Nuclear suppression of charmonium at RHIC and LHC in Glauber-Gribov approach

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Outline

1. Introduction - why is RHIC/LHC “high energy”?
2. Nuclear Modification Factor
   - results for J/psi in d+Au @ RHIC
   - Predictions for p+Pb @ LHC
   - tools for Pb+Pb modeling
3. Charmonium suppression in a final state model
4. $\alpha(x_F)$ dependence
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   - scaling - breaking - appearance
5. Conclusions

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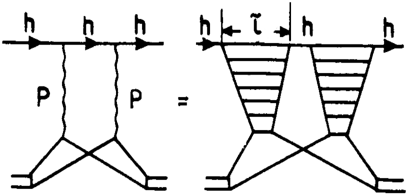
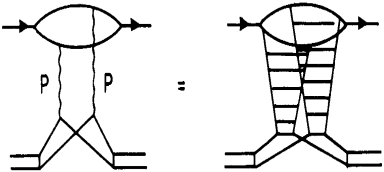
When is energy “high”?

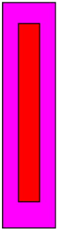
Coherence length in hadron-nucleus collision

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

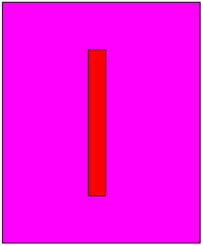




“Planar” diagram - Glauber model



“Non-planar” diagram



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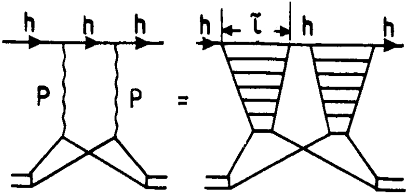

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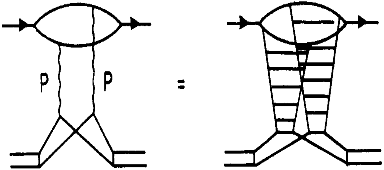

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- the space-time picture does not correspond to longitudinally ordered multiple scattering
- fluctuation prepared long before collision occurs
- LHC is definitely in “high-energy regime”. Coherent production for both light and heavy particles already at y=0!
- is RHIC?

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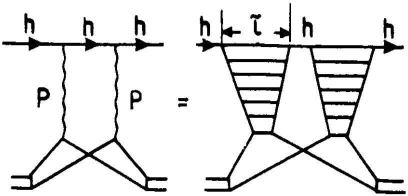

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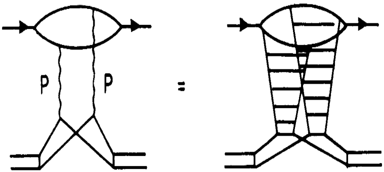

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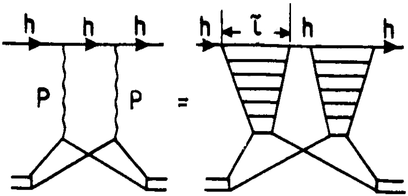

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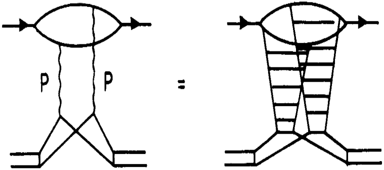

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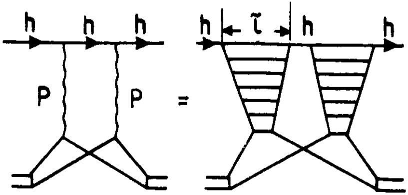

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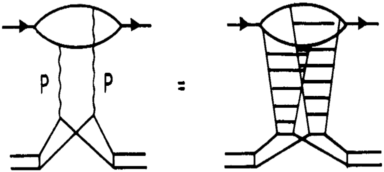

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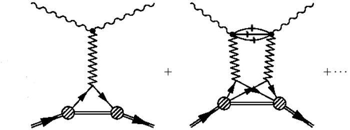
Calculation of total cross section

Rescattering series



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

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

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

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

Hard diffraction @ HERA

Parameterization of diffractive parton densities

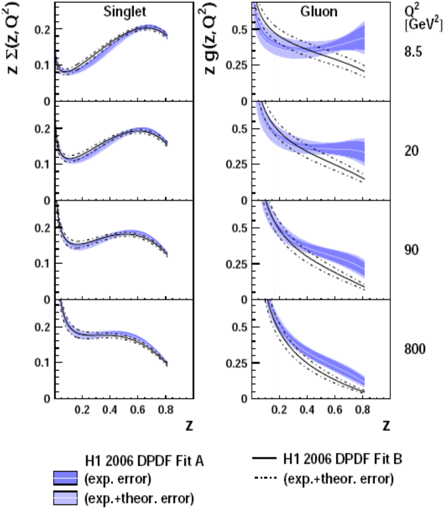
$$\left[\frac{d\sigma^{\mathcal{D}}_{\gamma^* N}}{dM^2 dt}\right]_{t=0} = \frac{4\pi^2\alpha_{em}B}{Q^2(Q^2+M^2)}\, x_{I\!P} F^{(3)}_{2\mathcal{D}}$$

FIT A

- parameterized at $Q_0 = 1.75$ GeV^2

FIT B

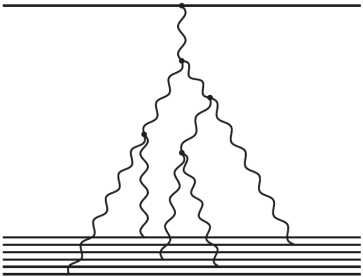
- parameterized at $Q_0 = 2.5$ GeV^2
- maximal uncertainty in gluon dPDF due to mixing with quarks at $\beta > 0.3$



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

Enhanced diagrams

Schwimmer model



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

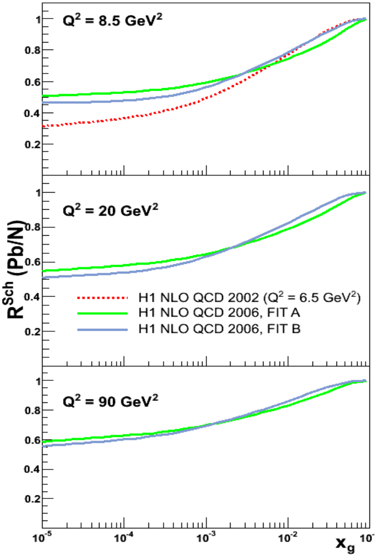
- similarity to the B-K equation of dipole splitting
- relevant for hA collisions at high energies
- exact solution of the Reggeon field theory

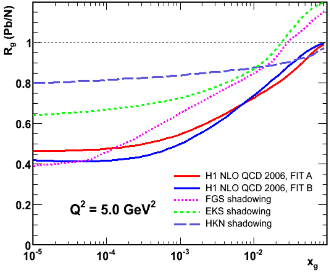
$$\sigma_{hA}^{Sch} = \sigma_{hN} \int \mathrm{d}^2 b \frac{A T_A(b)}{1 + (A-1) f(x, Q^2) T_A(b)} ,$$

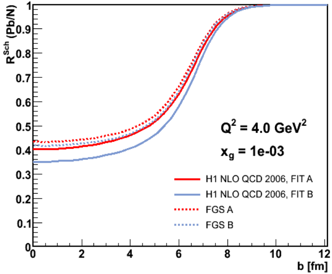
$$f(x, Q^2) = 4\pi \int_x^{x_P^{max}} \mathrm{d}x_{I\!P} B(x_{I\!P}) \frac{F_{2\mathcal{D}}^{(3)}(x_{I\!P}, Q^2, \beta)}{F_2(x, Q^2)} F_A^2(t_{min.})$$

Results for gluon shadowing within Schwimmer model

Details - `hep-ph/0705.1596`







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Production of a heavy-quark state at high-energy

Why is it important?

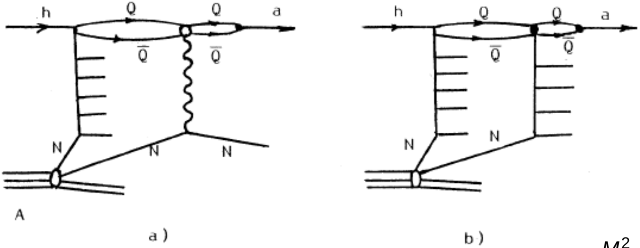
J/ψ production in pA collisions show interesting features at different energies:

- absorption in nuclear matter ($\sigma^{abs} \sim$ 5 mb) at low energies, interpreted within a probabilistic Glauber model
- puzzle at RHIC, σ^{abs} much smaller (nobody expected this)
- at high energies, production of heavy state probes the very low-x distribution of the nuclear structure function

Also Υ production should follow a similar pattern.
Important to understand what happens in pA to get a hold on final-state effects in AA!

Production of a heavy-quark state at high-energy

Appearance of “high-energy regime”



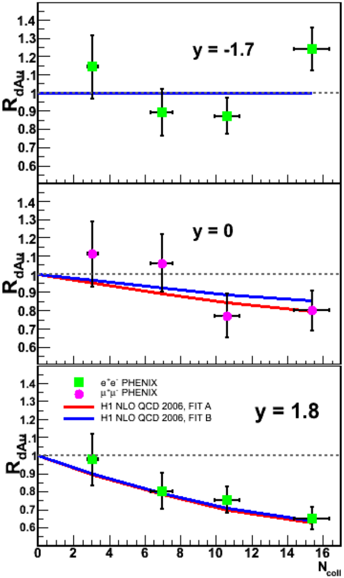
Critical energy for heavy quark production $E_C = \frac{M^2_{c\bar{c}}}{2x_+} \frac{R_A}{\sqrt{3}}$

- for $E < E_c$: AGK cancellation is not valid and absorptive corrections are present
  $\longrightarrow$ low-energy absorption formula!
- for $E > E_c$: coherent production of the heavy state

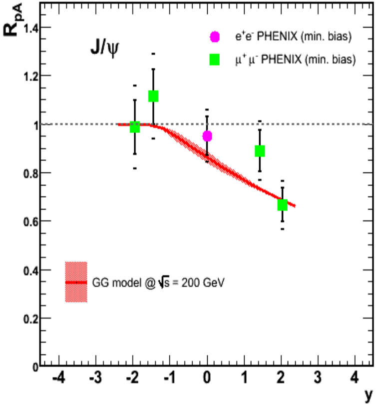
Boreskov, Capella, Kaidalov, Thanh Van, PRD **47** (1993) 919

J/ψ production @ RHIC

Shadowing and $\sigma_{abs} = 0$



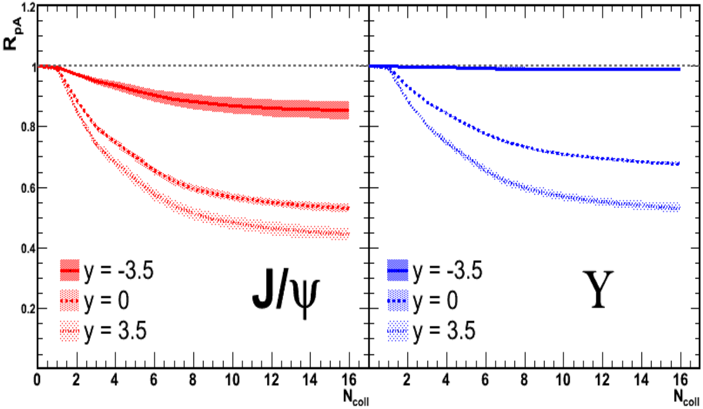
$\sigma_{abs} = 0$ and shadowing reproduce the data at RHIC.



Capella, Ferreiro, **`hep-ph/0610313`**

Predictions for p+Pb @ LHC

J/ψ,Υ and open heavy-flavour



The same suppression is predicted for open heavy-flavour.

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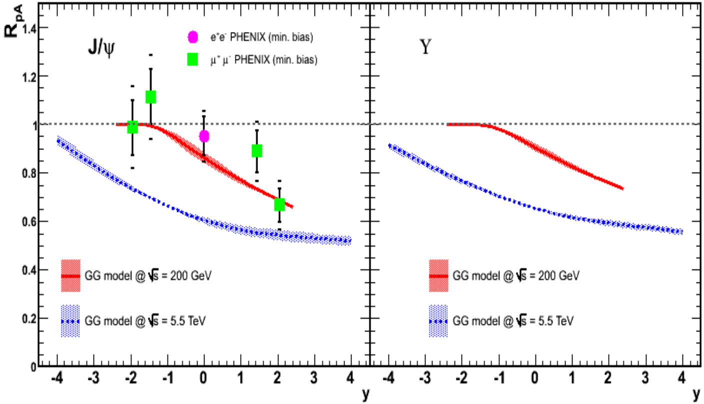

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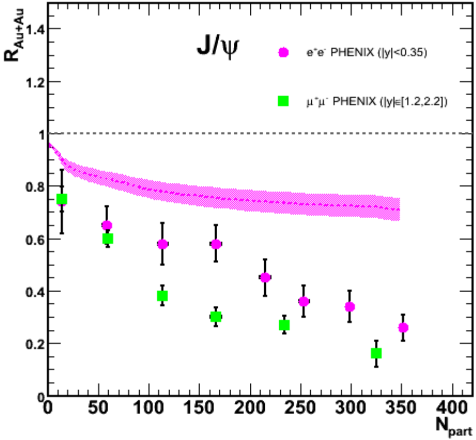
Cold-nuclear matter effects in A+A collisions

Shadowing



- 20% suppression from CNM effects alone
- important input - suppression from co-movers alone gives too strong effect!

Cold-nuclear matter effects in A+A collisions

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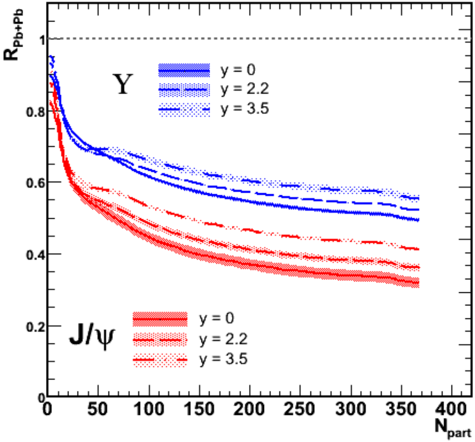
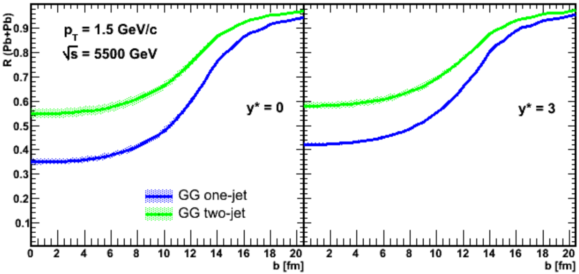
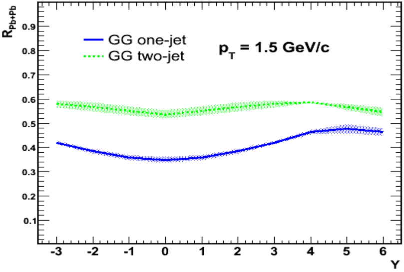


- strong shadowing effect, a factor of ~ 2.5
- shadowing decreases with rapidity

Cold-nuclear matter effects in A+A collisions

Density of produced particles





Shadowing effects are also crucial for total multiplicity and density of charged particles in the initial state of the collision.

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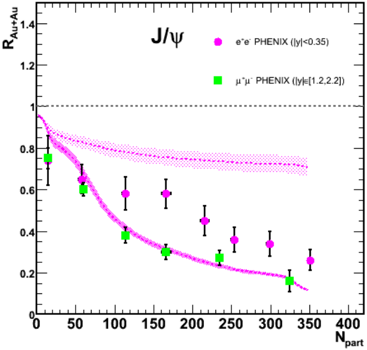
Comovers suppression

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

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

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



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.

Comovers suppression and recombination

Estimation of recombination effect

We modify the rate equation

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

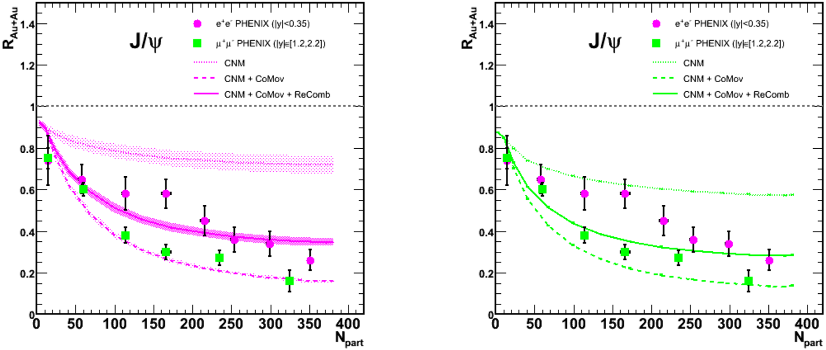
to incorporate the possible recombination of the abundantly produced charm to produce additional J/ψ's. Approximately

$$\begin{aligned} S^{CR}(b,s,y) &= \exp\left\{ -\sigma \left[N^{co} - C\, n(b,s) \right] \ln\left[\frac{N^{co}}{N_{pp}(0)} \right] \right\} \\ C &= \frac{\left(\mathrm{d}N_{pp}^{D}/\mathrm{d}y \right)^2}{\mathrm{d}N_{pp}^{J/\psi}/\mathrm{d}y} \end{aligned}$$

C can be estimated from pp data. Unfortunately, there are huge errorbars. First try: fit C to midrap R_{AA}!

Comovers suppression and recombination

Estimation of recombination effect

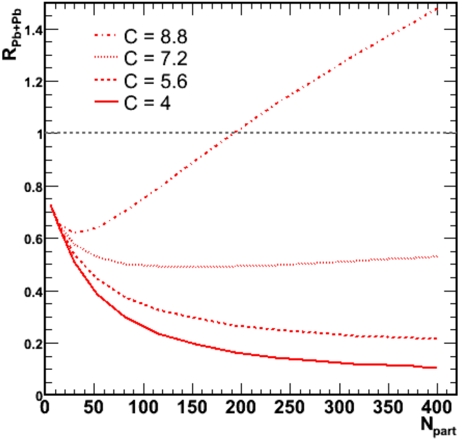


At mid-rapidity: $C = 0.8$ (recombination is 10% effect compared to dissociation)

At forward rapidity $C \approx 0$ and we are closer to the bottom curve.

Comovers suppression and recombination

Prediction for LHC



Recombination will be a crucial effect, depending very strongly on the cross section of charmonium production at this energy. The theoretical extrapolations are very uncertain at this point.

We estimate $C \approx 6$ at LHC (i.e. $\frac{\sigma_{c\bar{c}}@LHC}{\sigma_{c\bar{c}}@RHIC} \sim 10$)

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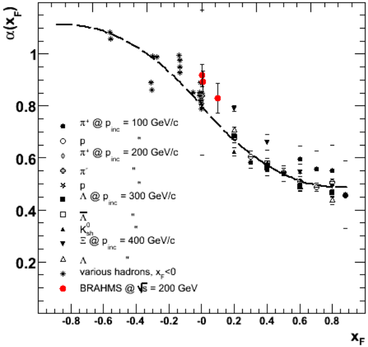
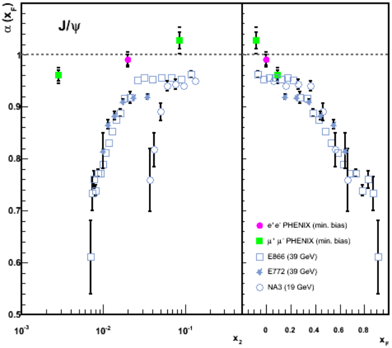
$\alpha(x_F)$ for light and heavy particles

Breaking of scaling! Reappearance...





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

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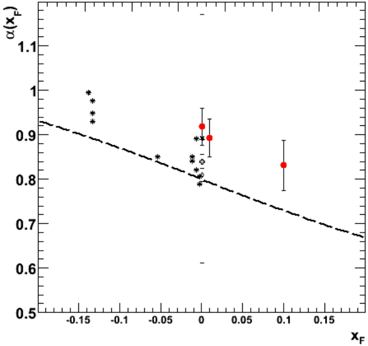

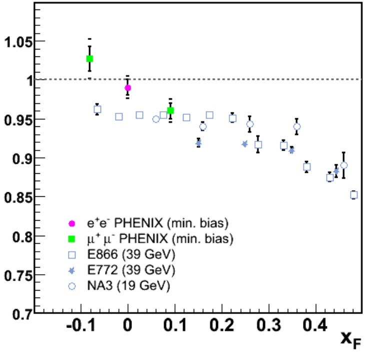

- change of behaviour of $\alpha(x_F)$ going from low-energy to high-energy regime
- $\alpha(x_F = 0)$ sensitive to the disappearance of low-energy effects and onset of shadowing
- RHIC on the border both for light and heavy particle production

$\alpha(x_F)$ for light and heavy particles

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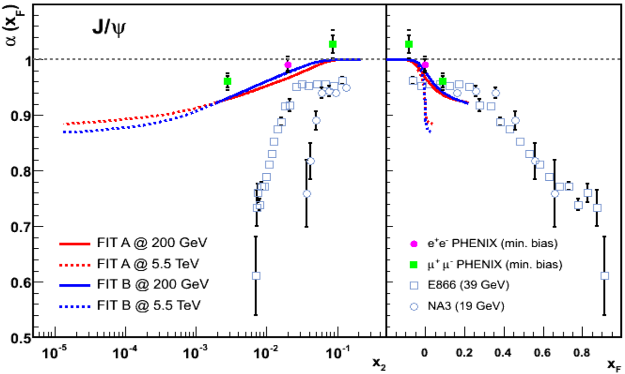

- scaling with x_F for low energies due to energy-momentum conservation
- scaling with x_2 will appear for RHIC and higher energies

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