LHCP2021
The Ninth Annual Conference on Large Hadron Collider Physics
Online
7-12 June 2021 ~~Paris (France), Sorbonne Université (IN2P3/CNRS,IRFU/CEA)~~

Tracking, flavour tagging and particle ID at the LHCb experiment

See related talks by LHCb speakers:
- LHCb Performance highlights by L. Henry; Monday
- Upgrades for LHCb by T. Szumlak; Friday
- Real-time analysis for Run 3 and beyond by M. Ramos Pernas; Tuesday
- GPUs in trigger and reconstruction by T. Boettcher; Wednesday

Vitalii Lisovskyi (TU Dortmund) on behalf of the LHCb Collaboration
vitalii.lisovskyi@cern.ch

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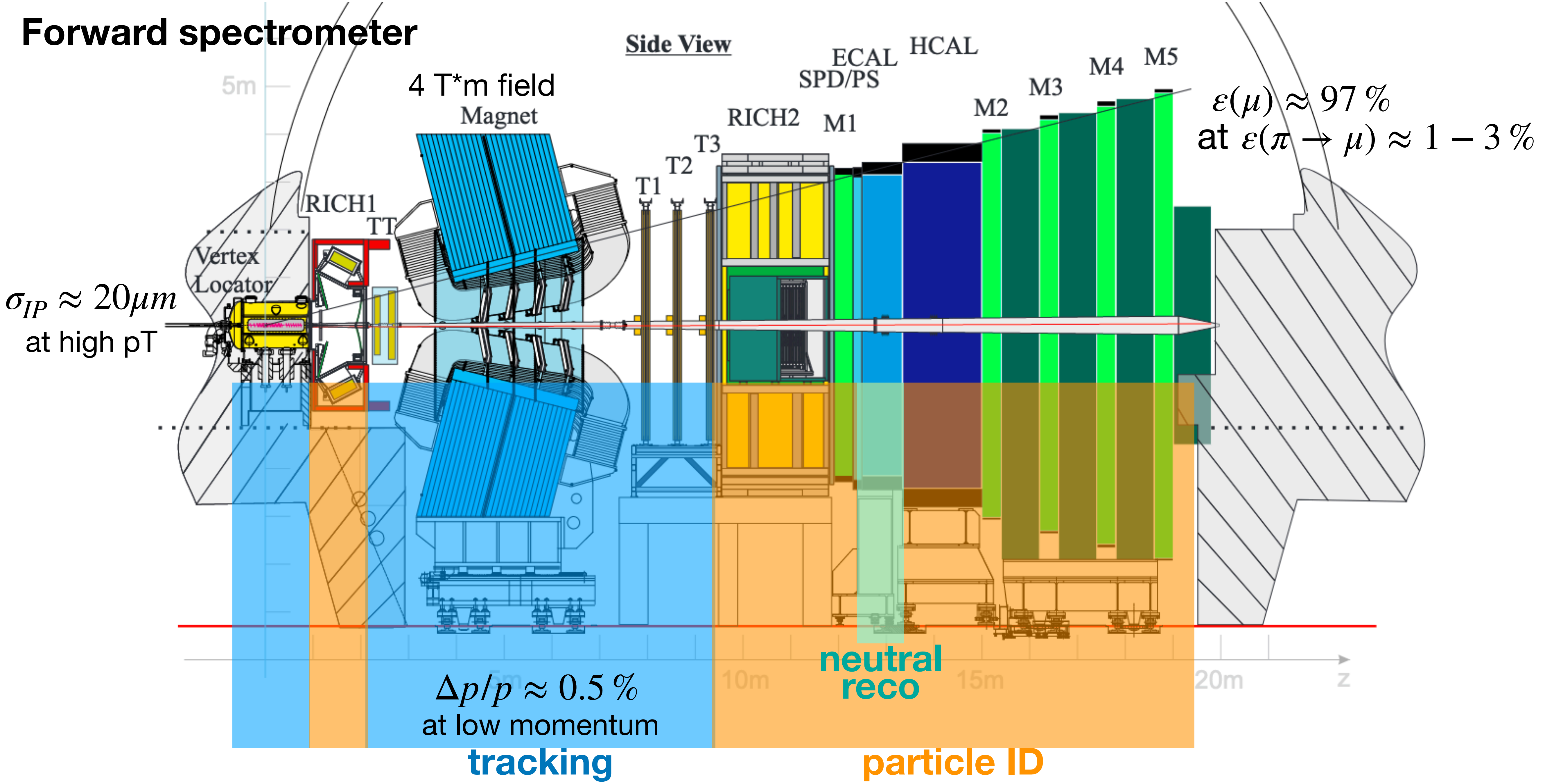
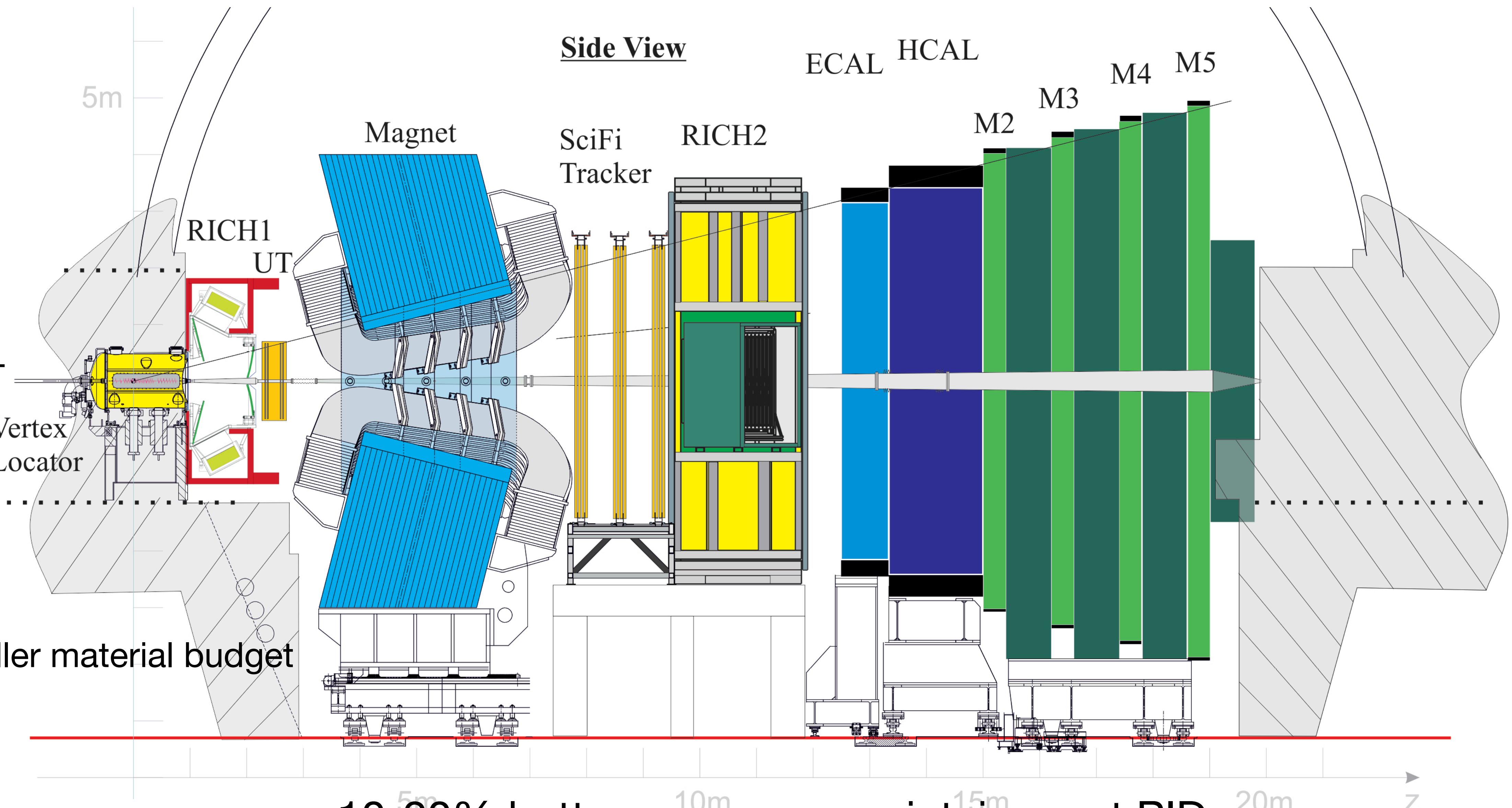


- Collected about $9\,\text{fb}^{-1}$ integrated luminosity with >90% data-taking efficiency
  - instantaneous lumi $\approx 3 \times 10^{-32}\,\text{s/cm}^2$

LHCb detector 2022 – …



better σ_{IP} at lower pT

smaller material budget

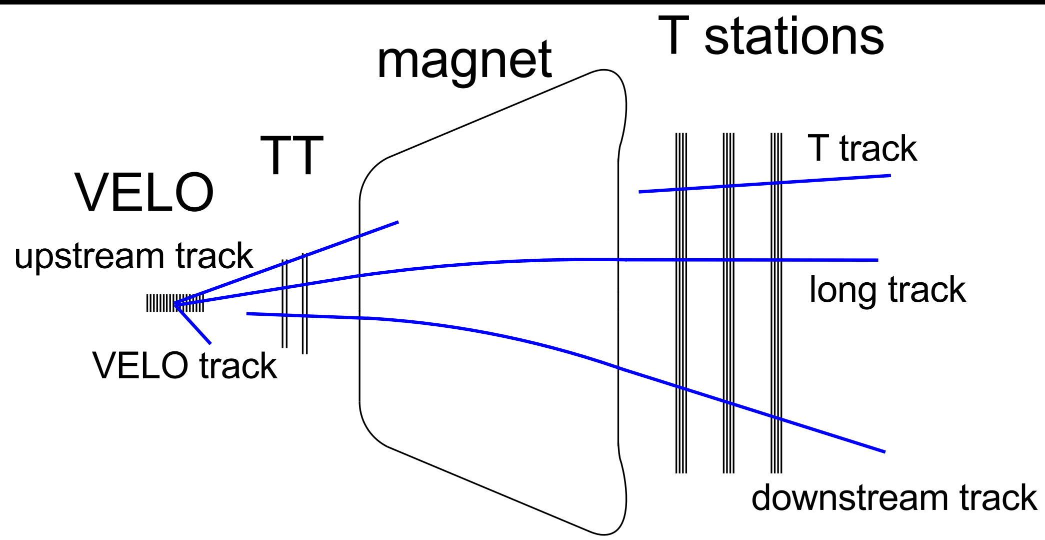
10-20% better momentum resolution

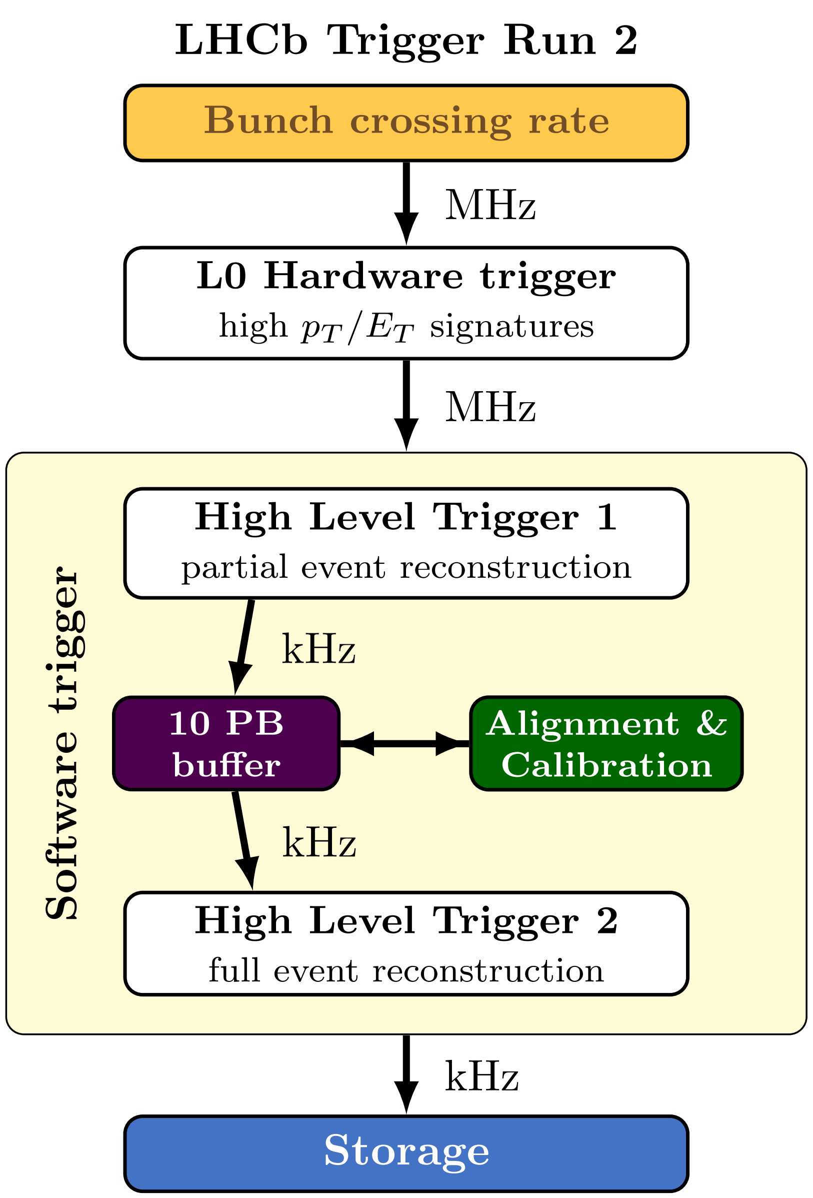
maintain great PID performance

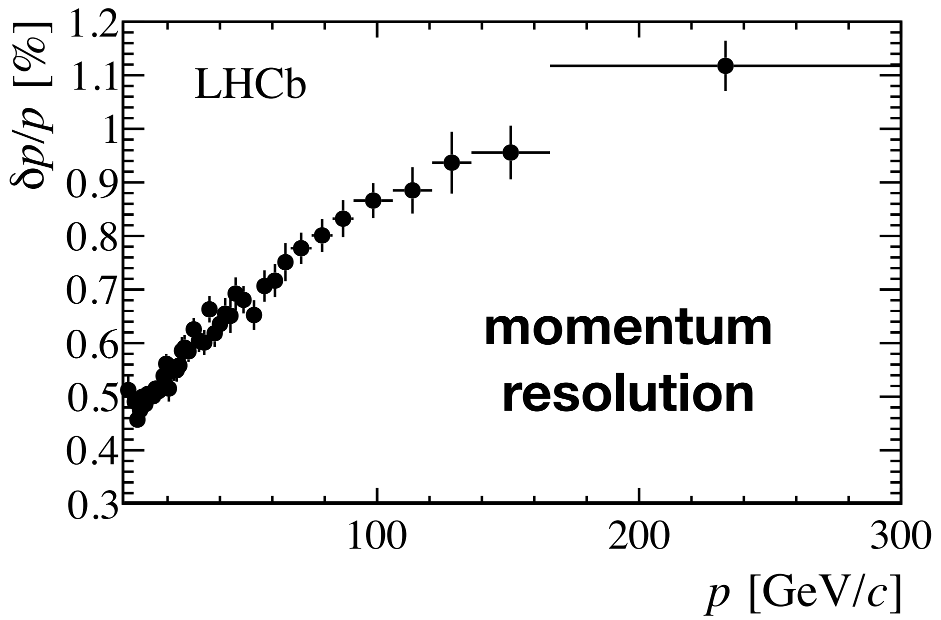
- 5x luminosity
  - higher occupancy and pile-up
- Fully software trigger (30 MHz detector readout) with real-time alignment and calibration

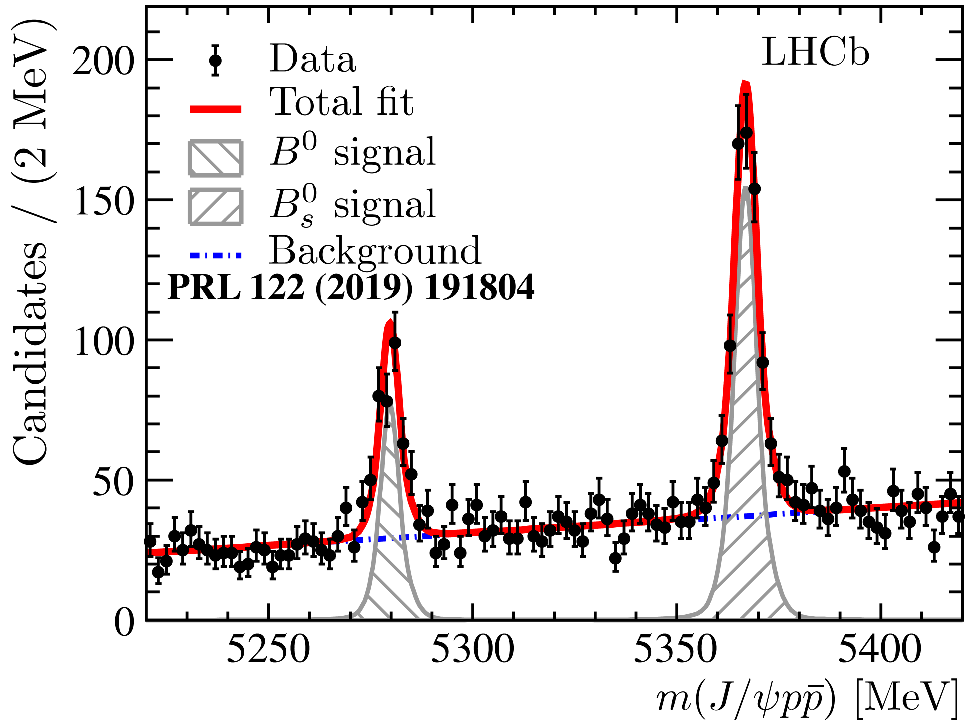
Tracking

- Long tracks used for most analyses
- Not only momentum measurement: displacement, track quality
- Alignment is a key!
  - happens in 'real-time' since 2015









resolve B^0 and B_s^0 peaks!

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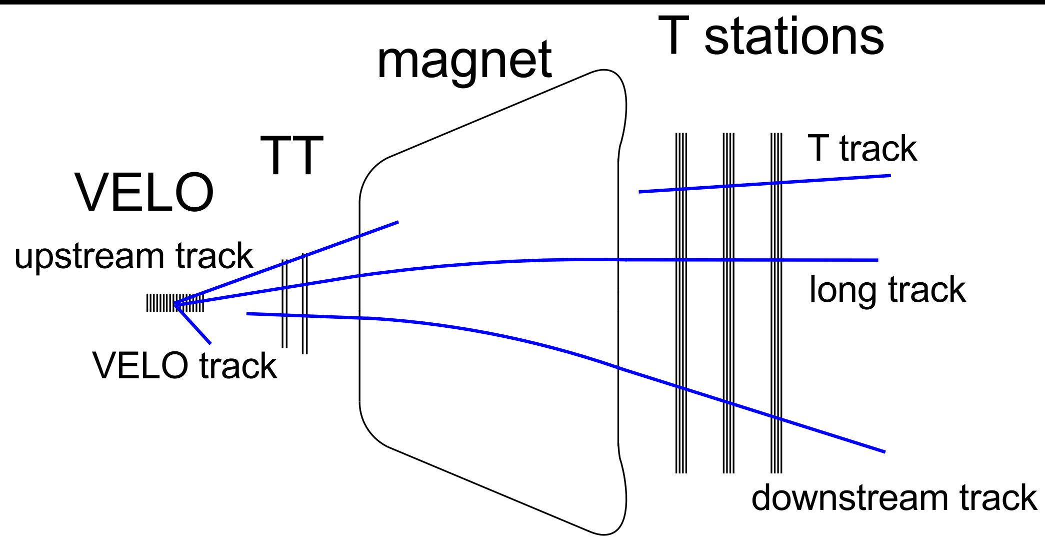

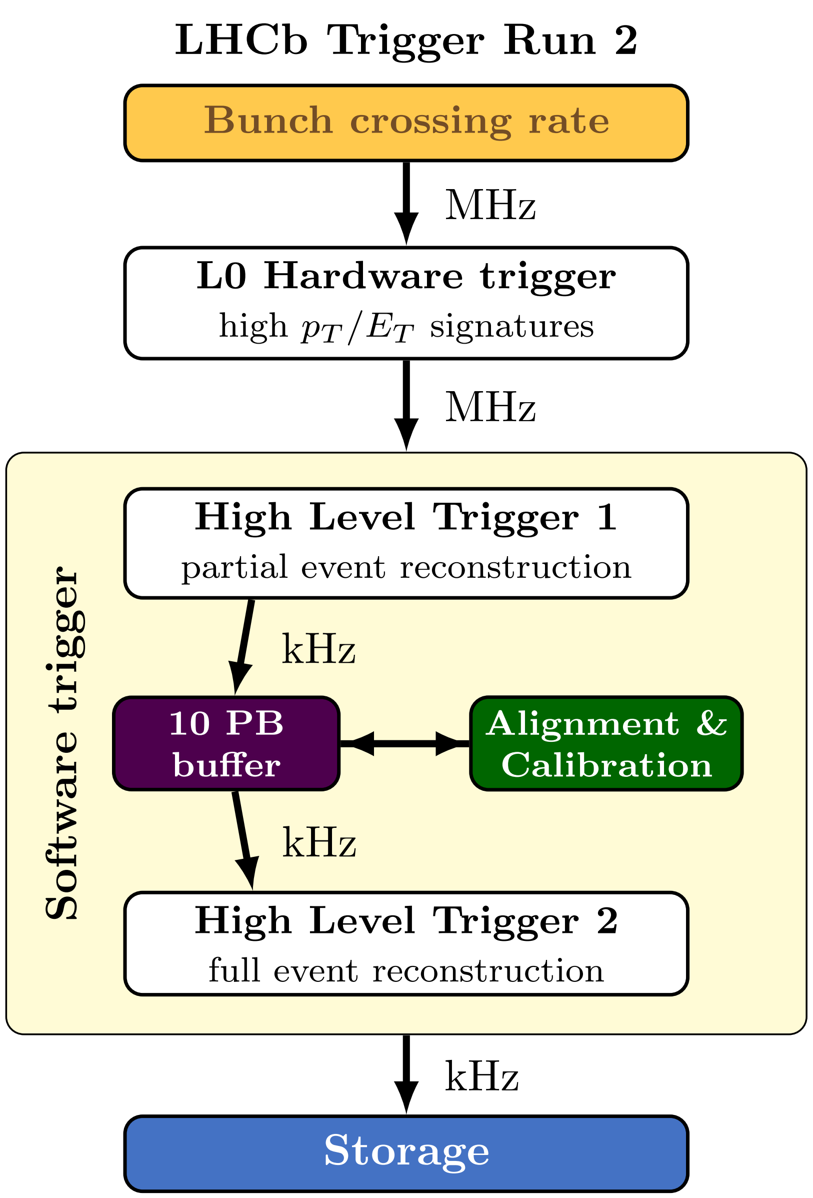

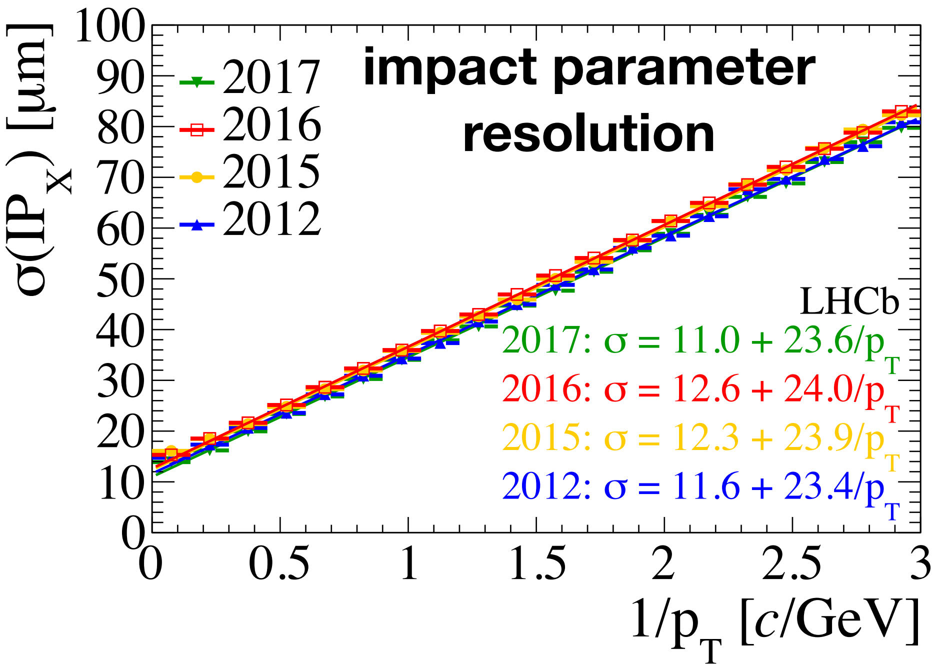

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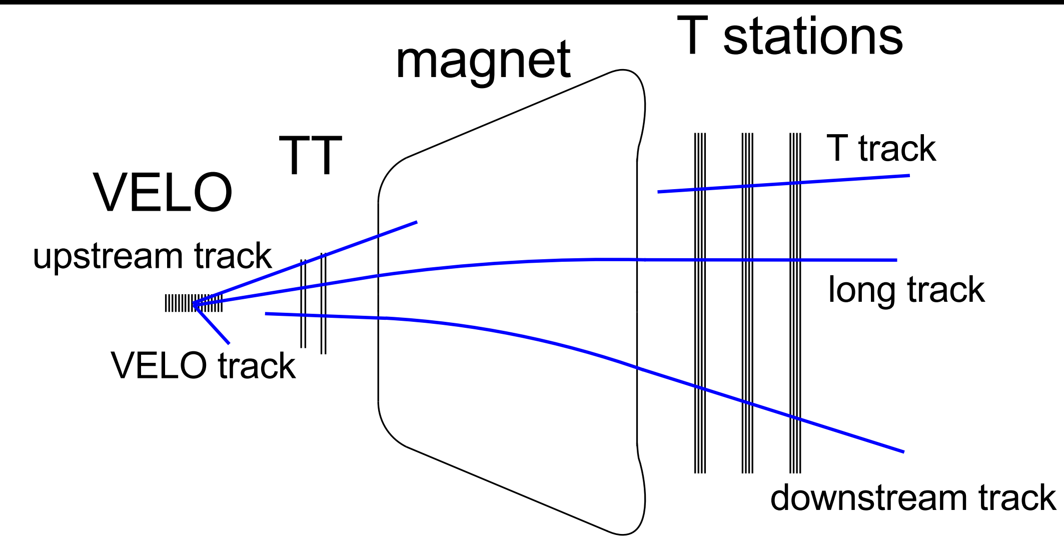
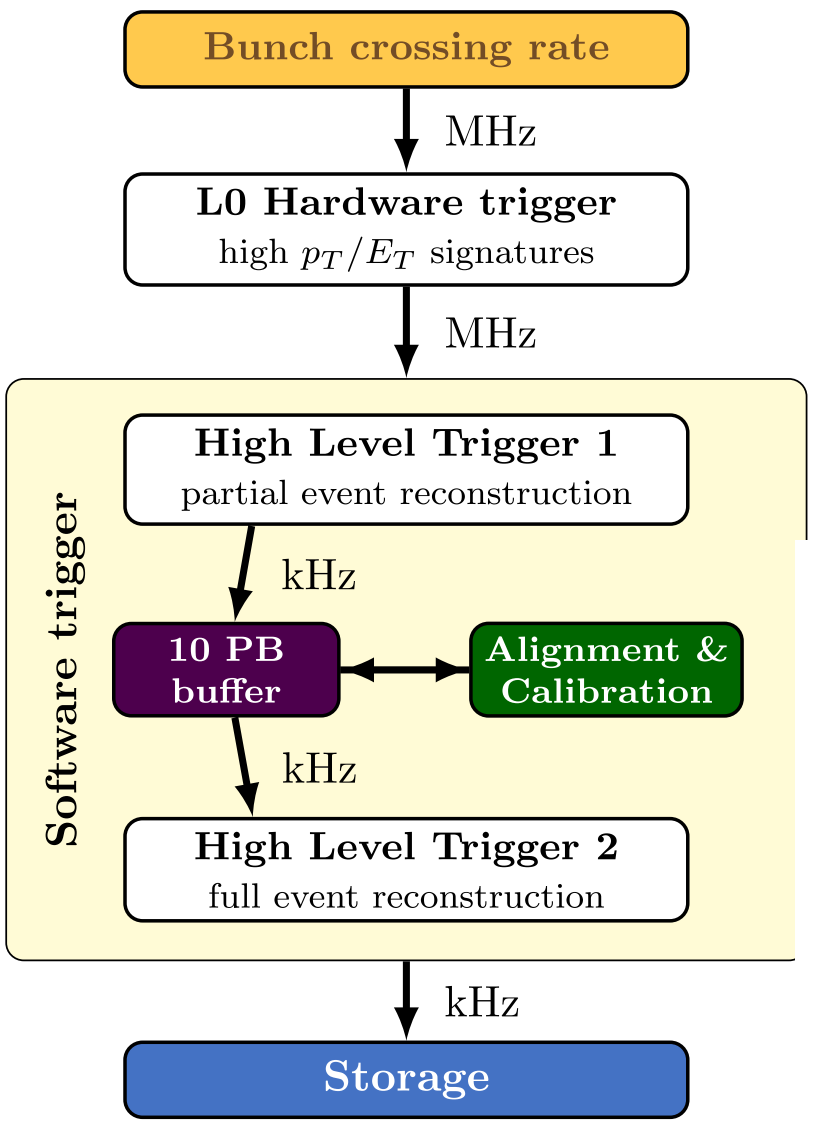
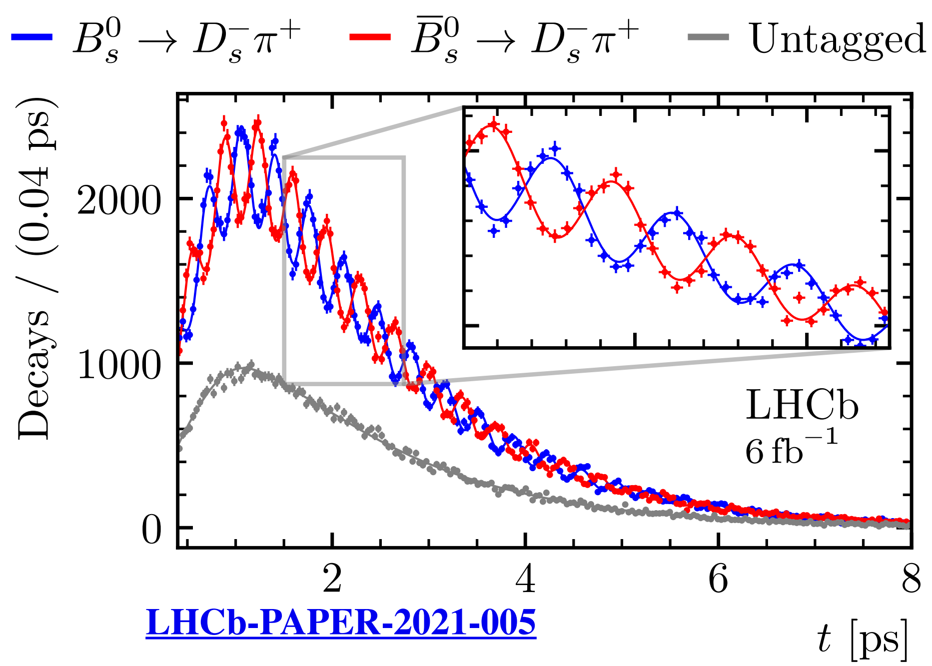




resolve B_s^0 oscillations!



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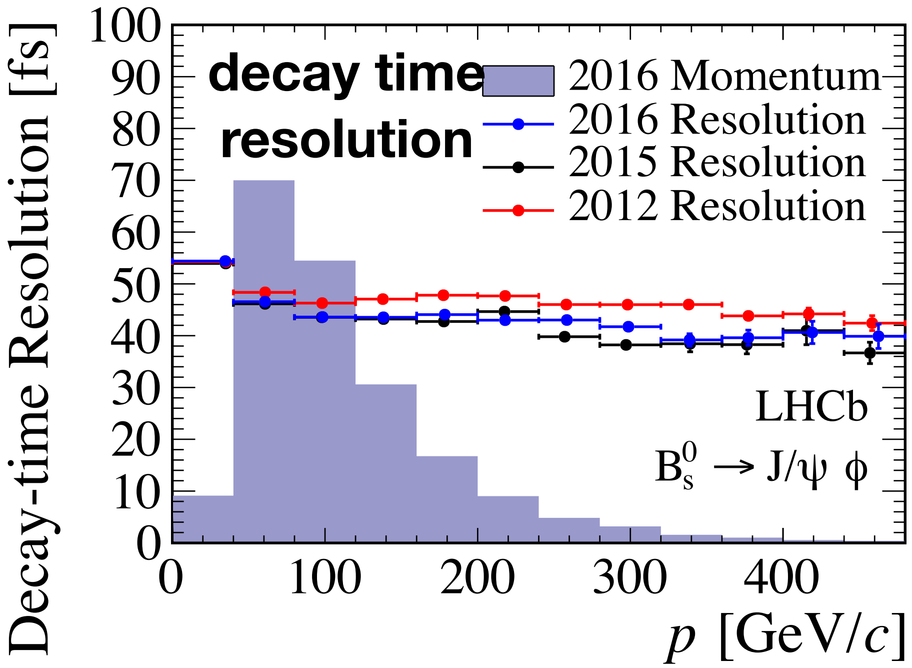

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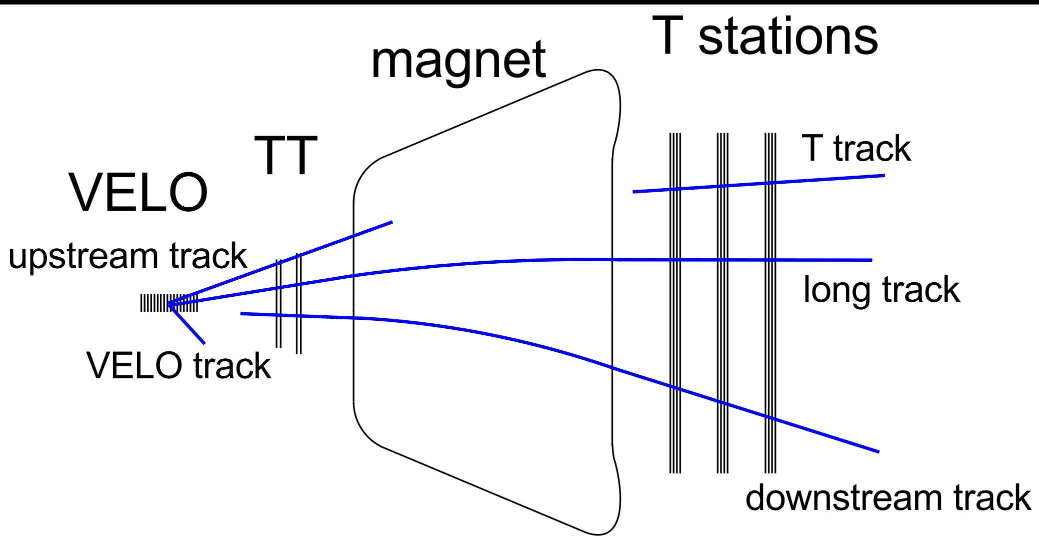
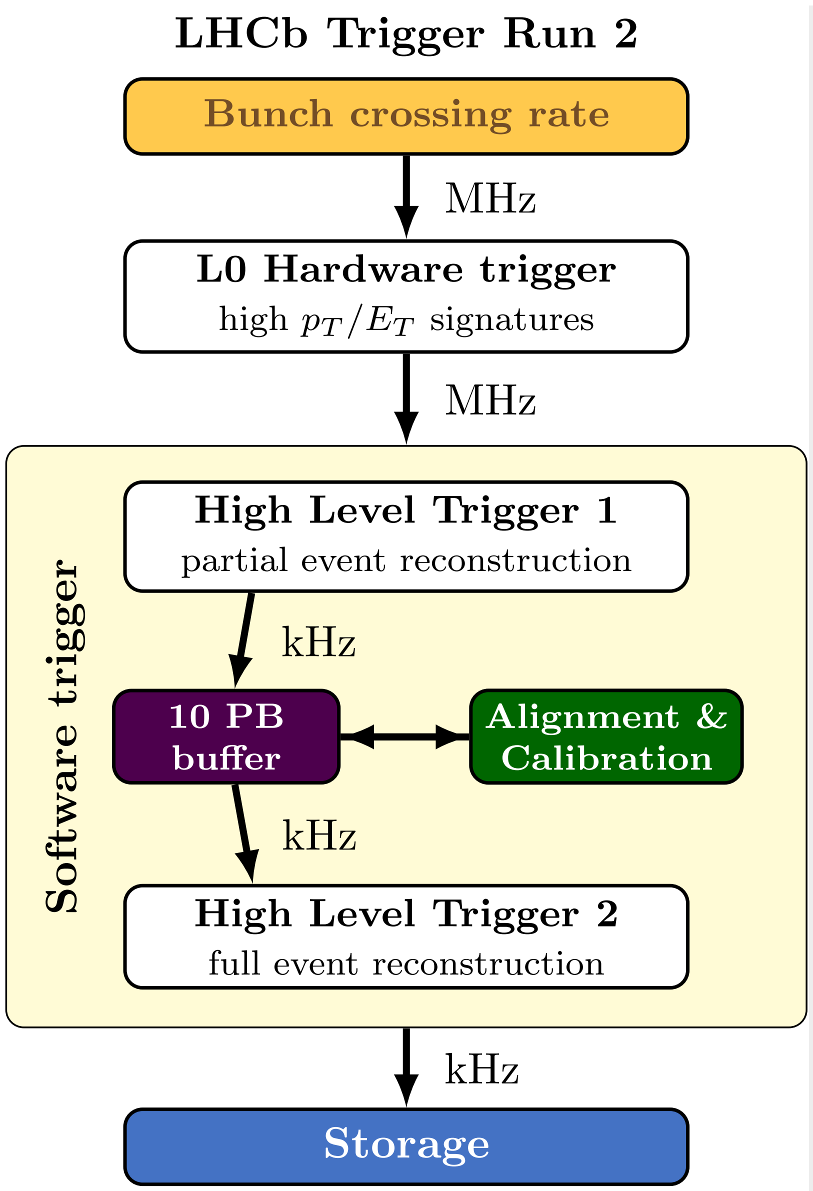
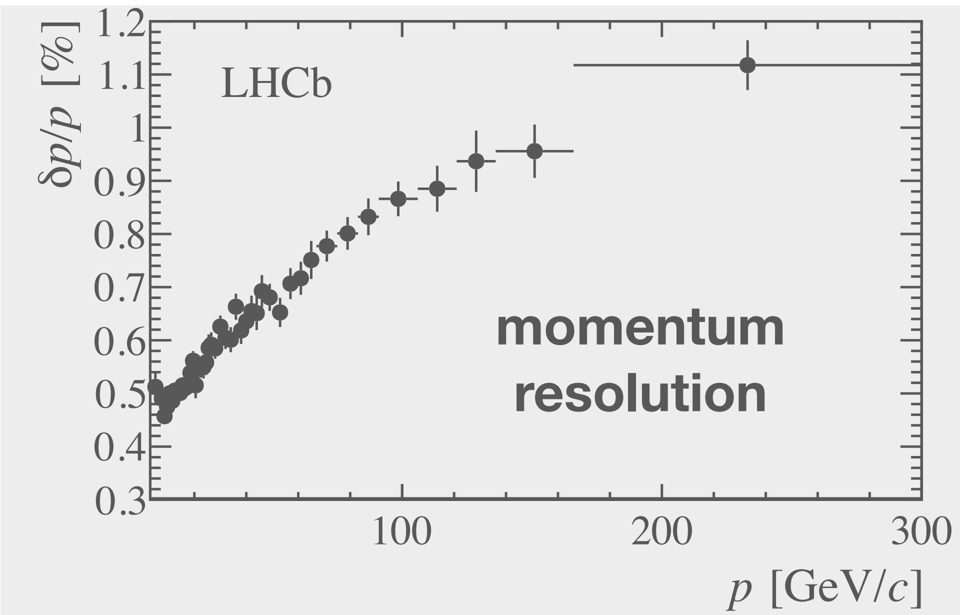
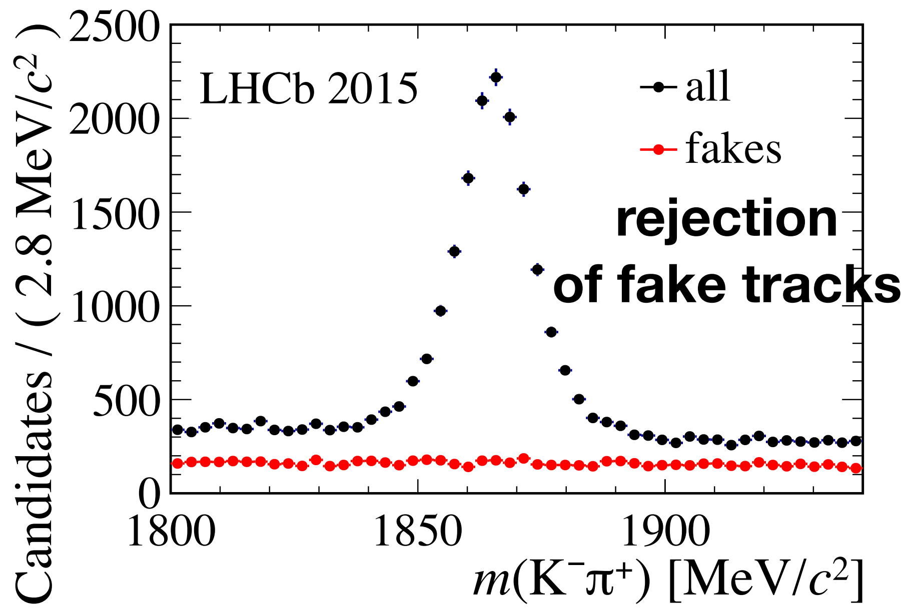
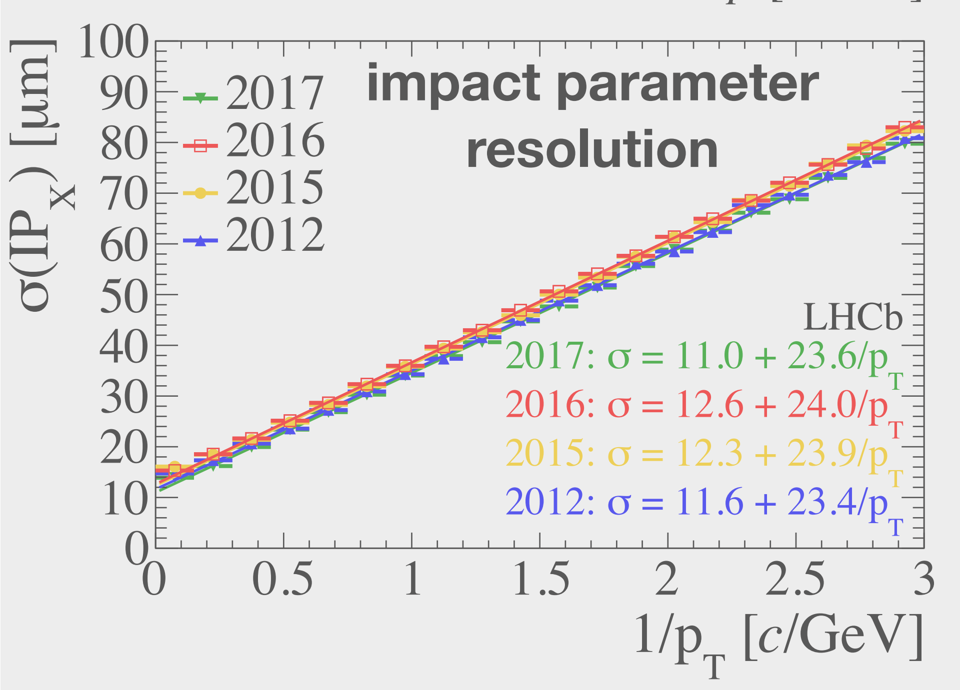
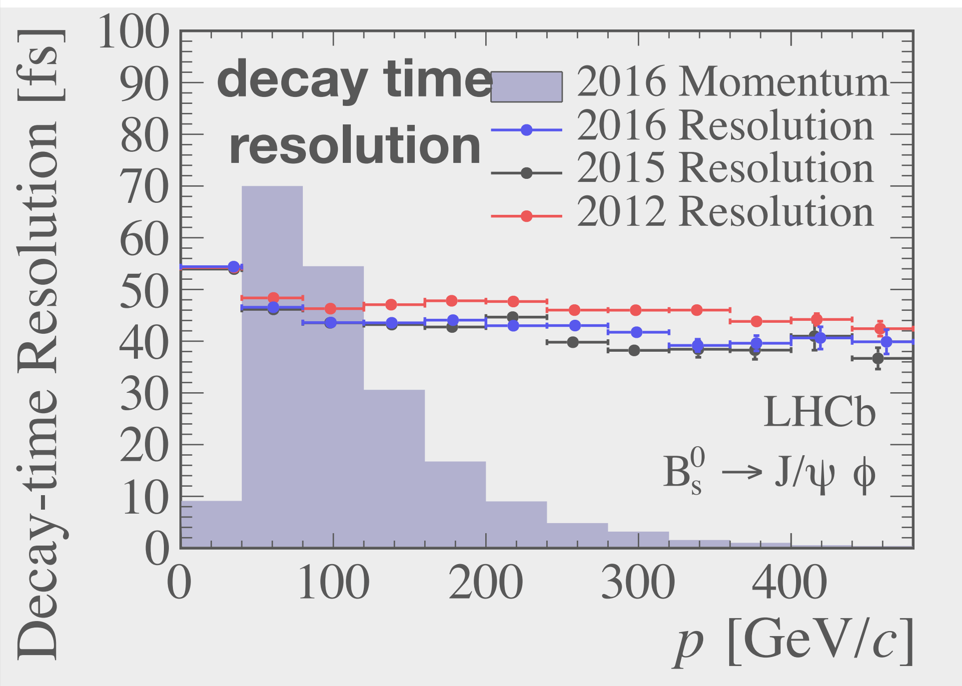








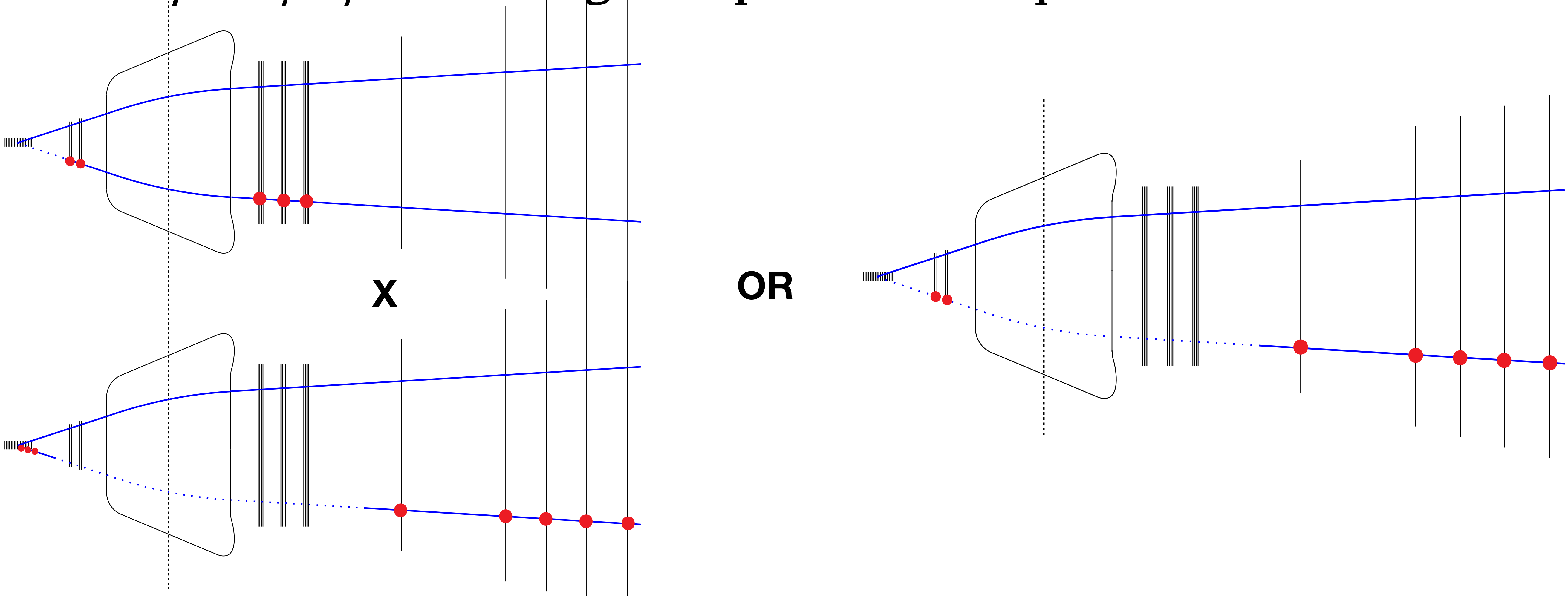


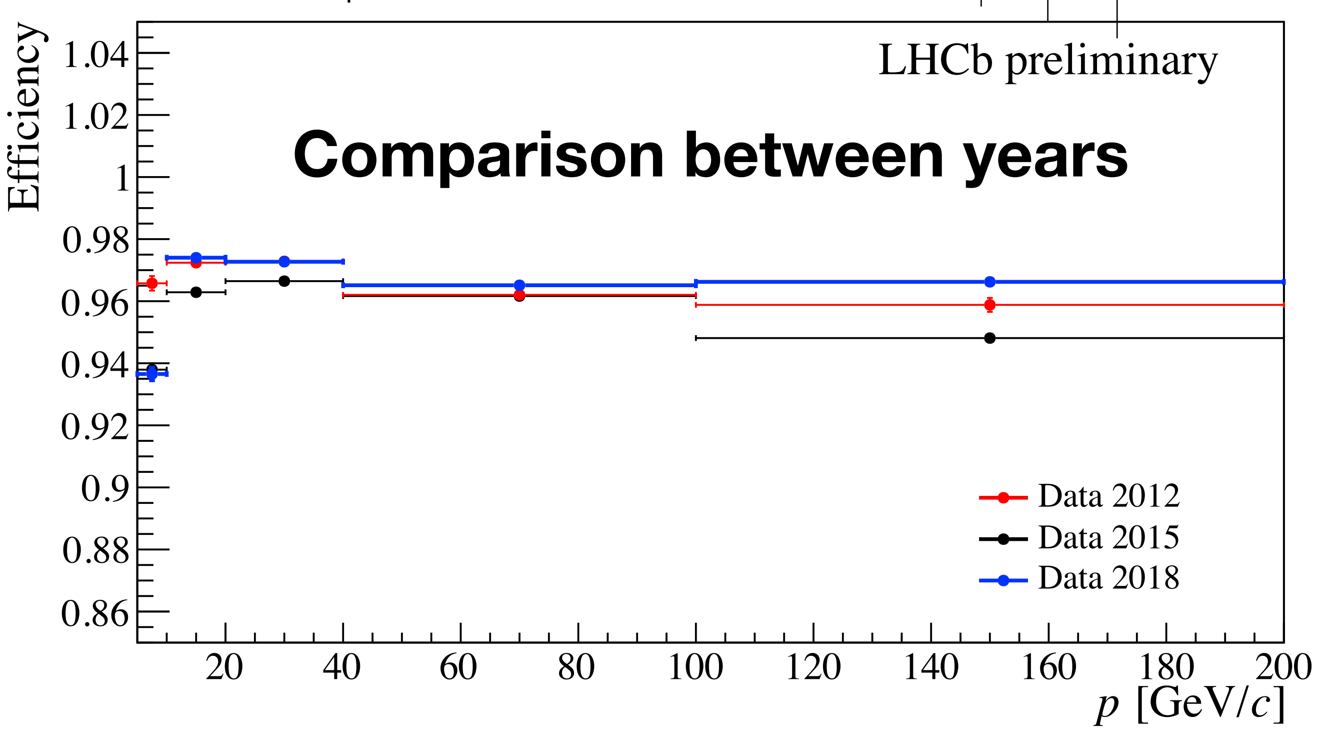


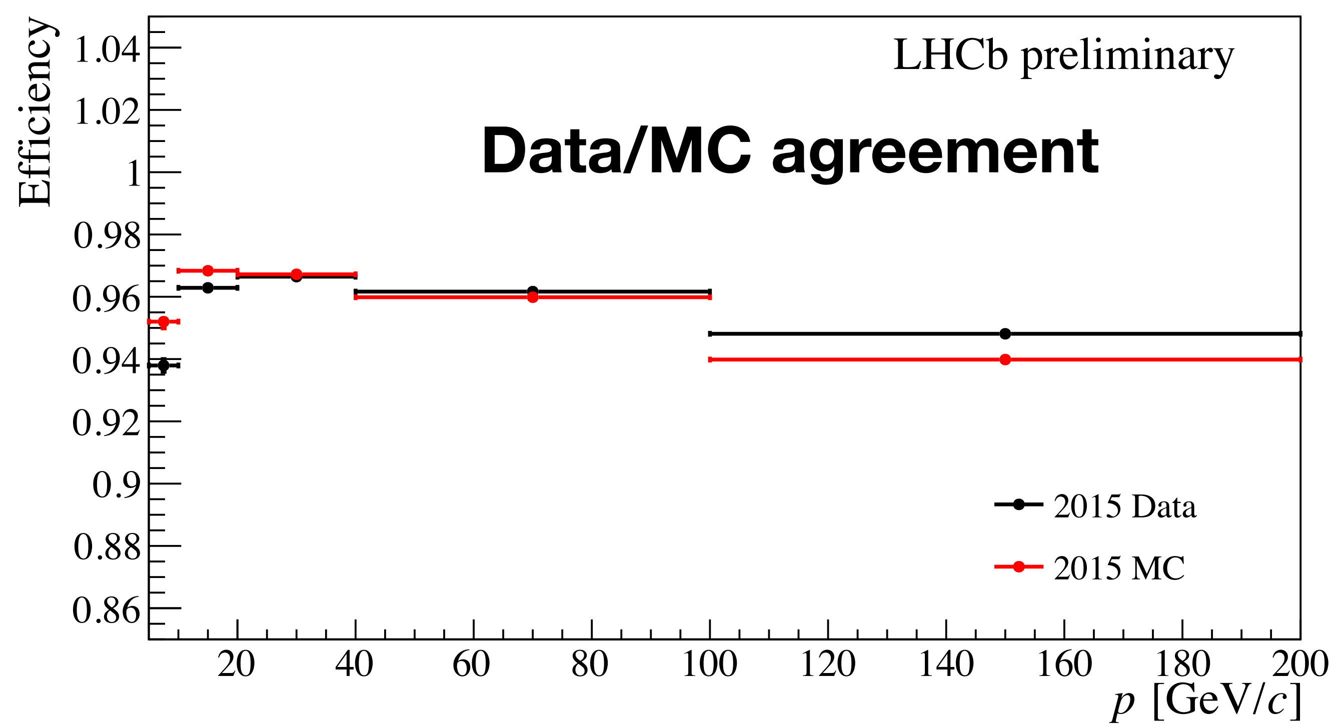
Tracking efficiencies: muons

JINST 10 (2015) P02007
LHCb-FIGURE-2020-010

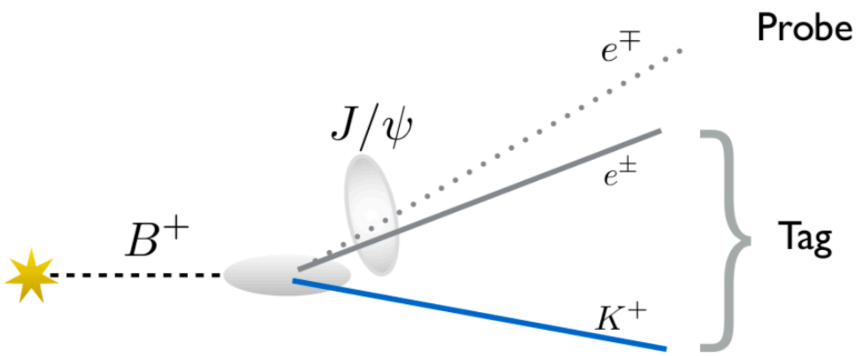
- Use $J/\psi \to \mu^+\mu^-$ with tag-and-probe technique

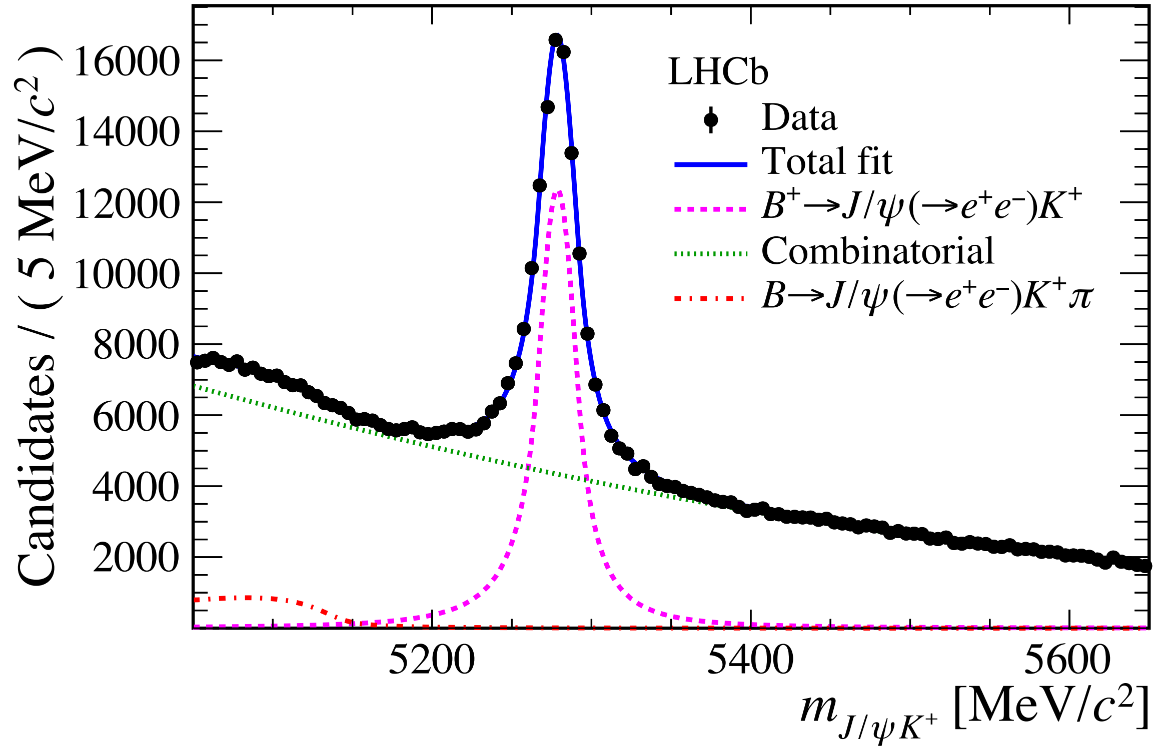






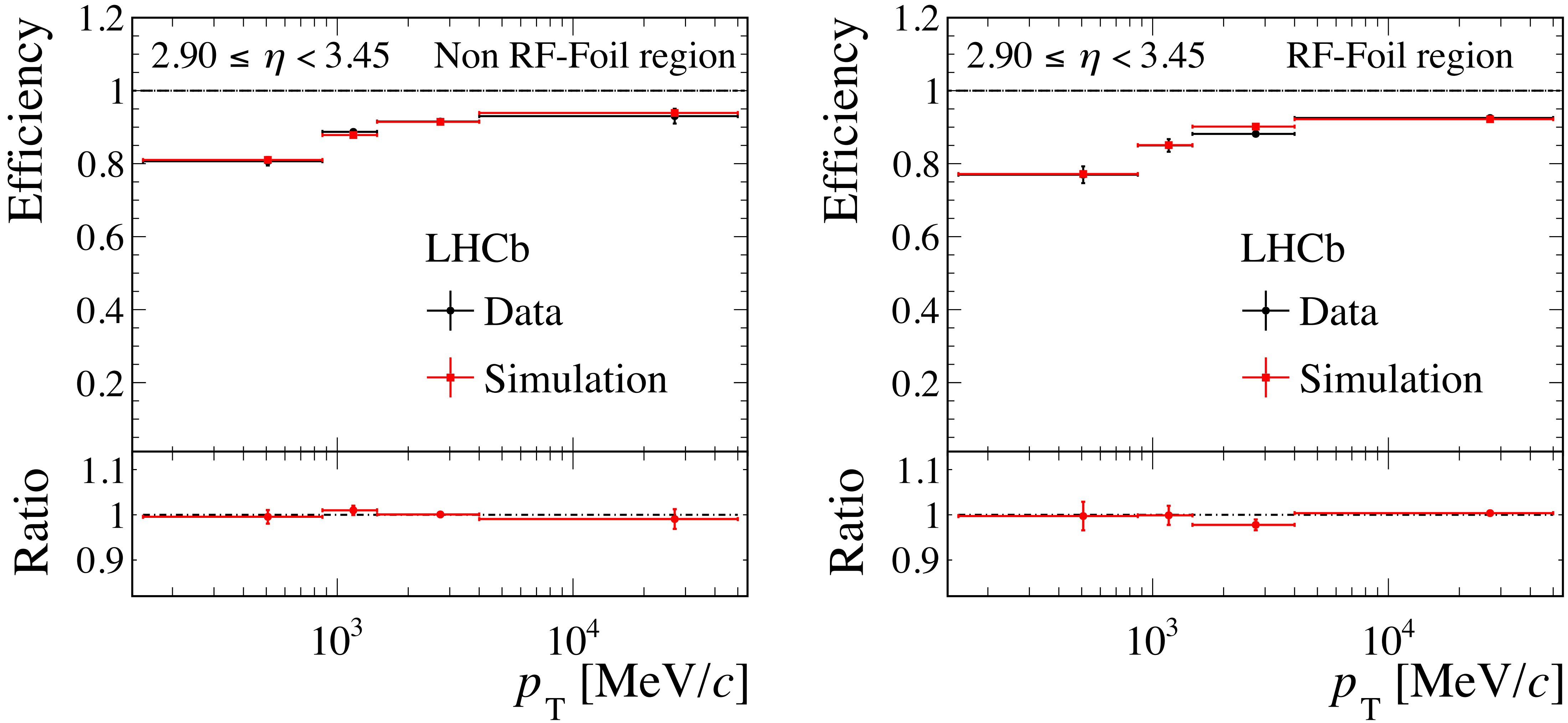
- Use $B^- \to (J/\psi \to e^+e^-)K^-$ with tag-and-probe technique
- Measure long track efficiency given the VELO track





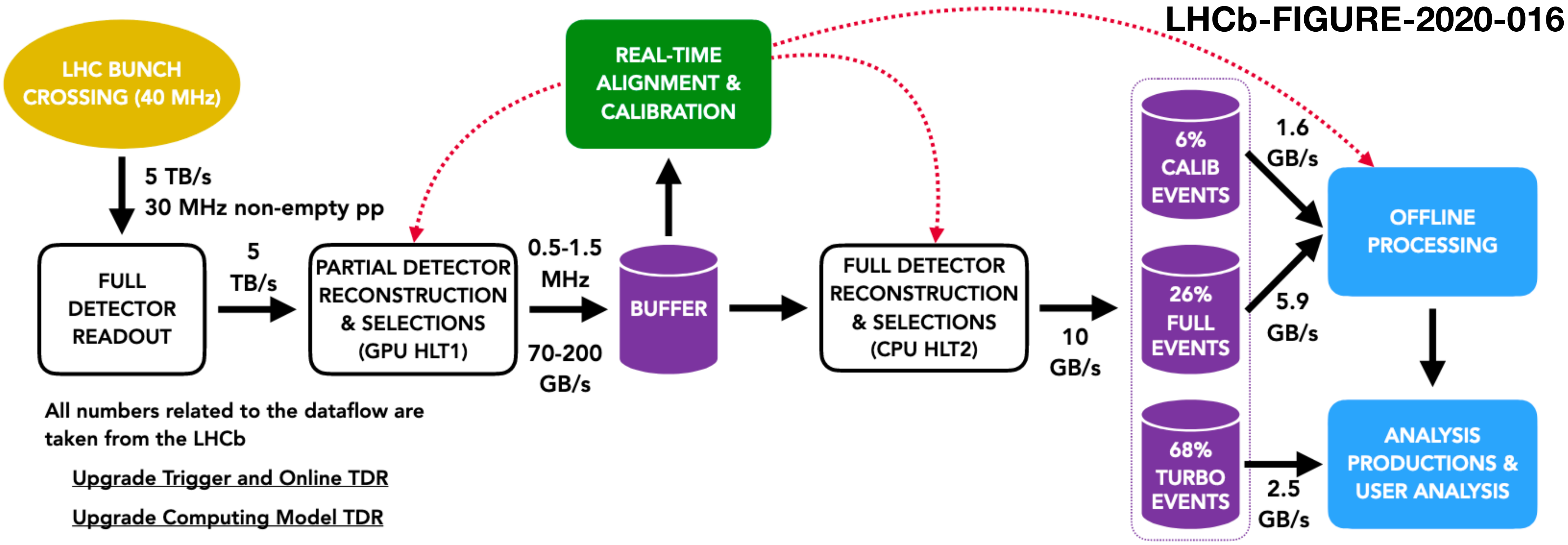
- Reasonable data-MC agreement

RF foil = extra material in VELO -> extra brem emission, secondaries etc



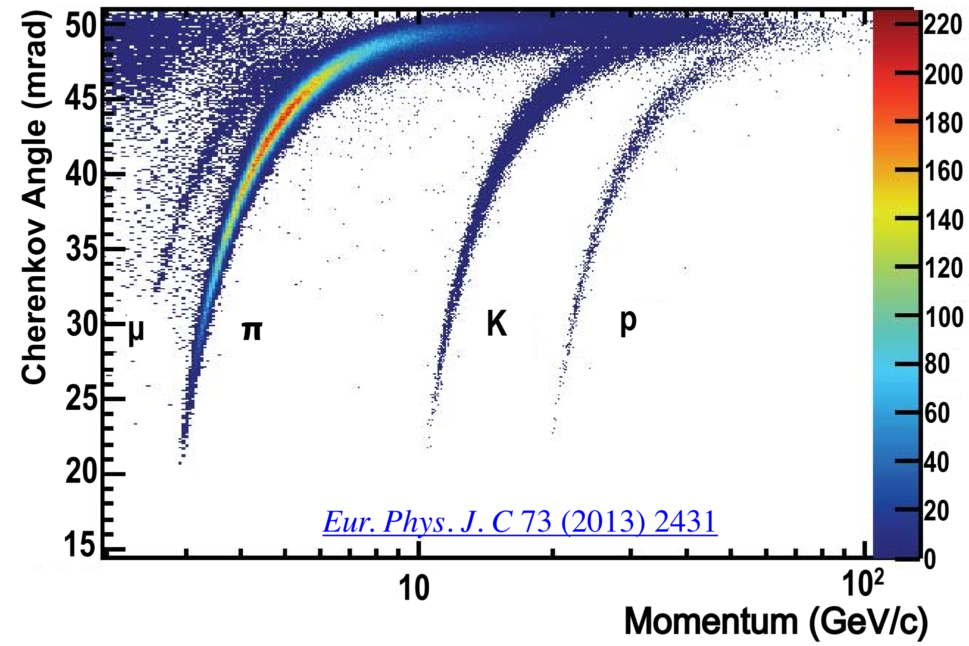
Tracking in the Upgrade

- Full reconstruction & alignment in the software trigger



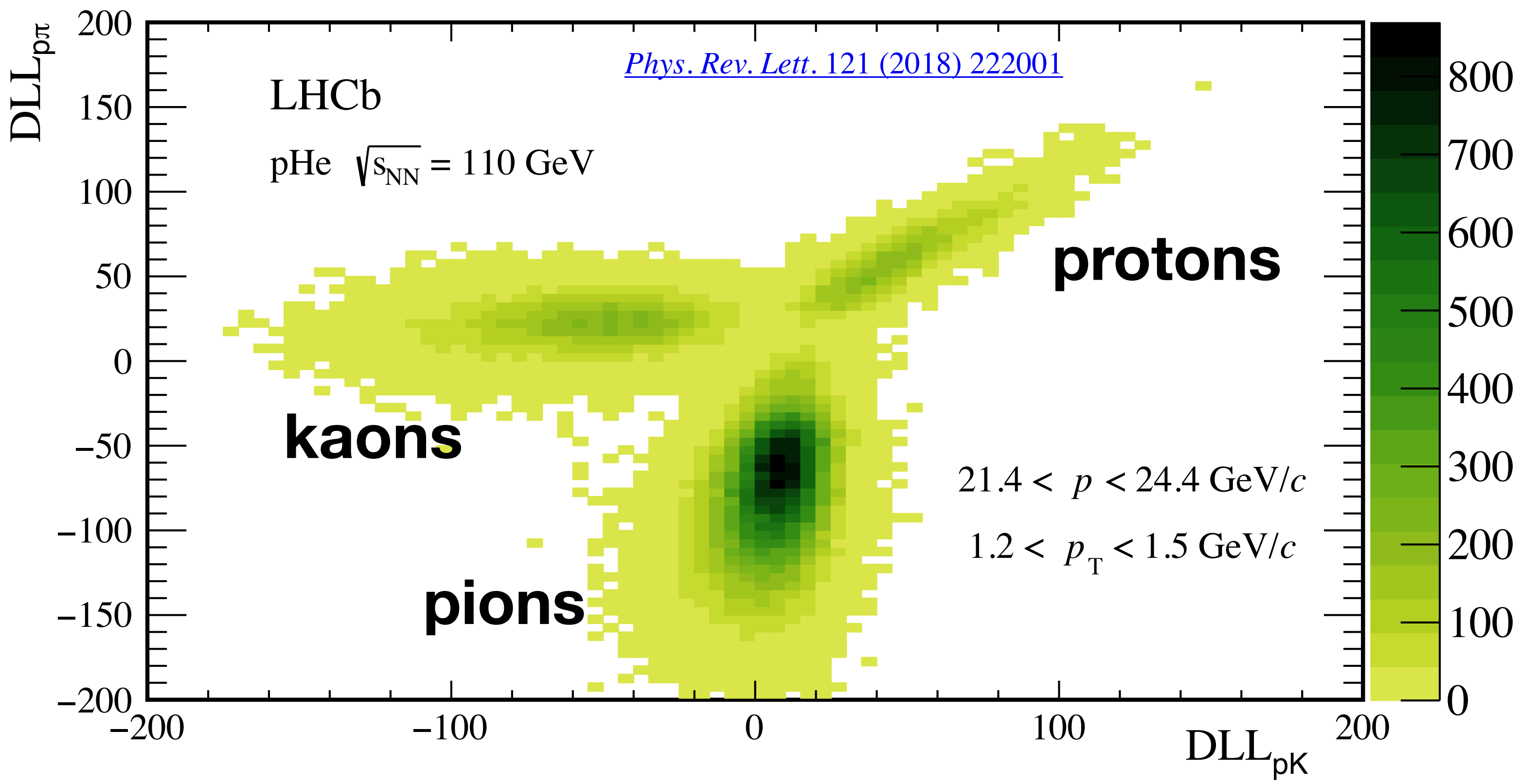
- See the talk by Louis Henry
- Challenges: high track multiplicity and number of primary vertices per event
- Full reconstruction at MHz rate
- Speed-ups must come with minimal losses for physics performance

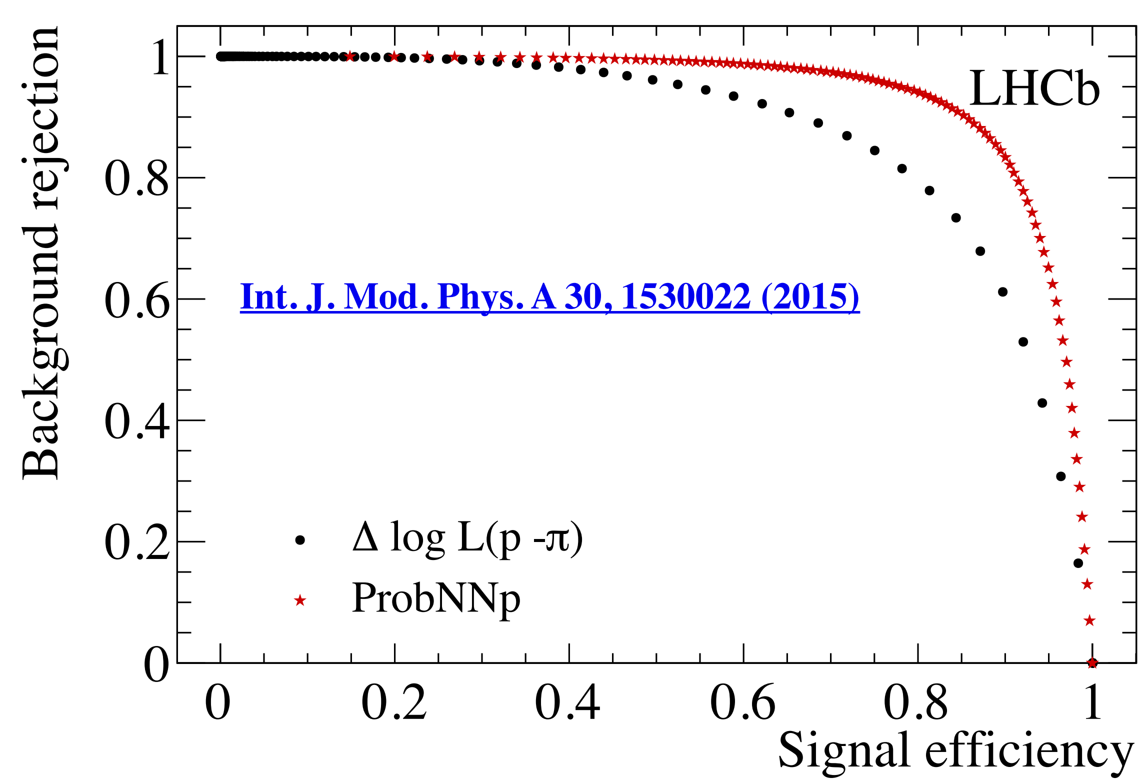
Charged PID



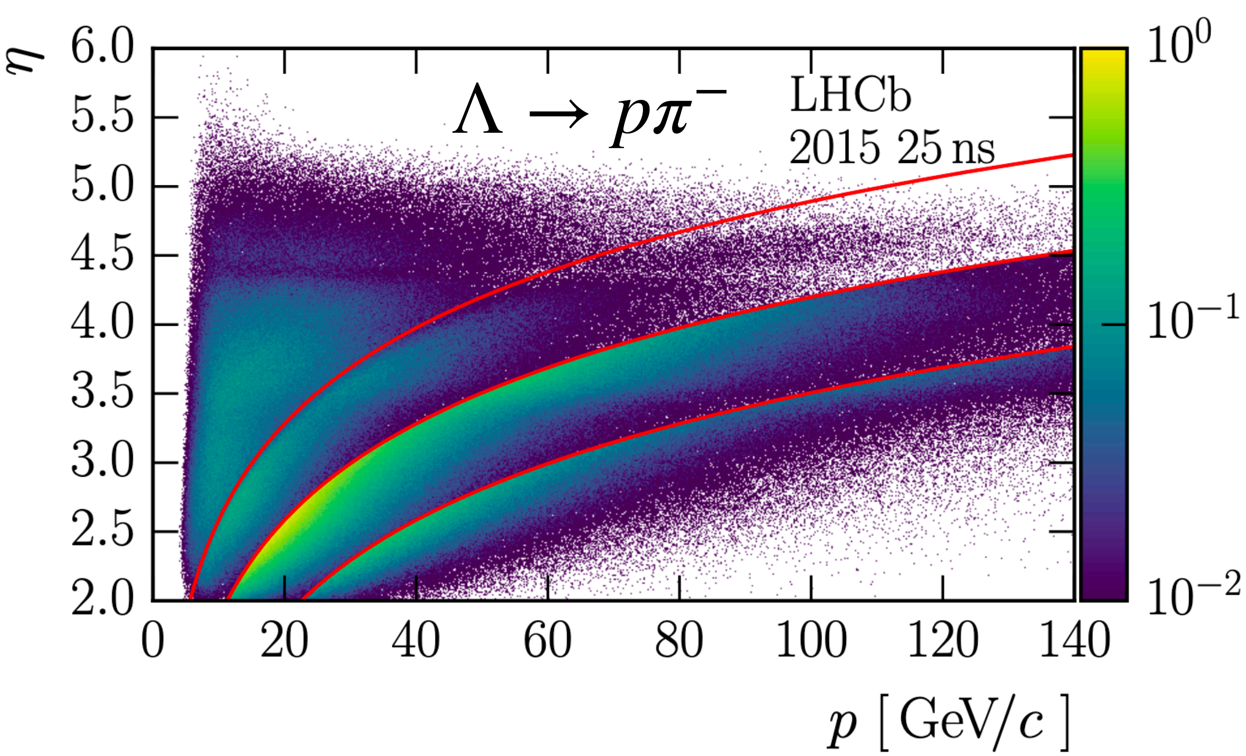
- RICH provides hadron ID
- Muon stations help with muons
- CALO: E/p for electron ID

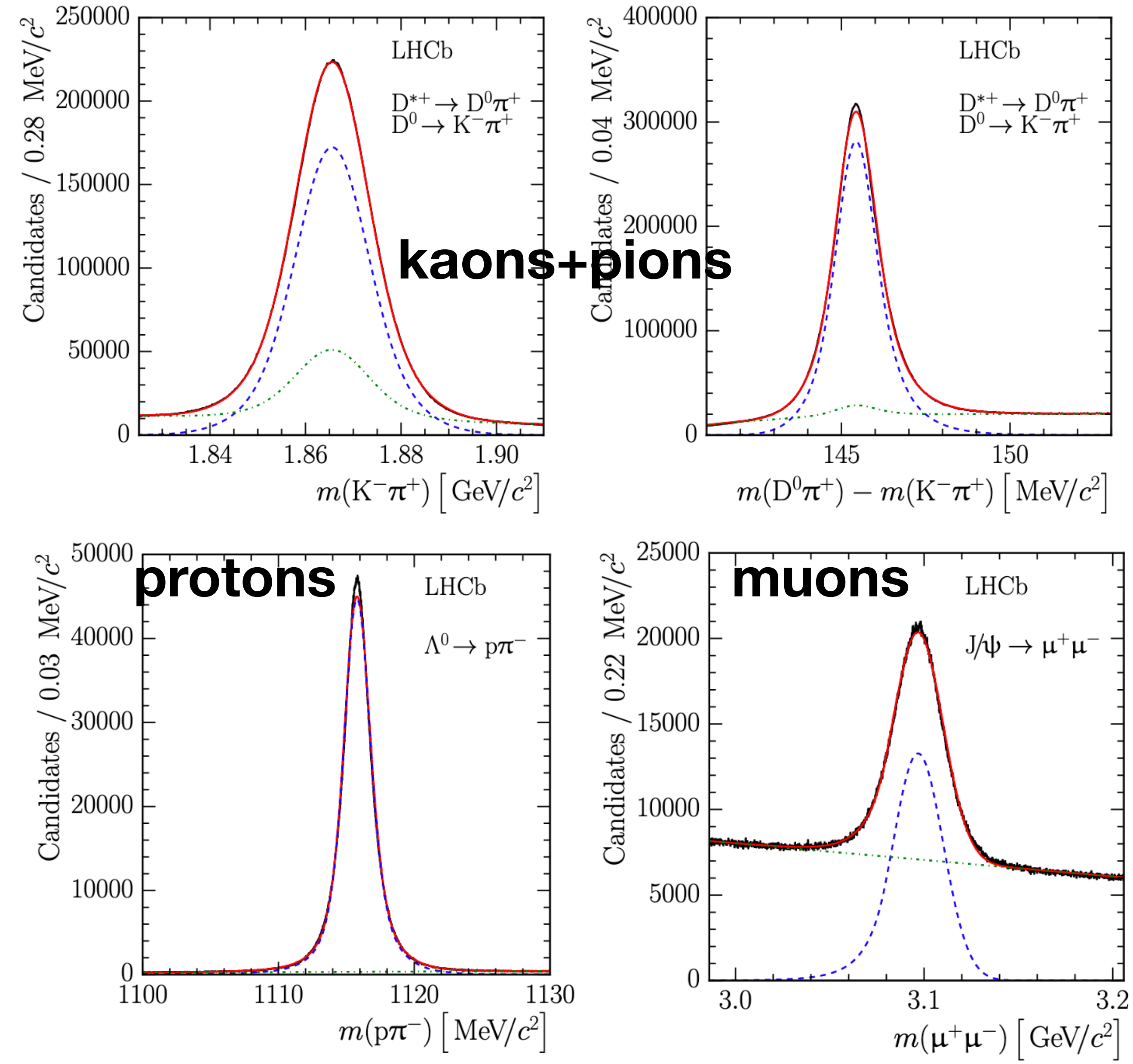
- Info from all subdetectors combined
- Alternative analysis-level variables:
  - "DLL": delta-log-likelihood of a given ID hypothesis compared to that of the pion
  - "ProbNN": probability of a given ID hypothesis predicted by a neural network
  - New muon ID variables designed for Run3, JINST 15 (2020) T12005
  - Work on better electron ID for Run3





- Large & clean calibration samples, minimally biased by the trigger, kinematic selection without PID cuts
- Kaons, pions: $D^0 \to K^- \pi^+$ from D^{*+}
- Protons: $\Lambda \to p\pi^-$; $\Lambda_c \to pK^-\pi^+$
- Leptons: $J/\psi \to \ell^+\ell^-$ from B decays

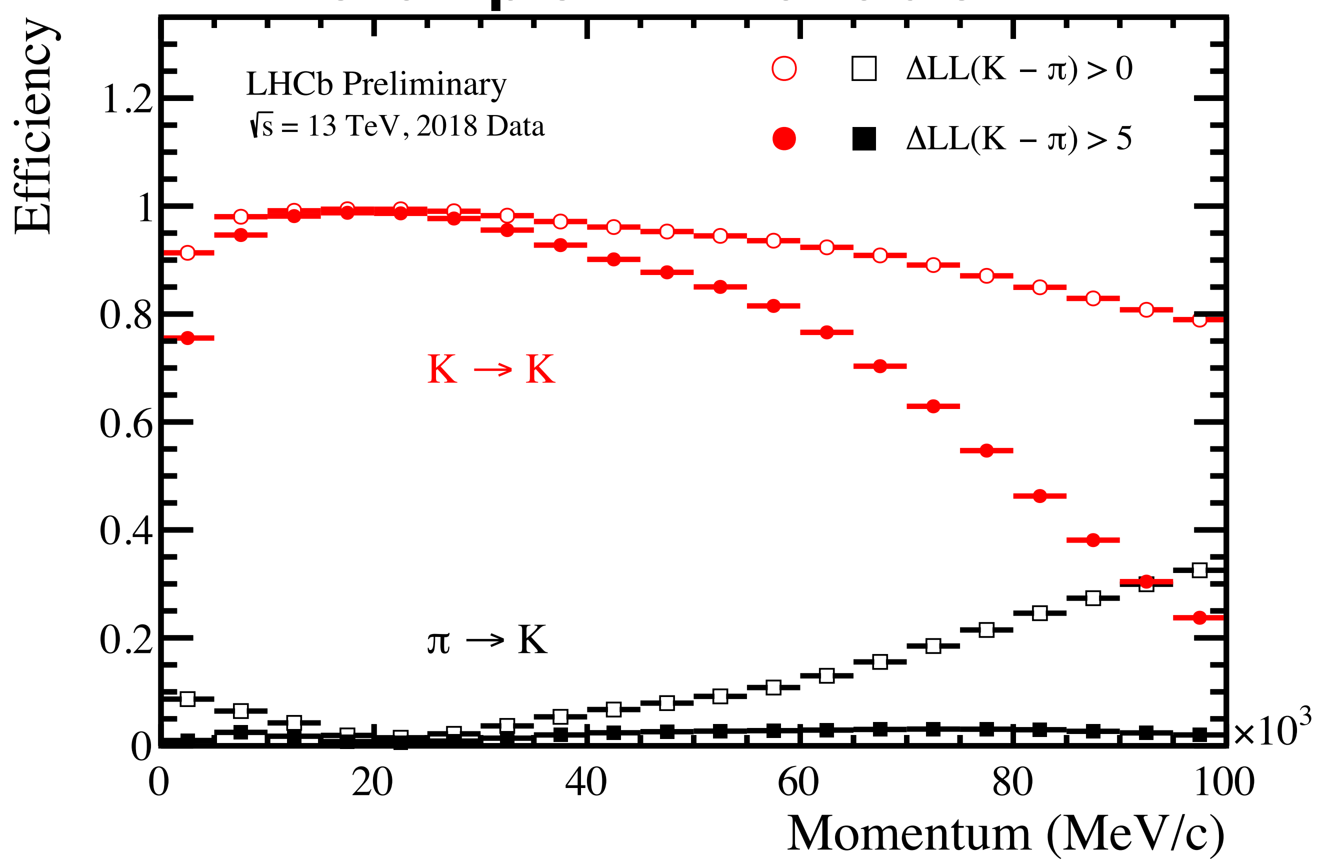


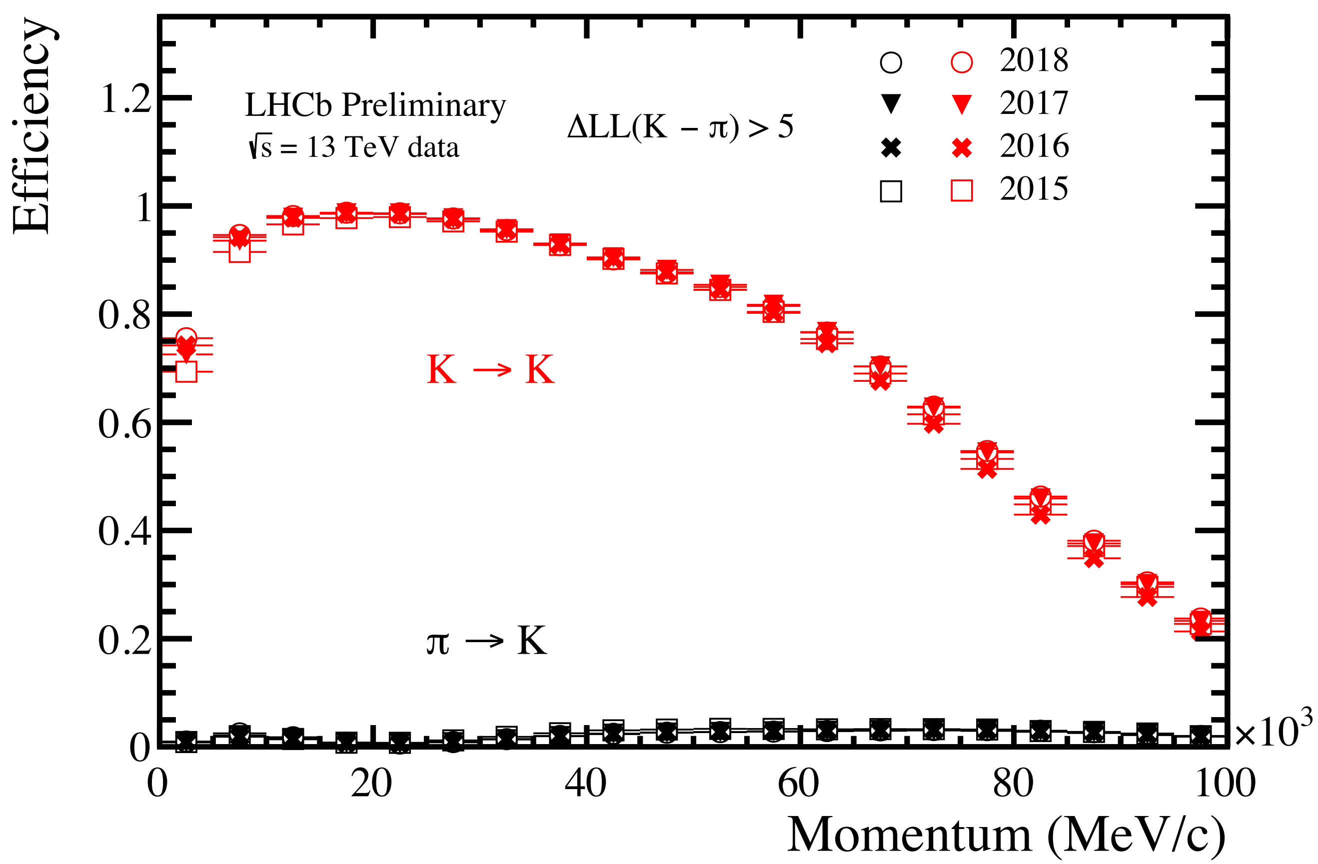


- selections designed to populate as large kinematic space as possible
  - + alternative samples for better kinematic coverage ($K_s \to \pi^+\pi^-$, etc)
- Usage: sPlot approach or fit-and-count approach
- Similar approach in Run3, but faster and more precise!

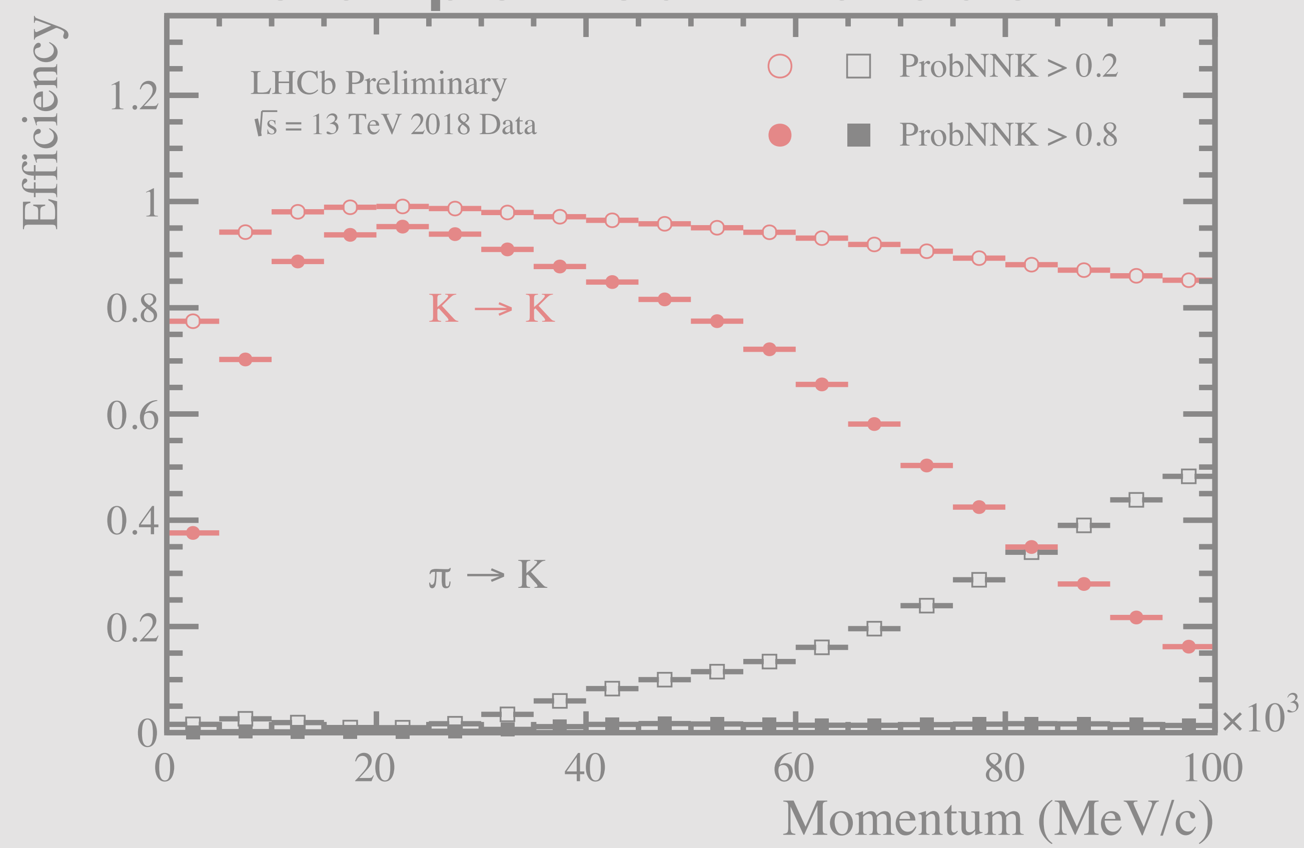
Charged PID: performance

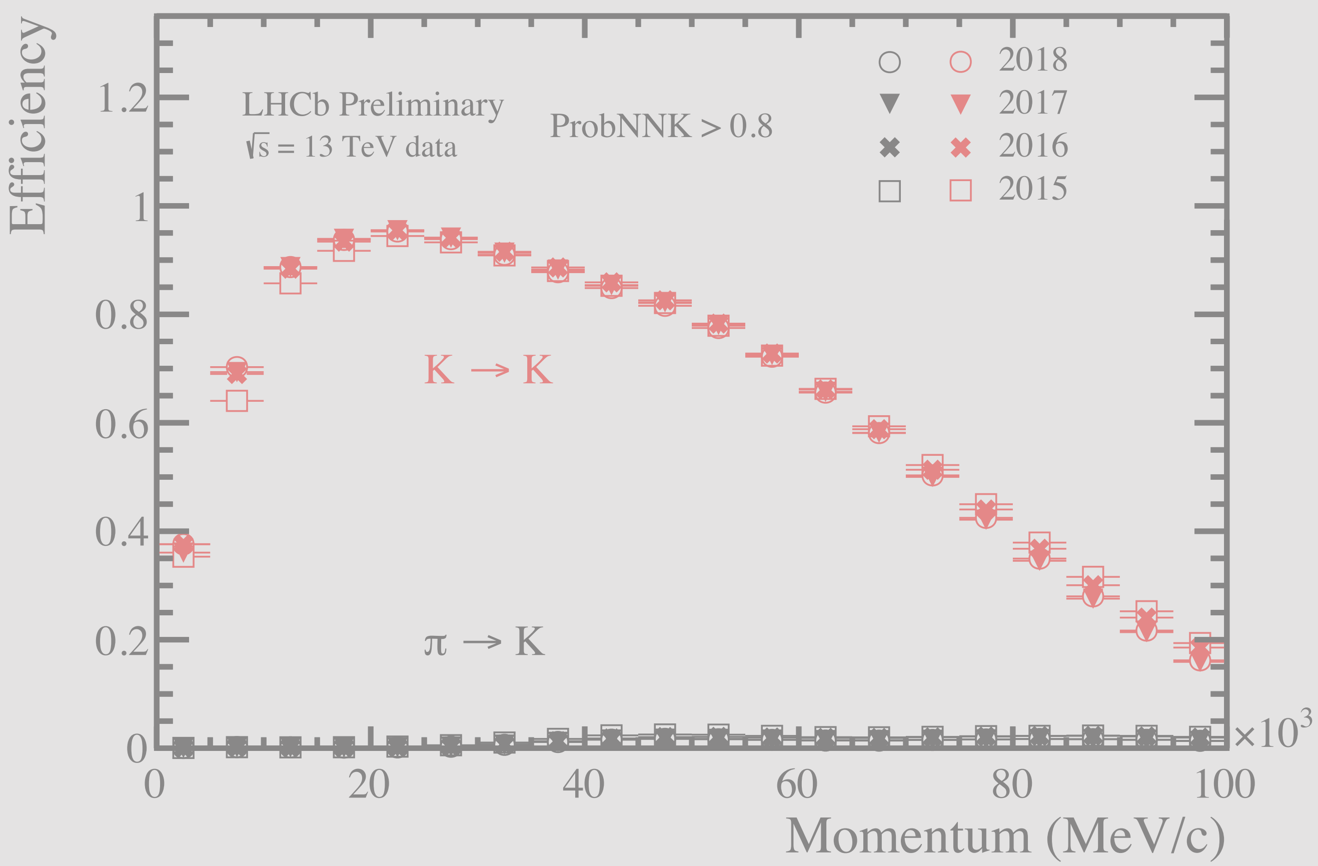
example DLL variable





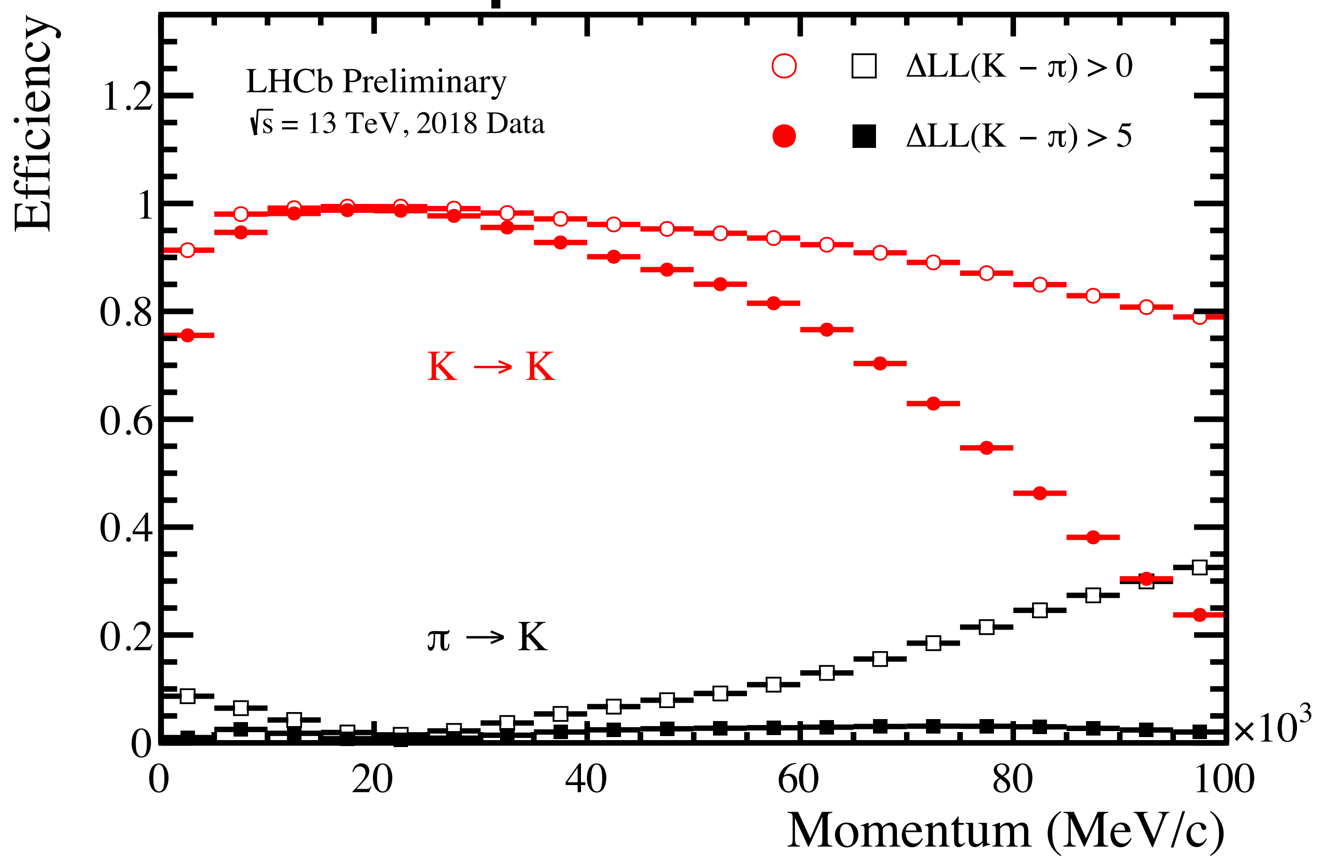
example ProbNN variable



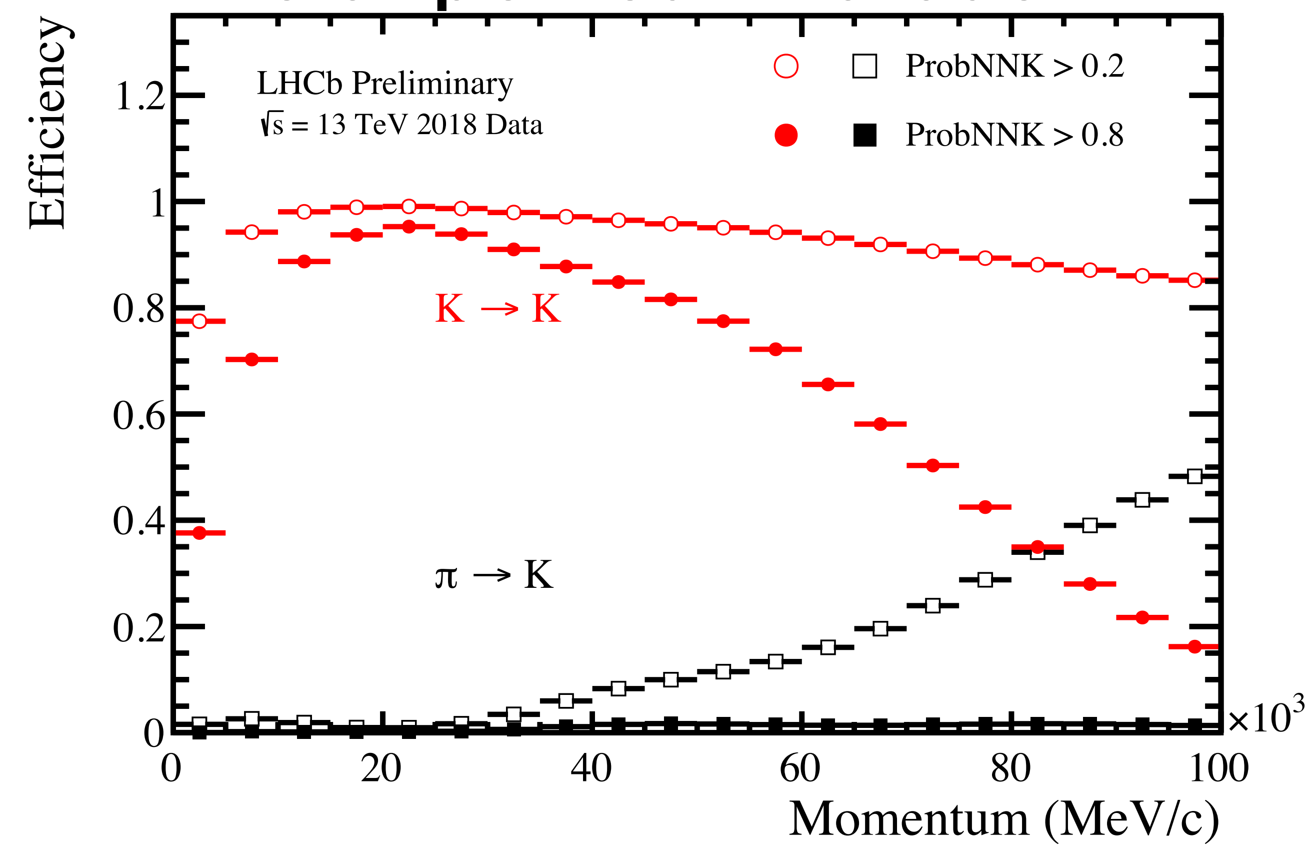


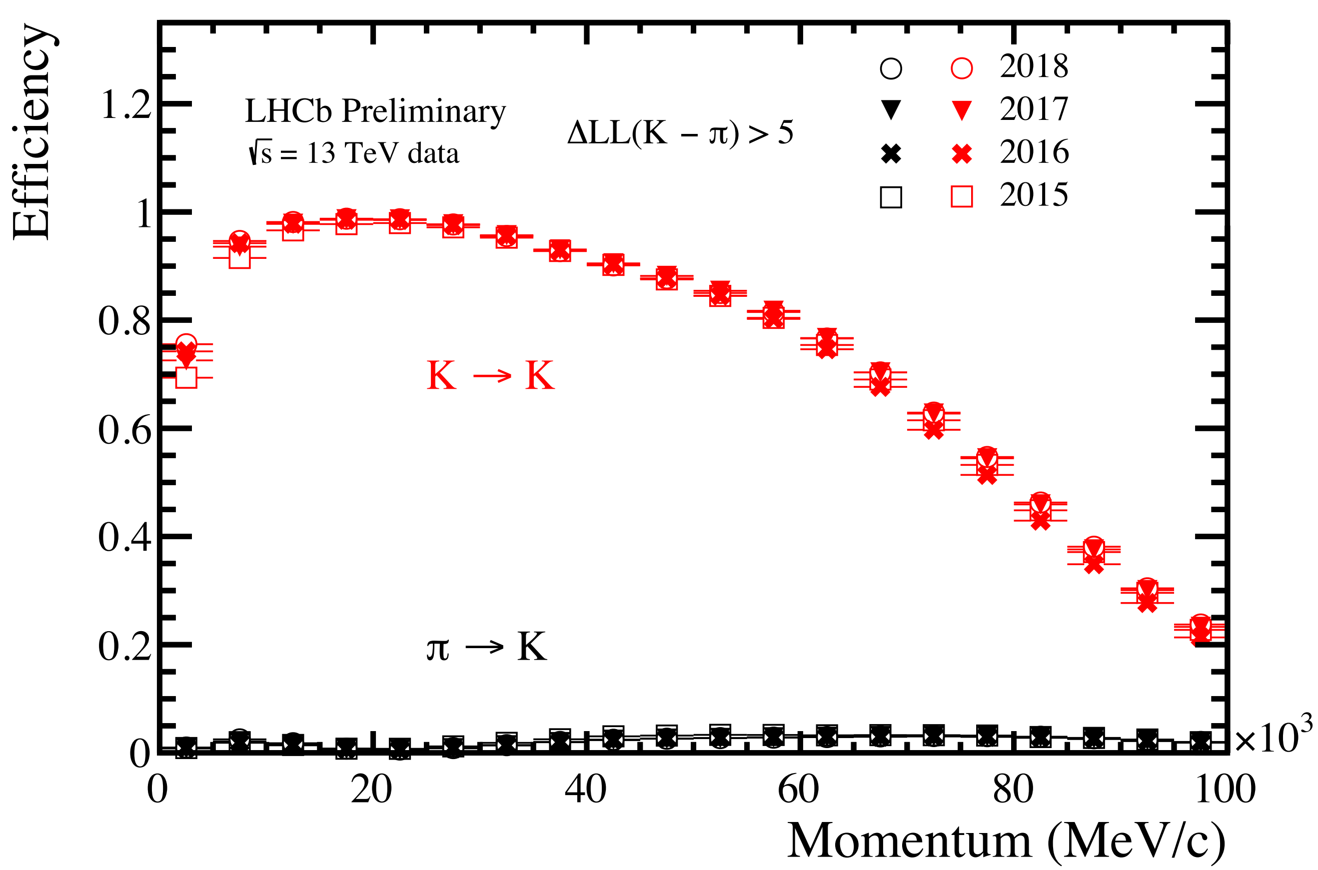
Charged PID: performance

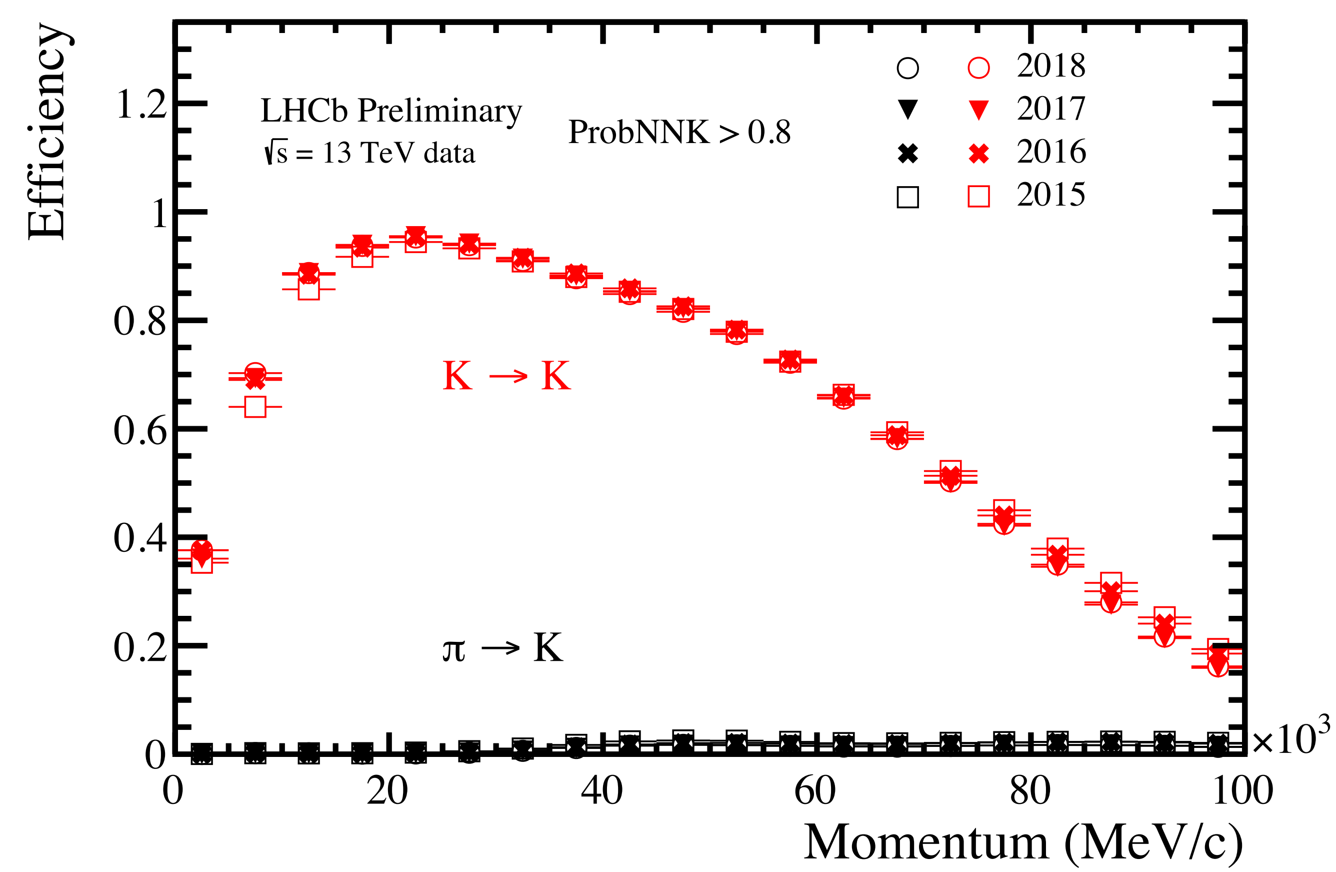
example DLL variable



example ProbNN variable



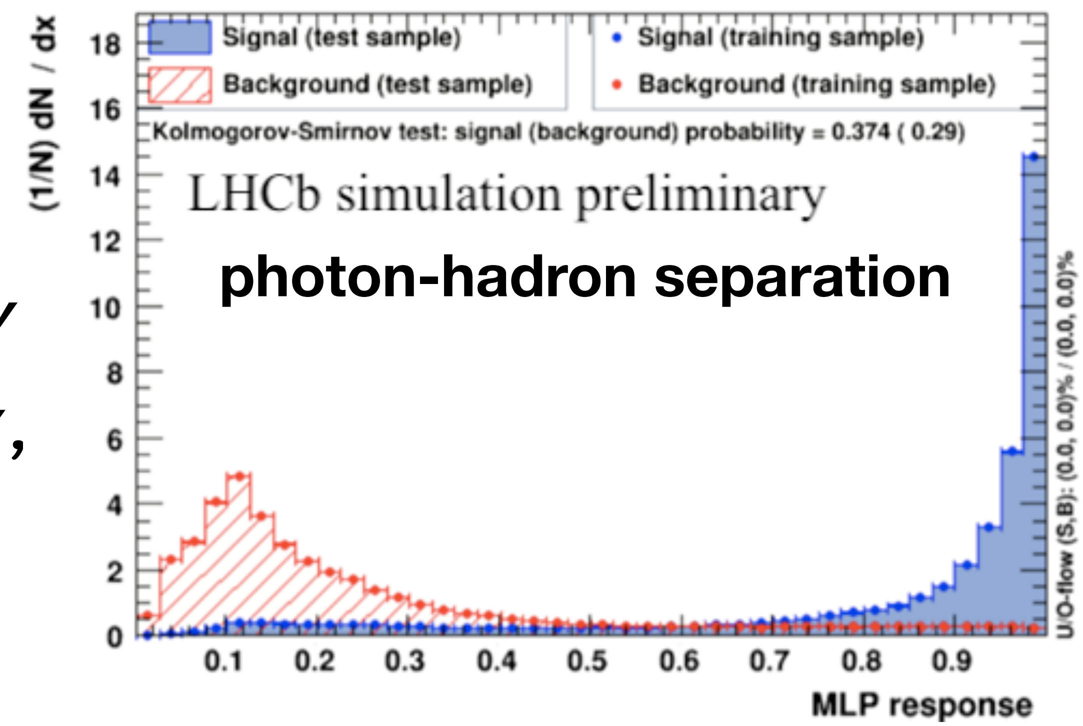


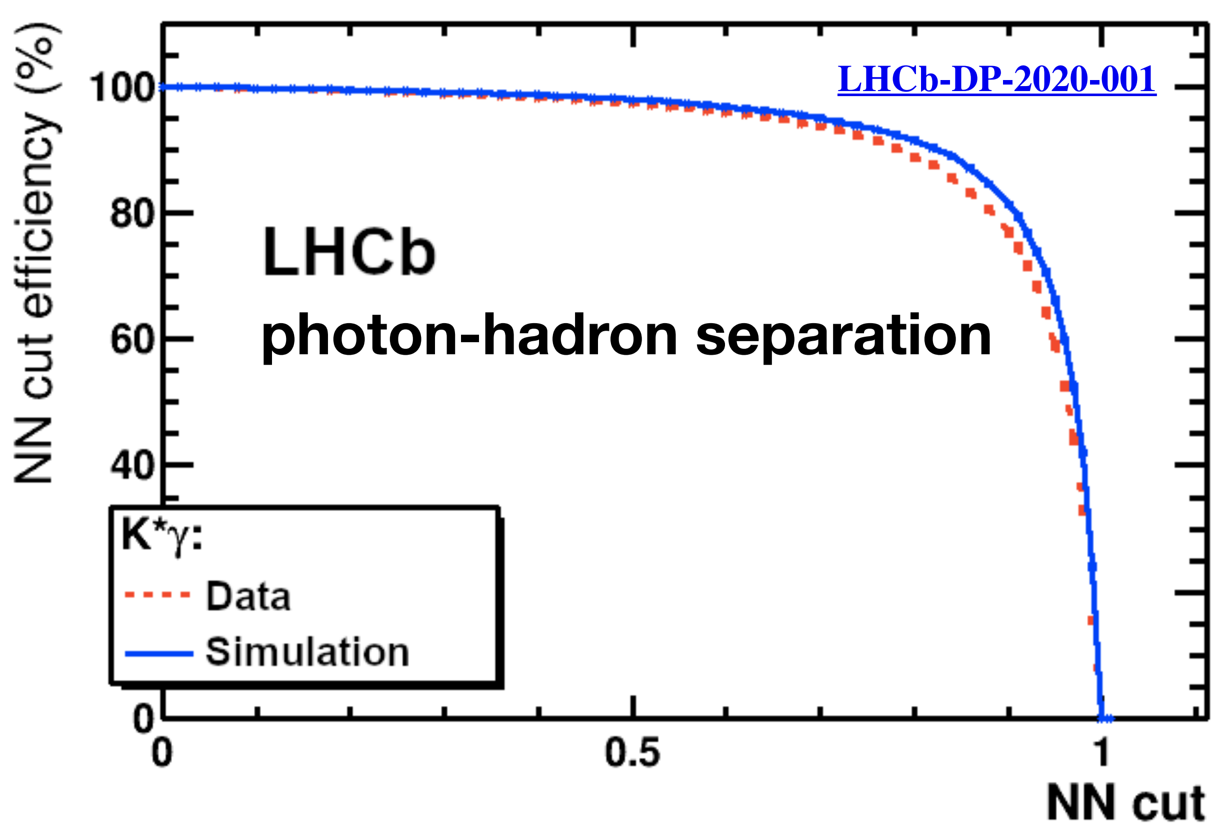


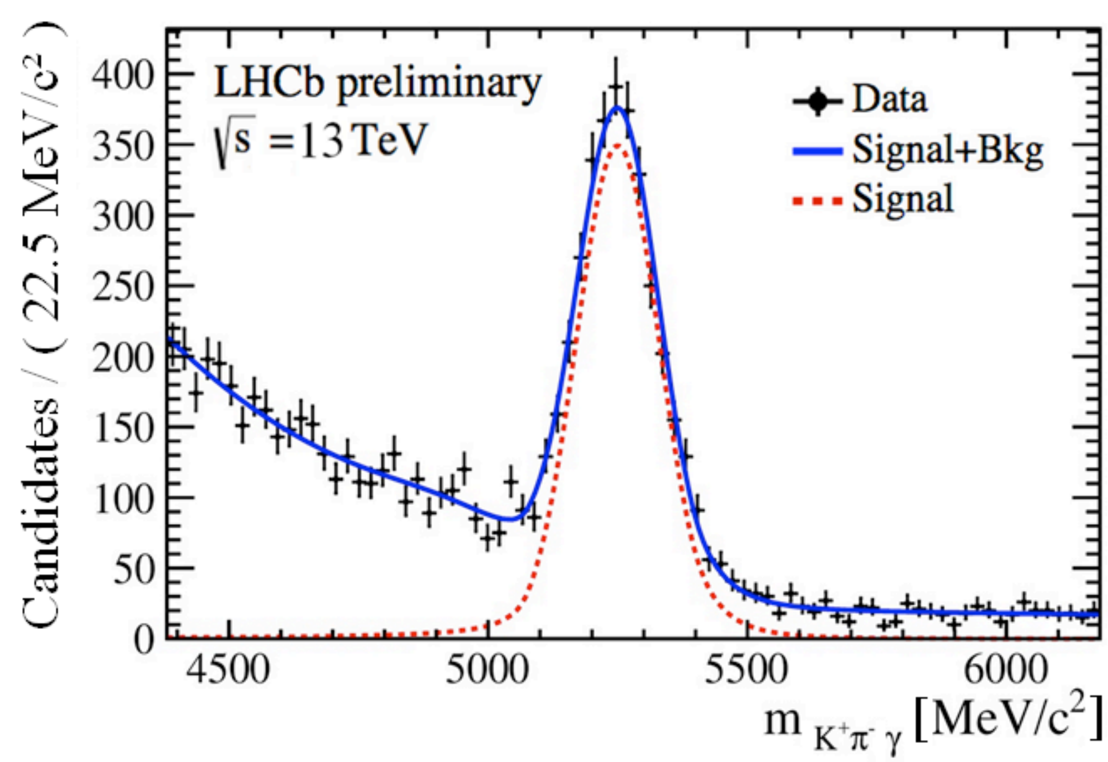
Neutral PID

- Separation of photons from charged hadrons and electrons, or photons from π^0 clusters

- Automated CALO calibration with $\pi^0 \to \gamma\gamma$
- ID calibration with $B \to K^*\gamma$, $D_s^{+*} \to D_s^+\gamma$, $\eta \to \mu^+\mu^-\gamma$, $D \to K\pi\pi^0$ etc



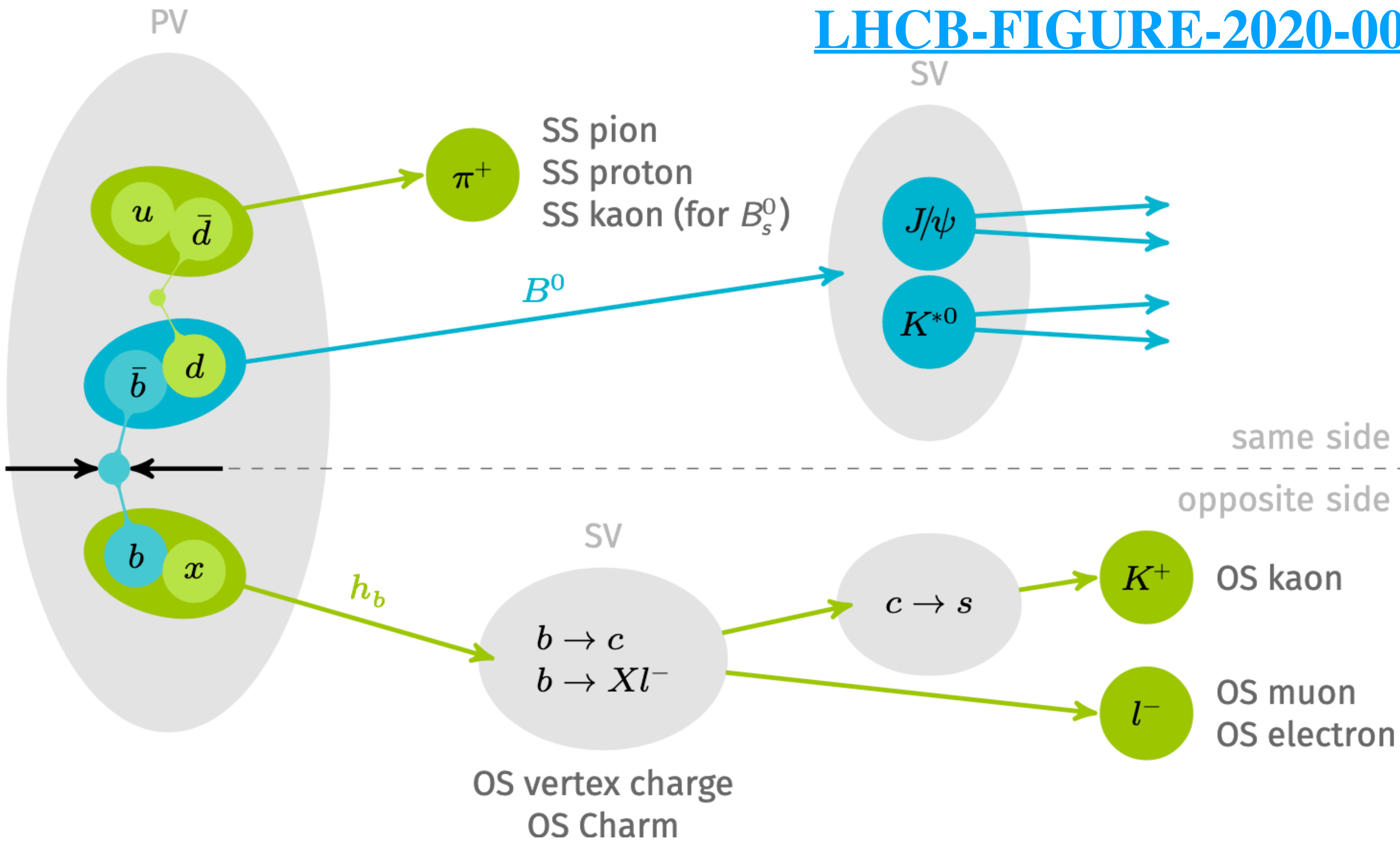




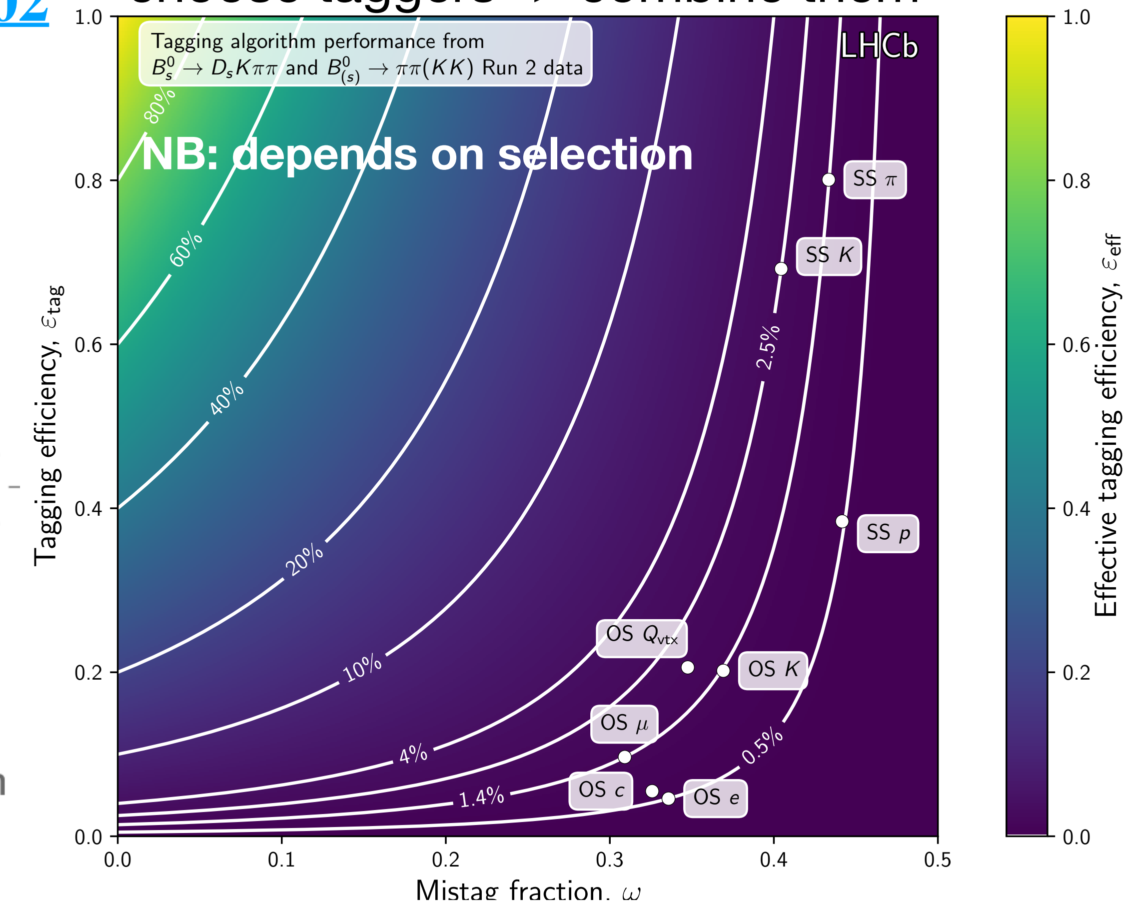
- Retuned tools for Run 3 due to removal of SPD/PS subdetectors

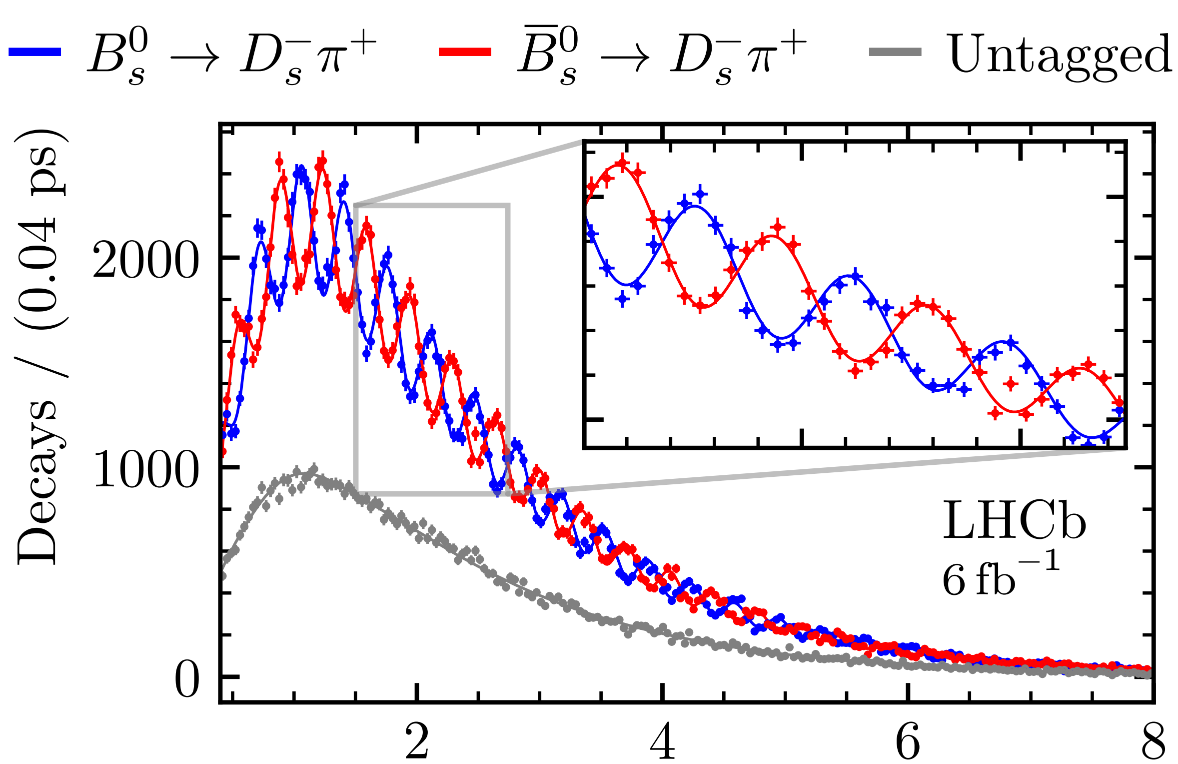
Flavour tagging: classical approach

[LHCB-FIGURE-2020-002](#)



choose taggers -> combine them





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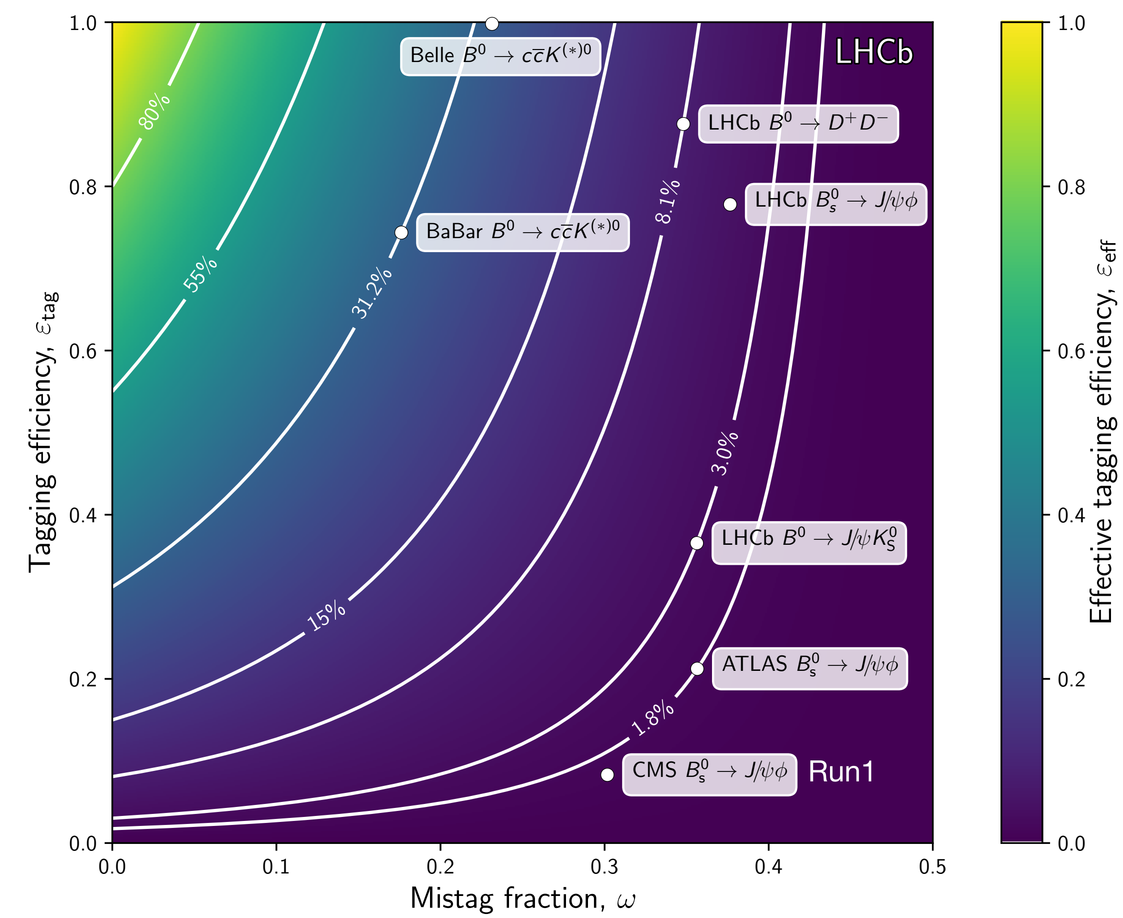
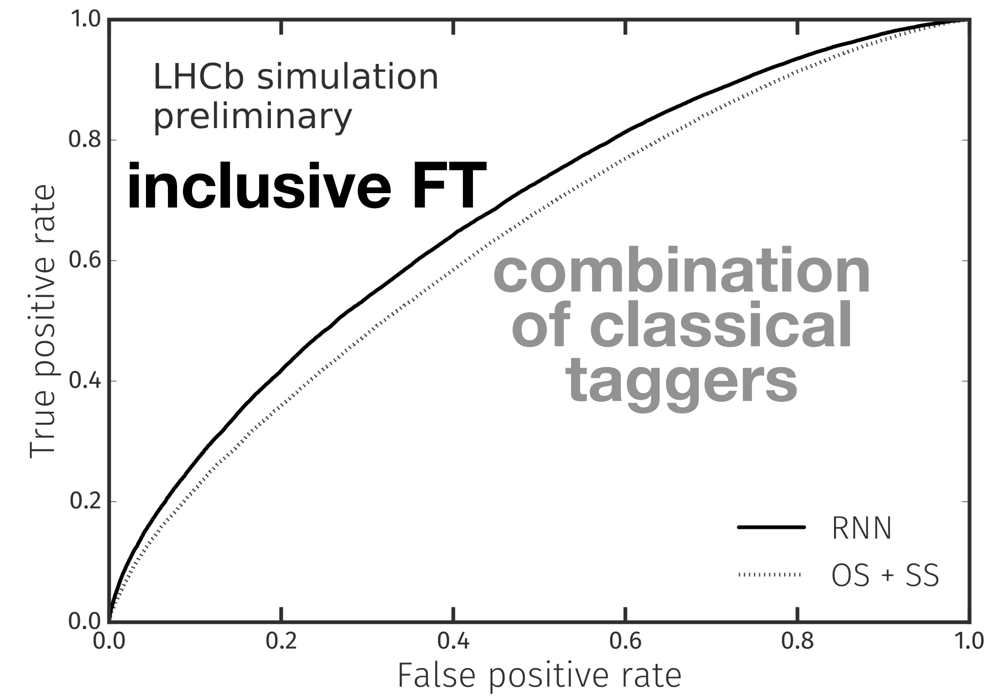


Inclusive flavour tagging

- Use state-of-the-art **deep learning** techniques: combine info of all non-signal tracks into the tag decision
  - tagging efficiency close to 100%
  - support one single framework (possibly with B^0/B_s^0 flavours) rather than 8 separate taggers
- Development of the optimal neural network architecture is the crucial part
  - Adapt to variable number of tracks
  - Avoid overtraining or learning biasing features
  - Validation on B^+/B^- data (self-tagging)



- Integration and validation into the Run3 software stack to ensure smooth transition
- Run 3 challenges:
  - FT performance degrades at high track multiplicity & pile-up
  - Event model must store enough information to run FT

- For more details, see this poster

Summary

- Excellent performance of all LHCb subsystems in Run 2
- Lots of experience gained to ensure smooth performance in the Upgrade(s)
- Looking forward to Run 3!

(placeholder for a funny cat picture)

Questions?