Quarkonium production in pp, p-Pb, and peripheral Pb-Pb collisions with ALICE

Yvonne Pachmayer for the ALICE Collaboration
(Physikalisches Institut of the Heidelberg University)

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EUROPEAN PHYSICAL SOCIETY HEP2021 VIRTUAL EDITION

ALICE

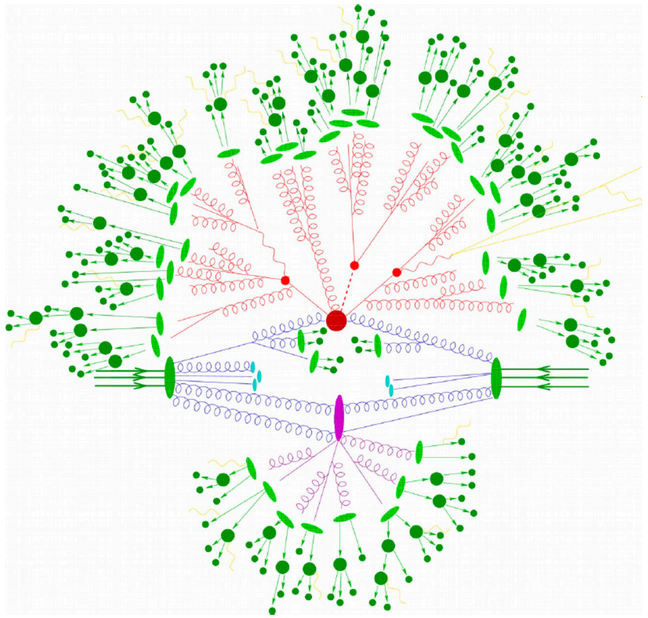
UNIVERSITÄT HEIDELBERG ZUKUNFT SEIT 1386

Physics motivation

- pp collisions
  - Study production mechanisms at the partonic level → benchmark for perturbative and non-perturbative quantum chromodynamic (QCD) models
  - High-multiplicity regime: study role of multiple parton interactions (MPIs)

    T. Sjöstrand, M. van Zijl, PRD36(1987)2019

  - Reference measurements for p-Pb and Pb-Pb analyses

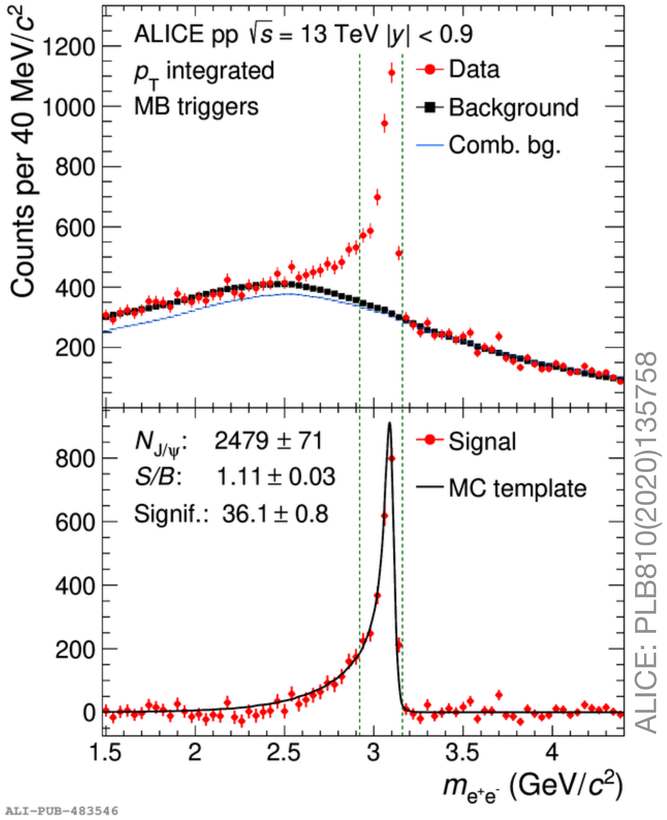


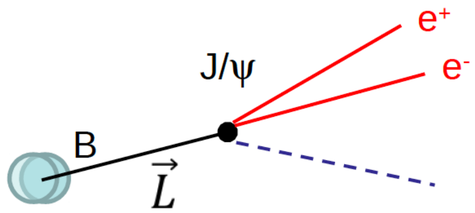
- p-Pb collisions
  - Investigate so-called cold-nuclear-matter effects
  - Possible final state interactions

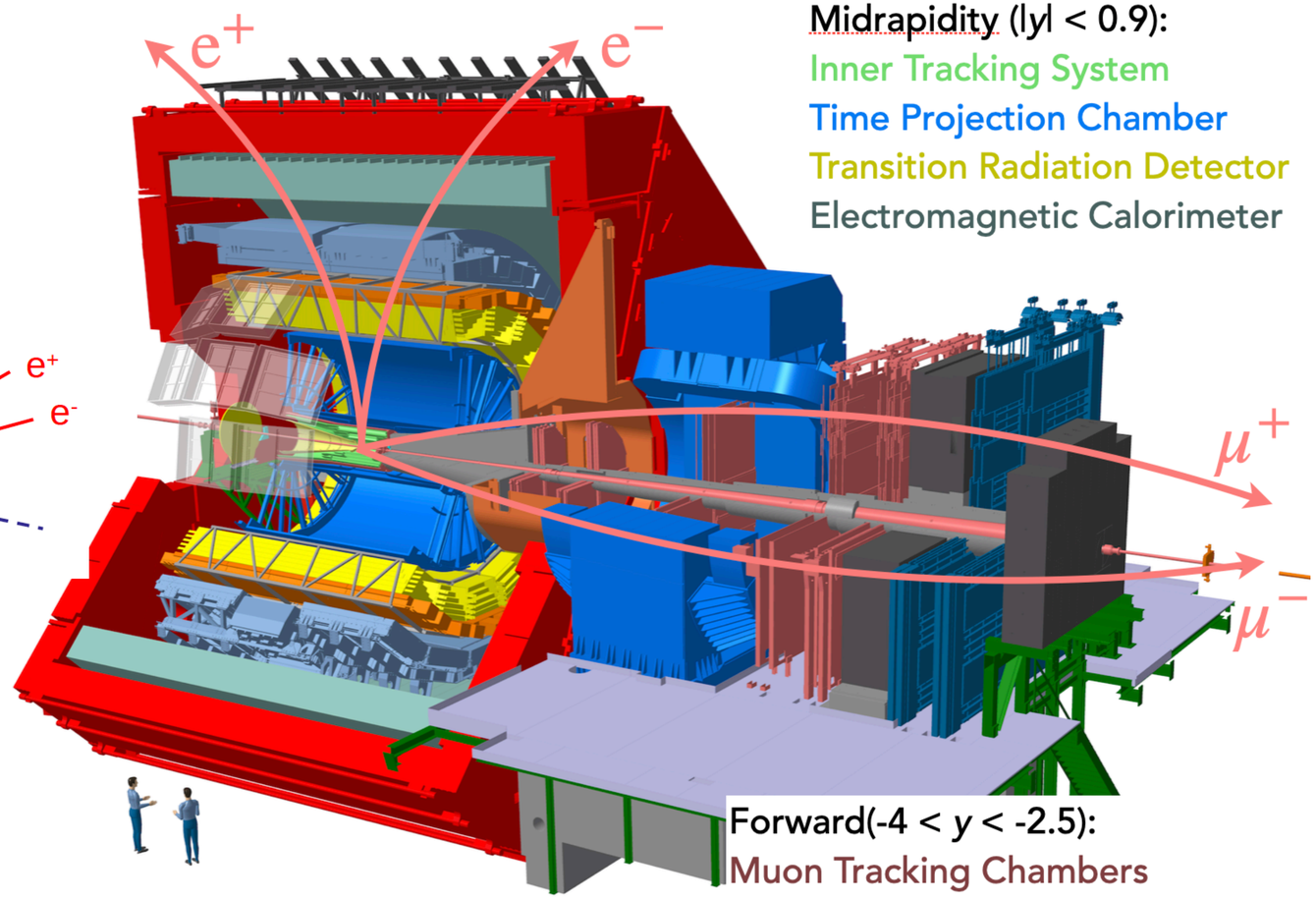
- Pb-Pb collisions - photonuclear interactions within hadronic collisions
  - Probe the gluon density down to very low Bjørken-*x*

ALICE detector

- Quarkonium measurements down to $p_T = 0$
  - Central barrel: inclusive, prompt/non-prompt J/ψ
  - Muon arm: inclusive J/ψ, ψ(2S), Υ(1S), Υ(2S), Υ(3S)







Midrapidity (|y| < 0.9):
Inner Tracking System
Time Projection Chamber
Transition Radiation Detector
Electromagnetic Calorimeter

Forward(-4 < y < -2.5):
Muon Tracking Chambers
Muon Trigger Chambers

Charmonium cross sections

pp

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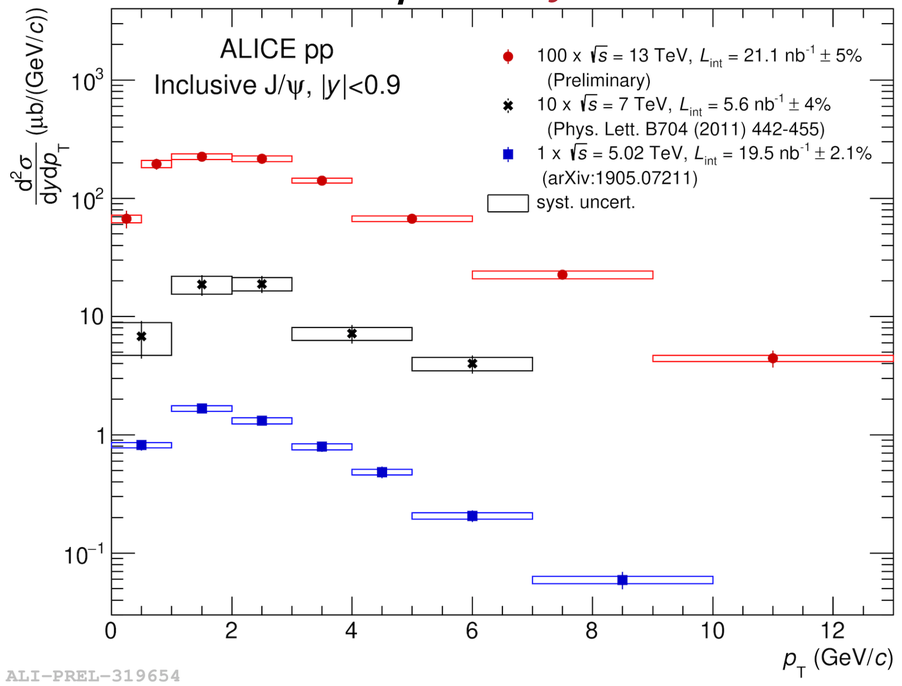
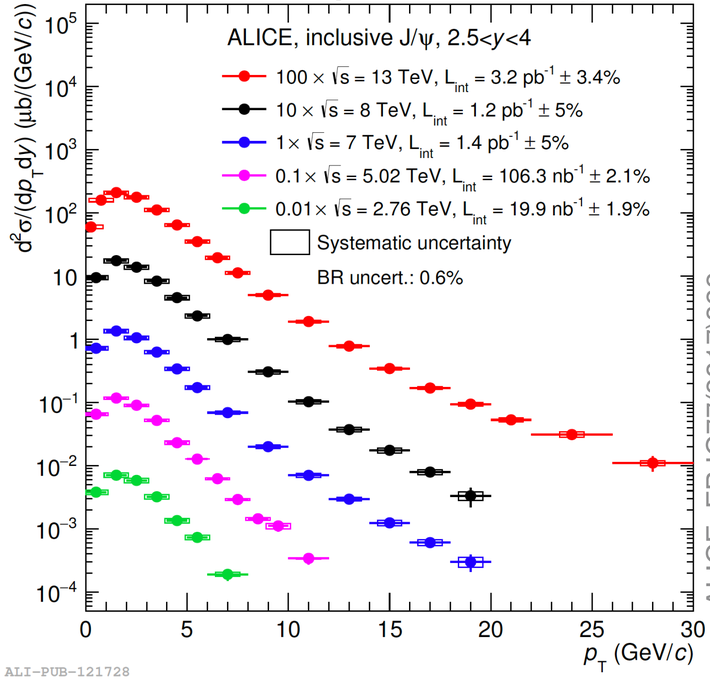
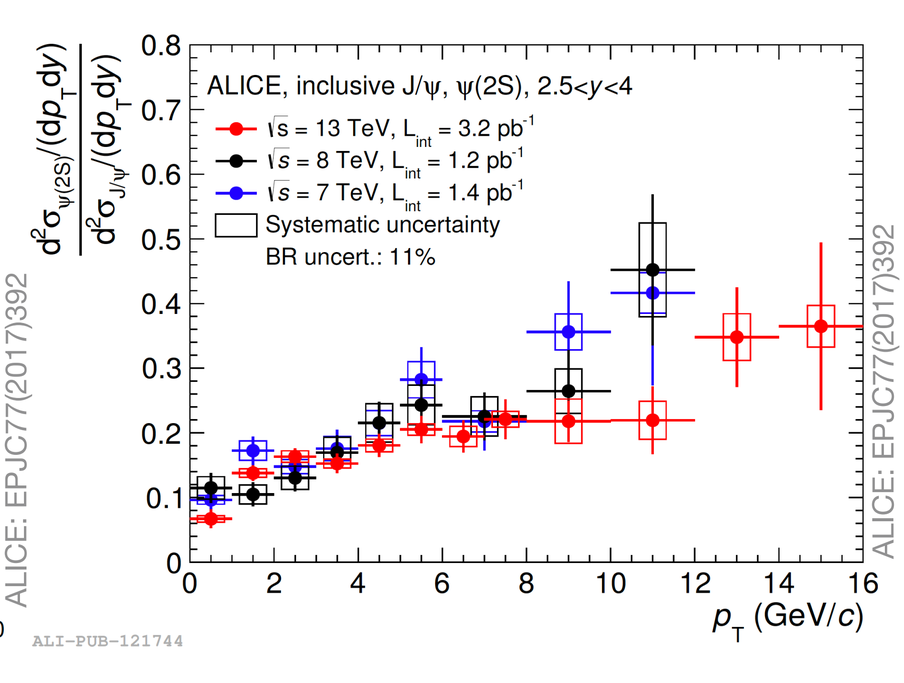
J/ψ mid-y



J/ψ forward-y



$\psi(2S)$ / J/ψ forward-y

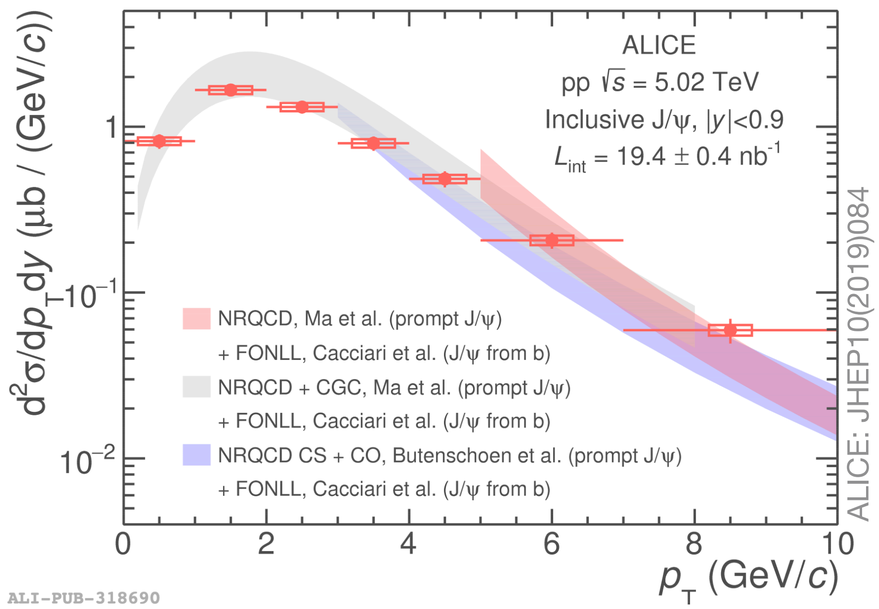


- Precise measurements at different centre-of-mass energies at mid- and forward rapidity down to $p_T = 0$
- Hardening of the spectra with increasing $\sqrt{s}$
- $\psi(2S)$ / J/ψ ratio exhibits increasing trend with p_T

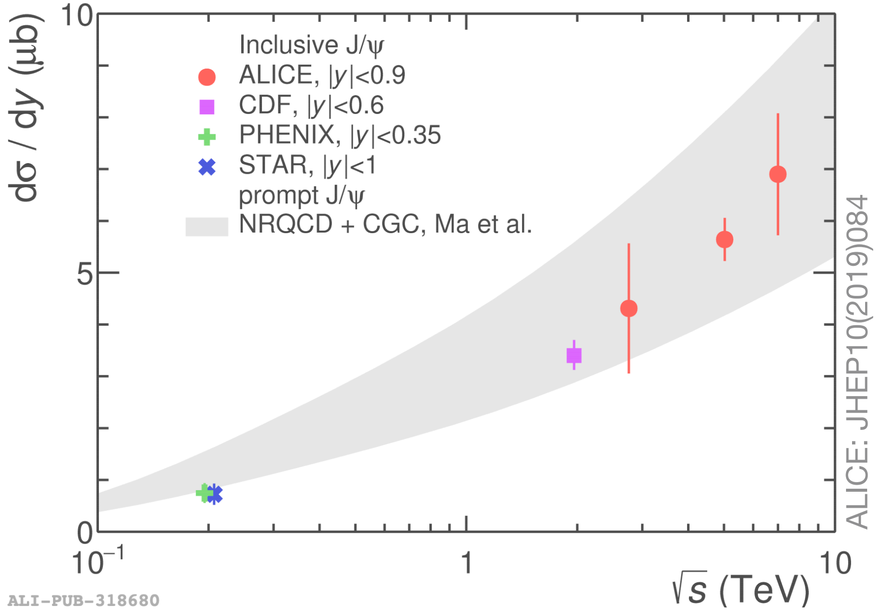
Charmonium cross sections

in comparison with theory

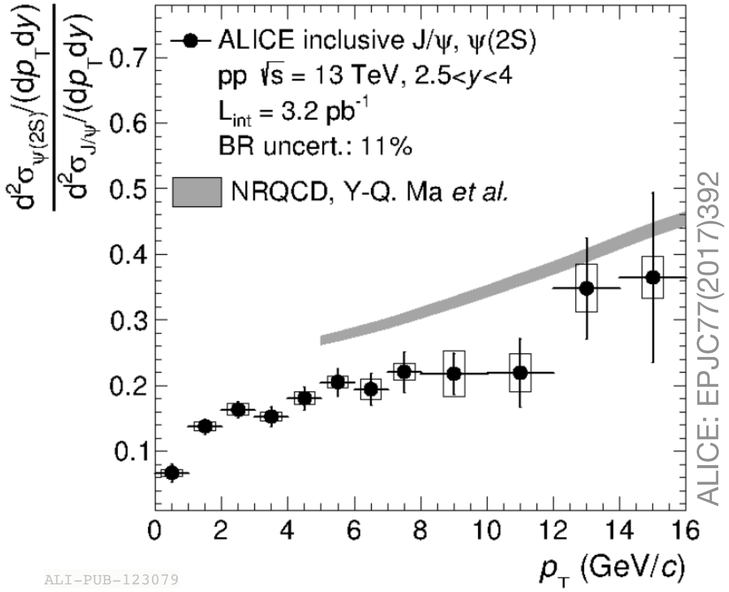
J/ψ mid-y



J/ψ mid-y



$\psi(2S)$ / J/ψ forward-y



- J/ψ: NRQCD+CGC (+FONLL) calculations describe the p_T-differential and inclusive cross section vs $\sqrt{s}$ well
- $\psi(2S)$ / J/ψ ratio (w/o FONLL): still some tension between data and calculation

NRQCD+CGC: PRL113(2014)192301
NRQCD: PRL106(2011)42002, PRL106(2011)022003
FONLL: JHEP10(2012)137

Non-prompt J/ψ and beauty production cross section

pp

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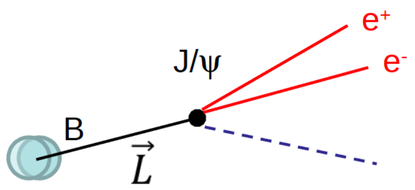
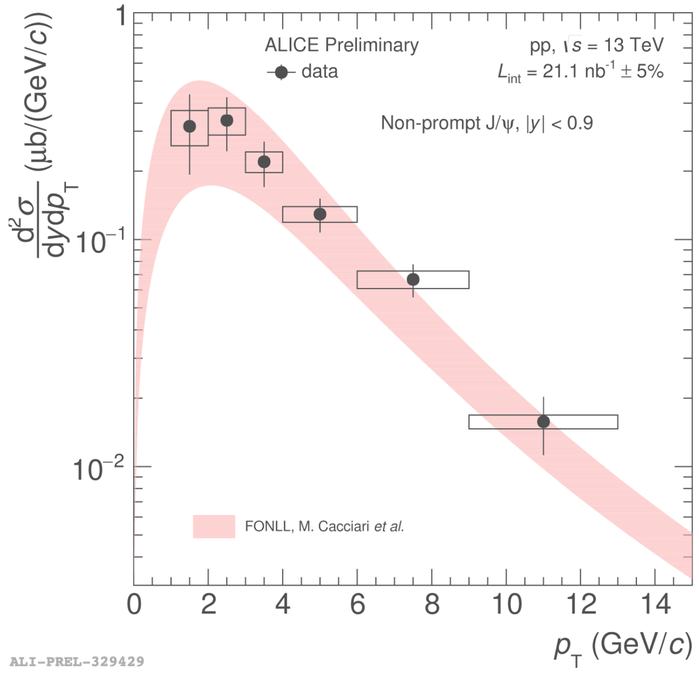
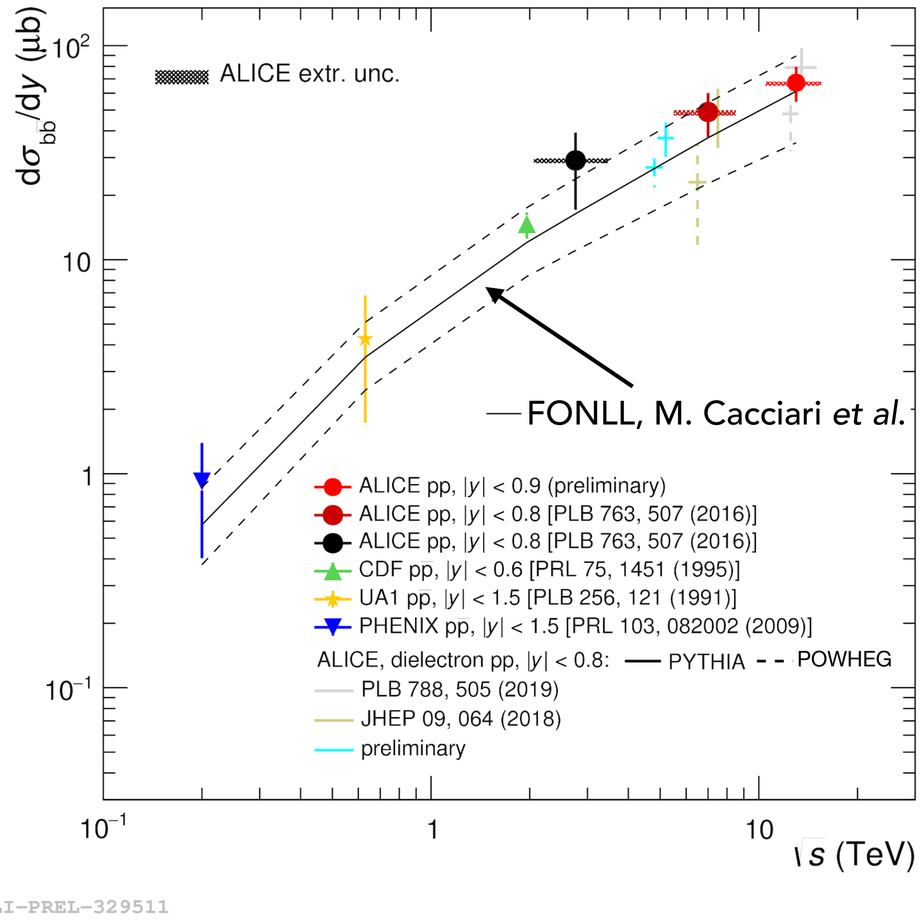


non-prompt J/ψ mid-y



$b\bar{b}$ cross section mid-y

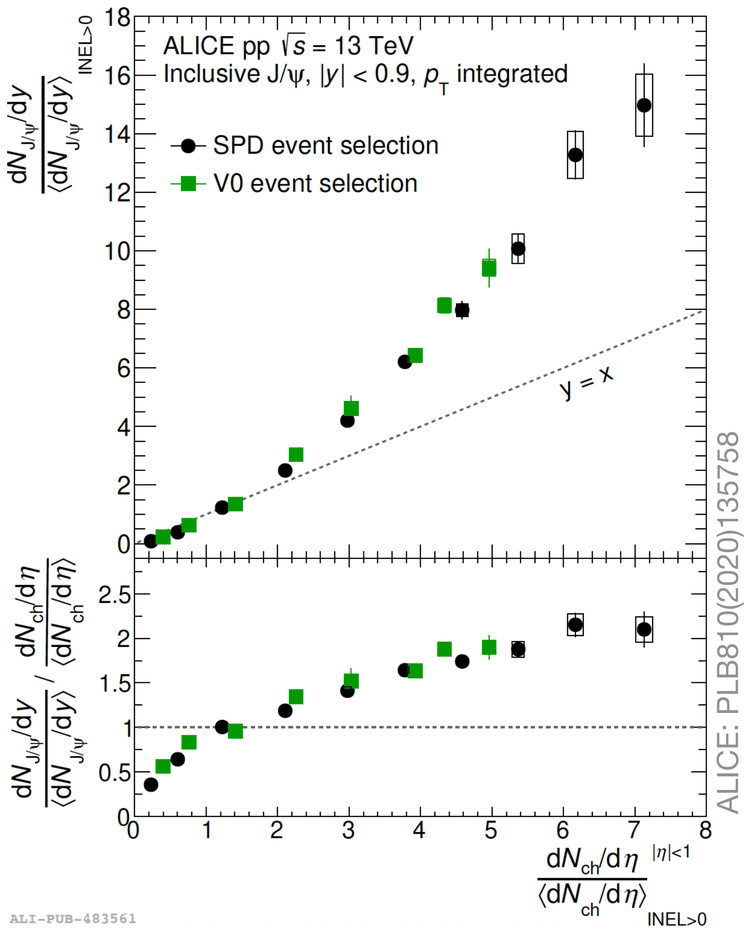


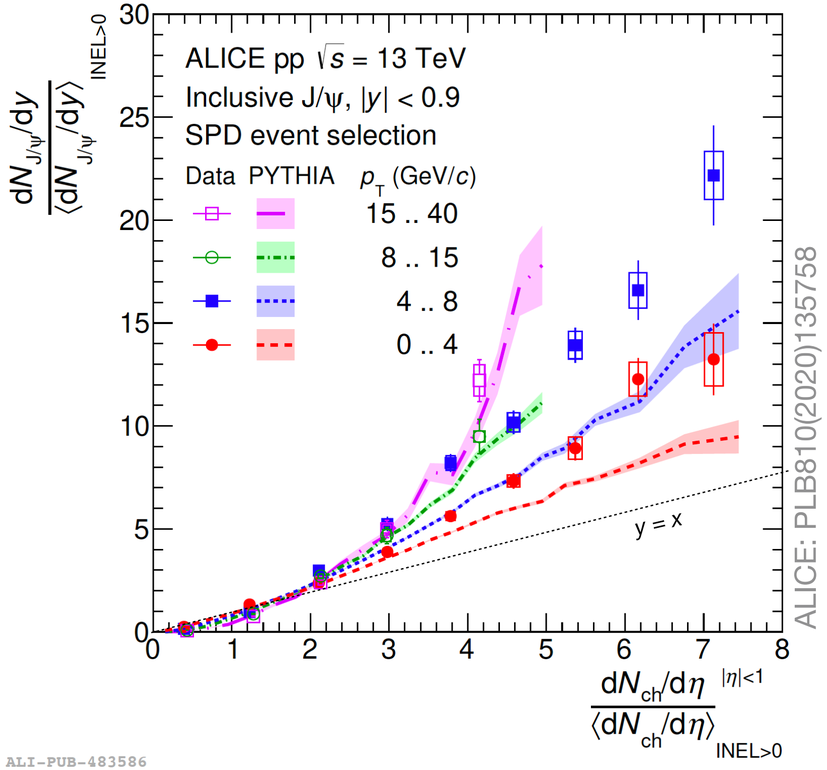
- Non-prompt J/ψ well described by FONLL calculations
- Beauty quark production cross section at midrapidity extracted via small (~11%) extrapolation
  - FONLL calculations in good agreement

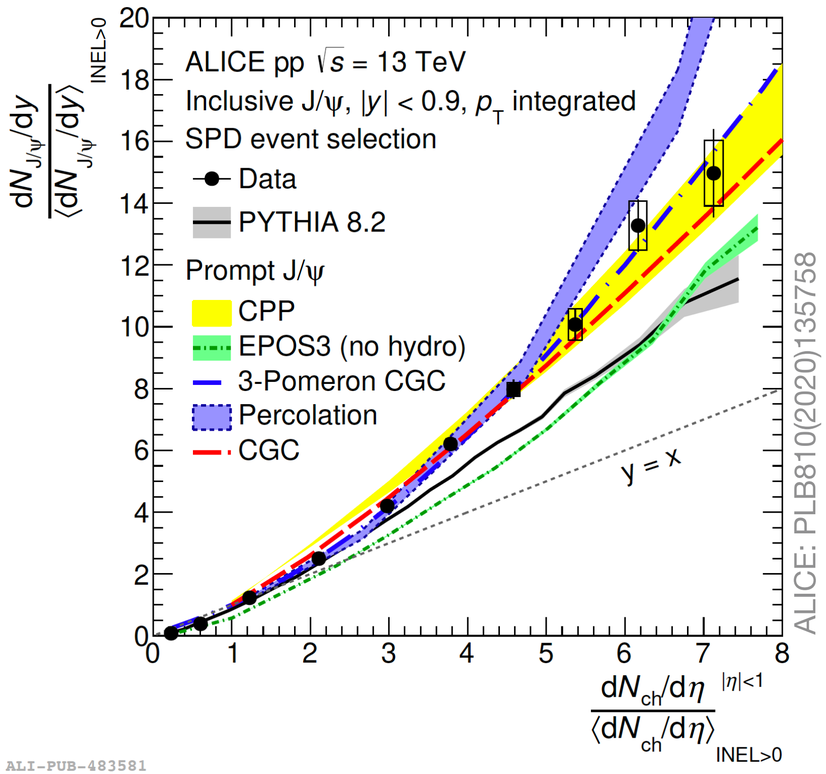
FONLL: JHEP10(2012)137

Multiplicity-dependent quarkonium measurements

J/ψ mid-y







J/ψ measurement: |y|<0.9

Multiplicity: |η|<1

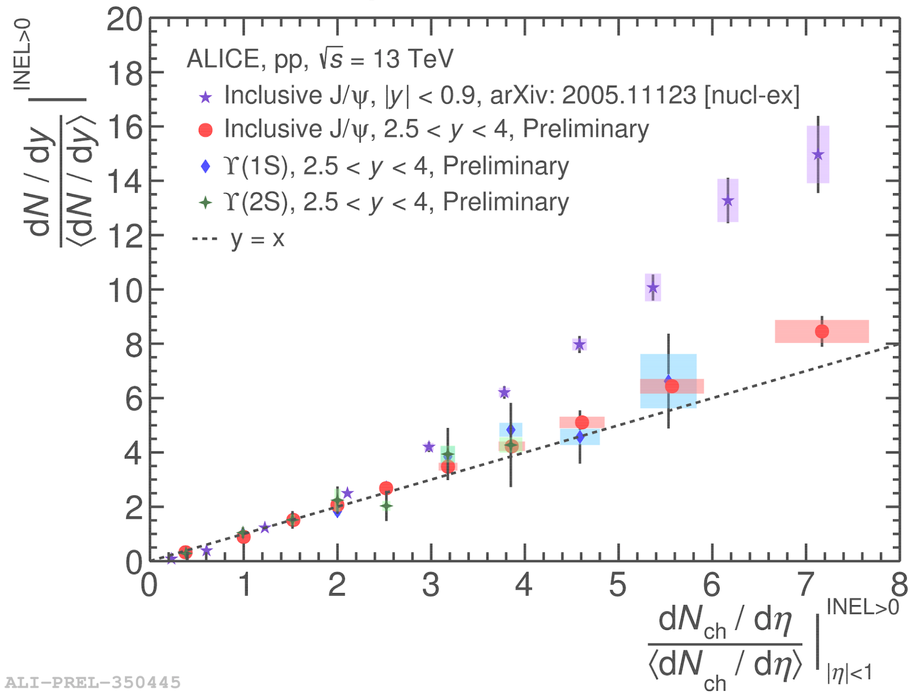
Multiplicity: 2<|η|<5

- J/ψ normalised yields increase stronger than linear with multiplicity at mid-y, for multiplicity estimators at mid-y and forward-y
- Models shows same trend, via different mechanisms of a reduction of charged particle multiplicity

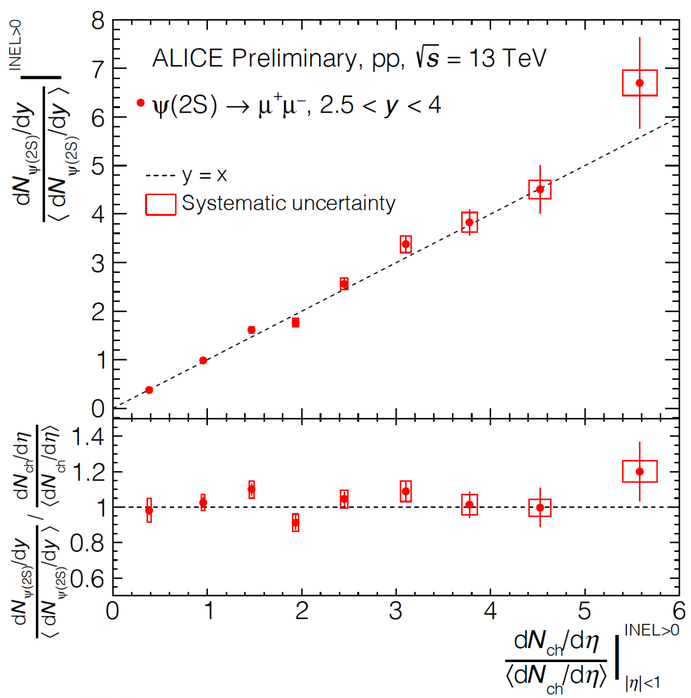
Multiplicity-dependent quarkonium measurement

forward-y

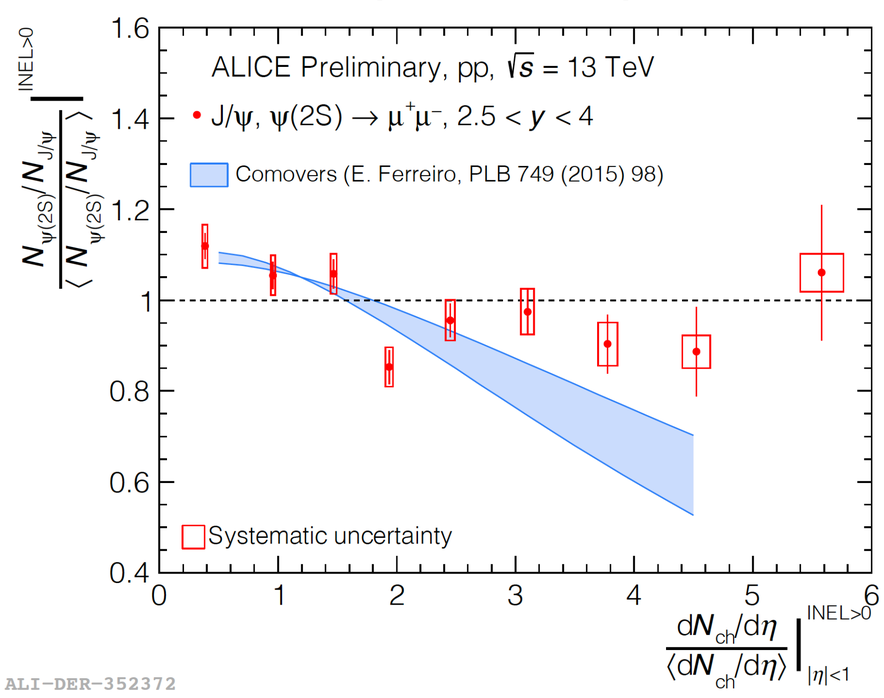
J/ψ, Υ(1S), Υ(2S)



ψ(2S)



ψ(2S) / J/ψ



- Quarkonium normalised yields at forward-y compatible with linear dependence on multiplicity at mid-y
- Similar multiplicity dependence for charmonia and bottomonia
- Double ratio of normalised yields of $\psi(2S)$ / J/ψ described by comovers model at low multiplicity, but underestimated at high multiplicity

J/ψ and ψ(2S) production

p-Pb

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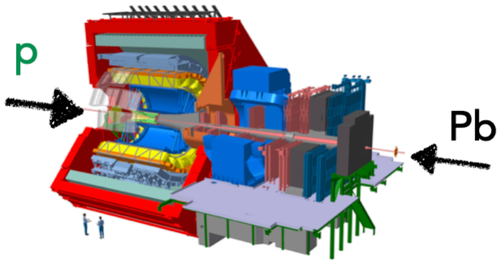
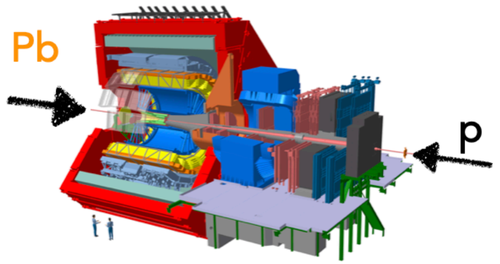
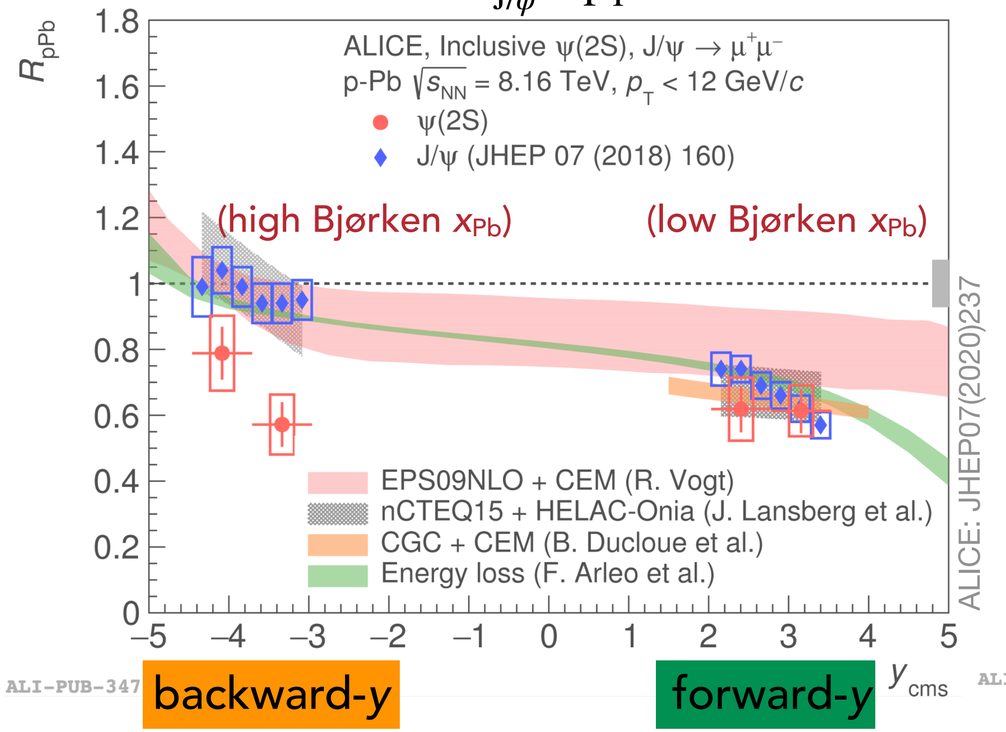


p-going side
forward-y
$2.03 < y_{cms} < 3.53$

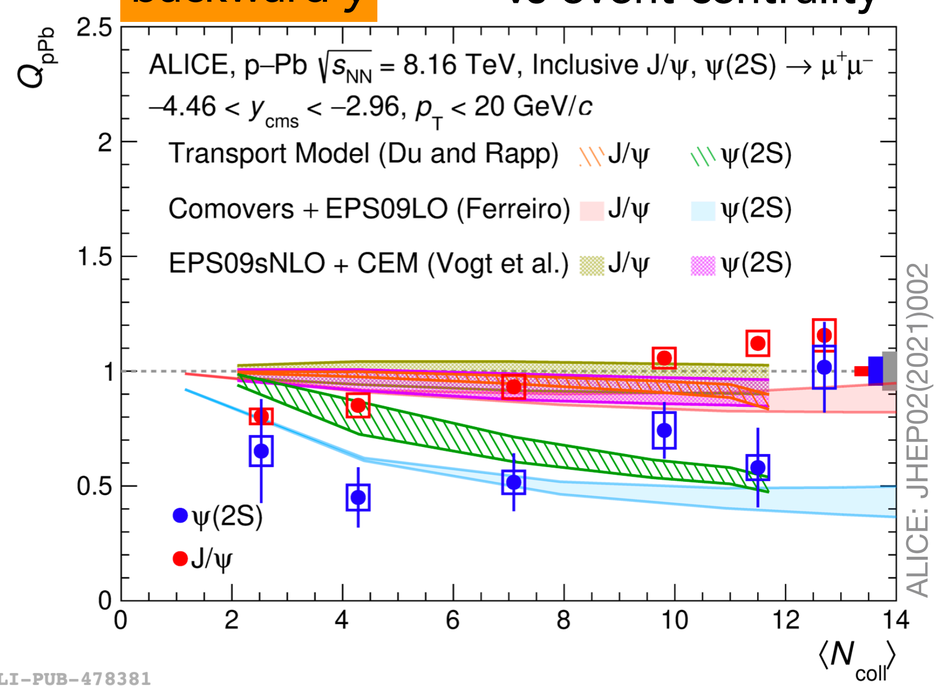


Pb-going side
backward-y
$-4.46 < y_{cms} < -2.96$

$$R_{pPb} = \frac{d\sigma^{pPb}_{J/\psi}/dp_T}{A \times d\sigma^{pp}_{J/\psi}/dp_T}$$



backward-y vs event centrality



- Forward-y: strong suppression described by calculations considering CNM effects
- Backward-y: stronger modification for $\psi(2S)$ compared to J/ψ
  - Qualitatively described by models including final-state interactions

J/ψ production at midrapidity

p-Pb

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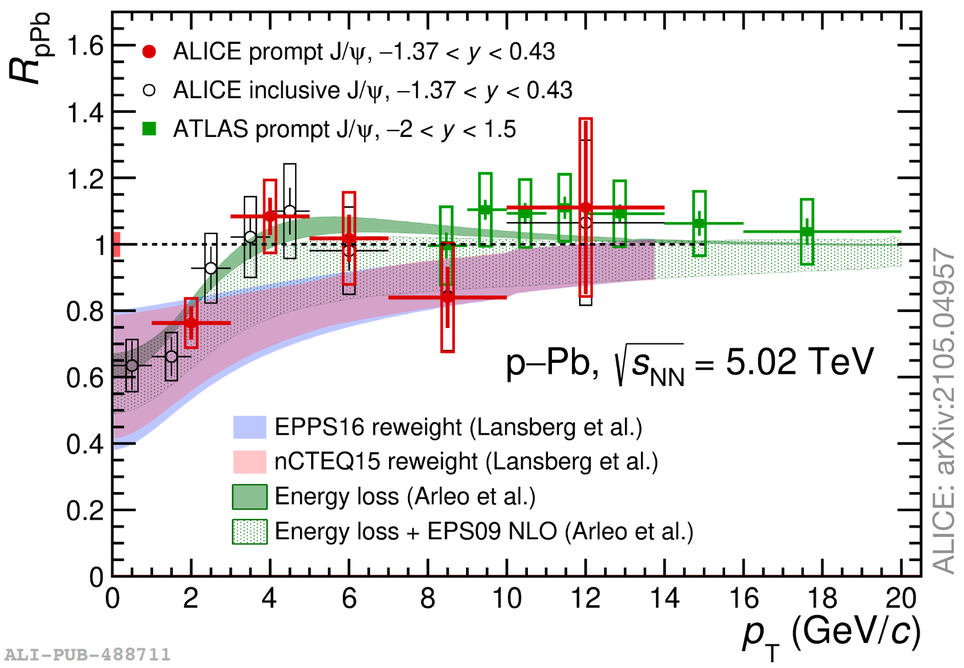
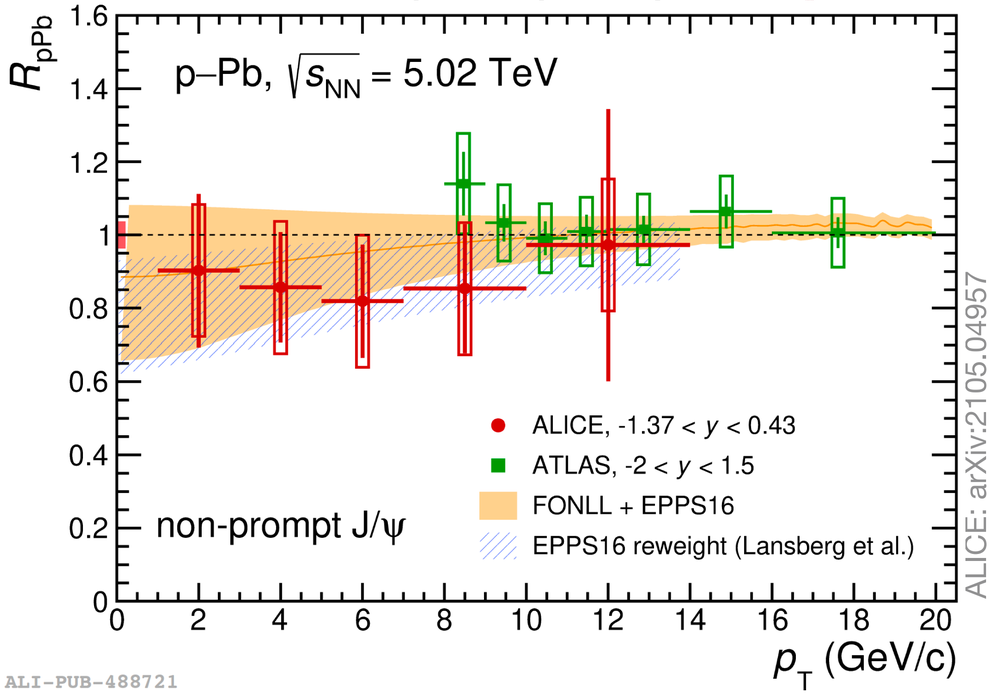
inclusive & prompt J/ψ mid-y



non-prompt J/ψ mid-y



- Inclusive and prompt J/ψ: suppression at low p_T, described by models, with modified nuclear PDFs and also including energy loss
- Non-prompt J/ψ: consistent with EPPS16 parameterisations (suggesting little shadowing)

Υ(nS) production

p-Pb

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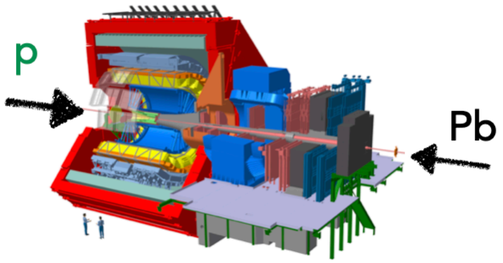
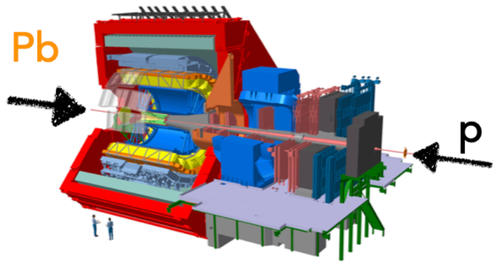


p-going side
forward-y
$2.03 < y_{cms} < 3.53$



Pb-going side
backward-y
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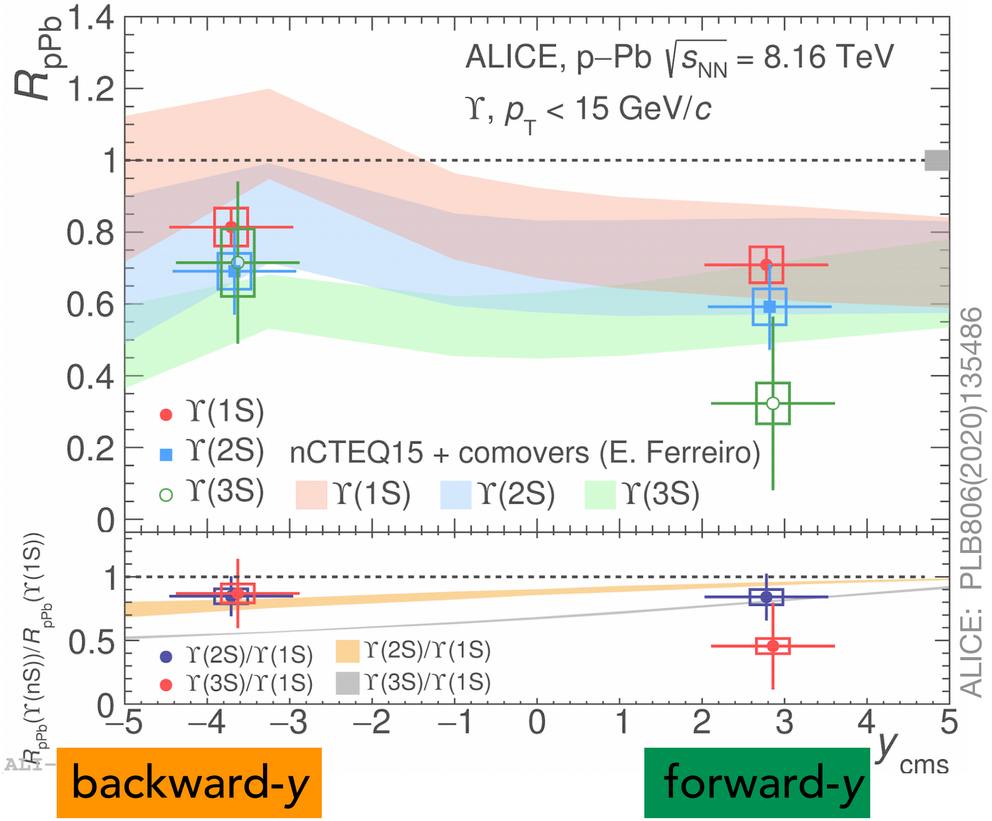


backward-y

forward-y

- Similar suppression for Υ(1S) and Υ(2S) at forward-y and backward-y
- First measurement of Υ(3S)

E. Ferreiro and J. Lansberg JHEP10(2018)094

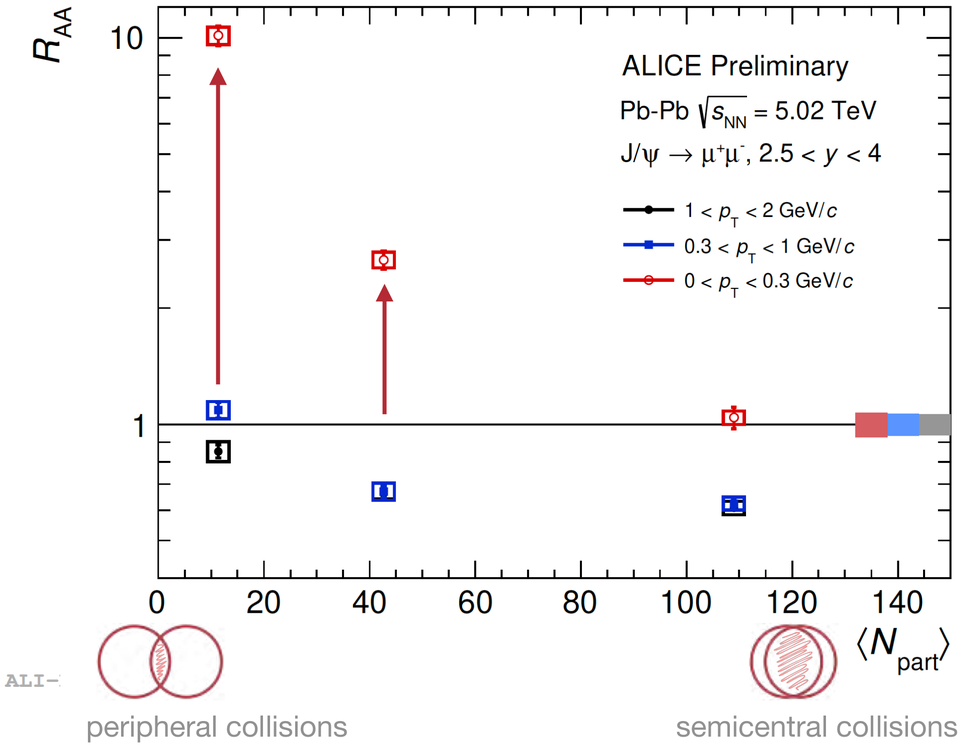
- Comovers model predicts an ordering in the suppression of Υ(nS) at backward-y

J/ψ: low-p_T and coherent photoproduction

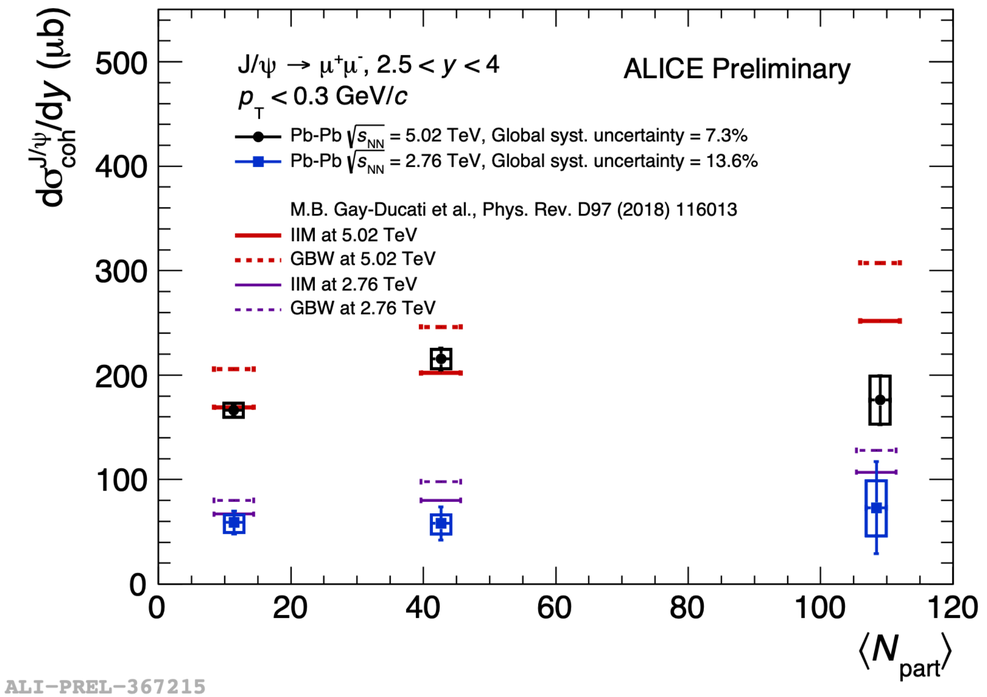
Pb-Pb

Talk: Kunal Garg, T05: HI Physics Part2

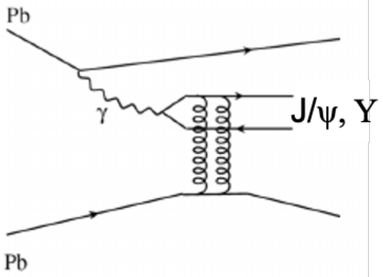
Low-p_T J/ψ forward-y



J/ψ coherent photoproduction forward-y



- Low-p_T : R_{AA} always larger than hadronic R_{AA} (reference interval 1-2 GeV/c)
- Coherent photoproduction: increase of cross section with energy
  - Models with modification of photon flux (purely electromagnetic) wrt to ultra-peripheral collisions qualitatively describe the data; some tension for semicentral collisions



Summary and outlook

- pp collisions
  - Precise differential measurements providing important insight into particle production
    - Described by NRQCD+CGC calculations, some tension remaining
    - Multiplicity dependence of quarkonium: faster than linear increase of J/ψ yields at midrapidity, trend described by models
- p-Pb collisions
  - Stronger CNM effects at low p_T
  - Relative suppression of $\psi(2S)$ wrt J/ψ suggests final-state effects
  - Y(nS) states: Similar suppression for $\Upsilon(1S)$ and $\Upsilon(2S)$, first measurement of $\Upsilon(3S)$
  - Hint that p-Pb is not a simple case for studying CNM effects anymore
- Pb-Pb collisions - coherent photoproduction
  - Measurements qualitatively described by UPC models; some tension in semicentral collisions
- Outlook Run 3 and 4 - physics programme
  - pp (also dedicated HM triggers): target luminosity: 200 pb^{-1} ALICE: ALICE-PUBLIC-2020-005
  - p-Pb: target luminosity 0.3 pb^{-1}

Back-Up

Charmonium Cross Sections

$\langle p_T \rangle$ and $\langle p_T^2 \rangle$

pp

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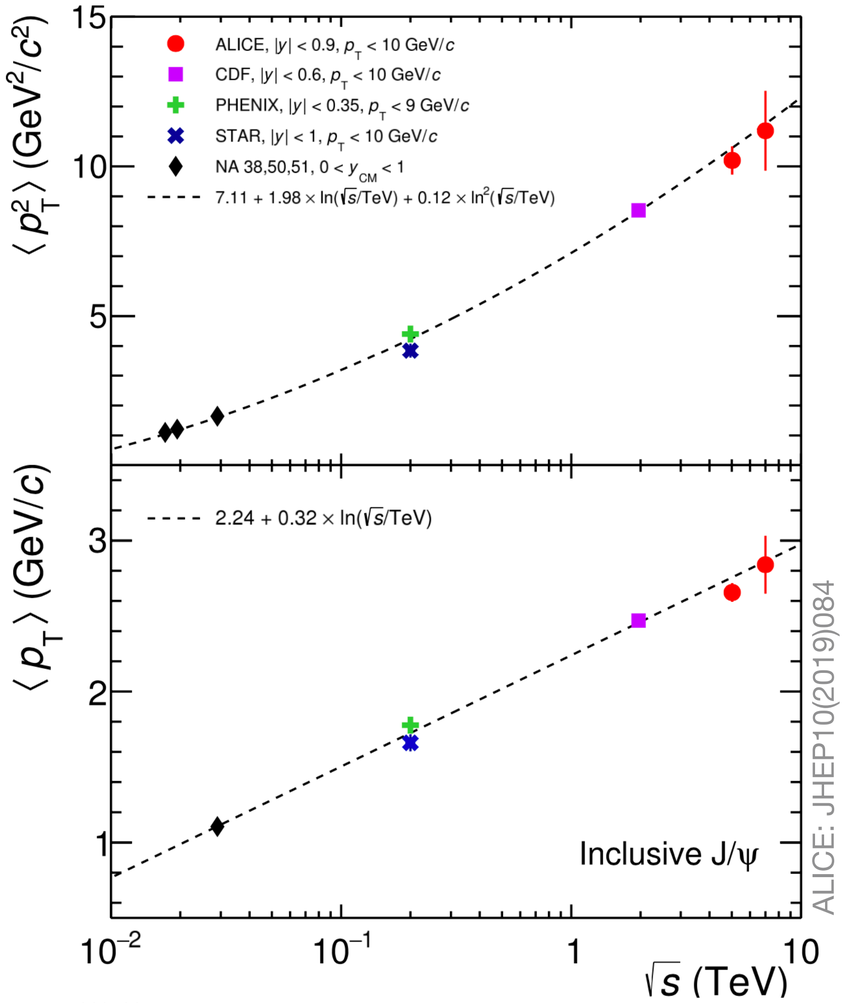
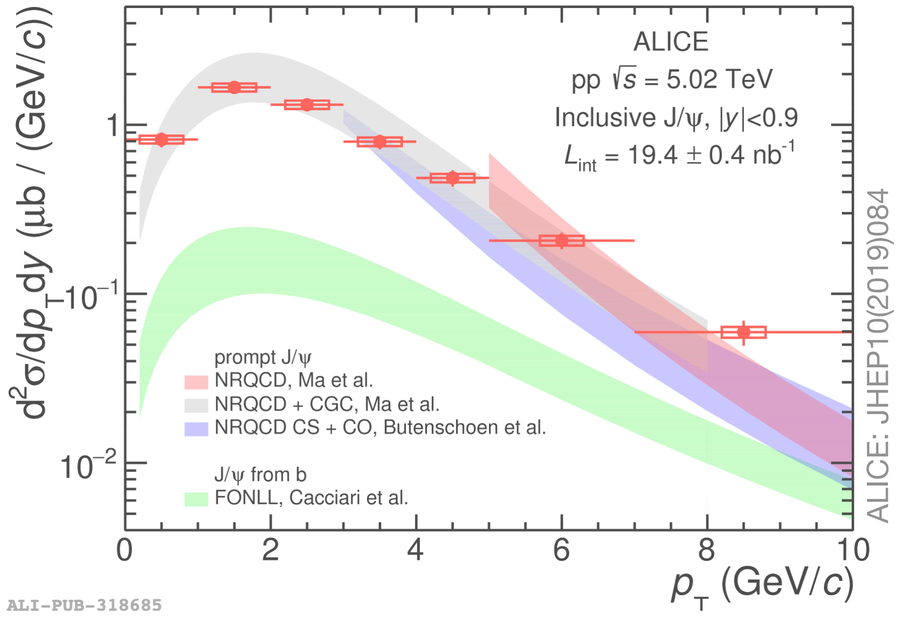
J/ψ mid-y





ALI-PUB-318685

J/ψ and ψ(2S) production

Event centrality dependence

pA

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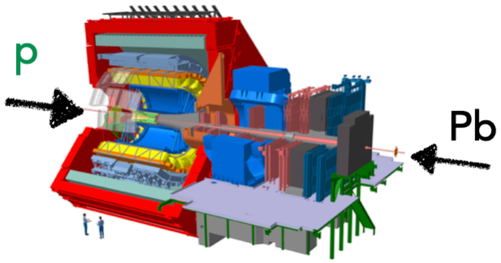

p-going side
forward-y
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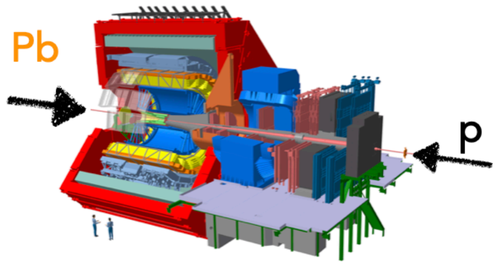
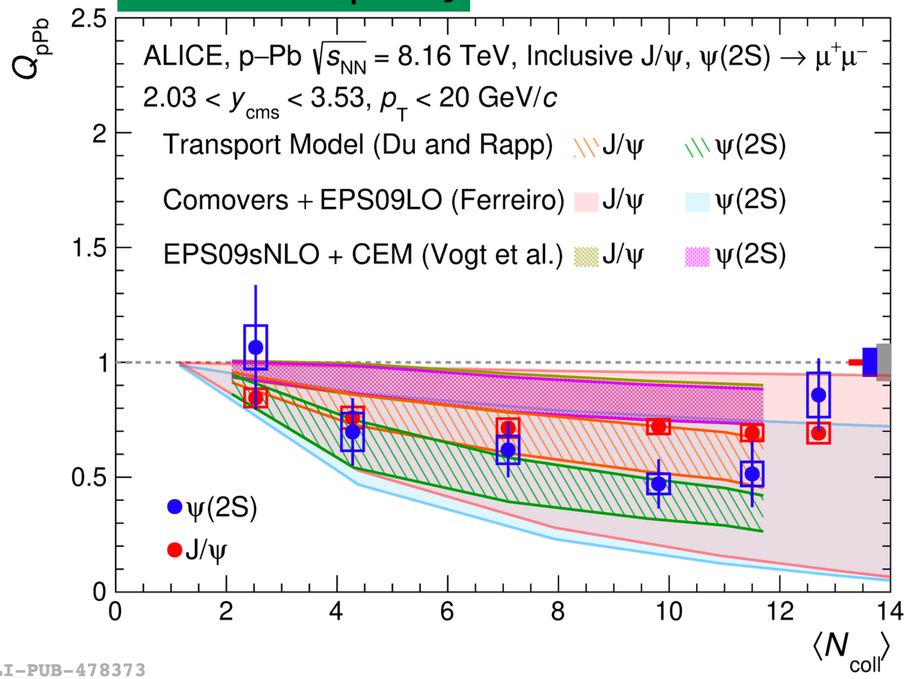


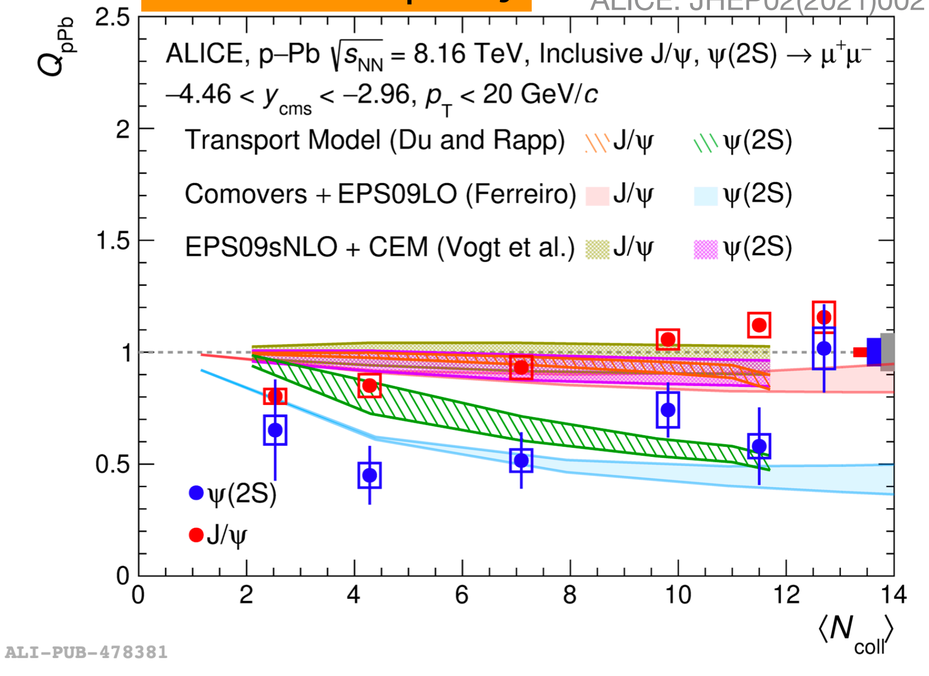
Pb-going side
backward-y
$-4.46 < y_{cms} < -2.96$

forward rapidity



backward rapidity

ALICE: JHEP02(2021)002



- Forward rapidity: similar centrality dependence for both chromium states
- Backward rapidity: stronger suppression for $\psi(2S)$ compared to J/ψ
  - Qualitatively described by models including final-state interactions

J/ψ and ψ(2S) production