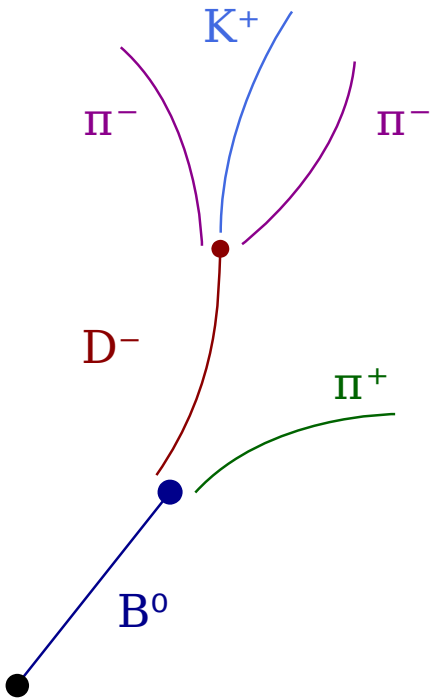
A Large Ion Collider Experiment

Study of open beauty production with the ALICE detector at LHC

(Mid-term defence)

PhD supervisors: Iouri BELIKOV & Christian KUHN

Mid-term Defence, 28.06.23, Alexandre BIGOT

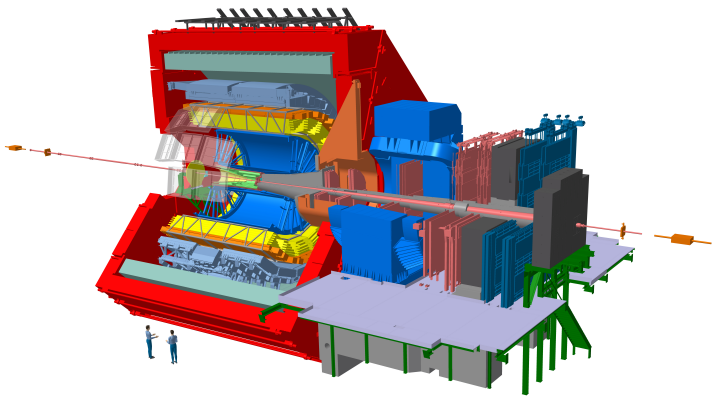


From fits to invariant mass spectra

$$\left.\frac{d^2\sigma(B^0)}{dp_{\mathrm{T}}dy}\right|_{|y|<0.5} = \frac{1}{\Delta p_{\mathrm{T}}} \cdot \frac{1}{\mathrm{BR} \cdot \mathcal{L}_{\mathrm{int}}} \cdot \frac{\frac{1}{2}\left.N_{\mathrm{raw}}^{B^0+\bar{B}^0}(p_{\mathrm{T}})\right|_{|y|<y_{\mathrm{fid}}}}{(\mathrm{Acc} \times \varepsilon)(p_{\mathrm{T}}) \cdot c_{\Delta y}(p_{\mathrm{T}})}$$

Corrections for reconstruction and selection efficiency

Study of open beauty production with the ALICE detector at LHC



Contents

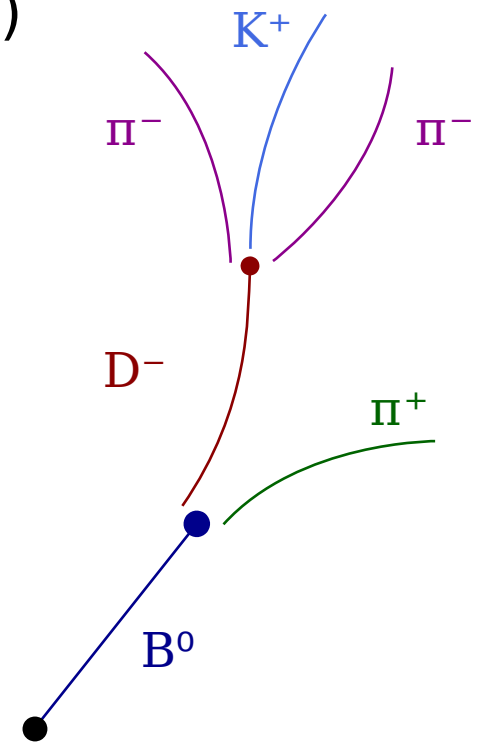
I - Introduction (physics motivations, ALICE, ...)

II - Heavy Flavour Triggers

III - B^0 meson analysis in pp collisions

IV - Other activities

1. Trainings
2. Lectures
3. Scientific communication



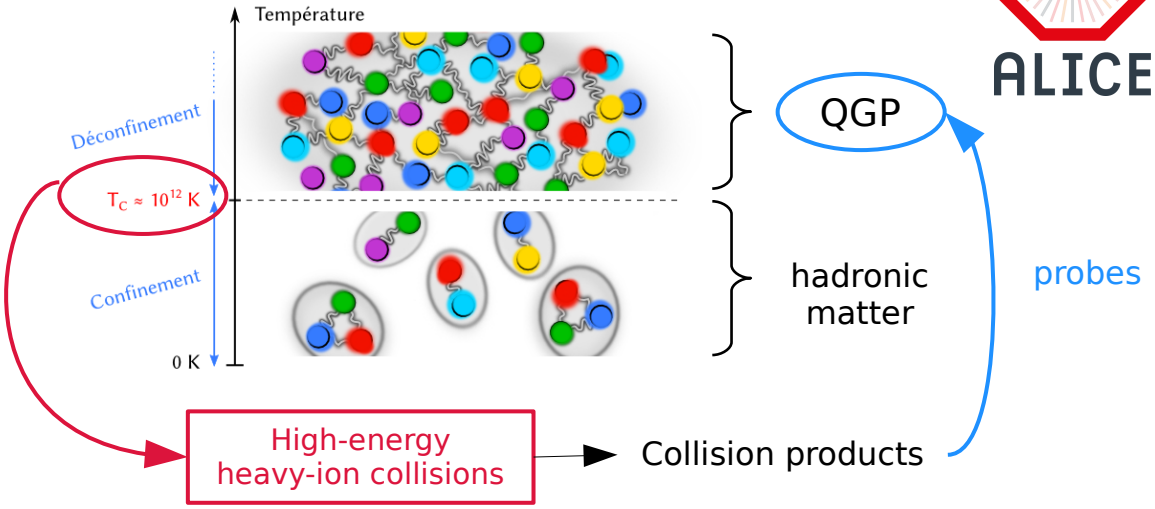
I - Introduction

- Heavy flavour physics
- ALICE 2 (a new experiment!)

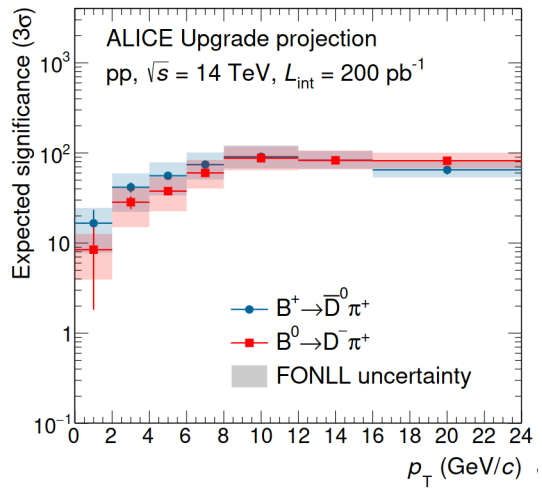
ALICE (heavy flavour) physics

ALICE

- Determine the properties of Quark Gluon Plasma (QGP)



- Heavy Flavours (HF) of quarks: *charm (c)* and *beauty (b)*
  - Produced during hard processes, before formation of QGP
  - Unique access to interactions in QGP
    - Thermalization and hadronization in medium
    - In-medium energy losses and their mass dependence
- HF in **pp collisions** [system studied for this thesis]:
  - important test of perturbative QCD
  - necessary reference for p-A and A-A results



ALICE 2 detector

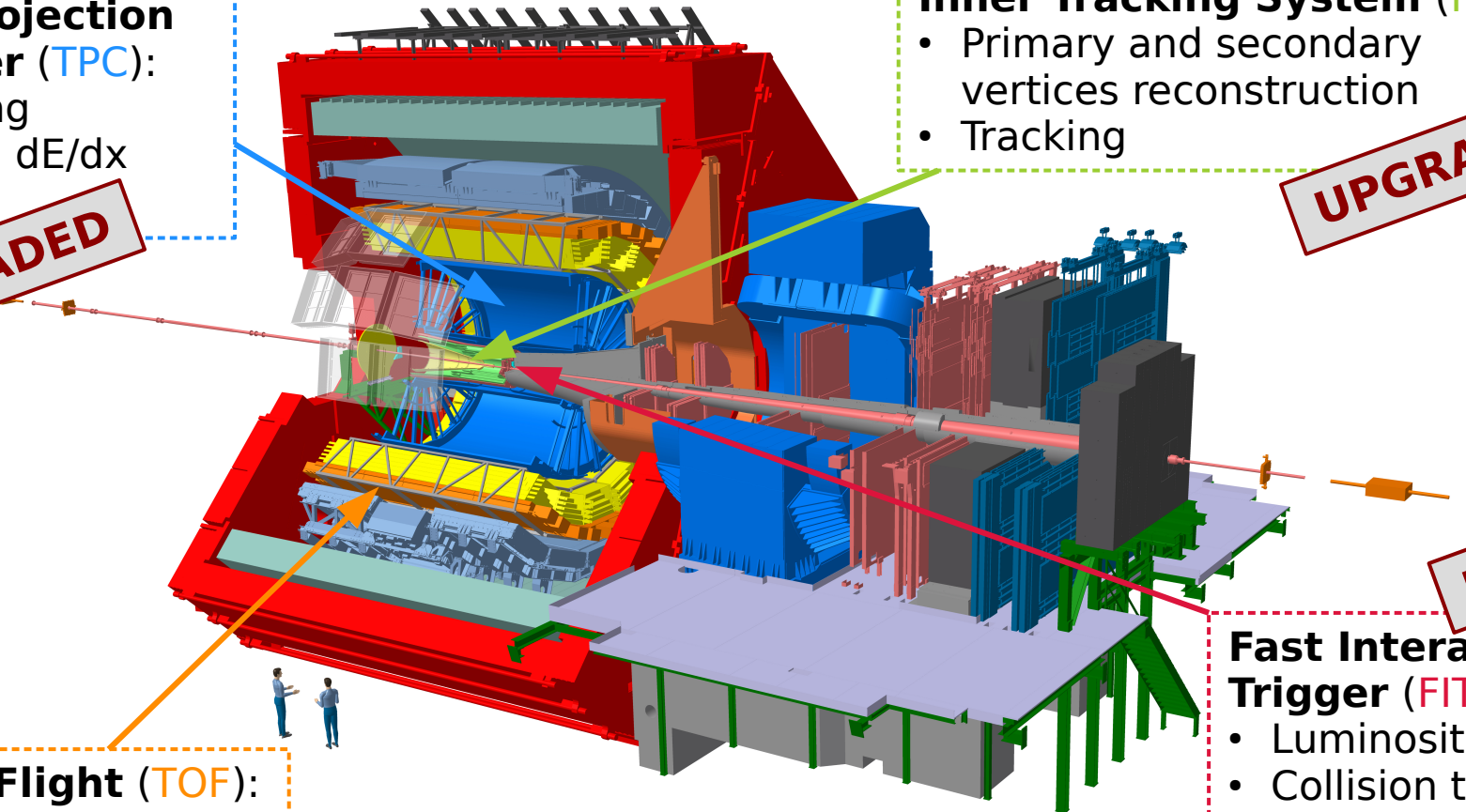
ALICE

Time Projection Chamber (TPC):
- Tracking
- PID via dE/dx

UPGRADED

Inner Tracking System (ITS):
- Primary and secondary vertices reconstruction
- Tracking

UPGRADED

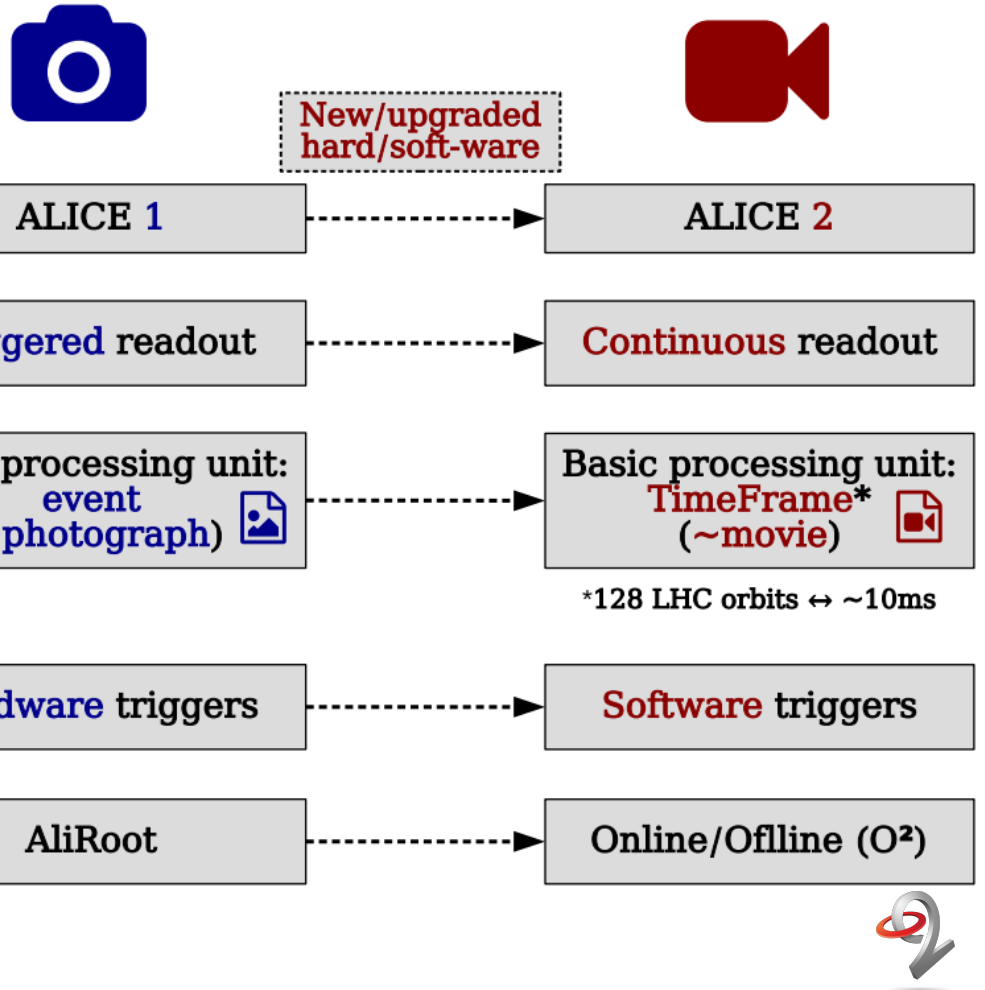


Time Of Flight (TOF):
- PID via time-of-flight measurements

Fast Interaction Trigger (FIT):
- Luminosity
- Collision time and position

UPGRADED

ALICE 2 (LHC Runs 3&4 – 2022→ 2032)



- Studying processes that are not "triggerable"
- Record O(x100) more collisions than before

- Store O(x100) more events → need to filter (disk space limitation)

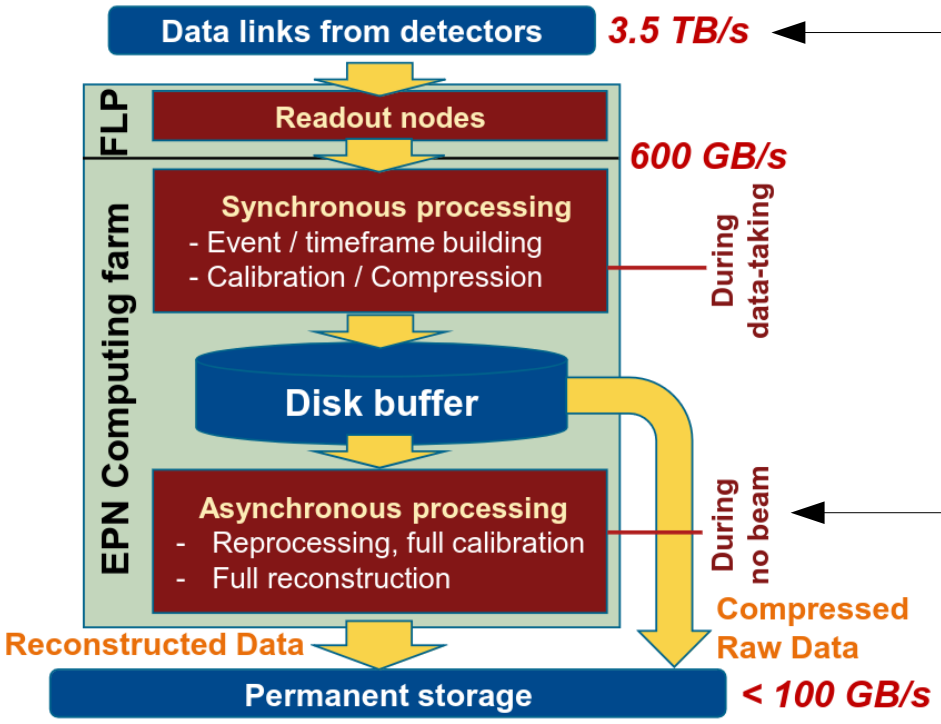
II – Heavy Flavour Triggers (pp collisions)

ALICE

- Run 3 processing scheme
- Strategy and BDT-based selection
- Goal: reach 10^{-4} selectivity

Run3 processing scheme in pp collisions

ALICE



All statistics are *temporarily* stored

Filter interesting events according to dedicated triggers

+ Flag data for analysis
feature not available yet

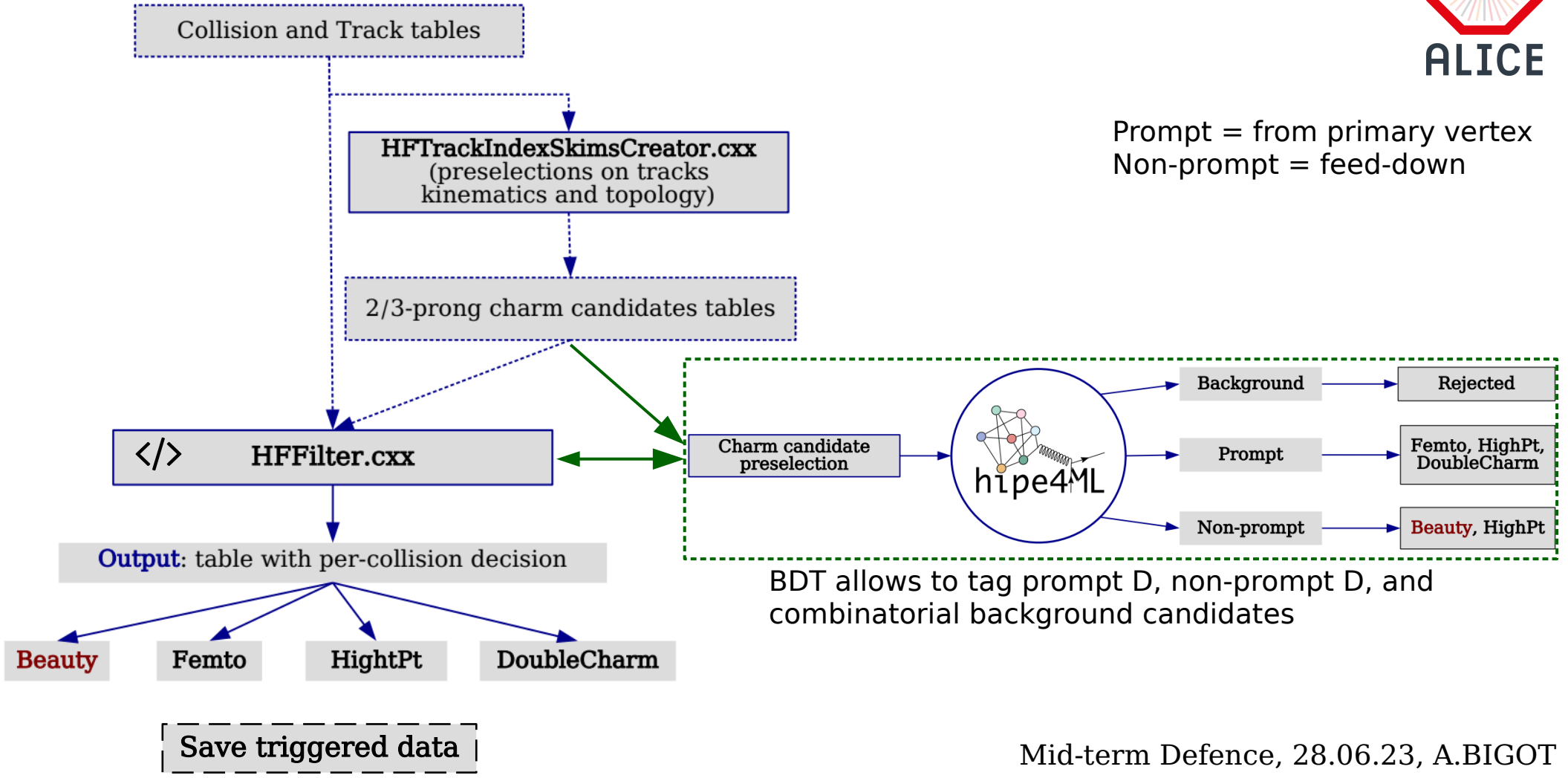
Only selected events are *permanently* stored

Investigation of huge MB statistics
200 pb^{-1} in Runs 3-4

(ALICE Run2 MB statistics: 32 nb^{-1})

(FLP) First Level Processors
(EPN) Event Processing Nodes (8GPUs, 64 CPUs)

Strategy - BDT-based selection



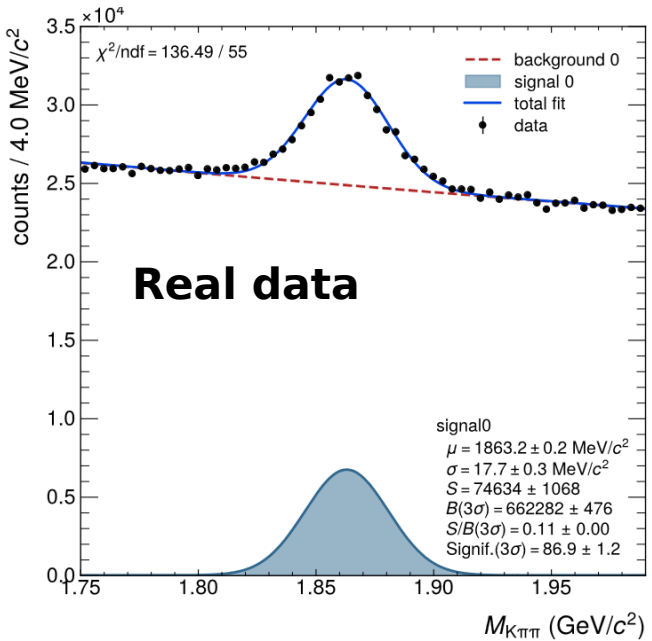
Prompt = from primary vertex
Non-prompt = feed-down

BDT allows to tag prompt D, non-prompt D, and combinatorial background candidates

Invariant mass distributions

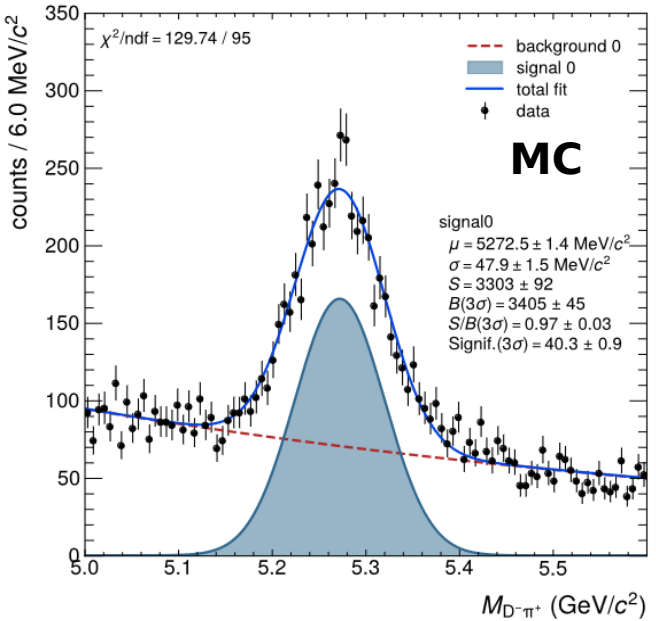
pT ∈ [0,50] GeV/c

D⁺ in real data (1.7G events)



Width x2 compared to Run2
(TPC space charge distortion)

B⁰ in MC B forced (5M events)



- D⁺ peak already visible with filtering only (!)
- B⁰ peak:
  - Observable in MC
  - **Yet** unseen in real data → need more selections

- Triggers offer already good performance/selectivity but are still work in progress
  - e.g. flags not available yet

Is B⁰ observable in 2022 pp data?

ALICE

$17\,\mathrm{pb}^{-1}$

$5.58 \cdot 10^7\,\mathrm{pb}$ $\quad$ 0.41

$$S_{\mathrm{exp}} = 2 \cdot \sigma^{\mathrm{FONLL}}_{\mathrm{b\bar{b}}} \cdot \mathrm{FF}(\mathrm{b} \to B^0) \cdot (Acc \times \varepsilon) \cdot \mathrm{BR} \cdot \mathcal{L}_{\mathrm{int}} \simeq 1.8 \cdot 10^3$$

hypothesis $Acc \times \varepsilon \sim 10\%$

$\mathrm{BR} = 0.251\% \times 9.38\% \simeq 2.35\,10^{-4}$

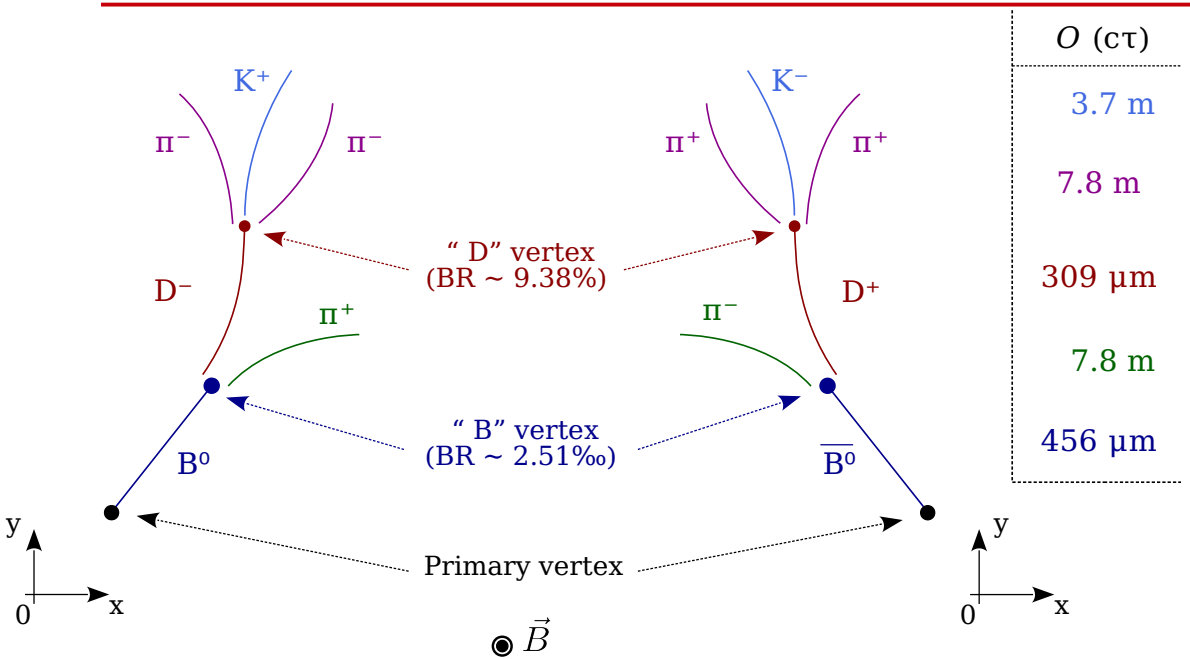
μ, σ obtained by fitting signal curve in MC

$$B_{\mathrm{exp}} = B^{[\mu-3\sigma,\mu+3\sigma]}_{\mathrm{real\ data}} \cdot \frac{N^{\mathrm{expected}}_{\mathrm{events}}}{N^{\mathrm{analyzed}}_{\mathrm{events}}} = 8.2 \cdot 10^6 \,(1.6 \cdot 10^7)$$

σ → 2σ to take into account miscalibration

$$\frac{S_{\mathrm{exp}}}{\sqrt{S_{\mathrm{exp}} + B_{\mathrm{exp}}}} = 6.38\,(4.57)$$

III – B^0 analysis (… D^+ analysis)



Decay channel reconstructed fully topologically:

- Reconstruct (non-prompt) D^+ candidate first
- Associate D^+ candidate with a π^- to build B^0 candidate

- D mesons:
  - Non-prompt natural fraction: only 5-10% of total production
  - similar decay topologies between prompt and non-prompt

→ BDT selection

- B mesons:
  - rare signal
  - impossible to see by ALICE in Runs 1&2 data → require higher integrated luminosity (Runs 3&4)

$B^0 \rightarrow (D^- \rightarrow \pi^- K^+ \pi^-)\pi^+$ workflow

ALICE

Personal contribution to software development

Flag πKπ triplets with loose preselections

Reconstruct secondary vertex and create candidate

Apply selections on kinetmatics, topological variables, PID

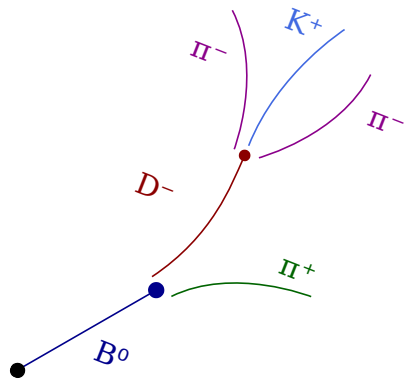
Fill histograms with candidates information

Track skimming → D^+ candidate creator → D^+ candidate selector ⇢ D^+ analysis task

D^+ workflow

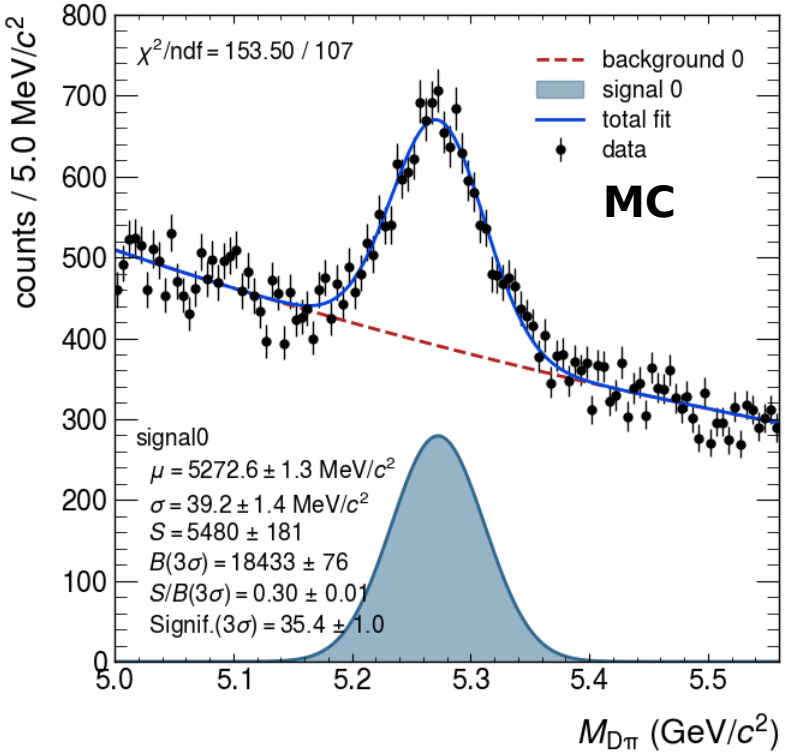
B^0 candidate creator → B^0 candidate selector → B^0 analysis task

- B^0 analysis requires to first go through D^+ workflow
- Work in progress:
  - Implement Machine Learning inference in O²Physics
  - Train BDT models to select **non-prompt D^+**



First results on MC data (~5M events)

ALICE



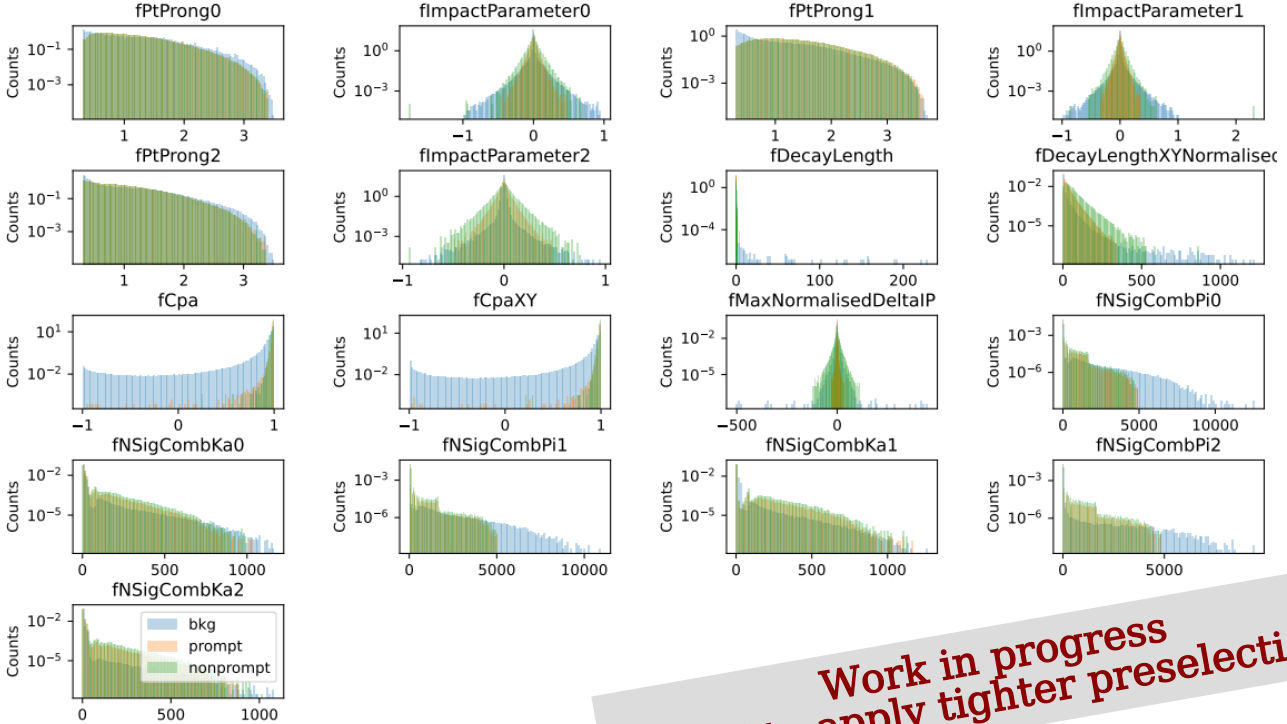
- pT integrated ([0, 24] GeV/c)
- Loose selections on B^0
- A bit tighter selection on D^+
- Need to improve selections
  - Use BDT in D^+ selector

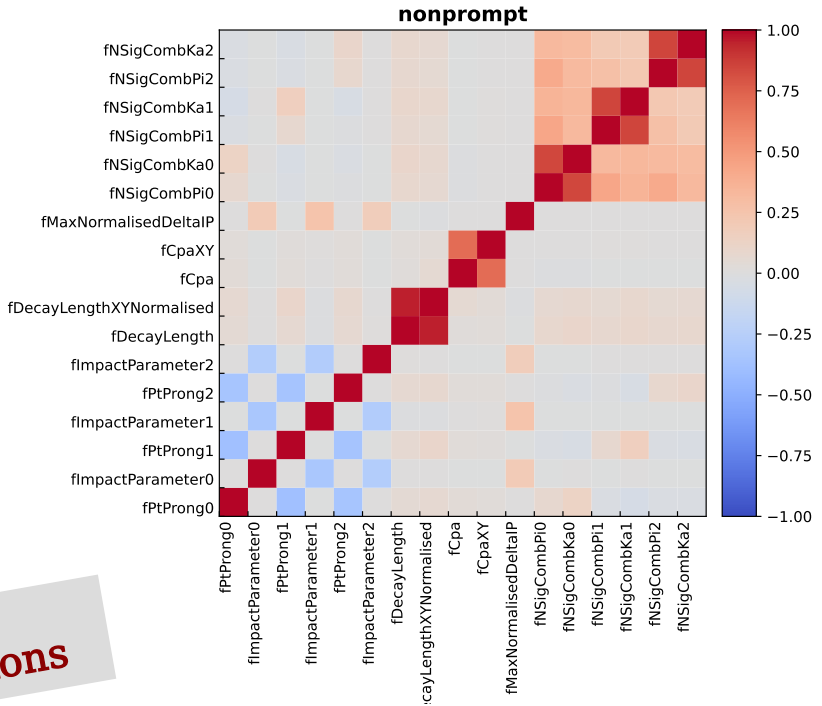
Work in progress

BDT-based selection for D^+

ALICE

- Train one BDT model for each pT bin [0, 2, 4, 6, 10, 36] GeV/c
- More training variables than for HF triggers (9 → 17)

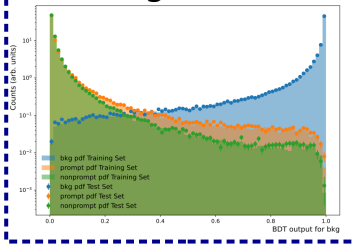




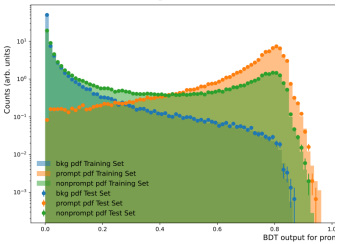
Work in progress
Need to apply tighter preselections

BDT output $p_T \in [4, 6]\mathrm{GeV/c}$

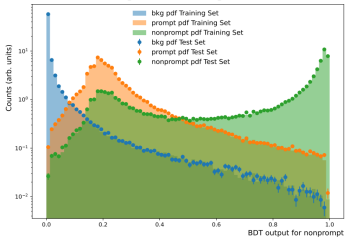
Bkg score

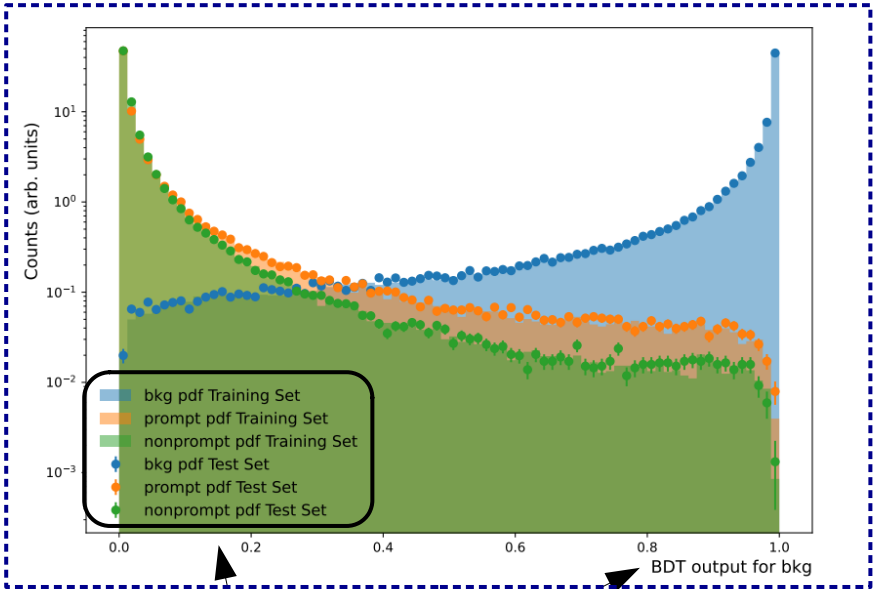


Prompt score

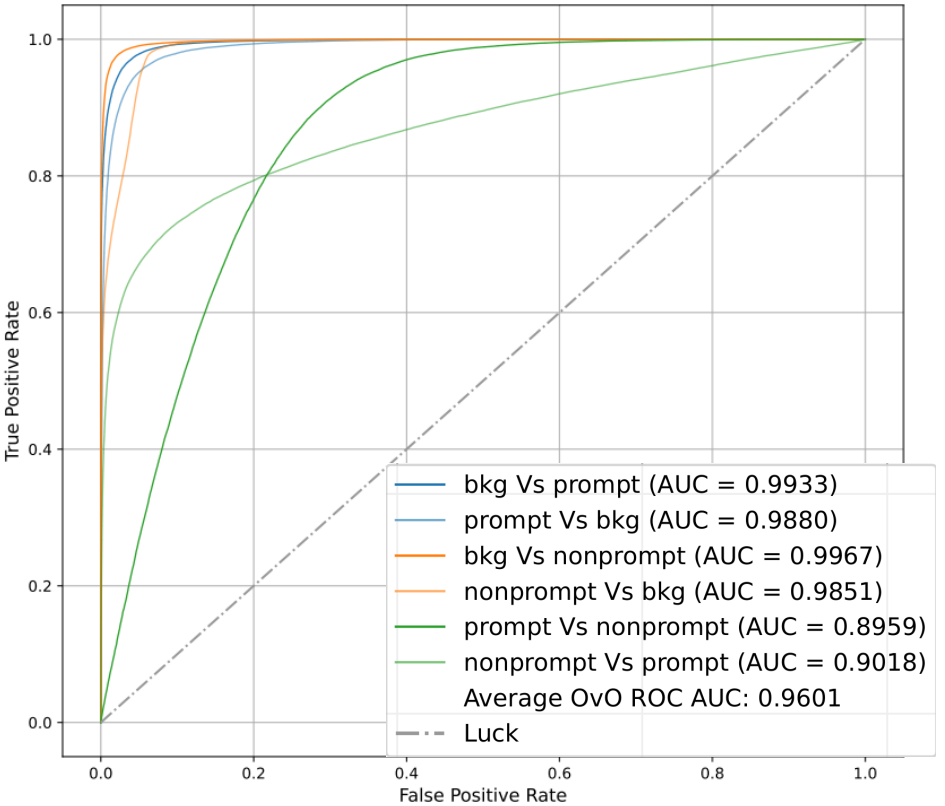


Non-prompt score





(truth) labels ≠ class (prediction)



- Good separation between signal and background (AUC > 98%)
- Good separation between prompt and non-prompt contributions (AUC > 89%)

Classification = regression + threshold

Where to cut?

Working point optimization

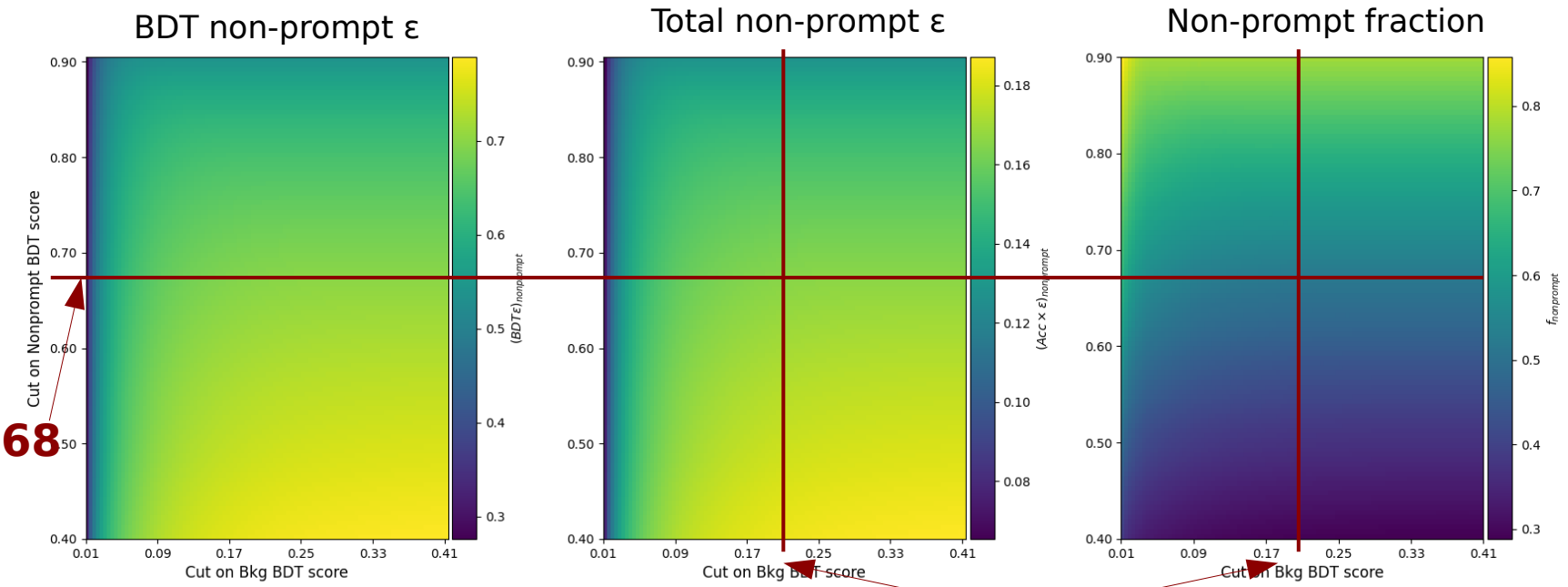
$p_T \in [4, 6] \mathrm{GeV/c}$

ALICE

$$\mathrm{Acc} \times \varepsilon = \frac{N^{D^\pm}_{\mathrm{reco+sel}}}{N^{D^\pm}_{\mathrm{gen}}\big|_{|y|<0.5}}$$

$$f_{\text{non-prompt}} = \left(1 + \frac{(\mathrm{Acc} \times \varepsilon)_{\text{prompt}} \cdot (d_{p_T}\sigma)^{\mathrm{FONLL}}_{\text{prompt}}}{(\mathrm{Acc} \times \varepsilon)_{\text{non-prompt}} \cdot (d_{p_T}\sigma)^{\mathrm{FONLL}}_{\text{non-prompt}}}\right)^{-1}$$

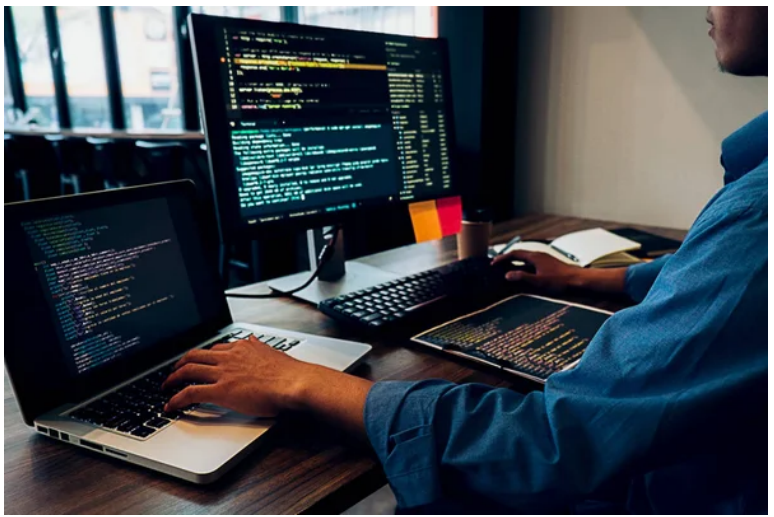
Motivation: non-prompt fraction > 60% & preserve efficiency



Software developments in O²(Physics)

ALICE

```
/// \file candidateSelectorB0ToDPi.cxx
/// \brief B0 → D- π+ candidate selector
///
/// \author Alexandre Bigot <alexandre.bigot@cern.ch>, IPHC Strasbourg
```



- B^0 workflow:
  - Candidate creator
  - Candidate selector
  - Analysis task
- Contributions to D^+ selector
- Responsible for workflow splitting in my Heavy Flavour analysis group (see backup)

IV.1 - Trainings

ALICE

Université de Strasbourg

ATTESTATION DES FORMATIONS SUIVIES

édité le :

Tuesday 20 june 2023

Bigot Alexandre

Doctorant(e) à

- **Etablissement** : Université de Strasbourg
- **Ecole Doctorale** : École doctorale Physique et chimie-physique

Total du nombre d'heures comptabilisées : 98:00

Total autres modes de comptabilisations éventuels :

a suivi les formations ci-dessous :

Catégorie : Disciplinaire

Nombre d'heures comptabilisées dans la catégorie : 39:00

Catégorie : Transversale

Nombre d'heures comptabilisées dans la catégorie : 59:00

Autres mode de comptabilisation éventuel :

IV.2 - Teaching

ALICE

- 2021-2022:
  - [24h] Mécanique classique (L1 SV)
  - [32.5h] Méthodes mathématiques pour la physique (L1 PSI)
  - [8h] Accompagnement du projet de l'étudiant (L1 PSI)
- 2022-2023:
  - [10h] Pré-rentrée M2PSA
  - [32.5h] Méthodes mathématiques pour la physique (L1 PSI)
  - [24h] Physique expérimentale (L1)
- Creation of M2PSA Pre-entry (with Nicolas DARI-BAKO)
  - 3 days just before the start of M2PSA [~20h in total]
  - Nuclear & Particle Physics recap, lectures and exercises

IV.3 - Scientific communication

ALICE

- Présentation orale:
  - *Cluster shape analysis and strangeness tracking for the ALICE upgrade*
  - Journées de Rencontre des Jeunes Chercheurs 2021, La Rochelle 17-23 octobre 2021
- Proceeding lié à la présentation aux Journées de Rencontre des Jeunes Chercheurs 2021

- Présentation orale:
  - *Cluster shape analysis and strangeness tracking for the ALICE upgrade*
  - Rencontres QGP France 2022, Tours 2-5 mai 2022

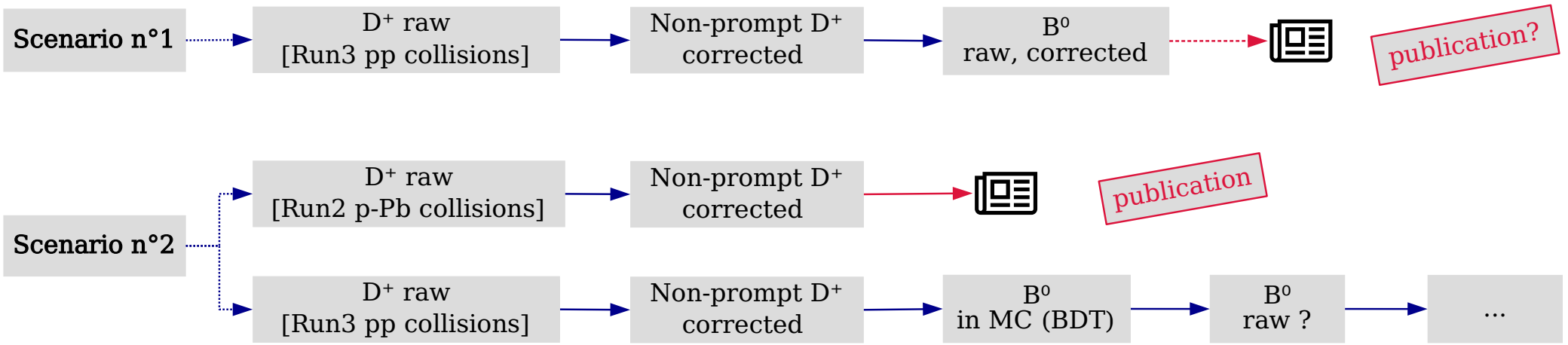
Conclusions

ALICE

- LHC is ~1year late data wise
- TPC space charge calibration delay → impact on thesis

HOWEVER

- Progress made in software development
- Thesis manuscript written @50%



- 2 spare months for thesis?
  - Thesis will already be extended of 28 days (duration of paternity leave)

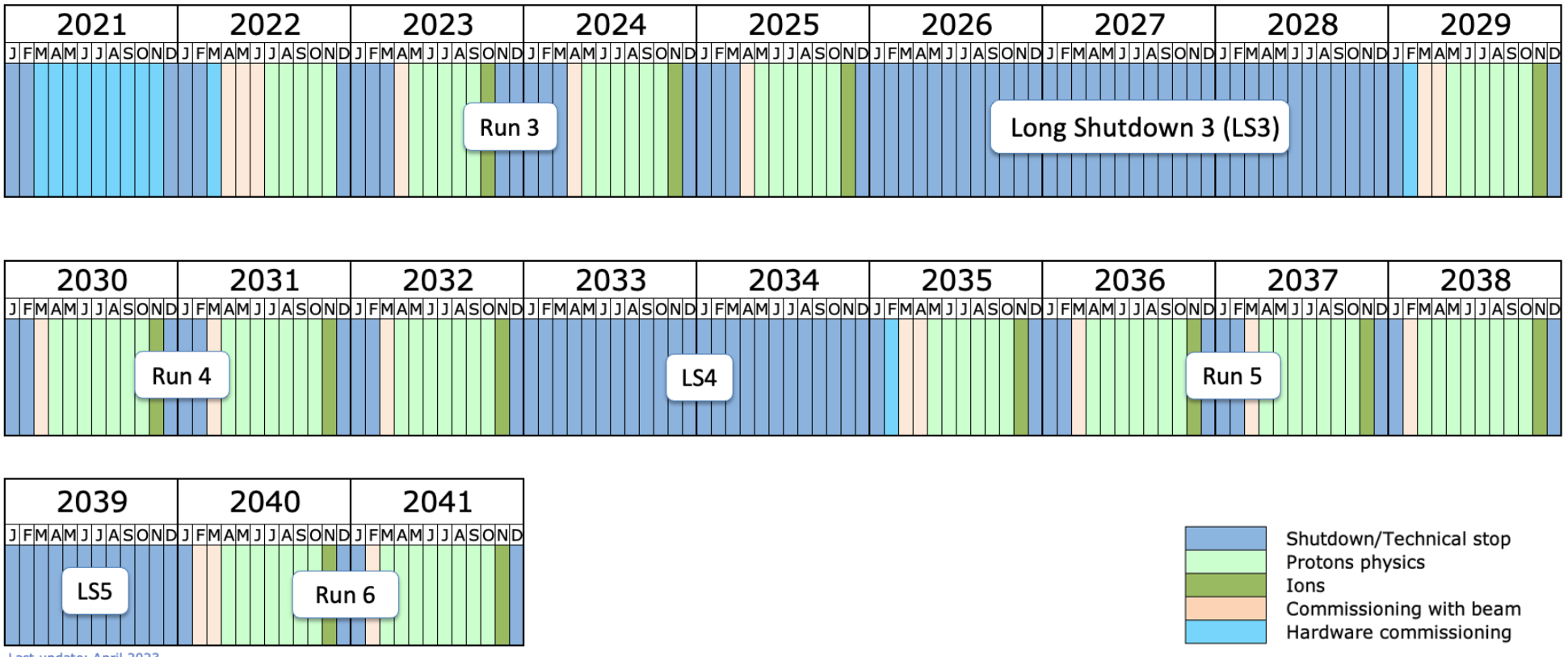
THANK YOU !


BACKUP
SLIDES

LHC schedule

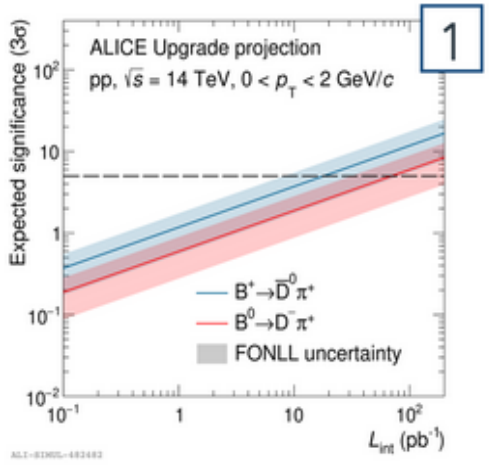
Longer term LHC schedule

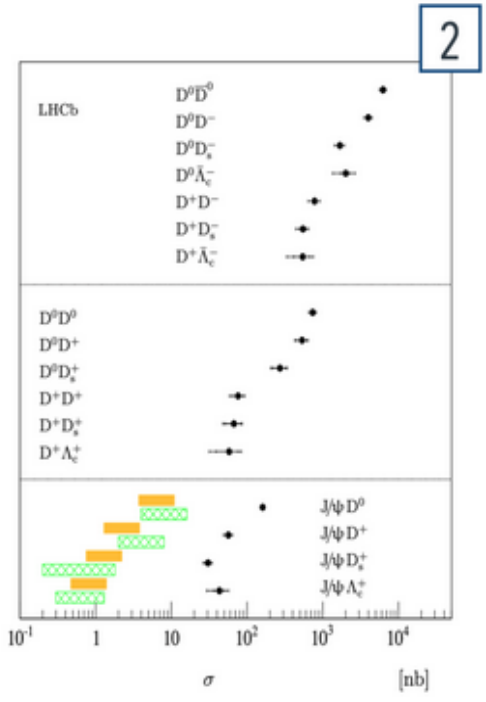
In January 2022, the schedule was updated with long shutdown 3 (LS3) to start in 2026 and to last for 3 years. HL-LHC operations now foreseen out to end 2041.

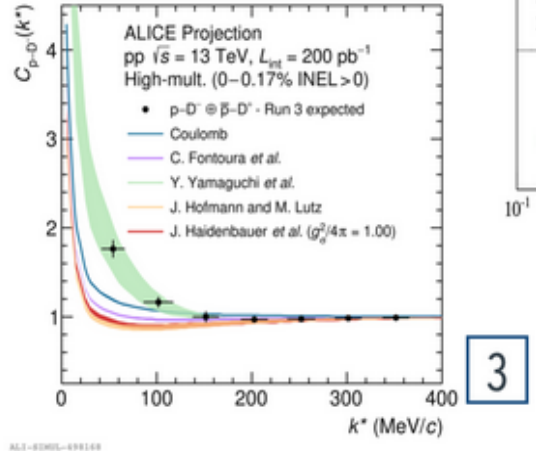


Physics motivations

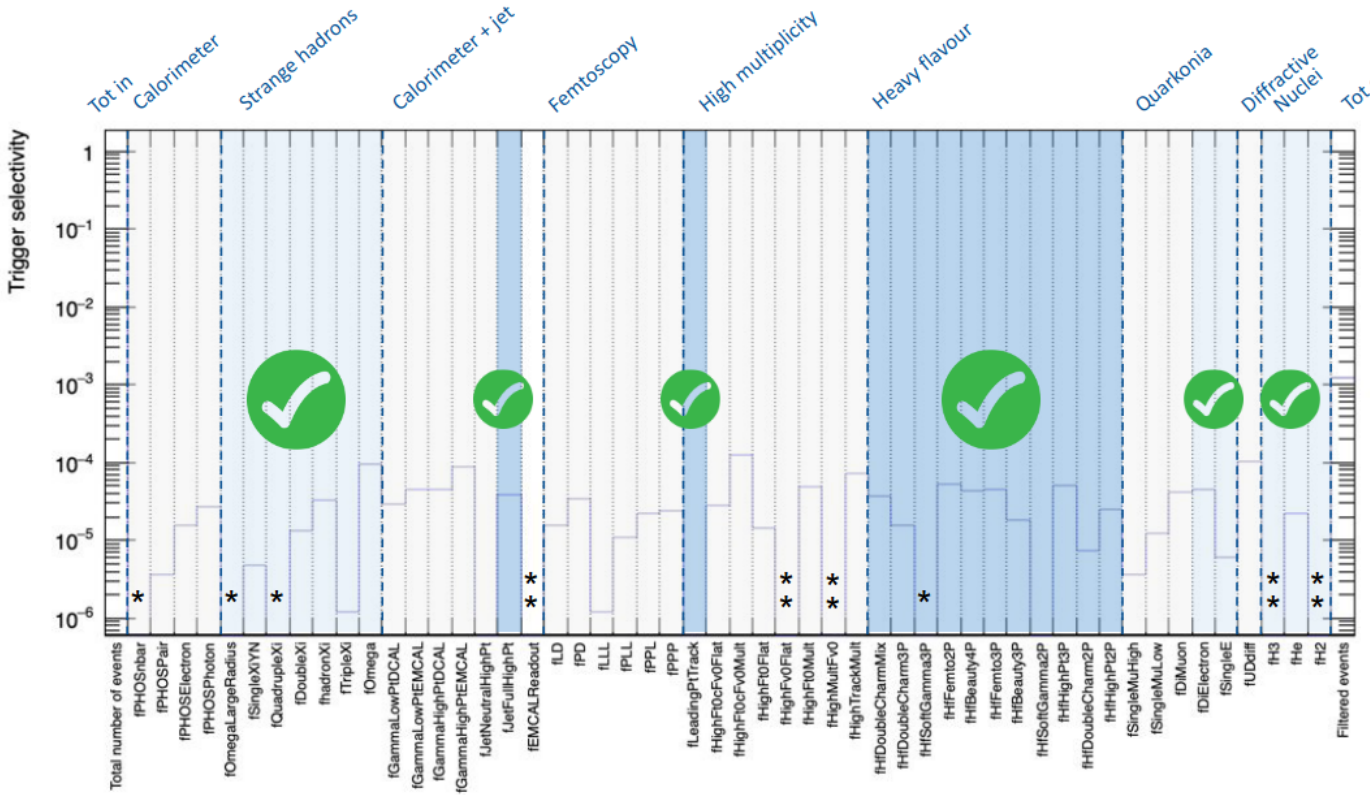
1. Measure production of b hadrons down to low p_T
   - ➔ provide pp reference for heavy ions
2. Measure double charm hadron production cross section at mid-rapidity
3. Precisely measure strong residual interaction between charm hadrons and protons
4. Measure "high" p_T charm hadrons for charm-tagged jet studies

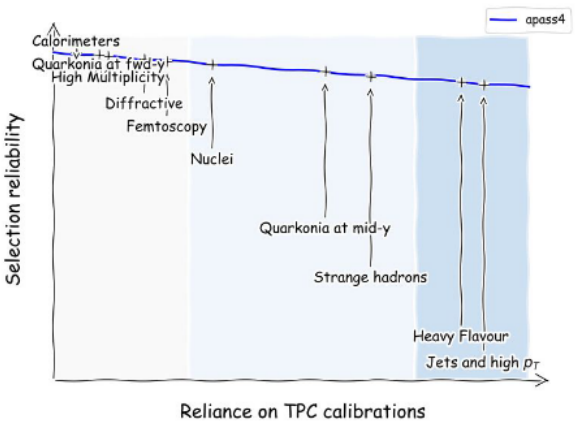






Triggers

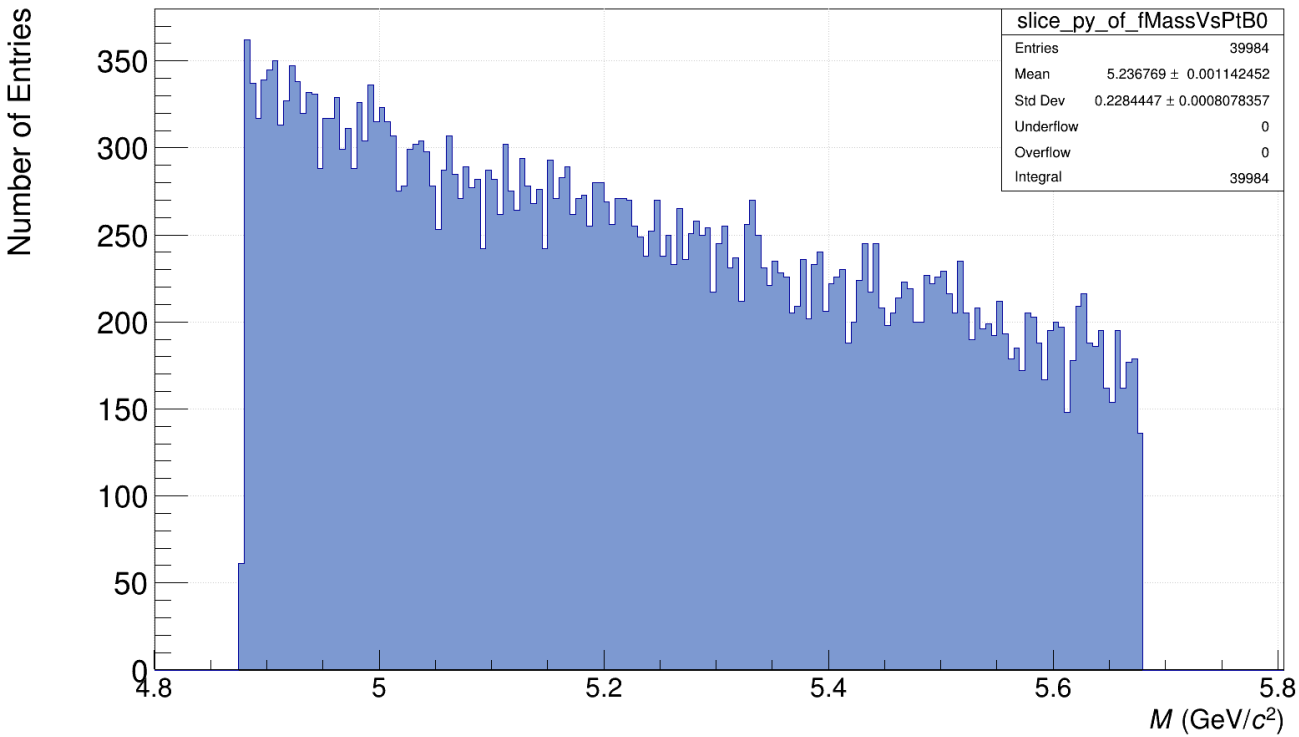

Tot in
Calorimeter
Strange hadrons
Calorimeter + jet
Femtoscopy
High multiplicity
Heavy flavour
Quarkonia
Diffractive
Nuclei
Tot out
Trigger selectivity
1
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
Total number of events
fPHOSnbar
fPHOSPair
fPHOSElectron
fPHOSPhoton
fOmegaLargeRadius
fSingleXiYN
fQuadrupleXi
fDoubleXi
fhadronXi
fTripleXi
fOmega
fGammaLowPtDCAL
fGammaLowPtEMCAL
fGammaHighPtDCAL
fGammaHighPtEMCAL
fJetNeutralHighPt
fJetFullHighPt
fEMCALReadout
fLD
fPD
fLLL
fPLL
fPPL
fPPP
fLeadingPtTrack
fHighPt0cFv0Flat
fHighPt0cFv0Mult
fHighPt0Flat
fHighFv0Flat
fHighPt0Mult
fHighMultFv0
fHighTrackMult
fHfDoubleCharmMix
fHfDoubleCharm3P
fHfSoftGamma3P
fHfFemto2P
fHfBeauty4P
fHfFemto3P
fHfBeauty3P
fHfSoftGamma2P
fHfHighPt3P
fHfDoubleCharm2P
fHfHighPt2P
fSingleMuHigh
fSingleMuLow
fDiMuon
fDiElectron
fSingleE
fUDdiff
fH3
fHe
fH2
Filtered events


apass4
Calorimeters
Quarkonia at fwd-y
High Multiplicity
Diffractive
Femtoscopy
Nuclei
Quarkonia at mid-y
Strange hadrons
Heavy Flavour
Jets and high p_T
Selection reliability
Reliance on TPC calibrations

B⁰ invariant mass in real data (1.7G events)

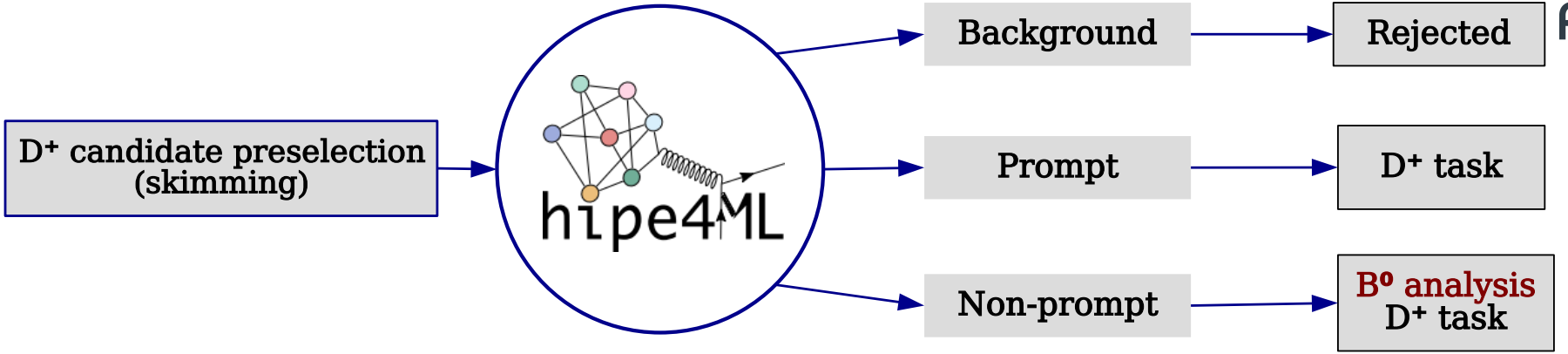
ALICE

Obtained with HF filter



BDT models for D^+ selection

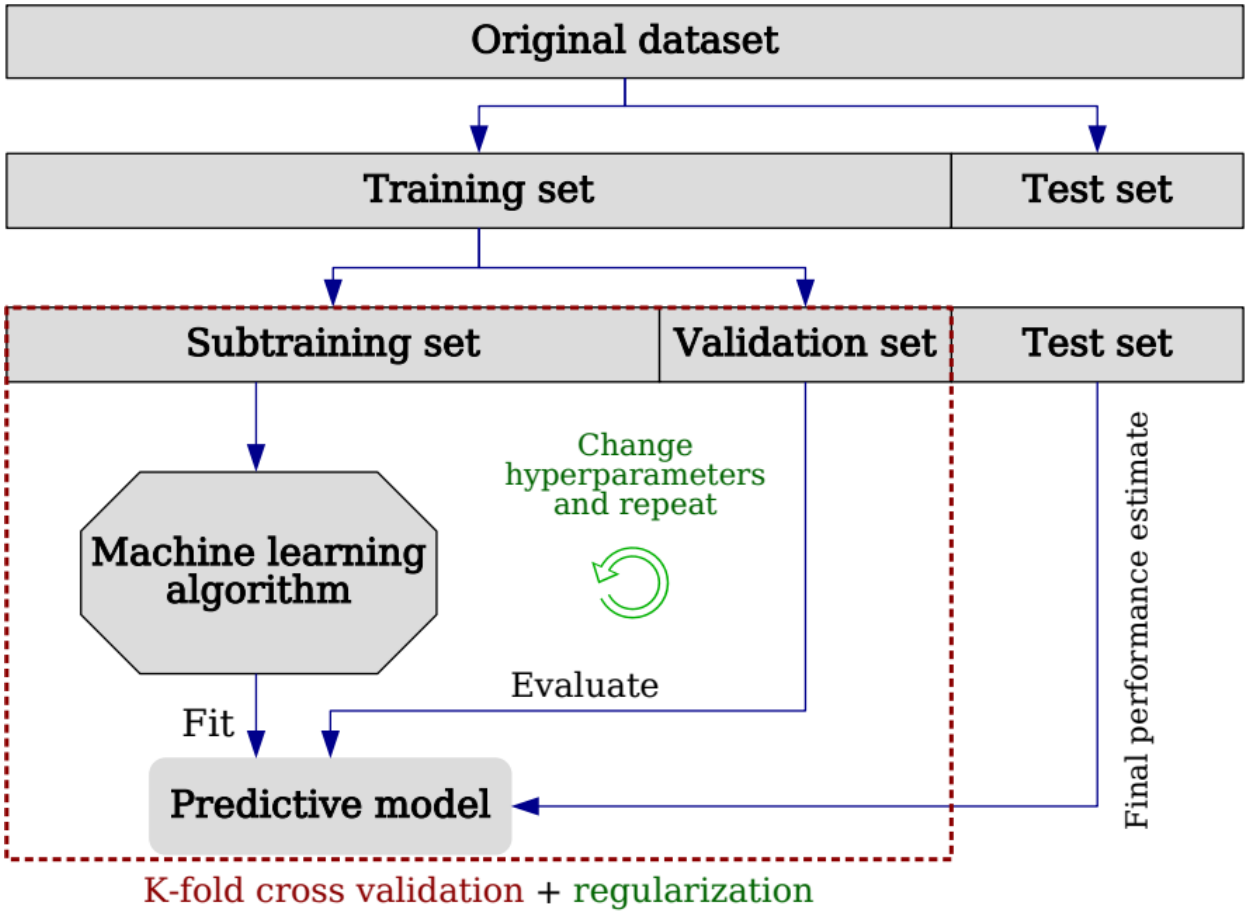
ALICE



- Training
  - Signal (Prompt & Non-prompt):
    - LHC22b1a (b enriched)
    - LHC22b1b (c enriched)
  - Background:
    - LHC23o_pass4_small
- pT ∈ [0, 2, 4, 6, 10, 36] GeV/c

Training samples obtained via D^+ tree creator

BDT strategy



Training variables for D^+/B^0 BDT

ALICE

$$n\sigma^{\pi,K}_{\text{comb}} = \begin{cases} |n\sigma^{\pi,K}_{\text{TPC}}| & \text{if PID TPC only} \\ |n\sigma^{\pi,K}_{\text{TOF}}| & \text{if PID TOF only} \\ \frac{1}{\sqrt{2}}\sqrt{\left(n\sigma^{\pi,K}_{\text{TPC}}\right)^2 + \left(n\sigma^{\pi,K}_{\text{TOF}}\right)^2} & \text{if PID TPC and TOF} \end{cases}$$

Transverse momentum of daughters	p_{T} (0) p_{T} (1) p_{T} (2)
Impact parameter of daughters	$d_0(0)$ $d_0(1)$ $d_0(2)$
Max normalized impact parameter difference	$\max\lvert d_0 - d_0^{\text{exp}}\rvert^{\text{prong}}(n\sigma)$
Decay length	L
Normalized decay length xy	L_{xy}/σ_{xy}
Cosine pointing angle	$\cos\theta_{\text{p}}$
Transverse cosine pointing angle	$\cos\theta_{\text{p}}^{xy}$
Combined $n\sigma$ of daughters	$n\sigma^{\pi}_{\text{comb}}(0)$ $n\sigma^{\pi}_{\text{comb}}(1)$ $n\sigma^{\pi}_{\text{comb}}(2)$ $n\sigma^{K}_{\text{comb}}(0)$ $n\sigma^{K}_{\text{comb}}(1)$ $n\sigma^{K}_{\text{comb}}(2)$

Table 4: Training variables used for D^+ mesons.

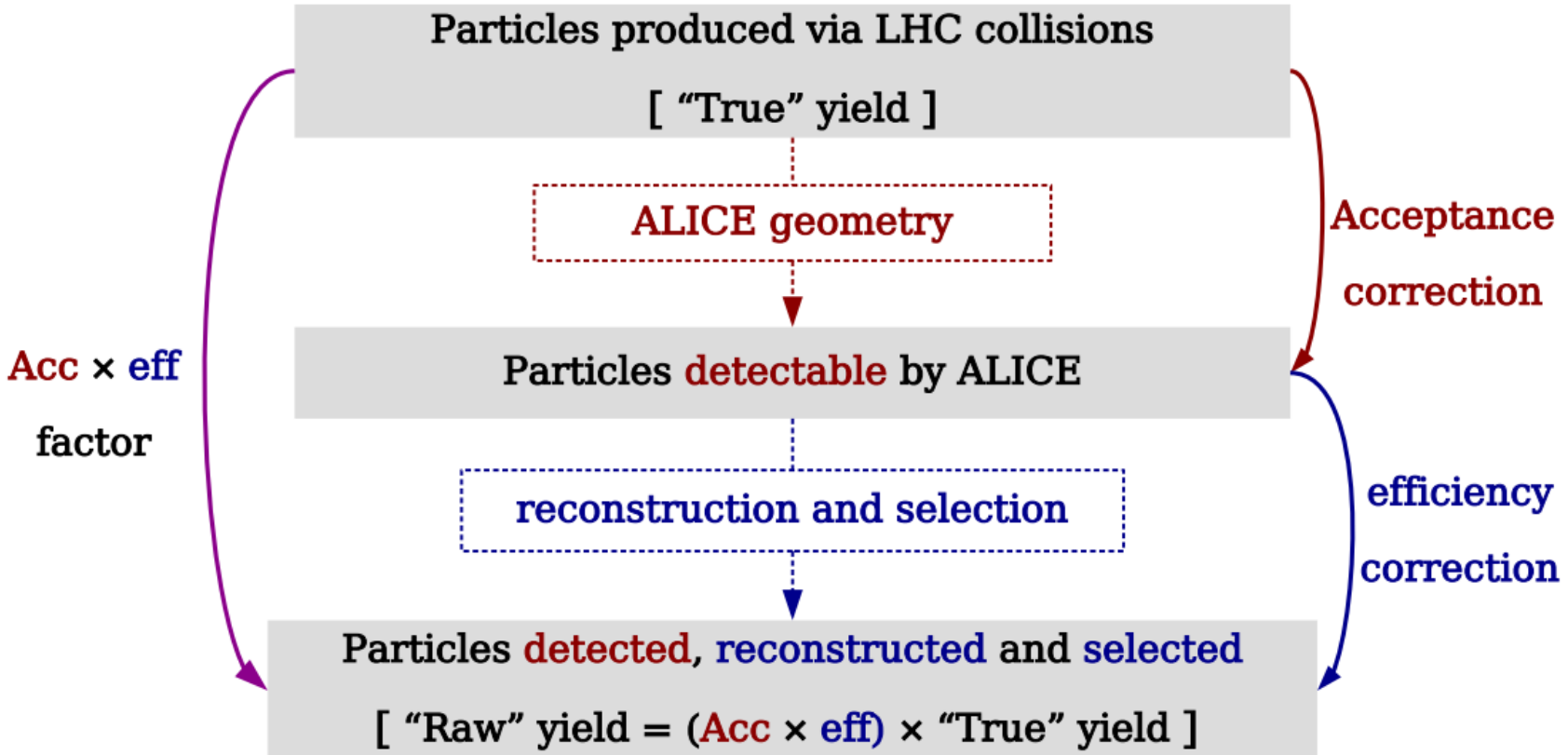
Work in progress

Next step
(not initiated yet/not final)

Transverse momentum of daughters	p_{T} (0) p_{T} (1)
Impact parameter product of daughters	$d_0(0) \times d_0(1)$
Max normalized impact parameter difference	$\max\lvert d_0 - d_0^{\text{exp}}\rvert^{\text{prong}}(n\sigma)$
Decay length	L
Normalized decay length xy	L_{xy}/σ_{xy}
Cosine pointing angle	$\cos\theta_{\text{p}}$
Transverse cosine pointing angle	$\cos\theta_{\text{p}}^{xy}$
Sum of (non-weighted) distances of the secondary vertex to its prongs	χ^2_{PCA}
Combined $n\sigma$ of daughter 1	$n\sigma^{\pi}_{\text{comb}}(1)$ $n\sigma^{K}_{\text{comb}}(1)$

Table 5: Training variables used for B^0 mesons.

Acc x efficiency



Workflow splitting