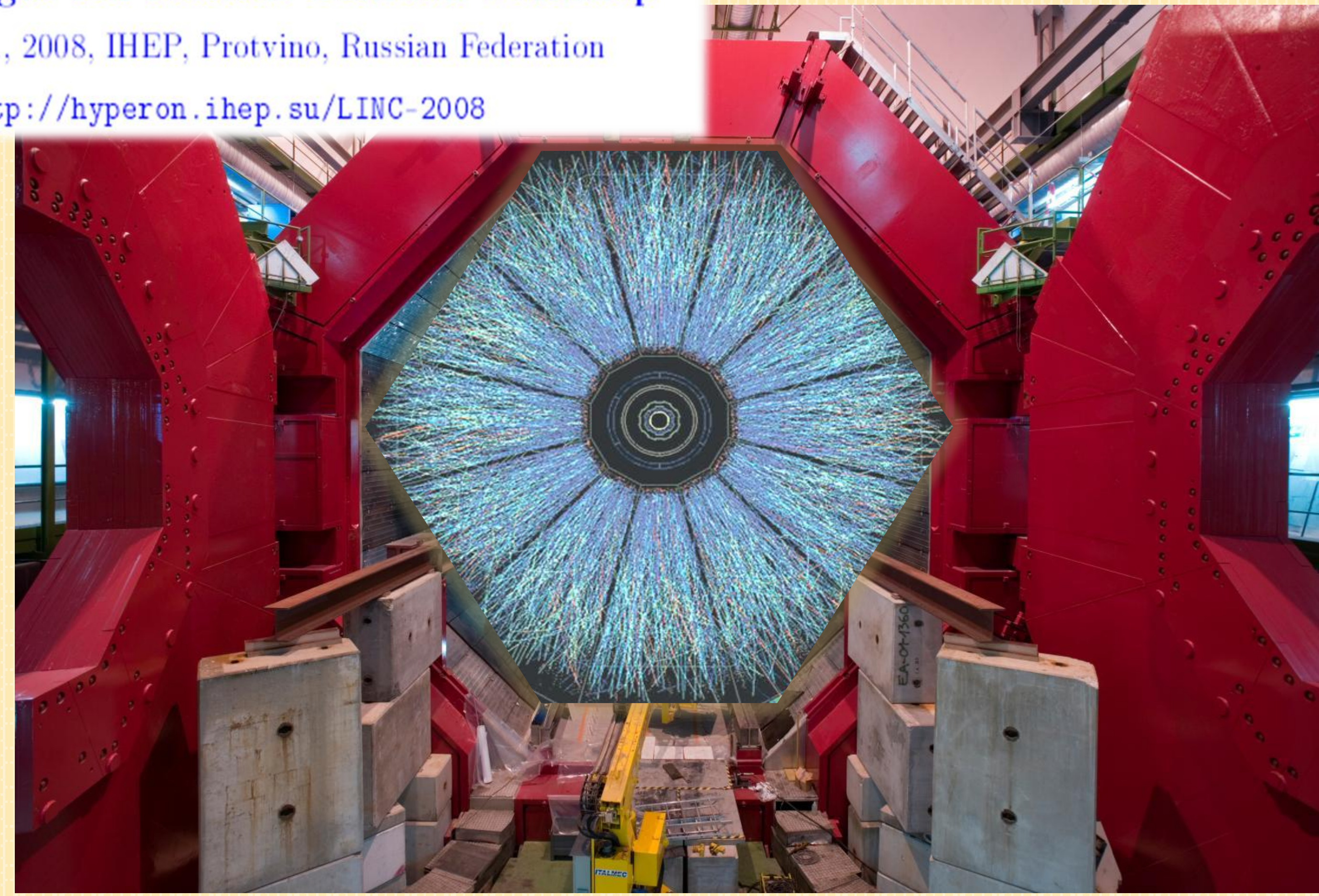
LINC-2008
The 3rd Light Ion Nuclear Collision workshop
June 18-21, 2008, IHEP, Protvino, Russian Federation
http://hyperon.ihep.su/LINC-2008

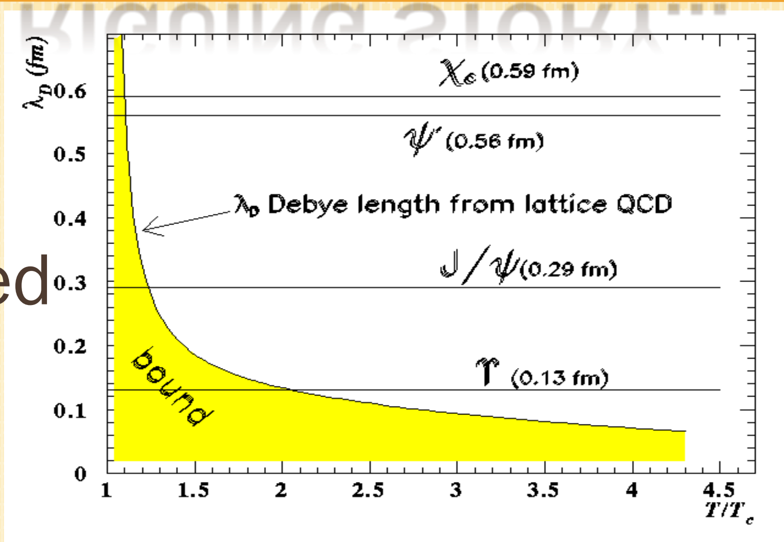


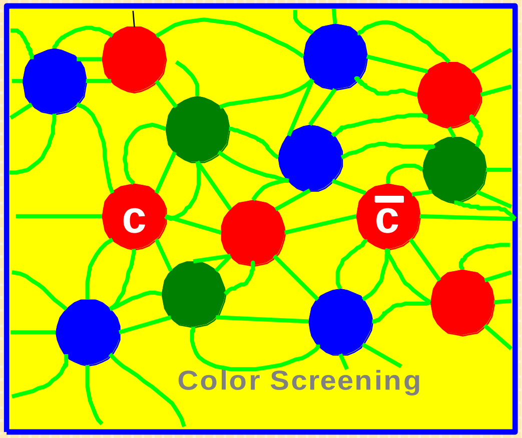
Konrad Tywoniuk
University of Oslo

CAN THE RHIC J/Ψ PUZZLE(S) BE SETTLED AT LHC?

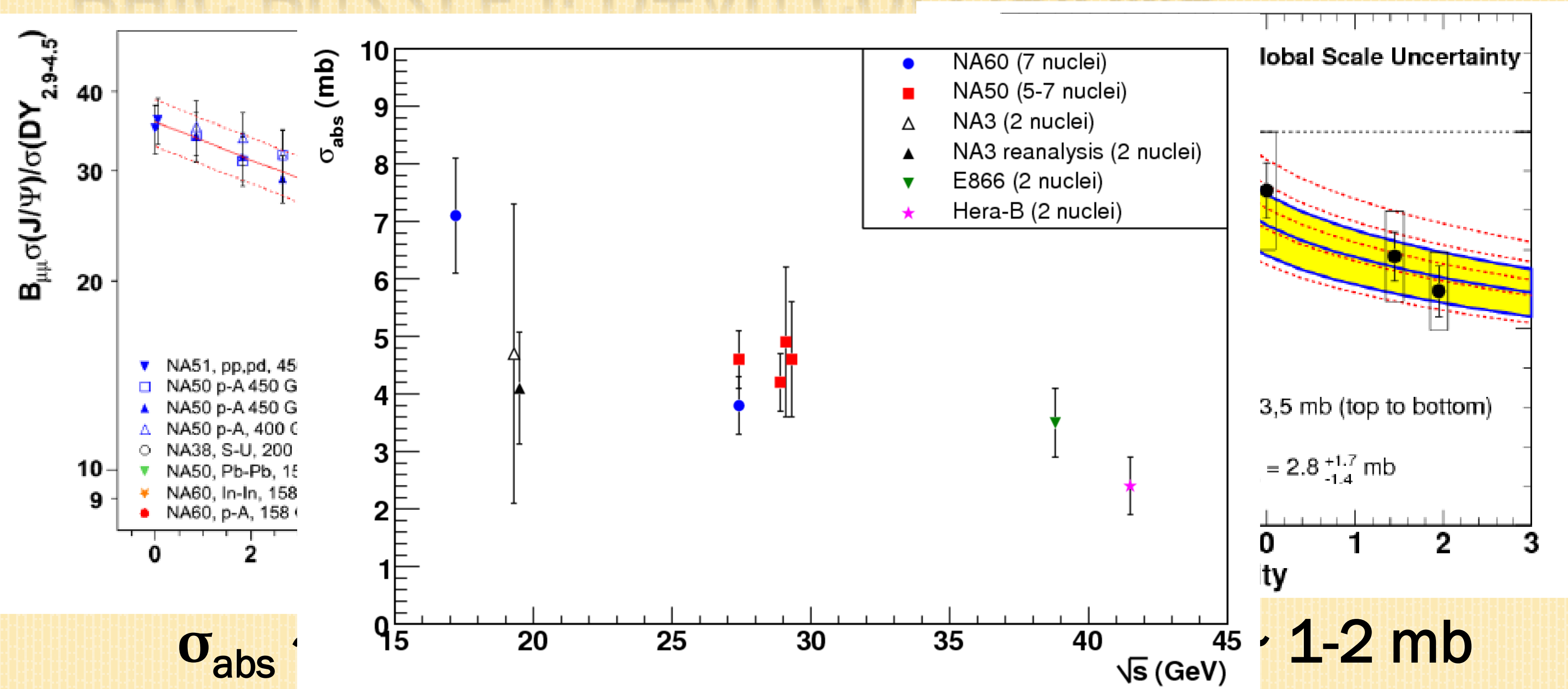
J/Ψ PRODUCTION: AN INTRIGUING STORY...

- Matsui & Satz prediction
  - J/ψ destruction in a deconfined medium by colour Debye screening
  - different states melting at different temperatures due to different binding energies
- today situation is more confusing than ever?





RHIC PUZZLE I: D+AU COLLISIONS



σ_{abs} … 1-2 mb

- vanishing σ_{abs} at some critical energy?

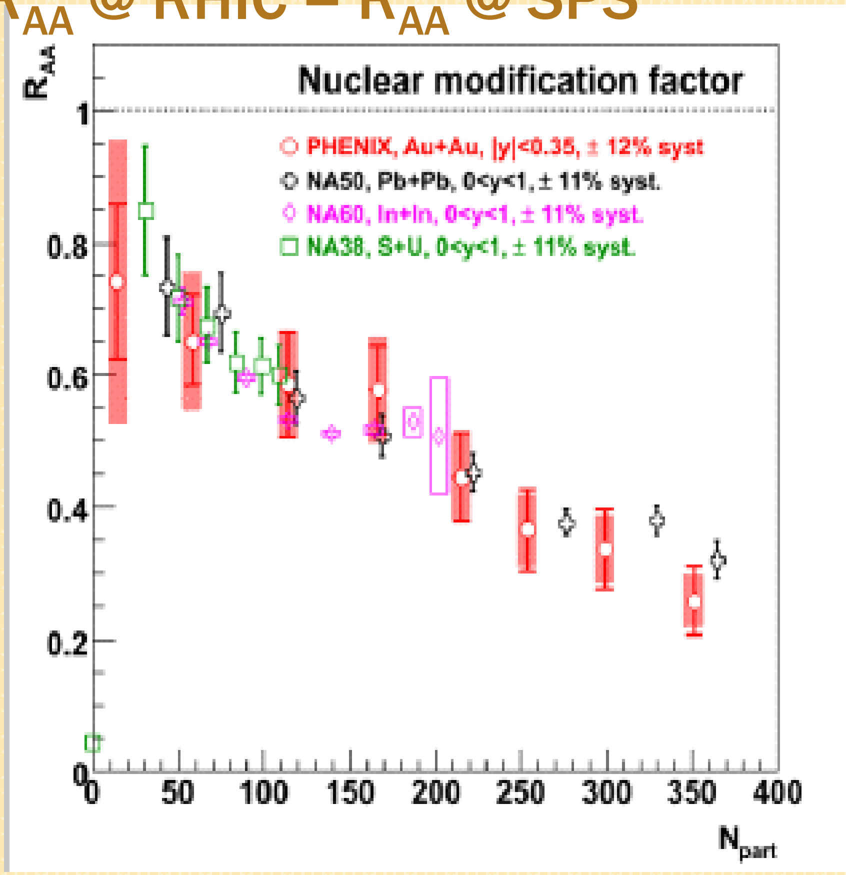
Old data analyzed in Glauber model: S ~ exp($-\sigma_{abs}$L ρ)

– what is the meaning of $\sigma_{break\text{-}up}$??

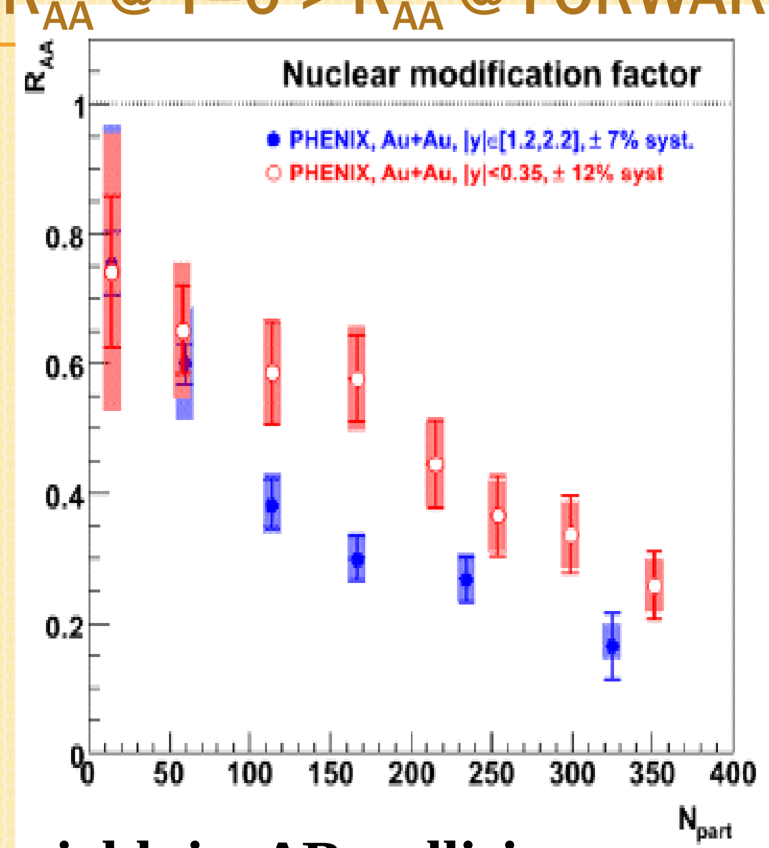
– need several nuclear targets

RHIC PUZZLE II: AU+AU COLLISIONS

R_{AA} @ RHIC = R_{AA} @ SPS



R_{AA} @ Y=0 > R_{AA} @ FORWARD



$$R_{AB} = \frac{\text{yield in AB collision}}{(\text{\# of collisions}) \times (\text{yield in pp collision})}$$

CHARMONIUM IS INTERESTING

- $E<E_C$: rescattering of J/ψ
  - absorption in nuclear medium
- $E>E_C$: J/ψ is produced coherently
  - "probe" modified nuclear gluon distribution
  - strong impact on AA observables @ RHIC, LHC

pA, dA

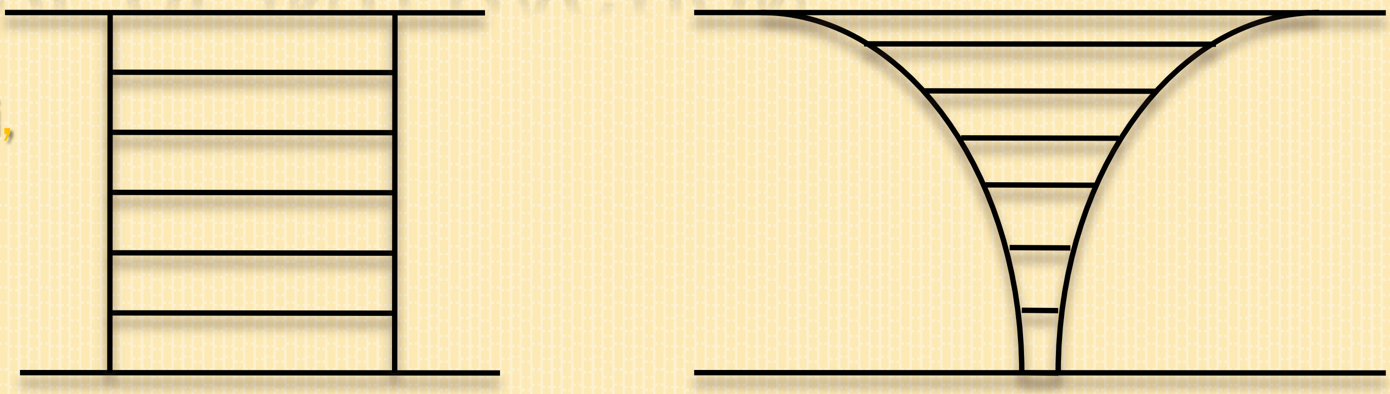
- interacts with the "medium"
  - suppression hint of large density
  - regeneration hint of thermal equilibrium

AA

Collaborators: A.B. Kaidalov, A. Capella, L. Bravina, E.G. Ferreiro, E. Zabrodin

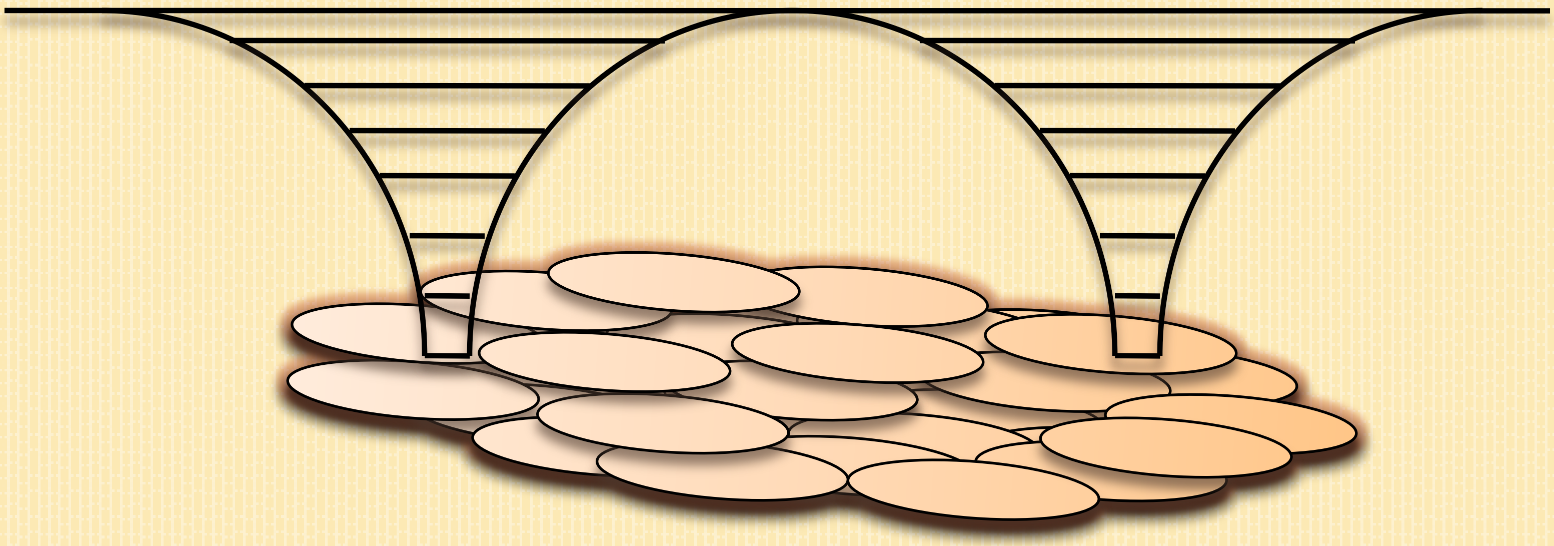
PICTURE OF INTERACTION

Amati, Fubini, Stanghellini
Gribov



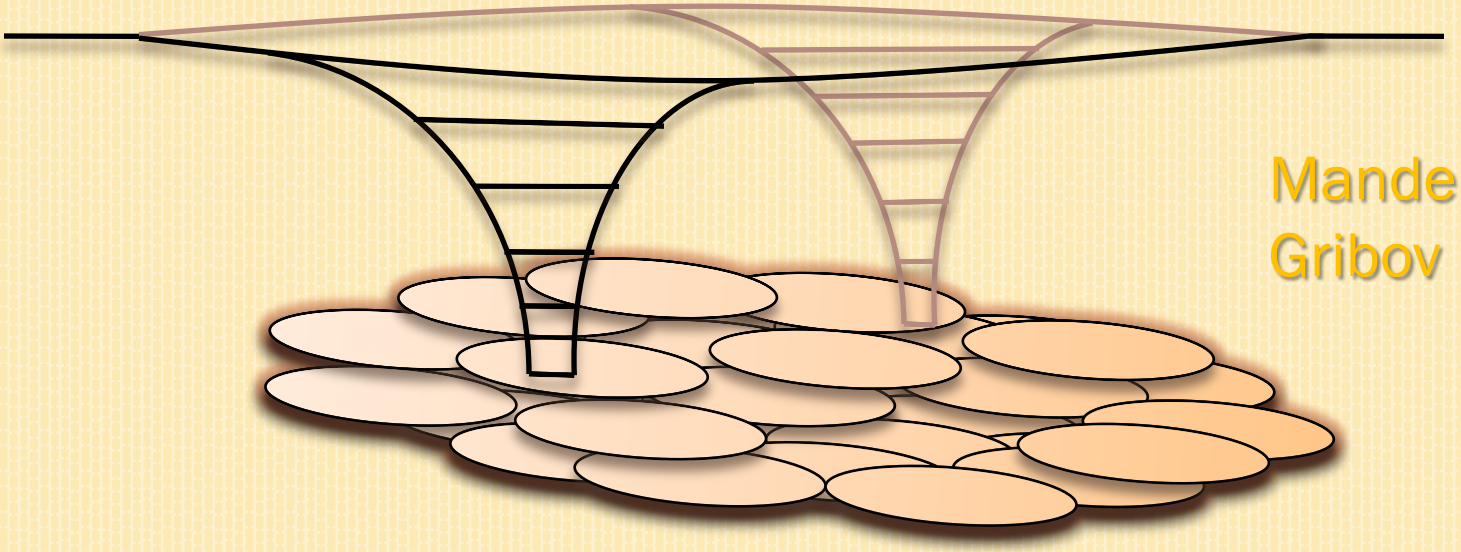
- reggeon/pomeron exchange – multiperipheral model
- the reggeon can be seen as an exchanged ladder of particles in the t-channel
  - a highly non-local object!
  - space-time picture
- particle production from cuts

PLANAR REGIME



- "classical" rescattering picture
- coherence length of fluctuation: $l_C = \dfrac{1}{m_N x}$
- large probability of rescattering
  - strong absorption effects
  - controlled by σ_{abs}

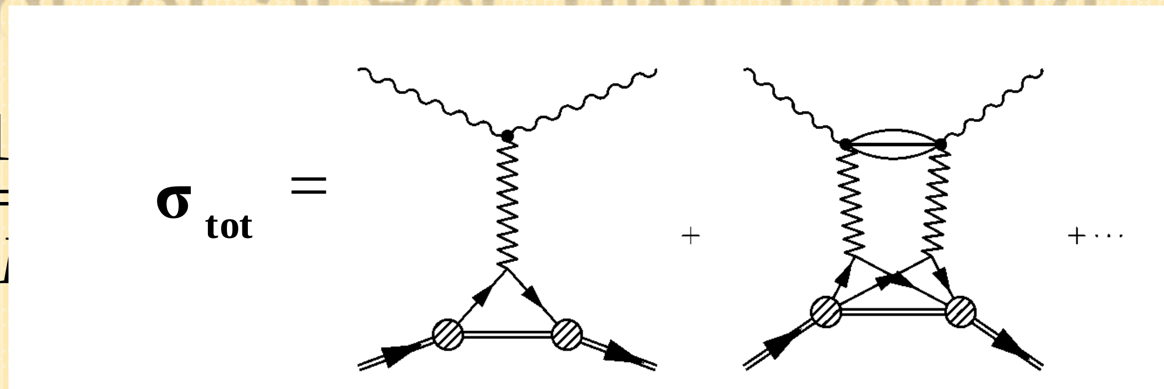
NON-PLANAR REGIME



- planar diagram vanishes at high energies
  - ladders require a long time to develop
  - critical x ~ 0.1
- the projectile goes into a fluctuation long before the collision takes place
  - ladders develop at the same time

CHANGE OF SPACE-TIME PICTURE

$\sigma^{(2)}_{tot} = \frac{1}{\sqrt{\ldots}}$



+ . . .

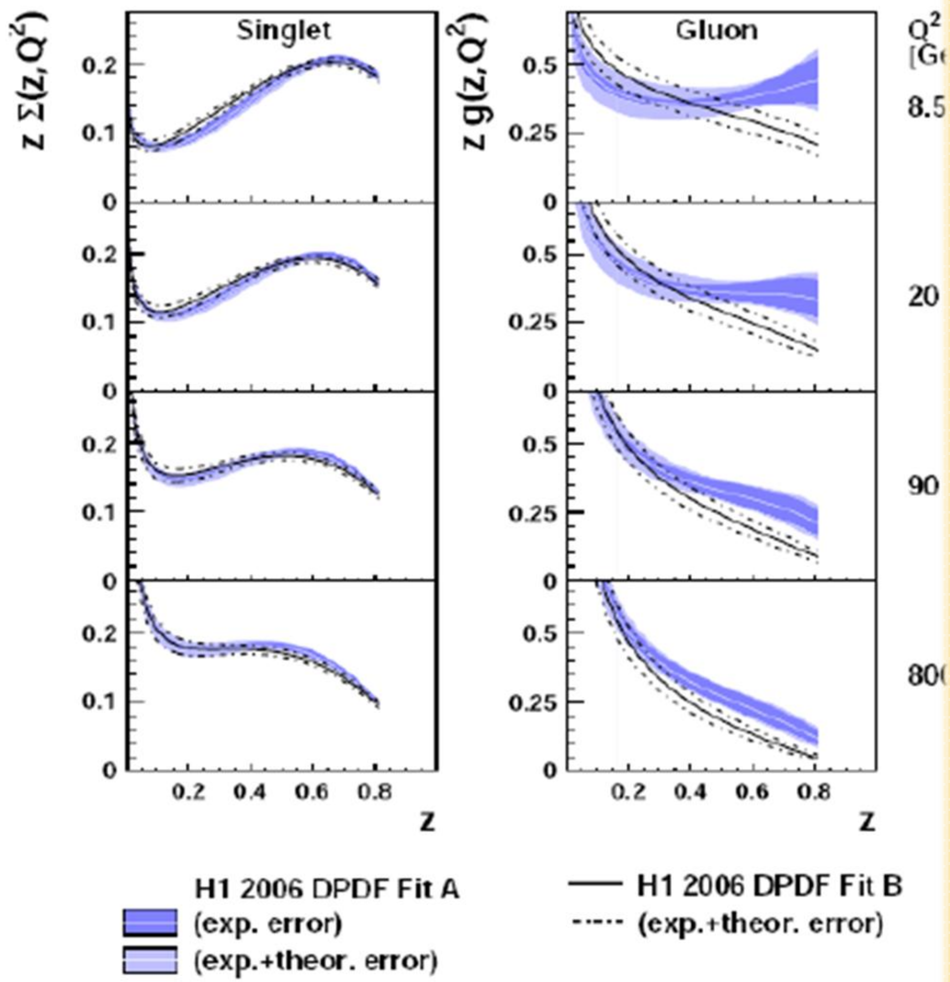
- the diagrams corresponding to ”classical” rescatterings are suppressed at high energies!
- Gribov trick: Glauber is OK after all! Almost…
- have to take into account diffractive intermediate states!

HARD DIFFRACTION @ HERA

$$\left[\frac{d\sigma^{\mathcal{D}}_{\gamma^* N}}{dM^2 dt}\right]_{t=0} = \frac{4\pi^2 \alpha_{em} B}{Q^2(Q^2+M^2)} x_{I\!P} F^{(3)}_{2\mathcal{D}}$$

FIT A and B

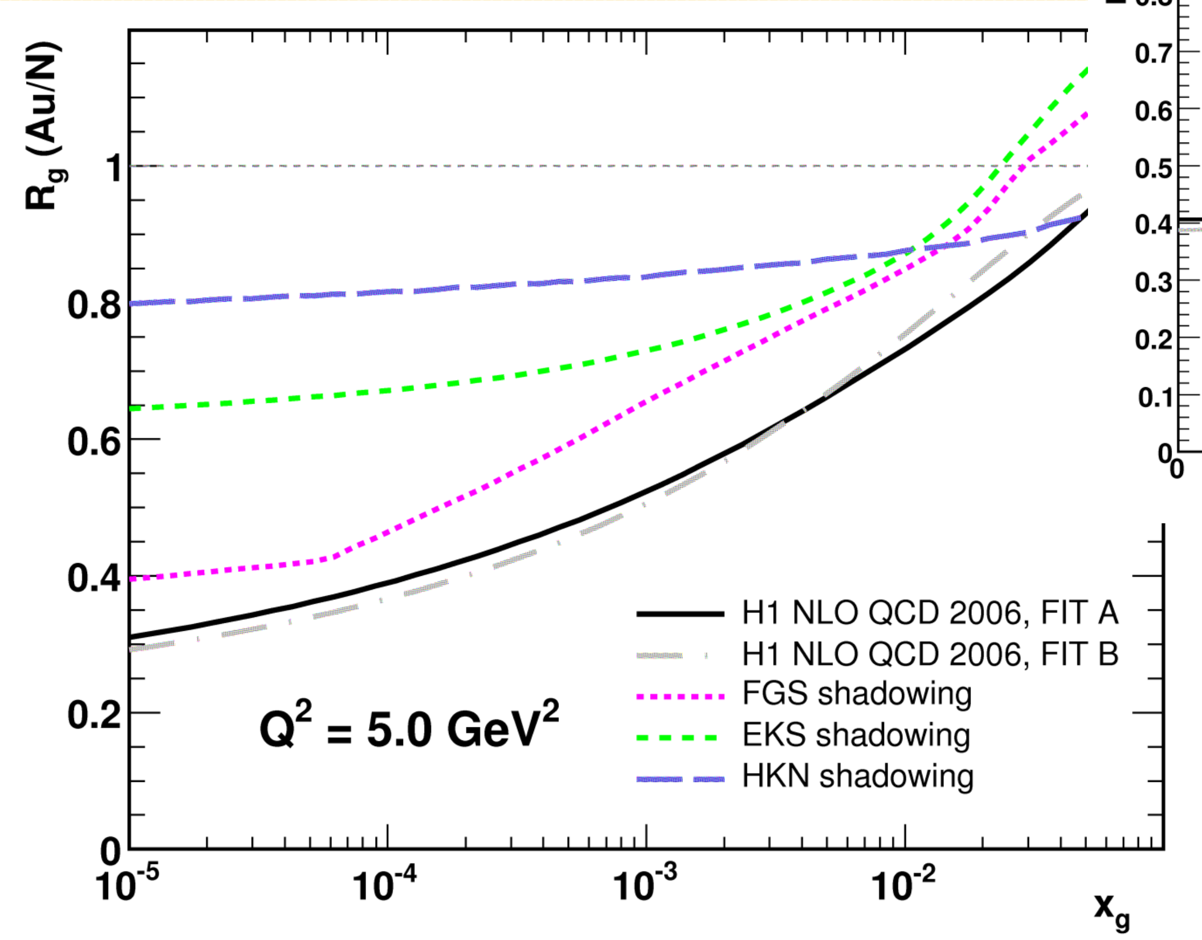
- two available fits, parameterized at low $Q_0 = 1.75 - 2.5\ \mathrm{GeV}^2$
- maximal uncertainty in gluon dPDF due to mixing with quarks at $\beta > 0.3$
- can be further constrained by combined fit to additionally diffractive dijets and heavy flavor

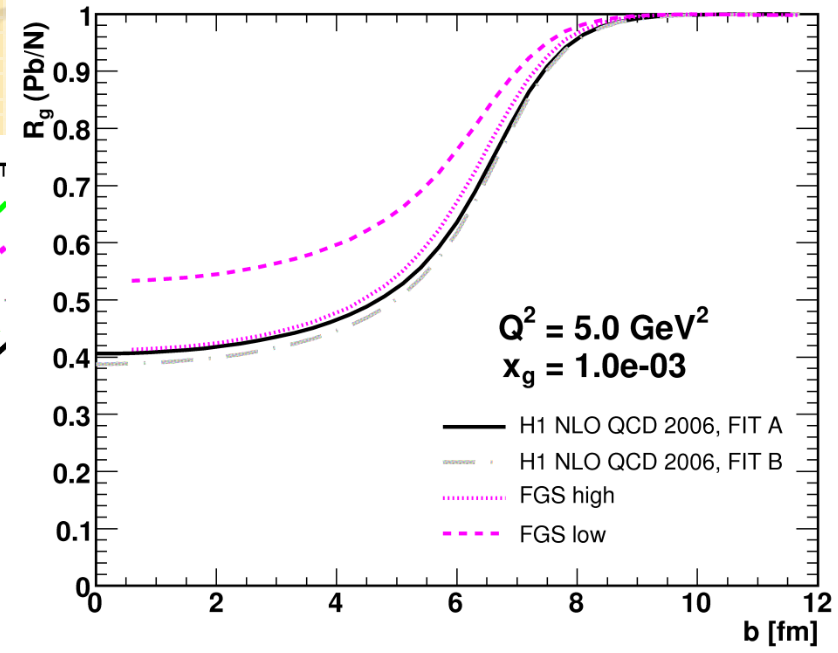


H1 Collaboration, hep-ex/0606003,

GLUON SHADOWING RESULTS

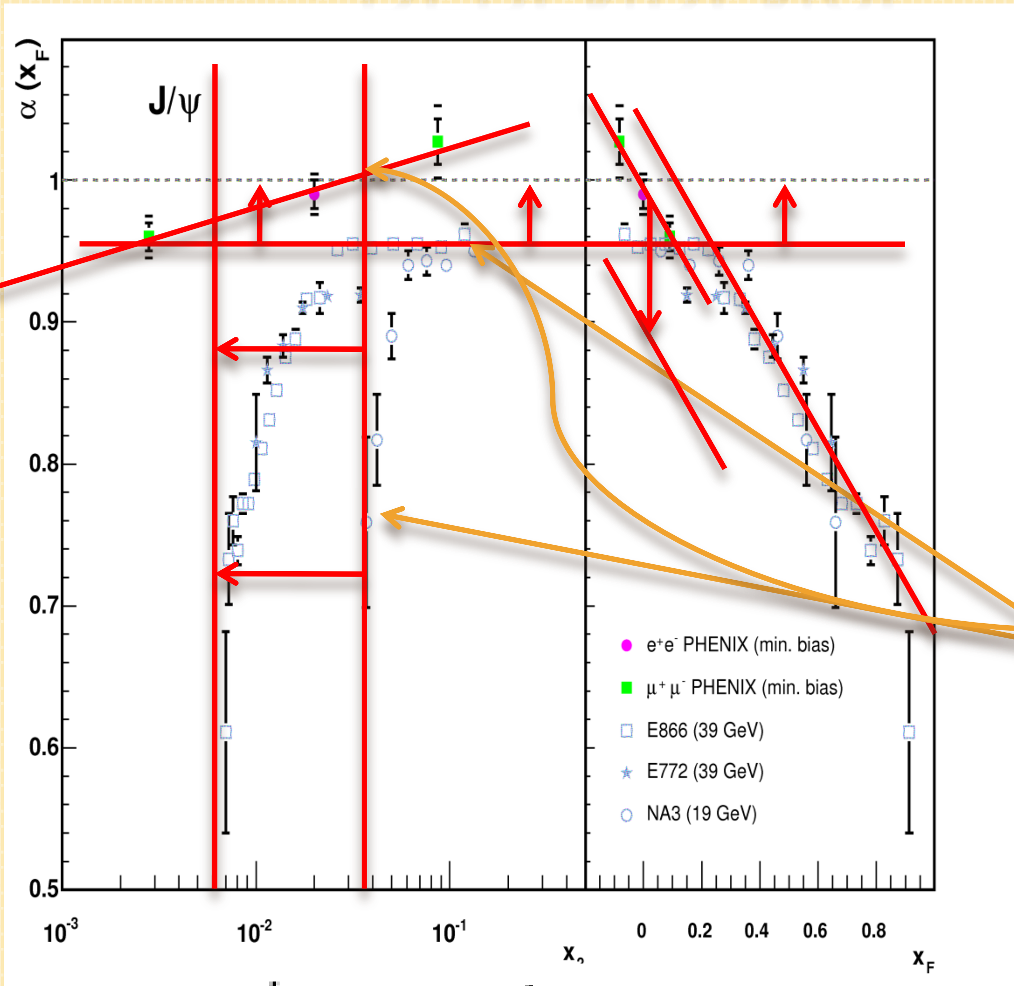
Arsene, Bravina, Kaidalov, Tywoniuk, Zabrodin
PLB 657 (2007) 170





- valid for $x < 0.05$ and $Q^2 > 2$ GeV^2

$\alpha(X_F)$ DEPENDENCE



$$\frac{d\sigma_{pA}}{dy} = \frac{d\sigma_{pp}}{dy} A^{\alpha(x_F)}$$

- change of behaviour when increasing $\sqrt{s}$
- $\alpha(x_F=0)$ sensitive to changing initial-state

energy-momentum conservation

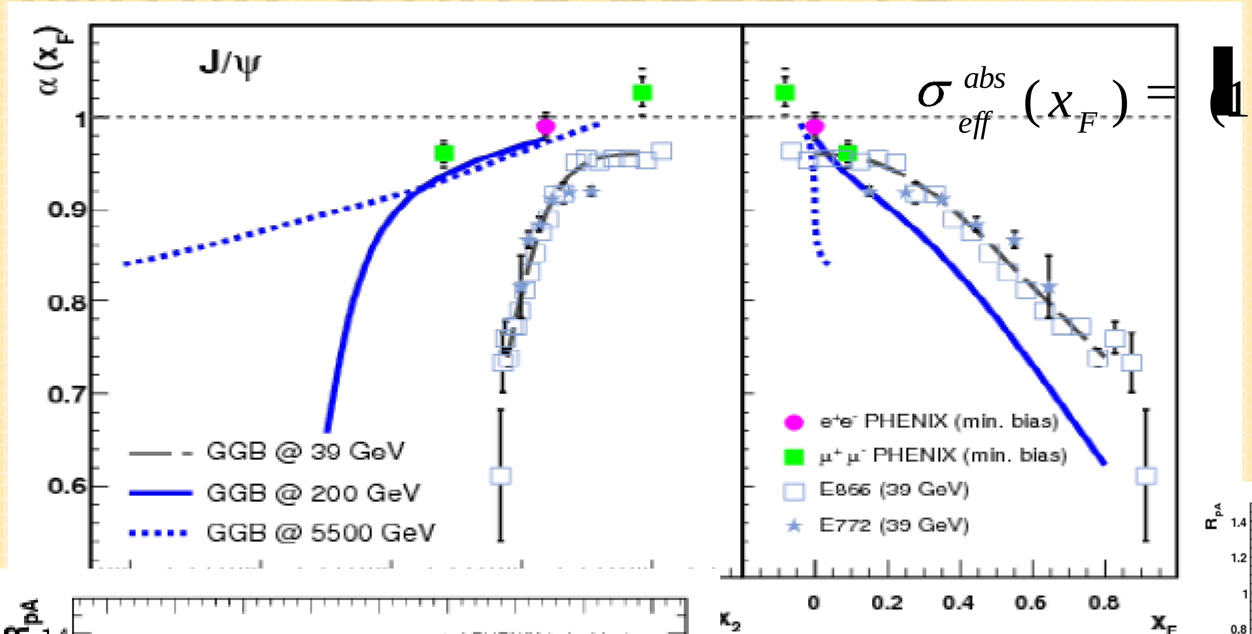
shadowing

absorption

- $\alpha(x_F \approx 1)$ has universal behaviour
- x_2 scaling at high energies

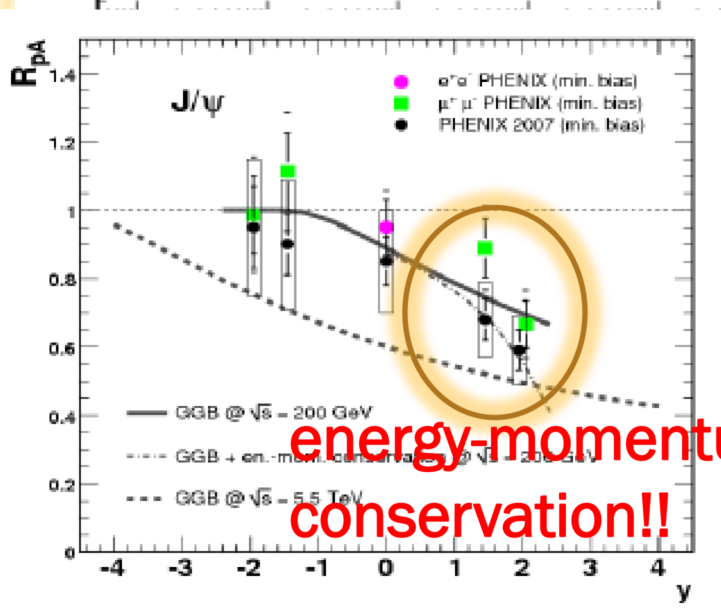
INITIAL STATE EFFECTS

Tywoniuk et al. PLB 660 (2008) 176
Capella, Ferreiro PRC 76 (2007) 064906



$$\sigma_{eff}^{abs}(x_F) = \left[(1-\varepsilon)\Phi(t_{min}) + \varepsilon x_+^2\right]\sigma_{c\bar{c}-N}$$

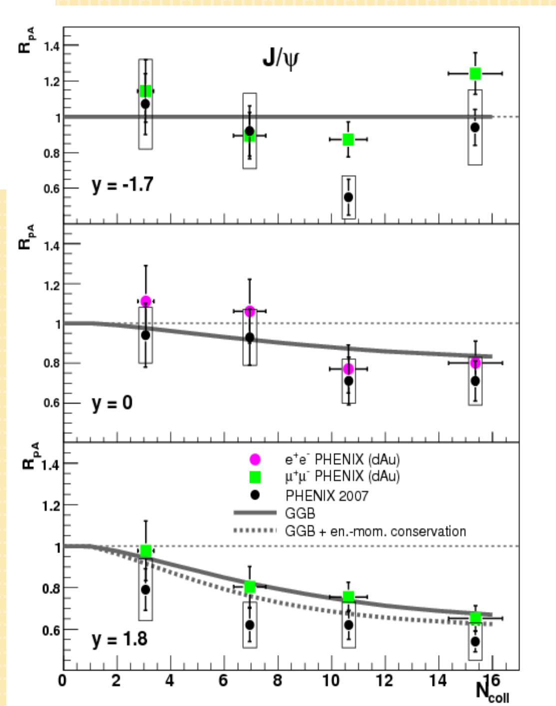
LHC will be free of LE effects!



energy-momentum conservation!!

rapidity and centrality are under control

$\sigma_{abs}(y=0)=0$



COMOVERS INTERACTION MODEL

Capella, Armesto, Ferreiro, Sousa, Kaidalov... finite energy effects - DPM

- rescattering → "J/ψ's fall apart"
- what is the medium?
  - directly related to the multiplicity of the collision

$$N^{co} = \frac{3}{2}\left[C_1(b,y) N_{part}(b,y) + C_2(b,y) N_{coll}(b,y) \right] S^{sh}(b,y)$$

  - not necessarily thermalized
- interaction can take place with
  - "partonic" medium – early times
  - hadronic medium – late times
- the cross section should be averaged over p_T distributions of colliding particles and time

COMOVERS INTERACTION MODEL

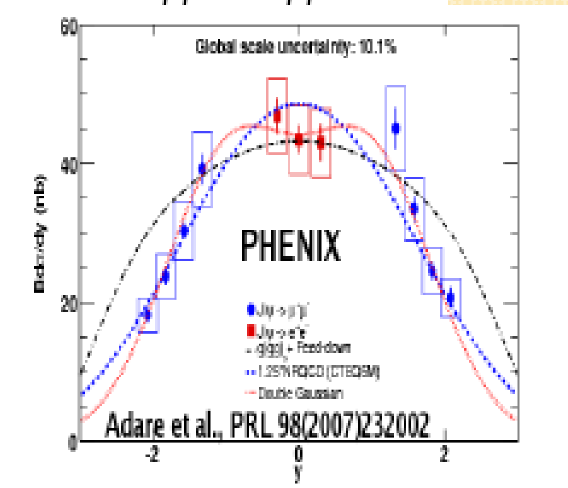
- Solving rate equation

$$\tau \frac{d}{d\tau}\frac{dN^{J/\psi}}{d\tau}(b,s,y) = -\sigma\left\{N_{J/\psi}N^{co} - N_D N_{\bar{D}}\right\}, s, y)$$

- Charmonium survival probabilty

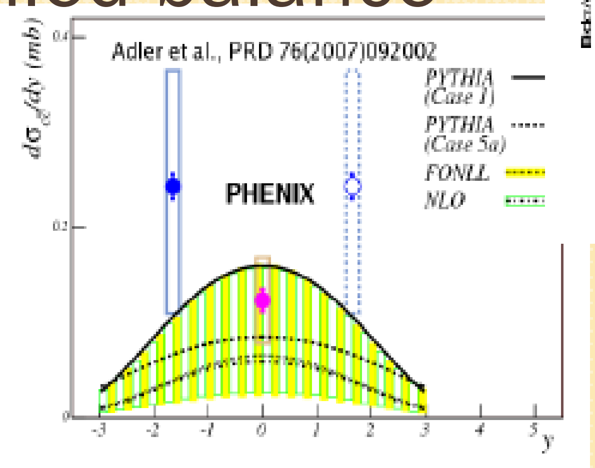
$$S^{co}(b,s,y) = \exp\left\{-\sigma N^{co}\ln\left[\frac{N^{co}}{N_{pp}}\right]\right\} \times (N^{co}(b, \quad C = \frac{\left(d\sigma_{pp}^{c\bar{c}}/dy\right)^2}{\sigma_{pp}^{ND}\, d\sigma_{pp}^{J/\psi}/dy}$$

$$\exp\left\{\sigma\, Cn(b,s)\ln\left[\frac{N^{co}}{N_{pp}}\right]\right\}$$



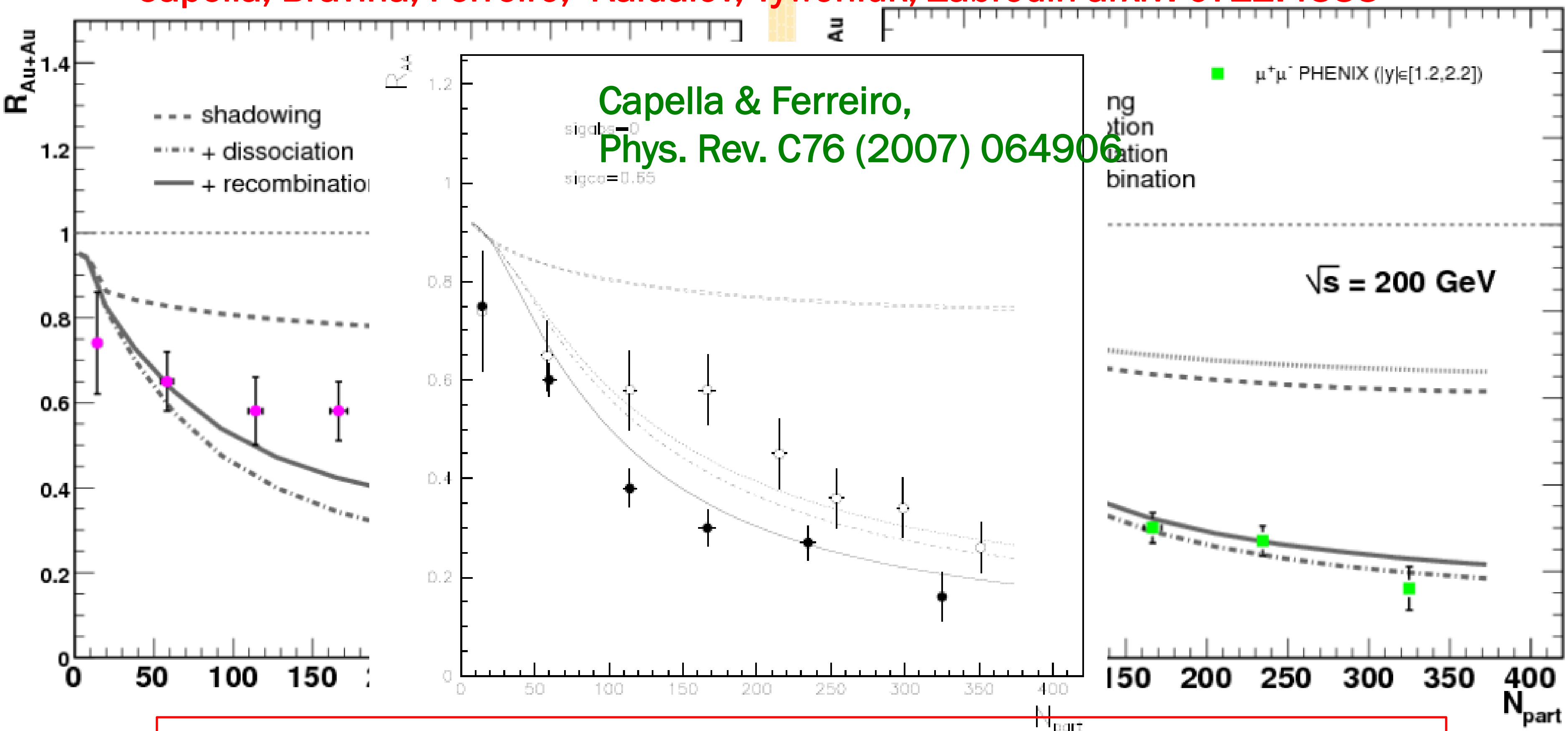
- natural from detailed balance
- input from pp →
- from NA50 fit:

$$\sigma = 0.65 \text{ mb}$$



CIM RESULTS: AU+AU @ 200 GEV

Capella, Bravina, Ferreiro, Kaidalov, Tywoniuk, Zabrodin arxiv: 0712.4333

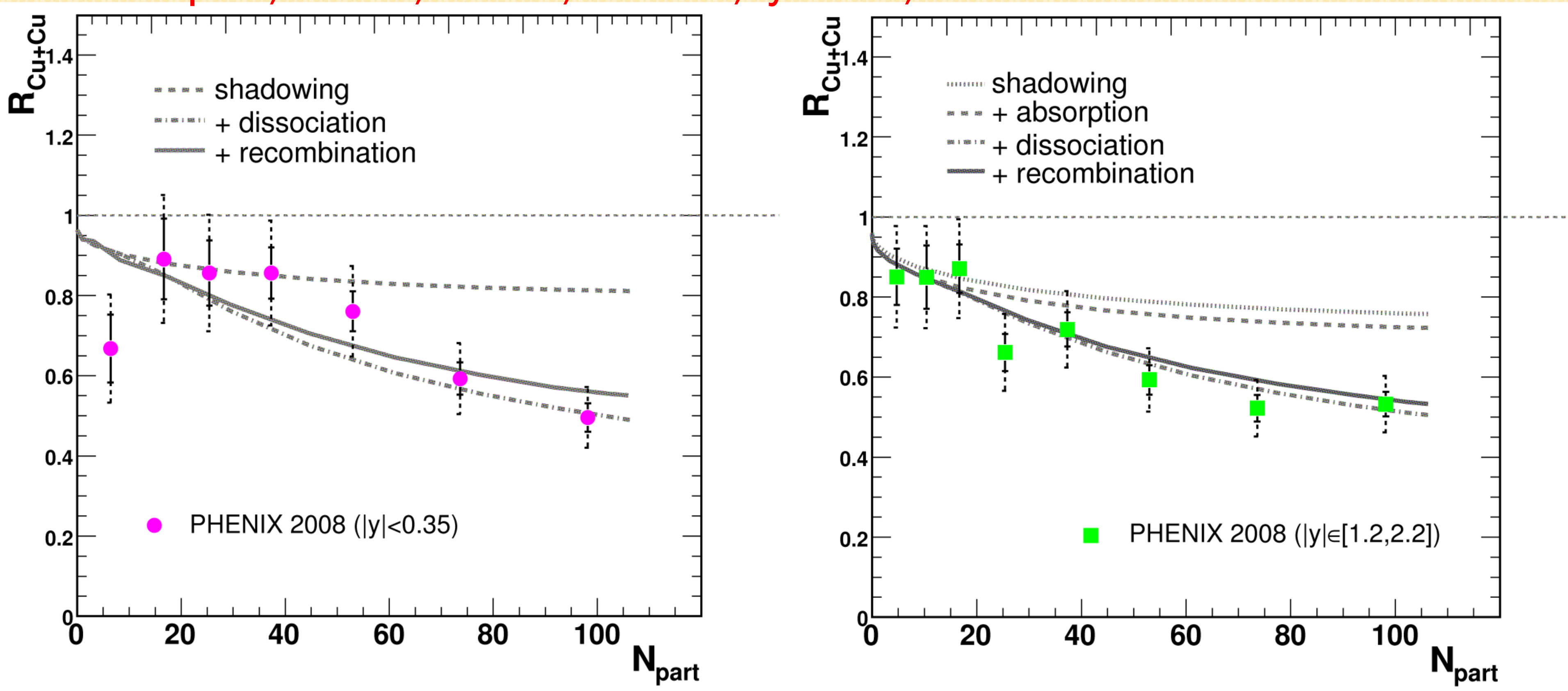


- ❑ weaker comover suppression at forward
- ❑ weaker recombination at forward
- ❑ stronger initial state effects!

no adjusted parameters!

CIM RESULTS: CU+CU @ 200 GEV

Capella, Bravina, Ferreiro, Kaidalov, Tywoniuk, Zabrodin arxiv: 0712.4333

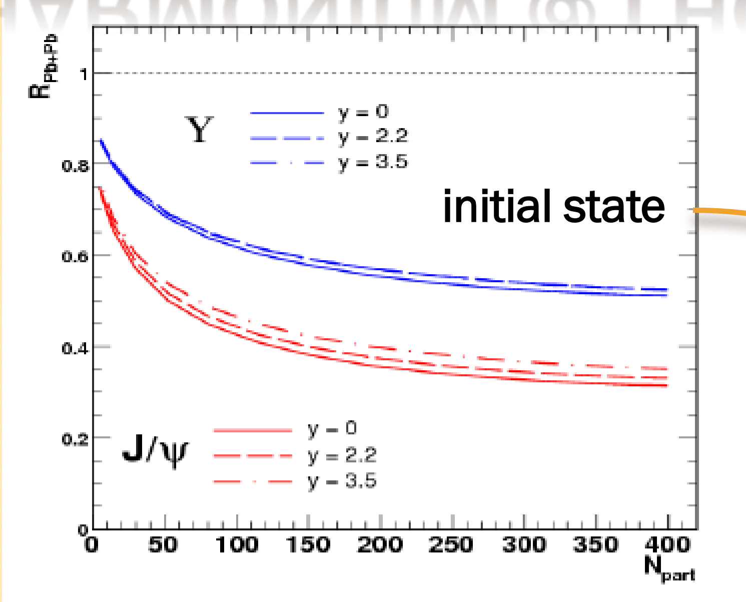


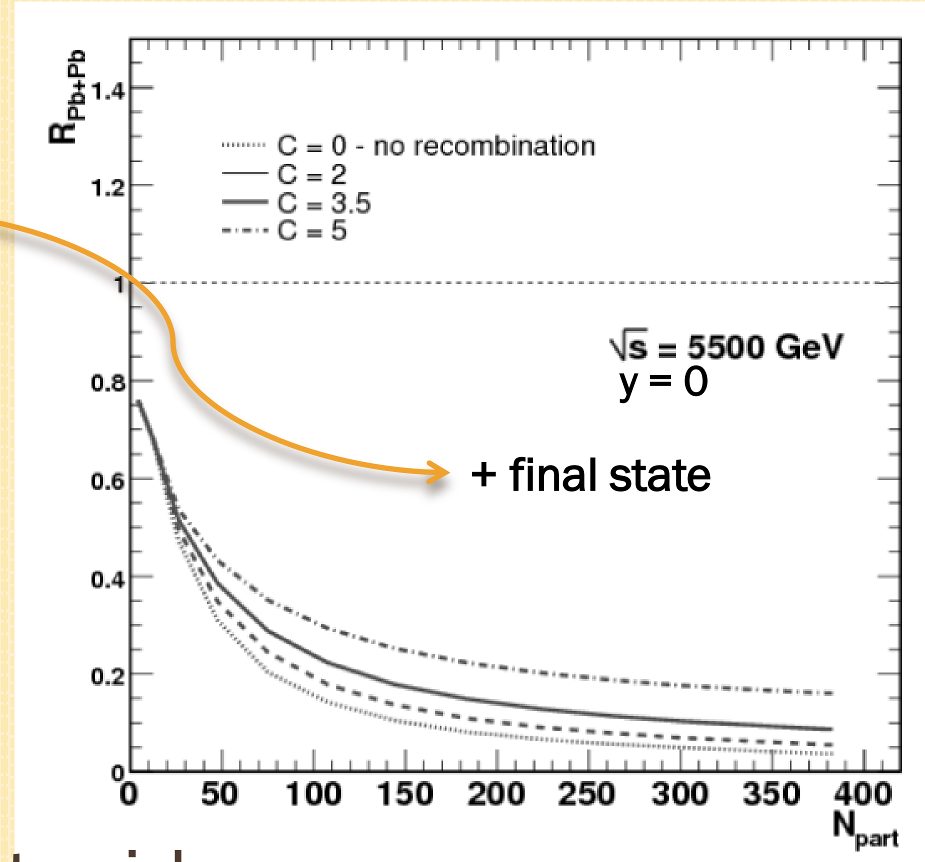
Recombination a small but important correction!

Consistent with HSD with pre-hadron interaction

Linnyk et al. arXiv:0801:4282

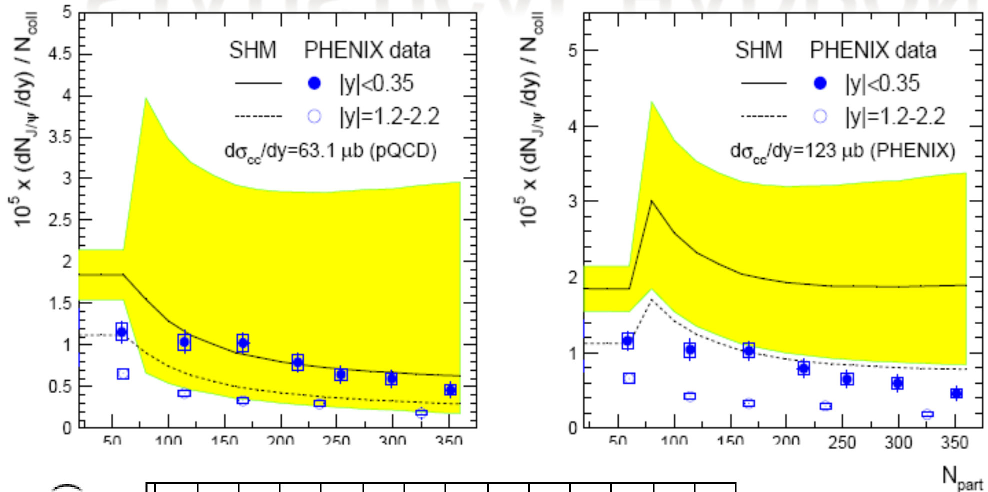
CHARMONIUM @ LHC

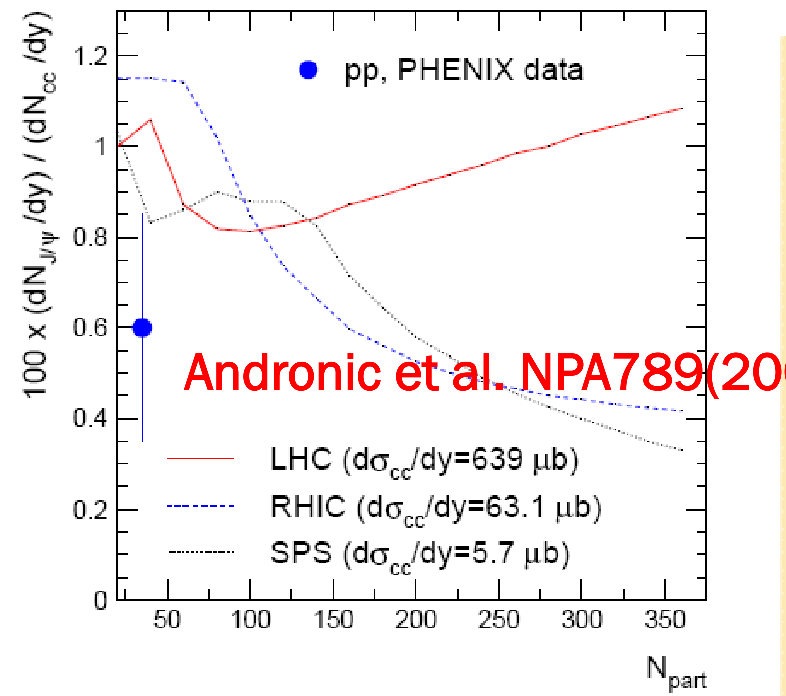




- large gluon shadowing
- prediction: N^{co} ~ 1800 at mid-rap
- final state suppression ≈ @RHIC
- $\sigma_{(c\ c\text{-bar})} \sim s^{0.3} \sim 1$ mb @ LHC

STATISTICAL HADRONIZATION





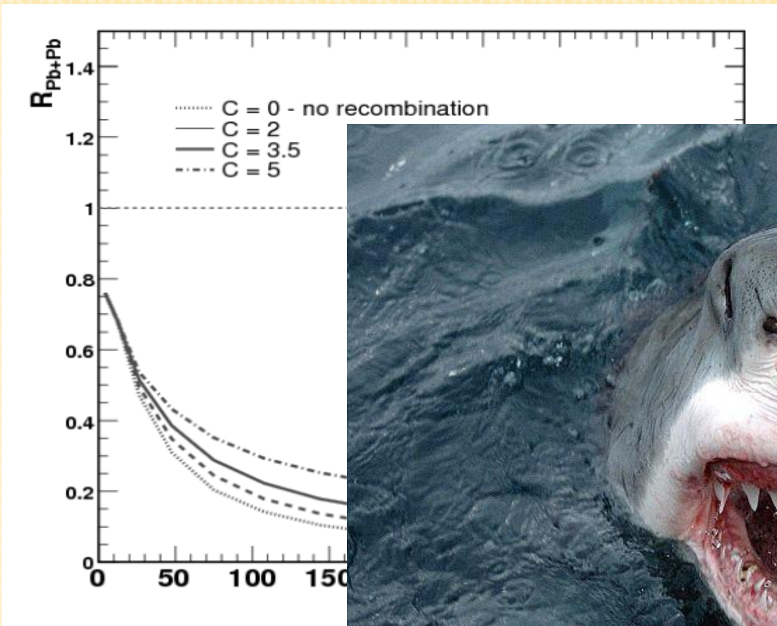
Andronic et al. NPA789(2007)334

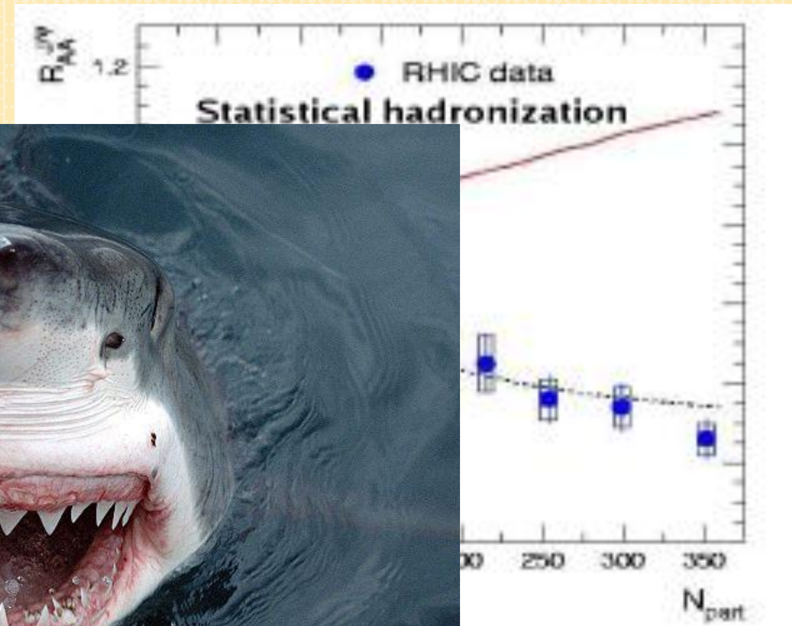
- thermalization of heavy quarks lead to opposite results!
- NOTE:
  - no "b-separation"
  - whole volume interacts!
- strong dependence on pp cross section
- doesn't care about dA
- suppression for Y!

FINALLY SOME ANSWERS?

- the large lever arm in energy can discriminate between different physical mechanisms
  - recombination wins in thermal eq. scenario
  - strong suppression in ”step-wise” comover interaction scenario
- initial-state is non-trivial!
  - geometry...
  - less charmonium in ”pre-equilibrium” phase
  - thermalization can arise from highly coherent gluon field?

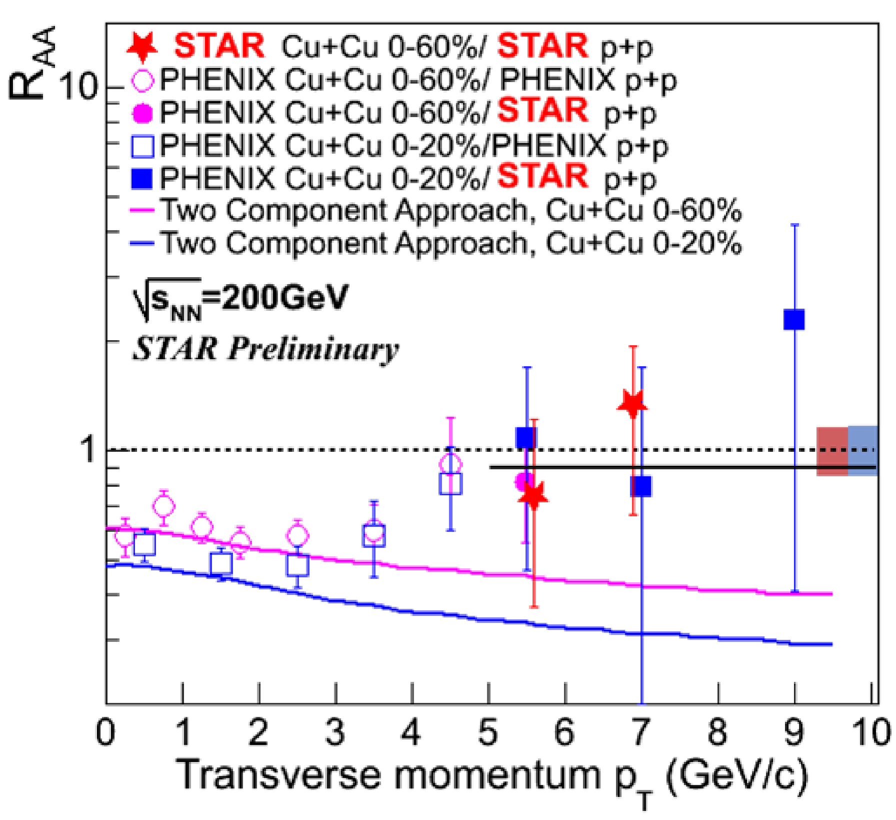
SO….



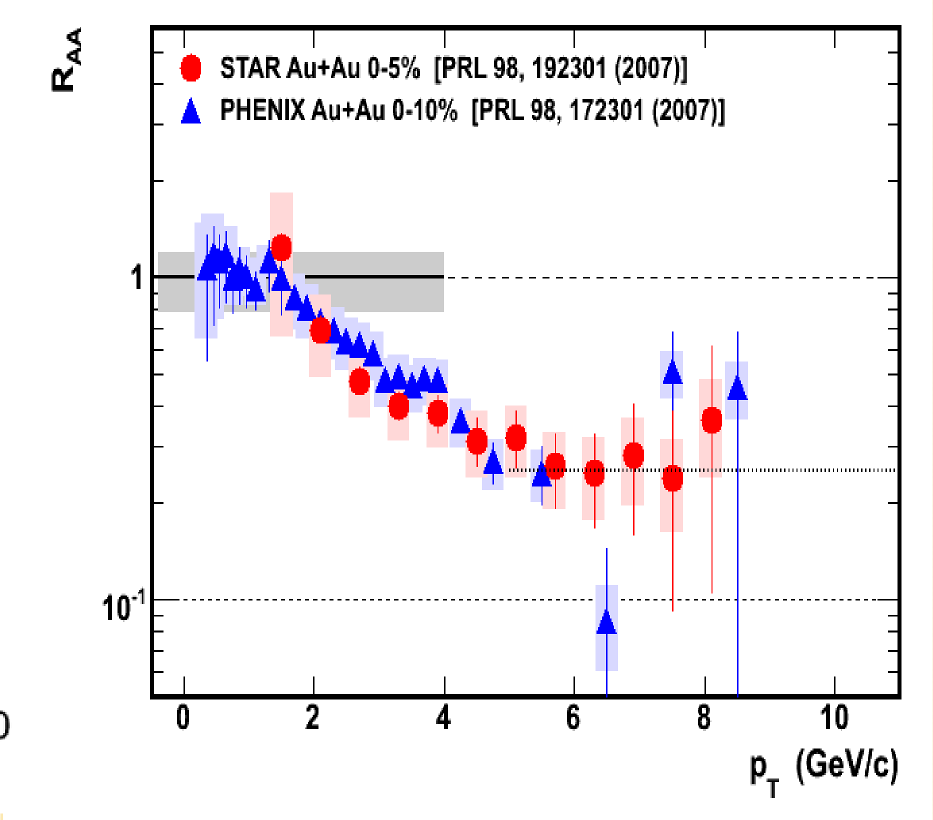


THANK YOU FOR YOUR ATTENTION!

J/Ψ SUPPRESSION

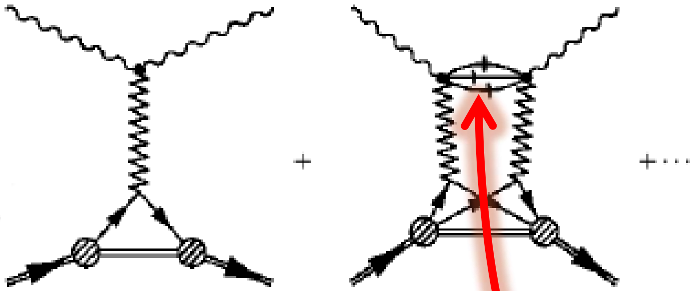


OPEN CHARM SUPPRESSION



ANOTHER RHIC PUZZLE?

GLAUBER-GRIBOV RESCATTERING



- The contribution from 1, 2. . . scatterings can be expanded in $\sigma_{pA} = \sigma_{pA}^{(1)} + \sigma_{pA}^{(2)} + \ldots .$

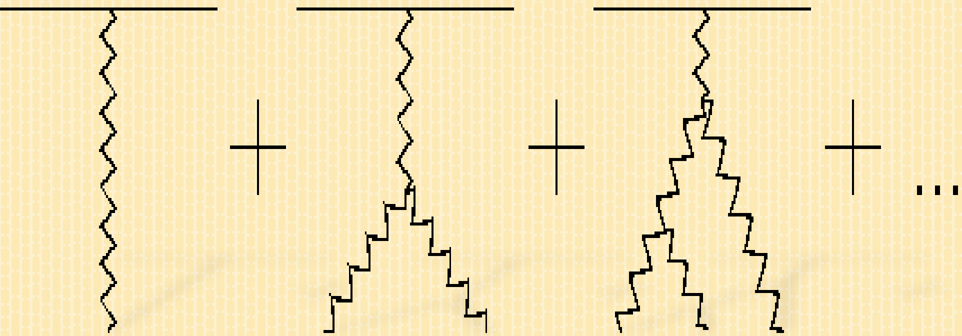
$$\sigma_{pA}^{(1)} = A \cdot \sigma_{NN} ,$$

$$\sigma_{pA}^{(2)} = -4\pi A(A-1) \int d^2 b T_A^2(b) \int_{M_{min}^2}^{M_{max}^2} dM^2 \left[\frac{d\sigma_{\gamma^* N}^{\mathcal{D}}(Q^2, x_P, \beta)}{dM^2 dt} \right]_{t=0} F_A^2(t_{min})$$

Karmanov, Kondratyuk, Pisma Zh.Eksp.Teor.Fiz.**18** (1973) 451
Armesto et al., Eur.Phys.J.C **29** (2003) 531
Frankfurt, Guzey, Strikman, Phys. Rev. D **71** (2005) 054001

SHADOWING FROM FAN DIAGRAMS

- Schwimmer model
- good for ep, eA, pA
- similiar to BK eq
- similiar to eikonal



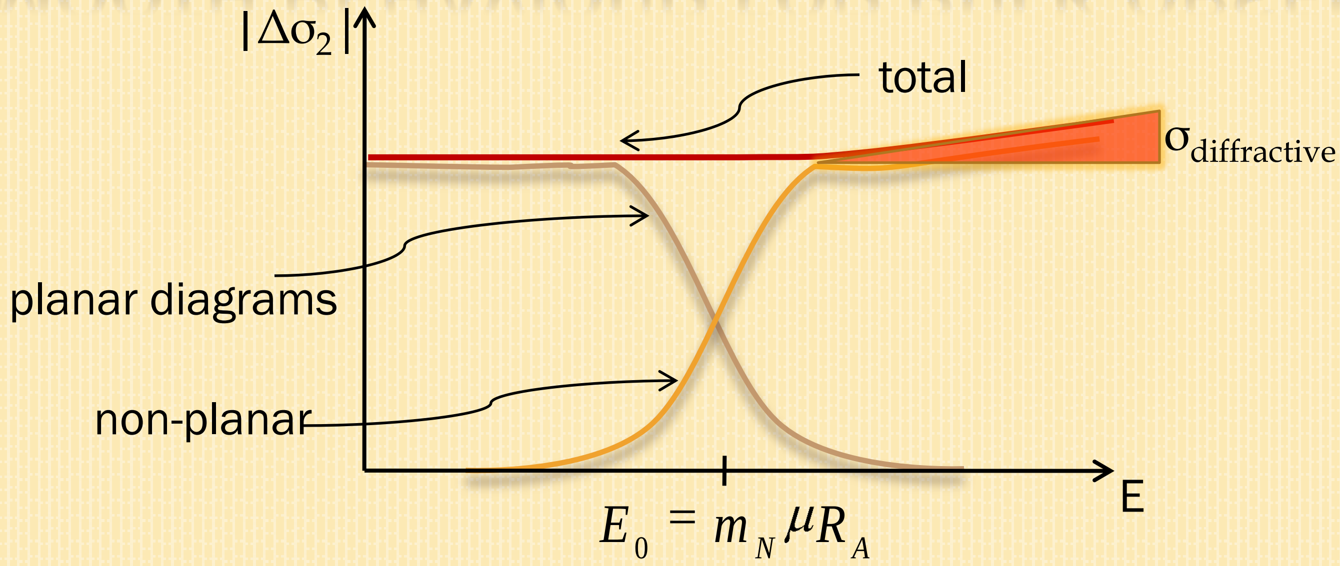
diffractive structure function = "Pomeron PDF" H1 2006

$$\sigma_{hA}^{tot} = \sigma_{hN} \int d^2b \frac{A\,T_A(b)}{1 + (A-1)\,f(x,Q^2)\,T_A(b)}$$

proton PDF CTEQ

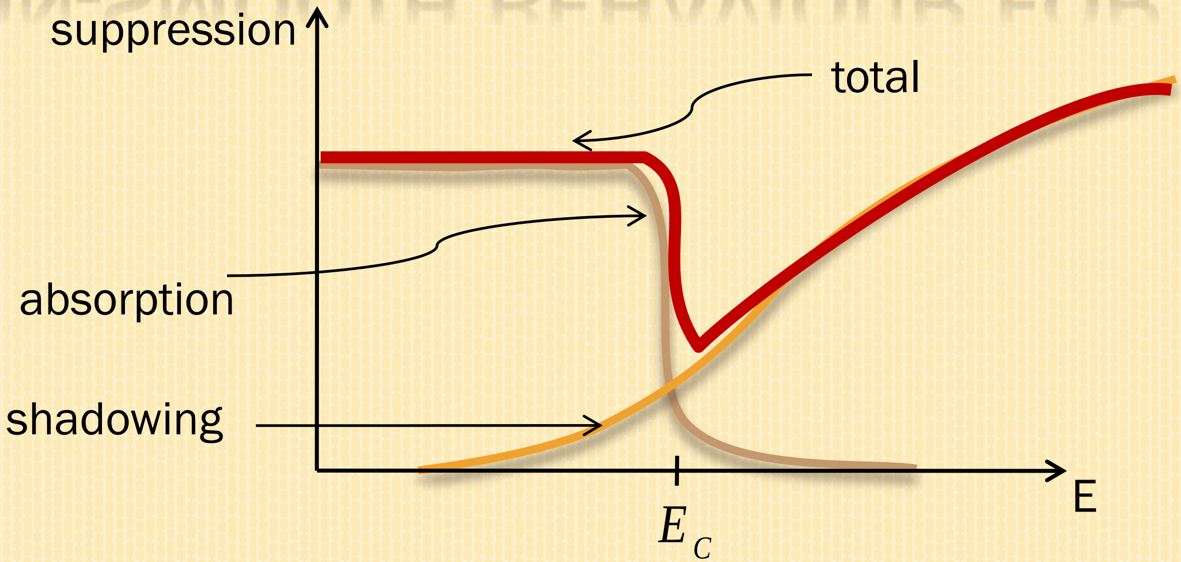
$$f(x,Q^2) = 4\pi \int_x^{x_P^{max}} dx_P\, B(x_P) \frac{F_{2D}^{(3)}(x_P, Q^2, \beta)}{F_2(x,Q^2)} F_A^2(t_{min})$$

SMOOTH BEHAVIOUR FOR BULK OBSERVABLES



- most of the observables do not feel the change of space-time picture
- appears at high energy: nuclear shadowing
- are there any observables that are sensitive to the transition?

NON-SMOOTH BEHAVIOUR FOR J/Ψ?



- critical scale depends on mass: $E_C = \frac{M^2}{2x_+}\frac{R_A}{\sqrt{3}}$
- transition between
  - successive rescattering: nuclear absorption
  - coherent production: shadowing
- happens around RHIC energies

COMOVERS INTERACTION MODEL

SUPPRESSION OF HIGH-P_T PARTICLES

- particles are not absorbed
- possibility of **soft** interaction
  - p_T shifted to smaller values
  - $\delta p_T \sim (p_T - \langle p_T \rangle)^{\alpha}$
  - vansihes for bulk, soft particles
  - strong effect since spectra are steep
- strong suppression
- strong azimuthal asymmetry
  - non-flow effect!

J/Ψ SUPPRESSION

- absorption in normal, nuclear matter
  - controlled by σabs
  - present in pA and small AA systems
  - changes with rapidity
- interaction with co-movers
  - controlled by σco

→ **transformed into DD pair**

CIM PREDICTIONS FOR LHC: R_{AA}