J/ψ Measurements with the ALICE Experiment at the LHC

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EMMI

ALICE

J/ψ Measurements with ALICE
Motivation

pp Collisions

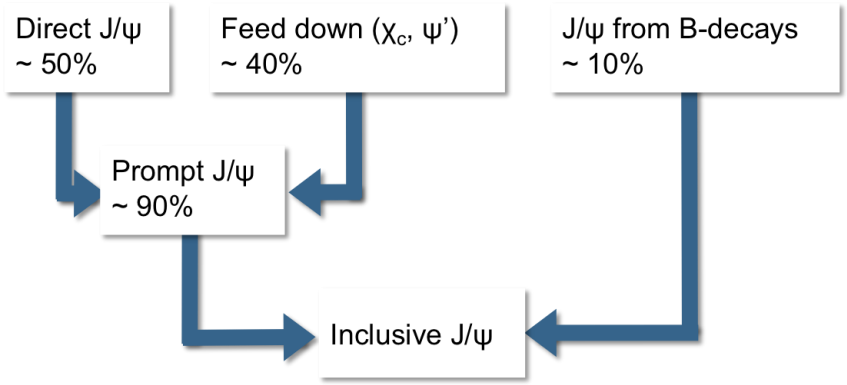
Understanding of elementary production processes (→ cross section, polarization)

Different model approaches: Color Singlet Model (CSM)
Color Evaporation Model (CEM)
NRQCD, includes Color Octet (CO) contributions

Effect of Multi Parton Interactions (MPI) (→ multiplicity dependence)

Measurement of beauty cross section (→ J/ψ from B-decays)

Important reference for Pb-Pb



J/ψ Measurements with ALICE
Motivation

Pb-Pb Collisions

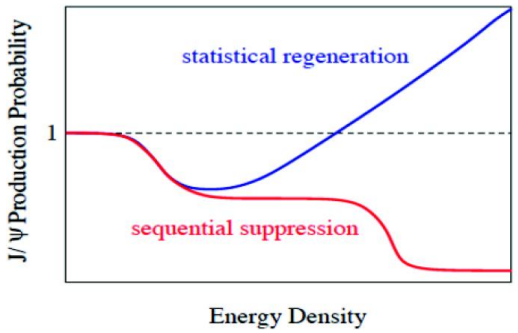
Probe the properties of the hot and dense medium

J/ψ suppression via color screening → QGP signature

T. Matsui and H. Satz, Phys. Lett. **B178**, 416 (1986).

Regeneration mechanisms

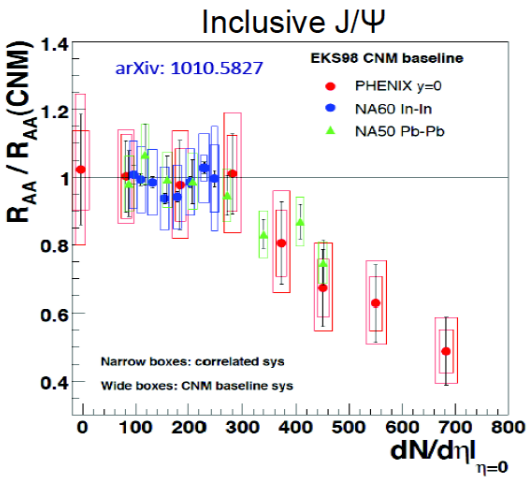
Can counteract suppression at LHC energies



Measurements at SPS and RHIC

Significant suppression relative to Cold Nuclear Matter (CNM) effects (nuclear absorption, shadowing → pA data)

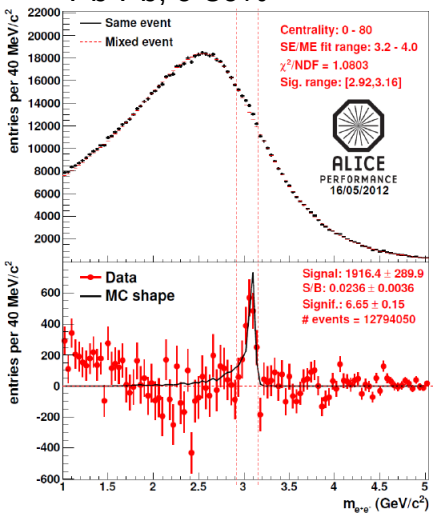
Larger suppression at forward than at mid-rapidity seen at RHIC



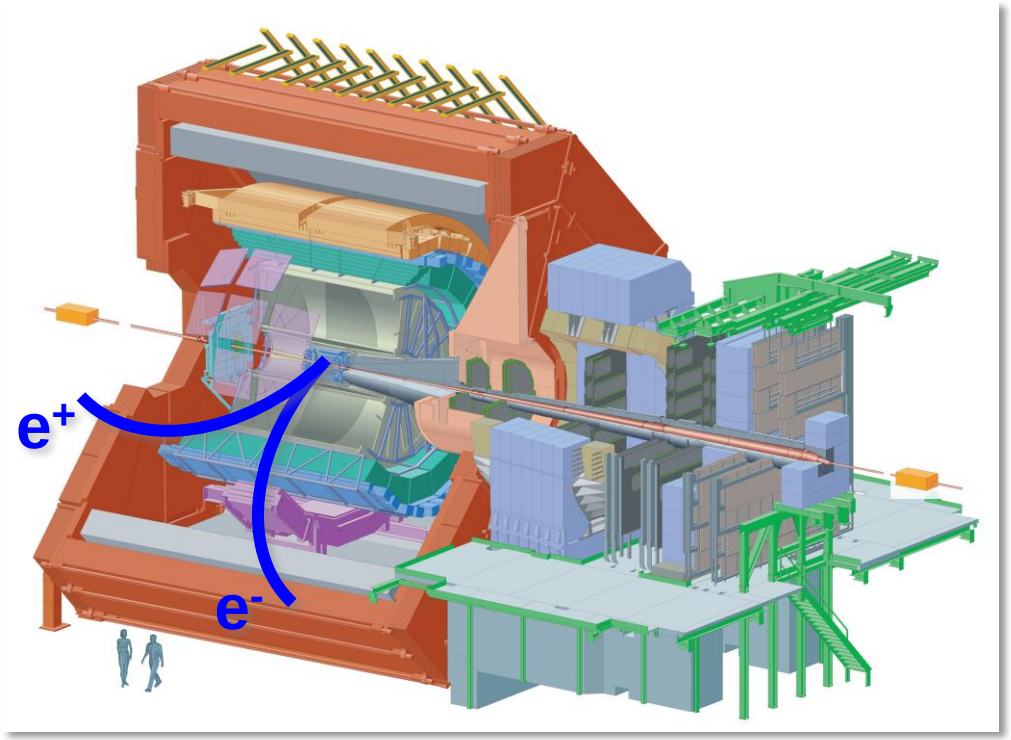
J/ψ Measurements with ALICE
The Detector

Central barrel
Tracking: ITS + TPC + TRD
PID: TPC + TRD + TOF
Secondary vertex: ITS

Pb-Pb, 0-80%

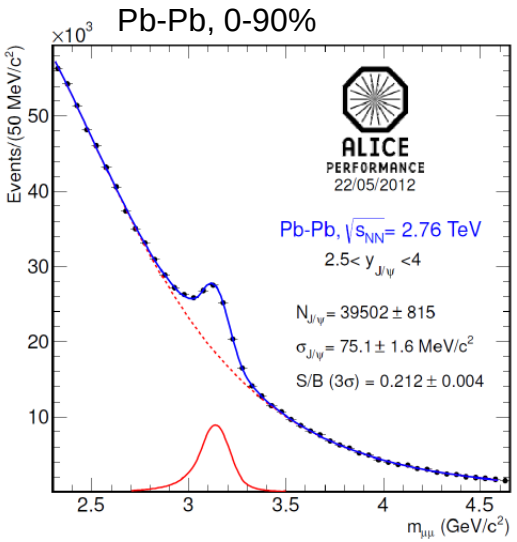


Acceptance
$|\eta_e| < 0.9$
$0 < \phi < 2\pi$
$p_t > 0$!

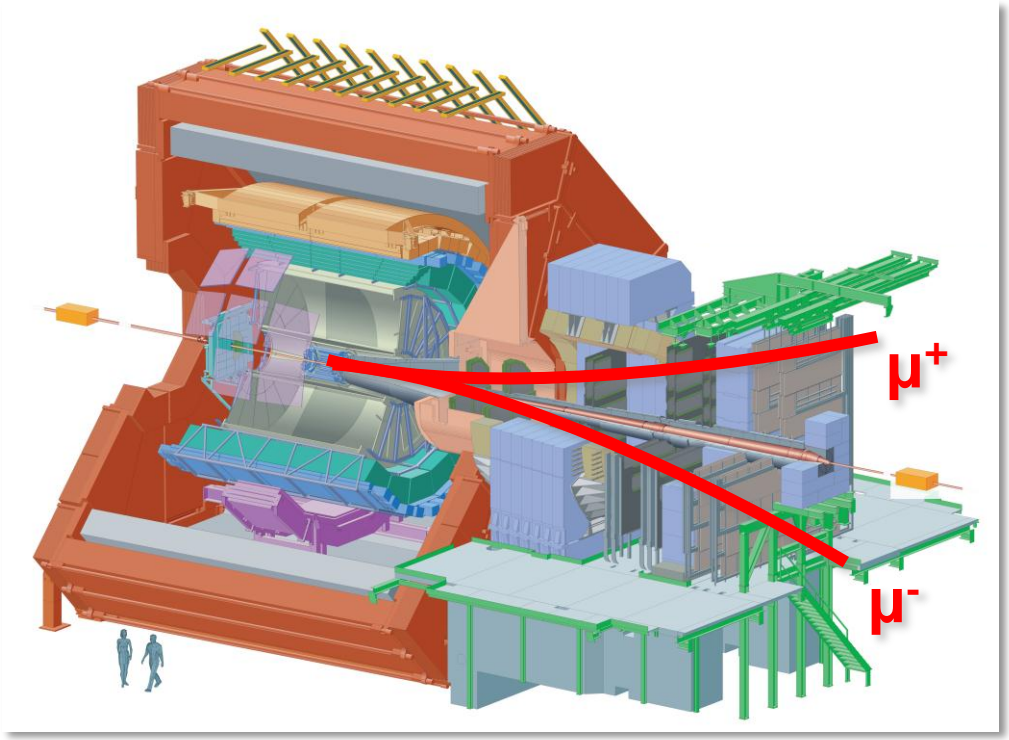


J/ψ Measurements with ALICE
The Detector

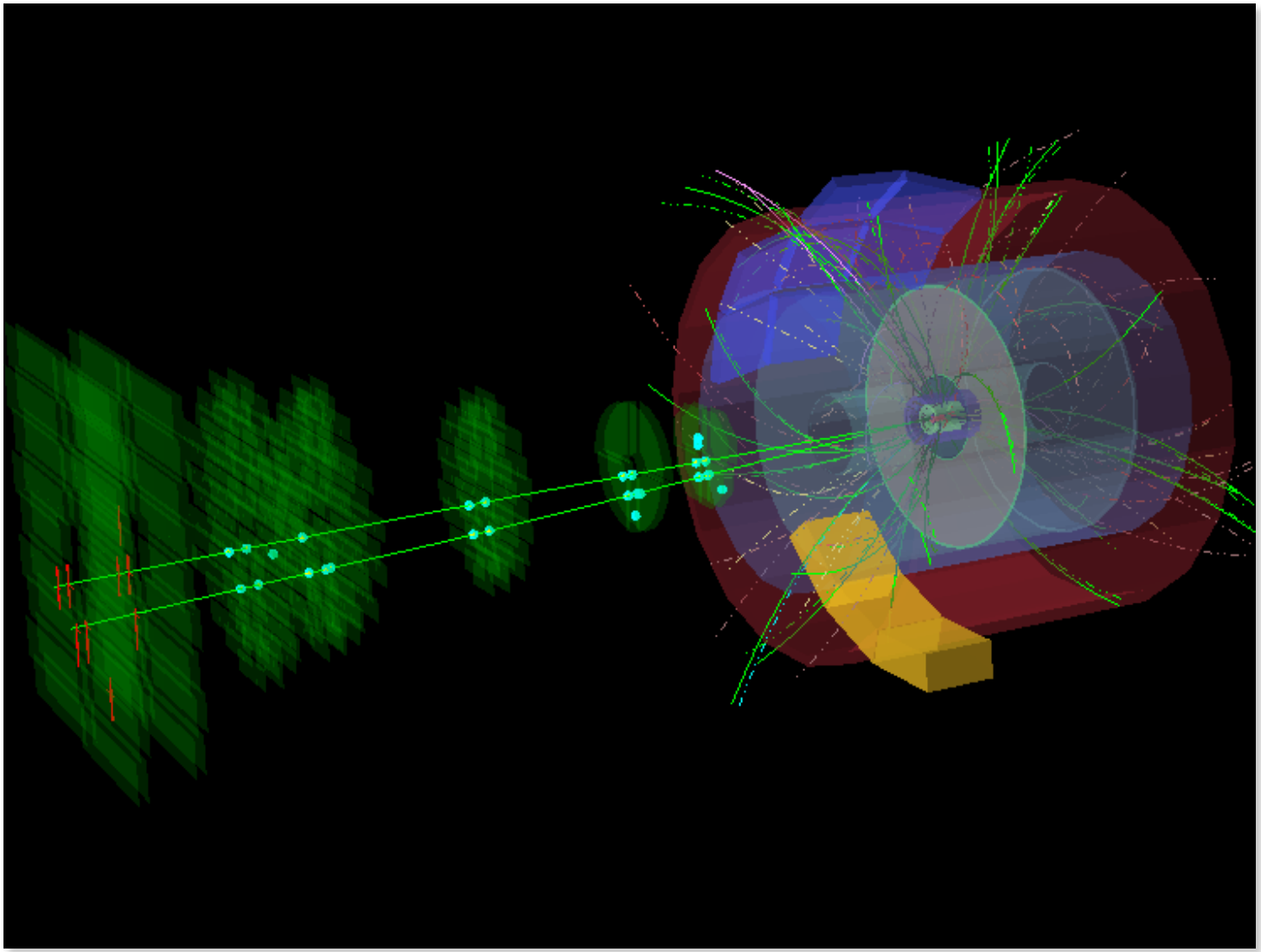
Muon arm
Tracking: 10 CPC planes
PID: Hadron absorbers
Trigger on single + di-muons



Acceptance
$2.5 < \eta_\mu < 4$
$0 < \phi < 2\pi$
$\boldsymbol{p_t > 0}$



pp Collisions



pp Collisions
Inclusive J/ψ: Transverse Momentum Spectra

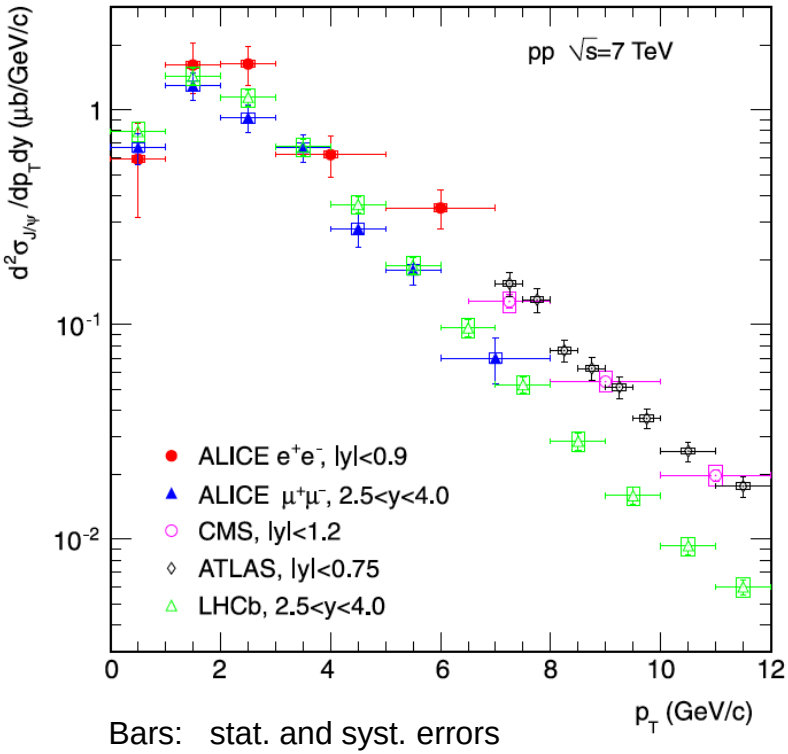
pp @ $\sqrt{s}$ = 7 TeV
ALICE: Phys. Lett. **B704**, 442 (2011).

Forward rapidities
Good agreement with LHCb

Mid-rapidity
Covers p_t range down to 0

Extends ATLAS and CMS measurements

CMS: Eur. Phys. J. **C71**, 1575 (2011).
ATLAS: Nucl. Phys. **B850**, 387 (2011).
LHCb: Eur. Phys. J. **C71**, 1645 (2011).



Bars: stat. and syst. errors w/o lumi. and pol.
Boxes: syst. errors on lumi.

Int. Luminosity (nb^{-1})	
J/ψ → ee	5.6
J/ψ → μμ	15.6

pp Collisions
Inclusive J/ψ: Rapidity Spectra

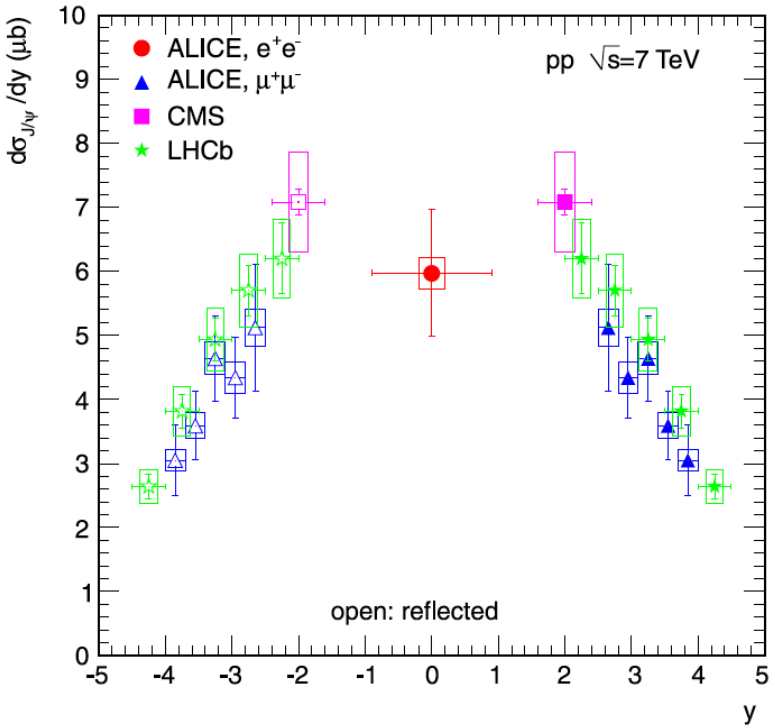
pp @ $\sqrt{s}$ = 7 TeV
ALICE: Phys. Lett. **B704**, 442 (2011).

Forward rapidities
Good agreement with LHCb

Mid-rapidity
Covers p_t range down to 0

Allows to fill gap at mid-rapidity in $d\sigma_{J/\psi}/dy$ measurements

CMS: Eur. Phys. J. **C71**, 1575 (2011).
ATLAS: Nucl. Phys. **B850**, 387 (2011).
LHCb: Eur. Phys. J. **C71**, 1645 (2011).



Bars: stat. and syst. errors w/o lumi. and pol.
Boxes: syst. errors on lumi.

Int. Luminosity (nb^{-1})	
J/ψ → ee	5.6
J/ψ → μμ	15.6

pp Collisions
Inclusive J/ψ: $\sqrt{s}$ = 2.76 TeV

pp @ $\sqrt{s}$ = 2.76 TeV

ALICE: arXiv:1203.3641.

Int. Luminosity (nb^{-1})	
J/ψ → ee	1.1
J/ψ → μμ	19.9

Good description by NRQCD

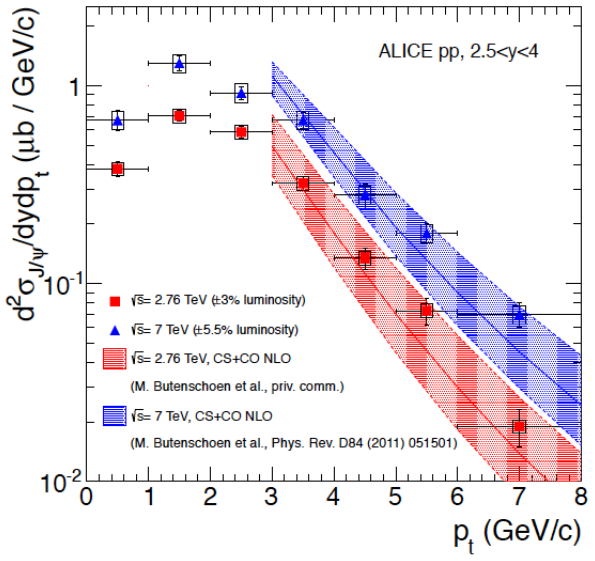
Both, at $\sqrt{s}$ = 2.76 TeV and $\sqrt{s}$ = 7 TeV

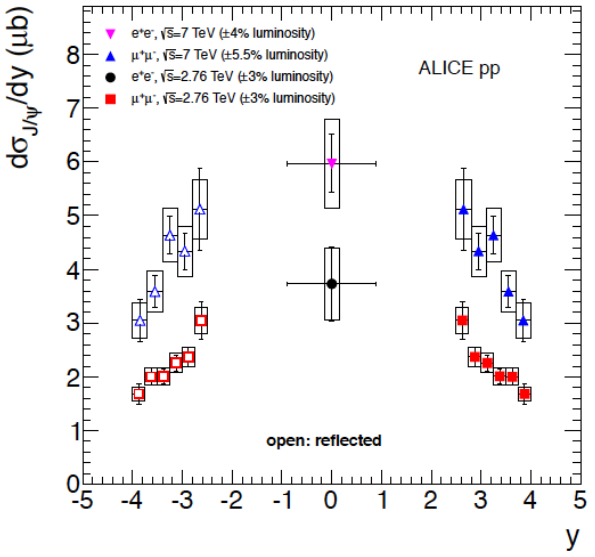
M. Butenschoen et al.,
Phys. Rev. **D84**, 051501 (2011).

Reference data for R_{AA}

$$R_{AA} = \frac{dN^{AA}_{J/\psi}/(dp_t dy)}{\langle T_{AA}\rangle \times d\sigma^{pp}_{J/\psi}/(dp_t dy)}$$

Currently main contribution to systematic error:
2.5 < *y* < 4: 9%
|*y*| < 0.9: 26%





pp Collisions
J/ψ Polarization

pp @ $\sqrt{s}$ = 7 TeV
ALICE: PRL **108**, 082001 (2011).

Forward rapidities $2.5 < y < 4$
p_t coverage: $2 < p_t < 8$ GeV/c

Observables:
Angular distributions of decay muons

Azimuthal angle ϕ:

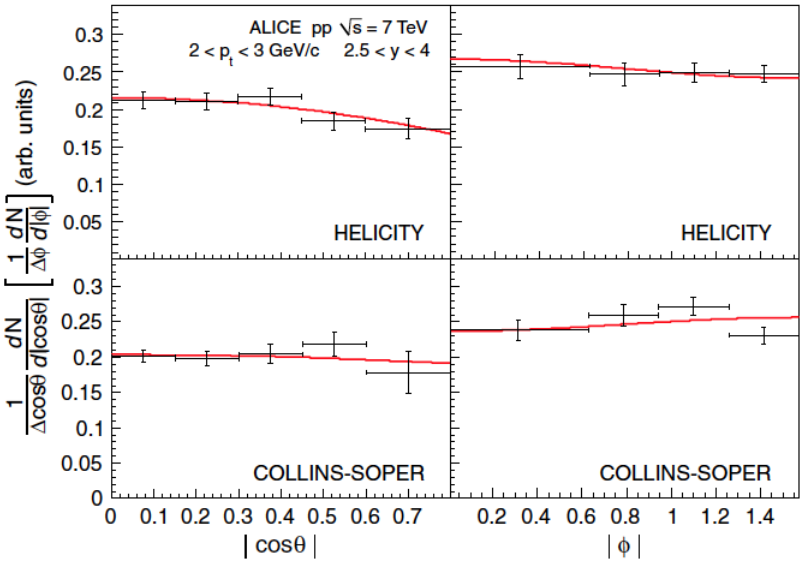
$$W(\phi) \propto 1 + \frac{2\lambda_\phi}{3+\lambda_\theta}\cos 2\phi$$

Polar angle θ:

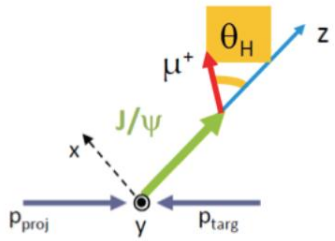
$$W(\cos\theta) \propto \frac{1}{3+\lambda_\theta}(1+\lambda_\theta \cos^2\theta)$$

Transversal polarization: $\lambda_\theta > 0$
Longitudinal polarization: $\lambda_\theta < 0$

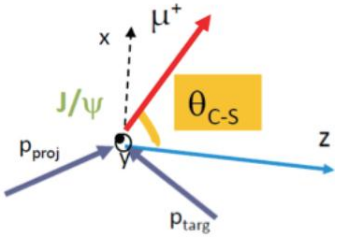
Reference frames
Helicity (HE) + Collins-Soper (CS)



Helicity:



Collins-Soper:



pp Collisions
J/ψ Polarization

pp @ $\sqrt{s}$ = 7 TeV

ALICE: PRL **108**, 082001 (2011).

Forward rapidities $2.5 < y < 4$

p_t coverage: $2 < p_t < 8$ GeV/c

Polarization very small

λ_θ and λ_ϕ close to zero

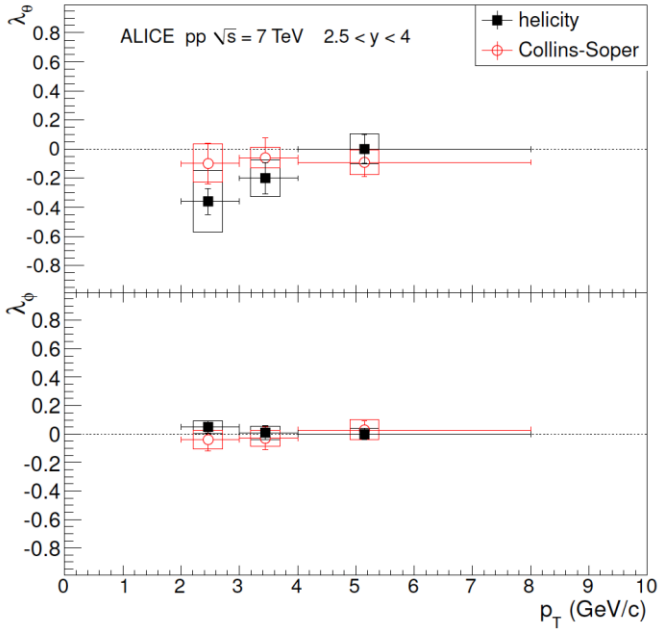
Inclusive J/ψ (ψ', χ_c, and B-decays)

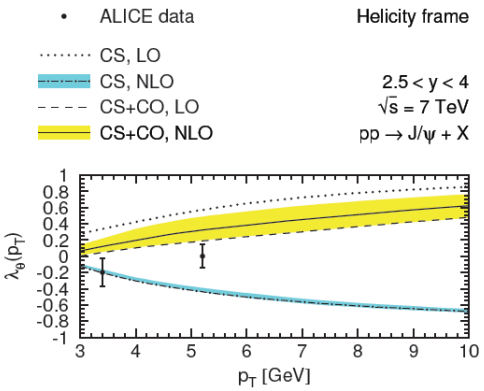
Crucial test for models

E.g. NLO CSM predicts large longitudinal polarization in HE frame ($\lambda_\theta \sim -0.6$ for $p_t \sim 5$ GeV/c)

J. P. Lansberg, Eur. Phys. J. **C61**, 693 (2008).

Next: extend measurement to higher p_t





M. Butenschoen and B.A. Kniehl, Nucl. Phys. Proc. Suppl. **222**, 151 (2012).

pp Collisions
J/ψ From B-Decays

pp @ $\sqrt{s}$ = 7 TeV
ALICE: arXiv:1205.5880.

Pseudo-proper decay length

$$x = \frac{c\, L_{xy}\, m_{J/\psi}}{p_t^{J/\psi}} \quad \text{with} \quad L_{xy} = \vec{L}\, \vec{p}_t^{J/\psi} / p_t^{J/\psi}$$

J/ψ→ee @ mid-rapidity, p_t > 1.3 GeV/c
→ unique at LHC

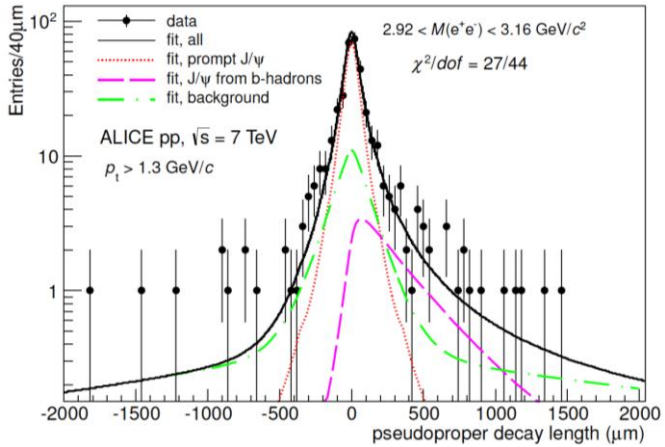
Impact parameter res.: $\sigma_{r\phi}$ < 75 μm

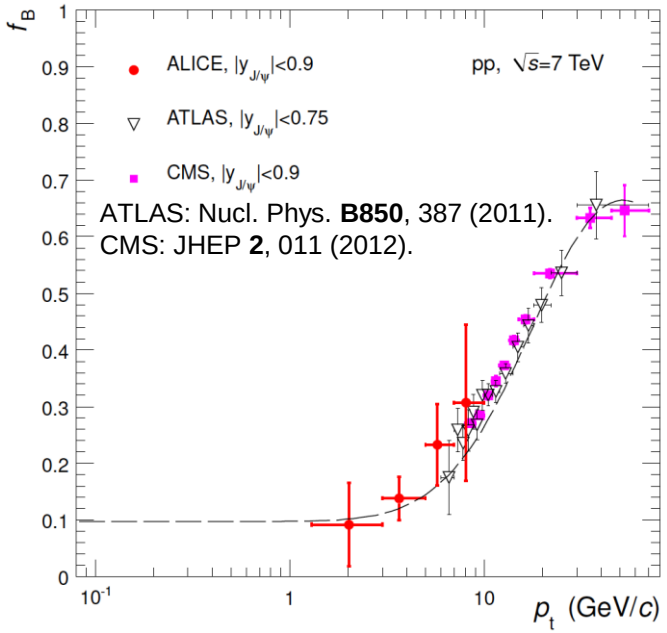
Fraction of J/ψ from B:

$$f_B = 0.149 \pm 0.037(\text{stat.})^{+0.018}_{-0.027}(\text{syst.})^{+0.025}_{-0.021}(\text{pol.})$$

⇒ Cross section for prompt J/ψ
($|y|$ < 0.9, p_t > 1.3 GeV/c):

$$\sigma^{\text{prompt}}_{J/\psi} = 7.2 \pm 0.7(\text{stat.}) \pm 1.0(\text{syst.})^{+1.3}_{-1.2}(\text{pol.})\,\mu\text{b}$$





pp Collisions
J/ψ From B-Decays

pp @ $\sqrt{s}$ = 7 TeV
ALICE: arXiv:1205.5880.

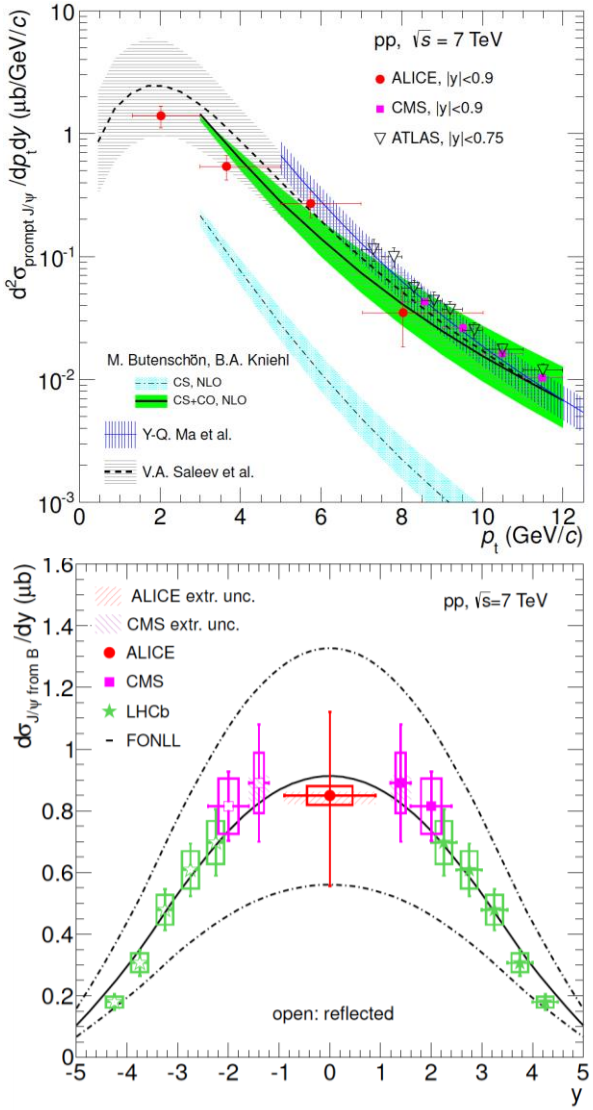
p_t-Spectrum of prompt J/ψ
Good agreement to NRQCD calculations (NLO) incl. CS+CO

M. Butenschön and B.A. Kniehl, PRL **106**, 022003(2011).
Y.-Q. Ma. K. Wang, and K.T. Chao, PRL **106**, 042002 (2011).

Total $b\bar{b}$ cross section
Using FONLL for extrapolation to p_t=0

M. Cacciari et al., JHEP **07**, 033 (2004).

$$\sigma(pp \to b\bar{b} + X) = 244 \pm 64(\text{stat.})^{+50}_{-59}(\text{syst.})^{+7}_{-6}(\text{extr.})\mu b$$



pp Collisions
J/ψ Production vs Multiplicity

pp @ $\sqrt{s}$ = 7 TeV
ALICE: Phys. Lett. **B712**, 165 (2012).

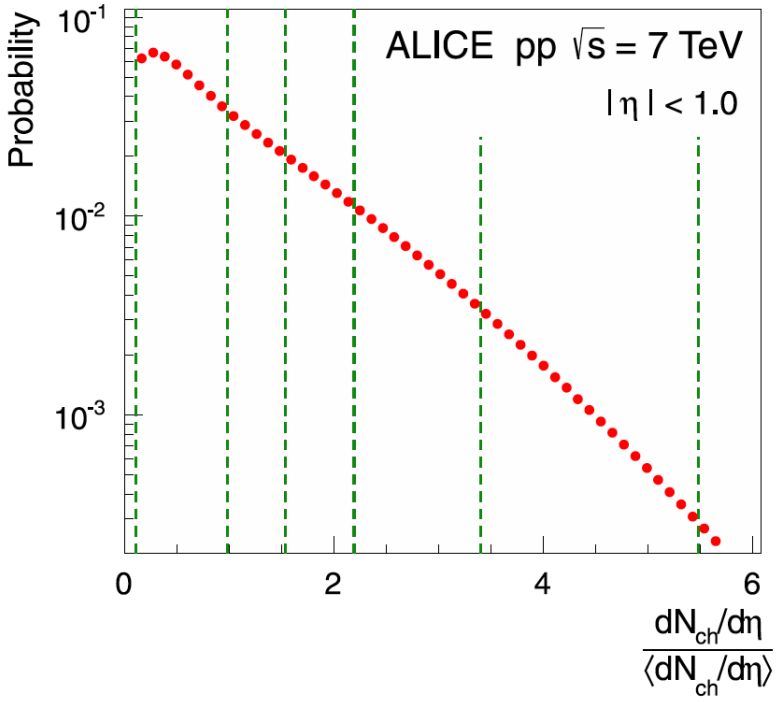
Division into event classes
Up to ~ five times mean multiplicity ($dN_{ch}/d\eta$ ~ 30)

Comparable to semi-peripheral Cu-Cu collisions with $\sqrt{s}$ = 200 GeV (RHIC)

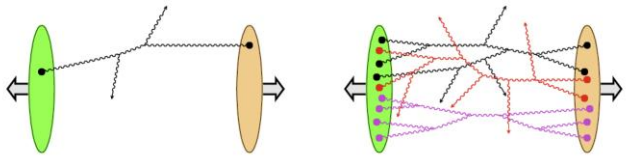
Probes impact parameter of collision

Interplay soft + hard physics
$dN_{ch}/d\eta$: soft scale, described via Multi Parton Interactions (MPI)

J/ψ production: hard scale, also affected by MPI ?



Hard: Soft:



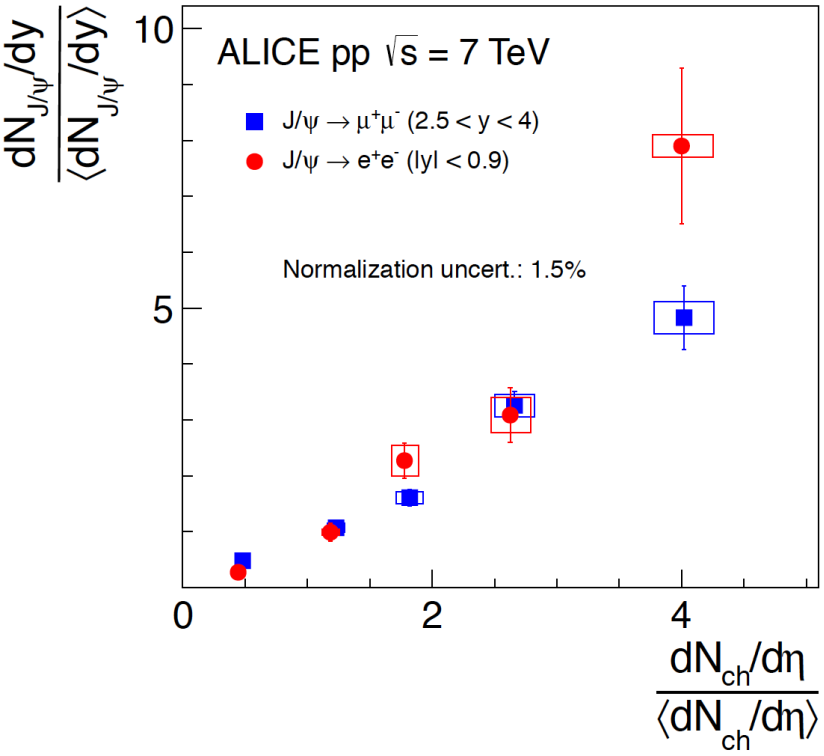
C. Marquet, MPI Workshop, Perugia (2008)

pp Collisions
J/ψ Production vs Multiplicity

pp @ $\sqrt{s}$ = 7 TeV
ALICE: Phys. Lett. **B712**, 165 (2012).

Approx. linear increase of J/ψ yield
Relative yields shown
→ reduced systematic errors

Similar at mid- and forward rapidity
($dN_{ch}/d\eta$ always at mid-rapidity)



pp Collisions
J/ψ Production vs Multiplicity

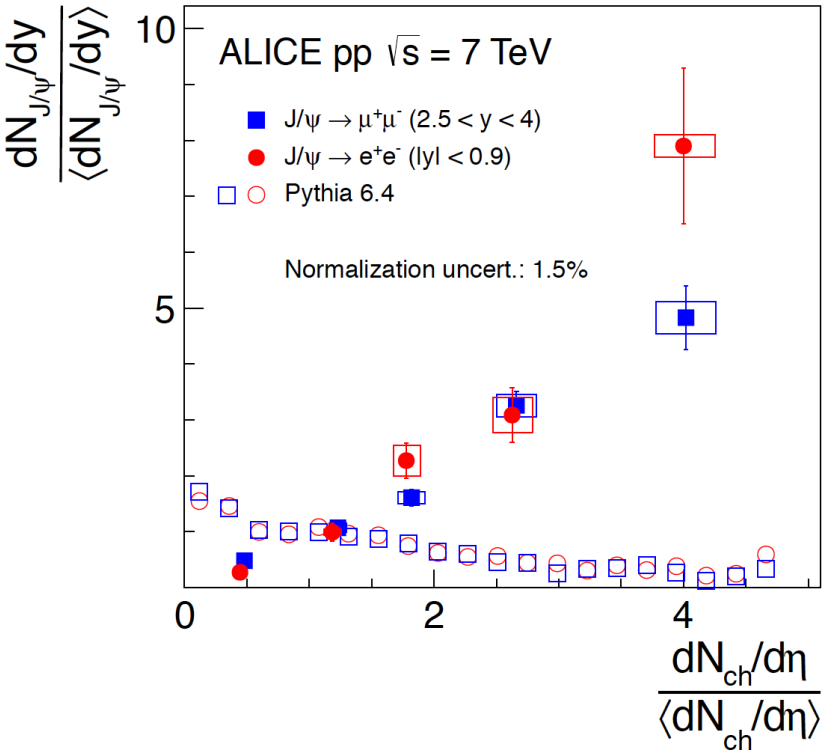
pp @ $\sqrt{s}$ = 7 TeV
ALICE: Phys. Lett. **B712**, 165 (2012).

Approx. linear increase of J/ψ yield
Relative yields shown
→ reduced systematic errors

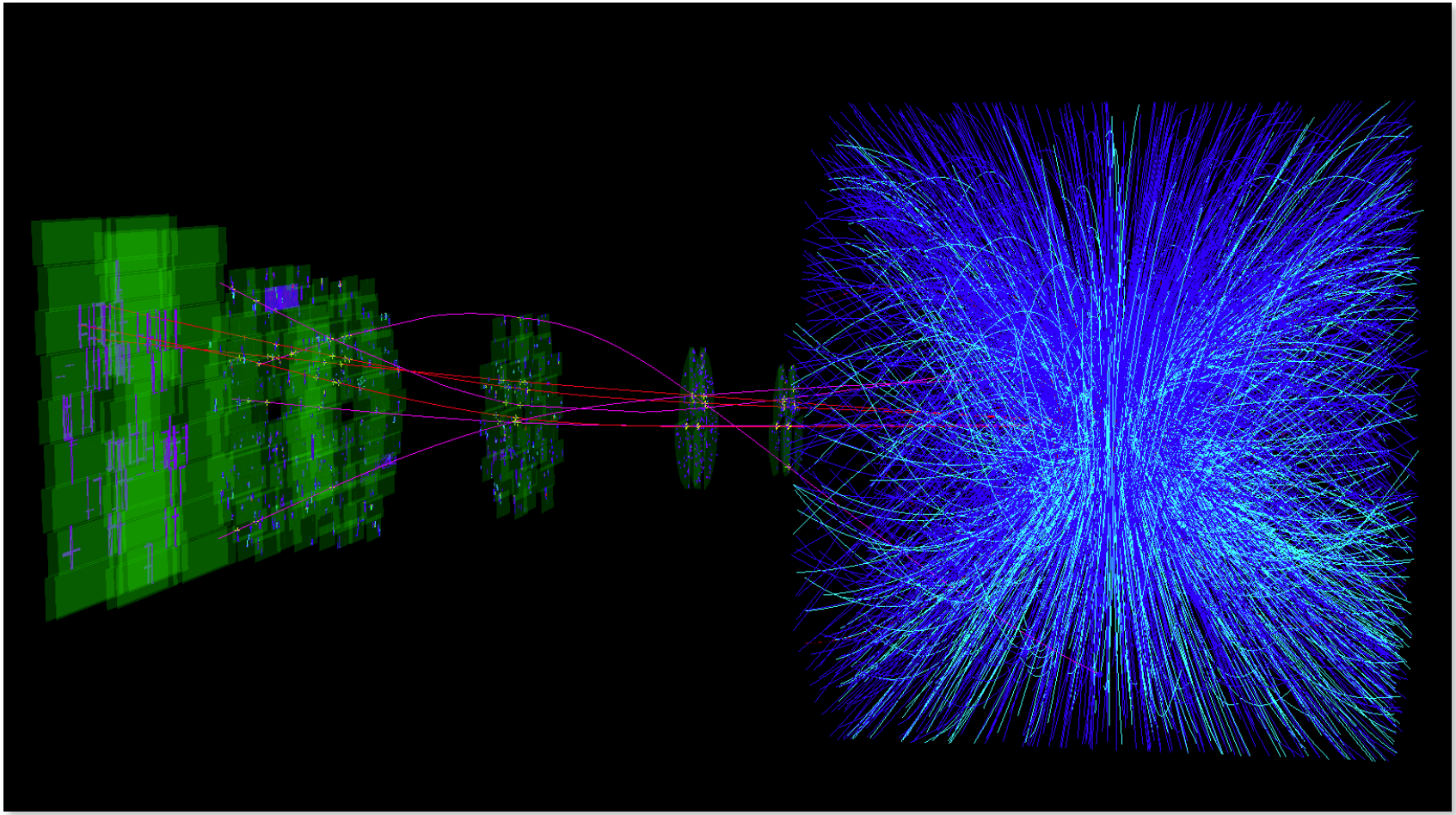
Similar at mid- and forward rapidity ($dN_{ch}/d\eta$ always at mid-rapidity)

Not seen in models
E.g. J/ψ from hard processes from Pythia 6.4 (cluster formation excl.)

Next: look at other observables (e.g. D-mesons), extension to higher multiplicities



Pb-Pb Collisions



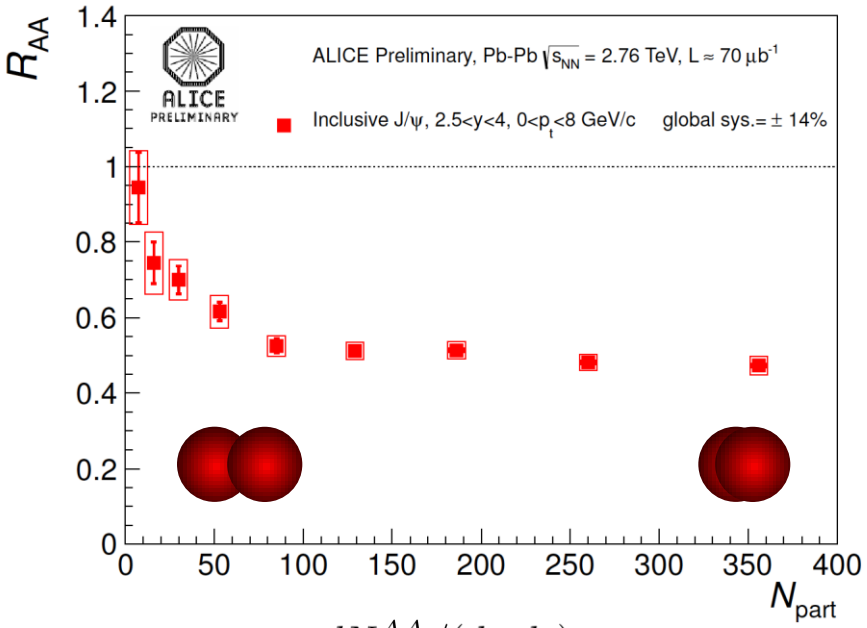
Pb-Pb Collisions
J/ψ R_{AA} vs Centrality

J/ψ → μμ
$2.5 < y < 4$,
$0 < p_t < 8$ GeV/c

Inclusive J/ψ suppressed relative to pp

$R_{AA} \simeq 0.5$ for $N_{part} > 100$, independent of centrality

Averaged R_{AA}(0-90%)
$= 0.497 \pm 0.006(\text{stat.}) \pm 0.078(\text{syst.})$



$$R_{AA} = \frac{dN^{AA}_{J/\psi}/(dp_t dy)}{\langle T_{AA}\rangle \times d\sigma^{pp}_{J/\psi}/(dp_t dy)}$$

Int. Luminosity (μb^{-1})	
J/ψ → ee (2010 data)	1.7
J/ψ → μμ (2011 data)	70

C. Suire (for the ALICE Collaboration), Hard Probes 2012

Pb-Pb Collisions
J/ψ R_{AA} vs Centrality

J/ψ → μμ
$2.5 < y < 4$
$0 < p_t < 8$ GeV/c

Inclusive J/ψ suppressed relative to pp

$R_{AA} \simeq 0.5$ for $N_{part} > 100$, independent of centrality

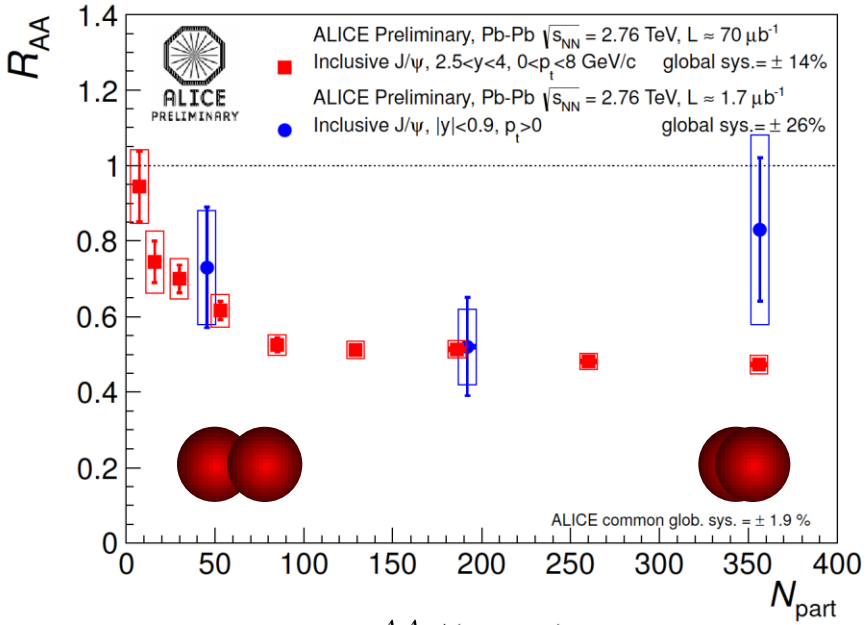
Averaged R_{AA}(0-90%)
= 0.497 ± 0.006(stat.) ± 0.078(syst.)

J/ψ → ee
$|y| < 0.9$
$p_t > 0$

Similar to forward rapidity

Larger uncertainties

Averaged R_{AA}(0-80%)
= 0.66 ± 0.10(stat.) ± 0.24(syst.)



$$R_{AA} = \frac{dN^{AA}_{J/\psi}/(dp_t dy)}{\langle T_{AA}\rangle \times d\sigma^{pp}_{J/\psi}/(dp_t dy)}$$

Int. Luminosity (μb^{-1})	
J/ψ → ee (2010 data)	1.7
J/ψ → μμ (2011 data)	70

J. Wiechula (for the ALICE Collaboration), Hard Probes 2012

Pb-Pb Collisions

J/ψ R_{AA} vs Centrality and p_t: Comparison to CMS

ALICE: 0 < p_t < 8 GeV/*c*

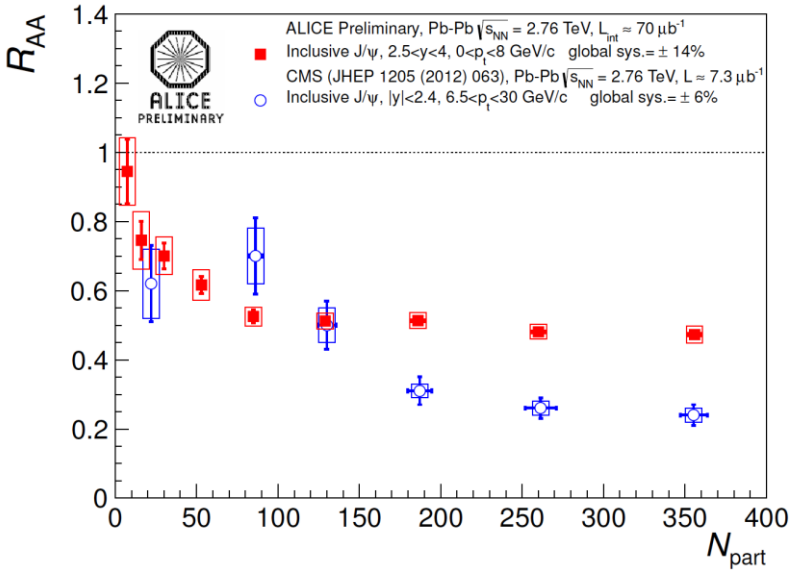
2.5 < y < 4

$R_{AA} \simeq 0.5$ for $N_{part} > 100$, independent of centrality

CMS: 6.5 < p_t < 30 GeV/*c*

$|y| < 2.4$

R_{AA} decreases continuously with increasing cent. down to $R_{AA} = 0.24$



Pb-Pb Collisions

J/ψ R_{AA} vs Centrality and p_t: Comparison to CMS

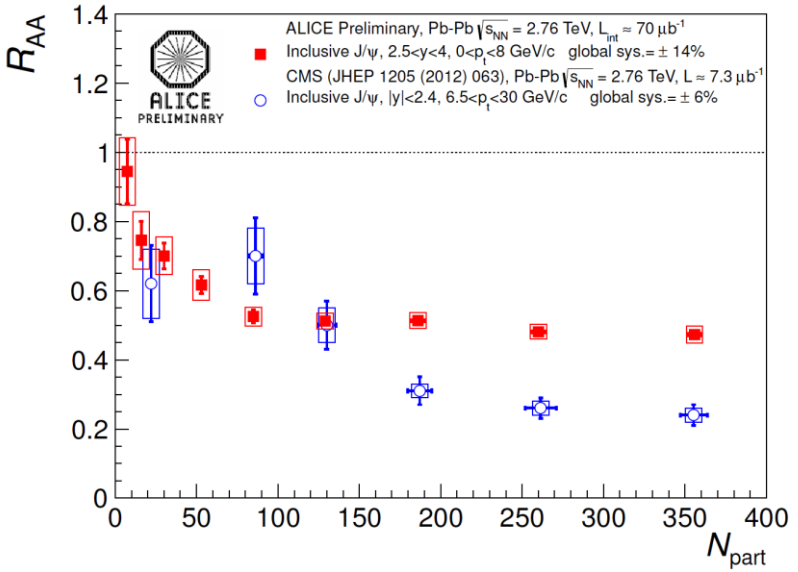
ALICE: 0 < p_t < 8 GeV/*c*
2.5 < *y* < 4

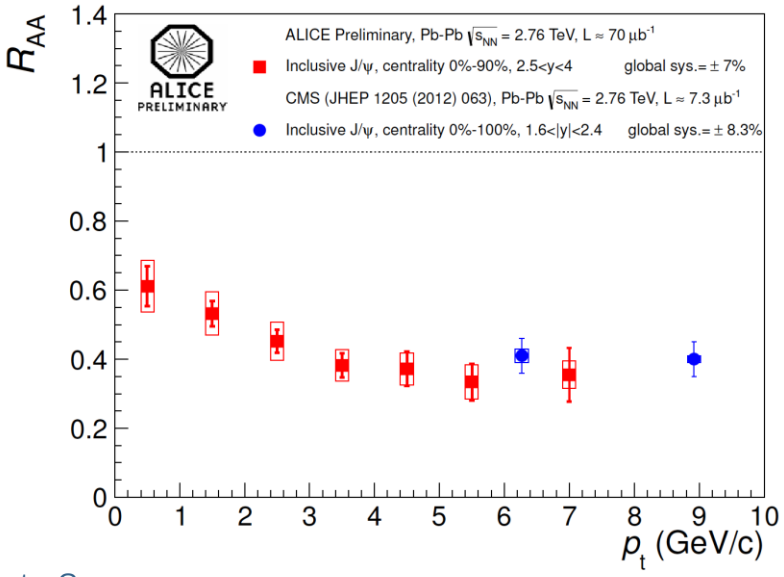
R_{AA} ≈ 0.5 for N_{part} > 100, independent of centrality

CMS: 6.5 < p_t < 30 GeV/*c*
|*y*| < 2.4

R_{AA} decreases continuously with increasing cent. down to R_{AA} = 0.24

Clear p_t dependence of J/ψ suppression observed
ALICE: 2.5 < *y* < 4
CMS: 1.6 < *y* < 2.4





Pb-Pb Collisions

J/ψ R_{AA} vs Centrality: Comparison to PHENIX

R_{AA}(ALICE) > R_{AA}(PHENIX)

Forward rapidity

Clear difference for N_{part} > 100

ALICE: $2.5 < y < 4$, $0 < p_t < 8$ GeV/c

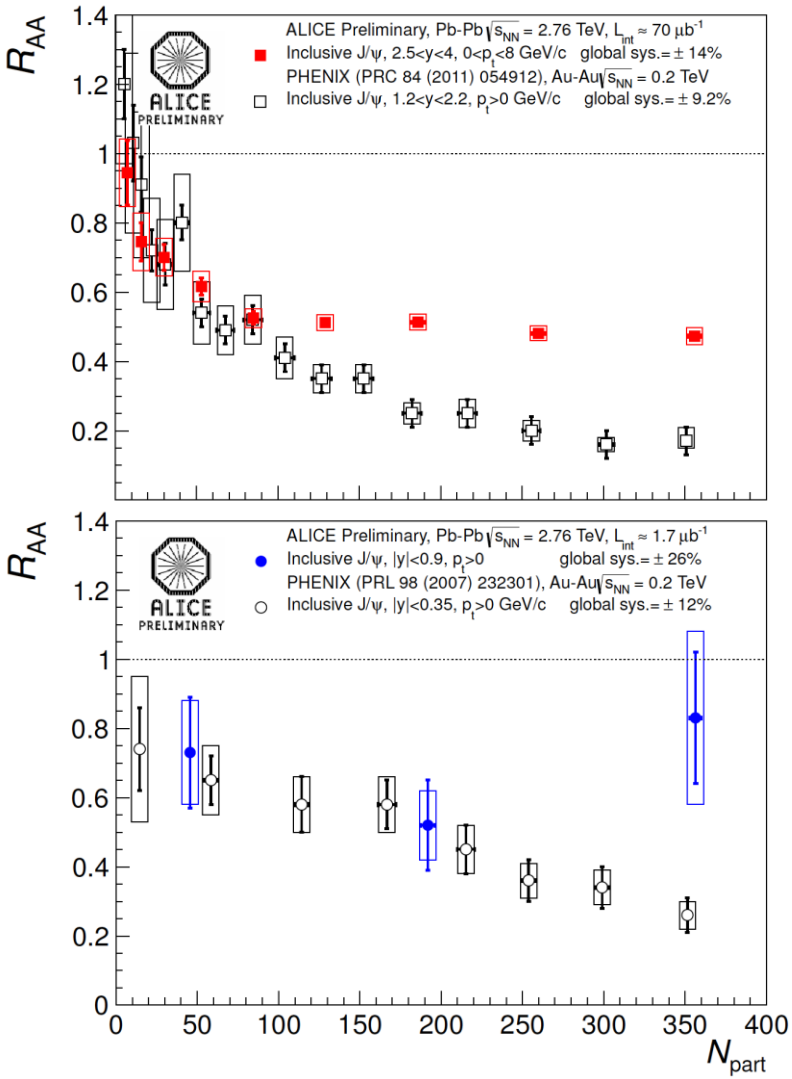
PHENIX: $1.2 < y < 2.2$, $p_t > 0$

Mid-rapidity

Significant difference for most central

ALICE: $|y| < 0.9$, $p_t > 0$

PHENIX: $|y| < 0.35$, $p_t > 0$



Pb-Pb Collisions

J/ψ R_{AA} vs Centrality: Model Comparisons

Transport models

Cold nuclear matter effects
(shadowing, absorption)
Suppression in hot medium
Feed down from B mesons
J/ψ from regeneration (≥ 50%)

X. Zhao and R. Rapp, Nucl. Phys. **A859**, 114 (2011).
Y.-P. Liu et al., Phys. Lett. **B678**, 72 (2009).

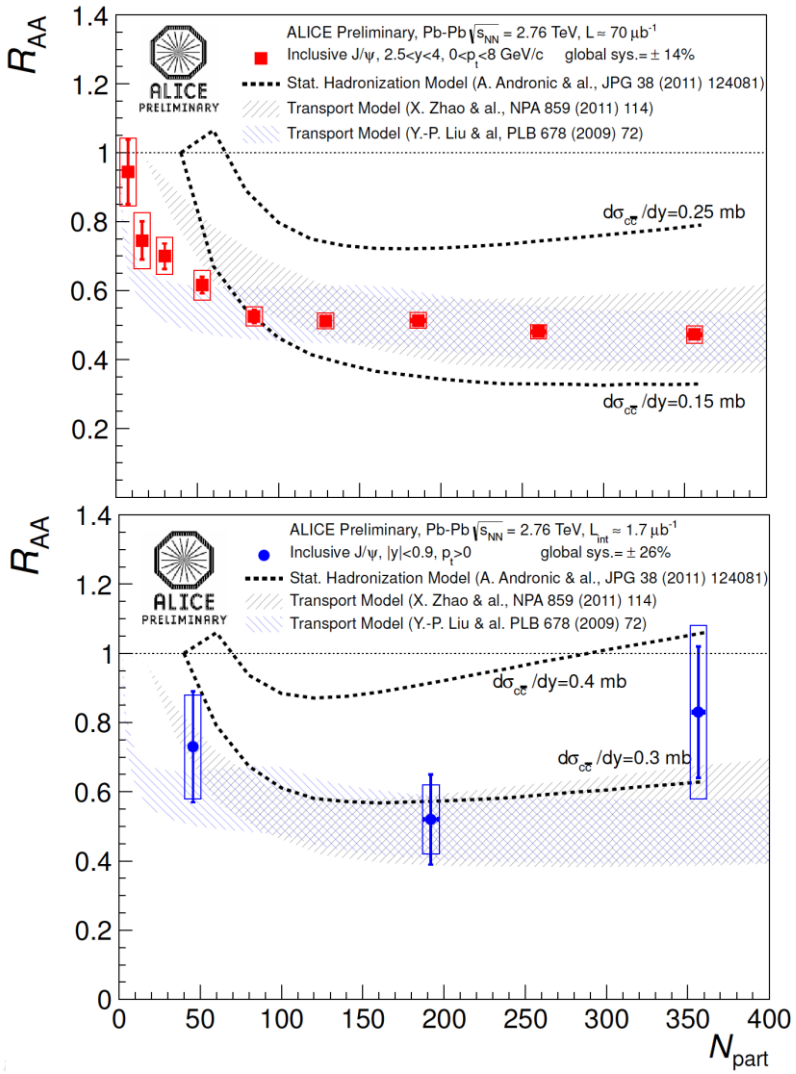
Statistical hadronization

Charm from initial hard processes
All J/ψ formed at hadronization

A. Andronic et al., J. Phys. **G38**, 124081 (2011).

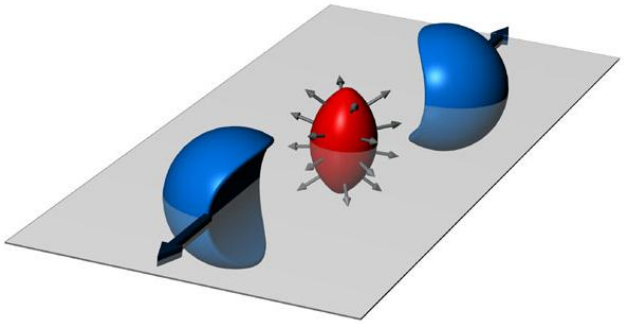
CNM effects

Still to be determined (pA data)



Pb-Pb Collisions
J/ψ Elliptic Flow

J/ψ relative to event plane
Di-muon channel, 2.5 < y < 4



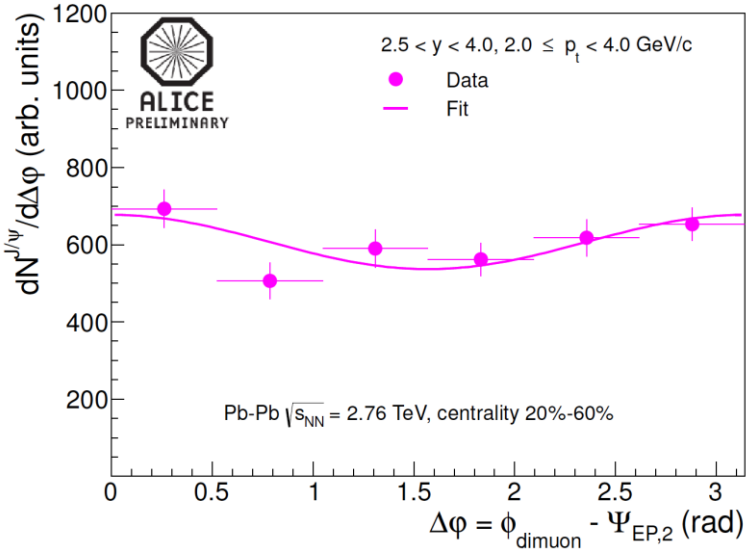
Event plane measured with VZERO (2% resolution)

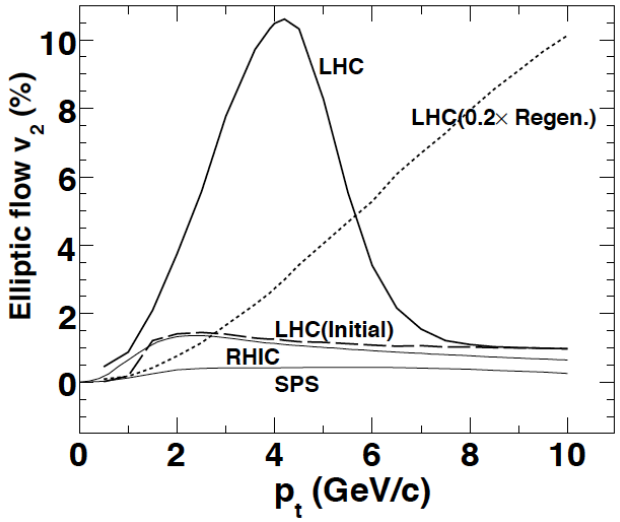
Fourier decomposition:

$$\frac{dN^{J/\psi}}{d\Delta\phi} \propto 1 + 2\, v_2^{obs} \cos(2\,[\phi_{dimuon} - \Psi_{EP,2}])$$

J/ψ from regeneration
Can cause signif. v_2 at intermediate p_t

Y. Liu, N. Xu, P. Zhuang, Nucl. Phys. **A834**, 317c (2010).



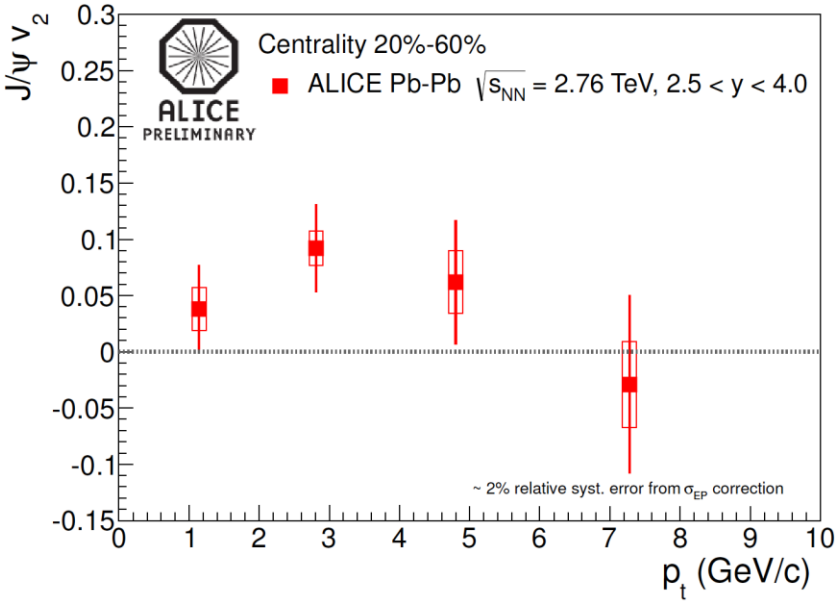


Pb-Pb Collisions
J/ψ Elliptic Flow: v_2 vs p_t

20%-60% most central Pb-Pb
Di-muon channel, 2.5 < y < 4

Indication for $v_2 > 0$
p_t –Range: 2 – 4 GeV/*c*

Significance: **2.2 σ**



L. Massacrier (for the ALICE Collaboration), Hard Probes 2012

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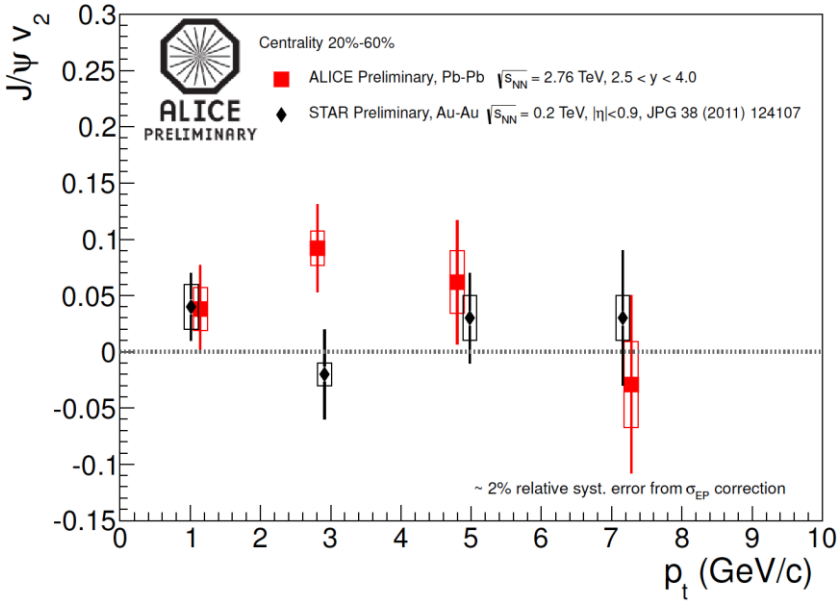
Significance: **2.2 σ**

Different to RHIC
$|\eta| < 0.9$

STAR: J. PHYS. **G38**, 124107 (2011).



L. Massacrier (for the ALICE Collaboration), Hard Probes 2012

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Different to RHIC
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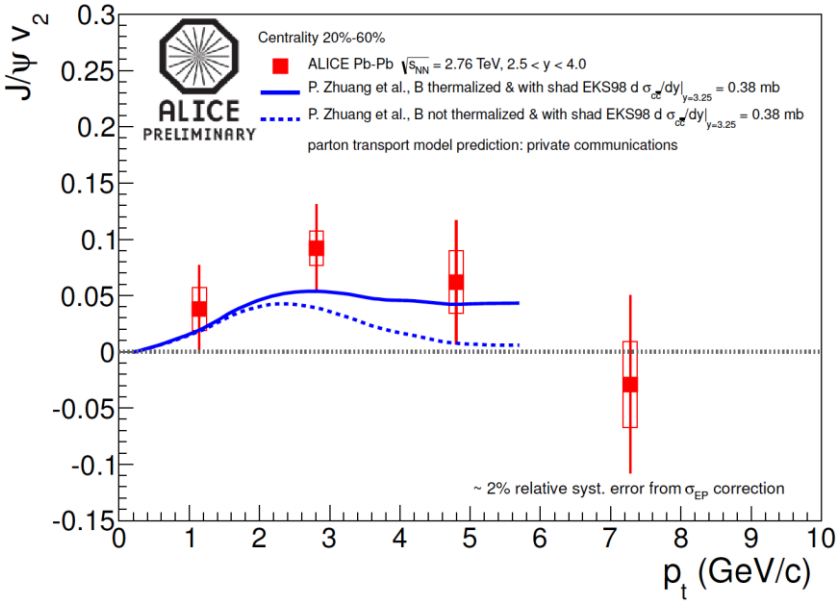
Model calculation
Parton transport model
P. Zhuang et al., priv. comm.

Charm cross section: 0.38 mb
Shadowing included
With and w/o thermalized b-quarks
→ feed down J/ψ

Matches data (with therm. b-quarks)



L. Massacrier (for the ALICE Collaboration), Hard Probes 2012

Conclusions

pp collisions

Inclusive spectra and cross section at $\sqrt{s}$ = 2.76 and 7 TeV down to $p_t = 0$
→ good agreement with NRQCD calculations

No significant polarization in the forward region ($\sqrt{s}$ = 7 TeV)

Results on non-prompt J/ψ and estimate of $b\bar{b}$ cross section ($|y| < 0.9$)

Linear increase of inclusive J/ψ yield ($|y| < 0.9$ and $2.5 < y < 4$) with $dN_{ch}/d\eta|_{y=0}$

Pb-Pb collisions

Nuclear suppression factor R_{AA} for $\sqrt{s_{NN}}$ = 2.76 TeV at forward and mid-rapidity
No centrality dependence for $N_{part} > 100$ (forward)
Possibly an increase towards central collisions at mid-rapidity (?)

Less suppression observed at low p_t ($2.5 < y < 4$)

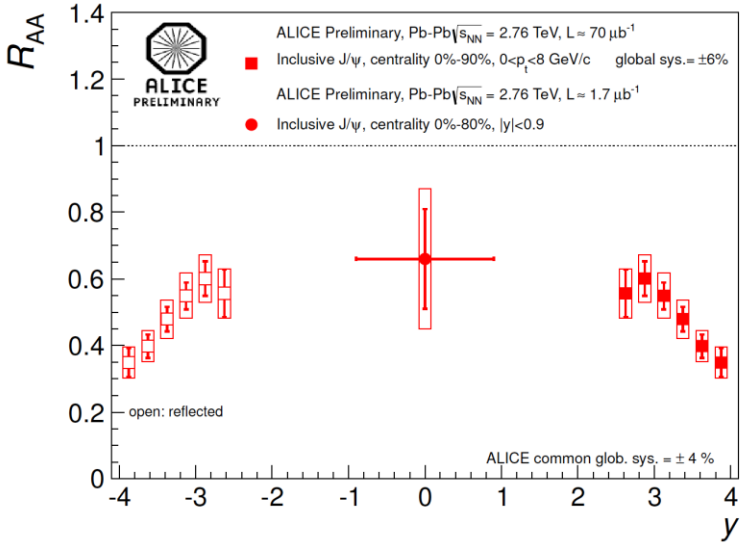
Less suppression seen than at RHIC

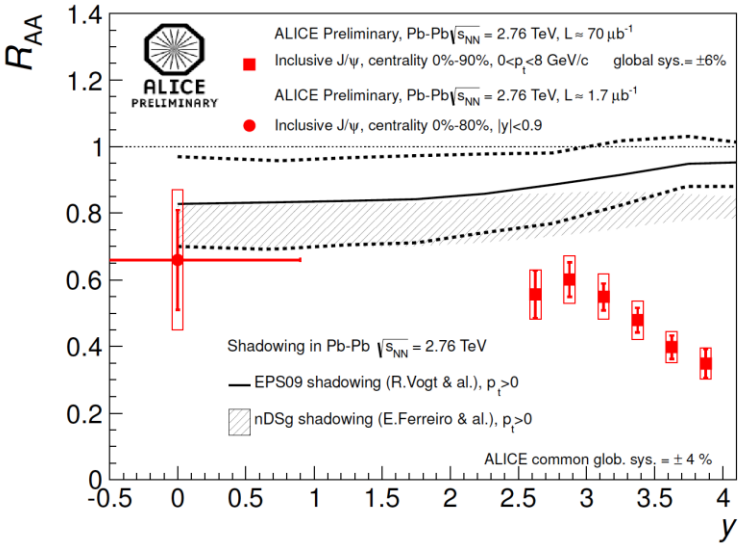
Indication for non-zero v_2 of J/ψ in the p_t-range 2 – 4 GeV/c, forward rapidity

Backup

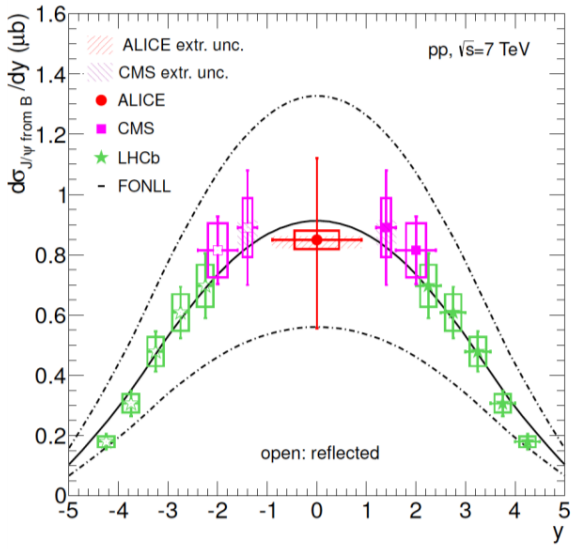
Pb-Pb Collisions

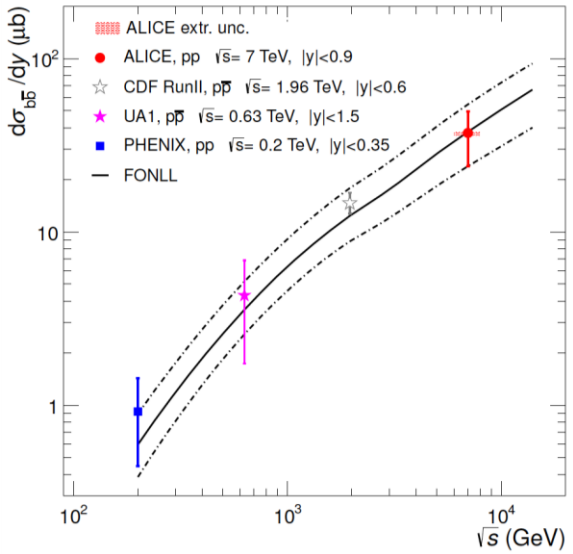
J/ψ R_{AA} vs Rapidity

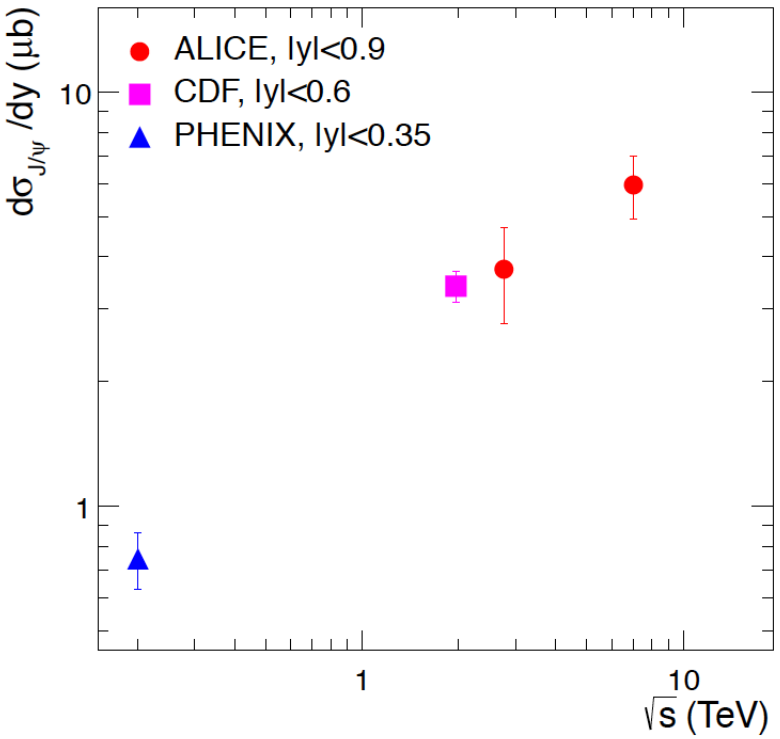


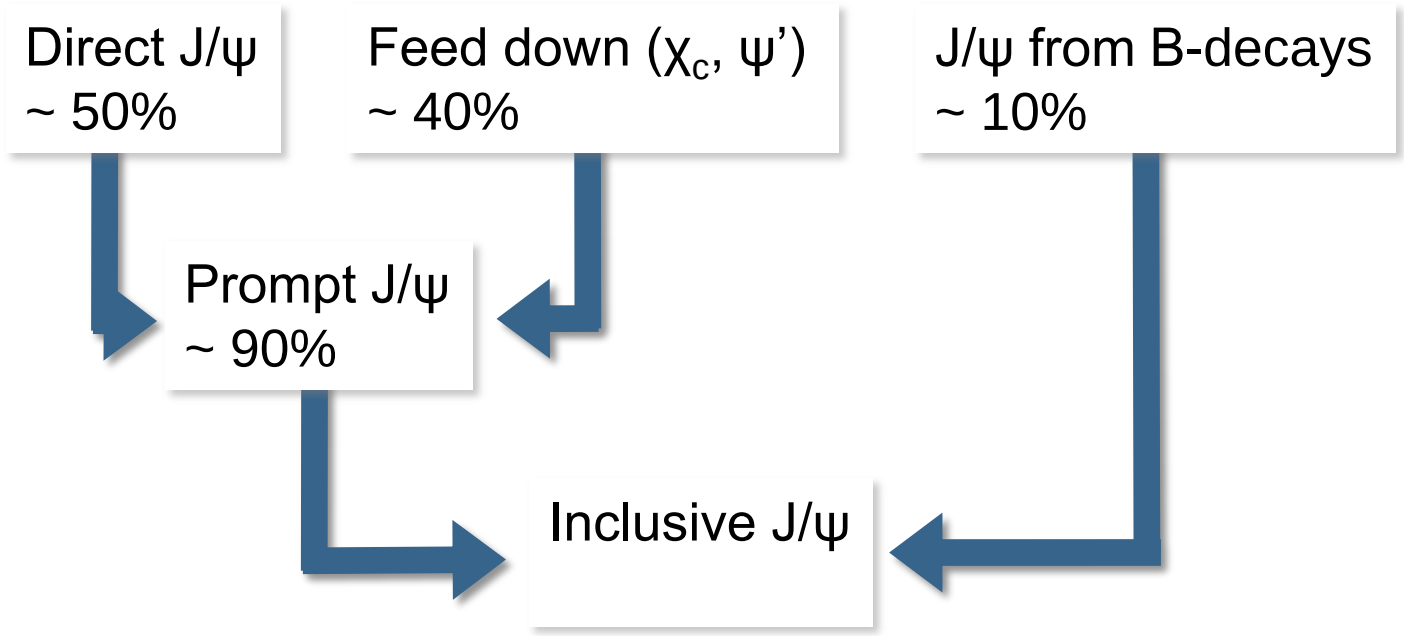


pp Collisions
J/ψ From B-Decays






ALICE, |y|<0.9
CDF, |y|<0.6
PHENIX, |y|<0.35
dσ_J/ψ /dy (μb)
10
1
1
10
√s (TeV)


Direct J/ψ
~ 50%
Feed down (χc, ψ')
~ 40%
J/ψ from B-decays
~ 10%
Prompt J/ψ
~ 90%
Inclusive J/ψ