LHCb status report

Elisabeth Maria Niel
on behalf of the LHCb collaboration
155 LHCC meeting
Open session
13/09/2023

LHCb Upgrade I

Overall major upgrade, >90 % of detector channels!

Completely new readout system for the full detector

LHCb-DP-2022-002
LHCb-TDR-12

Fully software trigger

New tracking stations UT + SciFi

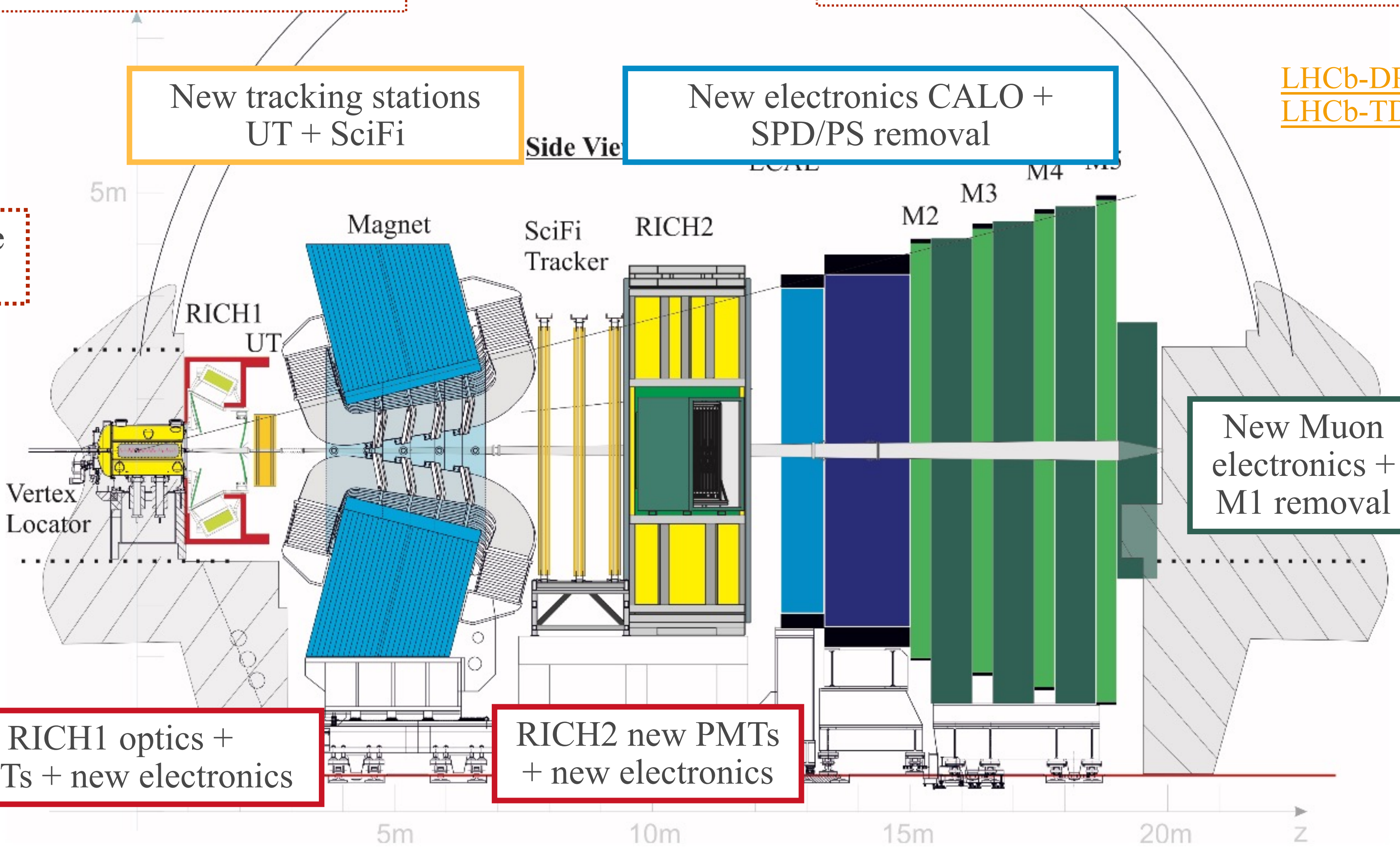
New electronics CALO + SPD/PS removal

New pixel VELO

New Muon electronics + M1 removal

New RICH1 optics + new PMTs + new electronics

RICH2 new PMTs + new electronics

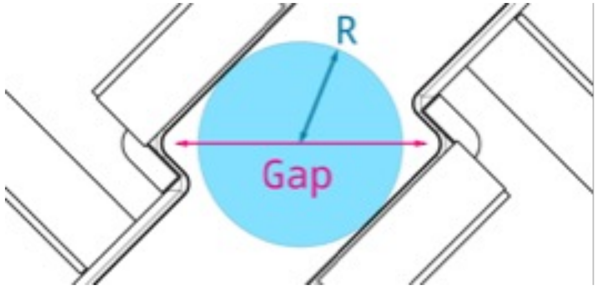


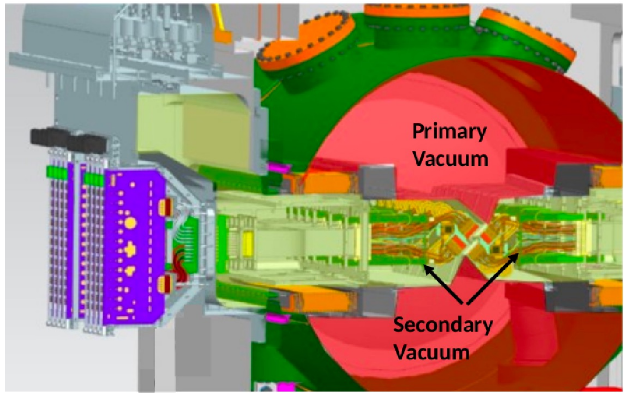
Position of the VErtex LOcator (VELO)

- January 2023: LHC vacuum incident in the VELO volume caused the deformation of the RF foil towards the beam vacuum
- Last LHCC: smallest VELO closure position possible with RF foil deformation was estimated at **32 mm** GAP

→ after TS1 further investigations performed
→ full inspection of the motion system

Decision not to move at every fill



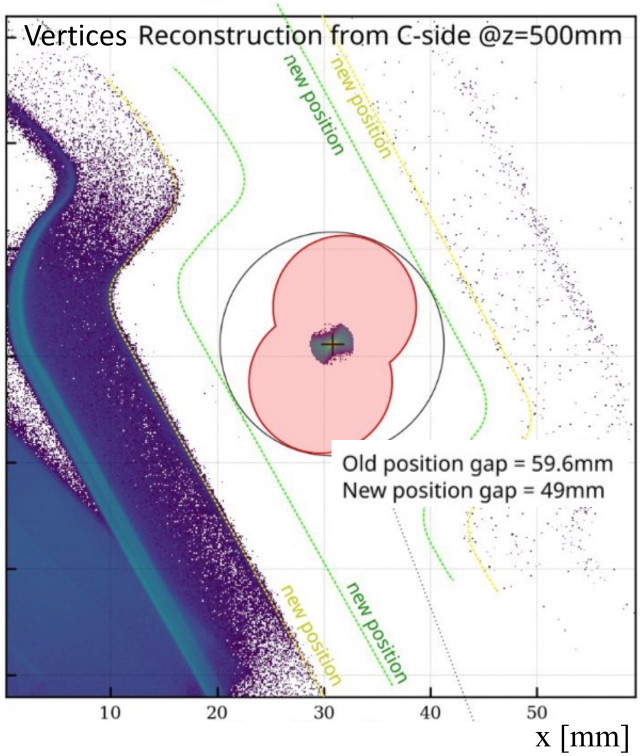


- For 2023 we run with VELO at a fixed position with smallest aperture possible.
  - requirements from beam size at injection + RF foil deformation

→closest possible safe position : **49 mm** GAP and R = 10.5 mm

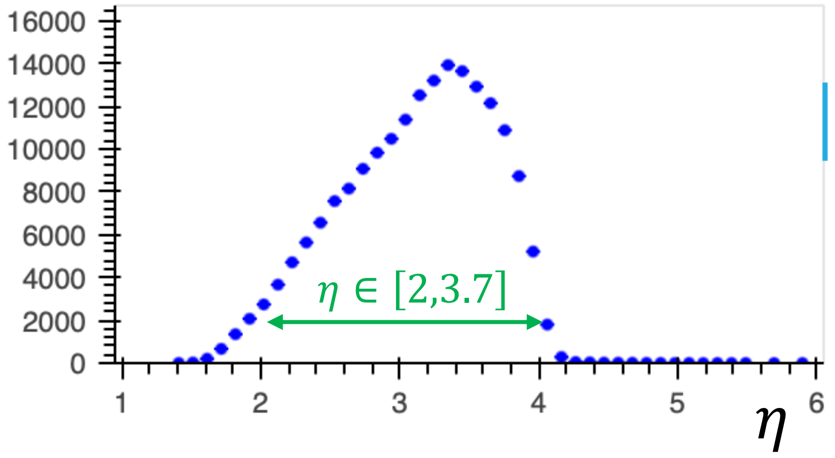
- RF box replacement foreseen during the YETS 2023-2024

→production of a new RF Box pair and of a spare pair on track

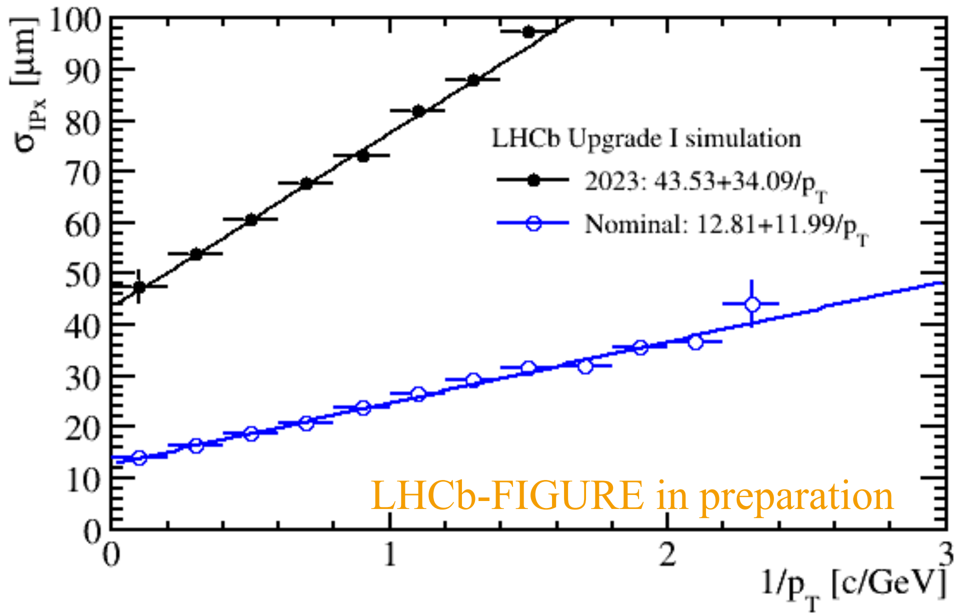


Impact of VELO position choice

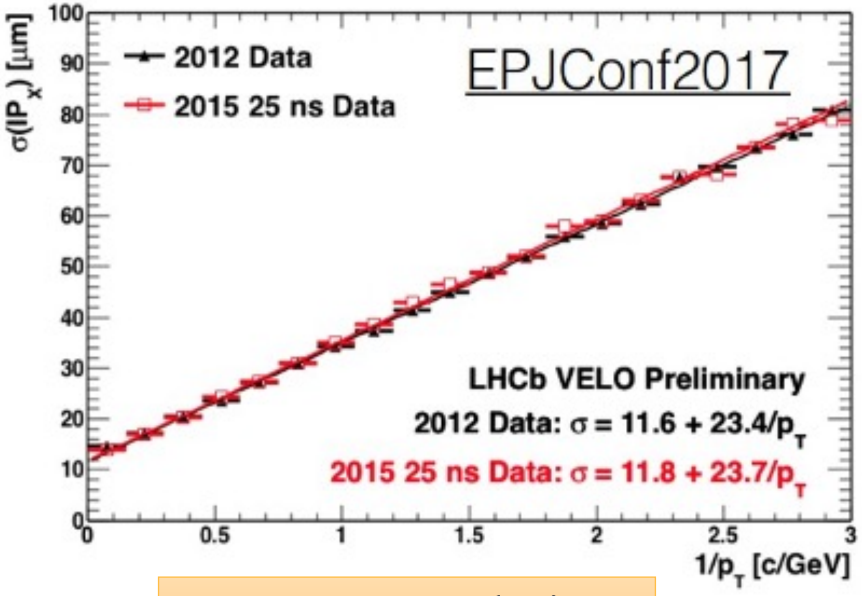
- Acceptance reduced:
  from $\eta \in [2,5]$ to $\eta \in [2,3.7]$
- IP resolution degraded with new VELO opening at 49 mm gap



Long tracks, up to end of the tracking stations



Current IP resolution from simulation



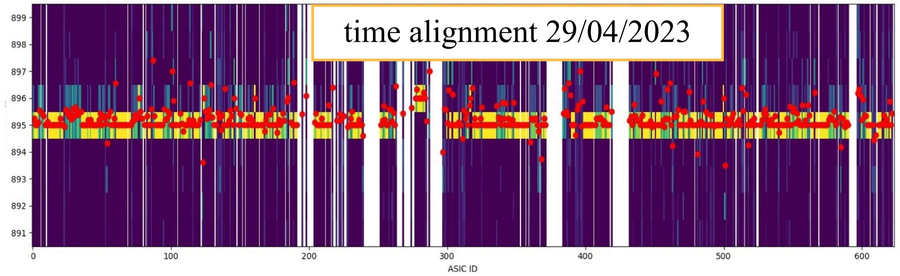
Run 2 IP resolution

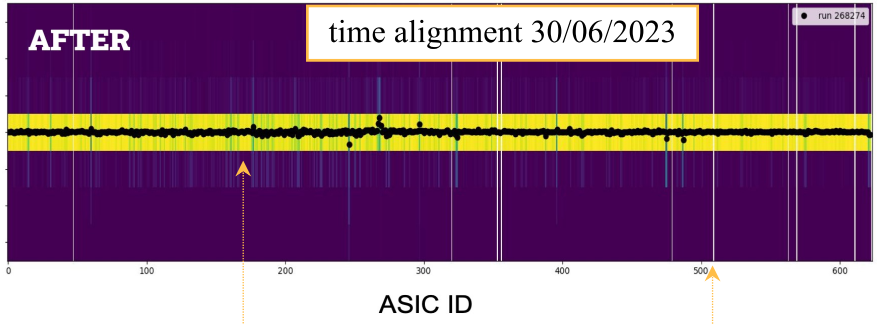
VELO commissioning

- Commissioning : working towards stability of data taking involving backend and frontend stability, time alignment and equalization of the detector

  →Moving from 10 % inefficiency in April up to only 0.38 % now

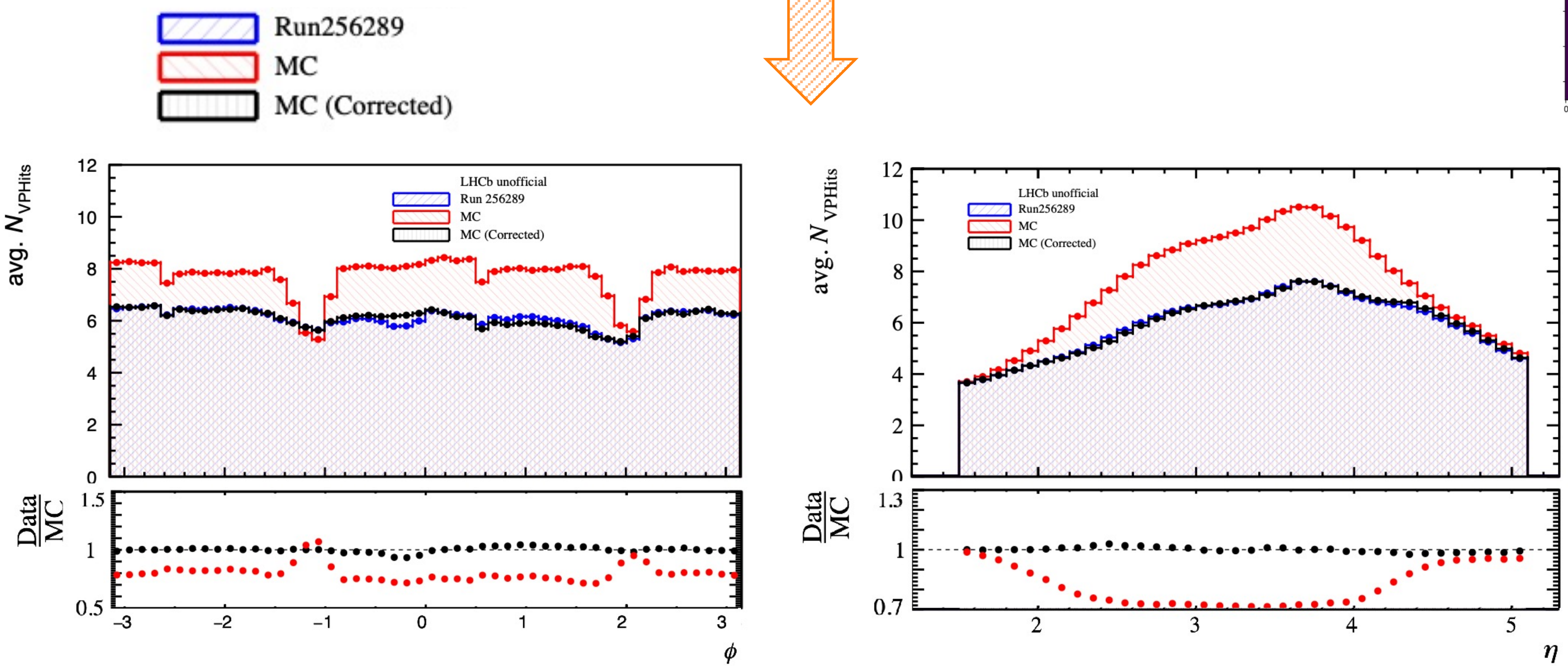
- Reproduce detector inefficiencies in the simulation to correctly reproduce expected hit distributions





central band: channels aligned in the same BXID

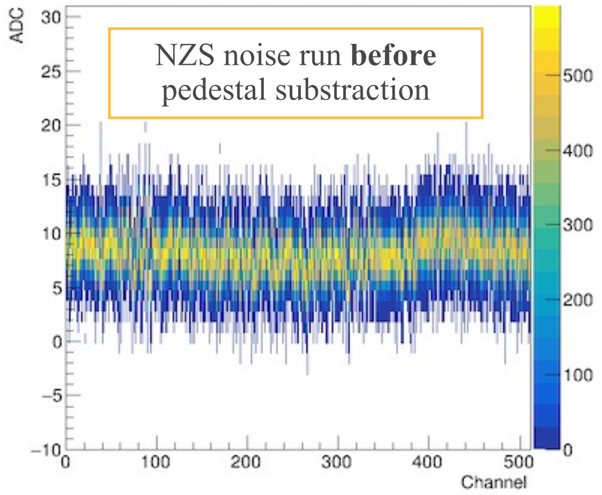
white lines are inefficient channels

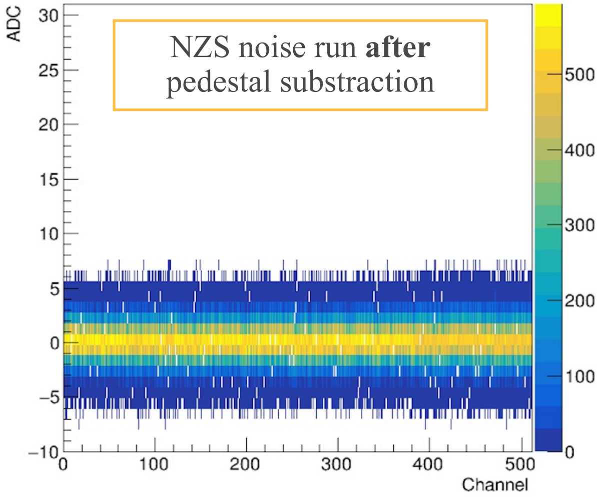


Upstream Tracker commissioning status

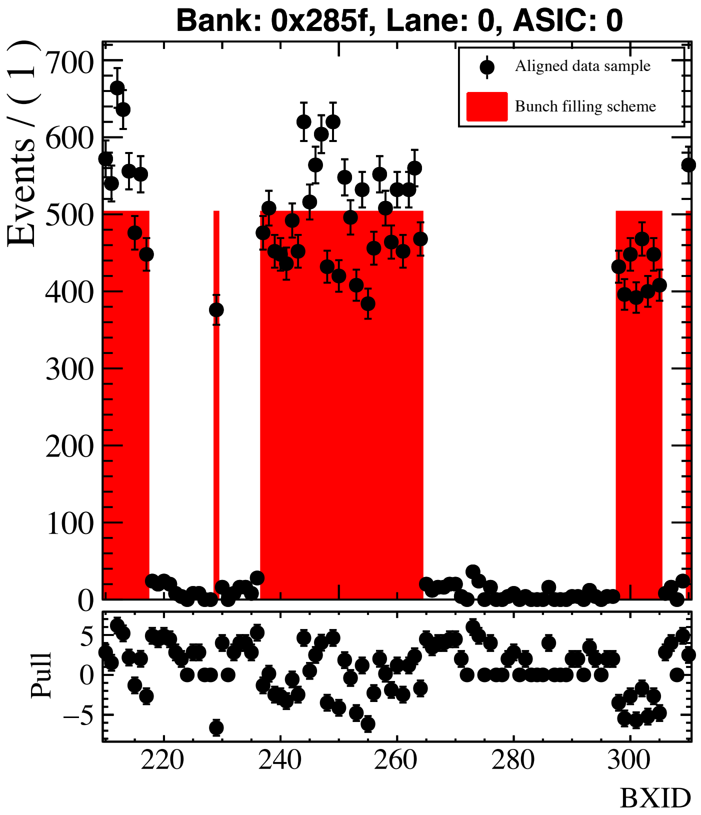
Road towards data taking:

1. A working firmware: 4 different flavors developed
2. Control the detector: DCS, high voltage and DAQ basic functionality working: refinements in progress
3. Detector safety system in place: good progress on monitoring, alarms and safety system
4. Correct timing: procedure to do coarse time alignment validated →need collisions for further testing
5. Correct pedestals obtained, thresholds determination in progress
6. Implementation of decoding in HLT in progress





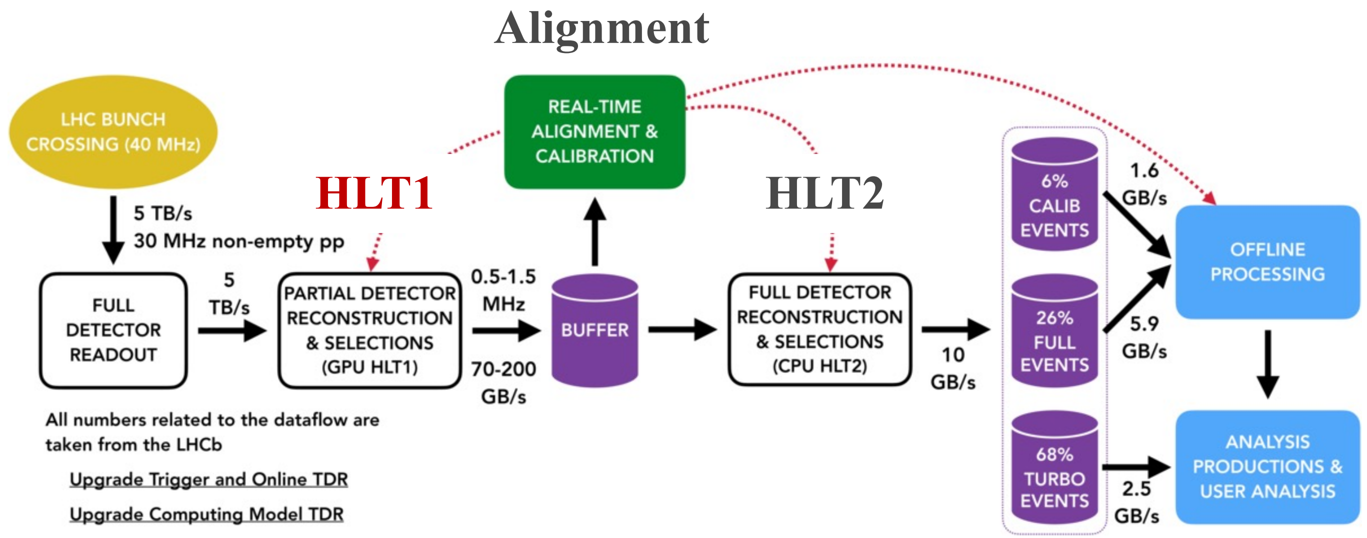
Time alignment, synchronization with bunch crossing LHC



Operation of the detector

LHCb data flow:

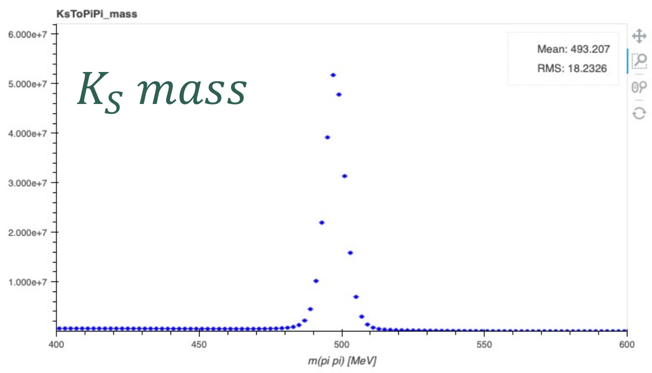
1. **HLT1**: partial reconstruction data to buffer
2. **Alignment** and calibration online
3. **HLT2** concurrent processing

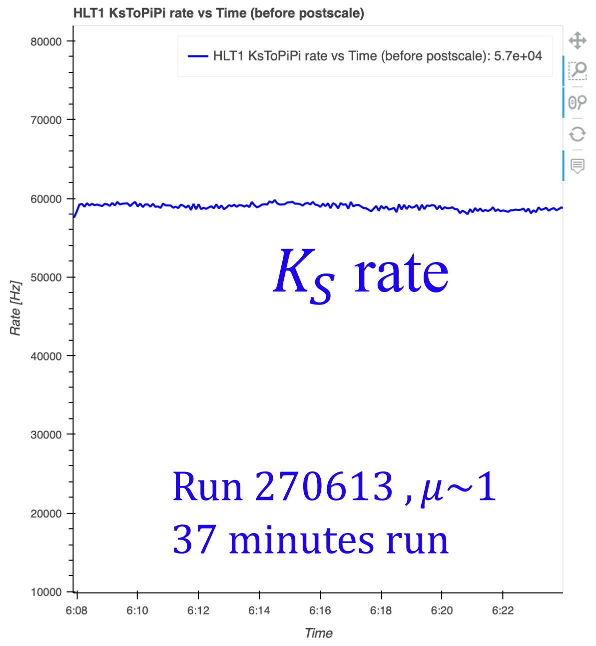


HLT1: new monitoring online developed to keep track of the performances

→ K_S rate stability is a good indicator of the overall detector performance

→ monitoring of particle masses out of HLT1





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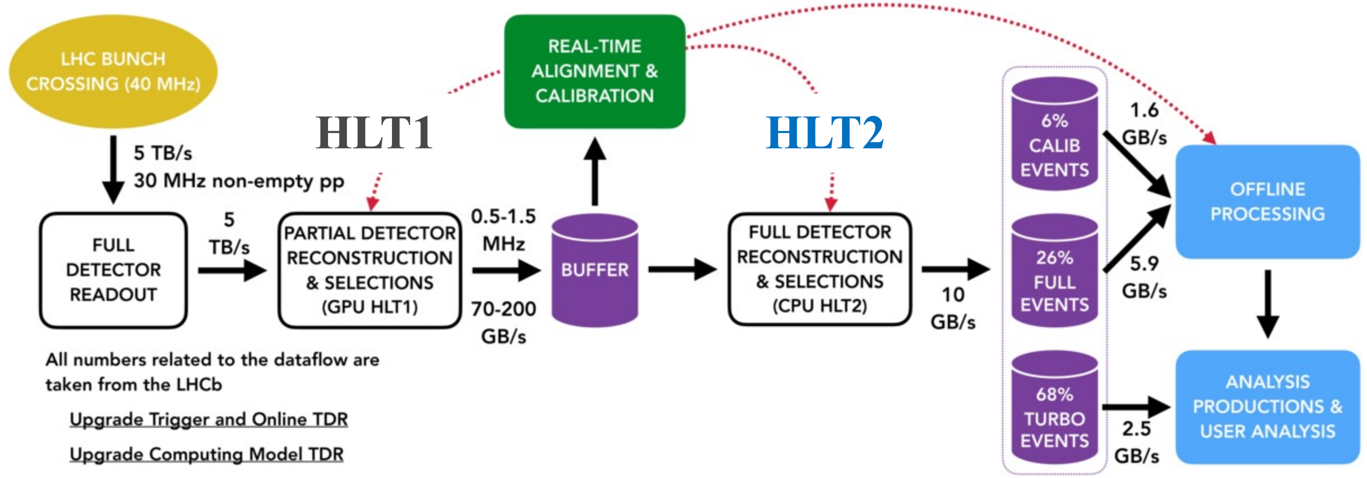
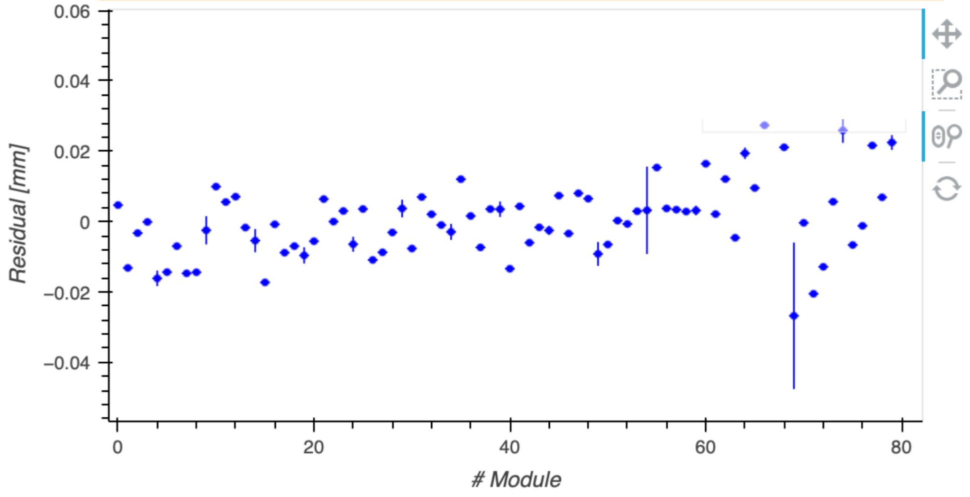


Alignment:

- Running online with automatic update of alignment constants
- Monitor relevant quantities online, e.g. unbiased residuals

Unbiased residuals of one SciFi station



HLT2:

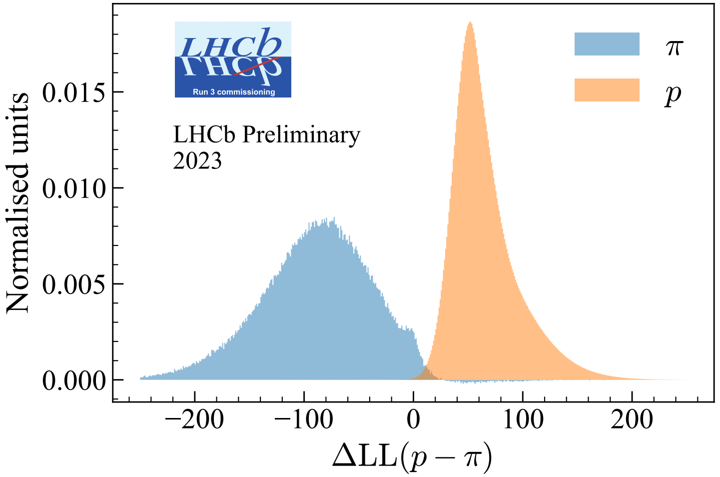
- After LHC vacuum issue in July, we stopped data processing, to make the most out of our data, technical development done to add additional trigger lines
- Progress towards concurrent processing

Performances of LHCb: PID

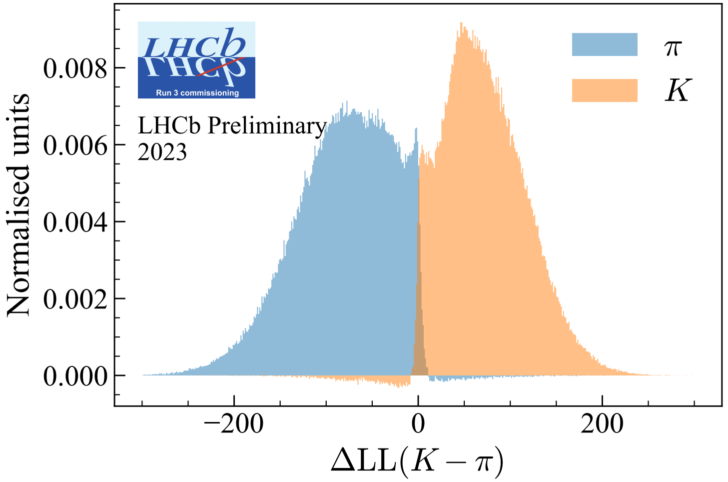
- Particle identification by combining information from different subdetectors
  →Difference in log-likelihood between different hypothesis:
  $\Delta LL(K) = \log L(K) - \log L(\pi)$

First ΔLL performances studies with Run 3 LHCb data

ΔLL for p and π



ΔLL for K and π



LHCb-FIGURE in preparation

- from $\Lambda \to p\pi^-$
- excellent separation between protons and pions

- from $D^{*+} \to D^0\pi^-$
- excellent separation between kaons and pions

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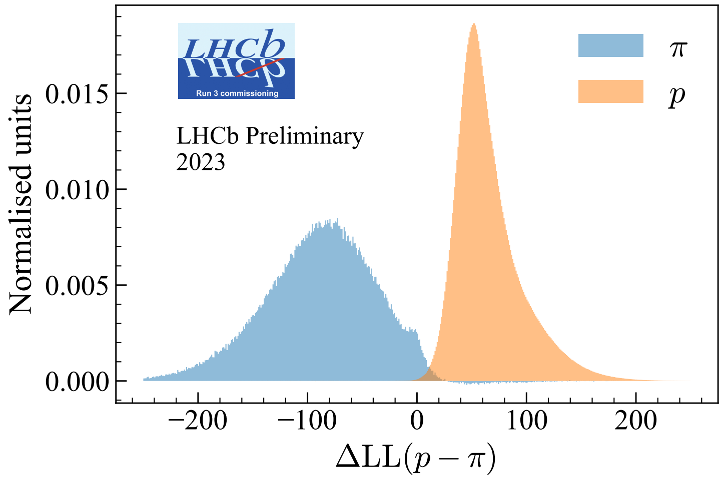
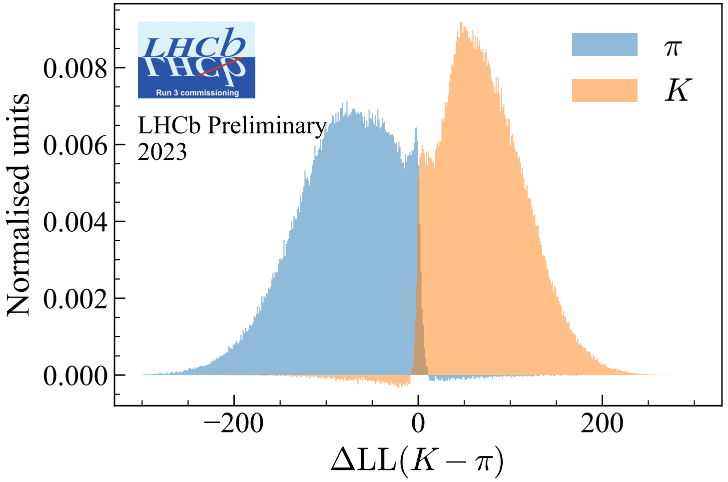
ΔLL for p and π



ΔLL for K and π



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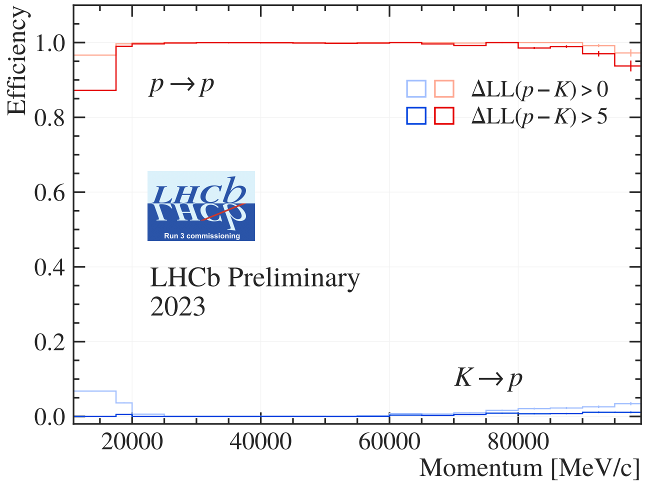
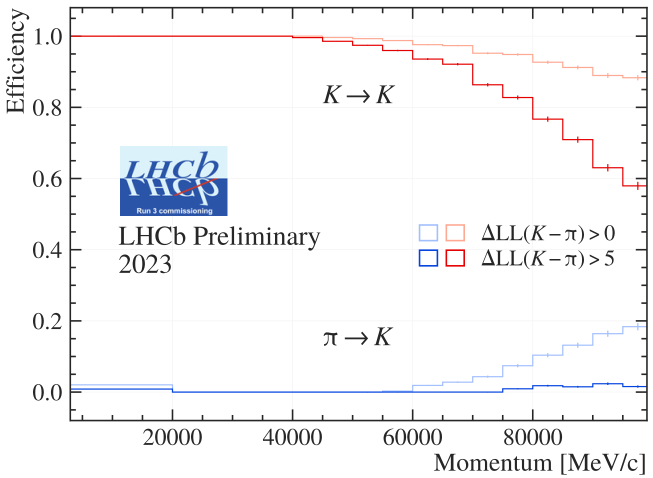
Efficiency of ΔLL p vs momentum



Efficiency of ΔLL K vs momentum

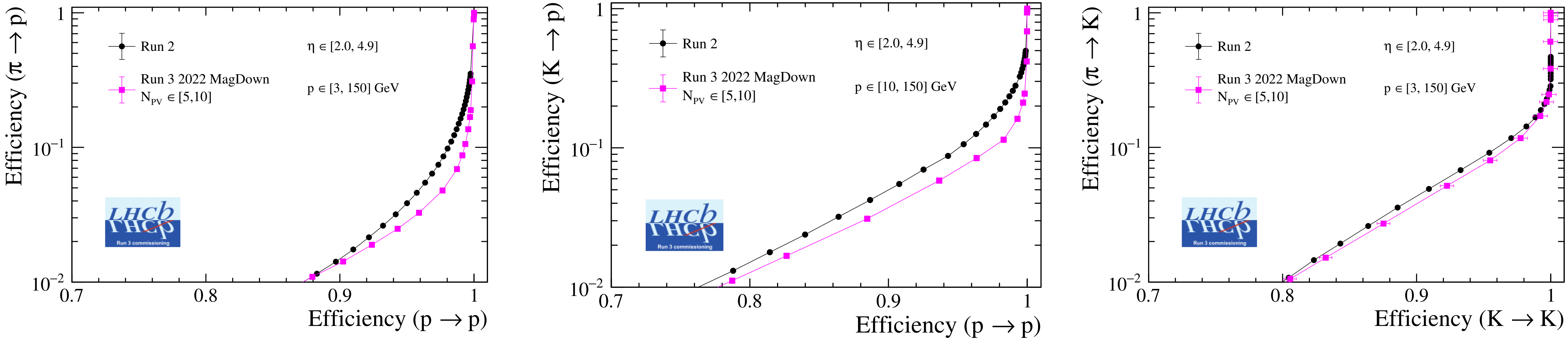


Performances of LHCb: PID

- Charge hadrons identified by RICH detectors (Ring Imaging Cherenkov detectors)
- Study PID efficiency for ΔLL variables with fit and count method

Mis-identification versus identification efficiency on 2022 Data

LHCb FIGURE-2023-019



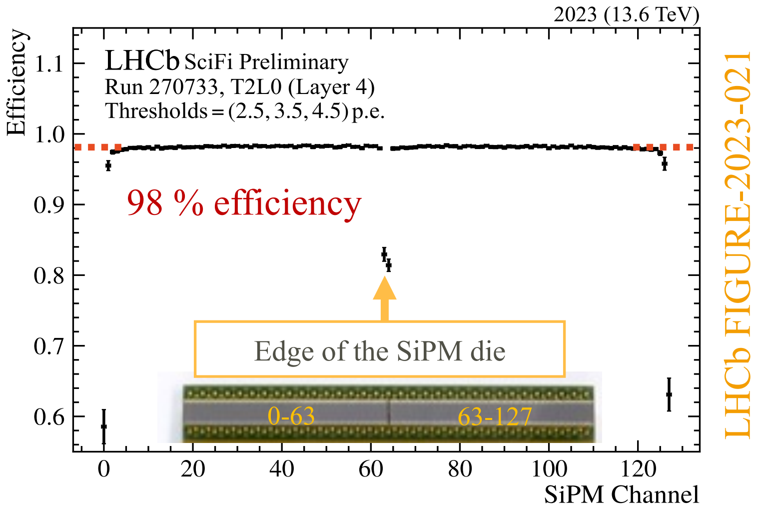
Similar performance for Run 3 at higher luminosity (μ~5) as in Run 2 (μ~1), design goal achieved!

Performances of LHCb: hit efficiencies

➢ VELO and SciFi first estimate of hit efficiency with recent 2023 data (July)

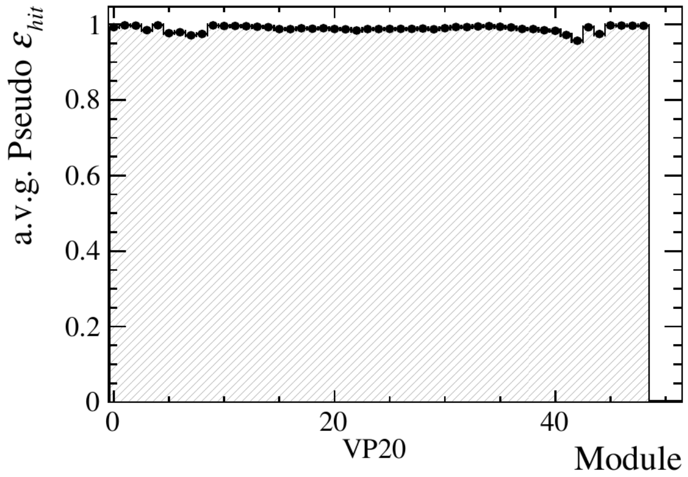
SciFi:

- 98 % hit efficiency
- close to design goal of 99 %

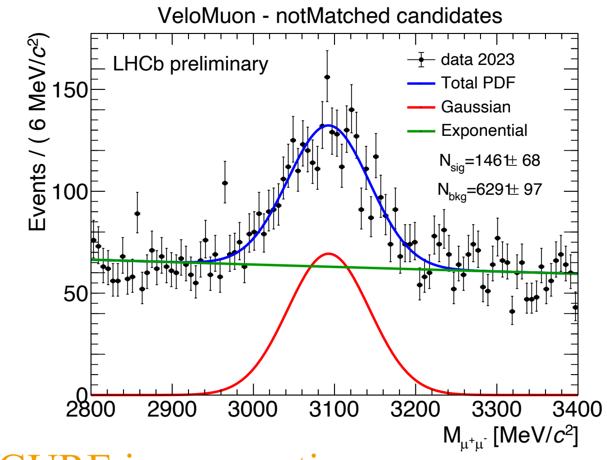


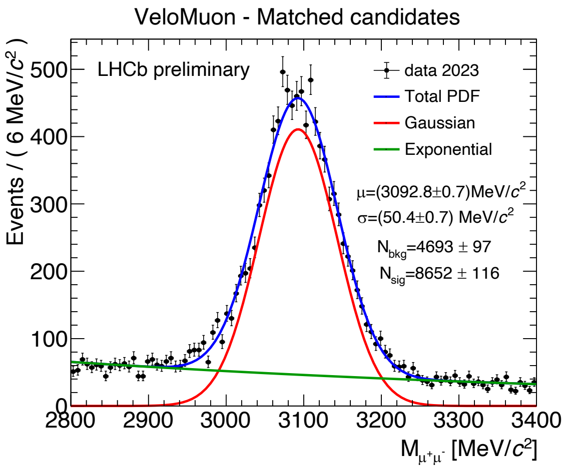
VELO:

- over all excellent efficiency
- monitored online



➢ Work on tracking efficiency evaluation on-going



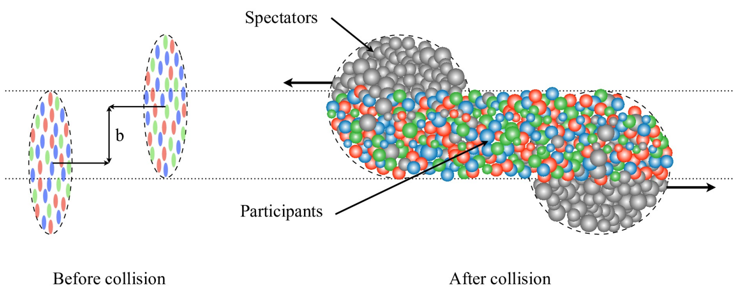


Example of mass fit of $J/\psi \rightarrow \mu^+\mu^-$ used to study SciFi tracking efficiencies in data:

results match simulation at 5-10 % level
→residual discrepancies are being investigated (most likely linked to hardware inefficiencies to be implemented in simulation)

LHCb-FIGURE in preparation

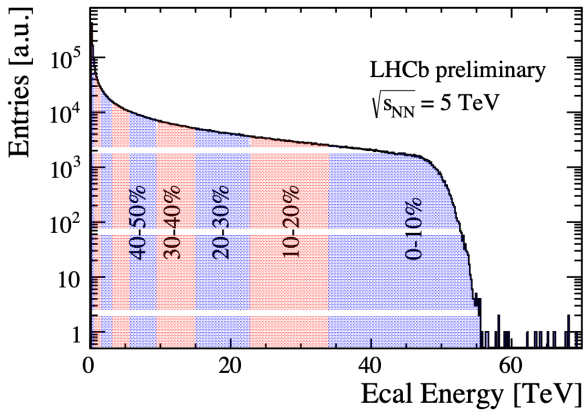
Preparation of the PbPb run

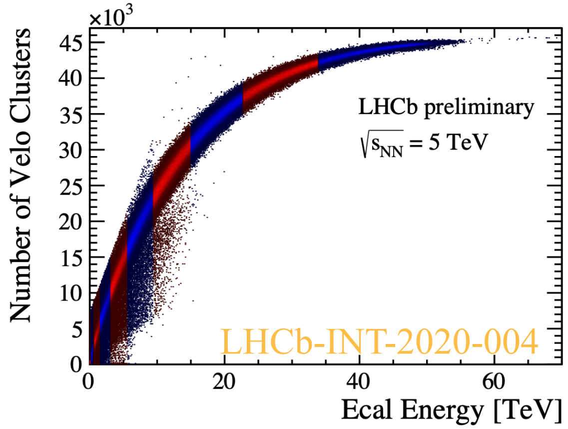


Centrality of the collision determined based on calorimeter activity

Run 2→linearity up to 50 % centrality, up to 5 TeV deposit in calorimeter

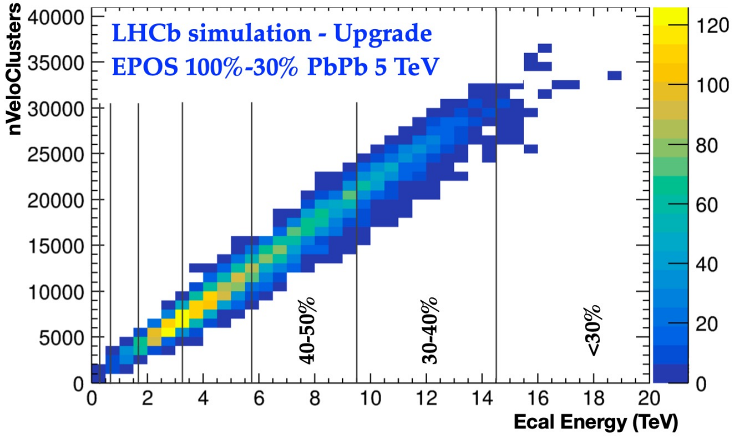
Run 2 performance (**data**)

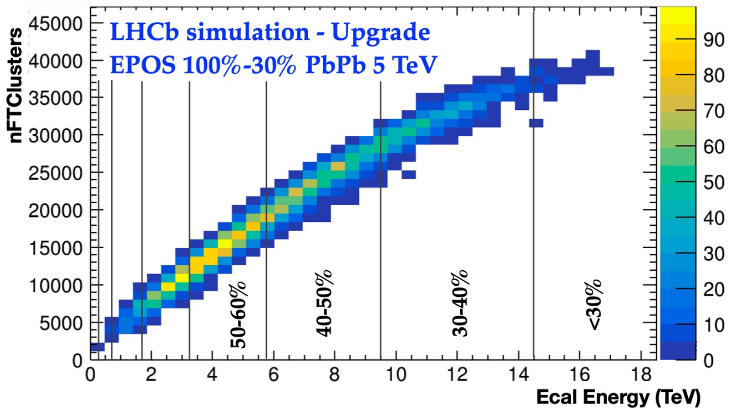




Run 3→new tracking system, VELO not expected to saturate, the scintillating fiber tracker may saturate at 30 % centrality.

Run 3 **simulation**



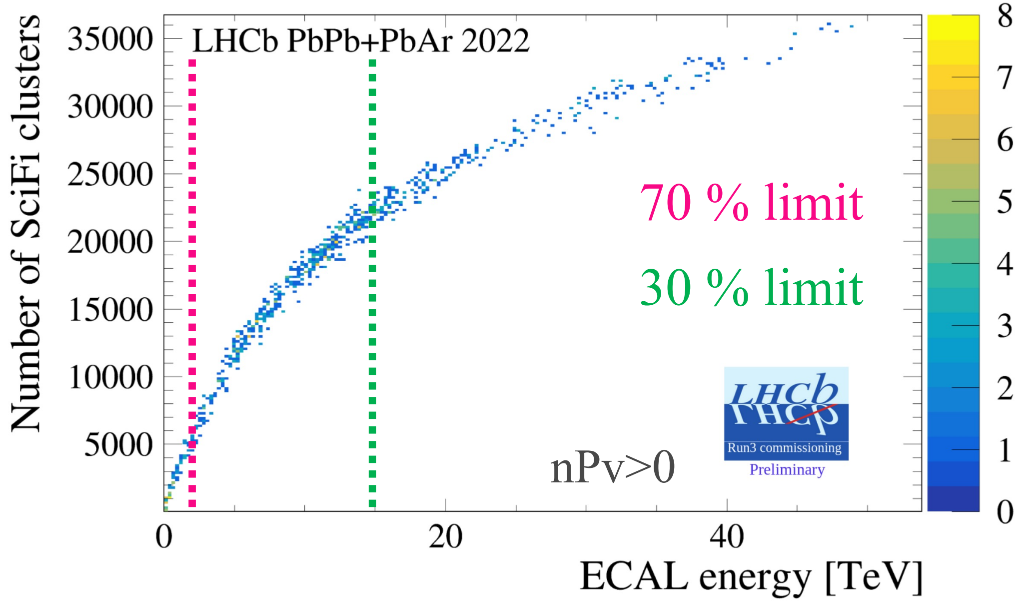


LHCb-INT-2020-004

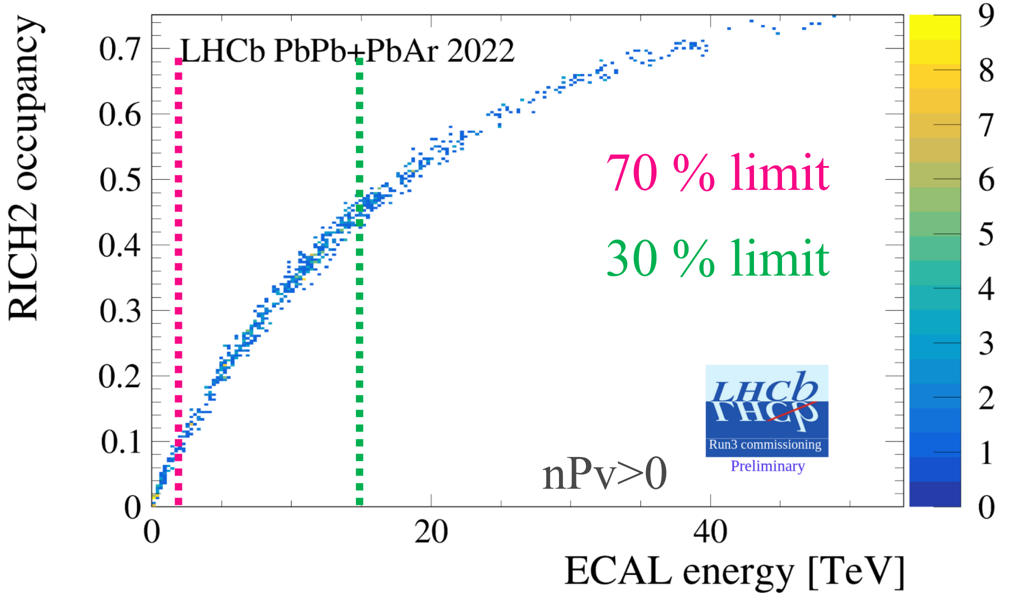
Preparation of the PbPb run

- 2022 PbPb pilot run used to estimate expected occupancy
- **Gas injected** (using SMOG system): PbPb + PbSMOG data

LHCb FIGURE-2023-022



LHCb FIGURE-2023-020



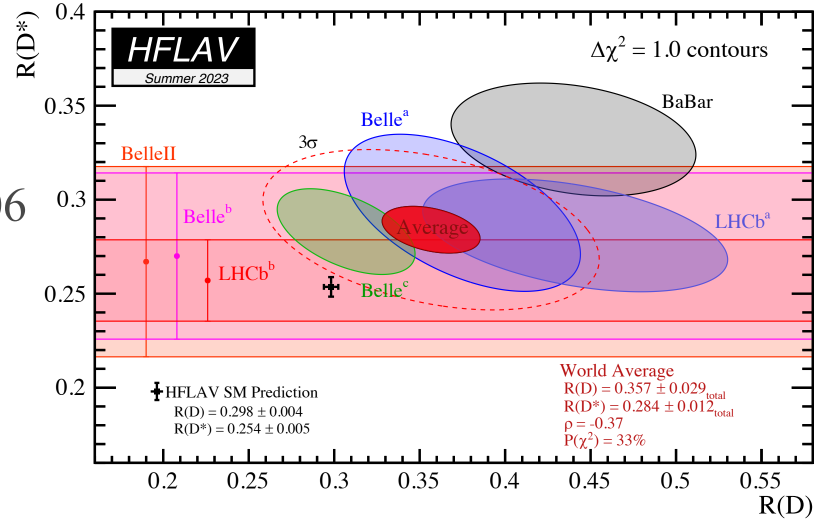
- Preparing HLT1 trigger configuration in case UT commissioning not completed
- Adapting sub-detector firmware to accommodate high occupancy: e.g. SciFi can readout ~ 4 600 extra clusters
- SMOG2 injection foreseen with Argon
- *pp* reference run: inject SMOG→ enlarge physics reach at $\sqrt{s_{NN}}$~70 GeV

Physics results

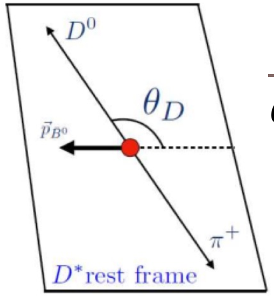
Paper	Title
	Submitted since the May 2023 LHCC
PAPER-2022-048	Search for $B \to D\mu^+\mu^-$ decays
PAPER-2023-002	Bose Einstein Correlation in pPb
PAPER-2023-005	Search for local CPV in $D^0 \to \pi^-\pi^+\pi^0$ using the energy test with Run 2
PAPER-2023-006	Prompt D^+/D_s^+ meson production in pPb collisions at $\sqrt{s_{NN}}$=5.02 TeV at LHCb
PAPER-2023-007	Measurement of the CP asymmetry in B^- decays to two open charm mesons
PAPER-2023-008	Observation of new baryons in the $\Xi_b^-\pi^+\pi^-$ and $\Xi_b^0\pi^+\pi^-$
PAPER-2023-010	Z cross section measurement at 5.02 TeV
PAPER-2023-011	Study of Ω_c two-body decays
PAPER-2023-015	Observation and branching fraction measurement of the decay $\Xi_b \to \Lambda\pi$
PAPER-2023-014	Observation of the $B^0_{(s)} \to D_{s1}^{\mp}(2536)K^{\pm}$ decays
PAPER-2023-016	Improved measurement of CP violation parameters in $B_s^0 \to J/\psi K^+K^-$ ...
	Preliminary results since the May 2023 LHCC
PAPER-2023-019	Search for CPV in $D^0 \to K_S K\pi$ Energy Test
PAPER-2023-020	D^* polarisation measurement in $B^0 \to D^*\tau\nu$
PAPER-2023-021	Observation of strangeness enhancement with charm mesons in high-mult. pPb collisions at 8.16 TeV
PAPER-2023-022	Measurement of double charmonium production cross-sections in pp collisions at $\sqrt{s} = 13$ TeV
PAPER-2023-023	Measurement of J/ψ-$\psi(2S)$ production cross-section in pp collisions at $\sqrt{s} = 13$ TeV
PAPER-2023-024	Prompt and nonprompt $\psi(2S)$ production in pPb collisions at $\sqrt{s_{NN}} = 8.16$ TeV
PAPER-2023-025	A measurement of $\Delta\Gamma_s$
PAPER-2023-026	Modification of $\chi_c(3872)$ and $\psi(2S)$ in pPb
PAPER-2023-027	Λ_b Production in high multiplicity
PAPER-2023-028	Fraction of χ_c decays in prompt J/ψ measured in pPb and Pbp collisions 8.16 TeV
PAPER-2023-029	Measurement of gamma in $B \to D^*h$, $D \to K_S hh$ using partial reconstruction method
PAPER-2023-030	Studies of η and η' production in pp and pPb collisions
PAPER-2023-031	Long range charged hadron correlations in PbPb at 5 TeV
CONF-2023-001	Study of Ξ_b and $\Omega_b \to \Lambda_c hh$
CONF-2023-002	Hypertriton observation
DP-2023-002	Helium identification

Longitudinal D^* polarization in $B^0 \to D^{*-}\tau^+\nu_\tau$

- Deviation of $R(D^*) - R(D)$ from SM predictions (3 σ)
- Study of kinematics and angular distributions → additional sensitivity to NP
- Observable: longitudinal polarization $F_L^{D^*}$ → SM prediction $F_L^{D^*} = 0.441 \pm 0.006$ arXiv:1808.03565
- Measurement by Belle $F_L^{D^*} = 0.60 \pm 0.08 \pm 0.04$ BELLE-CONF-1805



Use $D^{*-} \to \overline{D}^0\pi^-$ and hadronic τ decay $\tau^+ \to \pi^+\pi^-\pi^+\nu_\tau$

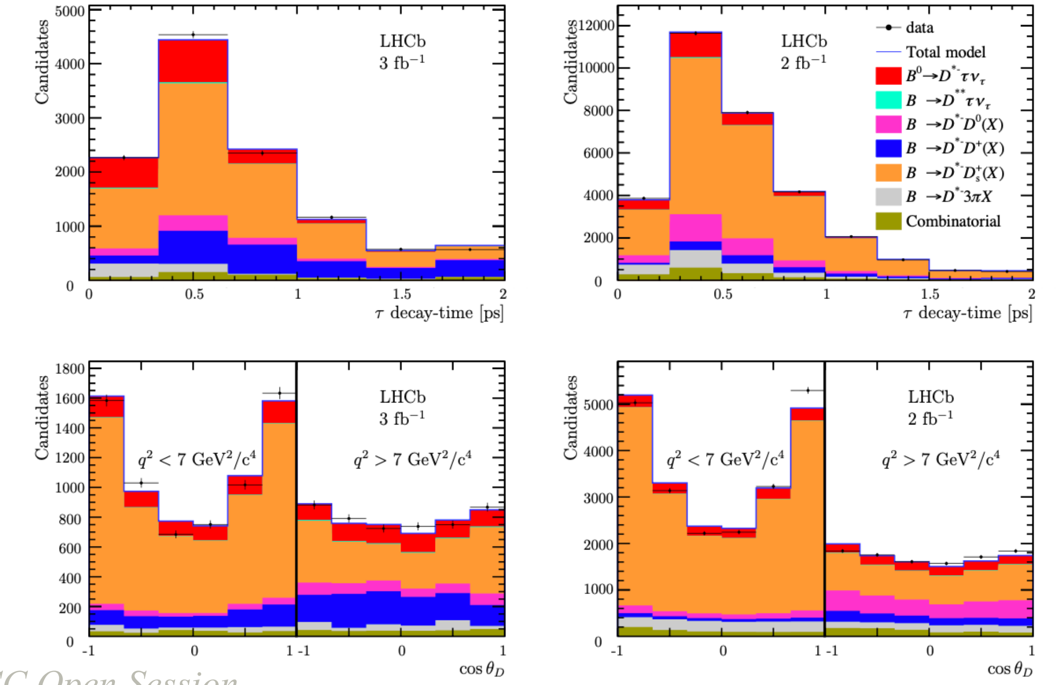


$$\frac{d^2\Gamma}{dq^2 d\cos\theta_D} = a_{\theta_D}(q^2) + c_{\theta_D}(q^2)\cos\theta_D^2$$

$$F_L^{D^*} = \frac{a_{\theta_D}(q^2) + c_{\theta_D}(q^2)}{3a_{\theta_D}(q^2) + c_{\theta_D}(q^2)}$$

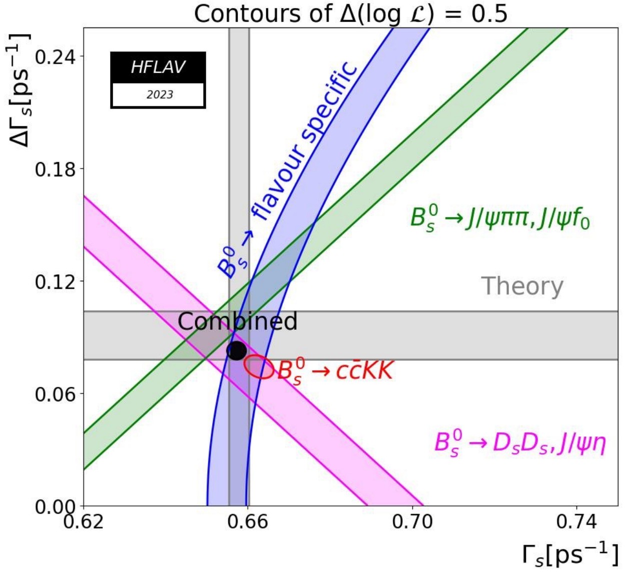
Result compatible with SM LHCb PAPER-2023-20

$$q^2 < 7\,\mathrm{GeV}^2/c^4: \quad 0.51 \pm 0.07(stat) \pm 0.03(syst)$$
$$q^2 > 7\,\mathrm{GeV}^2/c^4: \quad 0.35 \pm 0.08(stat) \pm 0.02(syst)$$
$$q^2\text{integrated}: \quad 0.43 \pm 0.06(stat) \pm 0.03(syst)$$



New measurement of $\Delta\Gamma_s$

HFLAV average
$\Delta\Gamma_s = 0.083 \pm 0.005\ \text{ps}^{-1}$

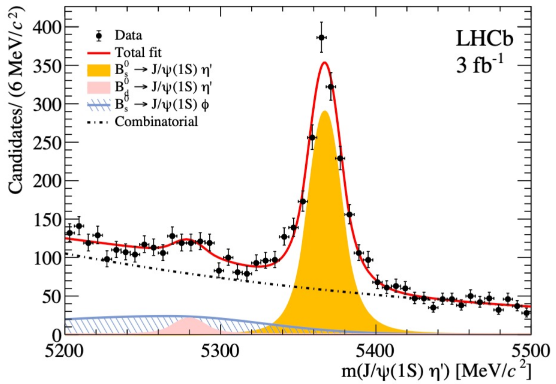


- Decay width difference between B_s^0 mass eigenstates $\Delta\Gamma_s = \Gamma_L - \Gamma_H$
- Usually measured using $B_s^0 \to J/\psi\phi$, tension btw different experimental results

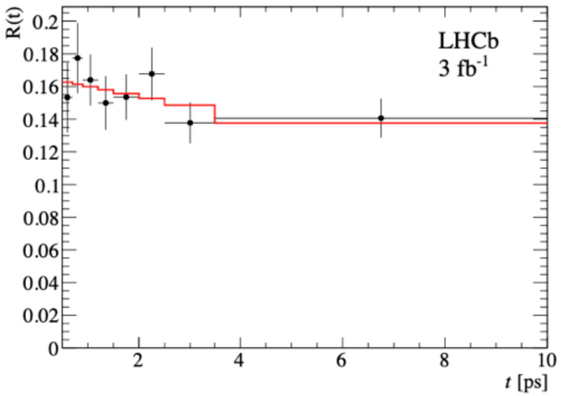
Use different method, combine lifetime measurement of CP-even $B_s^0 \to J/\psi\eta'$ and CP-odd $B_s^0 \to J/\psi\pi^+\pi^-$

integrate time dependent decay rate for CP even/odd:

$$\Gamma(B_s^0(t) \to f) \propto e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) \pm \sinh\left(\frac{\Delta\Gamma_s t}{2}\right)\right]$$

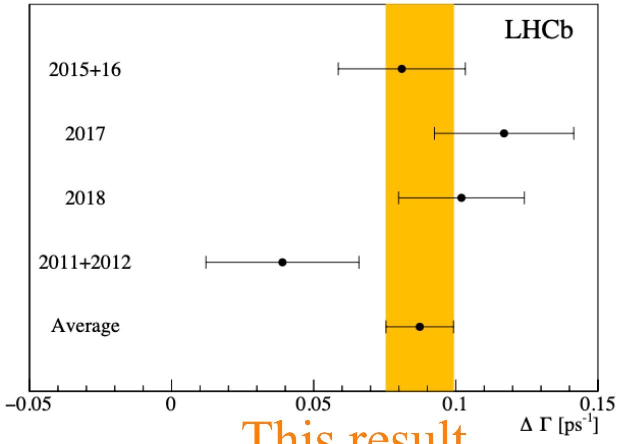


$$N_L \propto \left[\frac{e^{t(\frac{-\Delta\Gamma_s}{2}-\Gamma_s)}}{\Gamma_s + \frac{\Delta\Gamma_s}{2}}\right]_{t_1}^{t_2} \Rightarrow R(t) = A_r(t)\cdot\frac{N_L^{RAW}}{N_H^{RAW}}$$



$\Delta\Gamma_s$ is extracted from the yields ratio of two modes corrected by the $A_r(t)$ acceptance

LHCb PAPER-2023-25



This result

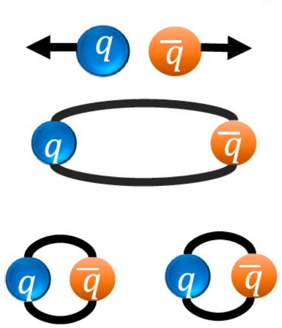
$\Delta\Gamma_s = 0.087 \pm 0.012 \pm 0.009\ \text{ps}^{-1}$

Beauty baryons in high multiplicity *pp* collisions

Test universality of hadronization process→ is the underlying event influencing the hadronization process?

Fragmentation:

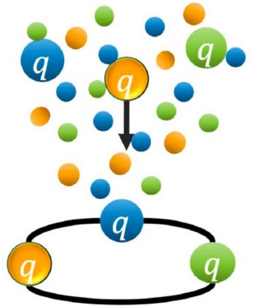
$(e^+e^-$ *collisions in vacuum*)



Universal: not dependent on the colliding system

Coalescence:

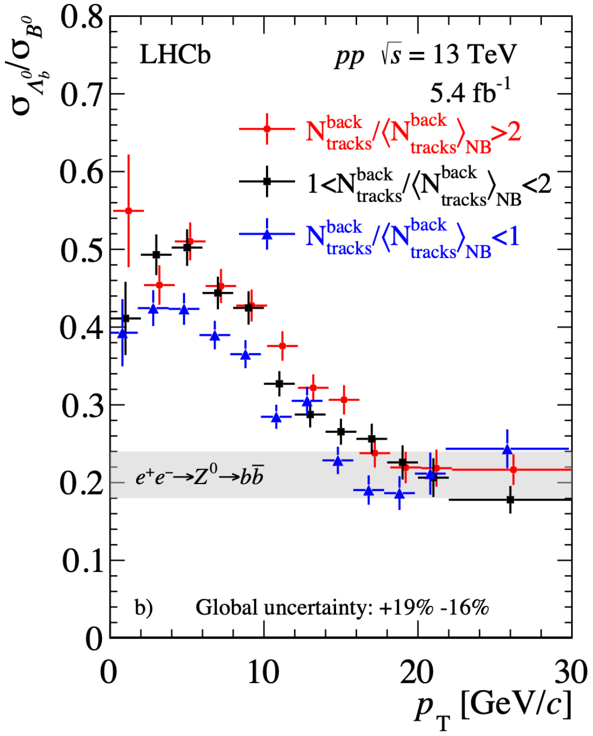
(*quark – rich environment*)



New baryons production mechanism?

need overlap of the partons wave function to combine, likely at low p_T

Study ratio $\sigma_{\Lambda_b^0}/\sigma_{B^0}$ as a function of kinematic and colliding systems



- Multiplicity dependence visible
- Matches e^+e^- at high p_T for any multiplicity
  →little effect of underlying event

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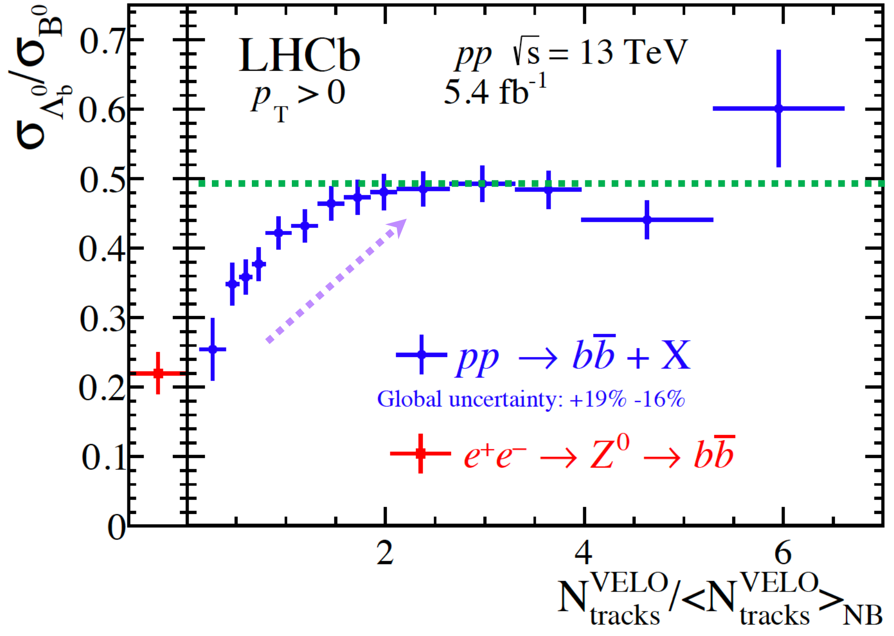
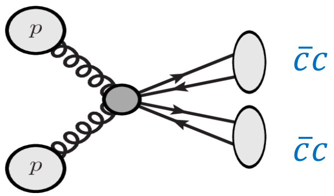


- e^+e^- from LEP matched at low multiplicity
- Plateau for > 2
- Rise between 0 and 2

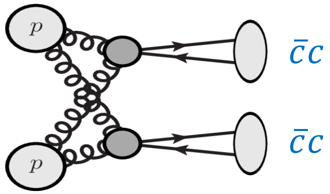
Double charmonium production cross-sections

Hadronization mechanism in QCD: **NRQCD** describes hadronization mostly well → fails to describe differential cross-sections & polarization simultaneously in whole kinematic region

Single-parton scattering (SPS)



Double-parton scattering (DPS)



independent partonic interaction

Charmonium pair production

$$\sigma^{\text{DPS}}_{\mathcal{Q}_1\mathcal{Q}_2} = \frac{1}{1+\delta_{\mathcal{Q}_1\mathcal{Q}_2}} \frac{\sigma_{\mathcal{Q}_1}\sigma_{\mathcal{Q}_2}}{\sigma_{\text{eff}}}$$

single prod. cross section

effective cross. sec. to normalize DPS

Results:

- effective cross-section σ_{eff} measured as

$$\frac{\sigma_{J/\psi}\sigma_{\psi(2S)}}{\sigma_{J/\psi\text{-}\psi(2S)}} = 7.1 \pm 1.1 \text{ (stat)} \pm 0.8 \text{ (syst) mb}$$

- ratio double to single cross sections:

$$\frac{\sigma_{J/\psi\text{-}\psi(2S)}}{\sigma_{J/\psi\text{-}J/\psi}} = 0.274 \pm 0.044 \text{ (stat)} \pm 0.008 \text{ (syst)}$$

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Closer to DPS prediction

0.94 ± 0.30 for SPS $\qquad$ 0.282 ± 0.027 for DPS

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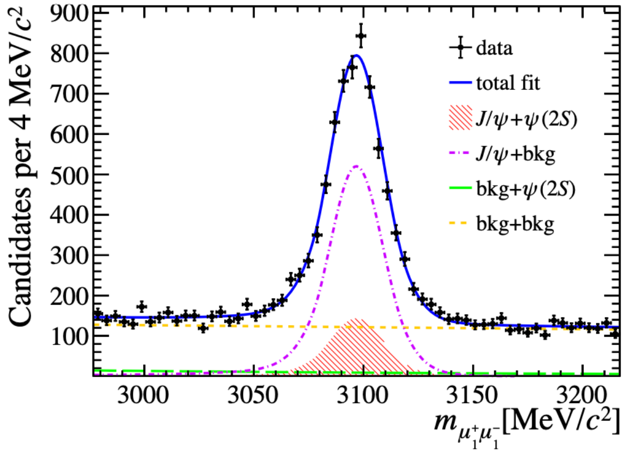
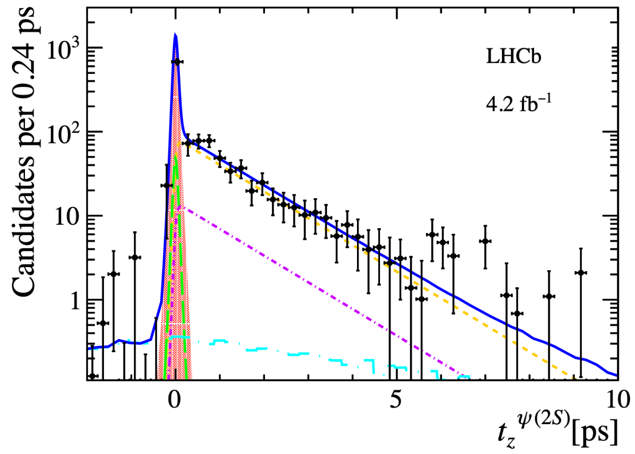
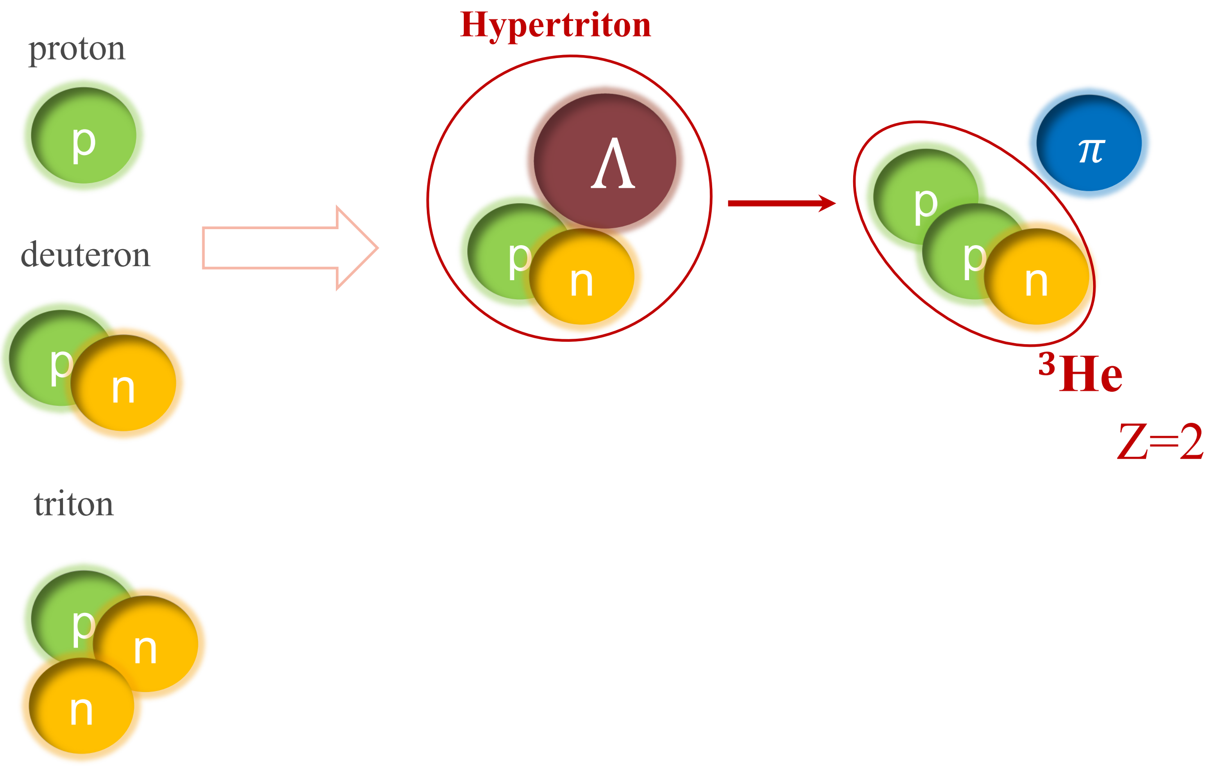




- 2D fit simultaneous fit to the J/ψ and ψ(2S) mass
- separation of prompt candidates using pseudo proper time t_z

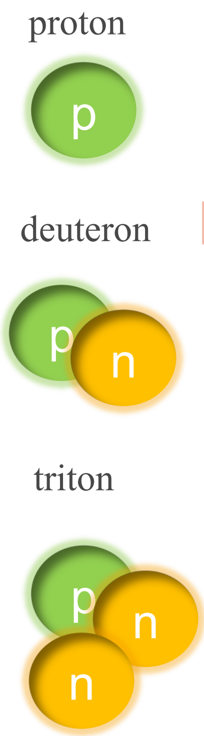
Hypertriton observation

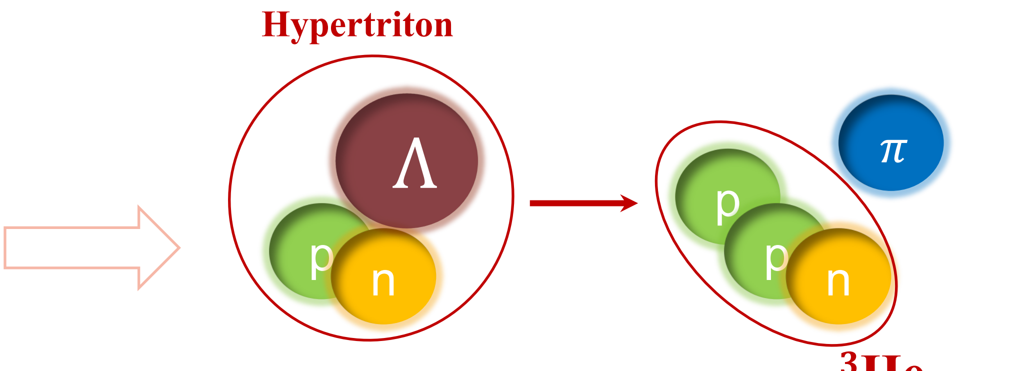
- Observation of hypertriton ${}^{3}_{\Lambda}H \rightarrow {}^{3}\mathbf{He}\,\pi^{-}$ using 5.5 fb^{-1}



Hypertriton observation

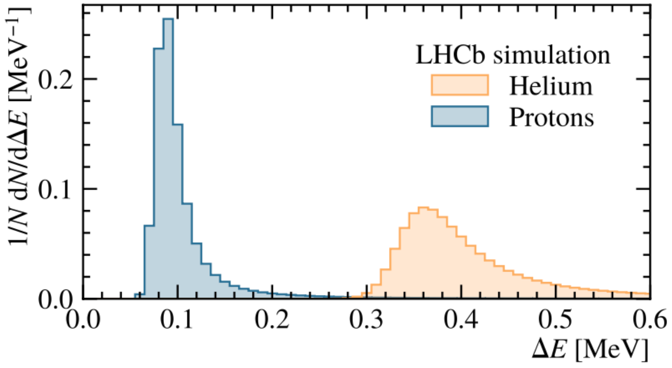
- Observation of hypertriton ${}^{3}_{\Lambda}H \rightarrow {}^{3}\mathbf{He}\,\pi^{-}$ using 5.5 fb^{-1}
  - → developing new particle identification techniques! based on:
    - ionization losses in **LHCb silicon sensors**
    - timing information in the Outer Tracker drift tubes

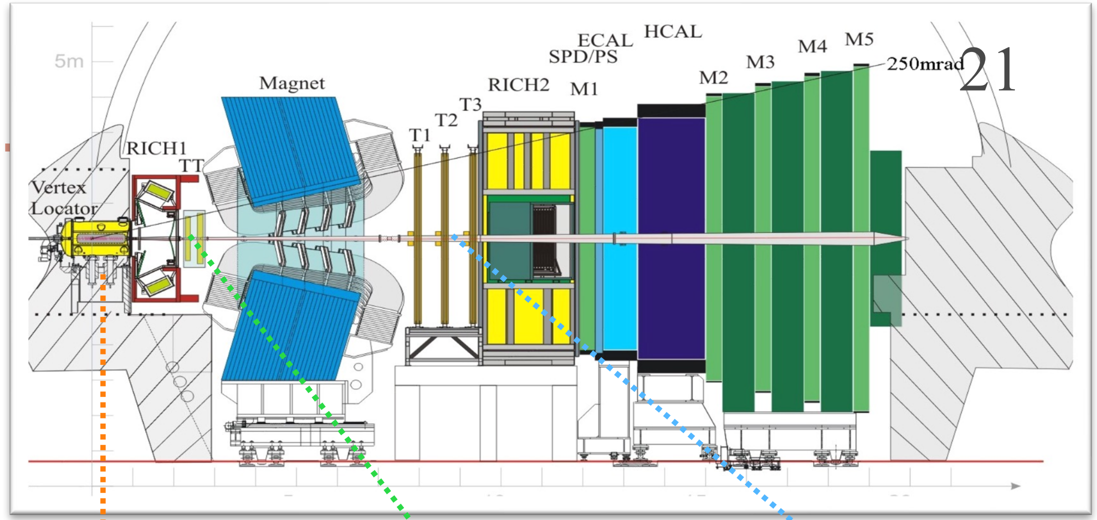


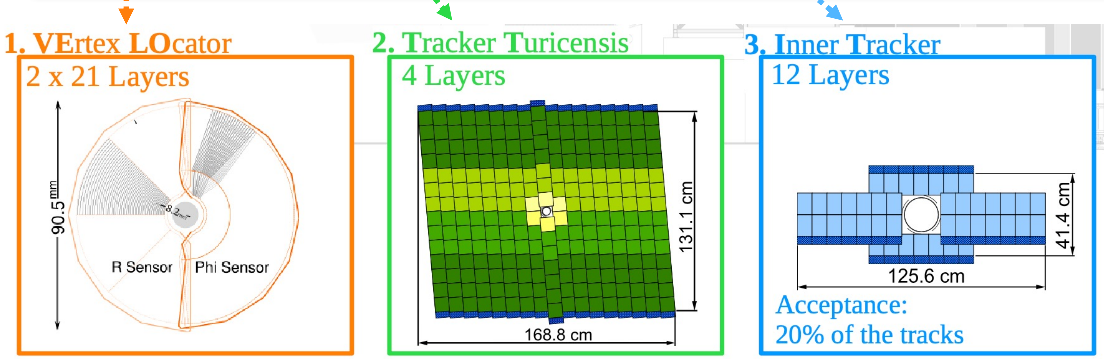


Z=2

No helium identification in LHCb
→ new method, exploit **Bethe Bloch**







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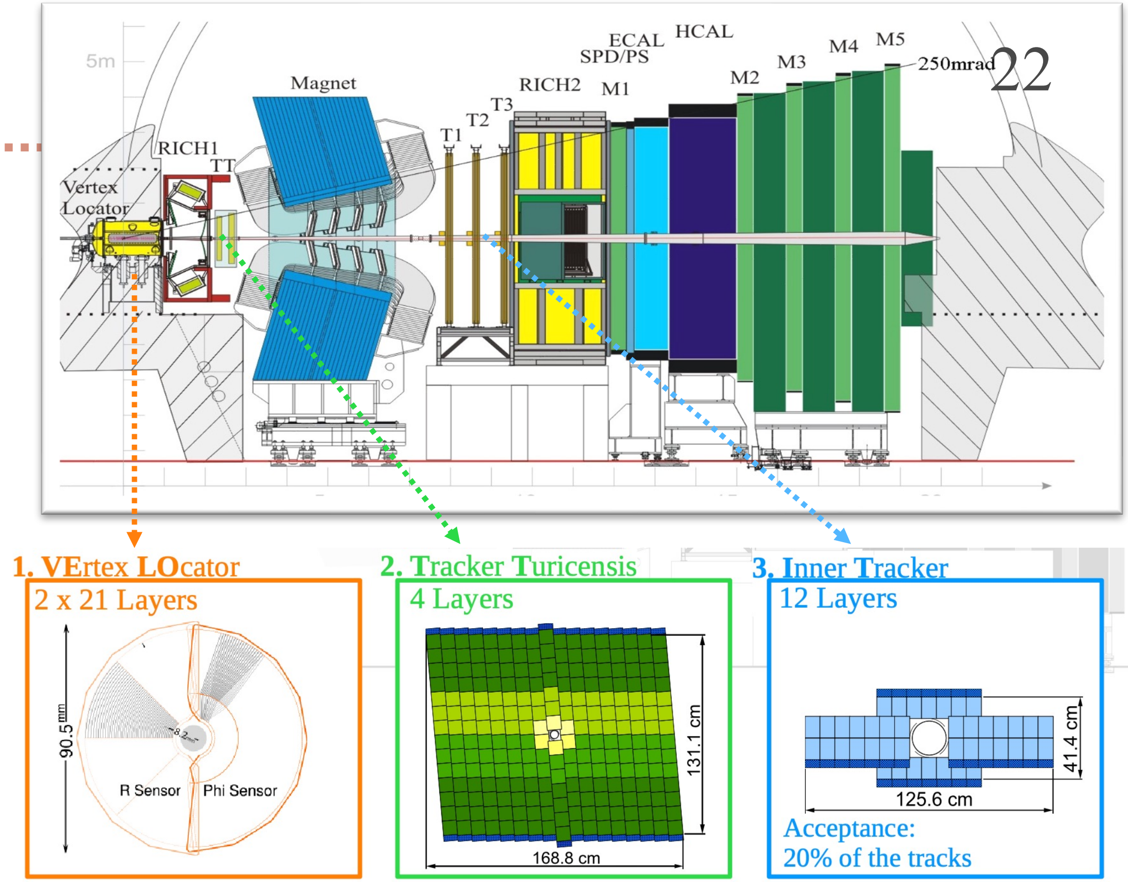

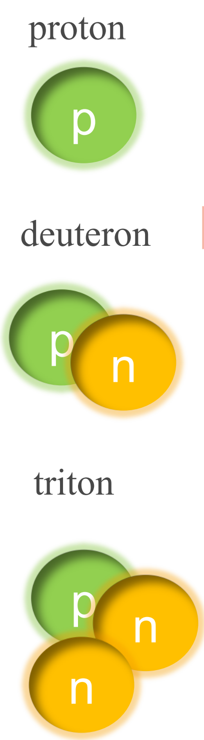

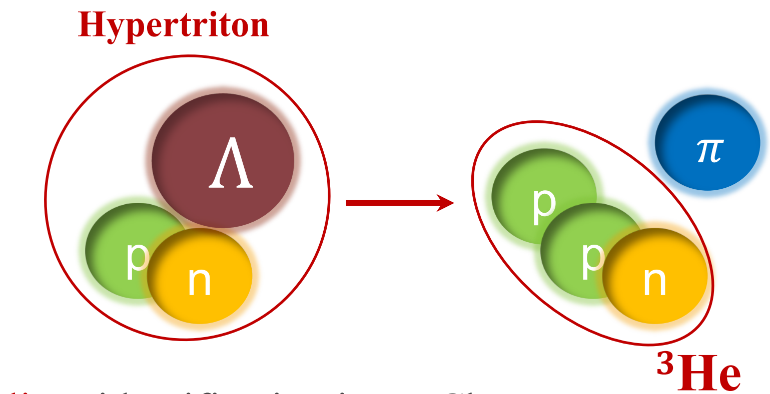

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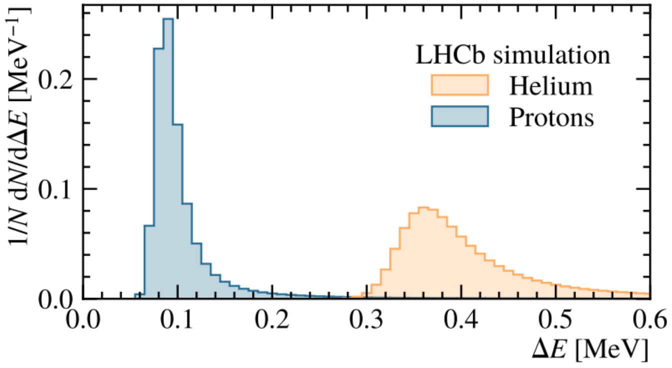

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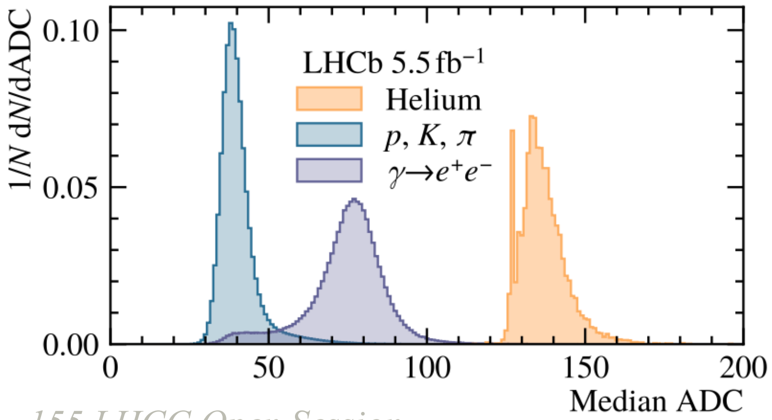

Construct likelihood estimators to identify Helium tracks
→based on ADC counts dependance on Z
Details in :
LHCb-DP-2023-002

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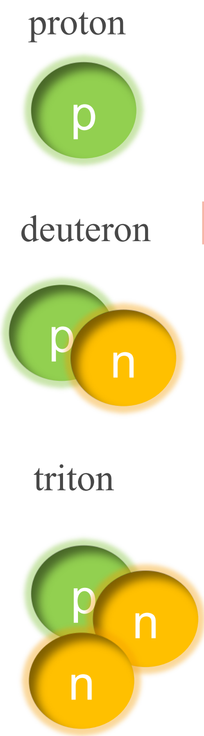
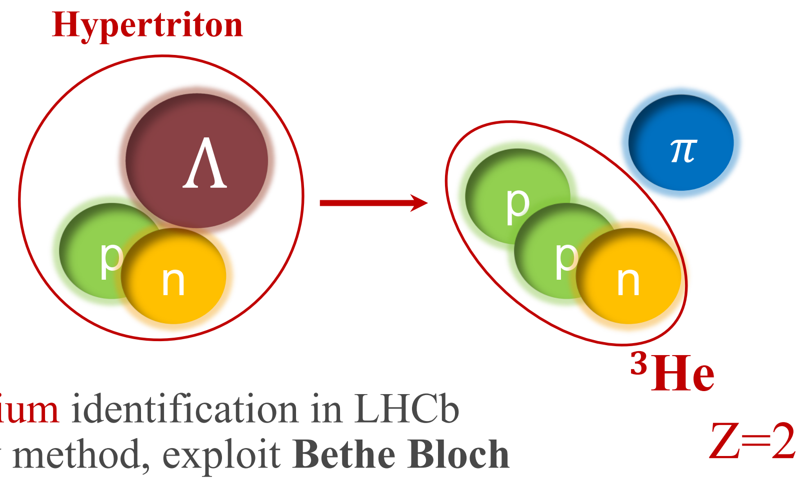
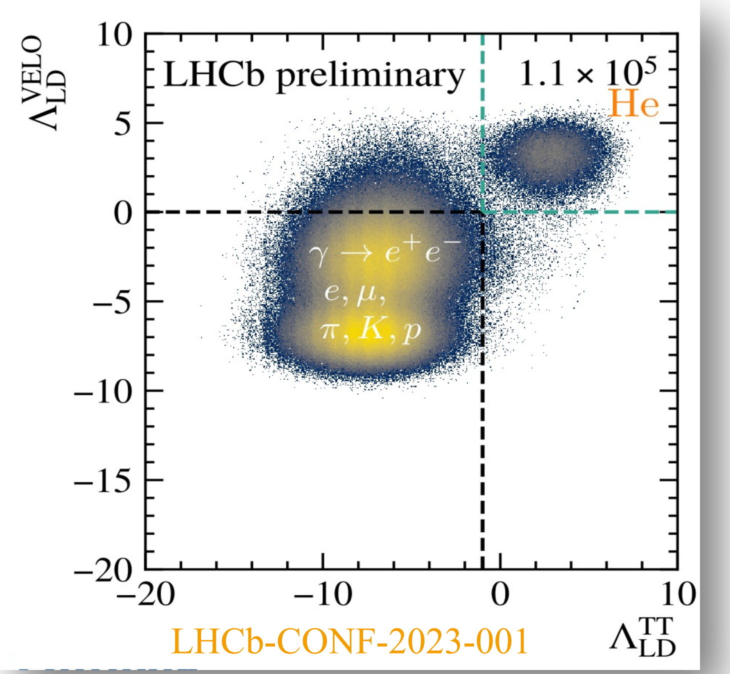
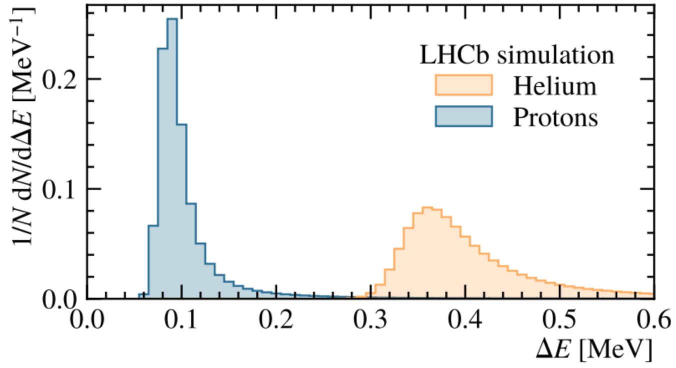


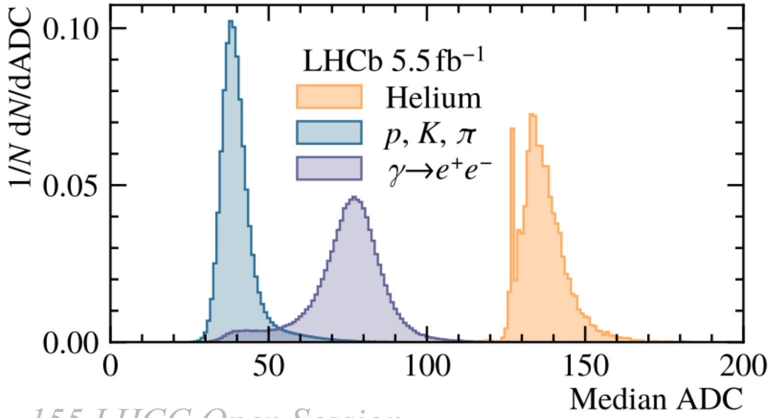




~ 10^5 prompt helium/antihelium candidates in 2016 to 2018 data, **very promising!**

No helium identification in LHCb
→ new method, exploit **Bethe Bloch**





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Details in:
LHCb-DP-2023-002

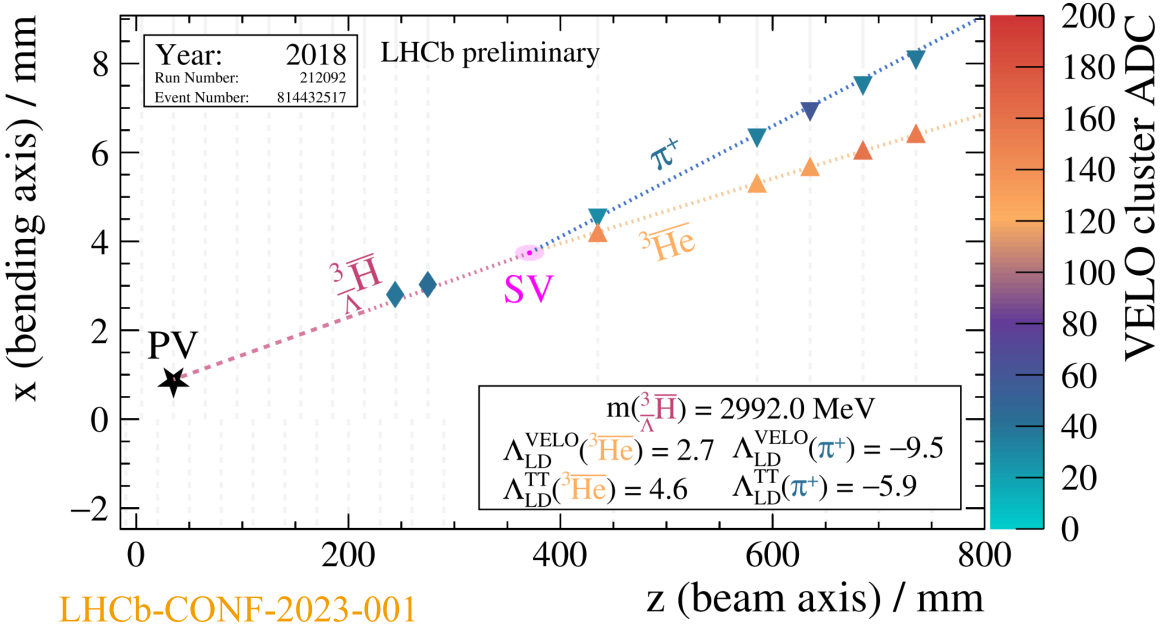
Hypertriton observation

- Observation of ${}^{3}_{\Lambda}H \rightarrow {}^{3}\mathbf{He}\,\pi^{-}$ using 5.5 fb^{-1}
  - 107 ± 11 (anti)hypertriton candidates
  - stat. precision on hypertriton mass ~0.16 MeV

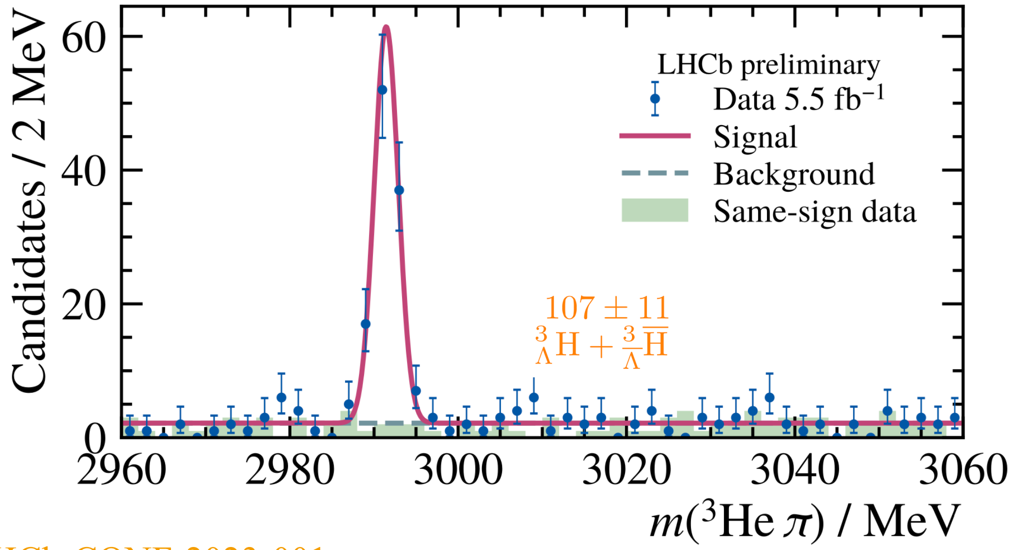
$N({}^{3}_{\Lambda}\mathrm{H}) = 61 \pm 8$

$N({}^{3}_{\Lambda}\overline{\mathrm{H}}) = 46 \pm 7$

→more in CERN page or LHCb outreach page



LHCb-CONF-2023-001



LHCb-CONF-2023-001

- ALICE recently measured ${}^{3}_{\Lambda}H$ lifetime and binding energy Phys. Rev. Lett. **131**, 102302

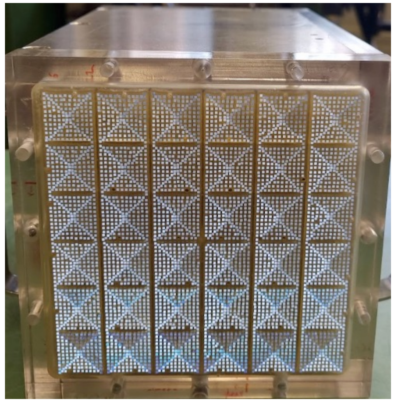
First observation of ${}^{3}_{\Lambda}H$ at LHCb

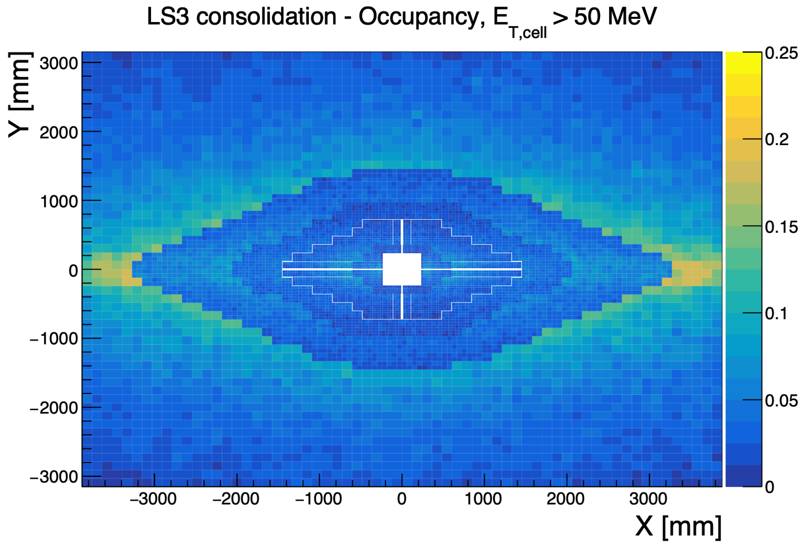
PID enhancement for Run 4

- New TDR submitted to LHCC this week on:
  LHCb particle identification enhancement during LS3
- Upgrade of RICH and ECAL

ECAL: detector modules have not been replaced during LS2

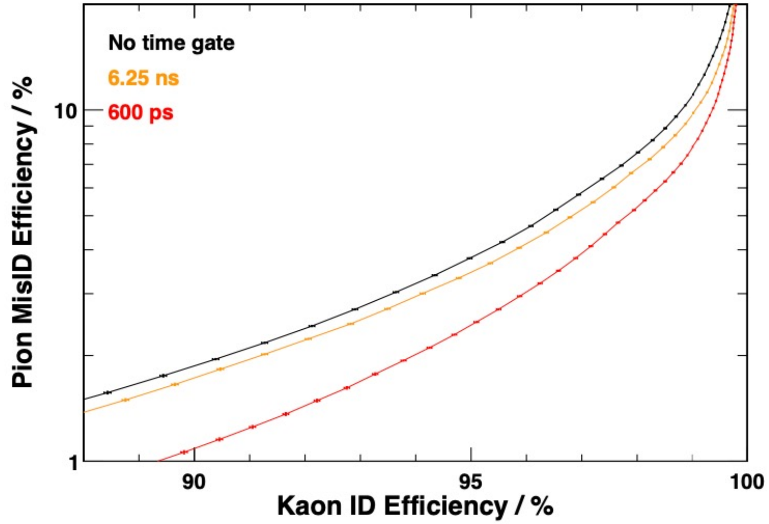
Prototype module





Innermost region needs replacing after Run 3
→plan to replace with new SpaCal modules (reused for Upgrade II)
→rearrange outer modules in a rhombic shape (following occupancy)

RICH: new electronics time-stamping photon hits

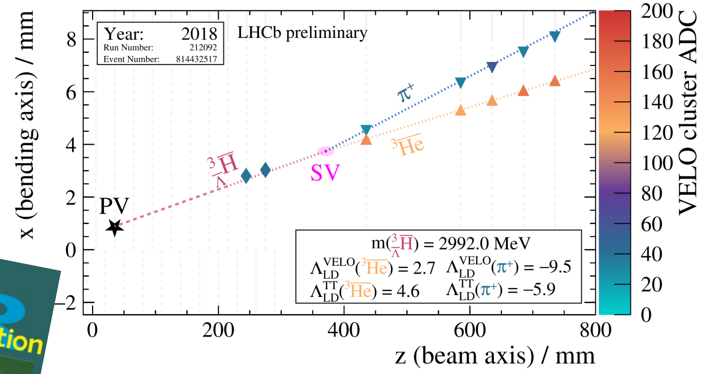


For Run 4 MaPMT photodetectors (σ ~ 150 ps) remains the major limitation for timing

Conclusions

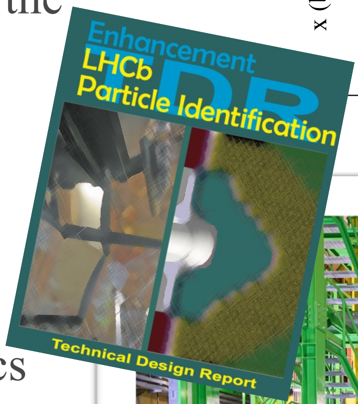
Physics results

- Exploiting Run 1 and Run 2 datasets to produce world leading results:
  - → Yet developing innovative PID techniques, first helium identification in LHCb
  - → Large variety of results for ion physics → major contributions in the understanding of the hadronization process
  - → Keep probing SM predictions

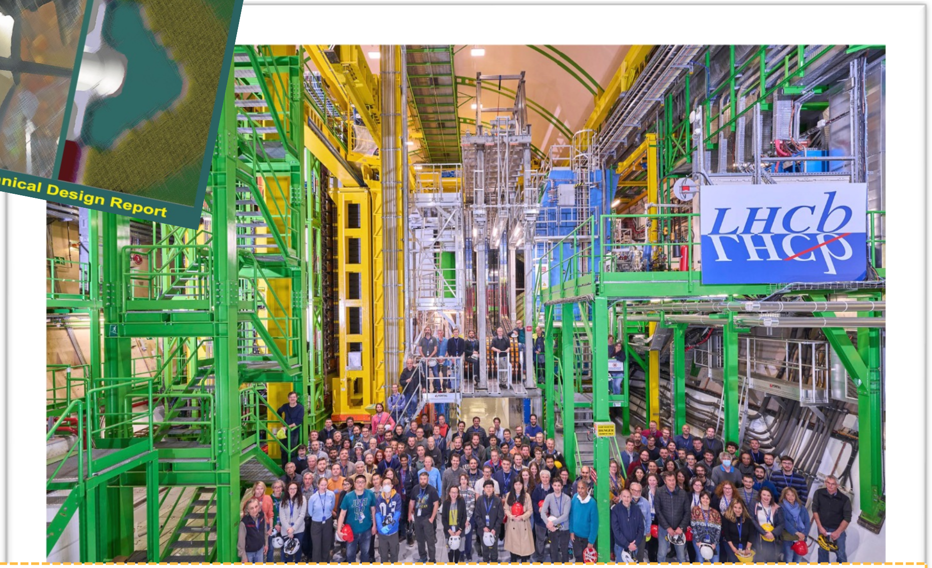


Road towards stable and efficient data-taking

- Despite the difficulties encountered, we are exploiting our data:
  - → we continued with sub-detector work to reach optimal efficiency
  - → thanks to our flexible trigger, we could adapt and prepare for physics



- First performances studies on particle identification and hit efficiency extremely promising: the detector is performing well, work to do to reach design goals
- Large effort to prepare at best for the ion run, interesting physics cases are at reach!



We warmly thanks the LHC for their support!

LS3 enhancement in view of Upgrade II

- Getting ready to install new technologies for enhanced PID performances already during LS3!