Gluon shadowing and J/ψ suppression in p A collisions: uncertainties and constraints

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Outline

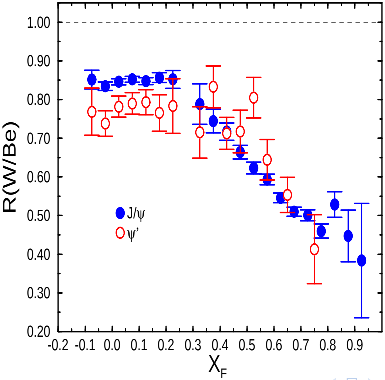
- Motivations
  - final state interaction vs. gluon nPDF
- World data analysis
  - impact of nPDF uncertainties
- Constraints on gluon nPDF from J/ψ data
  - specific analysis of E866/NuSea

References

- FA, V.-N. Tram, Eur. Phys. J. C 55 (2008) 449
- V.-N. Tram, FA, Eur. Phys. J. C 61 (2009) 847
- FA, Phys. Lett. B 666 (2008) 31

Experimentally

$$R \equiv \frac{\sigma(p\ A \rightarrow J/\psi\ \mathrm{X})}{A\ \sigma(p\ p \rightarrow J/\psi\ \mathrm{X})} < 1$$



J/ψ suppression in nuclear collisions

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Why is $R \neq 1$?

Two usual suspects

- Inelastic interaction with nuclear matter
- Effects of nuclear parton densities (nPDF)

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- Need to know nPDF to understand J/ψ suppression data
- Possibility to use J/ψ suppression data to constrain nPDF

Strategy

Aim of this analysis

To determine quantitatively the J/ψ inelastic cross section from a χ^2 analysis of all available data on J/ψ production on nuclei

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- Inelastic hadroproduction $h\ A \to J/\psi\ \mathrm{X}$
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Nuclear effects considered

- J/ψ inelastic interaction in nuclear matter
- Nuclear modifications of parton distribution functions

Production cross section

Hadroproduction

Colour Evaporation Model is assumed

$$\frac{\mathrm{d}\sigma^{\text{no abs}}}{\mathrm{d}x_{\mathrm{F}}} \propto \int_{2m_c}^{2m_D} \mathrm{d}m \, \frac{2m}{\sqrt{x_{\mathrm{F}}^2 s + 4m^2}} \left[f_g^h(x_1)\; f_g^A(x_2) \;\; \hat{\sigma}_{gg\to c\bar{c}} \right.$$

$$\left. + \sum_{q=u,d,s} \left\{ f_q^h(x_1)\; f_{\bar{q}}^A(x_2) + f_{\bar{q}}^h(x_1)\; f_q^A(x_2) \right\} \; \hat{\sigma}_{q\bar{q}\to c\bar{c}} \right]$$

- f_i^h: parton distributions functions in the hadron
- $\hat{\sigma}$: LO partonic cross sections
- x_1 / x_2: projectile / target parton momentum fractions

Production cross section

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Leptoproduction

$$\frac{d\sigma^{\text{no abs}}}{dx} \propto f_g^A(x)$$

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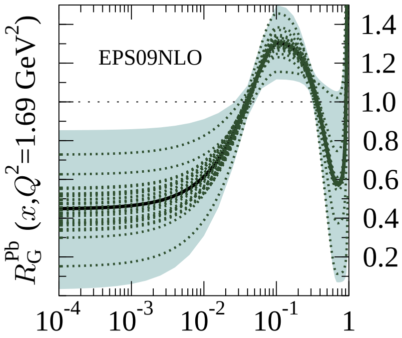
What should be taken for the nuclear densities f_i^A ?

nPDF

PDFs in nuclei differ significantly from those in a proton



This should affect the nuclear dependence of J/ψ production

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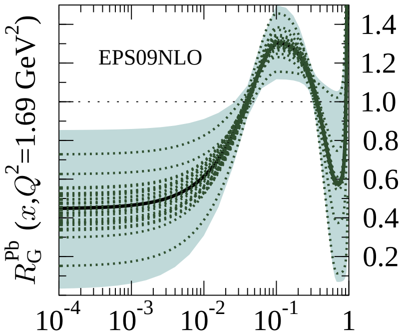

Issue: large uncertainties

- in the gluon sector
- at small x and low scales

nPDF parametrizations

Several LO/NLO determinations of

$$f_i^A(x, Q^2) \;/\; f_i^p(x, Q^2) \qquad (i = q, \bar{q}, g)$$

from DIS and DY (and hadron prod. for EPS08) data can be used

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- Eskola–Kolhinen–Salgado — EKS98 LO (1998)
- Hirai–Kumano–Miyama — HKM LO (2001)
- Eskola–Paukkunen–Salgado — EPS08 LO (2008)

- de Florian–Sassot — nDS / nDSg NLO (2003)
- Hirai–Kumano–Nagai — HKN NLO (2007)
- Eskola–Paukkunen–Salgado — EPS09 NLO (2009)
- I. Schienbein et al. — nCTEQ NLO (2009)

Differences come from the various data sets and fitting procedures

Nuclear absorption

Assume factorization between production and rescattering

$$\frac{d\sigma}{dx} = S^{\rm abs}(A, \sigma_{J/\psi N}) \times \frac{d\sigma^{\rm no\ abs}}{dx}$$

$S^{\rm abs}$ survival probability of J/ψ in the target nucleus

$$S^{\rm abs} = \frac{1}{(A-1)\,\sigma_{J/\psi N}} \int d\mathbf{b} \left(1 - e^{-(1-1/A)\ T_A(\mathbf{b})\ \sigma_{J/\psi N}}\right)$$

with $T_A(\mathbf{b})$ thickness function

Minimization

Cross section determined from the usual χ^2 minimization

$$\chi^2(\hat{\sigma}_{J/\psi \mathrm{N}}) = \min \left[\chi^2(\sigma_{J/\psi N}) \right]$$

with sophisticated definition of χ^2 to account for correlated errors

1σ error $\delta\hat{\sigma}_{J/\psi \mathrm{N}}$ defined as

$$\Delta\chi^2 \equiv \chi^2(\hat{\sigma}_{J/\psi \mathrm{N}} \pm \delta\hat{\sigma}_{J/\psi \mathrm{N}}) - \chi^2_{\min} = 1$$

No longer true when correlated errors not properly taken into account !

[Stump et al. 2002]

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Rescaling of the 1σ error (PDG prescription)

$$\delta\bar{\sigma}_{J/\psi \mathrm{N}} \ = \ \mathrm{S} \ \times \ \delta\sigma_{J/\psi N}$$

$$\mathrm{S} \ \equiv \ \left[\chi^2 \Big/ (n-1)\right]^{1/2} \quad \text{if} \quad \chi^2/\mathrm{ndf} > 1$$

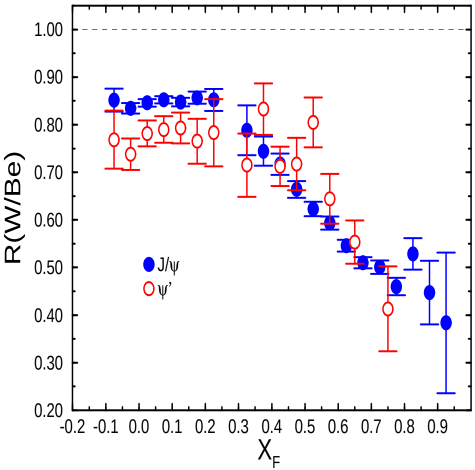
Data selection

- Data sets
  - SPS: NA3, NA38, NA50
  - FNAL: E537, E866, E672
  - RHIC: PHENIX
  - DIS : NMC
- J/ψ – N energy range $\sqrt{s_{J/\psi \mathrm{N}}} \simeq 6.5 - 25 \quad \mathrm{GeV}$
- Kinematic cuts

  J/ψ suppression not really understood at large x_F [→]

  $x_F \leq 0.3$ cut imposed to all hadroproduction data

- E772 data rejected because of a $x_F - p_\perp$ correlation bias
- NA60 not used since only 1 nucleus available (at the time)



[E866/NuSea 1999]

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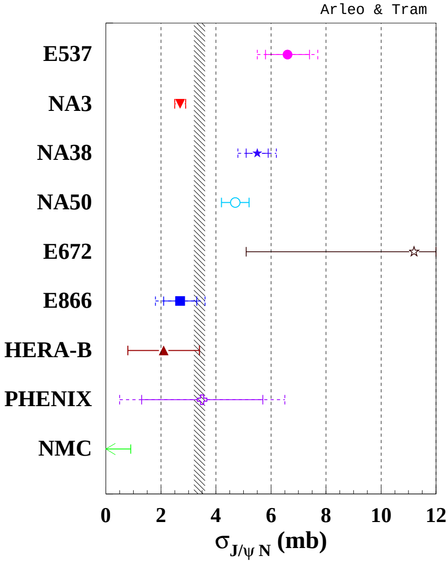
Results



Global fit

$$\sigma_{J/\psi N} = 3.4 \pm 0.2 \text{ mb}$$

$$(\chi^2/\text{ndf} = 1.4)$$

Results

Main observations

- Clear tension between
  - NA3, E866, HERA-B $\sigma_{J/\psi N} \simeq 1\text{–}3$ mb
  - E537, NA38, NA50 $\sigma_{J/\psi N} \simeq 4\text{–}7$ mb
- PHENIX data do not constrain much $\sigma_{J/\psi N} = 3.5 \pm 3.0$ mb
  - need more d Au statistics
  - reduced systematic errors
- Muoproduction data consistent with no absorption

$\sigma_{J/\psi N} \leq 0.9$ mb

Nuclear parton densities

Similar result using nDS parton densities

$$\sigma_{J/\psi N} = 3.5 \pm 0.2 \ \ \mathrm{mb} \qquad (\chi^2/\mathrm{ndf} = 1.4)$$

- Almost identical cross sections
- Same χ^2 than with proton densities

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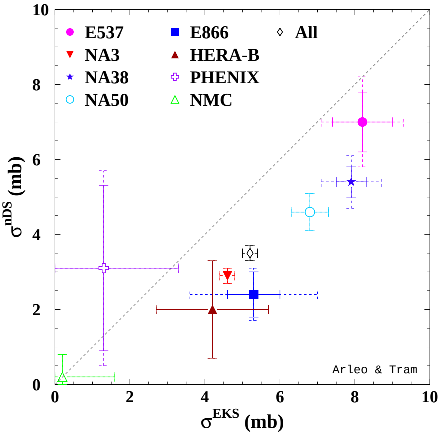
. . . unlike using EKS98 parton densities

$$\sigma_{J/\psi N} = 5.2 \pm 0.2 \ \ \text{mb} \qquad (\chi^2/\text{ndf} = 1.6)$$

because of the stronger antishadowing

Nuclear parton densities



$\sigma_{J/\psi\mathrm{N}}^{\mathrm{EKS}} \simeq \sigma_{J/\psi\mathrm{N}}^{\mathrm{nDS}}$ + 2 mb, except at RHIC

Nuclear parton densities

Comparing to more nPDF sets

	Proton	nDS	nDSg	EKS98	EPS08	HKM
$\sigma_{J/\psi\mathrm{N}}^{\mathrm{nPDF}}$ (mb)	3.4 ± 0.2	3.5 ± 0.2	4.0 ± 0.2	5.2 ± 0.2	6.0 ± 0.2	3.6 ± 0.2
χ^2/ndf	1.4	1.4	1.5	1.5	1.7	1.4

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Global fit from all experiments and nPDF sets

$$\sigma_{J/\psi N} = 3.5 \pm 0.2 \ (\mathrm{stat.}) \pm 2.6 \ (\mathrm{syst.}) \ \mathrm{mb}$$

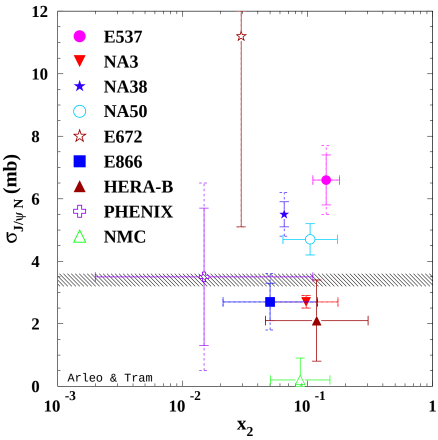
- Huge spread from the unknown gluon nPDF
- Extrapolation to higher energies (smaller x) even more problematic

Energy dependence

Naively, $\sigma_{J/\psi N}$ should be a function of

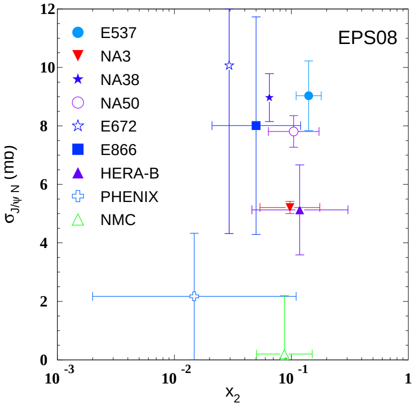
$$\sqrt{s_{J/\psi \mathrm{N}}} \simeq m_{J/\psi} \sqrt{\frac{1+x_2}{x_2}}$$

Energy dependence



- No statistically significant energy dependence of $\sigma_{J/\psi N}$ found in data

Energy dependence



- . . . yet again this interpretation depends on which nPDF set is used!

Interlude

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nPDF sets currently use

- DIS on nuclei — valence quarks
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A few candidates for the gluon sector

- Jets
- Large $p_\perp$ dileptons
- Heavy-bosons $W^\pm$, Z^0
- Prompt photons

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What about using also heavy-quarkonium production?

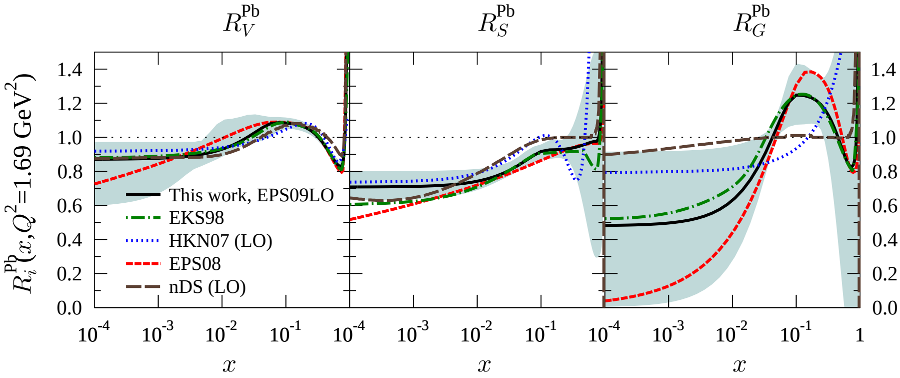
- Surprising at first sight because of the inelastic interaction processes
- Accurate data on large kinematical range might give interesting constraints

Gluon nPDF from J/ψ data

The behavior of $G^A/G^p(x)$ pretty different from one set to another

- nDS, HKM
  - rather flattish, (anti)shadowing not too pronounced
- nDSg, EKS98, EPS09
  - (anti)shadowing more pronounced
- EPS08
  - very strong gluon (anti)shadowing
  - related to the use of forward hadron production data at RHIC

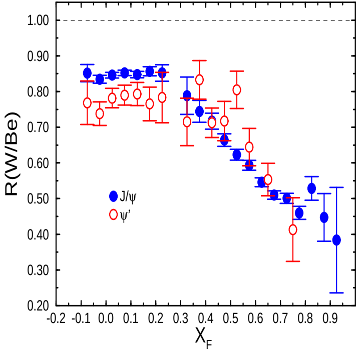
Gluon nPDF from J/ψ data



- Behavior particularly different in the range $10^{-2} \lesssim x \lesssim 10^{-1}$
- A fast variation of $G^A/G^p(x)$ could be seen (in principle) in J/ψ data

Gluon shadowing and E866/NuSea data

- $10^{-2} \lesssim x_2 \lesssim 10^{-1}$ corresponds to $0 \lesssim x_F \lesssim 0.3$ at $\sqrt{s_{pA}} \simeq 40$ GeV at the J/ψ mass scale
- Precise E866/Nusea measurements in this range



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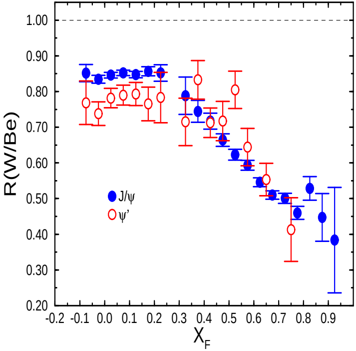

Rather flat behavior which tend to rule out a fast variation of $G^A/G^p(x)$

A simple analysis

Fitting E866/NuSea J/ψ data

- using all nPDF sets (proton PDF, nDS/nDSg, EKS98, HKM, EPS08)
- inelastic cross section as a constant free parameter

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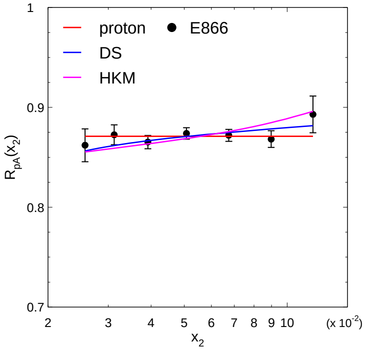

- Behavior consistent with nDS and HKM

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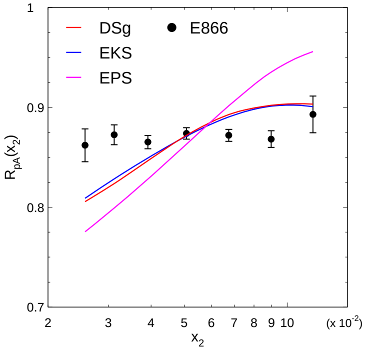

- Conflict with nDSg and EKS98, worse with EPS08

A simple analysis

χ^2

nPDF set	proton	DS	DSg	EKS	EPS	HKM
χ^2/ndf	0.5	0.6	12.0	10.1	35.9	1.2

Normalizations

	nDS	nDSg	EKS98	EPS08	HKM
$\sigma_{J/\psi N}$ (mb)	2.5	2.7	4.2	4.1	2.5
S_{abs}	0.89	0.88	0.82	0.82	0.89

Remarks

Caveat

- Assumption of constant absorption cross section can be questioned
- Suppose the absorption weakens with decreasing x_2 (increasing x_F) the disagreement would not be as pronounced

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"Fine tuning issue"

How come a very strong variation of $G^A/G^p(x)$ be perfectly balanced by nuclear absorption with opposite behavior, resulting into a constant J/ψ suppression? Rather unnatural

Summary

- Systematic study of J/ψ suppression in $\gamma^\star$ A and p A collisions
  - Results somehow spoiled by nPDF uncertainties

- Constraints on nPDF from specific J/ψ data sets
  - E866/NuSea favor nPDF sets with moderate variation in the $10^{-2} \lesssim x \lesssim 10^{-1}$ range