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

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Initial Stages 2014

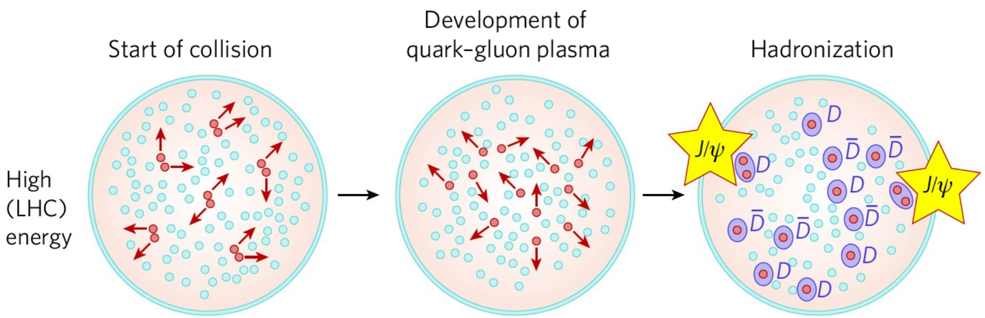
J/ψ in nucleus-nucleus collisions

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



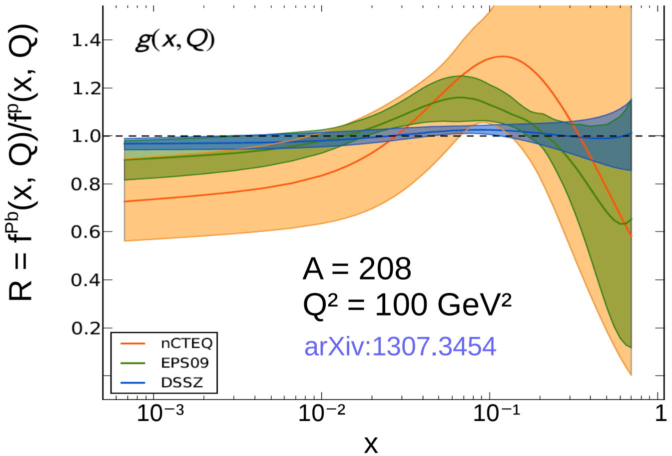
P. Braun-Munzinger and J.Stachel, Nature 448 (2007)

- 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

Clear interpretation: pA as baseline for non-QGP nuclear effects

Predicted J/ψ modifications in p-Pb at the LHC



leading twist gluon shadowing

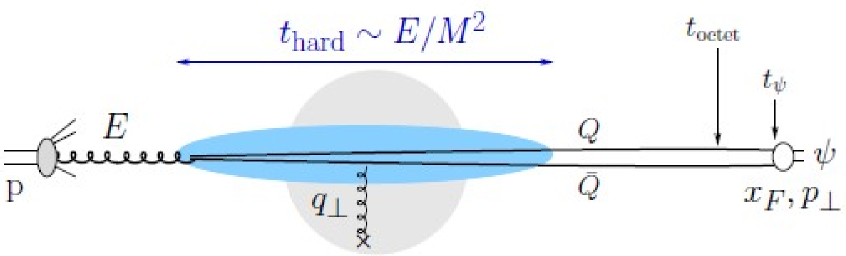
Color Evaporation Model (CEM) R. Vogt, , link: arXiv:1003.3497 Phys.Rev.C 81 (2010)
Color Singlet Model (CSM) E. Ferreiro et al., link: arXiv:1305.4569 Phys.Rev.C 88 (2013)

saturation via Colour Glass Condensate (CGC)

H. Fujii et al., arXiv:1304.2221 Nucl.Phys. A915 (2013),
also soon in NRQCD approach: R. Venogopalan et al., link: talk at Quarkonium '14

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

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)

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

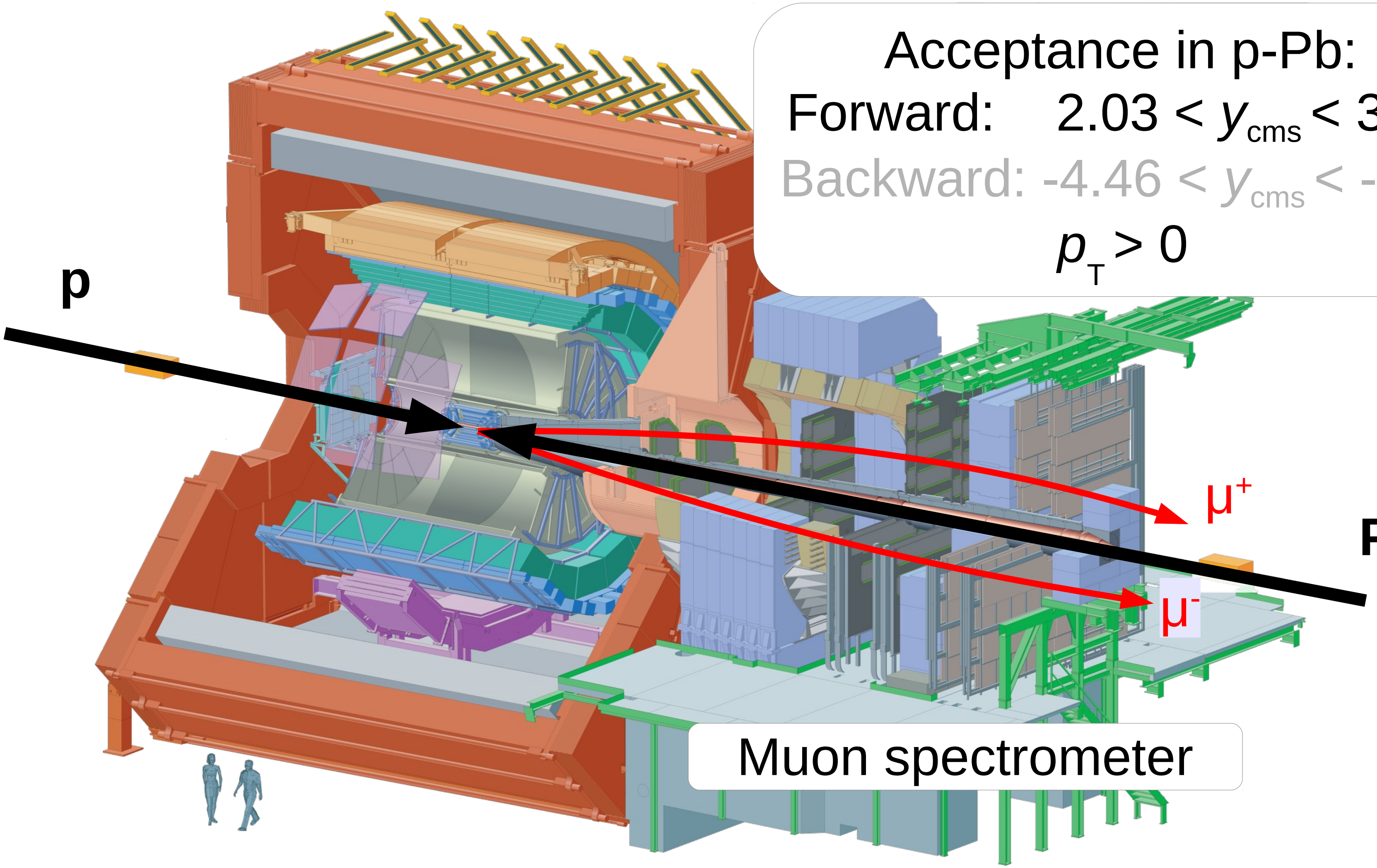
Charmonium with ALICE at the LHC

Acceptance in p-Pb:

Forward: $2.03 < y_{cms} < 3.53$

Backward: $-4.46 < y_{cms} < -2.96$

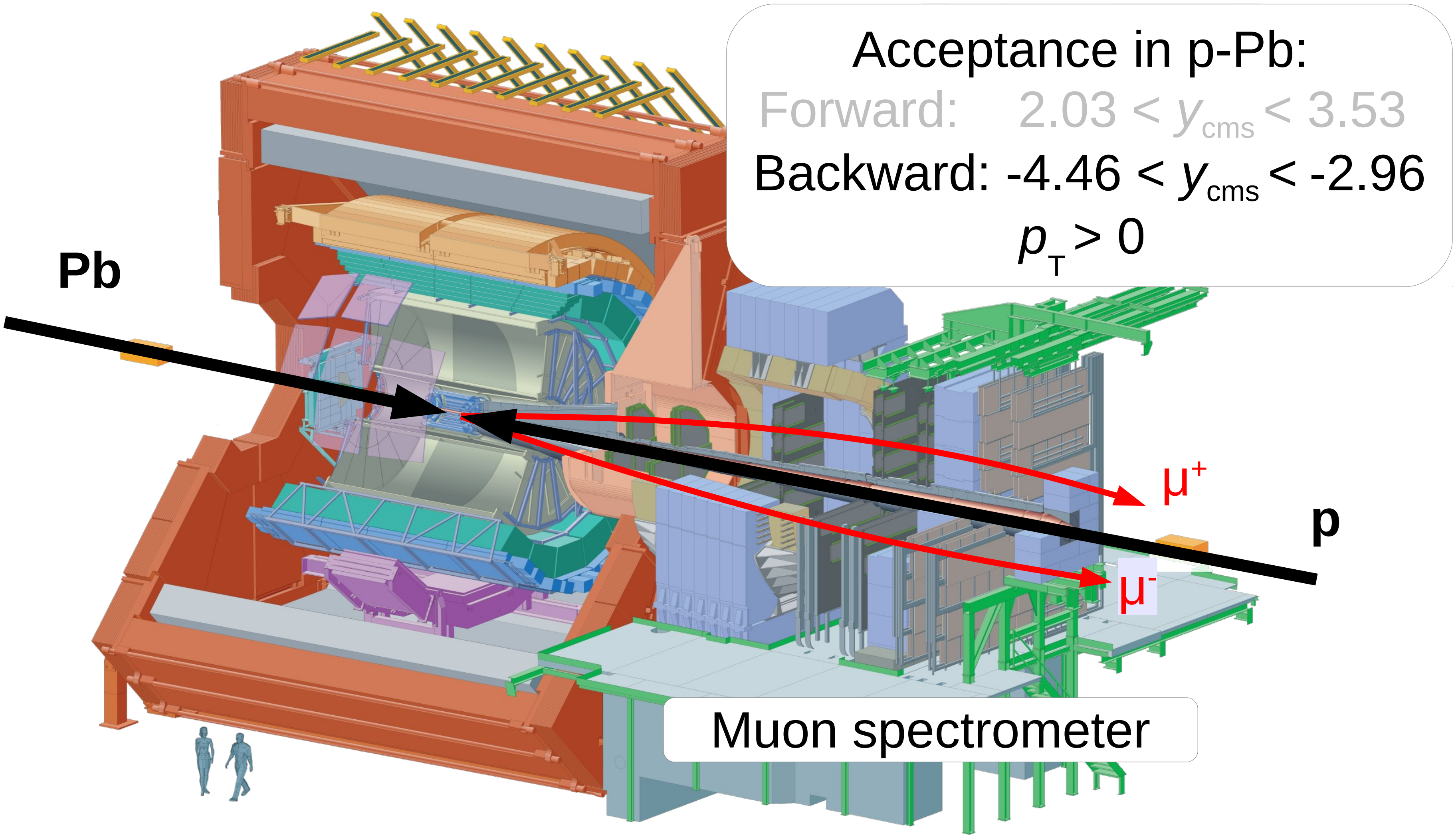
$p_T > 0$



Inclusive J/ψ and ψ(2S) down to $p_T = 0$ GeV/c at forward rapidity

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

Charmonium with ALICE at the LHC



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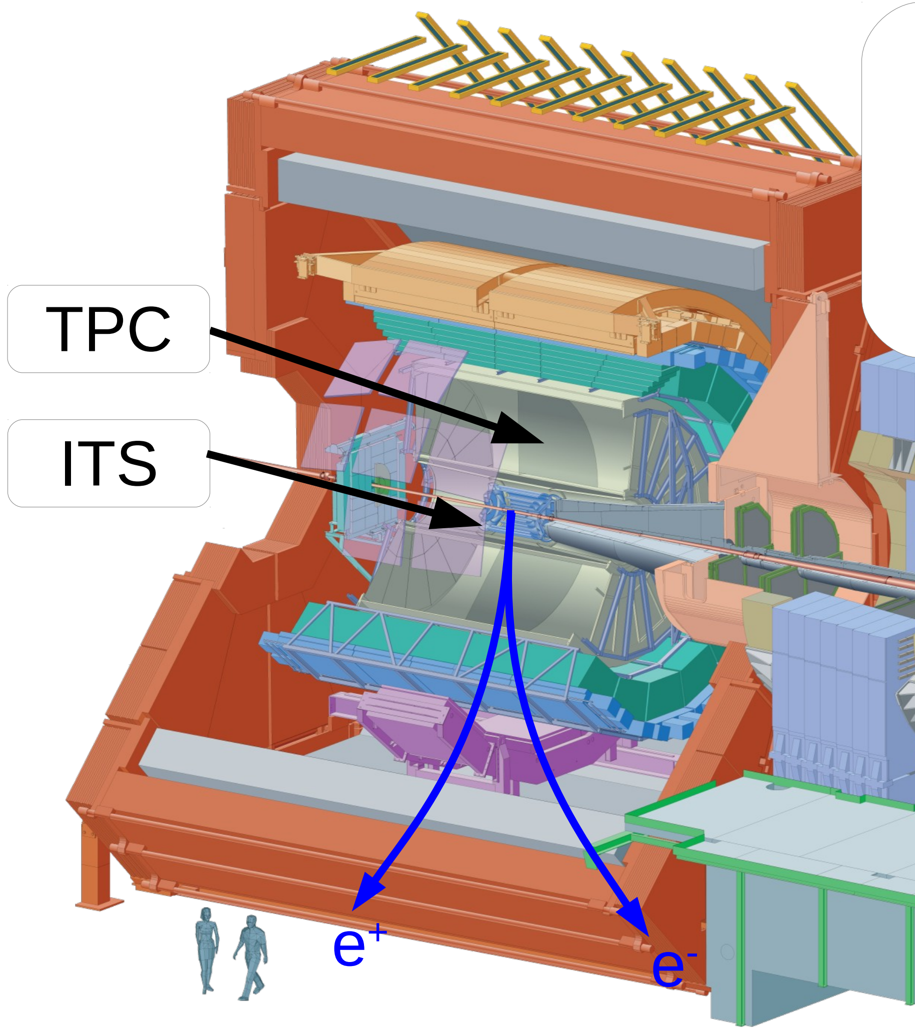
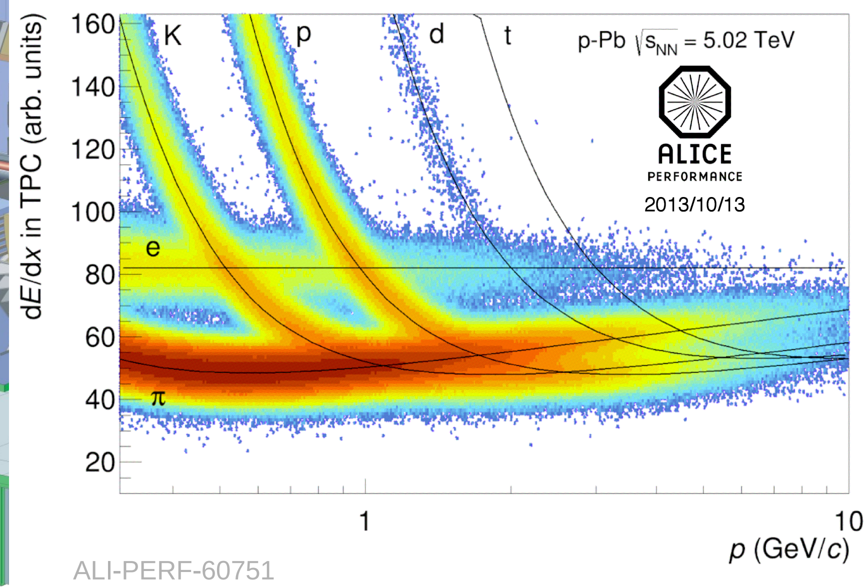


Acceptance in p-Pb:

$-1.37 < y_{cms} < 0.43$

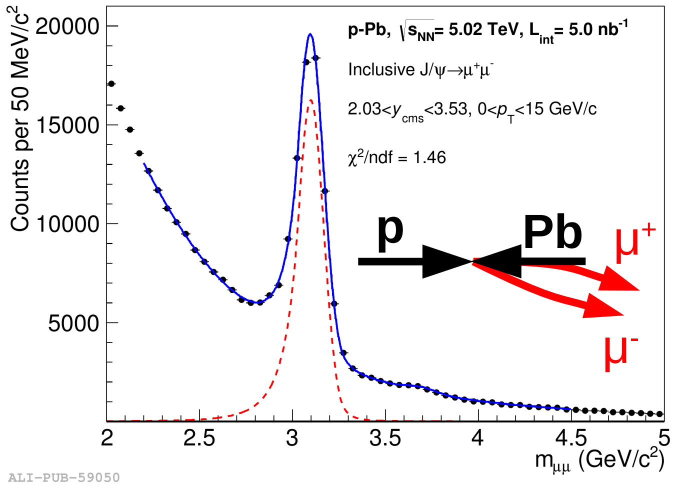
$p_T > 0$

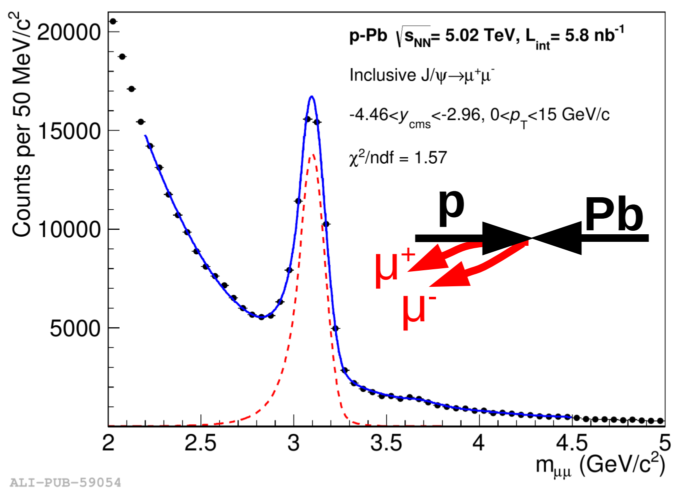


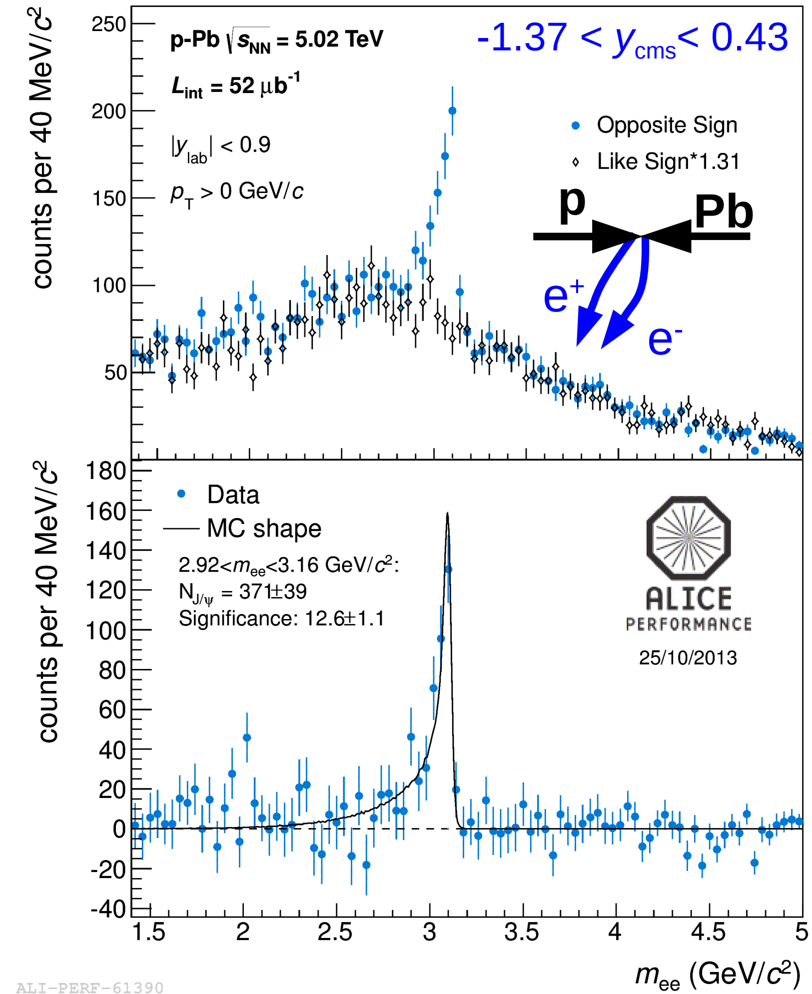
Inclusive J/ψ down to p_T= 0 GeV/c at midrapidity

Prompt and non-prompt J/ψ down to low p_T

2013 p-Pb run







Dimuons: dedicated trigger

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

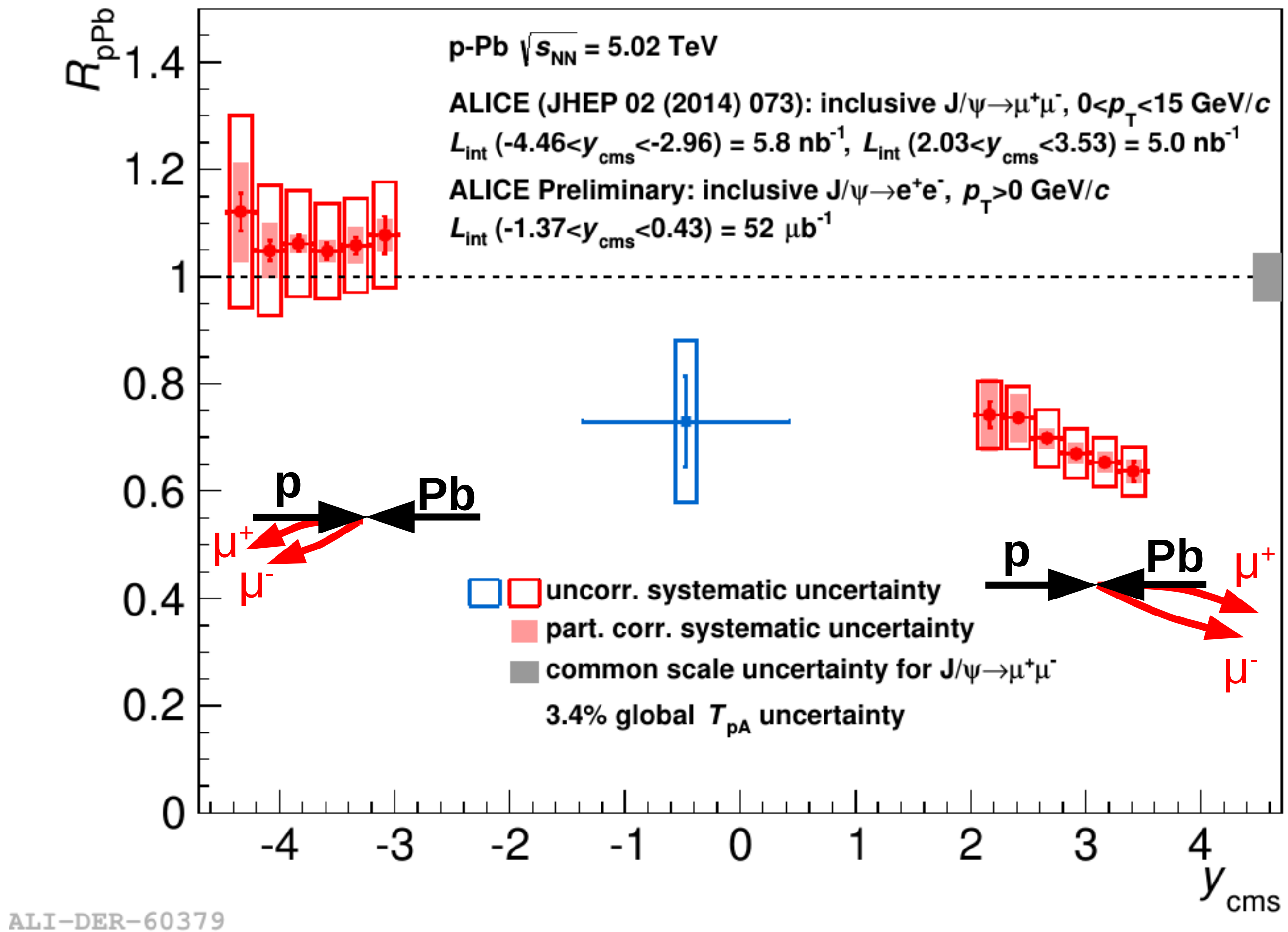
L_{int} = 5.8 nb^{-1} (backward)

Dielectrons: Minimum Bias

L_{int} = 52 μb^{-1}

all plots p_T-and y-integrated here

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



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

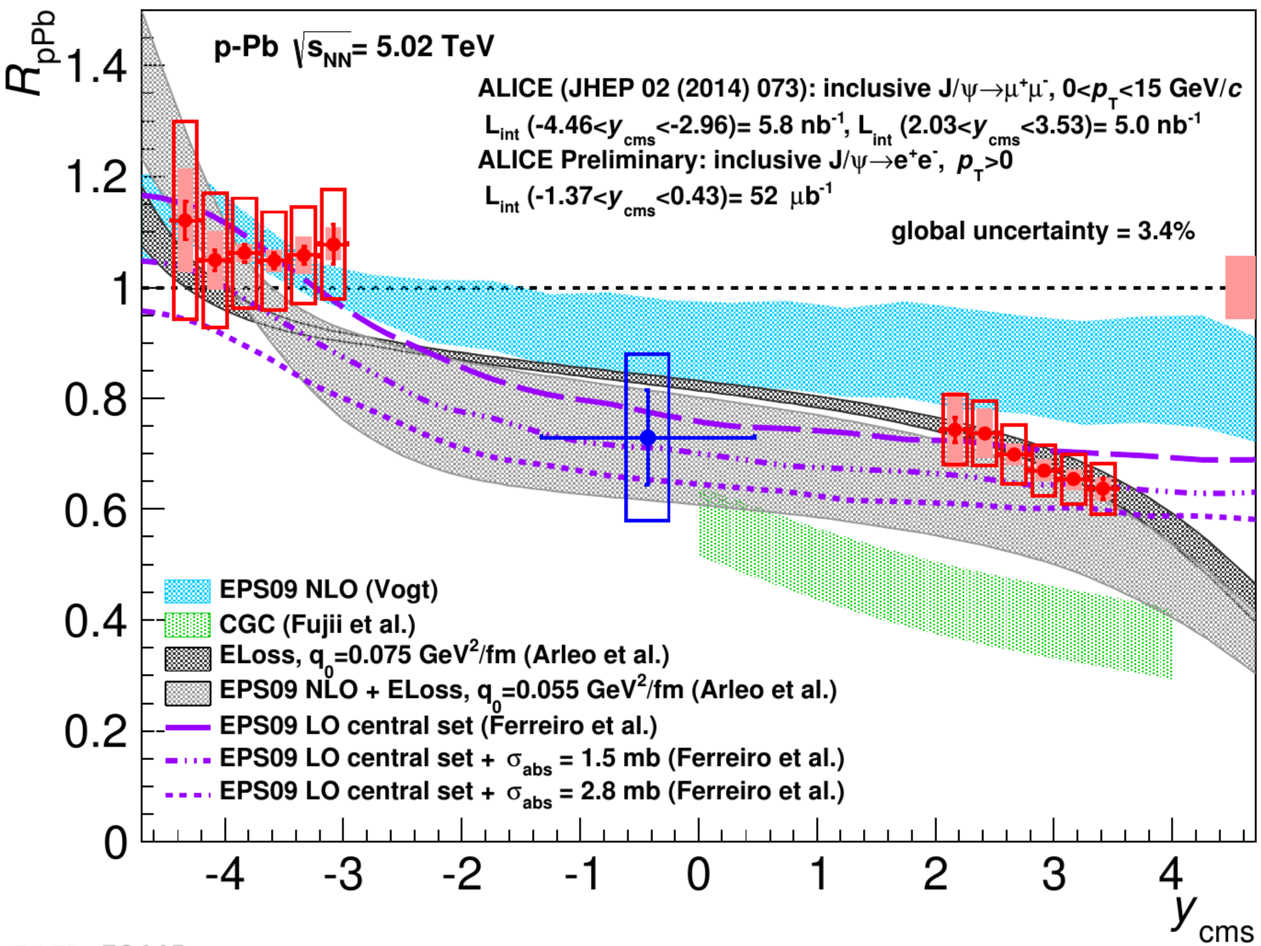
Prelim. HP' 13 e^+e^-:
link: arXiv:1404.1615

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

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



ALI-PREL-73445

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

Prelim. HP' 13 e^+e^-:
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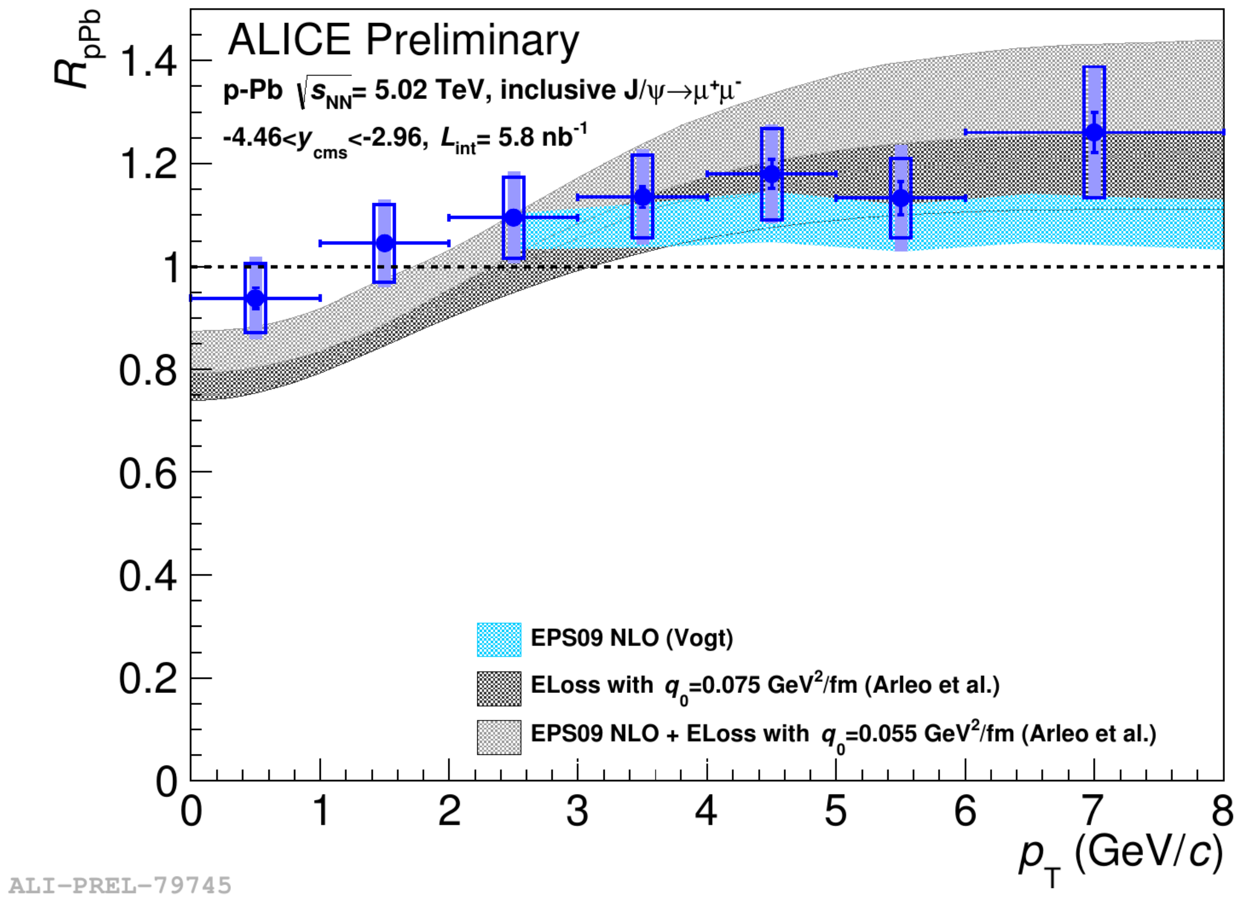
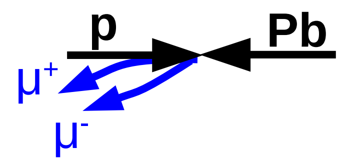
Forward and backward rapidity results consistent with LHCb:
link: arXiv:1308.6729
JHEP 1402 (2014) 072

- EPS09 shadowing combined with CEM/CSM consistent with data
- energy loss models with/without shadowing consistent with data
- this CGC-based model disfavoured

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

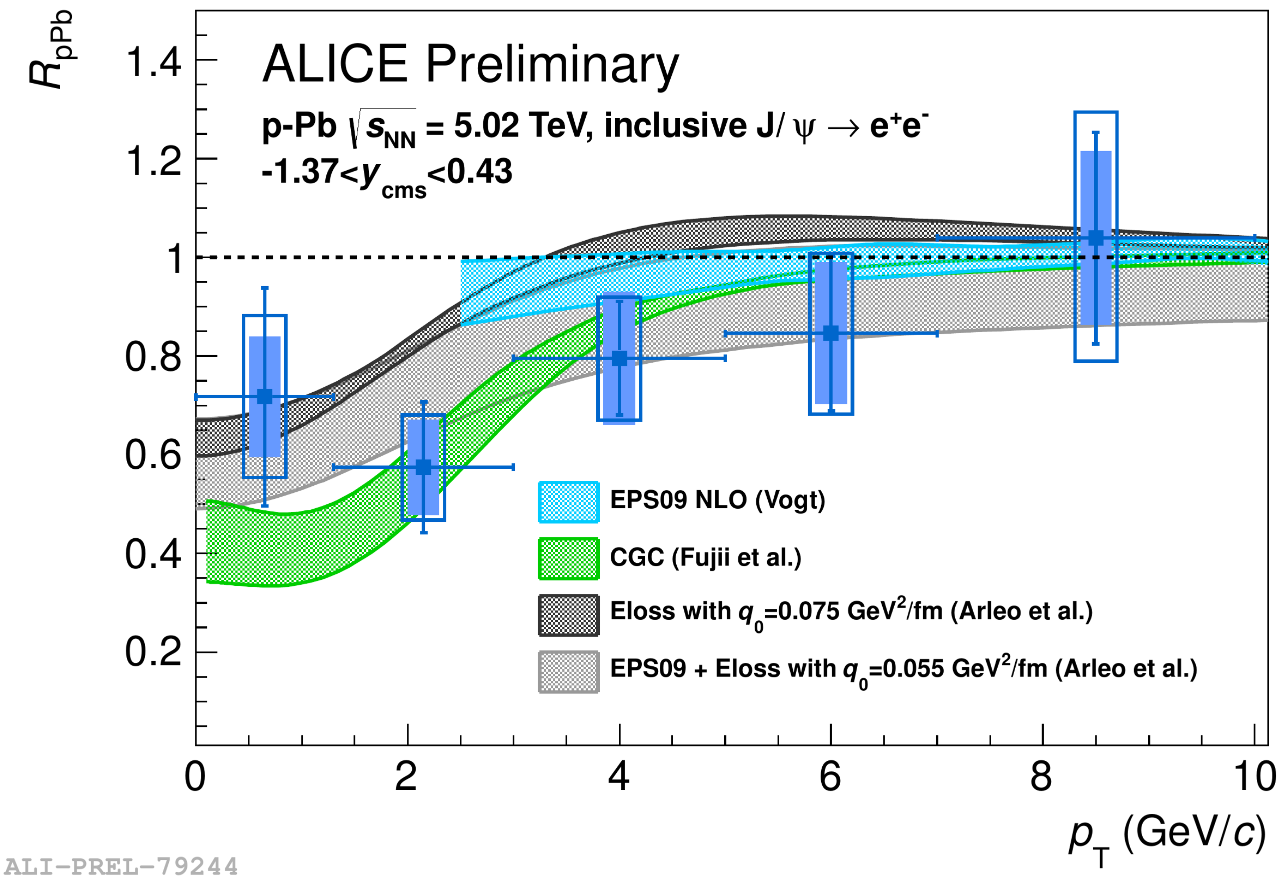


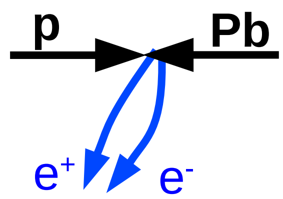


Systematic uncertainties:
- coloured boxes: uncorrelated
- filled areas: (part.) correlated

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

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

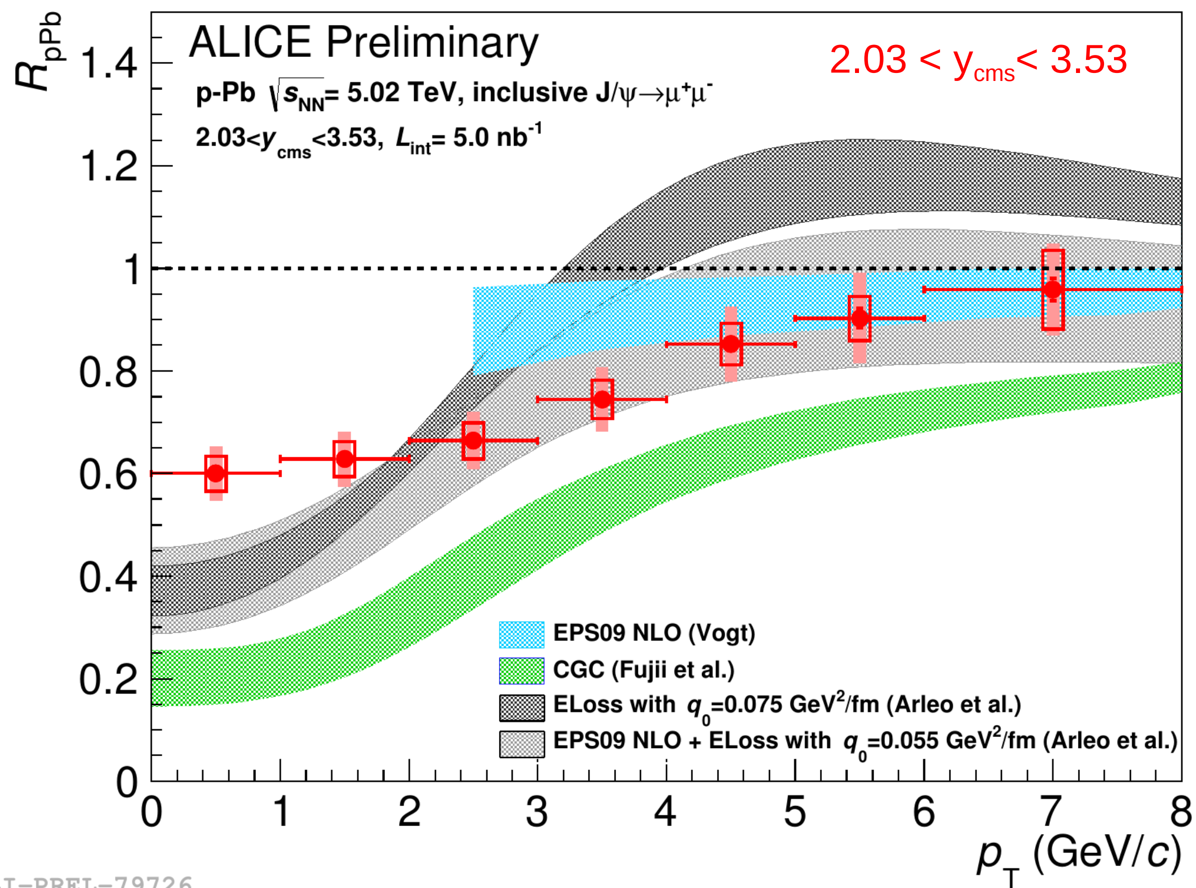


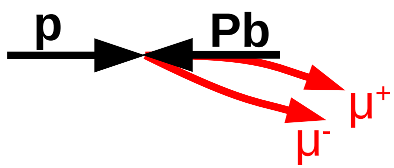


Systematic uncertainties:
- coloured boxes: uncorrelated
- filled areas: correlated

- rise of R_{pPb} with increasing p_T
- EPS09 shadowing with CEM production consistent with data
- coherent energy loss models consistent with data
- this CGC-based model consistent with data in this rapidity range

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

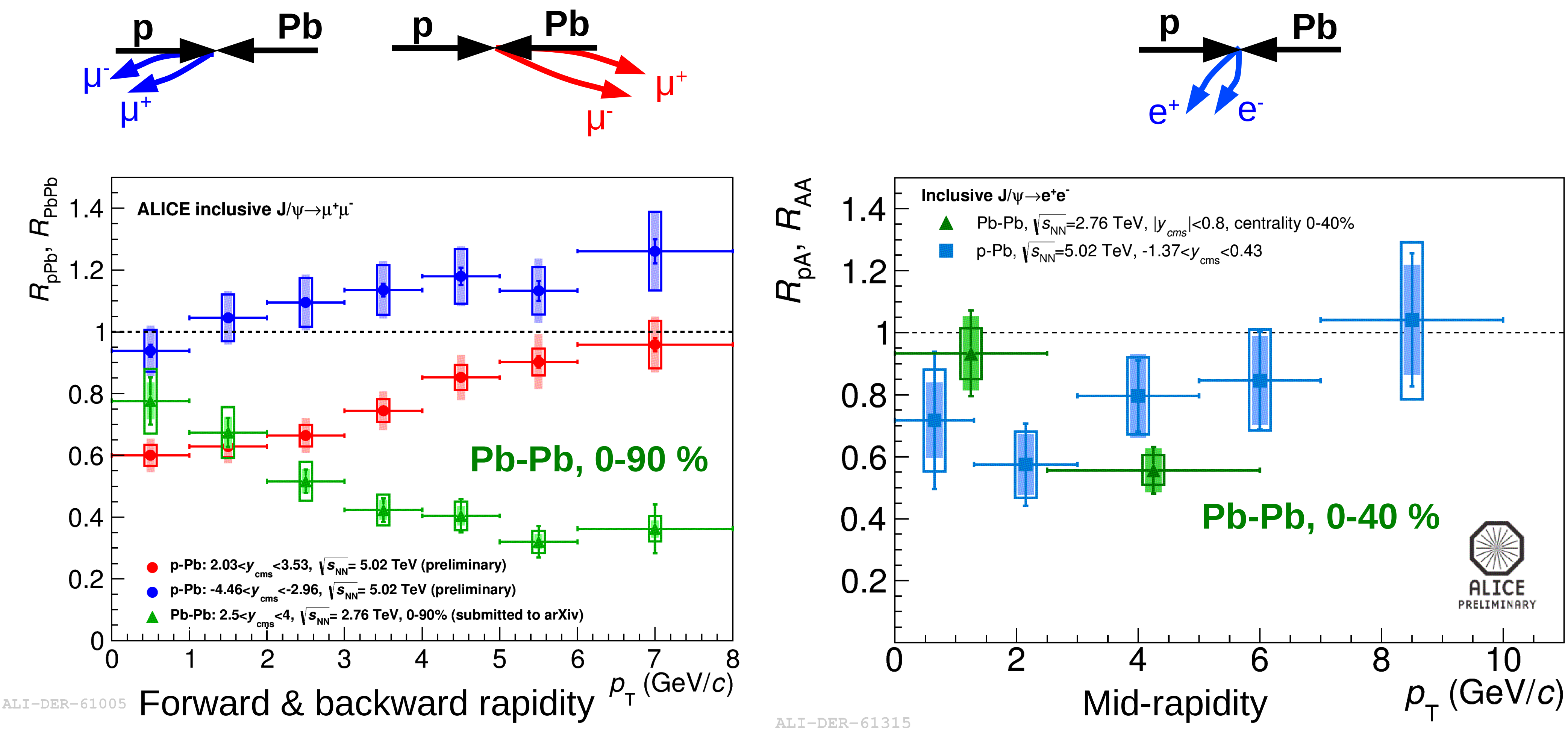




Systematic uncertainties:
- coloured boxes: uncorrelated
- filled areas: (part.) correlated

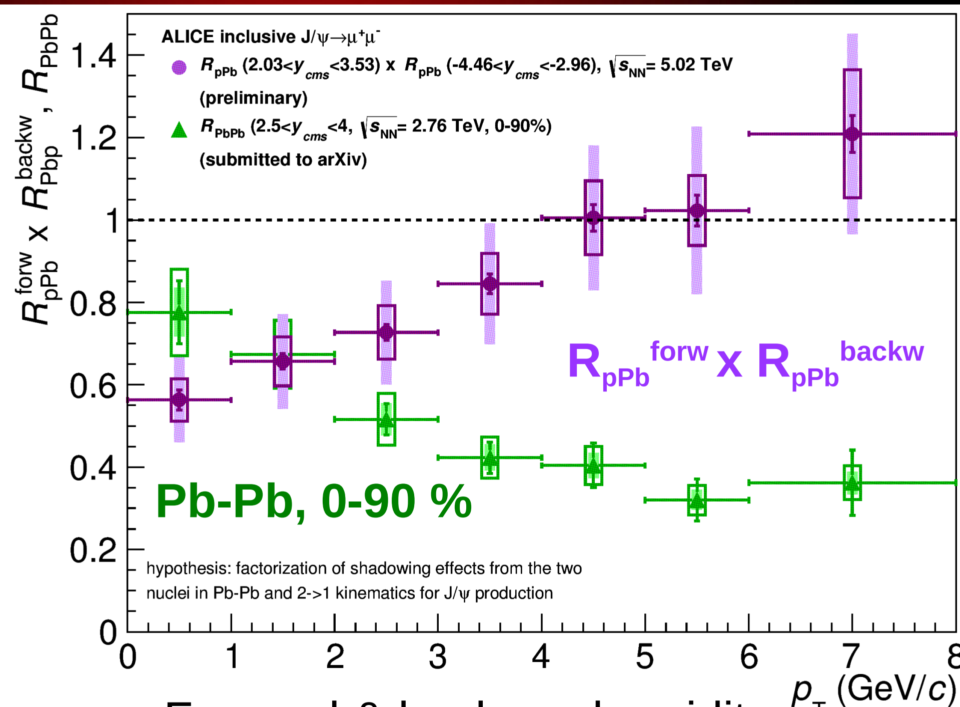
- similar pattern as at midrapidity
- consistent with EPS09 shadowing with CEM for p_T > 4 GeV/c
- underpredicted by energy loss models at low p_T with/without shadowing
- underpredicted by this CGC-based model

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

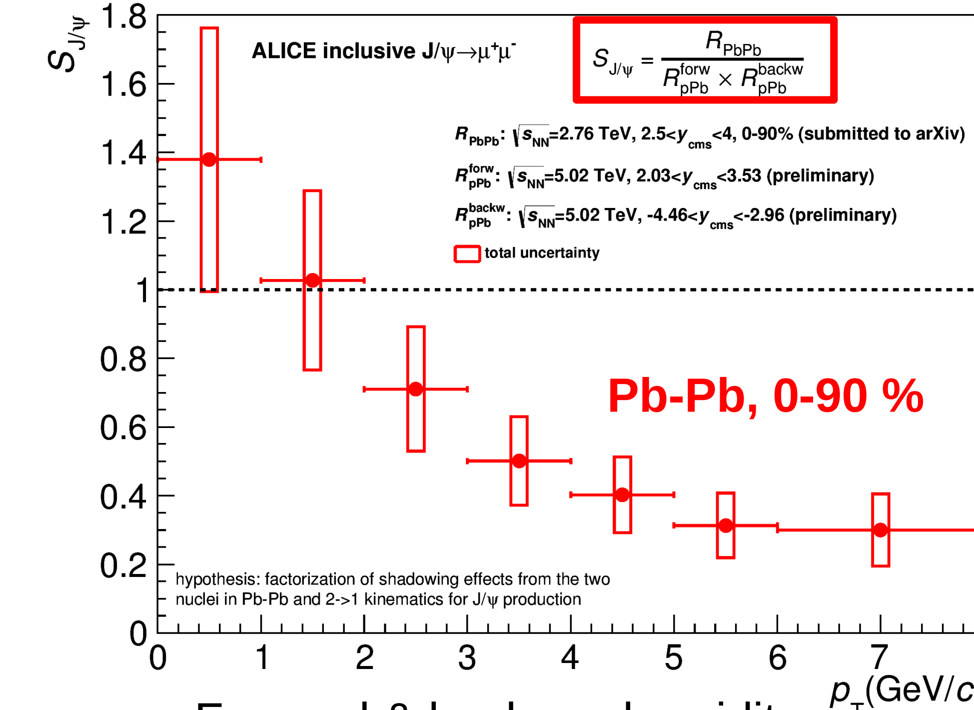


- different p_T-dependences of nuclear modification factor in Pb-Pb and p-Pb at forward and backward rapiditiy

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



Forward & backward rapidity



Forward & backward rapidity

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 as nucl. effects in pA)

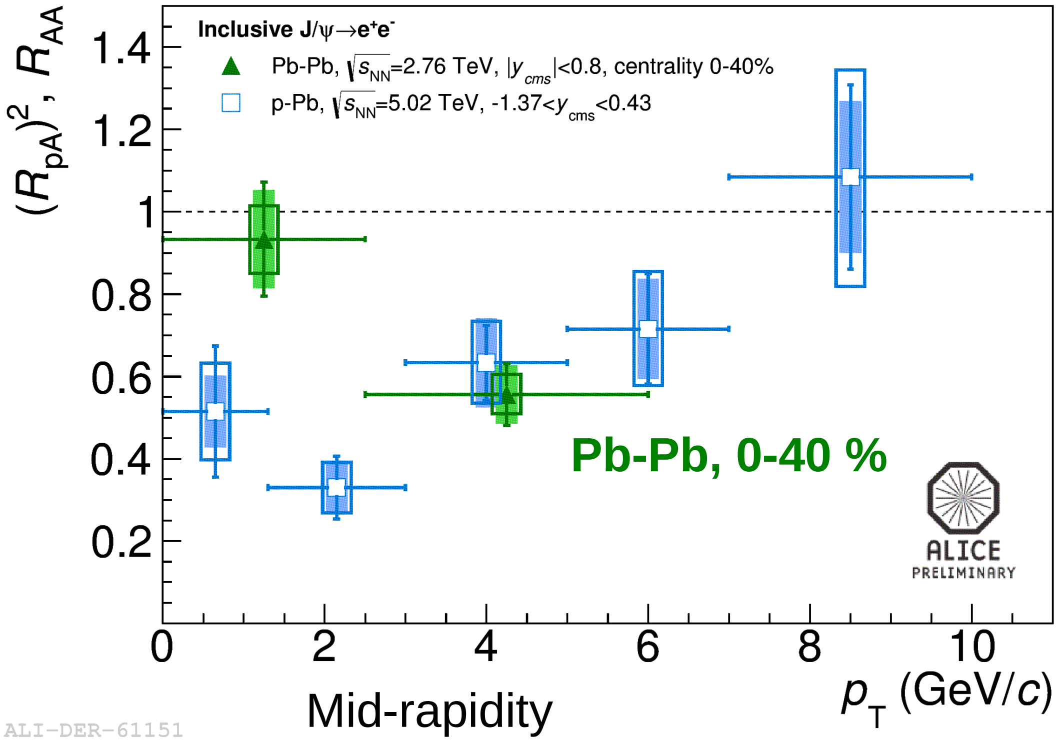
→ R_{pPb}^{forw} x R_{pPb}^{backw} (R_{pPb}^{2}): can be used as Pb-Pb expectation

→ **enhancement at low-p_T + suppression at high-p_T in Pb-Pb**

'extrapolation' also approximate for 2 → 2 kinematics within CEM at finite p_T

→see talk by R. Vogt at Quarkonium 2014: link

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



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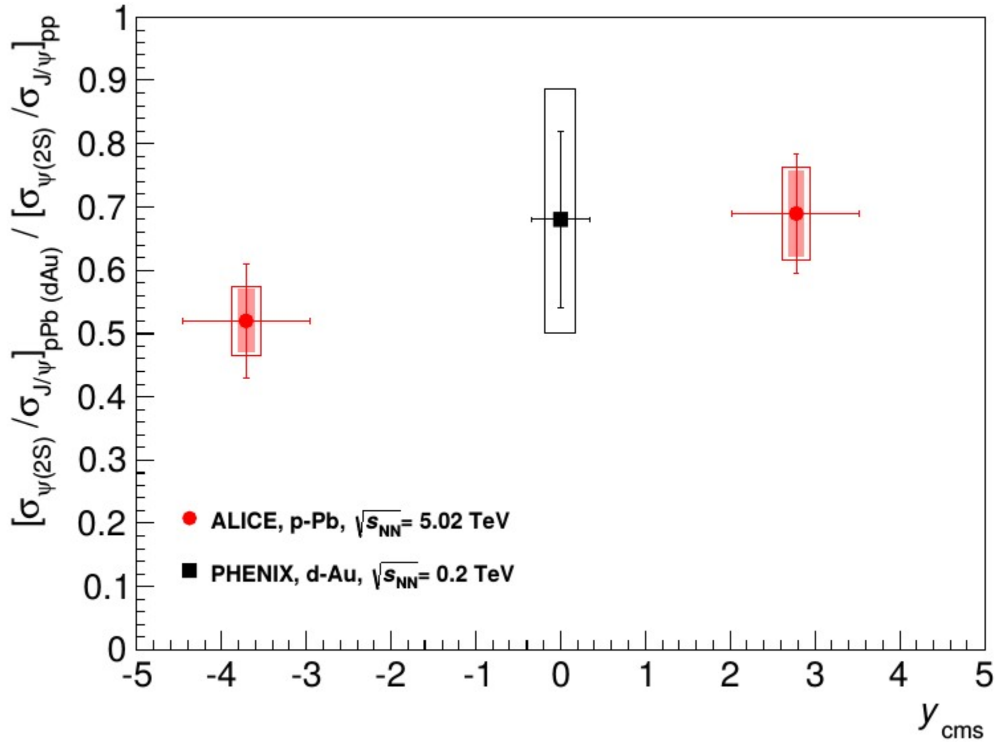
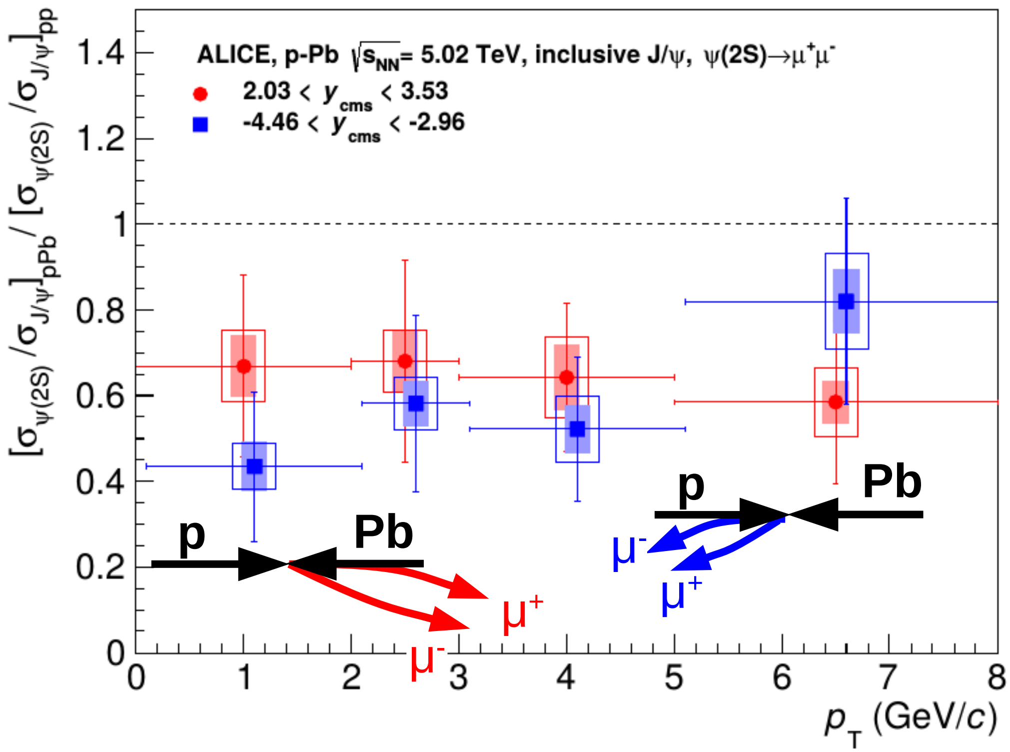
ψ(2S) in p-Pb: more suppressed than J/ψ





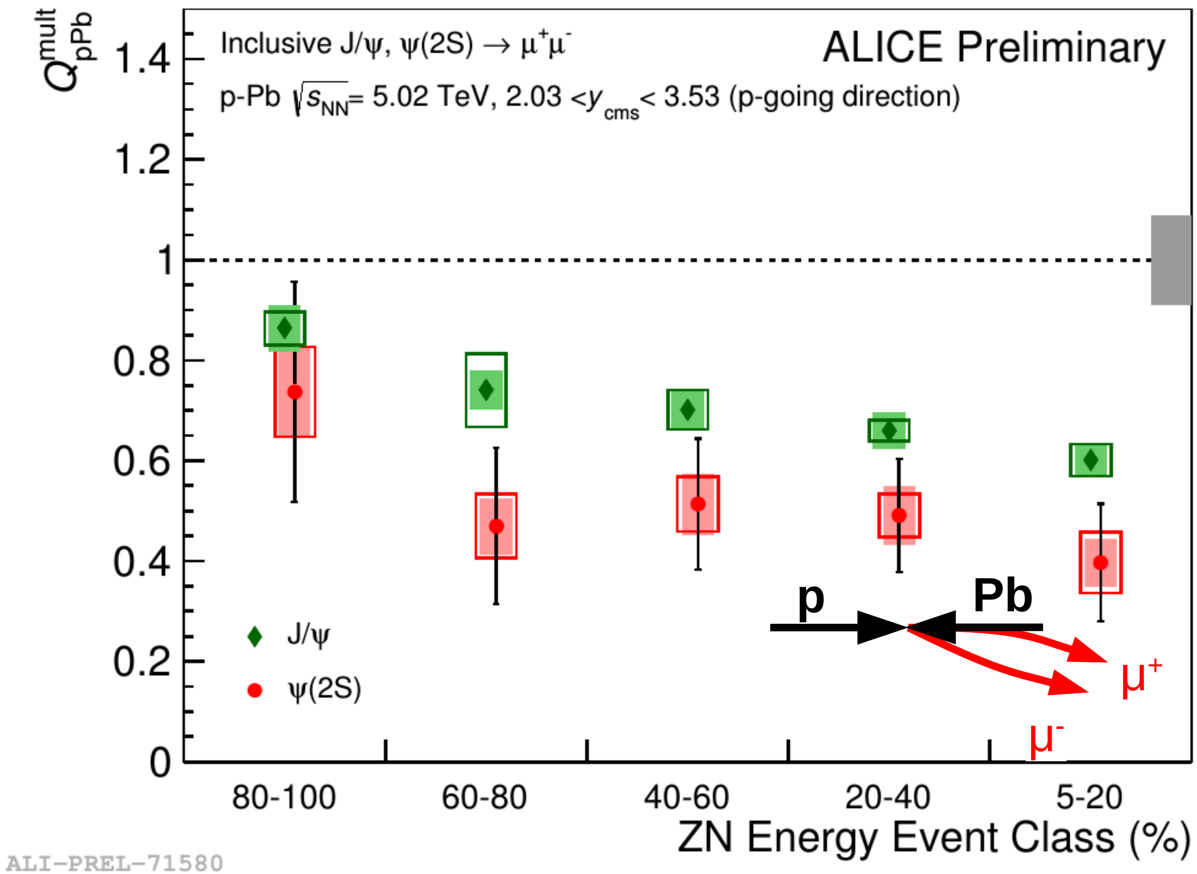
link: arXiv:1405.3796

Accepted by JHEP

- Decrease of ψ(2S)/J/ψ-ratio from pp to p-Pb
- Hint of rapidity dependence, no dependence on p_T within uncertainties
- 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

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



'event' activity dependence called Q_{pPb} instead of R_{pA} due to weaker correlation between estimator and geometry than in AA, and due to biases

ALICE: slicing events in signal from neutron energy measured by the Zero Degree Calor. to avoid biases:

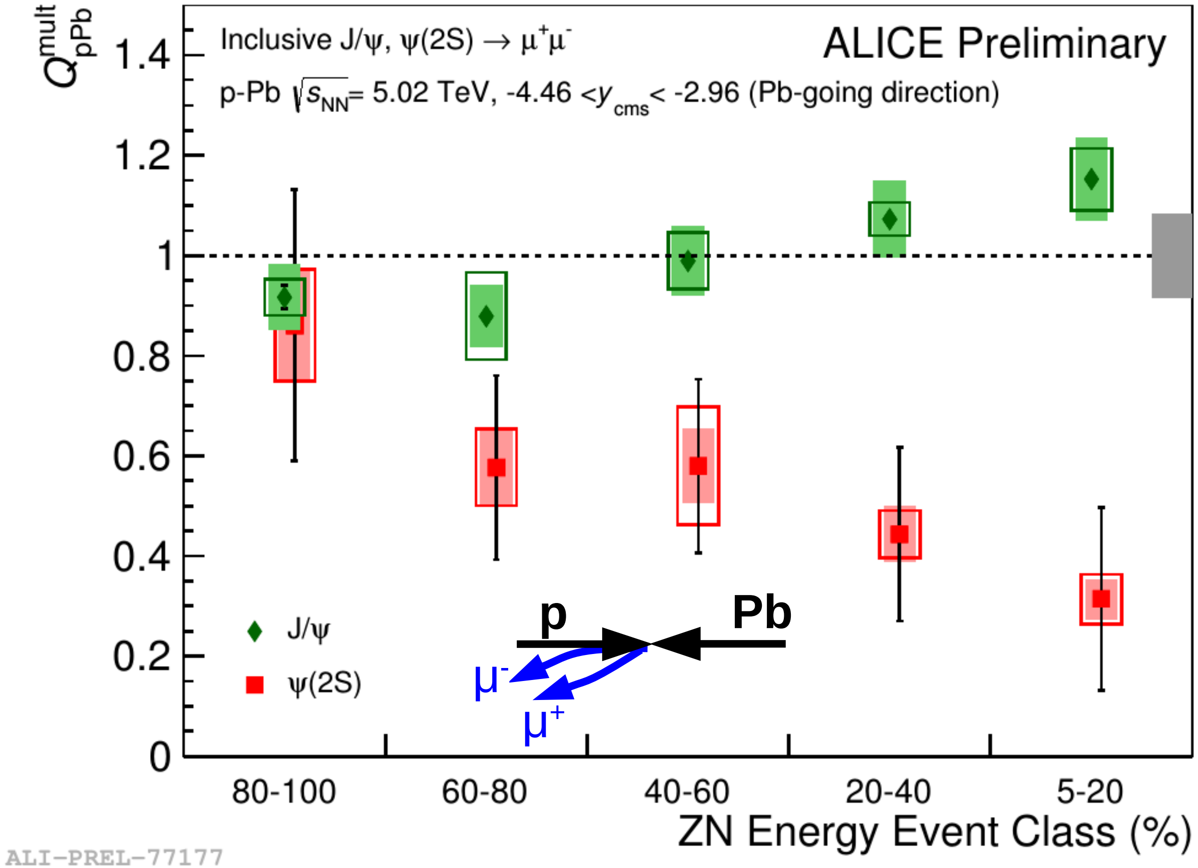
$$Q_{pPb}^{mult.} = \frac{N_{J/\psi \text{ in pPb in ZNA perc.}}}{\langle T_{pPb} \rangle \cdot \sigma_{J/\psi \text{ in pp}}}$$

$\langle T_{pPb} \rangle$ constructed such that multiplicity at midrapidity fulfills N_{part} scaling

At forward rapidity (p-going):

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

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



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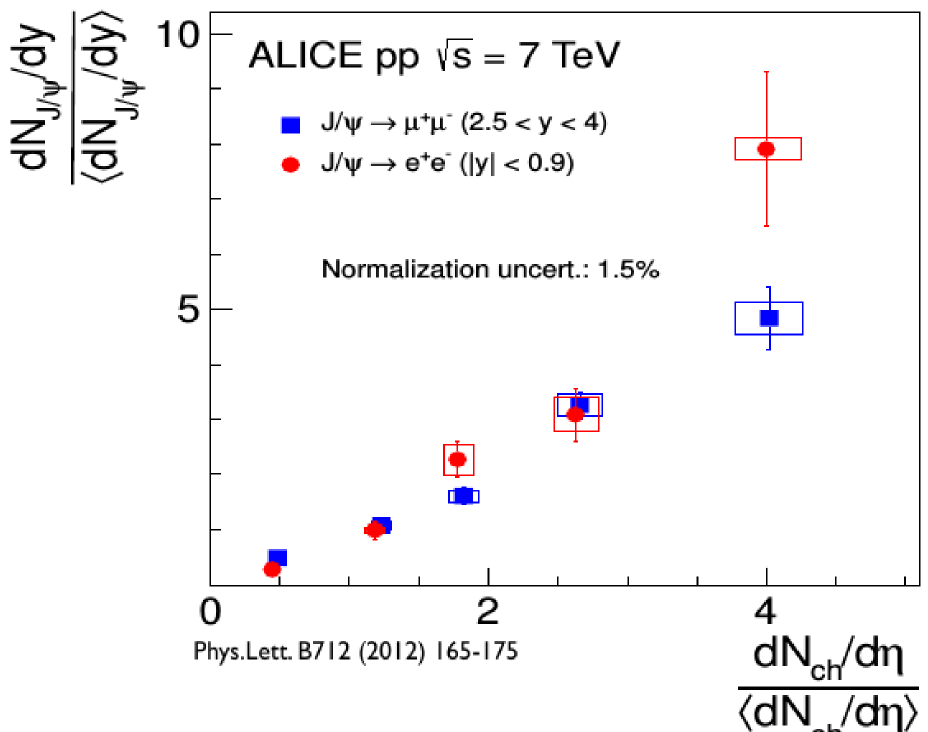
$\langle T_{pPb} \rangle$ constructed such that multiplicity at midrapidity fulfills N_{part} scaling

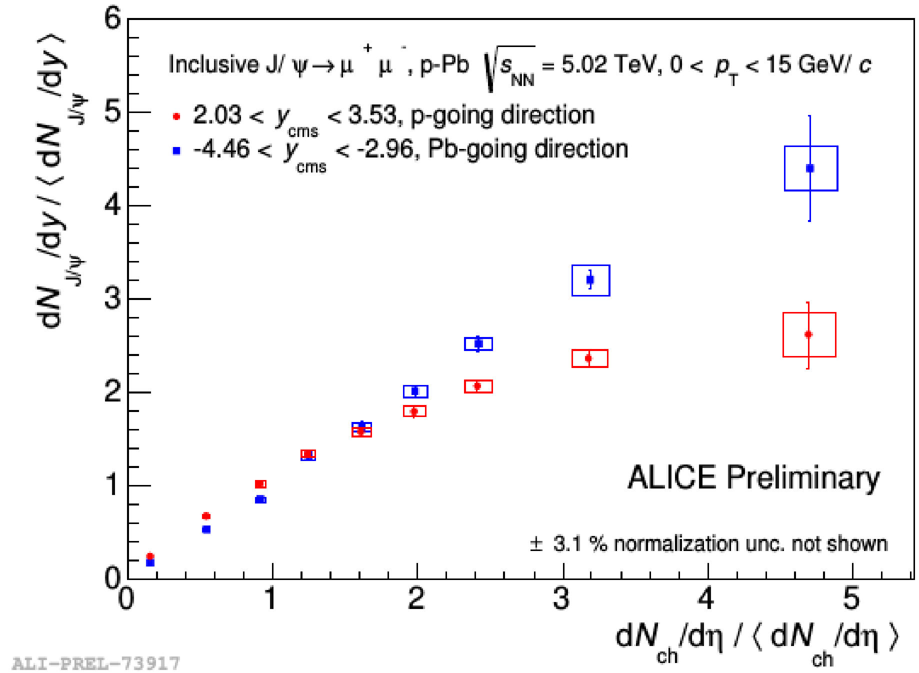
At backward rapidity (Pb-going):

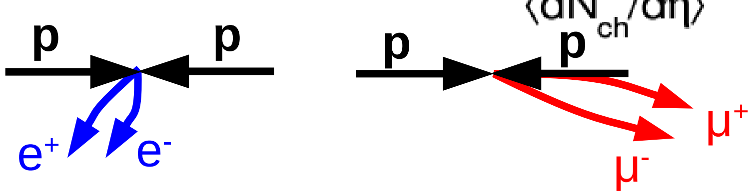
- Q_{pA} of J/ψ consistent with unity

- Q_{pA} of ψ(2S) decreasing with increasing event activity

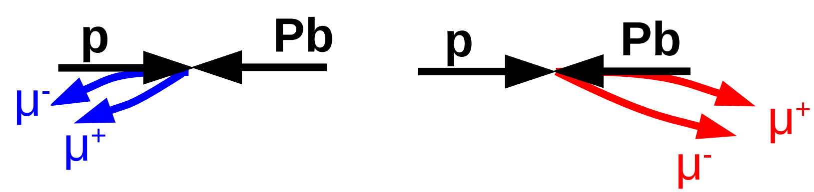
Multiplicity dependence of J/ψ: pp vs p-Pb







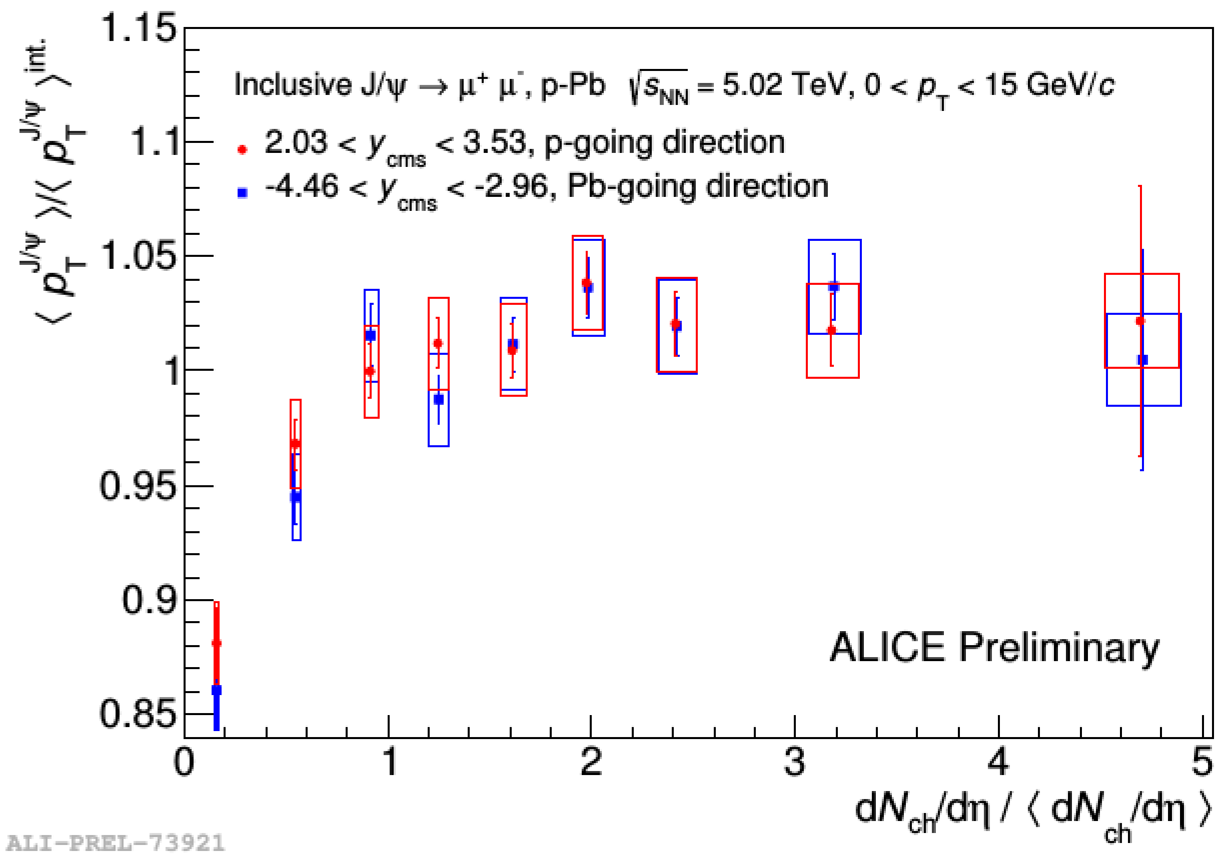
multiplicity measured in $|\eta_{lab}|<1.0$

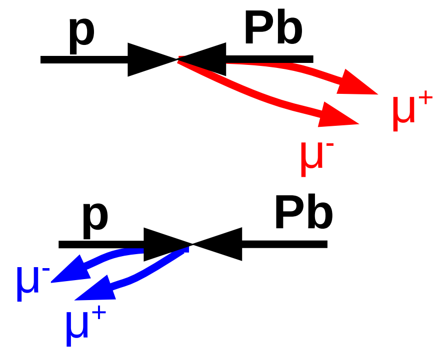


multiplicity measured in $|\eta_{lab}|<0.5$

- 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)

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





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

- saturation of increase at about 1.5 • $<dN_{ch}/d\eta>$

- same behaviour at forward and backward rapidity within uncertainties

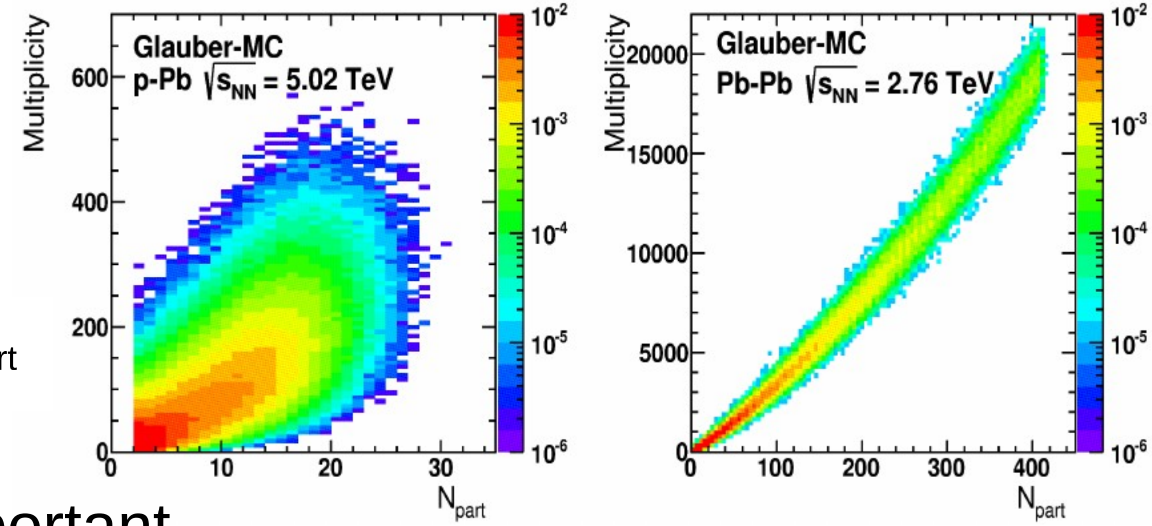
Conclusions

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

  some discrepancies for $R_{pPb}^{J/\psi}(p_T)$ at low p_T
- $R_{pPb}^{J/\psi}$ versus $R_{PbPb}^{J/\psi}$
  - 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
- $Q_{pPb}^{J/\psi}$ vs. event activity: suppression at forward rapidity & close to unity at backward rapidity
- Multiplicity dependence of relative J/ψ yields similar to pp
- $\langle p_T^{J/\psi} \rangle$ increasing with multiplicity and saturating at forward & backward rapidity
- $R_{pPb}^{\psi(2S)}$ at backward/forward rapidity: stronger suppression than J/ψ

Back-up: explanations to Q_{pA}

p-Pb vs Pb-Pb:



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

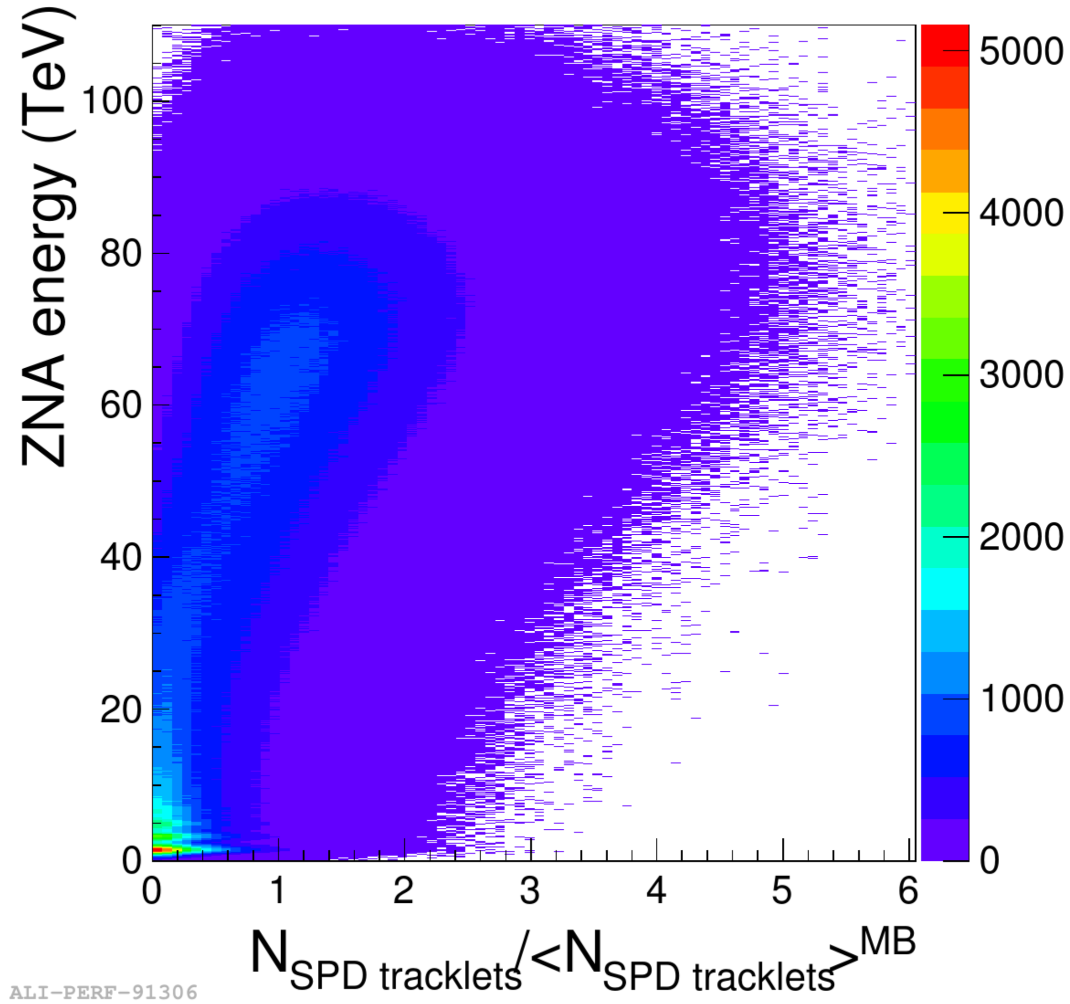
  → fluctuations much more important
  → biases associated with experimental estimator choice important

- ALICE approach as consequence of observations in data:
  → slice events in zero degree neutron energy deposit on the Pb remnant side (ZNA), build T_{pA} such that:
  a) midrapidity $dN/d\eta$ scales with N_{part}
  b) Pb-side $dN/d\eta$ scales with N_{part}^{target}
  c) high-pT yield at midrapidity scales with $dN/d\eta$ N_{coll}

  All values within deviations of at most 10 %

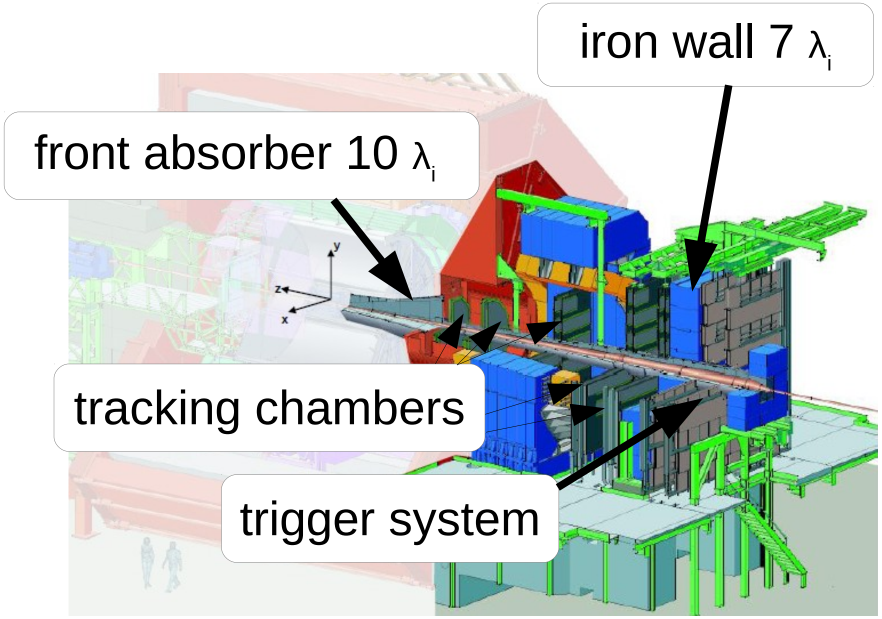
Underlying assumption: ZN insensitive to dynamical biases
Details in new p-Pb centrality publication

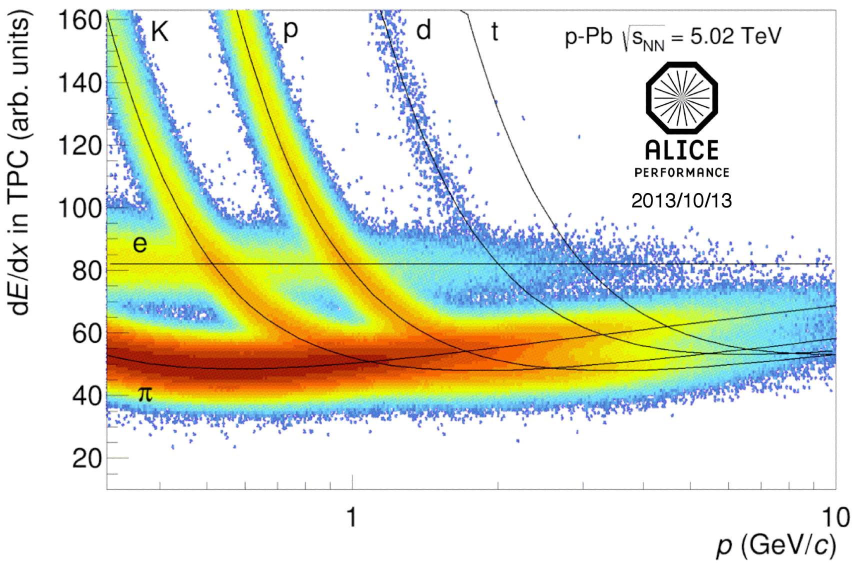
Back-up: correlation between used estimators



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)

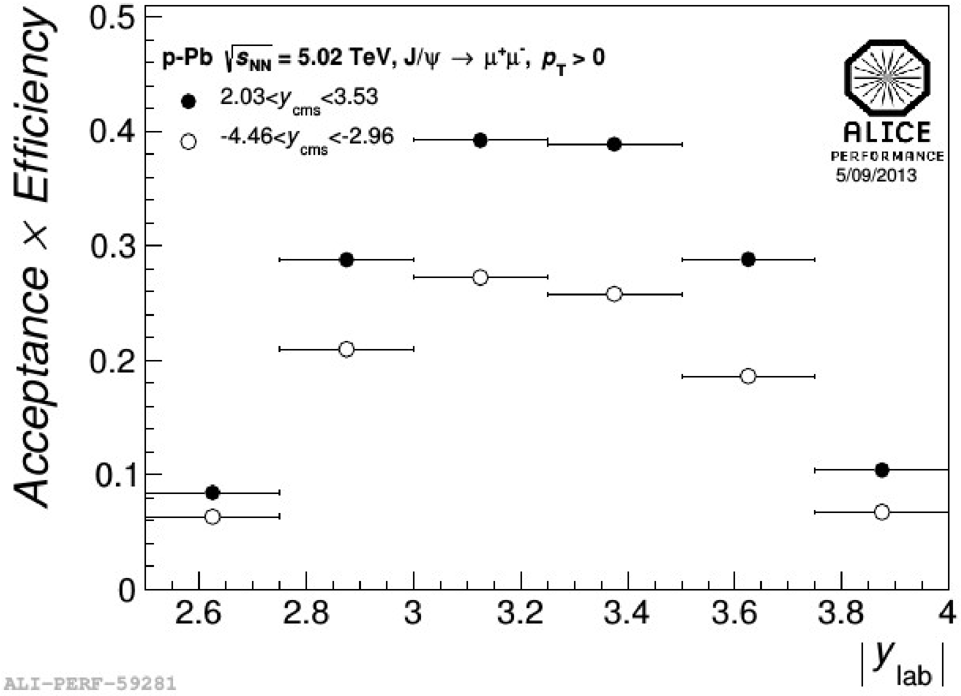
L_{int}=5.8 nb^{-1} (backward)

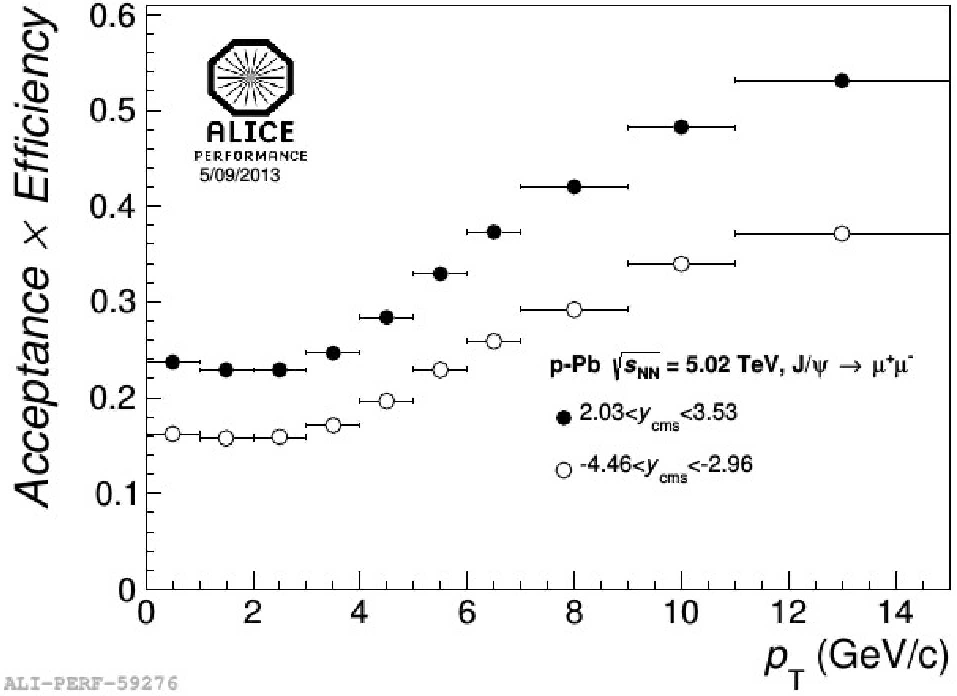
Dielectrons: Minimum Bias

L_{int}= 52 μb^{-1}

extensive usage of TPC-PID

Back-up: Acceptance x efficiency for muon channel

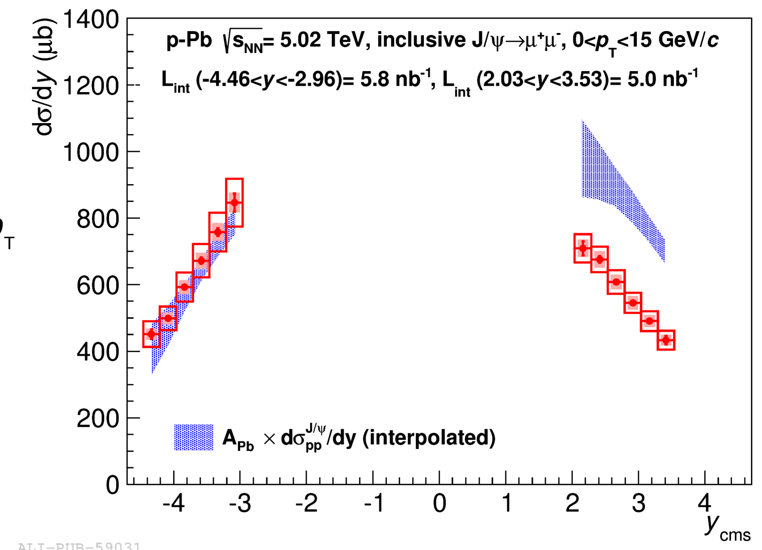




Back-up: pp-reference at $\sqrt{s} = 5.02$ TeV

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:

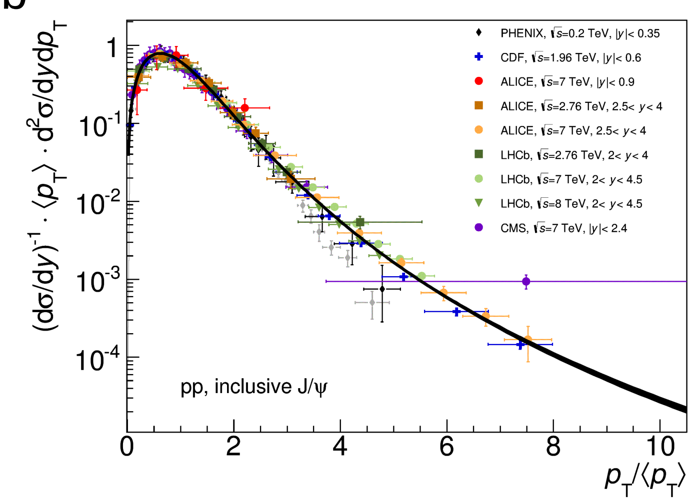
- dσ/dy via interpolation of results (PHENIX, CDF, ALICE) at y≈0:

  $BR(J/\psi \rightarrow ee) \times d\sigma/dy_{pp,y\approx0}(\sqrt{s} = 5.02\text{ TeV}) = 368 \pm 91$ nb

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

- p_T-dependence from phenomenological scaling

  inspired by arXiv:1103.2394



Back-up: Uncertainties: $R^{J/\psi}_{pA}$ at midrapidity

	p_T-integrated R_{pA}	p_T-differential R_{pA}
Statistical uncertainty	11.6 %	14 - 31 %
Systematic uncertainties		
Signal extraction & PID uncorr. between p_T-bins	11.1 %	10 - 20 %
Tracking efficiency uncorr. between p_T-bins	6.0 %	6.0 %
MC kinematics	3.0 %	negligible
Total syst. uncert. on yield uncorr. between p_T-bins	12.9 %	12 - 21 %
T_{pA} fully corr. w.r.t. forward and backward results	3.4 %	not used consistent with use of MB cross section
MB cross section corr. between p_T-bins and w.r.t. forward result	not used consistent with use of T_{pA}	3.4 %
pp-reference 16.6 % correlated between p_T-bins	16.6 %	17.0 - 27.0 %

Back-up: Bjoerken-x ranges for J/ψ in p-Pb and Pb-Pb in 2→1 kinematics

For 2 → 1 kinematics: $$x_{1/2} = \frac{m_T}{\sqrt{s_{NN}}} \exp(-/+y_{cms})$$

Values for p_T = 0 GeV/c for the analysed data samples in 2010-2013:

Dimuons:

p-Pb forward rapidity ($\sqrt{s_{NN}}$ = 5.02 TeV) $x_{Pb} = 1.8 - 8.1 \cdot 10^{-5}$

p-Pb backward rapidity ($\sqrt{s_{NN}}$ = 5.02 TeV) $x_{Pb} = 1.1 - 5.3 \cdot 10^{-2}$

Pb-Pb ($\sqrt{s_{NN}}$ = 2.76 TeV) $x_{Pb1} = 1.4 - 6.1 \cdot 10^{-2}$

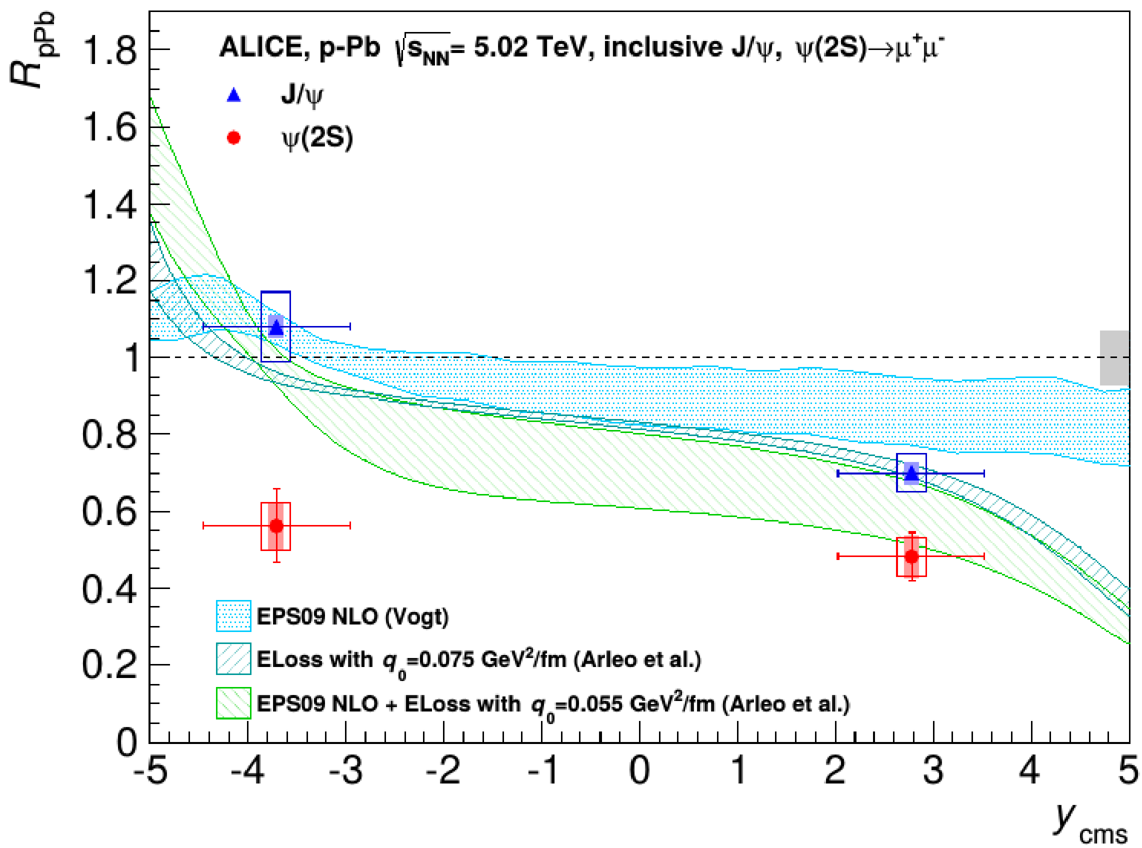
$x_{Pb2} = 2.1 - 9.2 \cdot 10^{-5}$

Dielectrons:

p-Pb ($\sqrt{s_{NN}}$ = 5.02 TeV) $x_{Pb} = 0.4 - 2.4 \cdot 10^{-3}$

Pb-Pb ($\sqrt{s_{NN}}$ = 2.76 TeV) $x_{Pb} = 0.5 - 2.5 \cdot 10^{-3}$

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:1308.6726
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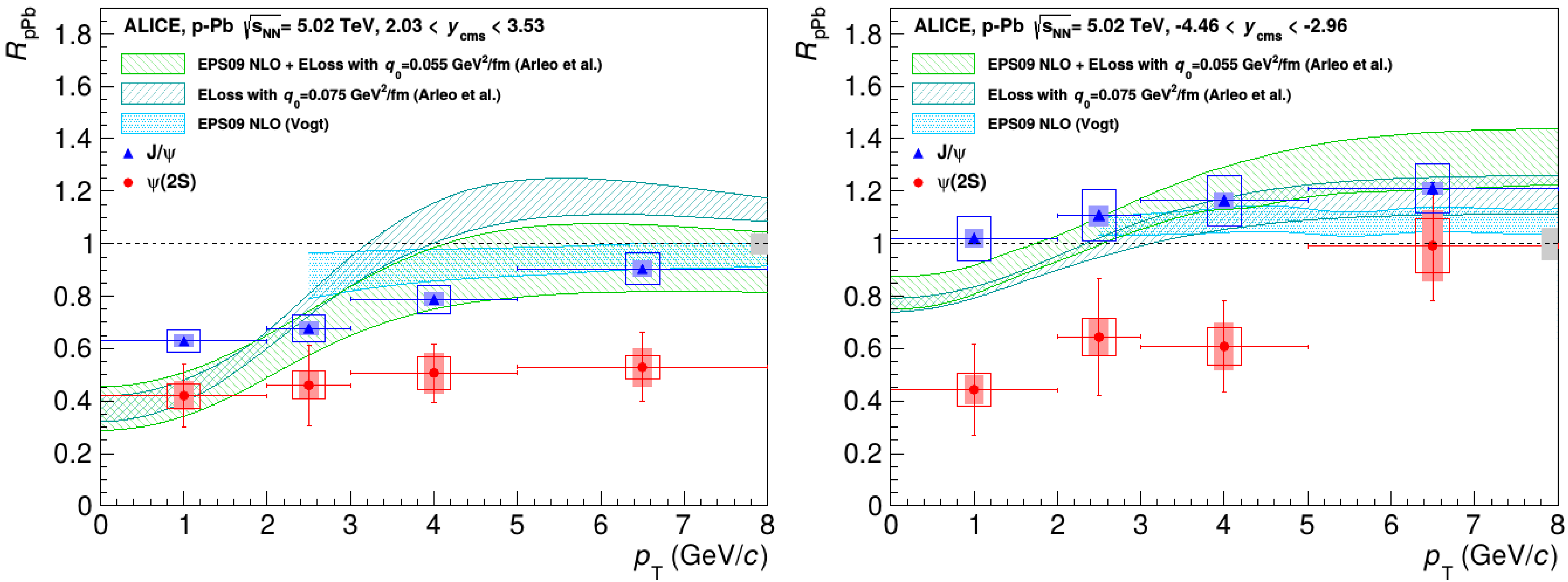
Shadowing & E-loss models: identical treatment of ψ(2S) & J/ψ

→ no explanation for ψ(2S) behaviour

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



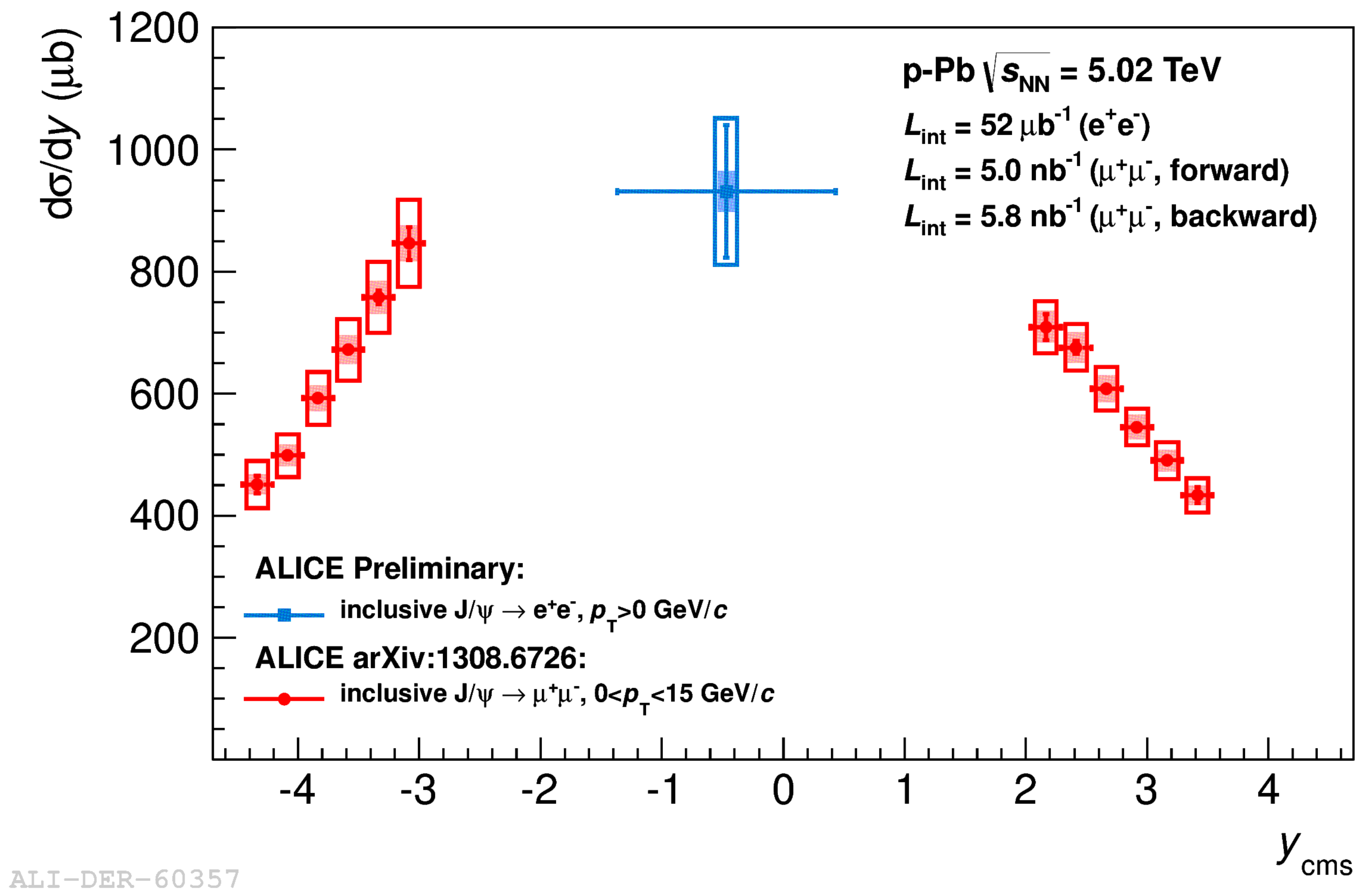
Same uncertainty display as
on previous slide

link: arXiv:1308.6726
JHEP 1402 (2014) 073

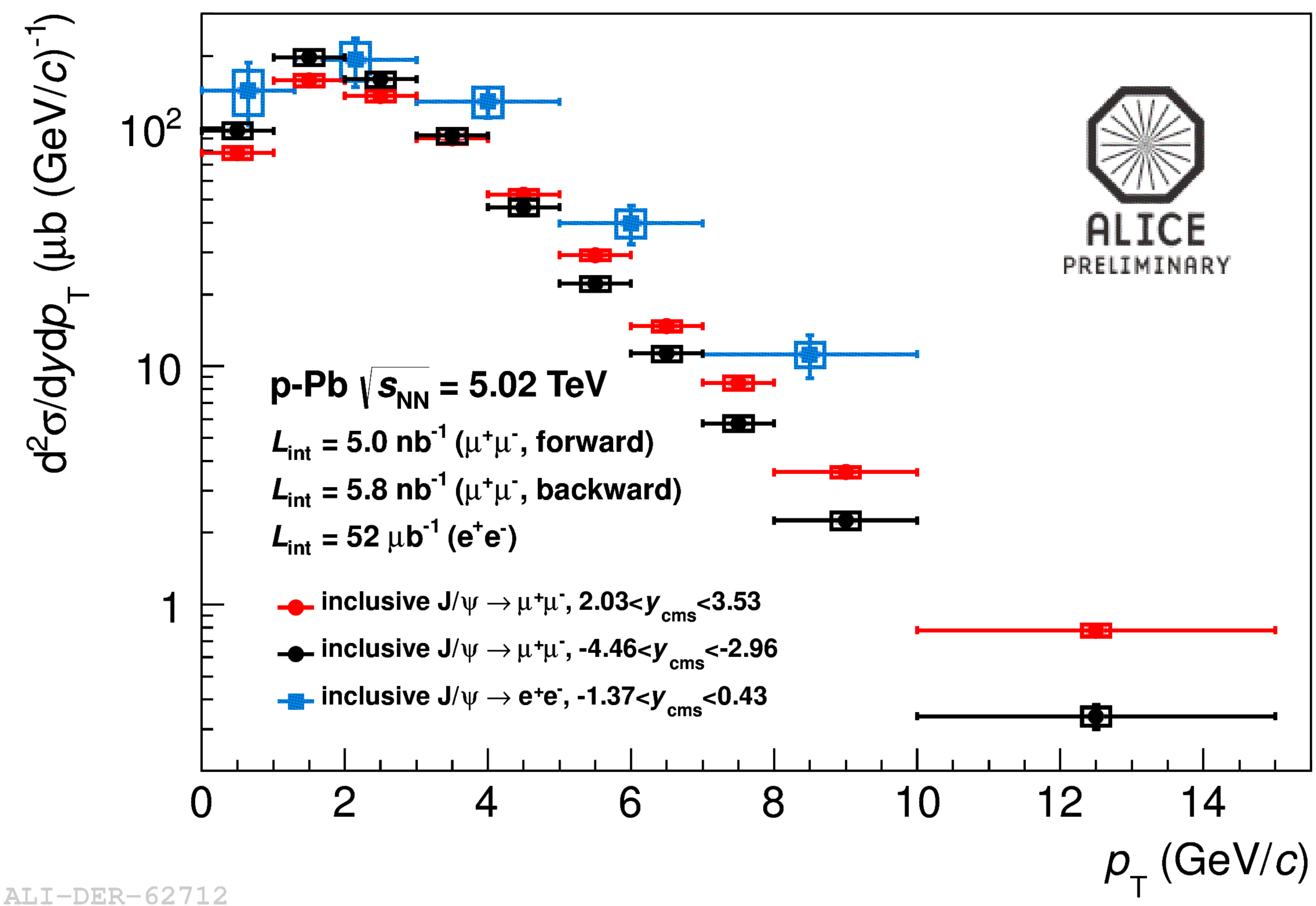
Shadowing & E-loss models: identical treatment of ψ(2S) & J/ψ

→ no explanation for ψ(2S) behaviour

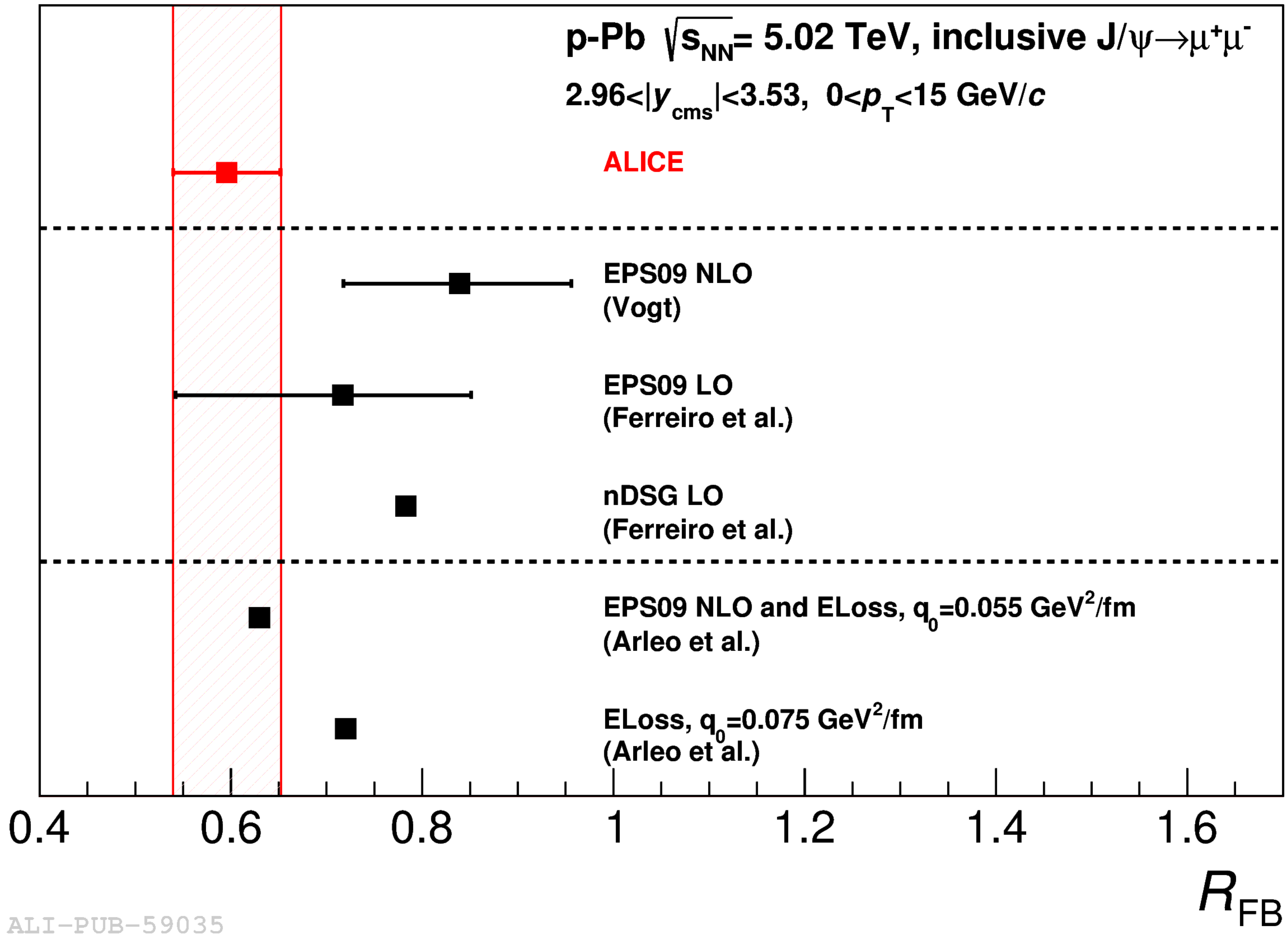
Back-up: $d\sigma/dy^{J/\psi}_{pA}$



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



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



link: arXiv:1308.6726
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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
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Back-up: Uncertainties: $R_{pA}^{J/\psi}$ at forward/backward rapidity

Preliminary

	p_T-differential $R_{pA}^{J/\psi}$ forward (backward)
Statistical uncertainty	1.5 - 2.3 % (1.5 - 3.1 %)
Systematic uncertainties	
Uncorrelated including uncertainty on tracking eff., matching between trigger system and tracking chambers, signal extraction, trigger and MC kinematics	4.8 - 8.0 % (6.8 - 10.1 %)
Partially correlated including uncertainty on pp-reference and MB cross section	8.4 - 9.7 % (8.1 - 9.9 %)

Q_{pA} has an additional uncertainty due to pile-up: 2 %

Q_{pA} has an additional bin-by-bin uncorrelated $\langle T_{pPb} \rangle$ between 1.5-9.5 % depending on the bin

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
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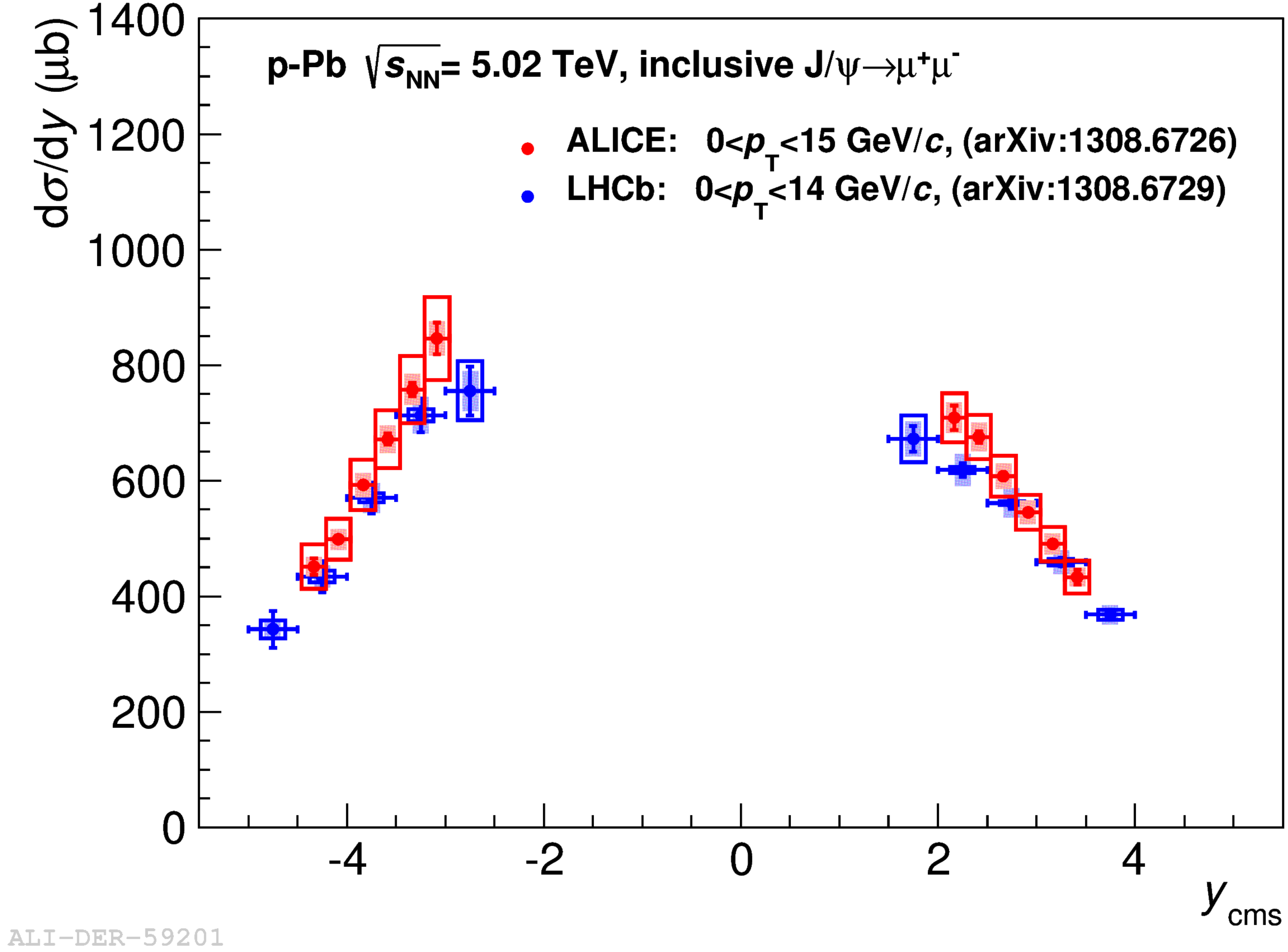
Back-up: Uncertainties: relative yield and $<p_T>$ of J/ψ vs midrapidity multiplicity

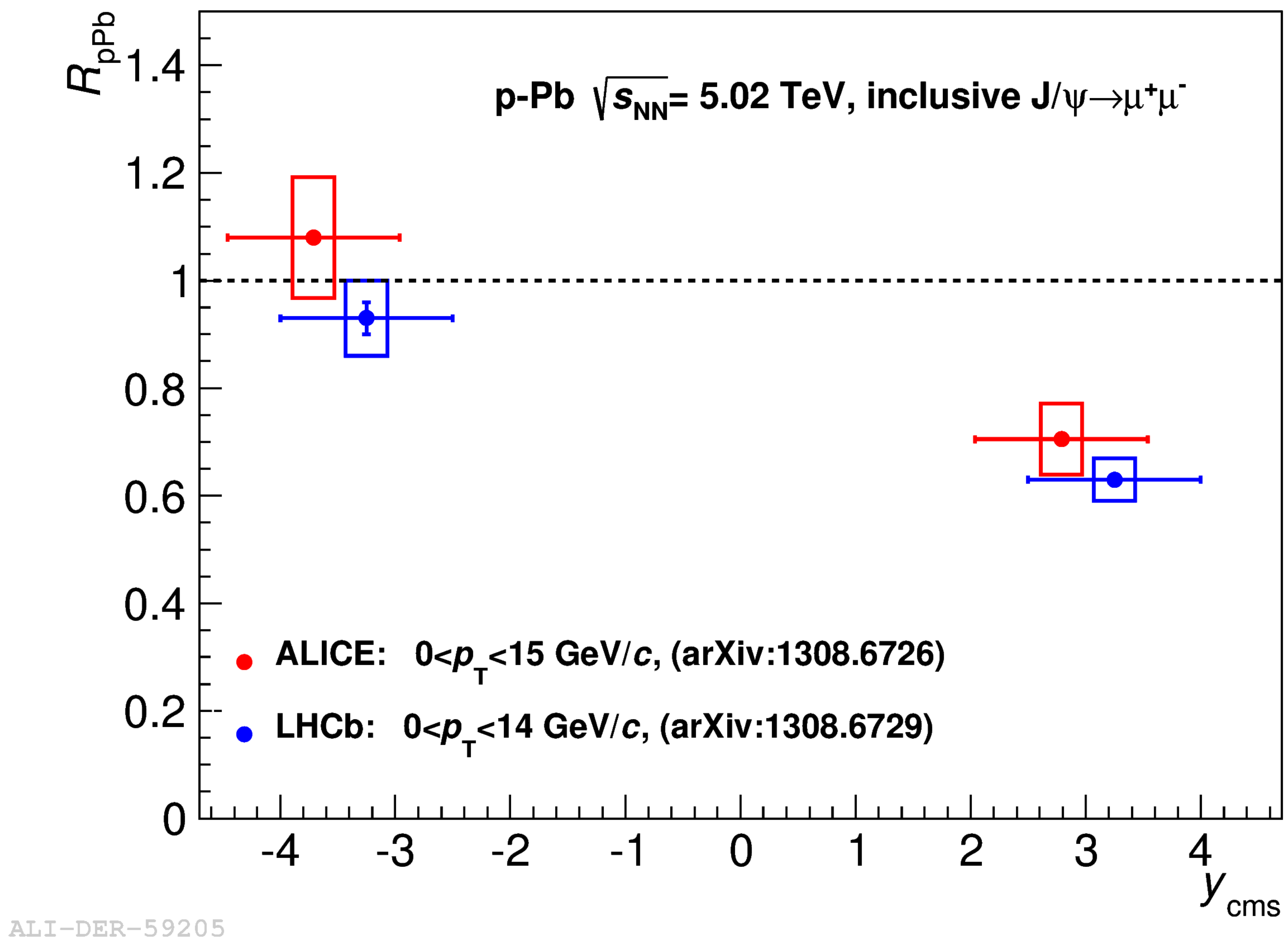
Only uncorrelated uncertainties remain in relative quantities to first order

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 %
$<p_T>$ MC input	2 %	2 %
Extraction $<p_T>/<p_T>^{int}$	0.1-0.4 %	0.1-1.2 %
F	1-7 %	1-4%
$<dN_{ch}/d\eta>$	3.9 %	3.9 %
Pile-up	1-4 %	1.-2 %

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



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



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