
$R(D^*)$	0.027 ± 0.002
$\mathcal{B}(B^0 \rightarrow D_{0,1,2}^{*-} e^+ \nu_e)$	$(4.62 \pm 0.52) \times 10^{-5}$
$\mathcal{B}(B^+ \rightarrow D_{0,1,2}^{*0} e^+ \nu_e)$	$(5.01 \pm 0.34) \times 10^{-5}$
$\mathcal{B}(B^0 \rightarrow (D_{1,2}^{*-} / D(2S)^-) e^+ \nu_e)$	$(5.87 \pm 0.48) \times 10^{-5}$
$\mathcal{B}(B^+ \rightarrow (D_{1,2}^{*0} / D(2S)^0) e^+ \nu_e)$	$(5.16 \pm 0.32) \times 10^{-5}$
$\mathcal{B}(B^0 \rightarrow D^0 (X_c \rightarrow e^+ \nu_e X') X)$	$(5.03 \pm 0.59) \times 10^{-5}$
$\mathcal{B}(B^+ \rightarrow D^0 (X_c \rightarrow e^+ \nu_e X') X)$	$(1.047 \pm 0.046) \times 10^{-4}$
$N_{WS D^{*-} e^-}$ in block 5	$(4.3297 \pm 0.0235) \times 10^5$
N_{mis-ID} in block 5	$(1.7386 \pm 0.171) \times 10^4$
$N_{WS D^{*-} e^-}$ in block 6	$(3.3689 \pm 0.0196) \times 10^5$
N_{mis-ID} in block 6	$(9.7584 \pm 1.20) \times 10^3$
$N_{WS D^{*-} e^-}$ in block 7	$(2.8519 \pm 0.0185) \times 10^5$
N_{mis-ID} in block 7	$(1.8360 \pm 0.138) \times 10^4$
$N_{WS D^{*-} e^-}$ in block 8	$(2.3820 \pm 0.0180) \times 10^5$
N_{mis-ID} in block 8	$(4.9951 \pm 0.153) \times 10^4$
$f_{B^0 \rightarrow D^{*-} e \nu}$	0.596 ± 0.001
$f_{B^0 \rightarrow D^{*-} \tau \nu}$	0.805 ± 0.034
$f_{D^{*-} e \nu}$	0.362 ± 0.010

Blinded parameters obtained with BB

The relative statistical uncertainty of $R(D^*)_{\tau/e}$ is 4.7 %

The systematic uncertainty for template size is

$$\sigma_{BB} = \sqrt{\sigma_{with BB}^2 - \sigma_{stat}^2} \approx 5.7\%$$

Run 1 muonic $R(D^*)_{\tau/\mu}$: 5.3 % [ref](#) with 3 fb^{-1}

Run 2 hadronic $R(D^*)_{\tau/\mu}$: 1.8 % [ref](#) with 2 fb^{-1}

Run 2 muonic $R(D^*)_{\tau/\mu}$: 7.5 % [ref](#) with 2 fb^{-1}

Run 3 electronic $R(D^*)_{\tau/e}$: 5.7 % with 3.3 fb^{-1}

Experiment	τ reconstruction	Luminosity	Yields of normalization (signal)	σ_{rel} of $R(D^*)$
Run 1 LHCb	$\tau^+ \rightarrow \mu^+ \nu_\mu \bar{\nu}_\tau$	3 fb^{-1}	1,282,000 (46,000) [53]	6.4% [53]
Run 2 LHCb	$\tau \rightarrow \text{hadronic states}$	2 fb^{-1}	$2,600^\dagger$ [54]	5.8% [54]
Run 2 LHCb	$\tau^+ \rightarrow \mu^+ \nu_\mu \bar{\nu}_\tau$	2 fb^{-1}	$29,000^\dagger$ [55]	20% [55]
BaBar with hadronic B tagging	$\tau^+ \rightarrow \ell^- \nu_\ell \bar{\nu}_\tau$	426 fb^{-1}	24,000(1,800) [48]	7.2% [48]
Belle with hadronic B tagging	$\tau^+ \rightarrow \ell^- \nu_\ell \bar{\nu}_\tau$	711 fb^{-1}	3,800(500) [49]	13.0% [49]
Belle with hadronic B tagging	$\tau \rightarrow \text{hadronic states}$	711 fb^{-1}	7,200(300) [51]	13.0% [51]
Belle with semileptonic B tagging	$\tau^+ \rightarrow \ell^- \nu_\ell \bar{\nu}_\tau$	711 fb^{-1}	Not shown in Ref. [52]	6.3% [52]
Belle II with semileptonic B tagging	$\tau^+ \rightarrow \ell^- \nu_\ell \bar{\nu}_\tau$	365 fb^{-1}	4,300(270) [56]	11.4% [56]
Belle II with hadronic B tagging	$\tau^+ \rightarrow \ell^- \nu_\ell \bar{\nu}_\tau$	365 fb^{-1}	5,500(230) [57]	7.9% [57]
Run 3 LHCb blinding $R(D^*)_{\tau/e}$	$\tau^+ \rightarrow e^+ \nu_e \bar{\nu}_\tau$	3.3 fb^{-1}	$4,742,000(187,000)^\dagger$	4.7%
Full Runs 3 $R(D^*)_{\tau/e}$ projection	$\tau^+ \rightarrow e^+ \nu_e \bar{\nu}_\tau$	20.4 fb^{-1}	$29,314,000(1,156,000)^\dagger$	1.8%

Mis-ID templates syst. uncertainty

We have 3 binning scheme and unfolding methods for mis-ID template construction

- coarse, default and fine for binning scheme
- scipy, pyunfold and minuit for methods

Name	Binning scheme
Coarse	η : [2.2, 4.2]
	P [GeV/ c]: [2.5, 10, 15, 40, 70, 200]
	$n_{\text{LongTracks}}$: [0, 150, 225, 500]
Default	η : [2.2, 3.2, 4.2]
	P [GeV/ c]: [2.5, 10, 13, 16.5, 21, 40, 70, 200]
	$n_{\text{LongTracks}}$: [0, 150, 225, 500]
Fine	η : [2.2, 3.2, 4.2]
	P [GeV/ c]: [2.5, 7, 10, 12.5, 17, 22, 40, 70, 200]
	$n_{\text{LongTracks}}$: [0, 100, 175, 275, 500]

Mis-ID templates syst. uncertainty

We have 3 binning scheme and unfolding methods for mis-ID template construction

- coarse, default and fine for binning scheme
- scipy, pyunfold and minuit for methods

Procedure :

- Fit the data using each templates, e.g. coarse scipy, fine pyunfold, fine minuit ...
- Record the blinded $R(D^*)$ values using different templates
- For each template, get the difference in $R(D^*)$ compared with the default one (default pyunfold)
- Quote the largest difference as the syst. uncertainty

Mis-ID templates syst. uncertainty

We have 3 binning scheme and unfolding methods for mis-ID template construction

- coarse, default and fine for binning scheme
- scipy == misID scan summary (blinding retained when enabled) ==

Process	variant	RDst	error	shift	status	covQual
- Fit t	default_pyunfold	0.00943029	0.0007012686	0	0	3
- Reco	coarse_minuit	0.009846656	0.0007042	0.0004163661	0	3
- For	coarse_pyunfold	0.009933357	0.0006994474	0.0005030666	0	3
- Quo	coarse_scipy	0.009844523	0.0007029529	0.0004142331	0	3
	default_minuit	0.009495415	0.0007053907	6.512446e-05	0	3
	default_scipy	0.009470654	0.0007041252	4.036418e-05	0	3
	fine_minuit	0.009757718	0.0007049598	0.000327428	0	3
	fine_pyunfold	0.009782195	0.0007039014	0.0003519045	0	3
	fine_scipy	0.009711913	0.0007040791	0.0002816227	0	3

Largest absolute shift from default_pyunfold: 0.0005030666 (coarse_pyunfold)
Relative maximum shift: 5.335%

pyunfold)

Systematic uncertainty - Run 1 muonic $R(D^*)_{\tau/\mu}$

Internal fit uncertainties	$\sigma_{\mathcal{R}(D^*)}(\times 10^{-2})$	$\sigma_{\mathcal{R}(D^0)}(\times 10^{-2})$	Correlation
Statistical uncertainty	1.8	6.0	−0.49
Simulated sample size	1.5	4.5	
$B \rightarrow D^{(*)}DX$ template shape	0.8	3.2	
$\bar{B} \rightarrow D^{(*)}\ell^-\bar{\nu}_\ell$ form-factors	0.7	2.1	
$\bar{B} \rightarrow D^{**}\mu^-\bar{\nu}_\mu$ form-factors	0.8	1.2	
$\mathcal{B}(\bar{B} \rightarrow D^*D_s^-(\rightarrow \tau^-\bar{\nu}_\tau)X)$	0.3	1.2	
MisID template	0.1	0.8	
$\mathcal{B}(\bar{B} \rightarrow D^{**}\tau^-\bar{\nu}_\tau)$	0.5	0.5	
Combinatorial	< 0.1	0.1	
Resolution	< 0.1	0.1	
Additional model uncertainty	$\sigma_{\mathcal{R}(D^*)}(\times 10^{-2})$	$\sigma_{\mathcal{R}(D^0)}(\times 10^{-2})$	
$B \rightarrow D^{(*)}DX$ model uncertainty	0.6	0.7	
$\bar{B}_s^0 \rightarrow D_s^{**}\mu^-\bar{\nu}_\mu$ model uncertainty	0.6	2.4	
Baryonic backgrounds	0.7	1.2	
Coulomb correction to $\mathcal{R}(D^{*+})/\mathcal{R}(D^{*0})$	0.2	0.3	
Data/simulation corrections	0.4	0.8	
MisID template unfolding	0.7	1.2	
Normalization uncertainties	$\sigma_{\mathcal{R}(D^*)}(\times 10^{-2})$	$\sigma_{\mathcal{R}(D^0)}(\times 10^{-2})$	
Data/simulation corrections	$0.4 \times \mathcal{R}(D^*)$	$0.6 \times \mathcal{R}(D^0)$	
$\tau^- \rightarrow \mu^- \nu \bar{\nu}$ branching fraction	$0.2 \times \mathcal{R}(D^*)$	$0.2 \times \mathcal{R}(D^0)$	
Total systematic uncertainty	2.4	6.6	−0.39
Total uncertainty	3.0	8.9	−0.43

Systematic uncertainty - Run 2 hadronic $R(D^*)_{\tau/\mu}$

Table 5: Summary of relative systematic uncertainties on the ratio $\mathcal{K}(D^{*-})$.

Source	Systematic uncertainty (%)
Signal decay template shape	1.8
Signal decay efficiency	0.9
Fractions of signal τ^+ decays	0.3
Possible contributions from other τ^+ decays	1.0
Fixing the $\bar{D}^{**}\tau^+\nu_\tau$ and $D_s^{**+}\tau^+\nu_\tau$ fractions	+1.8 -1.9
Normalization mode PDF choice	1.0
Knowledge of the $D_s^+ \rightarrow 3\pi X$ decay model	1.0
Specifically the $D_s^+ \rightarrow a_1 X$ fraction	1.5
$B \rightarrow D^{*-} D_s^+(X)$ template shapes	0.3
$B \rightarrow D^{*-} D^0(X)$ template shapes	1.2
$B \rightarrow D^{*-} D^+(X)$ template shapes	+2.2 -0.8
Fixing $B \rightarrow D^{*-} D_s^+(X)$ bkg model parameters	1.1
Fixing $B \rightarrow D^{*-} D^0(X)$ bkg model parameters	1.5
$B \rightarrow D^{*-} 3\pi X$ template shapes	1.2
Combinatorial background normalization	+0.5 -0.6
PID efficiency	0.5
Kinematic reweighting	0.7
Vertex error correction	0.9
Normalization mode efficiency (modeling of $m(3\pi)$)	1.0
Preselection efficiency	2.0
Signal efficiency (size of simulation sample)	1.1
Normalization efficiency (size of simulation sample)	1.1
Empty bins in templates	1.3
PDF shapes uncertainty (size of simulation sample)	2.0
Total systematic uncertainty	+6.2 -5.9
Total statistical uncertainty	5.9

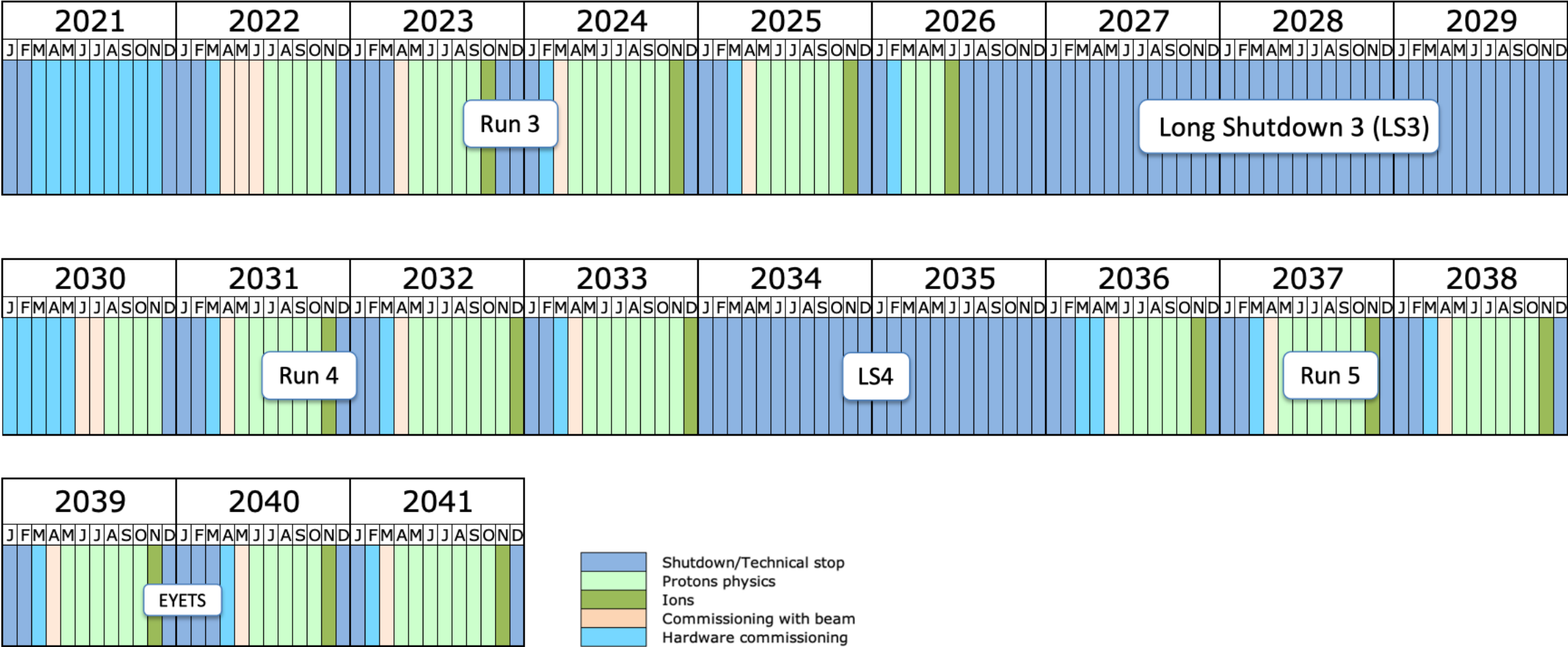
[PhysRevD.108.012018](#)

Systematic uncertainty - Run 2 muonic $R(D^*)_{\tau/\mu}$

Source	$R(D^+)$	$R(D^{*+})$
Form factors	0.023	0.035
$\bar{B} \rightarrow D^{**}[D^+ X]\mu/\tau\nu$ fractions	0.024	0.025
$\bar{B} \rightarrow D^+ X_c X$ fraction	0.020	0.034
Misidentification	0.019	0.012
Simulation size	0.009	0.030
Combinatorial background	0.005	0.020
Data/simulation agreement	0.016	0.011
Muon identification	0.008	0.027
Multiple candidates	0.007	0.017
Total systematic uncertainty	0.047	0.085
Statistical uncertainty	0.043	0.081

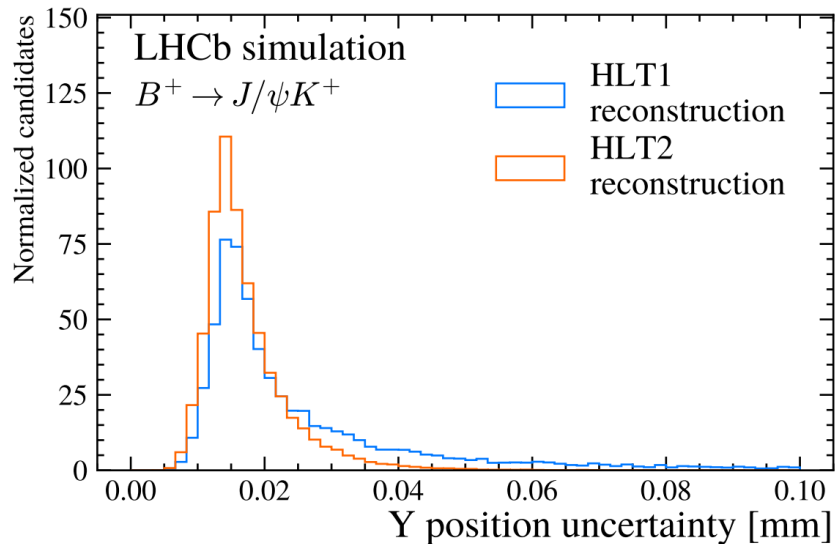
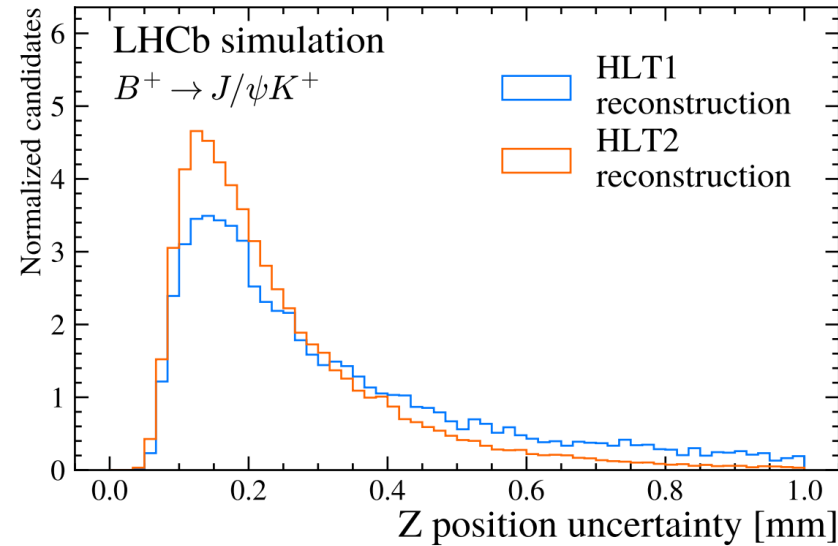
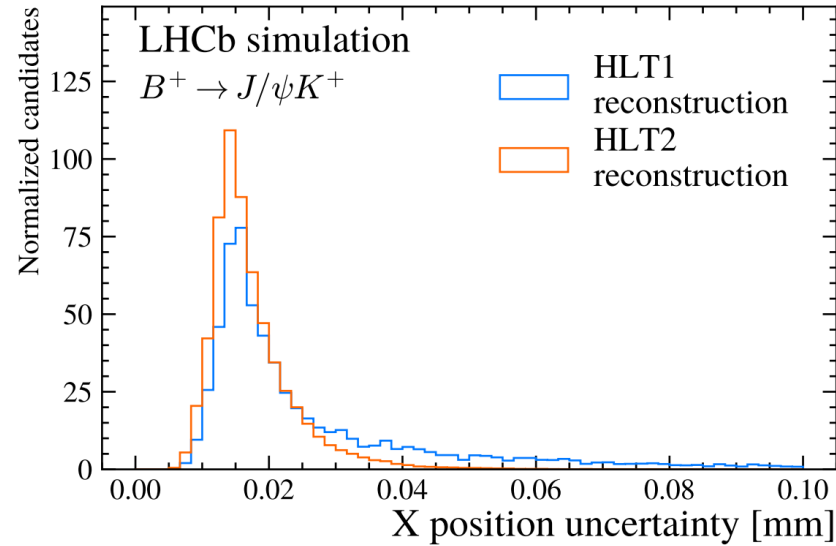
[PhysRevLett.134.061801](#)

LHCb future schedule



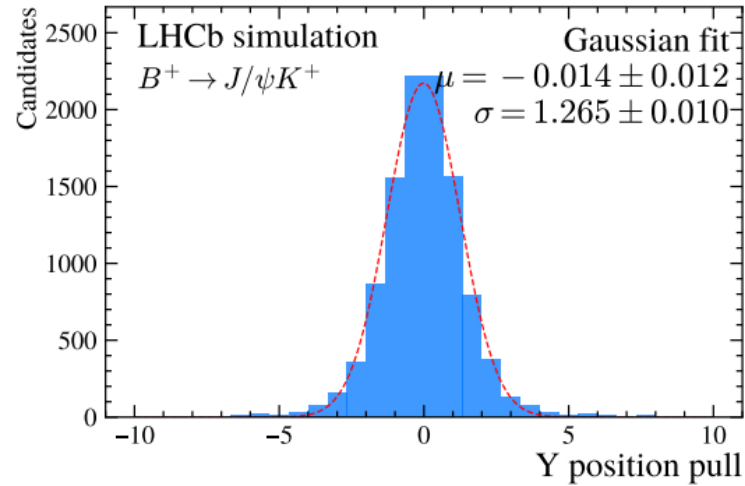
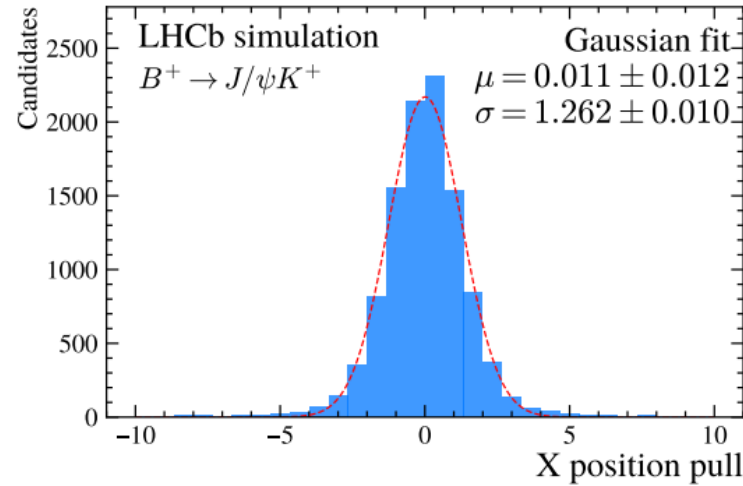
Last update: November 24

Position uncertainty in HLT1 and HLT2

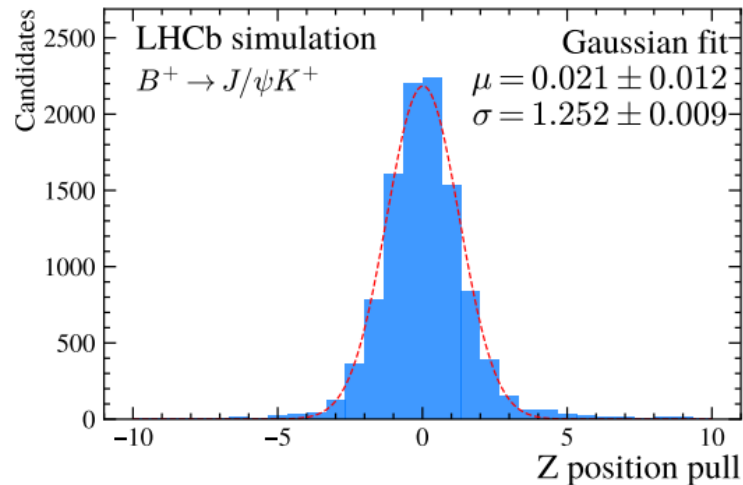


Uncertainties of vertex position are also worse in HLT1 (blue)

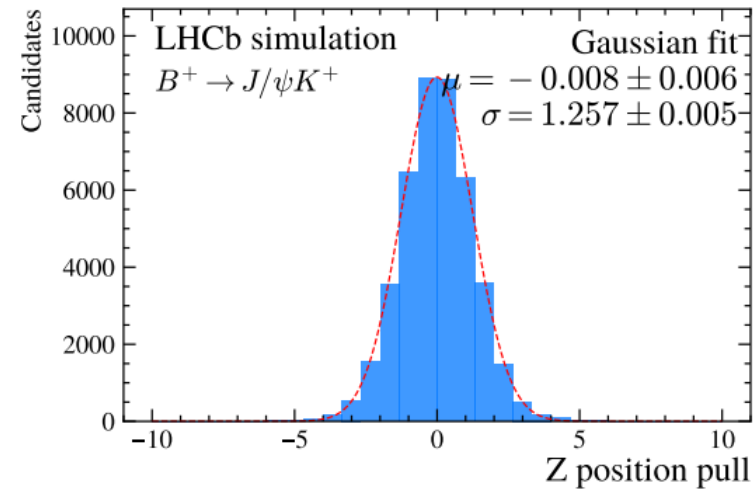
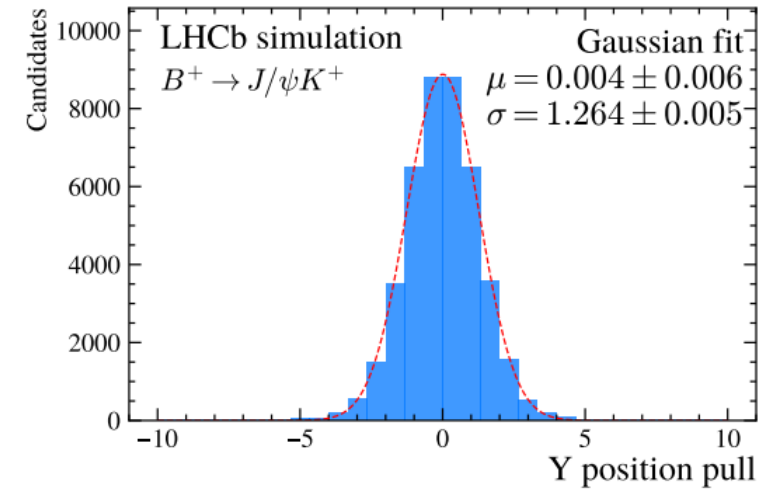
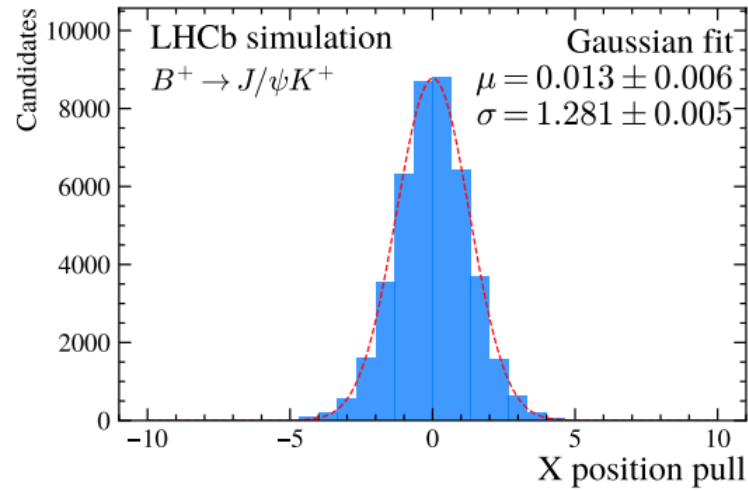
Pull of $J/\psi \rightarrow \mu^+ \mu^-$ vertex position - HLT1



$$\vec{r}_{\text{pull}} = \frac{\vec{r}_{\text{rec}} - \vec{r}_{\text{truth}}}{\sigma_{\vec{r}}}$$



Pull of $J/\psi \rightarrow \mu^+ \mu^-$ vertex position - HLT2



$$\vec{r}_{\text{pull}} = \frac{\vec{r}_{\text{rec}} - \vec{r}_{\text{truth}}}{\sigma_{\vec{r}}}$$