DGLAP analyses of nPDF: constraints from data

Carlos A. Salgado (CERN)

(carlos.salgado@cern.ch)

- Motivation
- DGLAP analyses
  - EKRS (EKS98)
  - Comparison EKRS–HKM
- Constraints and comparison with data
  - How neutrino data could help?

Workshop *4th NuFact '02.*

Imperial College (London), July 2002.

$\boxed{\text{Motivation}}$

- Subject interesting by itself:
  - Check QCD with nuclei: factorization, sum rules...
  - small–x $\longrightarrow$ saturation ...
- Practical: PDF are needed in order to compute hard cross sections (RHIC, LHC...):

$$\sigma^{AB\to kl} \sim \sum_{ij} f_i^A(x_1,Q^2) f_j^B(x_2,Q^2) \otimes d\hat{\sigma}^{ij\to kl}(x_1,x_2,Q^2)$$

DIS experimental data: $R^A_{F_2}(x,Q^2) \equiv \frac{F_2^A(x,Q^2)}{AF_2^N(x,Q^2)} \neq 1$

where (LT, LO) $F_2^A(x,Q^2) = x \sum_q e_q^2 \boxed{f_q^A(x,Q^2)}$

So, nuclear effects to structure functions can be described by nuclear effects to individual PDF.

In protons, PDF $\leftrightarrow$ global fits (CTEQ, MRST, GRV...)

The goal of nDGLAP analyses: $\boxed{\text{do the same for nuclei.}}$

Nuclear effects to PDF's

Several attempts to describe the nuclear modifications to PDF:

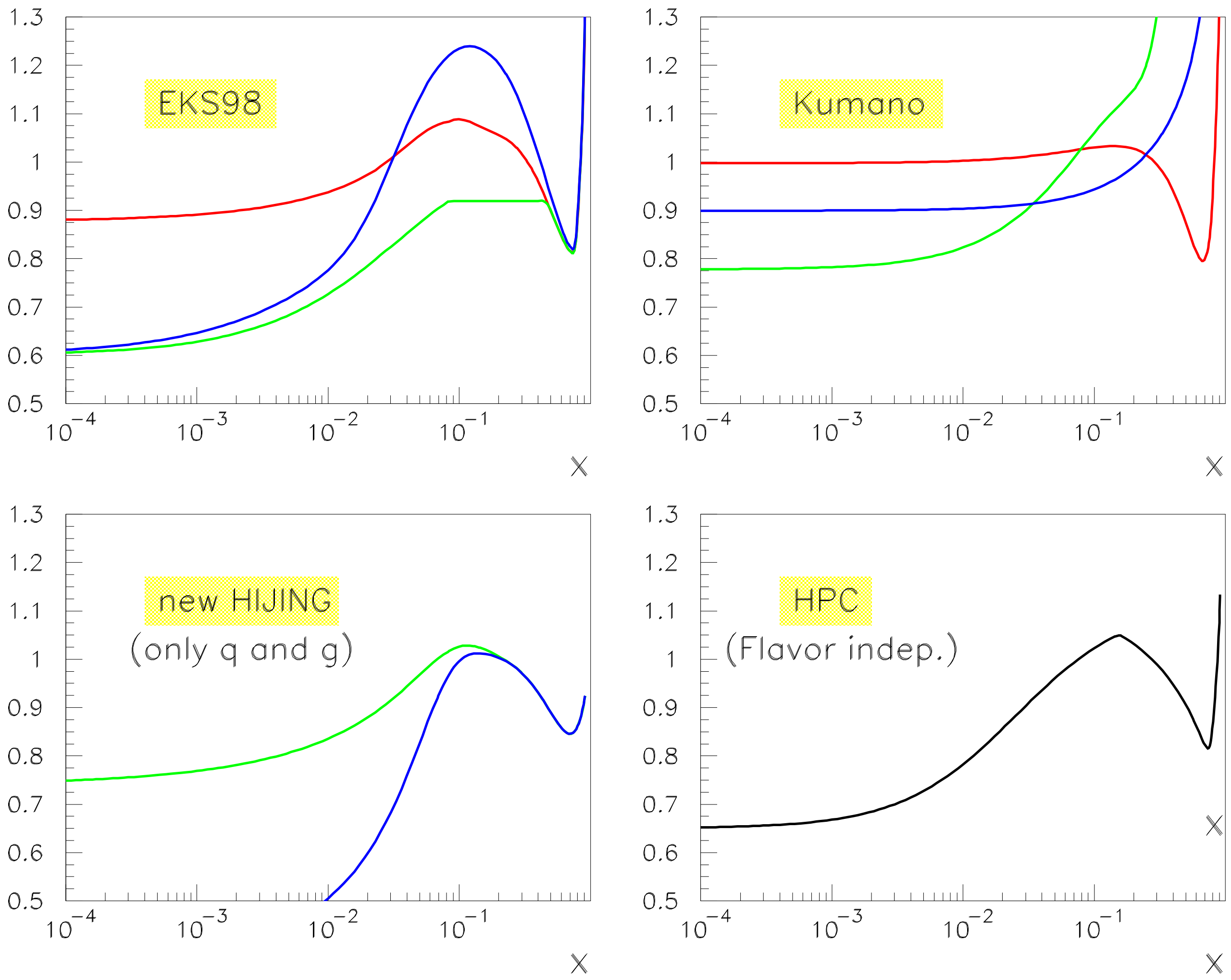
$$R_i^A(x,Q^2) \equiv \frac{f_i^A(x,Q^2)}{f_i^N(x,Q^2)}$$

1. Q^2-independent parametrizations:
   - Flavor-independent:
     $R_{Val}^A = R_{Sea}^A = R_g^A \equiv \boxed{R_{F_2}^A} \leftarrow$ data.
   - Flavor-dependent: new HIJING, different for glue and quarks.
2. Theoretical calculations: Eikonal, diffraction, pQCD, semiclassical (CGC), ...
3. DGLAP analyses – *Global fits*: EKRS, HKM.

Computations in 2. have normally Q^2-dependence.

(By pure DGLAP, or by non-linear equations.)

Different sets of $R_i^A(x)$ for Pb.



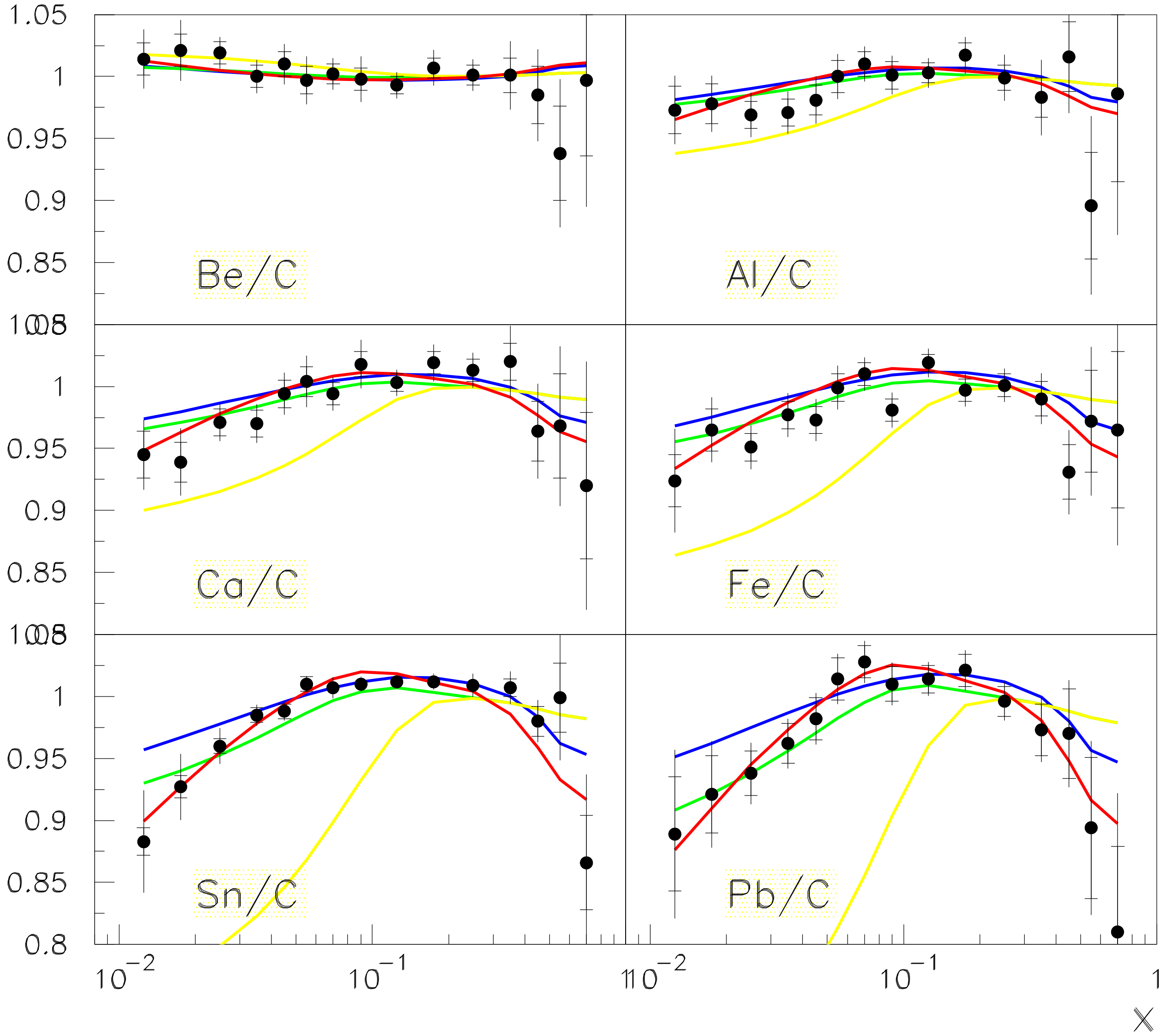
Green: sea quarks

Blue: gluons

Red: valence quarks

Different parametrizations to F_2^A/F_2^C

Comparison with NMC data.



Red: EKS98

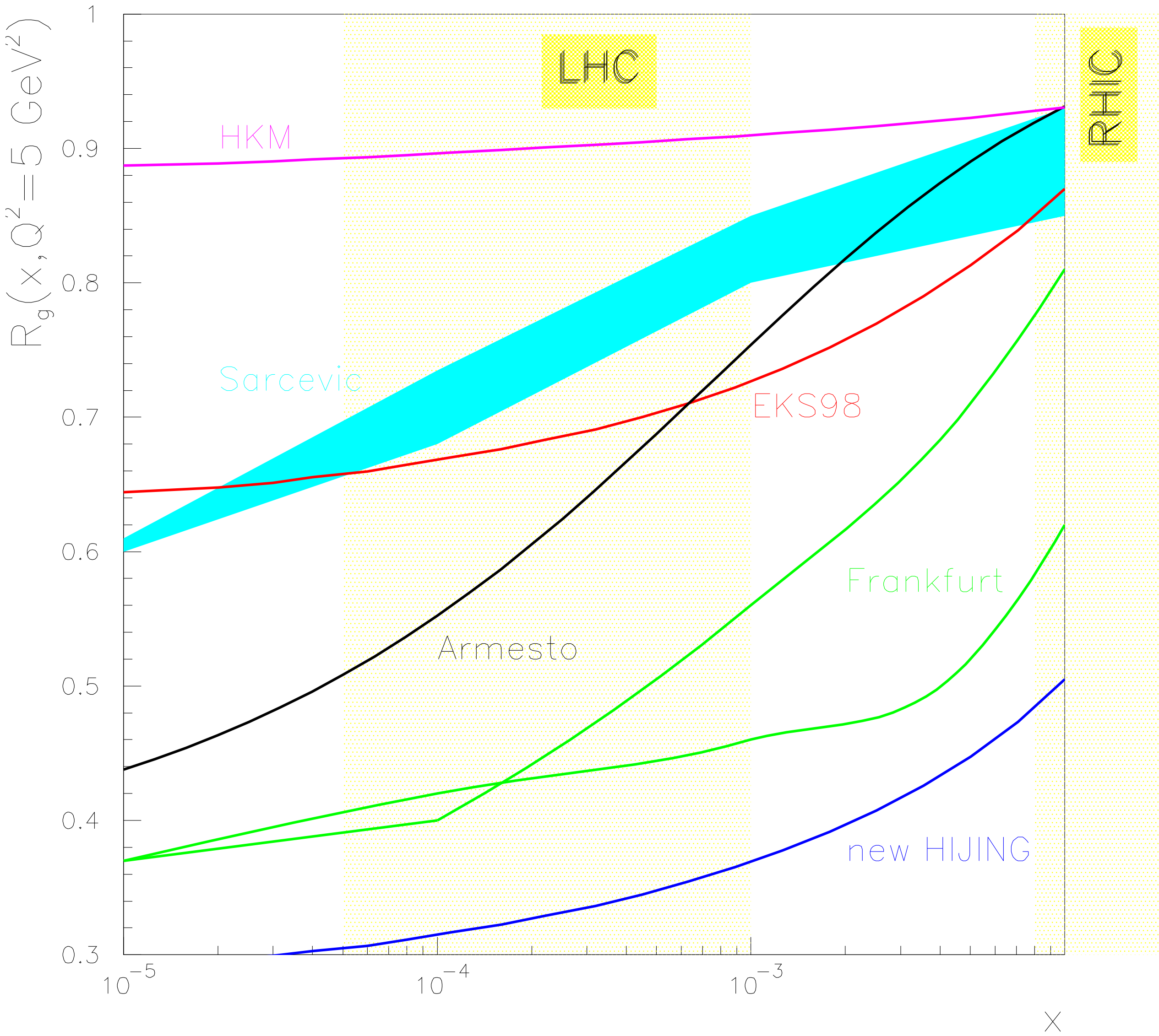
Blue: HKM

Green: new HIJING

Yellow: old HIJING

Data: Nucl. Phys. **B481**, 3.

Gluon Ratios for Pb at $Q^2 = 5$ GeV^2



HKM: M. Hirai *et al.* Phys Rev **D64** 034003.

EKS98: K.J. Eskola *et al* Nucl. Phys **B535** 351; Eur. Phys. J. **C9**, 61.

Sarcevic: Z. Huang *et al.* Nucl. Phys. A **637**, 79.

Frankfurt *et al* JHEP **0202**, 027.

Armesto *et al* Eur. Phys. J. C **22** 351.

new HIJING: S. y. Li and X. N. Wang, Phys. Lett. B **527** 85.

DGLAP analyses. How?

- Well established for protons:
  - Initial parametrization at Q_0^2 of each different flavor.
  - Constraints from momentum and baryon number conservation.
  - DGLAP evolution at LO, NLO, NNLO and fit to data.
- Do the same for nuclei. Problems (some):
  - Not many experimental data (mainly at large Q^2)
  - A new variable (A).
  - Theoretical uncertainties: higher twists, coherence, etc...

So, some assumptions need to be made for nuclei. But still, use the same method as for protons (with more parameters to describe A-dependence).

In practice: initial parametrization for $R_i^A(x, Q_0^2)$, taking some set of known PDF for protons:

$$f_i^A(x, Q_0^2) = R_i^A(x, Q_0^2) f_i^N(x, Q_0^2)$$

Eskola, Kolhinen, Ruuskanen and Salgado (EKS98).

- $R_{u_V} = R_{d_V} \equiv R_V$, $R_{\bar{u}} = R_{\bar{d}} = R_{\bar{s}} \equiv R_S$ (only for Q_0^2.)
- First step, fit $R_{F_2}^A(x, Q_0^2)$ then:
  - $R_V \sim R_{F_2}$ for large x.
  - $R_S \sim R_{F_2}$ for small x.
  - DY data $\longrightarrow$ R_V/R_S at medium x.

$$\sigma^{DY} \propto \sum_{\{q,\bar{q}\}} e_q^2 q(x_1, Q^2)\bar{q}(x_2, Q^2)$$

- Further assumptions:
  - Saturation of R_{F_2} at $x \longrightarrow 0$.
  - $R_g \sim R_{F_2}$ at small x.
  - EMC effect (large x) for R_S and R_g.
- Constraints:
  - Q^2-dep. data fixes x_0 where $R_g(x_0) = 1$.
  - Baryon number conservation $\longrightarrow$ valence.
  - Momentum sum rule $\longrightarrow$ gluon antishadowing.
- LO-DGLAP evolution and comparison with data.

Differences between EKRS-HKM.

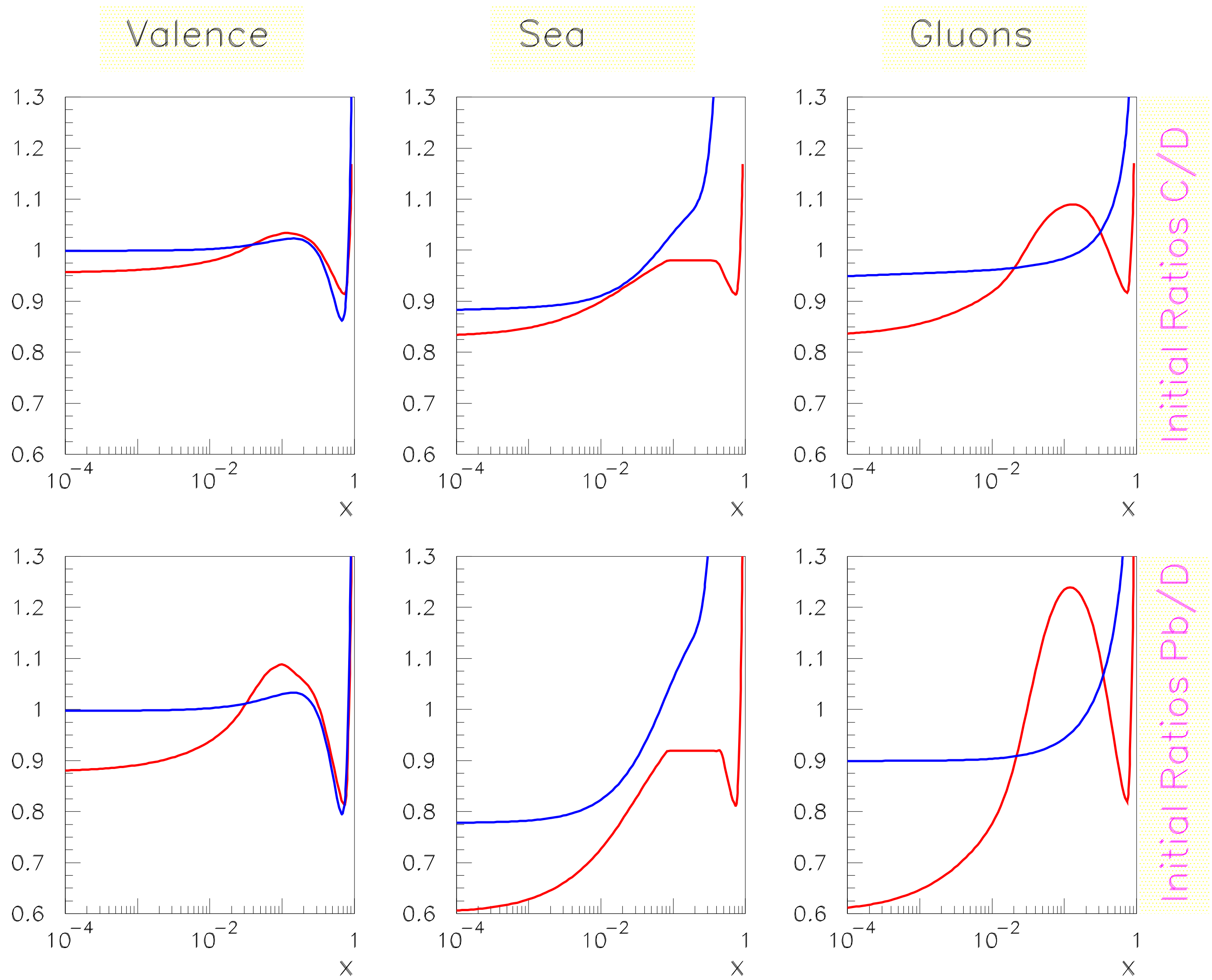
- HKM is a minimum-χ^2 fit.
- Main difference: two sets of important data in EKRS not taken into account in HKM:
  - DY data (E772) – Fixes the relative effects in valence and sea.

    these data makes $R_S(x, Q_0^2) < 1$ at medium x
  - Q^2–dependence of F_2^{Sn}/F_2^C (NMC)

    Used to estimate the point where $R_g = 1$
  - Also, data in A–dependence by NMC not taken in HKM (less important).

As a result sea and valence distributions are different in EKRS and HKM and gluons are weakly constrained in HKM.

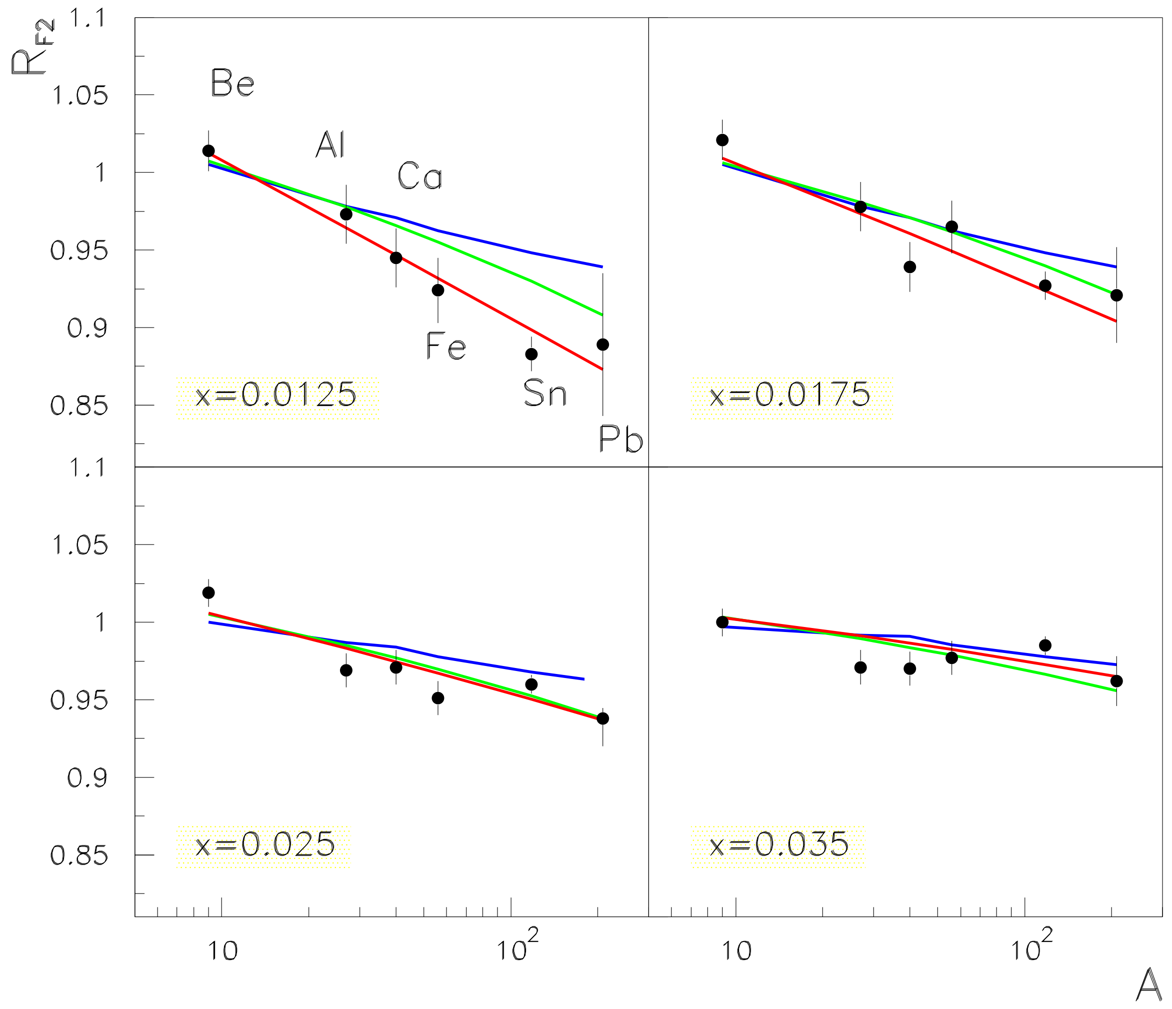
PDF DISTRIBUTIONS AT $Q_0^2 = 2.25$ GeV^2



Red: EKS98

Blue: HKM

A-dependence of F_2^A/F_2^C for different x



Data from NMC, Nucl. Phys. **B481**, 3.

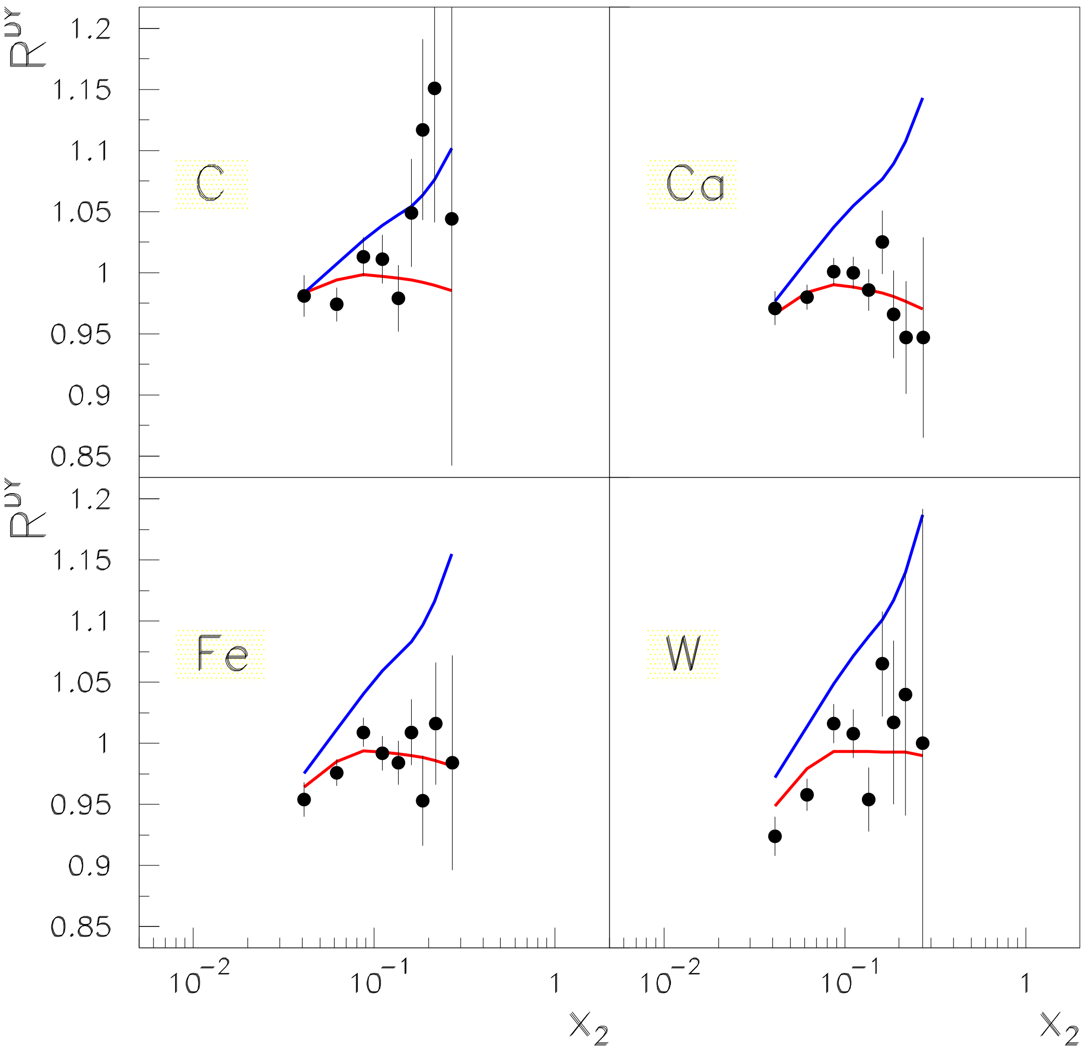
Red: EKS98

Blue: HKM

Green: new HIJING

DY data from E772

(Data: Phys. Rev. Lett. **64** (1990) 2479)



Red: EKS98

Blue: HKM

$\boxed{\text{Constraints to gluons from DIS data.}}$

At small values of x, LO–DGLAP gives

$$\frac{\partial F_2^{p(n)}(x,Q^2)}{\partial \log Q^2} \approx \frac{10\alpha_s}{27\pi} xg(2x,Q^2).$$

This leads to

$$\frac{\partial R_{F_2}^A(x,Q^2)}{\partial \log Q^2} \approx \frac{10\alpha_s}{27\pi} \frac{xg(2x,Q^2)}{\frac{1}{2}F_2^{\mathrm{D}}(x,Q^2)} \left\{ R_g^A(2x,Q^2) - R_{F_2}^A(x,Q^2) \right\},$$

NMC–data in Q^2–dependence of F_2^{Sn}/F_2^C has positive slope $\longrightarrow R_g^A(2x,Q^2) \geq R_{F_2}^A(x,Q^2)$.

We have computed this for full DGLAP (no approximation made).

Four different parametrizations for Q_0^2 used:

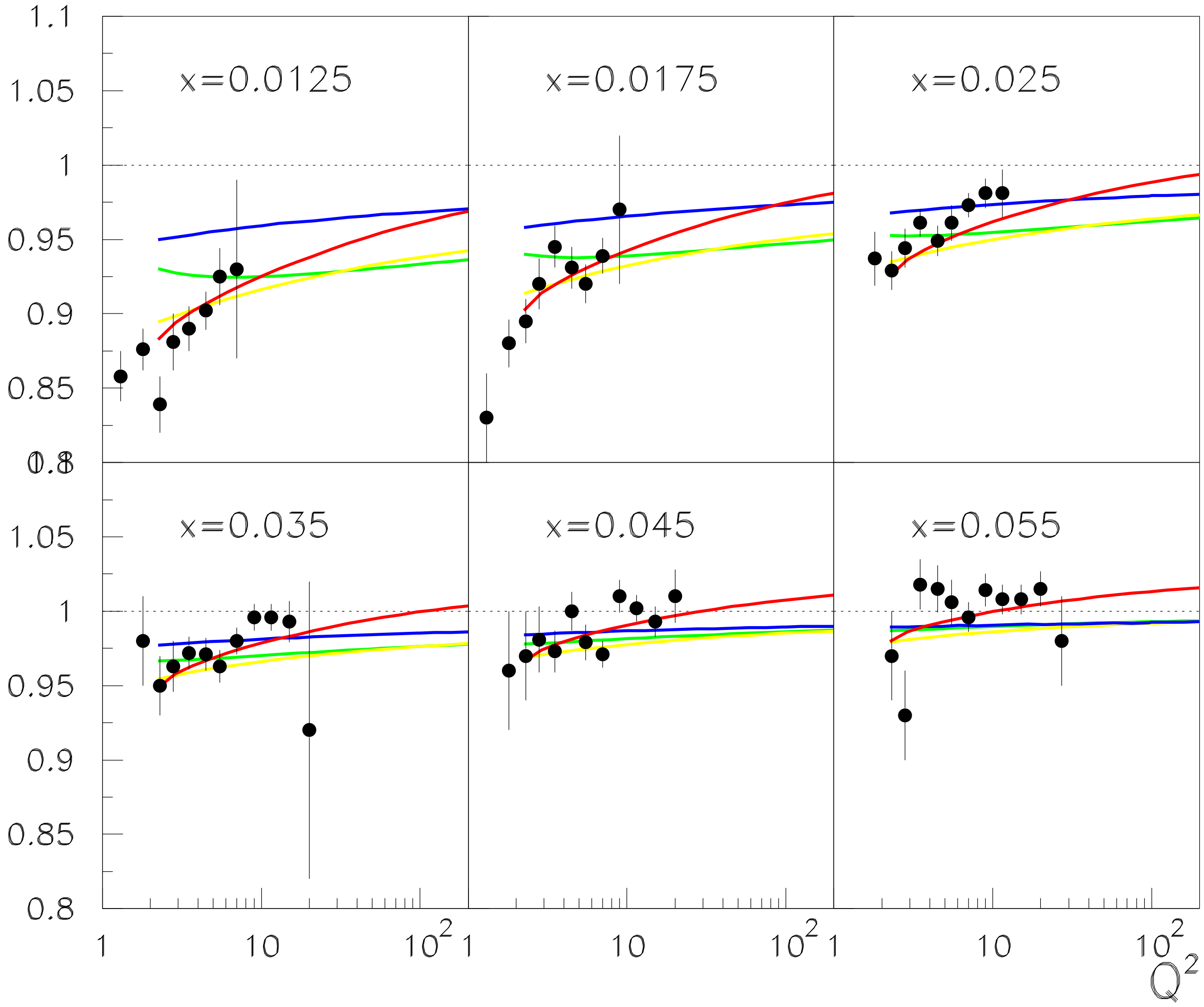
- EKS98
- HKM
- Hard Probe Collaboration (HPC)
- new HIJING $\leftarrow$ very strong gluon shadowing.

Q^2-dependence of the ratios F_2^{Sn}/F_2^{C}

Comparison with NMC data.

K. J. Eskola, H. Honkanen, V. J. Kolhinen and C. A. Salgado,

Phys. Lett. B **532** (2002) 222.



Red: EKS98

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Green: new HIJING

Yellow: HPC

Data: Nucl. Phys. **B481**, 3.

Constraints from neutrino data.

Neutrino structure functions for protons:

$$F_2^{\nu p} = 2x\,(\bar{u} + d + s + \bar{c}) \qquad F_2^{\bar{\nu} p} = 2x\left(u + \bar{d} + \bar{s} + c\right)$$

$$xF_3^{\nu p} = 2x\,(-\bar{u} + d + s - \bar{c}) \qquad xF_3^{\bar{\nu} p} = 2x\left(u - \bar{d} - \bar{s} + c\right)$$

(for neutrons, isospin invariance $\rightarrow u \leftrightarrow d$)

So, this allows to disentangle $u \pm \bar{u}$, $d \pm \bar{d}$, $s \pm \bar{s}$ (if c, $\bar{c}$ are small or known)

In particular, for nuclei,

- the separation valence/sea could be possible
- the sea quark (gluon ?) could be measured in the EMC region (no information with present data).
- shadowing of valence at small x?
- distinguish different flavors: R_{u_V}, R_{d_V}, $R_{\bar{u}}$...

Constraints from neutrino data II.

Moreover....

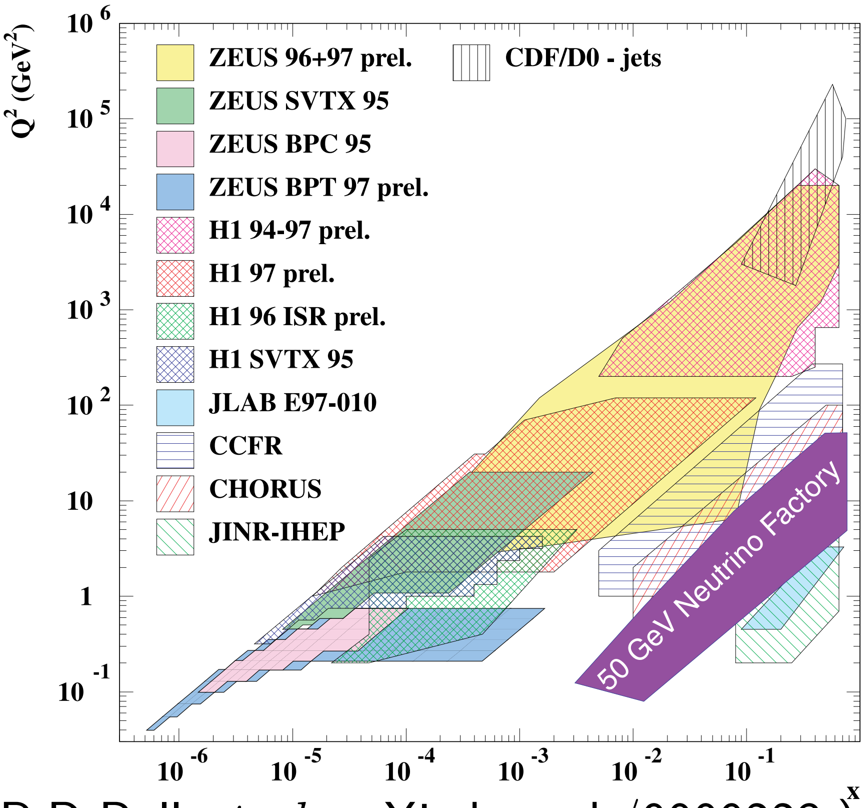
proton PDF's are often measured by several projectiles and processes in the same kinematical region:
$\Longrightarrow$ universality of PDF's.

In nuclei this is only an assumption up to now:
data on pA will (hopefully) come (RHIC, LHC), but

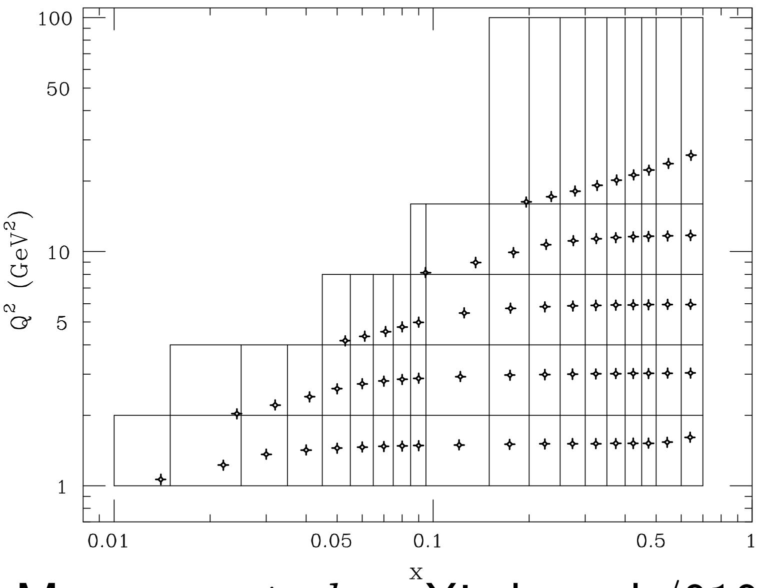
Neutrino DIS would be ideal:

- Separation valence/sea $\longrightarrow$ compare with DY $\Longleftrightarrow$ check of factorization.
- Shadowing of valence at small–x $\rightarrow$ check baryon number sum rule.
- ...

Kinematics.



(R.D.Ball *et al.* arXiv:hep-ph/0009223.)



(M. L. Mangano *et al.*, arXiv:hep-ph/0105155.)

So, $x \gtrsim 0.01$ for $Q^2 \gtrsim 1$ GeV^2

Conclusions.

- A description of nuclear effects in F_2^A is possible by including all the effects in nPDF. Problem: lack of experimental data.
- Two LT-LO-DGLAP analyses compared (EKRS, HKM). Including data on Q^2–dependence of F_2^{Sn}/F_2^C and DY production important to constraint sea and gluons.
- Rather strong constraint to nuclear gluons come from NMC data on Q^2–dependence. These data rules out very strong gluon shadowing for $x \sim 0.01$
- Neutrino DIS data could help to distinguish between different flavors:
  - small x: shadowing for valence.
  - intermediate x: difference valence/sea,
  - large x: EMC effect for sea quarks?
- Check of universality (factorization) in nuclear PDF! (higher twists, coherence...)

Non-linear terms.

When the density of gluons becomes very large, non-linear terms as gluon fusion are expected to become important in the evolution eqs.

Gluon fusion corrections to DGLAP were studied by e.g. Mueller and Qiu.

$$
\begin{aligned}
\frac{\partial x g_A}{\partial \log Q^2} &= \left(\frac{\partial x g_A}{\partial \log Q^2}\right)_0 - \frac{1}{Q^2}\mathcal{R}_{ggg}(x,Q^2) \\
\frac{\partial x \bar{q}_A}{\partial \log Q^2} &= \left(\frac{\partial x \bar{q}_A}{\partial \log Q^2}\right)_0 - \frac{1}{Q^2}\left[\mathcal{R}_{\bar{q}gg}(x,Q^2) - \mathcal{R}^{\mathrm{HT}}_{\bar{q}gg}(x,Q^2)\right] \\
\frac{\partial x g_{HT}}{\partial \log Q^2} &= -\mathcal{R}_{ggg}(x,Q^2)
\end{aligned}
$$

Where $(...)_0$ refers to the normal DGLAP. So, these terms modify Q^2–evolution.

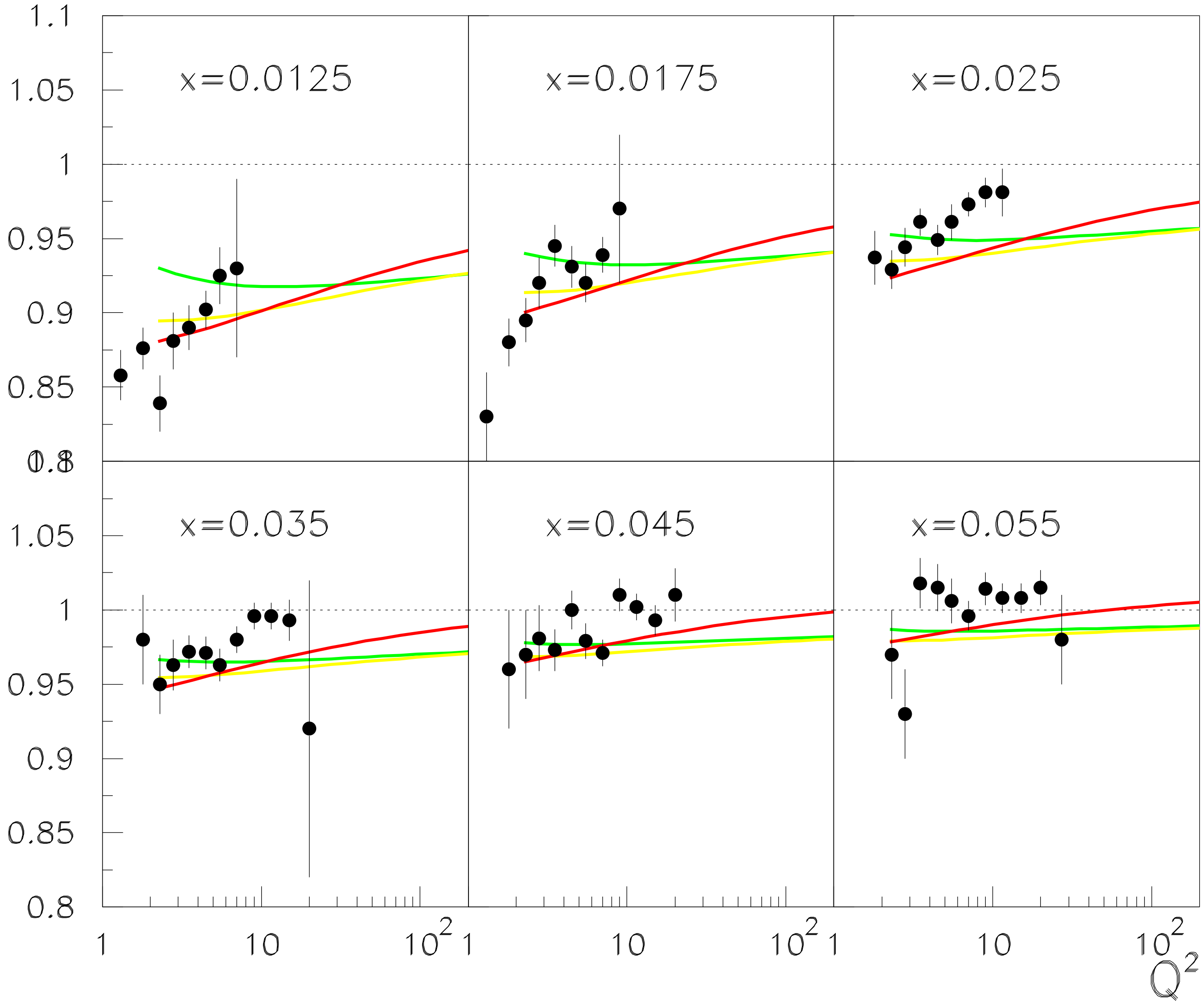
Does this allow for stronger gluon shadowing?

We repeat the evolution for EKS98, HPC and new HIJING including these terms.

(we don't try to repeat the fit, only see the influence)

MQ-terms reduce the slope

DGLAP corrected by MQ-terms



Red: EKS98

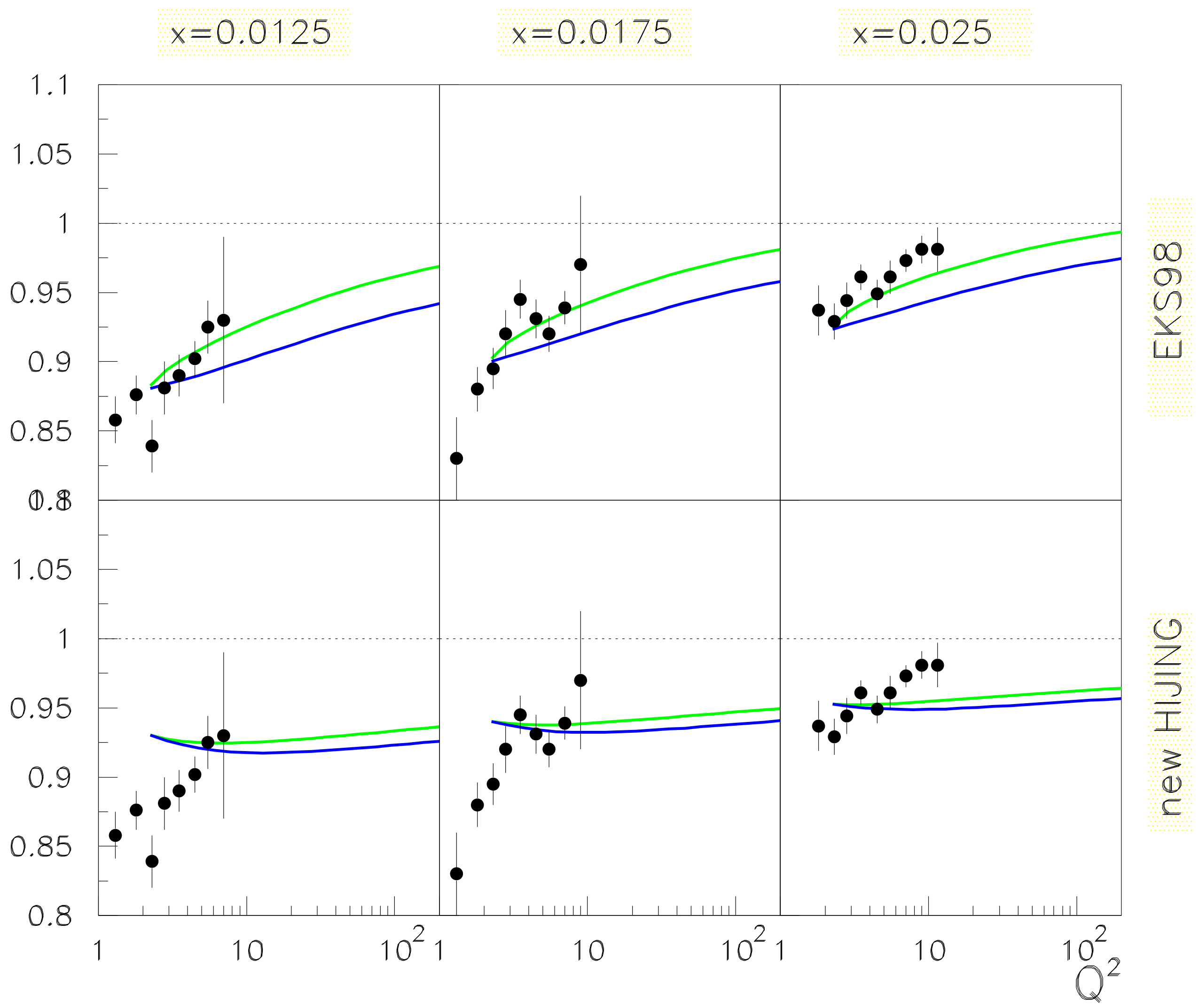
Green: new HIJING

Yellow: HPC

Data: Nucl. Phys. **B481**, 3.

Pure DGLAP vs DGLAP+MQ

EKS98 and new HIJING.



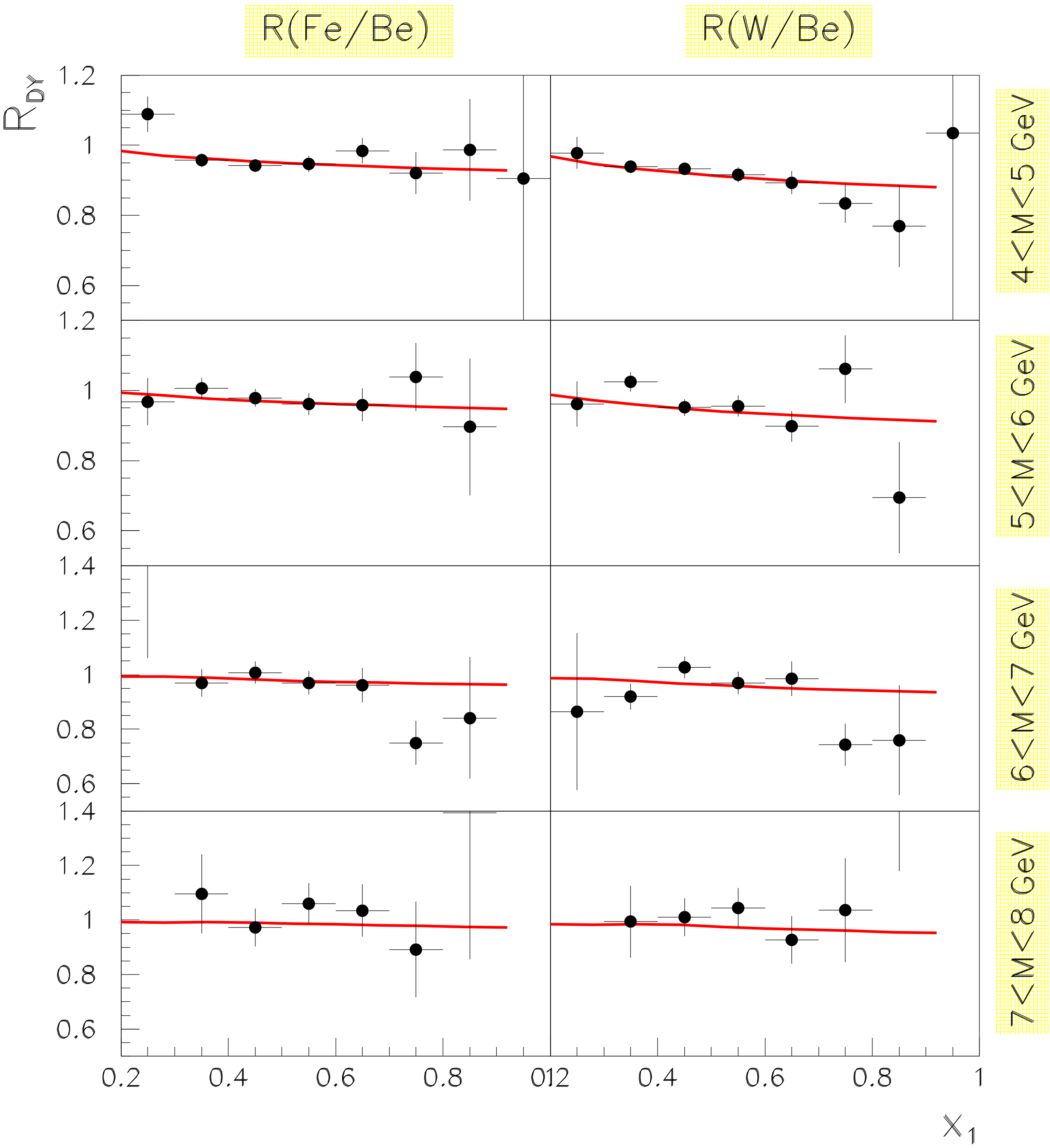
Green: DGLAP

Blue: DGLAP+MQ

Slopes are smaller with MQ.

(More negative at Q_0^2 in the case of strong gluon shadowing)

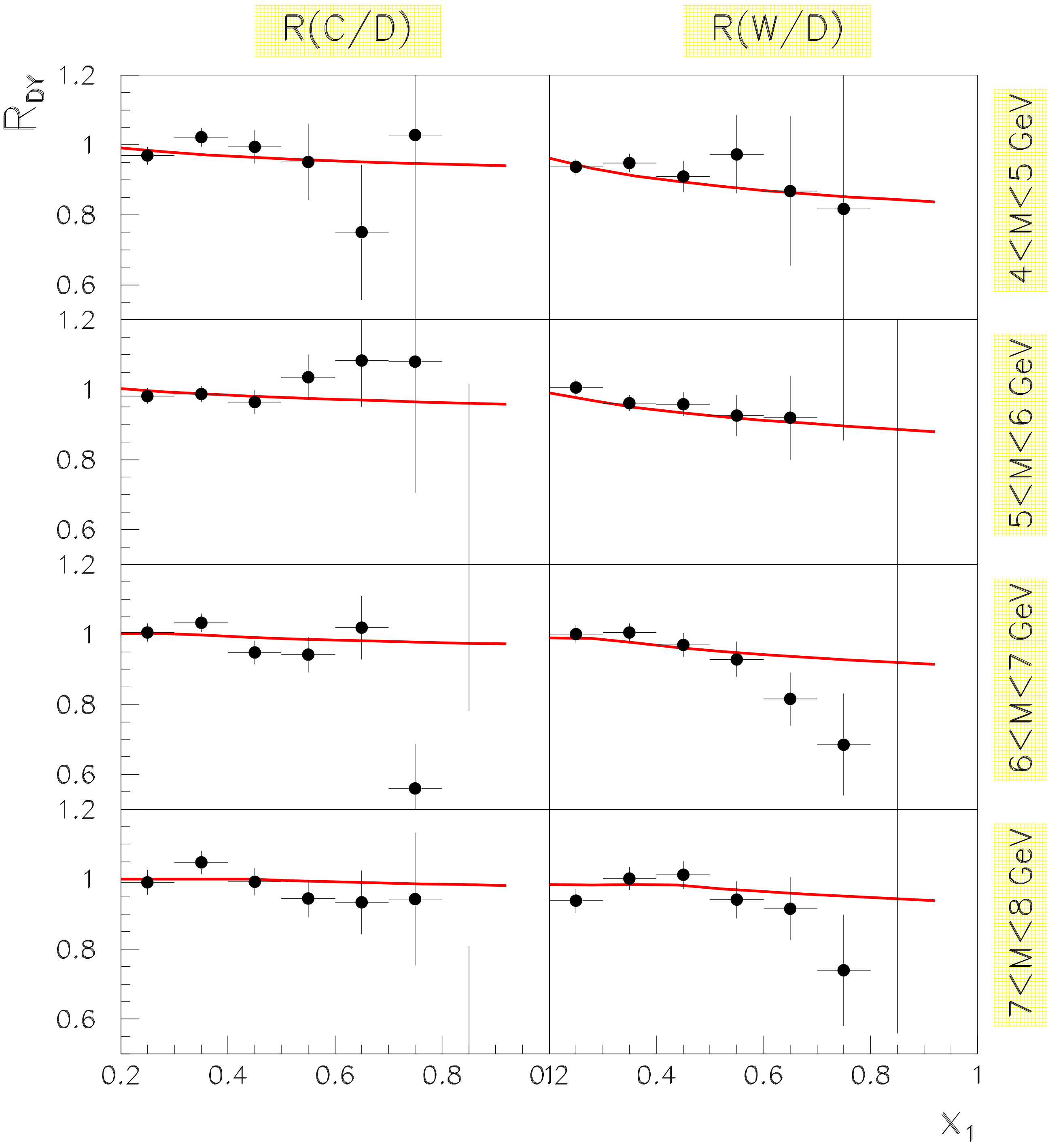
Comparison of EKS98 with DY data from E866



Data: Phys. Rev. Lett. **83** (1999) 2304

http://p25ext.lanl.gov/e866/papers/papers.html.

Comparison of EKS98 with DY data from E772



Data: Phys. Rev. Lett. **64** (1990) 2479

http://p25ext.lanl.gov/e866/papers/papers.html.