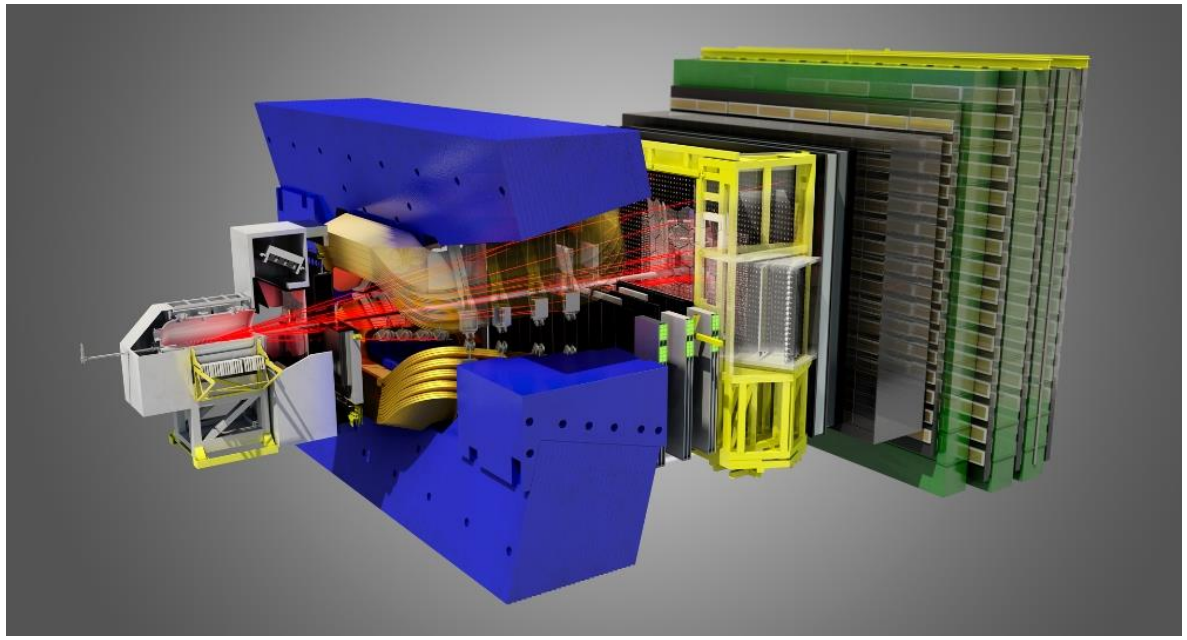


Highlights from the LHCb experiment

Emilie Maurice - Laboratoire Leprince Ringuet

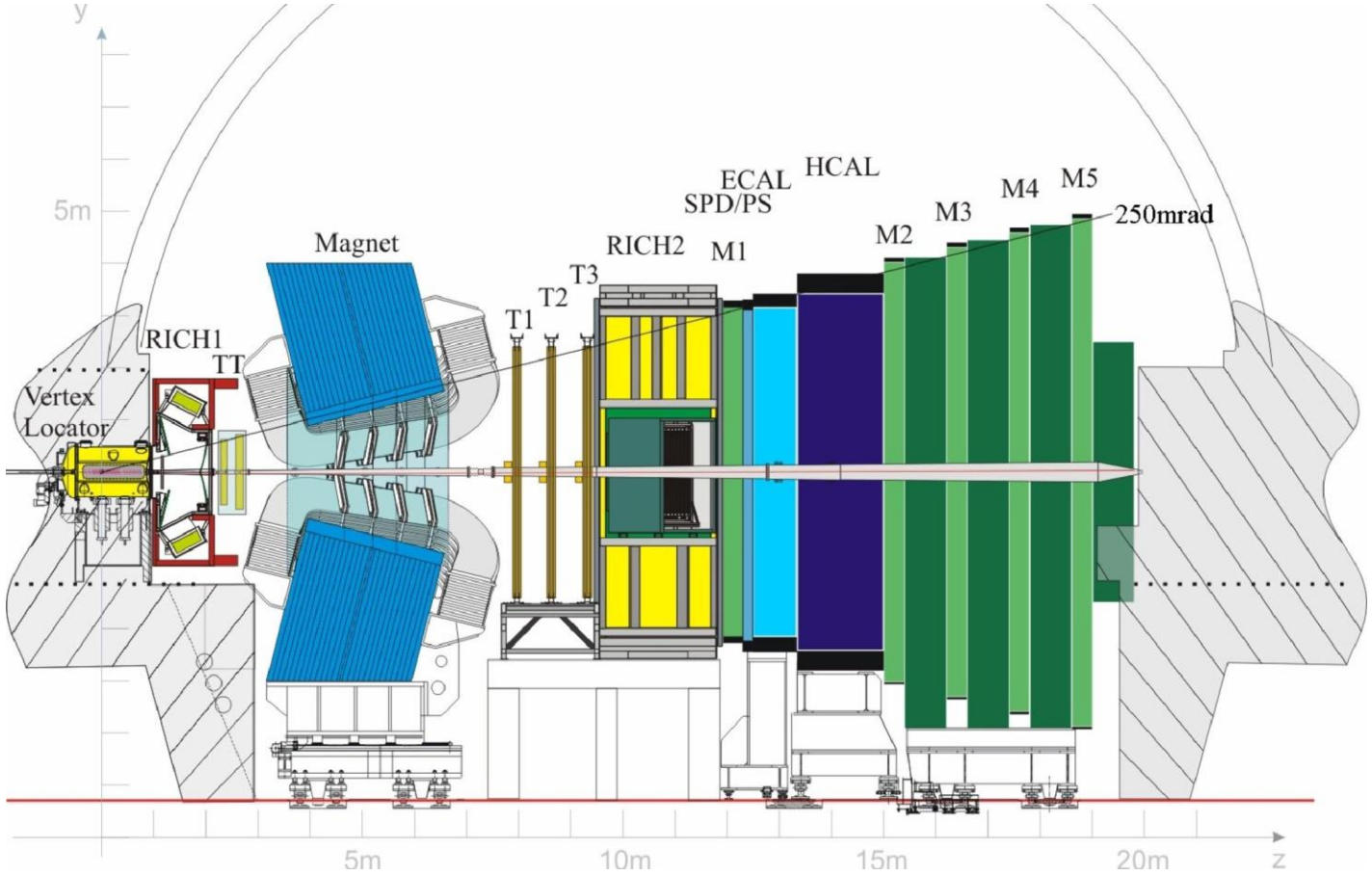
On behalf of the LHCb collaboration

QM QUARK MATTER KRAKÓW 2022

29TH INTERNATIONAL
CONFERENCE ON ULTRARELATIVISTIC
NUCLEUS - NUCLEUS COLLISIONS
APRIL 4-10, 2022
KRAKÓW, POLAND

The LHCb experiment [JINST 3 (2008) S08005]

LHCb was designed for heavy flavor physics but serves now as a general purpose detector



Fully instrumented in 2 < y < 5

Excellent performance :

[Int. J. Mod Phys. A30 (2015) 1530022]

- ✓ Vertex, IP and decay time resolution
- ✓ Momentum resolution
- ✓ Particle identification

  $\epsilon_{K\to K} \approx 95\%$, $\epsilon_{\pi\to K} \approx 5\%$

  $\epsilon_{\mu\to\mu} \approx 97\%$, $\epsilon_{\pi\to\mu} \approx 1\text{-}3\%$

- ✓ **Flexible trigger down to low-p_T**

- ✓ **Unique fixed-target configuration**

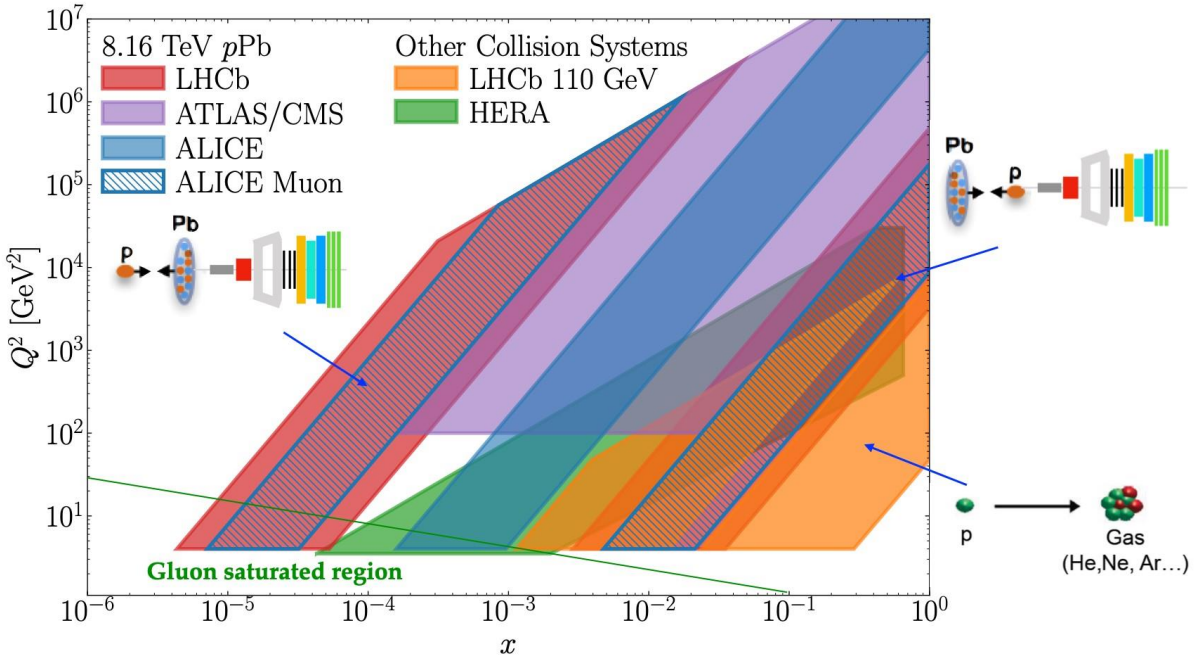
  [JINST 9 (2014) P12005]

LHCb heavy ions program

LHCb has unique capabilities to do high-precision measurements and search for exotic signatures in the forward region

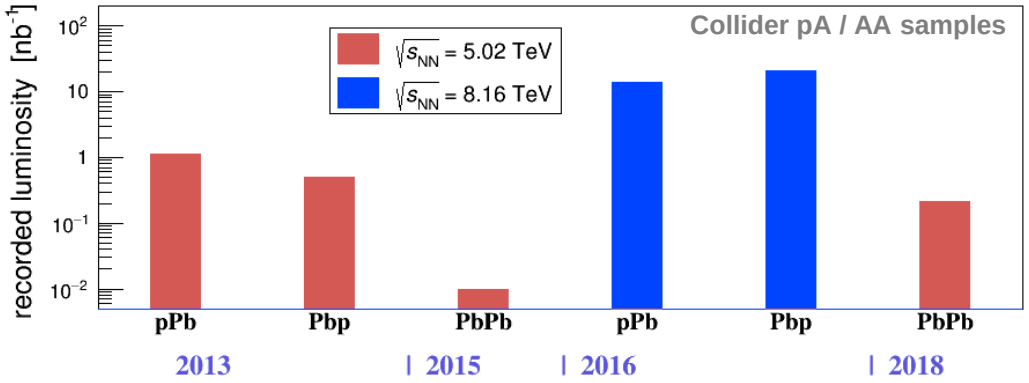
Large and complementary phase space coverage

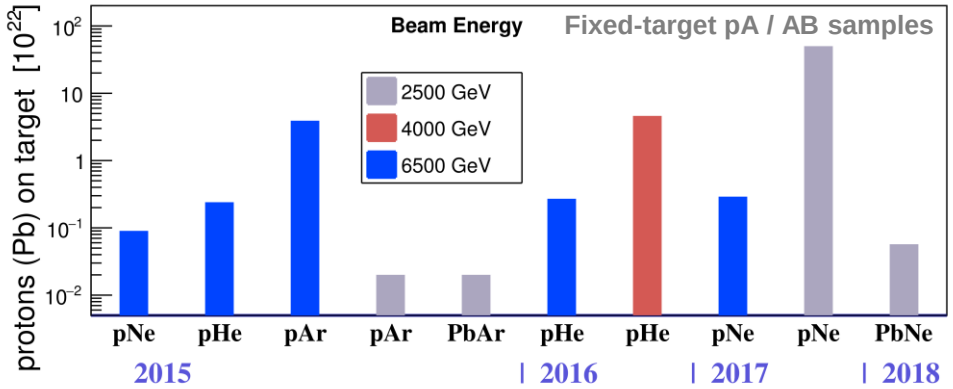
But saturation in PbPb collisions (up to 60% centrality)



In addition to pp collisions, large variety of p-nucleus and nucleus-nucleus collisions to study :

QCD precision measurements, ultra-peripheral and peripheral PbPb collisions physics, cosmics physics, and much more!





Quark Matter program

8 Talks

First performance results from upgraded LHCb and SMOG II, **Saverio Mariani**, April 6th, 11:30, T15: Future facilities and new instrumentation

Measurements of collectivity in the forward region at LHCb, **Cheuk Ping Wong**, April 7th, 9:00, T07: Correlations and fluctuations (II)

Quarkonia production in Ultraperipheral PbPb collisions at LHCb, **Samuel Belin**, April 7th, 9:40, T09: Ultra-peripheral collisions (I)

Production of exotic hadrons in high multiplicity pp and pPb collisions at LHCb, **Eliane Eppel**, April 7th, 10:00, T11: Heavy flavors, quarkonia

Studies of low-x phenomena with the LHCb detector, **Oscar Boente Garcia**, April 7th, 11:10, T09: Ultra-peripheral collisions (II)

Probing the valence quark region of nucleons with Z bosons at LHCb, **Tianqi Li**, April 7th, 16:50, T13: Electroweak probes (II)

Heavy flavour production at LHCb, **Benjamin Audurier**, April 7th, 15:00, T11: Heavy flavors, quarkonia, and strangeness production (IV)

New measurements in fixed-target collisions at LHCb, **Jiayin Sun**, April 7th, 15:20, T11: Heavy flavors, quarkonia, and strangeness production (IV)

7 Posters

Searching for the gluon saturation scale at x ~10^{-5} with the LHCb detector using direct photons, **Cesar Luiz Da Silva**, April 6th, Session 2 T07_2

Study of charmonium photoproduction in ultra-peripheral lead-lead collisions at LHCb, **Xiaolin Wang**, April 6th, Session 2 T08 / T09

Prompt open charm production in 5.02 TeV pPb collisions with LHCb, **Yiheng Luo**, April 8th, Session 3 T11_5

Prompt D^+ and D^+_s production in 8.16 TeV pPb collisions at LHCb, **Chenxi Gu**, April 8th, Session 3 T11_5

Prompt Λ^+_c production and Λ^+_c/D^0 ratio in pPb collisions at 8.16 TeV by LHCb, **Di Yang**, April 8th, Session 3 T11_5

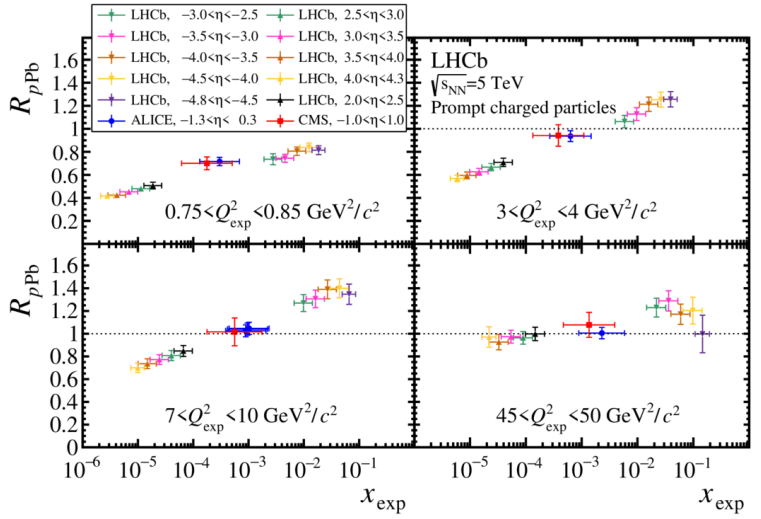
Studies on charm-strange baryon Xi_c+ in 8.16 TeV pPb collisions with LHCb, **Roman Litvinov**, April 8th, Session 3 T11_5

Fragmentation functions of identified charmed mesons, **Sara Sellam**, April 8th, Session 3 T11_5

First LHCb measurements of prompt charged particles in pPb and pp collisions

Measurements in the forward and backward regions at $\sqrt{s} = 5$ TeV [arXiv:2108.13115]

- Differential production cross-sections in p_T and η intervals
- Nuclear modification factor $R_{p\mathrm{Pb}}(\eta, p_\mathrm{T}) \equiv \frac{1}{A}\frac{\mathrm{d}^2\sigma^{\mathrm{ch}}_{p\mathrm{Pb}}(\eta, p_\mathrm{T})/\mathrm{d}p_\mathrm{T}\mathrm{d}\eta}{\mathrm{d}^2\sigma^{\mathrm{ch}}_{pp}(\eta, p_\mathrm{T})/\mathrm{d}p_\mathrm{T}\mathrm{d}\eta}$

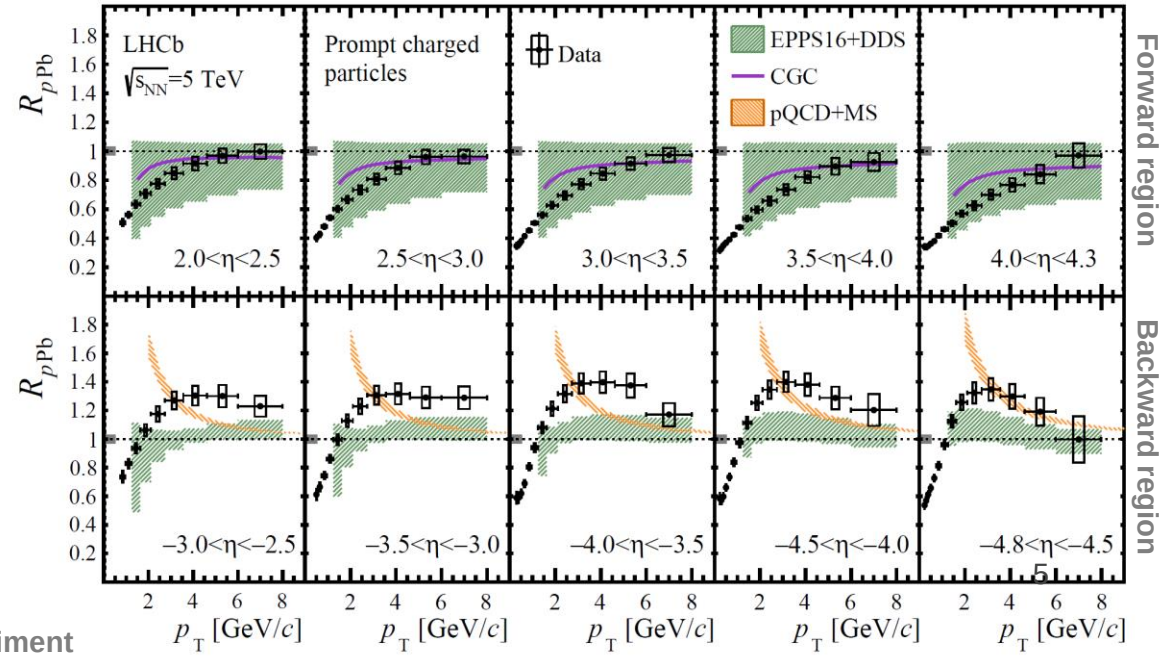


NEW

Complementary measurements in backward and forward η regions

In the forward region: a suppression is observed, especially for low p_T

In the backward region: significant enhancement for high p_T



- → Clear pseudorapidity dependence, that nPDFs alone cannot described
- → Differences with CGC calculations at the lowest p_T
- → Multiple scattering calculations fail to describe the backward region

Stringent constraints on non-perturbative QCD models

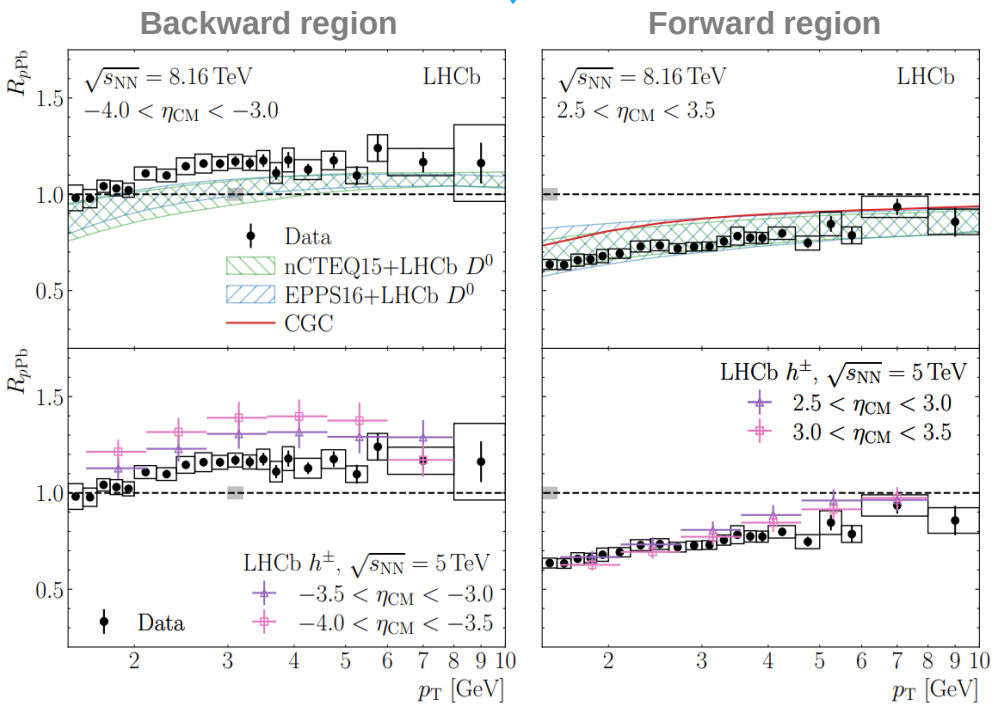
Measurement of π^0 production in pPb collisions at the LHC

First measurements in the forward and backward regions at $\sqrt{s} = 8.16$ TeV [LHCb-PAPER-2021-053]
in preparation

NEW

- Differential production cross-sections in p_T and η intervals
- Nuclear modification factor $R^{\pi^0}_{p\mathrm{Pb}} = \frac{1}{208} \frac{\mathrm{d}\sigma^{\pi^0}_{p\mathrm{Pb}}/\mathrm{d}p_\mathrm{T}}{\mathrm{d}\sigma^{\pi^0}_{pp}/\mathrm{d}p_\mathrm{T}}$

  using pp interpolation between 5 and 13 TeV results



Forward region

→ Suppression consistent with nPDF predictions, but larger than CGC calculations

→ Consistent with charged-particle $R_{p\mathrm{Pb}}$ at 5.02 TeV

Backward region

→ Enhancement larger than nPDF predictions, but smaller than charged particle $R_{p\mathrm{Pb}}$ (baryon enhancement ?)

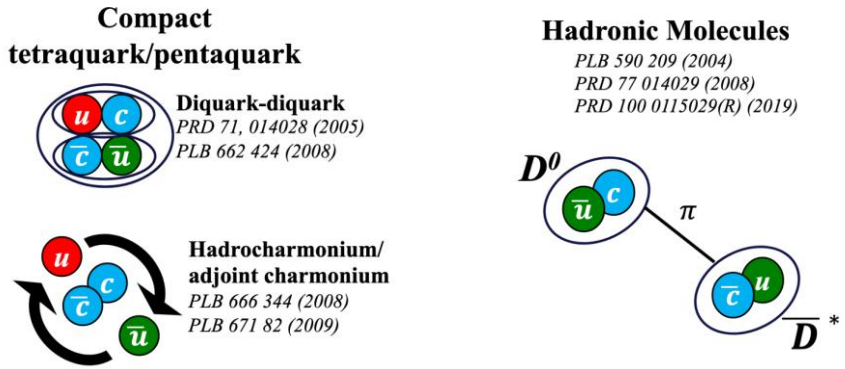
Precise and independent measurements (π^0 and charged particles) constraining nPDFs and saturation models in low-x region

Production of exotic hadrons in pp and pPb collisions

LHCb has demonstrated excellent capabilities to discover new particles, such as T^{+}_{cc} tetraquark **[arXiv:2109.01056]**

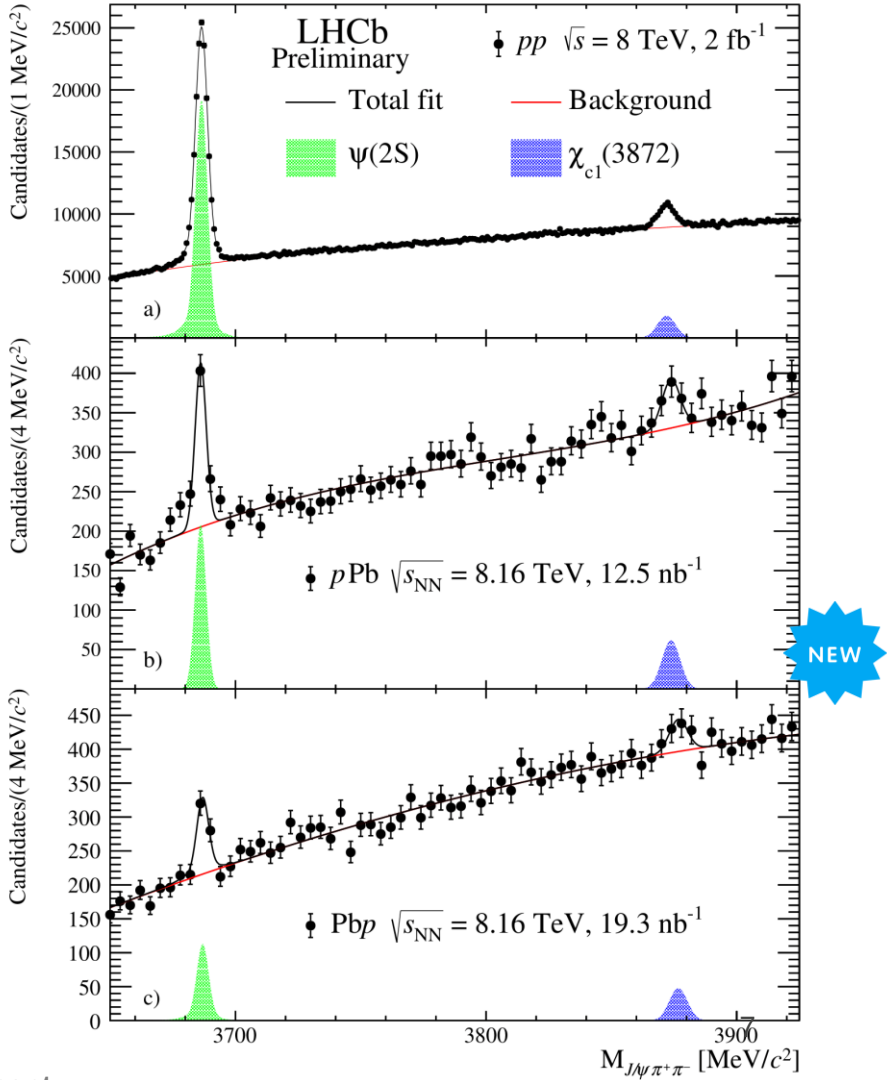
Investigation of $\chi_{c1}(3872)$ state

- Nature : tetraquark, molecule ?
- Probe of QCD medium ?



Measurement of relative $\chi_{c1}(3872)$ production with $\psi(2S)$, via their decays into J/ψ π^+ π^-

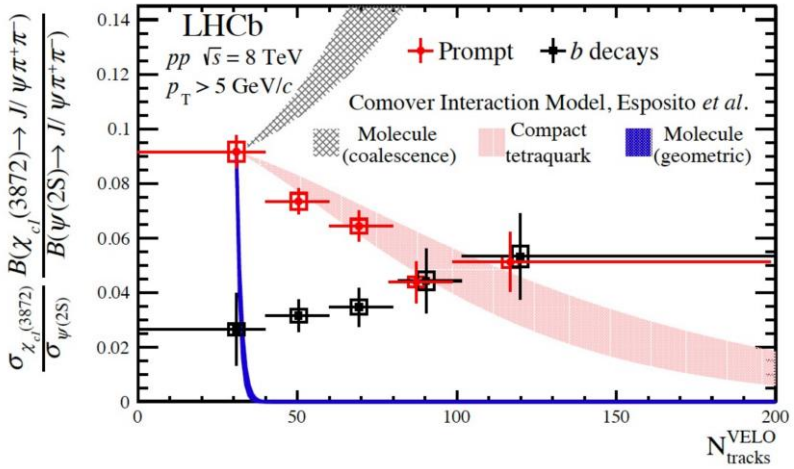
- In pp collisions at 8 TeV, with 2 fb^{-1} **[Phys. Rev. Lett. 126 (2021) 092001]**
- In pPb collisions, at 8.16 TeV, with 12.5 nb^{-1} **[LHCb-CONF-2022-001]**



Production of $\chi_{c1}(3872)$ / $\psi(2S)$ in pp and pPb collisions

First measurement of $\chi_{c1}(3872)$ / $\psi(2S)$ ratio in pp collisions versus multiplicity

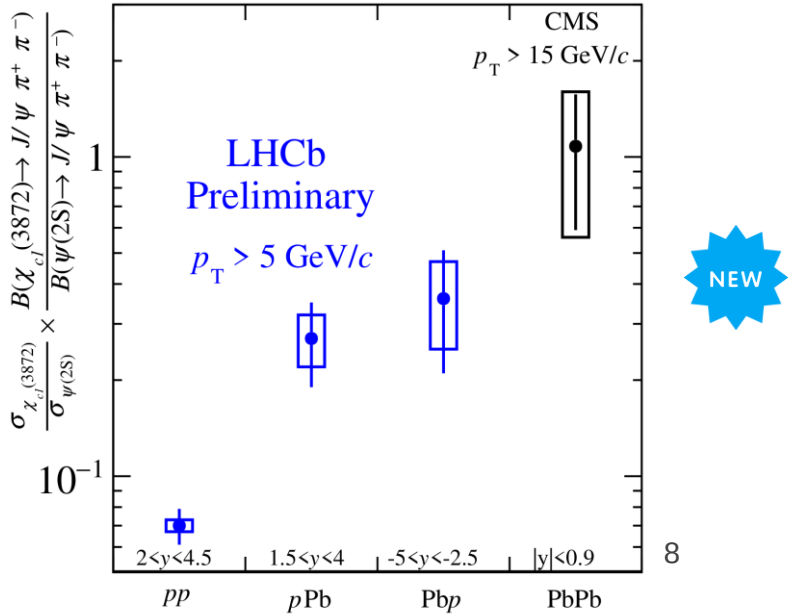
[Phys. Rev. Lett. 126 (2021) 092001]



- → Prompt ratio is suppressed with multiplicity in pp collisions
- → Consistent with a compact tetraquark modelisation
- → Dominated by comover breakup (PRD 103 (2021) 7, EPJC 81 (2021) 669)

First measurement of a tetraquark production, $\chi_{c1}(3872)$, in pPb collisions : increase medium temperature and also the multiplicity

[LHCb-CONF-2022-001]



- → $\chi_{c1}(3872)$ seems to behave quite differently than $\psi(2S)$
- → Current uncertainties preclude drawing firm conclusions
- → $\psi(2S)$ is suppressed in pPb and Pbp
- → $\chi_{c1}(3872)$ production may also be enhanced

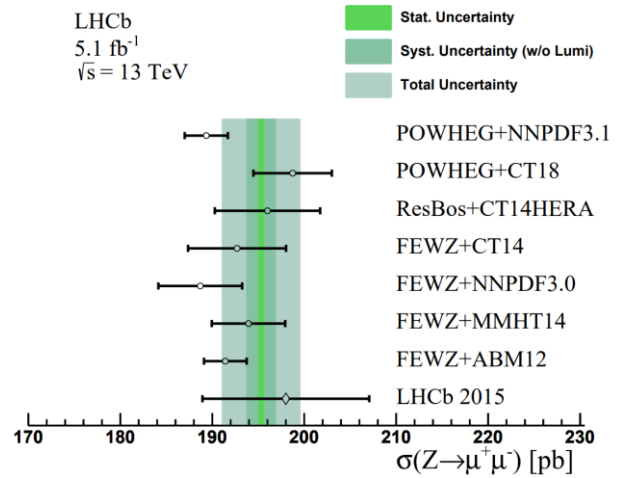
$\chi_{c1}(3872)$: a new QCD probe

Probing QCD with Z^0 bosons in pp collisions

NEW

Measurement of Z^0 boson production cross-section is particularly sensitive to parton distribution functions (PDFs):

- **First measurements of the angular coefficients of Drell-Yan** $\mu^+\mu^-$ pairs in the forward rapidity region **[arXiv:2203.01602]**
- Differential and total cross-section measurement at 13 TeV **[arXiv:2112.07458]**

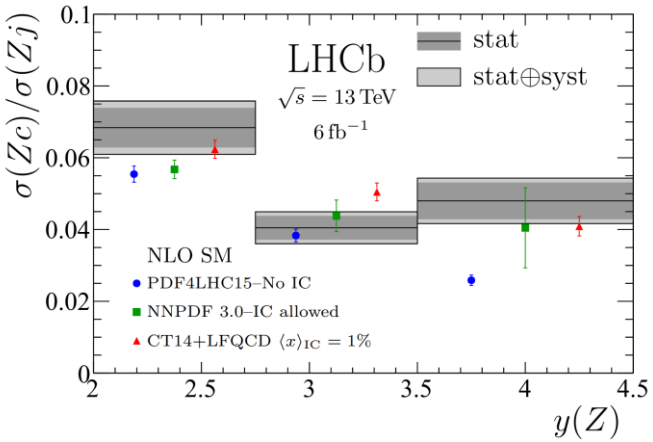


→ The most precise measurement to date of the Z^0 boson production cross-section in the forward region

→ **Test NNLO perturbative QCD with similar precision**

- **First measurement of the fraction of Z^0-boson + jet events containing a charm jet** **[arXiv:2109.08084]**

  Ratio in intervals of Z^0 rapidity and compared to NLO calculations in pp collisions at 13 TeV



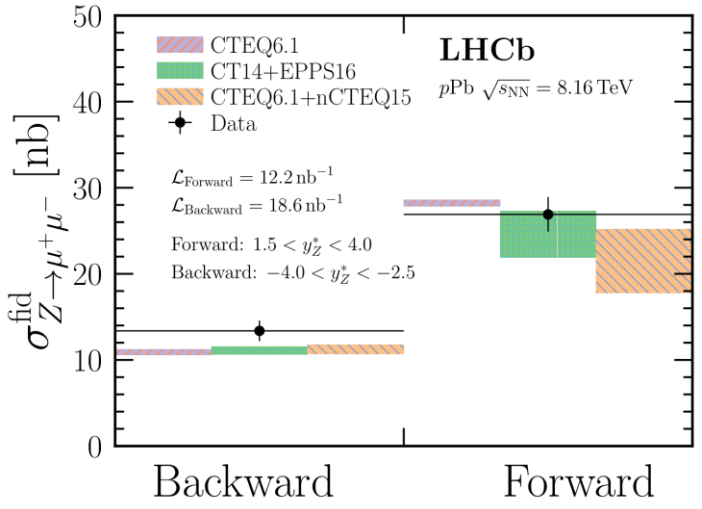
→ **Sizable enhancement at forward Z^0 rapidities**, consistent with a proton wave function containing $|uudc\bar{c}\rangle$ component (Intrinsic charm) predicted by LFQCD

Probing QCD with Z^0 bosons in pPb collisions

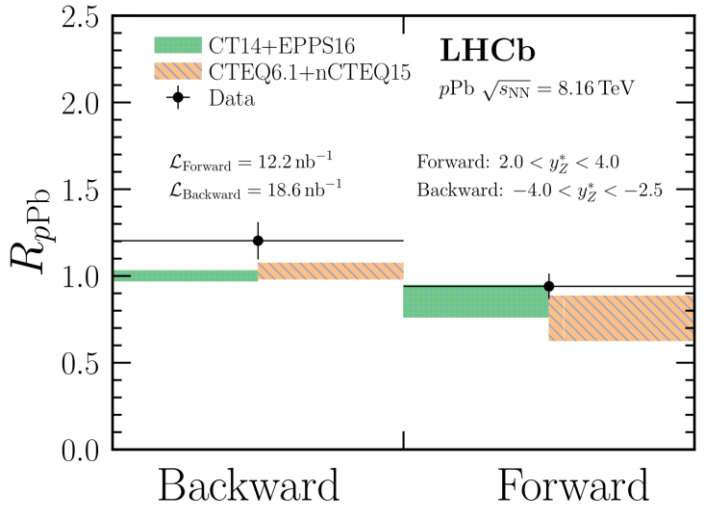
Measurement of Z^0 boson production in pPb collisions **[LHCb-PAPER-2022-009]**

- Z^0 production fiducial cross-section
- Forward-backward ratio
- Nuclear Modification factor

All are measured inclusively and differentially



NEW



Results are globally compatible with

→ Theoretical predictions from EPPS16 and nCTEQ16 nPDFs

→ Previous results at 5.02 TeV from various experiments

Z^0 measurements show strong constraining power for modeling the nPDFs

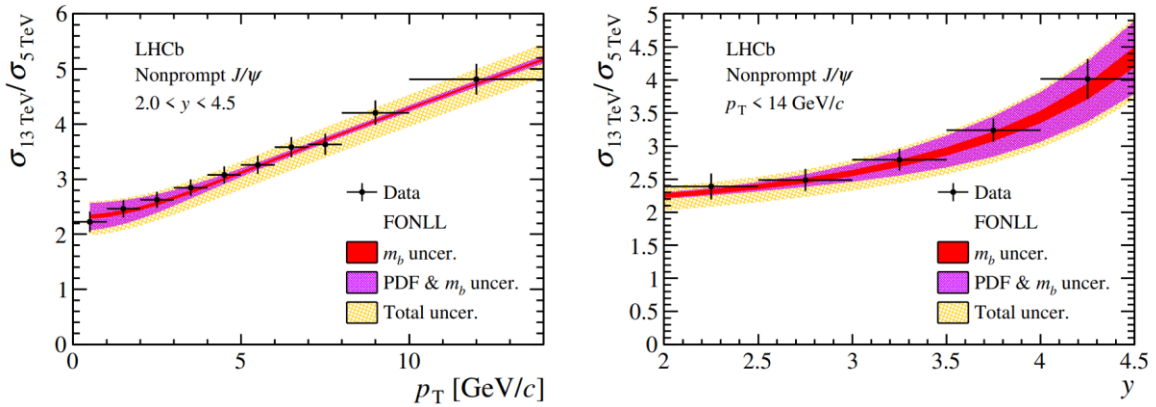
J/ψ production measurements in pp collisions at 5 TeV

NEW

[JHEP 11 (2021) 181]

Measurements with an integrated luminosity of 9.18 fb^{-1}

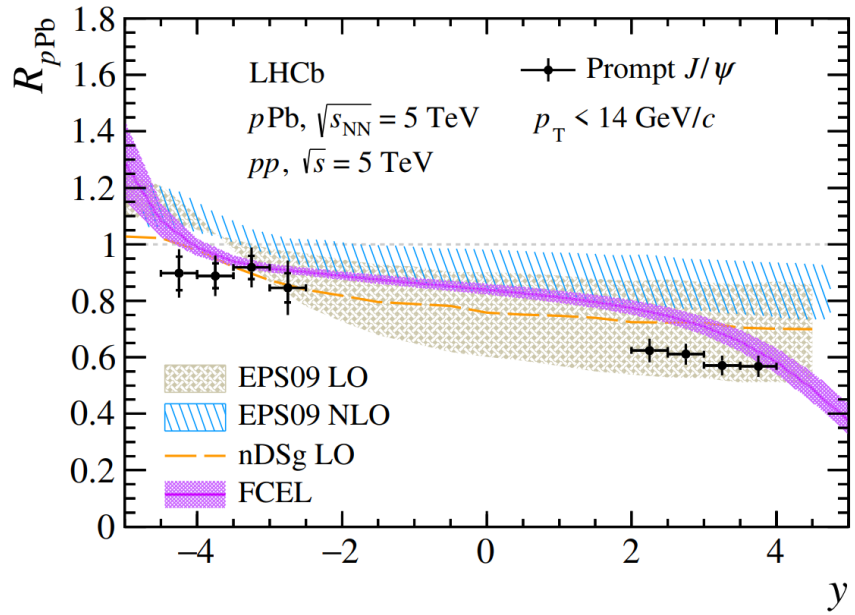
- J/ψ differential cross-sections, as functions of p_T and y
- Separately for prompt and non-prompt J/ψ
- Ratios between J/ψ production cross-section between
  - 8 TeV and 5 TeV
  - 13 TeV and 5 TeV



Prompt J/ψ measurements show :

→ **A good agreement with NLO NRQCD calculations in the high-p_T region**

→ **A small tension in the low-pT region for NRQCD and CGC calculations**



FONLL calculations describe well the non-prompt J/ψ measurements

The J/ψ nuclear modification factor R_{pPb} at 5 TeV is also updated

D^0 production in pPb collisions at 8.16 TeV

NEW

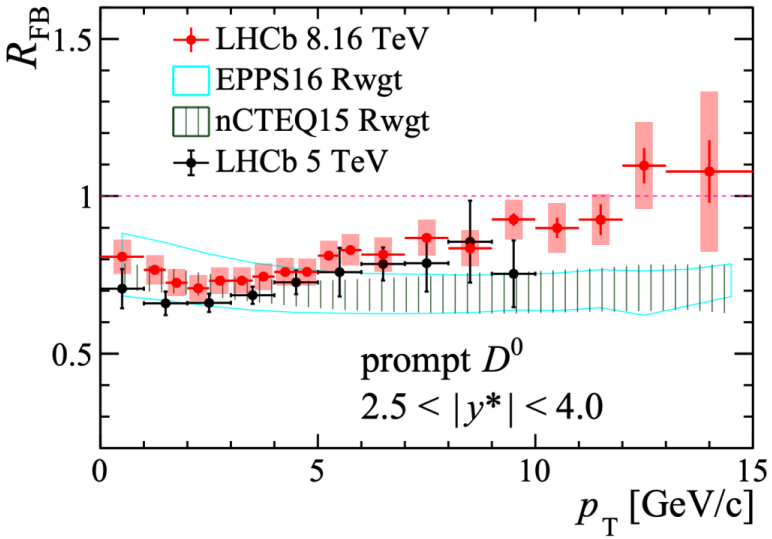
Most precise measurement of the prompt D^0 production in pPb collisions from the LHC to date

[LHCb-PAPER-2022-007]
in preparation

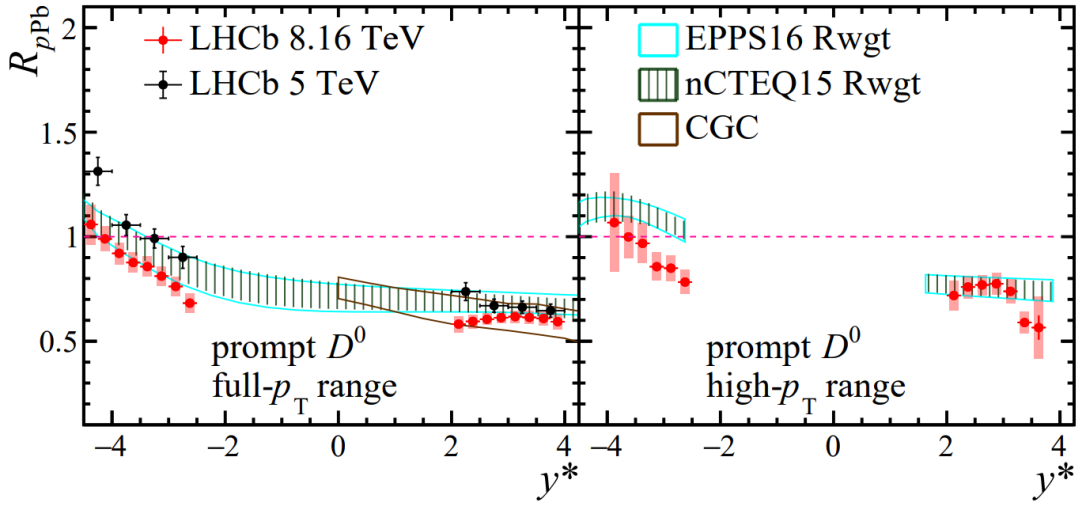
The nuclear modification factors and forward-backward production ratios

→ Large asymmetry between forward and backward production

→ **Higher R_{FB} than the predictions of nPDFs calculations for the high p_T region**



→ **A suppression of high p_T D^0 production in the backward rapidity is observed**



The measurement of R_{pPb} provides a stringent test of nPDF down to small x regions

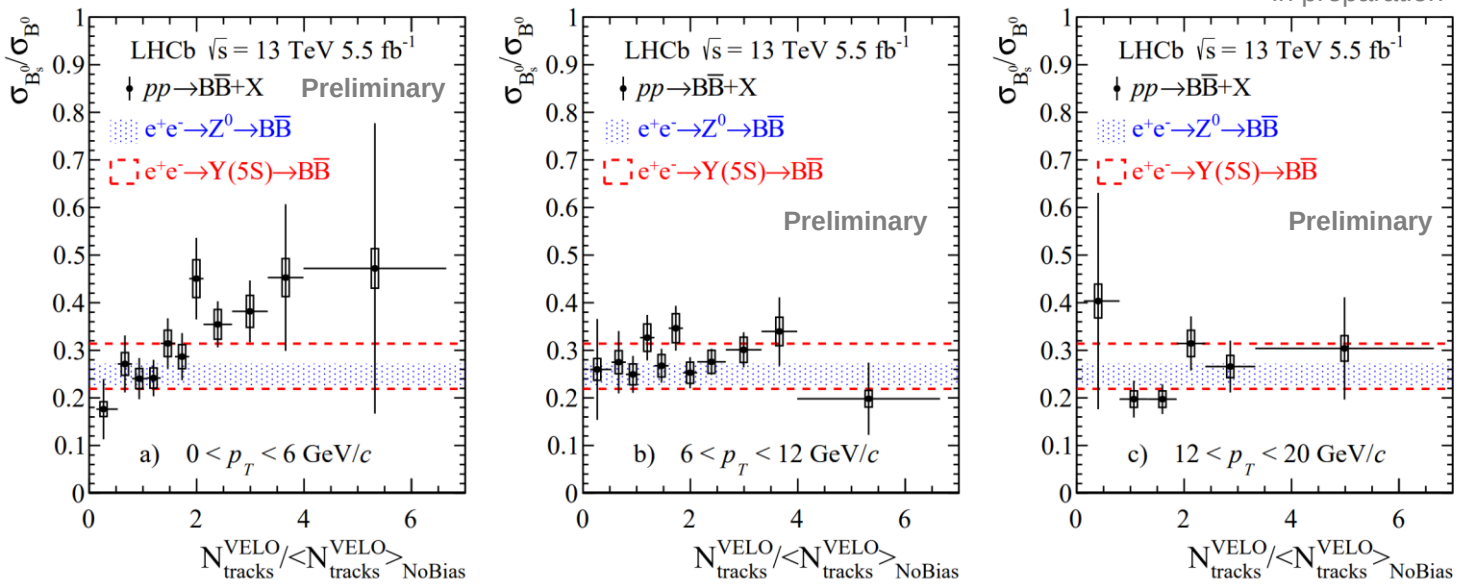
Modification of b hadronization in high multiplicity pp collisions

Bridges the gap between production in vacuum and dense hadronic environment by studying B^0_s /B^0 production versus multiplicity

Test strangeness production enhancement with multiplicity and possible b-hadronization via quark coalescence especially at low p_T where the bulk of particles is produced

$$\frac{\sigma(B_s^0)}{\sigma(B^0)} \quad B^0_{(s)} \to (J/\psi \to \mu^+\mu^-)\pi^+\pi^- \quad pp : \sqrt{s} = 13\,\text{TeV}\,(5.5\,\text{fb}^{-1})$$

[LHCb-PAPER-2022-001]
in preparation



NEW

→ **B^0_s/B^0 production at low-multiplicity consistent with previous e^+e^- measurements**

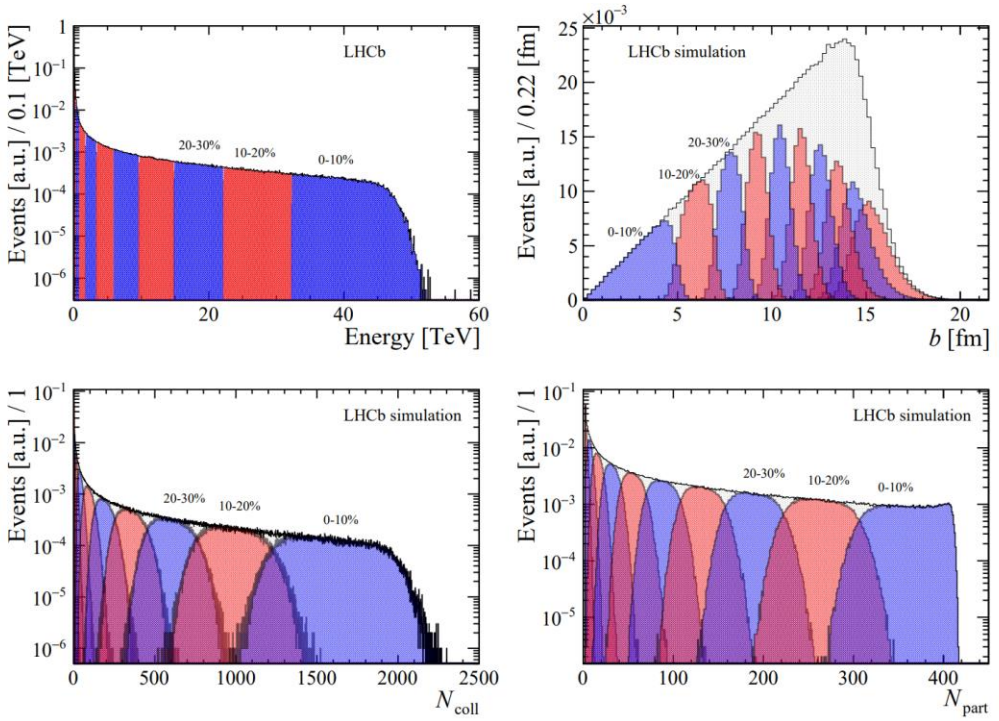
→ **At low p_T, increasing trend versus multiplicity**

Centrality determination in nucleus-nucleus collisions

Procedure to classify the data into geometric quantities from the Glauber MC model **[arXiv:2111.01607] accepted by JINST**

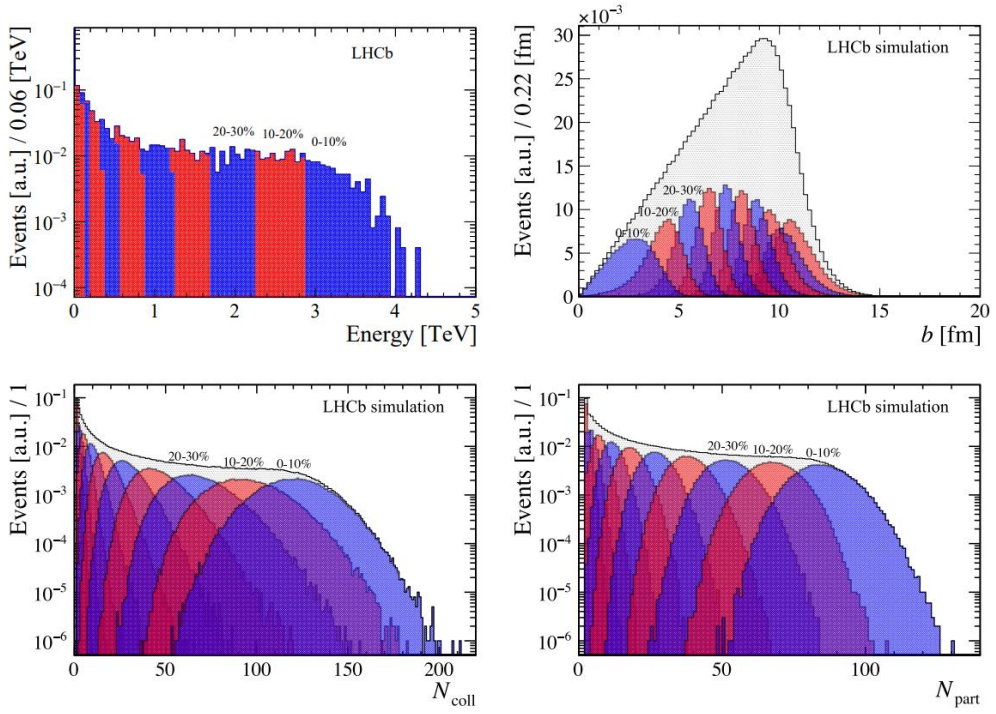
- Exploit the measured energy deposits in the electromagnetic calorimeter to map the real data

PbPb collisions at 5 TeV



NEW

PbNe collisions at 68.5 GeV



First centrality measurements at LHCb, and first measurements for fixed-target collisions at the LHC

J/ψ photo-production in PbPb collisions at 5 TeV

Precise measurement of coherent J/ψ and ψ(2S) production in UPC 2015, 2018 PbPb collisions [arXiv:2107.03223, LHCb-PAPER-2022-004]
in preparation

First LHCb measurements using PbPb peripheral collisions (up to 60%) [arXiv:2108.02681]

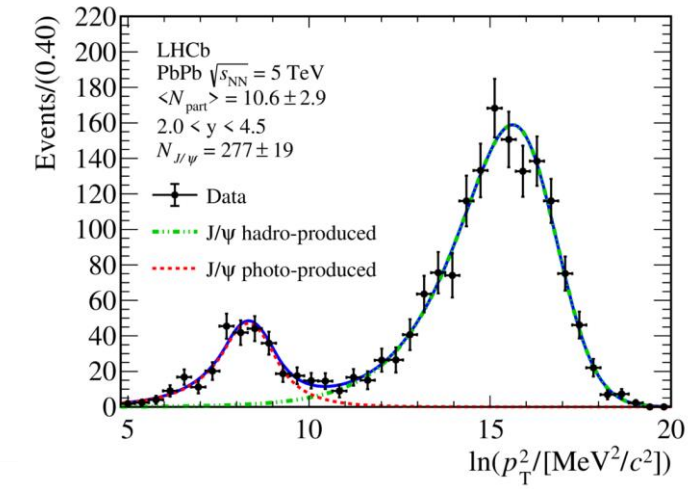
Photo-produced J/ψ disentangled from hadronically through dimuon p_T spectum fit

Photo-produced J/ψ differential yields study as a function of p_T, y and N_{part}

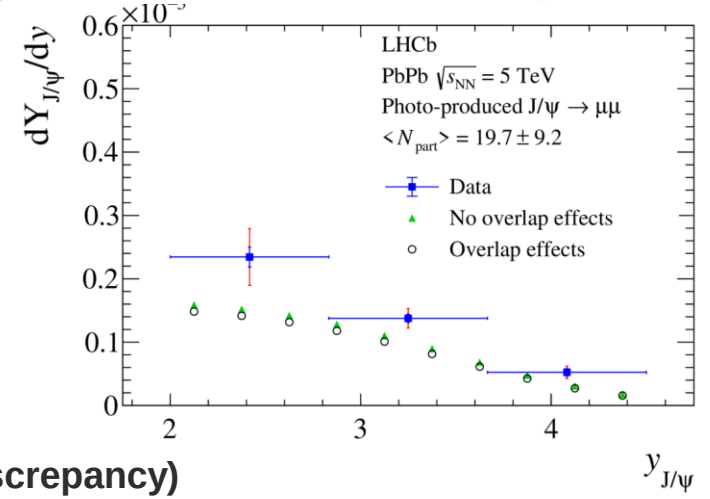
Measured yields of the photo-produced J/ψ

→ Higher at low rapidity than high rapidity

→ Consistent with being constant with respect to N_{part}



NEW

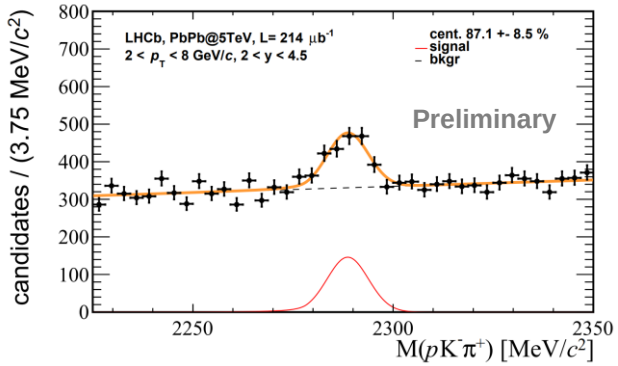


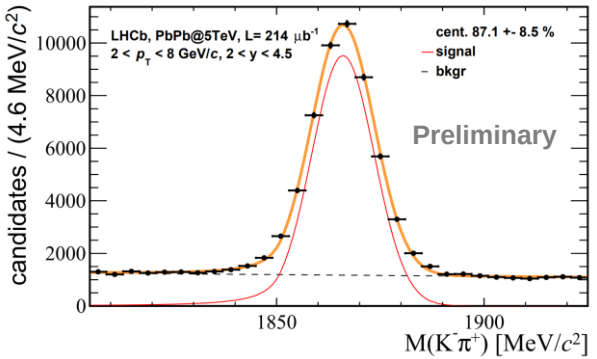
Confirmation of photo-produced J/ψ in PbPb peripheral hadronic collisions

Shape of the results are qualitatively described by the theoretical predictions (normalisation discrepancy)

First measurements Λ^+_c/D^0 production ratio in peripheral PbPb collisions

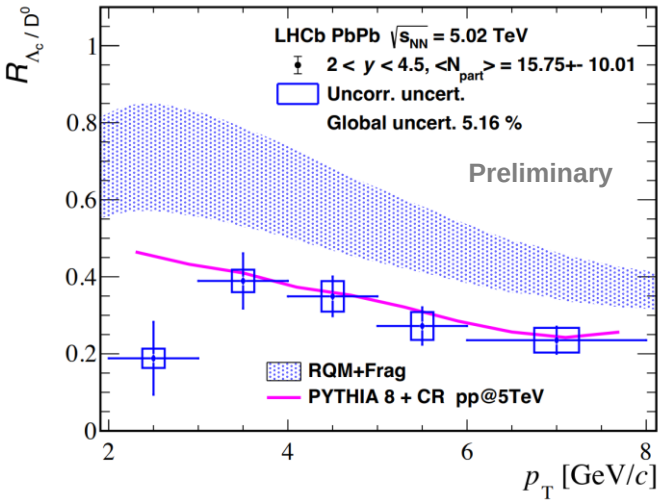
$$R = \frac{\sigma(\Lambda_c^+ \to pK^+\pi^-)}{\sigma(D^0 \to K^-\pi^+)}$$





NEW

Λ^+_c/D^0 differential ratio study as a function of p_T, y and N_{part} [LHCb-PAPER-2021-046]
in preparation



→ All are consistent with a constant trend around $R(\Lambda^+_c/D_0) \sim 0.27$

→ Consistent with previous LHCb measurements in pPb collisions

→ Compatible within 2σ with PYTHIA 8 prediction in pp collisions at 5.02 TeV including the color recombination mechanism

→ Systematic discrepancy versus p_T is observed with the statistical hadronization model prediction

→ Lower Λ^+_c/D^0 ratio in LHCb compared to ALICE experiment due to different rapidity range ?

Fixed target - astrophysics

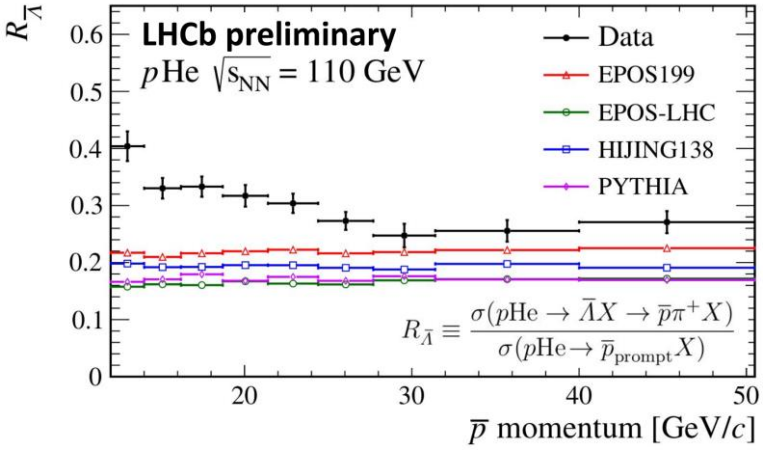
Space-born experiments (AMS-02) are searching for DM decays by comparing the antiproton abundance in cosmic rays

- Interpretation limited by models of antiproton production in cosmic rays collisions with the interstellar medium (H, He)

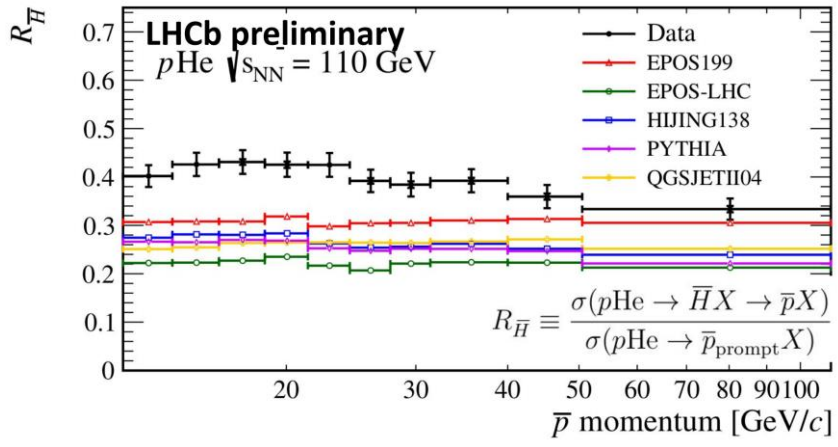
Dedicated measurements using pHe collisions:

- First LHCb result only dealing with prompt processes **[Phys. Rev. Lett. 121 (2018) 222001]**
- **Dedicated measurement to the component from anti-hyperon decays in pHe collisions [LHCb-PAPER-2022-006]** in preparation

Exclusive approach



Inclusive approach $\bar{H} = \bar{\Lambda}, \bar{\Sigma}, \bar{\Xi}, \bar{\Omega}$



NEW

→ Theoretical models largely underestimate the anti-hyperon contributions to the total antiproton yield

→ Ratios depend on the antiproton kinematics, usually neglected by theoretical models

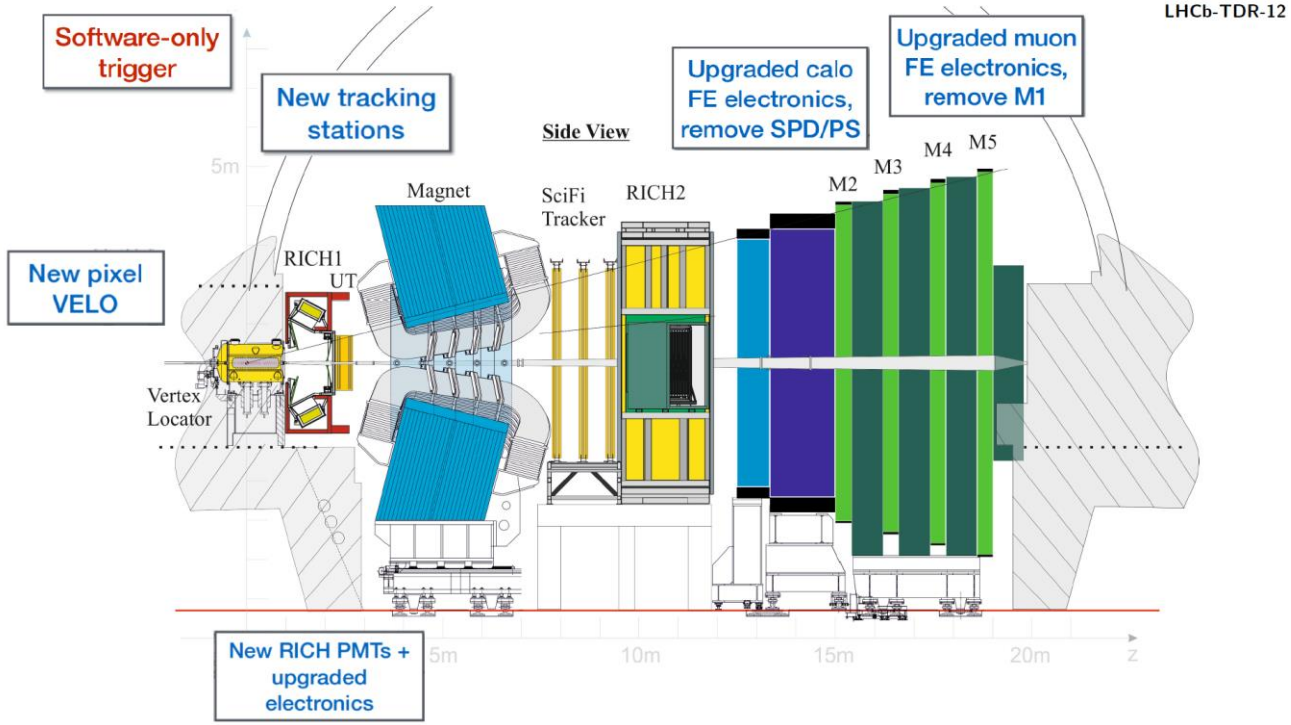
LHCb fixed-target configuration is also a privileged place for charm production studies

LHCb upgrade

LHCb is currently facing a major upgrade :

- Most of the detectors replaced
- Fully-software detector read-out and data processing

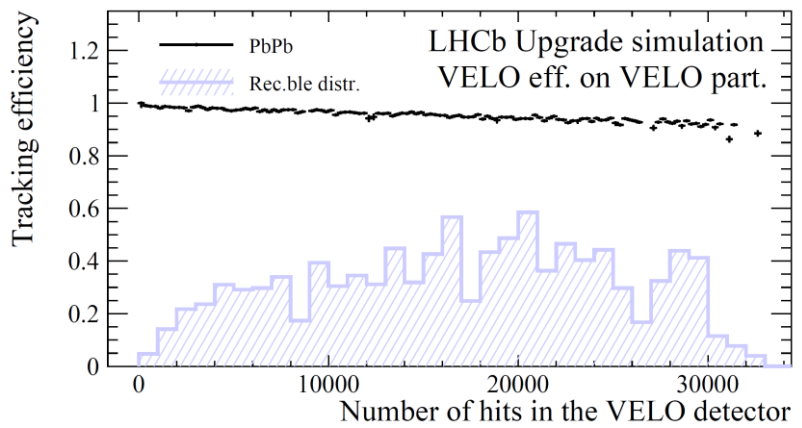
→ LHCb is a brand-new general purpose experiment



Study of central PbPb collisions during Run 3 ?

Simulation studies show that no saturation effects up to 30% centrality

LHCb-FIGURE-2022-002

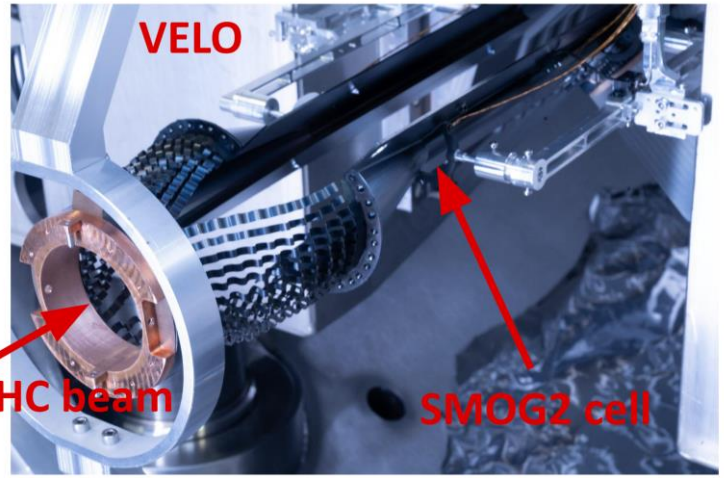


Next upgrades

~2025 : New tracking station inside the magnet

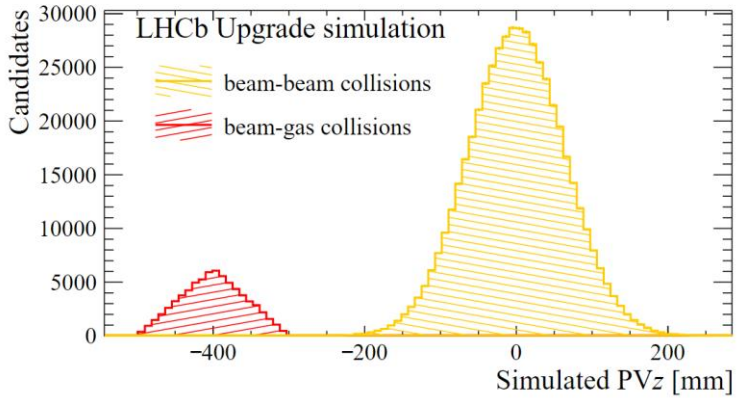
~2030 : Mighty tracker, no more centrality limitation

The LHCb fixed target upgrade



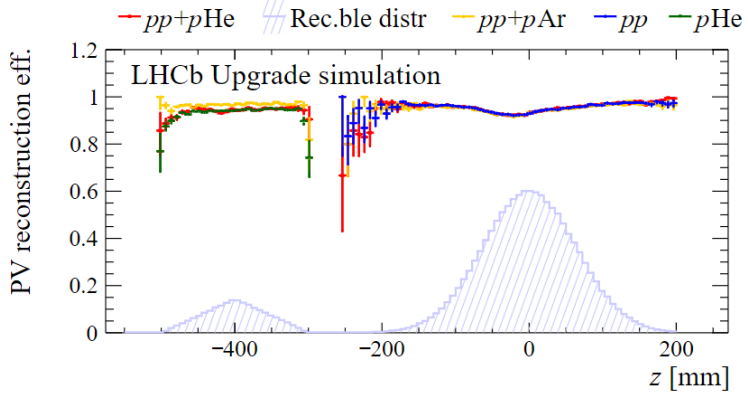
From 2022, 20-cm-long gas storage cell (SMOG2) upstream of the LHCb nominal IP

- Gas pressure up to x100 with the same flow as Run2
- Studies ongoing to also inject heavy noble (Kr, Xe) and non-noble (H_2, D_2, O_2) gases
- Opportunity to operate simultaneously in collider and fixed-target modes



Separation of the interaction region wrt beam-beam

- Dedicated reconstruction and trigger studies, with no-showstopper found
- First data-driven method for particle identification performance using fixed-target data only **[LHCb-DP-2021-007]**



With the LHCb fixed target upgrade
unique opportunities to extend heavy-ion, QCD and astrophysics program

Conclusions

LHCb has an expanding physics program

From QCD precise results : demonstration with LHCb run 1 & 2 data

- Many precise results from large pp/pPb/Pbp datasets
- UPC and PC measurement in LHCb PbPb pioneering samples
- Unique results with the fixed-target program at LHC

Toward QGP characterization and stringent QCD constraints: run 3 and beyond !

- New detector from 2022
- Improvement of the tracking performances
- Ambitious fixed-target program

Many new exciting opportunities ahead !

Talks

Saverio Mariani, April 6th, 11:30
Cheuk Ping Wong, April 7th, 9:00
Samuel Belin, April 7th, 9:40
Eliane Eppel, April 7th, 10:00
Oscar Boente Garcia, April 7th, 11:10
Tianqi Li, April 7th, 16:50
Benjamin Audurier, April 7th, 15:00
Jiayin Sun, April 7th, 15:20

Posters

Cesar Luiz Da Silva, April 6th
Xiaolin Wang, April 6th
Yiheng Luo, April 8th
Chenxi Gu, April 8th
Di Yang, April 8th
Roman Litvinov, April 8th
Sara Sellam, April 8th