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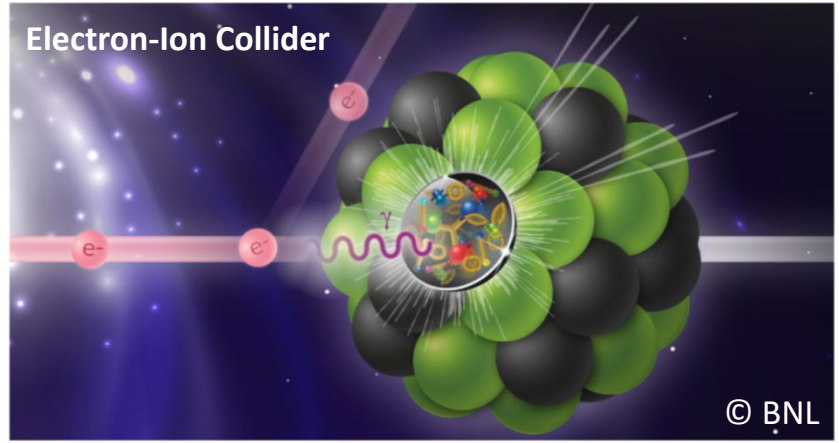
MATHEMATISCH-
NATURWISSENSCHAFTLICHE FAKULTÄT

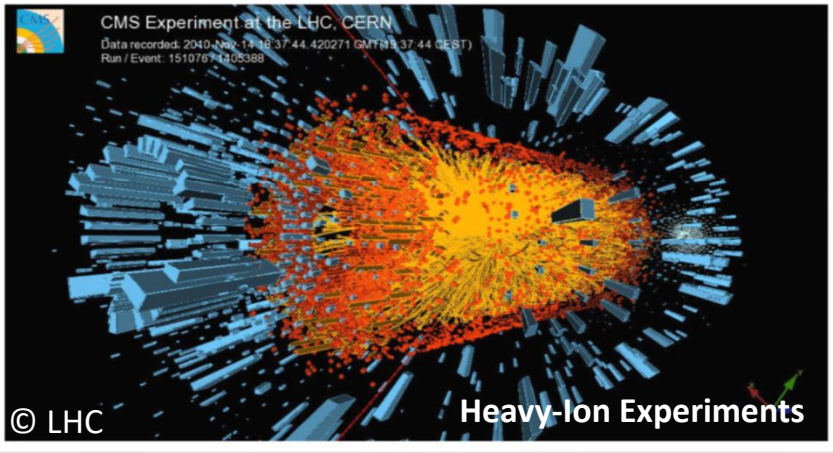
A QCD analysis for nuclear PDFs at NNLO

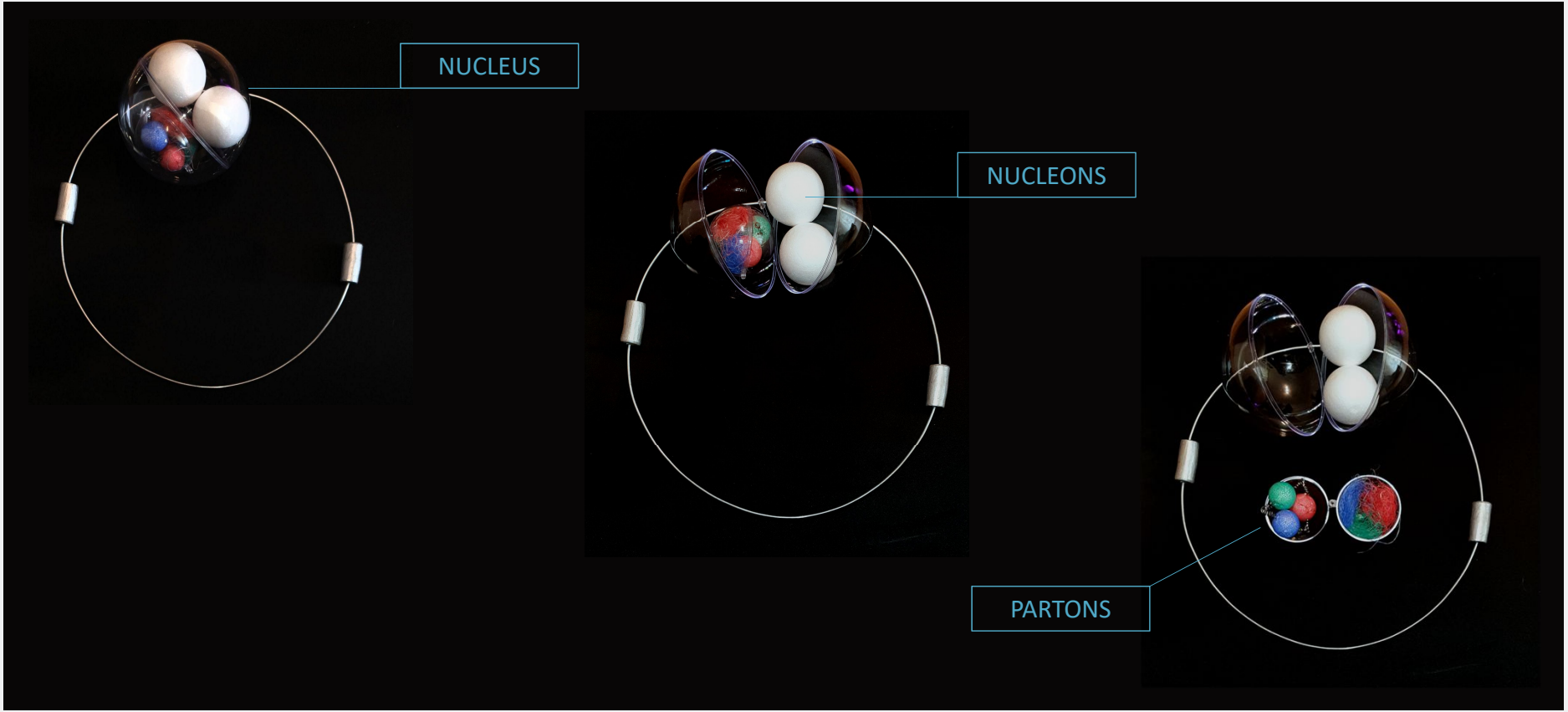
MARINA WALT,

In collaboration with Ilkka Helenius, Werner Vogelsang

INTRODUCTION

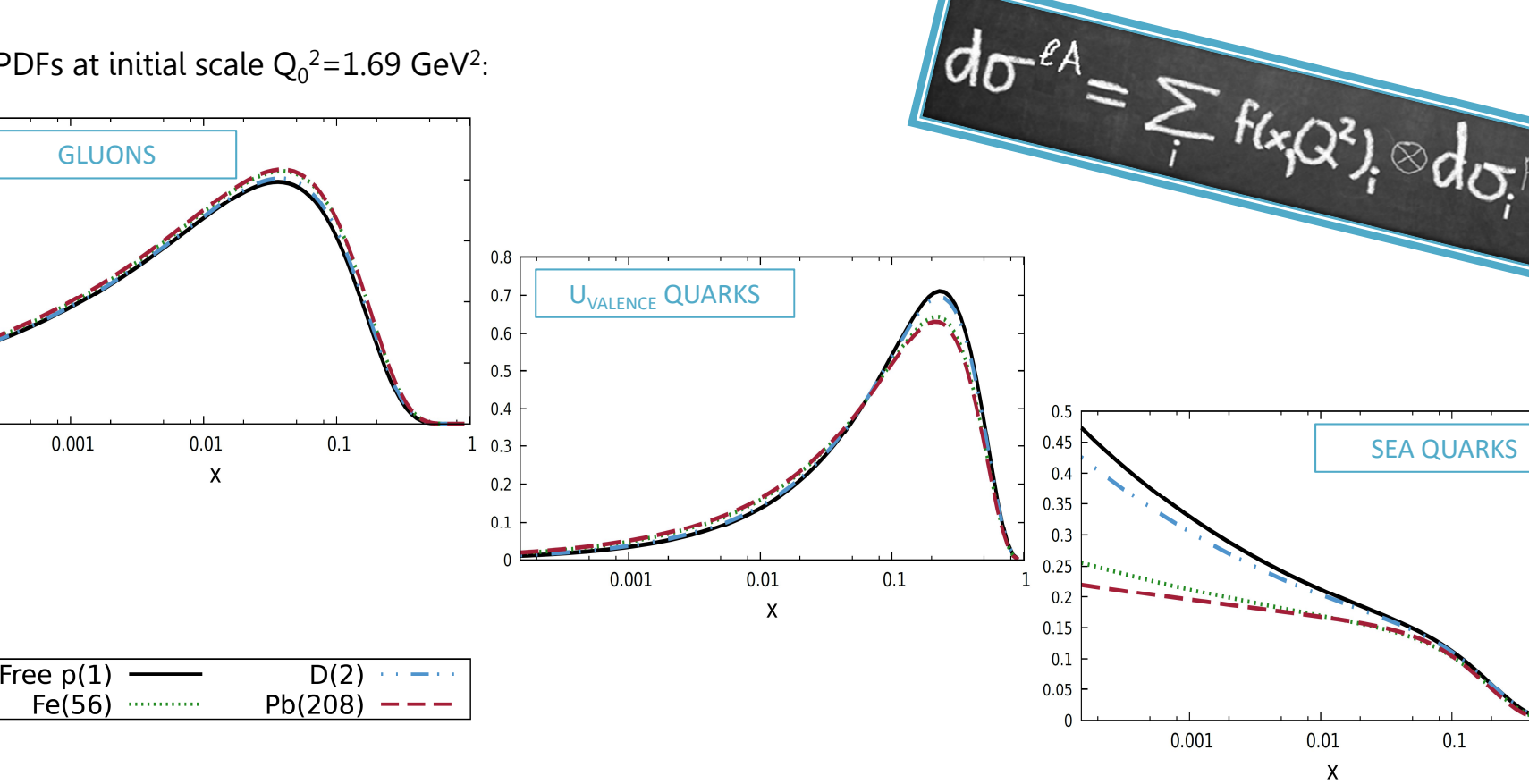





NUCLEUS
NUCLEONS
PARTONS

NNLO Results – Nuclear PDFs

nPDFs at initial scale Q_0^2=1.69 GeV^2:



NNLO Results – Nuclear PDFs

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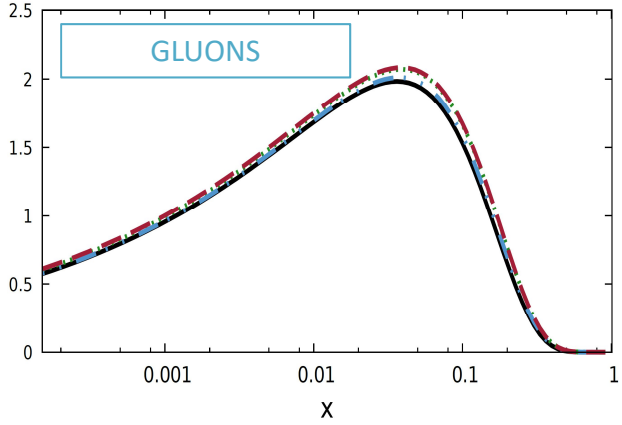
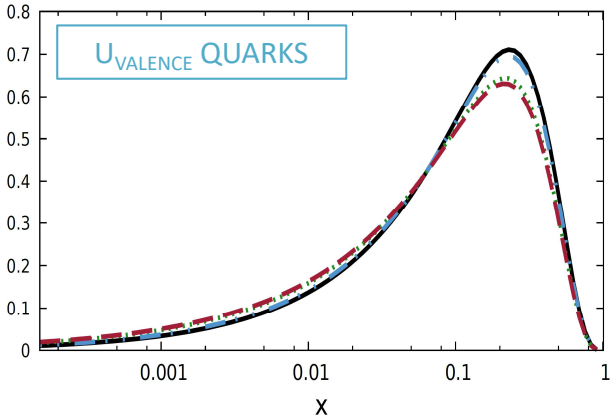
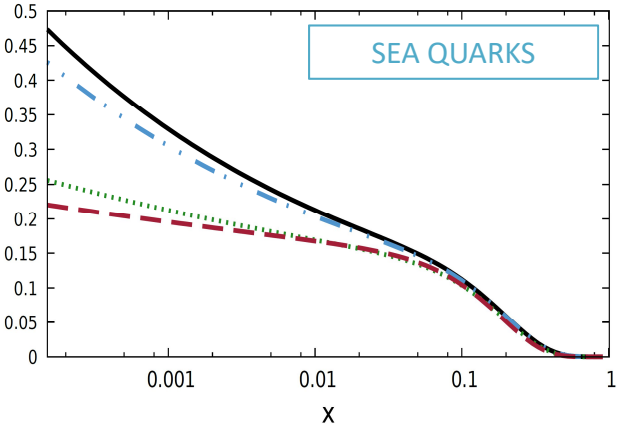
Preliminary NNLO nPDFs

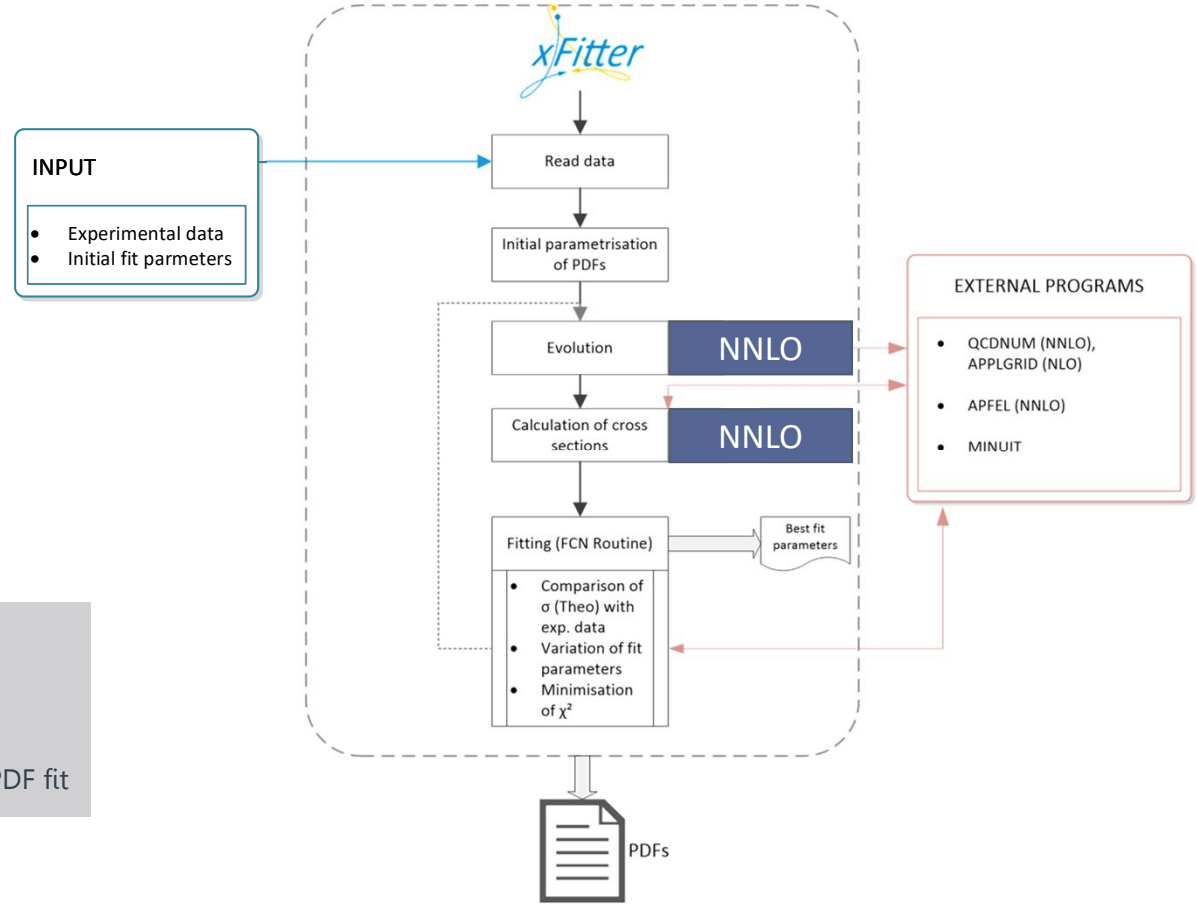
nPDFs at initial scale Q_0^2=1.69 GeV^2:







Analysis procedure at NNLO



xFitter modifications required for nuclear PDF fit

Free Proton PDFs vs. Nuclear PDFs

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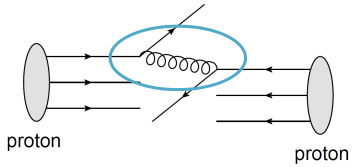
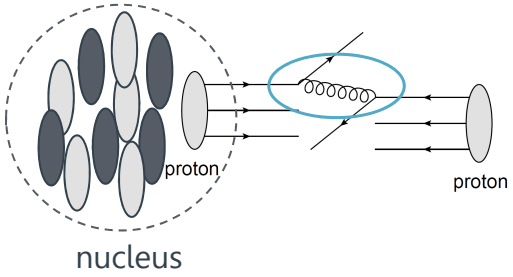
Free proton:



[HERAPDF2.0:
Eur.Phys.J. C75 (2015) no.12, 580]

Nucleus:



$$x f_i^{p/A}\left(x, Q_0^2\right) = c_0\, x^{c_1} (1-x)^{c_2} \left(1 + c_3\, x + c_4\, x^2\right)$$

$$c_k \rightarrow c_k(A) := c_{k,0} + c_{k,1}\left(1 - A^{-c_{k,2}}\right)$$

[nCTEQ: PRD 93, 085037 (2016)]

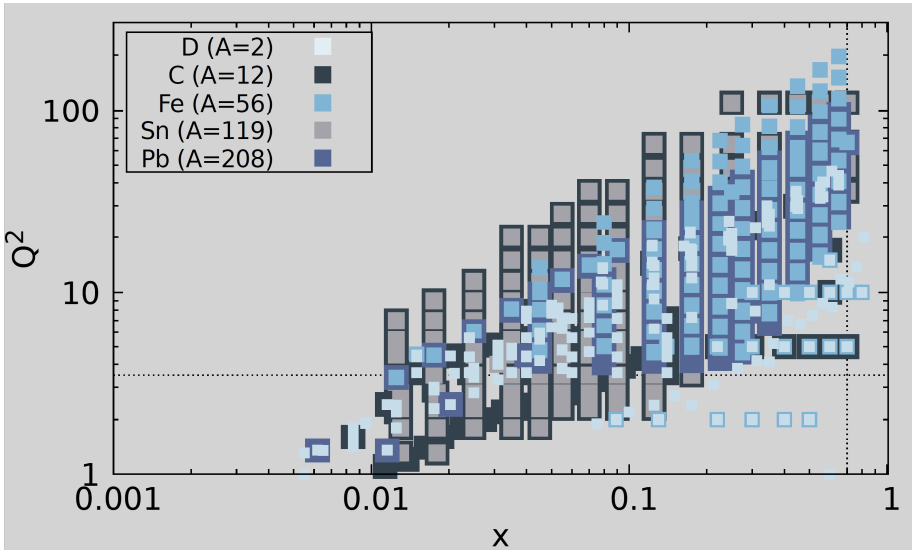
xFitter

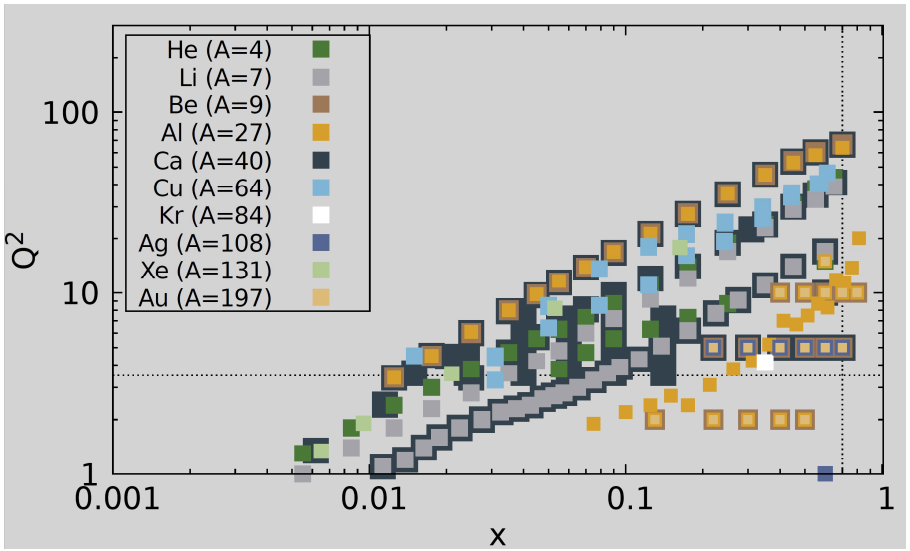
PDFType=‚nucleus‘
(A=1, Z=1 for proton)

A-Dependence

$$c_k \to c_k(A) := c_{k,0} + c_{k,1}\left(1 - A^{-c_{k,2}}\right)$$

A dependent coefficients





Used nuclear DIS data: neutral current DIS and charged current neutrino DIS data.

Free Proton PDFs vs. Nuclear PDFs

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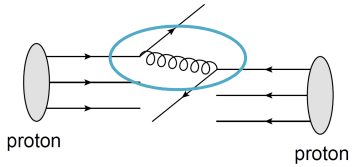
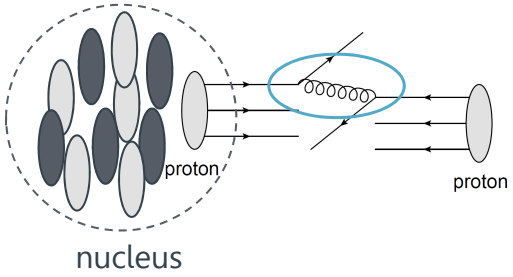
Free proton:



➔ PDF of a **free** proton

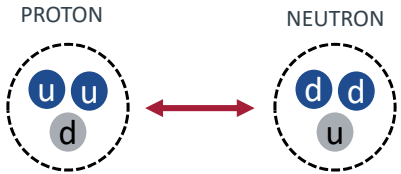
$f^{p}(Q^2, x)$

Nucleus:



➔ PDF of a **bound** nucleon

$$f^{A} = \frac{Z}{A} f^{p/A} + \frac{(A-Z)}{A} f^{n/A}$$



PDF decomposition of a bound nucleon.

Free Proton PDFs vs. Nuclear PDFs

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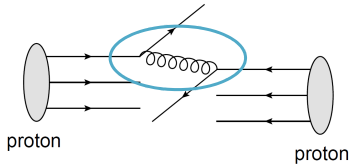
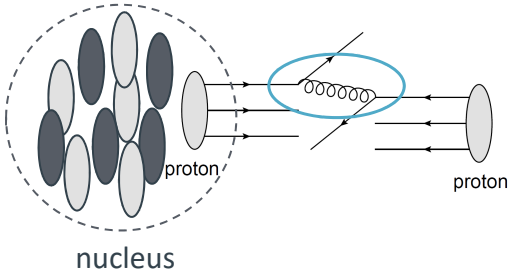
Free proton:



➔ PDF of a **free** proton

$f^{p}(Q^2, x)$

Nucleus:



➔ PDF of a **bound** nucleon

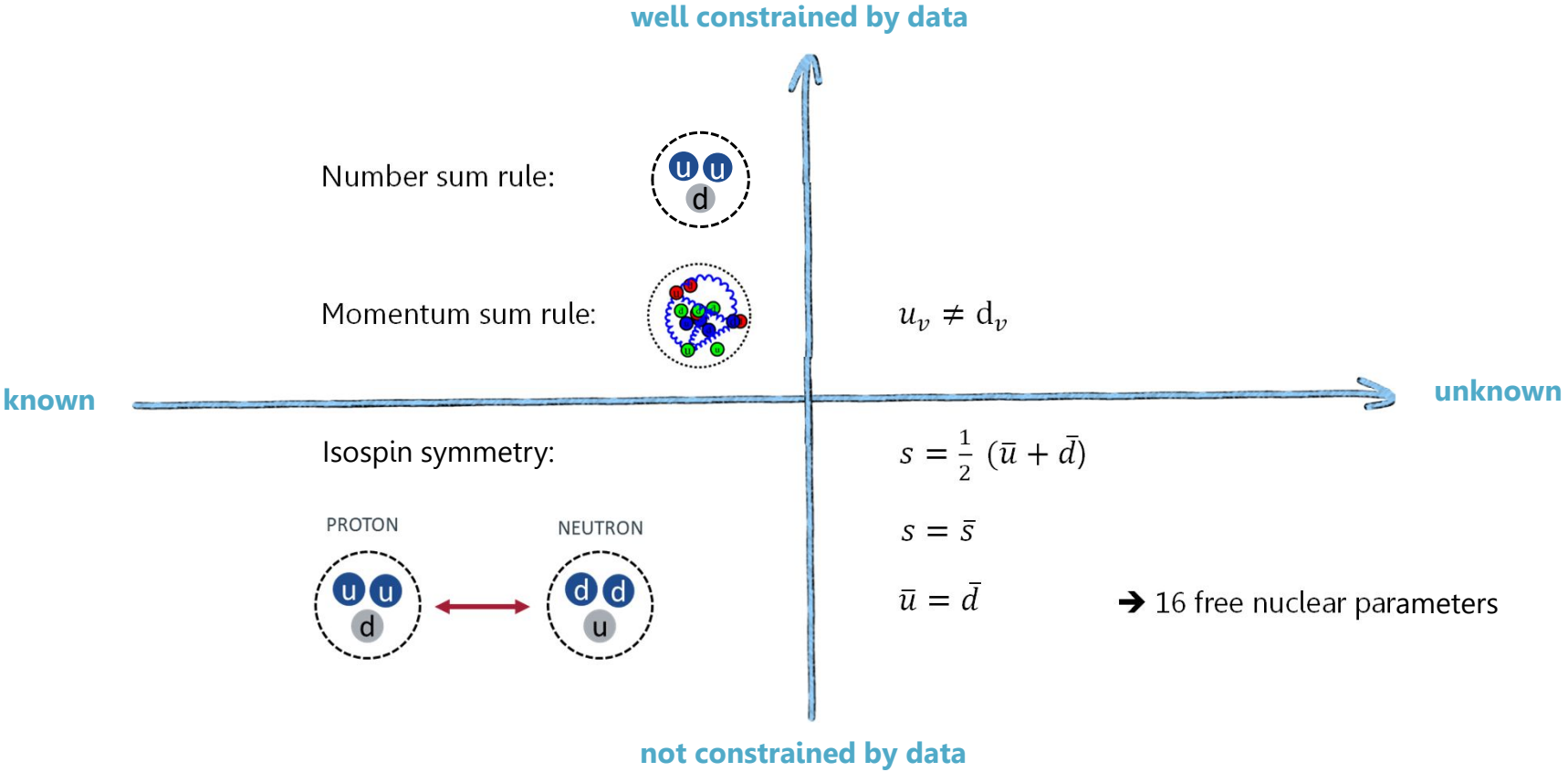
$$f^{A} = \frac{Z}{A} f^{p/A} + \frac{(A-Z)}{A} f^{n/A}$$

If $Z \neq \frac{A}{2}$ ➔ **isoscalar corrections** applied by experiments become relevant.

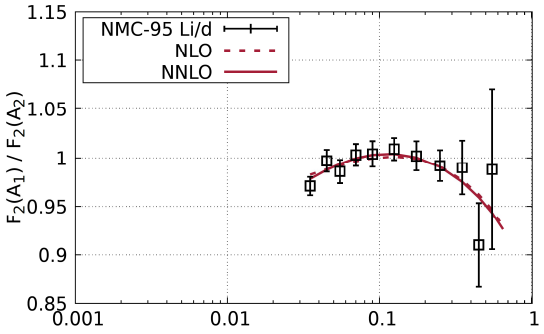
Flags for isoscalar corrections:

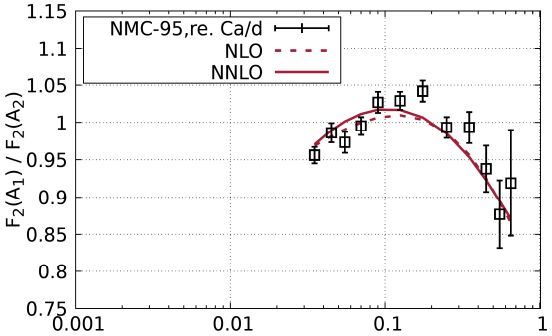
CInfo = ‚NMC', ‚EMC, ‚SLAC'.

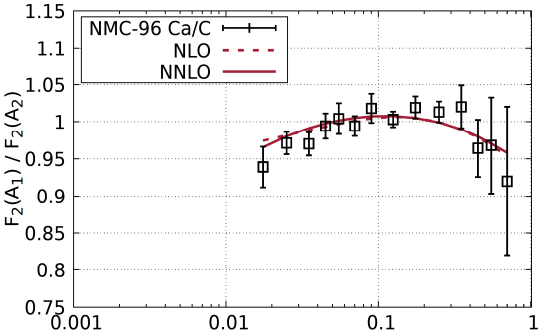
ASSUMPTIONS

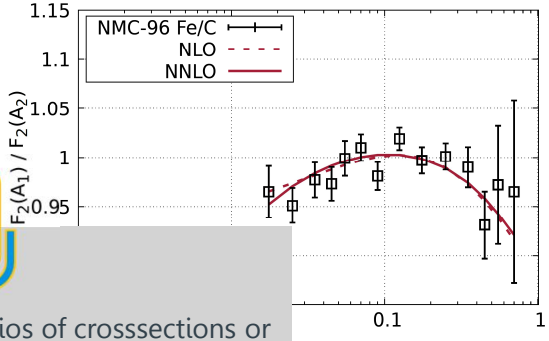


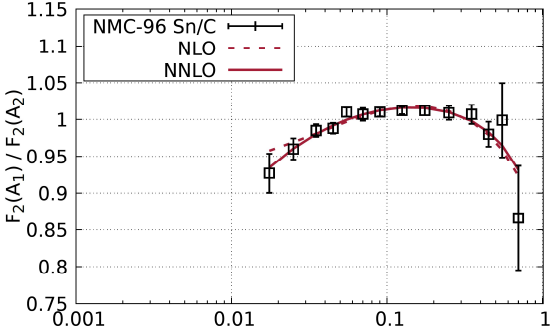
Comparison to DIS Data

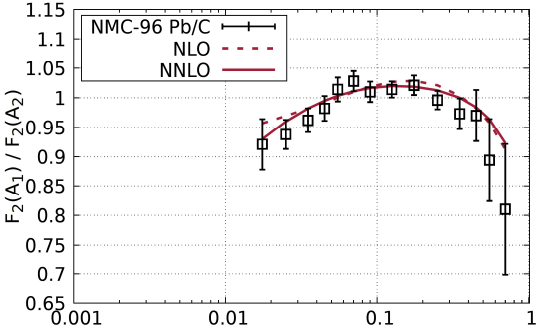








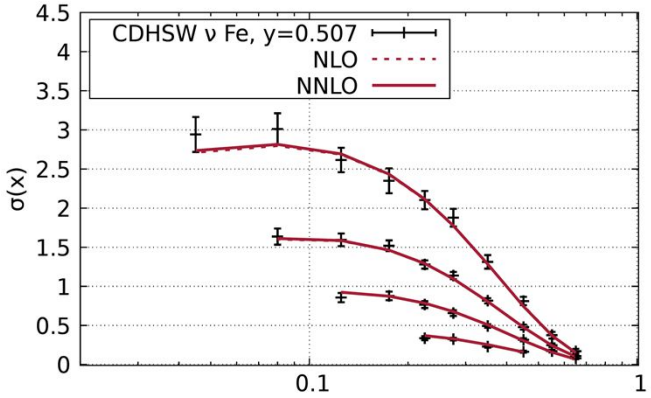


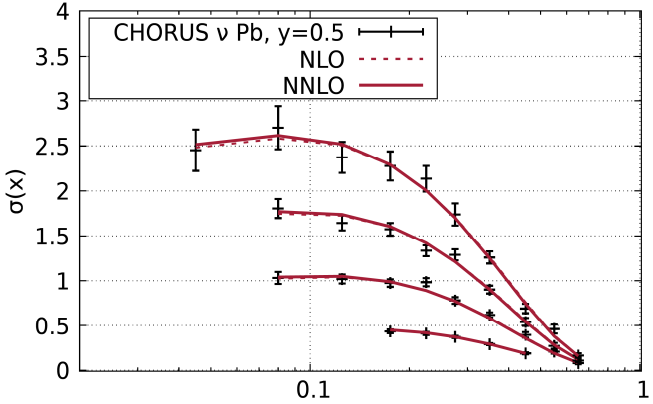


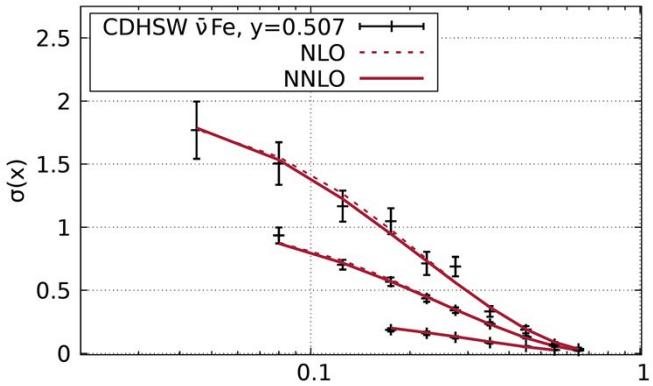
Ratios of crosssections or structure functions:

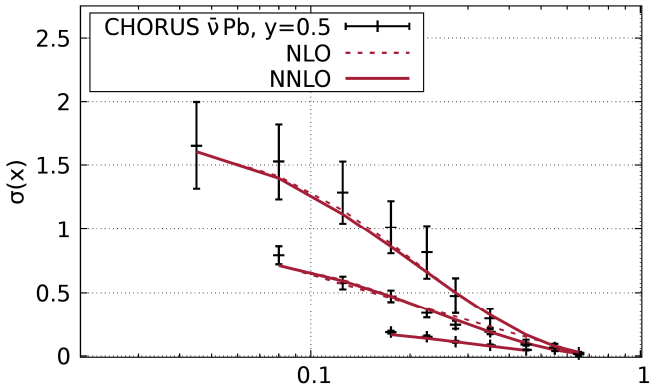
CInfo = ‚ratio‘

Comparison to neutrino DIS Data





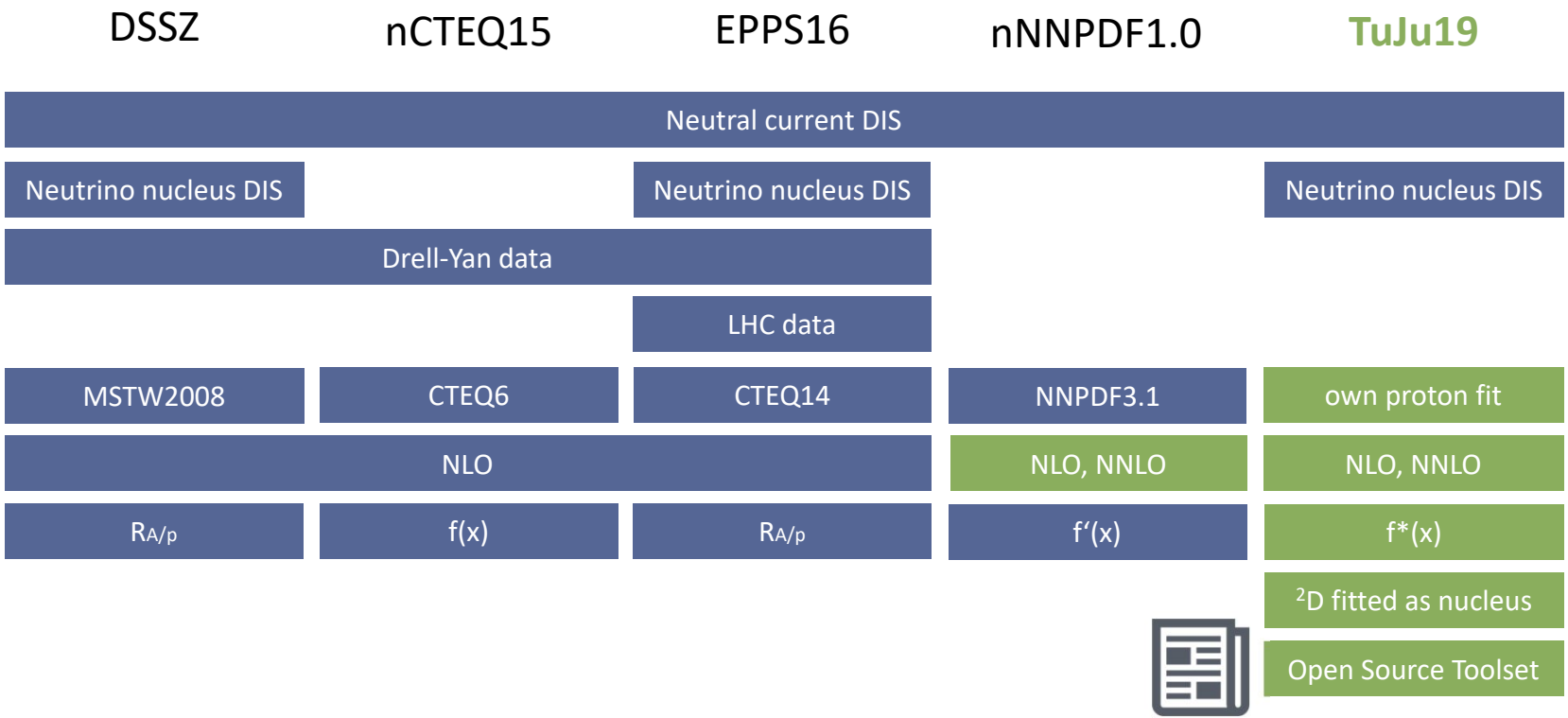




Charged Current DIS processes included:

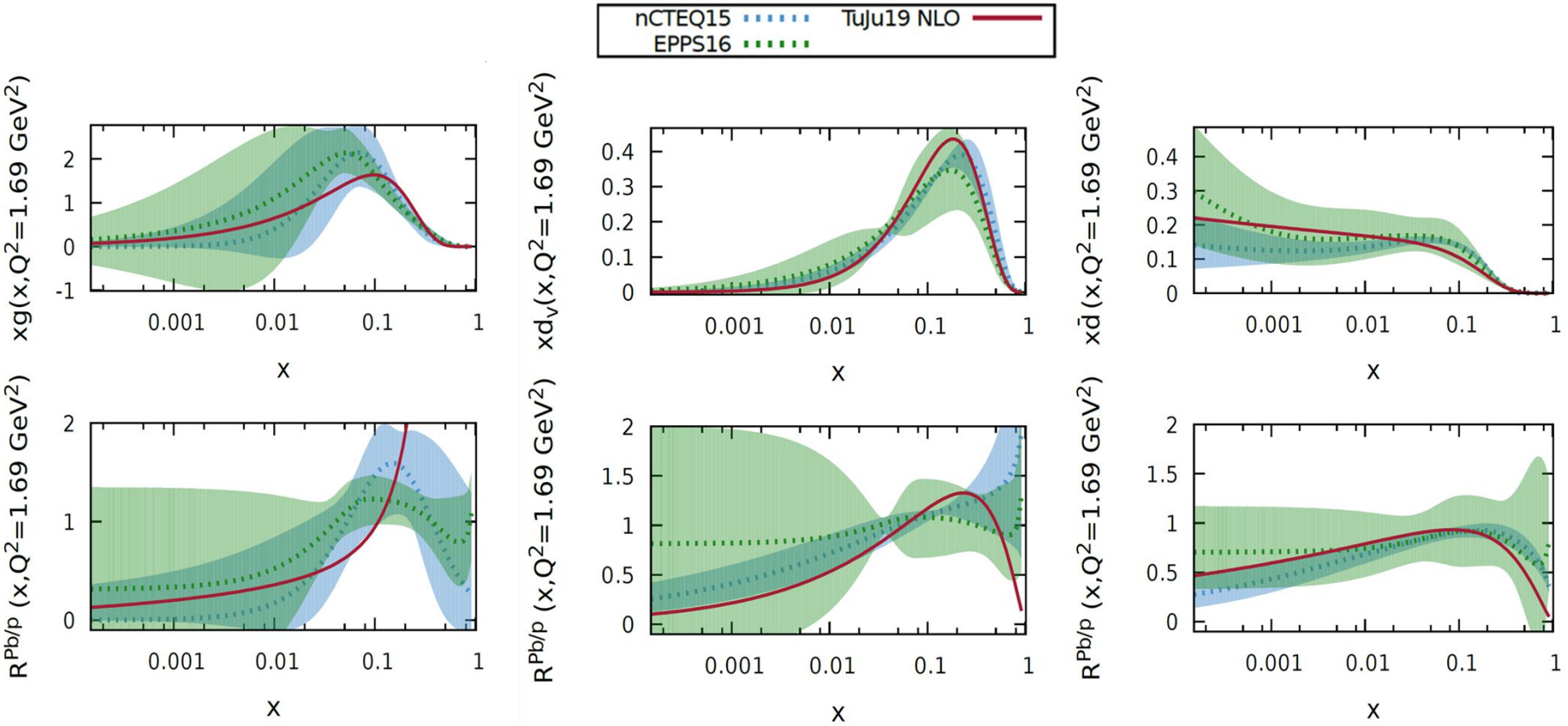
Reaction = ‚neutrino+p CC'

nPDFs Sets



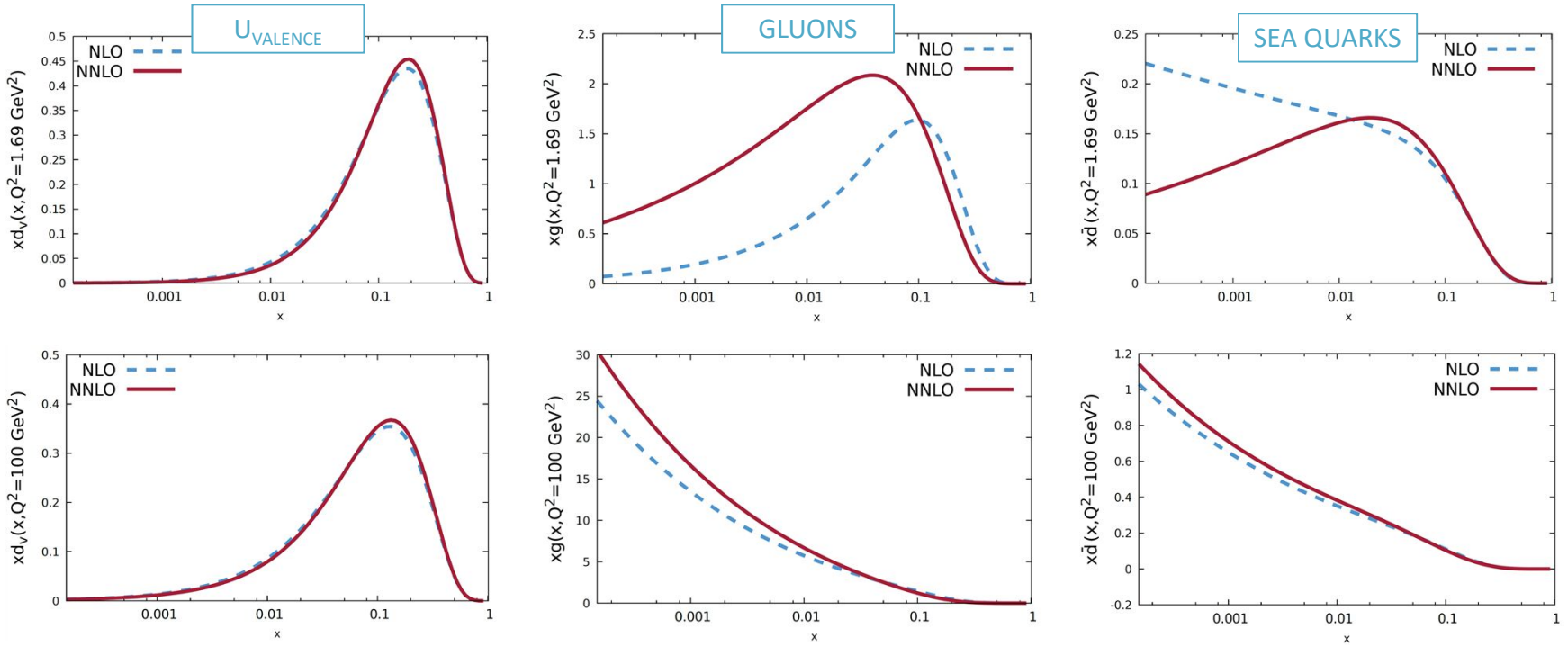
[xFitter 2.0.0: PoS DIS2017 (2018) 203]

nPDFs Sets


nCTEQ15
EPPS16
TuJu19 NLO
xg(x,Q²=1.69 GeV²)
xd_v(x,Q²=1.69 GeV²)
xd̄(x,Q²=1.69 GeV²)
R^Pb/p (x,Q²=1.69 GeV²)
R^Pb/p (x,Q²=1.69 GeV²)
R^Pb/p (x,Q²=1.69 GeV²)
x
x
x
x
x
x

NLO + NNLO Results

nPDFs for proton bound in lead Pb(208):

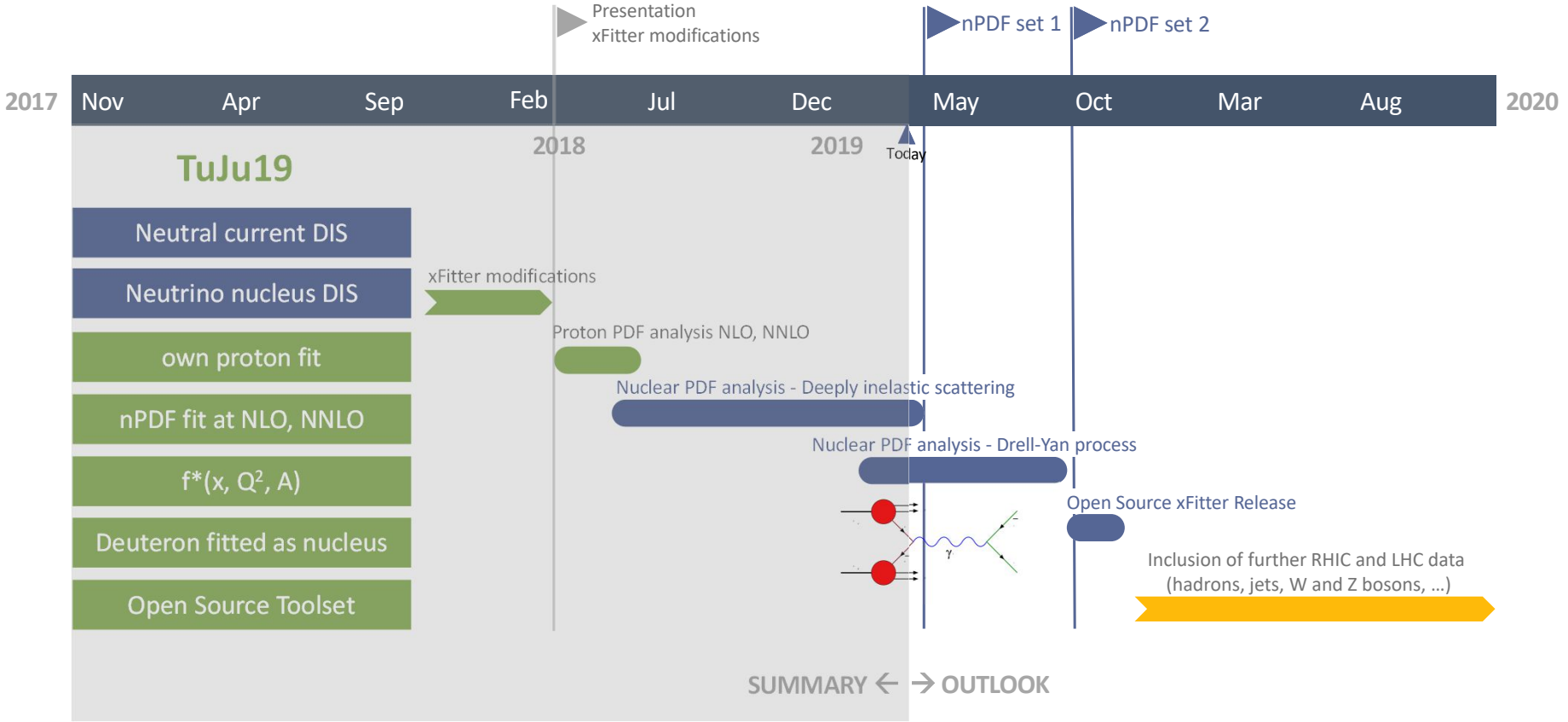


Summary & Outlook

TuJu19

- Neutral current DIS
- Neutrino nucleus DIS
- own proton fit
- nPDF fit at NLO, NNLO
- $f^*(x, Q^2, A)$
- Deuteron fitted as nucleus
- Open Source Toolset

Summary & Outlook



THANK YOU!

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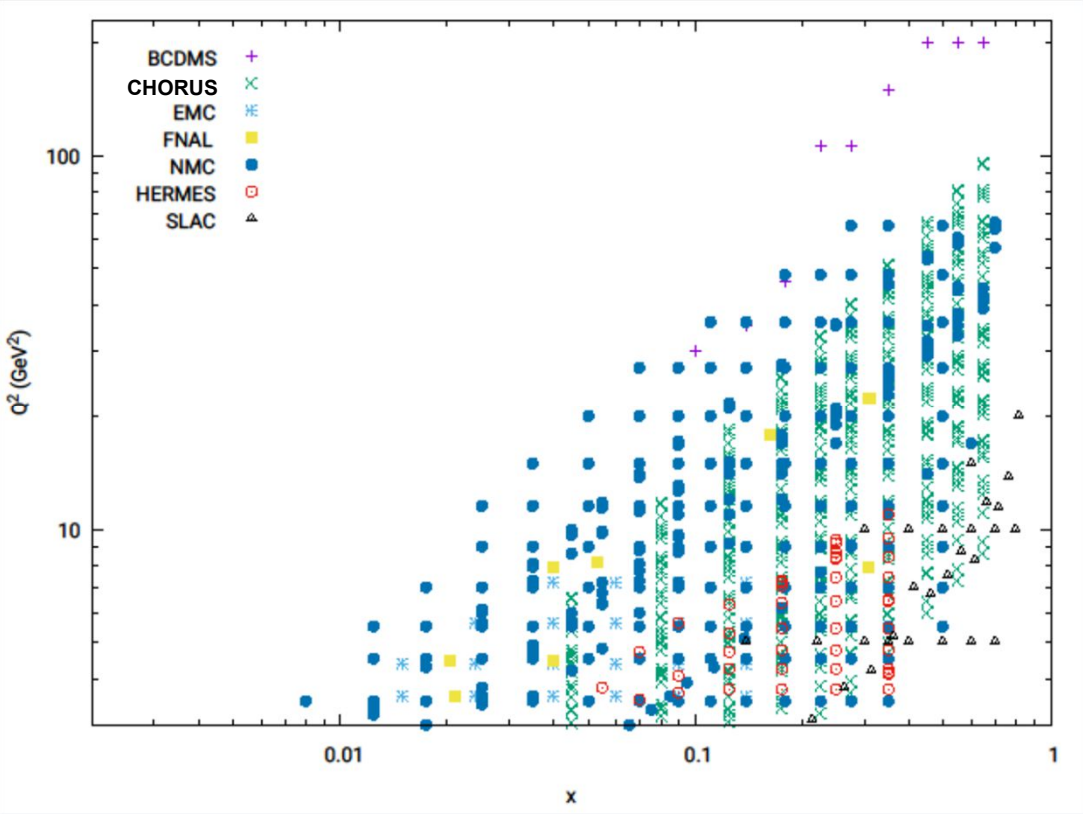
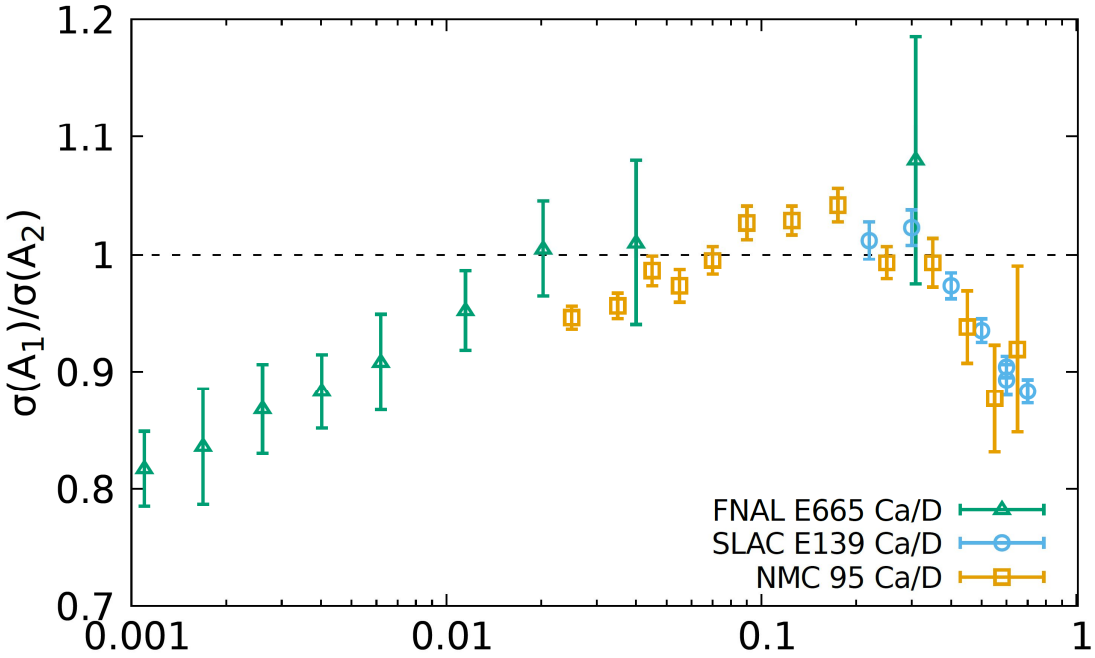
In collaboration with:
Dr. Ilkka Helenius
Prof. Dr. Werner Vogelsang

DIS Data



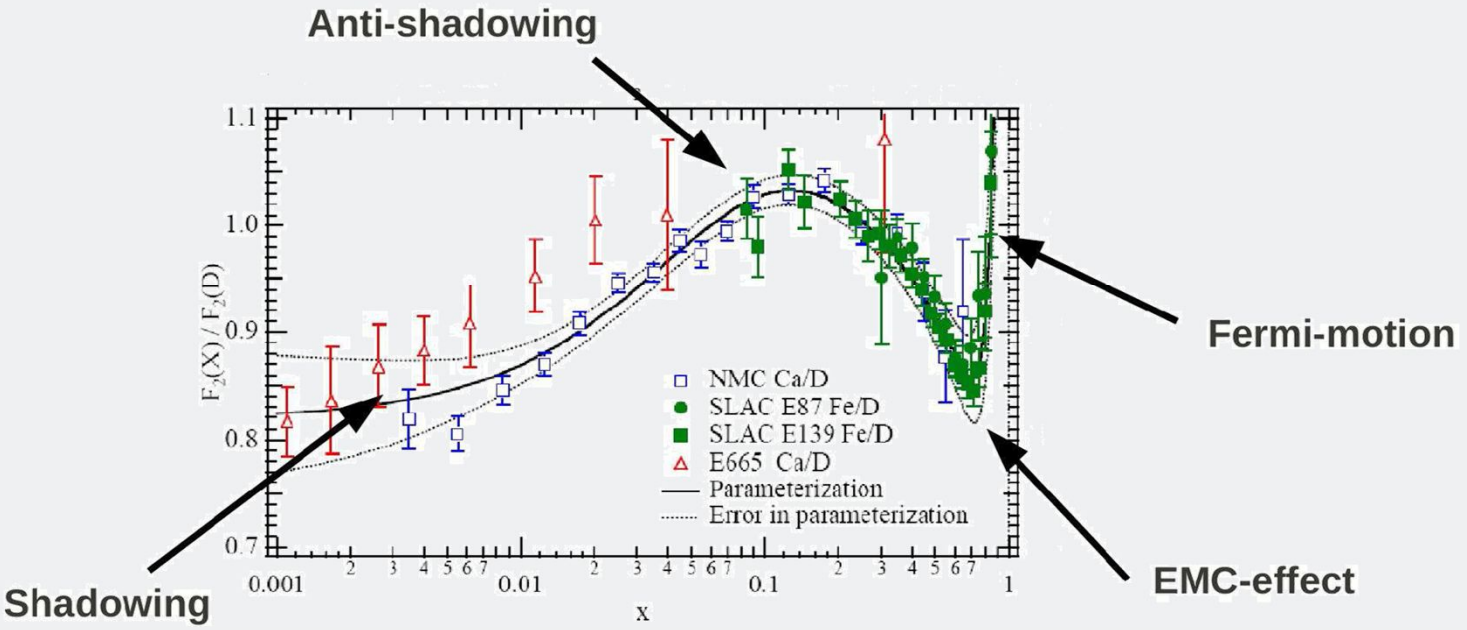
Nuclear Effects



Ratios of crosssections or structure functions:

CInfo = ‚ratio'

Nuclear Effects



[Picture: Ilkka Helenius, Hannu Paukkunen]

Isoscalar Corrections

$$\hat{F}_2^A = \beta F_2^A,$$

where

$$\beta = \frac{A}{2}\left(1 + \frac{F_2^{n,A}}{F_2^{p,A}}\right) / \left(Z + N\frac{F_2^{n,A}}{F_2^{p,A}}\right)$$

[arXiv:1612.05741v1]

– EMC parametrization :

$$\frac{F_2^n}{F_2^p} = 0.92 - 0.86x,$$

– SLAC parametrization :

$$\frac{F_2^n}{F_2^p} = 1 - 0.8x,$$

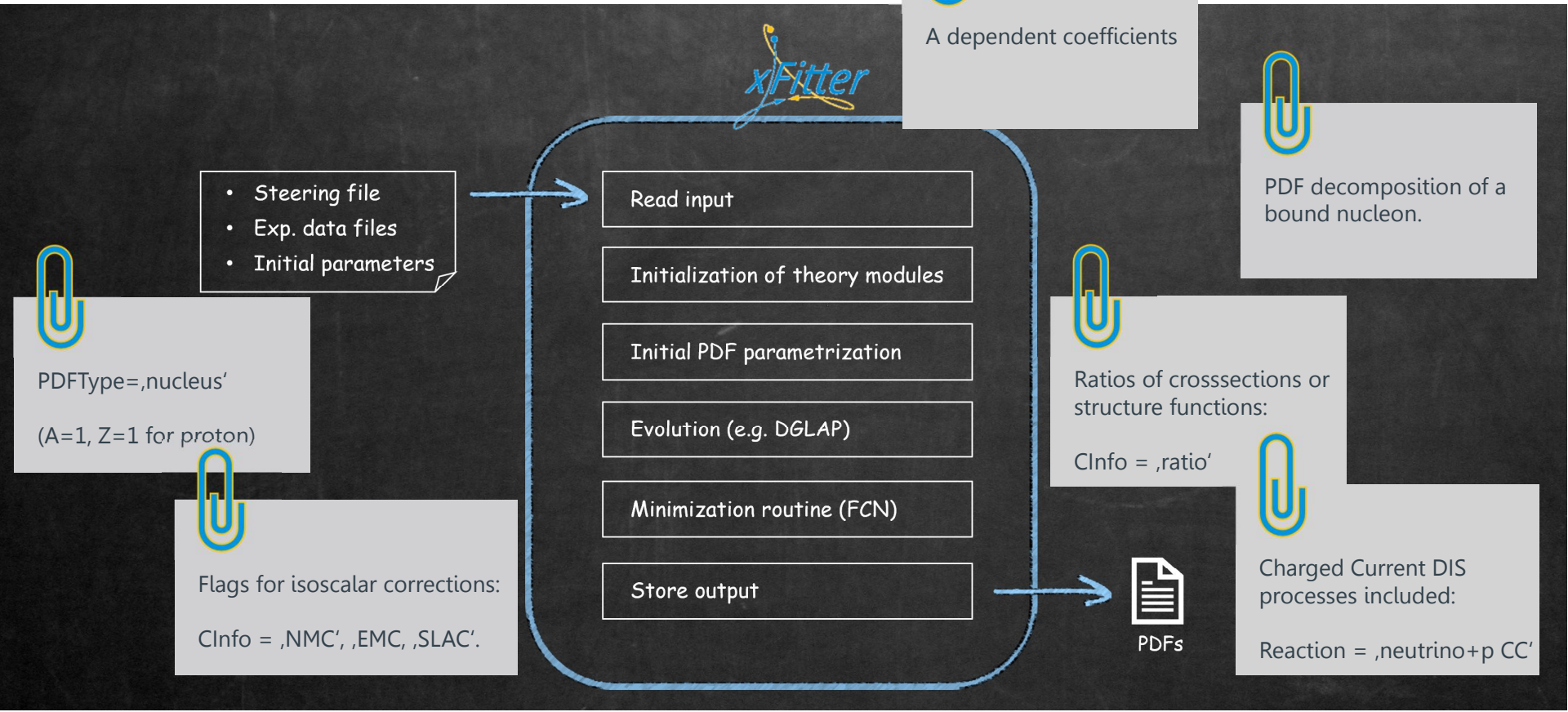
– NMC parametrization :

$$\frac{F_2^n}{F_2^p} = A(x)\left(\frac{Q^2}{20}\right)^{B(x)}\left(1 + \frac{x^2}{Q^2}\right)$$

$$A(x) = 0.979 - 1.692x + 2.797x^2 - 4.313x^3 + 3.075x^4$$

$$B(x) = -0.171x^2 + 0.244x^3.$$

THE ANALYSIS PROCEDURE



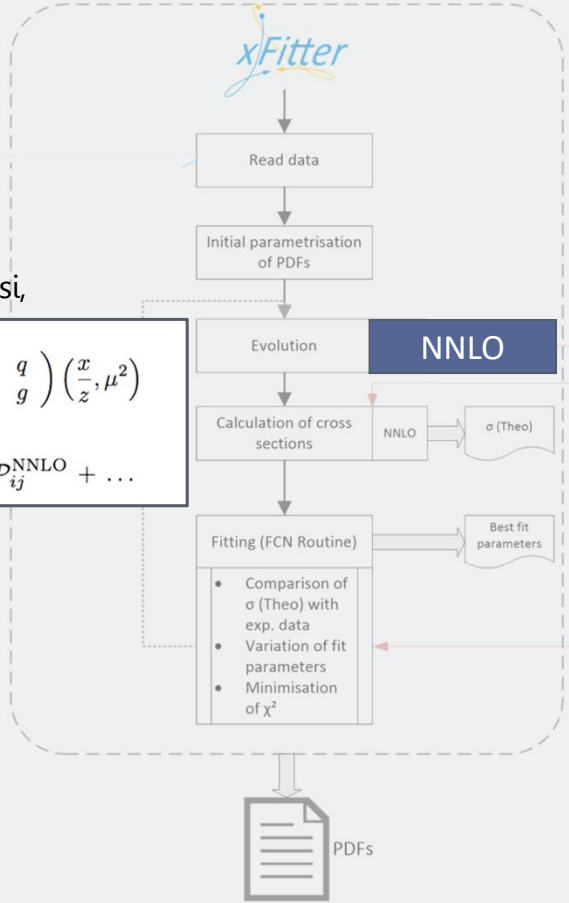
Analysis procedure at NNLO

DGLAP equations
by Dokshitzer, Gribov, Lipatov, Altarelli, Parisi,

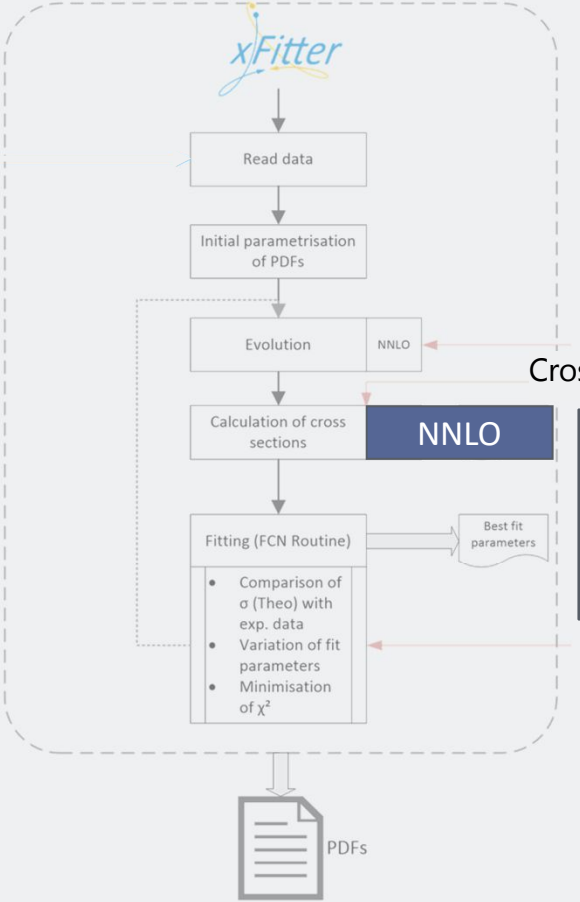
$$\mu^2 \frac{\mathrm{d}}{\mathrm{d}\mu^2} \begin{pmatrix} q(x,\mu^2) \\ g(x,\mu^2) \end{pmatrix} = \int_x^1 \frac{dz}{z} \begin{pmatrix} \mathcal{P}_{qq} & \mathcal{P}_{qg} \\ \mathcal{P}_{gq} & \mathcal{P}_{gg} \end{pmatrix} \begin{pmatrix} q \\ g \end{pmatrix} \left(\frac{x}{z}, \mu^2\right)$$

$$\mathcal{P}_{ij} = \frac{\alpha_s}{2\pi} \mathcal{P}_{ij}^{\mathrm{LO}} + \left(\frac{\alpha_s}{2\pi}\right)^2 \mathcal{P}_{ij}^{\mathrm{NLO}} + \left(\frac{\alpha_s}{2\pi}\right)^3 \mathcal{P}_{ij}^{\mathrm{NNLO}} + \ldots$$

[NNLO:
Nucl. Phys. B 688.1-2 (2004), 101-134,
Nucl. Phys. B 691.1-2 (2004), 129-181]



Analysis procedure at NNLO

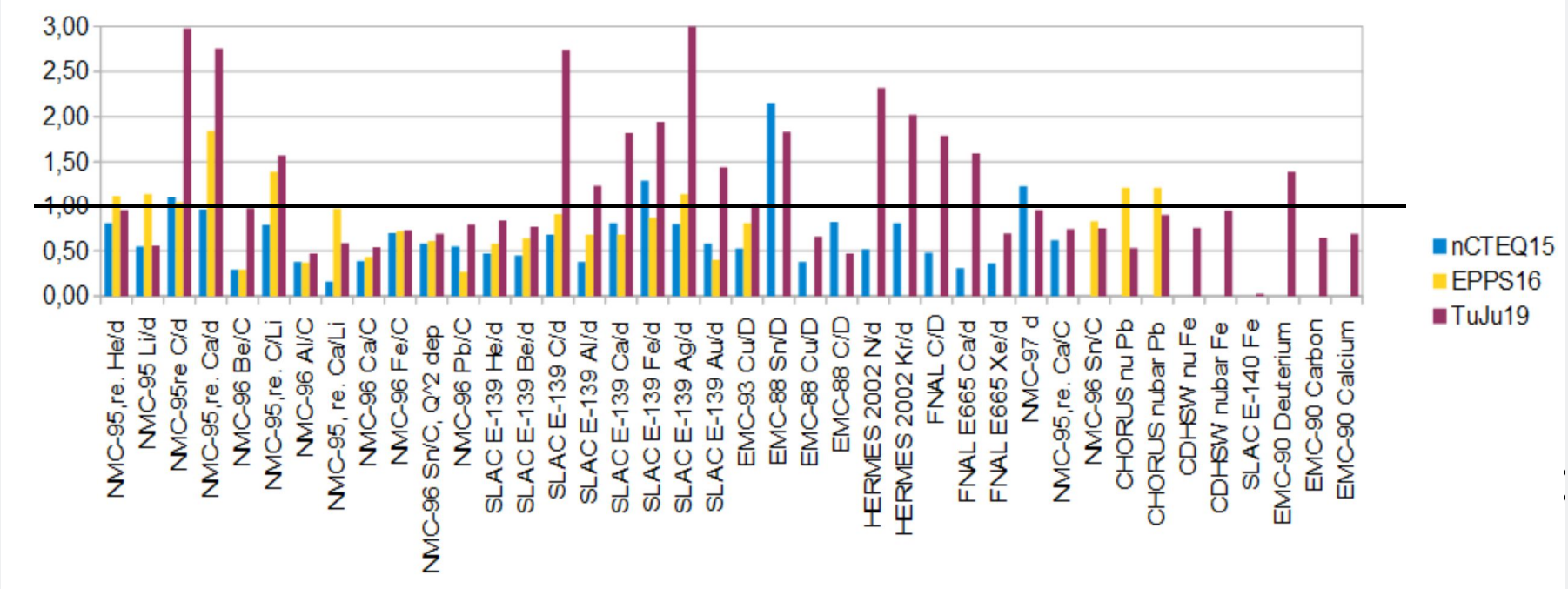


Cross sections for neutral- & charged-current DIS

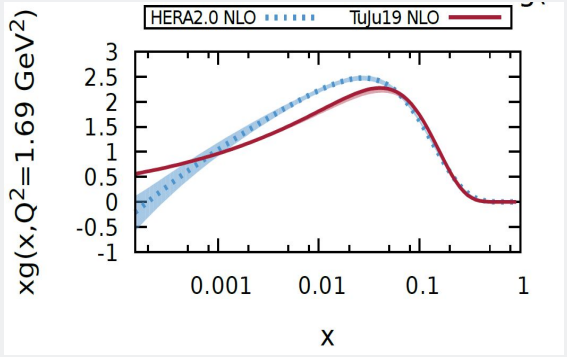
$$\frac{d^2\sigma^i}{dxdy} = \frac{4\pi\alpha^2}{xyQ^2}\,\eta^i \left\{ \left(1 - y - \frac{x^2y^2M^2}{Q^2}\right) F_2^i + y^2 x F_1^i \mp \left(y - \frac{y^2}{2}\right) x F_3^i \right\},$$

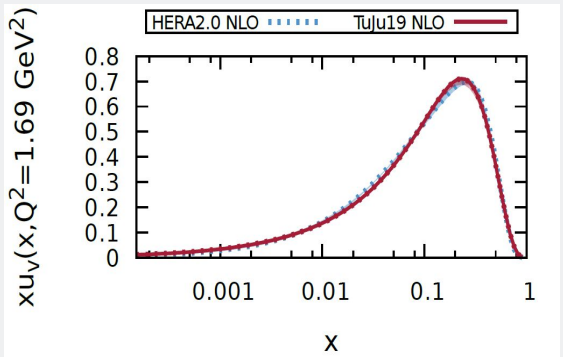
[NNLO F_2: Nucl. Phys. B 890 (2015), 48-151]

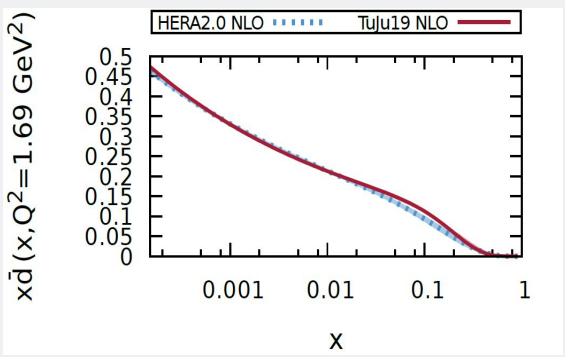
x^2/# DTPS

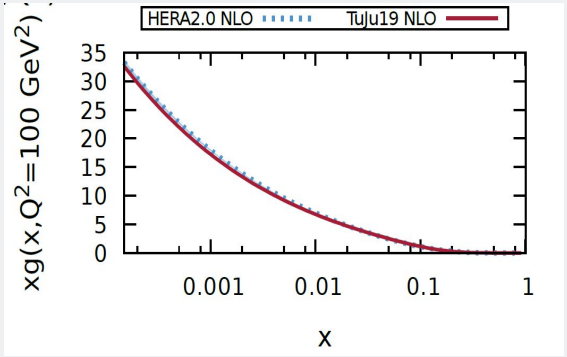

3,00
2,50
2,00
1,50
1,00
0,50
0,00
NMC-95,re. He/d
NMC-95 Li/d
NMC-95re C/d
NMC-95,re. Ca/d
NMC-96 Be/C
NMC-95,re. C/Li
NMC-96 Al/C
NMC-95, re. Ca/Li
NMC-96 Ca/C
NMC-96 Fe/C
NMC-96 Sn/C, Q^2 dep
NMC-96 Pb/C
SLAC E-139 He/d
SLAC E-139 Be/d
SLAC E-139 C/d
SLAC E-139 Al/d
SLAC E-139 Ca/d
SLAC E-139 Fe/d
SLAC E-139 Ag/d
SLAC E-139 Au/d
EMC-93 Cu/D
EMC-88 Sn/D
EMC-88 Cu/D
EMC-88 C/D
HERMES 2002 N/d
HERMES 2002 Kr/d
FNAL C/D
FNAL E665 Ca/d
FNAL E665 Xe/d
NMC-97 d
NMC-95,re. Ca/C
NMC-96 Sn/C
CHORUS nu Pb
CHORUS nubar Pb
CDHSW nu Fe
CDHSW nubar Fe
SLAC E-140 Fe
EMC-90 Deuterium
EMC-90 Carbon
EMC-90 Calcium
nCTEQ15
EPPS16
TuJu19

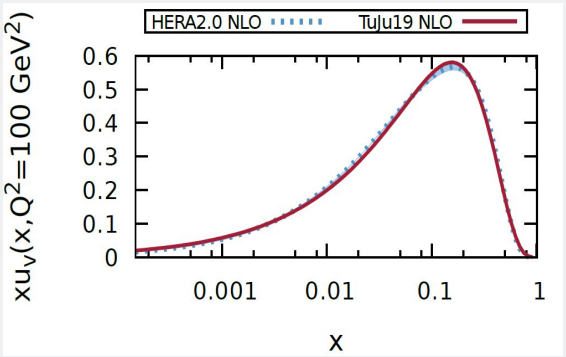
PROTON PDFS NLO

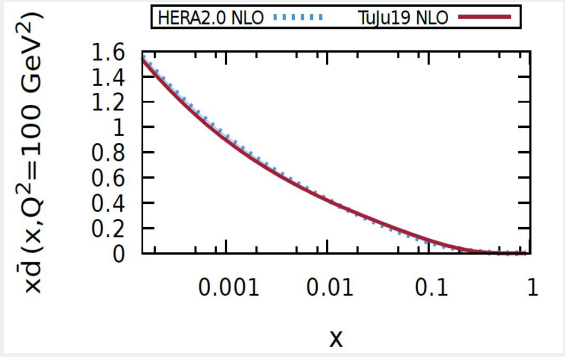












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