Quarkonium production in p-Pb collisions with ALICE at the LHC

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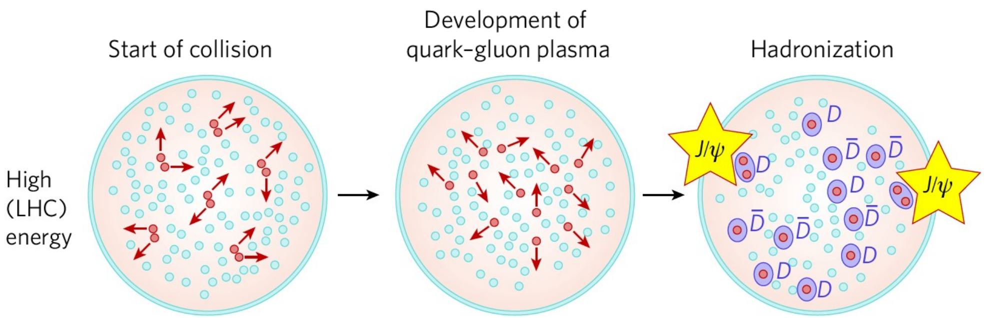
28.08.2015
Wuhan 2015

Charmonium in nucleus-nucleus collisions

J/ψ suppression via colour screening suggested as a probe of deconfinement in heavy-ion collisions in 1986
T. Matsui and H. Satz, Phys.Lett.B 178 (1986) link: DOI: 10.1016/0370-2693(86)91404-8

LHC energies: production from deconfined charm quarks as consequence of deconfinement in AA collisions

- J/ψ production at phase boundary
P. Braun-Munzinger and J. Stachel, Phys.Lett.B, 490 (2000) link: arXiv:0007059



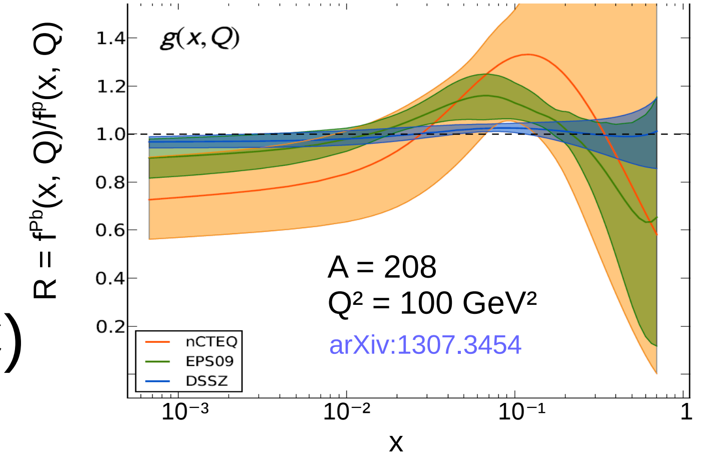
P. Braun-Munzinger and J.Stachel, Nature 448 (2007)

- J/ψ production and destruction during lifetime of deconfined phase

R. L. Thews, M. Schroeder, J. Rafelski, Phys.Rev.C, 63 (2001) link:arXiv:0007323

For interpretation: pA needed as ingredient for non-QGP nuclear effects

Predicted modifications in p-Pb at the LHC



leading twist gluon shadowing

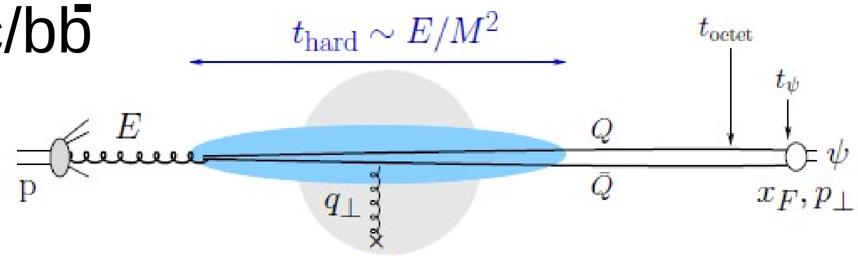
Color Evaporation Model (CEM) R. Vogt, , link: arXiv:1003.3497 Phys.Rev.C 81 (2010)
Color Singlet Model (CSM) E. Ferreiro et al., link: arXiv:1305.4569 Phys.Rev.C 88 (2013)

saturation via Colour Glass Condensate (CGC)

CEM: H. Fujii et al., arXiv:1304.2221 Nucl.Phys. A915 (2013),
NRQCD: Ma Yan-Qing et al., link: arXiv:1503.07772

coherent energy loss of pre-resonant $c\bar{c}$/$b\bar{b}$

Arleo et al., link: arXiv:1212.0434 JHEP 1303 (2013)



JHEP 1303 (2013)

charm shadowing & dipole break-up

Kopeliovich et al., link: arXiv:1012.5648 Nucl. Phys.A 864 (2011)

comover model

E.G. Ferreiro, link: arXiv:1411.0549

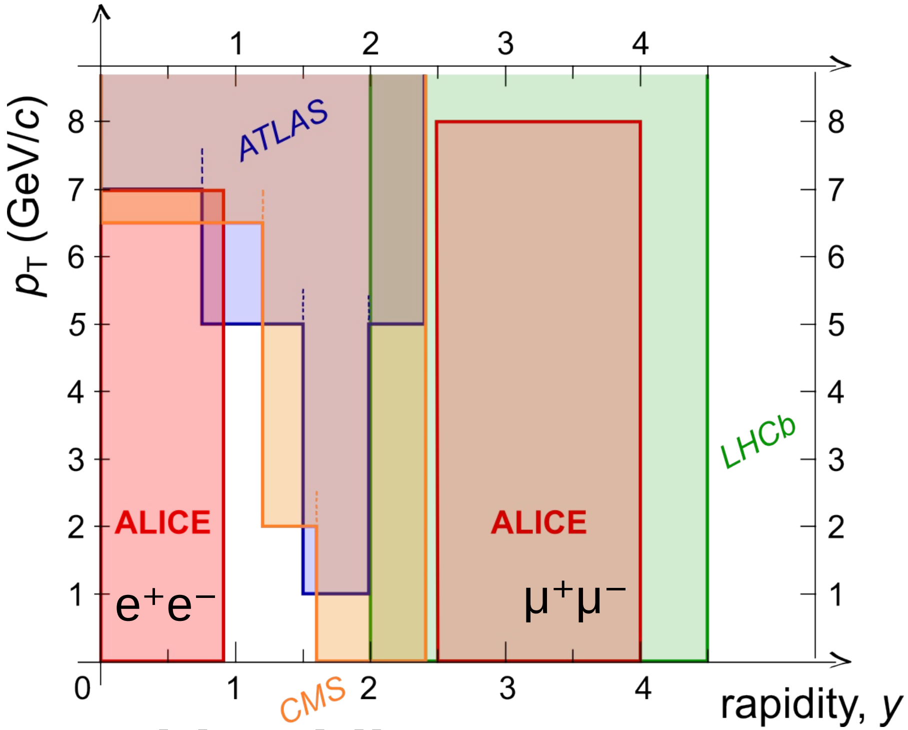
hot medium effects

Y. Liu et al., link: arXiv:1309.5113, Phys. Lett. B 728 (2014))

- negligible/small nuclear absorption expected

Caveats:
- no consensus about pp production mechanism
- besides direct J/ψ: feed-down from B hadrons, ψ(2S) and χ_c

Quarkonium capabilities in p-Pb at the LHC



J/ψ acceptance in first pp collision publications

→ similar reach of experiments in p-Pb collisions

→ all 4 experiments participated in p-Pb data taking

Graphics: courtesy of A. Maire

Midrapidity

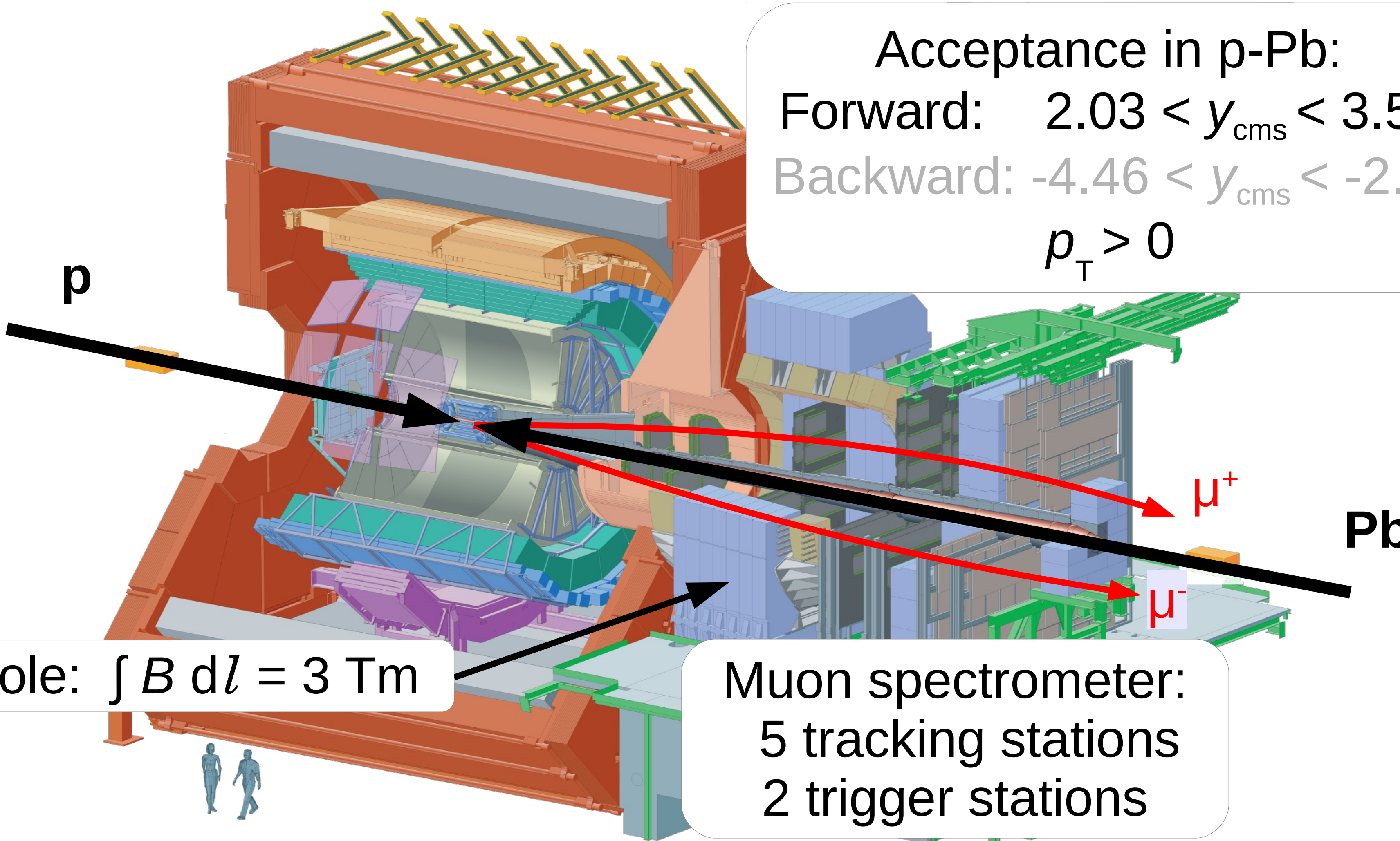
- ATLAS and CMS: J/ψ,ψ(2S) at high-p_T, Υ(1,2S,(3S)) down to 0 p_T
- ALICE: J/ψ down to 0 p_T

Forward rapidity

- LHCb and ALICE: J/ψ, ψ(2S), Υ(1S), Υ(2S) down to 0 p_T

Quarkonium with ALICE at the LHC

Acceptance in p-Pb:
Forward: $2.03 < y_{cms} < 3.53$
Backward: $-4.46 < y_{cms} < -2.96$
$p_T > 0$

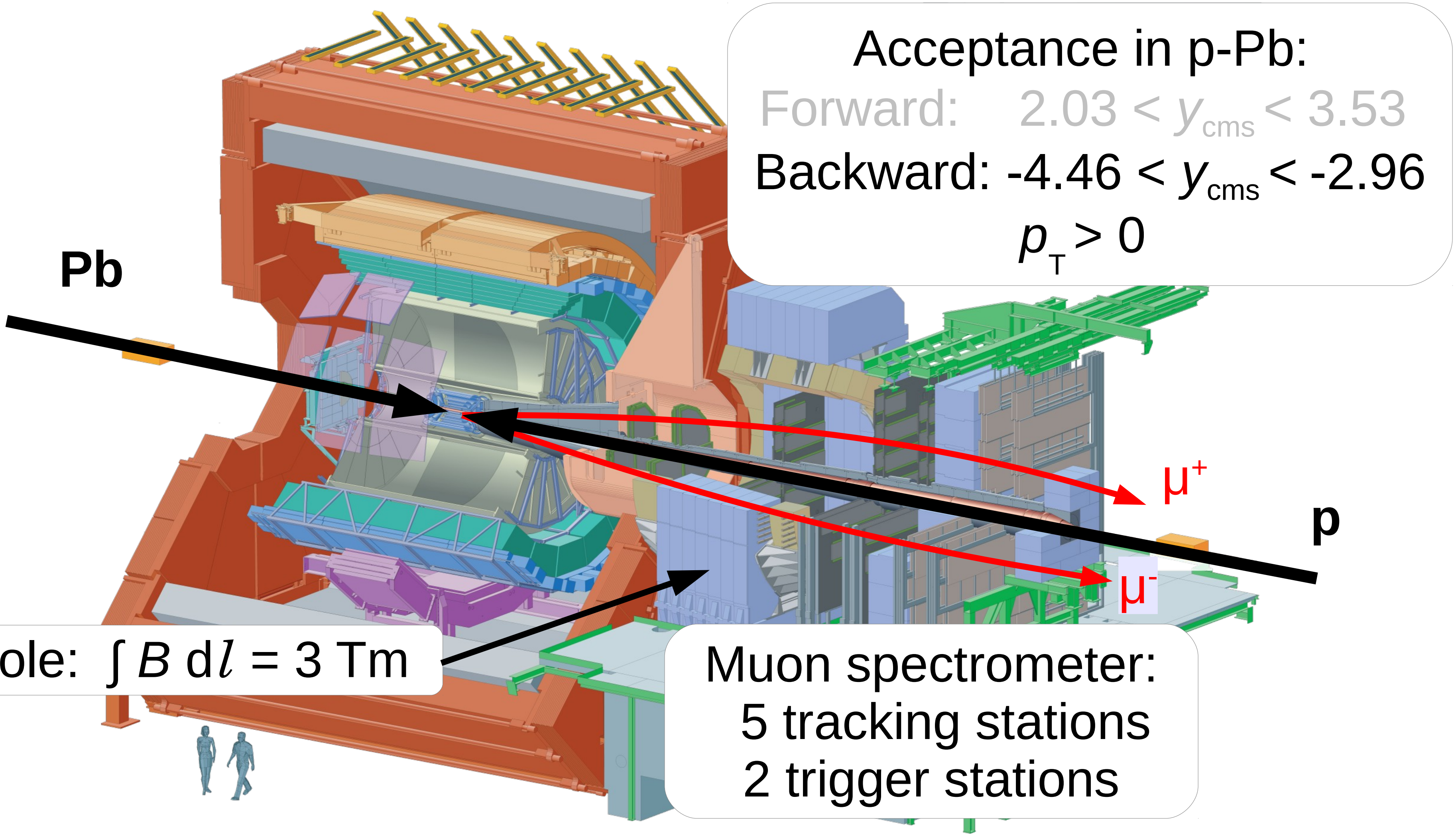


Dipole: $\int B \, \mathrm{d}l = 3$ Tm

Muon spectrometer:
5 tracking stations
2 trigger stations

Inclusive J/ψ, ψ(2S), Υ(1S), Υ(2S) down to $p_T = 0$ GeV/c at forward rapidity
p-Pb: forward and backward rapidity via beam direction inversion

Quarkonium with ALICE at the LHC



Inclusive J/ψ, ψ(2S), Υ(1S), Υ(2S) down to $p_T = 0$ GeV/*c* at forward rapidity

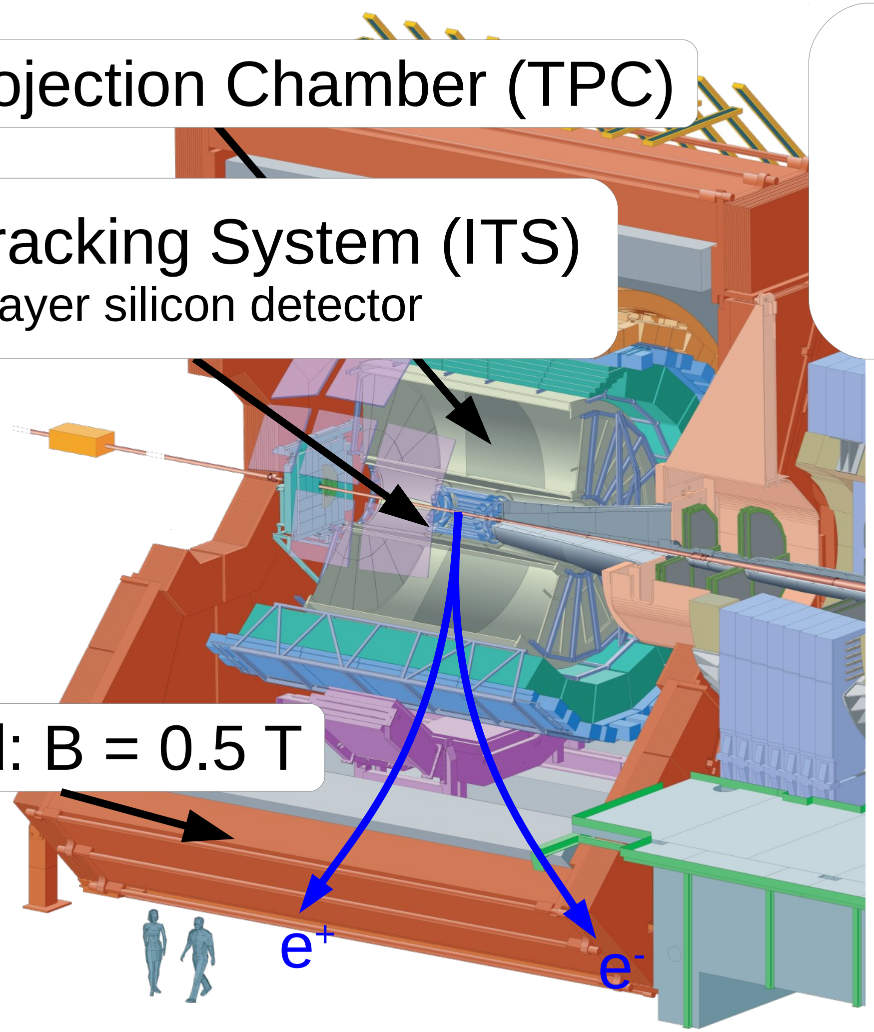
p-Pb: forward and backward rapidity via beam direction inversion

Quarkonium with ALICE at the LHC

Time Projection Chamber (TPC)

Inner Tracking System (ITS)
6 layer silicon detector

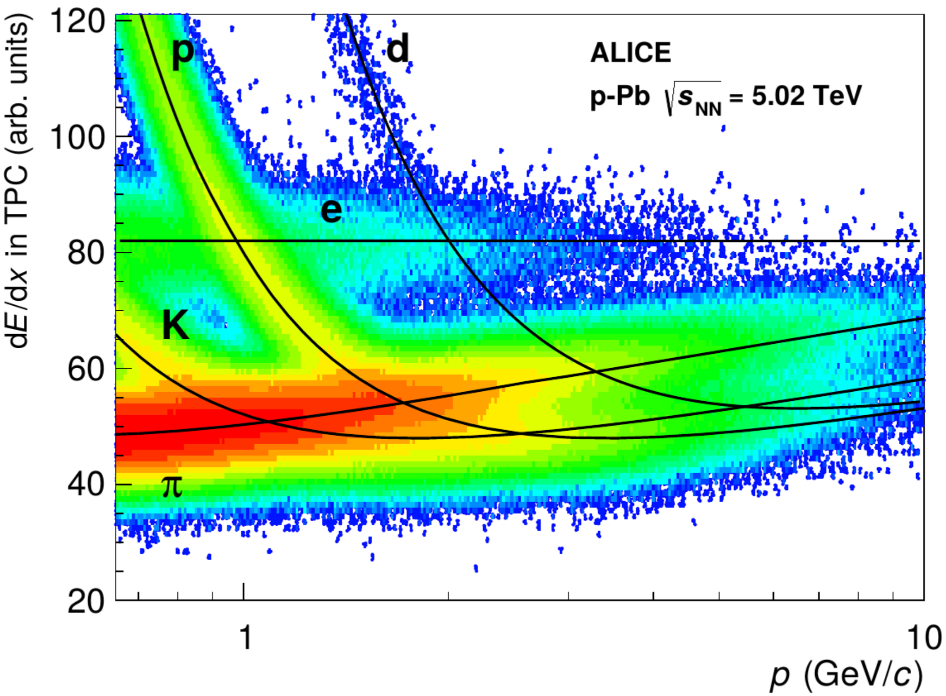
Solenoid: B = 0.5 T



Acceptance in p-Pb:

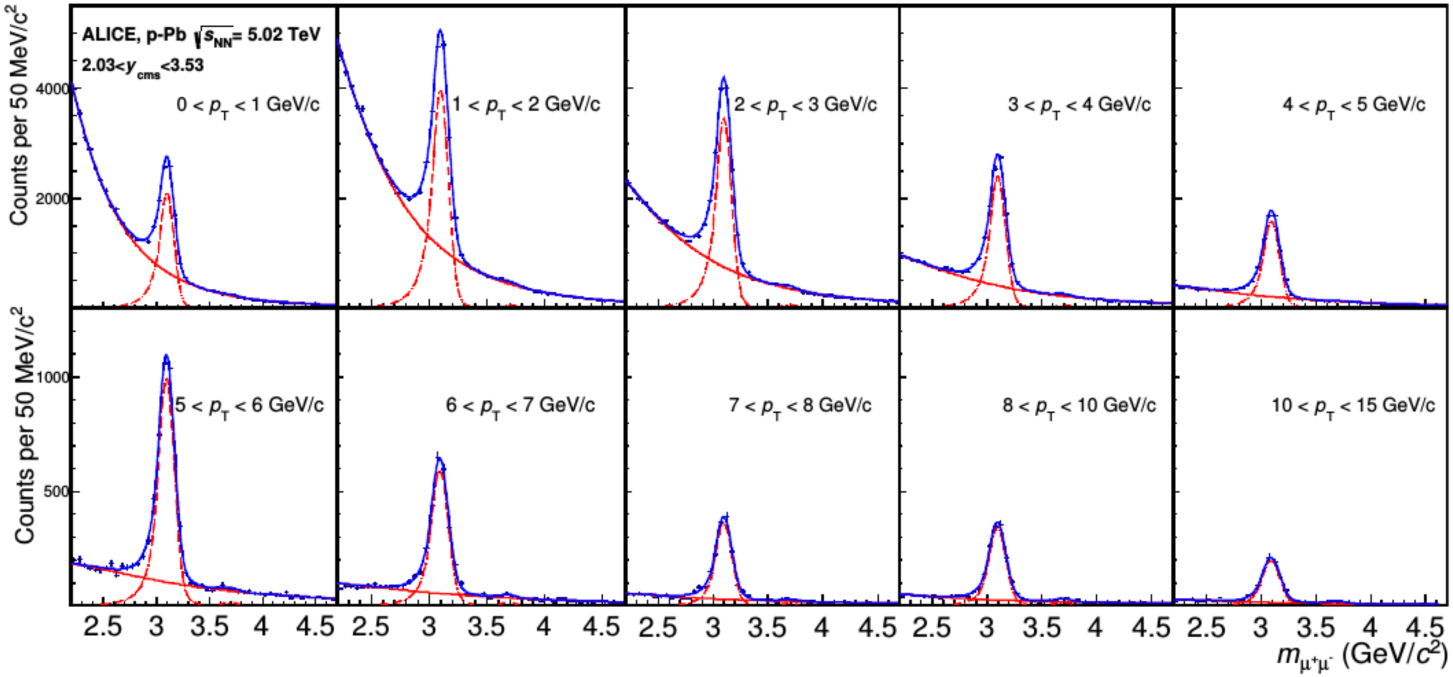
$-1.37 < y_{cms} < 0.43$

$p_T > 0$



Inclusive J/ψ down to p_T= 0 GeV/c at midrapidity

2013 p-Pb run



link: arXiv:1308.6726
JHEP 1402 (2014) 073

link: arXiv:1503.07179
JHEP 1506 (2015) 055

link: arXiv:1506.08808

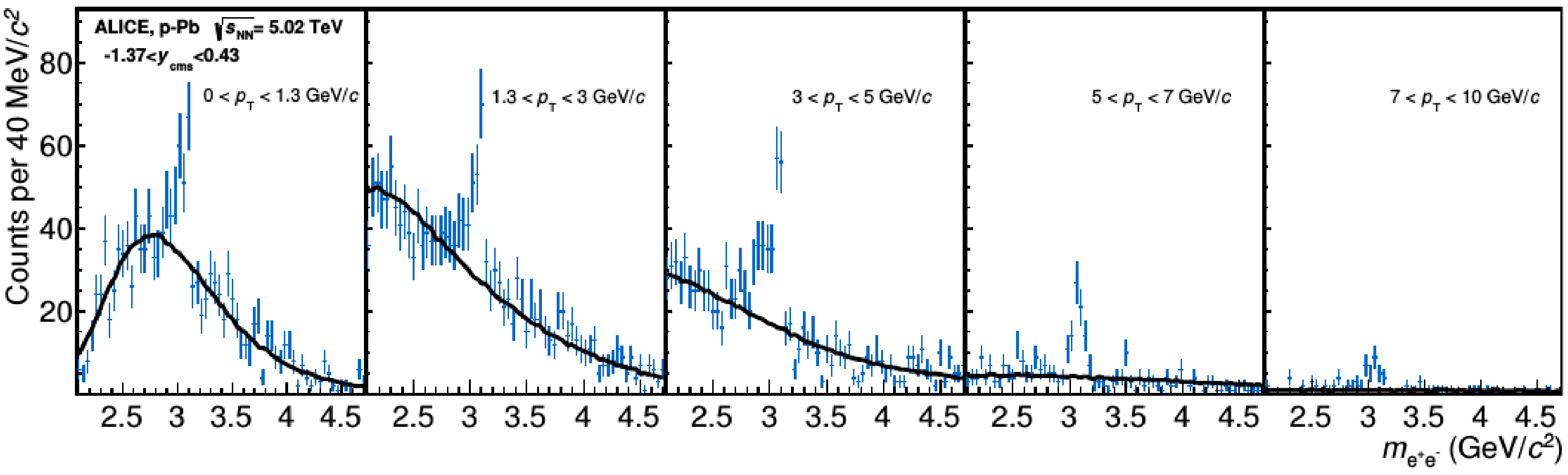
Dimuons: dedicated trigger

L_{int} = 5.0 nb^{-1} (forward)

L_{int} = 5.8 nb^{-1} (backward)

Same bunch pile-up probability: 1-3 %

2013 p-Pb run



Dielectrons at midrapidity: Minimum Bias

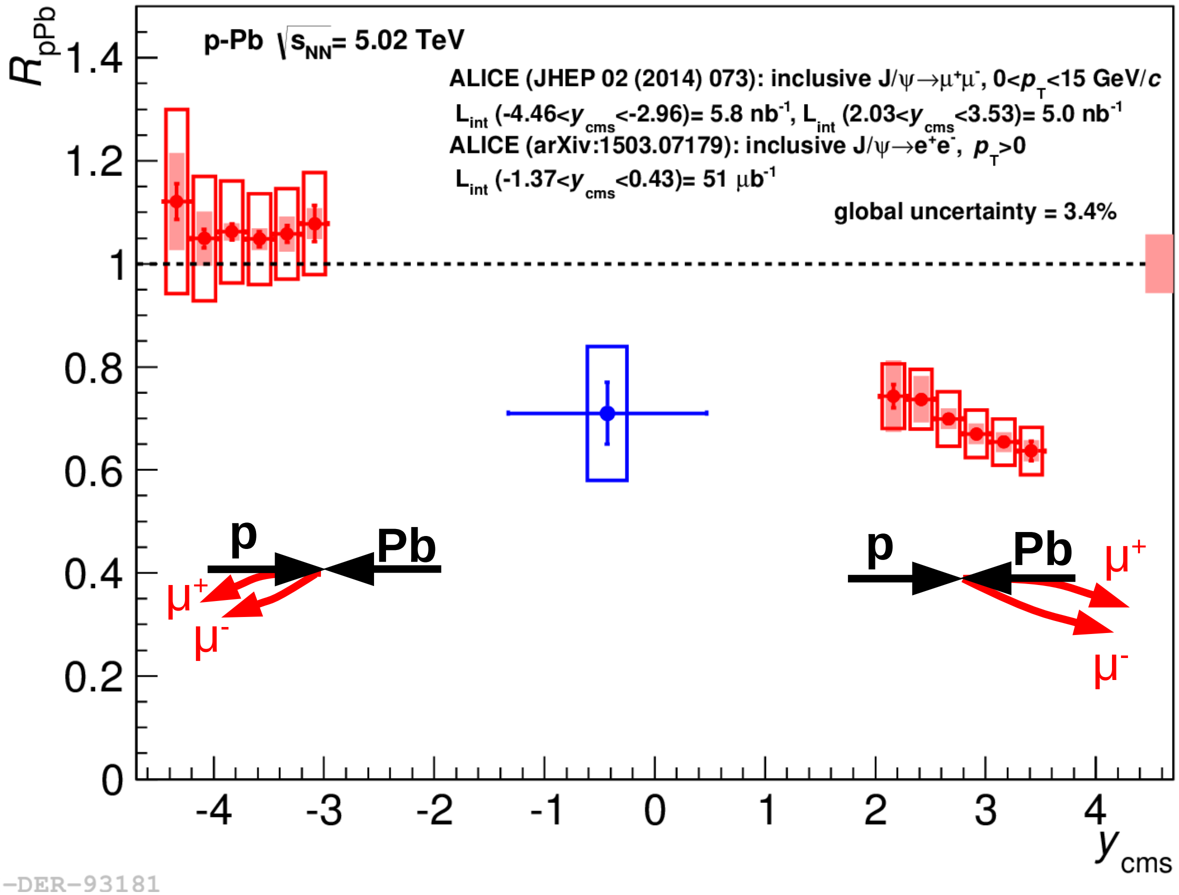
L_{int} = 52 μb^{-1}

Average same bunch pile-up probability: 2.3 per mille

link: arXiv:1503.07179
JHEP 1506 (2015) 055

link: arXiv:1506.08808

$R_{pPb}^{J/\psi}$ as a function of rapidity



$\mu^+\mu^-$: link: arXiv:1308.6726
JHEP 1402 (2014) 073

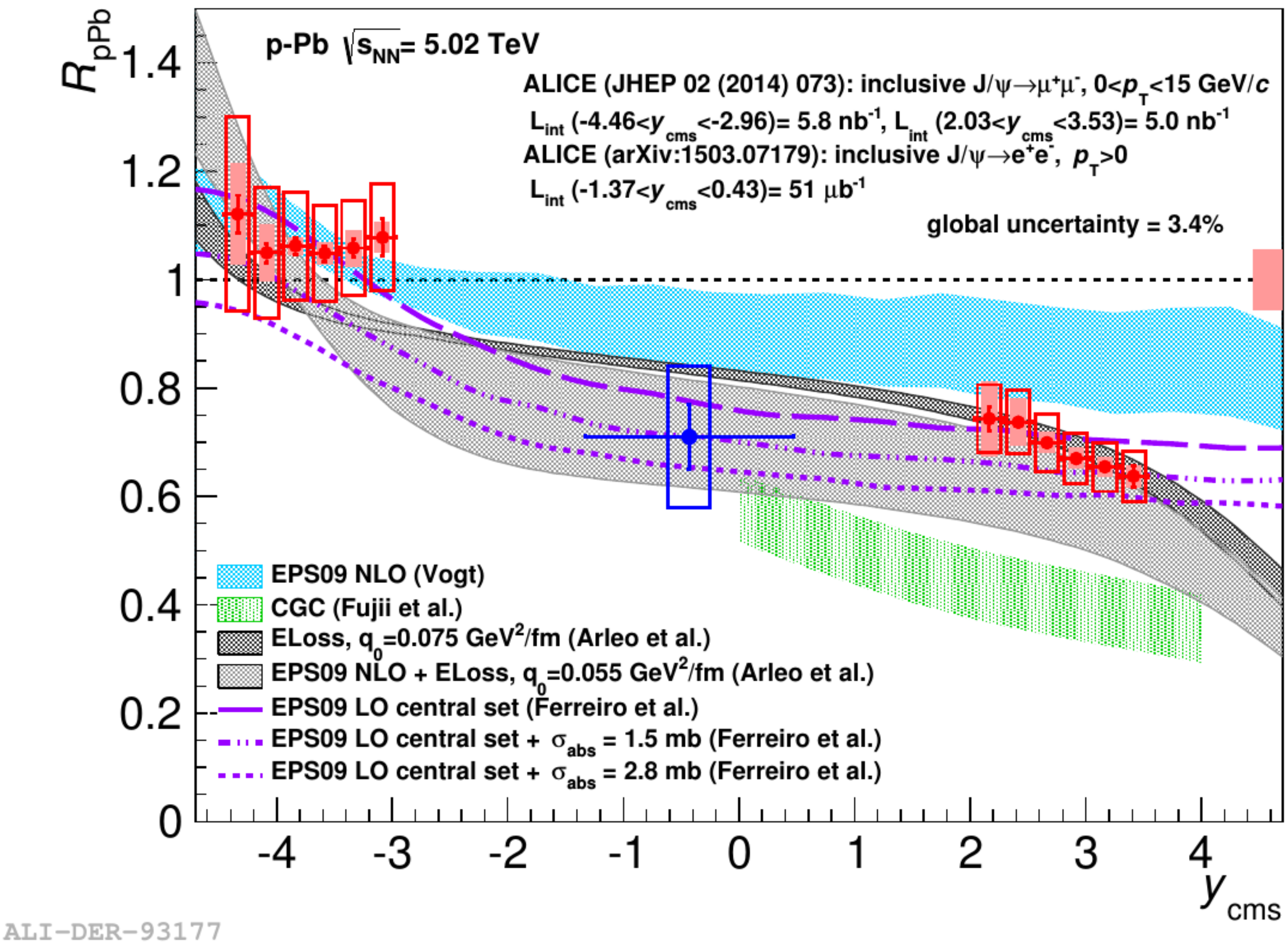
e^+e^- link: arXiv:1503.07179
JHEP 1506 (2015) 055

$$R_{pPb} = \frac{N_{J/\psi \text{ in } pPb}}{\langle T_{pA} \rangle \cdot \sigma_{J/\psi \text{ in } pp}}$$

Forward and backward rapidity results consistent with LHCb:
link: arXiv:1308.6729
JHEP 1402 (2014) 072

- significant suppression at forward rapidity
- mid-rapidity result compatible with forward rapidity result
- backward rapidity result consistent with no suppression

$R^{J/\psi}_{pPb}$ as a function of rapidity



μ⁺μ⁻: link: arXiv:1308.6726
JHEP 1402 (2014) 073

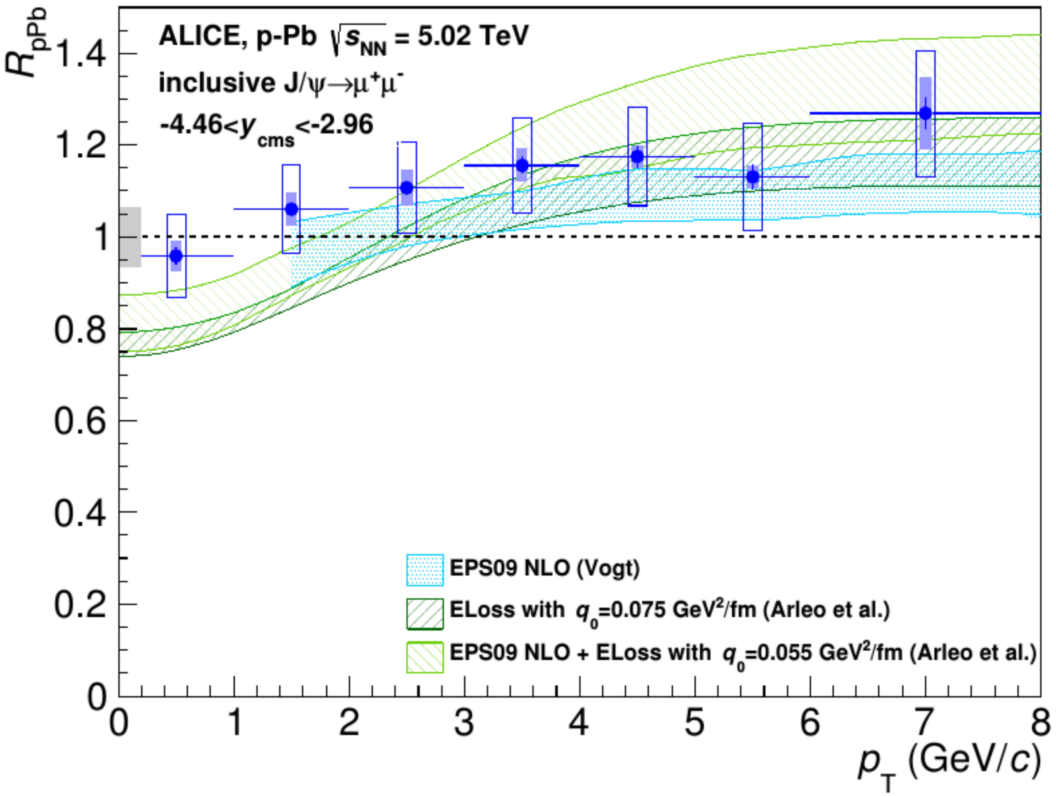
e⁺e⁻ link: arXiv:1503.07179
JHEP 1506 (2015) 055

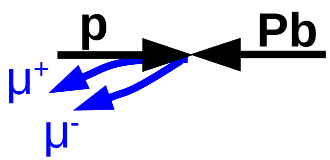
$$R_{pPb} = \frac{N_{J/\psi \text{ in } pPb}}{\langle T_{pA} \rangle \cdot \sigma_{J/\psi \text{ in } pp}}$$

Forward and backward rapidity results consistent with LHCb:
link: arXiv:1308.6729
JHEP 1402 (2014) 072

- EPS09 shadowing combined with CEM/CSM consistent with data
- energy loss models with/without shadowing consistent with data
- early CGC-based CEM inconsistent with data

Backward rapidity: $R_{pPb}^{J/\psi}(p_T)$

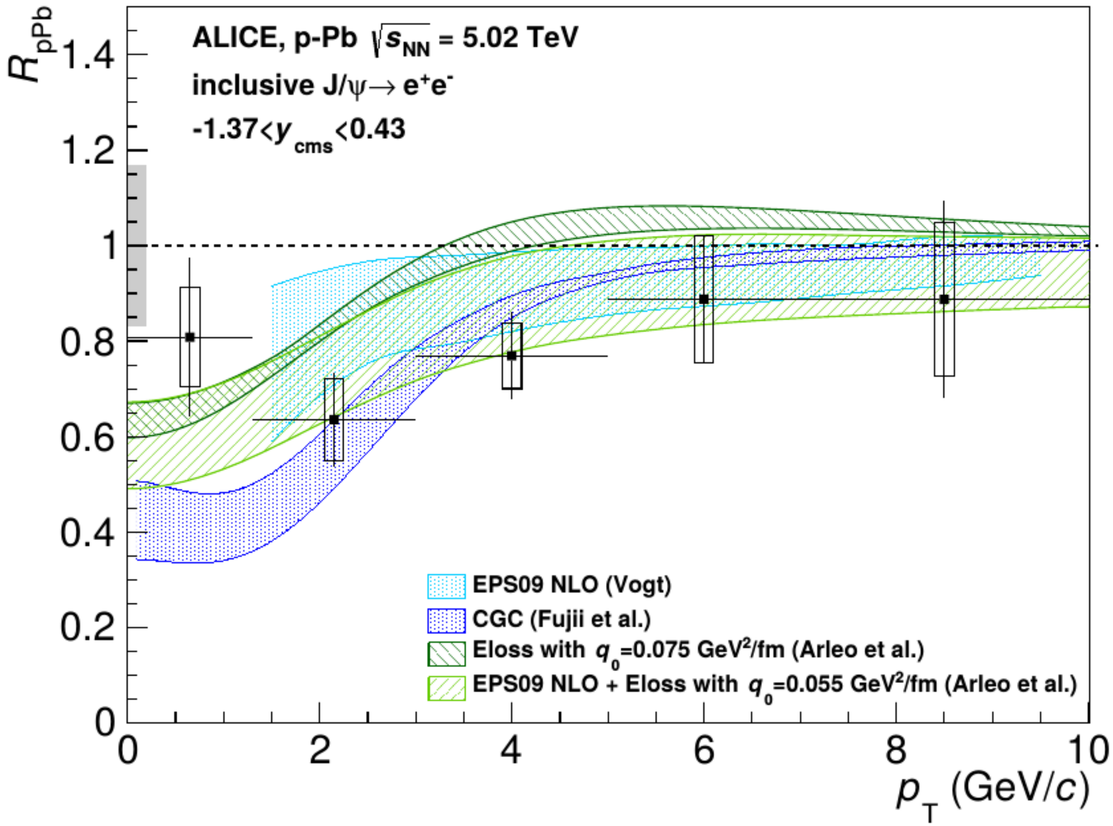


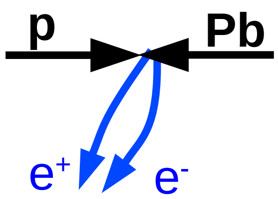


link: arXiv:1503.07179
JHEP 1506 (2015) 055

Systematic uncertainties:
- coloured boxes: uncorrelated
- filled areas: (part.) correlated

- EPS09 shadowing combined with CEM consistent with data
- roughly consistent with coherent energy loss models within uncertainties



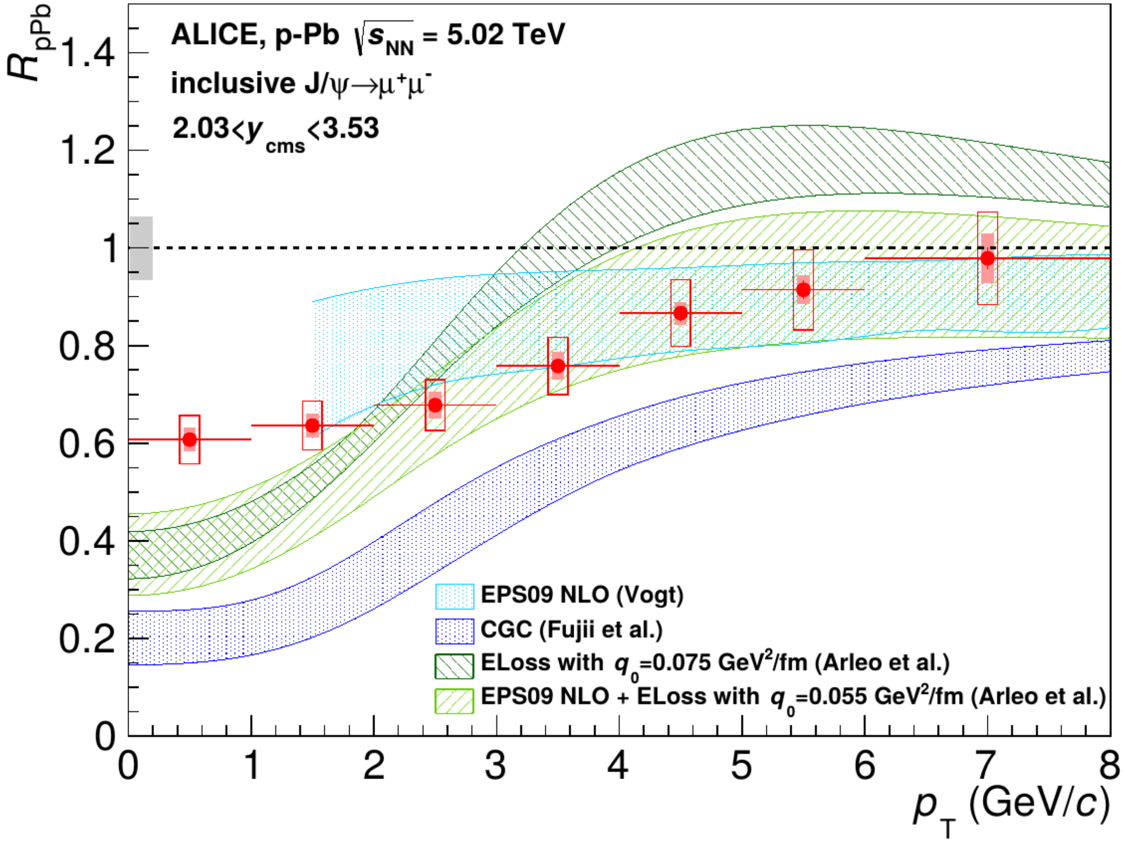


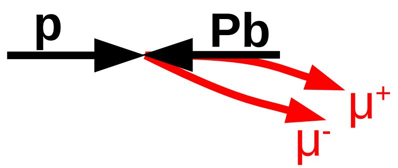
link: arXiv:1503.07179
JHEP 1506 (2015) 055

Systematic uncertainties:
- coloured boxes: uncorrelated
- filled areas: correlated

- EPS09 shadowing with CEM production consistent with data
- coherent energy loss models consistent with data
- early CGC-based model by Fujii et al. consistent with data in this rapidity range

Forward rapidity: $R_{pPb}^{J/\psi}(p_T)$



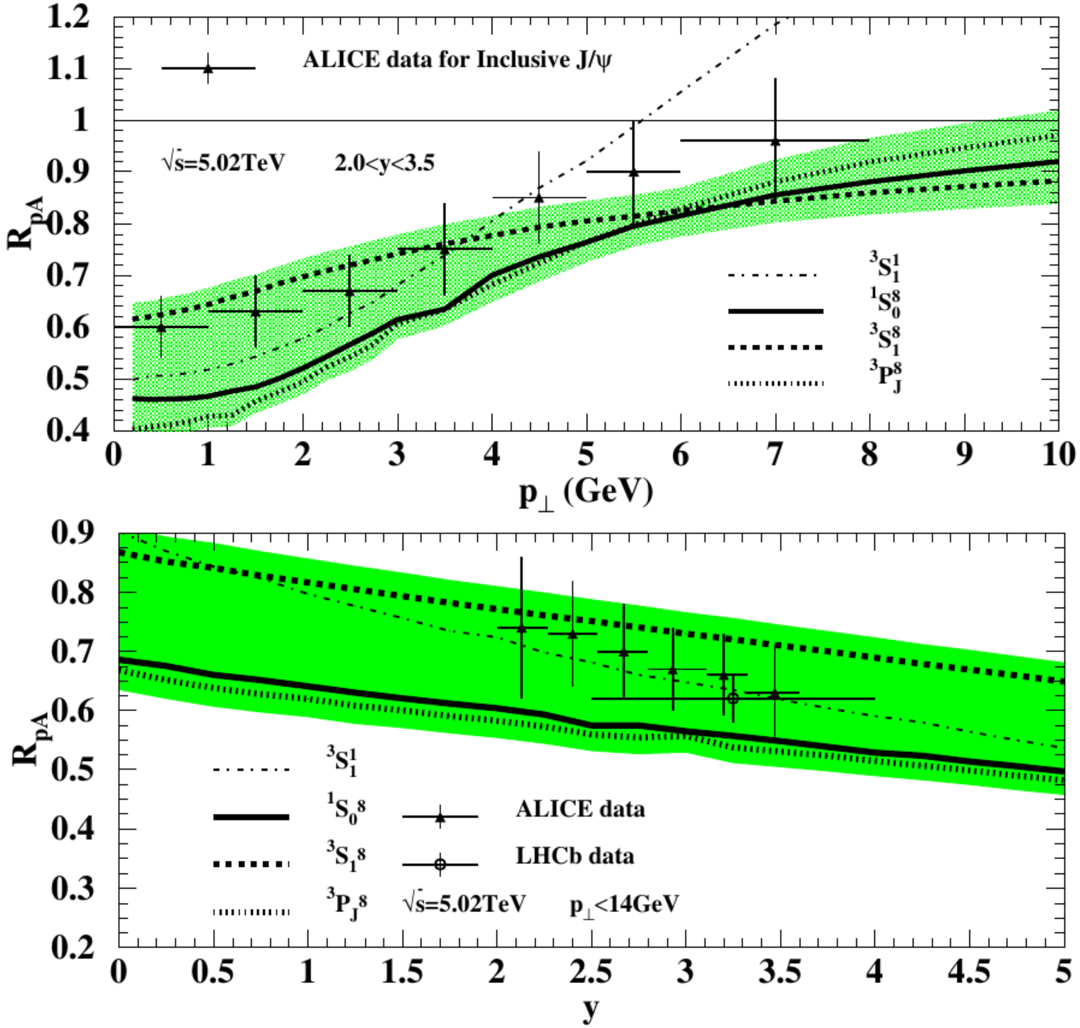


link: arXiv:1503.07179
JHEP 1506 (2015) 055

Systematic uncertainties:
- coloured boxes: uncorrelated
- filled areas: (part.) correlated

- rise as a function of transverse momentum
- EPS09 shadowing with CEM consistent with data
- tension with energy loss models at low p_T with/without shadowing
- underpredicted by the early CGC-based model by Fujii et al.

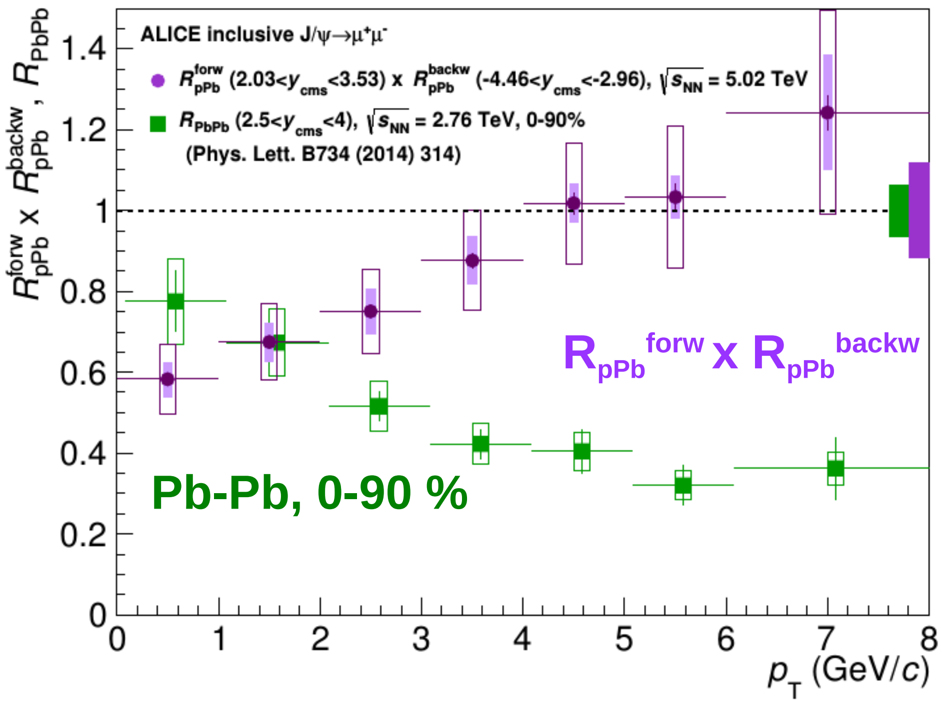
Forward rapidity: $R_{pPb}^{J/\psi}(p_T)$

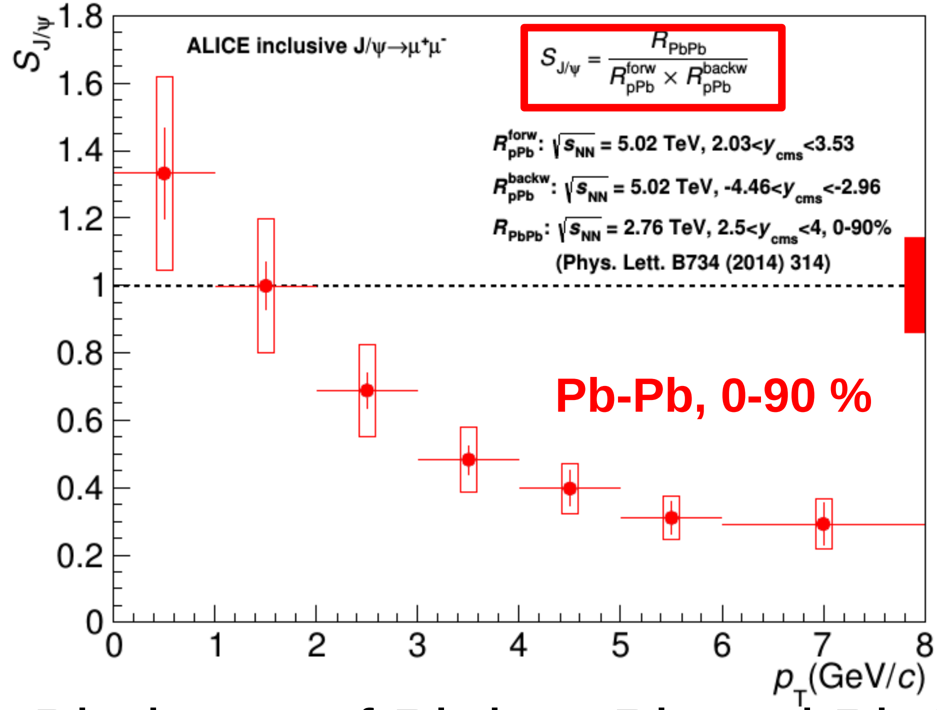


link: arXiv:1503.07772

- NRQCD CGC-model by Yan-Qing Ma et al. consistent with data

$R^{J/\psi}_{pPb}(p_T)$ versus $R^{J/\psi}_{PbPb}(p_T)$: forward & backward





2→1 kinematics probes ≈ the same Bjorken-x of Pb in p-Pb and Pb-Pb

- Assuming factorization of nuclear effects (e.g. only nPDF mod.)
  'extrapolation' also approximate for 2 → 2 kinematics
  within CEM at finite p_T→see talk by R. Vogt at Quarkonium 2014: link

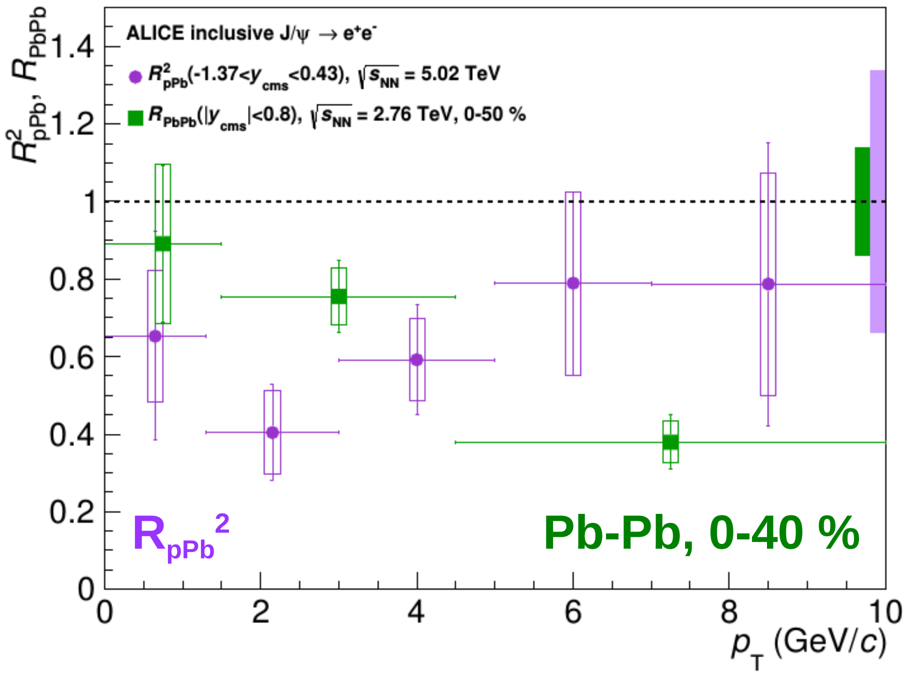
→ R_{pPb}^{forw} x R_{pPb}^{backw} (R_{pPb}^2): can be used as Pb-Pb expectation

low-p_T in Pb-Pb: enhancement →hint of regeneration

suppression at high-p_T → QGP induced

link: arXiv:1503.07179
JHEP 1506 (2015) 055

$R^{J/\psi}_{pPb}(p_T)$ versus $R^{J/\psi}_{PbPb}(p_T)$: midrapidity



link: arXiv:1503.07179
JHEP 1506 (2015) 055

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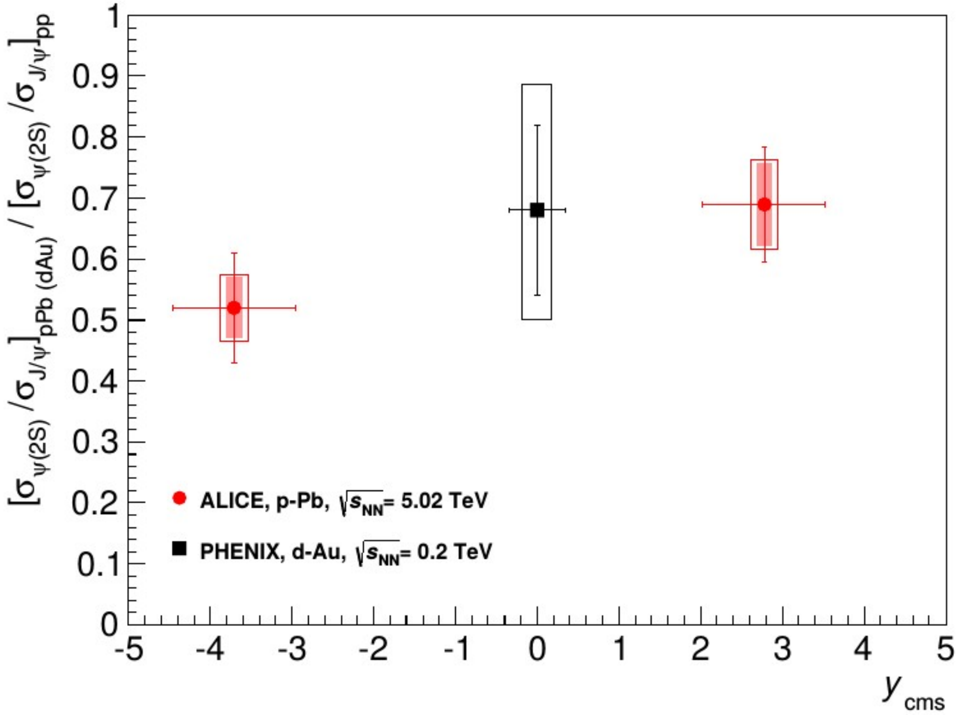
ψ(2S) in p-Pb: more suppressed than J/ψ

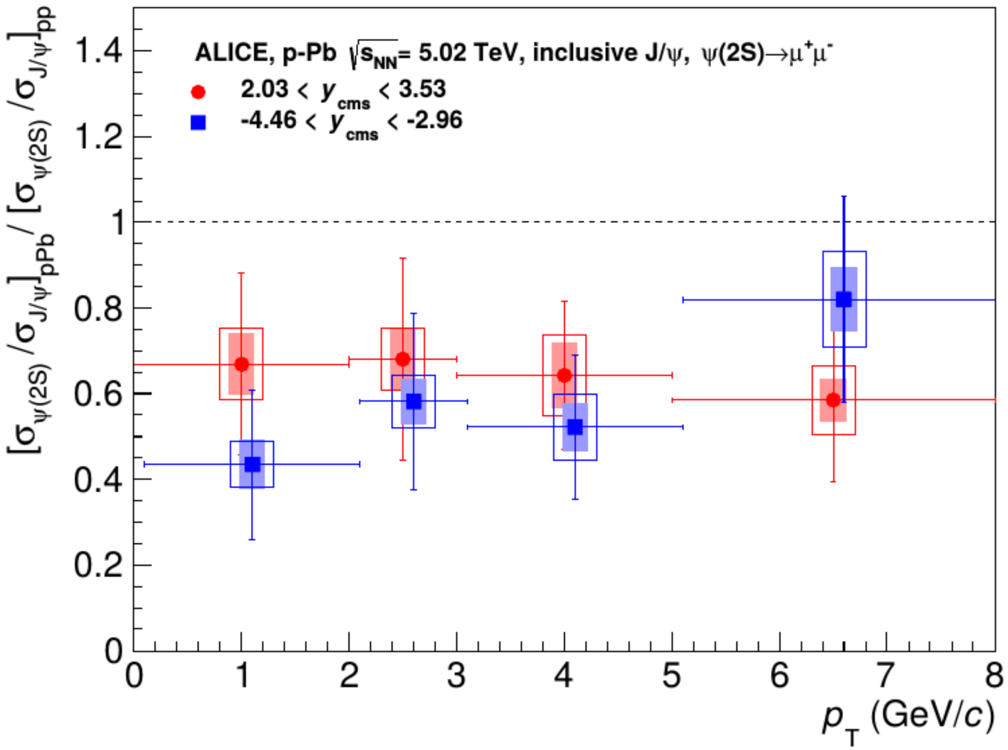


link: arXiv:1405.3796
JHEP 1412 (2014) 073

- Decrease of ψ(2S)/J/ψ-ratio from pp to p-Pb
- Hint of rapidity dependence
- Similar effect seen by PHENIX in d-Au collisions
  at midrapidity at $\sqrt{s_{NN}}$= 200 GeV Phys. Rev. Lett. 111, 202301 (2013), arXiv:1305.5516

Shadowing & E-loss models: identical treatment of ψ(2S) & J/ψ
→ no explanation for this behaviour with these mechanisms

ψ(2S) in p-Pb: more suppressed than J/ψ



link: arXiv:1405.3796
JHEP 1412 (2014) 073

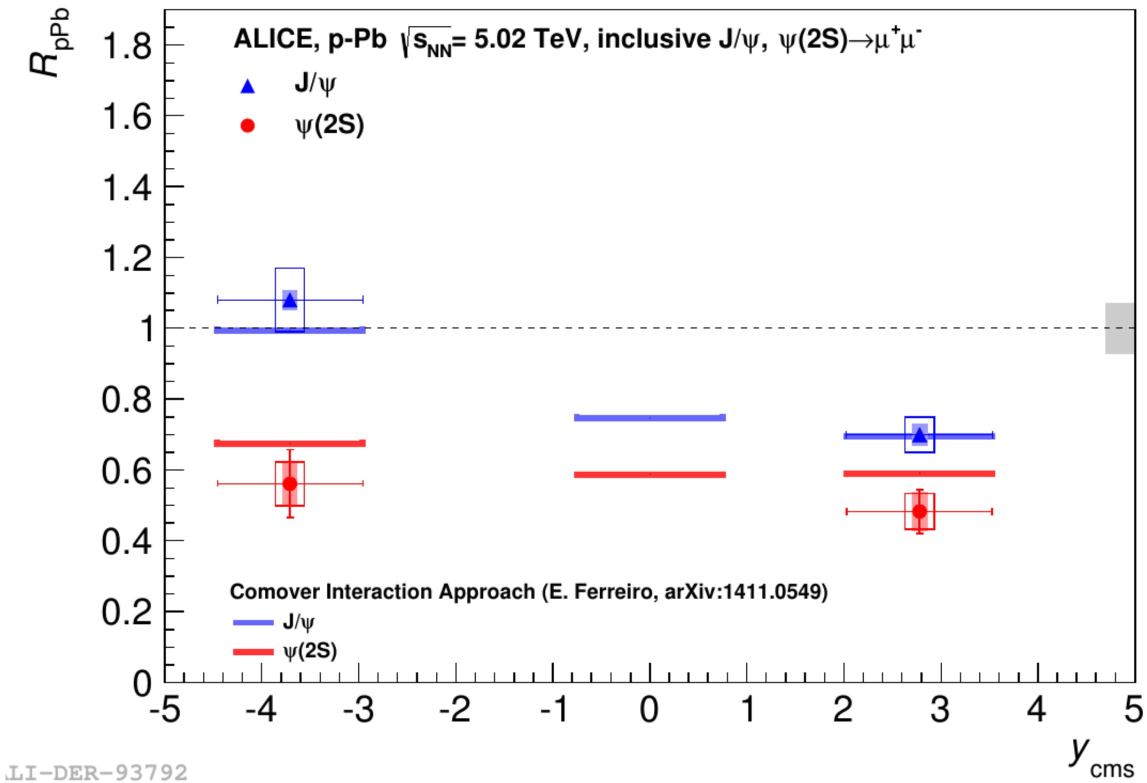
Backward rapidity
Forward rapidity

- Decrease of ψ(2S)/J/ψ-ratio from pp to p-Pb

- no dependence on p_T within uncertainties

Shadowing & E-loss models: identical treatment of ψ(2S) & J/ψ
→ no explanation for this behaviour with these mechanisms

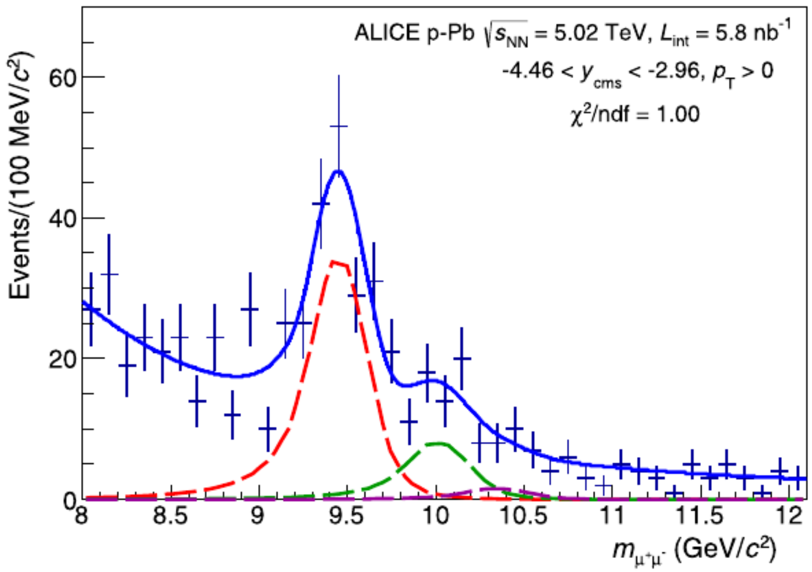
ψ(2S) in p-Pb: more suppressed than J/ψ



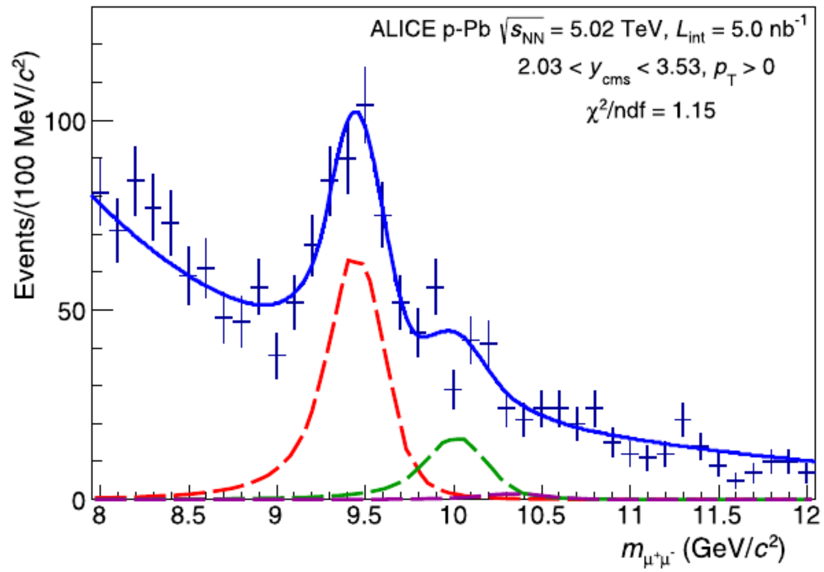
link: arXiv:1411.0549

- comover interactions proposed by E. G. Ferreiro as explanation of additional ψ(2S) suppression

Bottomonium



Forward rapidity



Backward rapidity

link: arXiv:1410.2234
PLB 740 (2015) 105-117

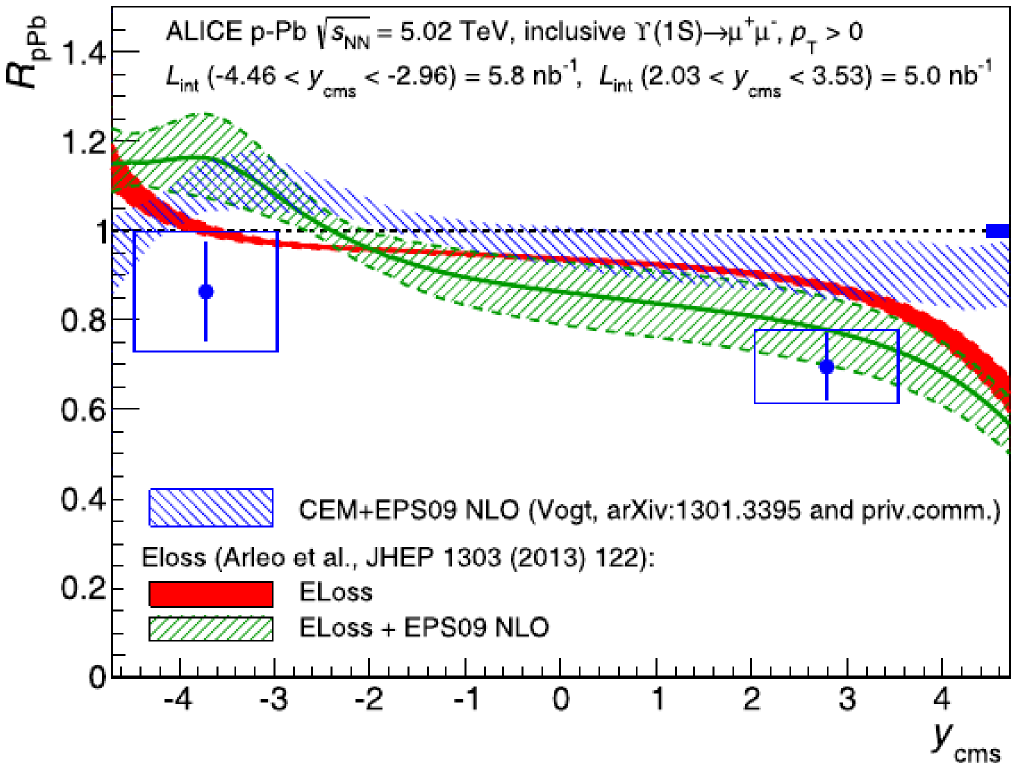
Extraction of Υ(1S), Υ(2S) possible in p-Pb data sample with muon arm at forward and backward rapidity

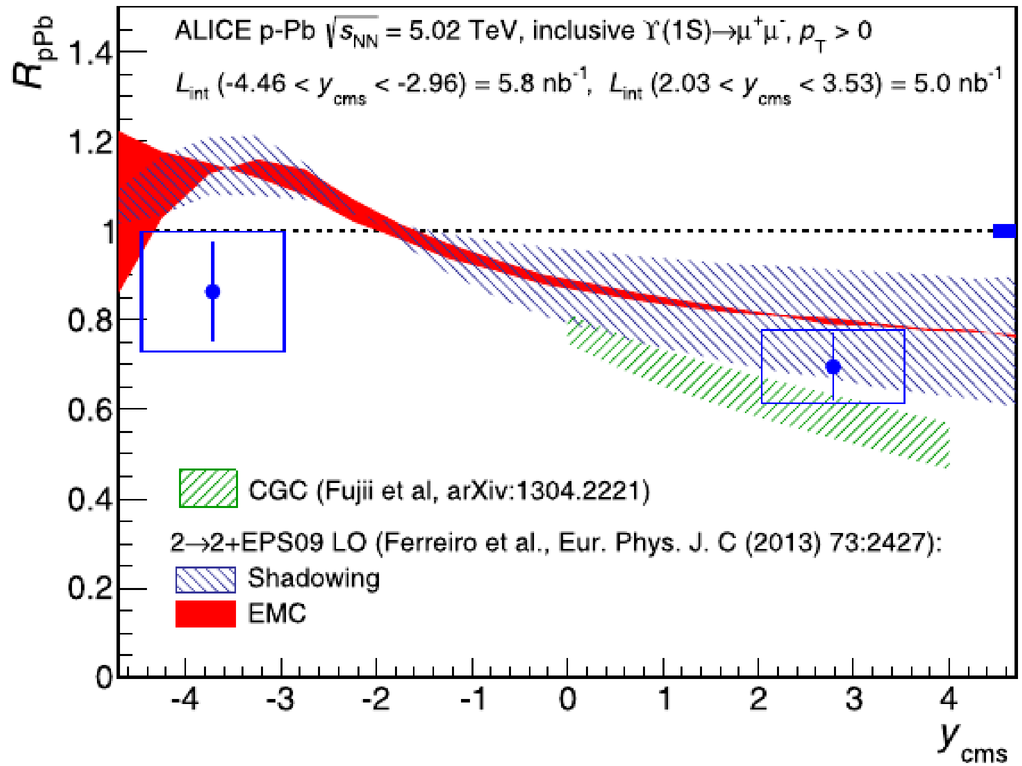
Υ(2S)/Υ(1S) ratio consistent with pp within sizeable uncertainties

CMS reports stronger suppression of Υ(2S) at midrapidity

Significiance of Υ(3S) in combined fit below 3 σ

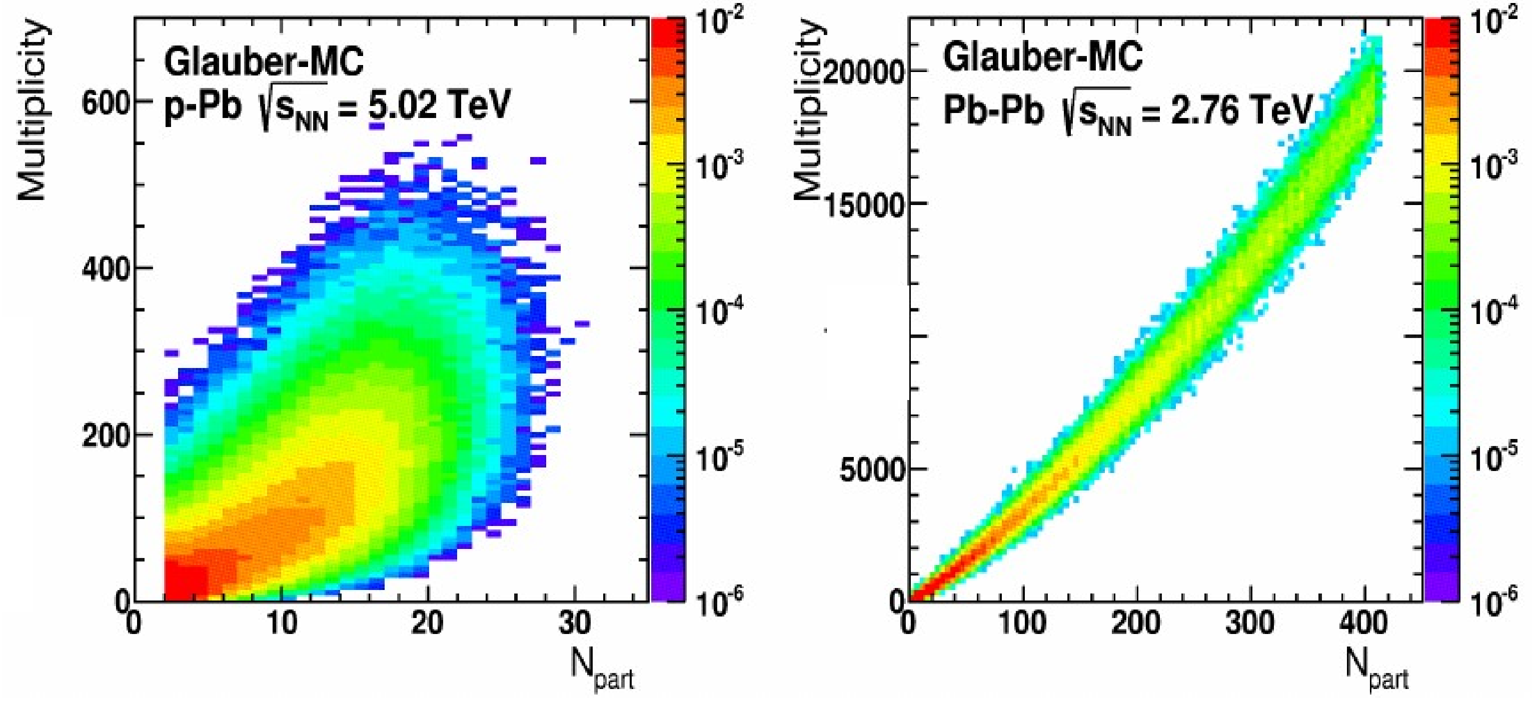
Bottomonium





- strong antishadowing in EPS09 disfavoured by data

ALICE 'centrality' determination in p-Pb



p-Pb vs Pb-Pb:

- looser correlation between N_{part} and impact parameter
- looser correlation between N_{part} and multiplicity

→ fluctuations much more important
→ biases associated with experimental estimator choice important

ALICE 'centrality' determination in p-Pb

ALICE approach as consequence of observations in data:

→ slice events in zero degree neutron energy deposit on the Pb remnant side, build T_{pA} such that:

a) midrapidity dN/dη scales with N_{part}

b) Pb-side dN/dη scales with N_{part}^{target}

c) high-p_T yield at midrapidity scales with dN/dη N_{coll}

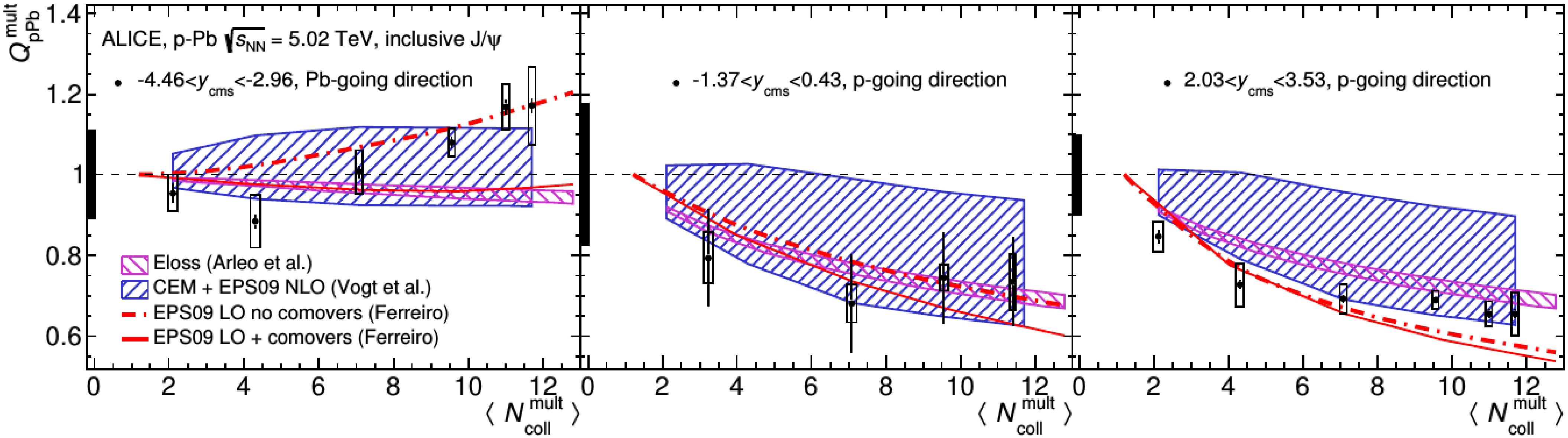
All values within deviations of at most 10 %
→ uncertainty estimtae

Underlying assumption: zero degree energy insensitive to dynamical biases

'centrality' dependent nuclear modification factor called Q_{pPb} instead of R_{pA} due to weaker correlation between estimator and geometry than in AA, and due to potentially unaccounted biases

$$Q_{pPb}^{mult.} = \frac{N_{J/\psi \text{ in pPb in ZN perc.}}}{\langle T_{pPb} \rangle \cdot \sigma_{J/\psi \text{ in pp}}}$$

Q_{pA}: 'centrality' dependence of J/ψ

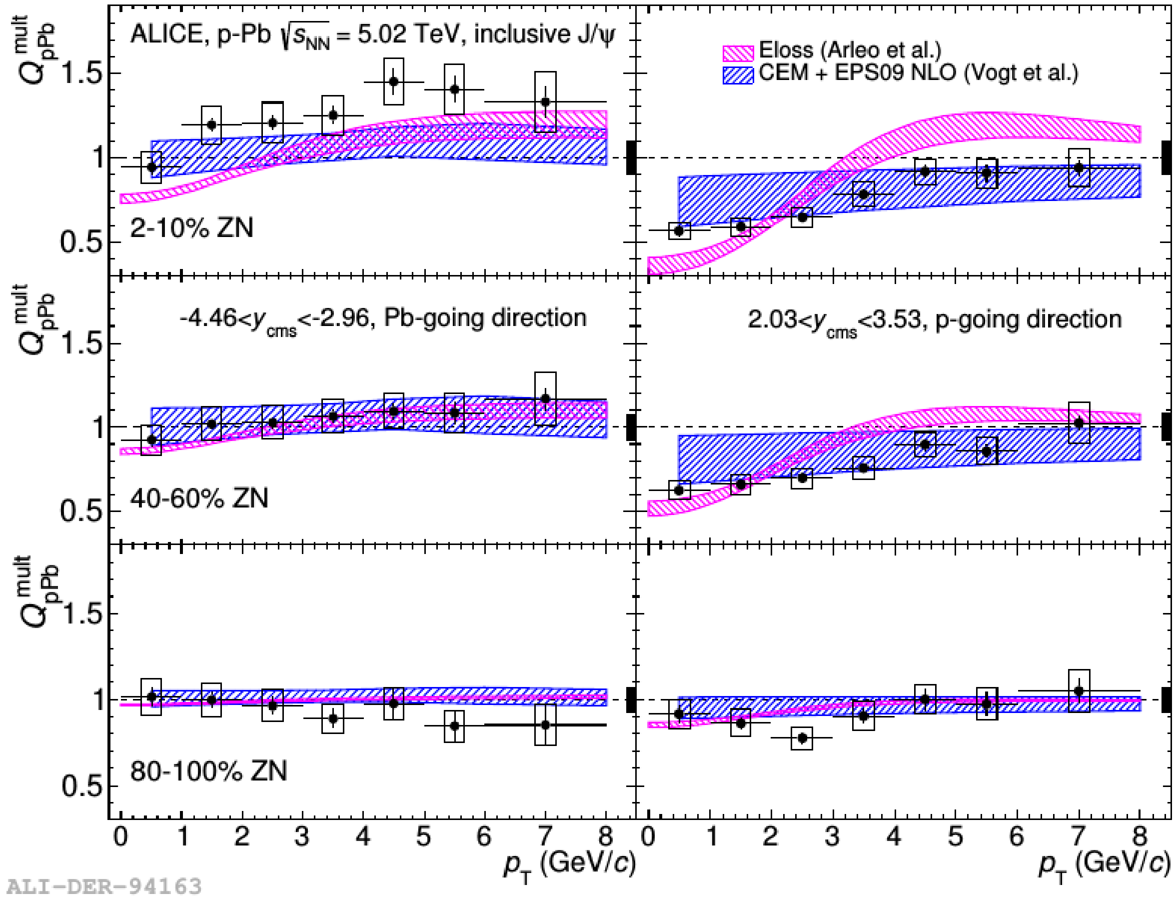


backward rapidity | midrapidity | forward rapidity

link: arXiv:1506.08808

- data favors a strong shadowing within the CEM EPS09 model
- the coherent energy loss compatible with the data at forward and midrapidity, but shows a different trend at backward rapidity
- the comover model compatible at forward and midrapidity: disfavored at backward rapidity

Q_{pA}: 'centrality' dependence of J/ψ

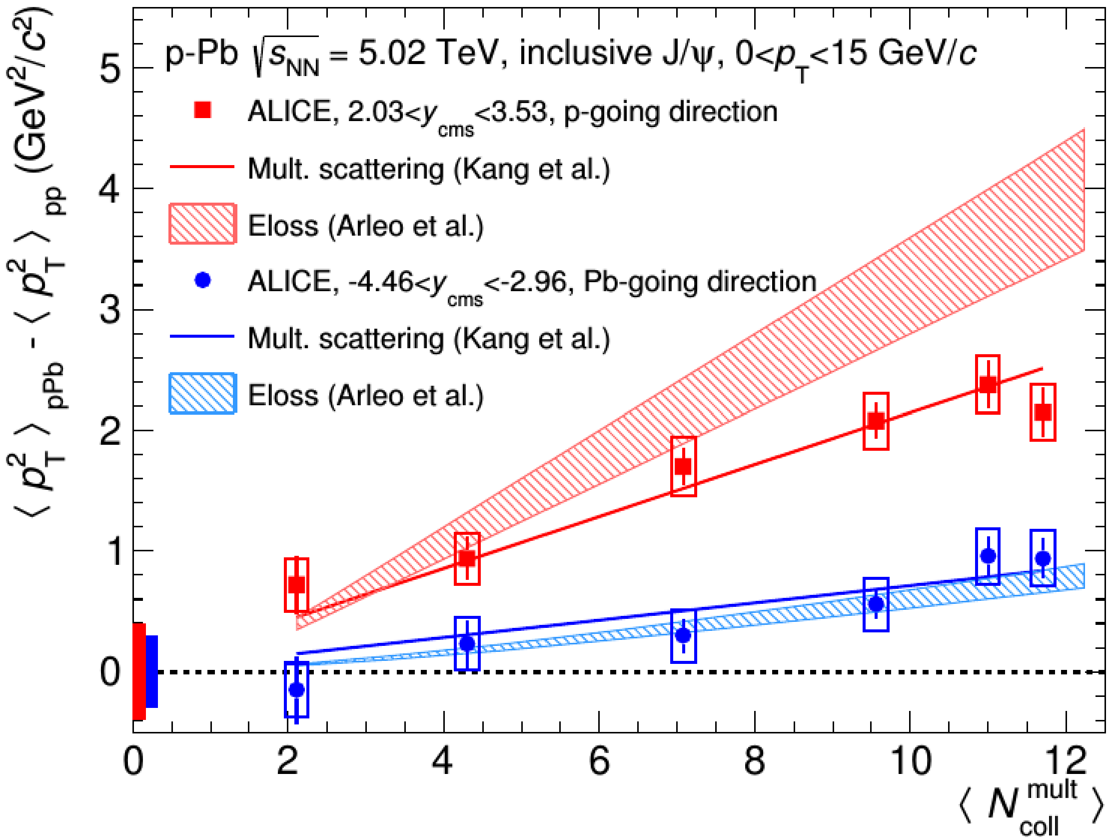


link: arXiv:1506.08808

- reasonable agreement with CEM with EPS09 shadowing considering all uncertainties

- coherent energy loss model overestimating steepness of the data at highest event activity at forward rapidity

p_T-broadening of J/ψ as function of centrality

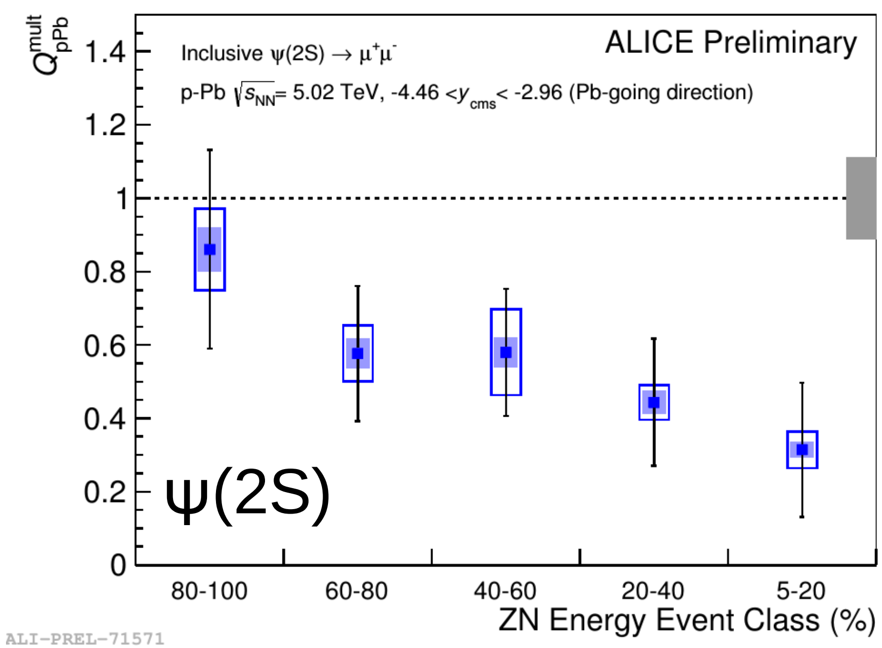


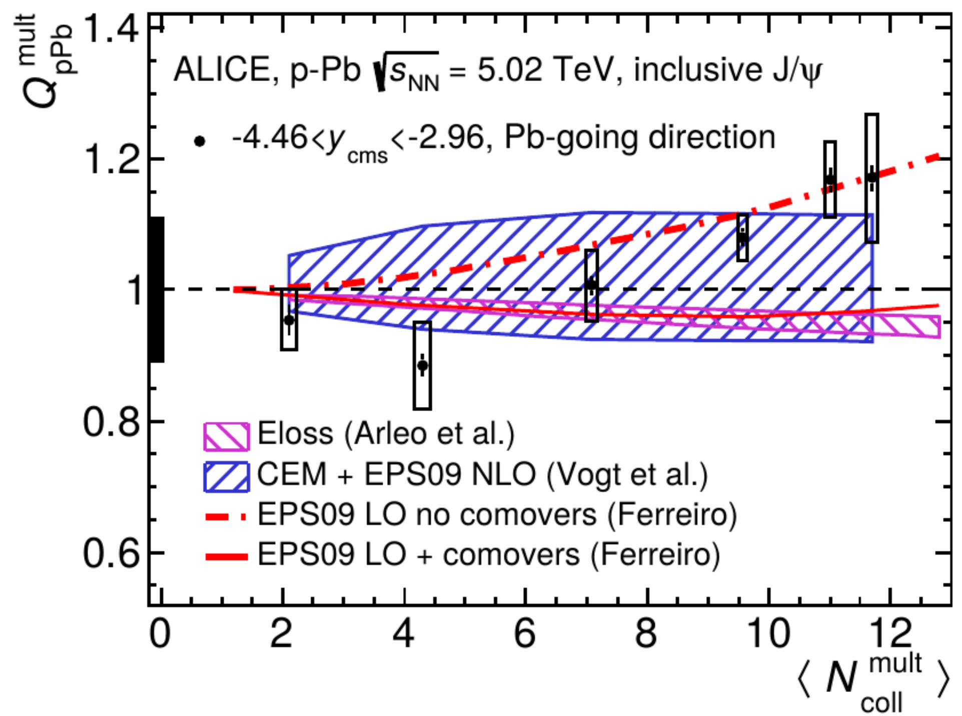
link: arXiv:1506.08808

Backward rapidity
Forward rapidity

- model by Kang et al. studying the impact of multiple scattering during the whole interaction reproduces well the data
- energy loss models reproduces well the observable at backward rapidity, but is steeper at forward rapidity

Q_{pA}: event activity dependence of J/ψ & ψ(2S)



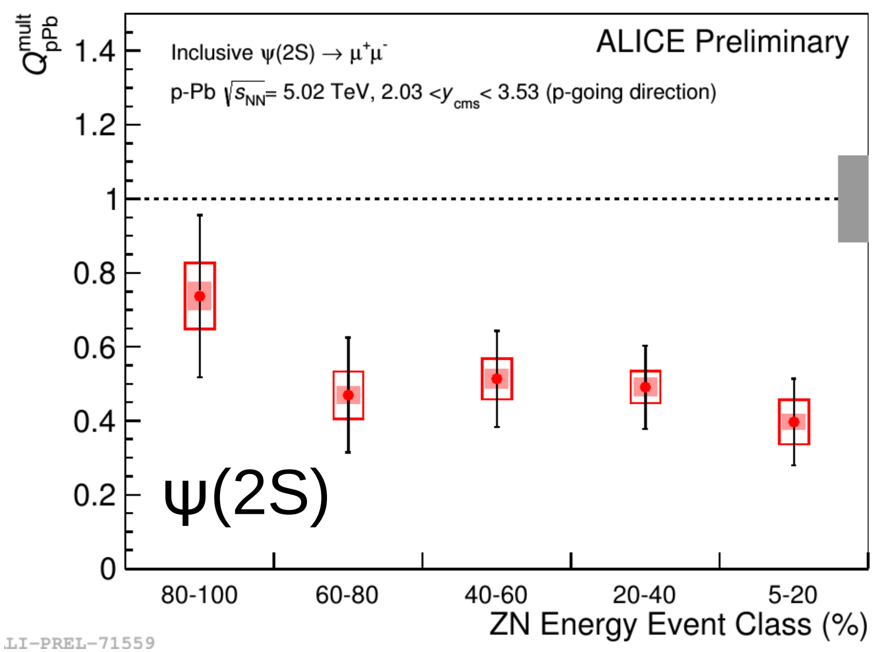


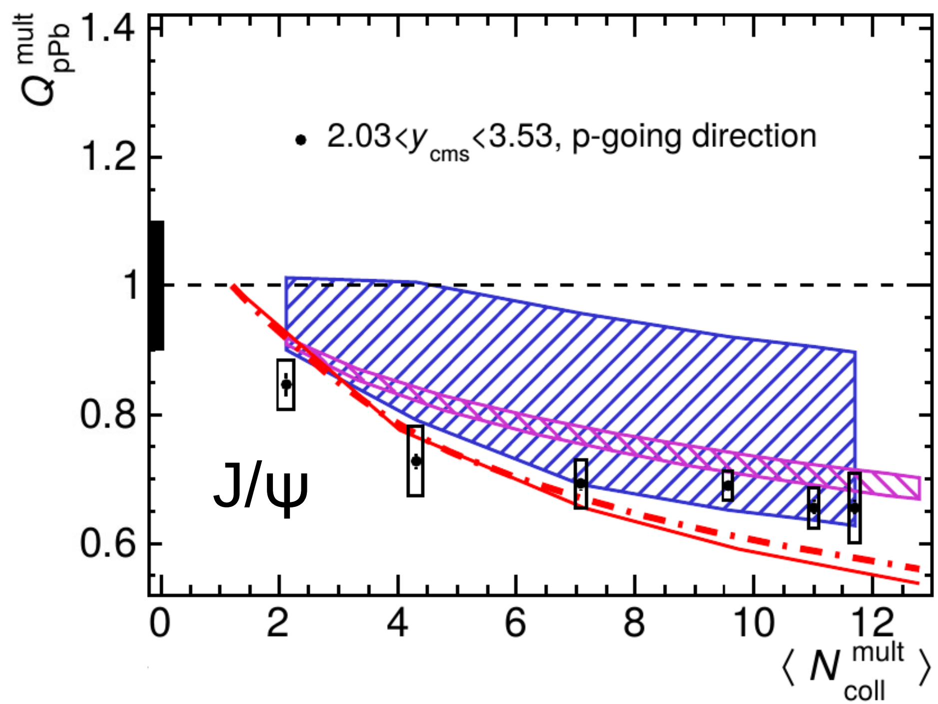
Backward rapidity (Pb-going):

- Q_{pA} of ψ(2S) decreasing with increasing event activity in contrast to J/ψ

ψ(2S):
Prelim. for QM'14
Link: Nucl.Phys. A931 (2014) 628-632

Q_{pA}: event activity dependence of J/ψ & ψ(2S)





ψ(2S):
Prelim. for QM'14
Link: Nucl.Phys. A931 (2014) 628-632

Forward rapidity (p-going):

- J/ψ and ψ(2S) exhibits stronger suppression with increasing event activity
- no dependence of additional ψ(2S) suppression w.r.t. J/ψ observed within uncertainties

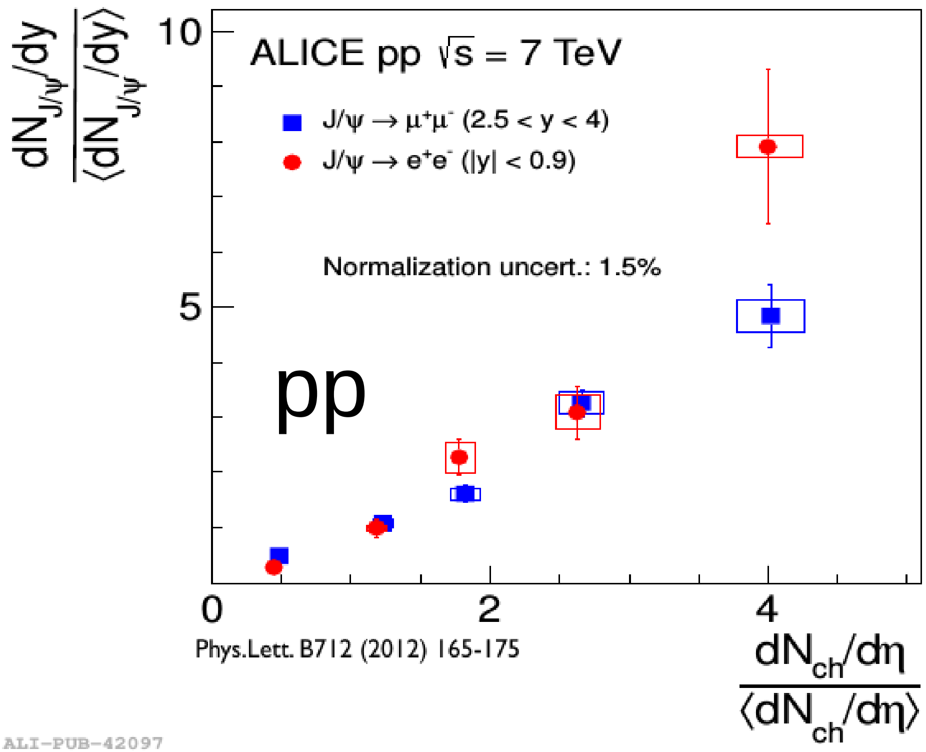
Multiplicity dependence of J/ψ: pp vs p-Pb

Analysis in pp collisions:

J/ψ yield at forward rapidity and midrapidity as function of multiplicity at midrapidity

- reaching rare event classes

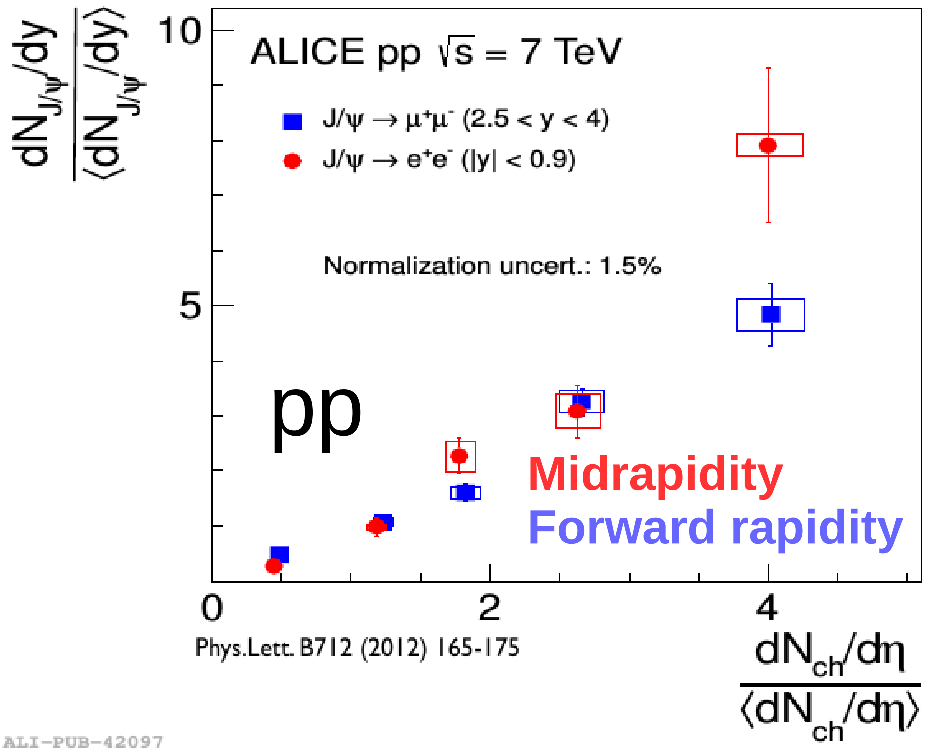
  highest multiplicity class: 3.3 % of selected MB trigger events



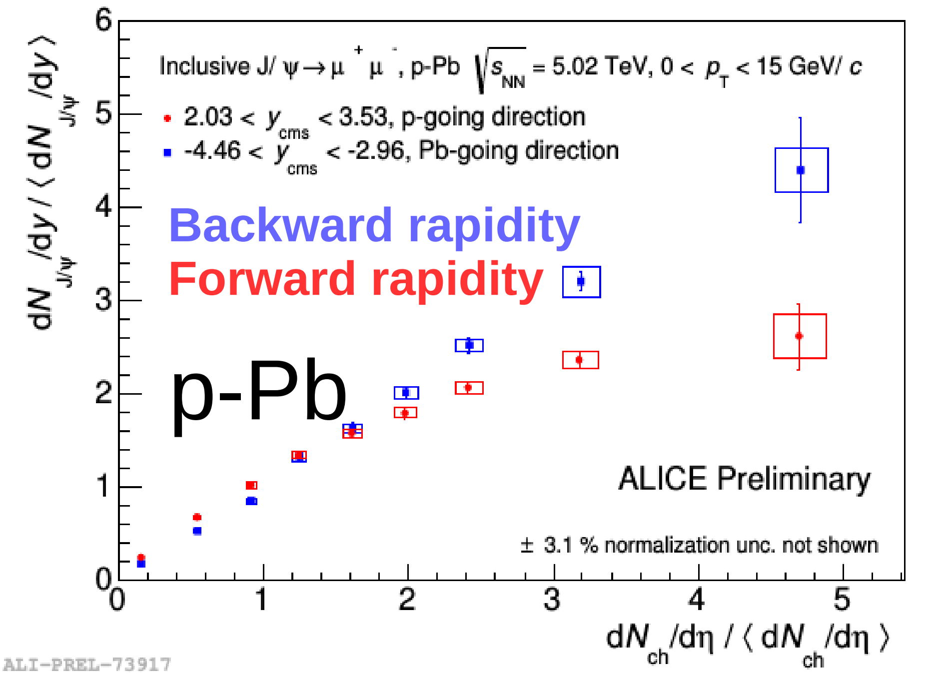
- behaviour often interpreted in terms of multi-parton interactions

→ measure in p–Pb!

Multiplicity dependence of J/ψ: pp vs p-Pb



multiplicity measured in $|\eta_{lab}|<1.0$

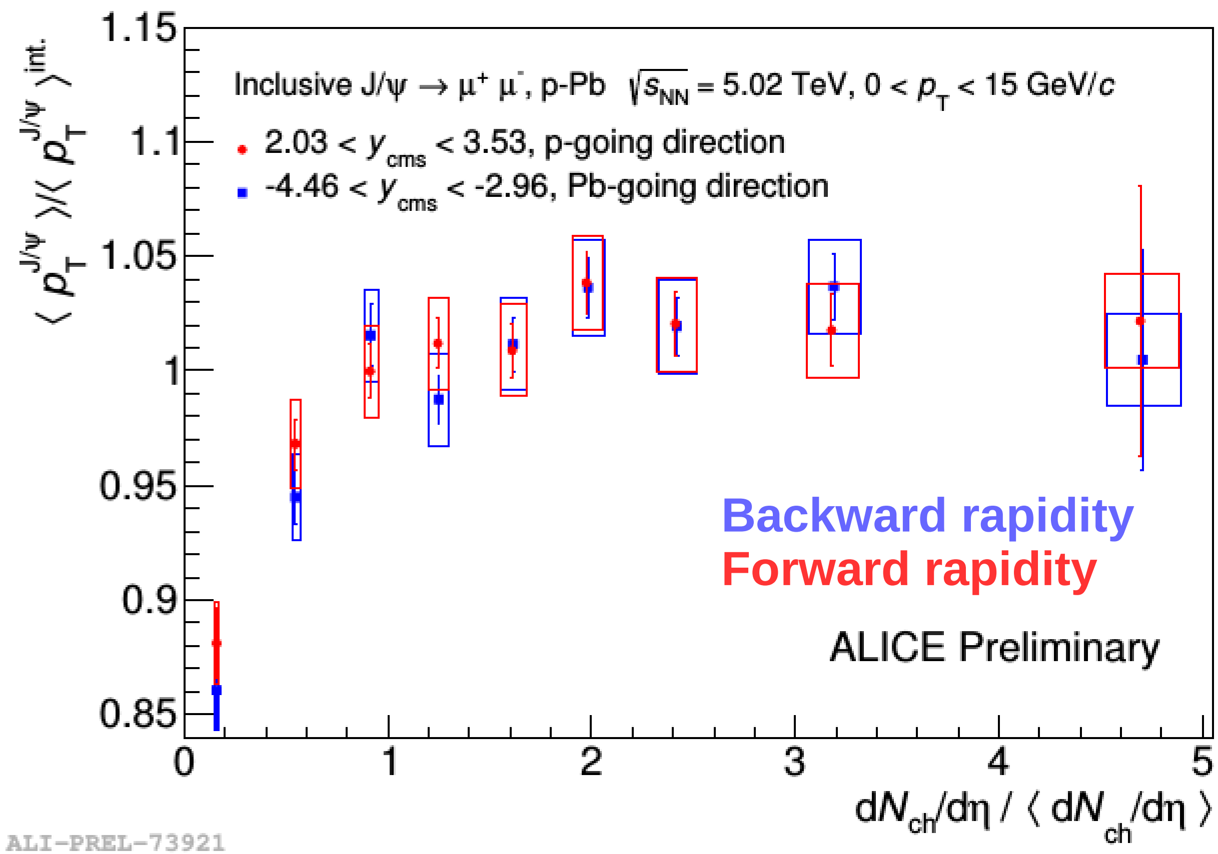


multiplicity measured in $|\eta_{lab}|<0.5$

- Clear increase of relative J/ψ yield in p-Pb at forw. & backw. rapidity
- Linear increase for backward rapidity (Pb-going) very similar to pp
- Onset of saturation at forward rapidity (p-going)

Prelim. for QM'14
Link: Nucl.Phys. A931 (2014) 612-616

Multiplicity dependence of $<p_T^{J/\psi}>$



Prelim. for QM'14
Link: Nucl.Phys. A931 (2014) 612-616

Increase of relative $<p_T^{J/\psi}>$ as function of multiplicity in $|\eta_{lab}|<0.5$

- saturation of $<p_T^{J/\psi}>$ at about 1.5 • $<dN_{ch}/d\eta>$

- same behaviour at forward and backward rapidity within uncertainties

Summary

- $R^{J/\psi}_{pPb}$ as a function of rapidity consistent with
  - EPS09 gluon shadowing combined with CEM/CSM
  - coherent energy loss with/without shadowing

  some discrepancies for $R^{J/\psi}_{pPb}(p_T)$ at low p_T

- $R^{J/\psi}_{pPb}$ versus $R^{J/\psi}_{PbPb}$
  - low p_T: enhancement in Pb-Pb w.r.t. simple 'extrapolation' from p-Pb
  - high p_T: stronger suppression in Pb-Pb with respect to p-Pb

Summary

- 'Centrality' dependence Q_{pPb} : suppression at forward rapidity & close to unity at backward rapidity

- Multiplicity dependence of relative J/ψ yields similar to pp

- $<p_T>$ increasing with multiplicity and saturating at forward & backward rapidity

- $R^{\psi(2S)}_{pPb}$ at backward/forward rapidity: stronger suppression than J/ψ

significant nuclear modification of Υ(1S):
not fully described by shadowing or coherent energy loss model

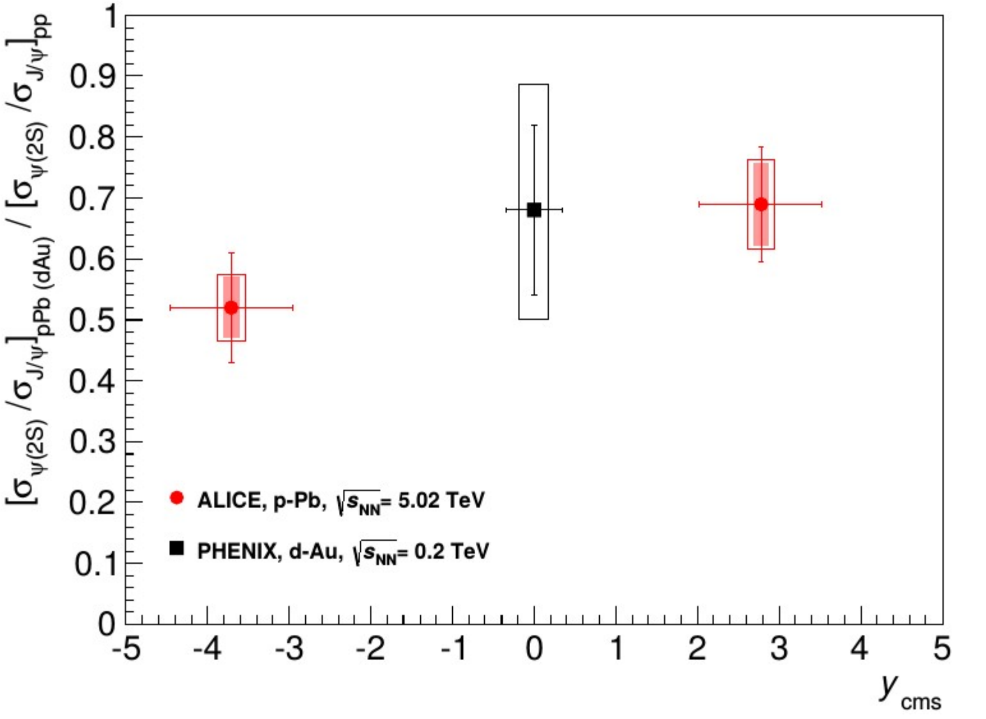
Conclusion

J/ψ and Υ(1S) qualitatively matching expectations from shadowing and/or coherent energy loss

Pattern of observed suppression strengthen evidence of an additional contribution at low p_T in Pb-Pb

ψ(2S) result not explained with shadowing/coh. energy loss

→ comover model as one possible scenario



Outlook

RUN1 p-Pb Results to come:

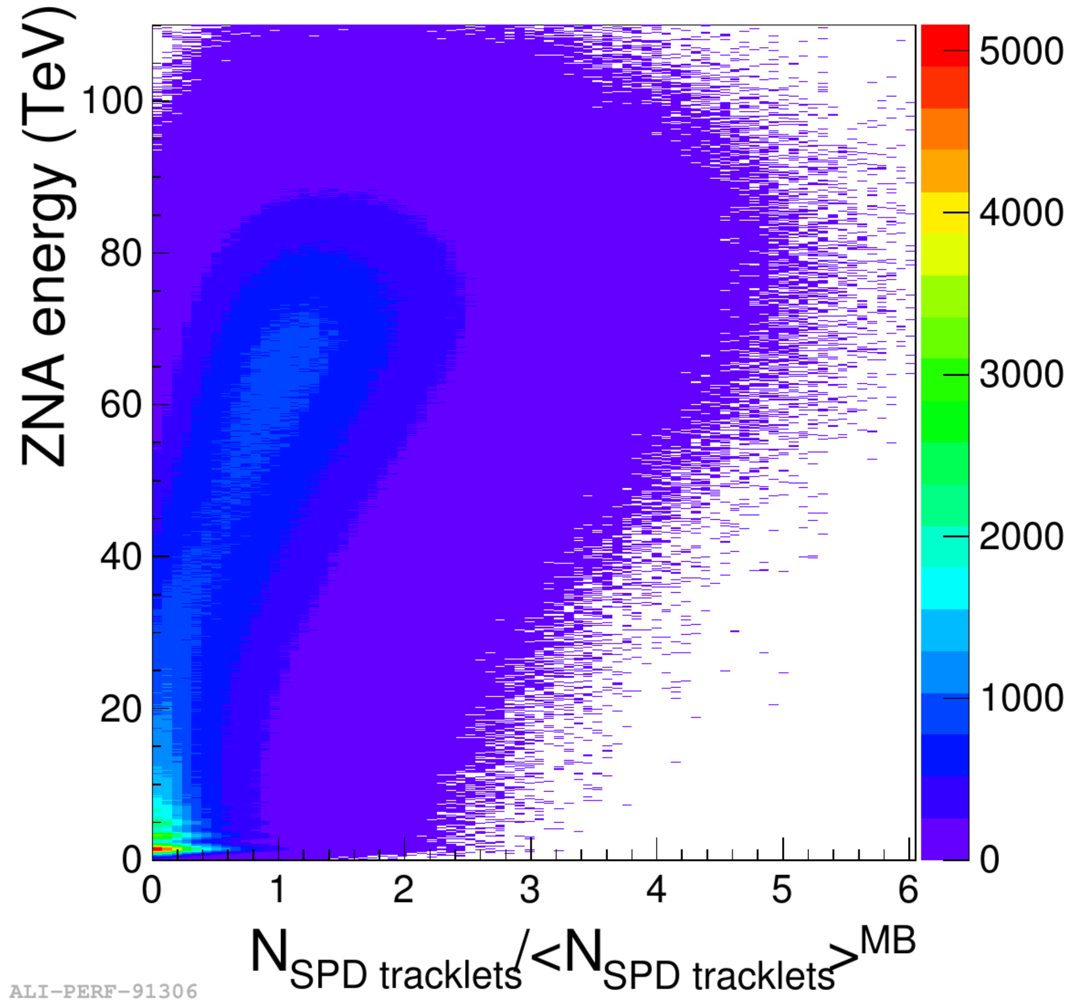
- final $\psi(2S)$ 'centrality' dependence

- multiplicity dependence of J/ψ production at midrapidity

  → final result to be published soon with final muon result

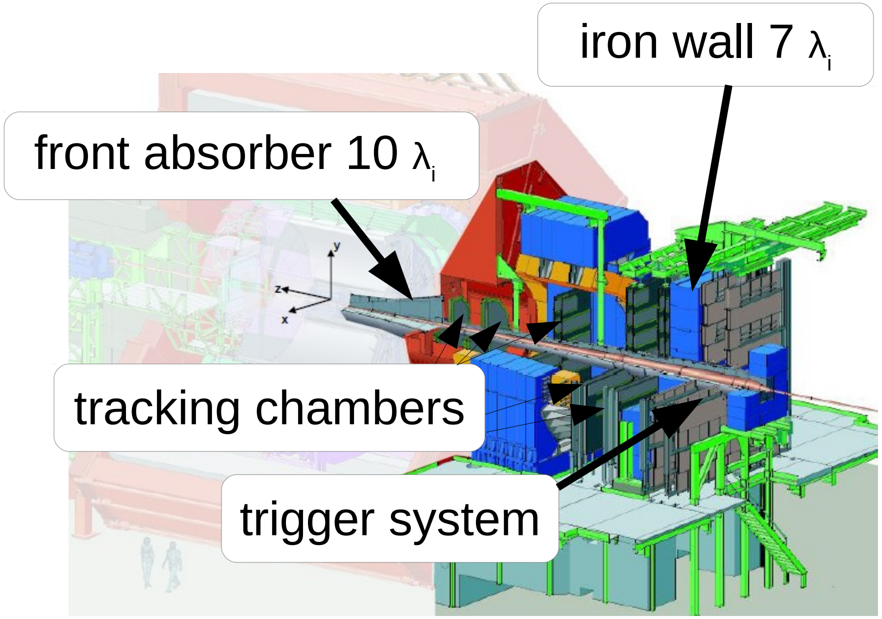
- non-prompt/prompt J/ψ separation at midrapidity

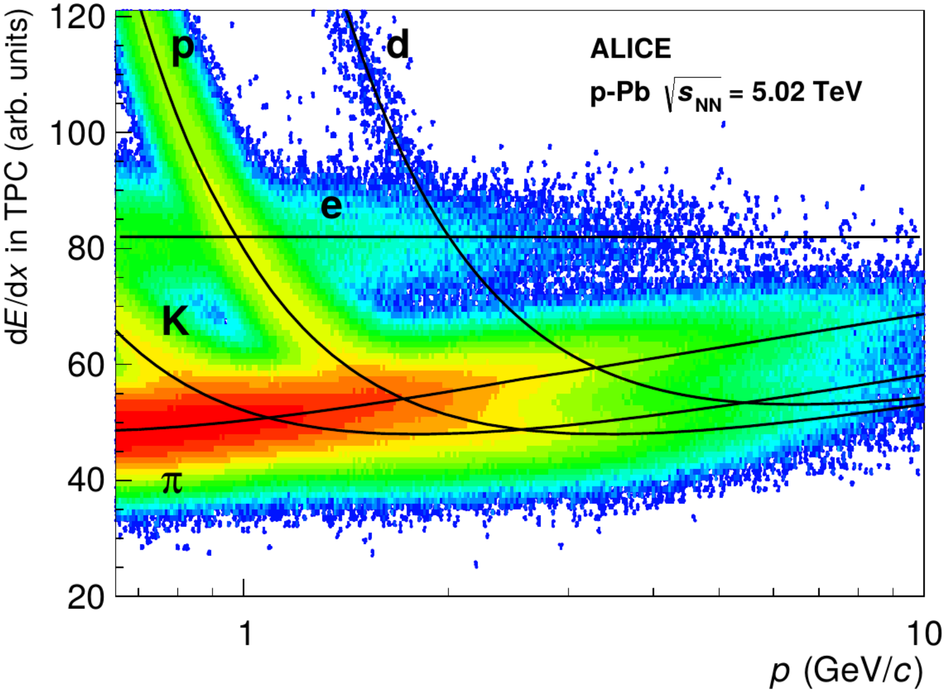
Back-up: correlation between used estimators



Comparison between the used multiplicity estimator and the variable used for the slicing in event activity bins for Q_{pPb}

Back-up: 2013 p-Pb Run





Dimuons: dedicated trigger

L_{int}=5.0 nb^{-1} (forward)

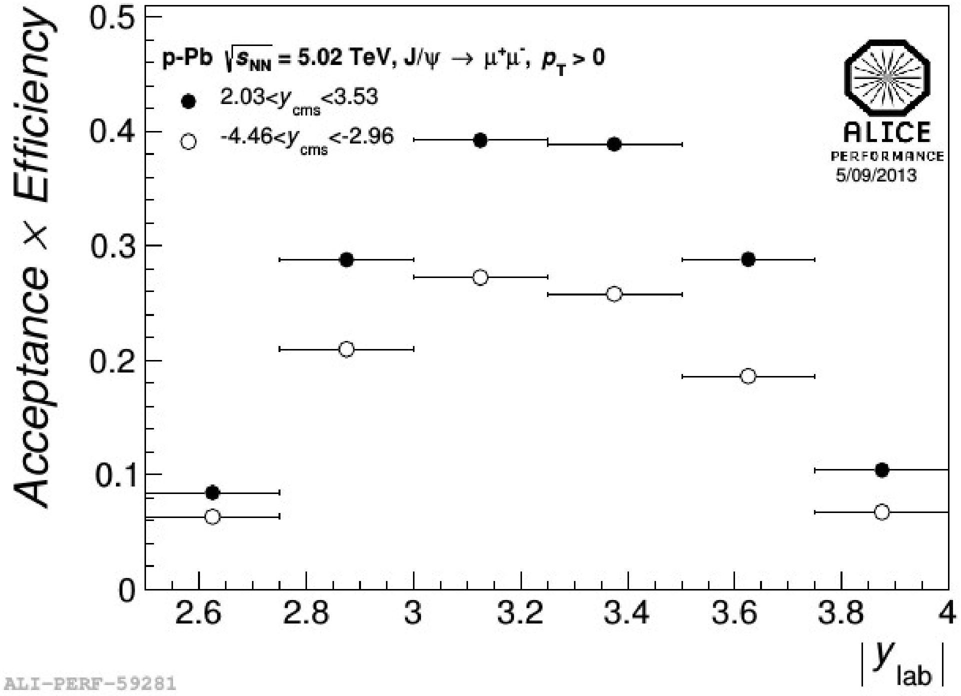
L_{int}=5.8 nb^{-1} (backward)

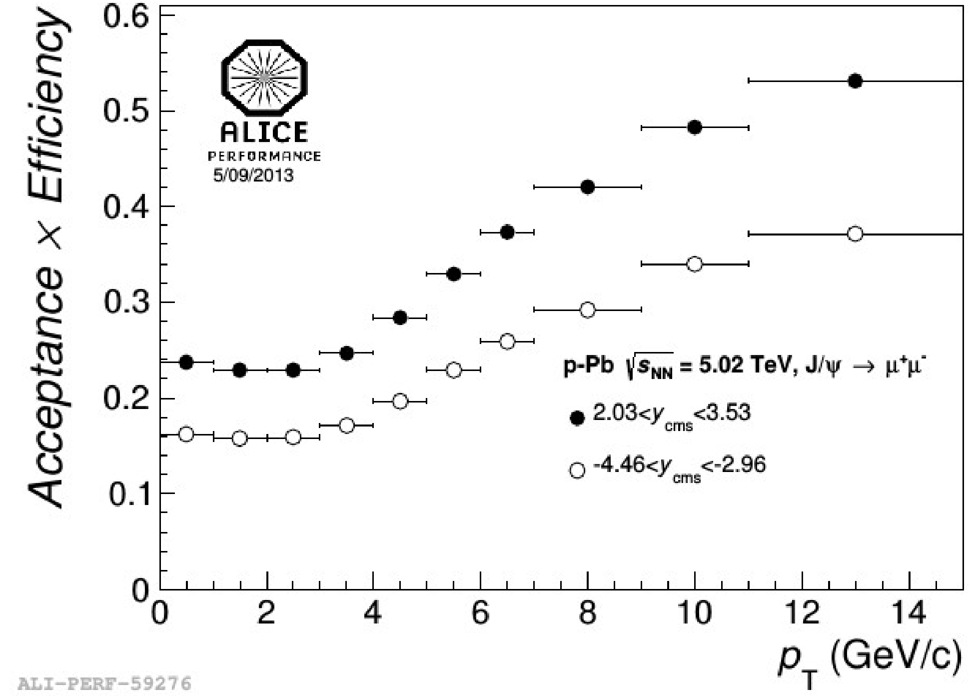
Dielectrons: Minimum Bias

L_{int}= 52 μb^{-1}

extensive usage of TPC-PID

Back-up: Acceptance x efficiency for muon channel



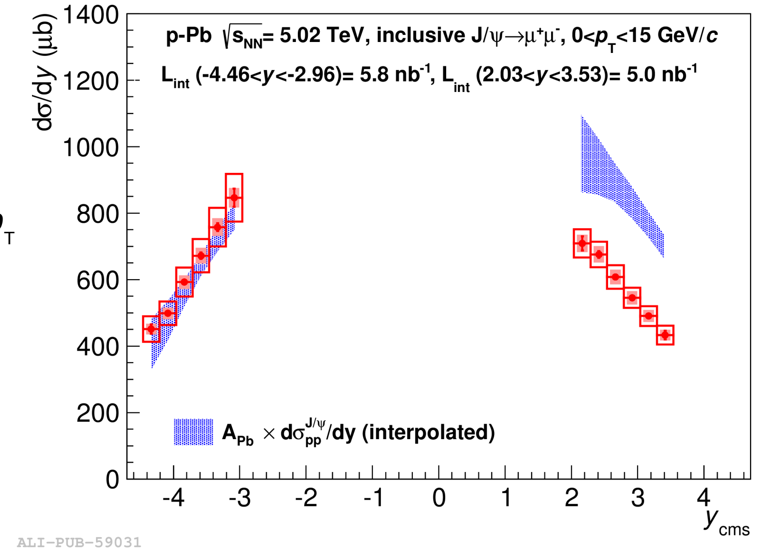


Back-up: pp-reference at $\sqrt{s} = 5.02$ TeV

Dimuons:

- interpolation of ALICE results in pp at $\sqrt{s} = 2.76$ TeV and $\sqrt{s} = 7.0$ TeV in bins of y, p_T
- extrapolation in y, where necessary

  y-ranges only partially overlapping between pp and p-Pb
  cross-checked with approach chosen for the dielectrons



Dielectrons:

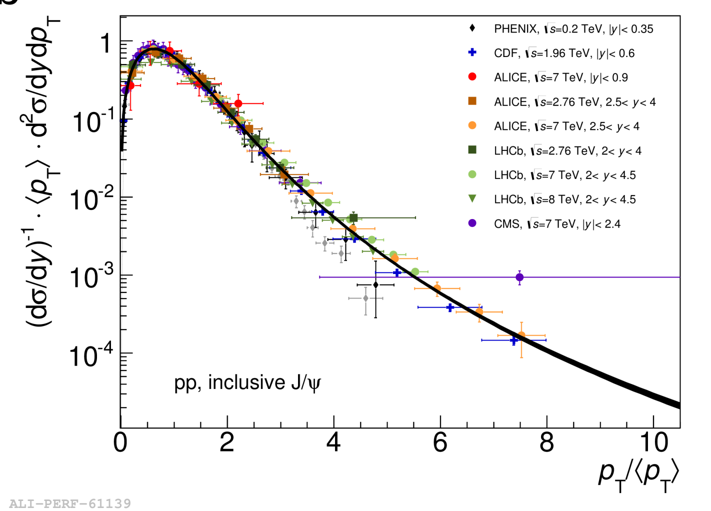
- dσ/dy via interpolation of results (PHENIX, CDF, ALICE) at y≈0:

  BR(J/ψ→ee) x $d\sigma/dy_{pp,y\approx0}$($\sqrt{s} = 5.02$ TeV) = 368 ± 91 nb

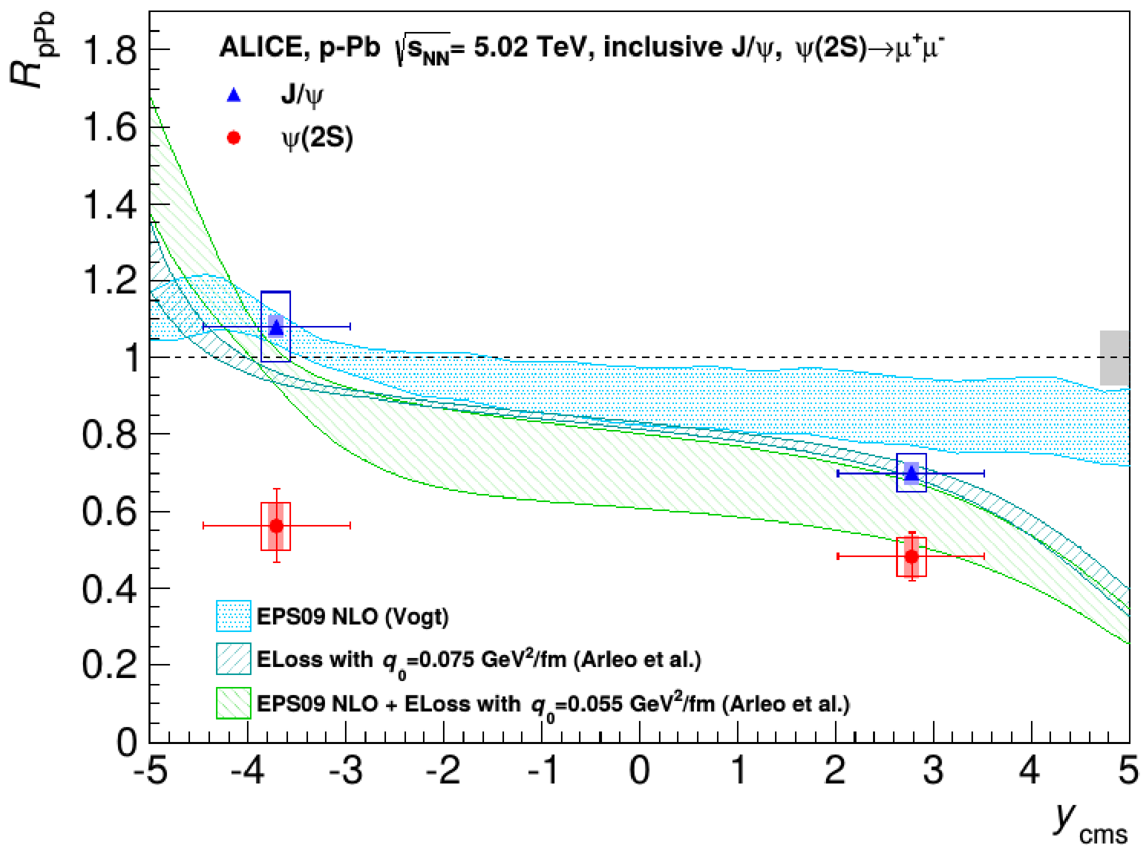
  effect of rapidity shift negligible w.r.t. total uncertainty

- p_T-dependence from phenomenological scaling

  inspired by arXiv:1103.2394



Back-up: R_{pA}: ψ(2S) and J/ψ model comparison



Model calculations for J/ψ: very minor differences expected for ψ(2S)

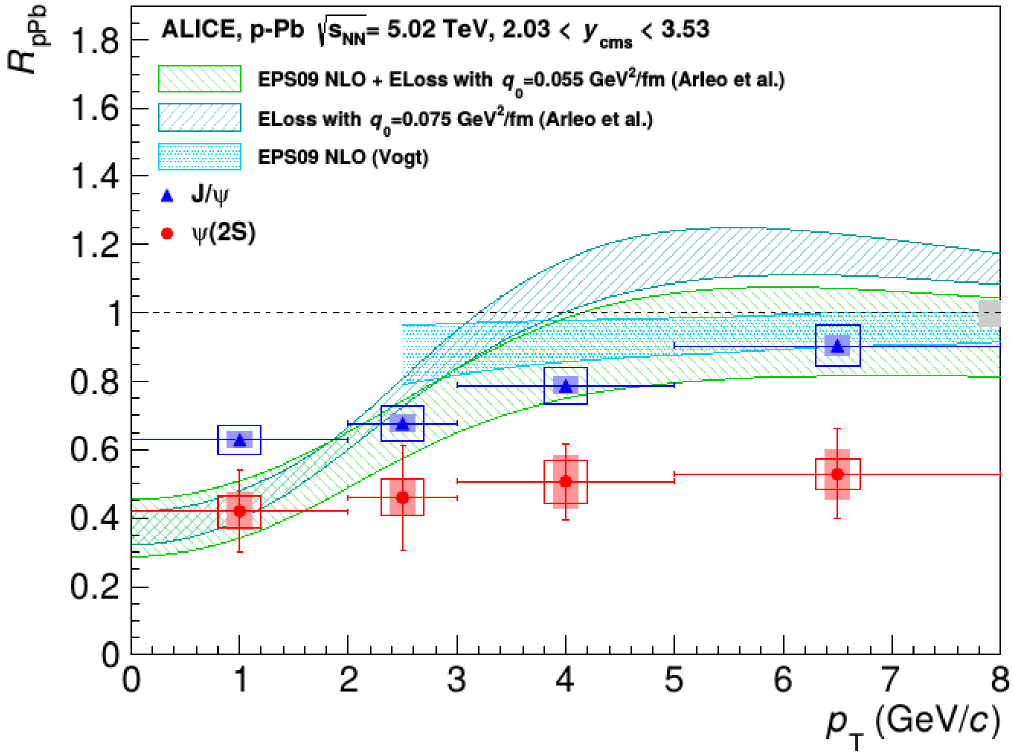
Systematic uncertainties:
- coloured boxes: uncorrelated
- filled areas: (part.) correlated
- grey box: fully correlated between ψ(2S) & J/ψ

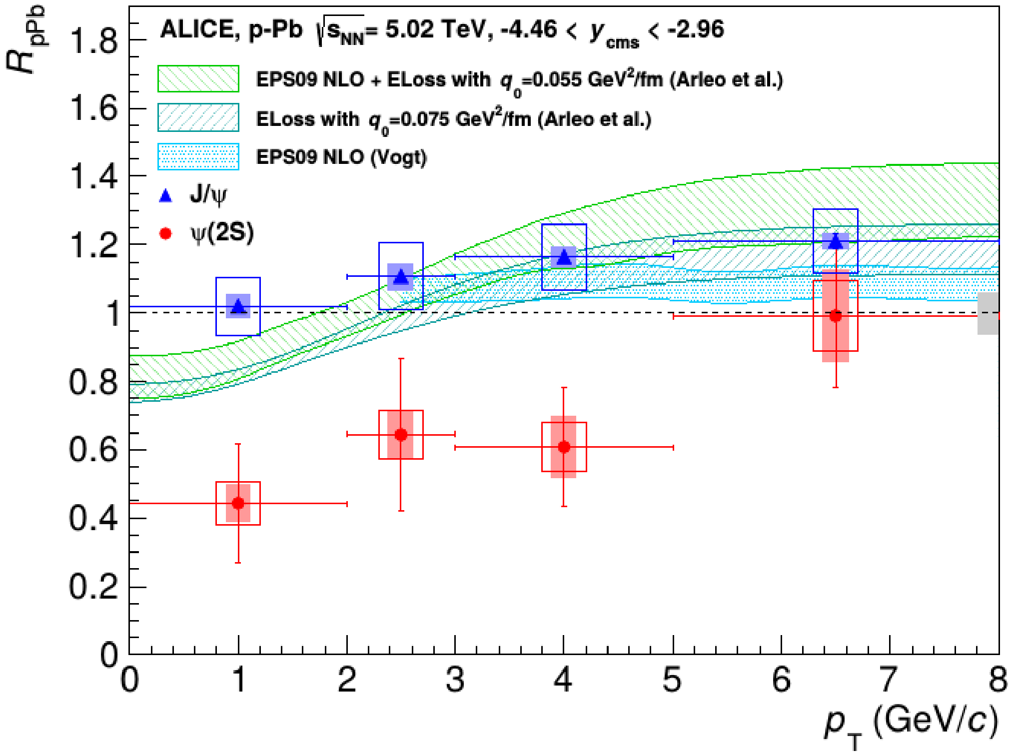
link: arXiv:1405.3796
JHEP 1412 (2014) 073

Shadowing & E-loss models: identical treatment of ψ(2S) & J/ψ

→ no explanation for ψ(2S) behaviour

Back-up: R_{pA}: ψ(2S) and J/ψ model comparison





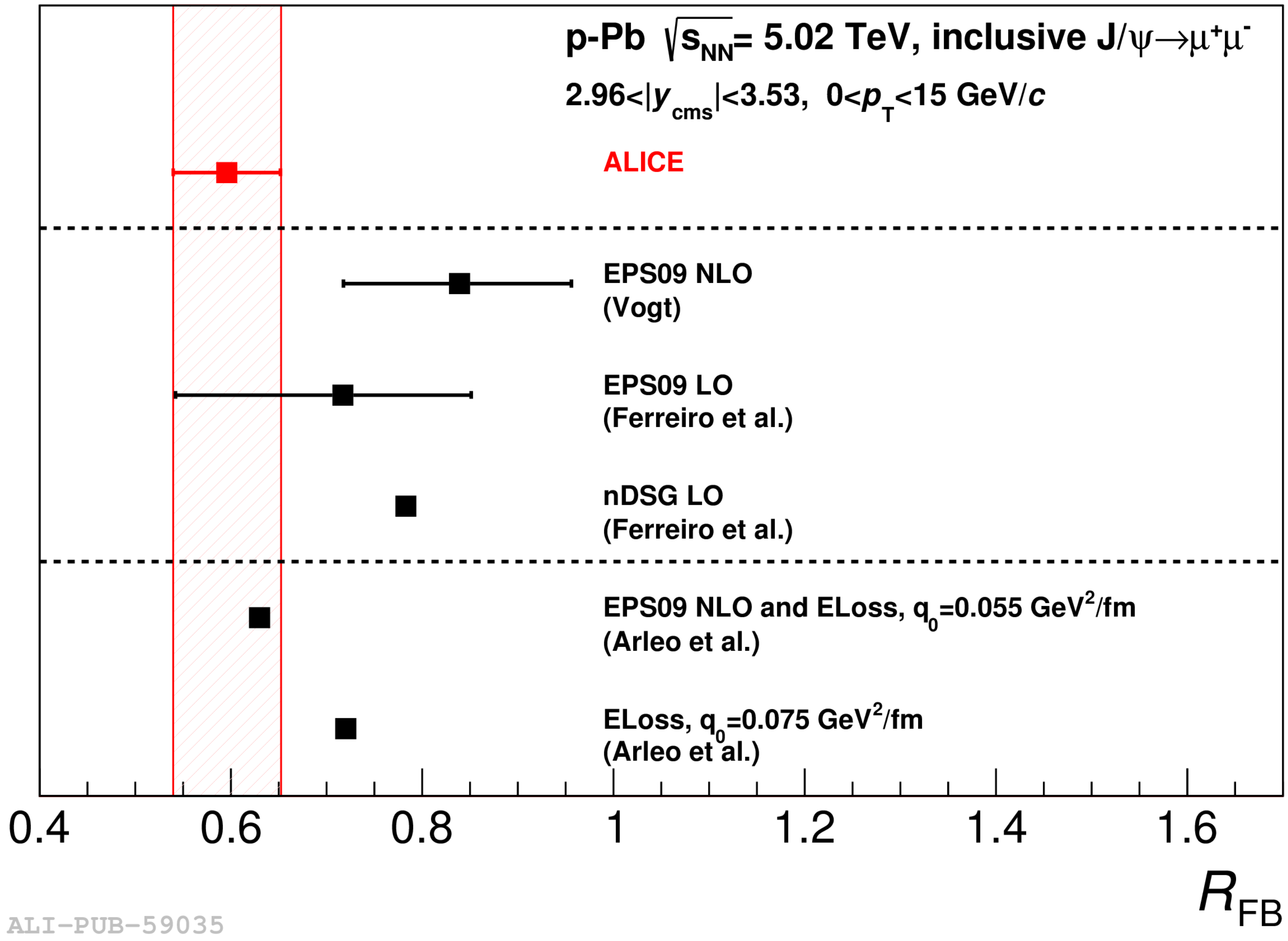
Same uncertainty display as
on previous slide

link: arXiv:1405.3796
JHEP 1412 (2014) 073

Shadowing & E-loss models: identical treatment of ψ(2S) & J/ψ

→ no explanation for ψ(2S) behaviour

Back-up: $R_{FB}^{J/\psi}$



link: arXiv:1308.6726

JHEP 1402 (2014) 073

Back-up: Uncertainties: $R_{pA}^{J/\psi}$ at forward/backward rapidity

	integrated $R_{pA}^{J/\psi}$ forward (backward)	y-differential $R_{pA}^{J/\psi}$
Statistical uncertainty	0.7 % (0.8 %)	1.3 - 3.2 %

Systematic uncertainties:

Source	$\sigma_{pPb}^{J/\psi}$, R_{pPb}	$\sigma_{Pbp}^{J/\psi}$, R_{Pbp}
Uncorrelated		
Tracking efficiency	4	6
Trigger efficiency	2.8	3.2
Signal extraction	1.3 (1.5 – 3.4)	1.2 (1.6 – 3.8)
MC input	1.5 (1.1 – 3)	1.5 (0.9 – 4.2)
Matching efficiency	1	1
F	1	1
$\sigma_{pp}^{J/\psi}$	4.3 (3.1 – 6.0)	4.6 (3.1 – 13.4)
Partially correlated		
σ_{pPb}^{MB}	3.2	3
$\sigma_{pp}^{J/\psi}$	3.7 (2.7 – 9.2)	3.1 (1.2 – 8.3)
Correlated		
B.R.	1	
$\langle T_{pPb} \rangle$	3.6	
$\sigma_{pp}^{J/\psi}$	5.5	

link: arXiv:1308.6726
JHEP 1402 (2014) 073

Back-up: Uncertainties: $R_{pA}^{\psi(2S)}$ at forward/backward rapidity

	integrated $R_{pA}^{\psi(2S)}$ forward (backward)
Statistical uncertainty	12 % (15 %)

Systematic uncertainties:

	B.R.$\cdot\sigma_{pPb}^{\psi(2S)}$	B.R.$\cdot\sigma_{Pbp}^{\psi(2S)}$
Uncorrelated		
Tracking efficiency	4	6
Trigger efficiency	2.8 (2 – 3.5)	3.2 (2 – 3.5)
Signal extraction	9.5 (8 – 11.9)	9.3 (8.6 – 12.7)
MC input	1.8 (1.5 – 1.5)	2.5 (1.5 – 1.7)
Matching efficiency	1	1
N_{MB}	1	1
Partially correlated		
σ_{pPb}^{MB}	3.2	3

link: arXiv:1308.6726
JHEP 1402 (2014) 073

Back-up: systematic uncertainties

Source	$\sigma^{J/\psi}_{pPb}$, R_{pPb} -1.37< y_{cms} <0.43	$\sigma^{J/\psi}_{pPb}$, R_{pPb} 2.03< y_{cms} <3.53	$\sigma^{J/\psi}_{Pbp}$, R_{Pbp} -4.46< y_{cms} <-2.96
Uncorrelated			
Tracking efficiency ($\mu^+\mu^-$)	—	4	6
Trigger efficiency ($\mu^+\mu^-$)	—	2.7–4.1	2.7–4.1
Matching efficiency ($\mu^+\mu^-$)	—	1	1
Reconstruction efficiency (e^+e^-)	4	—	—
Signal extraction	5.5–12.6	2–2.5	2–3.6
MC input	0.3–1.5	0.1–0.4	0.1–1.4
$\sigma^{J/\psi}_{pp}$	4.8–15.7	5.2–9.2	5.2–9.2
Partially correlated			
$\sigma^{J/\psi}_{pp}$ (corr. vs y and p_T)	-	2.8–5.9	2–5.6
Correlated			
B.R. ($J/\psi \to l^+l^-$)	1	1	1
$\mathcal{L}_{int}$(corr. vs. p_T, uncorr. vs. y)	3.3	3.4	3.1
$\mathcal{L}_{int}$(corr. vs. y and p_T)	1.6	1.6	1.6
$\sigma^{J/\psi}_{pp}$	16.6	5.2	5.2

link: arXiv:1503.07179
JHEP 1506 (2015) 055

Back-up: systematic uncertainties

Source of uncertainty	$-4.46 < y_{cms} < -2.96$ cent. (cent. and p_T)	$2.03 < y_{cms} < 3.53$ cent. (cent. and p_T)	$-1.37 < y_{cms} < 0.43$ cent.
Signal extraction	$2.0-2.4\%$ $(2.8-7.1\%)$	$2.0-2.1\%$ $(2.1-5.3\%)$	$3.7-7.4\%$
$\mu^+\mu^-$ tracking (I)	6%	4%	-
$\mu^+\mu^-$ trigger (I)	3.4% $(2.7-3.6\%)$	3% $(2.7-3.6\%)$	-
$\mu^+\mu^-$ matching (I)	1%	1%	-
e^+e^- reconstruction (I)	-	-	4%
MC input (I)	1.5% $(0.1-1.4\%)$	1.5% $(0.1-0.4\%)$	3%
MC input	-	-	1.4%
$F_{2\mu/MB}$ (III)	$1-3.5\%$	$1-2.7\%$	-
Uncertainties related to cross section only			
σ_{MB} (I,II,III)	1.6%	1.6%	1.6%
σ_{MB} (I,III)	3%	3.3%	3.3%
BR (I, II, III)	0.5%	0.5%	0.5%
Uncertainties related to Q_{pPb} only			
$\langle T_{pPb}^{mult} \rangle$ (I,II,III)	3.4%	3.4%	3.4%
$\langle T_{pPb}^{mult} \rangle$ (II,III)	$1.9-7.2\%$	$1.9-7.2\%$	$1.9-5.6\%$
σ_{pp} (I)	5.3% $(8.1-13\%)$	5.7% $(8.2-11\%)$	17%
σ_{pp} (I, II, III)	5.5%	5.5%	-

link: arXiv:1506.08808

Back-up: systematic uncertainties

Source	Backward rapidity	Forward rapidity
Signal extraction: $\Upsilon(1S)$	5%–6% (II)	4%–6% (II)
Signal extraction: $\Upsilon(2S)$	12% (II)	12% (II)
Input MC parameterization: $\Upsilon(1S)$	2%–5% (II)	4%–6% (II)
Input MC parameterization: $\Upsilon(2S)$	5% (II)	5% (II)
Tracking efficiency	6% (II)	4% (II)
Trigger efficiency	2% (II)	2% (II)
Matching efficiency	1% (II)	1% (II)
$\sigma_{pp}^{\Upsilon(1S)}$ (interpolation)	11%–13% (II)	7%–12% (II)
$\mathscr{L}$ (correlated)	1.6% (I)	1.6% (I)
$\mathscr{L}$ (uncorrelated)	3.1% (II)	3.4% (II)

link: arXiv:1410.2234

PLB 740 (2015) 105-117

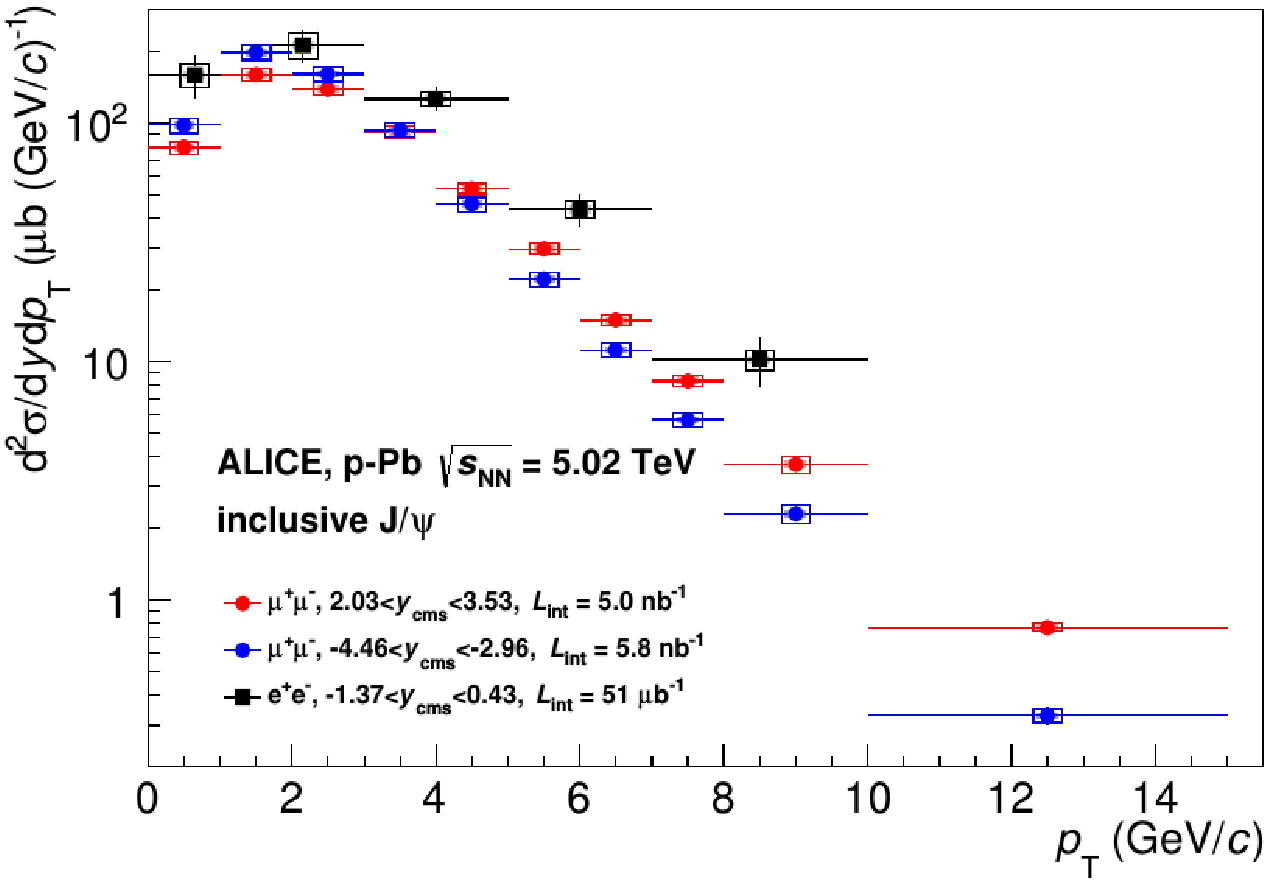
Back-up: Uncertainties: relative yield and $\langle p_T \rangle$ of J/ψ vs midrapidity multiplicity

Only uncorrelated uncertainties remain in relative quantities to first order

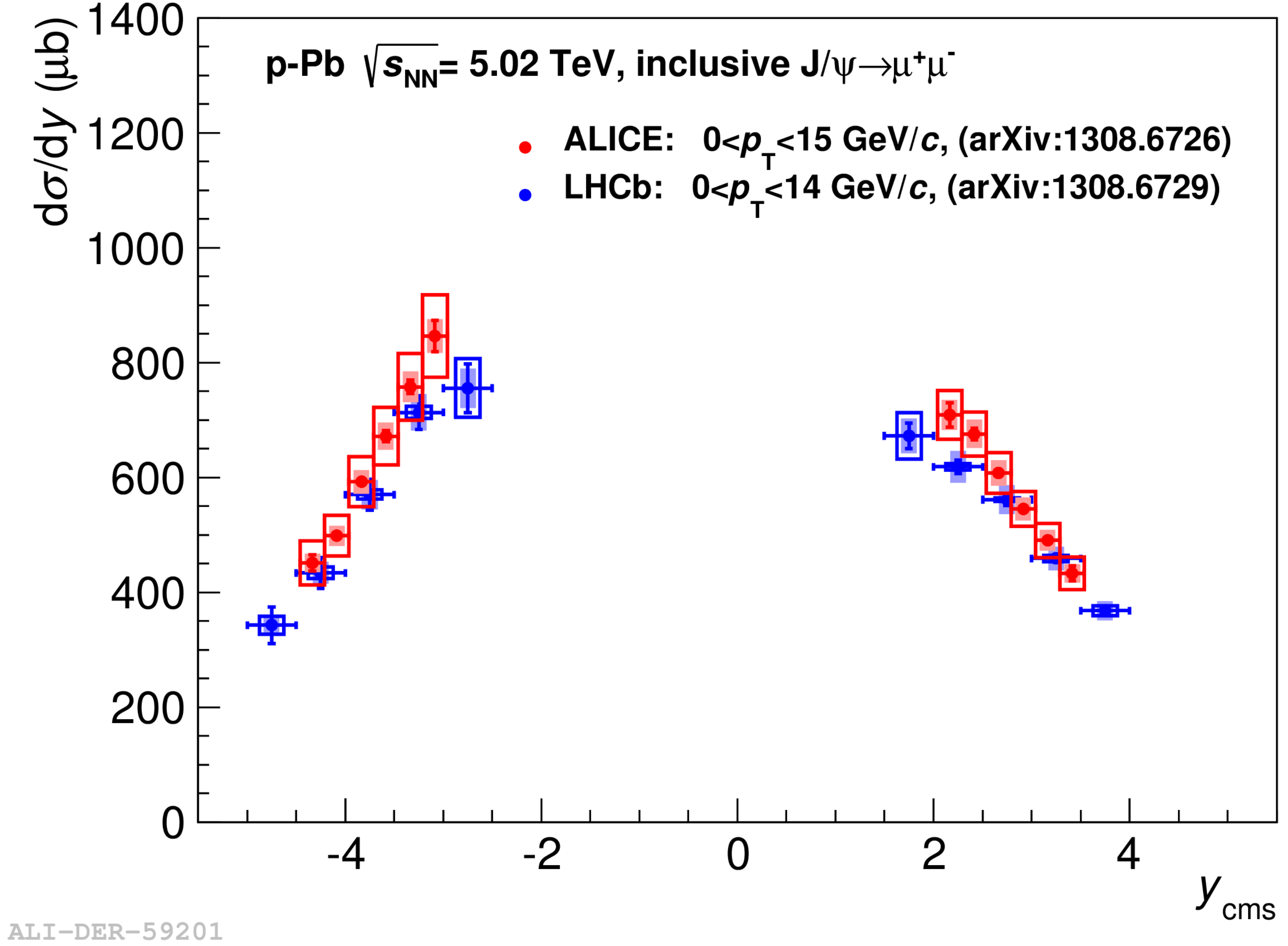
Systematic uncertainties	**forward rapidity**	**backward rapidity**
Signal method N_{bin}	1.5-3.3 %	1.5-4.6 %
Signal extraction $N_{bin}^{J/\psi}/N^{J/\psi}$	1.5-3.3 %	1.5-4.6 %
$\langle p_T \rangle$ MC input	2 %	2 %
Extraction $\langle p_T \rangle / \langle p_T \rangle^{int}$	0.1-0.4 %	0.1-1.2 %
F	1-7 %	1-4%
$\langle dN_{ch}/d\eta \rangle$	3.9 %	3.9 %
Pile-up	1-4 %	1-2 %

Prelim. for QM'14
Link: Nucl.Phys. A931 (2014) 628-632

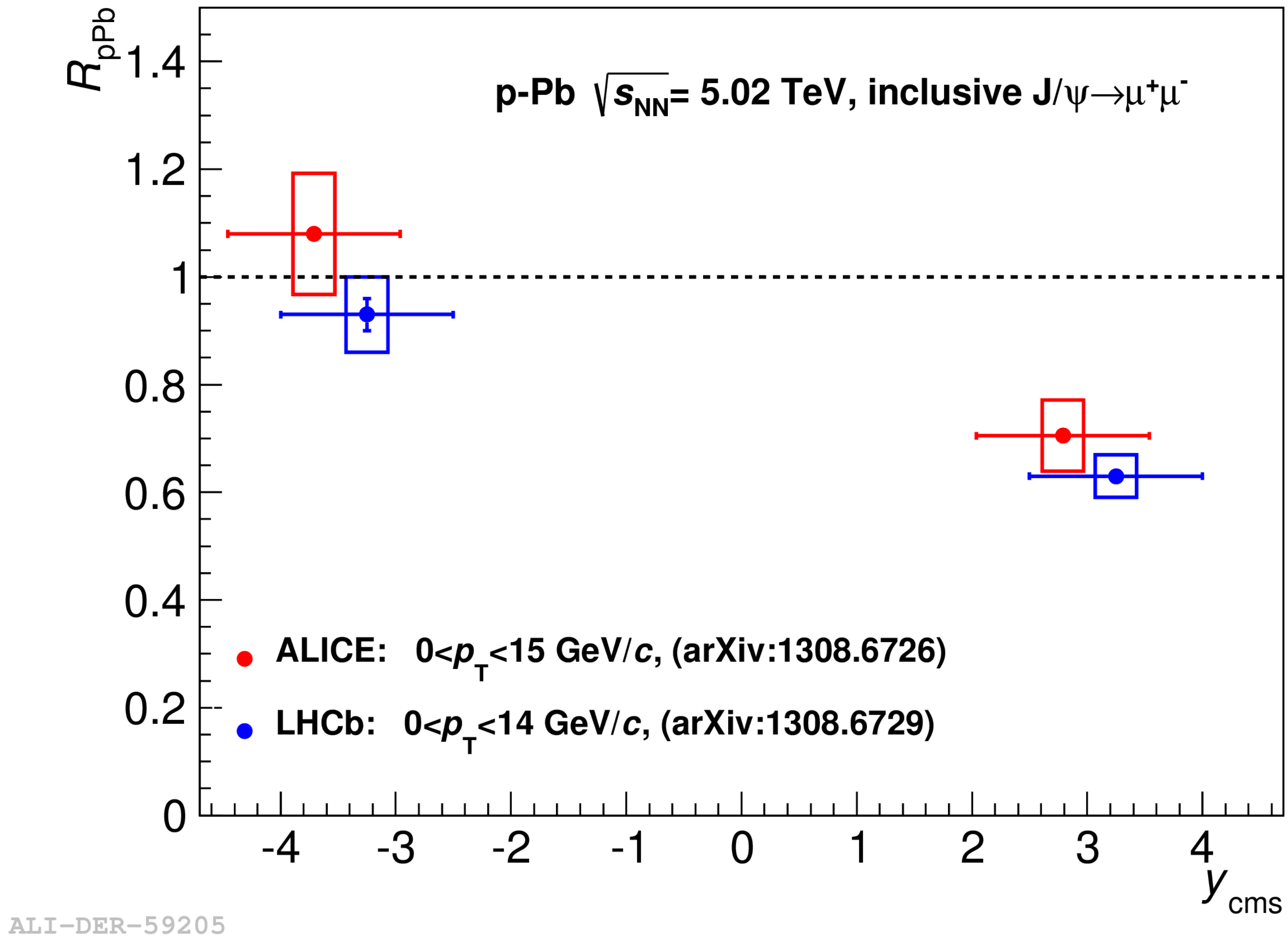
Back-up: $d^2\sigma/dydp_T{}^{J/\psi}_{pA}$



$d\sigma/dy^{J/\psi}_{pA}$: comparison with LHCb



$R_{pA}^{J/\psi}$: comparison with LHCb



$d^2\sigma/dydp_T{}^{J/\psi}{}_{pA}$: comparison with LHCb