# Recent results from LHCb

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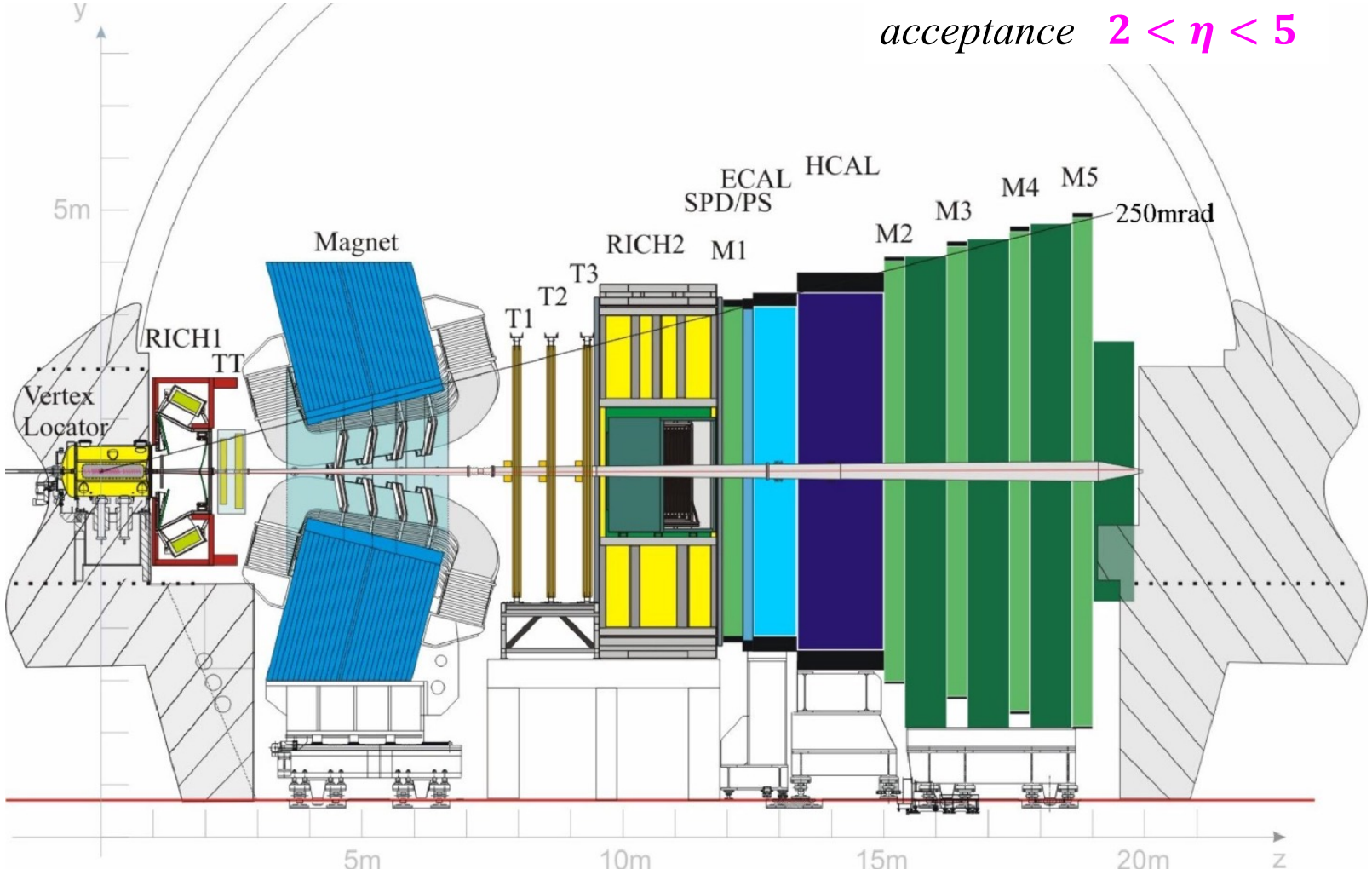
# The LHCb detector

A single arm **general-purpose detector** at **forward** rapidity !

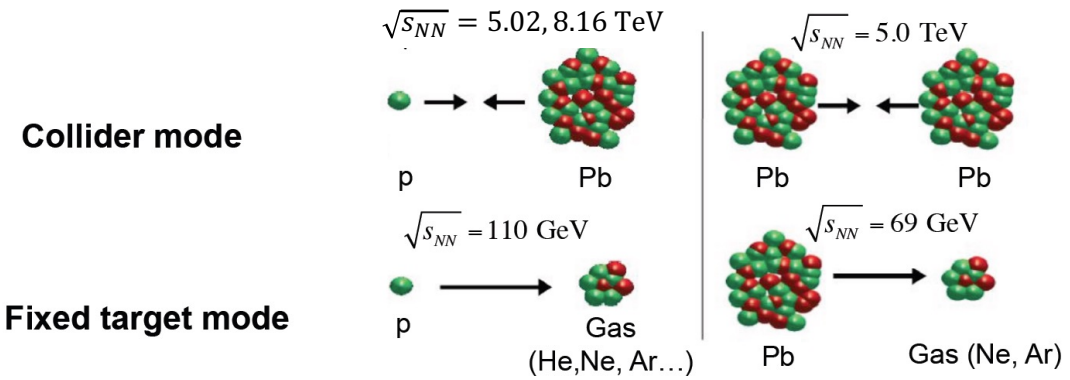
- **Precise tracking**
  clear separation between primary and decay vertices
- **Full PID**
  reconstruct resonances down to zero $p_T$
- **Flexible and fast trigger**
  precision access to rare probes: charm/bottom, higher quarkonia, exotic states
- **Fixed-target system (SMOG)**
  acquire beam-gas data ($p$A, PbA) simultaneously with beam-beam

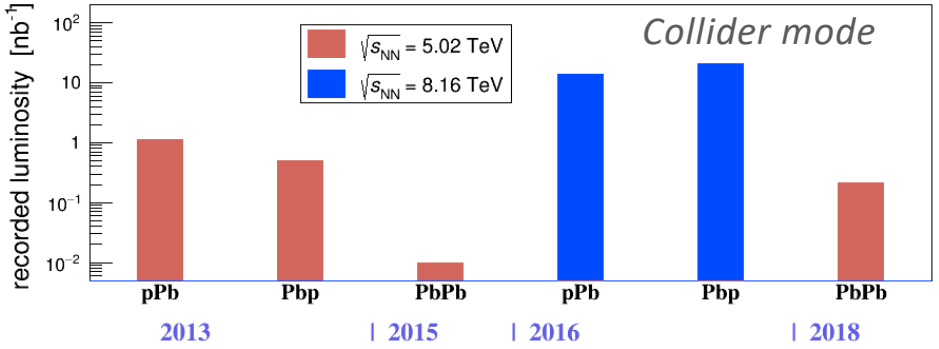
*acceptance* $2 < \eta < 5$

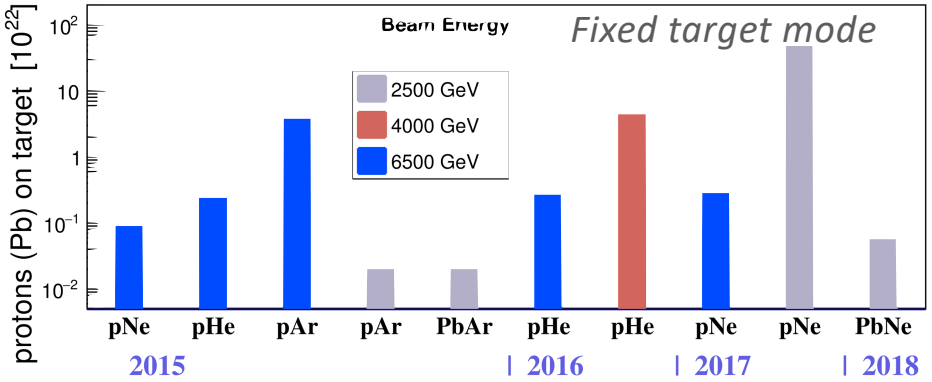



*JINST 3 (2008) S08005; IJMPA 30 (2015) 1530022; JINST 9 (2014) P12005*

# LHCb heavy ion datasets from Run1/Run2



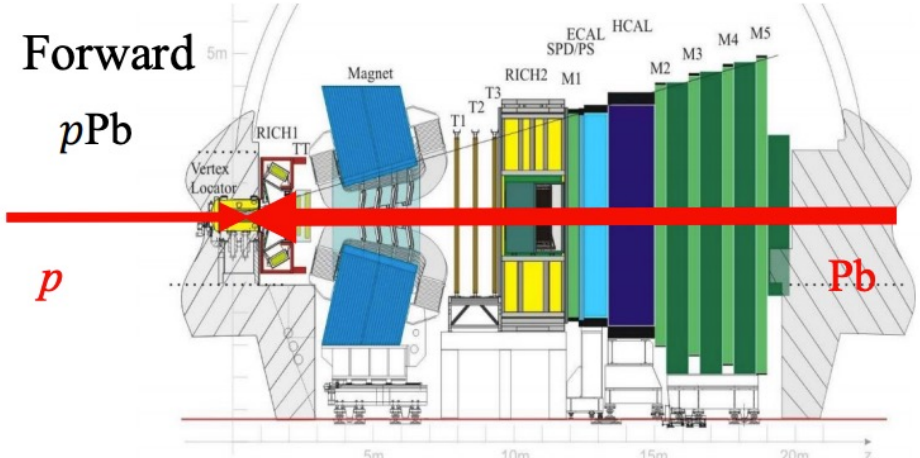



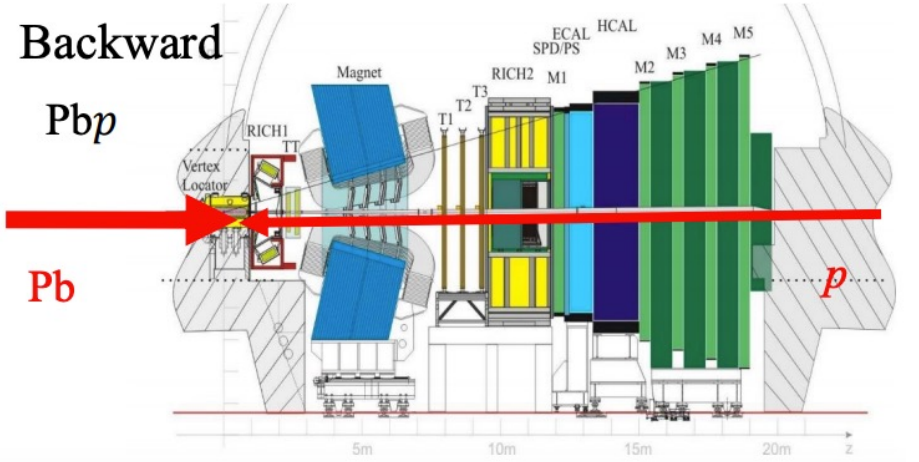

**PbPb:**
limited to 100-60% centrality

**+ huge pp collision datasets at various energies for small-system studies!**

**Proton-Pb data-taking modes:**

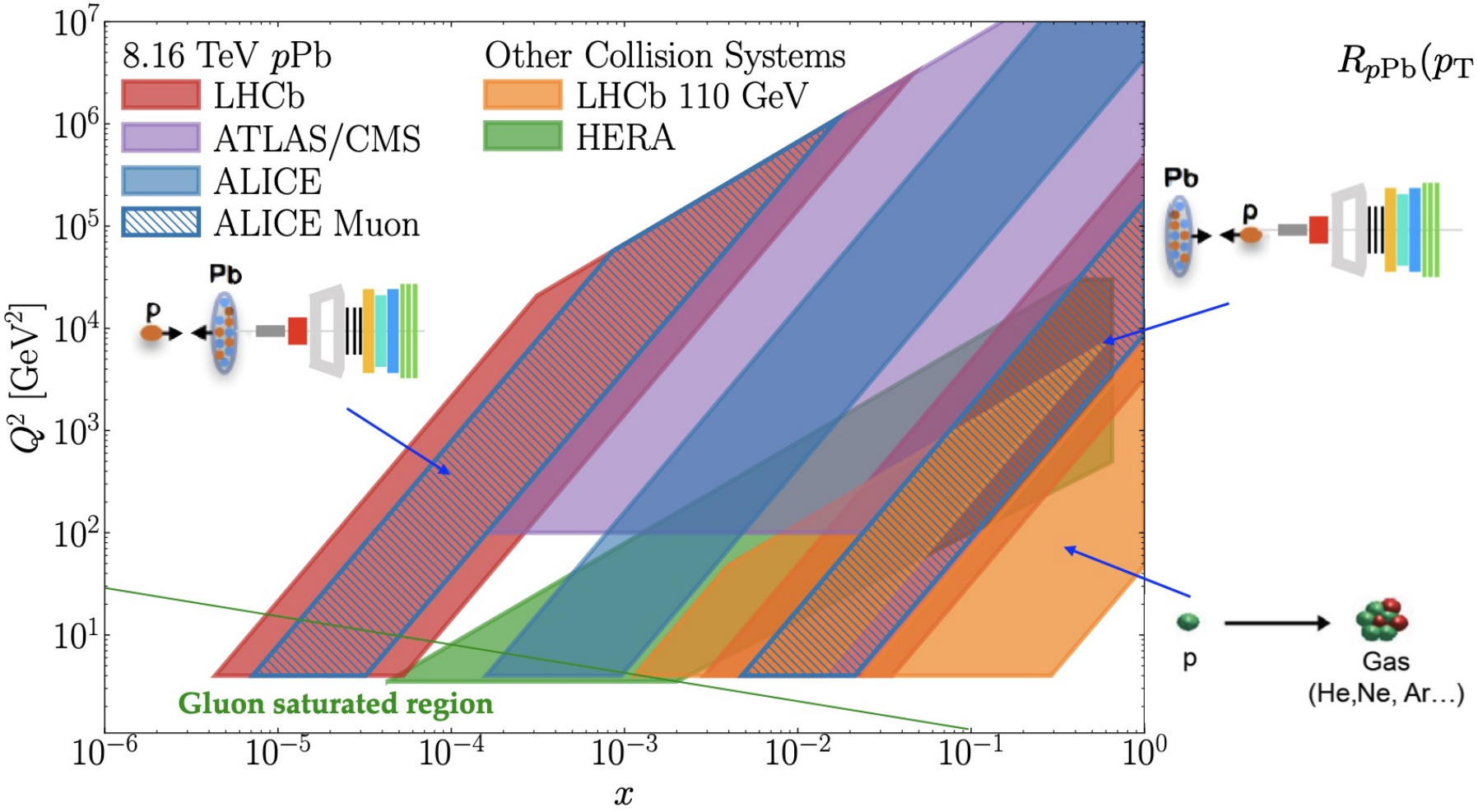



$1.5 < y < 4.0$




$-5.0 < y < -2.5$

# Mapping the initial state with LHCb



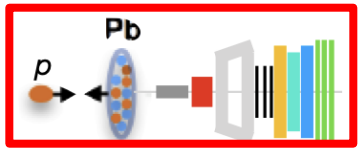

$$R_{p\mathrm{Pb}}(p_\mathrm{T}, y^*) \equiv \frac{1}{A}\frac{\mathrm{d}^2\sigma_{p\mathrm{Pb}}(p_\mathrm{T}, y^*)/\mathrm{d}p_\mathrm{T}\mathrm{d}y^*}{\mathrm{d}^2\sigma_{pp}(p_\mathrm{T}, y^*)/\mathrm{d}p_\mathrm{T}\mathrm{d}y^*}$$

$$x_{\mathrm{exp}} \equiv 2\frac{\sqrt{p_\mathrm{T}^2 + M^2}}{\sqrt{s_{\mathrm{NN}}}}\mathrm{e}^{-y^*}$$

$$Q^2_{\mathrm{exp}} \equiv p_\mathrm{T}^2 + M^2$$

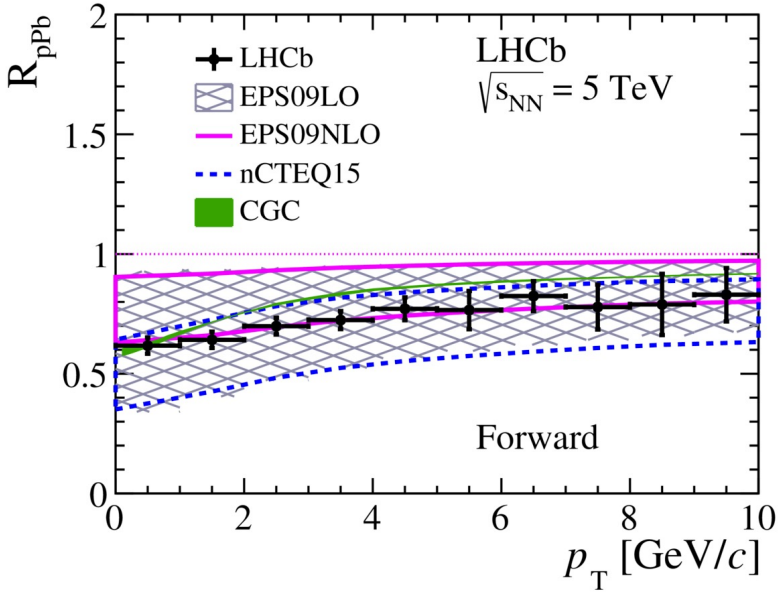
**Unique coverage of low-$x$ ($p$Pb), medium-$x$ (Pb$p$) and large-$x$ ($p$+gas) regions**

# Constraining nPDFs with $D^0$ meson in pPb



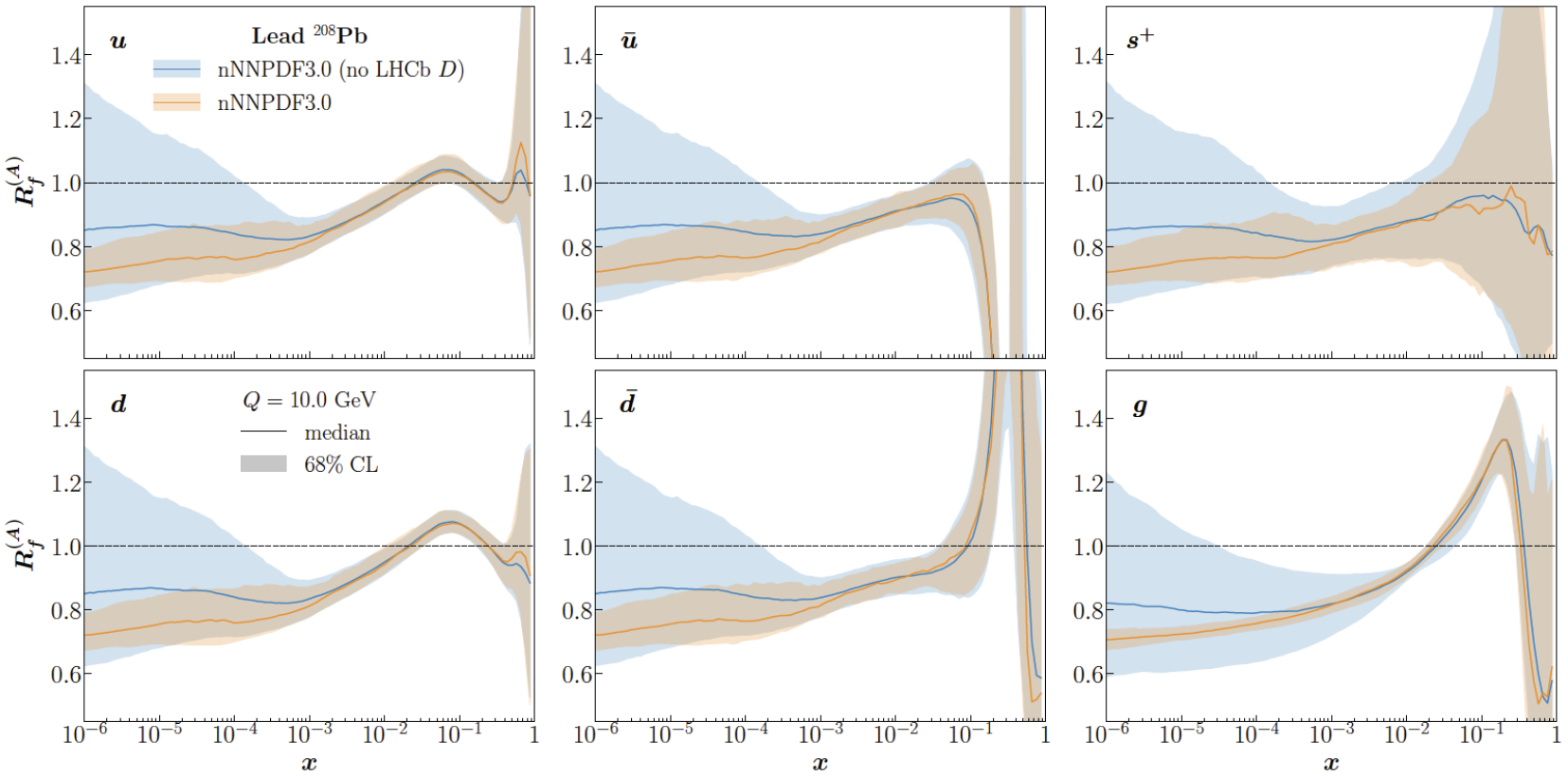

- LHCb measurement of prompt $D^0$ production in $p$Pb collisions at 5 TeV makes a stringent constraint on reducing nPDFs uncertainty down to $x \sim 10^{-6}$

**JHEP 10 (2017) 090**

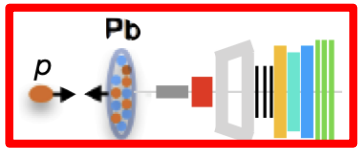



$$R_{p\mathrm{Pb}} = \frac{\sigma_{p\mathrm{Pb}}}{A\sigma_{pp}}$$

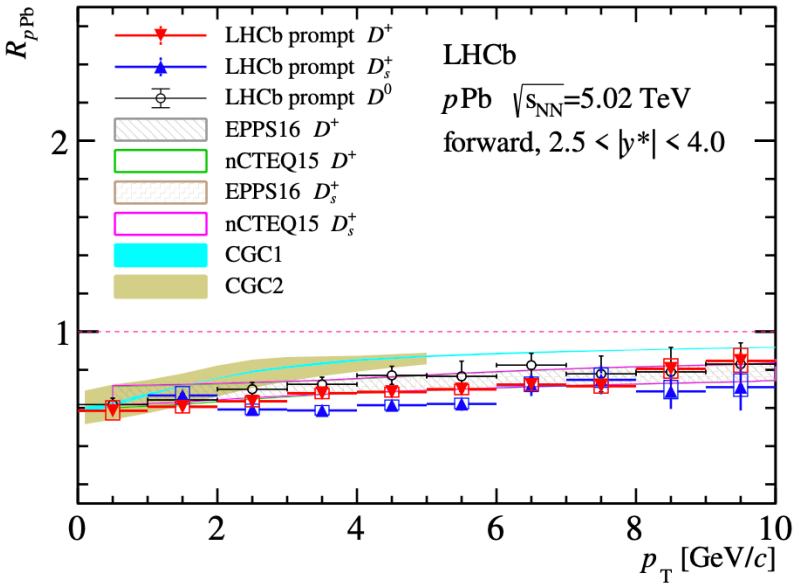
nNNPDF3.0, Eur. Phys. J. C 82 (2022) 507



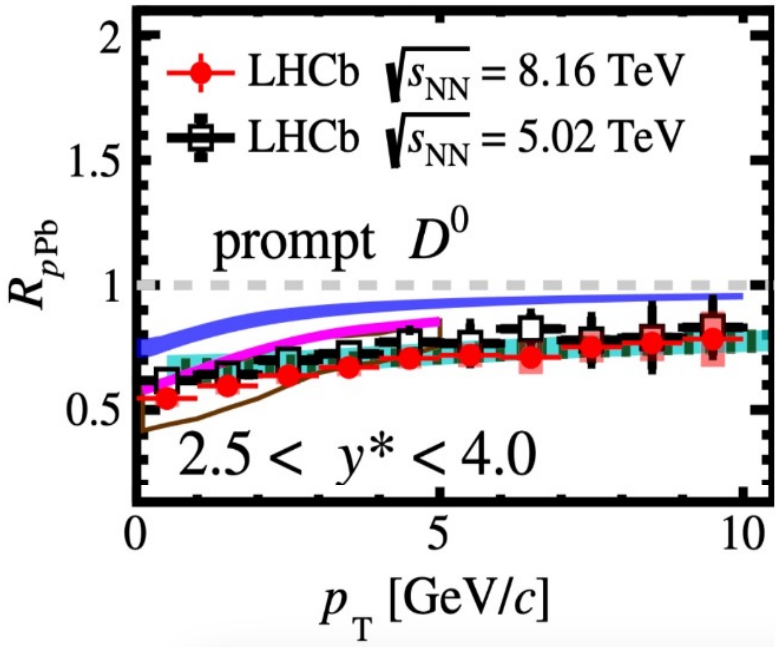
# Testing nPDFs with more *D* mesons in pPb



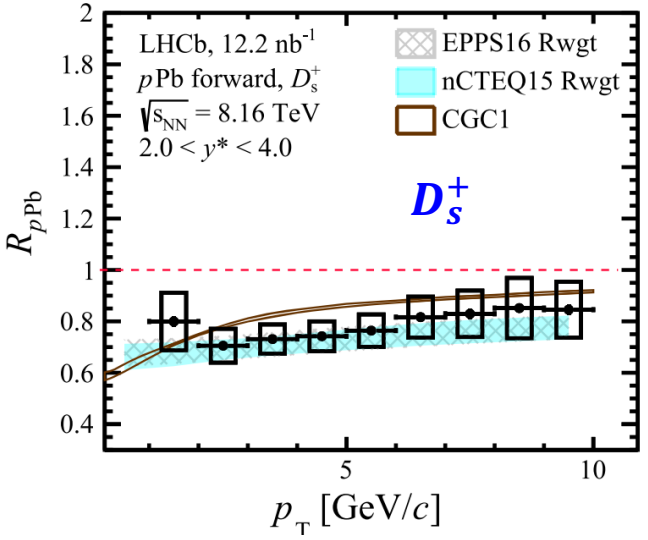

LHCb, JHEP 01 (2024) 070

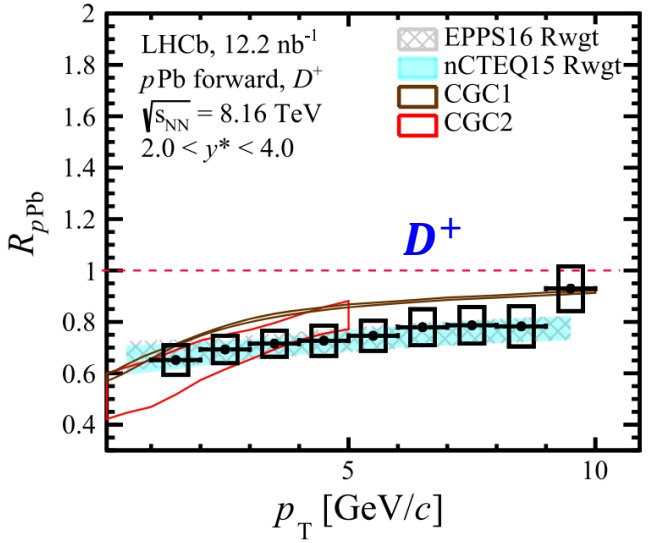



LHCb, PRL 131 (2023) 102301



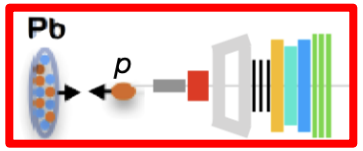

LHCb, PRD 110 (2024) L031105



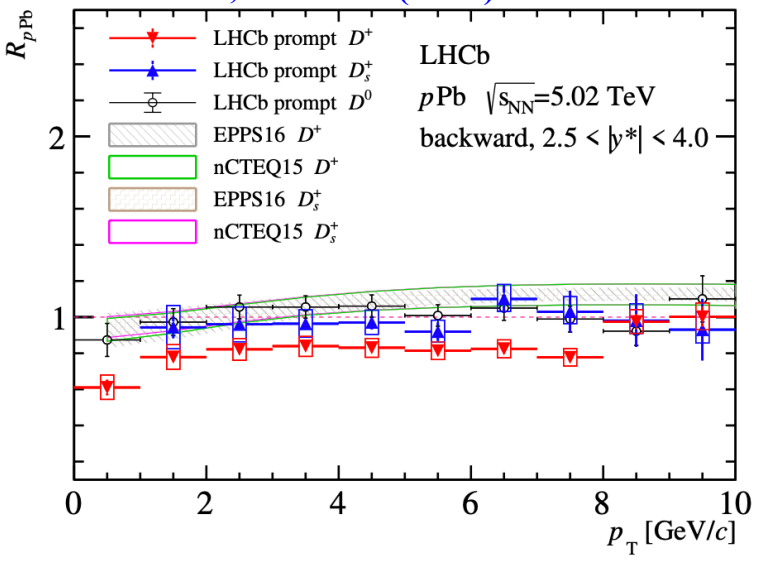




- All *D* mesons suppressed at forward rapidity at both collision energies (5.02 and 8.16 TeV)
  → gluon shadowing at small $x$

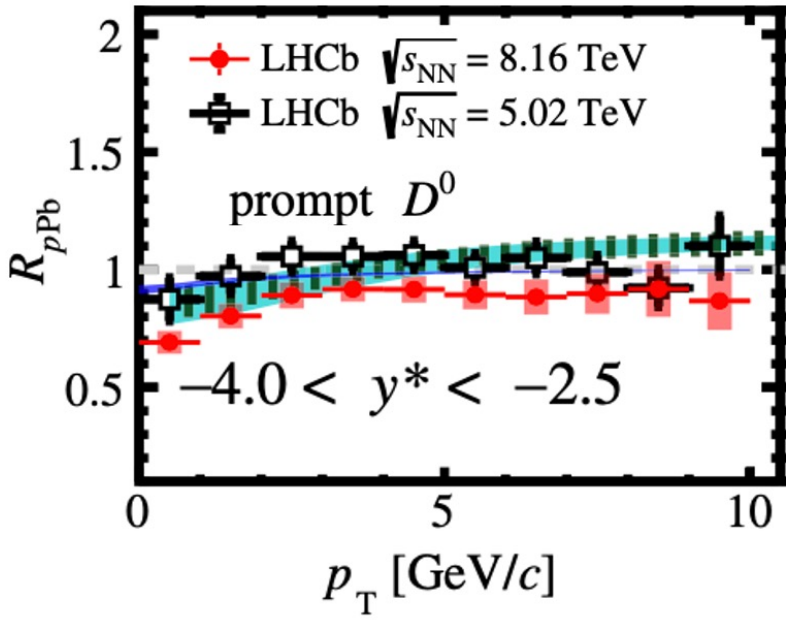
# Hint of final state effects with $D$ mesons in Pbp



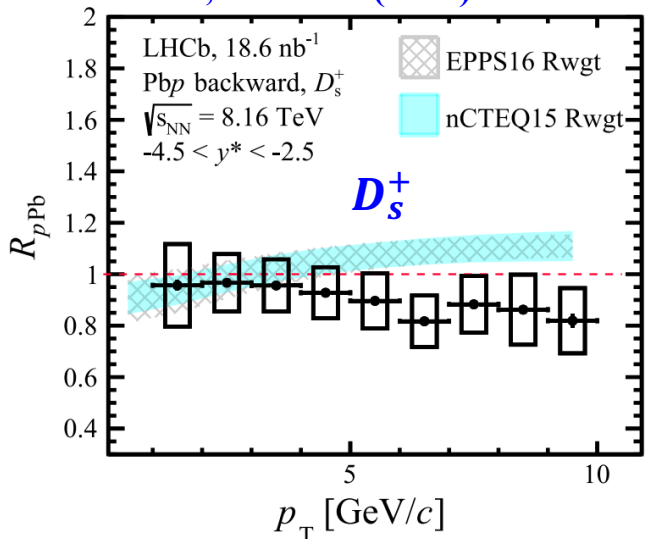

LHCb, JHEP 01 (2024) 070

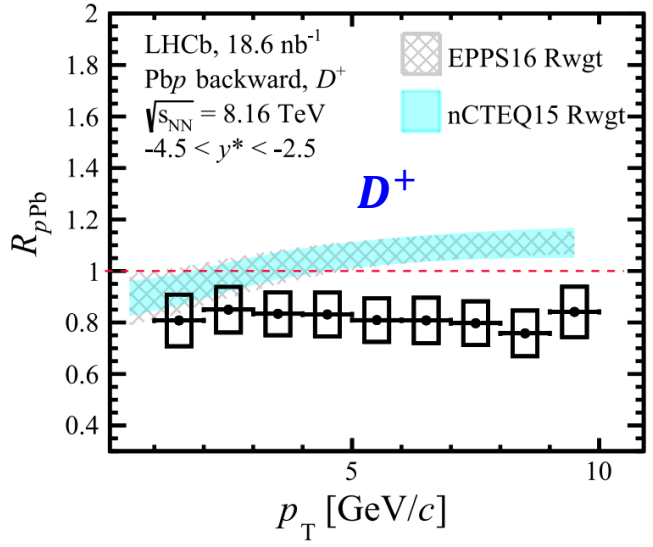



LHCb, PRL 131 (2023) 102301



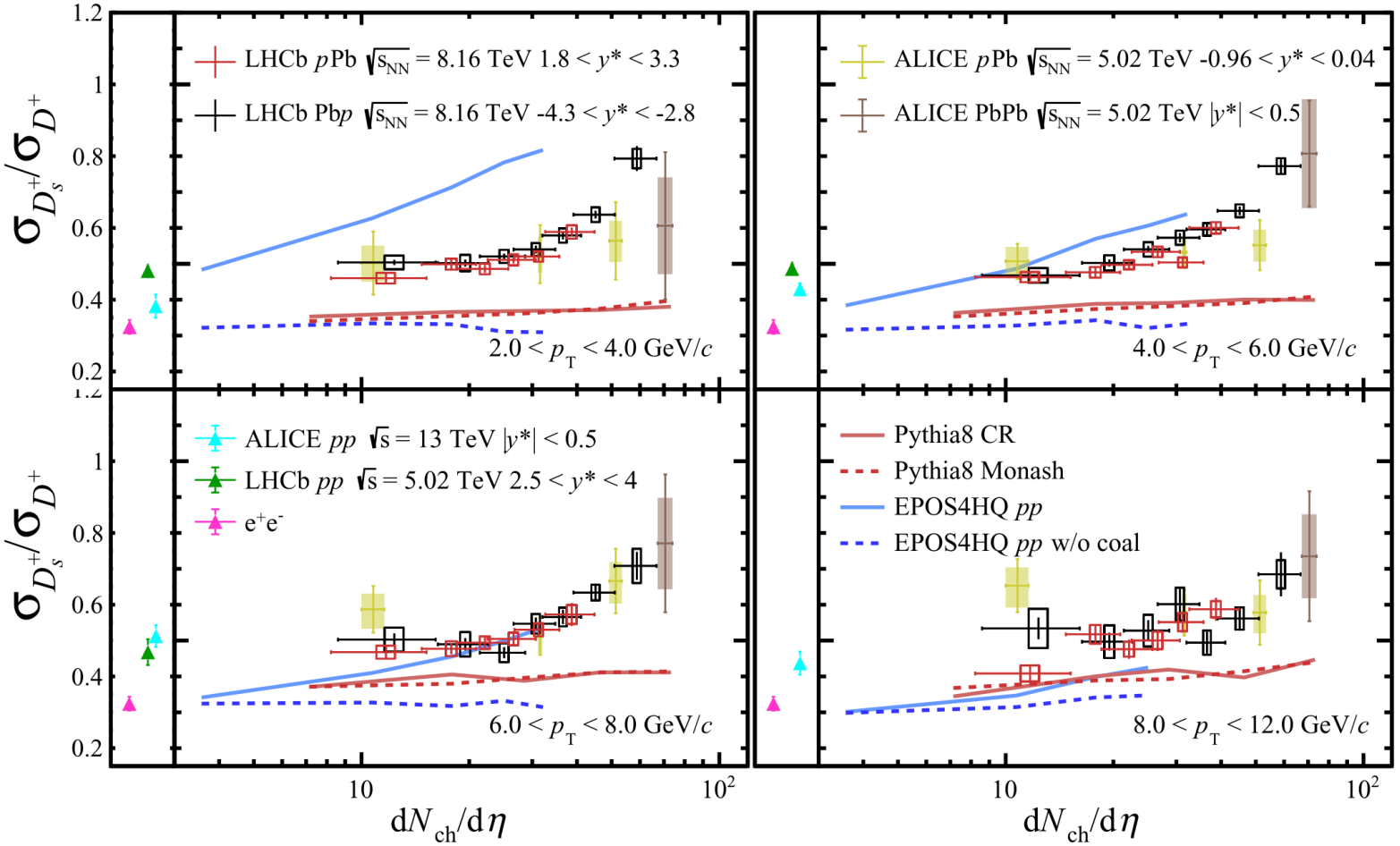

LHCb, PRD 110 (2024) L031105




- All $D$ mesons lower than nPDF calculations at high $p_T$ !
  → onset of charm energy loss in nuclear matter ?
- Slight $D$ meson species dependence
  → change of charm hadronization with multiplicity ?

# $D_s^+/D^+$ vs multiplicity in pPb

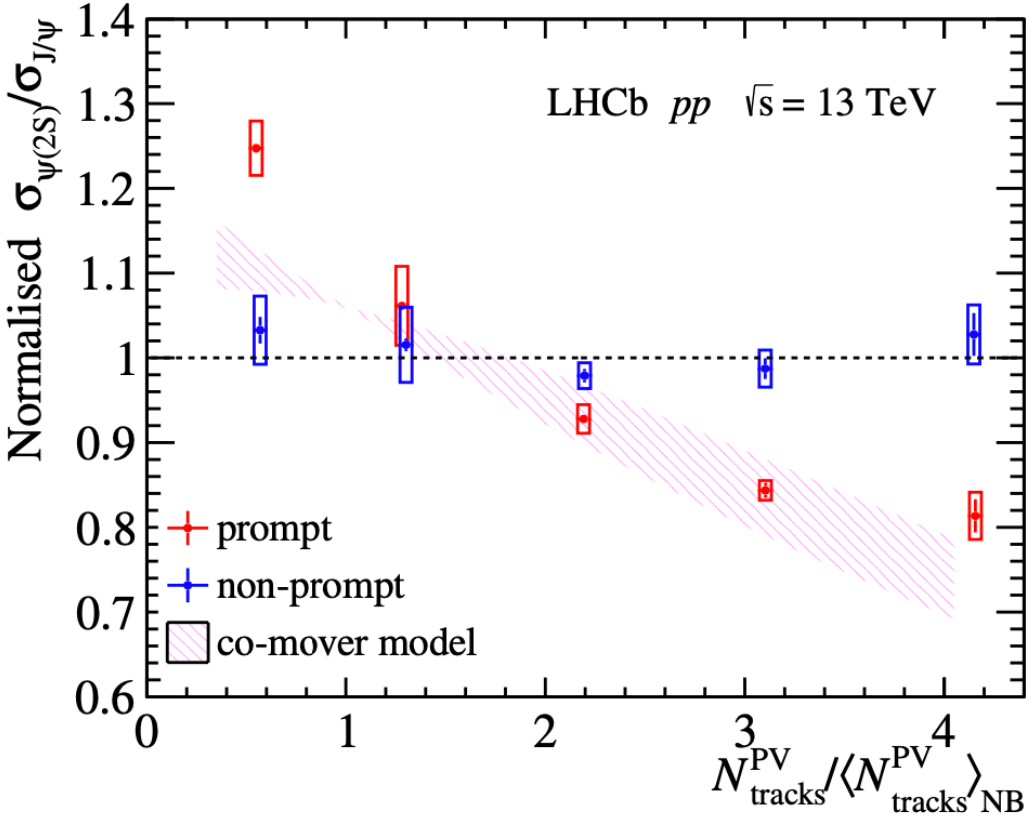


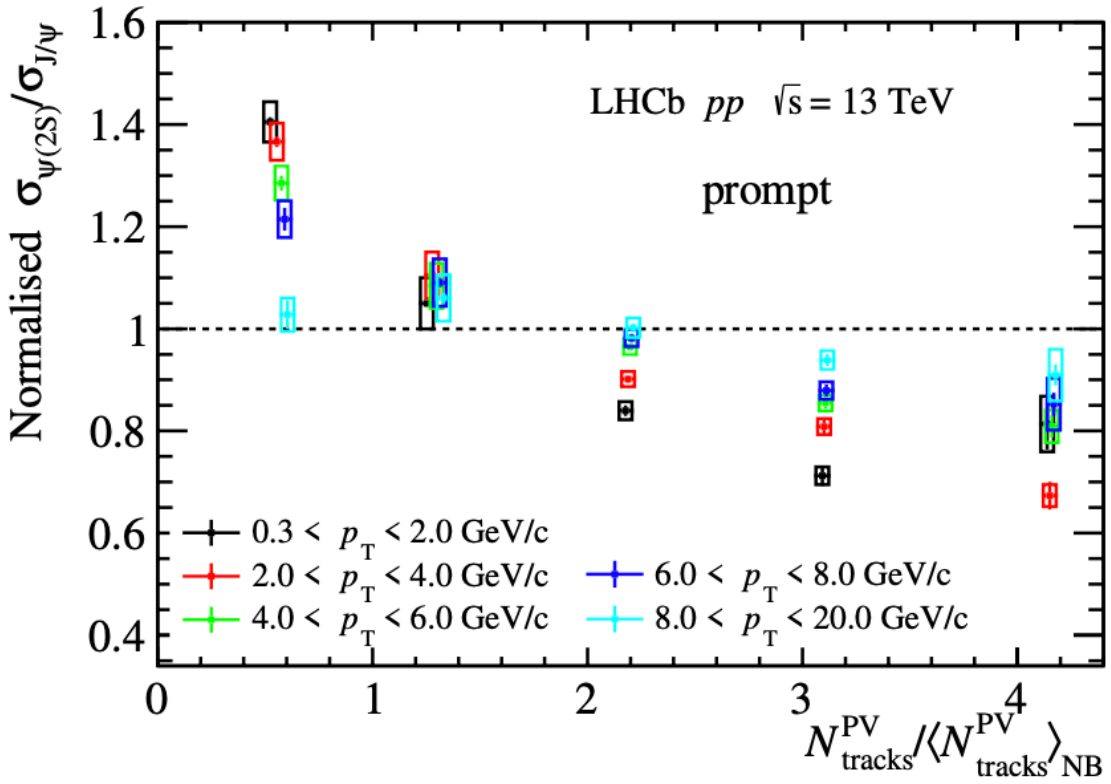

- The ratio increases with multiplicity significantly!
- The enhancement is more pronounced at backward rapidity and lower $p_T$.
- Modification of charm hadronization/production in high-multiplicity pPb collisions.

**LHCb, Phys. Rev. D 110 (2024) L031105**

# $\psi(2S)$ to J/$\psi$ ratio vs multiplicity in pp at 13 TeV

LHCb, JHEP 05 (2024) 243

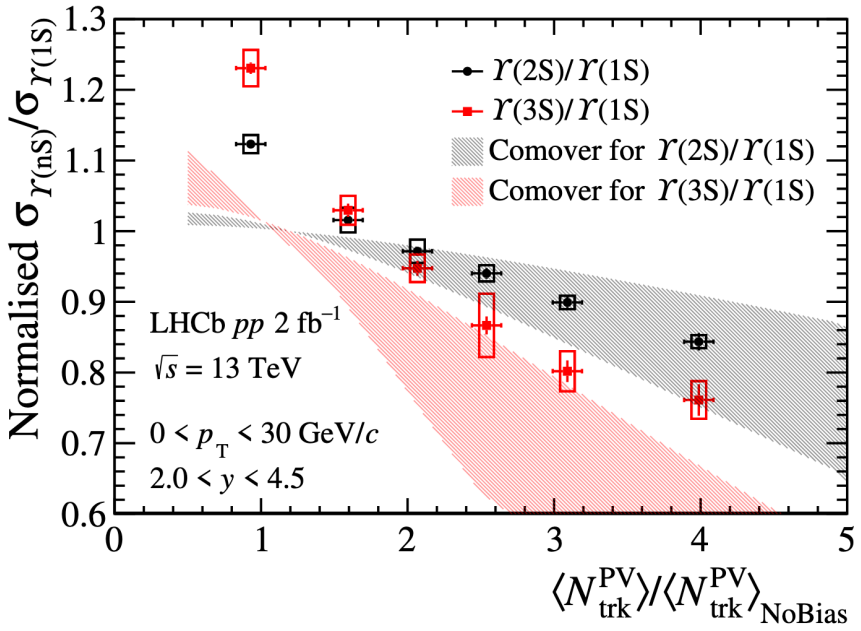


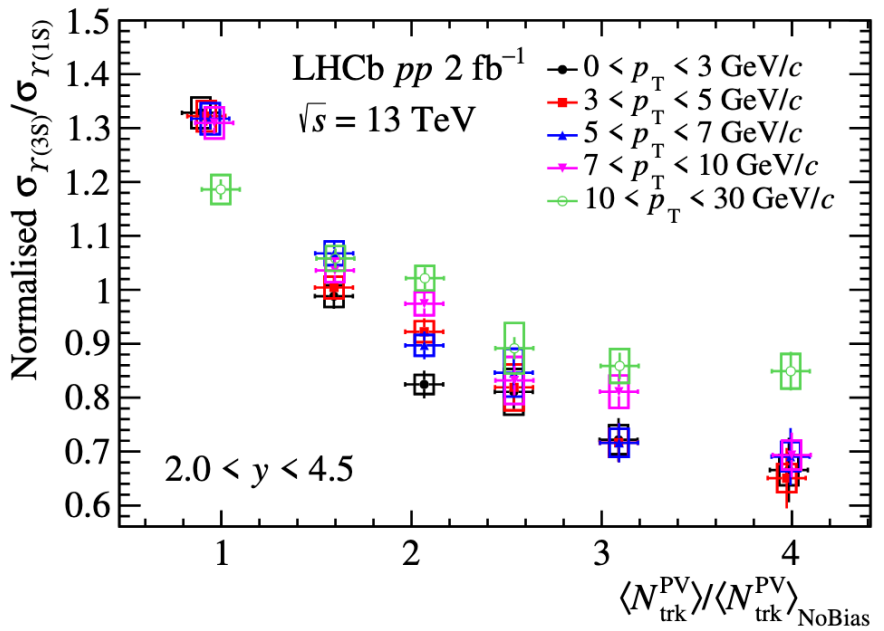



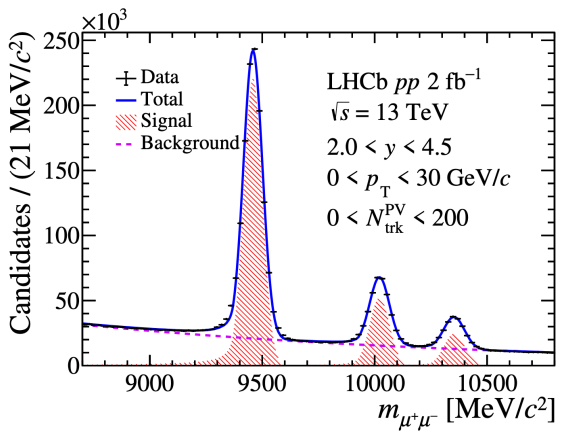

- Decreasing trend vs multipliticity observed for prompt contributions (in particular for low $p_T$), consistent with comover interactions

# $\Upsilon$(nS)/$\Upsilon$(1S) ratios in pp at 13 TeV

**LHCb, JHEP 05 (2025) 011**



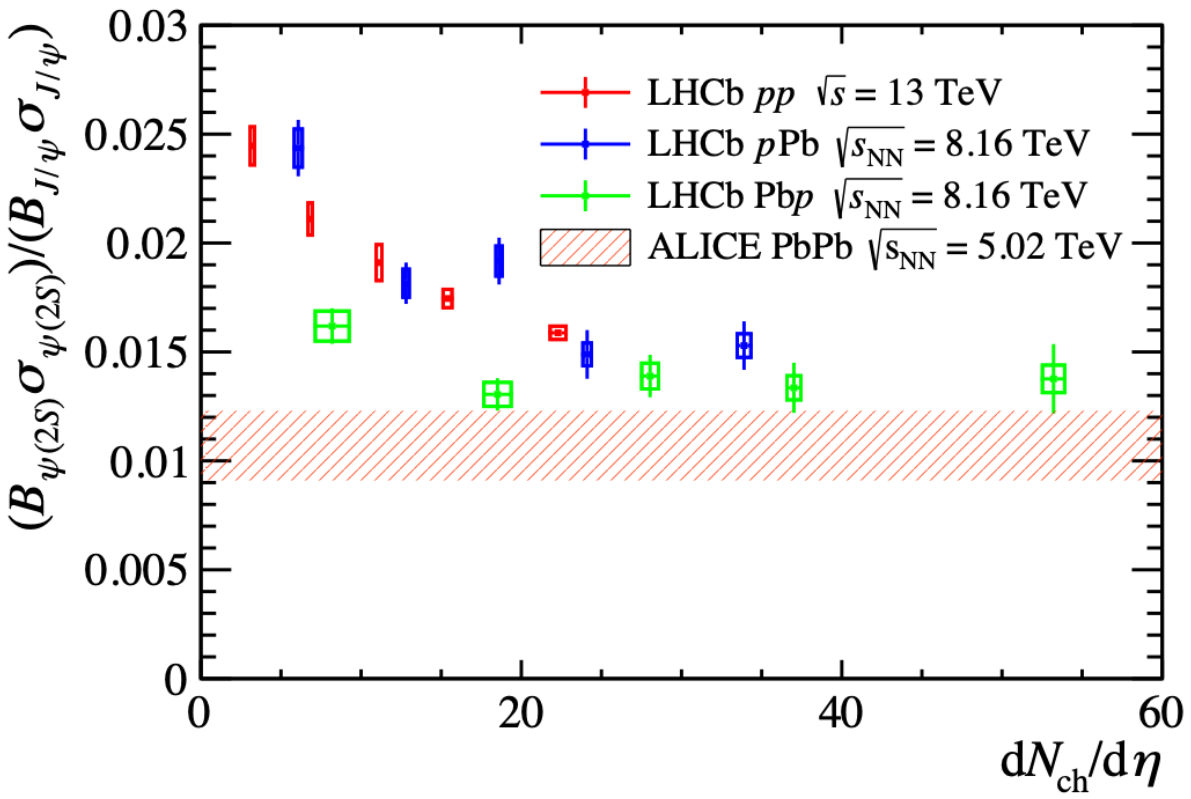




- Sequential suppression pattern observed in high multiplicity events.
- Suppression is more significant for low $p_T$ regions.
- Qualitatively consistent with comover model predictions.

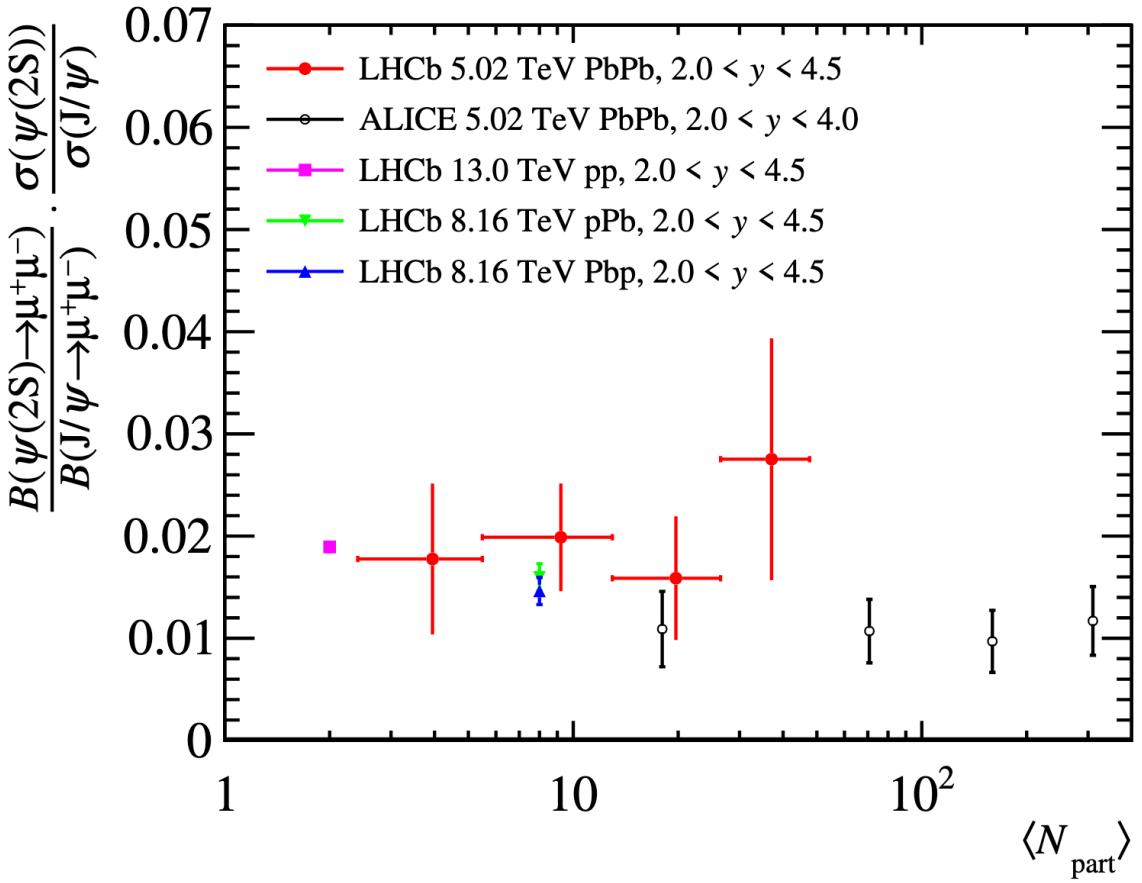
# $\psi(2S)$ to J/$\psi$ ratio in pPb and PbPb collisions

康有恩，Heavy Flavor III

LHCb, arXiv:2506.08624

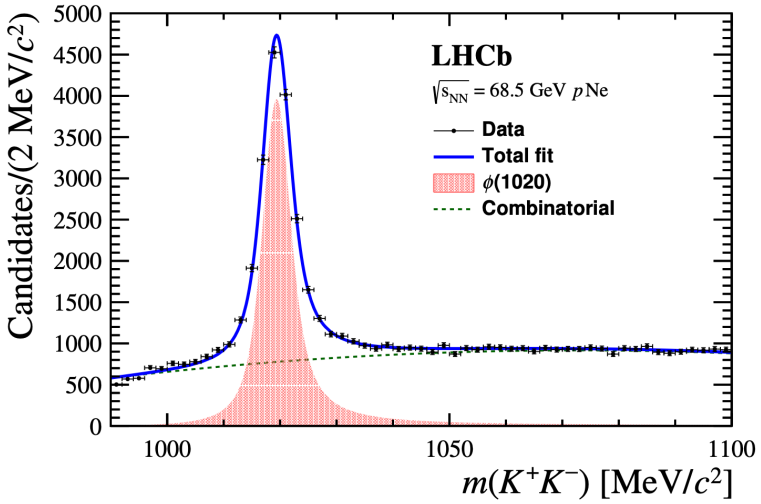


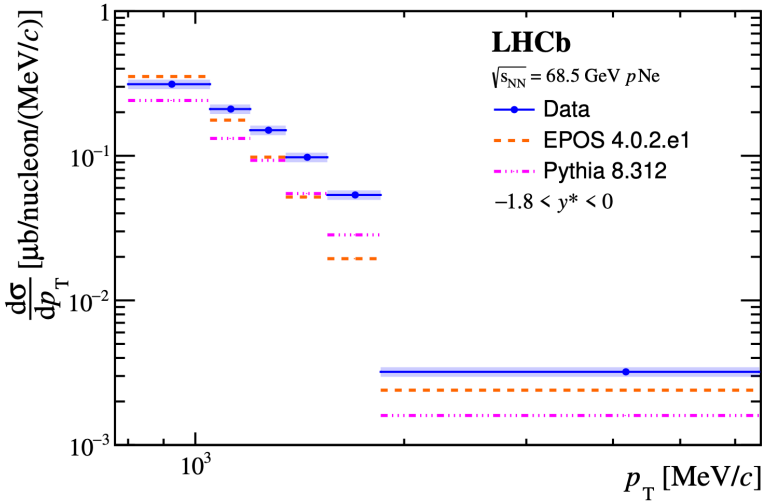

LHCb, JHEP 07 (2025) 235



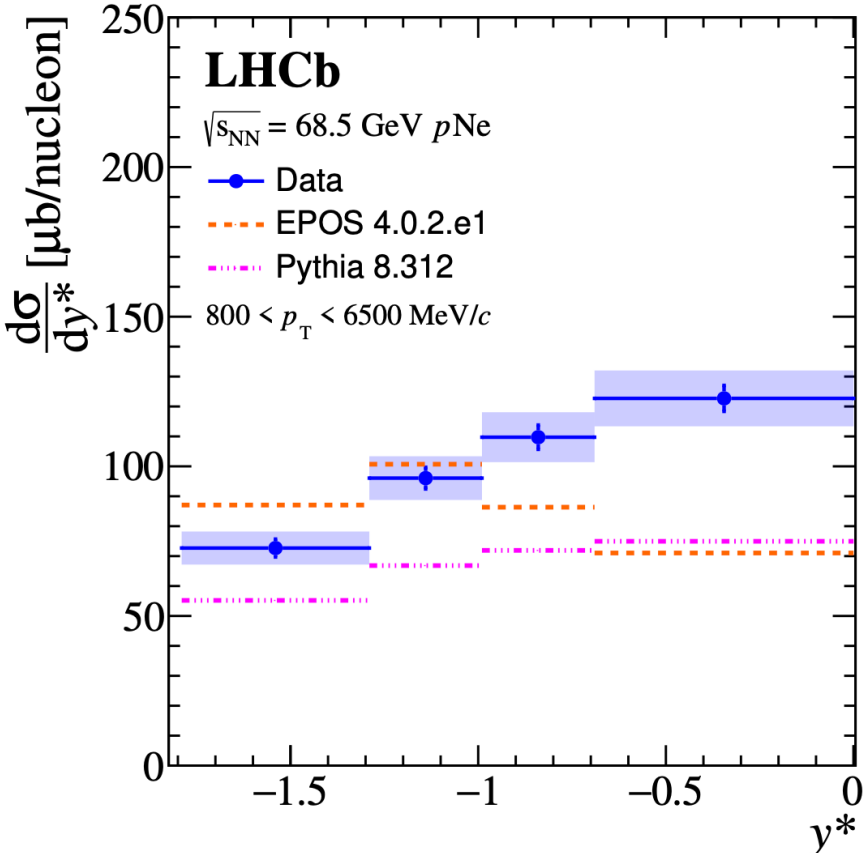

- Stronger suppression in the Pb-going direction, close to PbPb collisions.

# $\phi(1020)$ meson production in pNe at 68.5 GeV



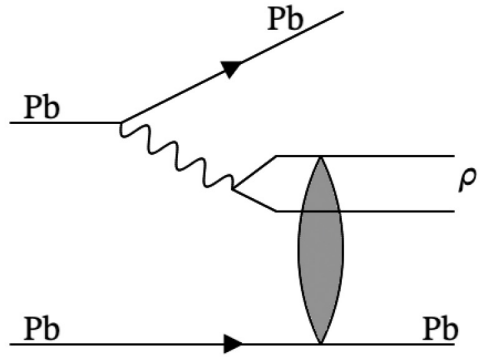

LHCb, JHEP 03 (2025) 151



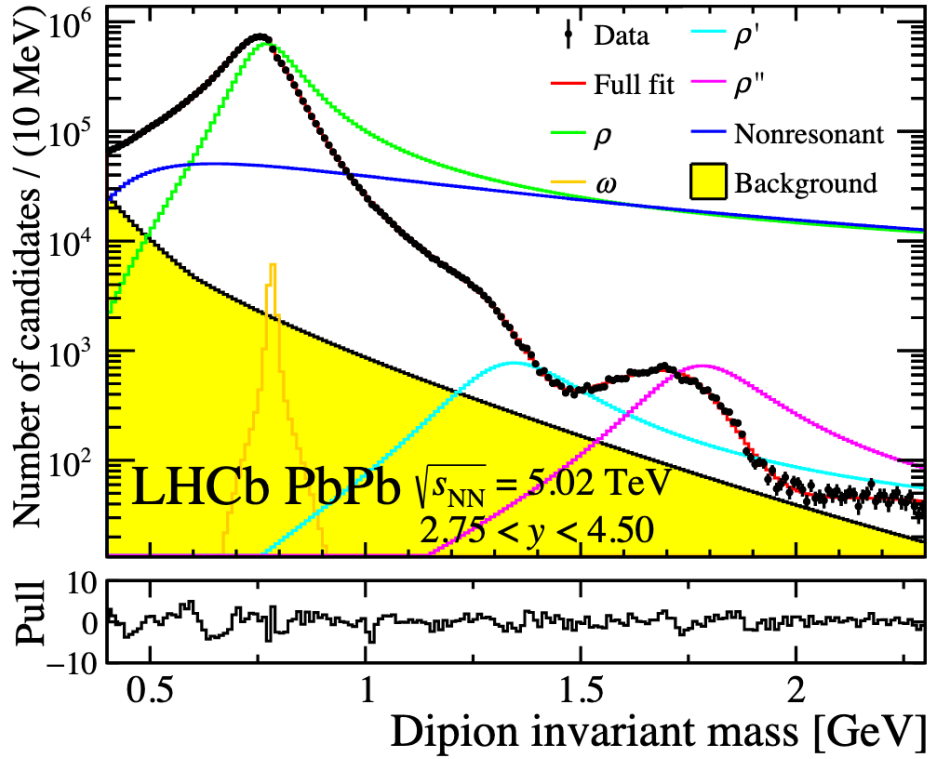

- Theoretical predictions slightly underestimate the result in $p$T and high $y^*$ regions
- Data constrain event generators in a relatively unexplored kinematic regime
- Reference for RHIC BES measurements

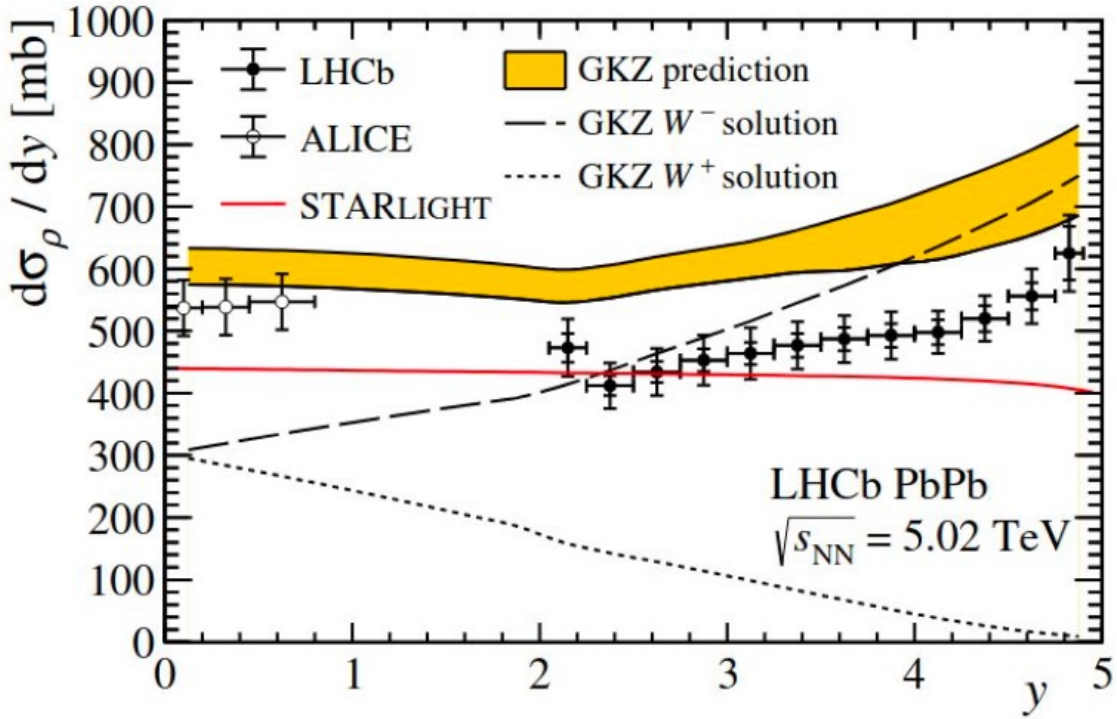
# Vector mesons in UPC PbPb collisions

- Very rich sample of $\pi^+\pi^-$ spectrum at forward rapidity, allowing to precisely model interference between $\rho, \omega, \rho', \rho''$
- The $\rho$ cross-sections vs $y$ shows similar trend as GKZ prediction, but with additional 30% suppression, could be caused by saturation effect



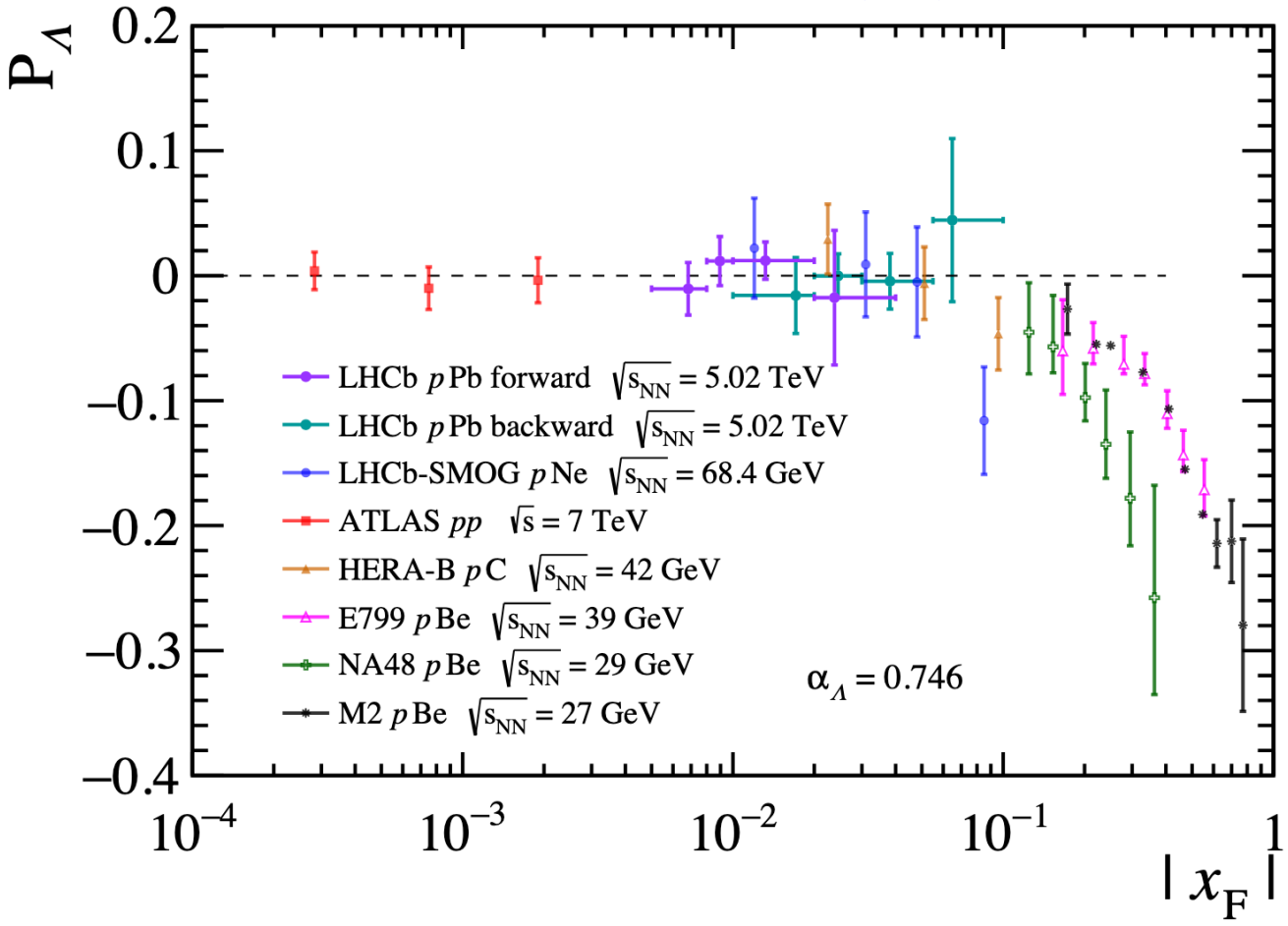

LHCb, arXiv:2506.06250



# Λ transverse polarization in pNe/pPb

LHCb, arXiv:2508.02009; JHEP 09 (2024) 082

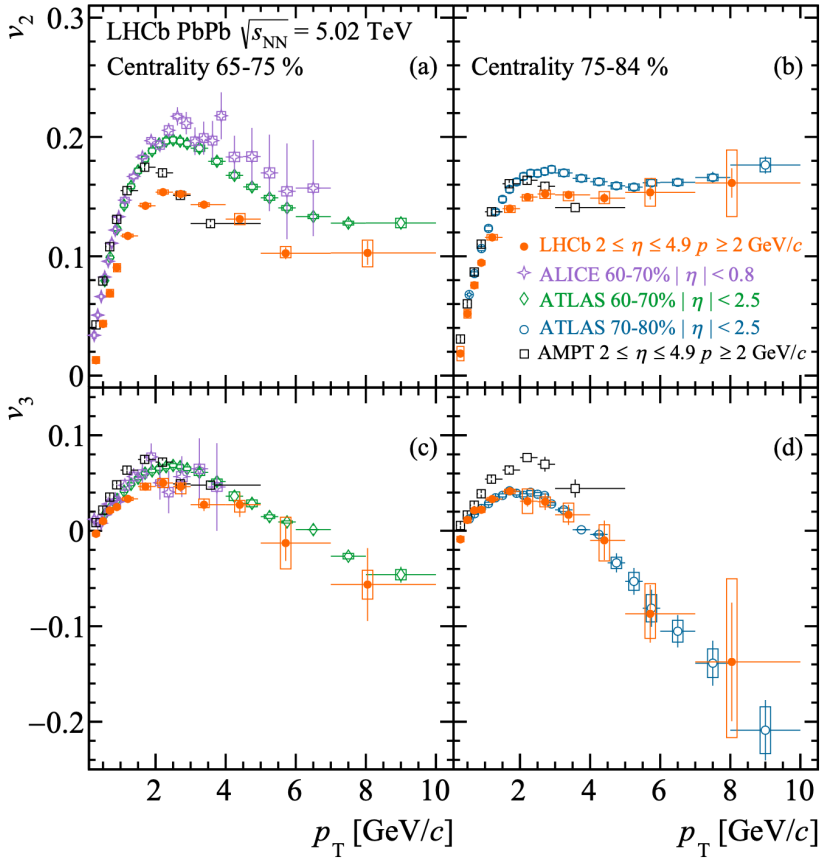



$$x_F = \frac{2p_L^*}{\sqrt{s_{NN}}}$$

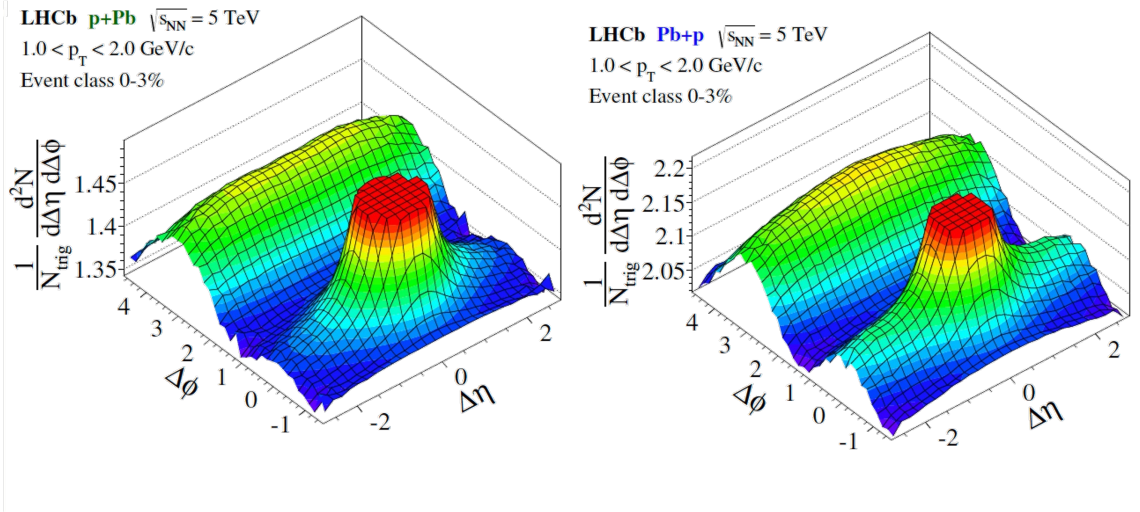
- Could result from convolution between TMDs fragmentation functions and the parton TMD PDFs
- Two independent analyses in Run2 pNe and pPb/Pbp data extracted polarization via fits to the proton angular distributions
- Consistent results in the common $x_F$ ranges, demonstrating the solidity of the results
- Can improve precision with SMOG2 and possibly increase the $x_F$ range by decreasing the center-of-mass collision energy

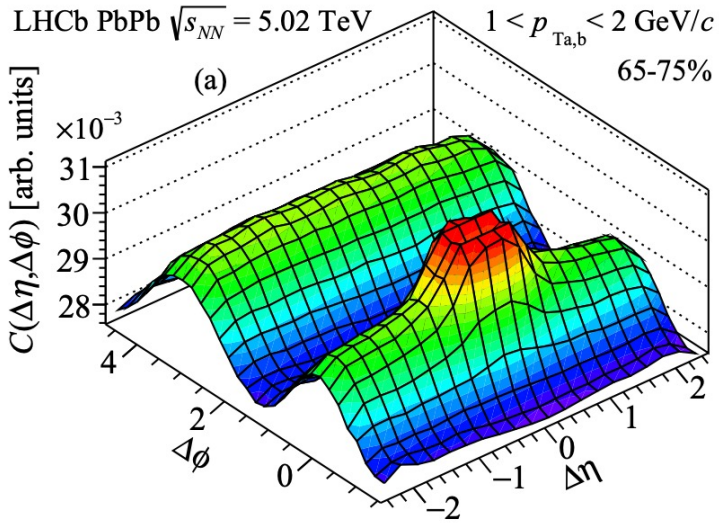
# Collectivity in PbPb

- Previous LHCb measurements confirmed presence of the ridge at forward rapidity in *p*Pb collisions
- New results show stronger ridge in PbPb
- First LHCb measurements of $v_{2,3}$ flow coefficient measurements




Phys. Lett. B762 (2016) 473



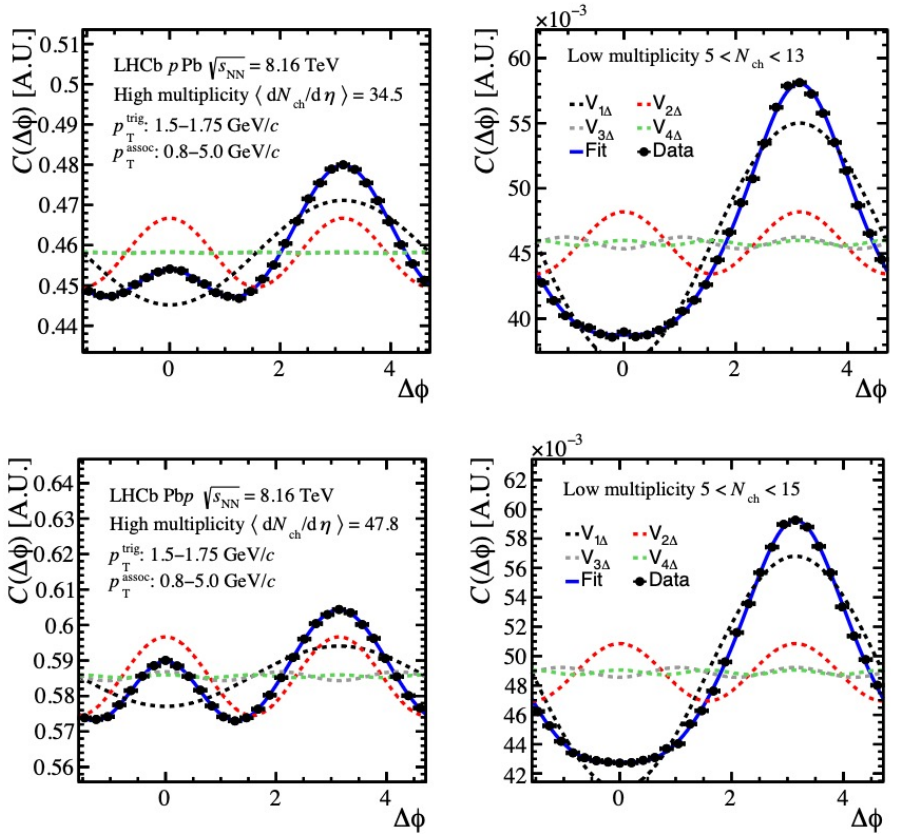



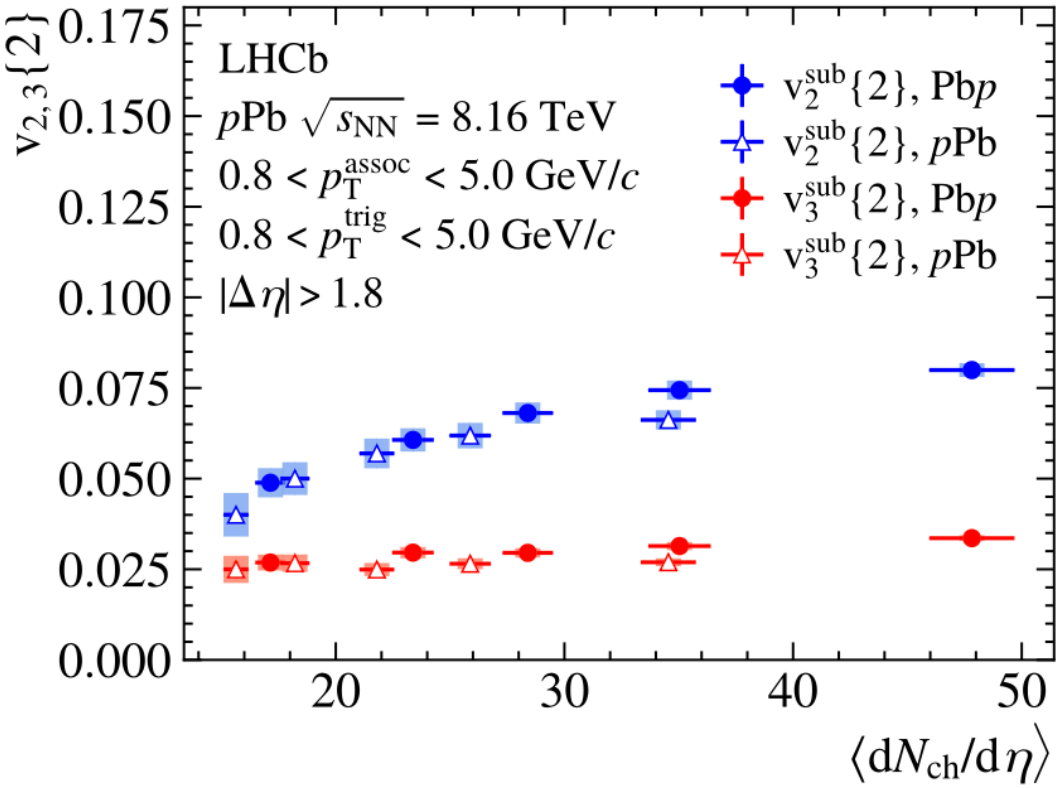

Phys.Rev.C 109 (2024) 054908

# Collectivity in pPb at 8.16 TeV

- Measuring both rapidity and multiplicity dependence of collectivity can help to understand the origin of ridge-like structure in small system
- Both pPb/Pbp configuration are compatible! It seems the long range correlation does not significantly depend on Bjorken-x

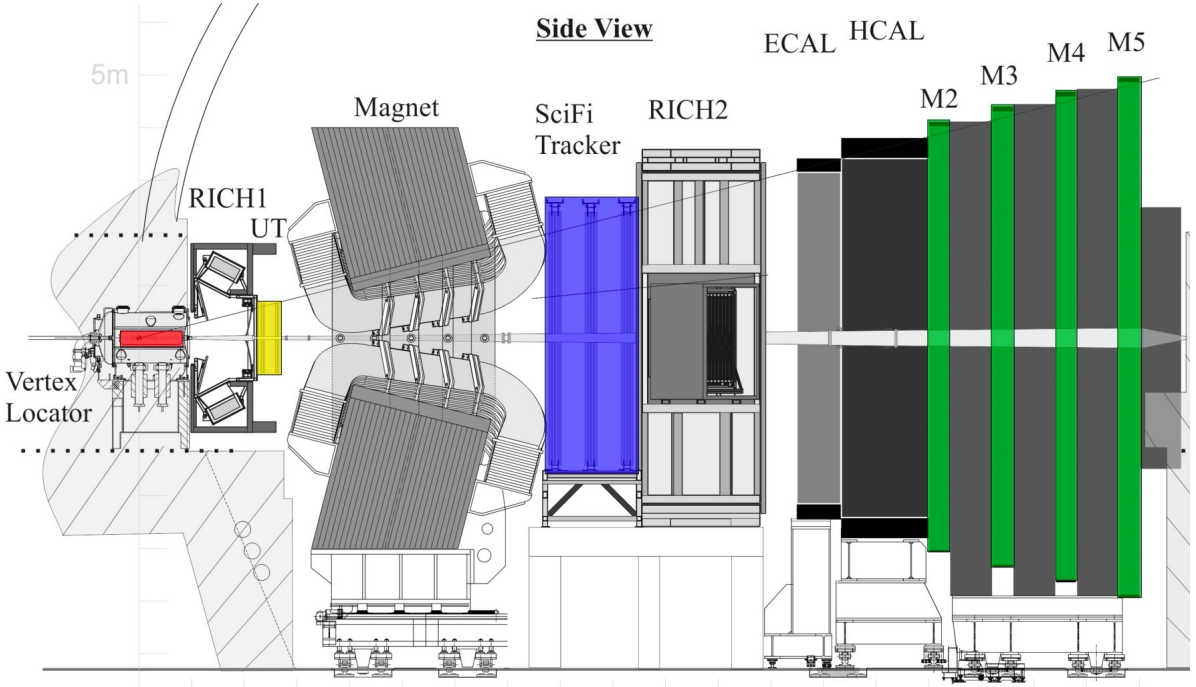
arXiv:2505.09273



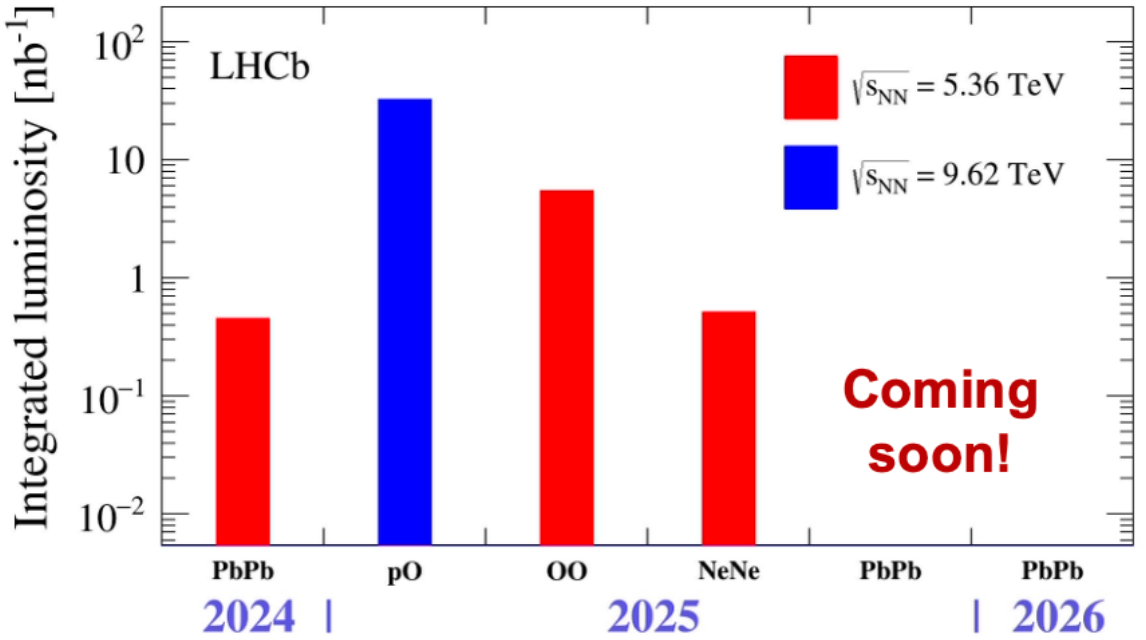



# LHCb Upgrade-I in Run3

- Major upgrade:
  - Replacement of full tracking and RICH1/2 detectors
  - Completely new readout electronics
  - New DAQ & online system at 40 MHz
- New tracking system allows reconstruction up to ~30% most central PbPb collisions

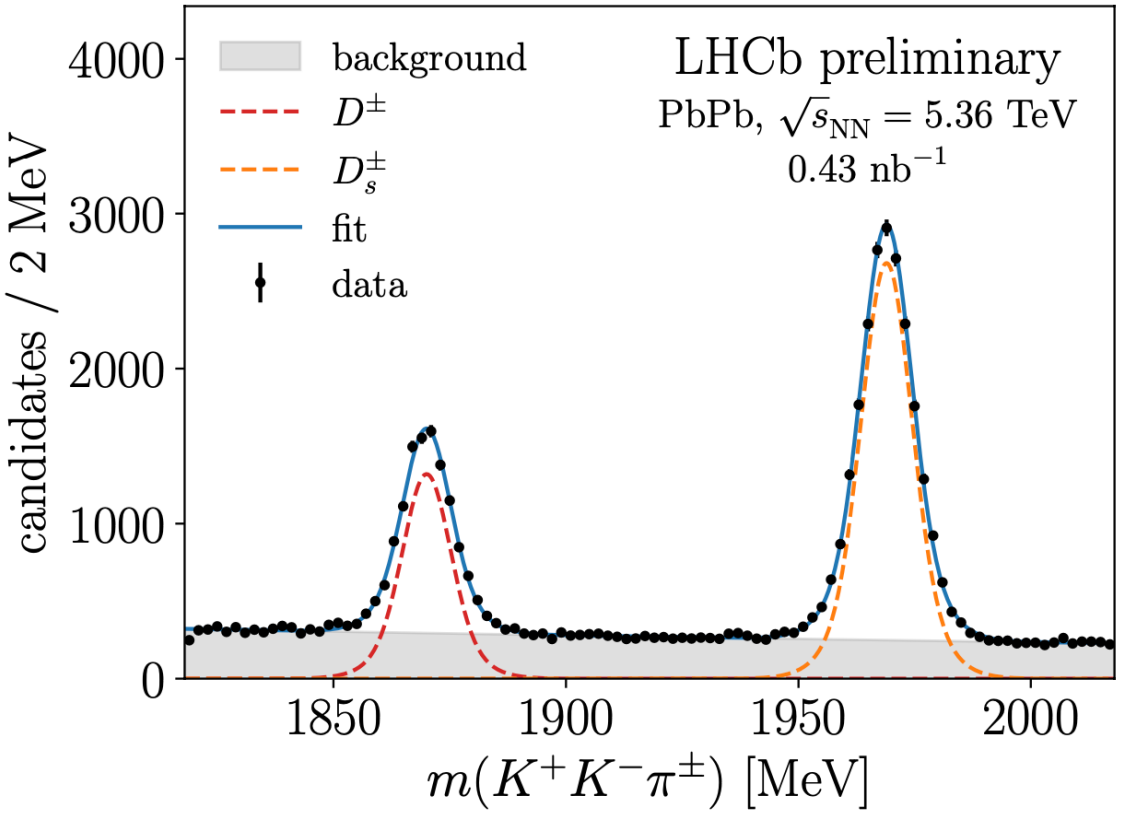


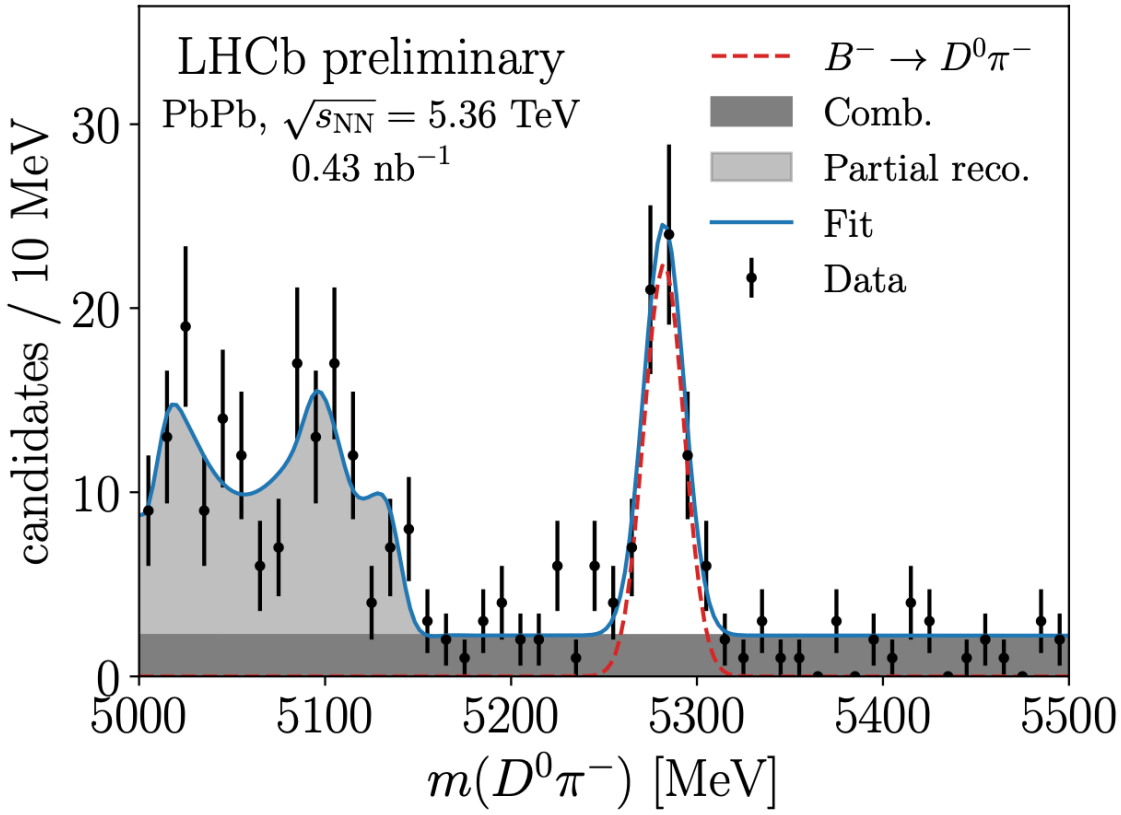

JINST 19 (2024) P05065



# Early signals from the 2024 PbPb run

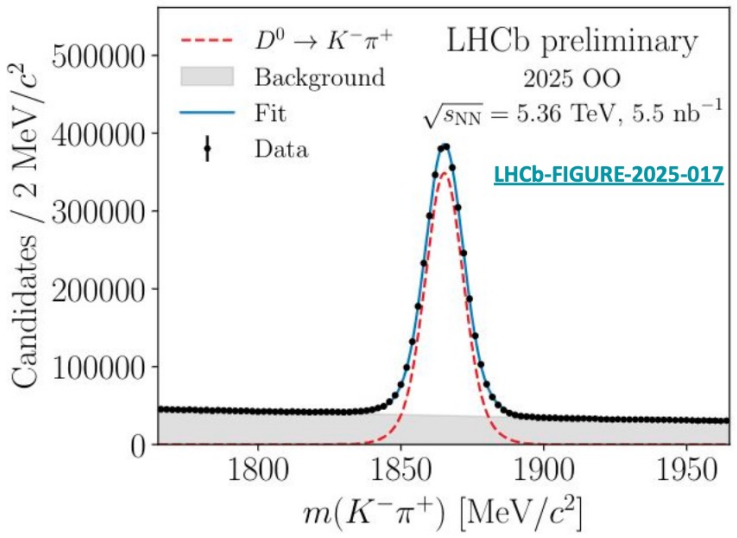
LHCb-FIGURE-2025-004

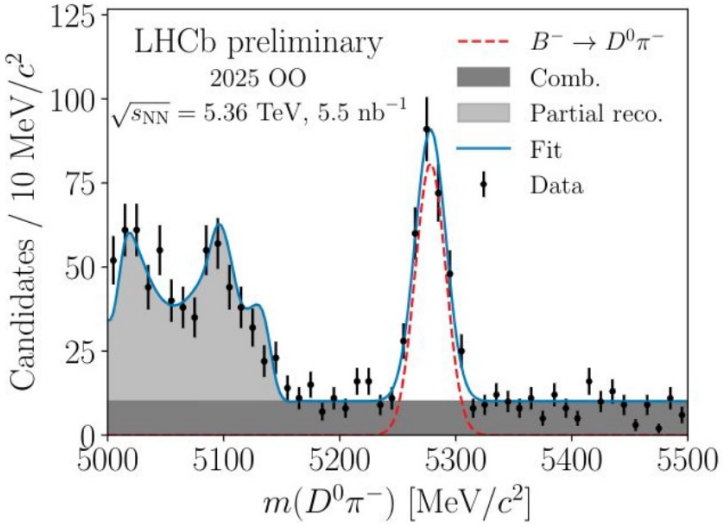


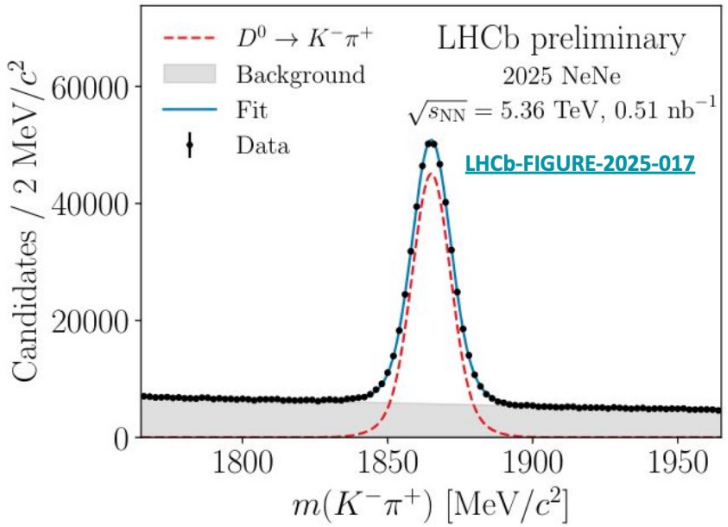



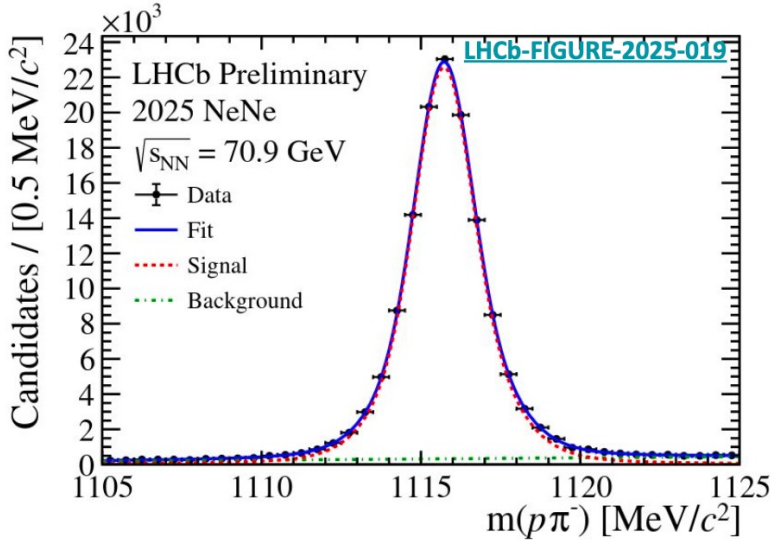

- Clean charm and fully hadronic B decays

# OO/NeNe data-taking in 2025



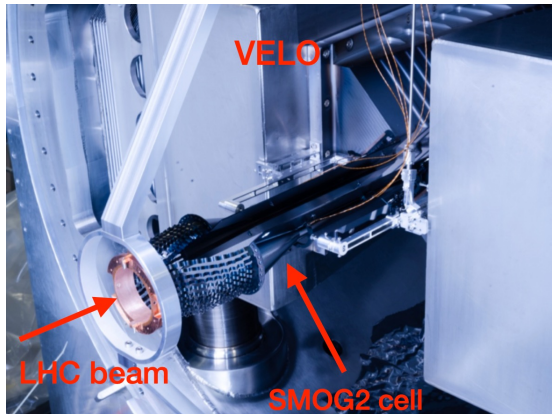



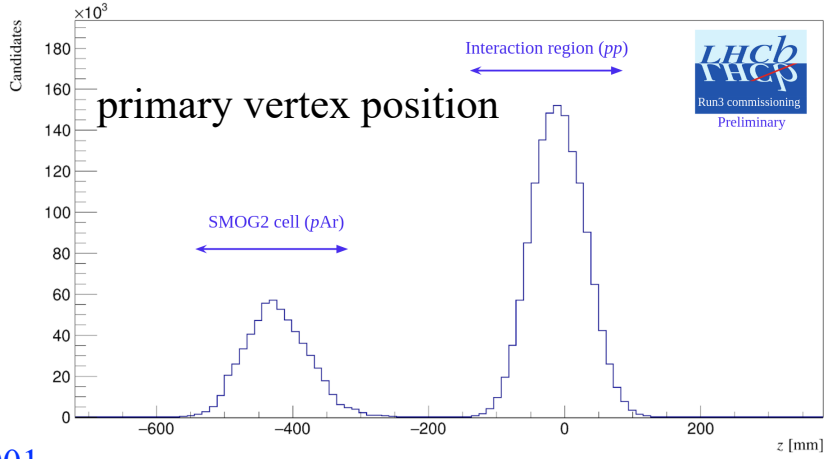

- Very clean charm and beauty signals collected during the OO and NeNe 2025 data-taking, study QGP signatures (energy loss, collectivity, quarkonia suppression) in small systems
- The pO data (~30 nb$^{-1}$) will allow very precise constraints to nPDF
- NeNe data acquired in both collider and fixed-target mode

# Fixed target upgrade – SMOG2

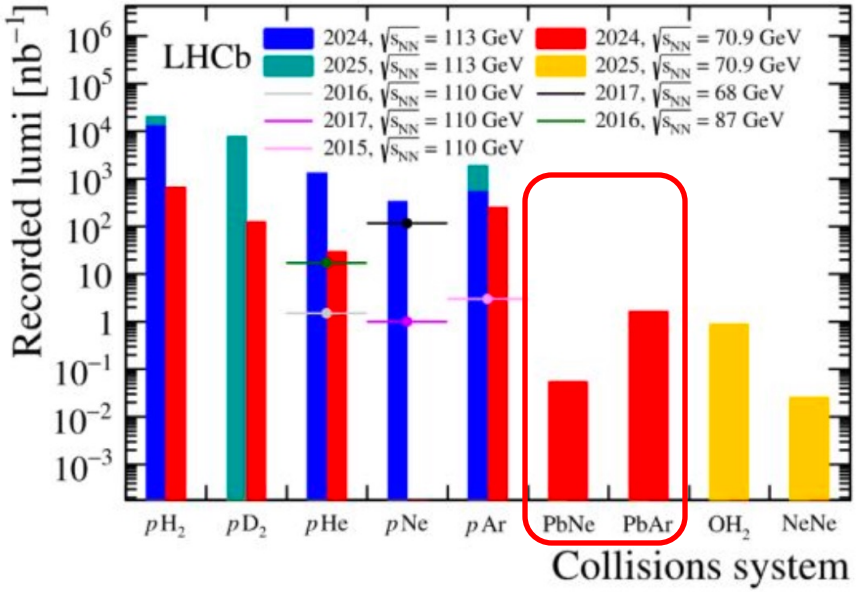
- Dedicated gas storage cell installed
- Greatly increased rates of beam+gas collisions
- Concurrent running with pp collisions
- New gases: $H_2$, $D_2$ and large nuclei (Kr, Xe)
- Energies: $\sqrt{s_{\mathrm{NN}}} \in [68.5, 110]$ GeV

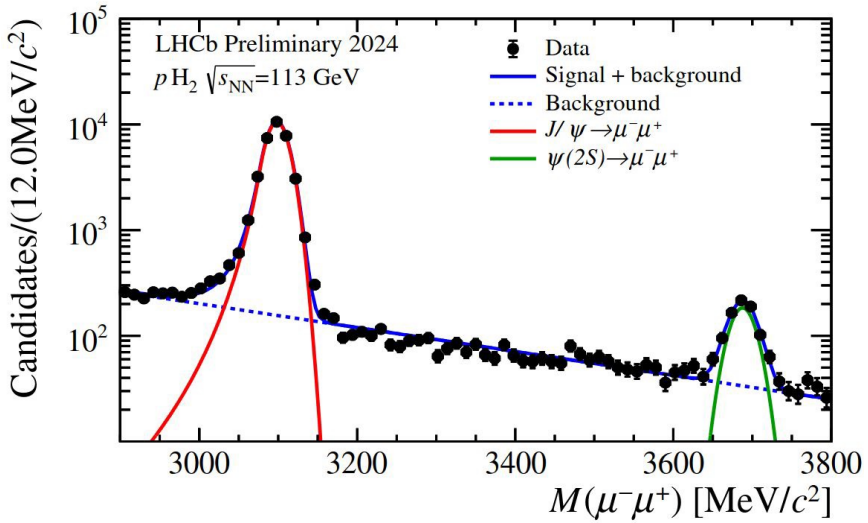



LHCb-FIGURE-2023-001

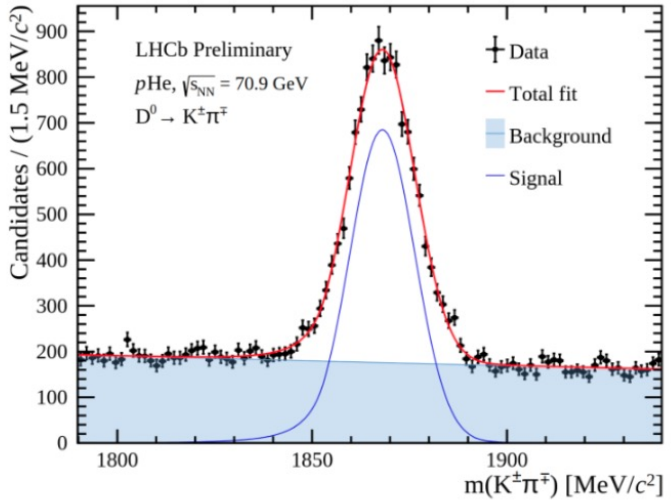



Phys. Rev. Accel. Beams 27 (2024) 111001



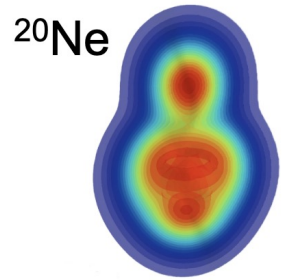

LHCb-FIGURE-2024-023

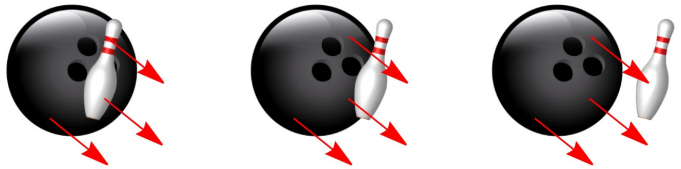



LHCb-FIGURE-2025-013

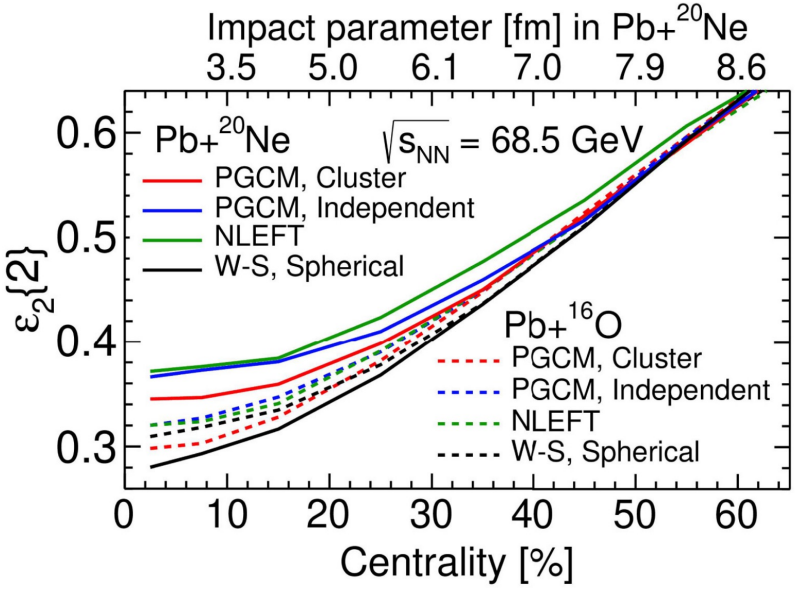
# Nuclear shape imaging of light nuclei with SMOG2

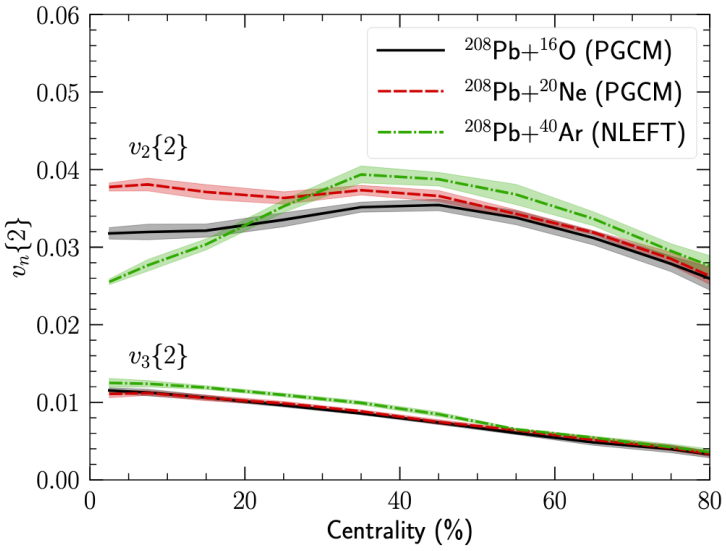
- The peculiar shape of $^{20}$Ne, bowling-pin-like $^{16}$O+$\alpha$ configuration, can be probed via flow measurements in Pb+Ne/Pb+Ar collisions, collected in 2024
- Large eccentricity in most central collisions results in significantly larger $v_2\{2\}$, compared to Pb+Ar collisions

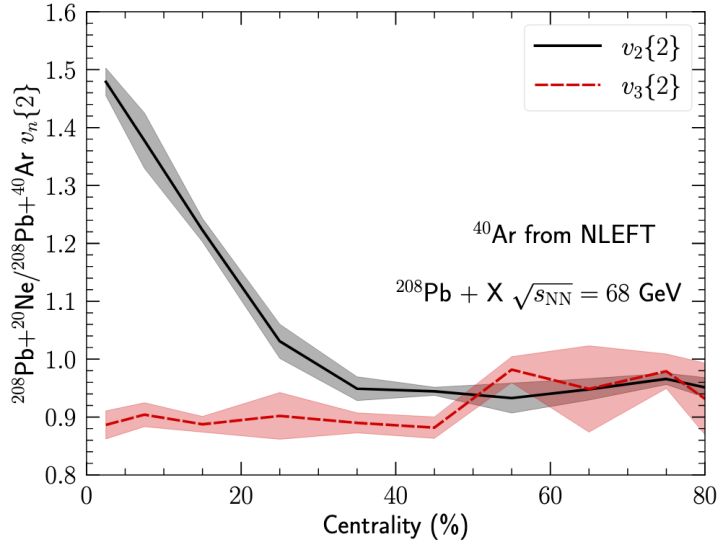


G. Giacalone, W. Zhao, et al. Phys. Rev. Lett. 134 (2025) 082301
C. Shen, QM2025

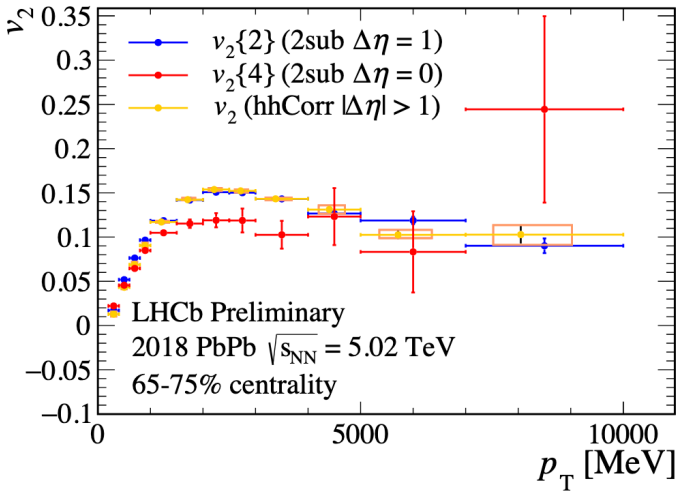


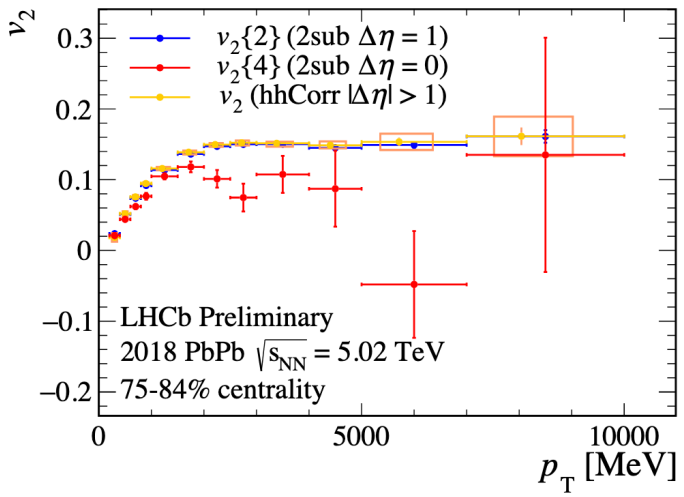



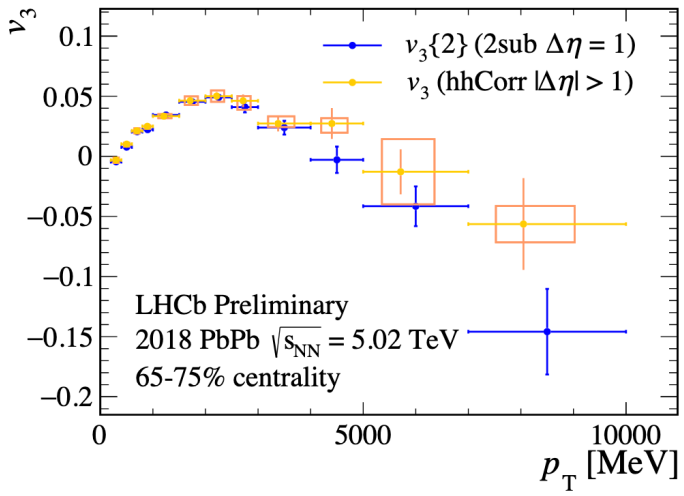



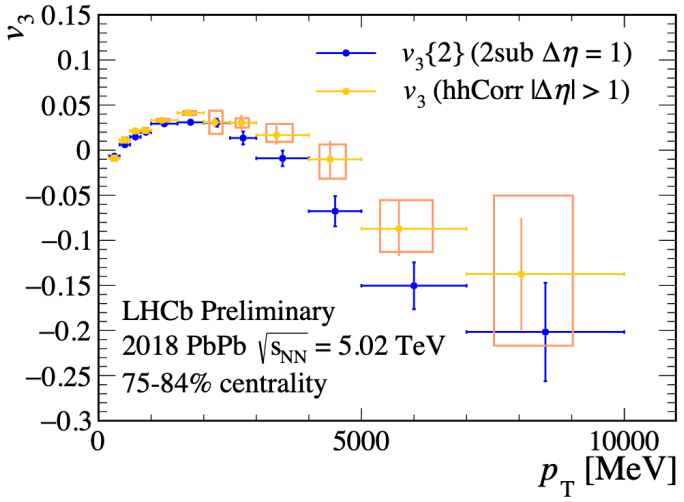
# Validation of cumulant method with PbPb

LHCb-CONF-2025-001



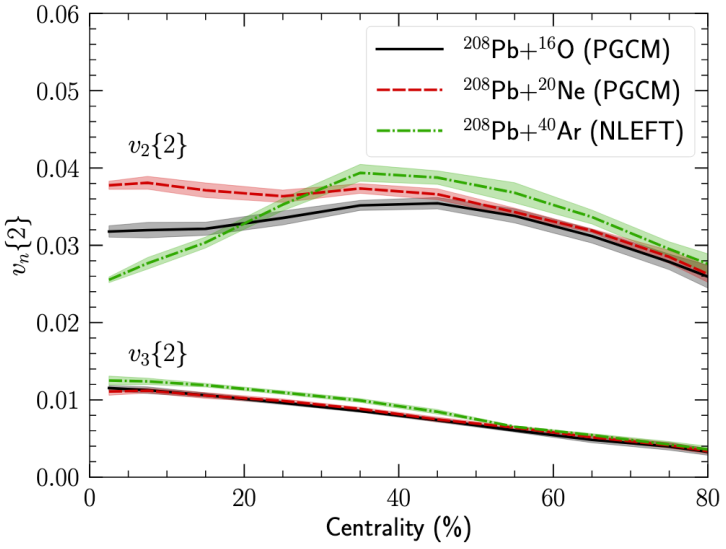



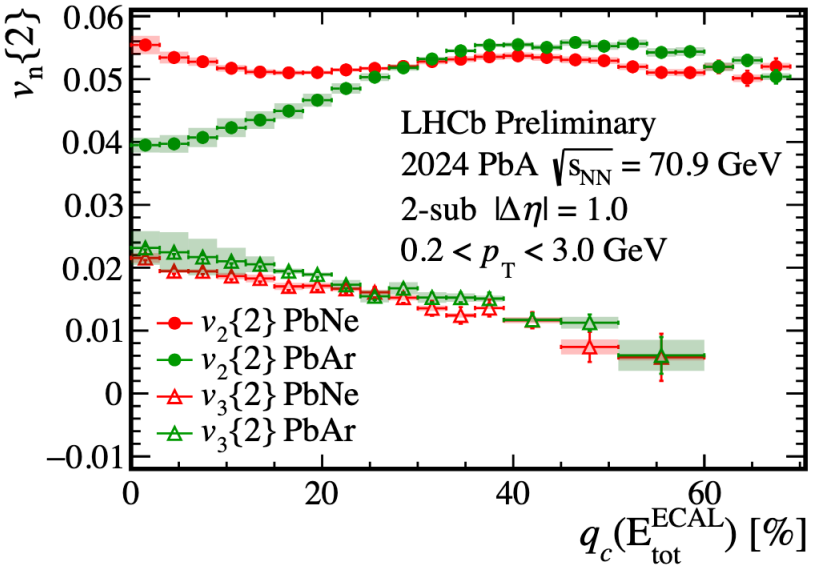

- Anisotropic flow coefficients computed on the 2024 PbNe/PbAr data with the multi-particle cumulants technique, first used at LHCb, with non-flow suppressed via the sub-event method (rapidity gap $\Delta\eta = 1$)
- Method validated by first applying it to peripheral 2018 PbPb data, where flow coefficients had already been published by the two-particle correlation technique
- Consistency between the two $v_2\{2\}$ measurements showing the solidity of the applied cumulant method

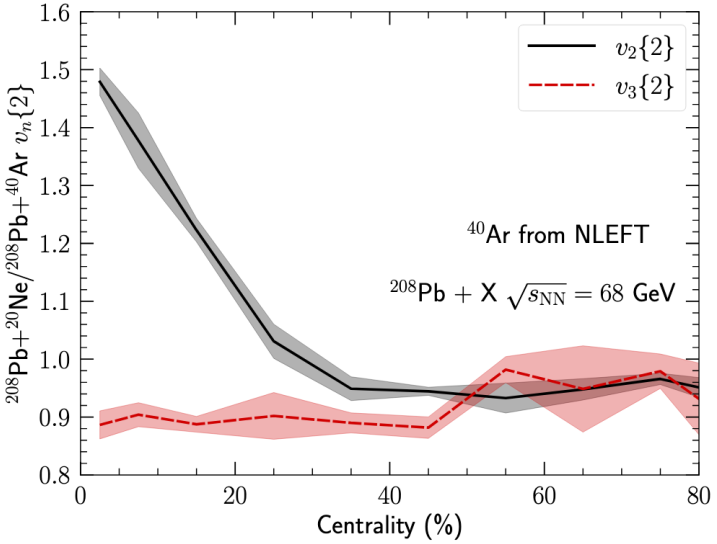
# Flow coefficients in PbNe/PbAr collisions

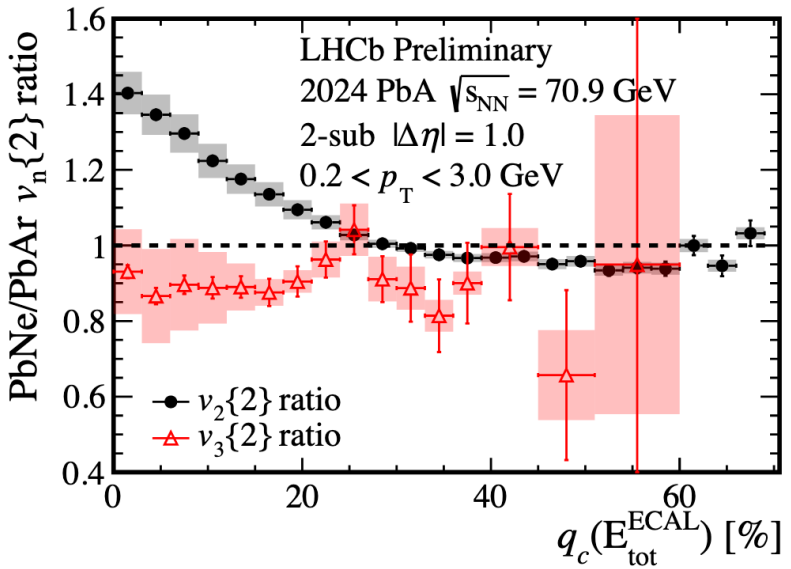
王剑桥，Flow & Correlation I

LHCb-CONF-2025-001



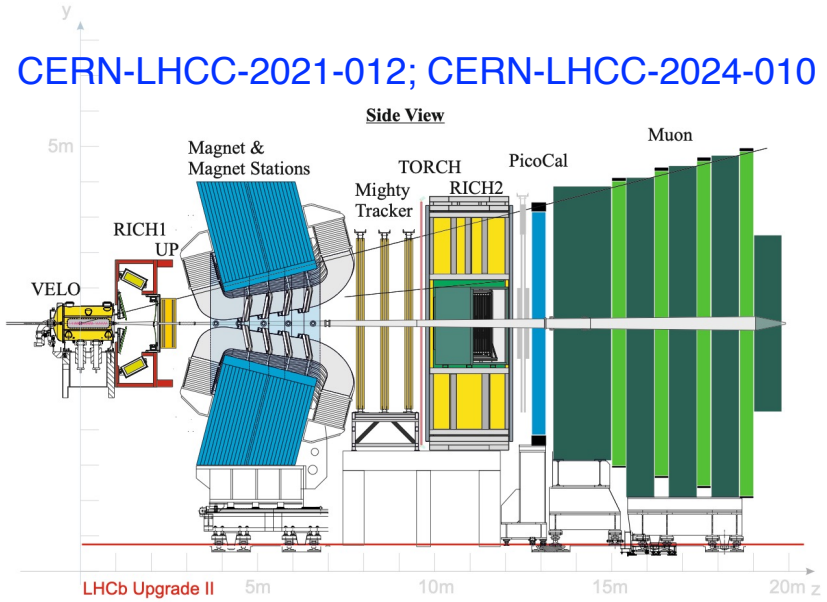



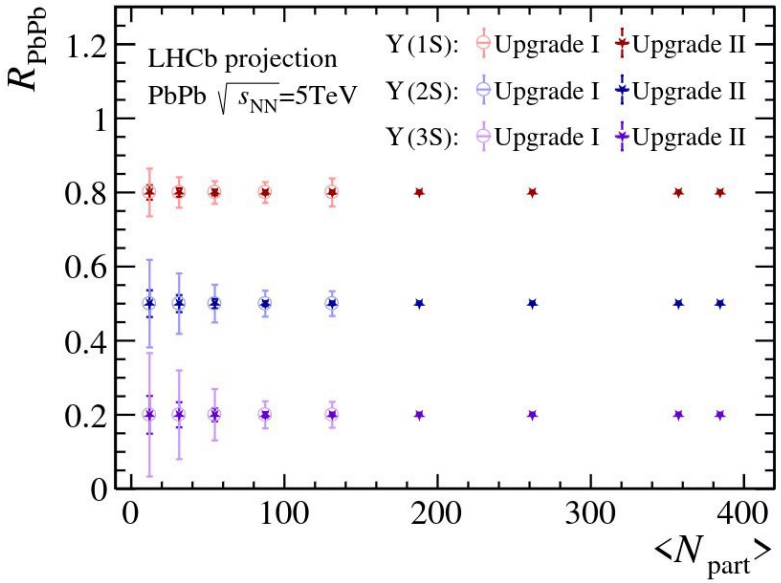

- Results as a function of a proxy for the centrality (ECAL energy percentile) show an evident flatter $v_2\{2\}$ values for PbNe than PbAr, and a similar $v_3\{2\}$
- This is clearly consistent with the predicted Ne bowling-pin shape, and confirms its major effect on the collective dynamics

$$q_c(E_{\mathrm{tot}}^{\mathrm{ECAL}}) \equiv 1 - q(E_{\mathrm{tot}}^{\mathrm{ECAL}})$$

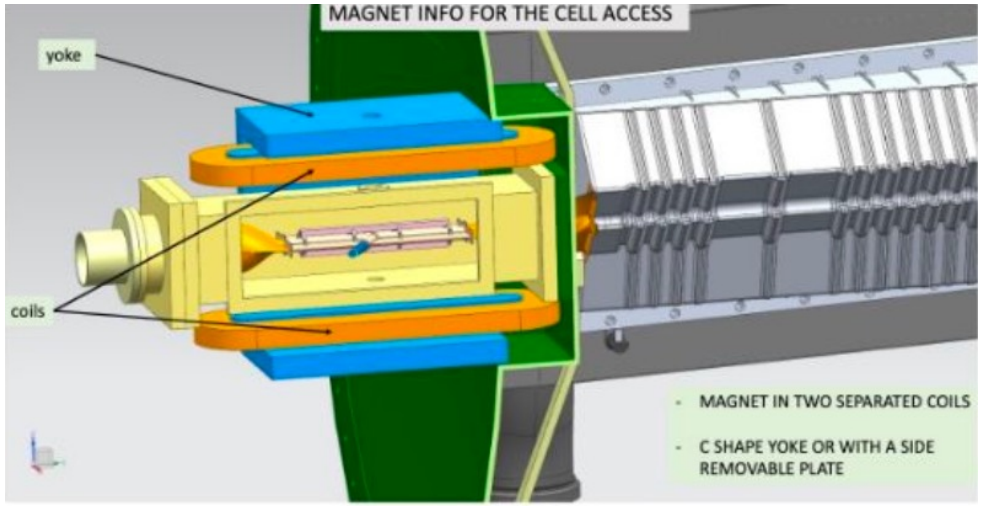
# LHCb Upgrade II (Run5)

CERN-LHCC-2021-012; CERN-LHCC-2024-010




- Conceived to cope with a x10 pp luminosity wrt Run3 and recently approved!
- Almost a 4D detector with precise timing added, and increased granularity
- Support for full centrality PbPb reach included by design
- In parallel, the LHCSpin R&D aims at polarizing the SMOG gas, and could open a new door for spin studies at the LHC(b) → unique insights into nucleon PDFs characterization




arXiv:2504.16034

# Summary & outlook

- LHCb has a very diverse heavy-ion and fixed target program, which profits of the variety of datasets
- Unique constraining power from small $x$ to large $x$ with large variety of collision species in collider and fixed-target mode, with multiple probes (heavy flavor, UPC, polarization, flow...)
- Unique probes of QGP with precise heavy flavors measurements in small system in forward rapidities
- Unique bowling alley with SMOG2 uncovers the shape of ground state nucleus, at the same time studies the medium response to well-defined initial geometry
- Stay tuned for the exciting new results from Run3 and SMOG2!