J/ψ production measurements in p-p and Pb-Pb collisions with ALICE

Physics at LHC

June 6th - 11th, 2011

Perugia, Italy

Cynthia Hadjidakis

on behalf of the ALICE collaboration

Quarkonium production as a probe of deconfinement

In Pb-Pb collisions at LHC a high density deconfined state is expected to be produced.

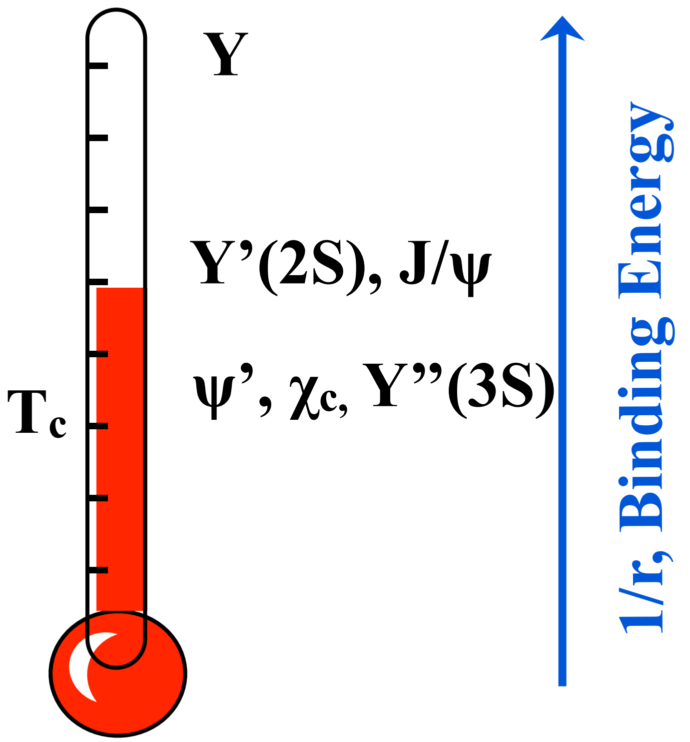
Quarkonium family to characterize the Quark Gluon Plasma

Formed at the early stage of the collisions

T. Matsui, H. Satz, Phys. Lett. B 178 (1986) 416

Debye screening in a high density deconfined state leads to quarkonia suppression

Different binding energy of bound states lead to sequential suppression of quarkonium family



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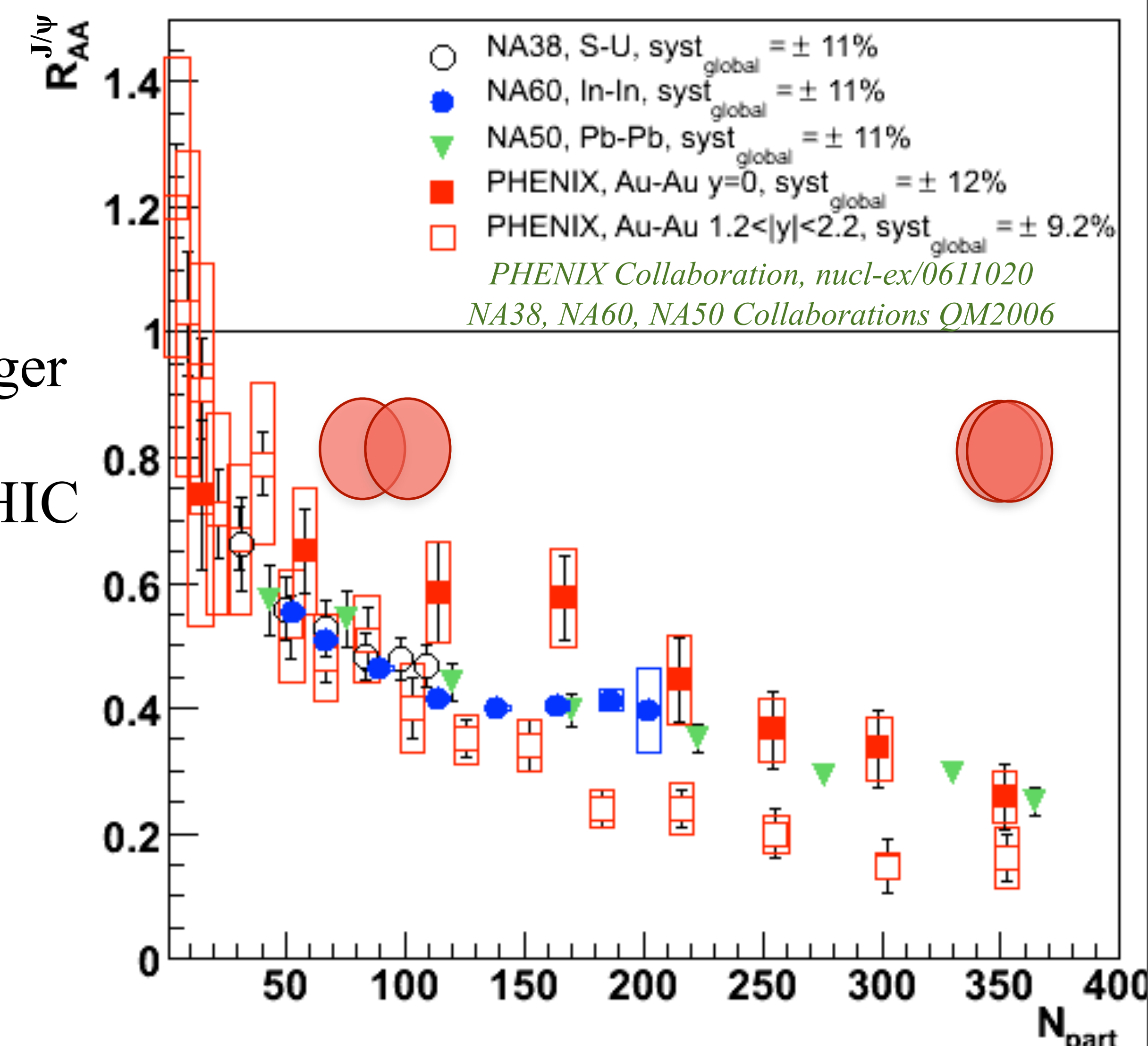
SPS and RHIC J/ψ measurements: puzzling results

$$R_{AA} = \frac{1}{N_{coll}} \frac{dN_{AA}}{dN_{pp}}$$

Suppression @SPS ~ @RHIC while energy density larger at RHIC

Different suppression at mid and forward rapidity @RHIC



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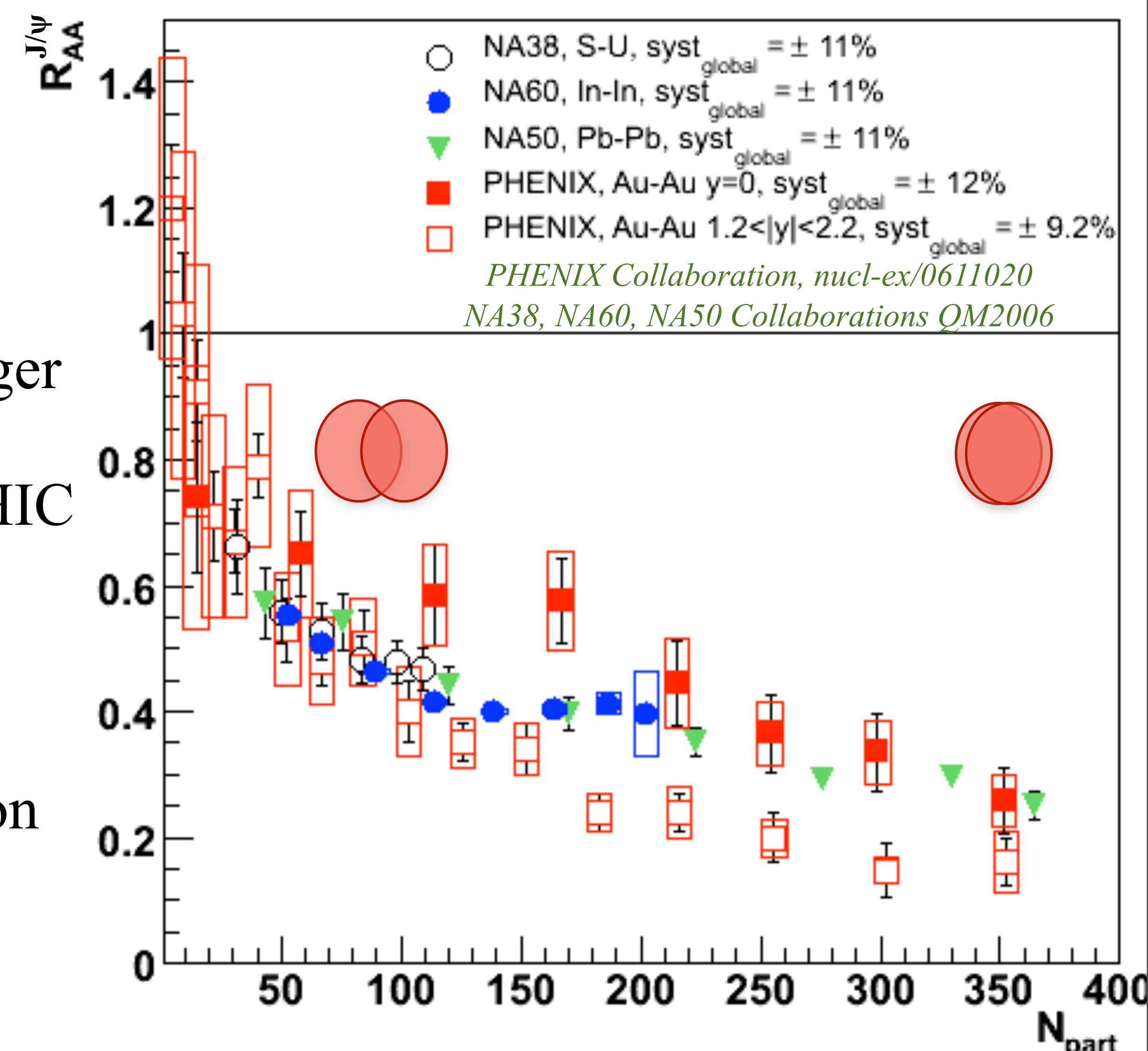

New energy regime at LHC

Heavy flavors are produced abundantly

Large statistics for J/ψ and Υ family

Open heavy flavour to normalize quarkonium production

Cold nuclear matter effects measured in p-Pb collisions

→ Hot nuclear matter effects on quarkonia production can be precisely measured at the LHC

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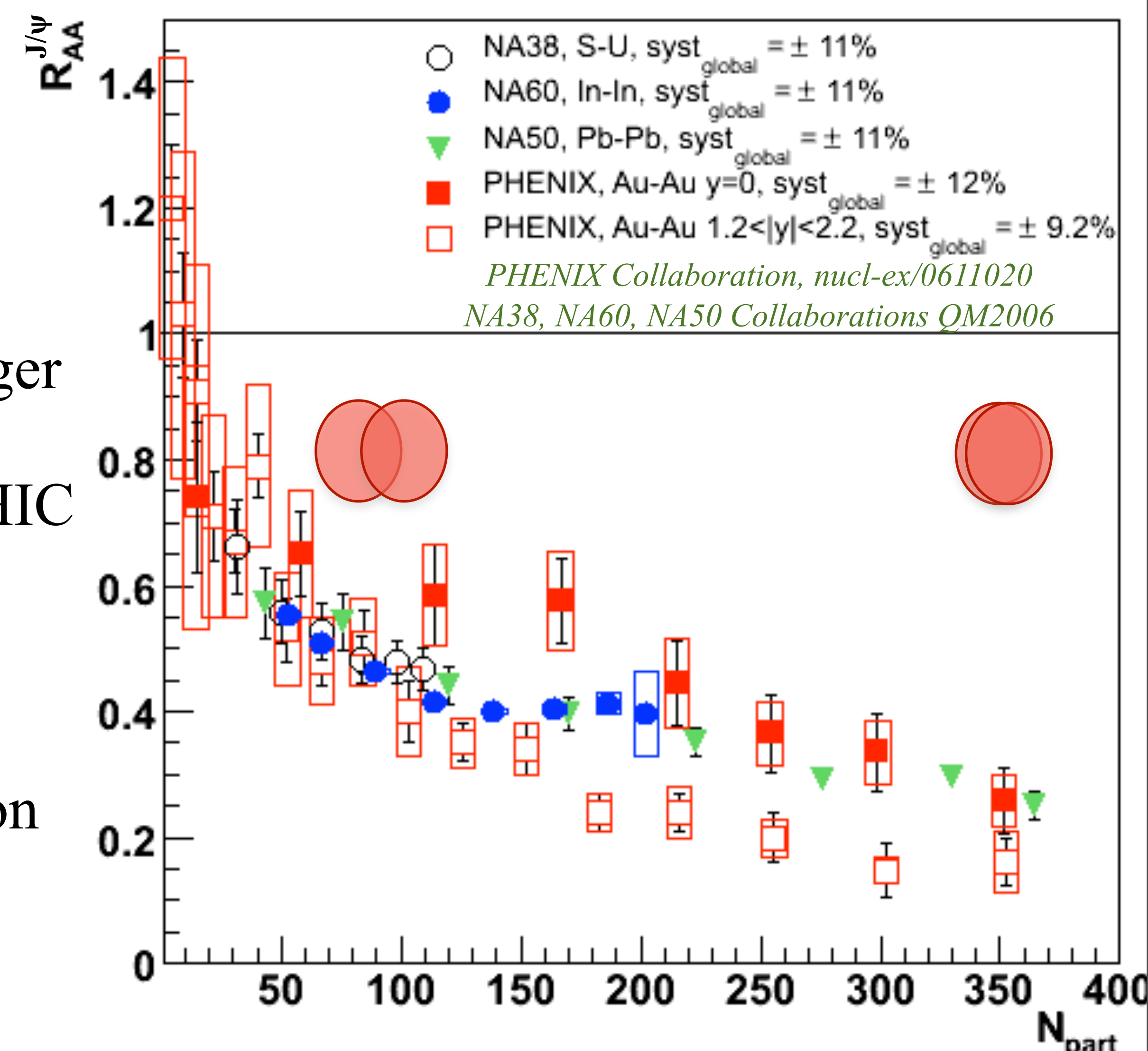

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Quarkonium production in p-p collisions

A reference for studying QGP effect in Pb-Pb!

Production mechanisms not fully understood: LHC data to constrain the models

J/ψ measurements in ALICE

Inclusive J/ψ measurements at $\sqrt{s}$ = 7 and 2.76 TeV in p-p collisions

Total and differential cross sections

$\sqrt{s}$ = 7 TeV → *ALICE coll., arXiv:1105.0380 (2011)*

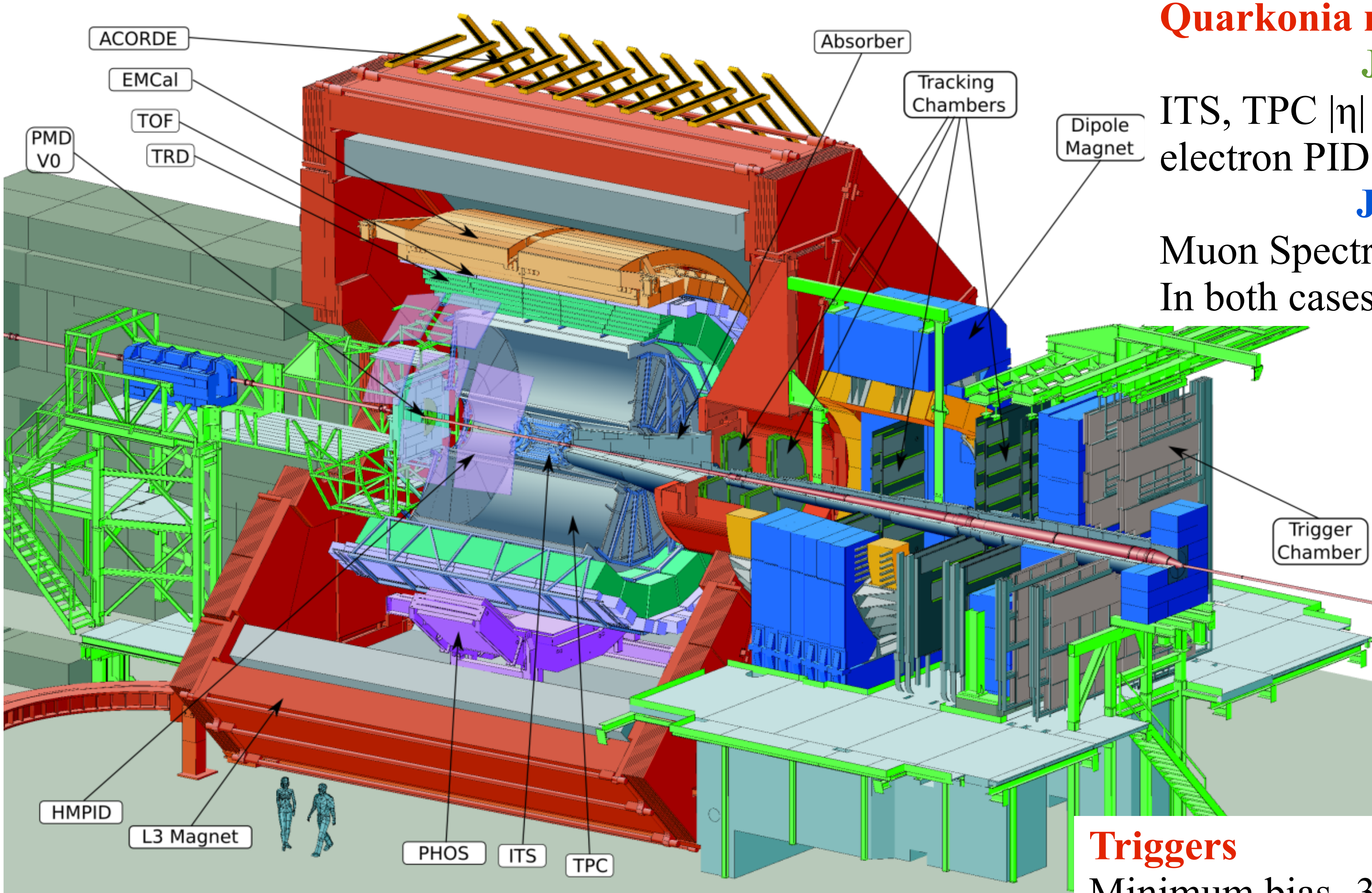
Multiplicity dependence at $\sqrt{s}$ = 7 TeV

Inclusive J/ψ measurements at $\sqrt{s_{NN}}$ = 2.76 TeV in Pb-Pb collisions

R_{AA} and R_{CP}

Ongoing analysis: exclusive J/ψ in ultra-peripheral collisions

Quarkonia measurements in ALICE



Quarkonia measurements

$J/\psi \rightarrow e^+e^-$

ITS, TPC $|\eta| < 0.9$

electron PID based on TPC dE/dx

$J/\psi \rightarrow \mu^+\mu^-$

Muon Spectrometer $-4 < \eta < -2.5$

In both cases, down to $p_T = 0$

see Johannes Wessels - 1B/Monday

Triggers

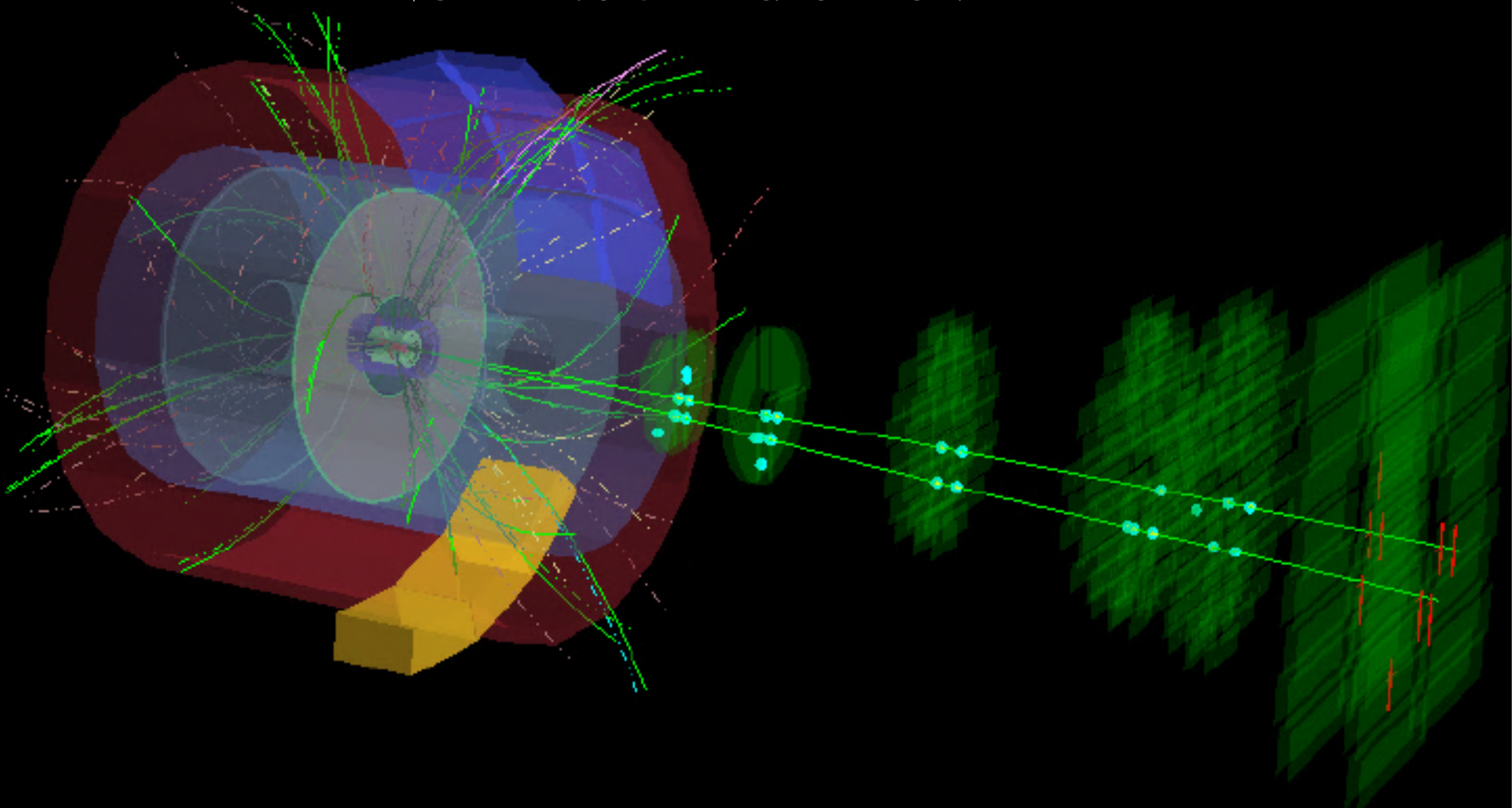
Minimum bias $-3.7 < \eta < 5.1$

V0A, V0C, Silicon Pixel Detector

Muon trigger $-4 < \eta < -2.5$

Min bias && muon trigger

J/ψ measurements in p-p collisions at √s = 2.76 and 7 TeV

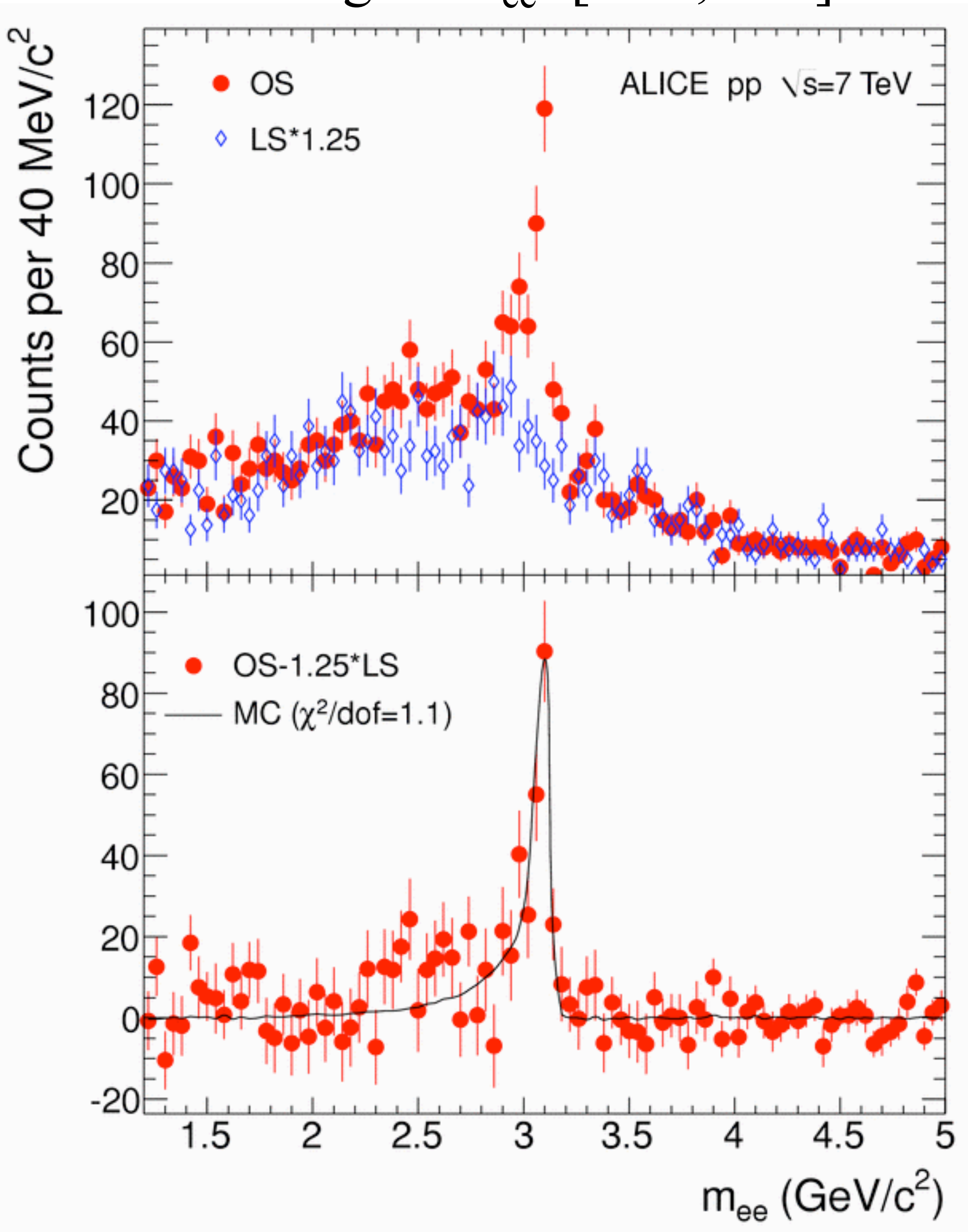


J/ψ signal extraction in p-p collisions at 7 TeV

ALICE coll., arXiv:1105.0380 (2011)

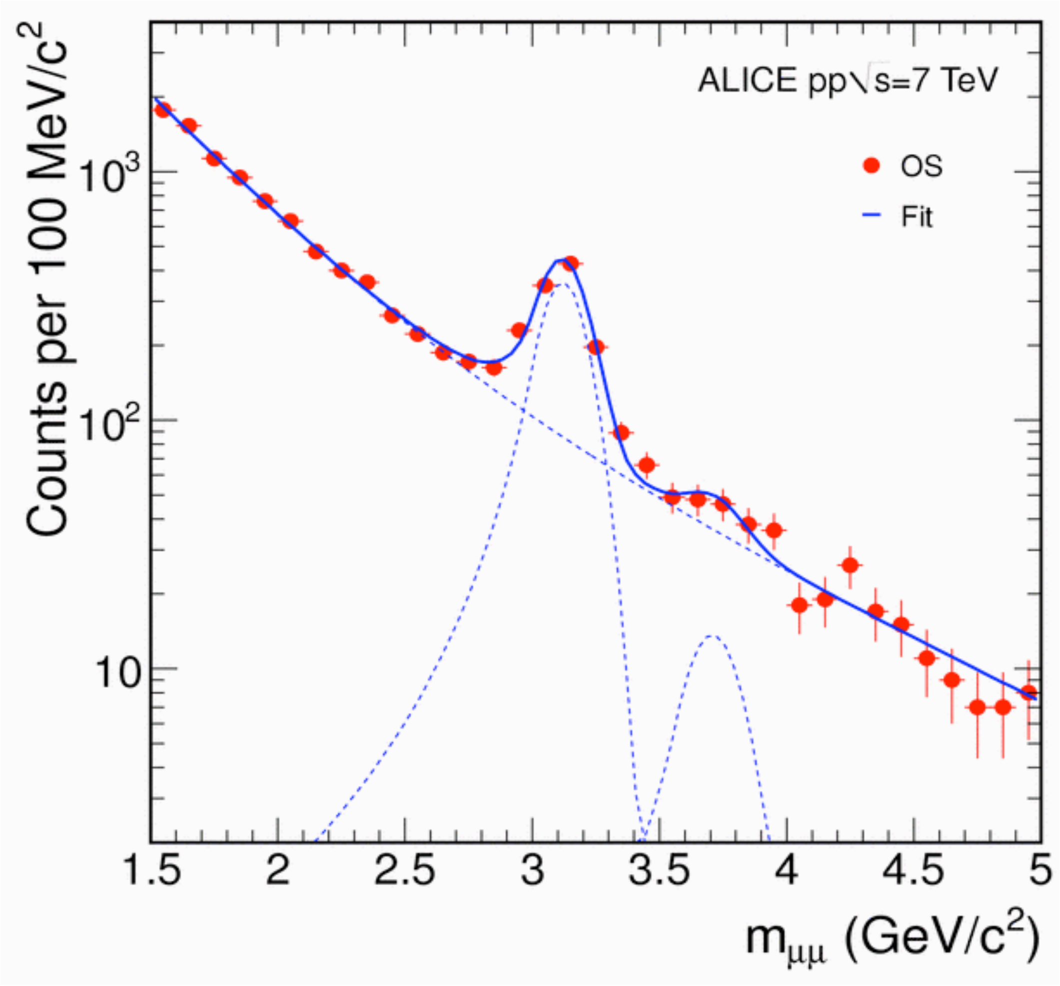
$J/\psi \rightarrow e^+ e^-$
$|y|<0.9$, $p_T>0$

Like sign normalized to unlike sign
Bin counting in M_{ee}=[2.92;3.16] GeV/c^2



$J/\psi \rightarrow \mu^+ \mu^-$
$2.5<y<4$, $p_T>0$

Fit the invariant mass distribution
Crystal Ball shape for the signal (J/ψ and ψ')
ψ' parameters bound to the J/ψ
Double exponential for the background



Systematics uncertainties ~ 8.5% ($e^+ e^-$) and 6-7.5% ($\mu^+ \mu^-$) on signal extraction

Integrated cross section

$\sqrt{s}$ (TeV)	electron L_{int} (nb^{-1})	muon L_{int} (nb^{-1})
7	3.9	16
2.76	1.1	20

Integrated cross section @ 7 TeV *ALICE coll., arXiv:1105.0380v1 (2011)*

$\sigma_{J/\psi}$ ($|y|<0.9$) = 10.7 ± 1.2 (stat) ± 1.7 (syst) + 1.6 (λ_{HE}=+1) -2.3 (λ_{HE}=-1) μb
$\sigma_{J/\psi}$ ($2.5<y<4$) = 6.31 ± 0.25 (stat) ± 0.72 (syst) + 0.95 (λ_{CS}=+1) -1.96 (λ_{CS}=-1) μb

Main uncertainty due to the unknown value of the J/ψ polarization
Polarization determination ongoing!

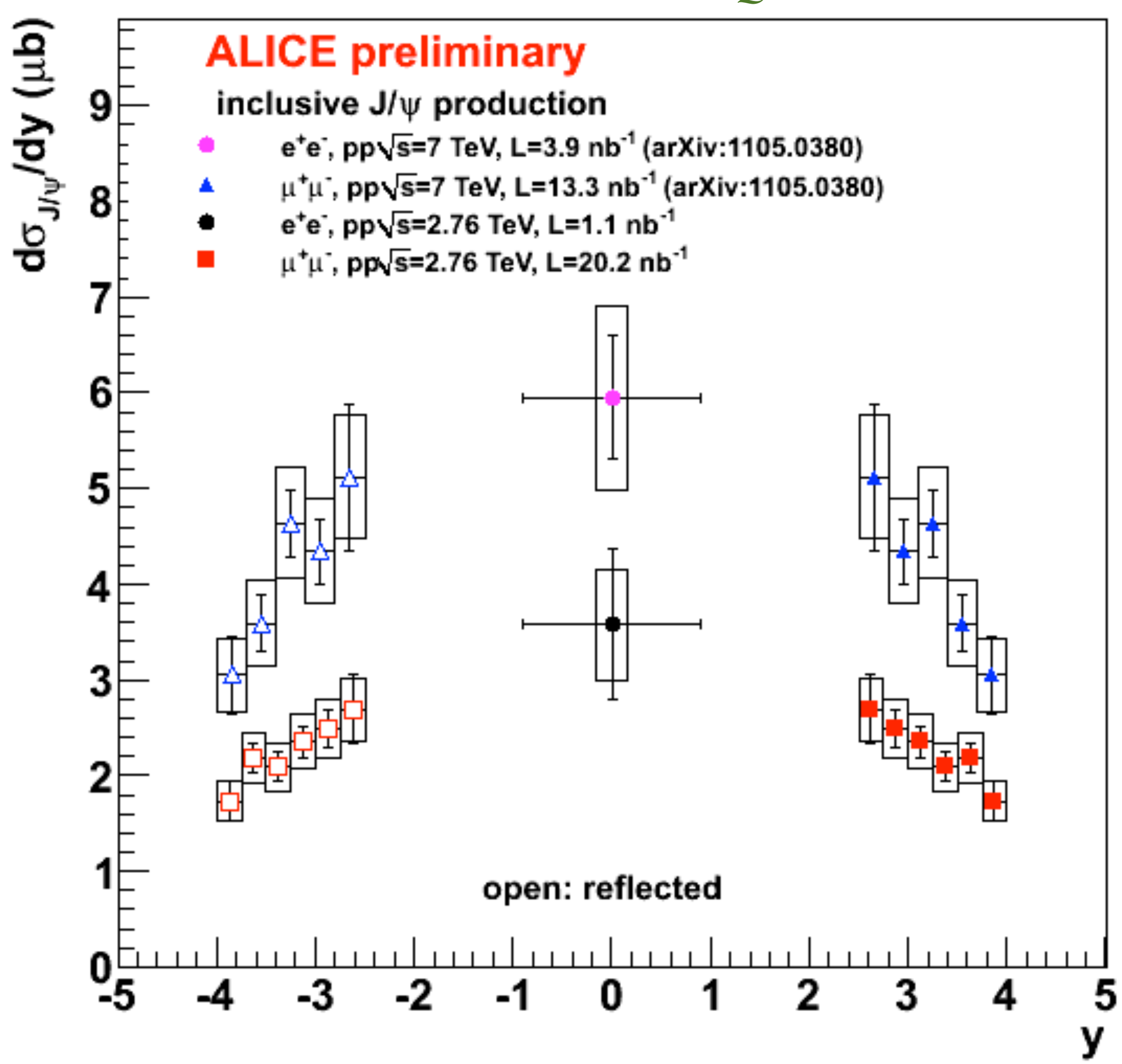
Integrated cross section @ 2.76 TeV *Quark Matter 2011*

$\sigma_{J/\psi}$ ($|y|<0.9$) = 6.44 ± 1.42 (stat) ± 0.88 (syst) ± 0.52 (lumi) + 0.64 (λ_{HE}=+1) -1.42 (λ_{HE}=-1) μb
$\sigma_{J/\psi}$ ($2.5<y<4$) = 3.46 ± 0.13 (stat) ± 0.32 (syst) ± 0.28 (lumi) + 0.55 (λ_{CS}=+1) -1.11 (λ_{CS}=-1) μb

→ baseline for Pb-Pb measurements!

y and p_T dependent cross section

Quark Matter 2011



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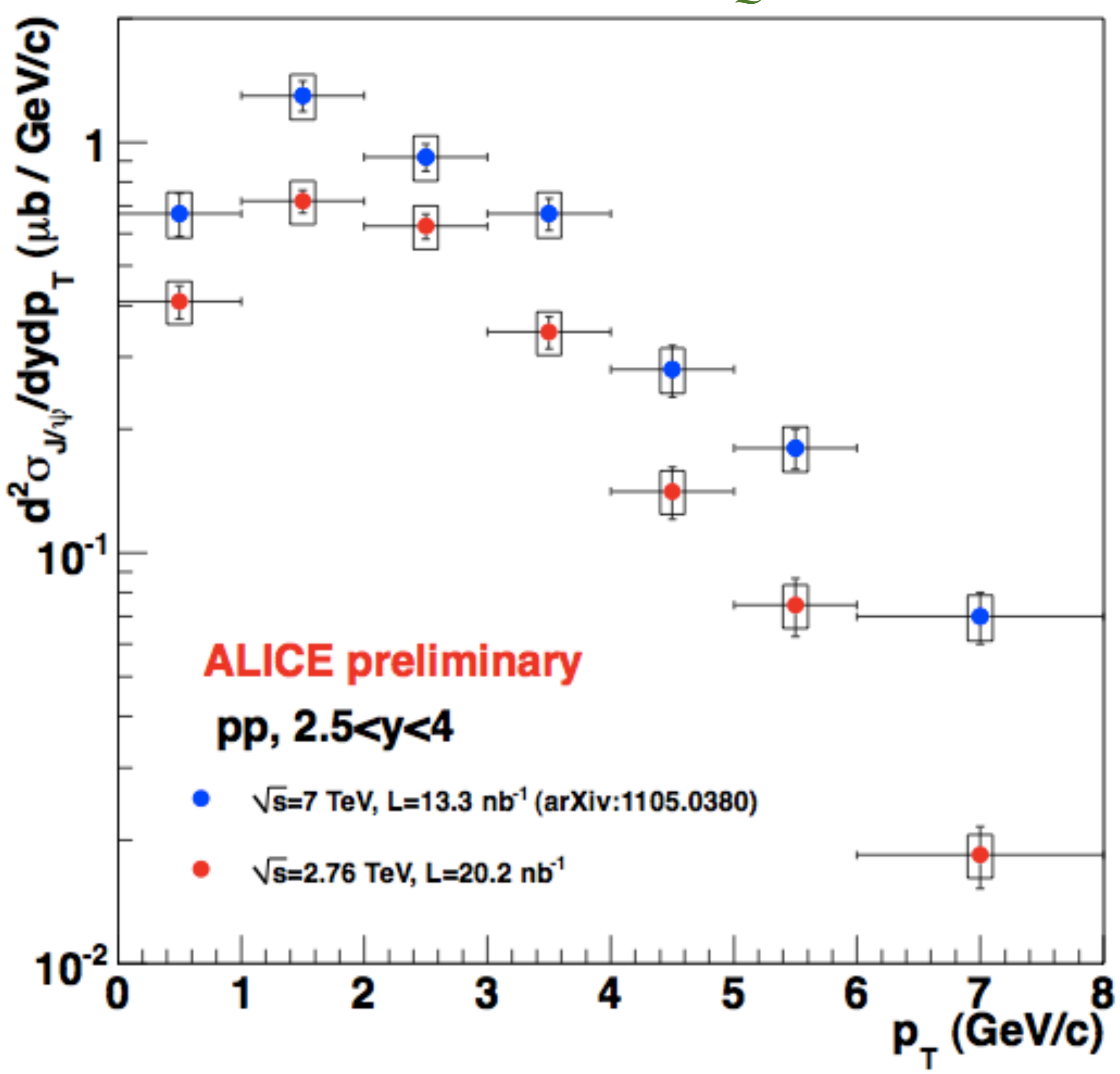
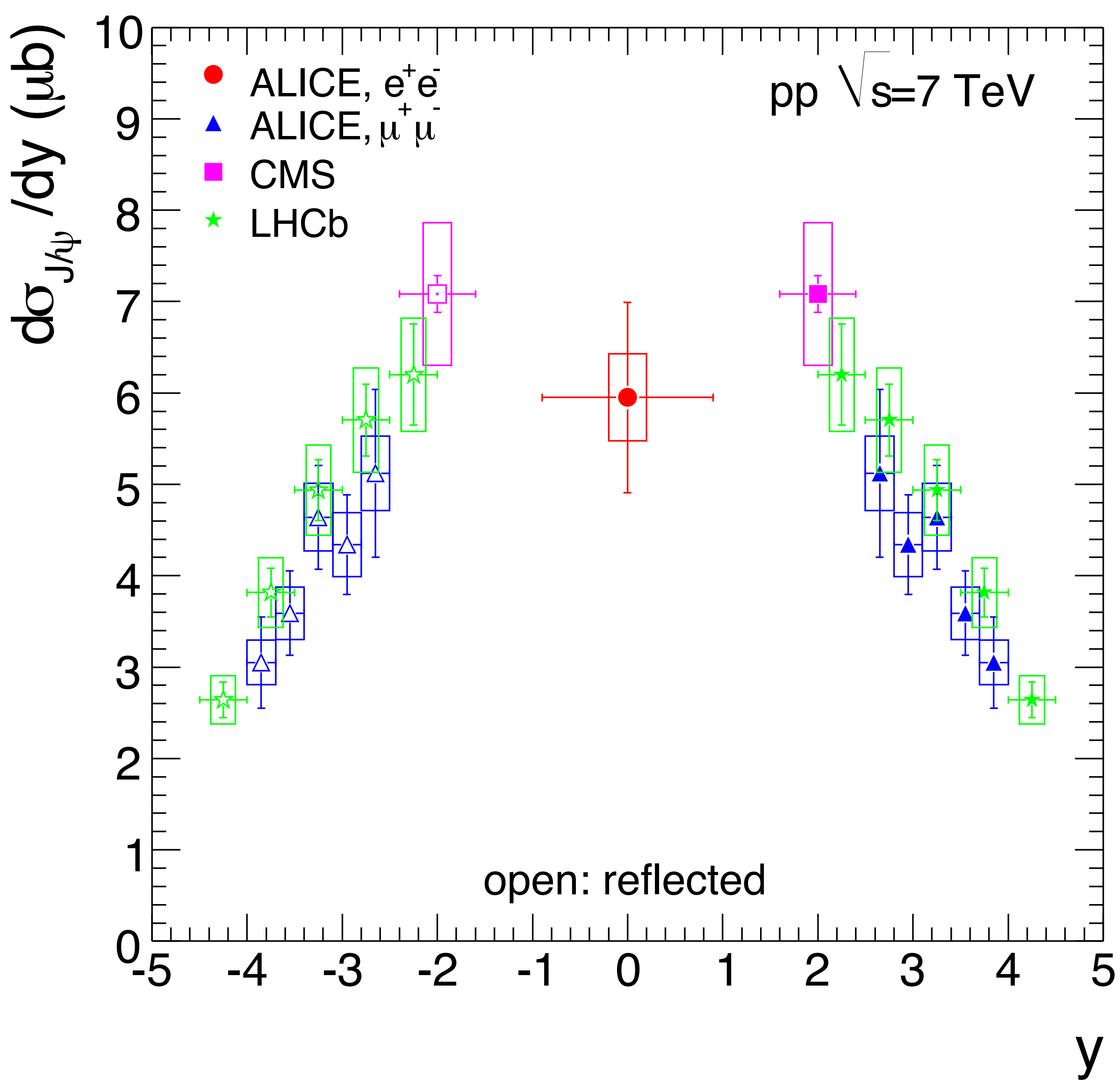
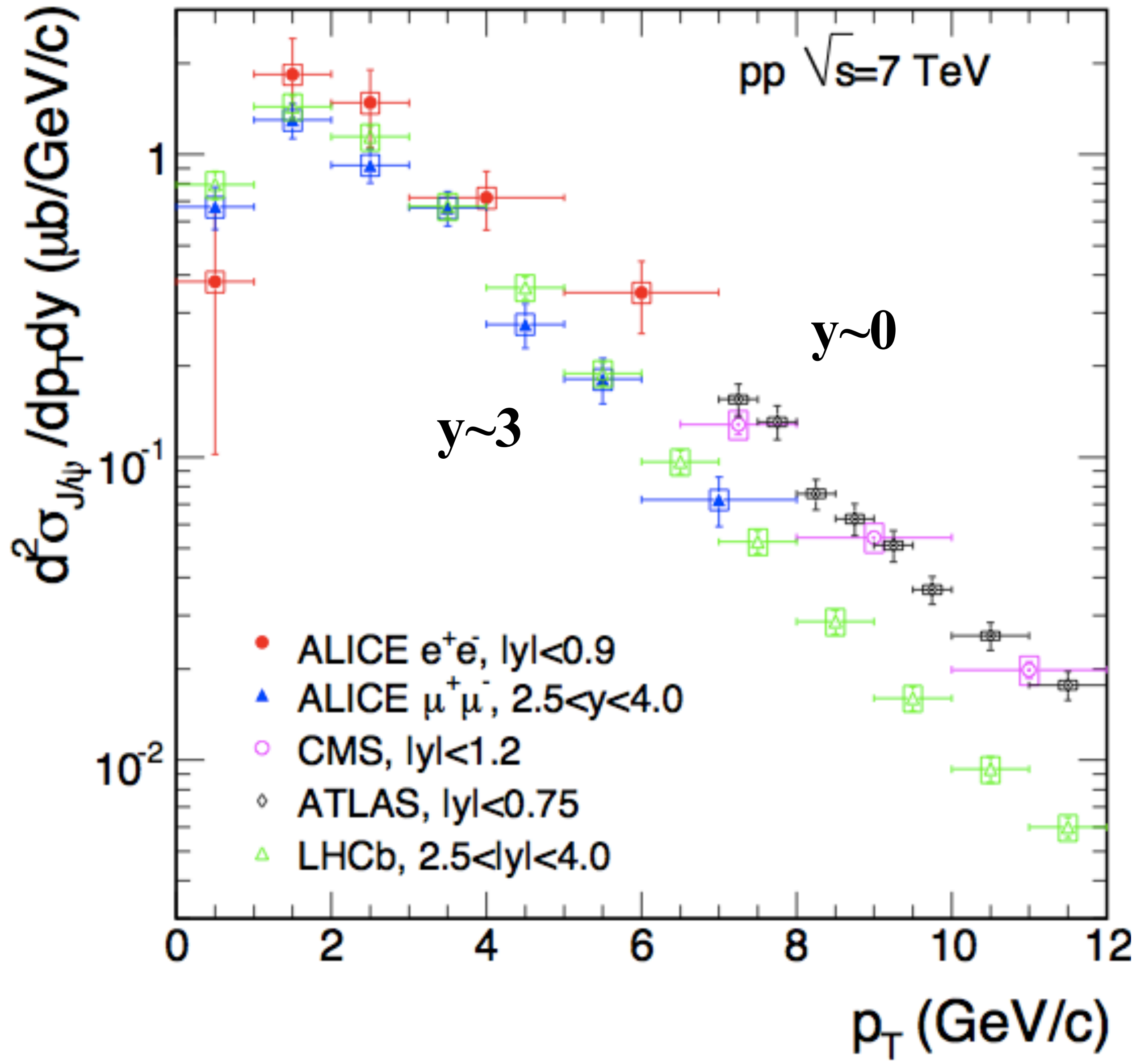


Broad y coverage down to p_T=0 → unique to ALICE

Comparison with other LHC experiments at 7 TeV

ATLAS Coll, arXiv:1104.3038, CMS Coll, arXiv:1011.4193, LHCb Coll, arXiv:1103.0423





Bars = statistical and systematic (except lumi and polarization sources)
Box = systematic from luminosity only
Good agreement between ALICE and LHCb for 2.5 < y < 4

Data vs Models

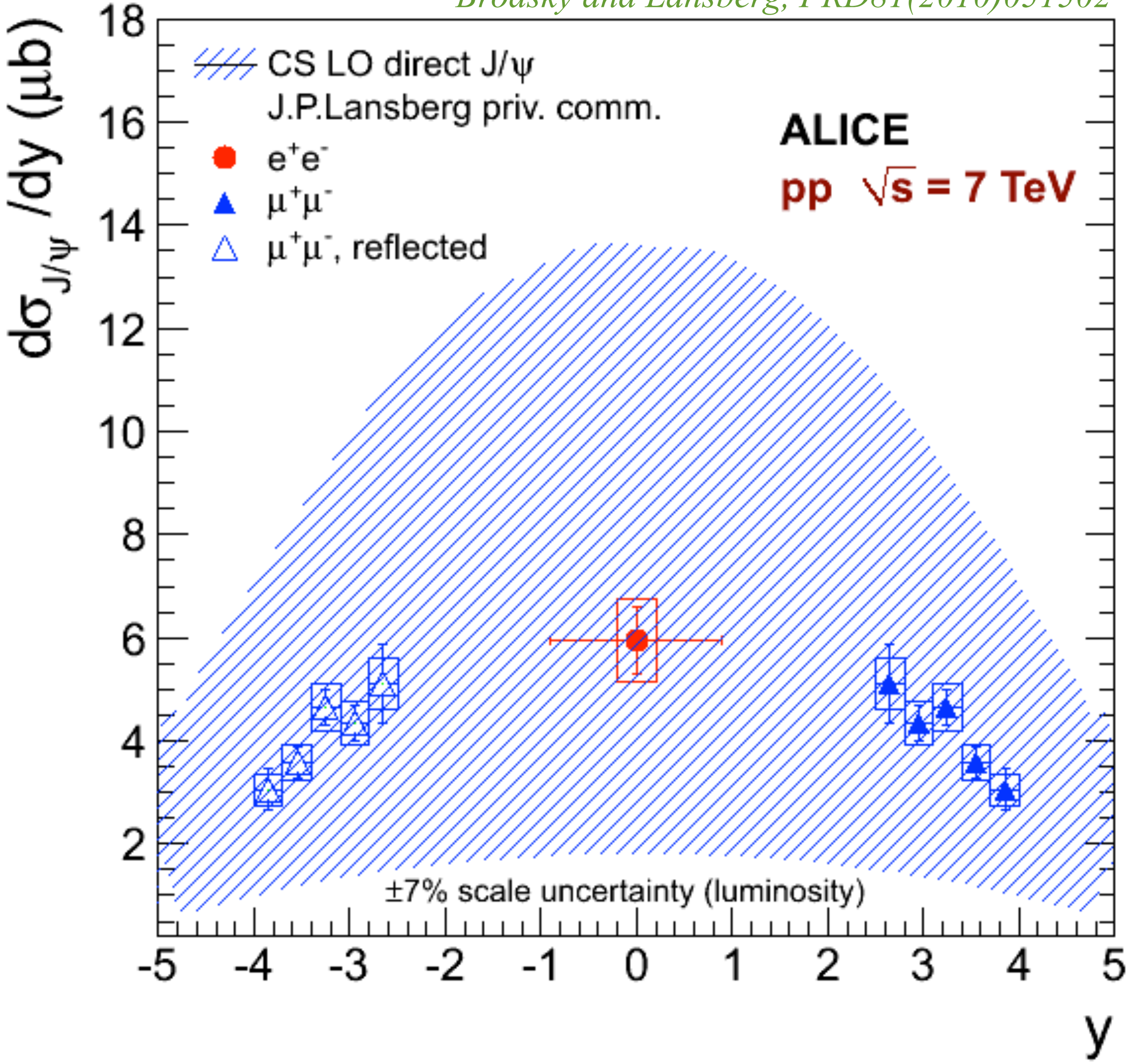
Inclusive J/ψ production @ LHC and low p_T

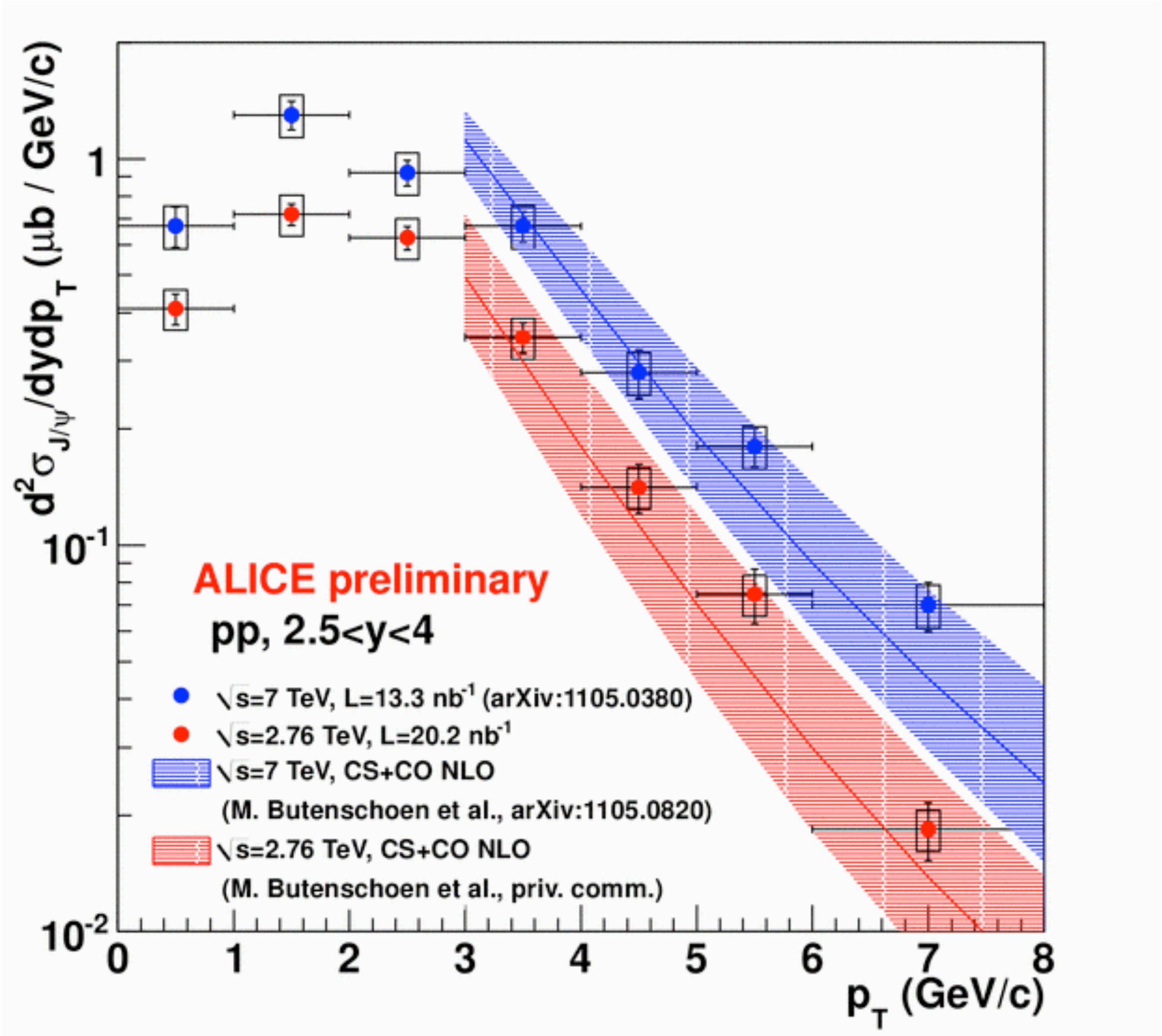
direct J/ψ ~ 50%

J/ψ feed-down from higher charmonium states χ_c and ψ' ~ 40% *PHENIX Collaboration, arXiv:1105.1966*

J/ψ from B-hadrons ~ 10% *LHCb Collaboration, arXiv:1103.0423*

Brodsky and Lansberg, PRD81(2010)051502





CS LO for direct J/ψ production ok but large uncertainty → CO not significant for low p_T

CS+CO NLO (NRQCD) fits to World data for inclusive J/ψ (included CDF and LHC@7 TeV) reproduces well the p_T dependence > 3 GeV/c

J/ψ production vs charged multiplicity

Highest charged particle multiplicity ($dN_{ch}/d\eta_{max}$ ~30) reached in pp @ 7 TeV is comparable with CuCu collisions (for semi-peripheral collisions 50-55%) @ 200 GeV

→ collective effects in p-p collisions at high multiplicity at LHC?

Silicon Pixel Detector for charged particle multiplicity measurement

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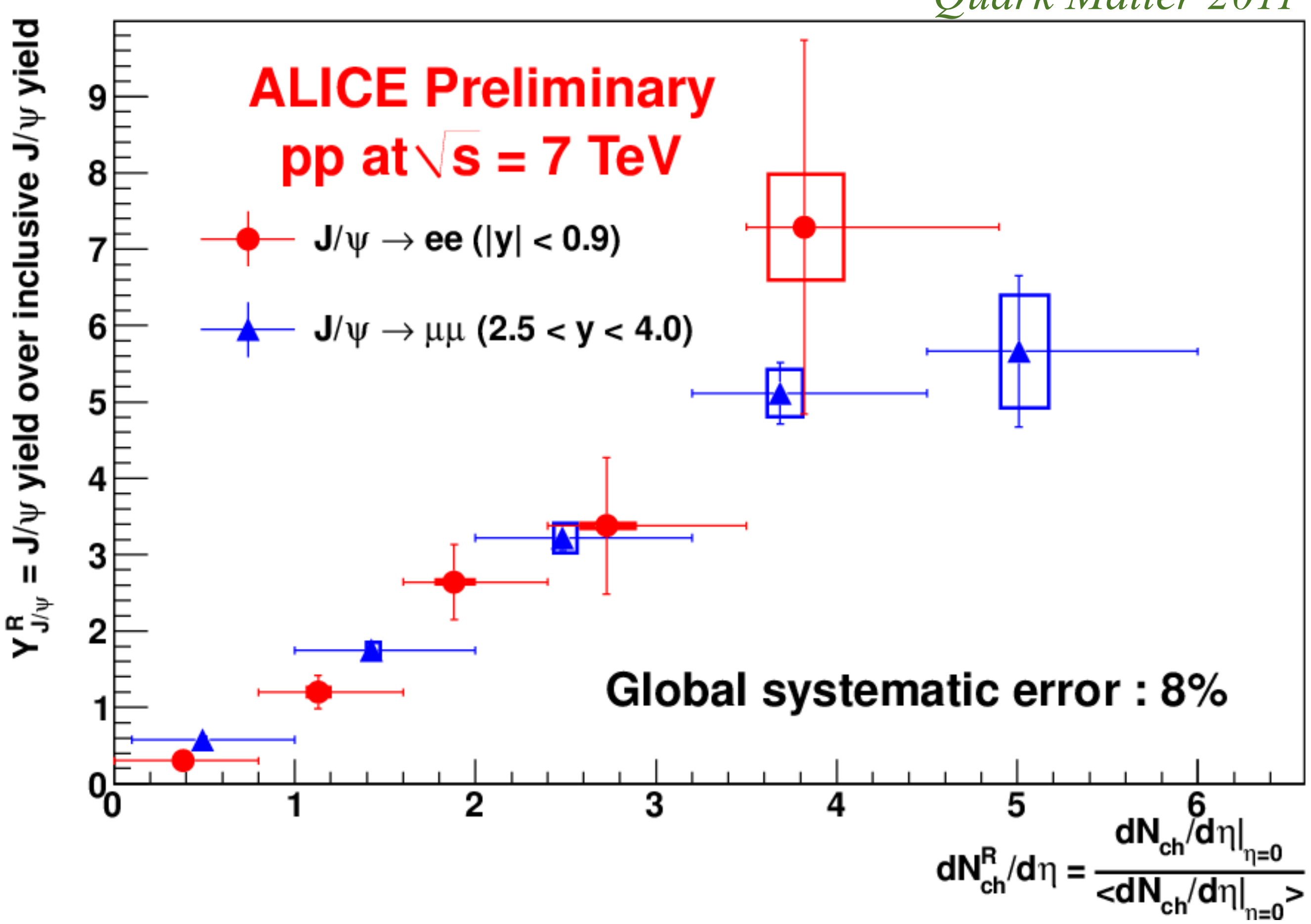

Linear increases of J/ψ yield with charged particle multiplicity

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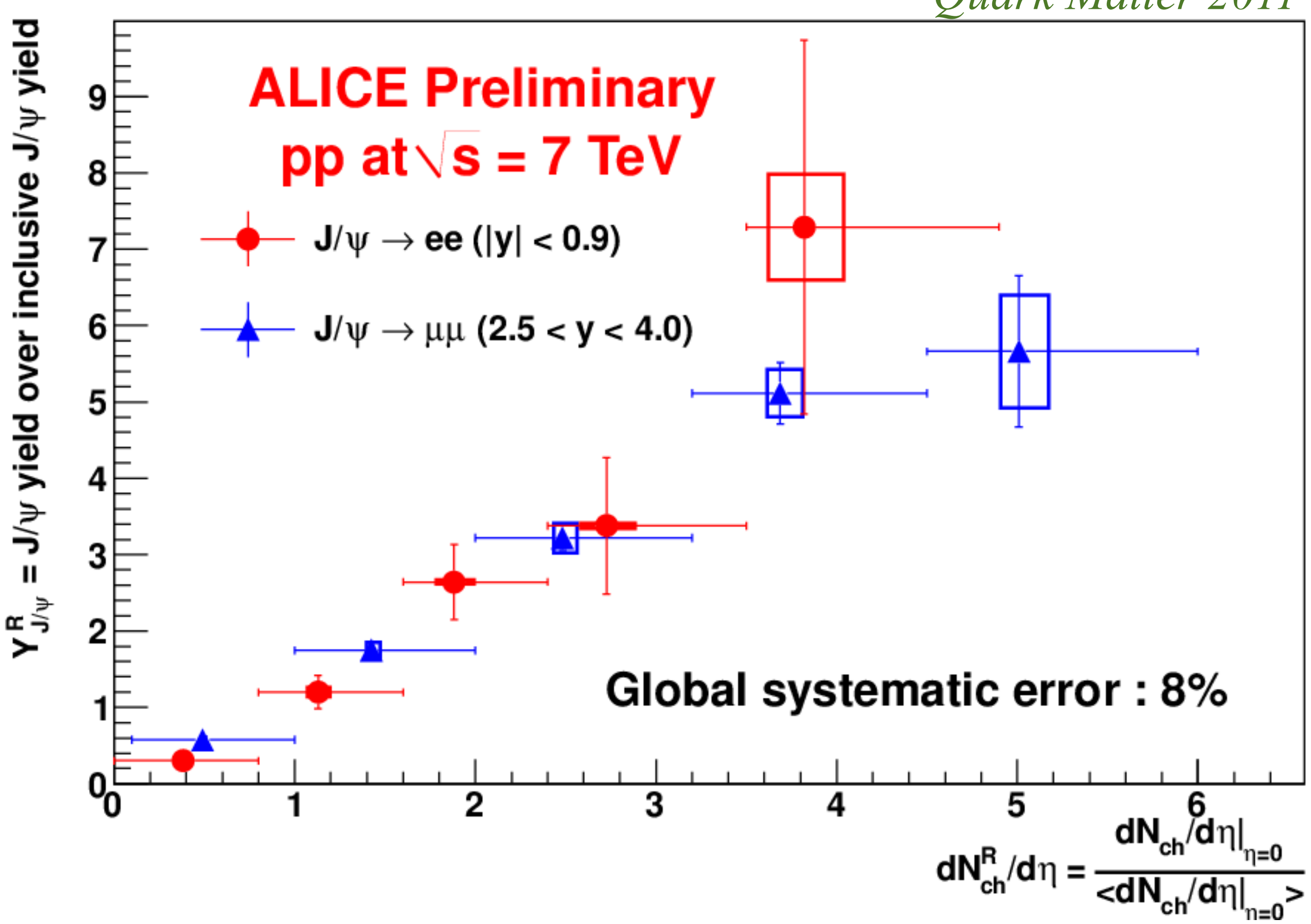
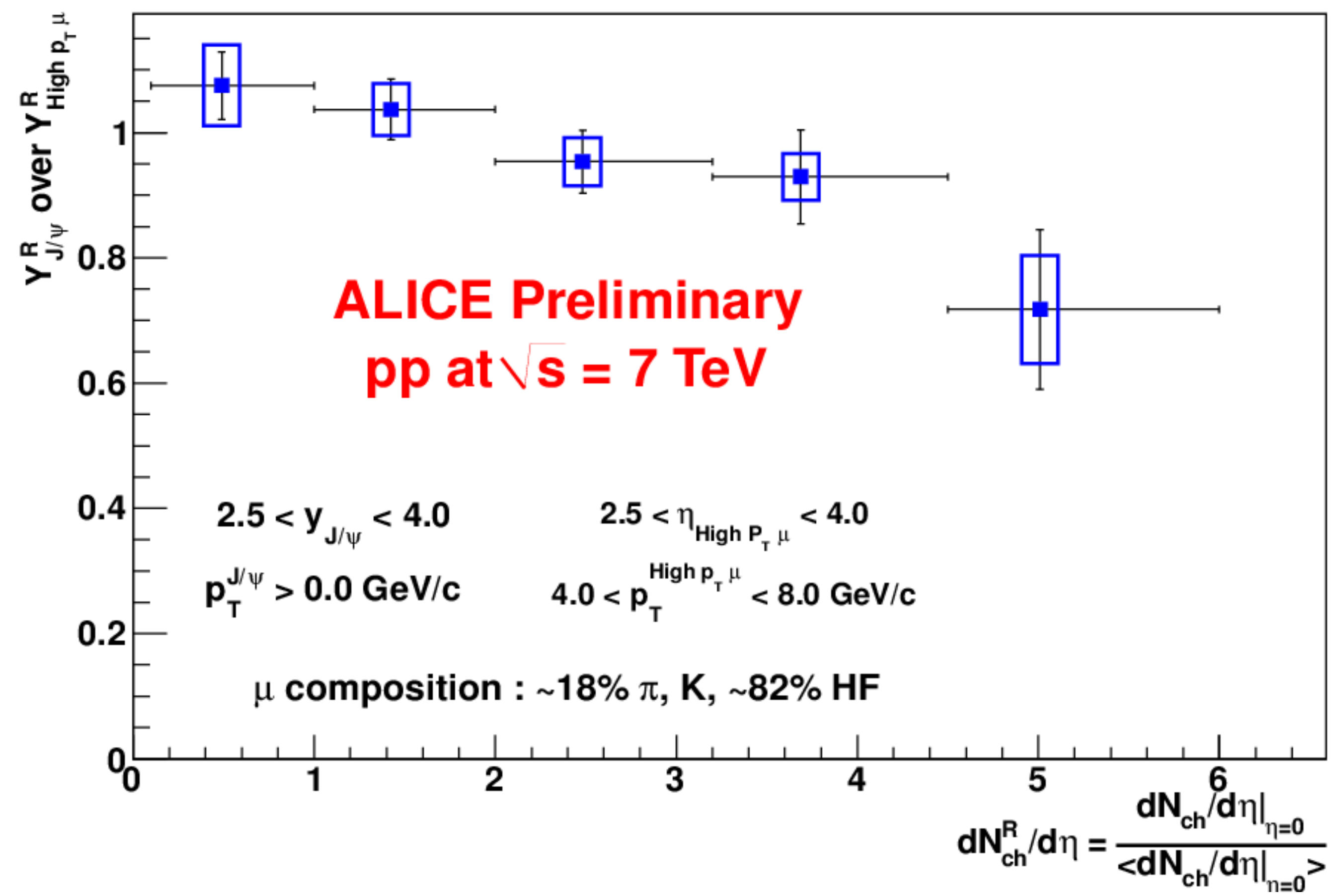




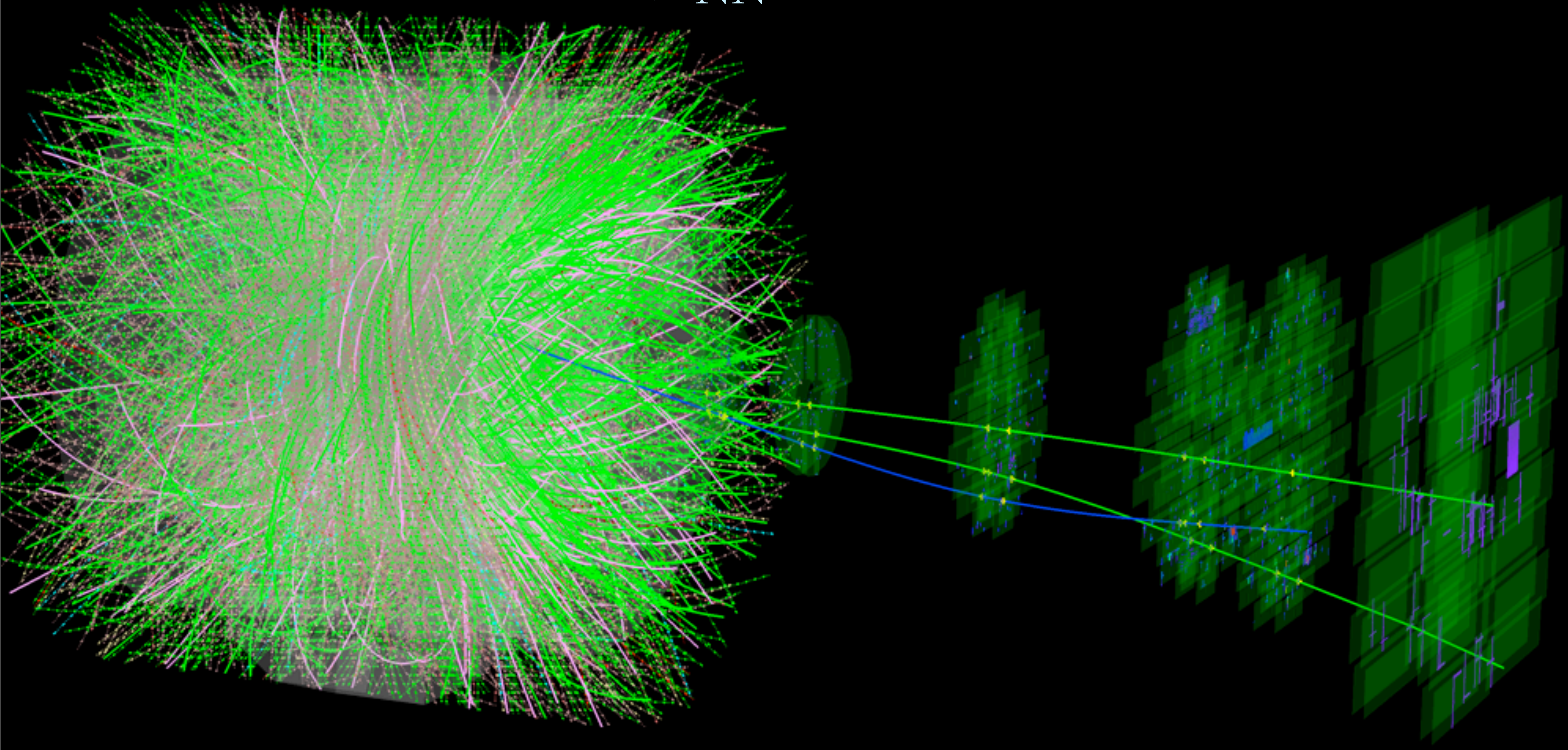
Linear increases of J/ψ yield with charged particle multiplicity

J/ψ yield increases different from high p_T muons (~80% heavy flavour decay)

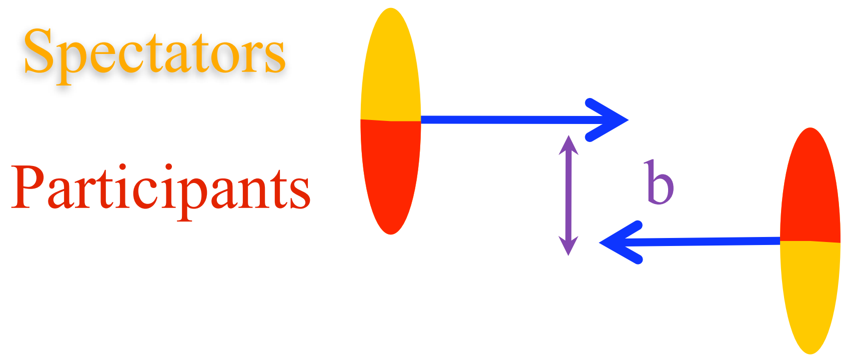
Different behaviors between J/ψ and high p_T muons at high multiplicity?

Understanding of multi-partonic interactions in p-p collisions needed to interpret these data.

J/ψ measurements in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV

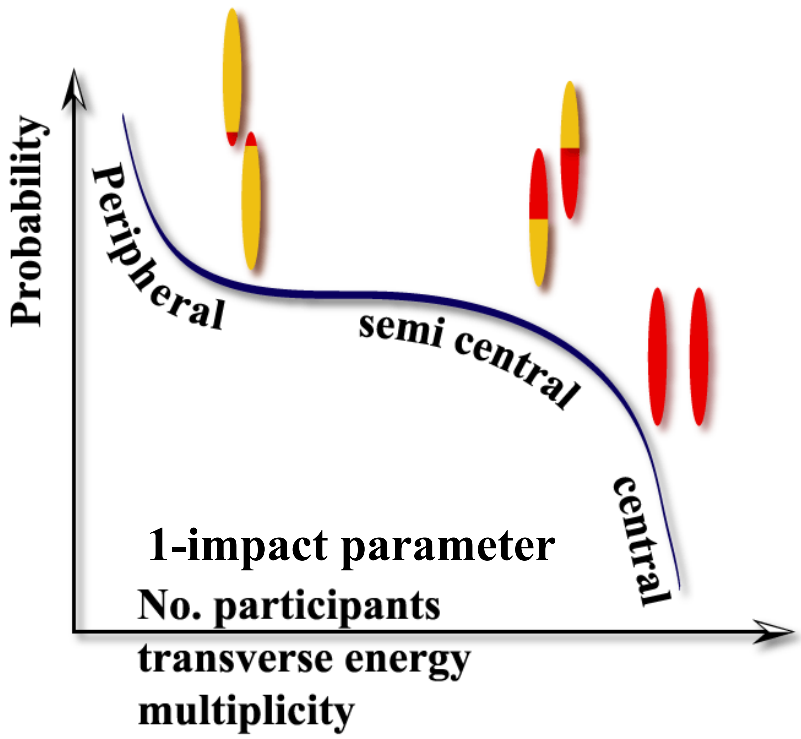


Geometry of the Pb-Pb collisions and event centrality determination



Small impact parameter b (b ~ 0)

→ high energy density
→ large number of participants N_{part}
→ large number of produced particles



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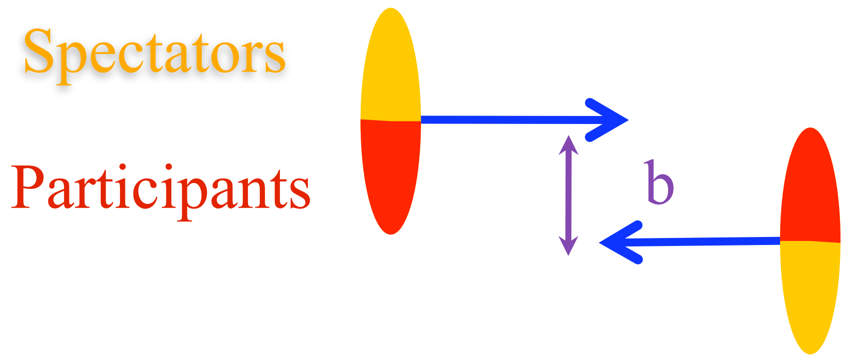

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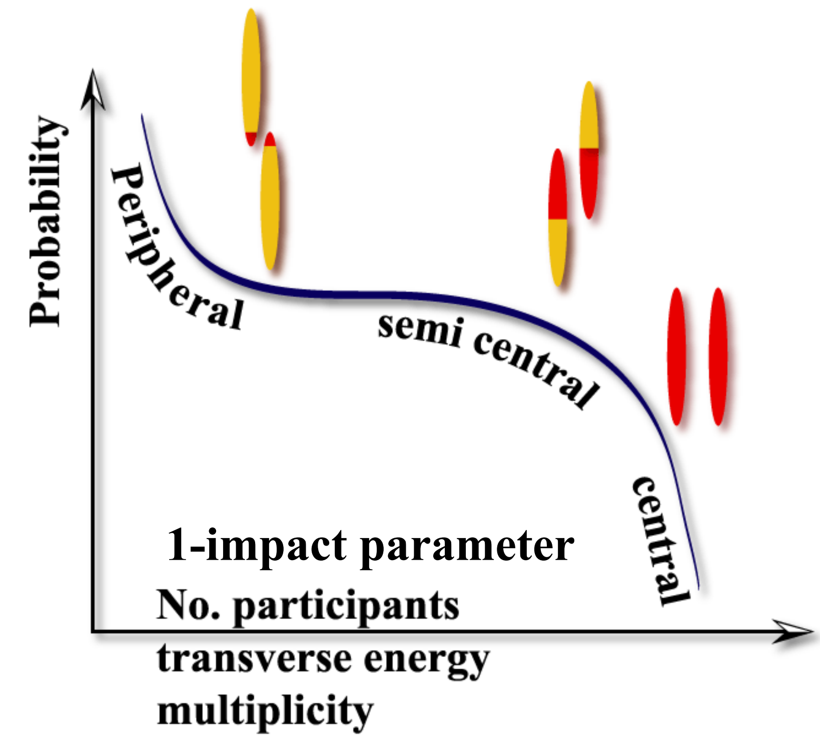


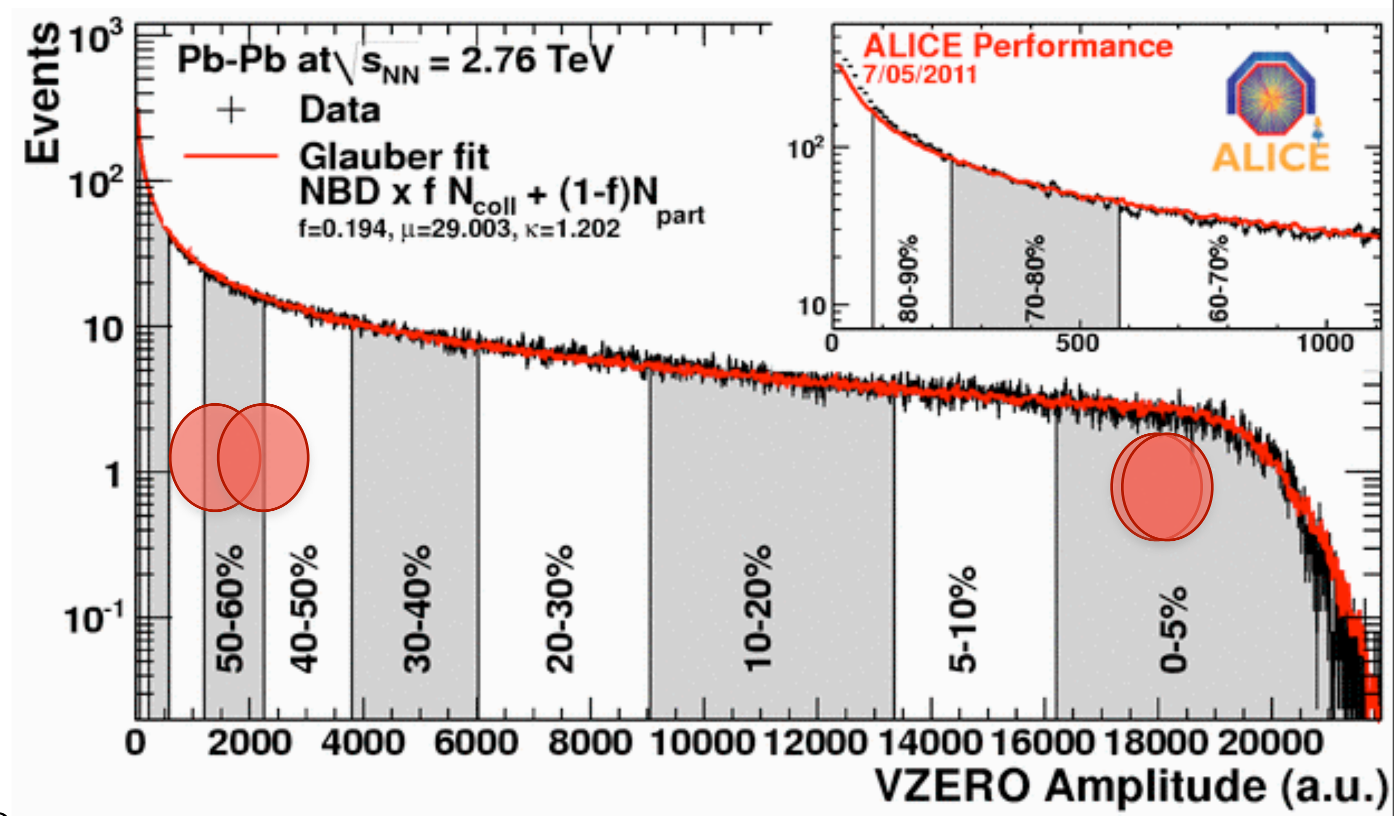
Determination of the geometry of the collisions

Centrality selection based on a Glauber model fit of the V0 amplitude

Centrality bins defined as a fraction of the inelastic Pb-Pb cross section = "event centrality"

From Glauber model:

centrality bin → b, N_{part}, N_{coll}



electrons

2 bins [0-40] and [40-80]%

muons

4 bins used [0-10], [10-20], [20-40] and [40-80]%

J/ψ signal extraction in Pb-Pb collisions at $\sqrt{s}$ = 2.76 TeV

$J/\psi \rightarrow \mu^+ \mu^-$
$2.5<y<4$, $p_T>0$

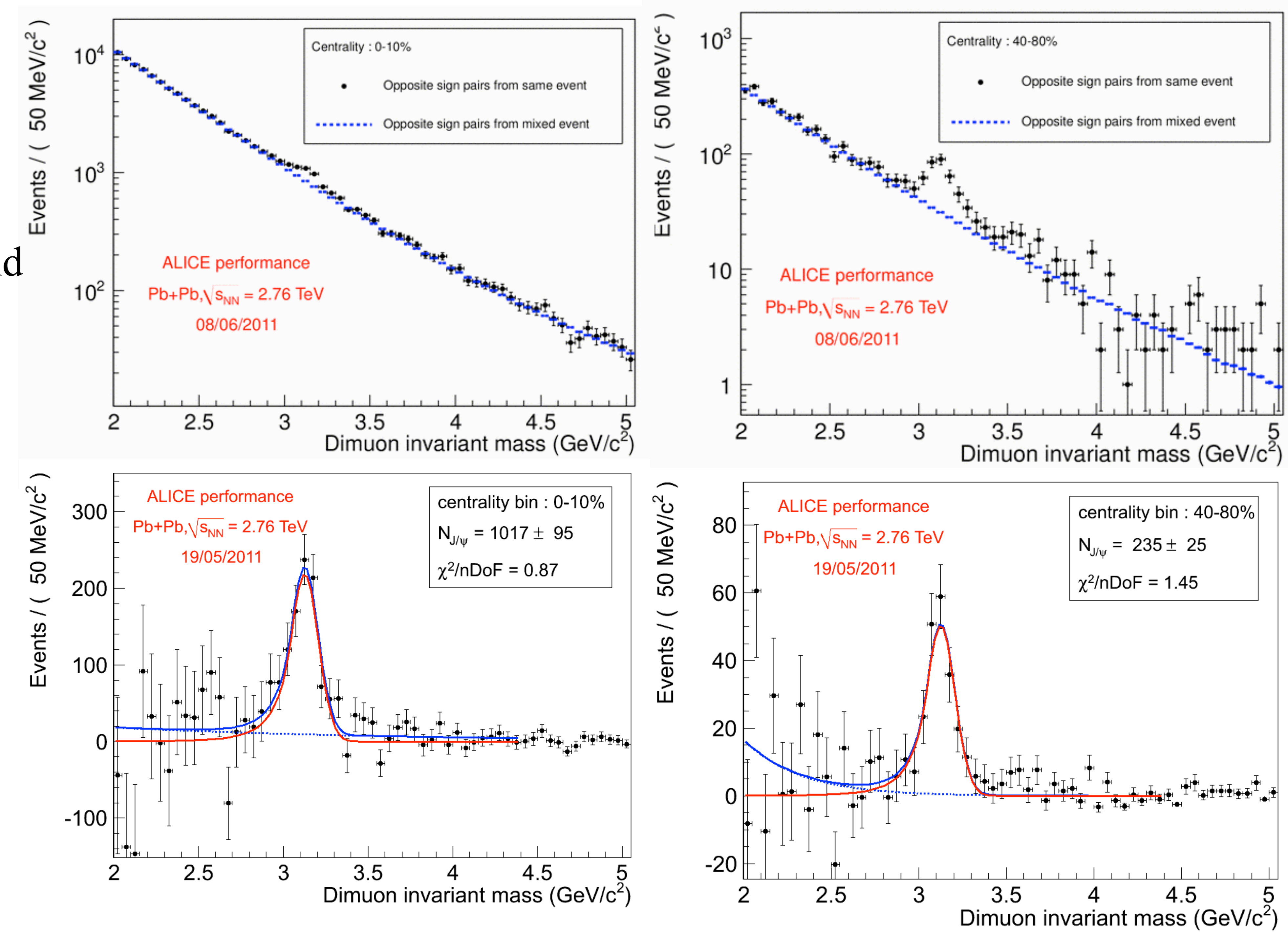
0-10%   40-80%

Event mixing technique

Muon pairs from different event = uncorrelated background

Mixed pair inv. mass normalized to data in [1.5;2.5] GeV/c^2

Residual background estimated by a Crystal Ball+ exponential fit



For central collisions, S/B~0.1 → main systematics from signal extraction

R_{AA} vs centrality

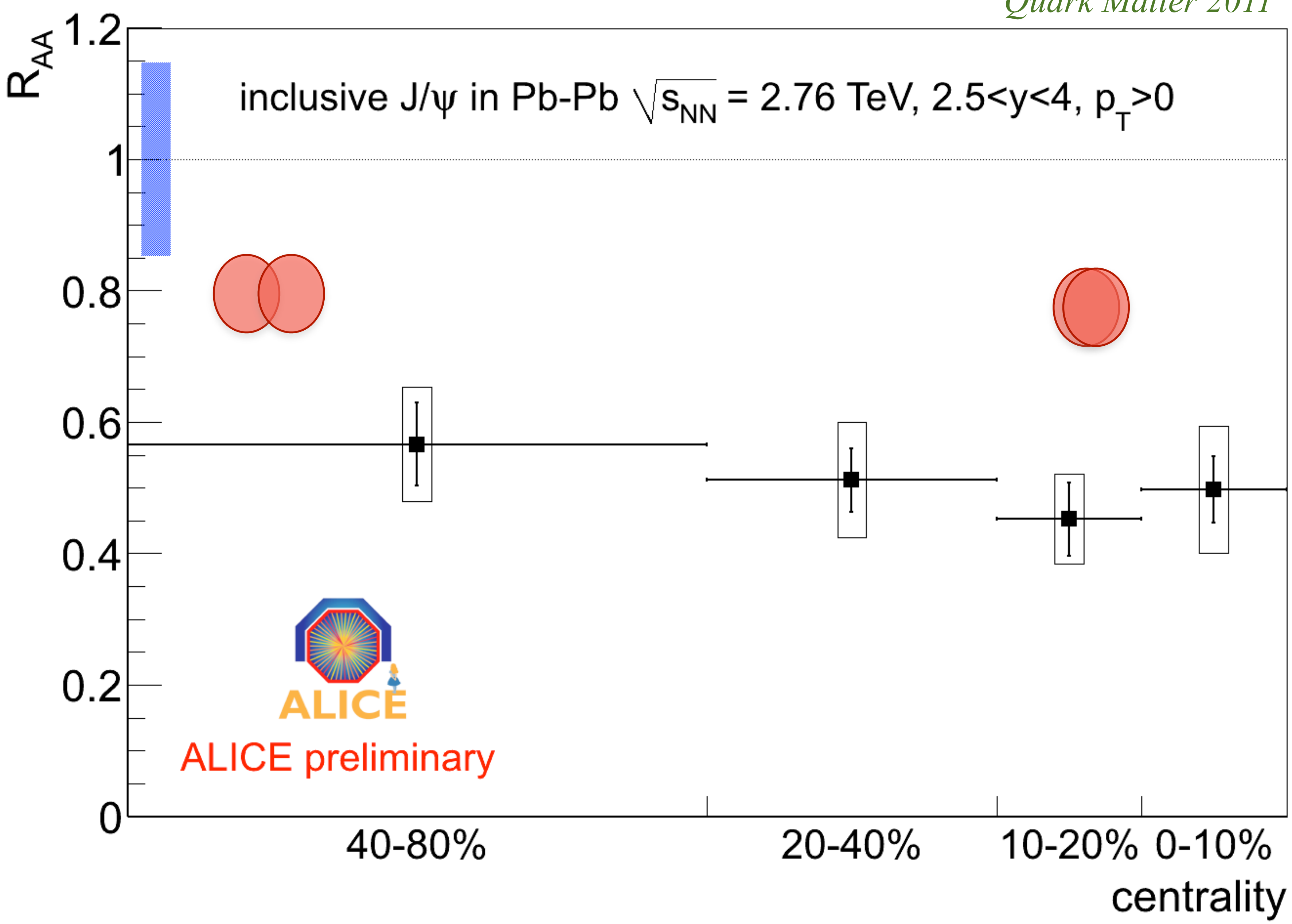
$$Y^i_{J/\psi} = \frac{N^i_{J/\psi}}{B.R. \times AccEff \times N^i_{MB}}$$

$$R^i_{AA} = \frac{Y^i_{J/\psi}}{< T^i_{AA} > \times \sigma^{inclusive}_{J/\psi}(2.76TeV)}$$

$L_{int} = 2.7\ \mu b^{-1}$

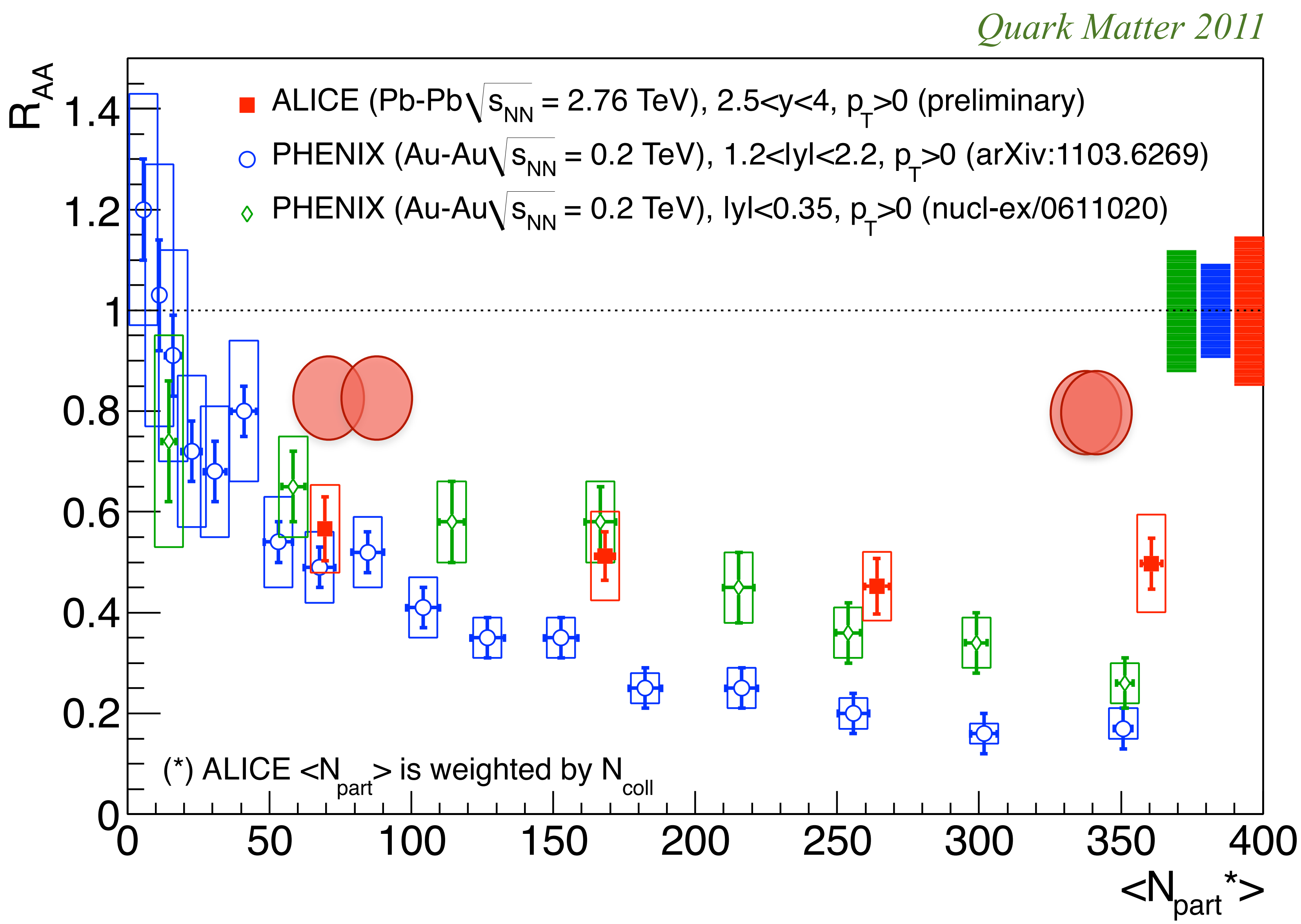
Inclusive J/ψ $R_{AA}^{0\text{-}80\%} = 0.49 \pm 0.03$ (stat.) ± 0.11 (sys.)

Quark Matter 2011



Almost flat centrality dependence !

R_{AA} vs N_{part}



In the most central collisions, larger suppression measured at RHIC for p_T>0!
Role of ccbar recombination?

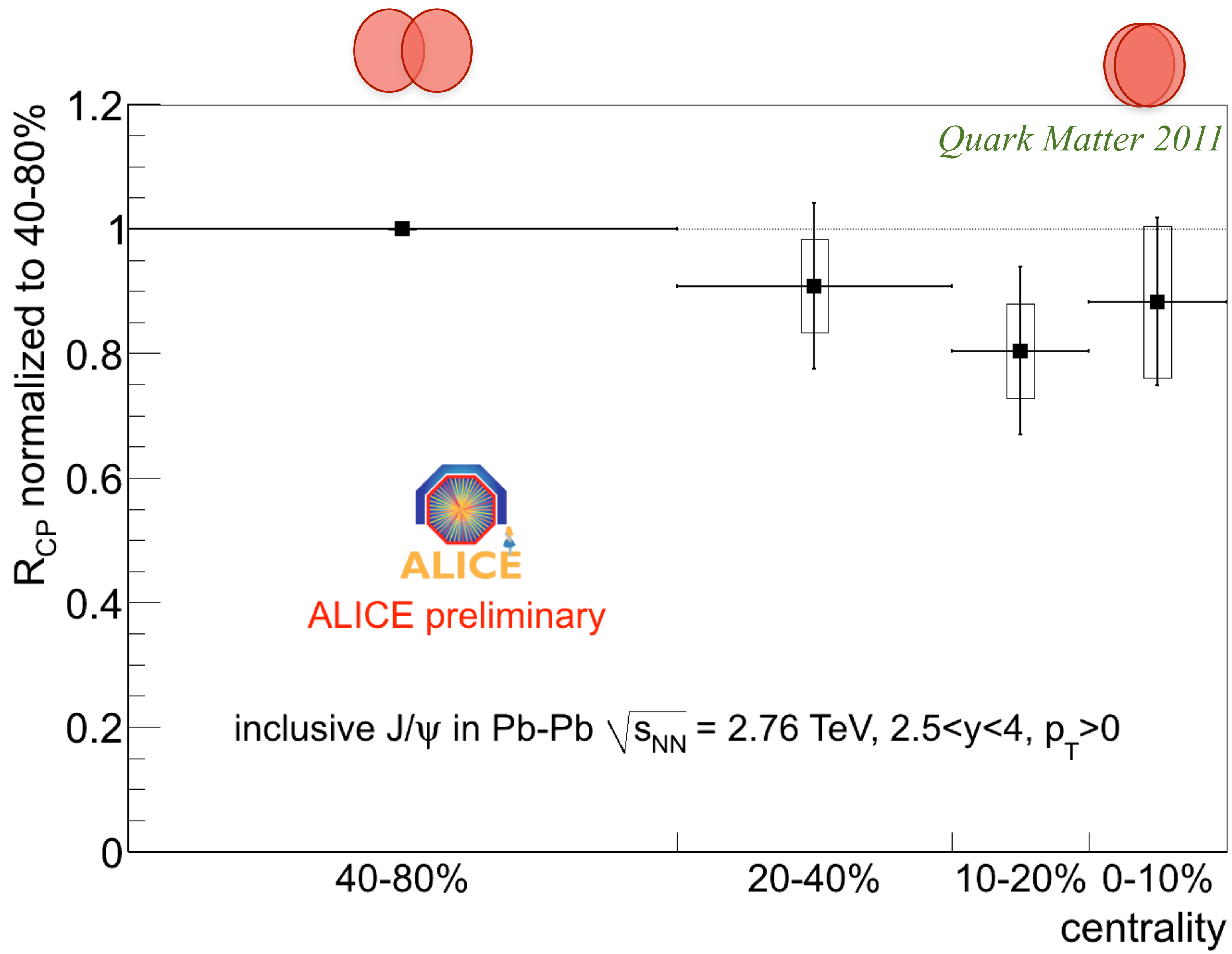
Cold nuclear matter effects unknown at LHC → p-Pb

R_{CP} vs centrality in Pb-Pb collisions

$$Y^i_{J/\psi} = \frac{N^i_{J/\psi}}{B.R. \times AccEff \times N^i_{MB}}$$

$$R^i_{CP} = \frac{Y^i_{J/\psi} \times < T^{40-80\%}_{AA} >}{< T^i_{AA} > \times Y^{40-80\%}_{J/\psi}}$$

R_{CP} normalized to the centrality bin 40-80%



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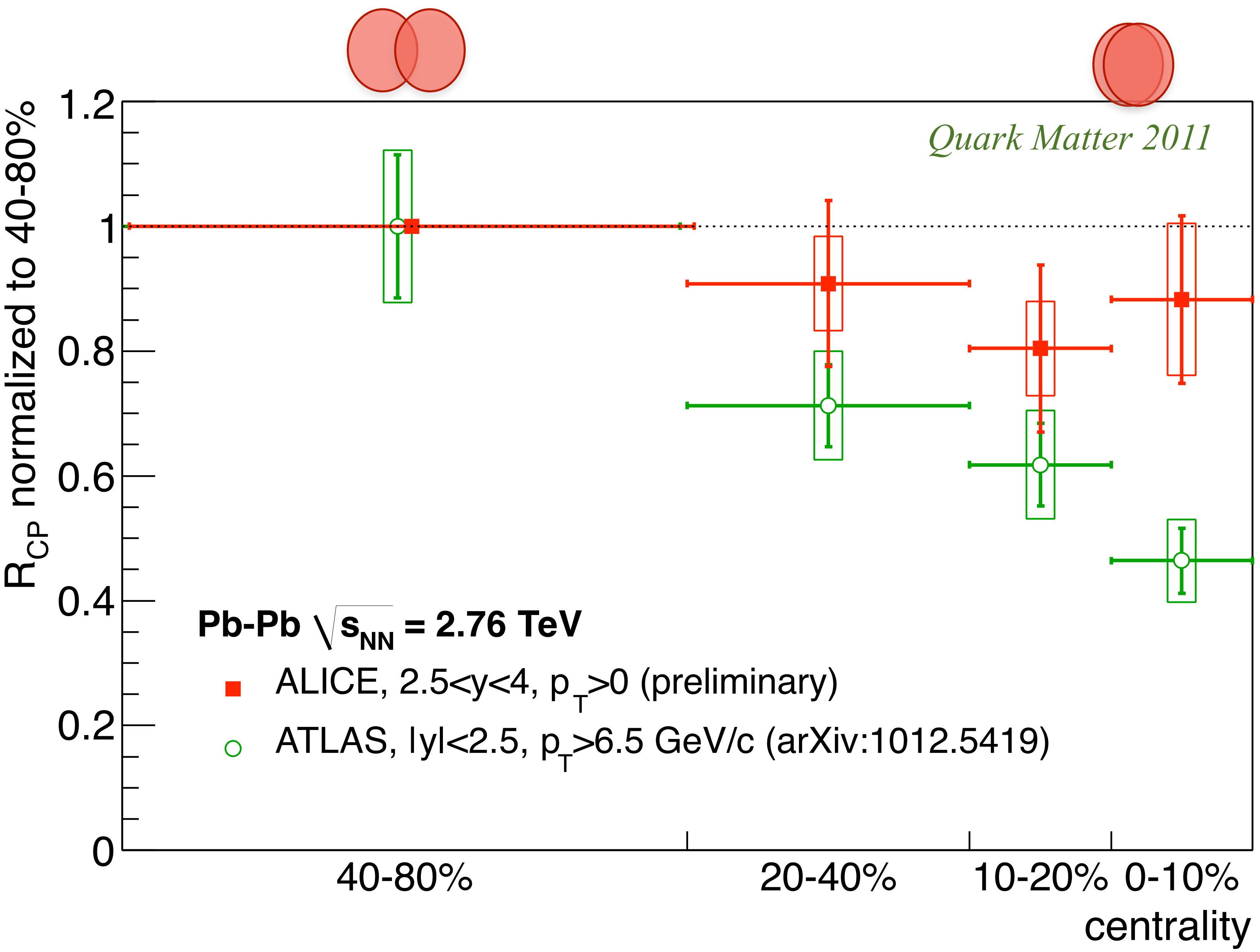
ALICE
- 2.5<y<4
- $p_T > 0$

ATLAS
- |y|<2.5
- 80% of J/ψ with $p_T > 6.5$ GeV/c

R_{CP} larger for ALICE than for ATLAS in the most central collisions… but different kinematical region

R_{CP} normalized to the centrality bin 40-80%



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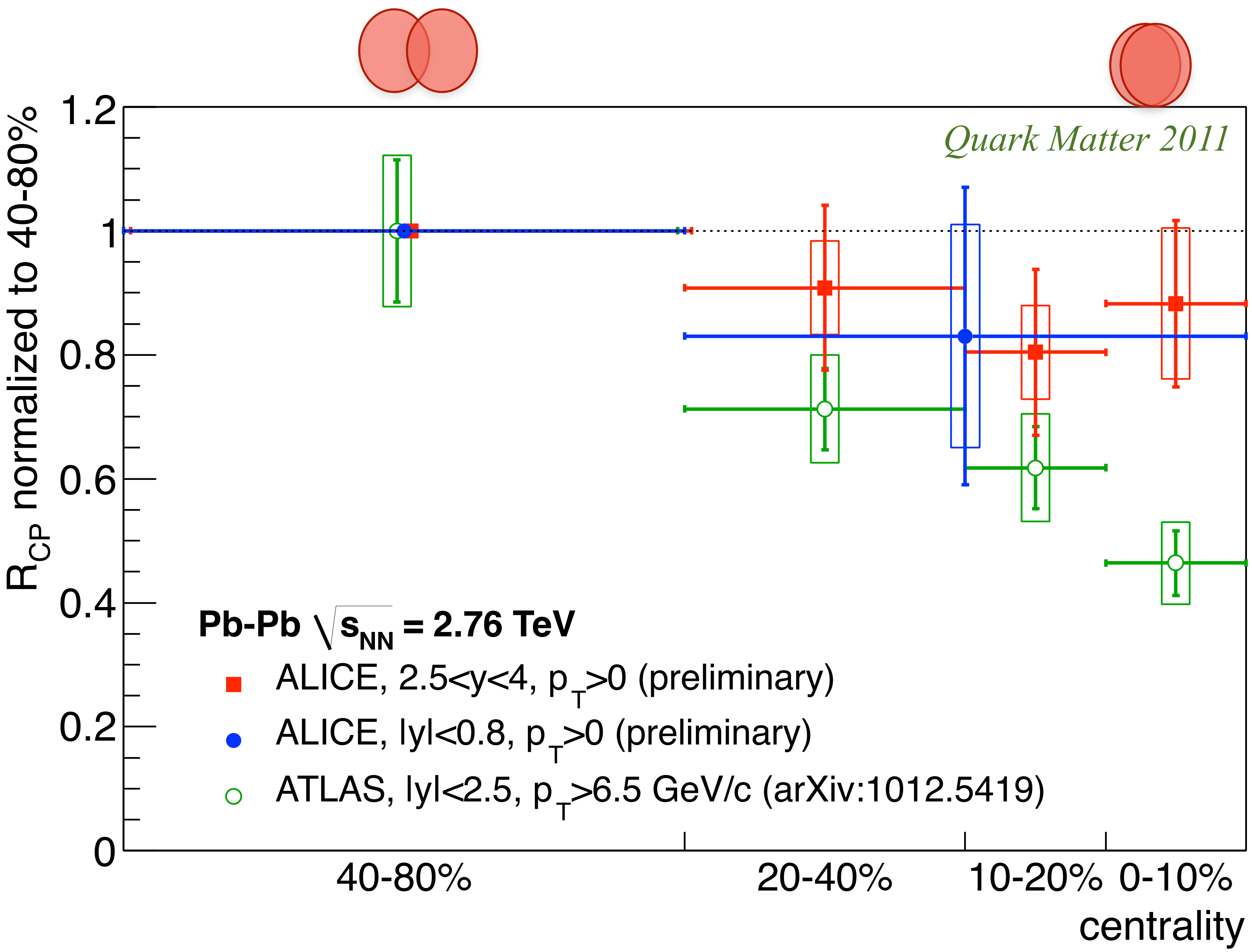
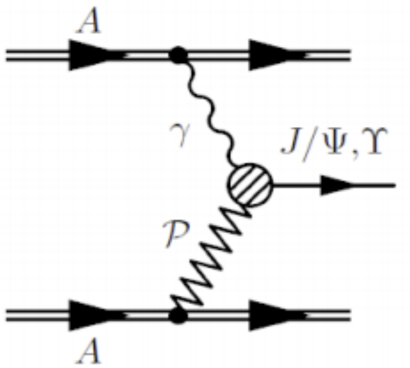


J/ψ → $e^+ e^-$ challenging analysis but crucial for y-dependent measurement

Ongoing analysis: J/ψ production in ultra-peripheral Pb-Pb collisions

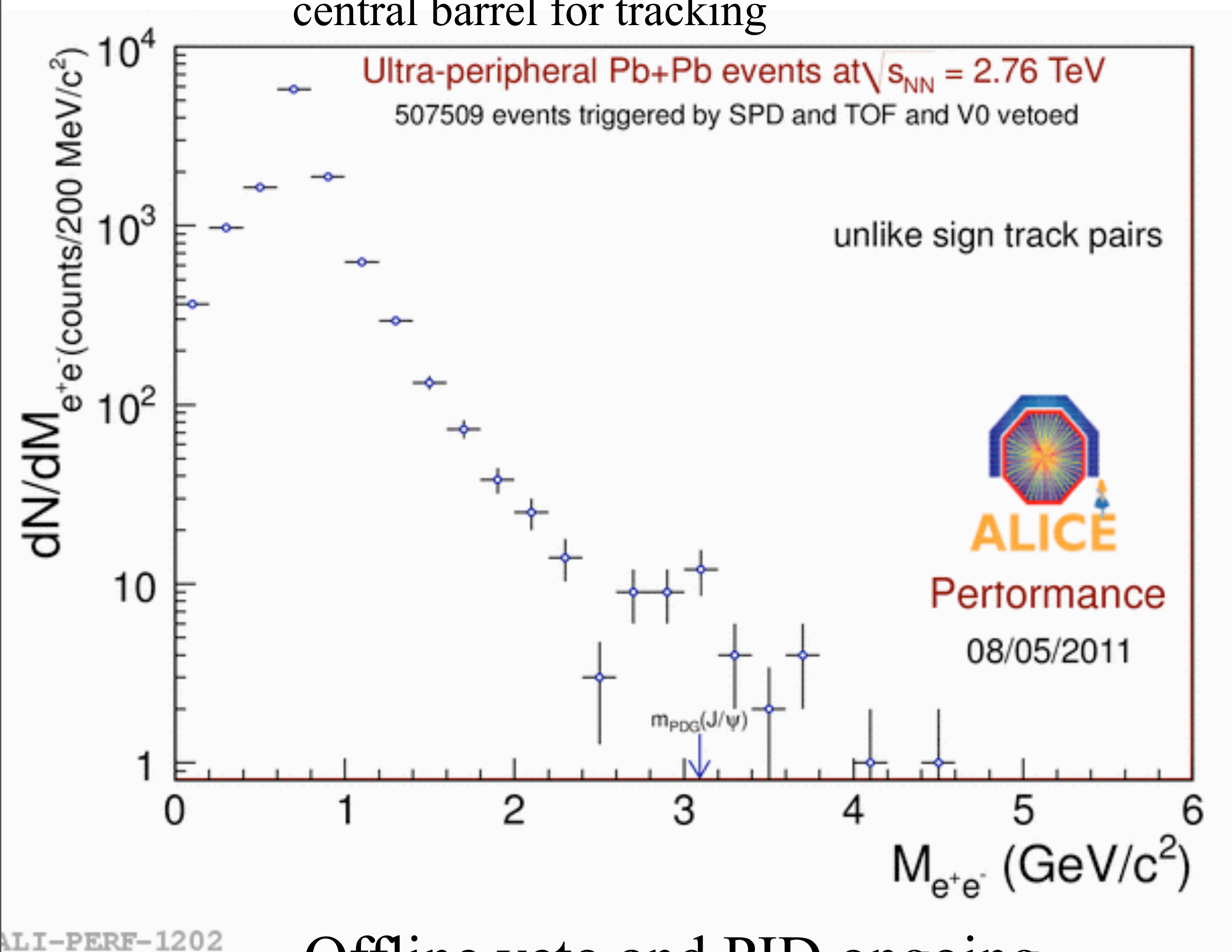


Probe the gluon distribution of the nuclei

Tag the exclusive reaction with veto on
ALICE detectors ~ 8 units of rapidity

Mid-rapidity

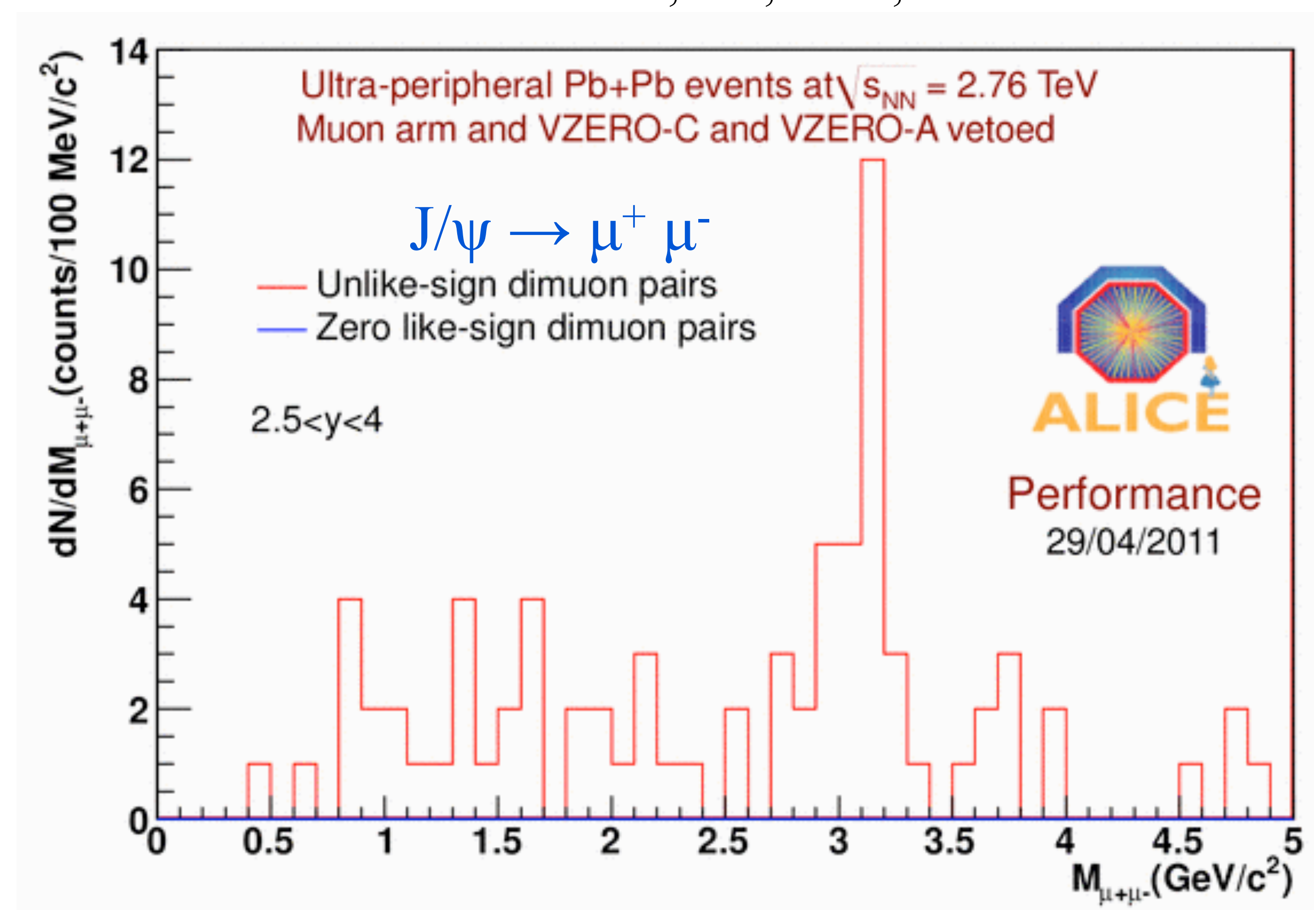
trigger on TOF && Pixel && !V0
central barrel for tracking



Offline veto and PID ongoing

Forward rapidity

trigger on Muon && V0C && !V0A
offline veto on TPC, ITS, FMD, ZDC



No like-sign dimuons!

Few tens of exclusive J/ψ candidates seen at forward and mid-rapidity
Absolute cross section measurement ongoing

Conclusion and outlook

Inclusive J/ψ measurements at $\sqrt{s}$ = 7 and 2.76 TeV in p-p collisions

- Total and differential cross sections for a broad y range and down to p_T=0
  - Cross section @ 2.76 TeV is our reference for Pb-Pb
- Yield measurement in high multiplicity events

Inclusive J/ψ production at $\sqrt{s_{NN}}$ = 2.76 TeV in Pb-Pb collisions

- Surprising results for inclusive J/ψ R_{AA} and R_{CP}
  - Almost flat centrality dependence
  - R_{AA} larger than at RHIC for most central collisions
  - Cold nuclear matter effects unknown at LHC → p-Pb needed to estimate it

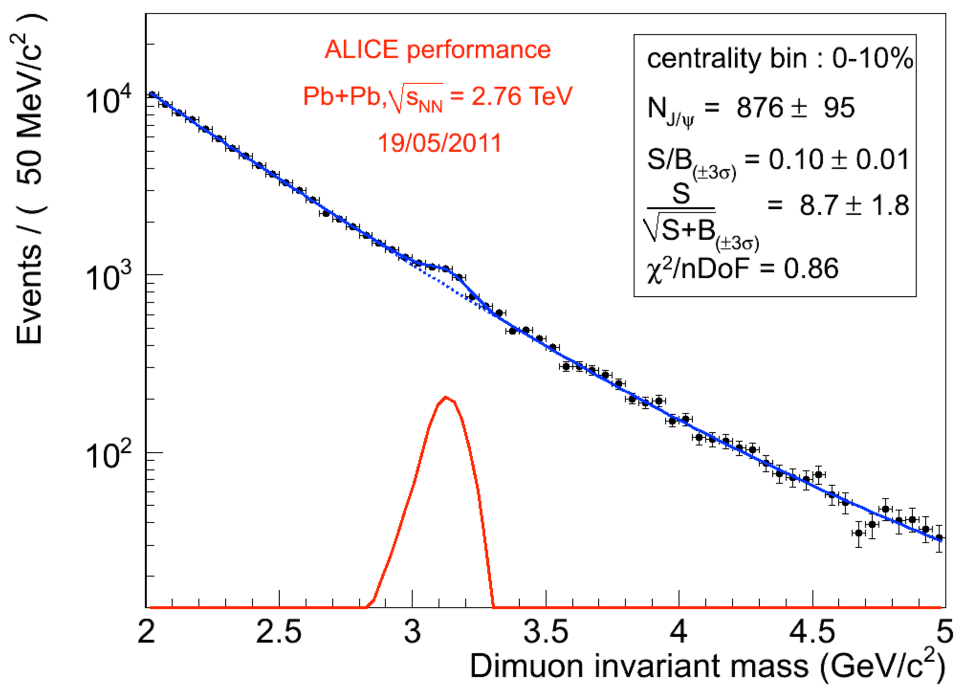
Back-up slides

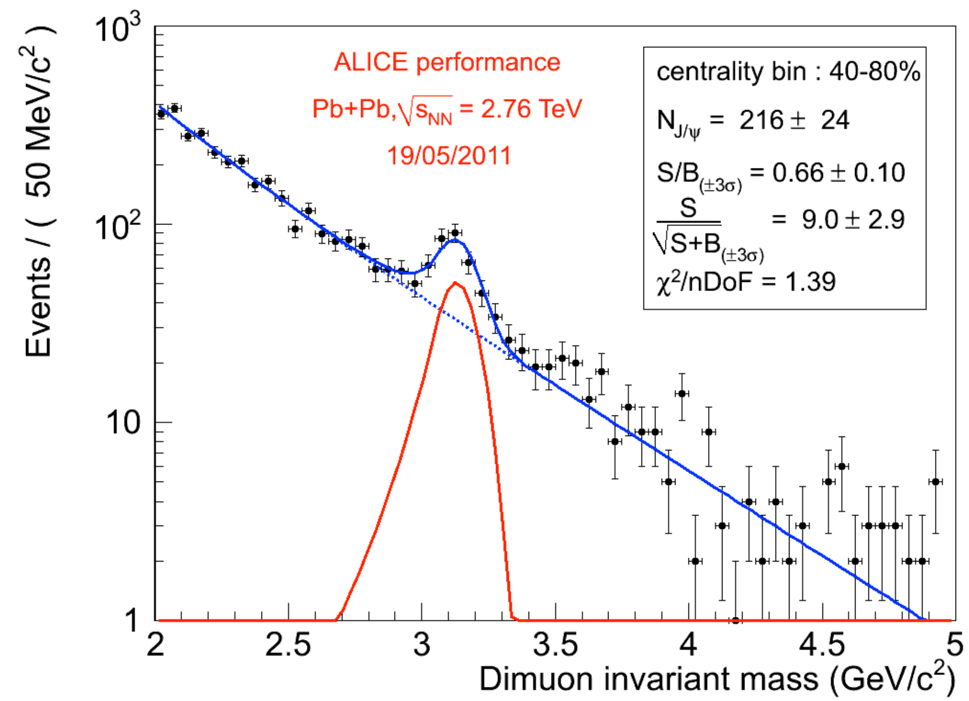
J/ψ signal extraction in Pb-Pb collisions at √s = 2.76 TeV

J/ψ → $\mu^+ \mu^-$
2.5<y<4, p_T>0

0-10% 40-80%

Invariant mass fit





Event mixing technique

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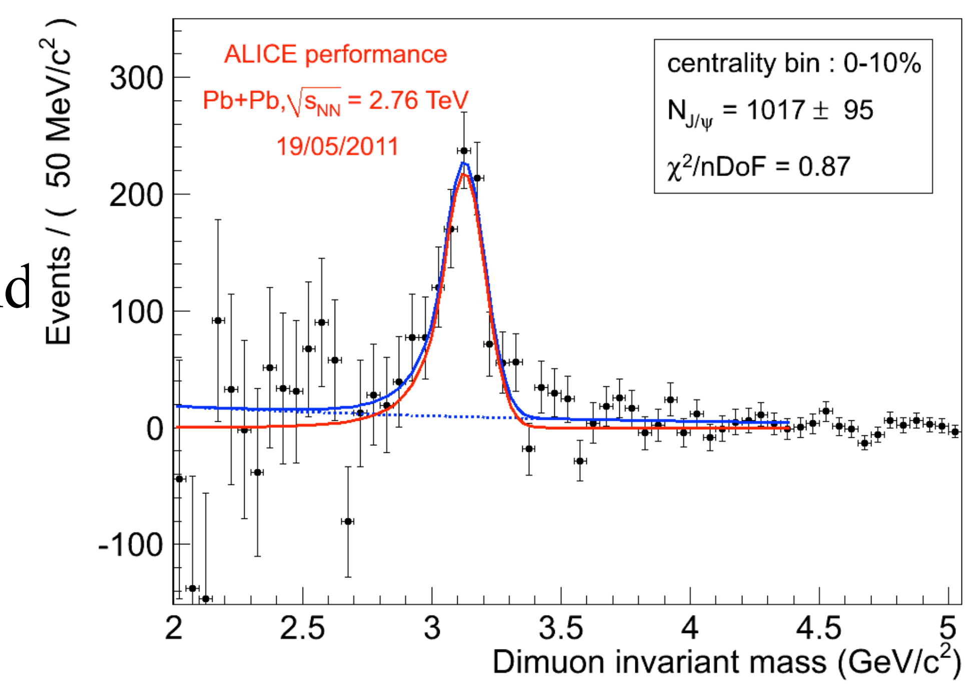
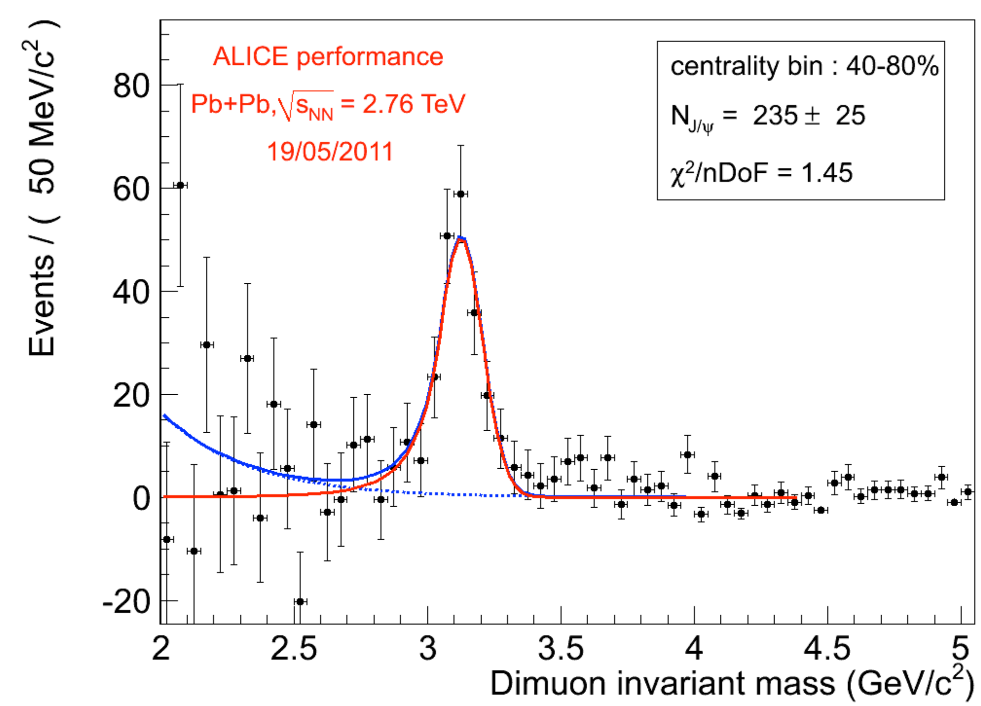




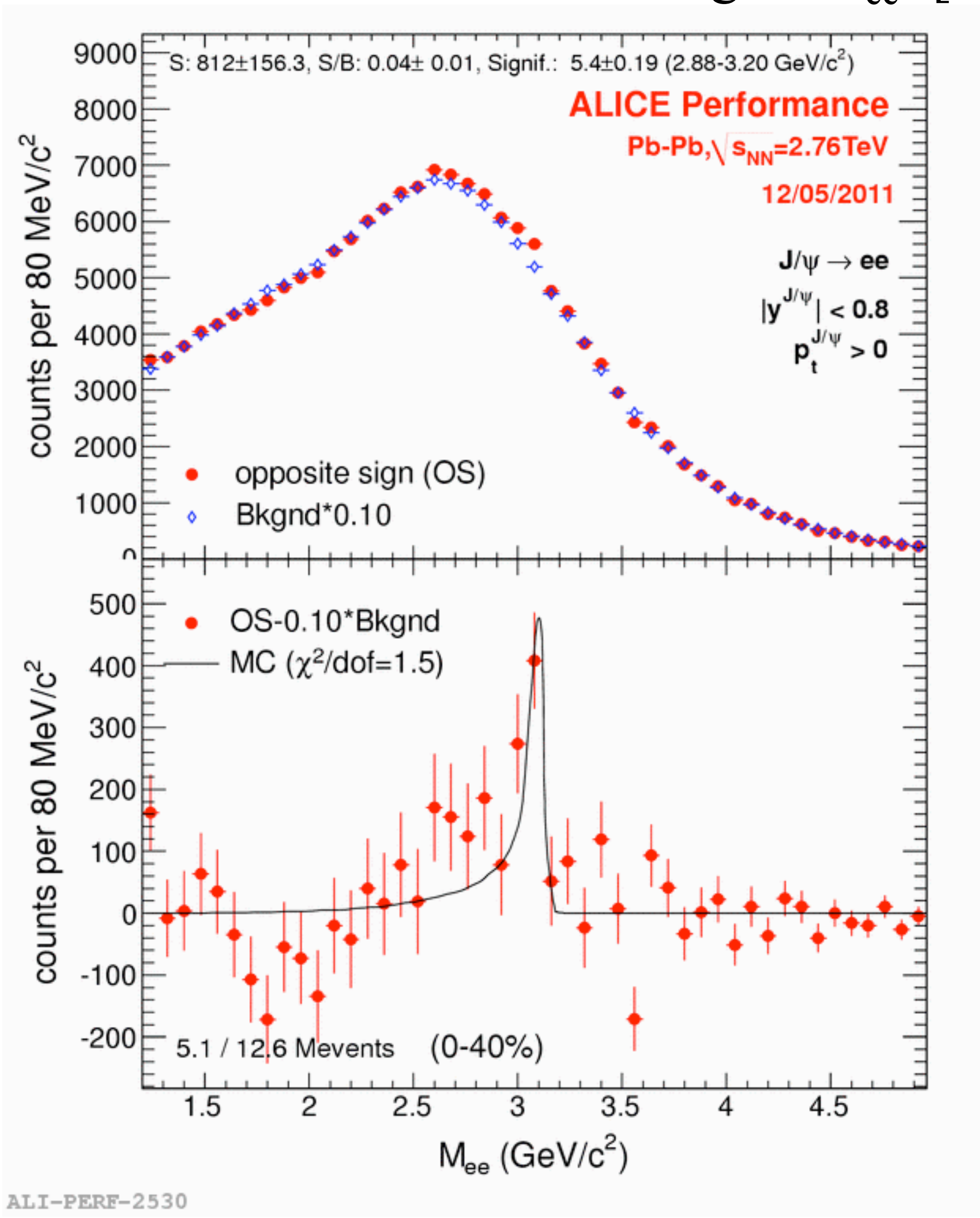
For central collisions, S/B~0.1 → main systematics from signal extraction

Signal extraction

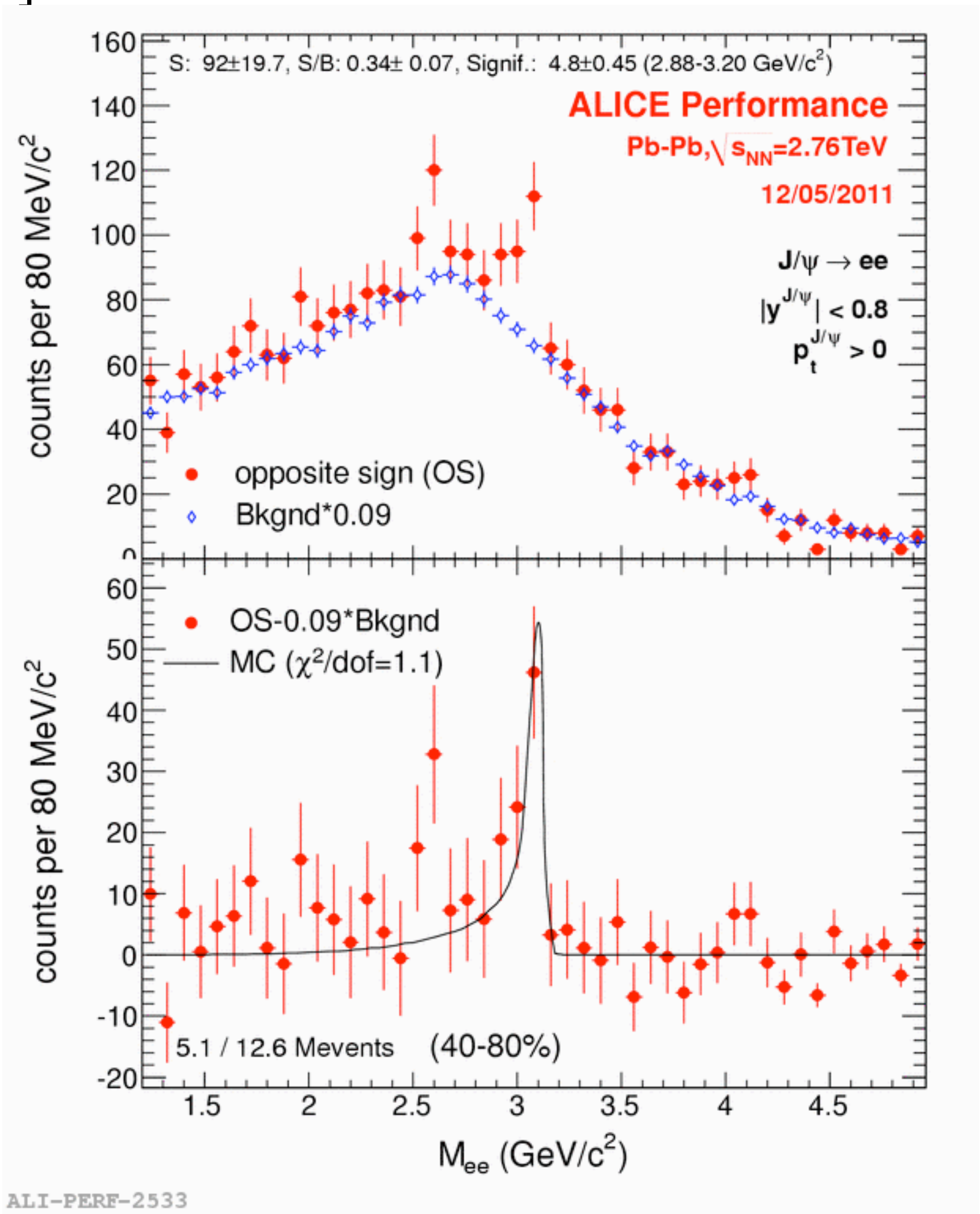
$J/\psi \rightarrow e^+ e^-$

Distribution from rotation technique normalized to like sign
Bin counting in M_{ee}=[2.88;3.2] GeV/c^2

0-40%



40-80%



Different PID strategy (TPC alone, TPC+TOF), signal extraction techniques tested
Main systematics from signal extraction and electron PID

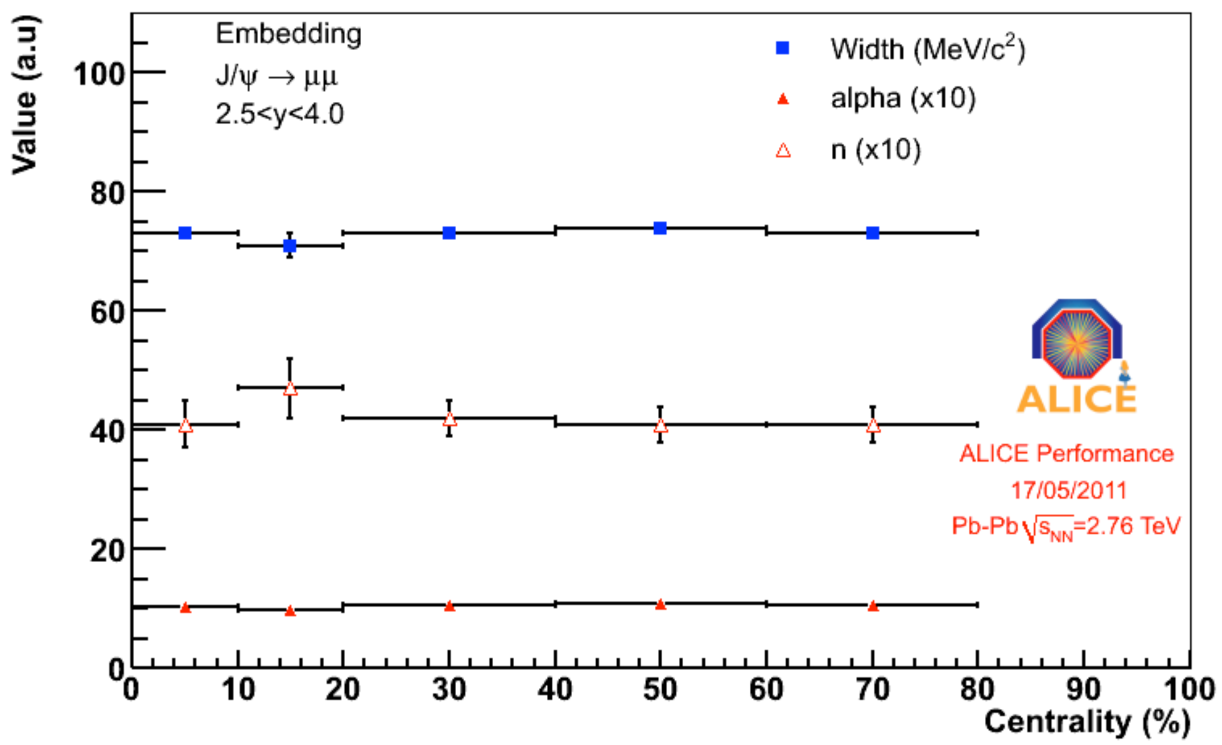
Studies on high multiplicity environment effect

$J/\psi \rightarrow \mu^+ \mu^-$

Embedding

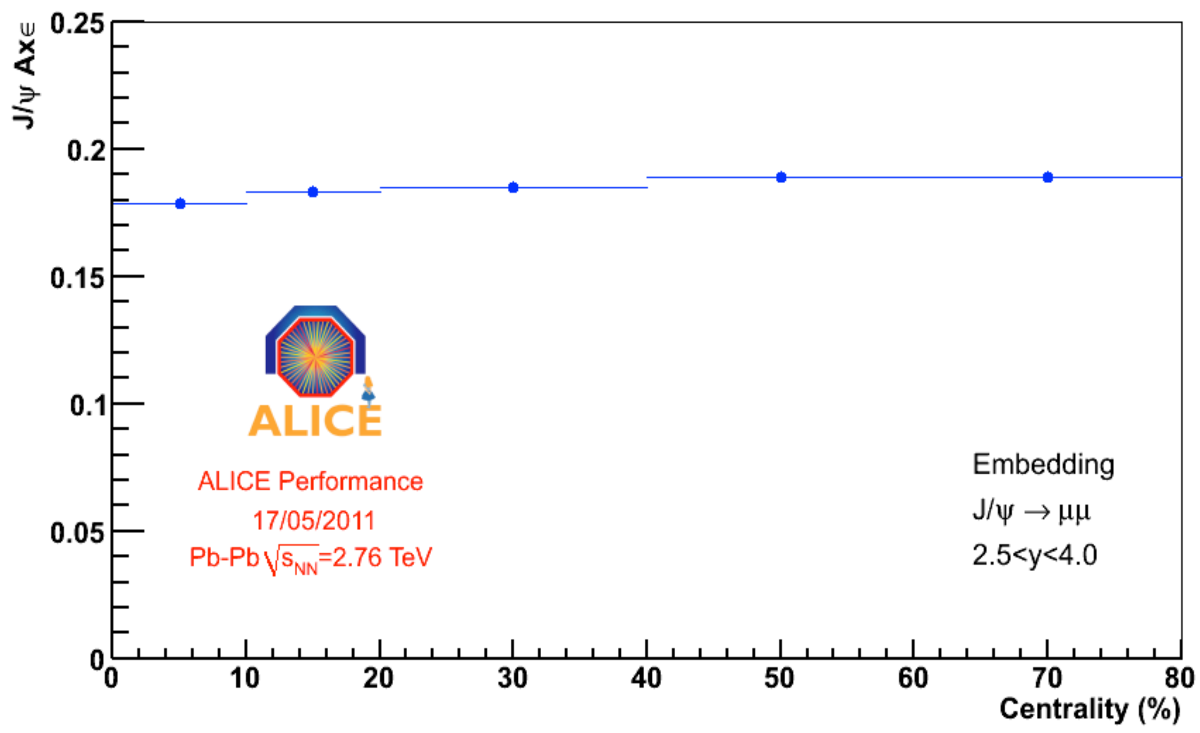
One simulated J/ψ embedded into each real event to study a possible bias of the measurements with the centrality of the collision

Signal extraction



No sizable evolution of the parameters with the centrality

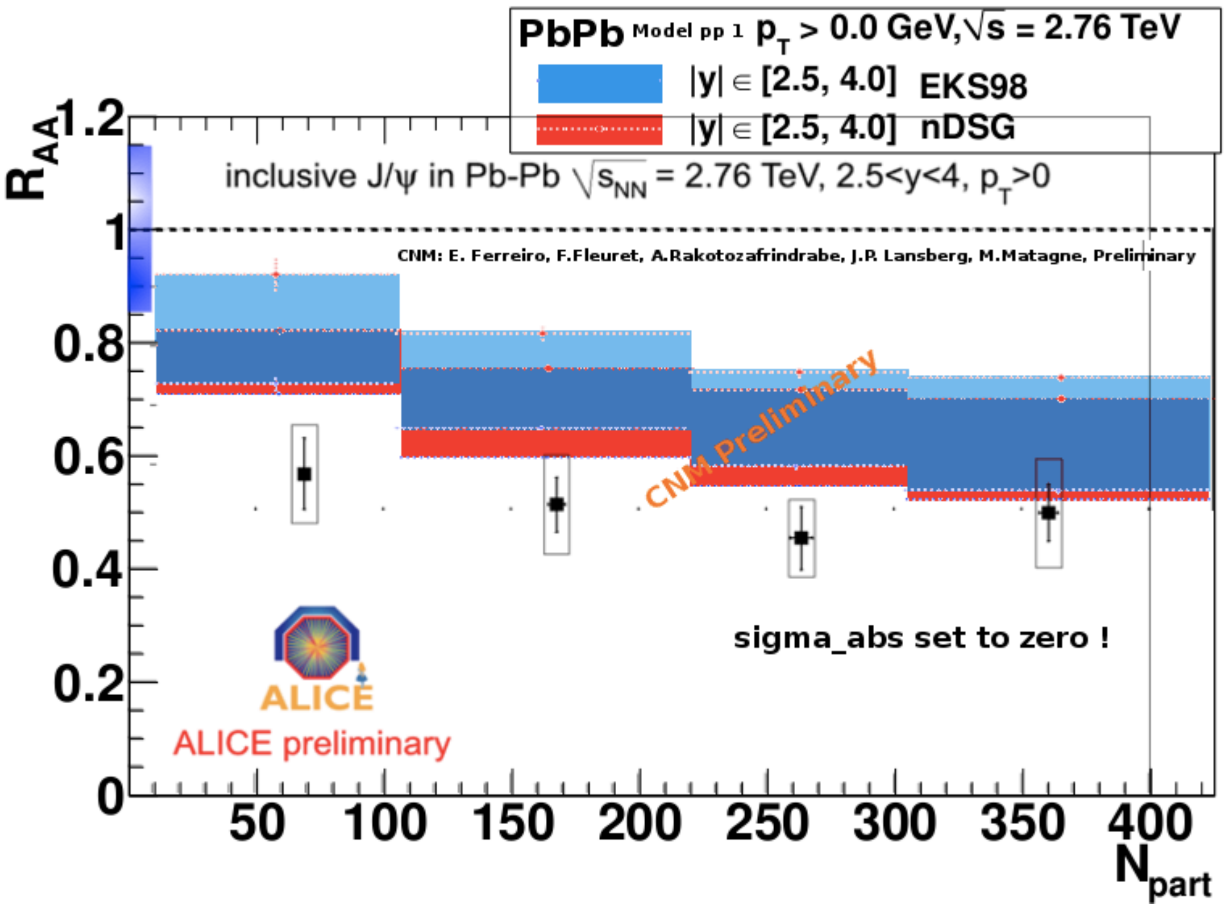
Acceptance x efficiency

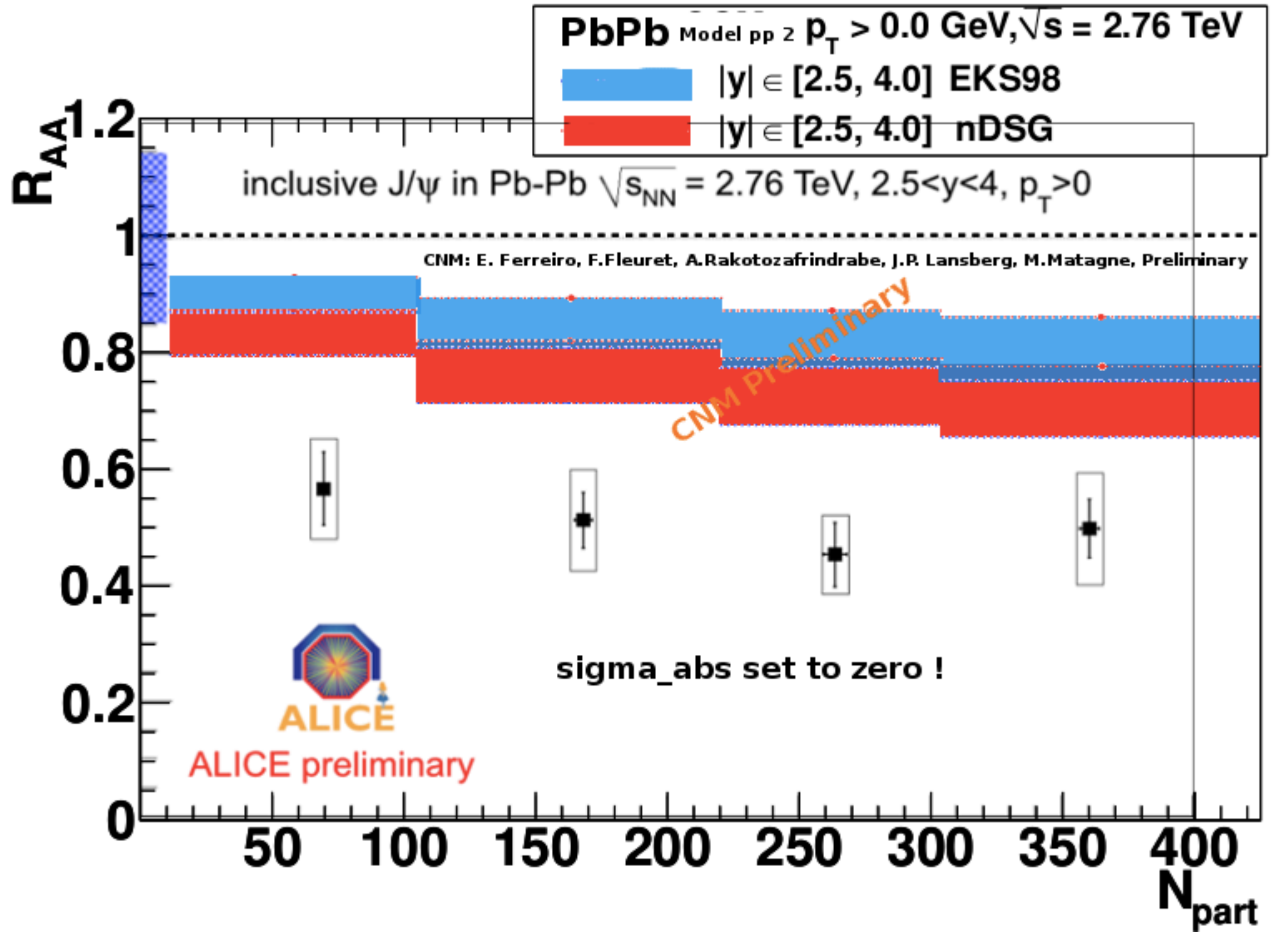


Acc x eff ~ 19 %

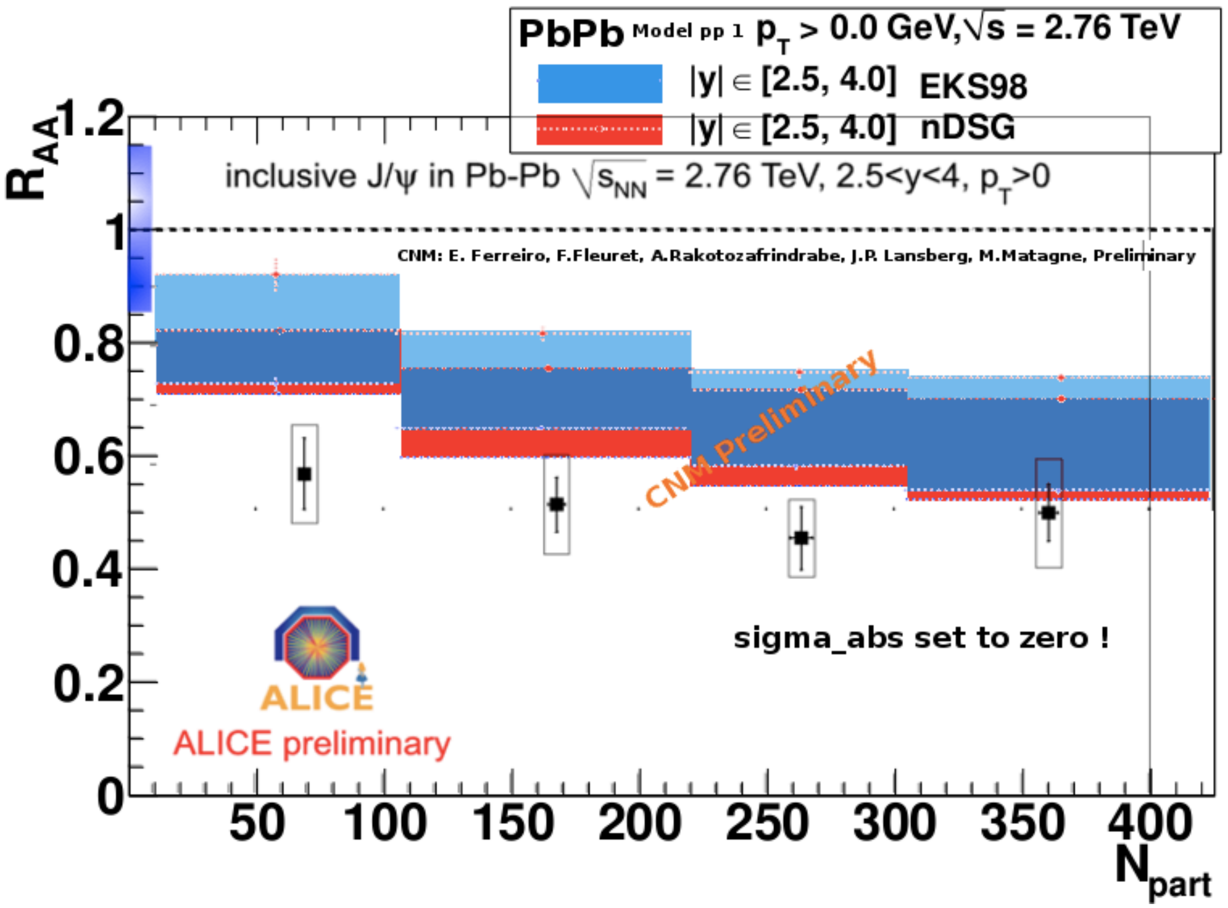
4% efficiency decrease in the most central collisions (similar efficiency loss estimated with data). Added in the systematics.

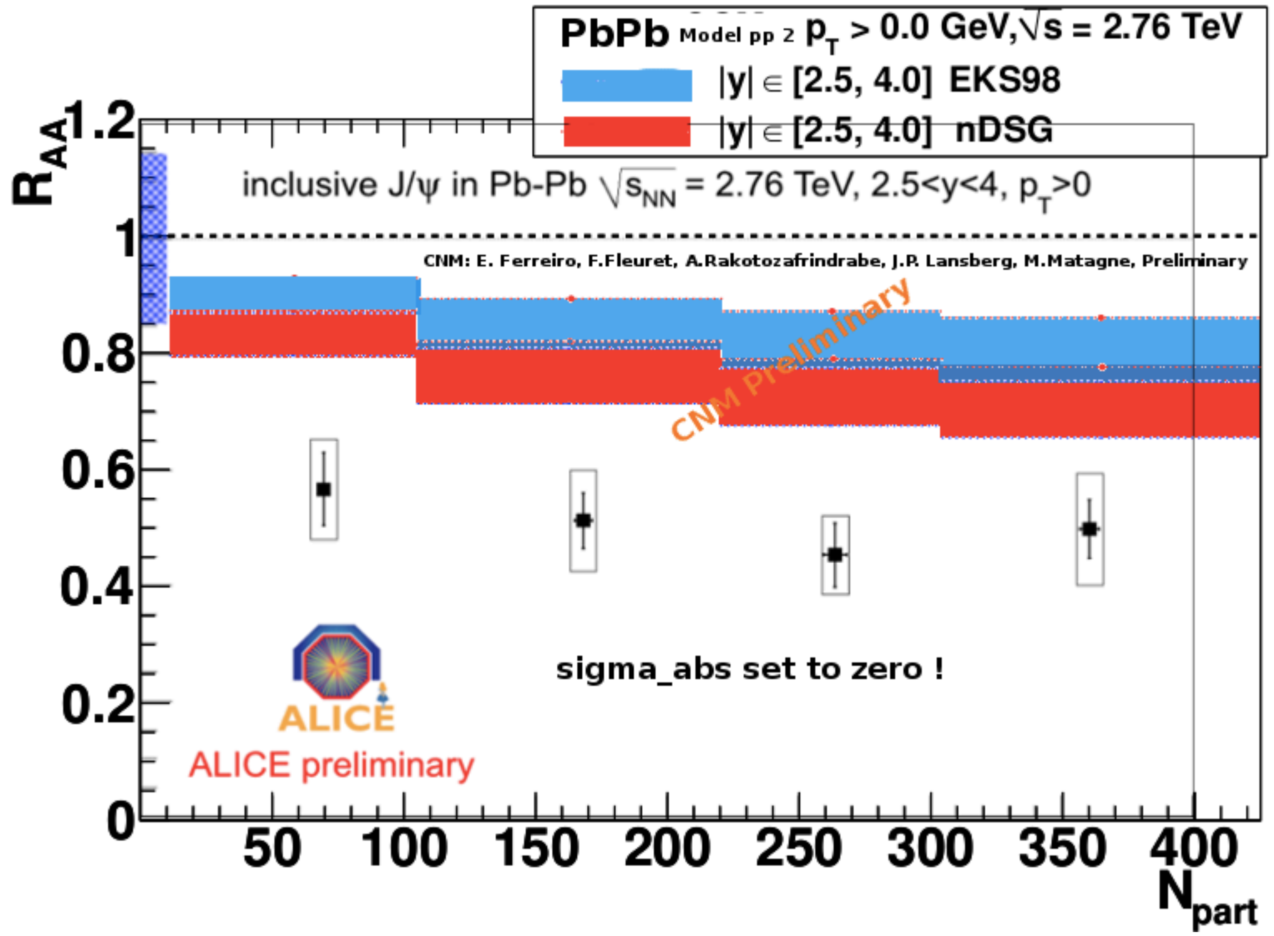
Nuclear shadowing in Pb-Pb collisions

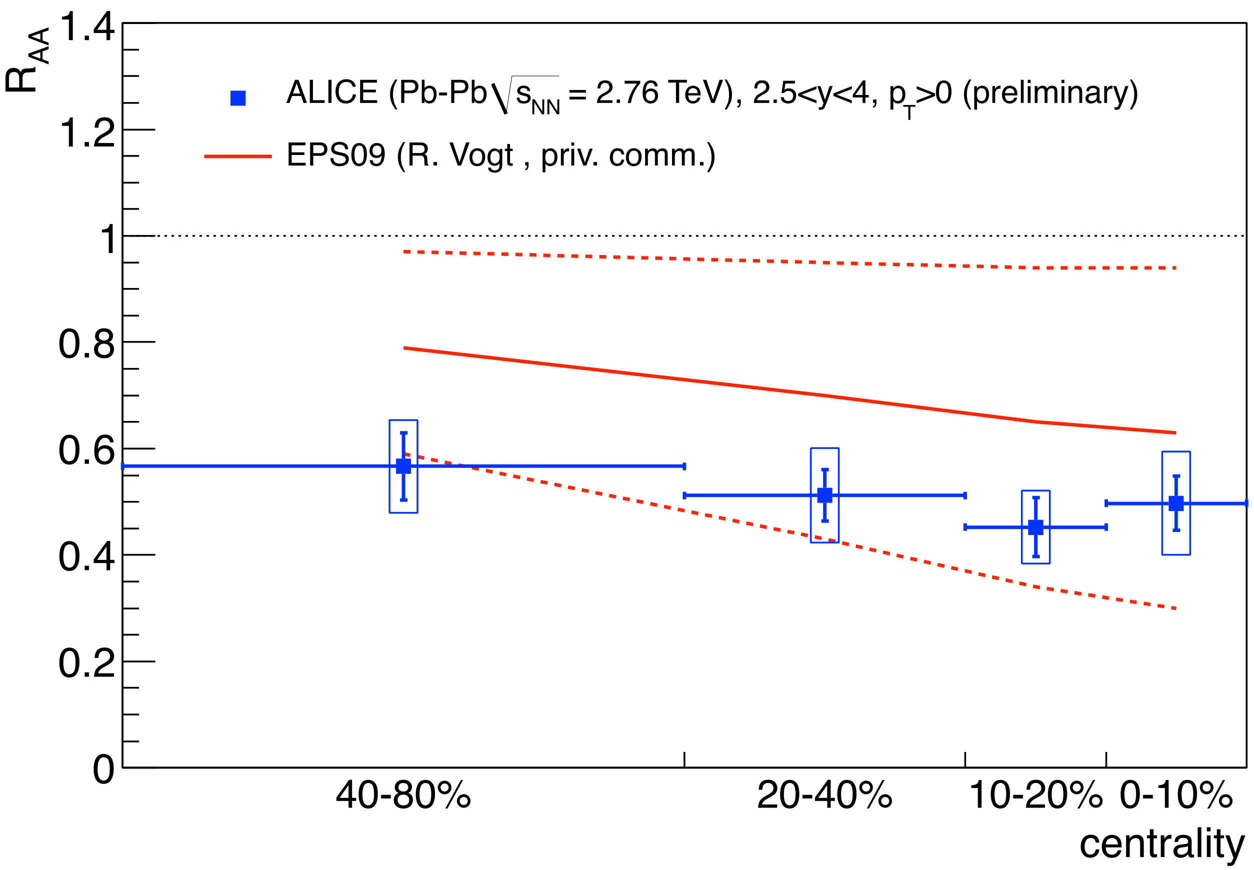




Nuclear shadowing in Pb-Pb collisions







p-p collisions: event and track selection

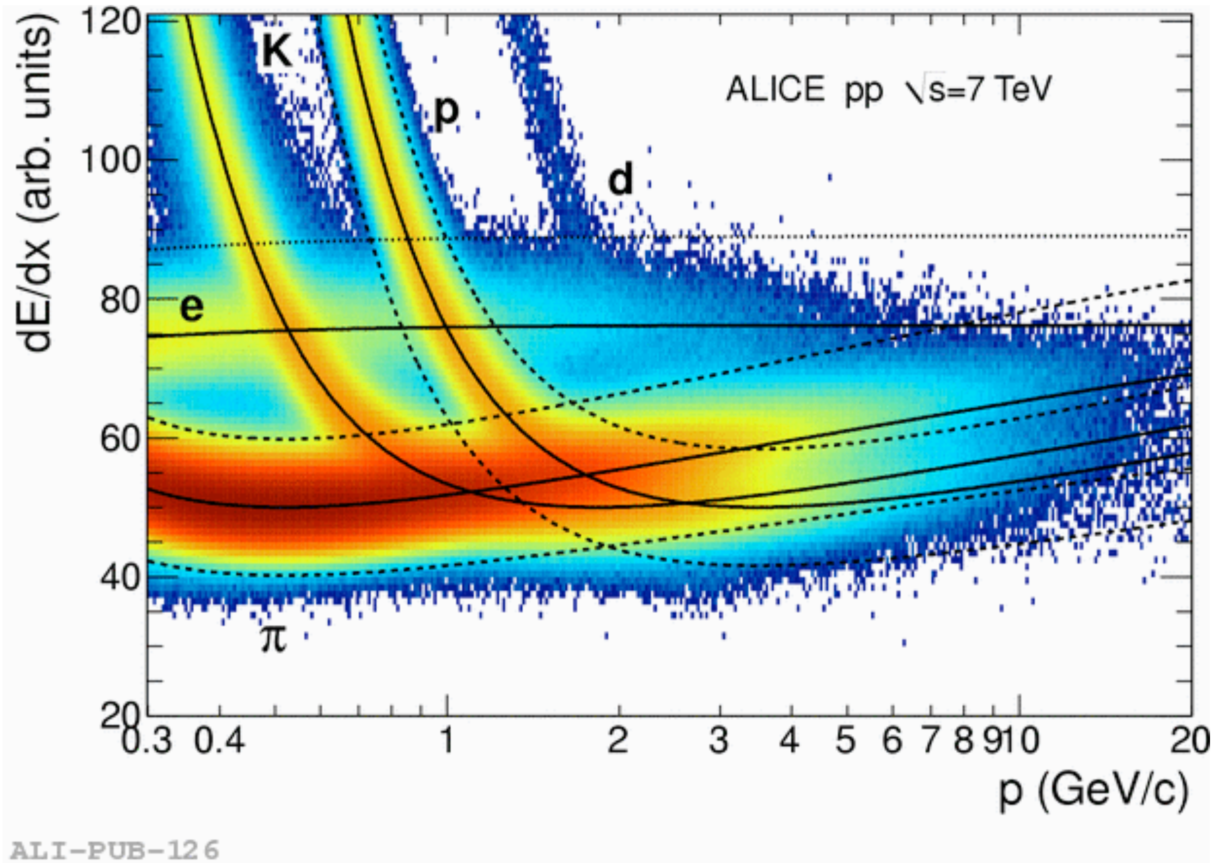
Triggers

Minimum bias $-3.7<\eta<5.1$

V0A || V0C || Pixel

Muon $-4<\eta<-2.5$

Min bias && muon trigger



Track selection

electrons

tracking with ITS and TPC

$|z_{vertex}| < 10$ cm

at least one hit in Pixel

$|\eta| < 0.9$

$p_T > 1$ GeV/c

electron PID based on TPC dE/dx

muons

1 muon trigger matching

at least one interaction vertex in Pixel

$-4<\eta<-2.5$

$17.6<R_{abs}<89$ cm (radial track position at the end of the absorber)

Acceptance x efficiency correction

Detector simulation based on realistic (time-dependent) detector conditions

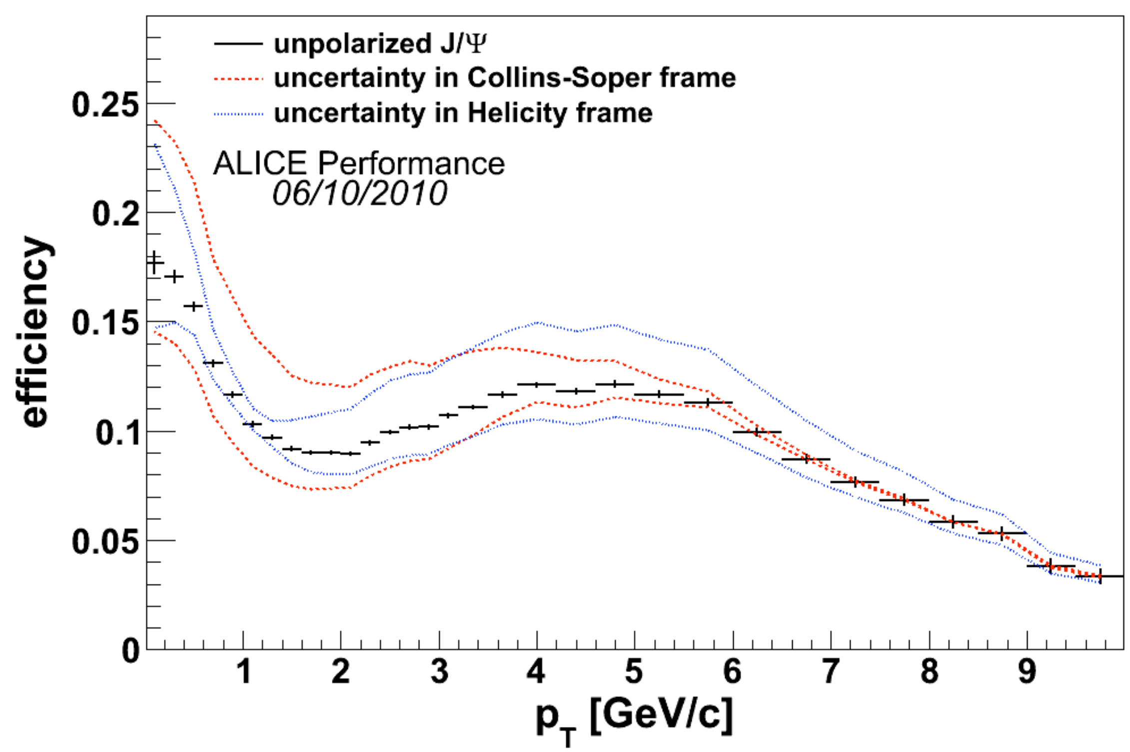
Monte Carlo generator

p_T-dependence from CDF extrapolation and y-dependence from CEM model

@ 2.76 TeV: p_T and y interpolated from data (PHENIX, CDF, LHC)

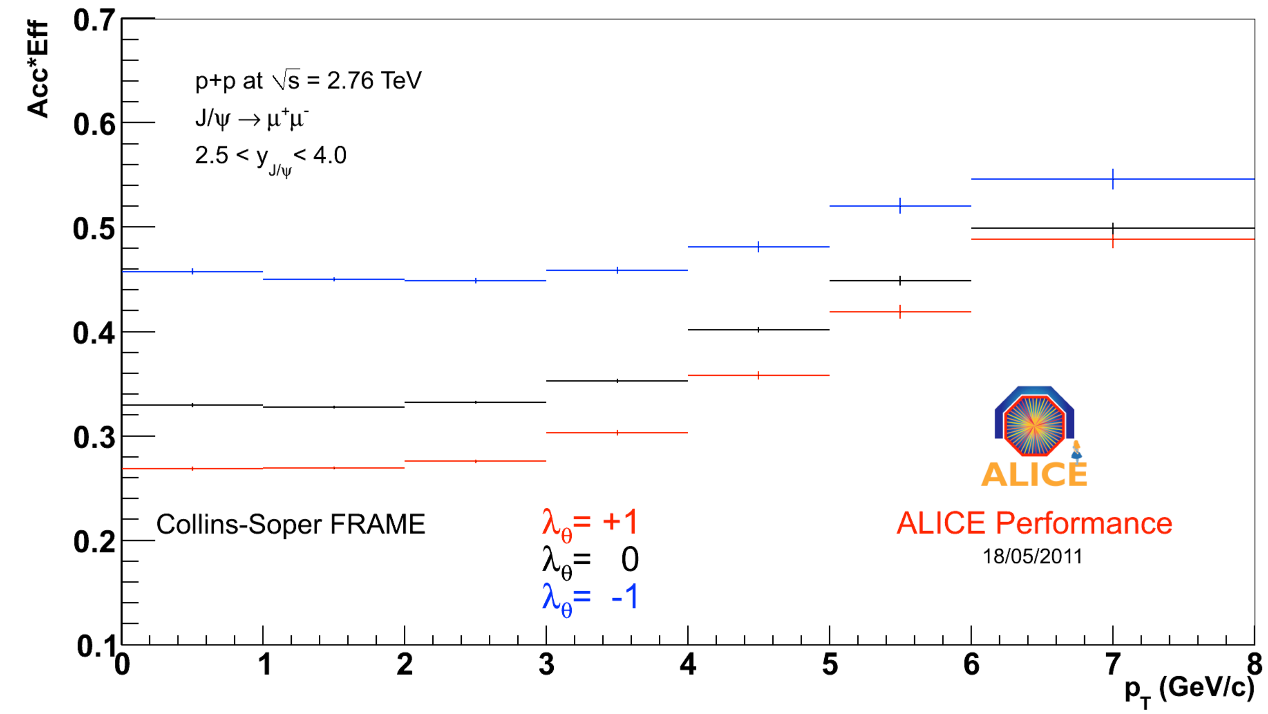
F. Bossu et al., arXiv:1103.2394

$J/\psi \rightarrow e^+ e^-$ @ 7 TeV



Acc x Eff = 10%

$J/\psi \rightarrow \mu^+ \mu^-$ @ 2.76 TeV



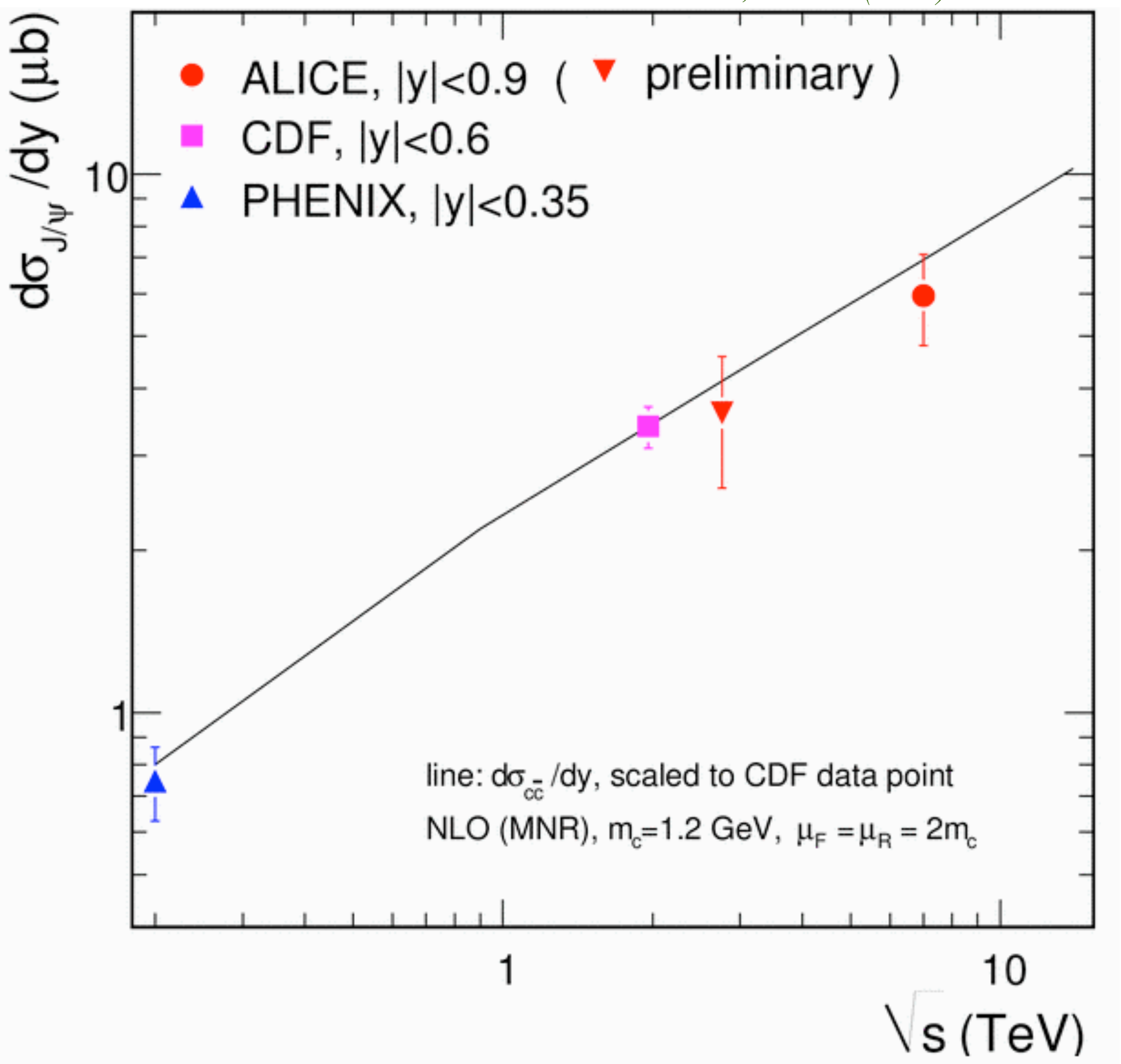
Acc x Eff = 33%

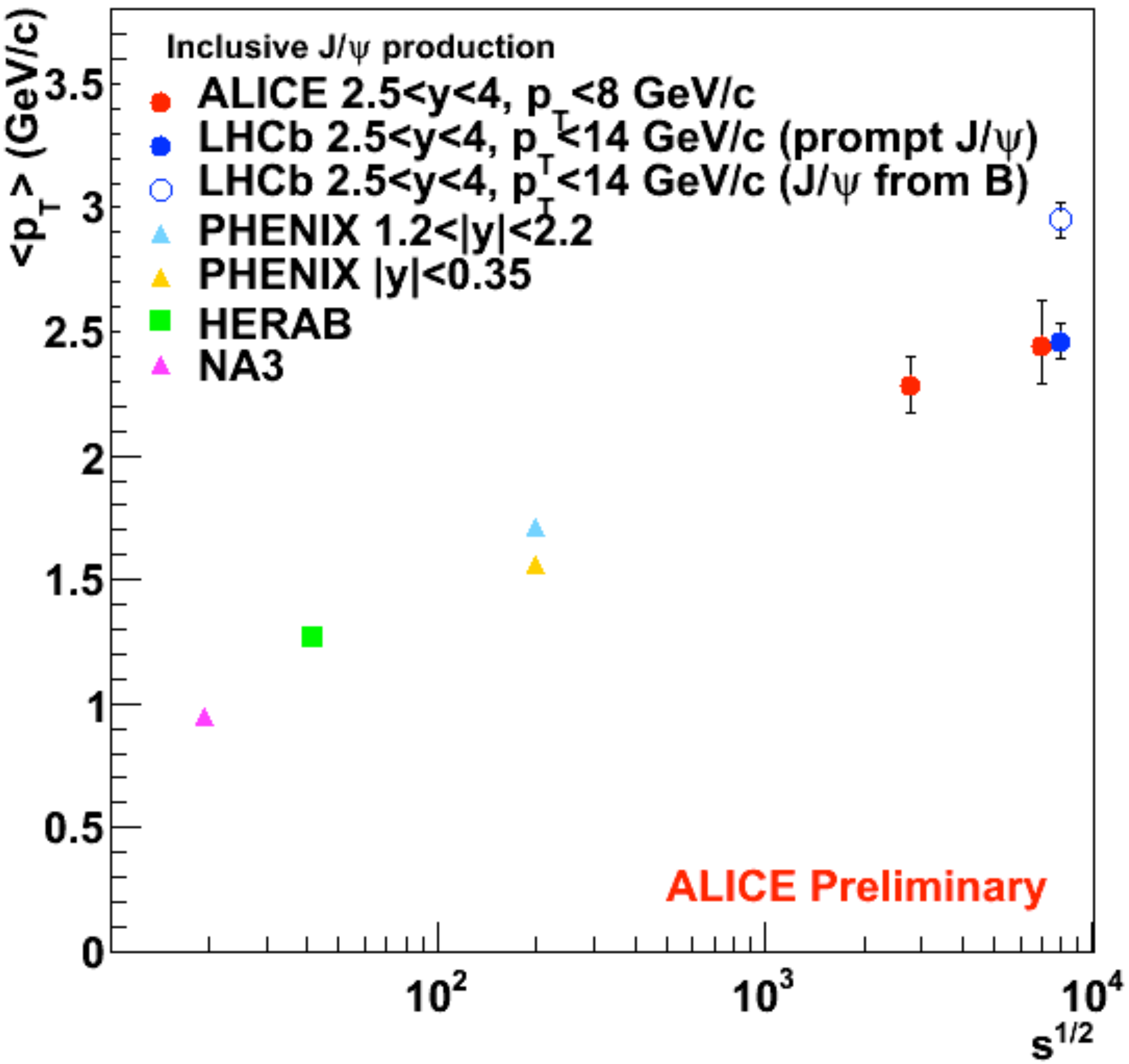
Large uncertainties from unknown polarization quoted separately

Systematics uncertainties ~ 11% ($e^+ e^-$) and 5% ($\mu^+ \mu^-$) on AccxEff correction

Energy dependence

CDF Collaboration PRD71 (2005) 032001
PHENIX Collaboration, PRL 98 (2007) 232002

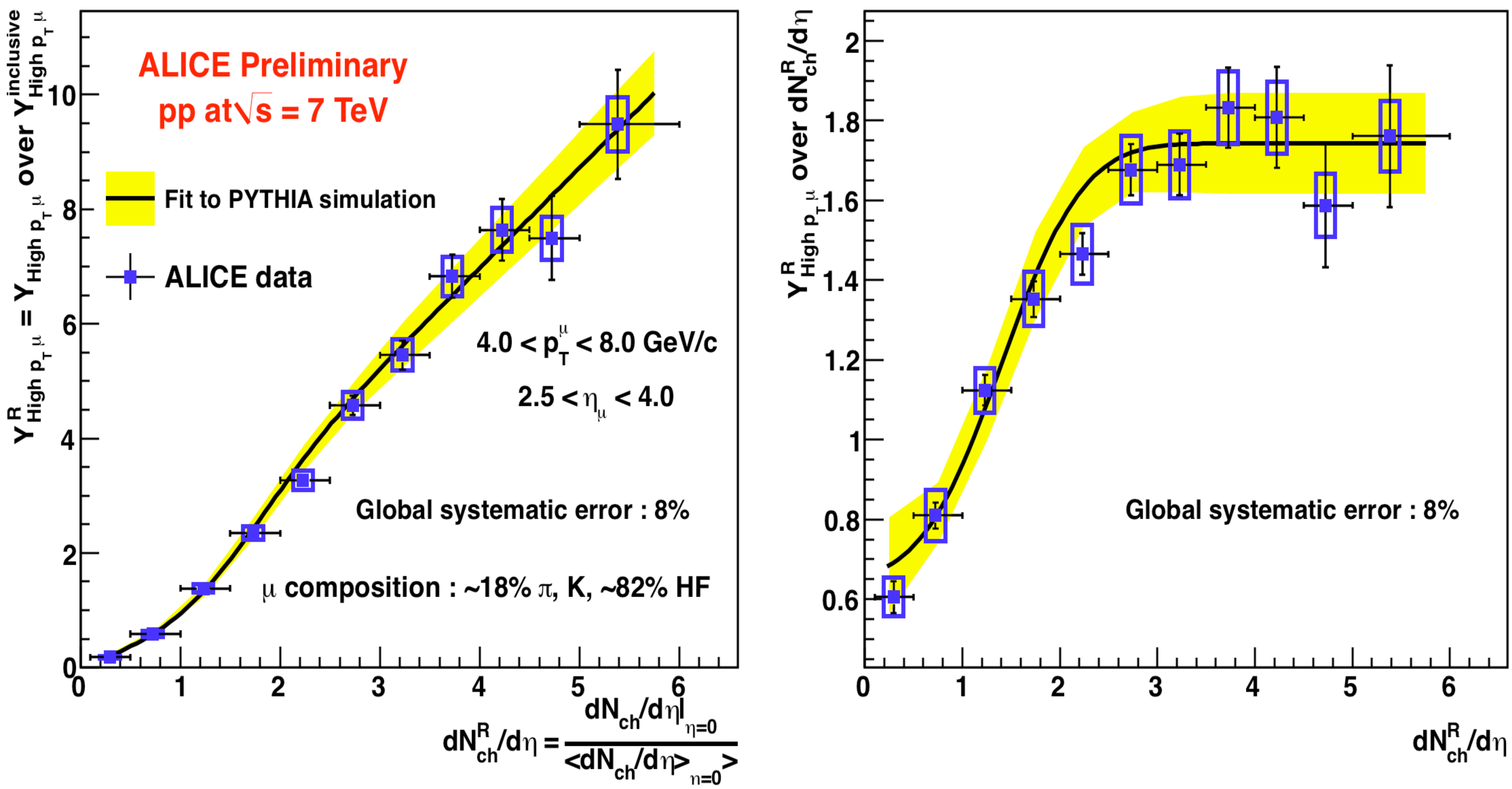




line = NLO cross section calculation for ccbar scaled to CDF data

$\langle p_T \rangle$ ~ logarithmic increase with $\sqrt{s}$

Single muon yield vs multiplicity in p-p: data vs PYTHIA



Very nice data description by PYTHIA (perugia-0)

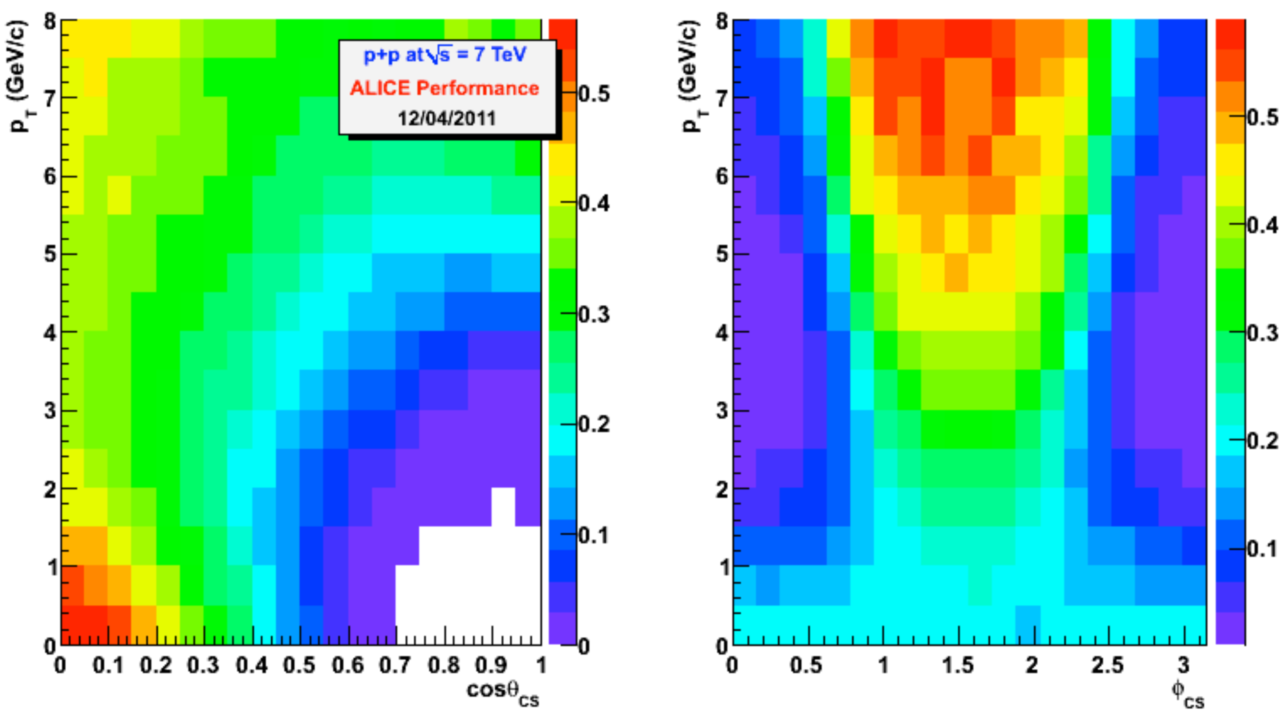
Ongoing analysis

J/ψ polarization

Key observable to study the production mechanism

Determination ongoing for the full angular dependence of the J/ψ (λ_θ, λ_φ, $\lambda_{\theta\varphi}$)

$J/\psi \rightarrow \mu^+ \mu^-$

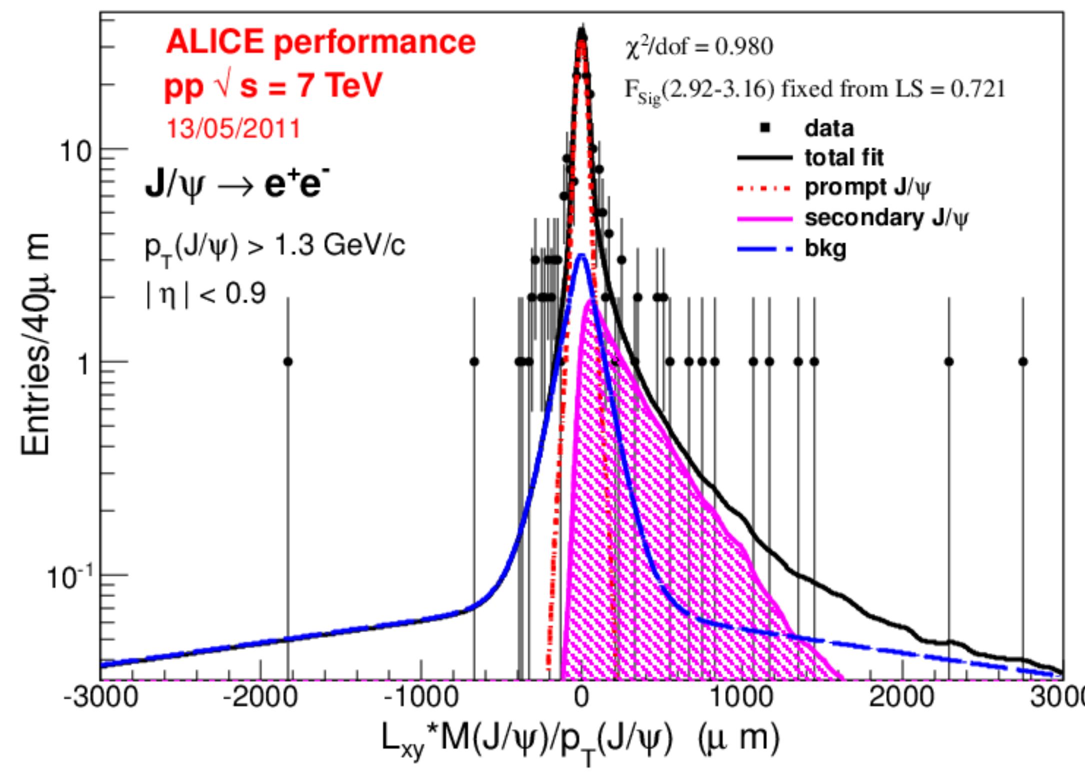


Expected error on $\lambda_\theta \sim 0.15$ for $3<p_T<8$ GeV/c

prompt J/ψ determination at mid-rapidity

Impact parameter resolution excellent in the central barrel ($\sigma_{r\varphi} < 75$ μm for $p_T>1$ GeV/c)

B decay contribution estimated from the pseudo proper decay length distribution



High statistics sample to be collected this year with electron trigger

Also with higher statistics: Υ family measurements, in central barrel: J/psi-hadron correlations and radiative decay from higher charmonium state (χ_c and ψ')

p-p data: systematic uncertainties

Source of systematic uncertainty	$J/\psi \to \mu^+\mu^-$	$J/\psi \to e^+e^-$
signal extraction	6 %	8.5 %
Acceptance inputs	2.5%	1 %
Trigger efficiency	4%	-
Reconstruction efficiency	4%	11 %
Trigger enhancement	3%	-
Luminosity	8%	8 %
Total systematic uncertainty	**12.1 %**	**16.1%**

Polarization	λ=-1 λ=+1	λ=-1 λ=+1
Collins-Soper	+32 -16 %	+19 -13 %
Helicity	+24 -12 %	+21 -15 %

Systematic uncertainties in Pb-Pb

$J/\psi \rightarrow \mu^+ \mu^-$

centrality	0-10%	10-20%	20-40%	40-80%	Common
$N_{J/\psi}$	0,19	0,14	0,17	0,14	-
$N_{J/\psi} / N_{J/\psi}^{40-80\%}$	0,12	0,08	0,07	-	-
Acceptance	-	-	-	-	0,03
Eff. Tracker	0,04	0,02	0,01	0	0,05
Eff. Trigger	-	-	-	-	0,04
Reco.	-	-	-	-	0,02
B.R.	-	-	-	-	0,01
X-section	-	-	-	-	0,13
$\langle T_{AA} \rangle$	0,04	0,04	0,04	0,06	-
$\langle T_{AA} \rangle^i / \langle T_{AA} \rangle^{40-80\%}$	0,06	0,05	0,04	-	-
Total for R_{AA}	**0,2**	**0,15**	**0,17**	**0,15**	**0,15**
Total for R_{CP}	**0,14**	**0,1**	**0,08**	**-**	**-**

$J/\psi \rightarrow e^+ e^-$

Systematics = 22% from electron PID and signal extraction