Open heavy flavour and quarkonium production in ALICE at the LHC

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GDR 2013

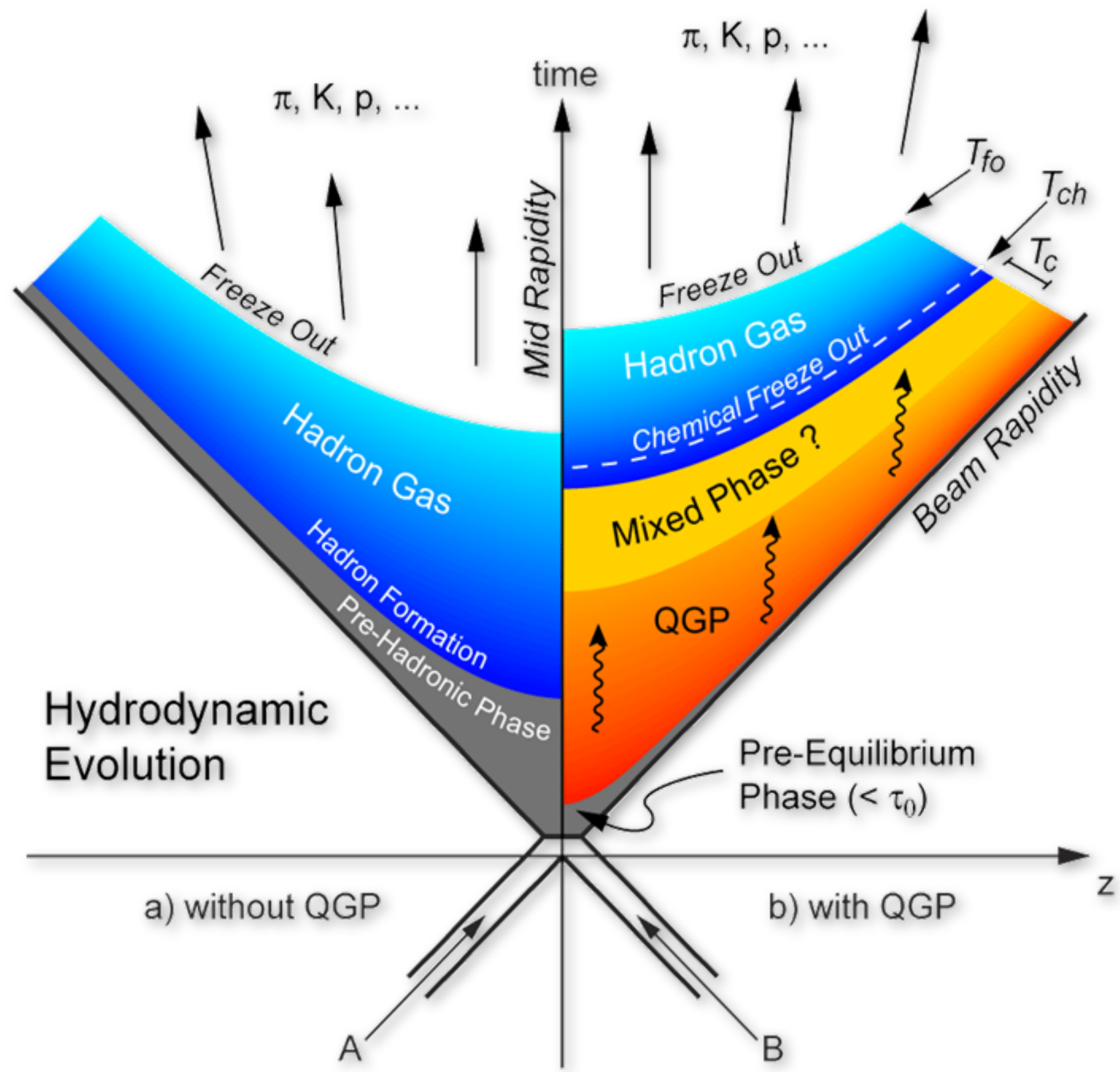
Saclay, November 26th 2013

- Probing the Quark Gluon Plasma with open heavy flavour and quarkonia
- Selected results in pp, p-Pb and Pb-Pb collisions

Ultra-relativistic heavy-ion collisions

Nuclear matter at high temperature and high density = Quark Gluon Plasma (QGP)
- Partons are deconfined (not bound into composite object)
- Chiral symmetry is restored (partons are massless)

Space-time evolution of an URHIC



Studying the Quark Gluon Plasma at the LHC
- Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV→ Characterize the QGP phase properties (energy, density, size, lifetime, temperature, ...)
- p-Pb collisions at $\sqrt{s_{NN}}$= 5.02 TeV→ Cold Nuclear Matter effects (initial and final state effects)
- pp collisions at $\sqrt{s}$ = 2.76 and 7 TeV → test of pQCD predictions and reference for Pb-Pb and p-Pb

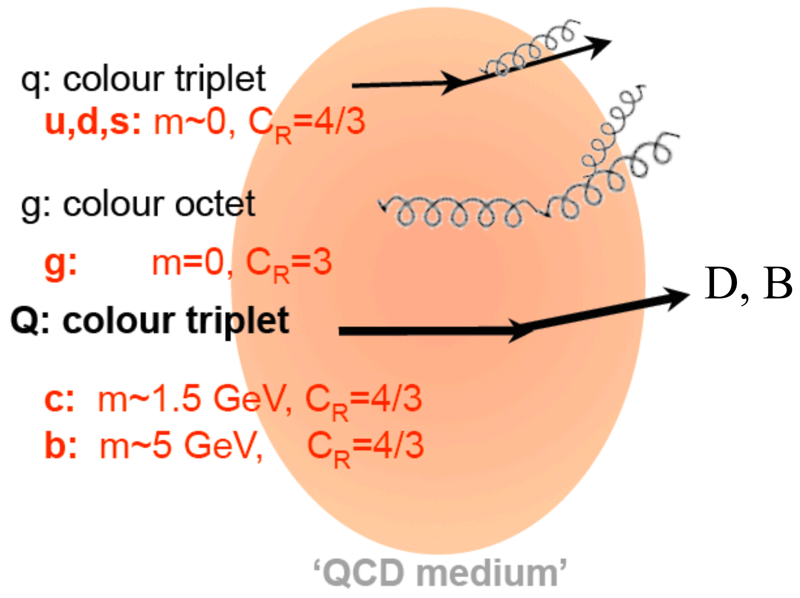
Probing the QGP with open HF and quarkonia

Properties of heavy flavour

- mass = hard scale (m_c = 1.5 GeV/c^2, m_b = 4 GeV/c^2) → can be described with pQCD
- produced in the initial hard partonic collisions ($\tau \simeq 1/m_Q \simeq$ 0.05-0.15 fm/c) → sensitive to the hot medium

Open heavy flavours: energy loss of heavy quark in the hot medium

- ΔE depends on color: $\Delta E_g > \Delta E_{u,d,s}$
- ΔE depends on quark mass: ΔE (light hadrons) > ΔE (charm) > ΔE (beauty)
- prediction: suppression larger for light, charm then beauty hadrons



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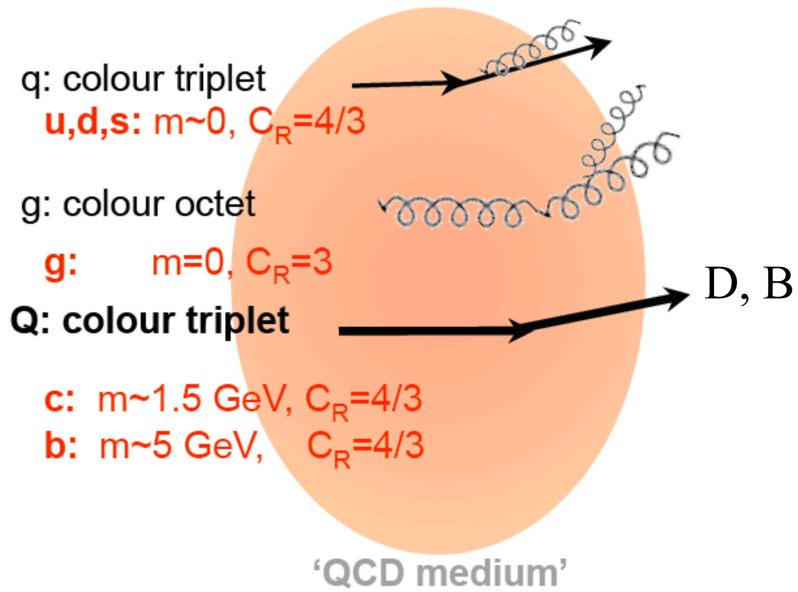
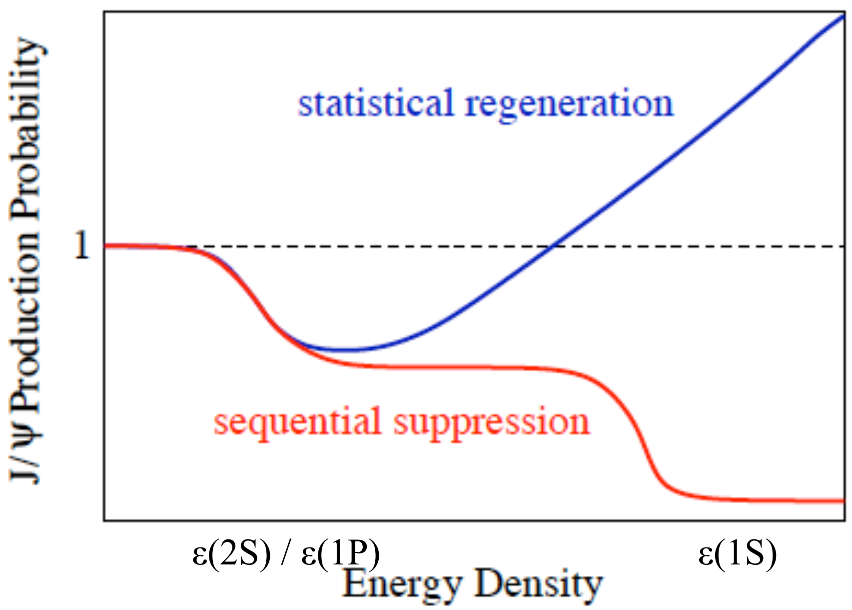
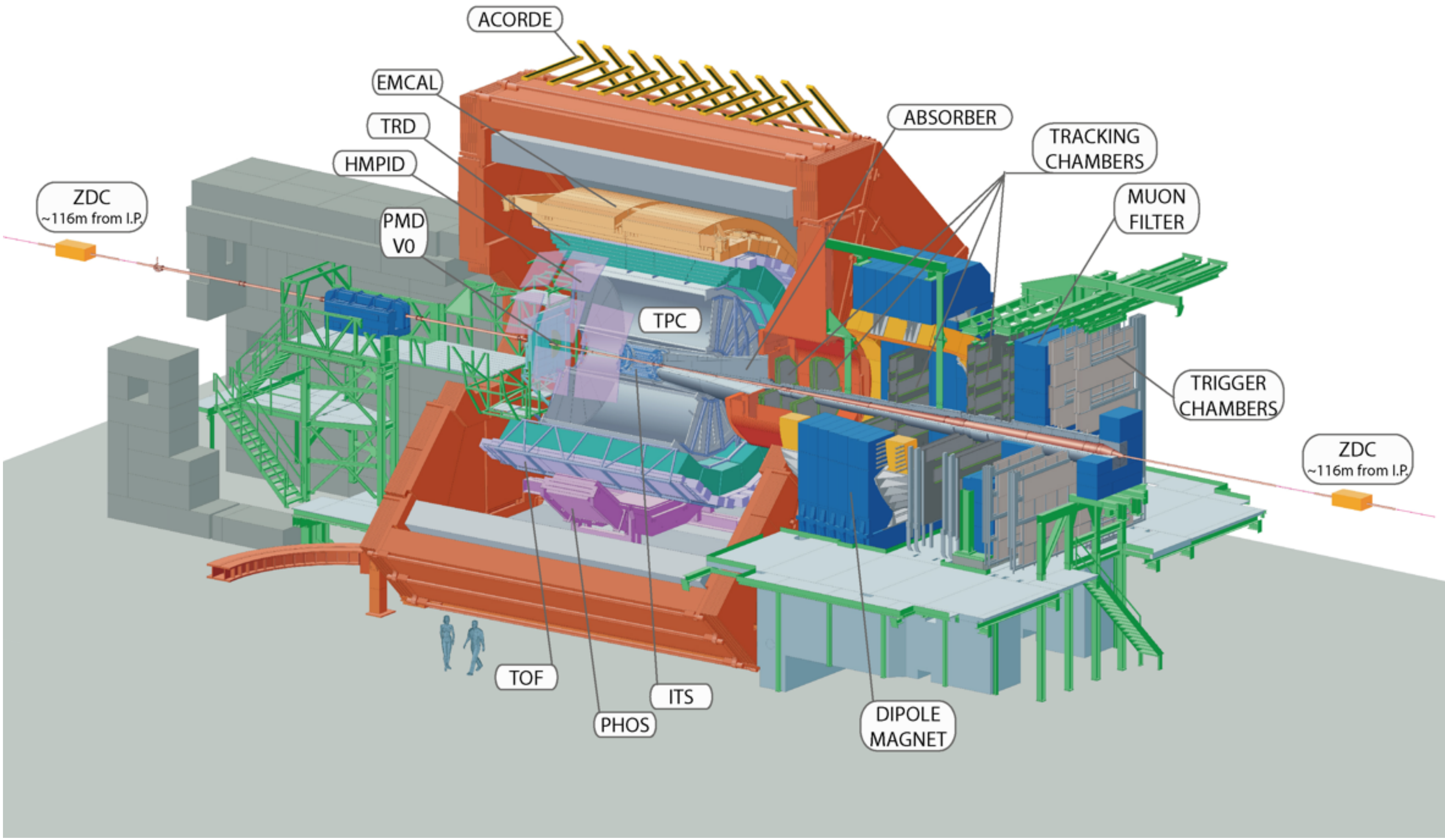




Quarkonia: sequential suppression or quark pair combination?

- Debye screening: melting of quarkonia in the QGP depends on the binding energy: sequential suppression of quarkonium family
- heavy flavour cross-sections increase with energy: recombination of heavy quark pairs (specially for the charm) in the QGP or at the phase boundary: quarkonium (re)generation

A Large Ion Collider Experiment



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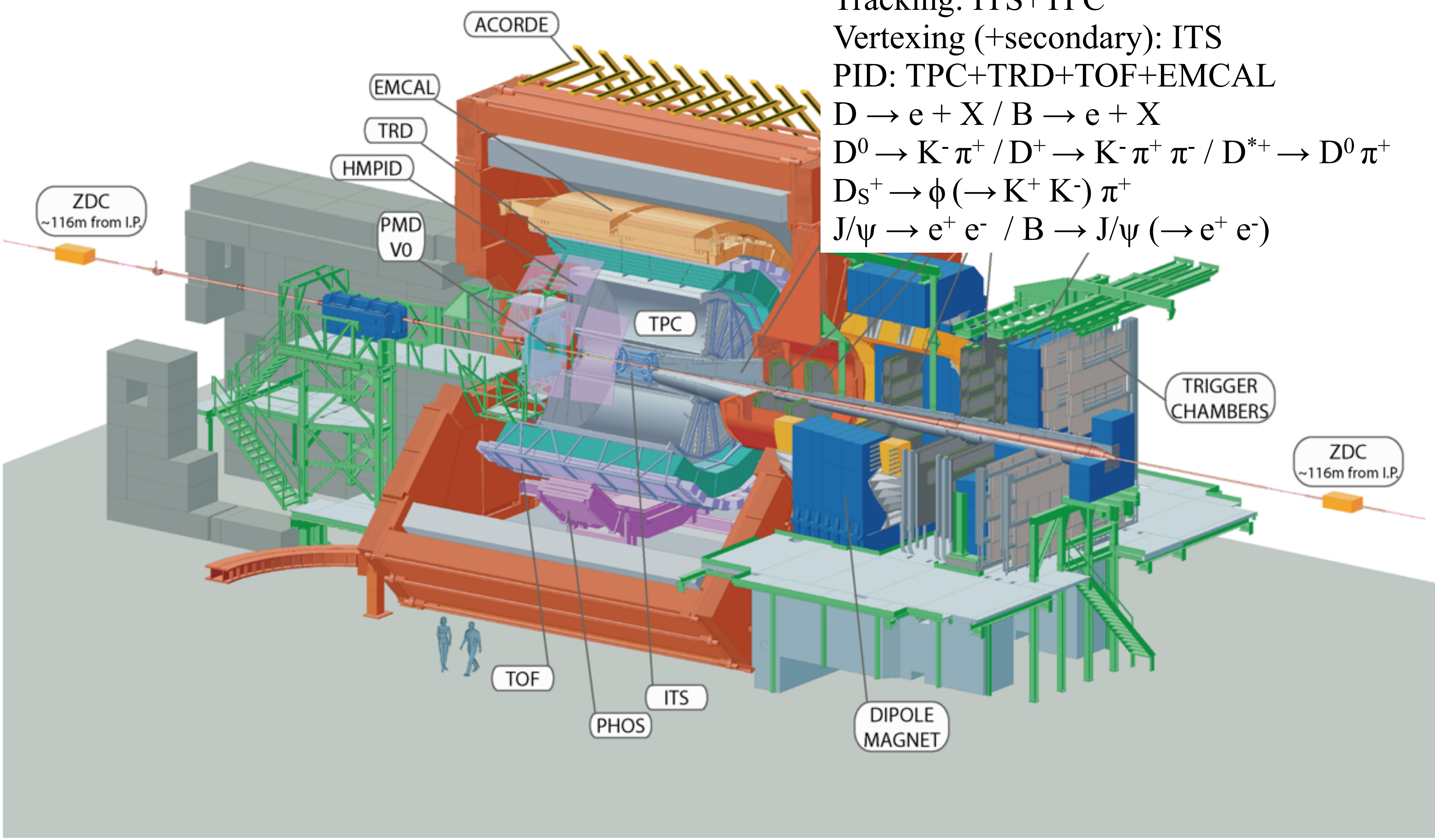


Central barrel: $|\eta| < 0.9$

Tracking: ITS+TPC

Vertexing (+secondary): ITS

PID: TPC+TRD+TOF+EMCAL

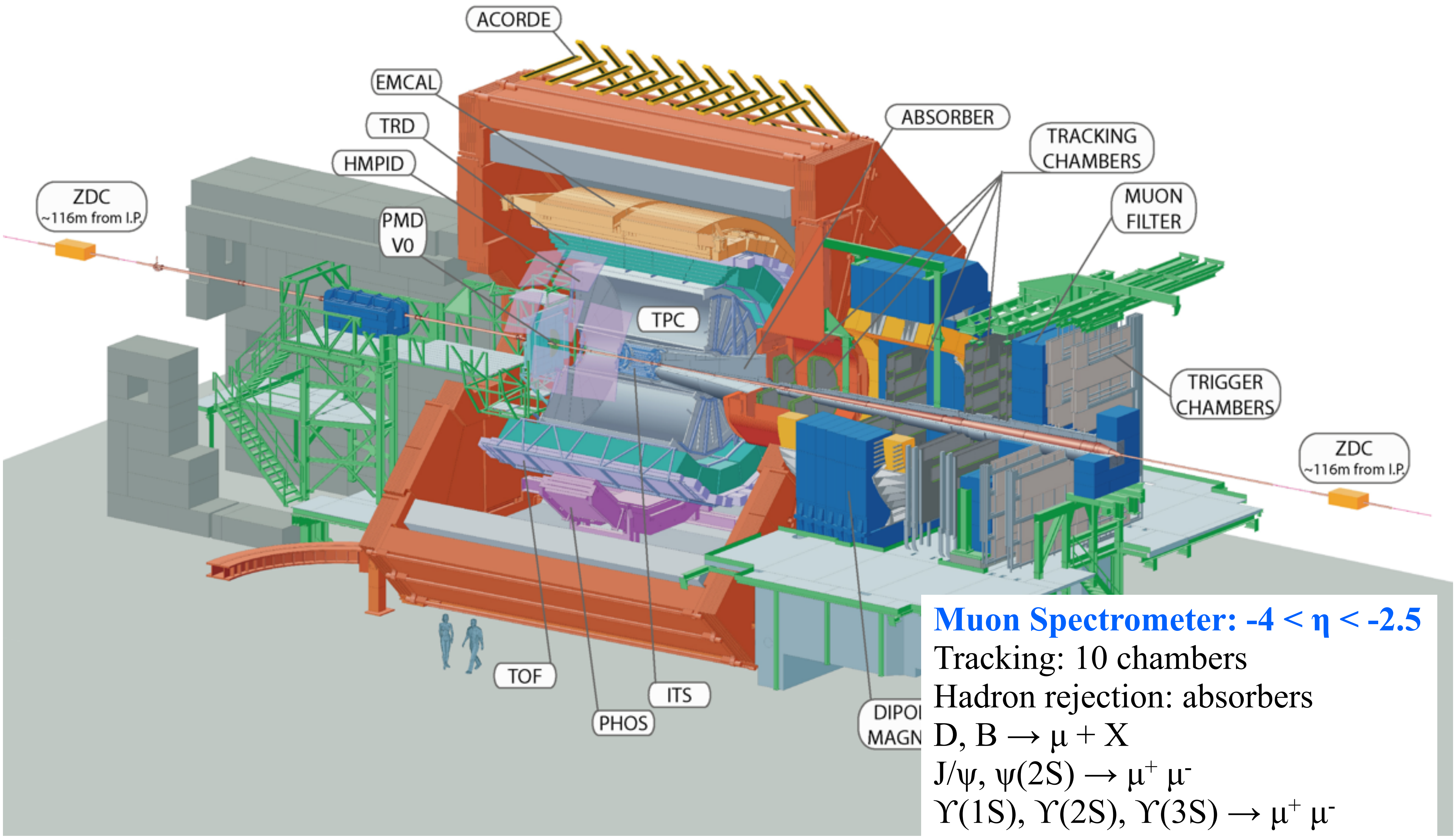
$D \rightarrow e + X$ / $B \rightarrow e + X$

$D^0 \rightarrow K^- \pi^+$ / $D^+ \rightarrow K^- \pi^+ \pi^-$ / $D^{*+} \rightarrow D^0 \pi^+$

$D_S^+ \rightarrow \phi\,(\rightarrow K^+ K^-)\,\pi^+$

$J/\psi \rightarrow e^+ e^-$ / $B \rightarrow J/\psi\,(\rightarrow e^+ e^-)$

A Large Ion Collider Experiment



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

Tracking: 10 chambers

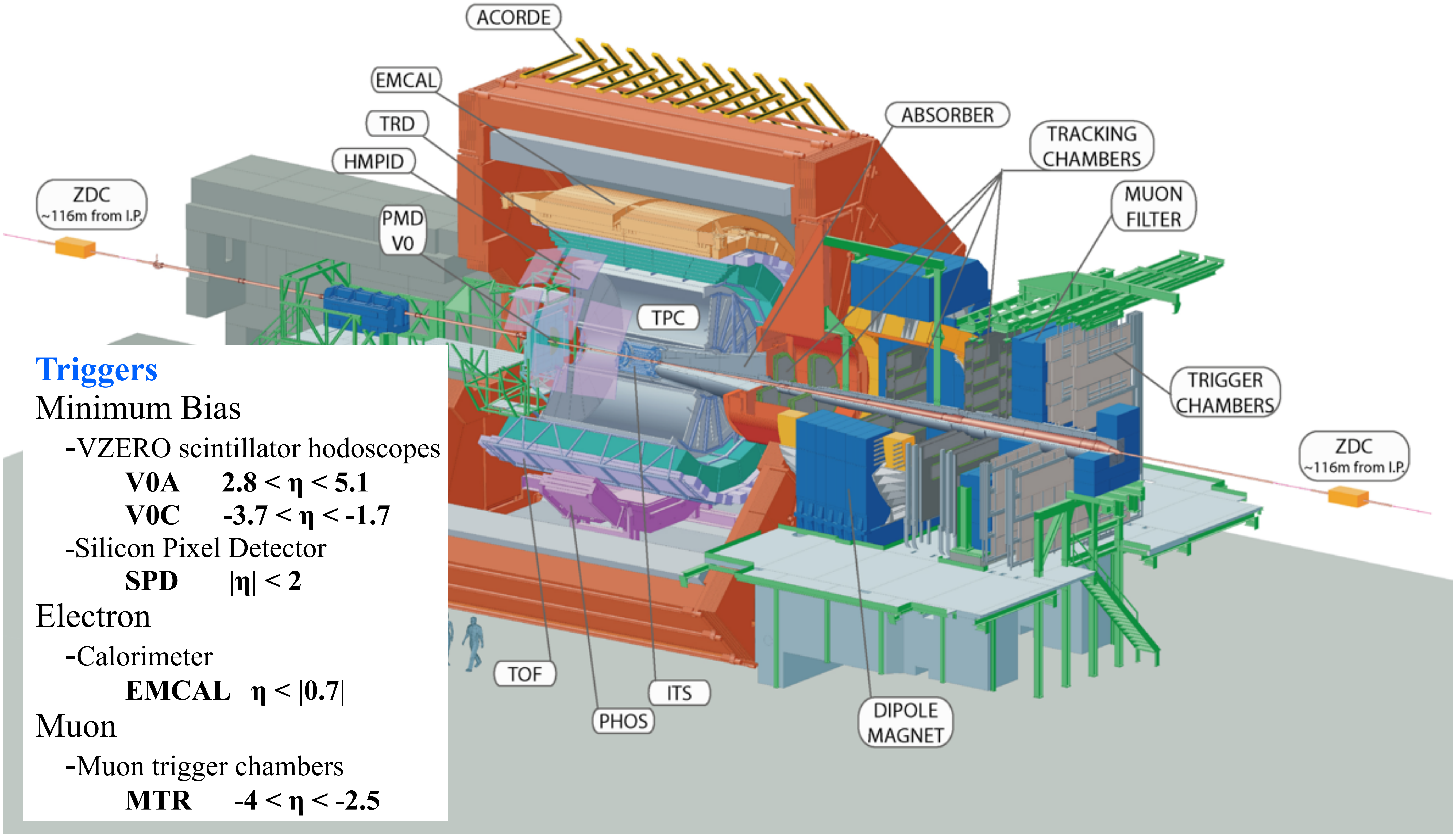
Hadron rejection: absorbers

$D, B \rightarrow \mu + X$

$J/\psi, \psi(2S) \rightarrow \mu^+ \mu^-$

$\Upsilon(1S), \Upsilon(2S), \Upsilon(3S) \rightarrow \mu^+ \mu^-$

A Large Ion Collider Experiment



Triggers

Minimum Bias

-VZERO scintillator hodoscopes

V0A $2.8 < \eta < 5.1$

V0C $-3.7 < \eta < -1.7$

-Silicon Pixel Detector

SPD $|\eta| < 2$

Electron

-Calorimeter

EMCAL $\eta < |0.7|$

Muon

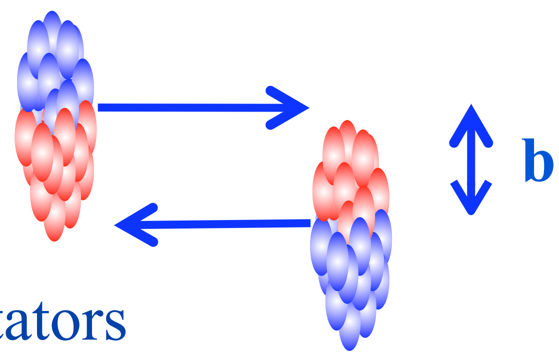
-Muon trigger chambers

MTR $-4 < \eta < -2.5$

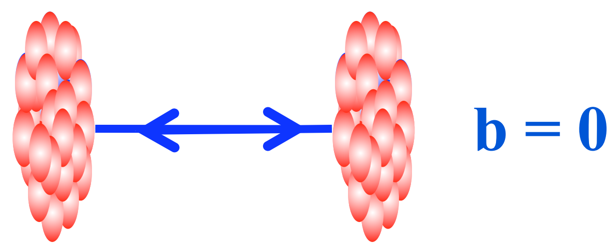
Centrality of the collisions in AA

Centrality of the collisions

semi-central coll.



central coll.



	$N_{part} = 2$	$N_{coll} = 1$
	$N_{part} = 5$	$N_{coll} = 6$
Pb-Pb cent.	$N_{part} = 380$	$N_{coll} = 1700$
p-Pb cent.	$N_{part} = 16$	$N_{coll} = 15$

Spectators
Participants
Binary collisions

→ Glauber model used to determine the geometry of the collision

Centrality of the collisions in AA

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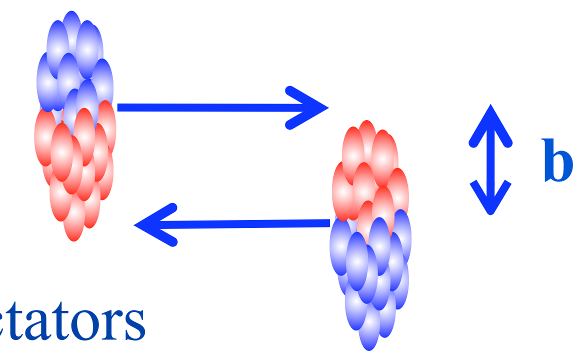
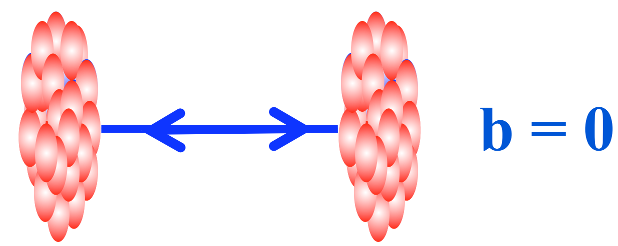


central coll.



	N_{part} = 2	N_{coll} = 1
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Pb-Pb cent.	N_{part} = 380	N_{coll} = 1700
p-Pb cent.	N_{part} = 16	N_{coll} = 15

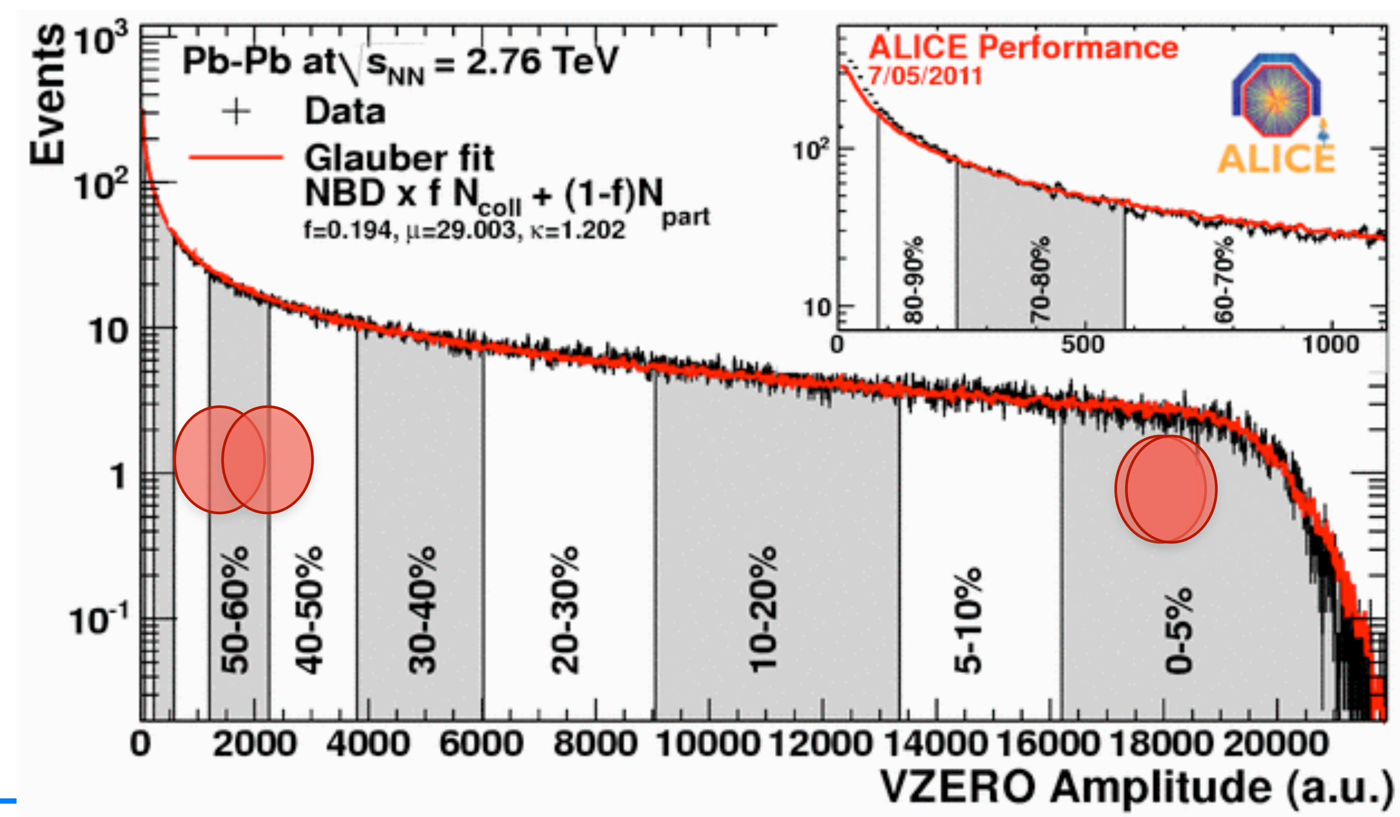
Spectators
Participants
Binary collisions

→ Glauber model used to determine the geometry of the collision

Centrality determination

Multiplicity measurements with forward or central detectors

Relate the measured multiplicity in A-A collisions to N_{part} and N_{coll}



Observables

- **Invariant yield and/or cross-section**

$$Y = \frac{N}{N_{MB}\, A\, \epsilon} \qquad \sigma = Y\, \sigma_{MB}$$

- **Yield ratio**

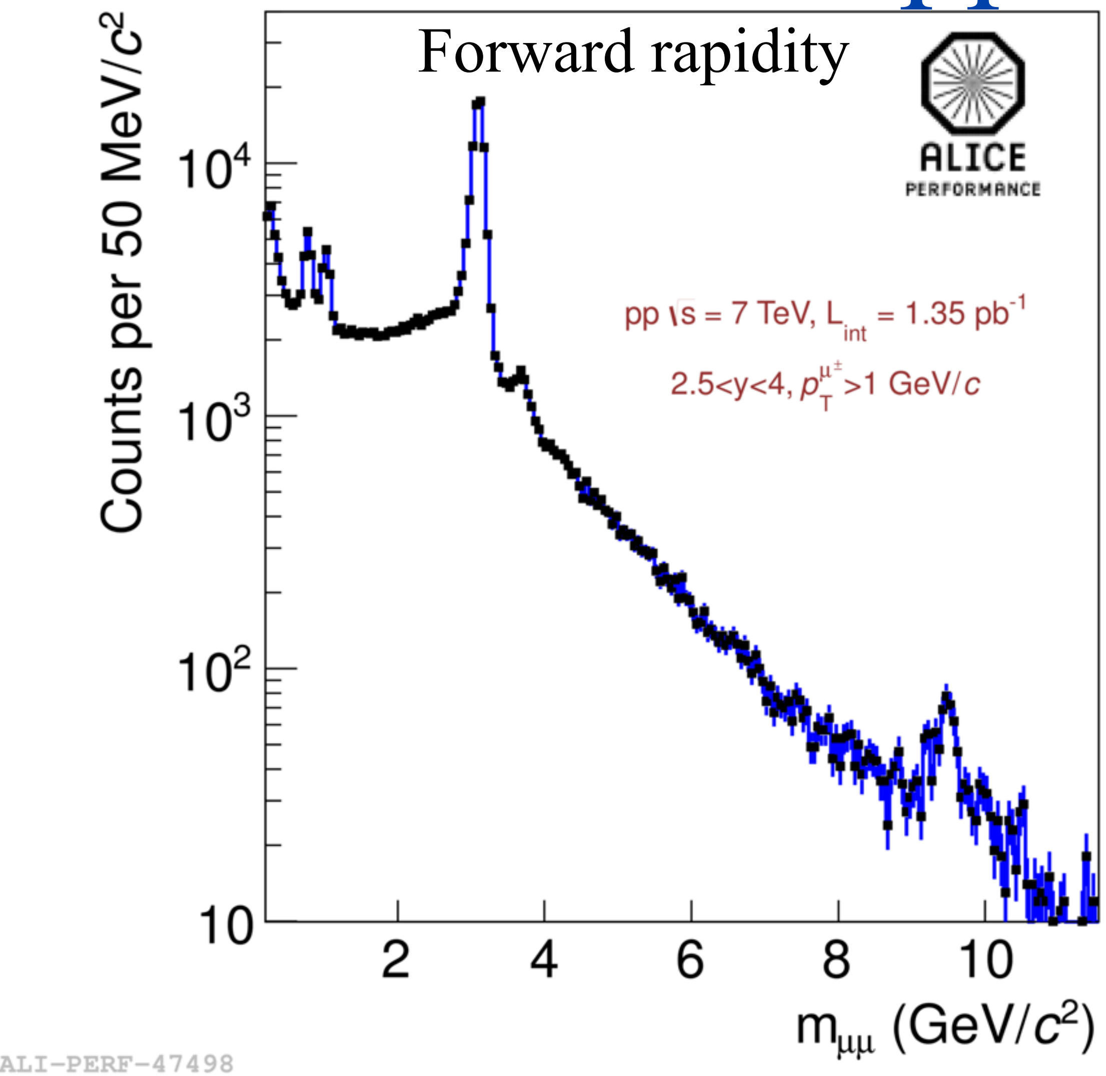
Between different species, rapidity domain, etc.

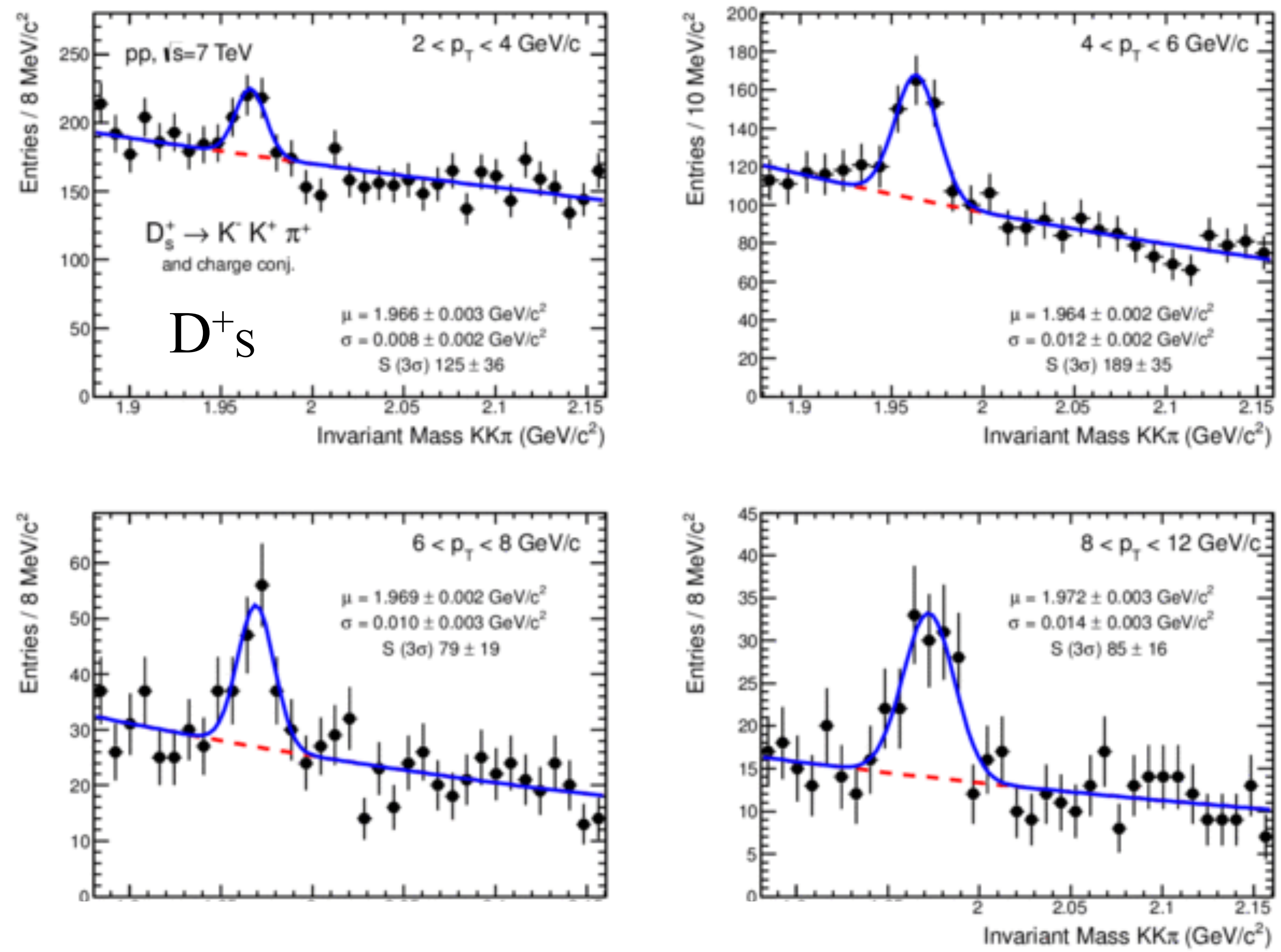
- **Nuclear modification factor**

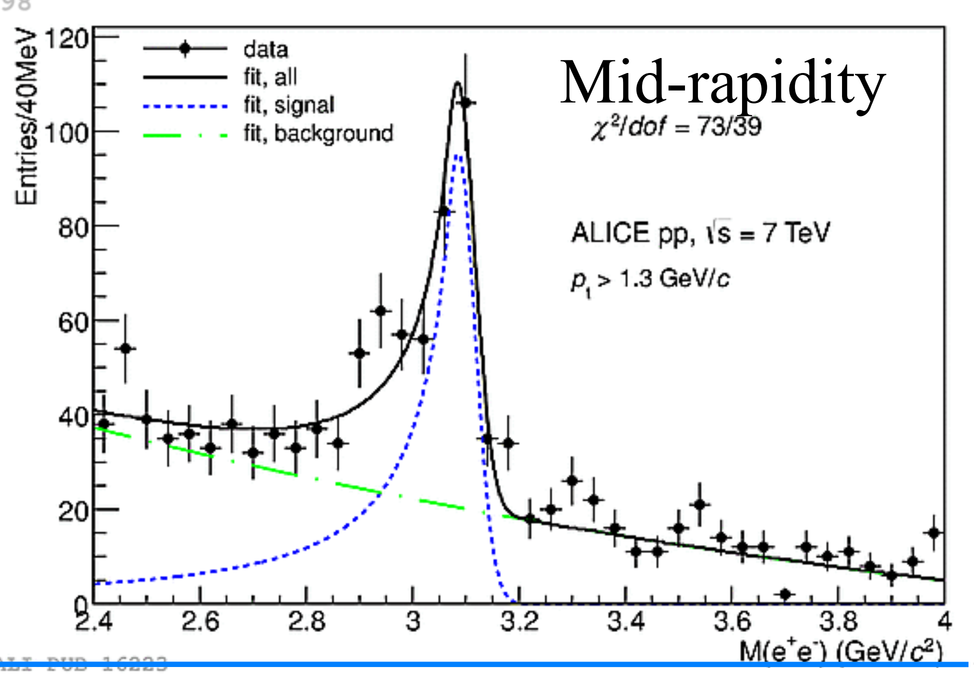
$$R_{AA} = \frac{dY^{AA}/dp_T\,dy}{\langle T_{AA}\rangle\, d\sigma^{pp}/dp_T\,dy}$$

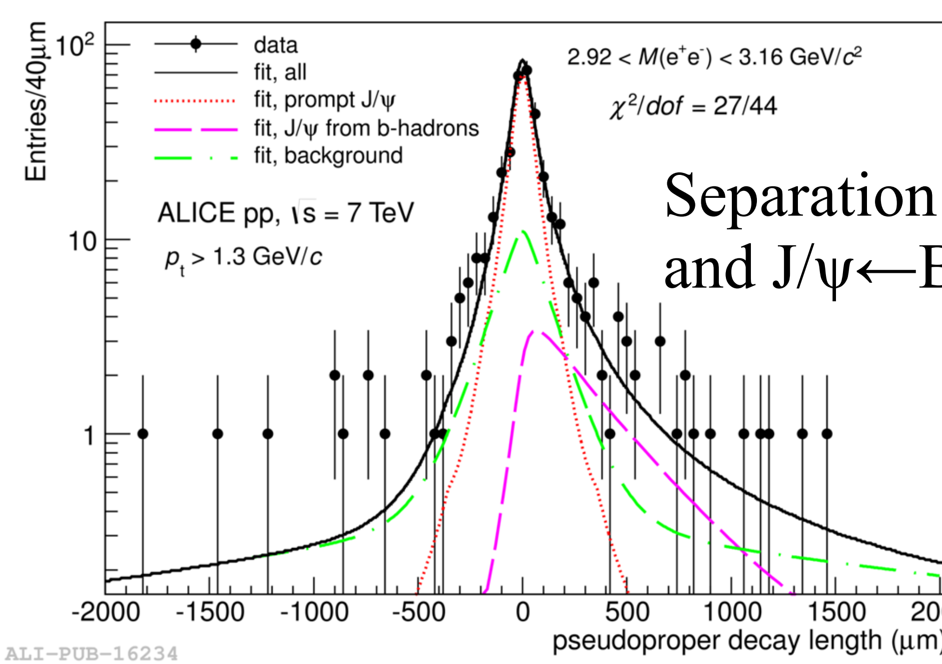
$R_{AA} \neq 1 \rightarrow$ nuclear effect in AA

pp measurements





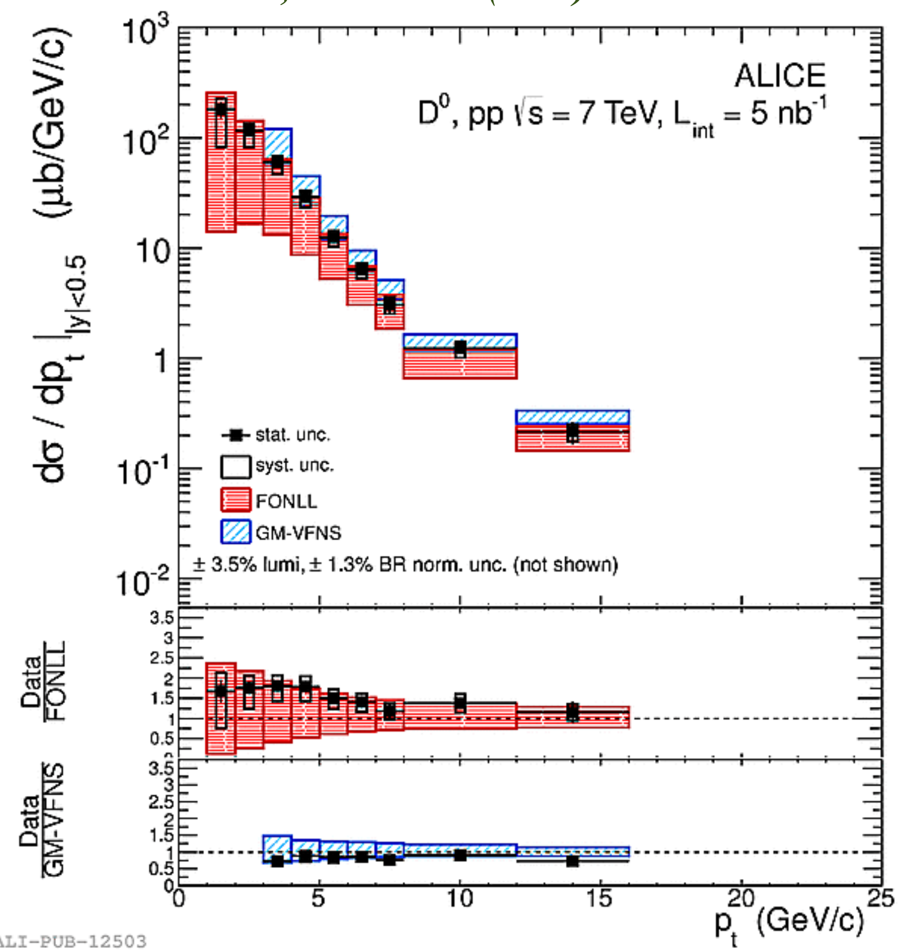




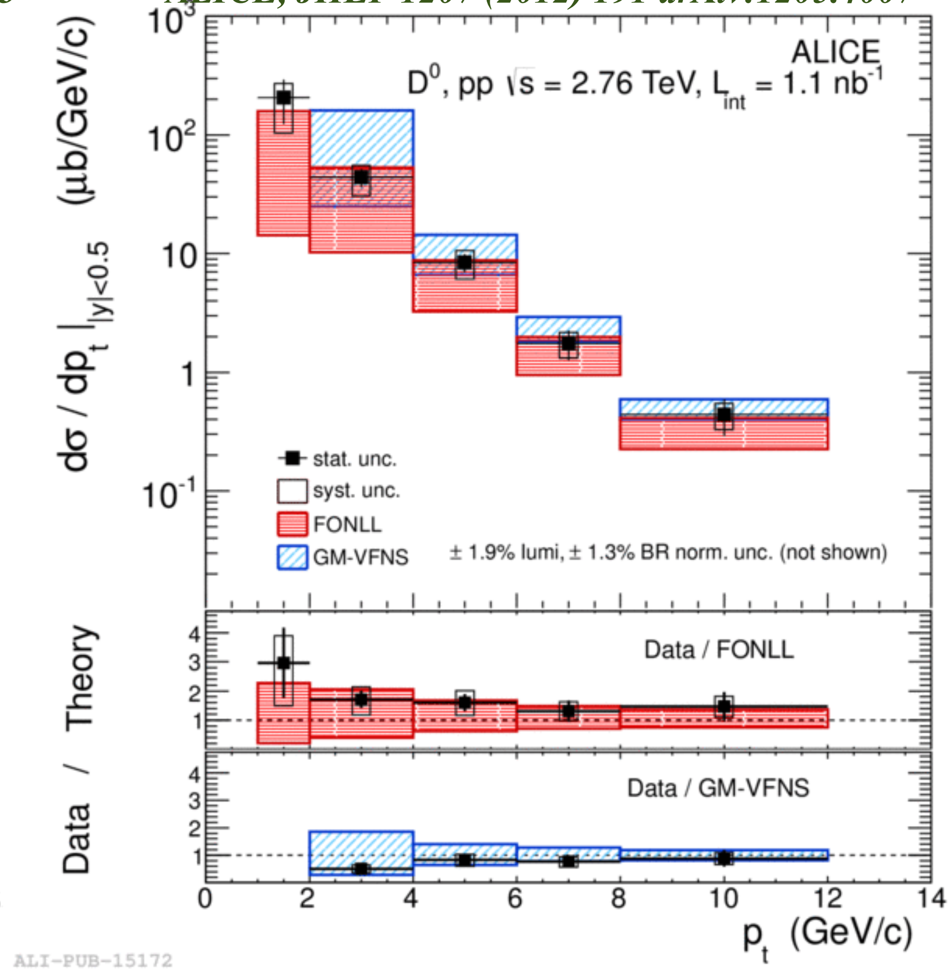
Separation of prompt J/ψ and J/ψ←B at mid-rapidity

D mesons

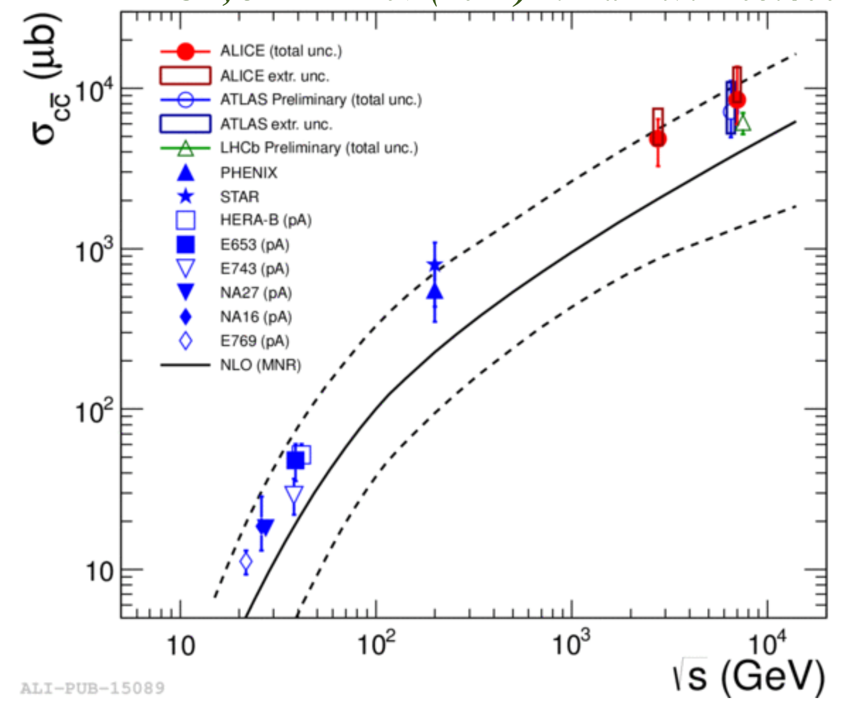
ALICE, JHEP 1201 (2012) 128 arXiv:1111.1553



ALICE, JHEP 1207 (2012) 191 arXiv:1205.4007



ALICE, JHEP 1207 (2012) 191 arXiv:1205.4007

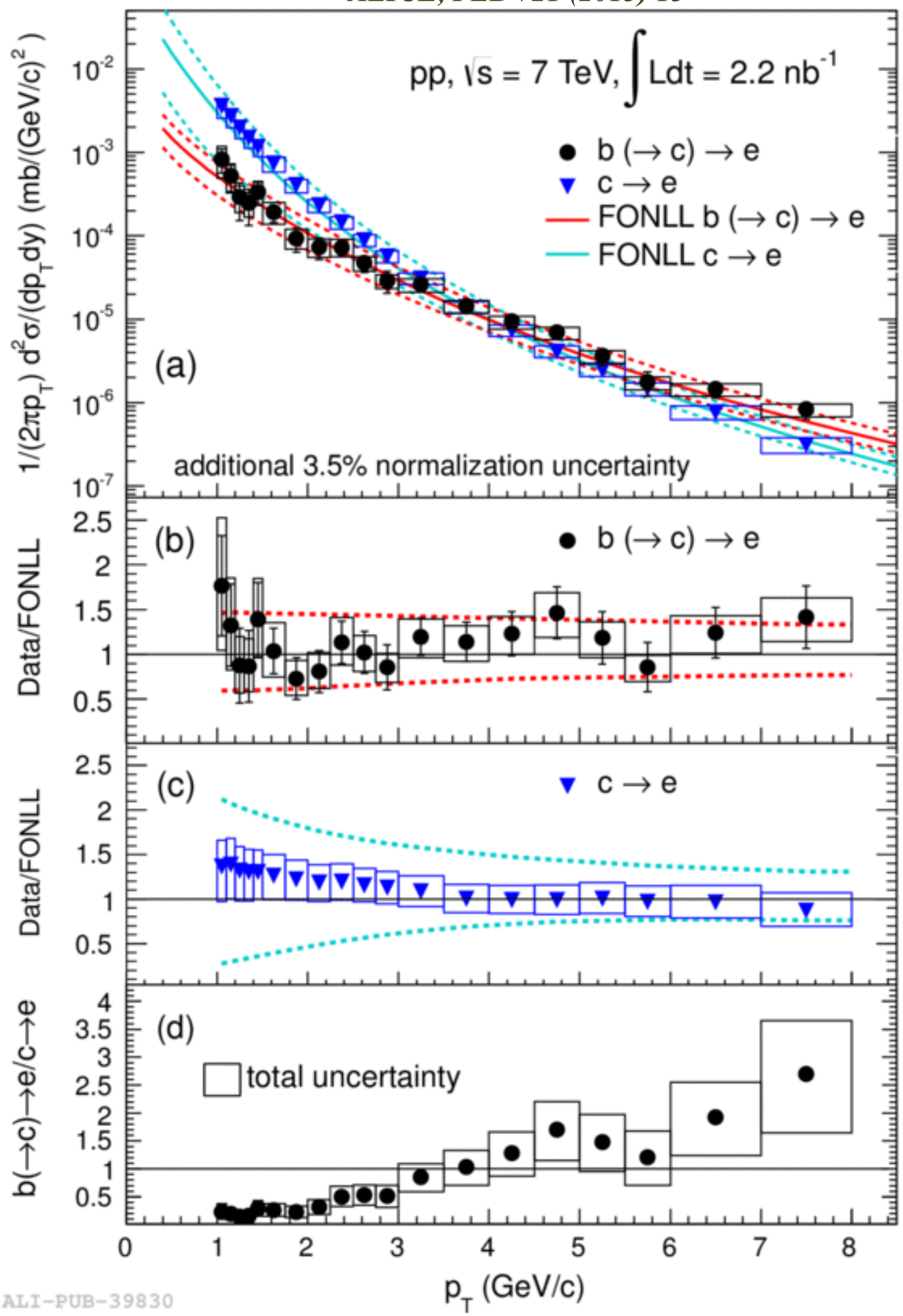


Cross-sections measured for all D mesons channels in pp at √s = 2.76 and 7 TeV
pQCD calculations in agreement with the data
Reference at 2.76 TeV (Pb-Pb) and 5.02 TeV (p-Pb) interpolated from data and based on pQCD-based calculations

Single lepton

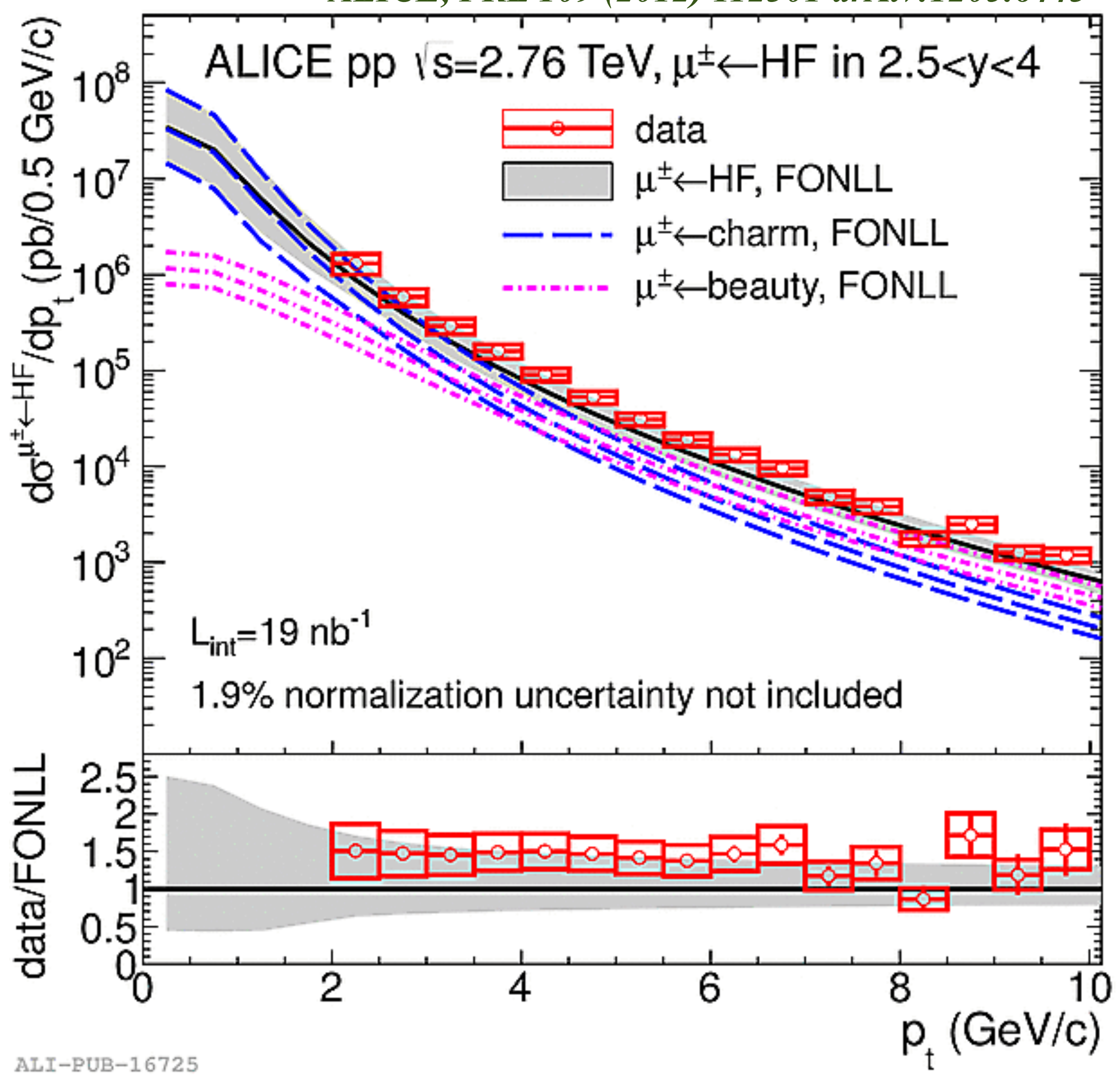
Single electron

ALICE, PLB 721 (2013) 13



Single muon

ALICE, PRL 109 (2012) 112301 arXiv:1205.6443

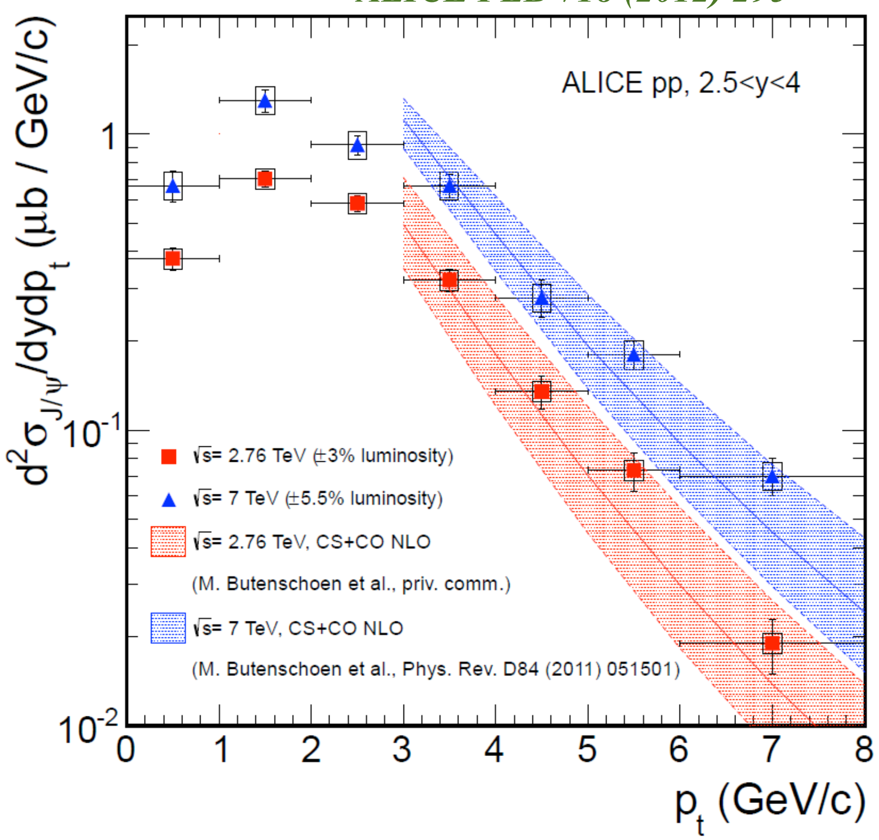


pQCD calculations in agreement with data
Single muon: 2.76 TeV measurements used as reference for Pb-Pb for muon
Single electrons: reference at 2.76 TeV (Pb-Pb) and 5.02 TeV (p-Pb) interpolated from data and based on pQCD-based calculations

Quarkonia

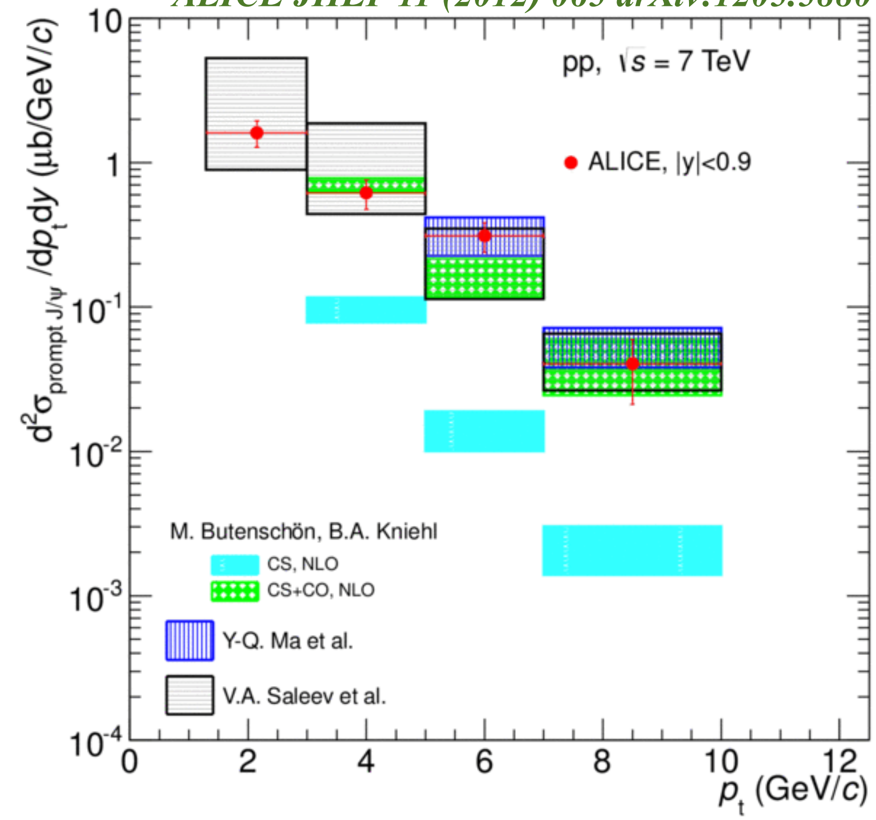
Inclusive J/ψ at forward rapidity

ALICE PLB 718 (2012) 295

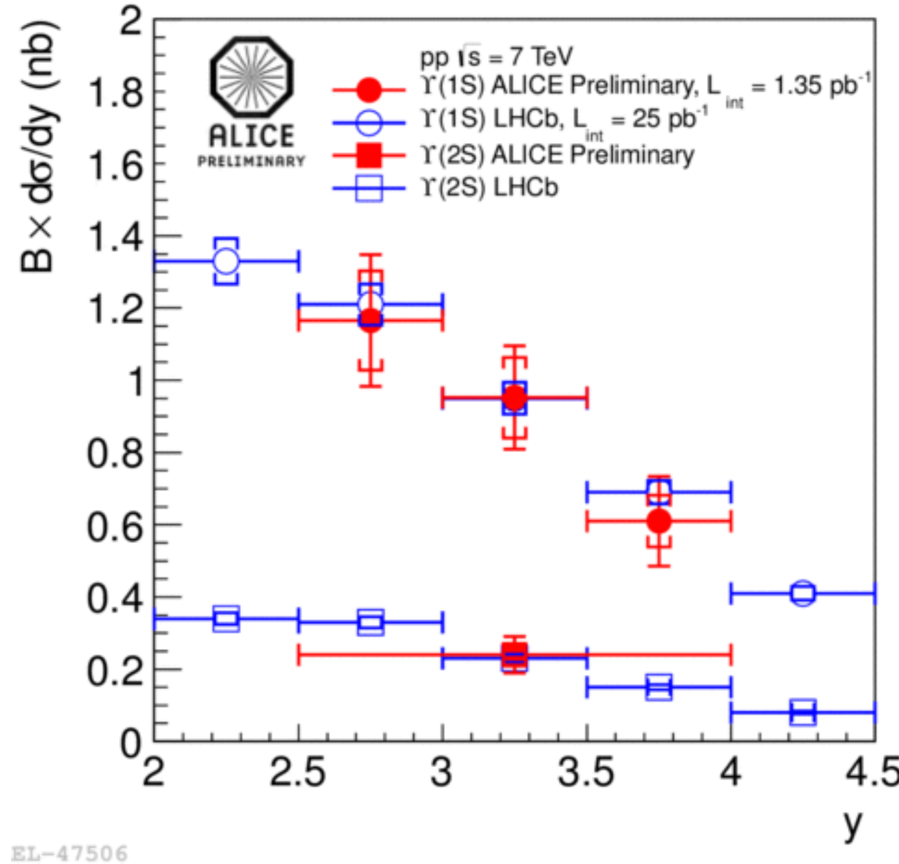


Prompt J/ψ at mid-rapidity

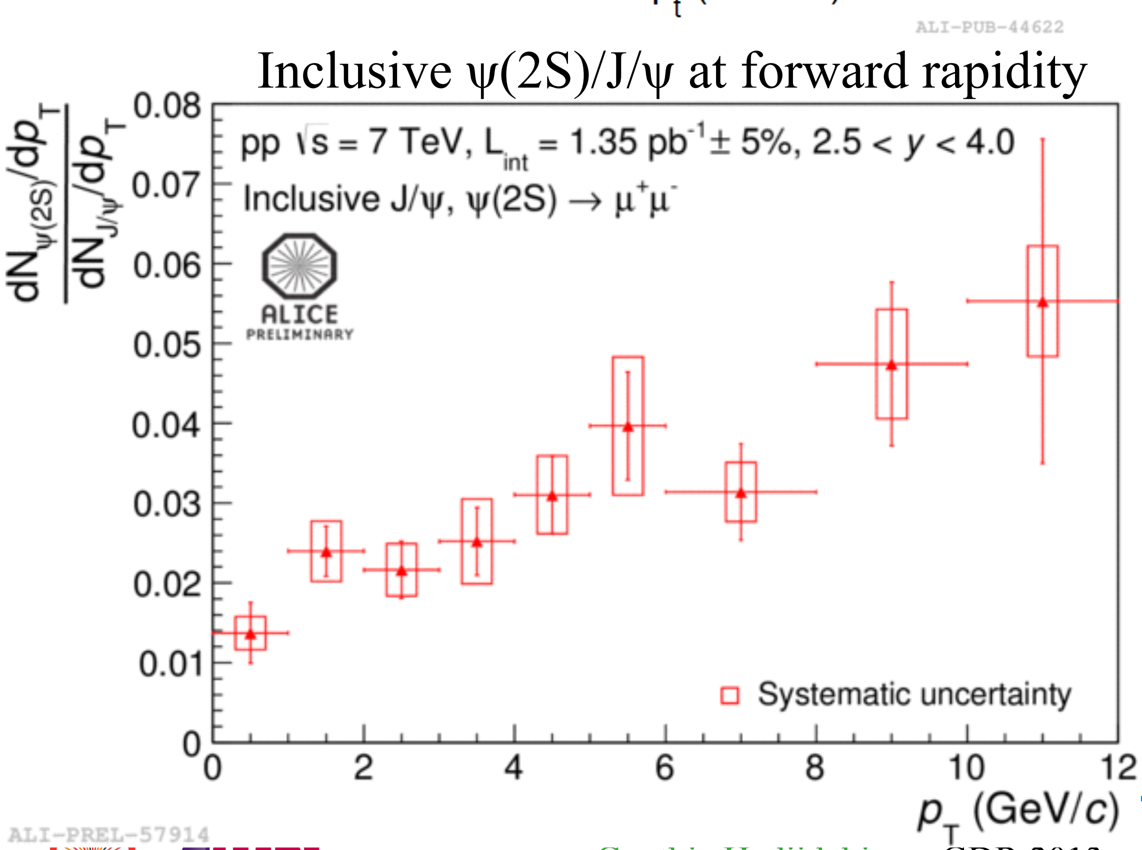
ALICE JHEP 11 (2012) 065 arXiv:1205.5880



ϒ at forward rapidity



Inclusive ψ(2S)/J/ψ at forward rapidity



Inclusive J/ψ at low p_T range down to 0 at mid and forward rapidity

Prompt J/ψ and B→J/ψ at mid-rapidity

J/ψ cross-sections well described by NLO NRQCD but not the polarization (not shown)

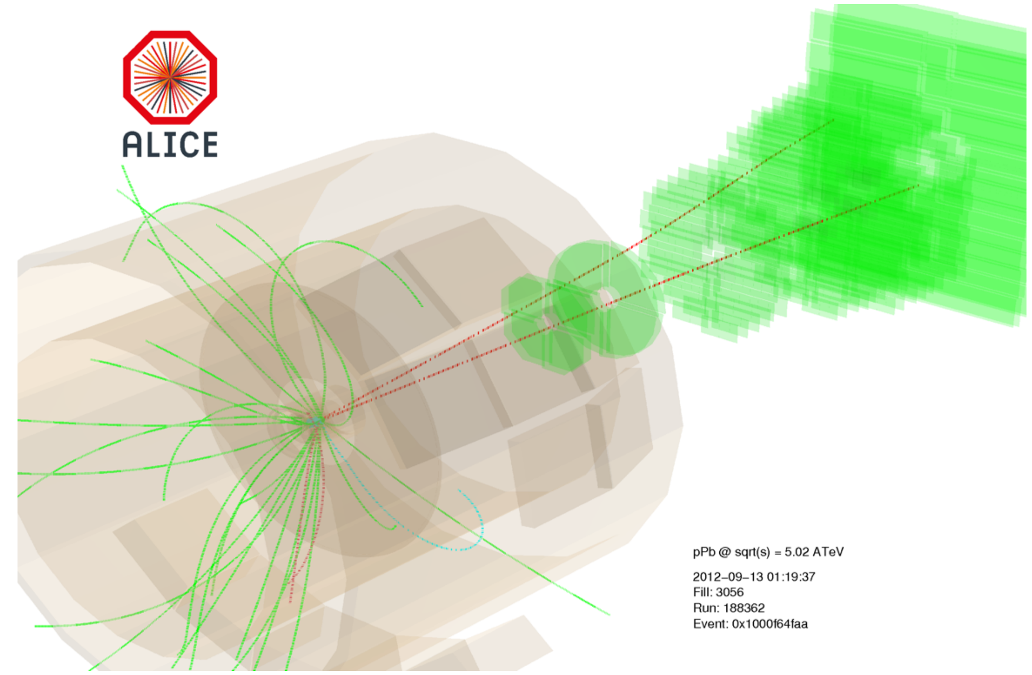
ψ(2S), Y(1S) and Y(2S) in agreement with LHCb

Reference at 2.76 TeV (Pb-Pb) and 5.02 TeV (p-Pb) interpolated from data except for forward rapidity J/ψ at 2.76 TeV (Pb-Pb)

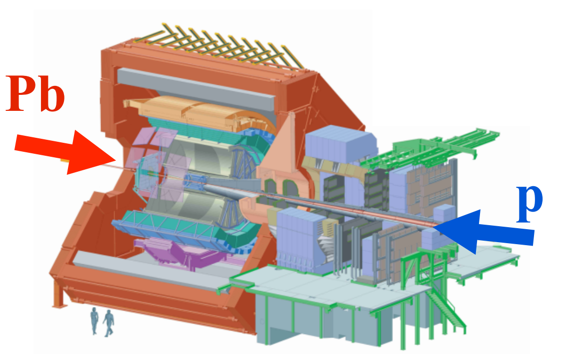
p-Pb measurements

Jan/Feb. 2013 data sample

- p (E_p = 4 TeV) + Pb (E_{Pb} = 1.58 A·TeV) collisions at $\sqrt{s_{NN}}$ = 5.02 TeV: center of mass shifted in rapidity in the proton beam direction by $\Delta y = 0.465$
- 2 beam configurations (p-Pb and Pb-p): two rapidity ranges for the Muon Spectrometer → possibility to measure forward to backward yield ratio

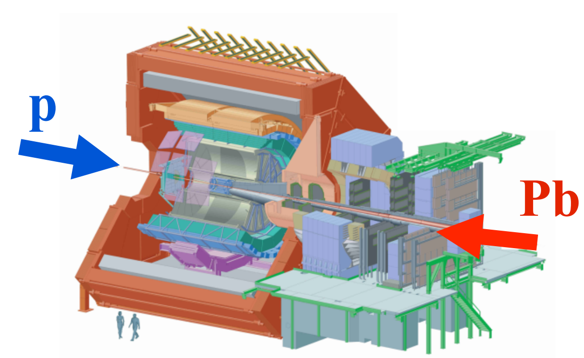


Pb-p



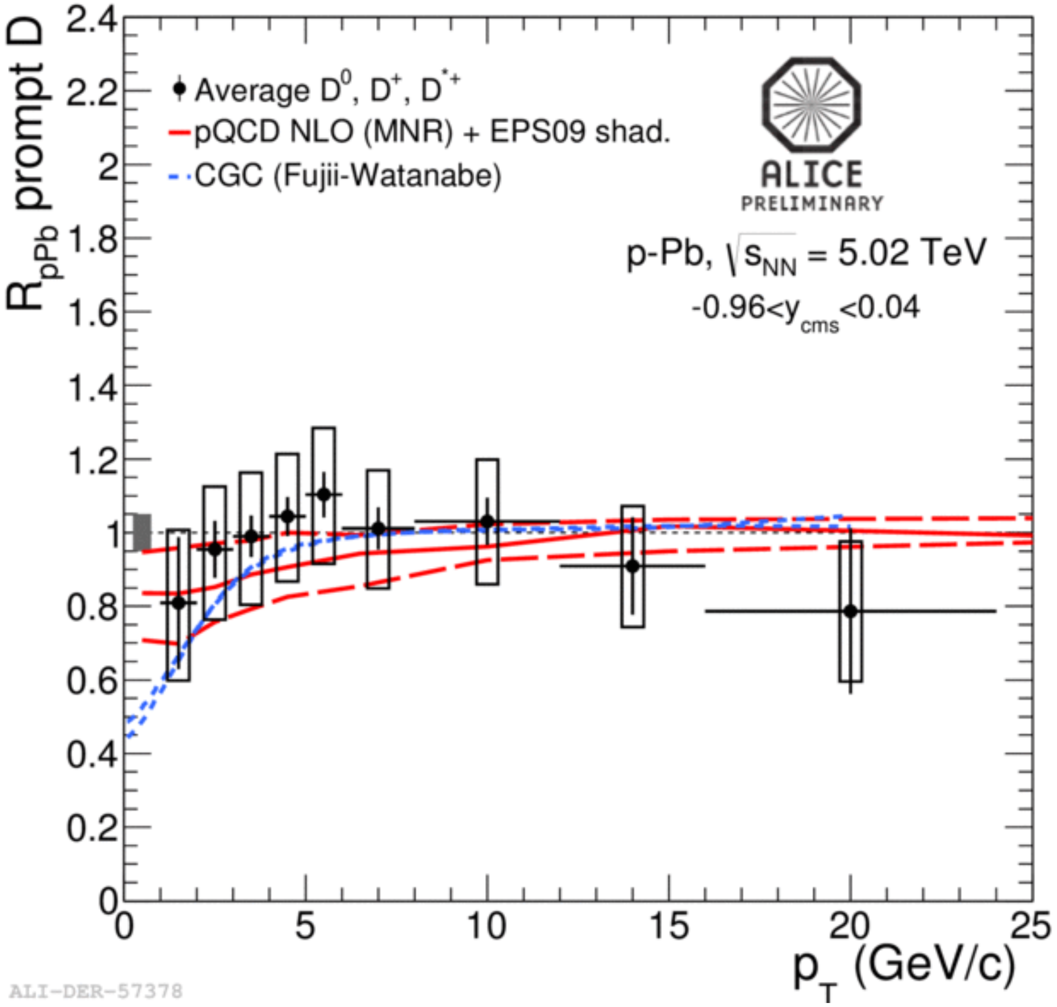
Muon Spectrometer in Pb-going side
Backward rapidity: $-4.46 < y_{cms} < -2.96$

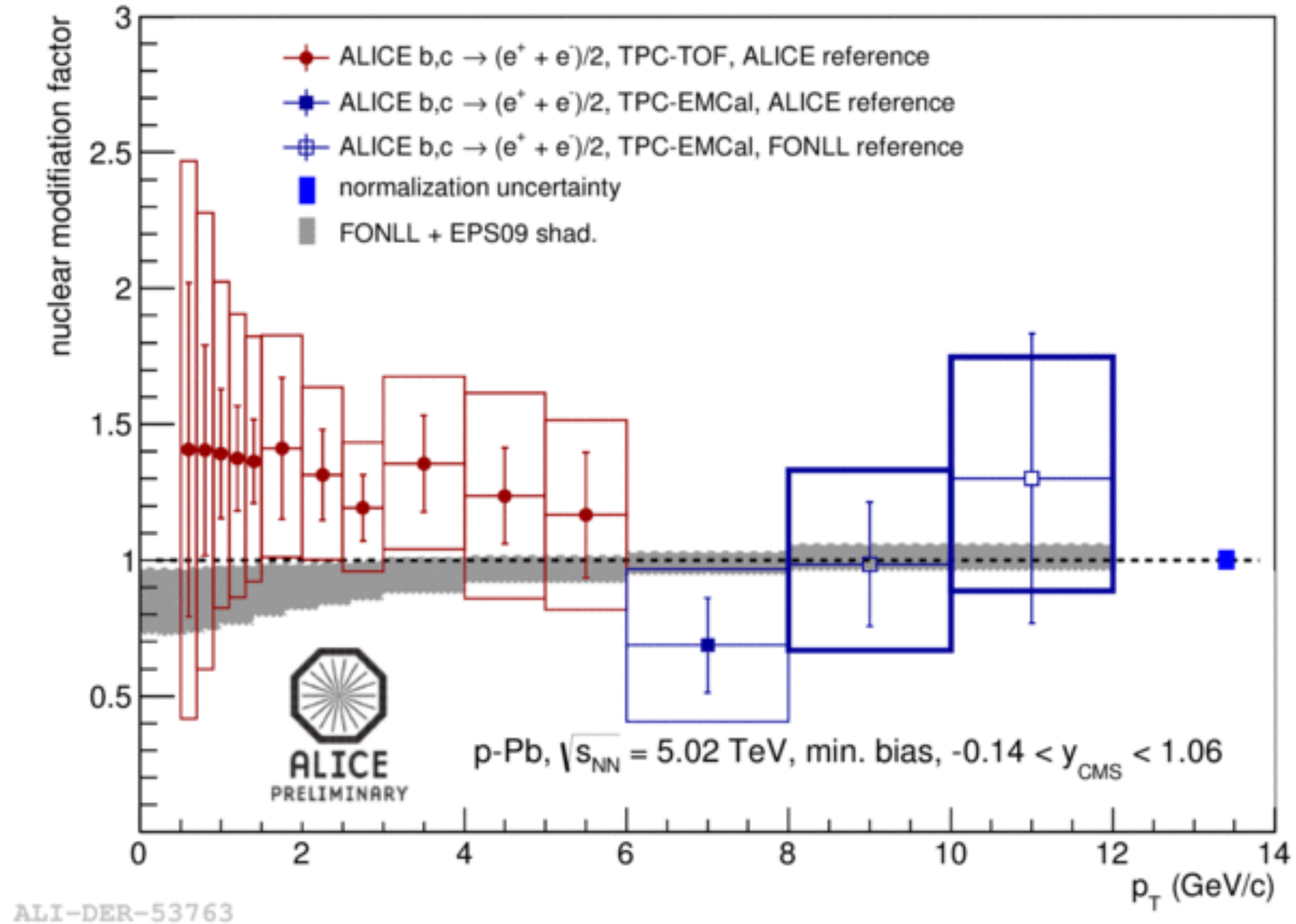
p-Pb



Muon Spectrometer in p-going side
Forward rapidity: $2.03 < y_{cms} < 3.53$
Mid-rapidity: $-1.37 < y_{cms} < 0.43$

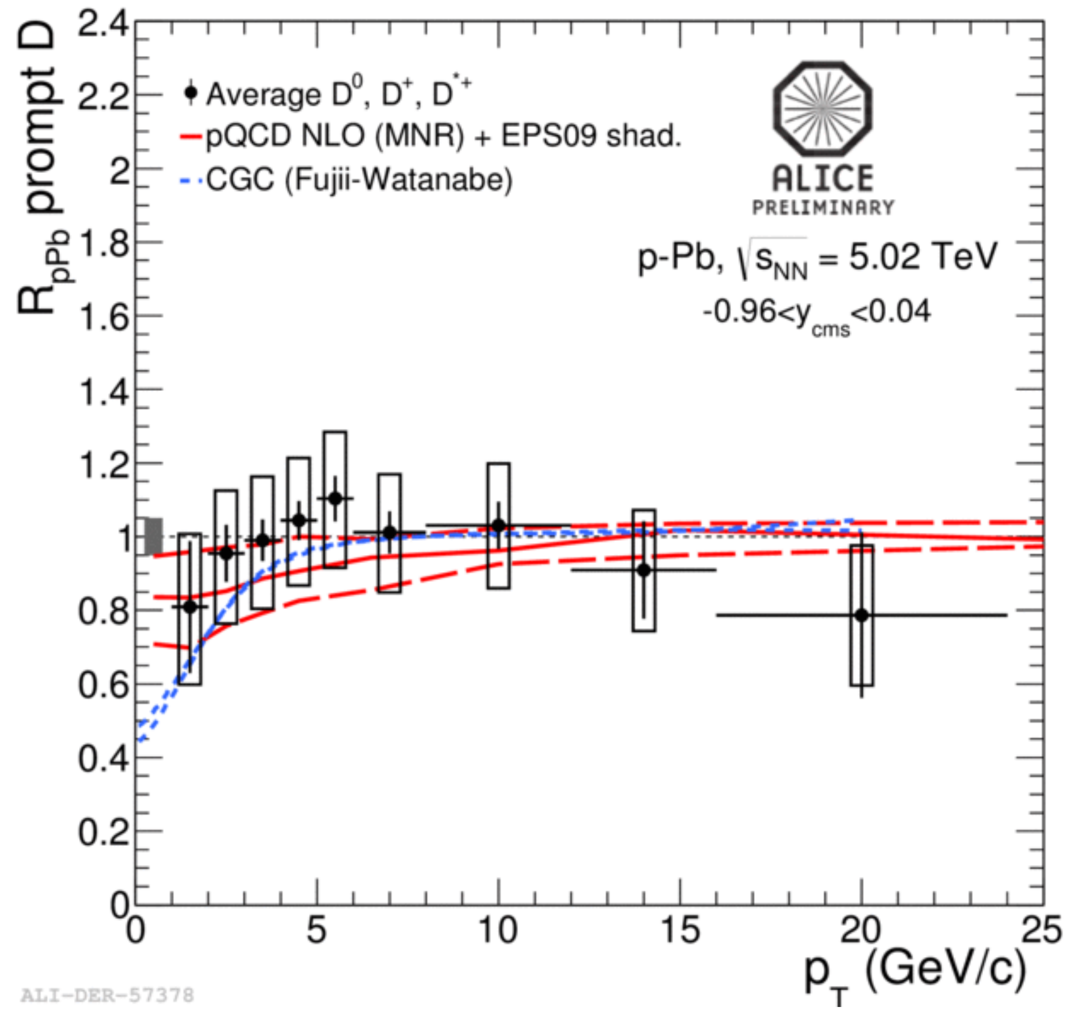
Open heavy flavour

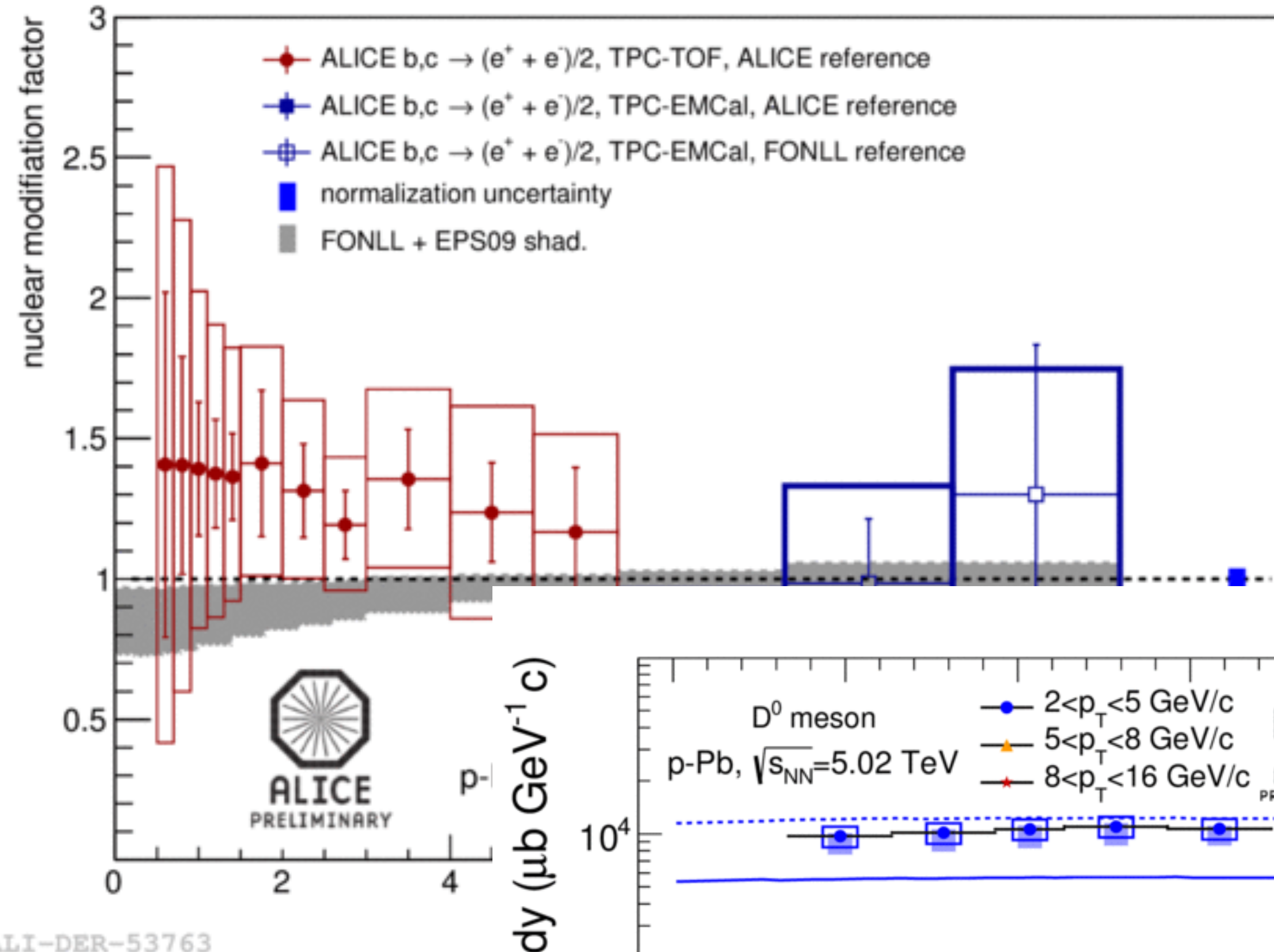


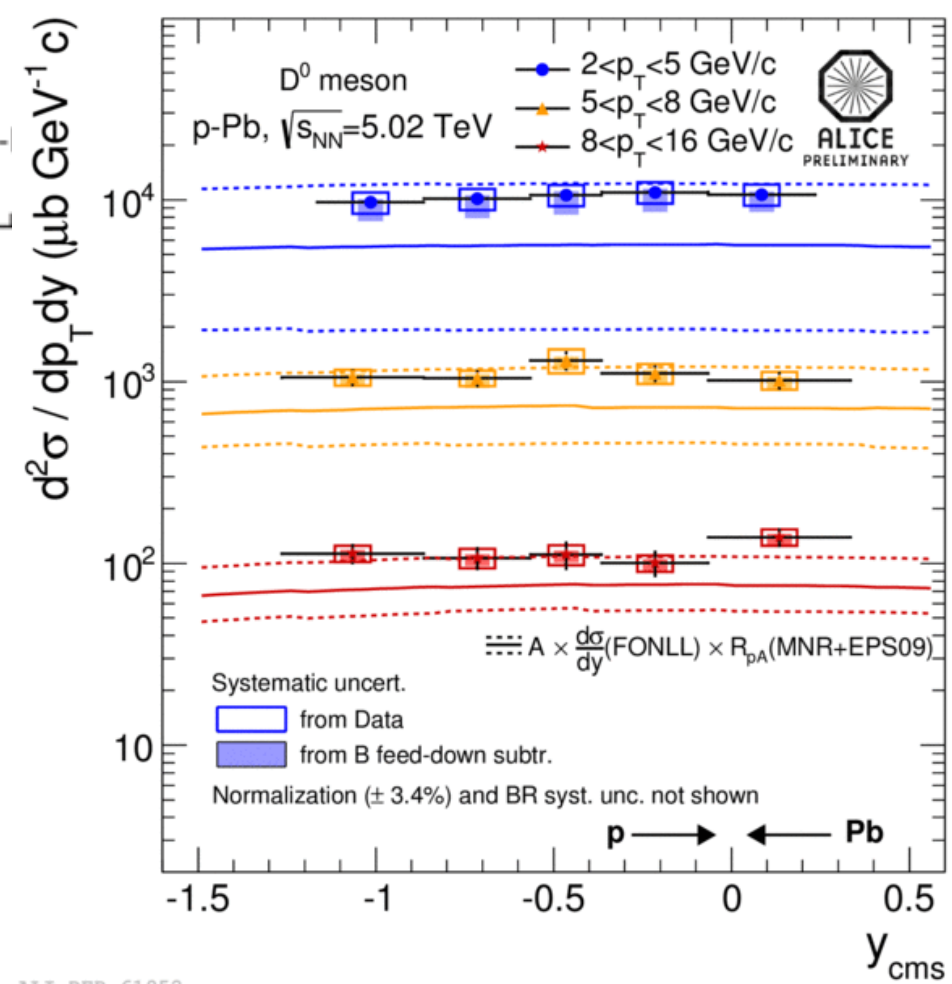


R_{pPb} consistent with unity within uncertainties
MNR or FONLL calculations with EPS09 NLO in good agreement with the data

Open heavy flavour







R_{pPb} consistent with unity within uncertainties
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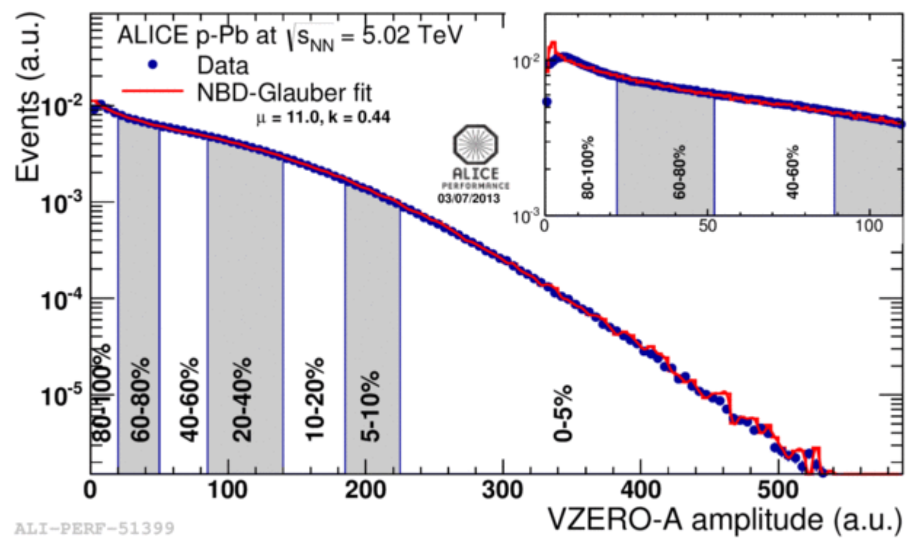
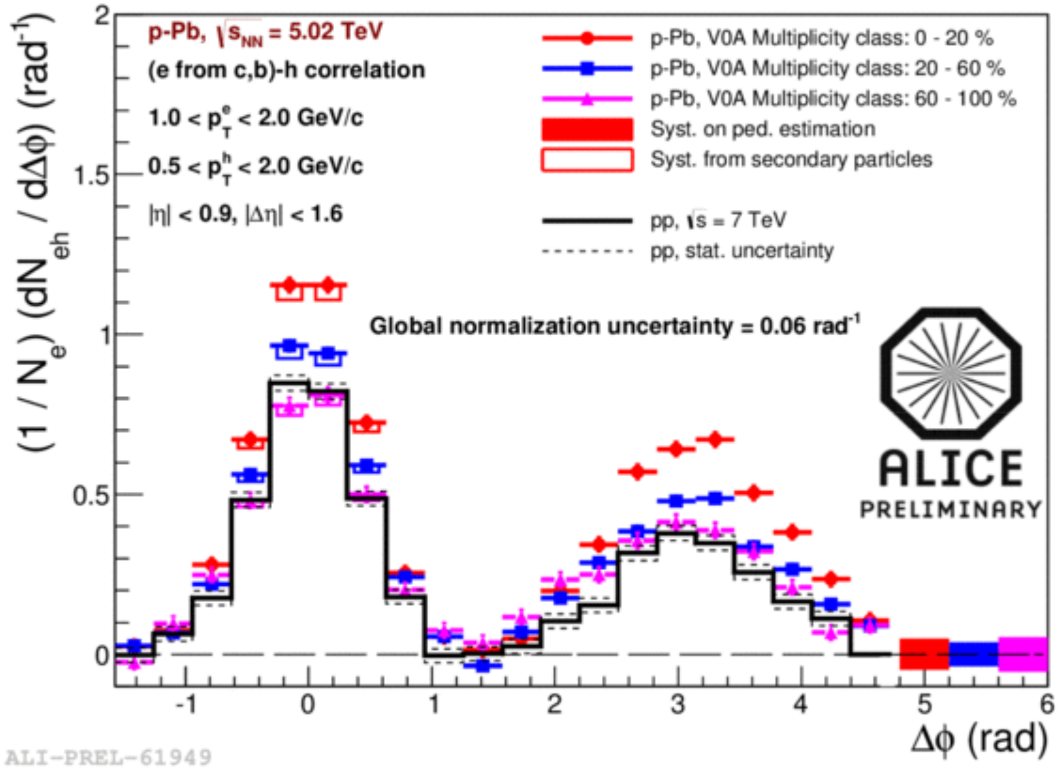
No rapididity dependence for D mesons cross-sections in $-1.25 < y_{cms} < 0.35$

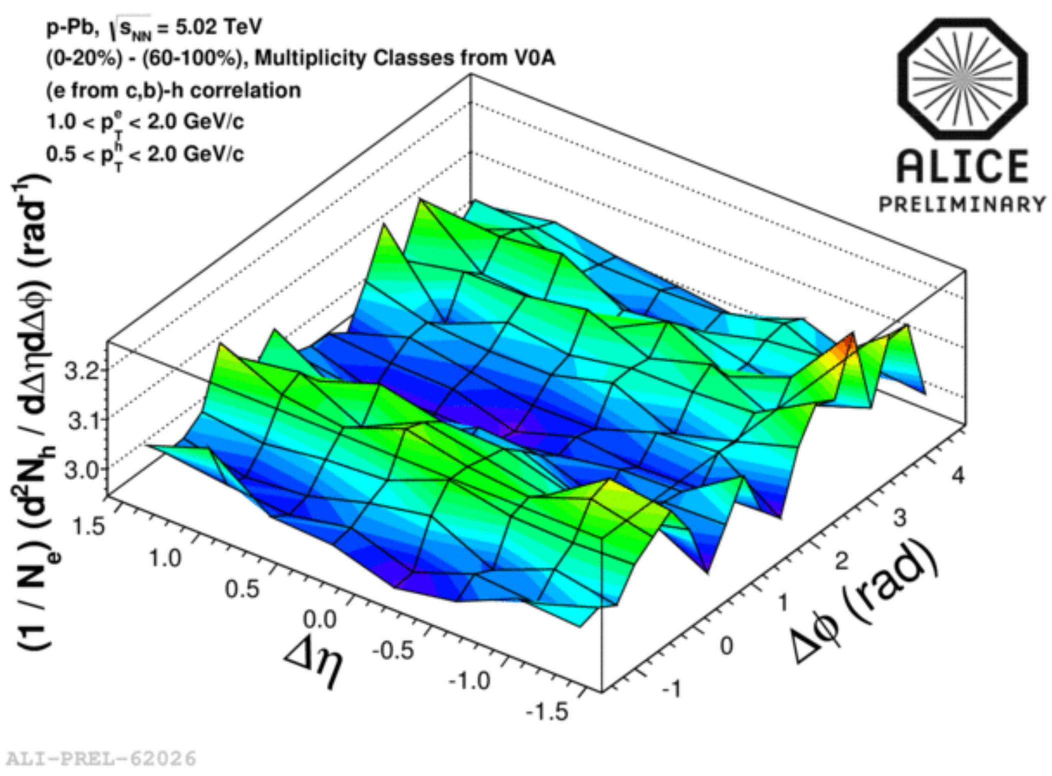
Electron-hadron correlations

Correlation function between trigger particles (electrons from heavy-flavour decay) and associated particles (charged hadrons)

Event multiplicity measured with V0A (Pb-side)







Low p_T triggered HF decay electrons: enhancement in the away and near-side peak for the highest multiplicity events

Double-ridge structure as observed in hadron-hadron correlations

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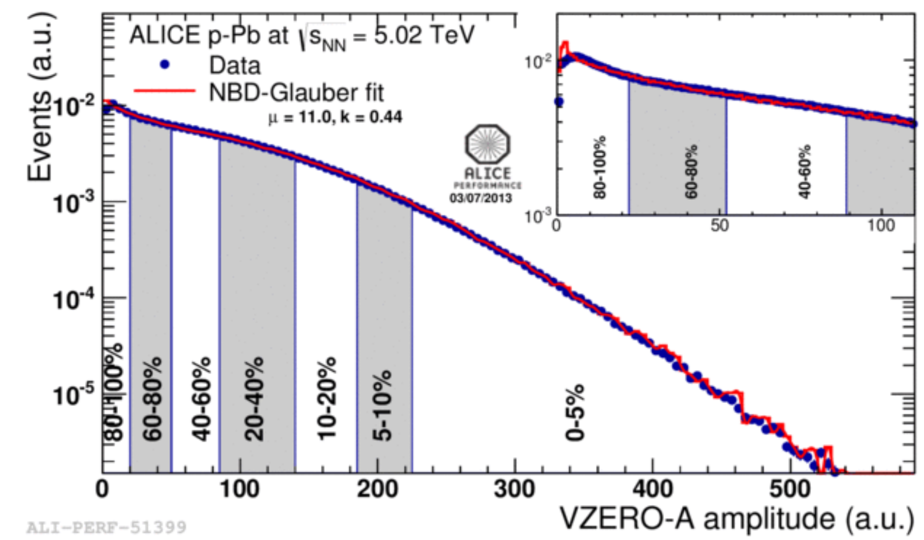

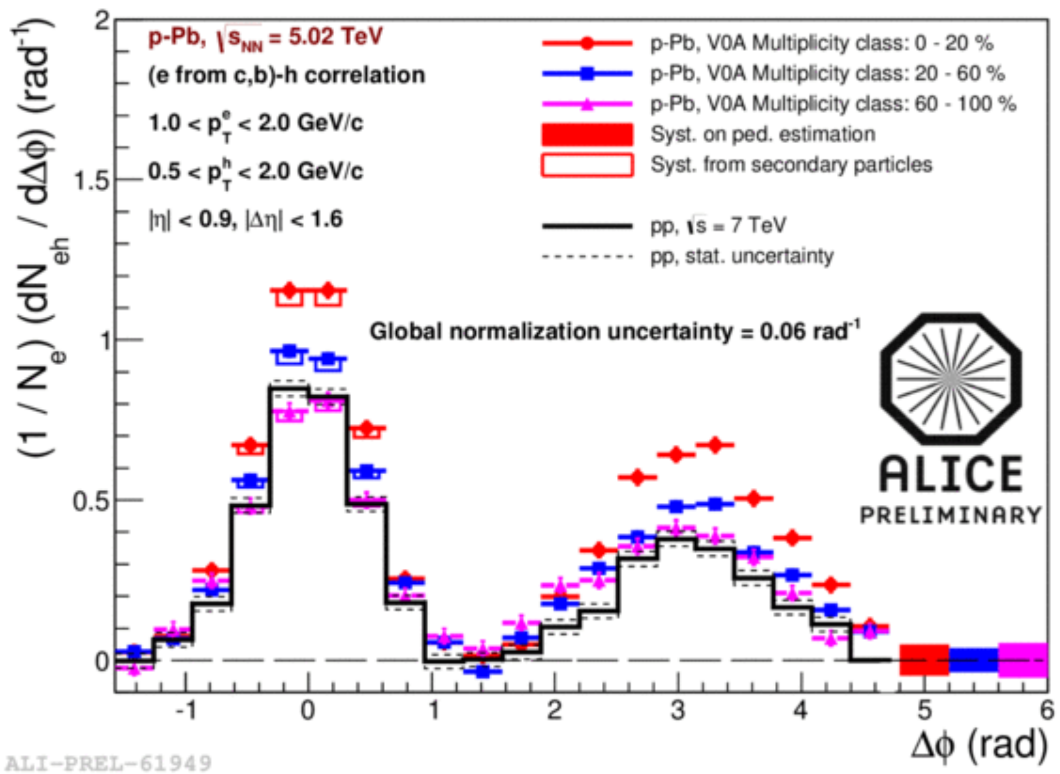

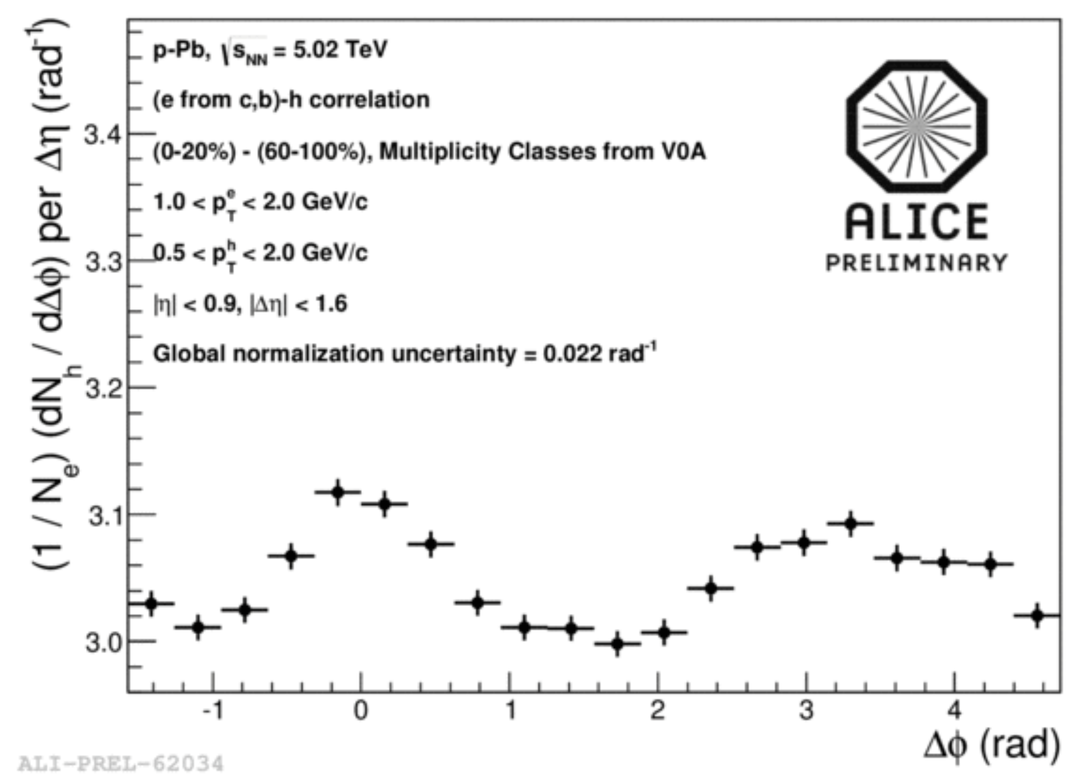

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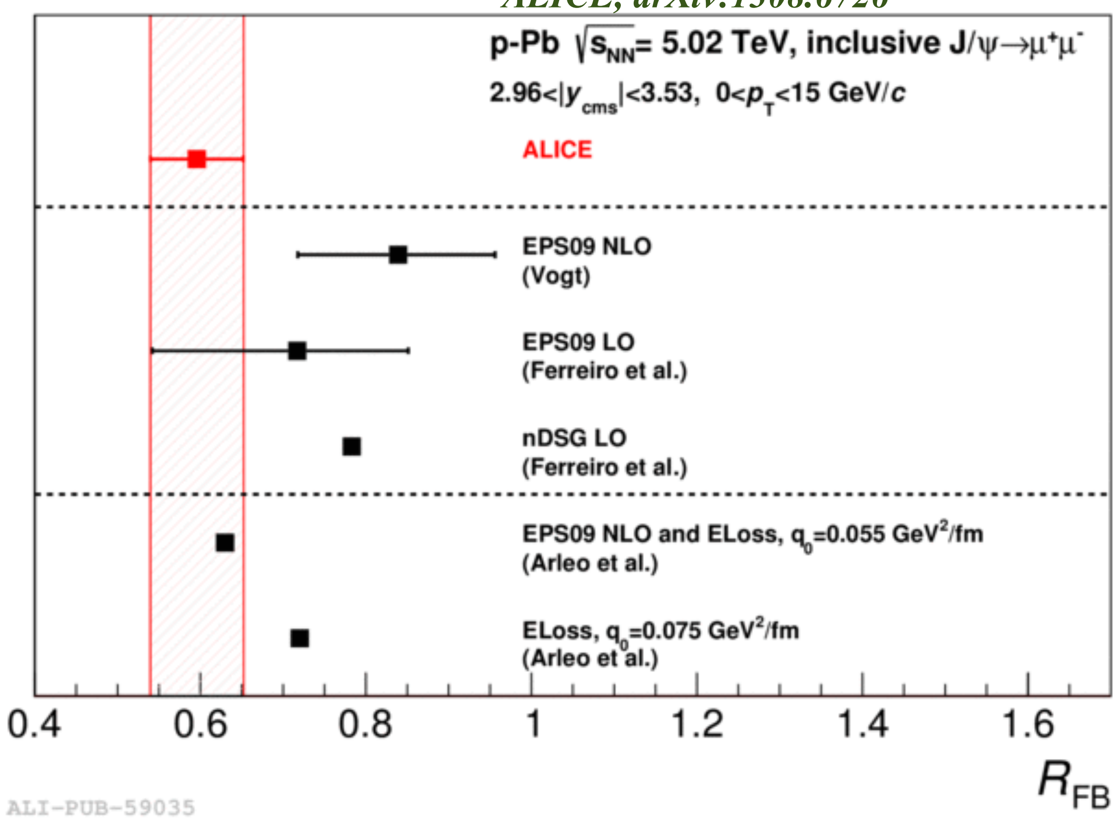
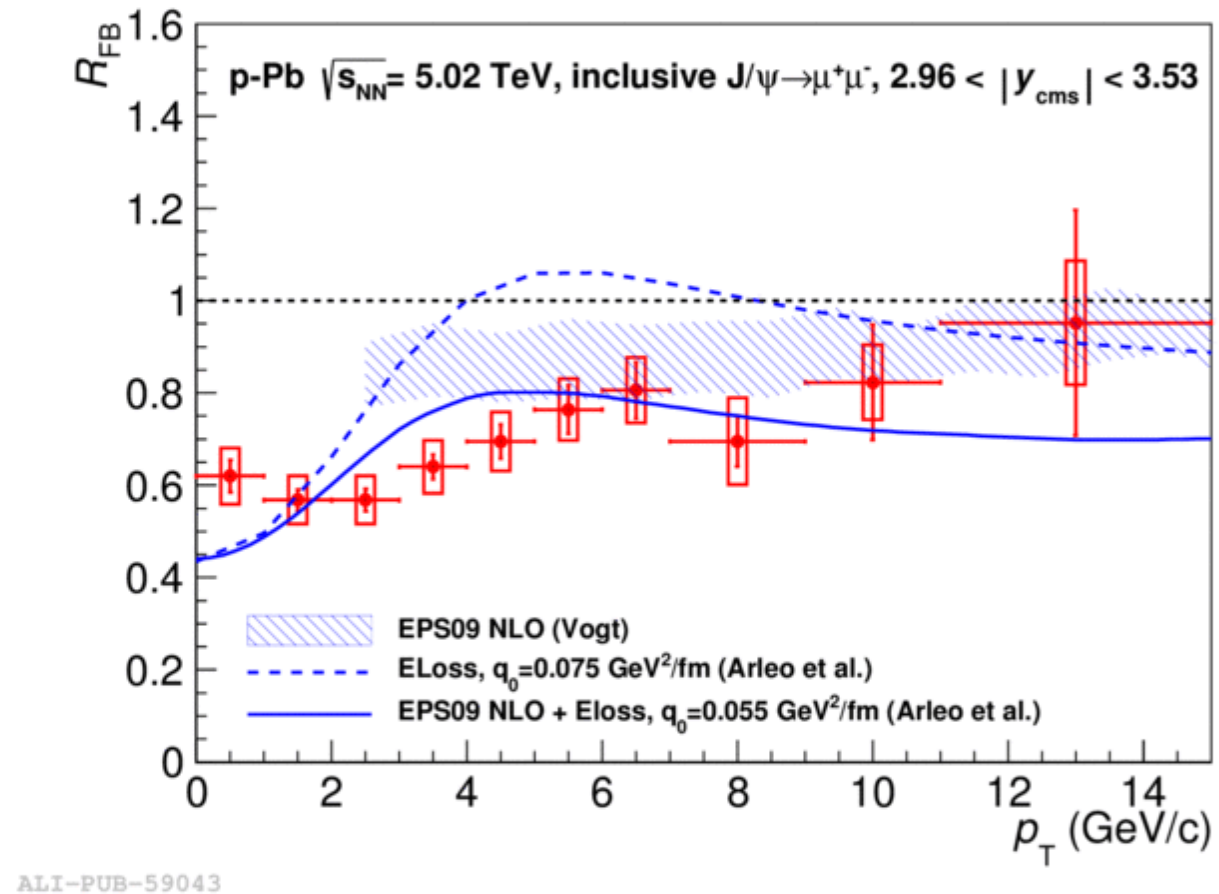
Double-ridge structure as observed in hadron-hadron correlations

J/ψ R_{FB} integrated and vs p_T

$$R_{FB}(|y_{cms}|) = \frac{R_{pPb}(y_{cms})}{R_{pPb}(-y_{cms})} = \frac{Y_{pPb}(y_{cms})}{Y_{pPb}(-y_{cms})}$$

ALICE, arXiv:1308.6726



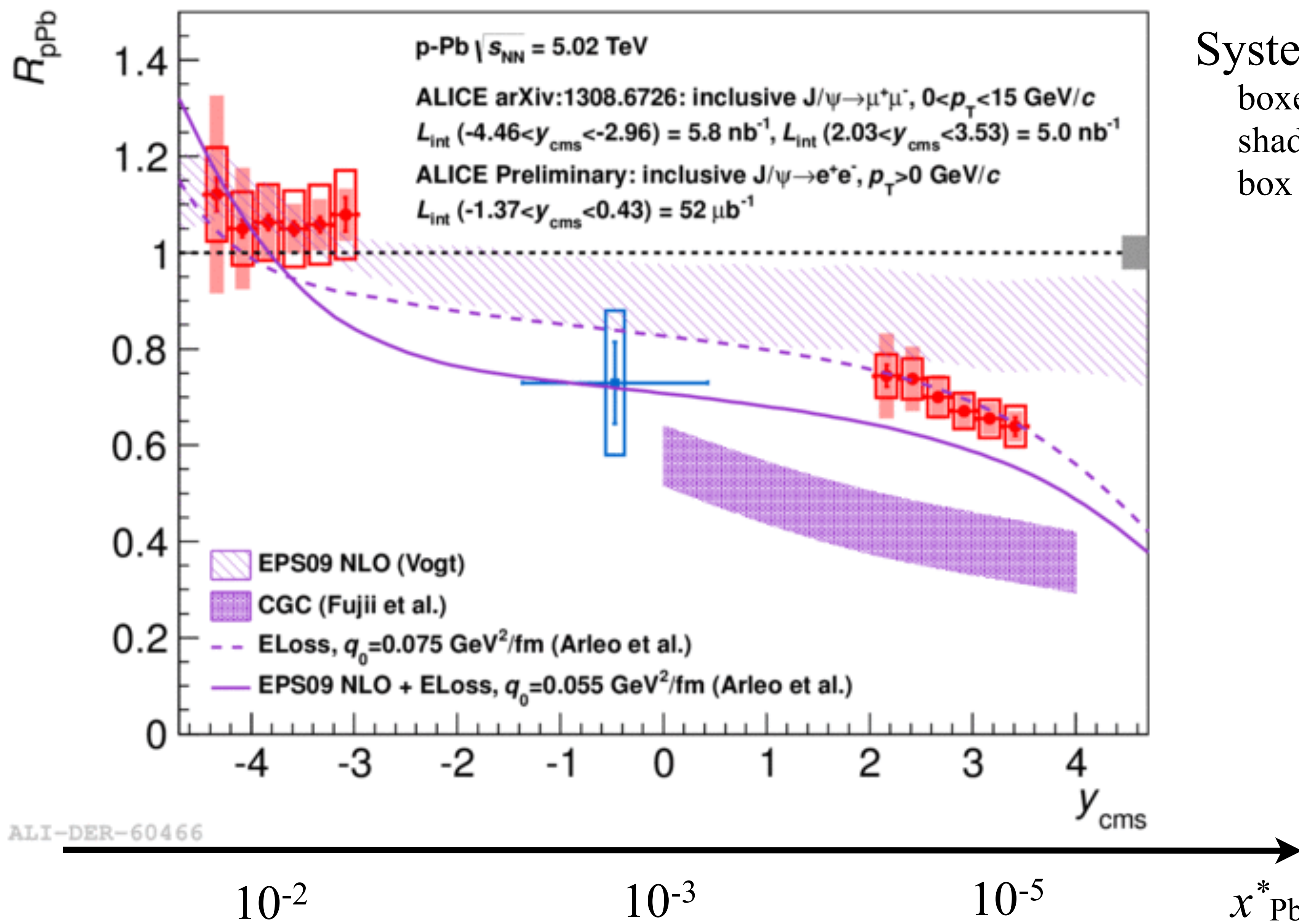


R_{FB} decreases at low p_T down to 0.6 and is consistent with unity for $p_T > 10$ GeV/c
B feed-down does not contribute much to this ratio

LHCb, arXiv:1308.6929

Pure shadowing models tend to overestimate the data
Shadowing + energy loss model reproduces fairly well the data but with a steeper p_T dependence at low p_T

J/ψ R_{pPb} vs rapidity



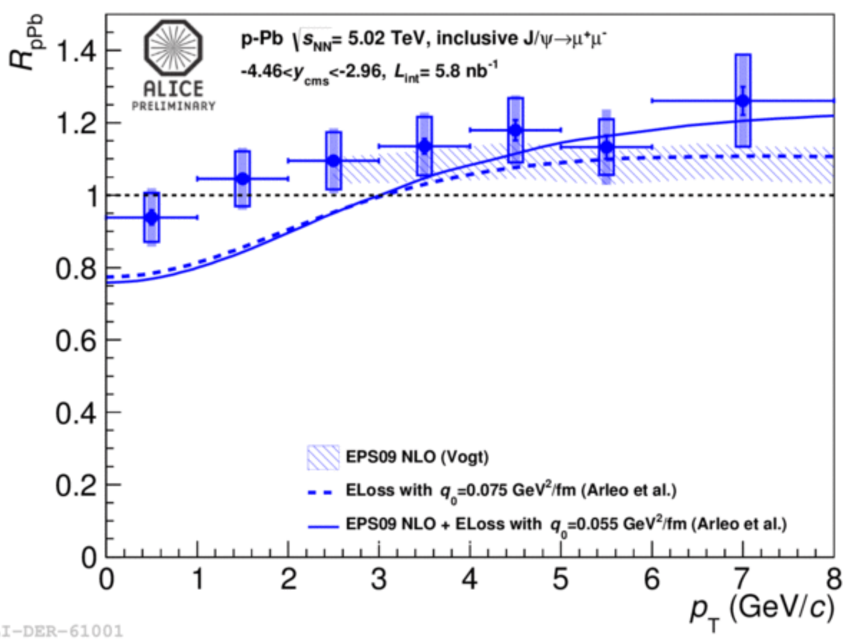
Systematic uncertainties
- boxes: uncorrelated
- shaded area: (partially) correlated
- box at unity: fully correlated

* Momentum fraction of probed gluons in nucleus assuming 2→1 J/ψ production mechanism

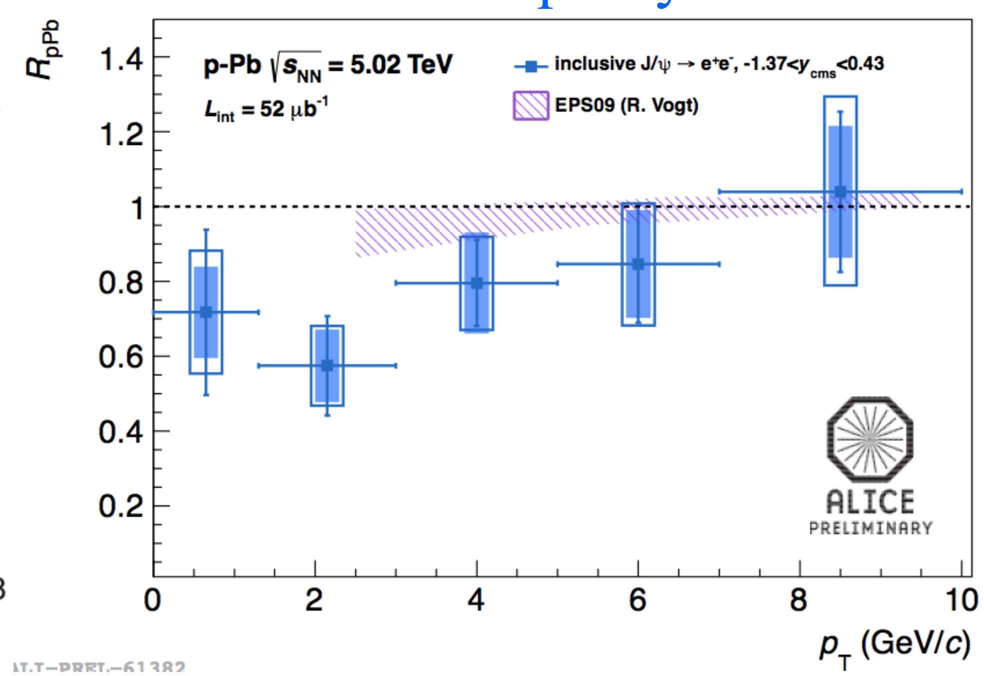
Shadowing: backward rapidity data well reproduced, strong shadowing favoured at forward rapidity
Coherent energy loss: y-dependence well reproduced, better agreement with pure energy loss
CGC calculations underestimate the data

J/ψ R_{pPb} vs transverse momentum

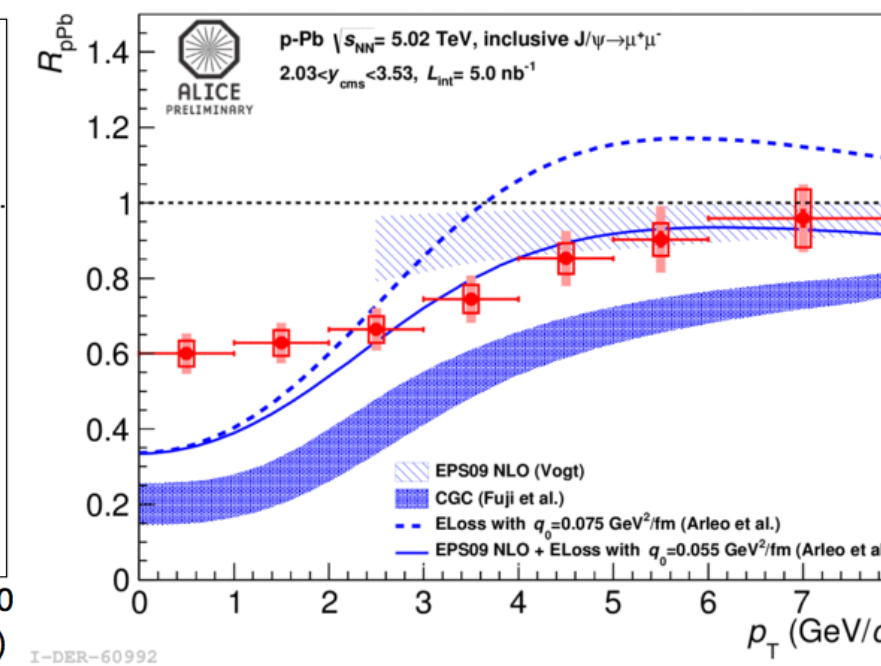
backward rapidity



mid-rapidity



forward rapidity



Backward rapidity

R_{pPb} shows a small p_T dependence and is close to unity

Mid rapidity

R_{pPb} tends to increase with p_T

Forward rapidity

R_{pPb} increases with p_T and is compatible with unity for p_T larger than 5 GeV/c

At forward rapidity data favours a strong shadowing

Coherent energy loss model overestimates the suppression at forward rapidity for $p_T < 2$ GeV/c

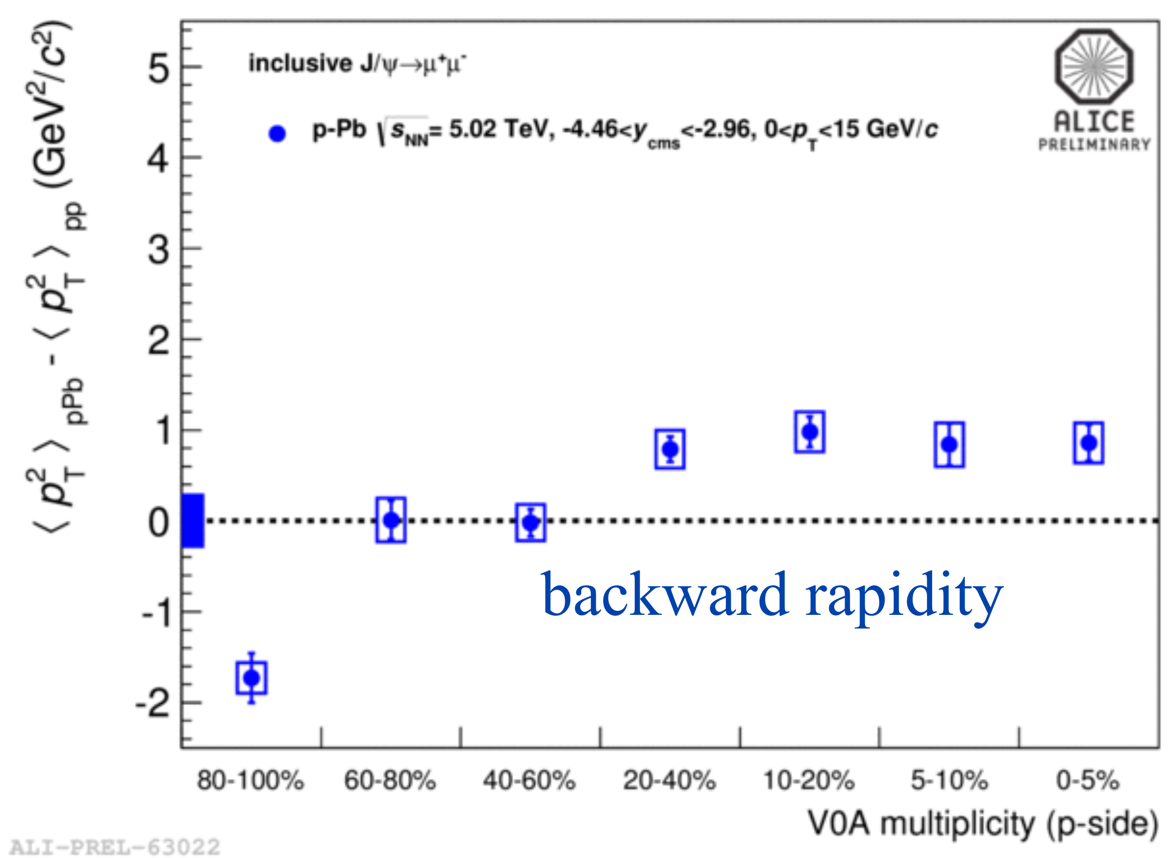
CGC calculations underestimate the data in the full p_T range

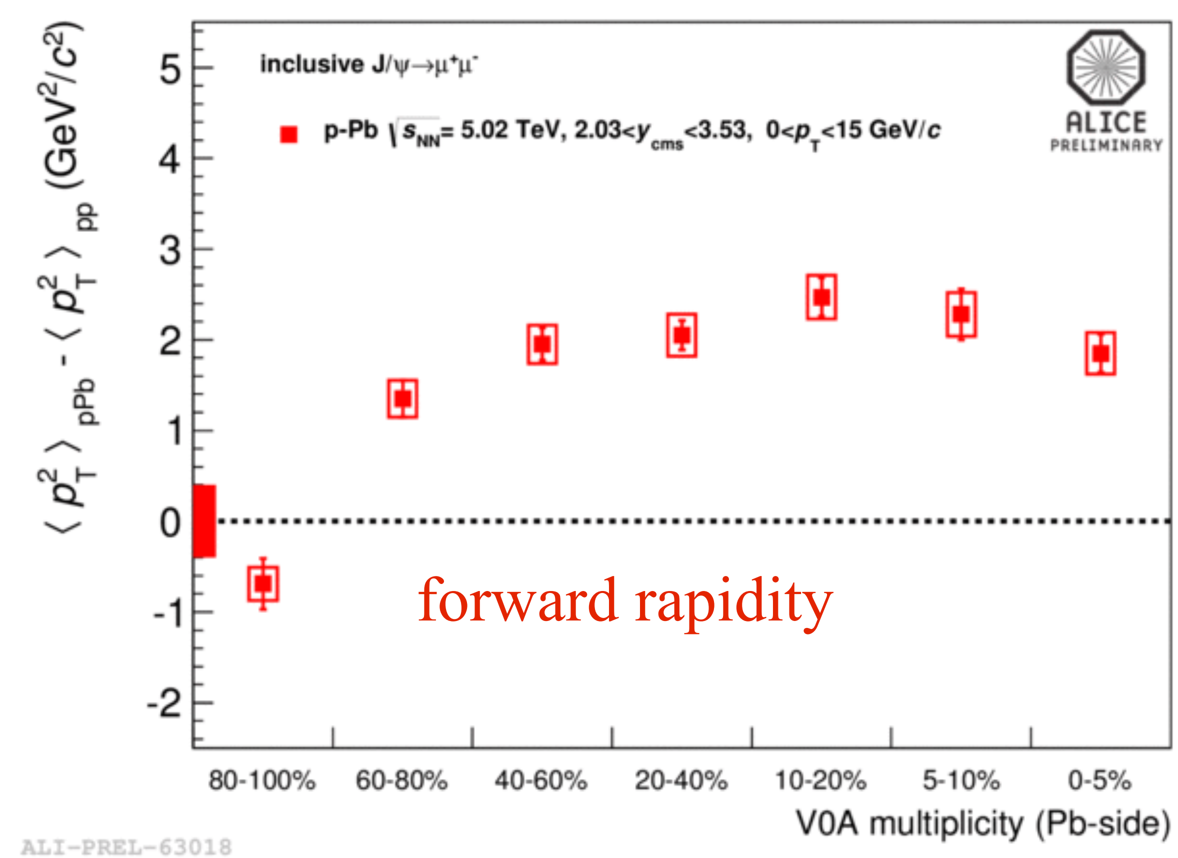
J/ψ p_T broadening vs event multiplicity

$\Delta\langle p_T^2\rangle = \langle p_T^2\rangle_{pPb} - \langle p_T^2\rangle_{pp}$ for different event multiplicity measured with V0A

$\langle p_T^2\rangle_{pp}$ from interpolated pp distributions at $\sqrt{s}$ = 5.02 TeV

Systematic uncertainties
- boxes: uncorrelated
- box at unity: correlated



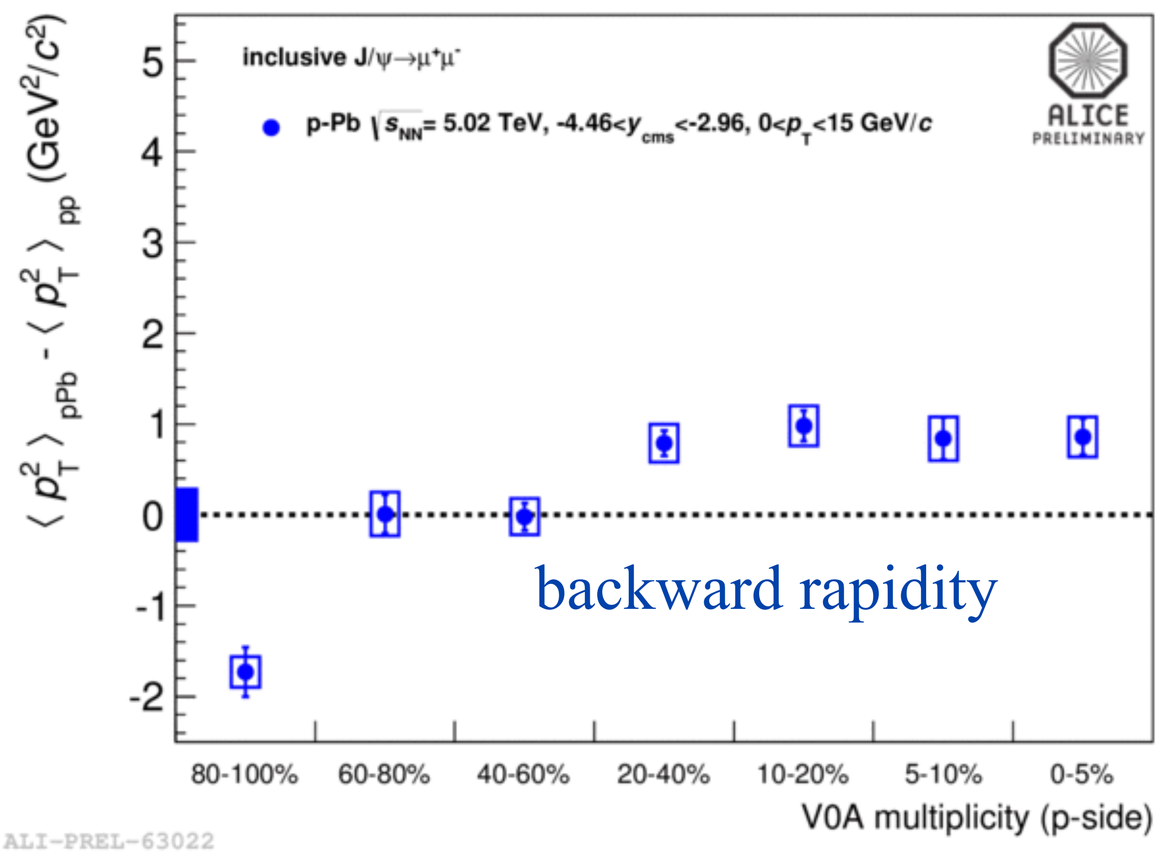


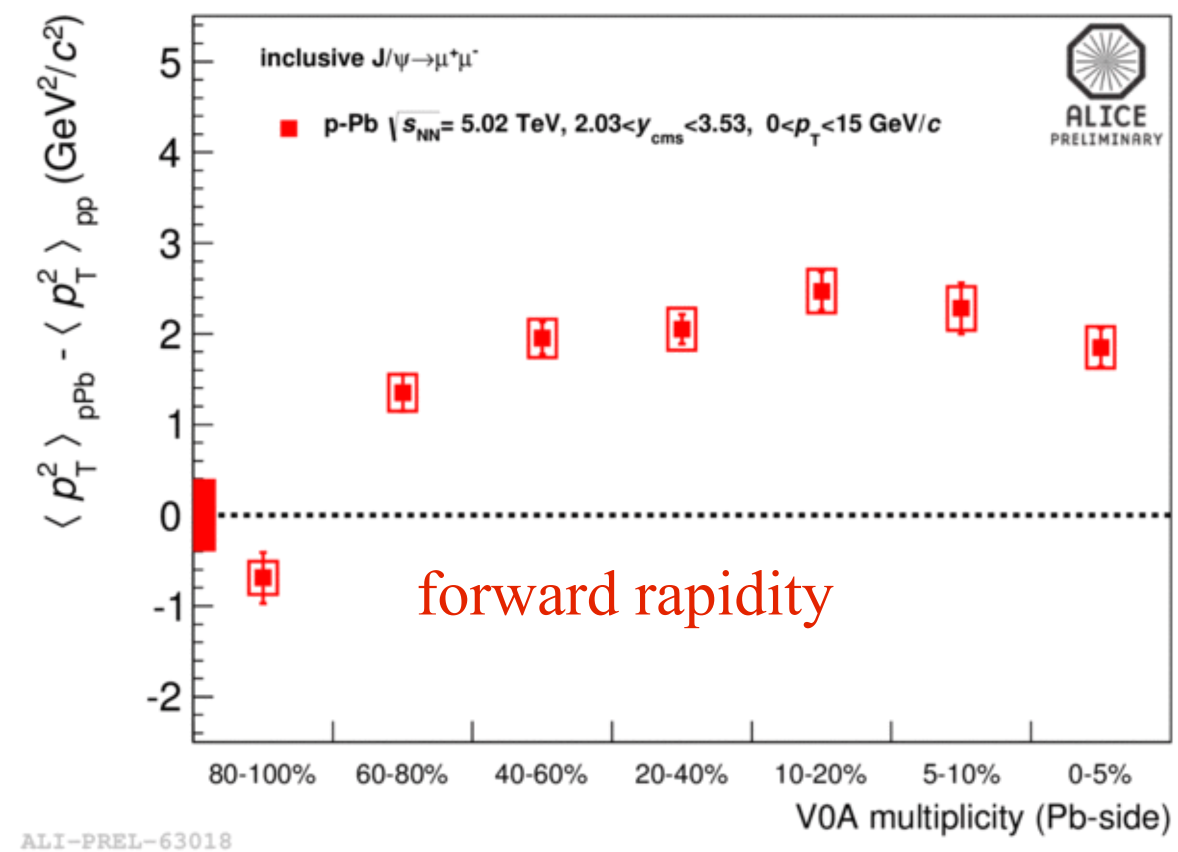
J/ψ p_T broadening vs event multiplicity

$\Delta\langle p_T^2\rangle = \langle p_T^2\rangle_{pPb} - \langle p_T^2\rangle_{pp}$ for different event multiplicity measured with V0A

$\langle p_T^2\rangle_{pp}$ from interpolated pp distributions at $\sqrt{s}$ = 5.02 TeV

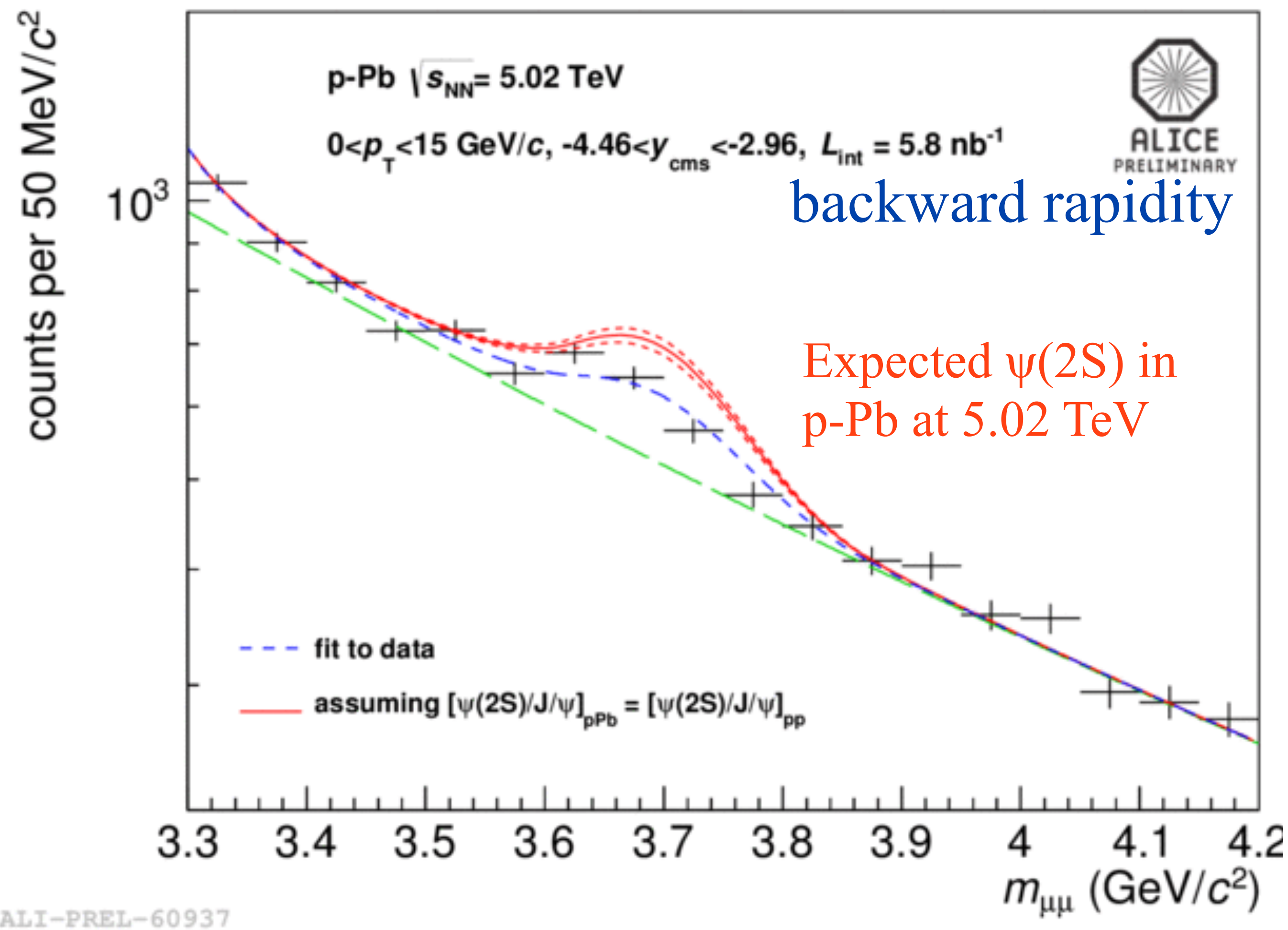
Systematic uncertainties
- boxes: uncorrelated
- box at unity: correlated

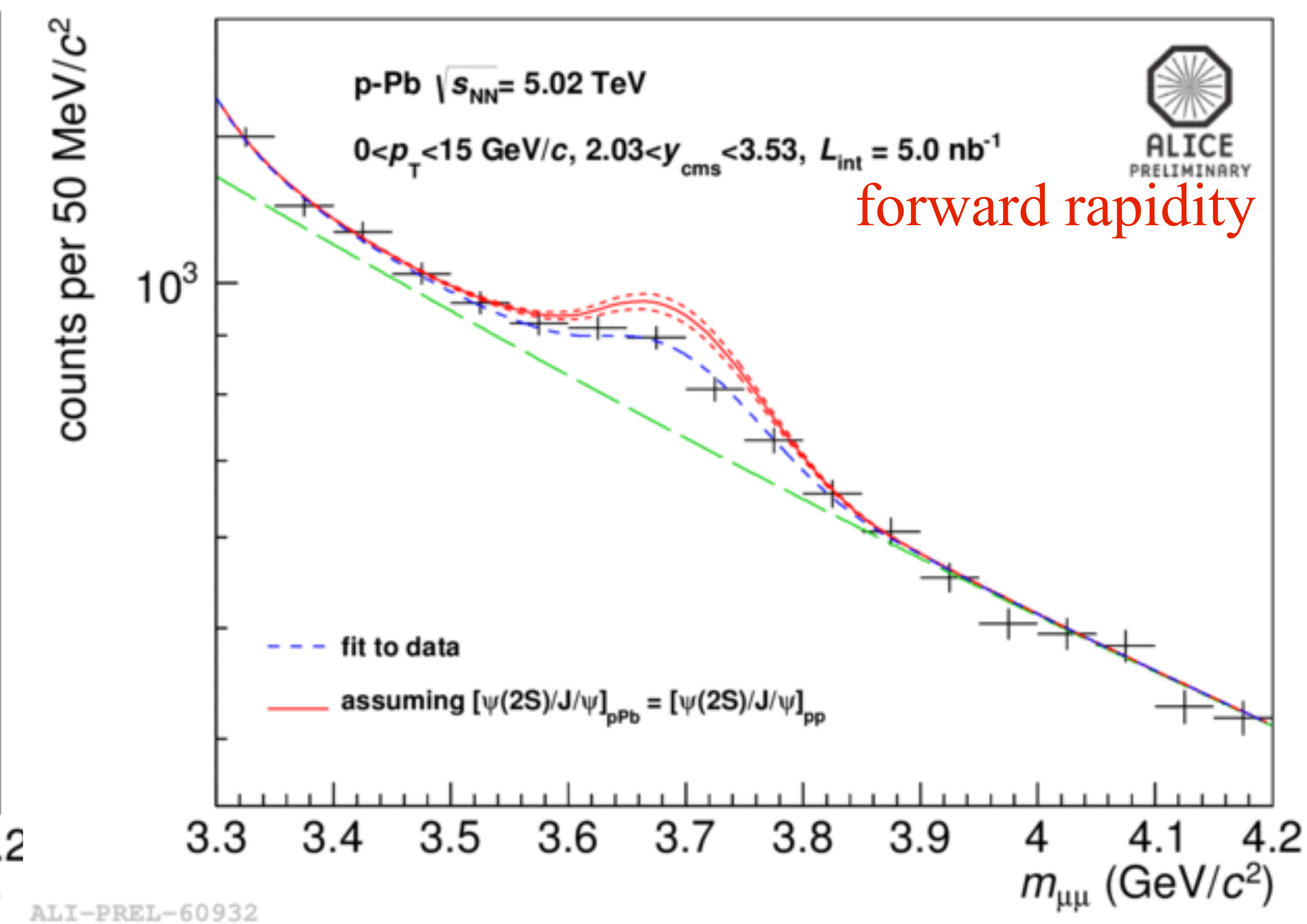




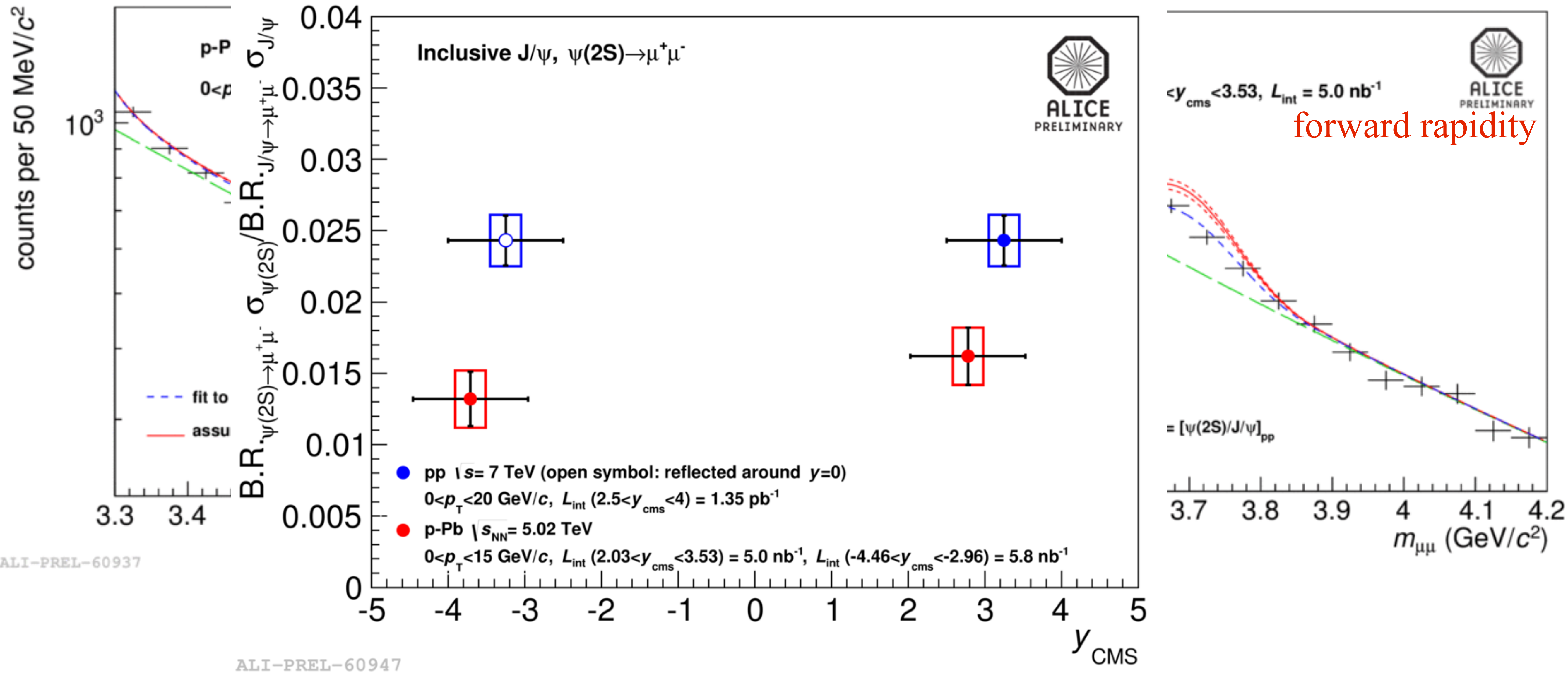
$\Delta\langle p_T^2\rangle$ larger at forward rapidity
$\Delta\langle p_T^2\rangle$ increases with event multiplicity but saturates at 20-40% V0A multiplicity

$\psi(2S)$ measurements in p-Pb: $[\psi(2S)/J/\psi]$



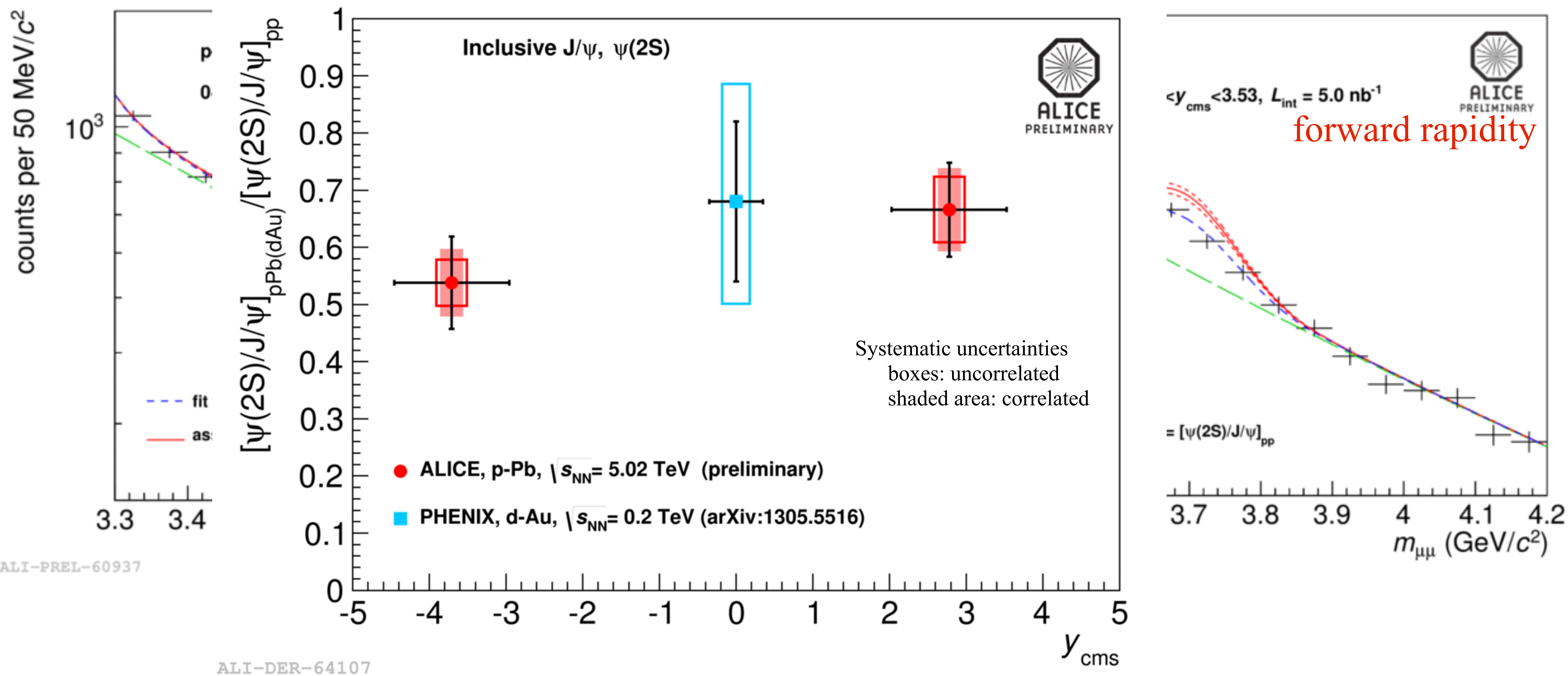


ψ(2S) measurements in p-Pb: [ψ(2S)/J/ψ]



[ψ(2S)/J/ψ]$_{pPb}$ clearly suppressed as compared to pp @ $\sqrt{s}$ = 7 TeV

ψ(2S) measurements in p-Pb: [ψ(2S)/J/ψ]

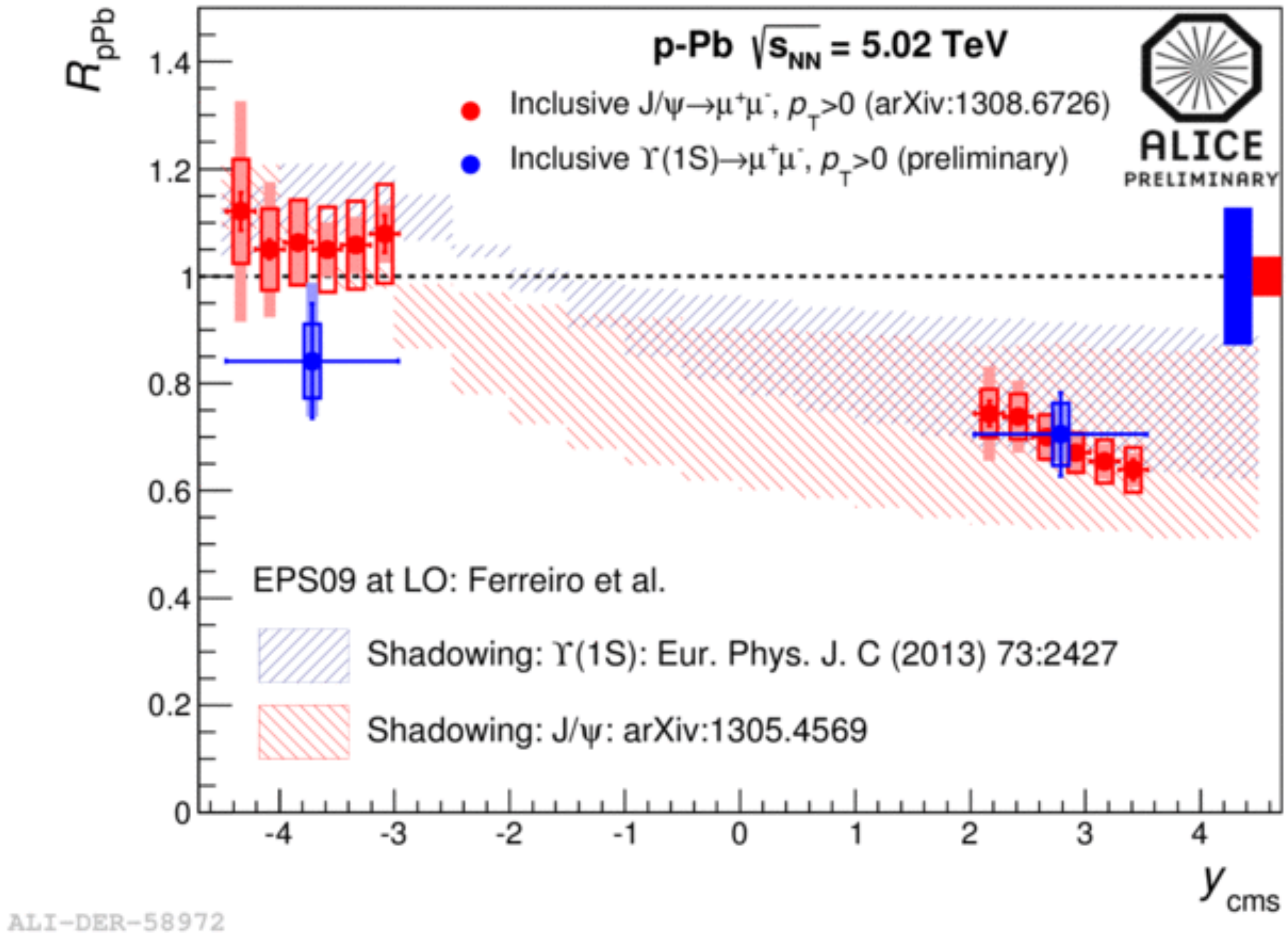


$[\psi(2S)/J/\psi]_{pPb}$ clearly suppressed as compared to pp @ $\sqrt{s}$ = 7 TeV

ψ(2S) to J/ψ suppression also observed at RHIC at mid-rapidity

Relative ψ(2S) suppression not described by initial state CNM and coherent energy loss → final state effect?

Υ(1S) measurements: R_{pPb}

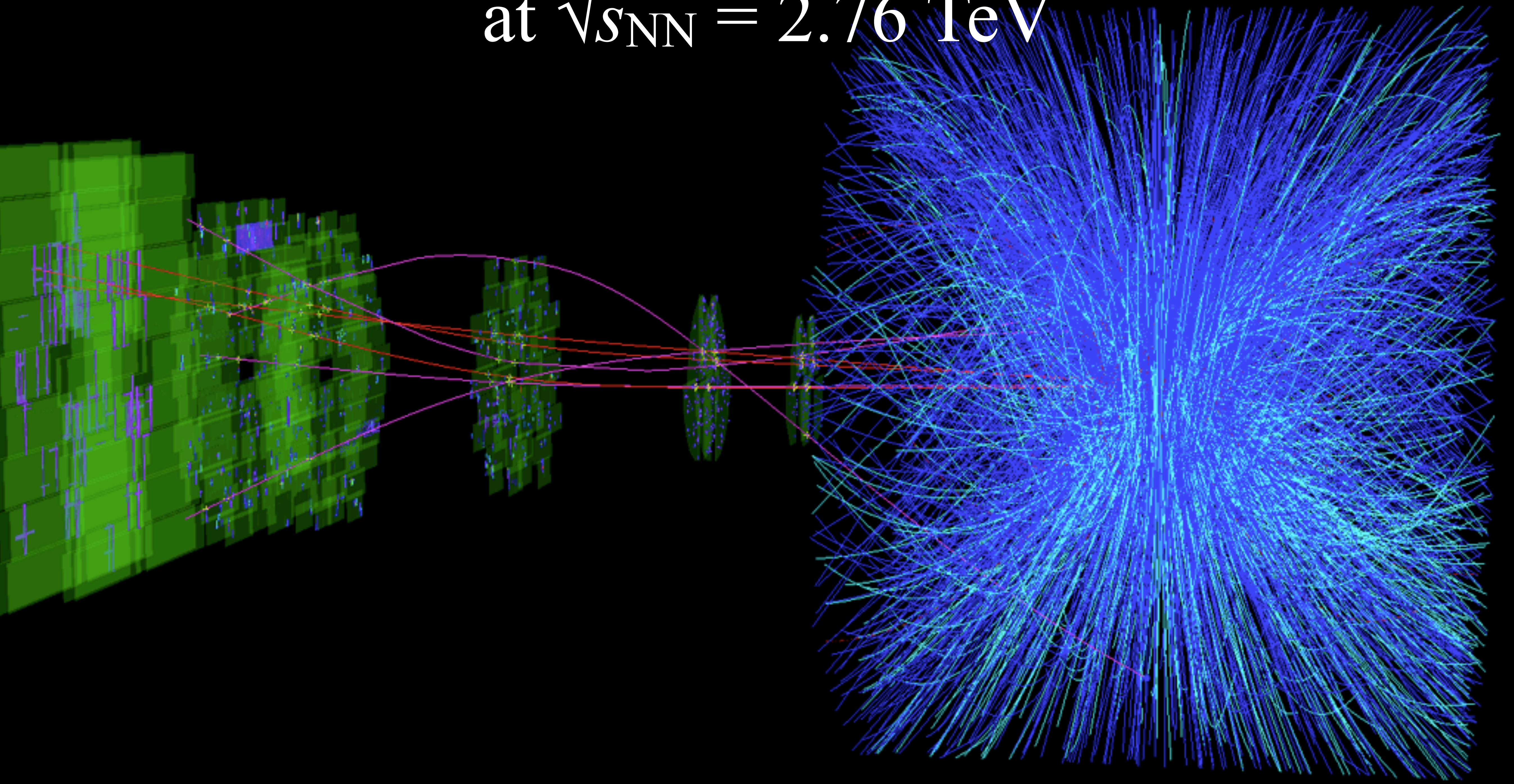


Systematic uncertainties

- boxes: uncorrelated
- shaded area: (partially) correlated
- box at unity: fully correlated

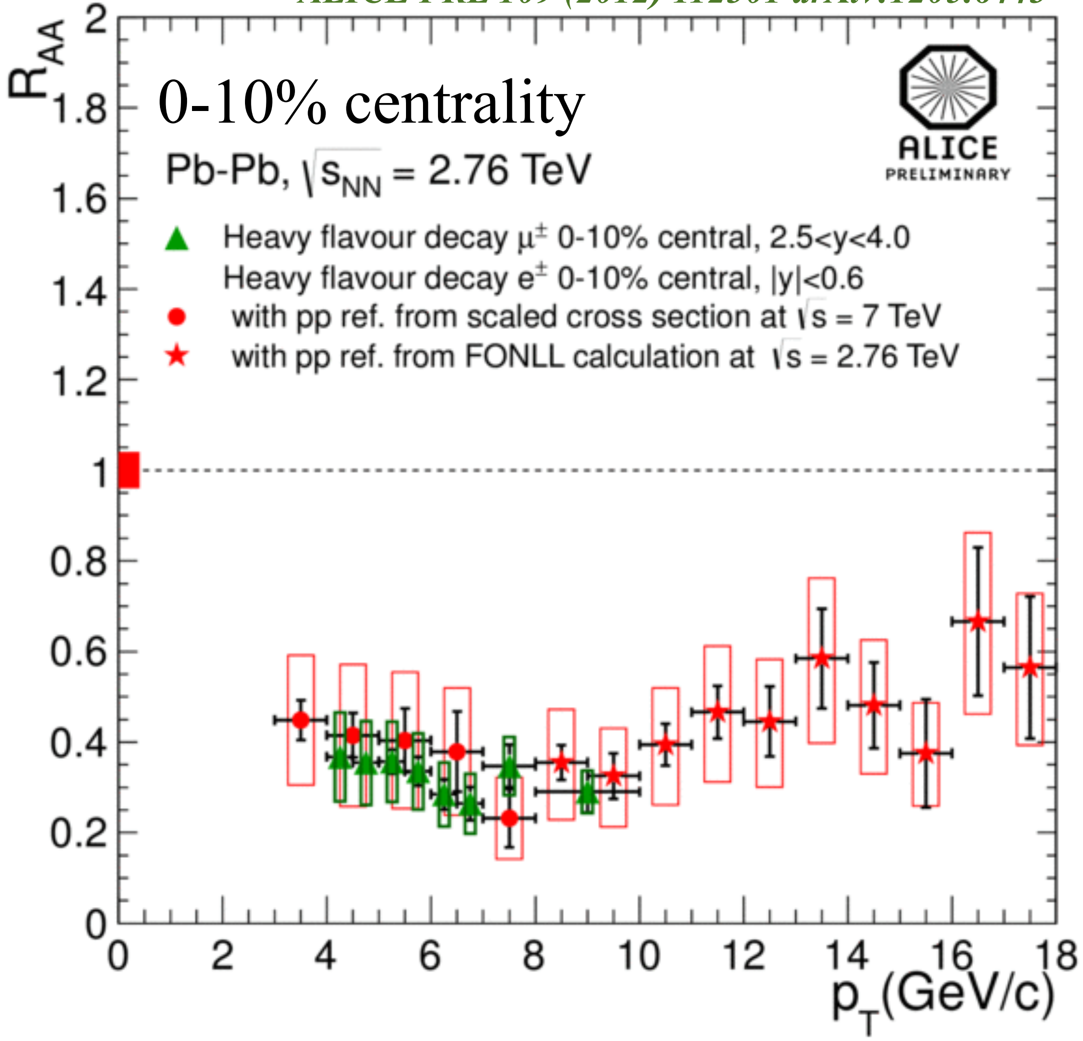
Υ(1S) seems more suppressed than predicted by shadowing (CEM+EPS09 NLO and CSM EPS09 LO shown here) or coherent energy loss models but in agreement within the large fully correlated uncertainty from pp cross-section energy interpolation

Latest Pb-Pb measurements at $\sqrt{s_{NN}} = 2.76$ TeV

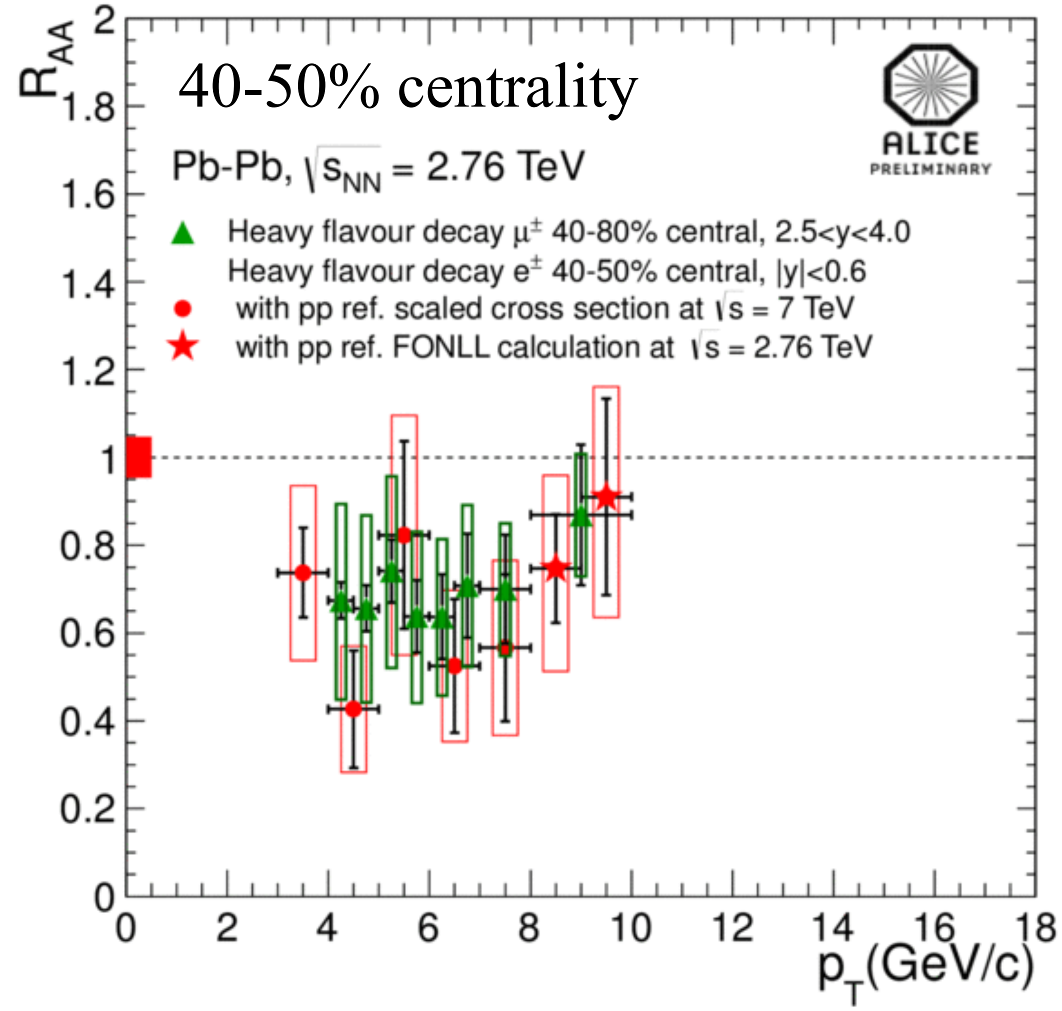


Heavy flavour decay electrons and muons

ALICE PRL 109 (2012) 112301 arXiv:1205.6443



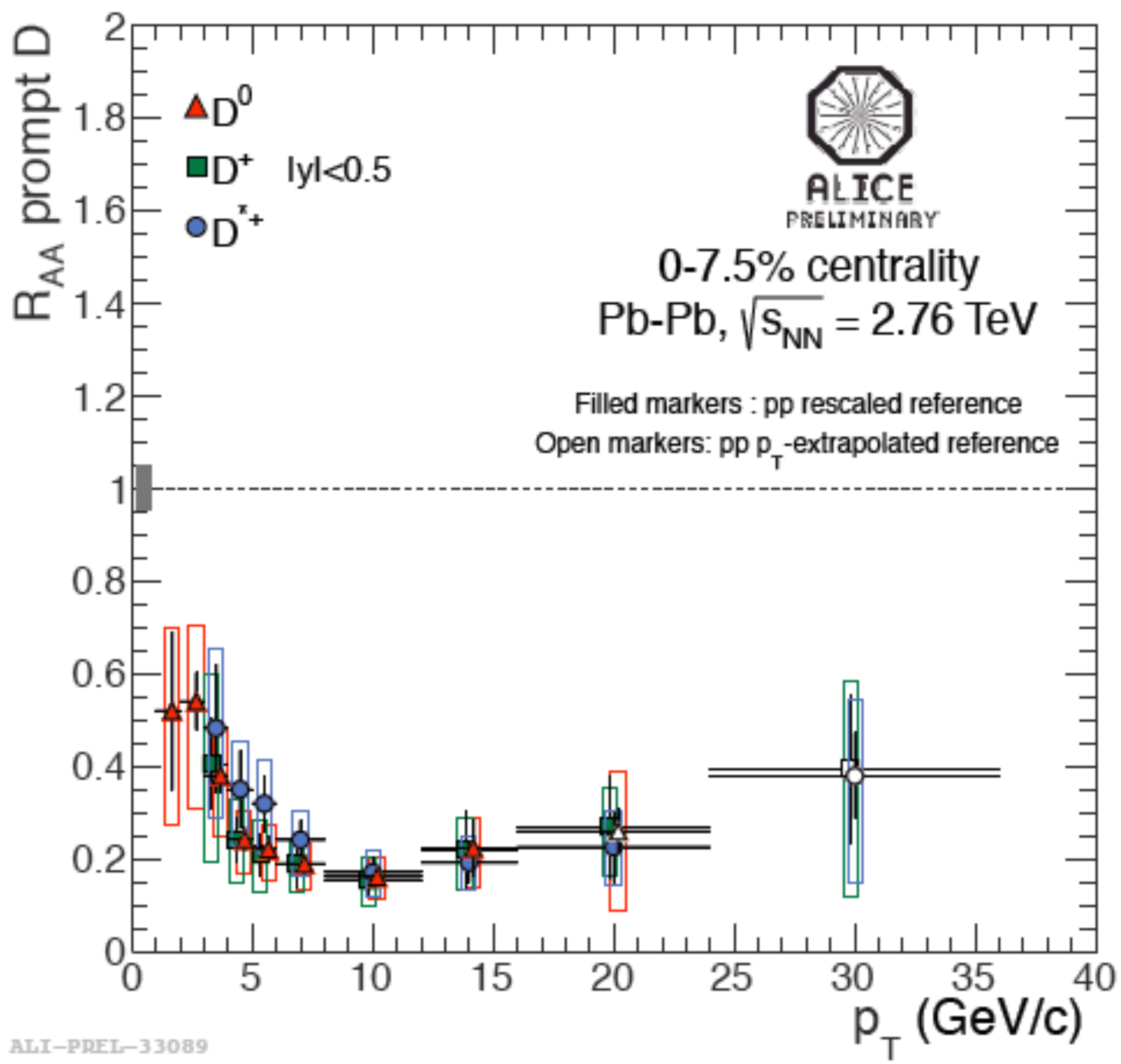
ALI-DER-36791



ALI-DER-53851

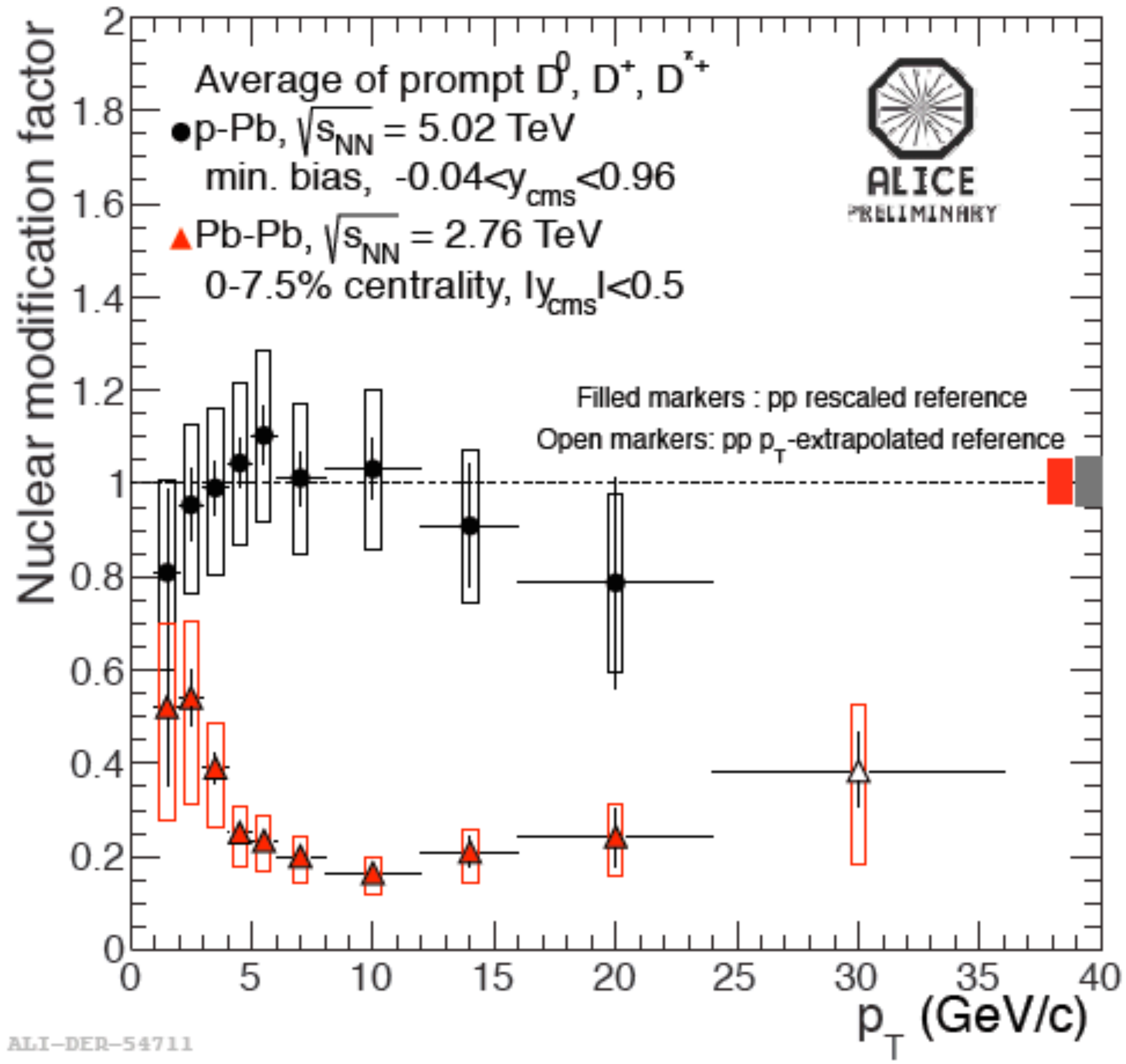
Clear suppression observed in most central collisions
Similar suppression in central (electrons) and forward (muons) rapidity

D mesons



Suppression up to a factor of 5 at $p_T \sim 10$ GeV/c for central collisions

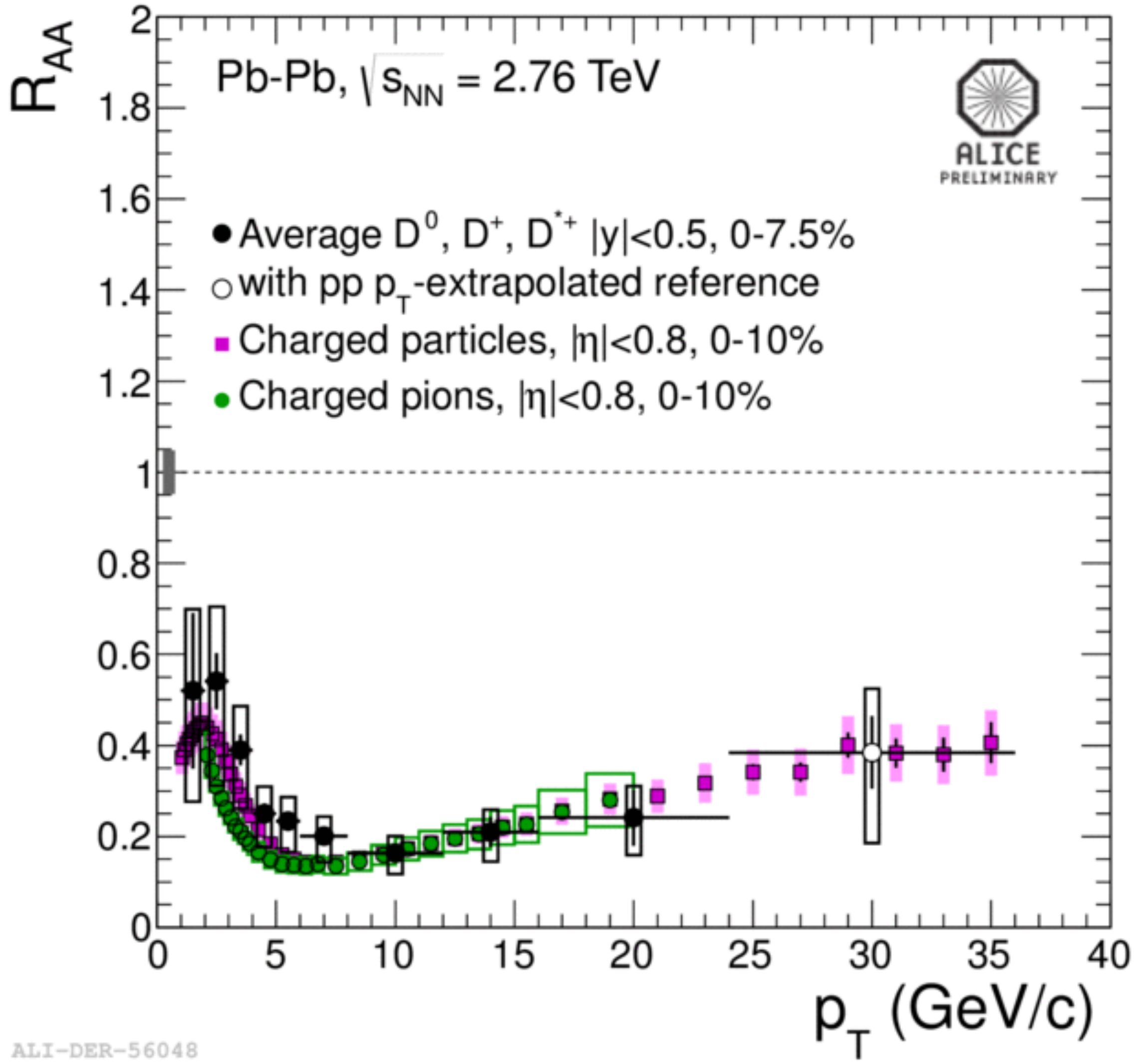
D mesons

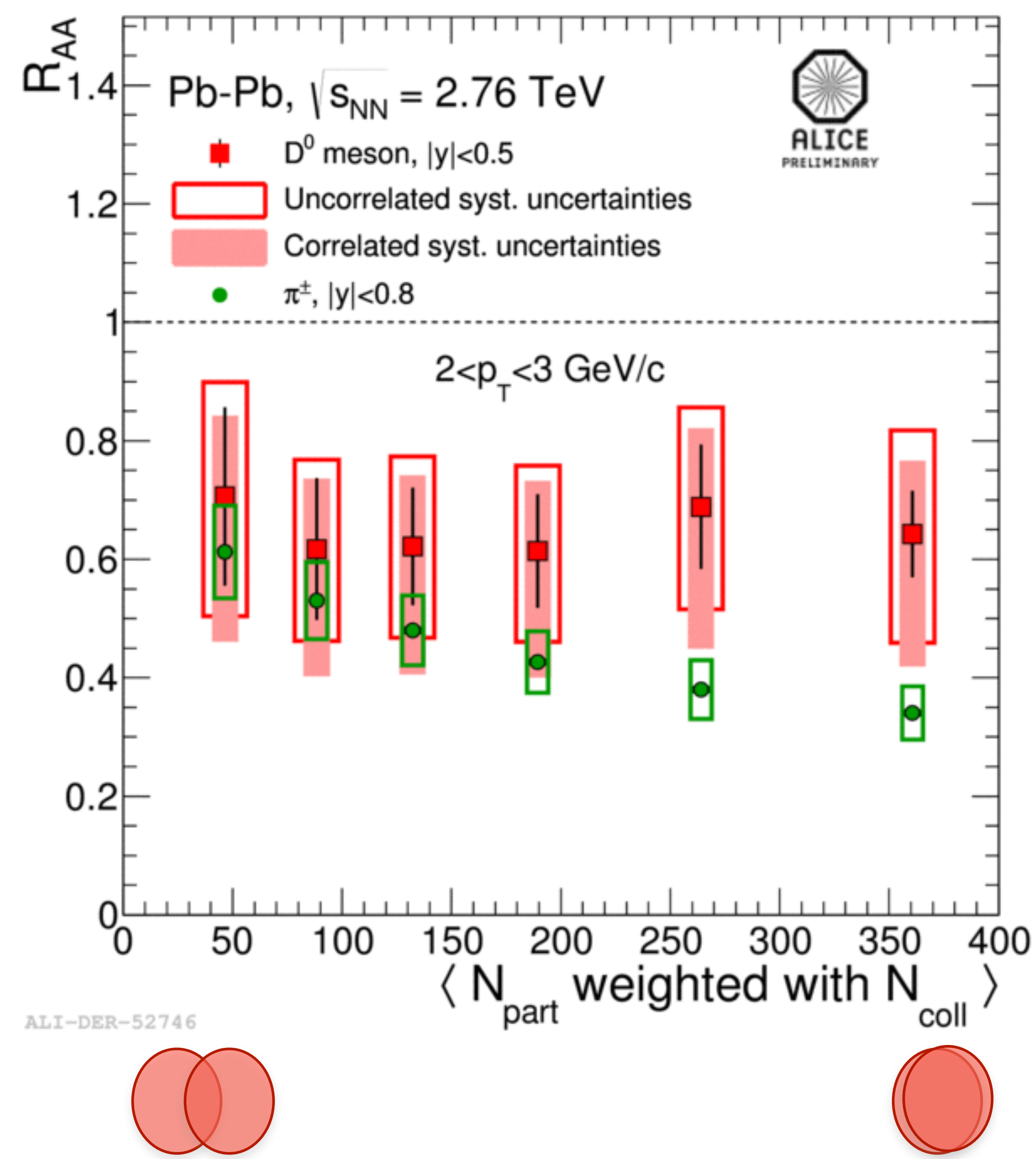


Suppression up to a factor of 5 at $p_T \sim 10$ GeV/c for central collisions

p-Pb measurements show that the observed suppression in Pb-Pb comes from a final state effect

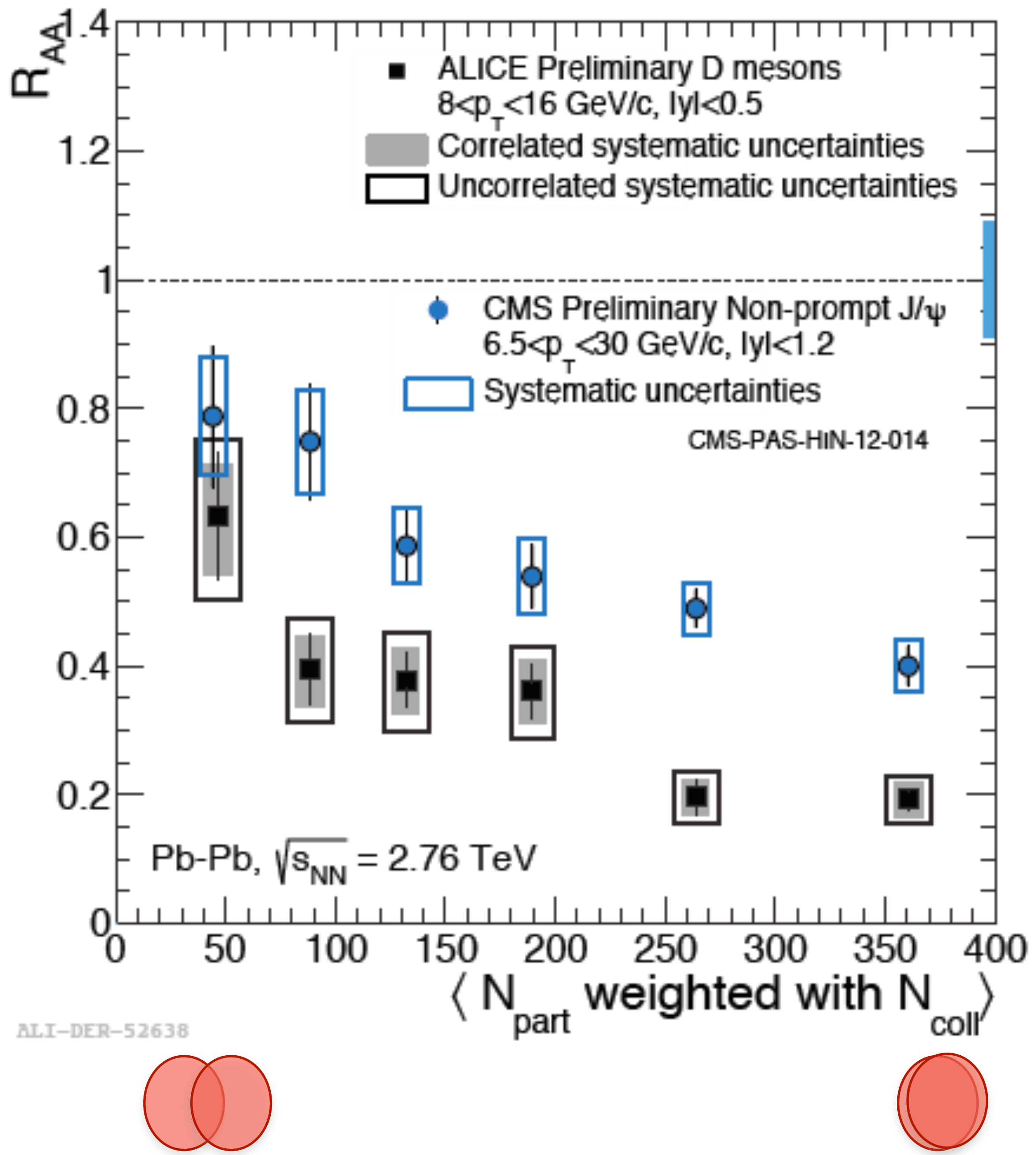
D mesons vs light hadrons





ΔE (q,g) > ΔE (c) expected from color-charge dependence of energy loss
π and D mesons: comparable suppressions for within uncertainties → not conclusive yet

High p_T D mesons vs J/ψ from B

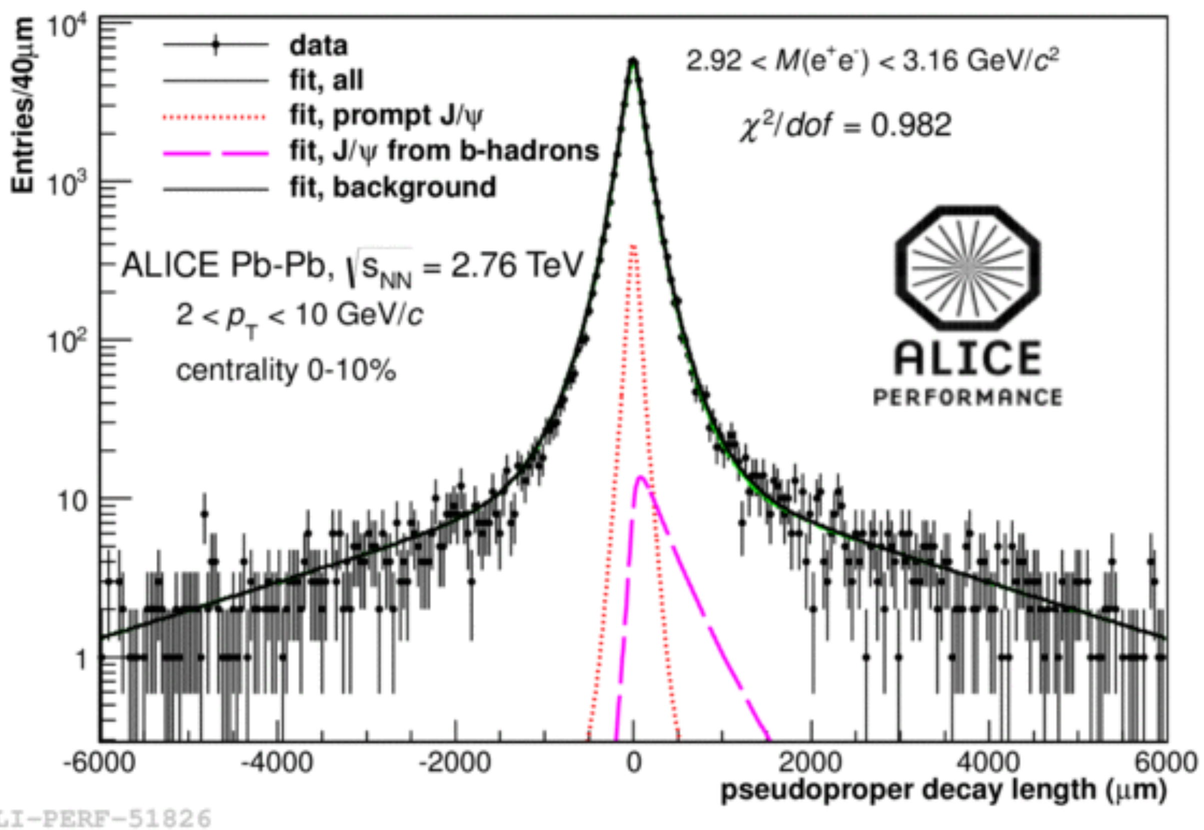


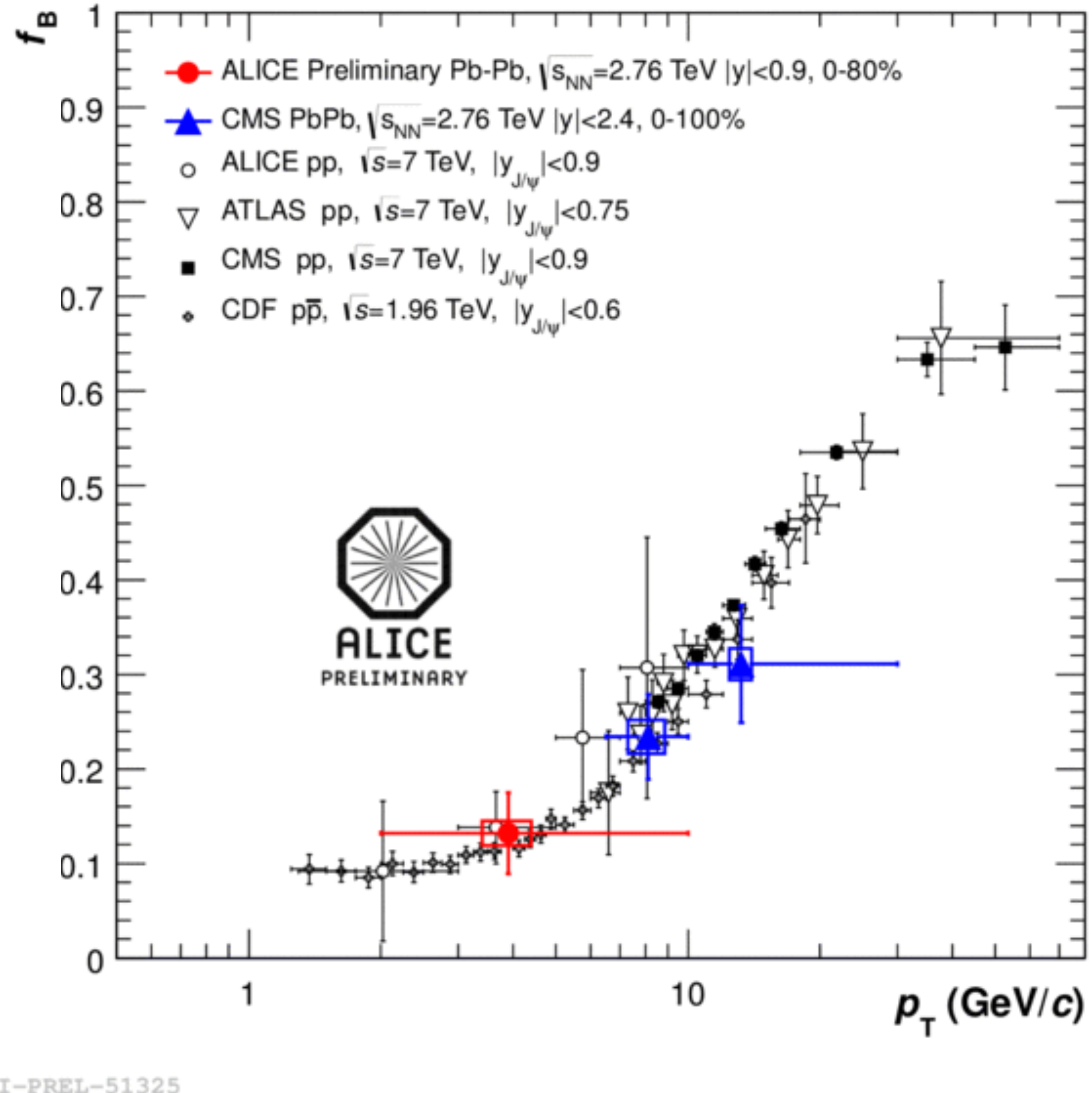
Quark-mass dependence of energy loss: ΔE (c) > ΔE (b)

ALICE D mesons more suppressed than CMS B→J/ψ with B and D mesons <p_T> ~ 10 GeV/c

→ indication of a larger suppression for charm than beauty

Fraction of non-prompt J/ψ at mid-rapidity





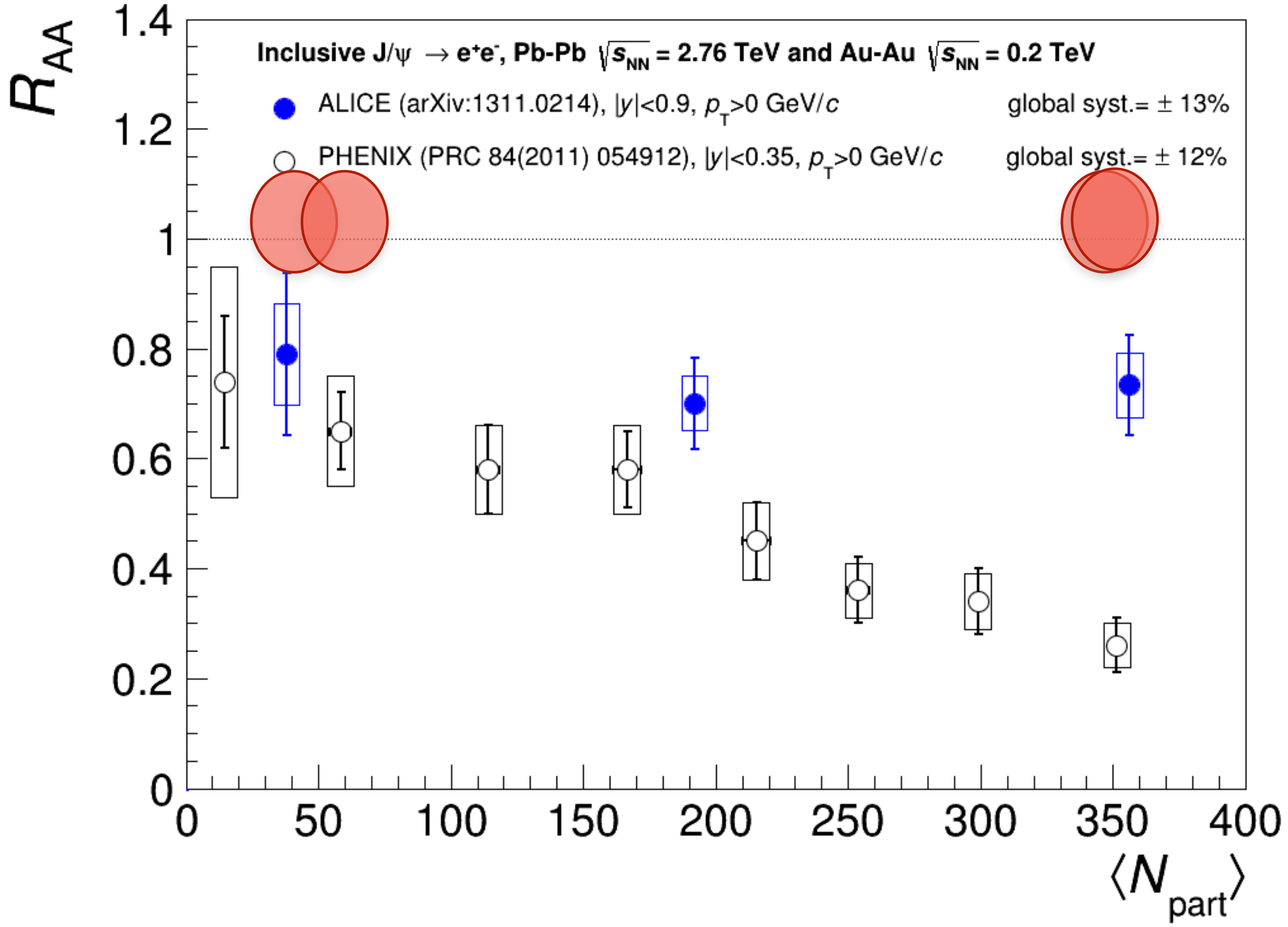
ALICE measured fraction of non-prompt J/ψ at mid-rapidity in Pb-Pb for $2 < p_T < 10$ GeV/c

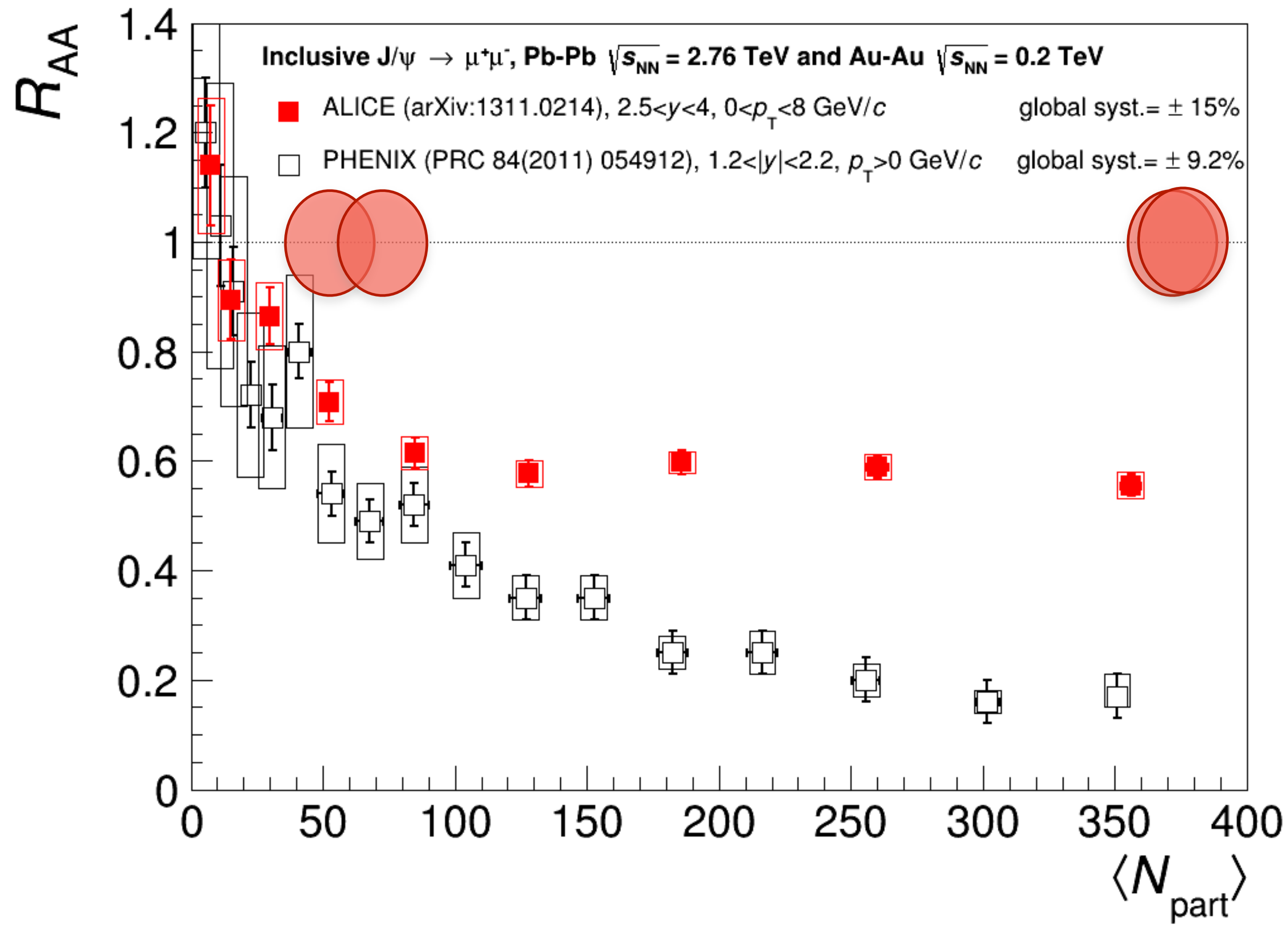
→ Similar value and p_T dependence in Pb-Pb and pp

→ B feed-down contribution has a negligible effect on inclusive J/ψ nuclear modification factor at low p_T

R_{AA} on beauty will come shortly!

J/ψ R_{AA} vs centrality

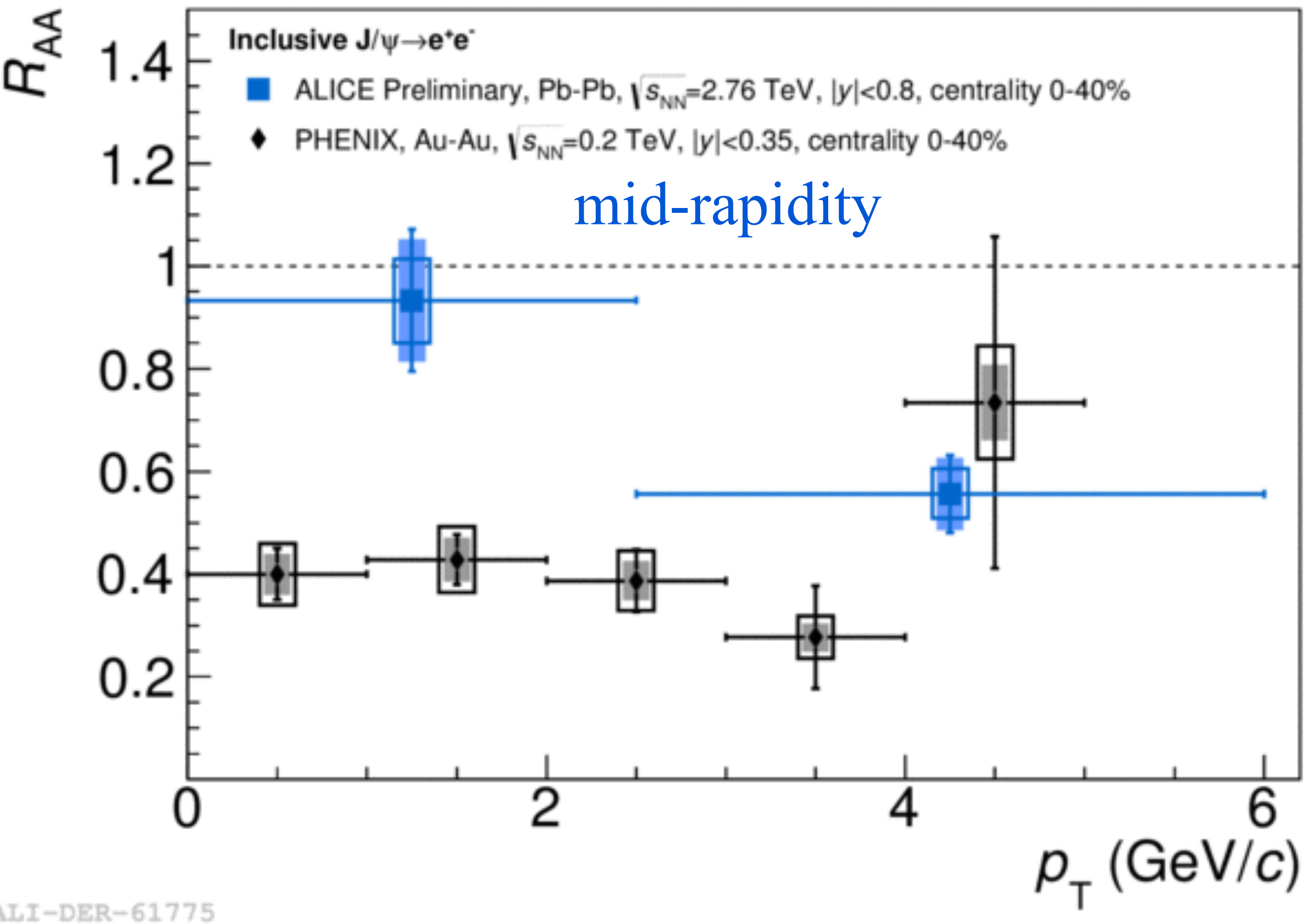


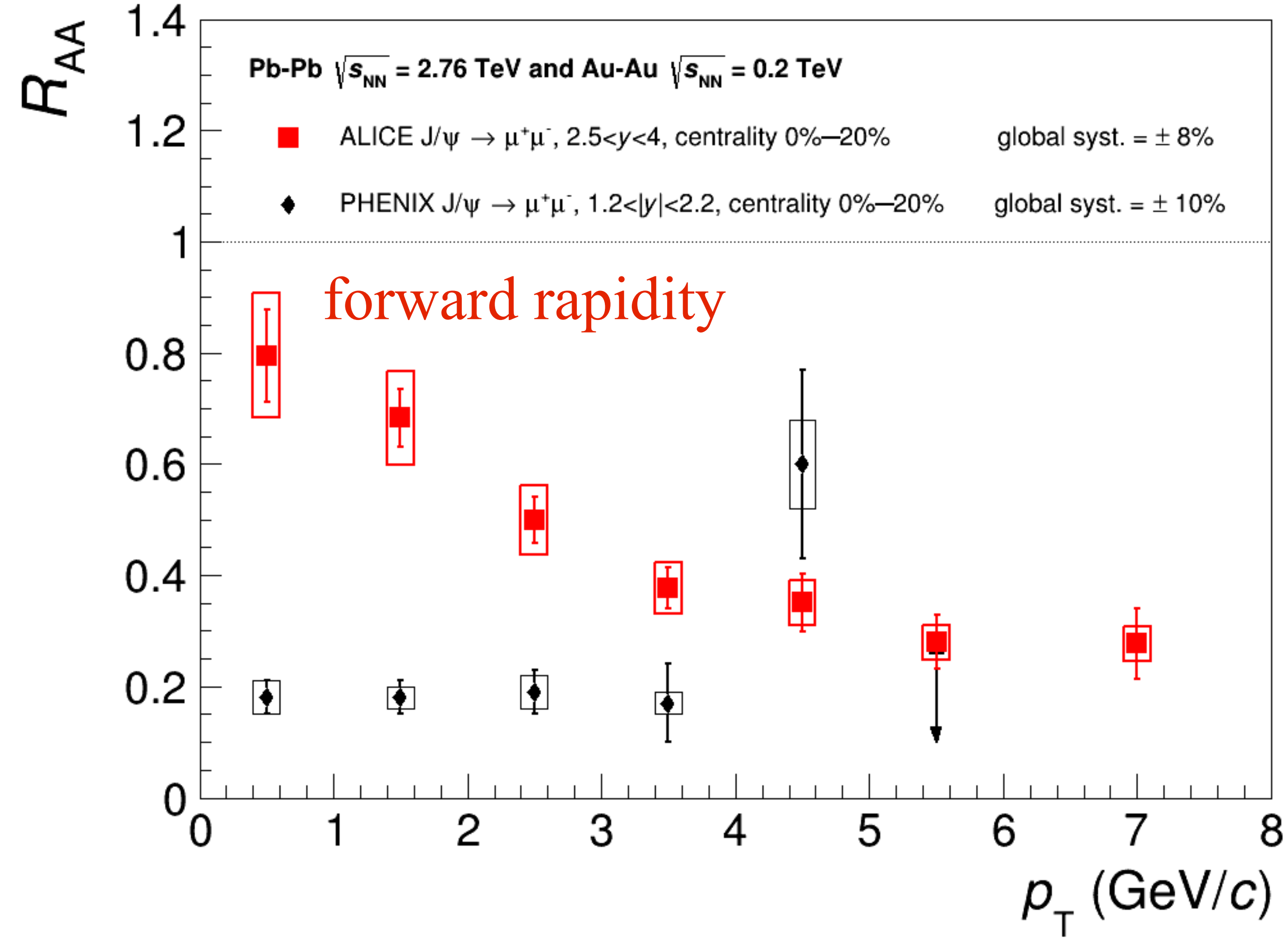


Forward rapidity: clear J/ψ suppression with no centrality dependence for $N_{part} > 100$
Mid-rapidity: no significant dependence with centrality but large uncertainty
Larger suppression at forward rapidity than mid-rapidity

Different centrality dependence of R_{AA} at LHC and RHIC energy

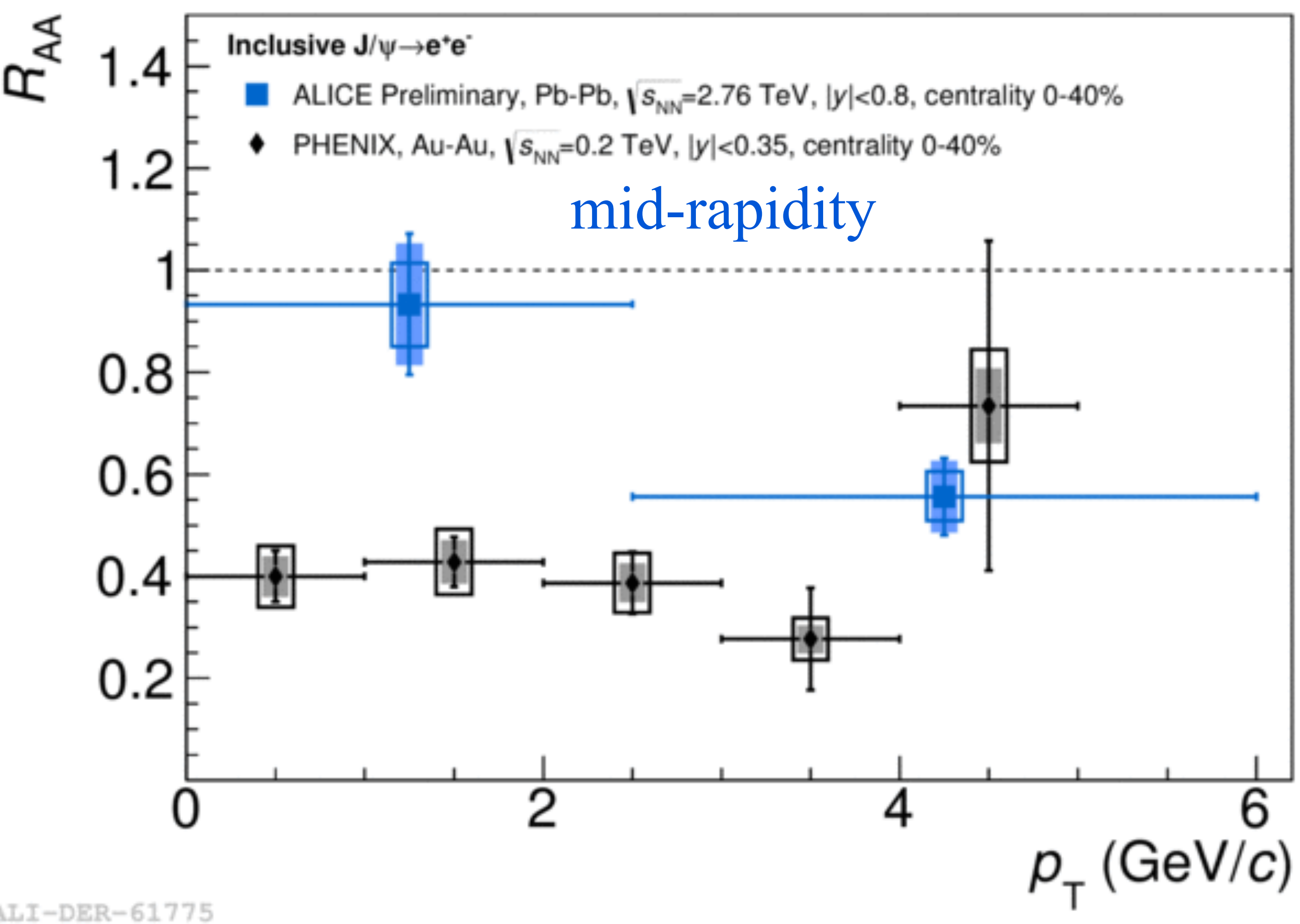
J/ψ R_{AA} vs p_T for most central collisions

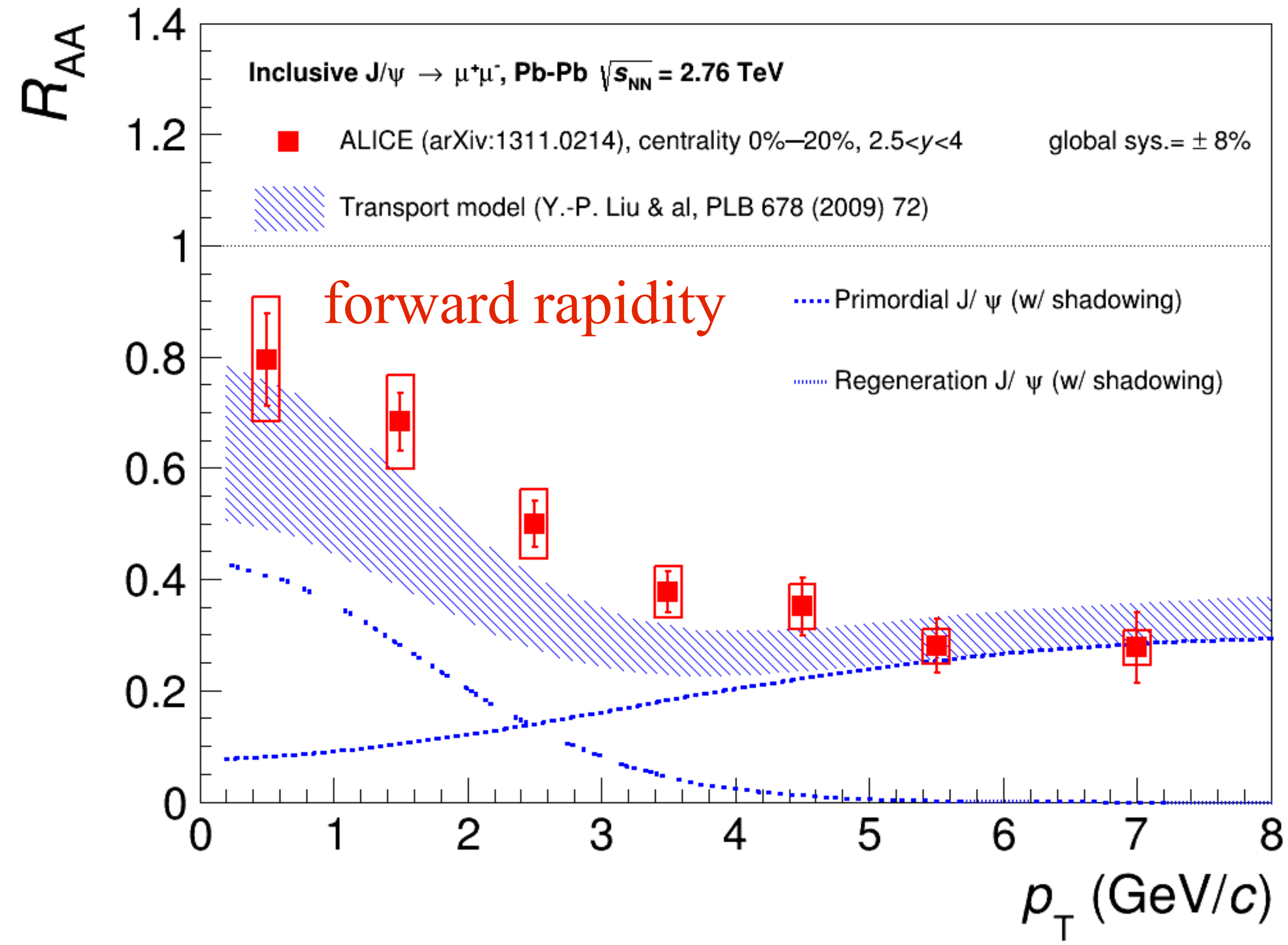




J/ψ less suppressed at low p_T than high p_T
Different p_T dependence of R_{AA} at LHC and RHIC

J/ψ R_{AA} vs p_T for most central collisions





J/ψ less suppressed at low p_T than high p_T
Different p_T dependence of R_{AA} at LHC and RHIC

Model:

- Transport (Zhao et al.): suppression and regeneration, with or without shadowing

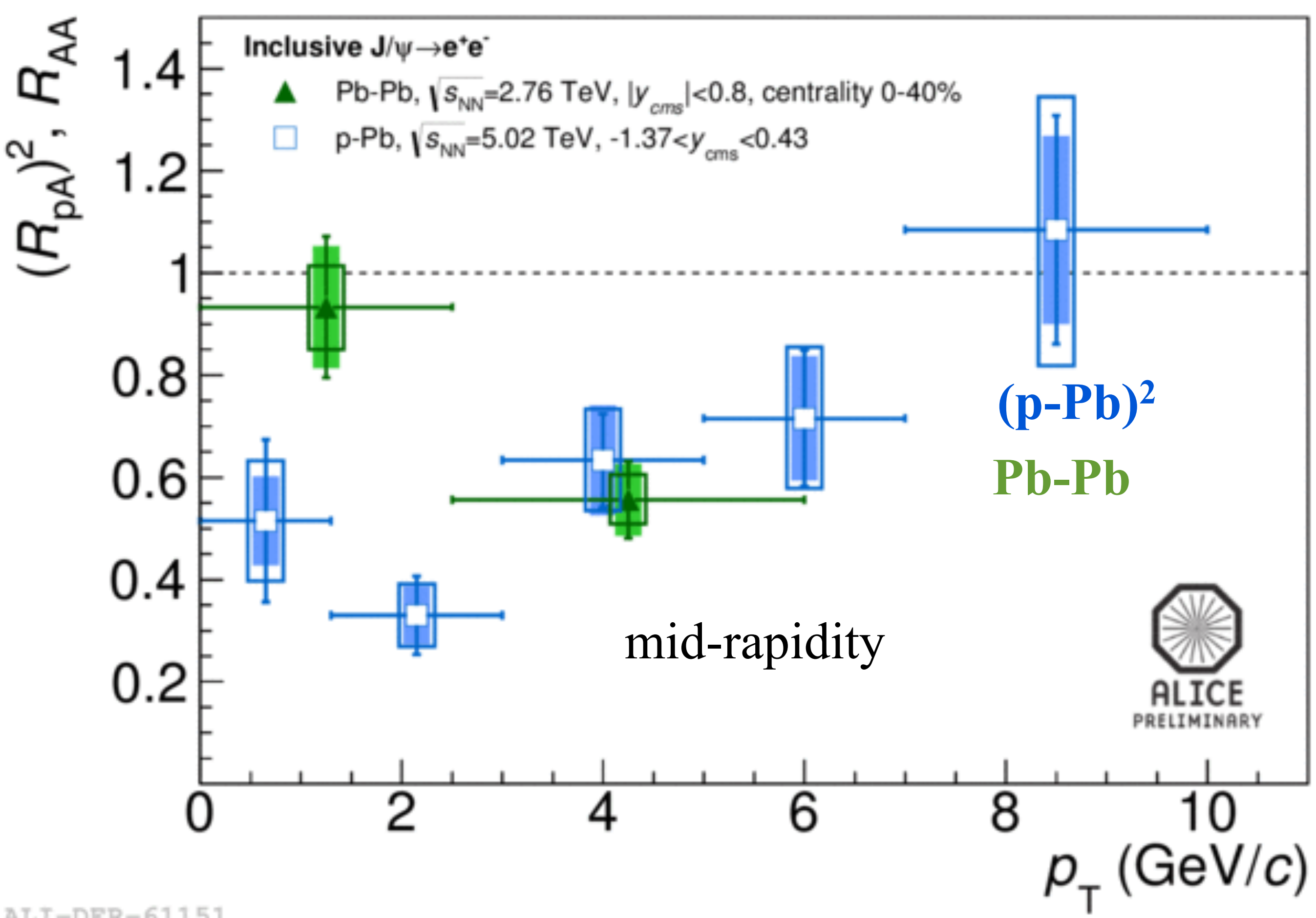
→ Regeneration contribution important for p_T < 3 GeV/c and negligible at larger p_T

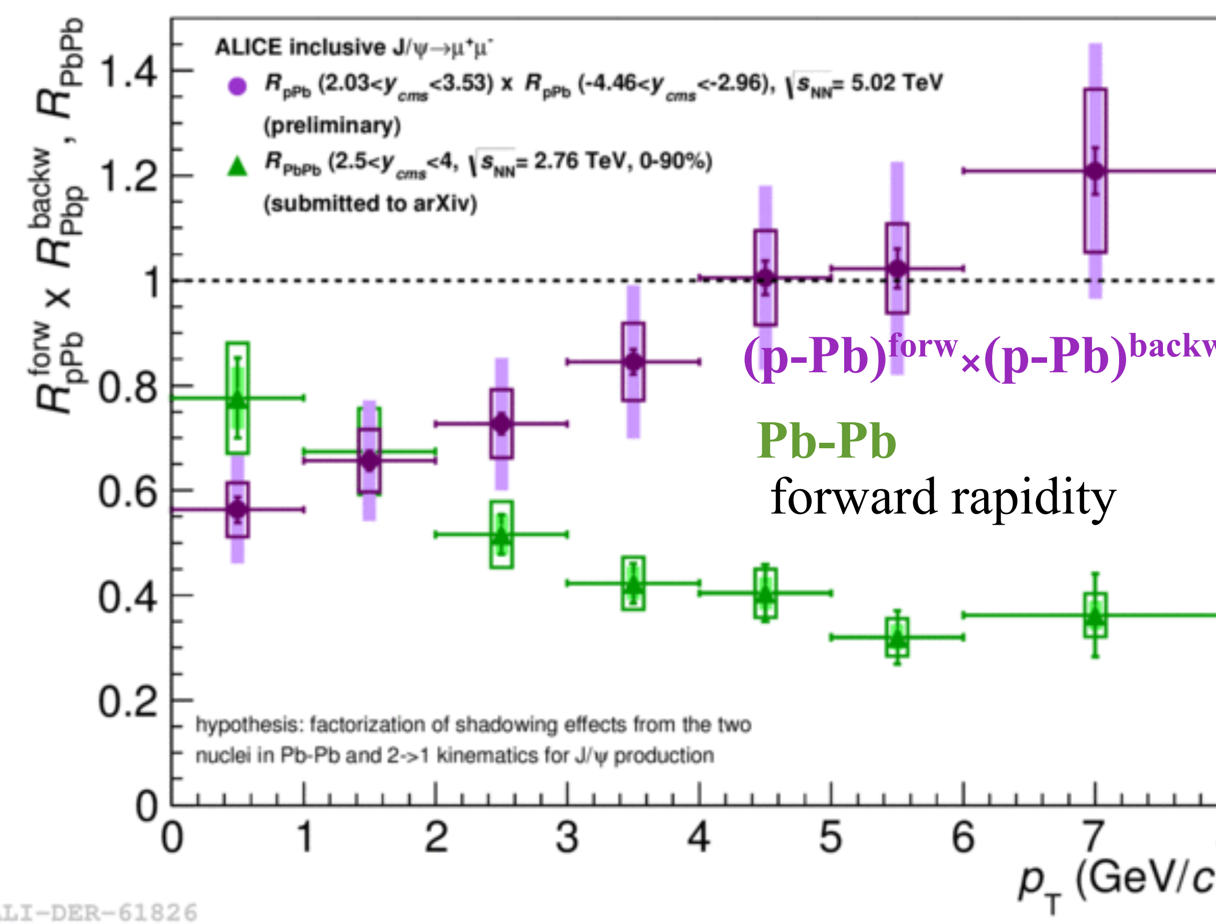
J/ψ p-Pb measurements extrapolated to Pb-Pb

Hypothesis

- J/ψ production mechanism (2→1 kinematics) ⇒ similar x_g in Pb for p-Pb@$\sqrt{s_{NN}}$=5.02 TeV and Pb-Pb@$\sqrt{s_{NN}}$=2.76 TeV despite different energies and rapidity domains
- Factorization of shadowing effects in p-Pb and Pb-Pb ⇒ $R_{PbPb}^{Shad} = R_{pPb}(y\geq0) \times R_{pPb}(y\leq0)$ ⇒ $S_{J/\Psi} = R_{PbPb} / R_{PbPb}^{Shad}$

Note: R_{PbPb}^{Shad} is integrated over centrality and is compared to R_{PbPb} for different bins in centrality [0-40%] and [0-90%]





At p_T > 7 (4) GeV/c at mid (forward) rapidity, small effects from extrapolated shadowing

At low p_T, less or same suppression in Pb-Pb than R_{PbPb}^{Shad}

→ R_{PbPb} enhanced if corrected by such shadowing effects

J/ψ p-Pb measurements extrapolated to Pb-Pb

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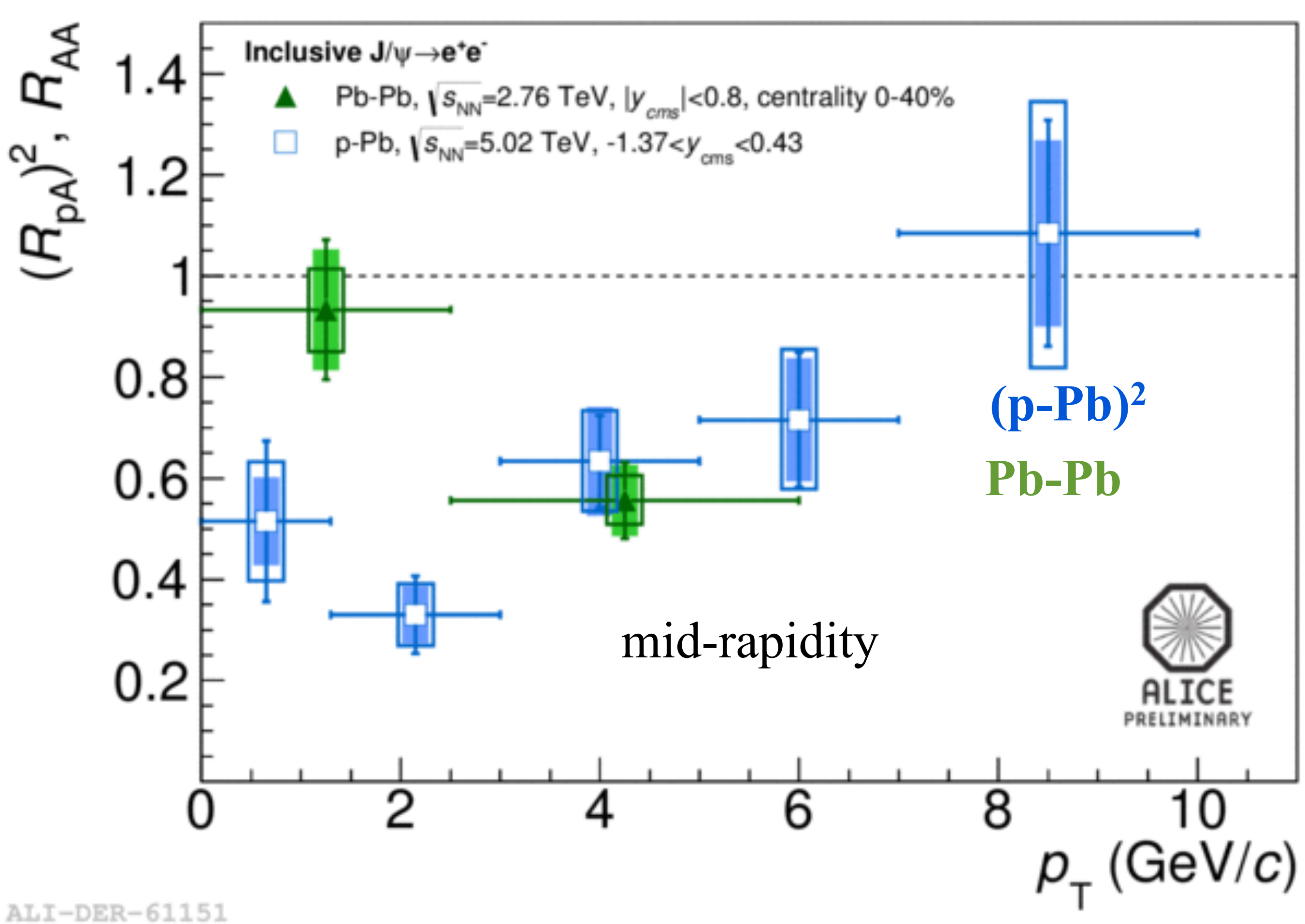

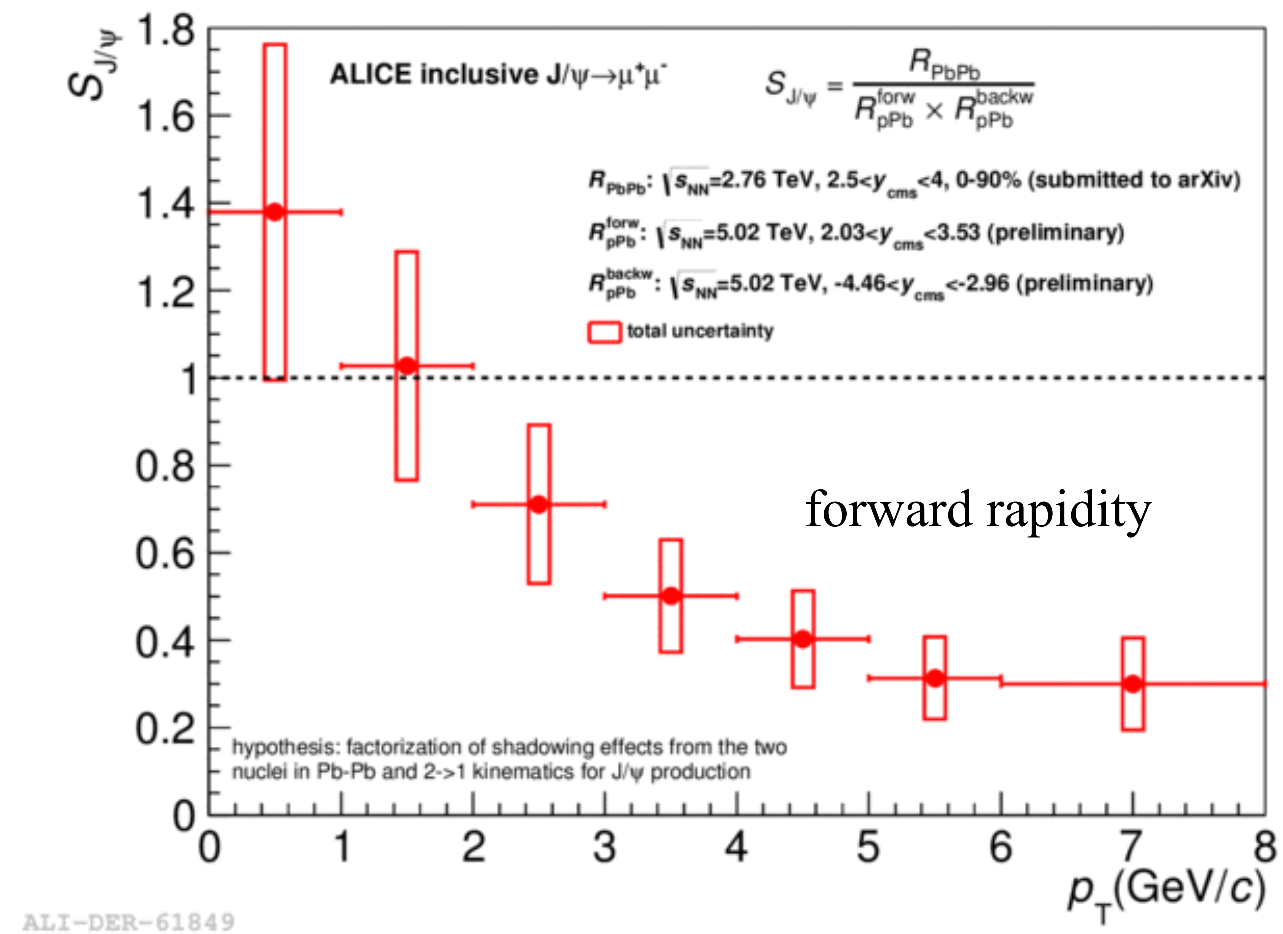

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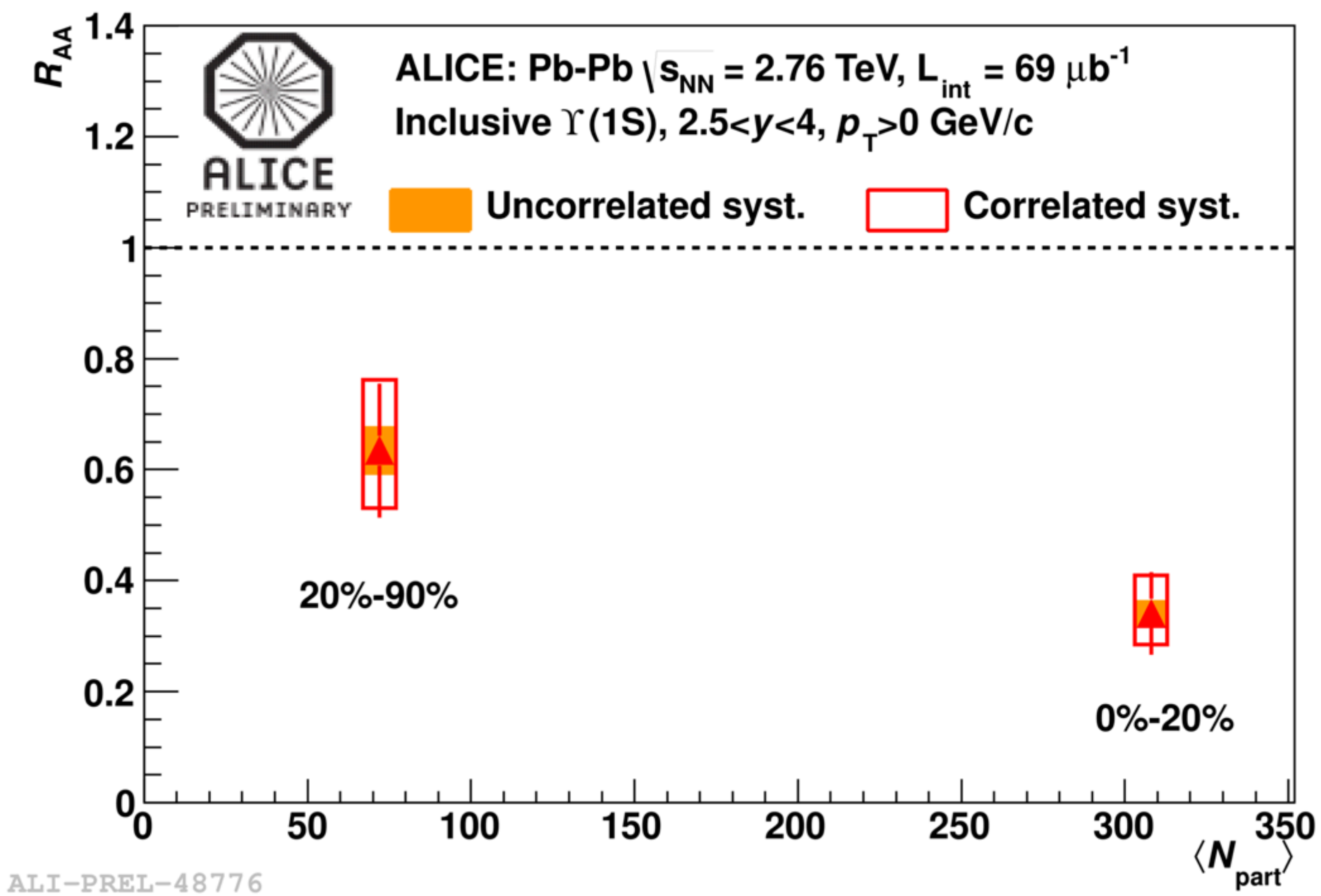
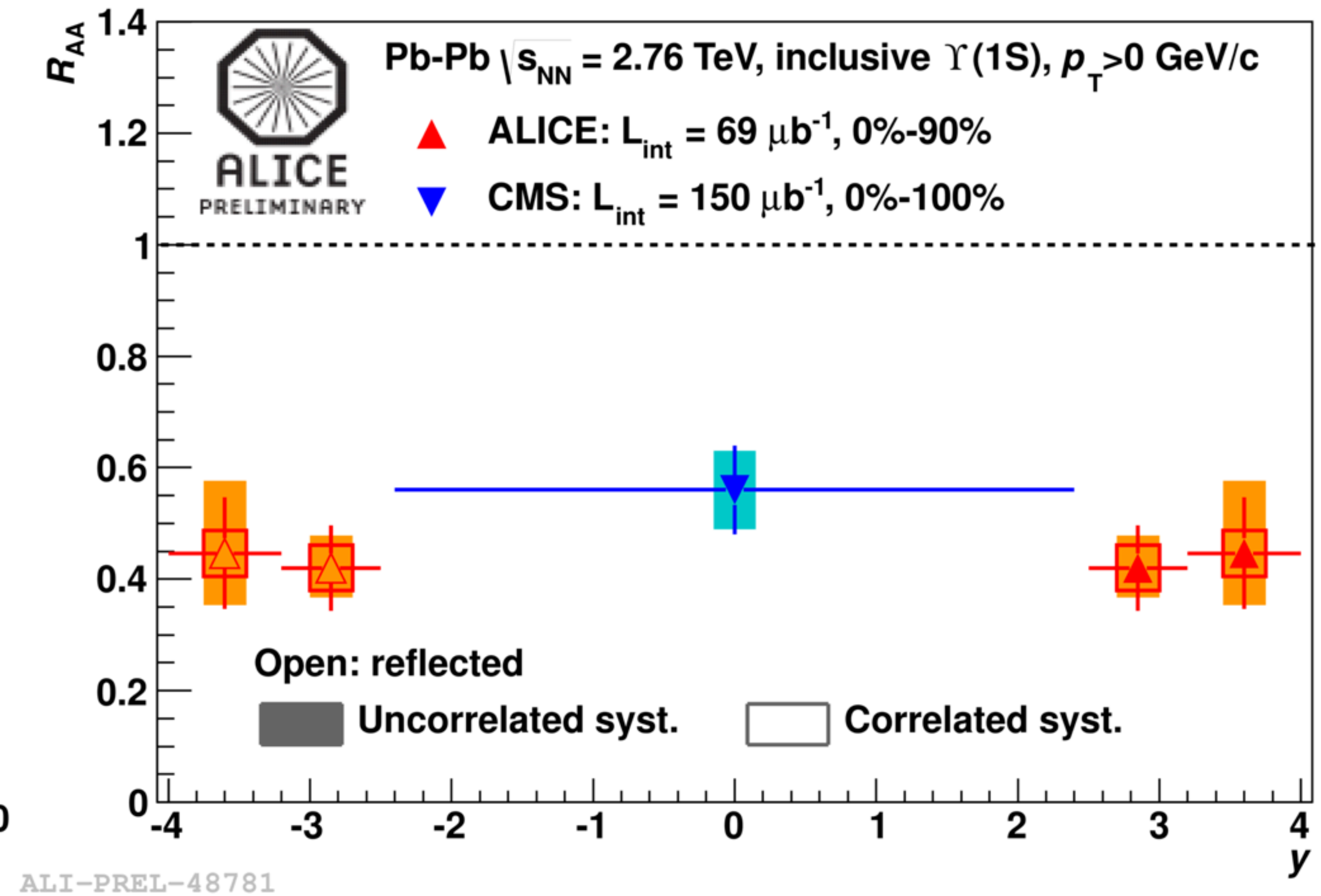
Υ(1S) measurements at forward rapidity

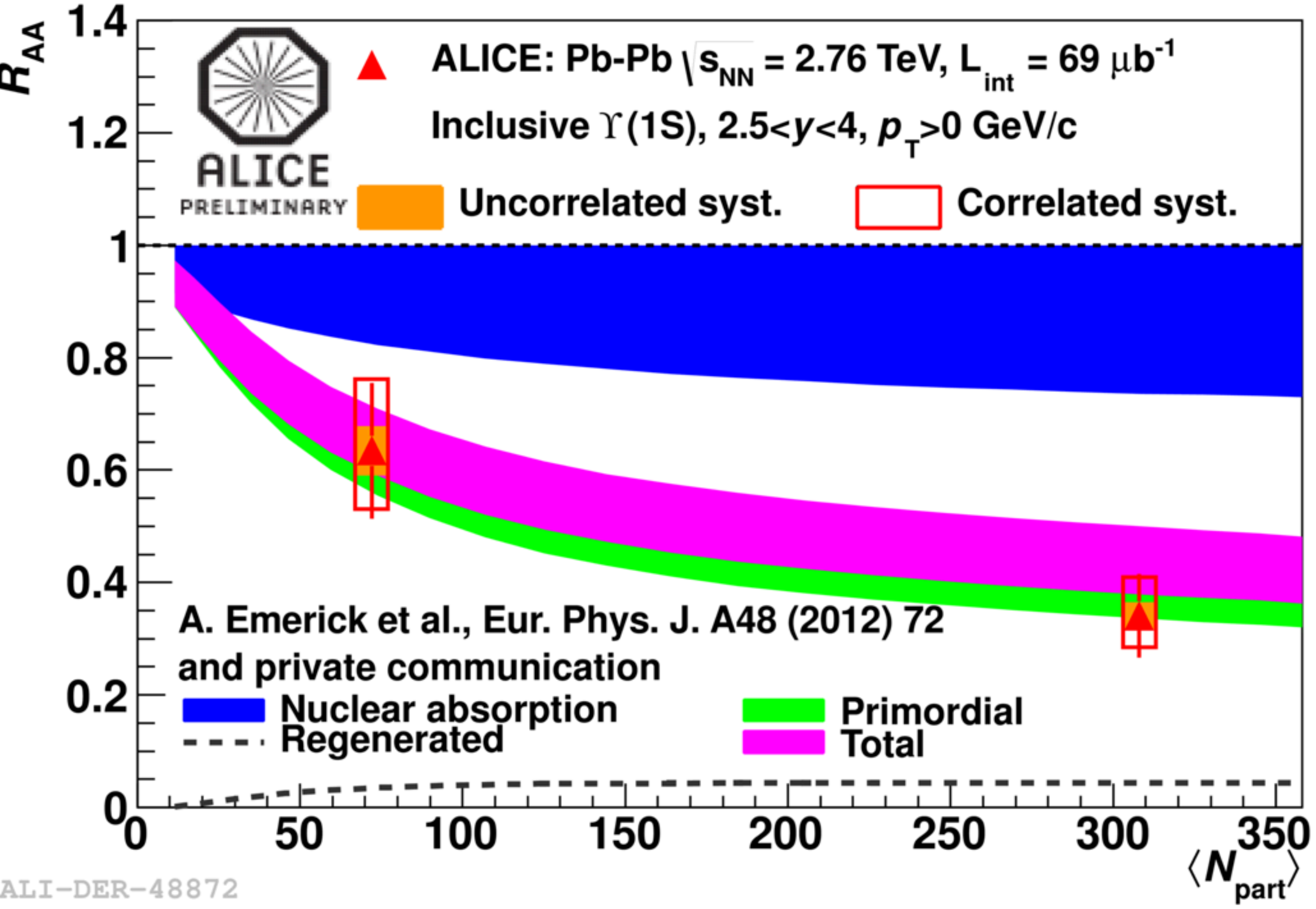


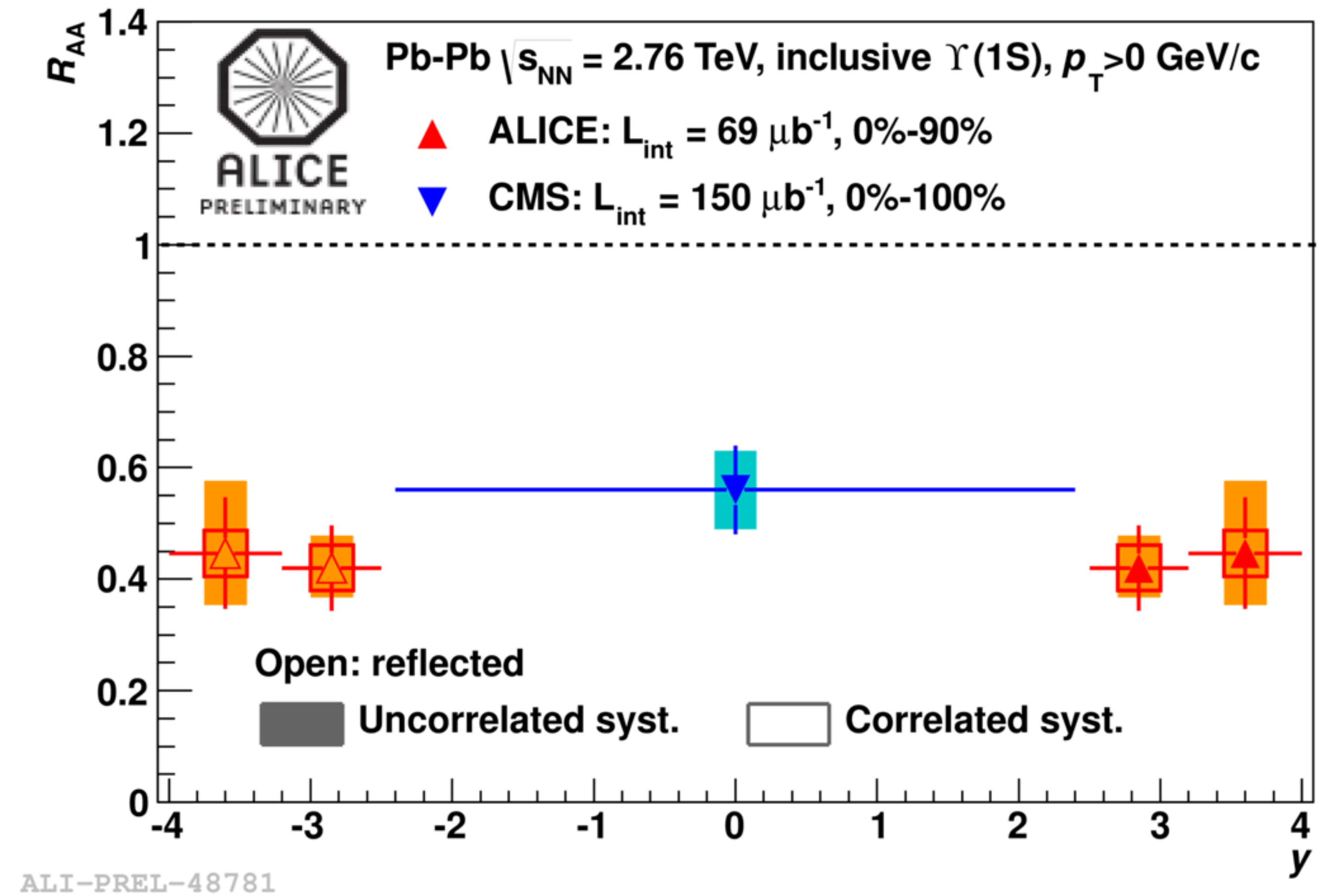


Suppression increases for most central collisions

Small rapidity dependence as compared with CMS

Υ(1S) measurements at forward rapidity



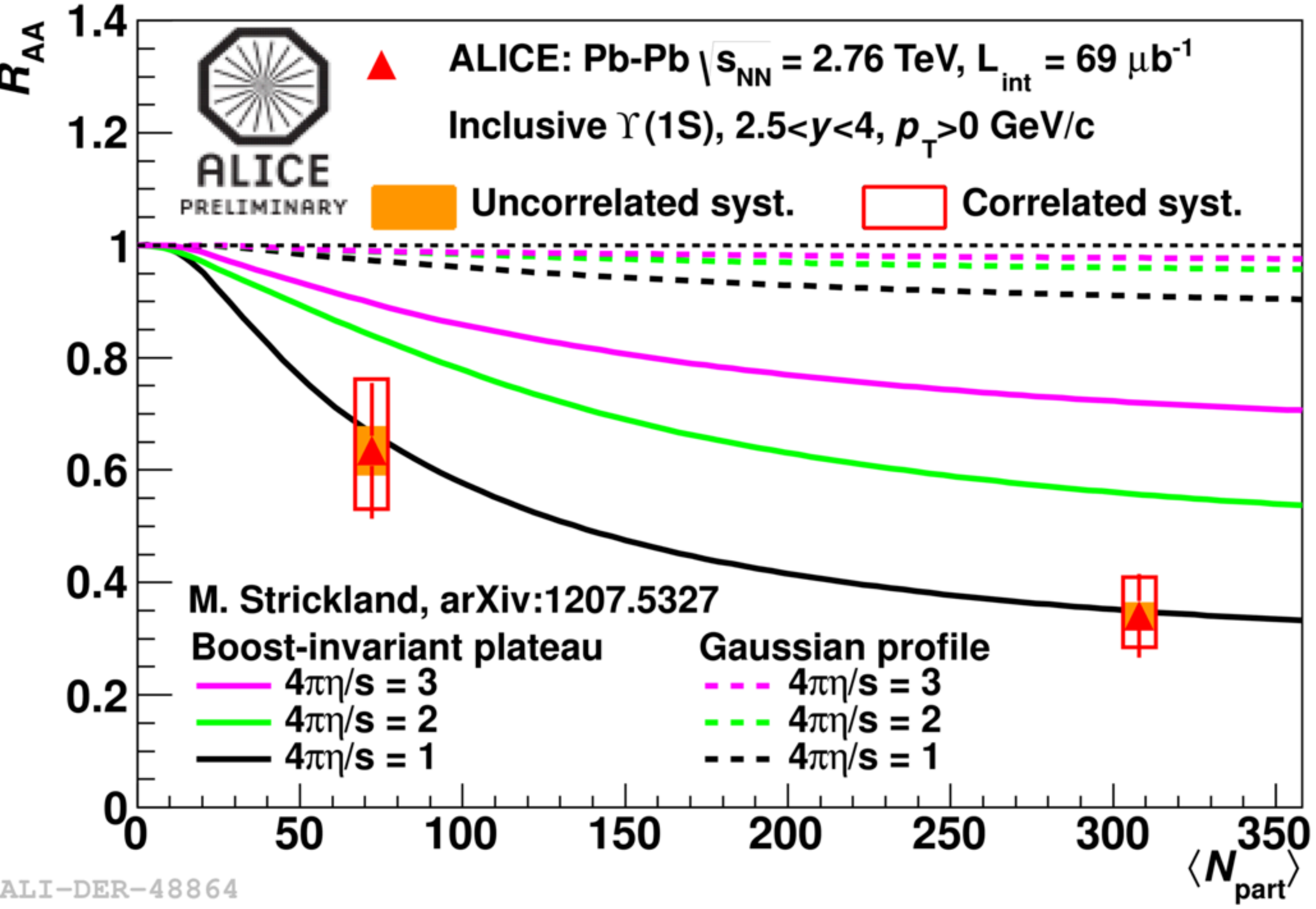


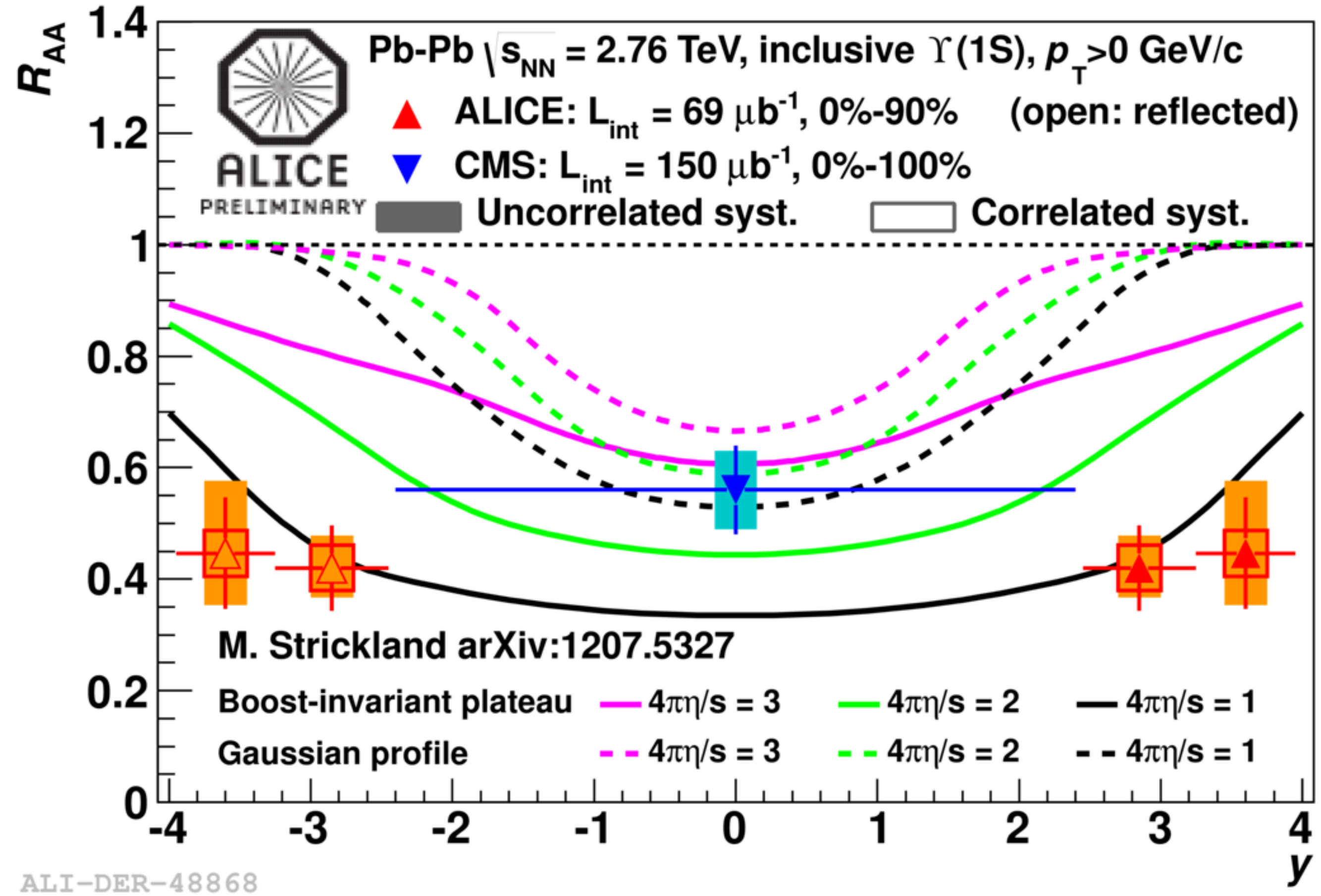
Models:

- Rate equation approach (Emerick et al.): suppression from dissociation and Υ(1S) regeneration (small contribution), various absorption cross-sections (0 and 2 mb)
- Hydrodynamic model (Strickland): thermal dissociation and dynamic model, different hypothesis for the initial temperature profile suppression and the shear viscosity, no initial or final state cold nuclear effect

Rate equation model in good agreement with ALICE data

ϒ(1S) measurements at forward rapidity





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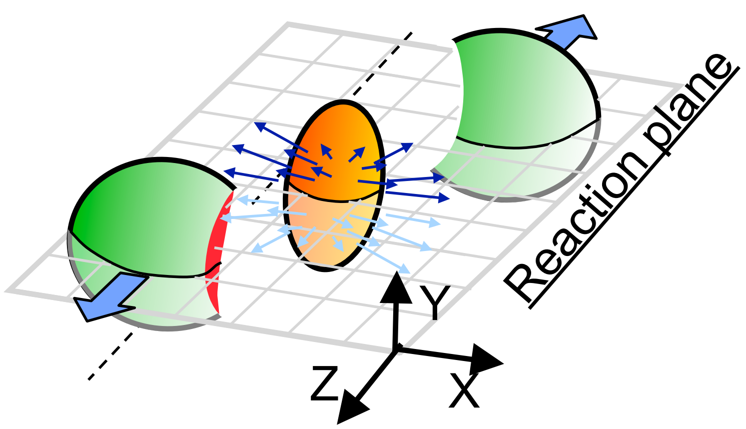
Rate equation model in good agreement with ALICE data

Hydro model reproduces well ALICE data but not both ALICE and CMS data

Azimuthal anisotropy



Initial spatial anisotropy of the overlap region → anisotropy of the particle momentum distribution

$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_t dp_t dy}\left(1+\sum_{n=1}^{\infty} 2v_n \cos[n(\phi-\Psi_R)]\right)$$

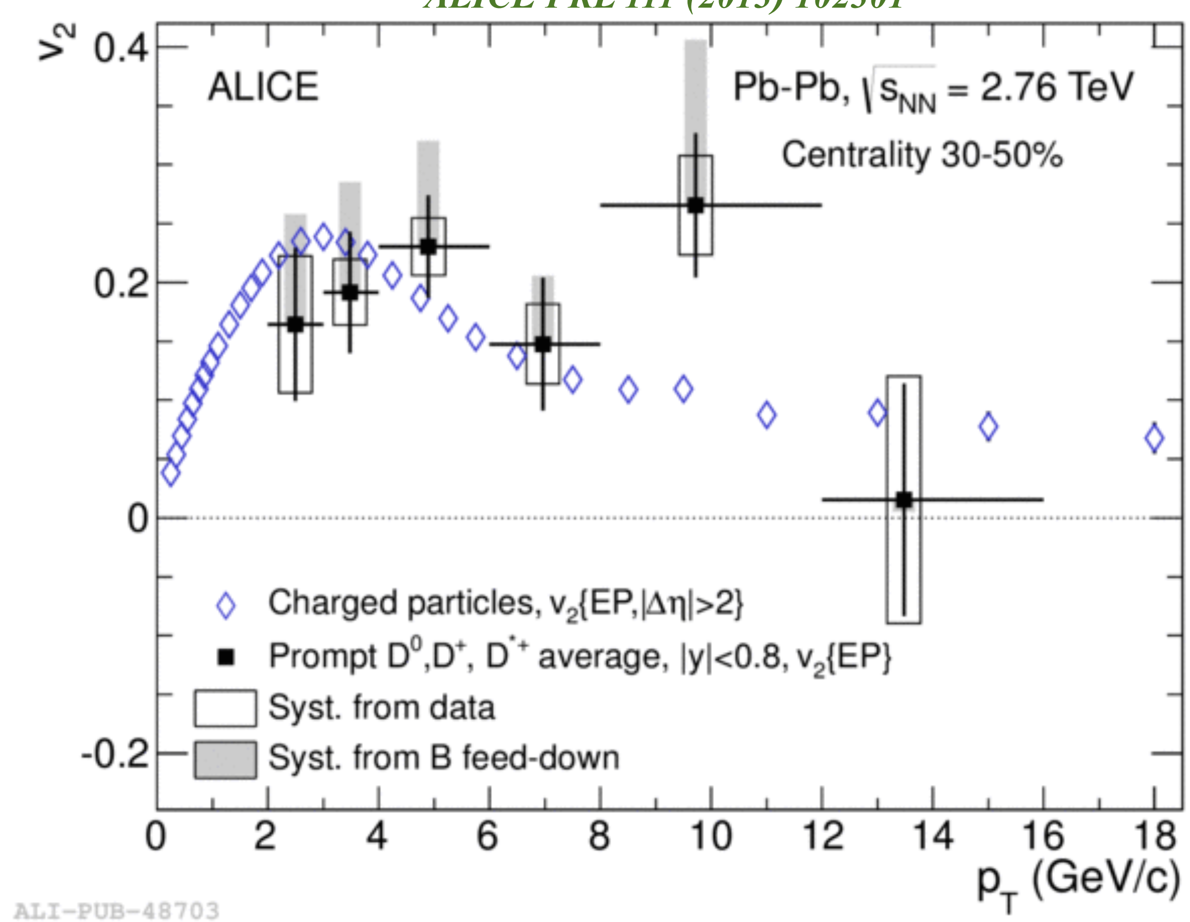
The elliptic flow (n=2) is defined as:

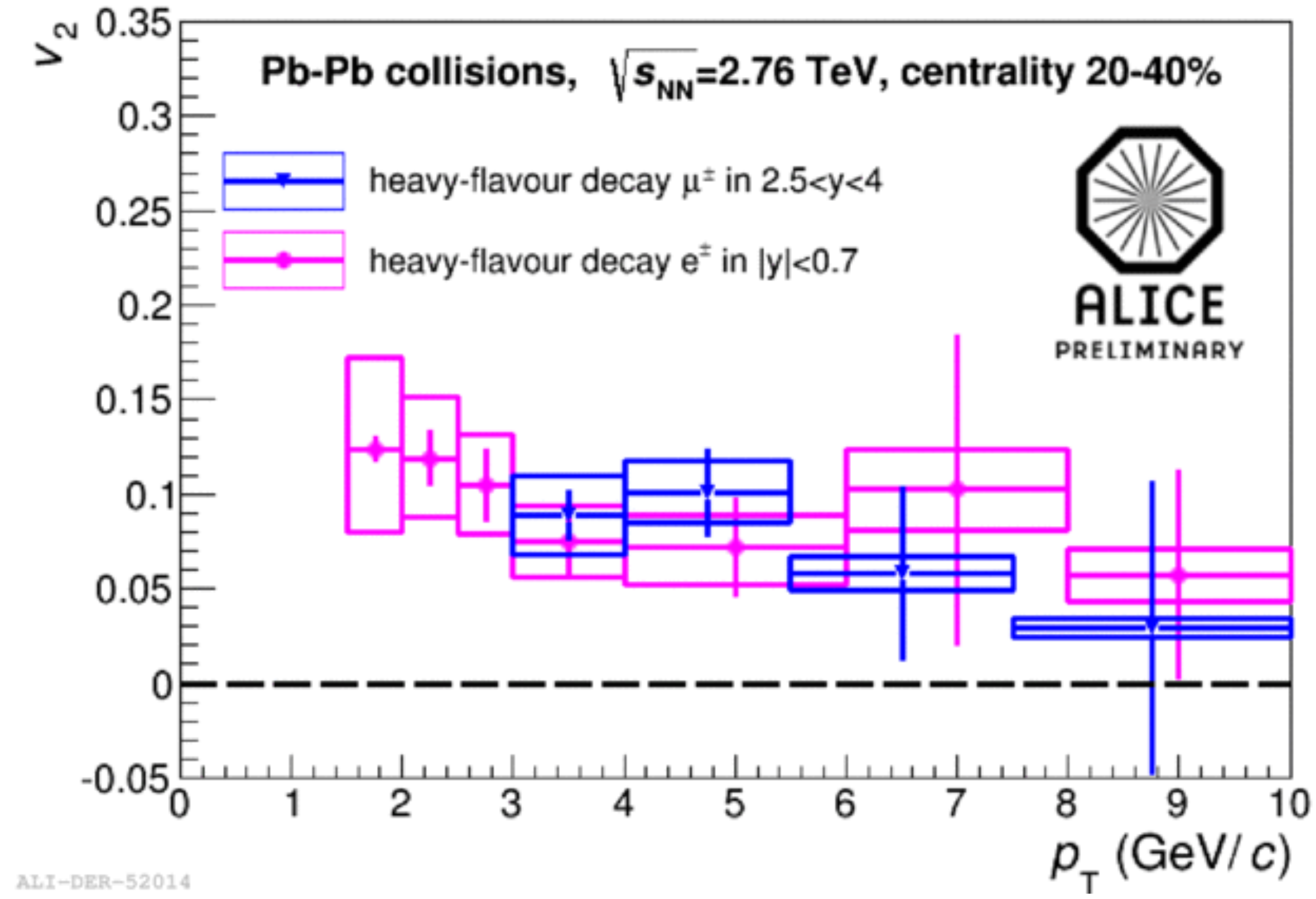
$$v_2(p_T) = \langle cos2(\phi - \Psi_R)\rangle(p_T)$$

Elliptic flow (n=2) expected at low p_T if heavy quarks participate to the collective motion of the QGP

Open heavy flavour flow

ALICE PRL 111 (2013) 102301

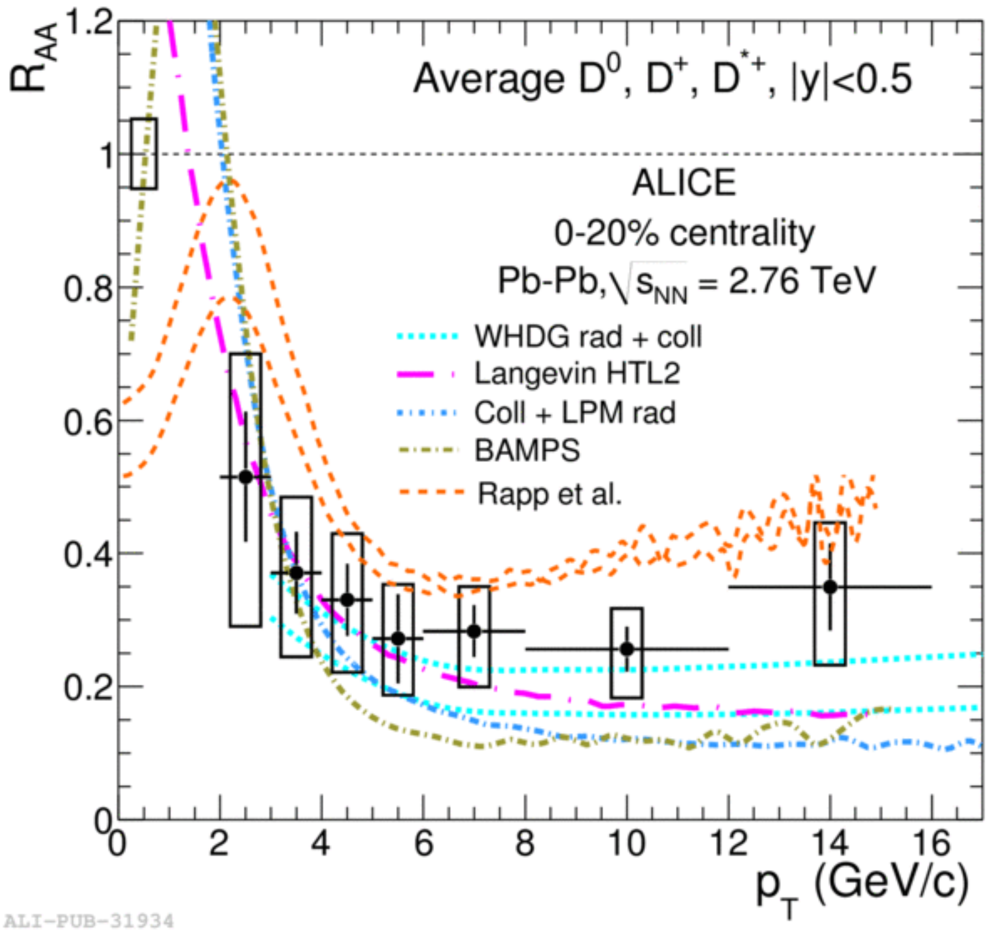




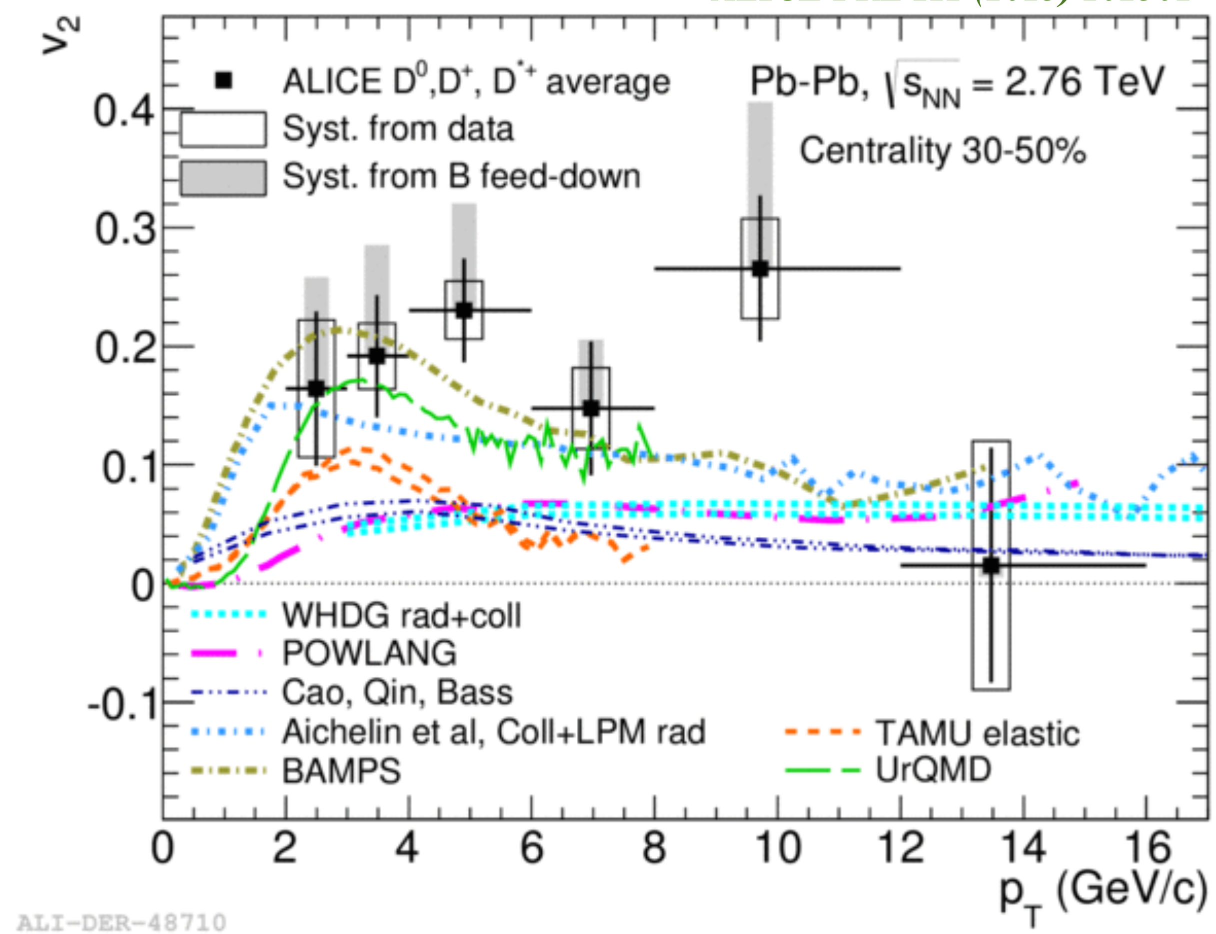
Non-zero v_2 observed for all open heavy flavour channels
Similar v_2 for charged hadrons and D mesons
→ initial azimuthal anisotropy transferred to charm quarks (as for light particles)
→ suggest that low p_T charm quarks participate to the collective motion of the system
Similar v_2 for HF decay electrons and muons for different rapidity

D mesons R_{AA} and v_2

ALICE JHEP 1209 (2012) 112 arXiv:1203.2160



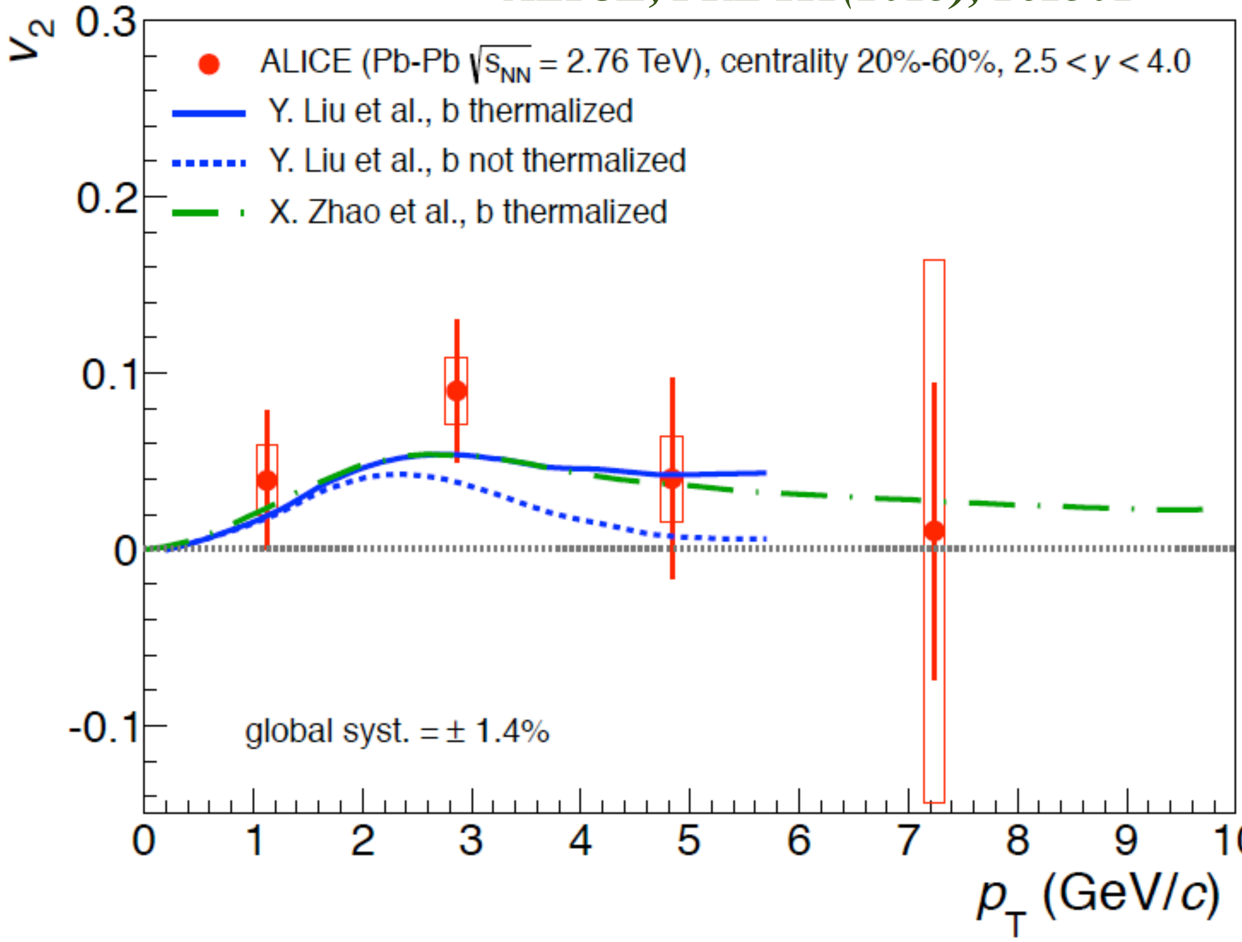
ALICE PRL 111 (2013) 102301



Simultaneous description of v_2 and R_{AA} is challenging
R_{AA} and v_2 give constraints on heavy quark transport coefficients of the medium

Inclusive J/ψ v_2 and R_{AA} vs p_T

ALICE, PRL 111(2013), 162301

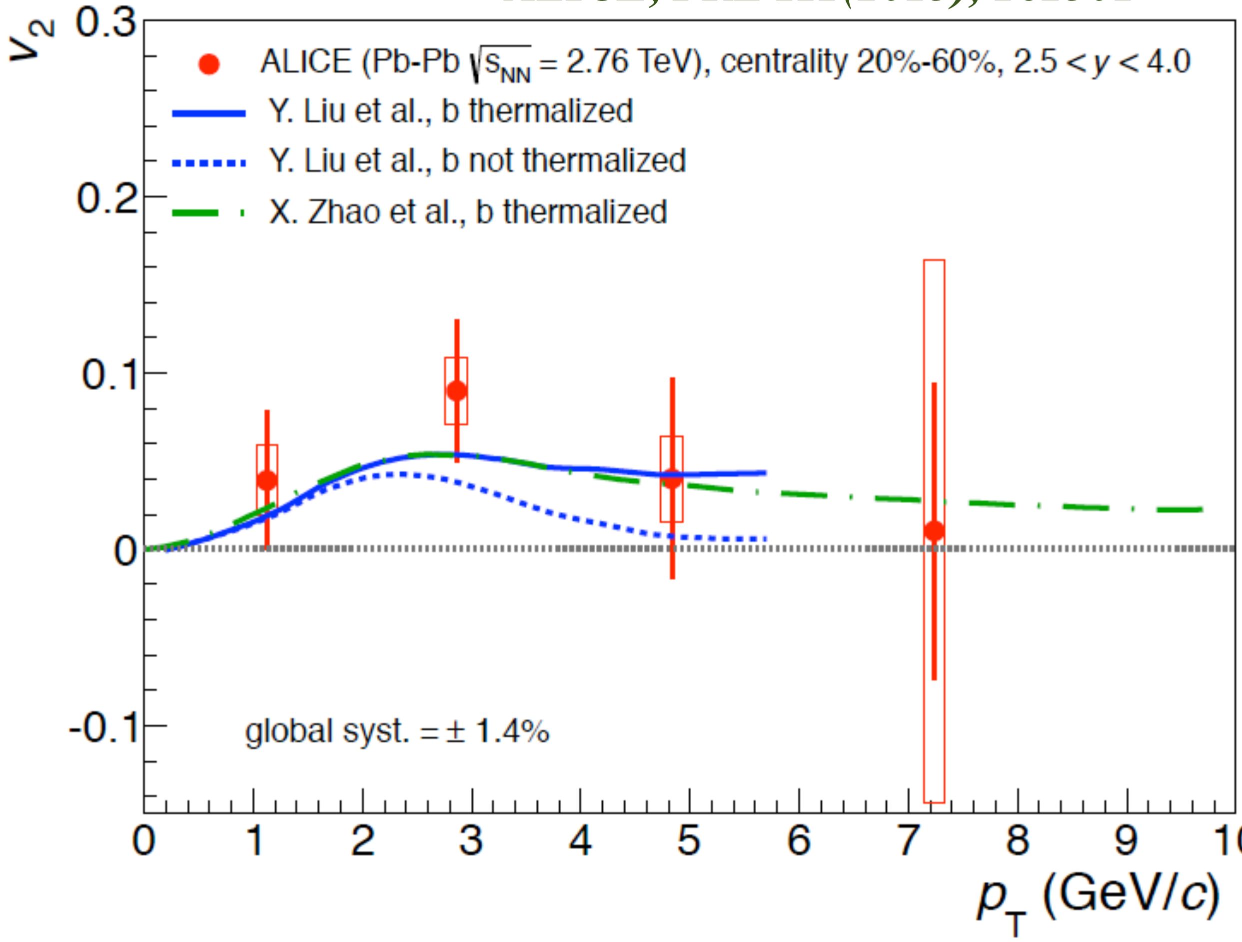


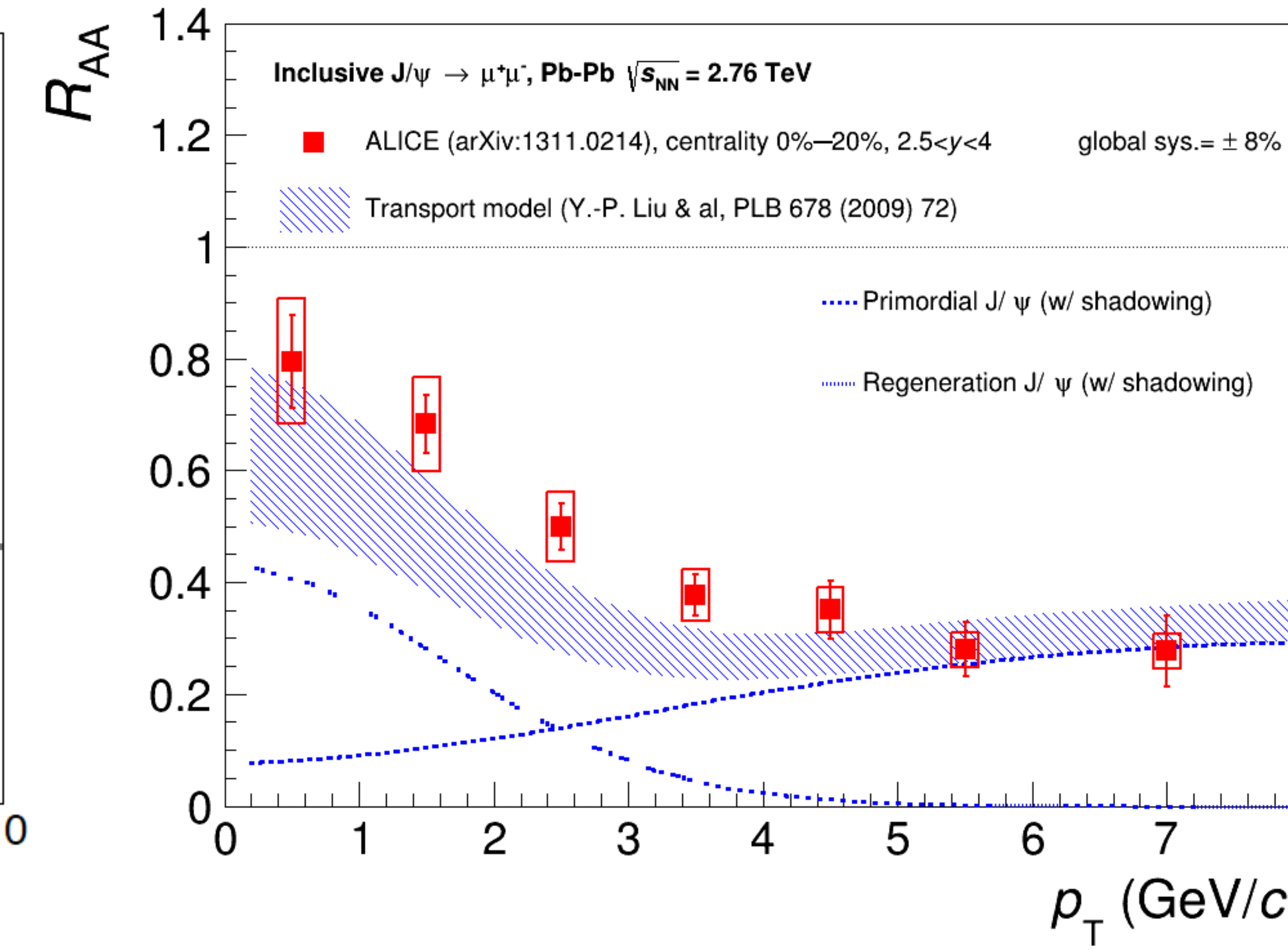
Indication of a non-zero J/ψ v_2 at intermediate p_T for semi-central collisions

v_2 complements R_{AA}: both are qualitatively well described by transport models including regeneration where J/ψ inherits from the charm elliptic flow

Inclusive J/ψ v_2 and R_{AA} vs p_T

ALICE, PRL 111(2013), 162301





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v_2 complements R_{AA}: both are qualitatively well described by transport models including regeneration where J/ψ inherits from the charm elliptic flow

Conclusions

Quarkonium and open heavy flavour as a probe of the cold nuclear matter effects in p-Pb and of the hot medium formed in heavy-ion collisions

p-p measurements

- Open heavy flavour cross-section in good agreement with pQCD calculations
- Quarkonium measurements bring new constraints to test the hadroproduction mechanism

p-Pb measurements

- Open heavy heavy flavour R_{pPb} compatible with no suppression and in agreement with pQCD models + shadowing
- Low p_T heavy flavour decay electron-hadron correlations show similar structure as for h-h correlations for most central collisions (double ridge)
- J/ψ measurements at forward rapidity support a strong shadowing and/or the coherent energy loss model
- ψ(2S) suppressed relatively to J/ψ by up to 45% at backward rapidity: final state effect? Other mechanism in p-Pb?

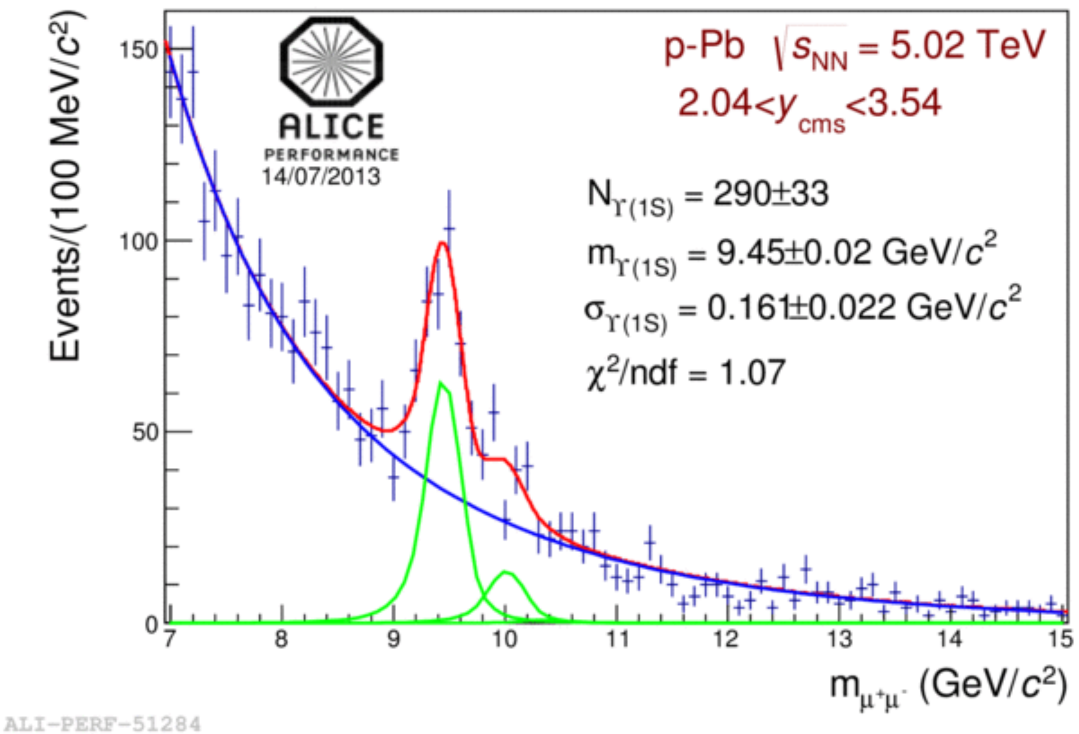
Pb-Pb measurements

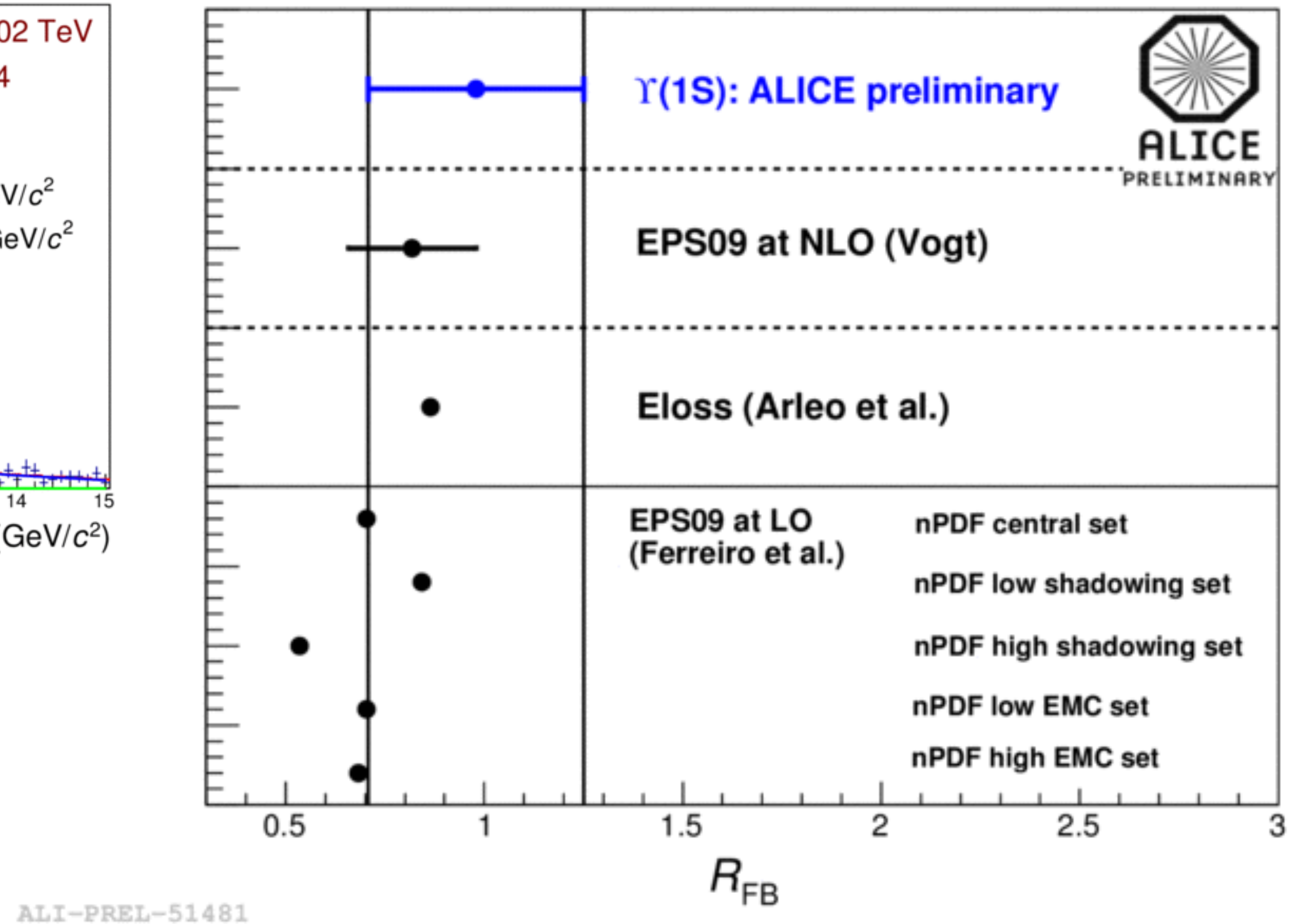
- All heavy flavour channels show a large suppression in central Pb-Pb measurements: p-Pb results confirm this is a final state effect
- Quark-mass ordering suppression confirmed from D and B←J/ψ R_{AA}.
- Non-zero v_2 for HF at low p_T suggest that charm quarks participate to the collective motion of the system
- J/ψ : R_{AA} measurements show a different behaviour wrt lower energy measurements. Models including J/ψ production from deconfined charm quarks in the QGP phase reproduce well the R_{AA}. The indication of a non zero v_2 is also in agreement with expectations from (re)generation models.
- ϒ(1S) R_{AA} at forward rapidity: combined with CMS data, results show a suppression with a small rapidity dependence

More results to come soon from Run1, more statistics in Run2, Upgrade for Run3 (2018)

back-up slides

Υ(1S) measurements: R_{FB}



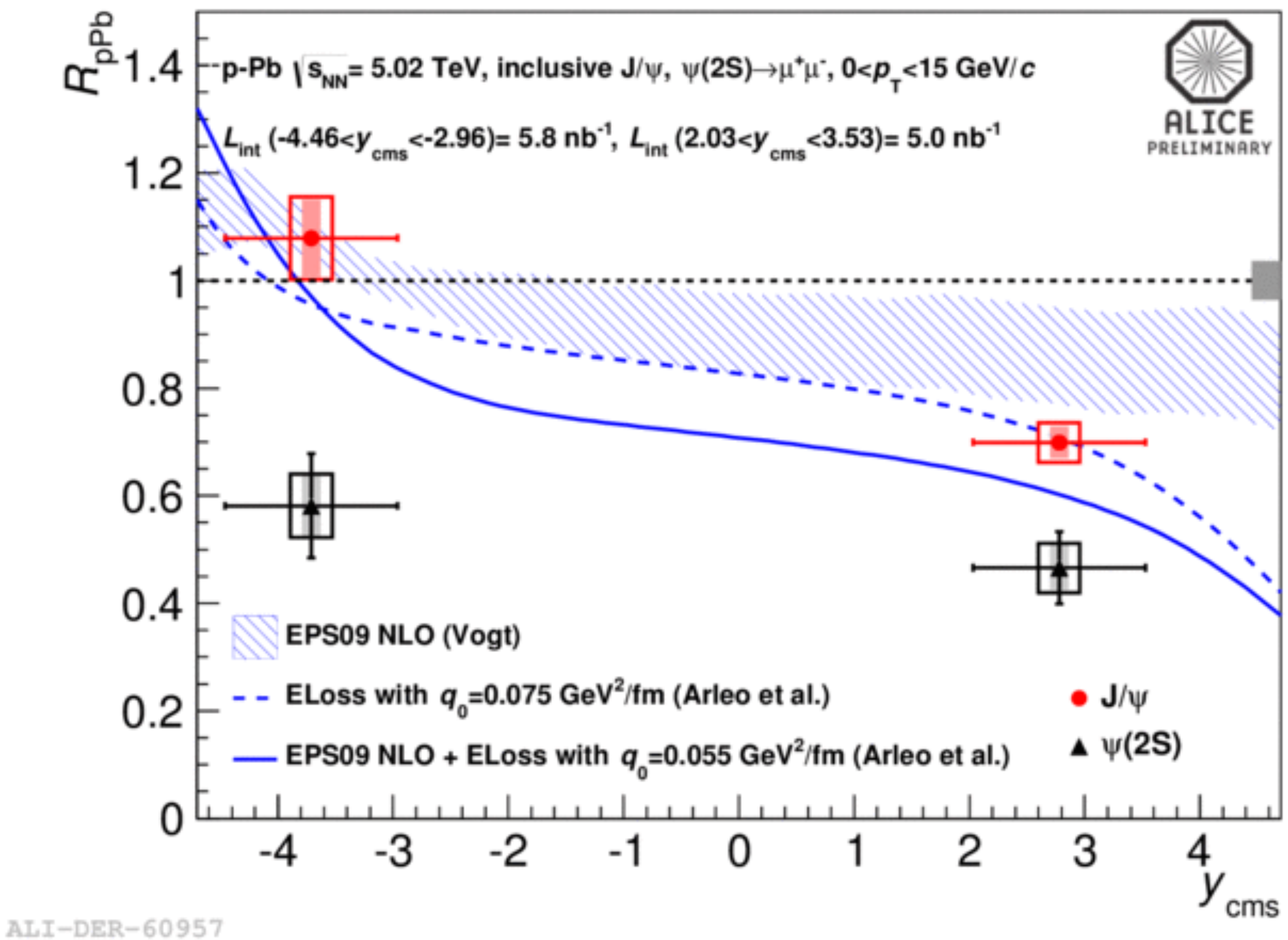


R_{FB} is compatible with unity and larger than the J/ψ R_{FB} = 0.60±0.01(stat)±0.06(syst)
Limited statistics does not allow to discriminate among models

$\psi(2S)$ measurements in p-Pb: R_{pPb}

New

$$R_{pPb}^{\psi(2S)} = R_{pPb}^{J/\psi} \frac{\sigma_{pPb}^{\psi(2S)}}{\sigma_{pPb}^{J/\psi}} \frac{\sigma_{pp}^{J/\psi}}{\sigma_{pp}^{\psi(2S)}}$$



Systematic uncertainties
- boxes: uncorrelated
- shaded area: (partially) correlated
- box at unity: fully correlated

The stronger suppression of ψ(2S) relatively to J/ψ is not described by initial state CNM and coherent energy loss
→ final state effect? Other mechanisms?

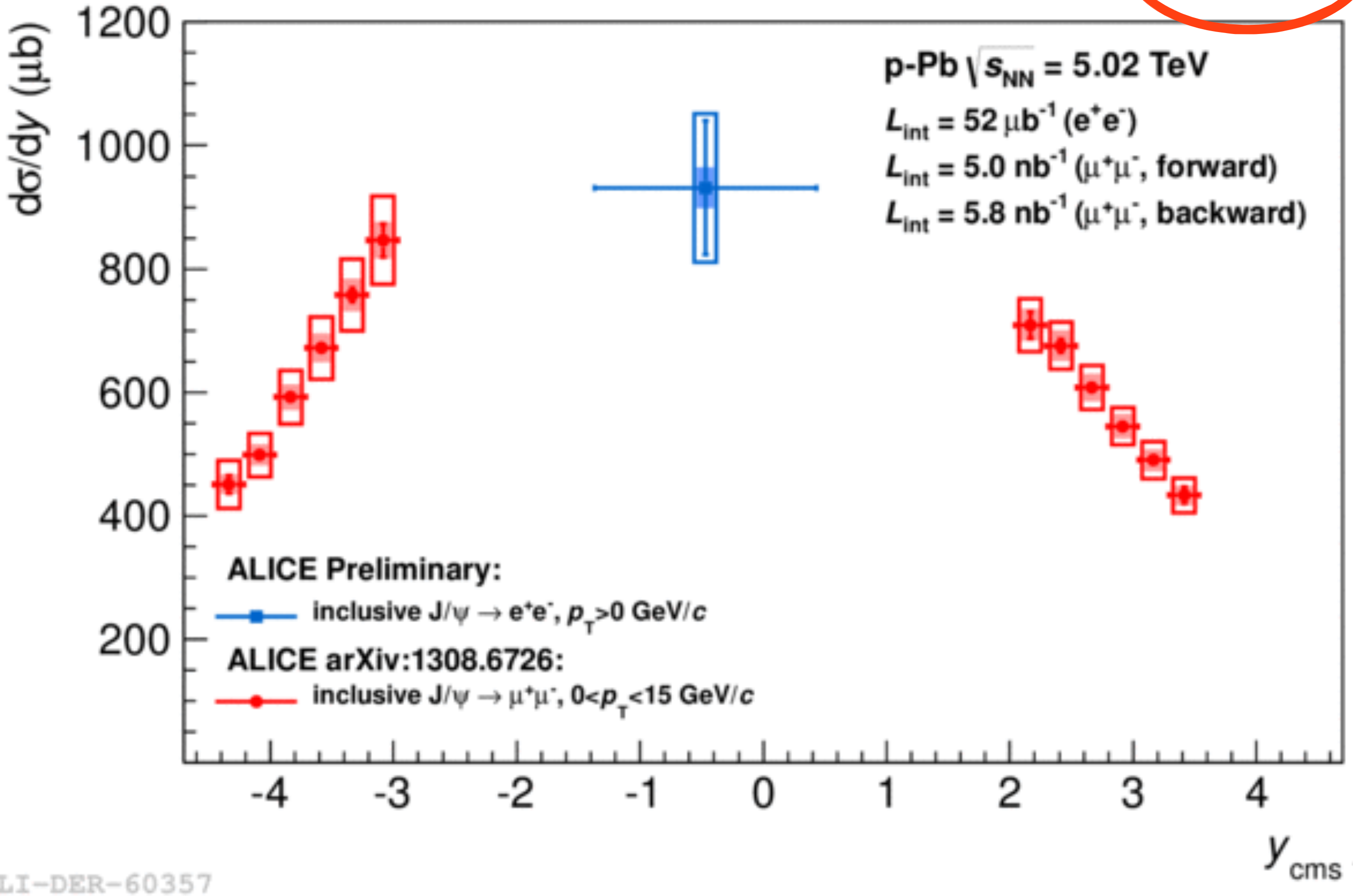
J/ψ cross-sections vs y and p_T

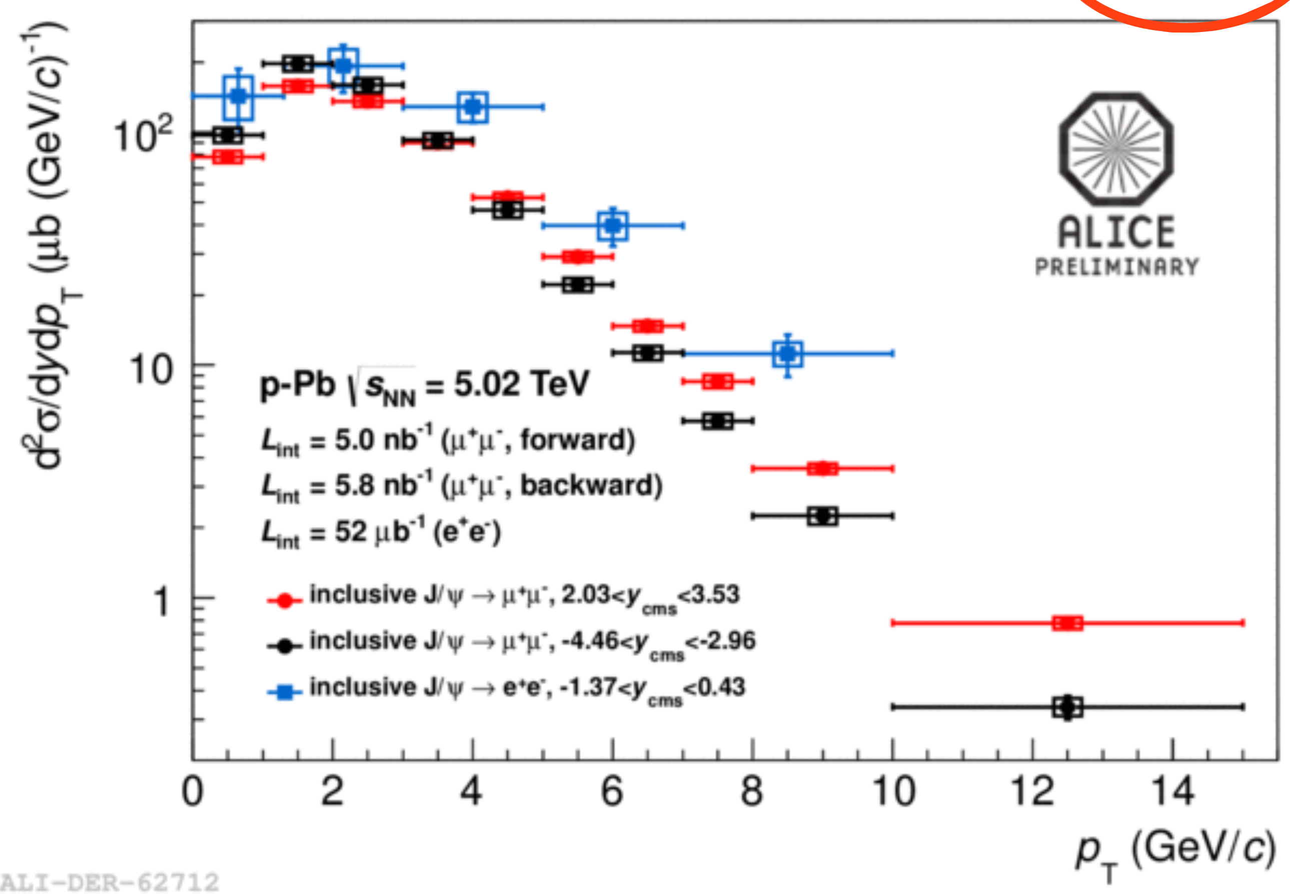
$$\sigma_{J/\psi} = \frac{N_{J/\psi \to l^+l^-}}{L_{int}\, A\, \epsilon\, BR_{J/\psi \to l^+l^-}}$$

New

Systematic uncertainties
boxes: uncorrelated
shaded area: (partially) correlated

New



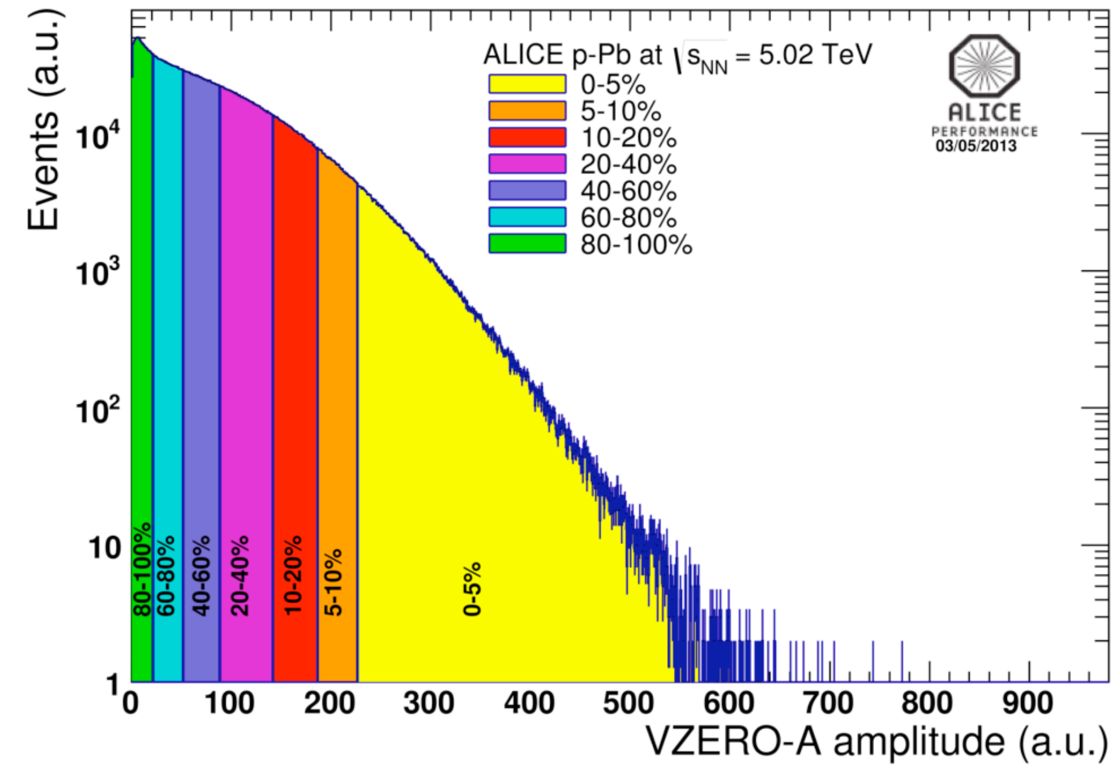


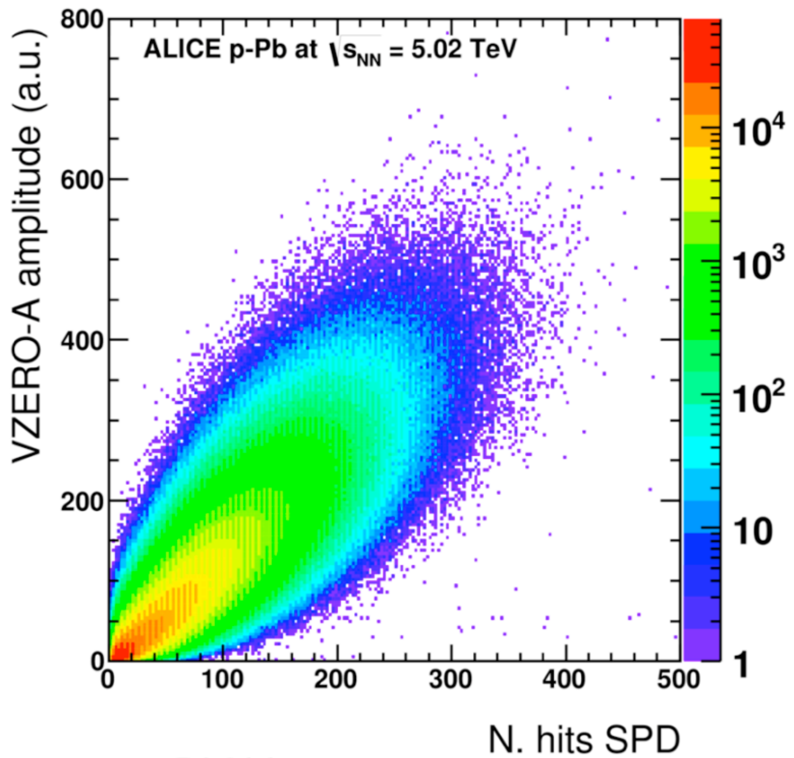
Forward rapidity: lower cross-sections and harder in p_T than at backward rapidity

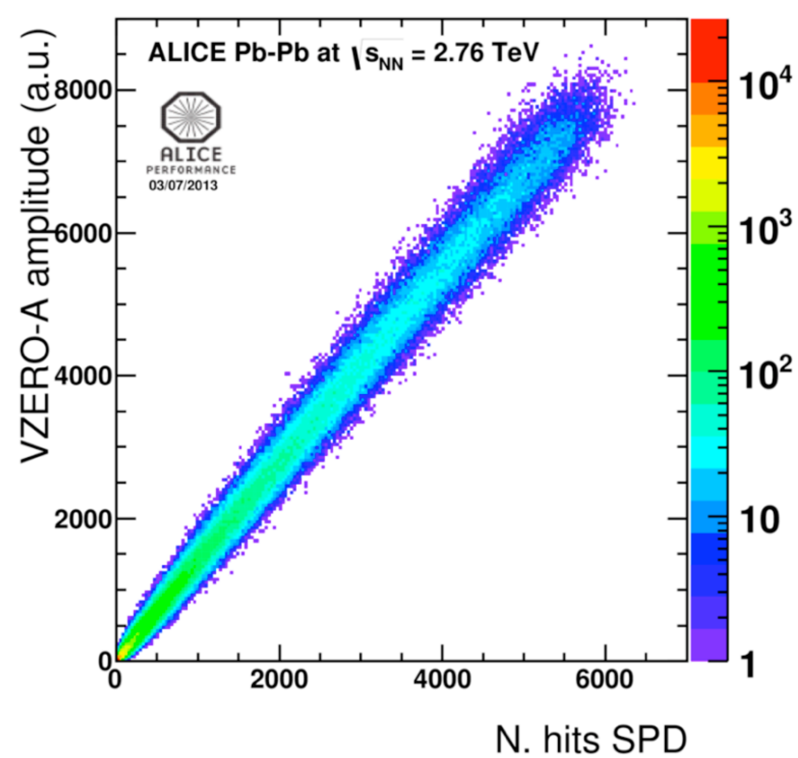
Centrality of the collisions in pA

Lower multiplicity wrt Pb-Pb → low resolution on binary collisions extracted from a Glauber fit

Correlations between signal and measured multiplicity







ALI-PERF-51411

pp cross-section interpolation at 5.02 TeV

J/ψ cross-section

Forward rapidity:

Energy interpolation of p_T and y-dep. with ALICE forward rapidity data @ 2.76 and 7 TeV
Rapidity extrapolation due to rapidity shift (0.5) in p-Pb
CEM and FONLL calculations used to validate the empirical functions used

ALICE + LHCb, public note in preparation

Mid-rapidity:

Energy interpolation at mid-rapidity with PHENIX @ 200 GeV, CDF @ 1.96 TeV, ALICE @ 2.76 and 7 TeV
$\langle p_T \rangle$ interpolation and p_T extrapolation with both forward and mid-rapidity data from PHENIX @ 200 GeV, CDF @ 1.96 TeV, ALICE @ 2.76 and 7 TeV, CMS @ 7 TeV, LHCb @ 2.76, 7 and 8 TeV

F. Bossù et al., arXiv:1103.2394

[ψ(2S)/J/ψ] ratio

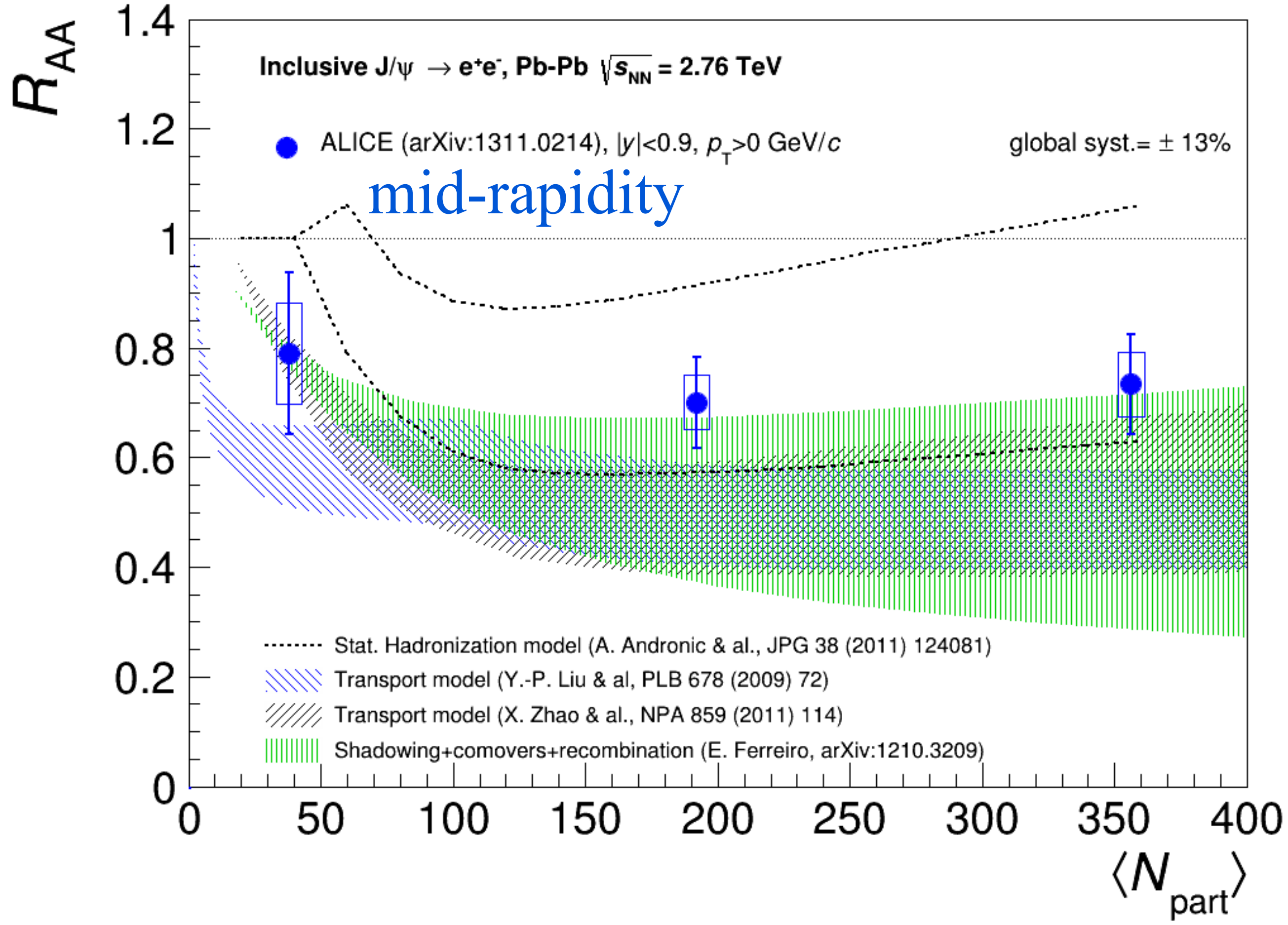
No energy and rapidity dependence of [ψ(2S)/J/ψ] in pp assumed. Systematics evaluated with CDF @ 1.96 TeV and LHCb @ 7 TeV

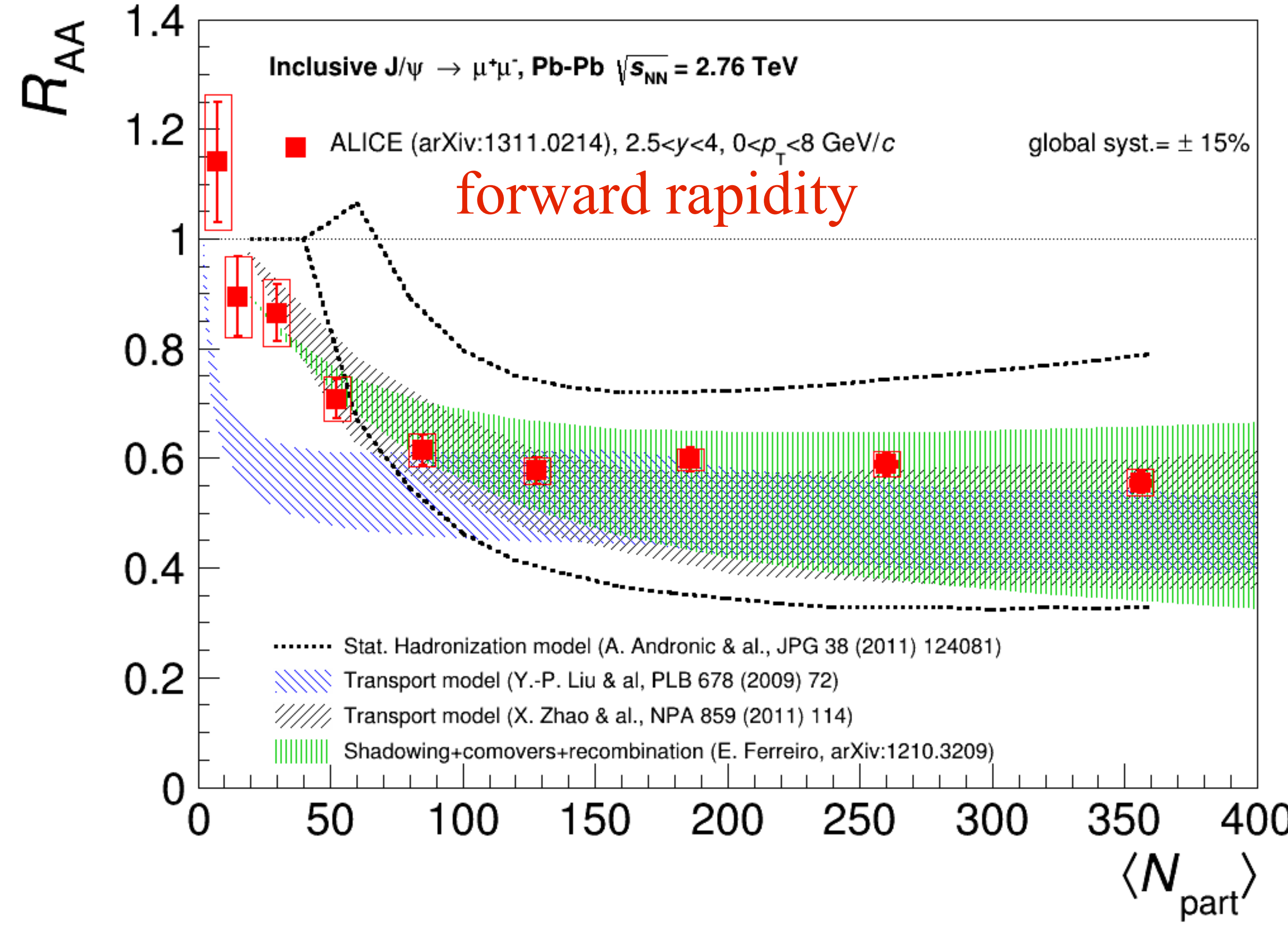
ϒ(1S) cross-section

Energy interpolation with mid-rapidity data from CDF @ 1.8 TeV, D0 @ 1.96 TeV, CMS @ 2.76 and 7 TeV
Rapidity extrapolation: Pythia tunings selected with rapidity dependence of CMS and LHCb @ 7 TeV

	Systematics
J/ψ (y>0)	6-17%
J/ψ (y~0)	16-27%
[ψ(2S)/J/ψ] (y>0)	4 %
ϒ(1S)	13-19%

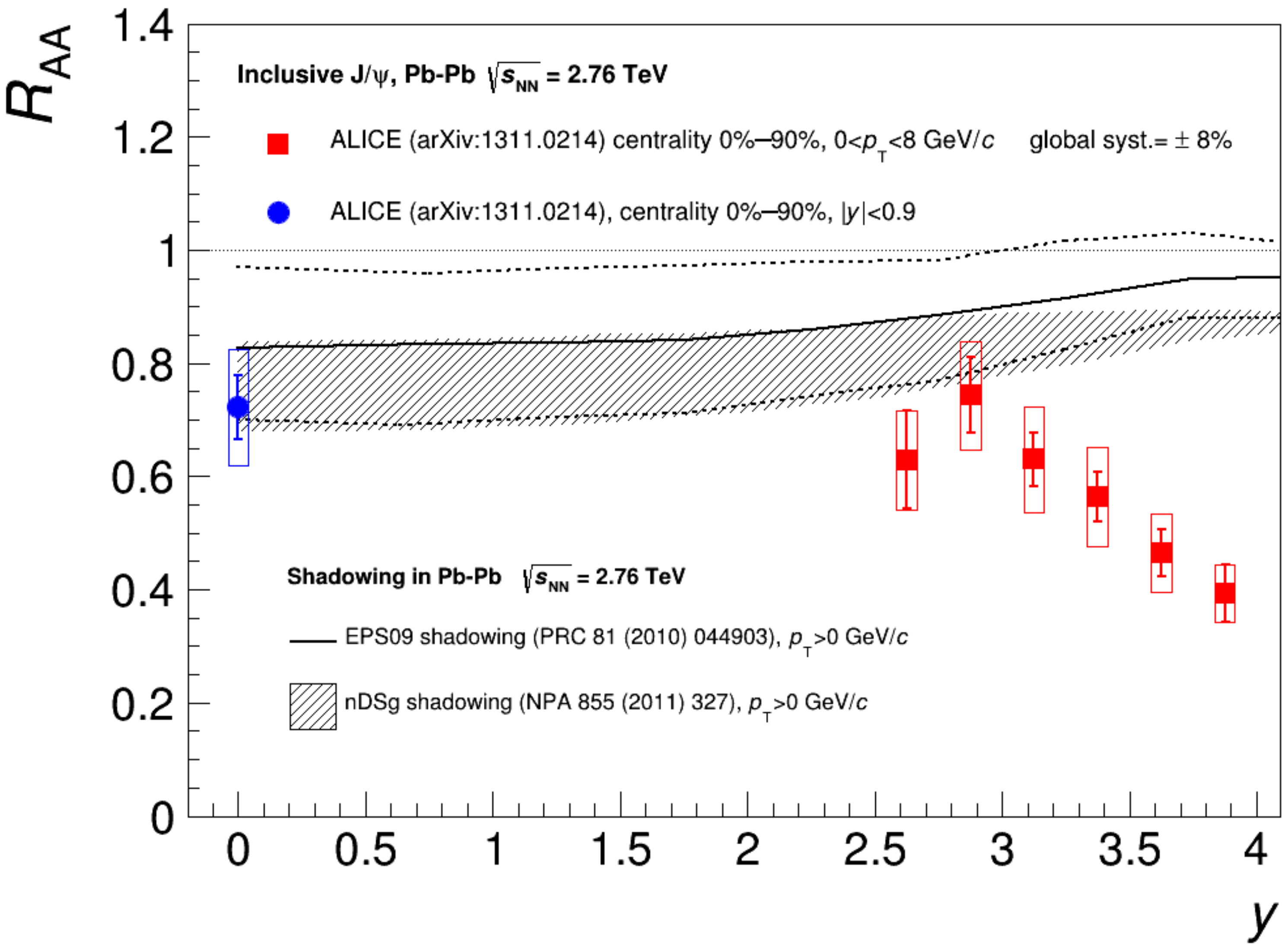
J/ψ R_{AA} vs centrality





These models include regeneration mechanism and describe well the data for semi-central and central collisions

J/ψ R_{AA} vs y



Suppression more important at forward rapidity

Shadowing models do not account for this rapidity decrease of R_{AA}

p-Pb measurements extrapolated to Pb-Pb

Hypothesis

2→1 kinematics of J/ψ production

Factorization of shadowing effects in p-Pb and Pb-Pb ⇒ $R^{Shad}_{PbPb} = R_{pPb}(x_1) \times R_{pPb}(x_2)$

Kinematics

p (x_1) + Pb (x_2) → J/ψ (y, p_T) with $x_{1,2} = \sqrt{(m^2+p_T^2)} / \sqrt{s_{NN}} \exp(\pm y_{cms})$

R_{pPb} ($\sqrt{s_{NN}}$= 5.02 TeV, y<0, p_T) = G(x_1)

R_{pPb} ($\sqrt{s_{NN}}$= 5.02 TeV, y>0, p_T) = G(x_2)

gluon x in nucleus	x_1	x_2
p-Pb @ 5.02 TeV and $-4.46<y_{cms}<-2.96$	$1.2\text{-}5.3\ 10^{-2}$	-
p-Pb @ 5.02 TeV and $2.03<y_{cms}<3.53$	-	$1.9\text{-}8.3\ 10^{-5}$
Pb-Pb @ 2.76 TeV and $2.5<y<4$	$1.2\text{-}6.1\ 10^{-2}$	$2.0\text{-}9.2\ 10^{-5}$
p-Pb @ 5.02 TeV and $-1.37<y_{cms}<0.43$	$4.0\ 10^{-4}\text{-}2.4\ 10^{-3}$	$4.0\ 10^{-4}\text{-}2.4\ 10^{-3}$
Pb-Pb @ 2.76 TeV and $-0.8<y<0.8$	$5.0\ 10^{-4}\text{-}2.5\ 10^{-3}$	$5.0\ 10^{-4}\text{-}2.5\ 10^{-3}$

⇒ gluon momentum fraction x_1, x_2 probed in nucleus similar in p-Pb @ 5.02 TeV and Pb-Pb @ 2.76 TeV

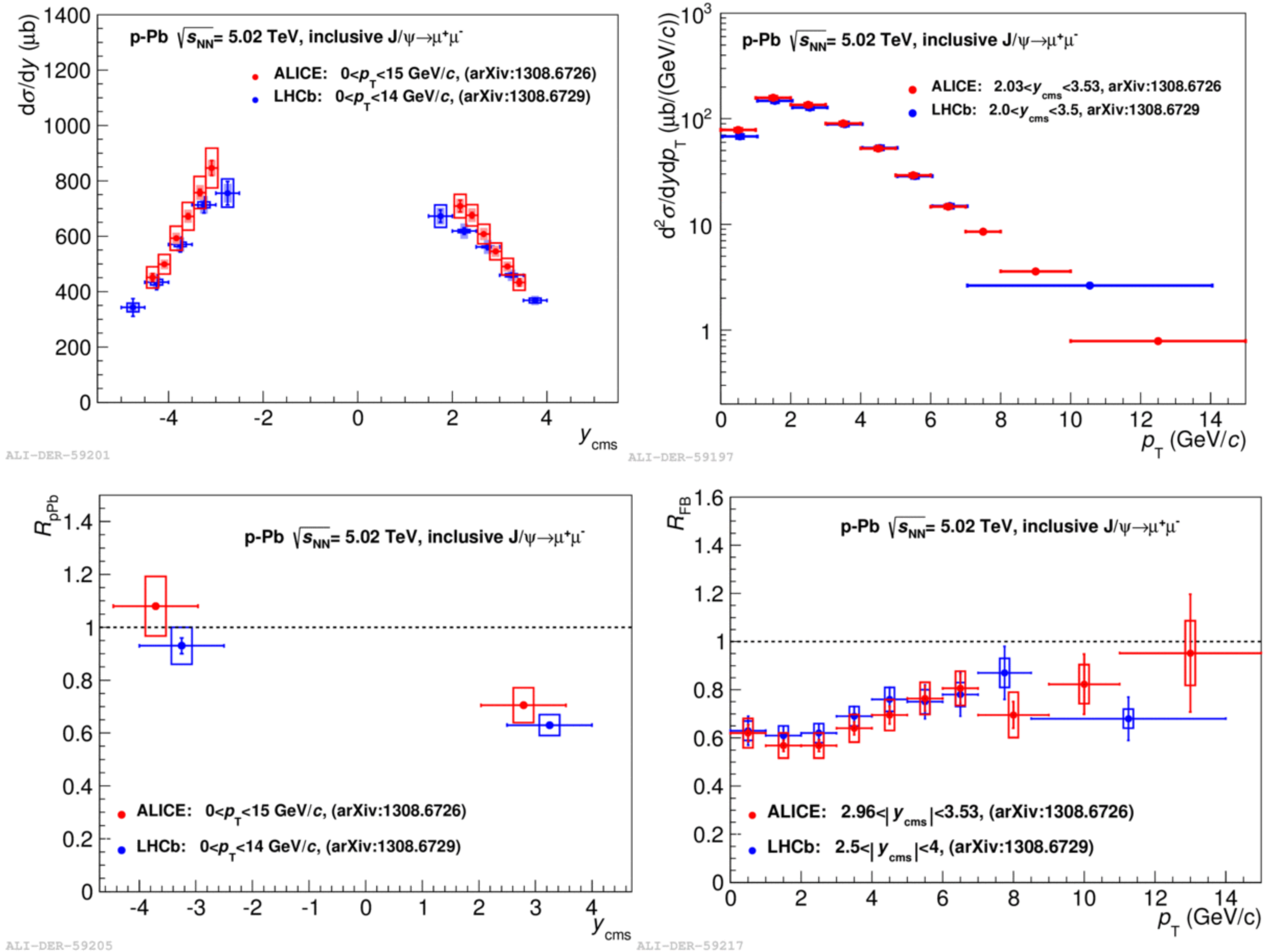
Cold nuclear matter contribution in Pb-Pb

R_{PbPb} ($\sqrt{s_{NN}}$=2.76 TeV, y, p_T)

= G(x_1) × G(x_2)

= R_{pPb} ($\sqrt{s_{NN}}$= 5.02 TeV, y<0, p_T) × R_{pPb} ($\sqrt{s_{NN}}$= 5.02 TeV, y>0, p_T)

Inclusive J/ψ in p-Pb: comparison to LHCb



J/Ψ polarization in pp at forward rapidity

Polarization is a critical observable to test the hadroproduction mechanisms

Unknown polarization results in large uncertainty on acceptance correction

First measurement at LHC:

- small longitudinal polarization that vanishes when increasing p_T
- azimuthal component compatible with zero

In the following analysis (Pb-Pb and p-Pb), the polarisation of the quarkonia is assumed to be zero

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