Inclusive J/ψ production in pp and Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with ALICE at the LHC

Journées de Rencontres des Jeunes Chercheurs (JRJC)
Centre Moulin Mer
https://indico.in2p3.fr/event/19350/

Chun-Lu Huang on behalf of the ALICE Collaboration

Content

Physics motivations

- Quark-Gluon Plasma (QGP) and J/ψ production in heavy-ion collisions
- J/ψ production mechanisms in pp collisions

LHC and ALICE detector

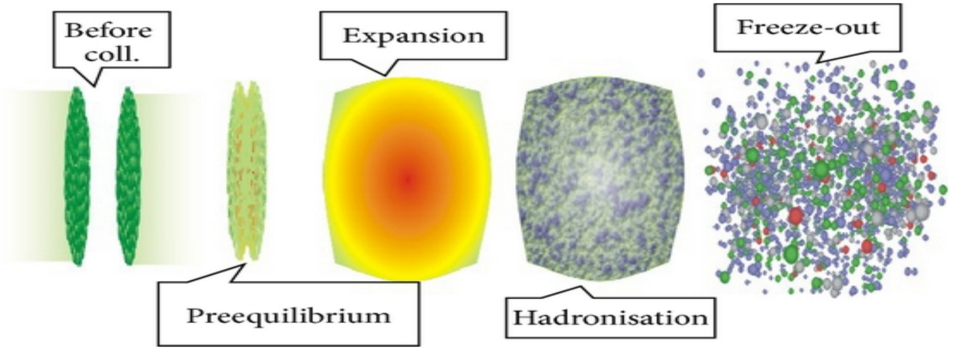
Data samples: Pb-Pb 2015+2018 and proton-proton (pp) 2017

Analysis of inclusive J/ψ production in Pb-Pb and pp collisions

- pp analysis
- Pb-Pb analysis

Conclusion and to do

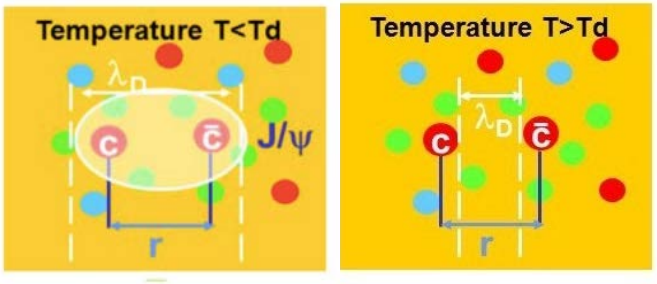
J/ψ as a probe of the QGP in heavy-ion collisions



Hard probes including prompt J/ψ produced in the early stage of the collision and cross the QGP

J/ψ (re)generated either during QGP phase and/or at the hadronization stage at the LHC energy

- **Color screening of** $c\bar{c}$ pair **in QGP → J/ψ suppression**



- **Parton energy loss by multiple scattering in QGP→ energy loss by quarks, gluons or** $c\bar{c}$ pairs?

J/ψ (re)generation in QGP → J/ψ enhancement

Satz, Matsui. Phys.Lett. B178(1986) 416-422
P. Braun-Munzinger and J. Stachel, Phys. Lett. B 490 (2000) 196
R.L. Thews, M. Schroedter, and J. Rafelski, Phys. Rev. C 63 (2001) 054905
M. Spousta, Phys. Lett. B 767 (2017) 10
F. Arleo, PRL 119 (2017) 062302

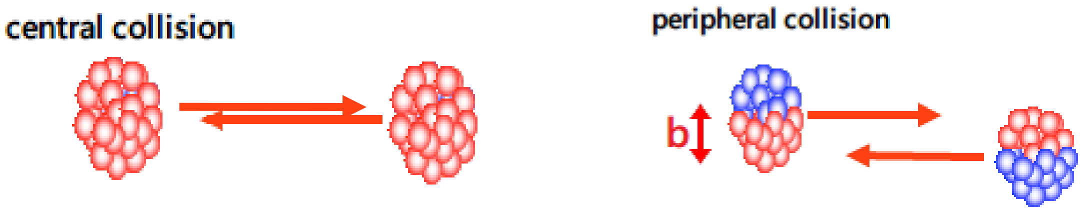
Observable in Pb-Pb: nuclear modification factor R_{AA}

$$R_{AA} = \frac{Y_{AA}^{J/\psi}}{<T_{AA}>\cdot\sigma_{J/\psi}^{pp}}$$

$Y_{AA}^{J/\psi}$ is the J/ψ invariant yield in nucleus-nucleus collisions (AA)

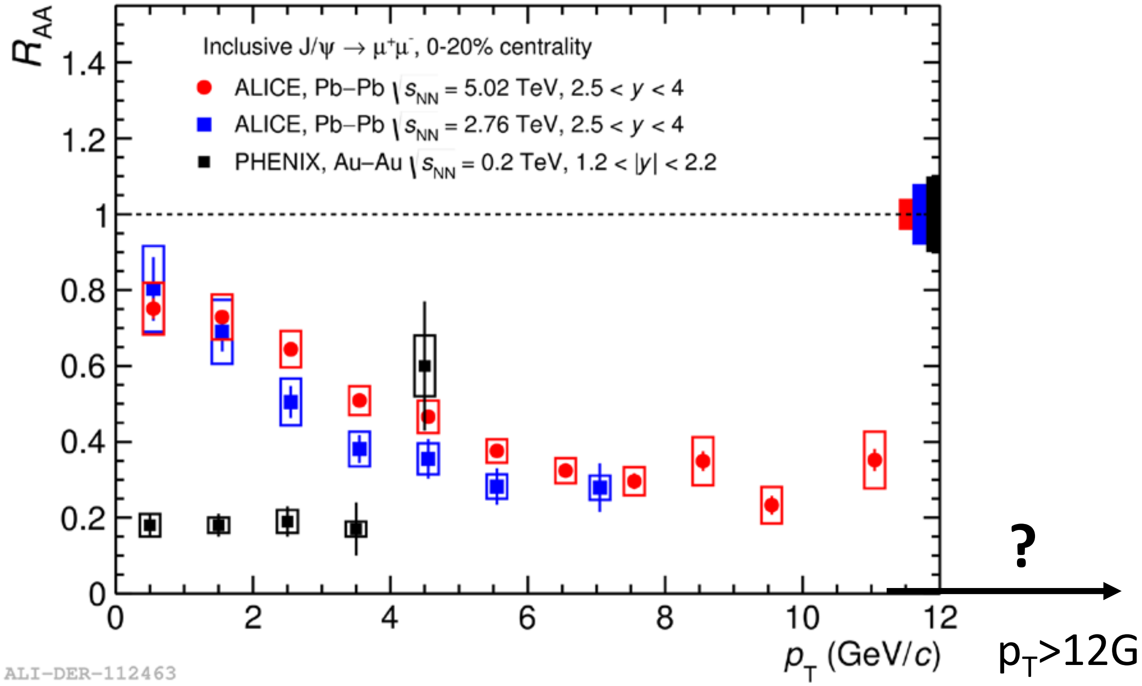
$\sigma_{J/\psi}^{pp}$ is the J/ψ production cross section in proton-proton (pp) collision at the same energy

$< T_{AA} >$ is the nuclear overlap function which quantifies the average nucleon-nucleon luminosity per AA collision

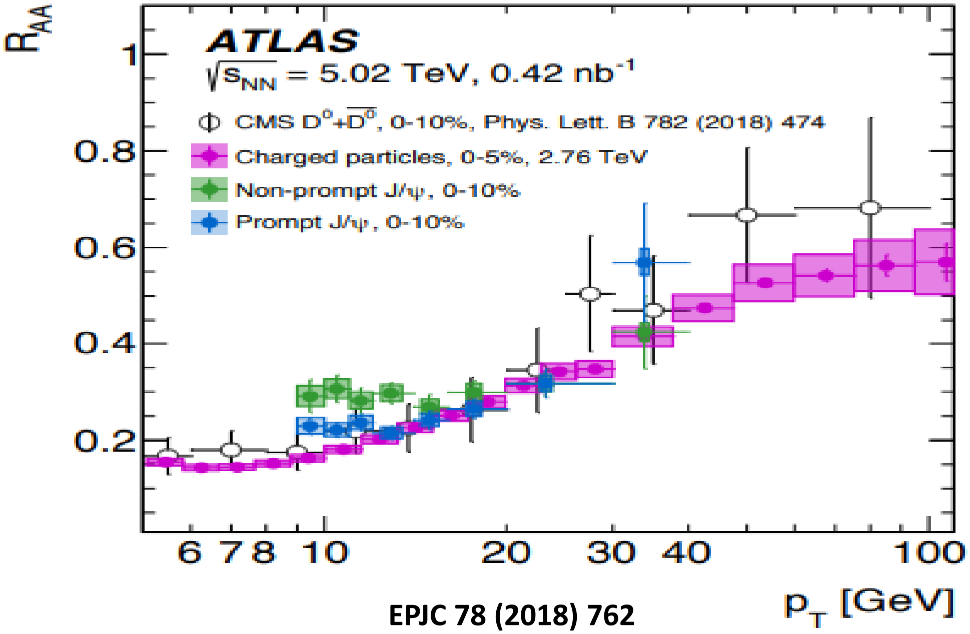


- $R_{AA} > 1$ → J/ψ enhancement
- $R_{AA} = 1$ → No significant medium effect
- $R_{AA} < 1$ → J/ψ suppression

J/ψ $R_{AA}(p_T)$ at RHIC (PHENIX) and LHC (ALICE, ATLAS, CMS)



p_T>12GeV



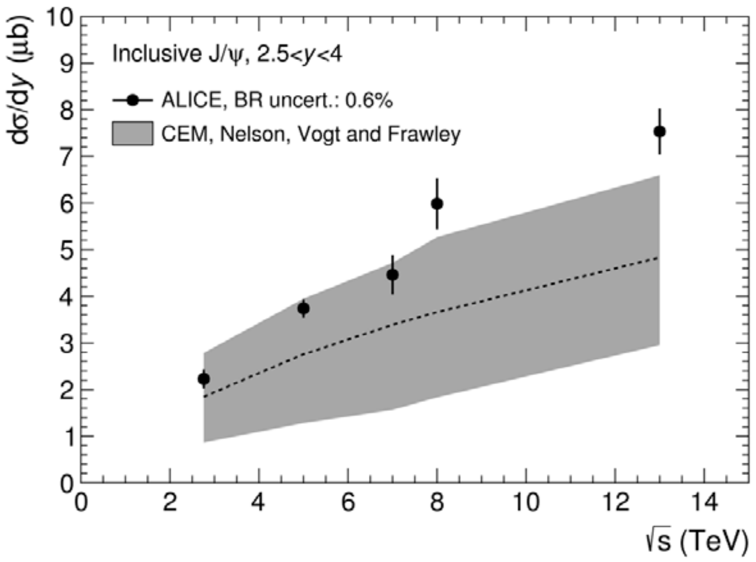
EPJC 78 (2018) 762

- $p_T < 6$ GeV: R_{AA} increases towards low p_T: hint of regeneration. Interplay between color screening and regeneration.
- $6 < p_T < 20$ GeV: $R_{AA} \sim 0.2 - 0.3$ and increases slightly at larger p_T. Indication of color screening mostly.
- $p_T > 20$ GeV: $R_{AA}^{J/\psi} \sim R_{AA}^{charged}$: energy loss signature. Interplay between color screening and energy loss.

J/ψ production mechanisms in pp

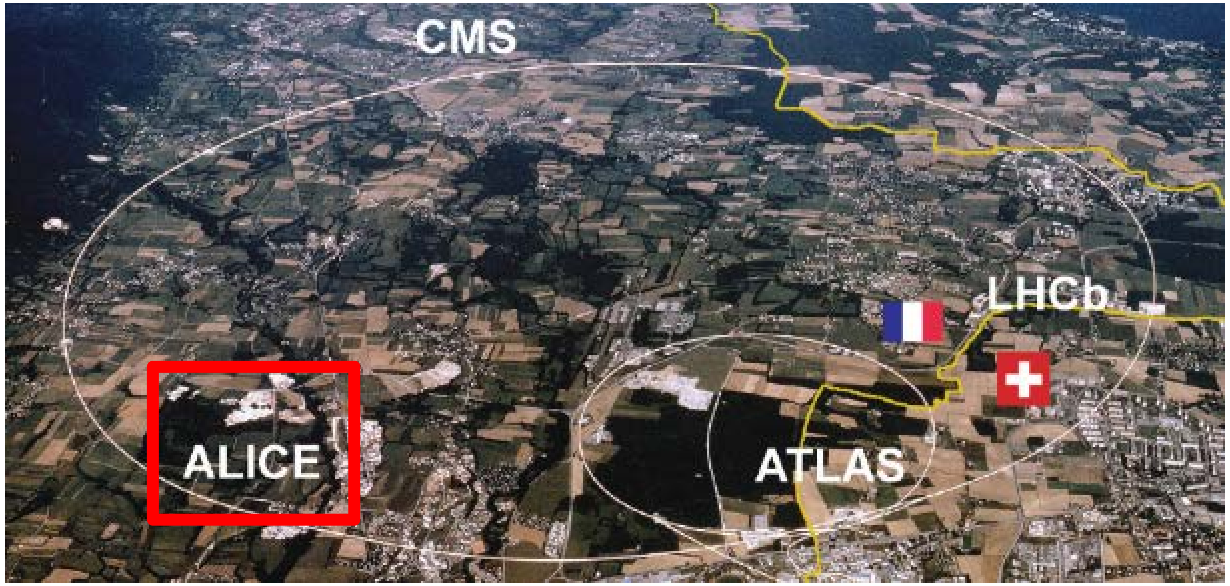
Three main models describe the quarkonium production in pp.

- Colour evaporation model (CEM): it considers all the $c\bar{c}$ pairs hadronizing into a charmonium state. It assumes the $c\bar{c}$ color “evaporates ” through gluon emission
- Colour singlet model (CSM): the color charge, the spin of the $c\bar{c}$ pair and the J/ψ are unchanged.
- Non-relativistic QCD (NRQCD): it includes the colour singlet and the colour octet contributions.



The Large Hadron Collider (LHC)

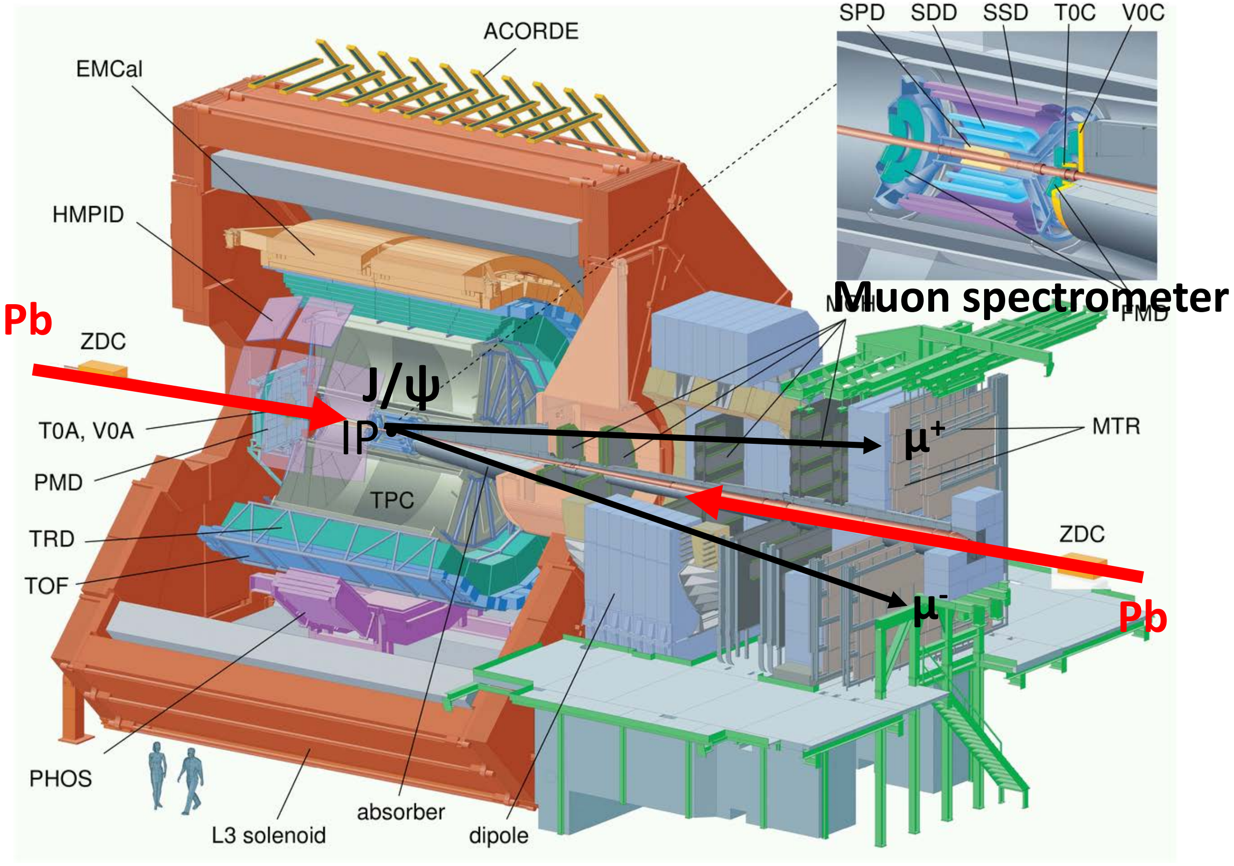
- LHC at CERN (Geneva) is the largest and most powerful particle collider for pp (currently up to $\sqrt{s}$ = 13 TeV) p-Pb (currently up to $\sqrt{s_{NN}}$ = 8.16 TeV) and Pb-Pb (currently up to $\sqrt{s_{NN}}$ = 5.02 TeV)
- Three types of collisions:
  - pp: investigate the quarkonium production mechanism
  - p-Pb: explore the cold nuclear matter effect
  - Pb-Pb: study the properties of quark-gluon plasma



27 km

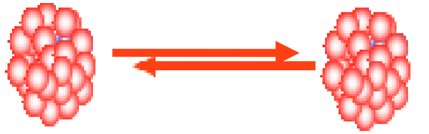
ALICE detector

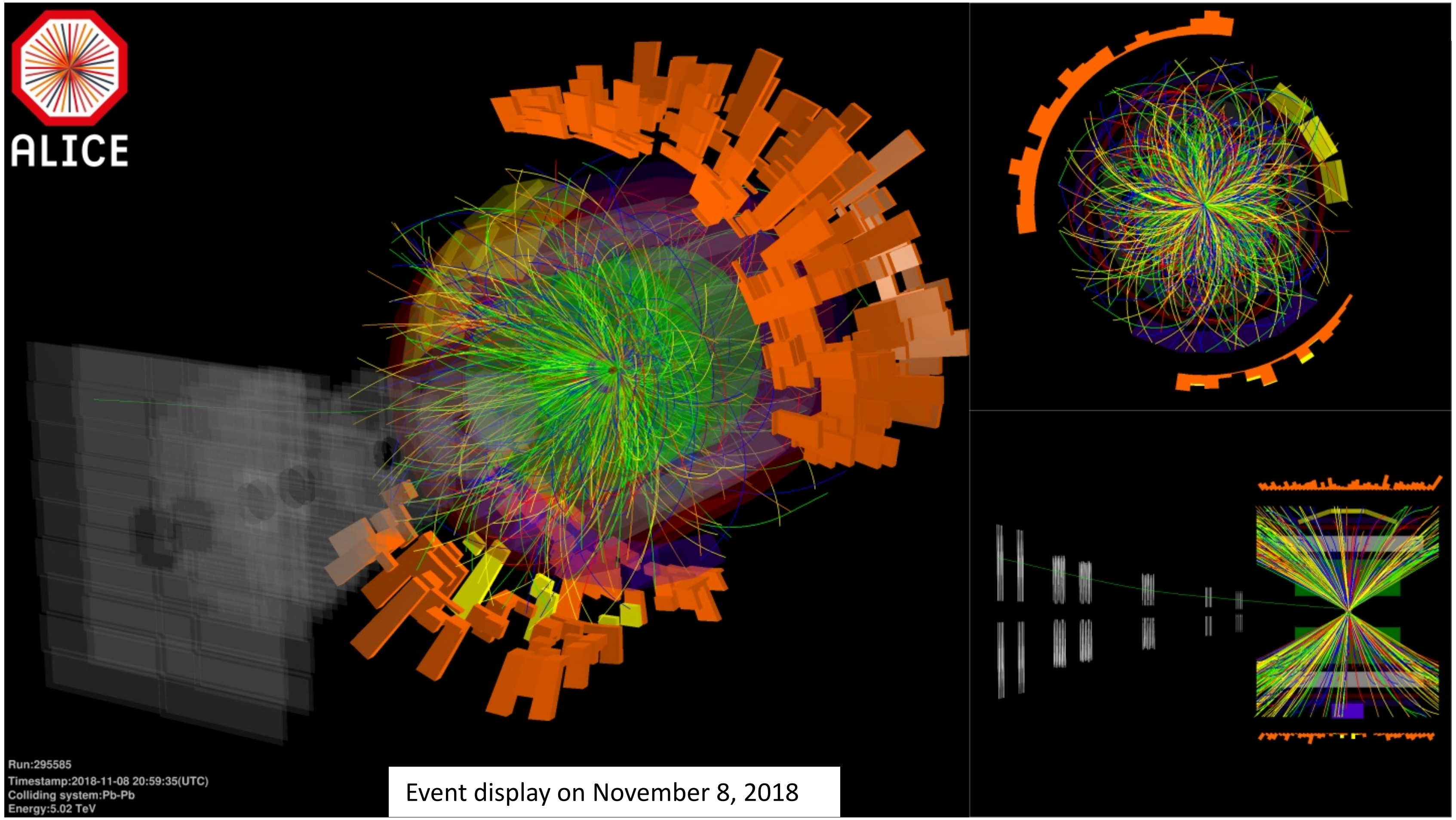
- ALICE (A Large Ion Collider Experiment) detector is designed to study the QGP in heavy-ion collisions
- Muon spectrometer
  - Absorber system: stop π, k and low momentum μ particles
  - Tracking system: provide the 3D position information of particles
  - Dipole magnet: bend particles to obtain momenta and charges (3 Tm)
  - Trigger system: trigger on opposite-sign dimuon and identify the single muon (2 trigger p_T thresholds: 0.5 & 1 GeV/c or 1 & 4 GeV/c)
- Other ALICE detector used for muon analysis
  - SPD: vertex determination
  - V0 (V0A & V0C): centrality estimator in Pb-Pb, luminosity determination in pp , minimum bias trigger and background event rejection
  - T0 (T0A & T0C): luminosity determination in pp
  - ZDC (≈ 100m before / after IP): background event rejection in Pb-Pb



Data taking in 2018 Pb-Pb collisions

central collision





Data samples: pp 2017 and Pb-Pb 2015+2018

	pp 2015 (published)	Pb-Pb 2015 (published)	pp 2017	Pb-Pb 2018
Luminosity	$\approx 107\ nb^{-1}$	$\approx 225\ \mu b^{-1}$	$\approx 1223\ nb^{-1}$	$\approx 537\ \mu b^{-1}$
$\sqrt{s_{NN}}$		5.02 TeV		

$L_{int}^{2018,Pb-Pb} \approx 2.4 \times L_{int}^{2015,Pb-Pb}$
$L_{int}^{2017,pp} \approx 11.4 \times L_{int}^{2015,pp}$

pp 2017:

- J/ψ signal extraction
- Acceptance x Efficiency (Aε) correction
- Normalization and luminosity
- Reference cross section measurement

Pb-Pb 2015 + 2018:

- J/ψ signal extraction
- Acceptance x Efficiency correction
- Normalization
- J/ψ R_{AA}

J/ψ differential cross sections in pp

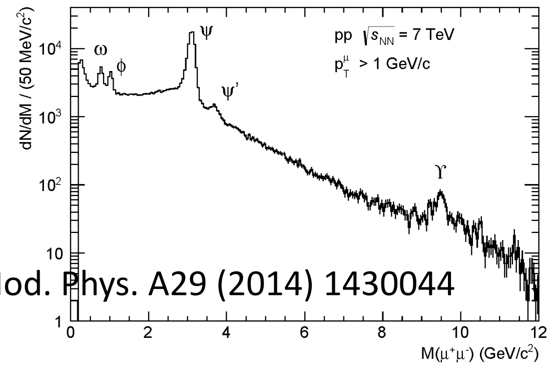
$$\frac{d^2\sigma^{pp}_{J/\psi}}{dp_T dy} = \frac{N_{J/\psi}(p_T,y)}{BR \cdot L^{pp}_{int} \cdot A\varepsilon(p_T,y) \cdot \Delta p_T \cdot \Delta y}$$

- BR: branching ratio of J/ψ decaying into dimuon, (5.93+/-0.06) %
- $N_{J/\psi}(p_T, y)$: raw number of J/ψ
- L^{pp}_{int}: integrated luminosity
- $A\varepsilon(p_T,y)$: acceptance times efficiency

J/ψ signal extraction in pp

Signal functions (for invariant mass of dimuons* $M_{\mu^+\mu^-}$):

- Extended Crystal Ball (CB2), tails from MC (Geant3 & Geant4) and 13 TeV pp data
- NA60 function, tails from MC (Geant3 & Geant4)



Int. J. Mod. Phys. A29 (2014) 1430044

Background functions:

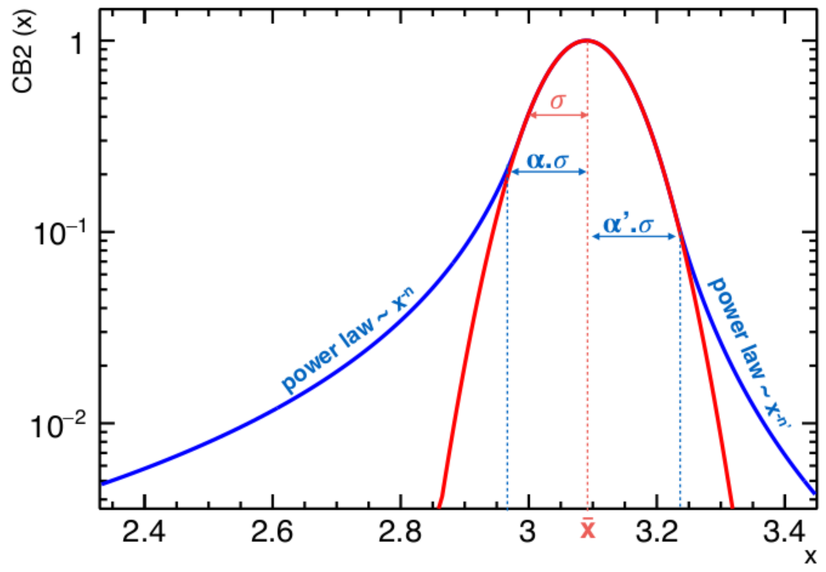
- Variable Width Gaussian (VWG1)
- Polynomial ratios (Pol1/Pol2)

Fitting ranges of invariant mass:

- pp: [2.0, 4.8], [2.2, 4.4] GeV/c^2

Total methods in pp: $(3 + 2) \times 2 \times 2 = 20$

Extended Crystal-Ball (CB2)

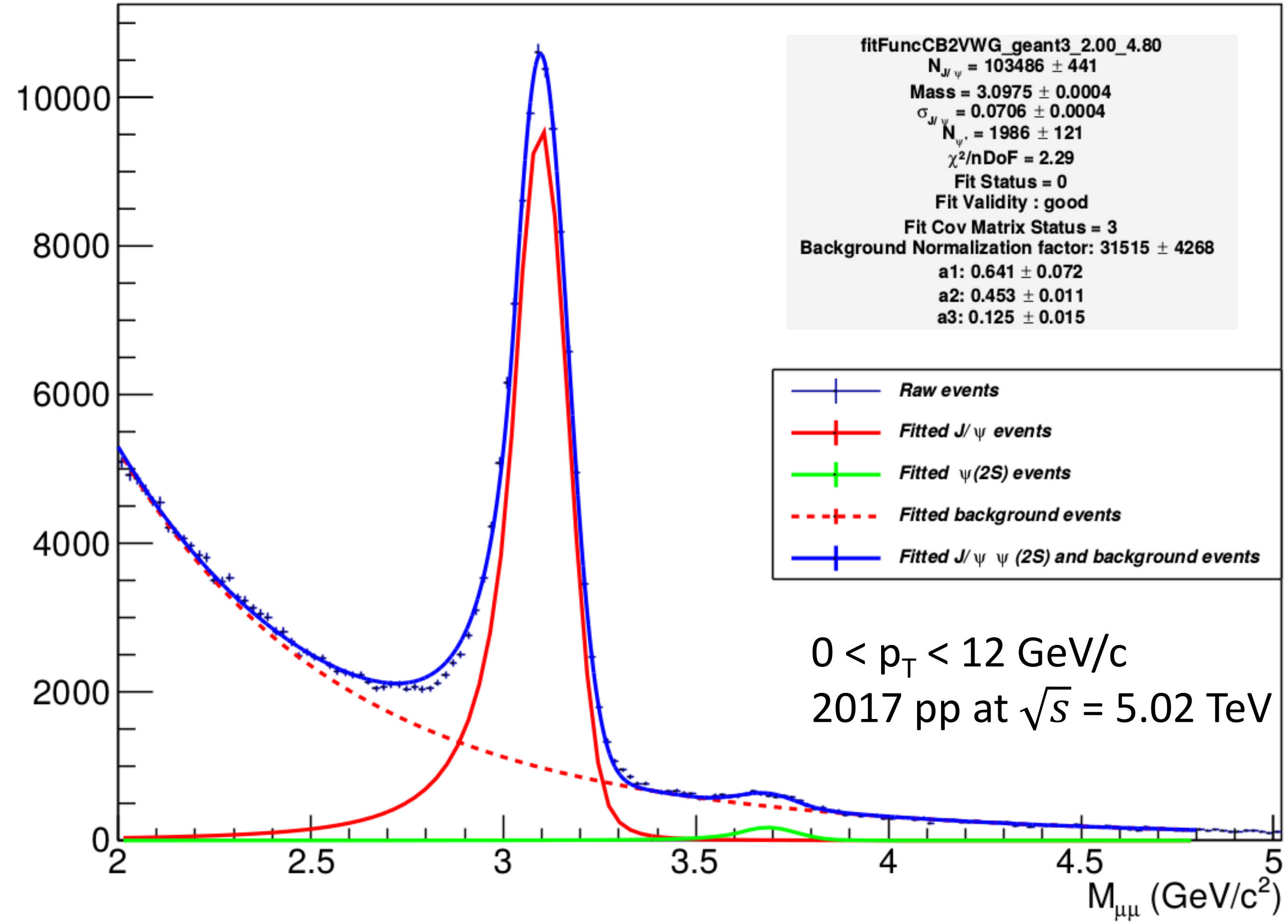


*: invariant mass $m^2 = E^2 - ||\boldsymbol{p}||^2$

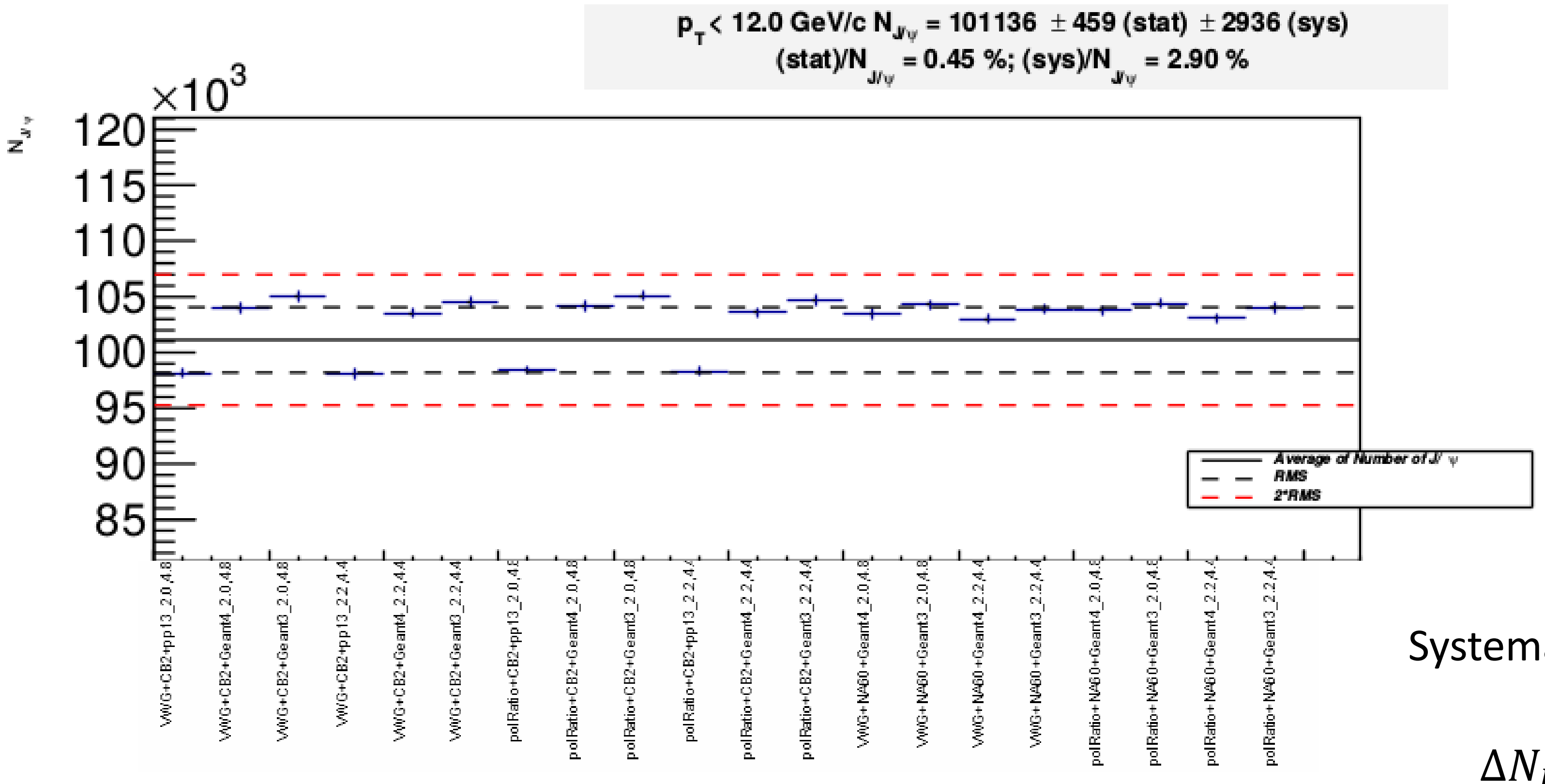
$$M_{\mu^+\mu^-} = \sqrt{m_{\mu+}^2 + m_{\mu-}^2 + 2(E_{\mu+}E_{\mu-} - \boldsymbol{p}_{\mu+} \cdot \boldsymbol{p}_{\mu-})}$$

$\bar{x}$: the mean. σ: the width. (α, n, α', n'): 4 tail parameters fixed from MC simulation and from free tails fit to large statistics pp data

J/ψ signal extraction in pp



J/ψ signal: extraction and systematic uncertainty



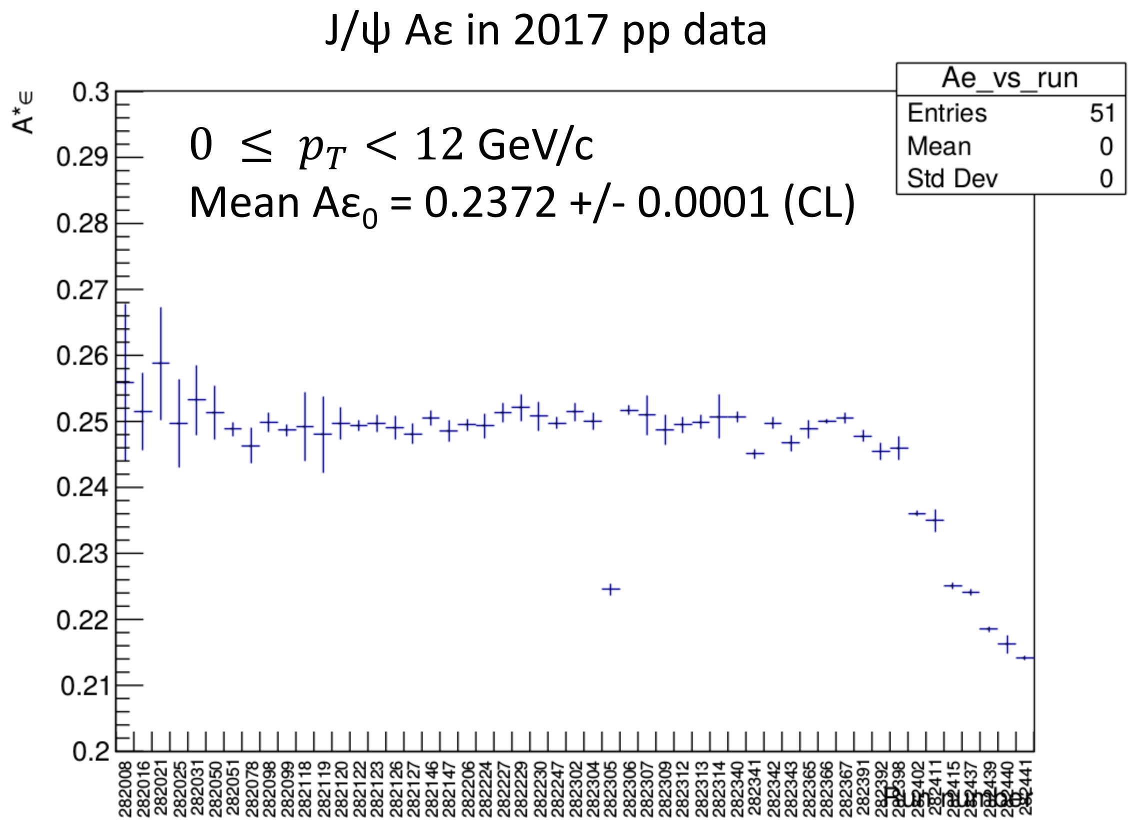
$\langle N_{J/\psi} \rangle$= 101136 +/- 459 (stat) +/- 2936 (sys)

$\langle N_{J/\psi} \rangle = \frac{\sum_i w_i N^i_{J/\psi}}{\sum_i w_i}$ gives an equal weight to the tests with pp and MC tails. Dominant source of uncertainty from the tail choices.

Systematic uncertainty:

$$\Delta N_{J/\psi} = \sqrt{\frac{\sum_i w_i \times N^2_{i,J/\psi}}{\sum_i w_i} - [\frac{\sum_i w_i \times N_{i,J/\psi}}{\sum_i w_i}]^2}$$

J/ψ Aε as a function of run in pp



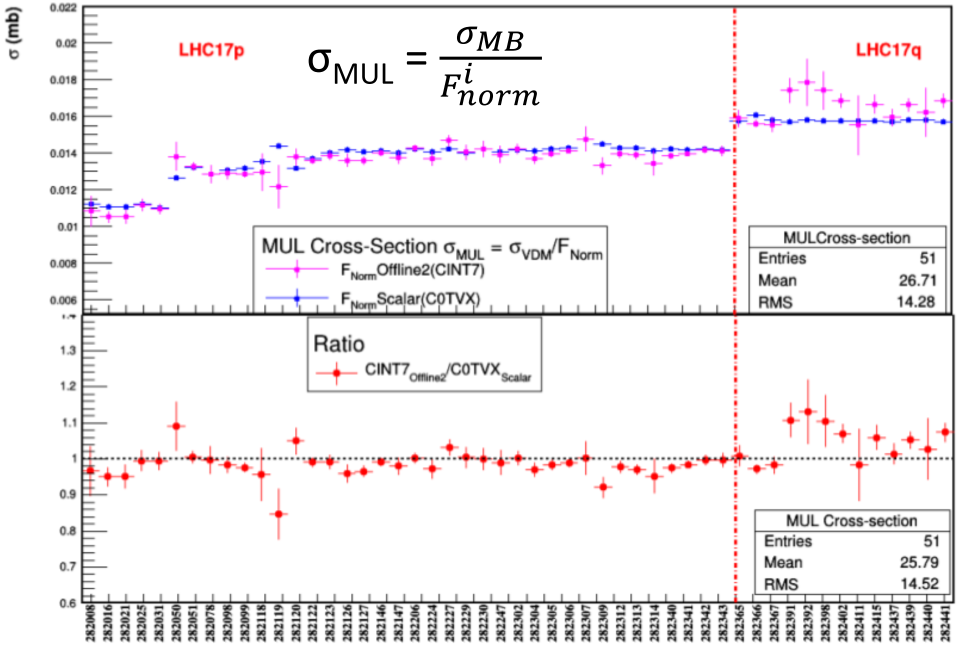
- To correct for detector effect and geometrical acceptance
- Acceptance x Efficiency

$$A\epsilon_i(p_T^{rec}) = \frac{N_i^{rec}(p_T^{rec})}{N_i^{gen}(p_T^{gen})}$$

- $A\epsilon_i$ varies run by run: a loss of efficiency is observed at the end of the data taking period because of high voltage trips in muon tracking chambers

Luminosity in pp

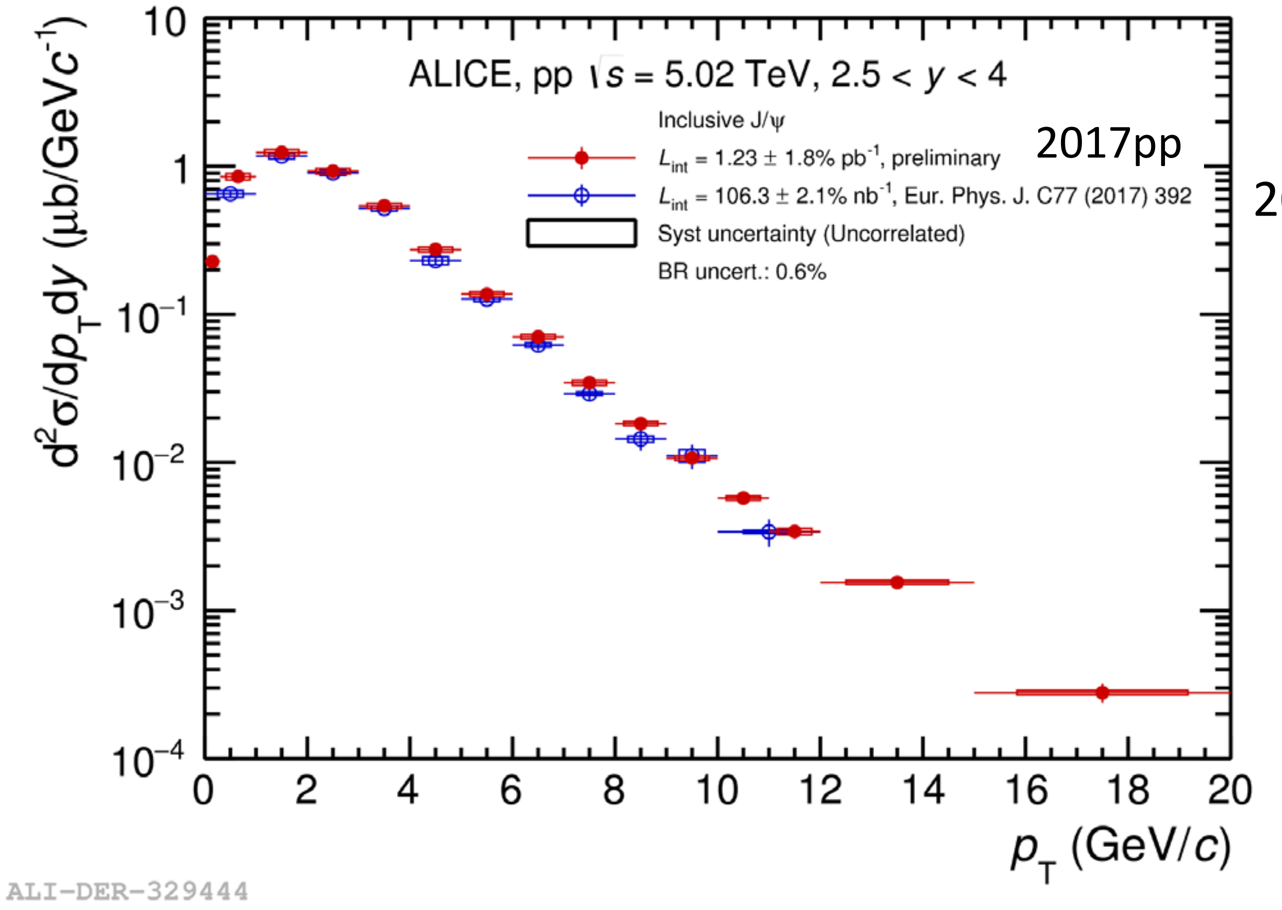
- $L_{int} = \frac{N_{MB}}{\sigma_{MB}} = \frac{N_{MUL} \times F_{norm}}{\sigma_{MB}}$
  - σ_{MB}: the minimum bias trigger cross section
  - $N_{MB} = F_{norm} \times N_{MUL}$: number of minimum bias events, computed from the number of dimuon triggered events
  - $N_{MUL,}$: the number of opposite-sign dimuon triggered events
  - F_{norm}: normalization factor to obtain the number of equivalent MB events from dimuon triggered events



σ_{CMUL7} as a function of run

L_{int} = 1219 +/- 22 (syst) nb^{-1}

Inclusive J/ψ differential cross section vs p_T

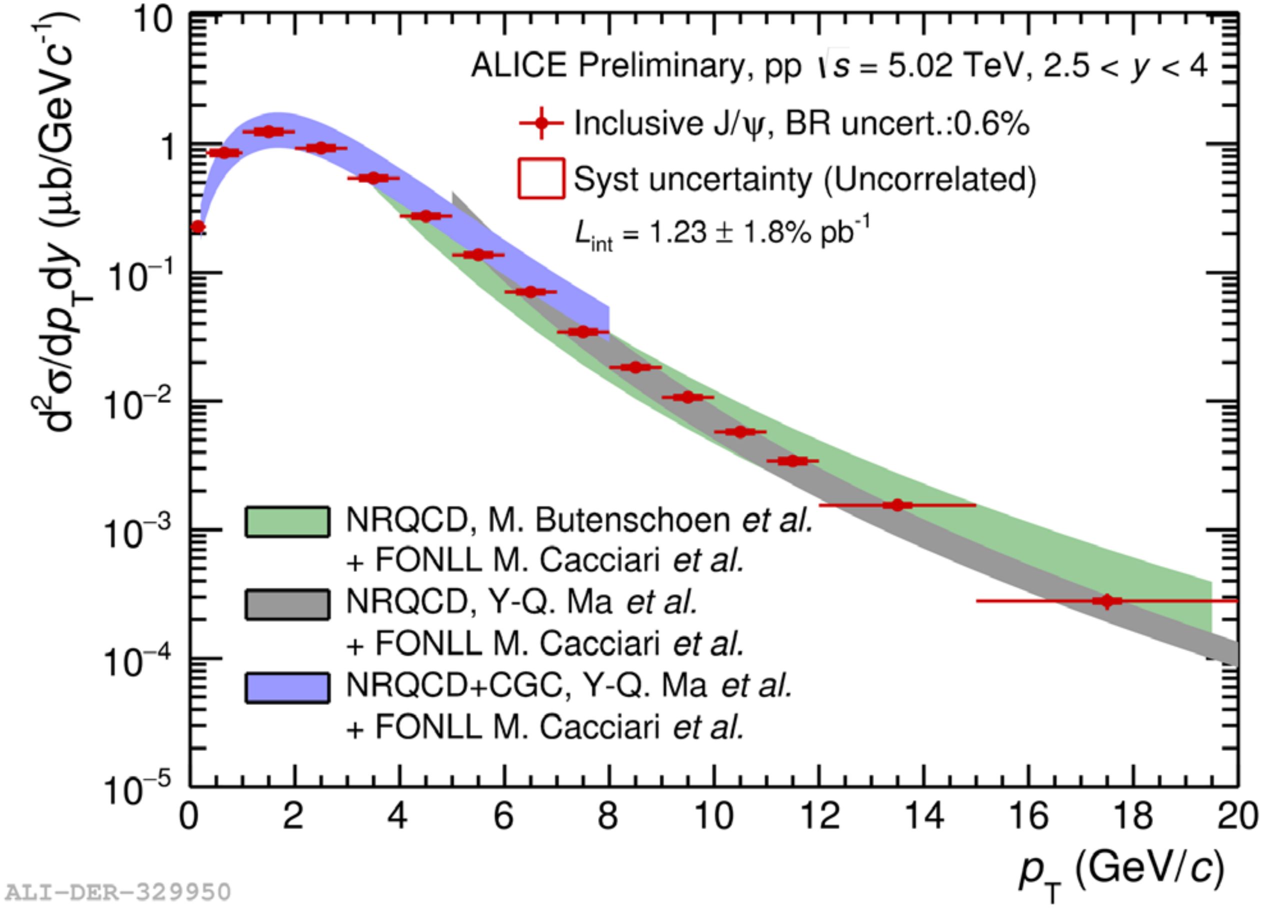


2017pp

2015 pp

Good agreement between the 2 data samples with more precise measurements in 2017 pp
2017 measurements extend the p_T reach to 20 GeV/c

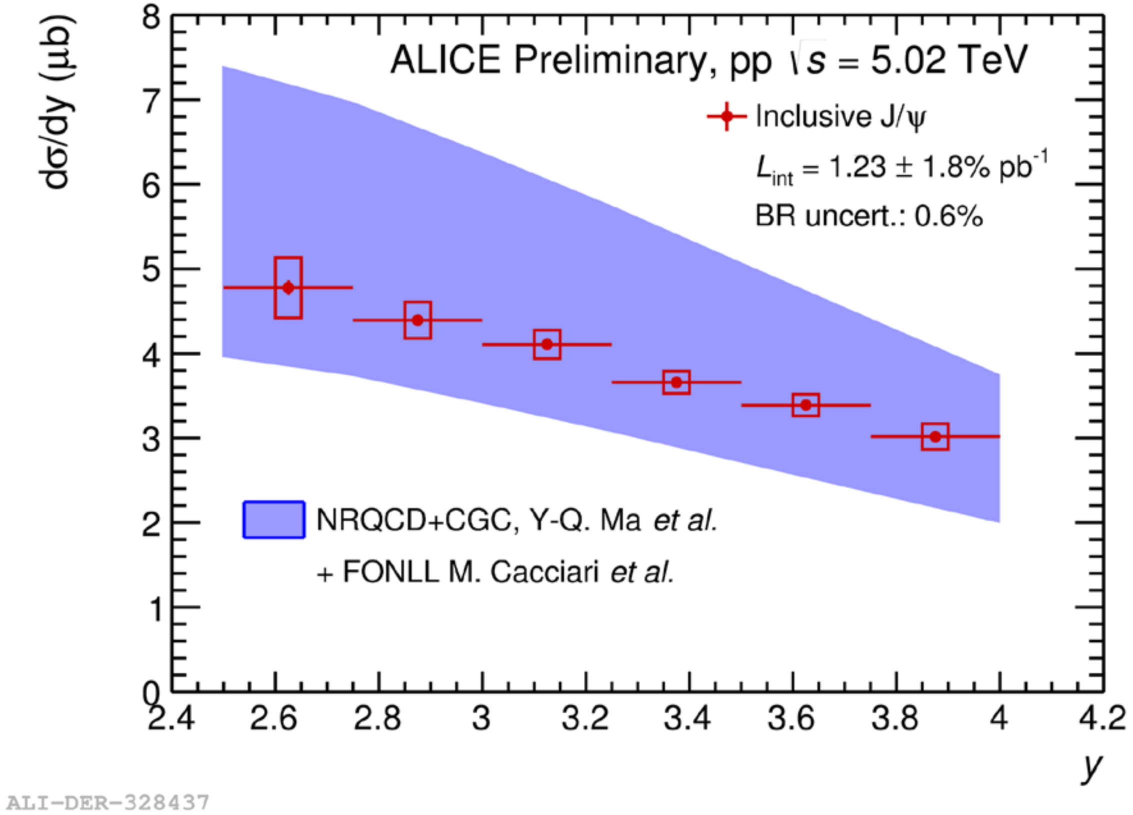
Inclusive J/ψ differential cross section p_T

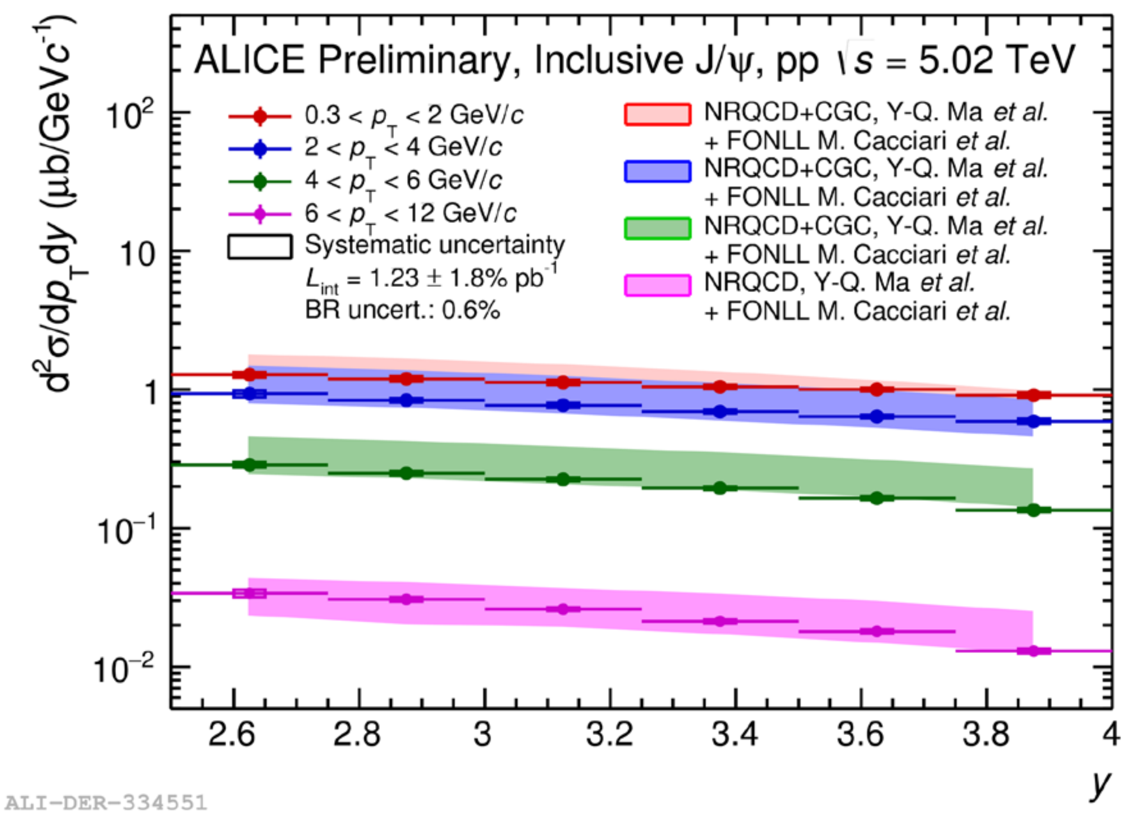


- NRQCD: the prompt J/ψ production is dominated by color octet diagrams at large p_T and the singlet color ones dominate at the low p_T.
- Colour Glass Condensate (CGC): it describes the saturation of the small-x gluons in the proton.
- FONLL: non-prompt contribution (B→J/ψ) added to compare the models to the inclusive J/ψ data.

Within model uncertainties, good agreement with the data

J/ψ differential cross section vs y



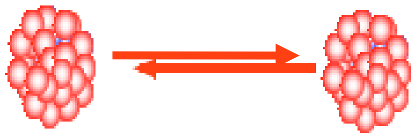


- Good agreement data / NRQCD+CGC+FONLL calculations: same y-dependence but large uncertainty.

Nuclear modification factor R_{AA} in Pb-Pb collisions

$$R_{AA} = \frac{N_{AA}^{J/\psi}(p_T, y)}{< T_{AA} > \cdot \frac{d^2\sigma_{J/\psi}^{pp}}{dp_T dy} \cdot BR \cdot A\varepsilon(p_T, y) \cdot N_{MB} \cdot \Delta p_T \cdot \Delta y}$$

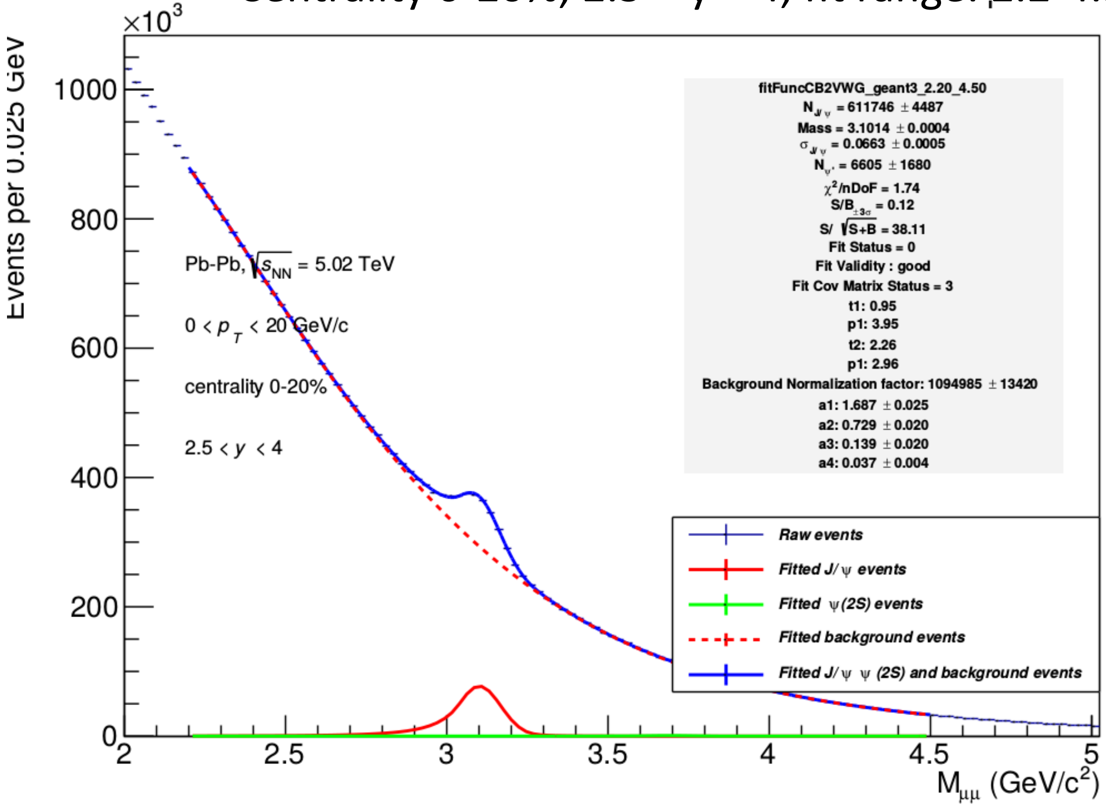
The most central collisions 0-20% are studied



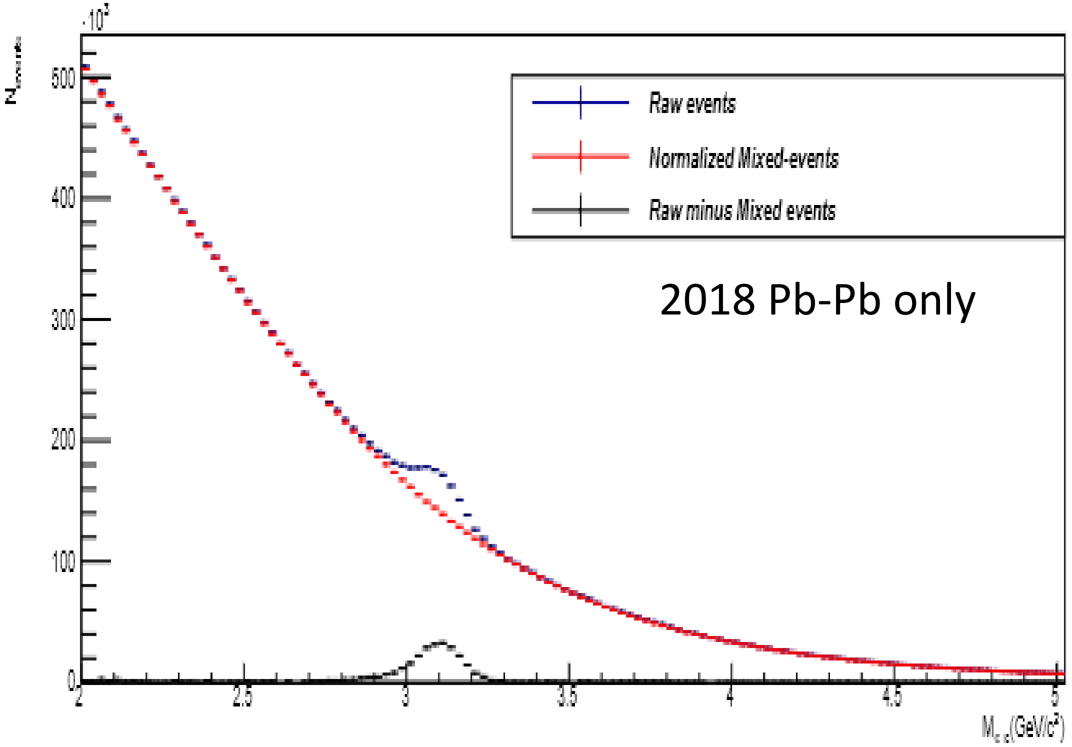
T_{AA} = 18.83 +/- 0.142 (syst) mb^{-1} from centrality determination: https://cds.cern.ch/record/2636623

J/ψ signal extraction in Pb-Pb

Centrality 0-20%, 2.5 < y < 4, fit range: 2.2-4.5



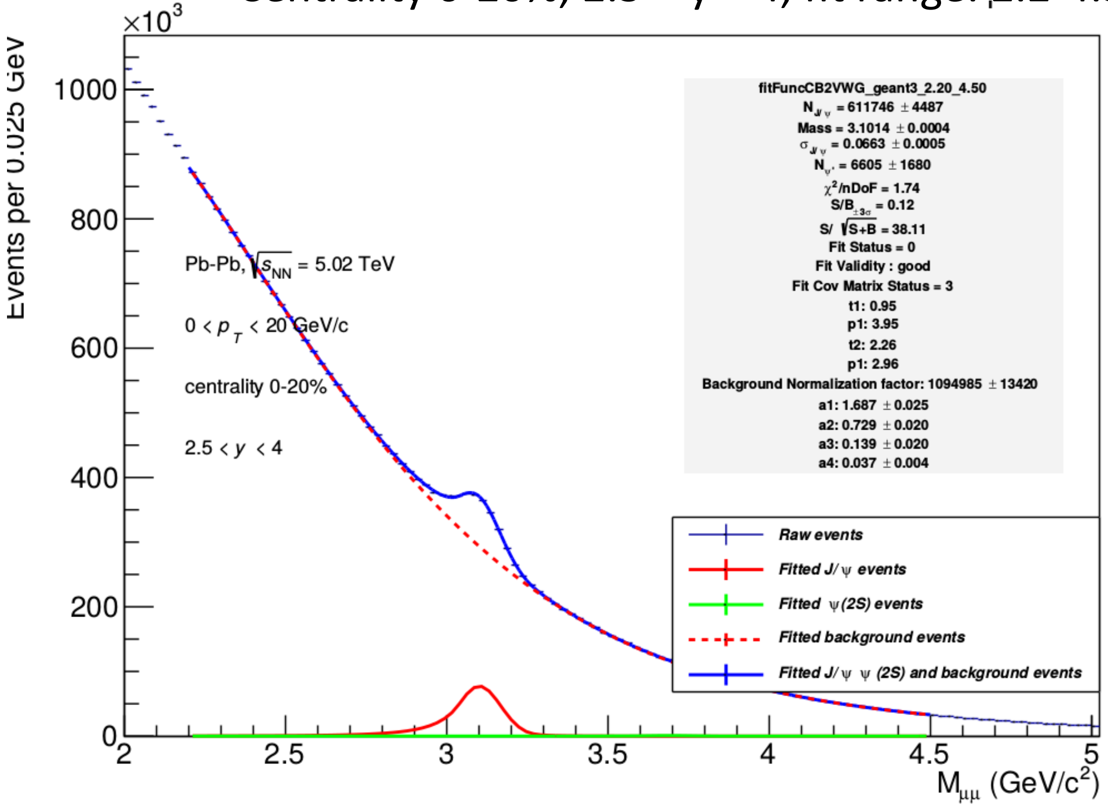
Event mixing technique, 0< p_T < 20 GeV/c, 0-10%



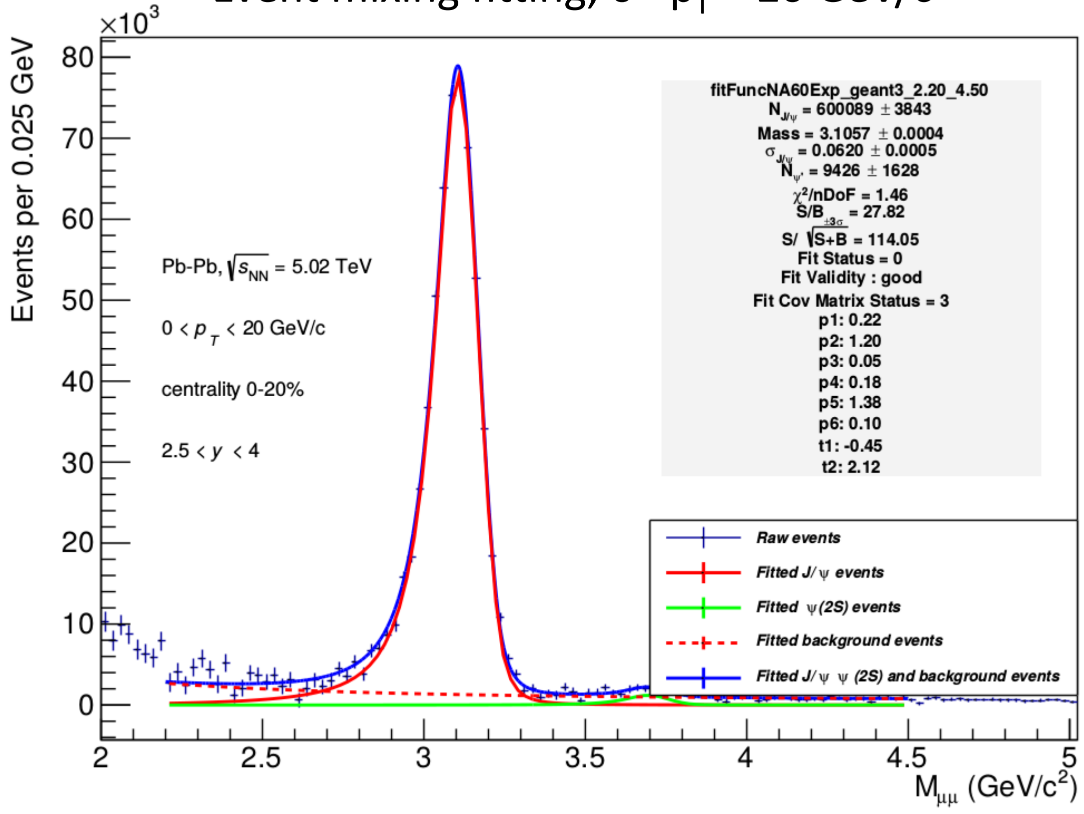
Event mixing technique used to describe the uncorrelated background by mixing muons from different events

J/ψ signal extraction in Pb-Pb

Centrality 0-20%, 2.5 < y < 4, fit range: 2.2-4.5

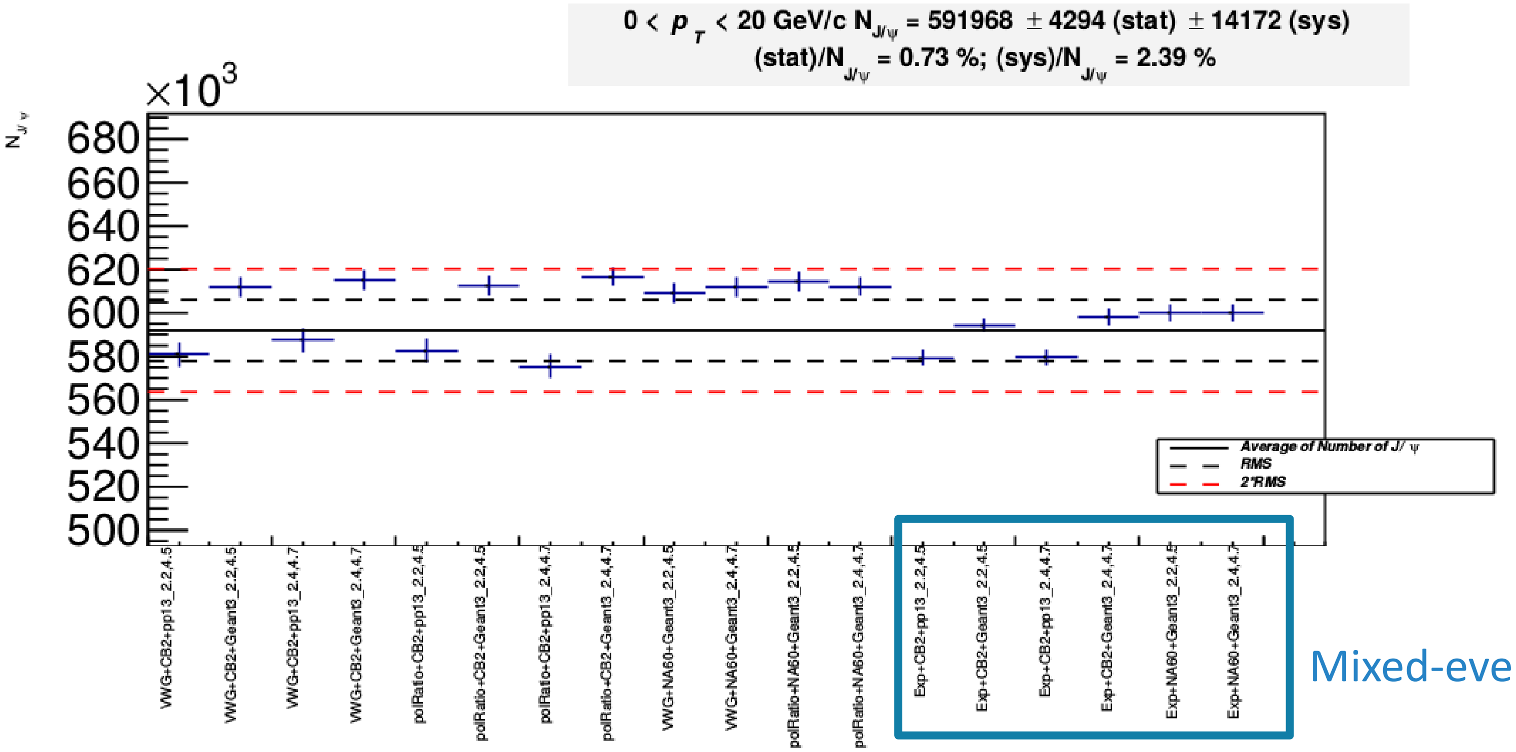


Event mixing fitting, $0 < p_T < 20$ GeV/c



Event mixing technique used to describe the uncorrelated background by mixing muons from different events

J/ψ signal extraction in Pb-Pb



Centrality 0-20%

2.5 < y < 4

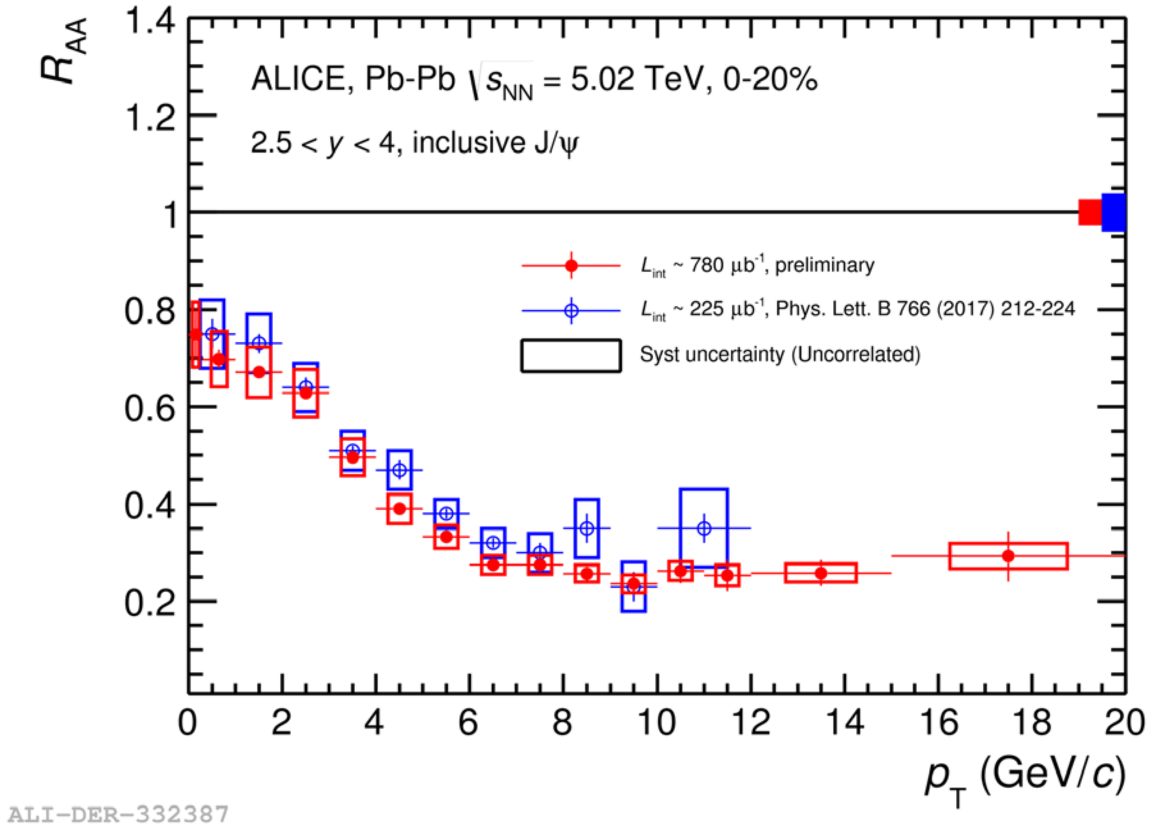
0< p_T < 20 GeV/c

Mixed-event methods

Total fitting methods: 18.

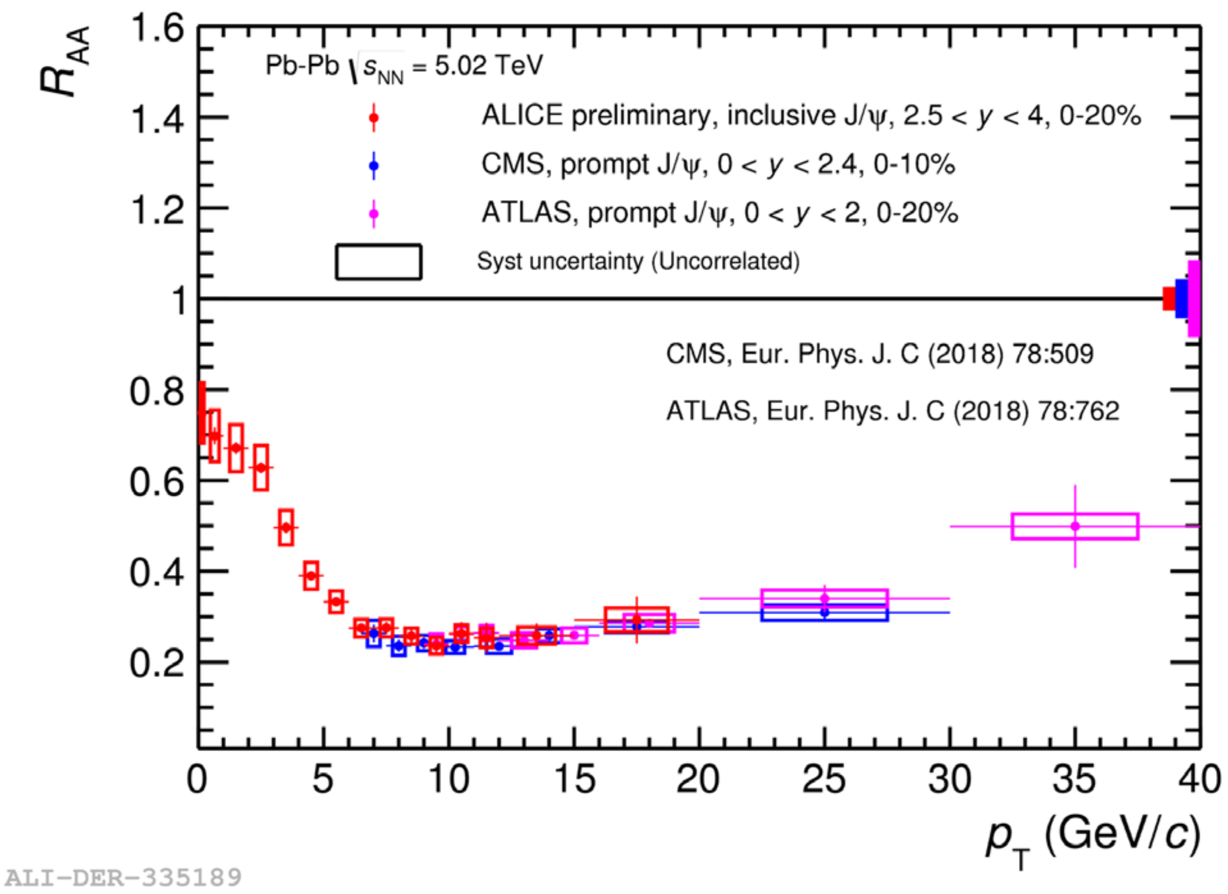
$N_{J/\psi}$ = 591968 +/- 4294 (stat) +/- 14712 (syst)

J/ψ R_{AA} as a function of p_T



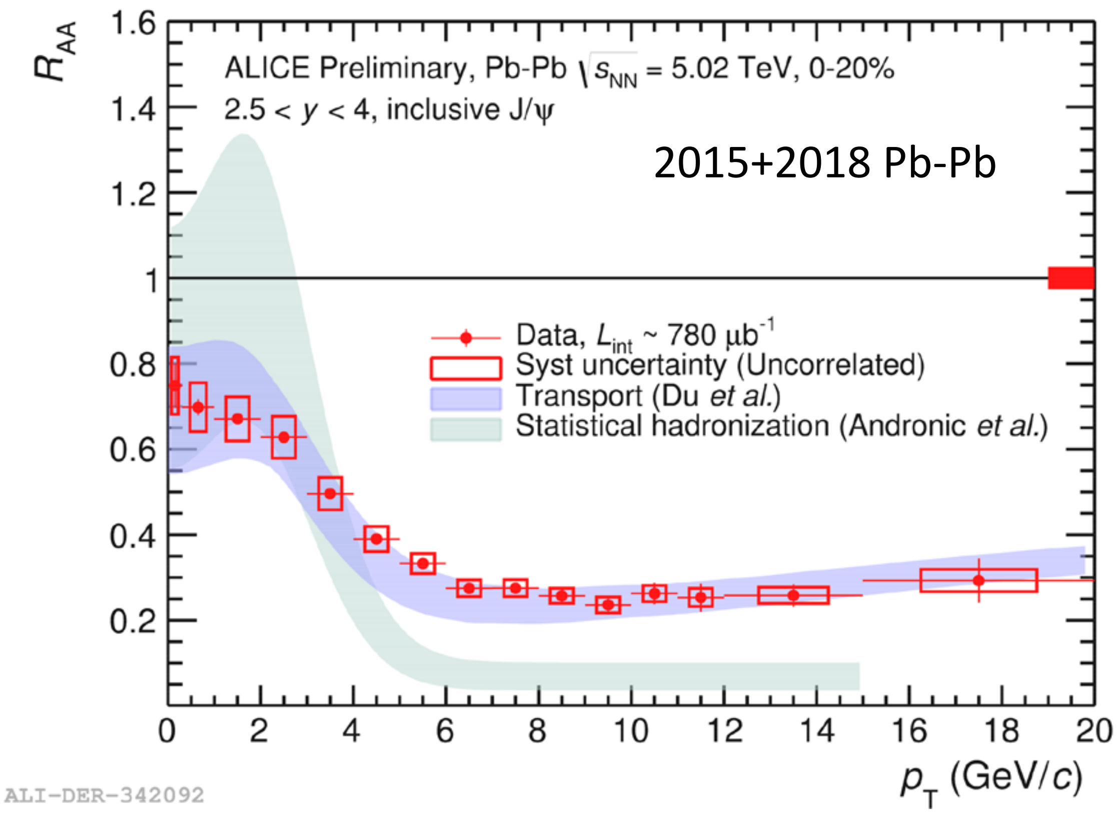
- New measurements (pp and Pb-Pb): more precise data and extension of the p_T reach up to 20 GeV/c
- R_{AA} increases towards low p_T
- R_{AA} is constant for $6 < p_T < 20$ GeV/c

J/ψ R_{AA} comparison



Good agreement ALICE with ATLAS and CMS despite different rapidity regions
Note that ATLAS and CMS measurements are prompt J/ψ

J/ψ R_{AA} comparison



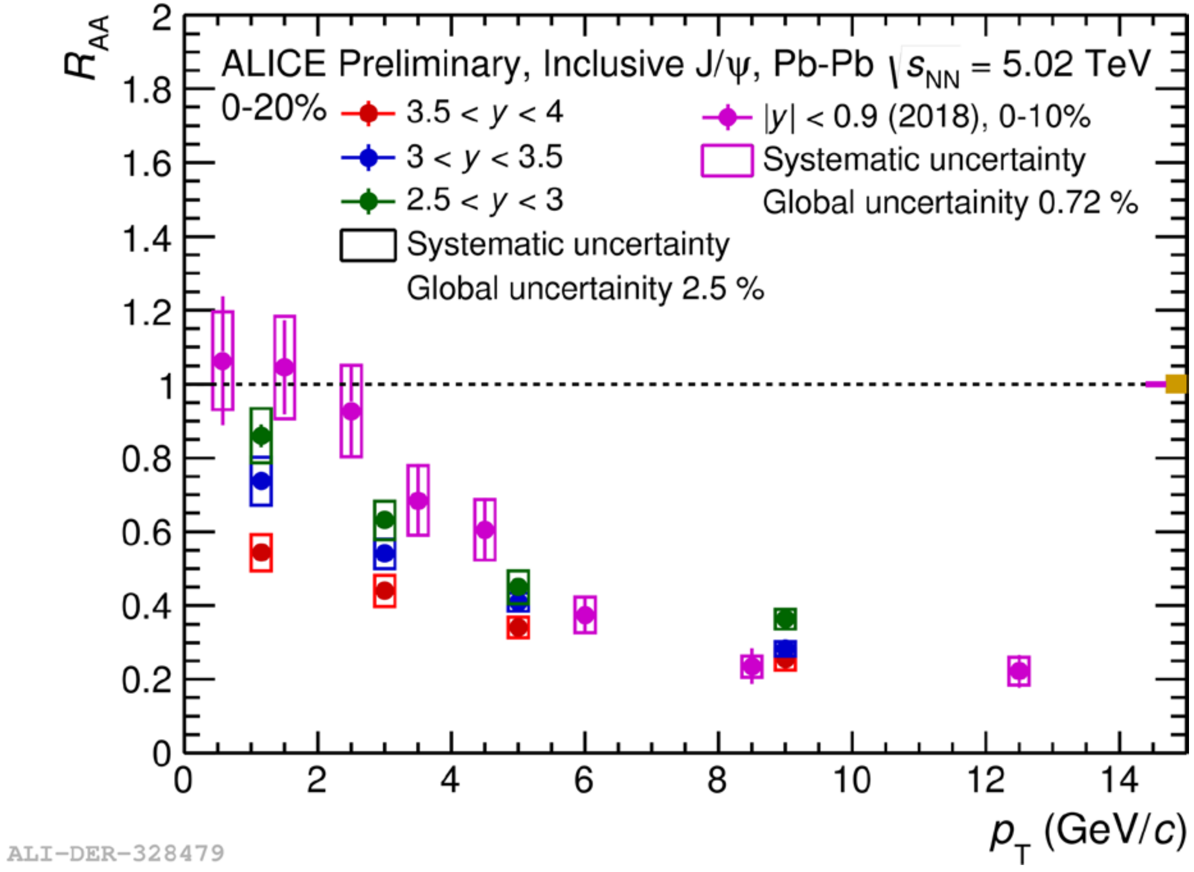
In transport model, good description on data for the full p_T range.

- p_T < 6 GeV/c dominated by J/ψ regenerated from $c\bar{c}$ pair in the QGP phase
- p_T > 6 GeV/c dominated by primordial J/ψ that are suppressed in the QGP by color screening

In the stat. hadronization model:

- all the initially produced J/ψ in the nucleus core are suppressed. Good description of the p_T dependence of the data for p_T < 4 GeV.
- initially produced J/ψ survive in the nucleus corona where there is no QGP: this contribution gives a non-zero R_{AA} that underestimates the data for p_T > 4 GeV

J/ψ R_{AA} in double-differential bin



- With 2017 pp cross section measurements: more precise data allow for a double-differential study
- R_{AA} is larger towards mid-rapidity for central collisions where charm quark density is expected to be larger

Conclusion and to do

- Measuring J/ψ production cross section in 2017 pp collisions at $\sqrt{s}$=5.02 TeV is important to study J/ψ production mechanisms
- It is also an important reference for the new J/ψ R_{AA} measurement in Pb-Pb with 2015 + 2018 data which allow one to reach larger p_T and perform double differential analysis in p_T / y
- Inclusive J/ψ R_{AA} measured for the most central collisions:
  - R_{AA} as a function of p_T
    - J/ψ less suppressed towards low p_T (< 6 GeV) in line with J/ψ regeneration contribution
    - R_{AA} ~0.25 and constant for p_T (> 6 GeV) in line with J/ψ suppression from color screening (transport model calculations)
  - R_{AA} as a function of y
    - J/ψ less suppressed towards mid-rapidity where charm quark density is expected to be larger

Todo:

- To measure J/ψ R_{AA} accumulating 2015+2018 Pb-Pb data in other centrality classes

Back up

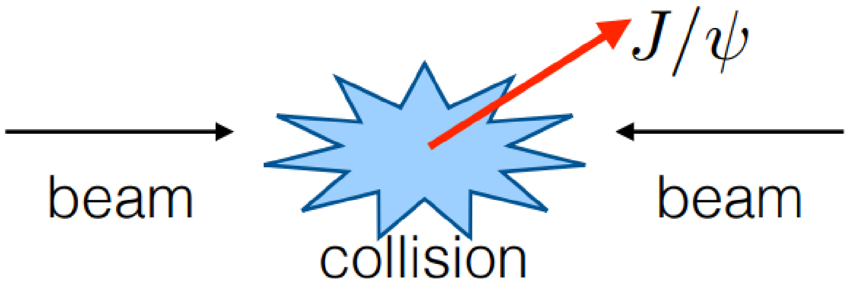
Prompt and non-prompt J/ψ

- Inclusive J/ψ:
  - Prompt J/ψ (~85%):
    - o direct J/ψ production (75%)
    - o J/ψ feed-down from decays of charmonium excited states (25%)
  - Non-Prompt J/ψ (~15%):
    - J/ψ from beauty (B) mesons

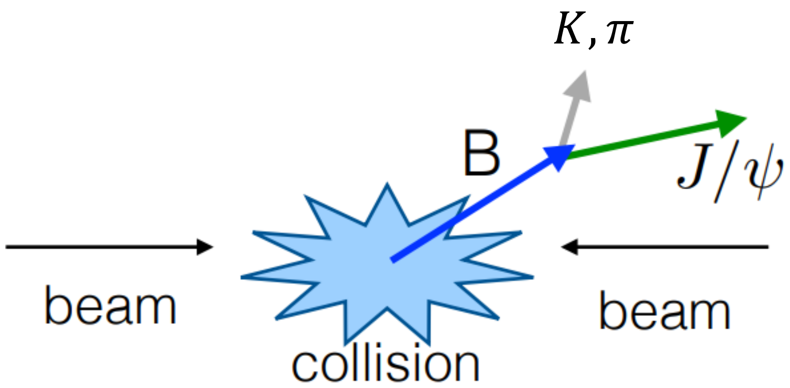
e.g. Eur.Phys.J. C76 (2016) no.3,107

pp collisions

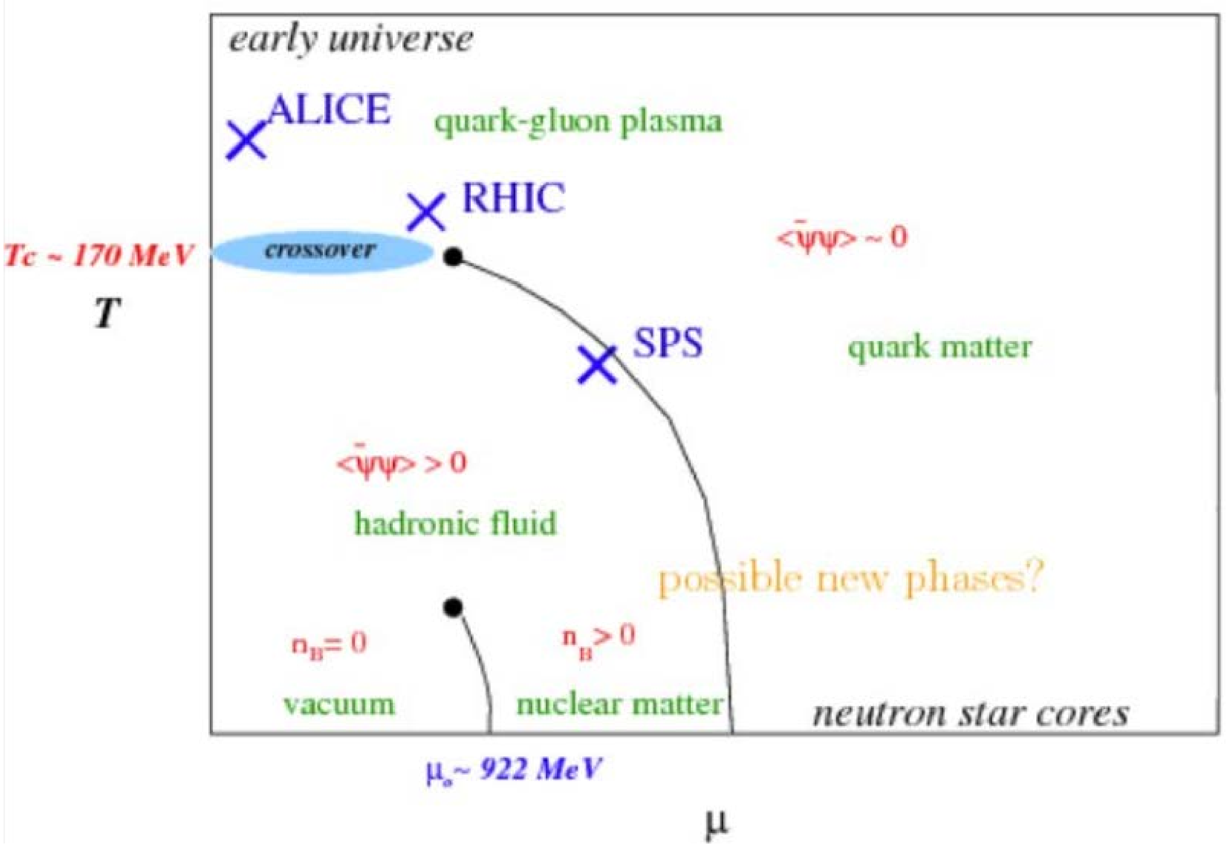
Prompt J/ψ



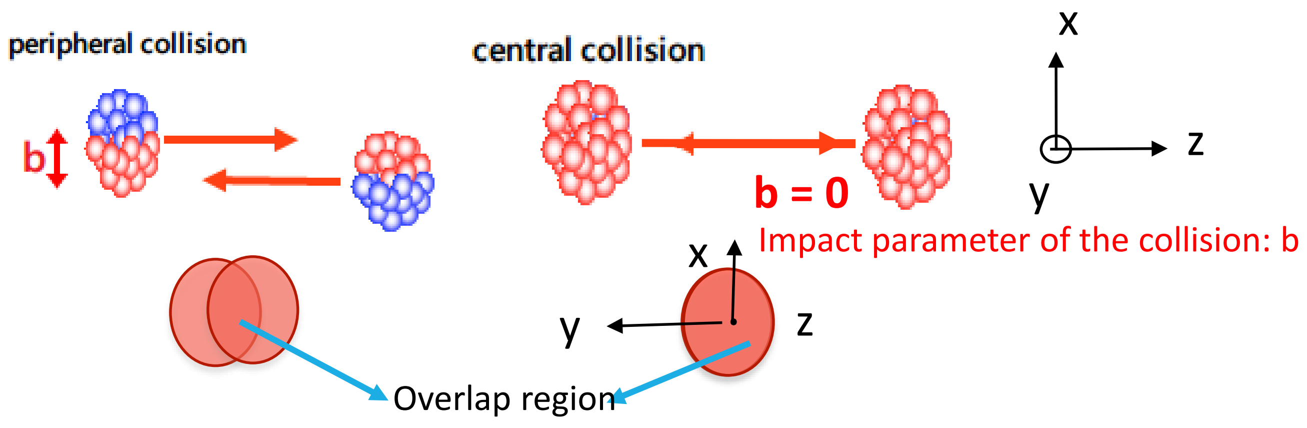
Non-prompt J/ψ

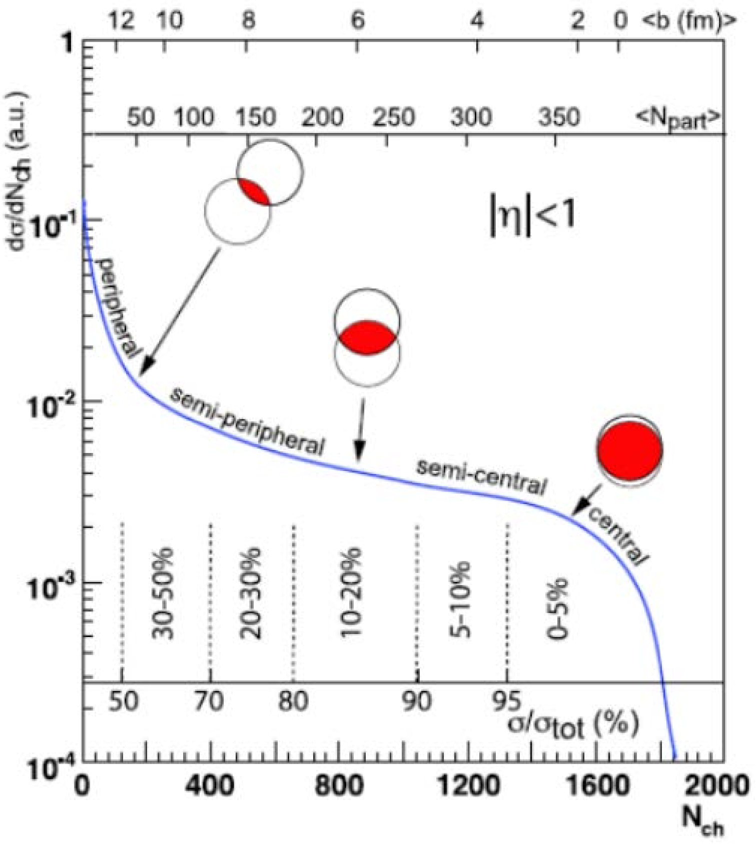


QCD phase diagram



Relating Glauber to real collisions

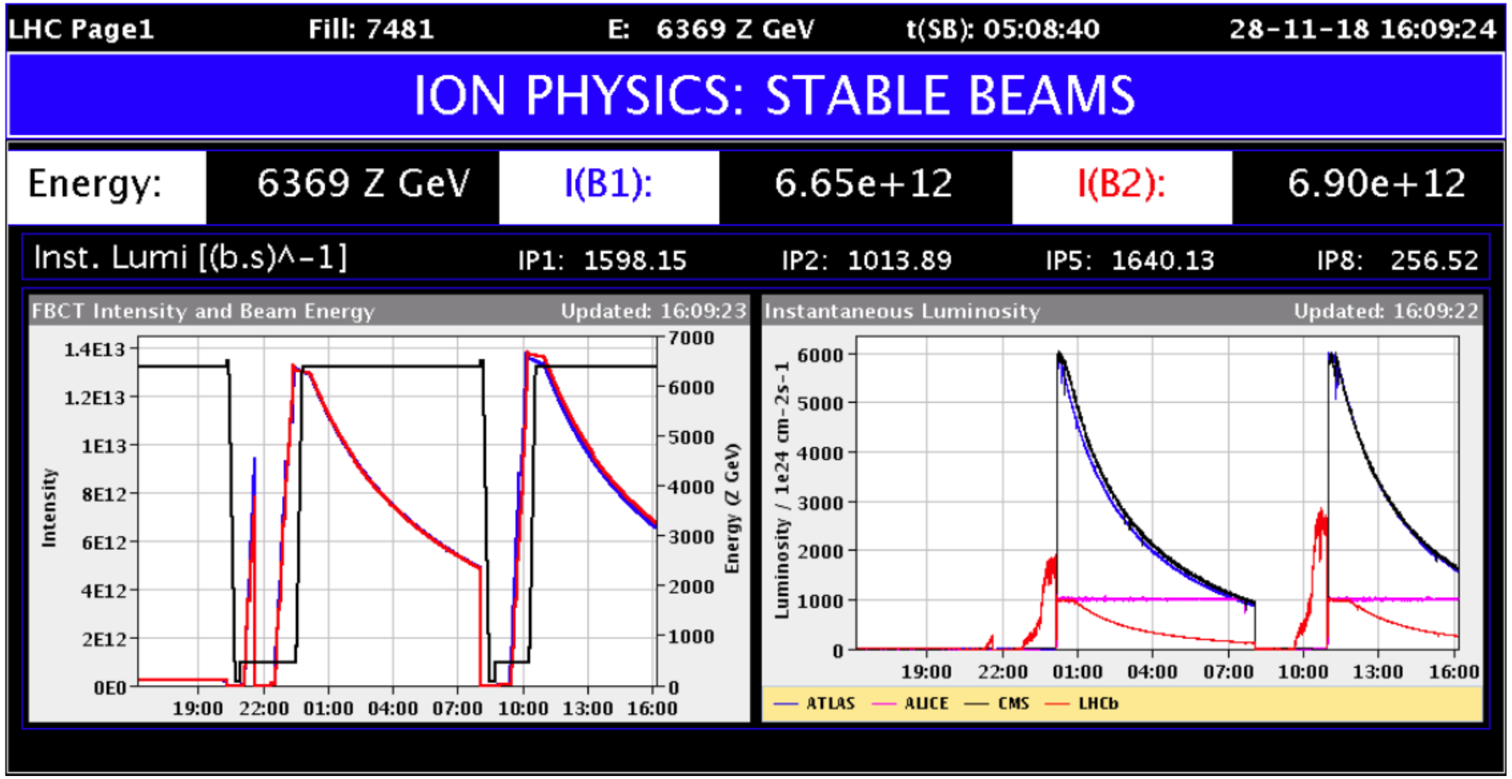


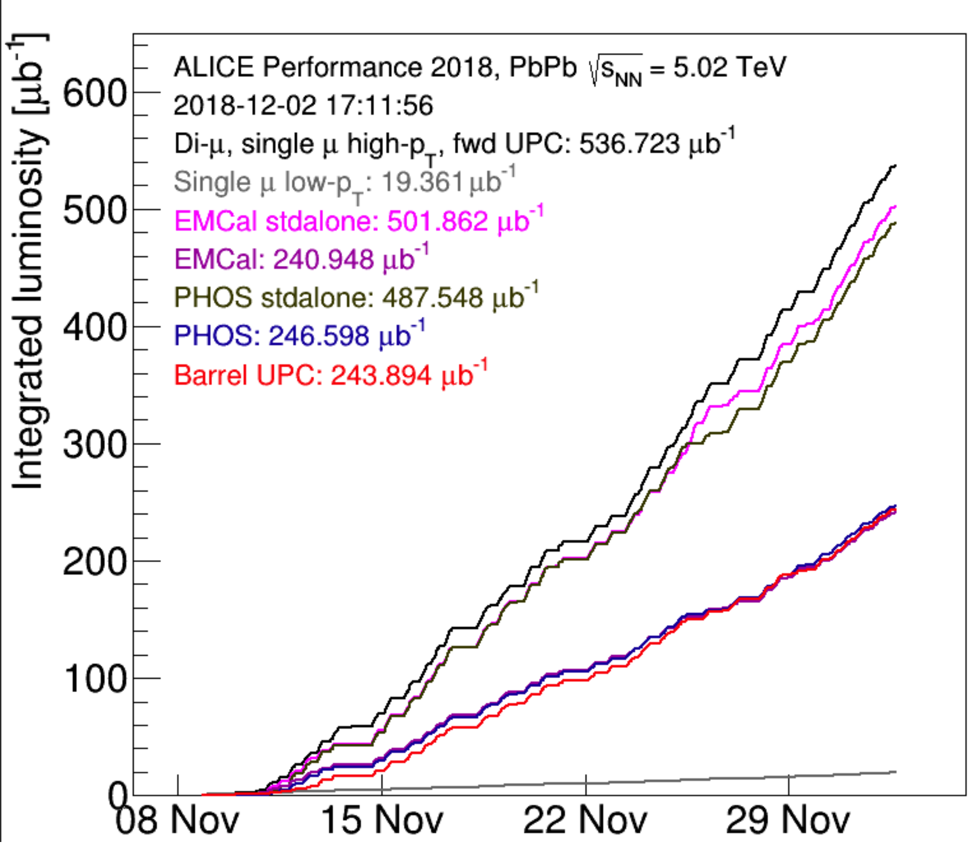


- Centrality describes how large the overlap area is
- Centrality (in %) can be mapped into $<T_{AA}>$ by Glauber model*
- $< T_{AA} >$ is higher if the overlap area is large

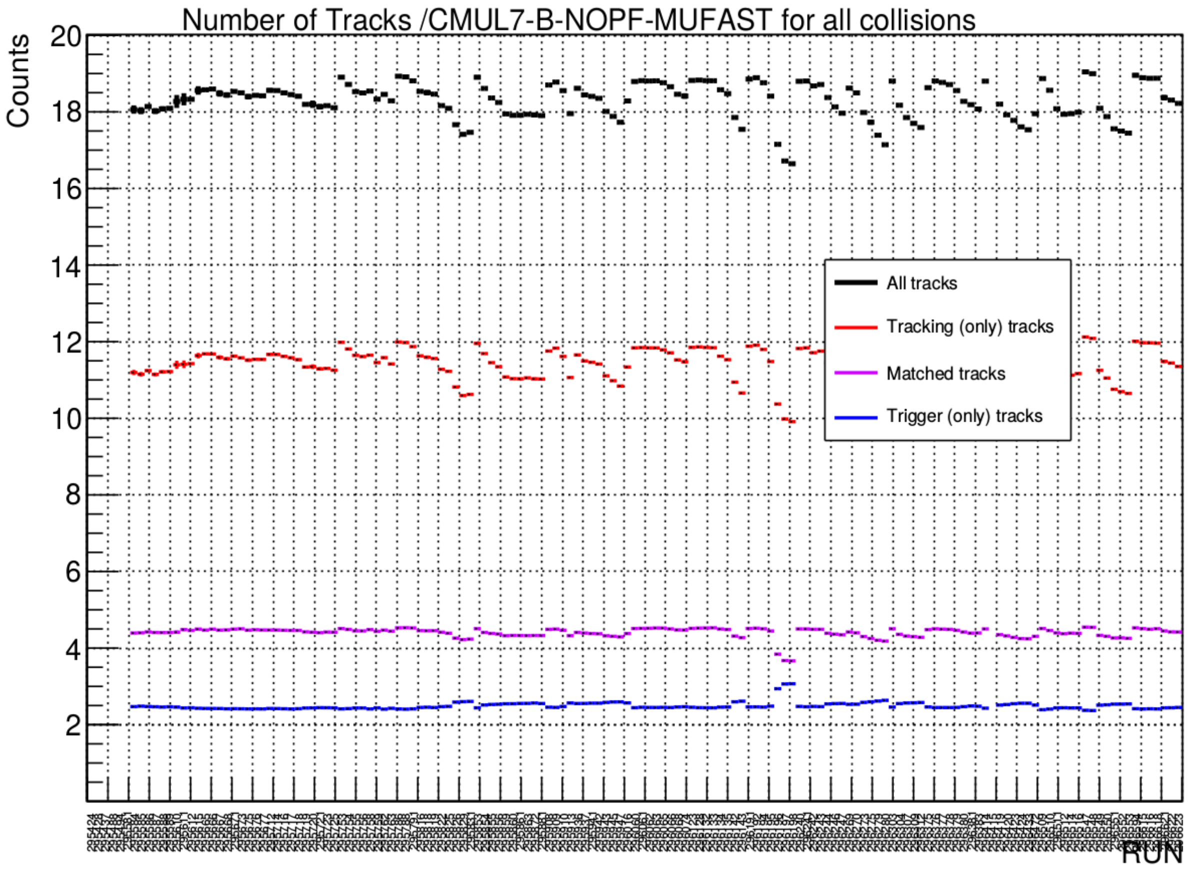
*:https://alice-notes.web.cern.ch/system/files/notes/public/711/2018-06-18-ALICE_public_note.pdf

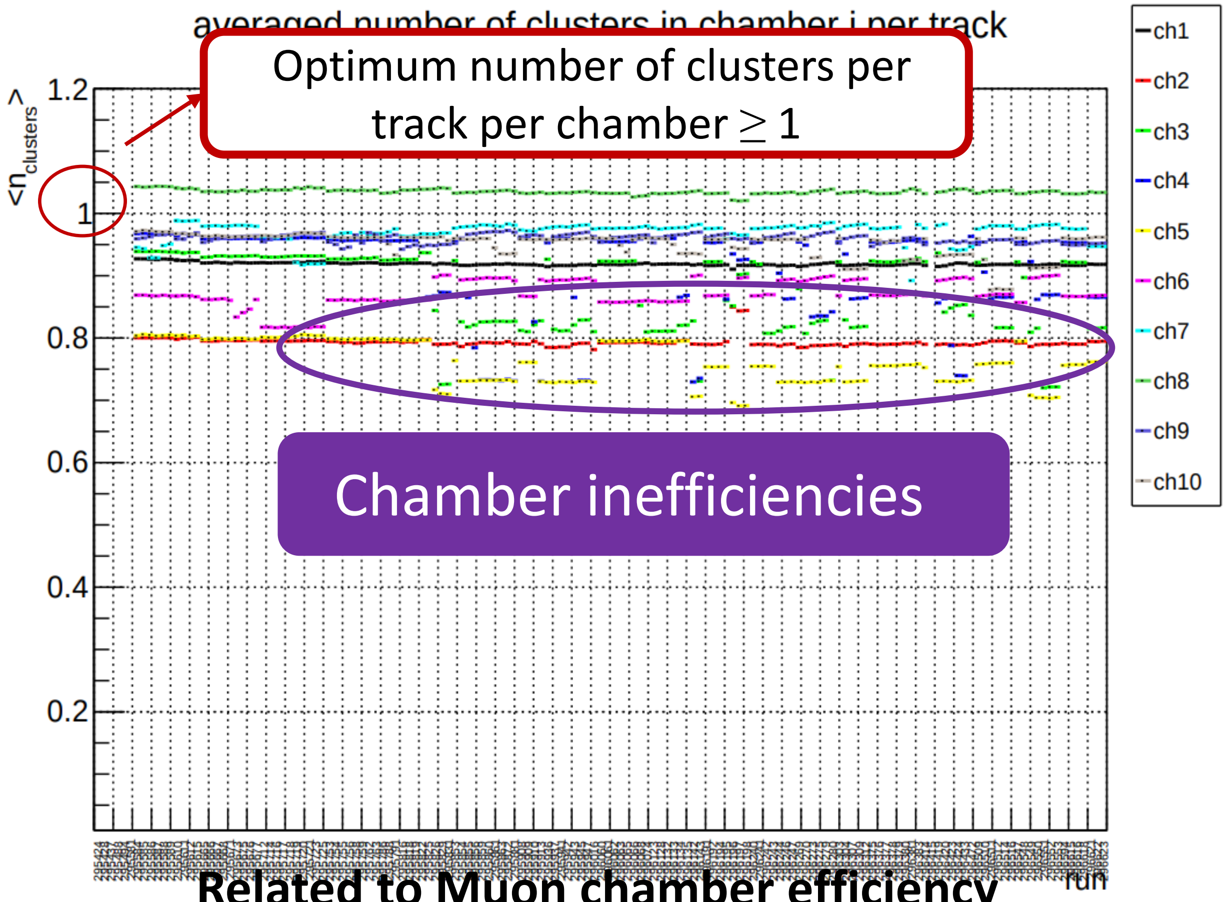
Luminosity at the LHC in 2018





Quality of muon data in 2018 Pb-Pb



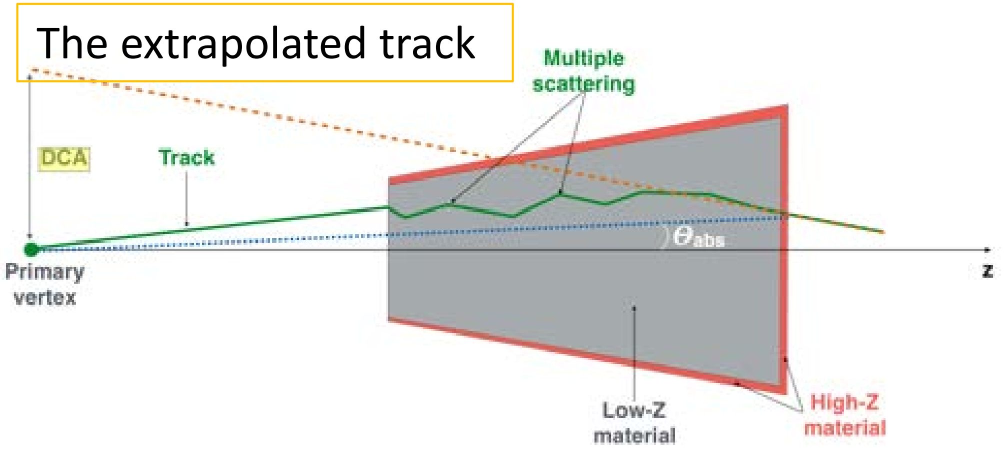


Related to Muon chamber efficiency

- Matched tracks: Matching of tracking tracks with trigger tracks with p_T threshold of 1 GeV/c
- Stable trending plots in 2018
- Chamber inefficiencies are reproduced in MC simulation

pp Data and MC samples: event and track selections

Data samples:
- Quality assurance checked runs



Event selections:
- Trigger selection: opposite-sign dimuon triggers
- Physics selection: to reject the background events

Track selections:
- θ_{abs}: 2-10 degree
- p*DCA cut: to reject beam-gas tracks
- Pseudo-rapidity η: 2.5 – 4.0: the geometrical acceptance of the muon spectrometer
- Matching of tracking tracks with trigger tracks with p_T threshold of 0.5 GeV/c

Dimuon selection:
- Rapidity: 2.5 < **y** < 4.0
- Opposite-charge muons

Analysis of inclusive J/ψ in 2015 and 2018 Pb-Pb data

Data samples

137 QA checked runs (2015)

228 QA checked runs. 2018 data taking reconstruction finished in January,2019

Event selection

- Trigger selection: Dimuon trigger
- Centrality selection: With V0A and V0C
- Physics selection: To reject background events

Track selection (Single muon)

- Pseudo rapidity selection: 2.5-4.0. The geometrical acceptance of the muon spectrometer
- θ_{abs} selection: 2 – 10^{o}
- Matching of tracking tracks with trigger tracks with p_T threshold of 1GeV/c
- $p \times DCA$ (momentum times Distance of Closest Approach) selection: To reject beam gas tracks

Dimuon selection

- Rapidity: 2.5 < **y** < 4.0: The acceptance of the measurement

J/ψ signal extraction in pp & Pb-Pb

Signal functions (for invariant mass of dimuons $M_{\mu^+\mu^-}$):

- Extended Crystal Ball (CB2), tails from MC (Geant3 & Geant4) and 13 TeV pp data
- NA60 function, tails from MC (Geant3 & Geant4)

Background functions:

- Variable Width Gaussian (VWG2 & VWG1)
- Polynomial ratios (Pol2/Pol3 & Pol1/Pol2)
- Exponential function – for mixed-event method only

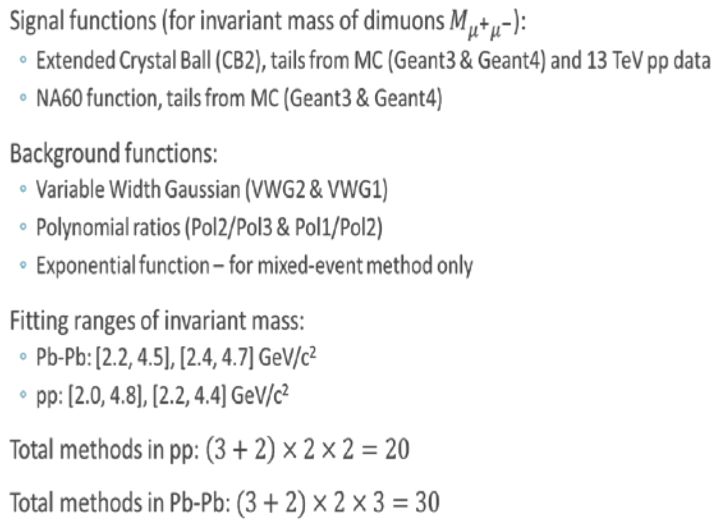
Fitting ranges of invariant mass:

- Pb-Pb: [2.2, 4.5], [2.4, 4.7] GeV/c^2
- pp: [2.0, 4.8], [2.2, 4.4] GeV/c^2

Total methods in pp: $(3+2)\times 2\times 2=20$

Total methods in Pb-Pb: $(3+2)\times 2\times 3=30$

Extended Crystal-Ball (CB2)



Signal functions (for invariant mass of dimuons $M_{\mu^+\mu^-}$):
- Extended Crystal Ball (CB2), tails from MC (Geant3 & Geant4) and 13 TeV pp data
- NA60 function, tails from MC (Geant3 & Geant4)

Background functions:
- Variable Width Gaussian (VWG2 & VWG1)
- Polynomial ratios (Pol2/Pol3 & Pol1/Pol2)
- Exponential function – for mixed-event method only

Fitting ranges of invariant mass:
- Pb-Pb: [2.2, 4.5], [2.4, 4.7] GeV/c^2
- pp: [2.0, 4.8], [2.2, 4.4] GeV/c^2

Total methods in pp: $(3+2)\times 2\times 2=20$

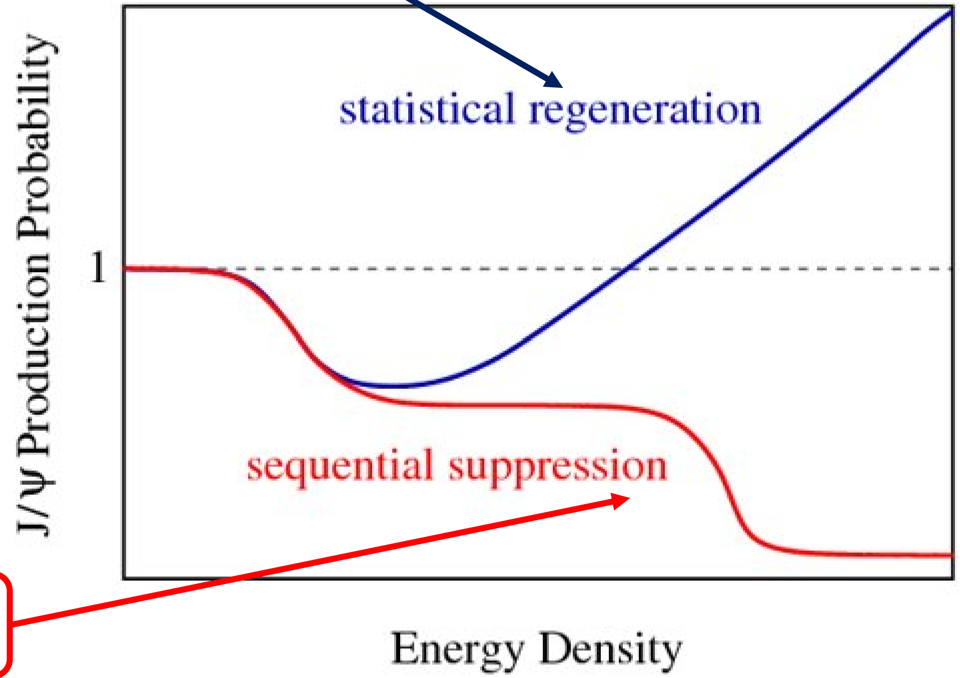
Total methods in Pb-Pb: $(3+2)\times 2\times 3=30$

$\bar{x}$: the mean. σ: the width. (α, n, α', n'): 4 tail parameters fixed by MC simulation and data

J/ψ sequential suppression

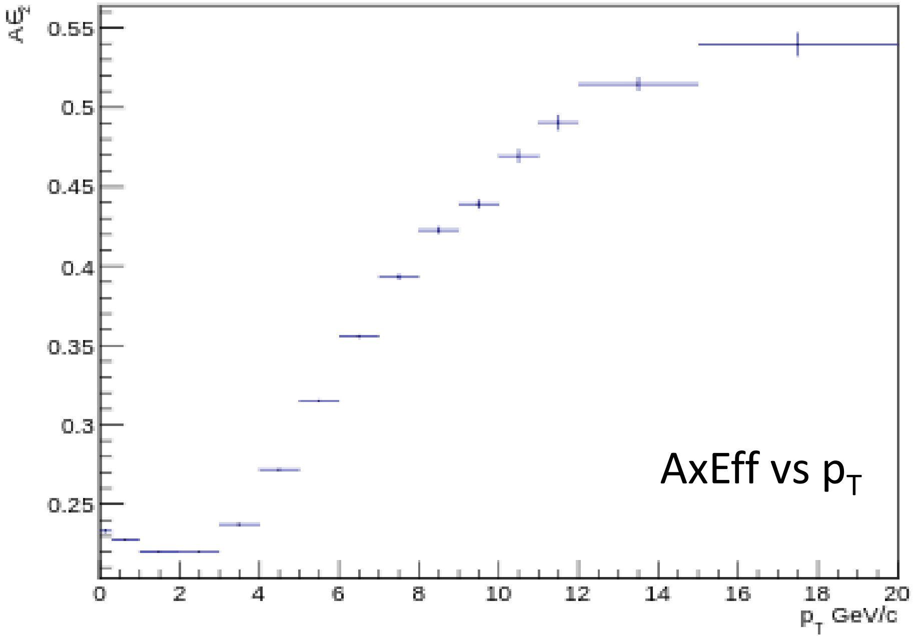
J/ψ regeneration

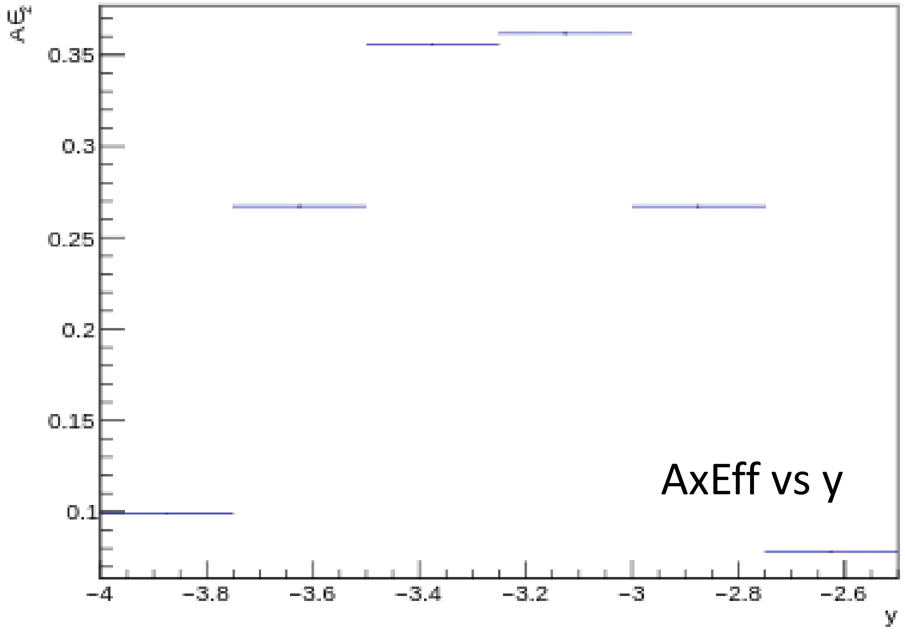
J/ψ production probability as a function of energy density



Color screening

J/ψ Aε as a function of p_T and y





Fit functions

Extended Crystal-Ball (CB2)

$$CB2(x) = N \cdot \begin{cases} \exp(\frac{-(x-\bar{x})^2}{2\sigma^2}) & \text{for } \alpha' > \frac{x-\bar{x}}{\sigma} > -\alpha \\ A.(B - \frac{x-\bar{x}}{\sigma})^{-n} & \text{for } \frac{x-\bar{x}}{\sigma} \leq -\alpha \\ C.(D + \frac{x-\bar{x}}{\sigma})^{-n'} & \text{for } \frac{x-\bar{x}}{\sigma} \geq \alpha' \end{cases}$$

with

$$A = \left(\frac{n}{|\alpha|}\right)^n \cdot exp\left(-\frac{|\alpha|^2}{2}\right), B = \frac{n}{|\alpha|} - |\alpha|$$

$$C = \left(\frac{n'}{|\alpha'|}\right)^{n'} \cdot exp\left(-\frac{|\alpha'|^2}{2}\right), D = \frac{n'}{|\alpha'|} - |\alpha'|$$

NA60

$$NA60(x) = N \cdot \exp\left(-0.5\left(\frac{t}{t_0}\right)^2\right)$$

$$t = \frac{x-\bar{x}}{\sigma}$$

$$\begin{cases} t_0 = 1 + p_1^L(\alpha^L - t)^{(p_2^L - p_3^L\sqrt{\alpha^L - t})} & \text{for } t < \alpha^L \\ t_0 = 1 & \text{for } \alpha^L < t < \alpha^R \\ t_0 = 1 + p_1^R(t - \alpha^R)^{(p_2^R - p_3^R\sqrt{t-\alpha^R})} & \text{for } t > \alpha^R \end{cases}$$

Variable Width Gaussian (VWG2)

This function has a normalization factor N, and four parameters ($\bar{x}$, α, β, γ):

$$VWG2(x) = N.exp\left(\frac{-(x-\bar{x})^2}{2\sigma^2}\right), \text{where } \sigma = \alpha + \beta\left(\frac{x-\bar{x}}{\bar{x}}\right) + \gamma\left(\frac{x-\bar{x}}{\bar{x}}\right)^2$$

Polynomials ratio (Pol2/Pol3)

In addition to the normalization factor N, this function has 5 parameters (a_1, a_2, b_1, b_2, b_3) and it is defined by:

$$Pol2/Pol3(x) = N.\frac{1 + a_1x + a_2x^2}{b_1x + b_2x^2 + b_3x^3}$$

Weight in calculation of A*ε

Run number Weighting

Weighted Acceptance x Efficiency $\overline{A\epsilon_j} = \frac{\sum_i N_{CMUL}^{i,j} \cdot A\epsilon_{i,j}}{\sum_i N_{CMUL}^{i,j}}$,

the weighted uncertainty $\sigma_{\epsilon,j} = \sqrt{\frac{\sum_i (N_{CMUL}^{i,j})^2 * \sigma_{\epsilon,i,j}^2}{(\sum_i N_{CMUL}^{i,j})^2}}$,

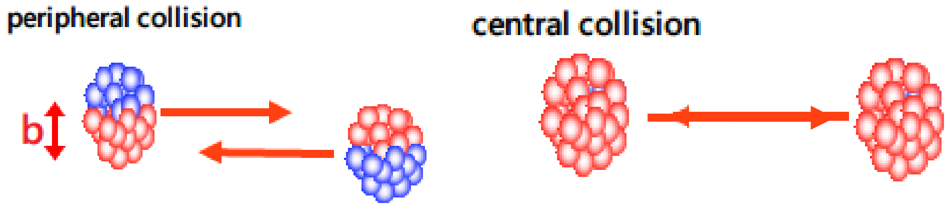
Centrality Weighting

Weighted Acceptance x Efficiency $\overline{A\epsilon} = \frac{\sum_j N_{CMUL}^{j} \overline{A\epsilon_j}}{\sum_j N_{CMUL}^{j}}$

where $N_{CMUL}^{i,j}$ is the number of events in run number i in centrality bin j for CMUL trigger from real data.

Monte-Carlo(MC) simulation of Pb-Pb collisions

- High occupancy of the detectors in central Pb-Pb collisions -> decrease of the detector efficiency



Principle of an embedding MC simulation

MC simulation
1 J/ψ per event

Raw data
MB trigger

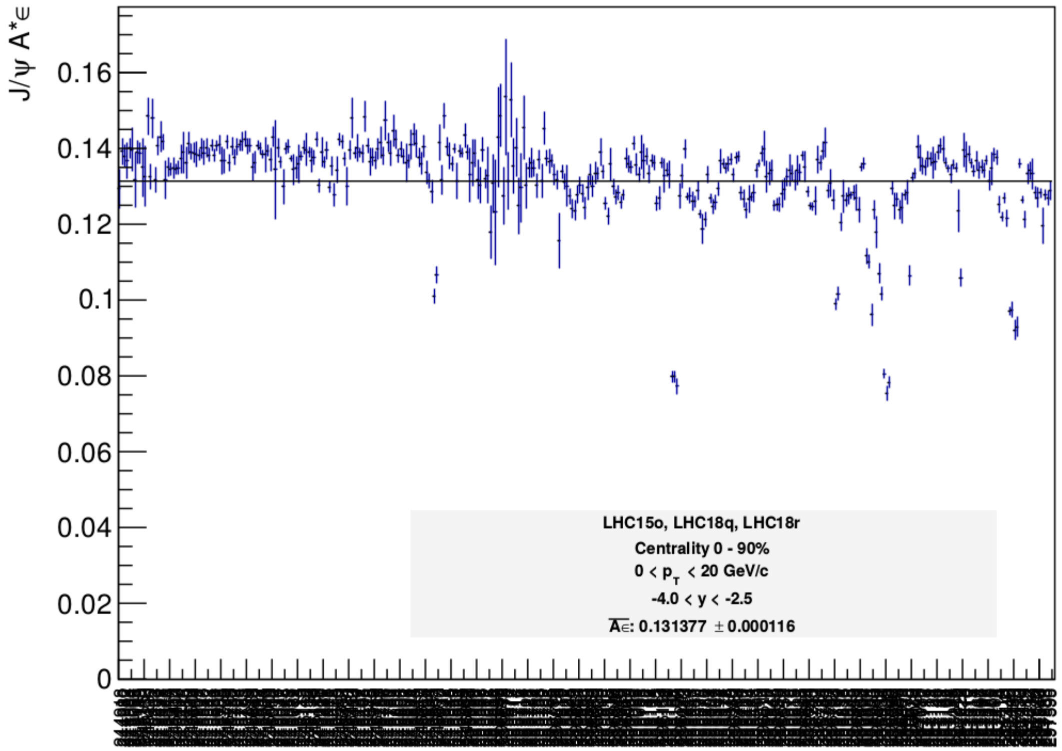
The centrality bin width of 10%

Merge at hit level in the detector → Reconstruction → Analysis code

Embedding MC simulation: merge at hit level raw data and pure signal → allow to simulate the high occupancy of the detectors

AxEff estimated for each run, centrality, y and p_T bins

J/ψ Aε as a function of run



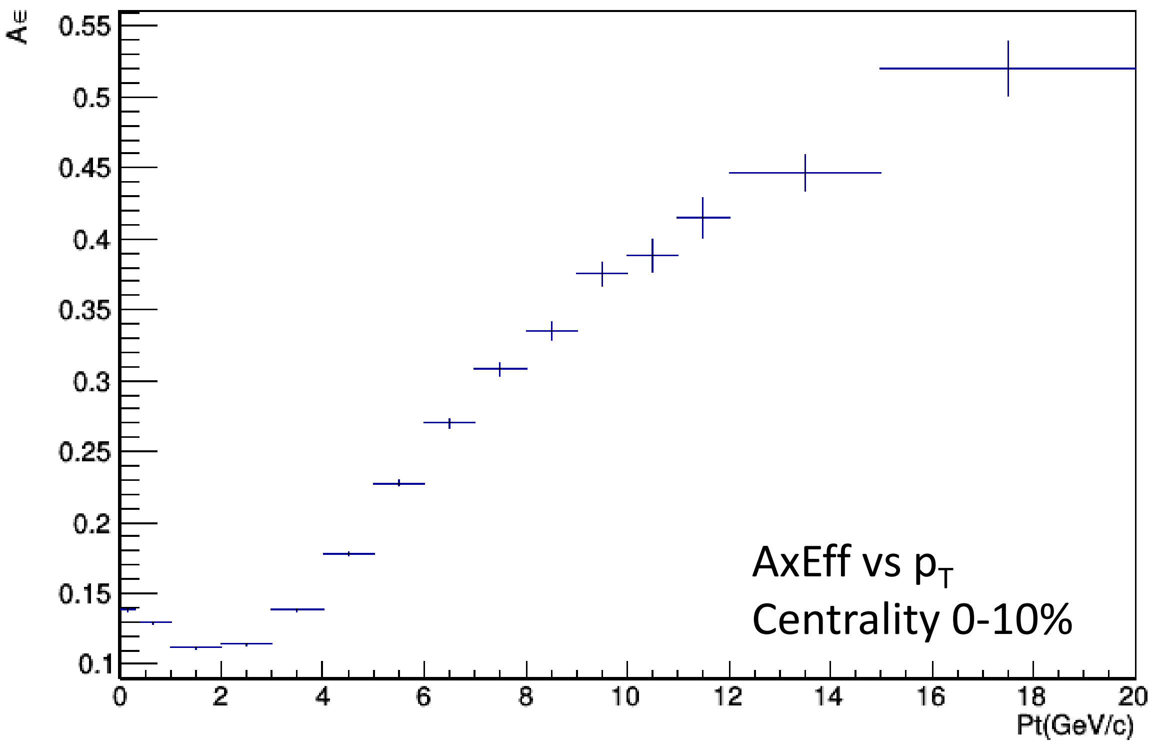
0-90% centrality class

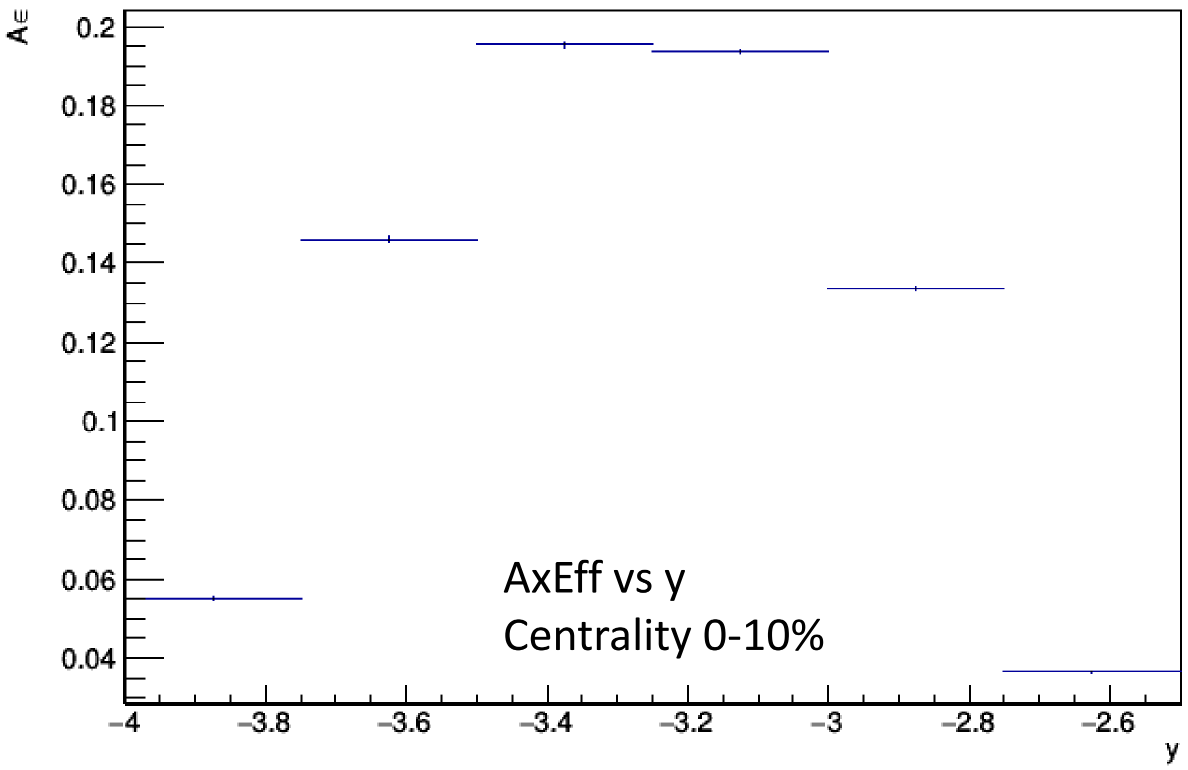
2.5 < y < 4

0 < p_T < 20 GeV/c

The average AxEff: 0.131 +/- 0.0001

J/ψ Aε as a function of p_T and y



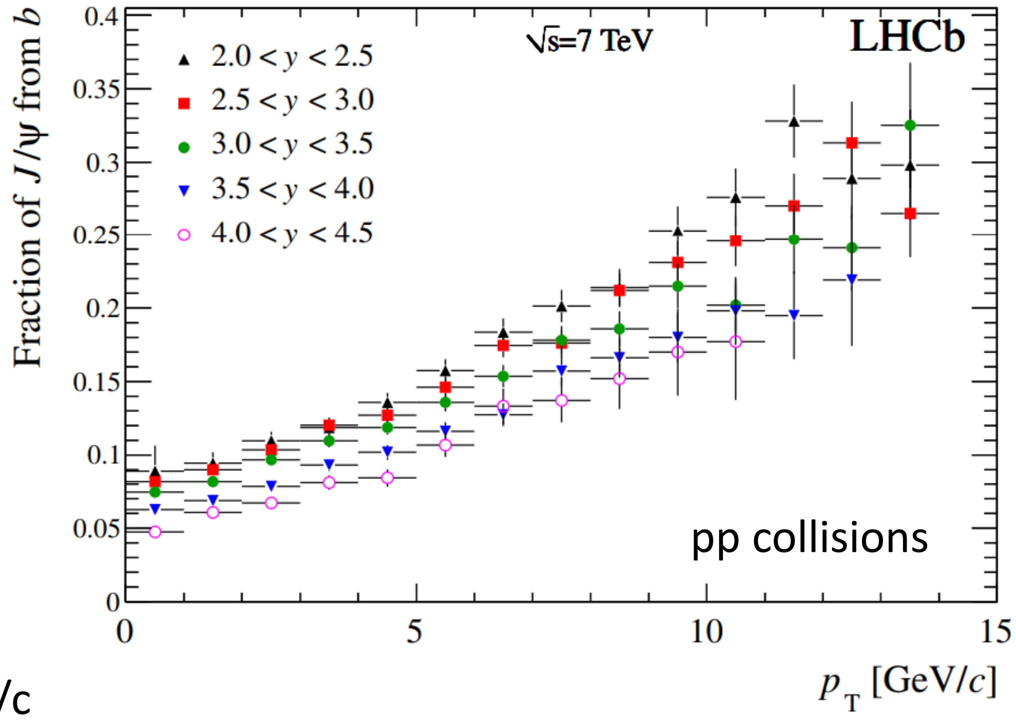


Effect of non-prompt J/ψ on R_{AA}

$$R_{AA}^{pro} = R_{AA}^{inc} + f_B(R_{AA}^{inc} - R_{AA}^{npro})$$

f_B is the fraction of non-prompt J/ψ to prompt J/ψ measured in pp collisions

R_{AA}^{npro} is the suppression factor of B-hadron production in Pb-Pb collisions

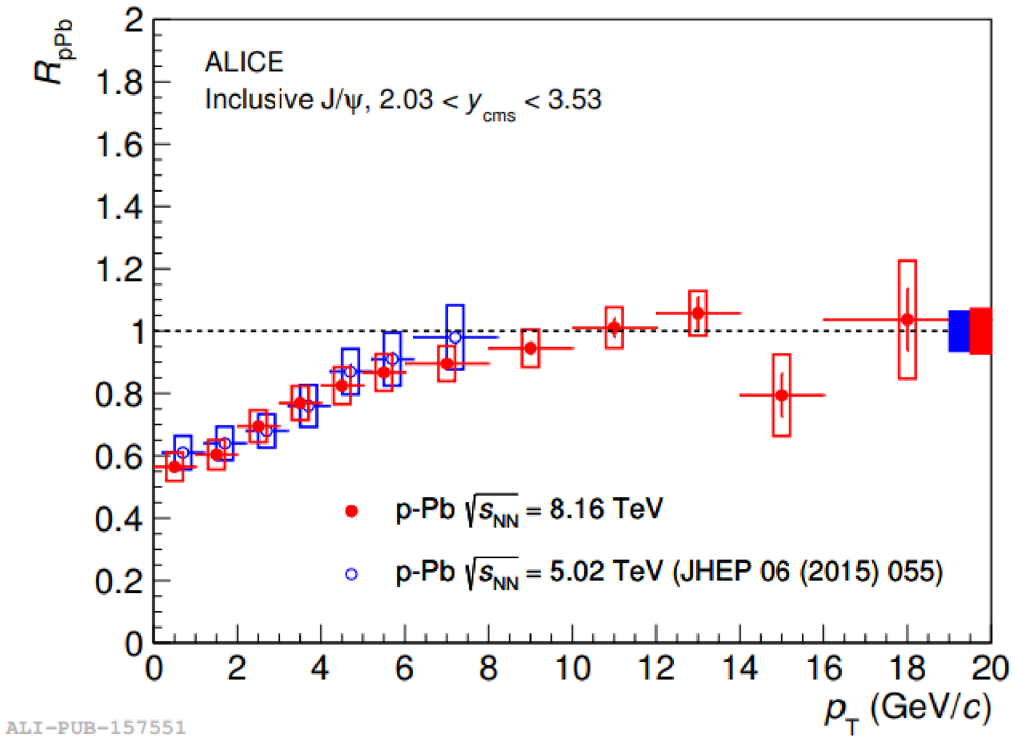


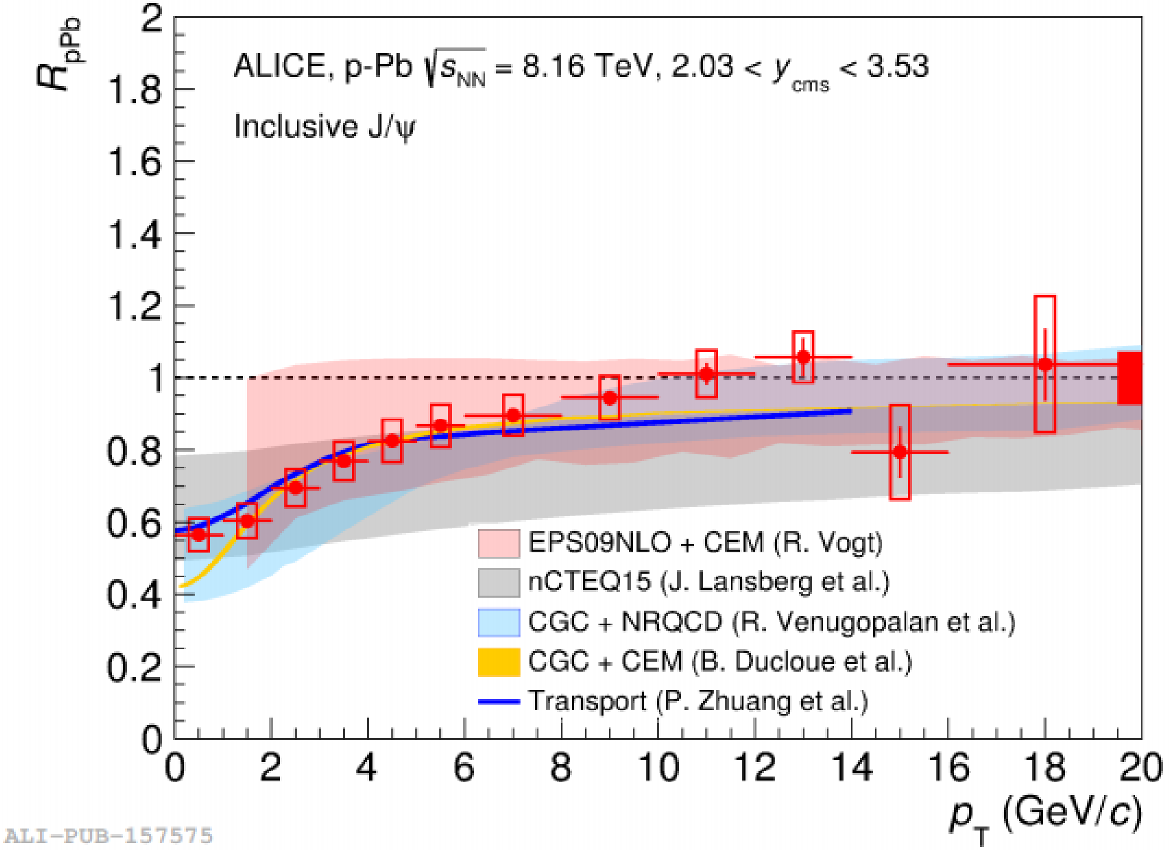
Integrated over p_T, it represents 10%. It exceeds prompt J/ψ for p_T >15 GeV/c

Figure 7: Fraction of J/ψ from b as a function of p_T, in bins of y.

Eur. Phys. J. C71 (2011) 1645

R_{pA} vs p_T at $\sqrt{s_{NN}} = 5.02 \,\&\, 8.16\, TeV$





CNM effects (shadowing, gluon saturation, energy loss, ...) studied by measuring the nuclear modification factor R_{AB} in light systems

Newest R_{AA} vs p_T in LHC and models