Global reanalysis of the nuclear PDFs

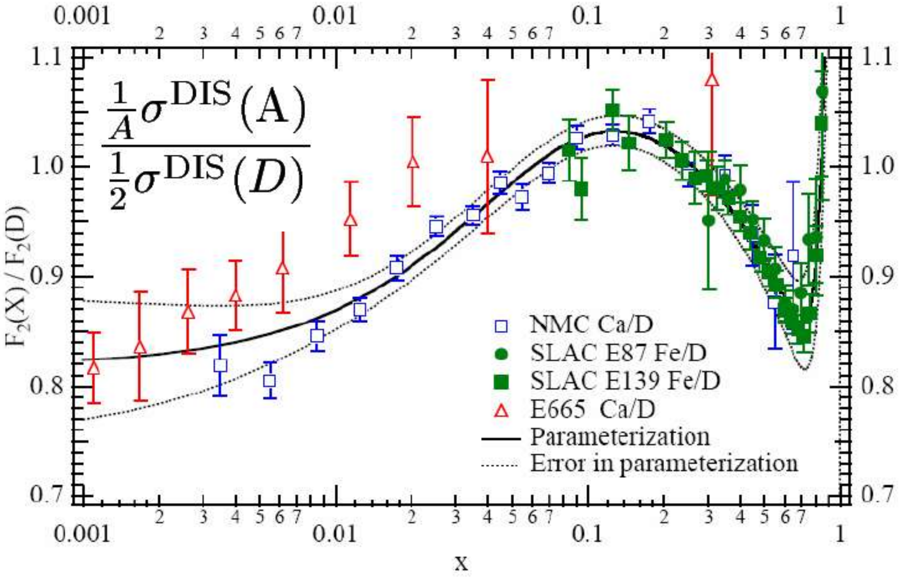
JHEP 0705:002,2007

Hannu Paukkunen

University Of Jyväskylä, Department of Physics &
Helsinki Institute Of Physics

Kari J. Eskola, Vesa J. Kolhinen, Carlos A. Salgado

Global nPDF analysis in a nutshell



- **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 PDFs – do they effectively factorize.**

Previous global DGLAP analyses

- **Free proton PDFs: CTEQ, MRST, GRV, ...**
- **Nuclear PDFs:**

EKS98 (Eskola, Kolhinen, Ruuskanen, Salgado)
[hep-ph/9802350,hep-ph/9807297]
- **1st** global analysis for nPDFs
- very good fits to nuclear **DIS & DY** data obtained with sum rules imposed – **it works**!

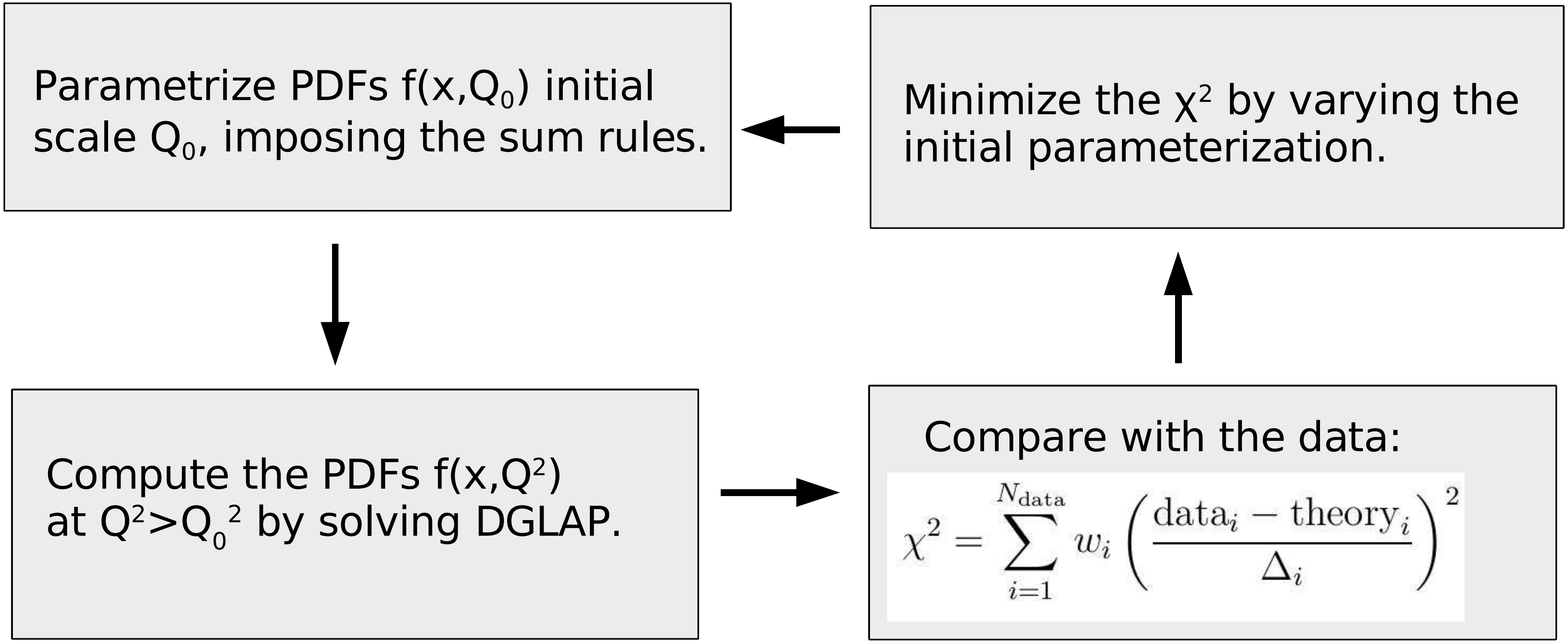
HKN, HKM (Hirai, Kumano, Nagai, Miyama)
[hep-ph/0103208,hep-ph/0404093]
- **automated chi^2 minimization**
- **uncertainty estimates**

nDS (de Florian, Sassot)
[hep-ph/0311227]
- first NLO global analysis for nPDFs

Why to do reanalysis?

- **Try to improve the old EKS98 global analysis by**
  - Automated χ2 minimization (EKS98 was fitted by eye)
  - Uncertainty estimates
  - Simpler and more transparent fitting functions
- **Study the possibility for stronger gluon shadowing**
- **Necessary 'stepping stone' for our upcoming NLO analysis of the nPDFs.**

Recipe of Global PDF analysis



Parametrize PDFs $f(x,Q_0)$ initial scale Q_0, imposing the sum rules.

Compute the PDFs $f(x,Q^2)$ at $Q^2>Q_0^2$ by solving DGLAP.

Compare with the data:

$$\chi^2 = \sum_{i=1}^{N_\mathrm{data}} w_i \left(\frac{\mathrm{data}_i - \mathrm{theory}_i}{\Delta_i} \right)^2$$

Minimize the χ^2 by varying the initial parameterization.

The Framework

- We define the PDFs of bound protons in a nucleus A as

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

- PDFs of bound neutrons from: $u_{\mathrm{neutron}} = d_{\mathrm{proton}}$

- We parametrize the initial distributions 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 are required

- Assume the A-dependence of the fit parameters z_i to follow power law

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

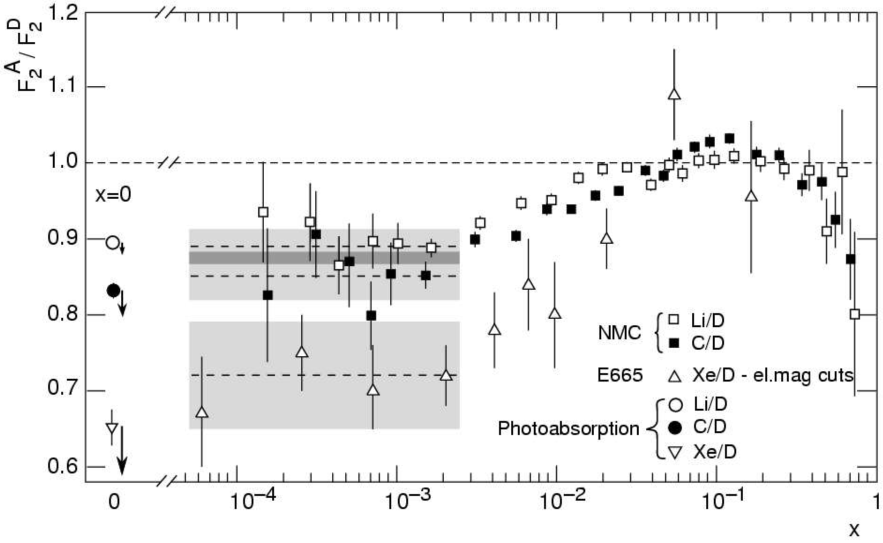
The Framework

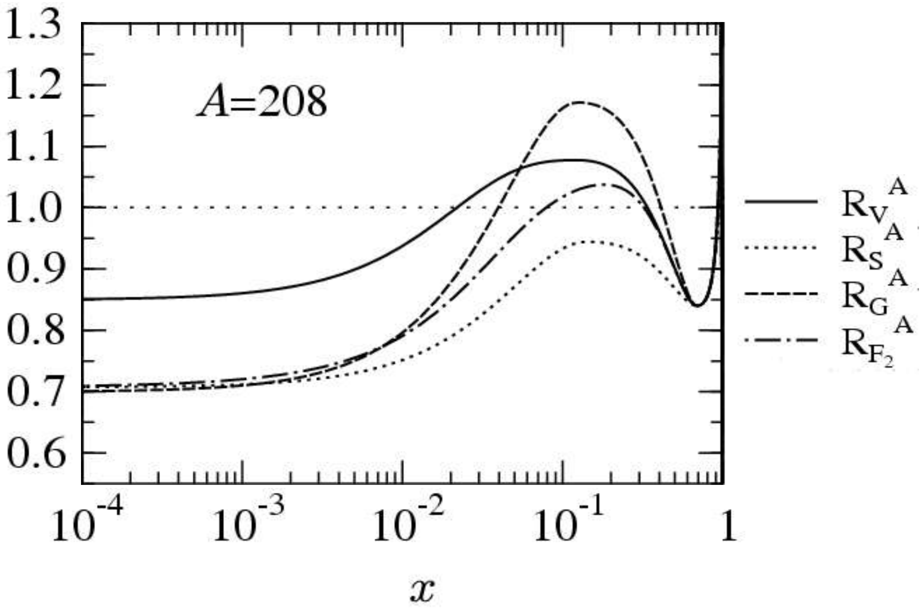
- **Piecewize parametrization of R$_i$’s:**

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

motivation from NMC data...

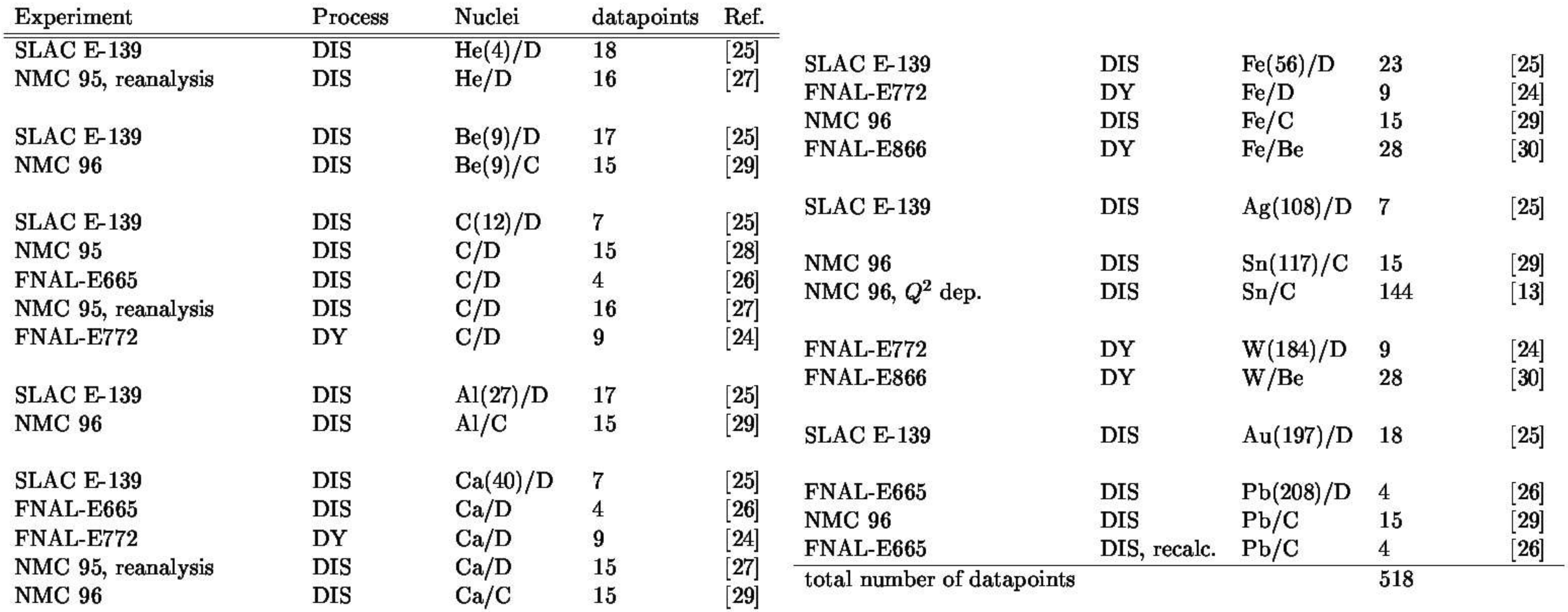
...and how it finally looks like





The experimental data sets

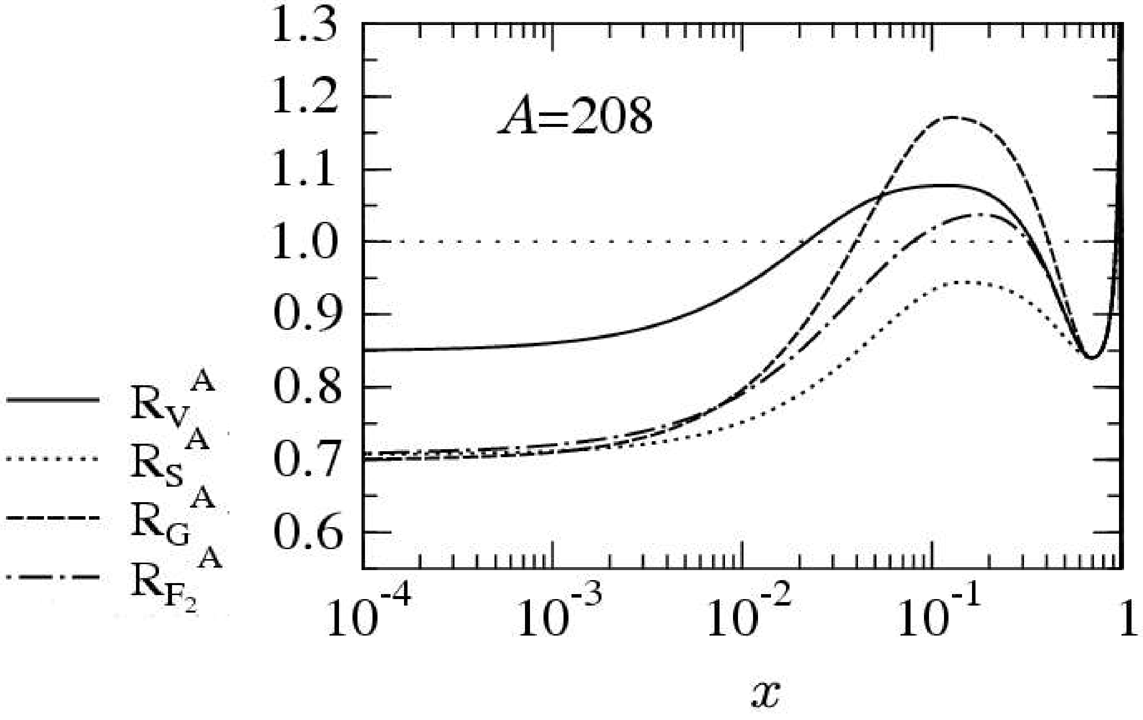
- **Over 500 Deep Inelastic & Drell-Yan data points covering 11 elements:**



Experiment	Process	Nuclei	datapoints	Ref.
SLAC E-139	DIS	He(4)/D	18	[25]
NMC 95, reanalysis	DIS	He/D	16	[27]
SLAC E-139	DIS	Be(9)/D	17	[25]
NMC 96	DIS	Be(9)/C	15	[29]
SLAC E-139	DIS	C(12)/D	7	[25]
NMC 95	DIS	C/D	15	[28]
FNAL-E665	DIS	C/D	4	[26]
NMC 95, reanalysis	DIS	C/D	16	[27]
FNAL-E772	DY	C/D	9	[24]
SLAC E-139	DIS	Al(27)/D	17	[25]
NMC 96	DIS	Al/C	15	[29]
SLAC E-139	DIS	Ca(40)/D	7	[25]
FNAL-E665	DIS	Ca/D	4	[26]
FNAL-E772	DY	Ca/D	9	[24]
NMC 95, reanalysis	DIS	Ca/D	15	[27]
NMC 96	DIS	Ca/C	15	[29]
SLAC E-139	DIS	Fe(56)/D	23	[25]
FNAL-E772	DY	Fe/D	9	[24]
NMC 96	DIS	Fe/C	15	[29]
FNAL-E866	DY	Fe/Be	28	[30]
SLAC E-139	DIS	Ag(108)/D	7	[25]
NMC 96	DIS	Sn(117)/C	15	[29]
NMC 96, Q^2 dep.	DIS	Sn/C	144	[13]
FNAL-E772	DY	W(184)/D	9	[24]
FNAL-E866	DY	W/Be	28	[30]
SLAC E-139	DIS	Au(197)/D	18	[25]
FNAL-E665	DIS	Pb(208)/D	4	[26]
NMC 96	DIS	Pb/C	15	[29]
FNAL-E665	DIS, recalc.	Pb/C	4	[26]
total number of datapoints			518	

Finding the Parameters

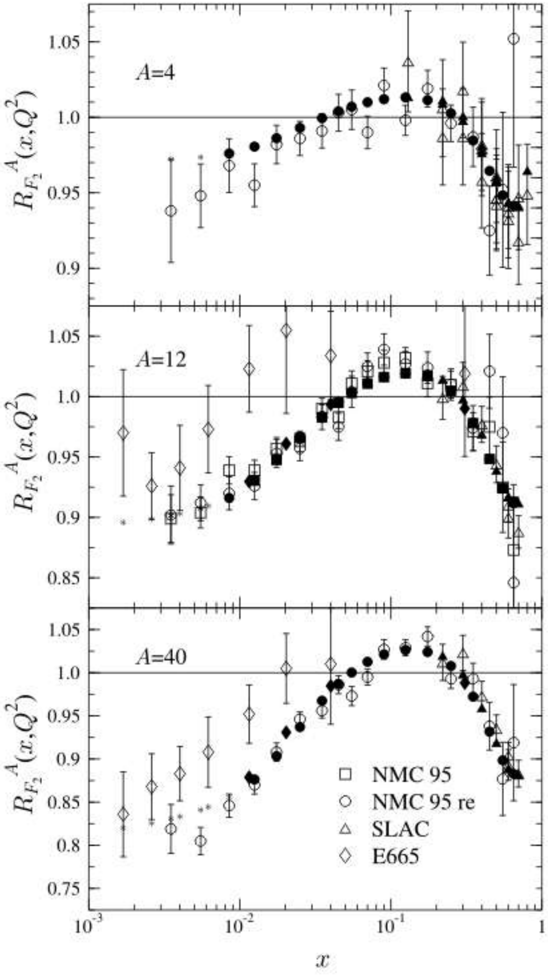
- The data constrain large-x gluons & sea quarks very weakly.
  - → They were fixed to follow the valence
- Lot of manual work was needed to find out what parameters are relevant and what can be fixed.
- Of 42 initial parameters 16 was left free.
- $\frac{X^2}{N} \approx 0.8$ Good fit!

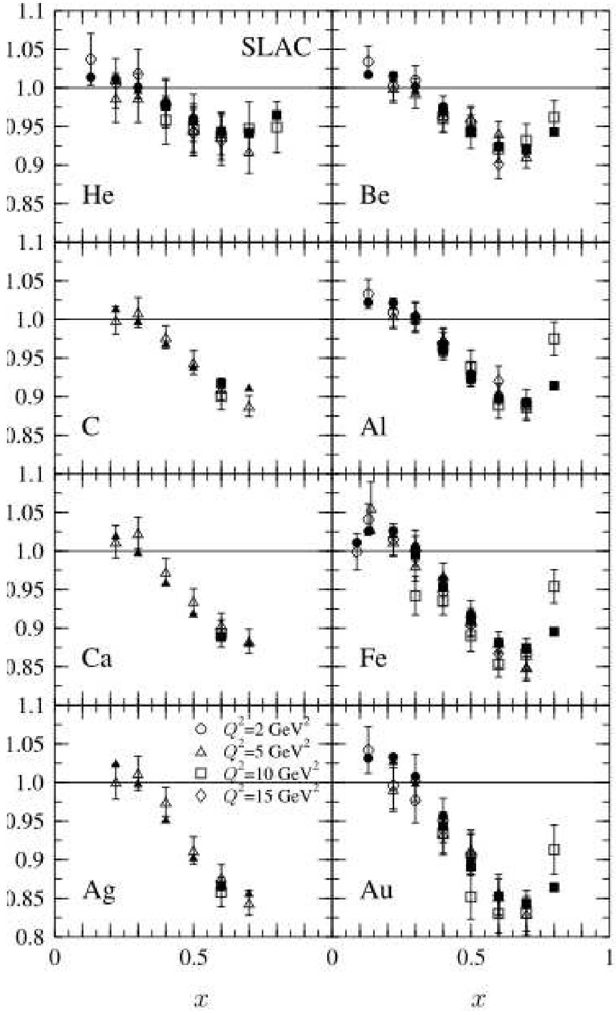


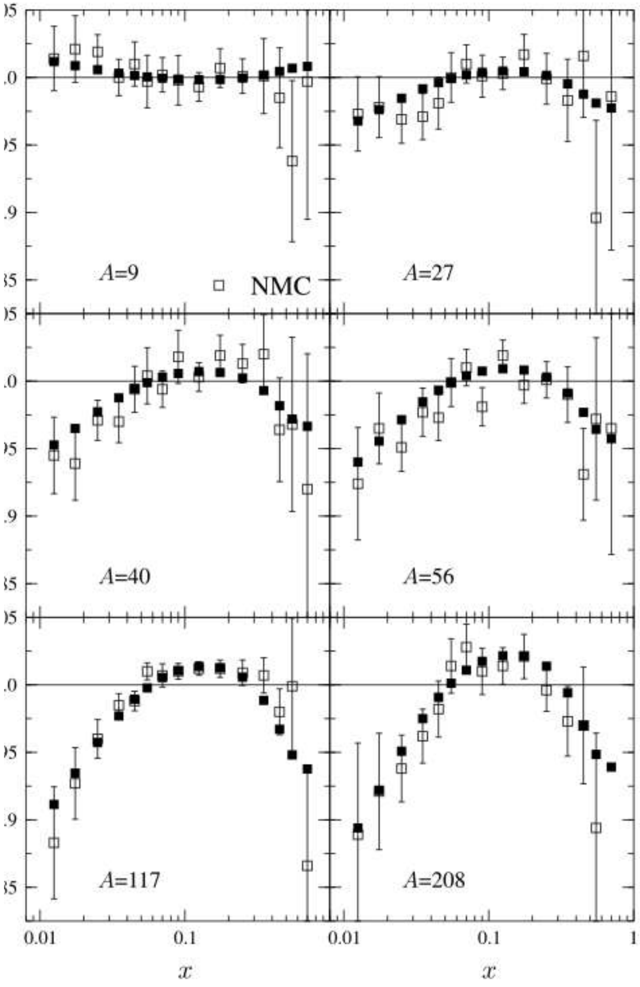
Comparison with data: DIS F_2

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

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

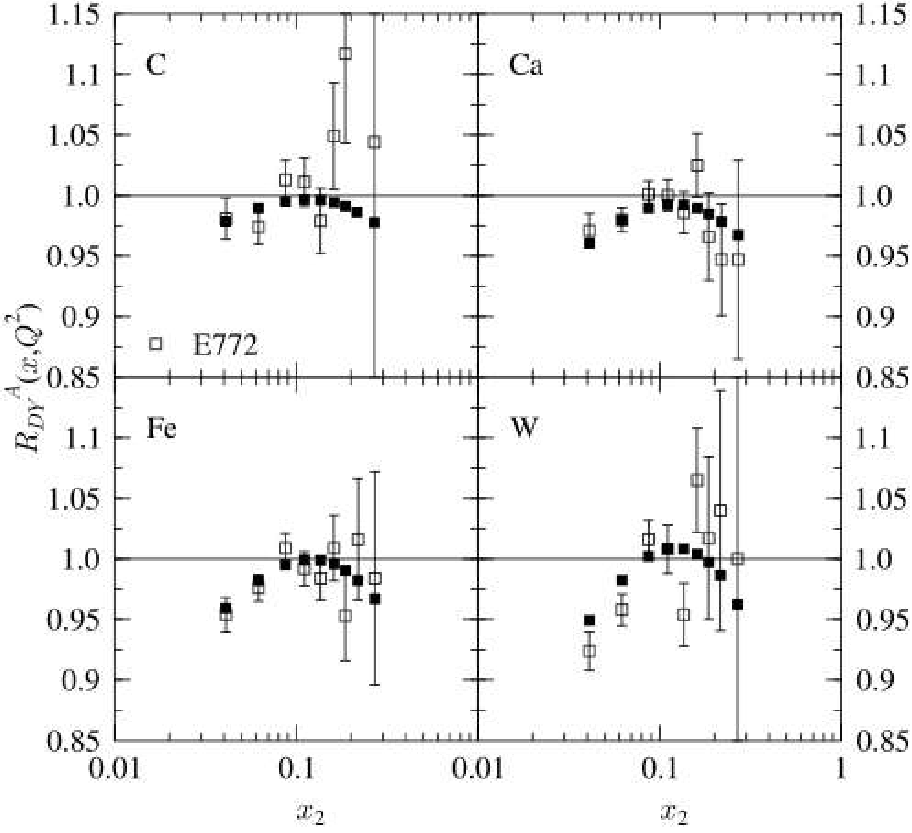




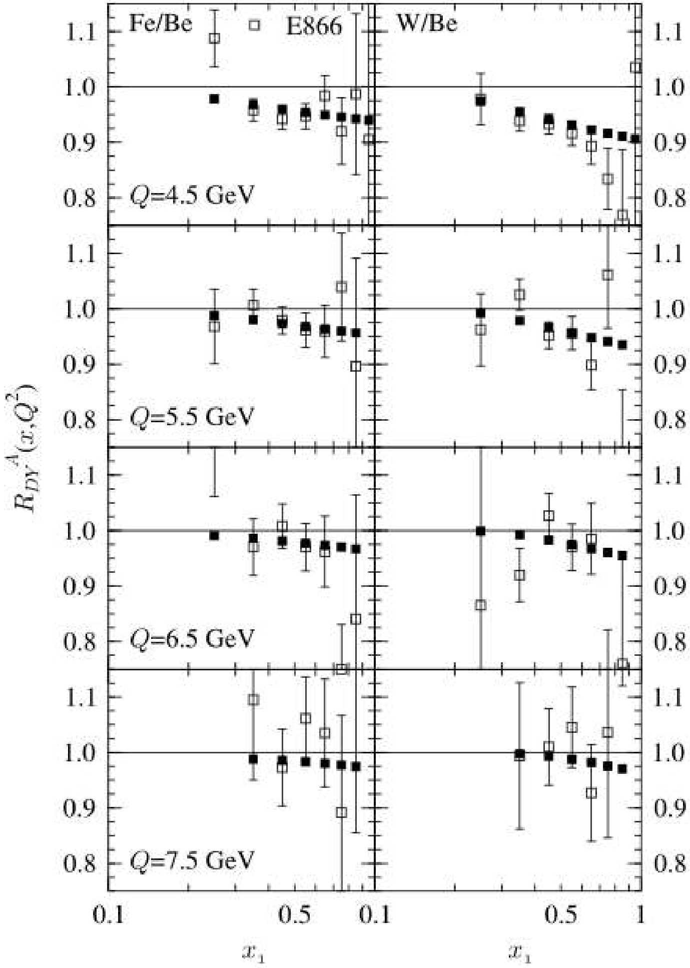


Comparison with data: Drell-Yan

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



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

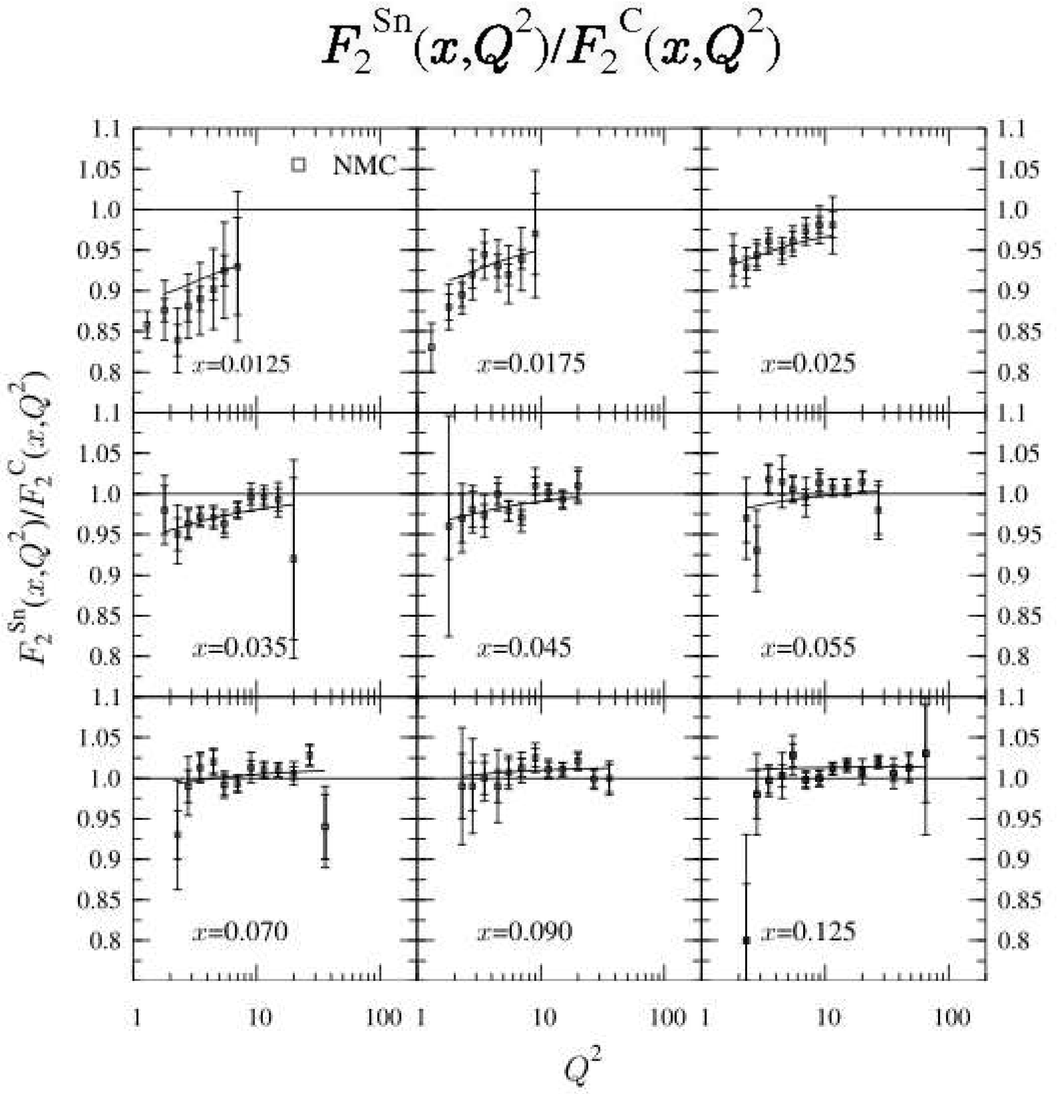


Comparison with data: Q^2-slopes

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

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

- **This data set does not favor very strong gluon shadowing around x ~0.03.**



Few words about error analysis:

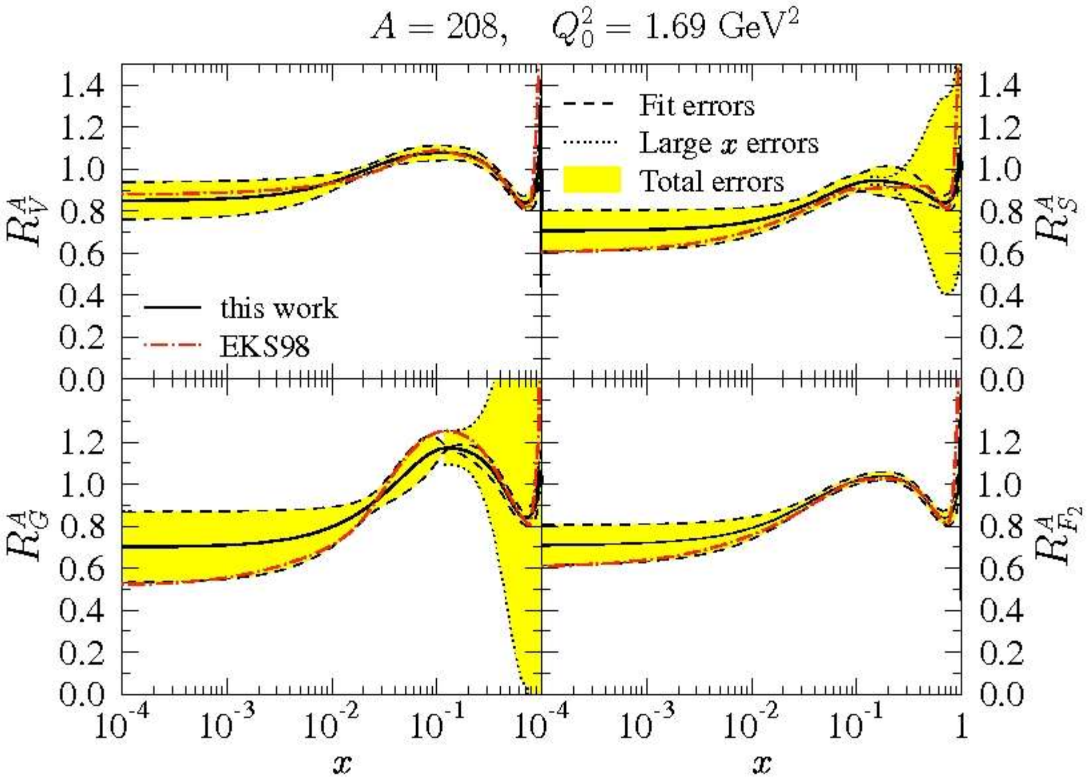
…and why not to take them too seriously

- **Hessian method to quantify errors:**

$$\Delta\chi^2 = \chi^2(\hat{\xi}+\delta\xi) - \chi^2(\hat{\xi}) = \sum_{i,j} H_{ij}\,\delta\xi_i\,\delta\xi_j$$

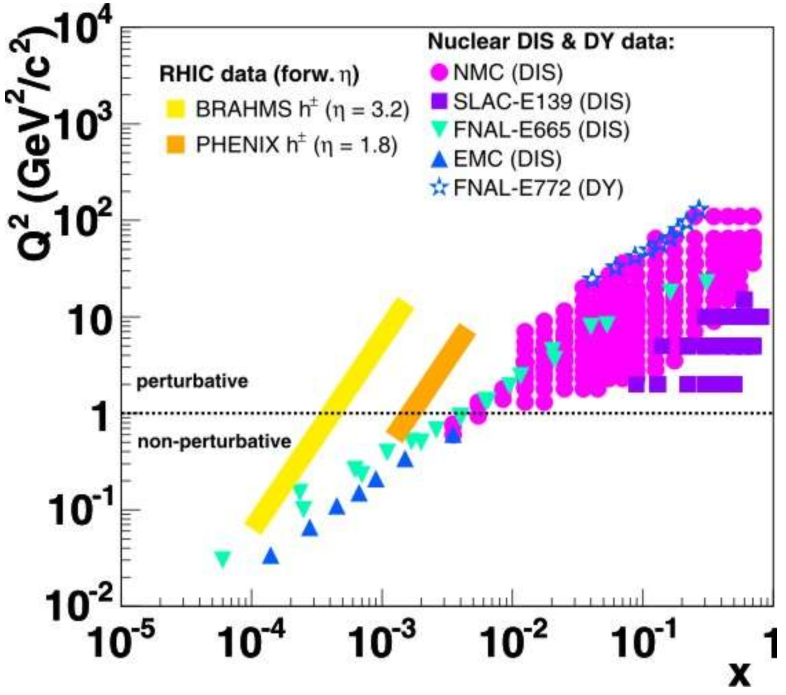
$$[\delta F(x,\hat{\xi})]^2 = \Delta\chi^2 \sum_{i,j} \left(\frac{\partial F(x,\xi)}{\partial \xi_i}\right) H^{-1}_{ij} \left(\frac{\partial F(x,\hat{\xi})}{\partial \xi_j}\right)$$

- **We take: Δχ2 ≅ 18**

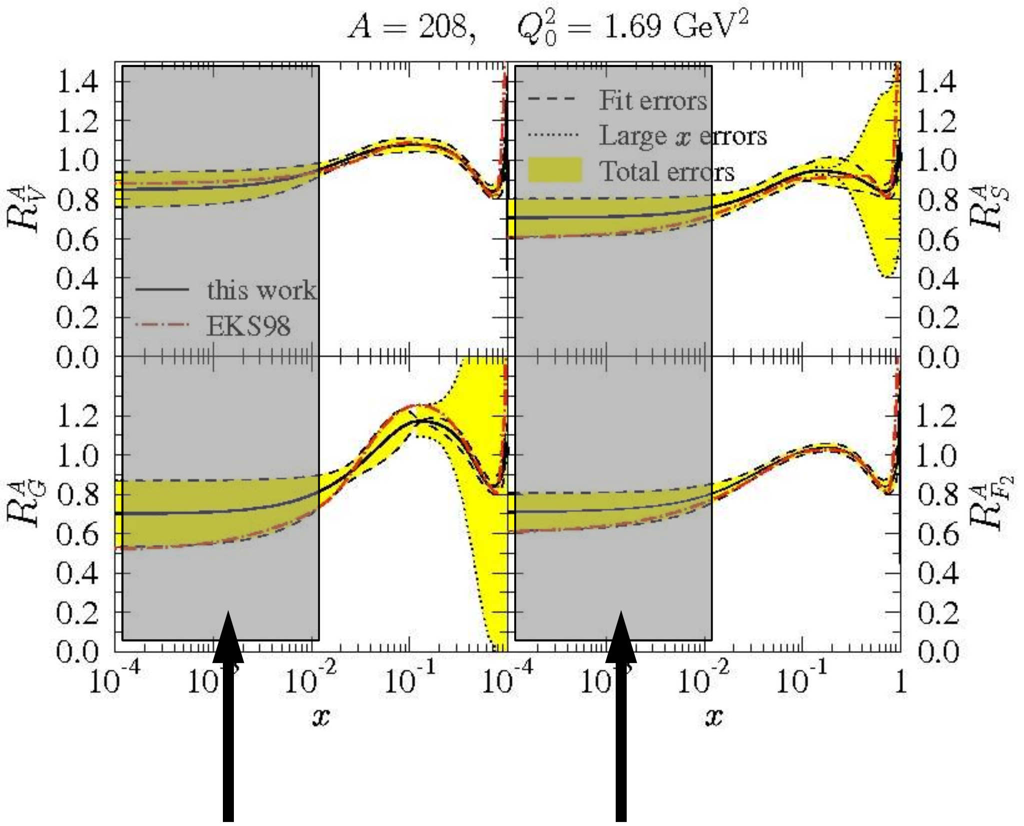


Few words about error analysis:

...and why not to take them too seriously



D'Enterria, *J. Phys.* G **30** S767



These regions are not constrained by the data – only by the sum rules!

Few words about error analysis:

…and why not to take them too seriously

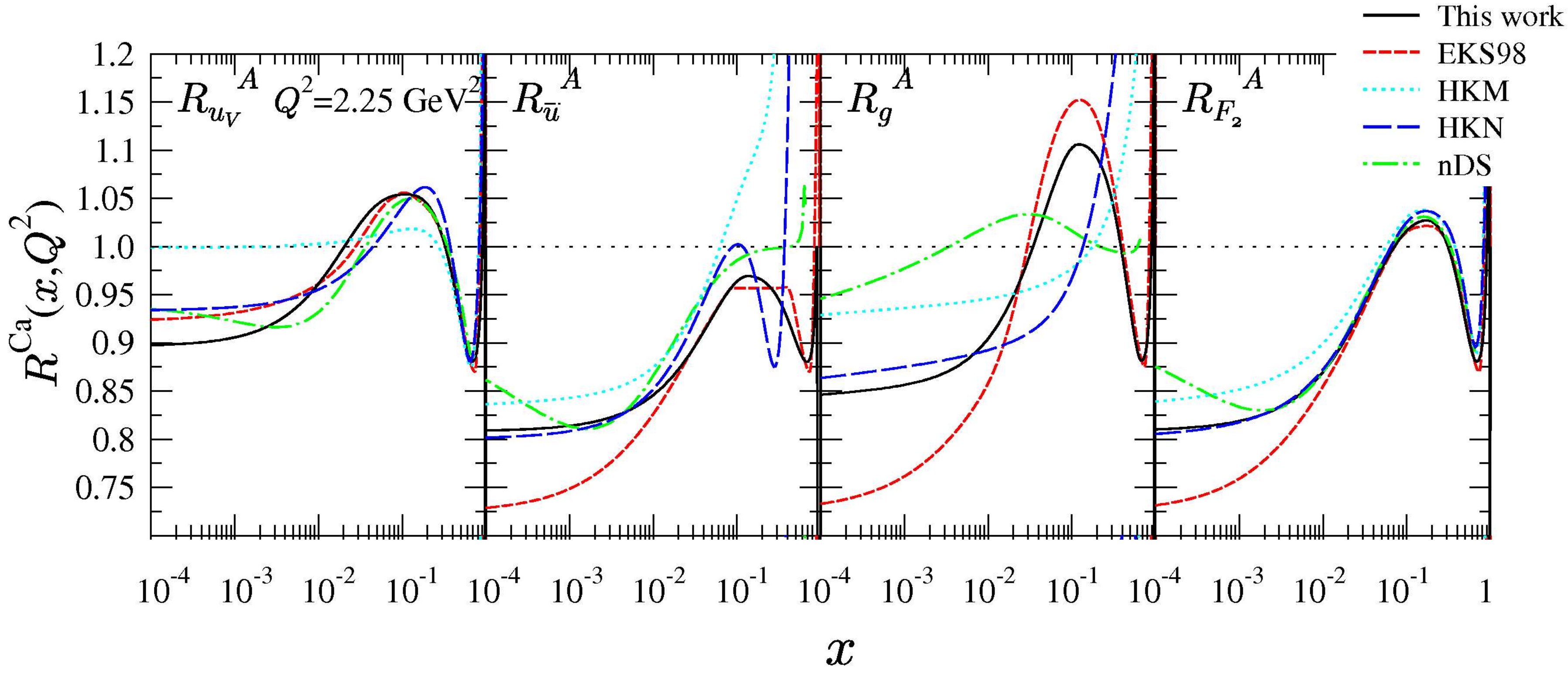
- **The PDF error bands only reflect the experimental errors after adopting a set of choices and conventions:**

  - Choosing the fit functions
  - Choice of Data sets
  - Weights of data sets in χ2
  - Kinematical cuts
  - Treatment of heavy quarks
  - Choosing the factorization scale
  - etc…

- **The PDFs themselves depend on these conventions and none of these 'theoretical uncertainties' are included in PDF error bands.**

- **There is no universally accepted way to choose Δχ2.**

Comparison with other works



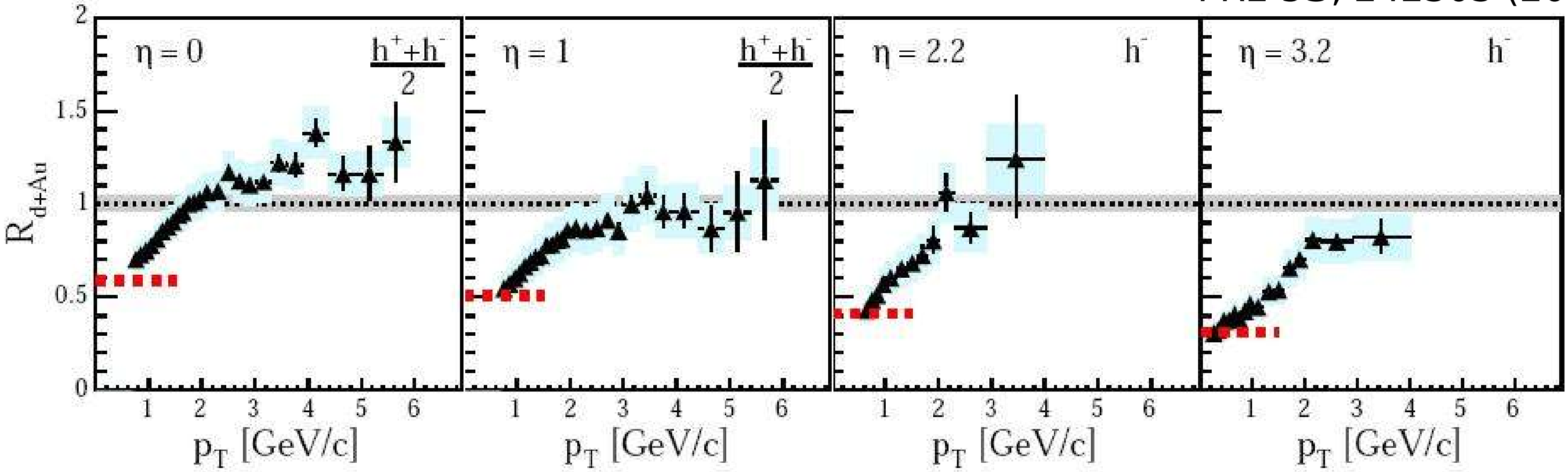
- **No major difference to old EKS98. New parametrization is not released.**

- **DIS & DY data leaves the gluons still very unconstrained...**

Stronger gluon shadowing?

- **One possible constrain for nuclear gluons comes from the inclusive hadron production in d+Au at RHIC BRAHMS.**

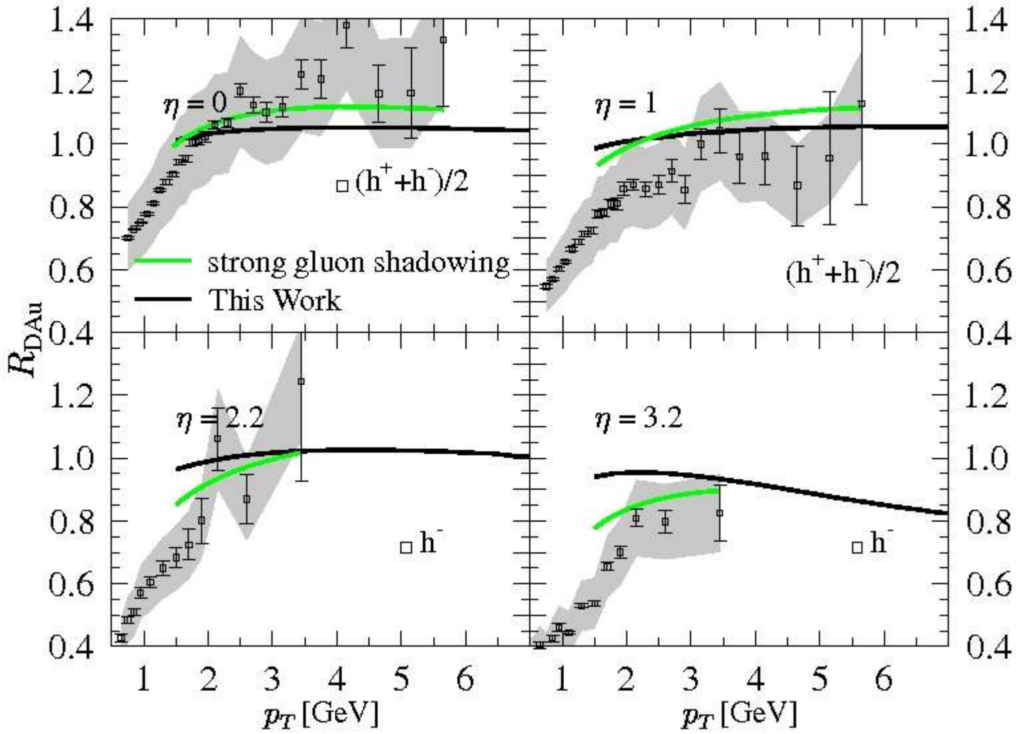
PRL **93**, 242303 (2004)

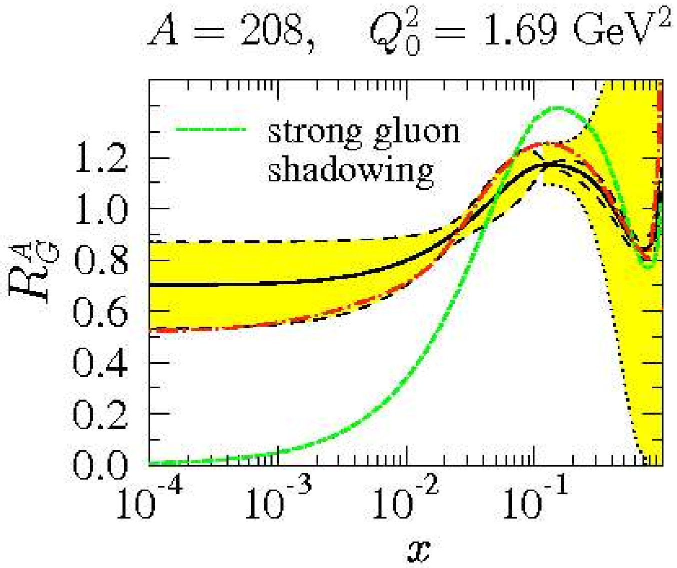


- **The corresponding factorized QCD cross-sections are of the form**

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

Stronger gluon shadowing?





- **Reaching the datapoints at low-p_T would require extremely strong gluon shadowing --- probably too strong to be consistent with the DIS & DY data!**

- **But be aware of other possible effects at low-p_T region! (intrinsic k_T, saturation, $(Q^2)^{-n}$ -corrections, etc...)**

Conclusions

- **Present:**

  The Global LO DGLAP analysis of nuclear PDFs seem to give a very good description of DIS & DY data, $\chi 2/N \cong 0.8$.

  No major difference to old EKS98 fit (it's within $\Delta\chi 2 < 18$ band). No new parametrization is thus released.

- **Open question:**

  The gluons remain only weakly constrained by DIS & DY data, but the BRAHMS data would suggest clearly stronger gluon shadowing. The precision of the BRAHMS data is not, however, very conclusive.

- **Future:**

  Extension of the analysis to NLO QCD. Does the the total $\chi 2$ improve?