Charmonium production @ ALICE

Christophe Suire
IPN Orsay
Université Paris XI, CNRS

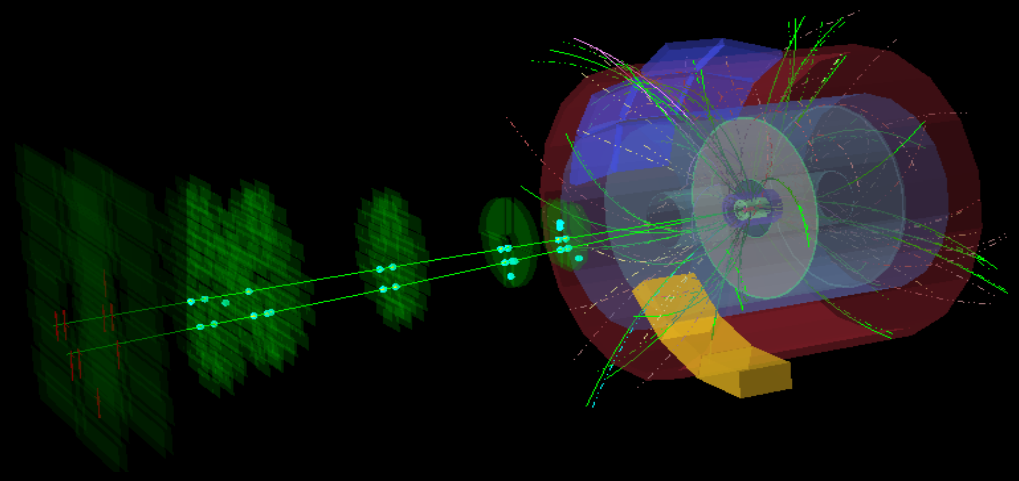
for the ALICE collaboration

Christophe.Suire@ipno.in2p3.fr

Outline

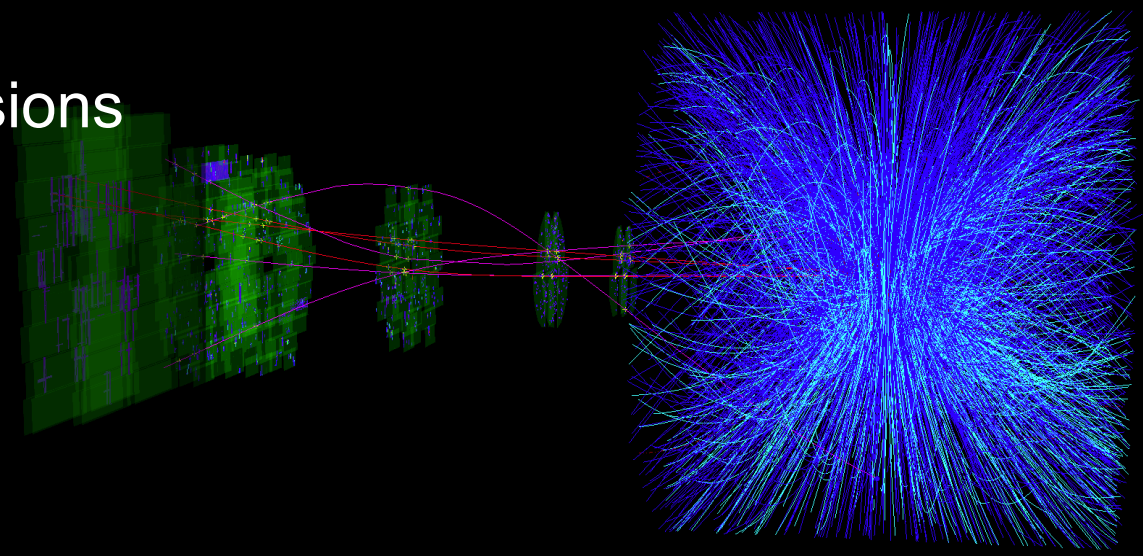
Physics motivations

ALICE detector



Charmonia in pp collisions
→ “Highlights”
→ Reference for R_{AA}

Charmonia in Pb-Pb collisions
→ J/Ψ R_{AA}
→ J/Ψ v_2



Conclusions

Quarkonia suppression

J/ψ suppression in heavy-ion collisions is a signature of deconfinement.

T. Matsui and H. Satz, J/ψ Suppression by Quark-Gluon Plasma Formation, Phys. Lett. B178, 416(1986)

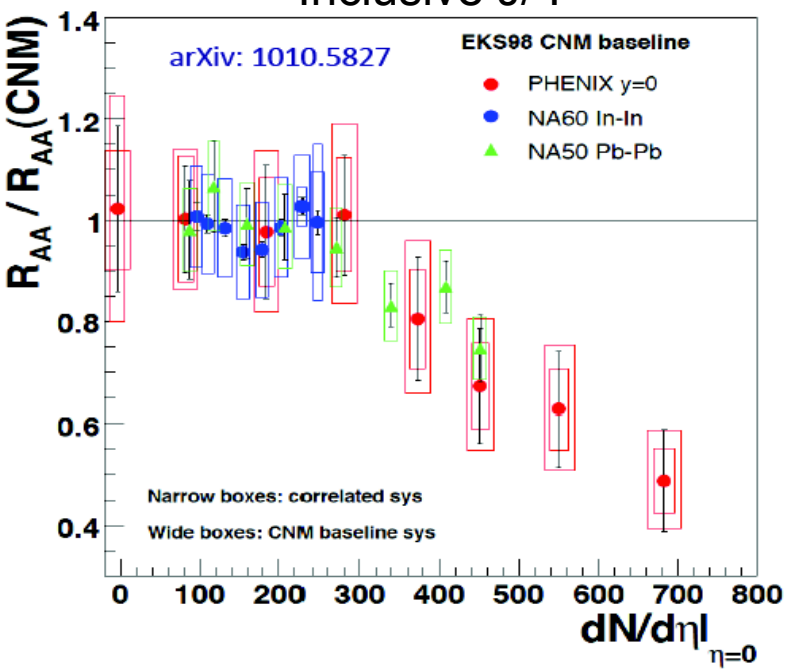
SPS and RHIC measurements of J/Ψ suppression

- Suppression above cold nuclear matter effects is not so large neither at SPS nor at RHIC.
  + RHIC measure higher suppression at forward rapidity than at mid rapidity.

- suppression of ψ', χ_C (~ 40% of the observed J/Ψ) only
→ $R_{AA}/R_{AA}(CNM) \sim 0.6$

- Cold nuclear matter effects are important
  → nuclear absorption
  → gluon PDF modification (anti-) shadowing

Inclusive J/Ψ

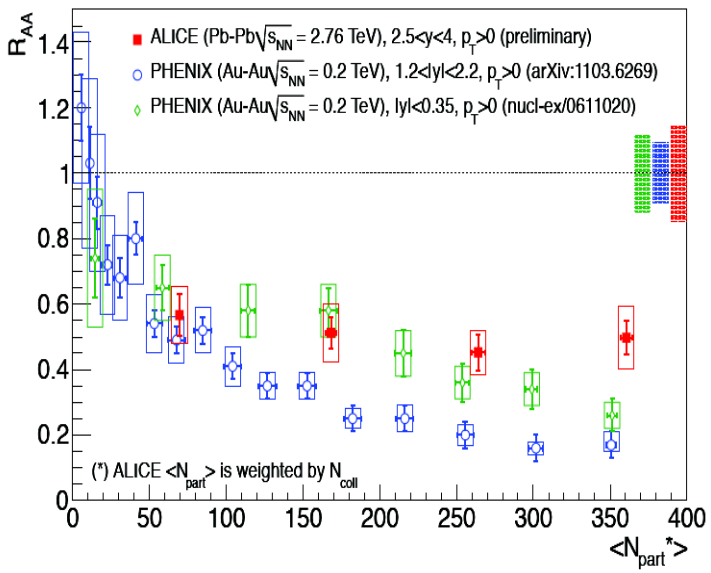


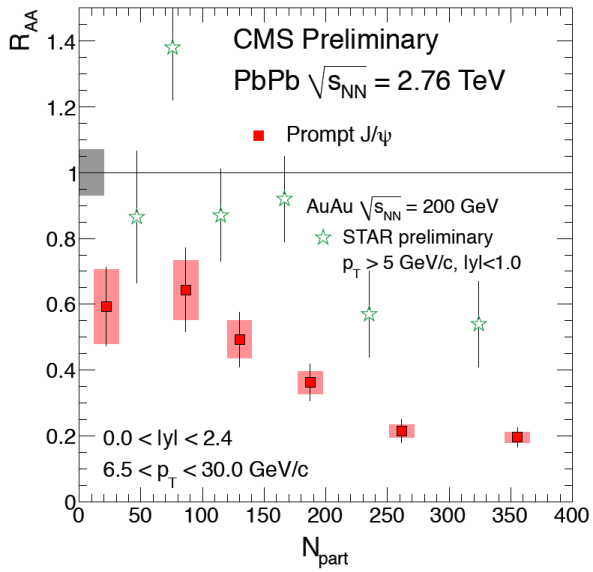
Quarkonia suppression or...

$$\frac{\Upsilon(2S+3S)/\Upsilon(1S)|_{\text{Pb-Pb}}}{\Upsilon(2S+3S)/\Upsilon(1S)|_{pp}} = 0.31^{+0.19}_{-0.15}(\text{stat}) \pm 0.03(\text{syst}),$$

CMS collaboration Phys. Rev. Lett. 107 (2011) 052302

CMS results are pointing to "Indications of Suppression of Excited Y States in Pb-Pb Collisions"
→ **J/Ψ dissociation temperature reached ?**

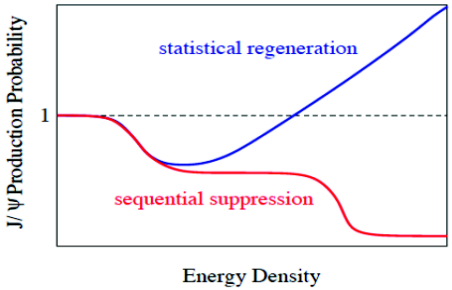




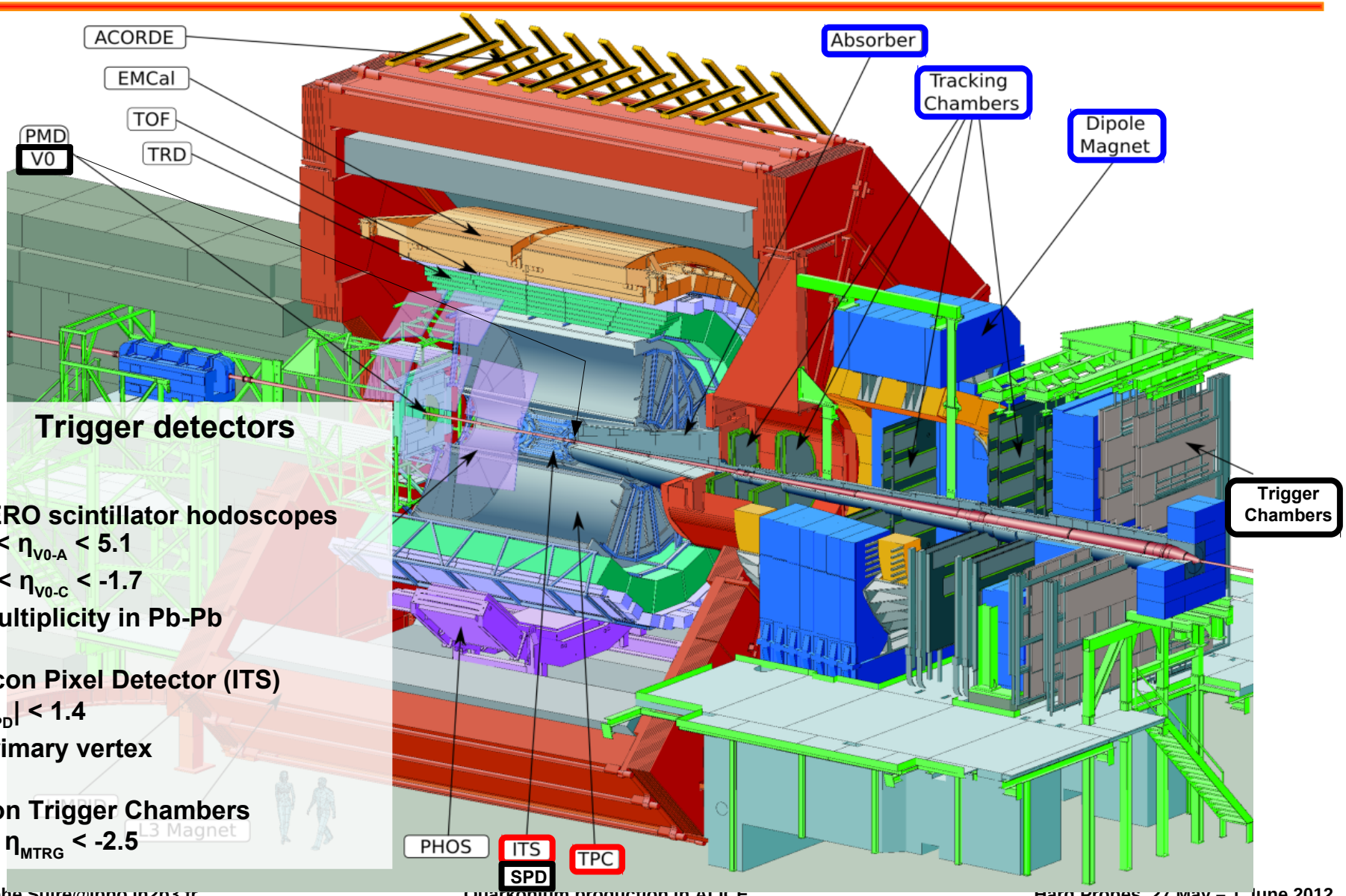
One year ago, QM'11:
- ALICE shows that forward y low-p_t J/Ψ are less suppressed than at RHIC.
- CMS shows that mid y high-p_t J/Ψ are more suppressed than at RHIC

In most central A-A collisions	SPS 20 GeV	RHIC 200 Gev	LHC 2.76 TeV
N_{ccbar}/event	~0.2	~10	~60

Large number of charm quarks created in central Pb-Pb collisions at LHC:
→ re-generation at work ?
→ can we see a clear signature ?



The ALICE detector



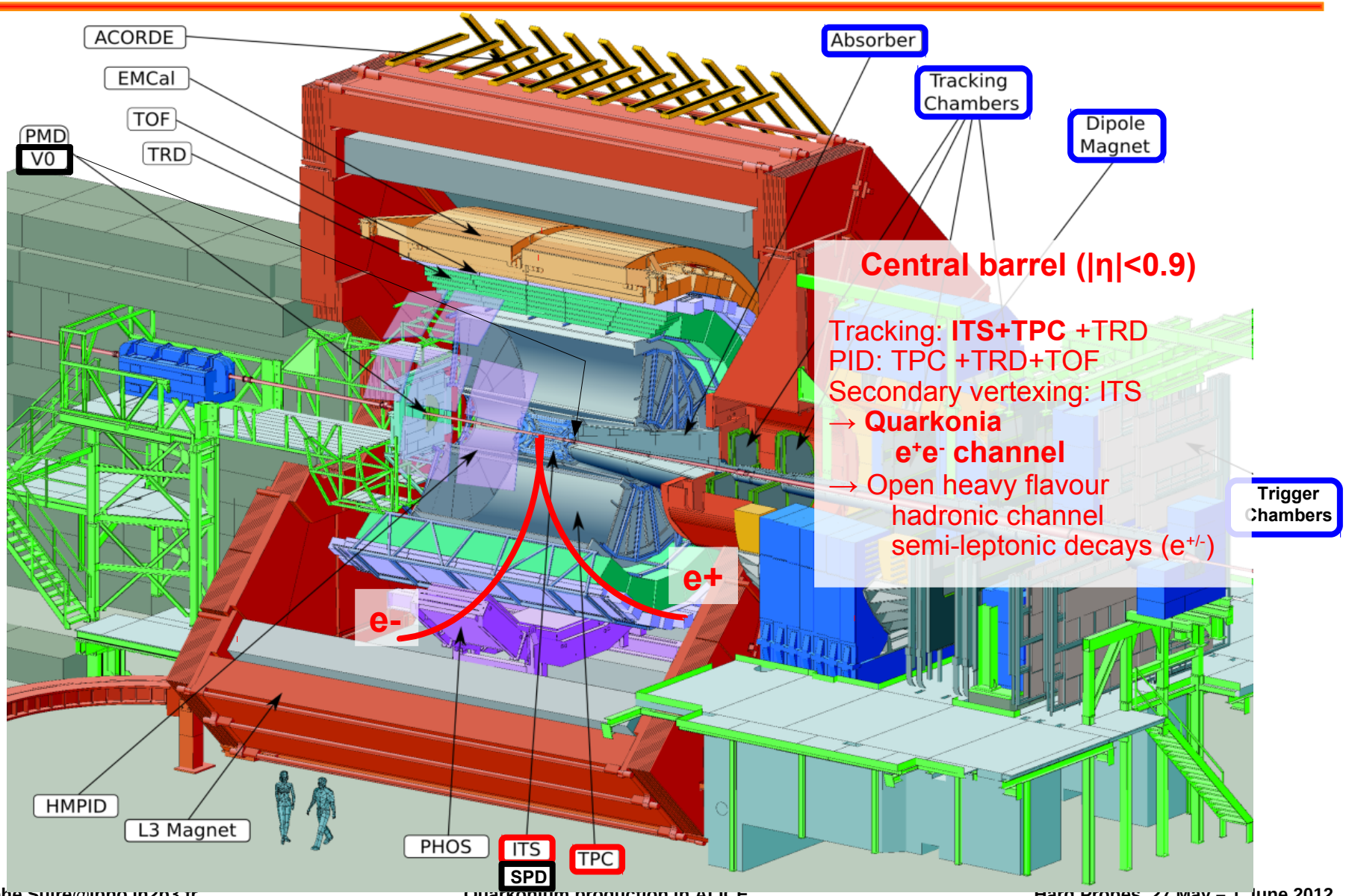
Trigger detectors

VZERO scintillator hodoscopes
$2.8 < \eta_{V0\text{-}A} < 5.1$
$-3.7 < \eta_{V0\text{-}C} < -1.7$
+ multiplicity in Pb-Pb

Silicon Pixel Detector (ITS)
$|\eta_{SPD}| < 1.4$
+ primary vertex

Muon Trigger Chambers
$-4 < \eta_{MTRG} < -2.5$

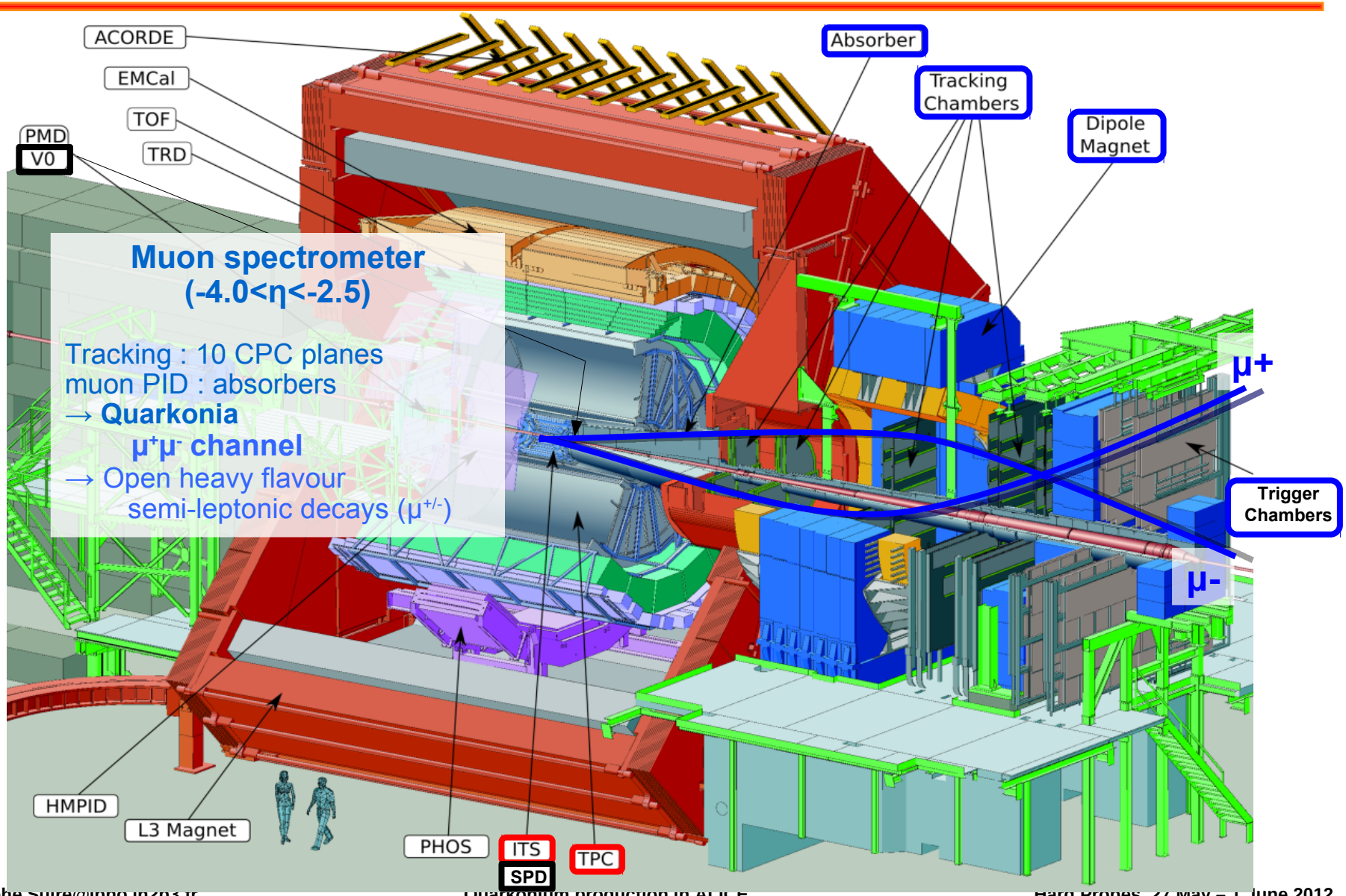
The ALICE detector



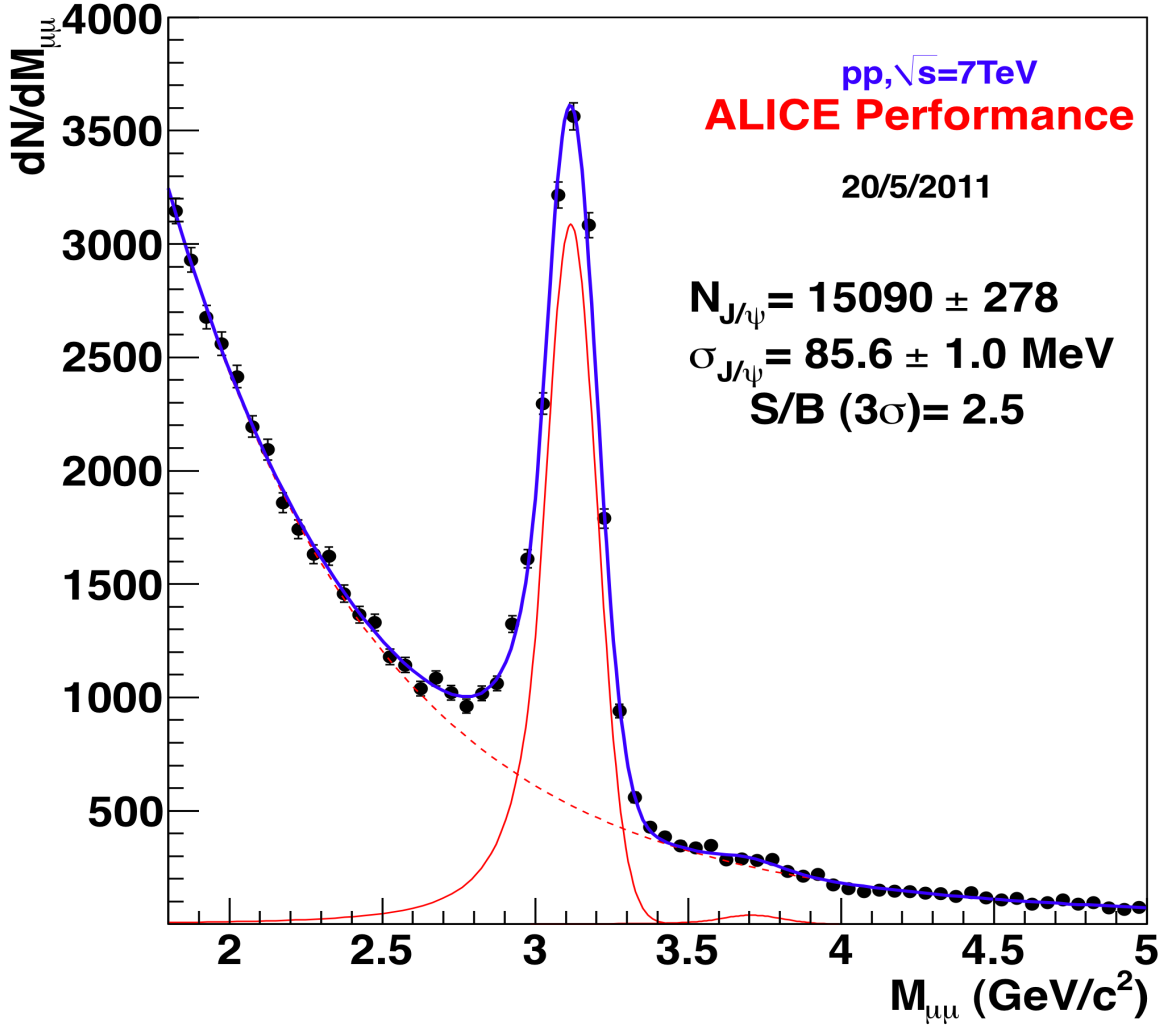
Central barrel (|η|<0.9)

Tracking: **ITS+TPC** +TRD
PID: TPC +TRD+TOF
Secondary vertexing: ITS
→ **Quarkonia**
e^+e^- channel
→ Open heavy flavour
hadronic channel
semi-leptonic decays ($e^{+/-}$)

The ALICE detector



Quarkonia in ALICE



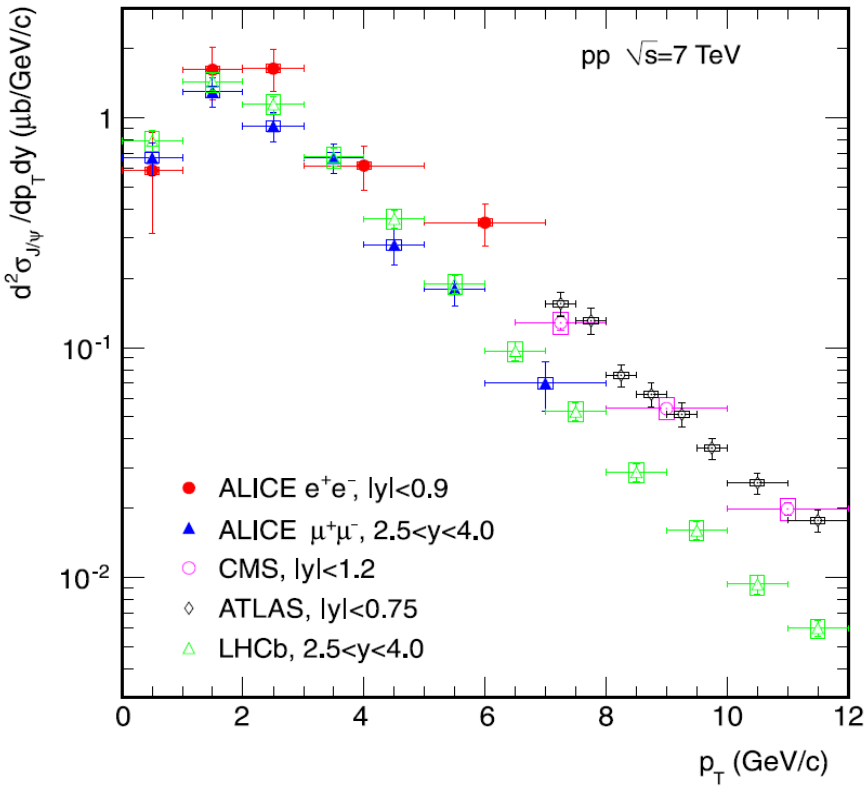
In pp collisions, ALICE has measured charmonia

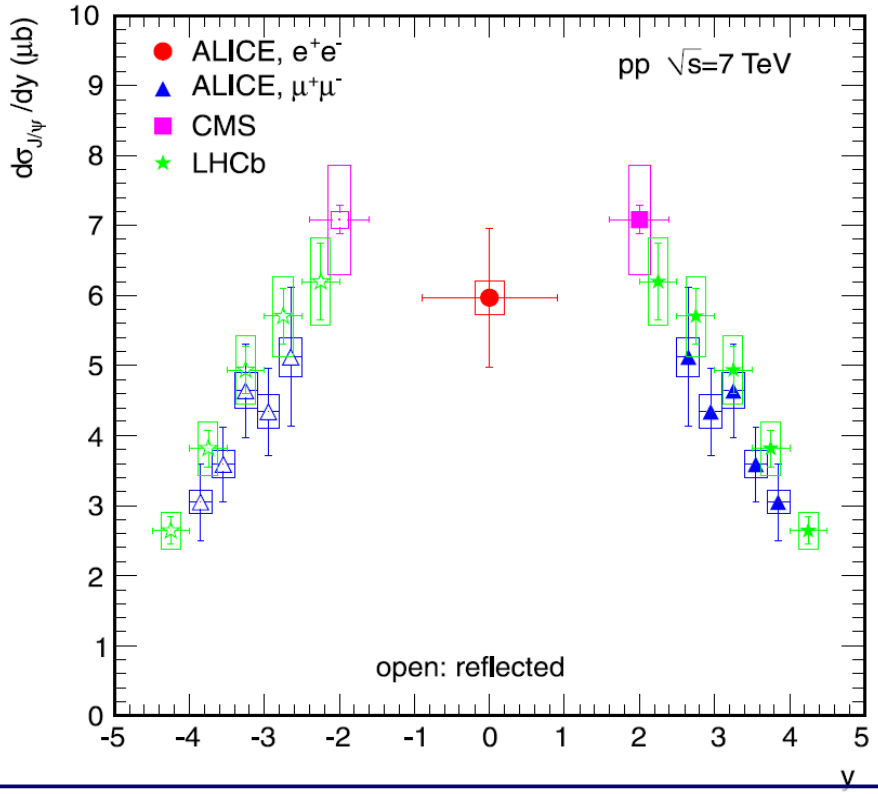
→ in $\mu^+\mu^-$, e^+e^- channels
→ at y [4;2.5] and [-0.9;0.9]
→ down to $p_t = 0$
→ differentially in p_t, y

→ at $\sqrt{s_{NN}}$ = 2.76 and 7 TeV
→ as a function of $dN_{ch}/d\eta$
→ polarization
→ from B decay

J/Ψ in ALICE/LHC: pp collisions at √s = 7 TeV

Rapidity and transverse momentum dependence of inclusive J/Ψ production in pp collisions at √s = 7 TeV Physics Letters B 704 (2011), pp. 442-455.





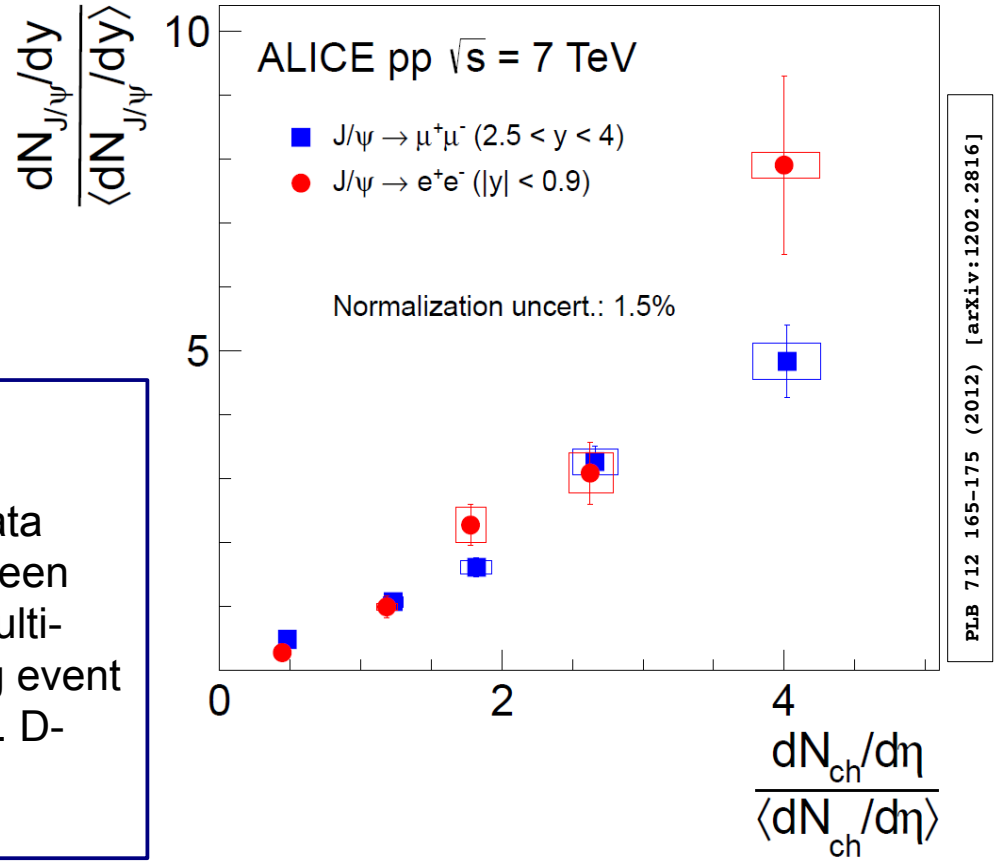
V. Khachatryan, et al., CMS Collaboration, Eur. Phys. J. C 71 (2011) 1575.
R. Aaij, et al., LHCb Collaboration, Eur. Phys. J. C 71 (2011) 1645.
G. Aad, et al., ATLAS Collaboration, Nucl. Phys. B 850 (2011) 387.

Bars = statistical and systematic errors, excluding luminosity and polarisation
Box = systematic uncertainties on luminosity
→ Good agreement between ALICE and LHCb for 2.5 < y < 4
→ extension of p_t range measured by ATLAS and CMS down to 0 GeV/c

J/Ψ production vs multiplicity in pp collisions at √s = 7 TeV

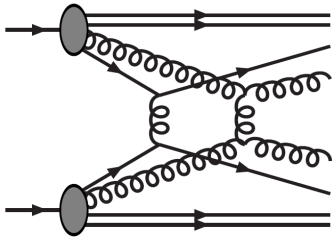
Highest charged particle multiplicity ($dN_{ch}/d\eta$ ~30) in this analysis is comparable with Cu-Cu collisions (50-55%) @ 200 GeV.

$< dN_{ch}/d\eta > = 6.0$



Relative J/ψ yield increases linearly with the relative multiplicity.
→ model predictions do not reproduce the data
→ should help understand the interplay between hard and soft interactions in the context of multi-partonic interactions (MPI), and/or underlying event
→ study ongoing with other observables, e.g. D-mesons

arXiv:0402078

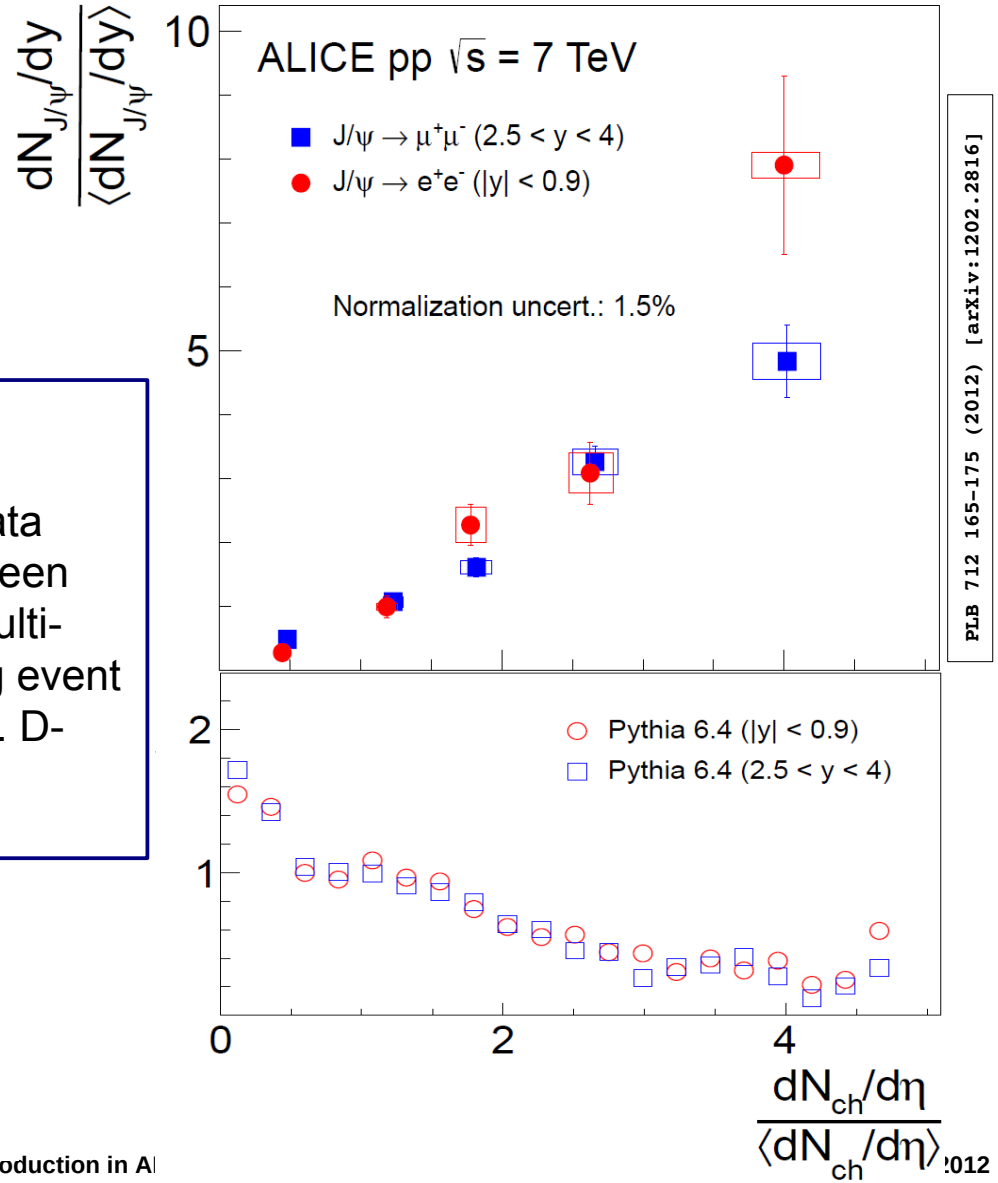


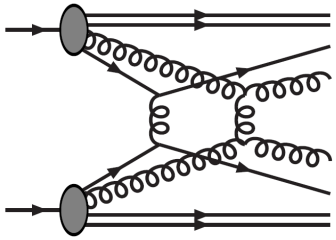
J/Ψ production vs multiplicity in pp collisions at √s = 7 TeV

Highest charged particle multiplicity ($dN_{ch}/d\eta$ ~30) in this analysis is comparable with Cu-Cu collisions (50-55%) @ 200 GeV.

$< dN_{ch}/d\eta > = 6.0$

Relative J/ψ yield increases linearly with the relative multiplicity.
→ model predictions do not reproduce the data
→ should help understand the interplay between hard and soft interactions in the context of multi-partonic interactions (MPI), and/or underlying event
→ study ongoing with other observables, e.g. D-mesons





arXiv:0402078

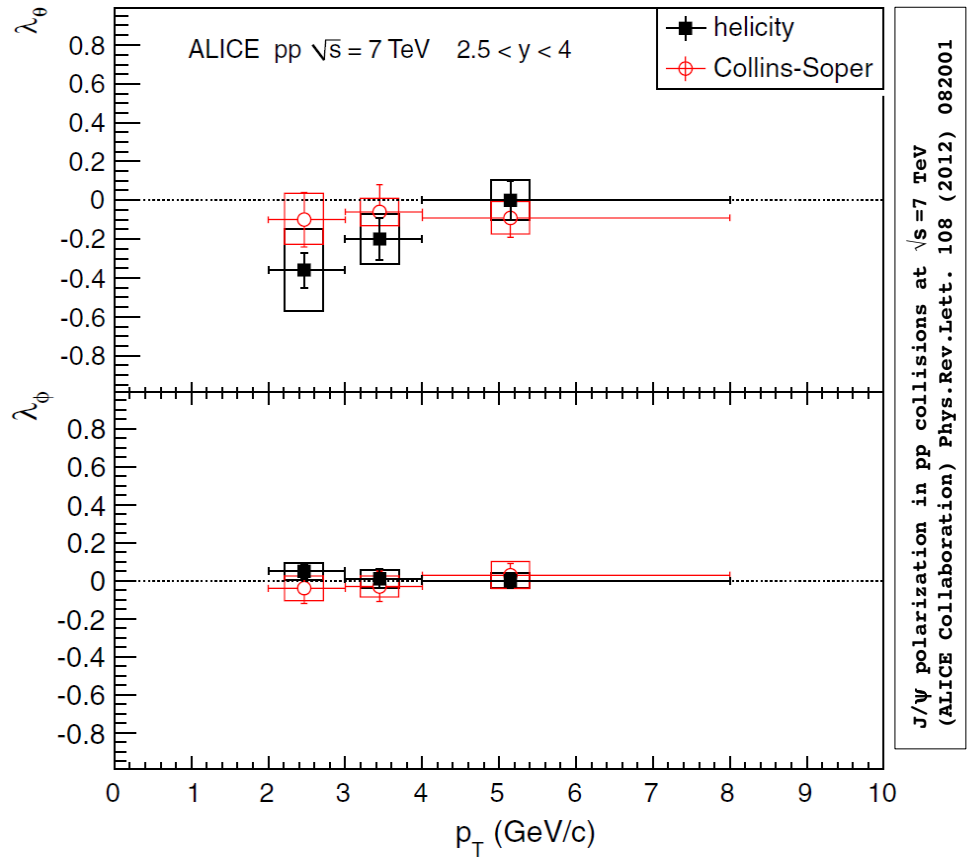
J/Ψ polarization in pp collisions at $\sqrt{s_{NN}}$ = 7 TeV

Polarization measurements provide a crucial test for theoretical calculations of quarkonia production.

First measurement of J/Ψ polarization at LHC:
→ polarization parameters λ_θ and λ_φ are consistent with zero

(Inclusive J/Ψ (ψ',χ_C and J/Ψ ← B) with $2.5 < y_{J/\Psi} < 4$.)

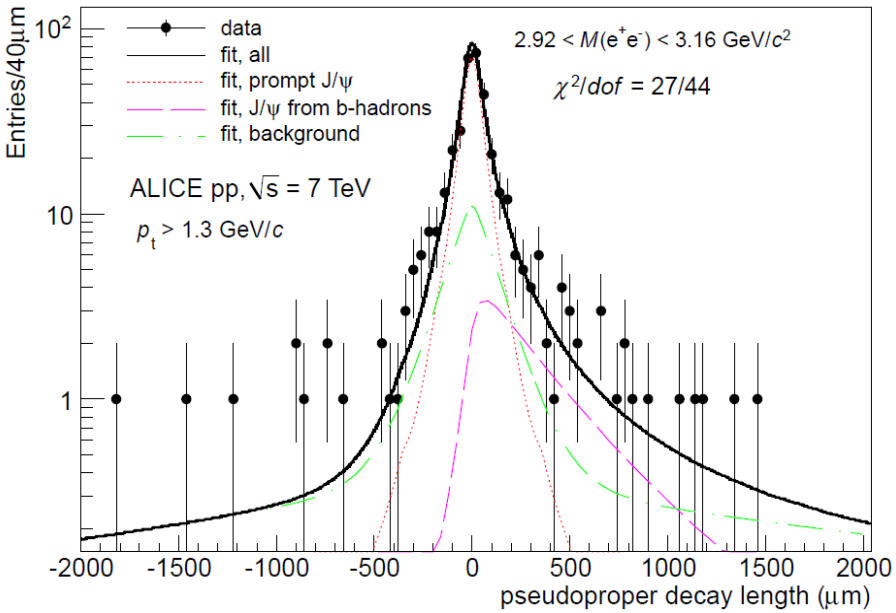
C.Geuna, Parallel 3A, may 29th

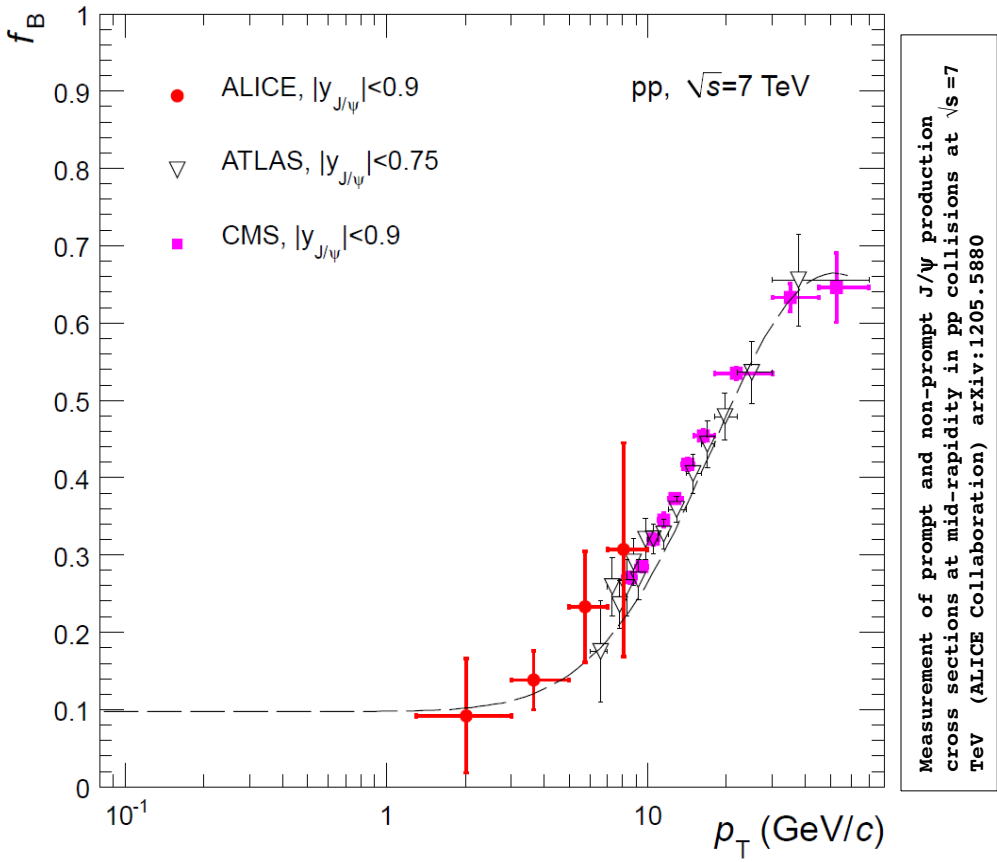


Next:
→ increase p_t range for a more stringent test of theoretical models (e.g arxiv:1201.3862) and compare to upcoming measurements at LHC
→ ongoing analysis of J/ψ polarization in Pb-Pb collisions

J/Ψ from B-hadrons decay

Impact parameter resolution: $\sigma_{r\varphi}$ < 75 μm for p_t>1 GeV/c, at mid-rapidity
→ contributions from B decays estimated from the pseudo-proper decay length





J/ψ from B decays at mid rapidity and low p_t

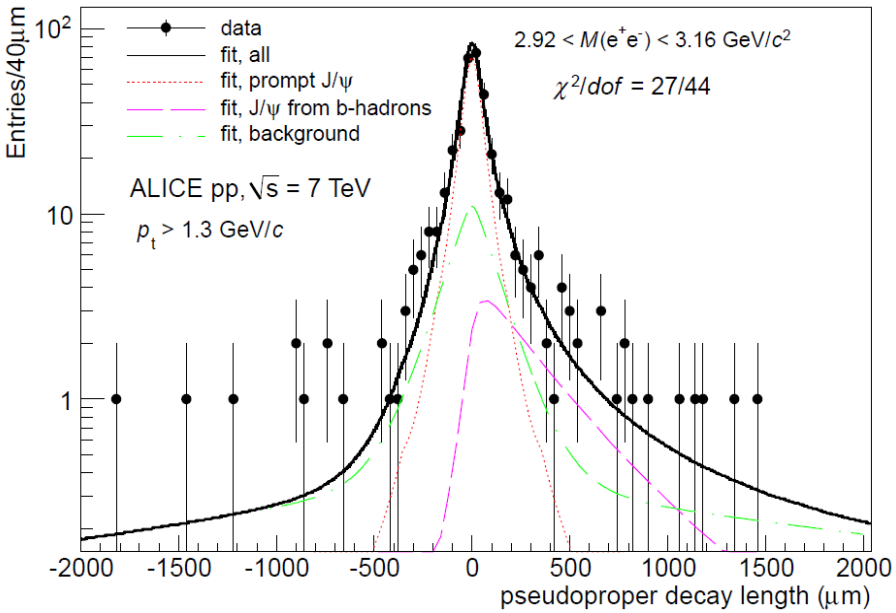
$\sigma_{J/\psi}$ (prompt, |y|<0.9, p_t>1.3 GeV/c) = 7.2 ± 0.7 (stat) ± 1.0 (syst) $^{+1.3\ (\lambda HE=1)}_{-1.2\ (\lambda HE=-1)}$ μb

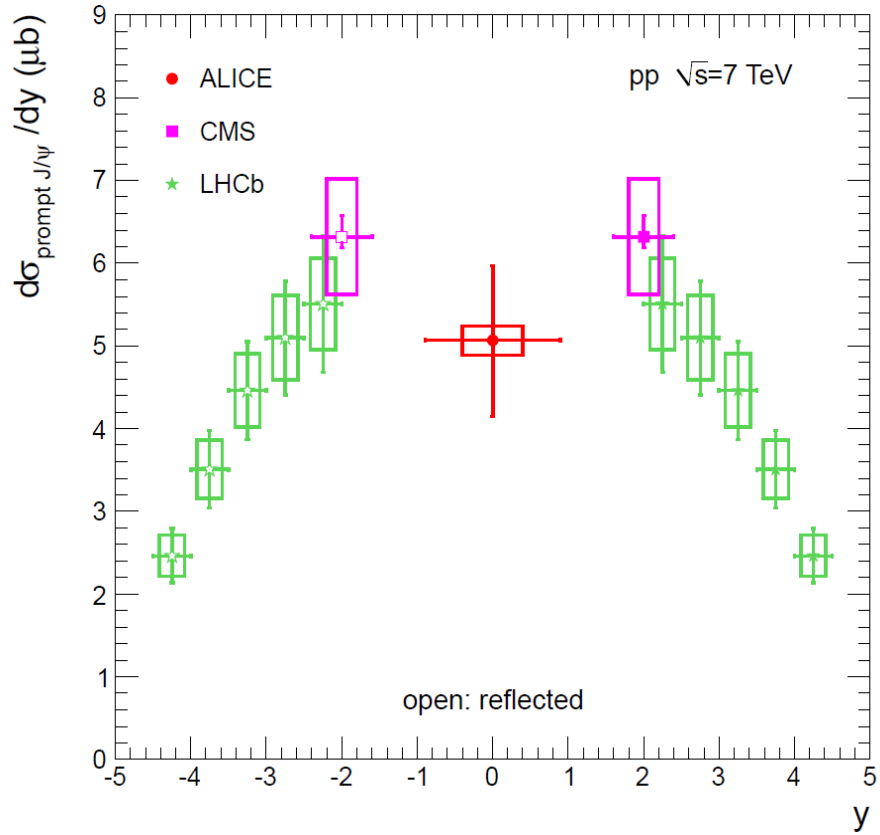
→ improvements to come: higher stat. and dedicated trigger.

J/Ψ from B-hadrons decay

Impact parameter resolution: $\sigma_{r\varphi}$ < 75 μm for p_t>1 GeV/c, at mid-rapidity

→ Contributions from B decays estimated from the pseudo-proper decay length



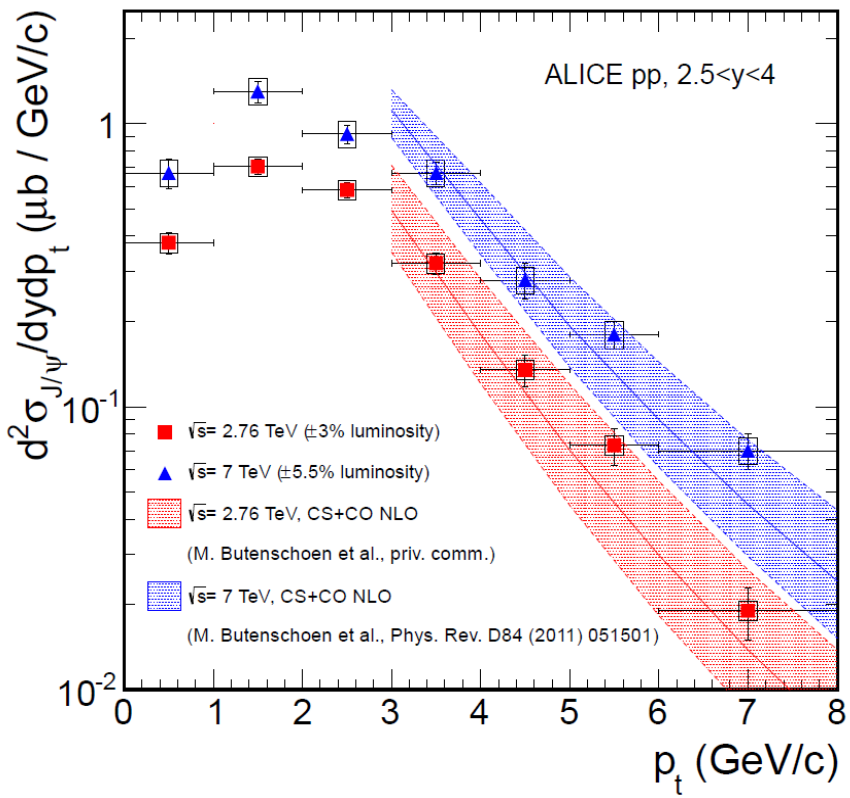


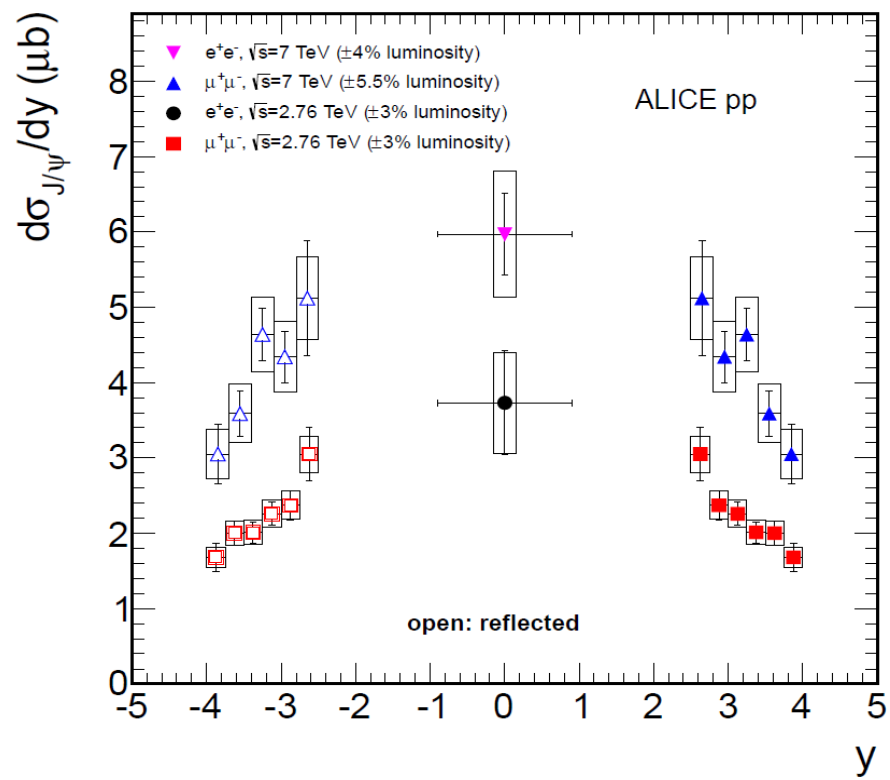
J/ψ from B decays at mid rapidity and low p_t

$\sigma_{J/\psi}$ (prompt, |y|<0.9, p_t>1.3 GeV/c) = 7.2 ± 0.7 (stat) ± 1.0 (syst) $^{+1.3\ (\lambda HE=1)}_{-1.2\ (\lambda HE=-1)}$ μb

→ improvements to come: higher stat. and dedicated trigger.

J/Ψ in ALICE: pp collisions at $\sqrt{s}$ = 2.76 TeV





Inclusive J/Ψ production in pp collisions at sqrt(s) = 2.76 TeV. ALICE Collaboration, ArXiv:1203.3641

NRQCD calculation describes the measured p_t dependence at both 7 and 2.76 TeV

pp @ 2.76 TeV reference for the nuclear modification factor R_{AA} in Pb-Pb collisions

$$R^i_{AA} = \frac{Y^i_{J/\psi}(\Delta p_t, \Delta y)}{\langle T^i_{AA}\rangle \times \sigma^{pp}_{J/\psi}(\Delta p_t, \Delta y)}$$

the pp reference is the main source of systematic uncertainty in the R_{AA} computation:

→ J/Ψ (2.5<y<4), total uncertainty of 9%

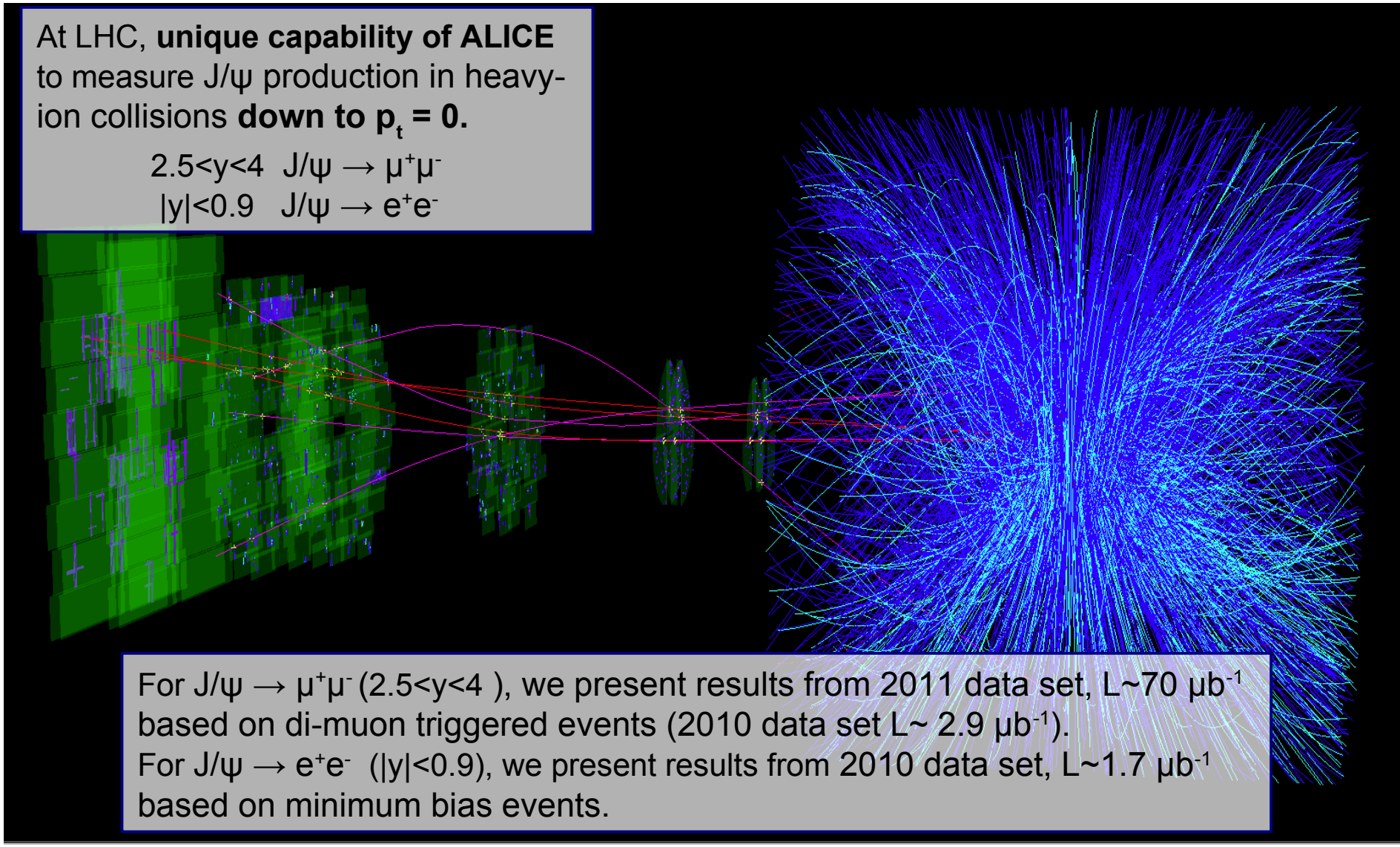
→ J/Ψ (|y|<0.9), total uncertainty of 26%

Pb-Pb collisions

At LHC, **unique capability of ALICE** to measure J/ψ production in heavy-ion collisions **down to p_t = 0.**

$2.5<y<4$ $J/\psi \rightarrow \mu^+\mu^-$

$|y|<0.9$ $J/\psi \rightarrow e^+e^-$



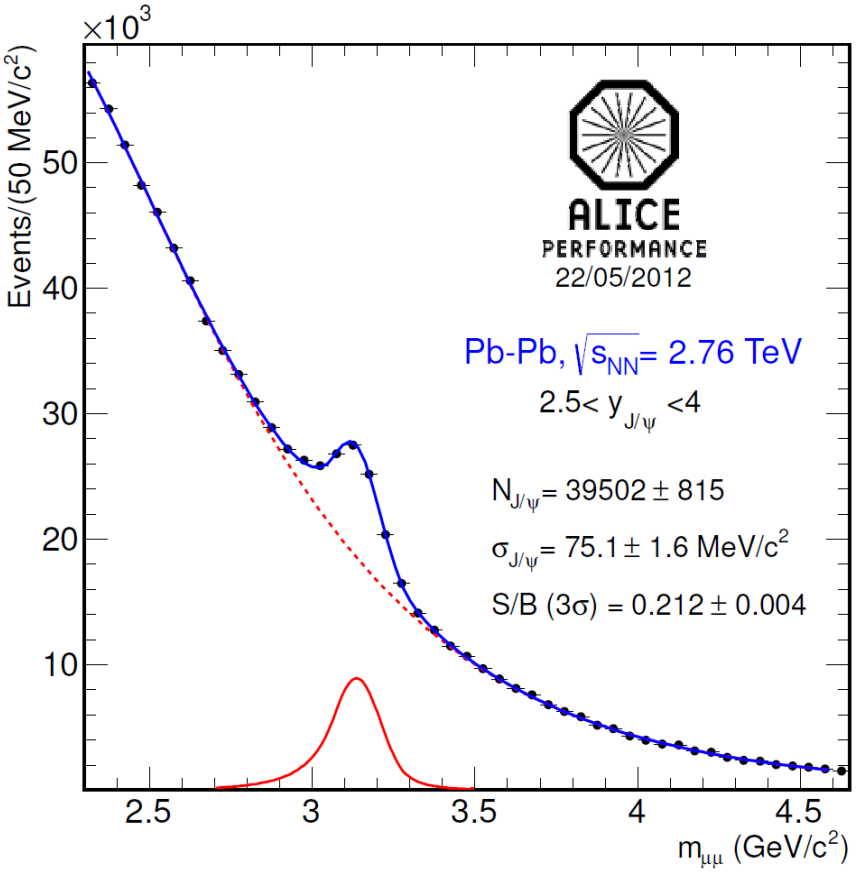
For $J/\psi \rightarrow \mu^+\mu^-$ ($2.5<y<4$), we present results from 2011 data set, L~70 μb^{-1} based on di-muon triggered events (2010 data set L~ 2.9 μb^{-1}).

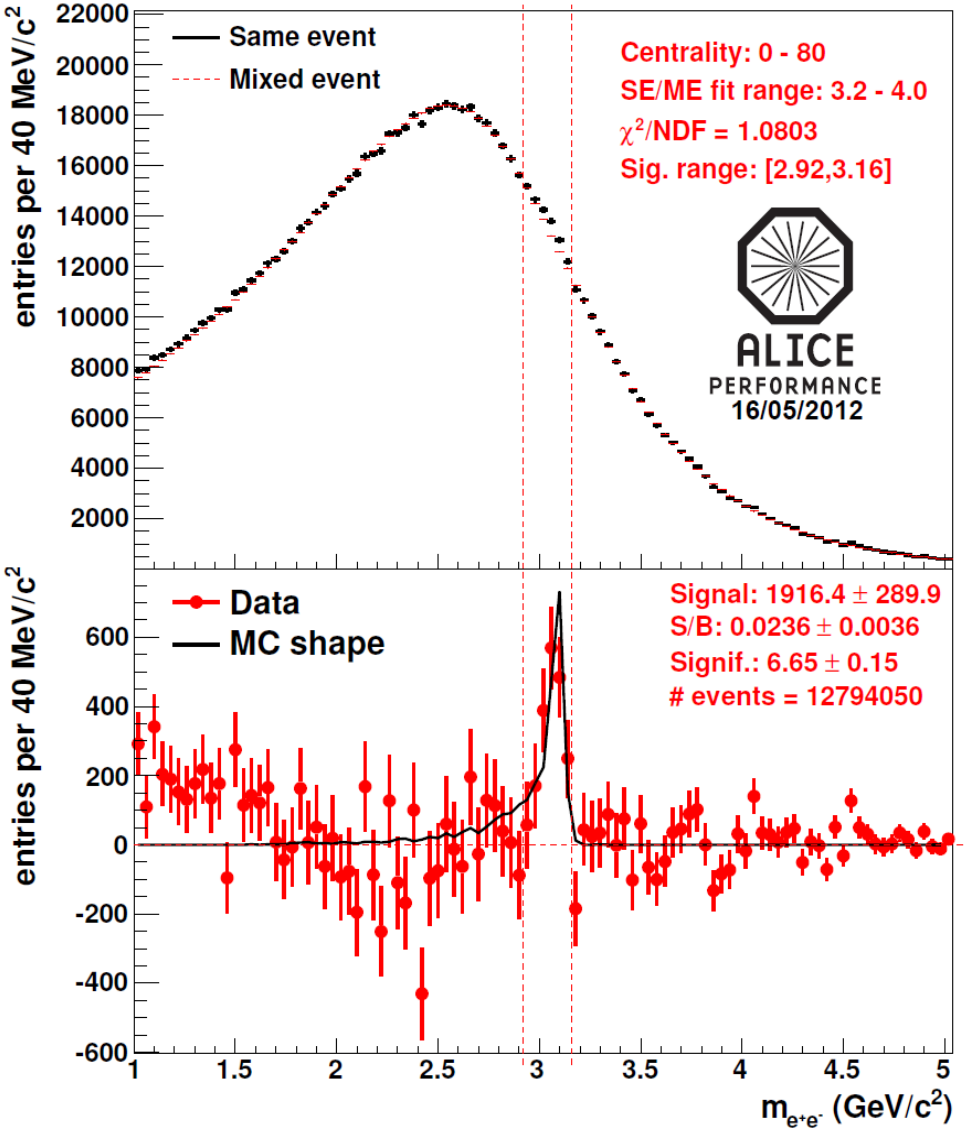
For $J/\psi \rightarrow e^+e^-$ ($|y|<0.9$), we present results from 2010 data set, L~1.7 μb^{-1} based on minimum bias events.

Pb-Pb collisions: J/Ψ signals

$J/\psi \rightarrow e^+e^-$, 0-80%, $|y|<0.9$, $p_t > 0$ ►

▼ $J/\psi \rightarrow \mu^+\mu^-$, 0-90%, $2.5<y<4$, $p_t > 0$

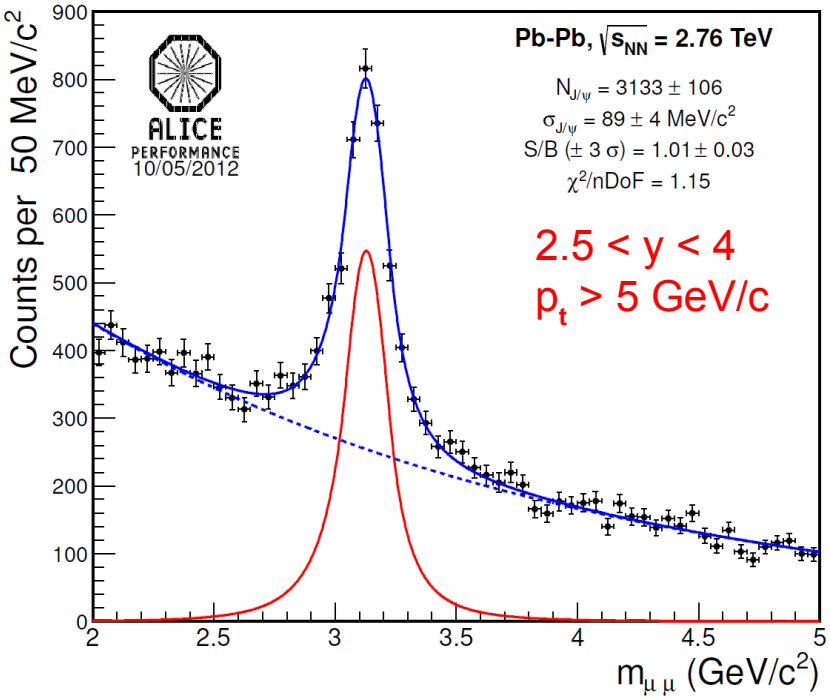


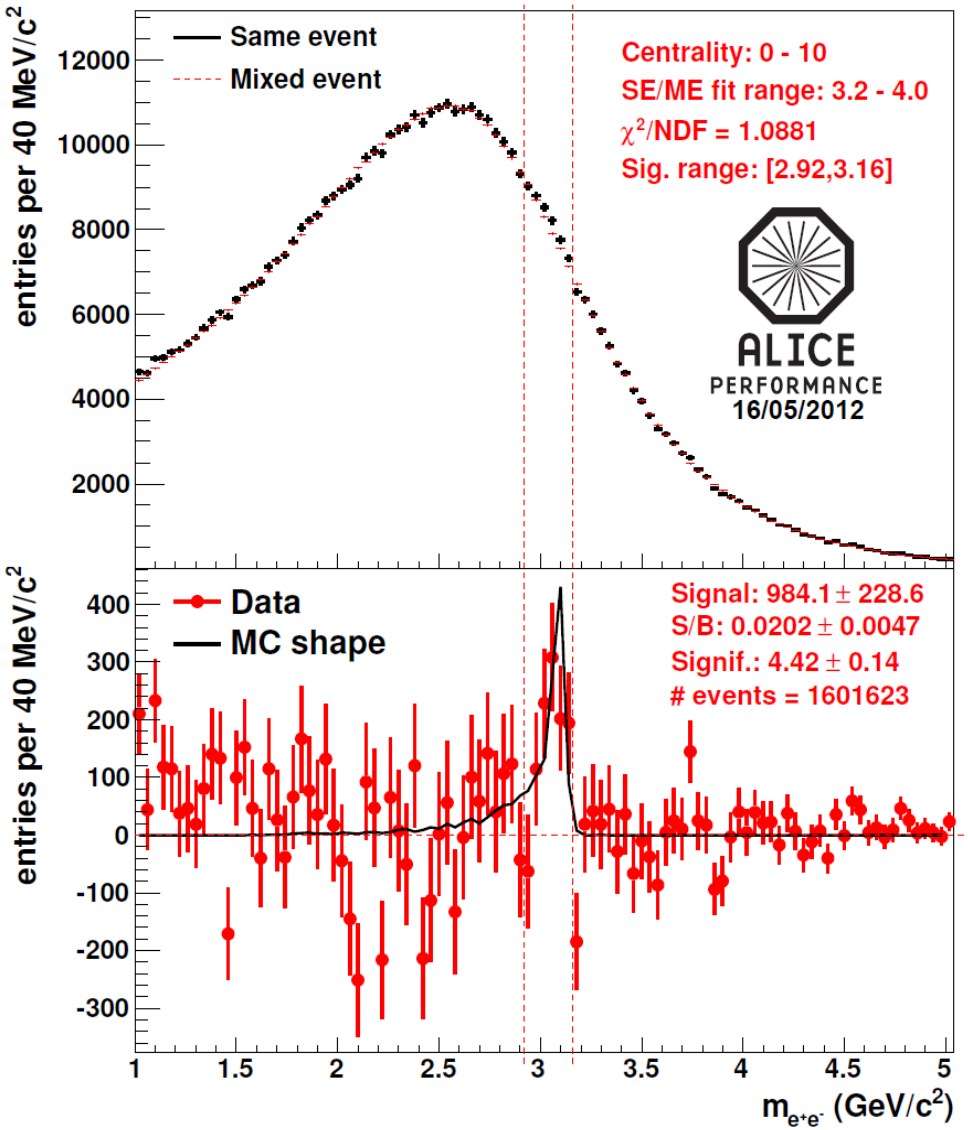


Pb-Pb collisions: J/Ψ signals

$J/\psi \rightarrow e^+e^-$, 0-10%, $|y|<0.9$, $p_t > 0$ ►

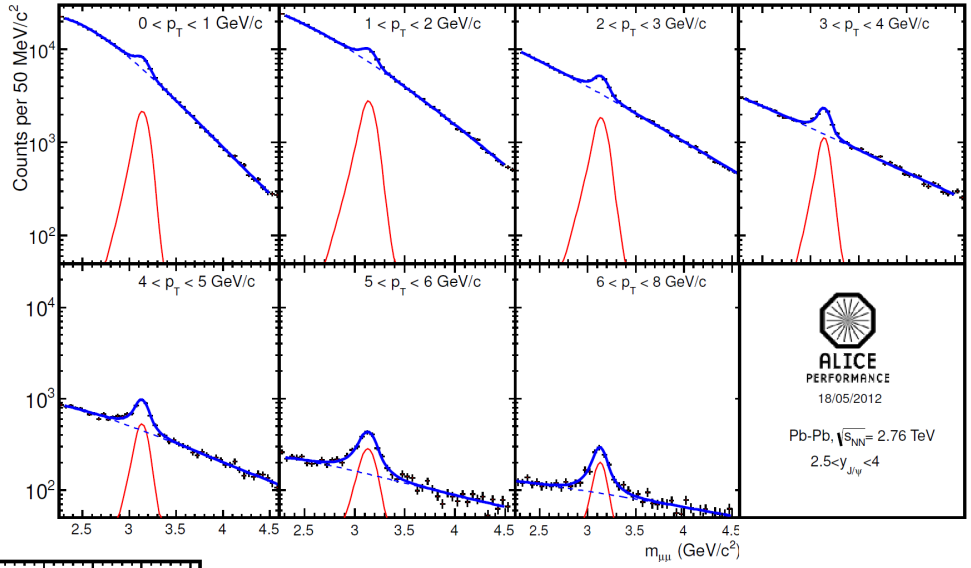
$J/\psi \rightarrow \mu^+\mu^-$, 0-90%, $2.5<y<4$, $p_t > 5$ GeV/c ▼

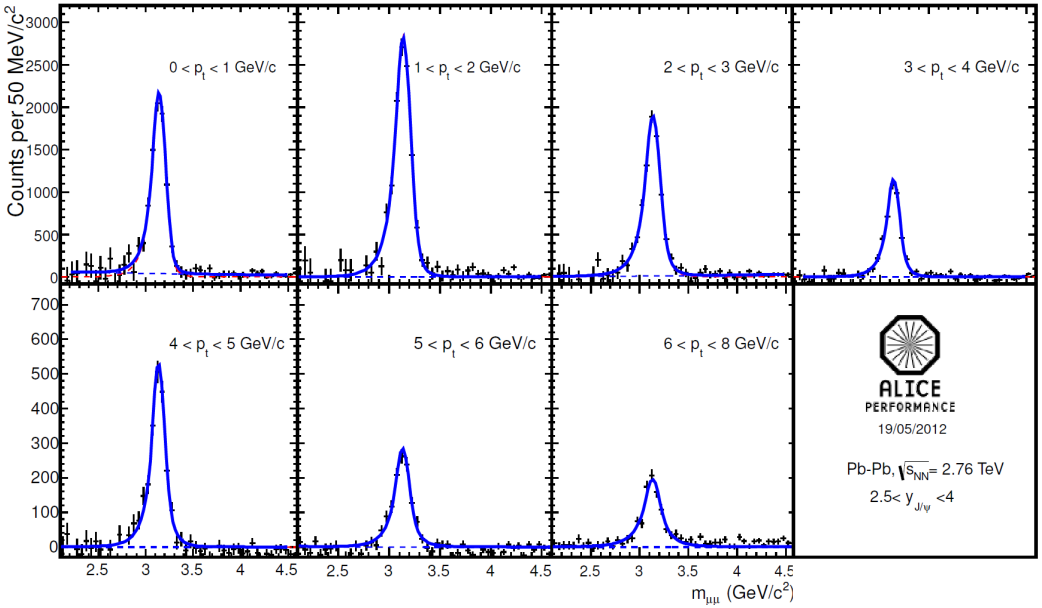




Pb-Pb collisions: J/Ψ signals

At forward rapidity, thanks to the large statistics collected in 2011:
- rapidity dependence
- transverse momentum dependence





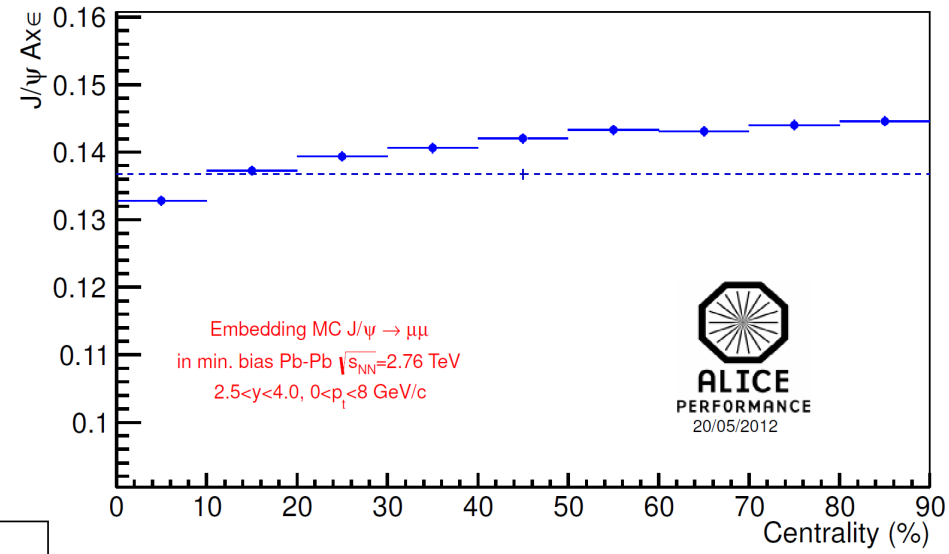
J/ψ signal in p_t bins:

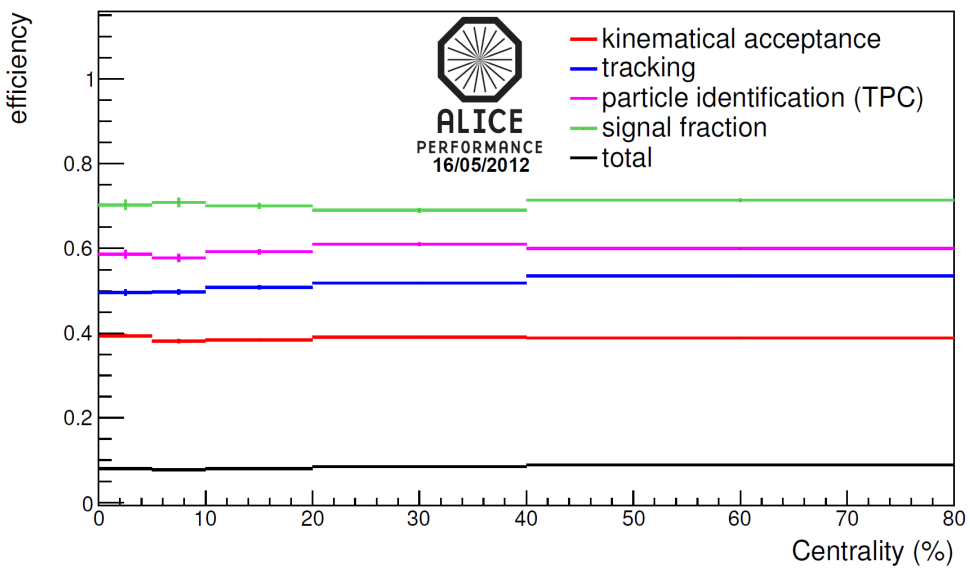
▲fit of the opposite sign dimuon invariant mass

◀fit of the opposite sign dimuon invariant mass after background subtraction (event mixing)

Pb-Pb collisions: J/Ψ Aε corrections

J/ψ Aε computed with MC simulations:
Pb-Pb real event enriched with MC $J/\psi \rightarrow \mu^+\mu^-$ (embedding) ▶
▼ HIJING enriched with $J/\psi \rightarrow e^+e^-$

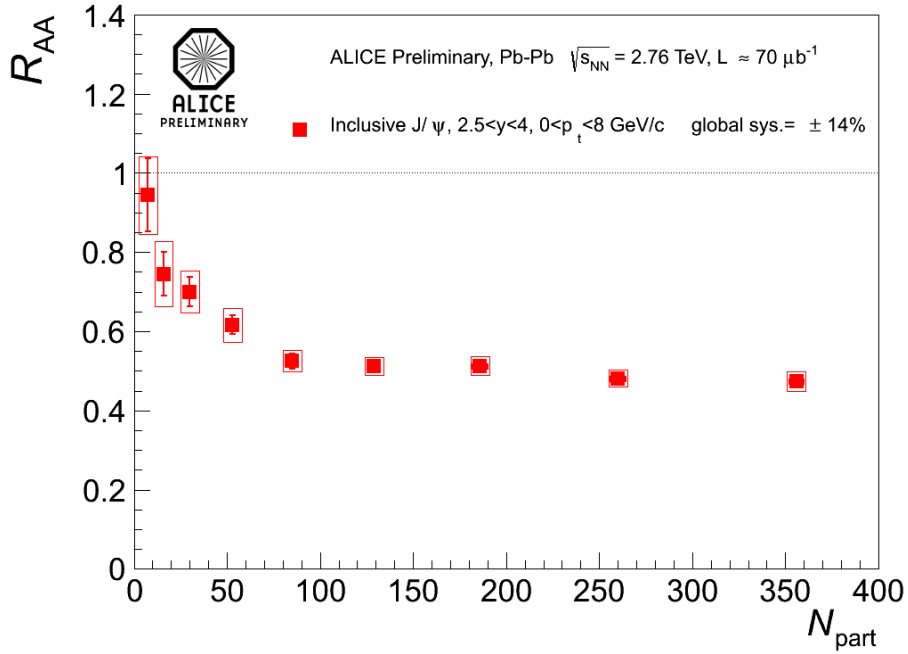


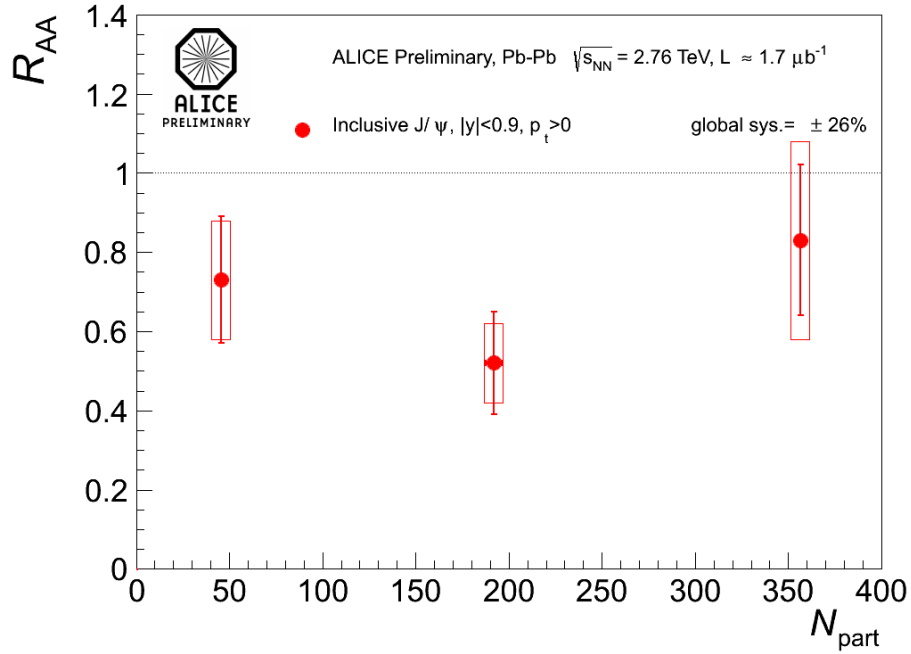


J/ψ Aε is weakly centrality dependent.
$J/\psi \rightarrow e^+e^-$, Aε 7.8% to 8.9%
$J/\psi \rightarrow \mu^+\mu^-$, Aε 13.3% to 14.5%

In most central Pb-Pb collisions, ALICE detector can handle the large particle multiplicity with small (<10%) loss of efficiency.

J/ψ R_{AA} vs centrality





Clear J/Ψ suppression at forward rapidity.

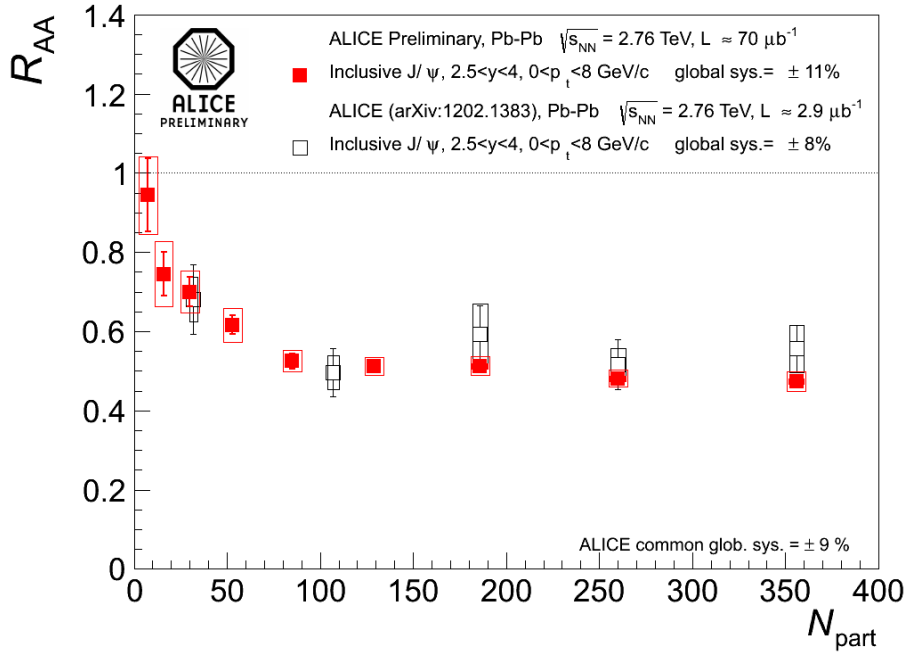
→ almost no centrality dependence above N_{part} ~ 100.

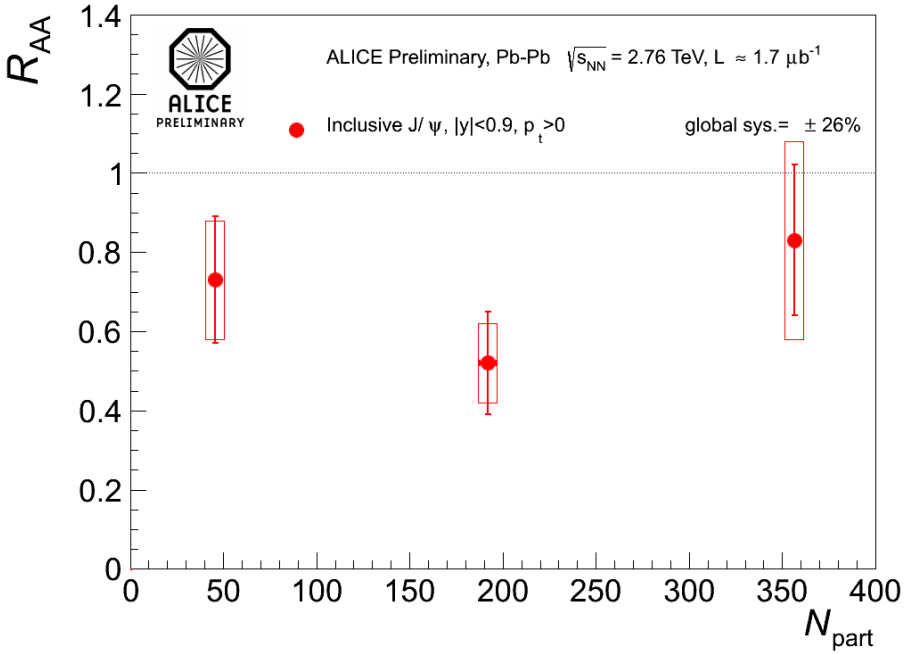
At mid rapidity, similar pattern but but large uncertainties prevent a firm conclusion.

ALICE inclusive J/ψ → $\mu^+\mu^-$ $R_{AA}^{0\text{-}90\%}$ = 0.497 ± 0.006 (stat.) ± 0.078 (sys.)

ALICE inclusive J/ψ → e^+e^- $R_{AA}^{0\text{-}80\%}$ = 0.66 ± 0.10 (stat.) ± 0.24 (sys.)

J/ψ R_{AA} vs centrality





Clear J/Ψ suppression at forward rapidity.

→ almost no centrality dependence above $N_{part} \sim 100$.

At mid rapidity, similar pattern but but large uncertainties prevent a firm conclusion.

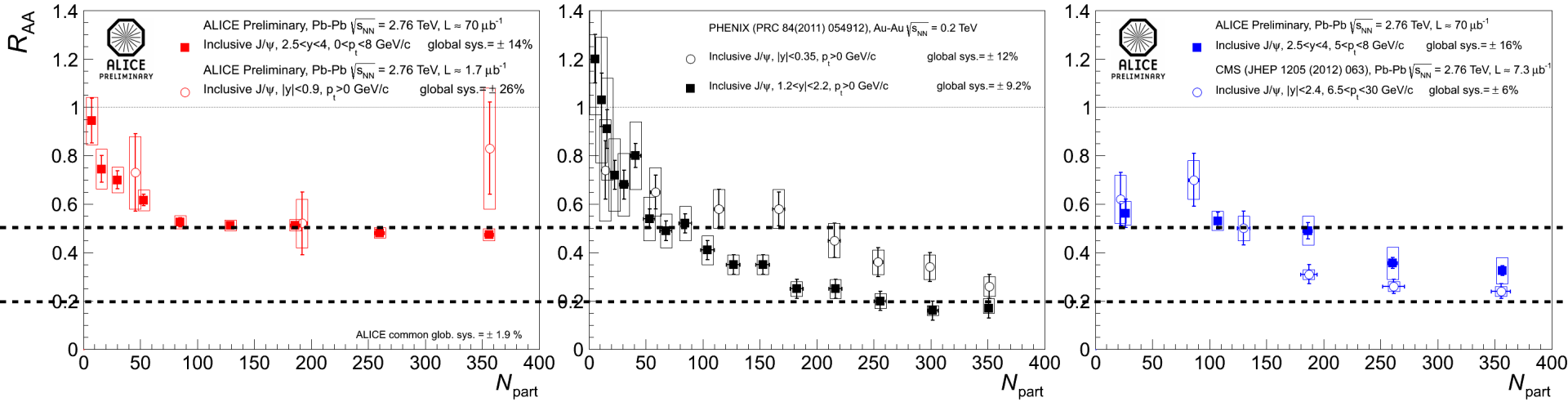
ALICE inclusive J/ψ → $\mu^+\mu^-$ $R_{AA}^{0\text{-}90\%} = 0.497 \pm 0.006$ (stat.) ± 0.078 (sys.)

→ good agreement with 2010 results: $R_{AA}^{0\text{-}80\%} = 0.545 \pm 0.032$ (stat.) ± 0.084 (sys.)

ALICE inclusive J/ψ → e^+e^- $R_{AA}^{0\text{-}80\%} = 0.66 \pm 0.10$ (stat.) ± 0.24 (sys.)

J/ψ R_{AA} vs centrality

ALICE $p_t > 0$ | PHENIX $p_t > 0$ | ALICE/CMS high p_t



At low-pt, ALICE $R_{AA} \geq 0.5$, no centrality dependence

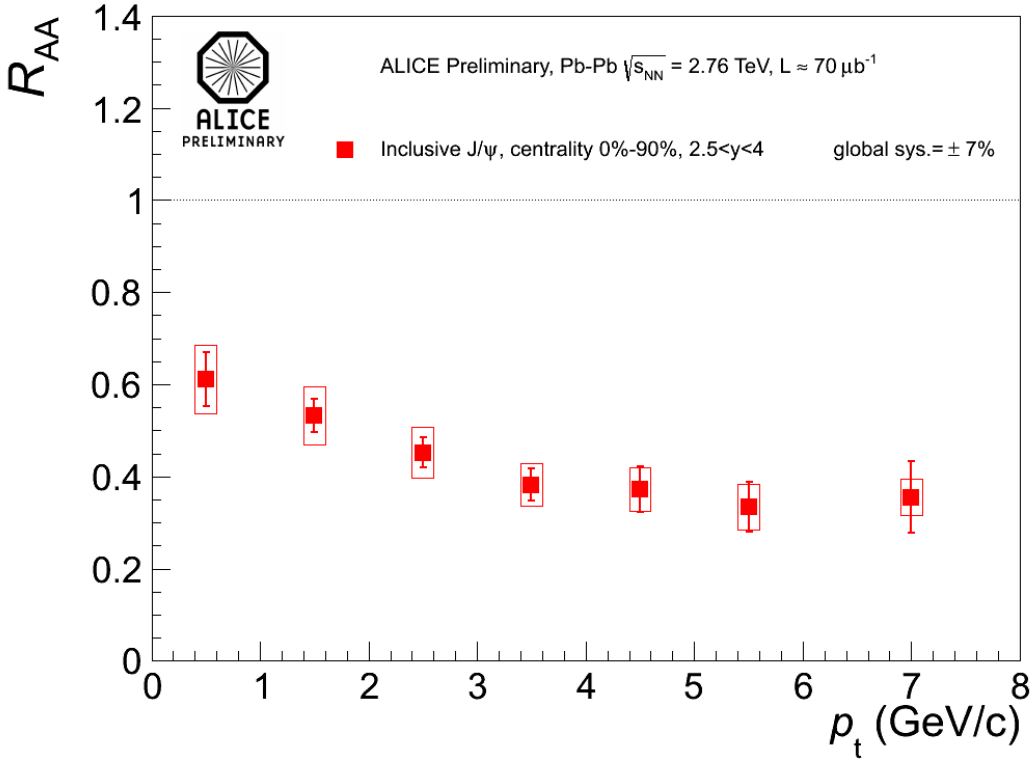
→ behavior clearly different to the one observed in PHENIX where a larger suppression and a strong centrality dependence is seen

At high-p_t, larger suppression seen both by ALICE and CMS

→ behavior is similar to the one observed at low energy

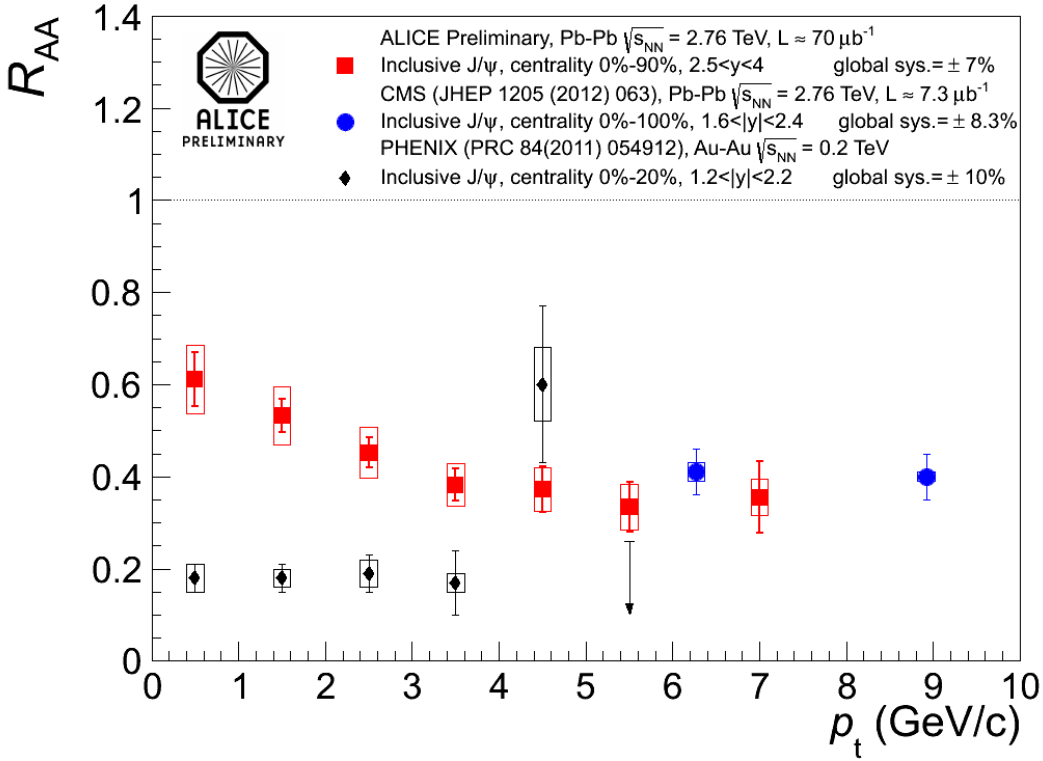
Indication that the suppression is p_t dependent

J/ψ R_{AA} vs p_t



◀ ALICE inclusive J/ψ → μ+μ- at forward rapidity.
R_{AA} ~ 0.6 at low-p_t down to R_{AA} ~ 0.35 at high-p_t. Suppression increases with increasing p_t.

J/ψ R_{AA} vs p_t

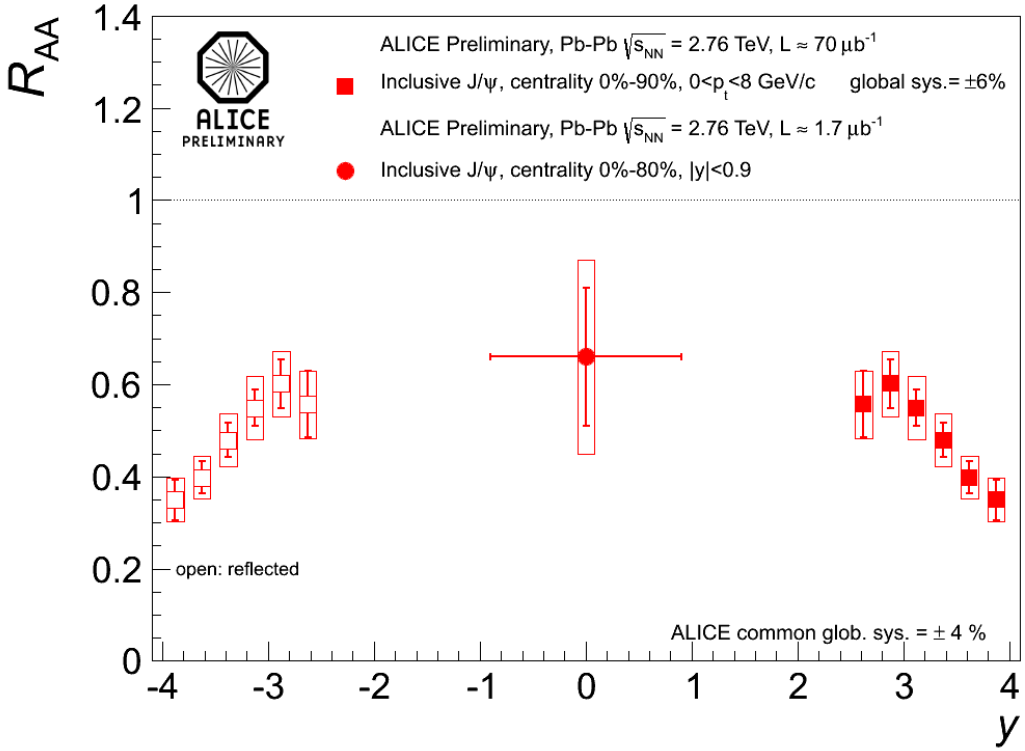


◀ ALICE inclusive J/ψ → μ+μ- at forward rapidity.
R_{AA} ~ 0.6 at low-pt down to R_{AA} ~ 0.35 at high-p_t. Suppression increases with increasing p_t.

◀ Agreement with CMS data at high-p_t (1.6<|y|<2.4) .

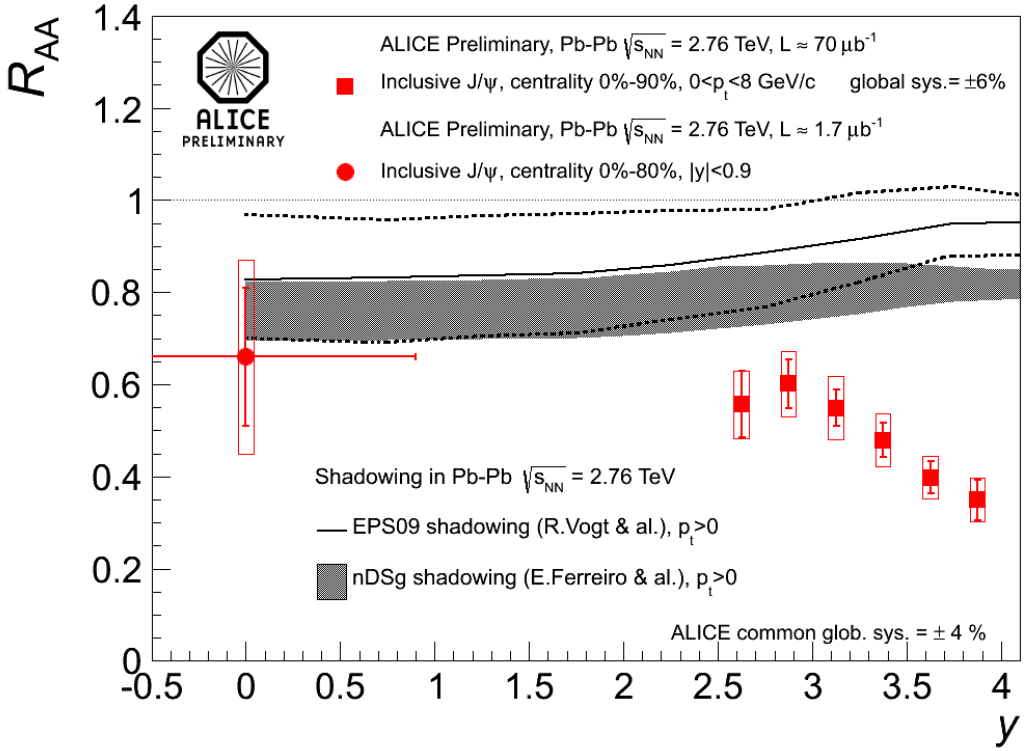
◀ PHENIX measured larger suppression at low-p_t (0-20% central, 1.2<|y|<2.2)

J/ψ R_{AA} vs y



◄ Inclusive J/ψ measured in ALICE at both mid and forward rapidity.
R_{AA} decrease by 40% from y=2.5 to y=4.
Possible flat dependence toward mid rapidity.

J/ψ R_{AA} vs y



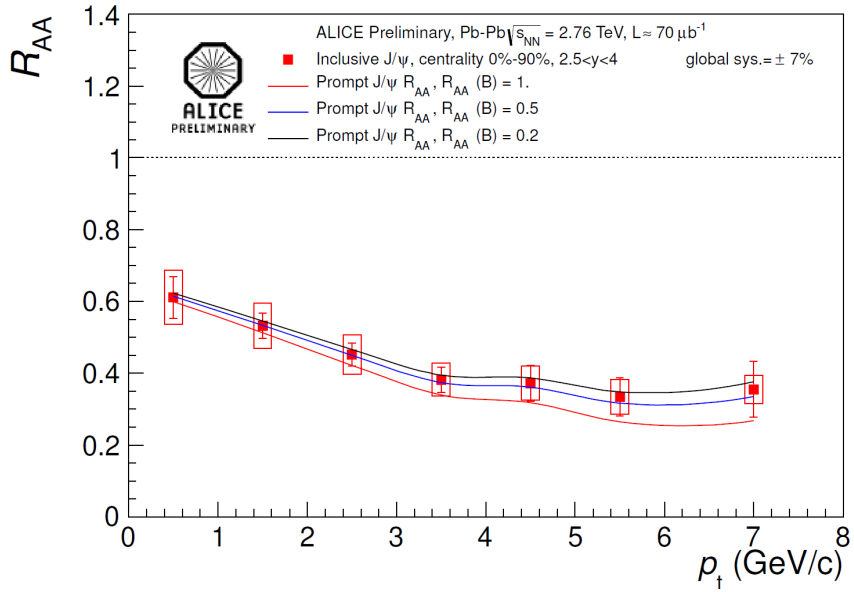
◄ Inclusive J/ψ measured in ALICE at both mid and forward rapidity.
R_{AA} decrease of 40% from y=2.5 to y=4.
Possible flat dependence toward mid rapidity.

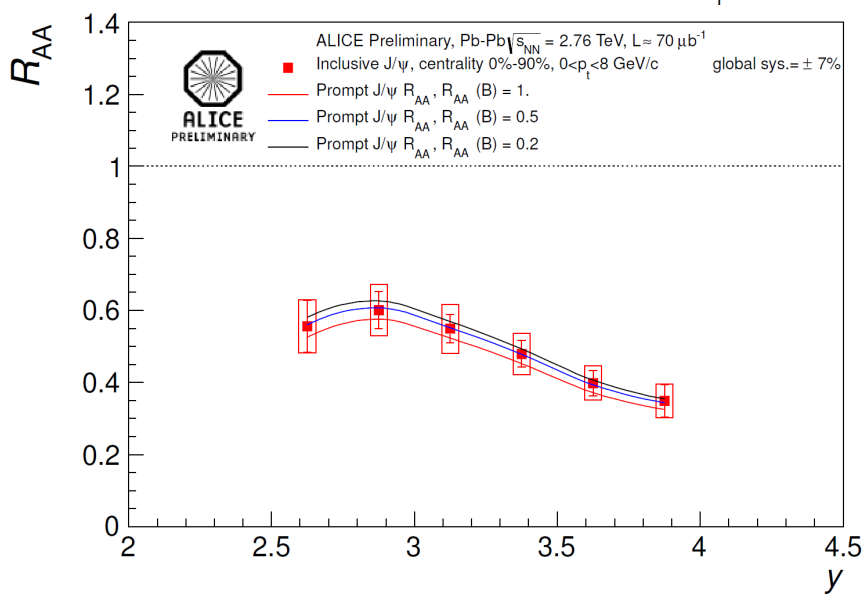
◄ Suppression beyond the current estimate of shadowing at forward rapidity.

→ importance to measure cold nuclear matter effects.

C.Hadjidakis, Poster Session , may 29th

J/ψ R_{AA} vs y,p_t: beauty-full results ?





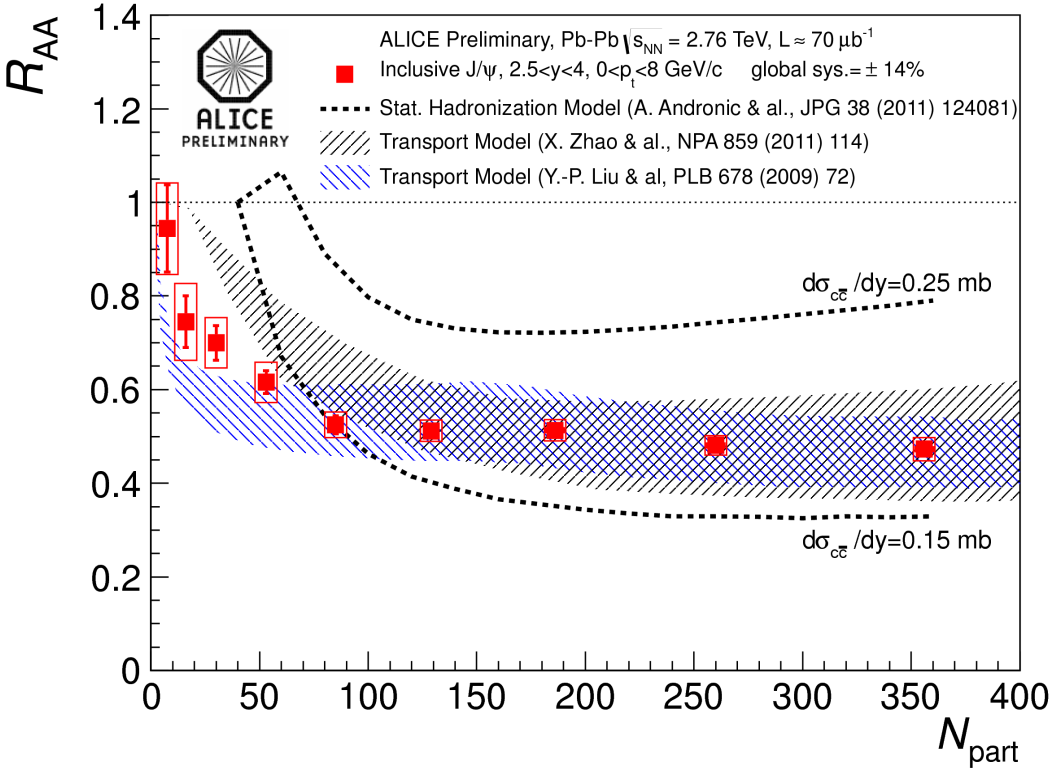
◀ Inclusive J/ψ measured in ALICE

Estimate of the prompt J/ψ R_{AA} using:

- b-fraction measured by CDF, CMS and LHCb
- interpolation at √s = 2.76 TeV
- different b-quenching hypothesis from $R_{AA}(B) = 0.2$ to $R_{AA}(B) = 1$

→ J/ψ from b-hadrons decays have a negligible influence on our measurement.

J/ψ R_{AA} vs N_{part}: model comparison



◄ Inclusive J/ψ → $\mu^+\mu^-$

Comparison to models including hot and cold nuclear matter suppression, regeneration, b feed-down, …

In both transport models, the amount of J/ψ produced from regeneration is ≥ 50% in the most central collisions.

In SH model, all J/ψ are formed at hadronization.

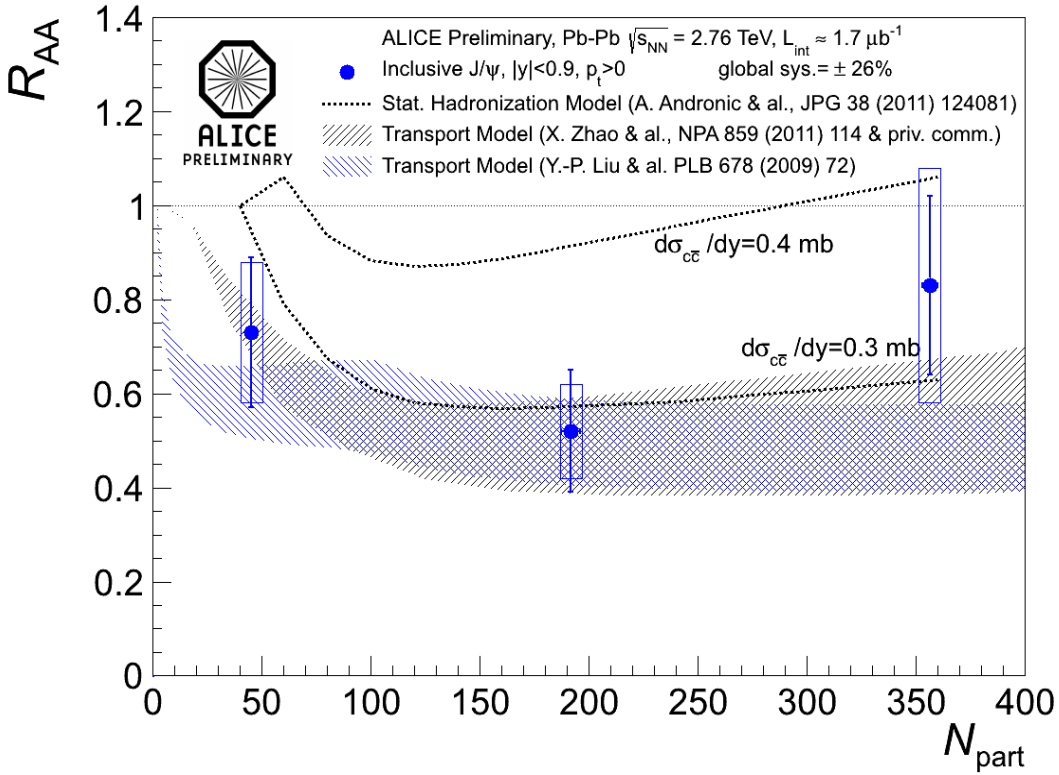
Main ingredients of the models.

1_ Stat. hadronization (Andronic & al.). Thermal model T =164 MeV, μ_B ~ 1MeV from particle ratio fits. All charm produced in initial hard scatterings. Charmonium production fully occurs at phase boundary.

2_ Transport (Rapp, Zhao). Boltzman transport eq. for J/ψ. dNch/dy from measurement. $\sigma_{CC}|_{y=3.25}$ ~ 0.5 mb. Shadowing ad hoc. σ_{Abs} = 0. 10% of J/ψ ← B, no quenching. .

3_ Transport (Liu,Qu,Xu & Zhuang). Boltzman transport eq. for J/ψ. $\sigma_{CC}|_{y=3.25}$ ~ 0.38 mb. EKS98 shadowing. σ_{Abs} = 0. J/ψ ← B, w/ and w/o quenching. Recent increase of σ_{CC}.

J/ψ R_{AA} vs N_{part}: model comparison



◄ Inclusive J/ψ → e^+e^-

Comparison to models including hot and cold nuclear matter suppression, regeneration, b feed-down, …

In both transport models, the amount of J/ψ produced from regeneration is ≥ 50% in the most central collisions.

In SH model, all J/ψ are formed at hadronization.

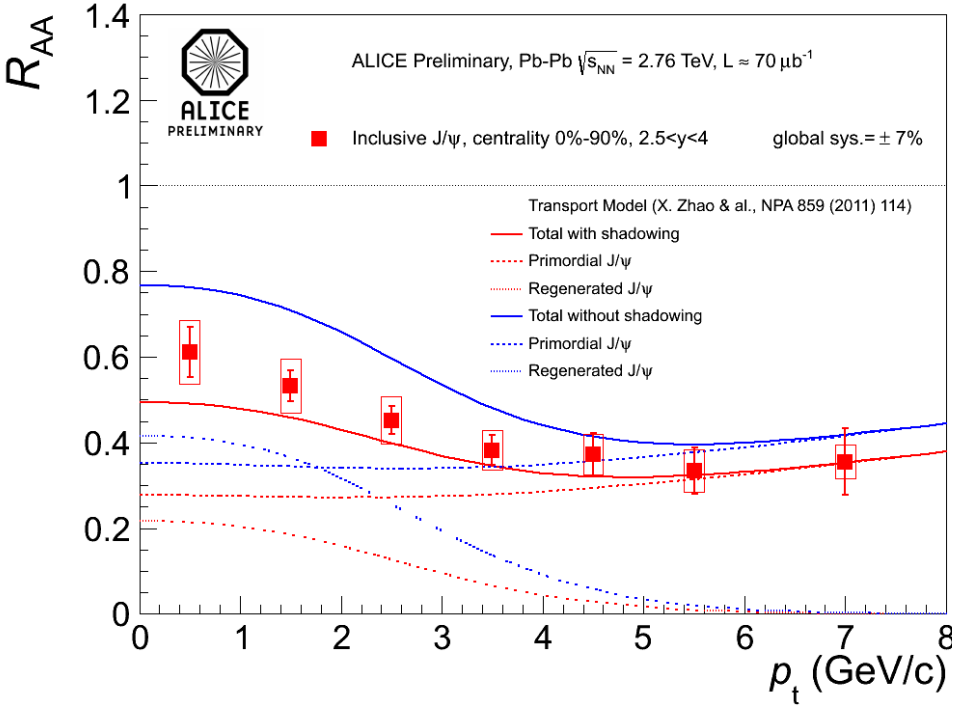
Main ingredients of the models.

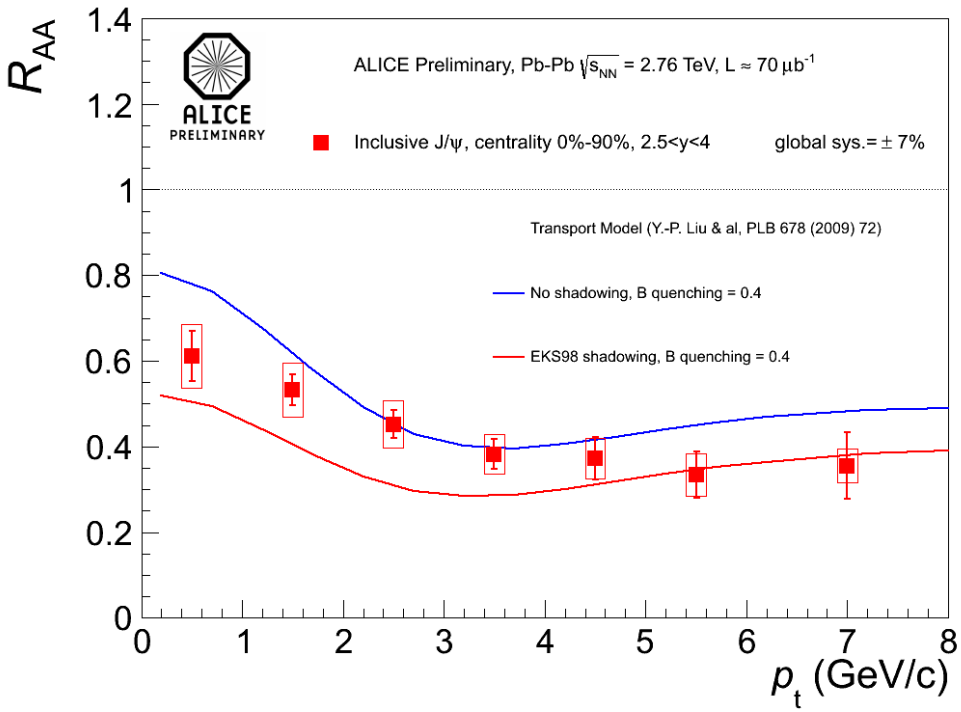
1_ Stat. hadronization (Andronic & al.). Thermal model T =164 MeV, μ_B ~ 1MeV from particle ratio fits. All charm produced in initial hard scatterings. Charmonium production fully occurs at phase boundary.

2_ Transport (Rapp, Zhao). Boltzman transport eq. for J/ψ. dNch/dy from measurement. $\sigma_{CC}|_{y=0}$ ~ 0.75 mb. Shadowing ad hoc. σ_{Abs} = 0. 10% of J/ψ ← B, no quenching. .

3_ Transport (Liu,Qu,Xu & Zhuang). Boltzman transport eq. for J/ψ. $\sigma_{CC}|_{y=3.25}$ ~ 0.38 mb. EKS98 shadowing. σ_{Abs} = 0. J/ψ ← B, w/ and w/o quenching. Recent increase of σ_{CC}.

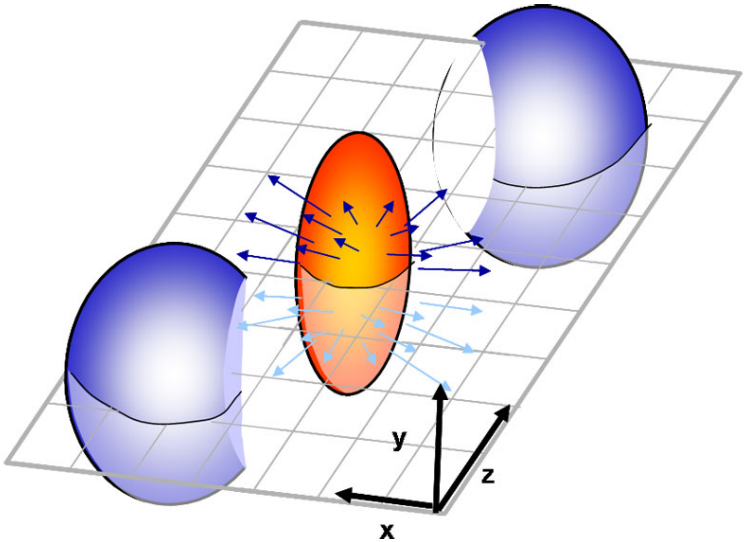
J/ψ R_{AA} vs p_t: model comparison

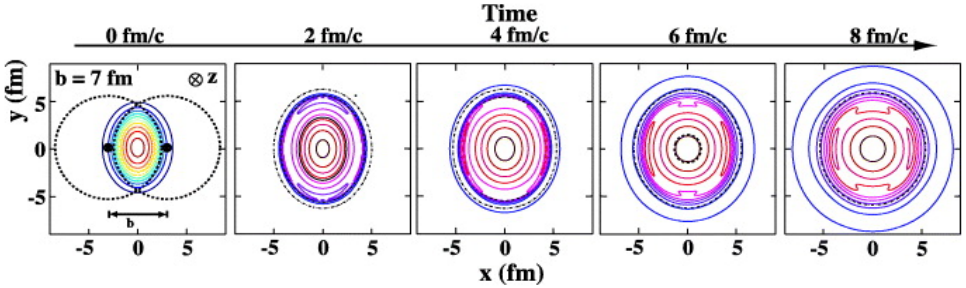




Both models correctly reproduce our measurement
In both models, a large fraction of regenerated J/Ψ have p_t < 3-4 GeV/c

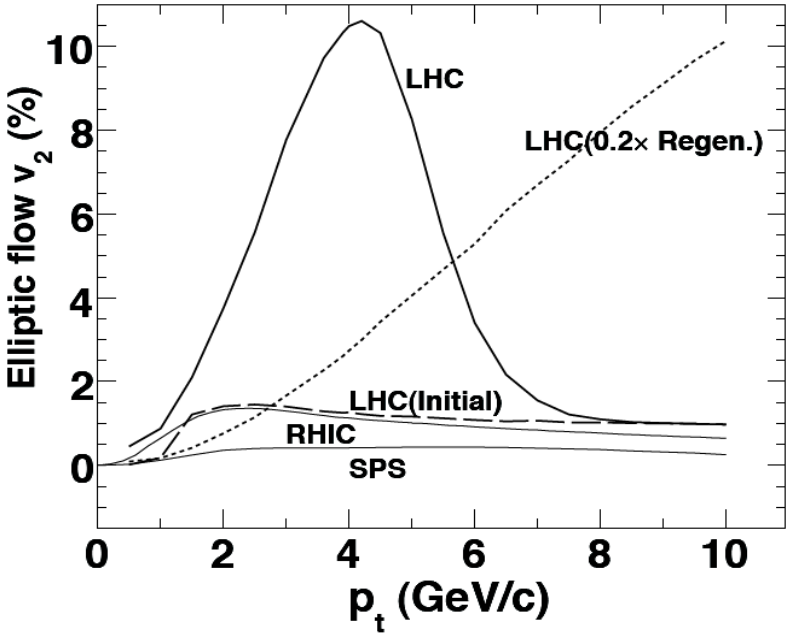
J/ψ elliptic flow





pressure gradients in a thermalized medium convert spatial anisotropy into momentum space

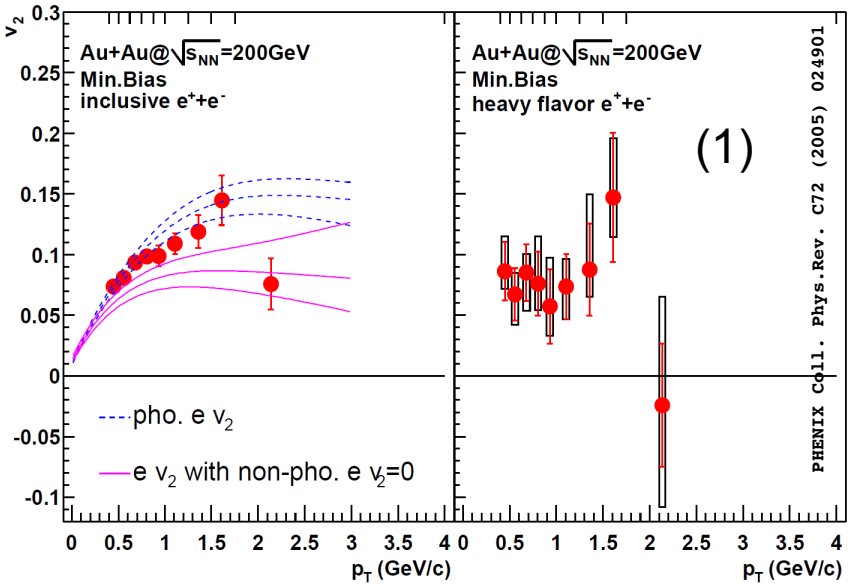
$$\frac{dN}{d\phi} = N\left(1 + 2v_2 \cos 2(\phi - \psi)\right)$$

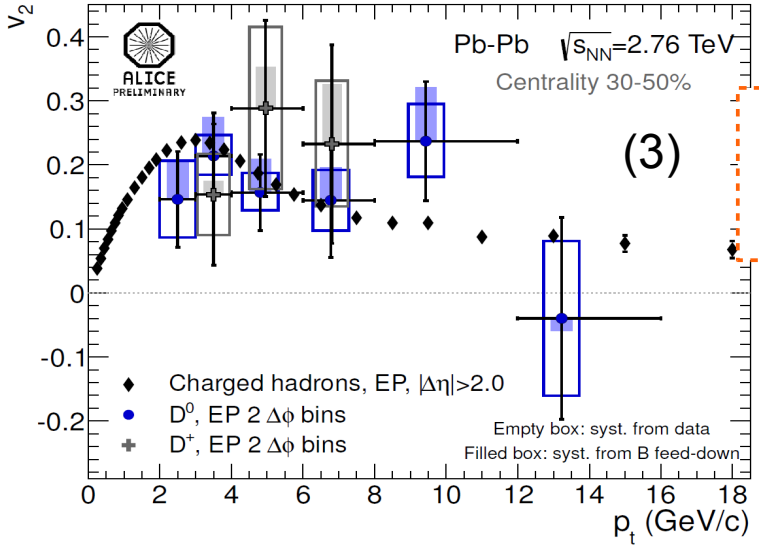


Y. Liu, N. Xu, P. Zhuang, Nucl.Phys.A834 (2010) 317c

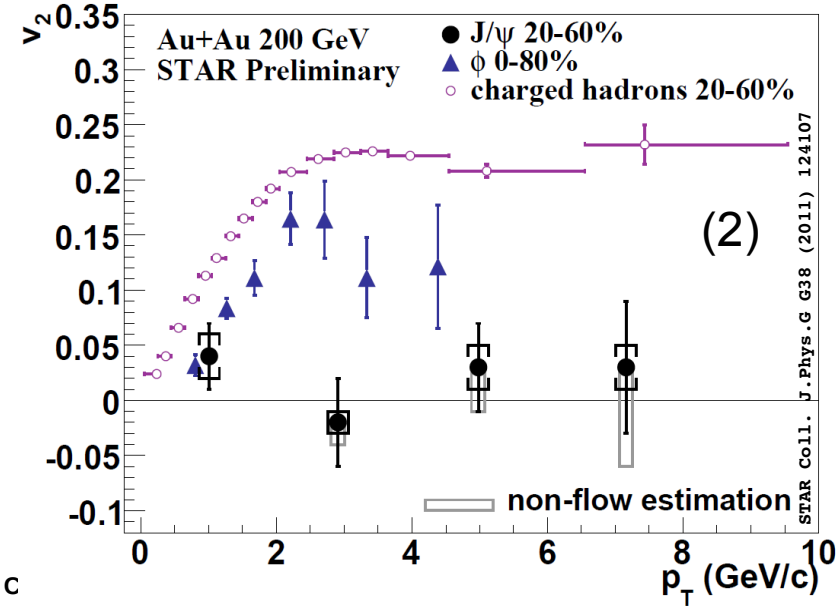
Regeneration or recombination of charm quarks for J/Ψ production will dominate the J/Ψ flow at LHC comparing to that at lower energies.
→ low and mid p_t ranges are crucial

Charm and J/ψ elliptic flow





G.Ortona
Parallel
2A
may 28th



At RHIC:

(1) Charm (non-photonic electrons) measured v_2 is ~ 8%

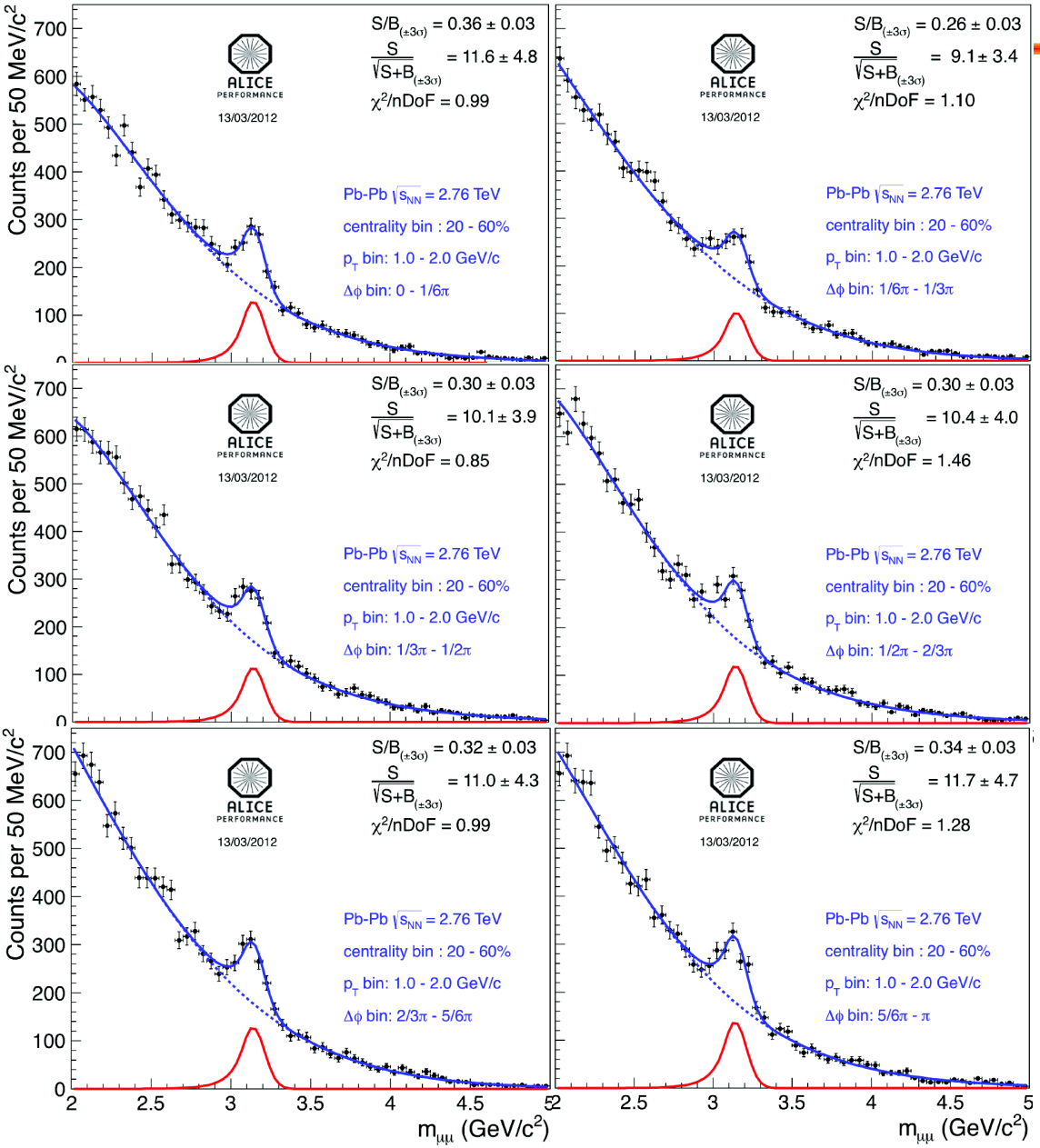
(2) J/Ψ v_2 is consistent with 0

At LHC:

(3) v_2 from D^+ and D^0 mesons larger than 10%

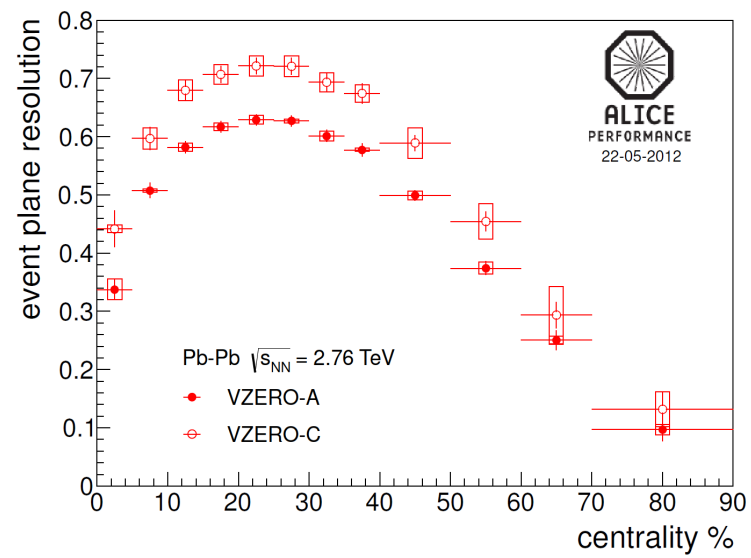
Do J/Ψ exhibit elliptic flow at LHC ?

J/ψ elliptic flow



◀ $J/\psi \rightarrow \mu^+\mu^-$ signal extraction in 6 $\Delta\varphi$ bins where $\Delta\varphi = \varphi_{\mu+\mu-} - \psi_{RP}$

▼ Event plane determined from 3 different sub-detectors with large η gaps
→ 2% systematic uncertainty

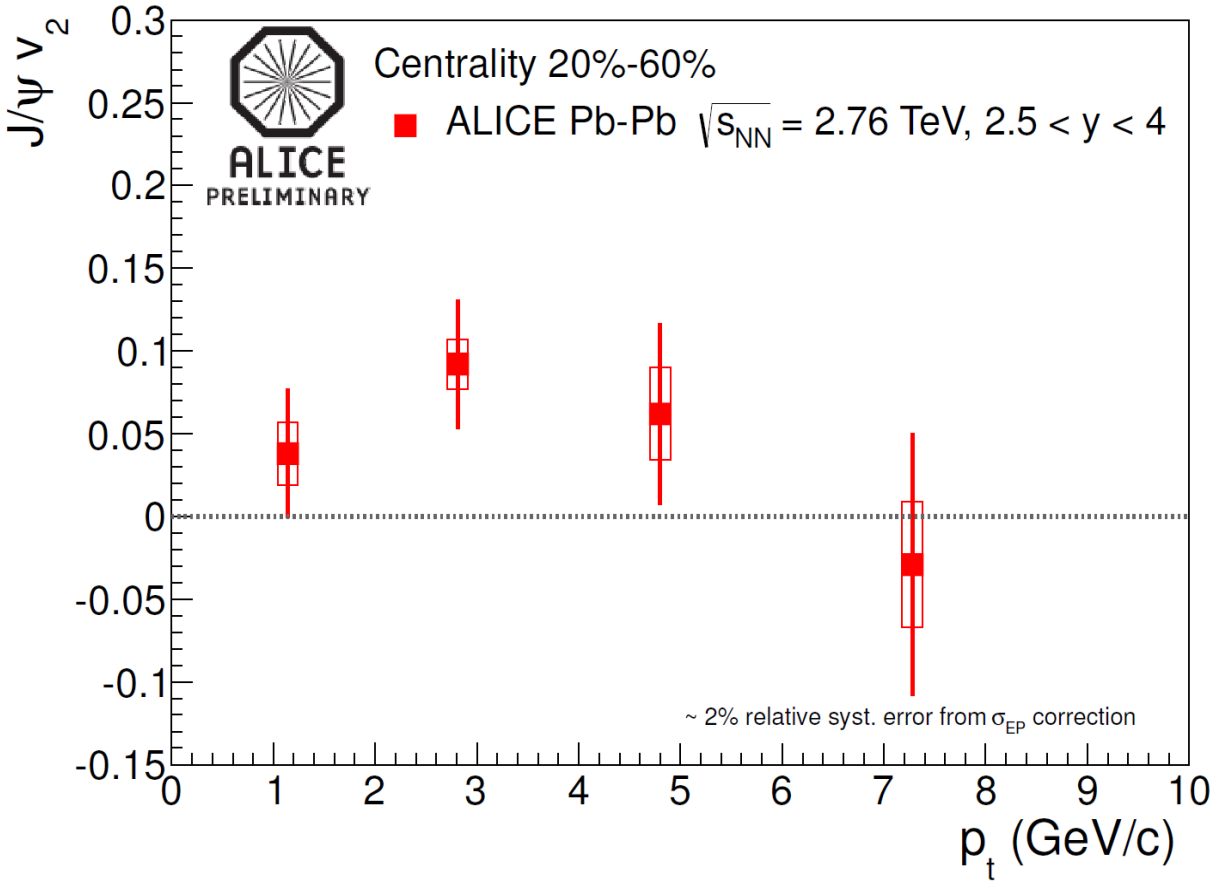


L.Massacrier, Parallel 1A, may 28th

J/ψ elliptic flow

J/Ψ v_2 as a function pt for 20%-60% most central Pb-Pb collisions

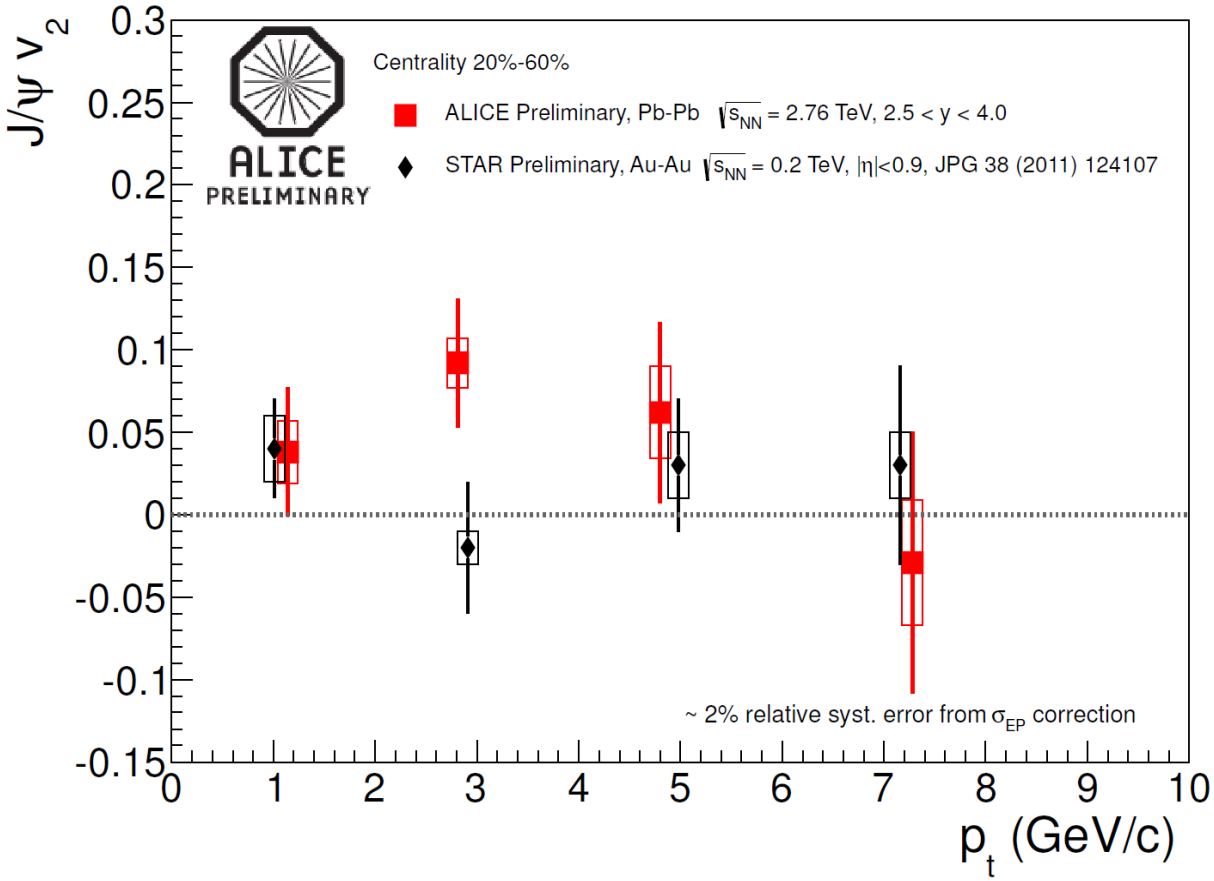
Hint of non-zero J/Ψ v_2 at intermediate p_t (2-4 GeV/c): significance = 2.2 σ



J/ψ elliptic flow

J/Ψ v_2 as a function pt for 20%-60% most central Pb-Pb collisions

Hint of non-zero J/Ψ v_2 at intermediate p_t (2-4 GeV/c): significance = 2.2 σ

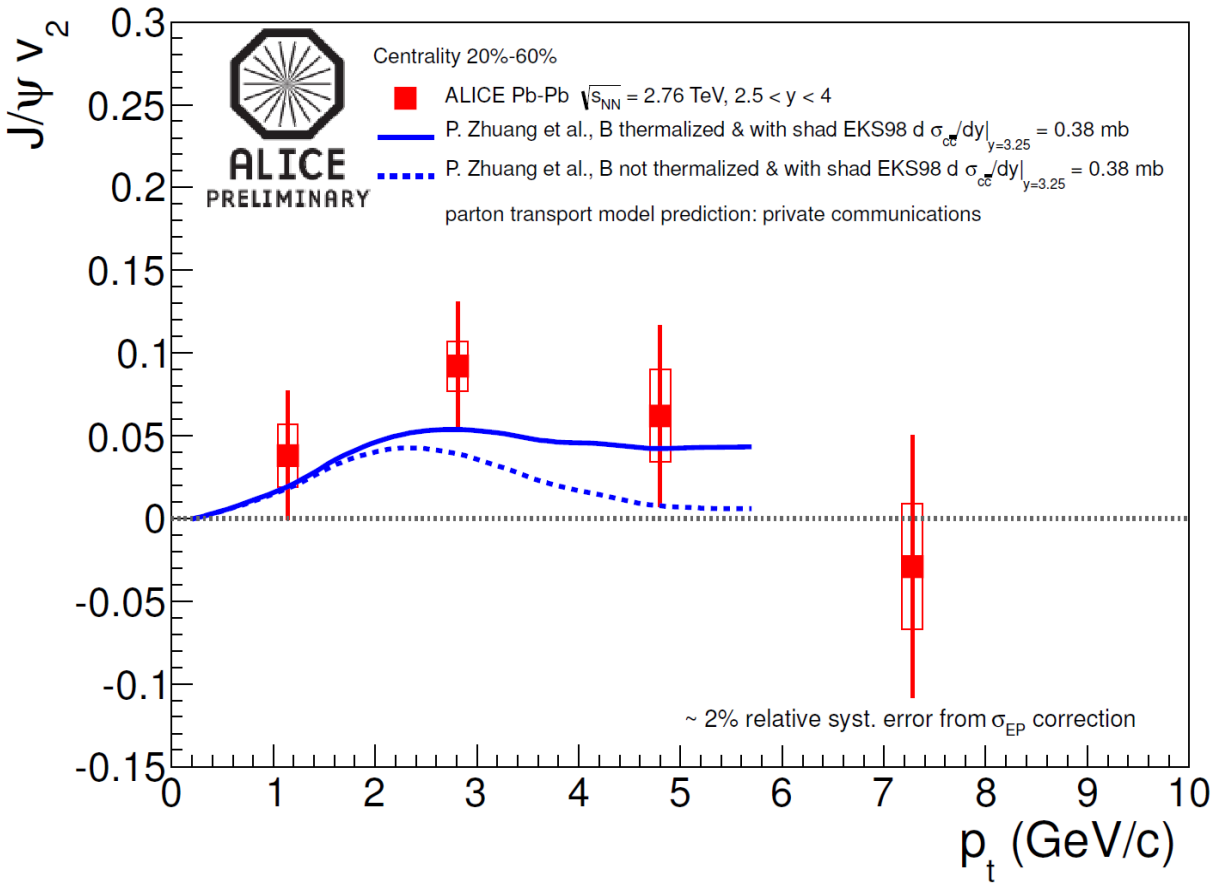


J/ψ elliptic flow

J/Ψ v_2 as a function pt for 20%-60% most central Pb-Pb collisions

Clear hint of non-zero J/Ψ v_2 at intermediate p_t (2-4 GeV/c): significance = 2.2 σ

Model prediction for v_2 shown here succeeds well at reproducing J/ψ R_{AA}.



Conclusions

- **ALICE has measured important features of J/ψ production in pp collisions**
  - **weak/null polarization, scaling with event multiplicity, feed down from b-hadrons.**
  - **cross-section at mid and forward rapidity [→ reference for Pb-Pb collisions]**

- **J/ψ nuclear modification factor, R_{AA} and elliptic flow ,v_2 have been measured in Pb-Pb collisions at 2.76TeV.**
  - **J/ψ R_{AA} in Pb-Pb collisions exhibits a novel behavior with respect to PHENIX (lower energy) and CMS (high-p_t J/ψ)**

    → flat centrality dependence at forward rapidity, with possible increase at mid rapidity for most central collisions

    → R_{AA} is larger at low-p_t; low-p_t J/ψ are crucial at LHC to understand possible re-generation mechanisms

    → R_{AA} decrease by 40% from y = 2.5 to y = 4.
  - **Models including J/ψ production from deconfined charm quarks succeed well in reproducing the J/ψ R_{AA} vs centrality and p_t.**
  - **First measurement of J/ψ elliptic flow: hint of non-zero v_2**

- **Prospects**
  - **measure cold nuclear matter effects in the p-Pb 2012 run**
  - **improve the R_{AA} and elliptic flow measurement**