# Charmonium dynamics in dA and AA at RHIC and LHC

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# Outline

1. Motivation
2. Initial state effects in charmonium production
   - shadowing, absorption, energy-momentum conservation
   - results for J/psi in d+Au @ RHIC
3. Charmonium suppression in a final state model
   - Comovers' interaction model
   - results for J/psi in Cu+Cu and Au+Au @ RHIC
   - predictions for Pb+Pb @ LHC
4. Conclusions

# Production of a heavy-quark state at high-energy

## Why is it important?

### $J/\psi$ production in pA collisions:

- absorption in nuclear matter ($\sigma^{abs} \sim 5$ mb) at low energies, interpreted within a probabilistic Glauber model
- puzzle at RHIC: vanishing $\sigma^{abs}$
- at high energies, production of heavy state probes the very low-x distribution of the nuclear structure function

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- what is the underlying mechanism behind $J/\psi$ suppression
  $\rightarrow$ QGP screening, melting, comovers' interaction
- puzzle at RHIC I: same amount of suppression as at SPS
- puzzle at RHIC II: stronger suppression at forward than at mid-rap
- from color screening to recombination?

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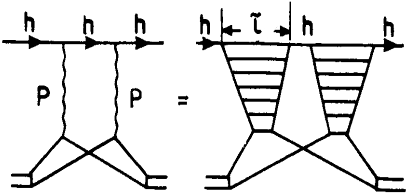
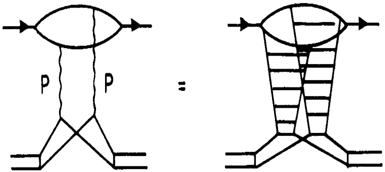
# Space-time picture of high-energy interactions

Mandelstam Nuov. Cim. **30** (1963) 1113, 1127,1148; Gribov JETP **56** (1959) 982




“Planar” diagram




“Non-planar” diagram

- low energy scattering - longitudinal ordering
  - → Glauber multiple scattering
  - → absorptive cross section
- high energy scattering - change in space-time picture
  - → Gribov inelastic shadowing
  - → fluctuation prepared long before the collision
- critical energy scale depends on mass
  - → observables sensitive to this transition?

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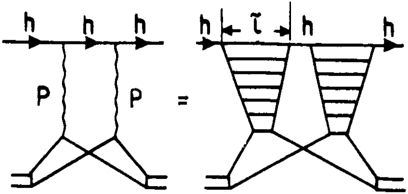


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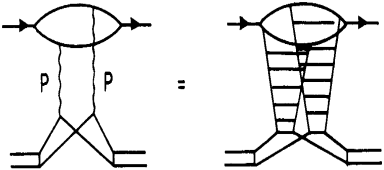


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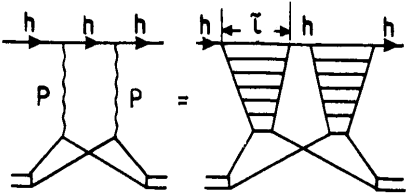


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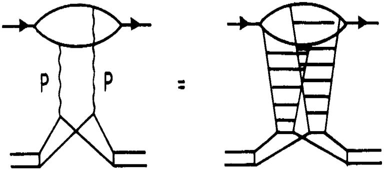


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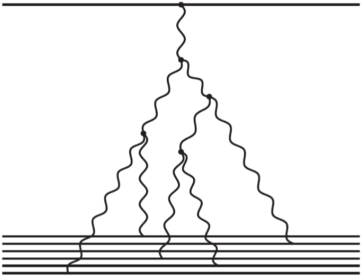
# Nuclear shadowing in Schwimmer model

## Enhanced diagrams



Schwimmer Nucl.Phys.B **94** (1975) 445

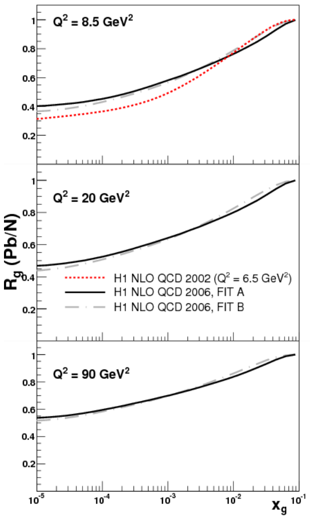
- similar to the B-K equation of dipole splitting
- OK for hA collisions at high energies
- exact solution of the Reggeon field theory
- parameterizations from diffractive HERA data and CTEQ

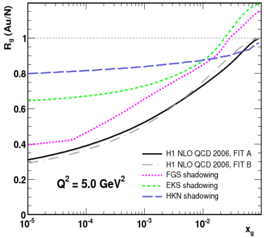
$$\sigma_{hA}^{Sch} = \sigma_{hN} \int \mathrm{d}^2 b \frac{A T_A(b)}{1 + (A-1) f(x,Q^2) T_A(b)} ,$$

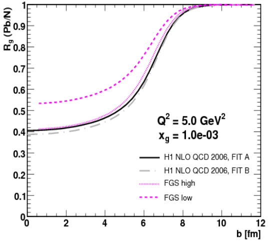
$$f(x,Q^2) = 4\pi \int_x^{x_P^{max}} \mathrm{d}x_{I\!P} B(x_{I\!P}) \frac{F_{2\mathcal{D}}^{(3)}(x_{I\!P},Q^2,\beta)}{F_2(x,Q^2)} F_A^2(t_{min.})$$

# Gluon shadowing - results

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




- strong shadowing obtained
- no fitting or free parameters!
- shadowing is a “rescattering effect” - slow $Q^2$ behaviour
- in MC generator HYDJET

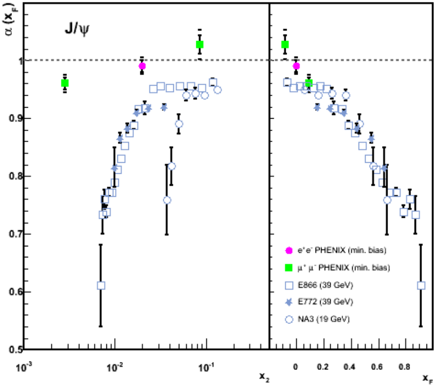
Lokhtin, Snigirev Eur. Phys. J. C **46** (2006) 211

Brodsky et al. PRD **65** (2002) 114025

# $\alpha(x_F)$ dependence

## ... and what can we learn from it?

- change of behaviour of $\alpha(x_F)$ going from low-energy to high-energy regime
- $\alpha(x_F = 0)$ sensitive to the disappearance of low-energy effects and onset of shadowing
- no scaling of RHIC data (neither in $x_F$ nor $x_2$)!




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

Boreskov, Capella, Kaidalov, Van Phys. Rev. D **47** (1993) 919;
Salgado Phys. Lett. B **521** (2001) 211; Kharzeev, Tuchin Nucl. Phys. A **770** (2006) 40

# $\alpha(x_F)$ dependence

... and what can we learn from it?

Treat nuclear absorption and energy-momentum conservation on equal footing! Arsene, Bravina, Kaidalov, Tywoniuk, Zabrodin, arXiv:0711.4672 [hep-ph] (PLB, *in press*)

Low energy absorption + em.

$$\frac{1}{\xi(x_+)\,\sigma_{Q\bar{Q}}}\left(1 - \exp\left\{-\xi(x_+)\,\sigma_{Q\bar{Q}}\,T_A(b)\right\}\right)$$

High energy absorption + em.

$$T_A(b)\,\exp\left\{-\xi(x_+)\,\sigma_{Q\bar{Q}}\,T_A(b)/2\right\}$$

Universal behaviour: $\xi(x_+) = (1-\epsilon)\exp\left\{-(x_c/x_2)^2\right\} + \epsilon x_+^\gamma$

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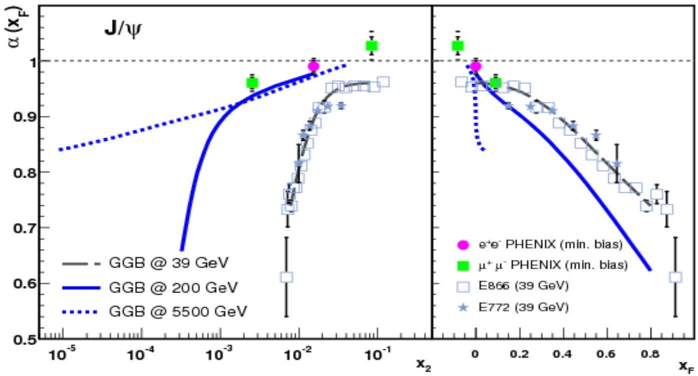
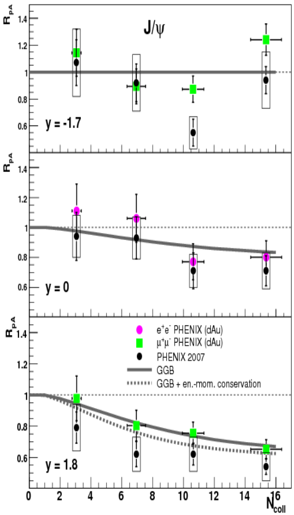



- scaling with $x_F$ for low energies due to energy-momentum conservation
- scaling with $x_2$ will appear for RHIC and higher energies

# J/$\psi$ production in pA @ RHIC and LHC

Arsene, Bravina, Kaidalov, Tywoniuk, Zabrodin, arXiv:0711.4672 [hep-ph] (PLB, *in press*)

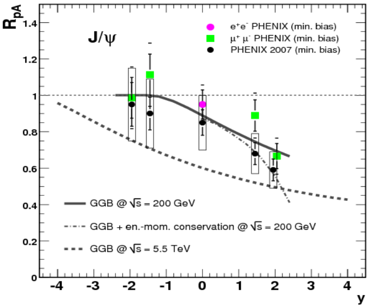
Capella, Ferreiro, Phys. Rev. C **76** (2007) 064906, Ferreiro, Fleuret, Rakotozafindrabe arXiv:0801.4949




→ $\sigma_{abs} = 0$ and shadowing reproduce the data at RHIC

→ first signal of coherent HQ production?

- at LHC - strong IS effect!



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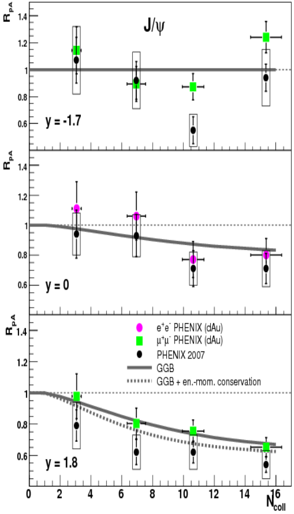


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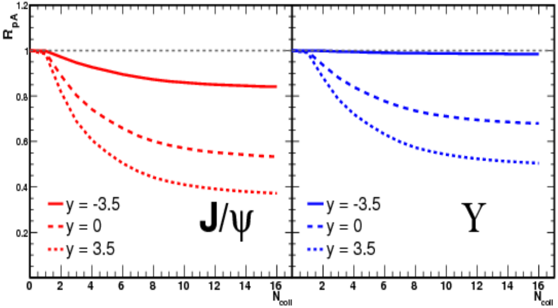
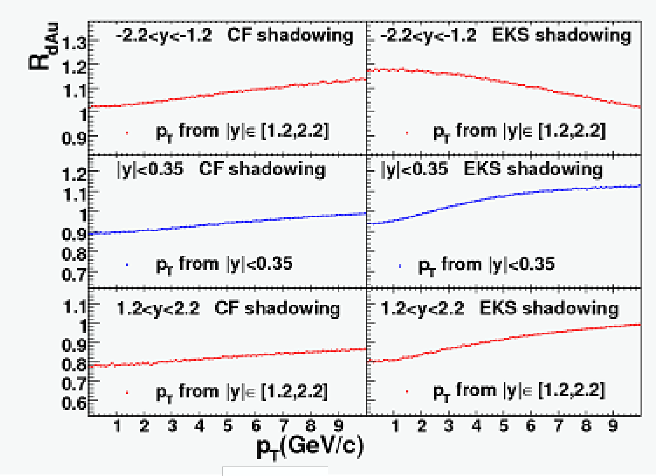


# $p_\perp$-dependence of J/$\psi$ production in dAu @ RHIC

## Discriminating between different models of anti-shadowing

Ferreiro, Fleuret, Rakotozafindrabe arXiv:0801.4949




CF shadowing is compared to EKS on MC generator level.

Stronger shadowing with CF!

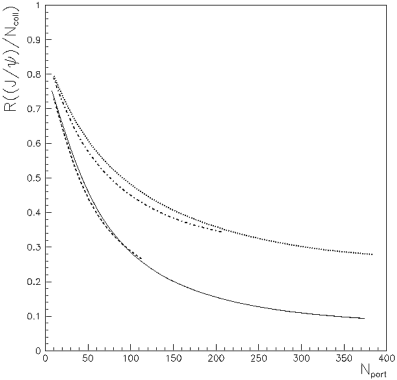
Different behaviour at backward rapidities!

# Comovers' interaction model

Gain and loss equation that govern the the final-state interactions with the co-moving medium - assuming only $J/\psi$ dissociation

$$\tau \frac{dN_{J/\psi}}{d\tau}(b,s,y) = -\sigma_{co} N_{J/\psi}(b,s,y) N^{co}(b,s,y)$$

$$S^{co}(b,s,y) = \exp\left[-\sigma_{co} N^{co}(b,s,y) \ln\left(N^{co}(b,s,y)/N_{pp}(0)\right)\right]$$




Gluon shadowing taken as before. Shadowing + comovers suppression with $\sigma = 0.65$ mb gives a too strong suppression. Recombination seems to be necessary at RHIC.

Capella, Ferreiro Eur.Phys.J. C42 (2005) 419

$\sigma$ – an effective cross section averaged over interaction time

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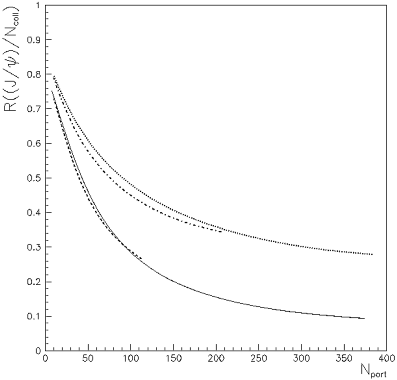


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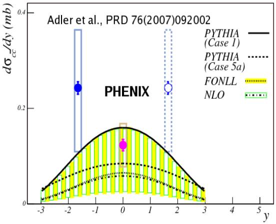
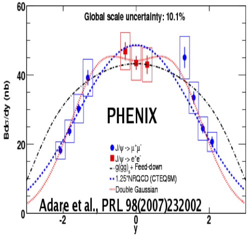
Capella, Bravina, Ferreiro, Kaidalov, Tywoniuk, Zabrodin arXiv:0712.4331 [hep-ph]

We modify the rate equation to include effects of recombination of $c\bar{c}$ pairs in the comovers' scenario.




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




Cross sections are taken from pp measurements @ $\sqrt{s} = 200$ GeV
$\rightarrow$ except $c\bar{c}$ at forward – from PYTHIA.

No free parameters in the model!

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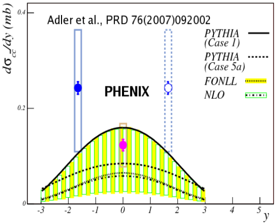
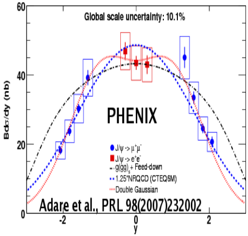
First approximation...

$$S^{CR}(b,s,y) = \exp\left\{-\sigma N^{co} \ln\left[\frac{N^{co}}{N_{pp}}\right]\right\} \times \exp\left\{\sigma\, C n(b,s) \ln\left[\frac{N^{co}}{N_{pp}}\right]\right\}$$

$$C = \frac{\left(\mathrm{d}\sigma_{pp}^{c\bar{c}}/\mathrm{d}y\right)^2}{\sigma_{pp}^{ND}\ \mathrm{d}\sigma_{pp}^{J/\psi}/\mathrm{d}y}$$

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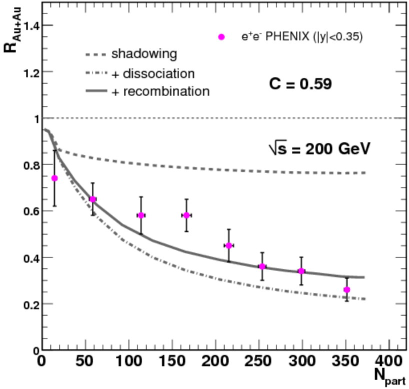


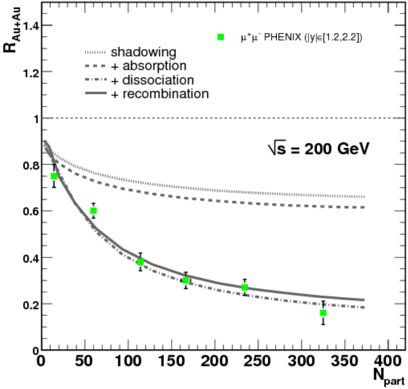


C = 0.59 C = 0.32

CIM describes properly the rapidity dependence of the suppression!

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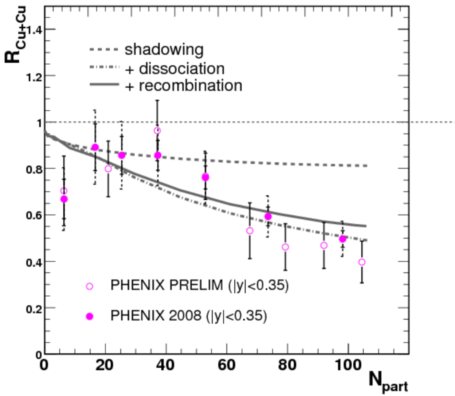


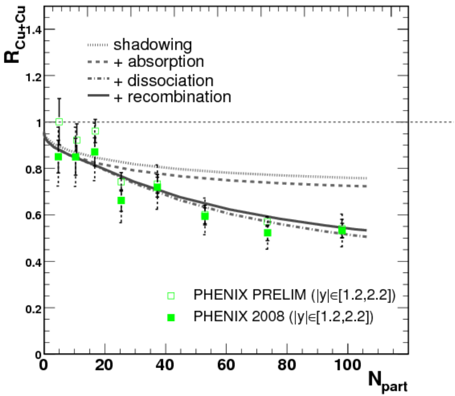


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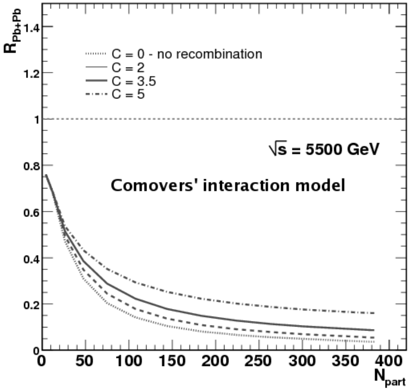
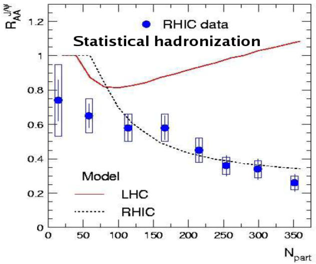
## Predictions for Pb+Pb @ LHC




- recombination a crucial effect
- strong dependence on the charm cross section
- theoretical extrapolations are very uncertain
- we assume $\sigma^{c\bar{c}} \propto s^{0.3}$




Capella et al. arXiv:0712.4331 [hep-ph]
Abreau et al. Heavy Ion Collisions at the LHC - Last Call for Predictions
Andronic, Braun-Munzinger, Redlich, Stachel Nucl. Phys. A **789** (2007) 334

# Conclusions

- d+Au data at RHIC are consistent with $\sigma_{abs} = 0$ and gluon shadowing
  - $\rightarrow$ novel scaling in $x_2$ will appear at LHC
- strong shadowing effects are predicted for LHC, important in p+Pb collisions and as initial condition for Pb+Pb modeling of final-state effects
- combined effect of co-movers suppression and recombination at RHIC is consistent with Cu+Cu and Au+Au data
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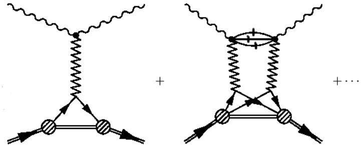
# BACKUP I

## Gribov inelastic shadowing




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

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

$$\sigma^{(2)}_{pA} = -4\pi A(A-1) \int \mathrm{d}^2 b T^2_A(b) \int_{M^2_{min}}^{M^2_{max}} \mathrm{d}M^2 \left[ \frac{\mathrm{d}\sigma^{\mathcal{D}}_{\gamma^* N}(Q^2, x_P, \beta)}{\mathrm{d}M^2 \mathrm{d}t} \right]_{t=0} F^2_A(t_{min})$$

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

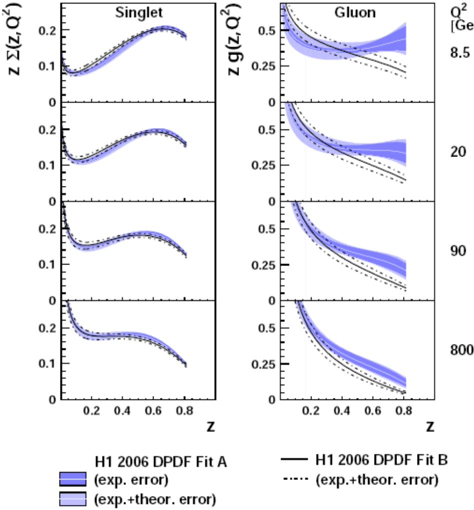
# BACKUP II

## 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

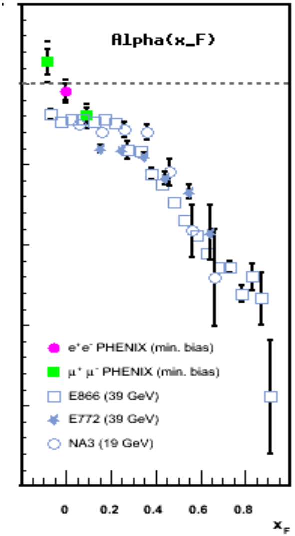



H1 Collaboration, **hep-ex/0606003**, **hep-ex/0606004**

# BACKUP III

## Why is $\sigma_{abs}$ suddenly decreasing?

- counterintuitive!
  - → Kopeliovich et al.: energy loss grows
  - → Kharzeev et al.: size of HQ grows
  - → double counting of low and high energy effects?
- Capella, Ferreiro
  - → field theoretical approach
  - → asypmtotic cross section exhibit self absorption
  - → leads to $A^1$ dependence




Capella, Ferreiro, PRC **76** (2007) 064906
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Boreskov, Capella, Kaidalov, Thanh Van, PRD **47** (1993) 919

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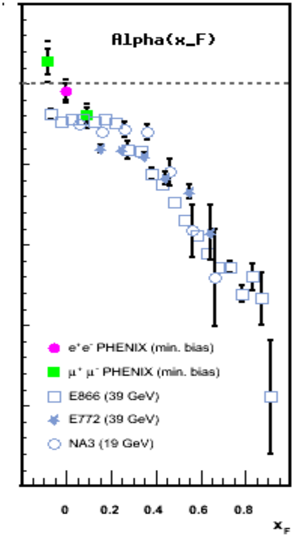
- Capella, Ferreiro
  - $\longrightarrow$ field theoretical approach
  - $\longrightarrow$ asypmtotic cross section exhibit self absorption
  - $\longrightarrow$ leads to $A^1$ dependence

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