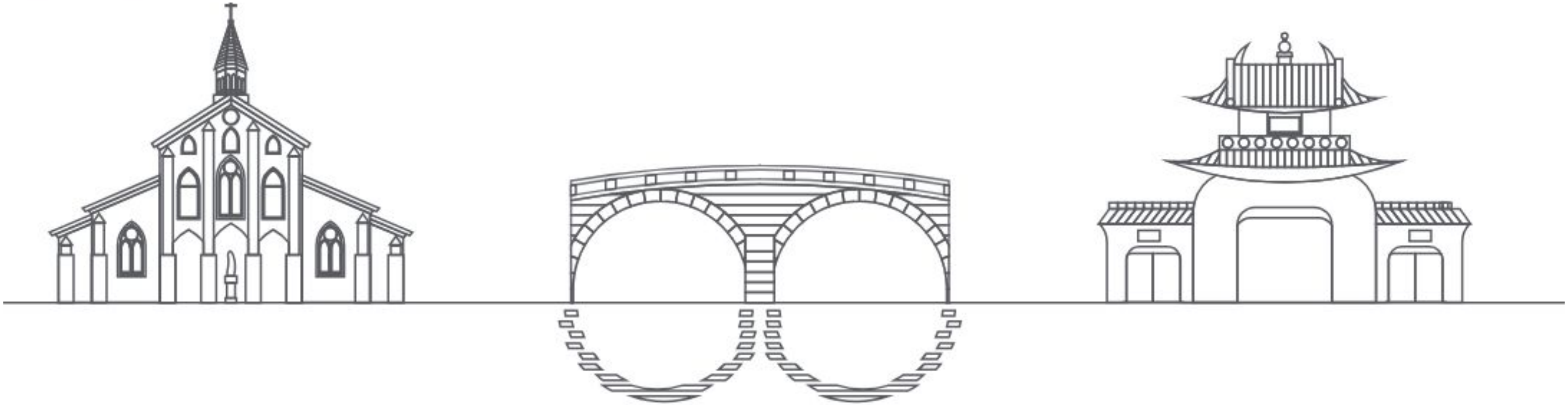


LHCb highlights

Saverio Mariani, on behalf of the LHCb collaboration

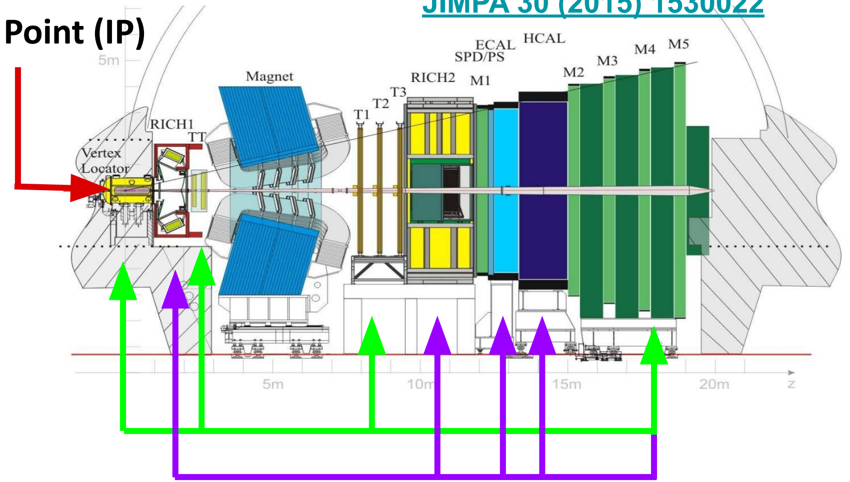
CERN

Nagasaki, 23/09/2024

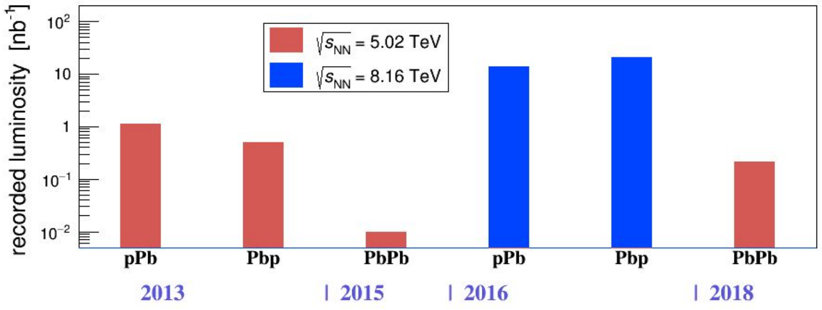
LHCb as a heavy-ion and fixed-target experiment

Nominal Interaction Point (IP)

JINST 3 S08005 (2008)
JIMPA 30 (2015) 1530022



Run 1-2 samples



- Clear primary and decay vertex separation, **precise tracking**, **full PID**, flexible and fast trigger and a unique acceptance make of **LHCb a general-purpose forward detector and a unique facility for heavy-ion physics**
  → constraints to nPDFs **down to x ~10^{-6}**

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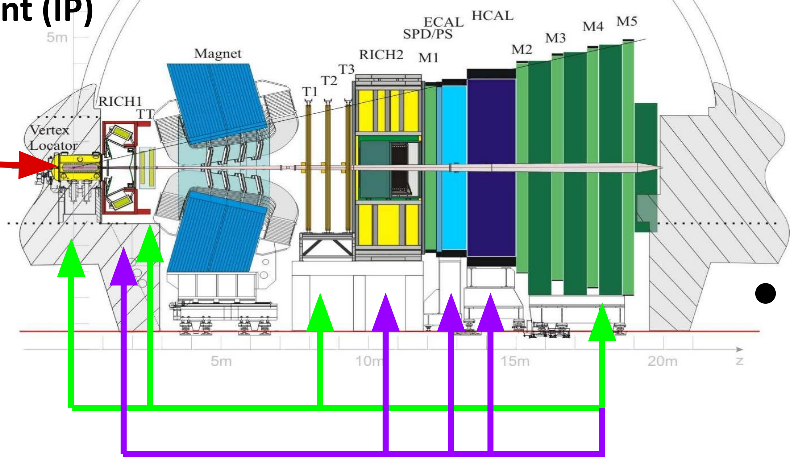

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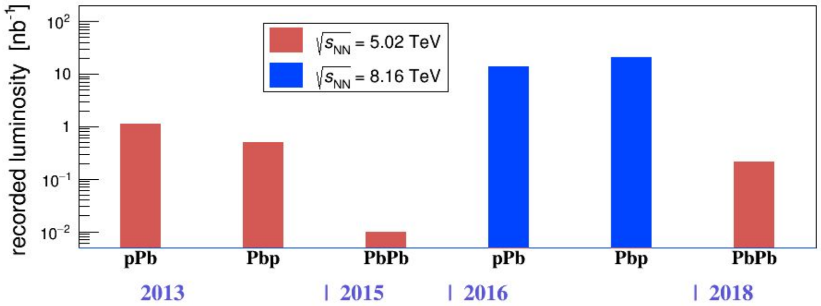
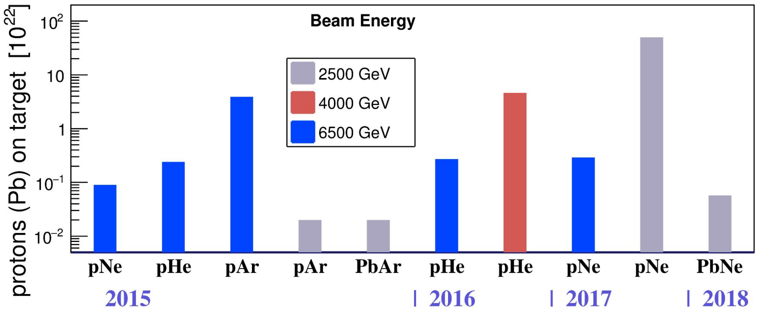
  → constraints to nPDFs **down to x ~10^{-6}**

- By injecting gases in LHC, can acquire beam-gas (pA, PbA) data **at the highest energy in fixed-target mode** and **simultaneously** with beam-beam

Run 1-2 samples





LHCb results at Hard Probes 2024

10 parallel talks:

- Charm production in LHCb fixed-target mode, Oscar Boente Garcia, Mon. 15:00
- Polarization measurement and prospects at LHCb, Youen Kang, Mon 15:40
- Strangeness studies in LHCb fixed-target collisions, Federica Fabiano, Mon. 17:30
- Recent LHCb probes for b-quark hadronization studies, Julie Lane Marie Berkeley, Mon. 18:10
- Charmonium production measurements in large systems at LHCb, Chenzhi Dong, Tue 09:20
- Charmonium production measurements in small systems at LHCb, Cesar Luiz Da Silva, Tue 14:40
- Exotic hadron production in pp and pPb collisions at LHCb, Matt Durham, Tue 15:00
- Prospects for heavy-ion data-taking with the LHCb Upgrade II, Samuel Belin, Tue 14:40
- Ultra-peripheral collisions at LHCb, Amanda Donohoe, Wed. 09:20
- Probing QCD dynamics with jet substructure in LHCb kinematics, Ezra Lesser, Wed. 11:30

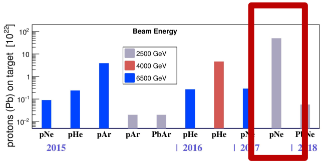
8 posters:

- Bottomonium production measurements at LHCb, Chenzhi Dong
- Exploring hadronization with heavy-flavour jets at LHCb, Matt Durham
- Flow and correlation measurements at LHCb, Zhengchen Lian
- Helium identification and production at LHCb, Julie Lane Marie Berkeley
- Recent studies of open-charm production at LHCb, Yiheng Luo
- SMOG2: a high-density gas target at the LHCb experiment, Federica Fabiano
- Strangeness studies in LHCb heavy-ion collisions, Jianqiao Wang
- Studies of nucleon structure at LHCb, Cesar Luiz da Silva

The highest LHCb representation in HP, reflecting our increasingly **rich and attractive programme**

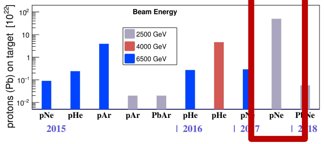
Just showing a selection in this talk, please attend if interest in the details!

Strange and charm physics in fixed-target collisions



- *p*Ne data with $\sqrt{s_{NN}}$ = 68.5 GeV, intermediate to SpS and RHIC top energy $\longrightarrow$ access to poorly explored high-x at moderate Q^2 $\Rightarrow$ **unique inputs** to models!
- **Discrimination of Quark Gluon Plasma from Cold Nuclear Matter effects** require precise measurements in different collision systems and c.m. energies

Strange and charm physics in fixed-target collisions



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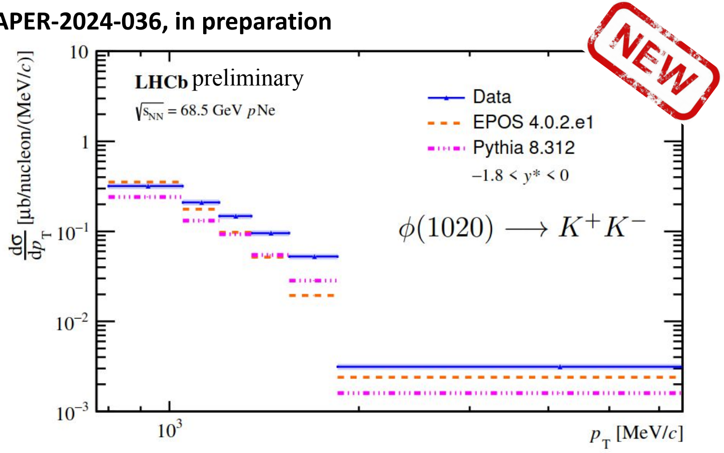
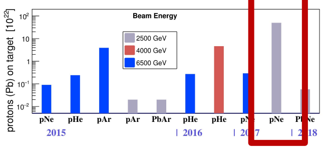
LHCb-PAPER-2024-036, in preparation



- Models found to **underestimate φ production** at this energy ⟶ good constraining power for strangeness in phenomenological models

Strange and charm physics in fixed-target collisions



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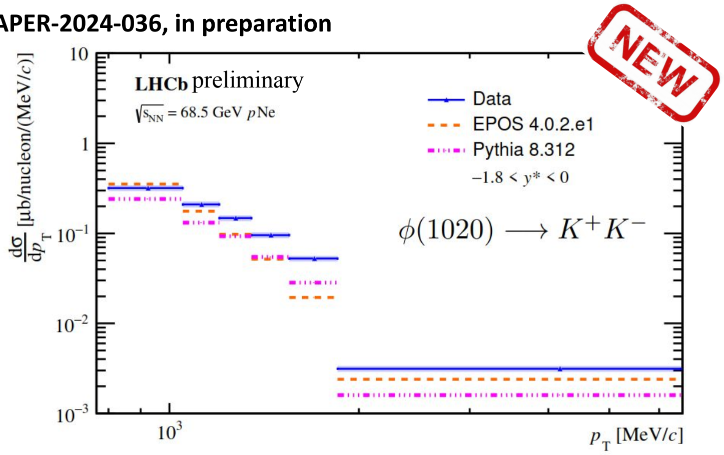
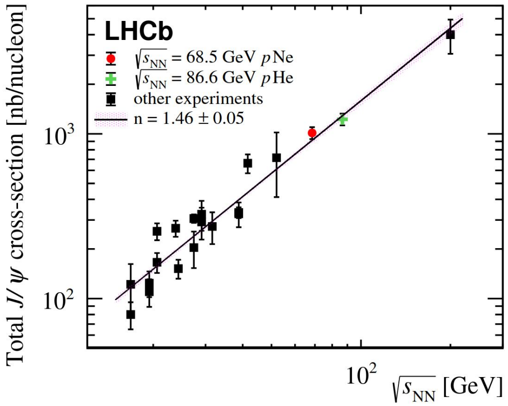
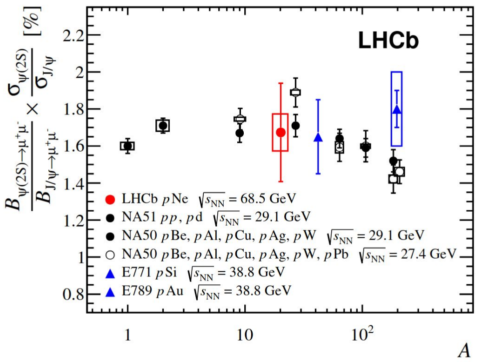


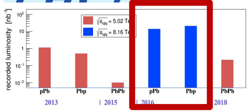
Eur. Phys. J. C83 (2023) 625

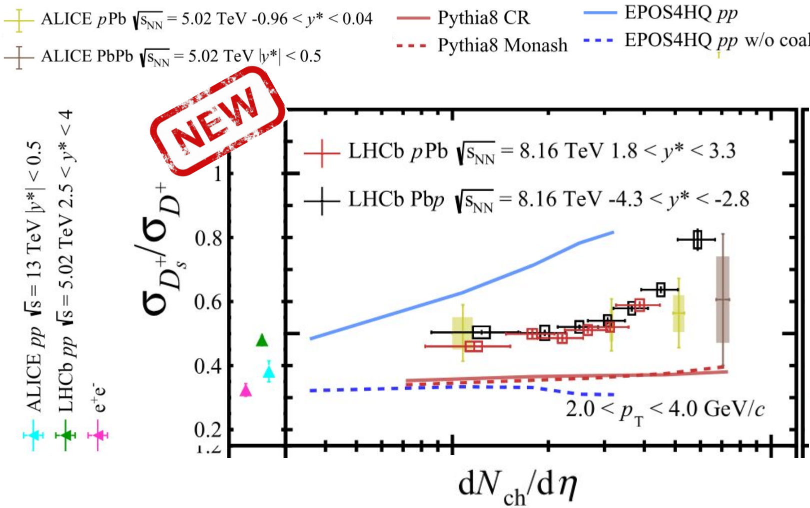




- Models found to **underestimate φ production** at this energy → good constraining power for strangeness in phenomenological models
- Better precision wrt previous experiments for J/ψ, but **statistically dominated** for heavier probes
- Motivates **fixed-target system upgrade** (SMOG2)

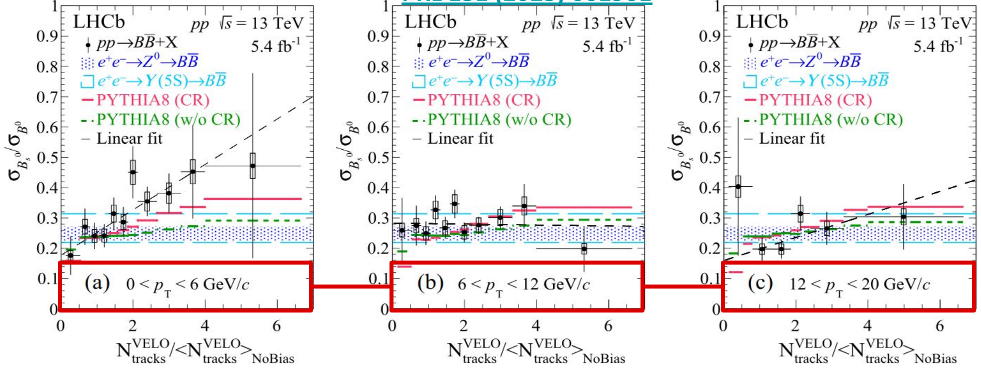
Strangeness enhancement in charm and beauty





PRD 110 (2024) L031105

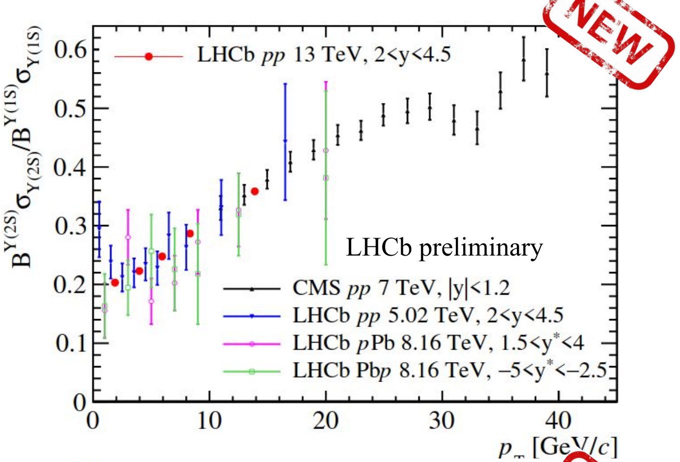
PRL 131 (2023) 061901

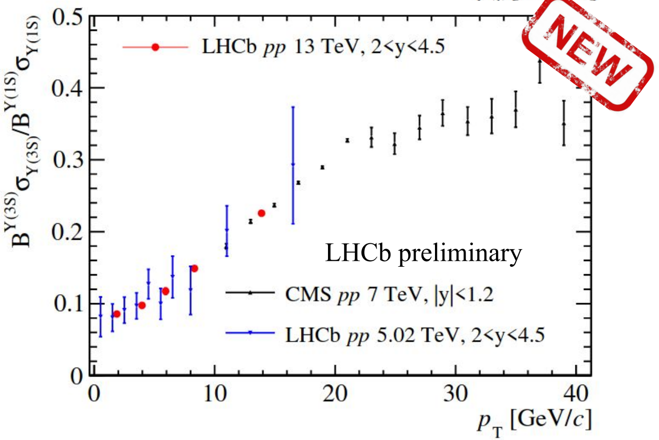


- By studying charm and beauty particle yields as a function of multiplicity, **observed clear indications of strangeness enhancement** in both the charm (left) and beauty (right) sectors, especially at low transverse momenta
- **Final state effects such as coalescence are important at low p_T and high multiplicity,** while the pure fragmentation limits from *ee* collisions are recovered elsewhere

Recent studies on charmonia and bottomonia

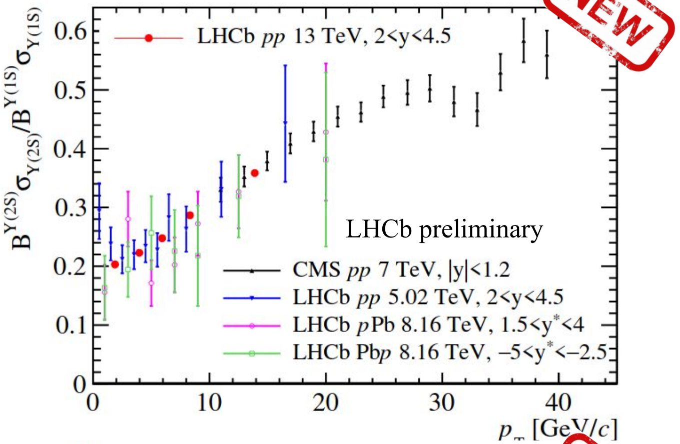
LHCb-PAPER-2024-038, in preparation

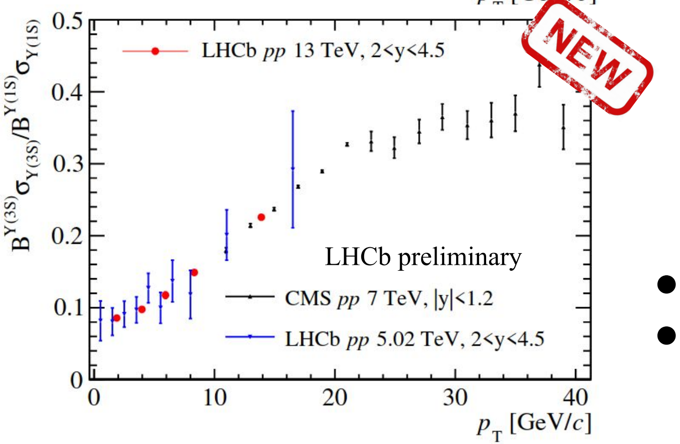




- New LHCb results for Υ(nS) production in *pp* as a function of multiplicity confirms **sequential suppression pattern**
- Comparison in line with previous LHCb and CMS results, with **remarkably small uncertainties** (smaller than the data points)

Recent studies on charmonia and bottomonia





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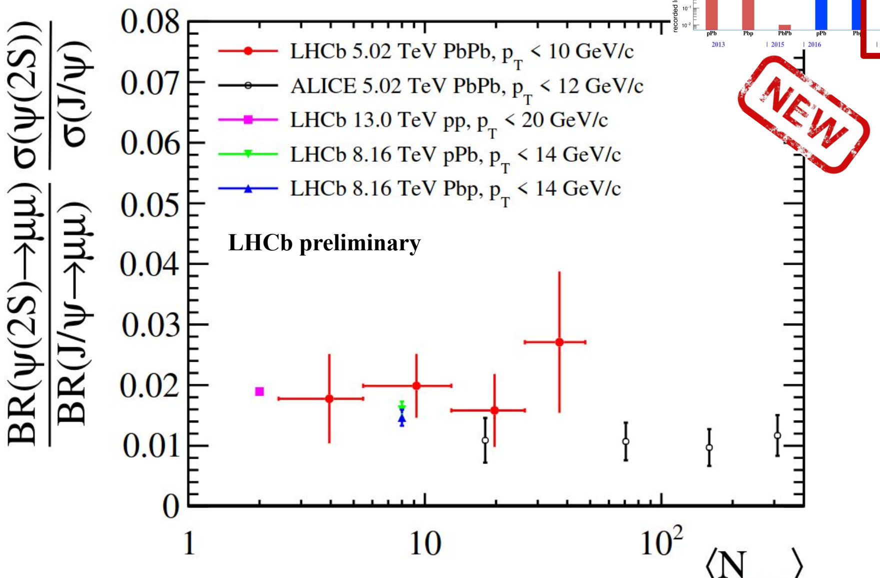
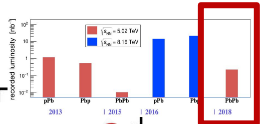
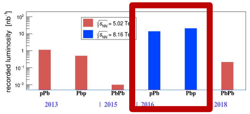


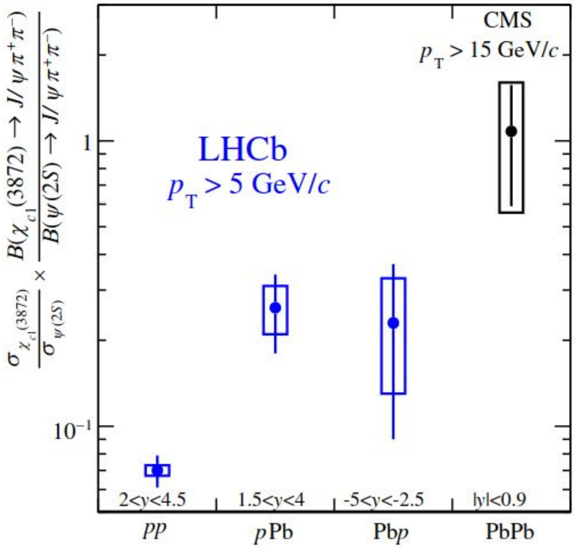


LHCb-PAPER-2024-041, in preparation

- Charmonia measurement also performed in a large system
- Statistical uncertainty on ψ(2s) dominant → **will be extended and improved with Run3 data**

Exotic hadrons in *pp* and *p*Pb collisions





PRL 132 (2024) 242301

- Exotic multi-quark states also provide a unique view on hadronization mechanisms: does X(3872) have **a compact, a molecular or a hadrocharmonium structure**?
- X enhancement wrt ψ(2s), despite ~cancellation of initial state effects, hints at a different interaction with the medium → is this X enhancement or ψ(2s) suppression?

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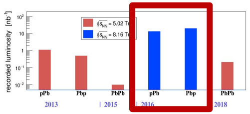
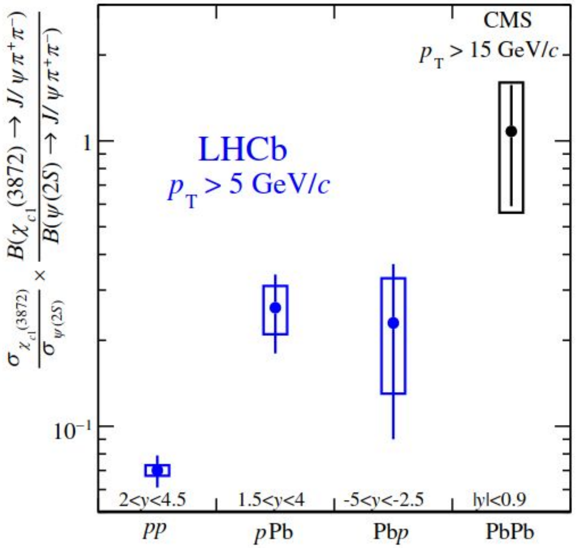
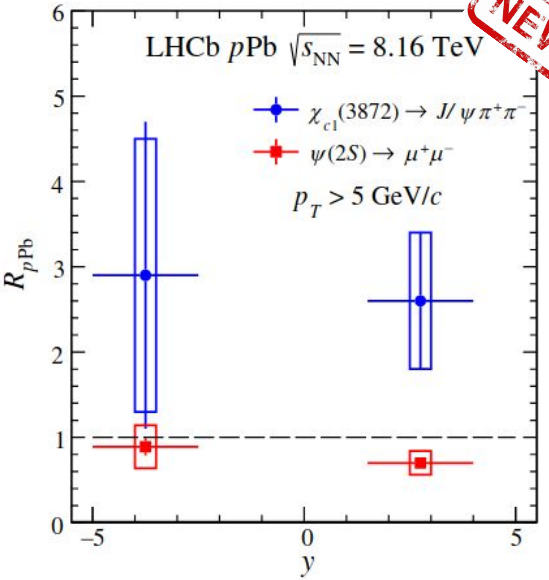




PRL 132 (2024) 242301



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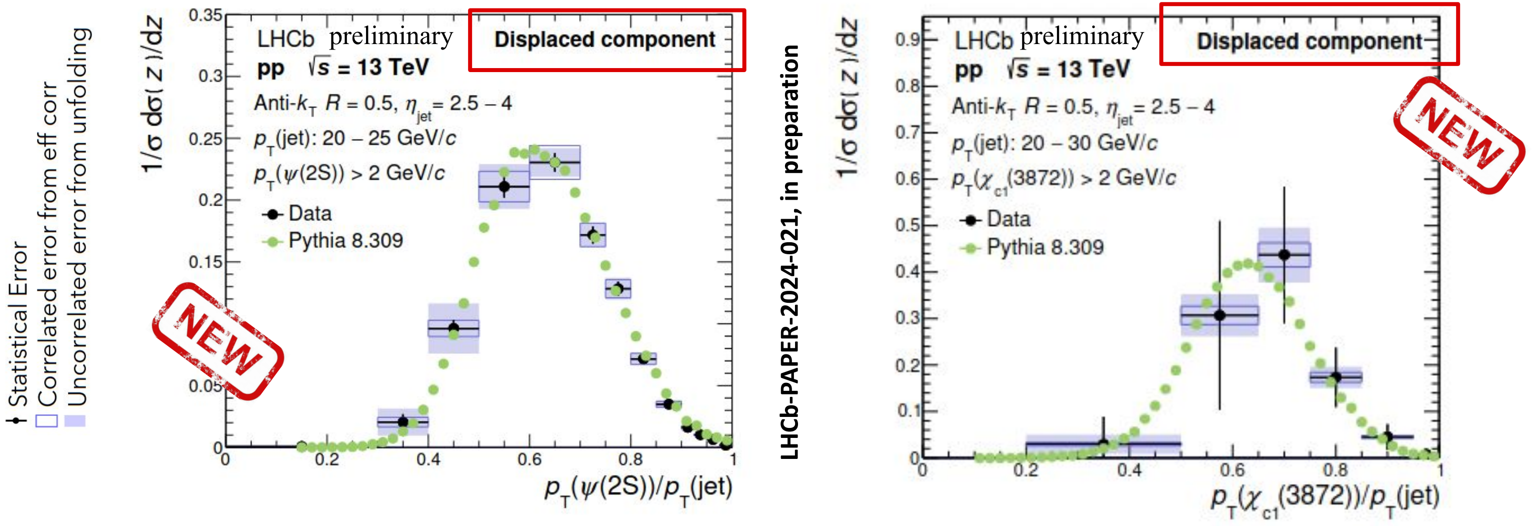
- X enhancement wrt ψ(2s), despite ~cancellation of initial state effects, hints at a different interaction with the medium → is this X enhancement or ψ(2s) suppression?
- **Nuclear modification factor shows X enhancement** → coalescence dominating over breakup?

Fragmentation in jets

- X(3872) and ψ(2s) also **reconstructed within jets** to learn more about their production mechanism



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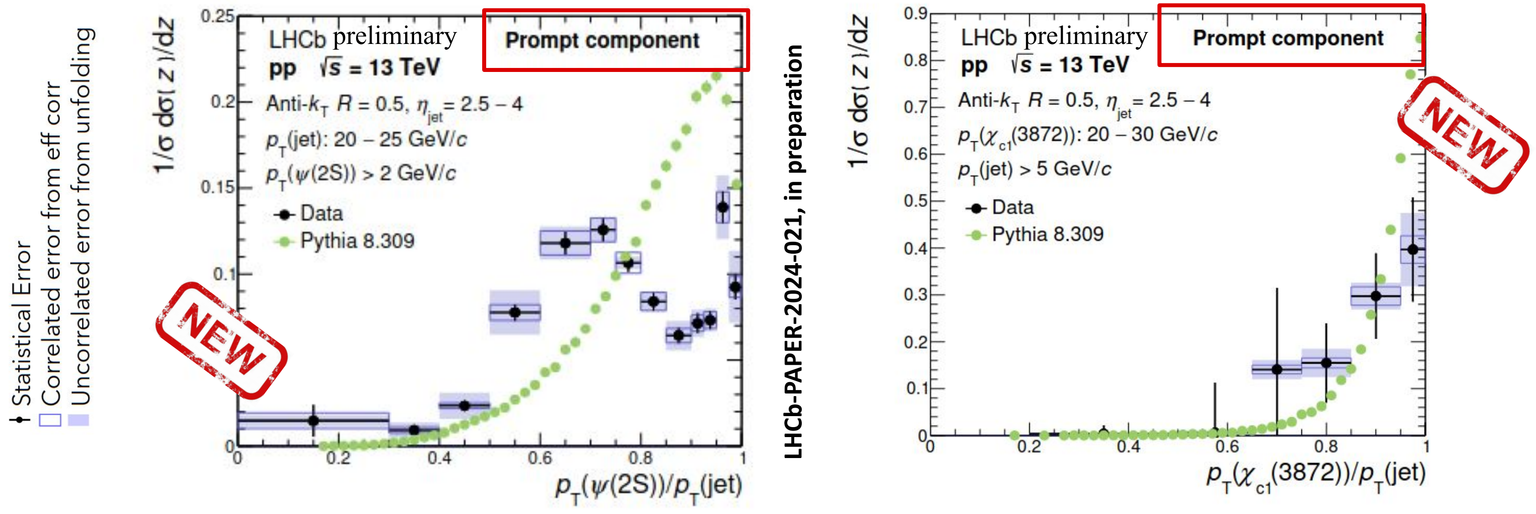
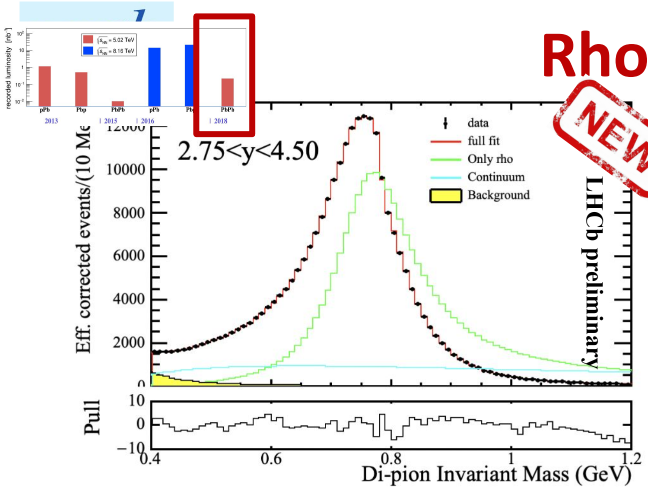


- Displaced (from *b*-decays) distributions of ψ(2s) and X(3872) similar and **well described by Pythia**
- **Two distinct components are found for prompt production**, especially for ψ(2s) at low p_T, not reproduced by Pythia
- **Further development of theoretical models is needed** to explore the nature of the two components

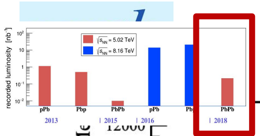
Rho lineshape in UPC PbPb collisions

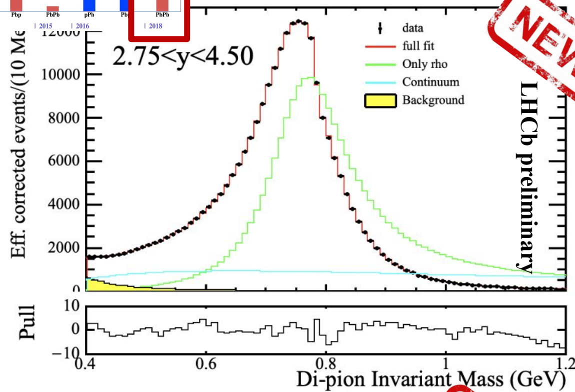


- Very **clean sample of UPC di-pions** selected by requiring no additional activity in the detector and with PID vetoes
- Fit model by H1 preferred wrt the STAR one in **modelling the distribution and the ρ - ω interference**

LHCb-PAPER-2024-042, in preparation

Rho lineshape in UPC PbPb collisions





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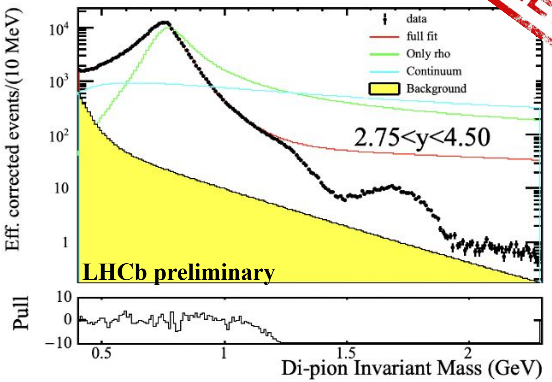
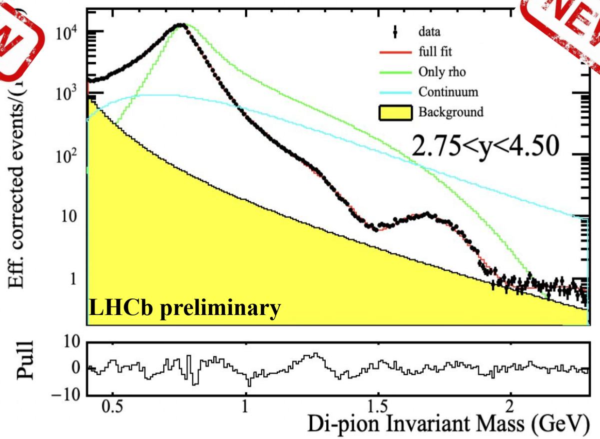


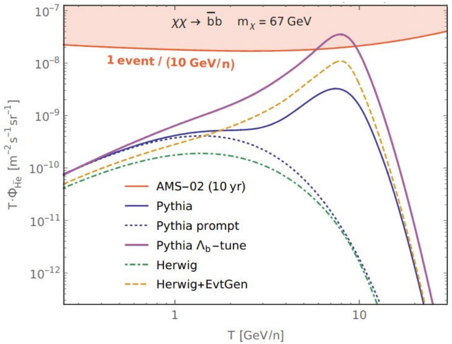


- …but extrapolating shows the model is clearly not correct
- **Unambiguous additional resonance**, confirming previous observation by ALICE and STAR
- Fit results **consistent with PDG ρ' particle**
- Cross-sections and p_T spectrum being measured

LHCb-PAPER-2024-042, in preparation

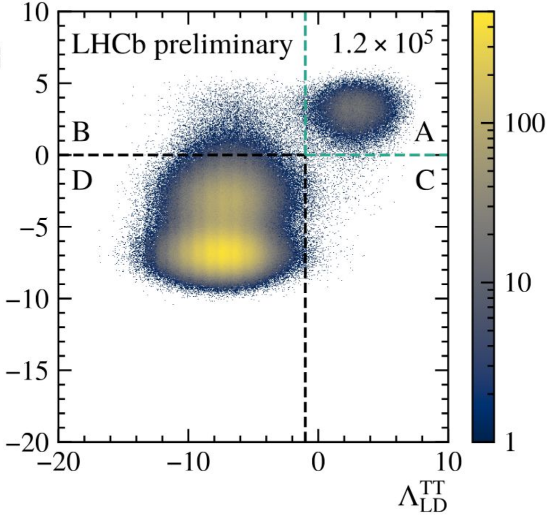
Nuclei production and identification at LHCb

PRL 126 (2021) 101101



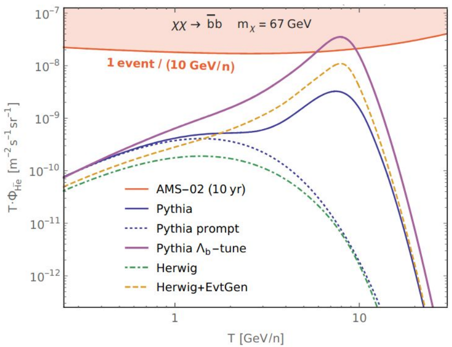
- Discussion ongoing about a **possible explanation of measured AMS He flux** due to Λb -> HeX decays (if BR ~ O(10^{-6})) PRC 108 (2023) 024903
- Innovative **He identification technique** via discriminators built from energy loss in LHCb detectors → **very clean** He samples (A)

JINST 19 (2024) P02010



Nuclei production and identification at LHCb

PRL 126 (2021) 101101



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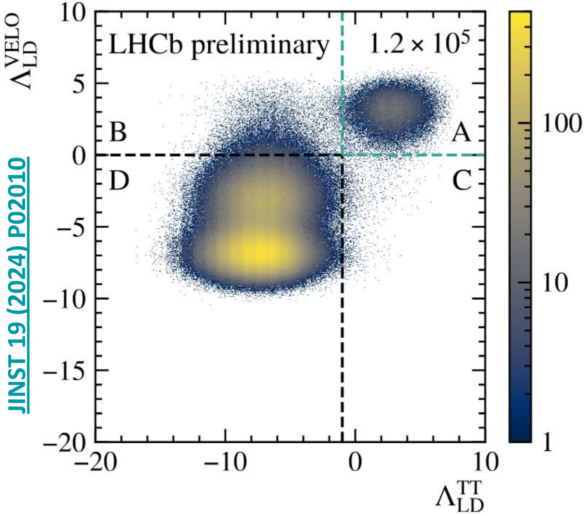
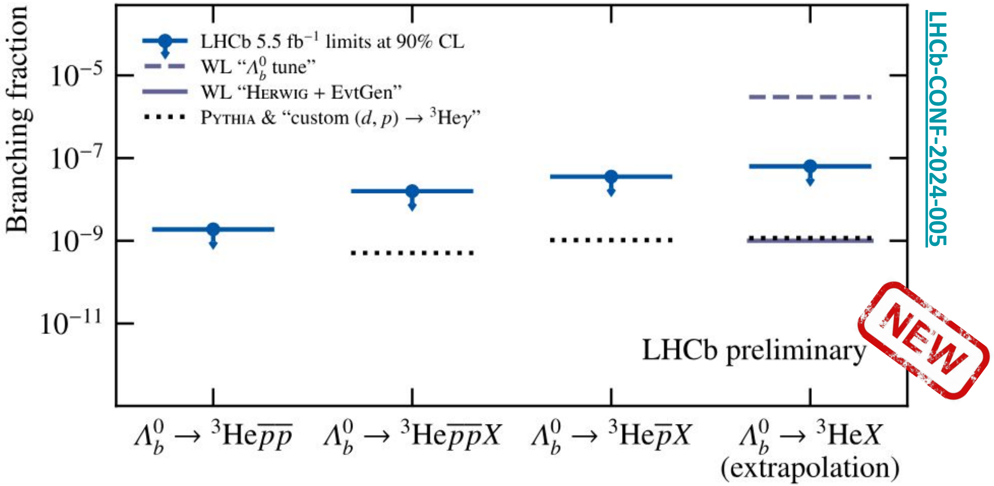


LHCb-CONF-2024-005

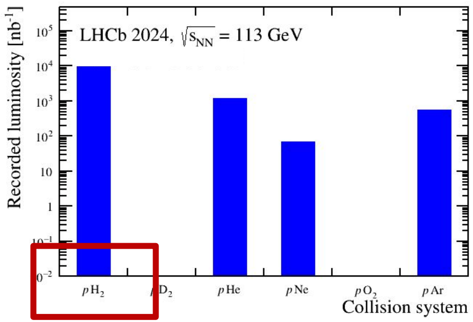


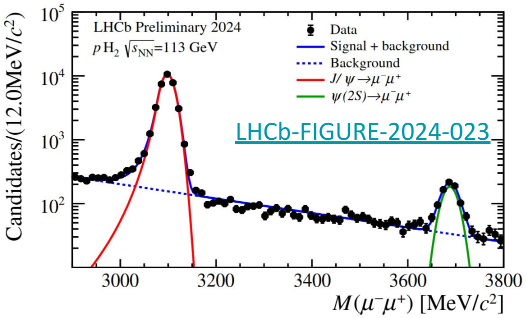
- $\Lambda_b^0 \to {}^3He\overline{pp}$ decay fully reconstructed and extrapolated limits to inclusive channels **significantly restricts He abundance in cosmic rays**

New possibilities with the LHCb Upgrade I

- Now operating at x5 luminosity in *pp* wrt Run 2, with increased granularity, a software-only real-time data processing and a **continuous beam-gas data-taking** (SMOG2)

arXiv:2407.14200





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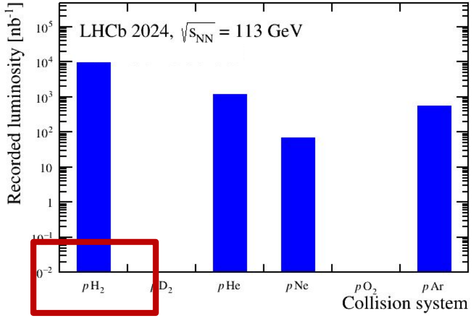

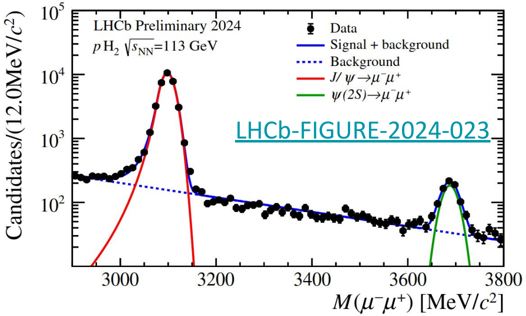

LHCb-FIGURE-2024-023

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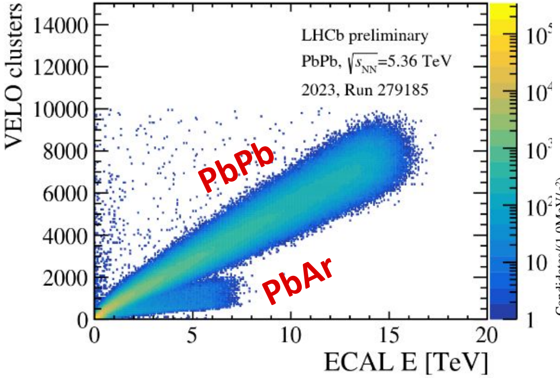
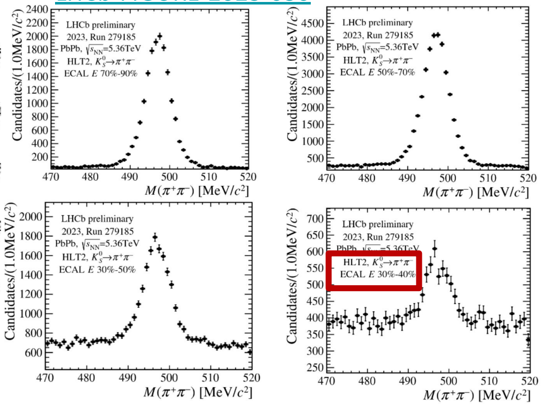
LHCb-FIGURE-2023-030



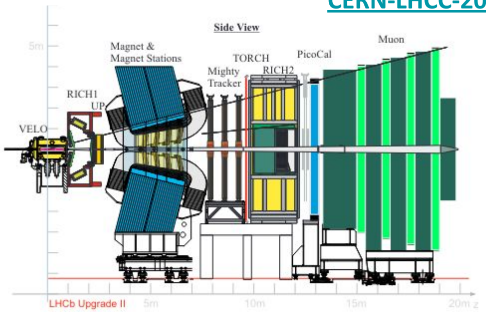
LHCb-FIGURE-2023-030



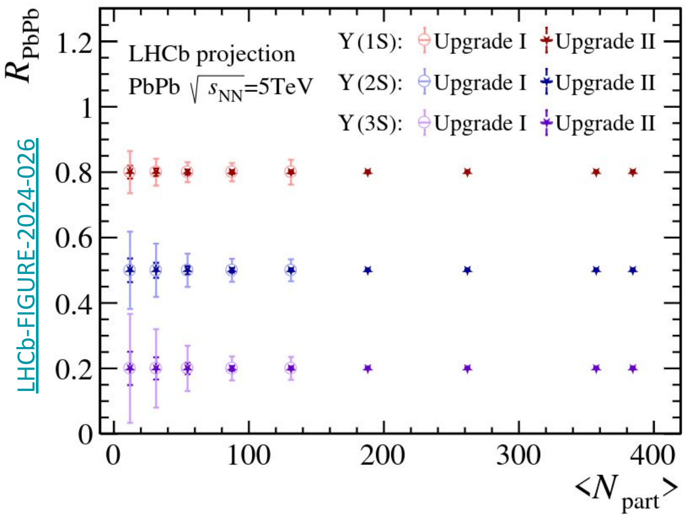
- Accessing full centrality PbA (SMOG2) and **up to semi-central PbPb**
- Several optimisations put in place for 2024 data-taking, with **+70% instantaneous luminosity wrt 2023**

… and even more with the LHCb Upgrade II

CERN-LHCC-2021-012



- Scoping scenarios recently submitted, with support for **full centrality PbPb reach** included by design
- Include **tracking stations in the magnet**, increasing acceptance down to 50 MeV p_T
- **Addition of timing** improves LHCb capabilities for nuclei ID



LHCb-FIGURE-2024-026

- **Unique prospects** recently discussed in a workshop with the theoretical community: from bulk physics to heavy-flavour, jets, high-statistics of exotica and electromagnetic probes, CEP and UPC
- In parallel, R&D ongoing to polarise the injected gas and open a new gate with the **study of polarised collisions at LHC** (highly complementary to EIC)

arXiv;1901.08002

Conclusions

- LHCb has a **unique** and continuously expanding heavy-ion and fixed-target programme
- Now embracing soft and hard probes production in small to large collisions systems, hadronization studies, UPC, collectivity and (hyper)nuclei production. **New ideas and interested people keep arriving**
- **Just started to exploit the Upgrade I detector**, i.e. semi-central PbPb collisions and high-statistics *p*A and PbA datasets at a unique energy scale
- **Upgrade II is on the horizon**, offering no centrality limitations, precise timing for nuclei identification and possibly a polarised fixed-target programme
- Stay tuned, **LHCb will keep surprising!**

Thanks for your attention!

Follow up? saverio.mariani@cern.ch

LHCb results at Hard Probes 2024

The highest LHCb representation in HP, reflecting our increasingly **rich and attractive programme**

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- Recent LHCb probes for b-quark hadronization studies, Julie Lane Marie Berkeley, Mon. 18:10
- Charmonium production measurements in large systems at LHCb, Chenzhi Dong, Tue 09:20
- Charmonium production measurements in small systems at LHCb, Cesar Luiz Da Silva, Tue 14:40
- Exotic hadron production in pp and pPb collisions at LHCb, Matt Durham, Tue 15:00
- Prospects for heavy-ion data-taking with the LHCb Upgrade II, Samuel Belin, Tue 14:40
- Ultra-peripheral collisions at LHCb, Amanda Donohoe, Wed. 09:20
- Probing QCD dynamics with jet substructure in LHCb kinematics, Ezra Lesser, Wed. 11:30

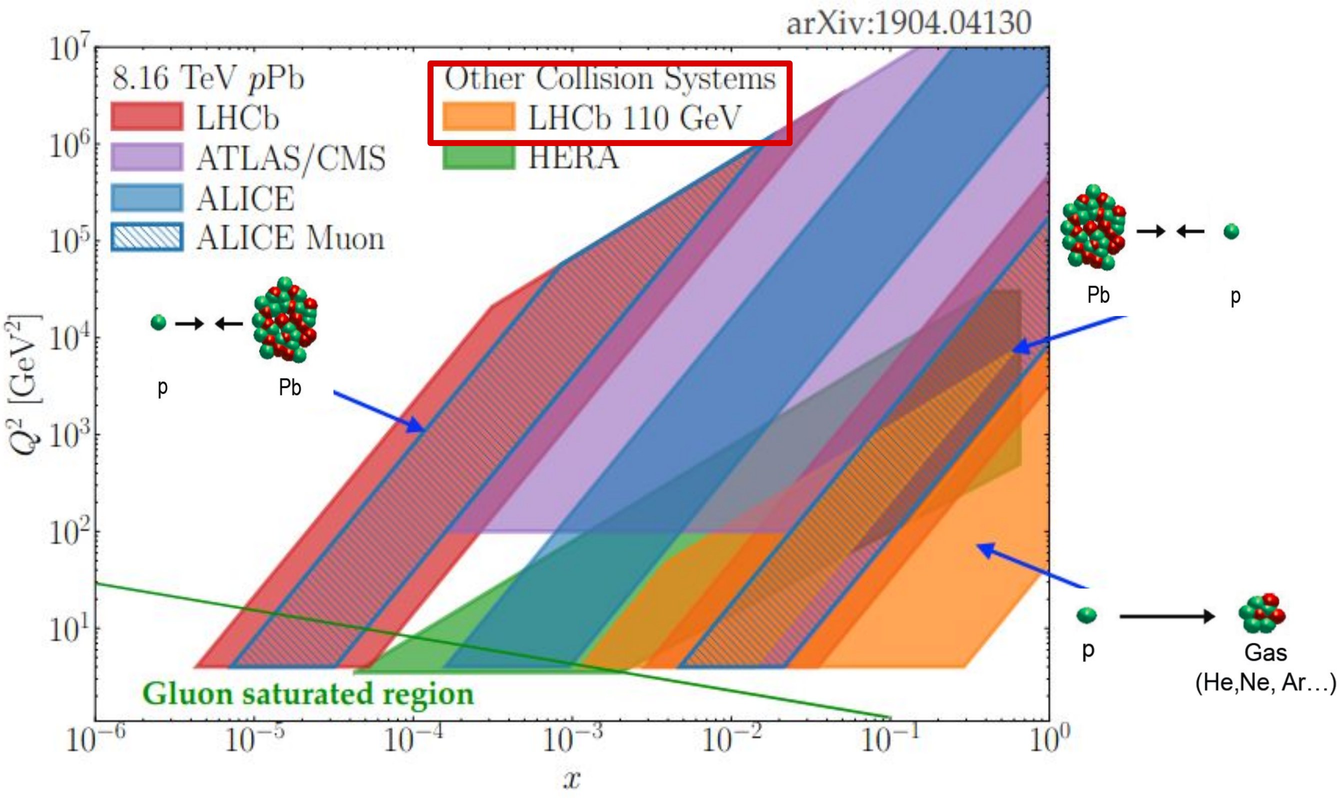
8 posters:

- Bottomonium production measurements at LHCb, Chenzhi Dong
- Exploring hadronization with heavy-flavour jets at LHCb, Matt Durham
- Flow and correlation measurements at LHCb, Zhengchen Lian
- Helium identification and production at LHCb, Julie Lane Marie Berkeley
- Recent studies of open-charm production at LHCb, Yiheng Luo
- SMOG2: a high-density gas target at the LHCb experiment, Federica Fabiano
- Strangeness studies in LHCb heavy-ion collisions, Jianqiao Wang
- Studies of nucleon structure at LHCb, Cesar Luiz da Silva

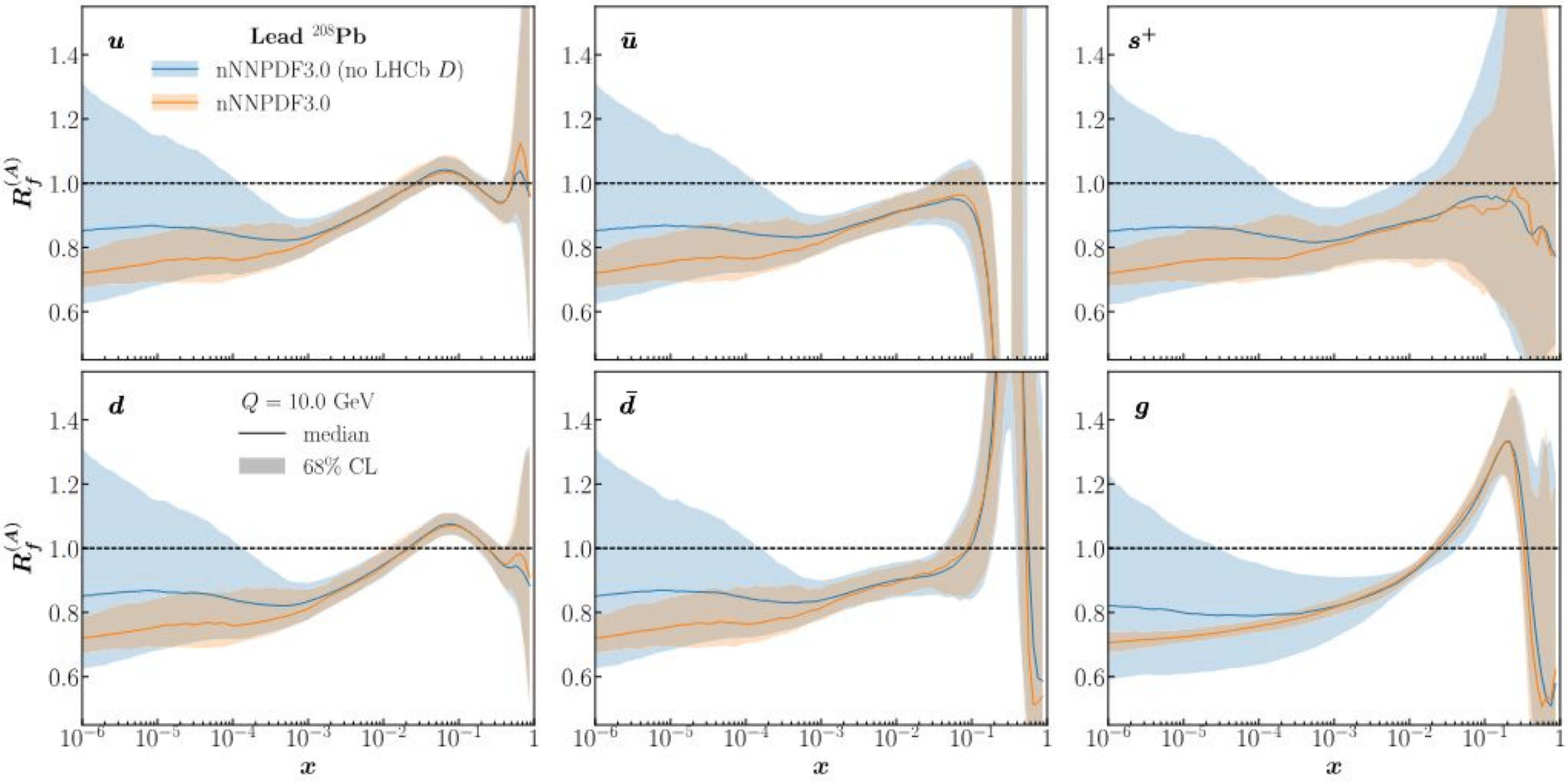
Just showing a selection in this talk, please attend if interest in the details!

Backup

LHCb acceptance for HI and fixed-target

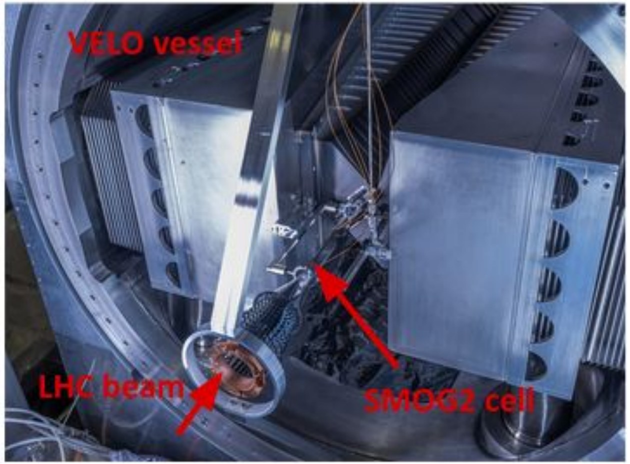


LHCb power in constraining nPDFs

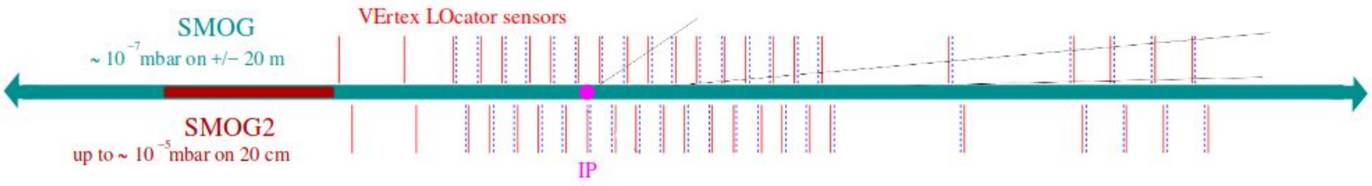


The SMOG2 system

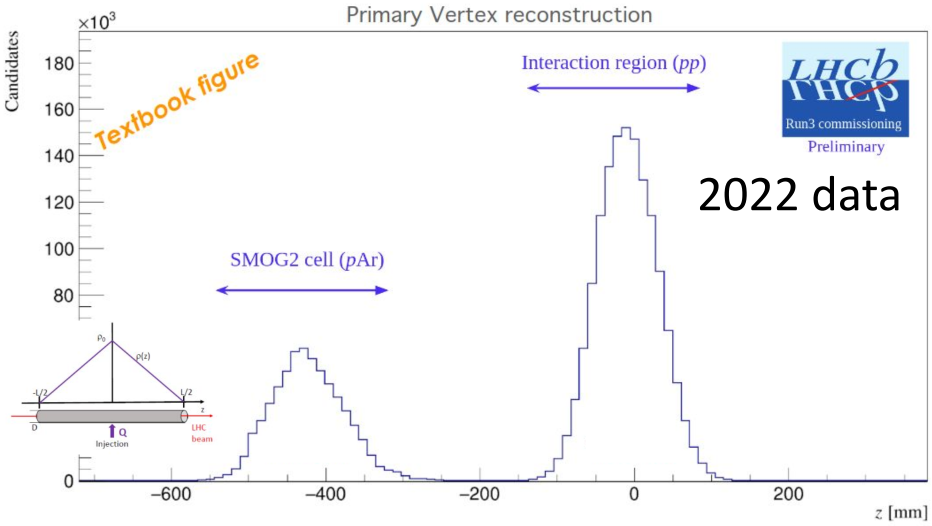
LHCb-TDR-020
LHCb-PUB-2018-015

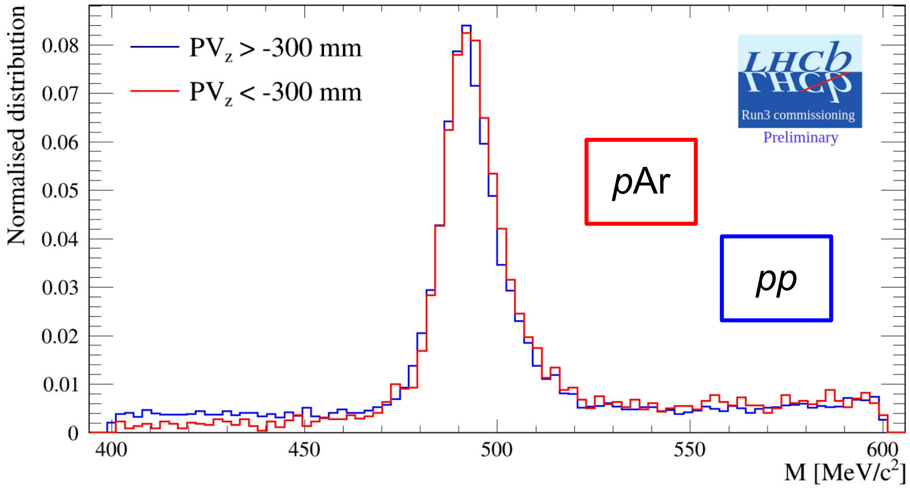


- **SMOG2:** **gas confinement in a cell upstream of the LHCb IP** (z ϵ [-541, -341] mm), installed in 2020
    - Cell **made up of two halves**, to be opened and closed together with the VELO
    - Up to x100 **density wrt SMOG for the same gas flow**
    - **Simultaneous beam-beam beam-gas data-taking**
    - **Heavy noble (Kr, Xe) and non-noble gases (H_2, D_2, O_2, N_2 …)** can be injected
- **New Gas Feed System**
    - Precise flow control → **direct lumi measurement**
    - More gas recipients → **fast gas replacement**



The SMOG2 system (II)





- **SMOG2 working simultaneously and continuously** with beam-beam operations, collecting two datasets in two different collision systems at two different cm energies
- Reconstruction performance and momentum resolution **similar between *pp* and *p*A**

Physics opportunities with the SMOG2 system

- The **wider choice of gases, the increase in injected pressure** and the simultaneous beam-beam and beam-gas data-taking open new possibilities

LHCb-PUB-2018-015

	SMOG largest sample p–Ne@68 GeV	SMOG2 example p–Ar@115 GeV
Integrated luminosity	$\sim 100\ \text{nb}^{-1}$	$100\ \text{pb}^{-1}$
syst. error on J/ψ x-sec.	6–7%	2–3 %
J/ψ yield	15k	35M
D^0 yield	100k	350M
Λ_c yield	1k	3.5M
$\psi(2S)$ yield	150	400k
$\Upsilon(1S)$ yield	4	15k
Low-mass ($5 < M_{\mu\mu} < 9\ \text{GeV}/c^2$) Drell-Yan yield	5	20k

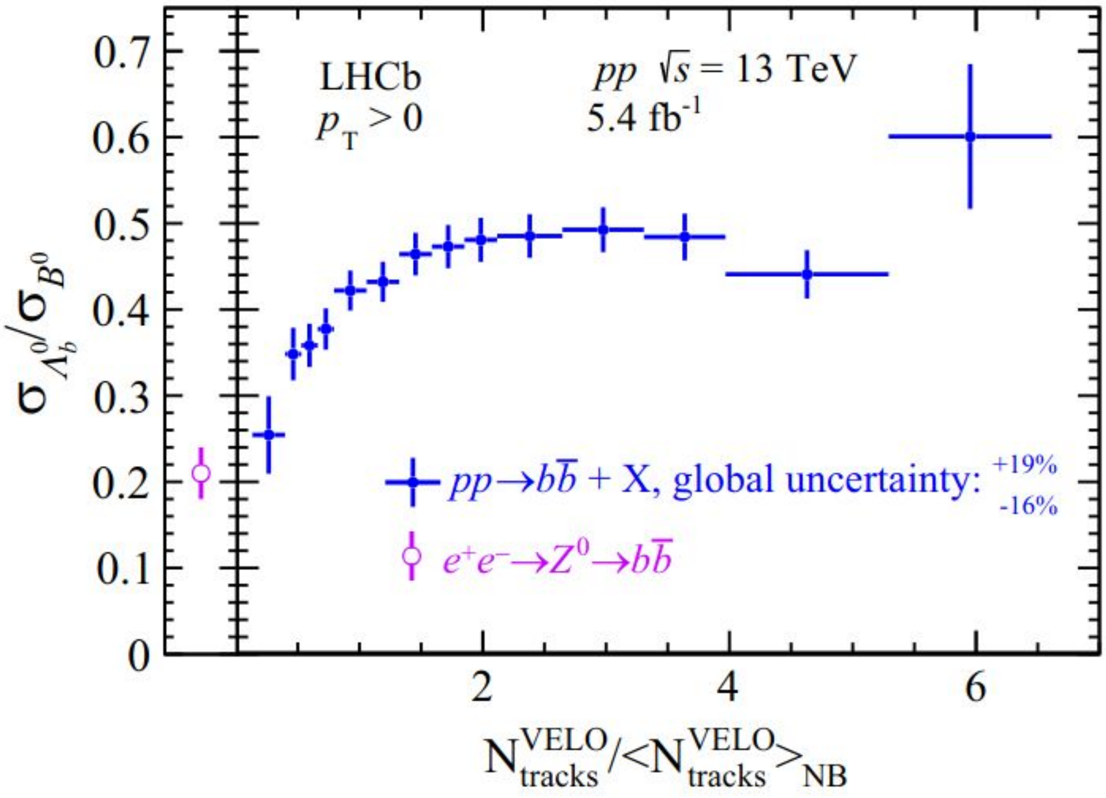
- Precision studies of **charm sequential suppression**, bottomonia, low-mass DY

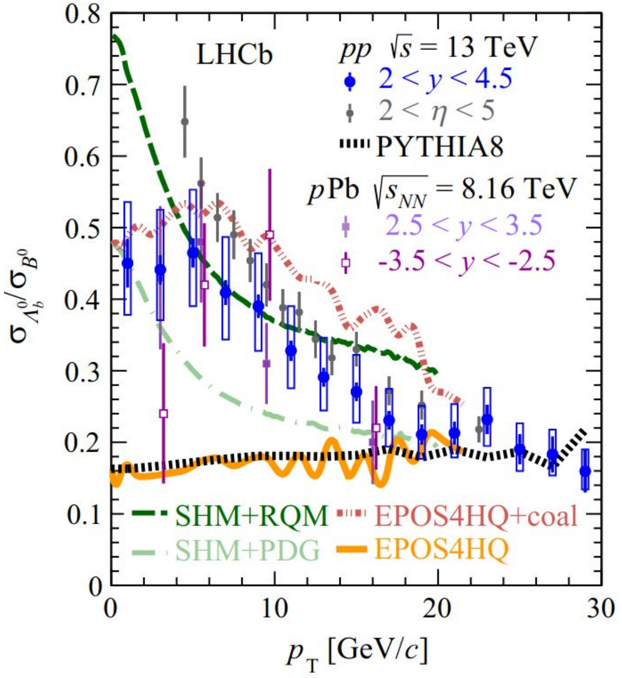
- Detailed study of the high-*x* **parton PDFs and probes for TMDs**
- High-statistics ultra-peripheral ρ, ω, charmonia and bottomonia states with **high-Z targets**
- Extension of the programme of cosmic rays interest: antimatter production in the galaxy **with H_2, D_2, He; atmospheric showers with N_2, O_2**

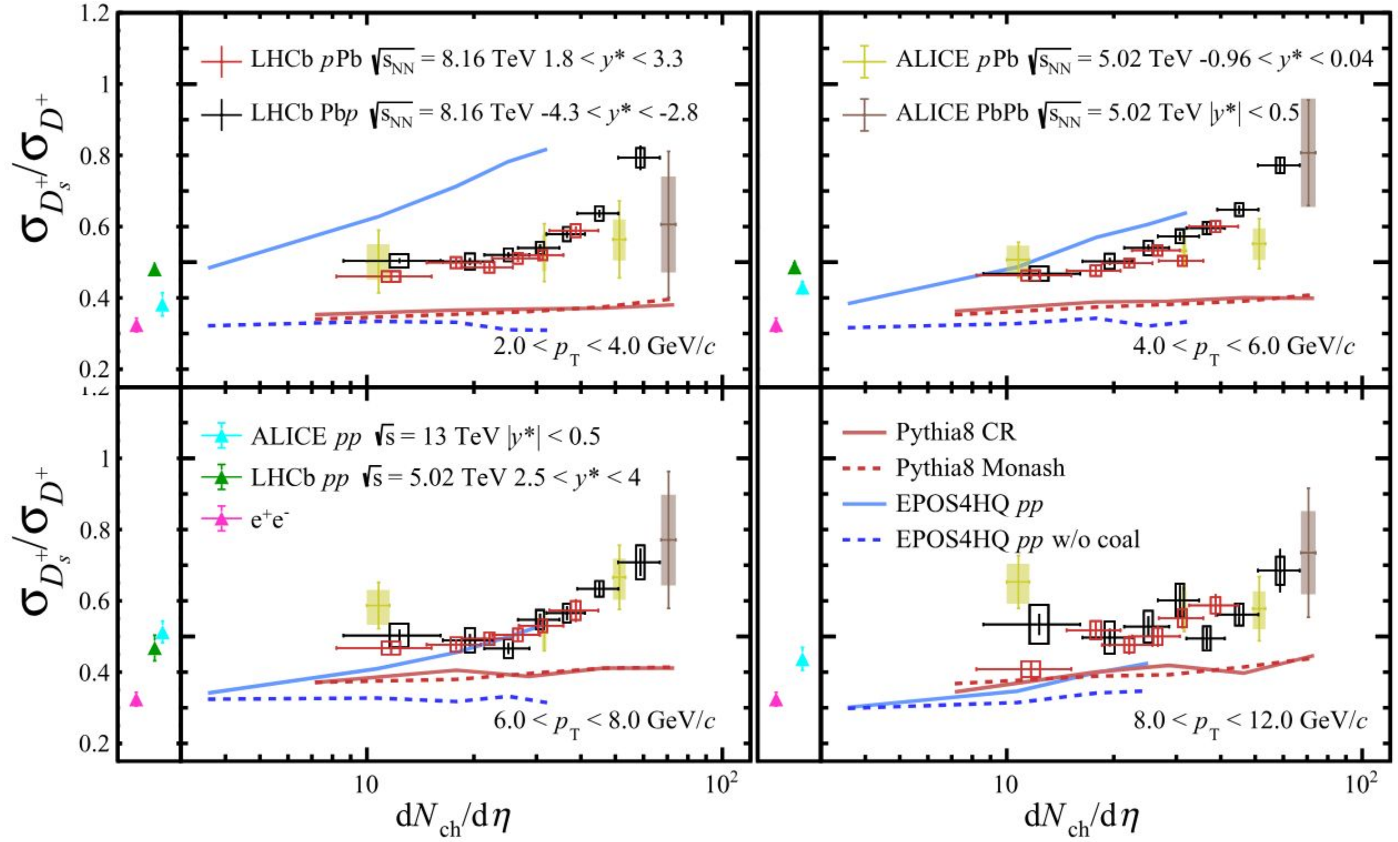
⇨ **A unique laboratory for many and diverse QCD studies at the LHC!**

Enhanced production of Λ_b baryons

PRL 132 (2024) 081901

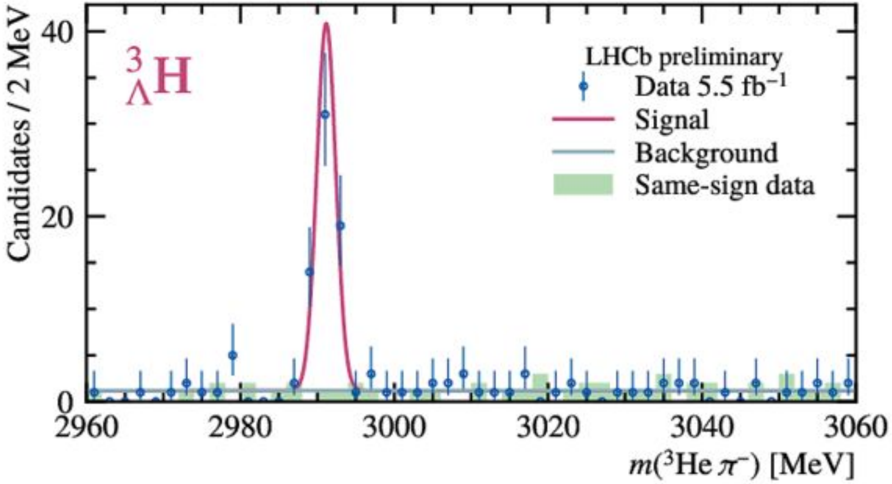


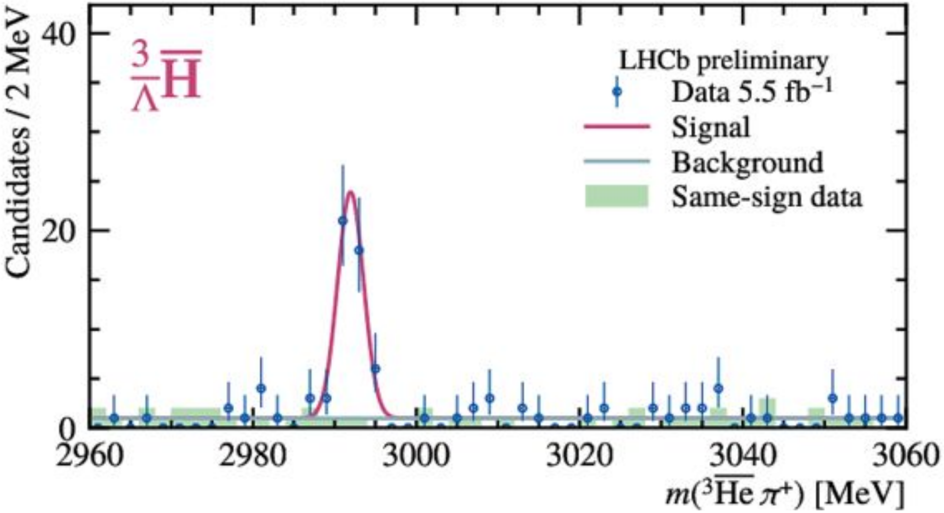




PRD 110 (2024) L031105

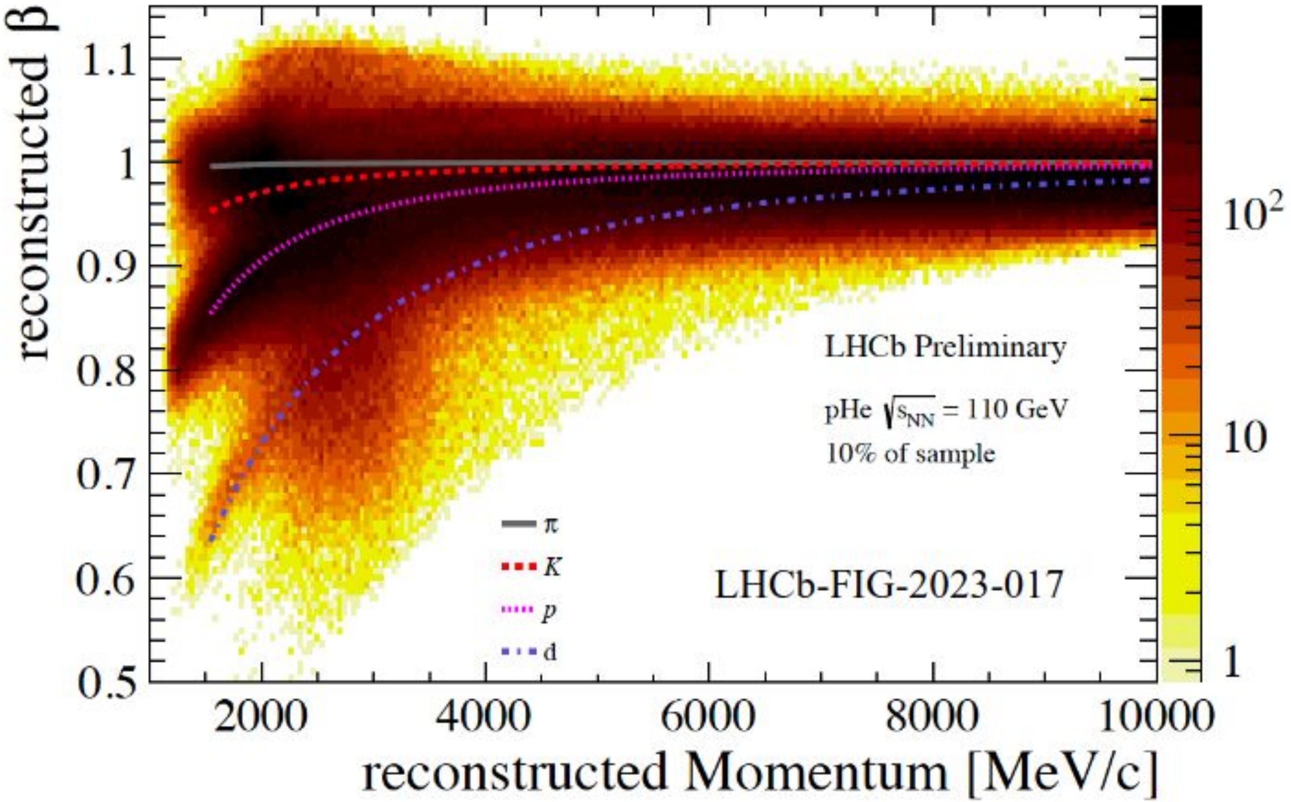
(Anti)hypertriton studies at LHCb





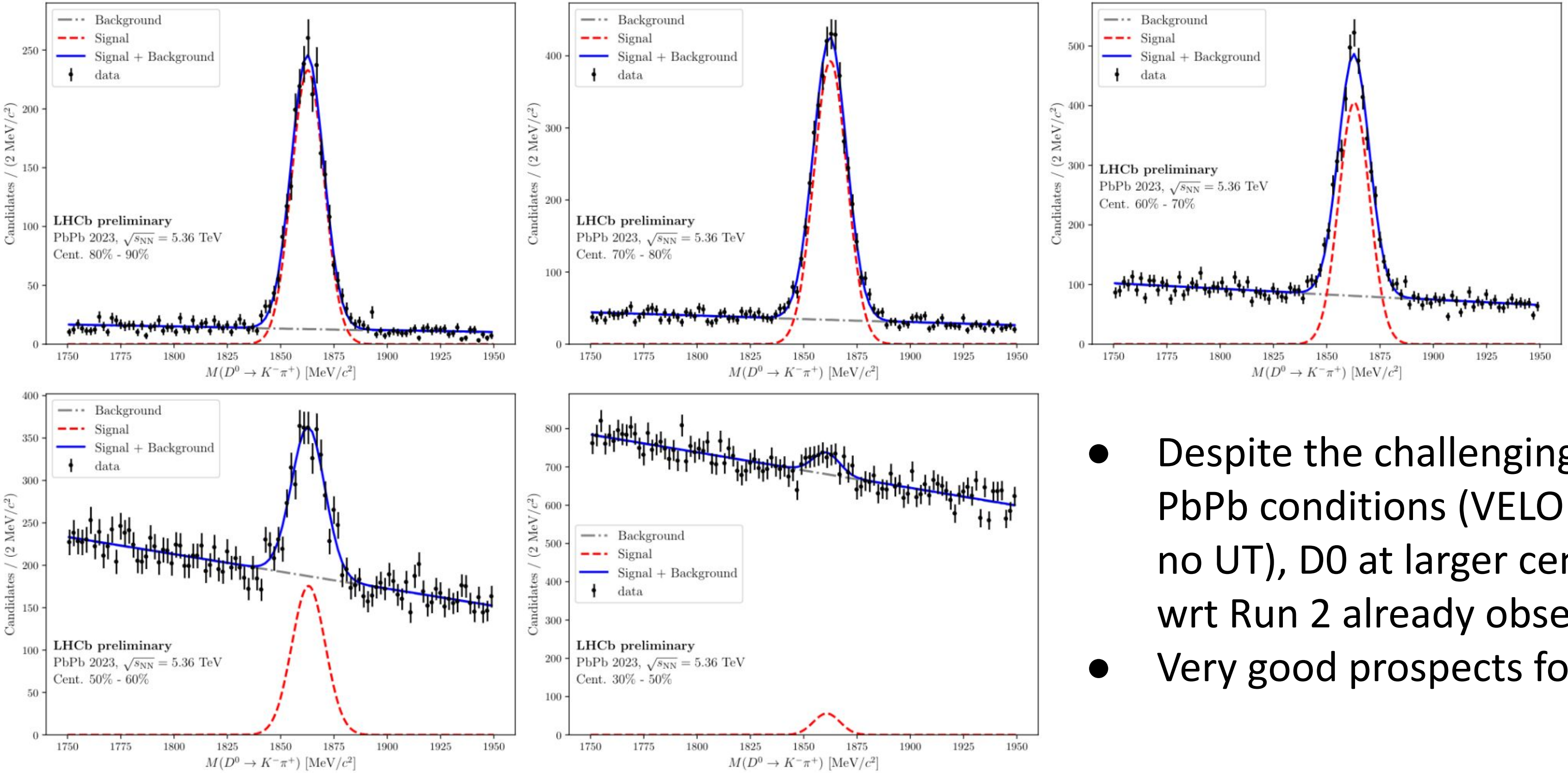
- Very clean sample of selected (anti)Helium nuclei + VELO pointing resolutions → very clean **anti-hypertriton peaks**!

Deuteron identification technique



- With SMOG *p*He data, deuteron nuclei identified via LHCb TOF capabilities
- First measurement of d production in *p*He collisions, largely impactful for the searches CR

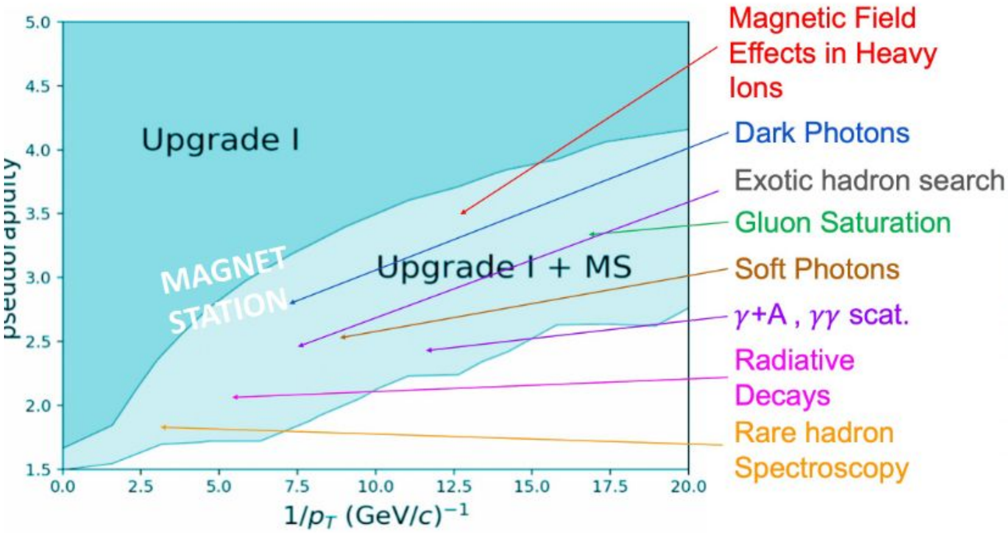
Charm mass peak in PbPb 2023

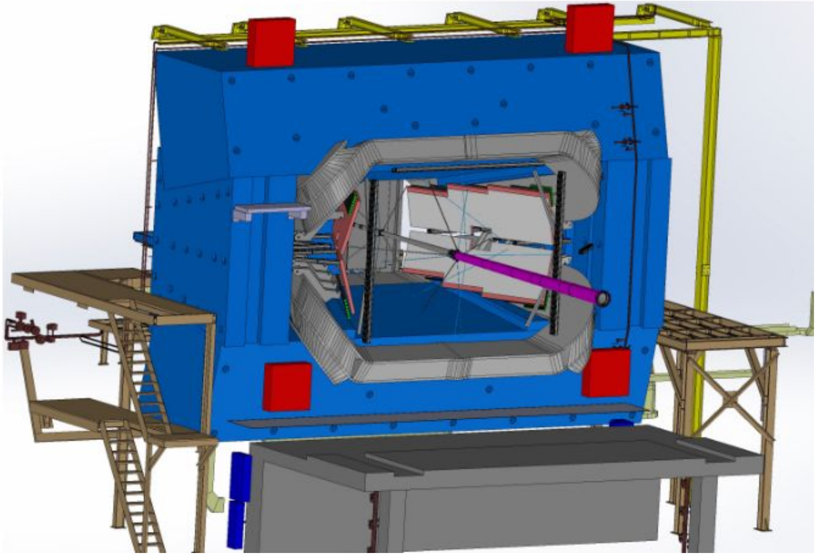


- Despite the challenging 2023 PbPb conditions (VELO open, no UT), D0 at larger centralities wrt Run 2 already observed!
- Very good prospects for 2024

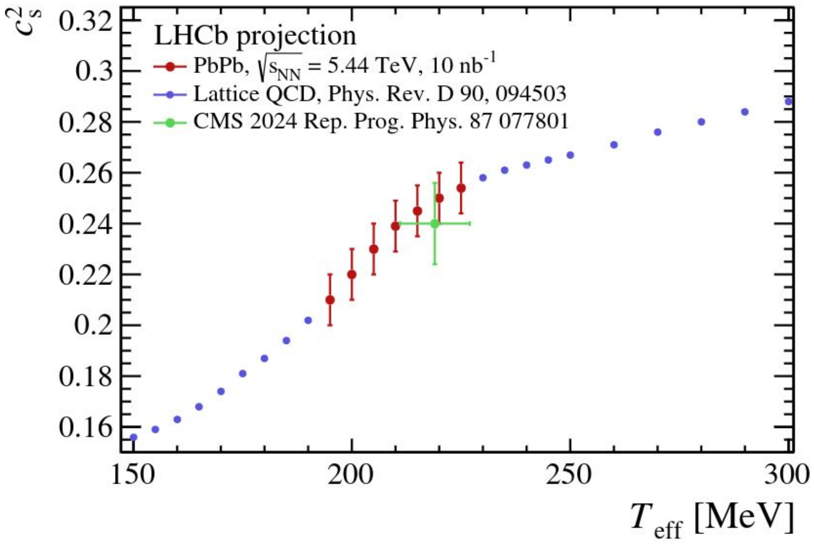
Magnet stations

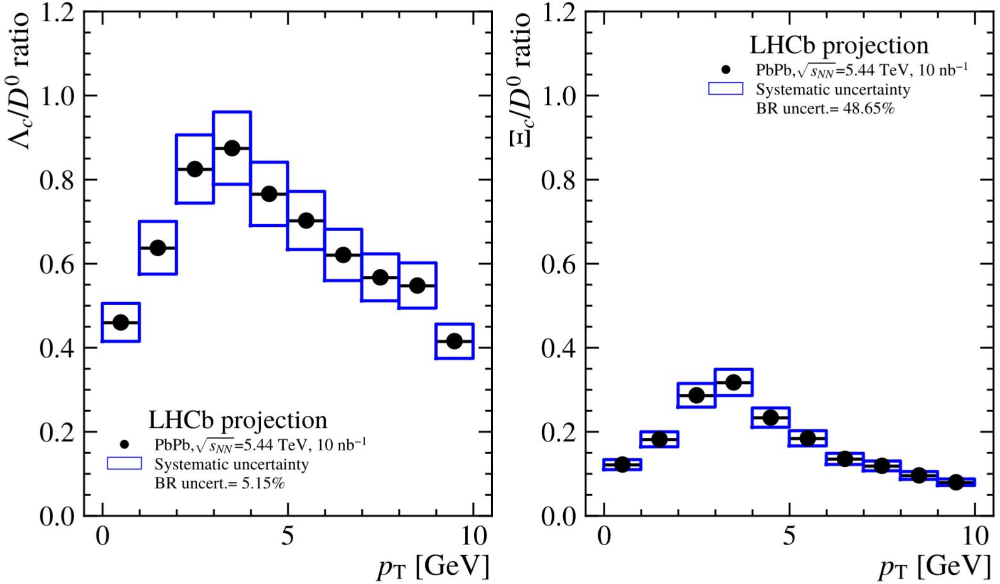
- Scintillating bar tracker for very soft particles at LHCb, start installation LS3
- Expands soft physics channels previously unreachable at the LHC.
- Allows access to very low x, Q^2 region where gluon saturation may exist in nuclei.





Some other opportunities for LHCb UII





- bulk physics → speed of sound
- open charm baryon-to-meson ratios

Prospects for LHCSpin (I)

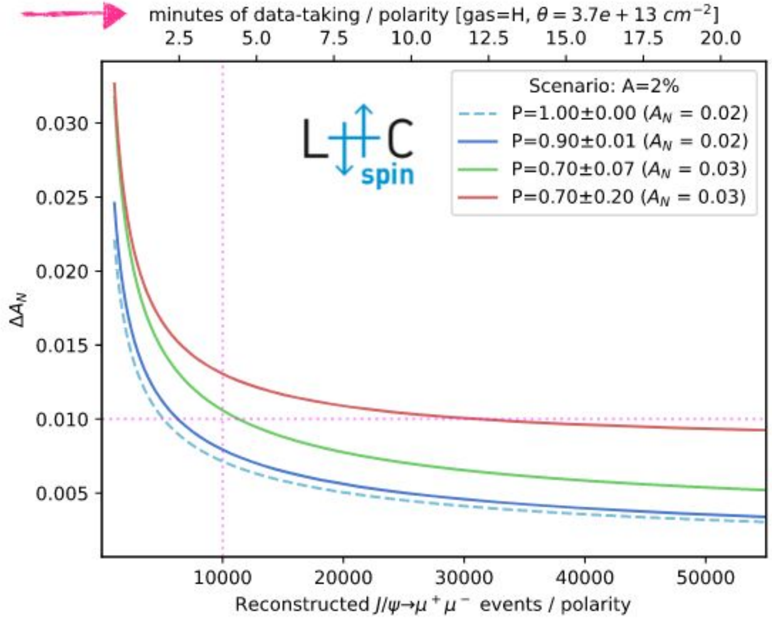
Channel	Events / week	Total yield
$J/\psi \to \mu^+\mu^-$	1.3×10^7 !!	1.5×10^9
$D^0 \to K^-\pi^+$	6.5×10^7	7.8×10^9
$\psi(2S) \to \mu^+\mu^-$	2.3×10^5	2.8×10^7
$J/\psi J/\psi \to \mu^+\mu^-\mu^+\mu^-$ (DPS)	8.5	1.0×10^3
$J/\psi J/\psi \to \mu^+\mu^-\mu^+\mu^-$ (SPS)	2.5×10^1	3.1×10^3
Drell Yan ($5 < M_{\mu\mu} < 9$ GeV)	7.4×10^3	8.8×10^5
$\Upsilon \to \mu^+\mu^-$	5.6×10^3	6.7×10^5
$\Lambda_c^+ \to pK^-\pi^+$	1.3×10^6	1.5×10^8

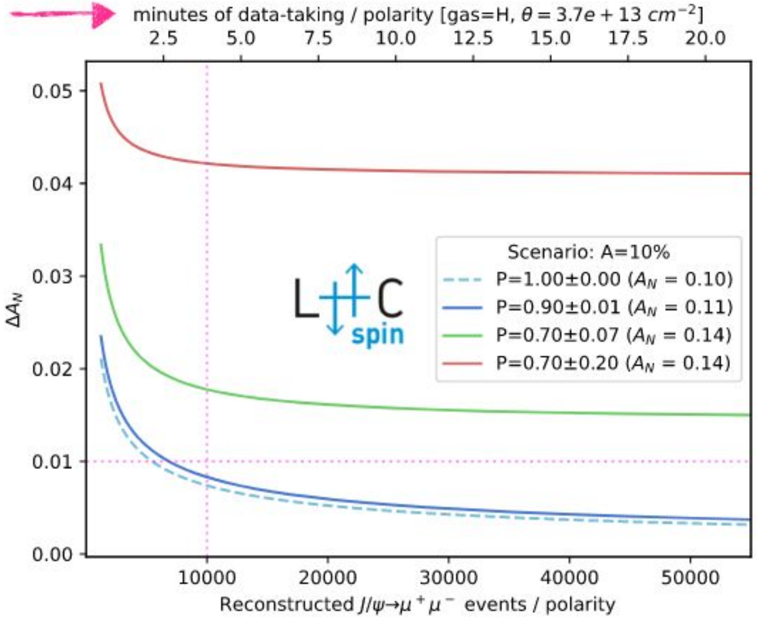
- **Unique prospects for TMD models!**

- By scaling 2022 performance (during commissioning) and assuming Run3 beam, 120 weeks of data-taking with 84h/week and expected LHCSpin areal density (3.7 10^{13}/cm^2)
- **Very large statistics of fully-reconstructed and selected events**!
- Lighter states also fine with the jet target option (x0.4 factor to be considered), challenging to get double J/ψ production

Prospects for LHCSpin (II)

$$A_N = \frac{1}{P}\frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}}$$





- Can reach very precise measurement in a few minutes of data-taking!