



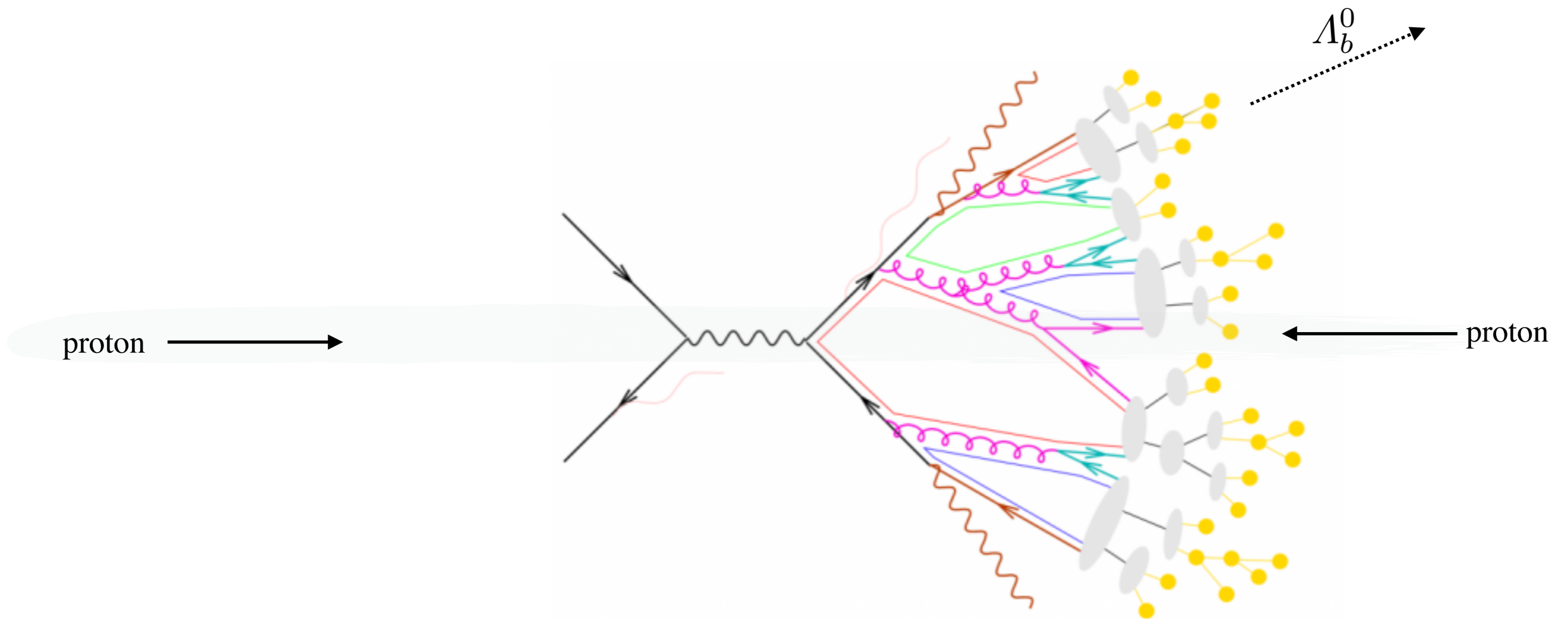
Observation of Λ_b - $\bar{\Lambda}_b$ production asymmetries in 7 and 8 TeV pp collisions (at LHCb)

LHCb-PAPER-2021-016, [arXiv:2107.09593](https://arxiv.org/abs/2107.09593)

EPS 2021 July 27, 2021

Laurent Dufour, on behalf of the LHCb collaboration

Production asymmetries



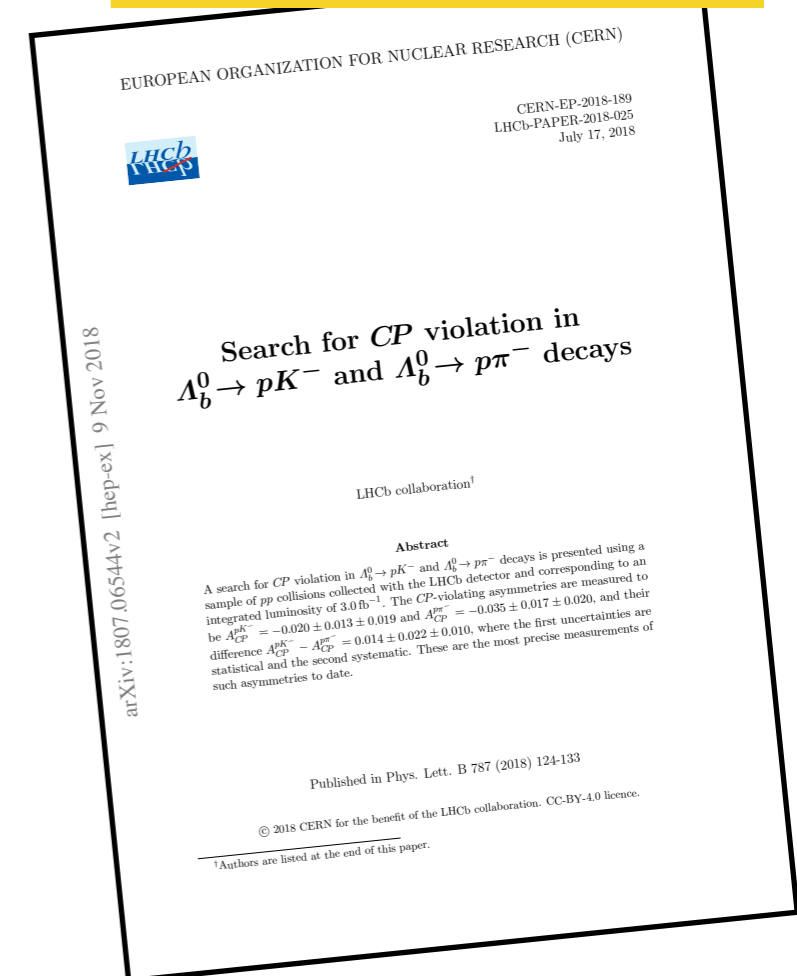
Lowest-order: b-hadron production symmetric
Initial state not symmetric: symmetry not perfect

Λ_b production asymmetries

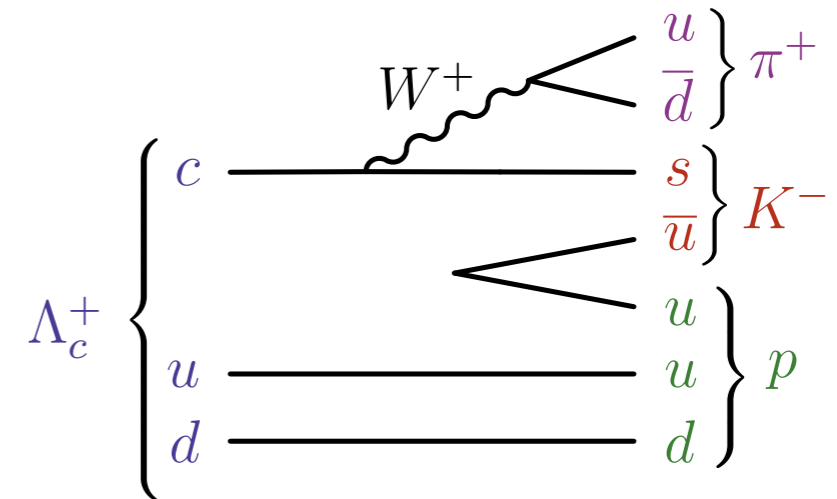
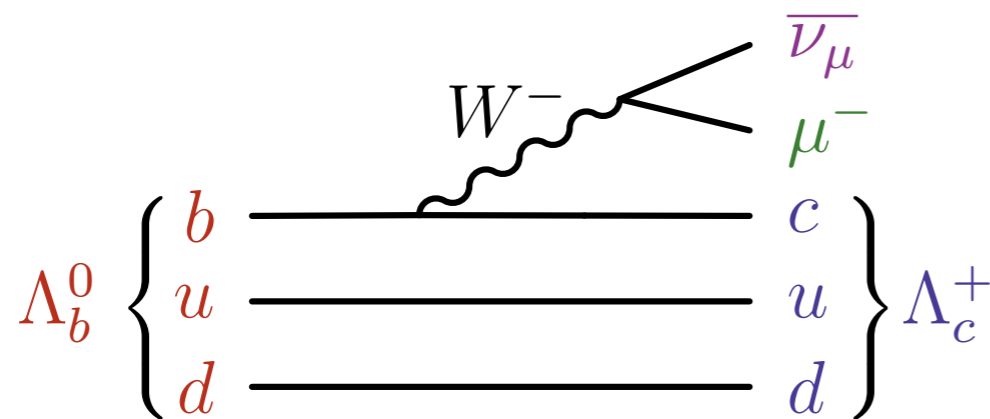
$$A_P \equiv \frac{\sigma(pp \rightarrow \Lambda_b^0 Y) - \sigma(pp \rightarrow \bar{\Lambda}_b^0 Y)}{\sigma(pp \rightarrow \Lambda_b^0 Y) + \sigma(pp \rightarrow \bar{\Lambda}_b^0 Y)}$$

- Background for measuring CP violation in Λ_b decays
Example: $\Lambda_b \rightarrow p h$
 - Experimental precision limiting systematic uncertainty
- Provides insights to the non-perturbative QCD relevant for heavy baryon production. Earlier results, e.g. from CMS collaboration (Phys. Lett. B 714 (2012) 136-157) sparked interest from theory community
- Expectations: percent-level for $y < 4$, higher in forward region
This measurement: A_P as a function of Λ_b p_T and rapidity, at 7 and 8 TeV (in forward region)

Phys. Lett. B 787 (2018) 124-133



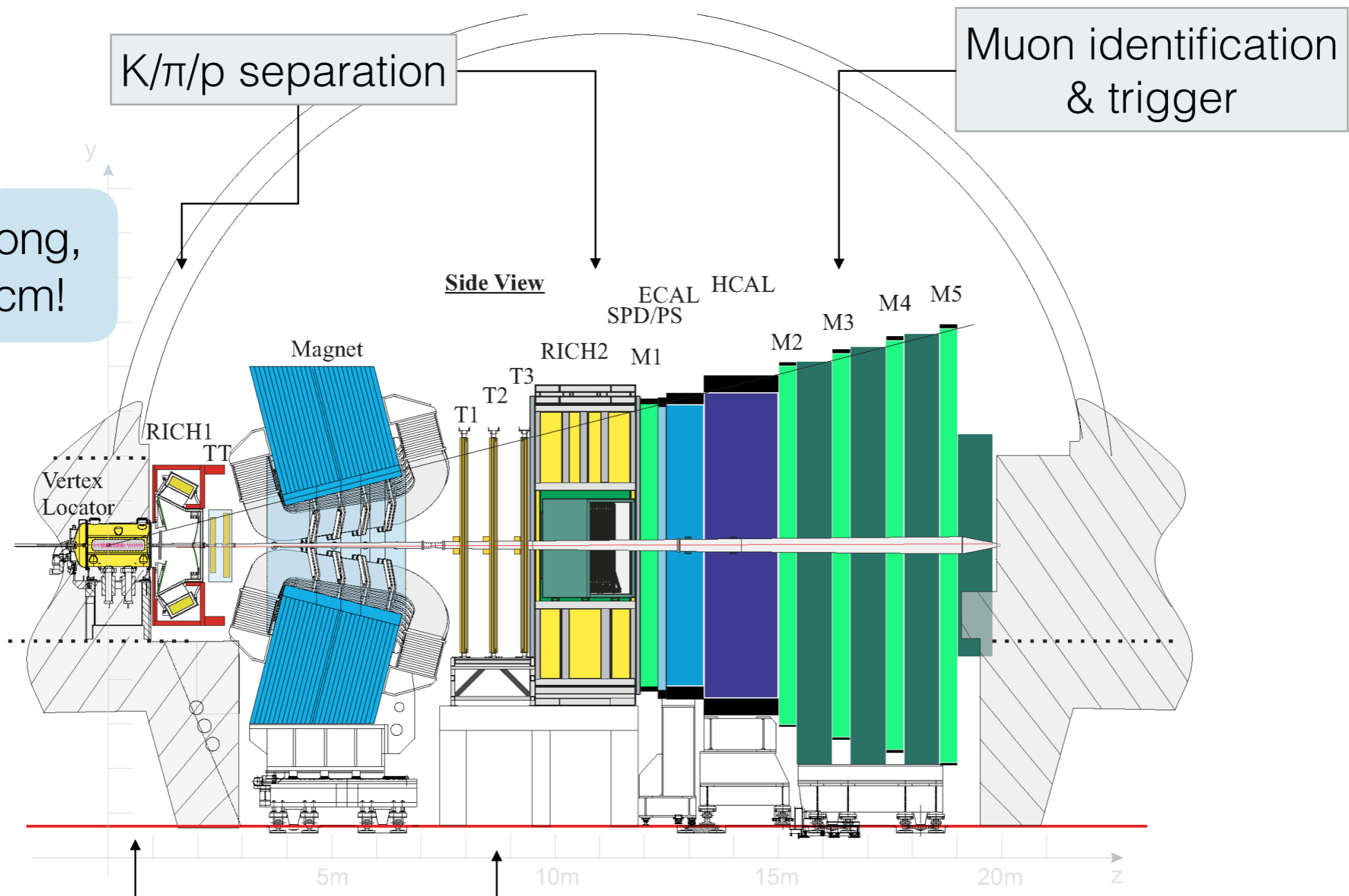
Semileptonic decays



- ✓ No CP violation (expected) in the decays
only probe the asymmetry in the baryon production
- ✓ High branching fraction: 1.7M signal decays
not limiting other measurements for CP violation
- ▶ Need corrections (“k-factors”) to estimate Λ_b p_T
needed for differential measurement due to unresolved neutrino

The LHCb detector

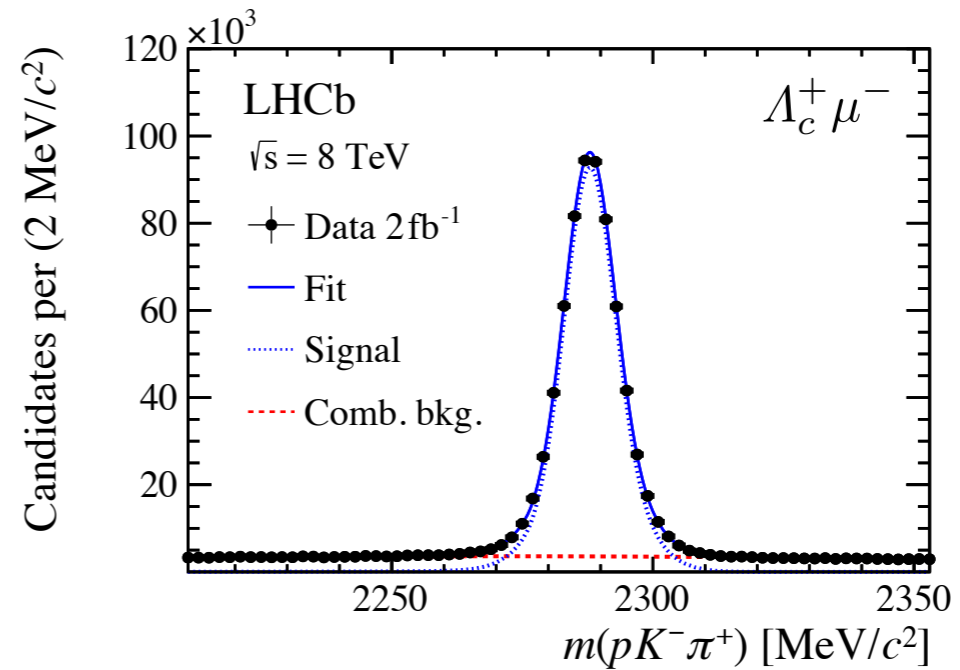
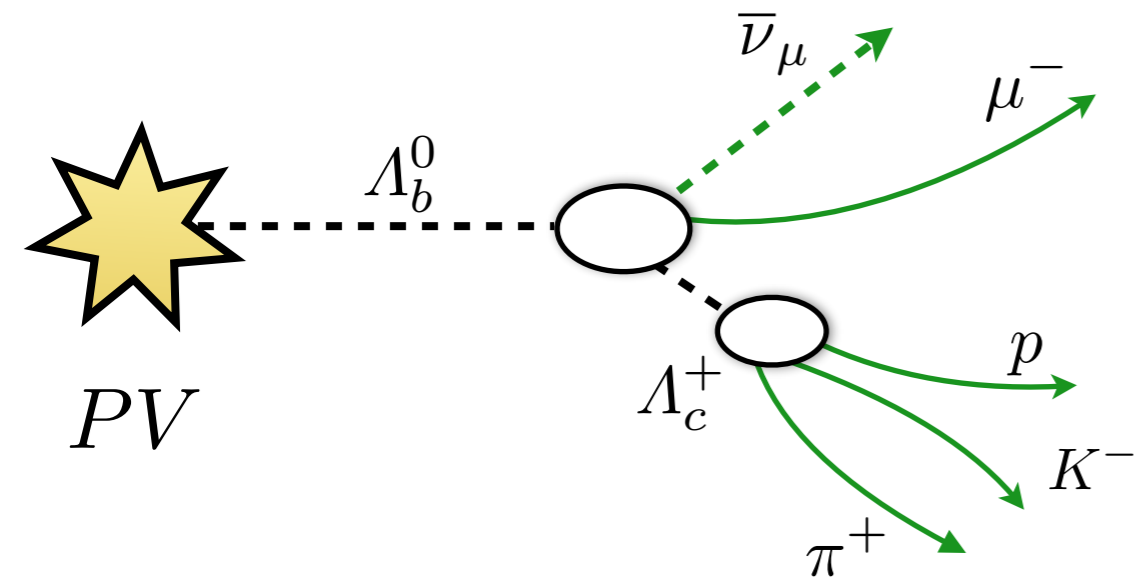
The Λ_b lives long,
easily flies a cm!



Excellent vertex resolution

$\Delta p/p = 0.4 - 0.8\%$
(5-100 GeV/c)

Signal in LHCb



What if the detector is more **efficient** in reconstructing $p K^- \pi^+ \mu^-$ than $\bar{p} K^+ \pi^- \mu^+$?

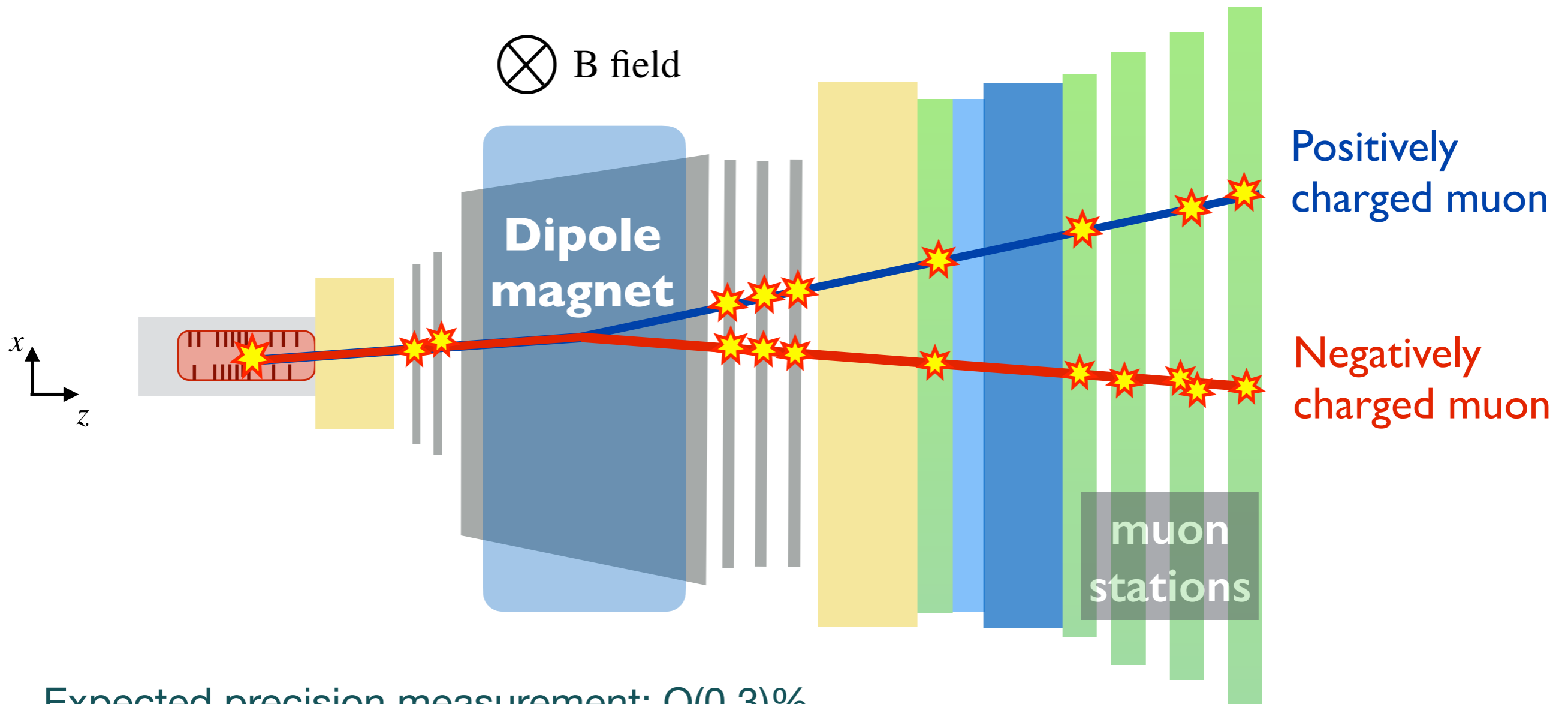
Asymmetry in measured yields

$$A_{\text{raw}} \approx A_P + A_D(pK^-\pi^+\mu^-)$$

$$A_{\text{det}} = \frac{\varepsilon^+ - \varepsilon^-}{\varepsilon^+ + \varepsilon^-}$$

(charge neutral final state, but not all particles have the same efficiency)

LHCb's charge separation

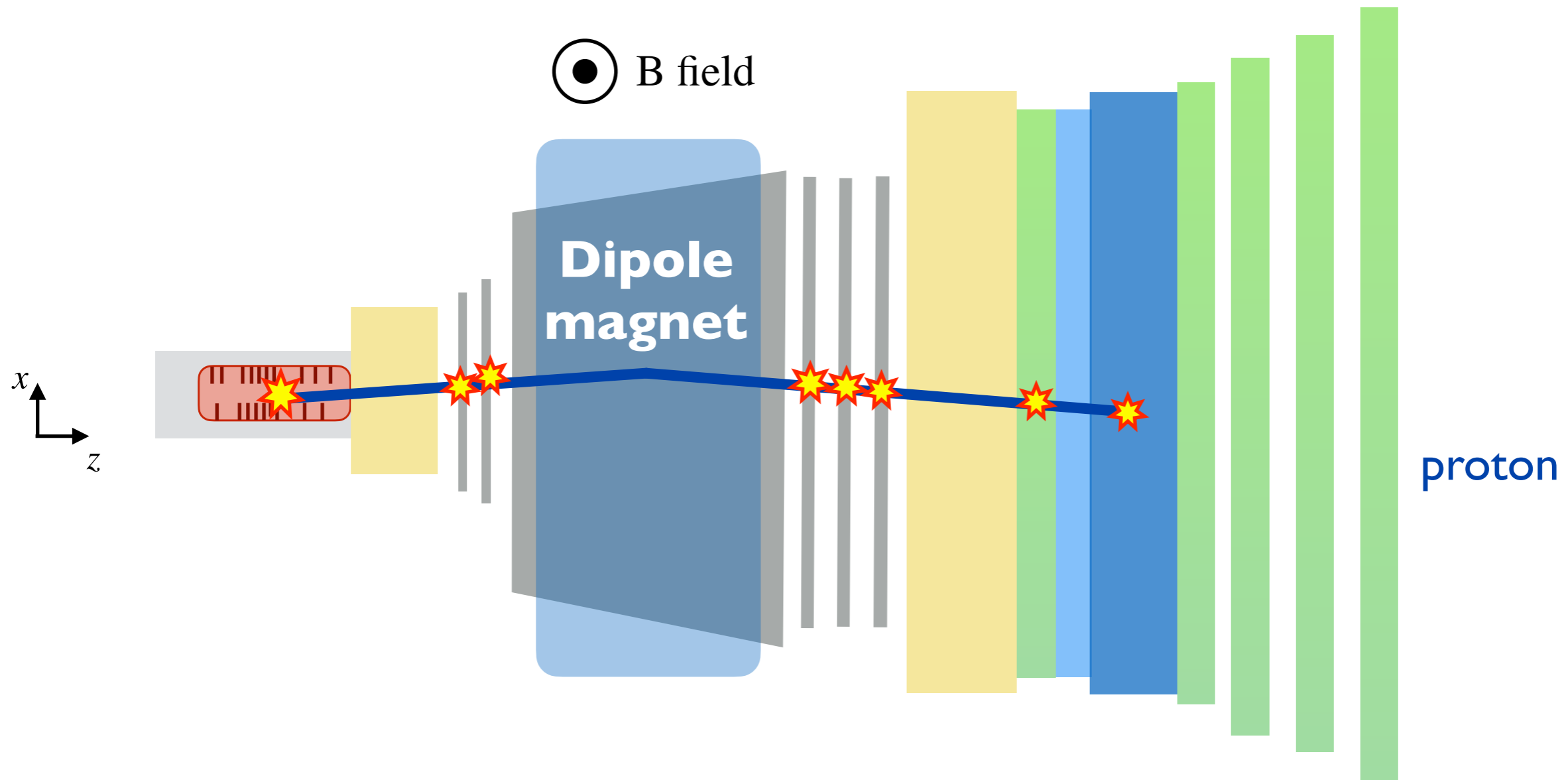


Expected precision measurement: $O(0.3)\%$

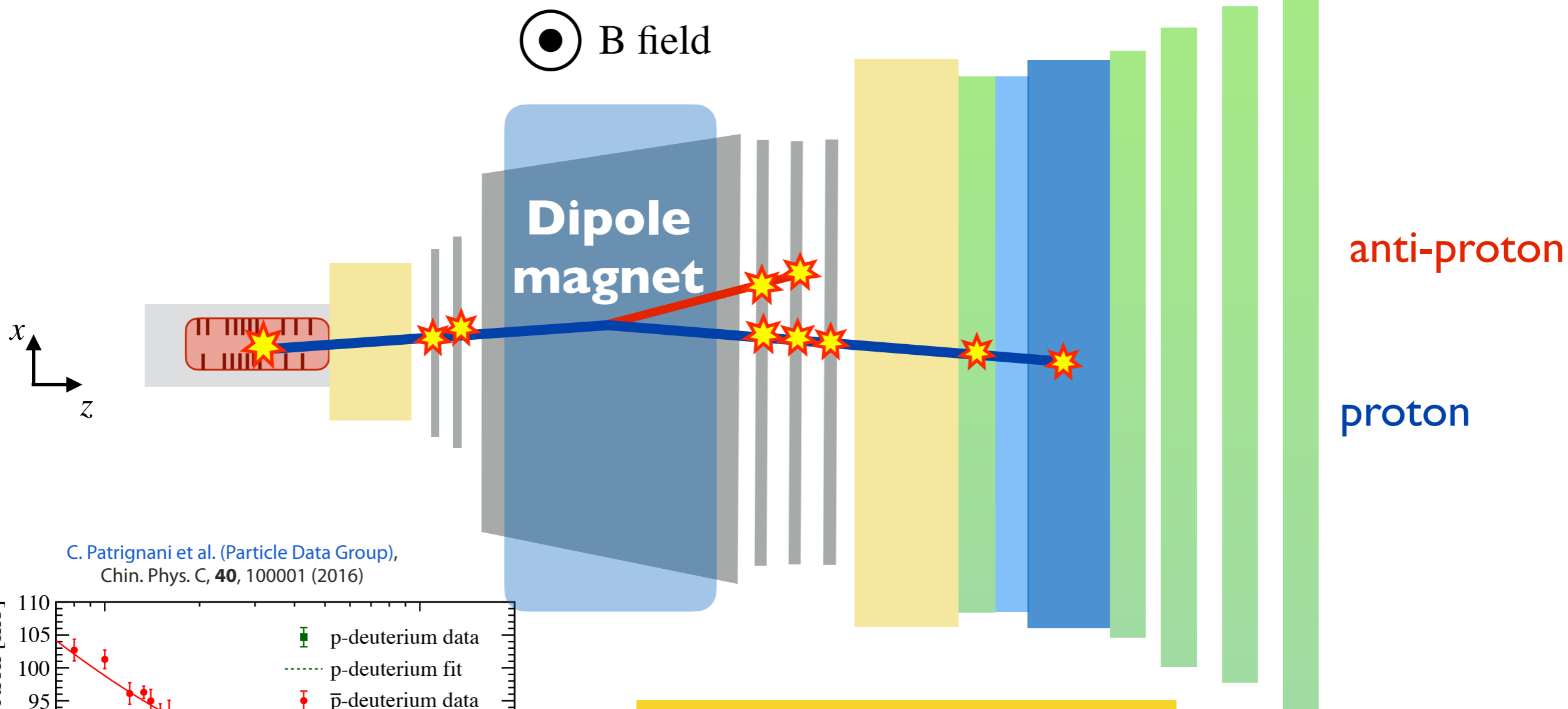
Reversing the magnet polarity doesn't cancel asymmetries of order 10^{-3}

Need to understand asymmetries for polarities separately - large tag-and-probe samples

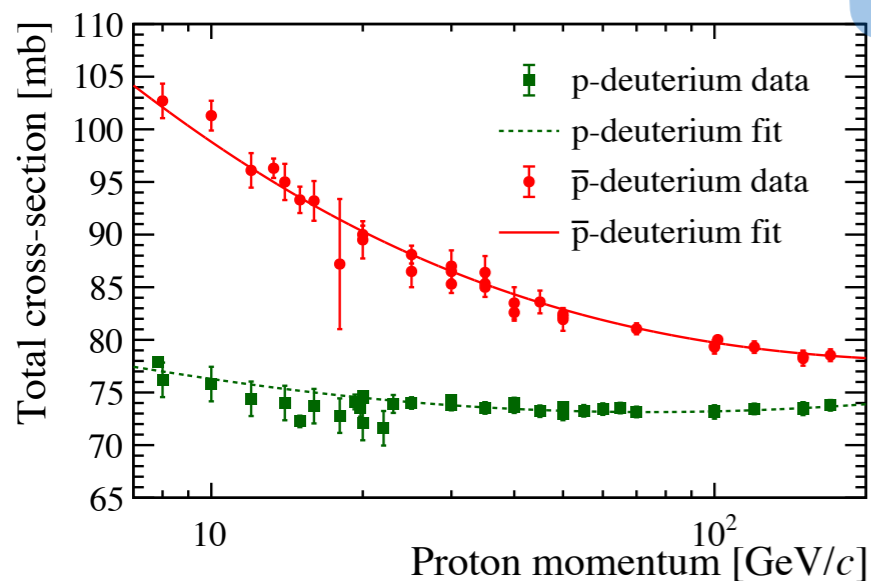
LHCb's charge separation



LHCb's charge separation



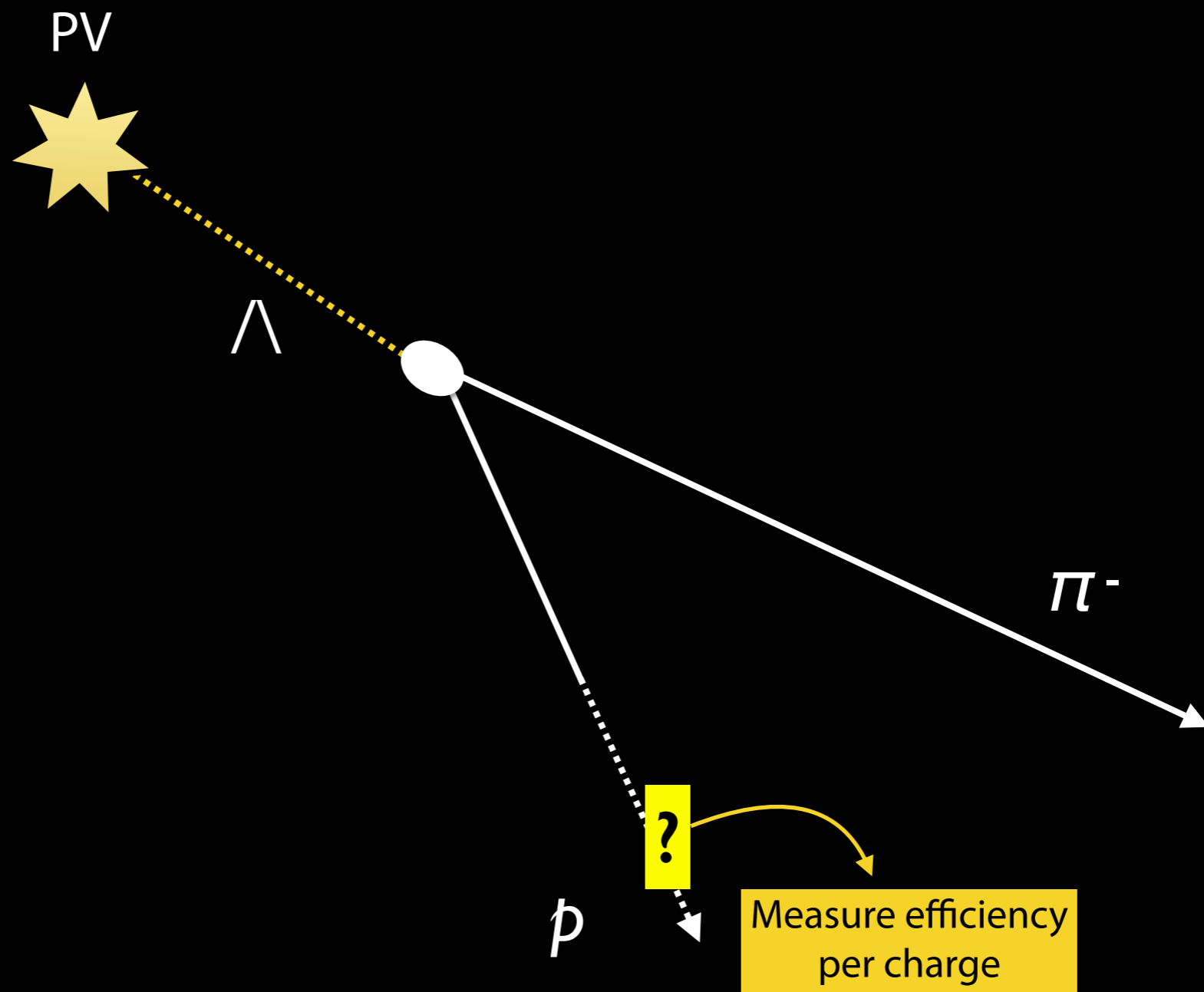
C. Patrignani et al. (Particle Data Group),
Chin. Phys. C, **40**, 100001 (2016)



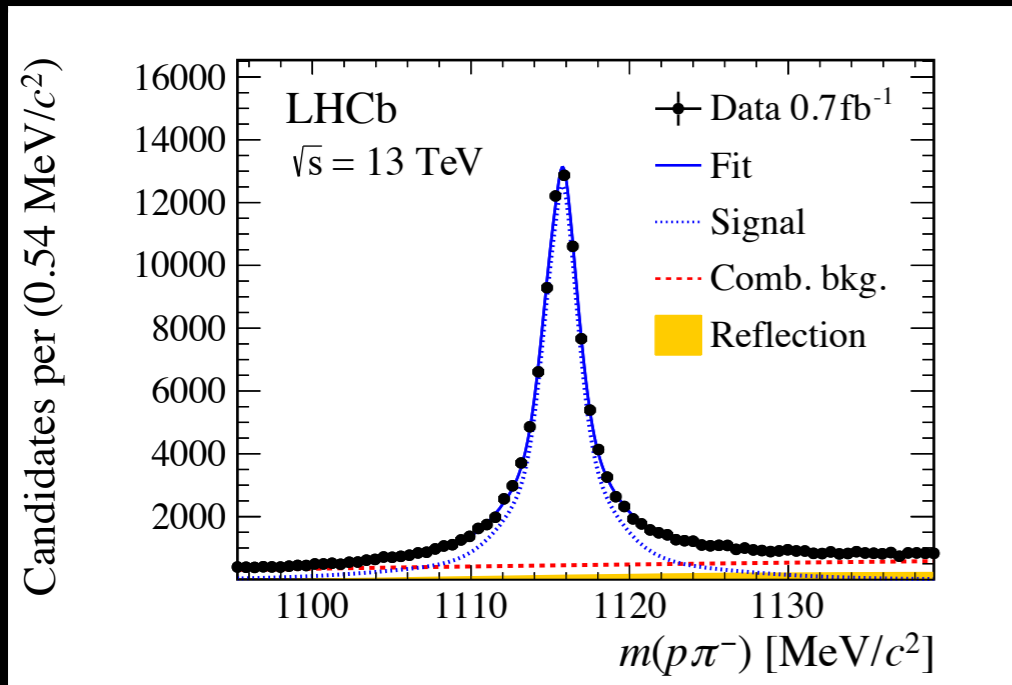
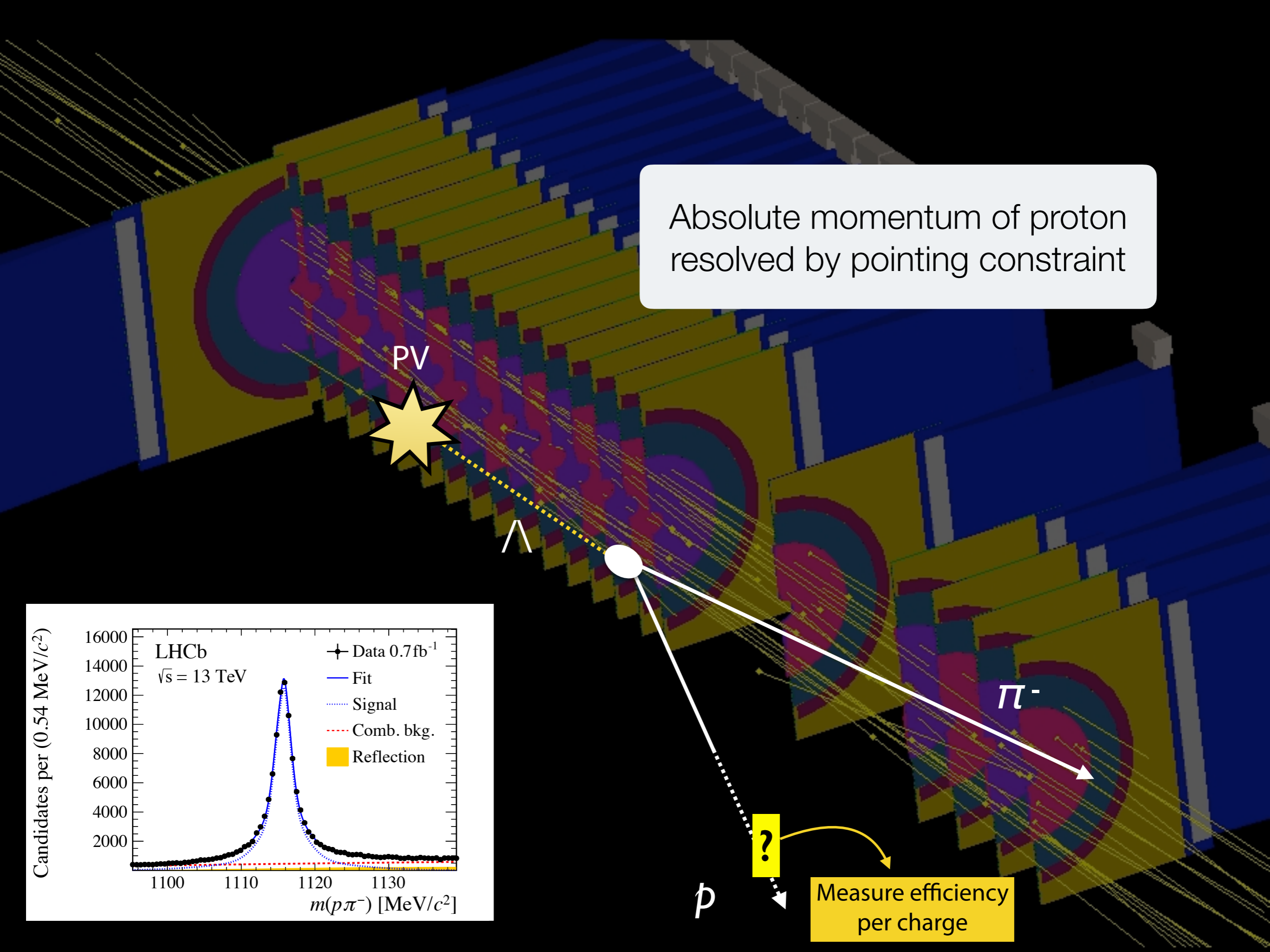
$$\varepsilon(\bar{p}) < \varepsilon(p)$$

Simulation: $O(1.5\%)$ effect
New calibration developed

Absolute momentum of proton
resolved by pointing constraint



Absolute momentum of proton resolved by pointing constraint

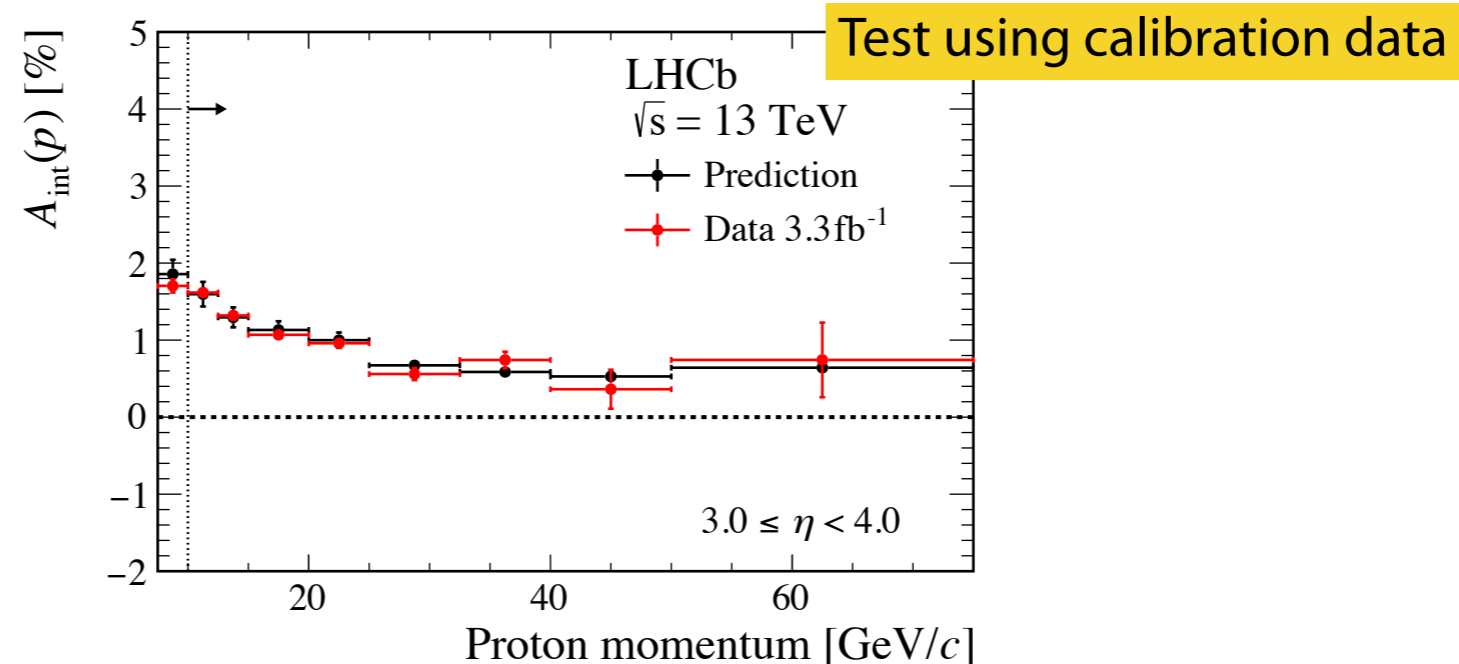


(Anti)Proton interaction calibration

Complication protons from Λ lower p_T than protons from b -hadrons

Ansatz: approximate detector as deuterium, use precise p-deut. cross-sections collected by COMPASS group, published in PDG

→ [Cross-sections] + [Detector material map]

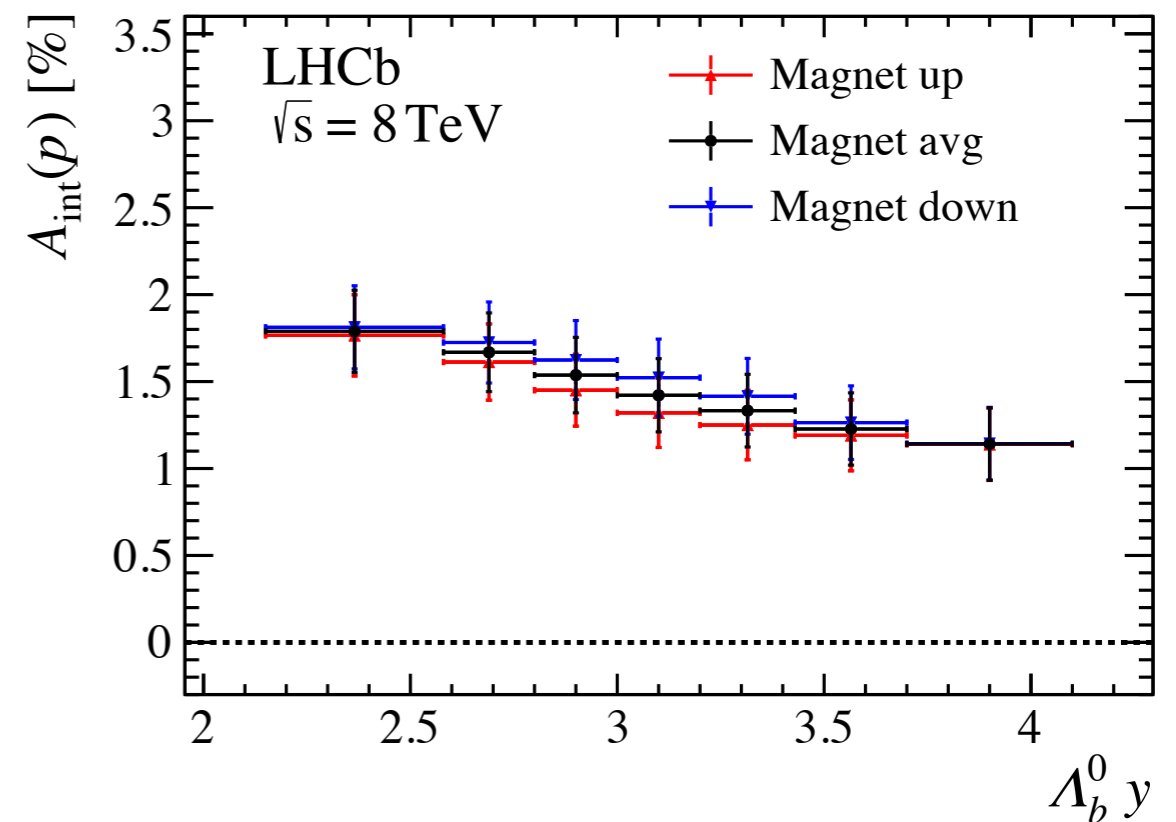


Resulting correction

Resulting *relative* precision for LHCb about 10%, with still room for improvement.

Gives rise to a correlated systematic uncertainty across rapidity bins.

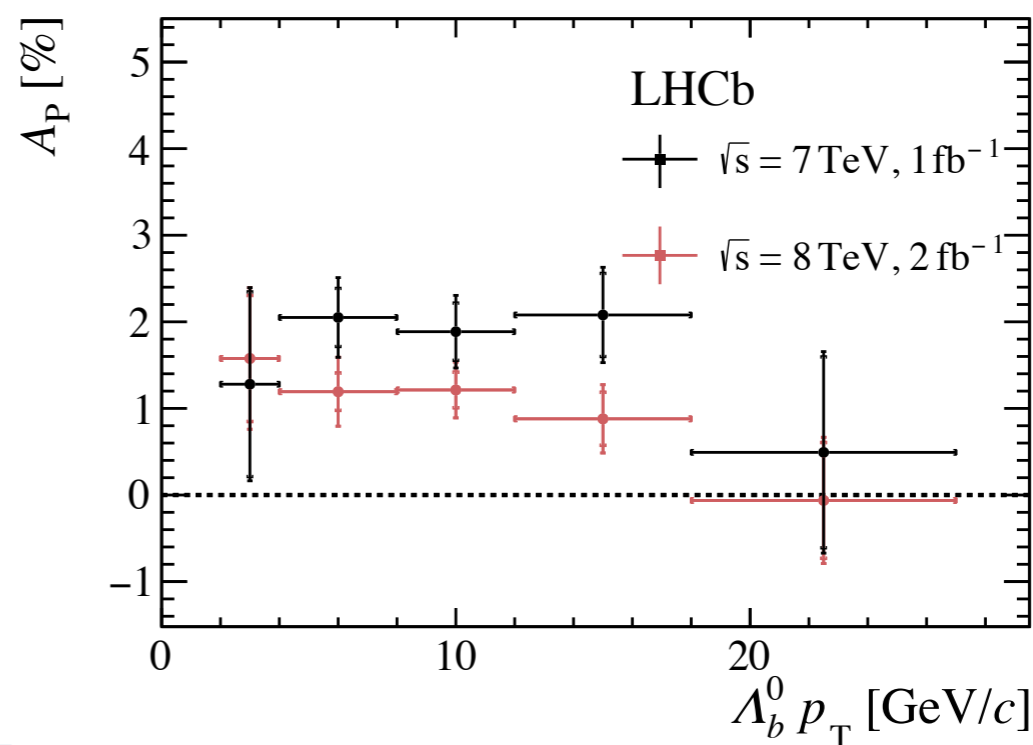
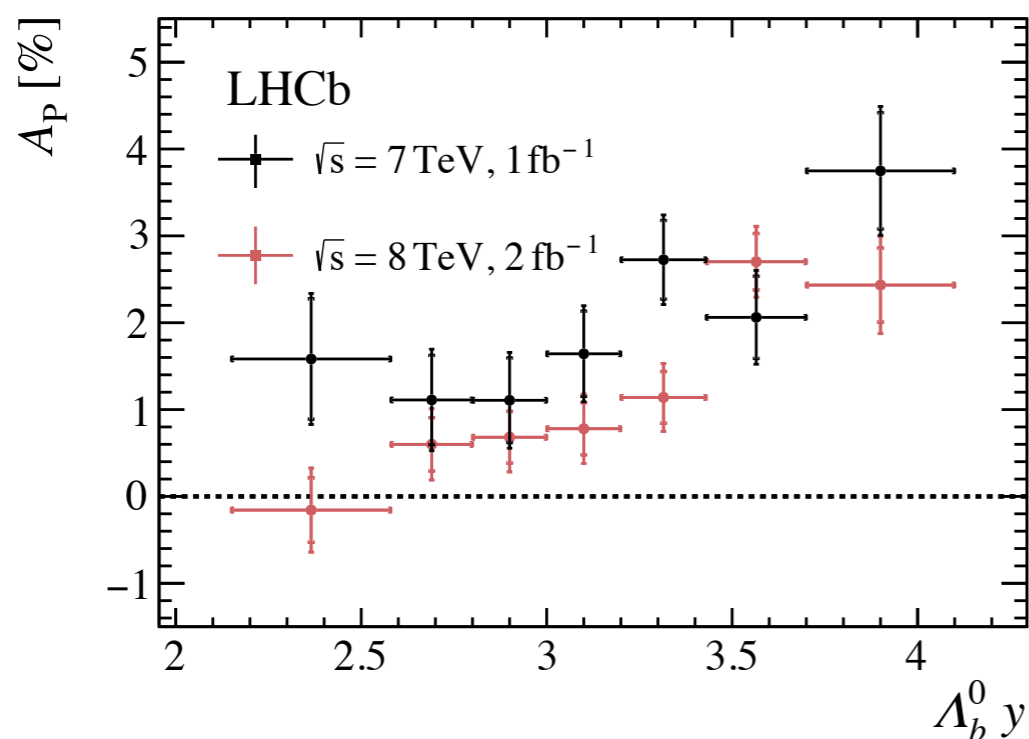
Comparable in size, but opposite in sign, to the **sum** of **all other** nuisance asymmetries.



Promising technique for other baryon-asymmetry measurements

Results

Correlated uncertainties!



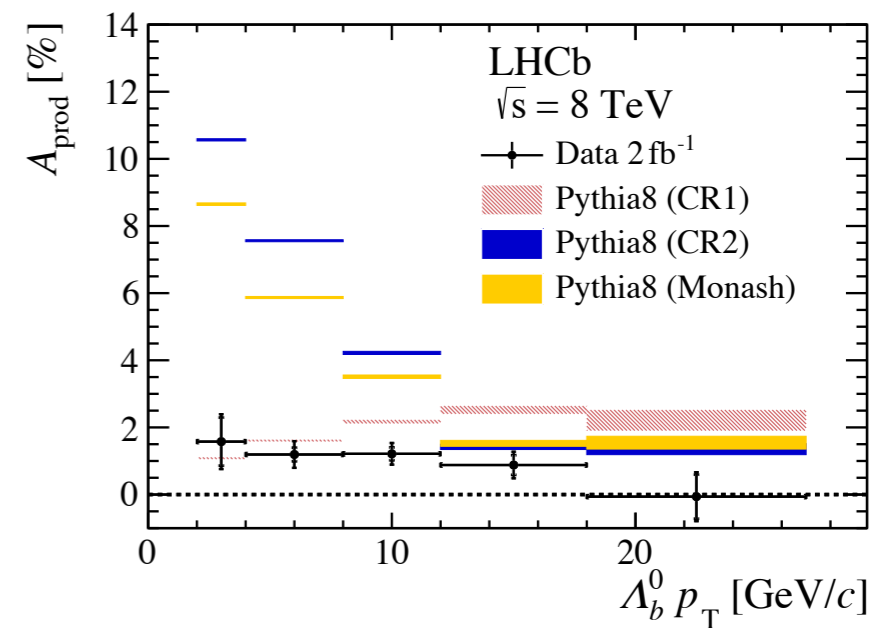
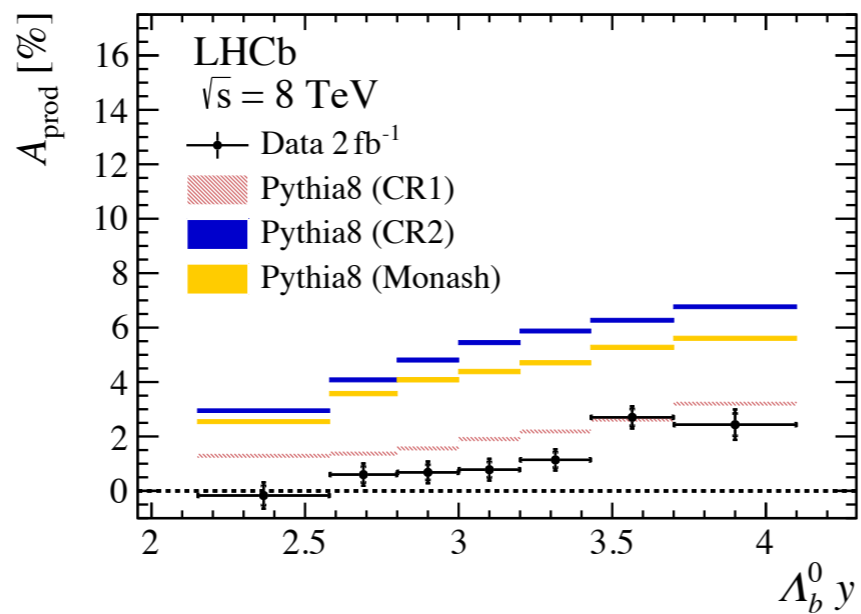
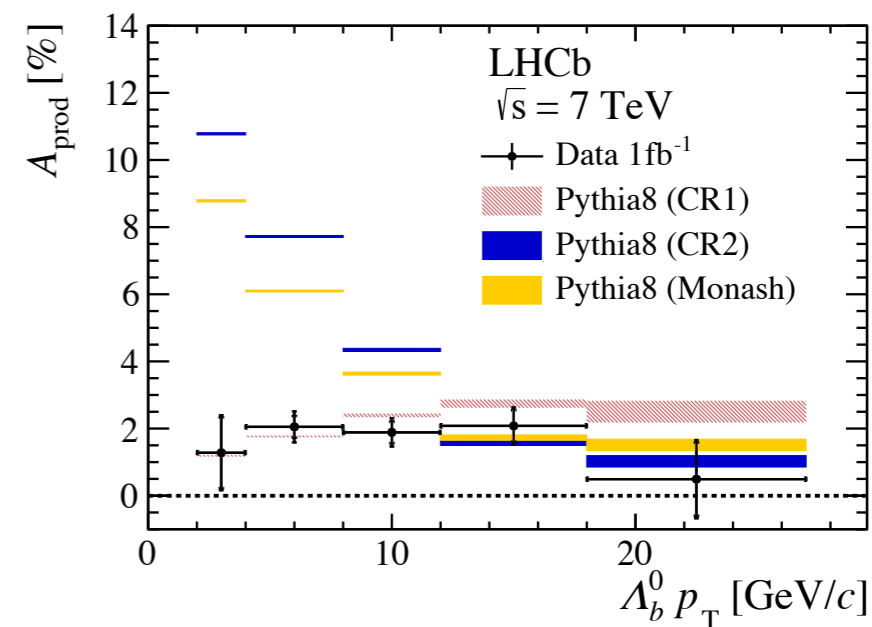
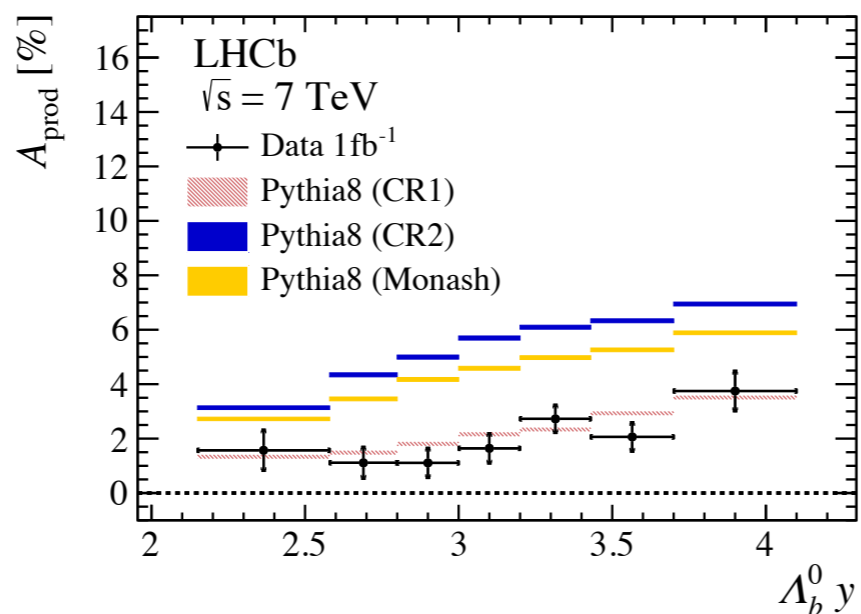
- **Not** compatible with **zero** (> 5 sigma)
- Significant **trend** as a function of **rapidity** (4.1 sigma)
- No significant variation as a function of **p_T**
- Hint for difference 8-7 TeV, not significant (2.6 sigma)
- Compatible w/sum of production asymmetries of other b-hadrons in the LHCb acceptance [[Phys. Lett. B 774 \(2017\) 139-158](#)] (uncertainty: $\sim 1.8\%$)

Theory comparisons: Pythia

Pythia: various models for **colour reconnection**

"CR1": introduced in JHEP 08 (2015), 003

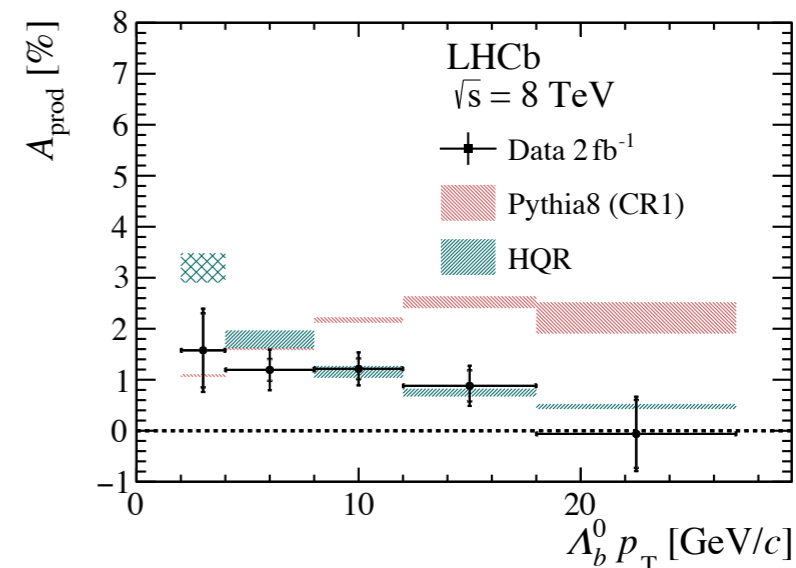
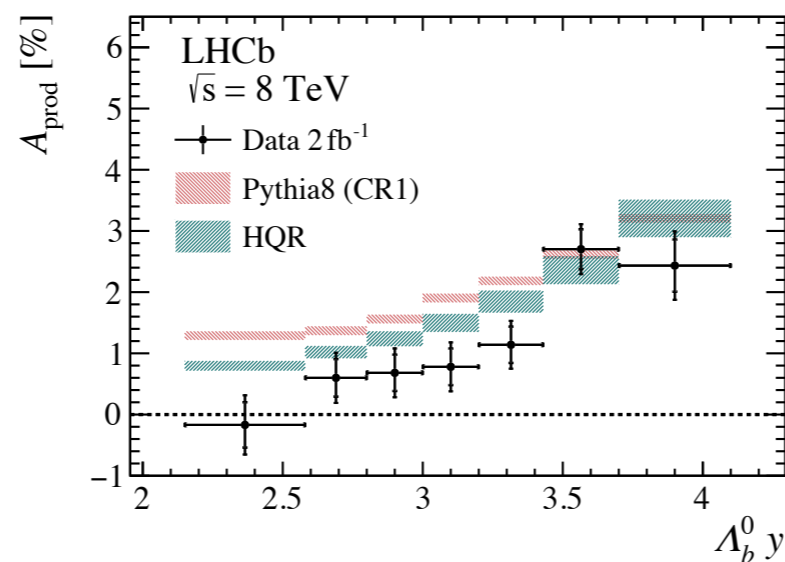
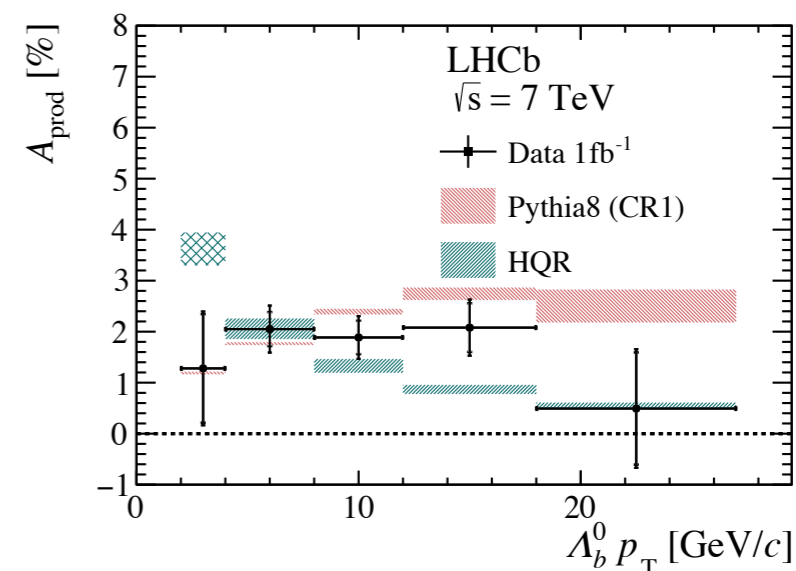
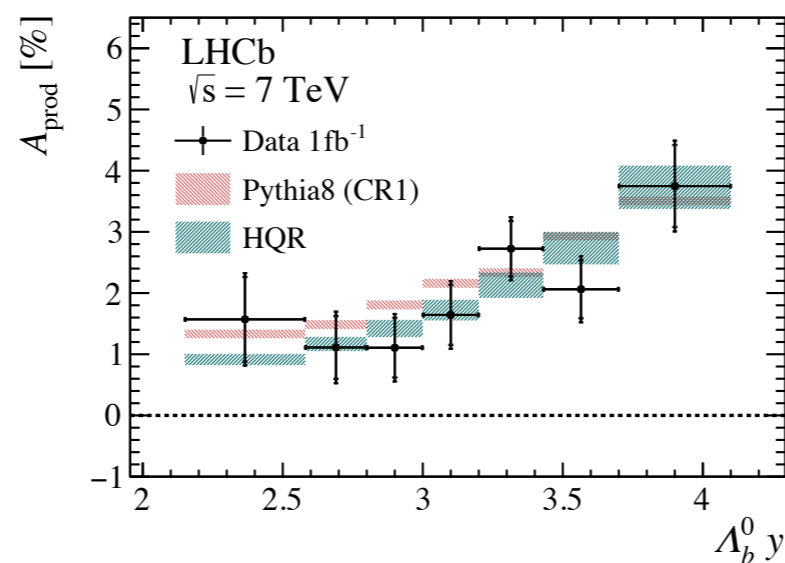
"CR2": "Gluon-move": introduced in JHEP 11 (2014), 043



"CR1" preferred

Theory comparisons: HQR

“**HQR**”: heavy-quark recombination,
A. Leibovich & W-K Lai
Phys. Rev. D 91, 054022 (2015)



Impressive agreement
8 TeV data slightly lower than expectations

Conclusion

- Observed particle-antiparticle asymmetries in b -hadron production at the LHC energies: slightly more Λ_b than $\bar{\Lambda}_b$ are produced in forward region. Large improvement in precision (from 1.8%¹ to 0.3%).
- A strong **evidence** for a dependence on the **rapidity** is seen; no trend in p_T .
- Predictions from heavy-quark recombination and one of the colour-reconnection models in Pythia8 provide a reasonable agreement
- Technique to estimate the nuisance asymmetry due to the proton interactions applicable to other measurements of CPV as well.

¹: [\[Phys. Lett. B 774 \(2017\) 139-158\]](#)



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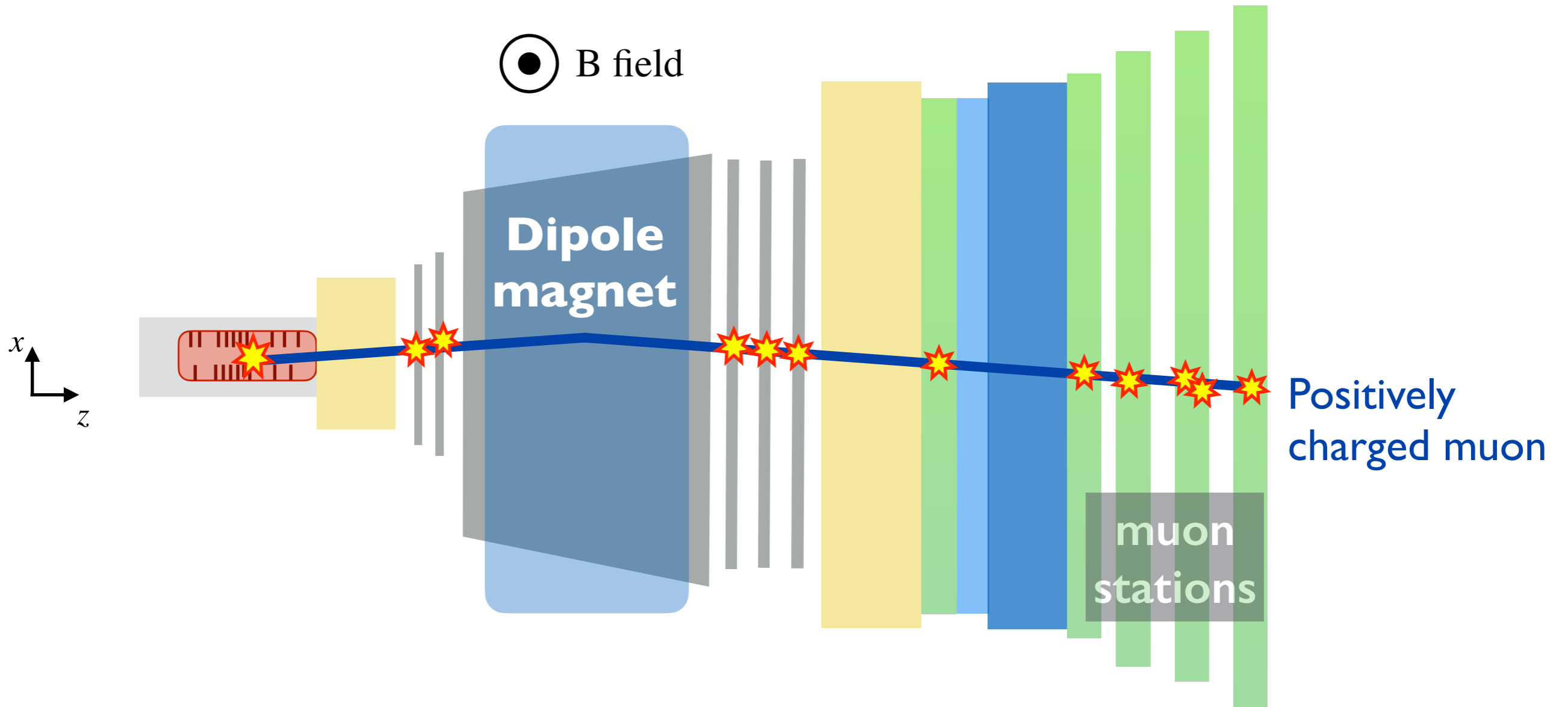
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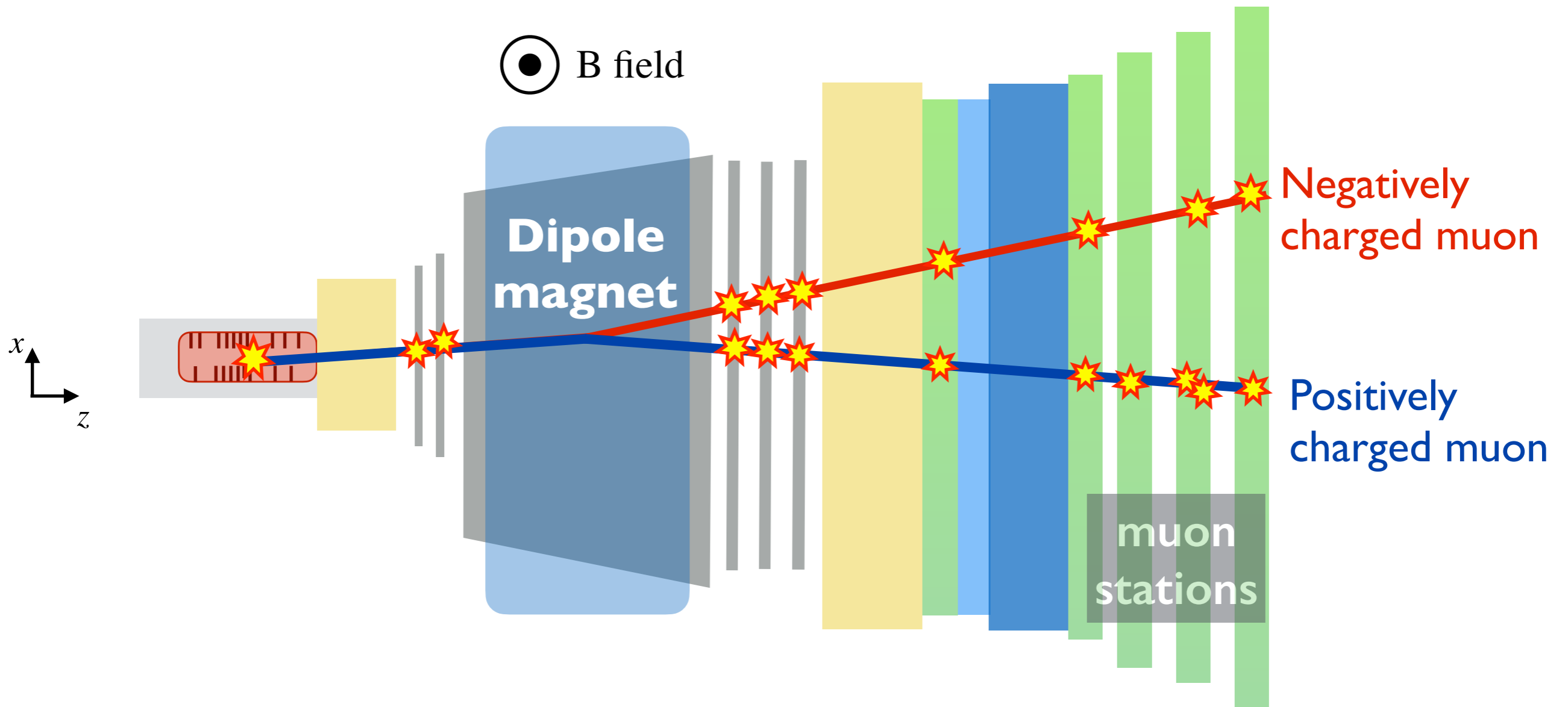
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LHCb's charge separation



LHCb's charge separation



Magnet: measurement of CP violation ~ the measurement of left-right symmetry

