A Large Ion Collider Experiment

J/ψ production in p-Pb with ALICE at the LHC

Outline

- Motivation
- Analysis
- Results
  - $d^2\sigma_{J/\psi}/dydp_T$
  - $d\sigma_{J/\psi}/dy$
  - R_{FB}(integrated)
  - $R_{FB}(p_T)$
  - pp interpolation
  - $R_{pPb}(y_{cms})$ and $R_{Pbp}(y_{cms})$

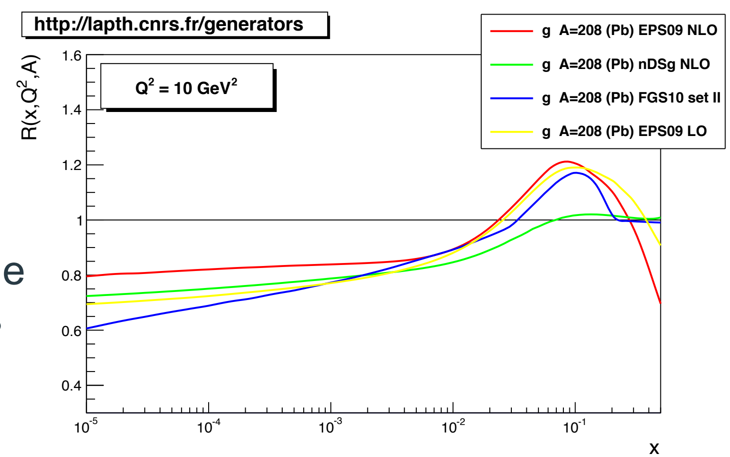
In red are **final results** from :

J/ψ production and nuclear effects in p-Pb collisions at $\sqrt{s_{NN}}$=5.02 TeV
arXiv:1308.6726

Cold Nuclear Matter effects

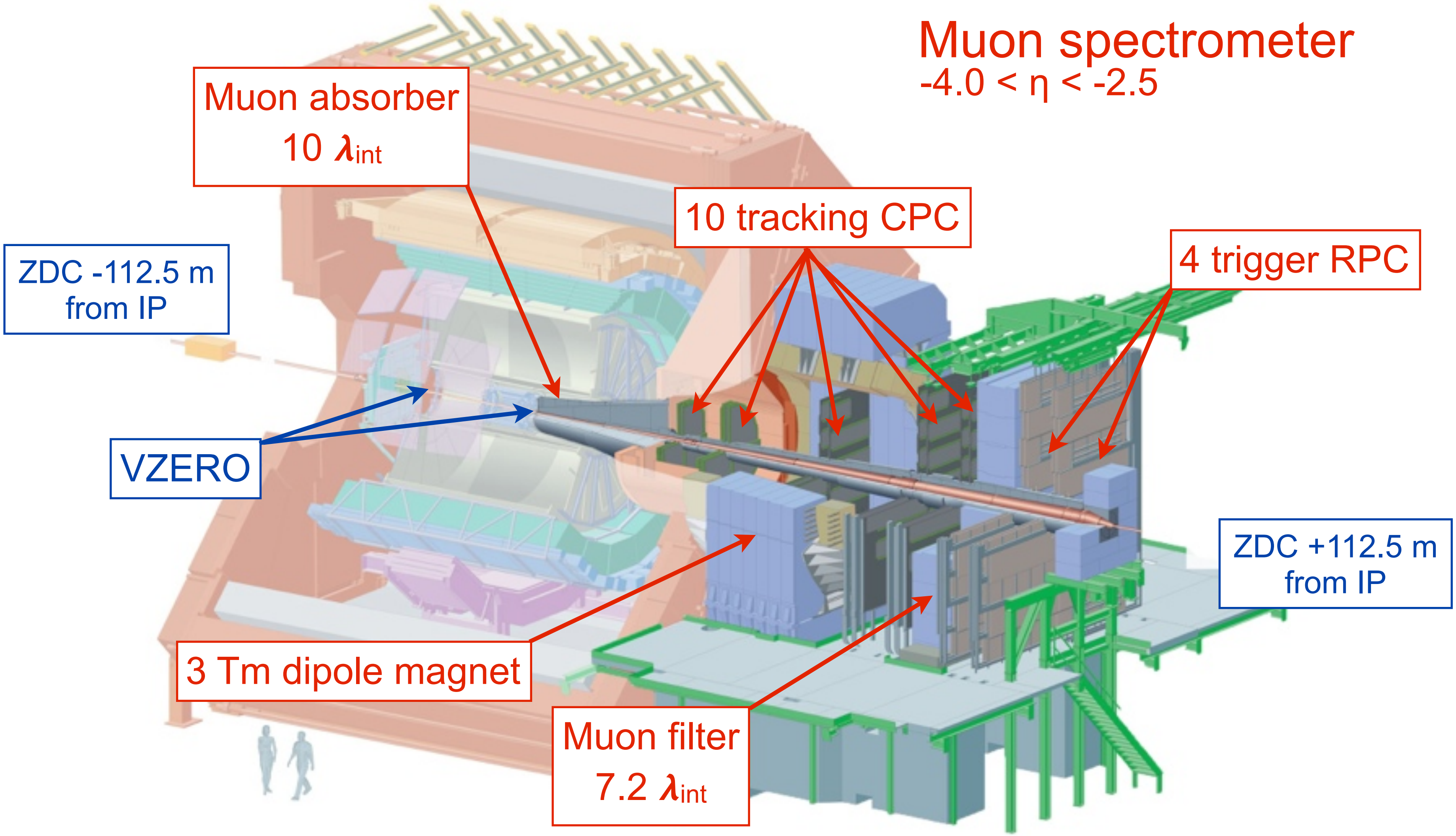
[1] see *e.g.* Nucl. Phys. A700(2002)539
[2] see *e.g.* Phys.Rev.Lett. 109(2012)122301
[3] see *e.g.* JHEP0904(2009)065

- nuclear **absorption** [1]
  - expected to be small at LHC
    - as $c\bar{c}$ pairs spend a very short time within nuclear matter due to large Lorentz factor of the pair with respect to the nucleus
- (coherent) **energy loss** [2]
  - the amount of medium-induced gluon radiation impacts the strength of the J/psi suppression
- initial state modification [3]
  - gluon **shadowing** (or saturation)
    - shadowing expected to be large at LHC (but large uncertainties on nPDFs at low x)



Study of the CNM effects in p-Pb interesting in itself as well as for its consequences for Pb-Pb collisions

ALICE detector (for muons)



Data selection

EVENT SELECTION

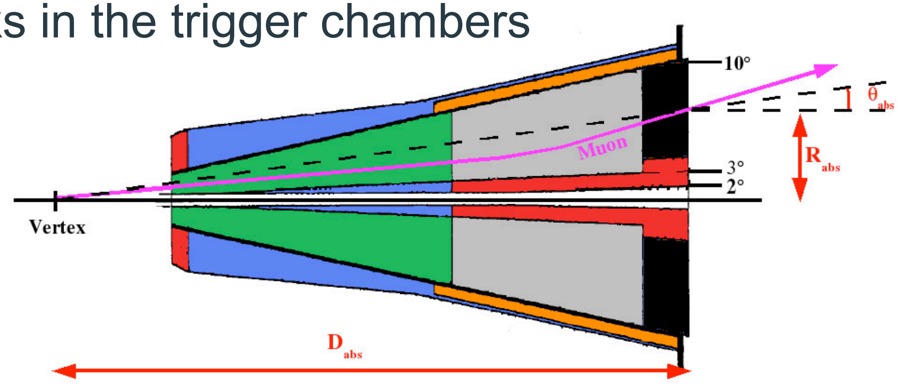
- Minimum Bias (MB) trigger : coincidence of the two sides of the VZERO (2.8 < η < 5.1 and -3.7 < η < -1.7)
- MB trigger efficiency ~ 99% for NSD events
- Rejection of beam-gas and electromagnetic interactions
- SPD used for vertex determination

DIMUON TRIGGER

- MB & two opposite sign muon tracks in the trigger chambers

ANALYSIS CUTS

- Muon trigger matching
- $-4.0 < \eta_\mu < -2.5$
- 17.6 cm < R_{abs} < 89.5 cm (where R_{abs} is the track radial position at the end of absorber)



LHC beam energies asymmetry induces a **rapidity shift** of the NN-cms in the direction of the proton

$$\Delta y \approx \frac{1}{2} \log \frac{Z_{Pb} A_p}{Z_p A_{Pb}} = 0.465$$

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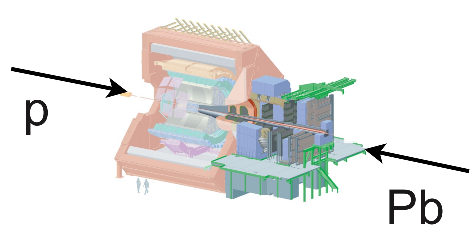
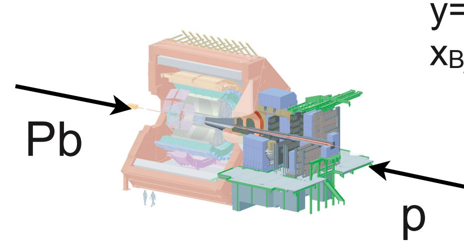
Data executive summary

	p-Pb (forward)	Pb-p (backward)
L_{int} (nb^{-1})	5.03 ± 0.18	5.81 ± 0.19
σ_{MB} (b) (from VdM scans)	2.08 ± 0.07	2.12 ± 0.07
$N_{J/\psi}$ (10^4)	6.69 ± 0.05 ± 0.08	5.67 ± 0.05 ± 0.07
y_{cms} range	[2.03 ; 3.53]	[-4.46 ; -2.96]
x_{Bj} range (assuming 2->1 kinematics)	1.8 - 8.1 x 10^{-5}	1.2 - 5.3 x 10^{-2}

Note : PHENIX
@ 200 GeV
y=0
$x_{Bj}=1.5\times10^{-2}$





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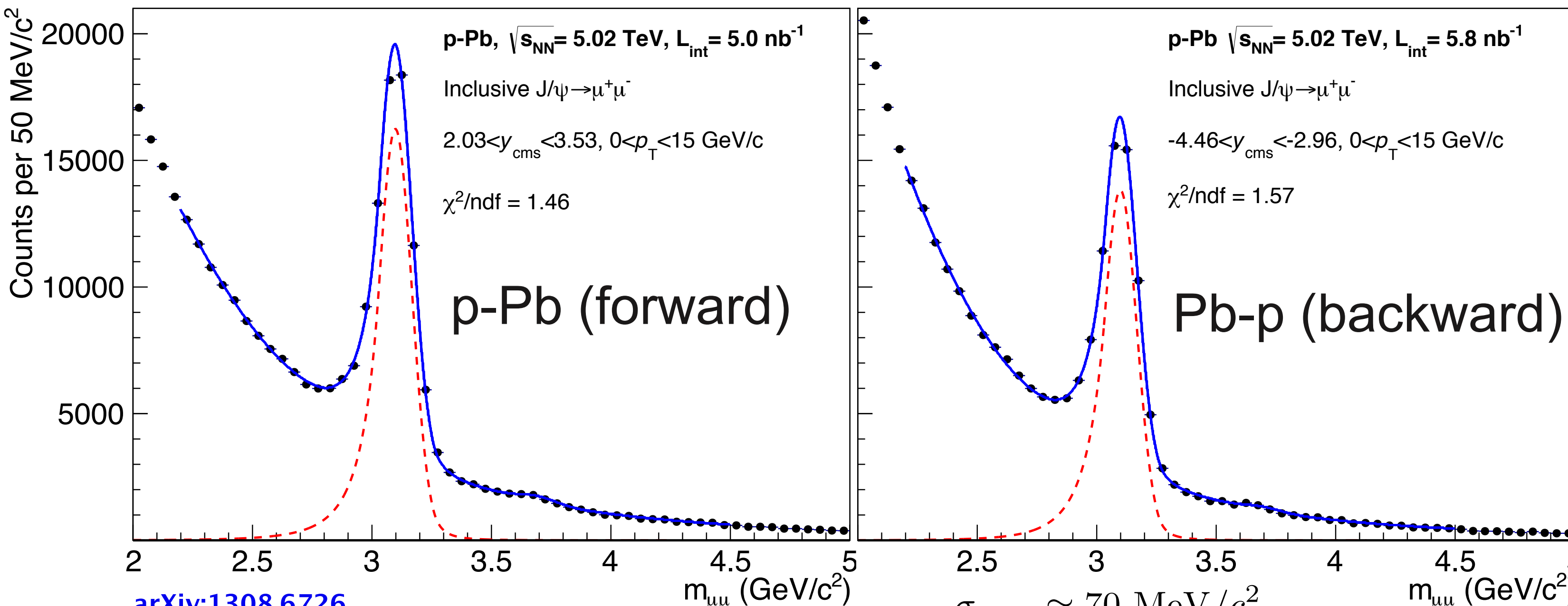
Signal extraction

Based on fits of the invariant mass of unlike-sign muon pairs



arXiv:1308.6726

$\sigma_{m_{\mu\mu}} \approx 70\ \mathrm{MeV}/c^2$

at $m_{\mu\mu} = m_{J/\psi}$

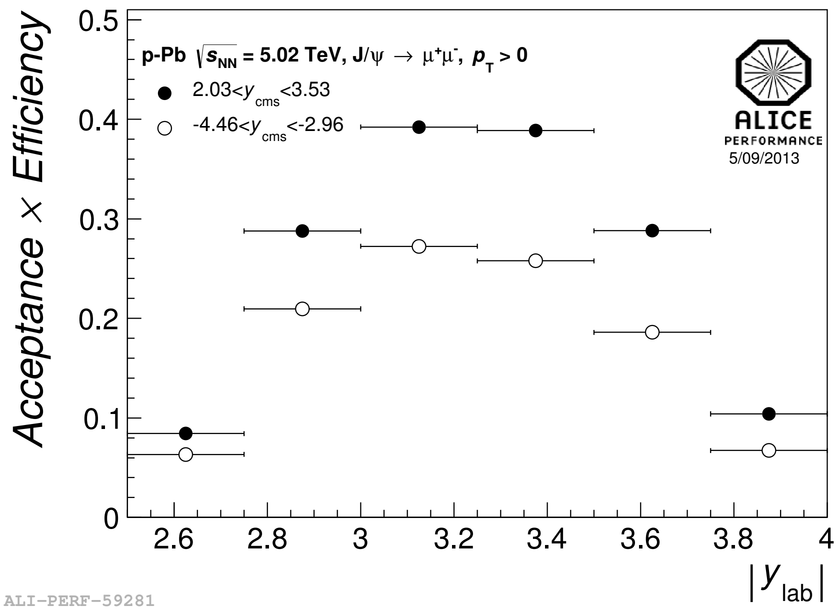
Syst. uncertainty computed varying :

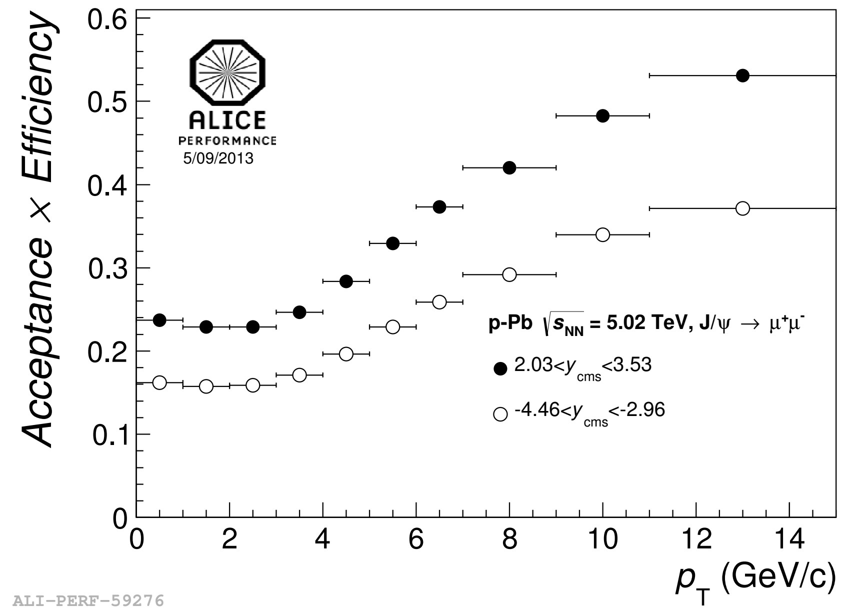
- **SIGNAL SHAPE** : extended Crystal Ball (CB2) or other pseudo-gaussian functions (tails tuned on the corresponding Monte Carlo (MC))
- **BACKGROUND SHAPE** : variable width gaussian (VWG) or polynomial x exponential
- **FITTING RANGE**

and amounts to **1-4%**

Sample plots above are for CB2+VWG

Acceptance x Efficiency





$$\langle Acc \times Eff \rangle_{pPb} = (25.4 \pm 1.3)\%$$

$$\langle Acc \times Eff \rangle_{Pbp} = (17.1 \pm 1.2)\%$$

Difference between p-Pb and Pb-p due to different efficiency of the detector in the two data-taking periods

Source of syst. unc.	<syst. unc.>
MC acceptance inputs	1.5%
tracking efficiency	4-6%
trigger efficiency	3 %
matching efficiency	1 %

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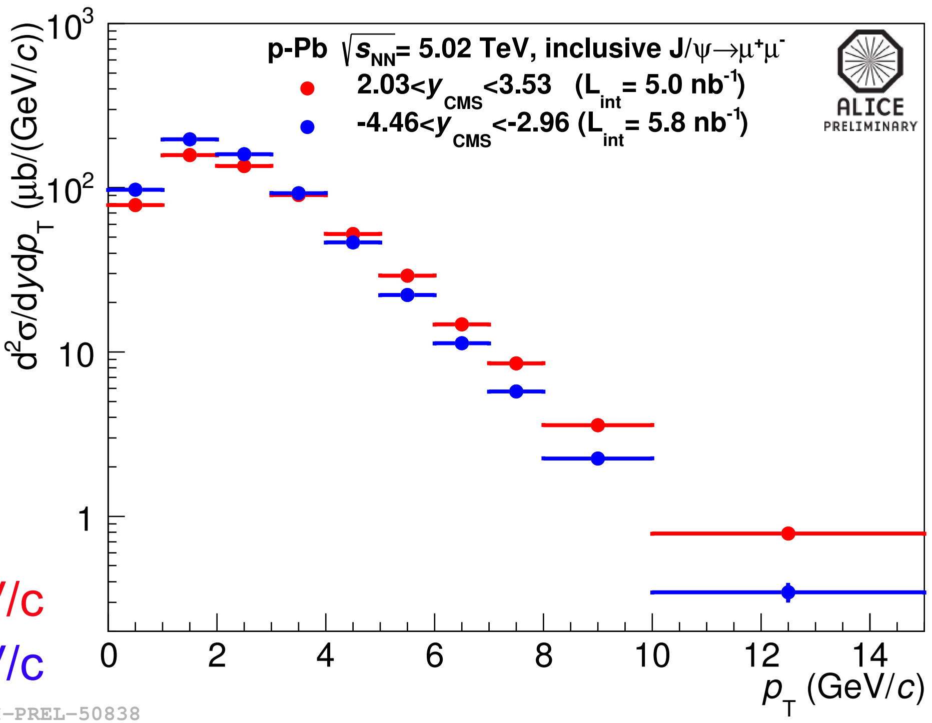
Differential J/Ψ cross-section

$$\sigma_{J/\psi\to\mu^+\mu^-} = \frac{N_{J/\psi\to\mu^+\mu^-}}{L_{int} \times Acc \times Eff \times BR_{J/\psi\to\mu^+\mu^-}}$$

$$L_{int} = \frac{N_{MB}}{\sigma_{MB}}$$

$$BR_{J/\psi\to\mu^+\mu^-} = (5.93 \pm 0.06)\%$$

Source of syst. unc.	syst. unc.
signal extraction	1-4%
Acc x Eff	5-7%
L_{int}	3.5 %



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$\langle p_T \rangle$=2.77±0.01(stat.)±0.02(syst.) GeV/c

$\langle p_T \rangle$=2.47±0.01(stat.)±0.02(syst.) GeV/c

$\langle p_T \rangle$ is computed within $0<p_T<15$ GeV/c

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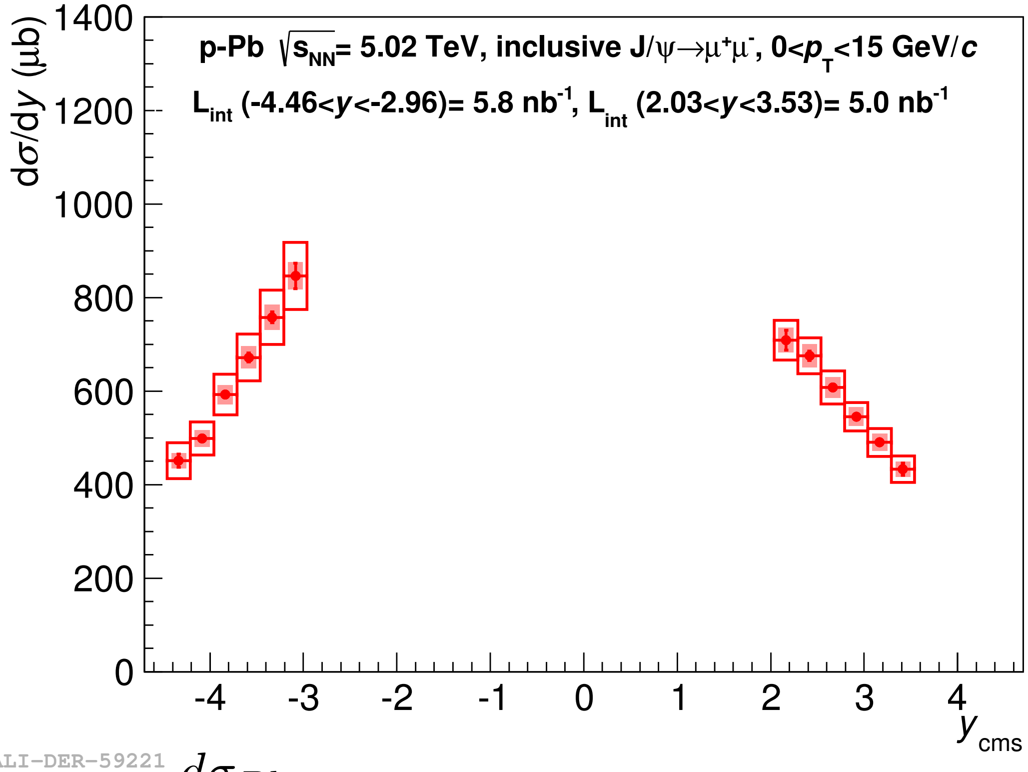
Cross-section vs rapidity



uncorrelated uncertainties : matching, trigger eff, tracking eff, acc. inputs, signal extraction

(partially) correlated uncertainties : luminosity, normalization factor, BR

statistical uncertainties

$$\frac{d\sigma_{Pbp}}{dy} = 644 \pm 5(stat.) \pm 51(syst.)\mu b$$

$$\frac{d\sigma_{pPb}}{dy} = 588 \pm 4(stat.) \pm 38(syst.)\mu b$$

Cross-sections are higher in the backward rapidity region (Pb-p)

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Forward to Backward Ratio

$$R_{FB}^{J/\psi} = \frac{Y_{J/\psi\to\mu^+\mu^-}^{Forward}}{Y_{J/\psi\to\mu^+\mu^-}^{Backward}} = \frac{R_{pPb}}{R_{Pbp}}$$

$$= \frac{N_{J/\psi\to\mu^+\mu^-}^{Forward}}{N_{J/\psi\to\mu^+\mu^-}^{Backward}} \times \frac{(Acc \times Eff)^{Backward}}{(Acc \times Eff)^{Forward}} \times \frac{N_{MB}^{Backward}}{N_{MB}^{Forward}}$$

computed in the y_{cms} range common to both p-Pb and p-Pb

- loss of 2/3 of statistics
- no pp cross-section needed

	p-Pb	Pb-p
common y_{cms} range	[2.96 ; 3.53]	
y_{lab} range	[3.43 ; 4]	[-3.07 ; -2.5]
x_{Bj} range	1.8 - 3.2 x 10^{-5}	1.2 - 2.1 x 10^{-2}

Integrated R_{FB}

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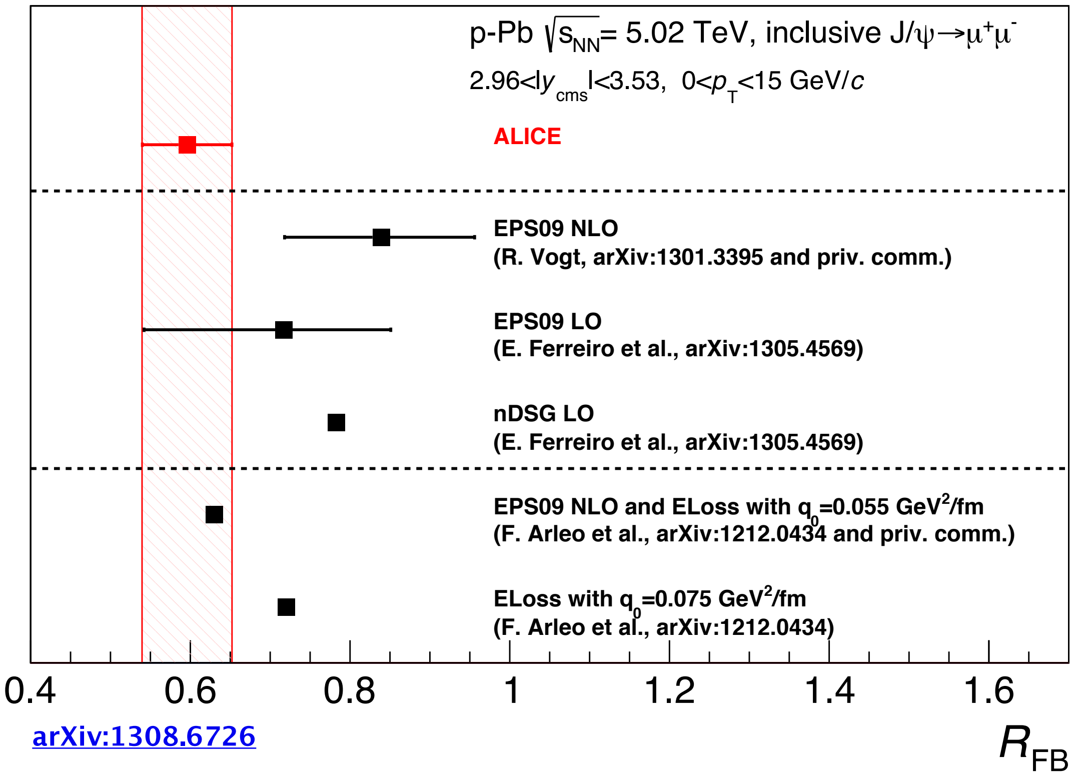
R_{FB}=0.60 ± 0.01(stat.) ± 0.06(syst.)



arXiv:1308.6726

exp. uncertainty reasonably small

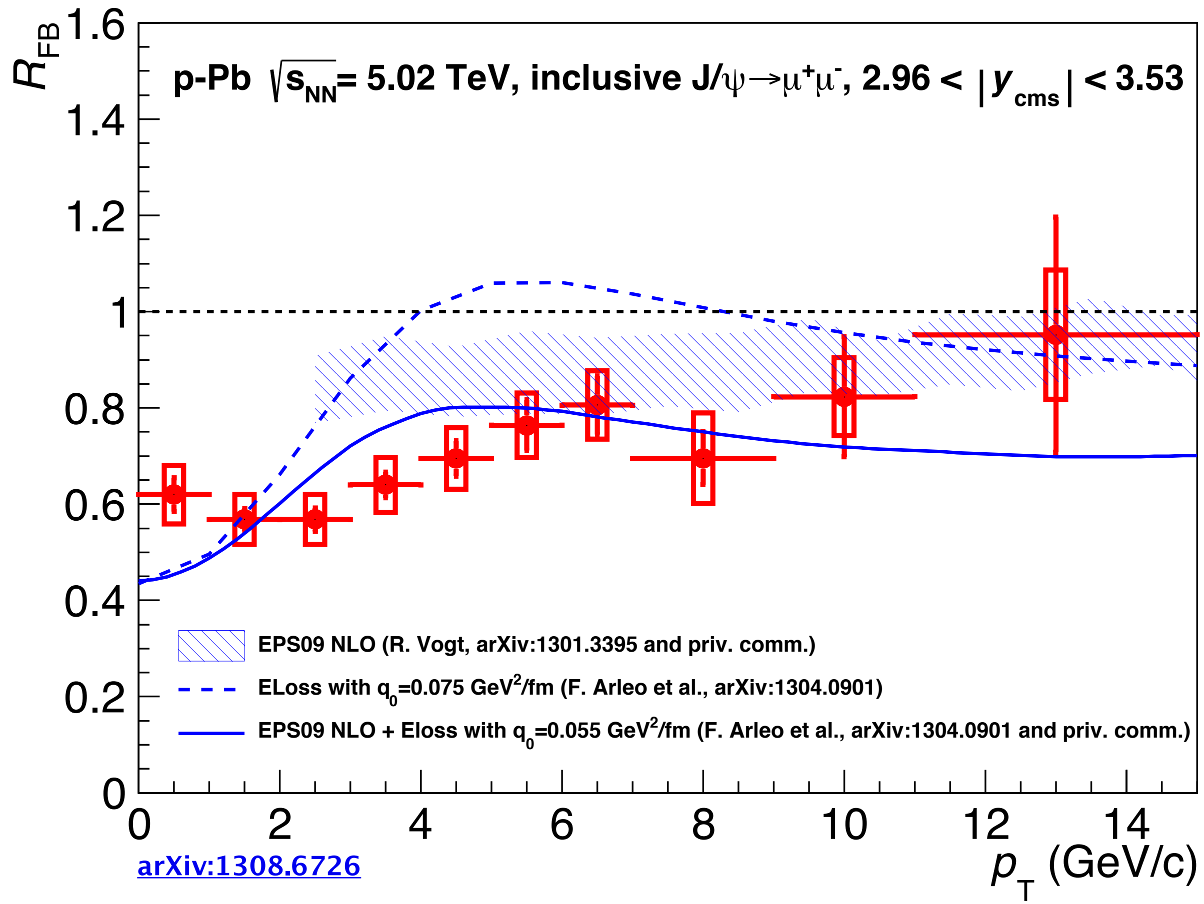
models w/ pure shadowing slightly overestimates the data

model including energy loss contribution shows good agreement with the data

(caveat: models over/undershooting the data can still get the R_{FB} right...)

R_{FB} y-dependence is flat, while p_T-dependence is not (next slide)

$R_{FB}(p_T)$



arXiv:1308.6726

- stronger suppression at low p_T
  - fairly well reproduced by models including energy loss
- observed p_T-dependence is smoother than expected in coherent energy loss models

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Further ingredients for R_{pPb} measurement

- Nuclear thickness function
  - $\langle T_{pPb} \rangle = 0.0983 \pm 0.0035\ \text{mb}^{-1}$ (from Glauber)
- pp reference : no measurement at the required energy, so need to **interpolate**
  - 2 steps procedure :
    - energy interpolation (for each y bin)
      - » using own available results for pp at 2.76 and 7 TeV ($2.5 < y_{cms} < 4.0$)
      - » 3 empirical shapes : linear, power law, exponential
    - rapidity extrapolation
      - » due to the Δy=0.465 shift, cannot directly use the above interpolations
      - » dσ/dy fitted by various shapes (gaussian, polynomials) to reach the required y ranges
  - cross-checked with CEM and FONLL models

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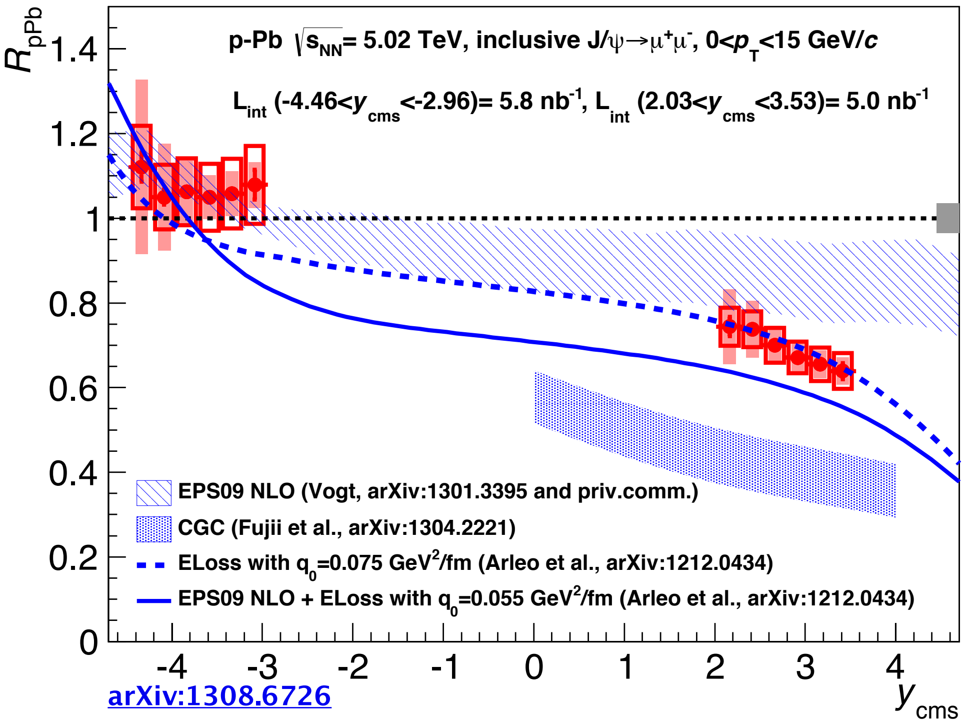
R_{pPb} and R_{Pbp} vs rapidity

$$R_{pPb} = \frac{N_{J/\psi\to\mu^+\mu^-}}{\sigma_{pp}^{J/\psi} \times \langle T_{pPb}\rangle \times N_{MB} \times Acc \times Eff \times BR_{J/\psi\to\mu^+\mu^-}}$$



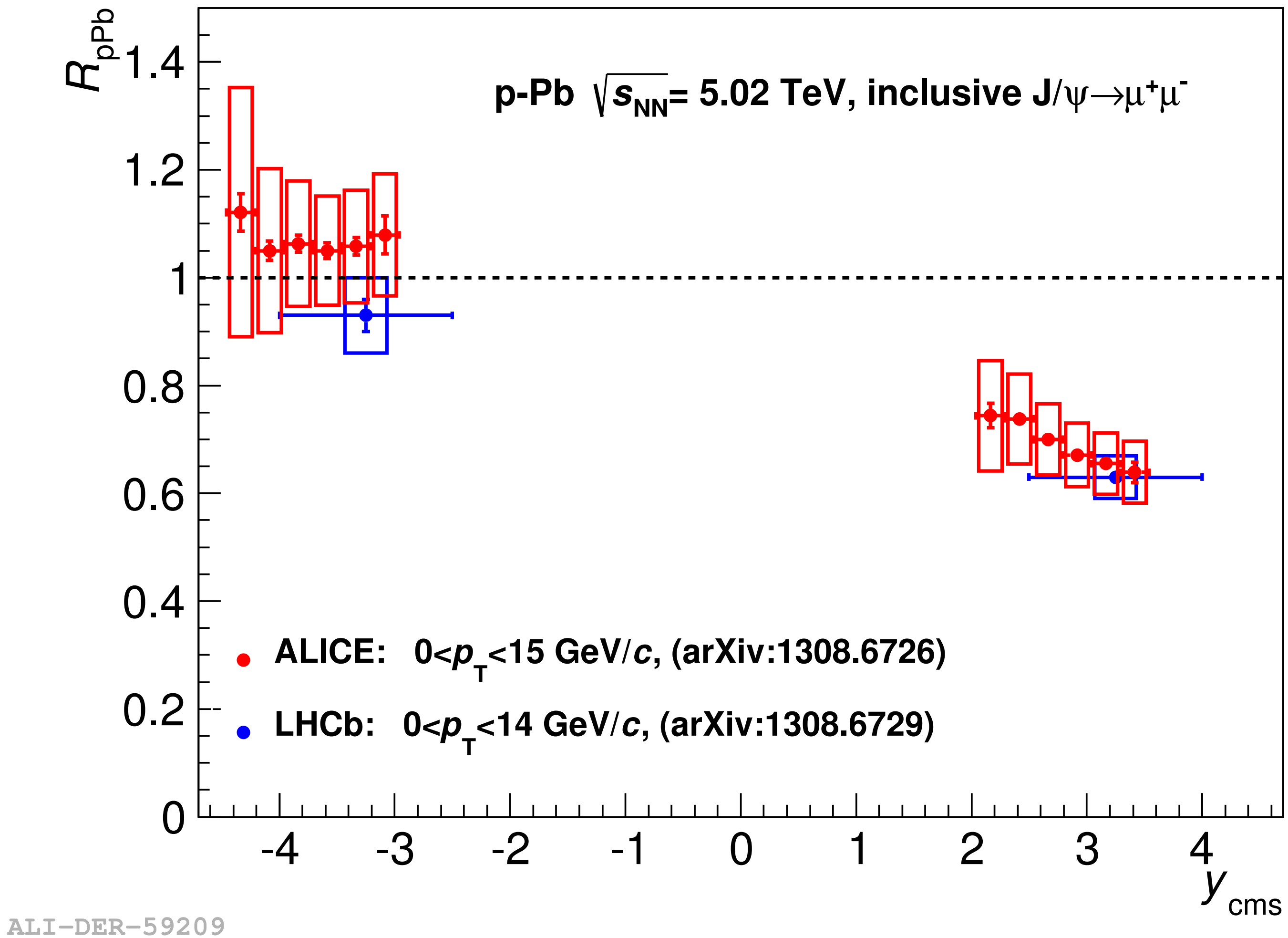
arXiv:1308.6726

Source of syst. unc.	syst. unc.
Signal extraction	1-4%
Acc x Eff	5-7%
N_{MB}	1 %
$\langle T_{pPb}\rangle$	3.4%
σ_{pp}	**5-18%**

- Suppression at forward y
- No suppression at backward y

- At forward *y* data in between shadowing and energy loss models
- At backward *y* models including coherent parton energy loss show a slightly steeper pattern than the observed one
- Color Glass Condensate model (Fuji et al., forward *y* only) overestimates the suppression

ALICE vs LHCb : R_{pPb}



In this plot all systematic uncertainties are quadratically summed up

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Conclusions

- R_{FB} shows a clear p_T dependence with a decrease at low p_T
  - in qualitative agreement with models including coherent energy loss contribution
- R_{pPb} show an increase of suppression towards forward rapidity
  - in agreement with energy loss model and/or shadowing model EPS09 NLO
- No suppression at backward rapidities

Thank you for your attention

BACKUPS

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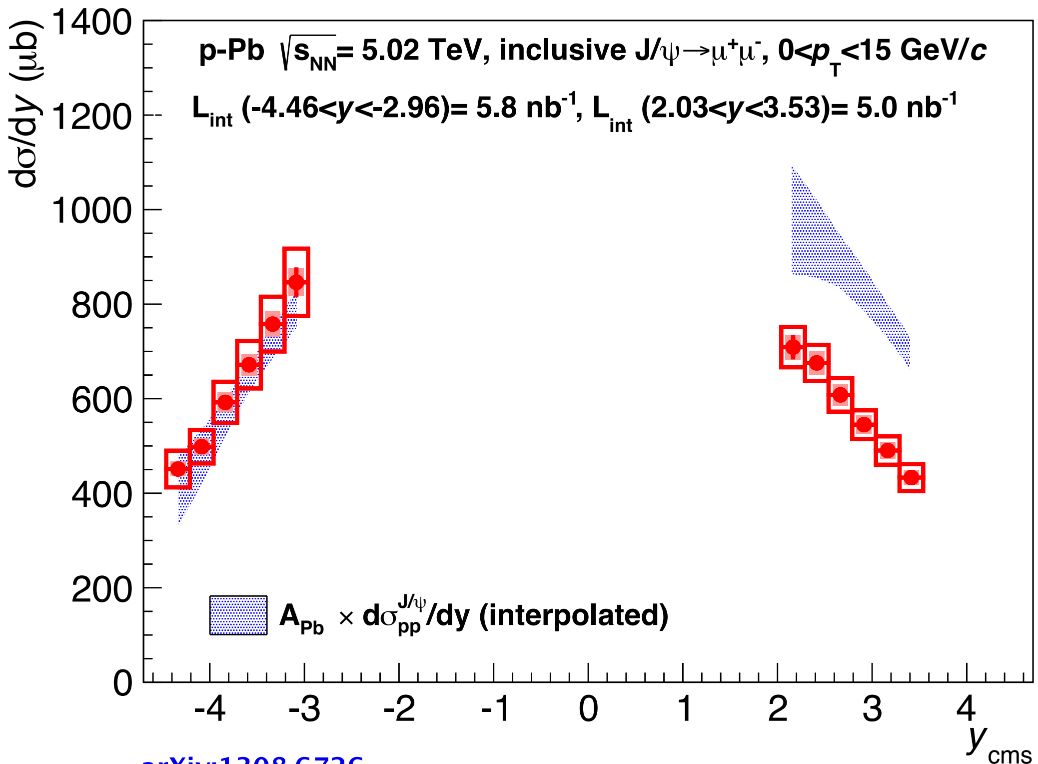
Cross-section vs rapidity in p-Pb vs pp interpolation



arXiv:1308.6726

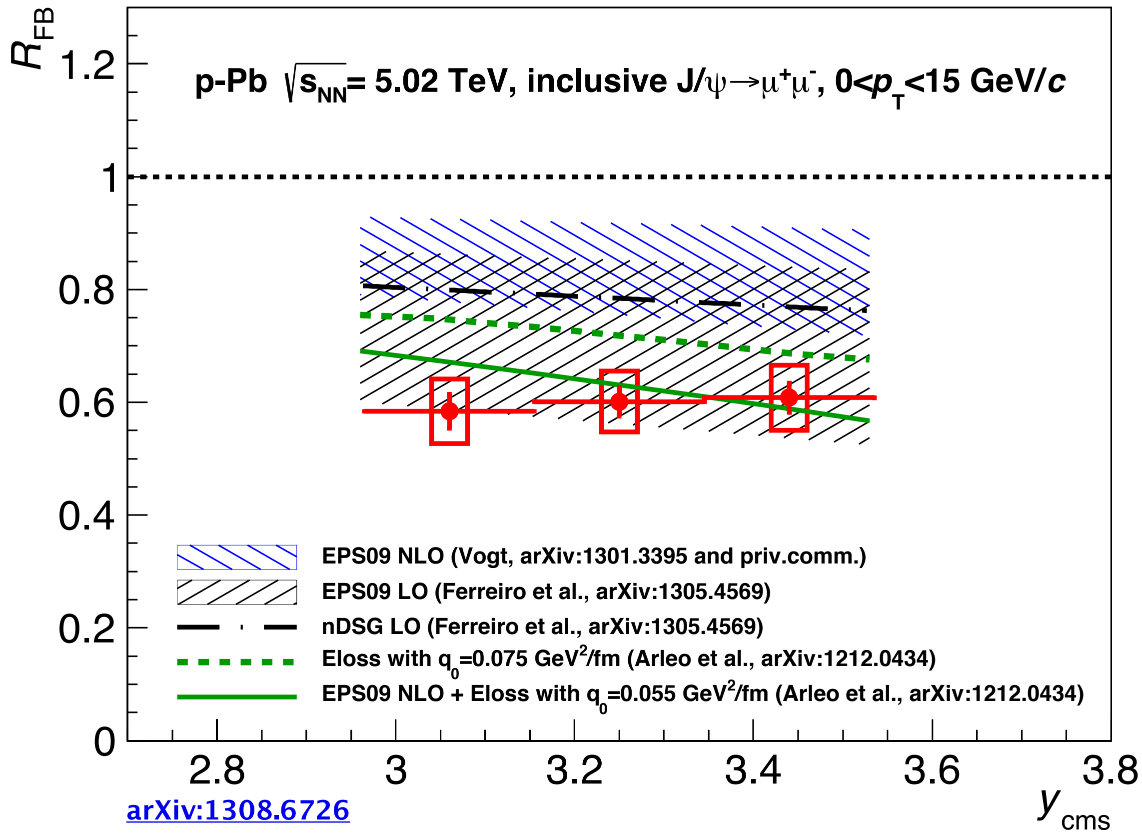
uncorrelated uncertainties : matching, trigger eff, tracking eff, acc. inputs, signal extraction

(partially) correlated uncertainties : luminosity, normalization factor, BR

statistical uncertainties

Suppression at forward rapidities

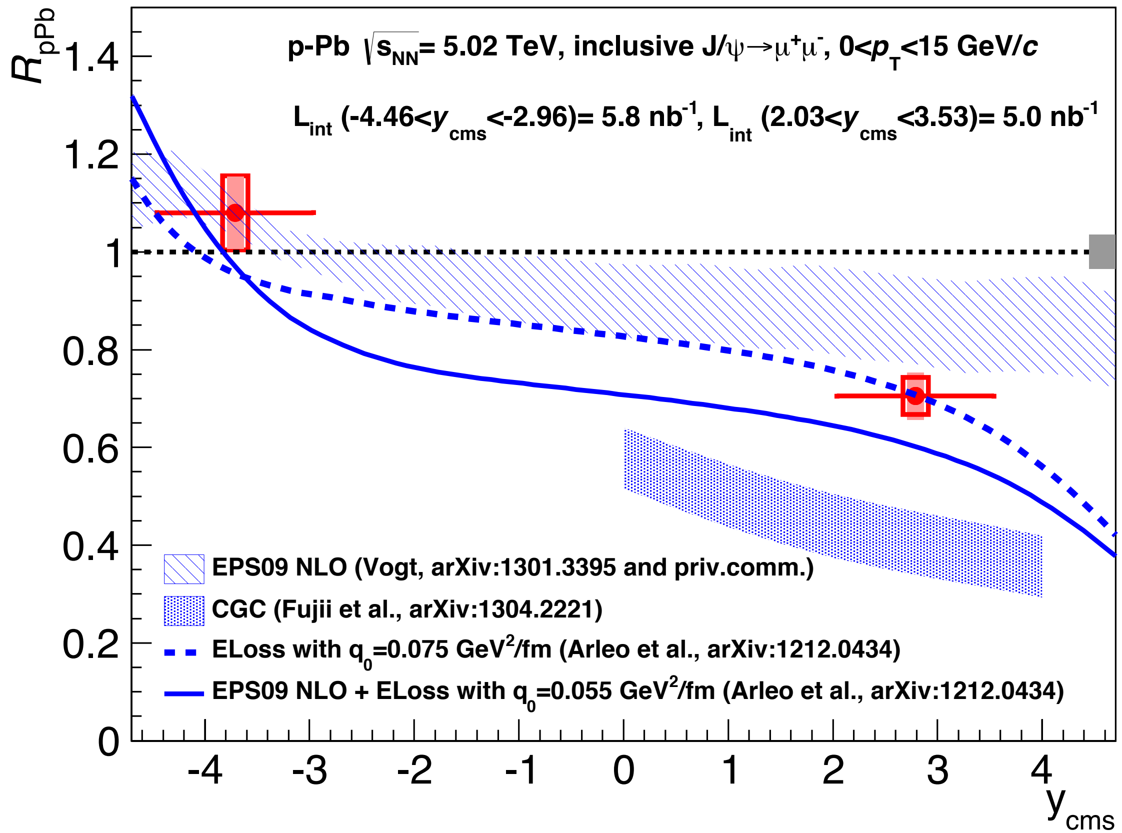
$R_{FB}(y_{cms})$



arXiv:1308.6726

- No dependence of R_{FB} on rapidity
- Calculations including both shadowing and energy loss seems consistent with data

Integrated R_{pPb}



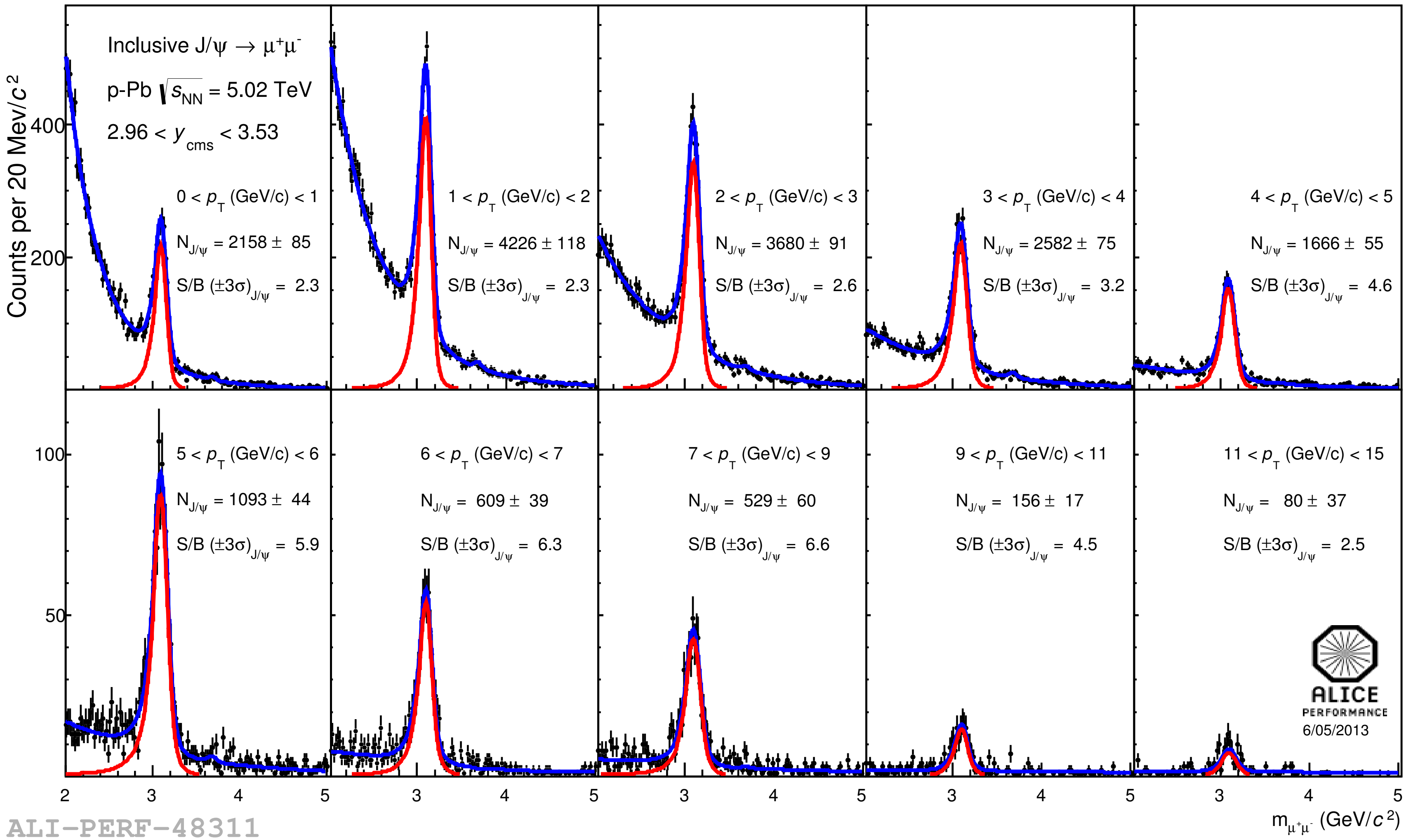
2.03<y<3.53

0.70 ± 0.01 (stat.) ± 0.04 (syst.uncorr.) ± 0.03 (syst.part.corr.) ± 0.03 (syst.corr.)

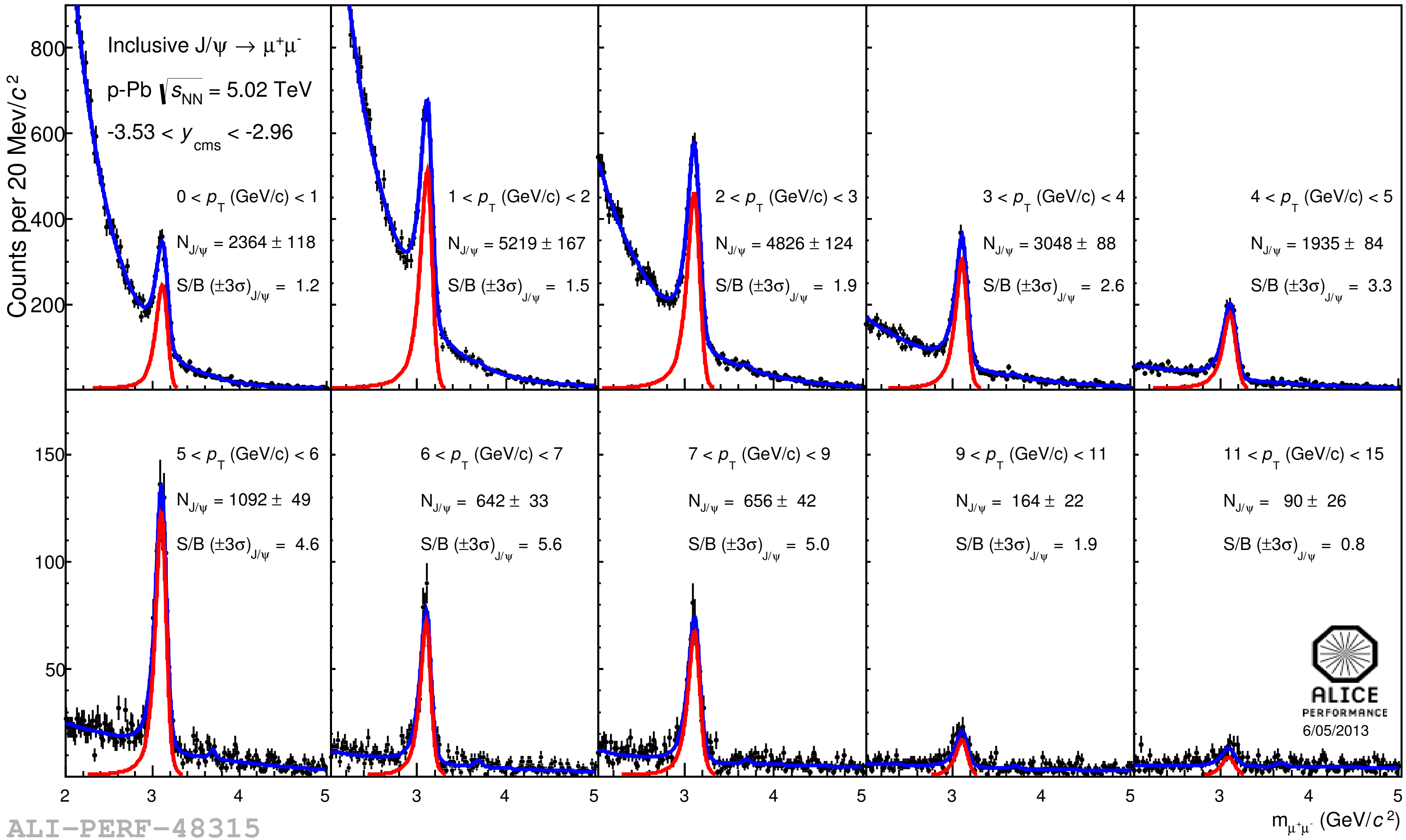
-4.46<y<-2.96

1.08 ± 0.01 (stat.) ± 0.08 (syst.uncorr.) ± 0.07 (syst.part.corr.) ± 0.04 (syst.corr.)

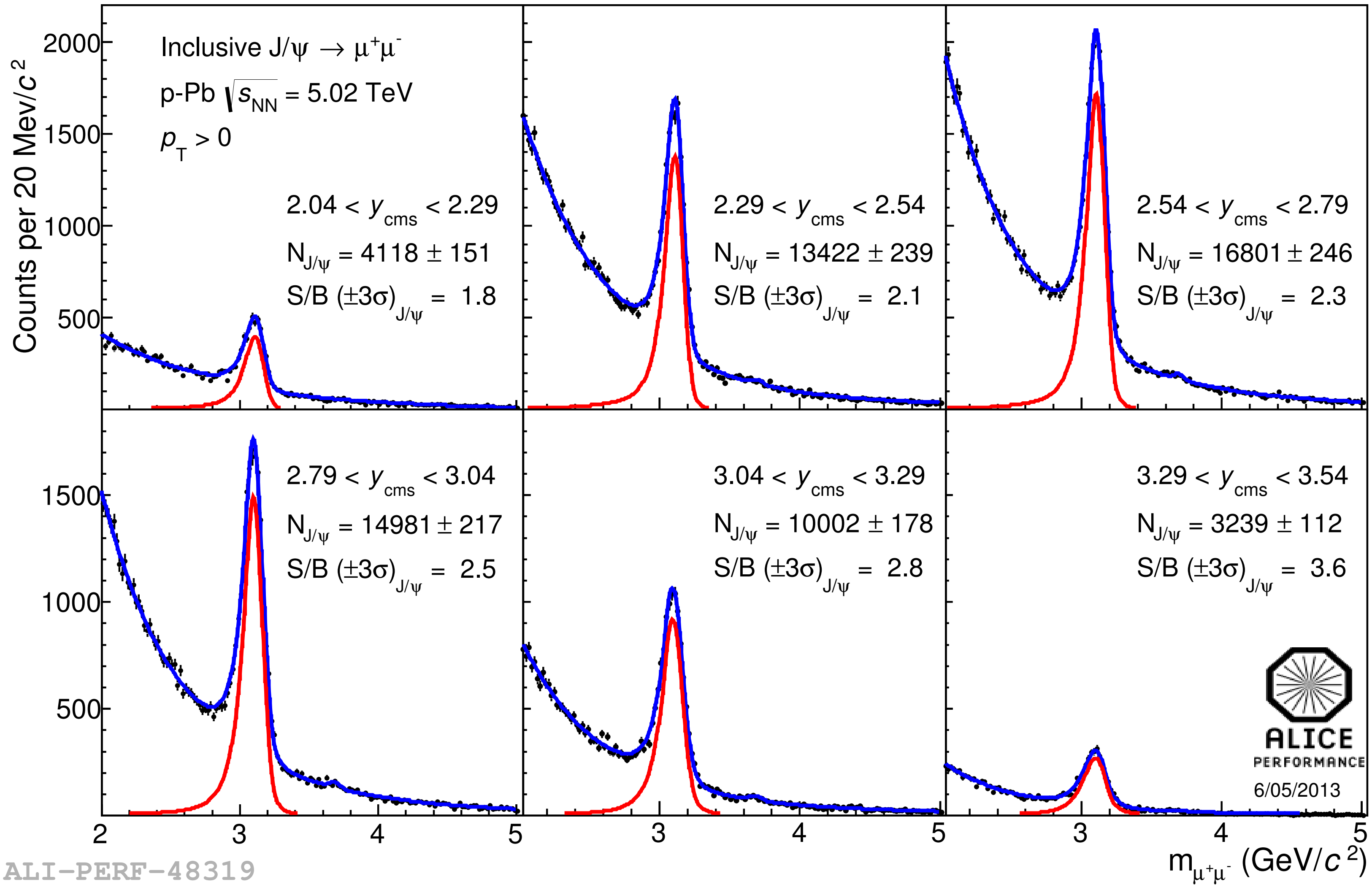
Signal extraction in different p_T bins (p-Pb)



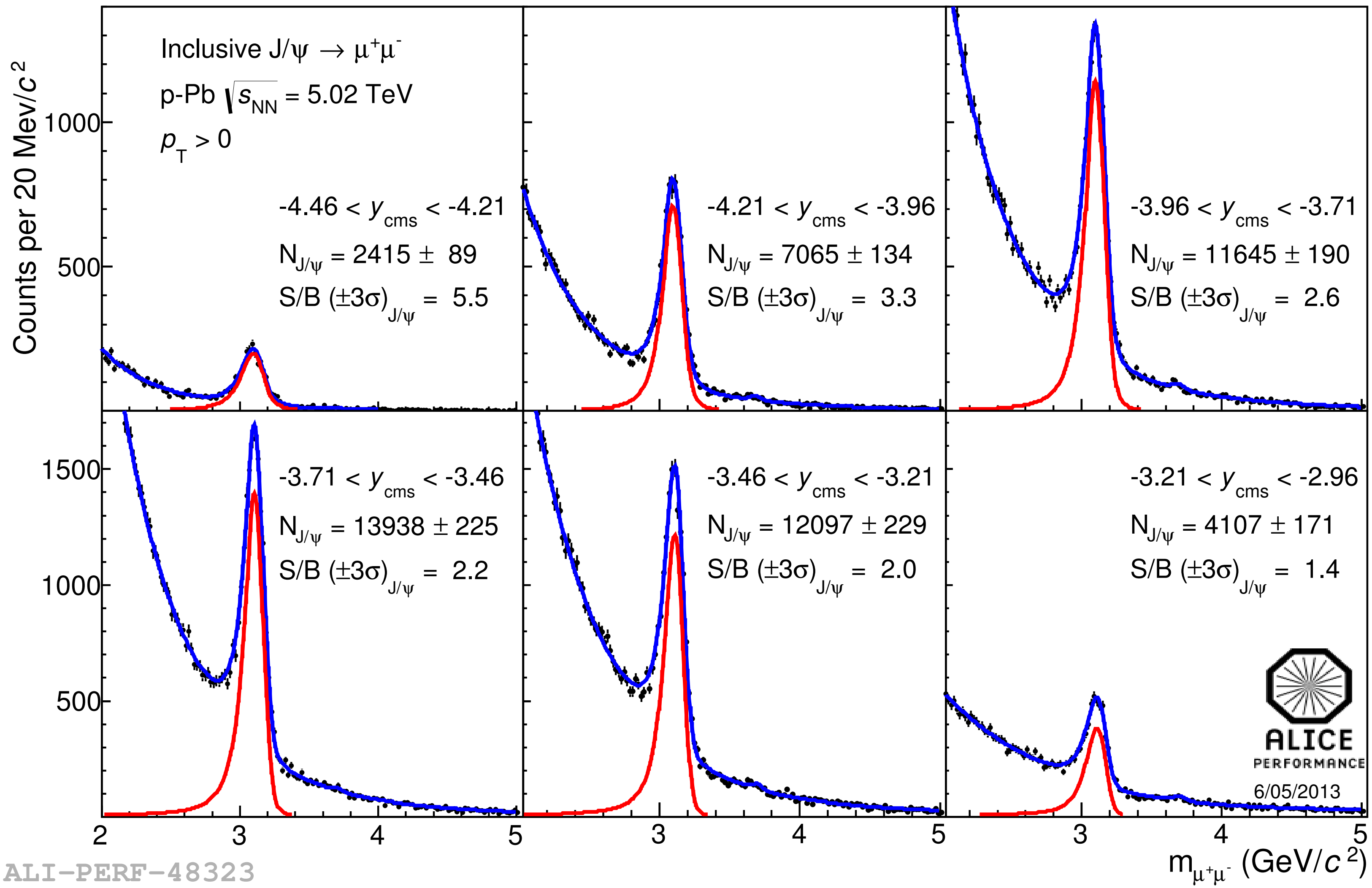
Signal extraction in different p_T bins (Pb-p)



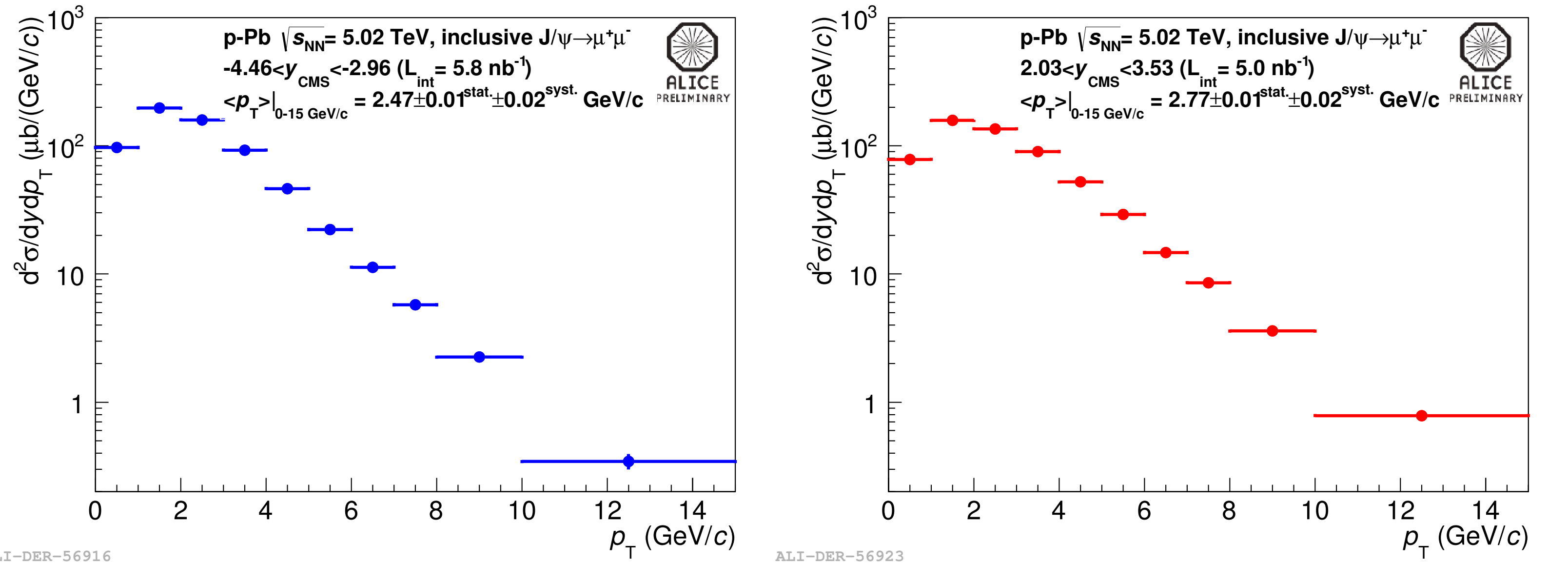
Signal extraction in different *y* bins (p-Pb)



Signal extraction in different *y* bins (Pb-p)

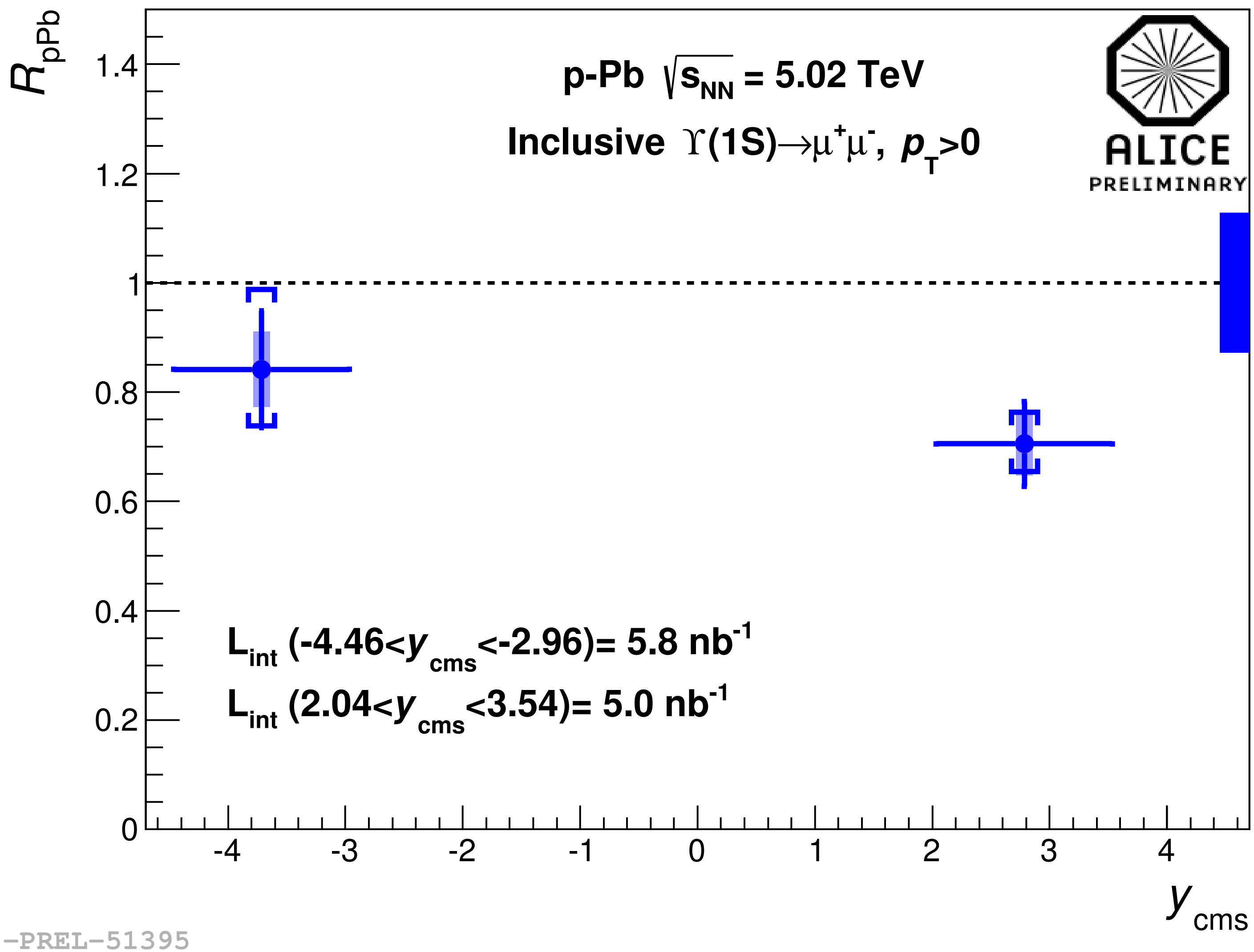


$d^2\sigma/dydp_T$ with $< p_T >$

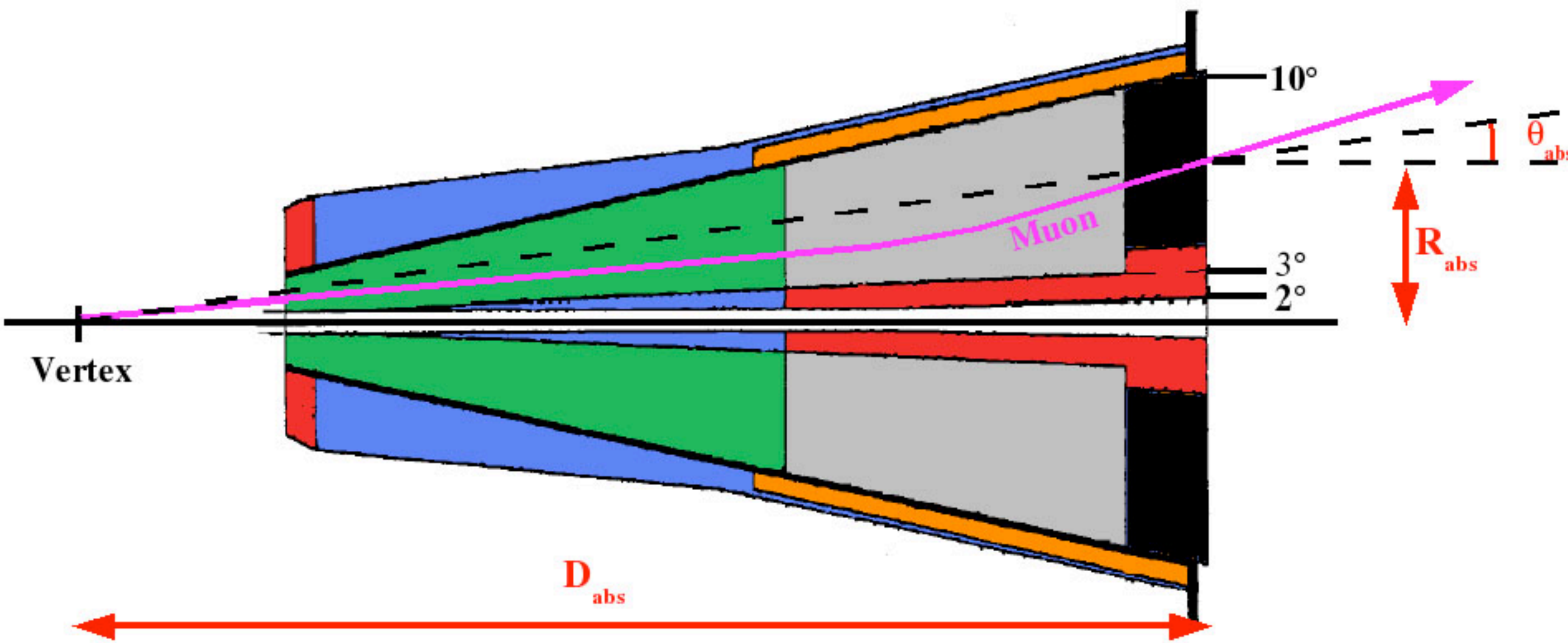


system (energy)	y_{cms}-range	$<p_T>$	$<p_T>$ computation range
pp (2.76 TeV)	2.5 - 4.0	2.28 ± 0.07 ± 0.04	$0 < p_T < 8$ GeV/c
pp (7 TeV)	2.5 - 4.0	2.44 ± 0.09 ± 0.06	$0 < p_T < 8$ GeV/c
Pb-p (5.02 TeV)	-4.46 ; -2.96	2.47 ± 0.01 ± 0.02	$0 < p_T < 15$ GeV/c
Pb-p (5.02 TeV)	**-3.53 ; -2.96 (common range)**	2.56 ± 0.01 ± 0.02	$0 < p_T < 15$ GeV/c
p-Pb (5.02 TeV)	**2.96 ; 3.53 (common range)**	2.71 ± 0.01 ± 0.02	$0 < p_T < 15$ GeV/c
p-Pb (5.02 TeV)	2.5 - 4.0	2.77 ± 0.01 ± 0.02	$0 < p_T < 15$ GeV/c

Upsilon R_{pPb}



Muon absorber



- Tungsten
- Lead
- Graphite
- Concrete
- Poly CH_2 borated 15%
- Steel

Signal shape functions formulas

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Extended Crystal Ball

$$f(m) = N \times \begin{cases} \exp\left(-\frac{(m-\overline{m})^2}{2\sigma^2}\right), & \text{for } \frac{(m-\overline{m})}{\sigma} > -\alpha \\ A\left(B - \frac{m-\overline{m}}{\sigma}\right)^{-n}, & \text{for } \frac{(m-\overline{m})}{\sigma} \leq -\alpha \\ C\left(D + \frac{m-\overline{m}}{\sigma}\right)^{-n'}, & \text{for } \frac{(m-\overline{m})}{\sigma} \geq -\alpha' \end{cases}$$

$$\begin{aligned} A &= \left(\frac{n}{|\alpha|}\right)^{n} \exp\left(-\frac{|\alpha|^2}{2}\right) \\ B &= \frac{n}{|\alpha|} - |\alpha| \\ C &= \left(\frac{n'}{|\alpha'|}\right)^{n'} \exp\left(-\frac{|\alpha'|^2}{2}\right) \\ D &= \frac{n'}{|\alpha'|} - |\alpha'| \end{aligned}$$

NA60 function

$$f(m) = N \times \exp\left(-\frac{(m-\overline{m})^2}{2\sigma_{NA60}^2}\right)$$

$$\sigma_{NA60} = \begin{cases} \sigma\left(1 + p_1(m_1 - m)^{p_2 - p_3\sqrt{m_1 - m}}\right), & \text{for } m < m_1 \\ \sigma, & \text{for } m_1 \leq m < m_2 \\ \sigma\left(1 + p_4(m - m_2)^{p_5 - p_6\sqrt{m - m_2}}\right), & \text{for } m \geq m_2 \end{cases}$$

N,σ (J/Ψ width), m (J/Ψ mass) are left free when fitting the data
all other parameters are fixed on tuned MC

Interpolation : preliminary vs paper

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Preliminary results (based on a different interpolation method)

$$BR \times \sigma_{pp}^{J/\psi} (2.03 < y_{cms} < 3.53) = 346^{+61(syst.)}_{-48(syst.)} \text{ nb}$$

$$BR \times \sigma_{pp}^{J/\psi} (-4.46 < y_{cms} < -2.96) = 238^{+60(syst.)}_{-40(syst.)} \text{ nb}$$

+5.5%

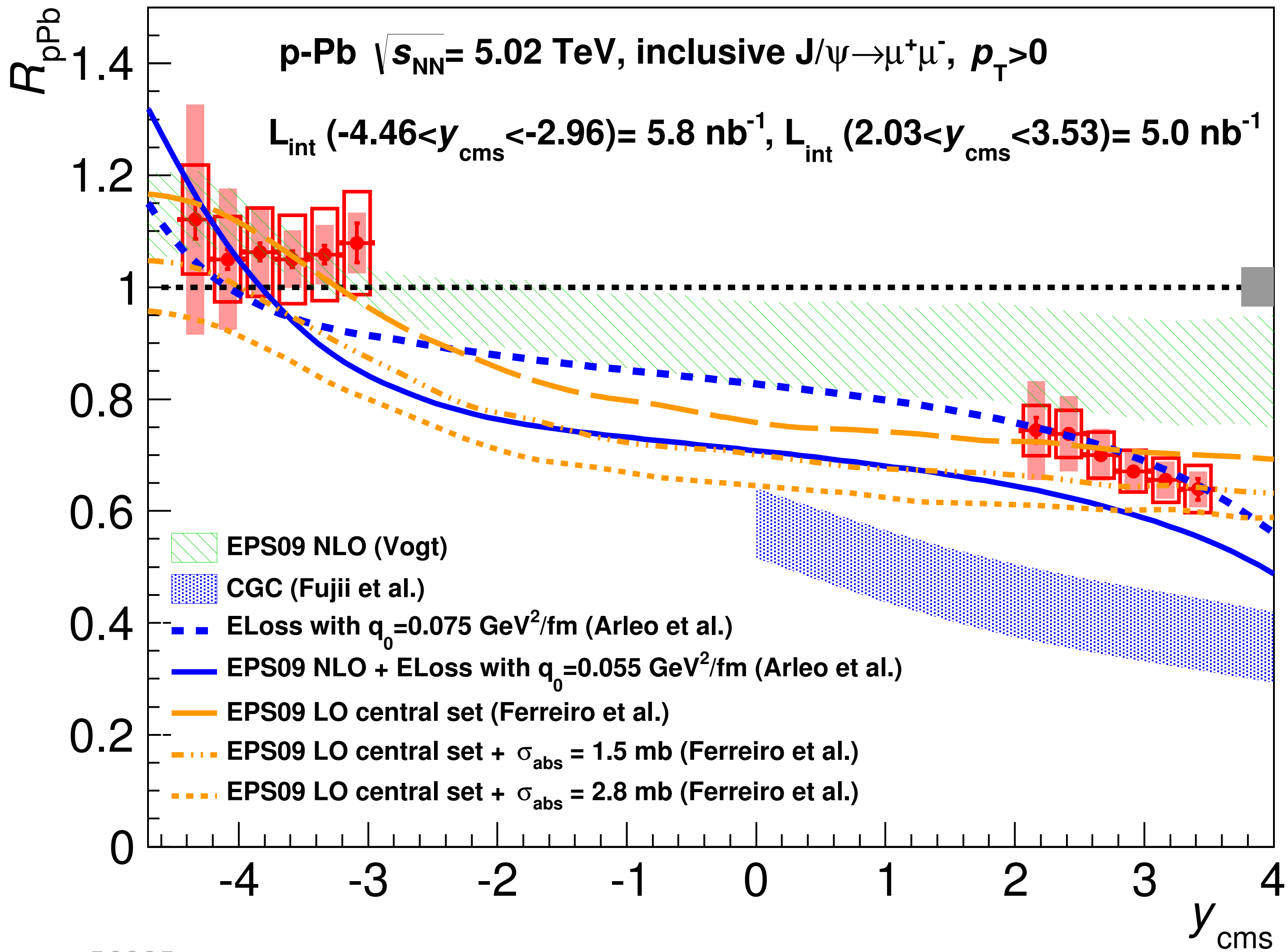
Paper results (this talk)

+7%

$$BR \times \sigma_{pp}^{J/\psi} (2.03 < y_{cms} < 3.53) = 366 \pm 24 \text{ nb}$$

$$BR \times \sigma_{pp}^{J/\psi} (-4.46 < y_{cms} < -2.96) = 255 \pm 16 \text{ nb}$$

J/ψ R_{pPb} and R_{Pbp} in *y* bins compared to models



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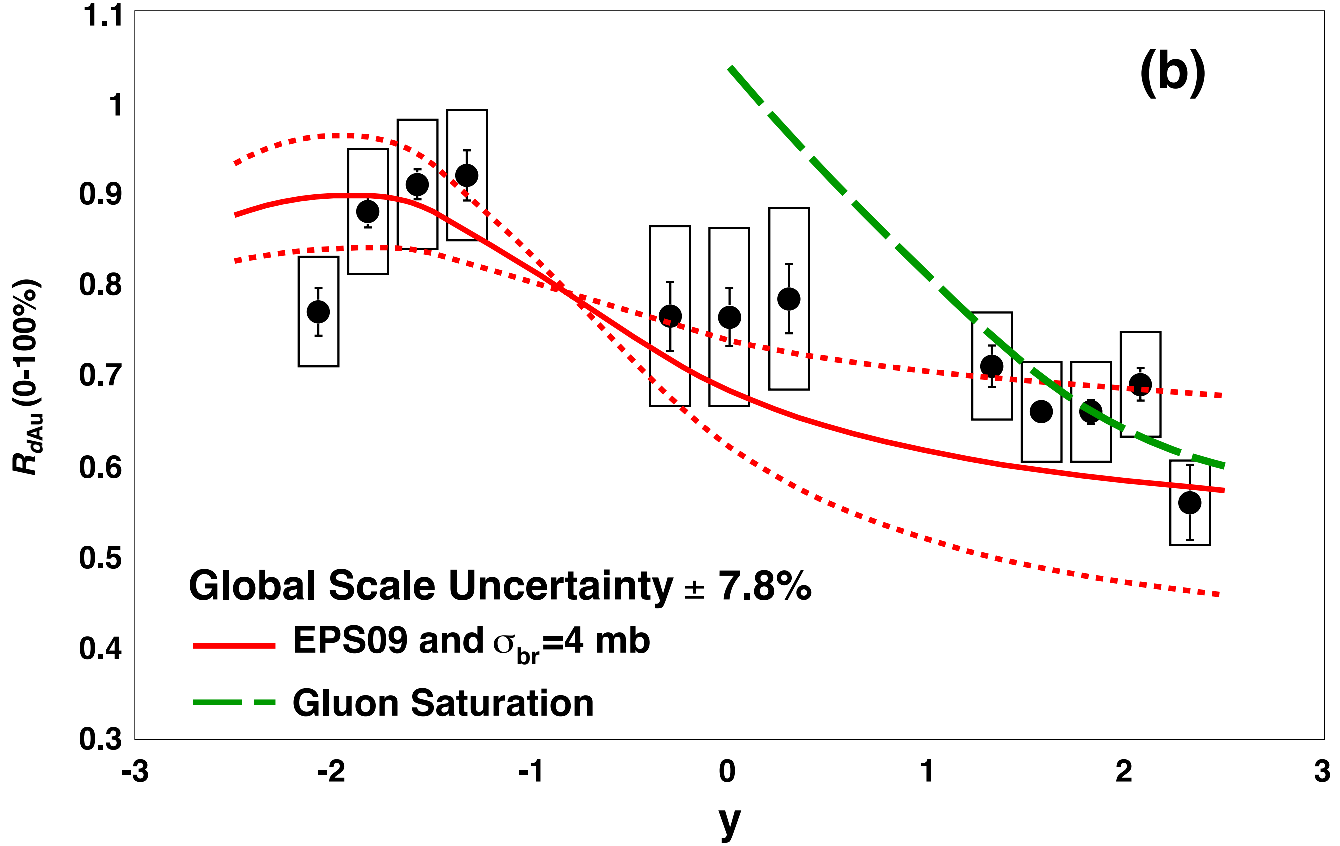
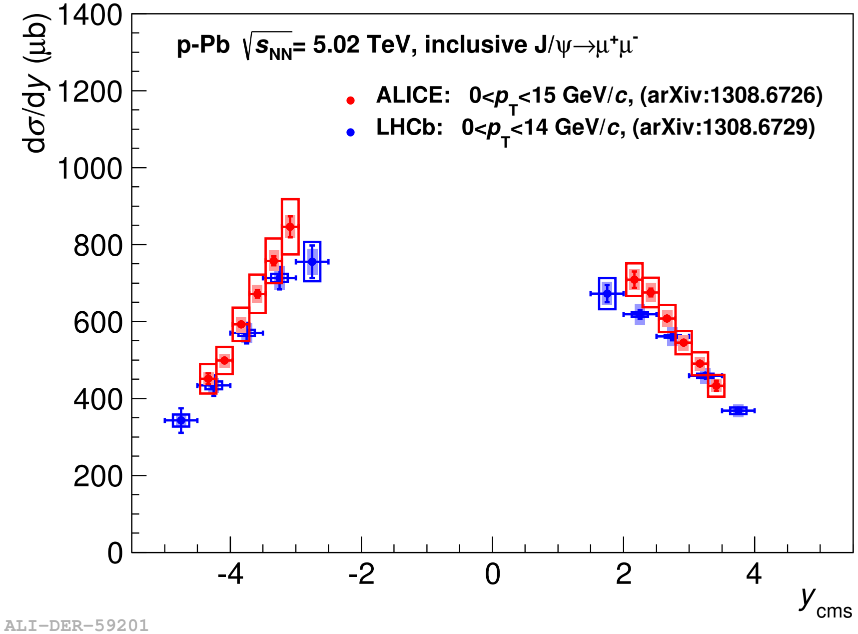
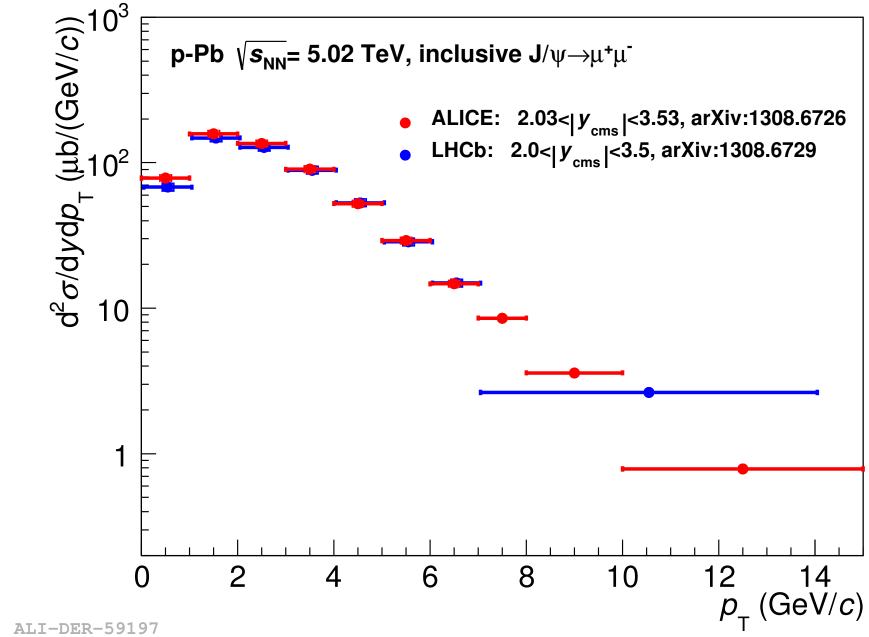
PHENIX data



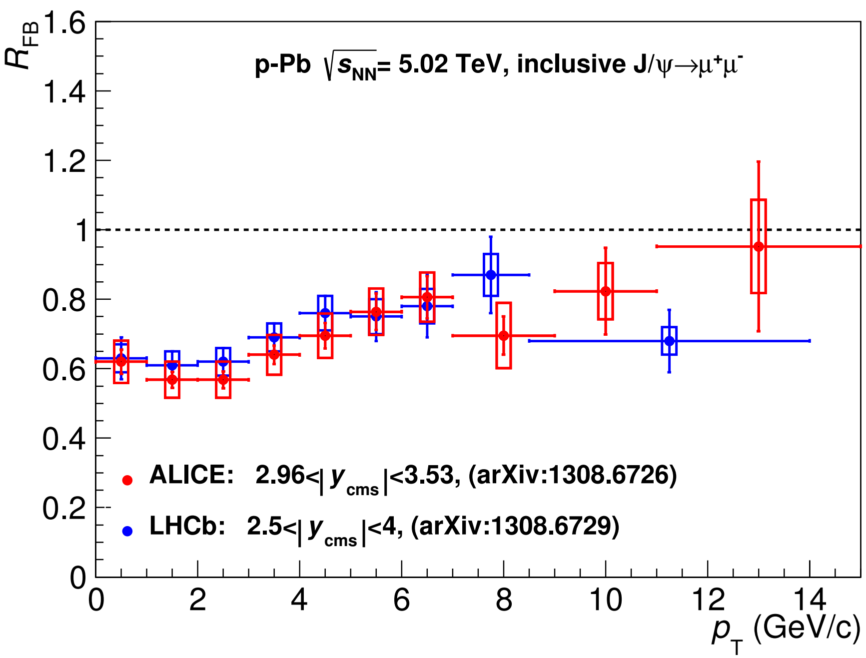
From PRL **107**, 142301 (2011) (Fig.1)

ALICE vs LHCb : cross-sections





ALICE vs LHCb : R_{FB}



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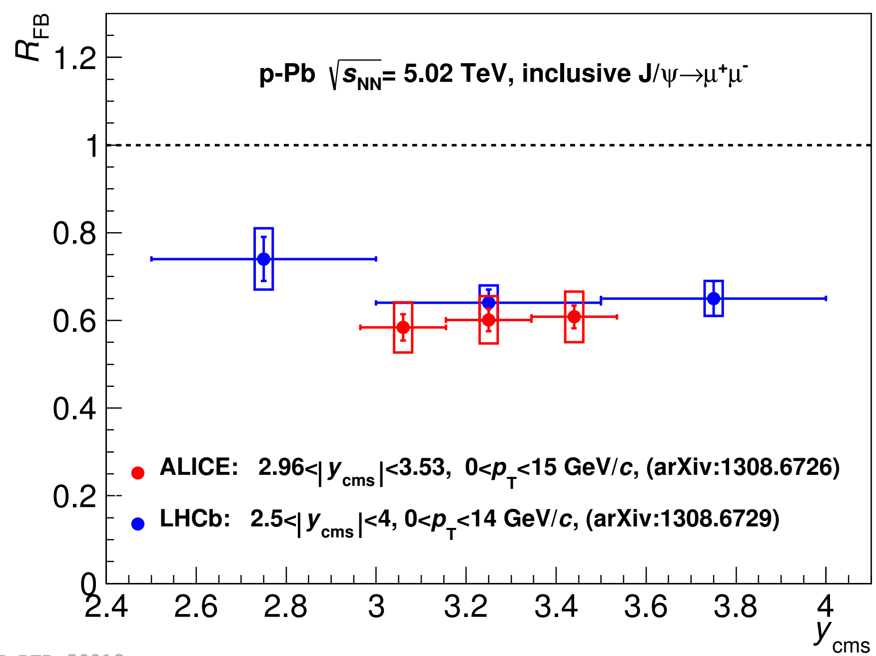

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ALICE vs LHCb : R_{pPb}