Latest measurements of heavy-flavour production in heavy-ion collisions at LHCb

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on behalf of the LHCb collaboration

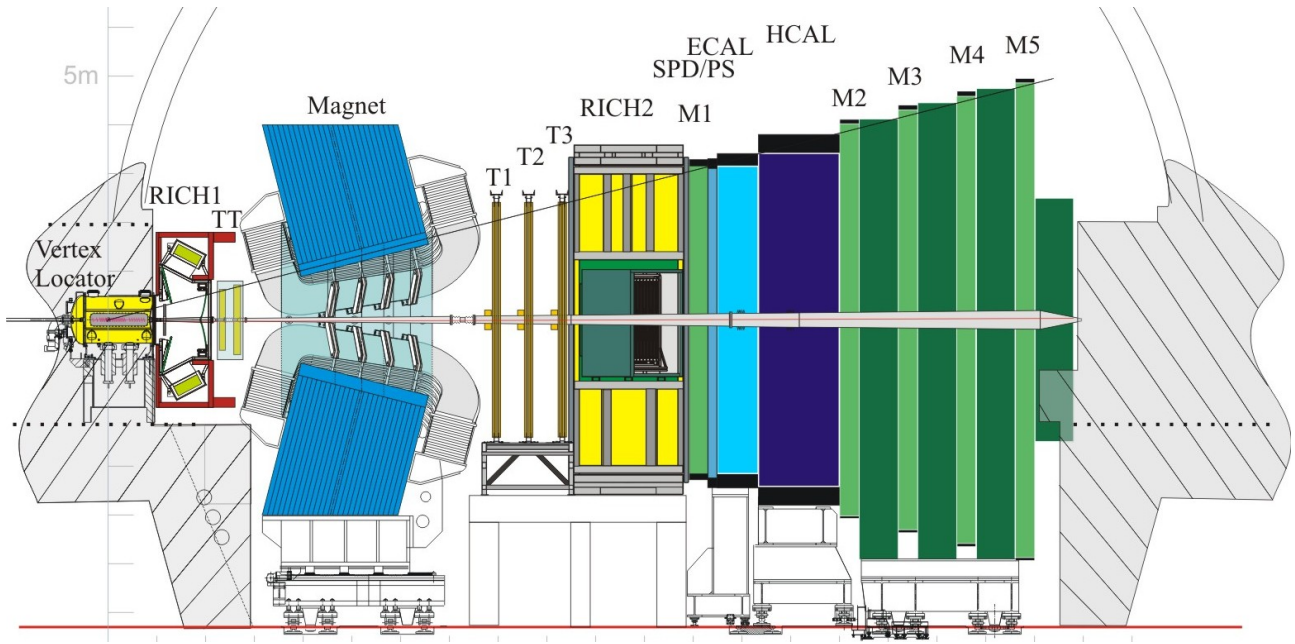
December 7, 2024

1. LHCb detector for heavy-ion physics
2. Open heavy-flavour production
3. Heavy quarkonia production
4. Charm production in fixed-target collisions
5. LHCb in Run3
6. Summary and prospect

LHCb detector

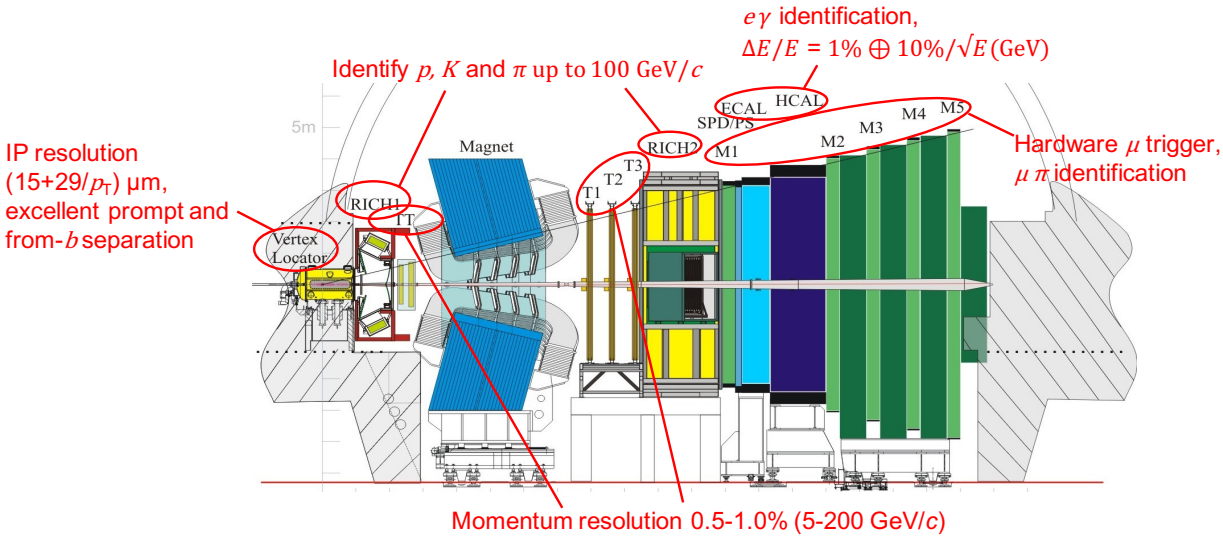
JINST 3 (2008) S08005
IJMPA 30 (2015) 1530022

- Single-arm forward spectrometer, covering the pseudo-rapidity range of $2 < \eta < 5$
- Designed for studying particles containing b or c quarks
- Playing more and more important roles in heavy-ion physics

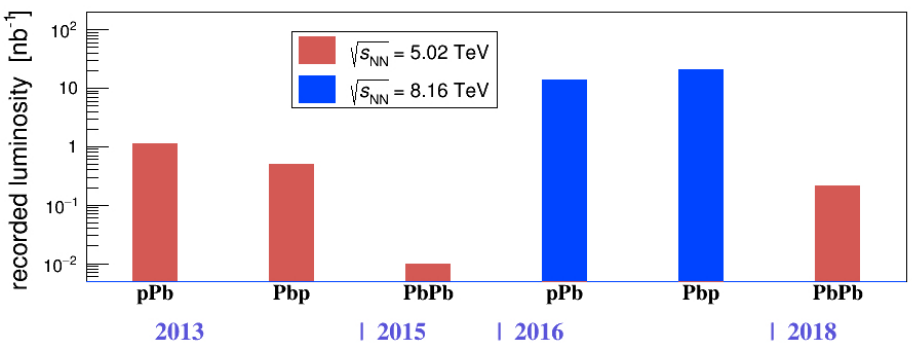


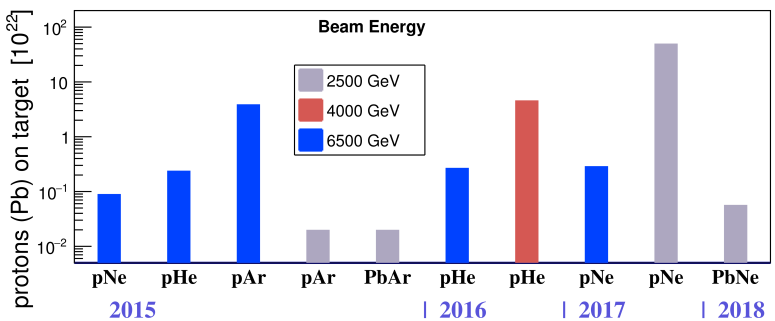
LHCb detector

- Provide excellent vertex reconstruction and seperation, precise tracking, full PID, efficient and fast trigger, and unique acceptance for heavy-ion physics



- Beam-gas fixed target mode can be aquired by injecting gases in VELO detector

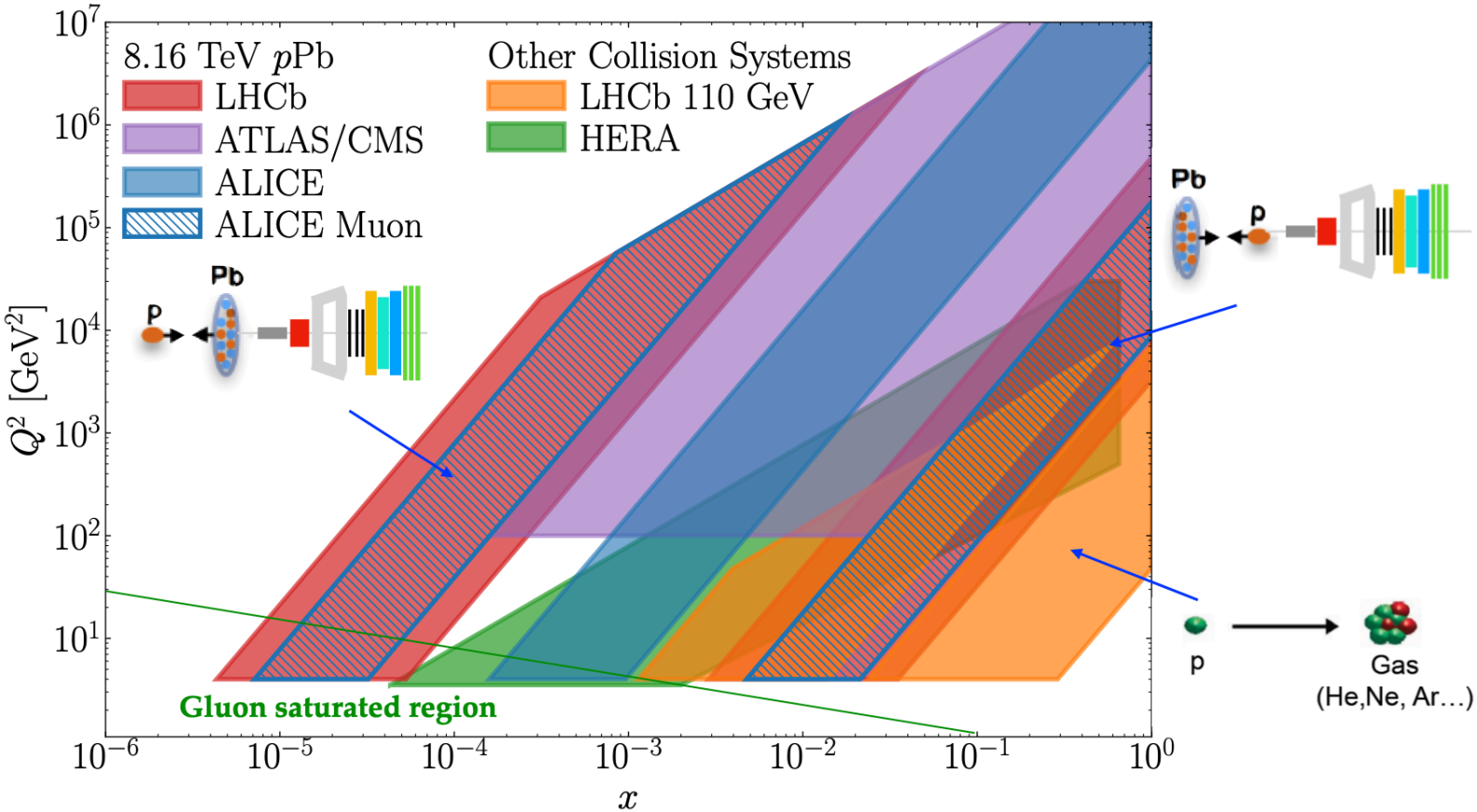




- Huge pp collision datasets for small-system studies

LHCb acceptance

- Unique kinematic coverage of low-x (pPb), medium-x (Pbp) and large-x (fixed target) regions



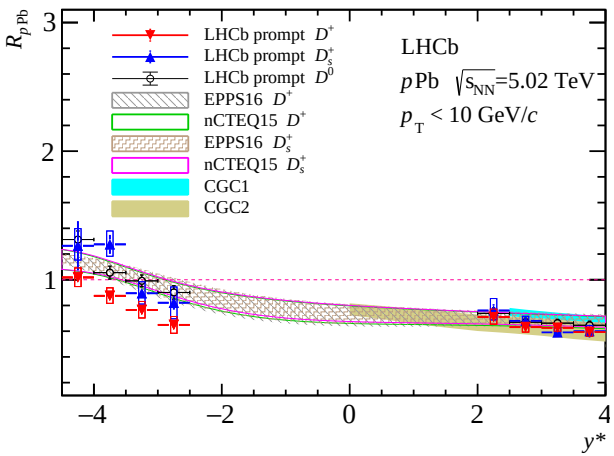
Open heavy-flavour production

- Prompt D^+ and D_s^+ in 5.02 TeV pPb: JHEP01(2024)070
- Prompt D^+ and D_s^+ in 8.16 TeV pPb: Phys.Rev.D110,L031105
- Prompt Ξ_c^+ in 8.16 TeV pPb: Phys.Rev.C109(2024)044901
- Λ_b^0/B^0 in 13 TeV pp: Phys.Rev.Lett.132(2024)081901

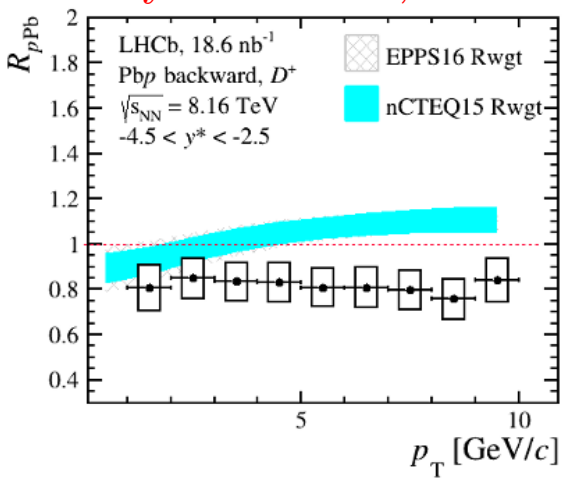
Modification of nPDFs in pPb

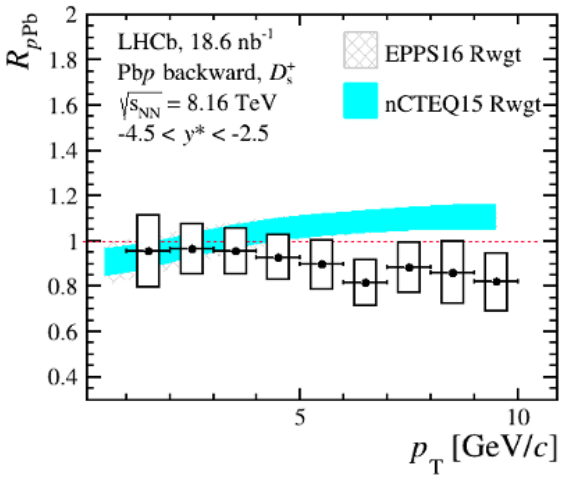
- Nuclear modification factor $R_{p\mathrm{Pb}}$ of charm hadrons help to constrain gluon nPDF below $x \sim 10^{-5}$

JHEP01(2024)070



Phys.Rev.D110,L031105



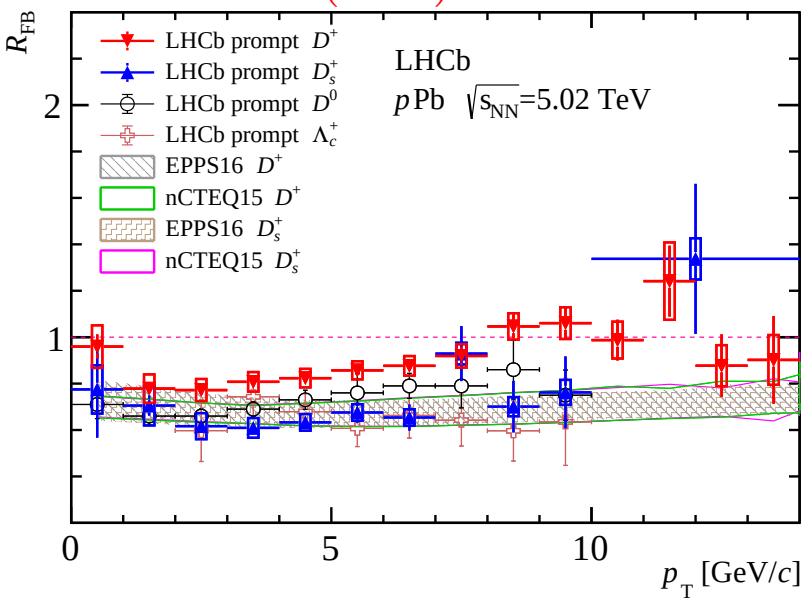


- Significant suppression at forward rapidity
- Slight differences between hadron species at backward, hinting at possible final-state effects

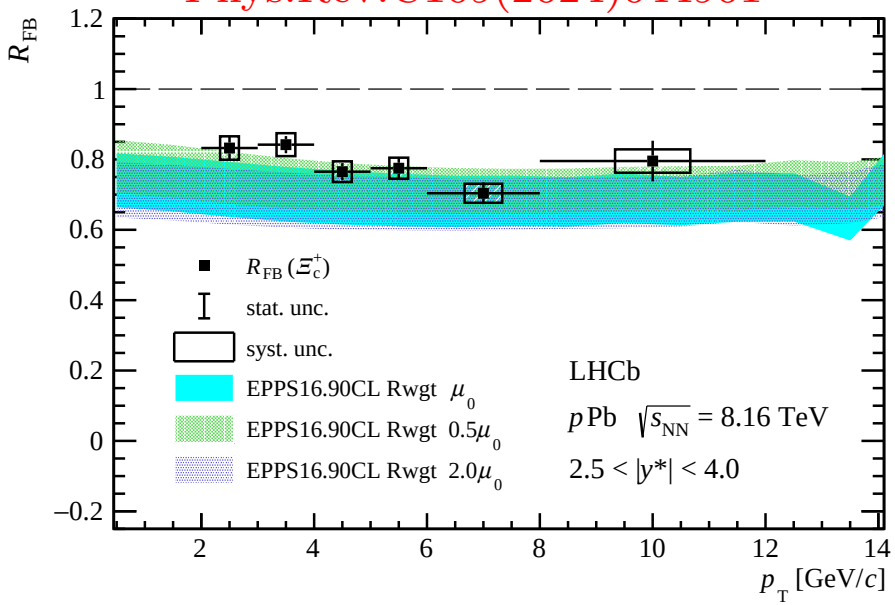
Modification of nPDFs in pPb

- Forward-backward production ratio can be calculated without pp reference

JHEP01(2024)070



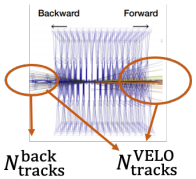
Phys.Rev.C109(2024)044901

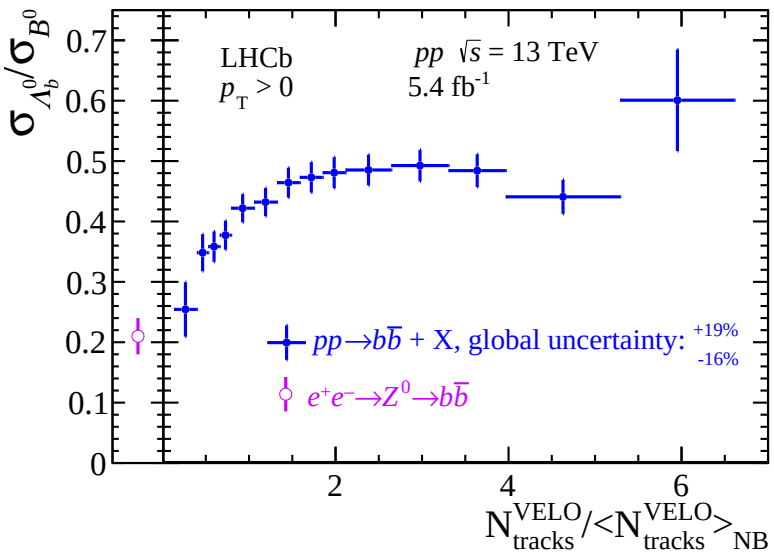


- The suppression at forward rapidity well reproduced by nPDF predictions
- Different trend towards high p_T for different hadrons

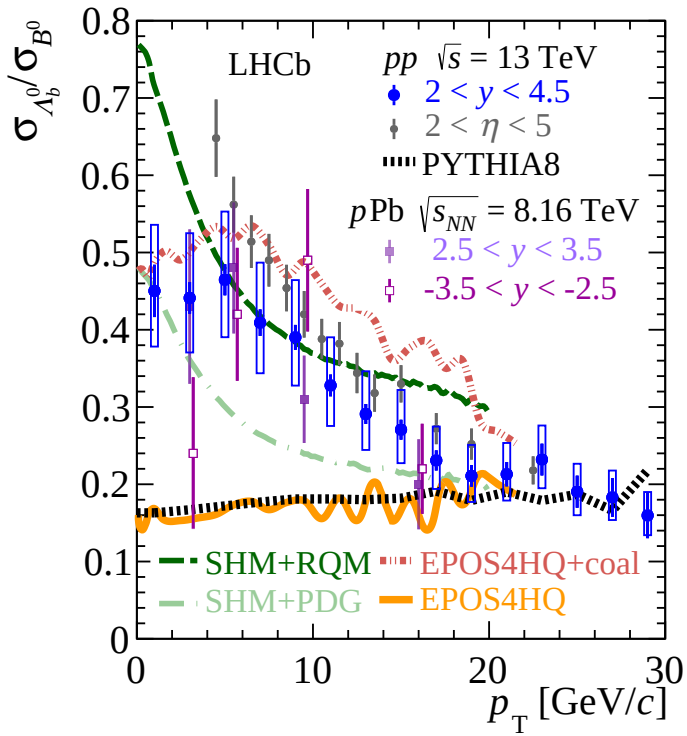
Baryon-to-meson ratio

- Enhanced baryon production considered as a signature of modification of hadronisation and existence of quark coalescence





Phys.Rev.Lett.132(2024)081901

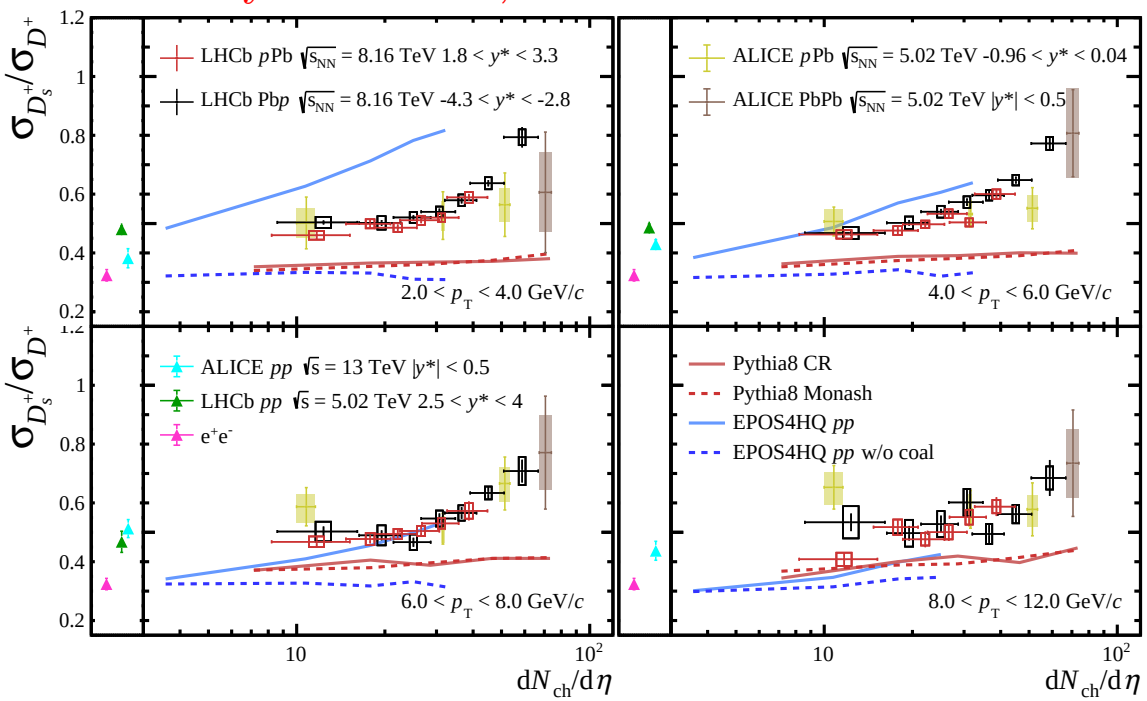


- Significant increasing trend of Λ_b^0/B^0 with multiplicity, suggesting the contribution from coalescence in addition to fragmentation in b quark hadronisation
- Λ_b^0/B^0 less enhanced at high p_T, where fragmentation is expected to become donimant

Strangeness ratio

- Strangeness enhancement is another signature of quark coalesence due to abundant $s\bar{s}$ pairs in medium

Phys.Rev.D110,L031105

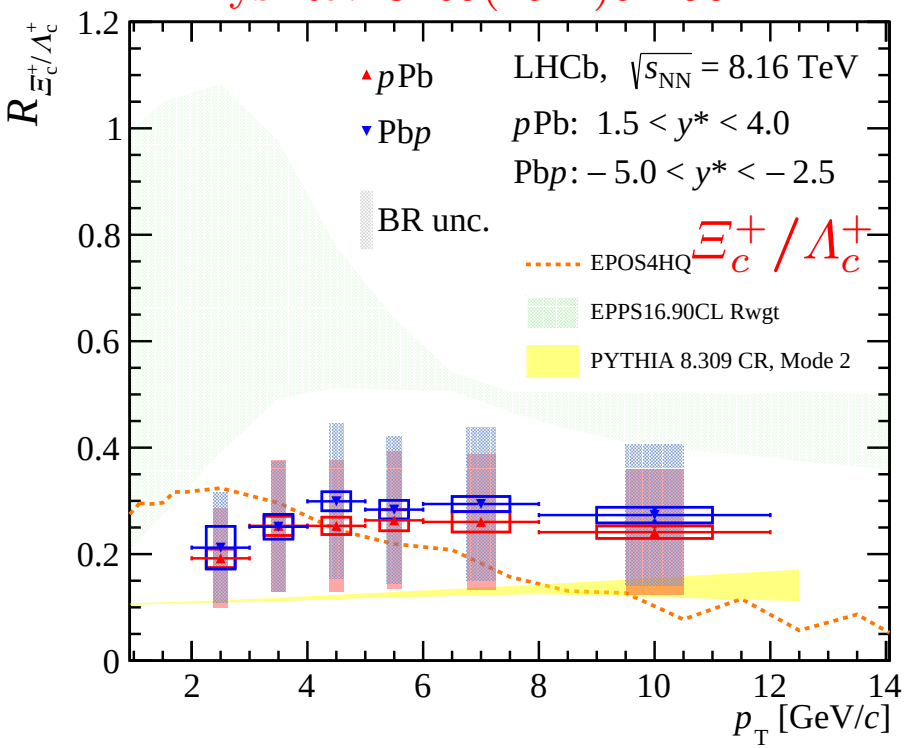


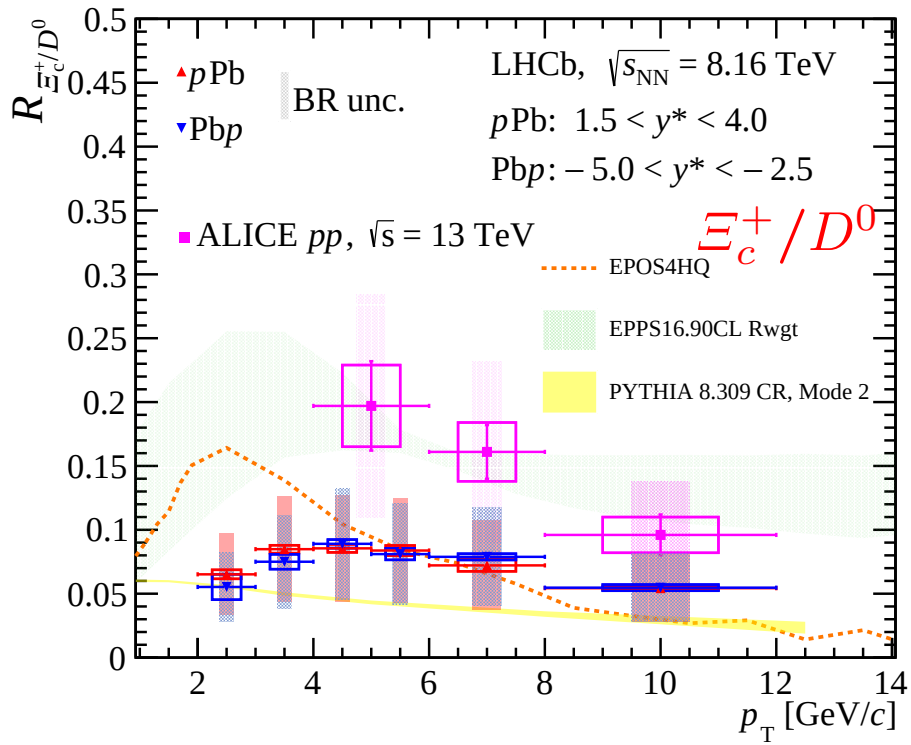
- First observation of strangness enhancement for charm production in small systems, consistent with the evidence from B_s^0/B^0 ratio
- Coalescence contribution need to be considered for a better description of data points

Ξ_c^+/Λ_c^+ and Ξ_c^+/D^0 production ratio

- Aim to study strangeness enhancement and modification of baryon-to-meson ratio at the same time in pPb

Phys.Rev.C109(2024)044901





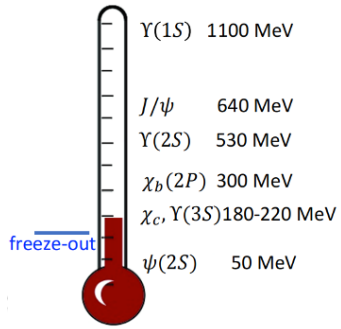
- No significant dependence on p_T of $R_{\Xi_c^+/\Lambda_c^+}$ and $R_{\Xi_c^+/D^0}$
- Discrepancy with ALICE results, hinting at rapidity dependence of the ratio

Heavy quarkonia production

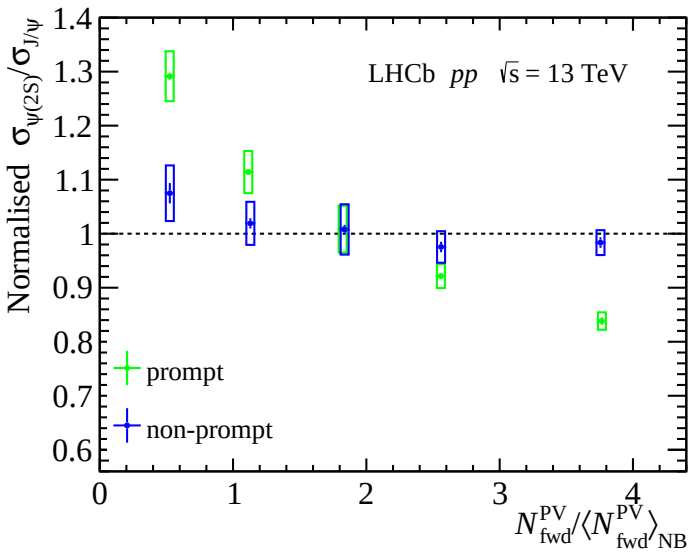
- Prompt $\psi(2S)/J/\psi$ with multiplicity in 13 TeV pp: JHEP05(2024)243
- Prompt and non-prompt $\psi(2S)$ in 8.16 TeV pPb: JHEP04(2024)111
- Prompt $\psi(2S)/J/\psi$ with centrality in 5.02 TeV PbPb: arXiv:2411.05669
- $\Upsilon(3S)$ and $\Upsilon(2S)/\Upsilon(1S)$ with multiplicity in 13 TeV pp: LHCb-PAPER-2024-038, in preparation
- χ_c into prompt J/ψ in 8.16 TeV pPb: Phys.Rev.Lett.132(2024)102302
- $\chi_{c1}(3872)$ and $\psi(2S)$ in 8.16 TeV pPb: Phys.Rev.Lett.132(2024)242301
- Exotic $J/\psi\,\phi$ resonance in CEP pp: arXiv:2407.14301

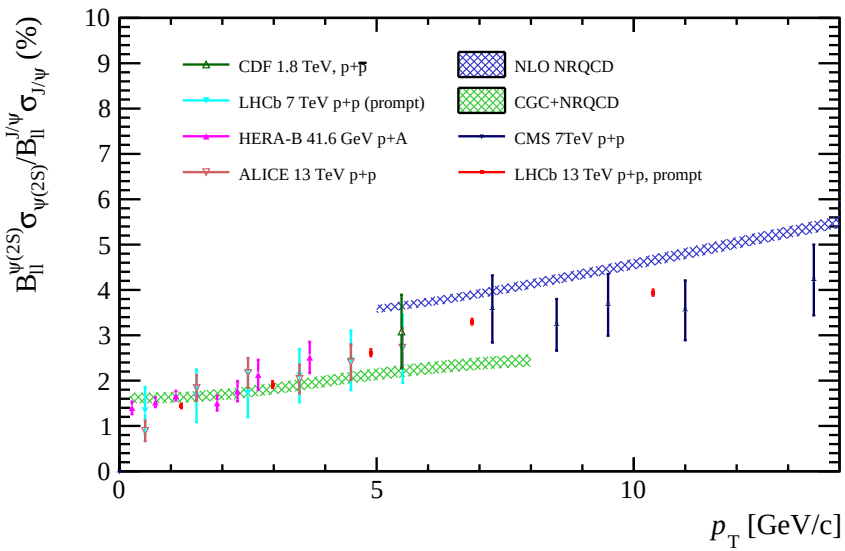
$\psi(2S)/J/\psi$ ratios in pp

- Heavy quarkonia considereda as a thermometer for studying the local temperature where it is produced
- Various bounding energies from 50 MeV to 1 GeV for heavy quarkonia



JHEP05(2024)243



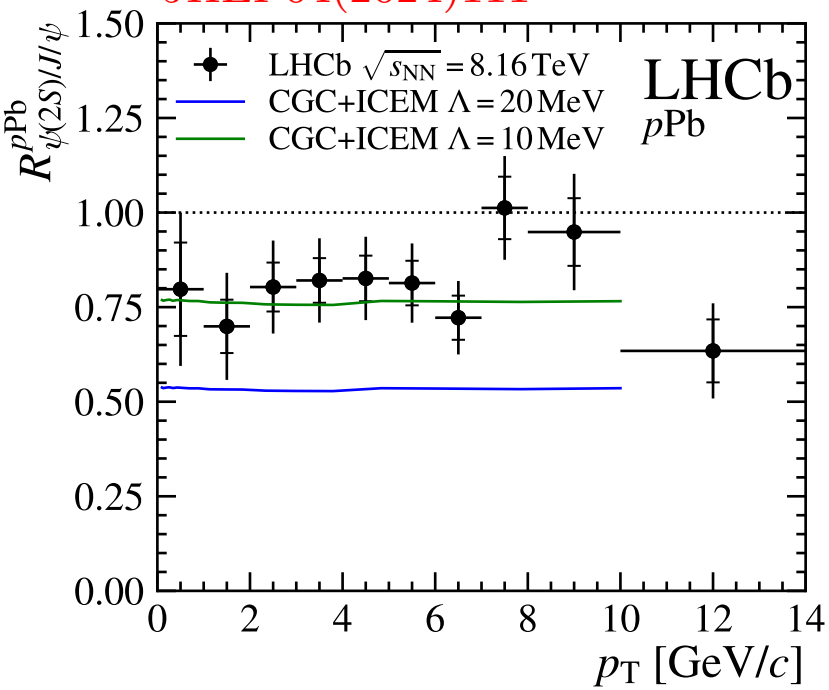


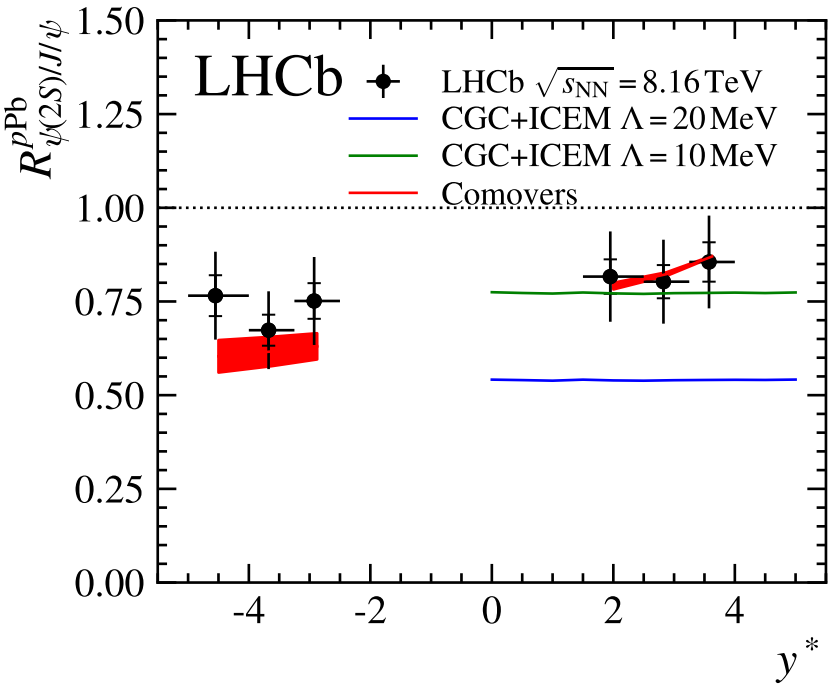
- Decreasing trend of prompt $\psi(2S)/J/\psi$ ratios with multiplicities, indicating that $\psi(2S)$ are more significantly broken by comoving particles
- Independent of multiplicities for non-prompt ratio
- Consistent ratios with p_T across different experiments

$\psi(2S)/J/\psi$ ratios in pPb

- Making comparisons of $R_{p\mathrm{Pb}}$ for J/ψ and $\psi(2S)$ states to cancel initial-state effects

JHEP04(2024)111

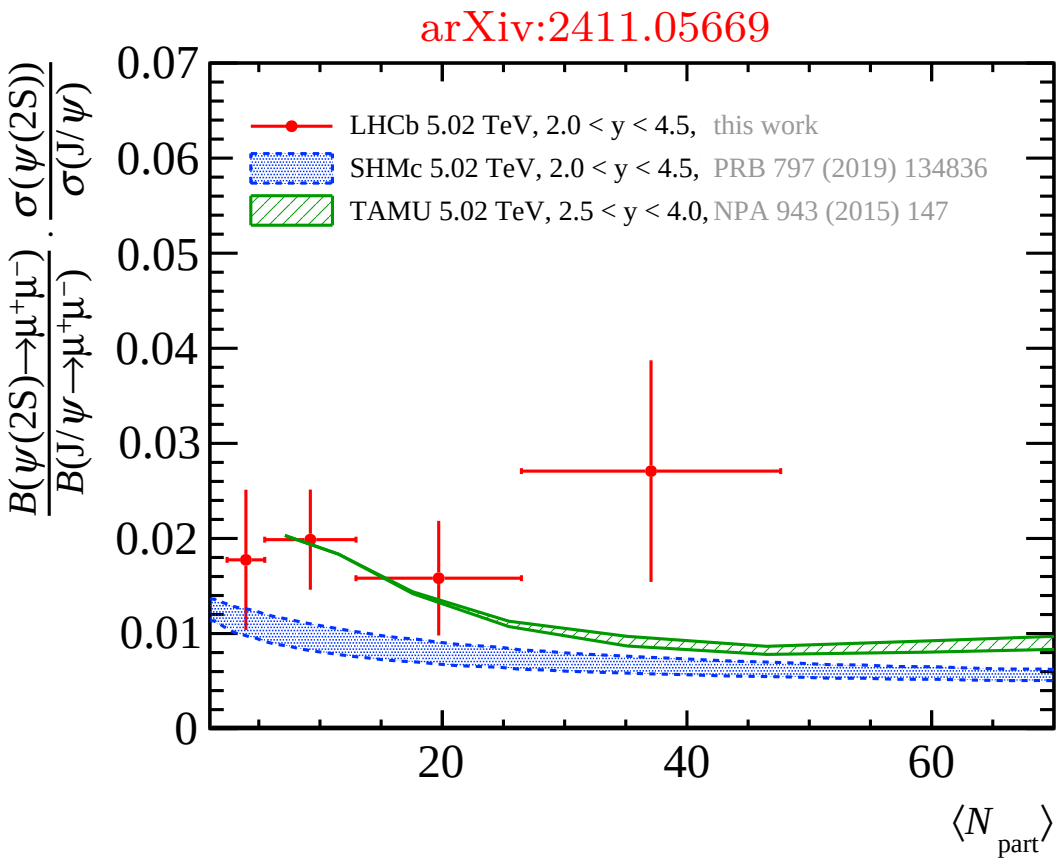




- A flat trend with p_{T}, generally reproduced by CGC models incorporating improved Color Evaporation Model (ICEM) with appropriate parameters
- Dependence with multiplicities and comparison with pp coming soon

$\psi(2S)/J/\psi$ ratios in PbPb

- Regeneration becomes obvious when system size increases

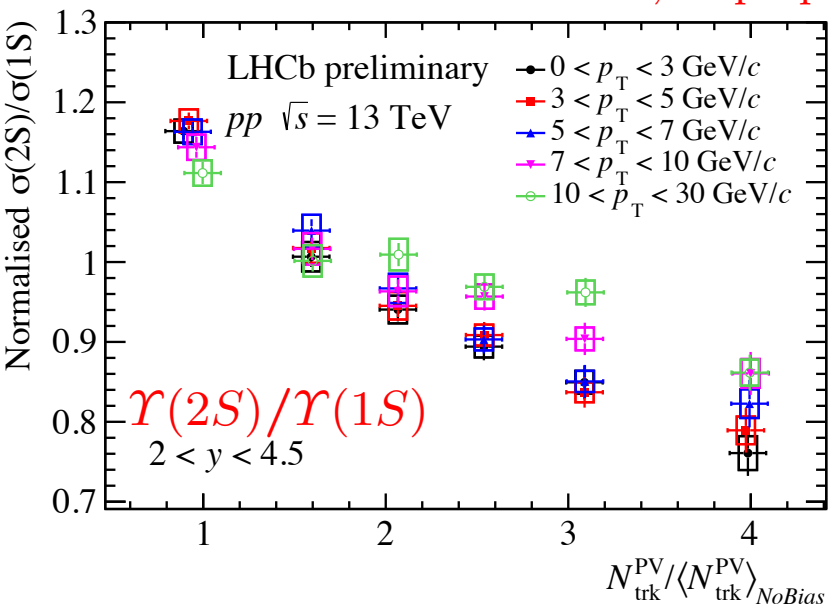


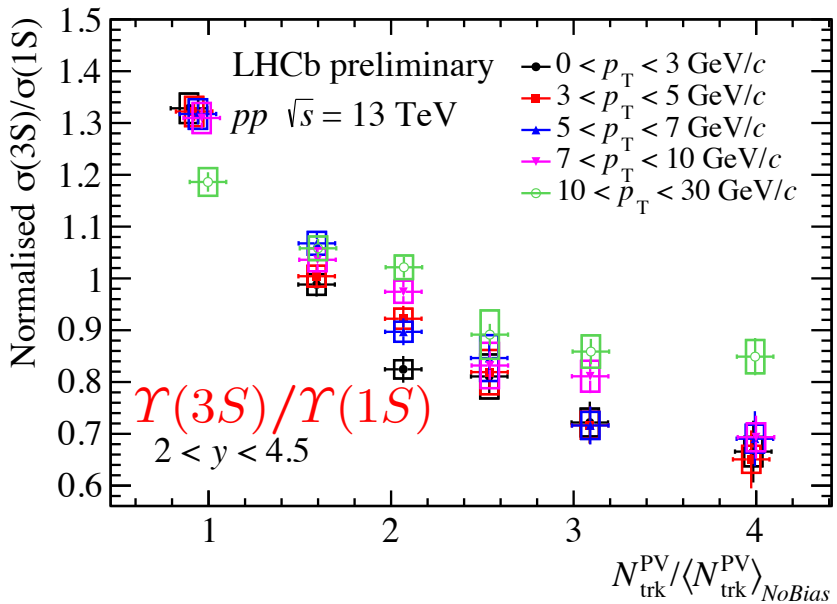
- Regeneration more possible to occur during medium evolution (TAMU) than during freeze-out (SHMc)
- With Run3 data, further investigation with higher precision and more central region will be accessible

$\Upsilon(2S)$ and $\Upsilon(3S)$ / $\Upsilon(1S)$ ratios

- Interactions with comoving particles dominate the nuclear effects in Υ production

LHCb-PAPER-2024-038, in preparation

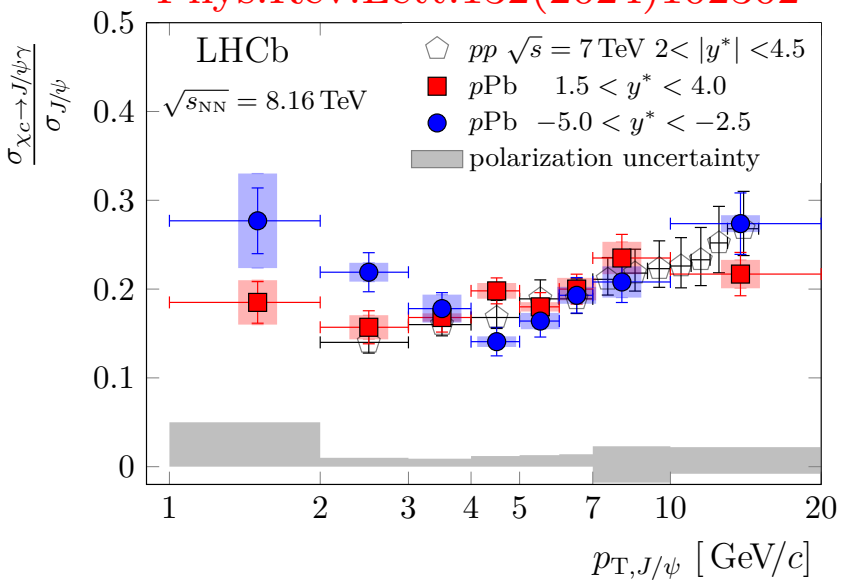


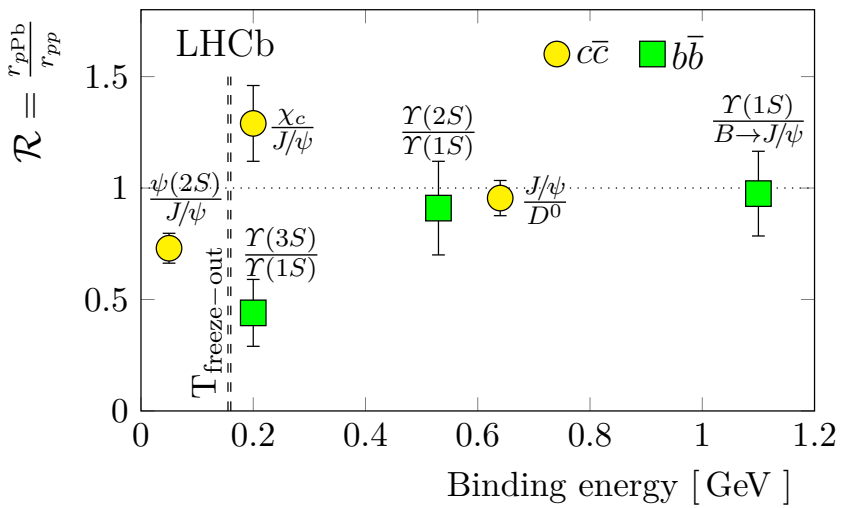


- Clear decreasing trend with multiplicity
- $\Upsilon(3S)$ found to be more suppressed with a sequential pattern
- About 35% $\Upsilon(2S)$ from $\chi_b(2P)$ and 40% $\Upsilon(3S)$ from $\chi_b(3P)$ according to previous χ_b measurement. Stronger suppression of $\Upsilon(3S)$ may originate from $\chi_b(3P)$ dissociation

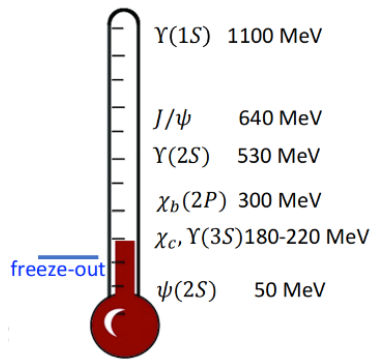
Fraction of χ_c decays in prompt J/ψ

Phys.Rev.Lett.132(2024)102302

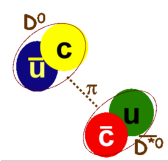




- No χ_c dissociation from final-state effects, suggesting that pPb collisions cannot inhibit the formation of charmonium with binding energy larger than 180 MeV
- χ_c states share similar binding energy (~ 180 MeV) with $\Upsilon(3S)$, while different double ratio measured
- $\chi_b(3P)$ dissociation can also explain this, which has a binding energy (~ 47 MeV) similar to $\psi(2S)$

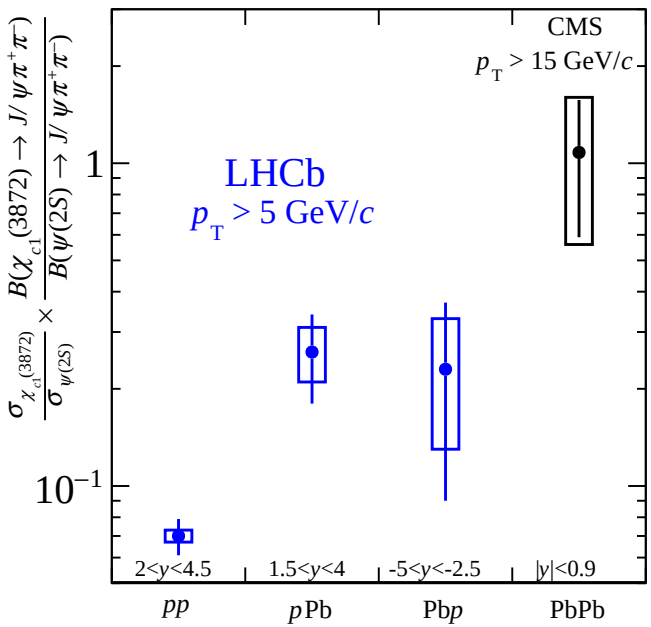


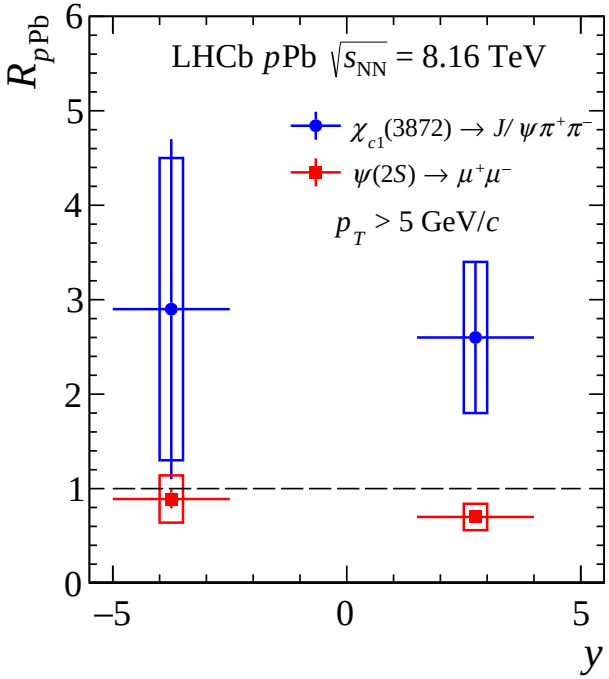
$\chi_{c1}(3872)$ production in pPb



- Heavy-ion collisions provide unique insights into structures of exotic states
- $\chi_{c1}(3872)$ state experiences different dynamics with conventional $\psi(2S)$ state

Phys.Rev.Lett.132,242301(2024)



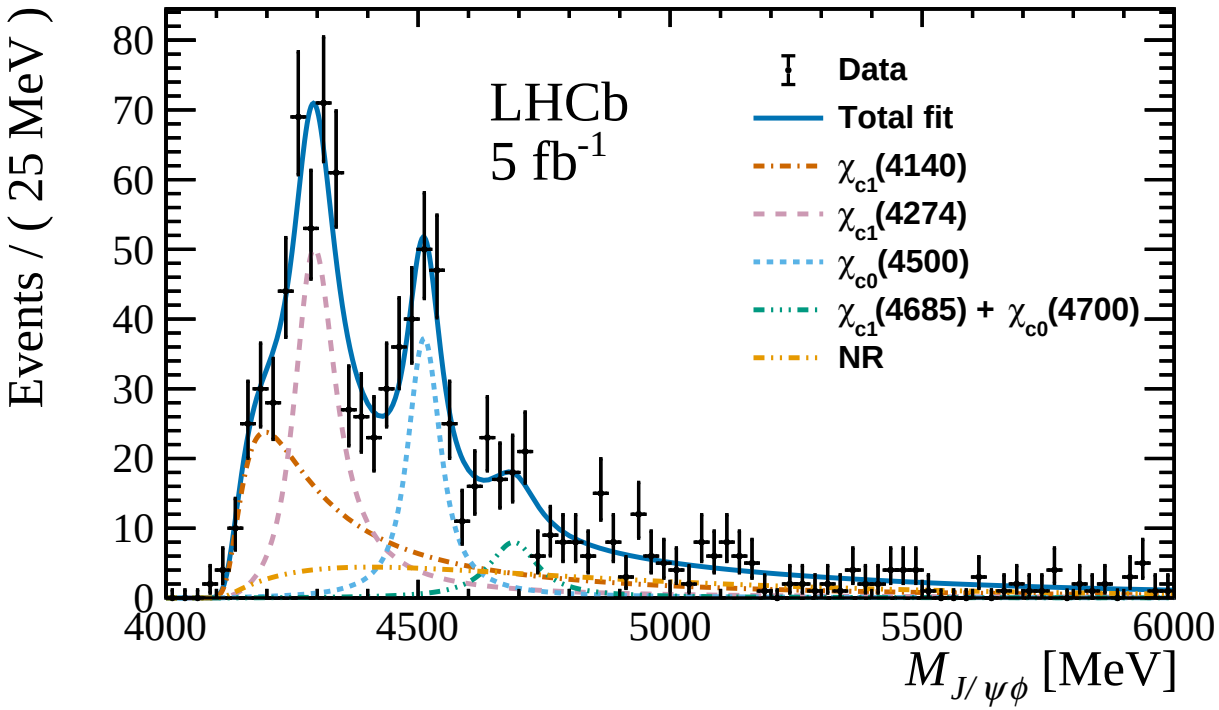


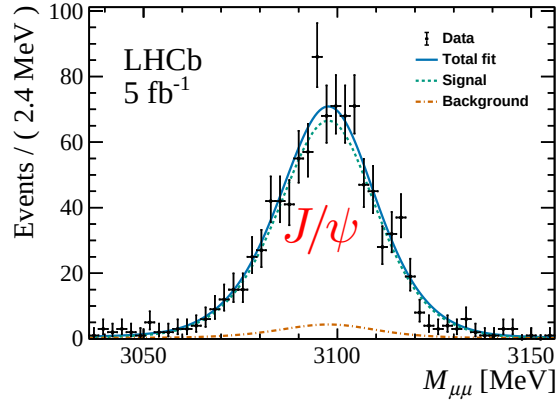
- Increasing trend with system size, different from the suppression with multiplicity in pp collisions, indicating that quark coalescence becomes dominant as system size increases

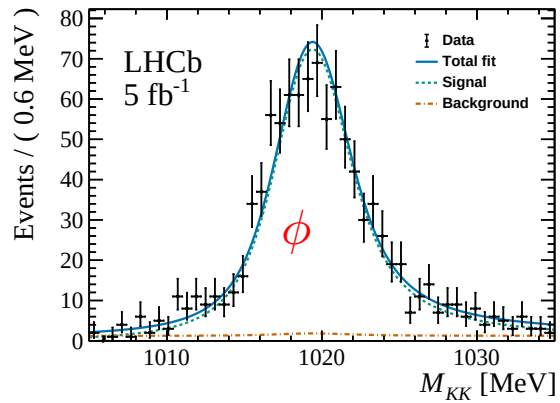
Exotic $J/\psi\,\phi$ resonance in CEP

- First observation of exotic hadrons in central exclusive pp collisions

arXiv:2407.14301







- Clean χ_c signals in $J/\psi\,\phi$ invariant mass spectrum with only four final-state tracks
- Provides new method to investigate exotic states with CEP/UPCs

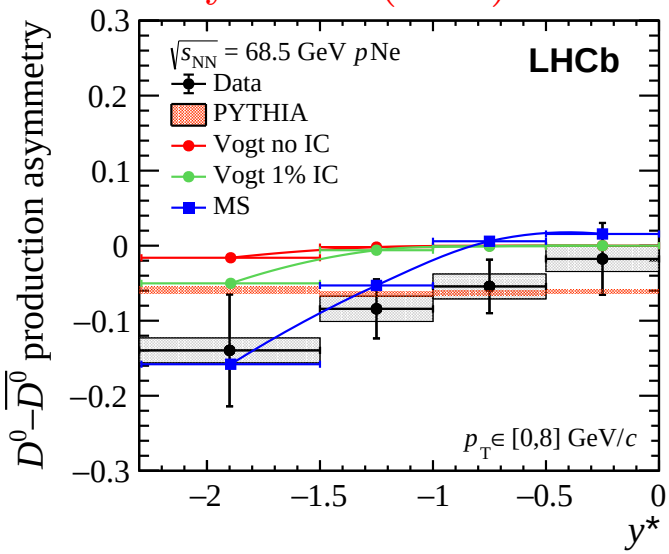
Charm production in fixed-target collisions

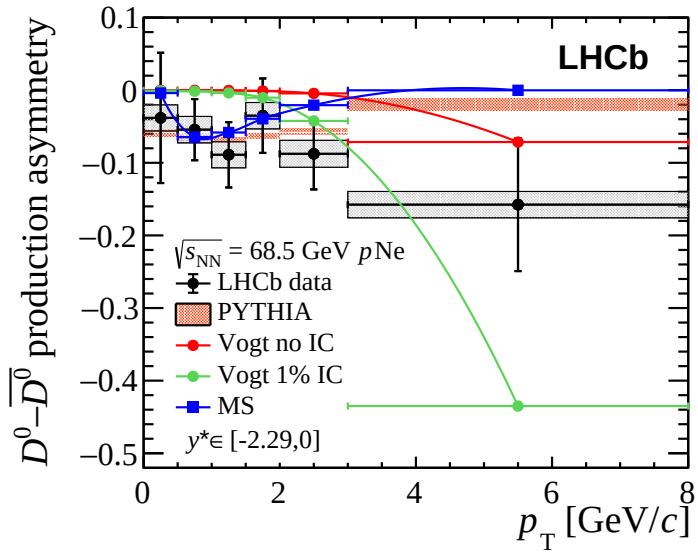
- $D^0 - \overline{D}^0$ asymmetry in 68.5 GeV pNe: Eur.Phys.J.C83(2023)541
- J/ψ and $\psi(2S)$ in 68.5 GeV pNe: Eur.Phys.J.C83(2023)625
- D^0 and J/ψ in 68.5 GeV PbNe: Eur.Phys.J.C83(2023)658

D^0-$\overline{D}^0$ production asymmetry in pNe

- Charm production involving high-x partons help to study intrinsic charm of nucleons and nPDFs at large x regions
  - *Intrinsic* charm: $c\bar{c}$ pairs as sea quarks of nucleons rather than from gluon splitting

Eur.Phys.J.C83(2023)541

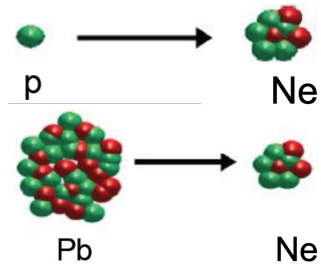




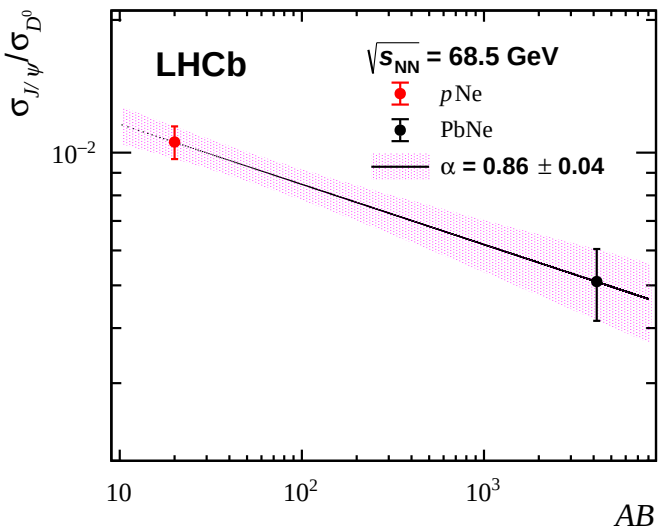
- Largest negative asymmetry of $\sim 15\%$ at $y^* \approx -2$
- MS model with 1% intrinsic charm and 10% recombination in good agreement with data

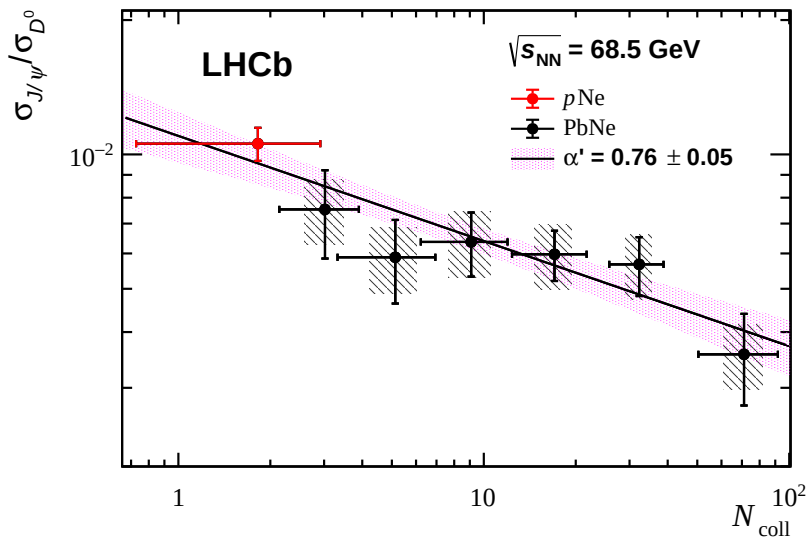
$J/\psi\,/D^0$ ratio in 68.5 GeV pNe and PbNe

- $J/\psi\,/D^0$ ratio measured as a function of collision size, where initial state effects on $c\bar{c}$ production canceled
  - AB: product of beam and target atomic mass number
  - $N_{\rm coll}$: number of binary nucleon-nucleon collisions



Eur.Phys.J.C83(2023)658



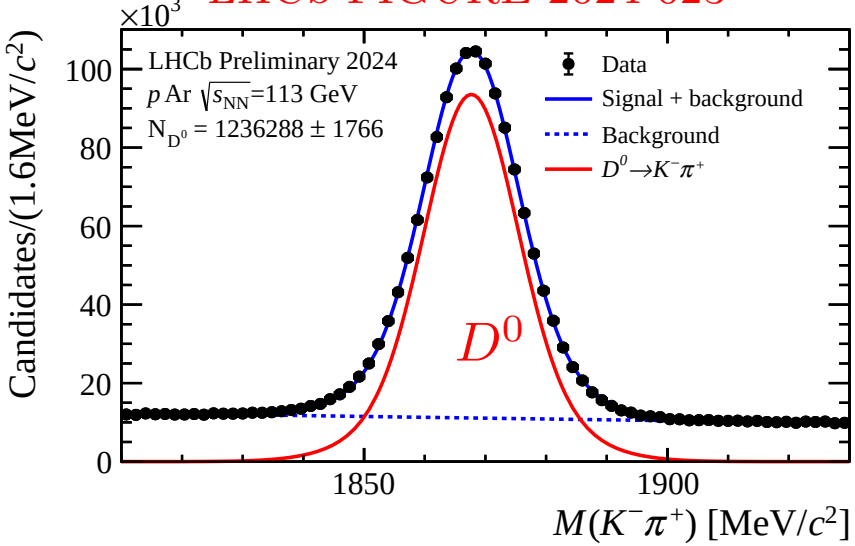


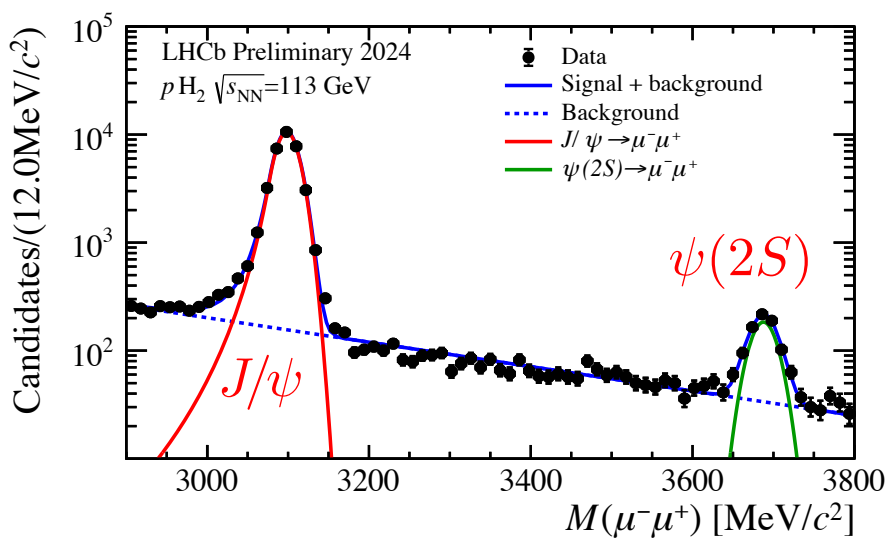
- The suppression with increasing collision size leads to $\alpha < 1$ and indicates additional nuclear effects of J/ψ than D^0 mesons
- Consistency of decreasing trend across pNe, peripheral PbNe and central PbNe collisions, with no evidence of anomalous suppression or QGP formation

Heavy flavour data in Run3

- Much larger sample size from the continuous beam-gas data-taking (SMOG2), which runs simultaneously with high-luminosity pp collisions
  - Large $p\mathrm{H}_2$ to pAr data collected
  - Significant optimisations for 2024 data-taking
- Clear D^0, J/ψ and $\psi(2S)$ peaks!

LHCb-FIGURE-2024-023





- Semi-central ($\sim 30\%$ centrality) data ideally accessible for PbPb 2024 data
- Full centrality for SMOG2 Pb-gas data

Summary and prospect

- Heavy flavour particles are sensitive to nuclear matter effects in heavy-ion collisions, and the LHCb experiment has strong capabilities to study them
- LHCb provide unique access to probes of nuclear matter with heavy flavour production
  - Give stringent test on nPDF at very small and large x regions
  - Help to study hadronisation mechanisms in heavy-ion collisions with strangeness ratio and baryon-to-meson ratio
  - Investigate quarkonium dissociation and regeneration in various collision systems across wide binding-energy coverage
  - Search for QGP signatures in different system sizes
- Stay tuned for more heavy flavour results with newly collected Run3 data!

Thanks

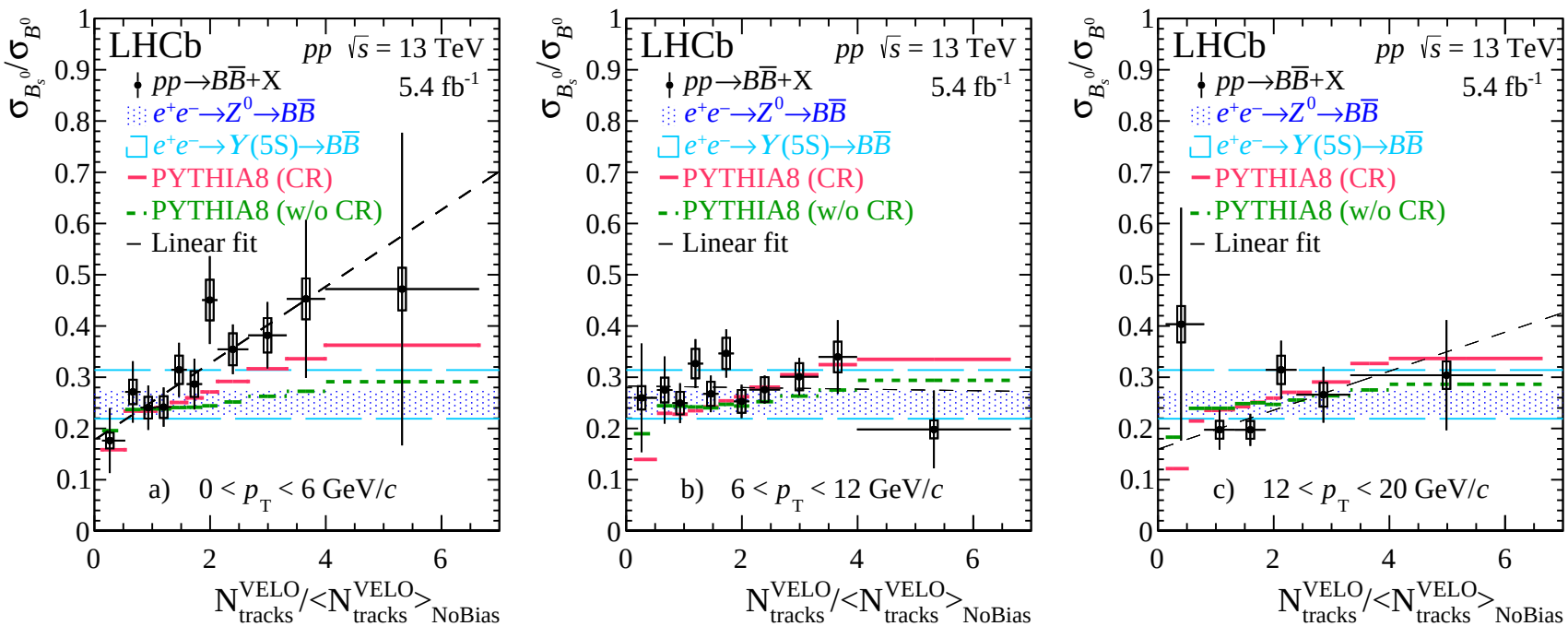
Backups

Previous heavy-flavour results with LHCb

- B_s^0/B^0 in 13 TeV pp: Phys.Rev.Lett.131(2023)061901
- Prompt Λ_c^+/D^0 in 5.02 TeV peripheral PbPb: JHEP06(2023)132
- Coherent J/ψ production in UPC PbPb: JHEP06(2023)146, Phys.Rev.C105(2022)L032201, JHEP07(2022)117
- Prompt D^0 production in 8.16 TeV pPb: Phys.Rev.Lett.131(2023)102301
- Prompt χ_{c1}/χ_{c2} in 8.16 TeV pPb: Phys.Rev.C103(2021)064905
- Prompt $\chi_c(3872)/\psi(2S)$ with multiplicity in 13 TeV pp: Phys.Rev.Lett.126(2021)092001
- Double charm in 8.16 TeV pPb: Phys.Rev.Lett.125(2020)212001
- B^+, B^0 and Λ_b^0 in 8.16 TeV pPb: Phys.Rev.D99(2019)052011
- D^0 and J/ψ in 87 GeV pHe: Phys.Rev.Lett.122(2019)132002
- Υ in 8.16 TeV pPb: JHEP11(2018)194
- Prompt Λ_c^+ in 5.02 TeV pPb: JHEP02(2019)102
- Prompt D^0 in 5.02 TeV pPb: JHEP10(2017)090
- J/ψ in 8.16 TeV pPb: Phys.Lett.B774(2017)159
- $\psi(2S)$ in 5.02 TeV pPb: JHEP03(2016)133
- Υ in 5.02 TeV pPb: JHEP07(2014)094
- J/ψ in 5.02 TeV pPb: JHEP02(2014)072

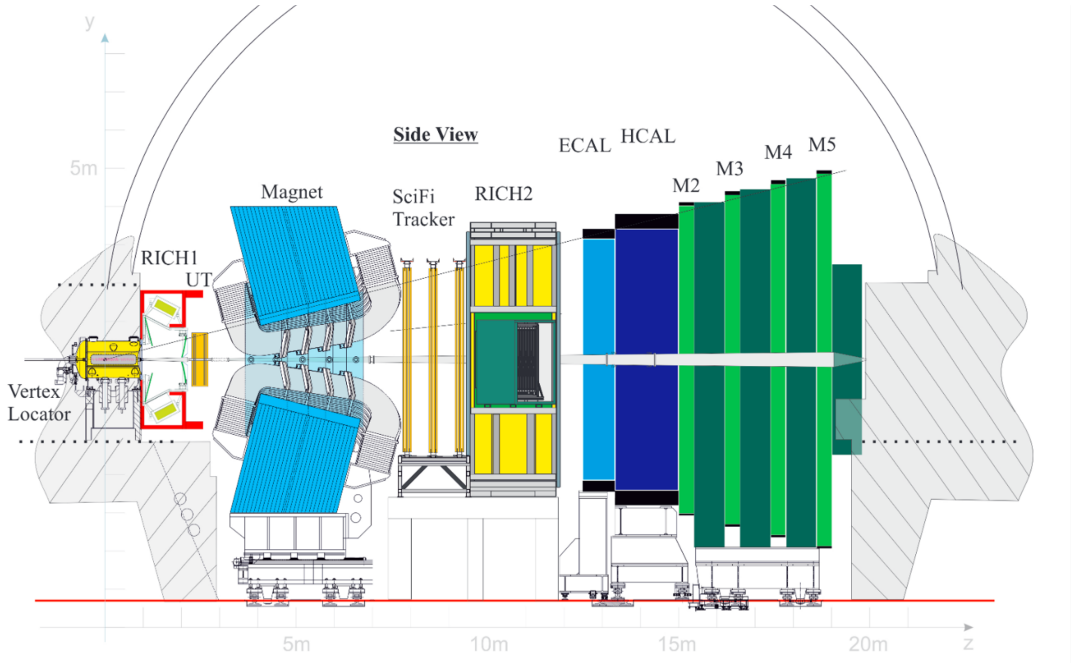
B_s^0/B^0 ratio in pp collisions

- First evidence of strangness enhancement in b-quark production



LHCb detector at Run3

CERN-LHCC-2012-007



- Collision rate at 40 MHz
- Pile-up factor $\mu \approx 5$
- New tracking system:
  - Silicon upstream detector (UT)
  - Scintillating tracking fibre (SciFi)
- Full software trigger:
  - Remove L0 triggers
  - Read out the full detector at 40 MHz