POLARIZATION AND STRANGENESS PRODUCTION AT LHCb

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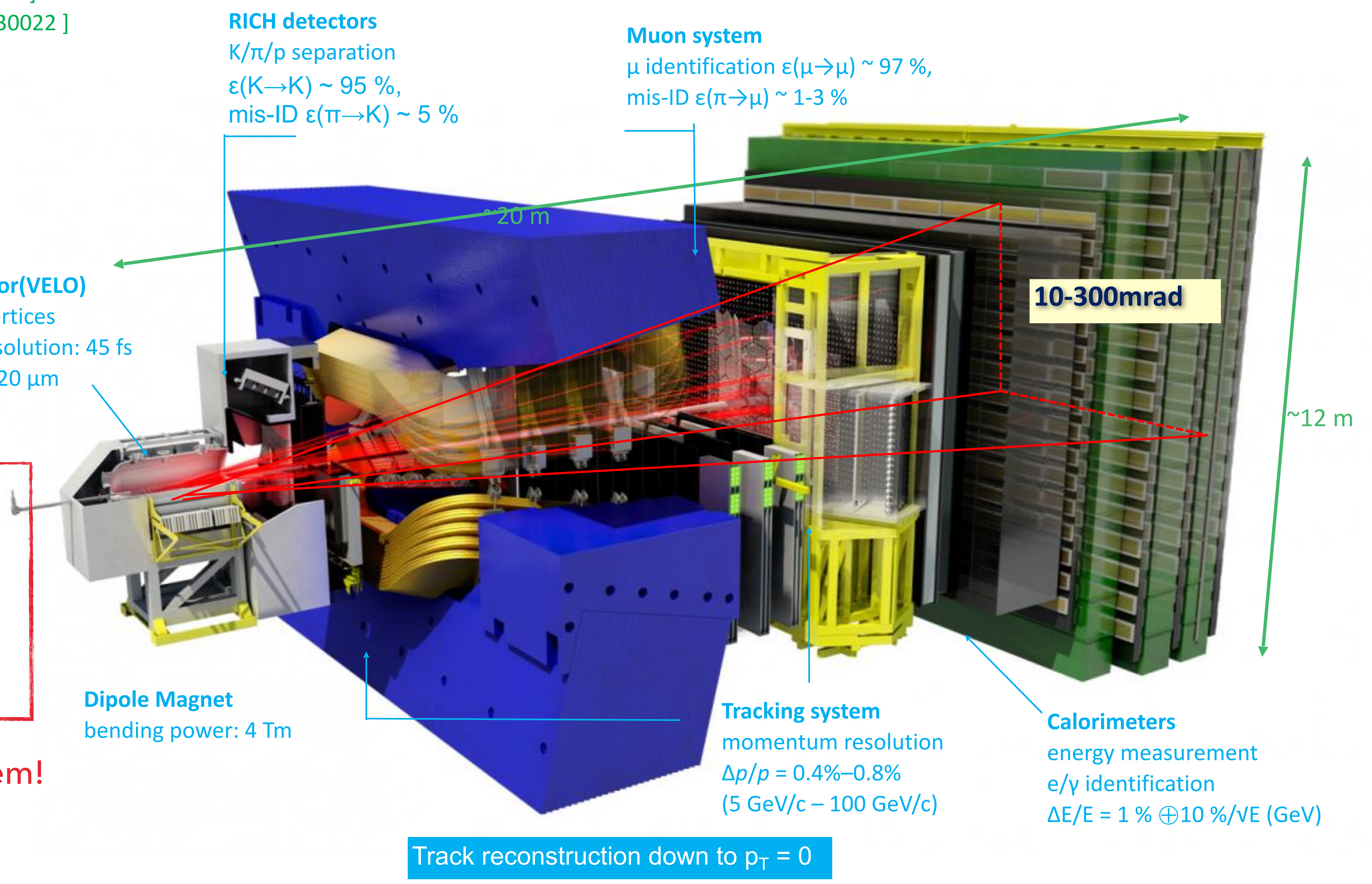
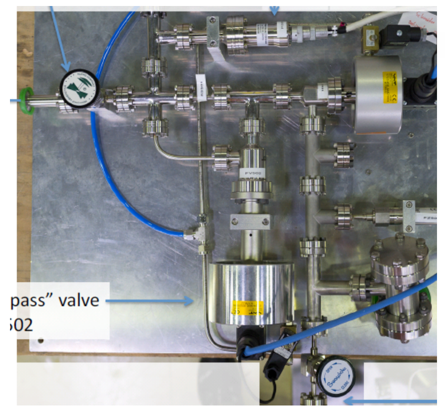
THE LHCb DETECTOR

- Single arm forward spectrometer with **unique coverage 2 < η < 5**

[JINST 3 (2008) S08005]
[IJMPA 30 (2015) 1530022]

- Designed for heavy-flavour physics, now a **general purpose experiment**
- **Forward and backward coverage** for asymmetric beams





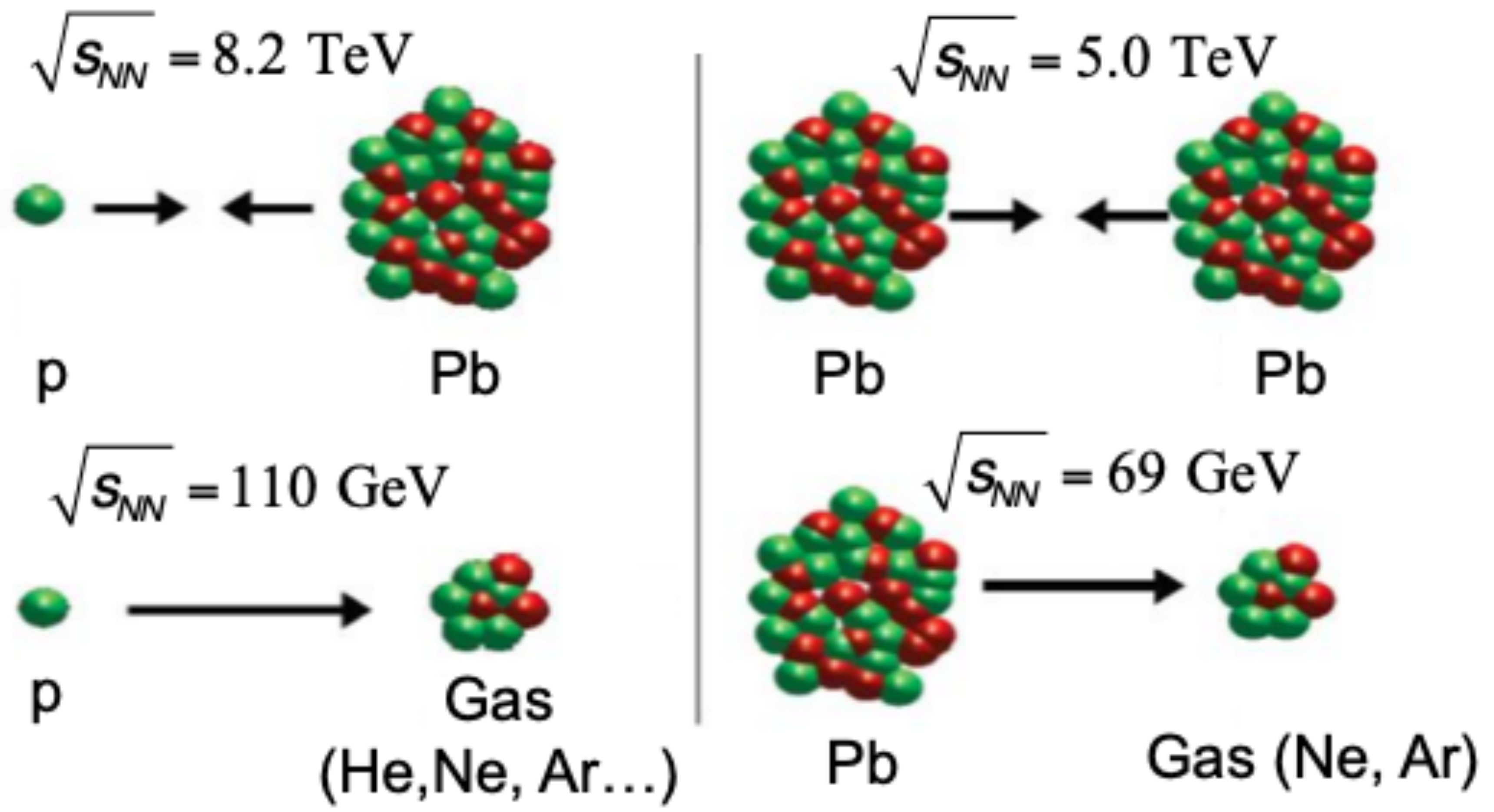
SMOG

Fixed-target system!

LHCb EXPERIMENTAL SET-UP

- Large variety of colliding system other than *pp*:

Cold Nuclear Matter **Quark Gluon Plasma**

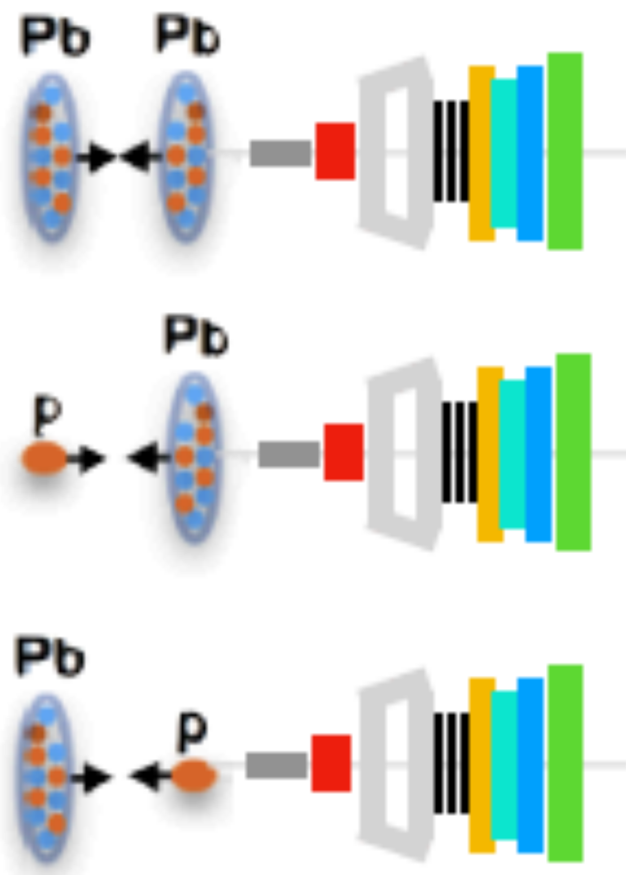


- *p*Pb/Pb*p*
- PbPb

} colliding beam mode

- *p*A
- PbA

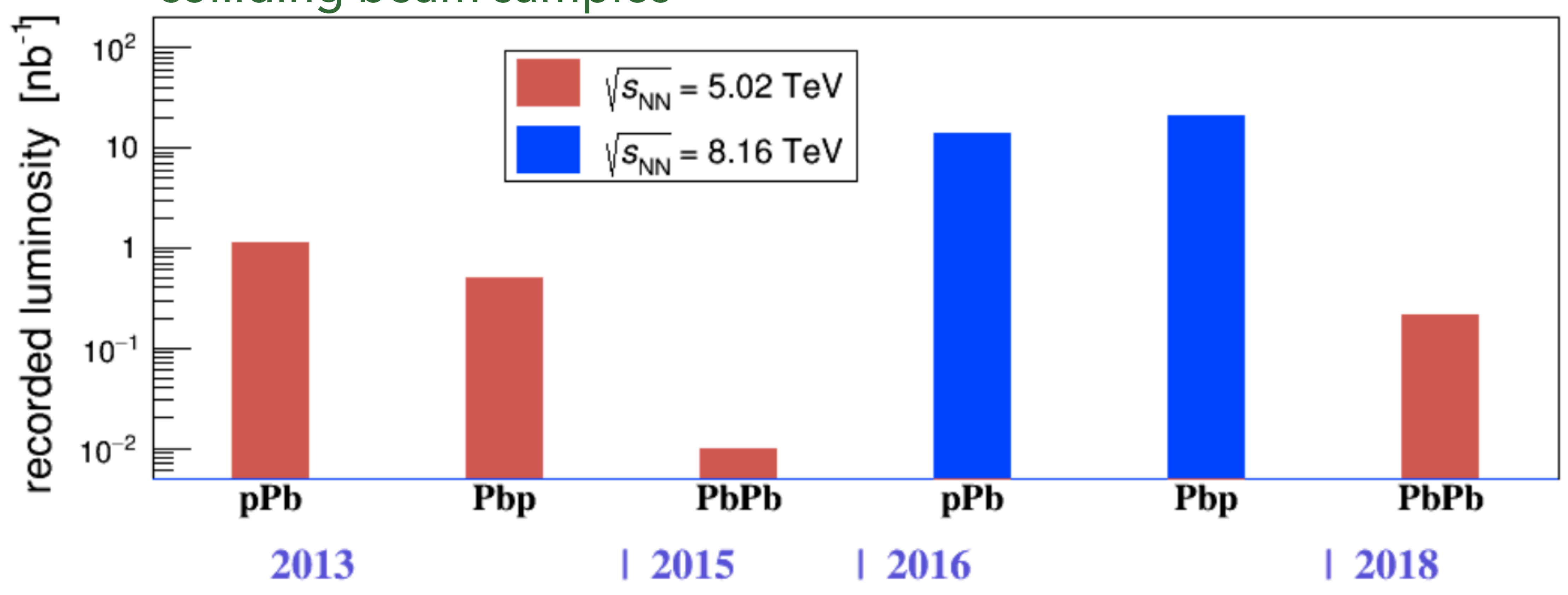
} fixed-target mode (SMOG)



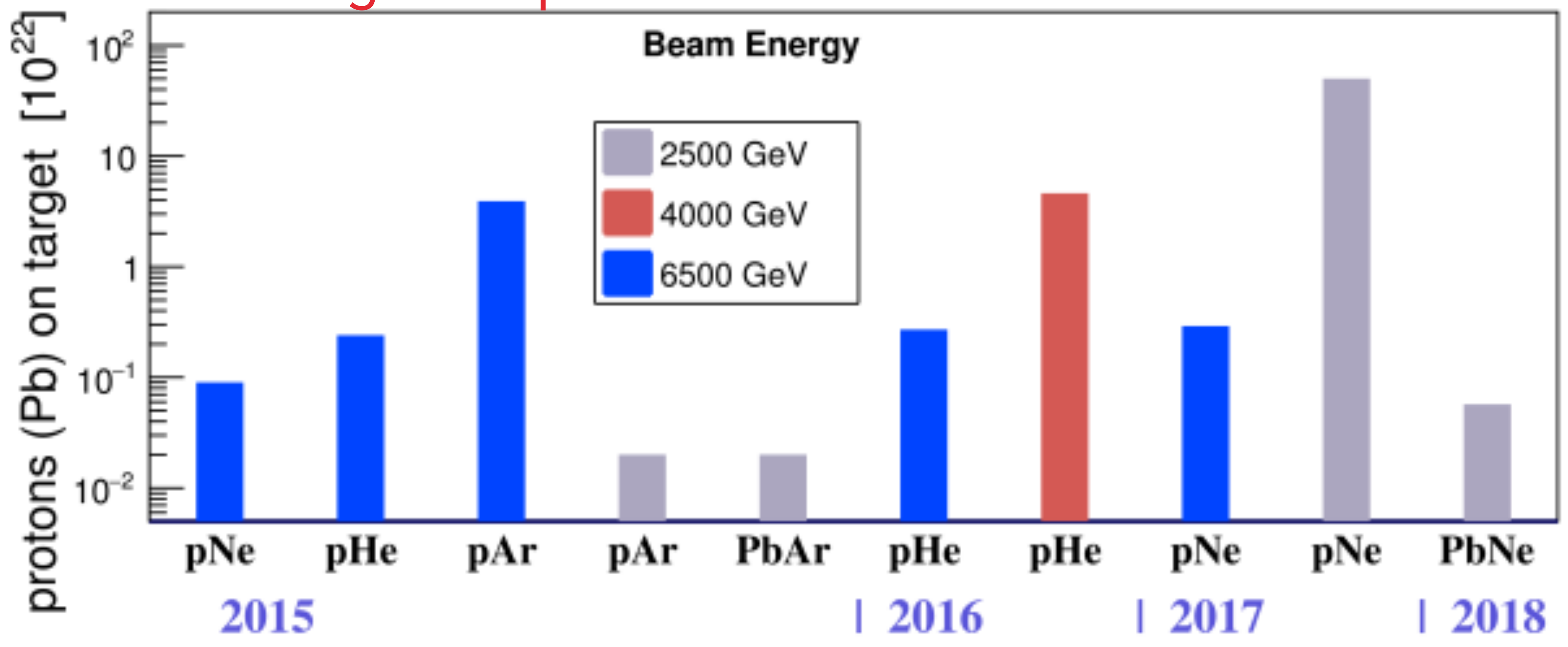
Injection of noble gases (He, Ne, Ar) into the interaction region → **unique kinematical region accessible!**

RUN2 SAMPLES

colliding beam samples

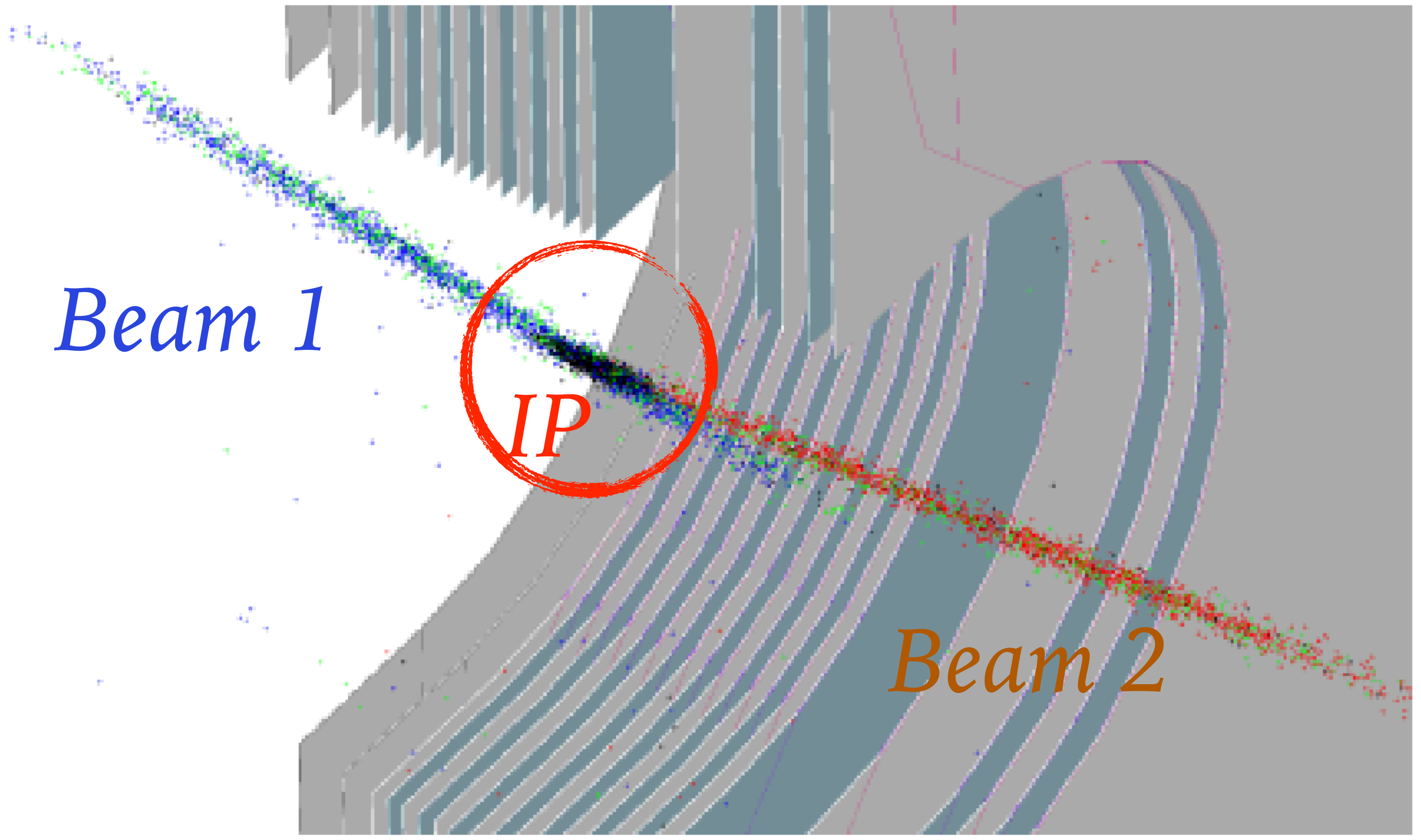


fixed target samples

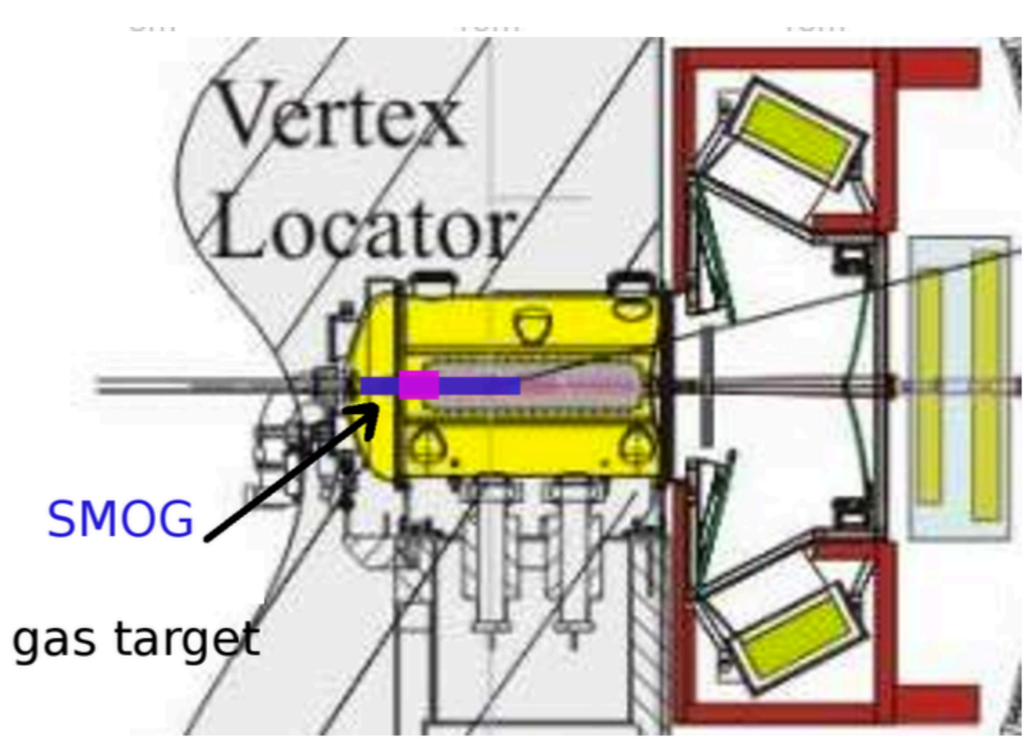


FIXED TARGET COLLISIONS AT LHCb: SMOG

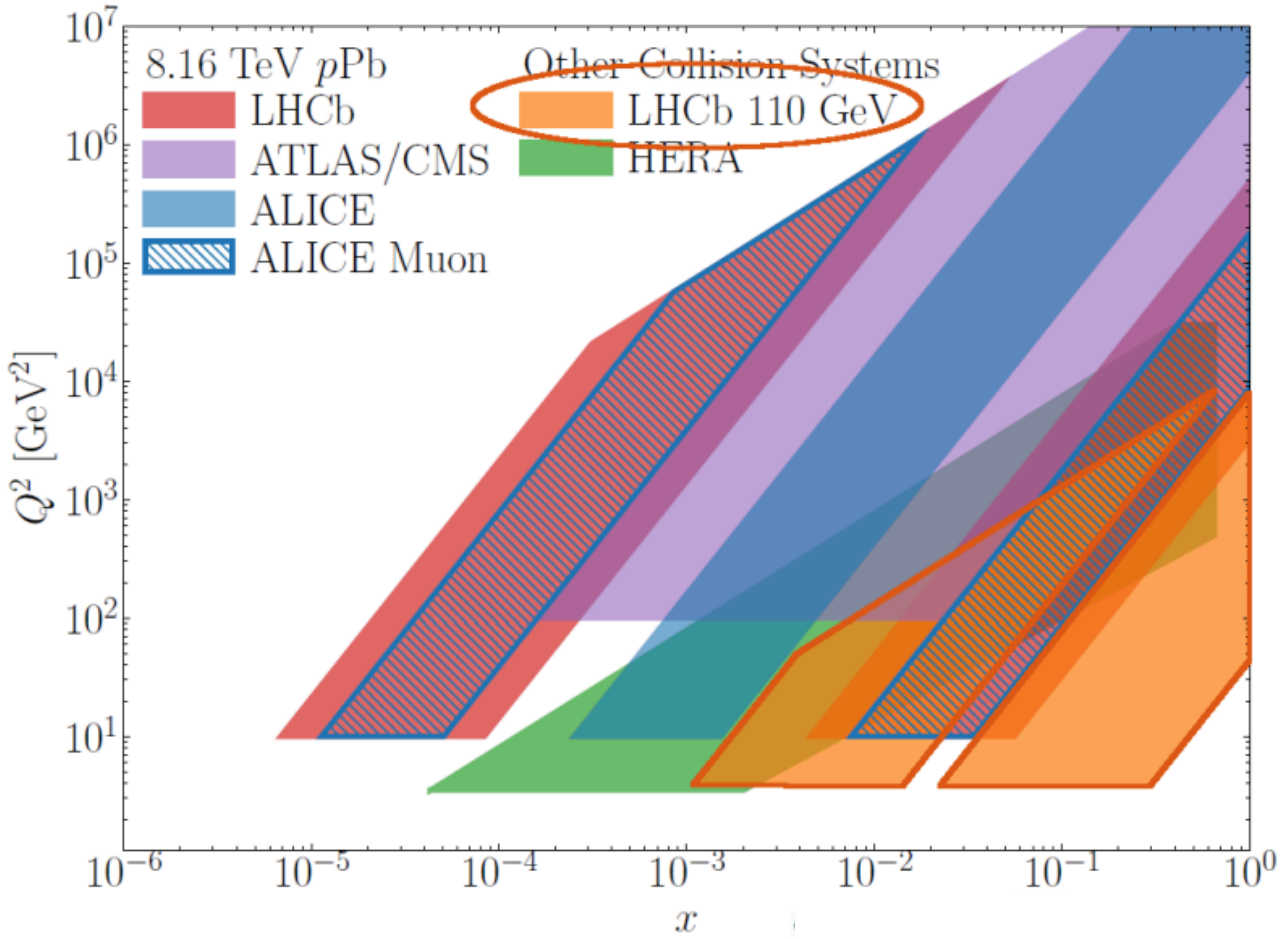
RUN2 CONFIGURATION



- **SMOG**: System for Measuring Overlap with Gas
  - **Noble gases (He, Ar, Ne) injected** into the LHC beam pipe around the Interaction Point (IP), pressure $\sim 10^{-7}$ mbar
  - **Highest-energy** fixed-target experiment ever built → bridge between the SPS and LHC energies



- **Unique kinematical region** accessible
- $\sqrt{s_{NN}} \sim \sqrt{2E_N M_N}$ = 41 - 115 GeV
- Investigates the **high-x** of the nucleon target at **intermediate Q^2**

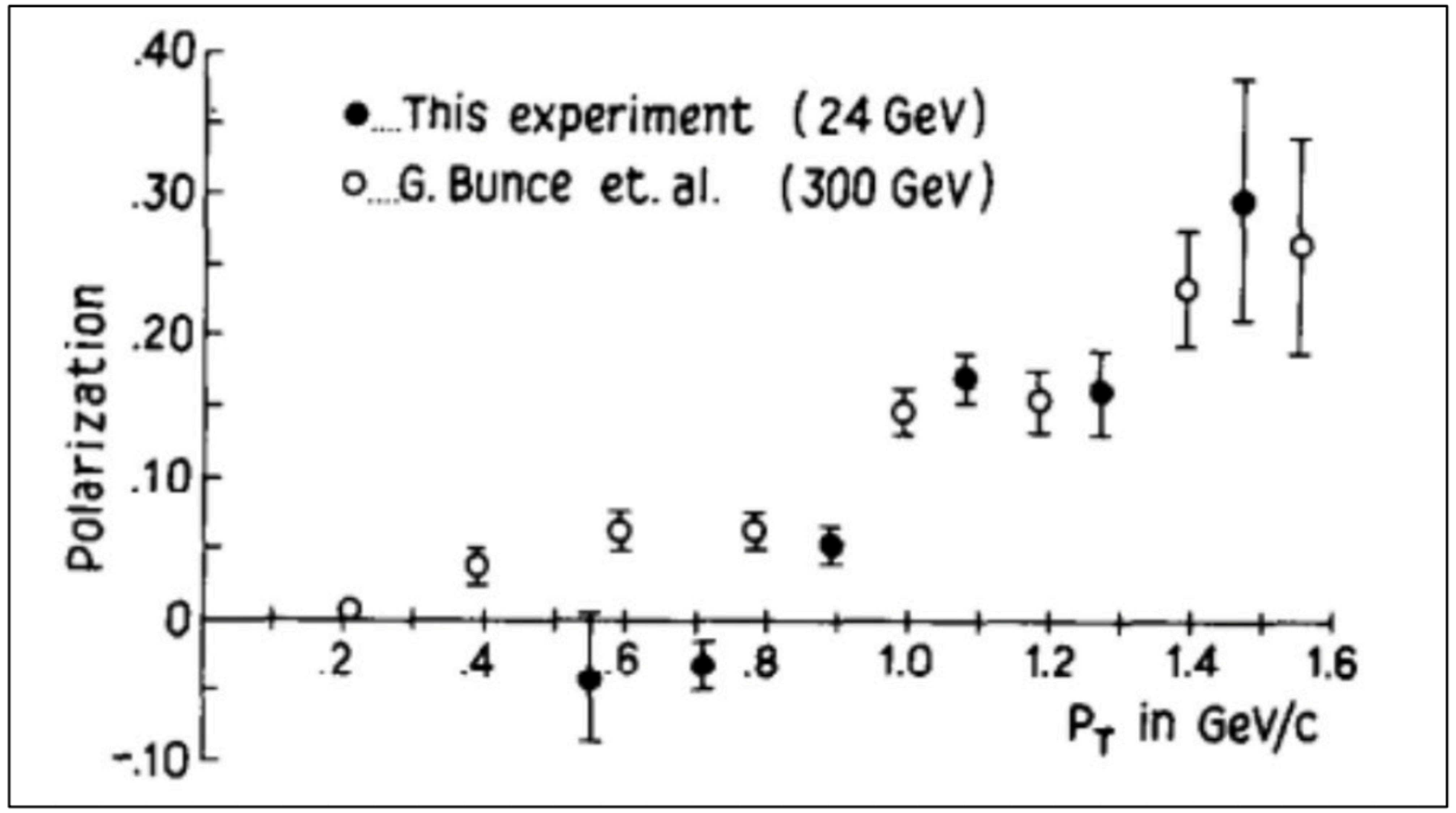


Λ^0 TRANSVERSE POLARIZATION

Λ^0 TRANSVERSE POLARIZATION

- Λ^0 **hyperon** composed by *uds* quarks
- **Transverse Λ^0 polarization:** discovered in 1976 in pBe collisions using 300 GeV unpolarized beam
- **Polarization effects not expected** in particle production from unpolarised beams at **high energy**
- **Leading order perturbative QCD calculations predicted very small polarization for light quarks and go to zero for increasing momentum**
- **Indicates that spin effects play an important role even in high energy collisions**

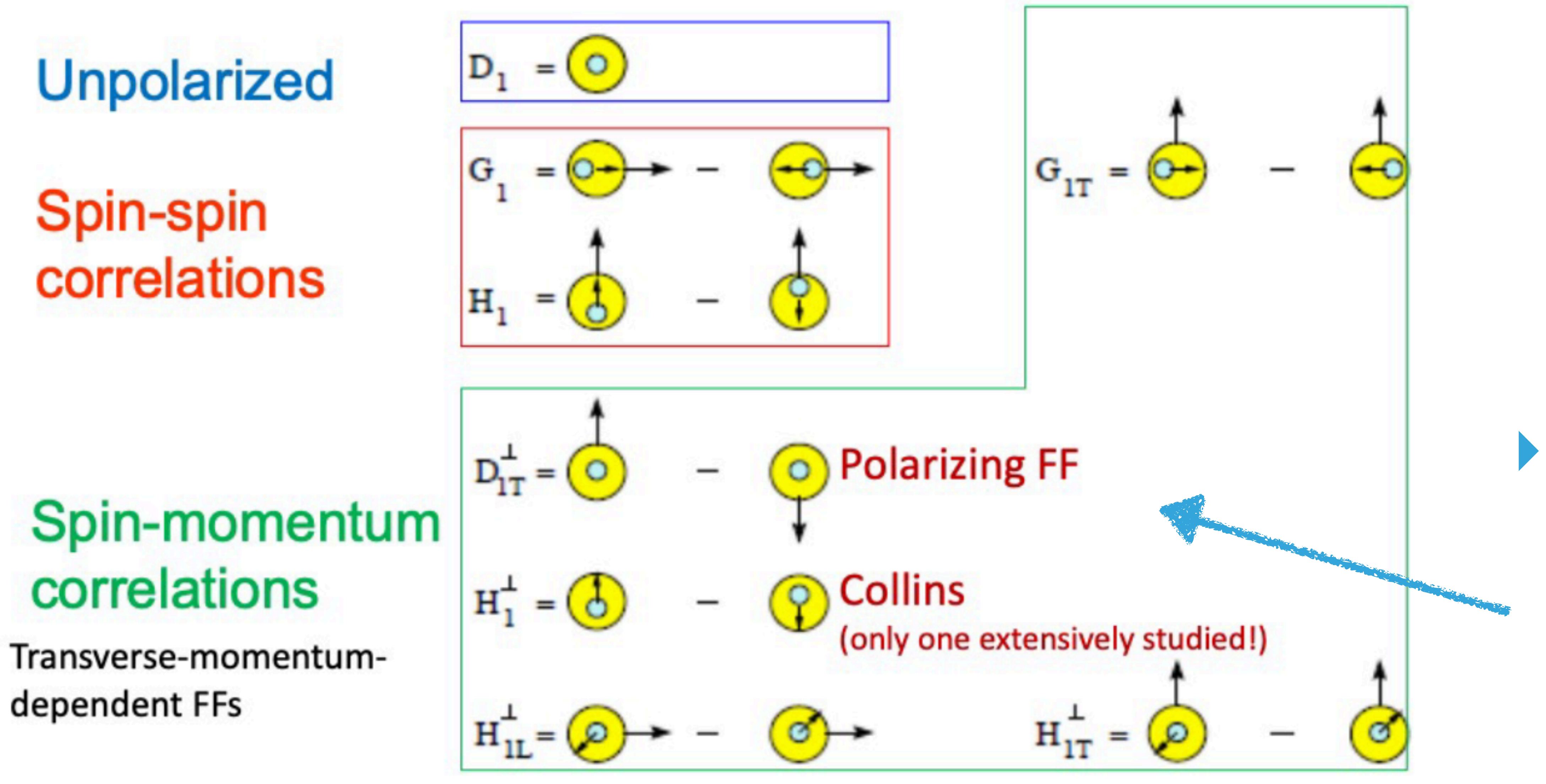
Phys. Rev. Lett. 36, 1113 (1976)



- **Despite many theories and experiments performed, still not a clear explanation!**

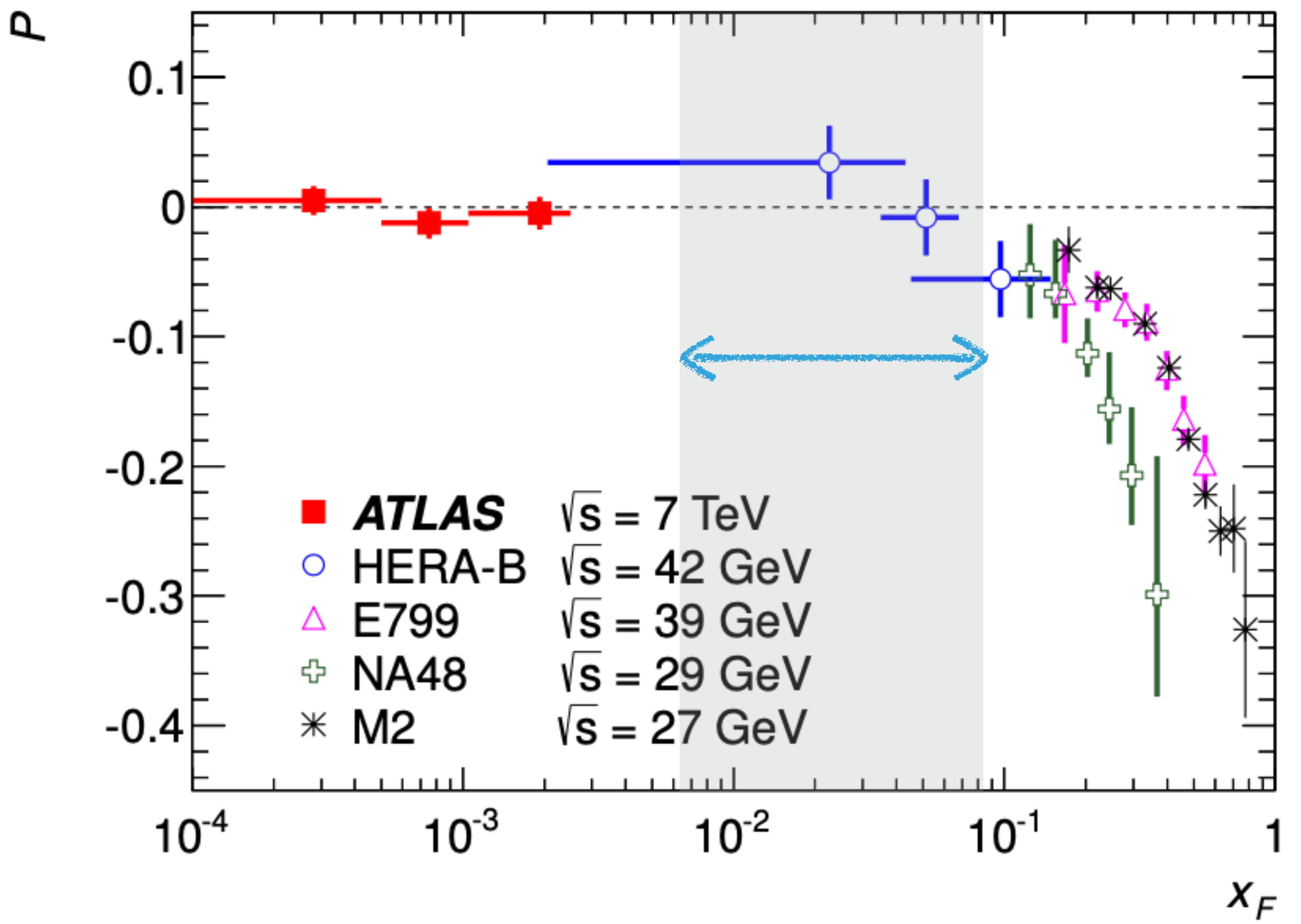
Λ^0 TRANSVERSE POLARIZATION

- **Common features** observed up to now:
  - **Polarization value increases with increasing x_F and p_T up to few GeV**
  - **Roughly independent of the beam energy and the atomic mass number of the colliding nuclei**
- Polarization observed also for other hyperons (Ξ^0, $\Xi^{\pm}$, $\Sigma^{\pm}$)



- **Most recent measurements in collider and fixed target experiments**
  - LHCb reach in the grey zone

Phys. Rev. D 91, 032004 (2015)

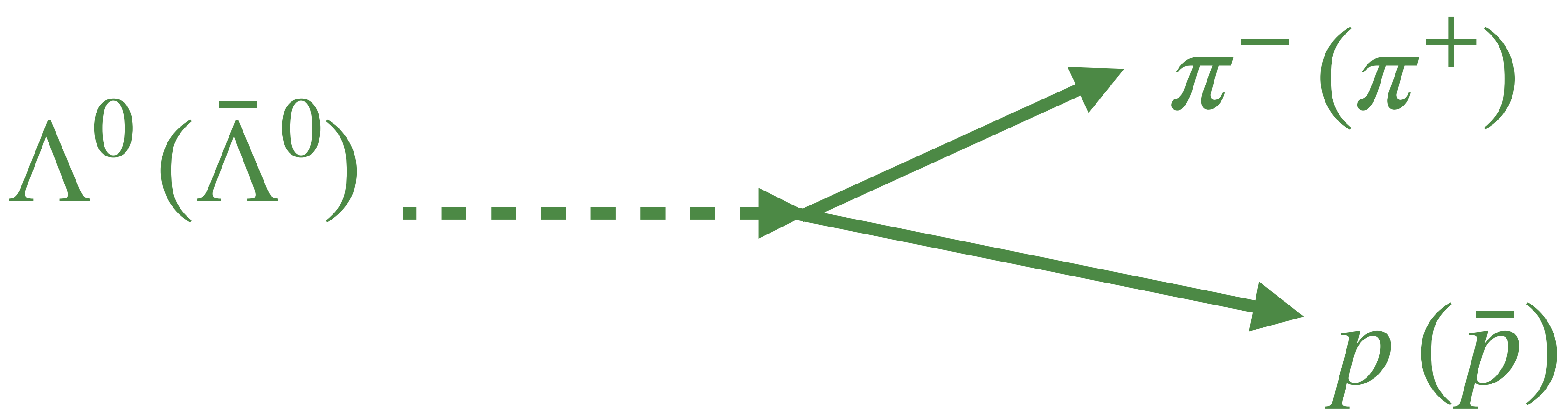


- **Phenomenological approach** in explaining the polarization
  - **Polarizing TMD fragmentation function (FF):** describes the fragmentation of an unpolarized quark into a transversely polarized hadron

Arxiv:0008186v1

STRATEGY FOR MEASURING THE POLARIZATION

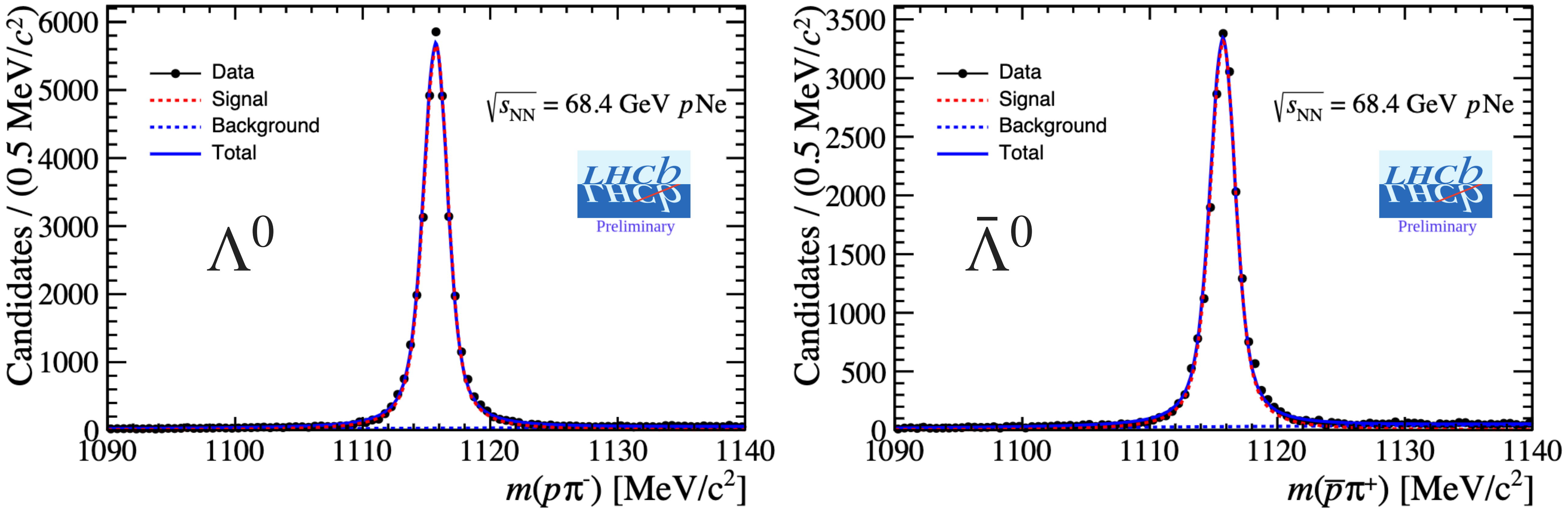
- **We measure the polarization in the 2017 pNe sample:**
  - It is studied exploiting the Λ^0 decay



Both Λ and $\bar{\Lambda}$ states analyzed

  - The **decay protons** are preferentially **emitted along the spin direction of the** Λ in its rest frame

LHCb-PAPER-2024-009, in preparation

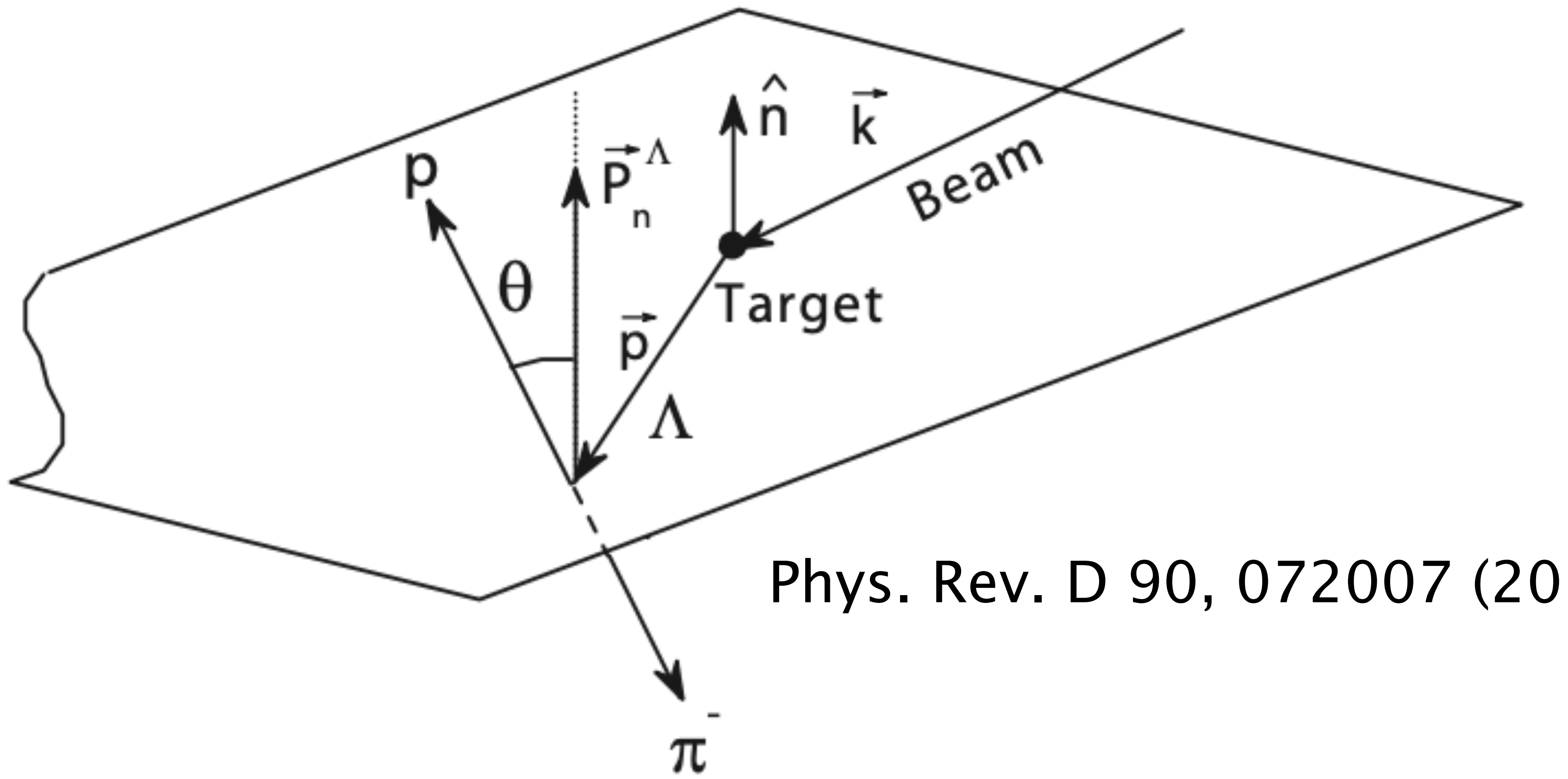


- Measuring the **asymmetry in the proton's angular distribution** if present, would provide access to the Λ^0 polarization

$$\frac{dN}{d\Omega} = \frac{dN_0}{d\Omega}\left(1 + \alpha P_n^{\Lambda} \cos\theta\right)$$

α parity-violating decay asymmetry for Λ^0

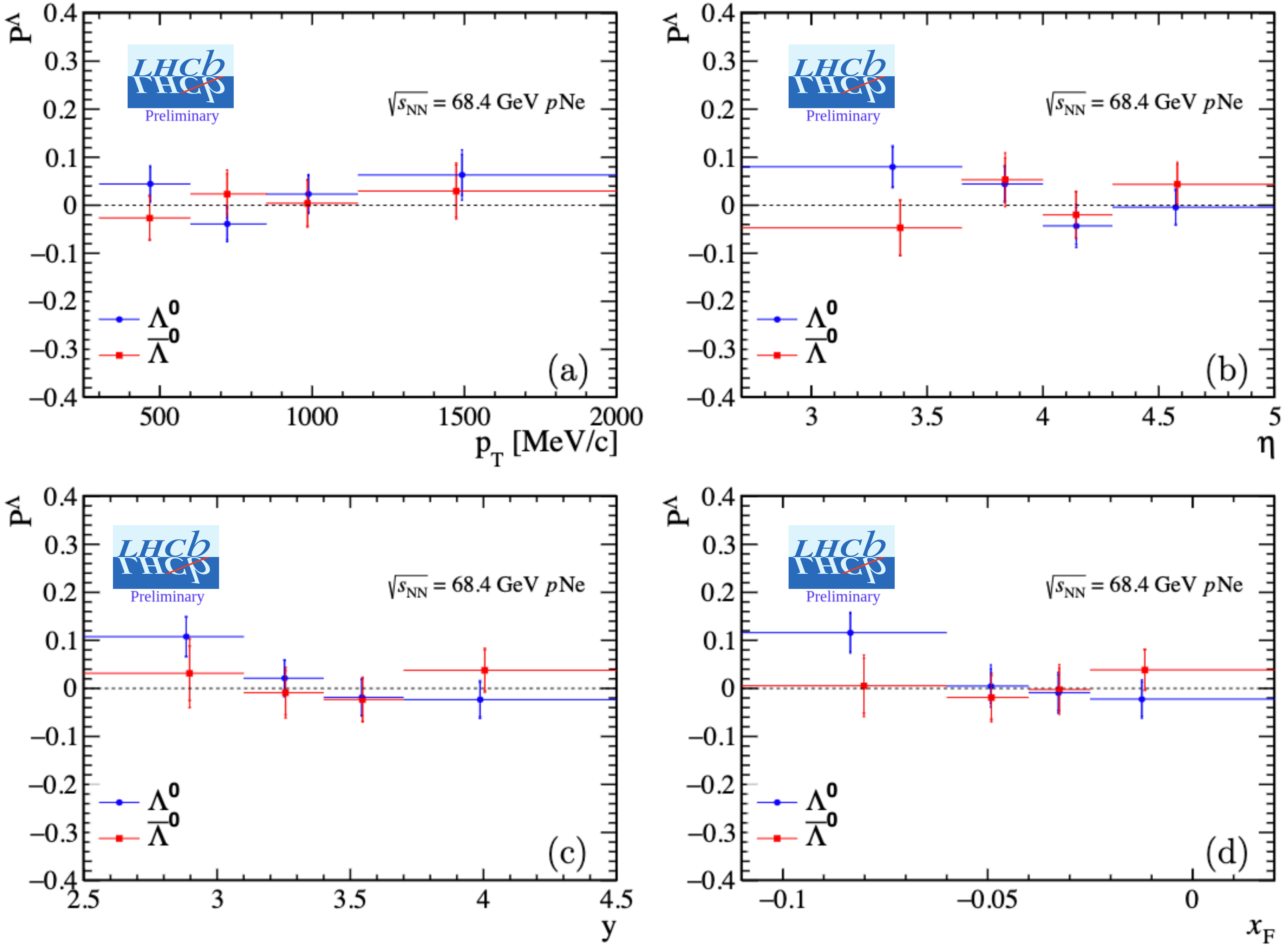
- Polarization to be extracted by the angular coefficient of the angular distribution!



Phys. Rev. D 90, 072007 (2014)

RESULTS

LHCb-PAPER-2024-009, in preparation



- **Polarization values obtained** in the kinematical range:
  300 < p_T < 3000 MeV/c & 2 < η < 5

$$P(\Lambda) = 0.029 \pm 0.019 \pm 0.012$$

$$P(\bar{\Lambda}) = 0.003 \pm 0.023 \pm 0.014$$

- **Polarization values studied as a function of:**

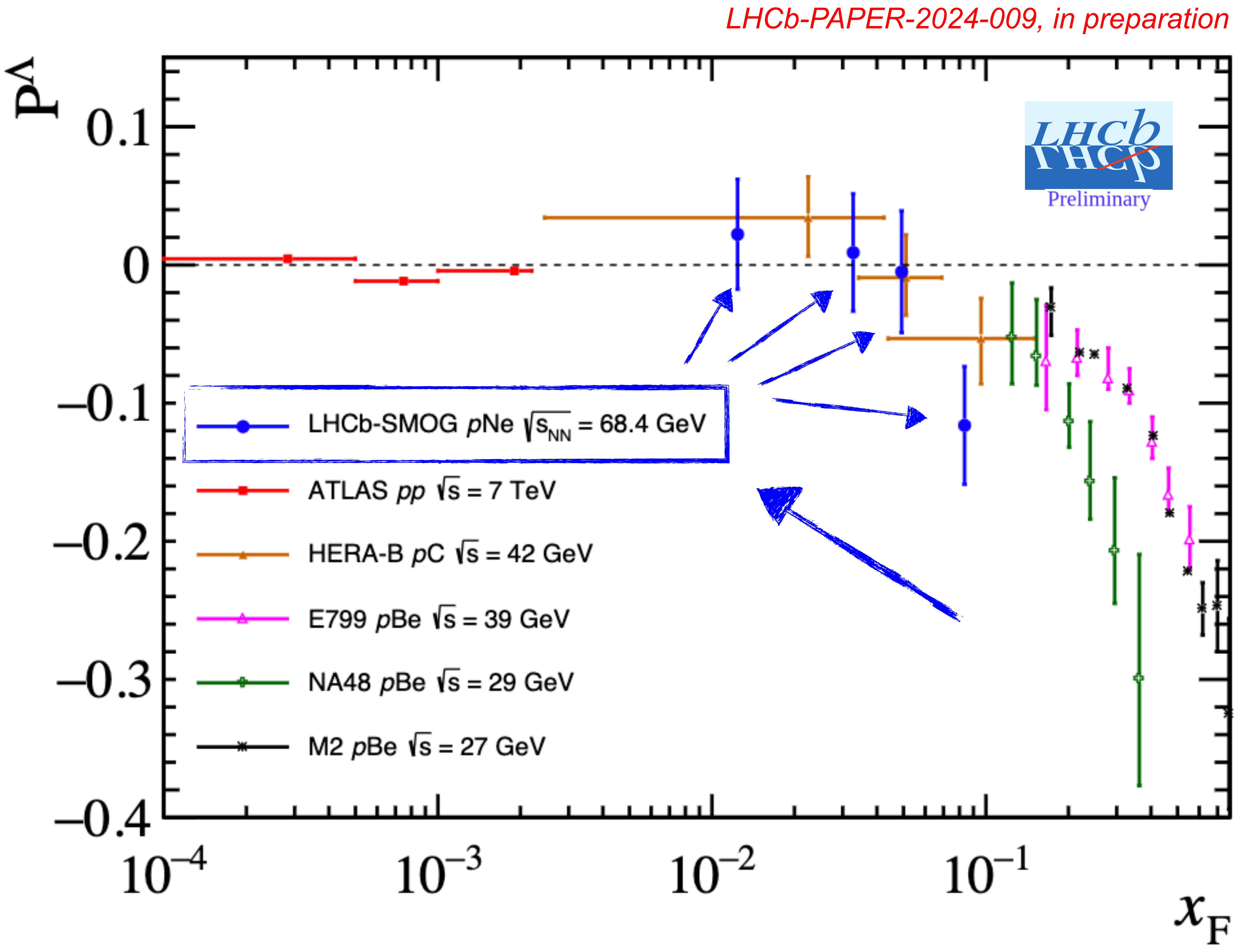
  (a) p_T (b) η

  (c) y (d) x_F

  - Error bars convolution of statistical and systematical uncertainties

y and η in the lab frame

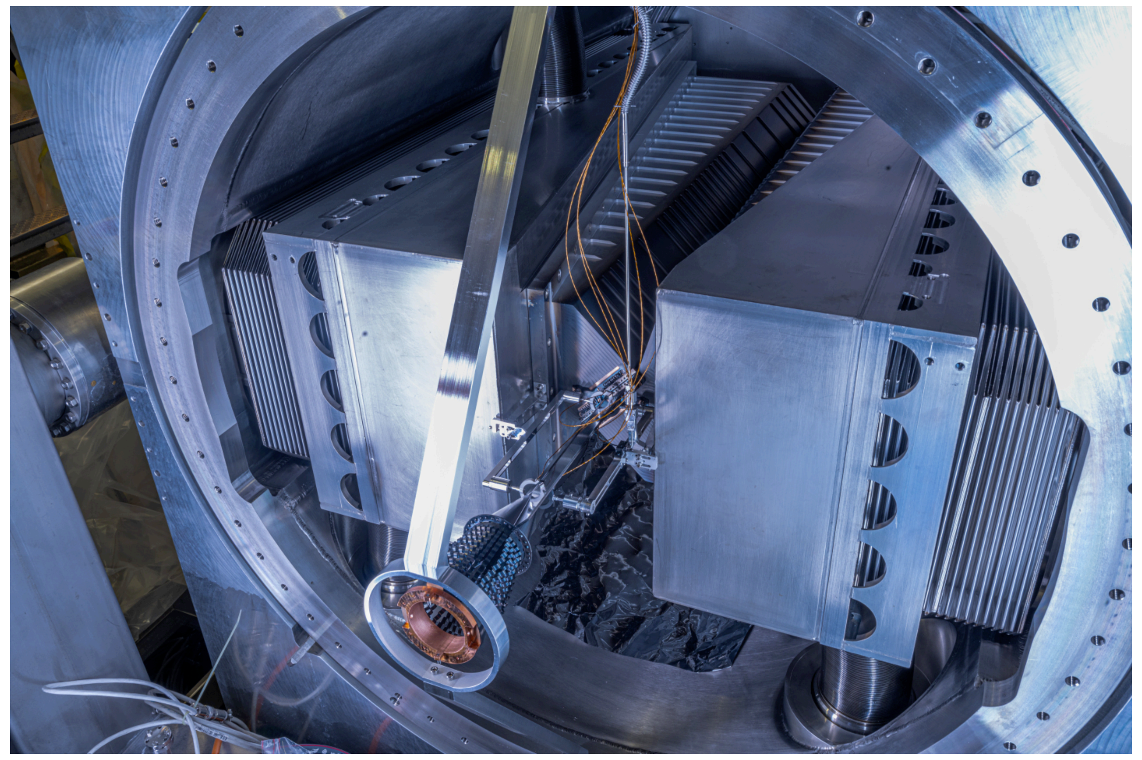
COMPARISON WITH OTHER EXPERIMENTS



- **Λ^0 polarization vs x_F**
  - **Comparison with results** from other experiments performed **in different kinematical regions and collision system**
  - **Very good agreement in the polarization values!!**

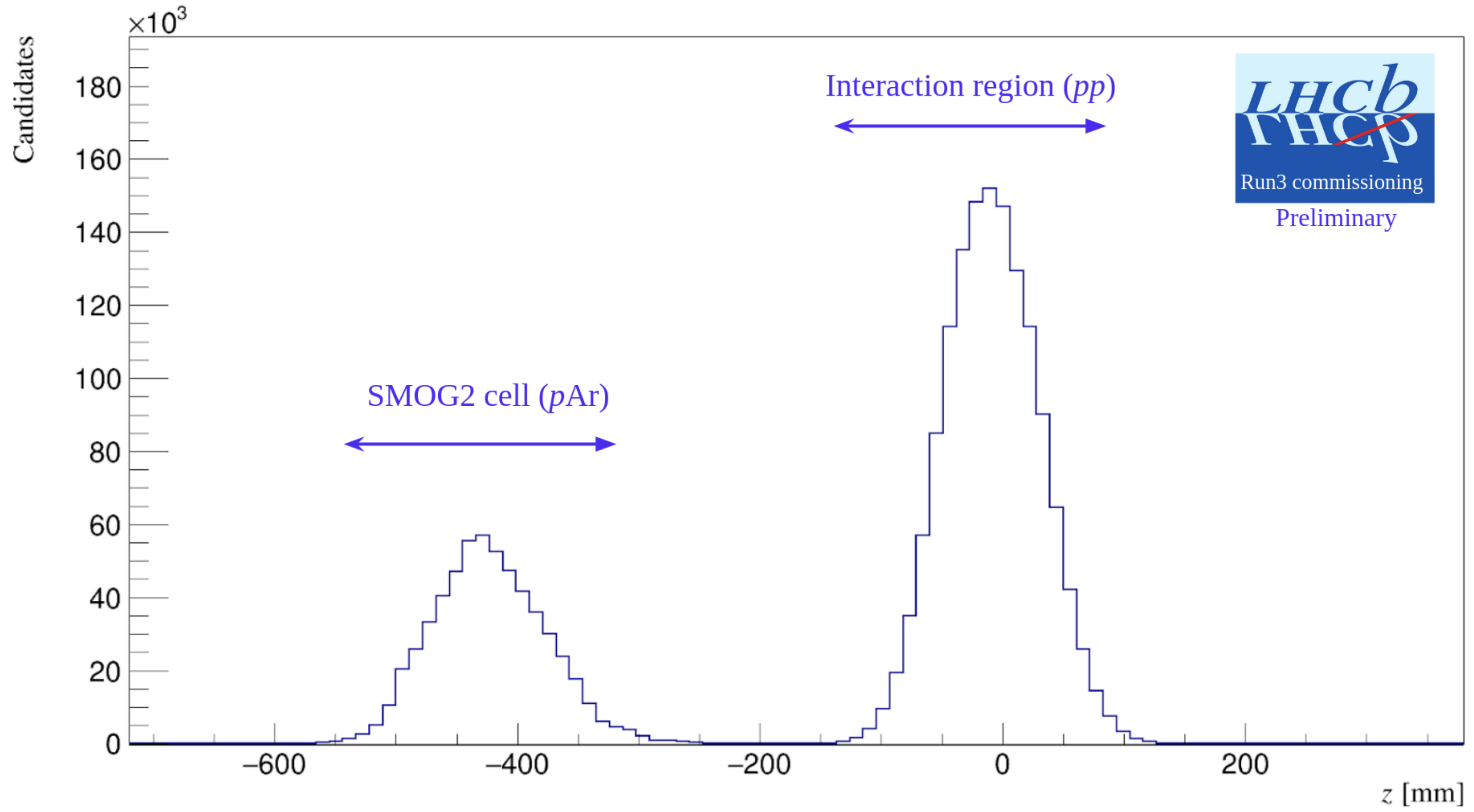
FIXED TARGET COLLISIONS AT LHCb: SMOG2

RUN3 CONFIGURATION



- **SMOG2:** gas confined in a 20 cm long **storage cell**
- **Higher areal density** than SMOG (luminosity increased up to ~ x 100)
- **Wider choice of gases to be injected:** He, Ne, Ar, H_2, D_2, N_2, O_2, Kr, Xe
- **Data taken simultaneously in** pp **and** pA **modes**

LHCb-FIGURE-2023-001



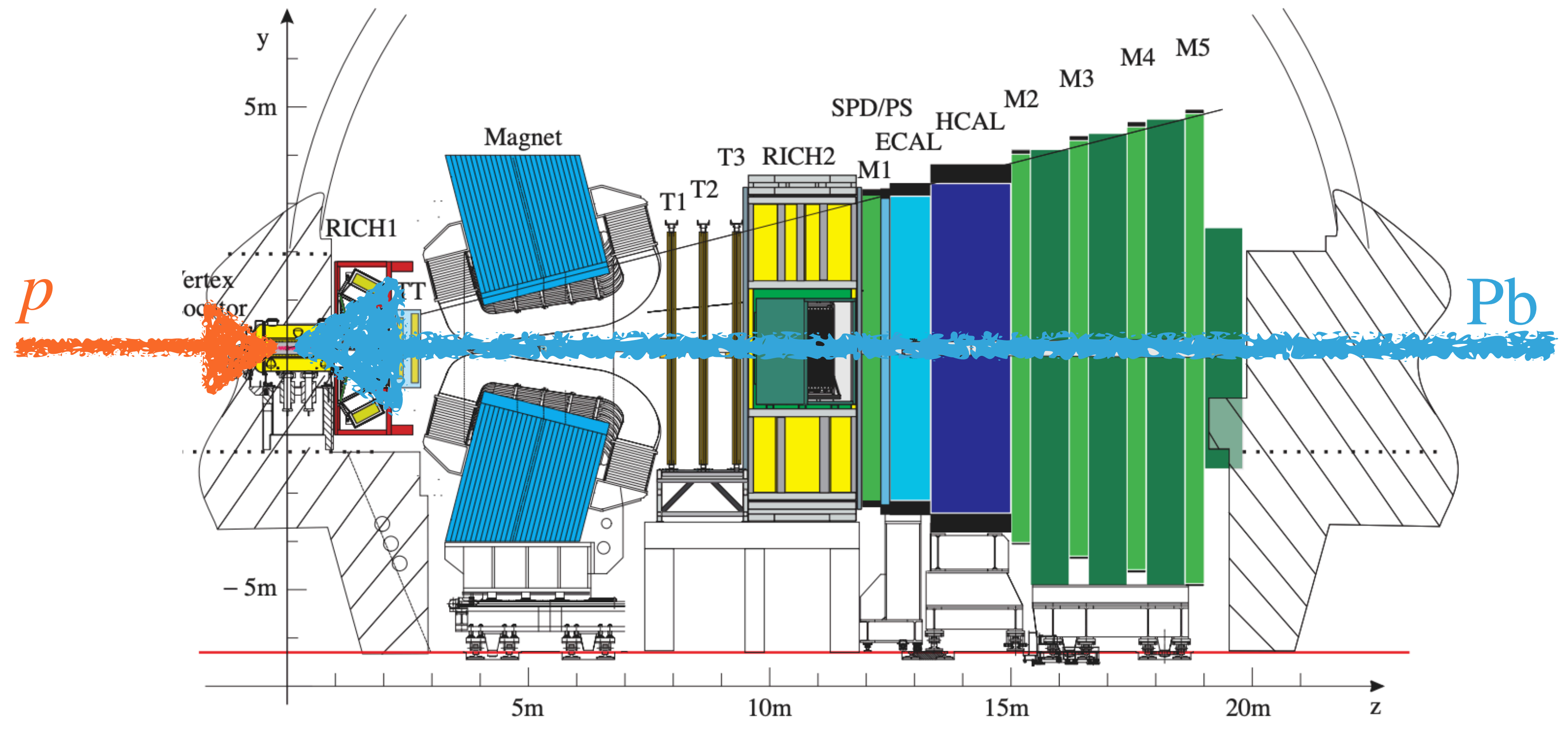
- **Possibility to improve the transverse polarization analysis:**
  - **Much higher luminosity → better statistical resolution**
  - **Measurements to be repeated with different mass target and beam energy to probe the polarization features listed before**
  - Possibility to look into other hyperon polarization!

STRANGENESS PRODUCTION

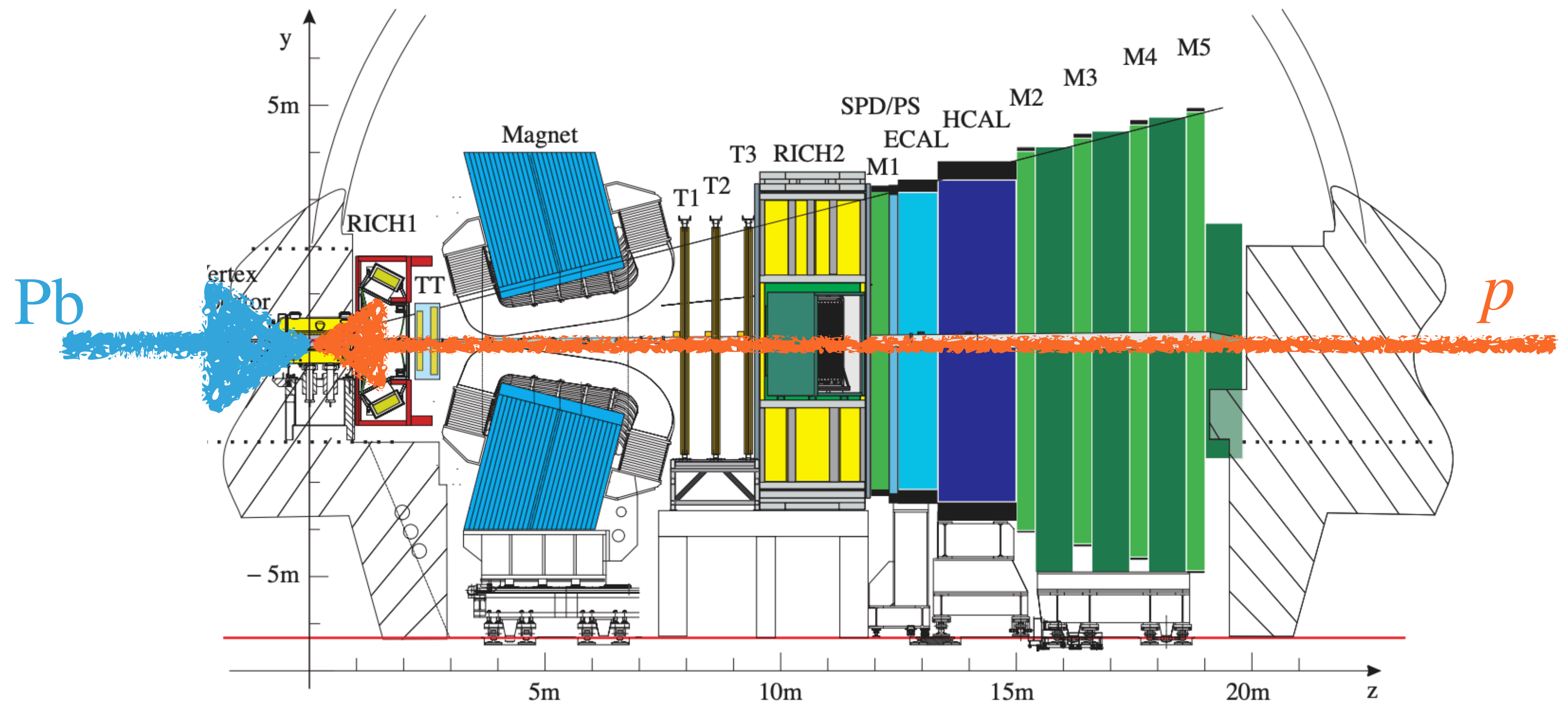
STRANGENESS ENHANCEMENT IN $p\mathrm{Pb}$ COLLISIONS

- **Strangeness enhancement is considered a signature for the QGP formation in heavy-ion collisions**
- **It is essential to characterize the cold nuclear matter effect (CNM) involved in these processes**

- In pPb collisions the energy density is not expected to be sufficient to produce a QGP medium:
  - **Optimal environment to study CNM effects**
  - **Possibility to test theories which predict QGP droplets in such collisions**



- **Forward** region: $1.5 < y^* < 4.0$
- pPb (2013) @ $\sqrt{s_{NN}} = 5.02$ TeV → L ~ 1.1 nb^{-1}
- pPb (2016) @ $\sqrt{s_{NN}} = 8.16$ TeV → L ~ 12.5 nb^{-1}



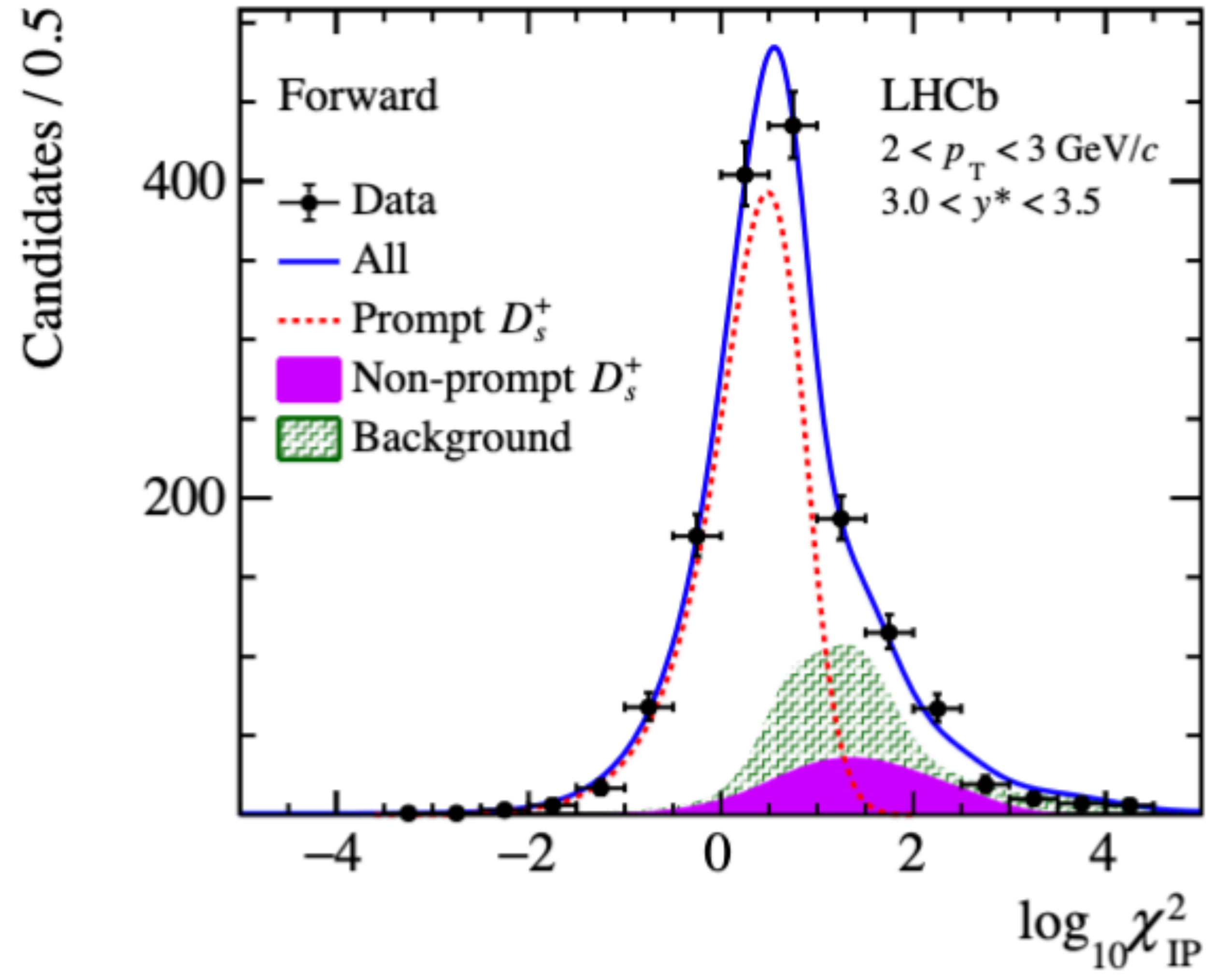
- **Backward** region: $-5.0 < y^* < -2.5$
- Pbp (2013) @ $\sqrt{s_{NN}} = 5.02$ TeV → L ~ 0.4 nb^{-1}
- Pbp (2016) @ $\sqrt{s_{NN}} = 8.16$ TeV → L ~ 17.4 nb^{-1}

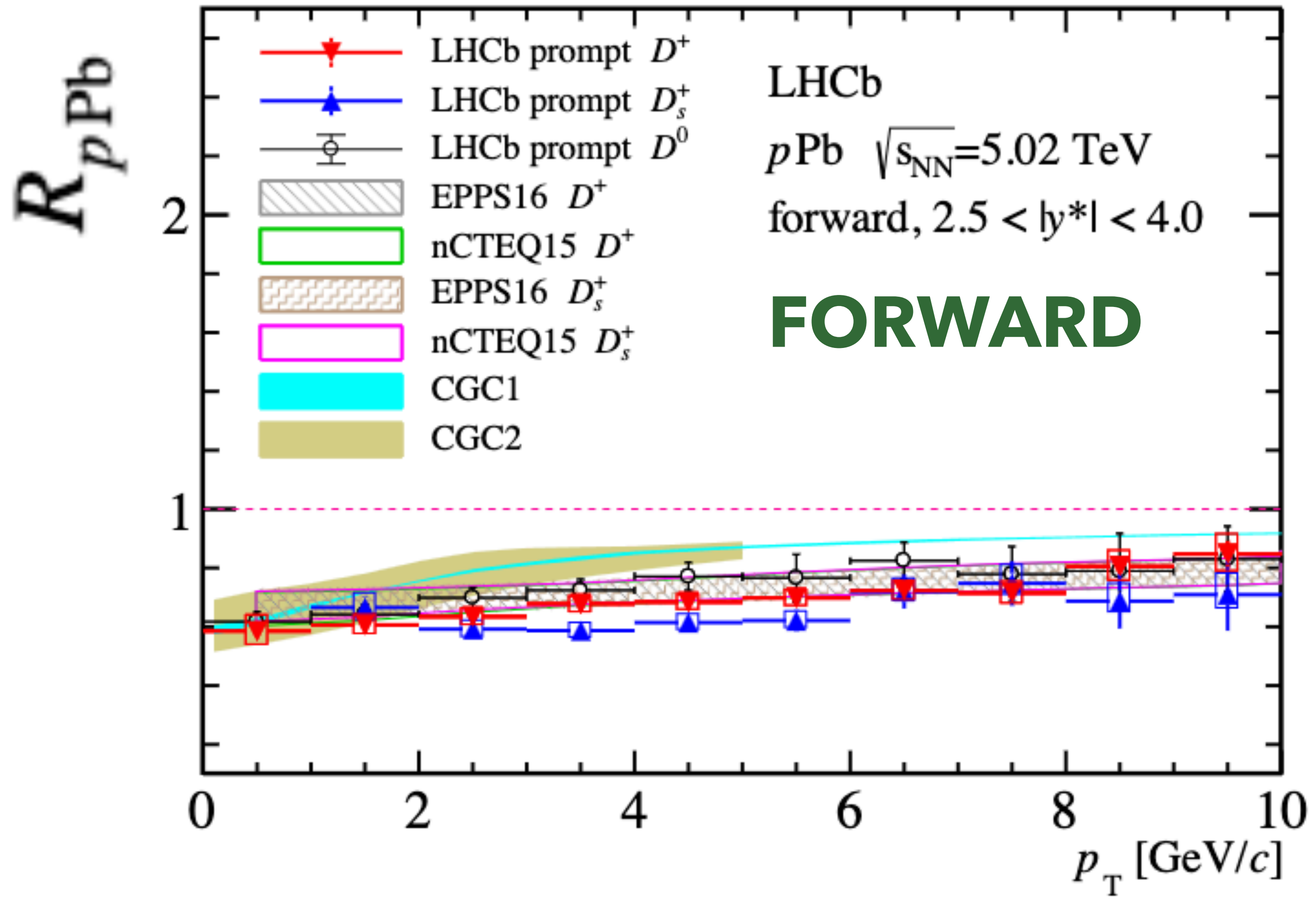
pPb and Pbp collisions configuration at LHCb

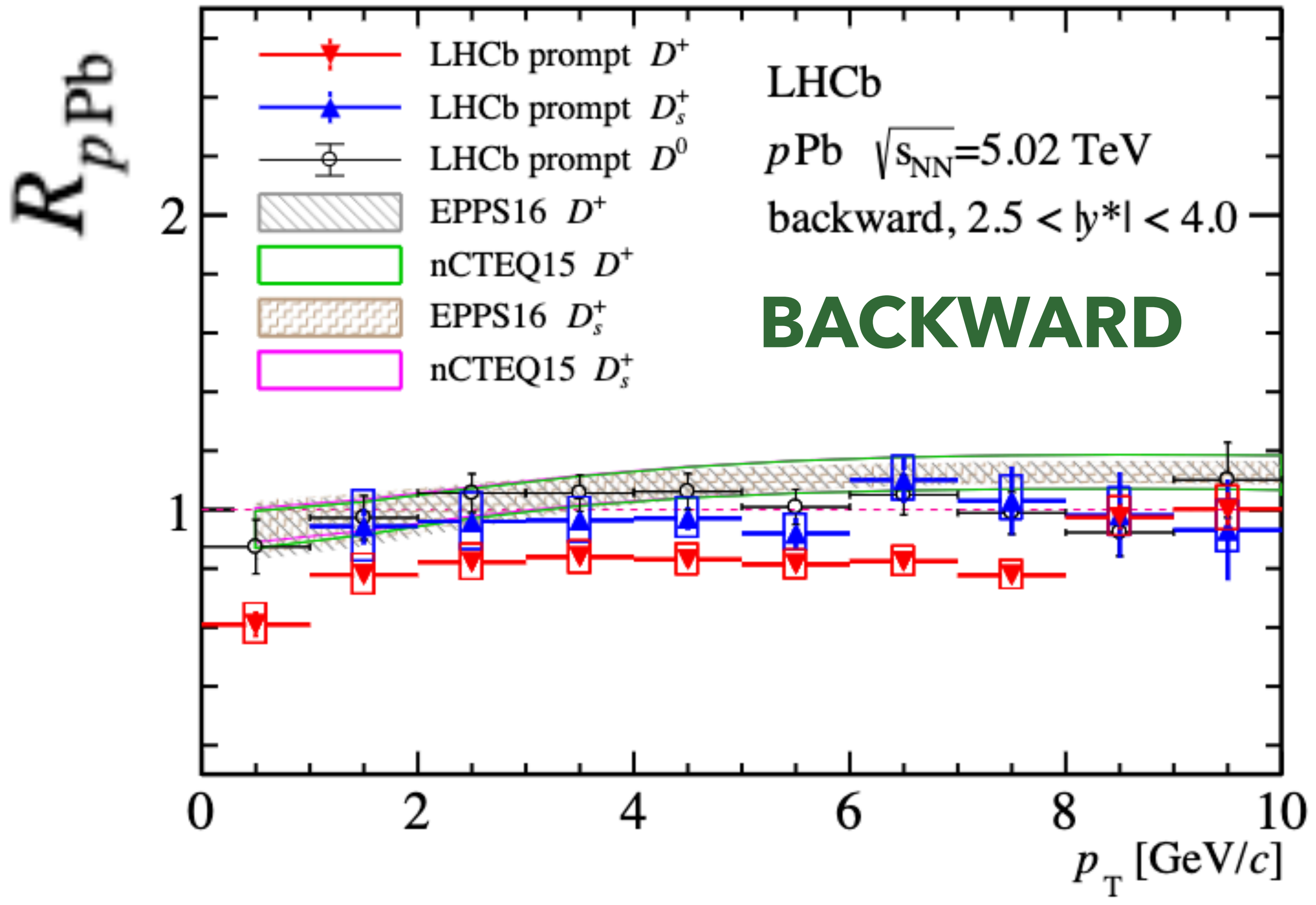
PROMPT D^+, D_s^+ PRODUCTION IN pPb COLLISIONS AT $\sqrt{s} = 5\ \mathrm{TeV}$

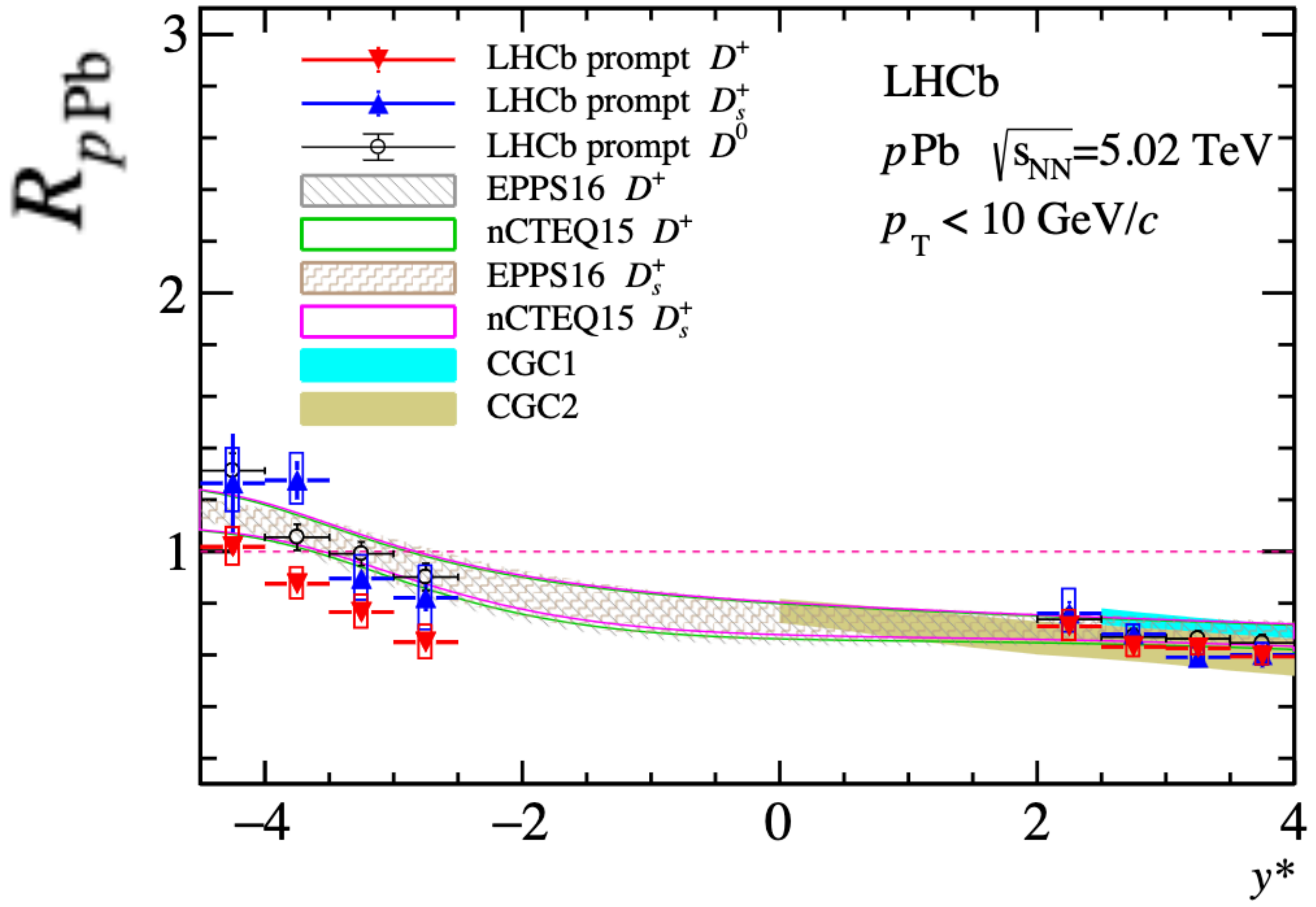
- **First measurement of prompt D^+ and D_s^+** at low p_T and forward rapidities in heavy ion collisions
- **Forward:**
  - Significant suppression consistent with nPDFs
  - Consistent between D^0, D^+ and D_s^+
- **Backward:**
  - D_s^+ and D^0 in agreement with nPDFs

$$R_{p\mathrm{Pb}} = \frac{1}{A}\frac{d\sigma_{p\mathrm{Pb}}/dp_T}{d\sigma_{pp}/dp_T}$$







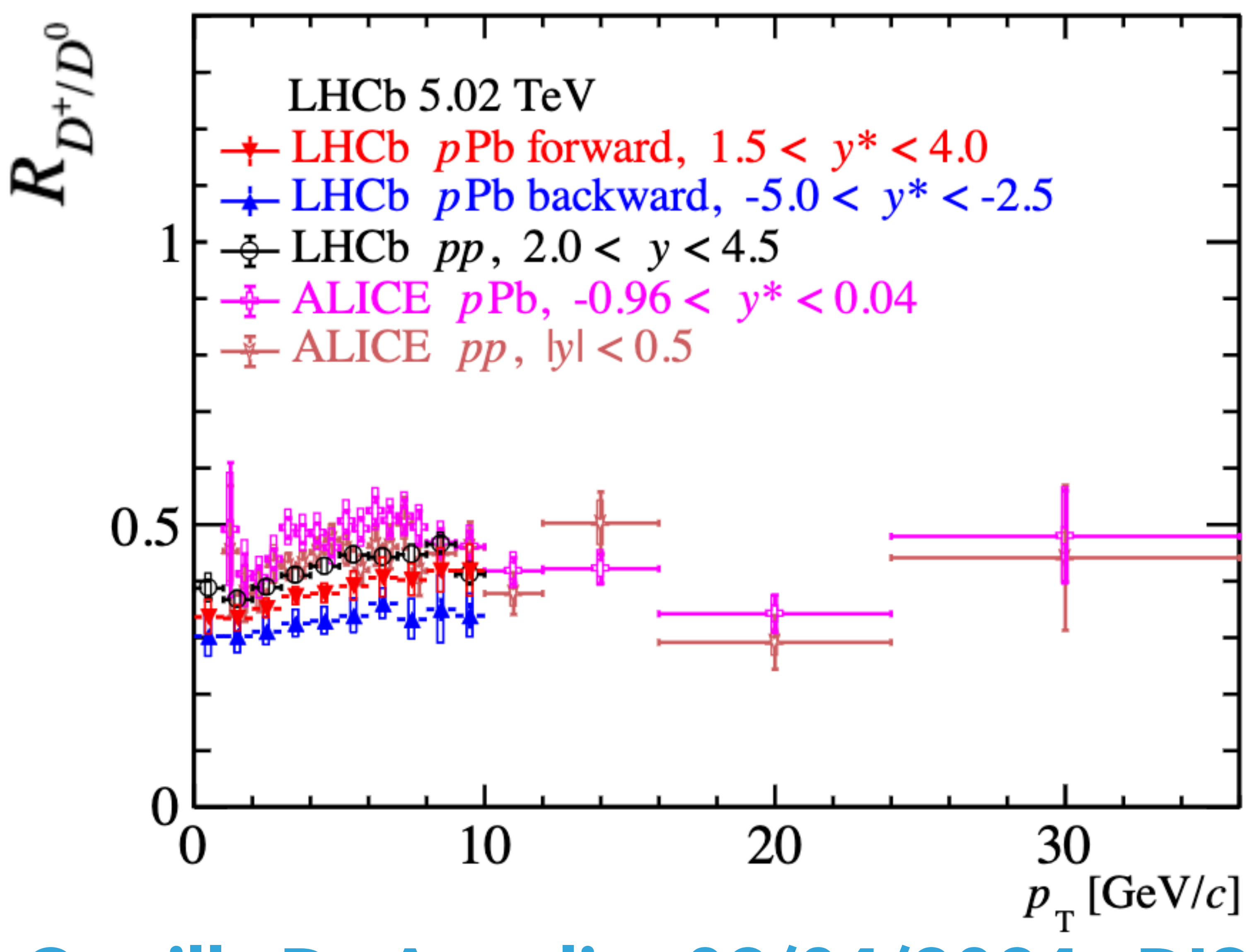


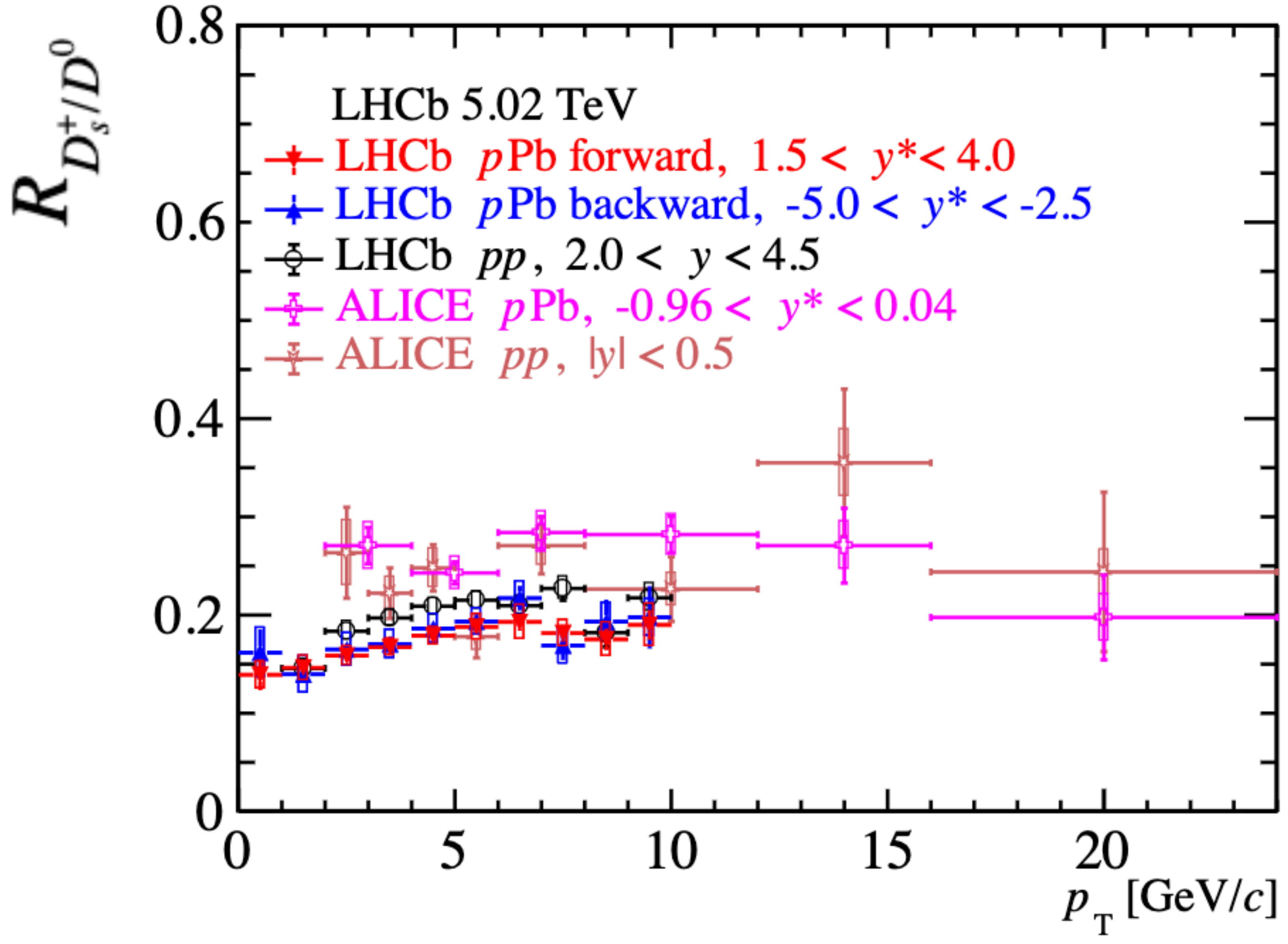
Arxiv:2309.14206, accepted by JHEP

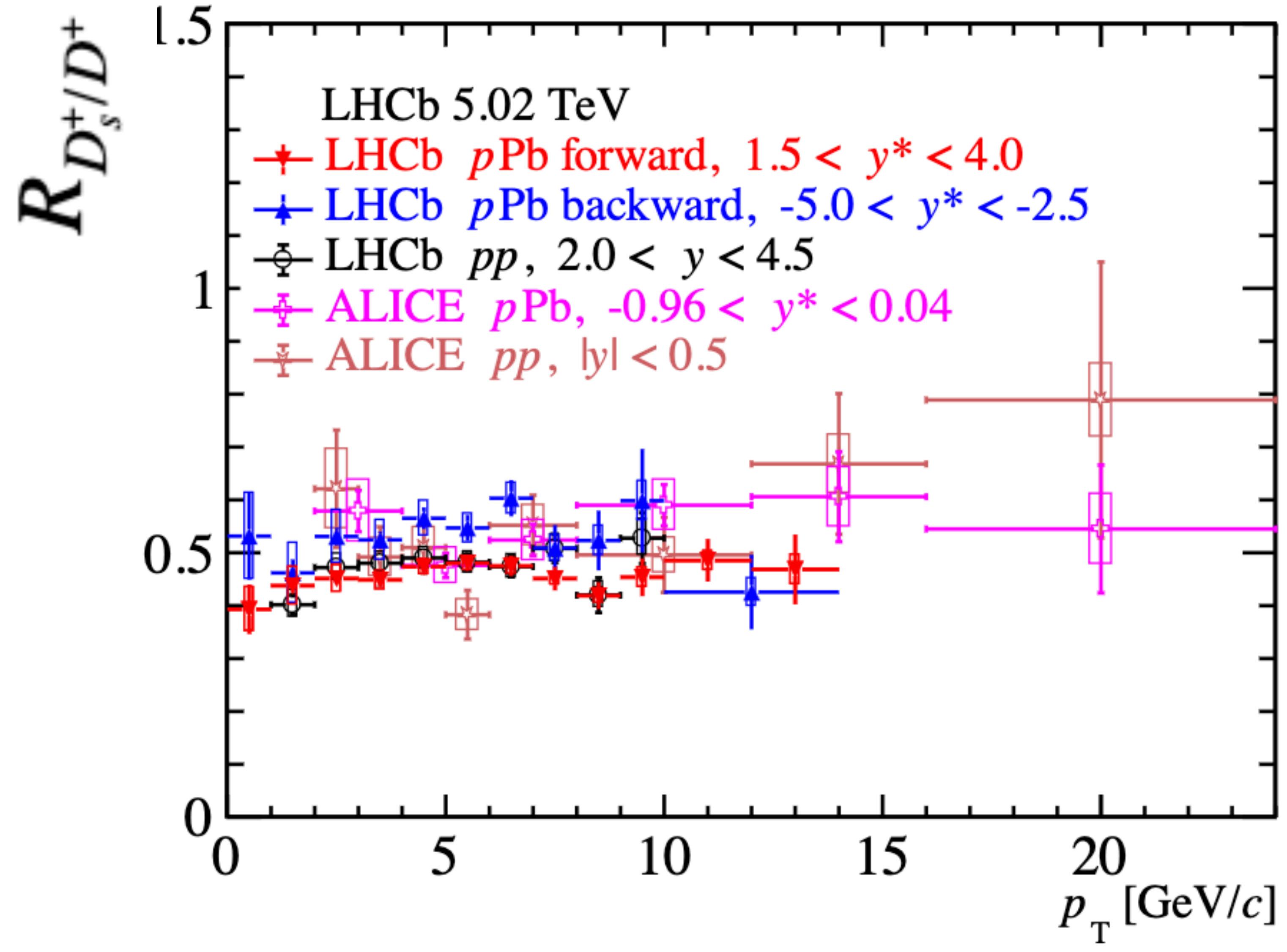
PROMPT D^+, D_s^+ PRODUCTION IN pPb COLLISIONS AT $\sqrt{s} = 5\,\mathrm{TeV}$

- **First measurement of prompt D^+ and D_s^+** at low p_T and forward rapidities in heavy ion collisions
- **Production ratios between D^+, D_s^+ and D^0 coming from an LHCb previous measurement** Arxiv:1707.02750
    - Consistent with LHCb pp and ALICE pp and pPb results
    - No enhancement in either the forward or backward region

Similar analysis performed in pPb collisions at $\sqrt{s}$ = 8.16 TeV in pPb, see talk by **Chenxhi Gu talk**, April 9, 9.50 in WG4



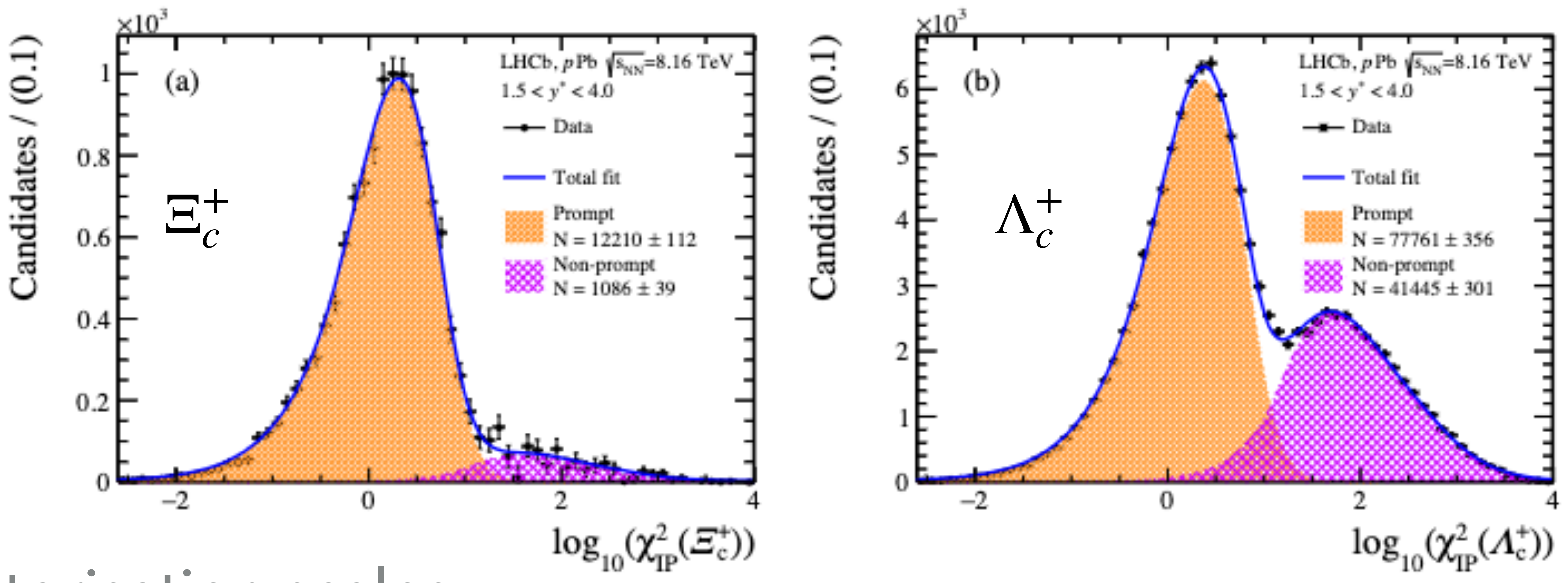




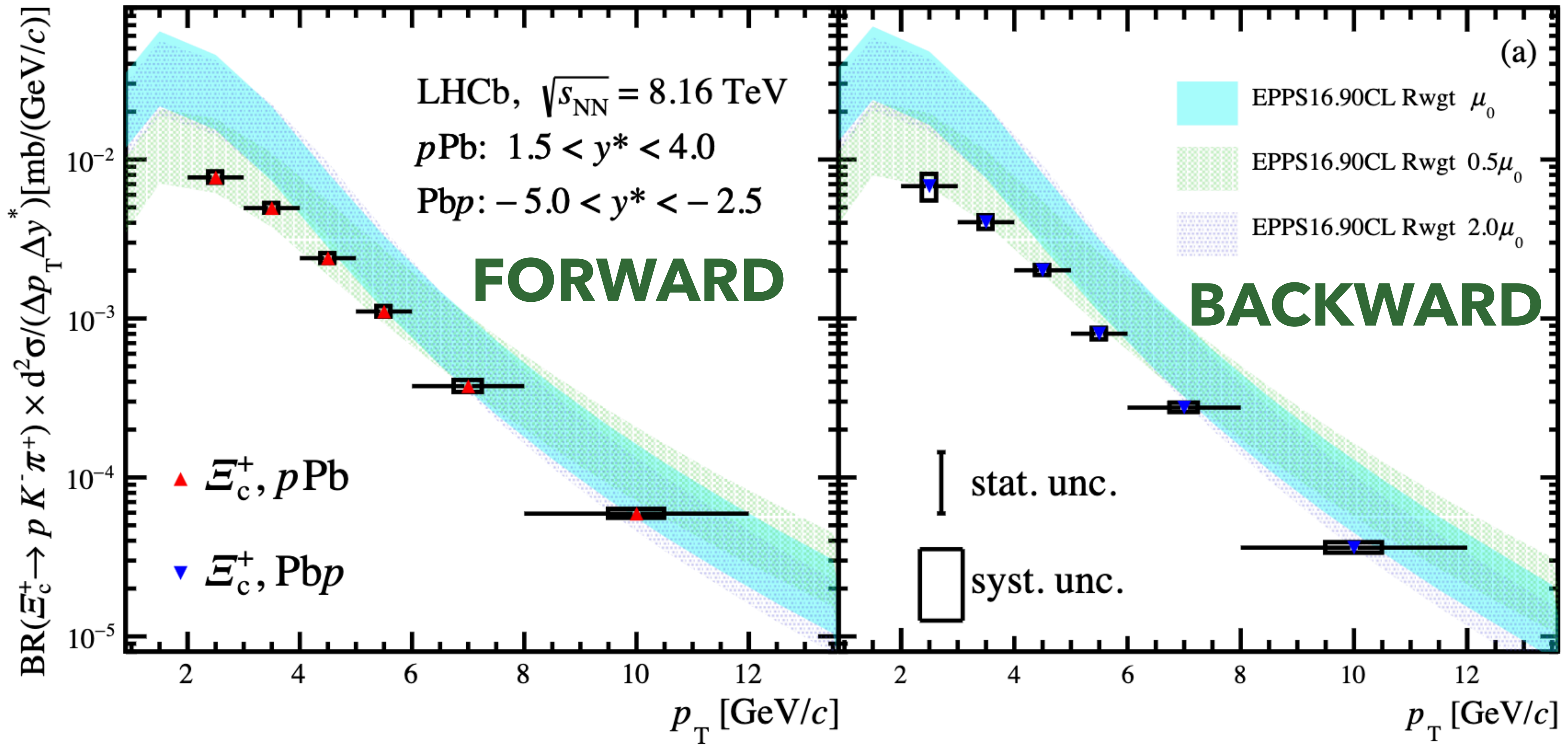
Arxiv:2309.14206, accepted by JHEP

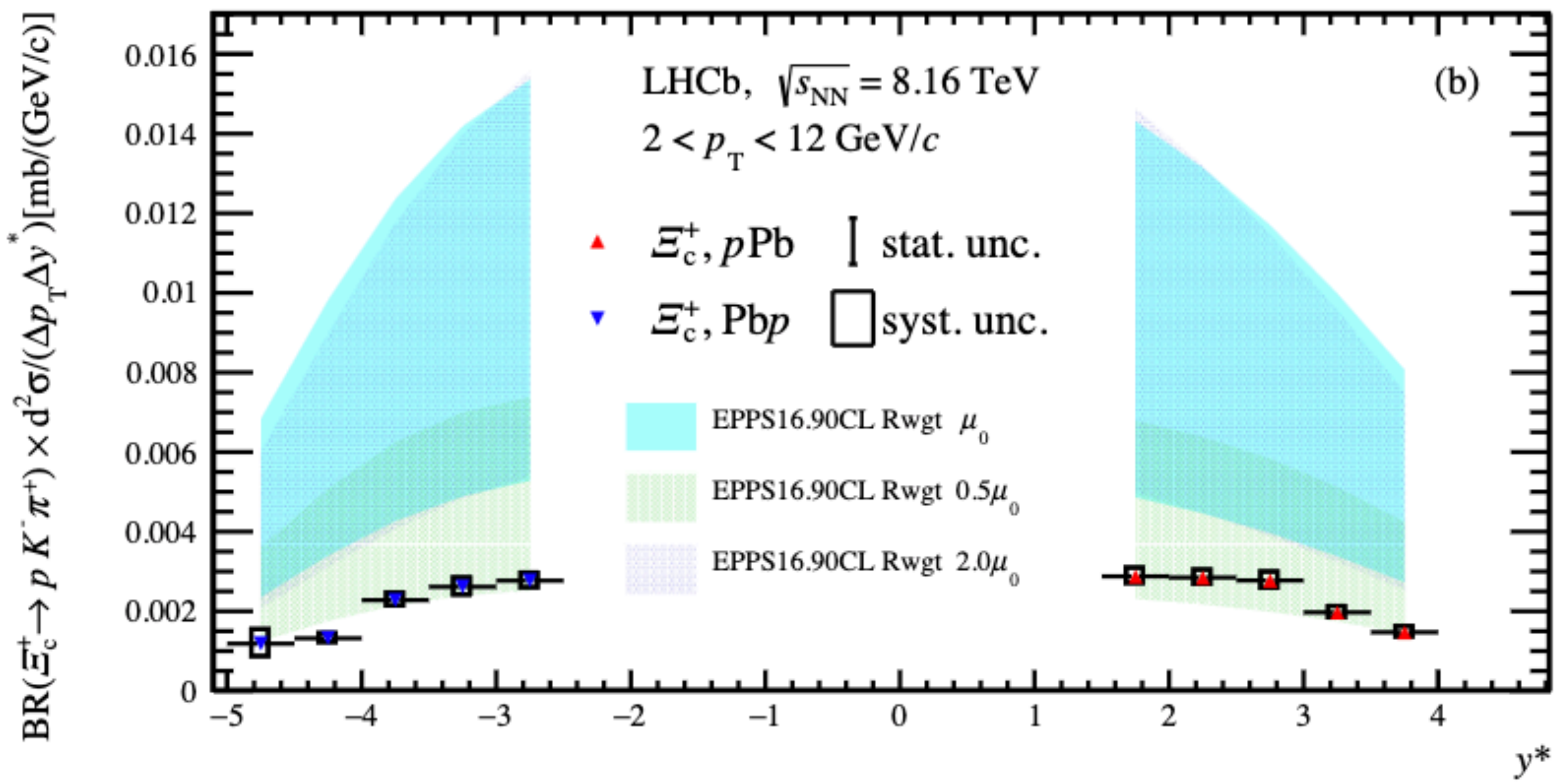
Ξ_c^+ PRODUCTION IN pPb COLLISIONS AT $\sqrt{s} = 8.16$ TeV

- **First measurement of this baryon in heavy-ion collisions: $\Xi_c^+ \to p K^- \pi^+$**
  - Prompt Ξ_c^+ cross-section measured as a function of p_T and y^*



- **Double Ξ_c^+ differential cross-section**
  - Data compared with HELAC-Onia simulations with 3 factorisation scales
  - Better agreement with factorisation scale $0.5\mu_0$

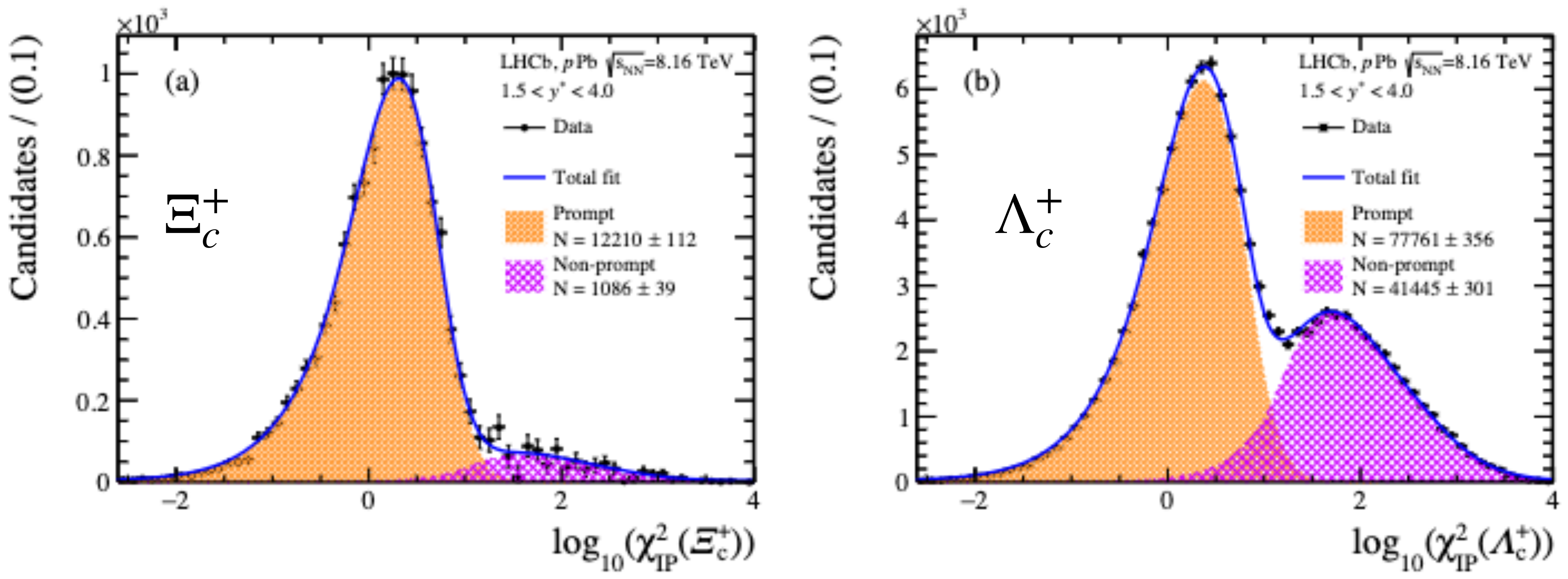




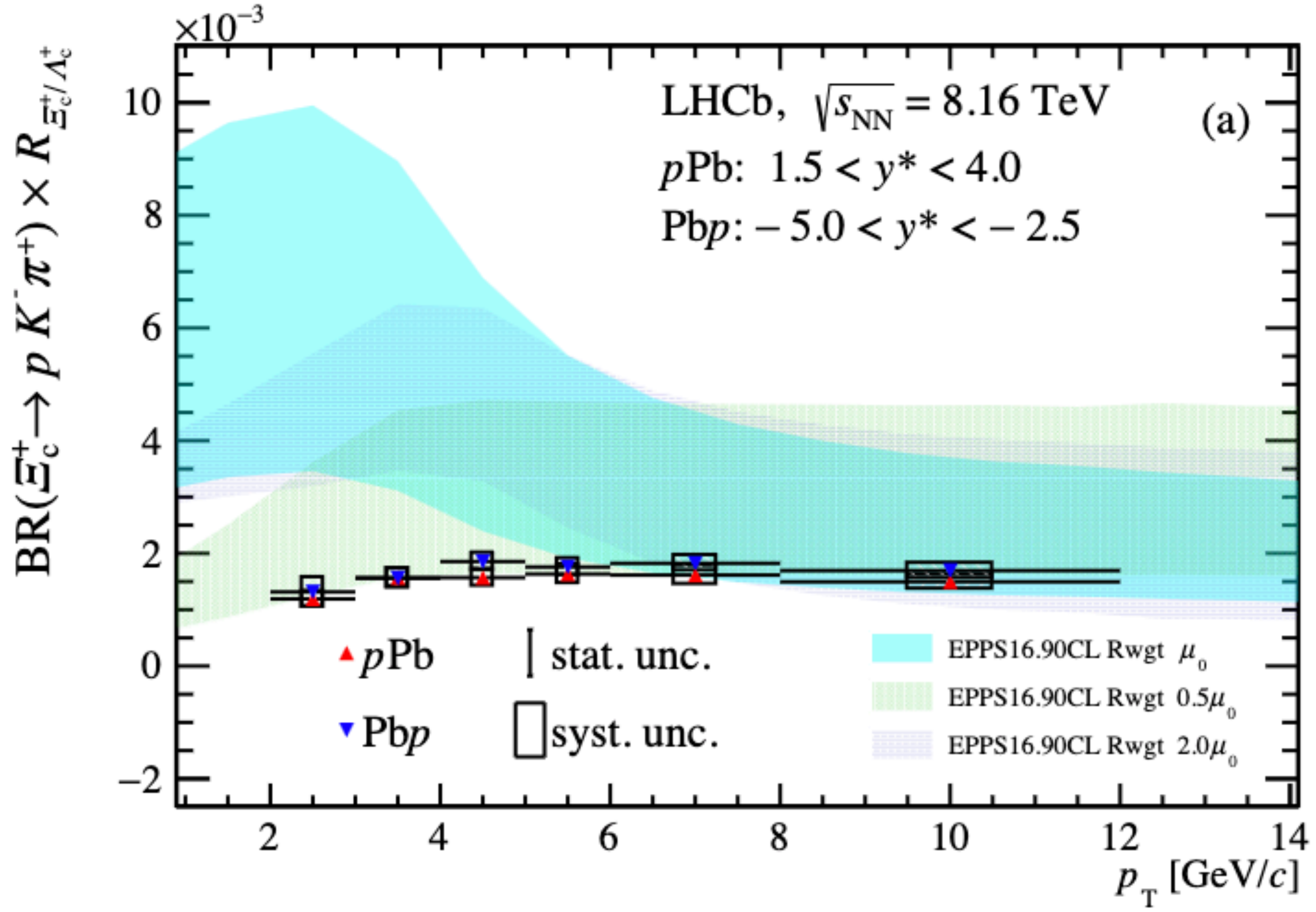
Arxiv:2305.06711, accepted by PRC

Ξ_c^+ PRODUCTION IN pPb COLLISIONS AT $\sqrt{s} = 8.16$ TeV

- **First measurement of this baryon in heavy-ion collisions: $\Xi_c^+ \to p\,K^-\pi^+$**
    - Important **input for strange hadronization**, studies in progress in different collisions systems to better understand the mechanism



- **Measurement of the production ratio Ξ_c^+ / Λ_c^+**
    - Data compared with HELAC-Onia simulations with 3 factorisation scales
    - Better agreement with factorisation scale $0.5\mu_0$
    - No clear sign of strangeness enhancement



Arxiv:2305.06711, accepted by PRC

CONCLUSIONS

- **Results shown from LHCb Run2!**
- New measurement using the **fixed-target system** which help in the understanding of the long-standing challenge of the transverse Λ polarization explanation
- Two measurements in pPb collisions which give input to characterize the strangeness enhancement QGP signature
- Many more results will come with Run3 data!

BACK UP

COSθ DISTRIBUTION

- Dividing the $\cos\theta$ distribution by the efficiencies → **linear distribution!**
- First order polynomial fit to extract the polarization:

  ➡ $f = p_0 \cdot (1 + \alpha^{\Lambda} \cdot p_1 \cdot x)$

  - $\alpha^{\Lambda} = 0.758$, is the world average value of the parity-violating decay asymmetry for Λ
  - $P_n^{\Lambda} = p_1$, polarization values