J/ψ production measurements in ALICE

High-p_T Probes of High-Density QCD at the LHC

May 30th - June 1st, 2011
École Polytechnique, Palaiseau

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- Physics motivations
- Inclusive J/ψ measurements at $\sqrt{s}$ = 7 and 2.76 TeV in p-p collisions
  - Total and differential cross sections
  - Multiplicity dependence at $\sqrt{s}$ = 7 TeV
  - Ongoing analyses at $\sqrt{s}$ = 7 TeV: polarization and prompt J/ψ extraction at mid-rapidity
- 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

Physics motivations

Quarkonium production as a probe of deconfinement

Suppression scenario

Debye screening in deconfined matter → quarkonium family suppression sequency

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

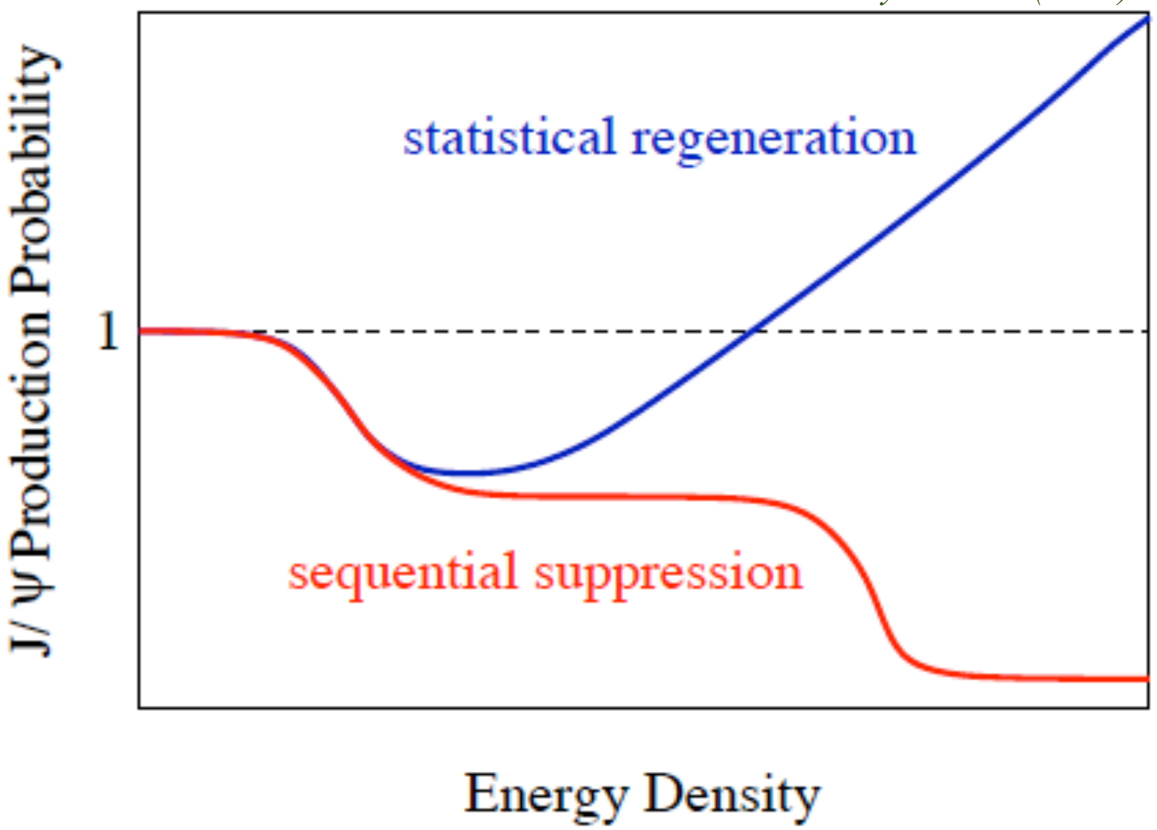
	Ψ’	χ	Υ”(3S)	Υ’(2S)	J/Ψ	Υ
T_d/T_c	1-1.2	1-1.2	1.1-1.3	1.2-2	1.5-2.5	3-5

Lattice QCD based predictions
T_d = 'melting' temperature
H.T. Ding et al, PoS LATTICE 2010 (2010), ...

Suppression for Υ"(3S) ≈ Ψ', Υ'(2S) ≈J/Ψ

→ quarkonium production in heavy ion collisions is a QGP thermometer

H. Satz J.Phys.G G32 (2006)



Regeneration scenario

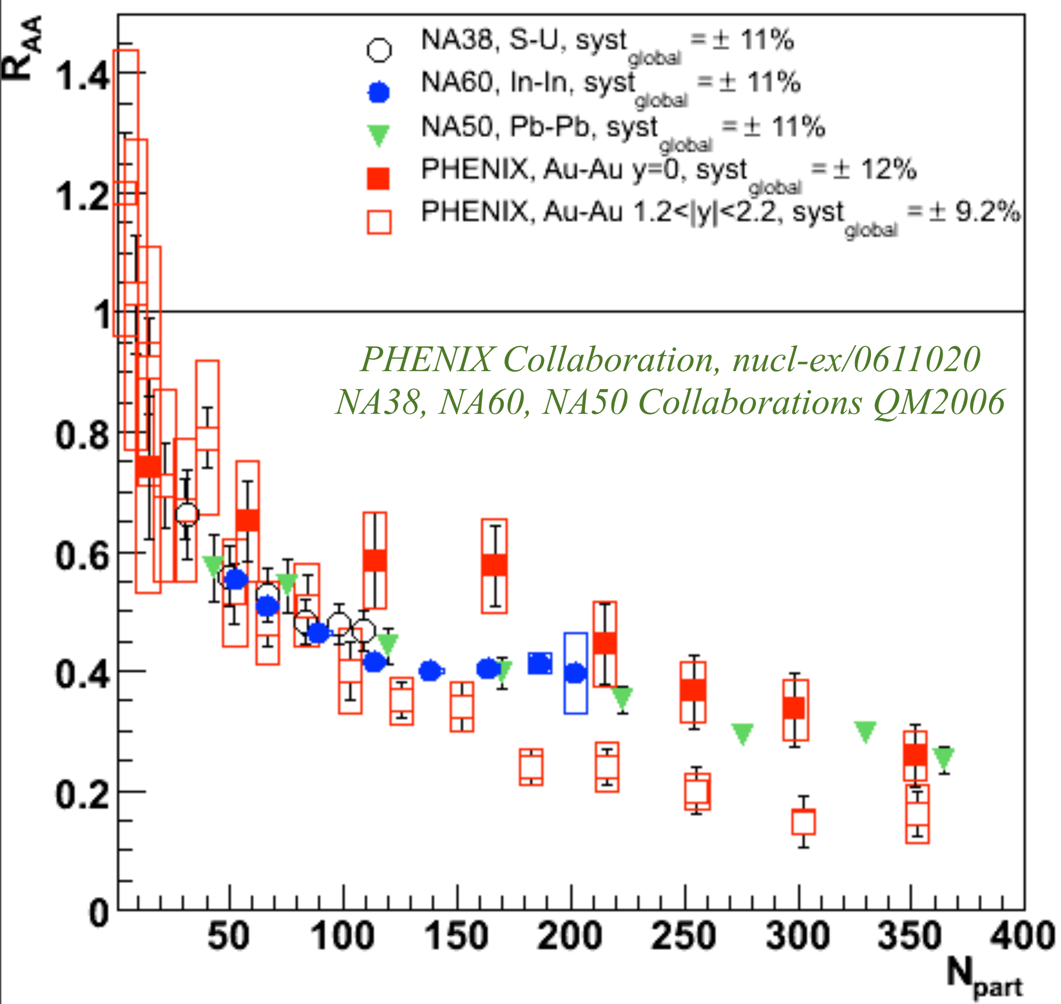
Large amount of ccbar pairs in hot nuclear matter → J/ψ production in A-A from ccbar recombination *B. Svetistky, PRD34, 2484 (1987)*
P. Braun-Munzinger and J. Stachel, Phys.Lett.B490:196-202,2000)
R. L. Thews et al., Phys. Rev. C 63 (2001)

If suppression and regeneration

Υ', Υ" ~ unaffected, increase of J/Ψ yield

Inclusive J/ψ measurements

SPS and RHIC measurements



Puzzling results from SPS and RHIC

Similar suppression at SPS and RHIC
Different suppression in central and forward rapidity at RHIC

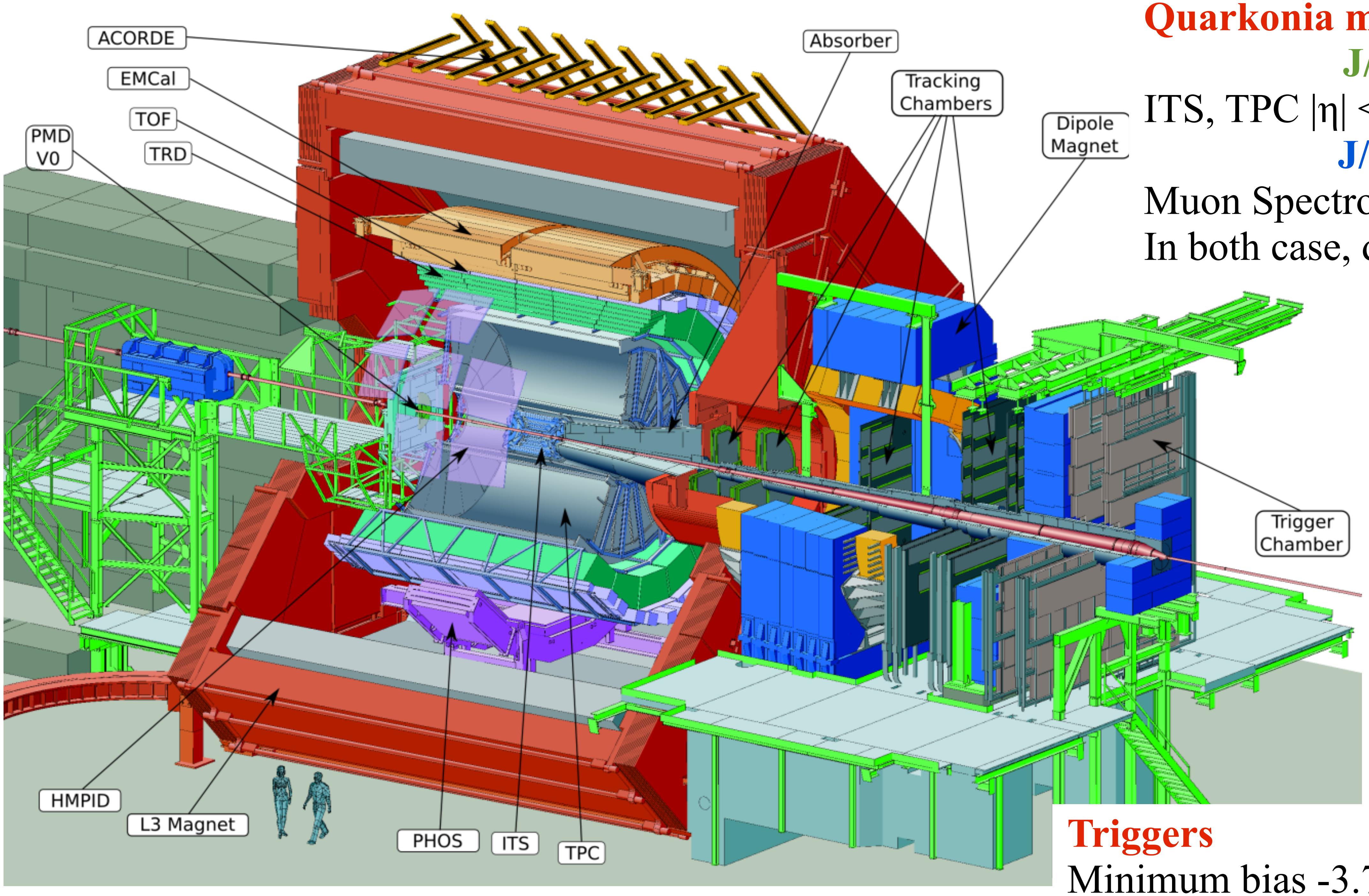
Cold nuclear matter effects (absorption, initial state as shadowing / saturation, ...) measurements is required to estimate precisely the hot nuclear effect leading to the J/ψ suppression.

New energy regime at LHC

Heavy flavour are produced abundantly
- J/ψ and Y family can be studied with large statistics
- Open heavy flavour can be used to normalize the quarkonium production
- Cold nuclear matter effect will be studied in p-Pb collisions

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

Quarkonia measurements in ALICE



Quarkonia measurements

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

ITS, TPC $|\eta| < 0.9$

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

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

In both case, down to $p_T = 0$

Triggers

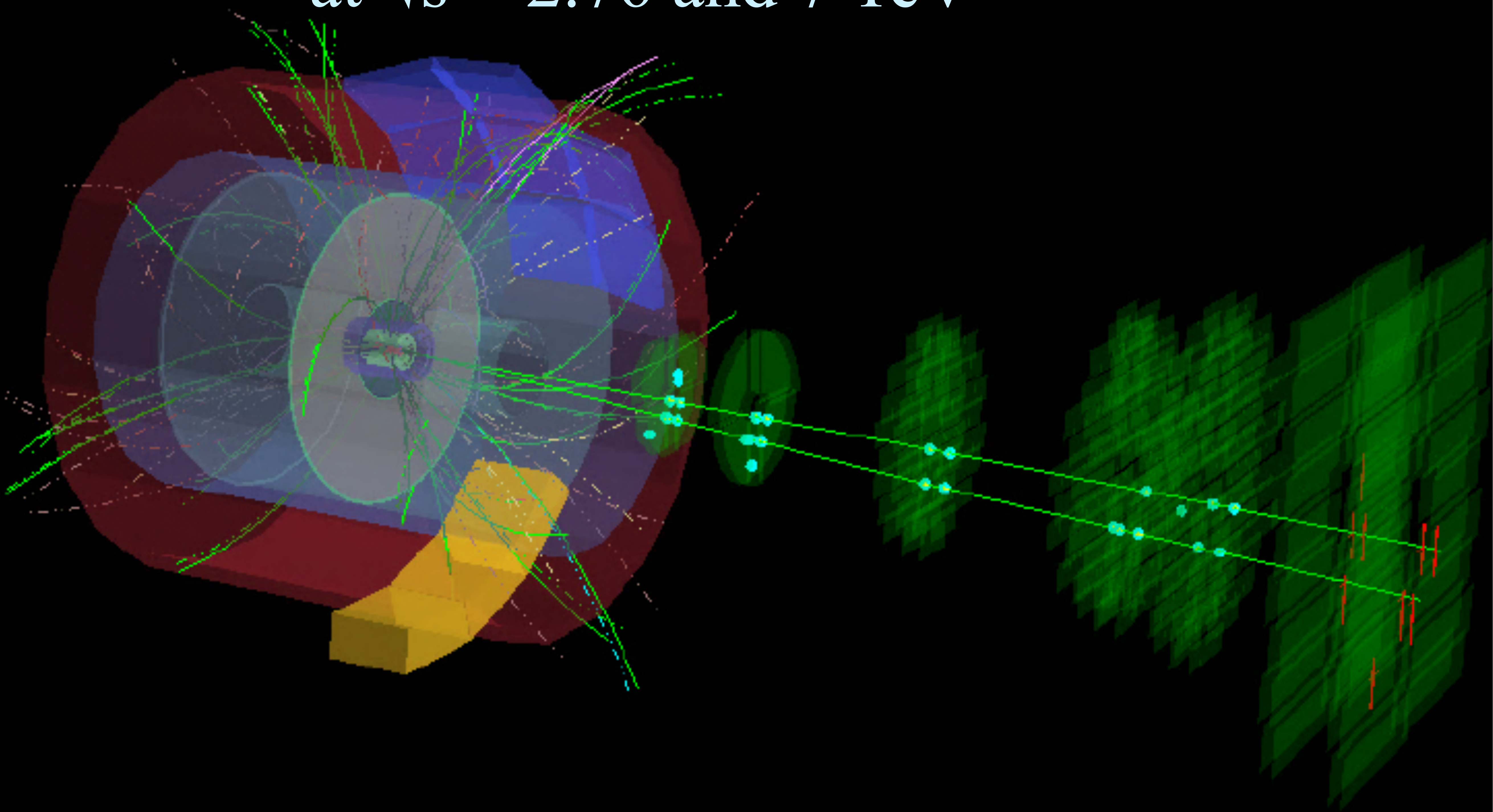
Minimum bias $-3.7 < \eta < 5.1$

V0A, V0C, Pixel

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

Min bias && Trigger chamber

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



p-p collisions: event and track selection

Triggers

Minimum bias $-3.7<\eta<5.1$

V0A || V0C || Silicon Pixel Detector

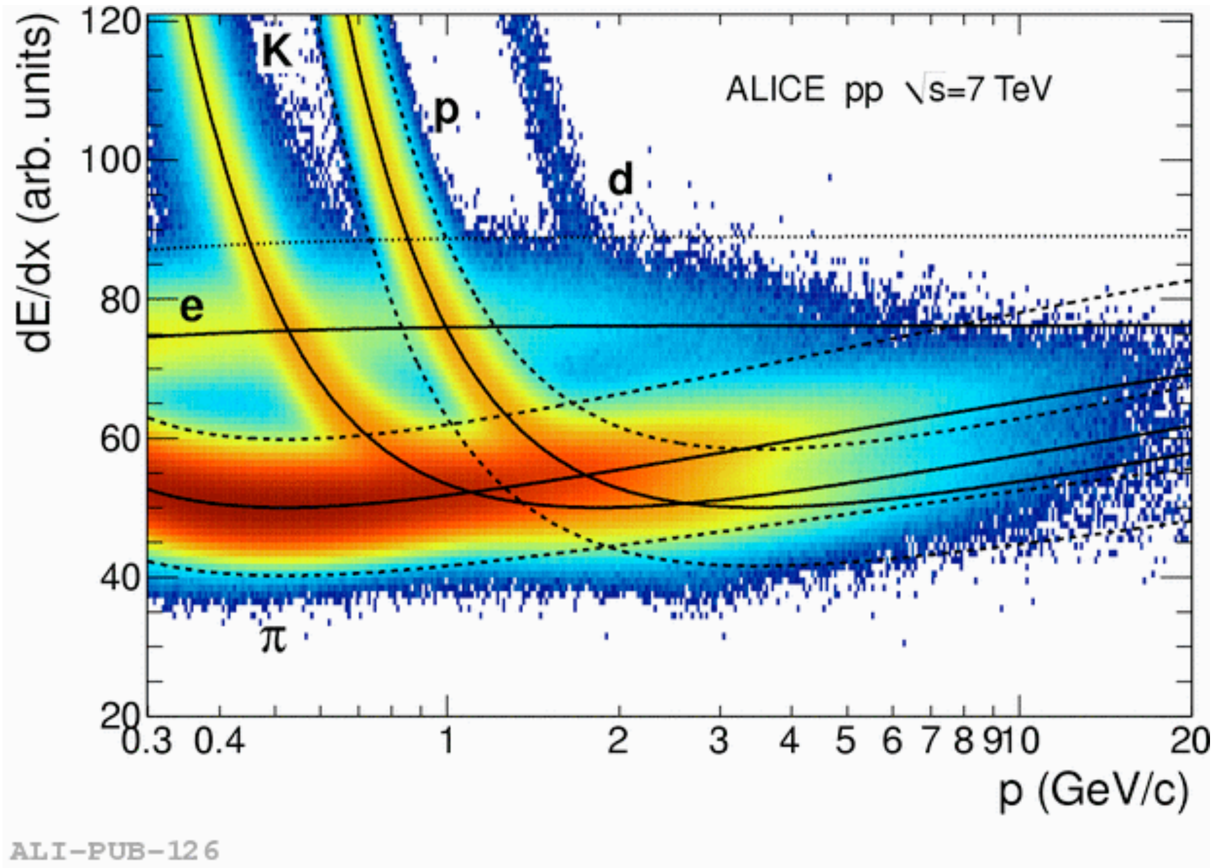
Muon $-4<\eta<-2.5$

Min bias && muon trigger

Event selection

V0 timing, Pixel cuts to reject beam-gas interaction

Run selection based on the stability of the detector performances



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)

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

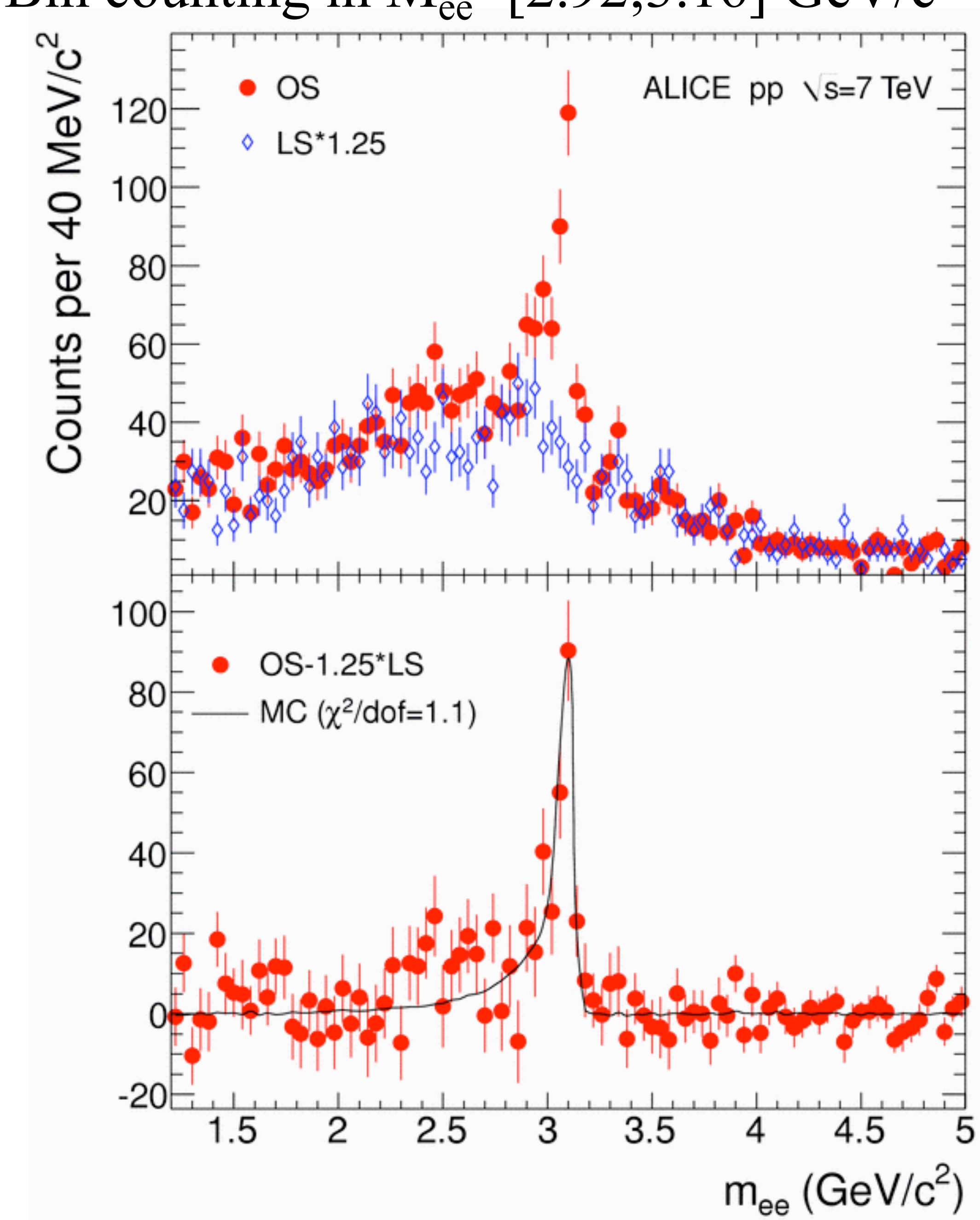
Signal extraction

ALICE coll., arXiv:1105.0380 (2011)

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

Like sign normalized to unlike sign

Bin counting in M_{ee}=[2.92;3.16] GeV/c^2



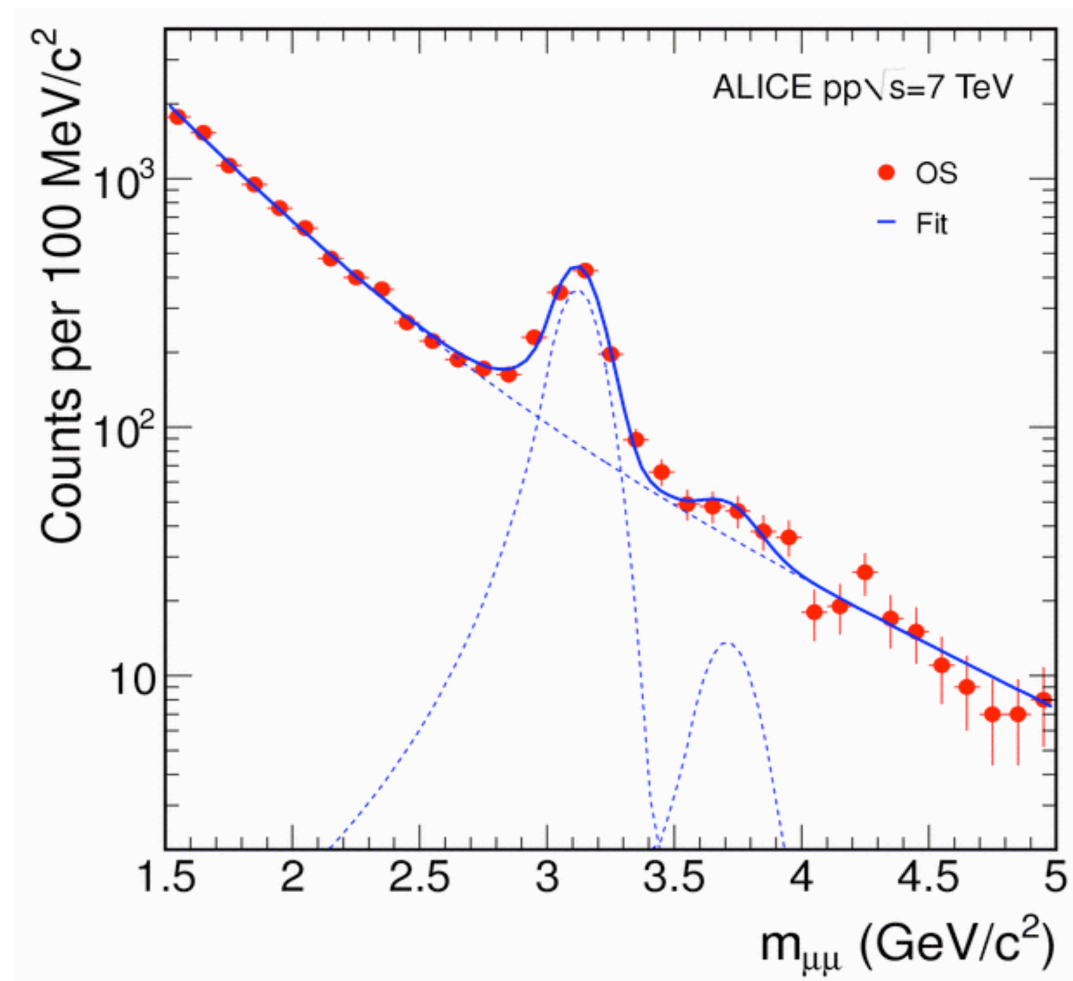
$J/\psi \rightarrow \mu^+ \mu^-$ @ 7 TeV

Fit of 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

Acceptance x efficiency correction

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

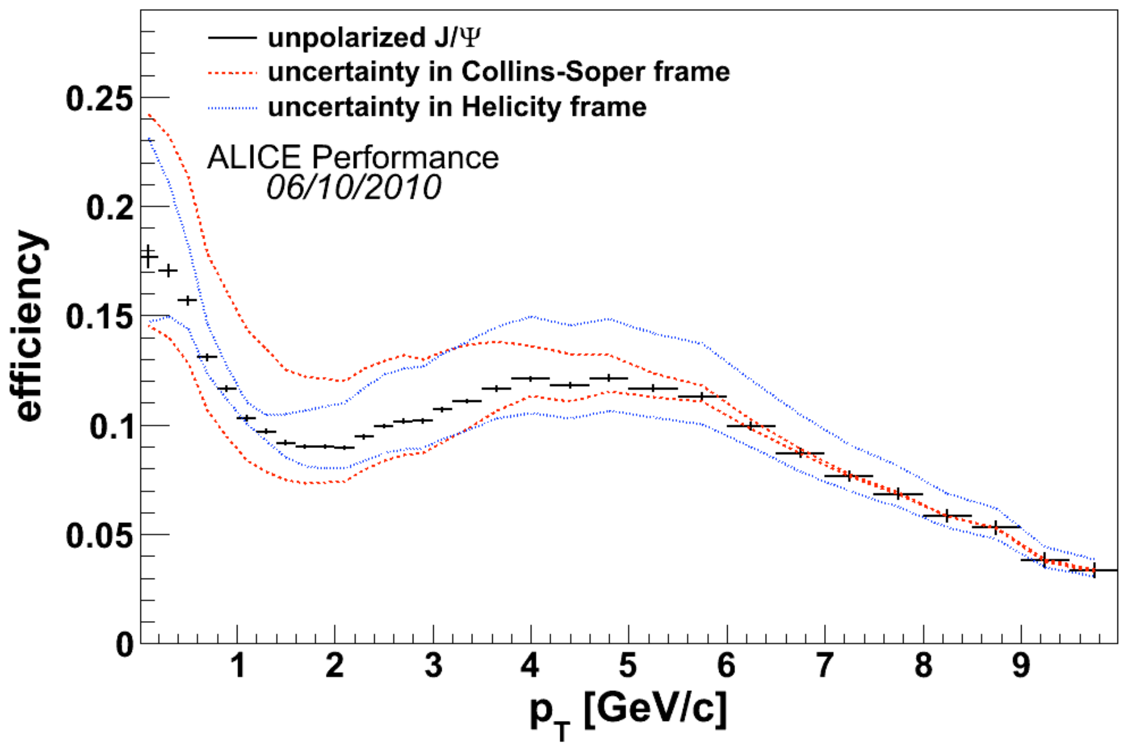
Monte Carlo generator

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)

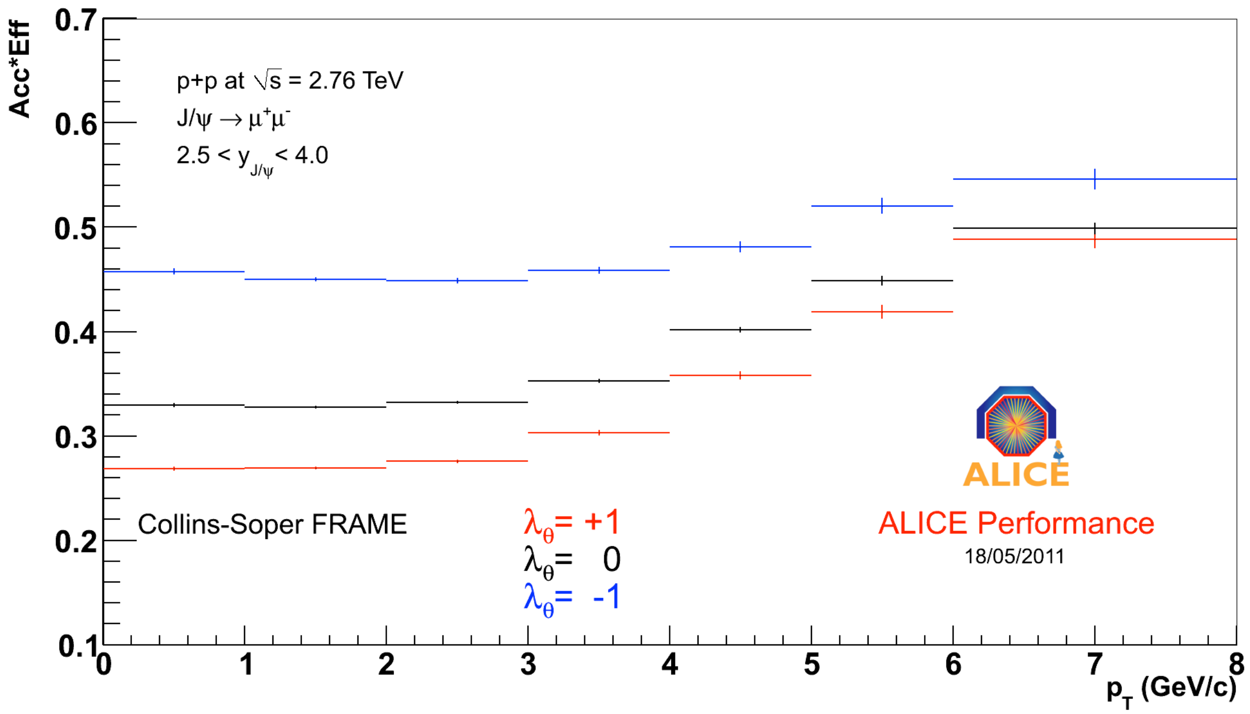
F. Bossu et al., arXiv:1103.2394

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

Normalization and integrated cross section

Van der Meer scan

Beam size determination and absolute cross section for Minimum Bias events

Ken Oyama Quark Matter 2011

7 TeV $\sigma_{MB} = 62.3 \pm 4.3$ (syst) mb   2.76 TeV $\sigma_{MB} = 54.2 \pm 3.8$ (syst) mb

Normalization

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

$$\sigma_{J/\psi} = \frac{N^{cor}_{J/\psi}}{BR(J/\psi \to \ell^+\ell^-)} \times \frac{\sigma_{MB}}{N_{MB}}$$

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

$$\sigma_{J/\psi} = \frac{N^{cor\,\mu-MB}_{J/\psi}}{BR(J/\psi \to \ell^+\ell^-)} \times \frac{\sigma_{MB}}{N_{MB}} \times N^{MB}_{\mu} / N^{\mu-MB}_{\mu}$$

Systematic uncertainties ~ 7% ($e^+ e^-$) and 7.6% ($\mu^+ \mu^-$) on normalisation

Integrated cross section @ 7 TeV

ALICE coll., arXiv:1105.0380 (2011)

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

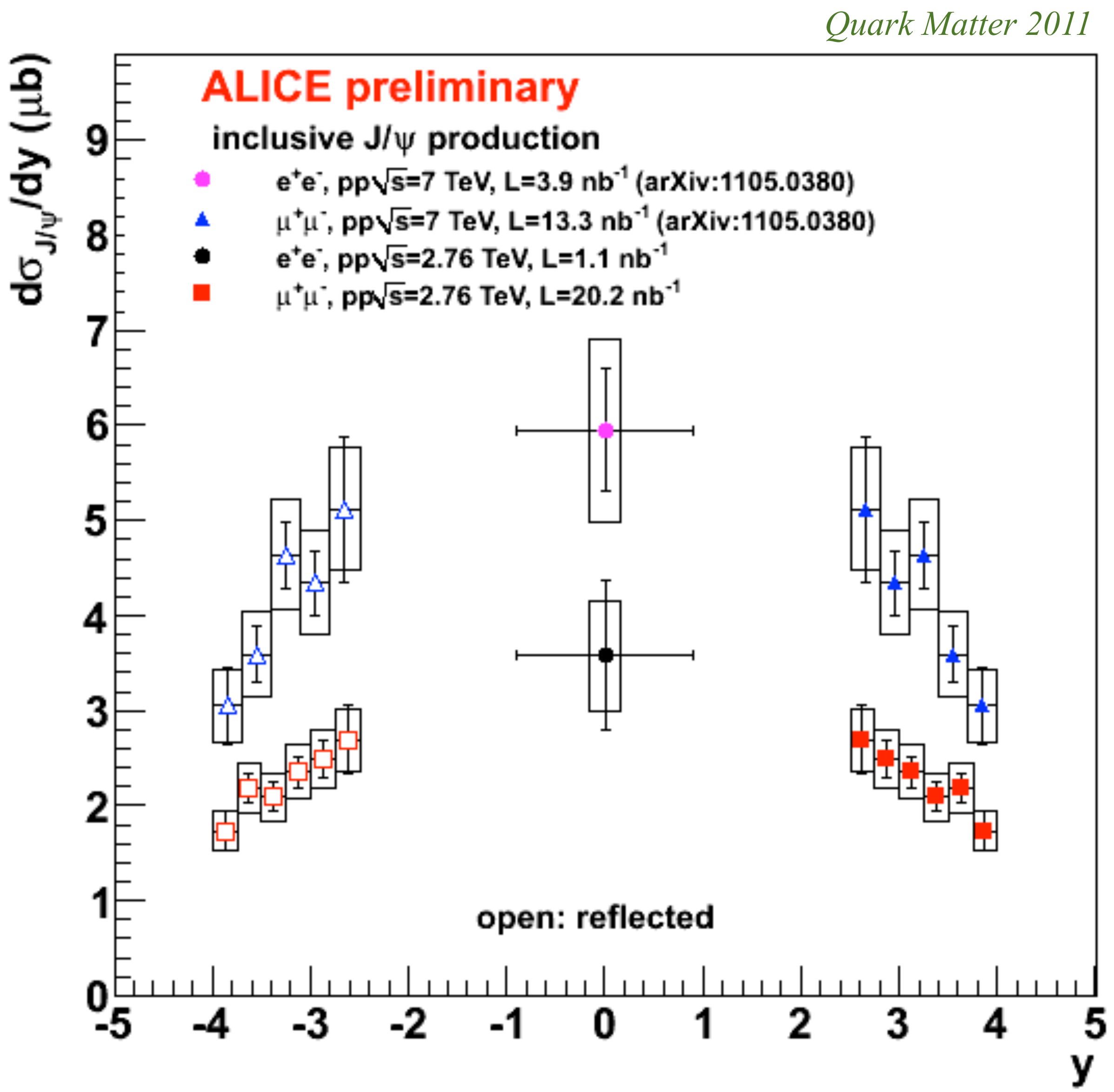
Integrated cross section @ 2.76 TeV

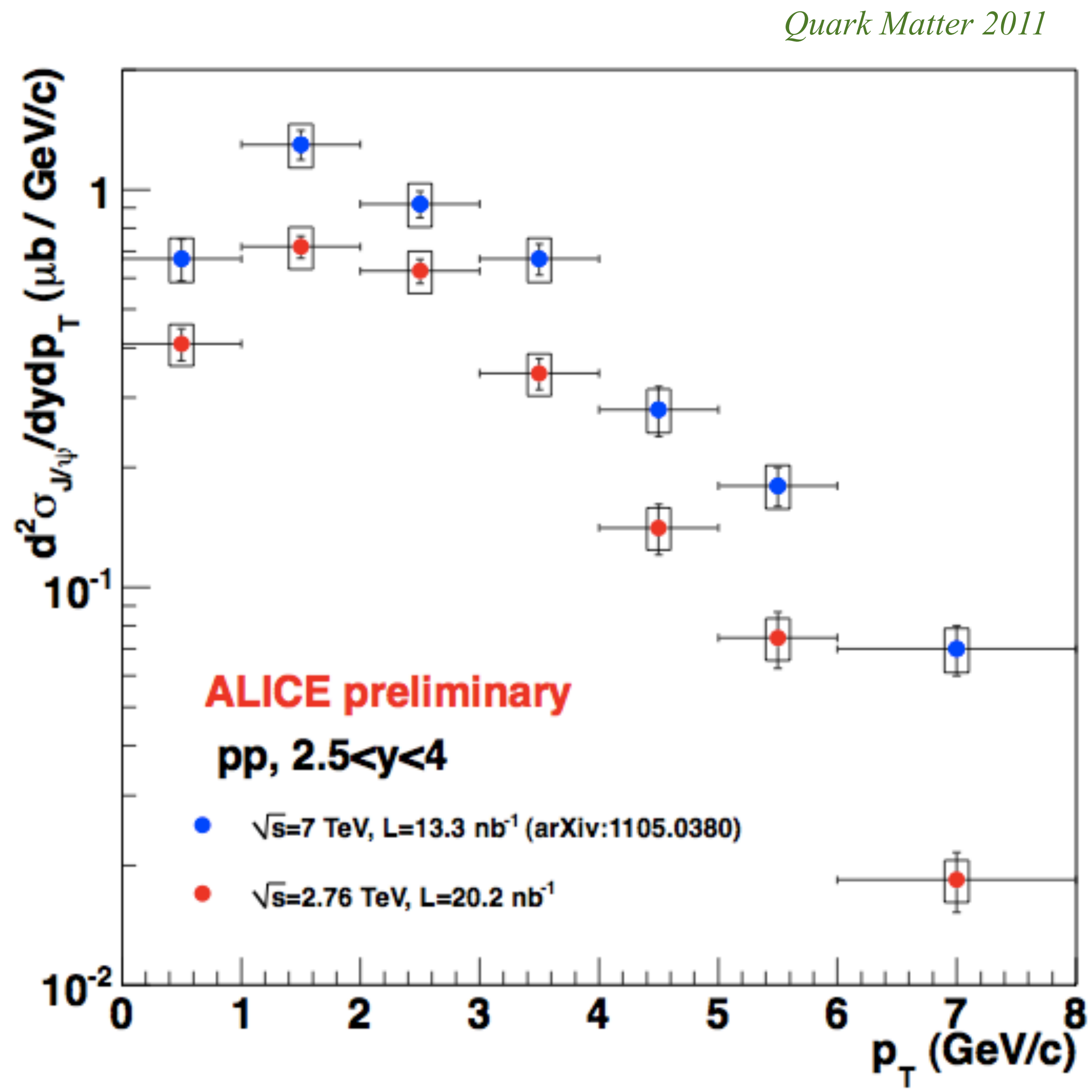
Quark Matter 2011

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

→ baseline for Pb-Pb measurements!

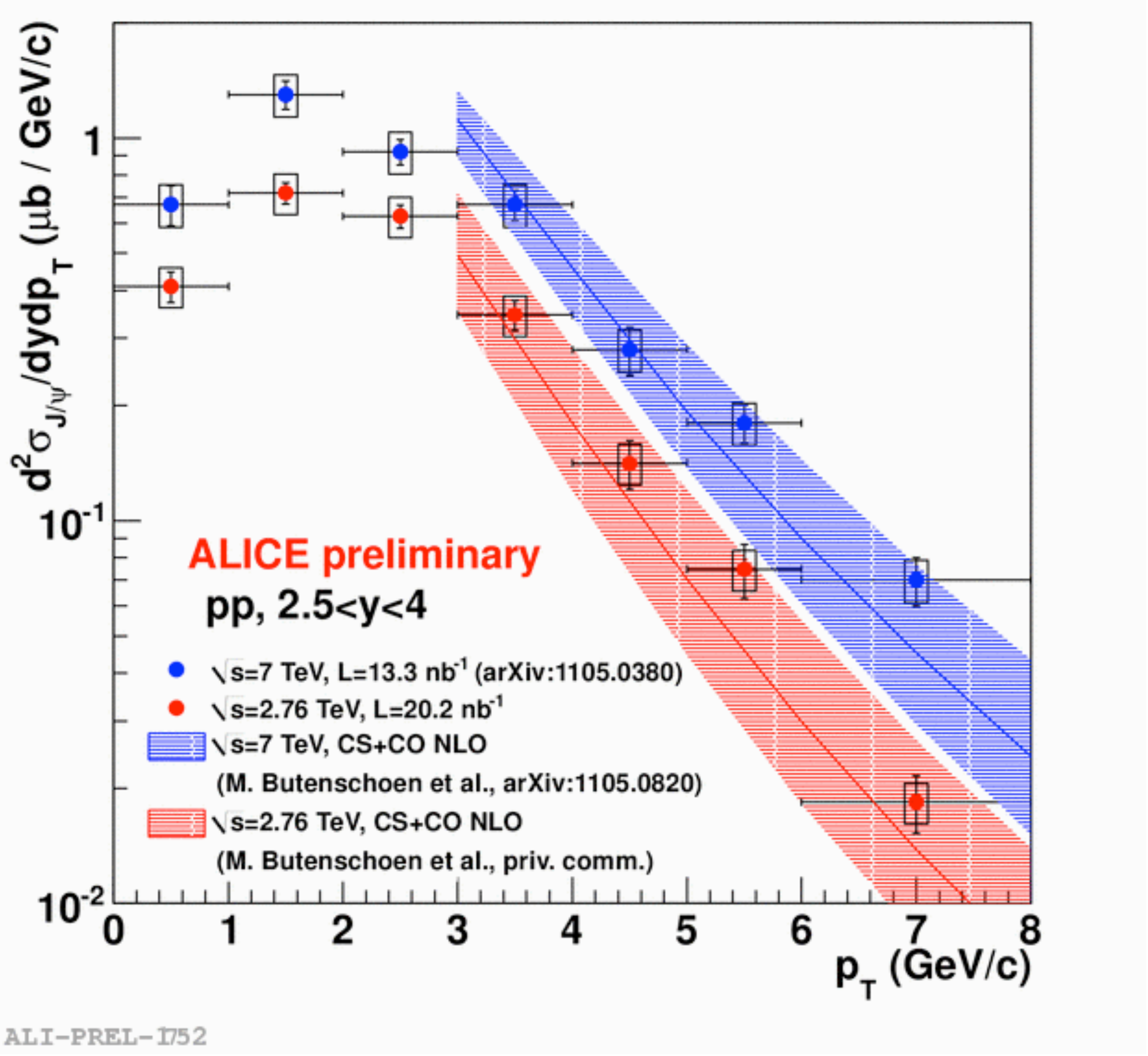
y and p_T dependent cross section





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

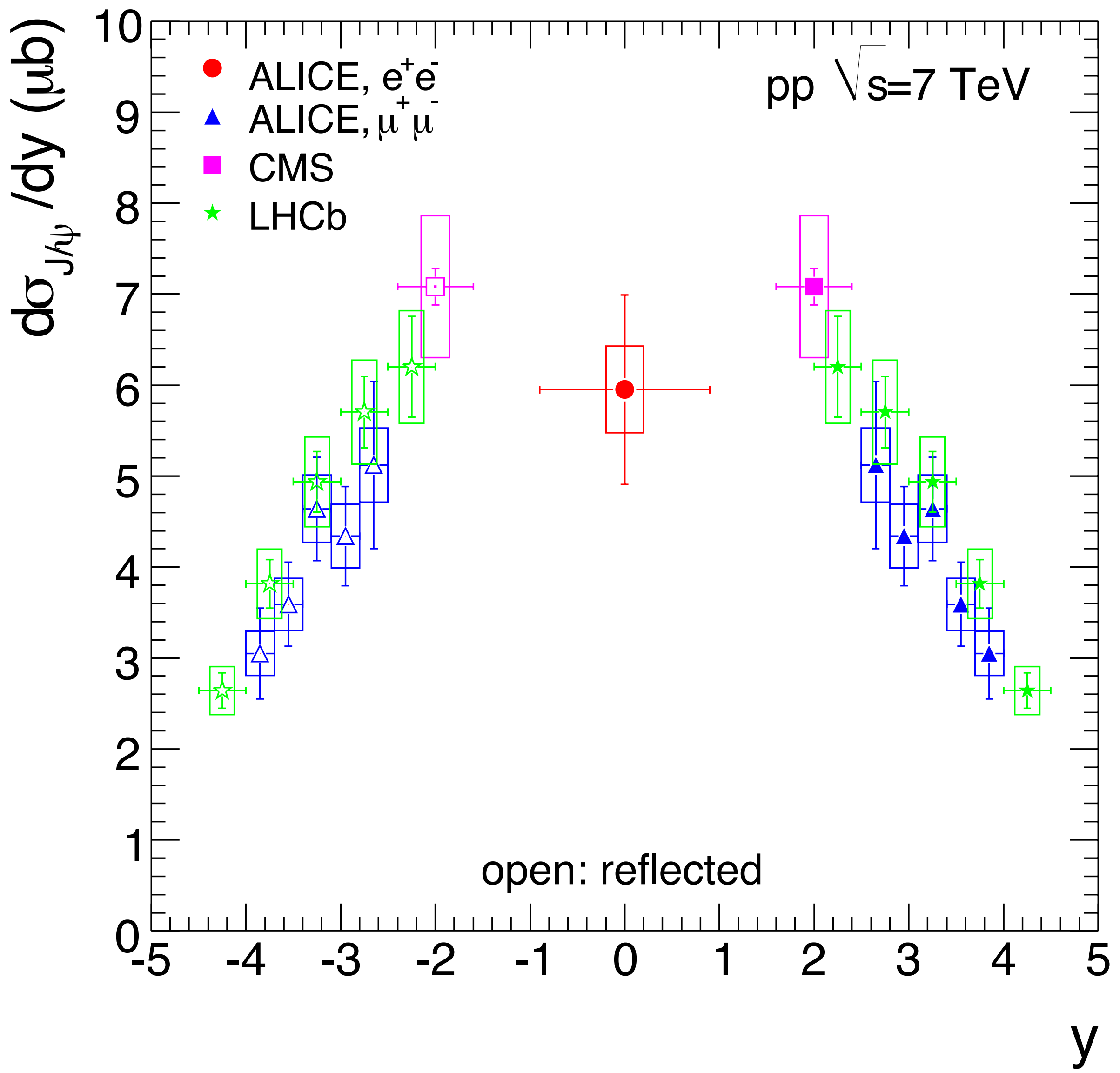
Model comparison

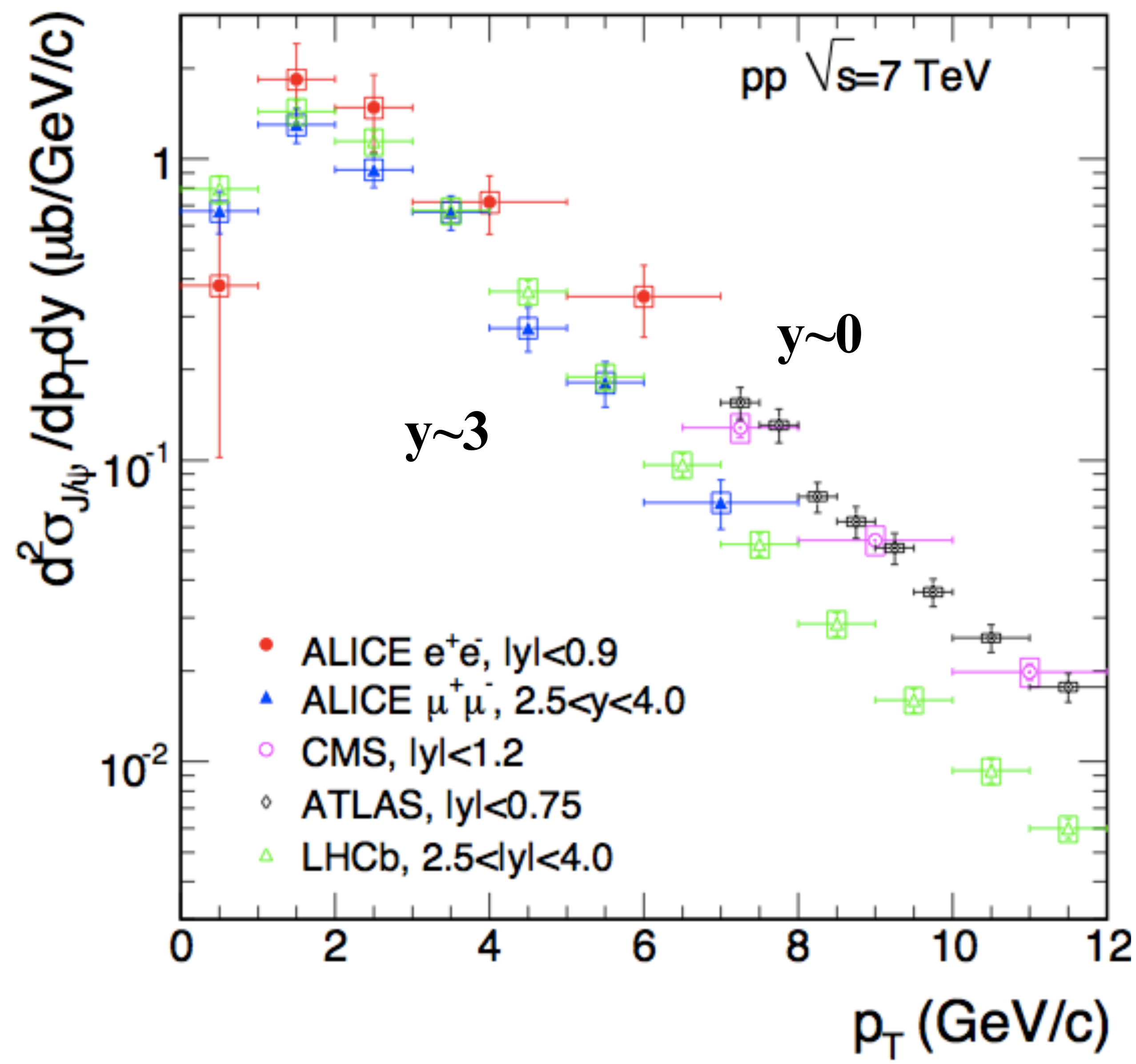


NRQCD fits to World data (included CDF and LHC @ 7 TeV) for inclusive J/ψ reproduces well the p_T dependence for both energy and p_T > 3 GeV/c

Comparison with LHC experiments

ALICE Coll.. arXiv:1105.0380. ATLAS Coll. arXiv:1104.3038, CMS Coll, arXiv:1011.4193, LHCb Coll, arXiv:1103.0423

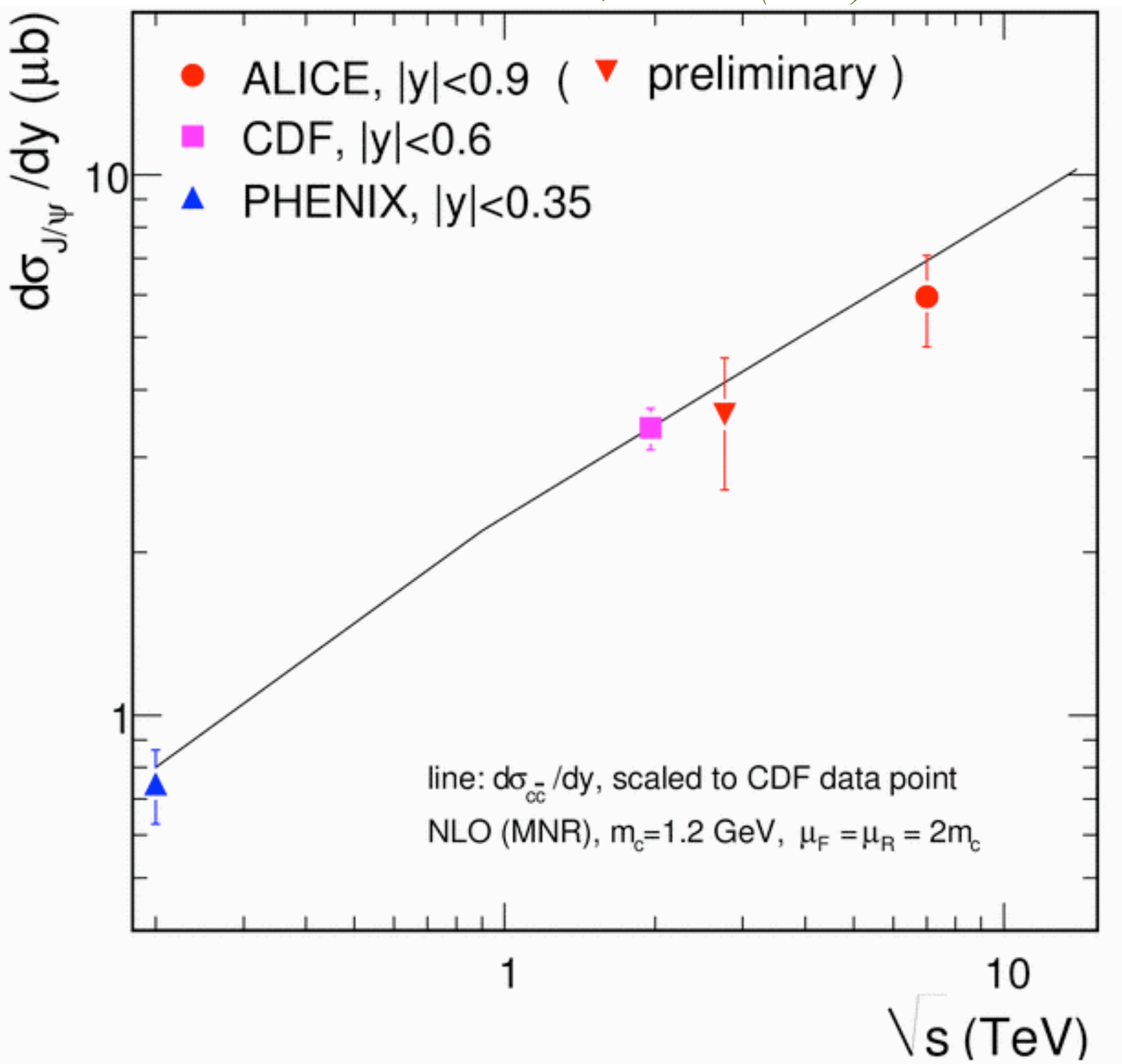




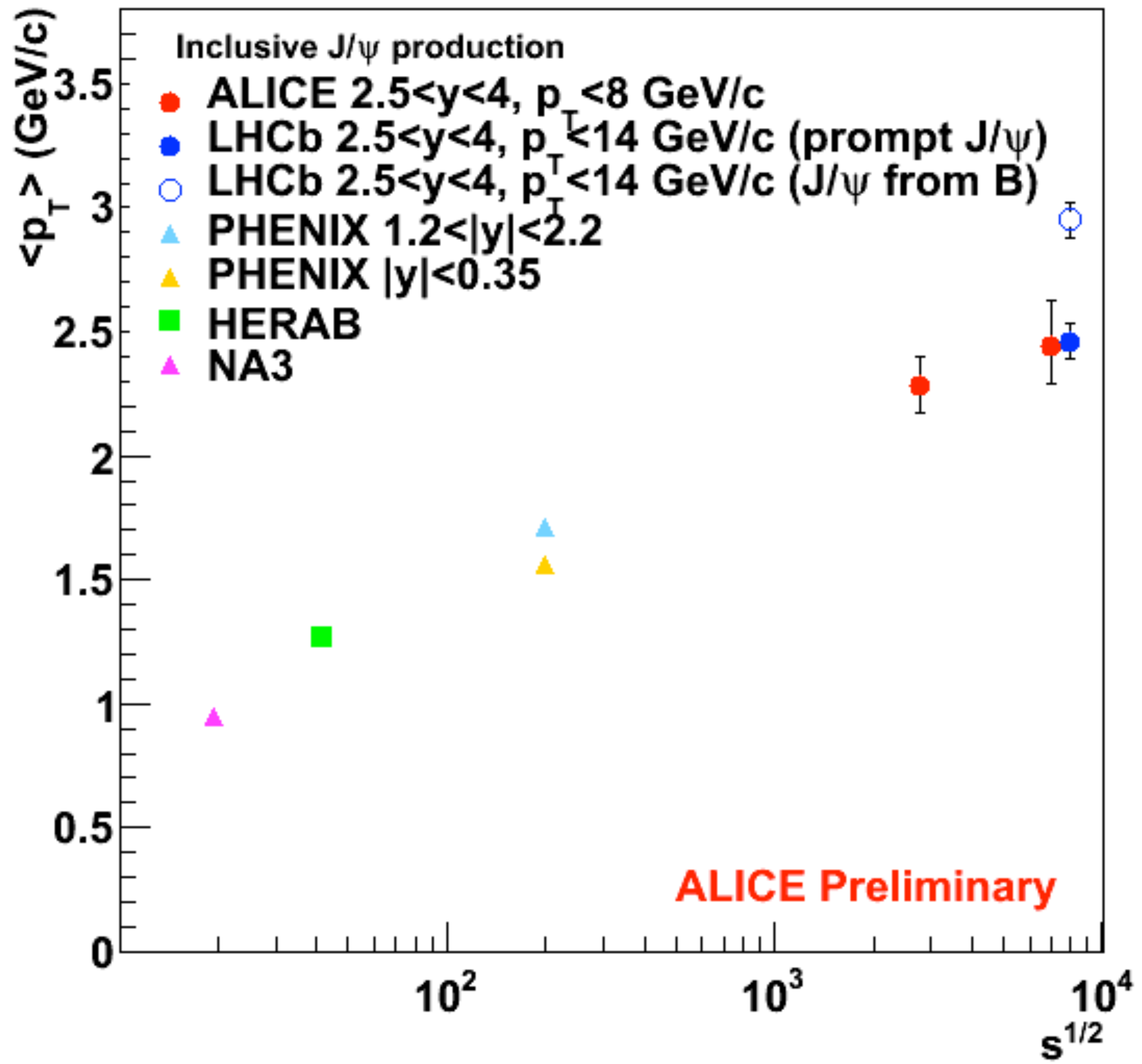
Bars = statistical and systematic (except lumi and polarization sources)
Box = systematic from luminosity only
Good agreement between ALICE and LHCb for 2.5 < y < 4

Energy dependence

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



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



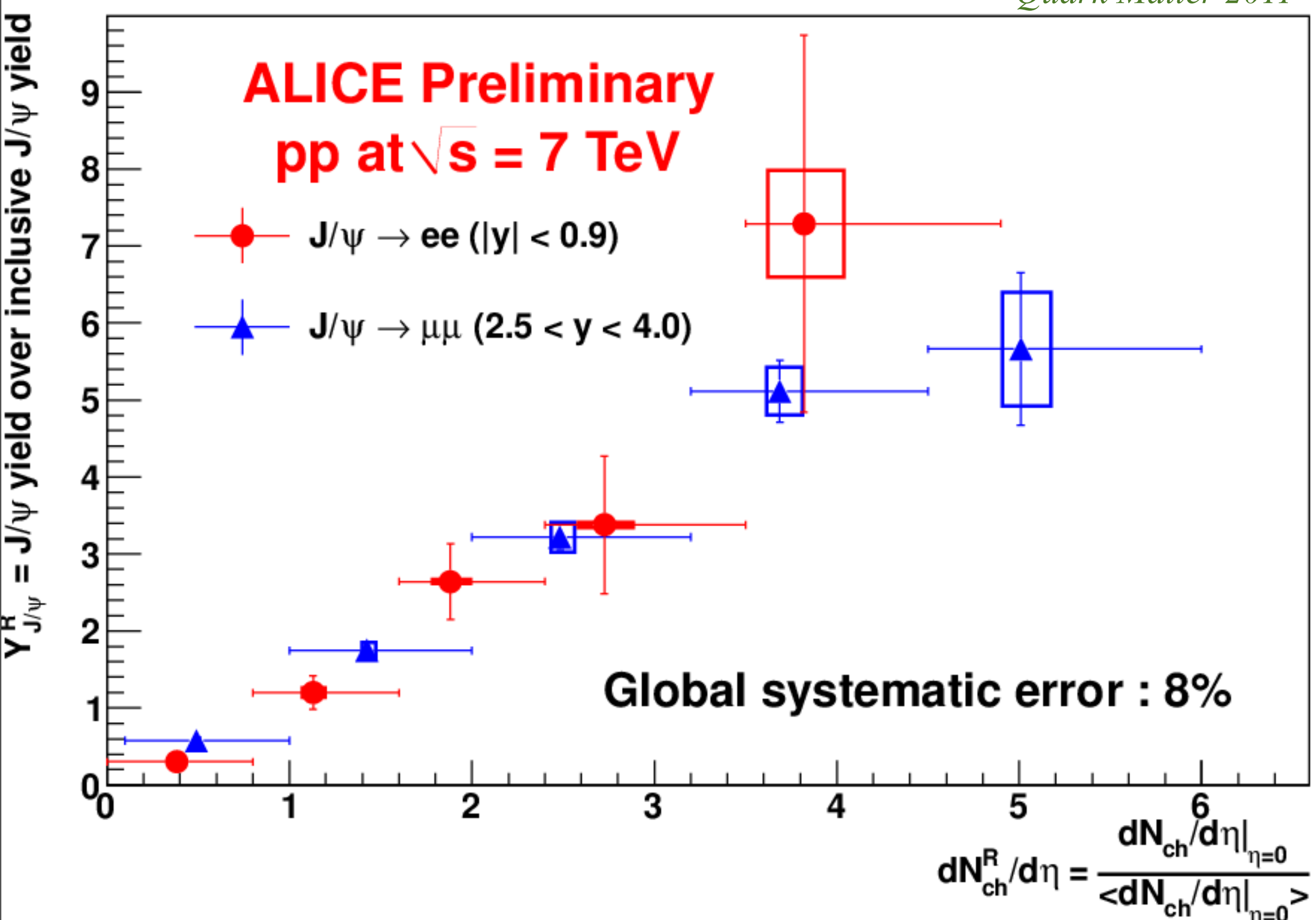
<p_T> ~ logarithmic increase with √s

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 (50-55%) @ 200 GeV → collective effects in p-p collisions at high multiplicity at LHC?

Silicon Pixel Detector charged particle multiplicity measurement

Quark Matter 2011



Linear increases of J/ψ yield with charged particle multiplicity

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 (50-55%) @ 200 GeV → collective effects in p-p collisions at high multiplicity at LHC?

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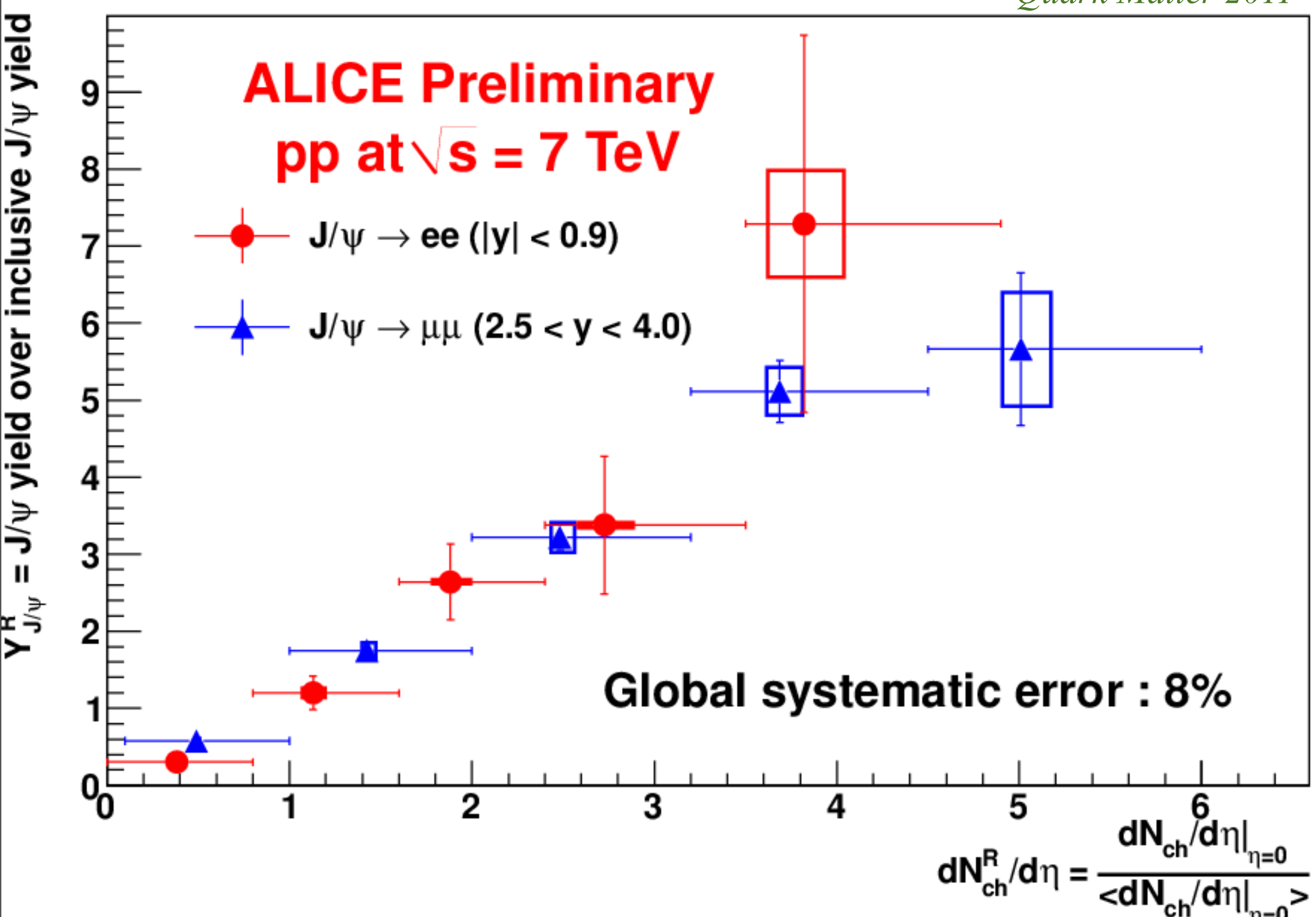
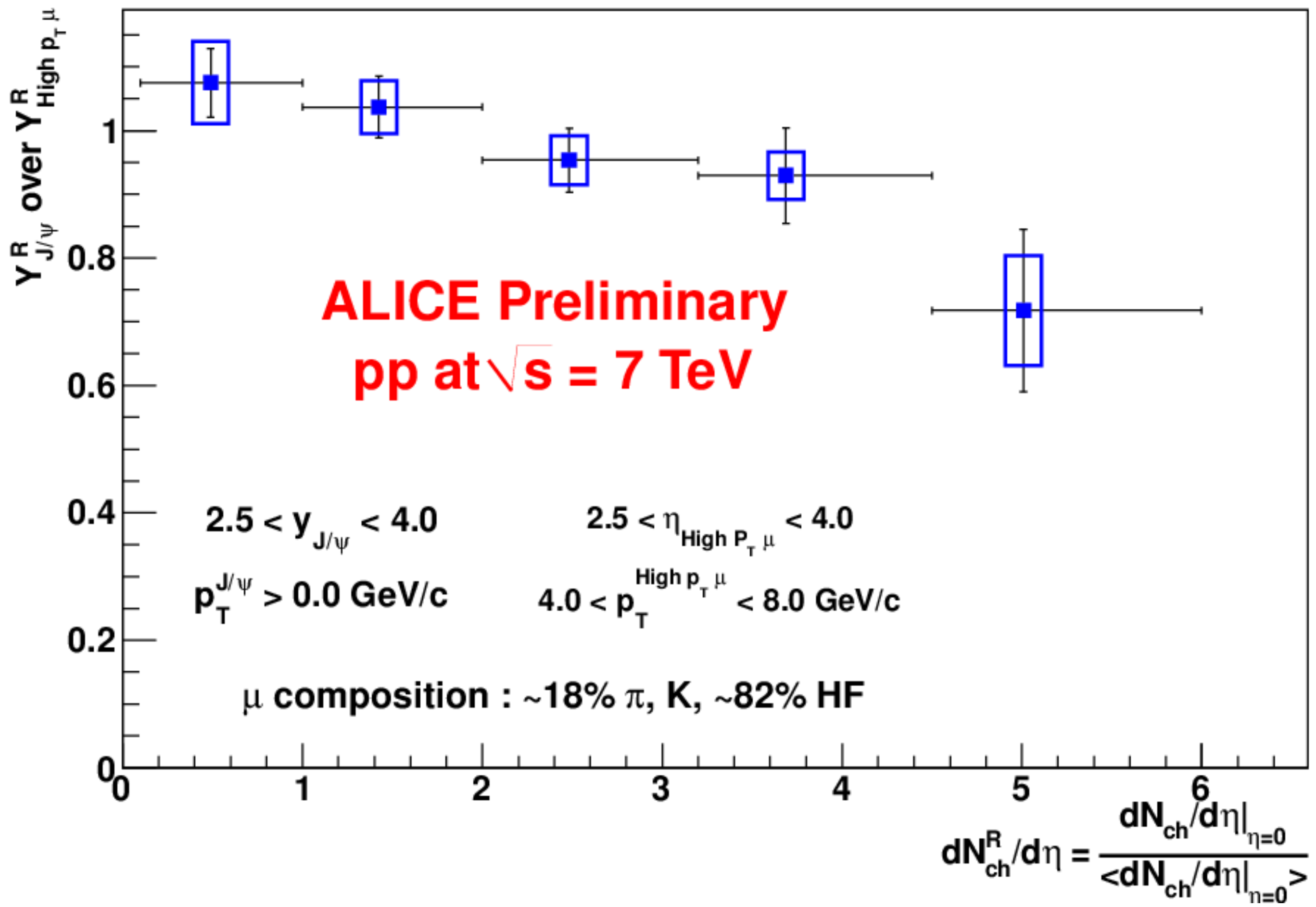




Linear increases of J/ψ yield with charged particle multiplicity

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

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

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

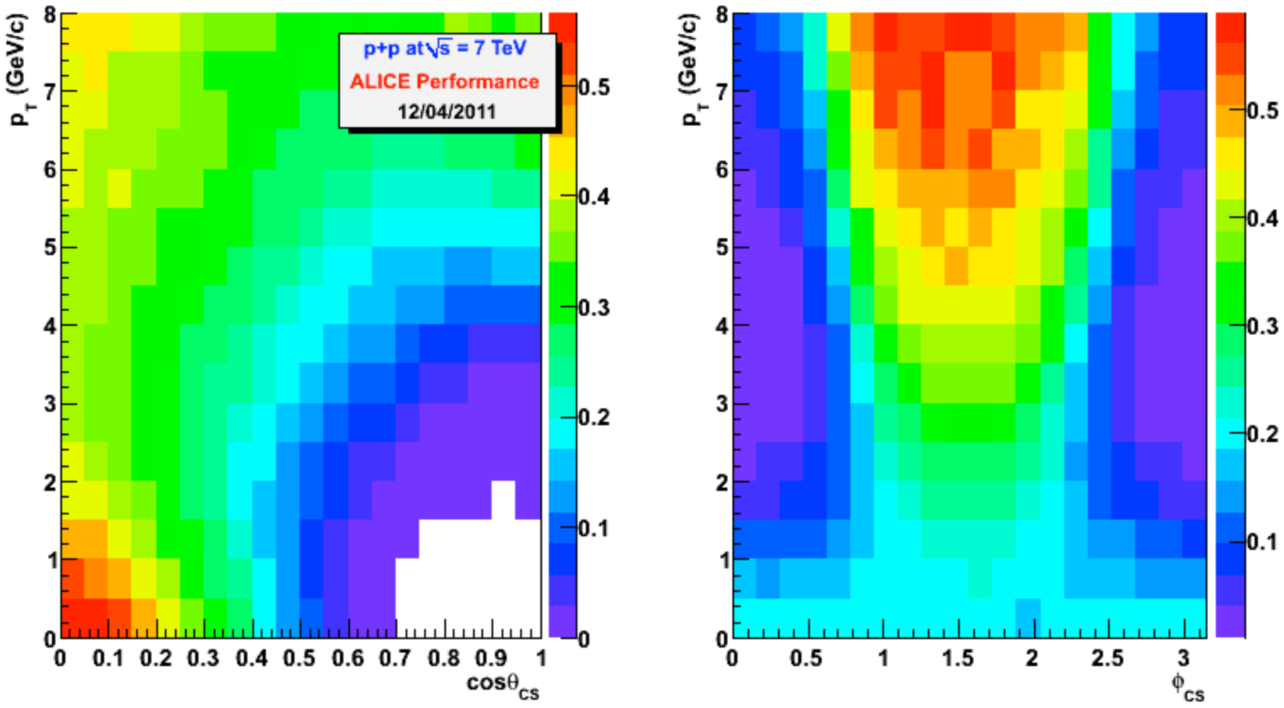
Ongoing analyses

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/ψ → $\mu^+ \mu^-$



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

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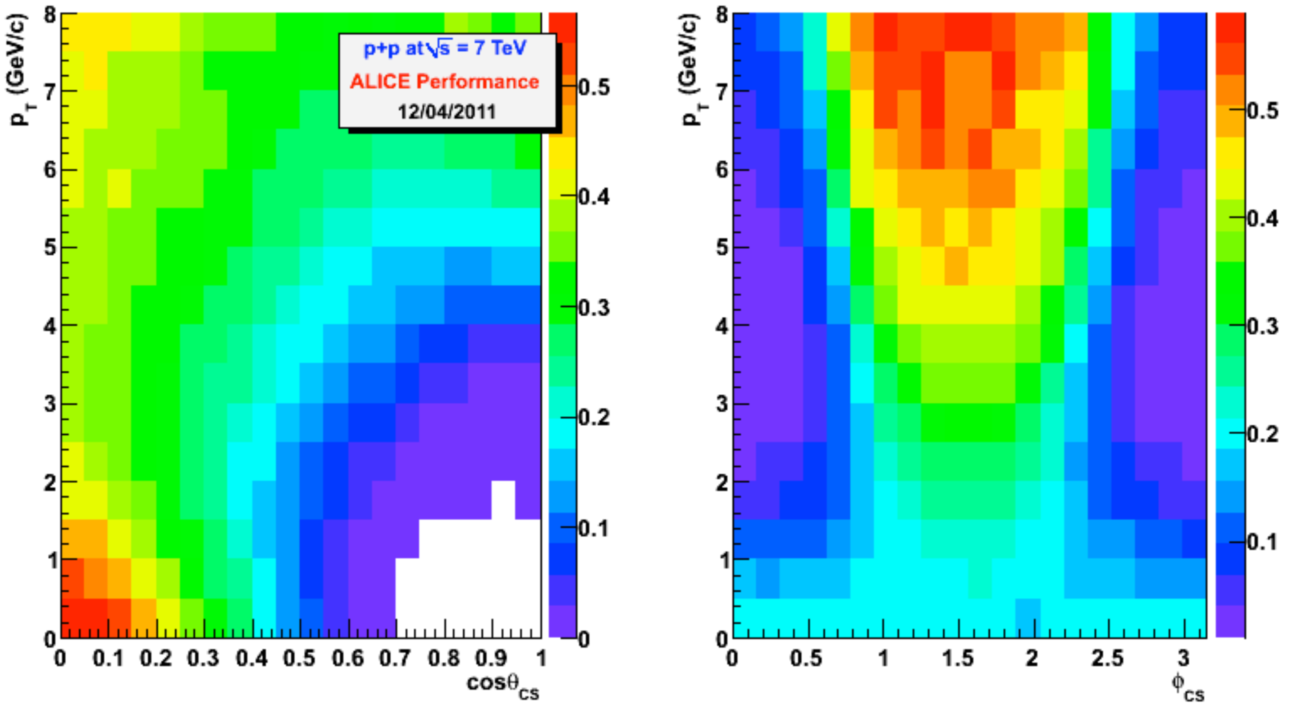
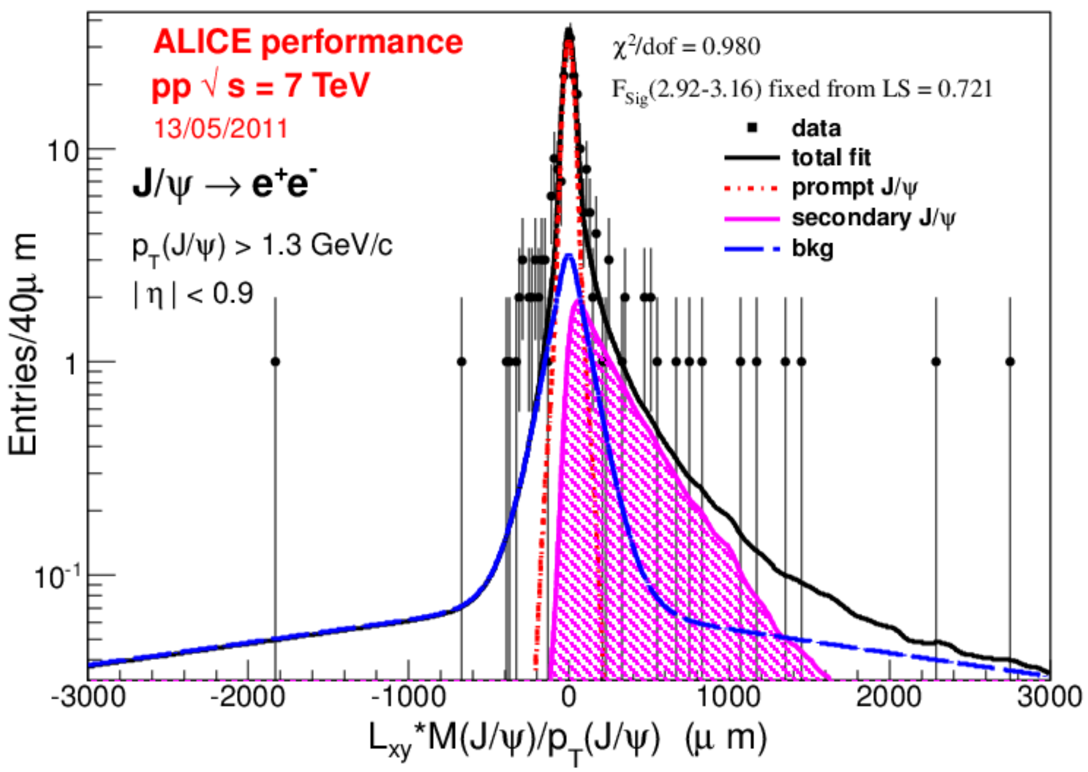


Expected error on $\lambda_\theta \sim 0.15$ for $3<p_T<8$ GeV/c

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

Ongoing analyses

J/ψ polarization

Key observable to study the production mechanism

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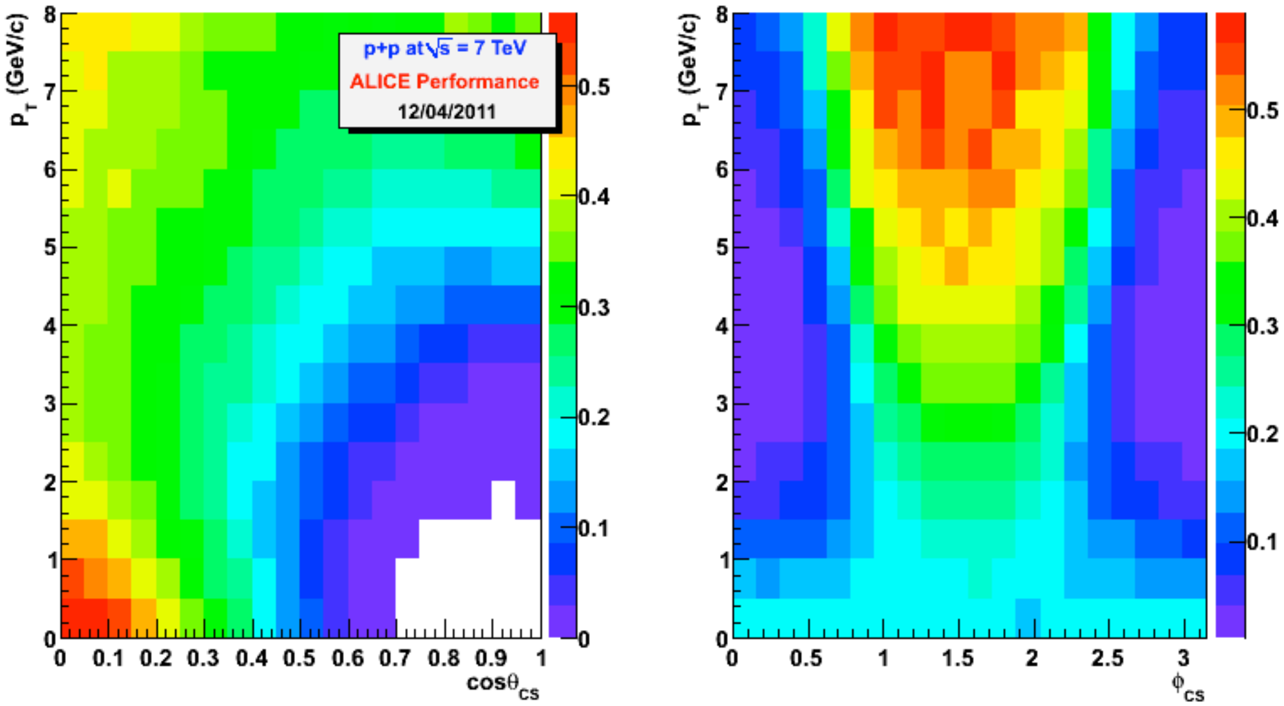

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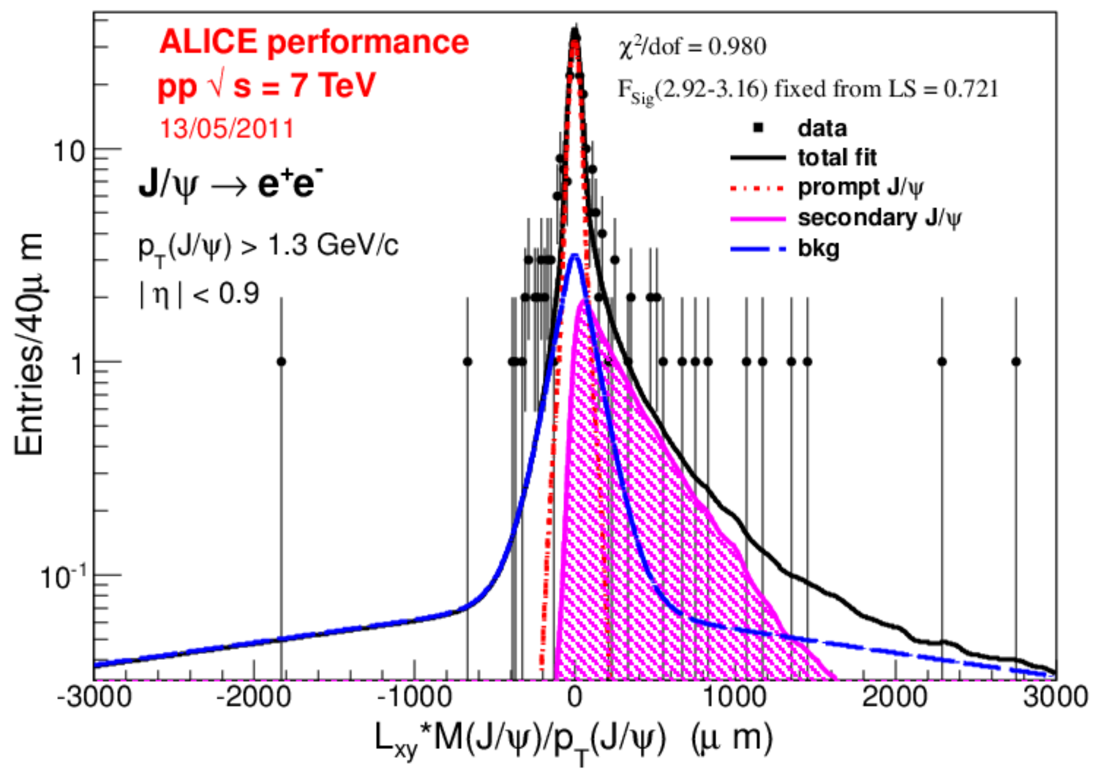
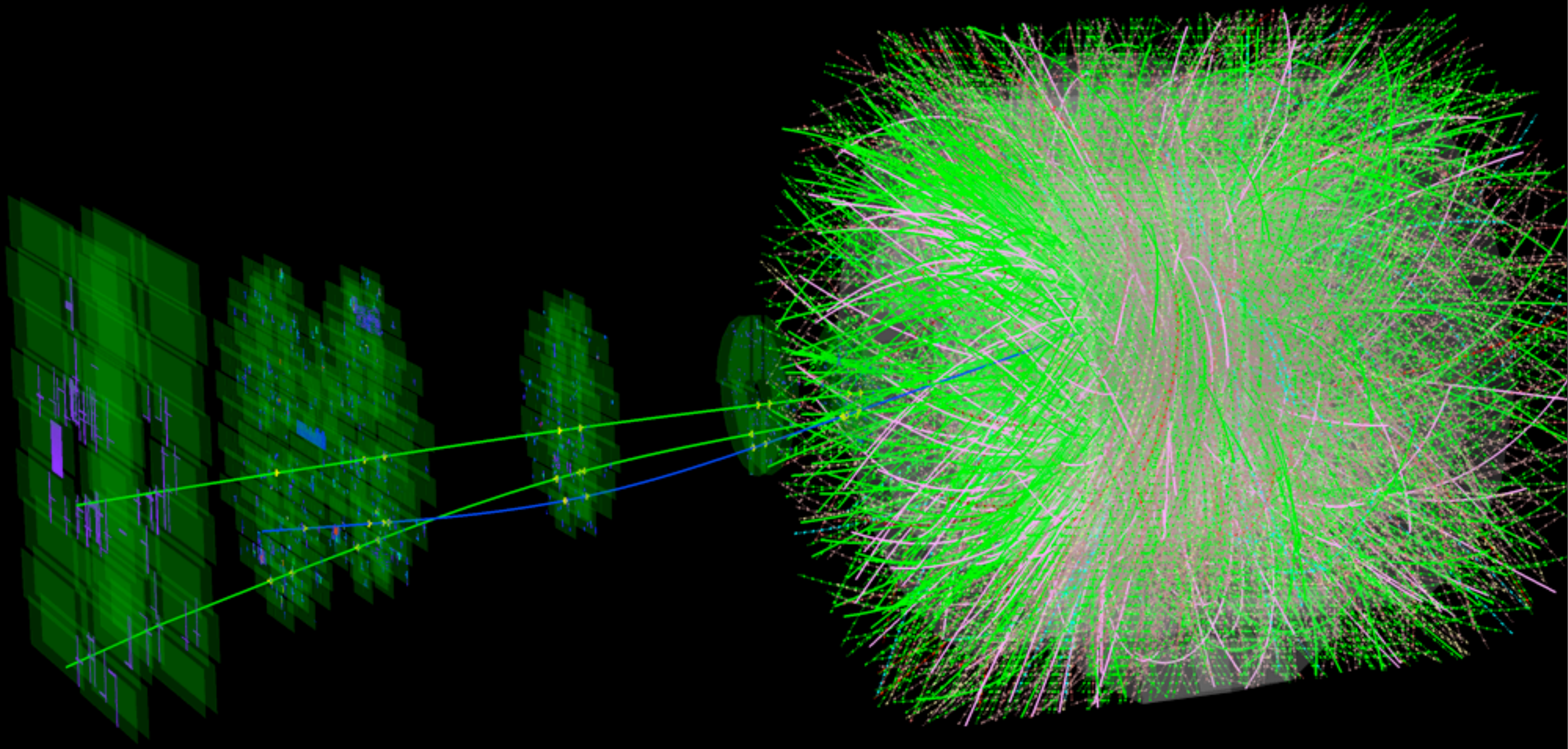


High statistics sample to be collected this year with electron trigger

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

J/ψ measurements in Pb-Pb collisions



Pb-Pb collisions: event and track selection

Triggers
Minimum bias $-3.7<\eta < 5.1$
V0A && V0C && Pixel

Event and track selection
Only differences with p-p collisions mentioned

electrons
electron PID based on TPC dE/dx or TPC and TOF

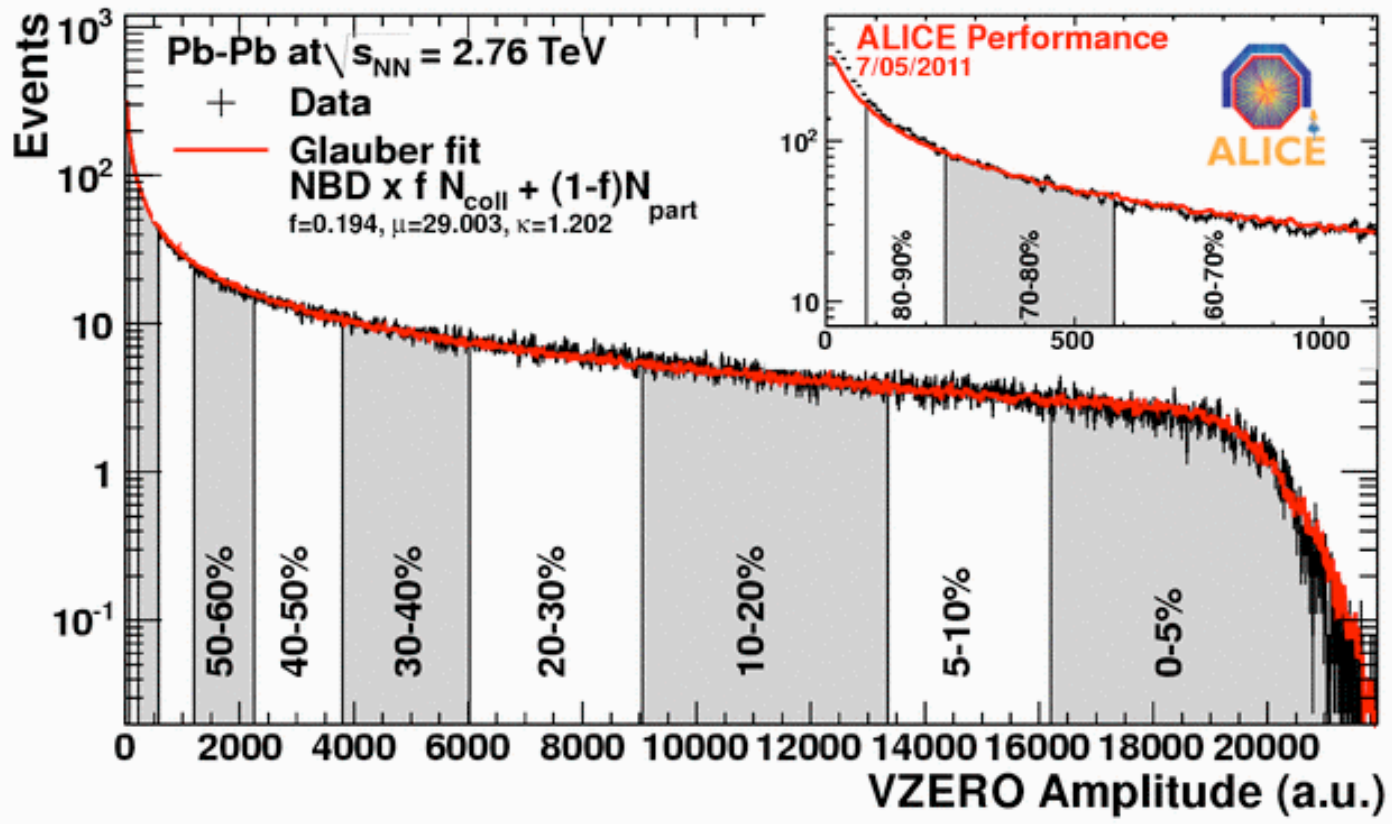
muons
2 muons trigger matching

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

Centrality determination
Based on a Glauber fit of the V0 amplitude
Electromagnetic interactions dominate for centrality > 90%

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

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

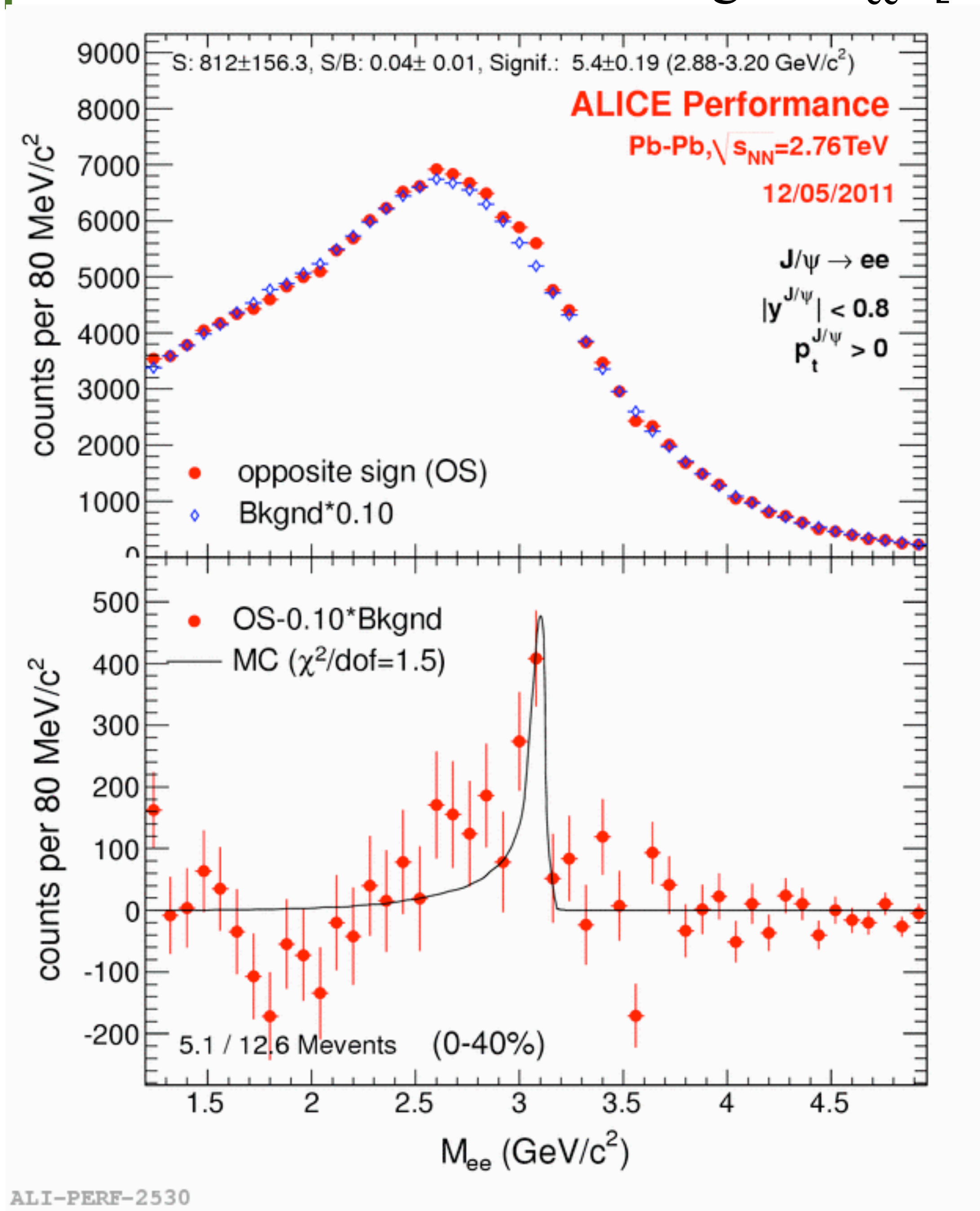


Signal extraction

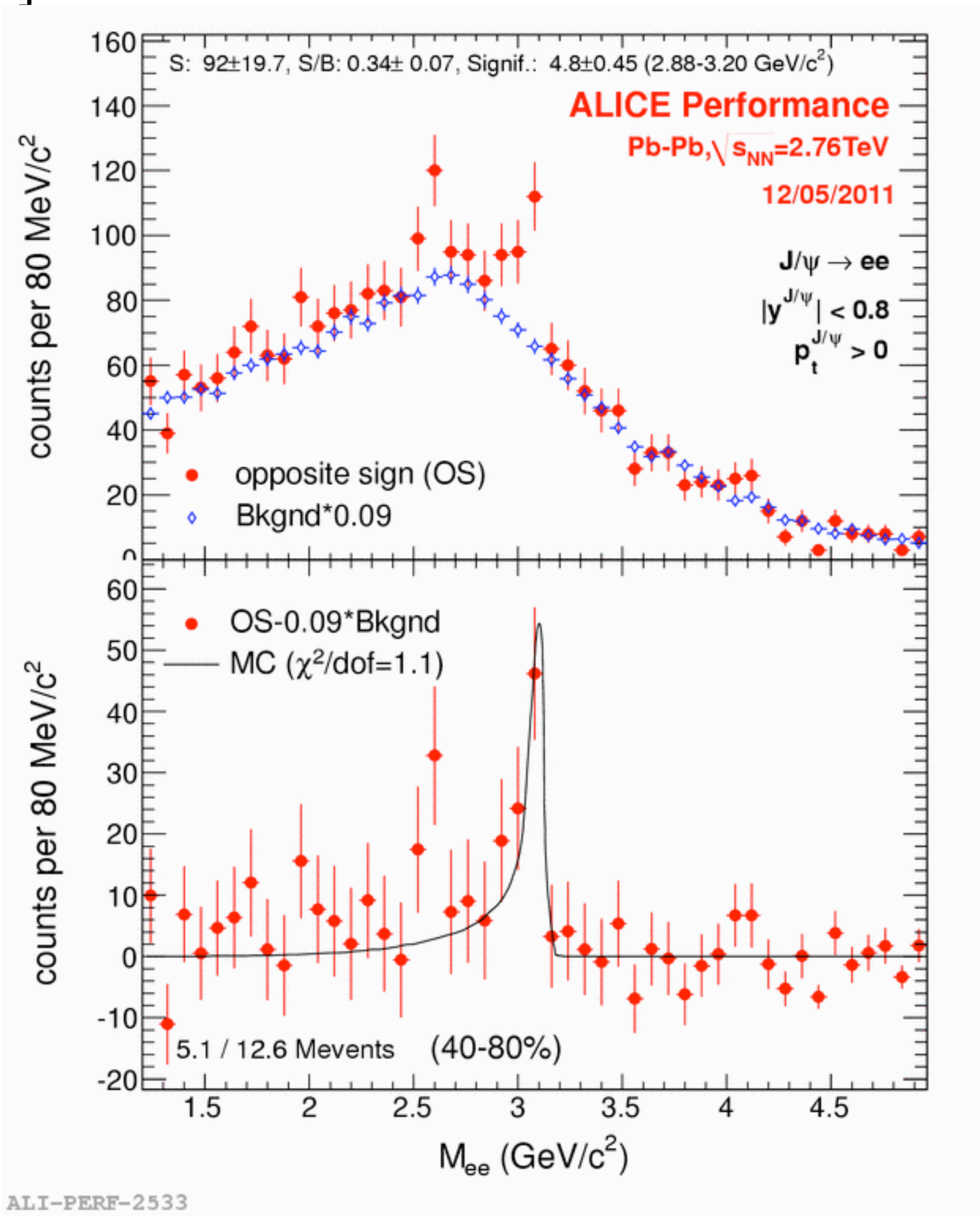
$J/\psi \rightarrow e^+ e^-$

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

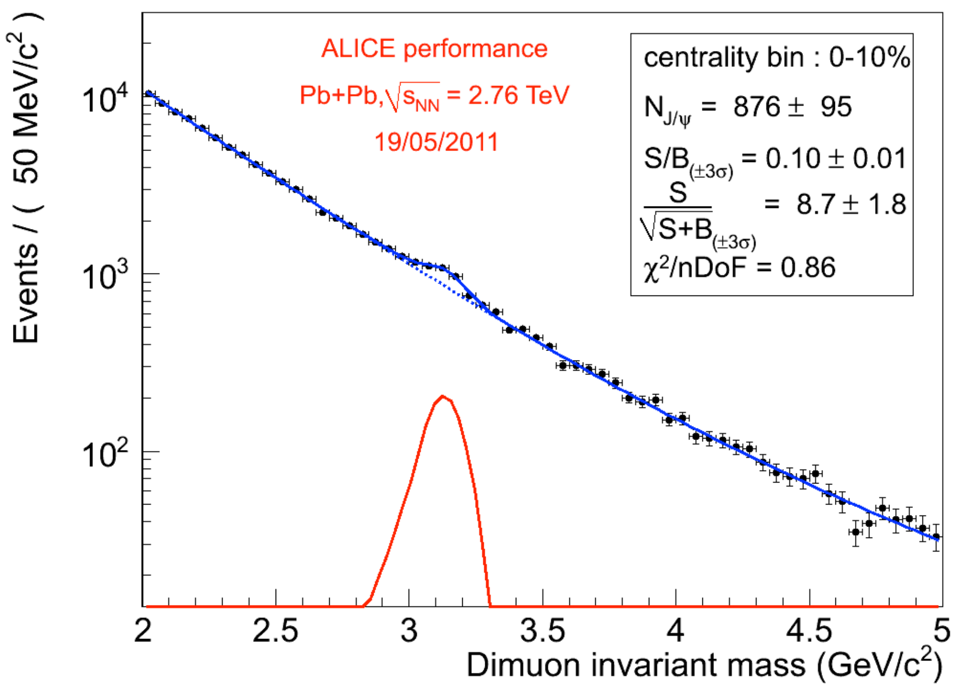
$J/\psi \rightarrow \mu^+ \mu^-$ Signal extraction

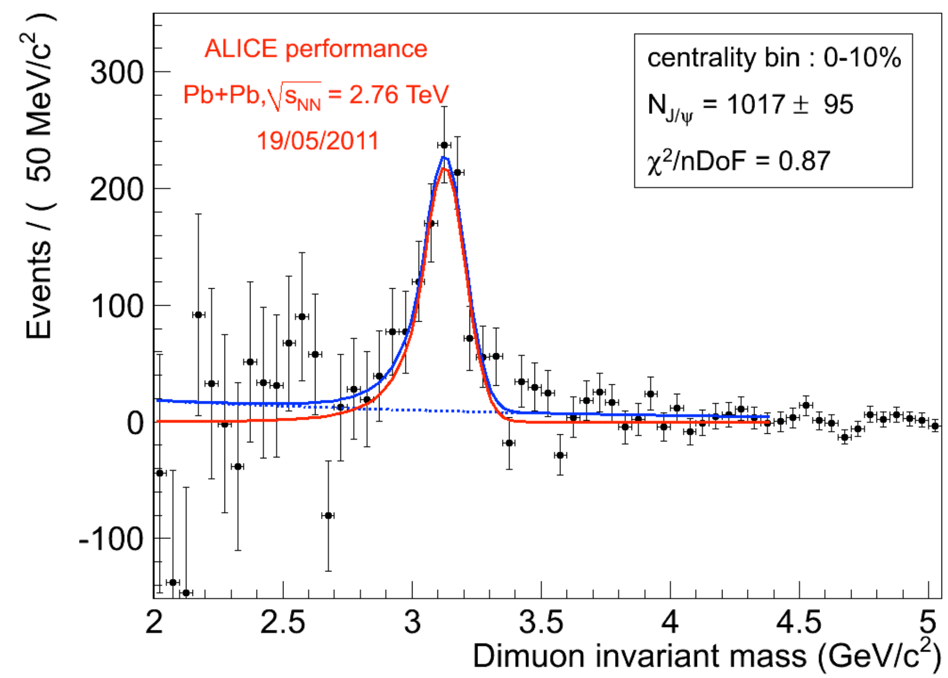
Fit of the inv. mass distribution

Crystal Ball (with 1 or 2 tails) + 2 exponentials
Shape fixed for the 4 centrality bins

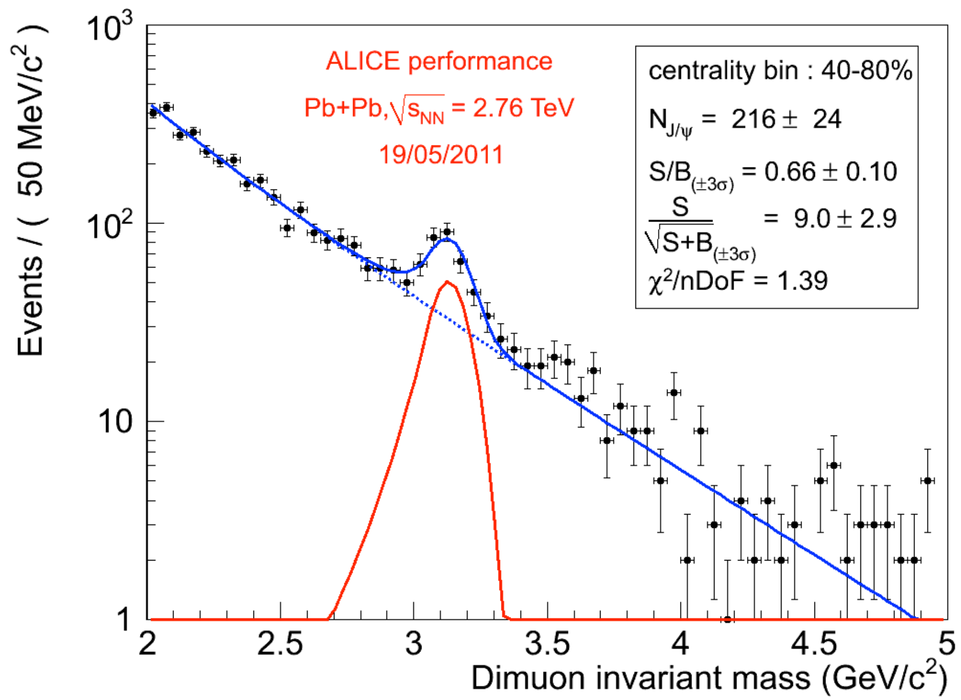
Event mixing technique

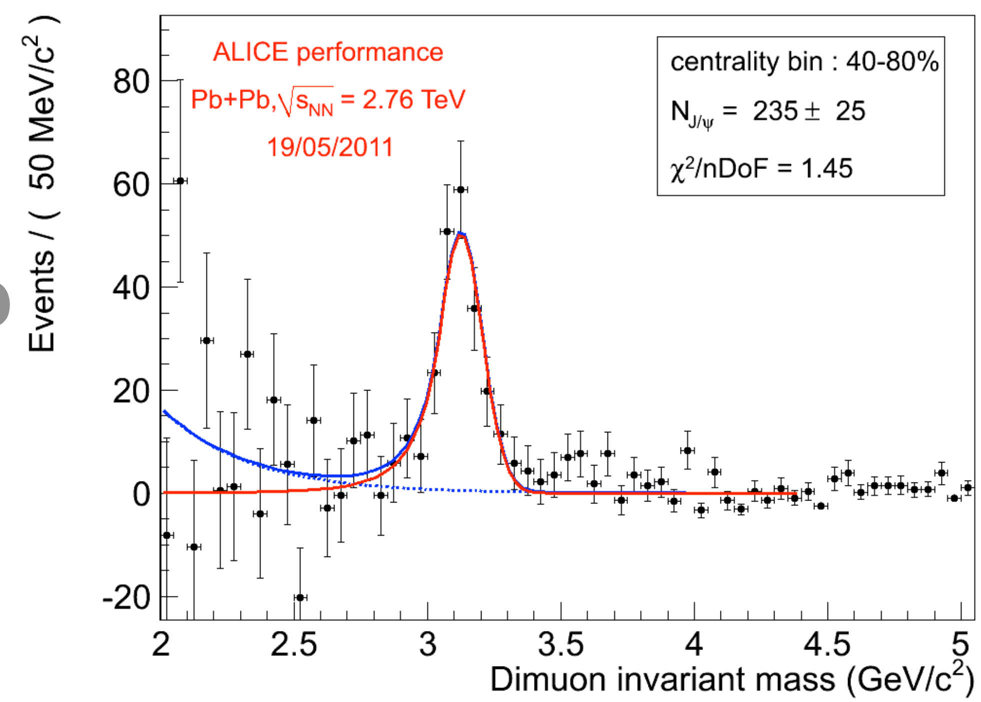
Mixed pair inv. mass normalized to data in [1.5;2.5] GeV/c^2 and subtracted
Residual background estimated by a Crystal Ball+ exponential fit





0-10%





40-80%

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

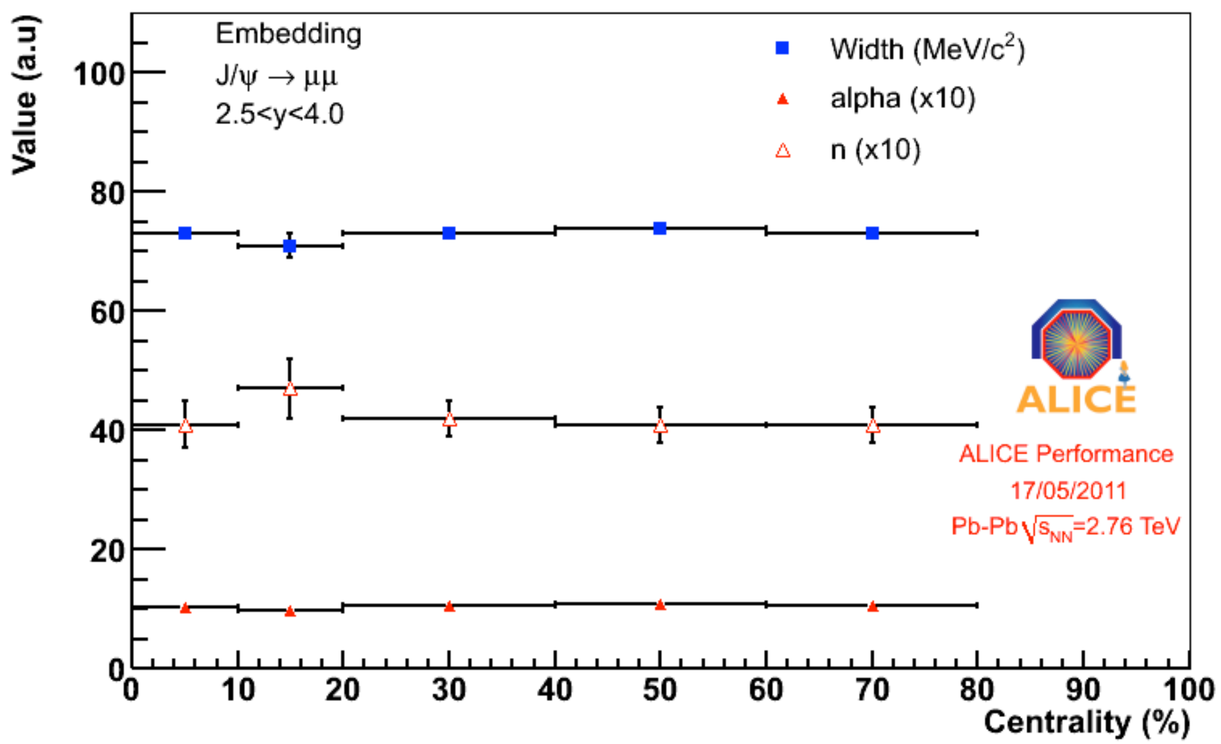
Studies on high multiplicity environment effect

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

Embedding

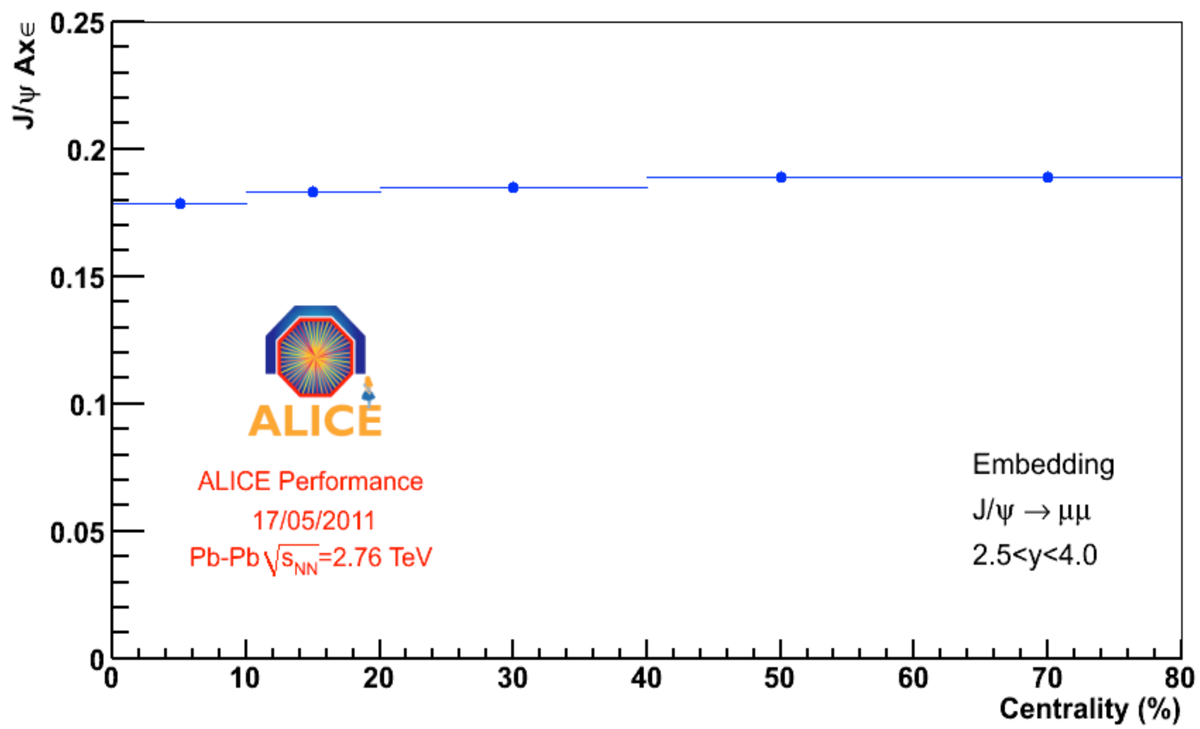
One simulated J/ψ embedded into each real event to study a possible bias of the measurements with the centrality of the collision

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.

R_{AA} vs centrality

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

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

Quark Matter 2011

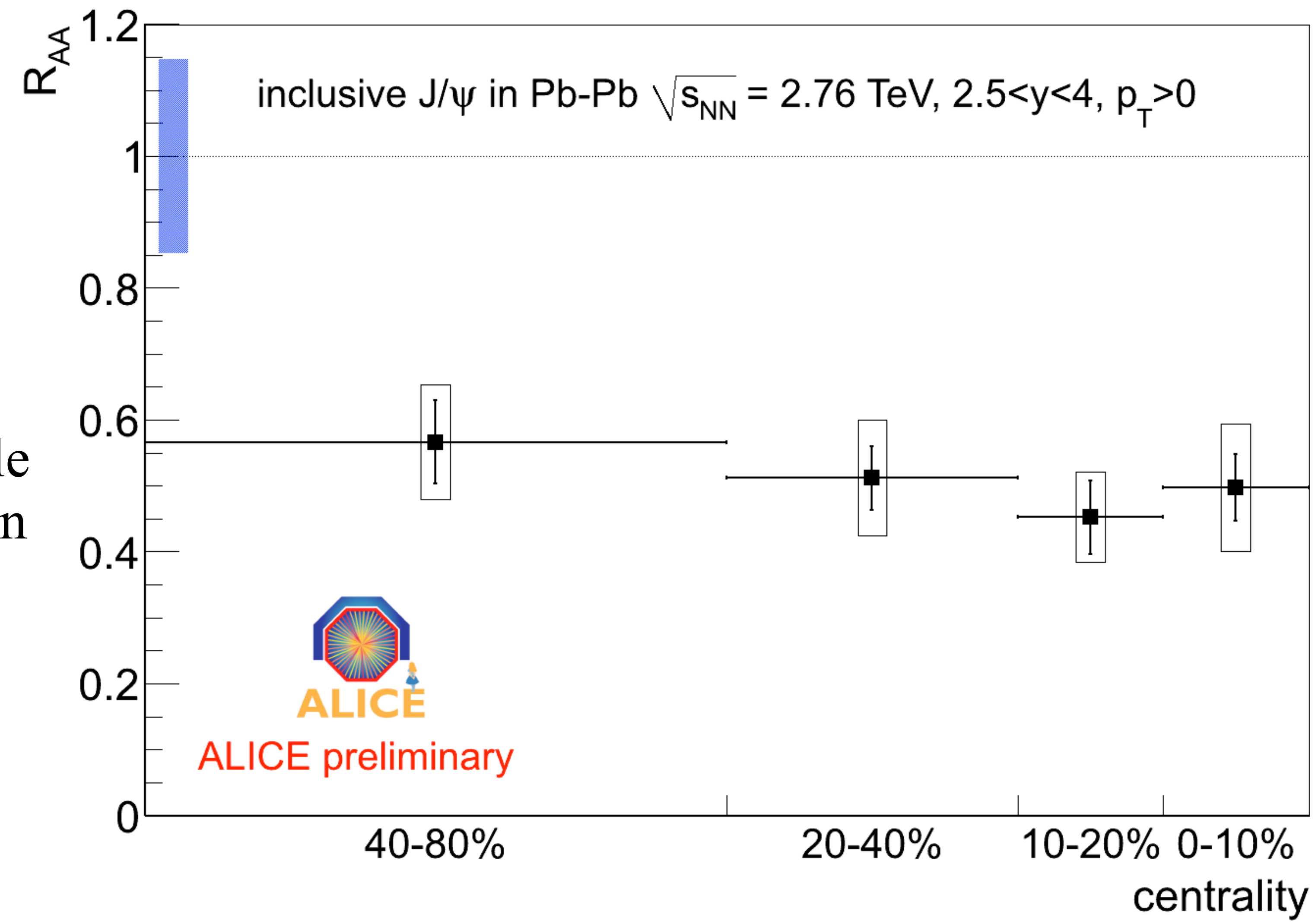
Inclusive J/ψ $R_{AA}^{0-80\%}$ = 0.49 ± 0.03 (stat.) ± 0.11 (sys.)

Contribution from B feed-down:

~ 10% from p-p measurement

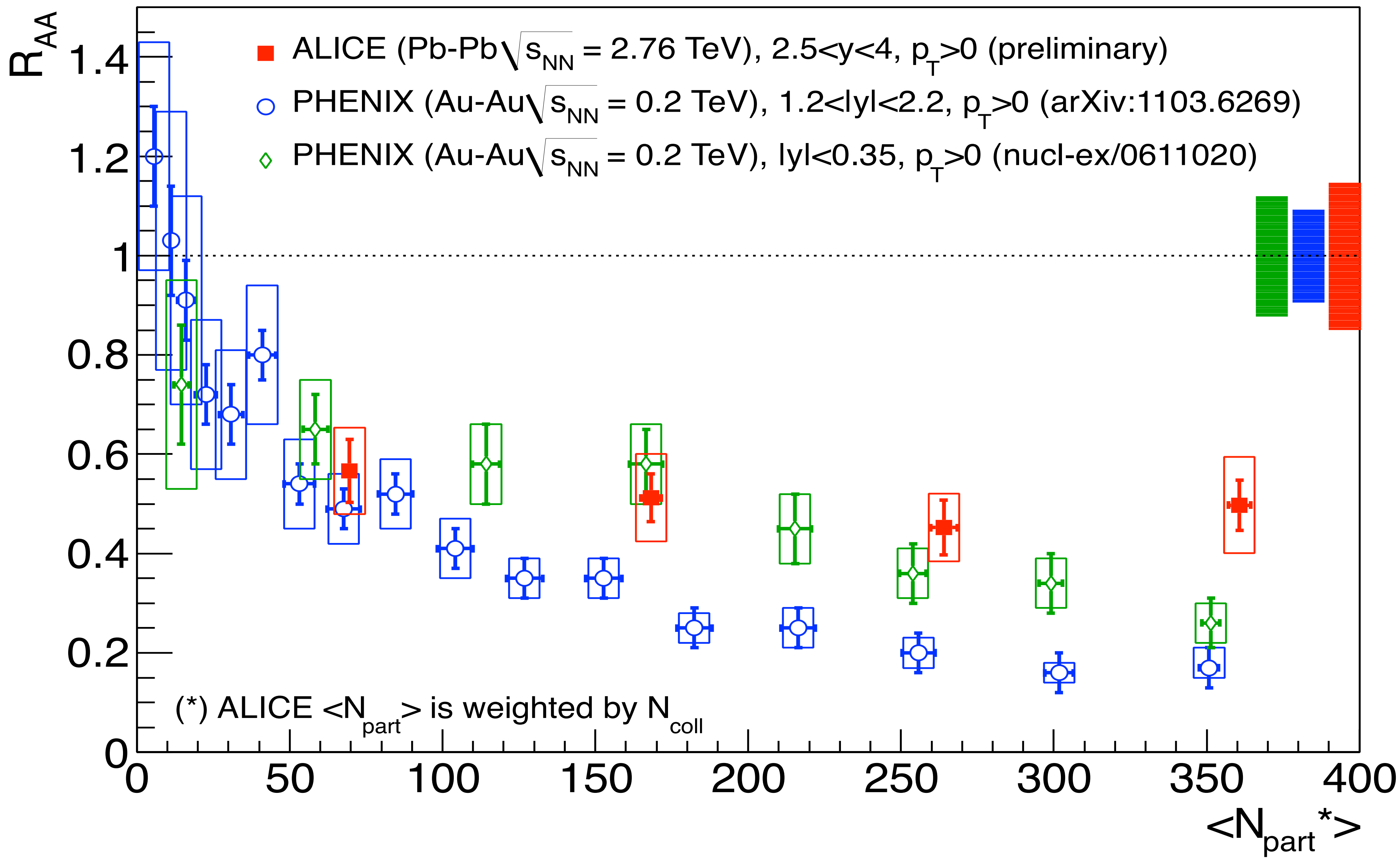
LHCb Collaboration, arXiv:1103.0423

Rough estimation assuming simple scaling with N_{coll}: ~ 11% reduction of $R_{AA}^{0-80\%}$



Almost flat centrality dependence !

R_{AA} vs N_{part} at RHIC and LHC



In the most central collisions, larger suppression measured at RHIC for p_T>0!

Role of regeneration?

CNM effect are expected to be larger at LHC

Surprising results but p-Pb needed to conclude

R_{CP} vs centrality

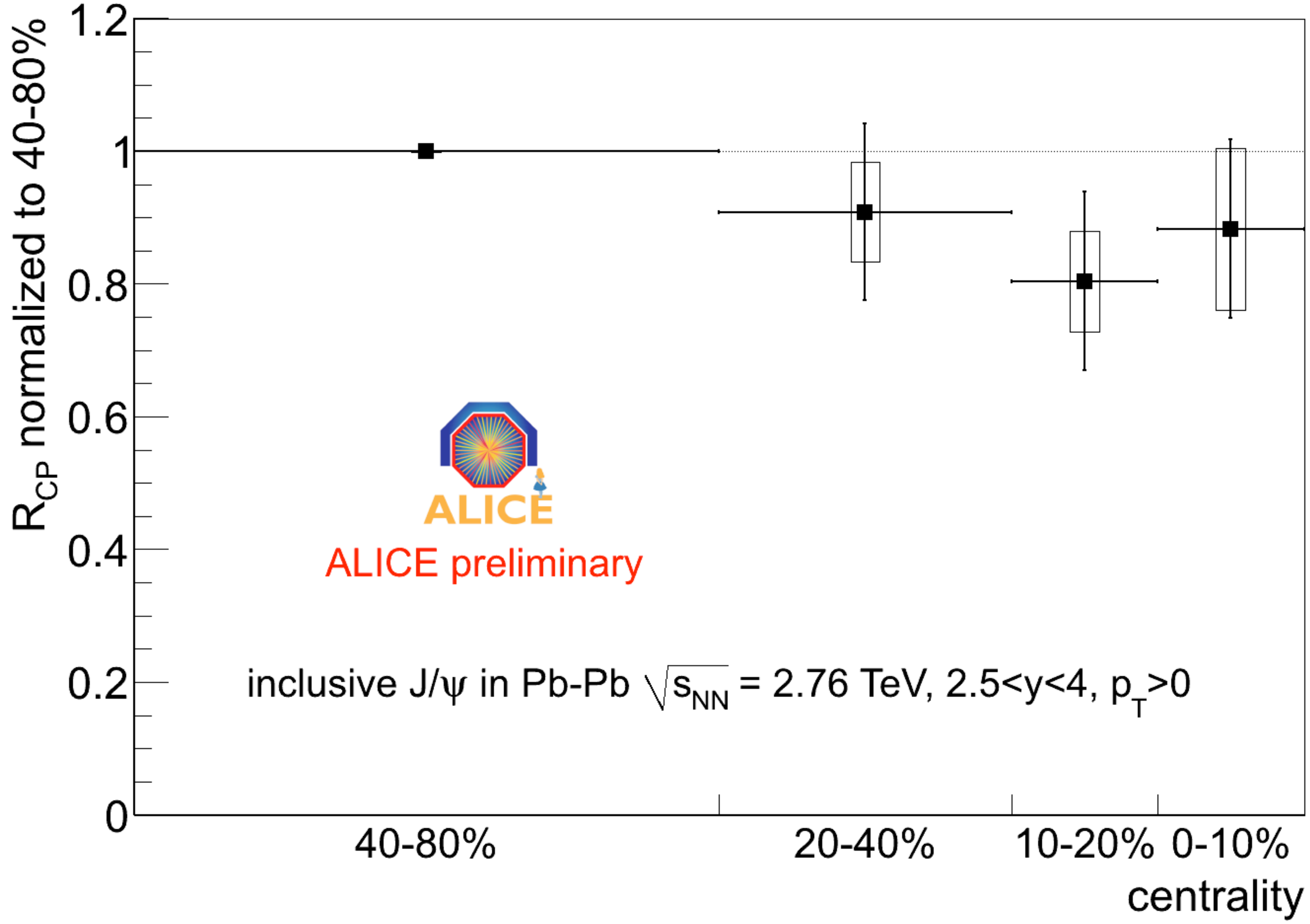
$$Y^i_{J/\psi} = \frac{N^i_{J/\psi}}{B.R. \times AccEff \times N^i_{MB}}$$

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

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

Statistical uncertainty of the reference propagated to the ratio

Systematic uncertainties of signal extraction and T_{AA} calculated considering the correlations → common systematic uncertainties vanish



R_{CP} vs centrality

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

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

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ALICE:

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

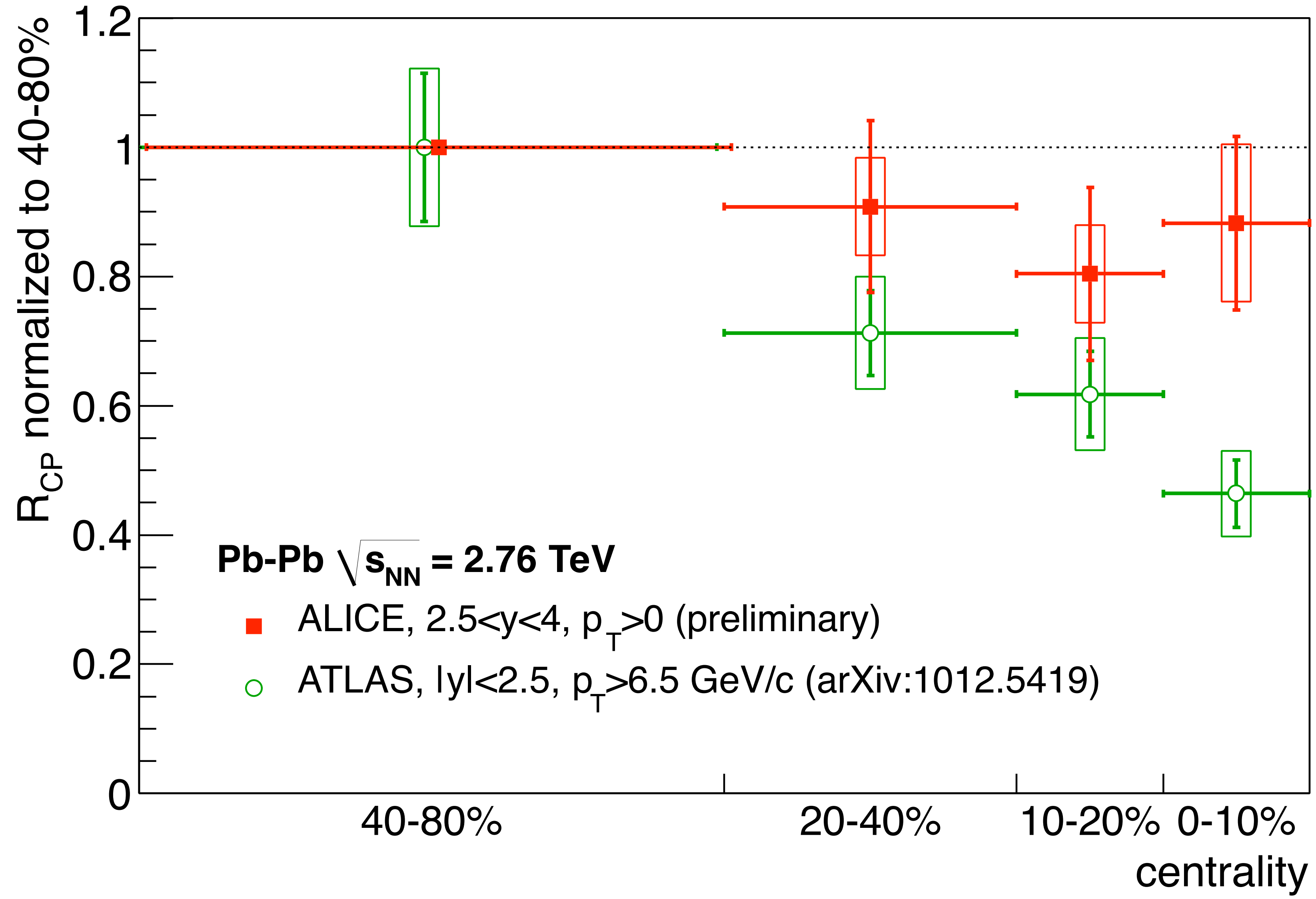
ATLAS:

- |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

Similar suppression as in ATLAS measured at CMS



R_{CP} vs centrality

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

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

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

Statistical uncertainty of the reference propagated to the ratio

Systematic uncertainties of signal extraction and T_{AA} calculated considering the correlations → common systematic uncertainties vanish

ALICE:

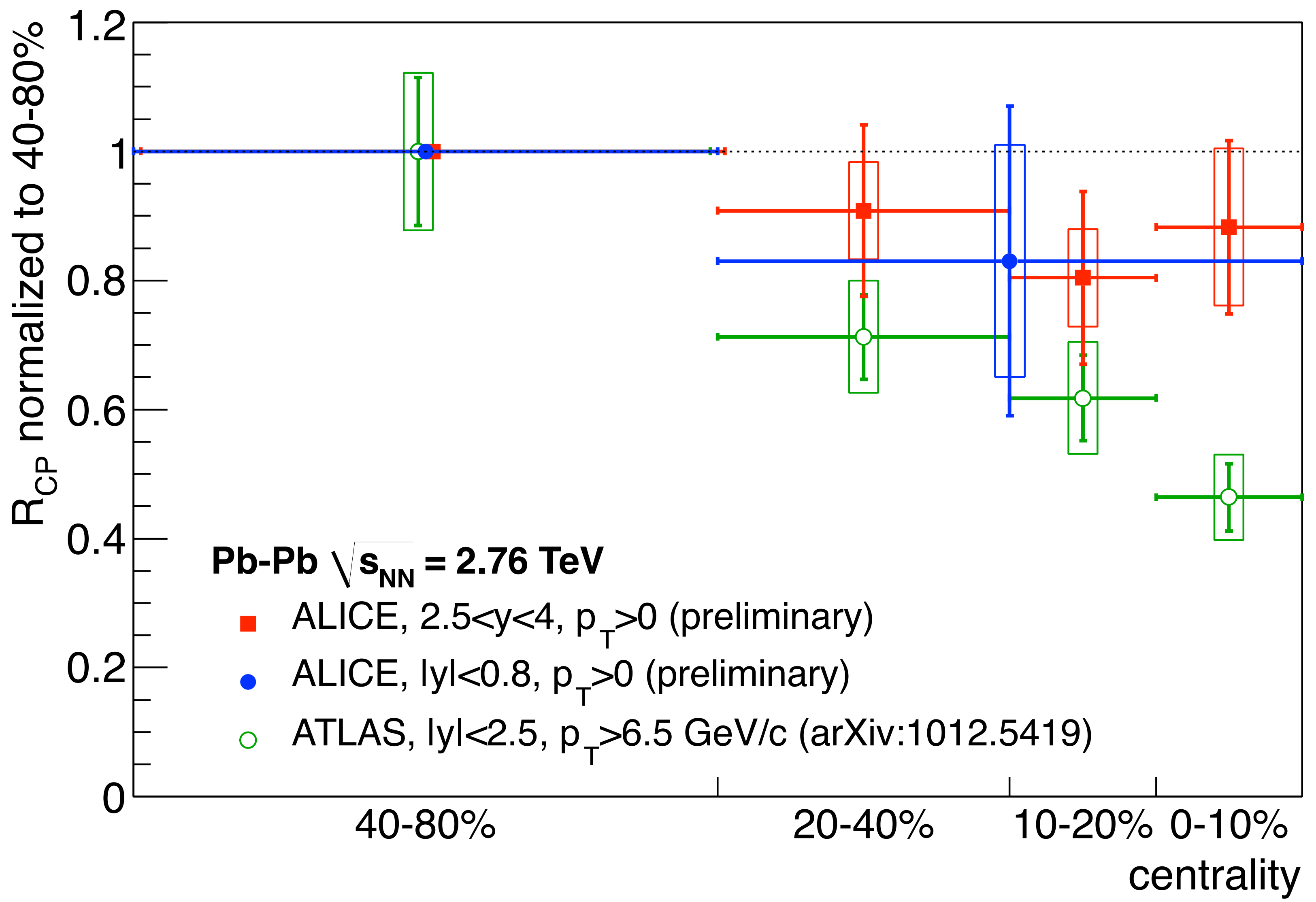
- 2.5<y<4
- $p_T > 0$

ATLAS:

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

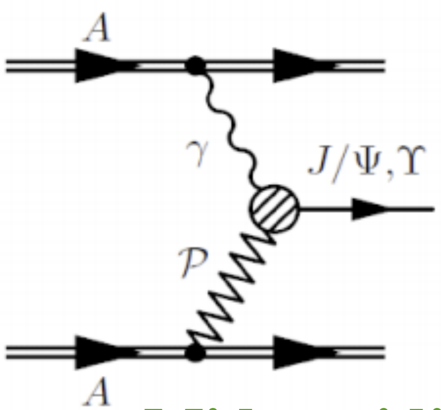
R_{CP} larger for ALICE than for ATLAS in the most central collisions…
… but different kinematical region

Similar suppression as in ATLAS measured at CMS



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

Ongoing analyses: J/ψ production in ultra-peripheral collisions



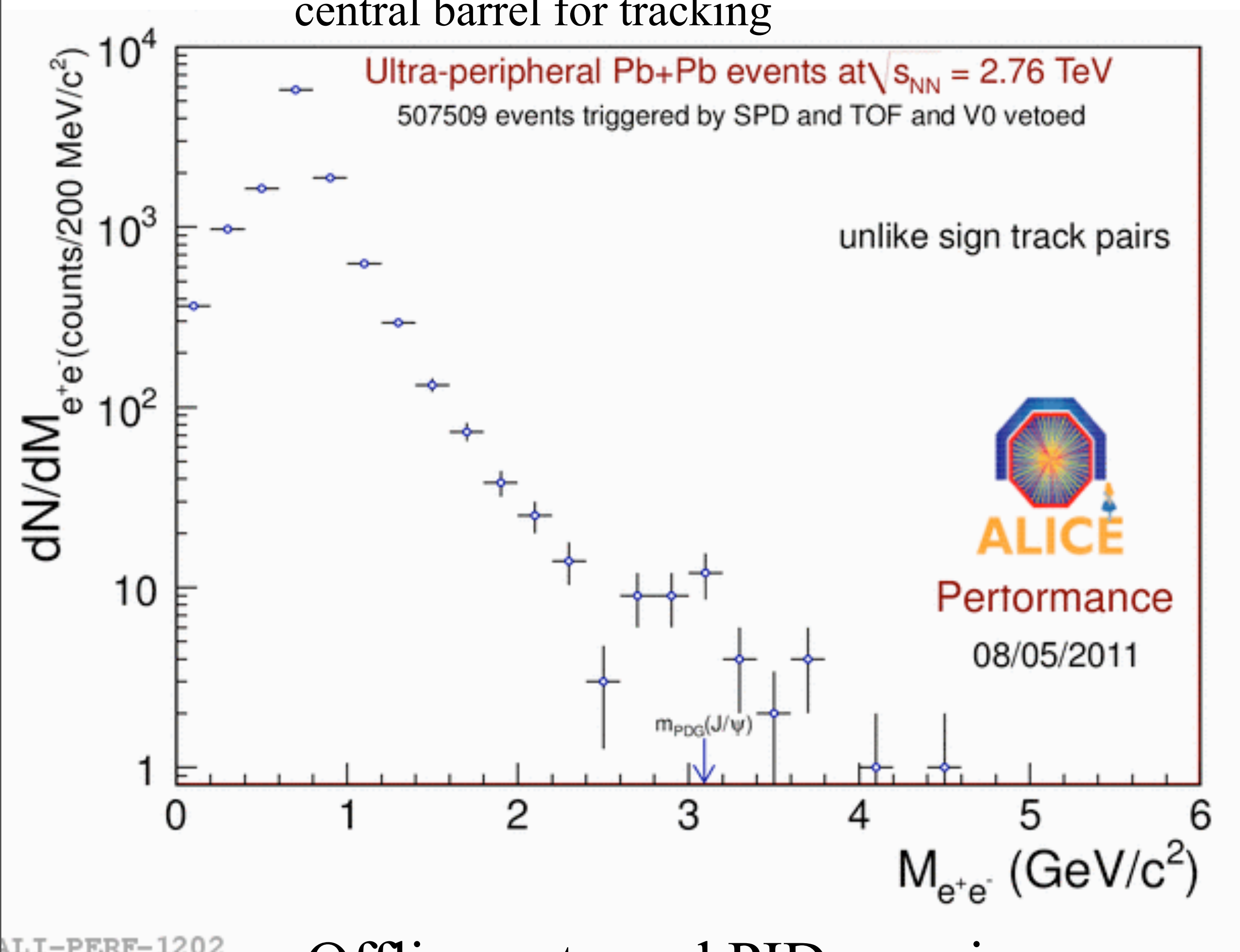
Probe the gluon distribution of the nuclei

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

Mid-rapidity

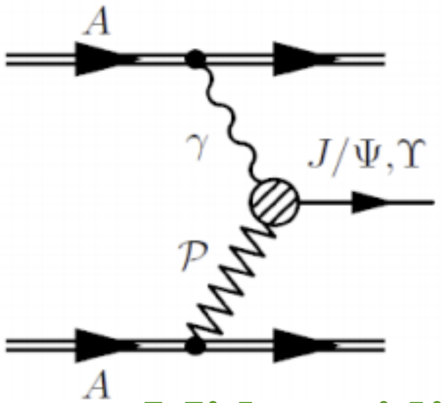
trigger on TOF && Pixel && !V0

central barrel for tracking



Offline veto and PID ongoing

Ongoing analyses: J/ψ production in ultra-peripheral collisions



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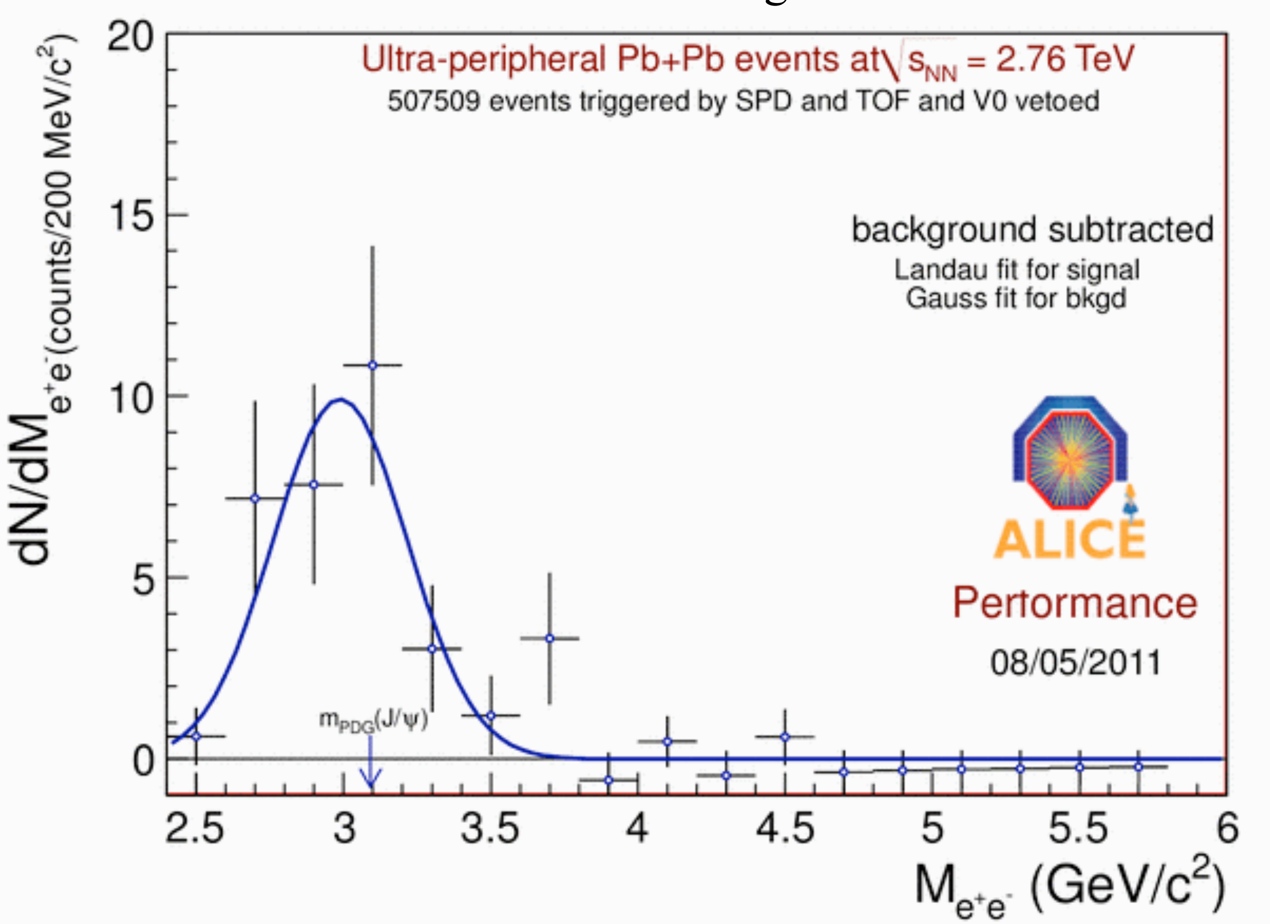

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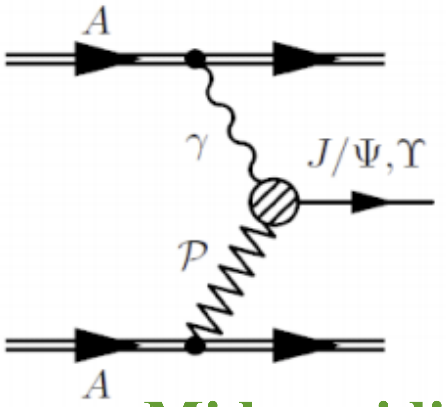

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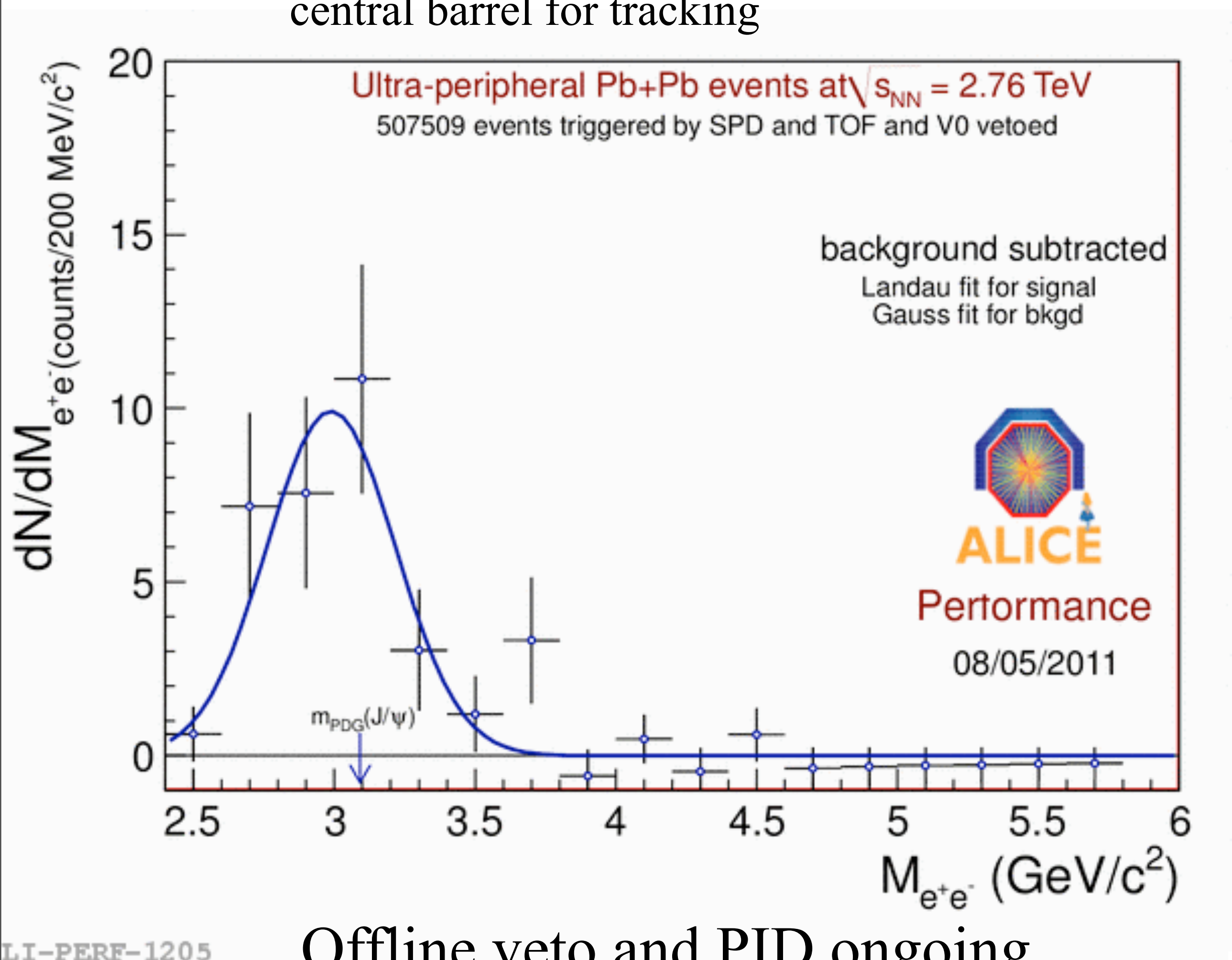
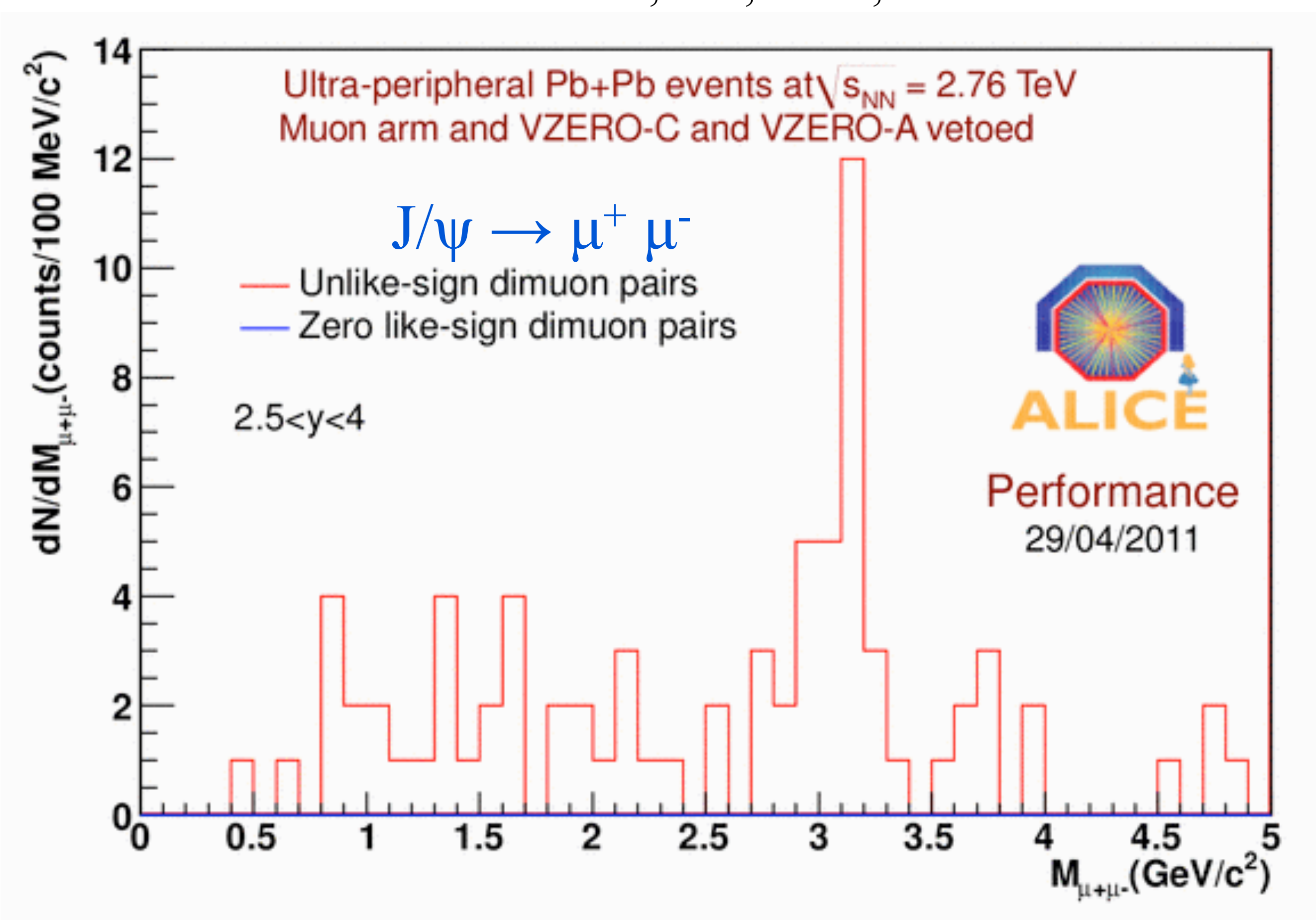


Offline veto and PID ongoing

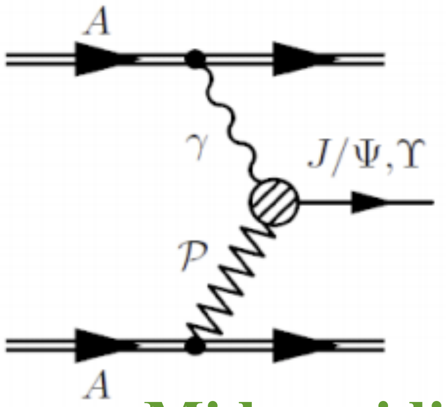
Forward rapidity

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



No like-sign dimuons!

Ongoing analyses: J/ψ production in ultra-peripheral collisions

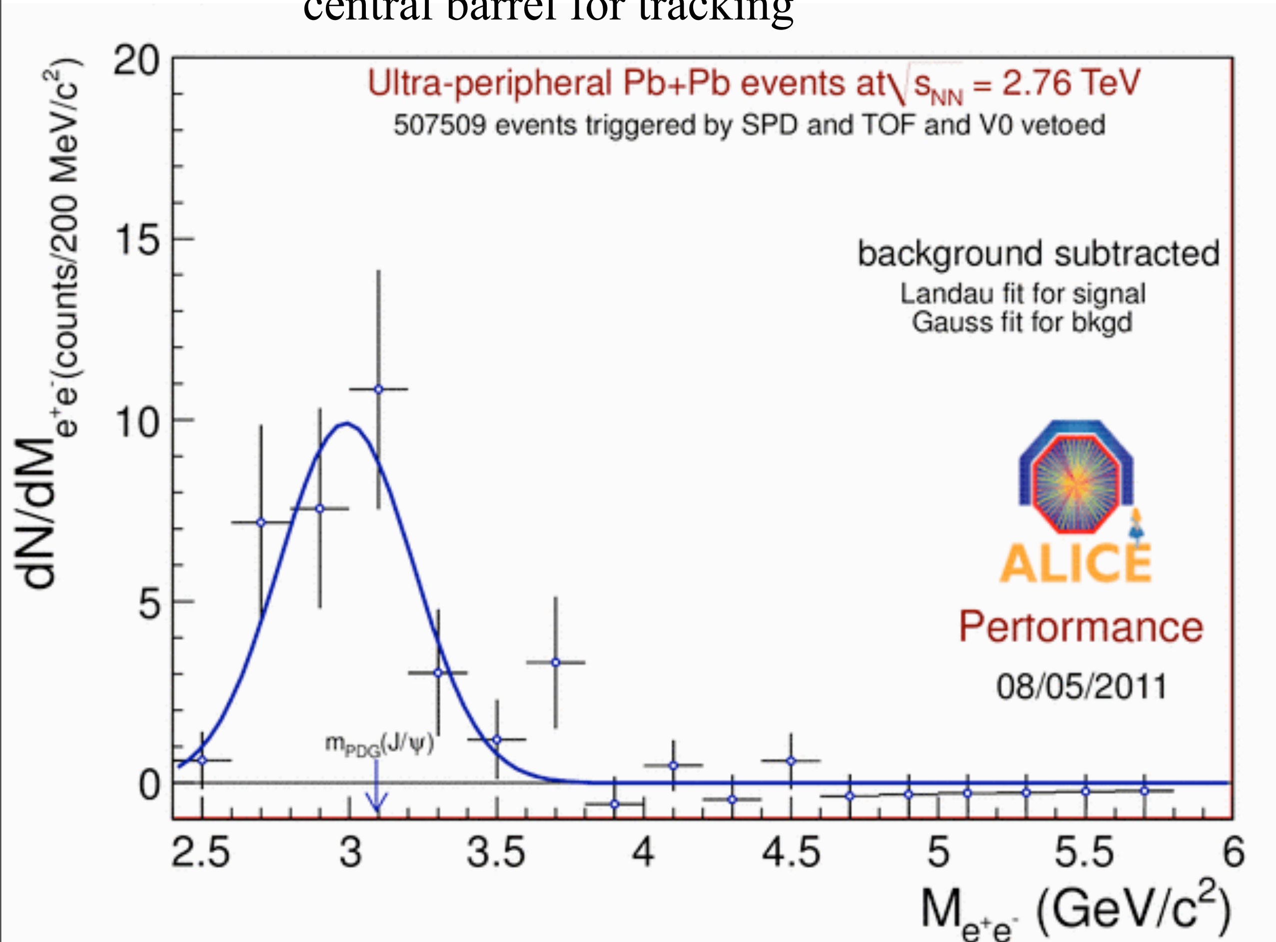


Probe the gluon distribution of the nuclei

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

Mid-rapidity

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



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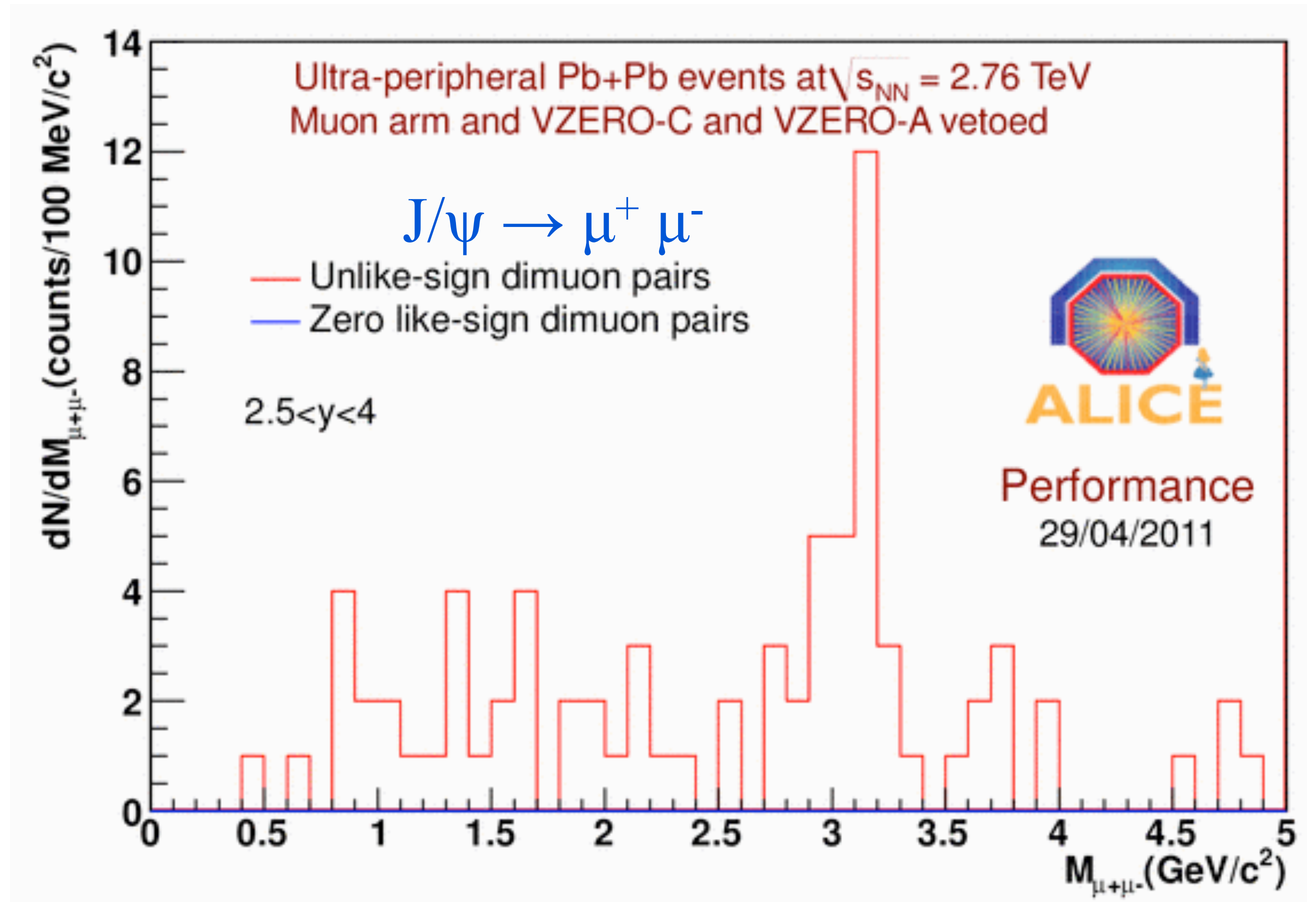
Offline veto and PID ongoing

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

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

Constraints for the models

Cross section @ 2.76 TeV is our reference for Pb-Pb

Yield measurement in high multiplicity events

Promising analyses: polarization and prompt J/ψ extraction at mid-rapidity

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

Ratio larger than at RHIC for most central collisions

Cold nuclear matter effects unknown at LHC → p-Pb needed to estimate hot nuclear matter effect!

Soon: exclusive J/ψ absolute cross section in ultra-peripheral collisions

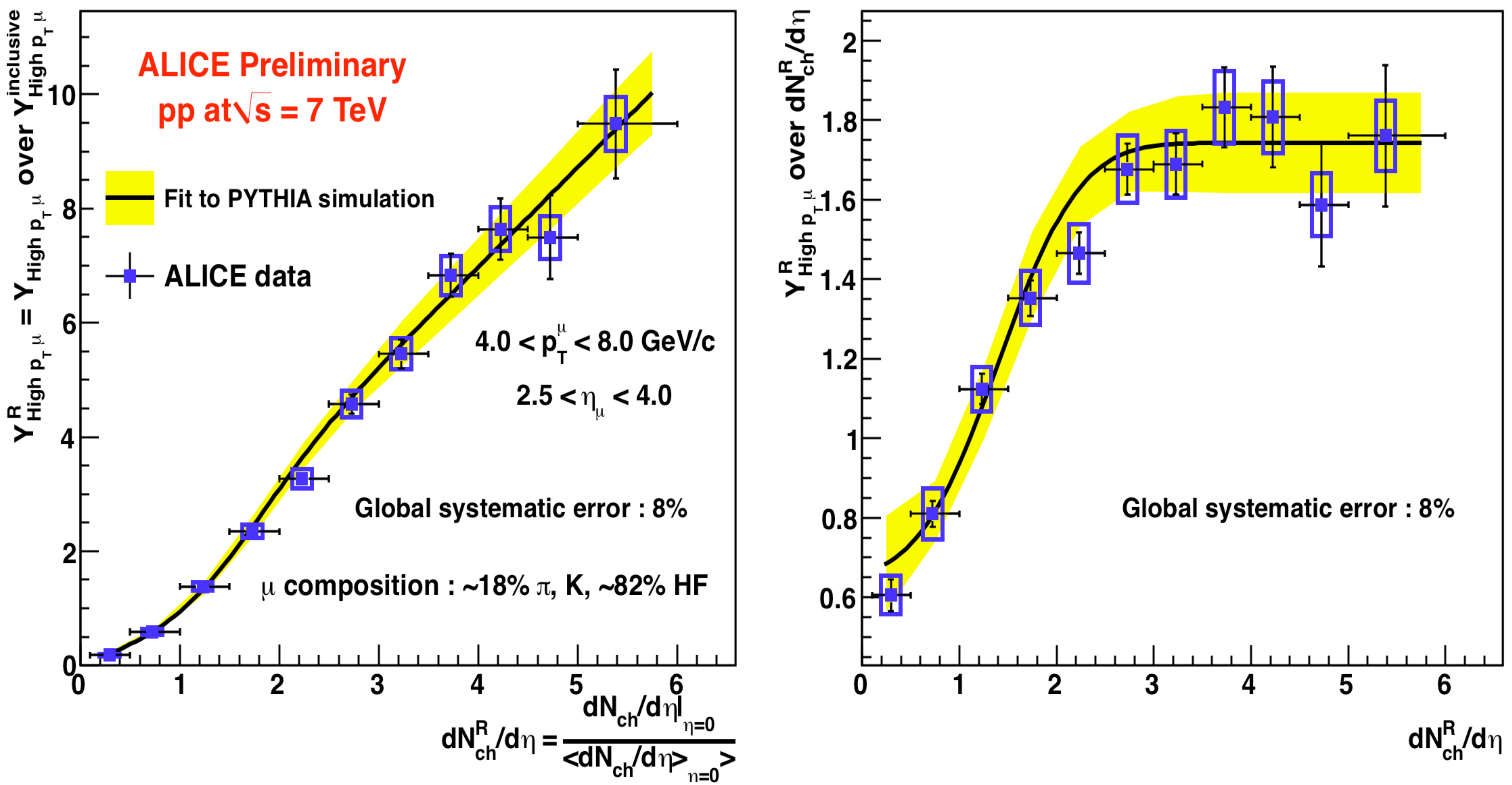
Back-up slides

p-p data: systematic uncertainties

Source of systematic uncertainty	$J/\psi \rightarrow \mu^+\mu^-$	$J/\psi \rightarrow e^+e^-$
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%**

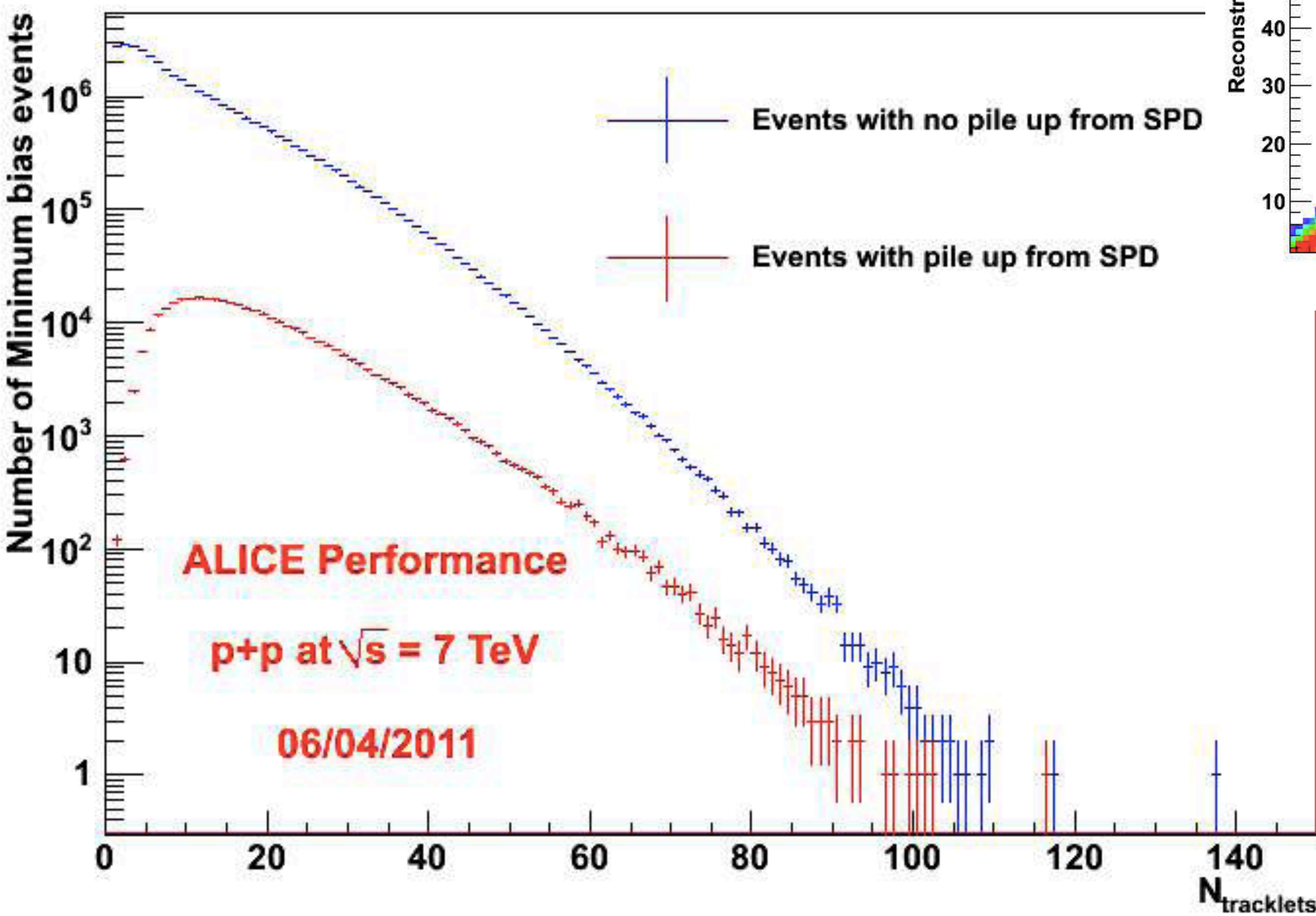
Polarization	**λ=-1 λ=+1**	**λ=-1 λ=+1**
Collins-Soper	+32 -16 %	+19 -13 %
Helicity	+24 -12 %	+21 -15 %

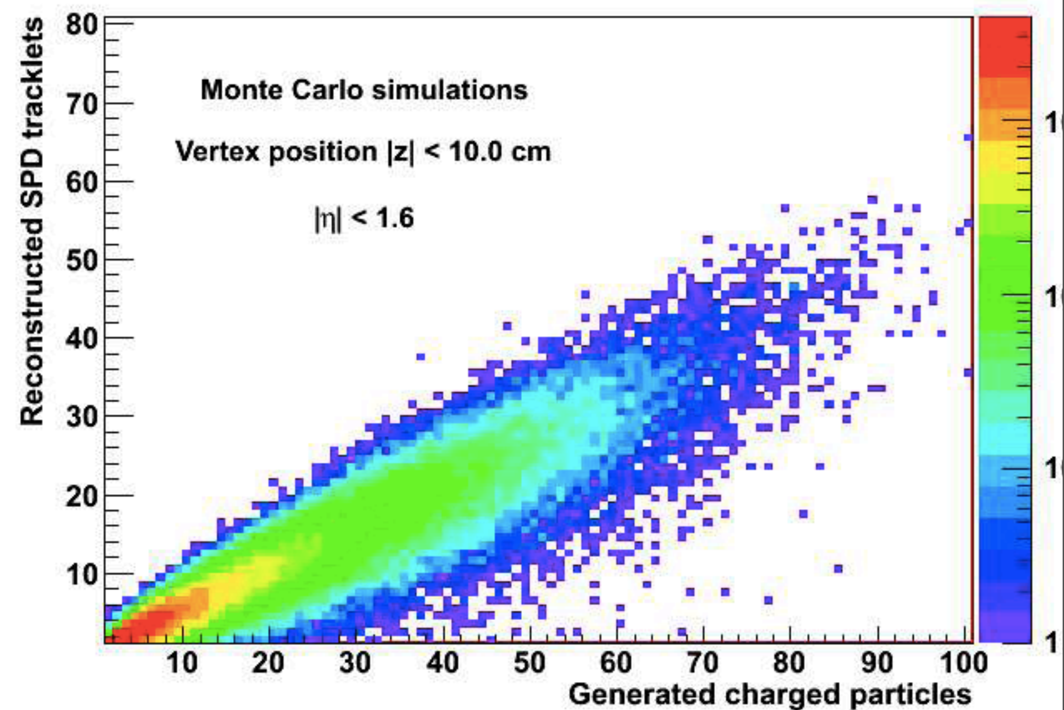
Single muon yield vs multiplicity: data vs PYTHIA



Very nice data description by PYTHIA simulation

Pile-up in high multiplicity events in p-p collisions





Pb-Pb data: systematic uncertainties

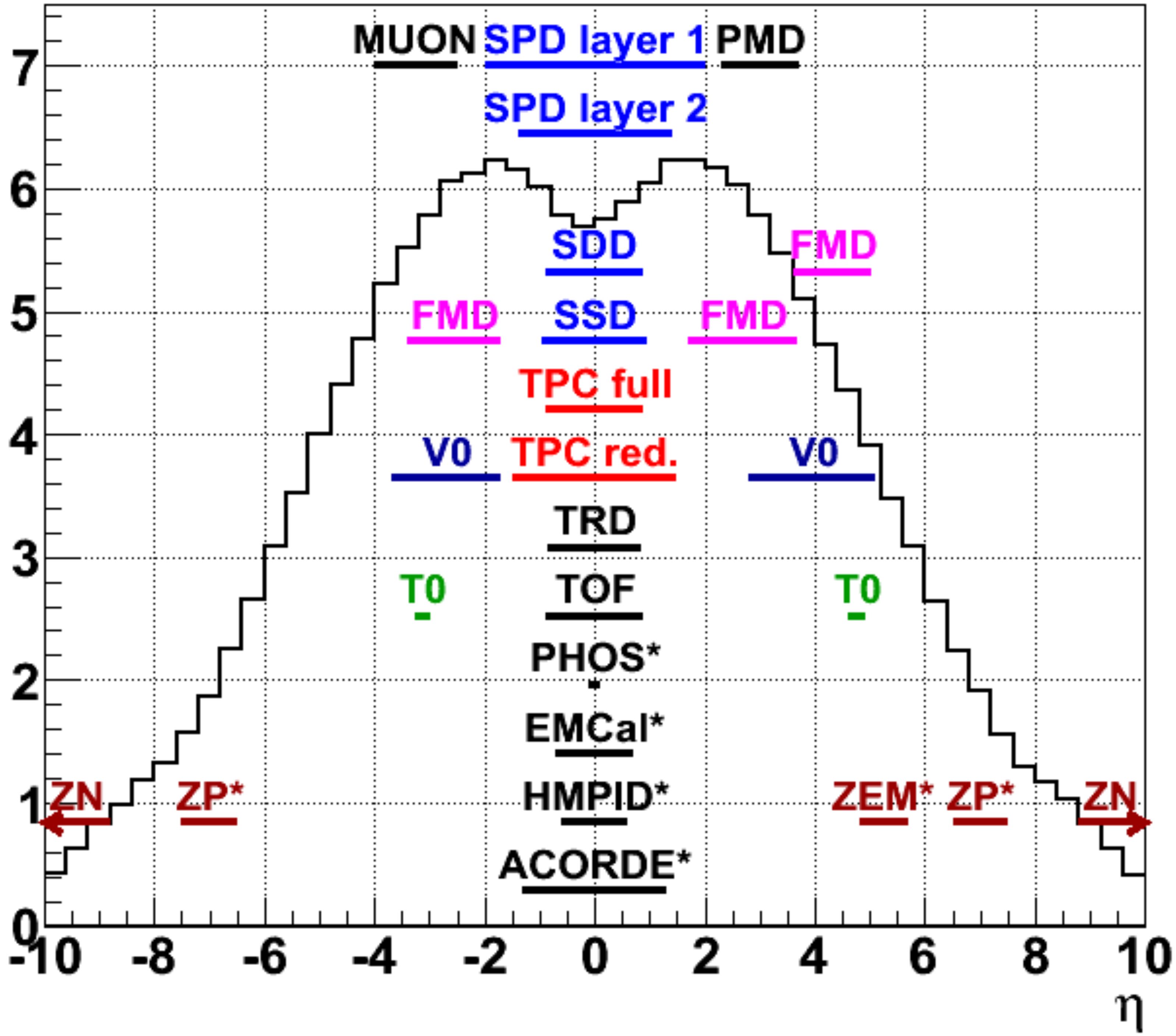
$J/\psi \rightarrow \mu^+ \mu^-$

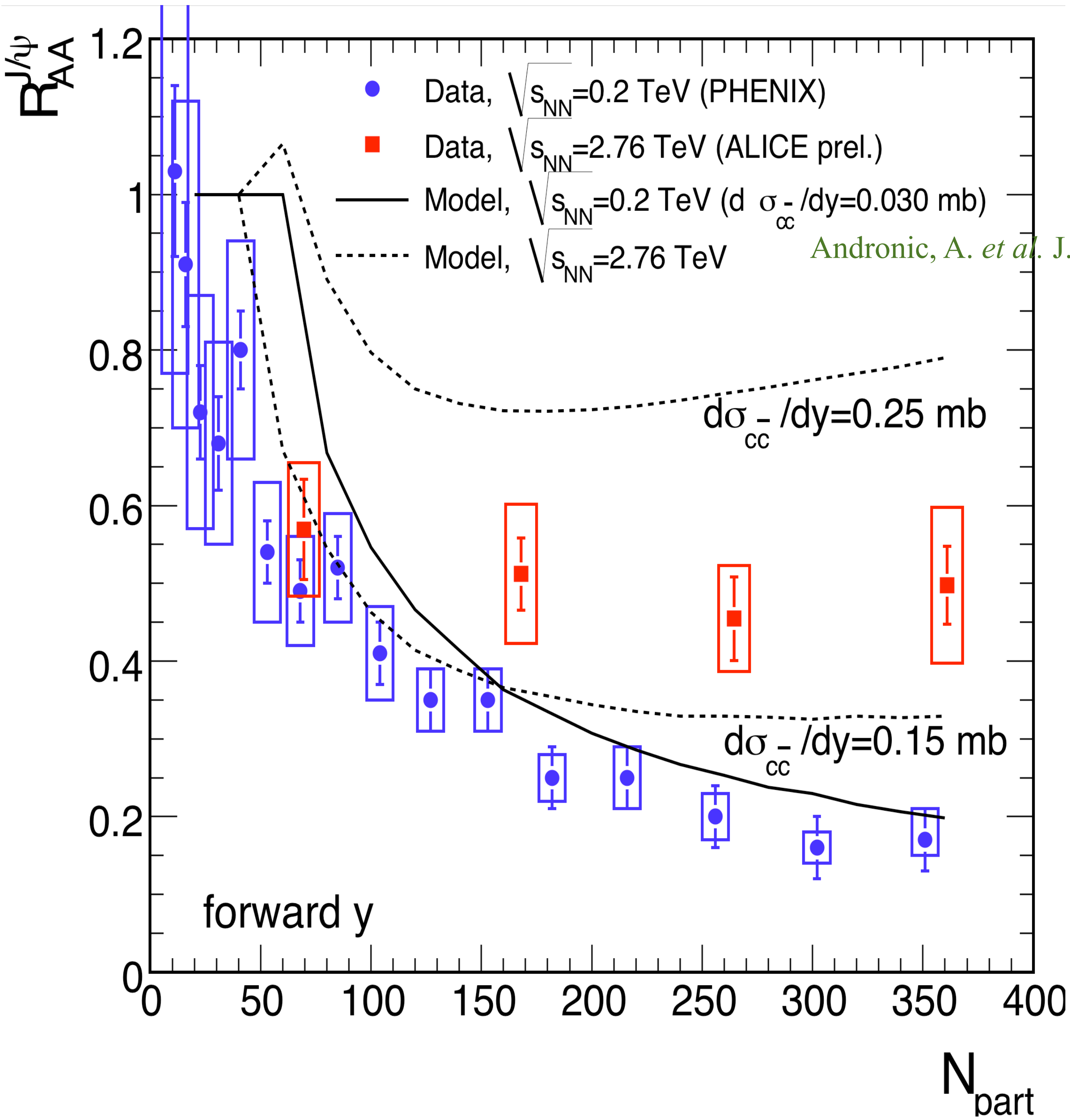
centrality	0-10%	10-20%	20-40%	40-80%	Common
$N_{J/\psi}$	0,19	0,14	0,17	0,14	–
$N_{J/\psi}$ / $N_{J/\psi}^{40-80\%}$	0,12	0,08	0,07	–	–
Acceptance	–	–	–	–	0,03
Eff. Tracker	0,04	0,02	0,01	0	0,05
Eff. Trigger	–	–	–	–	0,04
Reco.	–	–	–	–	0,02
B.R.	–	–	–	–	0,01
X-section	–	–	–	–	0,13
$\langle T_{AA} \rangle$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

ALICE detectors rapidity coverage





Andronic, A. *et al.* J.Phys.G G37 (2010)