Overview of recent ALICE highlights

Nicole BASTID
Laboratoire de Physique Clermont Auvergne, IN2P3-CNRS, UCA, France

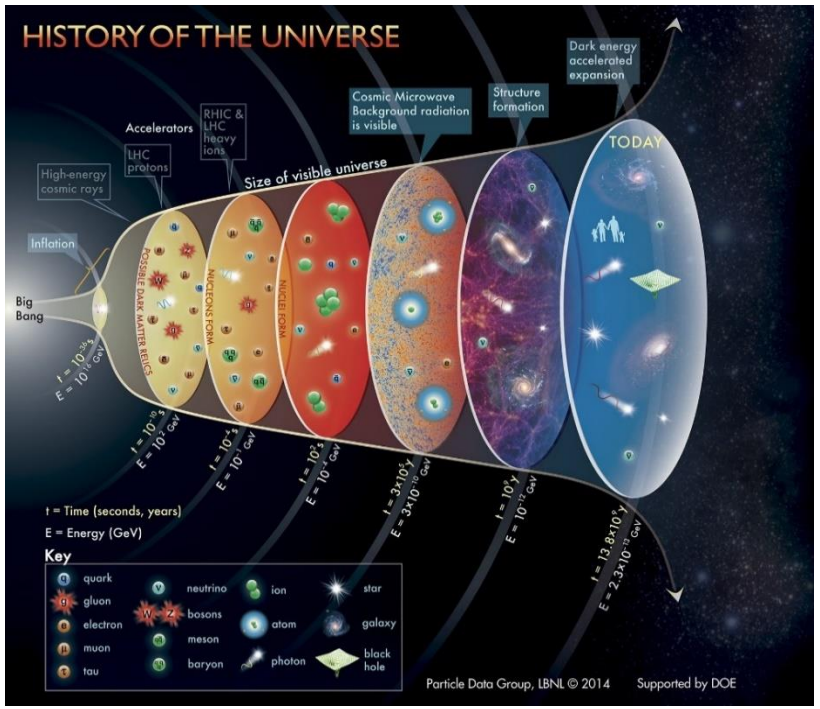
Disclaimer: only a selection can be presented (time constraint)

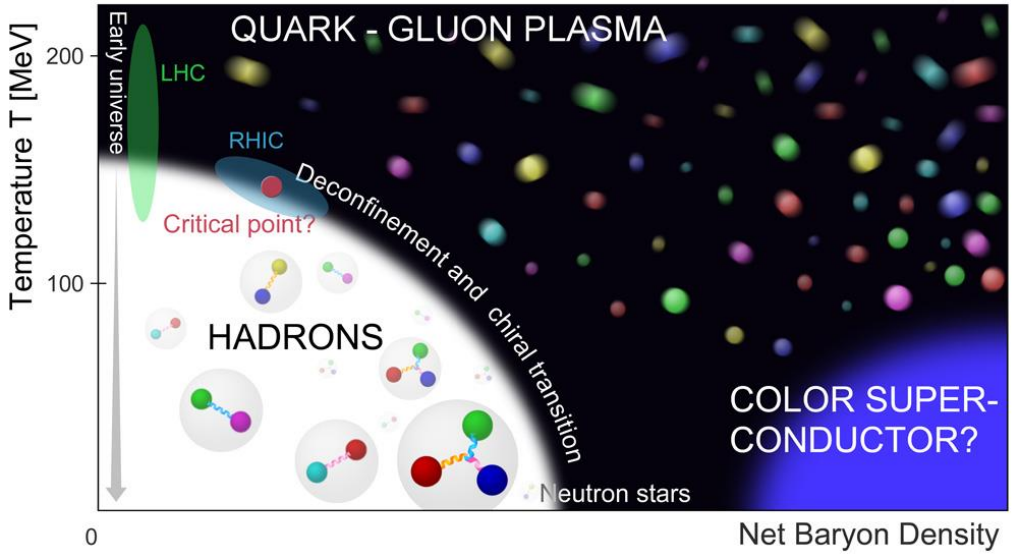
Main focus:

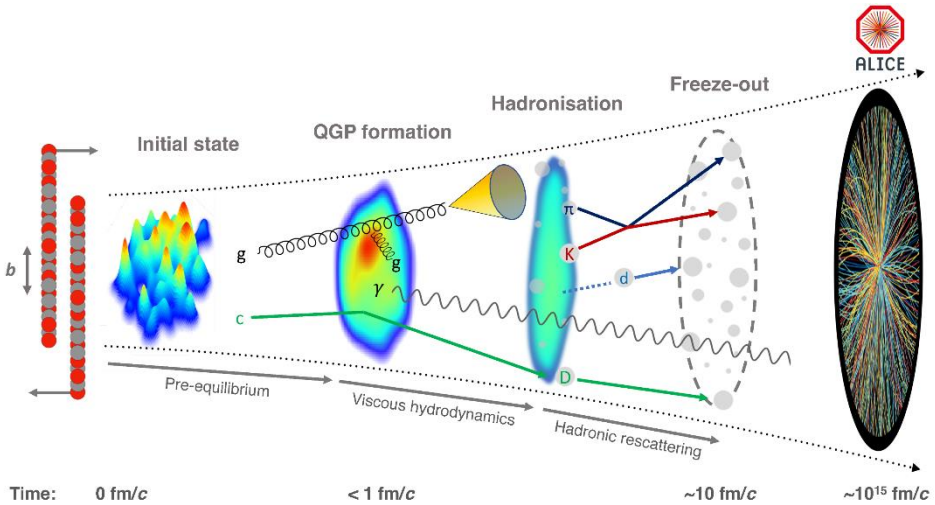
- ❖ Open heavy flavours
- ❖ Quarkonia

15th FCPPN/L Workshop | June 10-14, 2014 | Bordeaux, FRANCE

The QCD phase diagram and the quark-gluon plasma (QGP)







ALI-PUB-530950

arXiv:2211.04384

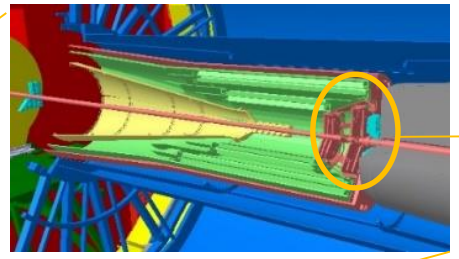
- Study the properties of nuclear matter at extreme conditions of temperature and energy density
  - Deconfined state of matter: quark-gluon plasma (QGP)
  - Predicted by QCD: T_c ~ 155 MeV, ε_c ~ 0.5 GeV/fm^3

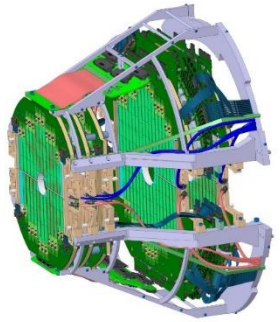
- A QGP state can be created using ultrarelativistic heavy-ion collisions
- ALICE at the LHC: dedicated experiment for heavy-ion physics

The ALICE detector: Run 3 setup

- Major upgrades installed in 2019-2021
- Taking data since mid 2022

New Inner Tracking System (ITS2)
Improved pointing resolution at midrapidity

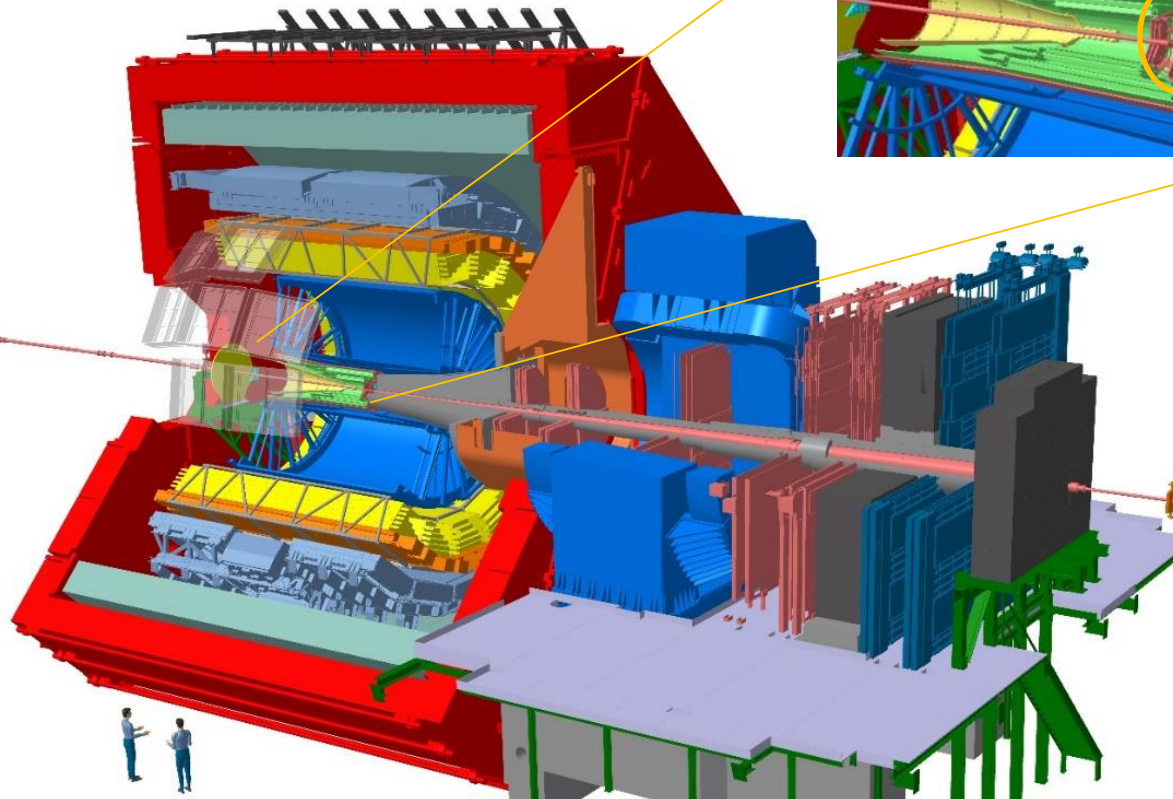


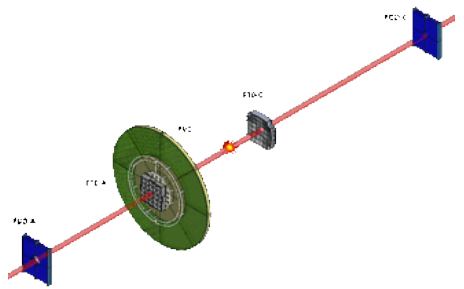


New Muon Forward Tracker (MFT)
Vertexing at forward rapidity

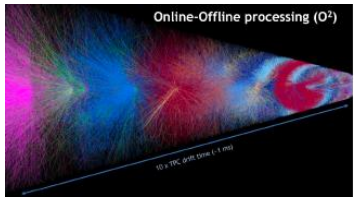
New GEM-based TPC

Upgraded readout for most subdetectors



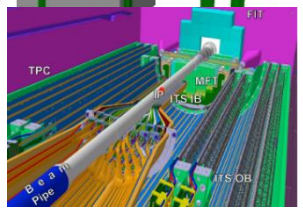


New Fast Integration Trigger



Integrated Online-Offline system (O^2)

New beam pipe



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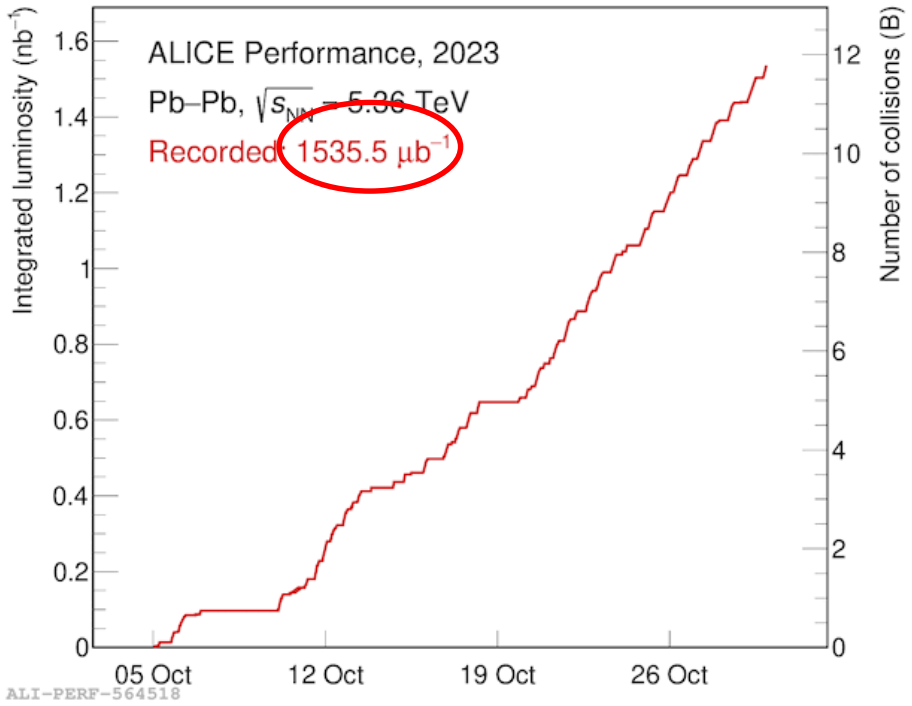
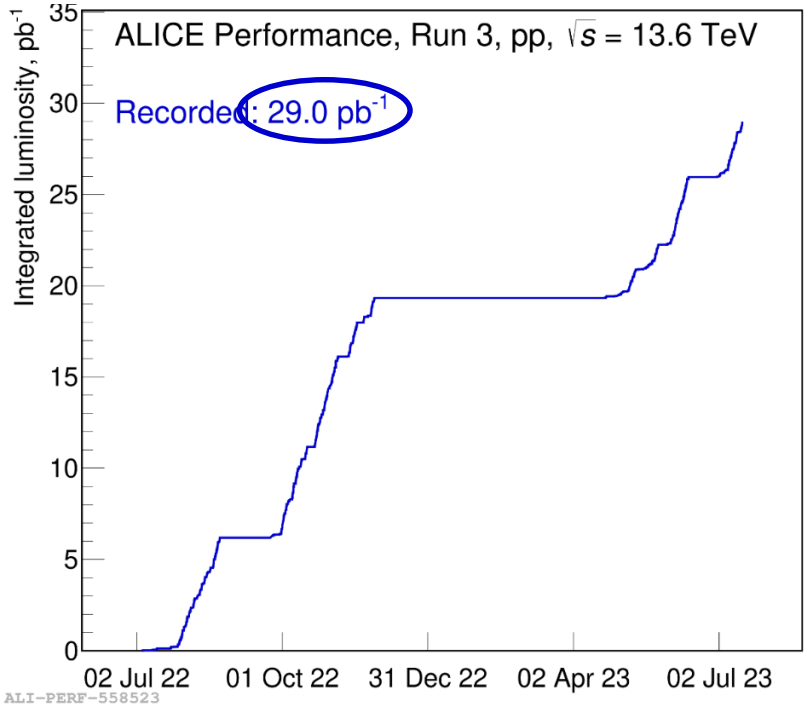
Data taking in Run 3

- Continuous readout: up to 500 kHz in pp collisions and 50kHz in Pb-Pb collisions

Pb-Pb



pp

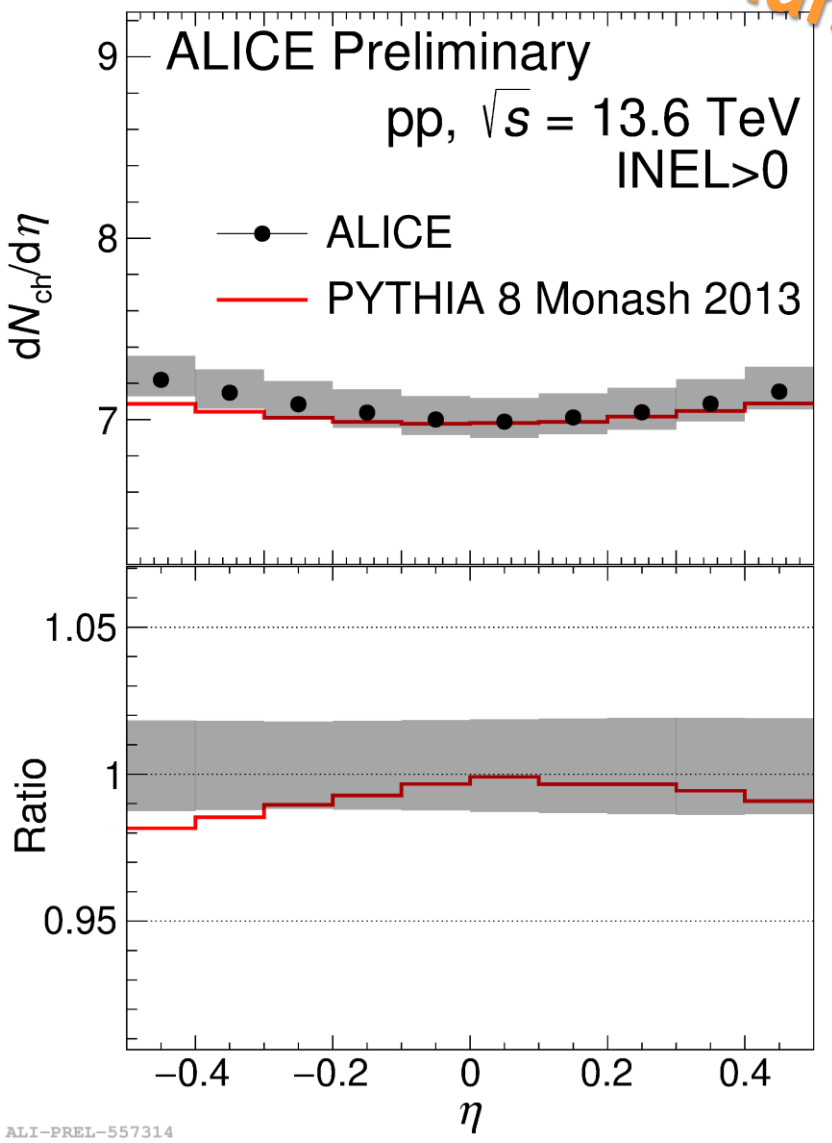


In 2024: 10.2 pb^{-1} already recorded

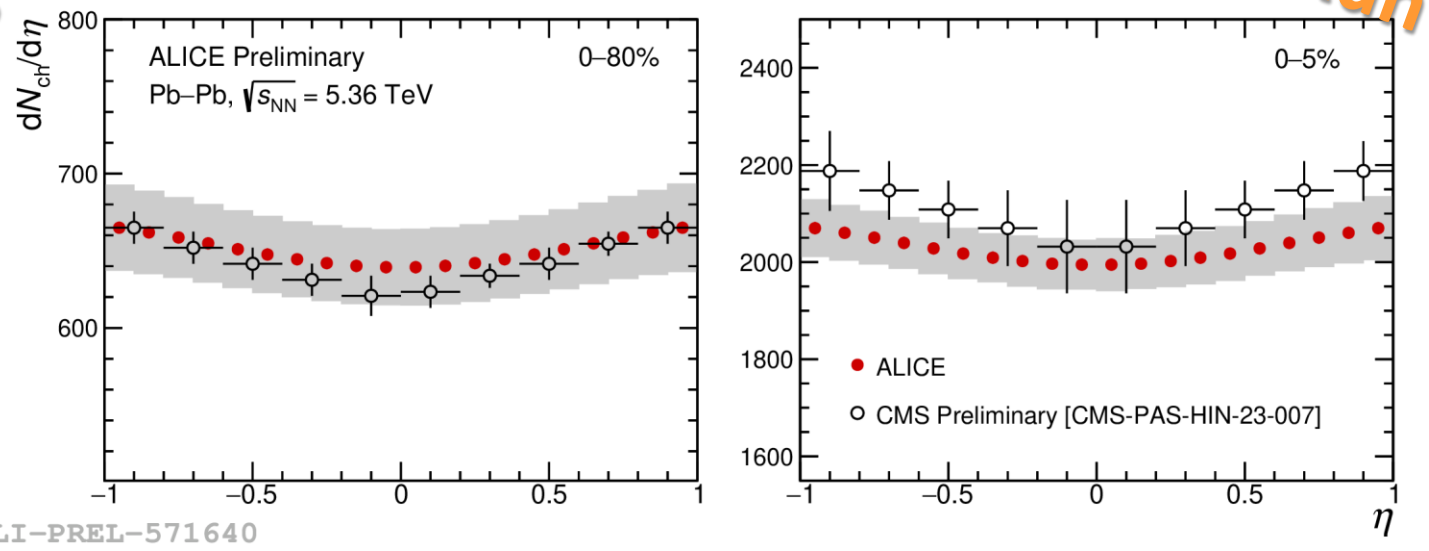
- pp data taking
  - needs be filtered to reduce the size on disk
  - selection of interesting physics events based on high-level offline triggers
- Pb-Pb data taking
  - All compressed timeframe data stored

Charged-particle multiplicity density in pp & Pb-Pb collisions (I)

Run 3

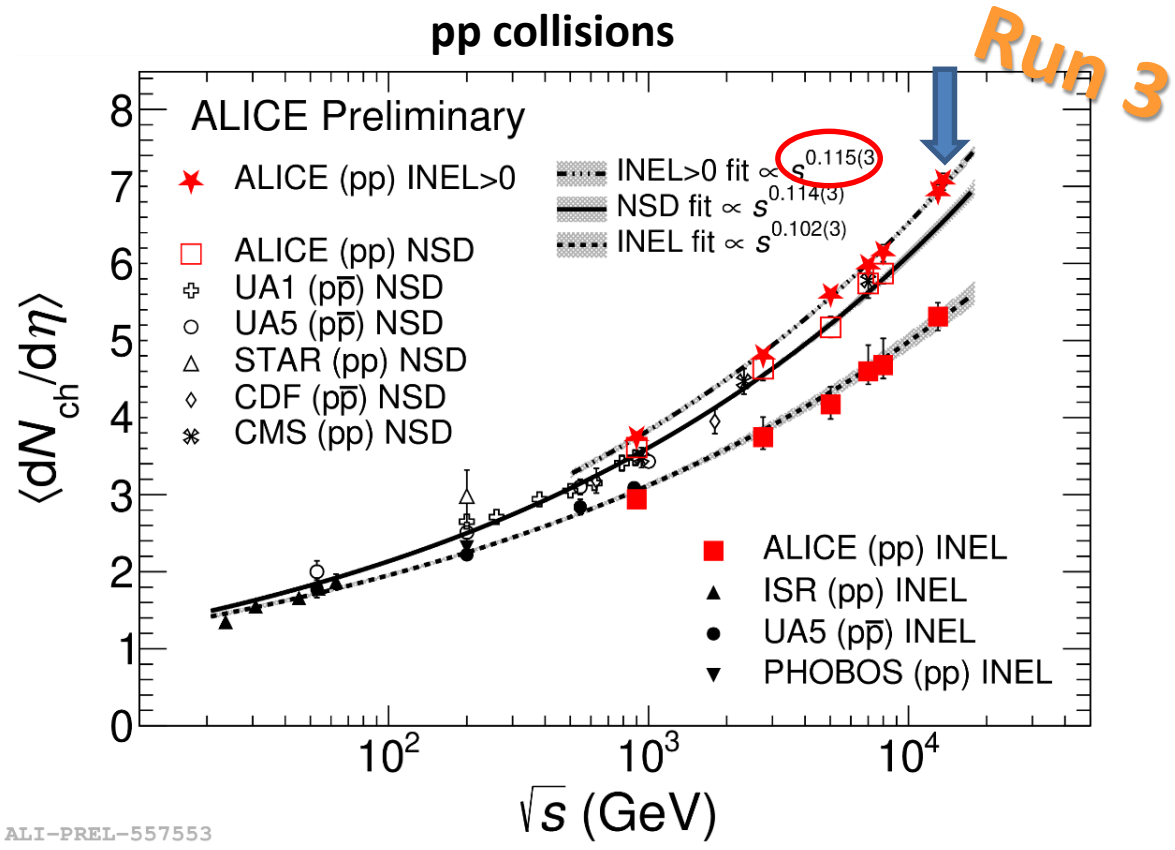


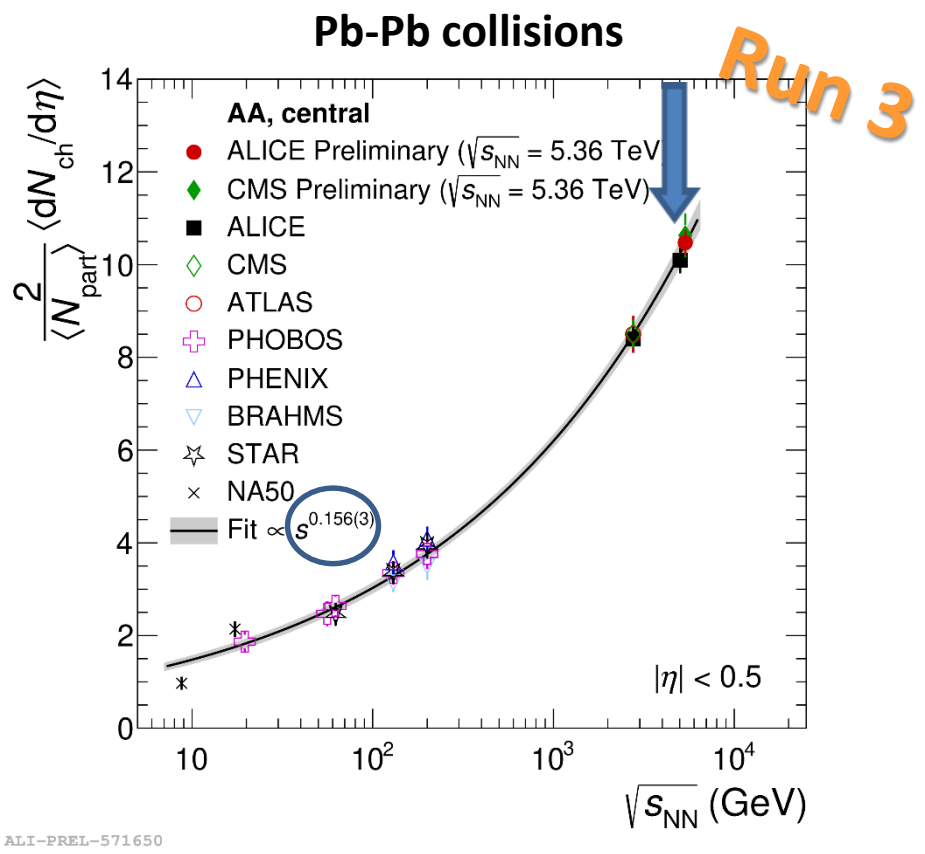
Run 3



- $dN_{ch}/d\eta$ distribution measured for the first time in pp collisions at $\sqrt{s}$ = 13.6 TeV and in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.36 TeV for the 80% and 5% most central collisions
  - pp results well described by PYTHIA8 for INEL > 0
  - Pb-Pb results in agreement with CMS measurement

Charged-particle multiplicity density in pp &collisions (II)





- $\langle dN_{ch}/d\eta \rangle$ vs. $\sqrt{s}$ in pp collisions described by a powerlaw up to $\sqrt{s}$ = 13.6 TeV
- Powerlaw dependence of $2/\langle N_{part} \rangle \langle dN_{ch}/d\eta \rangle$ vs. $\sqrt{s_{NN}}$ confirmed with the measurement for the 5% most central Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.36 TeV
  - Stronger increase with $\sqrt{s_{NN}}$ compared to pp collisions
- Confirmation that the upgraded ALICE detector is working well

Why study heavy flavours?

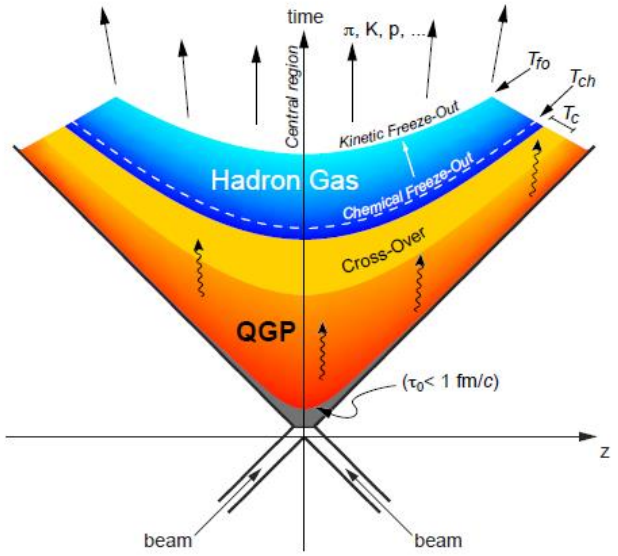
❖ A-A collisions:

❑ Charm and beauty quarks produced in initial hard scatterings, prior to the formation of the quark-gluon plasma (QGP)

$\tau_{c/b}$ ~ 0.01-0.1 fm/c < τ_{QGP} (~0.3 fm/c)

❑ Experience the full collision history

➢ Excellent probes to characterise the QGP

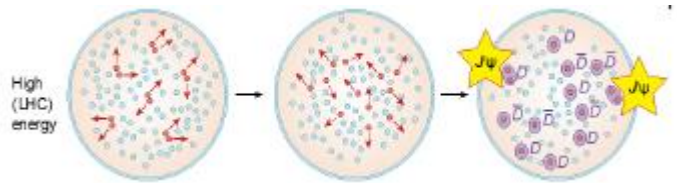


❑ Open heavy flavours:

- In-medium parton energy loss → colour-charge and quark-mass dependence
- Collective motion, thermalisation of the medium
- Modified hadronisation in the medium

❑ Quarkonia:

- Colour screening in the QGP → suppression
- Regeneration



❖ p–A collisions: reference for A-A, cold nuclear matter (CNM) effects, nuclear parton distribution functions

❖ pp collisions: reference for p-A & A-A, tests of pQCD-based predictions, production mechanisms

❖ High-multiplicity pp and p-A collisions: collective-like behaviour

Heavy-flavour measurements with ALICE

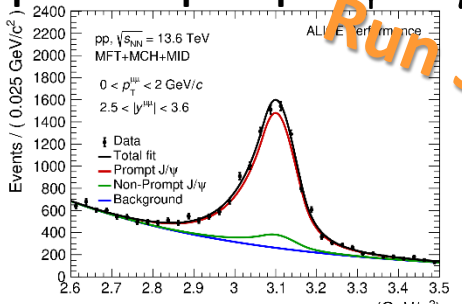
Open heavy flavours

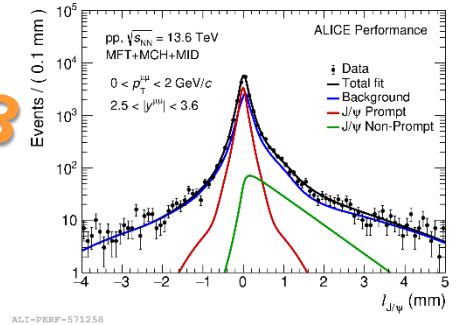
- **Hadronic decays (|*y*| < 0.8)**
  - $D^0 \rightarrow K^-\pi^+$
  - $D^+ \rightarrow K^-\pi^+\pi^+$
  - $D^{*+} \rightarrow D^0 (\rightarrow K^-\pi^+)\ \pi^+$
  - $D^+_s \rightarrow \phi (\rightarrow K^-K^+)\pi^+$
  - $D_{s1}{}^+ \rightarrow D^{*+}\ K^0_s$
  - $D_{s2}{}^{*+} \rightarrow D^+\ K^0_s$
  - $\Lambda_c{}^+ \rightarrow pK^0_s$, $\Lambda_c{}^+ \rightarrow pK^-\pi^+$
  - $\Lambda_c{}^+ \rightarrow e^+\Lambda\nu_e$
  - $\Xi_c{}^0 \rightarrow e^+\Xi^-\nu_e$, $\Xi_c{}^0 \rightarrow \pi^+\Xi^-$
  - $\Xi_c{}^+ \rightarrow \pi^+\pi^+\Xi^-$
  - $\Omega_c{}^0 \rightarrow \Omega^-\pi^+$
  - $\Sigma_c{}^{0,++}(2455) \rightarrow \Lambda_c{}^+\pi^{-,+}$
  - $\Sigma_c{}^{0,++}(2520) \rightarrow \Lambda_c{}^+\pi^{-,+}$
  - $B \rightarrow D$
- **Semi-leptonic decays**
  - $c, b \rightarrow \mu^{\pm}\ (2.5 < y < 4.0)$
  - $c, b \rightarrow e^{\pm}\ (|y| < 0.8$ or $0.6)$

Quarkonia

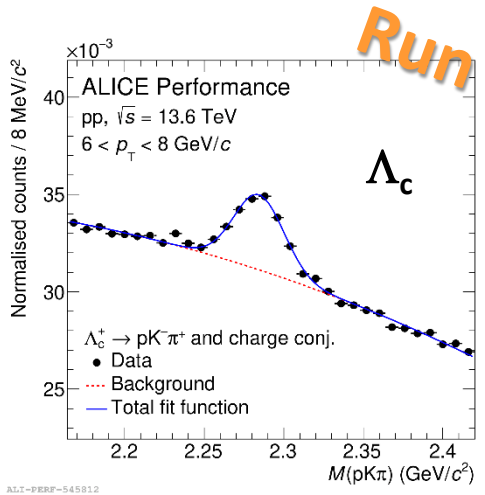
- $J/\psi, \psi(2S) \rightarrow e^-e^+$ ($|y| < 0.8$)
- $J/\psi, \psi\ (2S) \rightarrow \mu^-\mu^+$ ($2.5 < y < 4$)
- $\Upsilon\ (1S, 2S, 3S) \rightarrow \mu^-\mu^+$
- $B \rightarrow J/\psi \rightarrow e^+e^-$ ($|y| < 0.8$)
- $B \rightarrow J/\psi \rightarrow \mu^+\mu^-$ ($2.5 < y < 3.6$)

Prompt & non-prompt J/ψ via $\mu^+\mu^-$ Run 3

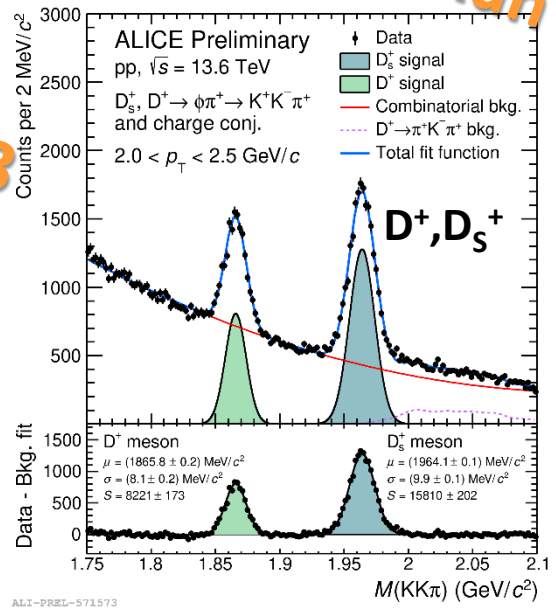




Run 3

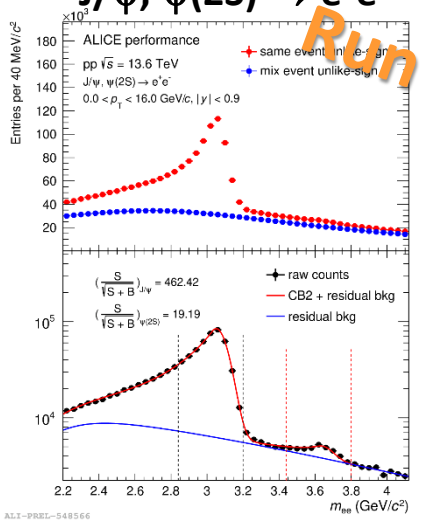


Run 3



Run 3

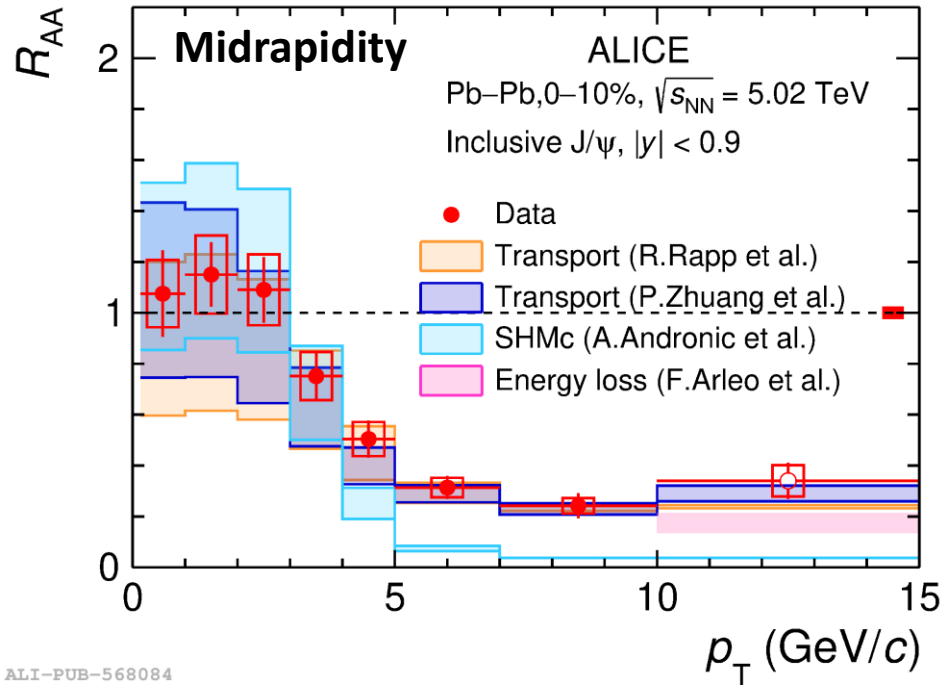
$J/\psi, \psi(2S) \rightarrow e^+e^-$

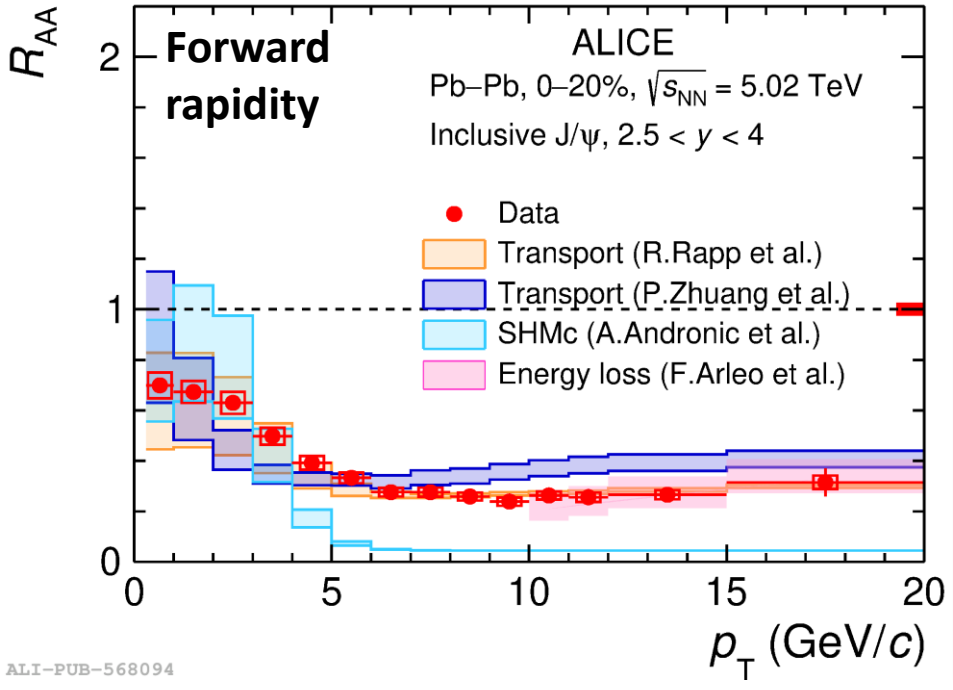


Selected recent highlights from quarkonium measurements

Inclusive J/ψ production in Pb-Pb collisions

$$R_{\mathrm{AA}}(p_{\mathrm{T}}) = 1/\langle T_{\mathrm{AA}} \rangle \times \frac{\mathrm{d}N_{\mathrm{AA}}/\mathrm{d}p_{\mathrm{T}}}{\mathrm{d}\sigma_{\mathrm{pp}}/\mathrm{d}p_{\mathrm{T}}}$$

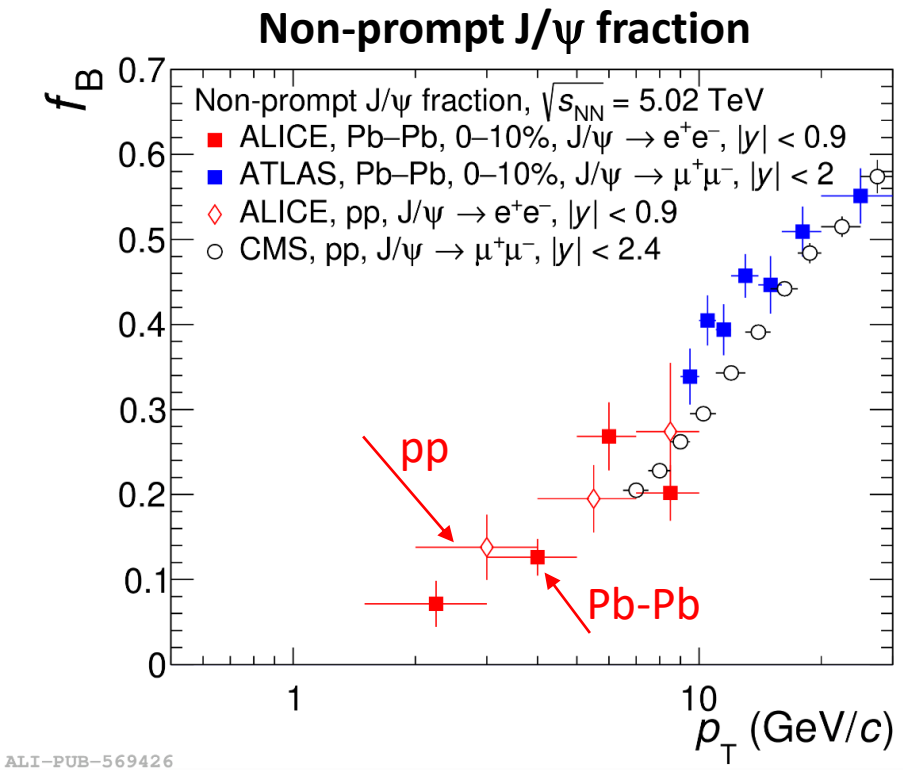


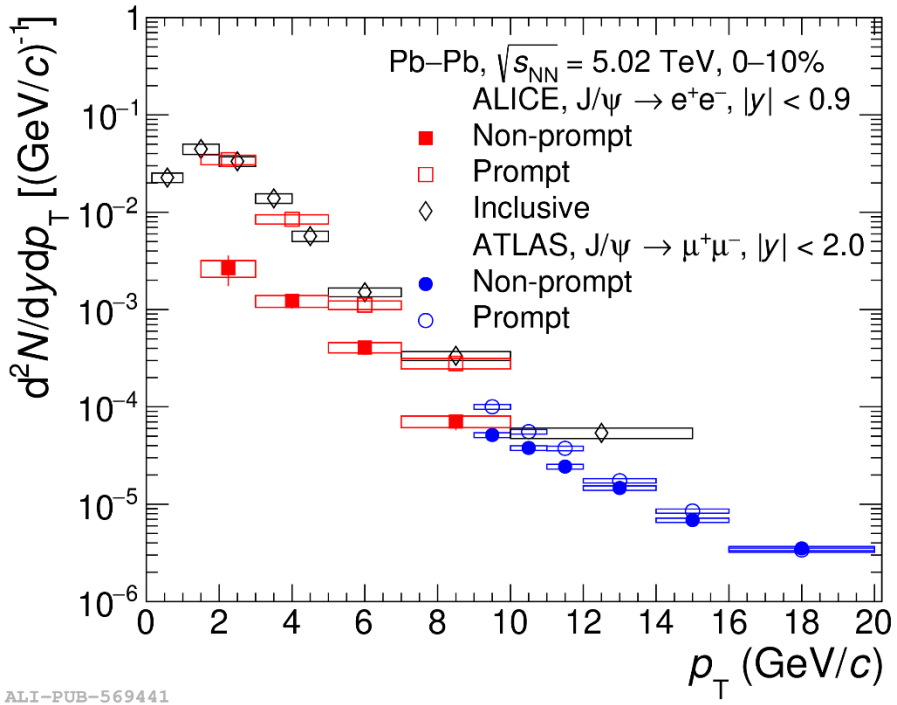


- Stronger suppression at high p_T than at low p_T at both midrapidity and forward rapidity
- R_{AA} larger at midrapidity compared to forward rapidity in the low p_T region
  - Interplay between suppression and regeneration from charm quarks
- Transport and energy loss models describe the data within uncertainties
- Some tension with the SHMc model at high p_T at both midrapidity and forward rapidity

PLB 849 (2024) 138451

Non-prompt J/ψ (B → J/ψ) production at midrapidity in Pb-Pb collisions

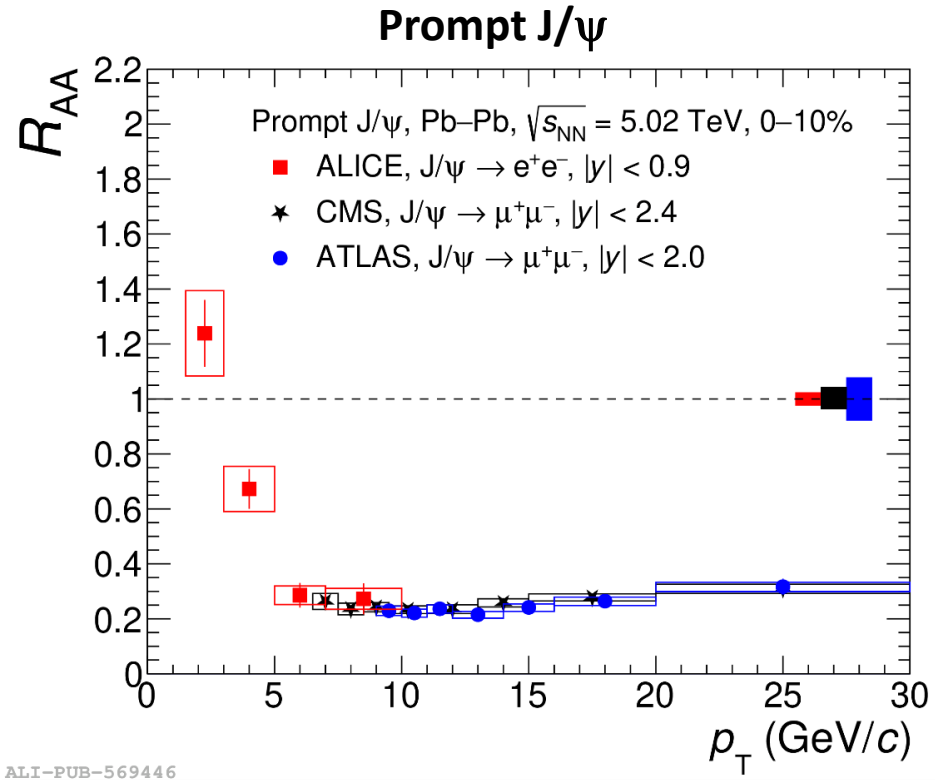


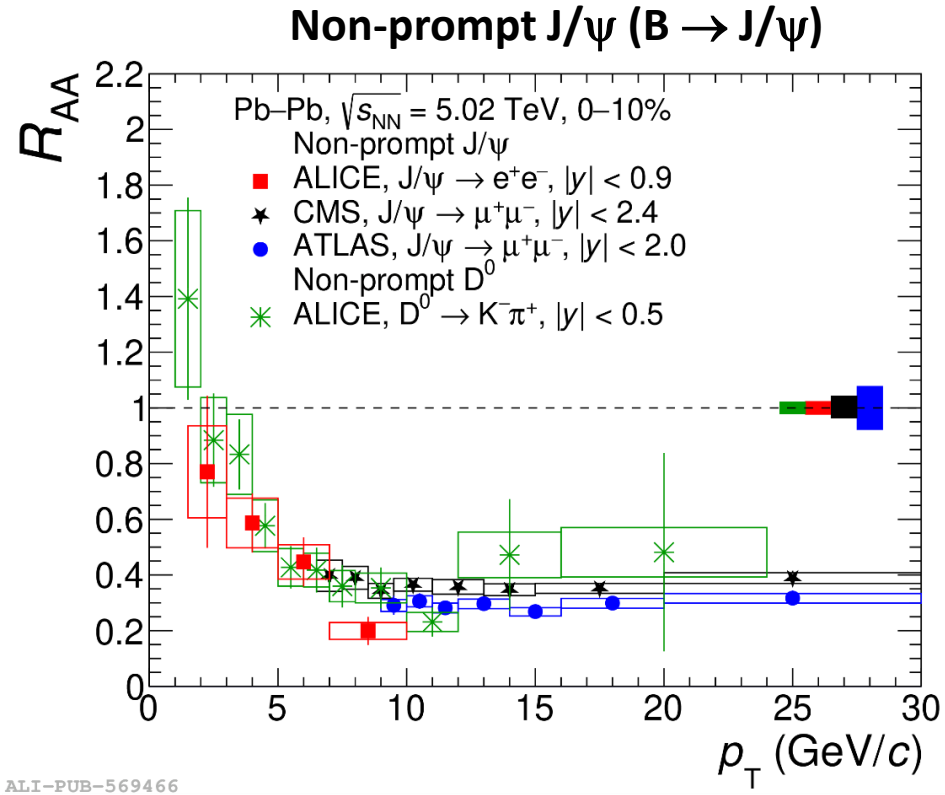


JHEP 02 (2024) 066

- Prompt and non-prompt J/ψ measured separately at midrapidity in the dielectron channel for $1.5 < p_T < 10$ GeV/c in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV, based on displaced vertex
  - Complement existing high-pT measurements by ATLAS and CMS
  - Compatible non-prompt J/ψ fraction in pp and Pb-Pb collisions at low p_T within uncertainties
  - Hint for a higher non-prompt J/ψ fraction in Pb-Pb than pp collisions at high p_T

Prompt and non-prompt J/ψ R_{AA} in Pb-Pb collisions





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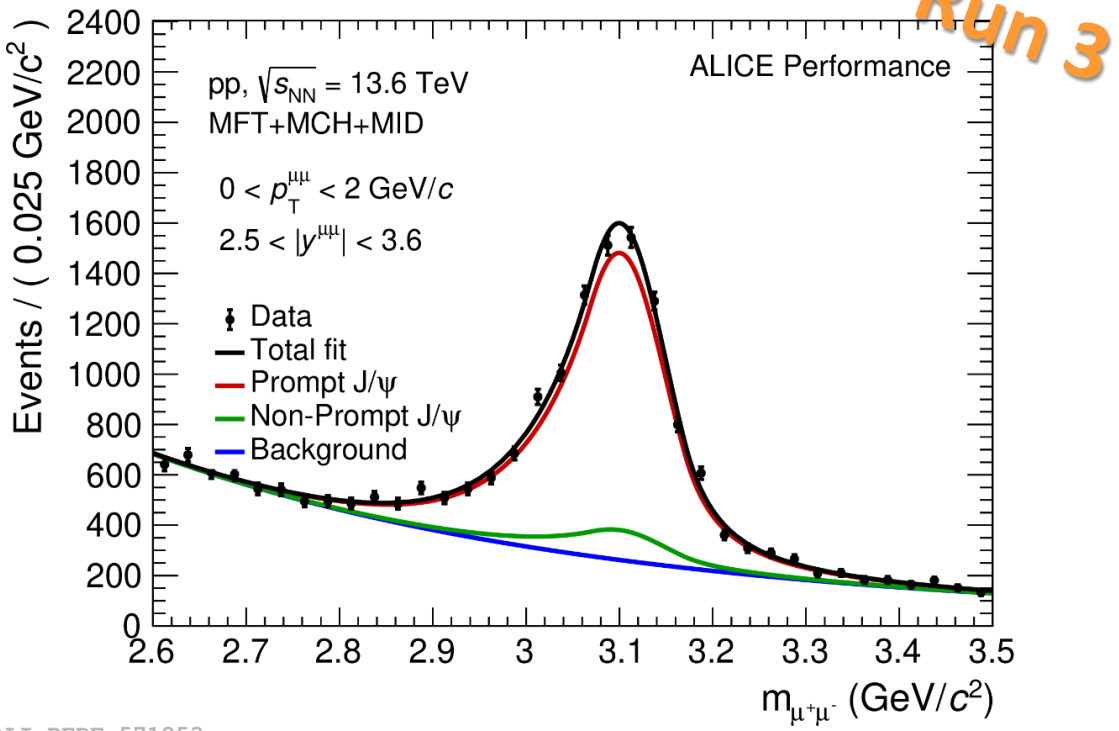
- Measurement of prompt and non-prompt J/ψ nuclear modification factor R_{AA} extended down to p_T = 1.5 GeV/c
  - Significant suppression measured for non-prompt J/ψ due to the QGP formation (R_{pPb} ~ 1 [JHEP 06 (2022) 011])
  - Smaller suppression at low p_T for prompt J/ψ compared to non-prompt J/ψ
  - Compatible results with ATLAS and CMS measurements in the overlapping region
  - Similar trends for non-prompt J/ψ and non-prompt D^0 R_{AA}, although different decay kinematics

Performance: prompt & non-prompt J/ψ at forward rapidity in Run 3



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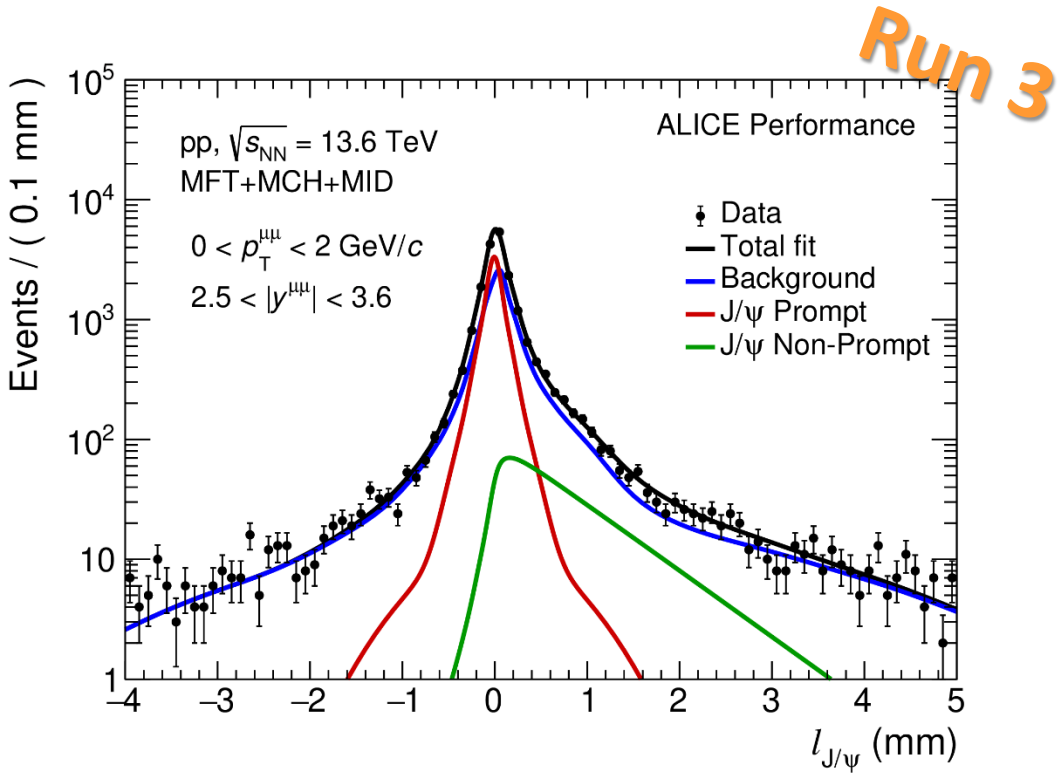

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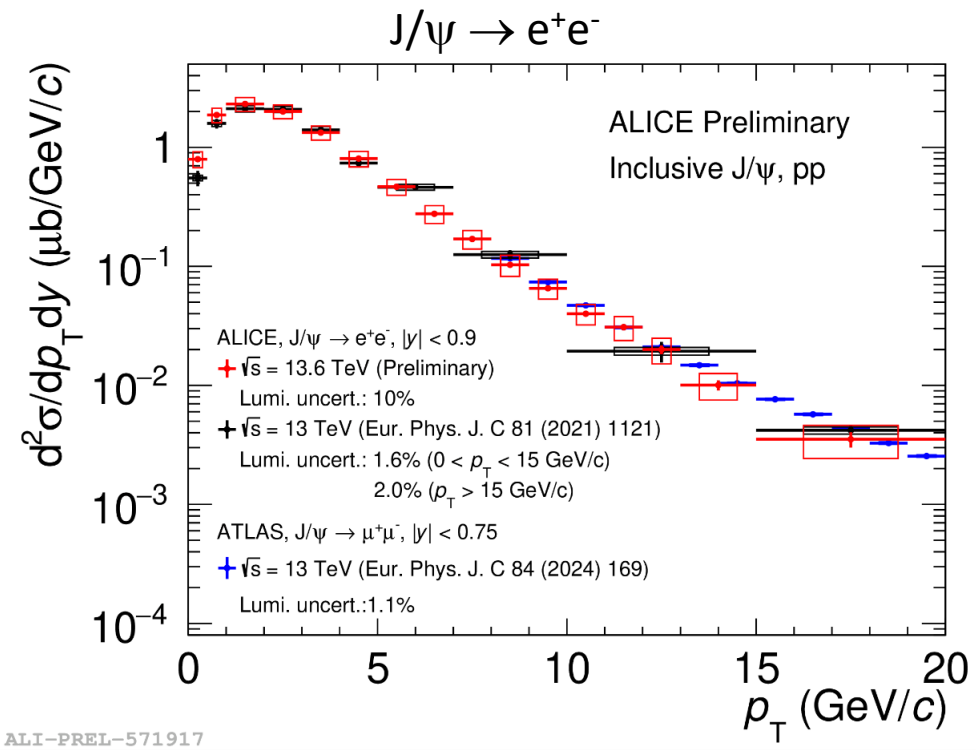
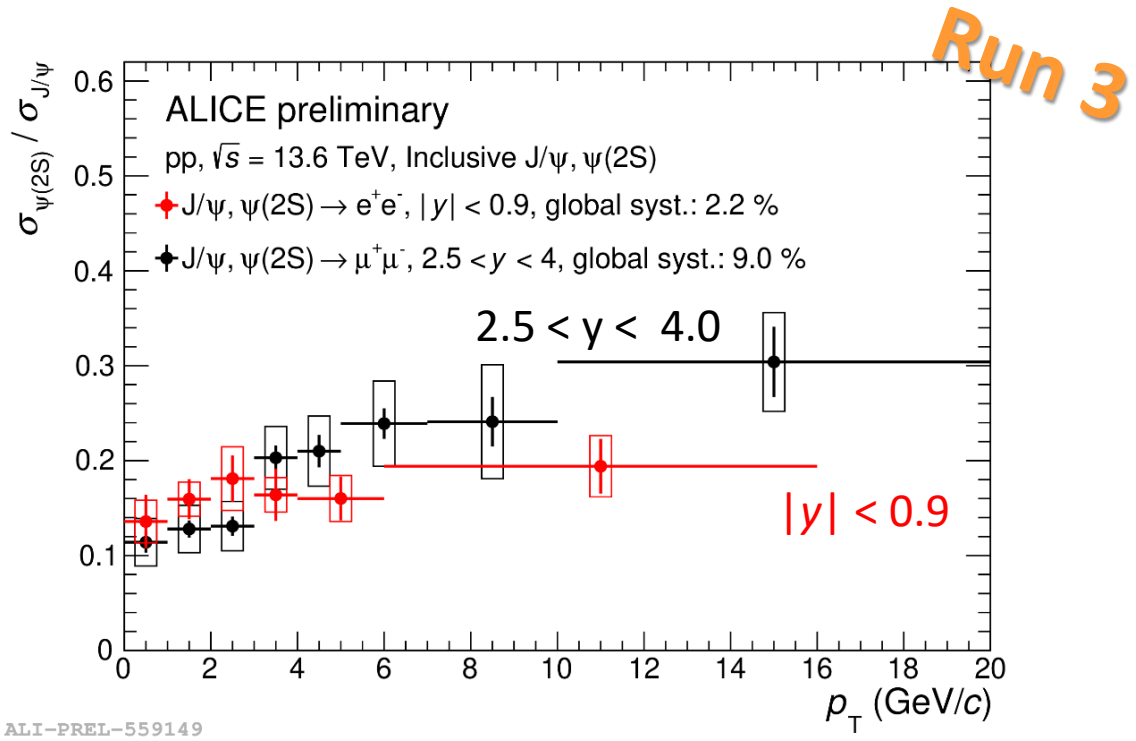
$$l_{J/\psi} = \frac{(z_{PV} - zSV)\, m_{J/\psi}}{p_z}$$

- Performance results in pp collisions at √s = 13.6 TeV using muon tracks in the muon spectrometer and MFT
- Possible to distinguish prompt and non-prompt J/ψ in the dimuon channel at forward rapidity in Run 3
- Measurement of the beauty production via displaced J/ψ possible down to $p_T = 0$ due to the boost at forward

J/ψ production in pp collisions at √s = 13.6 TeV

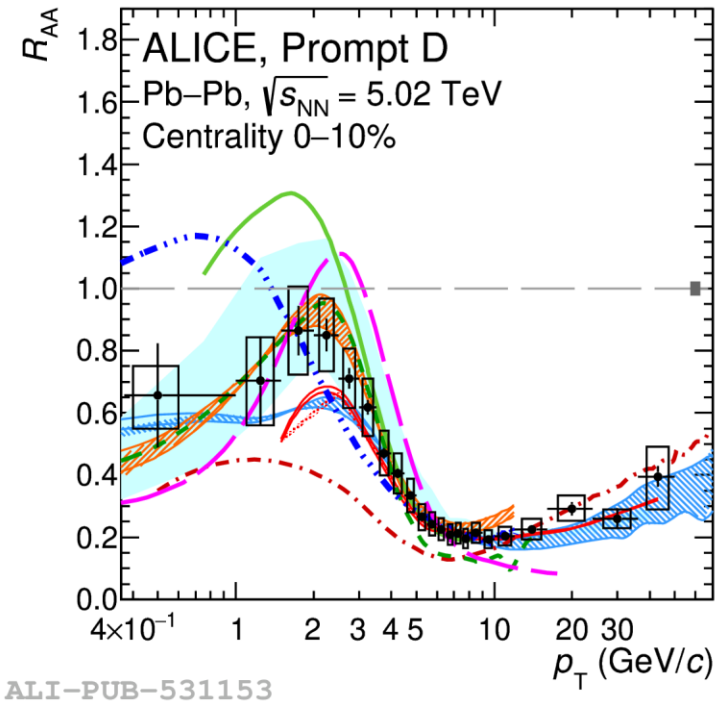


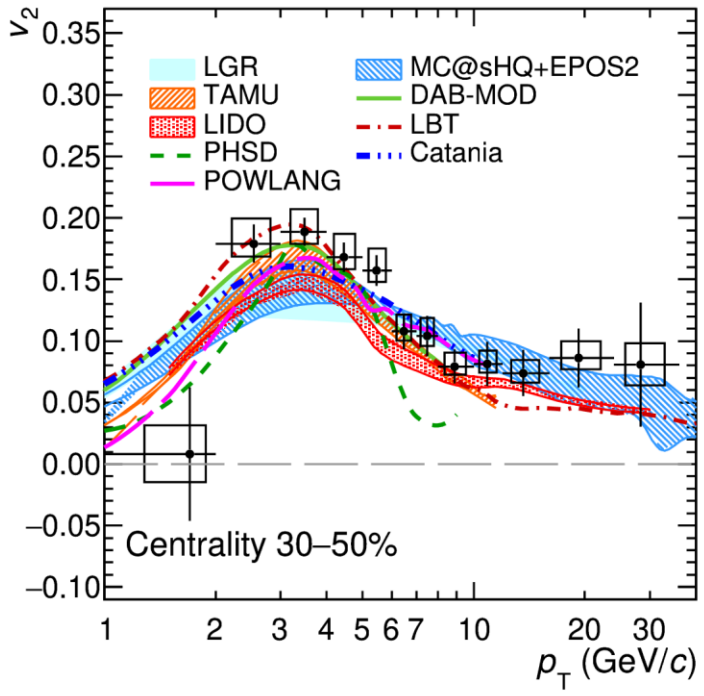


- First measurement of the p_T-differential inclusive J/ψ production cross section in pp collisions at $\sqrt{s}$ = 13.6 TeV
  - Measurement at midrapidity in agreement with Run 2 results
  - Higher granularity compared to Run 2
- First measurement of the $\sigma_{\psi(2S)}$ to $\sigma_{J/\psi}$ ratio in pp collisions at $\sqrt{s}$ = 13.6 TeV
  - Compatible results at midrapidity and forward rapidity

Select recent highlights from open heavy flavour measurements

D-meson nuclear modification factor and elliptic flow





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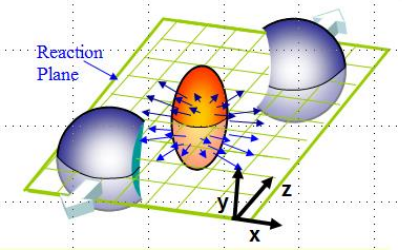

$$\frac{2\pi}{N}\frac{\mathrm{d}N}{\mathrm{d}\varphi} = 1 + \sum_{n=1}^{\infty} 2v_n \cos[n(\varphi - \Psi_n)]$$

v_2: collective expansion at low p_T
path-length dependence of parton in-medium energy loss at high p_T

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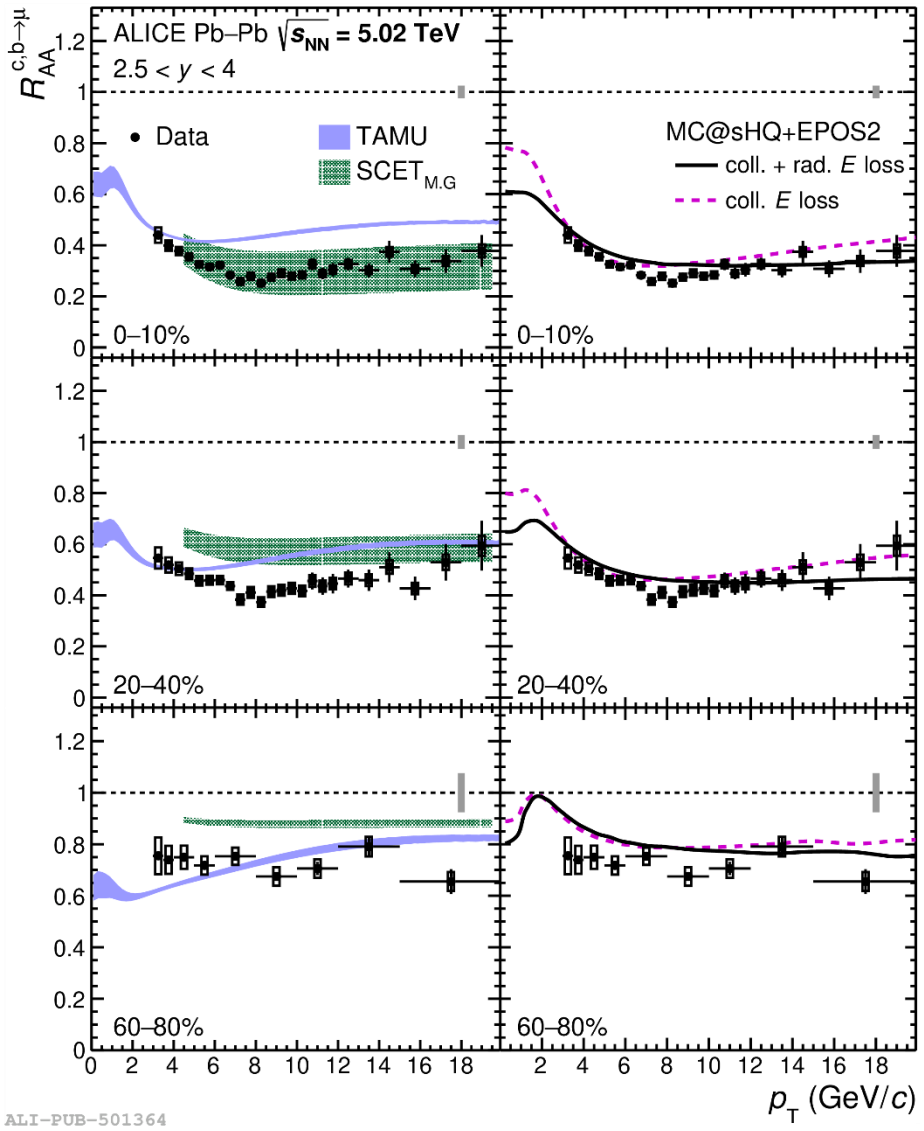
- R_{AA} and v_2 measurements of prompt D mesons over a wide p_T interval
- Strong suppression increasing with p_T and reaching a factor ~5 for 6< p_T < 8 GeV/c in the 10% most central collisions
  - Due to final-state effects induced by the hot and dense QGP medium
- Positive v_2 → participation of charm quarks to the collective expansion of the system
- Simultaneous description of R_{AA} and v_2 over the entire p_T range challenging for some models

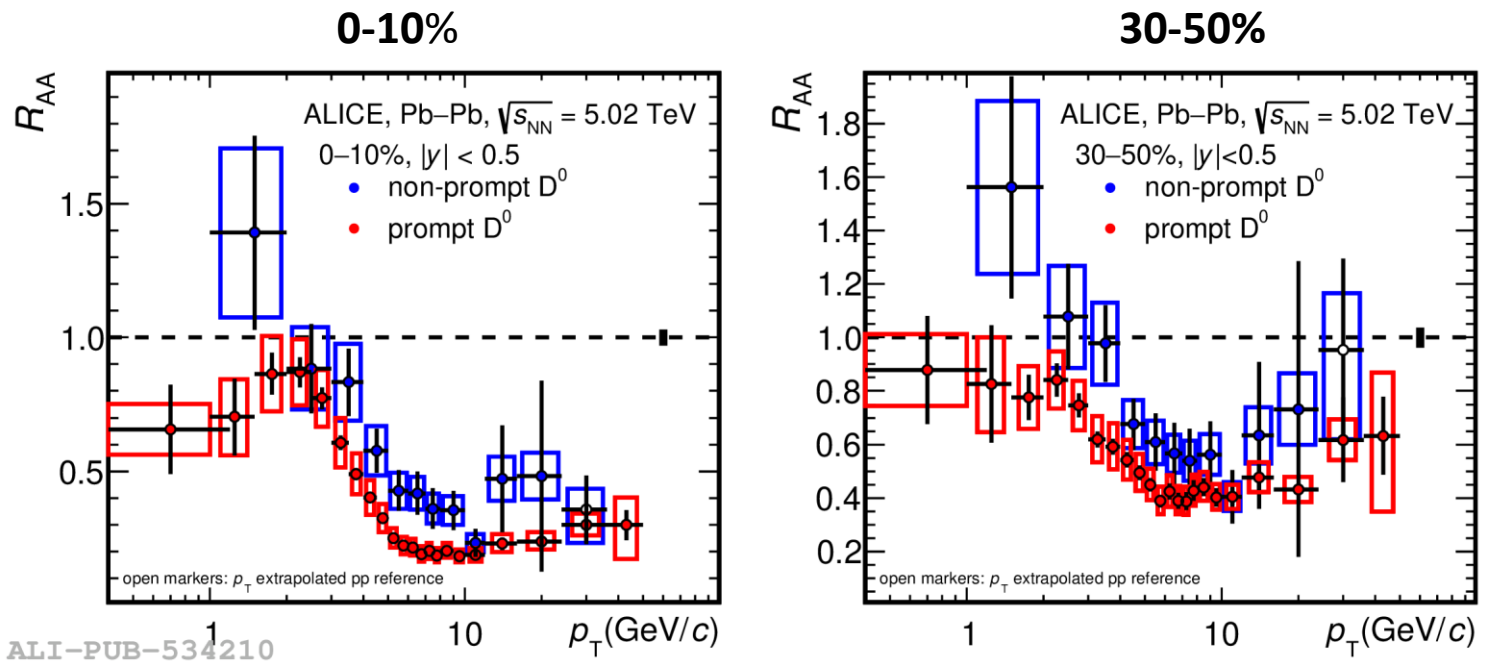
Nuclear modification factor of μ ← b,c at forward rapidity



- Strong suppression measured also at forward rapidity ($2.5 < y < 4.0$) for muons from heavy-flavour hadron decay muons which persists up to p_T = 20 GeV/c
  - Heavy quarks suffer strong in-medium energy loss over a wide rapidity interval
  - Indication that beauty quarks lose a significant fraction of their energy in the medium
- Decreasing trend of the suppression from central to peripheral collisions
- Precise measurements
  - Potential to distinguish between model predictions implementing different mechanisms of parton energy loss

PLB 820 (2021) 136558

Open heavy-flavour R_{AA} hierarchy



- Non-prompt D^0 ($B \rightarrow D^0$) measured for the first time down to p_T = 1 GeV/c
- Larger suppression in central (0-10%) than semicentral (30-50%) collisions
- Expected R_{AA} hierarchy observed at intermediate p_T via the measurement of prompt and non-prompt D^0
  - $\Delta E_b < \Delta E_c \Rightarrow R_{AA}(B \rightarrow D) > R_{AA}(B \rightarrow D)$

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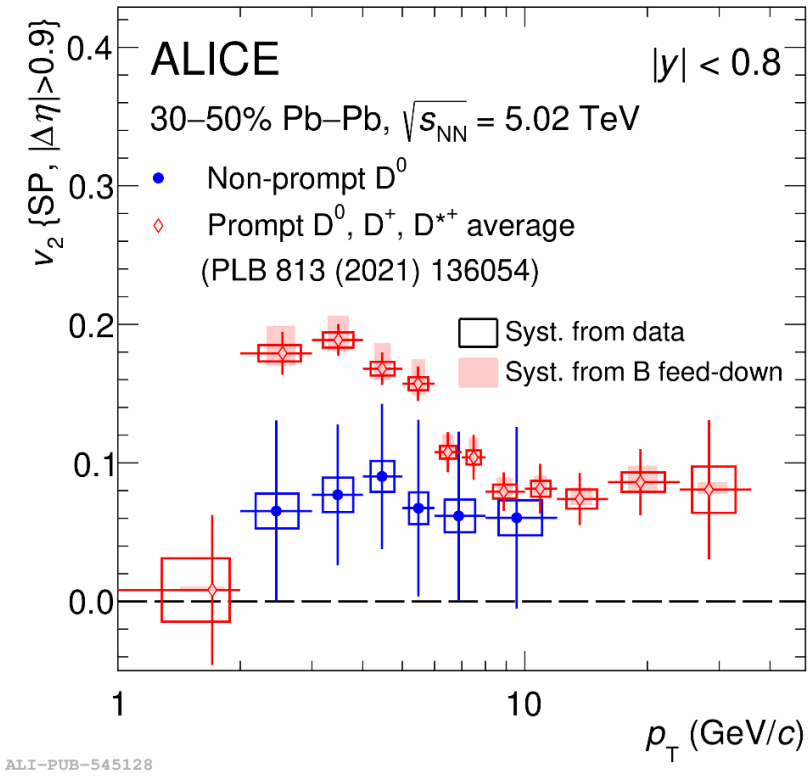
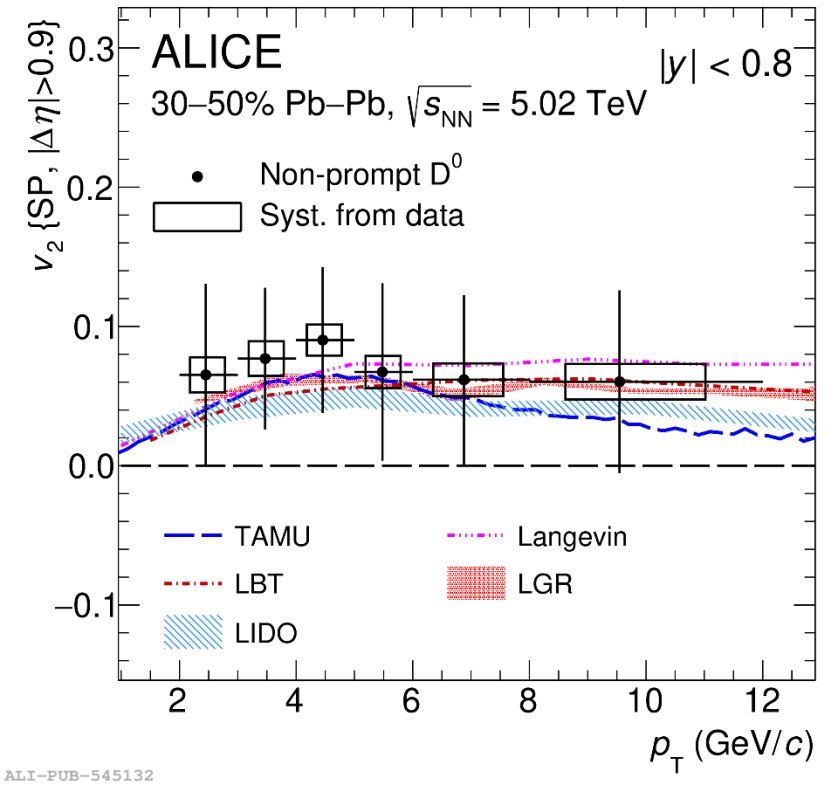
Non-prompt D^0 (B → D) elliptic flow

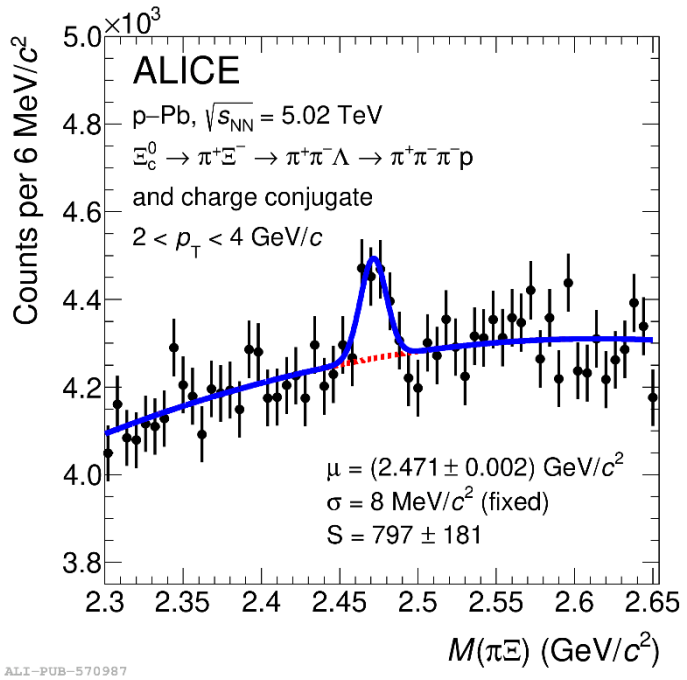


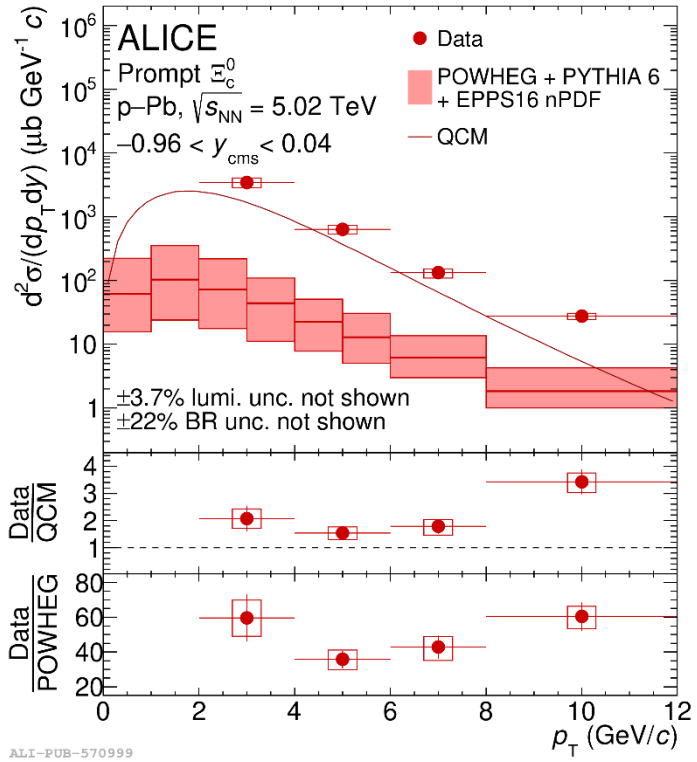


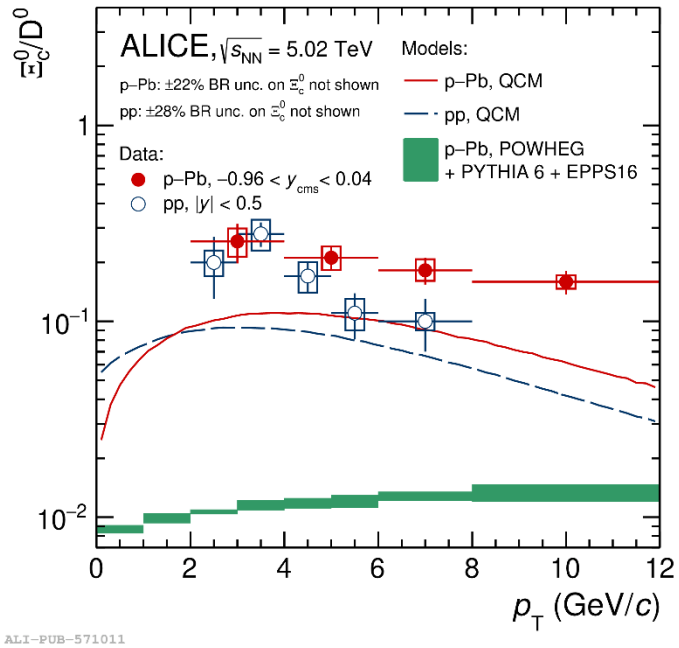
- Positive v_2 measured for non-prompt D^0 with a significance of 2.7σ
- No significant p_T dependence
- v_2 (B → D) < v_2 (D) with a significance of 3.2σ
  - Different degree of participation to the collection motion of the medium between charm and beauty quarks
- Measurement in fair agreement with beauty-quark transport models

EPJC 83 (2023) 1183

Production of prompt Ξ_c^0 baryons in p-Pb collisions



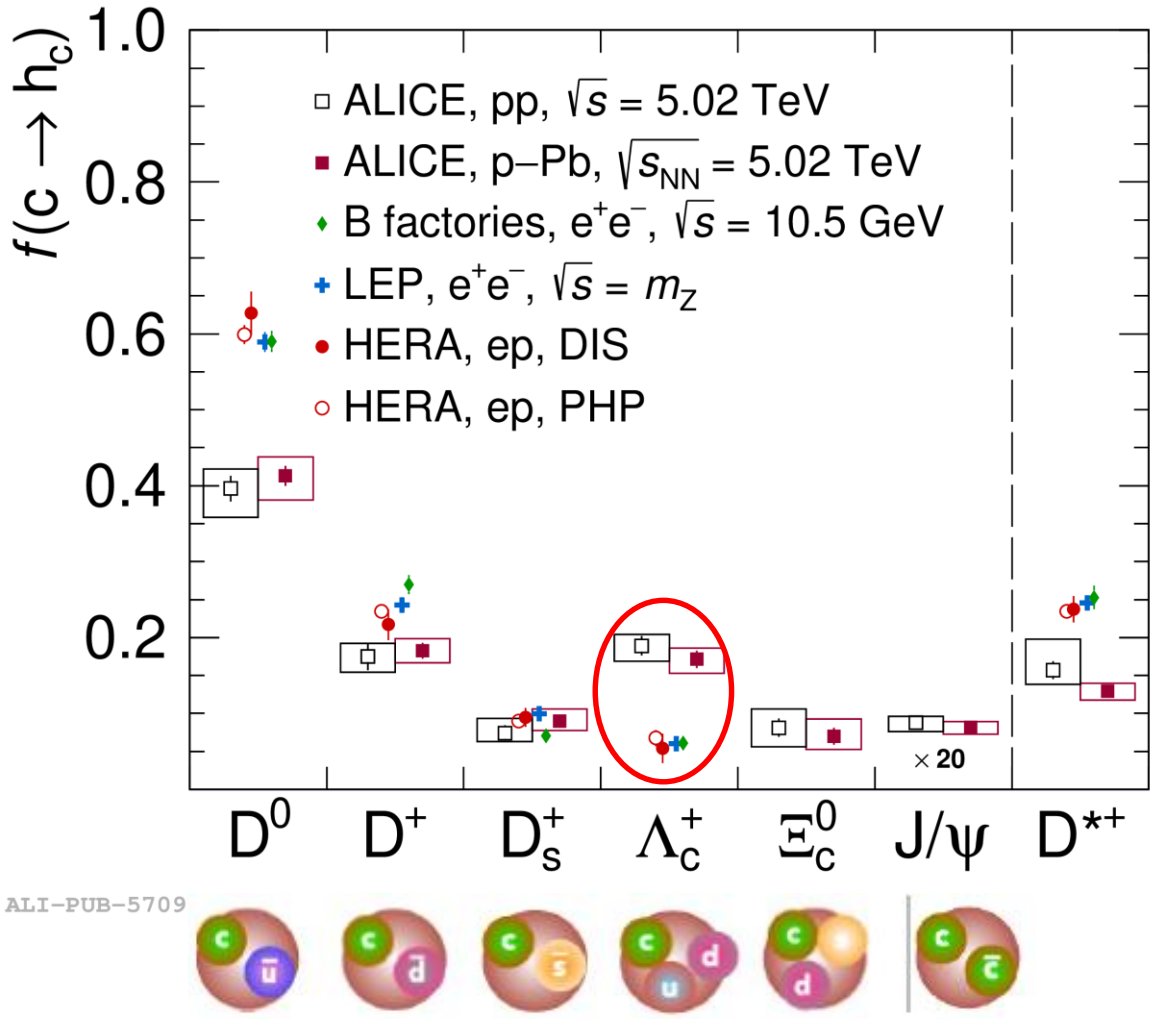




- p_T-differential prompt Ξ_c^0 production cross section measured in p-Pb collisions
  - Underestimated by POWHEG+PYTHIA 6 calculations with only CNM effects by a factor of ~50
  - Discrepancy reduced with QCM model which implements hadronisation via coalescence
- Hint for a slight decreasing trend with p_T of the Ξ_c^0/D^0 ratio in p-Pb collisions
- Ξ_c^0/D^0 ratio underestimated by QCM and POWHEG + PYTHIA6 by a factor ~2 and ~20, respectively
  - Provides important constraints to models of the hadronisation process

arXiv: 2405.14538

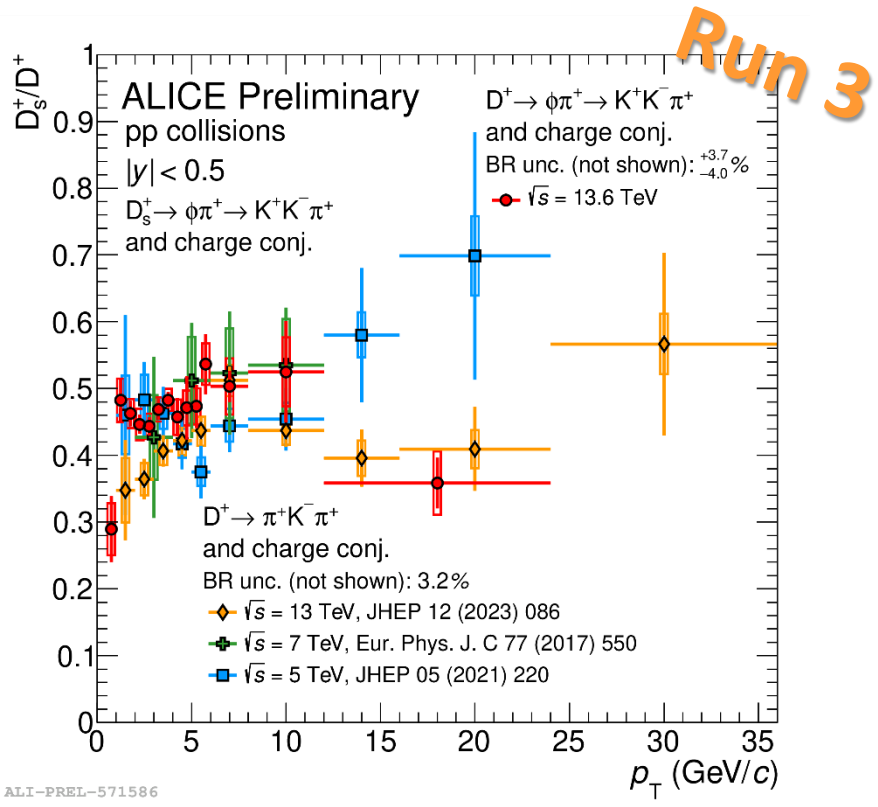
Charm fragmentation fractions in p-Pb collisions

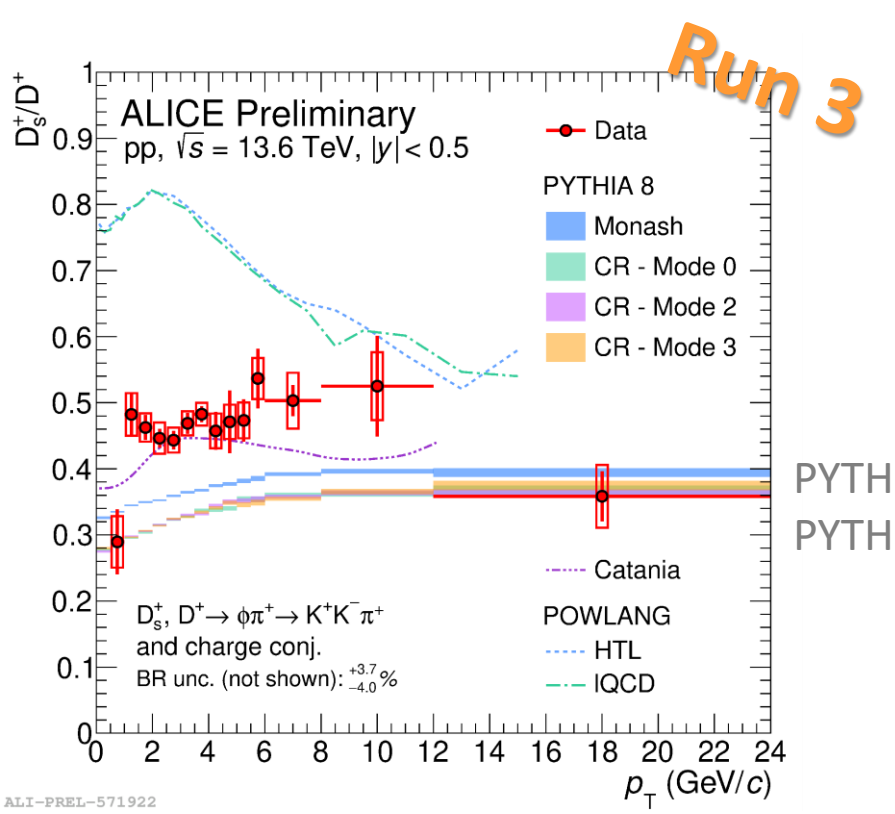


- Charm fragmentation fractions to different charm-hadron species measured for the first time in p-Pb collisions
- No significant modification of the hadronisation with the system size at the LHC
- Charm fragmentation fractions significantly increased for baryons with respect to e^+e^- and e^-p collisons
  - Different hadronisation in a parton-rich environment
- Constraints for hadronisation models

arXiv:2405.14571

D_s^+/D^+ ratio in pp collisions at $\sqrt{s}$ = 13.6 TeV



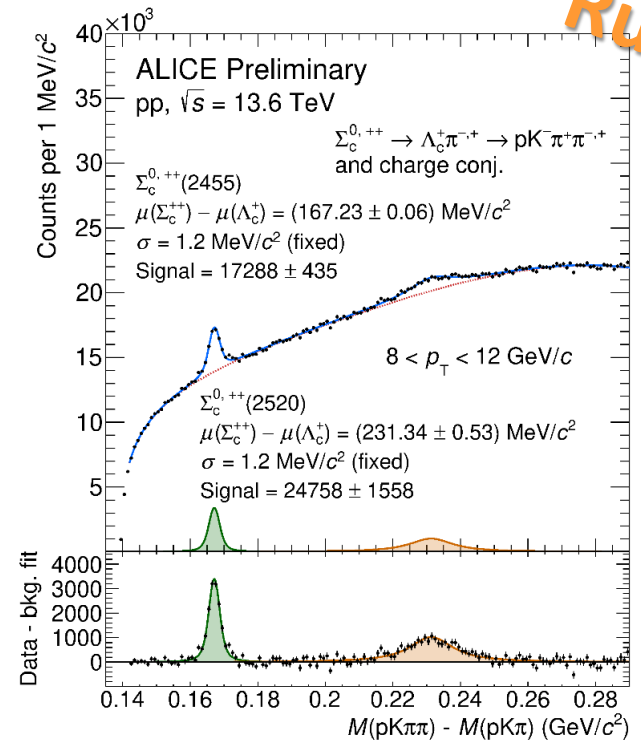


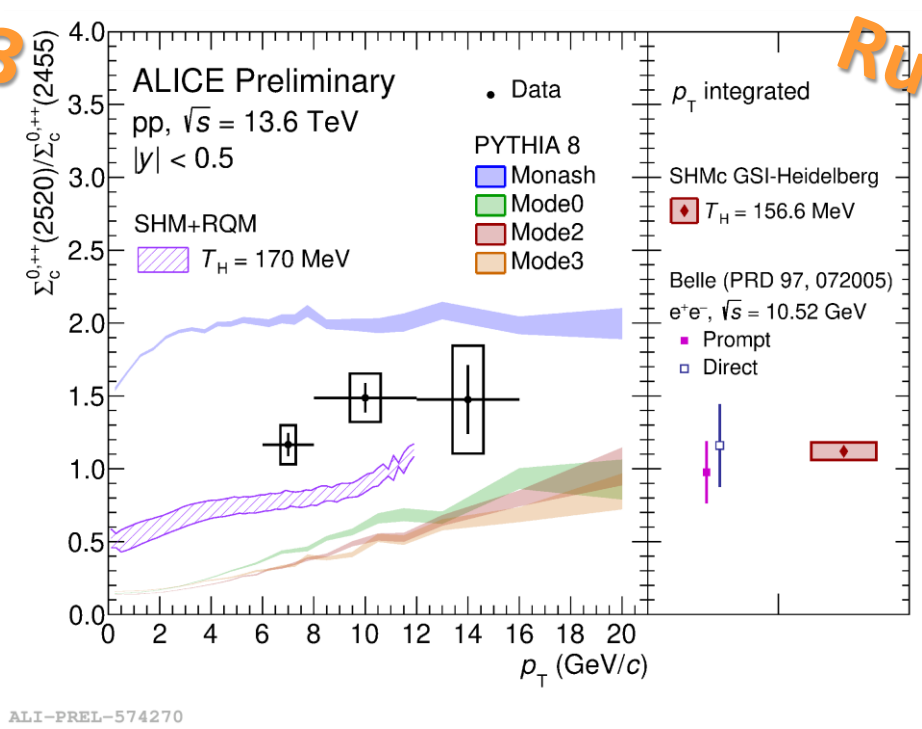
PYTHIA8 (Monash): EPJC 74 (2014) 3024
PYTHIA8 (CR 0,1,2): JHEP 08 (2015) 003

- New measurement of the D^+_s/D^+ ratio in Run 3
  - Extended down to p_T = 0.5 GeV/c
  - Higher granularity compared to Run 2
- No significant dependence on the collision energy
- Measurement challenging for PYTHIA 8 and POWLANG models, CATANIA model in qualitative agreement with the data at intermediate p_T

Production of $\Sigma_c^{0,++}$ in pp collisions at $\sqrt{s}$ = 13.6 TeV

First measurement at the LHC of the $\Sigma_c^{0,++}(2520)$ relative production

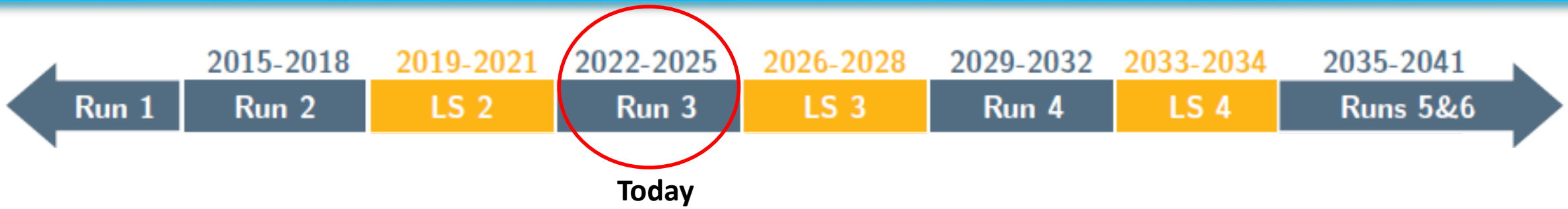




PYTHIA8 (Monash): EPJC 74 (2014) 3024
PYTHIA8 (CR 0,1,2): JHEP 08 (2015) 003
SHM+RQM: PBL 795 (2019) 117
SHMc: PLB 797 (2019) 134836

- Hint for $\Sigma_c^{0,++}(2455)$ /$\Sigma_c^{0,++}(2520)$ ratio larger than unity
- Measured ratio compatible with the p_T-integrated ratio obtained in e^+e^- collisions within uncertainties
- Measurement challenging for PYTHIA 8 Monash and CR-BLC
- In qualitative agreement with SHMc model, while SHM+RQM underestimates the ratio
  - Constraints on hadronisation models

Conclusion



- Impressive amount of new exiting results in the heavy-flavour sector have been obtained by ALICE with Run 2 and Run 3
  - 453 Run 2 publications submitted in arXiv, several Run 3 publications in preparation

- Run 3 allows more precise measurements with smaller uncertainties and gives access to new set of observables to characterize the QGP properties
- Run 3 analyses are just at the beginning
  - Several ongoing analyses with pp and Pb-Pb Run 3 data

More to come soon → Stay tuned!

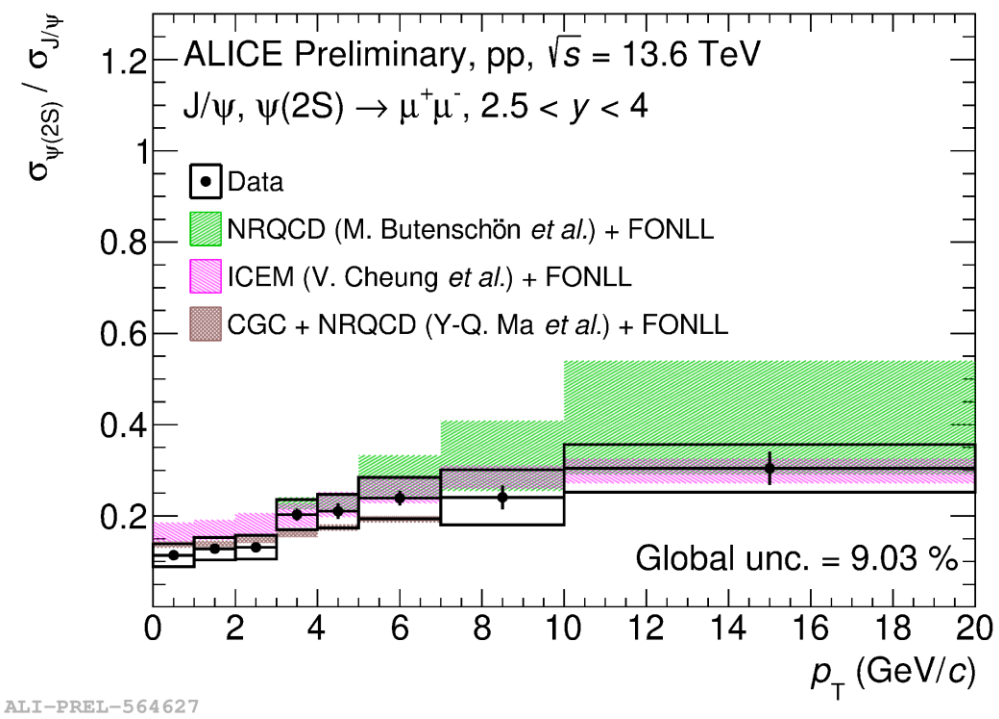
More physics results on:

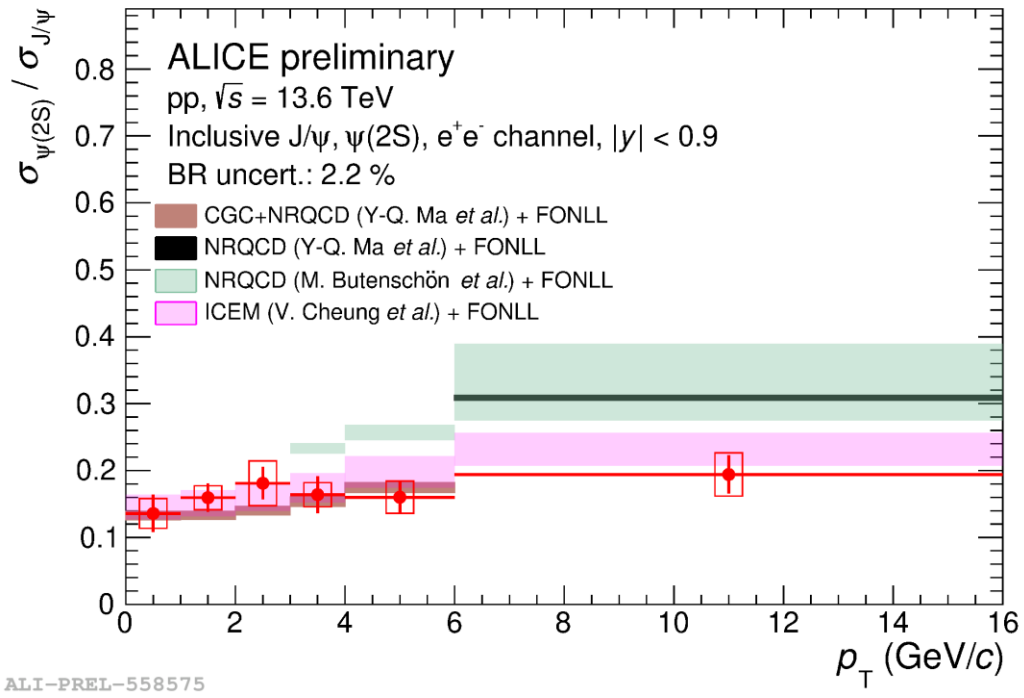
- Open heavy flavours via (di)muons: see Maolin Zhang's talk
- Quarkonium polarisation: see Xiaozhi Bai's talk
- Photons: see Gustavo Conesa Balbastre's talk
- Jets: see Yongzhen Hou's talk


Thank you for your attention
Merci pour votre attention
感谢您的聆听
ALICE
Run 3 Pb-Pb
$\sqrt{s_{NN}} = 5.36$ TeV
27 September 2023, 04:50

backup

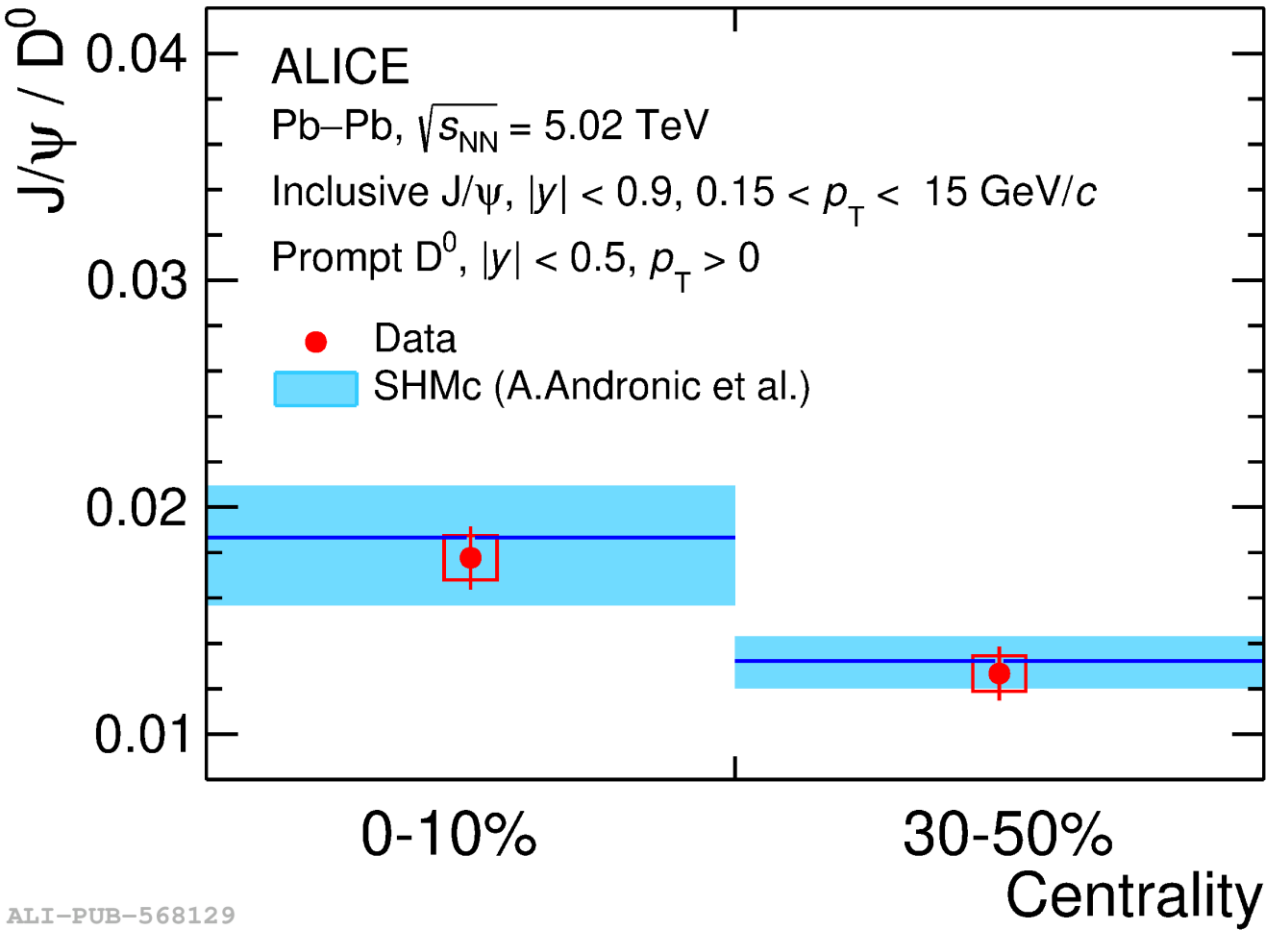
Charmonium production in pp collisions at $\sqrt{s}$ = 13.6 TeV



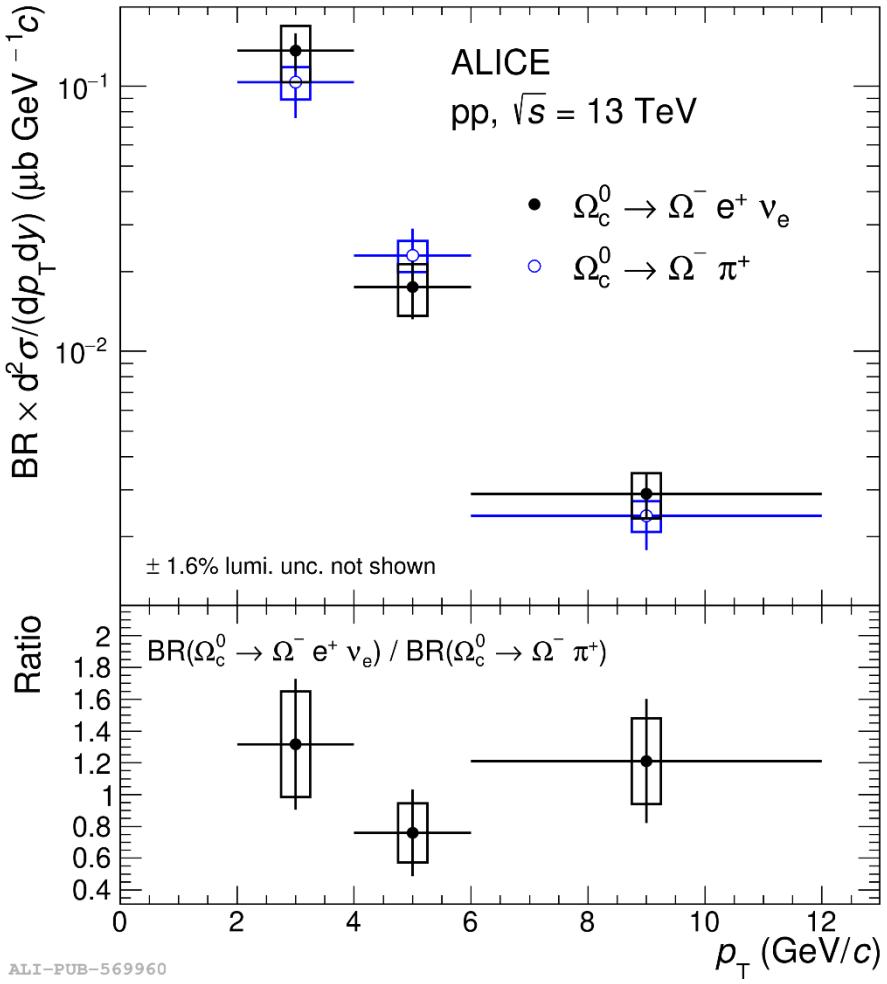


The new results at forward rapidity and midrapidity are described by model calculations

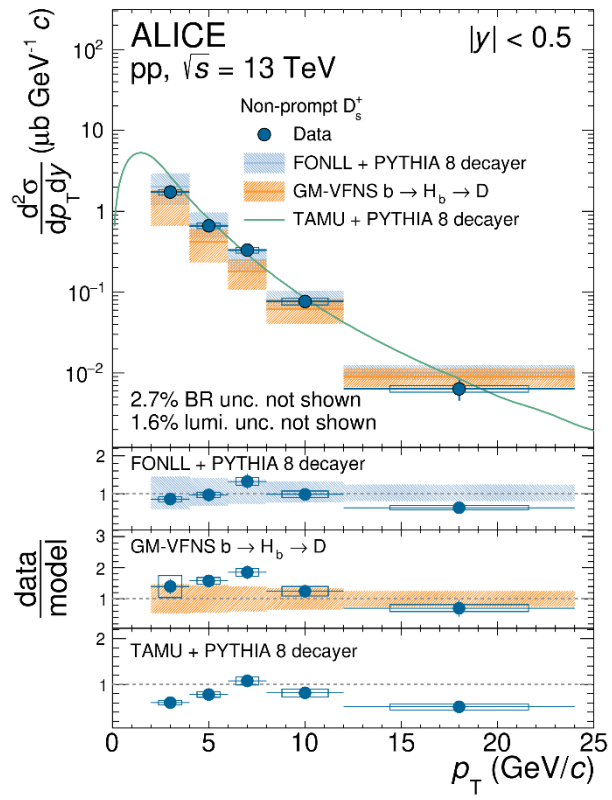
Charmonium production: J/ψ to D^0 ratio



Ω_c^0


ALICE
pp, $\sqrt{s}$ = 13 TeV
$\Omega_c^0 \rightarrow \Omega^- e^+ \nu_e$
$\Omega_c^0 \rightarrow \Omega^- \pi^+$
± 1.6% lumi. unc. not shown
BR × d²σ/(dp_T dy) (μb GeV⁻¹c)
Ratio
BR($\Omega_c^0 \rightarrow \Omega^- e^+ \nu_e$) / BR($\Omega_c^0 \rightarrow \Omega^- \pi^+$)
p_T (GeV/c)
ALI-PUB-569960

RATIOS



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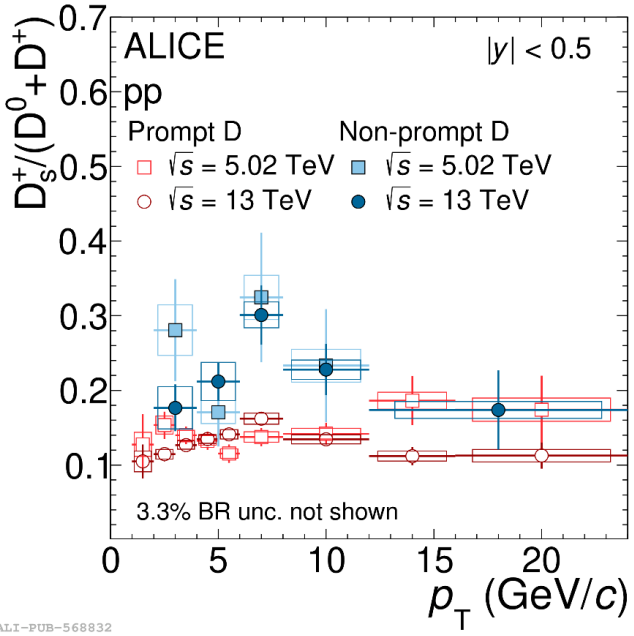
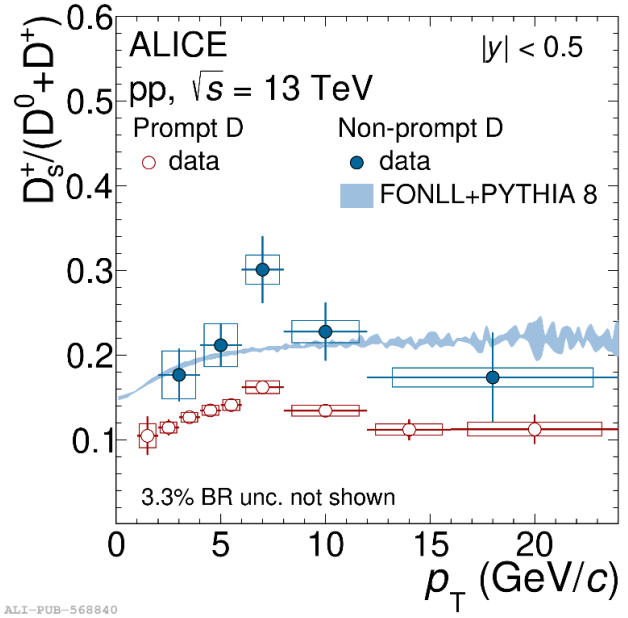
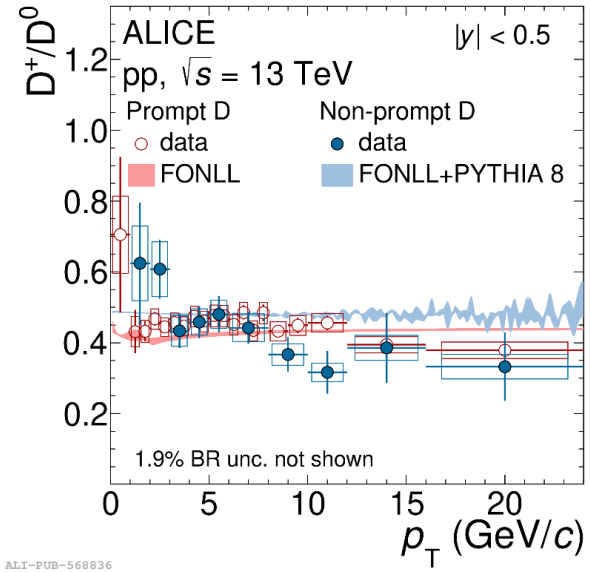


ALI-PUB-568832



ALI-PUB-568840

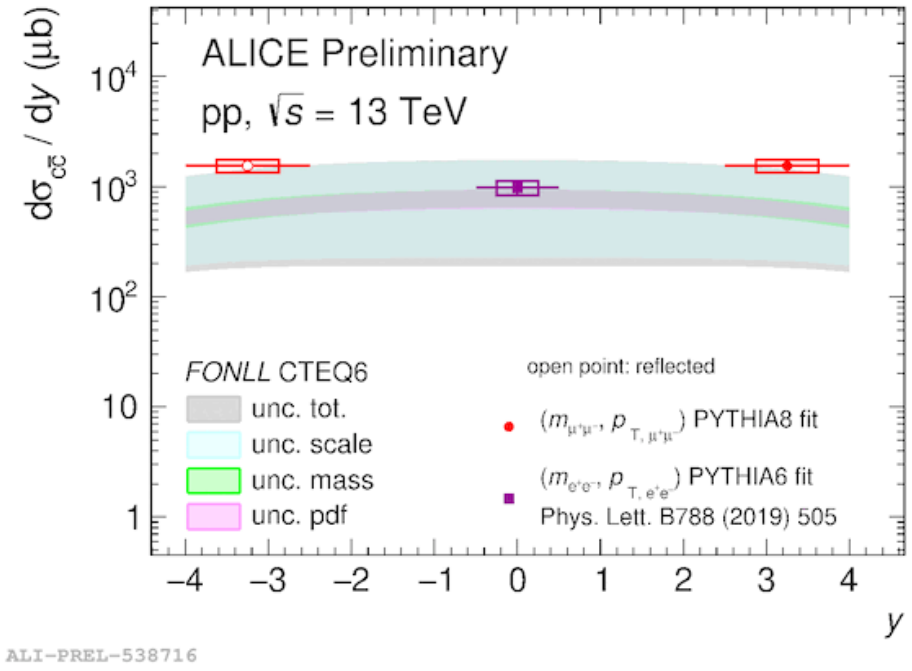


ALI-PUB-568836

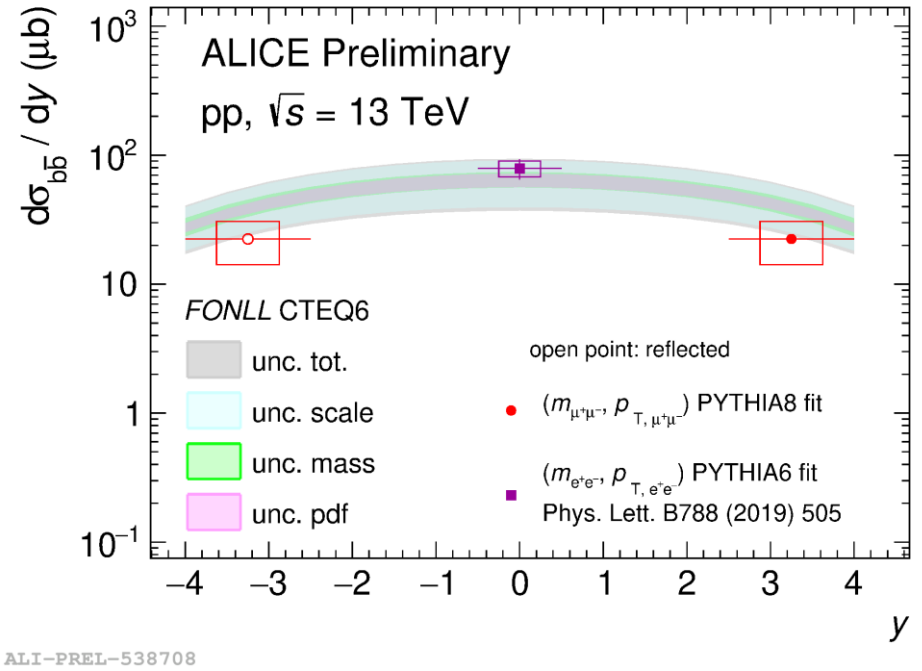
Coherent J/ψ photoproduction in peripheral Pb-Pb collisions

Charm and beauty production cross sections at forward y in pp collisions at $\sqrt{s}$ = 13 TeV

Charm



Beauty



- p_T-integrated charm and beauty production cross sections measured separately at forward rapidity via the dimuon continuum
- Results in agreement with FONLL predictions within uncertainties
  - lie in the upper and lower limit of the calculations for charm and beauty production cross section, respectively
- Complement the previously published results at midrapidity in the dielectron channel