



LHCb重离子碰撞实验进展

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清华大学

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April 24-28

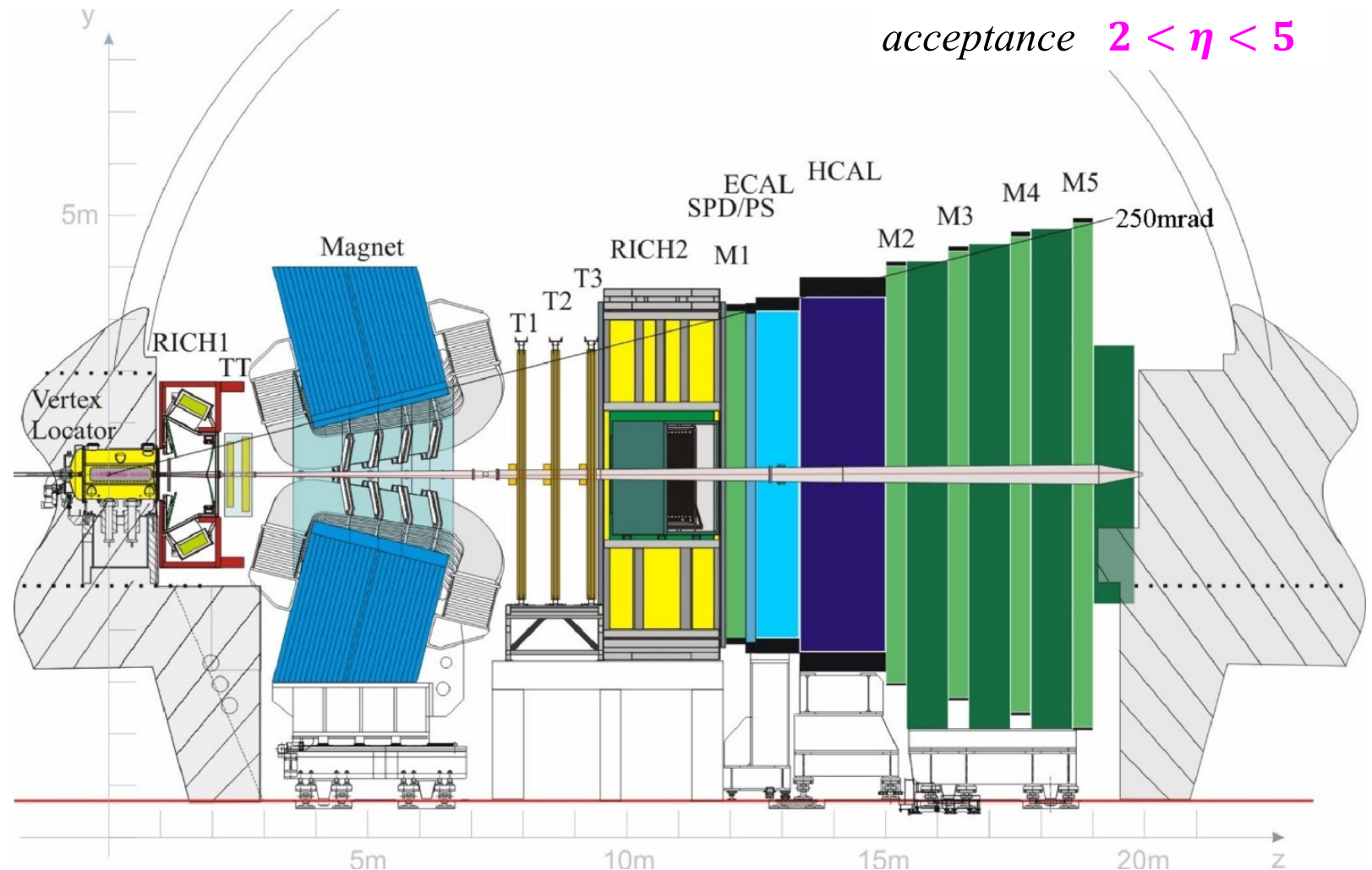
极端核物质前沿研讨会

Workshop on extreme nuclear matter frontiers

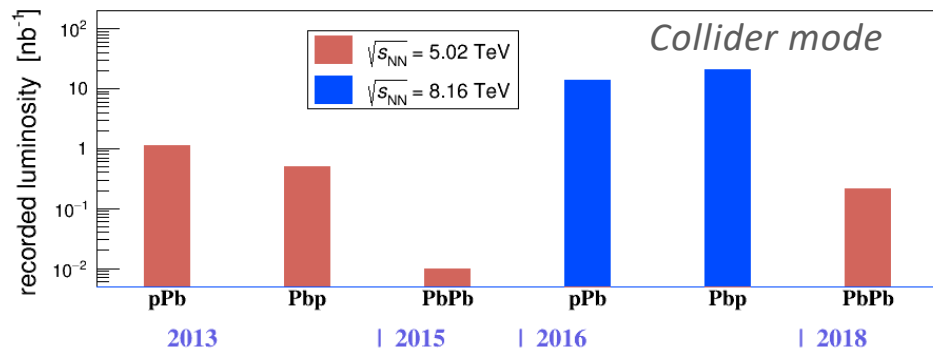
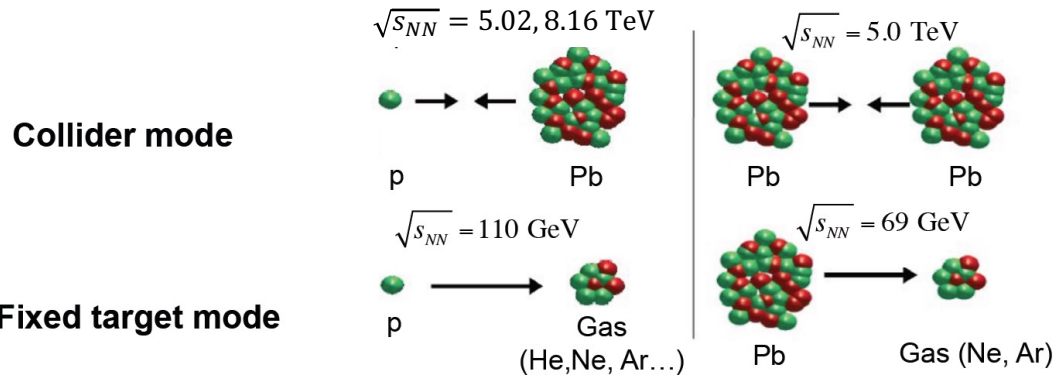
The LHCb detector

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

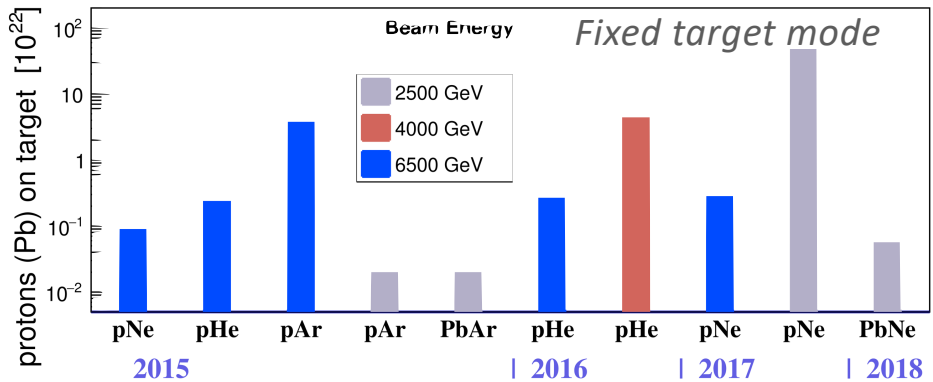
- **Precise tracking**
clear separation between primary and decay vertices
- **Full PID**
reconstruct resonances down to zero p_T
- **Flexible and fast trigger**
precision access to rare probes: charm/bottom, higher quarkonia, exotic states
- **Fixed-target system (SMOG)**
acquire beam-gas data (pA ,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



LHCb heavy ion datasets from Run1/Run2

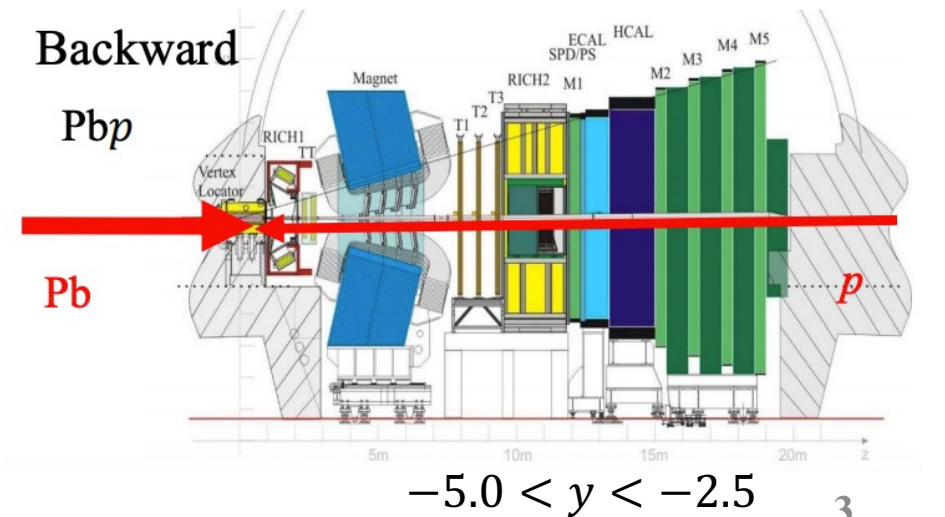
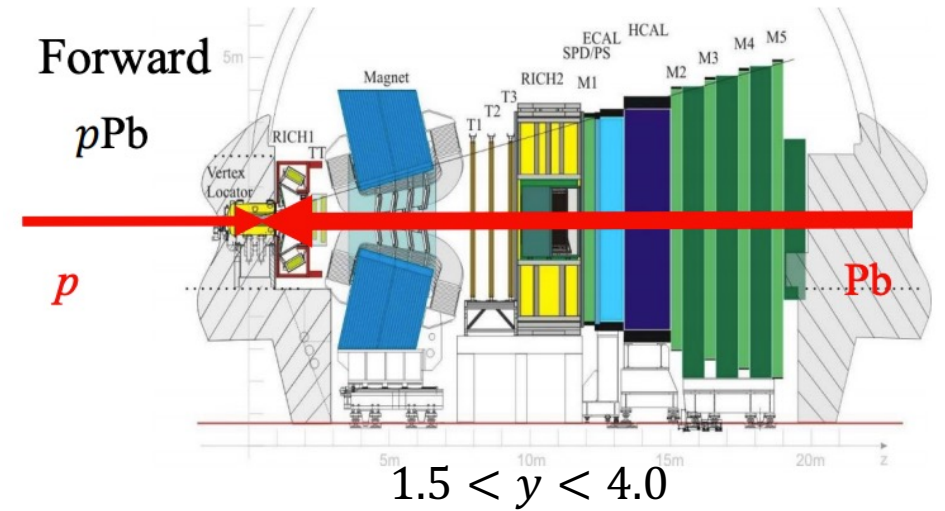


PbPb:
limited to 100-60% centrality

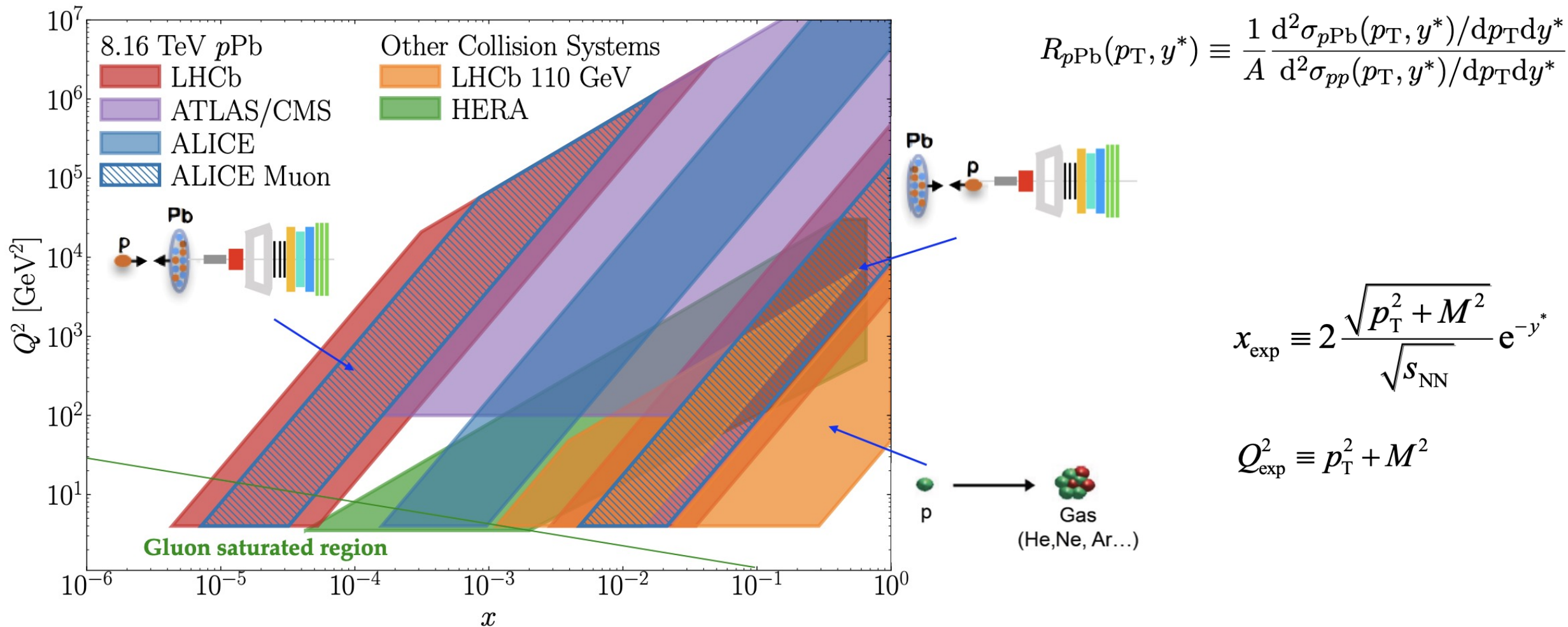


+ huge pp collision datasets at various energies for small-system studies!

Proton-Pb data-taking modes:

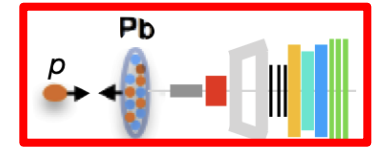


Mapping the initial state with LHCb



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

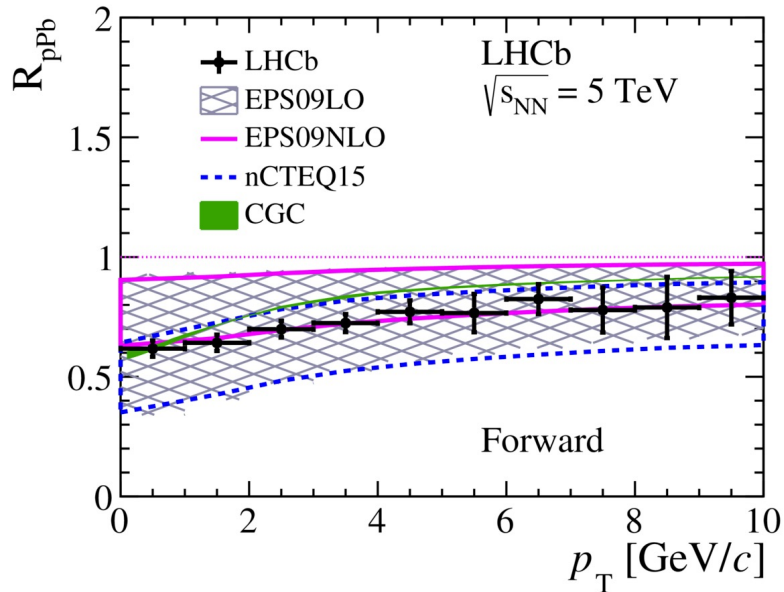
Constraining nPDFs with D^0 meson in pPb



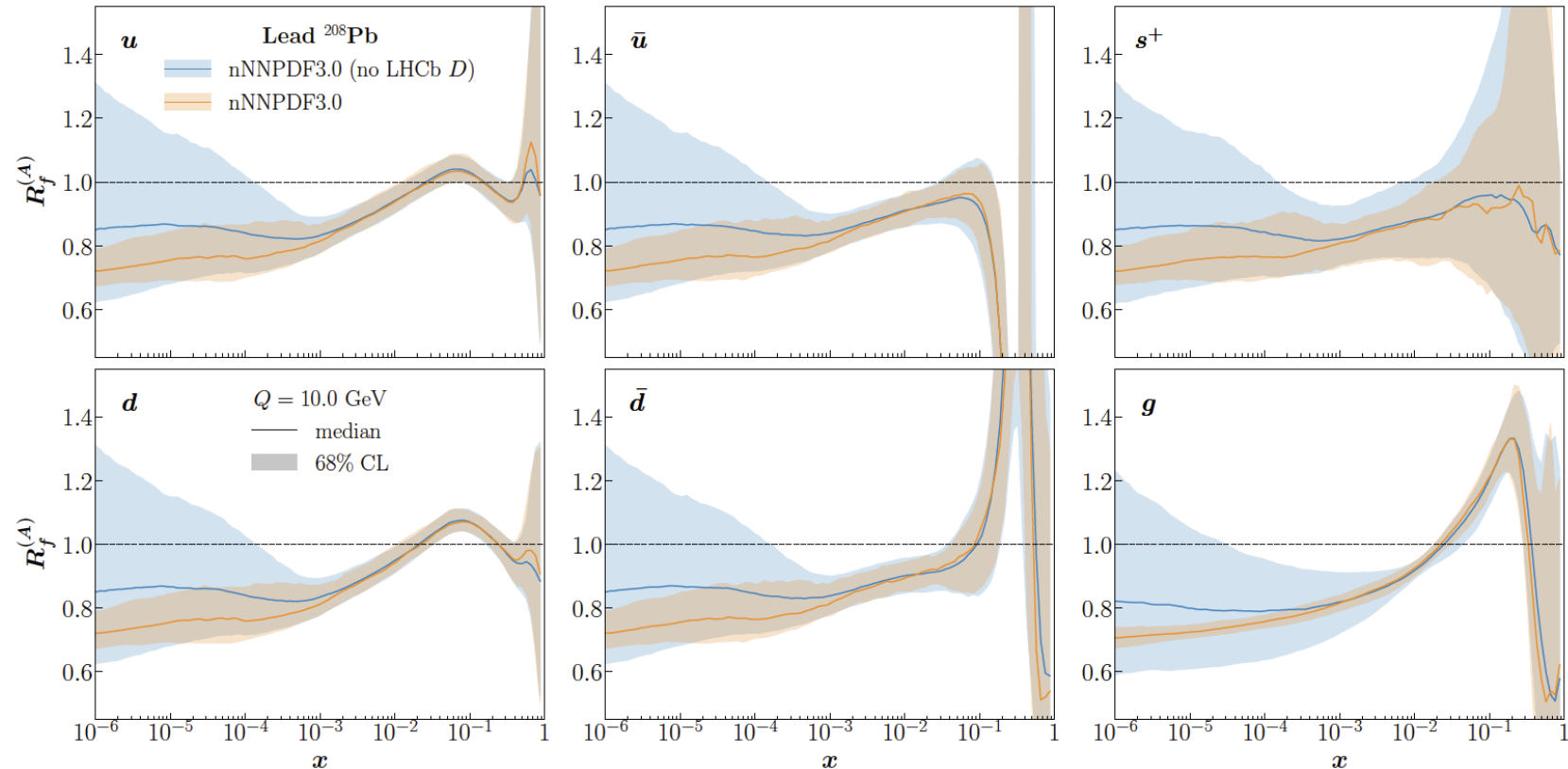
- LHCb measurement of prompt D^0 production in pPb collisions at 5 TeV makes a stringent constraint on reducing nPDFs uncertainty down to $x \sim 10^{-6}$

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

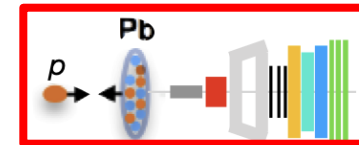
JHEP 10 (2017) 090



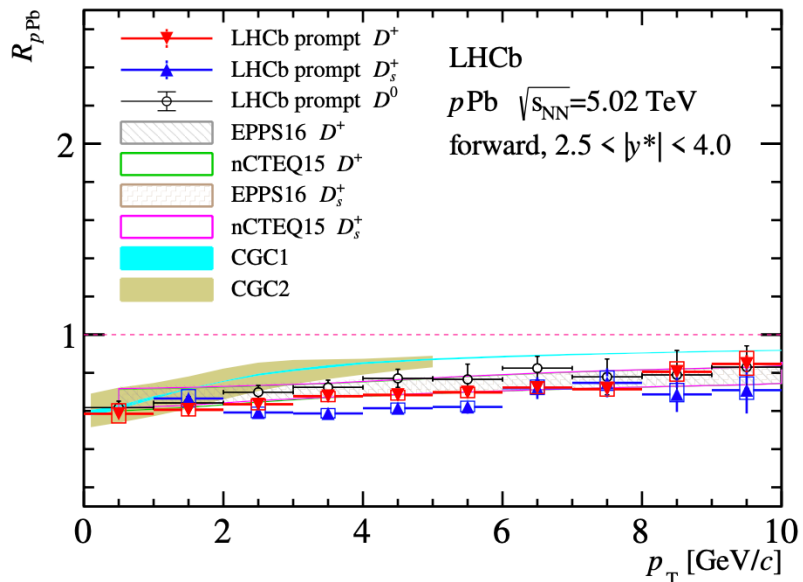
$$R_{pPb} = \frac{\sigma_{pPb}}{A\sigma_{pp}}$$



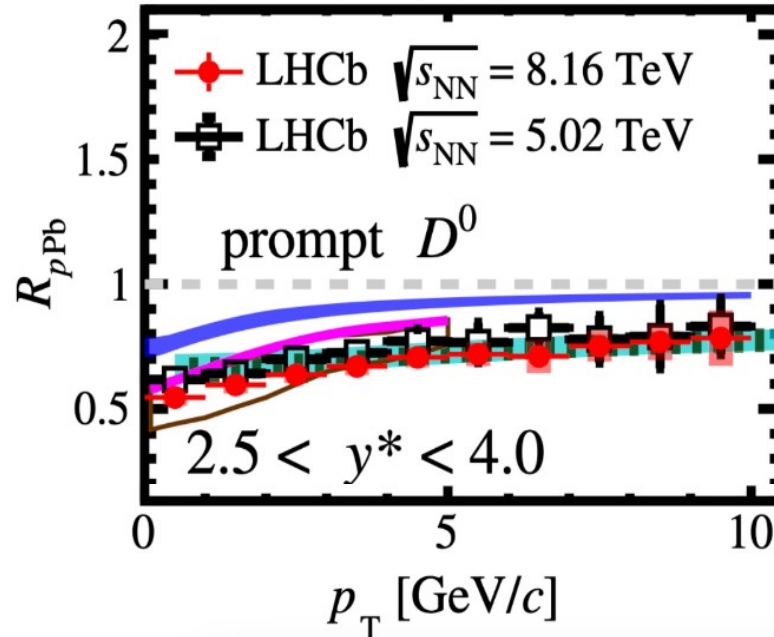
Testing nPDFs with more D mesons in pPb



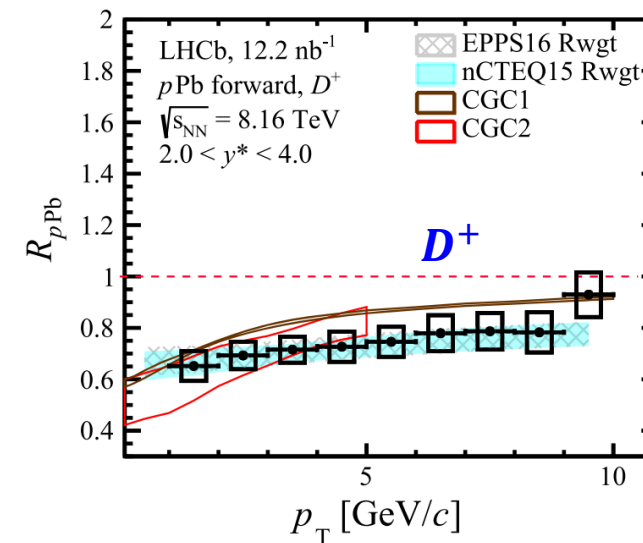
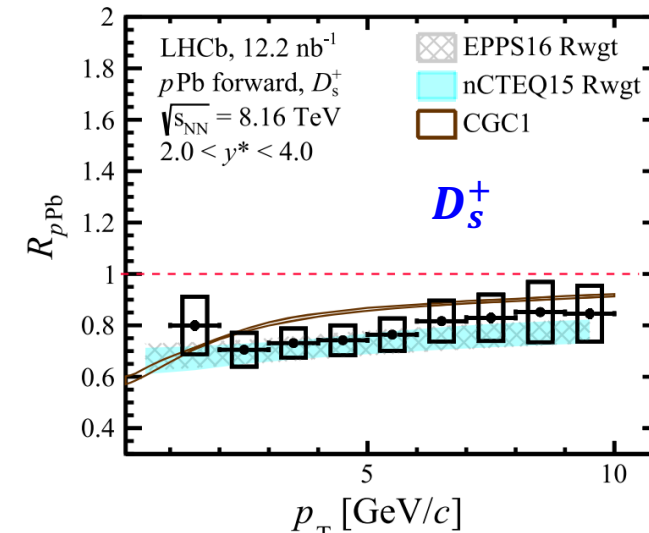
LHCb, JHEP 01 (2024) 070



LHCb, PRL 131 (2023) 102301

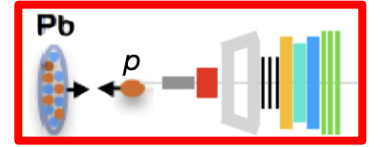


LHCb, PRD 110 (2024) L031105

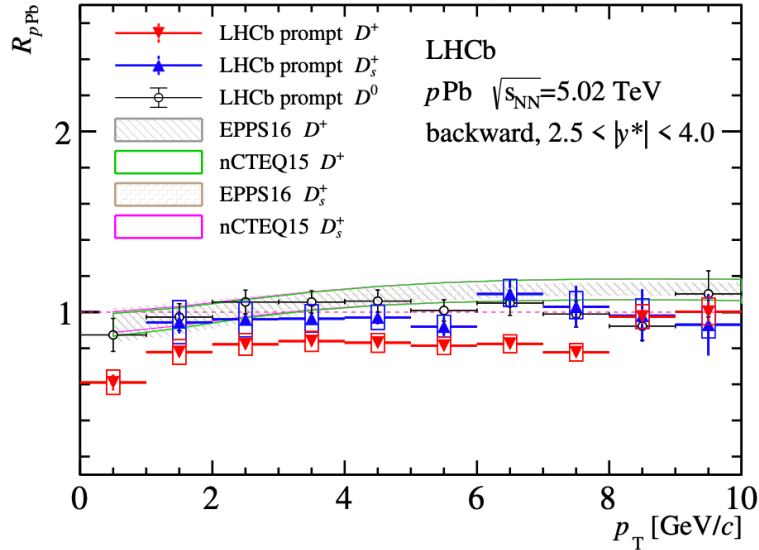


- All D mesons suppressed at forward rapidity at both collision energies (5.02 and 8.16 TeV)
 \rightarrow gluon shadowing at small x

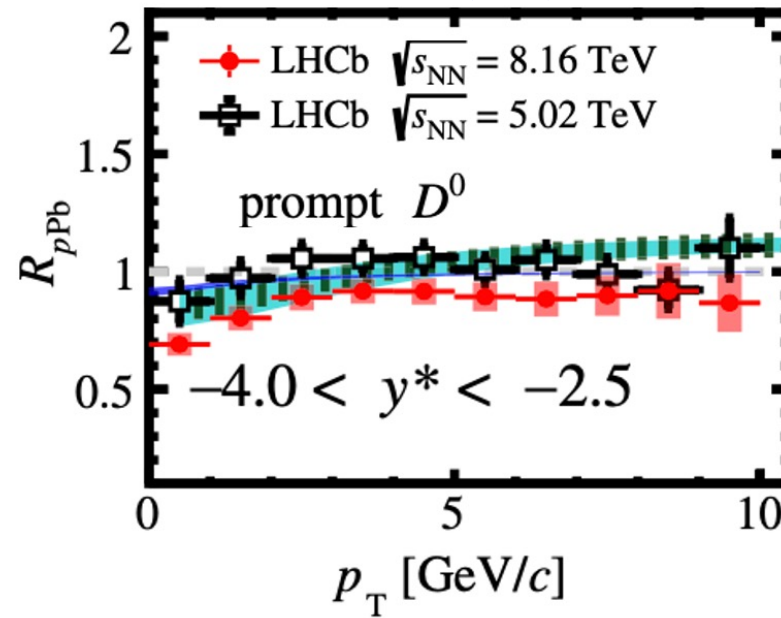
Hint of final state effects with D mesons in Pbp



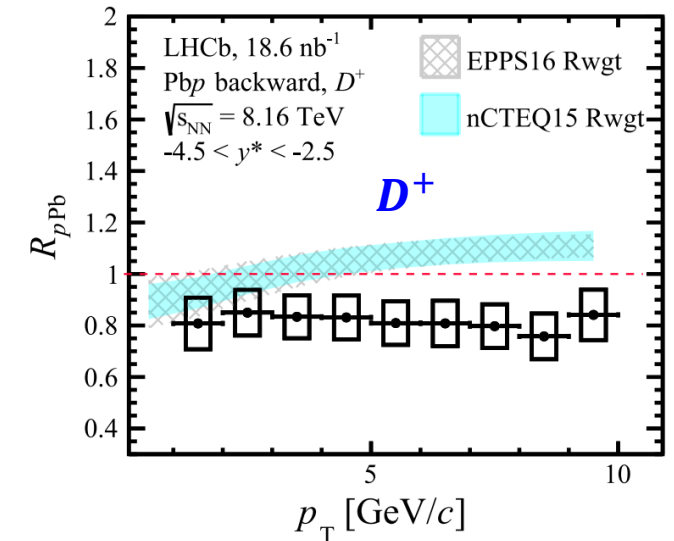
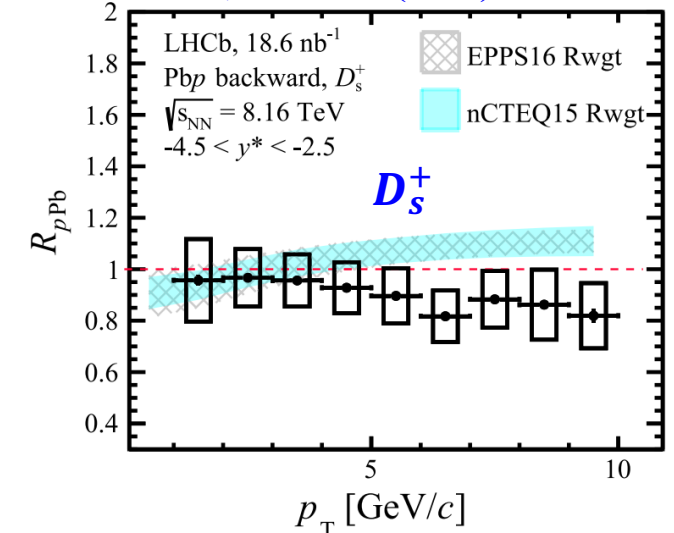
LHCb, JHEP 01 (2024) 070



LHCb, PRL 131 (2023) 102301

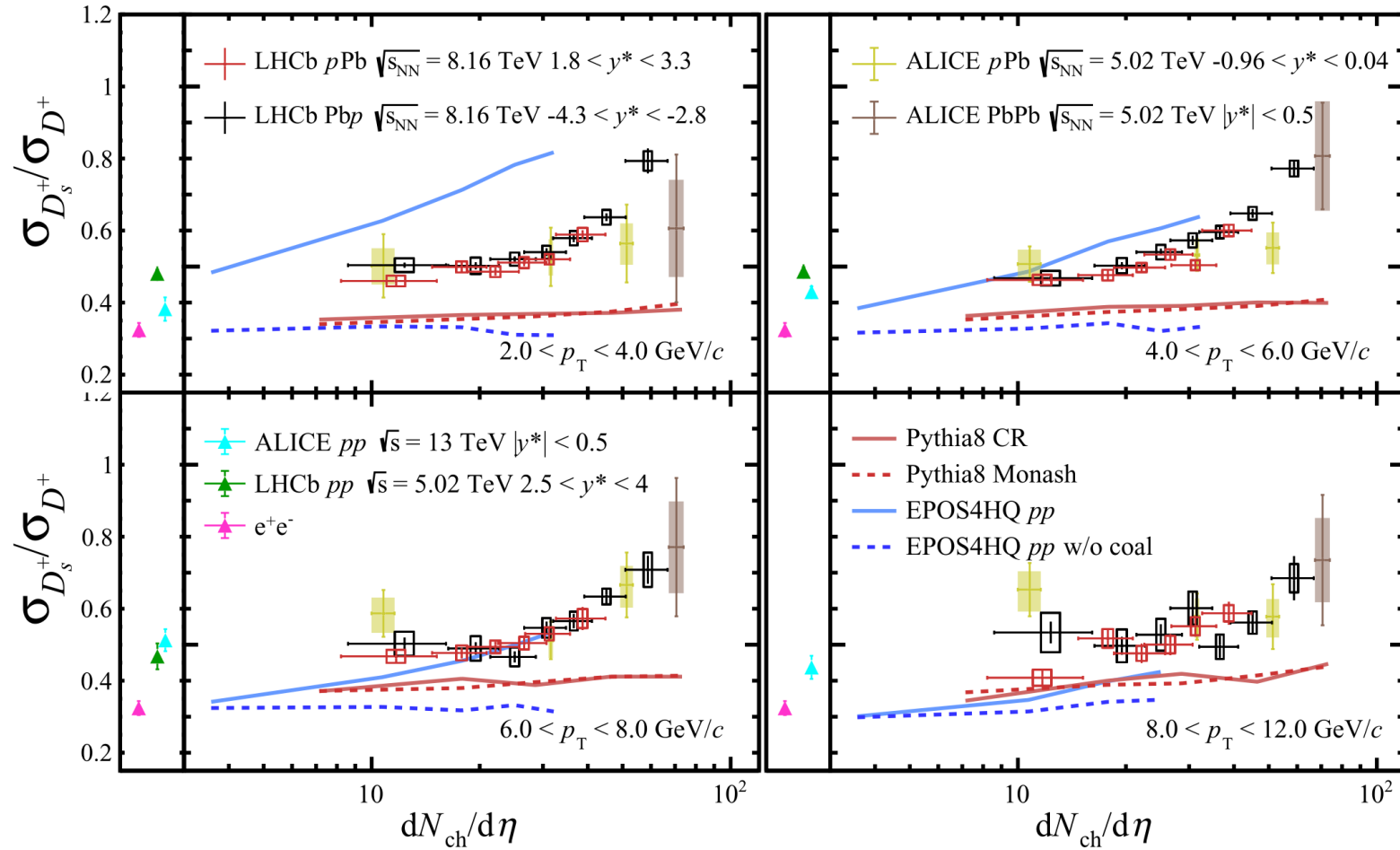


LHCb, PRD 110 (2024) L031105



- 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

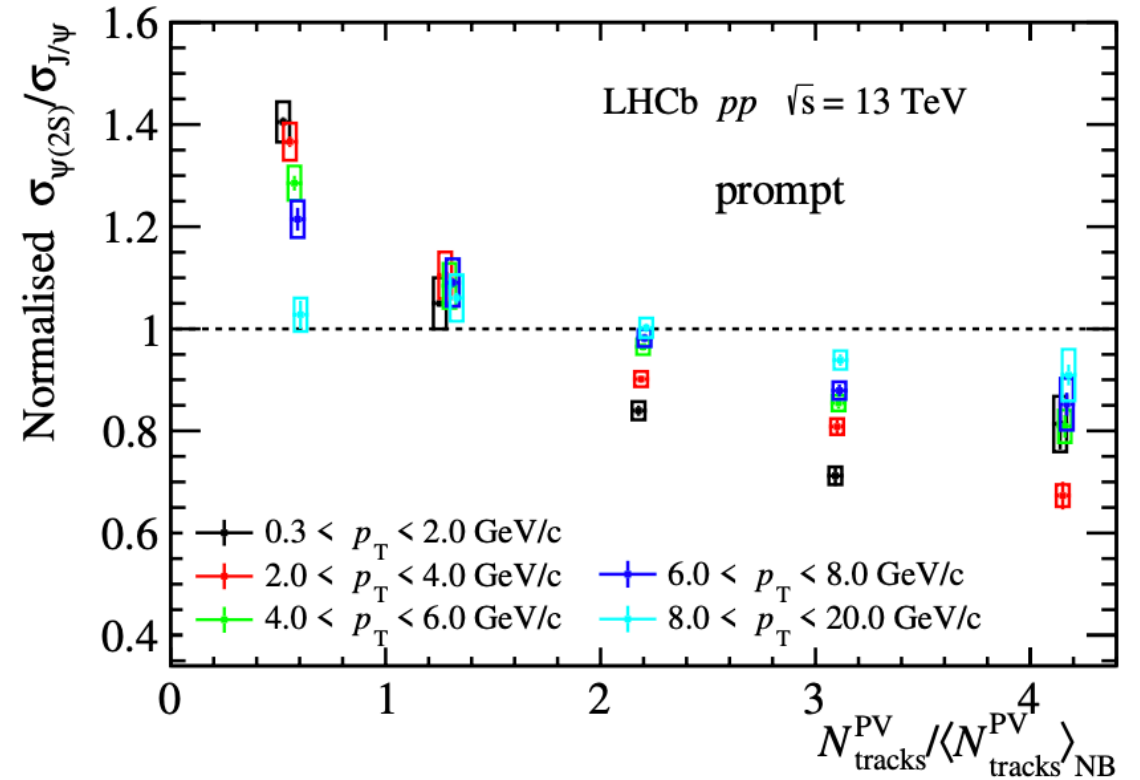
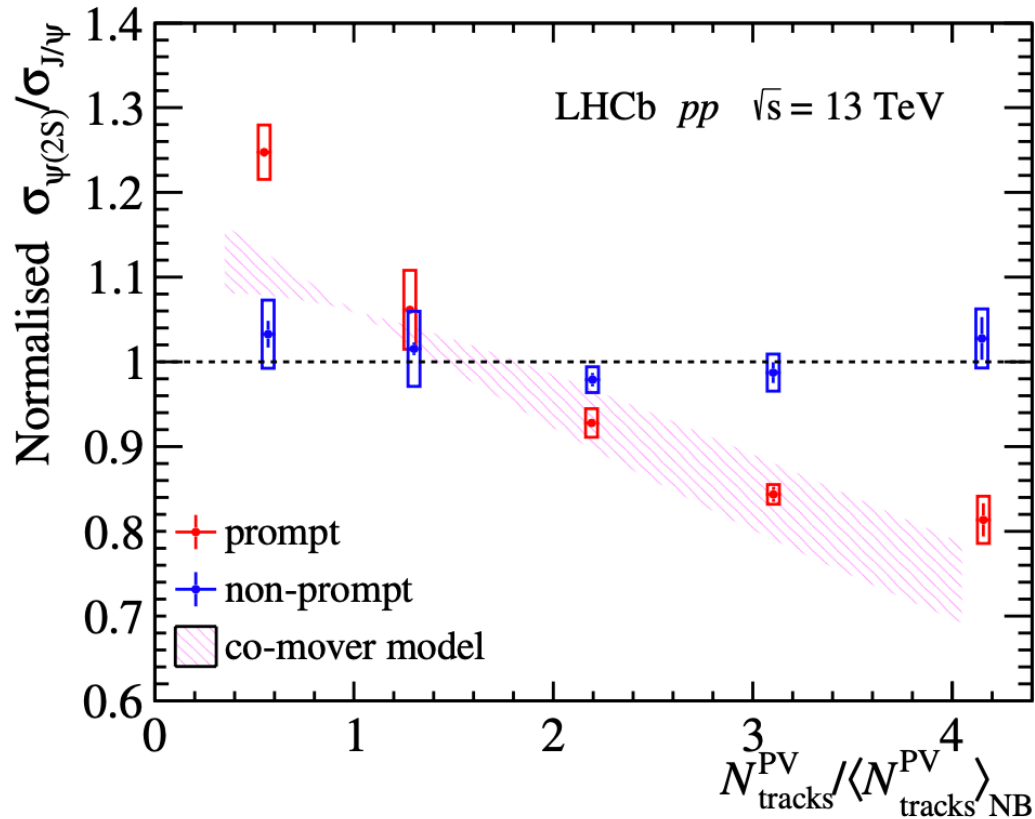


- The ratio increases with multiplicity significantly!
- The enhancement is more pronounced at backward rapidity and lower p_T .
- Modification of charm hadronization/production in high-multiplicity pPb collisions.

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

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

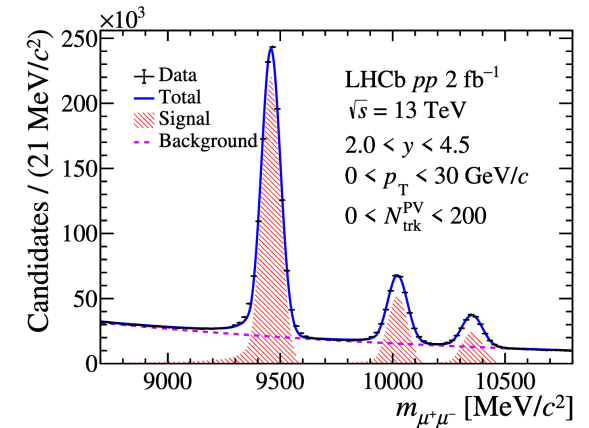
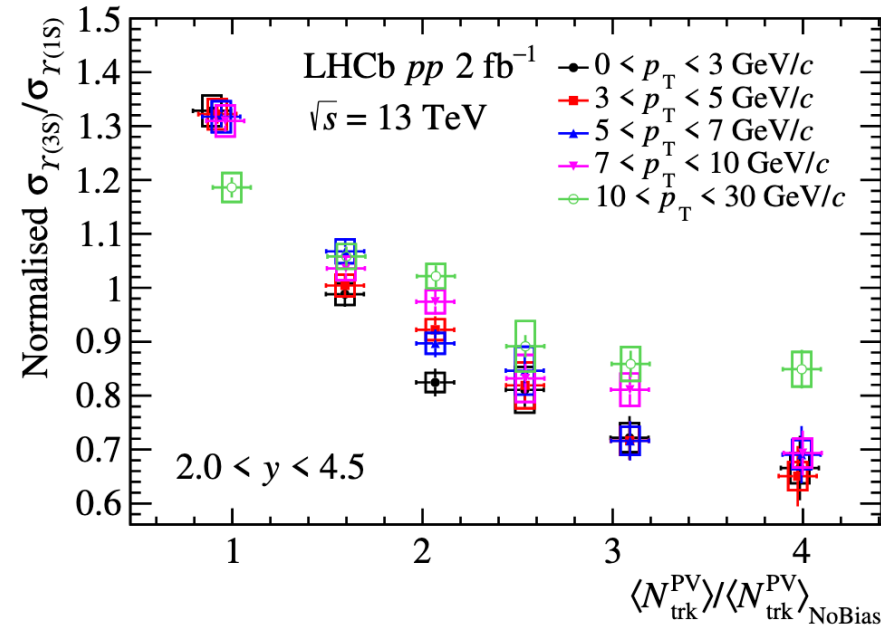
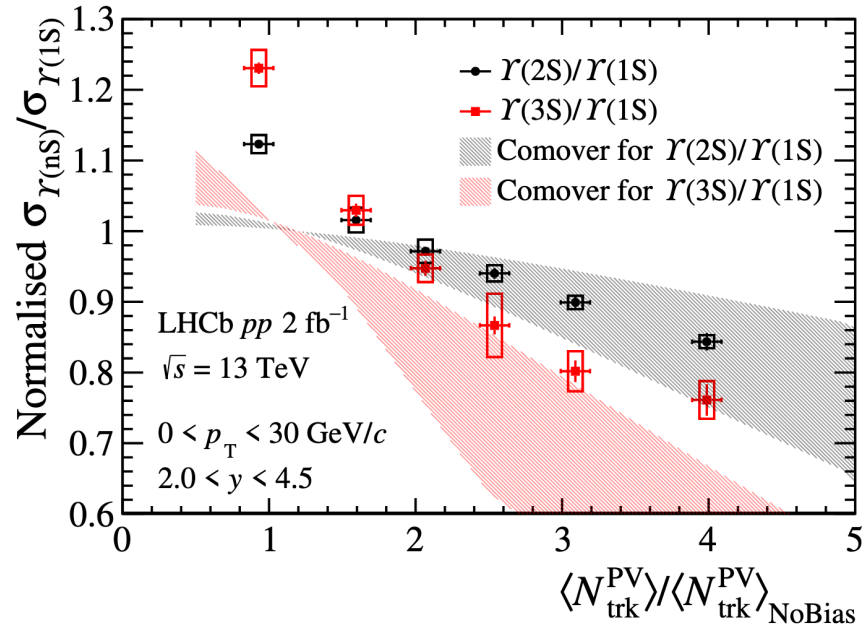
LHCb, JHEP 05 (2024) 243



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

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

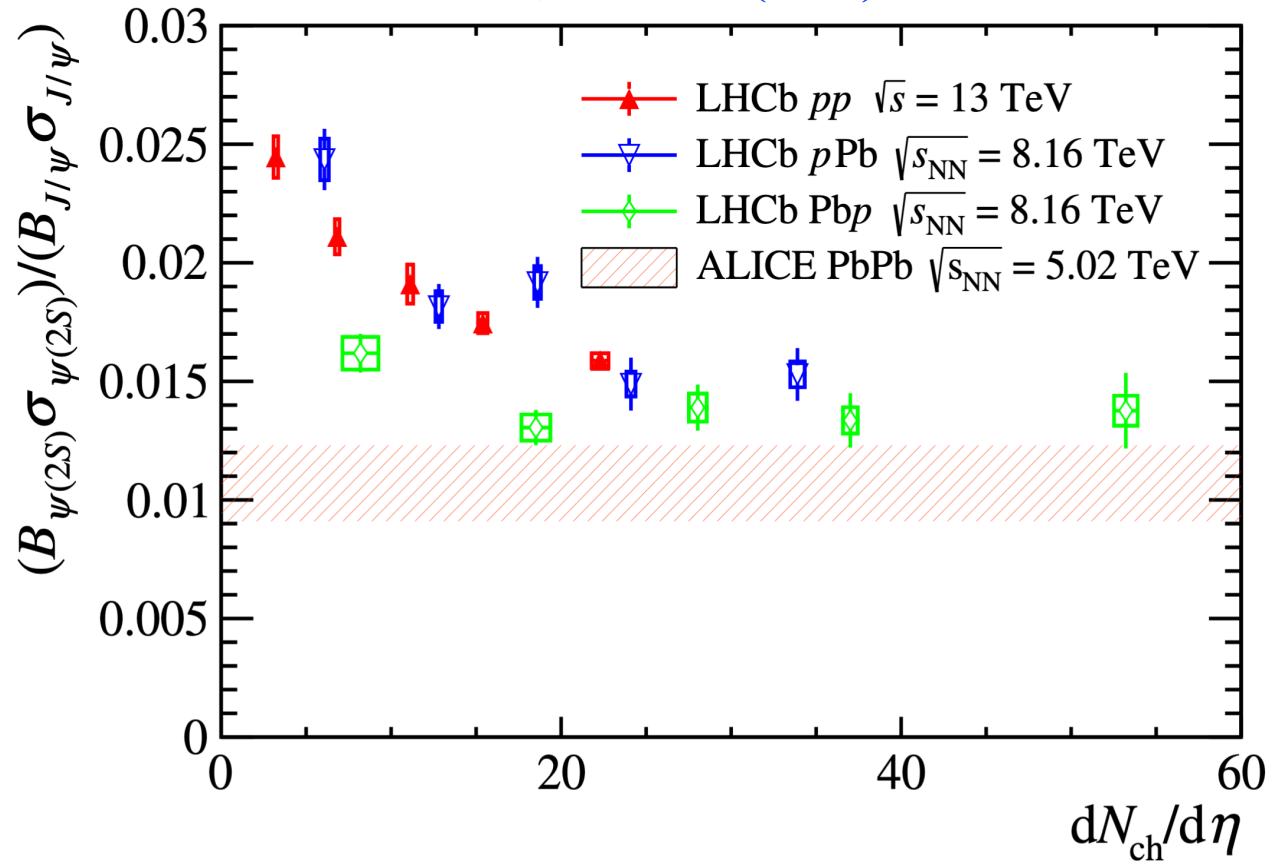
LHCb, JHEP 05 (2025) 011



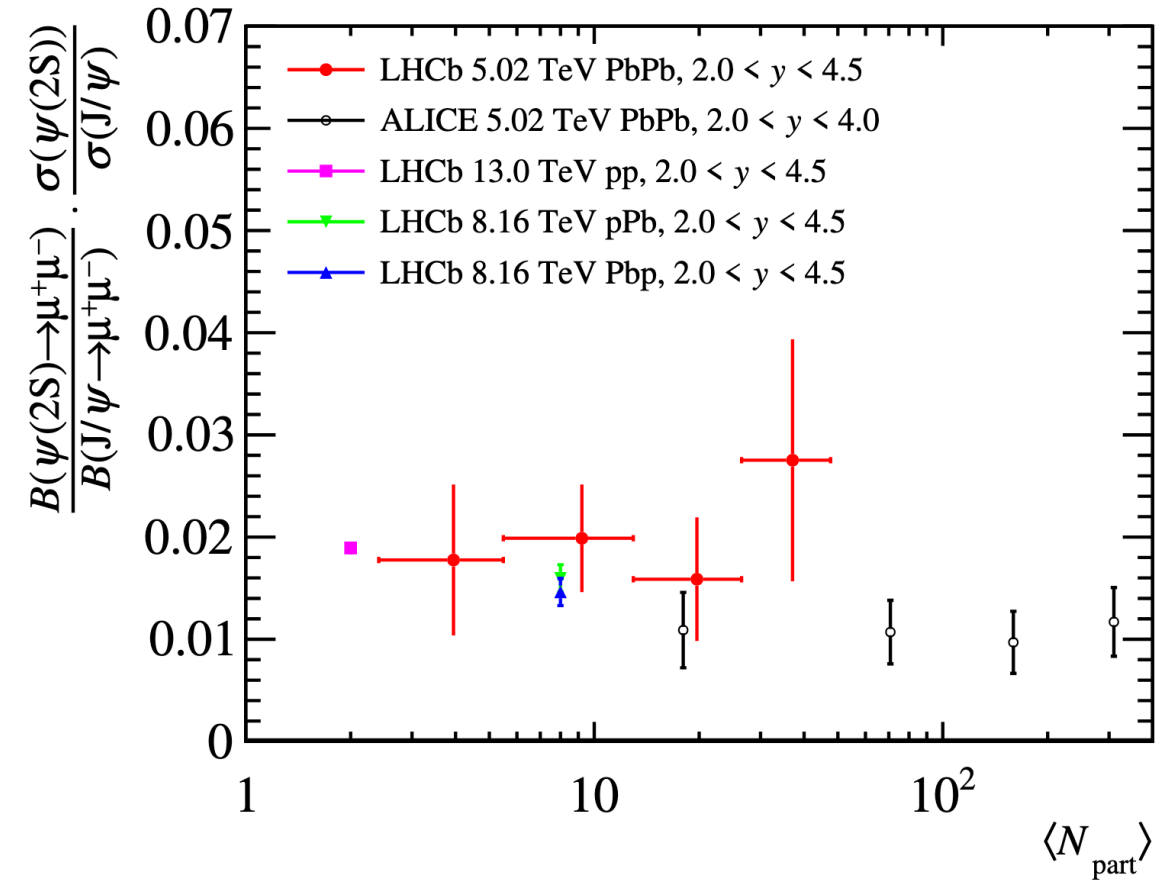
- Sequential suppression pattern observed in high multiplicity events.
- Suppression is more significant for low p_T regions.
- Qualitatively consistent with comover model predictions.

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

LHCb, JHEP 11 (2025) 169



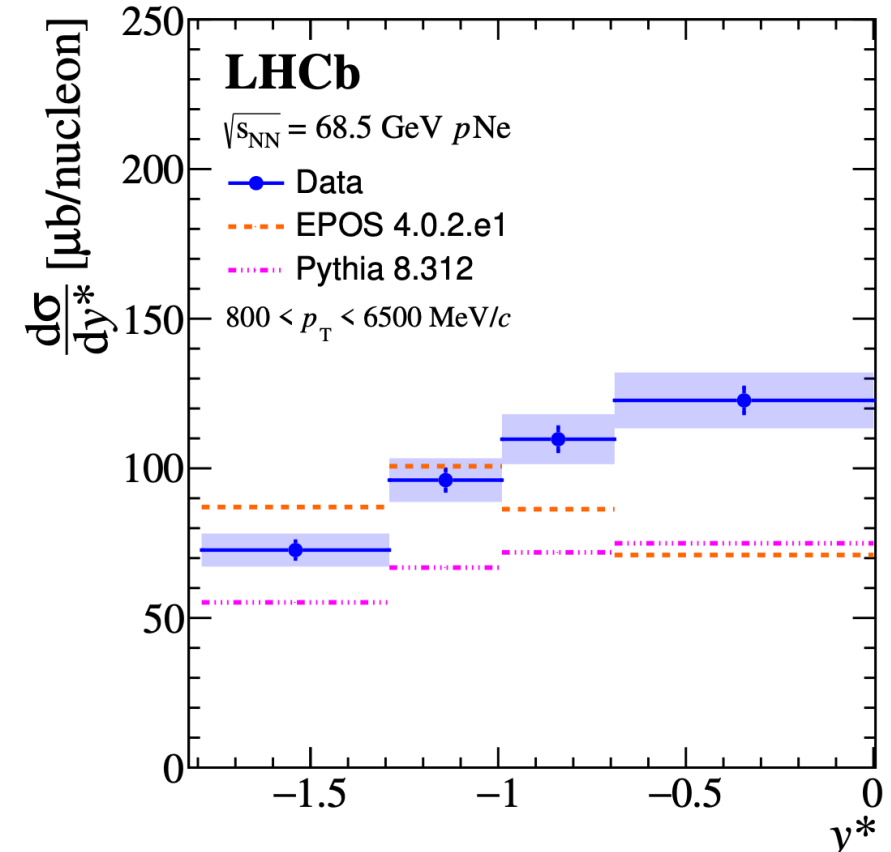
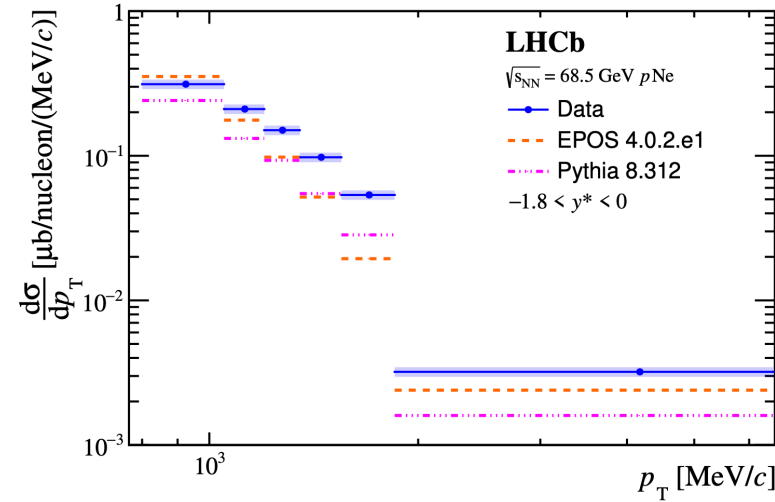
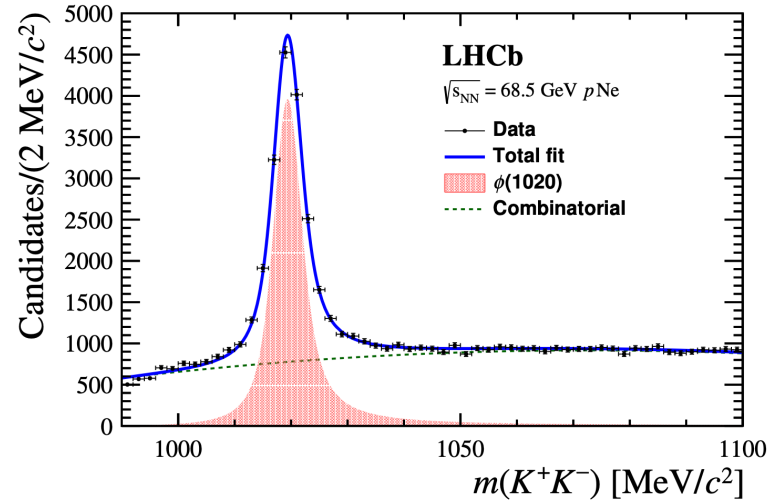
LHCb, JHEP 07 (2025) 235



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

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

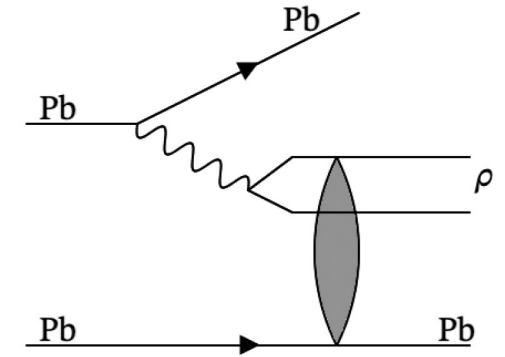
LHCb, JHEP 03 (2025) 151



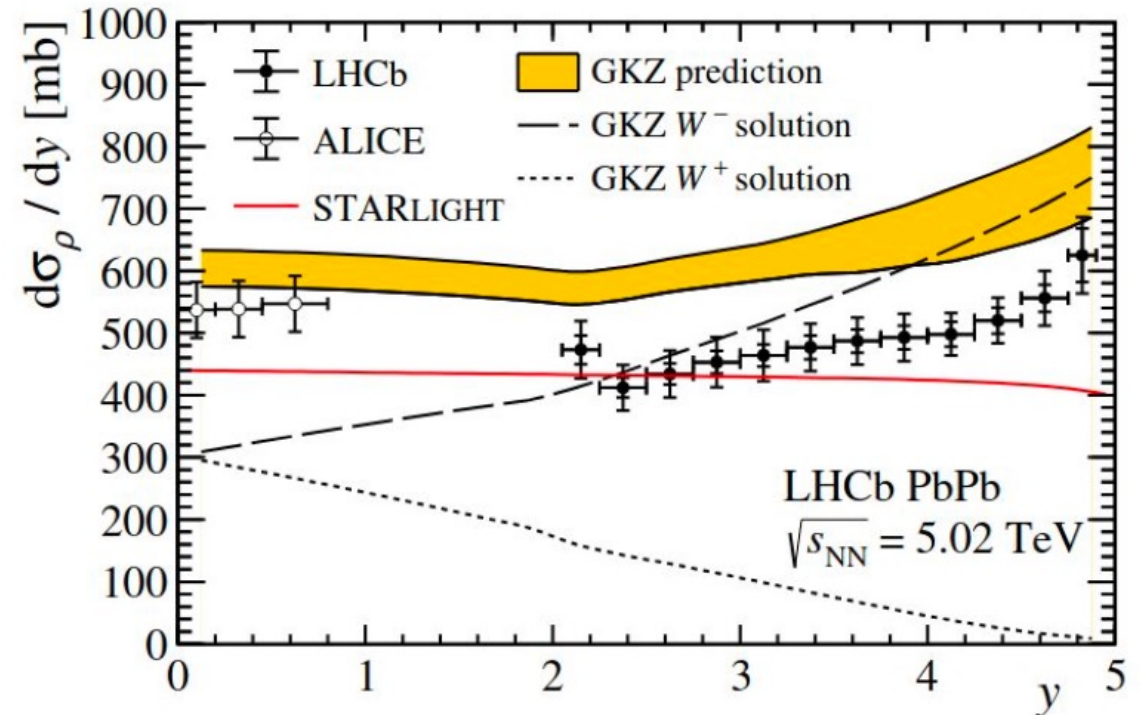
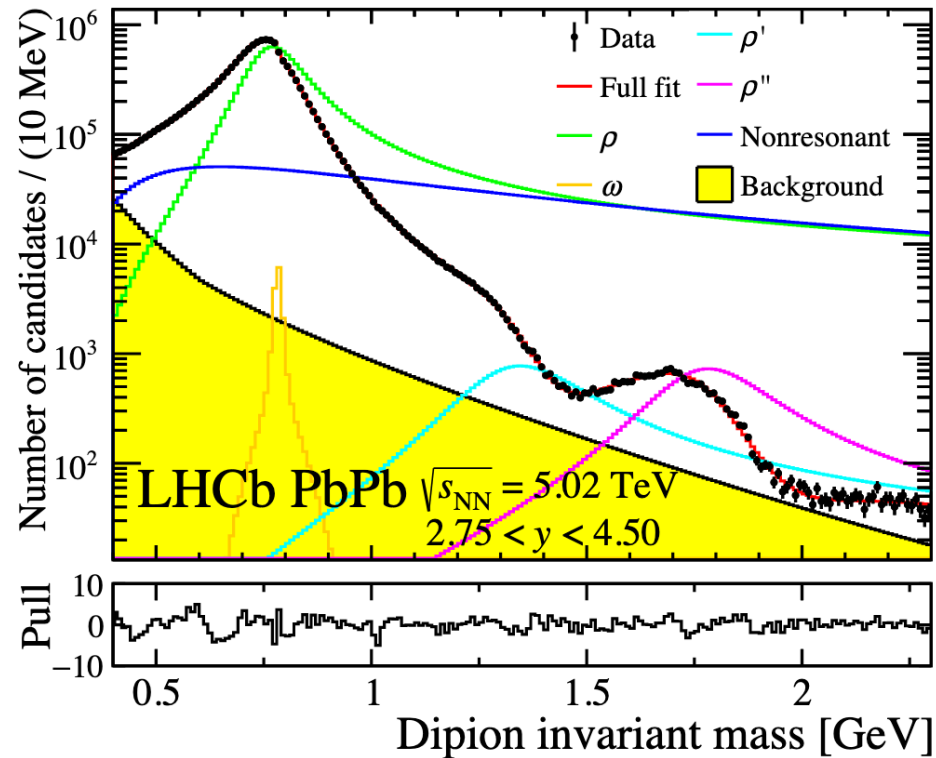
- Theoretical predictions slightly underestimate the result in p_T and high y^* regions
- Data constrain event generators in a relatively unexplored kinematic regime
- Reference for RHIC BES measurements

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 ρ cross-sections vs y shows similar trend as GKZ prediction, but with additional 30% suppression, could be caused by saturation effect

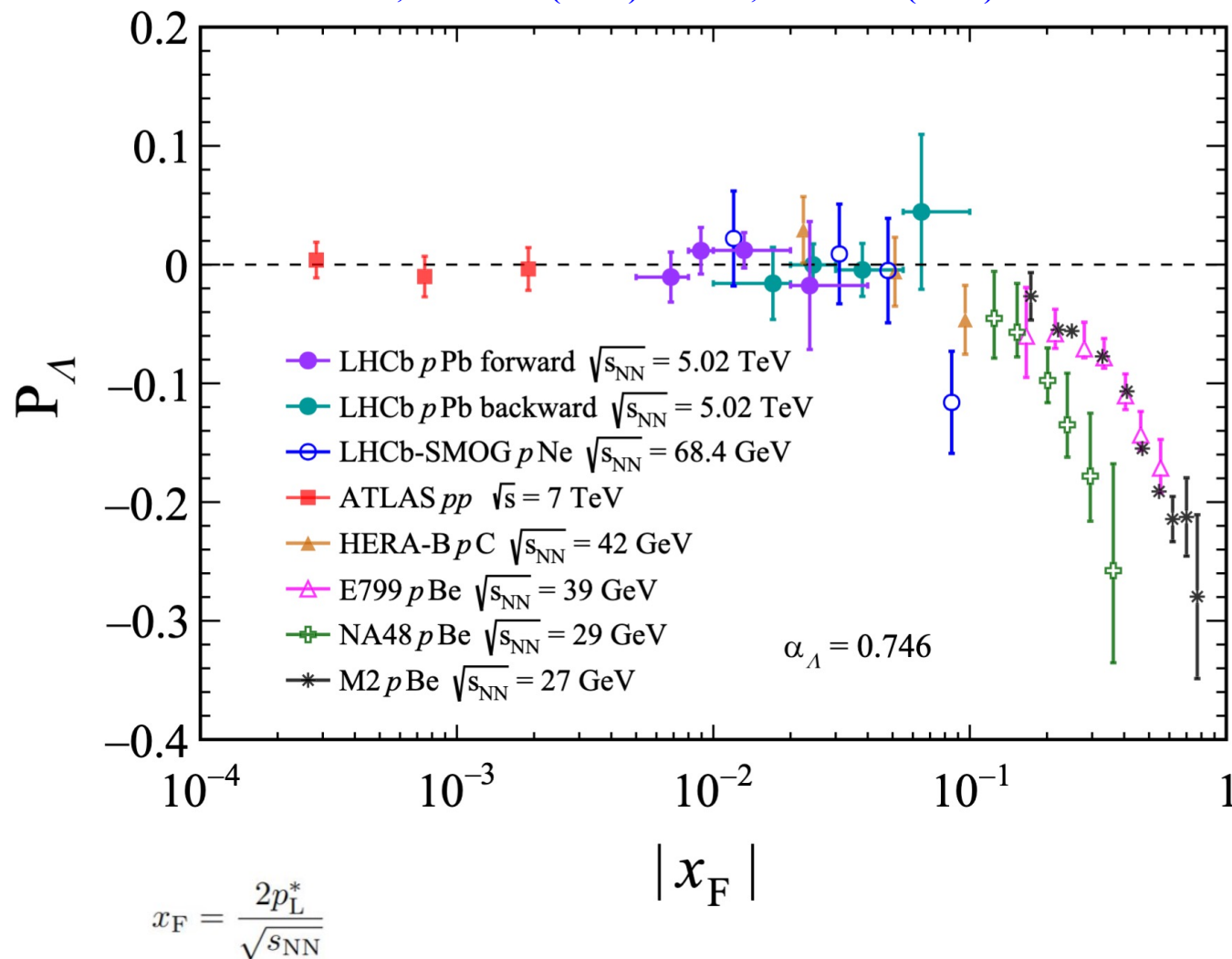


LHCb, JHEP 11 (2025) 103



Λ transverse polarization in pNe/pPb

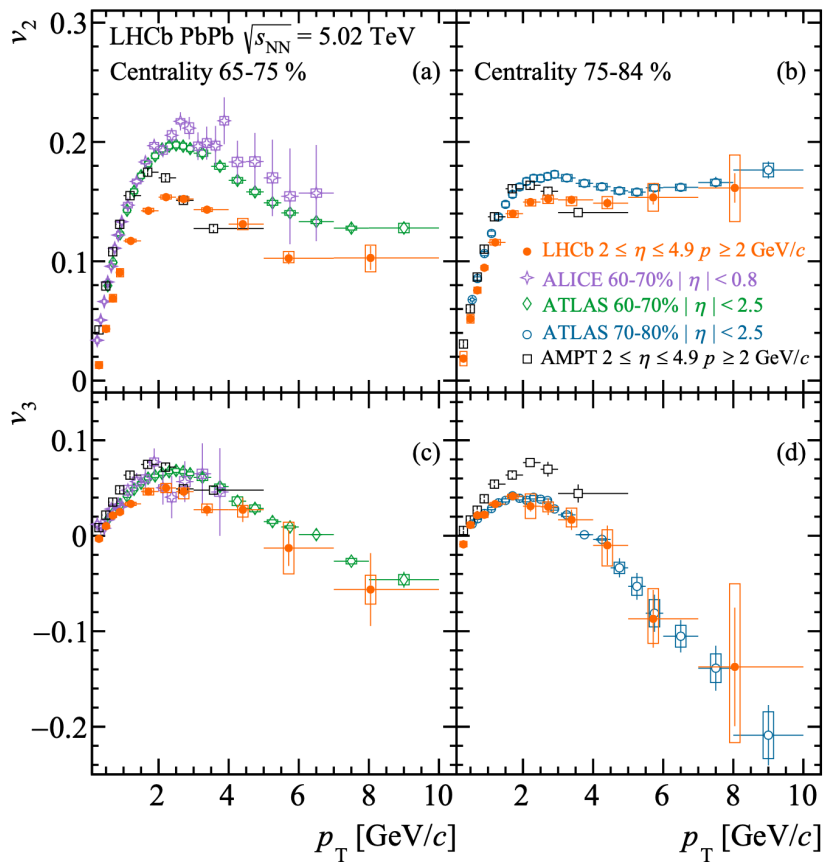
LHCb, PRD 112 (2025) 112022; JHEP 09 (2024) 082



- 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

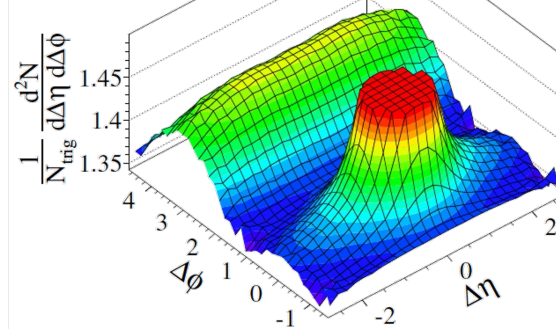
Collectivity in PbPb

- 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

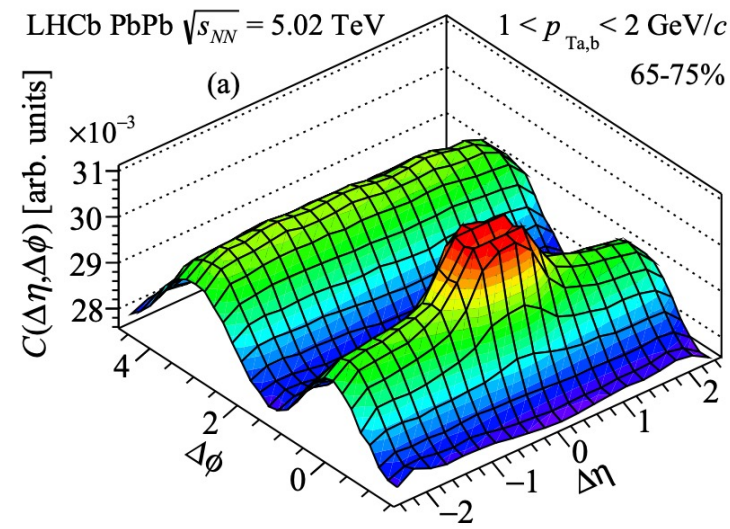
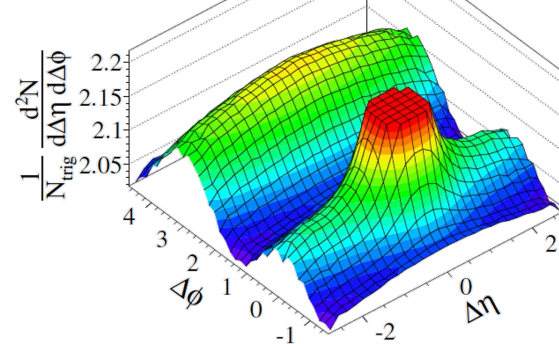


Phys. Lett. B762 (2016) 473

LHCb p +Pb $\sqrt{s_{NN}} = 5$ TeV
 $1.0 < p_T < 2.0$ GeV/c
 Event class 0-3%



LHCb Pb+p $\sqrt{s_{NN}} = 5$ TeV
 $1.0 < p_T < 2.0$ GeV/c
 Event class 0-3%

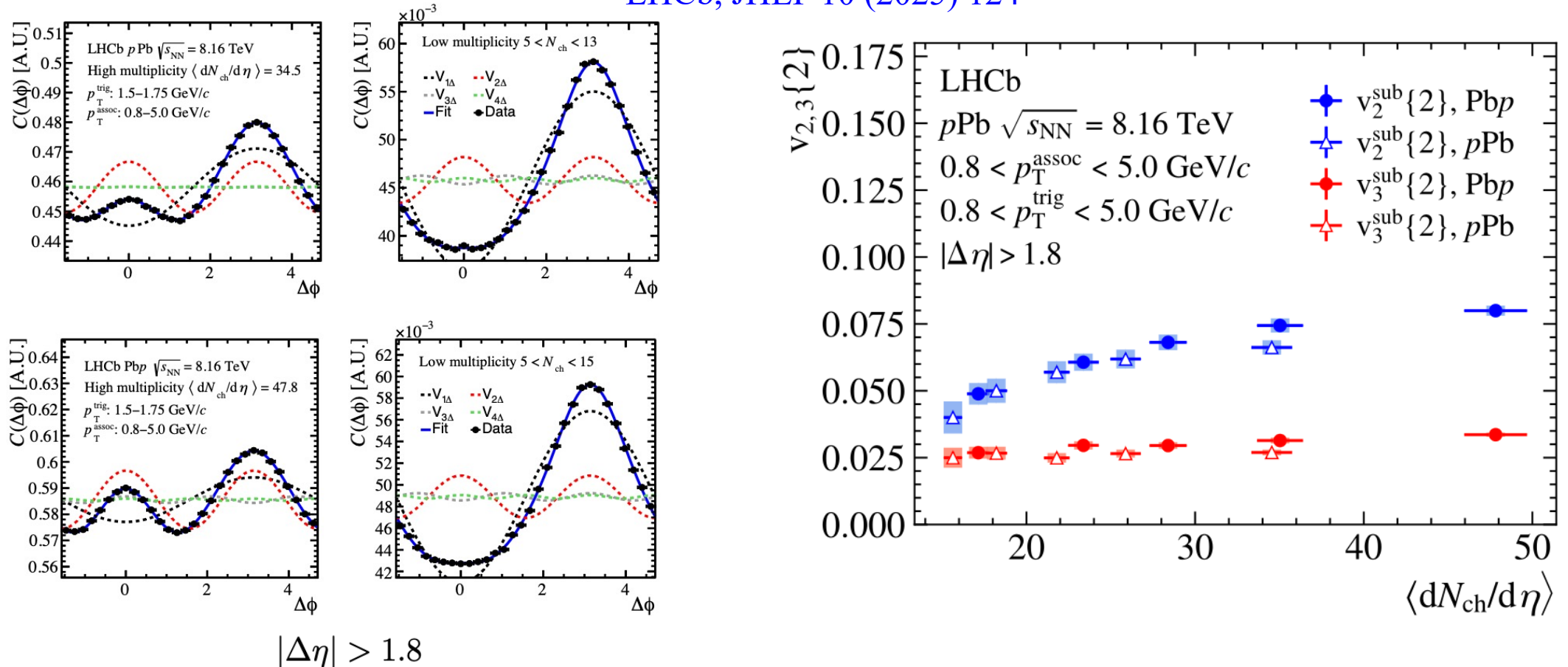


Phys.Rev.C 109 (2024) 054908

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

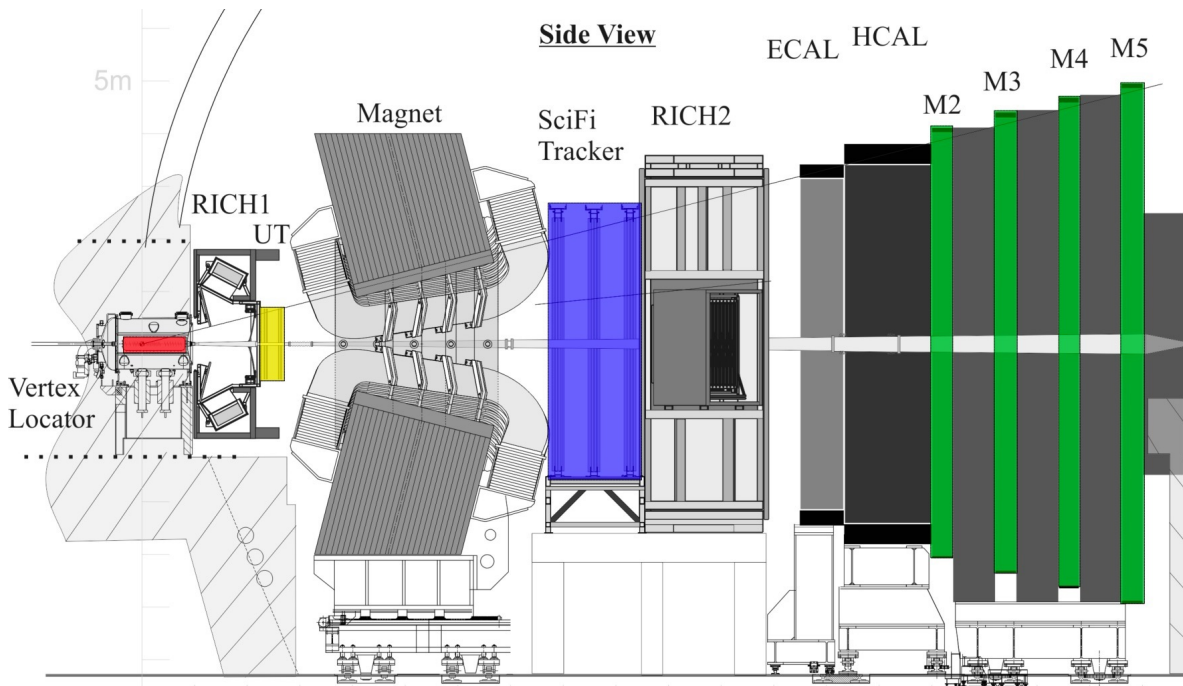
LHCb, JHEP 10 (2025) 124



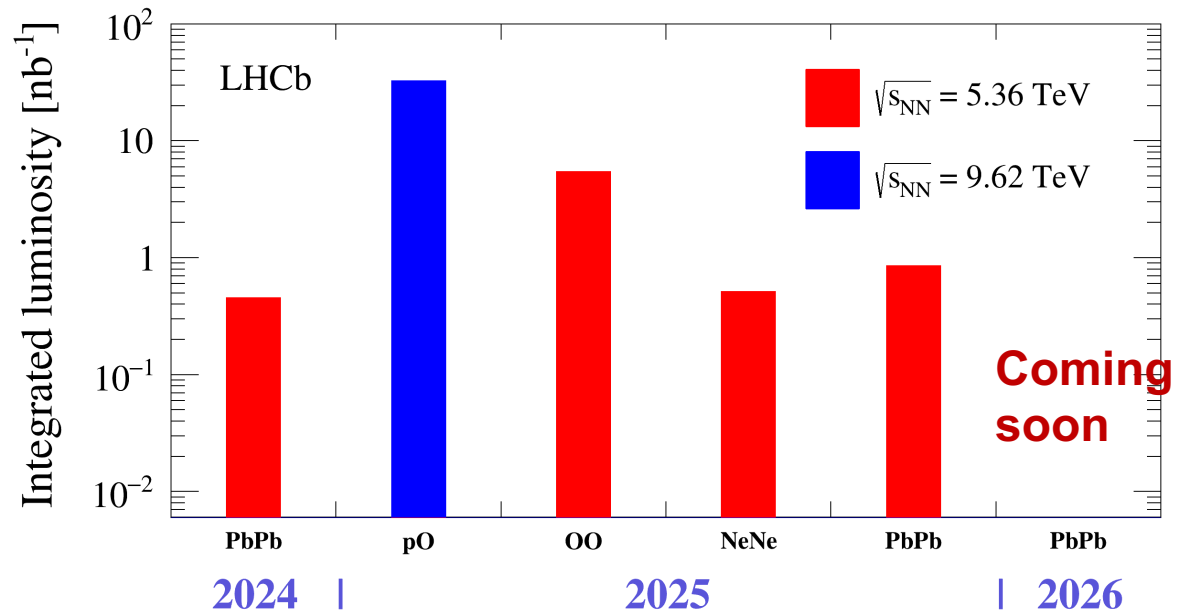
$|\Delta\eta| > 1.8$

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

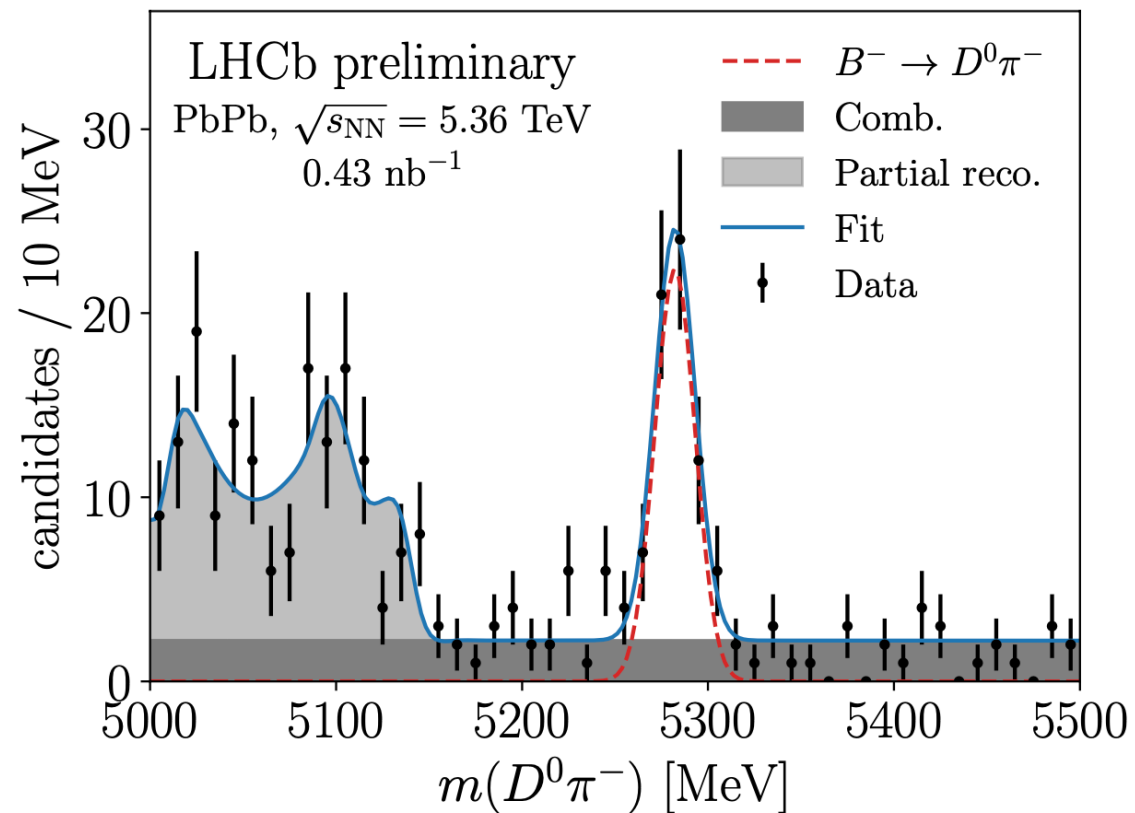
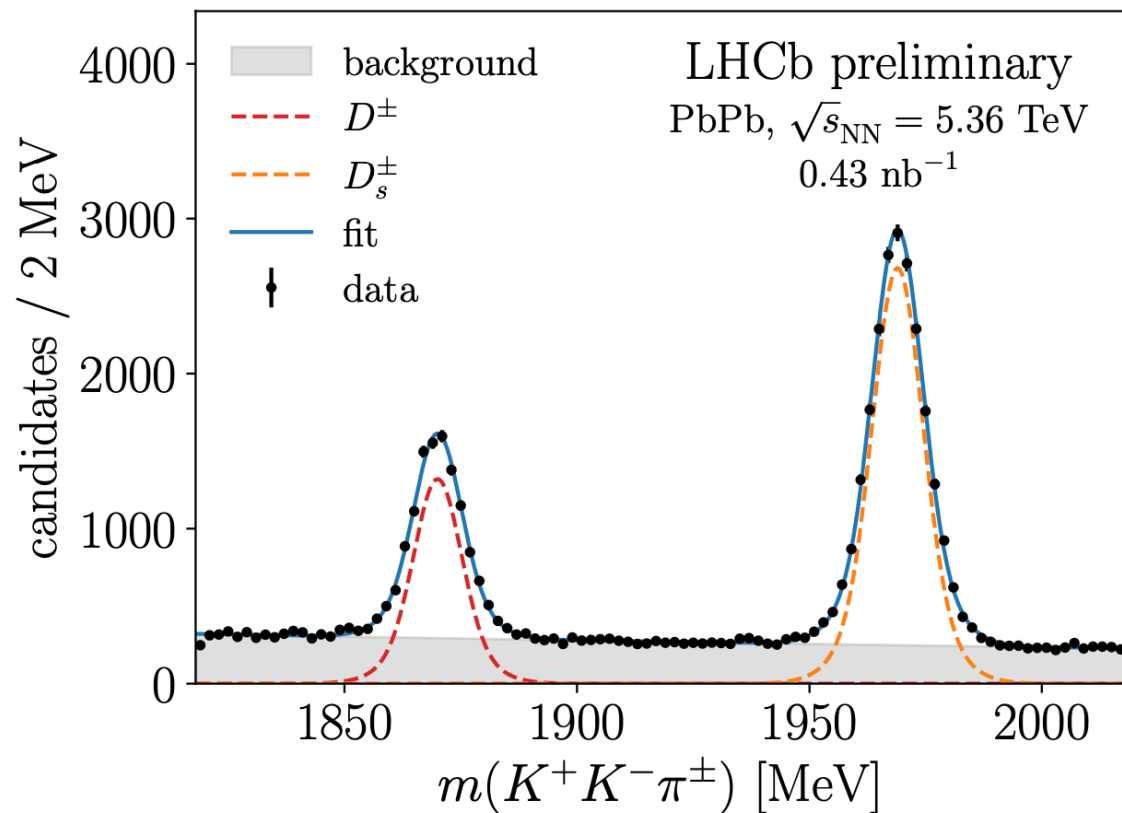


JINST 19 (2024) P05065



Early signals from the 2024 PbPb run

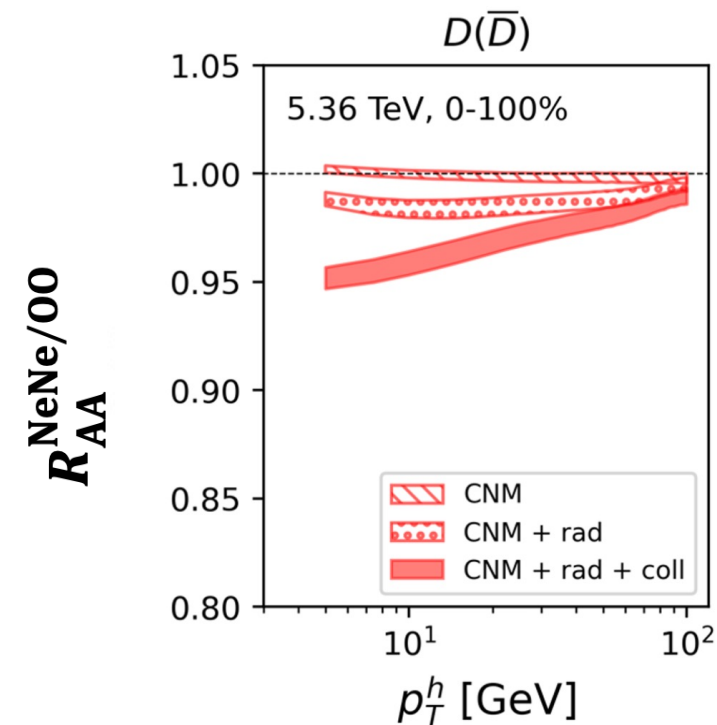
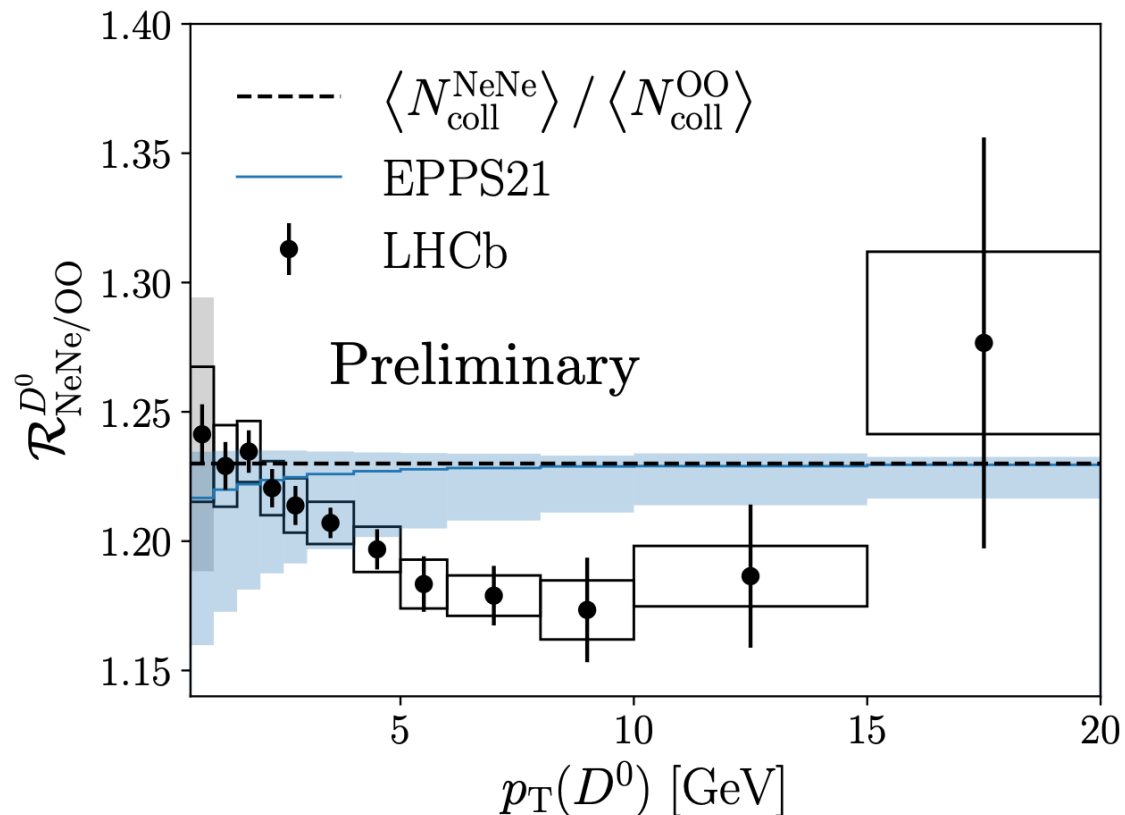
LHCb-FIGURE-2025-004



- Clean charm and fully hadronic B decays

First results from OO/NeNe collisions

$$\mathcal{R}_{\text{NeNe/OO}}^{D^0} \equiv \frac{dN_{D^0}^{\text{NeNe}}/dp_T}{dN_{D^0}^{\text{OO}}/dp_T} \frac{N_{\text{inel}}^{\text{OO}}}{N_{\text{inel}}^{\text{NeNe}}} \quad \text{LHCb-PAPER-2026-008}$$

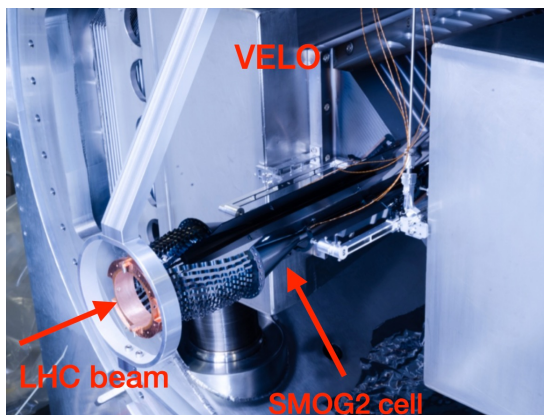


PRC 107 (2023) 06490

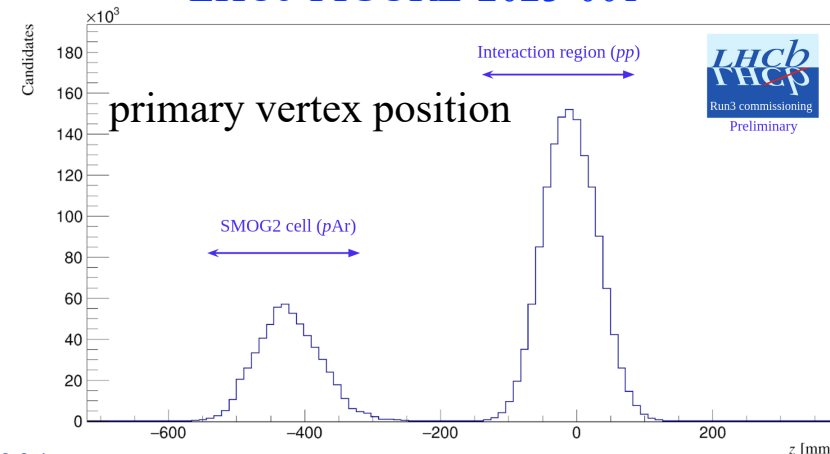
- Consistent with QGP induced energy loss in OO/NeNe collisions

Fixed target upgrade – SMOG2

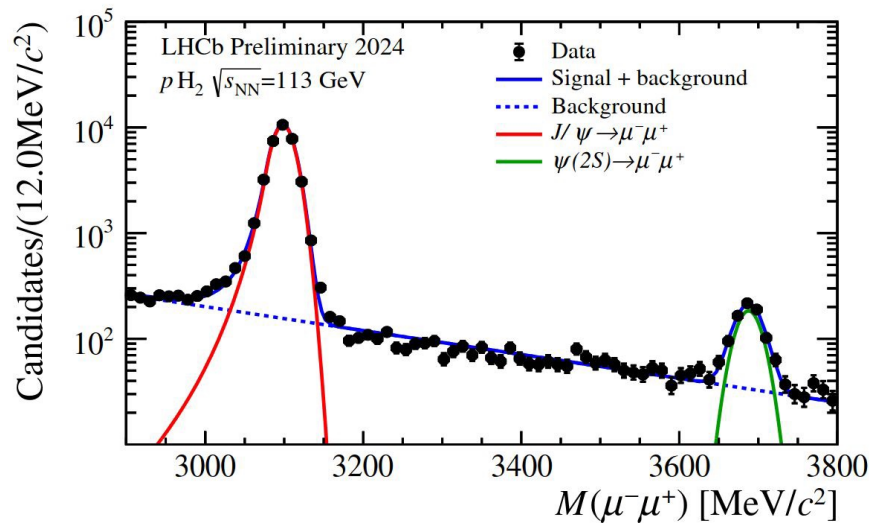
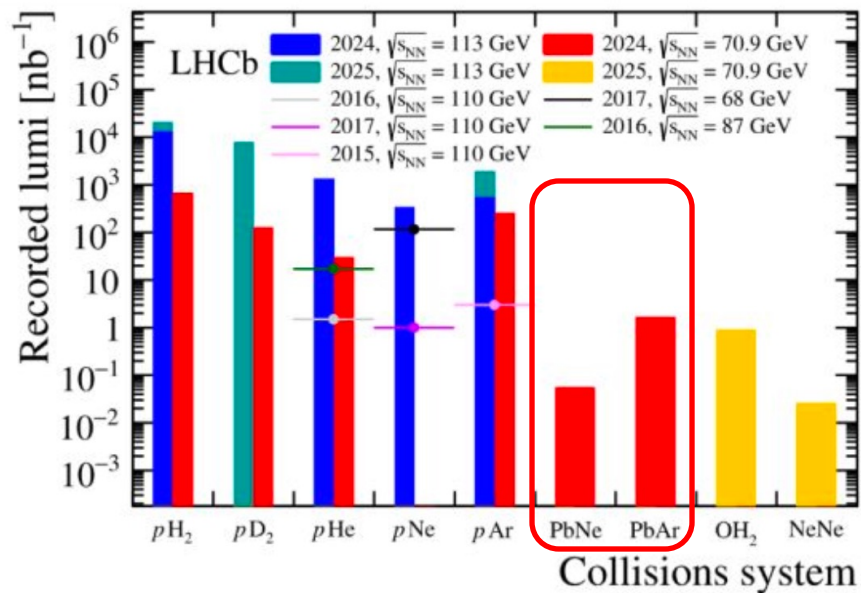
- Dedicated gas storage cell installed
- Greatly increased rates of beam+gas collisions
- Concurrent running with pp collisions
- New gases: H₂, D₂ and large nuclei (Kr, Xe)
- Energies: $\sqrt{s_{NN}} \in [68.5, 110]$ GeV



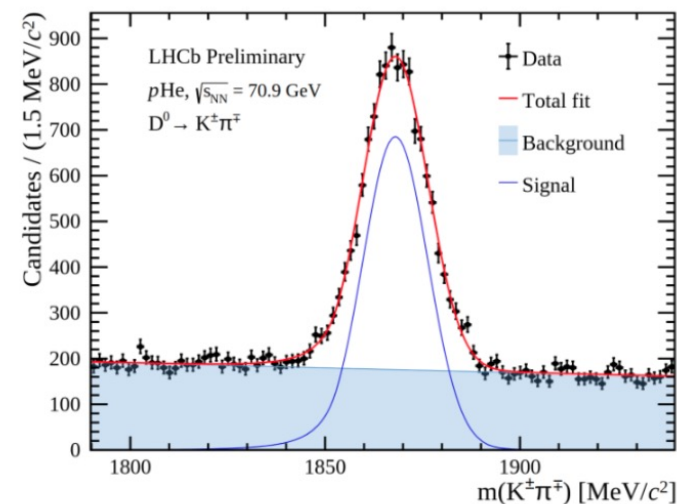
LHCb-FIGURE-2023-001



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



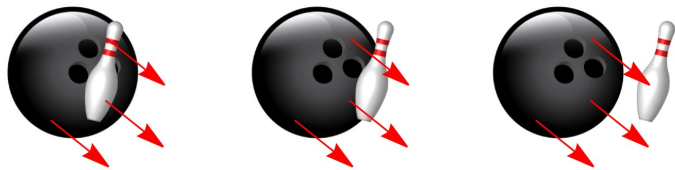
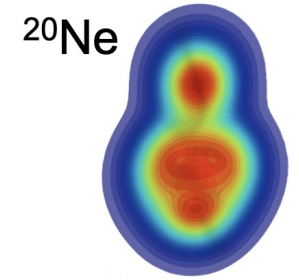
LHCb-FIGURE-2024-023



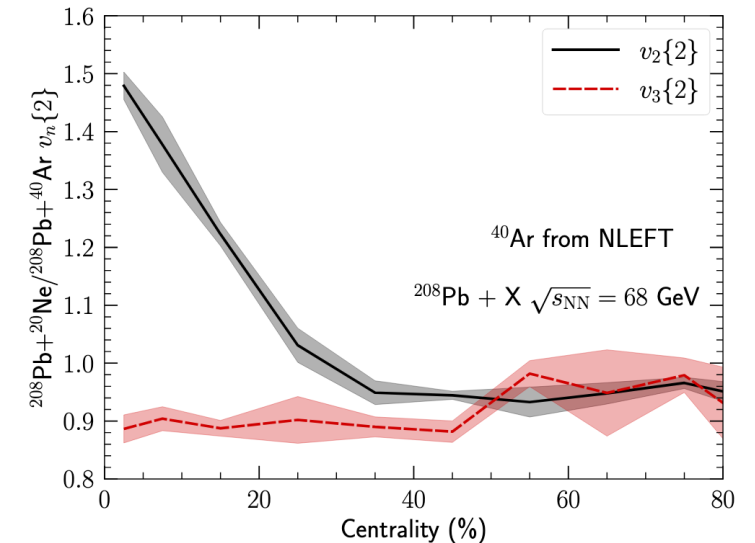
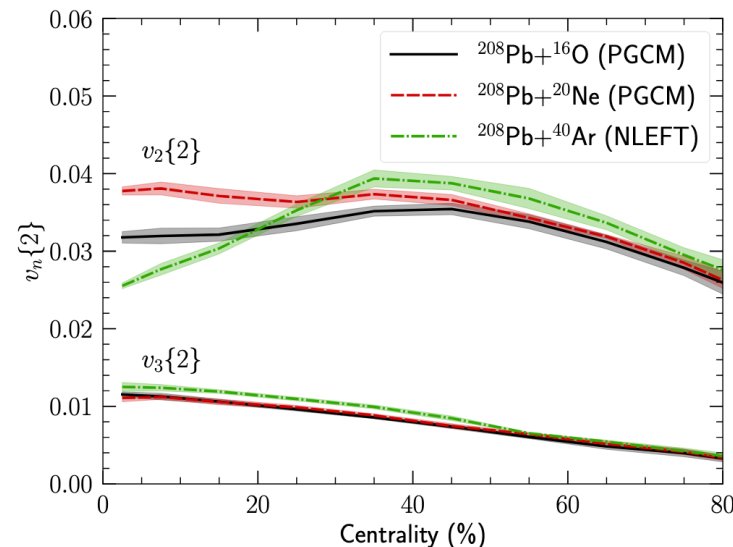
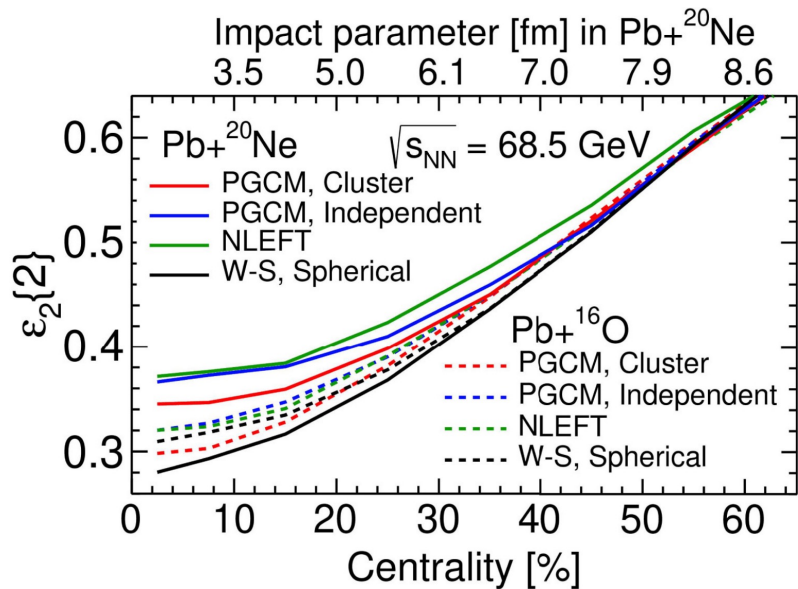
LHCb-FIGURE-2025-013

Nuclear shape imaging of light nuclei with SMOG2

- The peculiar shape of ^{20}Ne , bowling-pin-like $^{16}\text{O}+\alpha$ 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

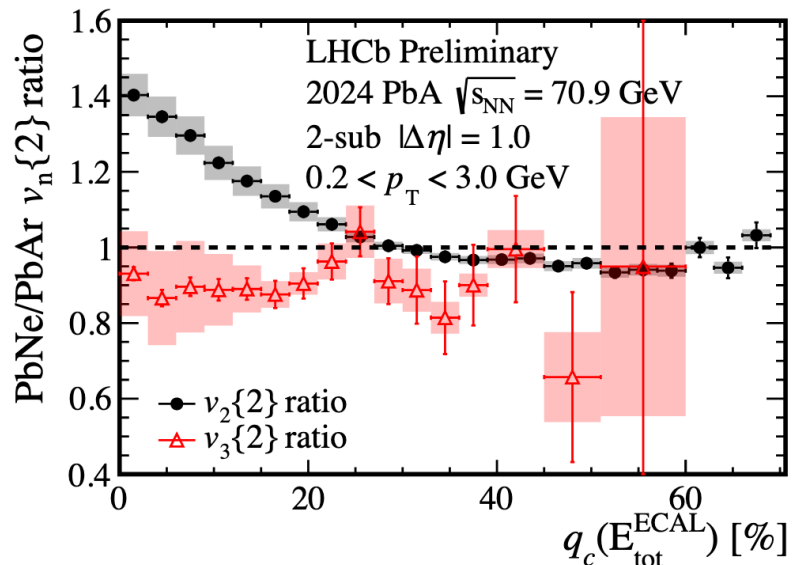
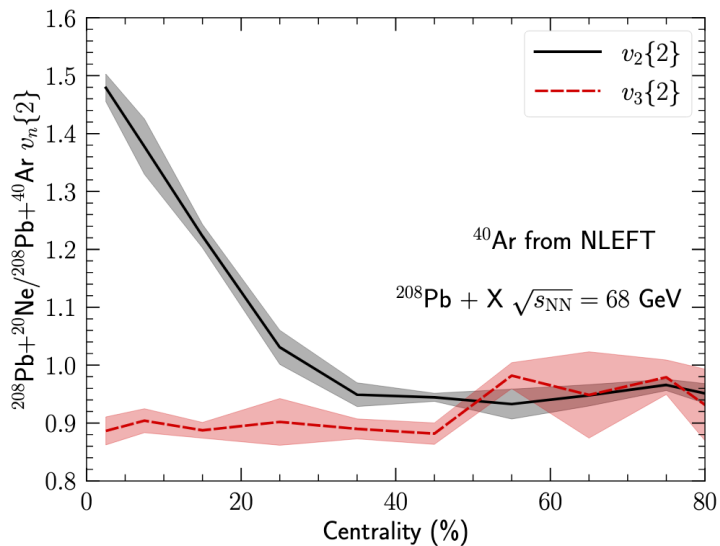
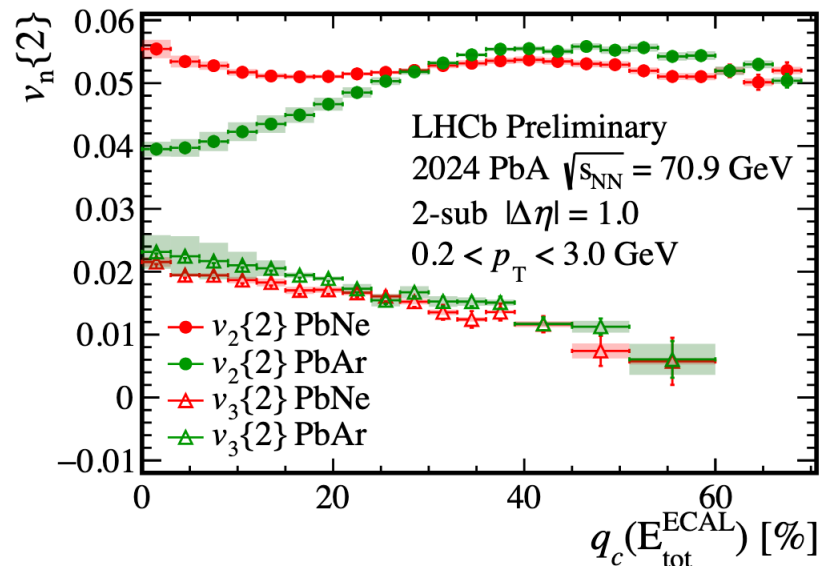
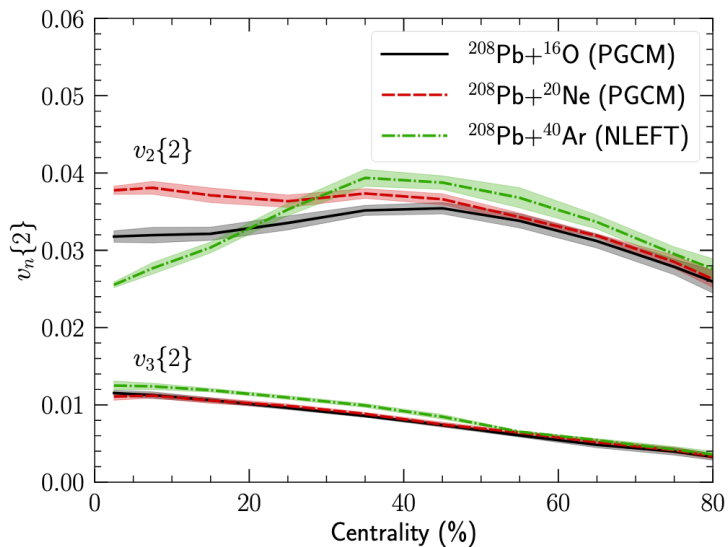


G. Giacalone, W. Zhao, et al. Phys. Rev. Lett. 134 (2025) 082301
C. Shen, QM2025



Flow coefficients in PbNe/PbAr collisions

LHCb-CONF-2025-001

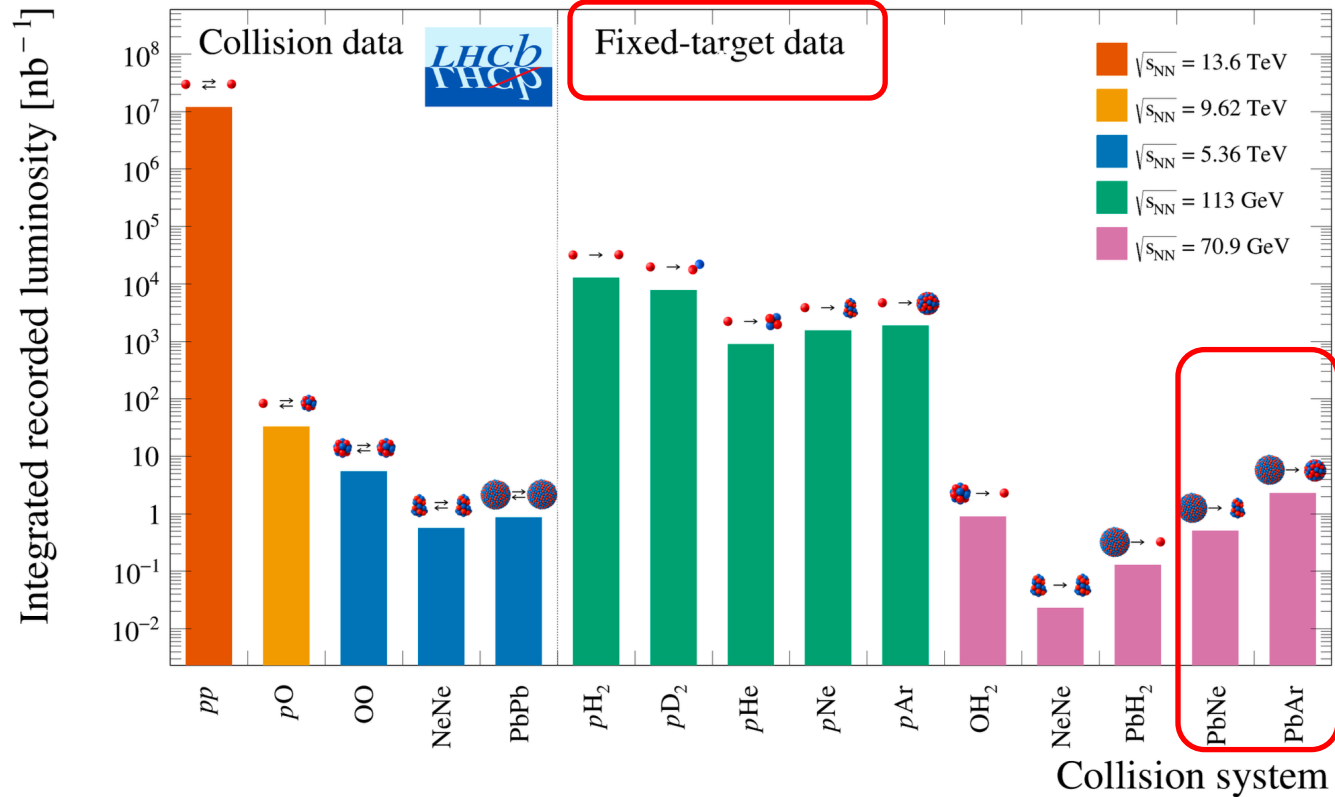


- Results as a function of a proxy for the centrality (ECAL energy percentile) show an evident flatter $v_2\{2\}$ values for PbNe than PbAr, and a similar $v_3\{2\}$
- This is clearly consistent with the predicted Ne bowling-pin shape, and confirms its major effect on the collective dynamics

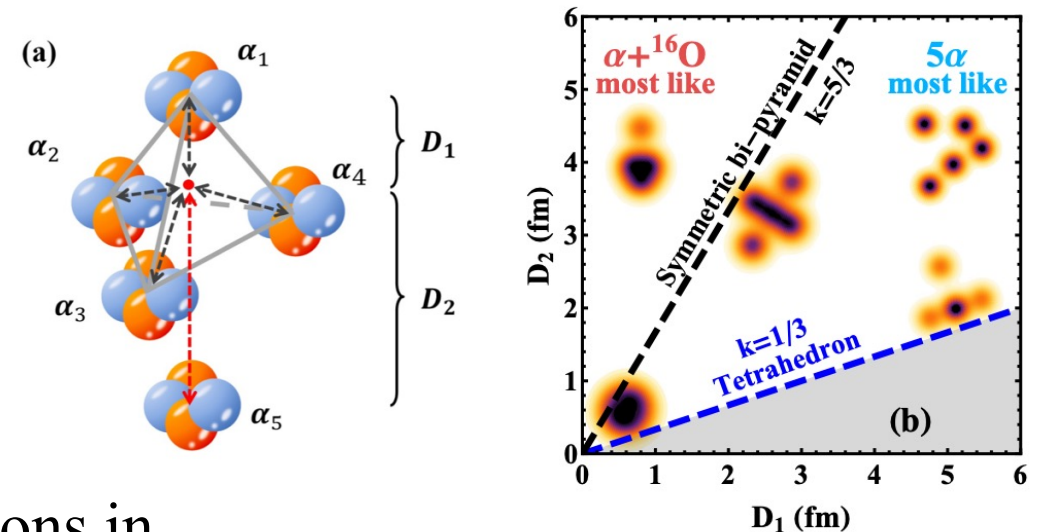
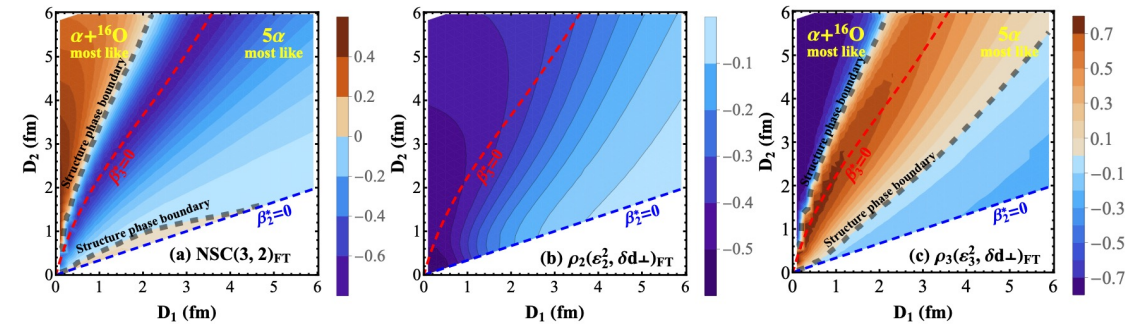
$$q_c(E_{\text{tot}}^{\text{ECAL}}) \equiv 1 - q(E_{\text{tot}}^{\text{ECAL}})$$

LHCb data-taking in 2025

Li, Zhou, Ma, PRL 136 (2026) 082302

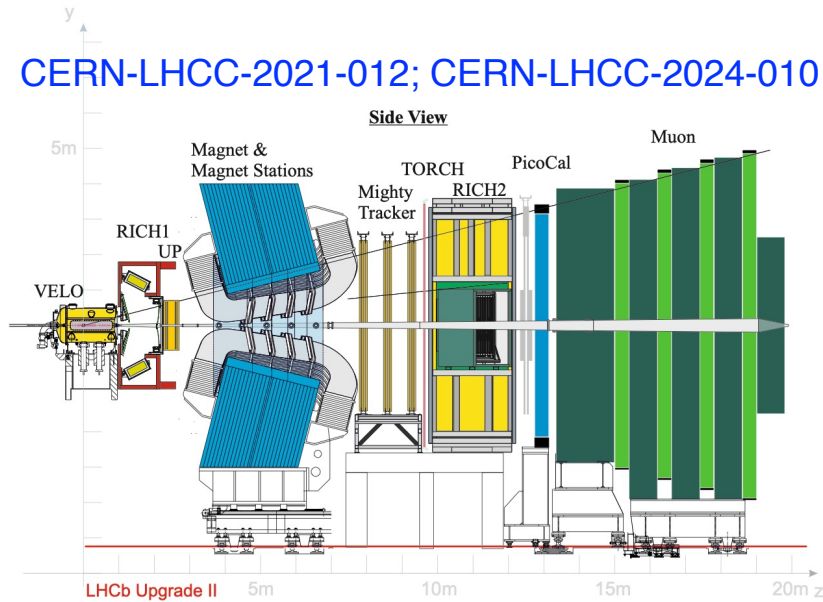


- 7 times more PbNe data taken in 2025
- Possibility of identifying alpha-cluster configurations in Ne-20 nucleus with precise flow measurements

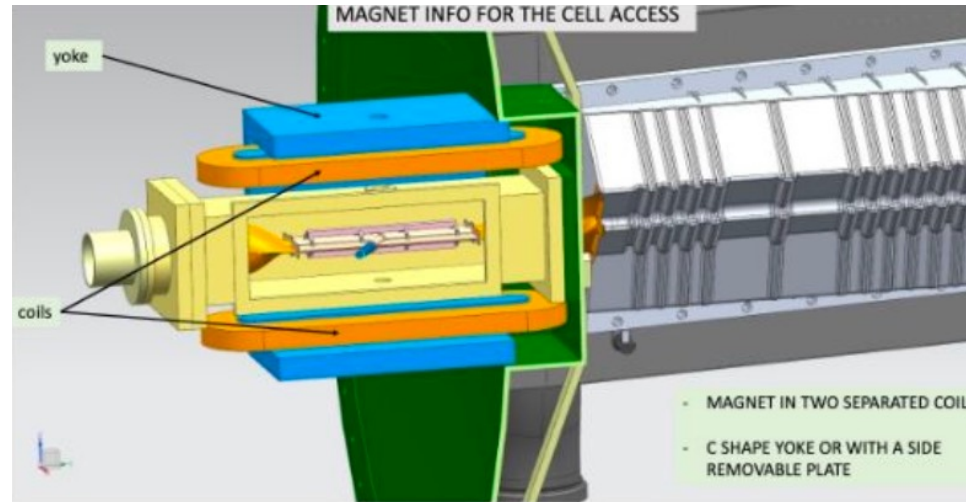
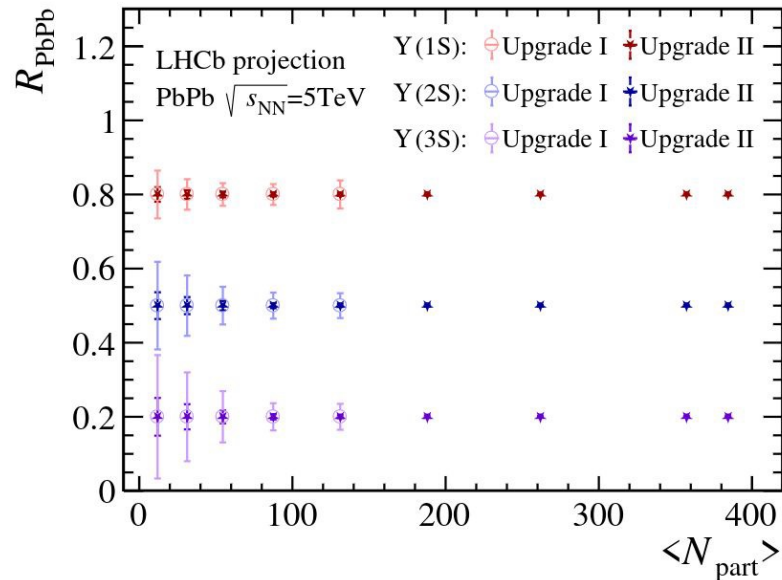


LHCb Upgrade II (Run5)

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



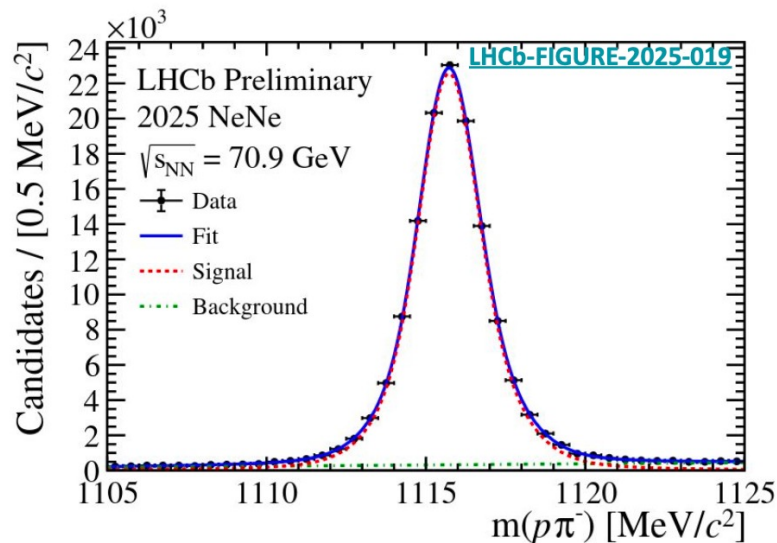
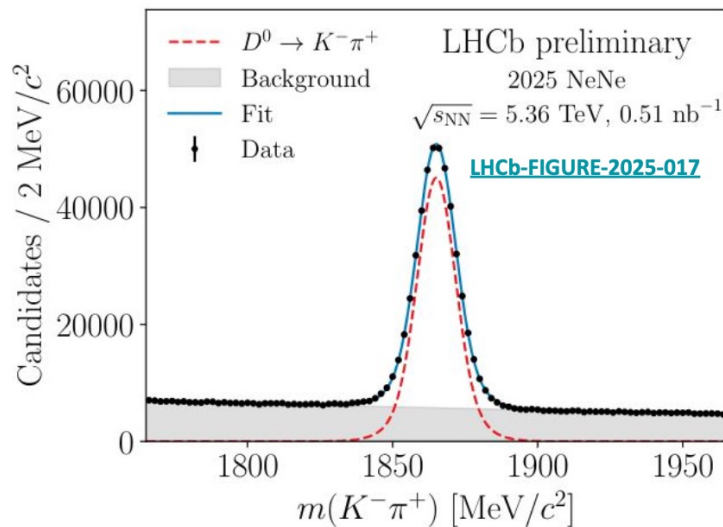
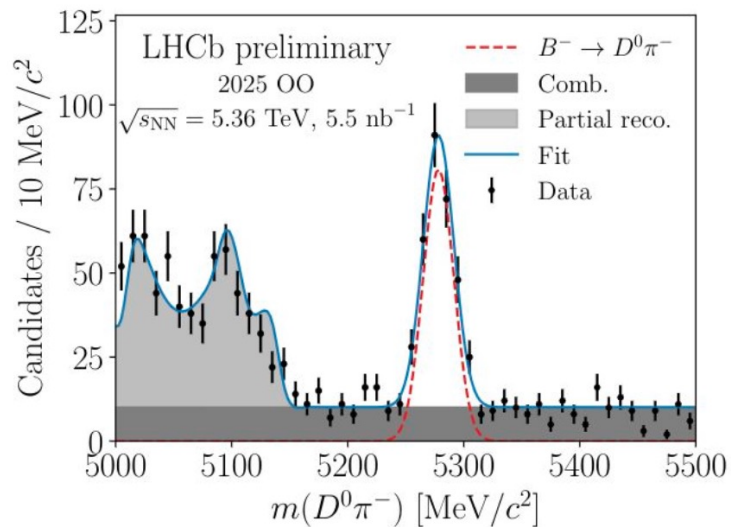
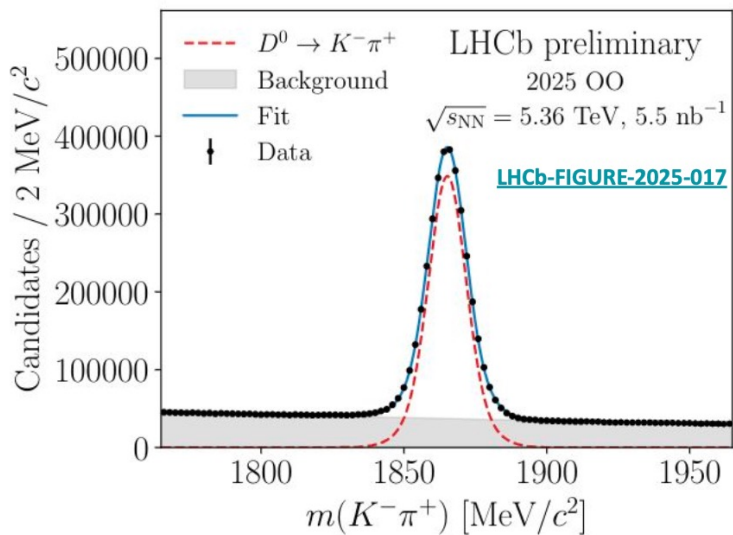
arXiv:2504.16034

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!

backup

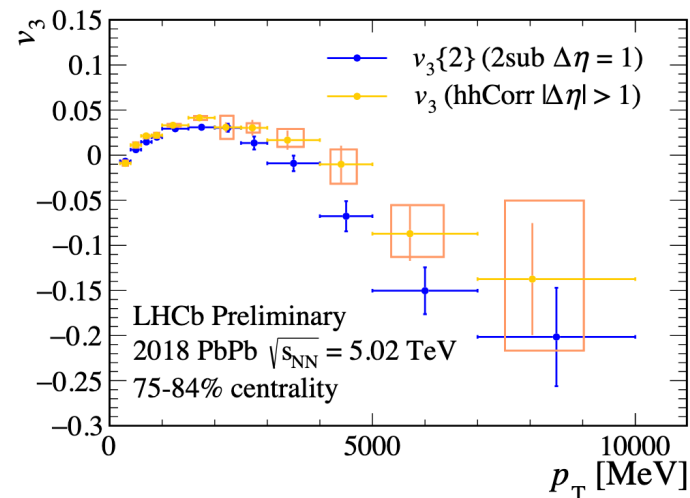
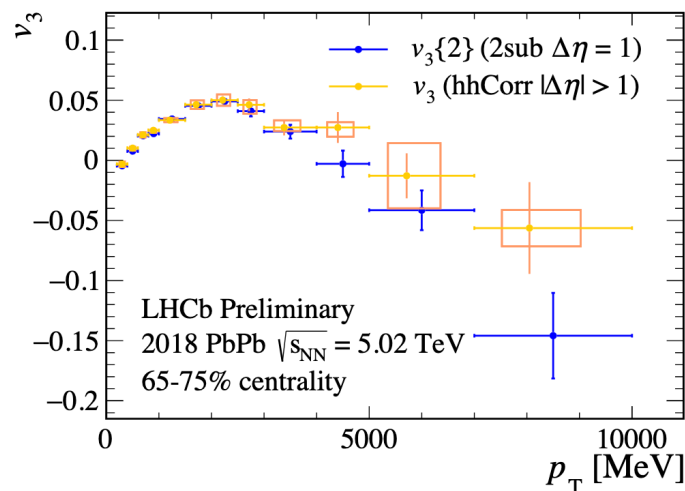
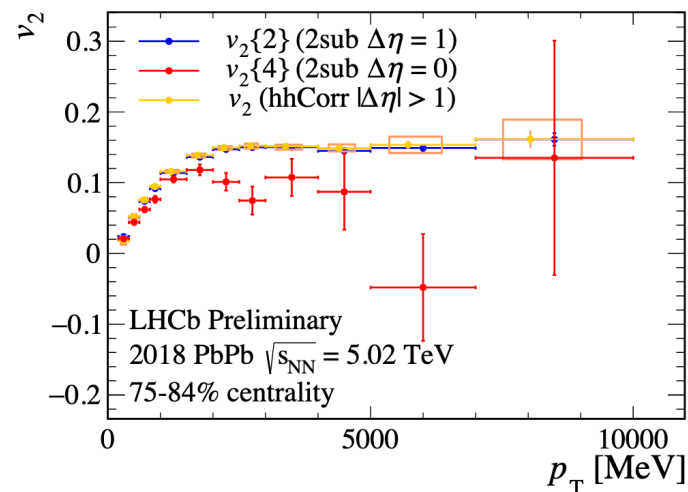
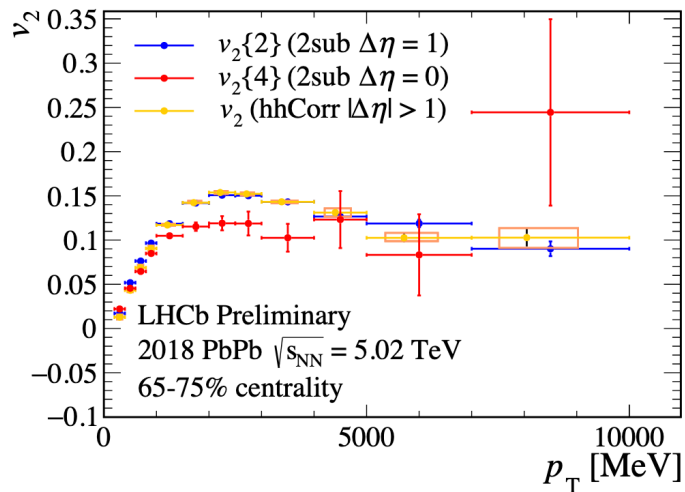
OO/NeNe data-taking in 2025



- 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 ($\sim 30 \text{ nb}^{-1}$) will allow very precise constraints to nPDF
- NeNe data acquired in both collider and fixed-target mode

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