BROOKHAVEN BULLETIN
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BROOKHAVEN NATIONAL LABORATORY

RHIC Begins World's Highest Energy Heavy-Ion Collisions

All Four RHIC Detectors Track Collisions

Last week, BNL's Relativistic Heavy Ion Collider (RHIC) made history
by achieving the highest-energy heavy-ion collisions ever produced by
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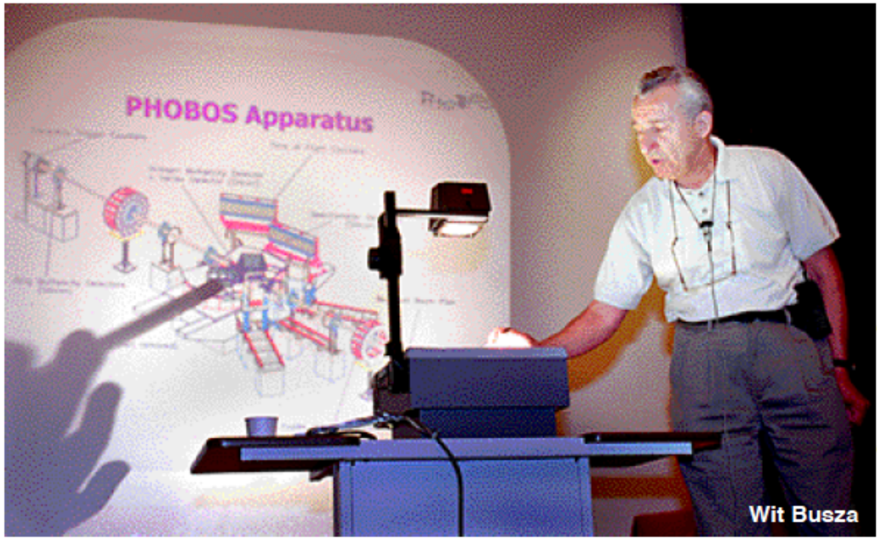
PHOBOS Collaboration Presents First Physics Results From RHIC



Roger Stoutenburgh D0160700

p-Pb Results from ALICE (part 2)

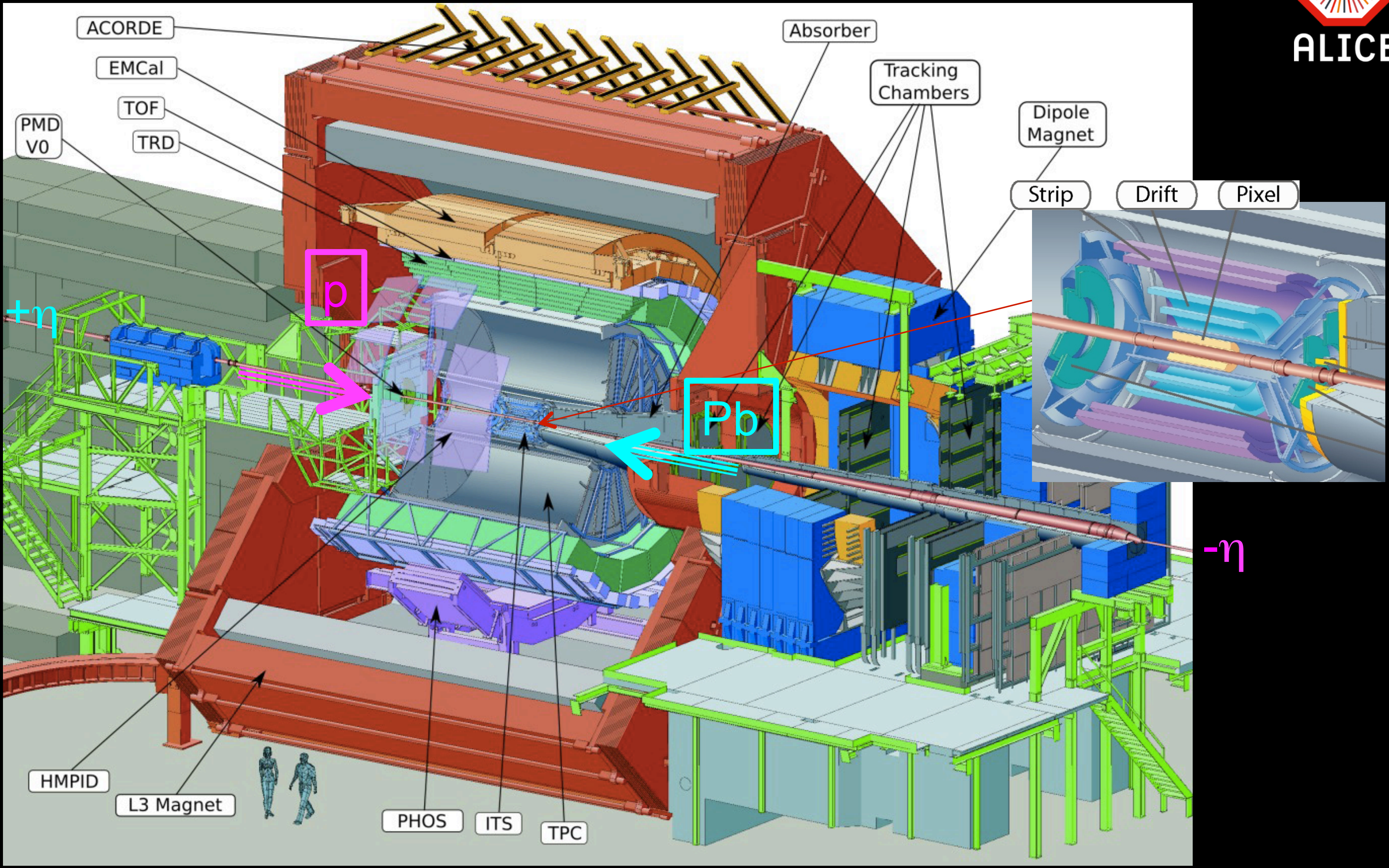
Charged Particle dn/dη & dn/dp_T

J/ψ Production

John Harris (Yale) for ALICE

pA Physics Workshop, MIT, 17 - 18 May 2013

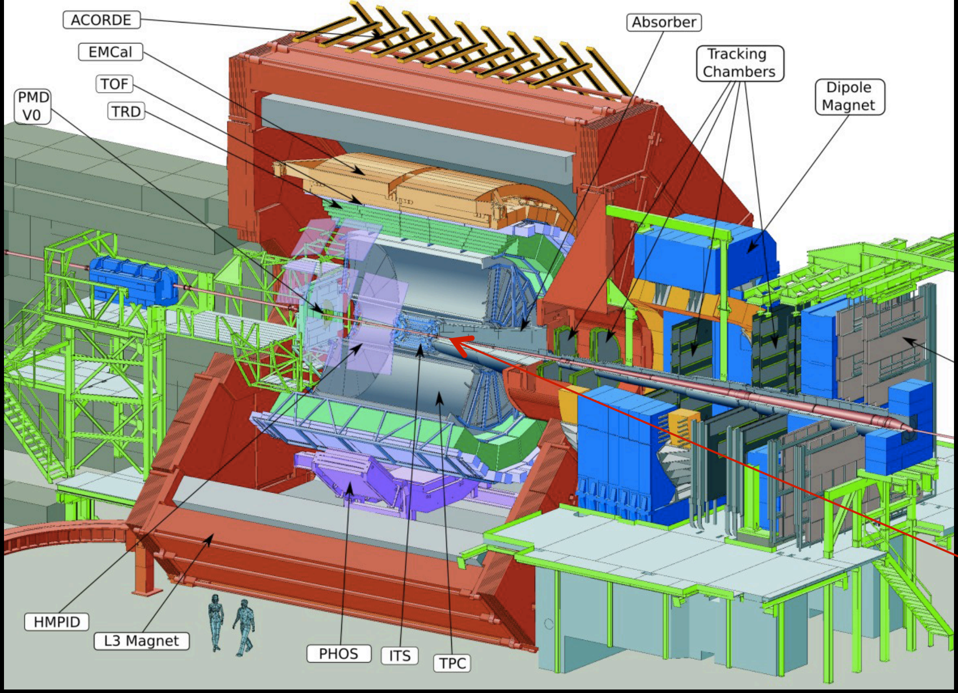
p-Pb in ALICE



4 TeV protons ⊖⟶ ✳ ⟵⊕ 1.58 A-TeV Pb $\sqrt{s_{NN}}$ = 5.02 TeV p-Pb Δy_{NN}=0.465 in p-dir

Charged Particle Pseudo-rapidity and Transverse Momentum Distn's in p-Pb

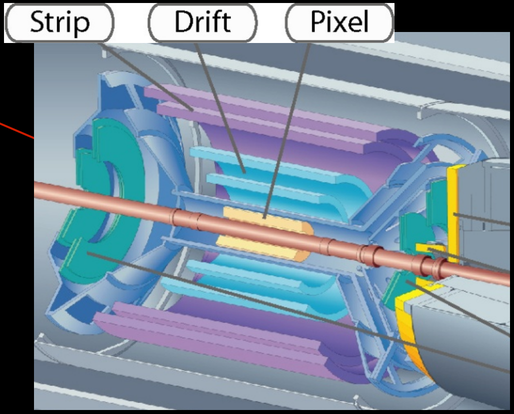
ALICE Data-taking in p-Pb Pilot Run



Detectors used in triggering:

- V0-A ($2.8 < \eta_{lab} < 5.1$)
- V0-C ($-3.7 < \eta_{lab} < -1.7$)
- Neutron zero degree calorimeters (ZNA, ZNC)

Non single-diffractive (NSD)
SD & EM contributions ~ 0



Detectors used in analyses:

- "Pseudo-rapidity density of charged particles…"
  Silicon Pixel Detector (SPD) $|\eta_{lab}| < 1.4$
- "Transverse momentum spectra and $R_{p\text{-}Pb}$…" &
  "Long-ranged correlations…"
  Inner Tracking System (ITS):
  Silicon Pixel, Drift & Strip Detectors (SPD, SDD, SSD)
  Time Projection Chamber (TPC)

LHC p-Pb Collision Simulations in ALICE

Why p-Pb at LHC?

Differentiate

initial state (cold nuclear matter)

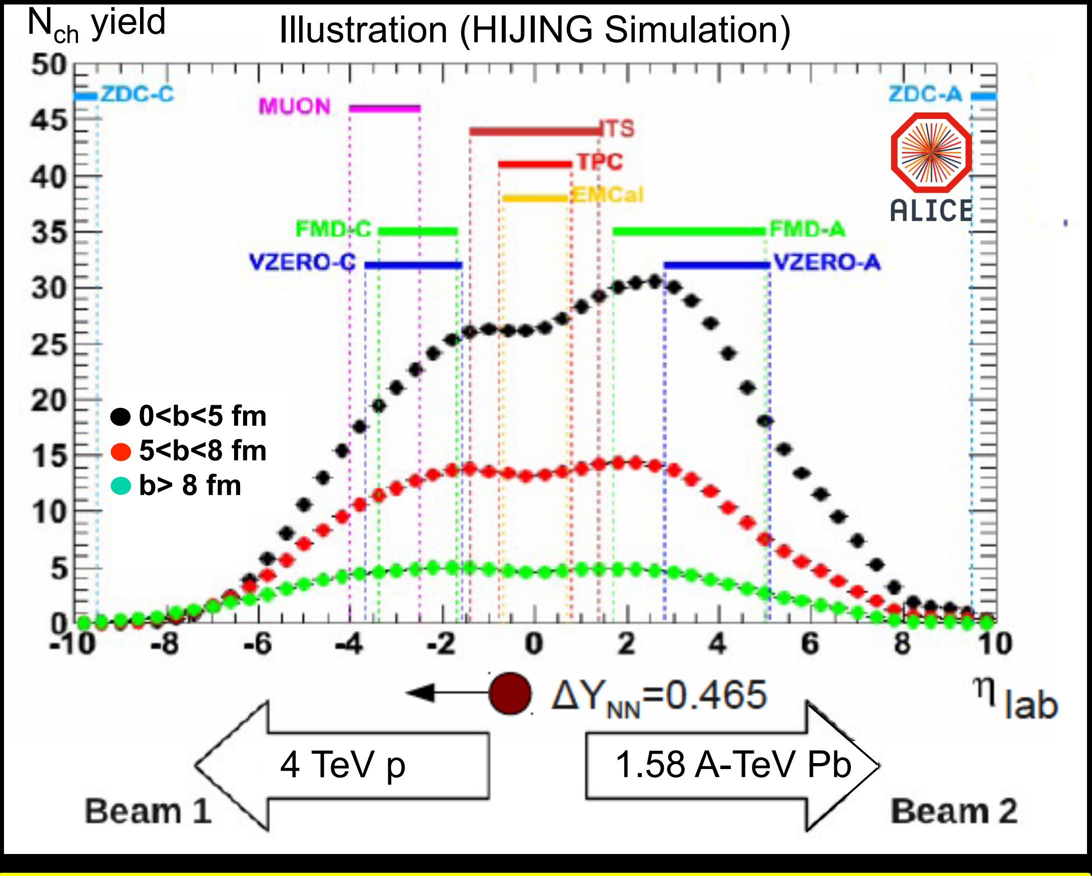
&

final state (QGP) effects

p-Pb at LHC → probes nuclear wave-function at small parton momentum fraction

$x = p_{parton} / p_{proton}$

QCD at high gluon density: parton shadowing, gluon saturation?



ALICE acceptance

HIJING p-Pb simulations $\eta_{lab} = - \frac{1}{2} \ln (\theta/2)$

(min bias $dn_{ch}/d\eta_{lab}$ $(\eta=0) = 17.5$)

ALICE p-Pb: $dN_{ch}/d\eta$ Distribution vs Models

Most Model Predictions within 20% of data.

Saturation Models:

Rise too steeply

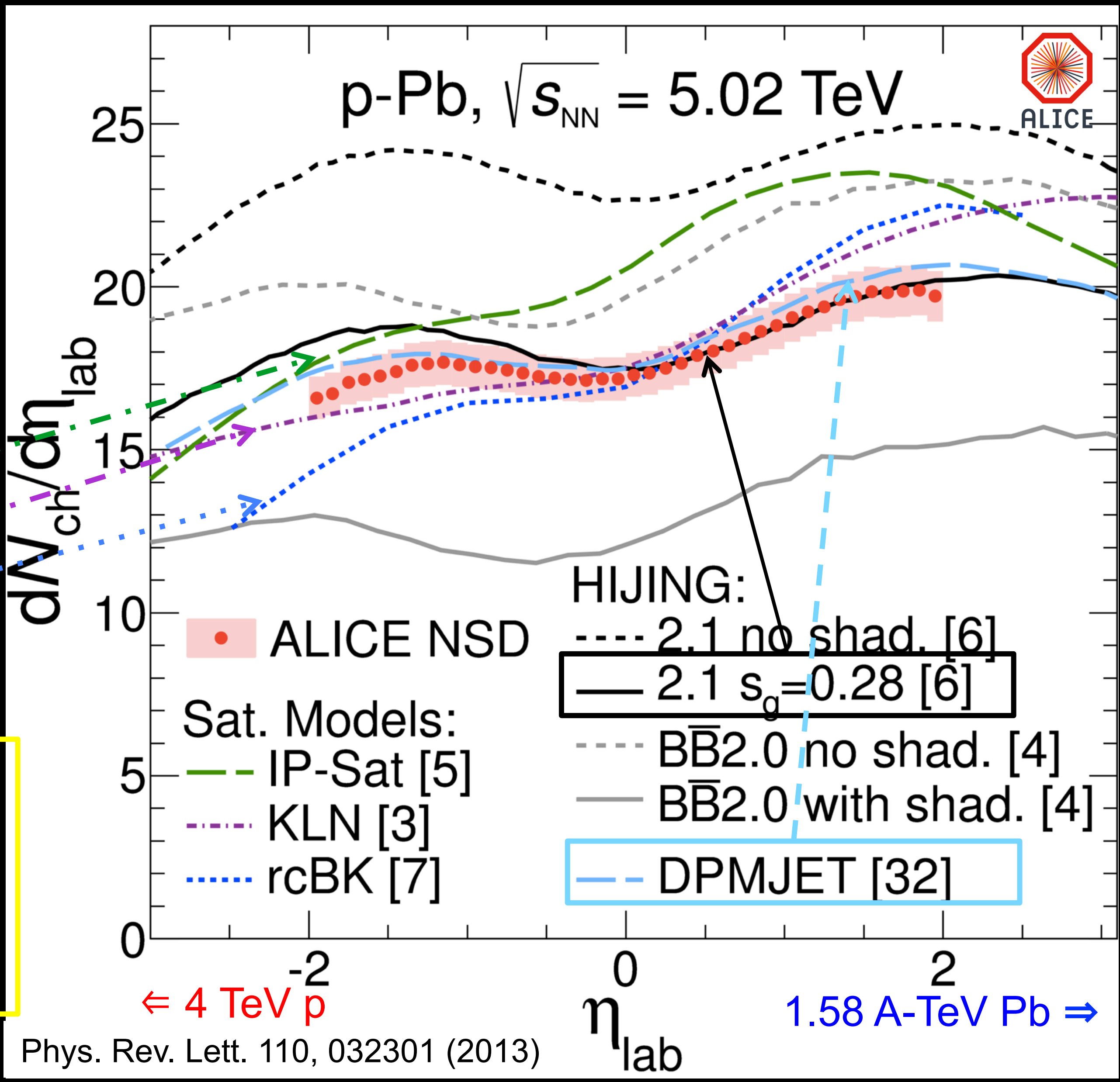
with η_{lab} !

pQCD-based MC models:

HIJING

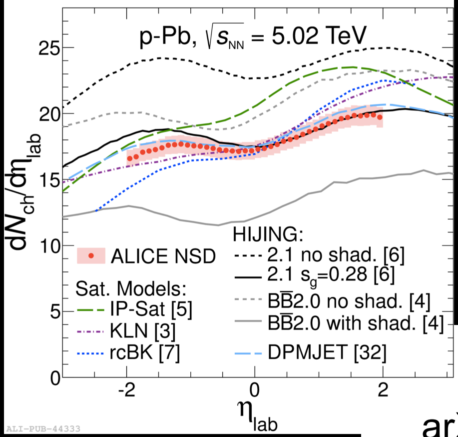
DPMJET

Describe $dn_{ch} / d\eta_{lab}$



Phys. Rev. Lett. 110, 032301 (2013)

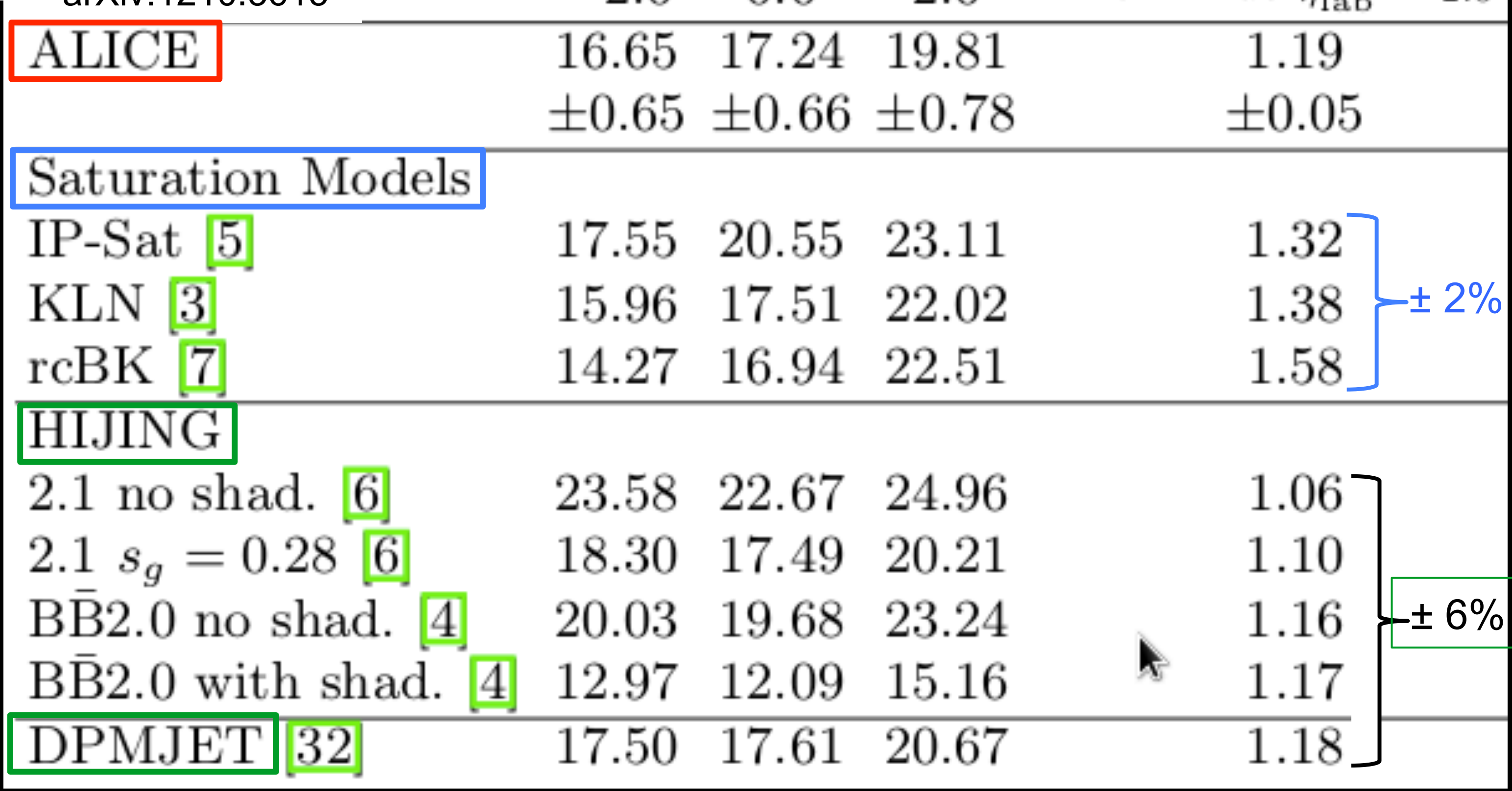
Details: ALICE p-Pb $dN_{ch}/d\eta$ vs Models



dN_{ch} / $d\eta_{lab}$ at η_{lab} =
-2 0 2

Ratio dN_{ch} / $d\eta_{lab}$ at
η_{lab} = 2 vs -2

arXiv:1210.3615



	$dN_{ch}/d\eta_{lab}$ -2.0	0.0	2.0	$\frac{dN_{ch}/d\eta_{lab}\|_{\eta_{lab}=2.0}}{dN_{ch}/d\eta_{lab}\|_{\eta_{lab}=-2.0}}$
ALICE	16.65 ±0.65	17.24 ±0.66	19.81 ±0.78	1.19 ±0.05
Saturation Models				
IP-Sat [5]	17.55	20.55	23.11	1.32
KLN [3]	15.96	17.51	22.02	1.38
rcBK [7]	14.27	16.94	22.51	1.58
HIJING				
2.1 no shad. [6]	23.58	22.67	24.96	1.06
2.1 $s_g = 0.28$ [6]	18.30	17.49	20.21	1.10
B$\bar{B}$2.0 no shad. [4]	20.03	19.68	23.24	1.16
B$\bar{B}$2.0 with shad. [4]	12.97	12.09	15.16	1.17
DPMJET [32]	17.50	17.61	20.67	1.18

± 2%

± 6%

ALICE p-Pb: Measured p_T Spectra

Primary charged particle spectrum

Slightly softer spectrum at higher η

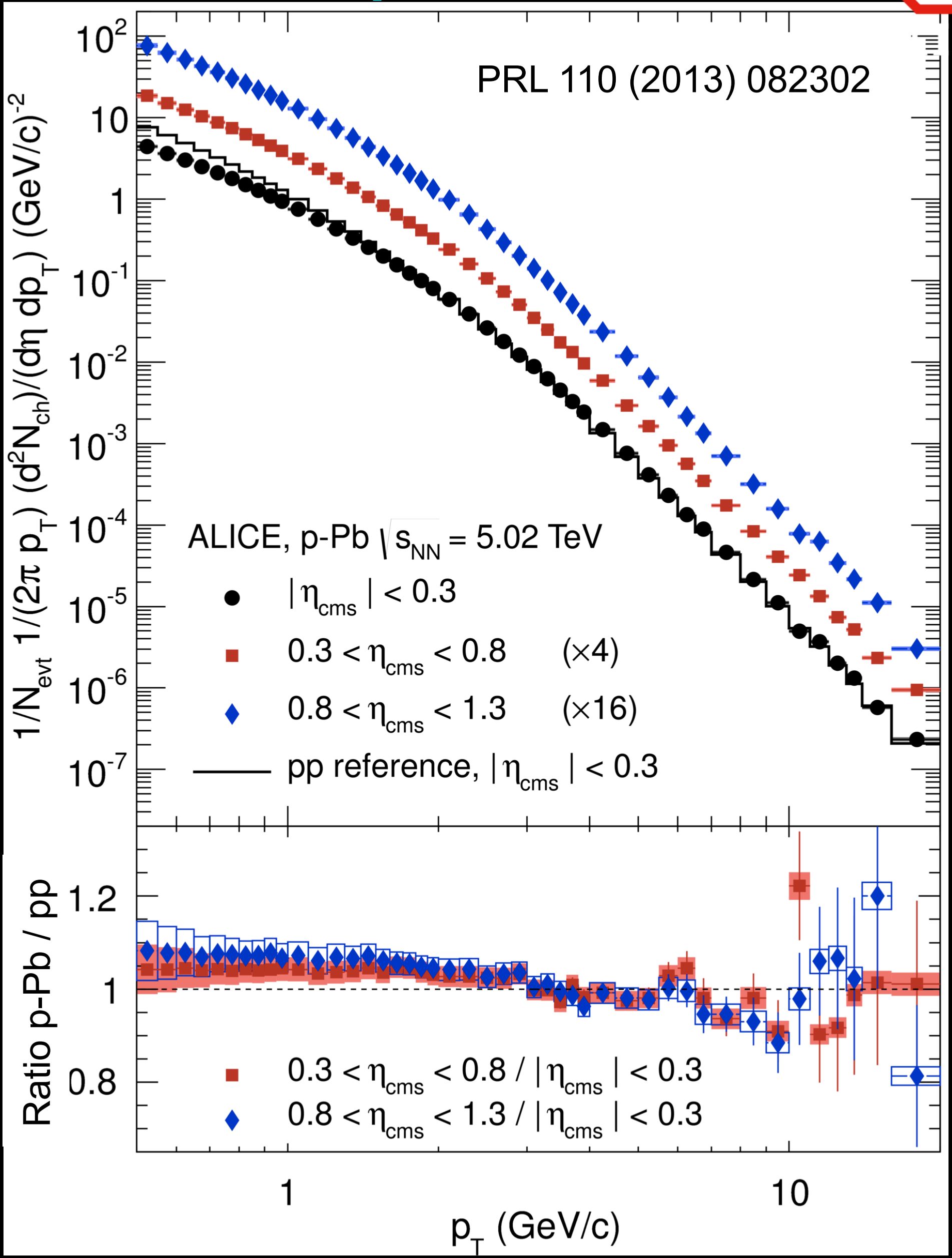
pp reference

Construct from 2.76 & 7 TeV pp

- $p_T < 5$ GeV
  Interpolate power law ~ $\sqrt{s}$
- $p_T > 5$ GeV
  Scale 7 TeV data ala NLO

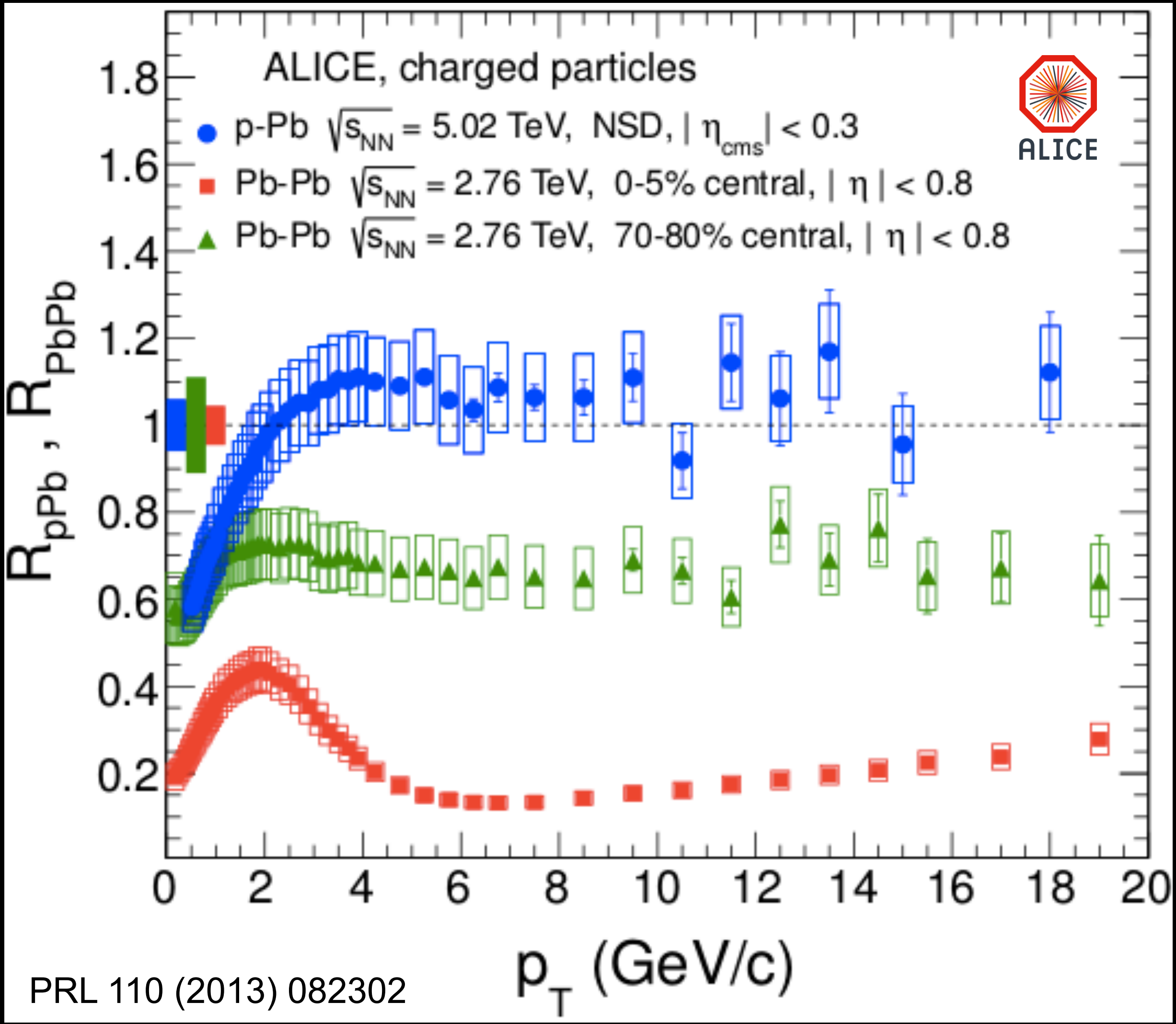
Scaled by Glauber overlap integral

$T_{pPb} = 0.0983 \pm 0.0035\ \mathrm{mb}^{-1}$



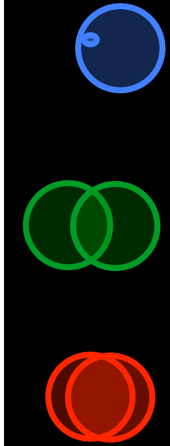
PRL 110 (2013) 082302

Comparison p-Pb and Pb-Pb Collisions



PRL 110 (2013) 082302

$$R_{AA} = \frac{N_{AA}^{particle}}{N_{coll} N_{pp}^{particle}}$$



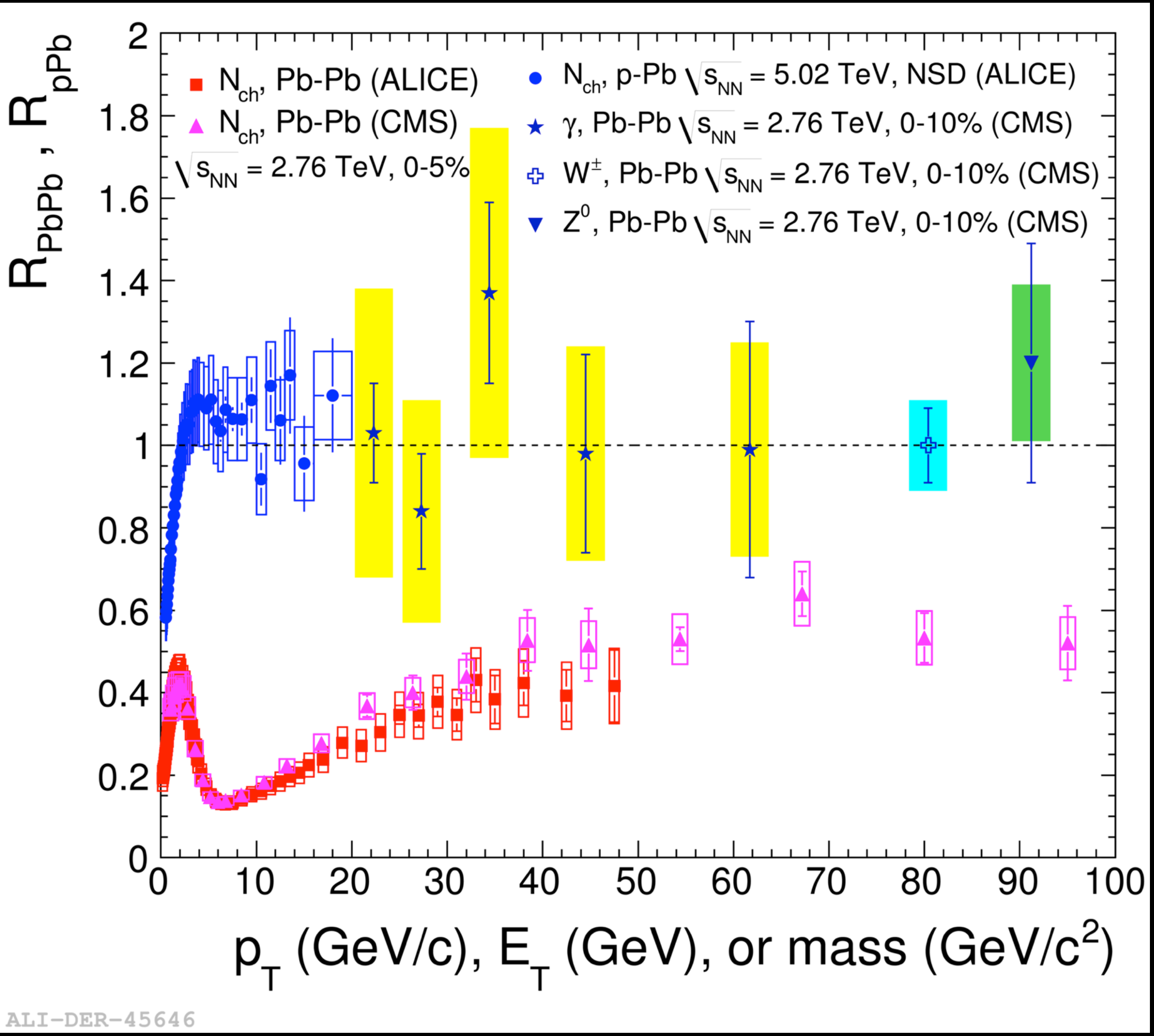
p-Pb (p_T > 2 GeV/c)

- Binary scaling (R_{pPb} ~ 1)
- Absence of Nuclear Modification
- Initial state effects small

Pb-Pb – Suppression!

- Increases with centrality
- Not initial state
- Final state effect (hot QCD matter)

Comparison p-Pb and Pb-Pb Collisions



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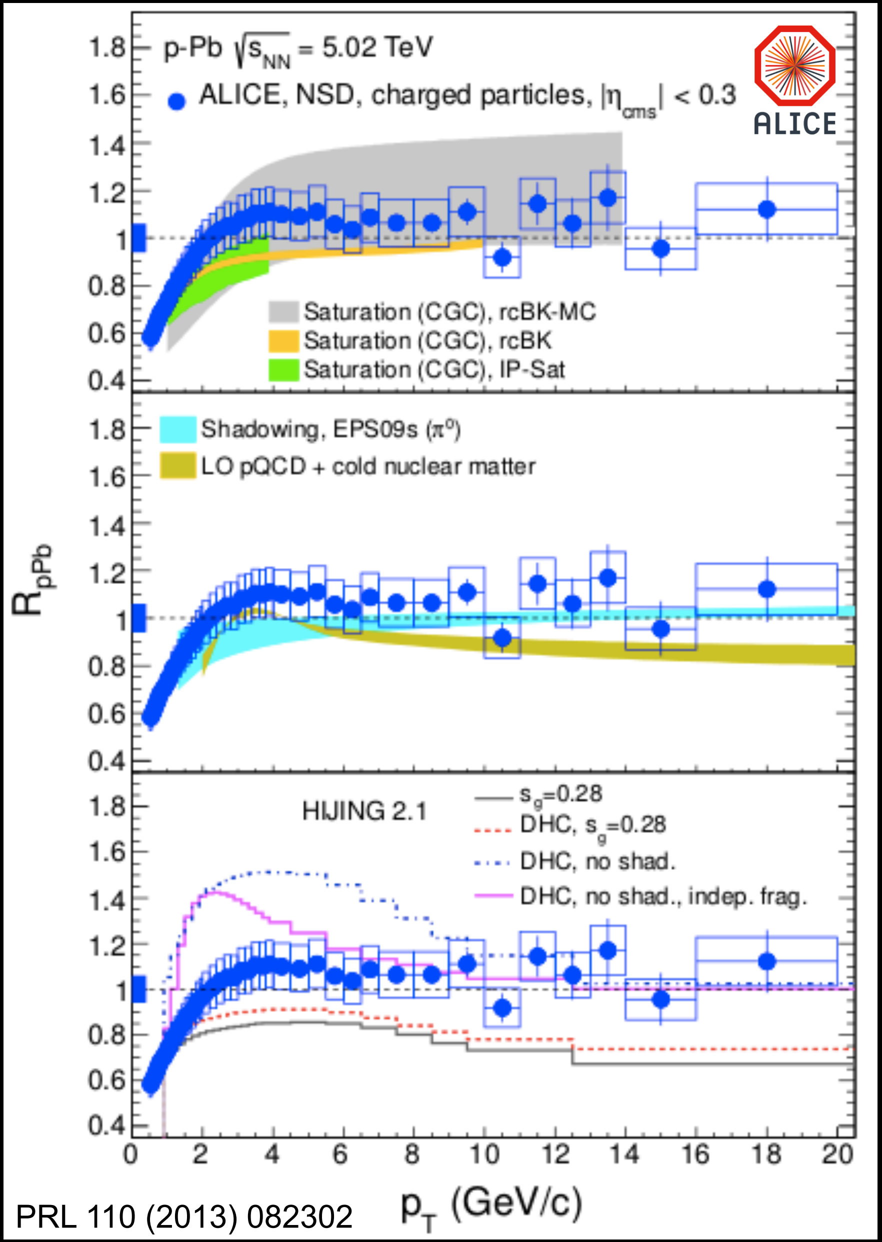
Comparison LHC p-Pb & Models



PRL 110 (2013) 082302

$$R_{AA} = \frac{N_{AA}^{particle}}{N_{coll} N_{pp}^{particle}}$$

High p_T R_{pPb}

Described by

Saturation (CGC) models

EPS09 – pQCD with shadowing

LOpQCD + CNM overshadows

Main differences at low p_T

HIJING 2.1 (s_g=0.28) overshadows

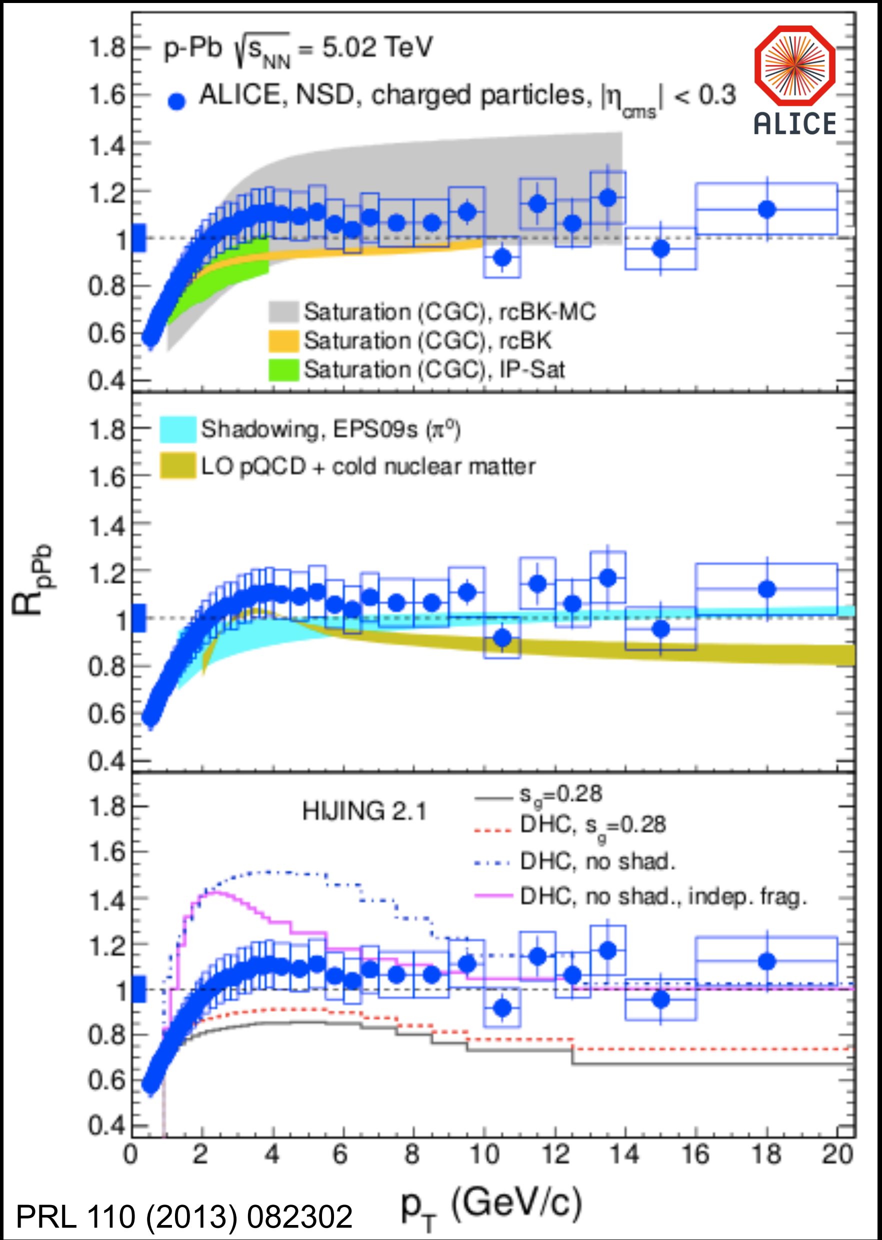
Neither HIJING 2.1 nor DPMJET describes R_{pPb} very well!

(although did well on dn/dη dist.)

Calls for identified particle p_T vs y dist's!

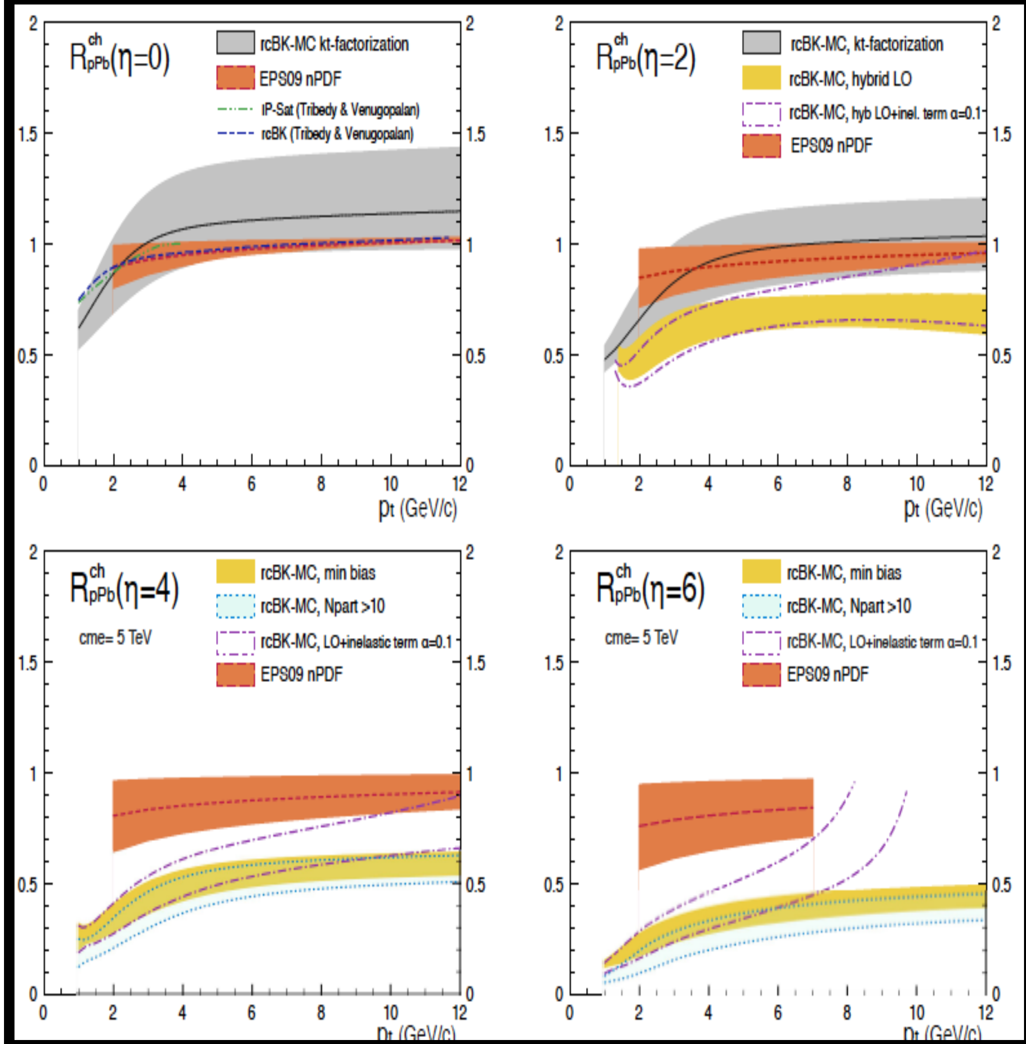
Challenge to models!

LHC p-Pb & Models – Future



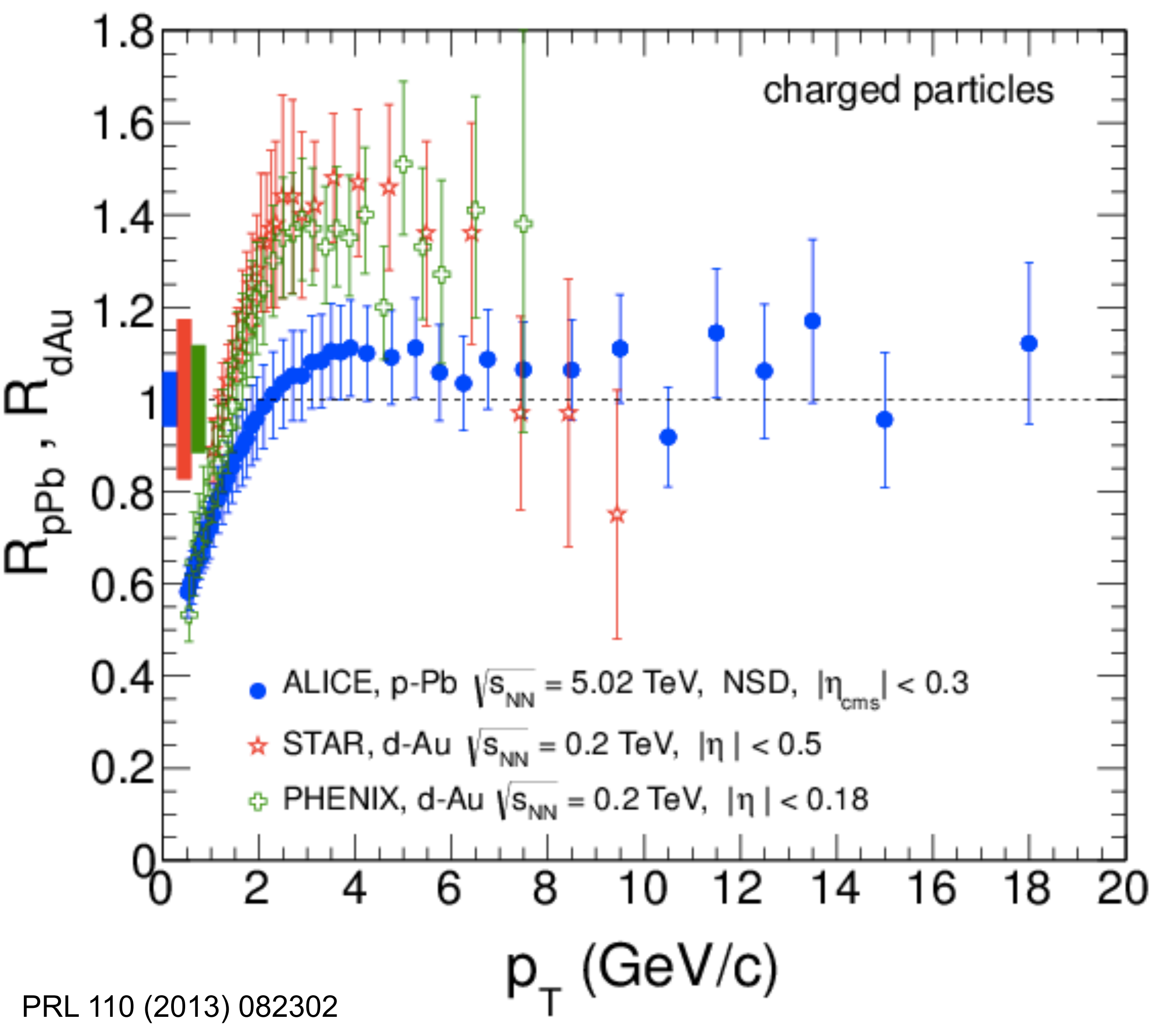
PRL 110 (2013) 082302

Albacete et al, 1209.2001



Forward measurements distinguish models?

Comparison LHC p-Pb & RHIC d-Au



PRL 110 (2013) 082302

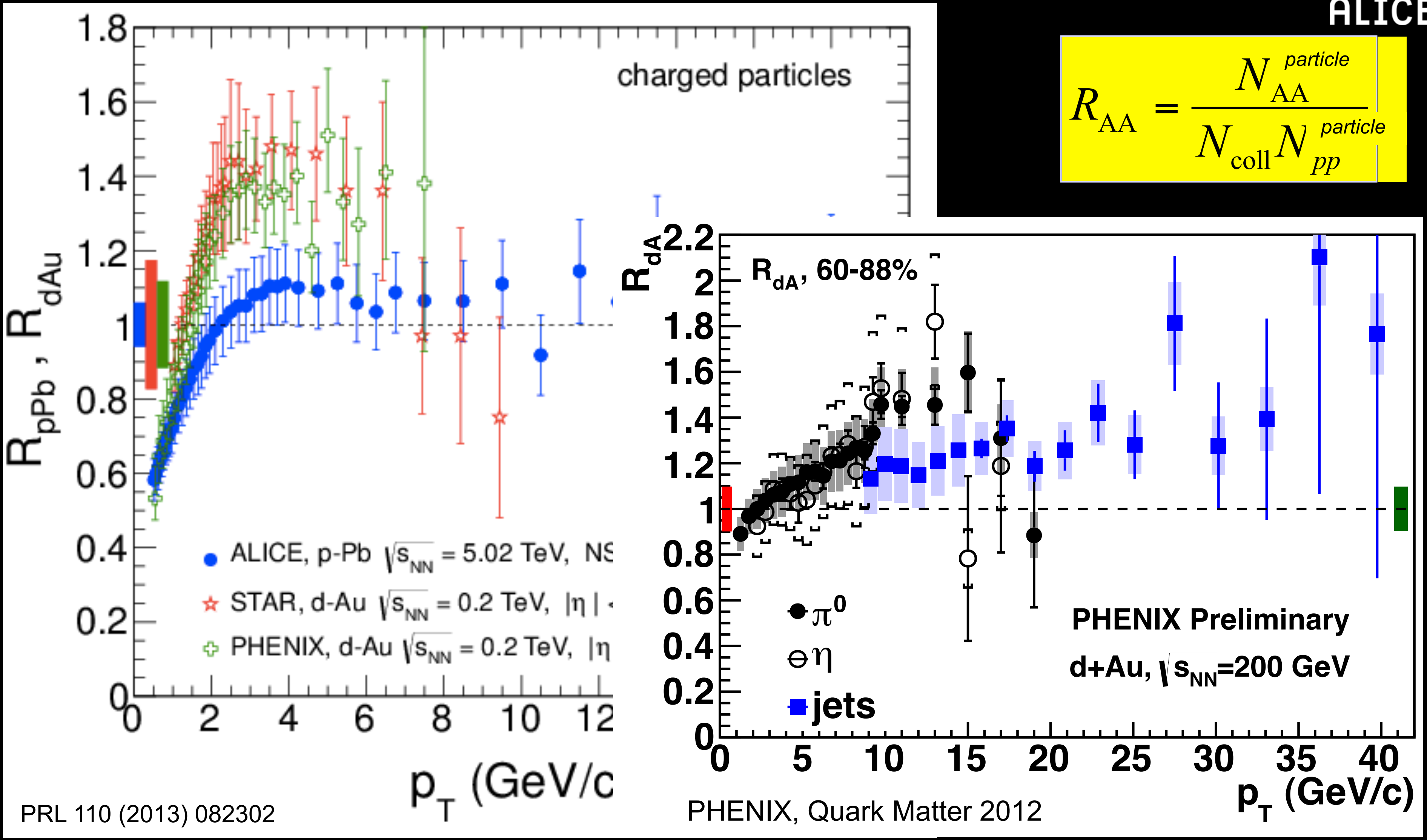
$$R_{AA} = \frac{N_{AA}^{particle}}{N_{coll} N_{pp}^{particle}}$$

At LHC:

Initial state nuclear effects (Cronin effect etc.) small compared to RHIC

Comparison LHC p-Pb & RHIC d-Au

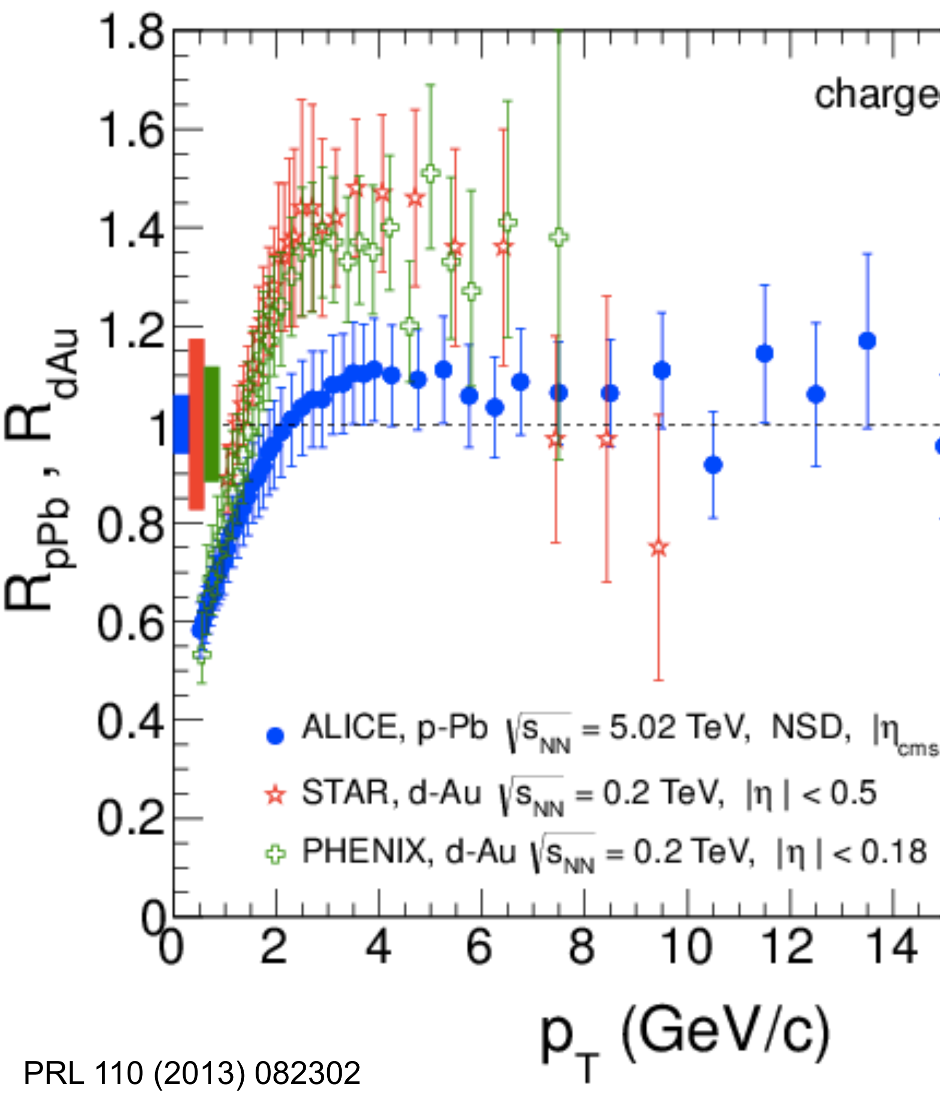
$$R_{AA} = \frac{N_{AA}^{particle}}{N_{coll} N_{pp}^{particle}}$$



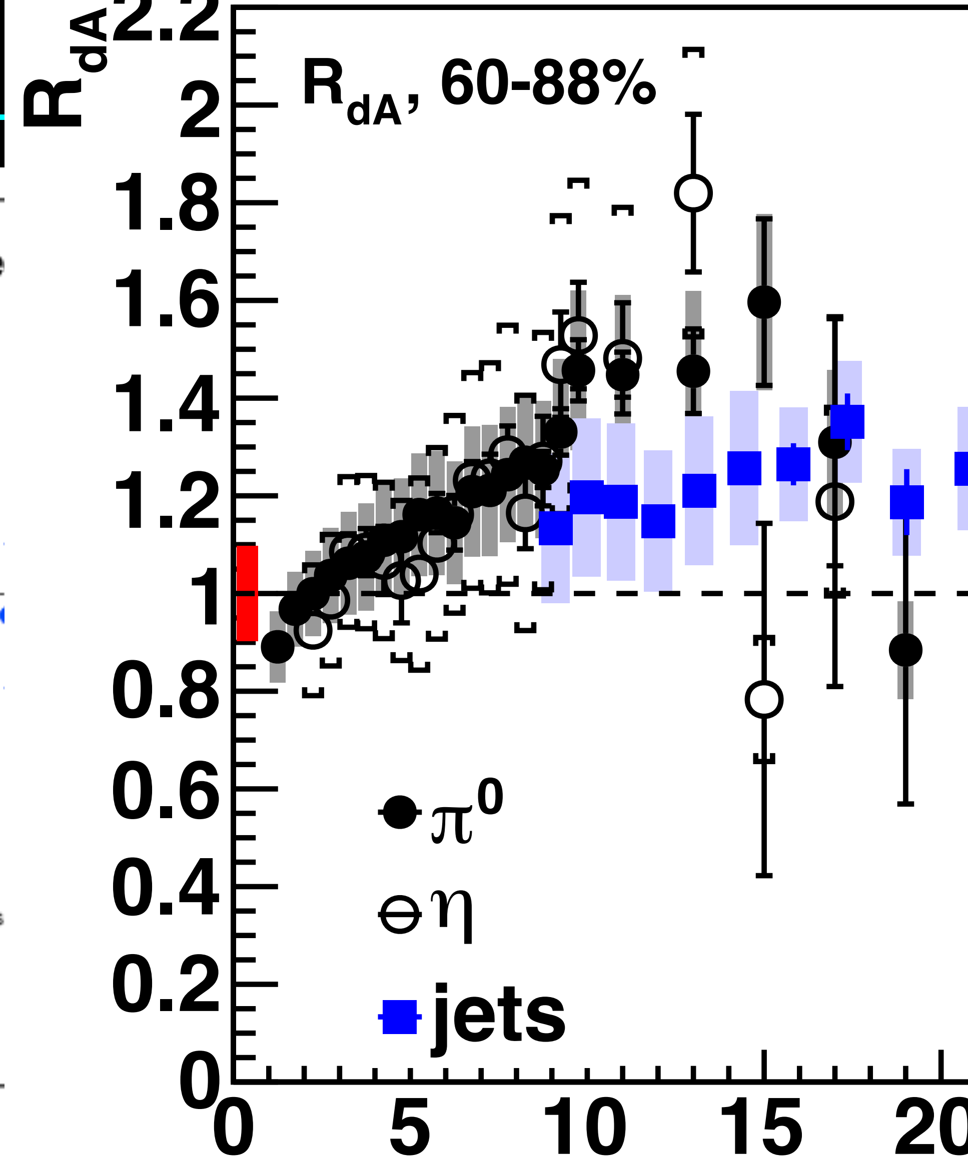
PRL 110 (2013) 082302

PHENIX, Quark Matter 2012

Comparison LHC



PRL 110 (2013) 082302



PHENIX, Quark Matter 2012

What's going on in d-Au at RHIC!

J/ψ Production in p-Pb

J/ψ Production in p-Pb

Study J/ψ in p-Pb to better understand its production,
initial state & final state effects (and dissociation).

Production:

Study of $c\text{-}\bar{c}$ in p-Pb constrains production models

→ strength of the interaction may depend on the $c\text{-}\bar{c}$ states and kinematics

(Vogt, Nucl.Phys. A700,539 (2002), Kopeliovich et al, Phys. Rev.D44, 3466 (1991))

Initial/final state nuclear effects:

Investigate J/ψ in cold nuclear matter (CNM) vs √s, system, kinematics (p_T, y)

→ complicated issue, an interplay between competing mechanisms

Initial state: shadowing, saturation,
initial state energy loss,
intrinsic charm

Final state: $c\text{-}\bar{c}$ in-medium
dissociation
final state energy loss

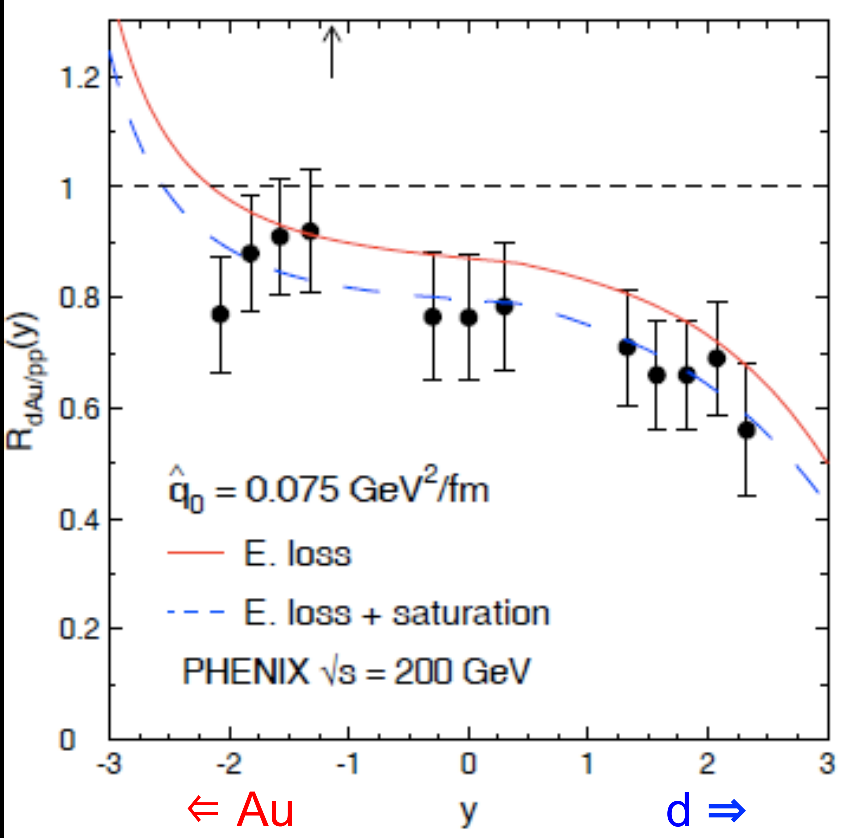
Reference for understanding dissociation in a hot medium:

Knowledge of J/ψ in p-Pb is fundamental to disentangle QGP effects in Pb-Pb

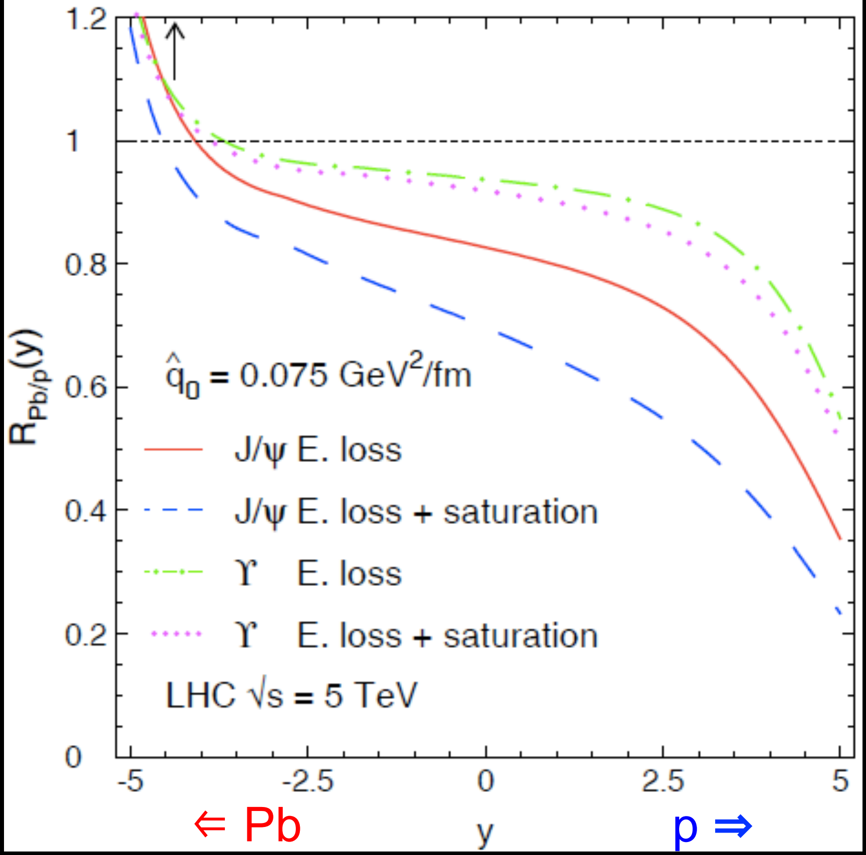
→ Similar to approach followed at SPS (p-A) and at RHIC (d-Au data)

J/ψ Production in d-Au at RHIC to p-Pb at LHC

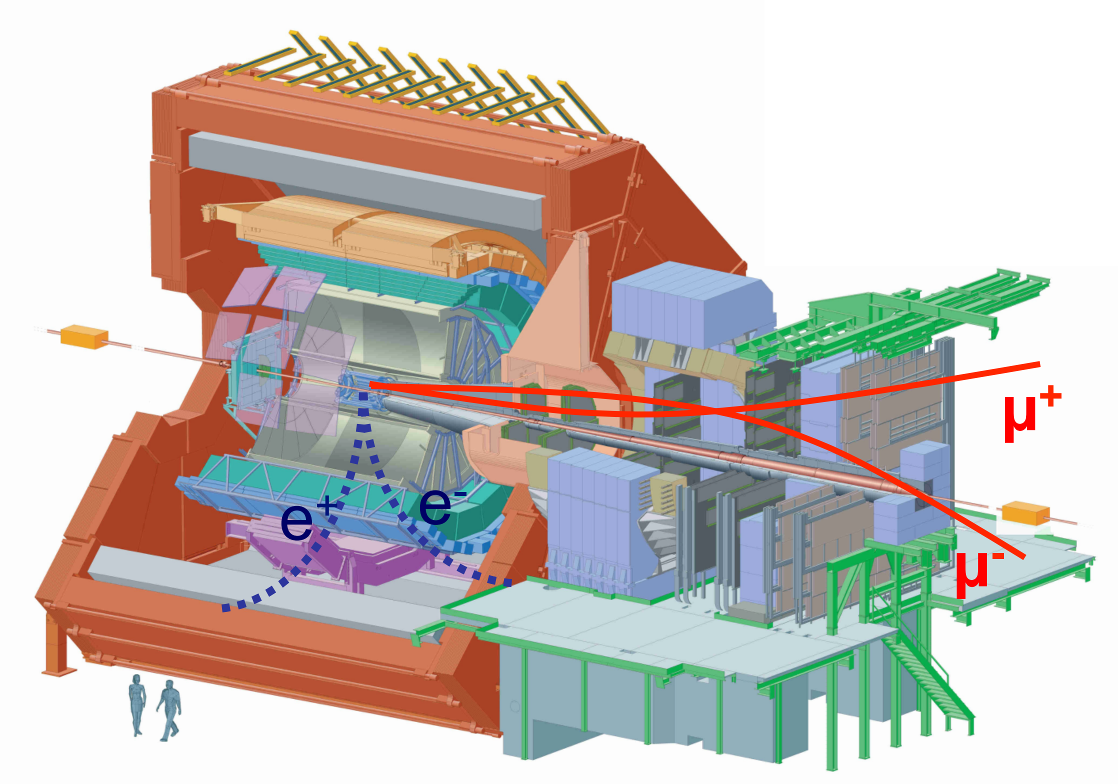
PHENIX, Phys. Rev. Lett. 107, 142301 (2011)



LHC p-Pb Predictions, JHEP 1303 (2013) 122



Measuring Quarkonia in ALICE in p-Pb



ALICE results in this talk:

- inclusive J/ψ production in $\mu^+\mu^-$ channel to $p_T \sim 0$

Central Barrel: $J/\psi \rightarrow e^+e^-$

$|y_{lab}| < 0.9$

Electrons tracked using ITS and TPC
Particle identification: TPC, TOF, TRD

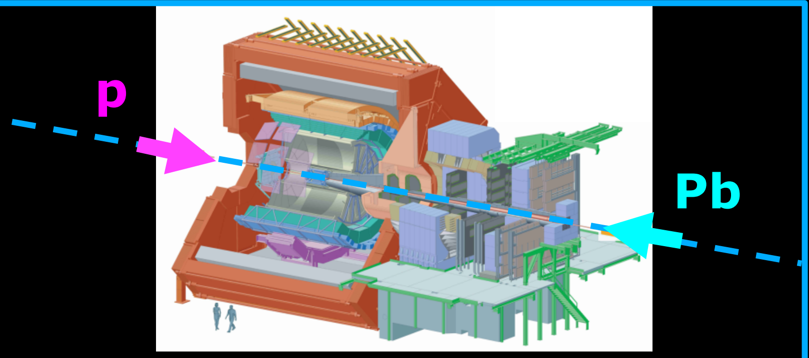
Forward muon arm: $J/\psi \rightarrow \mu^+\mu^-$

$2.5 < y_{lab} < 4$

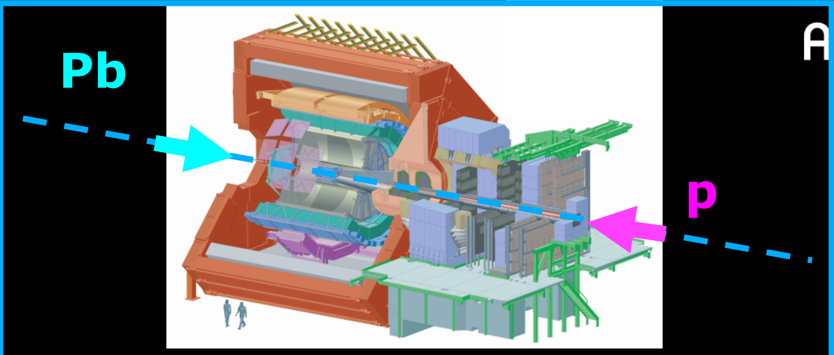
Muons identified and tracked in the muon spectrometer

Quarkonium Data Collection in p-Pb in ALICE

4 TeV protons ⊖⟶ ✳ ⟵⊕ 1.58 A-TeV Pb $\sqrt{s_{NN}}$ = 5.02 TeV p-Pb



$2.03 < y_{cms} < 3.53$



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

- Beam energy asymmetry: E_p = 4 TeV, E_{pb} = 1.58 A·TeV $\sqrt{s_{NN}}$ = 5.02 TeV
  → rapidity shift $\Delta y = 0.465$ in proton direction

- **Beam configurations**:

Data collected in $2.5 < y_{lab} < 4$ for each beam configuration – p-Pb & Pb-p

- **Integrated luminosity for this analysis:**

  p-Pb ($2.03 < y_{cms} < 3.53$) ~ 4.9 nb^{-1}
  p-Pb ($-4.46 < y_{cms} < -2.96$) ~ 5.5 nb^{-1}

pp Reference at √s = 5.02 TeV for J/ψ

No available pp data at √s = 5.02 TeV

√s Dependence:

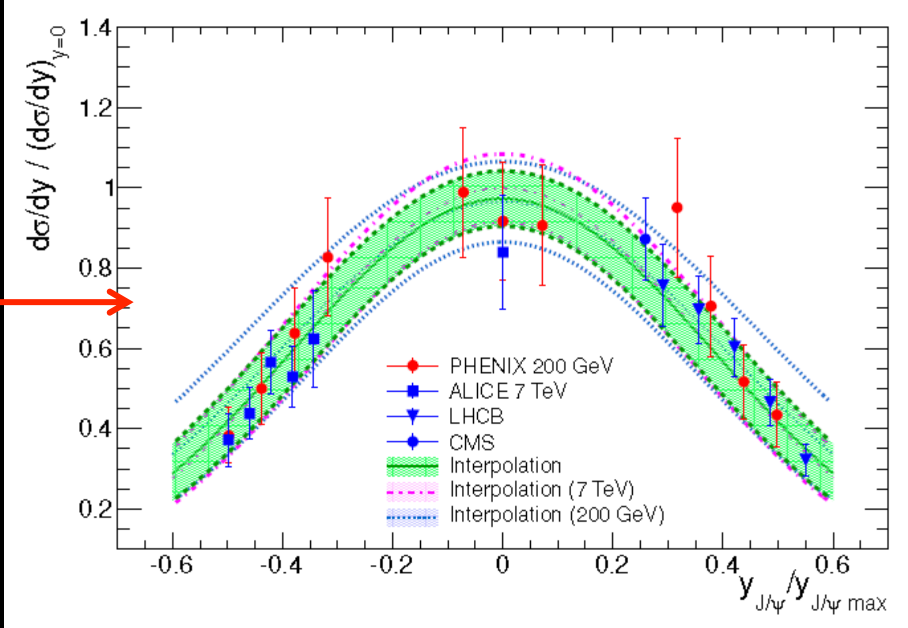
- Reference $\sigma_{pp}^{J/y}$ via interpolation procedure (F. Bossu' et al., arXiv:1103.2394)
- Interpolation to √s = 5.02 TeV from CDF data using a phen.(power-law) shape
- Systematic uncertainties evaluated (10 – 15% for √s interpolation)
- Results are in agreement with FONLL and LO calculations

Rapidity Dependence:

- Phenomenological approach, based on $(d\sigma_{pp}/dy) / (d\sigma_{pp}/dy)|_{y=0}$ vs $(y^{J/\psi} / y^{J/\psi,max})$ independent of √s.

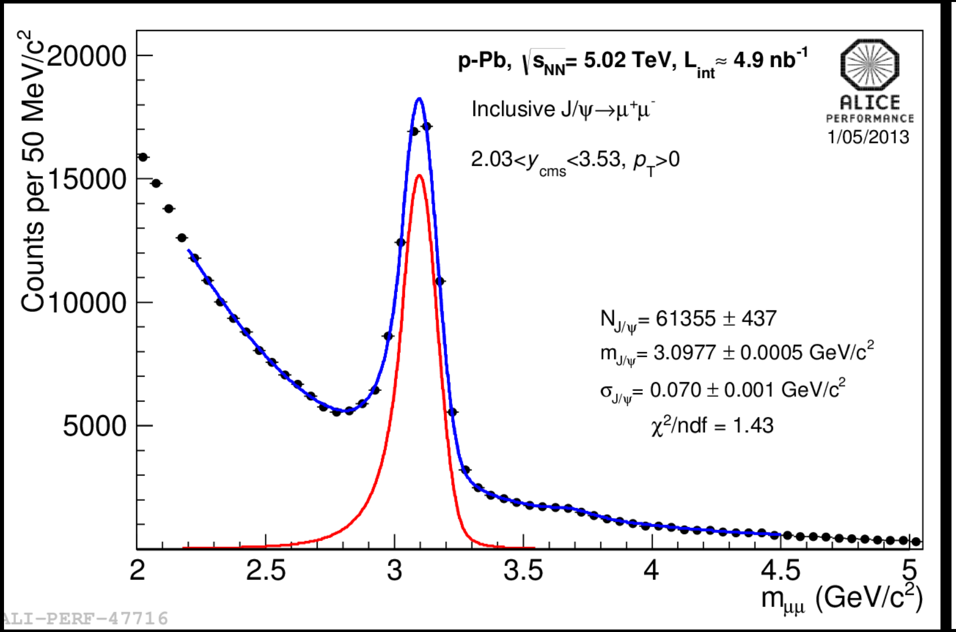
(Observation from PHENIX, ALICE & LHCb results)

- Systematic uncertainties (10 – 20%)

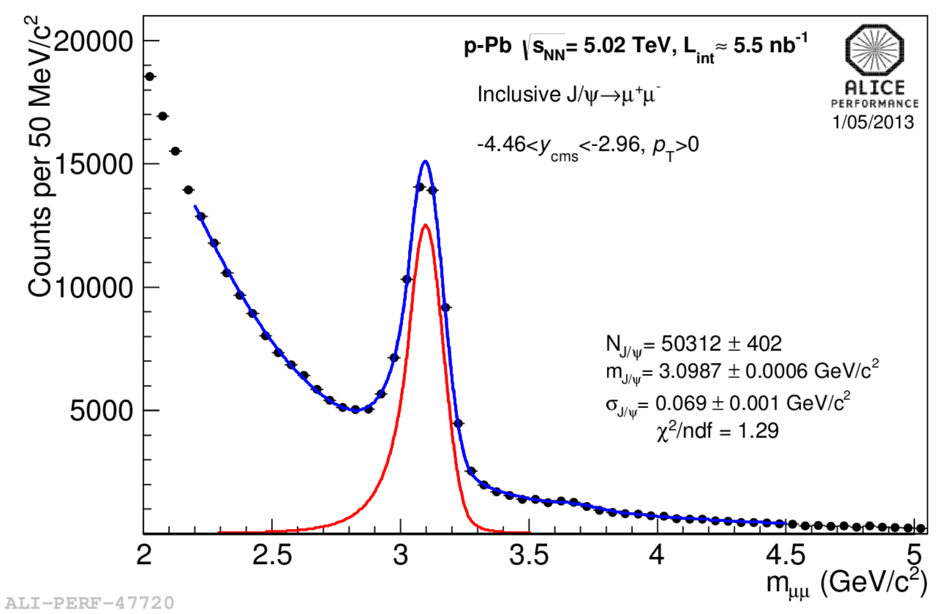


$J/\psi \rightarrow \mu^+\mu^-$ Signal in ALICE

J/ψ yield: fit opposite sign μμ mass spectrum with superposition of signal & background shapes:



ALI-PERF-47716



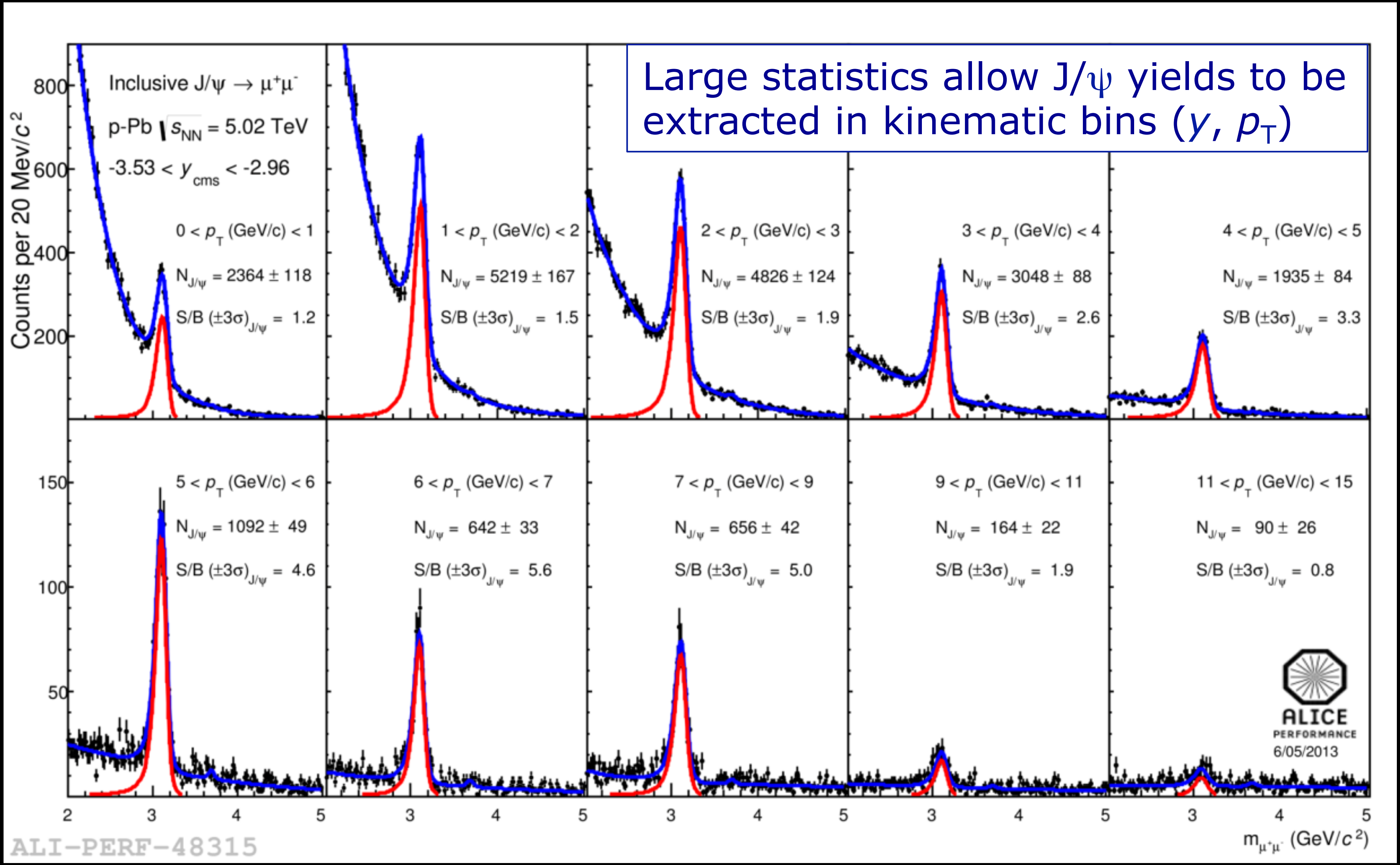
ALI-PERF-47720

Signal:

Shape is extended Crystal Ball function or other pseudo-Gauss. pheno. shape

Background: several functions tested, variable width Gaussian or combinations of exponential x polynomial functions

$J/\psi \rightarrow \mu^+\mu^-$ Signal in ALICE

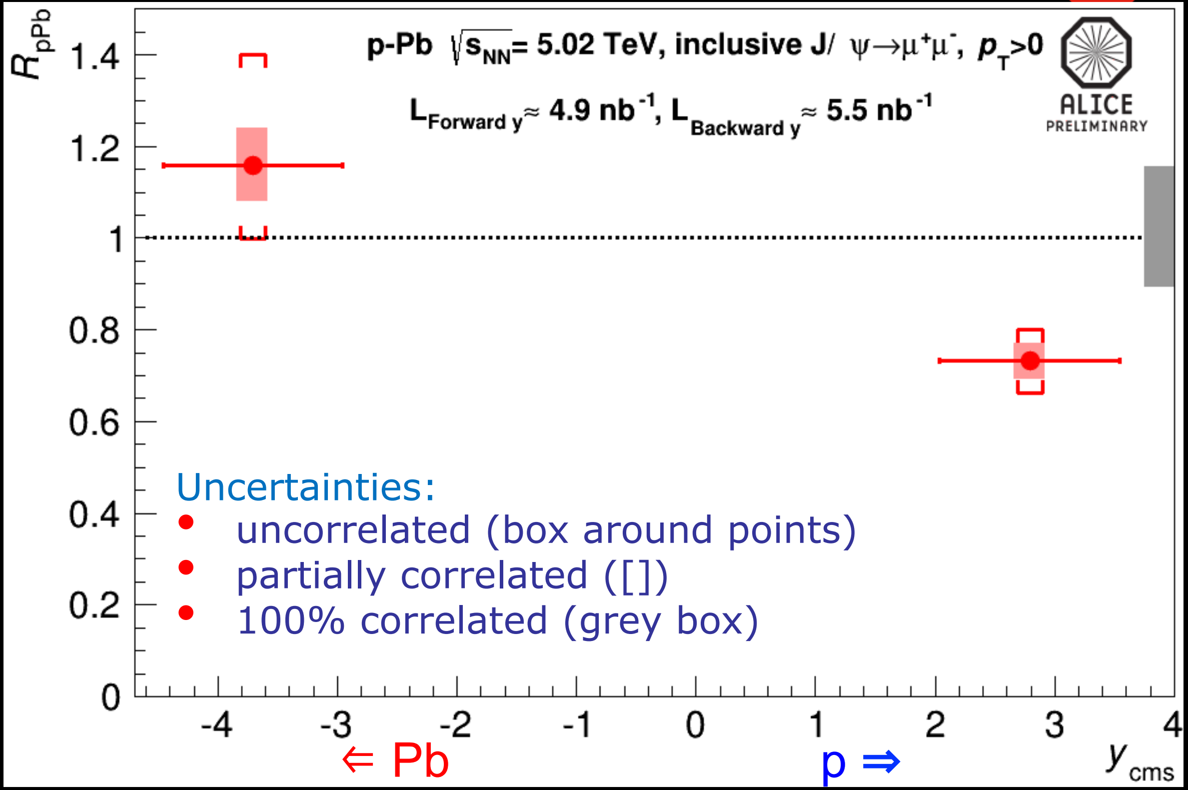


Large statistics allow J/ψ yields to be extracted in kinematic bins (y, p_T)

$J/\psi \rightarrow \mu^{+}\mu^{-}$ Nuclear Modification Factor

R_{pA} decreases at forward y

Dominant source of error is the normalization to pp



R_{pA} $(2.03 < y_{cms} < 3.53)$=

0.732 ± 0.005(stat) ± 0.059(syst) + 0.131(syst. ref) – 0.101(syst.ref)

R_{pA} $(-4.46 < y_{cms} < -2.96)$=

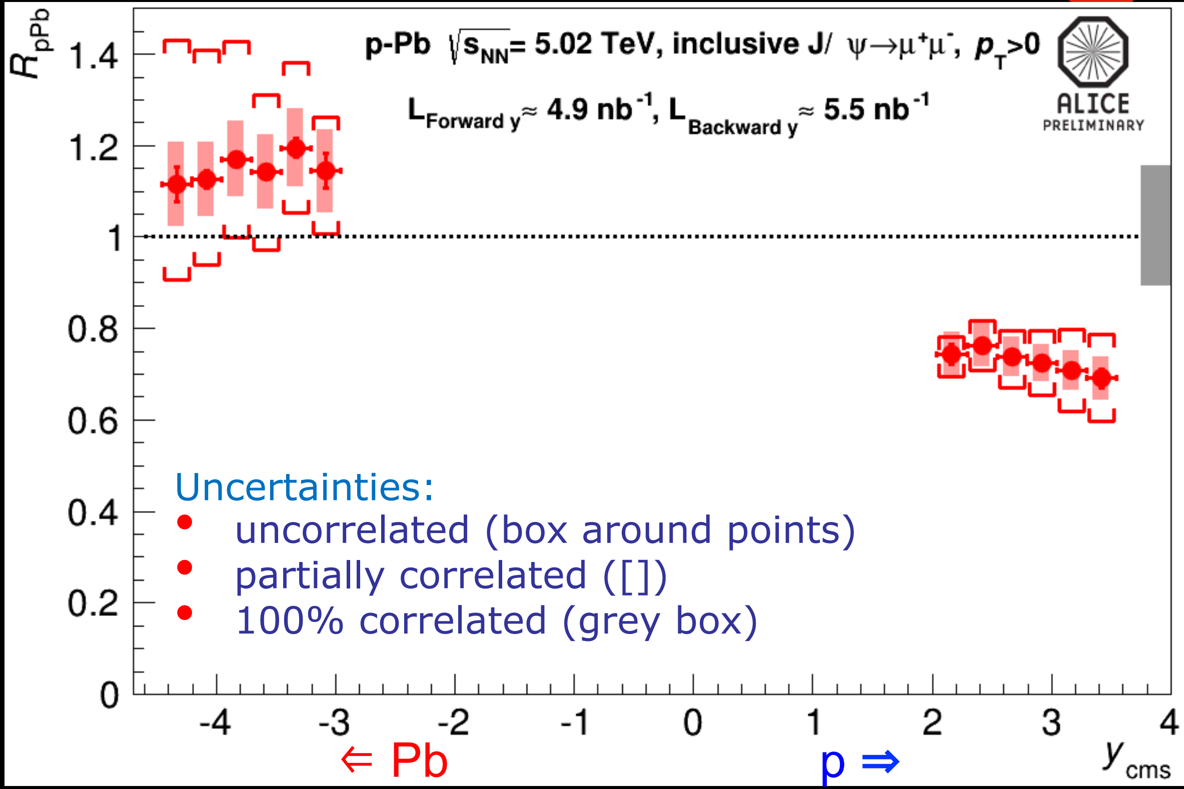
1.160 ± 0.010(stat) ± 0.096(syst) + 0.296(syst. ref) – 0.198(syst.ref)

$J/\psi \rightarrow \mu^+\mu^-$ Nuclear Modification Factor

R_{pA} decreases at forward y

Dominant source of error is the normalization to pp

No apparent rapidity dependence in backward region



R_{pA} $(2.03 < y_{cms} < 3.53)$=

$0.732 \pm 0.005(\text{stat}) \pm 0.059(\text{syst}) + 0.131(\text{syst. ref}) - 0.101(\text{syst.ref})$

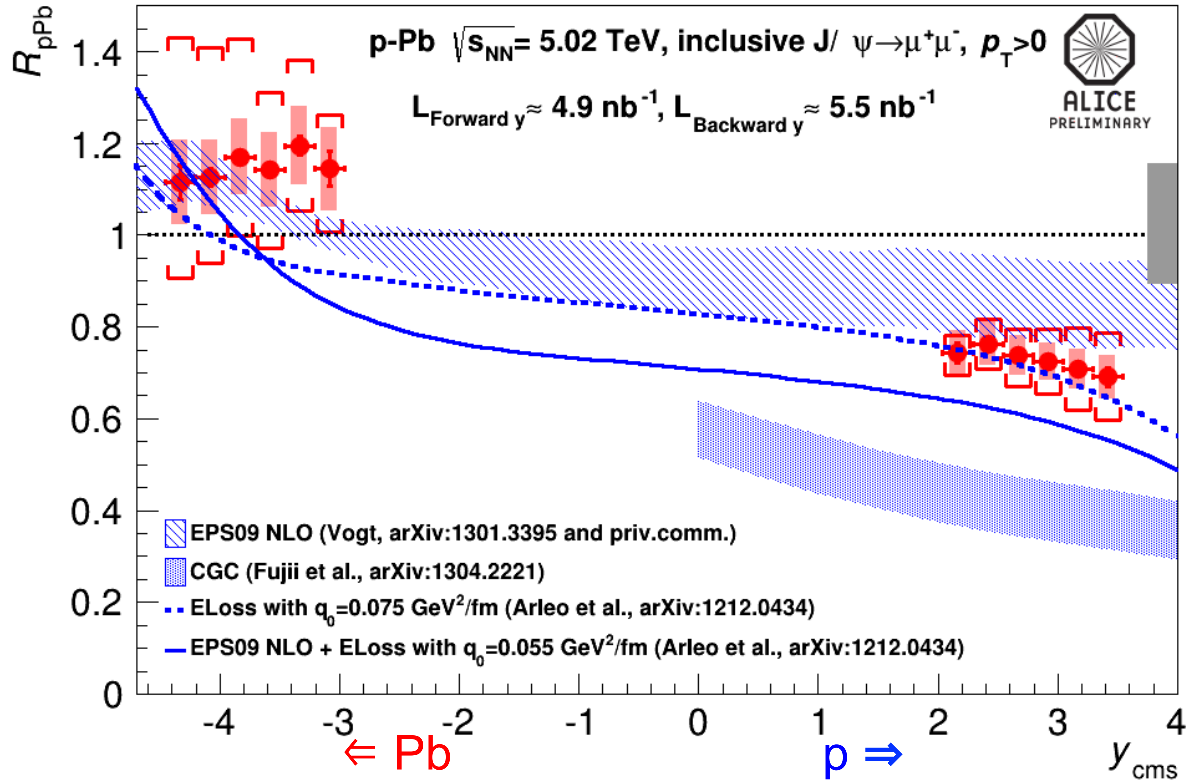
R_{pA} $(-4.46 < y_{cms} < -2.96)$=

$1.160 \pm 0.010(\text{stat}) \pm 0.096(\text{syst}) + 0.296(\text{syst. ref}) - 0.198(\text{syst.ref})$

$J/\psi \rightarrow \mu^+\mu^-$ Nuclear Modification Factor

R_{pA} decreases at forward y

Dominant source of error is the normalization to pp collisions

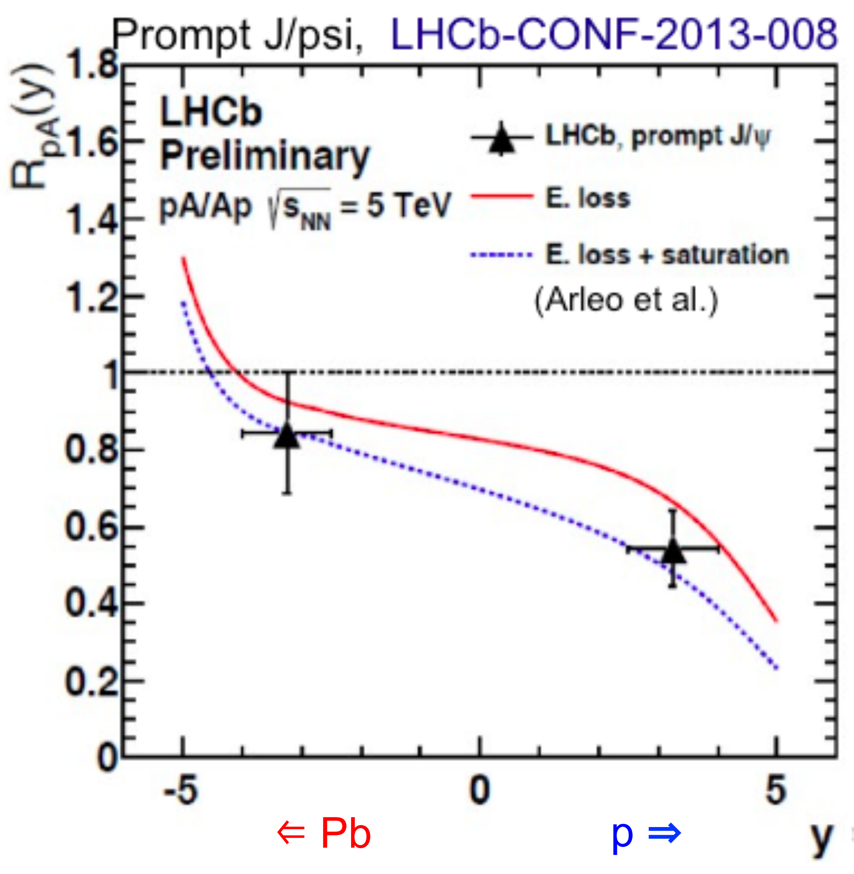


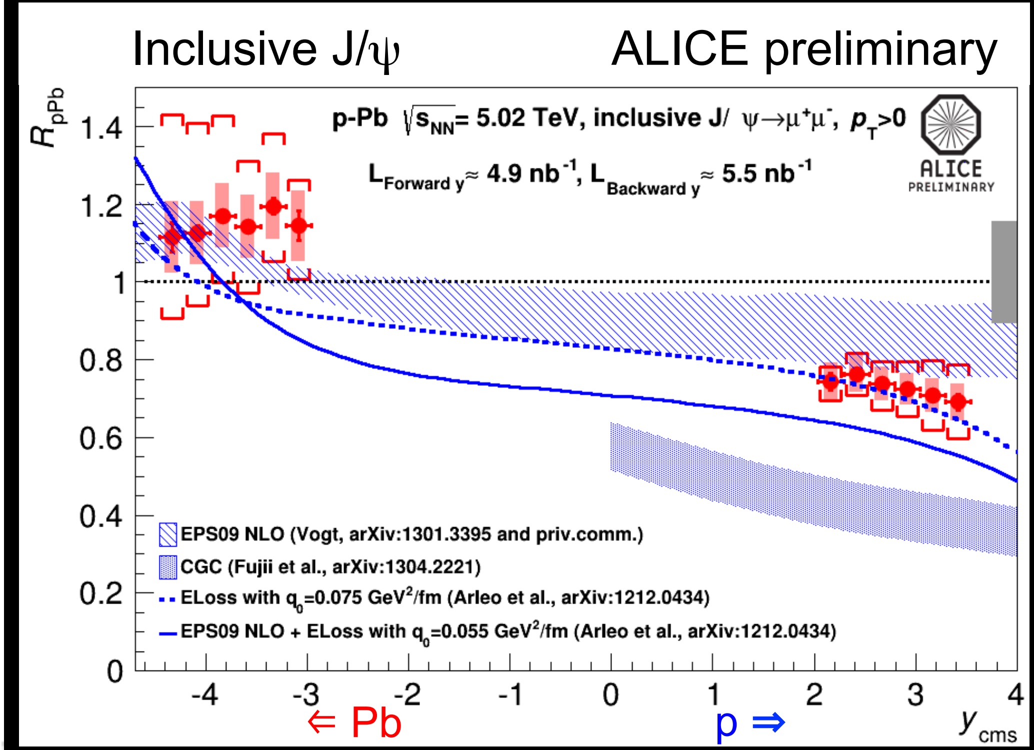
Comparison with models:

- Good agreement with models incorporating shadowing (EPS09 NLO) and/or a contribution of coherent parton energy loss (F. Arleo et al).
- CGC description (Q2S0,A = 0.7-1.2 GeV/c^2, H. Fujii et al) appears disfavored

Rapidity dependence in backward region may provide additional constraints.

R_{pPb} of Prompt vs Inclusive J/ψ

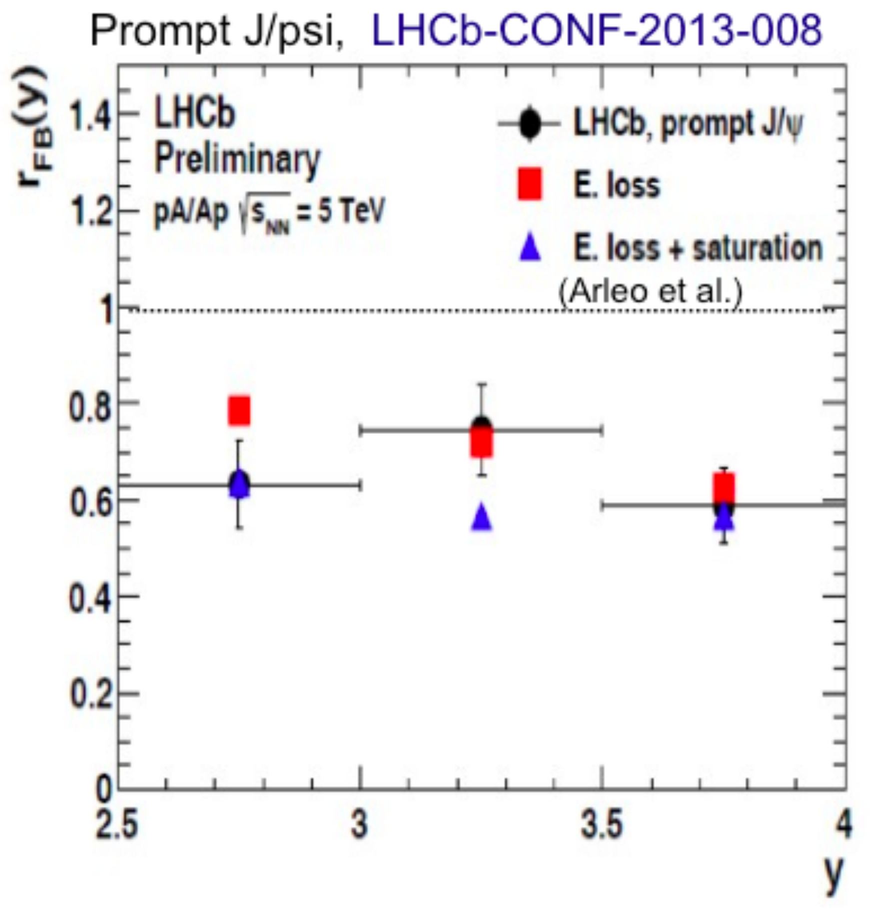


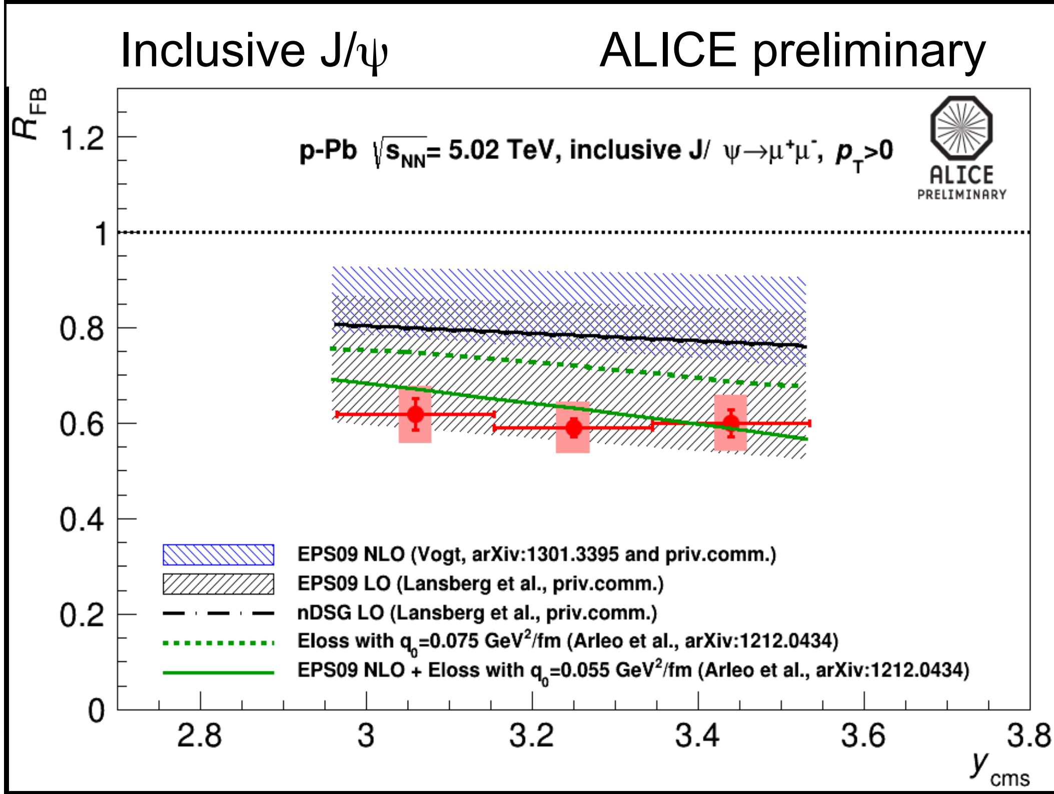


Comparison between prompt and inclusive J/ψ:

- Measurements are consistent within uncertainties, although prompt is ~ 30% lower overall.
- Similar conclusions for both with respect to models.

J/ψ: Forward-backward Asymmetry vs. y

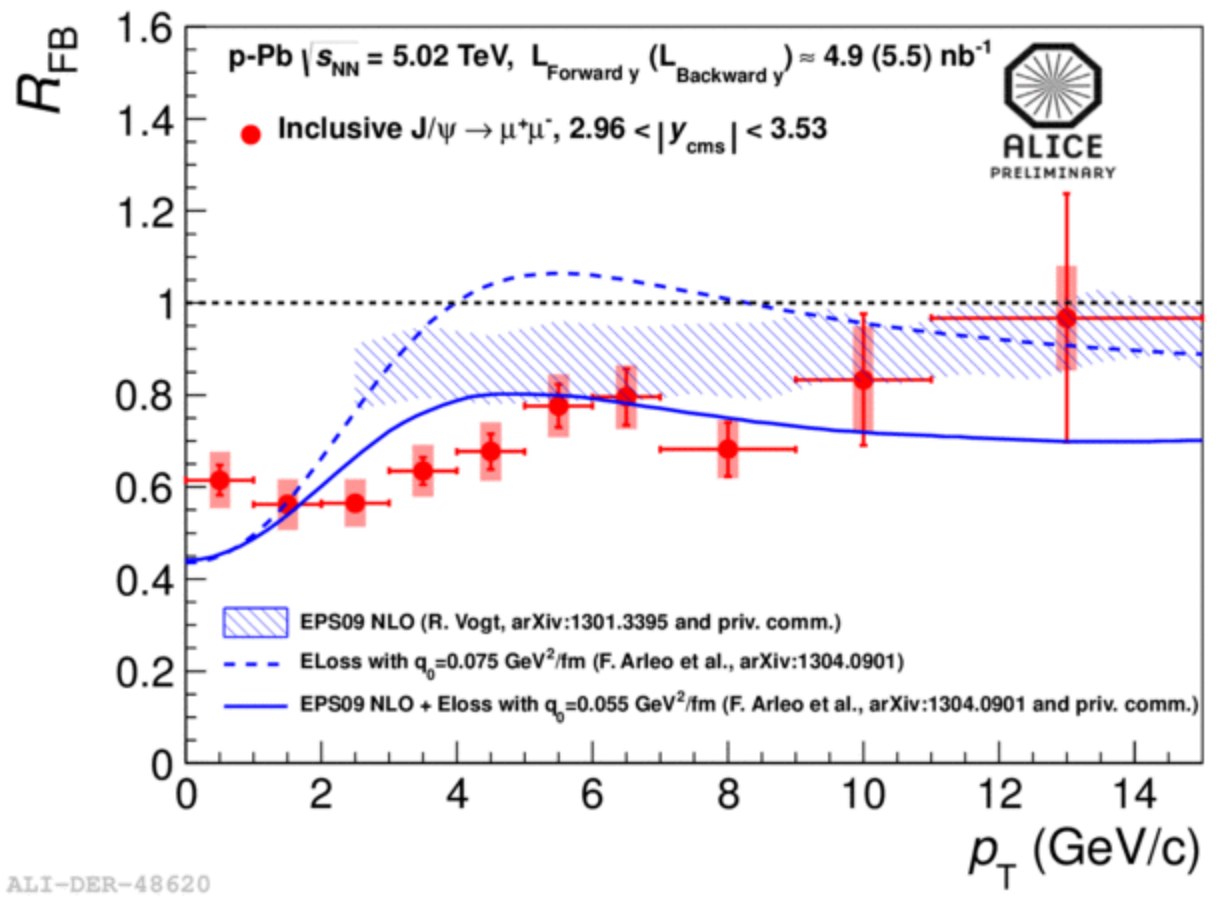




Comparison of forward-backward ratio in similar y_{cms} of prompt & inclusive J/ψ:

- No need for pp reference or its uncertainties.
- Prompt and inclusive R_{FB} agree.
- Models incorporating Shadowing and E-loss consistent with data.

J/ψ: Forward-backward Asymmetry vs. p_T



- Observe a p_T dependence with stronger suppression at low p_T .
- Models including energy loss show strong nuclear effects at low p_T , in reasonable agreement with the data.
- Observed p_T dependence is smoother than expected in coherent energy loss models.

Summary Conclusions Future

ALICE $\sqrt{s_{NN}}$ = 5.02 TeV p-Pb Results

- ALICE has measured $dn^{charged} / d\eta_{lab}$
  Saturation Models rise too steeply with η_{lab}
  pQCD-based MC models (HIJING, DPMJET) describe $dn_{ch} / d\eta_{lab}$
- ALICE measures $R_{pPb}^{charged}$ ~ 1 for p_T > 2 GeV/c, consistent with binary scaling
  Absence of nuclear modification → small initial state effects
  R_{PbPb} suppression (previously measured) → a final state effect
  ALICE R_{pPb} described by Saturation (CGC) models, EPS09 with shadowing.
  LOpQCD + CNM and HIJING 2.1 (s_g=0.28) overshadows compared to ALICE R_{pPb}
  Neither HIJING 2.1 nor DPMJET describes R_{pPb} very well!
- ALICE measures $R_{pPb}^{J/\psi}$ (y)
  Observes suppression that increases towards forward rapidity (y)
  $R_{FB}^{J/\psi}$ (p_T) ratio decreases (more suppresssed) at low p_T
  In reasonable agreement with models including coherent energy loss
  Nuclear shadowing and/or energy loss describe the data, indicates that final state absorption may be negligible at LHC energies

- Continue midrapidity measurements, statistics (understand multiplicity dependence!)
- Forward $R_{p\text{-}Pb}$ & forward-midrapidity correlations (test CGC, saturation....models!)
- Open charm and beauty, more on quarkonia (dep. on centrality, p_T, y, and ψ(2s),…)
- Implications for PbPb?