Quarkonium measurements at the LHC with the ALICE detector

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Subatech

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for the ALICE Collaboration

May 22nd-28th 2011, Annecy, France

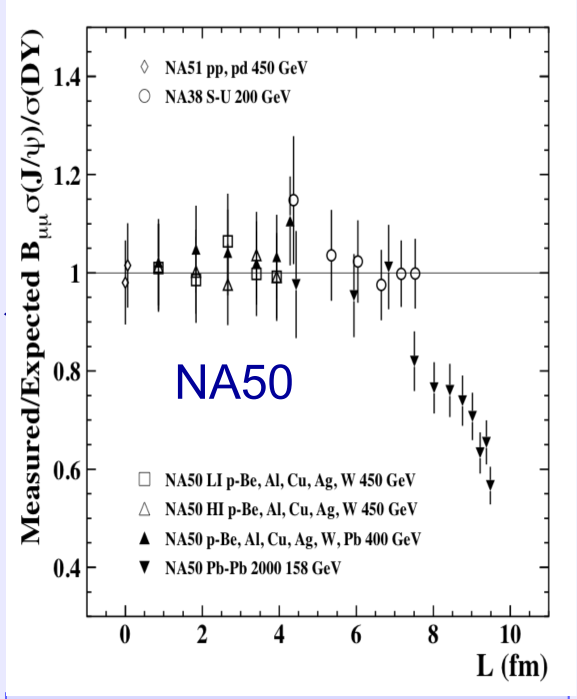
T.M & H. S. J/ψ suppression by quark-gluon plasma, PLB178, 416 (1986)

J/ψ suppression in HIC

SPS NA50

✓Suppression observed (~40%);

✓ψ′ suppression also measured;

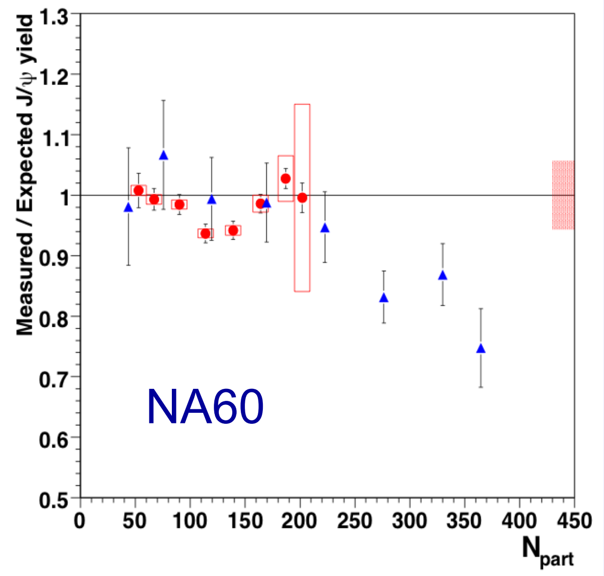


NA50, Eur. Phys. J. C39, 335 (2005)

SPS NA60

✓Absorption cross-section in cold nuclear matter is not constant;

✓Suppression still there (~20-30%);



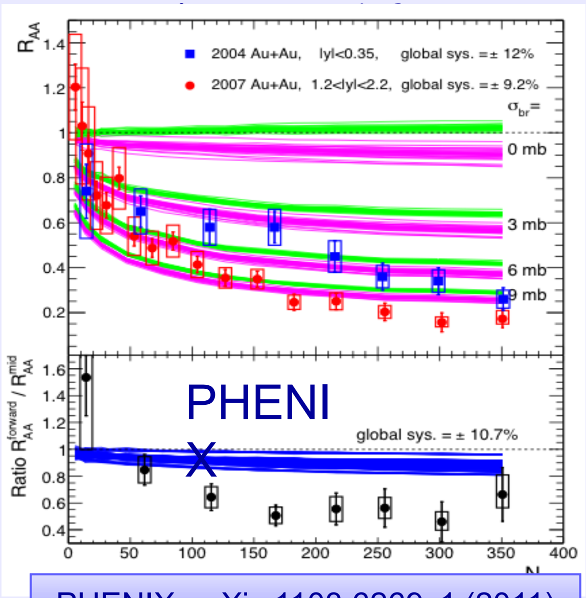
R. Arnaldi (NA60), arXiv:0907.5004v2, Nucl. Phys. A830, 345c (2009)

RHIC

✓ Suppression observed (~40-80%);

✓ Less suppression at high p_T;

✓ Larger suppression at large rapidity;

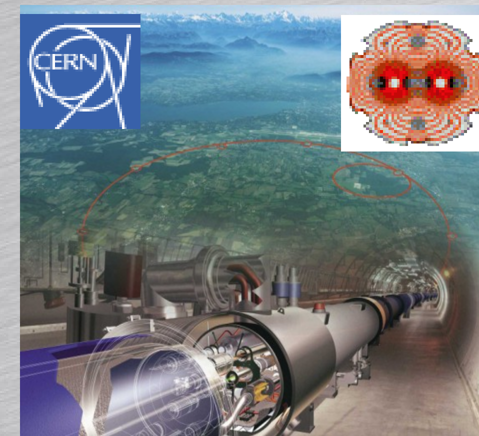


PHENIX, arXiv:1103.6269v1 (2011)

Quantitative conclusions missing. Open charm crucial. Other quarkonium species.

New Energy Regime @ LHC

- Higher cross-sections:
  - Open HF normalization;
- High J/ψ statistics;
- Upsilon family:
  - Complementary charmonium-bottomonium measurements;
- The question of the role of the recombination mechanisms will be experimentally addressed at LHC



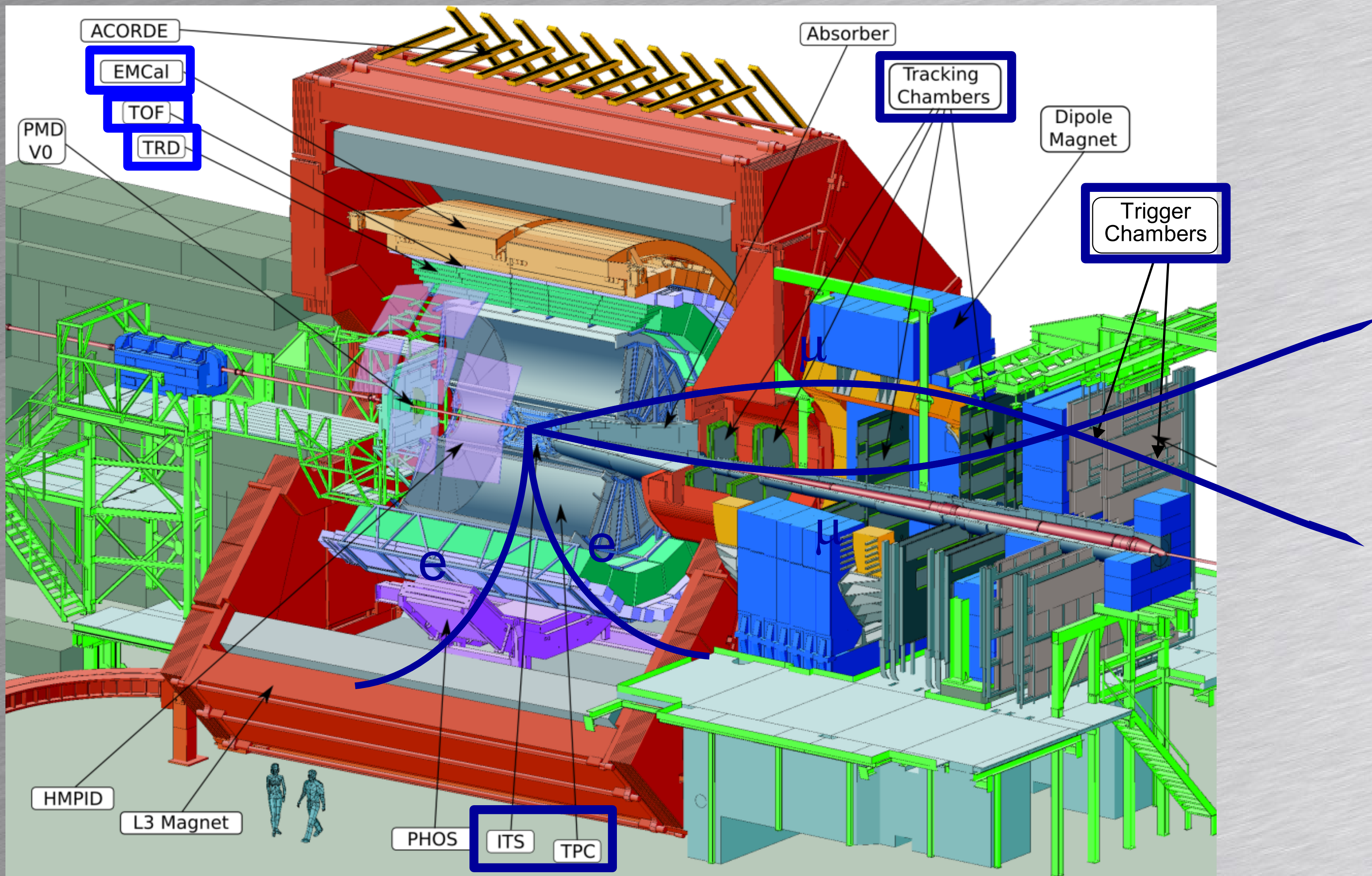
Exploring LHC Terra Incognita.
"*Caminante no hay camino se hace camino al andar …*" Poem of A. Machado
(Helmut Satz, Quark Matter 2002, Nantes, France).

Plan of the talk

- ✓ Physics Motivations;
- ✓ Experimental Apparatus;
- ✓ Inclusive J/ψ production cross-section in pp collisions;
- ✓ Preliminary results on J/ψ yield as a function of the charged particle density in pp collisions;
- ✓ Preliminary results on J/ψ nuclear modification factor R_{AA} and R_{CP} in Pb-Pb at 2.76 TeV;
- ✓ Conclusions.

2 talks and 9 posters on Quarkonium with ALICE detector.

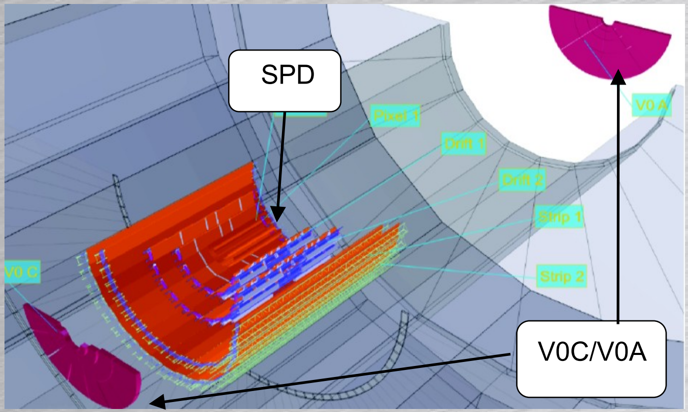
Quarkonium measurements



Down to p_T=0

|y|<0.9: ➔e^+e^-, J/ψ🡐B, e-trig & **2.5<y<4.0:** ➔$\mu^+\mu^-$, μ-trig.

Proton-proton collisions



- Triggers:
  - minimum bias (MB): $-3.7<\eta<5.1$
  - muon (μ-tri): MB && $-4.0<\eta_{\mu}<-2.5$
- Proton-proton collisions:
  - at 7 TeV, $L=16\ nb^{-1}$ (μ-tri) and $3.9\ nb^{-1}$(MB);
  - at 2.76 TeV, $L=20\ nb^{-1}$ (μ-tri) $1.1\ nb^{-1}$(MB);

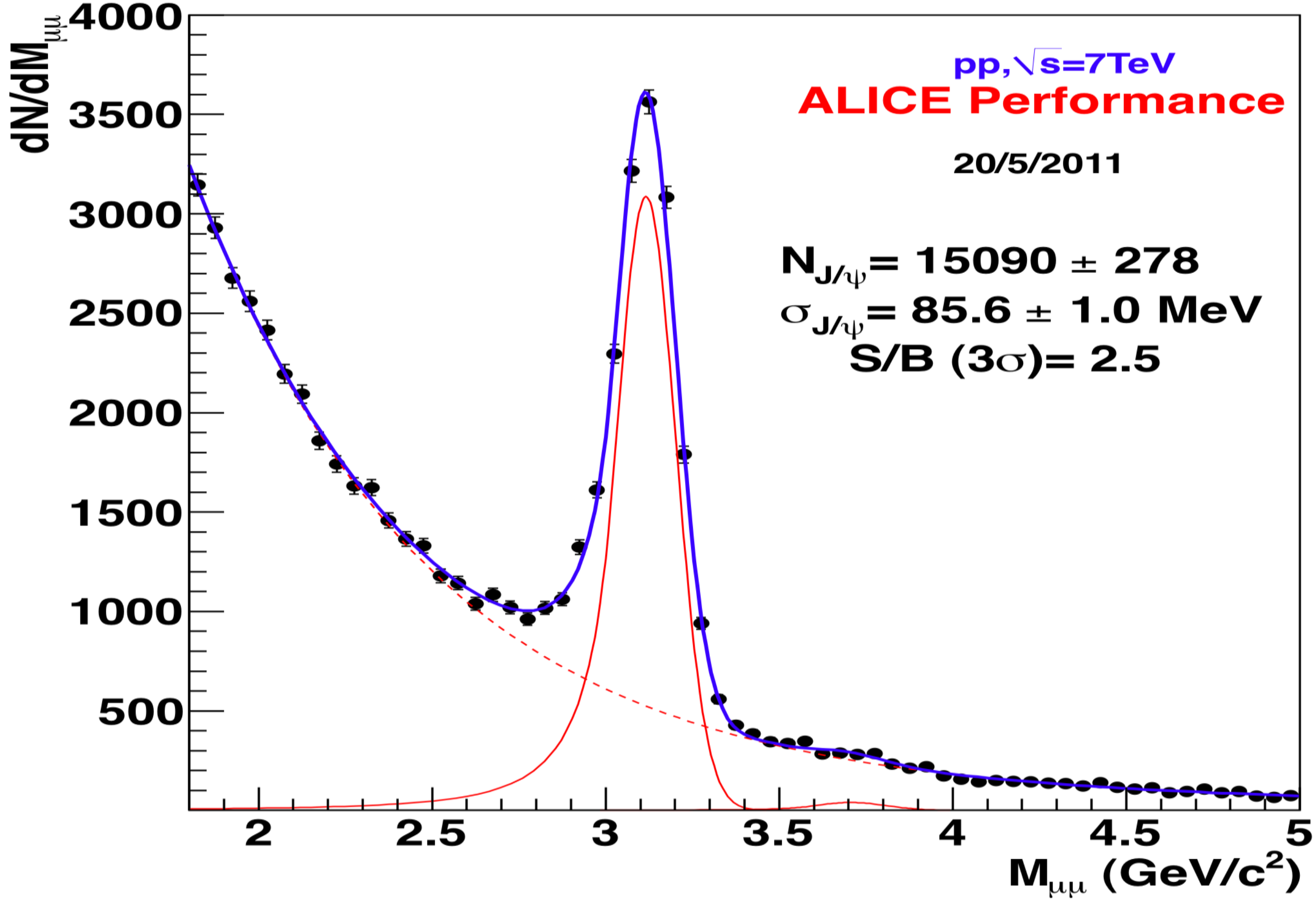
ALICE coll., arXiv:1105.0380v1 (2011)

- Normalization with respect to σ_{MB} measured in Van Der Meer scans;

K. Oyama « Instr. » on Thu May 26th 5:00pm

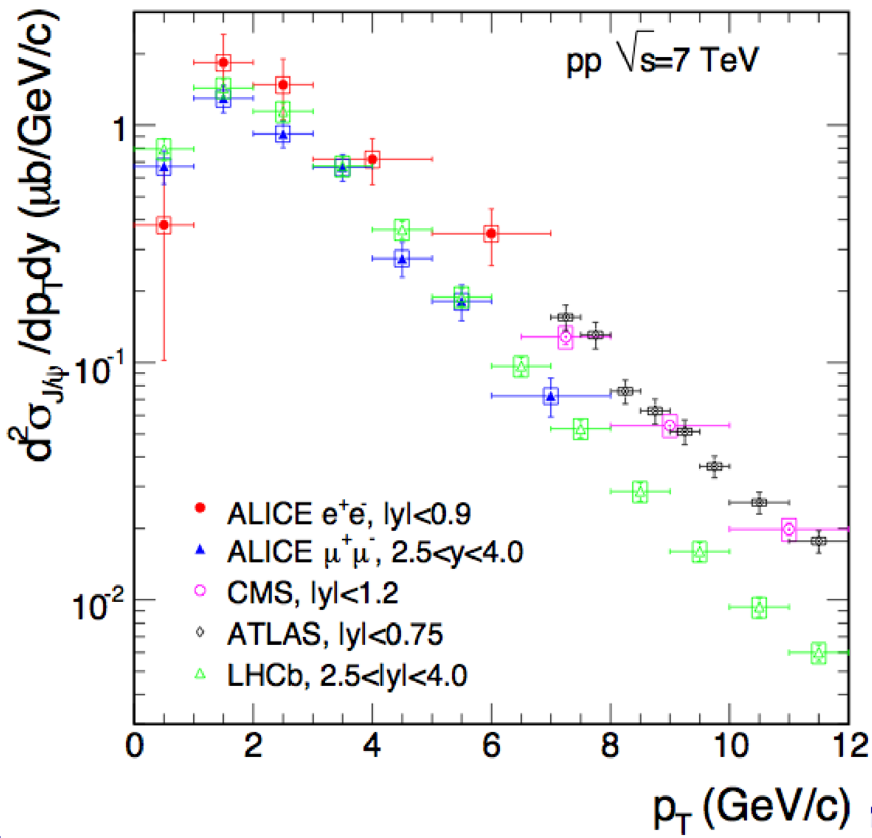
- Inclusive J/ψ (p_T-y) production;
- $|y|<0.9$ and $2.5<y<4$ & down to $p_T=0$.

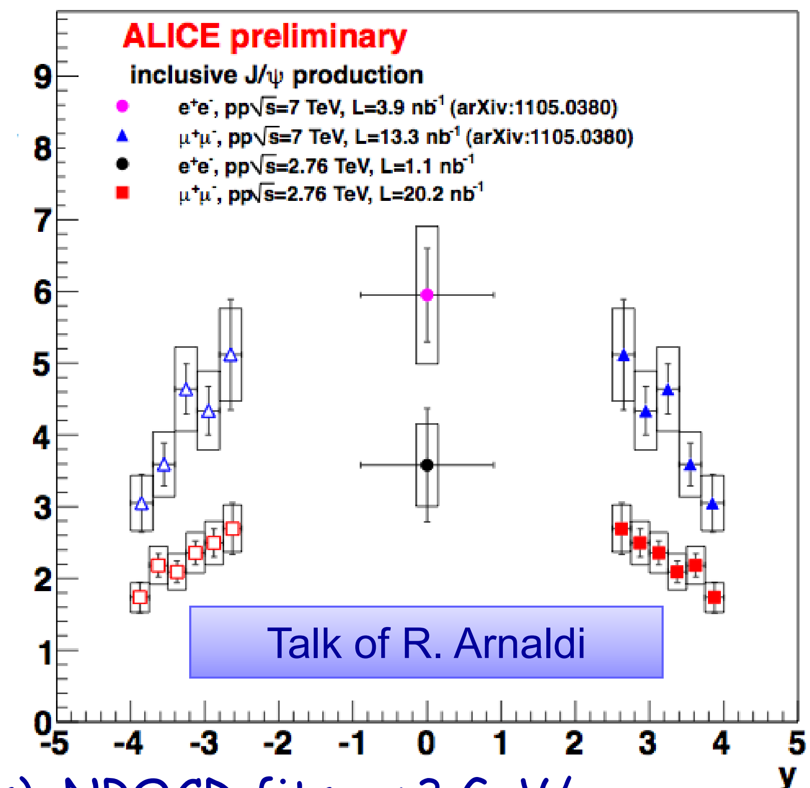
Quarkonium Signals in pp



J/ψ, $\mu^+\mu^-$, e^+e^-, 2.76 & 7 TeV, integrated, (p_T, y), pol., $dN_{ch}/d\eta$

$\sigma_{J/\psi}$ and p_T-y distributions



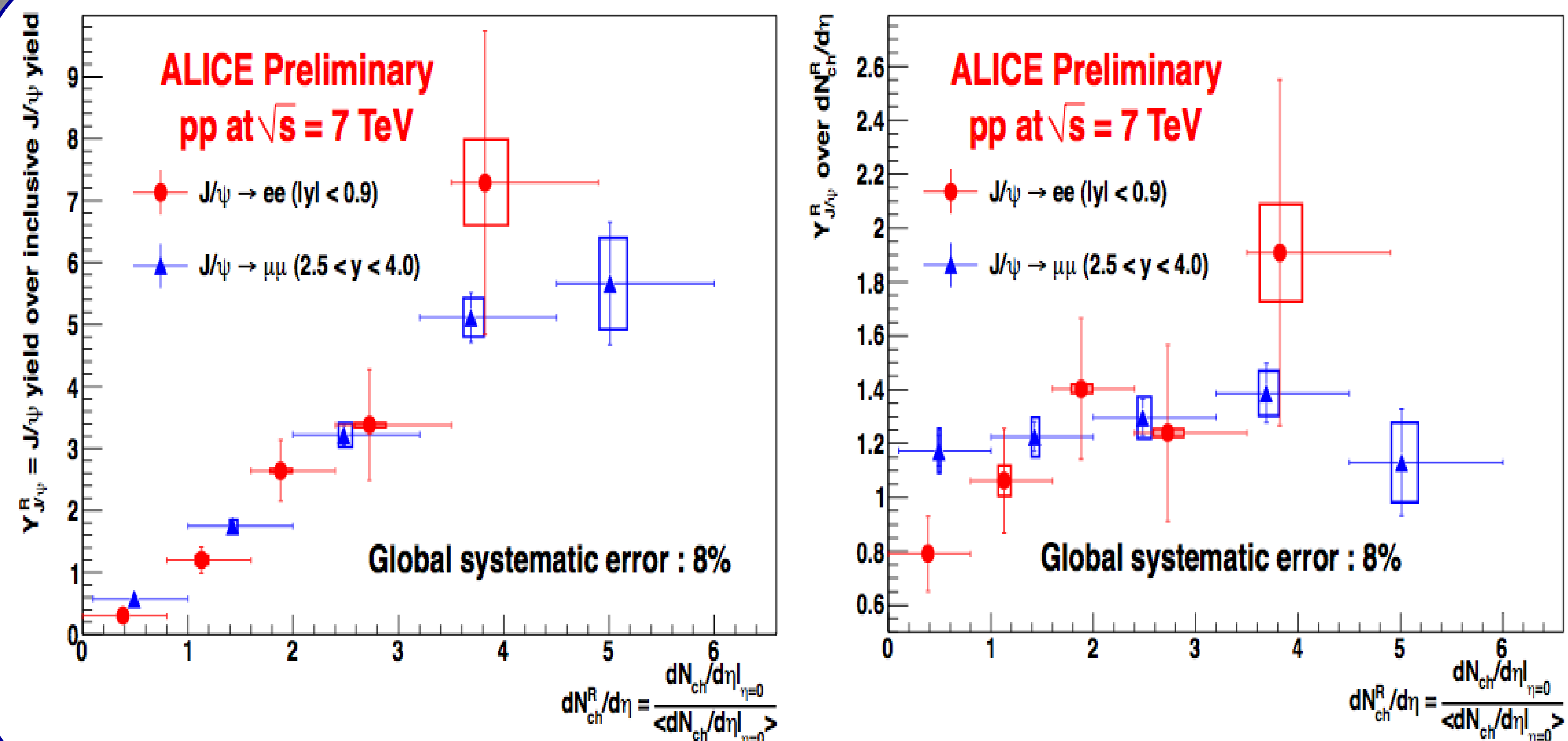


rs), NRQCD fits p_T>3 GeV/c

A factor 13(μ-tri), 3(MB) more in pp at 7 TeV run 2010.

J/ψ in high mult. pp events

Relative J/ψ yield: yield in multiplicity bin ($|\eta|<1.6$) over the yield per inelastic pp collision.

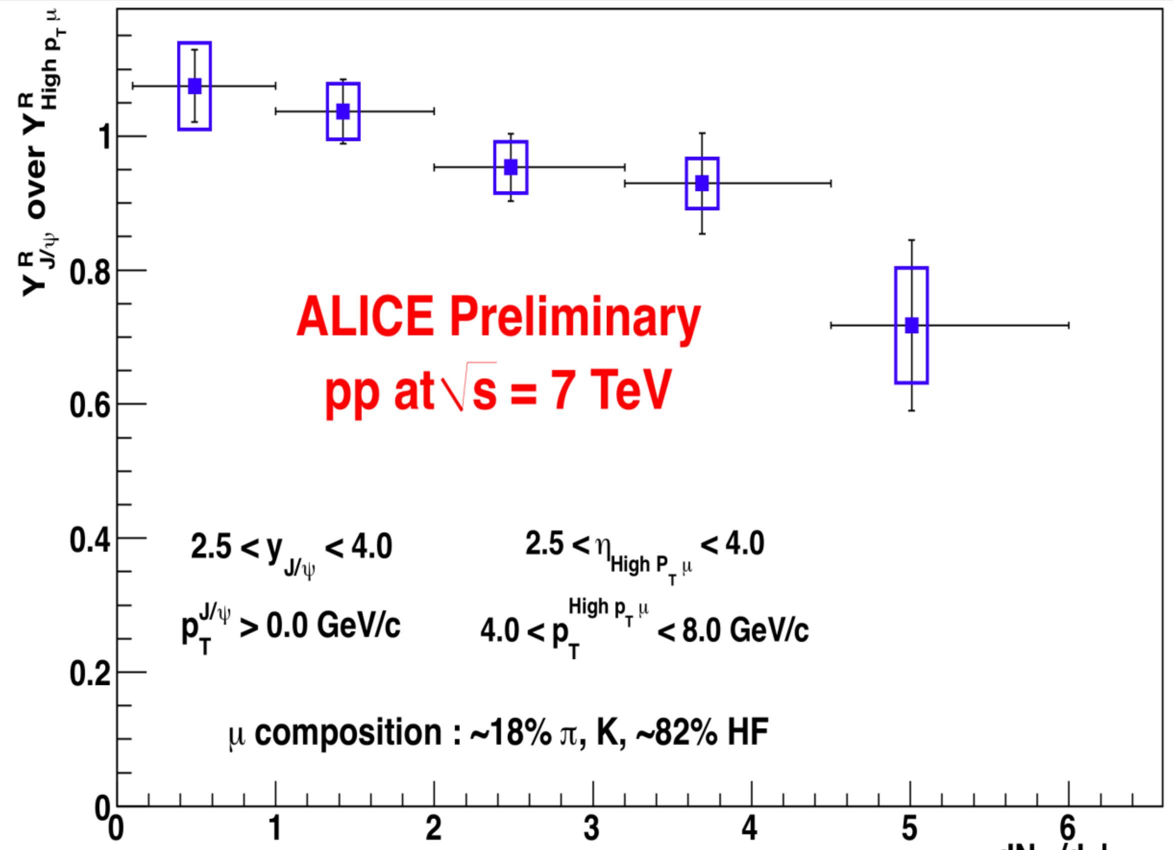


Poster #76 of F. Kramer & Poster #78 of M. Lenhardt

S. Porteboeuf & R. Granier, arXiv:1012.0719v1 (2011)

Linear increase of J/ψ yield with charged particle density.

J/ψ versus high p_T muons



Poster #78 of M. Lenhardt

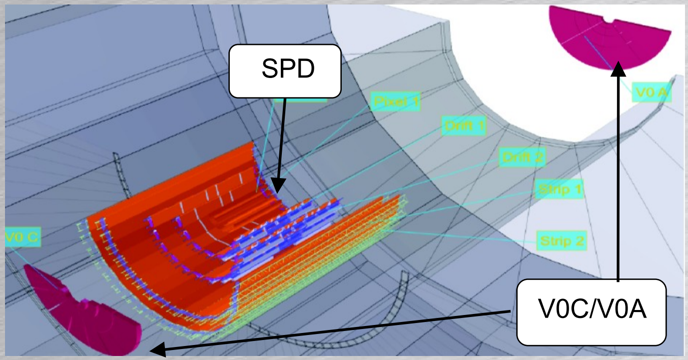
- ✓ High p_T muon ($4<p_T<8$ GeV/c);
- ✓ About ~18% π,K (decays), ~82% HF (~50%-c, ~50%-b);

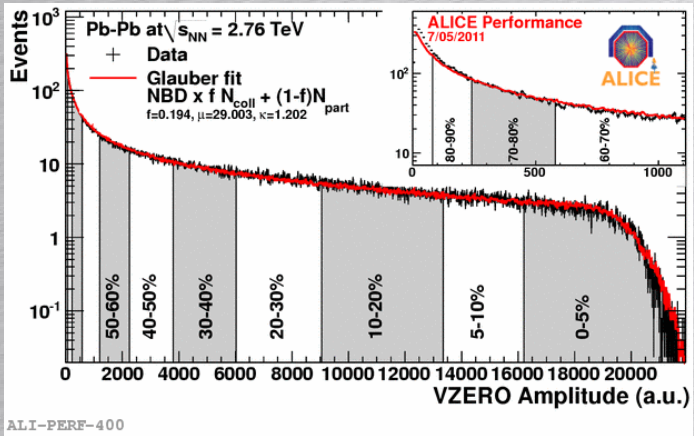
Talk of X. Zhang on Mon May 23rd 5:50 pm

Understanding multi-partonic interactions in pp collisions. Different behaviours between J/ψ and high p_T muon. Many interpretations are possible.

Pb-Pb collisions @ 2.76 TeV

- Trigger Minimum Bias (MB):
  - Defined as V0C && V0A && SPDor;
- Event Selection:
  - Rejection of beam-gas and EM interactions;
  - Integrated luminosity 2.7μb^{-1} (good QA MB data sample) ;
- Centrality selection:
  - V0 amplitude;
- Inclusive J/ψ R_{AA} and R_{CP};

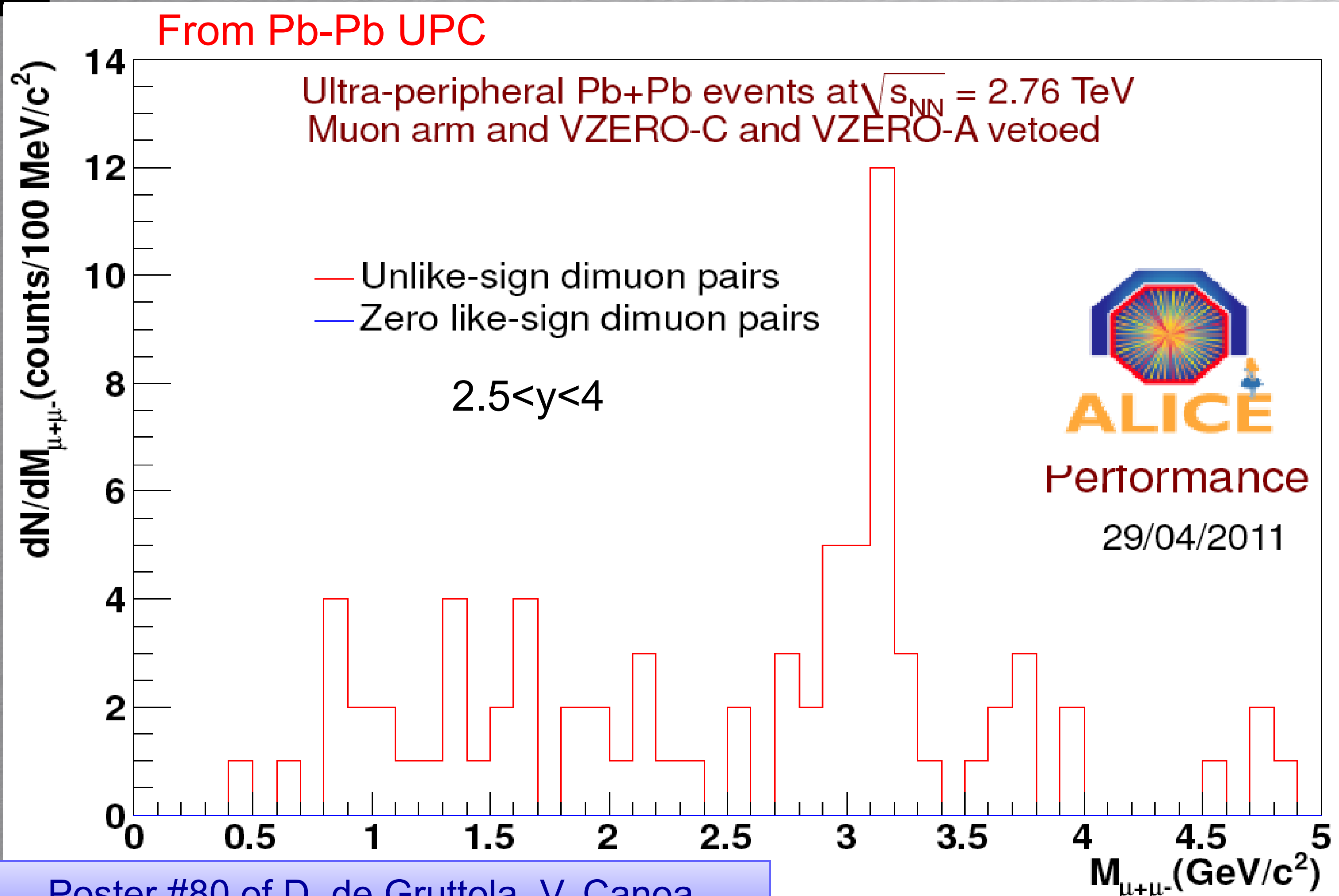




C. Loizides «Global» on Mon May 23rd 3:20 pm
A. Toia « Plenary » Tue May 24th 8:55 am

Parallel talk "HF session" by Philippe Pillot on Tue May 24th 5:20 pm.

J/ψ signals in Pb-Pb



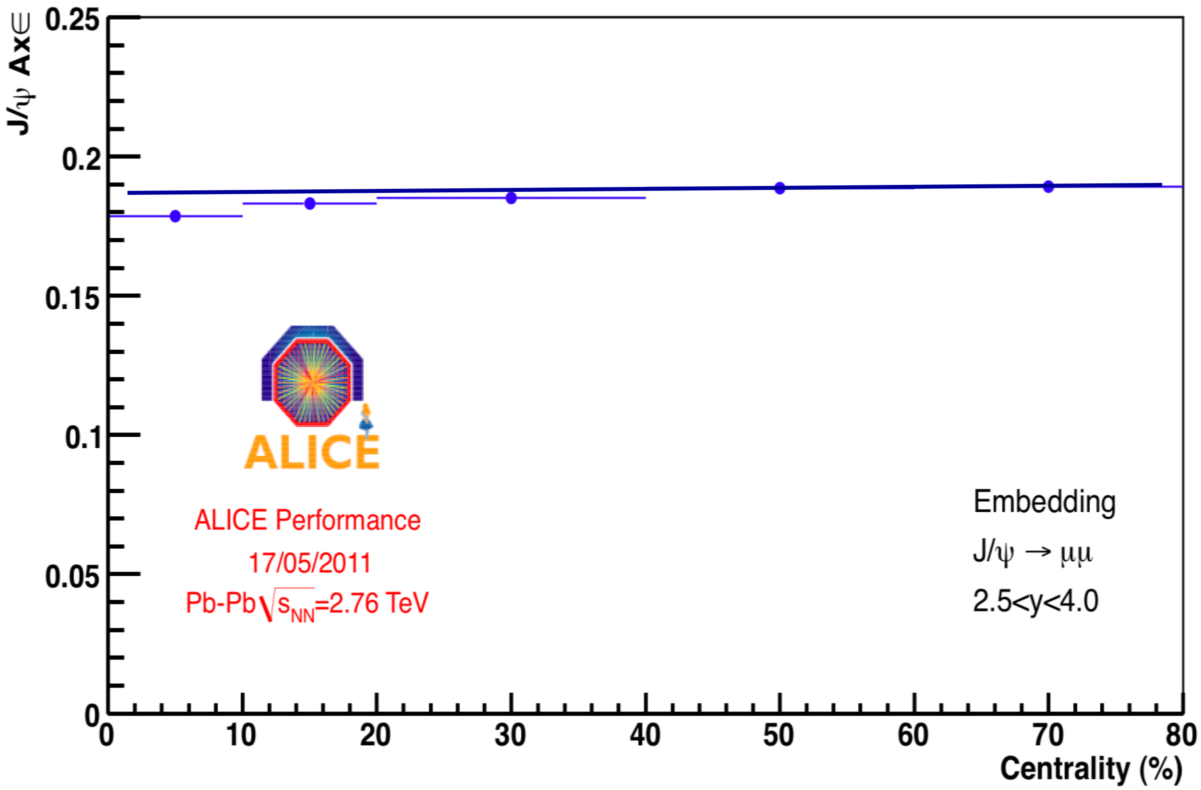
Poster #80 of D. de Gruttola, V. Canoa

Poster #75 of J. Book, J. Wiechula

J/ψ signal seen in PbPb central collisions in ALICE.

Efficiency in Pb-Pb

Embedding J/ψ signal in real Pb-Pb events.



J/ψ signal from interpolation studies

Poster #53 of M. Gagliardi

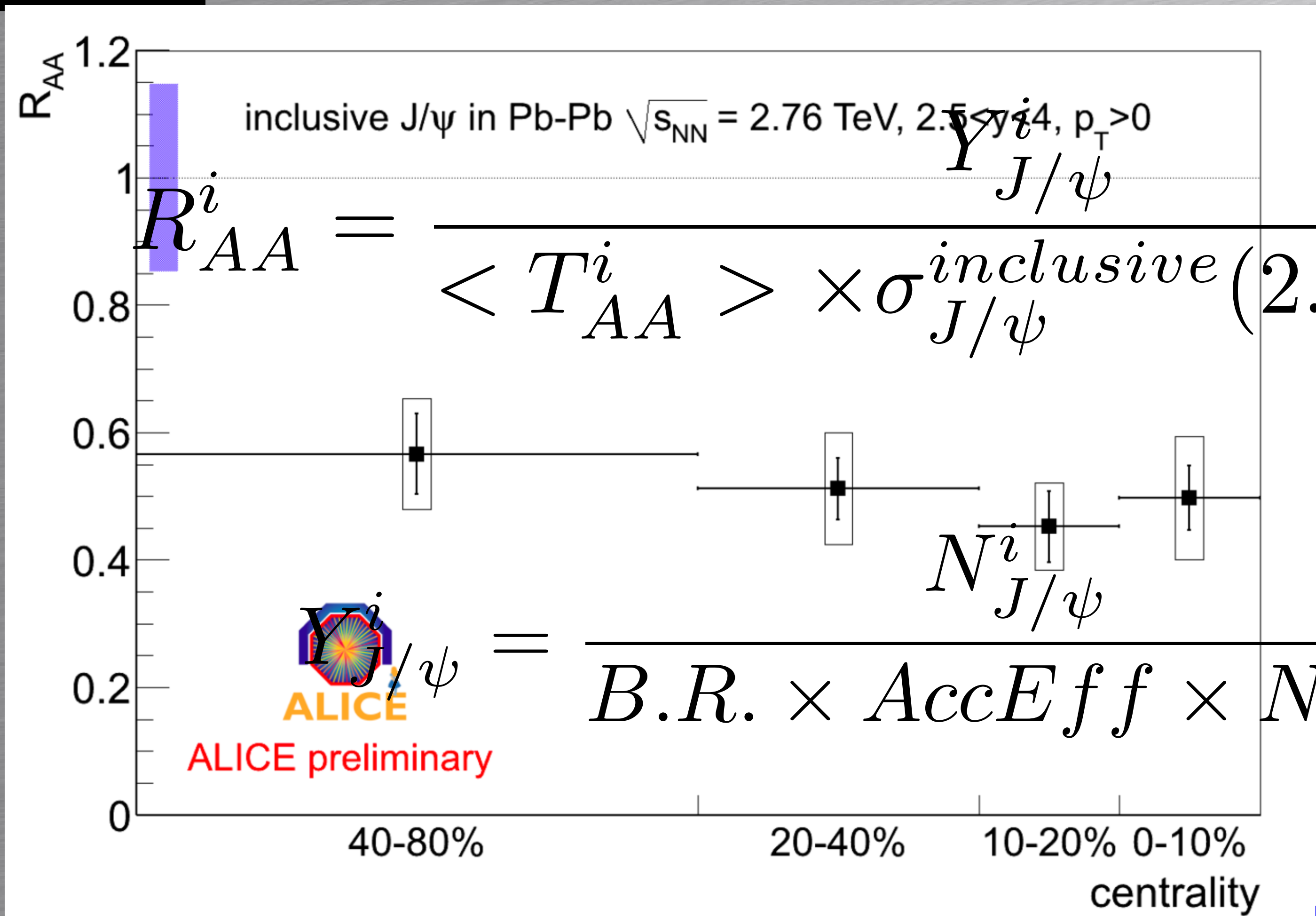
Poster #58 of A. Lardeux, L. Valencia

Only 4% efficiency loss in the most central collisions;
In agreement with measured tracking efficiency loss from data.

Systematics Errors

centrality	0-10%	10-20%	20-40%	40-80%	Common
$N_{J/\psi}$	19%	14%	17%	14%	-
$N_{J/\psi} / N_{J/\psi}^{40\text{-}80\%}$	12%	8%	7%	-	-
Acceptance	-	-	-	-	3%
Eff. Tracker	4%	2%	1%	0%	5%
Eff. Trigger	-	-	-	-	4%
Reco.	-	-	-	-	2%
B.R.	-	-	-	-	1%
X-section	-	-	-	-	13%
$\langle T_{AA} \rangle$	4%	4%	4%	6%	-
$\langle T_{AA} \rangle^{i} / \langle T_{AA} \rangle^{40\text{-}80\%}$	6%	5%	4%	-	-
Total for R_{AA}	**20%**	**15%**	**17%**	**15%**	**15%**
Total for R_{CP}	**14%**	**10%**	**8%**	**-**	**-**

J/ψ R_{AA} in Pb-Pb at 2.76 TeV



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

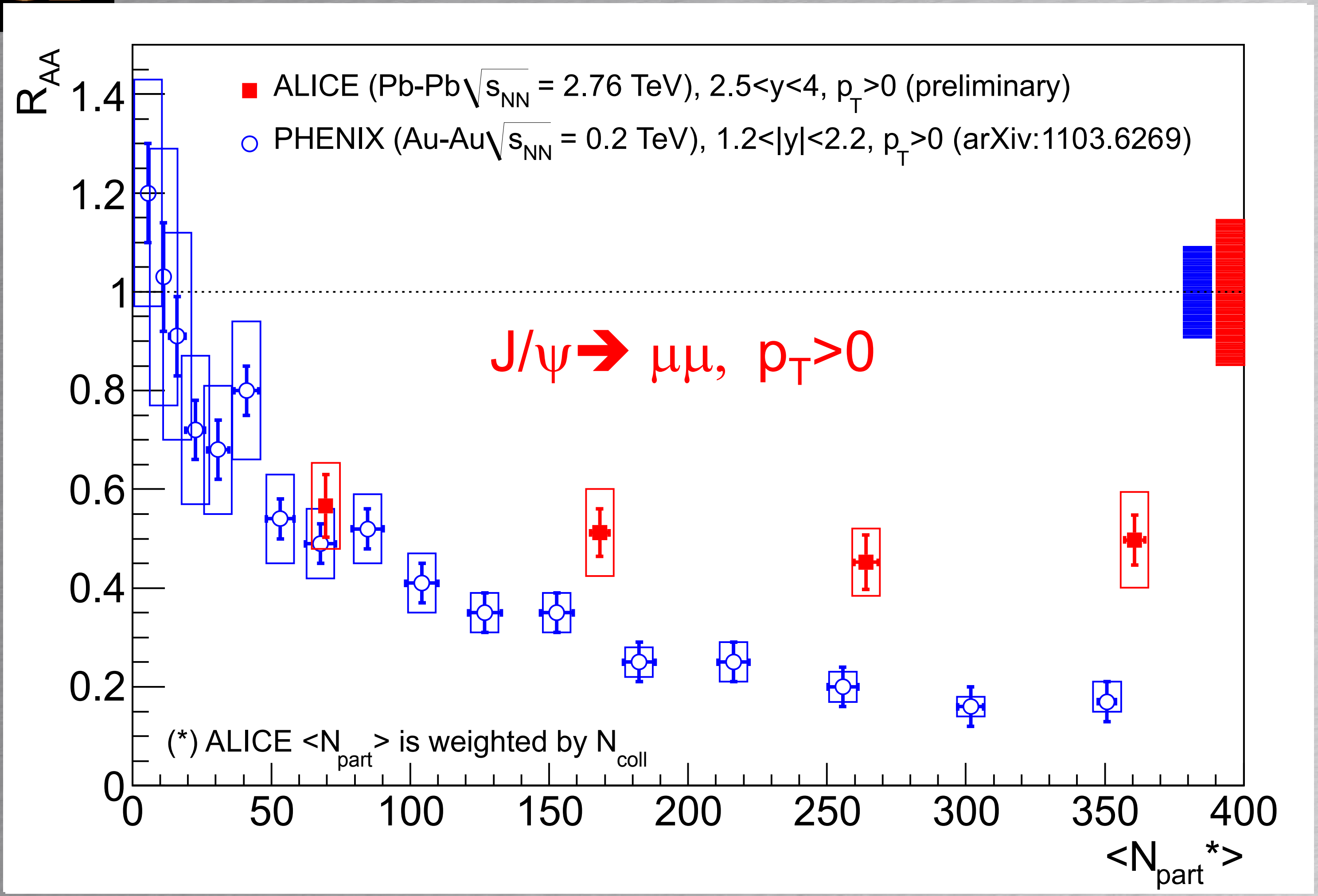
$$Y^i_{J/\psi} = \frac{N^i_{J/\psi}}{B.R. \times AccEff \times N^i_{MB}}$$

- ✓ Bars: statistical;
- ✓ Open box: systematic depending on centrality;
- ✓ Blue box: common systematics.

Talk of P. Pillot

Inclusive J/ψ $R_{AA}^{0\text{-}80\%}$ = 0.49 ± 0.03 (stat.) ± 0.11 (sys.)
Prompt J/ψ $R_{AA}^{0\text{-}80\%}$ is about 11% smaller due to beauty contribution.

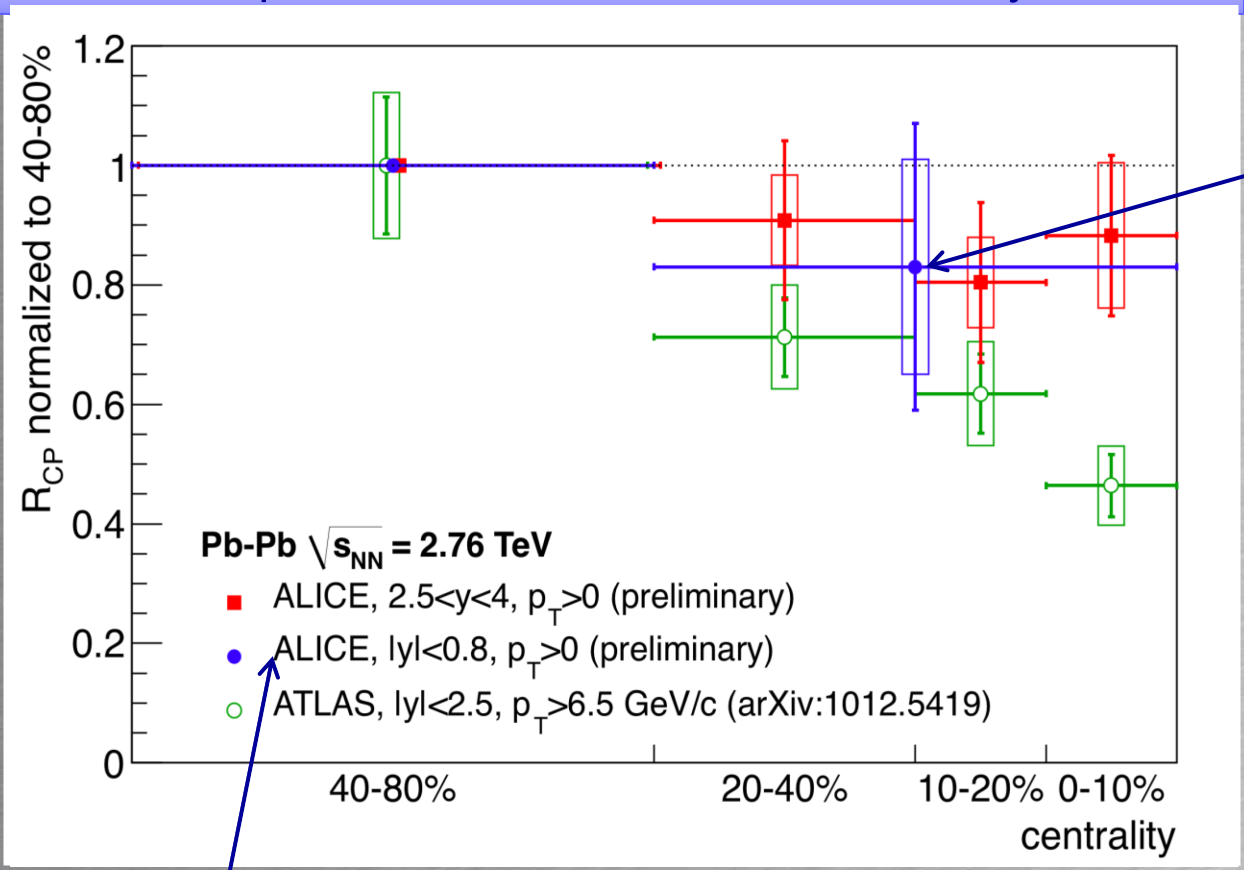
J/ψ R_{AA} 0.2 / 2.76 TeV



J/y R_{AA} larger at LHC (2.5<y<4) than at RHIC (1.2<|y|<2.2);
Similar as RHIC (|y|<0.35), except for the most central bin;
$dN_{ch}/d\eta(N_{part})^{LHC} \sim 2.1 \times dN_{ch}/d\eta(N_{part})^{RHIC}$ (A. Toia talk).

J/ψ R_{CP} ATLAS/ALICE

« Peripheral » reference 40-80% centrality bin



Poster #75 of J. Book, J. Wiechula

ALICE:

- 2.5<y<4.0;
- |y|<0.8
- $p_T \geq 0$ GeV/c;

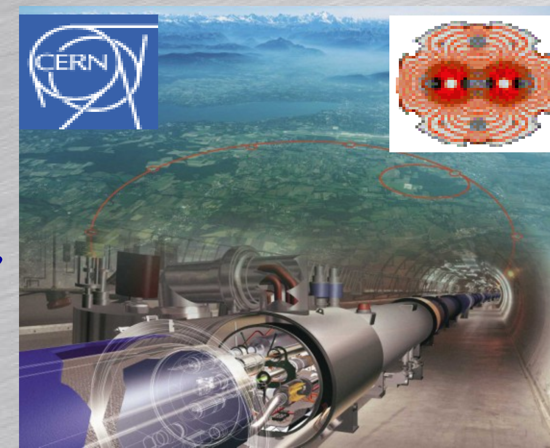
ATLAS:

- |y|<2.4
- 80% J/ψ, $p_T \varepsilon 6.5$ GeV/c;
- Error in 40-80% centrality bin not propagated.

ALICE 2.5<y<4.0 exhibits less suppression than ATLAS data (high p_T, |y|<2.4); Challenging measurement in the dielectron channel.

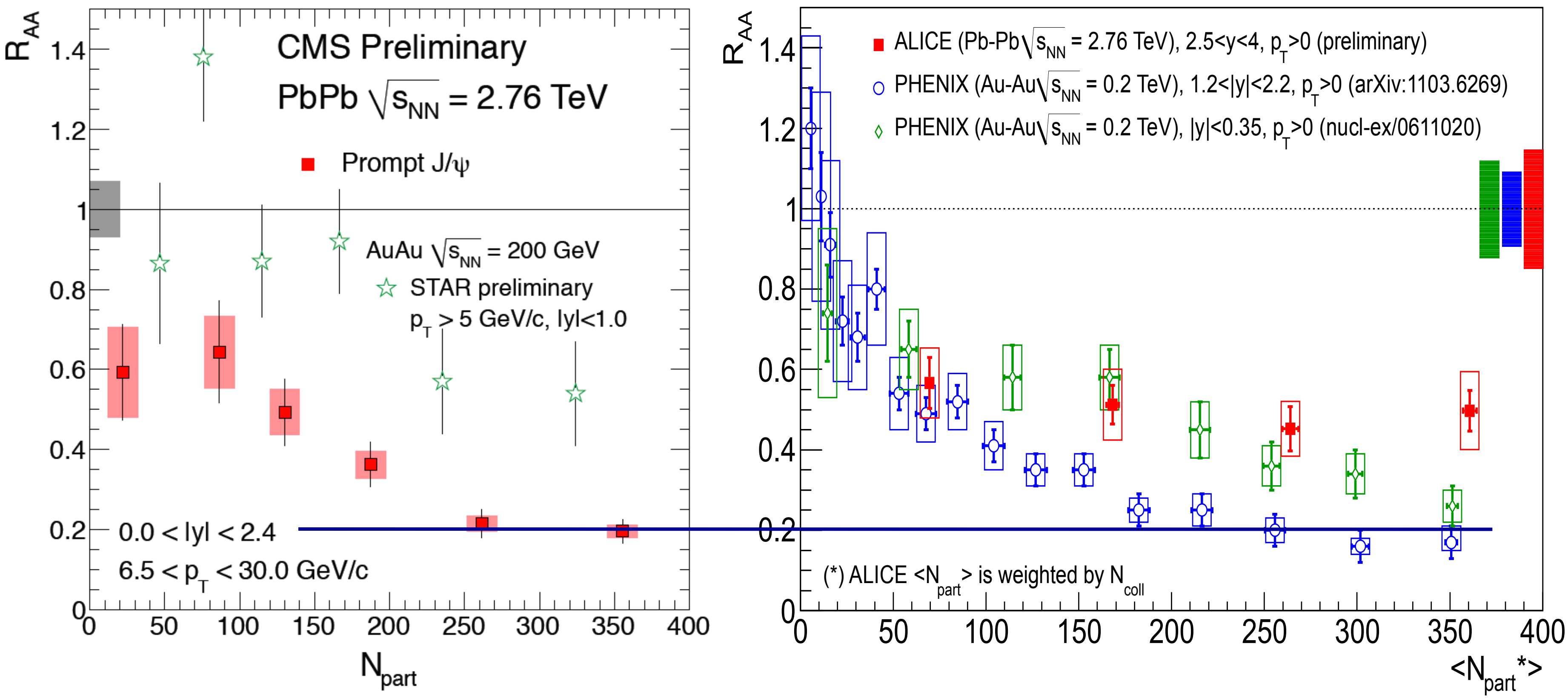
Conclusions

- ✓ Inclusive J/ψ measurement pp at 2.76 and 7 TeV;
- ✓ High multiplicity pp events (up to 5x $\langle dN_{ch}/d\eta \rangle$);
- ✓ Incl. J/ψ $R_{AA}^{0-10\%}$ (p_T>0) ~0.50 at LHC, flat cent. dependence, ≥ RHIC;
- ✓ Unknown CNM, namely shadowing;
- ✓ R_{AA}/CNM expected to increase the difference between RHIC and LHC;
- ✓ pA is now needed at LHC:
  - Higher suppression inferred from pA than the one measured in AA at LHC?



Merci - Dziekuje - Danke – Spasibo - Thanks – Gracies - Grazie - Gracias

LHC/RHIC comparison

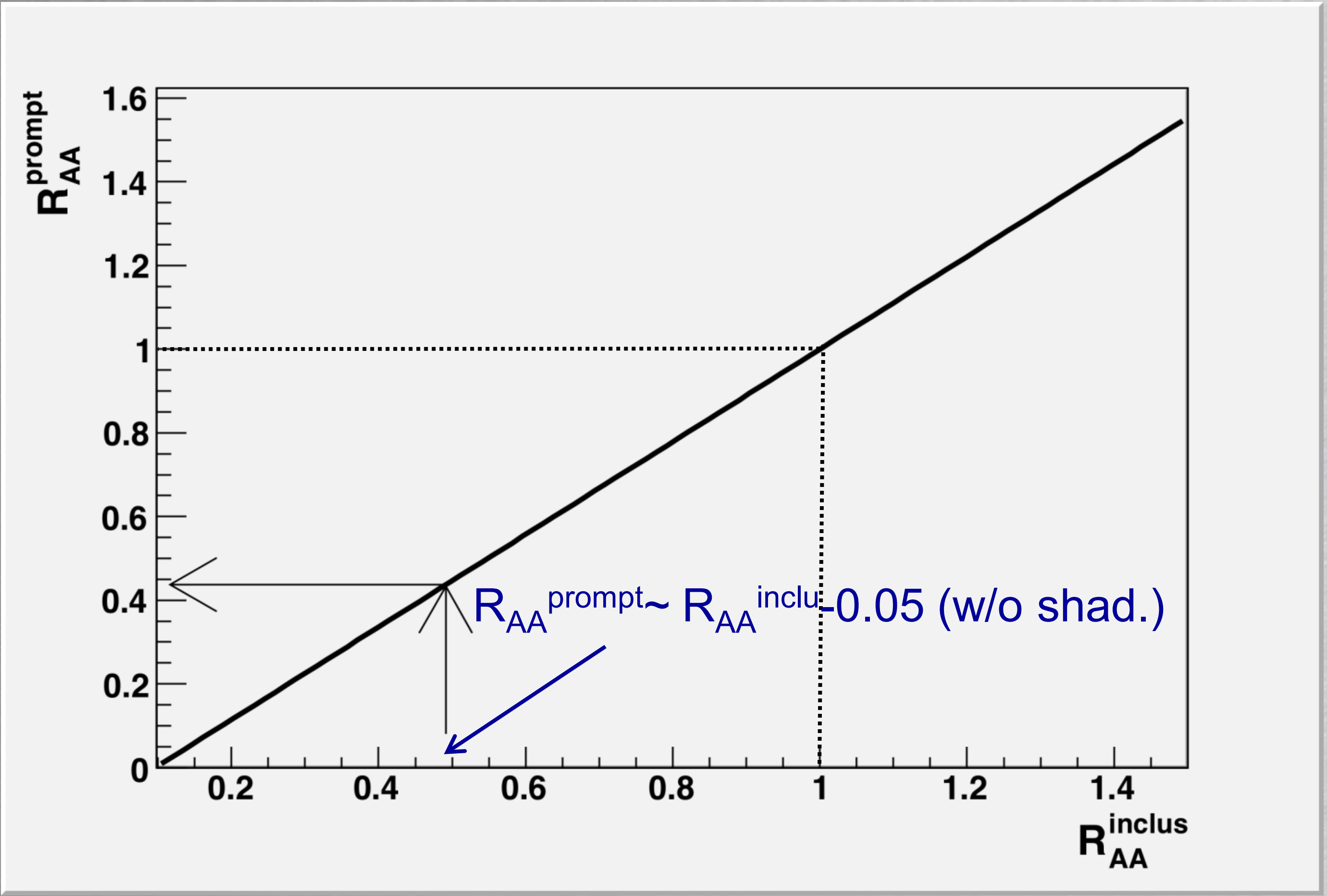


STAR (p_T>5 GeV) versus CMS (6.5<p_T<30 GeV)

PHENIX (p_T>0 GeV) versus ALICE (p_T>0 GeV)

Caveat: Different beam energy and rapidity coverage; $dN_{ch}/d\eta(N_{part})^{LHC} \sim 2.1 \times dN_{ch}/d\eta(N_{part})^{RHIC}$ (A. Toia talk).

Beauty Contribution Effect



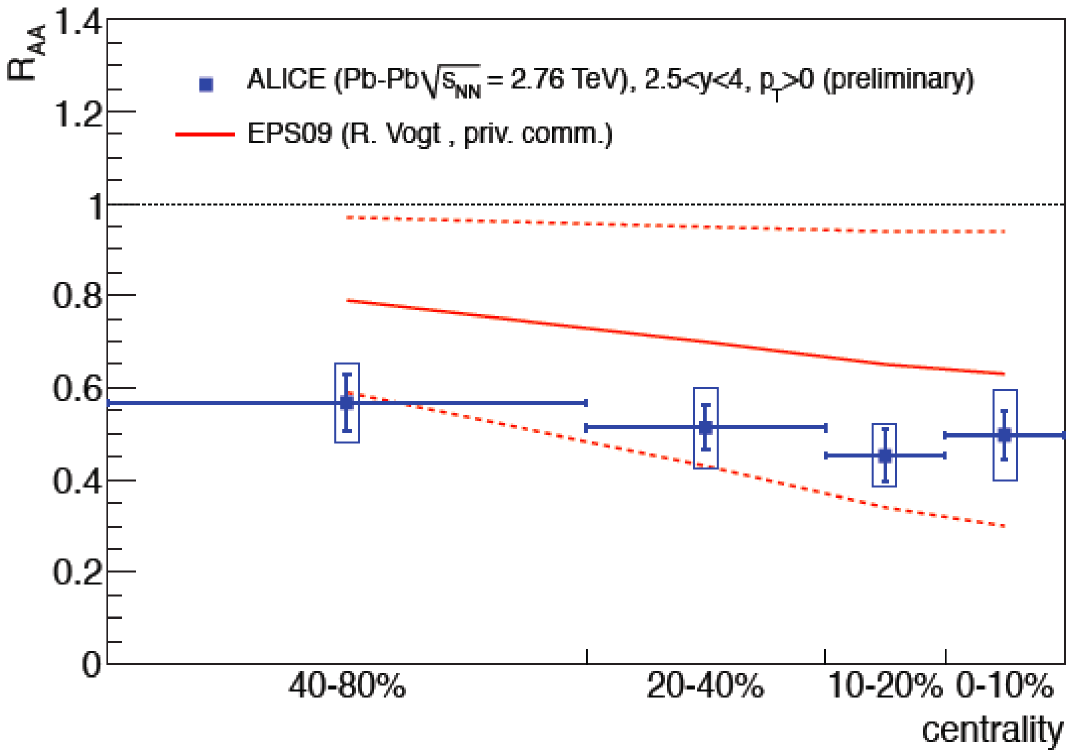
Beauty/Prompt ~ 10.7%; LHCb coll., arXiv:1103.0423 (2011)

Same rapidity coverage as ALICE muon spectrometer

Beauty production scales with Glauber scaling, w/o shadowing

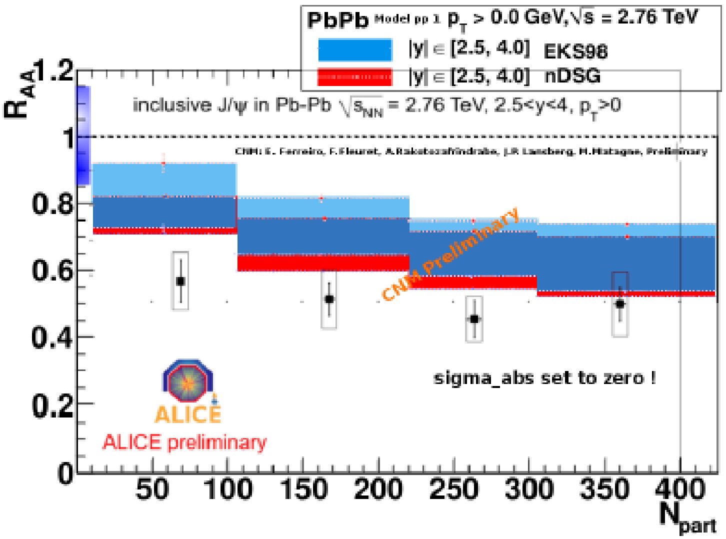
Comparison with EPS09

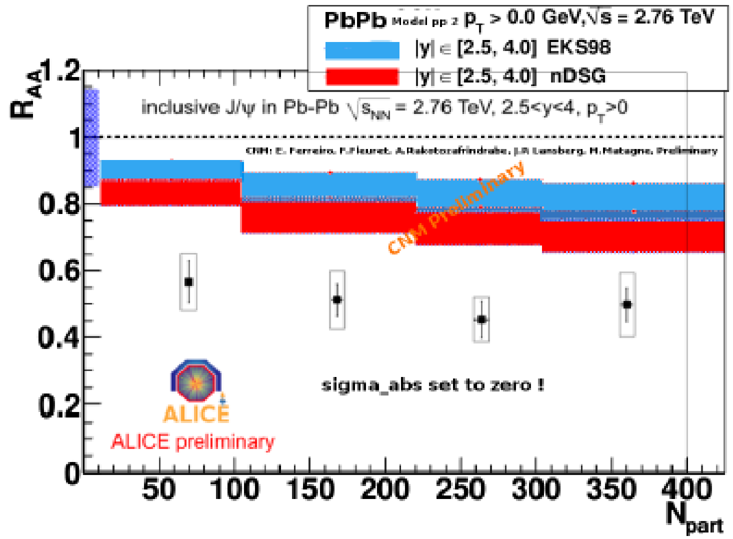
K.J.Eskola *et al.*, JHEP 0904:065, 2009
R. Vogt, Phys.Rev.C81:044903, 2010



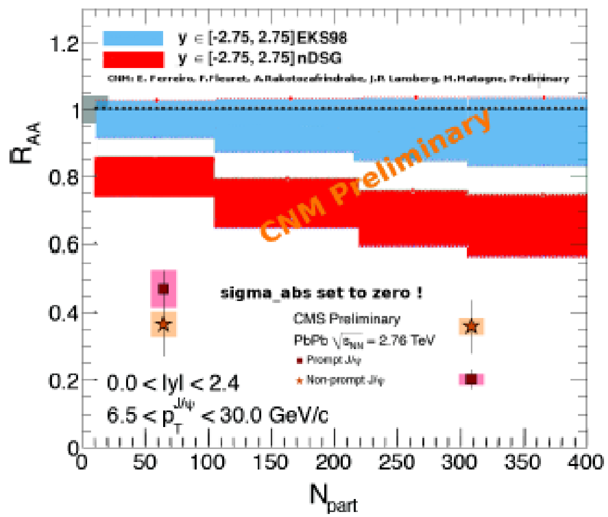
- If shadowing is considered, it could even lead to an enhancement of the J/ψ in central Pb-Pb with respect to cold nuclear matter effects
- Large uncertainties for shadowing prediction, p-A is then imperative at LHC

- Let us apply the lessons learnt in *pp* ($gg \to \psi g$) to compute CNM in PbPb:





Without P_T cut and forward (ALICE acceptance)



With $P_T > 6.5$ GeV cut and mostly central (CMS/ATLAS acceptance)

- Non trivial effect of the P_T cut. $\sigma_{abs}^{effective} = 0$mb ?

J/ψ Regeneration

B. Svetistky, PRD34, 2484 (1988)

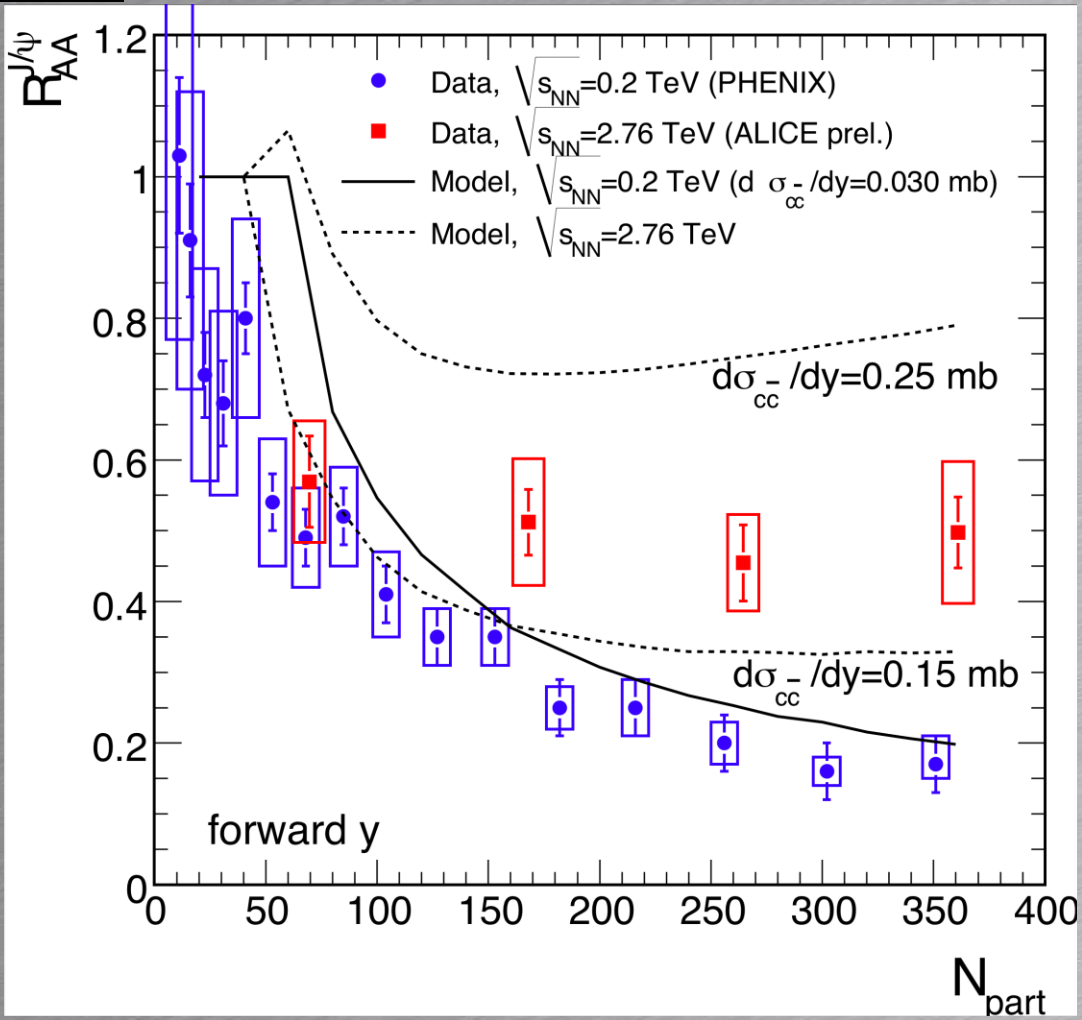
The other observation applies to a geometric argument[14] based on surface effects in the nuclear collision. This argument states that J/ψ's with large p_T, especially those created in nucleon-nucleon collisions near the nuclear surfaces, will escape the plasma without dissociation. According to our discussion, *any* J/ψ whose flight intersects the plasma region will be stopped there, to share in the fate of $c\bar{c}$ pairs created in the plasma in the first place. Thus if there is suppression of low-p_T J/ψ's, there should be suppression at high p_T as well. As mentioned in the Introduction, however, the large plasma drag could lead to *enhancement* of J/ψ production by preventing separation of charm pairs created in the $D\bar{D}$ continuum. This would obviously only apply to pairs created within the plasma volume.

B. Svetistky, PRD34, 2484 (1987) page 2488

FONLL charm densities

- $d\sigma_{ccbar}/dy$ (pp 200 GeV, y=0)=*A*;
- $d\sigma_{ccbar}/dy$ (pp 200 GeV, y=1.7)=0.64x*A*;
- $d\sigma_{ccbar}/dy$ (pp 2.76 TeV, y=0)=5.5x*A*;
- $d\sigma_{ccbar}/dy$ (pp 2.76 GeV, y=3.25)=3.5x*A*;

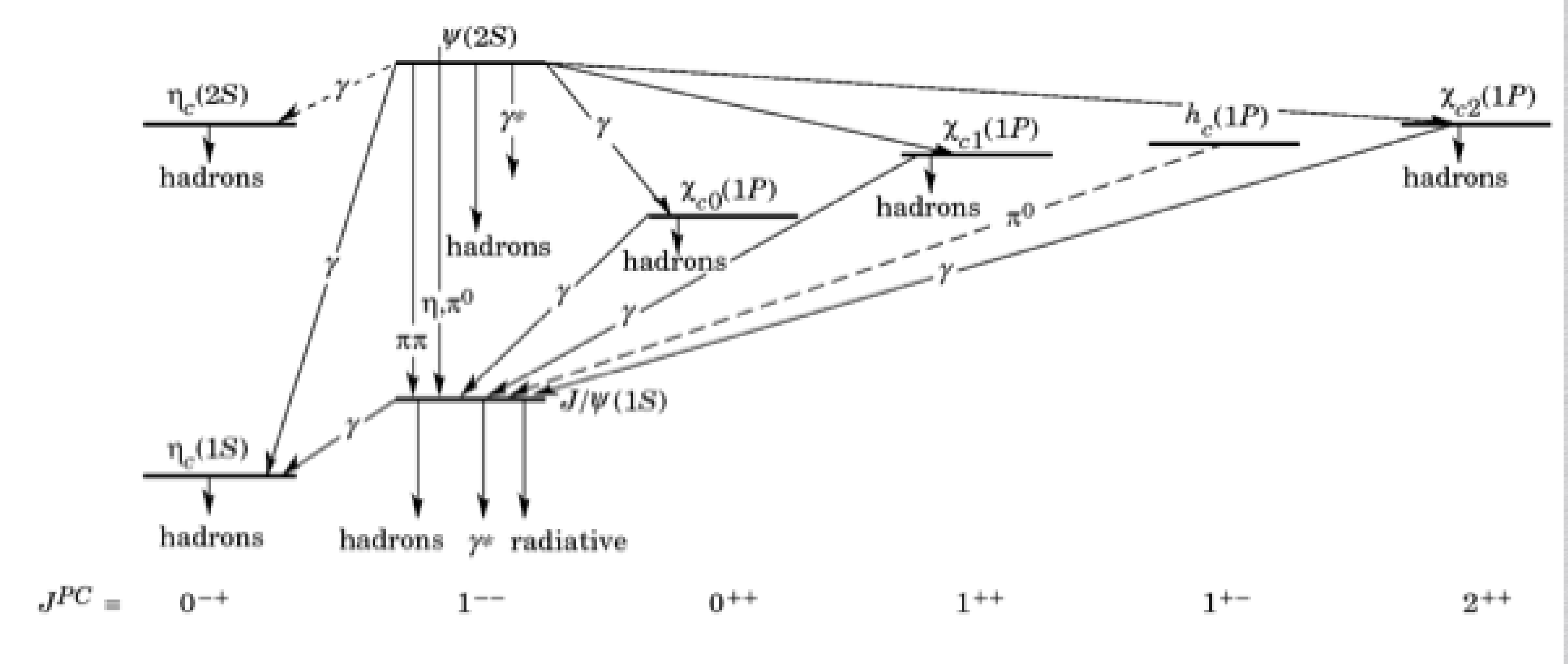
Statistical Hadronization



Talk of A. Andronic on Mon May 23rd

PBM & JS, PLB490, 196 (2000); A.A. et al., PLB571, 36 (2003)

Charmonium feed-down

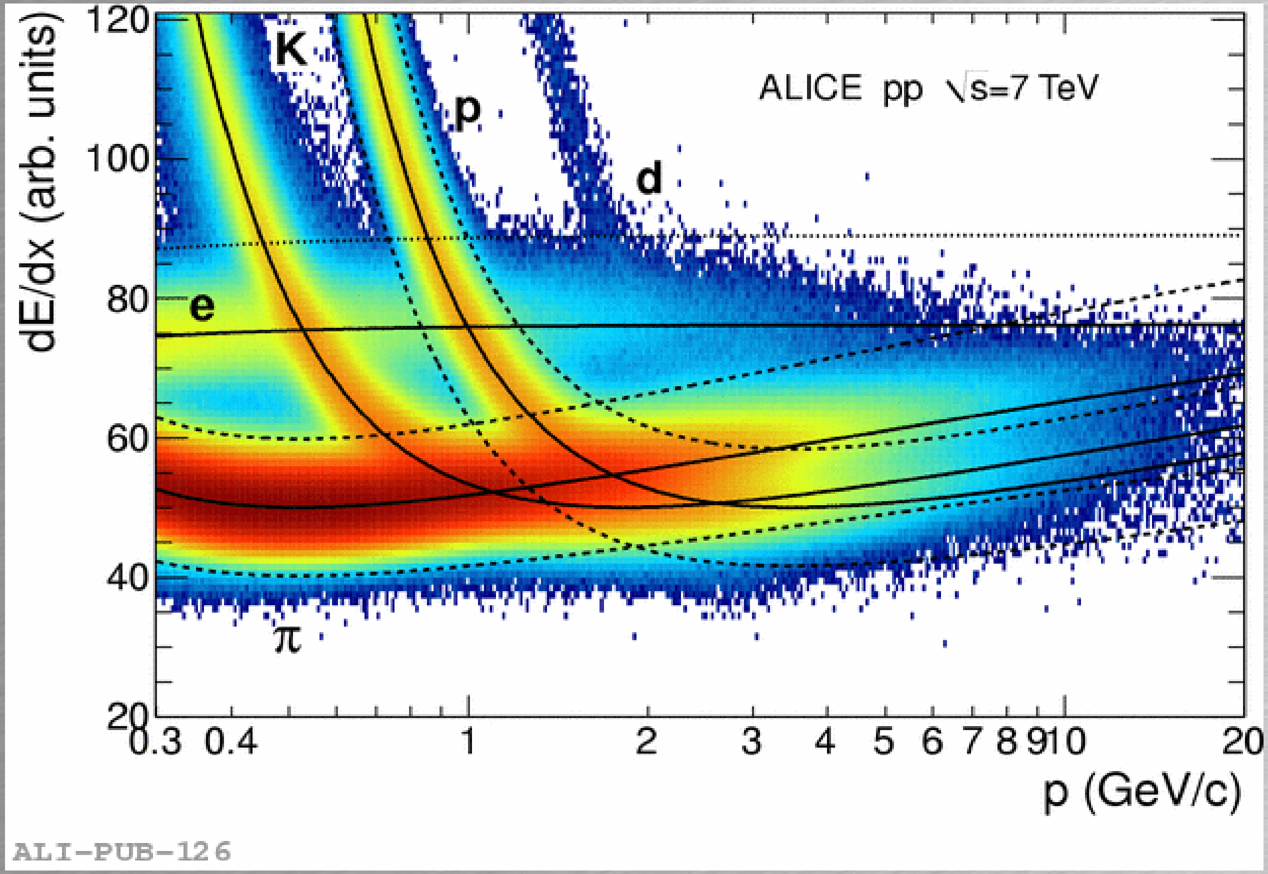


- In pp collisions:
  - ~90% direct and 10% B decay;
  - ~51% prompt J/ψ, ~32% from χ, ~7 from ψ′ and ~10% from B.

CERN Yellow Report, hep-ph/0311048v1 (2003)
LHCb, arXiv:1103.0423v1

Electron PID for J/ψ

Electron PID from TPC
dE/dx



Systematics in pp

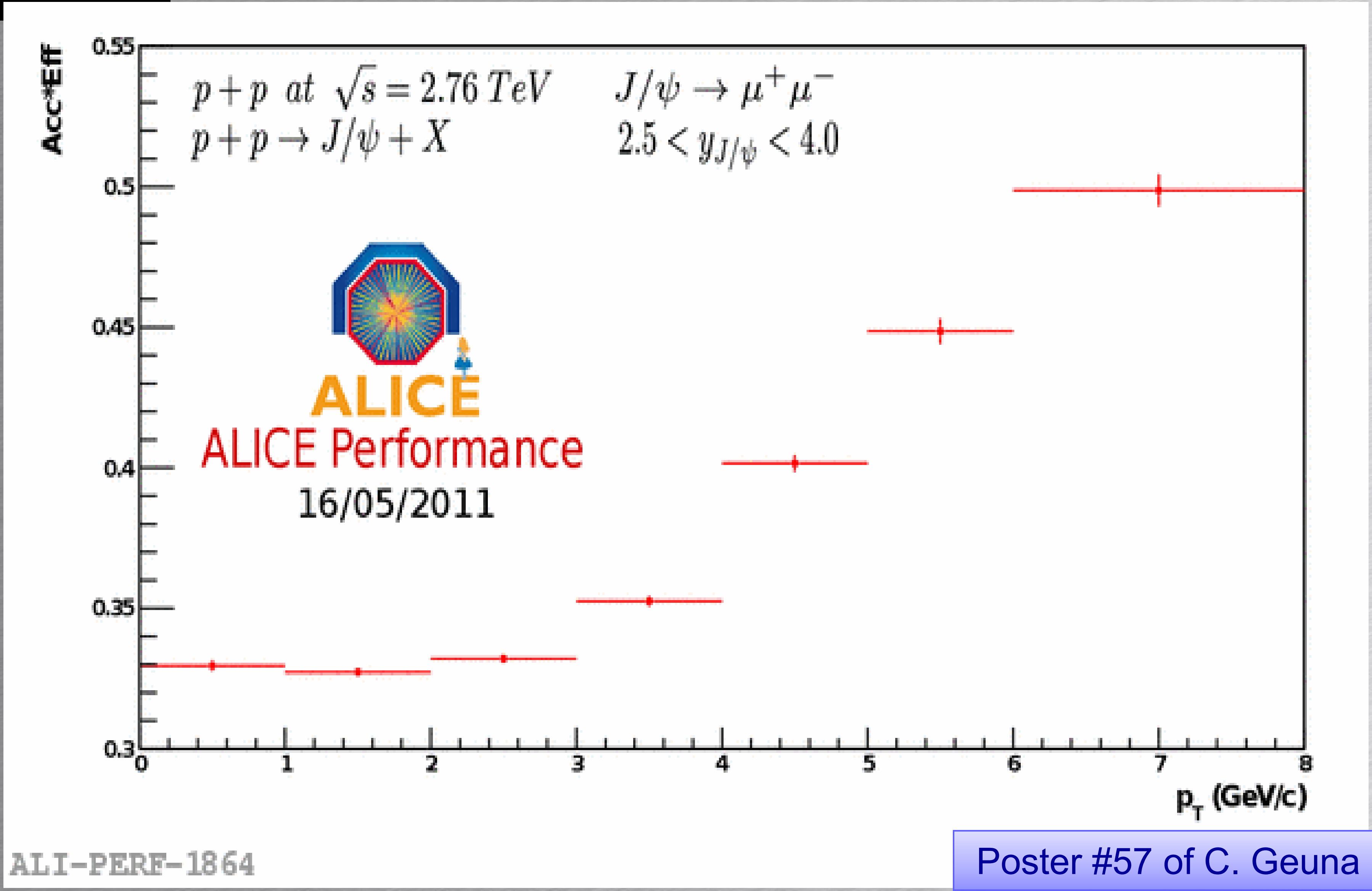
Channel	e^+e^-		$\mu^+\mu^-$	
Signal extraction	8.5		7.5	
Acceptance input	1		2	
Trigger efficiency	0		4	
Reconstruction efficiency	11		3	
R factor	0		3	
Luminosity	8			
B.R.	1			
Polarization	$\lambda = -1$	$\lambda = 1$	$\lambda = -1$	$\lambda = 1$
CS	+19	–13	+31	–15
HE	+21	–15	+22	–10

ALICE coll., arXiv:1105.0380v1 (2011)

Systematic μμ in PbPb

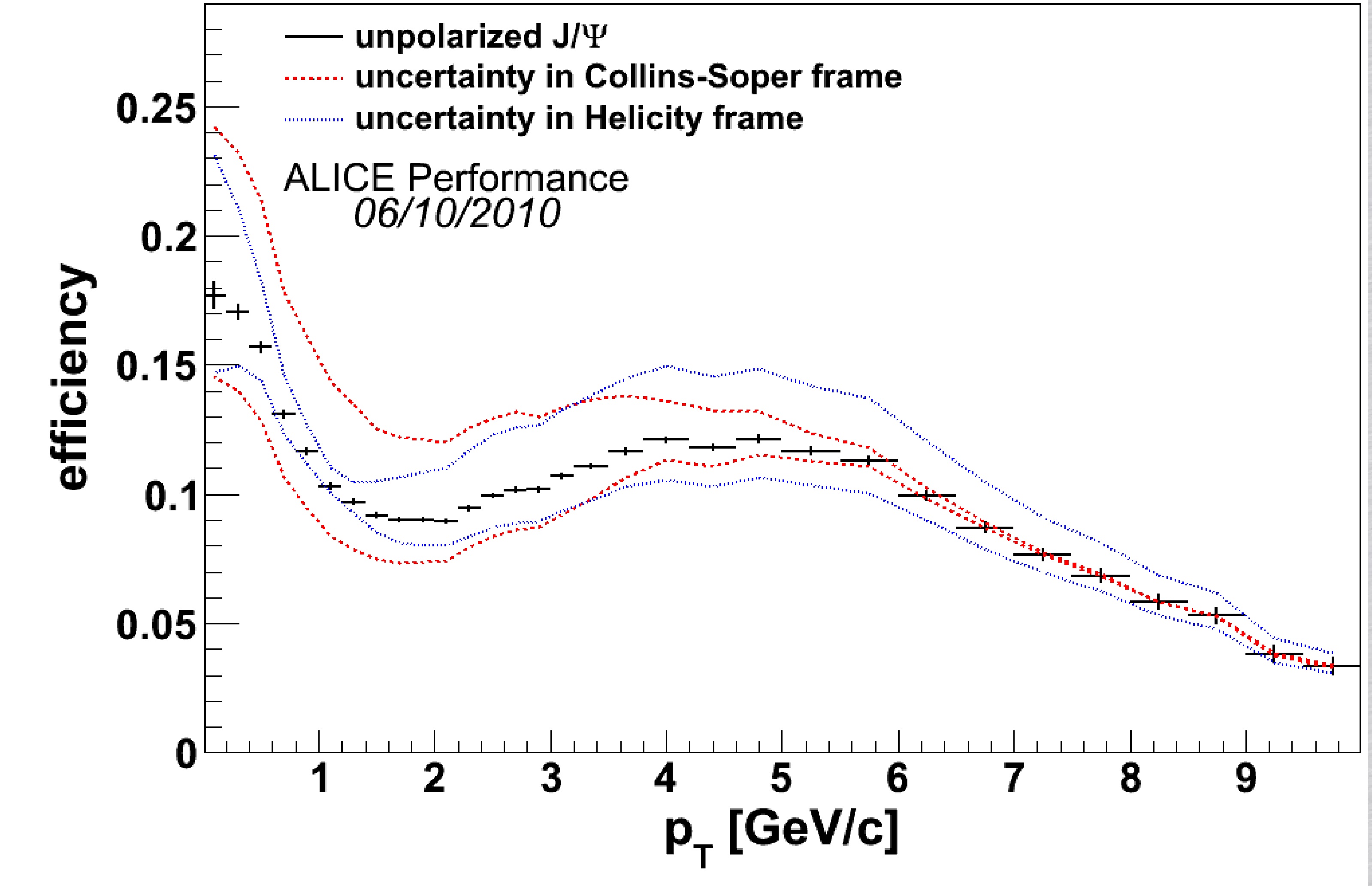
centrality	0-10%	10-20%	20-40%	40-80%	All
B.R.	-	-	-	-	1%
X-section	-	-	-	-	13%
$<T_{AA}>$	4%	4%	4%	6%	-
$<T_{AA}>^{i} / <T_{AA}>^{40-80\%}$	6%	5%	4%	-	-
$Y_{J/\psi}$	19%	14%	17%	14%	-
$Y_{J/\psi} / Y_{J/\psi}^{40-80\%}$	12%	8%	7%	-	-
Acceptance	-	-	-	-	3%
Eff. Tracker	4%	2%	1%	0%	5%
Eff. Trigger	-	-	-	-	4%
Reco.	-	-	-	-	2%
Total for R_{AA}	**20%**	**15%**	**17%**	**15%**	**15%**
Total for R_{CP}	**14%**	**10%**	**8%**	**-**	**-**

Acceptance x Efficiency

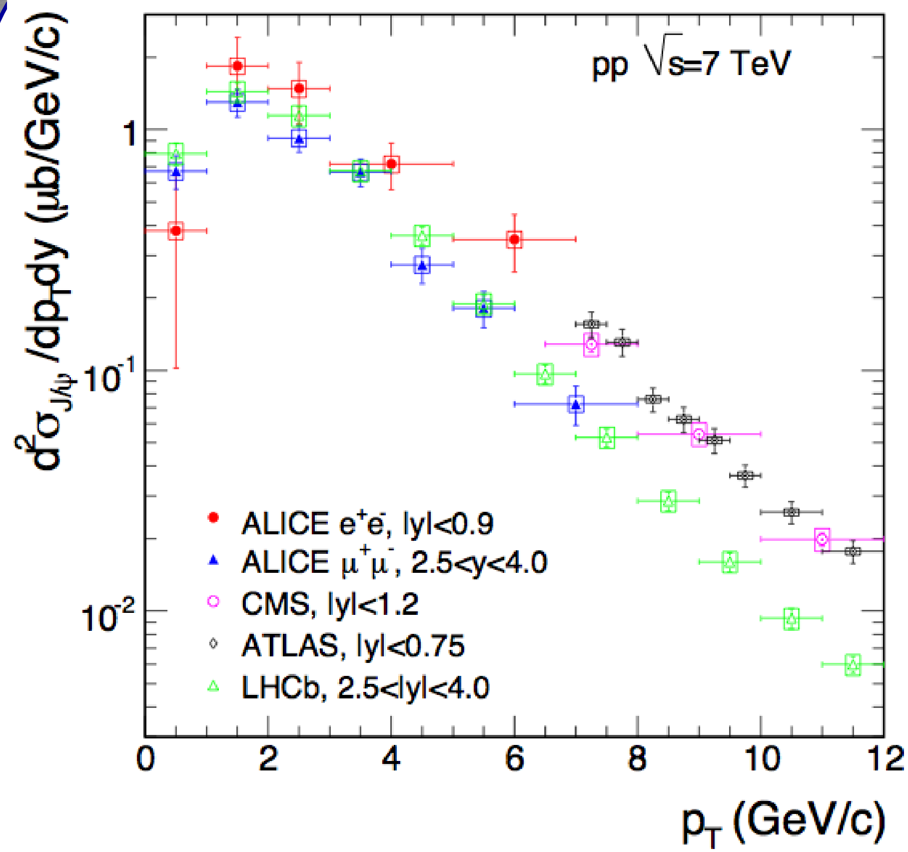


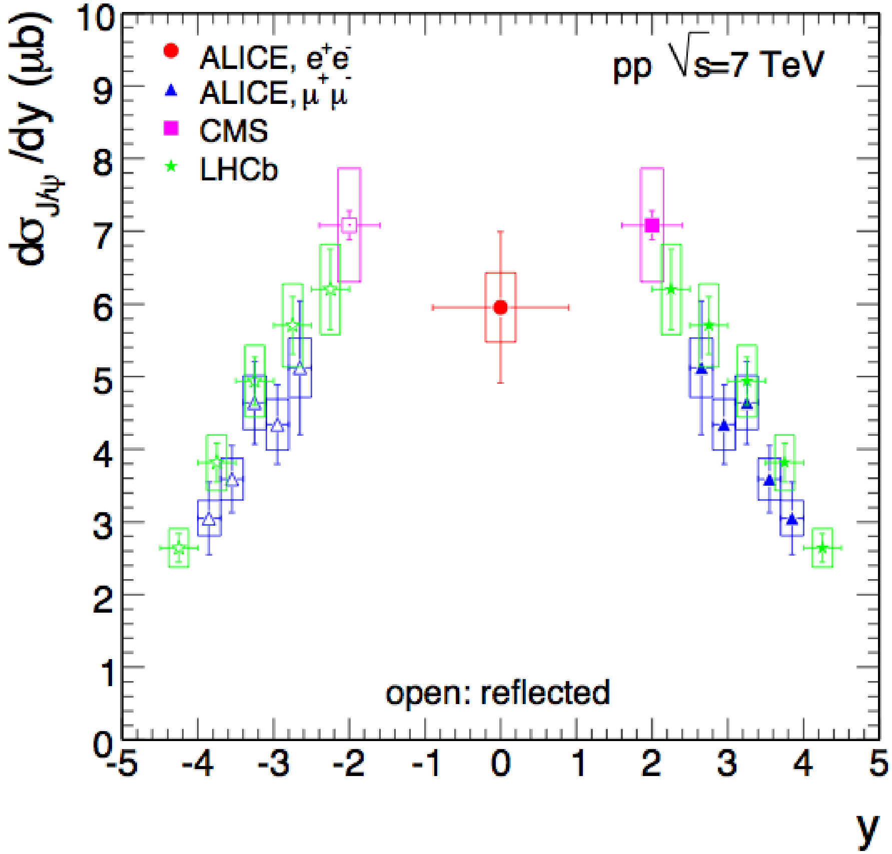
Poster #57 of C. Geuna

Acceptance x Efficiency



ALICE/LHCb/ATLAS/CMS

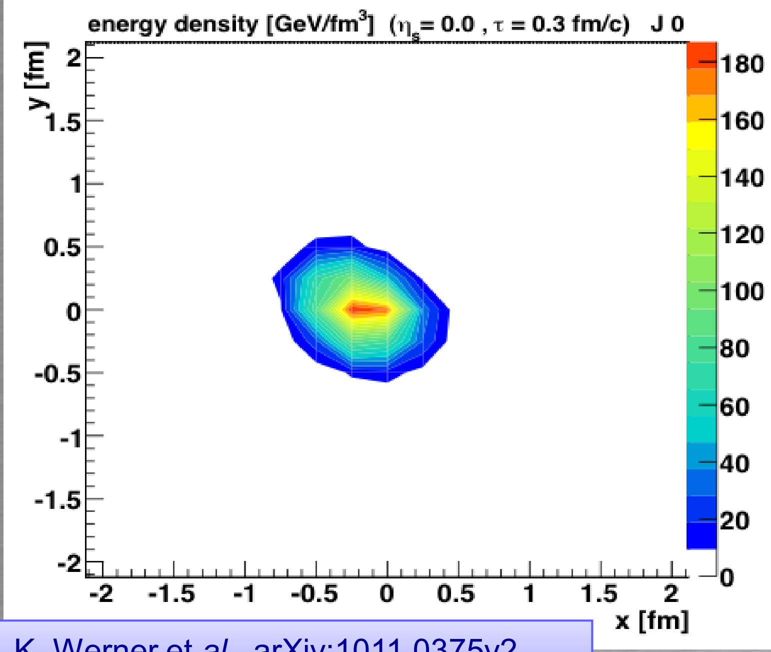




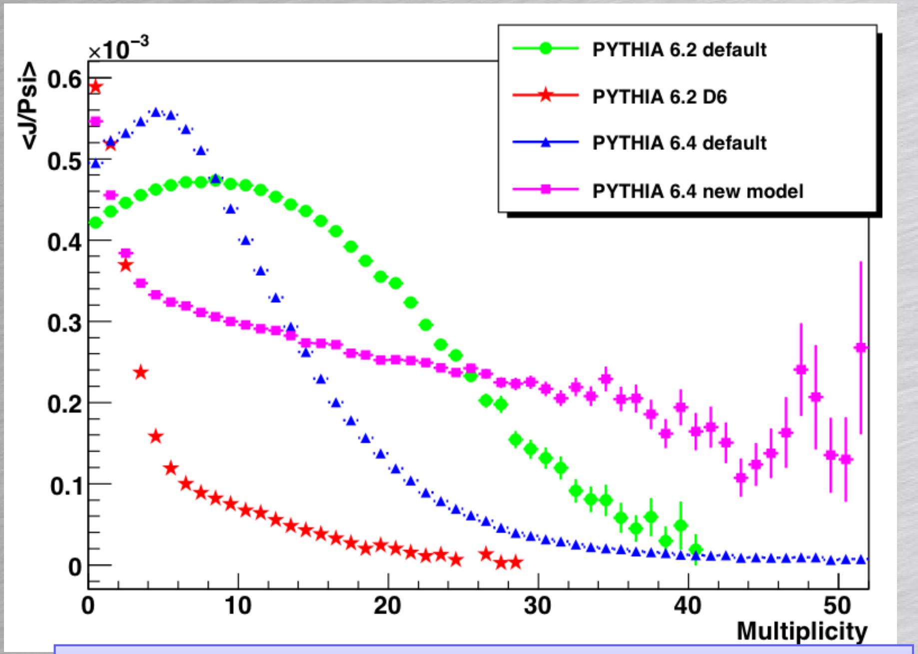
ALICE coll., arXiv:1105.0380v1 (2011)

High multiplicity events in pp

- Looking for collectiveness in high multiplicity proton-proton collisions :
  - Study of the J/ψ as a function of the charged particle density at mid-rapidity;



K. Werner et *al*., arXiv:1011.0375v2
Phys.. Rev. Lett. 106 122004 (2011)



S. Porteboeuf & R. Granier, arXiv:1012.0719v1 (2011)

Looking for QCD-matter in pp at LHC: a research topic on its own right.

Polarization

The total collected statistics at $\sqrt{s}$ = 7 TeV allows the determination of the full angular distribution of the J/ψ decay leptons.

$$W(\cos\theta, \varphi) \propto 1 + \lambda_\theta \cos^2\theta + \lambda_\varphi \sin^2\theta \cos 2\varphi + \lambda_{\theta\varphi} \sin 2\theta \cos\varphi$$

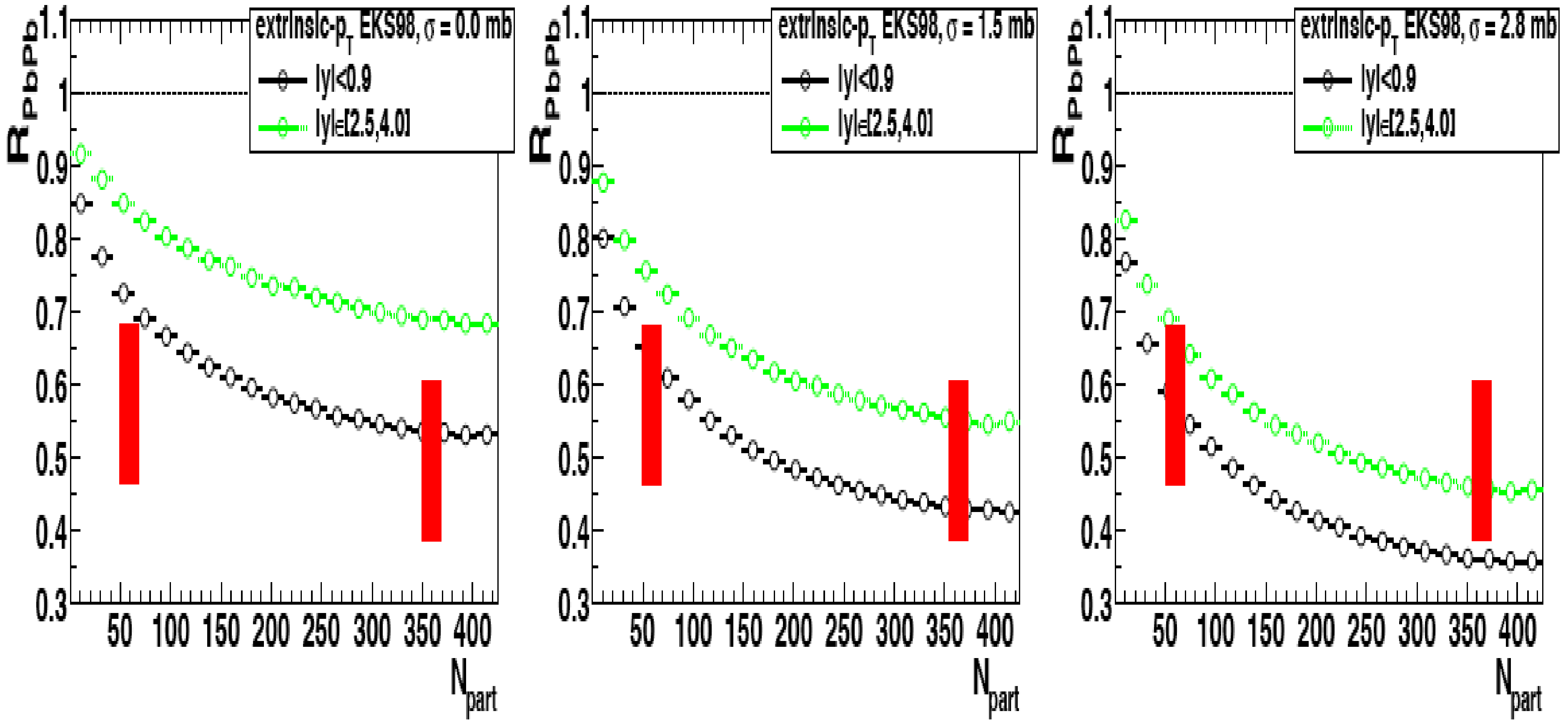
1D efficiency correction with an iterative procedure works well at the MC level.

In the muon channel, the expected error on the polarization parameters is not higher than 0.15 (λ_θ) for a p_T integrated analysis

Poster #79 of L. Bianchi

Shadowing

E. G. Ferreiro et al., arXiv:1101.0488v2, Nucl. Phys. A855 (2011) 327 (2011)



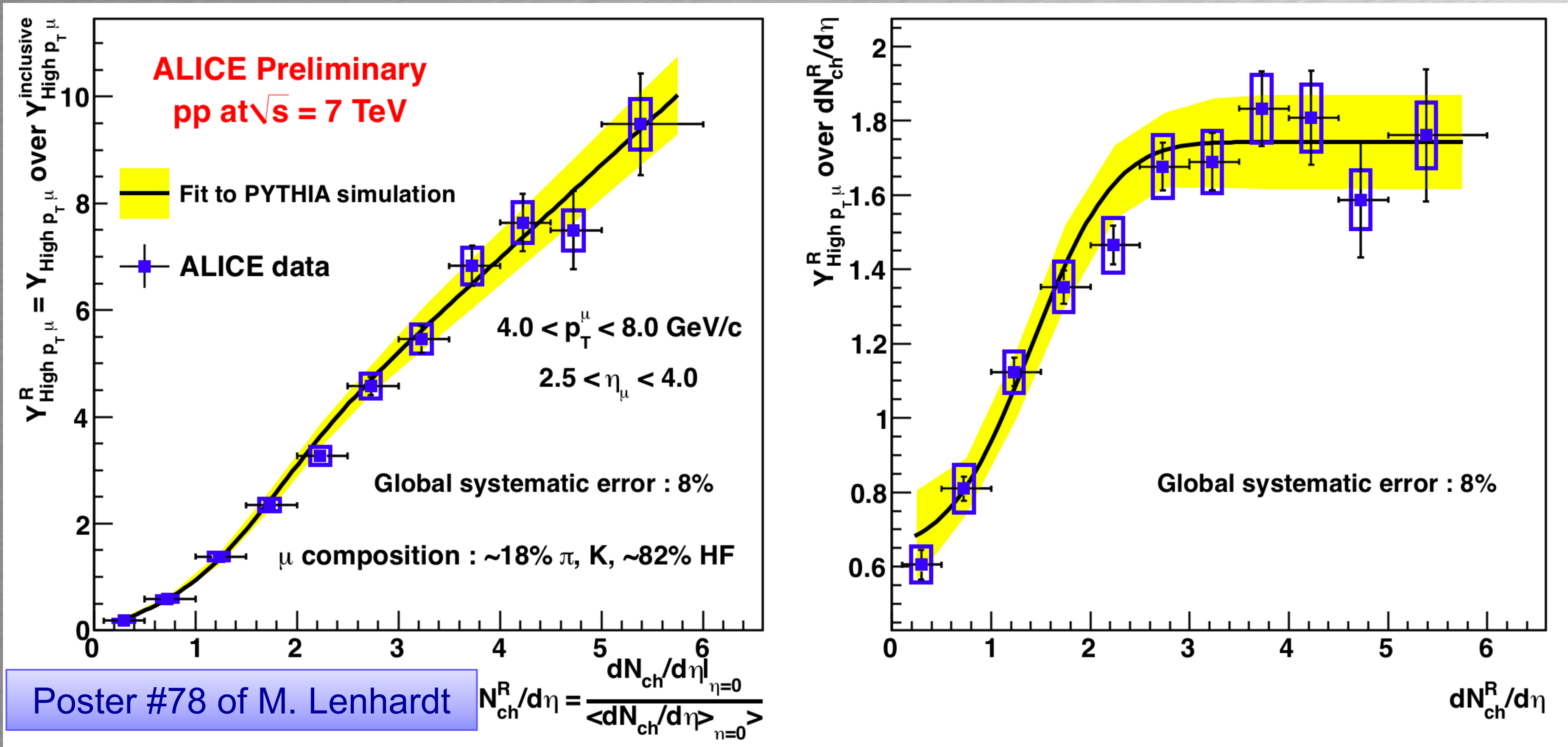
(a) σ_{abs} = 0 mb (b) σ_{abs} = 1.5 mb (c) σ_{abs} = 2.8 mb

ALICE Preliminary data; 15% correlated syst. error not included

High p_T muons

High p_T muon : 4 GeV/c < p_T < 8 GeV/c):

- ~18% π,K (decays), ~82% HF (~50%-c, ~50%-b);



Poster #78 of M. Lenhardt

Good agreement with Pythia predictions