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

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- LHCb detector & data flow
- Motivation of this analysis

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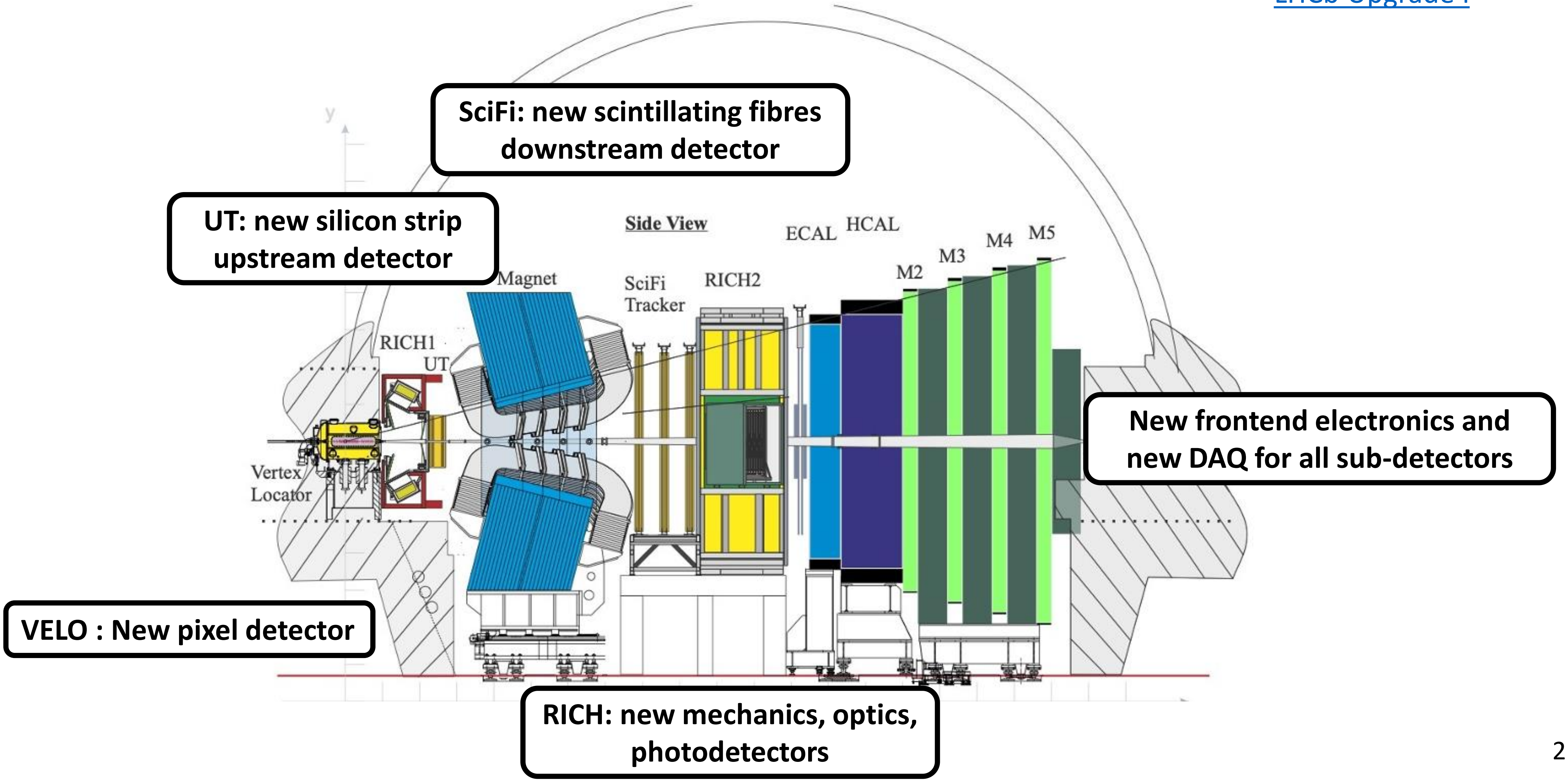
- Vertex isolation
- LFU determination

Status and outlook

Backup

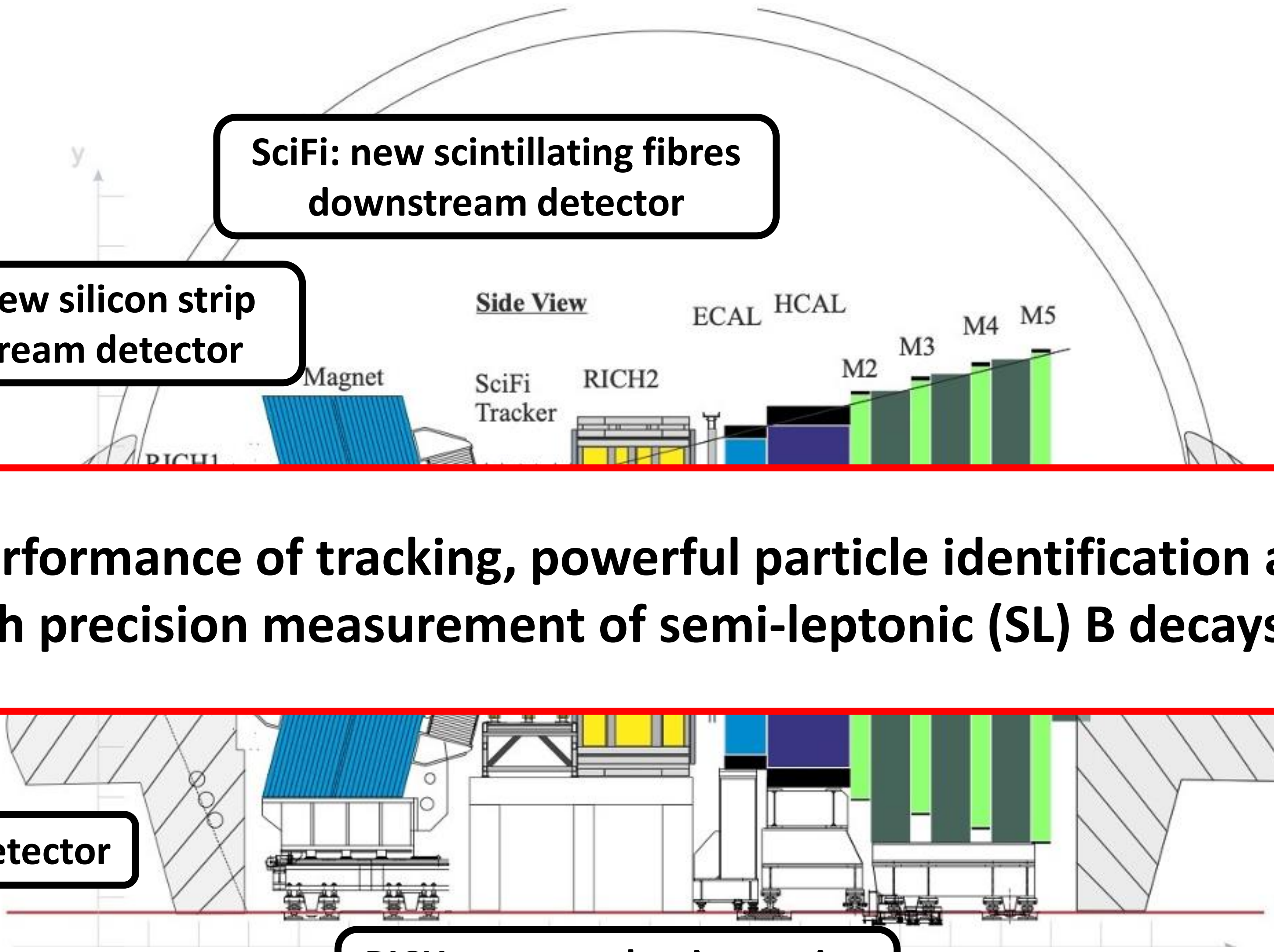
Introduction – LHCb detector

LHCb Upgrade I



Introduction – LHCb detector

LHCb Upgrade I



SciFi: new scintillating fibres downstream detector

UT: new silicon strip upstream detector

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ctors

Excellent performance of tracking, powerful particle identification allows to perform high precision measurement of semi-leptonic (SL) B decays !

VELO : New pixel detector

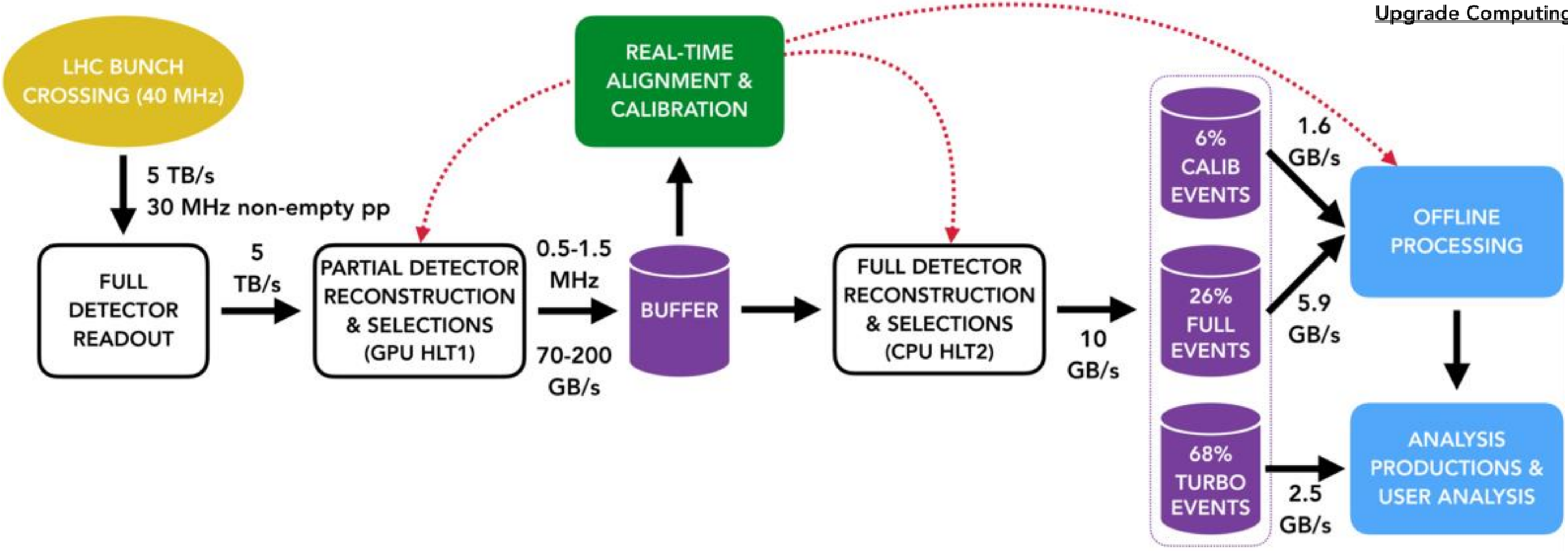
RICH: new mechanics, optics, photodetectors

Introduction – LHCb data flow

All numbers related to the dataflow are taken from the LHCb

Upgrade Trigger and Online TDR

Upgrade Computing Model TDR



- Data received by O(500) FPGAs and built into events in the event building (EB) farm servers
- In HLT1 trigger, perform partial reconstruction and selections. Reduce the rate by a factor of 30
- In buffer, real-time analysis and calibration are performed and used in next trigger
- In HLT2, perform full event reconstruction and exclusive selections.

Motivation of this analysis

In Run 3, we are benefited from

Better electron efficiency

Improved Bremsstrahlung reconstruction

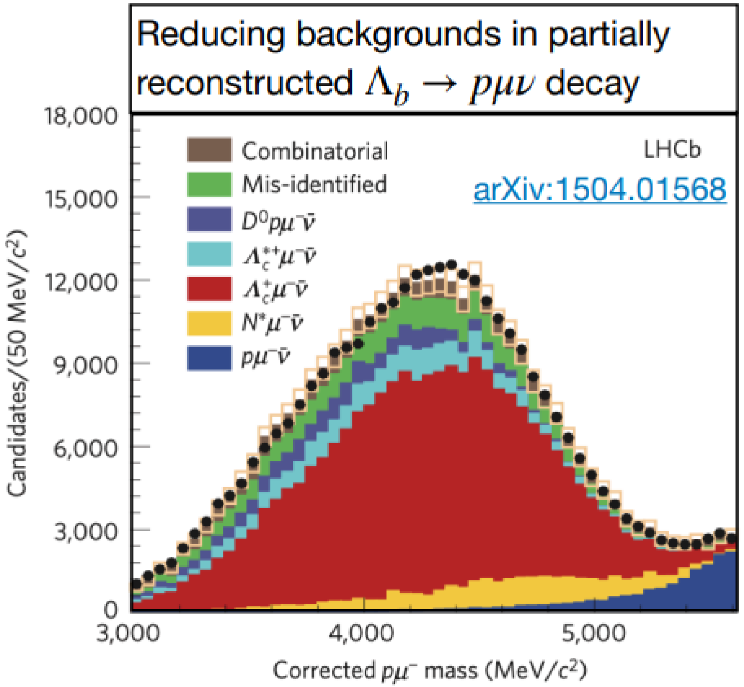
We have a lot of advantages measuring $R(D^*)_{\tau/e}$ compared to Run 1 & 2

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

→ It's the first time people test $\tau - e$ universality at LHCb !

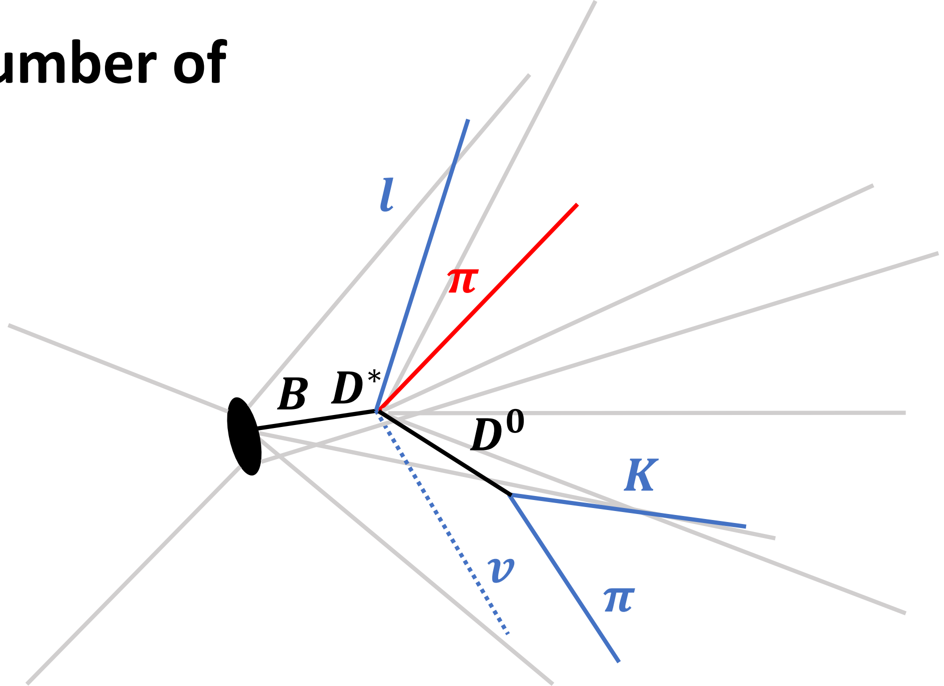
Charged isolation MVA

Challenge in SL analysis



In semi-leptonic analysis, due to the presence of neutrino, there are broad overlapping distributions
→ Hard to discriminate signal from background candidates

Necessary to reduce the number of background tracks !

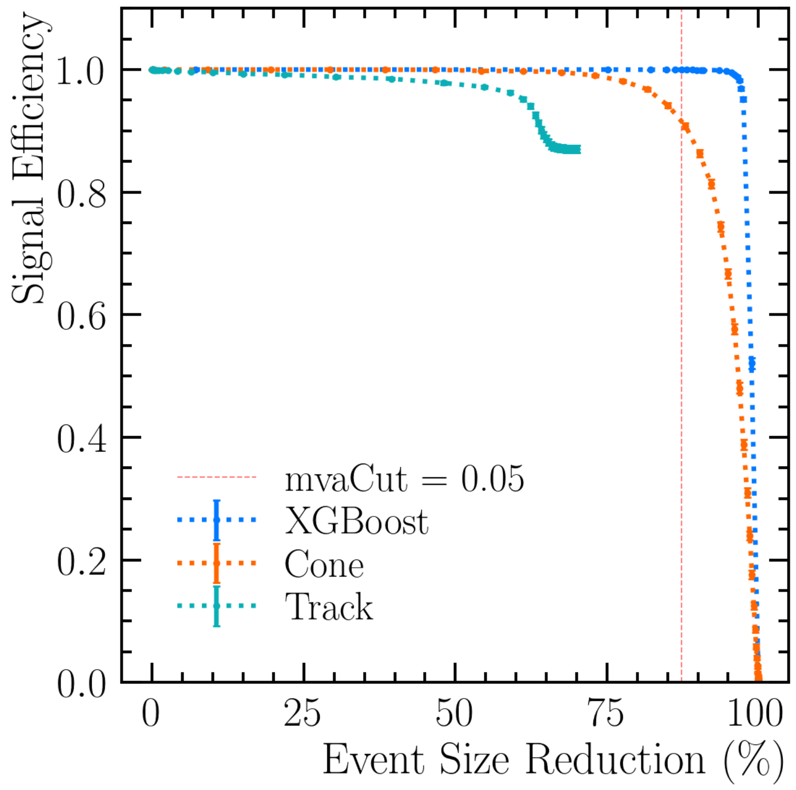


We save the ground state (D^0, lepton) and extra tracks and reconstruct the excited state (D^*) offline
→ In Run 3, we can't store all the extra tracks due to bandwidth limitations

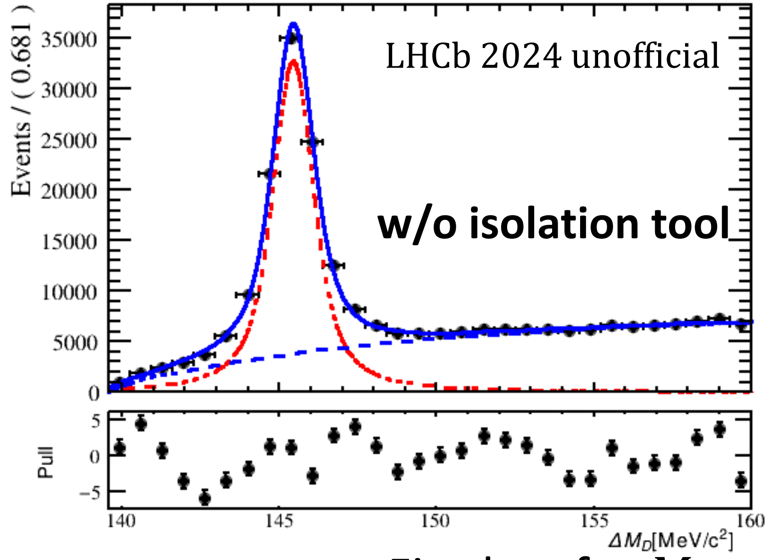
MVA study - performance

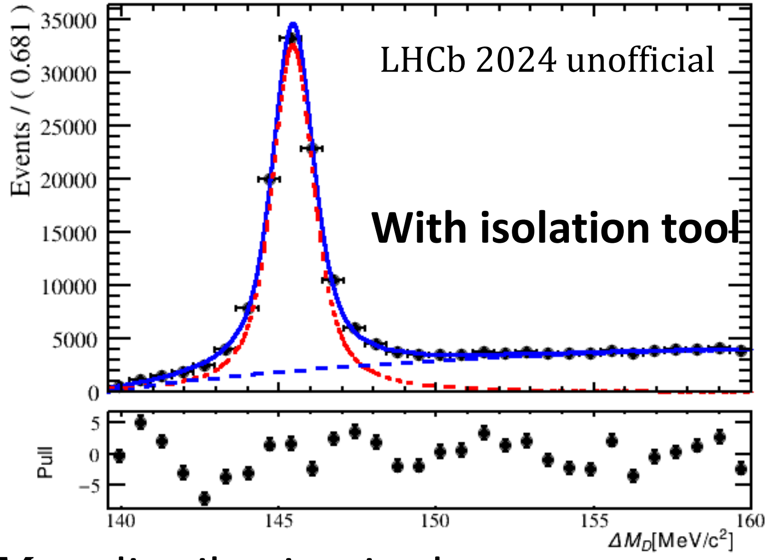
To identify tracks that likely originate from the B hadron decay, We train the model using **XGBoost**

Training features :
Geometric or kinematic properties of the extra track either by itself or relative to the signal candidate
Samples :
MC of 19 semileptonic decay channels with μ or e in the final state



ROC curve of isolation mva and the legacy methods





Fit plots for $M_{D^*} - M_{D^0}$ distribution in data

Remove ~ 40% background and only lose ~ 0.4% signal !

Methodology

Lepton Flavour Universality determination

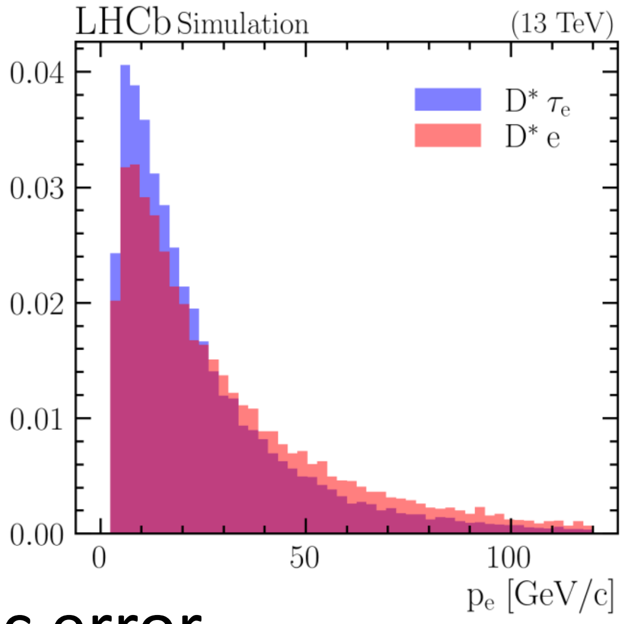
We study Lepton Flavour Universality by measuring

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

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

Extract signal yields using multi-dimensional fitter

Obtained efficiency from simulation and calibrated by data study



Both decays have electrons in final state

→ Measuring the ratio can cancel many sources of systematic error

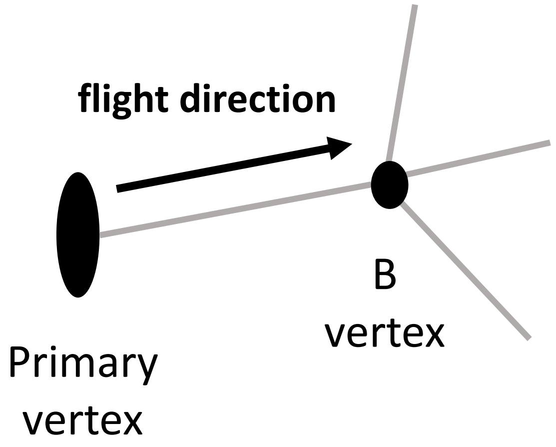
Kinematic reconstruction

Due to the presence of **neutrinos in the decay**, we can only reconstruct B meson partially

In this study, we reconstruct B-meson kinematics with the following procedure

Correct reconstructed $(\boldsymbol{p}_{\boldsymbol{B}^0})_z$ with true $\boldsymbol{m}_{\boldsymbol{B}^0}$

$$(p_{B^0})_z \approx \frac{m_{B^0,PDG}}{m_{B^0,reco}} \times (p_{B^0,reco})_z.$$



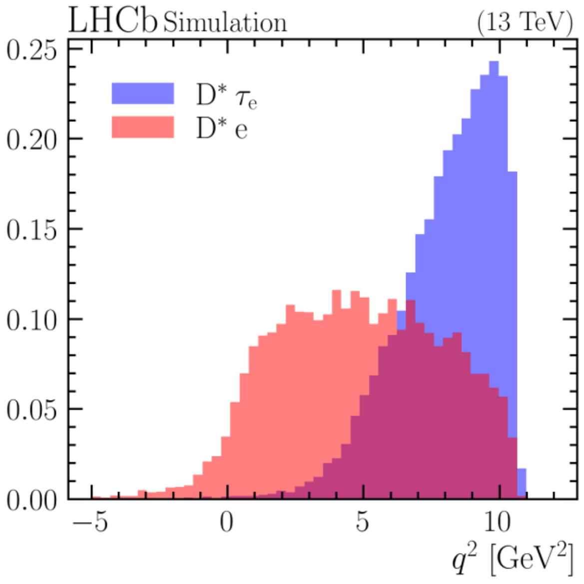
Derive $\left|\vec{\boldsymbol{p}}_{\boldsymbol{B}^0}\right|$ using the flight direction of $\boldsymbol{B}^0$ obtained from the positions of primary vertex and B^0 vertex

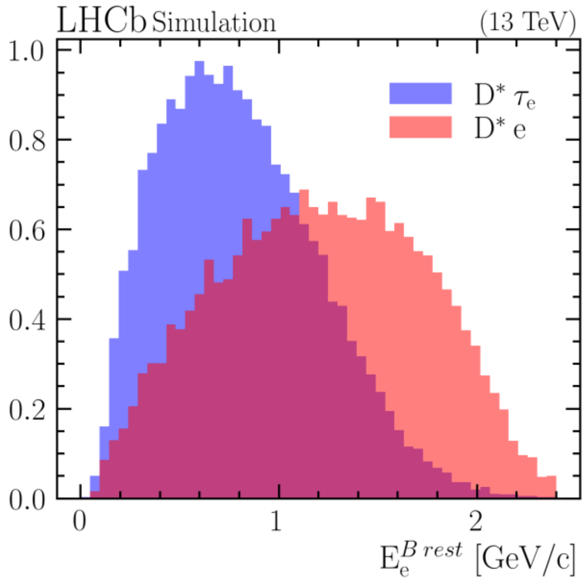
$\left|\vec{\boldsymbol{p}}_{\boldsymbol{B}^0}\right|$ = $(p_{B^0})_z / \cos\alpha$, where α is angle between flight direction and the z-axis

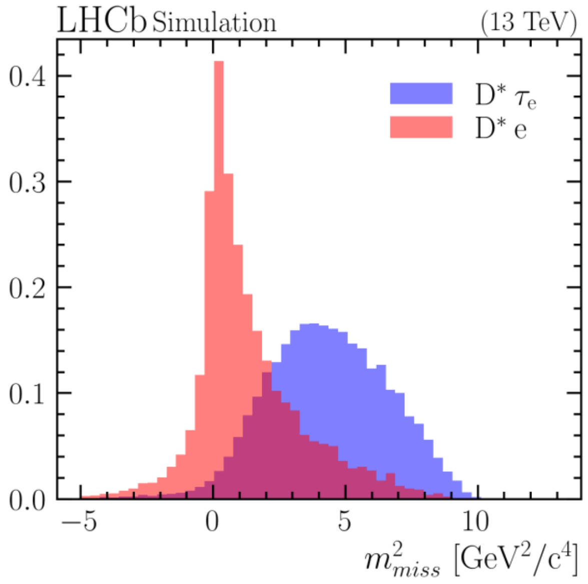
Fitting variables

Due to the success in $R(D^*)_{\tau/\mu}$ analysis, we plan to use the same fitting variables

- $M^2_{missing} = (p_{B^0} - p_{D^*} - p_e)^2$
- $q^2 = (p_{B^0} - p_{D^*})^2$
- E_e^*: Electron energy in B rest frame   which are derived from modified $\vec{p}_{B^0}$







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

Methodology - Vertex isolation

Dominated semi-leptonic background in Run 1 & 2 $R(D^*)_{\tau/\mu}$ analysis :

Higher excited background : $\bar{B} \to D^{**}(\to D^* n\pi) l v, (n \geq 1)$

In this analysis, the charge isolation mva is used to perform the vertex isolation – to remove the events which have multiple high mva score extra tracks

Double charmed background : $\bar{B} \to D^* H_c(\to l v X) X$

We plan to use the similar strategy to remove the background, and the preparation of simulation samples is in progress.

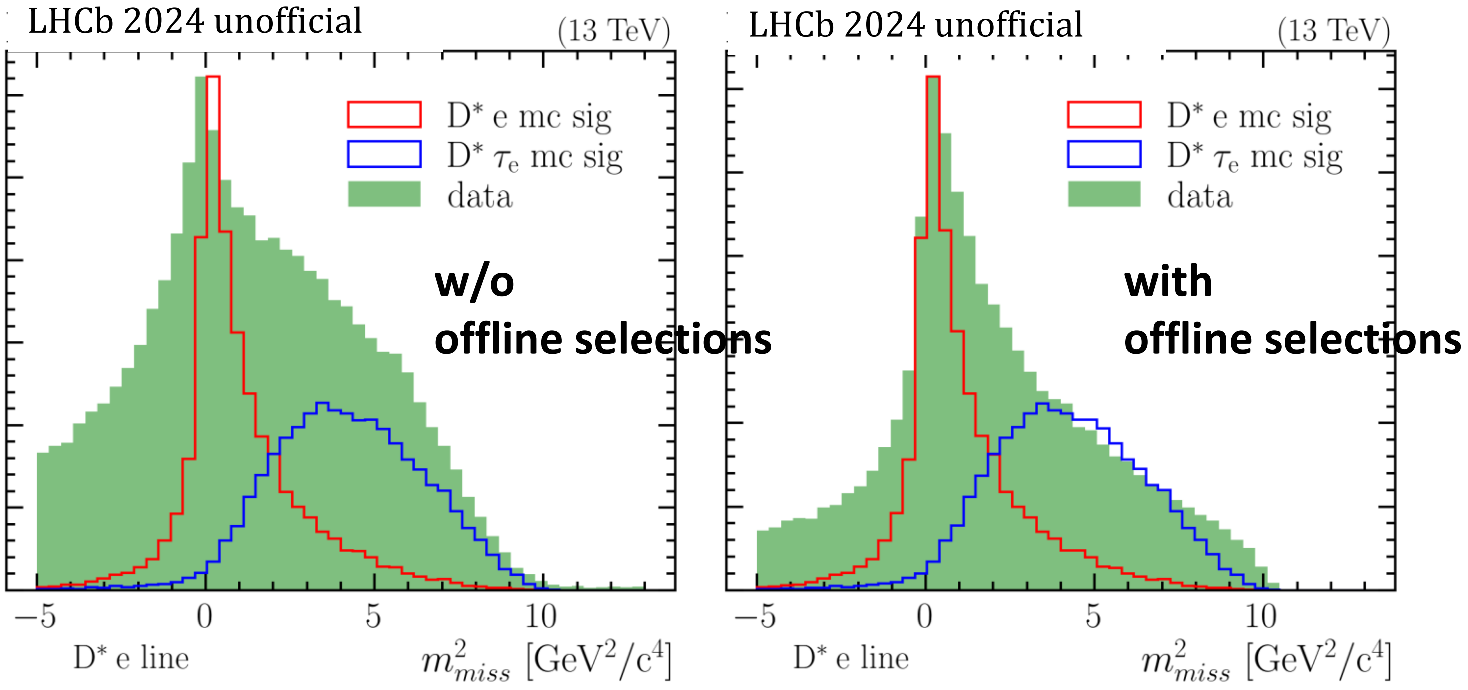
Status and outlook

Status

- Trigger selections have been tuned

- Isolation technique has been proven on data, with $\boldsymbol{B \rightarrow D^{*} e v}$ decays as first test case

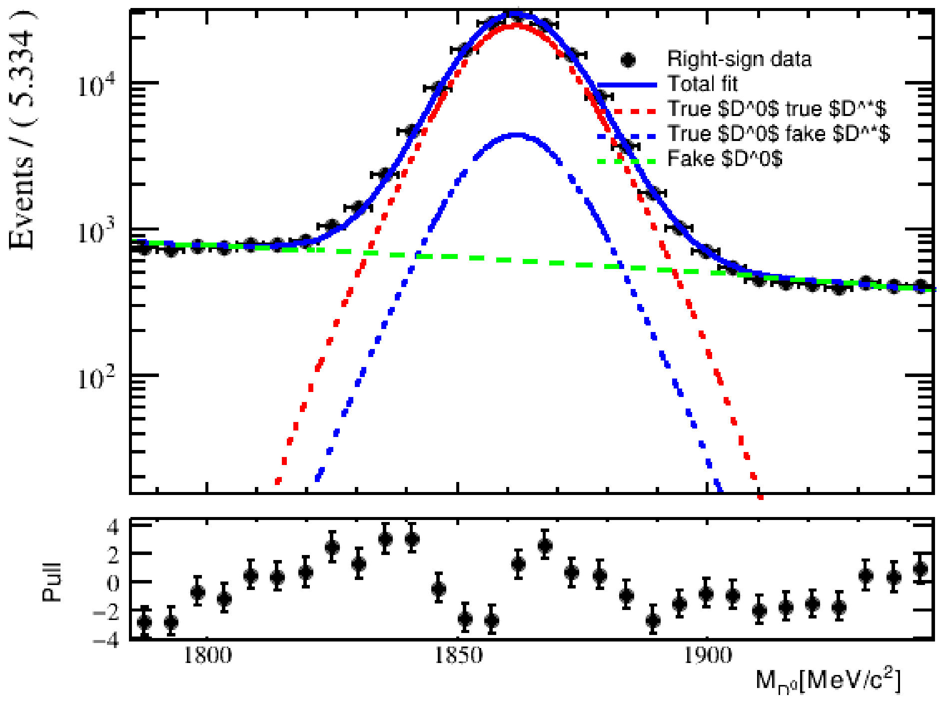
- Offline selection roughly in place



Status

- Request of MC samples for the physics backgrounds is in progress
- Higher excited states can be suppressed by using the isolation MVA
- Removing combinatorial background from charm decays with s-weights

LHCb 2024 unofficial



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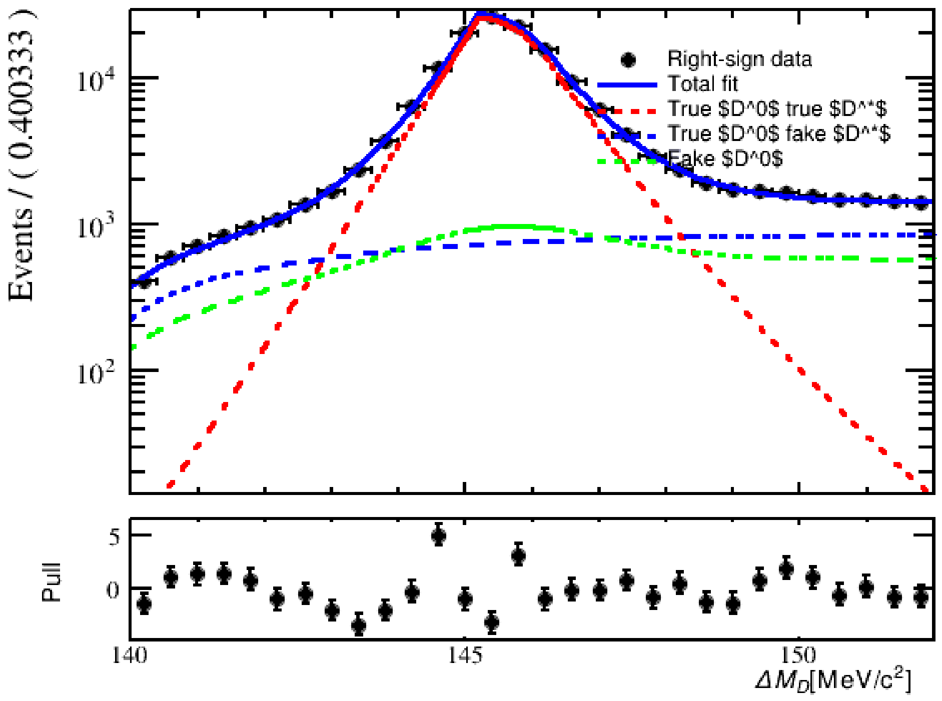
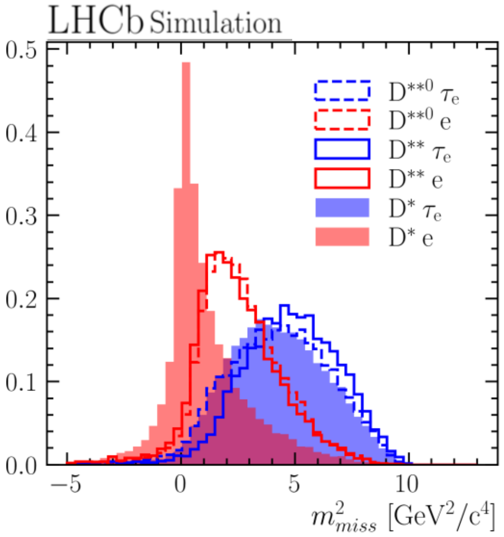


Next step

Fitter preparation

Templates from simulation

- Signal channels
- Double charm background
- Higher excited background



Data-driven templates

- Combinatorial background
- Fake lepton background

Further efficiencies study from simulated samples and real data

$$R(D^*)_{\tau/e} \equiv \frac{N(B^0 \to D^{*-}\tau^+\nu_\tau)}{N(B^0 \to D^{*-}e^+\nu_e)} \times \frac{\epsilon(B^0 \to D^{*-}e^+\nu_e)}{\epsilon(B^0 \to D^{*-}\tau^+\nu_\tau)}$$

Summary

- $R(D^*)_{\tau/e}$ measurement in Run 3 has started.

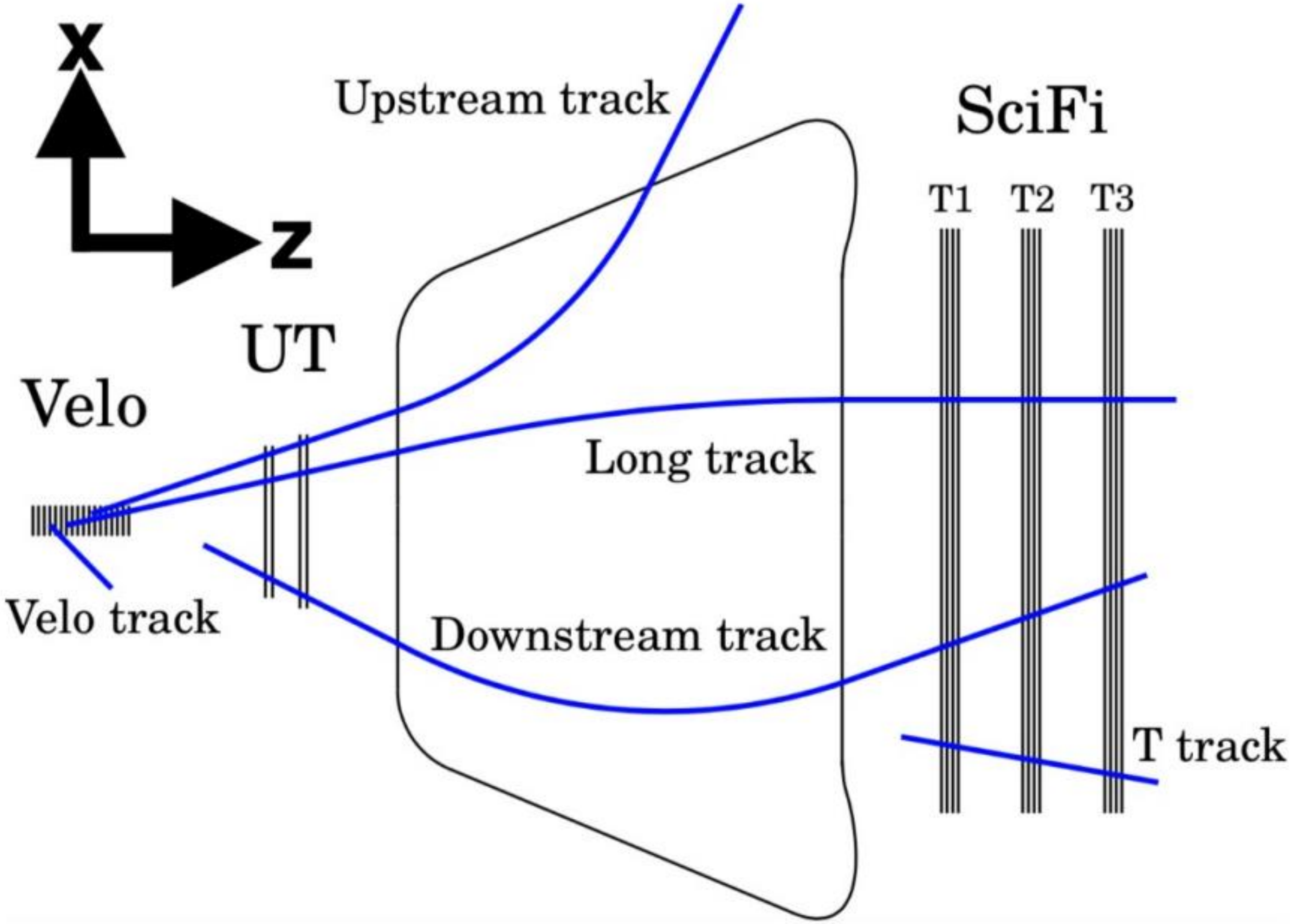
- The charged isolation MVA is implemented in working group and tested in both data and simulation.

- D^*e and $D^*\tau$ can be distinguished using the fitting variables from the $R(D^*)_{\tau/\mu}$ analysis.

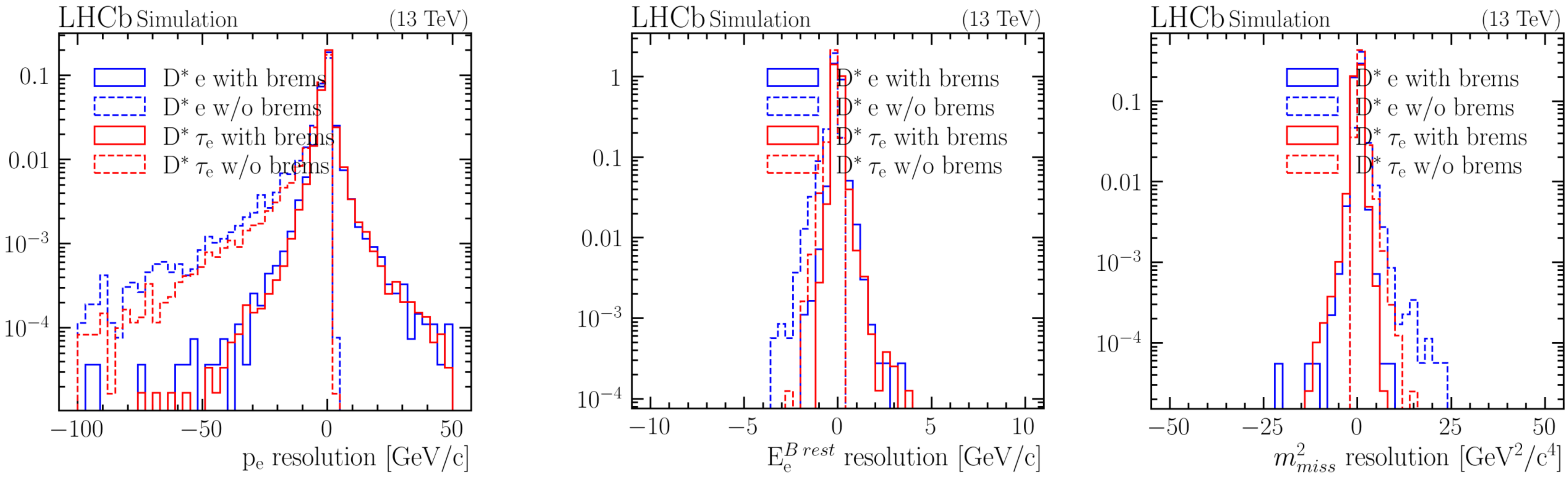
- The preparation of the background simulation samples is in progress.

Backup

Type of tracks in LHCb

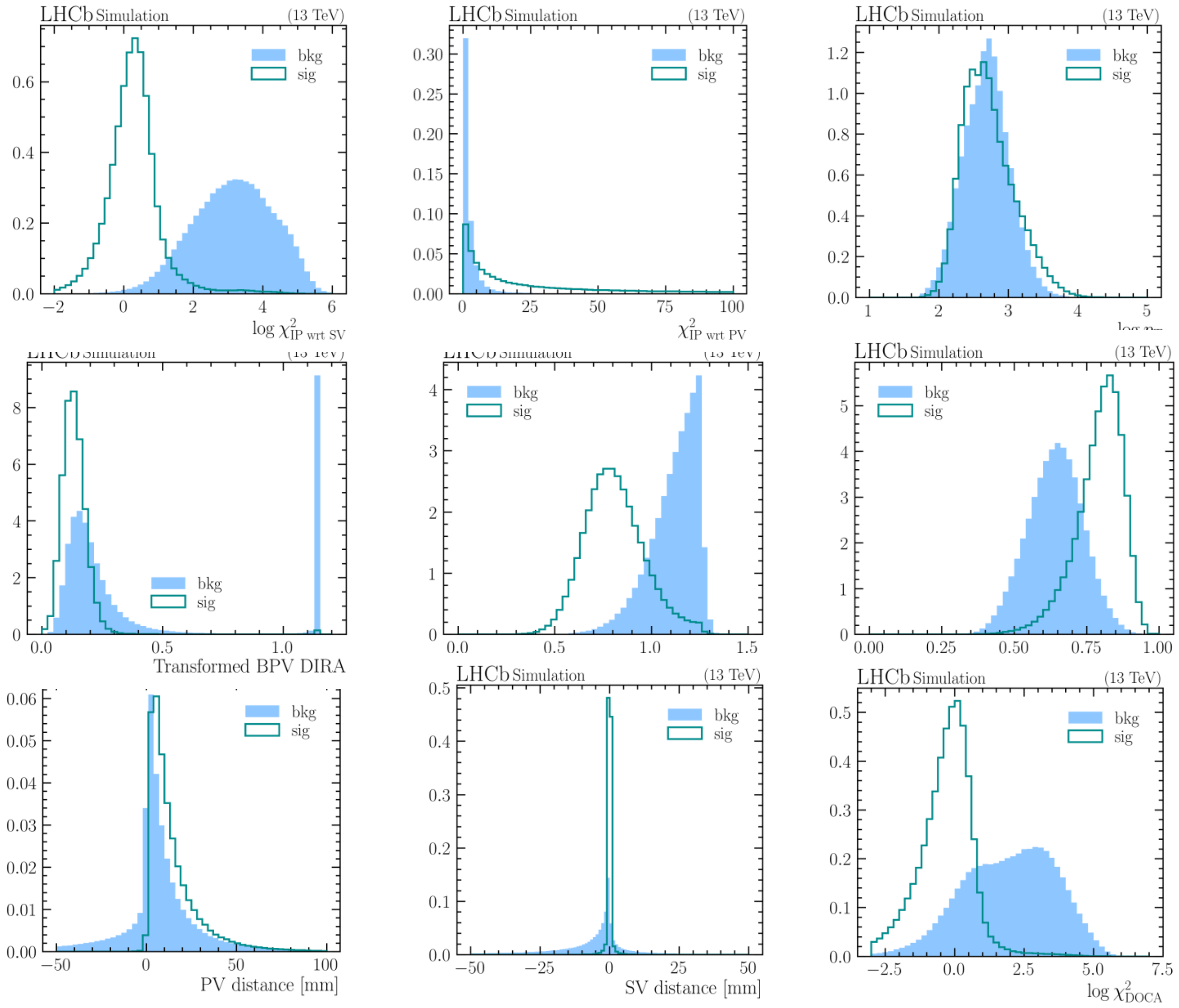


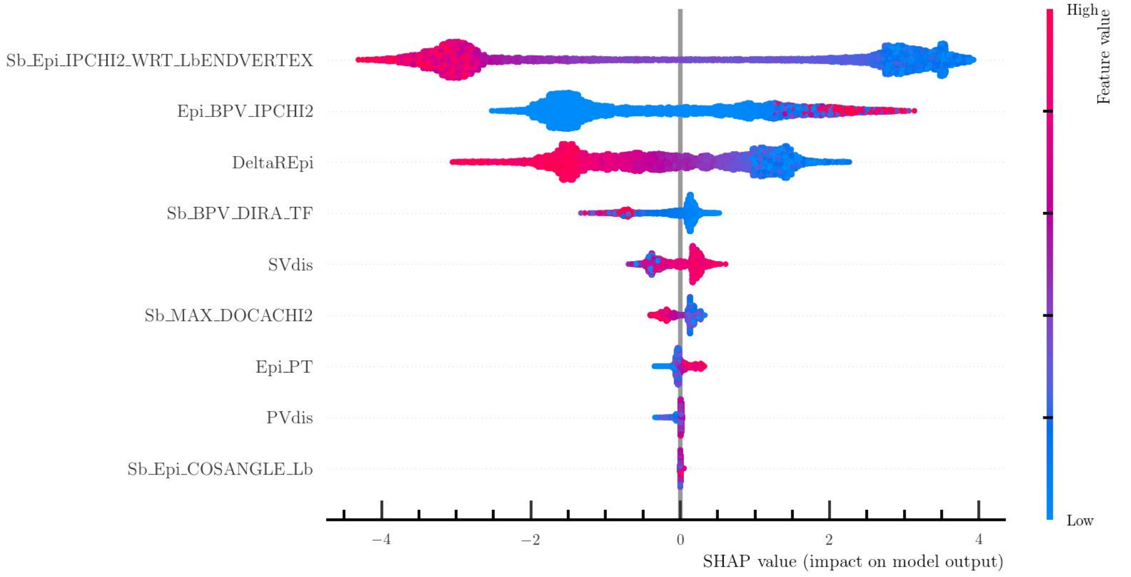
Bremstralung reconstruction



Resolution : $\boldsymbol{Variable^{Rec} - Variable^{Truth}}$

Isolation MVA - training





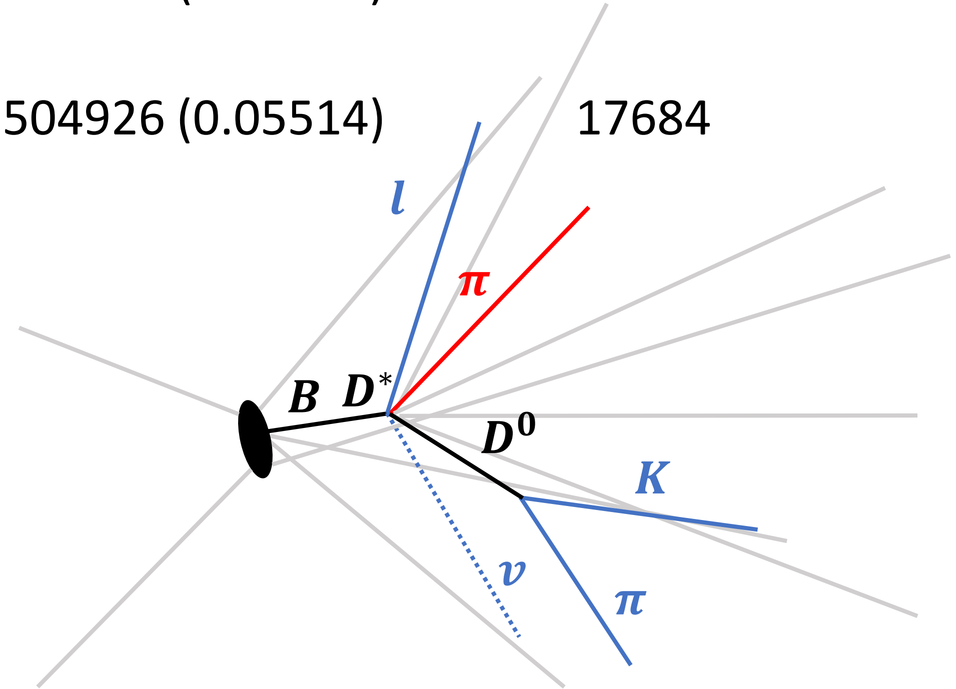
Sample :
30 k signal tracks and **50~100 times more bkg tracks** for each SL decay channels (19 in total).

Optimise hyper parameters by maximising the area under the ROC curve

Sample

	Cocktail Notes	MagUp # of event in DIGI	MagDown # of event in DIGI	# of sig* in tuple
$B^+ \to D^{**}e\nu$	$D^*(2640)^0, D(2S)^0$ $D_1(2420)^0, D_2^*(2460)^0$	501336	548972 (0.07168)	71957
$B^+ \to D^{**}\tau\nu$	$D_1(H)^0, D_1(2420)^0$ $D_2^*(2460)^0$	617623	500681 (0.05021)	98235
$B^0 \to D^{**}e\nu$	$D^*(2640)^-, D(2S)^-$ $D_2^*(2460)^-, D_1(2420)^-$	504953	500680 (0.07108)	64754
$B^0 \to D^{**}\tau\nu$	$D_0^{*-}, D_1(H)^-$ $D_2^*(2460)^-, D_1(2420)^-$	501585	504926 (0.05514)	17684

*With 2024 condition



Vertex isolation

Procedure :

- Choose the best $D^0 e$ combination in each event, then rank the mva score of the $B^{*-}_{best}\pi^+$ combinations.
- In a event, if the 2-th candidate has bdt>0.99, remove the event

Vertex isolation – performance of r-s sample

	Efficiency [%]				
	Vertex isolation	Highest mva	Offline selection	Xdigi (Generator cut eff [%])	# of candidates after offline sels
$B^+ \to D^* e v$	90.9	75.5	70.8	1011748 (0.17)	17124
$B^+ \to D^* \tau v$	91.9	76.6	72.3	1084565 (0.06)	38461
$B^+ \to D^{**} e v$	64.3	3.1	2.2	1050308 (0.07)	12698
$B^+ \to D^{**} \tau v$	67.4	3.9	2.8	1118304 (0.05)	8953
$B^0 \to D^{**} e v$	48.5	2.9	1.0	1005633 (0.07)	17901
$B^0 \to D^{**} \tau v$	88.8*	8.2	1.1	1006511 (0.06)	8953

Highest mva : Choose the candidate which has the highest bdt score

Right-side : Only select the right-side candidate (We will fit the right-side data sample to determine the signal yields)

Offline selection : eID > 0.5, η_e < 4.5 and 140 < ΔM_{D^*} < 152 MeV