Recent developments on nuclear PDFs

Pía Zurita

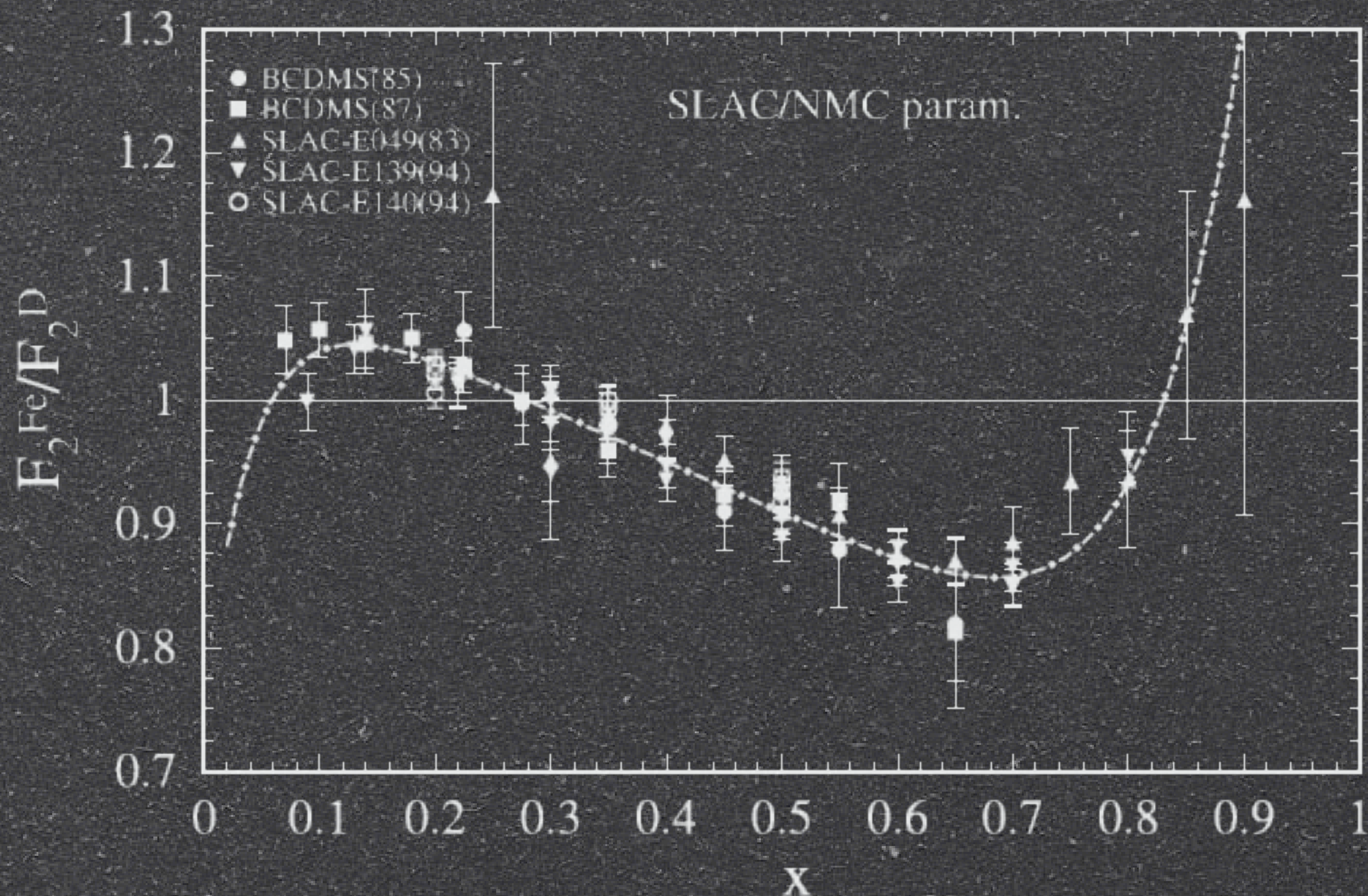
Universidade de Santiago de Compostela

Workshop on proton-nucleus collisions at the LHC, May 8th 2013, ECT*, Trento, Italy

Outline

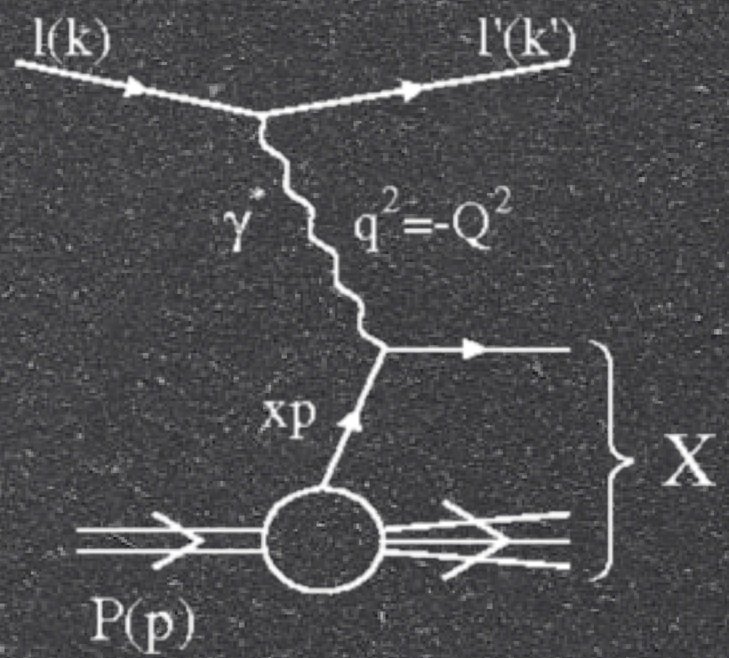
- What we know
- And what we assume
- Why nuclear PDFs?
- How do we determine nPDFs?
- Current status of nuclear PDFs
- DSSZ
- Summary

What we know



effects in cross-sections = effect on the PDFs?

factorization for electron-proton Deep Inelastic Scattering (DIS)



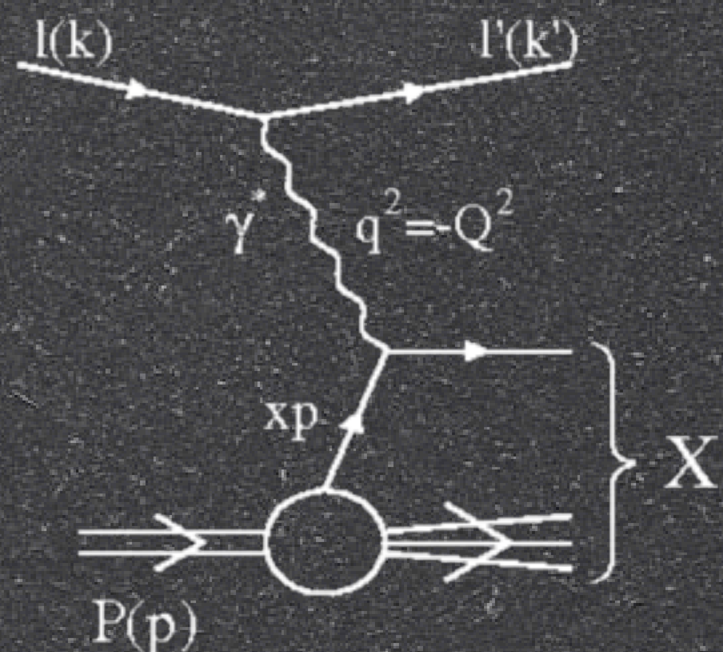
$$\frac{d^2\sigma}{dx dQ^2} = \sum_a f_a \otimes d\hat{\sigma}_{al\to l' X} + \mathcal{O}\left(\frac{1}{Q^2}\right)$$

soft

hard

What we assume

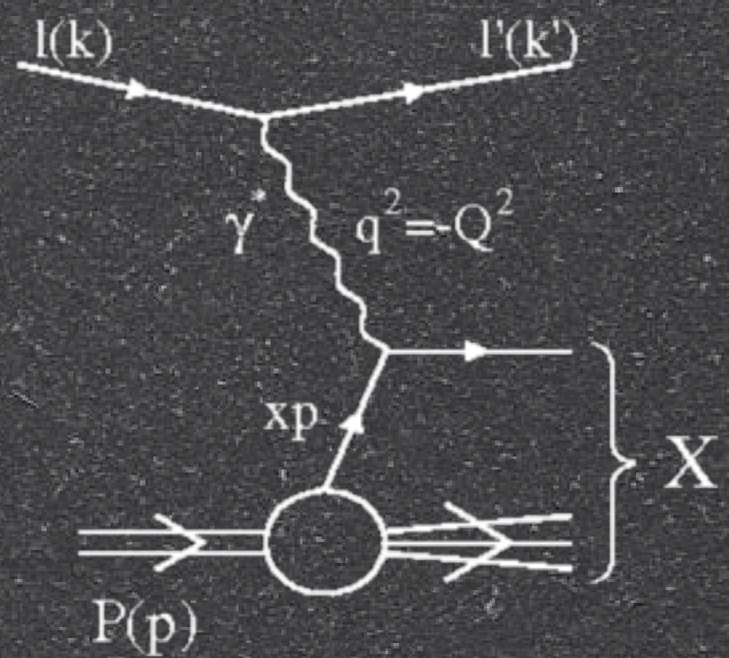
we assume factorization for electron-nucleus DIS



$$\frac{d^2\sigma}{dx\,dQ^2} = \sum_a f_a \otimes d\hat{\sigma}_{al\to l'X} + \mathcal{O}\left(\frac{1}{Q^2}\right)$$

we assume factorization for electron-nucleus DIS

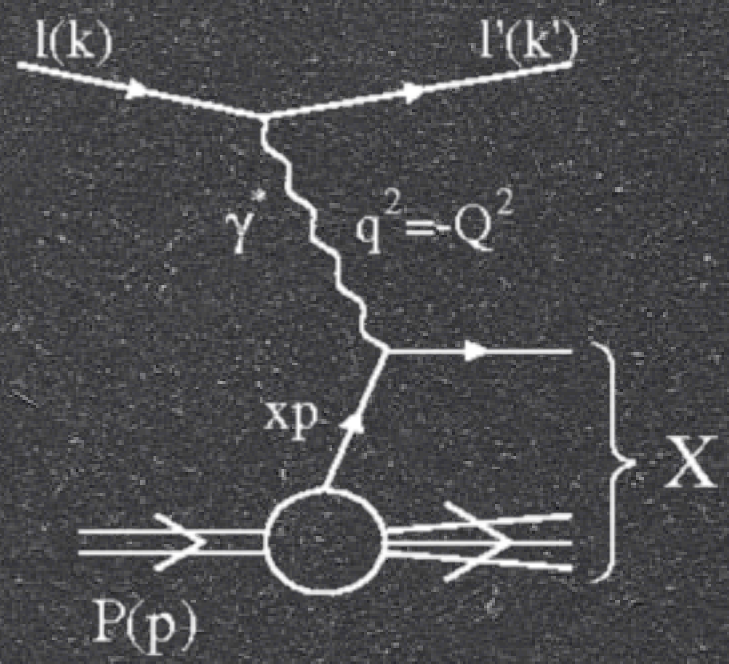
introduce universal nuclear PDFs



$$\frac{d^2\sigma}{dxdQ^2} = \sum_a f_a^A \otimes d\hat{\sigma}_{al\to l'X} + \mathcal{O}\left(\frac{1}{Q^2}\right)$$

we assume factorization for electron-nucleus DIS

introduce universal nuclear PDFs



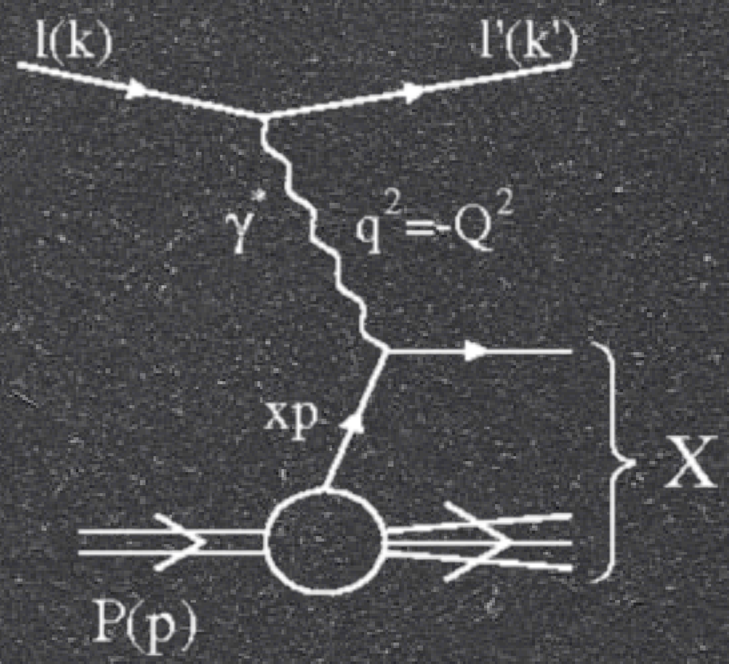
$$\frac{d^2\sigma}{dx\,dQ^2} = \sum_a f_a^A \otimes d\hat{\sigma}_{al\to l'X} + \mathcal{O}\left(\frac{1}{Q^2}\right)$$

- hard scattering cross sections
- DGLAP scale evolution

as for free proton PDFs

we assume factorization for electron-nucleus DIS

introduce universal nuclear PDFs



$$\frac{d^2\sigma}{dx dQ^2} = \sum_a f_a^A \otimes d\hat{\sigma}_{al \to l' X} + \mathcal{O}\left(\frac{1}{Q^2}\right)$$

- hard scattering cross sections
- DGLAP scale evolution

as for free proton PDFs

we absorb all nuclear effects into non-perturbative nPDFs

Why do we need nuclear parton densities?

Why do we need nuclear parton densities?

because they are crucial ingredient for the perturbative description of

Why do we need nuclear parton densities?

because they are crucial ingredient for the perturbative description of

- neutrino DIS with heavy targets:

  NuTeV, CHORUS, CDHSW, etc

- proton(deuteron)-heavy ion collisions:

  dAu @ RHIC, pPb @LHC

- electron DIS with nuclei:

  LHeC, EIC

- heavy ion collisions:

  Au-Au @RHIC, Pb-Pb@LHC

How do we determine nPDFs?

How do we determine nPDFs?

through a global QCD analysis

How do we determine nPDFs?

through a global QCD analysis

propose a functional form for the nPDFs at Q_0

How do we determine nPDFs?

through a global QCD analysis

propose a functional form for the nPDFs at Q_0

evolve the nPDFs to the observed Q

How do we determine nPDFs?

through a global QCD analysis

propose a functional form for the nPDFs at Q_0

evolve the nPDFs to the observed Q

minimize

$$\chi^2 = \sum_i \omega_i \frac{(d\sigma_i^{exp} - d\sigma_i^{th})^2}{\Delta_i^2}$$

How do we determine nPDFs?

through a global QCD analysis

propose a functional form for the nPDFs at Q_0

evolve the nPDFs to the observed Q

minimize

$$\chi^2 = \sum_i \omega_i \frac{(d\sigma_i^{exp} - d\sigma_i^{th})^2}{\Delta_i^2}$$

different strategies for parameterization ⟷ different nPDFs sets

Current sets

Convolute with a weight function

de Florian, Sassot [PRD69 (2004) 074028]

$$f_i^A(x_N, Q_0^2) = \int_{x_N}^{A} \frac{dy}{y} W_i(y, A, Z) f_i(x_N/y, Q_0^2)$$

- full coverage of the kinematical space
- economic: few parameters needed
- simple physical interpretation of the parameters

Convolute with a weight function

de Florian, Sassot
[PRD69 (2004) 074028]

$$f_i^A(x_N, Q_0^2) = \int_{x_N}^{A} \frac{dy}{y} W_i(y, A, Z) f_i(x_N/y, Q_0^2)$$

- full coverage of the kinematical space
- economic: few parameters needed
- simple physical interpretation of the parameters

* NC-DIS (384) & DY (36) data
* 3 active flavours
* GRV98 as proton PDFs
* No nuclear effect on deuteron

Find them from scratch

nCTEQ
[PRD80 (2009) 094004,
PRL 106 (2011) 122301]

$$f_i^A(x_N, Q_0^2) = f_i(x_N, Q_0^2, A, Z)$$

- A=1 recovers proton PDFs
- not full coverage of x
- useful to do a joint global proton/nucleus fit

Find them from scratch

nCTEQ
[PRD80 (2009) 094004,
PRL 106 (2011) 122301]

$$f_i^A(x_N, Q_0^2) = f_i(x_N, Q_0^2, A, Z)$$

- A=1 recovers proton PDFs
- not full coverage of x
- useful to do a joint global proton/nucleus fit

* NC-DIS (616), DY (92) and CC-DIS (3134) data
* CC-DIS data seem incompatible with NC-DIS
* Correlated systematic errors used

Relate to the proton PDFs by a multiplicative factor

Hirai, Kumano, Nagai [PRC76(2007)065207]
Eskola, Paukkunen, Salgado [JHEP0904(2009)065]
D. de Florian, R. Sassot, M. Stratmann, P. Z. [PRD85(2012)074028]

$$f_i^A(x_N, Q_0^2) = R_i(x_N, Q_0^2, A) f_i(x_N, Q_0^2)$$

- very popular
- not as time-consuming as the convolutional approach
- very different ways of parameterizing R

Relate to the proton PDFs
by a multiplicative factor

Hirai, Kumano, Nagai [PRC76(2007)065207]
Eskola, Paukkunen, Salgado [JHEP0904(2009)065]
D. de Florian, R. Sassot, M. Stratmann, P. Z. [PRD85(2012)074028]

$$f_i^A(x_N, Q_0^2) = R_i(x_N, Q_0^2, A) f_i(x_N, Q_0^2)$$

- very popular
- not as time-consuming as the convolutional approach
- very different ways of parameterizing R

For EPS09

* NC-DIS (817), DY (92) and RHIC (20) data
* weighted data
* CC-DIS data not included (see Paukkunen, Salgado JHEP 1007 (2010) 032)

The latest analysis:

DSSZ

Our analysis is global

NC-DIS (894)

Drell-Yan (92)

CC-DIS (532)

hadro-production (61)

1579 data points

Our analysis is global and up-to-date

NC-DIS (894)

Drell-Yan (92)

CC-DIS (532)

hadro-production (61)

1579 data points

reference PDFs: NLO MSTW2008 (GM-VFNS)
A. Martin et al. 2009

same conventions for evolution, alpha strong, F2 coeff.

massive coeff. for neutrino F2 and F3
J. Bluemlein et al. 2011

Our analysis is global and up-to-date

NC-DIS (894)

Drell-Yan (92)

CC-DIS (532)

hadro-production (61)

1579 data points

reference PDFs: NLO MSTW2008 (GM-VFNS)
A. Martin et al. 2009

same conventions for evolution, alpha strong, F2 coeff.

massive coeff. for neutrino F2 and F3
J. Bluemlein et al. 2011

error sets J. Pumplin et al. 2001

$$f_i^A(x_N, Q_0) = R_i^A(x_N, Q_0)\, f_i^p(x_N, Q_0)$$

$$R_v^A(x, Q_0^2) = \varepsilon_1 x^{\alpha_v}(1-x)^{\beta_1} \times (1+\varepsilon_2(1-x)^{\beta_2})(1+a_v(1-x)^{\beta_3})$$

$$R_s^A(x, Q_0^2) = R_v^A(x, Q_0^2)\,\frac{\varepsilon_s}{\varepsilon_1}\frac{1+a_s x^{\alpha_s}}{a_s+1}$$

$$R_g^A(x, Q_0^2) = R_v^A(x, Q_0^2)\,\frac{\varepsilon_g}{\varepsilon_1}\frac{1+a_g x^{\alpha_g}}{a_g+1}$$

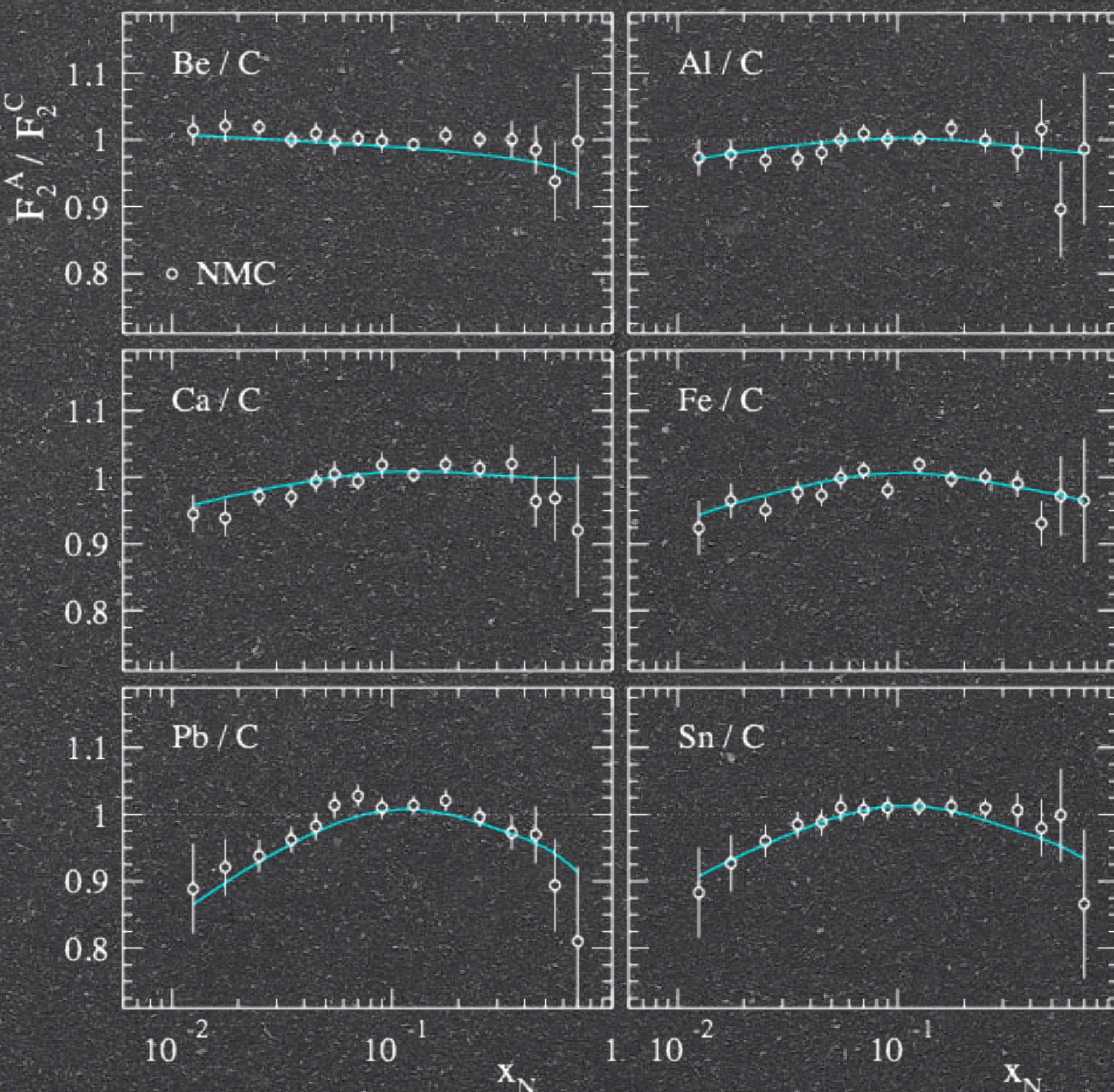
different normalization and low x behaviour

$\alpha_v, \alpha_s, \alpha_g, \beta_1, \beta_2, \beta_3, a_v, a_s, a_g$

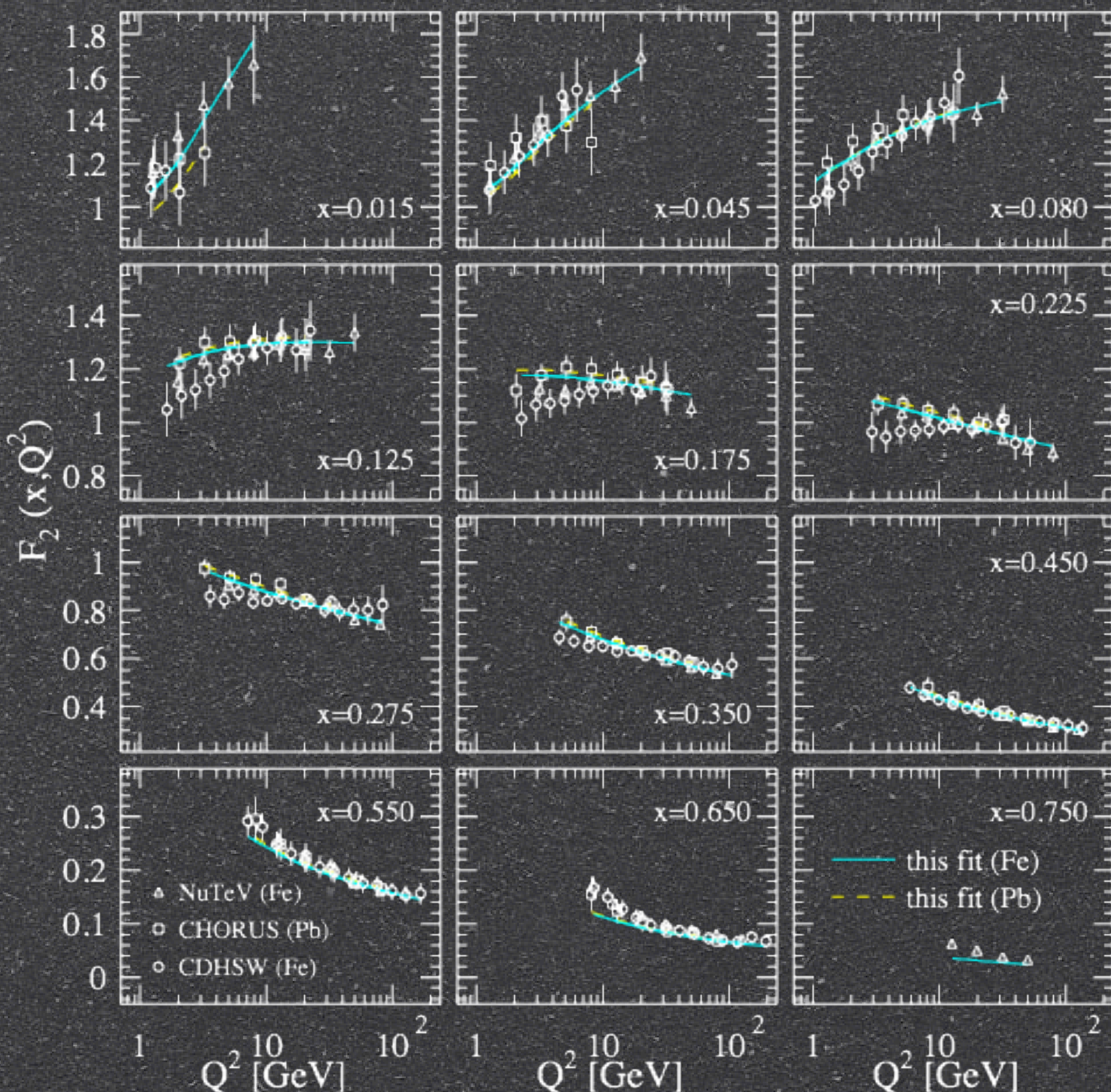
$\xi = \gamma_\xi + \lambda_\xi A^{\delta_\xi}$

25 free parameters

NC-DIS: good agreement (as usual)



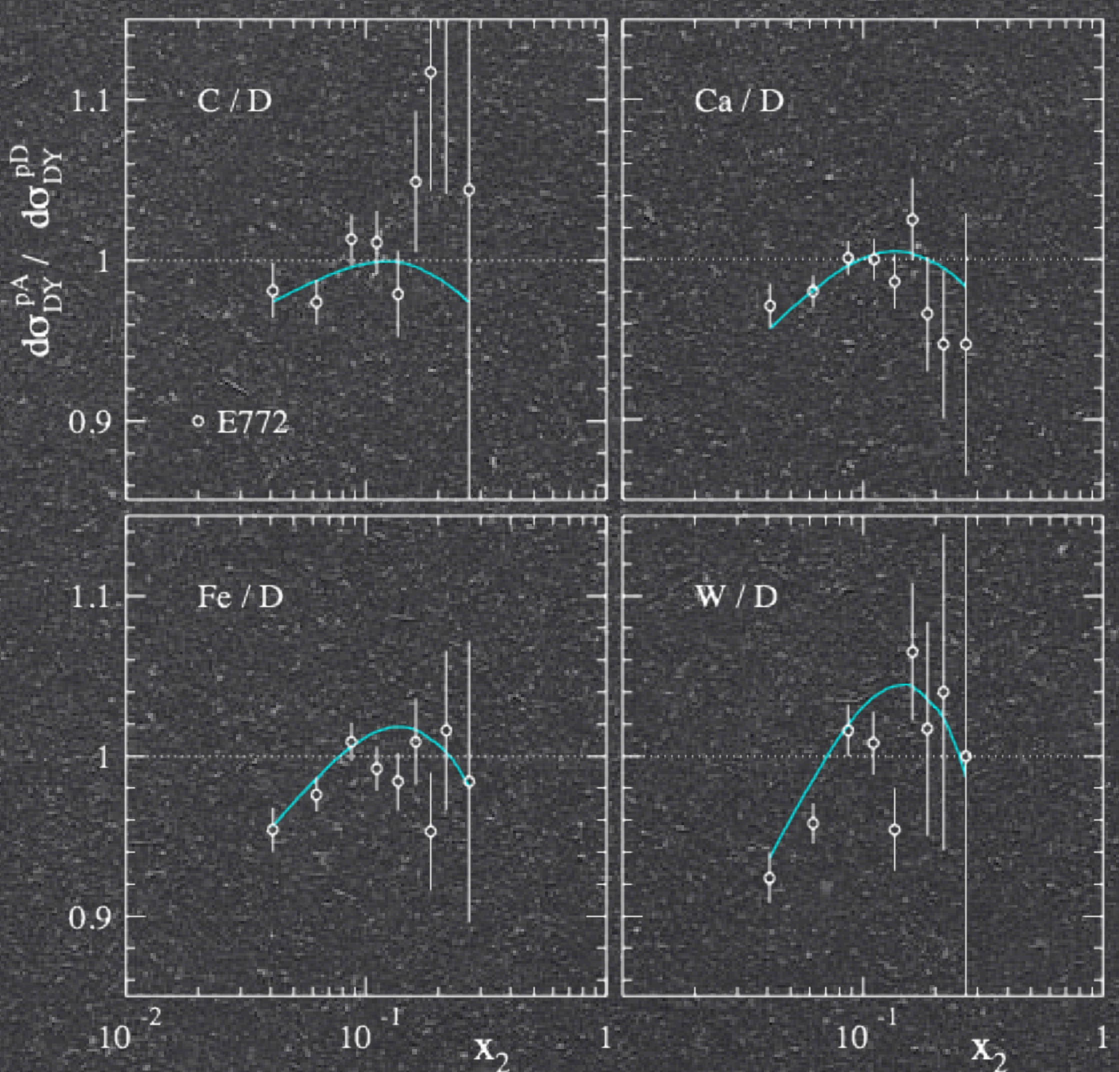
CC-DIS: fairly good agreement



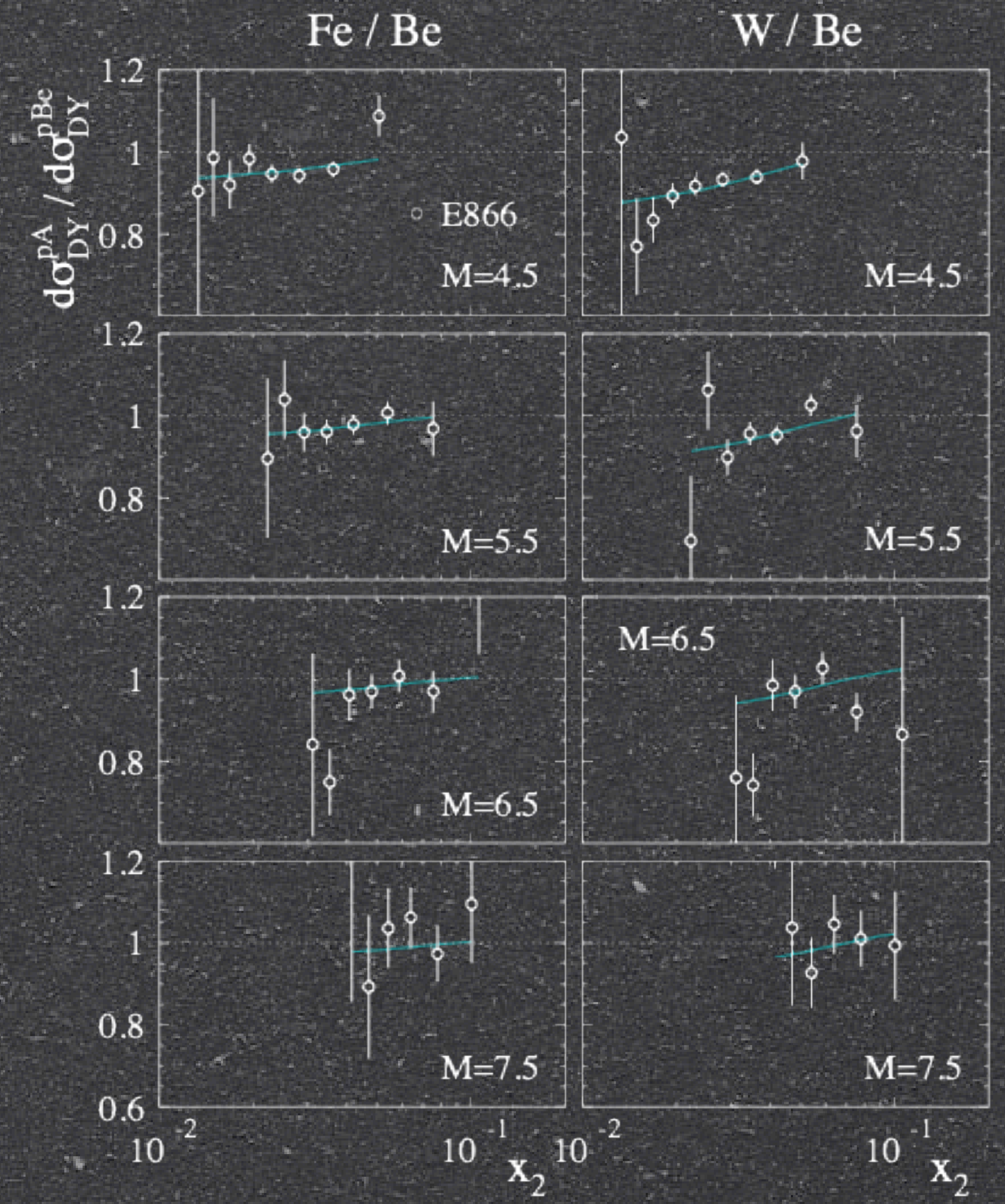
tension between NuTeV and CDHSW (Fe) for specific x bins

see Hannu Paukkunen's talk

Drell-Yan

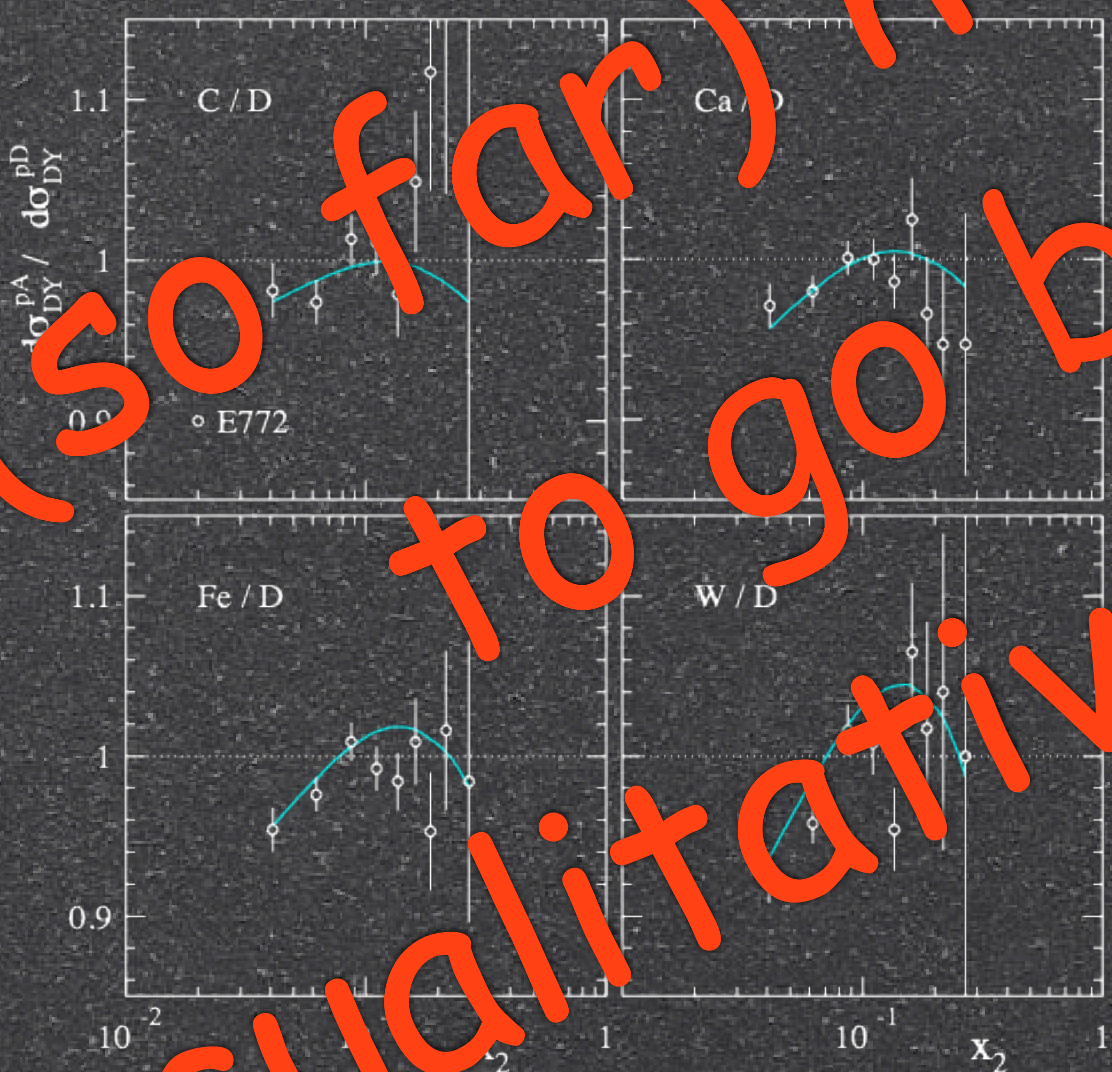


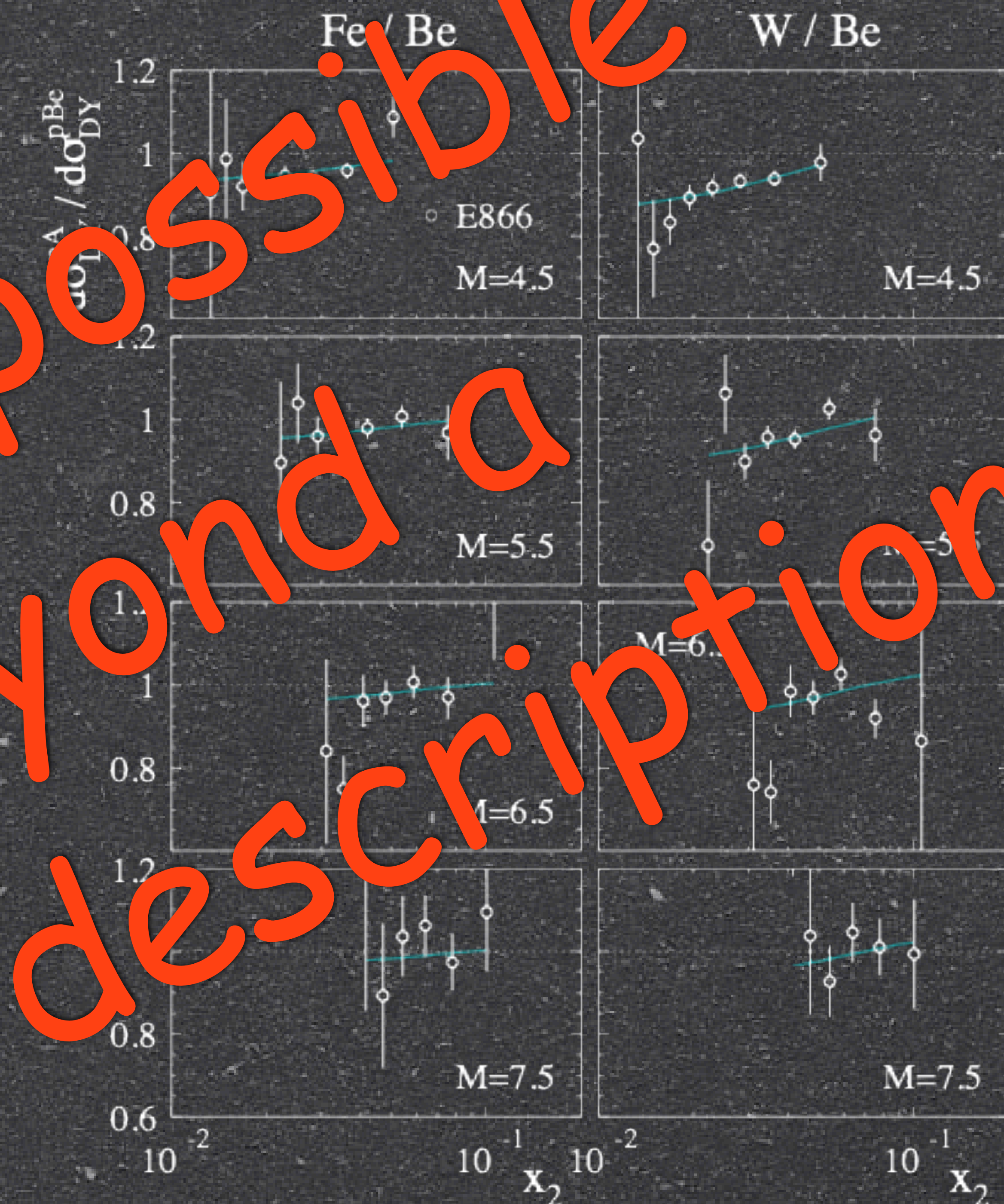
C / D
Ca / D
Fe / D
W / D
E772
$d\sigma^{pA}_{DY}$ / $d\sigma^{pD}_{DY}$
x_2



Fe / Be
W / Be
$d\sigma^{pA}_{DY}$ / $d\sigma^{pBe}_{DY}$
E866
M=4.5
M=5.5
M=6.5
M=7.5
x_2

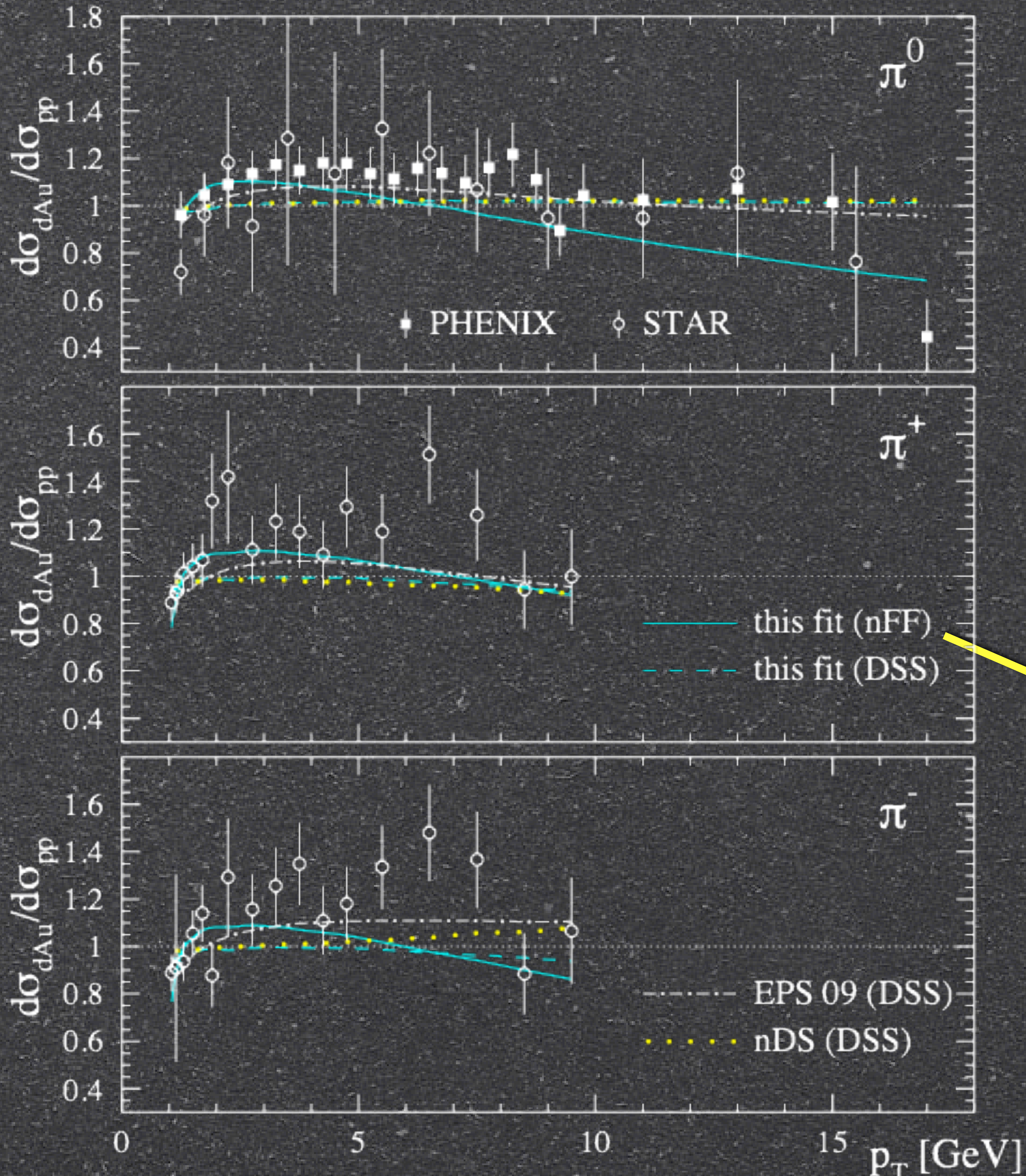
Drell-Yan





(so far) not possible to go beyond a cualitative description

single-inclusive hadro-production



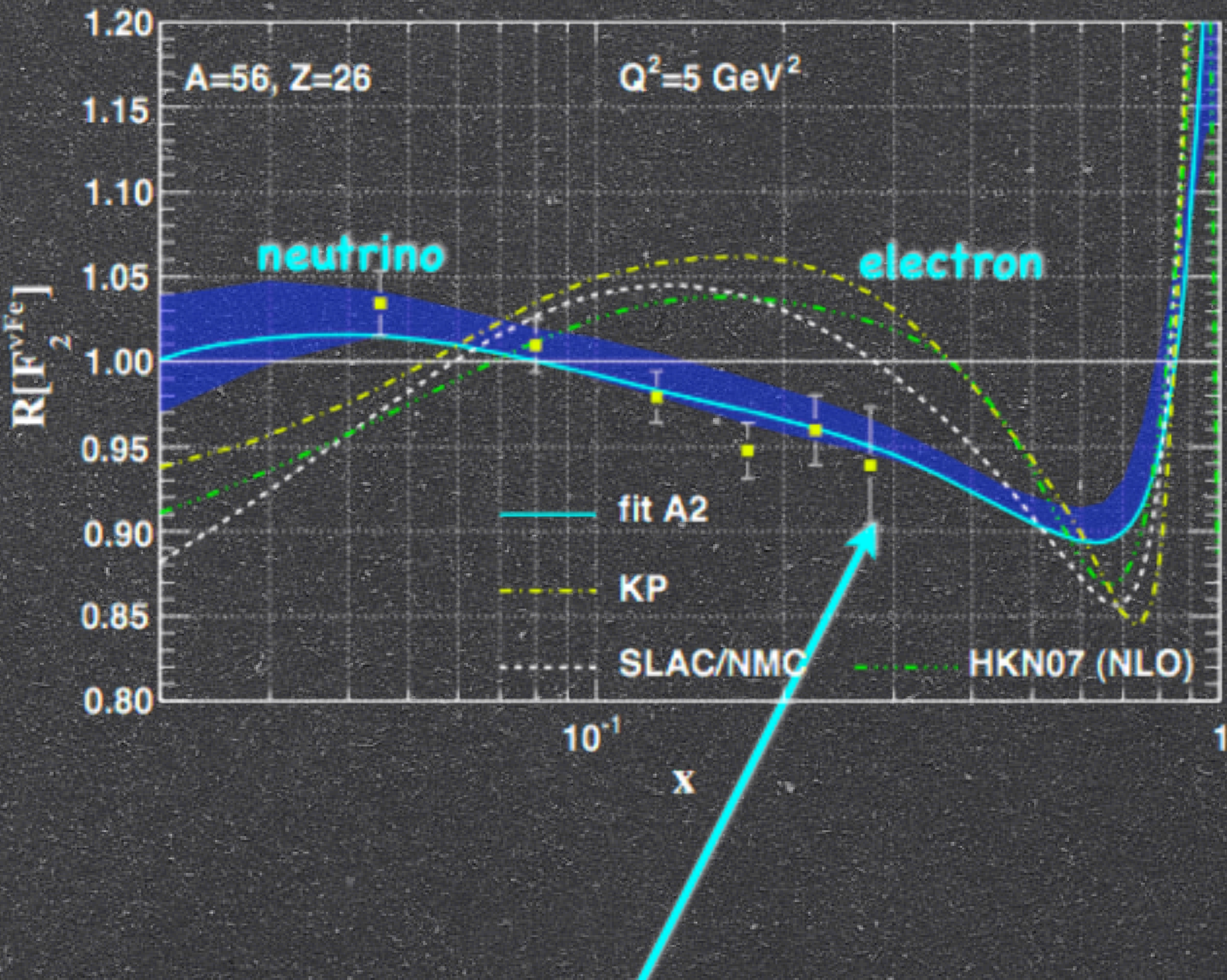
different behavior compared to other nPDFs sets

non trivial impact

What does DSSZ looks like when compared with previous analyses?

nCTEQ

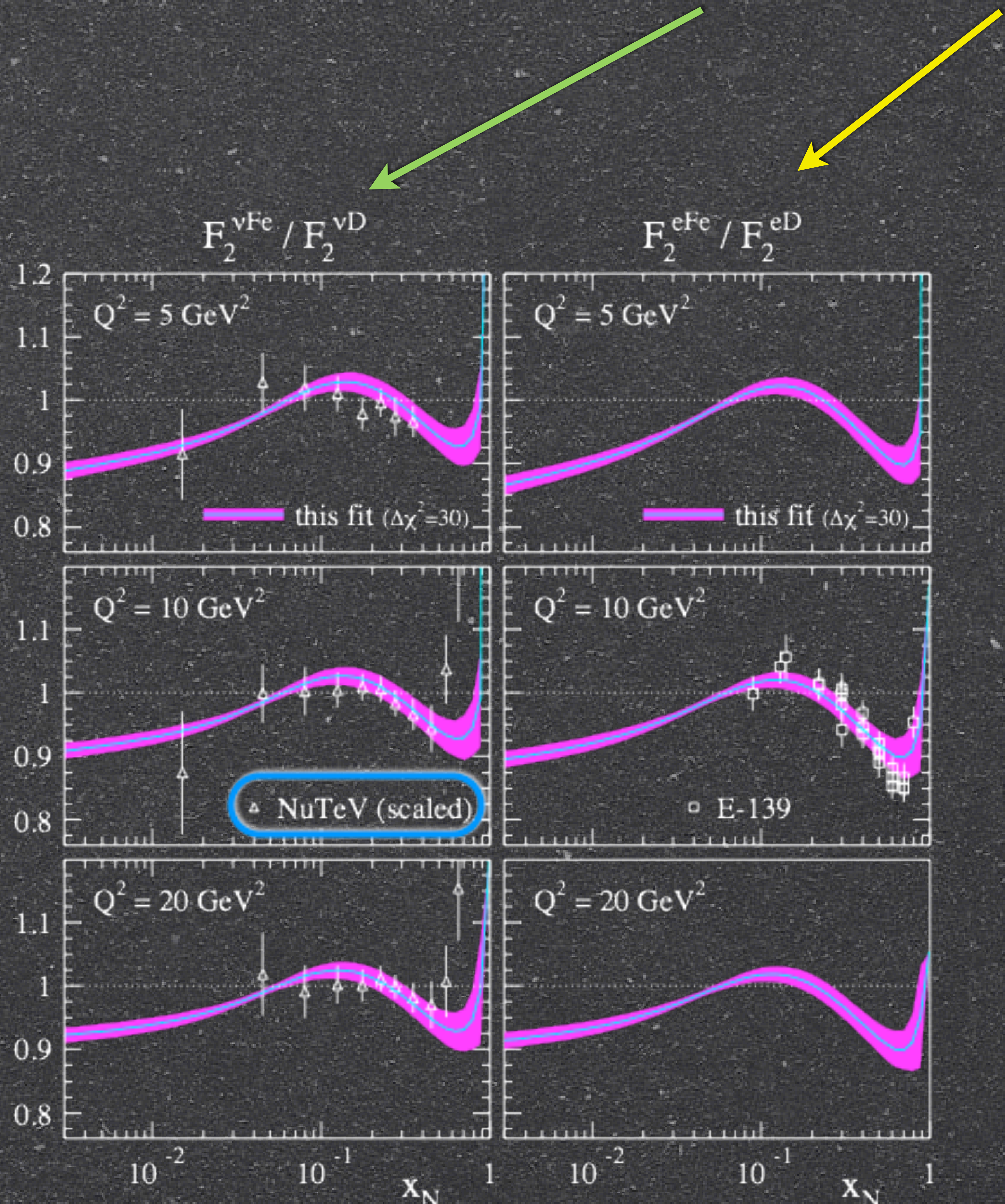
tension between electron and neutrino DIS data



breakdown of factorization

DSSZ

same pattern of nuclear effects for neutrino and electron DIS



what is so different?

"theoretical data": $\mathbf{F_2^{\nu D}}$ not measured → must be computed

nCTEQ

$$\frac{Z}{A}F_2^p + \frac{A-Z}{A}F_2^n$$

what we did

$$\frac{F_2^p + F_2^n}{2}$$

neglects nuclear effects in deuterium

plus:

nCTEQ

#CC-DIS ~ 5 * #NC-DIS

full study of
the correlation
matrix needed

DSSZ

#CC-DIS ~ 1/2 * #NC-DIS

in general not
available

plus:

nCTEQ

#CC-DIS ~ 5 * #NC-DIS

full study of the correlation matrix needed

DSSZ

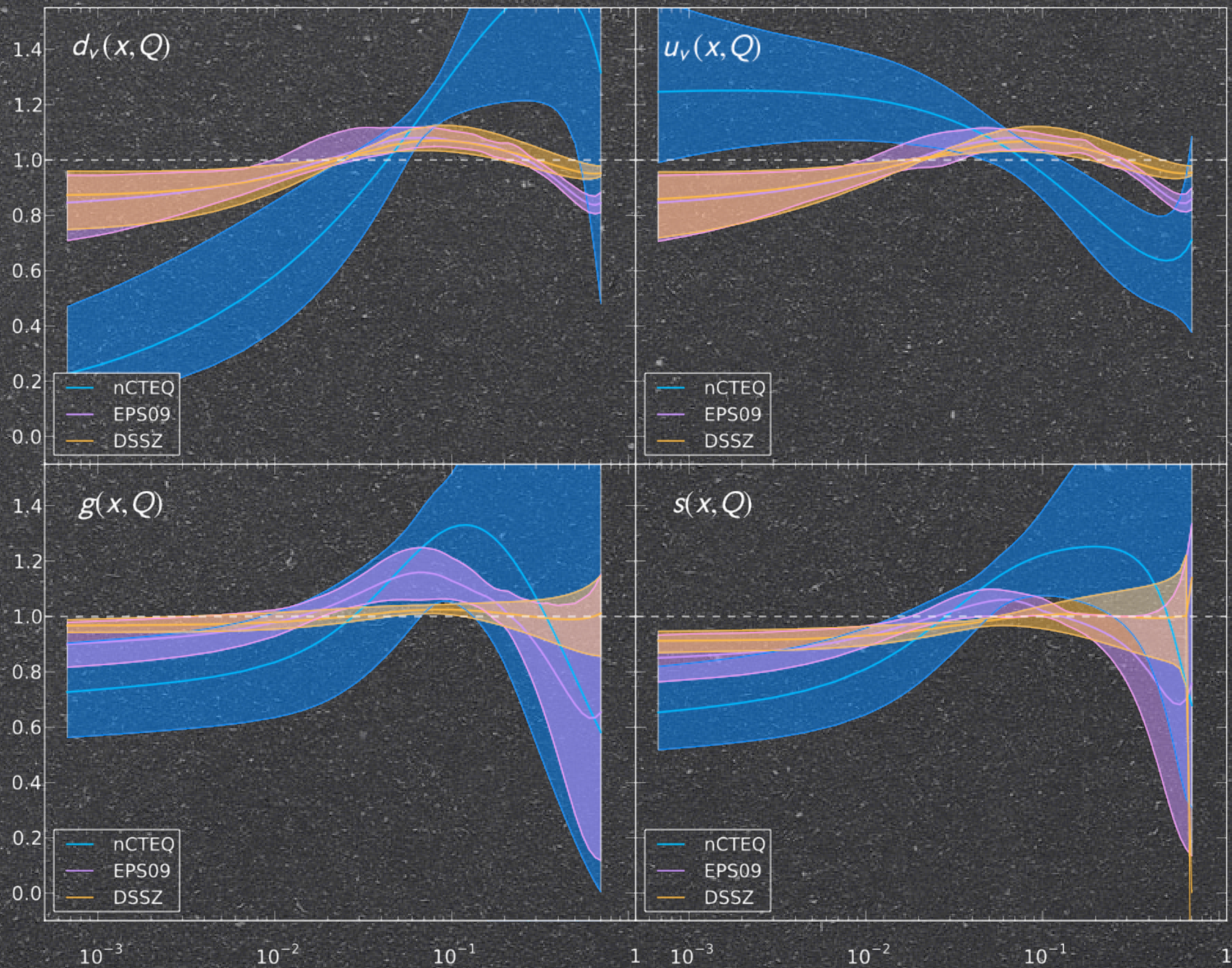
#CC-DIS ~ 1/2 * #NC-DIS

in general not available

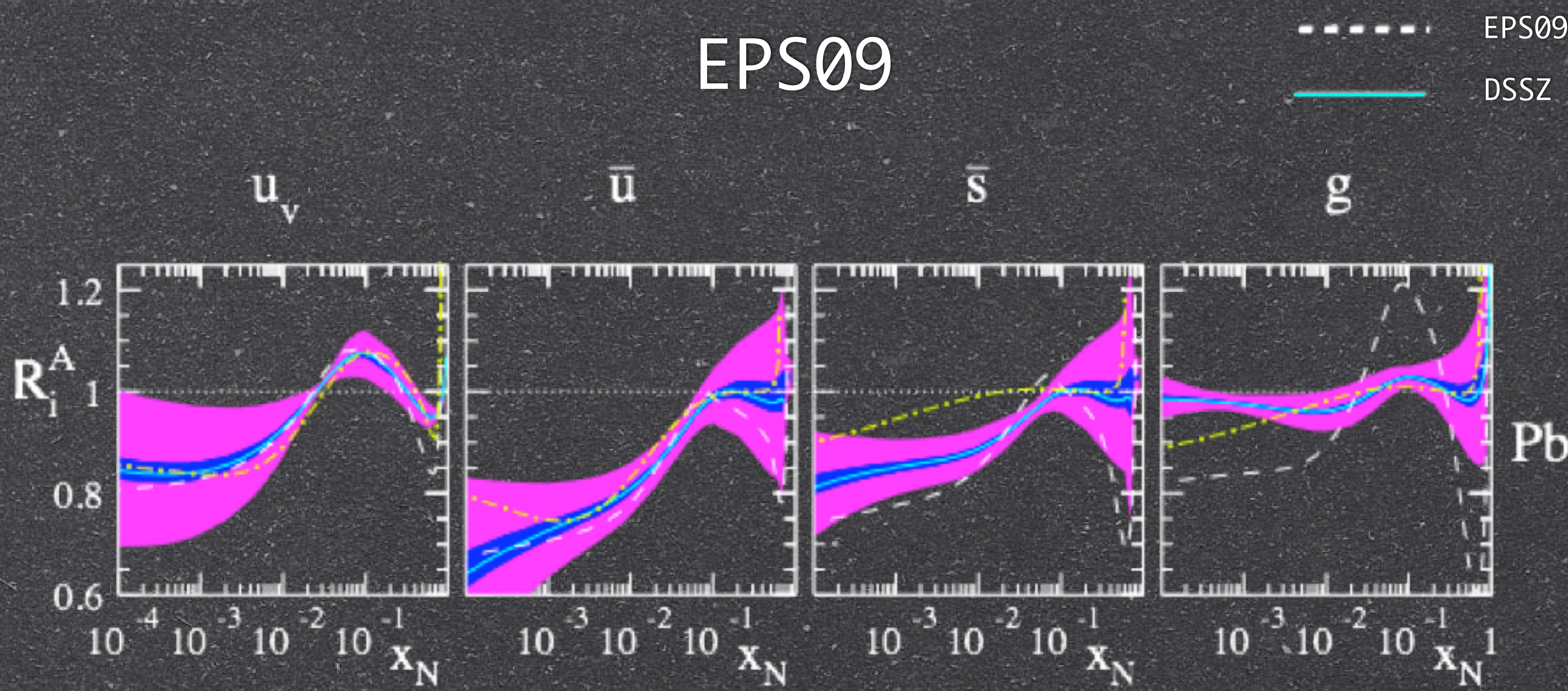
really important because neutrino data is used in the determination of proton PDFs

nCTEQ's new analysis

(preliminary results from Karol Kovaric)

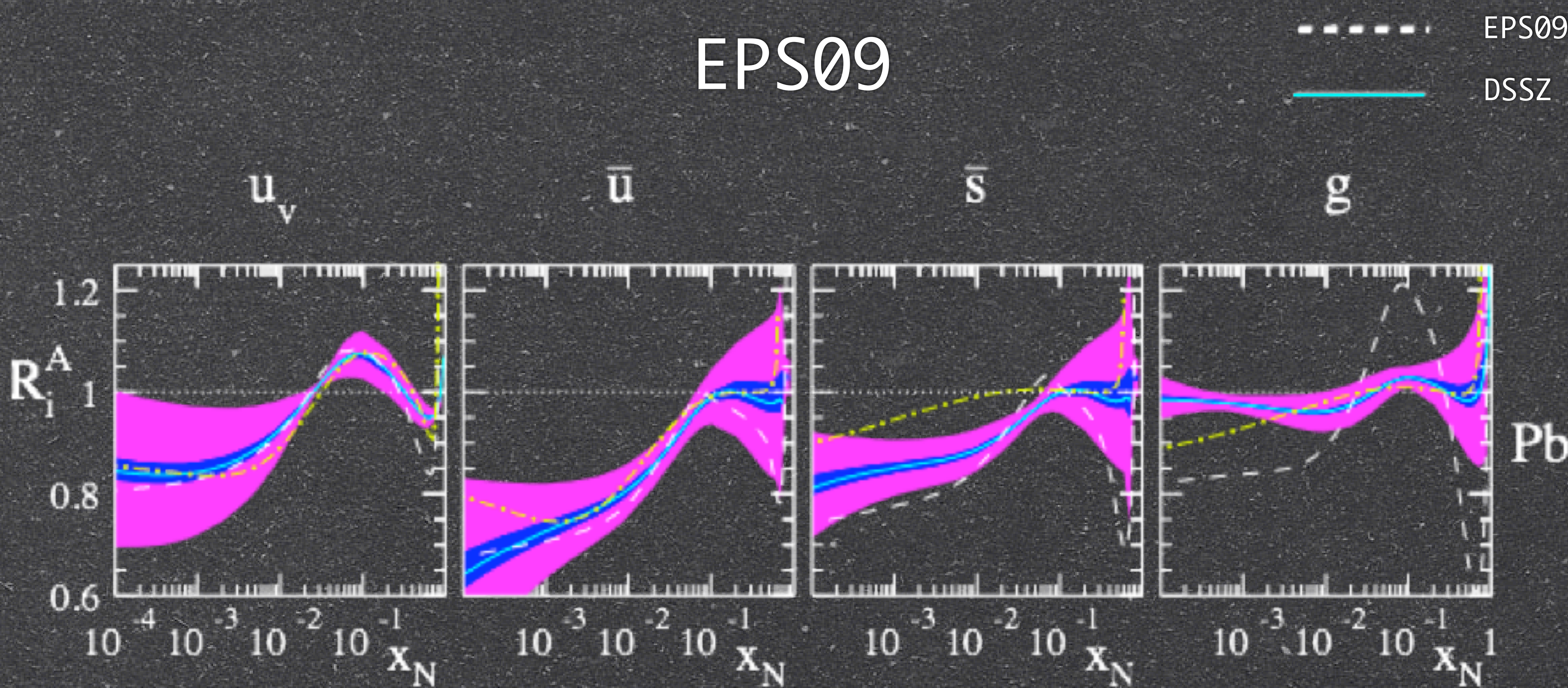


EPS09



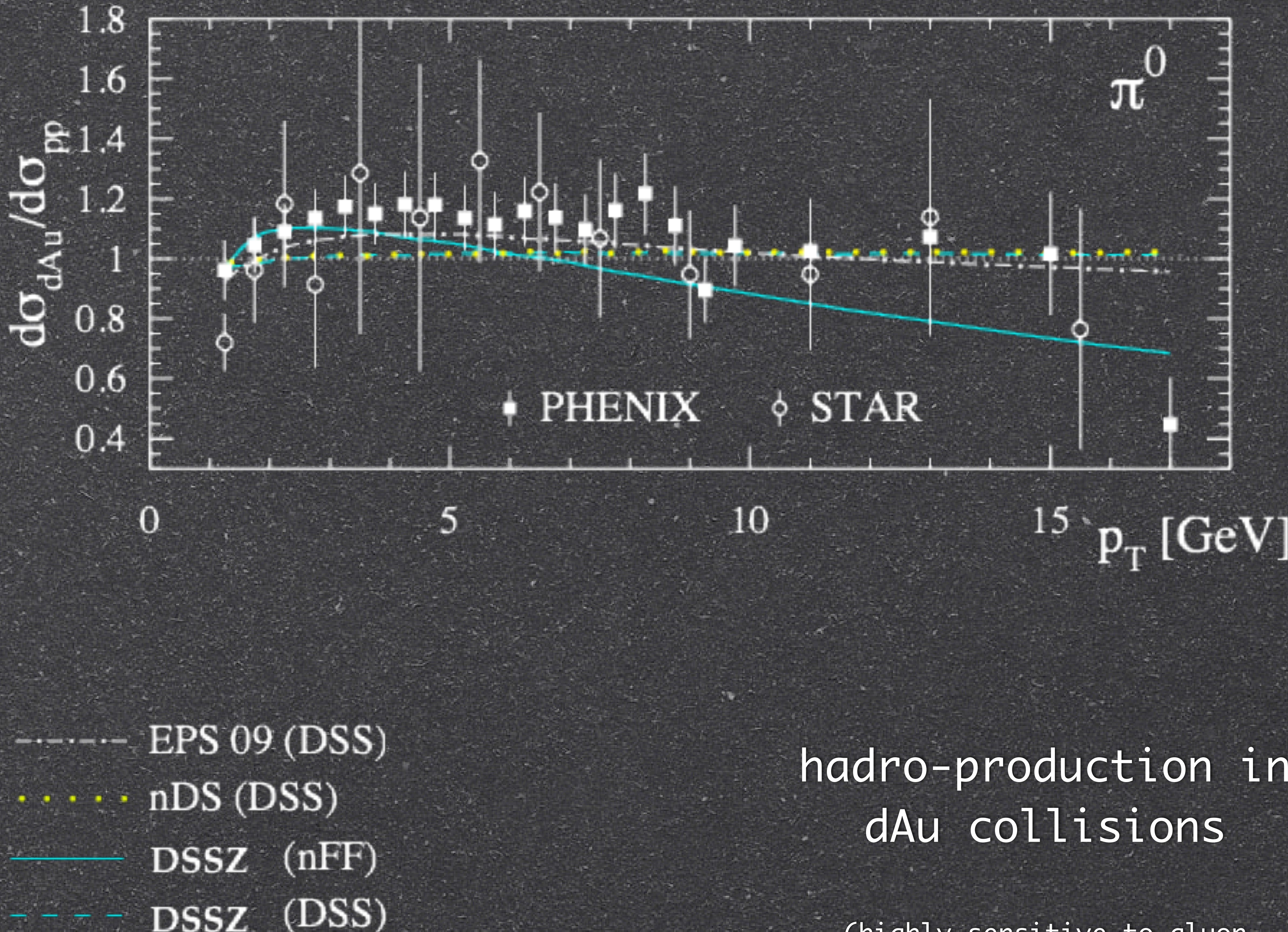
strange sea → CTEQ6M vs. MSTW2008

EPS09



strange sea → CTEQ6M vs. MSTW2008

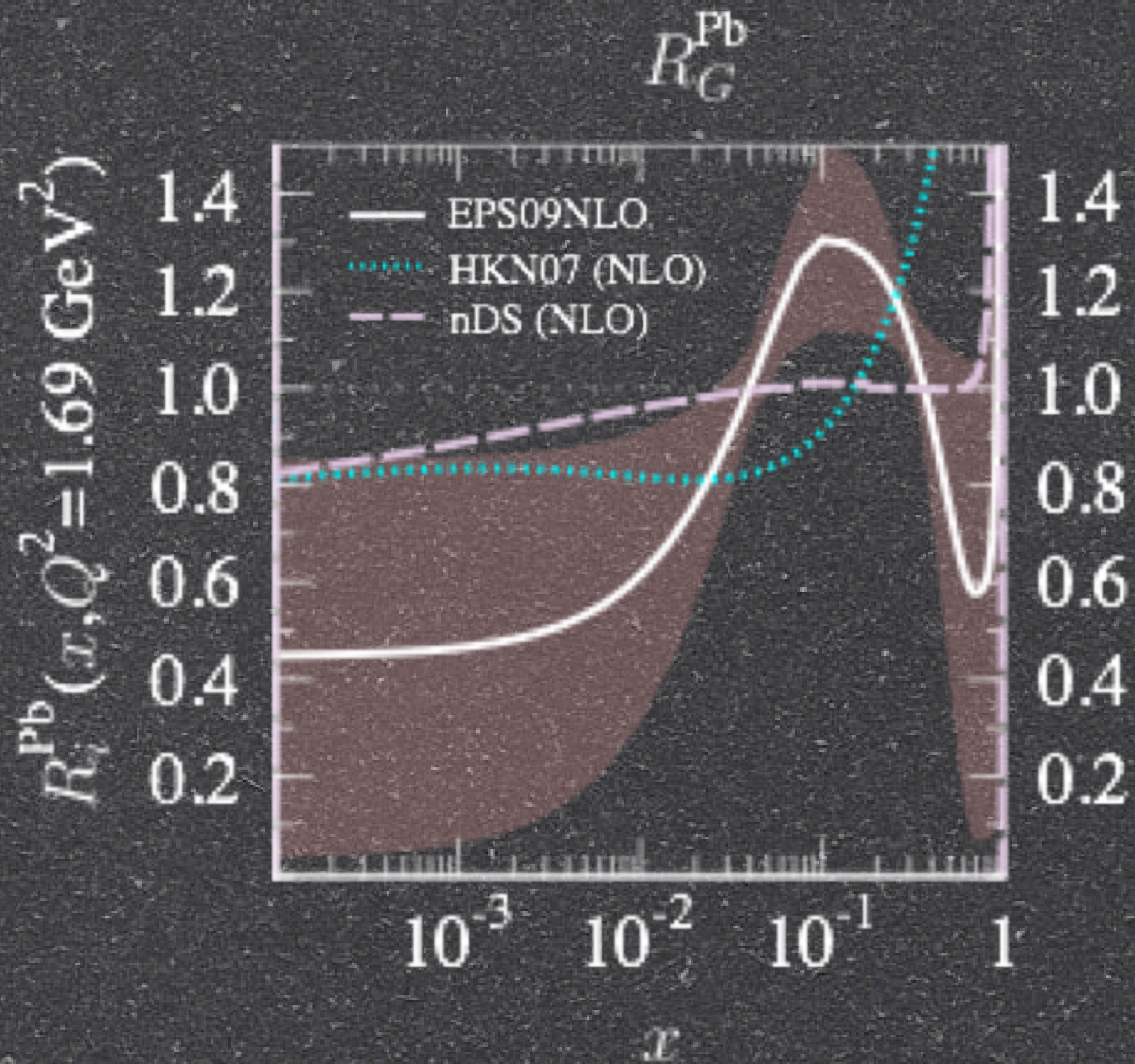
gluon → dAu data



hadro-production in dAu collisions

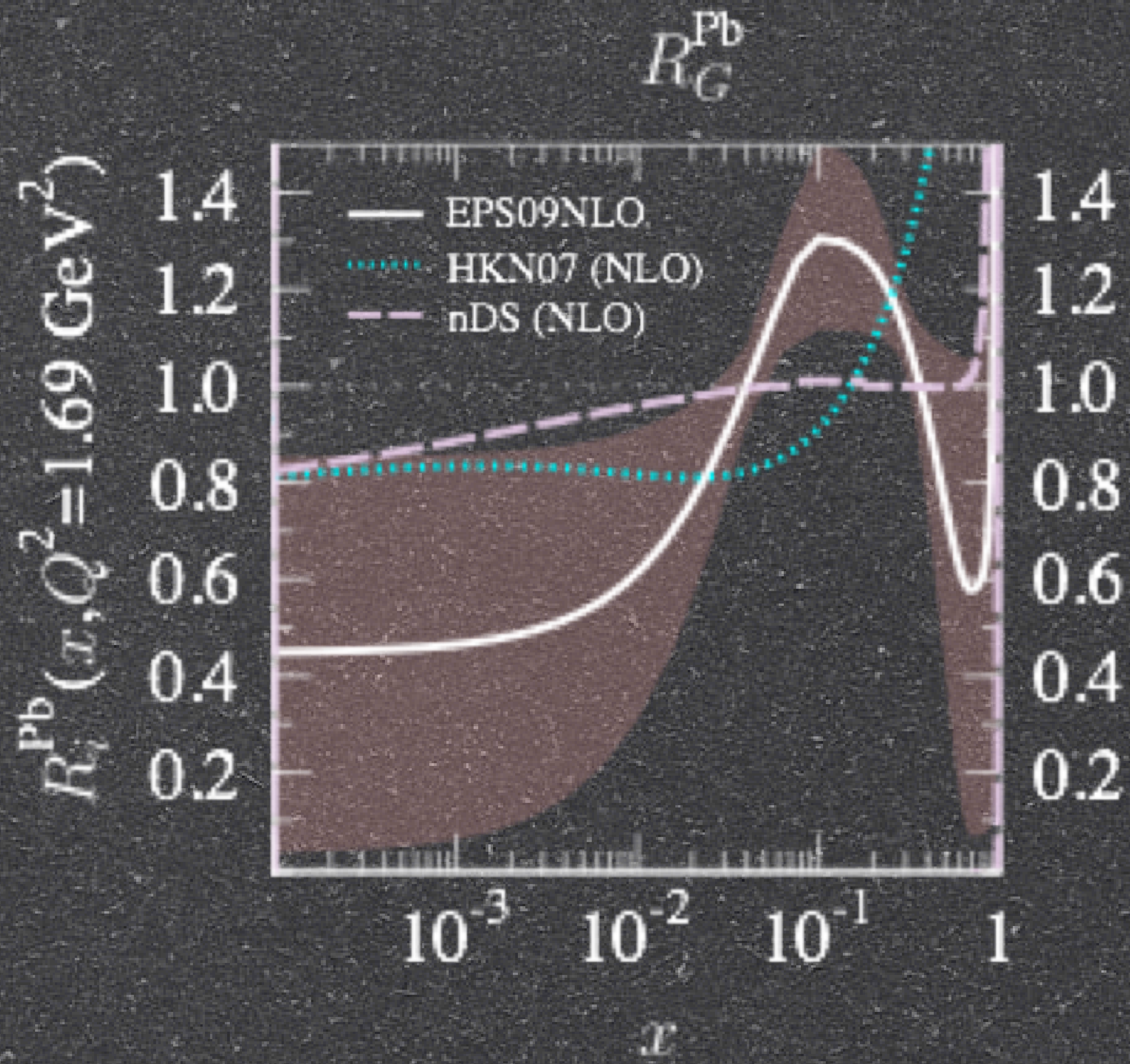
(highly sensitive to gluon distribution)

for EPS09



huge impact on gluon distribution

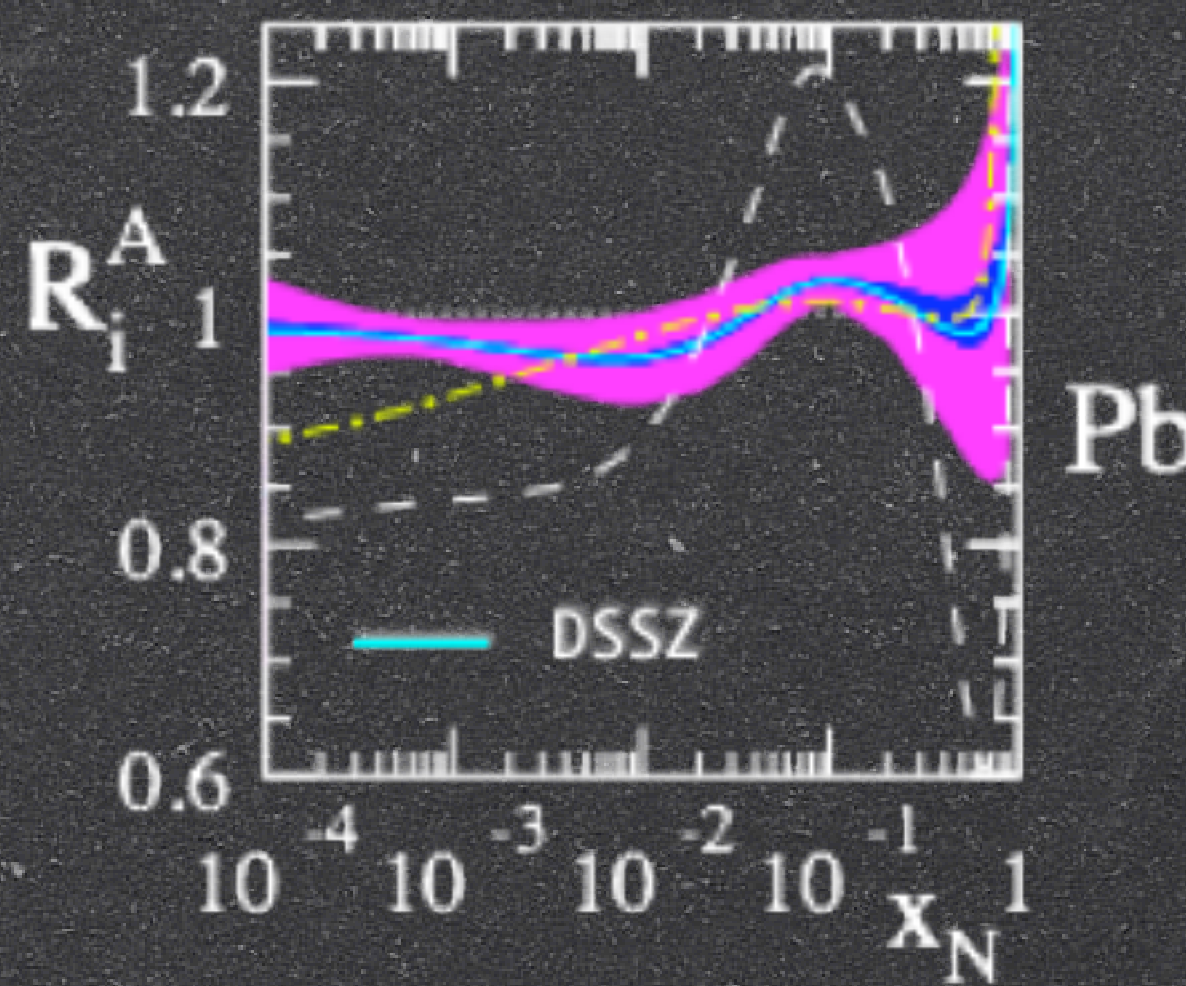
for EPS09



huge impact on gluon distribution

for DSSZ

small effect in gluons



why, if both analyses use similar strategies?

why, if both analyses use similar strategies?

EPS09		DSSZ
ZM-VFNS	compatible valence and non-strange sea	GM-VFNS
CTEQ		MSTW
no neutrino DIS	fairly similar strange density	neutrino DIS
parameterization in sectors		continuous parameterization

why, if both analyses use similar strategies?

EPS09		DSSZ
ZM-VFNS	compatible valence and non-strange sea	GM-VFNS
CTEQ		MSTW
no neutrino DIS		neutrino DIS
parameterization in sectors	fairly similar strange density	continuous parameterization

no effect for fragmentation in Au

medium-modified fragmentation functions

(R.Sassot, M.Stratmann, P. Z., PRD 2010)

Summing up...

- several sets of nPDFs available
- all (but one) agree on universality
- in general nice description of data
- centrality class nPDFs (see Ilkka Helenius' talk)
- nuclear gluon density not yet constrained
- extrapolations not reliable

open questions:

- nuclear effects truly universal?
- correlated errors?
- more data in DY or hadroproduction?
- cross-sections instead of structure functions?
- nuclear effects for deuteron?
- more flexible parameterizations?
- higher fixed-order analyses worthwhile?
- A-A collisions?
- final state nuclear effects?
- ...???