

Nuclear PDFs in the light of recent RHIC data

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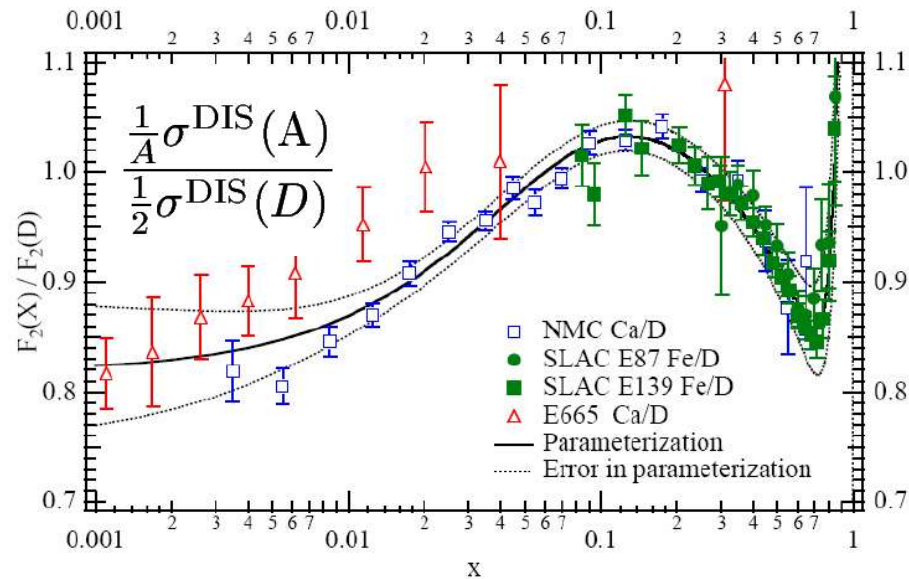
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Philosophy of Global nPDF analysis



- The Deep Inelastic structure functions F_2 of nuclear targets are different from the free proton ones.
- The purpose of the global DGLAP analysis of nPDFs is to see whether these effects can be consistently absorbed to the process independent PDFs – do they effectively factorize.

$$\sigma^{AB \rightarrow h+X} = \sum_{ijkl} f_i^A(x_1, Q) \otimes f_j^B(x_2, Q) \otimes \sigma^{i+j \rightarrow k+l} \otimes D_{k \rightarrow h+X}(z, Q_f)$$

Previous nPDF DGLAP analyses

- **Available nuclear PDFs:**

1998: EKS98	(Eskola, Kolhinen, Ruuskanen, Salgado)	LO
2001 : HKM	(Hirai, Kumano, Miyama)	LO
2004 : HKN04	(Hirai, Kumano, Nagai)	LO
2004 : nDS	(de Florian, Sassot)	NLO
2007 : EKPS	(Eskola, Kolhinen, Paukkunen, Salgado)	LO
2007 : HKN07	(Hirai, Kumano, Nagai)	NLO

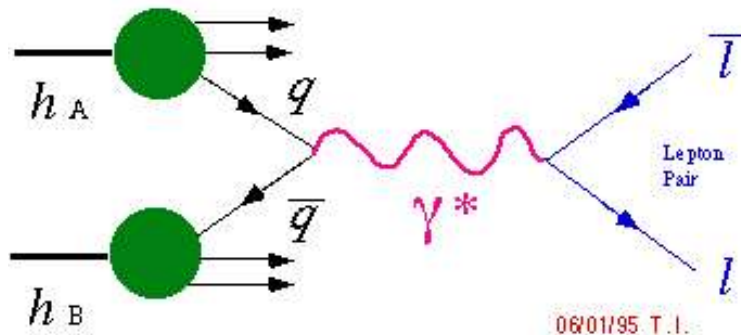
- **The experimental input has remained essentially the same for all 10 years!**
- **New data is obviously needed for any serious further progress.**

➡ RHIC d + Au collisions!

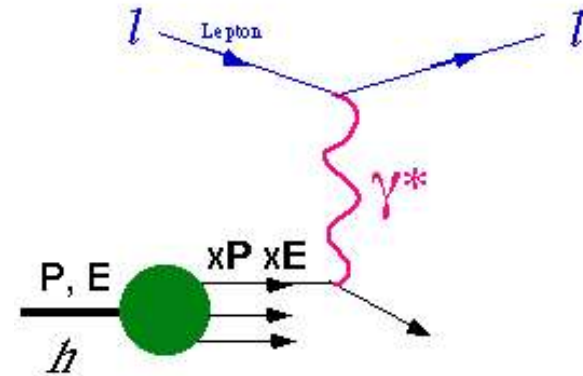
Reasons for new LO analysis

- In the leading order, DIS & DY are directly probing only the quark content of the nucleons. The gluons are constrained only by the DGLAP scale evolution equations

The Drell-Yan Process



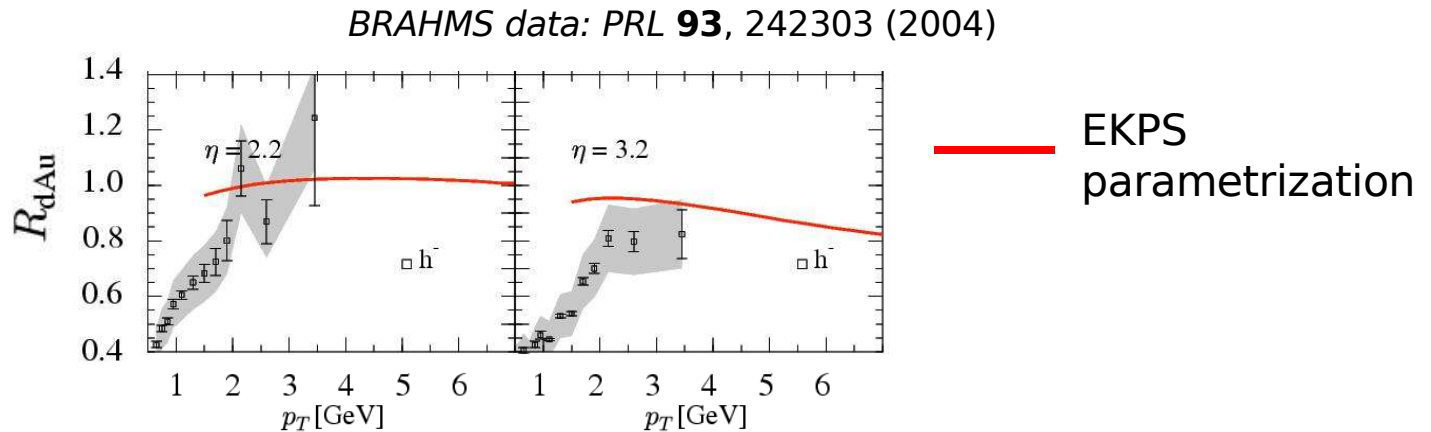
Deep Inelastic Scattering



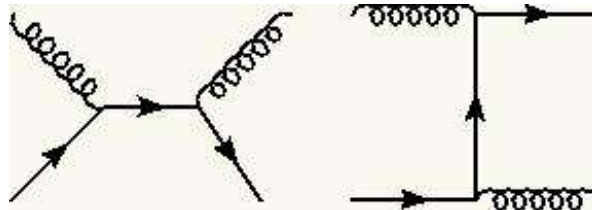
- Even in NLO, the gluons still remain only weakly constrained.

Reasons for new LO analysis

- Nuclear modification factor R_{dAu} for inclusive hadron production in d + Au collisions at RHIC BRAHMS show a increasing suppression towards low- p_T and forward direction.



- At forward rapidity, this probes the gluons in Au ($x > 5 \times 10^{-4}$)



$$\sigma^{AB \rightarrow h+X} = \sum_{ijkl} f_i^A(x_1, Q) \otimes f_j^B(x_2, Q) \otimes \sigma^{i+j \rightarrow k+l} \otimes D_{k \rightarrow h+X}(z, Q_f)$$

About The Framework

- We define the PDFs $f_i(x, Q)$ of bound protons in a nucleus A as

$$f_i^A(x, Q_0^2) = R_i^A(x, Q_0^2) f_i^{\text{CTEQ6L1}}(x, Q_0^2)$$

- We parametrize the nPDFs at $Q_0=1,3$ GeV with three R_i 's:

$R_V^A(x, Q_0^2)$	for all valence quarks
$R_S^A(x, Q_0^2)$	for all sea quarks
$R_G^A(x, Q_0^2)$	for gluons

- Baryon number & Momentum conservation sum rules are required

- The mass number (A) dependence of the fit parameters is assumed to follow a power law

$$z_i^A = z_i^{A_{\text{ref}}} \left(\frac{A}{A_{\text{ref}}} \right)^{p_{z_i}}$$

Generalized χ^2 , (new in nPDFs)

- The best parameters are found by minimizing the generalized global χ^2 -function:

Usual χ^2 :

$$\chi^2 = \sum_N \chi_N^2$$

$$\chi_N^2 = \sum_{i \in N} \left[\frac{D_i - T_i(\{z\})}{\sigma_i} \right]^2$$

Generalized χ^2 :

$$\chi^2 = \sum_N w_N \chi_N^2$$

$$\chi_N^2 = \left(\frac{1 - f_N}{\sigma_N^{\text{norm}}} \right)^2 + \sum_{i \in N} \left[\frac{f_N D_i - T_i(\{z\})}{\sigma_i} \right]^2$$

- With weight factors w_N we can emphasize certain data sets with important physics content (e.g BRAHMS).

D_i = Experimental values

T_i = Theory values

σ_i = Uncertainty

- Significant normalization uncertainty σ^{norm} in some data sets are handled by a normalization factor $f_N \in [1 - \sigma^{\text{norm}}, 1 + \sigma^{\text{norm}}]$. The effect is to shift all data up or down by a same amount.

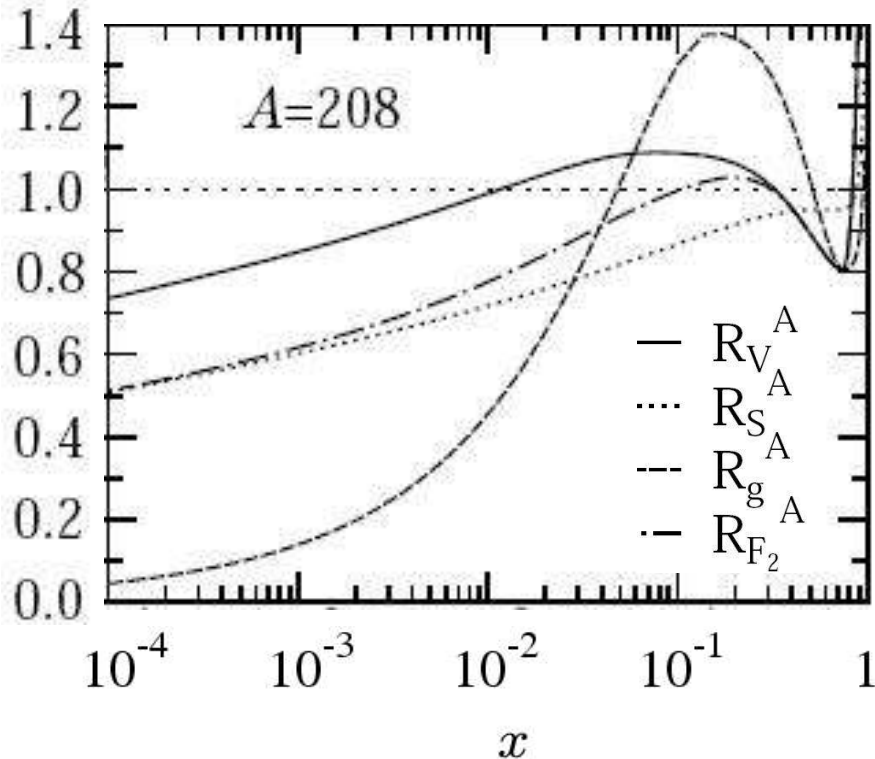
The experimental data

- The experimental input consists over 600 Deep Inelastic & Drell-Yan & inclusive hadron production data points covering 13 nuclei.

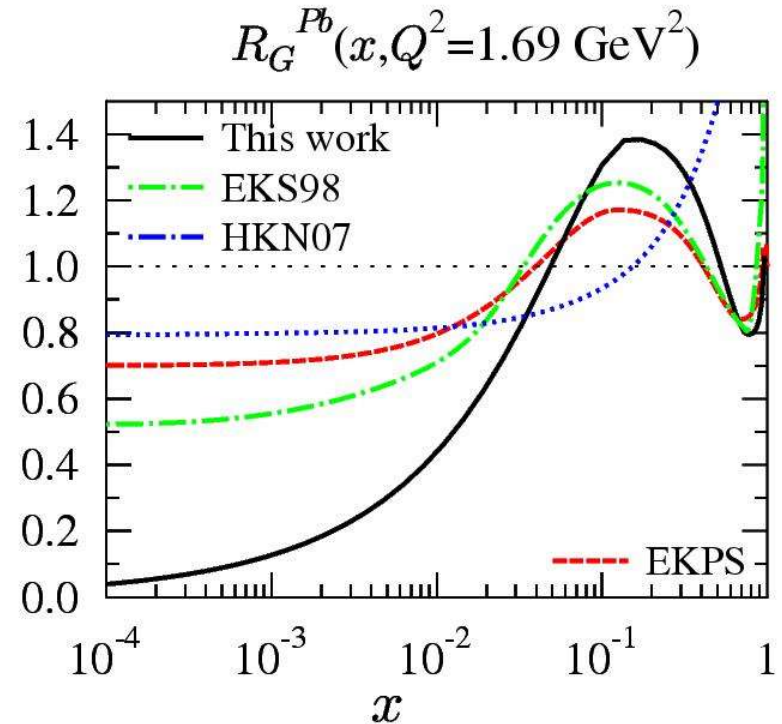
Experiment	Process	Nuclei	Datapoints	Weight					
SLAC E-139	DIS	He(4)/D	18	1	SLAC E-139	DIS	Fe(56)/D	23	1
NMC 95, reanalysis	DIS	He/D	16	1	FNAL-E772	DY	Fe/D	9	10
					NMC 96	DIS	Fe/C	15	1
NMC 95	DIS	Li(6)/D	15	1	FNAL-E866	DY	Fe/Be	28	1
SLAC E-139	DIS	Be(9)/D	17	1					
NMC 96	DIS	Be(9)/C	15	1	CERN EMC	DIS	Cu(64)/D	19	1
SLAC E-139	DIS	C(12)/D	7	1	SLAC E-139	DIS	Ag(108)/D	7	1
NMC 95	DIS	C/D	15	5					
NMC 95, reanalysis	DIS	C/D	16	5	NMC 96	DIS	Sn(117)/C	15	1
NMC 95, reanalysis	DIS	C/Li	20	1	NMC 96, Q^2 dep.	DIS	Sn/C	144	10
FNAL-E772	DY	C/D	9	10					
SLAC E-139	DIS	Al(27)/D	17	1	FNAL-E772	DY	W(184)/D	9	10
NMC 96	DIS	Al/C	15	1	FNAL-E866	DY	W/Be	28	1
SLAC E-139	DIS	Ca(40)/D	7	1	SLAC E-139	DIS	Au(197)/D	18	1
FNAL-E772	DY	Ca/D	9	10	BRAHMS	HH	dAu/pp	6	40
NMC 95, reanalysis	DIS	Ca/D	15	1	PHENIX	HH	dAu/pp	35	1
NMC 95, reanalysis	DIS	Ca/Li	20	1	STAR	HH	dAu/pp	10	1
NMC 96	DIS	Ca/C	15	1					
					NMC 96	DIS	Pb/C	15	1
								total number of datapoints	627

Final parametrization

Final parametrization looks like...



...and why it's different

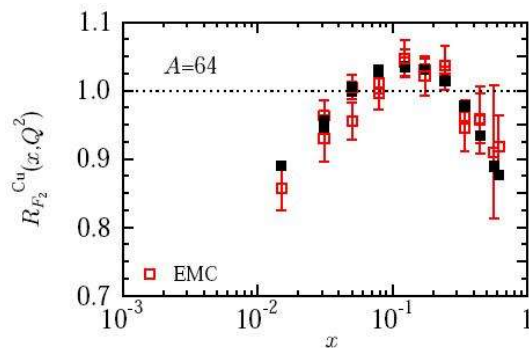
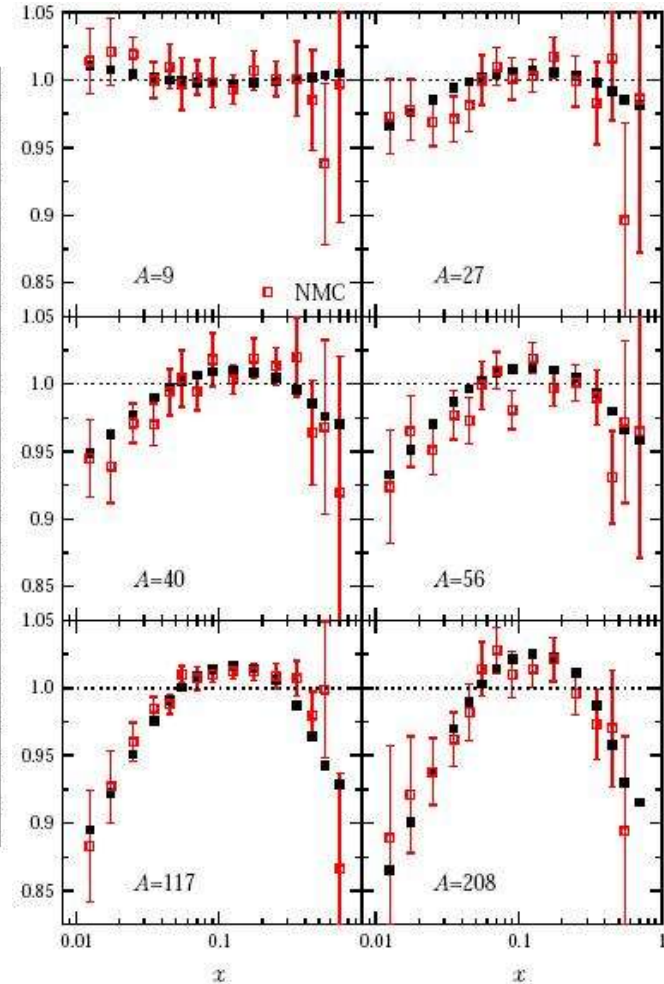
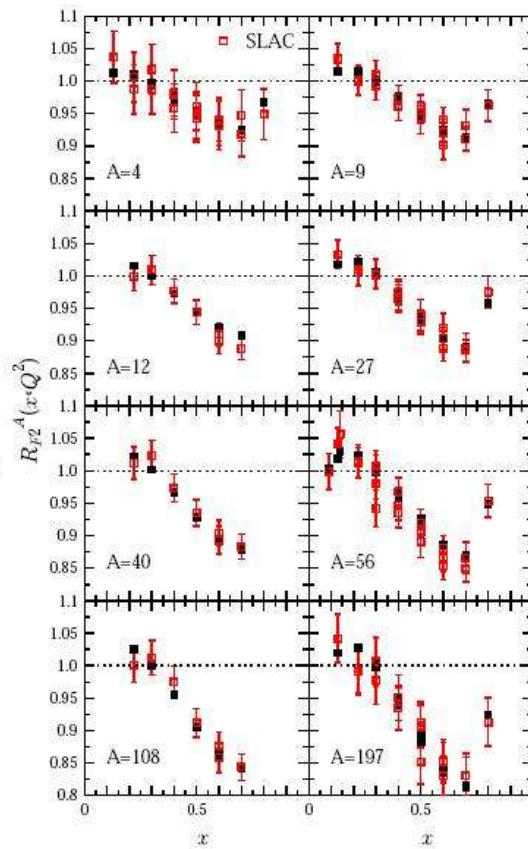
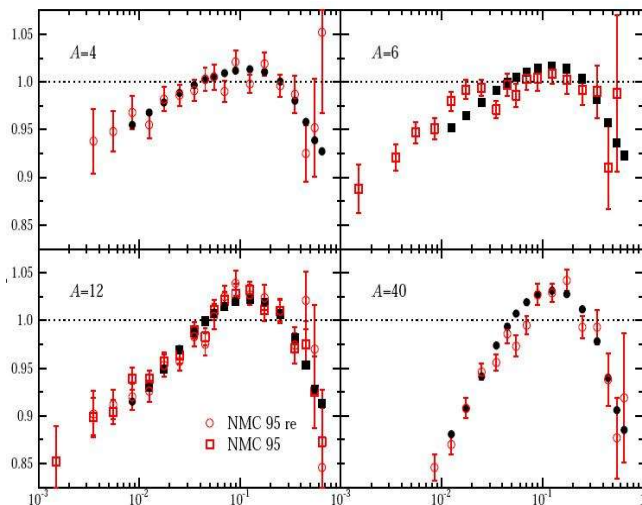


- At small- x there is a *major* difference to previous analyses!

Comparison with data: DIS F_2

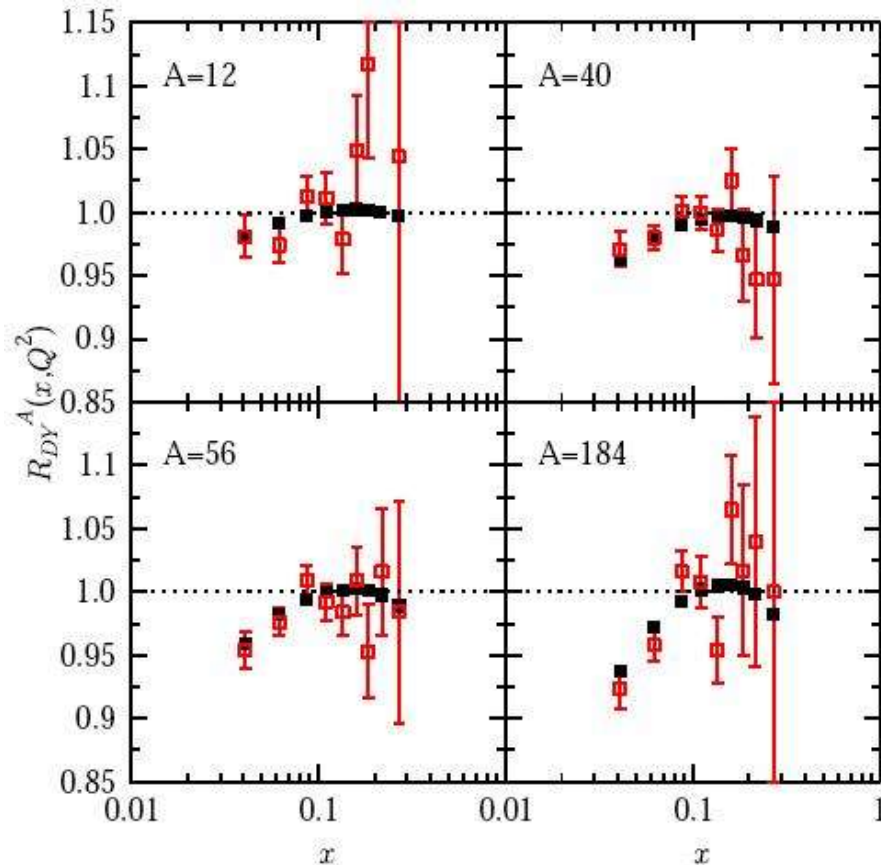
$$\frac{\frac{1}{A} d\sigma^{lA}/dQ^2 dx}{\frac{1}{2} d\sigma^{lD}/dQ^2 dx} \stackrel{\text{LO}}{=} R_{F_2}^A(x, Q^2)$$

$$\frac{\frac{1}{A} d\sigma^{lA}/dQ^2 dx}{\frac{1}{12} d\sigma^{lC}/dQ^2 dx} \stackrel{\text{LO}}{=} \frac{R_{F_2}^A(x, Q^2)}{R_{F_2}^C(x, Q^2)}$$

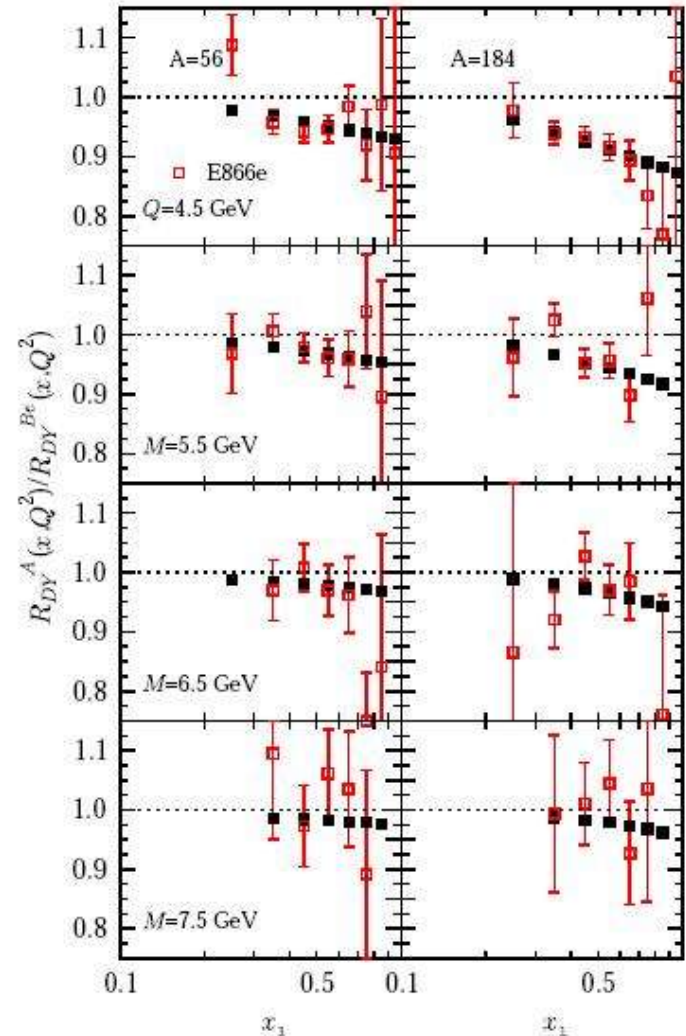


Comparison with data: Drell-Yan

$$\frac{\frac{1}{A} d\sigma_{DY}^{pA} / dx_2 dQ^2}{\frac{1}{2} d\sigma_{DY}^{pD} / dx_2 dQ^2}$$



$$\frac{\frac{1}{A} d\sigma_{DY}^{pA} / dx_1 dQ^2}{\frac{1}{9} d\sigma_{DY}^{pBe} / dx_1 dQ^2}$$



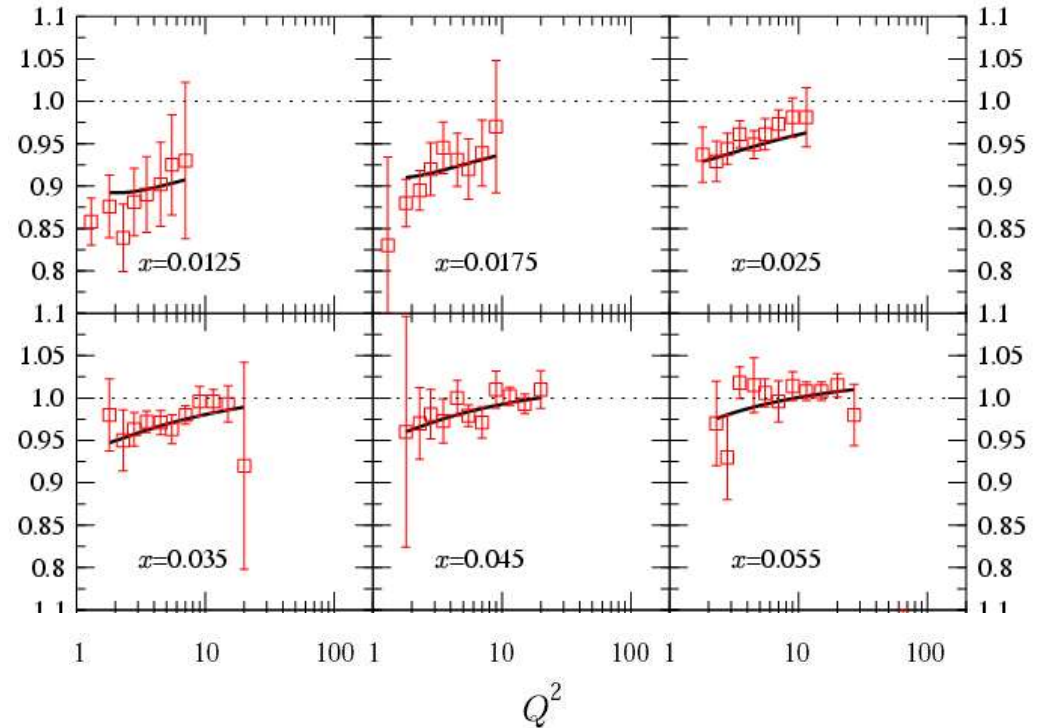
Comparison with data: Q^2 -slopes

- $$\frac{\partial (F_2^{Sn}(x, Q^2)/F_2^C(x, Q^2))}{\partial \log Q^2} \propto$$

$$\left[\frac{R_g^{Sn}(2x, Q^2)}{R_{F_2}^{Sn}(x, Q^2)} - \frac{R_g^C(2x, Q^2)}{R_{F_2}^C(x, Q^2)} \right]$$

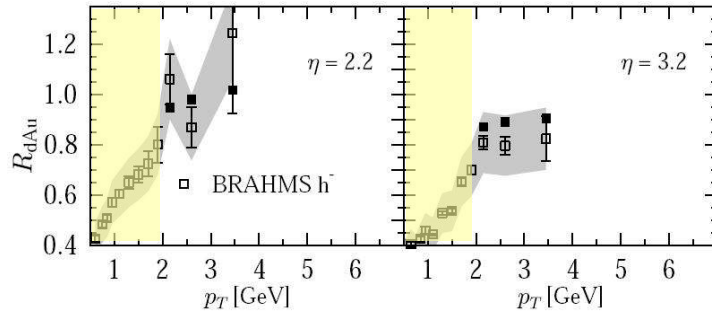
- Too strong gluon shadowing in Sn w.r.t C would render the log Q^2 -slopes *negative*!**

$$F_2^{Sn}(x, Q^2)/F_2^C(x, Q^2)$$

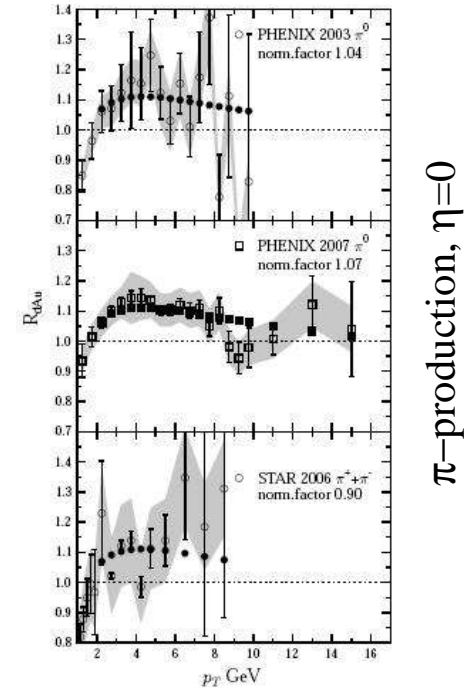
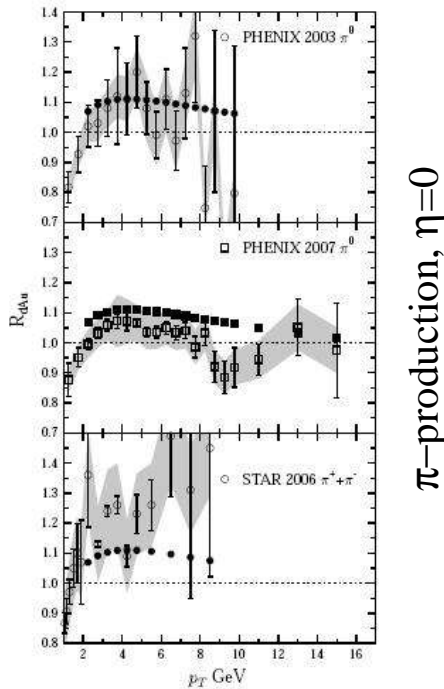
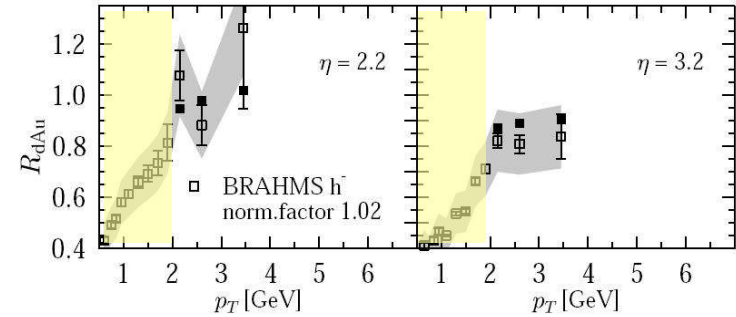


In our parametrization the gluon shadowing is close to being as strong as possible.

Comparison with data: RHIC-data



Normalization factor f_n included



- The normalization uncertainties must be taken seriously!!

Conclusions

- **Present:**
 - **Data from RHIC BRAHMS demands a clearly stronger gluon shadowing than what has been estimated before.**
 - **Being first one of the kind, our analysis demonstrates that it is possible to consistently combine inclusive hadron production data with the DIS & DY data to obtain a more complete pQCD picture of bound nucleons!**
 - **Effective factorization works!**
- **Future:**
 - **New data for nuclear modification expected from RHIC**
 - direct photons?
 - open charm?
 - **Extend the analysis to NLO**
- **Dreams:**
 - **Electron-Ion collider: eRHIC, eLHC, ...**