EPS08 – An improved global analysis of nuclear PDFs

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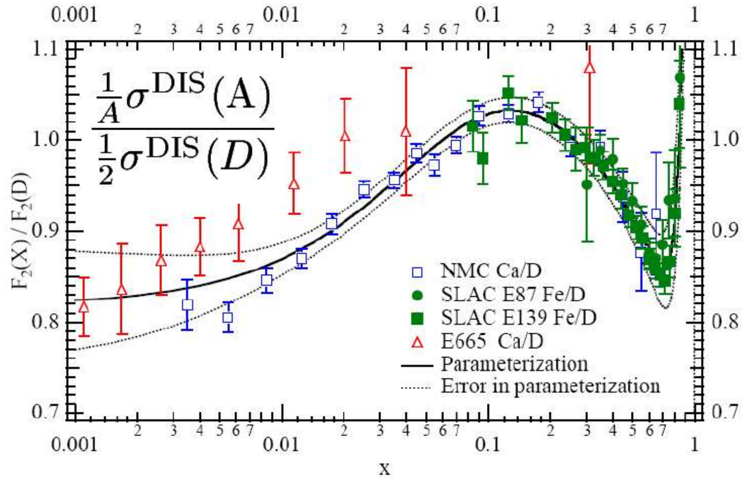
Philosophy of Global nPDF analyses



- **The DIS 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 <u>process independent</u> PDFs – do they effectively factorize:**

$$\sigma^{AB\to h+X} = \sum_{ijkl} \underbrace{f_i^A(x_1,Q) \otimes f_j^B(x_2,Q)}_{\text{Nuclear PDFs}} \otimes \underbrace{\sigma^{i+j\to k+l} \otimes D_{k\to h+X}(z,Q_f)}_{\text{Standard pQCD cross-sections \& fragmentation functions}}$$

Nuclear PDFs

Standard pQCD cross-sections & fragmentation functions

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**
2008 : EPS08	(Eskola, Paukkunen, Salgado)	**LO**

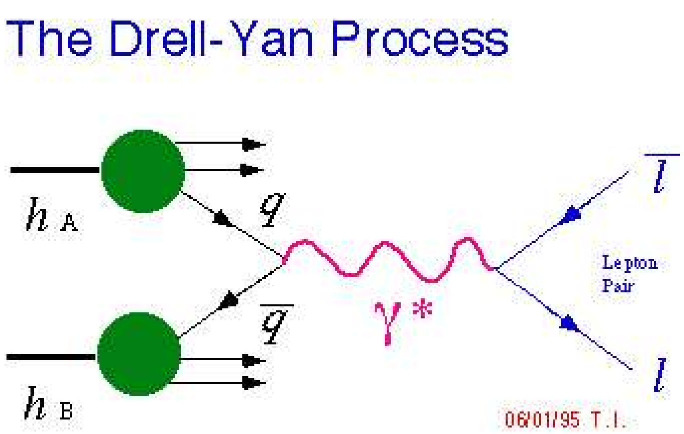
- **The experimental input has remained essentially the same for all 10 years!**

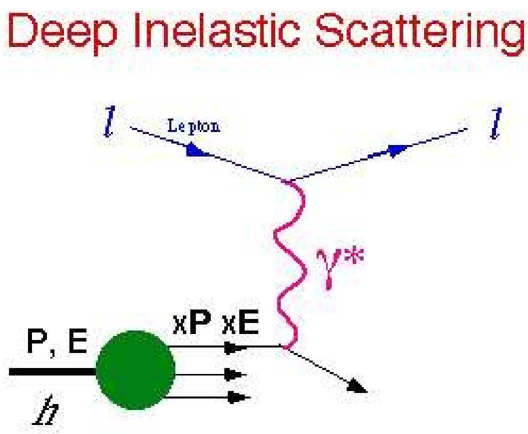
- **New constraints are obviously needed for any serious further progress.**

→ **RHIC d + Au collisions!**

Reasons for new LO analysis

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



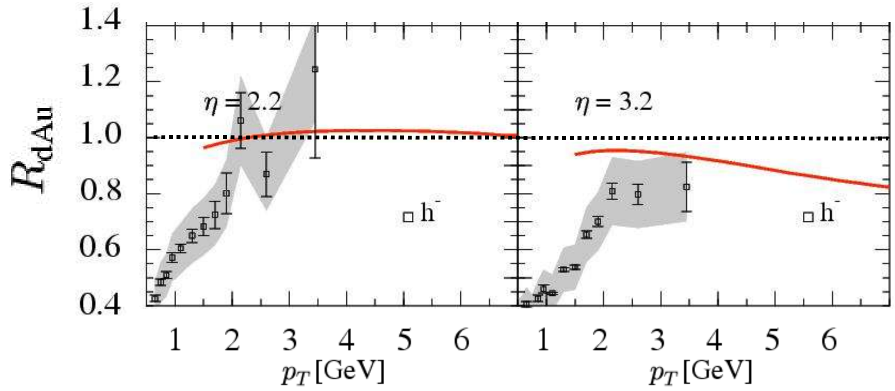


- The nuclear modifications for gluon PDFs have been largely dictated by the <u>assumed</u> form of the fit functions

Reasons for new LO analysis

- **Our earlier parametrizations fail to reproduce the nuclear modification R_{dAu} for inclusive hadron production for d+Au collisions at large rapidity & low-p_T.**

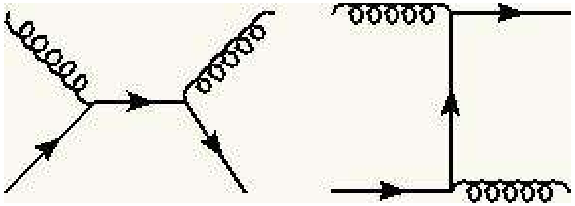
$$R_{\rm dAu} = \frac{1}{\langle N_{\rm coll}\rangle} \frac{d^2N^{\rm dAu}/dp_T d\eta}{d^2N^{\rm pp}/dp_T d\eta} \overset{\rm min.bias}{=} \frac{\frac{1}{2A} d^2\sigma^{\rm dAu}/dp_T d\eta}{d^2\sigma^{\rm pp}/dp_T d\eta}$$



BRAHMS data:
PRL **93**, 242303 (2004)

EKPS parametrization

- **Probes mainly the gluons in Au at $x > 5\times10^{-4}$**



- **Indicates a stronger gluon shadowing than estimated earlier. Consistent with DIS & DY data?**

About The Framework

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

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

- **For bound neutron PDFs we assume iso-spin symmetry**

- **nPDFs are parametrized 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 constrain R_i's**

About The Framework

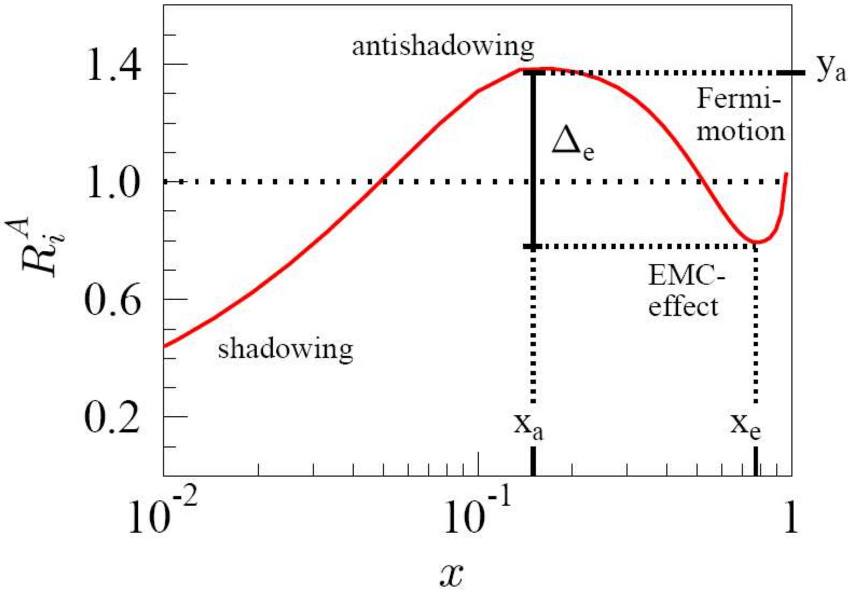
- **Piecewize parametrization of R_i's:**

$$\begin{aligned}
R_1^A(x) &= c_0^A + (c_1^A + c_2^A x^{\alpha^A})[\exp(-x/x_s^A) - \exp(-x_a^A/x_s^A)], & x \le x_a^A \\
R_2^A(x) &= a_0^A + a_1^A x + a_2^A x^2 + a_3^A x^3, & x_a^A \le x \le x_e^A \\
R_3^A(x) &= \frac{b_0^A - b_1^A x}{(1-x)^{\beta^A}} + b_2^A\,(x - x_e)^2\,, & x_e^A \le x
\end{aligned}$$

- **We assume that at small-x limit:** $R_i^A(x, Q_0^2) \overset{x\to 0}{\sim} x^{\alpha^A}, \qquad \alpha^A > 0$
  leading to power-law behaviour of nPDFs at small x.

- **The A dependence is in the fit parameters**

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



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 RHIC data sets are accounted by normalization factors $f_N \in [1-\sigma^{\text{norm}}, 1+\sigma^{\text{norm}}]$.**

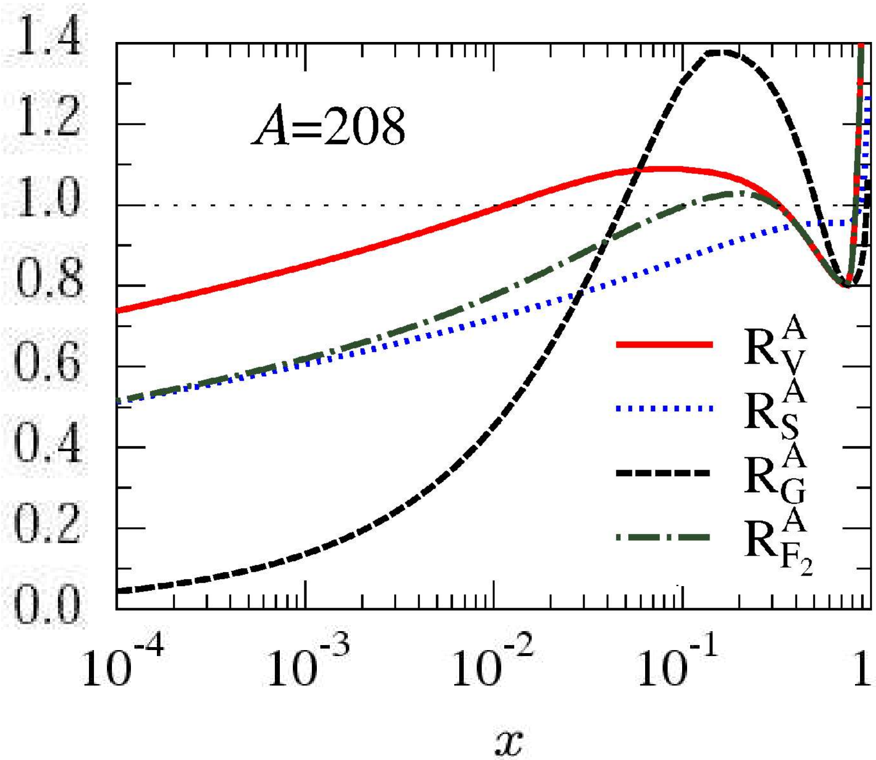
The experimental data

- **Our experimental input consists over 600 DIS, Drell-Yan, and inclusive hadron production data points covering 13 nuclei.**

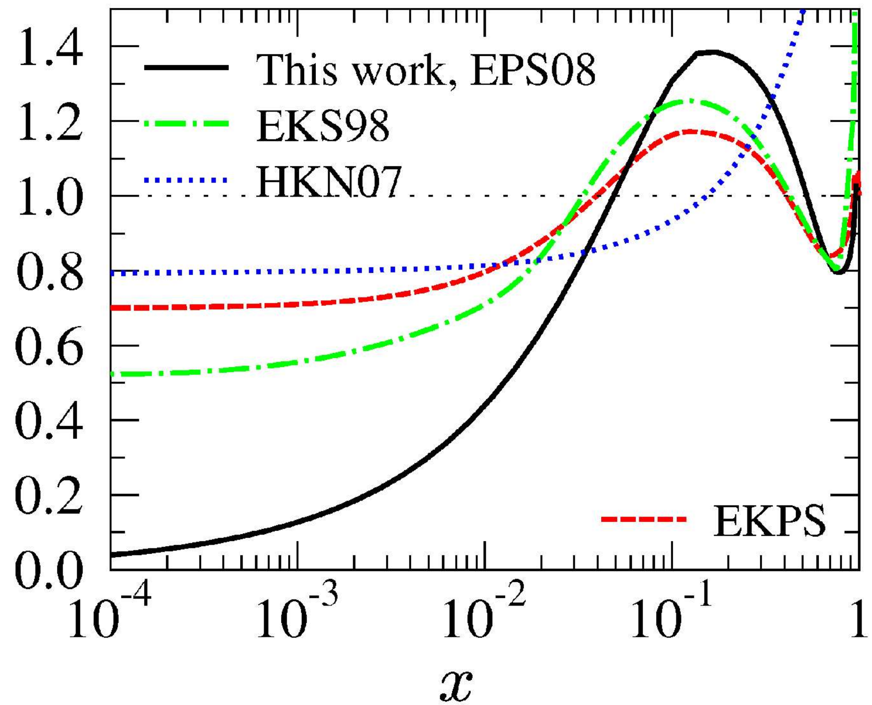
Experiment	Process	Nuclei	Datapoints	Weight
SLAC E-139	DIS	He(4)/D	18	1
NMC 95, reanalysis	DIS	He/D	16	1
NMC 95	DIS	Li(6)/D	15	1
SLAC E-139	DIS	Be(9)/D	17	1
NMC 96	DIS	Be(9)/C	15	1
SLAC E-139	DIS	C(12)/D	7	1
NMC 95	DIS	C/D	15	5
NMC 95, reanalysis	DIS	C/D	16	5
NMC 95, reanalysis	DIS	C/Li	20	1
FNAL-E772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

Final parametrization

Final parametrization looks like…



…and why it's different

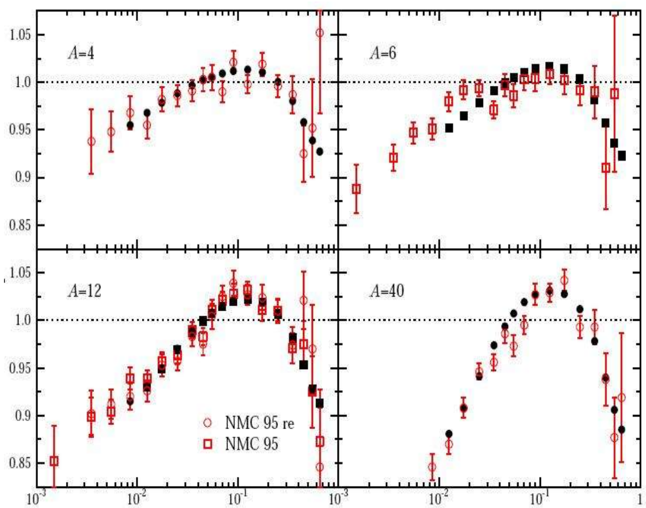


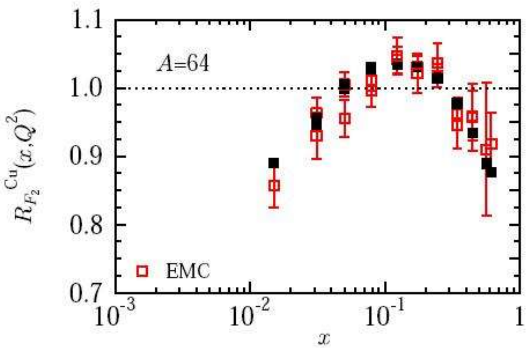
- **At small-x there is a *major* difference to previous analyses!**
- **Goodeness of the fit is $\chi^2/N_{data} \approx 0.71$**

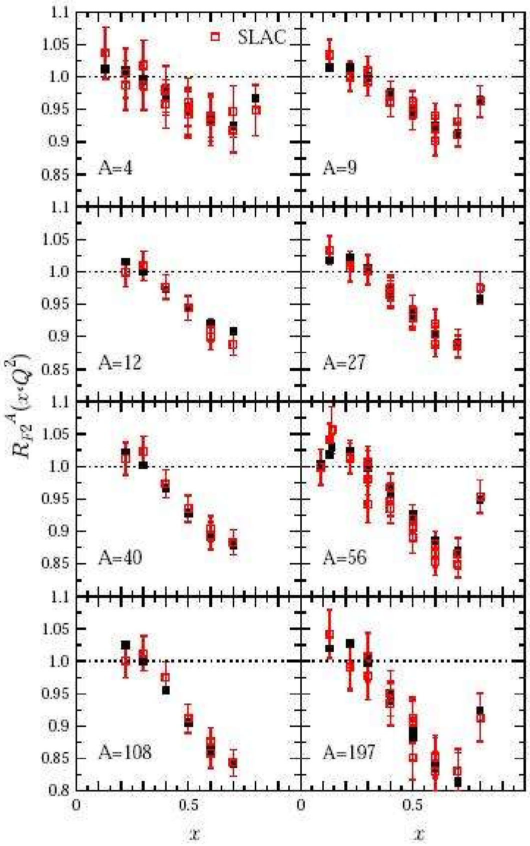
Comparison with data: DIS F_2

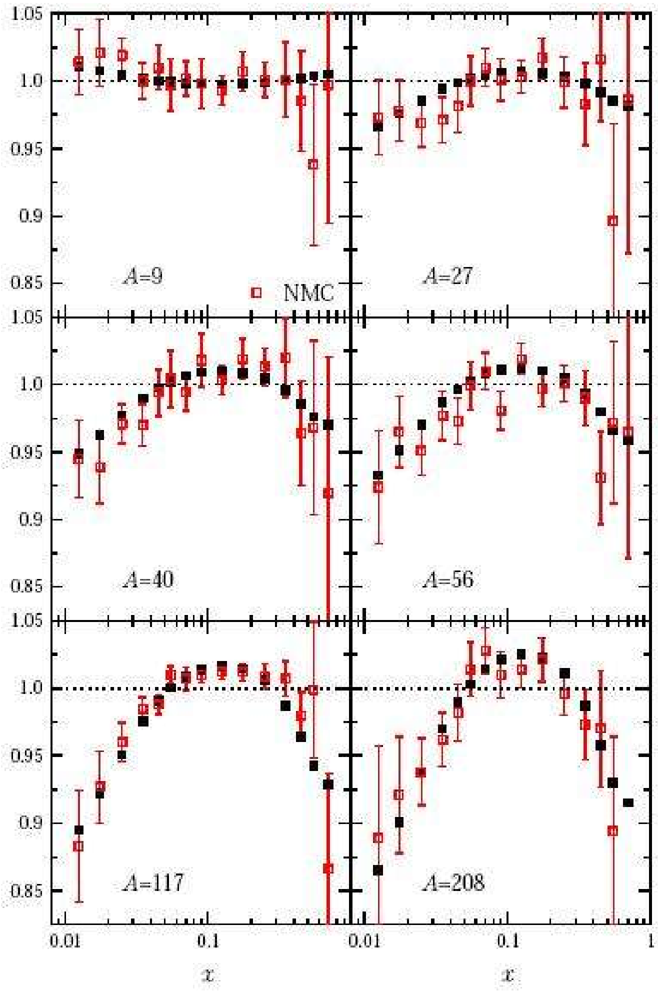
$$\frac{\frac{1}{A}d\sigma^{lA}/dQ^2dx}{\frac{1}{2}d\sigma^{l\mathrm{D}}/dQ^2dx} \stackrel{\mathrm{LO}}{=} R^A_{F_2}(x,Q^2)$$

$$\frac{\frac{1}{A}d\sigma^{lA}/dQ^2dx}{\frac{1}{12}d\sigma^{l\mathrm{C}}/dQ^2dx} \stackrel{\mathrm{LO}}{=} \frac{R^A_{F_2}(x,Q^2)}{R^{\mathrm{C}}_{F_2}(x,Q^2)}$$



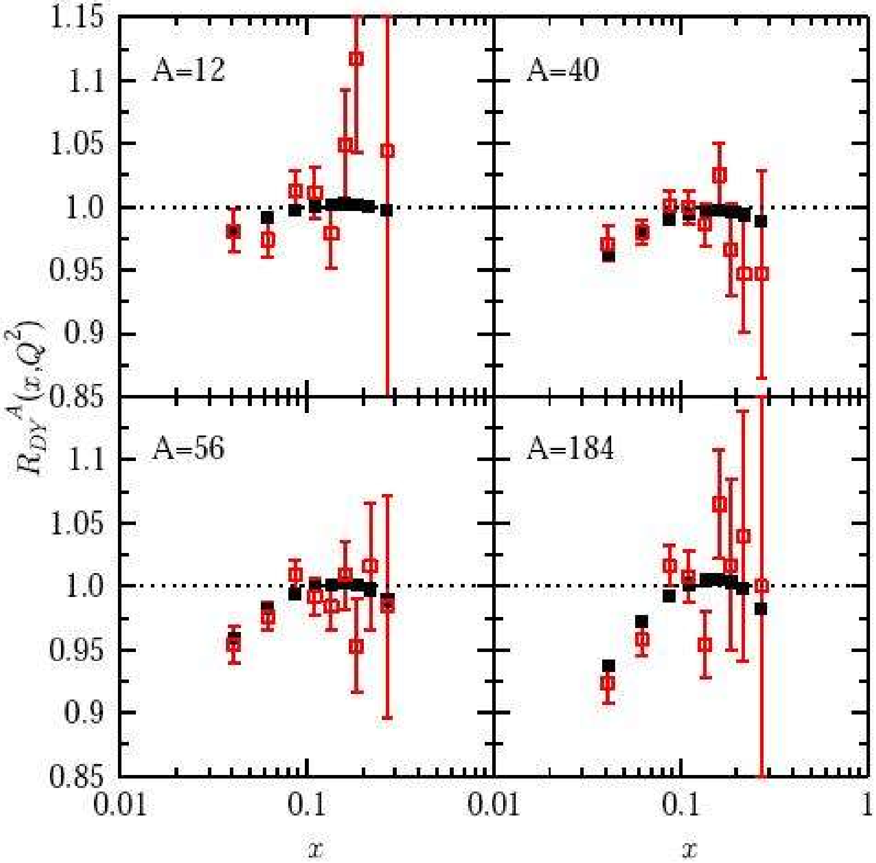




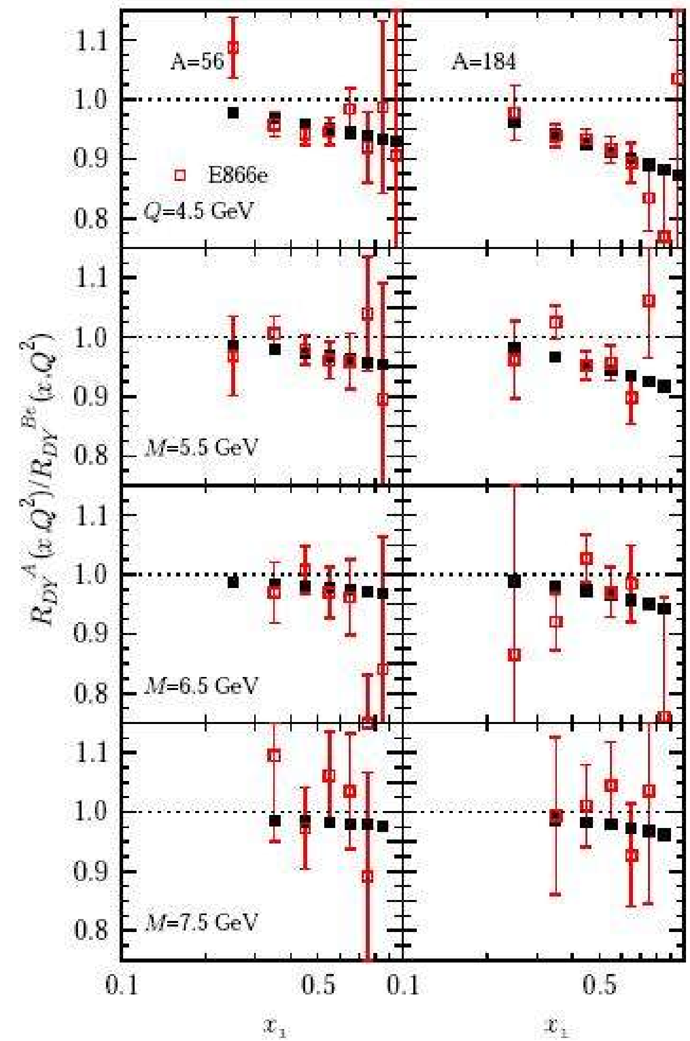


Comparison with data: Drell-Yan

$$\frac{\frac{1}{A}d\sigma_{DY}^{\mathrm{p}A}/dx_2dQ^2}{\frac{1}{2}d\sigma_{DY}^{\mathrm{pD}}/dx_2dQ^2}$$

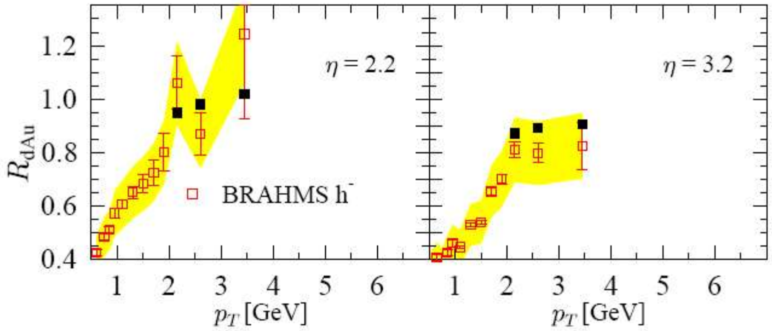


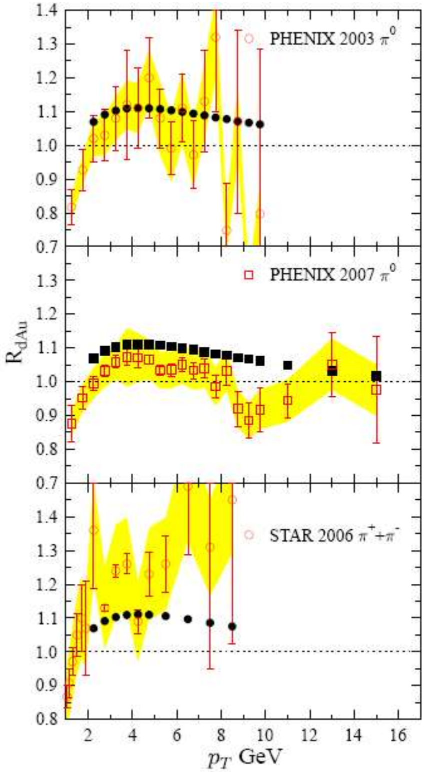
$$\frac{\frac{1}{A}d\sigma_{DY}^{\mathrm{p}A}/dx_1dQ^2}{\frac{1}{9}d\sigma_{DY}^{\mathrm{pBe}}/dx_1dQ^2}$$



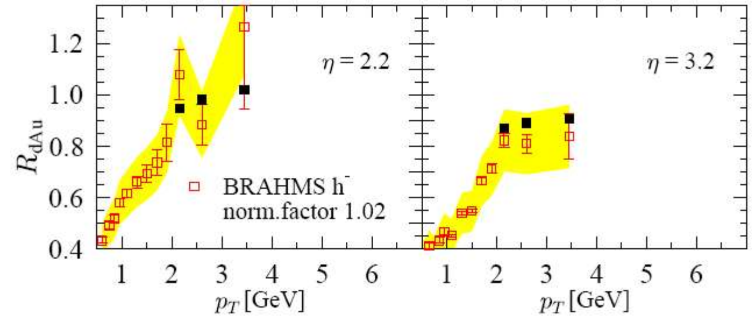
Comparison with data: RHIC-data

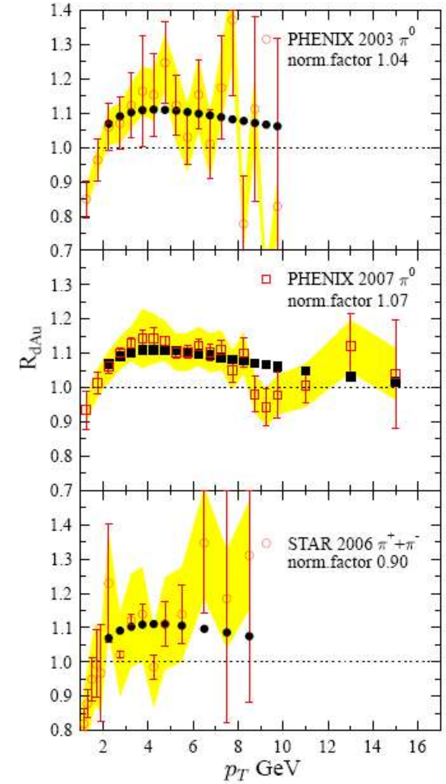
Optimized normalization factor f_N included





π–production, η=0



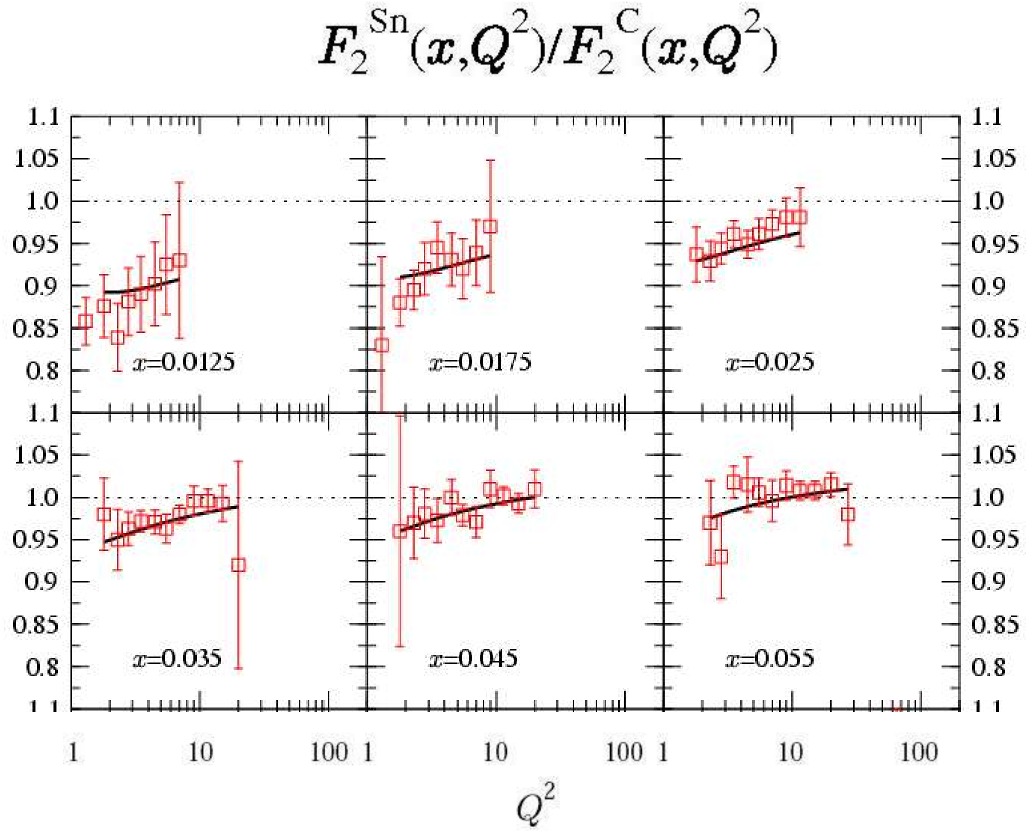


π–production, η=0

Q^2-slopes in DIS F_2-data

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

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



- **In EPS08 the gluon shadowing is close to being as strong as possible.**

Concluding remarks

- **Present:**
  - **For the first time, we have demonstrated that it is possible to consistently combine inclusive hadron production data with the DIS & DY to a well-working set of nuclear PDFs.**
  - **Requires a strong gluon shadowing!**

- **Our future plans:**
  - **New data for nuclear modification expected from RHIC:**
    - **-direct photons (p_T > 6GeV)**
    - **-open charm?**
  - **Extend the analysis to NLO**

- **Further future:**
  - **p-A runs also at LHC?**
  - **Electron-Ion collider: eRHIC, LHeC, ...**