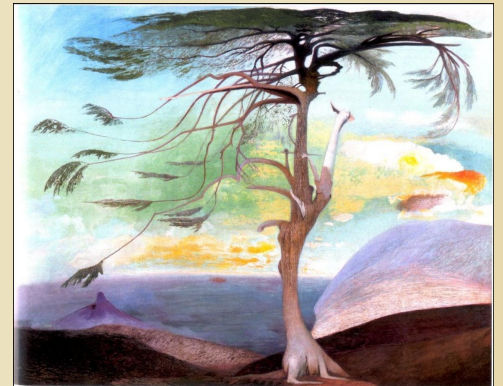


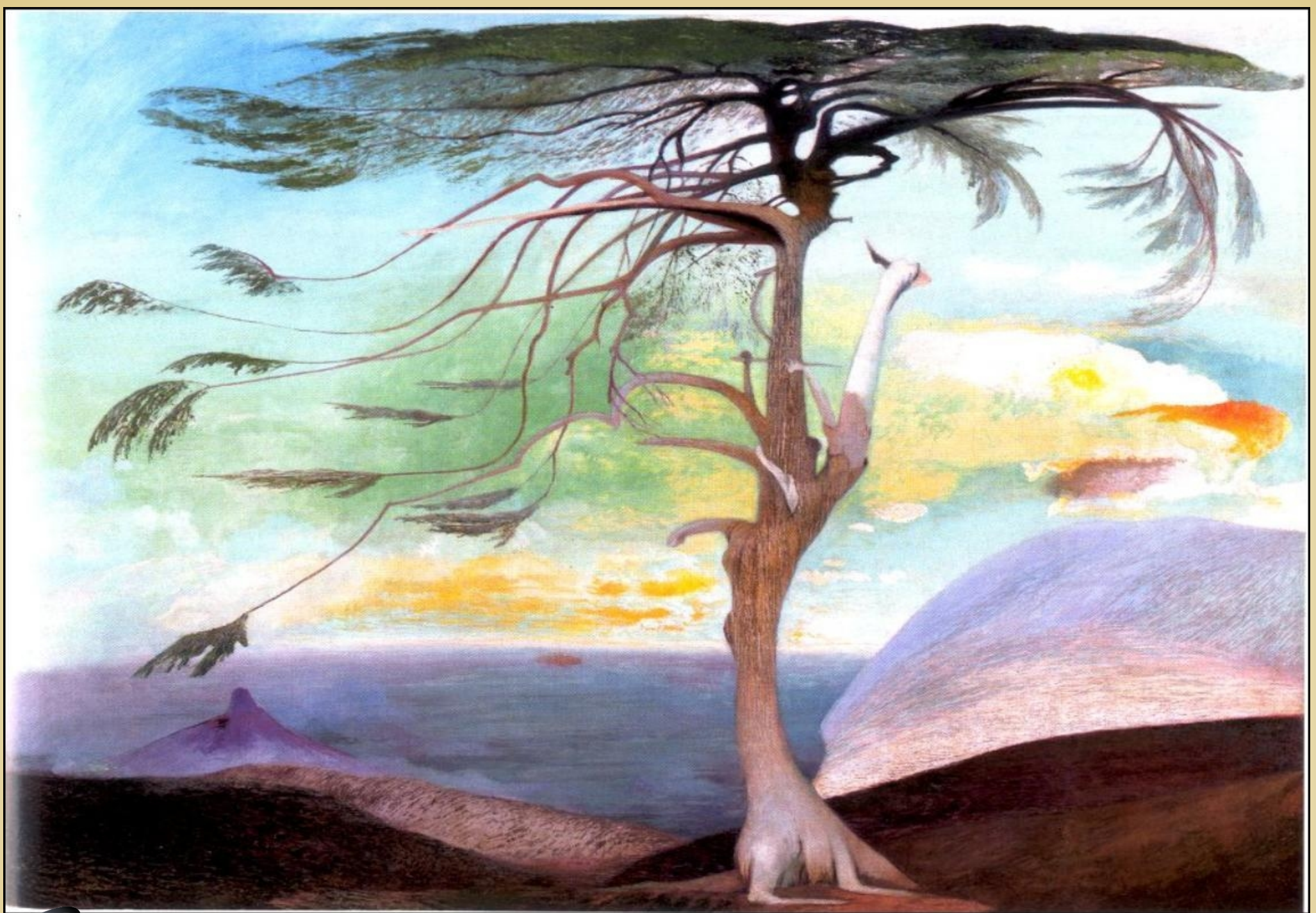
Nuclear Effects in pA Collisions at the Highest Energies (5.02 ATeV)

(PRC80 014903 2009; PRC85, 024903, 2012, arXiv:1211.2256v1)

Gergely Gábor Barnaföldi, J. Barrette, M. Gyulassy,
P. Lévai, G. Papp, V. Topor Pop

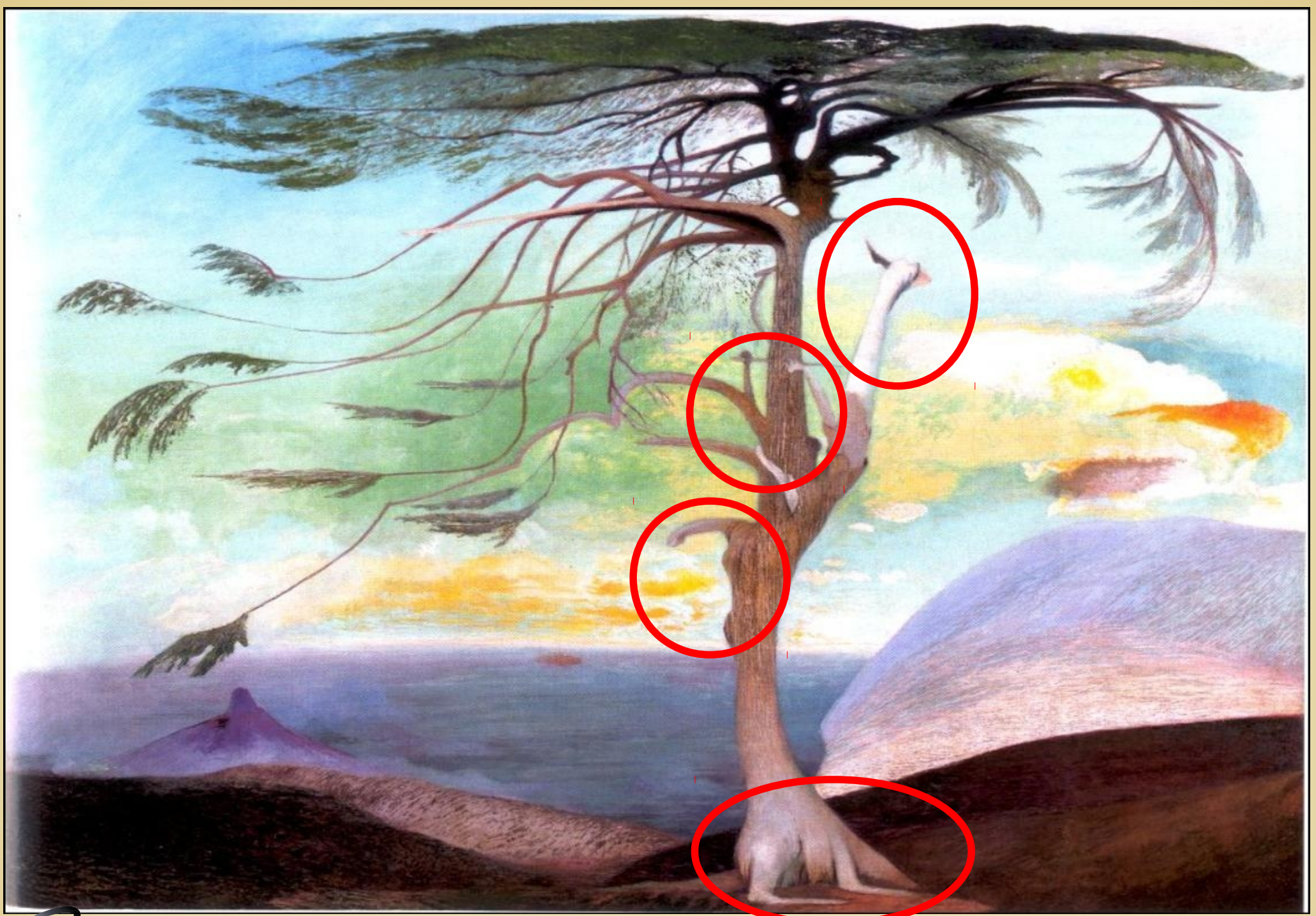
Wigner RCP RMI of the HAS, Eötvös Loránd University,
Columbia University, Mc Gill University





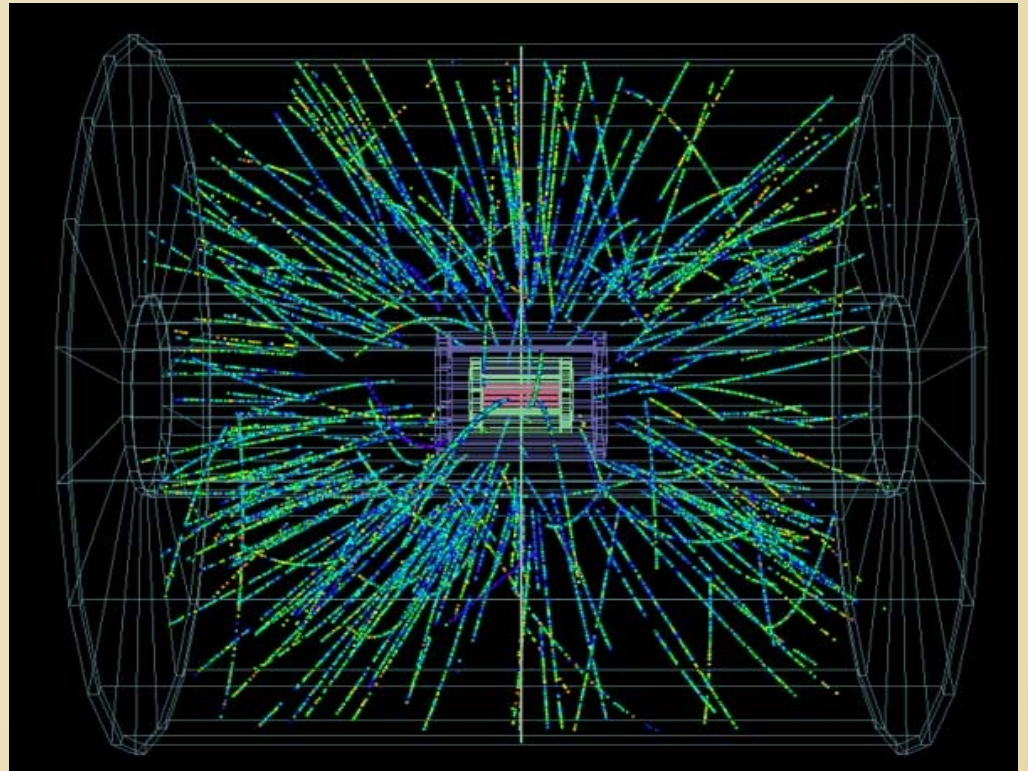
WIGNER

Tivadar Csontváry-Kosztka (1853-1919): Lonely Cheddar



OUTLINE

- Motivation for pA collisions
 - 09.2012 pA pilot test @ LHC
 - High & low- p_T hadron spectra incl. nuclear effect
 - Separation of initial/final state effects
 - 13/09/2012 ALICE
 $p+Pb$ @ 5.02 ATeV



OUTLINE

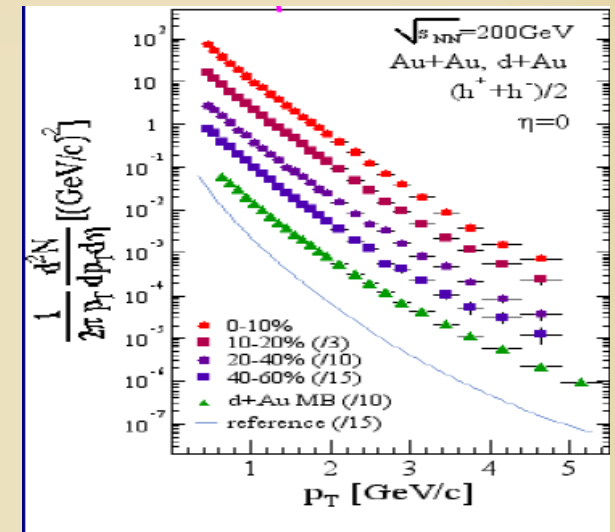
- Motivation for pA collisions
 - Next run ??? ATeV @ LHC in January 2013
 - High & low- p_T hadron spectra incl. nuclear effect
 - Separation of initial/final state effects
- Nuclear Modification, $R_{pA}(p_T)$
 - High- p_T nuclear effects @ midrapidity & large y
 - Low- x and high- x tests?
 - From SPS, RHIC, to LHC: finding proper scaling
- Rapidity dependence, asymmetry, $Y(\eta)$
 - Puzzle: interplay of nuclear effects

0. The Nuclear Modification Factor, R_{pA}

- Measuring nuclear effects 'precisely' ratio of the hadron spectra

$$R_{dAu} \equiv \frac{1}{\langle N_{coll} \rangle} \frac{d^2 N^{d+Au} / dp_T d\eta}{d^2 N_{inel}^{p+p} / dp_T d\eta}$$

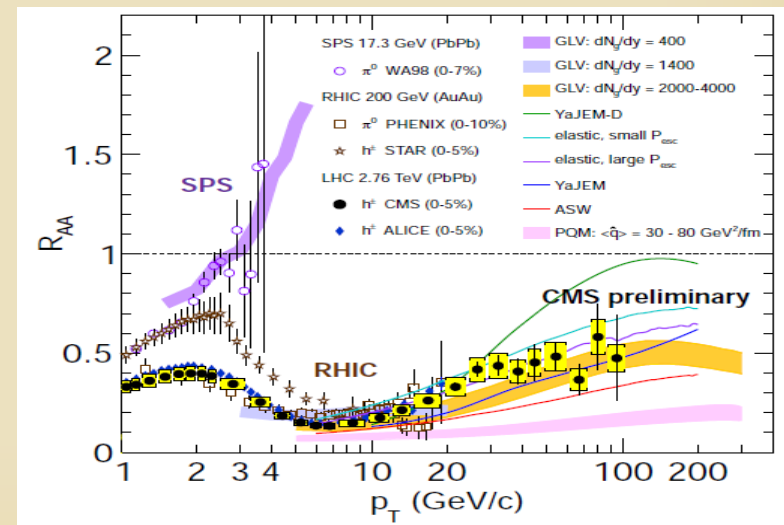
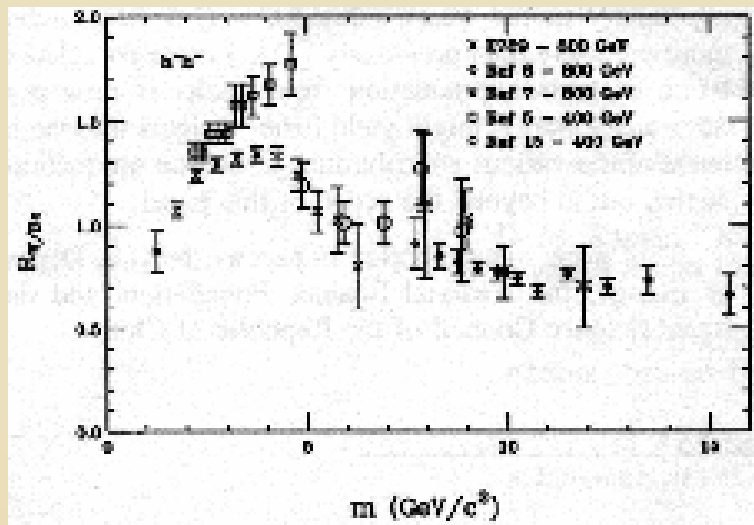
$$R_{AA}(p_T) = \frac{d^2 N_{ch}^{AA} / dp_T d\eta}{\langle T_{AA} \rangle d^2 \sigma_{ch}^{NN} / dp_T d\eta}$$



- Collisions:

proton-nucleus (pA)

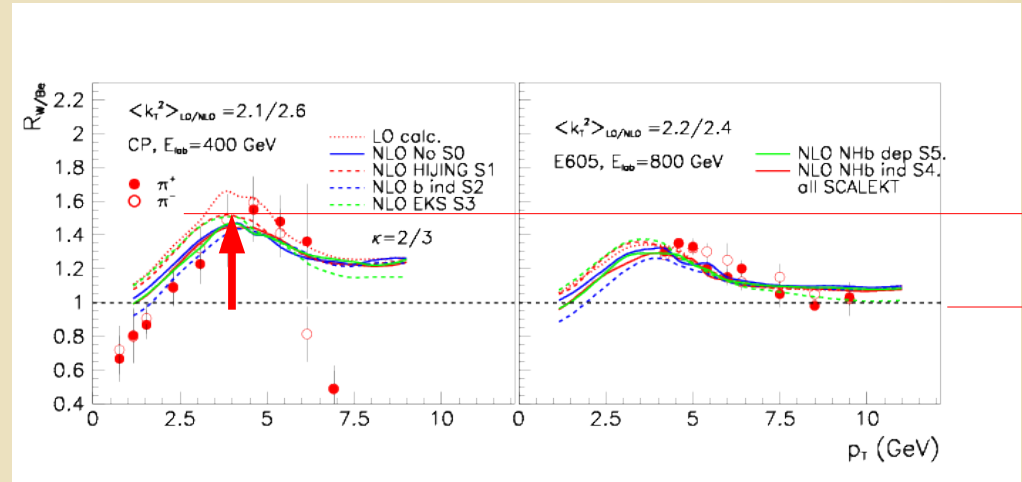
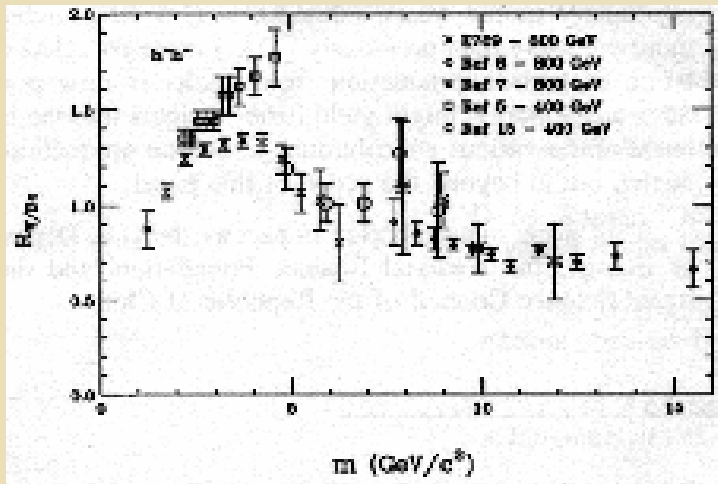
or nucleus-nucleus (AA, AA')



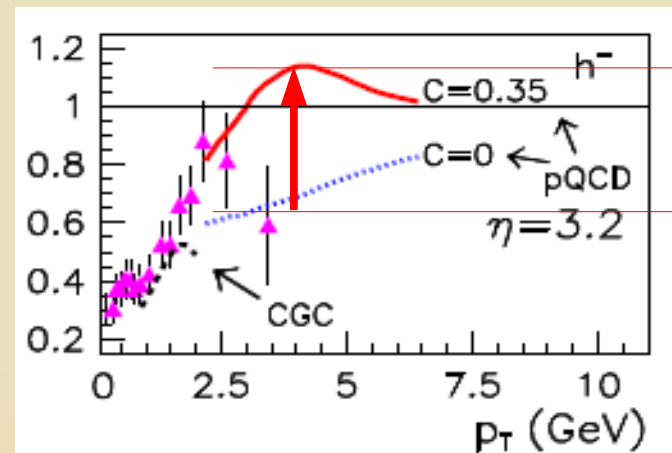
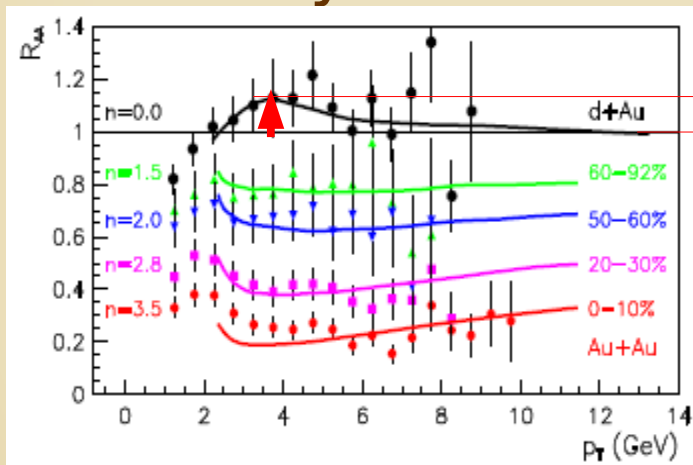
MOTIVATION

- Cronin effect at SPS energies

Brown et al: PRD11 (1975) 3105, Ric.Sci.Edu.Perm Suppl. 122 (2003) 541



- RHIC analysis on dAu and AuAu

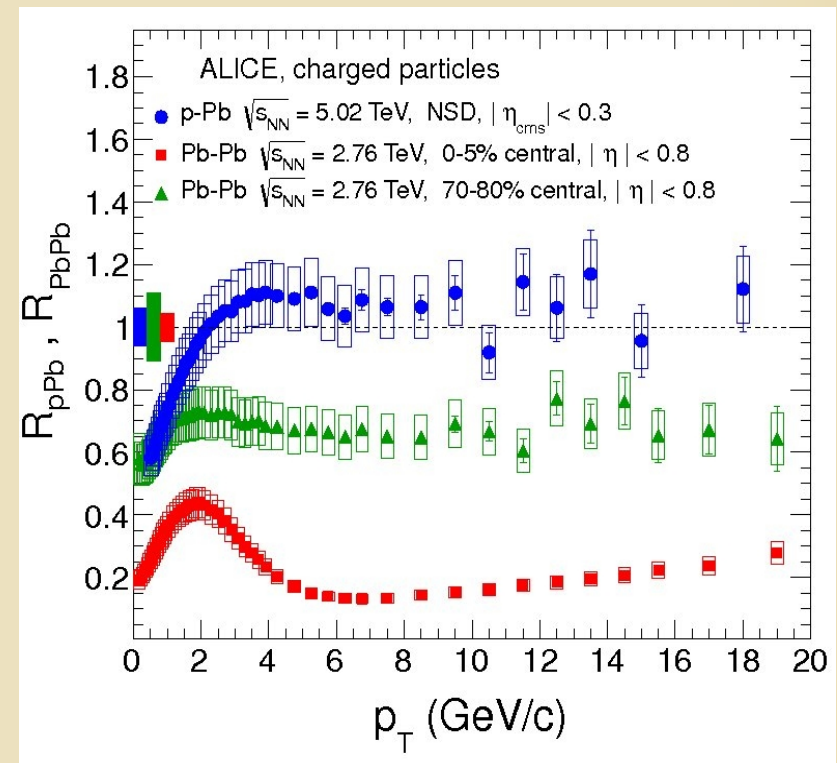
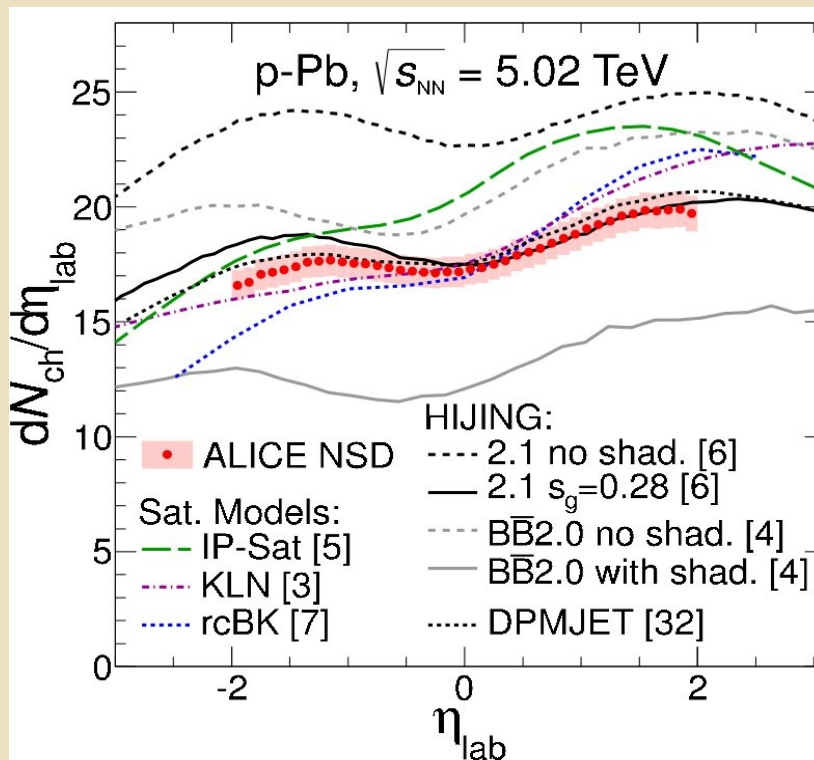


G.G. Barnaföldi: Nuclear Effects in pA Collisions at the Highest Energies (5.02 ATeV)

MOTIVATION

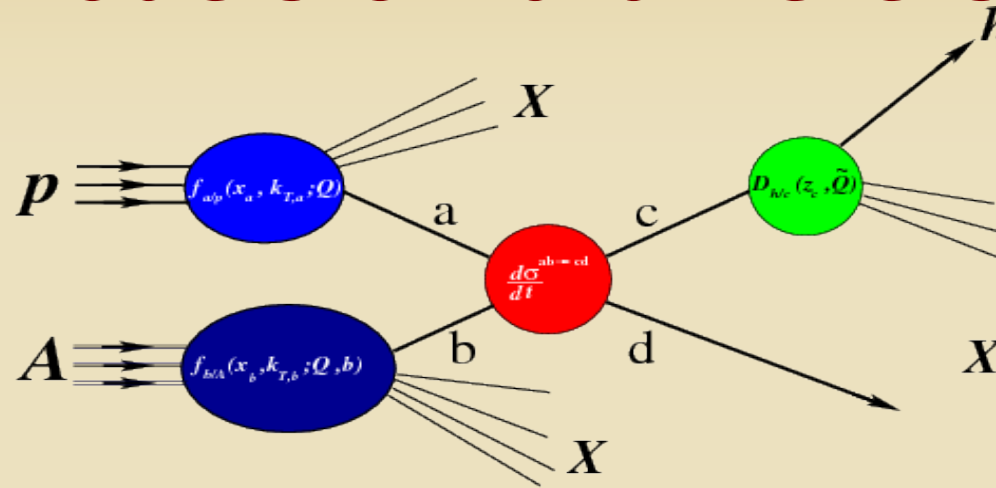
Motivation for pA collisions

- 13/09/2012 ALICE $p+Pb$ @ 5.02 ATeV
- Preliminary ALICE data arXiv: 1210.3615, 1210.4520



- Note, NO measured pp reference, only interpolated!

Models & Parameters



HIJING B/B 2.0

PRC83 024902, PRC84 022002 (2010)

Modified version of HIJING 2.0

Minijet cutoff: $p_0 = 3.1$ GeV/c

$$p_0(s, A) = 0.416 \sqrt{s}^{0.191} A^{0.128} \text{ GeV/c}$$

String tension: $\kappa = 2.9$ GeV/fm

$$\kappa(s, A) = \kappa_0 (s/s_0)^{0.06} A^{0.167} \text{ GeV/fm.}$$

PDF: GRV+ HIJING shadowing

FF: PYTHIA + minijet

kTpQCD_v2.0

PRC65 (2002)034903

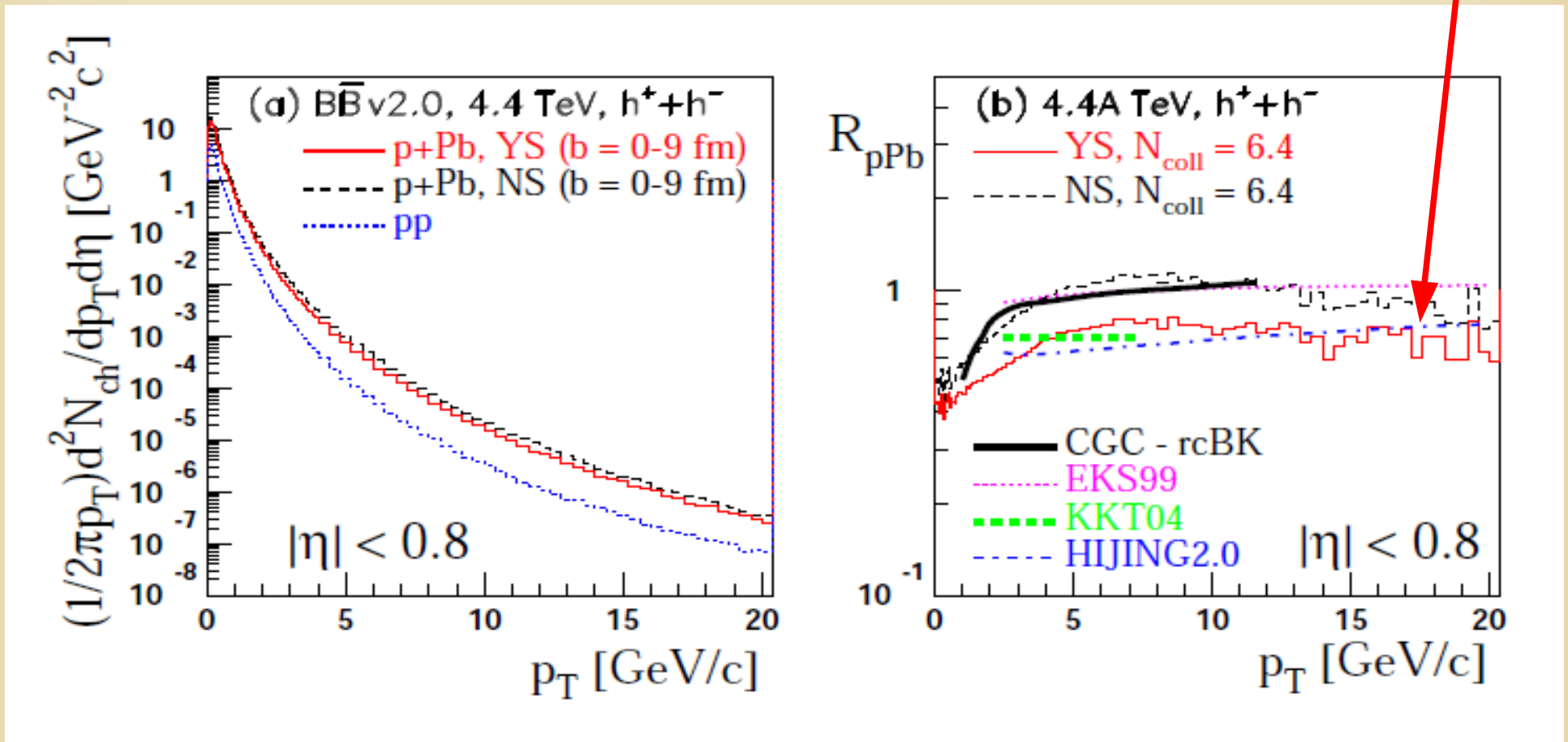
NLO pQCD based parton model with intrinsic- k_T , k_T -broadening, and various shadowing parametrization.

$$E_\pi \frac{d\sigma_\pi^{dAu}}{d^3p_\pi} = f_{a/d}(x_a, Q^2; k_{T,a}) \otimes f_{b/Au}(x_b, Q^2; k_{T,b}) \otimes \frac{d\sigma^{ab \rightarrow cd}}{d\hat{t}} \otimes \frac{D_{\pi/c}(z_c, \hat{Q}^2)}{\pi z_c^2}, \quad (1)$$

PDF:GRV/MRST+Shad, FF:KKP

The Spectra and $R_{pPb}(p_T)$ for $|\eta| < 0.8$

Charged hadron production with HIJING 2.0 @ 4.4 ATeV $R_{pA} \sim 0.7$



GGB, J. Barrette, M. Gyulassy, P. Lévai, V. Topor Pop PRC85 024903 (2012)

The Spectra and $R_{pPb}(p_T)$ for $|\eta| < 0.35$ & 0.8

Hadron production with HIJING2.0 @ 0.2 AGeV & 4.4 ATeV

Shadowing:

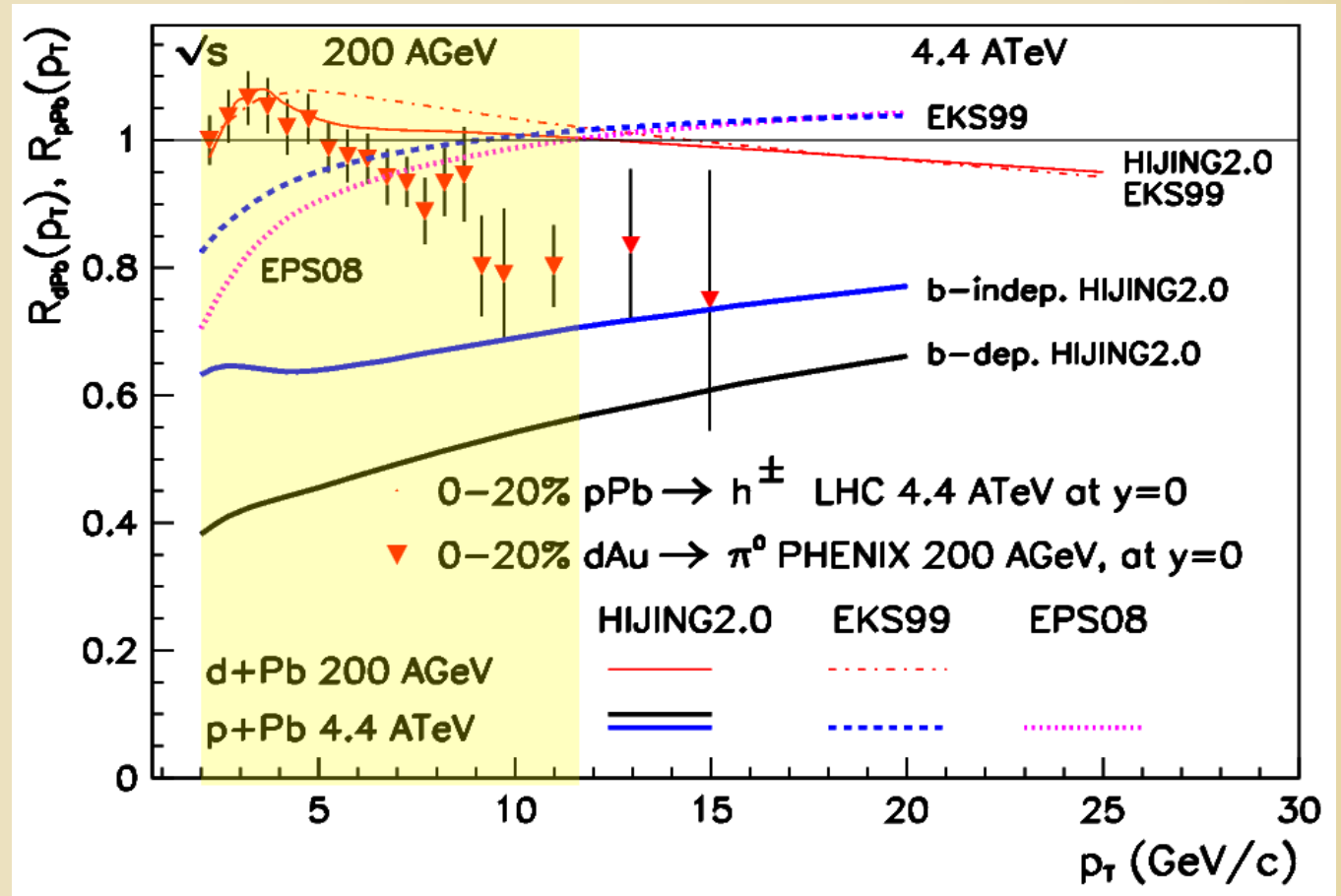
$$f_{a/A}(x, Q^2) = S_{a/A}(x, Q^2) f_{a/N}(x, Q^2)$$

b-dependent part

$$s_a(b) = s_a \frac{5}{3} \left(1 - \frac{b^2}{R_A^2} \right)$$

with

$$R_A = 1.12A^{1/3}$$



GGB, J. Barrette, M. Gyulassy, P. Lévai, V. Topor Pop PRC85 024903 (2012)

The Spectra and $R_{pPb}(p_T)$ for $|\eta| < 0.35$ & 0.3

Hadron production with HIJING2.0 @ 0.2 AGeV & 5.02 ATeV

Shadowing:

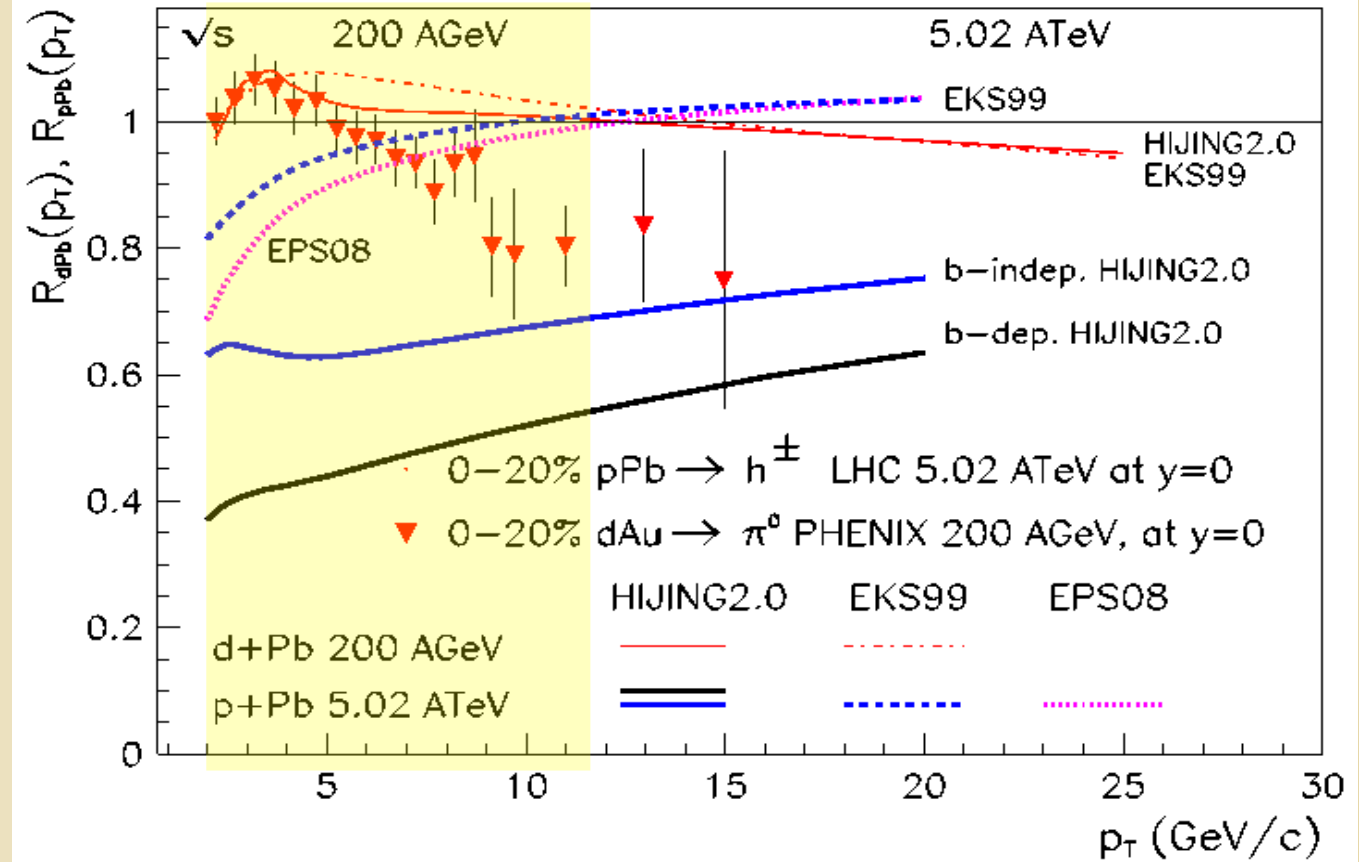
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GGB, J. Barrette, M. Gyulassy, P. Lévai, V. Topor Pop (arXiv:1211.2256)

The Spectra and $R_{pPb}(p_T)$ for $|\eta| < 0.35$ & **0.3**

Comparison of Prelim. ALICE data to HIJING2.0 @ 5.02 ATeV

Shadowing:

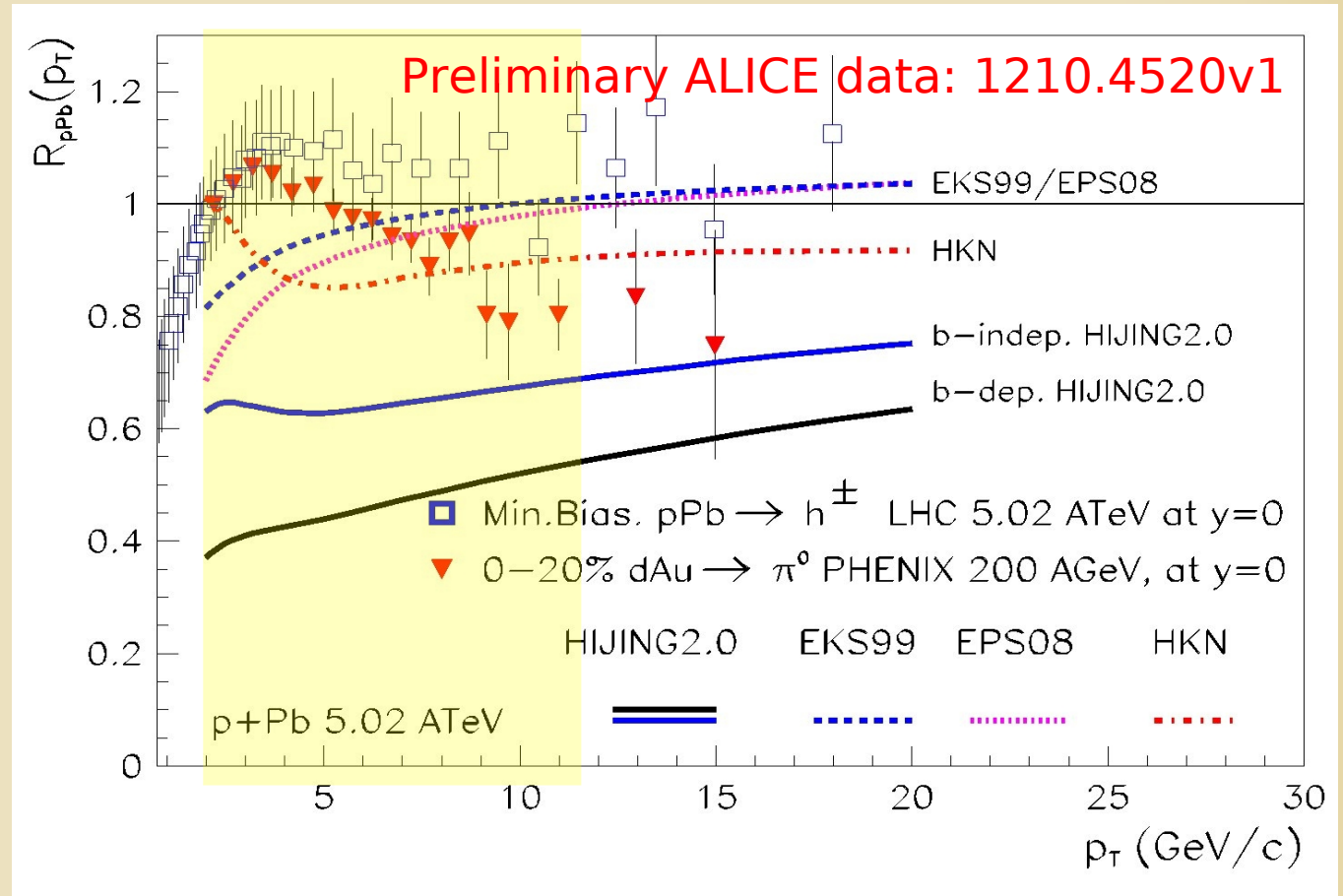
$$f_{a/A}(x, Q^2) = S_{a/A}(x, Q^2) f_{a/N}(x, Q^2)$$

b-dependent part

$$s_a(b) = s_a \frac{5}{3} \left(1 - \frac{b^2}{R_A^2} \right)$$

with

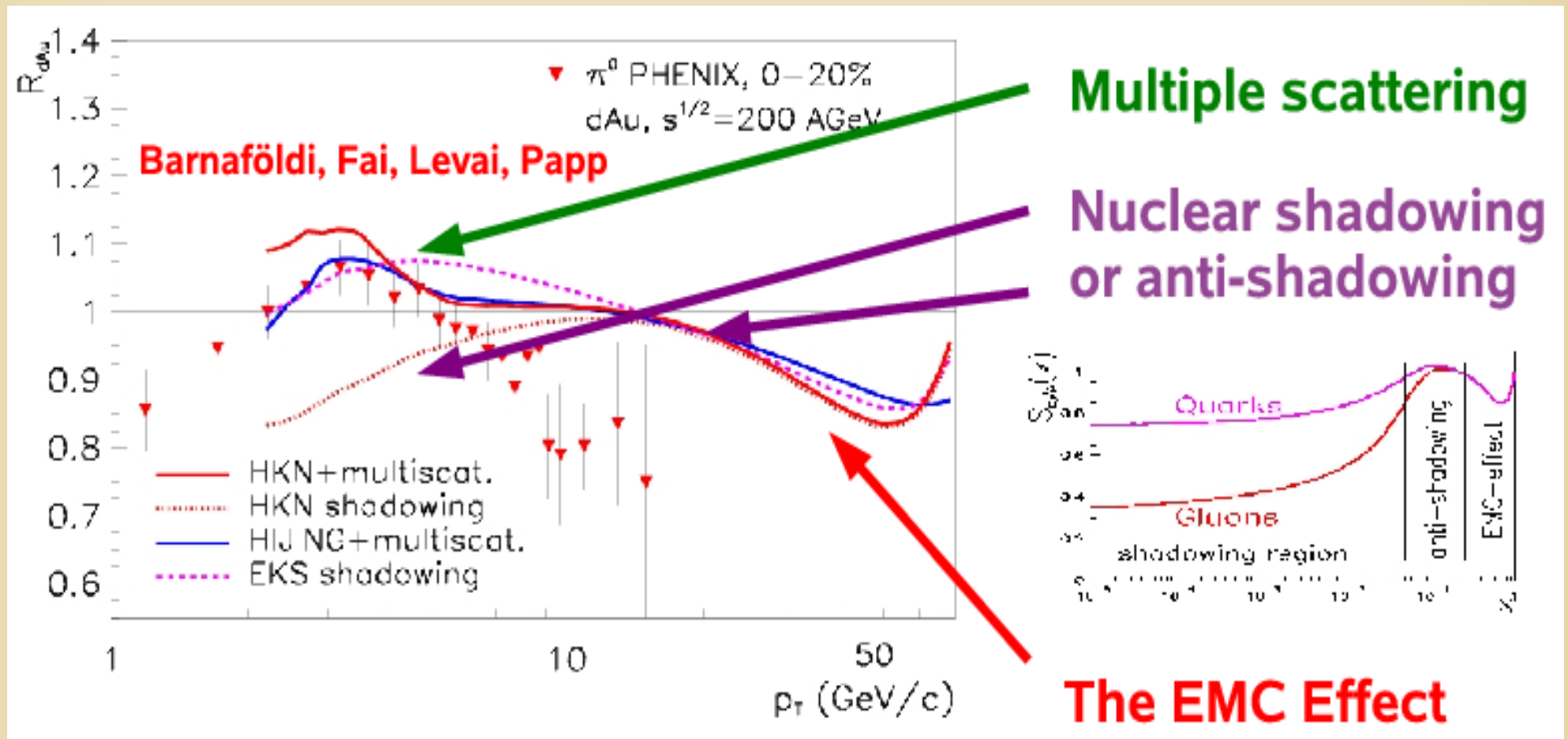
$$R_A = 1.12A^{1/3}$$



GGB, J. Barrette, M. Gyulassy, P. Lévai, V. Topor Pop (arXiv:1211.2256)

Shadowing effects on $R_{dAu}(p_T)$ for $|\eta| < 0.35$

Extreme high- p_T Pion production with kTpQCD @ 200 AGeV



BA Cole, GGB, G. Fai, P. Lévai, G. Papp, arXiv:08073384 (2007)

Midrapidity $R_{dA}(x_T)$ for $|\eta| < 0.35$

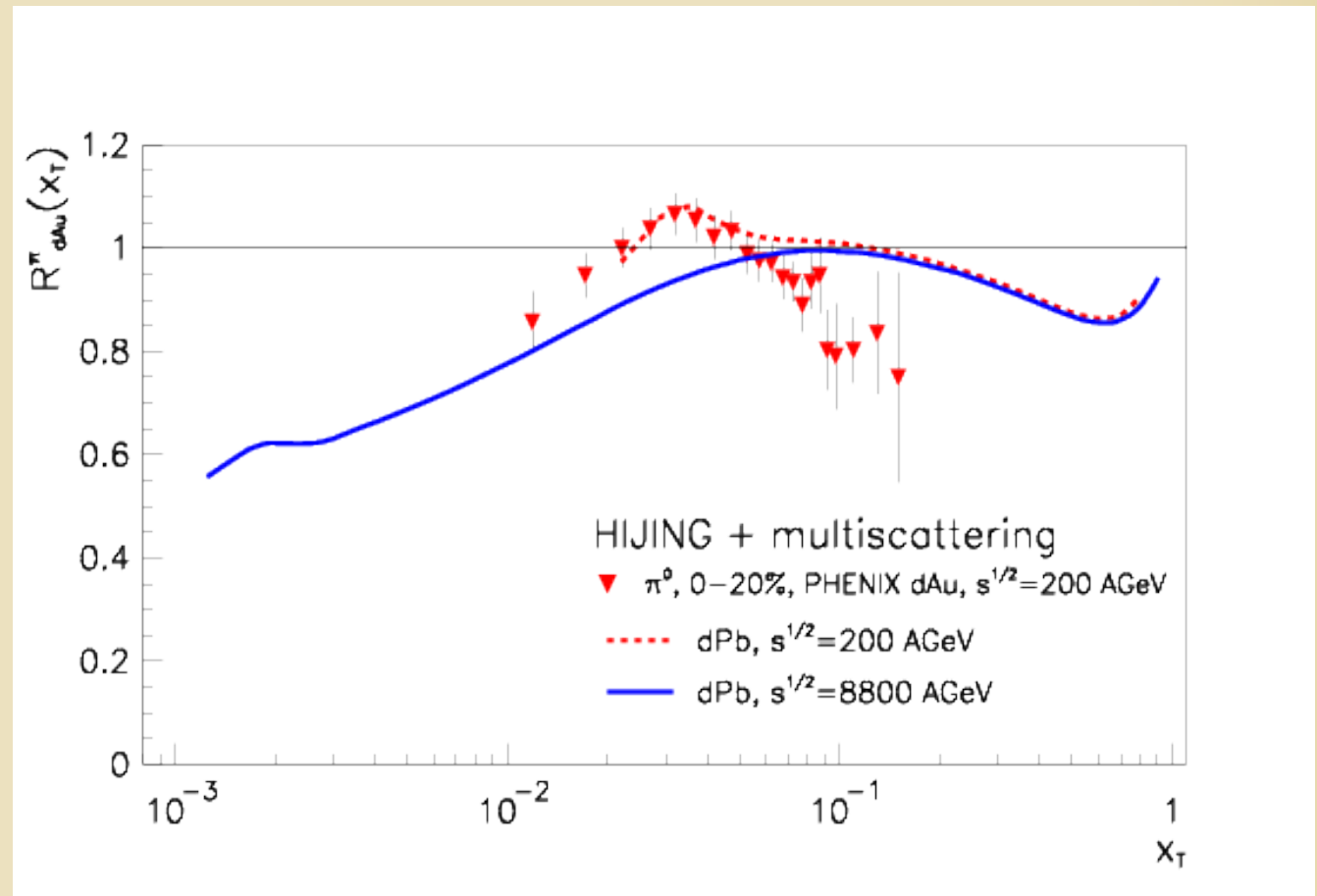
Pion production with HIJING shadowing kTpQCD @ 0.2 & 8.8 ATeV

HIJING Shadowing

x-scaling

DGLAP evolution

Need for additional multiple scattering



GGB, G. Fai, P. Lévai, BA Cole, G. Papp, Indian J.Phys. 84 (2010) 1721-1725

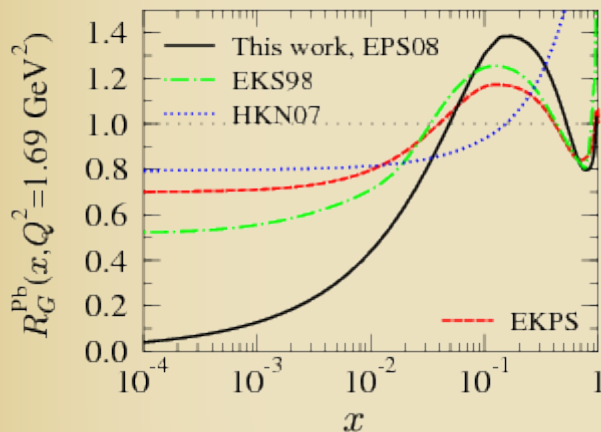
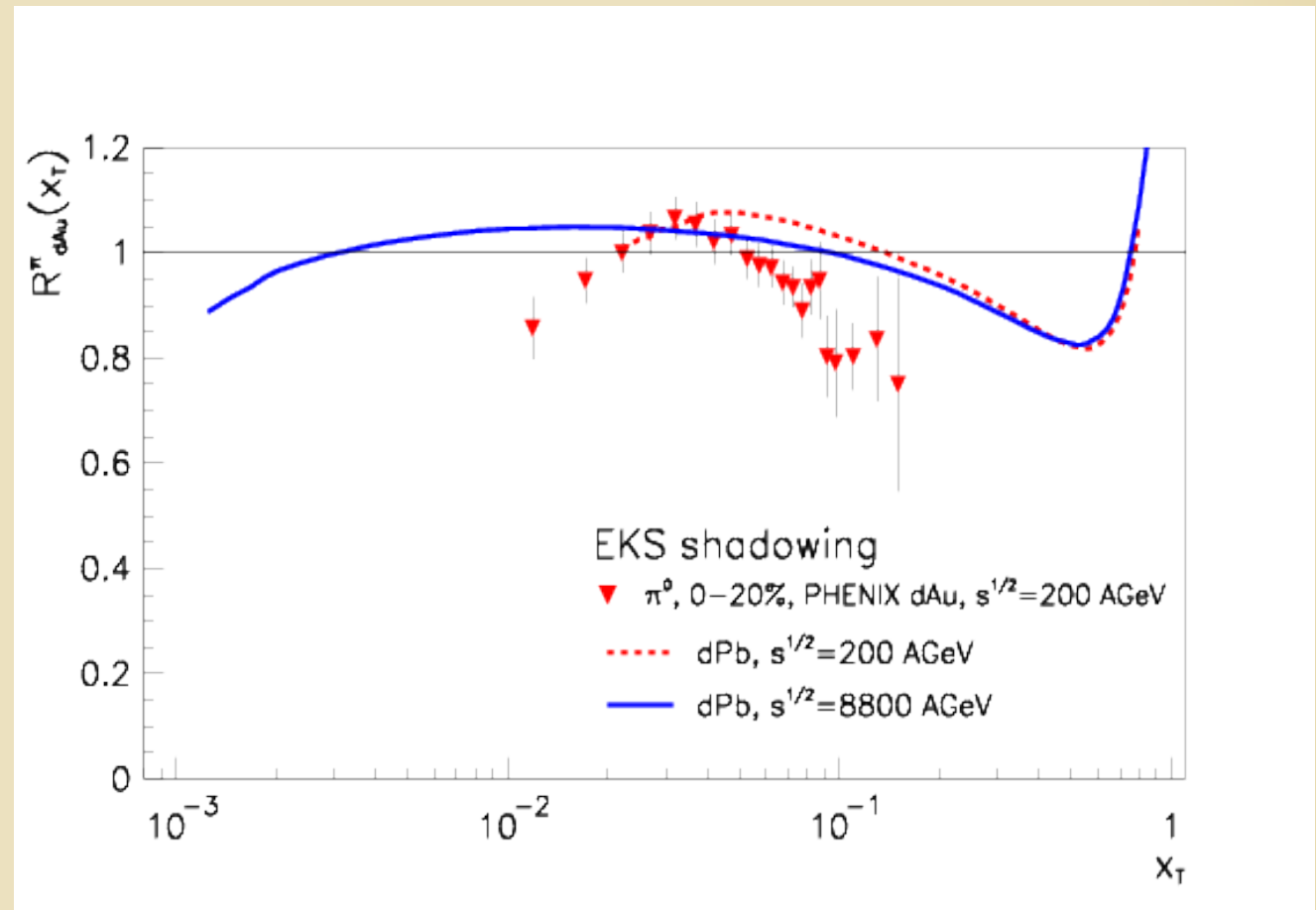
Midrapidity $R_{dA}(x_T)$ for $|\eta| < 0.35$

Pion production with EKS shadowing kTpQCD @ 0.2 & 8.8 ATeV

EKS Shadowing

x-scaling

DGLAP evolution



GGB, G. Fai, P. Lévai, BA Cole, G. Papp, Indian J.Phys. 84 (2010) 1721-1725

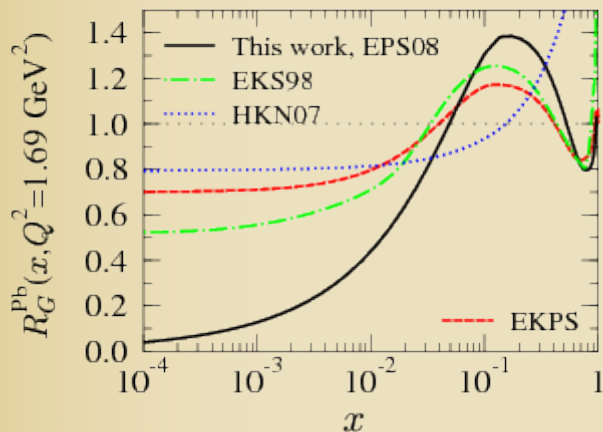
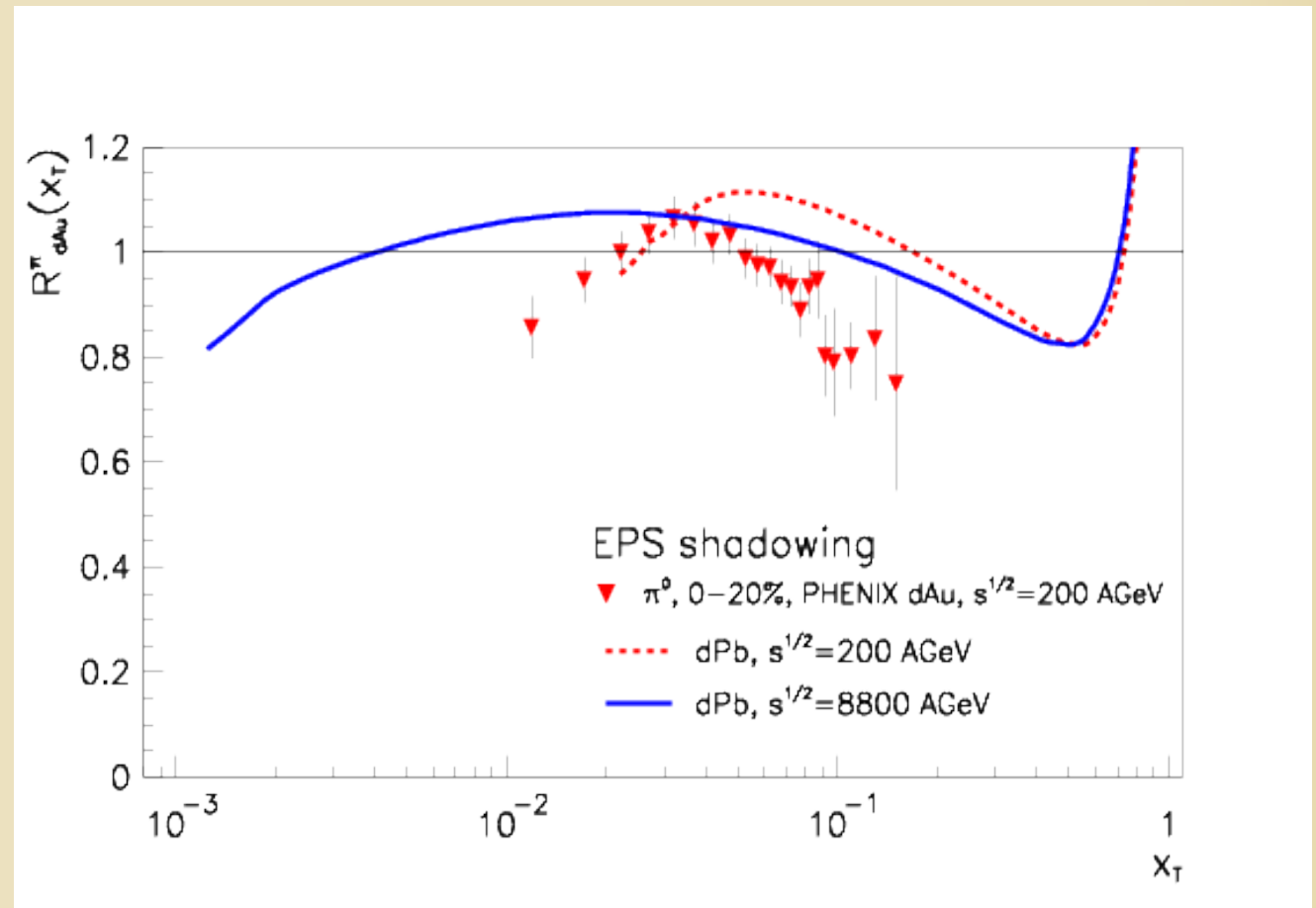
Midrapidity $R_{dA}(x_T)$ for $|\eta| < 0.35$

Pion production with EPS shadowing kTpQCD @ 0.2 & 8.8 ATeV

EPS Shadowing

x-scaling

DGLAP evolution



GGB, G. Fai, P. Lévai, BA Cole, G. Papp, Indian J.Phys. 84 (2010) 1721-1725

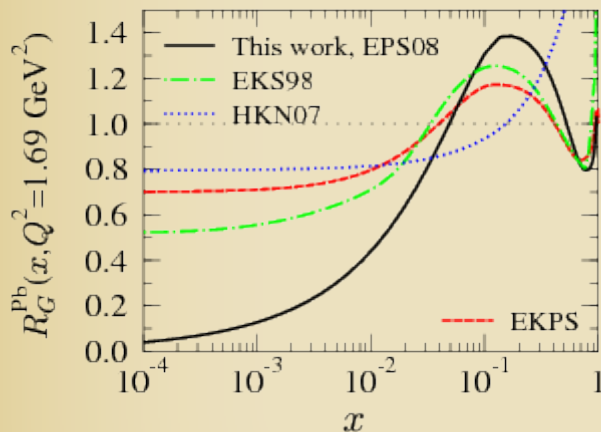
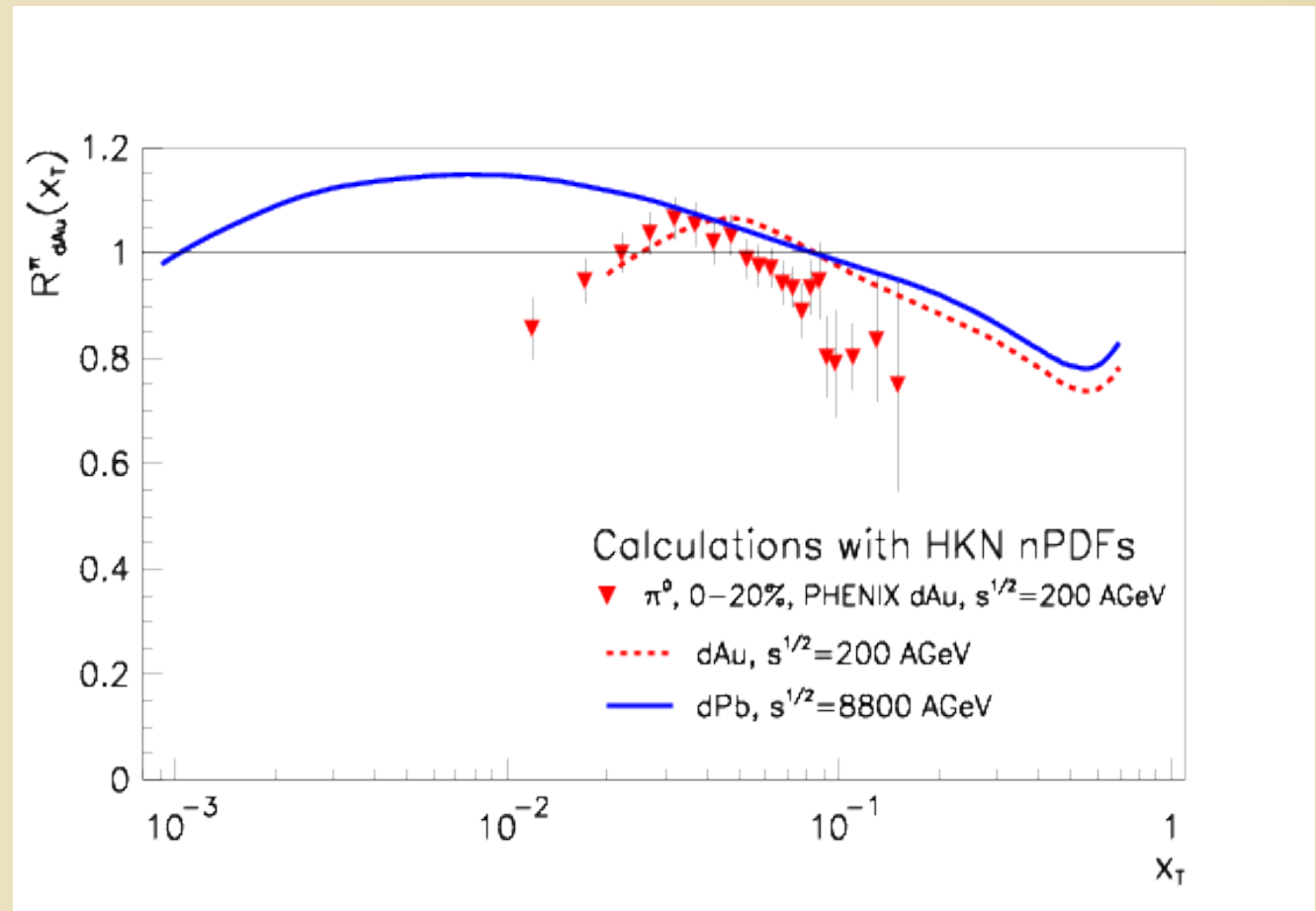
Midrapidity $R_{dA}(x_T)$ for $|\eta| < 0.35$

Pion production with HKN shadowing kTpQCD @ 0.2 & 8.8 ATeV

HKN Shadowing

x-scaling

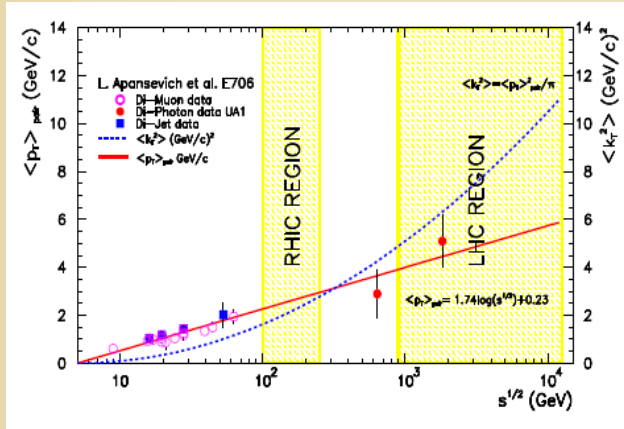
DGLAP evolution



BA Cole, GGB, G. Fai, P. Lévai, G. Papp, arXiv:08073384 (2007)

Midrapidity $R_{dA}(p_T)$ for LHC - Summary

Extreme high- p_T Pion production kTpQCD @ 0.2, 0.9, & 8.8 ATeV

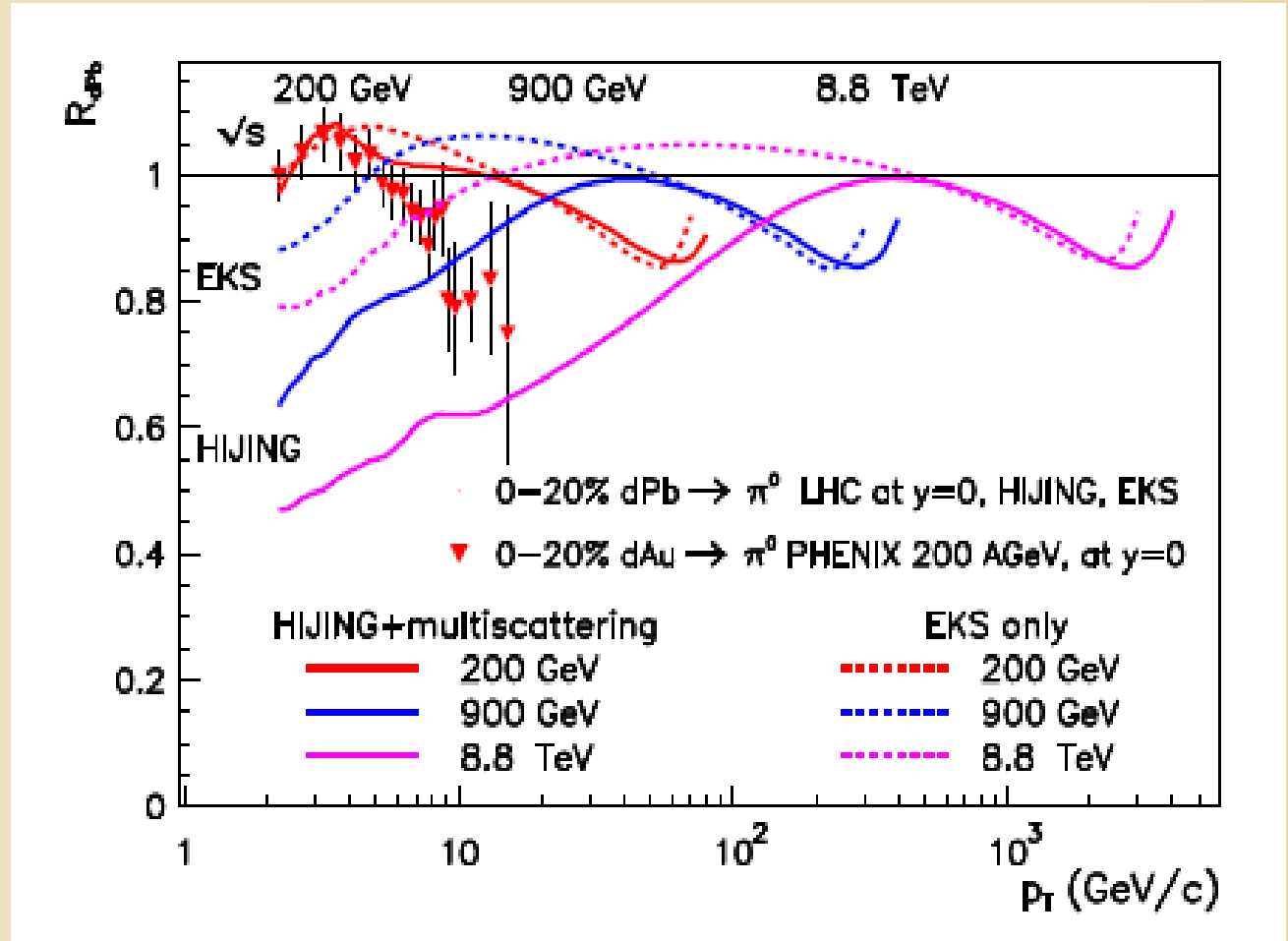


k_T -broadening:

$$f_{a/p}(x_a, k_{Ta}, Q^2) = f_{a/p}(x_a, Q^2) \cdot g_{a/p}(k_{Ta})$$

$$\langle k_T^2 \rangle_{pA} = \langle k_T^2 \rangle_{pp} + C \cdot h_{pA}(b)$$

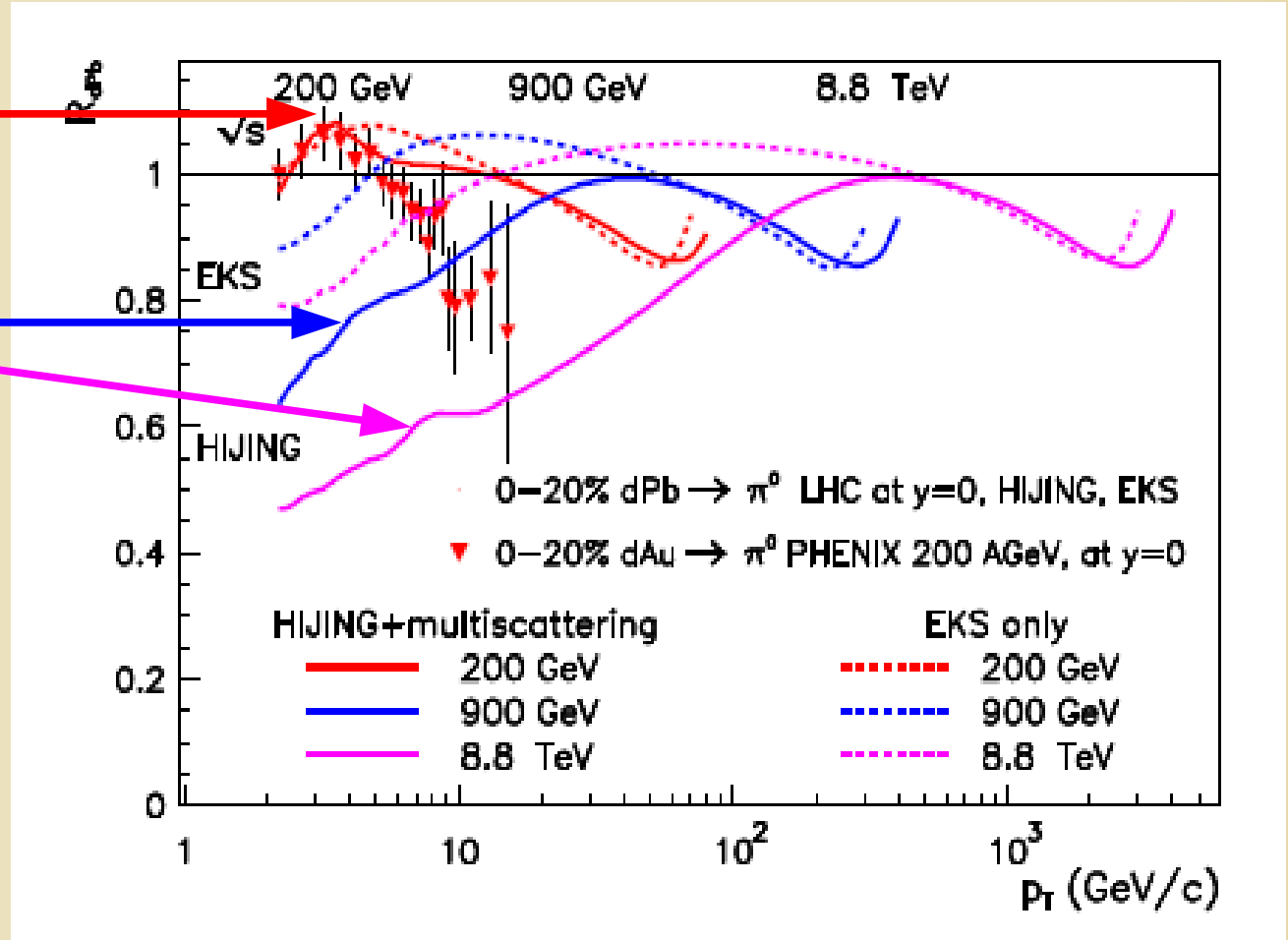
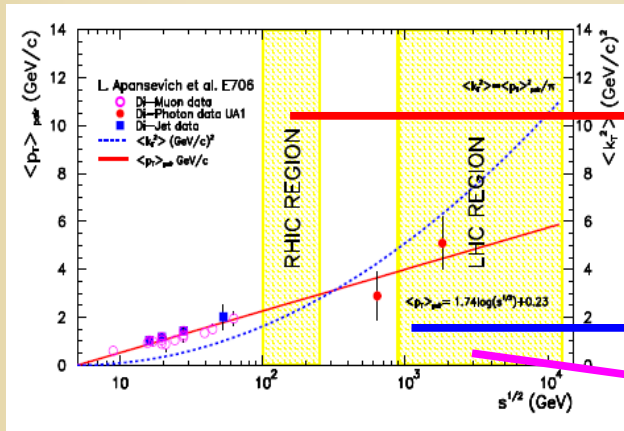
$$\langle k_T^2 \rangle_{pp} = \langle p_T \rangle_{\text{pair}}^2 / \pi$$



BA Cole, GGB, G. Fai, P. Lévai, G. Papp, arXiv:08073384 (2007)

Midrapidity $R_{dA}(p_T)$ for LHC - Summary

Extreme high- p_T Pion production kTpQCD @ 0.2, 0.9, & 8.8 ATeV



k_T -broadening:

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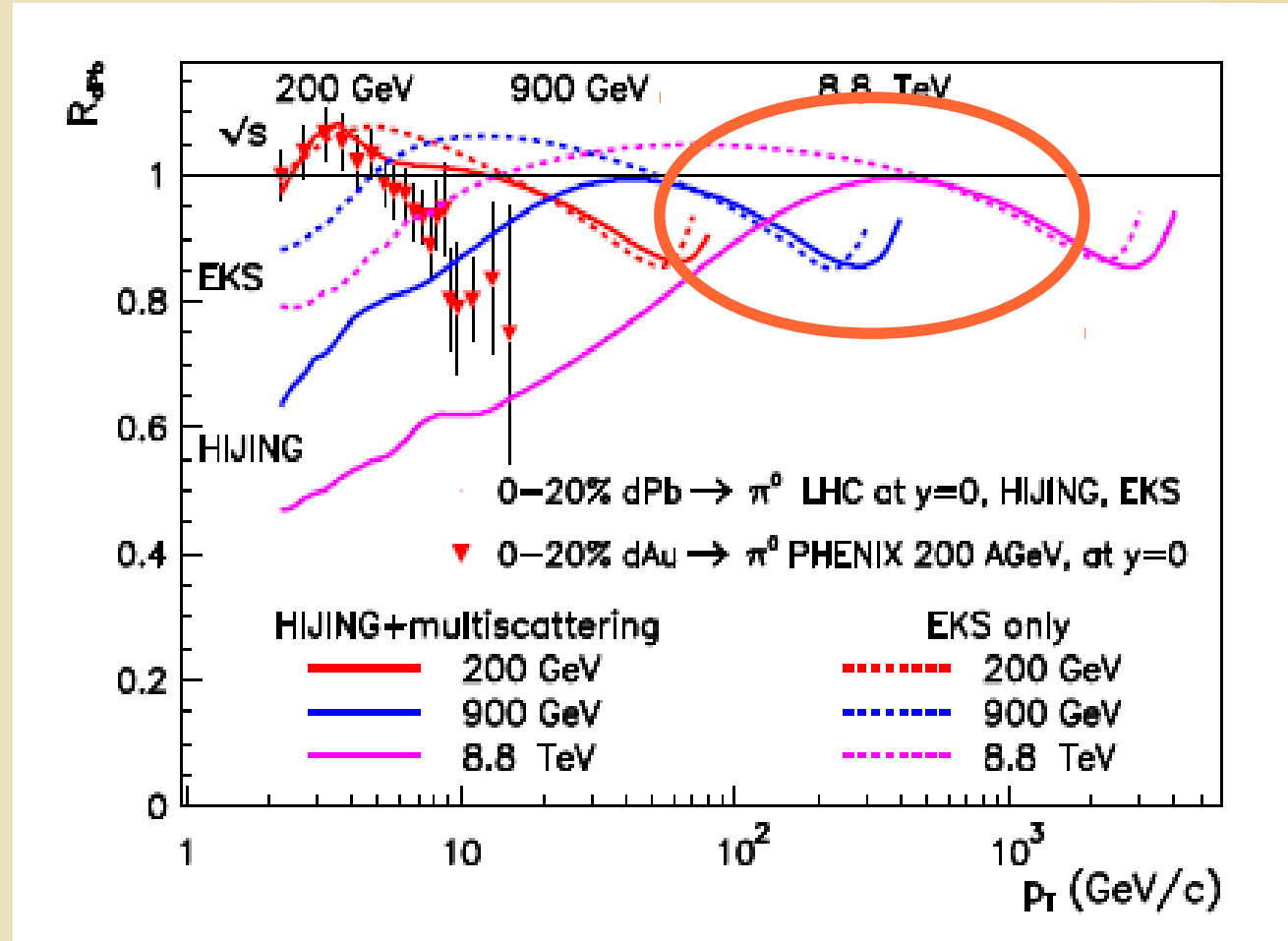
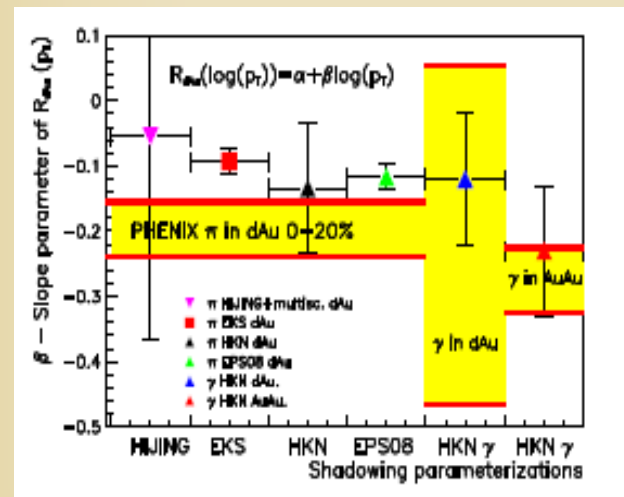
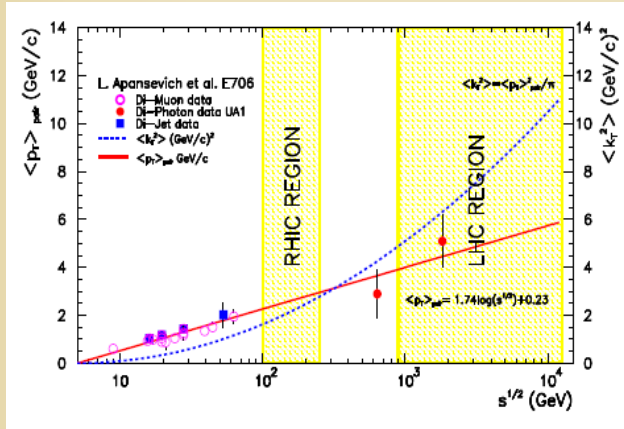
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BA Cole, GGB, G. Fai, P. Lévai, G. Papp, arXiv:08073384 (2007)

Midrapidity $R_{dA}(p_T)$ for LHC - Summary

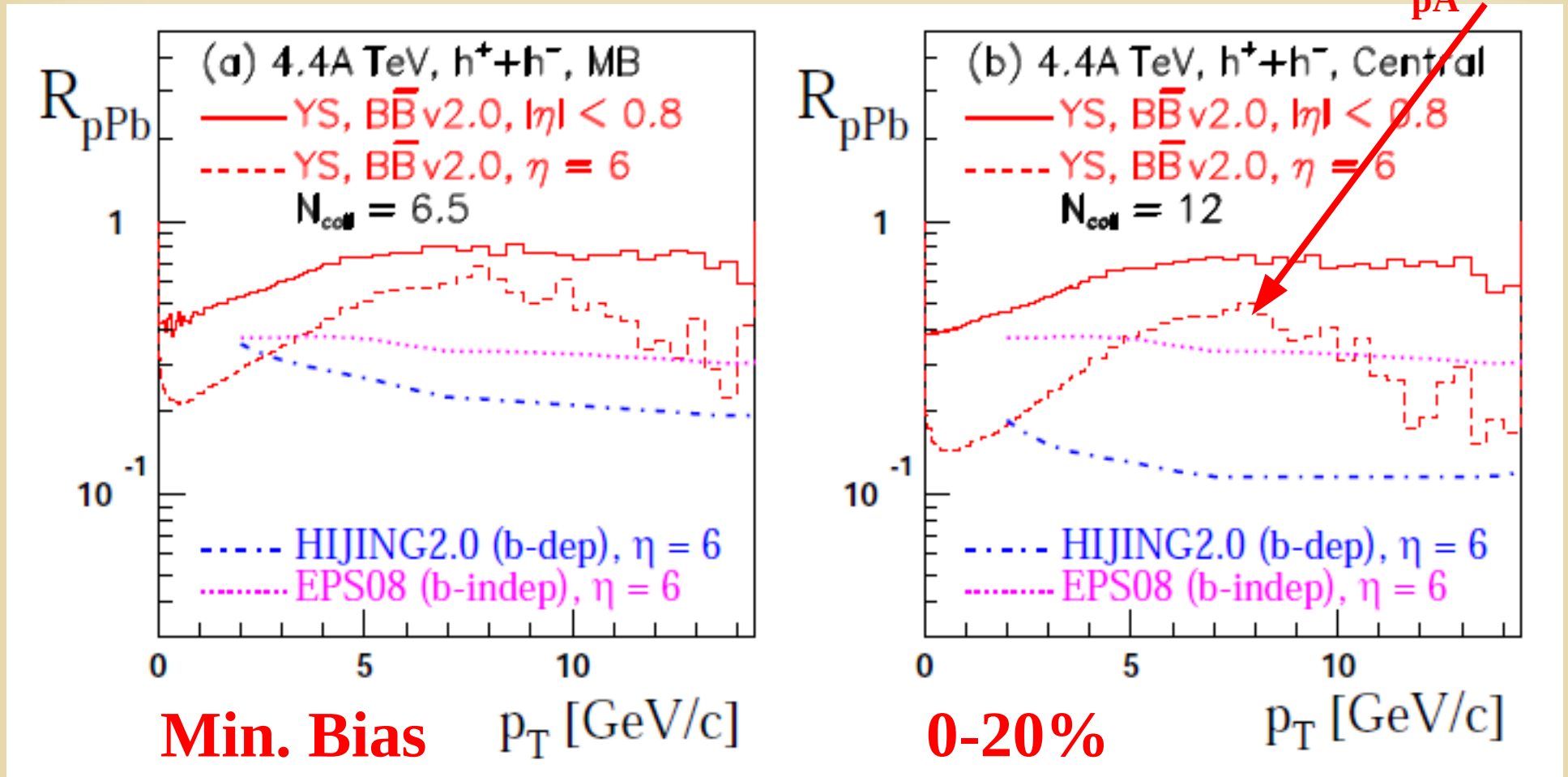
Extreme high- p_T Pion production kT-pQCD @ 0.2, 0.9, & 8.8 ATeV



BA Cole, GGB, G. Fai, P. Lévai, G. Papp, arXiv:08073384 (2007)

Forward $R_{pPb}(p_T)$ at $|\eta| < 0.8$ & $\eta = 6.0$

Charged hadron production with HIJING 2.0 @ 4.4 ATeV $R_{pA} \sim 0.35$



GGB, J. Barrette, M. Gyulassy, P. Lévai, V. Topor Pop PRC85 024903 (2012)

Rapidity asymmetry for dAu at RHIC

Pion production with kTpQCD @ 200 AGeV

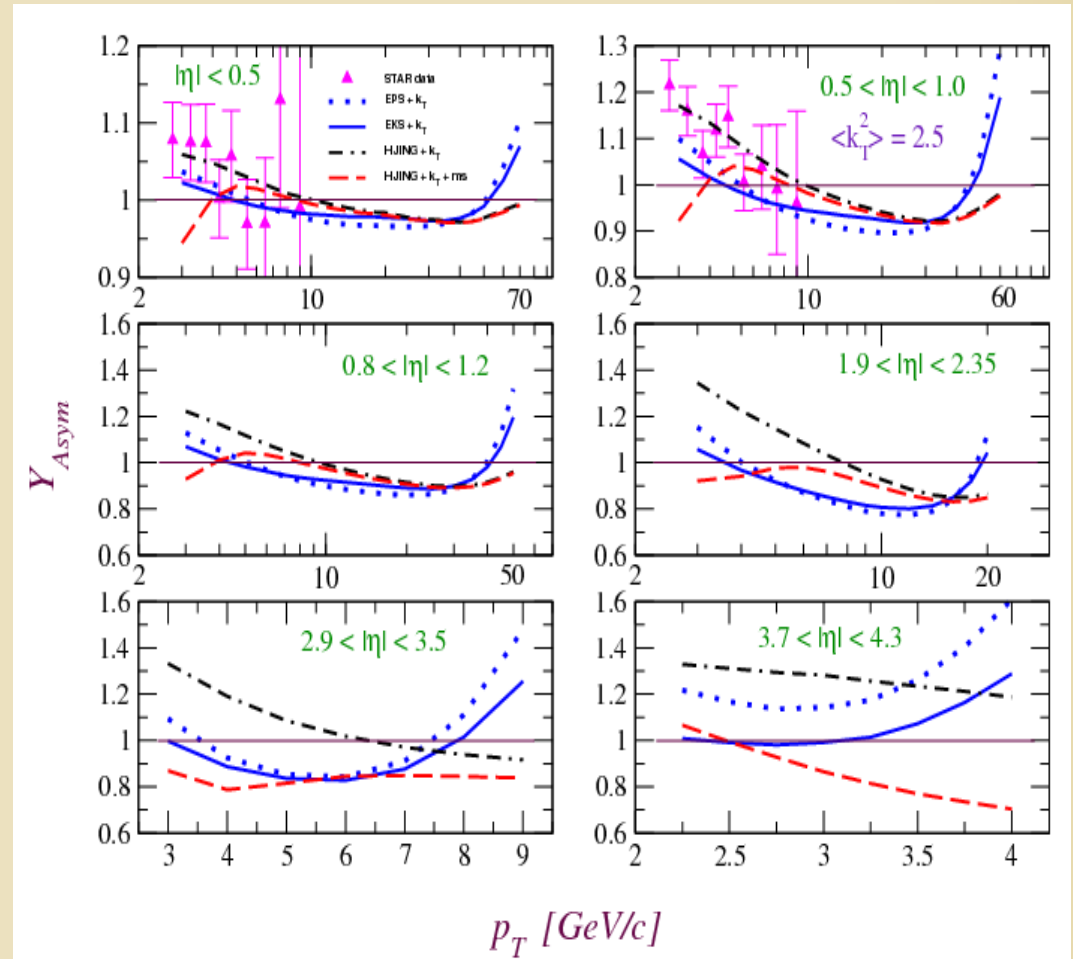
Rapidity asymmetry

$$Y_{Asym}^h(p_T) = E_h \frac{d^3\sigma_{AB}^h}{d^3p_T} \Big|_{\eta < 0} / E_h \frac{d^3\sigma_{AB}^h}{d^3p_T} \Big|_{\eta > 0}$$

Relation to NMF

$$Y_{Asym}^h(p_T) = R_{\eta}^h(p_T) = \frac{R_{dAu}^h(p_T, \eta < 0)}{R_{dAu}^h(p_T, \eta > 0)}$$

X-scaling is OK,
Multiscattering changes $Y(\eta)$

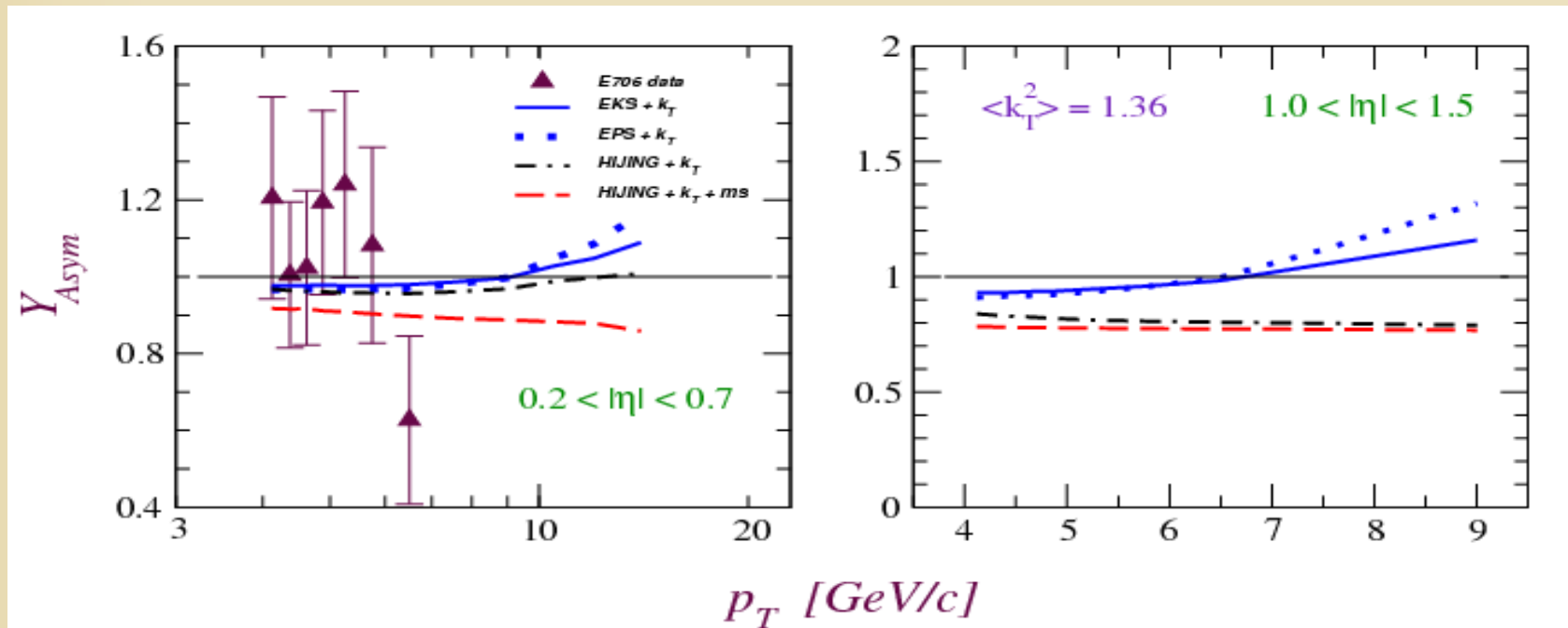


A. Adeluy, GGB, G. Fai, P. Lévai, PRC80 (2009) 014903

Rapidity asymmetry for pBe at FNAL

Pion production with kTpQCD @ 30.7 GeV

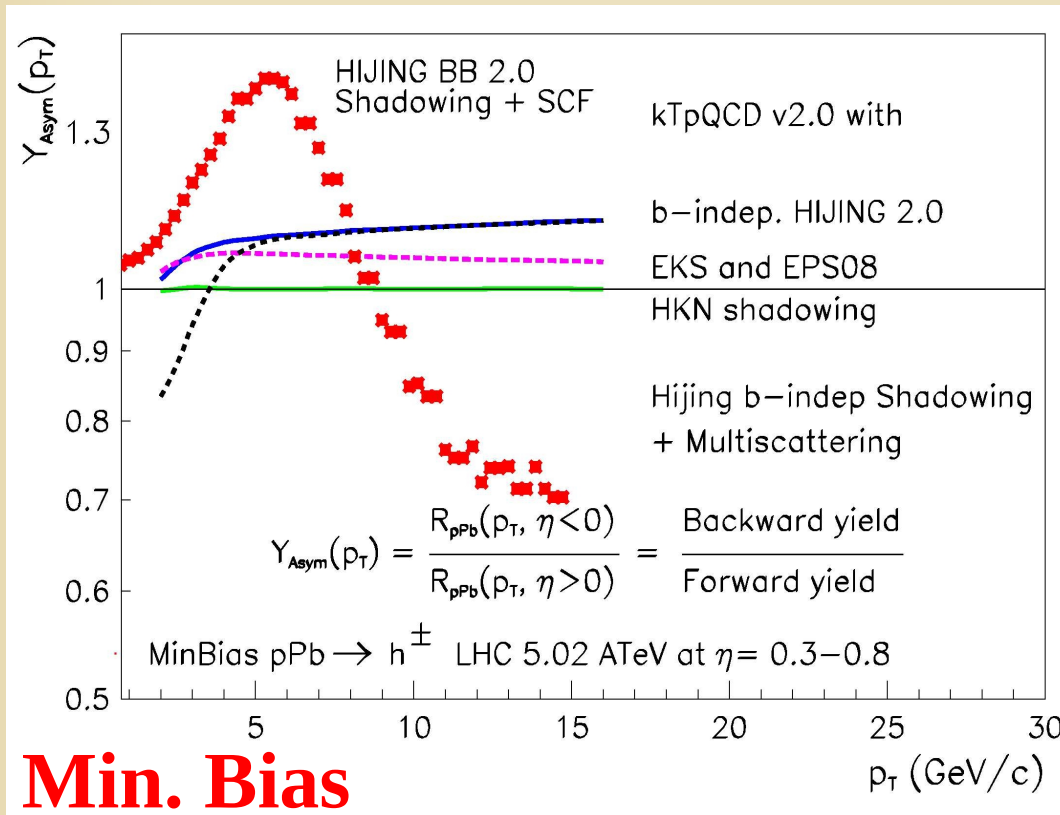
$$Y_{Asym}^h(p_T) = E_h \frac{d^3\sigma_{AB}^h}{d^3p_T} \Big|_{\eta < 0} / E_h \frac{d^3\sigma_{AB}^h}{d^3p_T} \Big|_{\eta > 0}$$



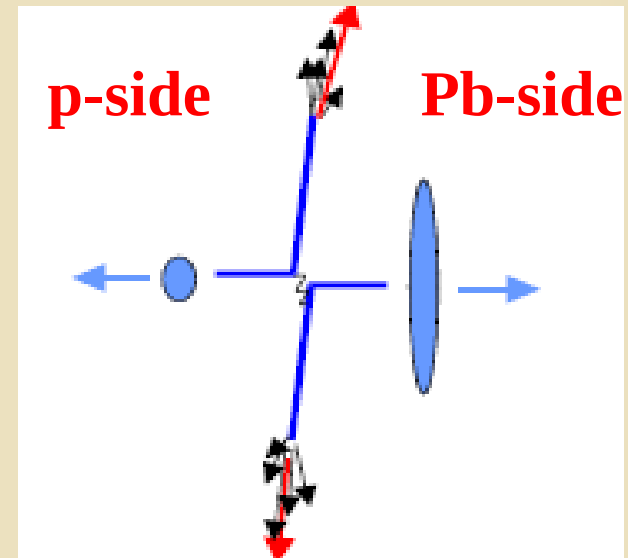
A. Adeluy, GGB, G. Fai, P. Lévai, PRC80 (2009) 014903

Rapidity asymmetry for pPb at LHC

Pion production with kTpQCD for pPb @ 5.02 ATeV $|\eta| [0.3:0.8]$



$$Y_{Asym}^h(p_T) = E_h \frac{d^3\sigma_{AB}^h}{d^3p_T} \Big|_{\eta < 0} / E_h \frac{d^3\sigma_{AB}^h}{d^3p_T} \Big|_{\eta > 0}$$

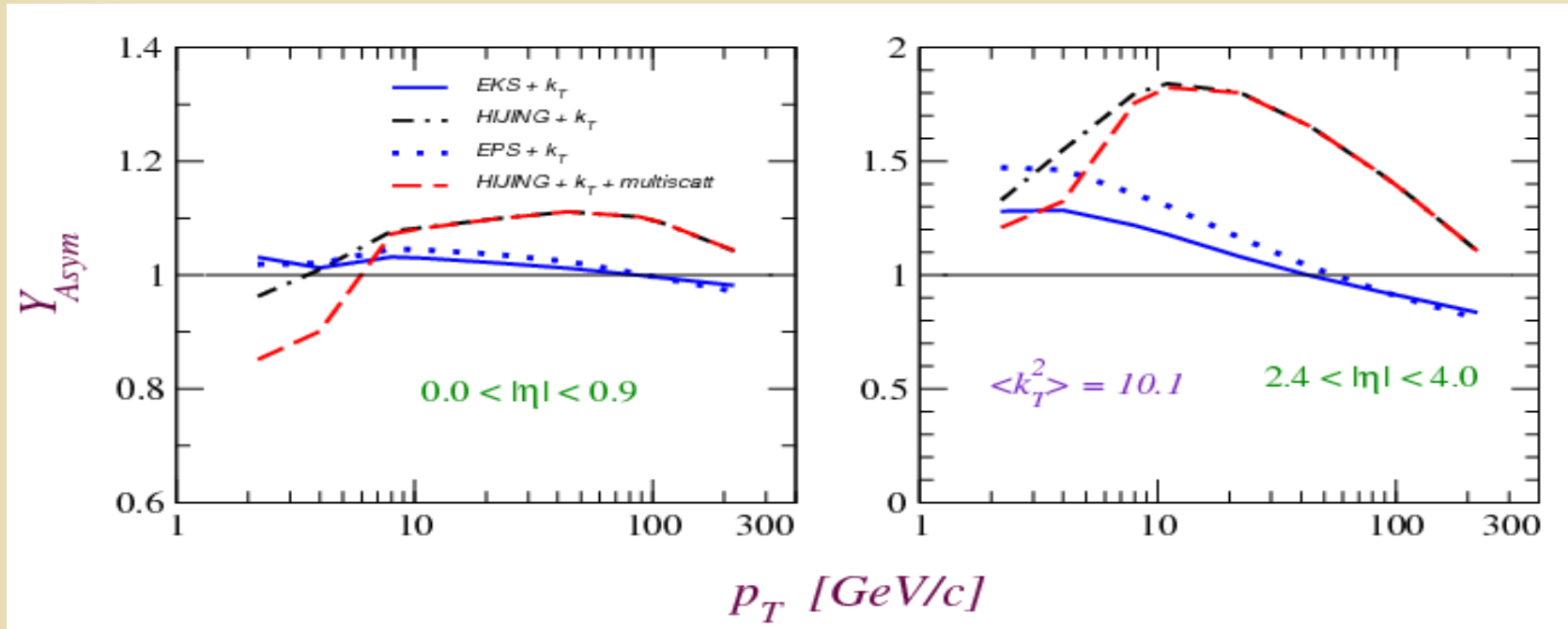


GGB, J. Barret, M. Gyulassy, P. Lévai, V. Topor Pop (arXiv:1211.2256)

Rapidity asymmetry for dPb at LHC

Pion production with kTpQCD @ 8.8 ATeV

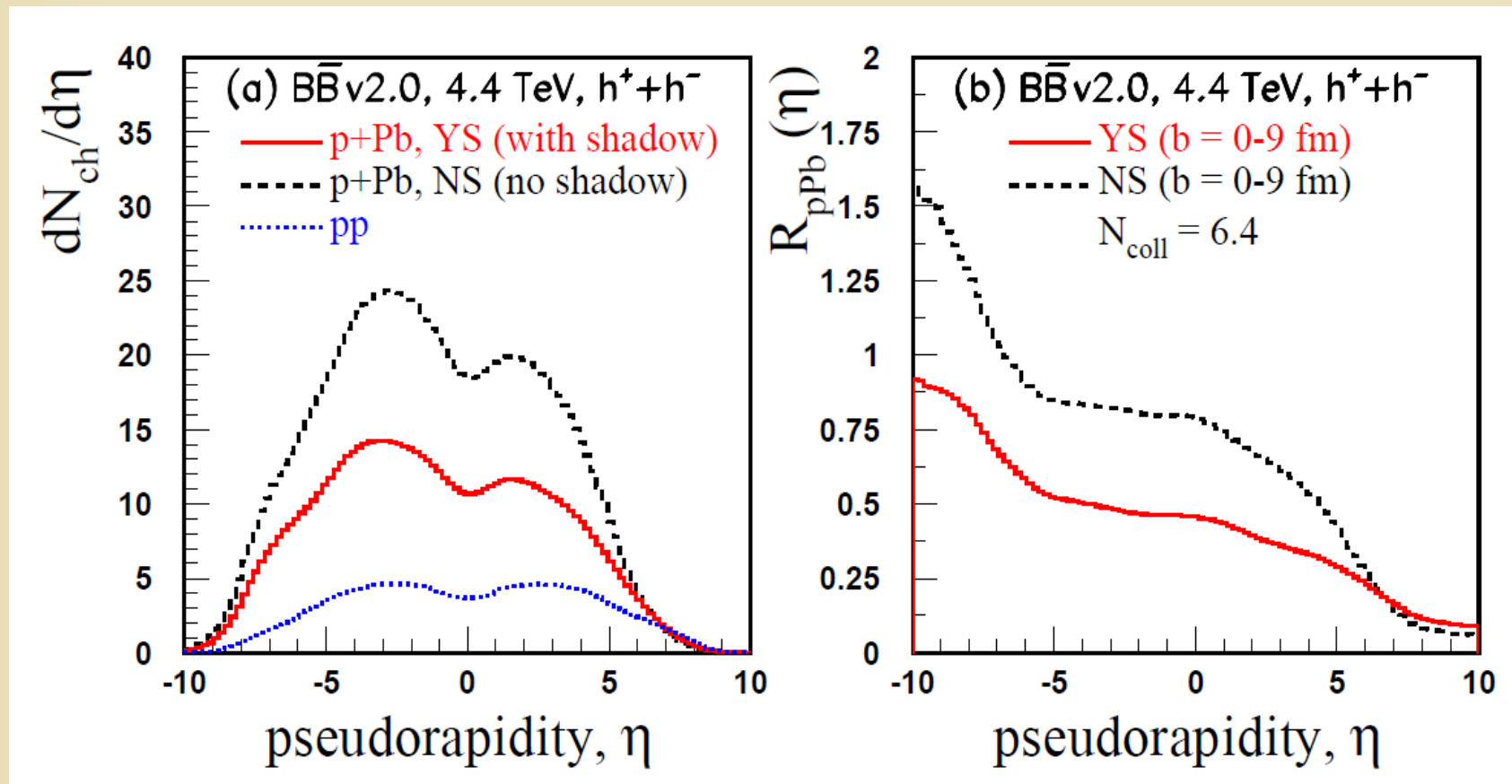
$$Y_{Asym}^h(p_T) = E_h \frac{d^3\sigma_{AB}^h}{d^3p_T} \Big|_{\eta < 0} / E_h \frac{d^3\sigma_{AB}^h}{d^3p_T} \Big|_{\eta > 0}$$



A. Adeluy, GGB, G. Fai, P. Lévai, PRC80 (2009) 014903

HIJINGB/B 2.0: Rapidity distribution for pp & pPb

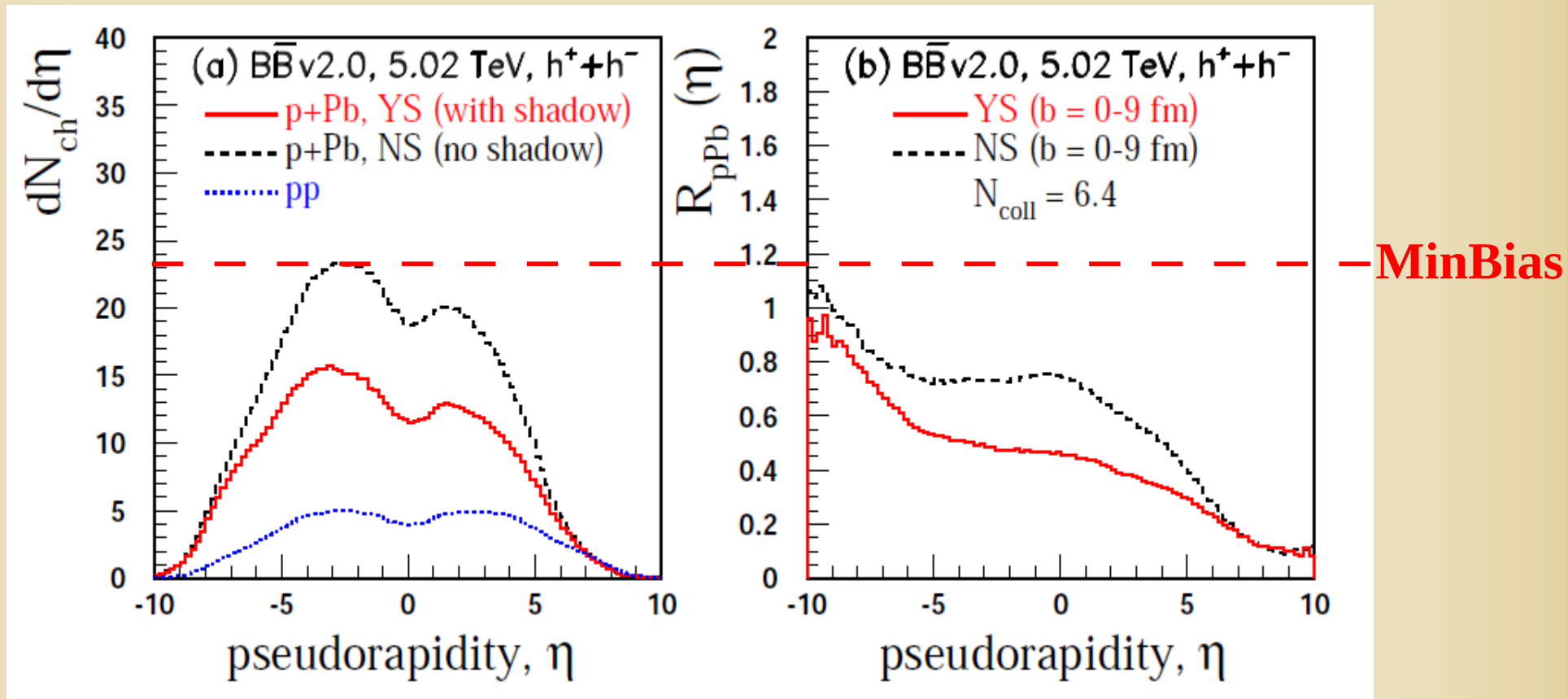
Charged hadron production with HIJING 2.0 @ 4.4 ATeV MinBias



GGB, J. Barret, M. Gyulassy, P. Lévai, V. Topor Pop PRC85 024903 (2012)

HIJINGB/B 2.0: Rapidity distribution for pp & pPb

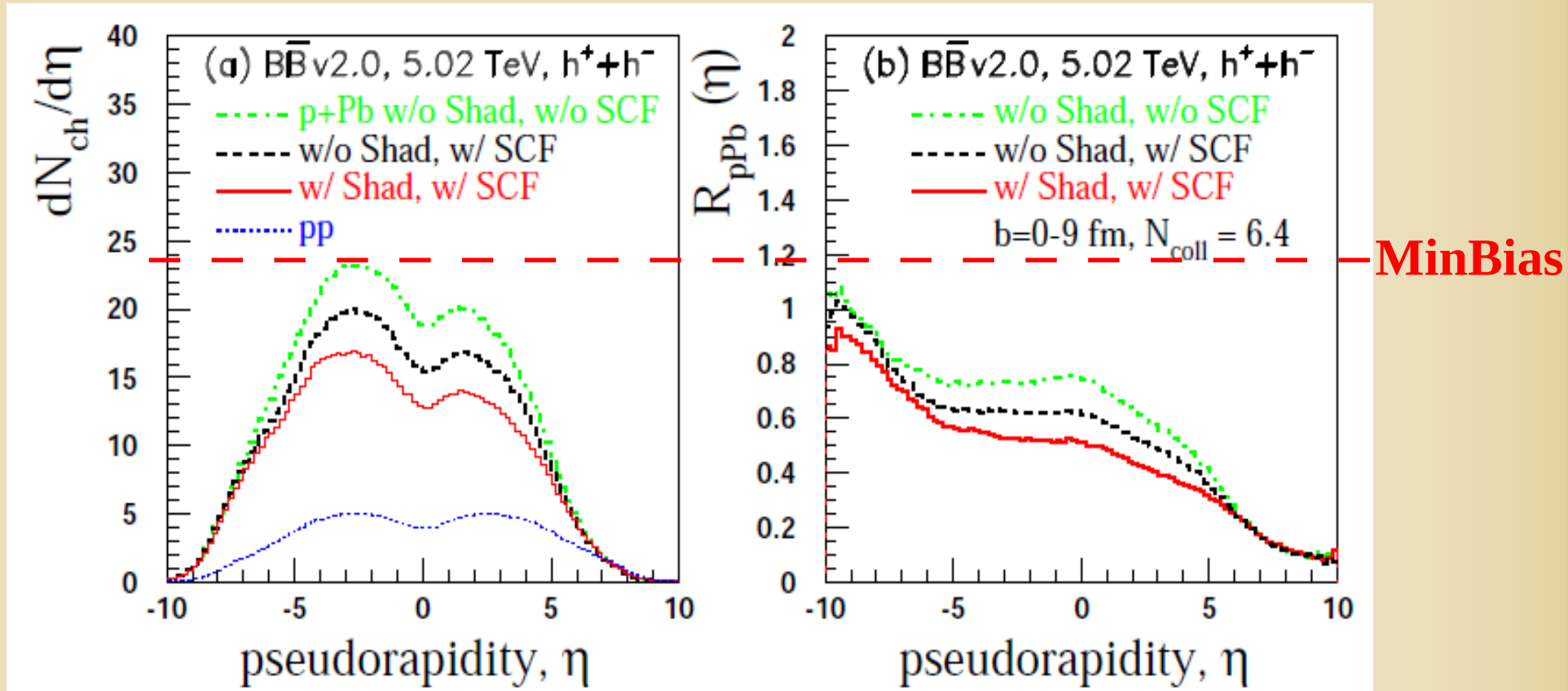
Charged hadron production with HIJING 2.0 @ 5.02 ATeV MinBias



GGB, J. Barret, M. Gyulassy, P. Lévai, V. Topor Pop (arXiv:1211.2256)

HIJINGB/B 2.0: Rapidity distribution for pp & pPb

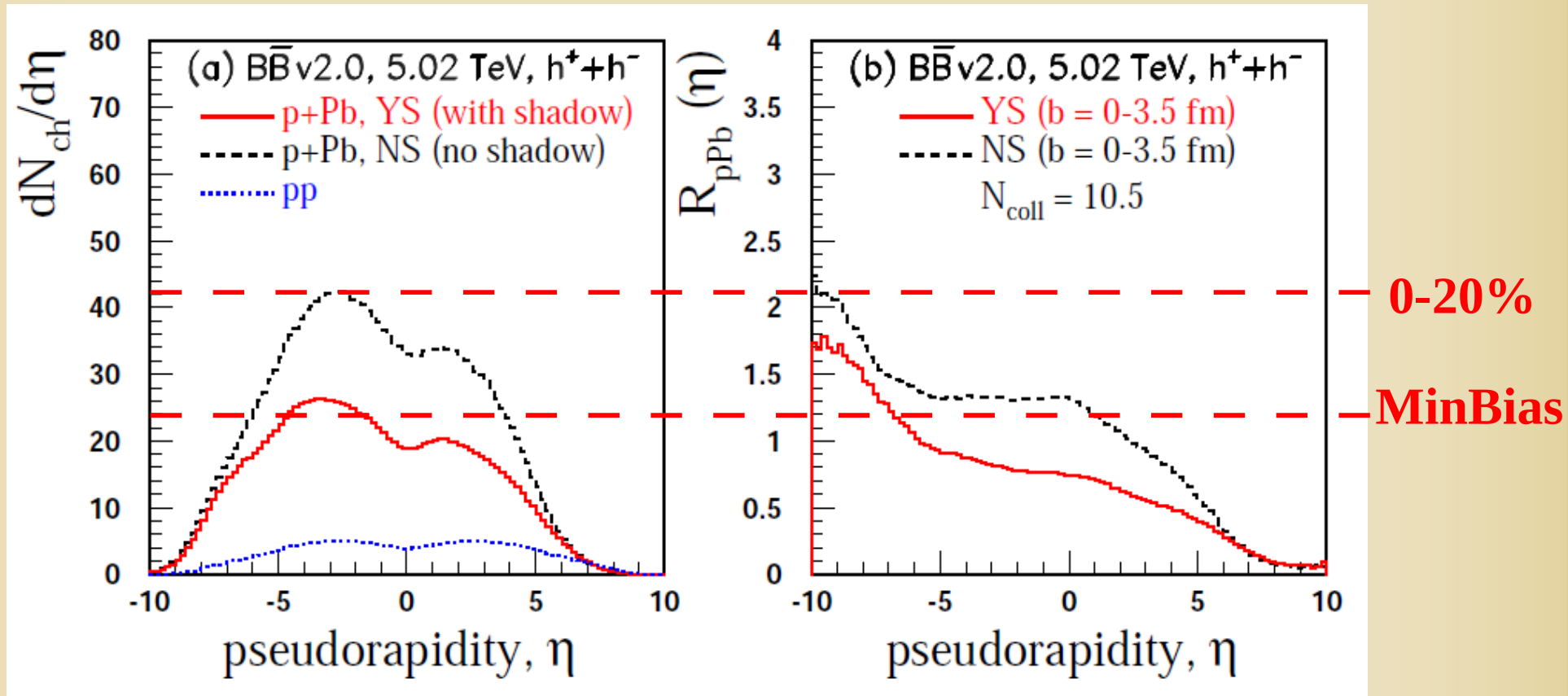
Charged hadron production with HIJING 2.0 @ 5.02 ATeV MinBias



GGB, J. Barret, M. Gyulassy, P. Lévai, V. Topor Pop (arXiv:1211.2256)

HIJINGB/B 2.0: Rapidity distribution for pp & pPb

Charged hadron production with HIJING 2.0 @ 5.02 ATeV (0-20%)



GGB, J. Barret, M. Gyulassy, P. Lévai, V. Topor Pop (arXiv:1211.2256)

S U M M A R Y

Data has been arrived

...we have several pictures

...we have to find the proper interpretation in the details

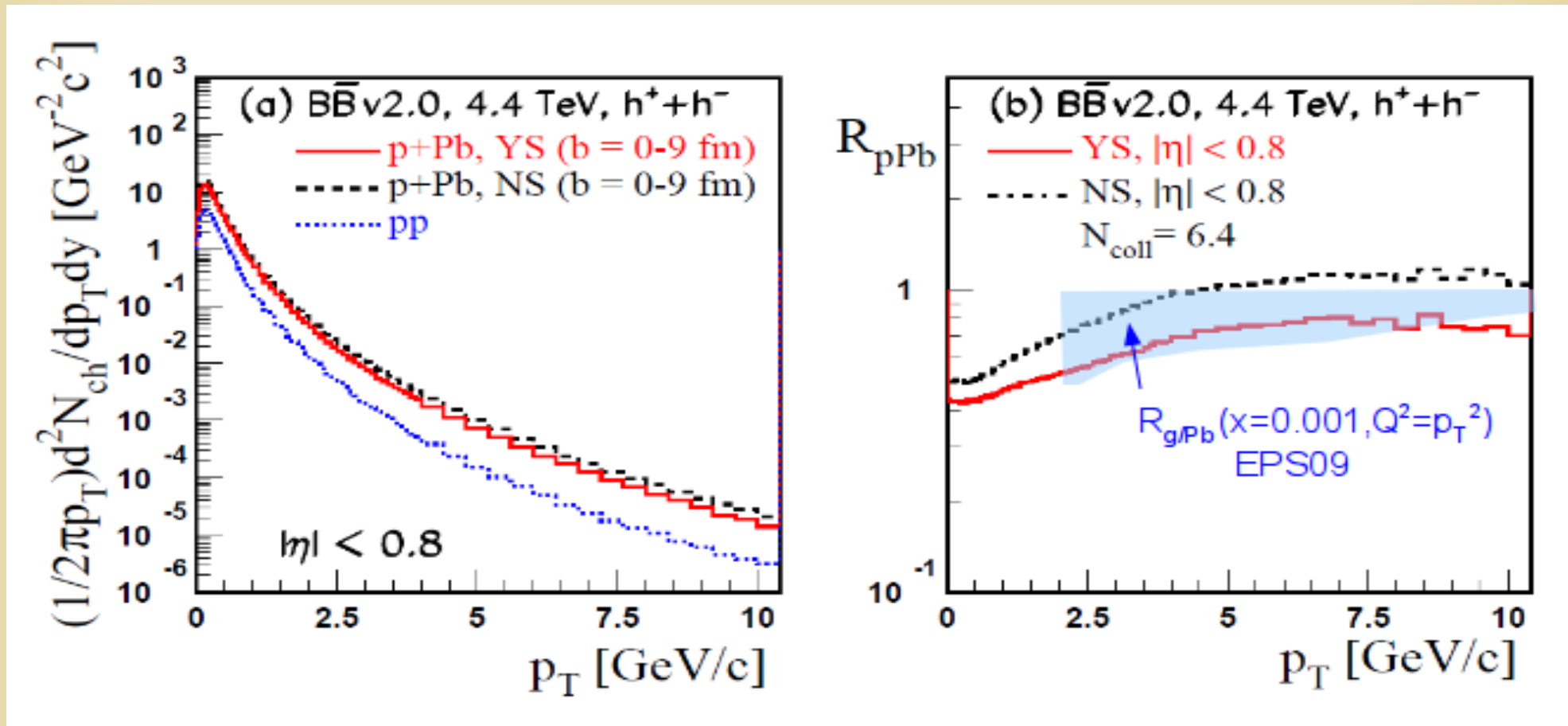


- Test of the Cronin Effect in pA
 - How strong is the effect at LHC
 - Scaling x_T , p_T , etc?
- Test of shadowing parameterizations
 - Test of existing parameterizations at low- x
- Test of the rapidity asymmetry
- Hadron correlation can be also tested

BACKUP

The Spectra and RpPb(pT) for $|\eta| < 0.8$

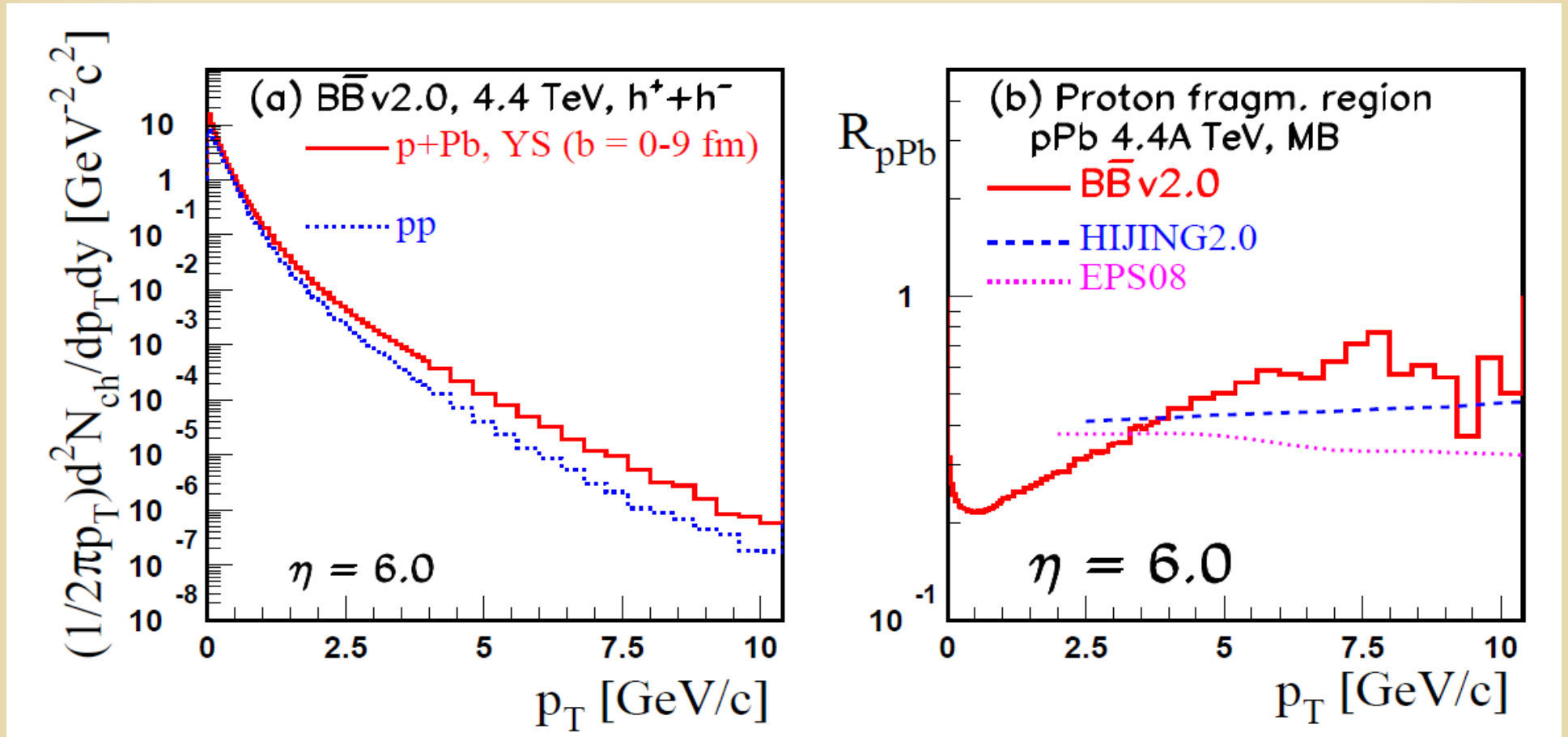
Charged hadron production with HIJING 2.0 @ 4.4 ATeV



GGB, J. Barrette, M. Gyulassy, P. Lévai, V. Topor Pop PRC85 024903 (2012)

Forward Spectra & $R_{pPb}(p_T)$ at $\eta=6.0$

Charged hadron production with HIJING 2.0 @ 4.4 ATeV



GGB, J. Barrette, M. Gyulassy, P. Lévai, V. Topor Pop PRC85 024903 (2012)