nCTEQ Wish List

Fred Olness w/ help from: Tim Hobbs, Aleksander Kusina, Pavel Nadolsky, Tomas Jezo, Thia Keppel, Michael Klasen, Karol Kovarik, Jorge Morfin, Ingo Schienbein, Efrain Segarra, Steve Sekula

nCTEQ
nuclear parton distribution functions

C T E Q

… how do we make sure the EIC can cover all we want/need

Synergy w/ "Inclusive Reactions" SubGroup

Low-Q:

Higher-Twist, Non-Pert, Resummation

Hi-x:

TMC, Nuclear x>1, …

Strange PDF:

Disentangle: 1) proton PDF
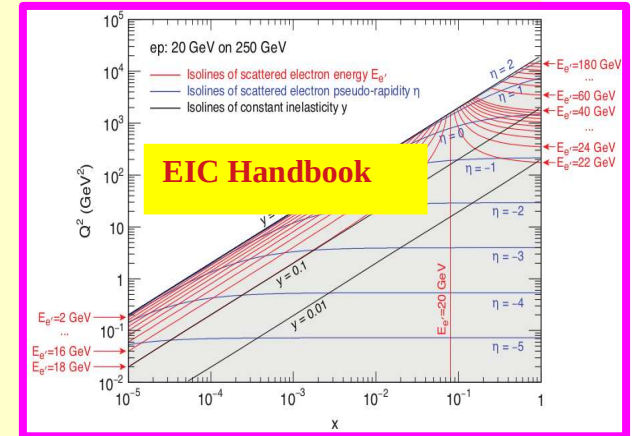
2) nuclear corrections

3) flavor components

EIC Handbook

Gluon (& Charm+Bottom):

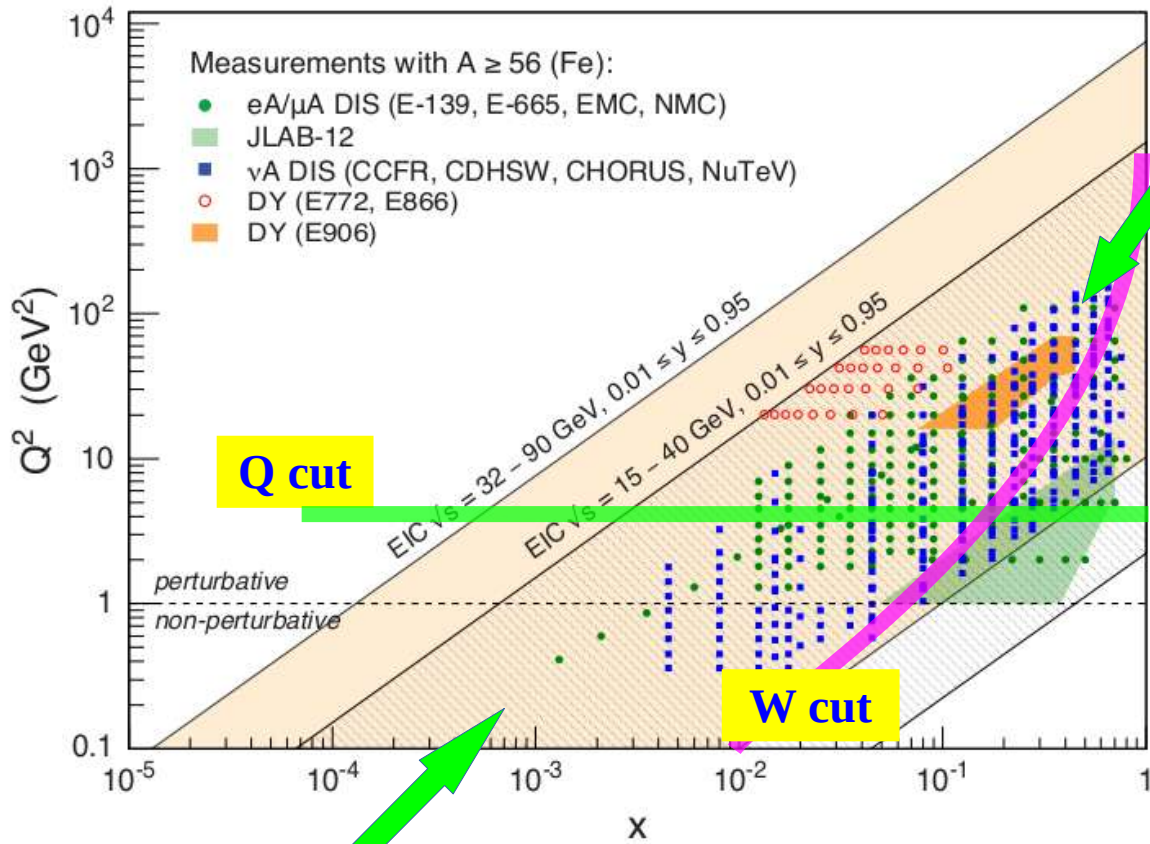Improve R_G via F_L: window on NLO and mass effects

Nuclear A:

Map out A dependence … and maybe beyond

EIC Yellow Report: Jets and Heavy Flavor Physics 20 April 2020

nPDFs: Extend Kinematic Reach in {x,Q²}

Measurements with A ≥ 56 (Fe):
- eA/μA DIS (E-139, E-665, EMC, NMC)
- JLAB-12
- νA DIS (CCFR, CDHSW, CHORUS, NuTeV)
- DY (E772, E866)
- DY (E906)

EIC √s = 32 − 90 GeV, 0.01 ≤ y ≤ 0.95
EIC √s = 15 − 40 GeV, 0.01 ≤ y ≤ 0.95

Q cut

W cut

perturbative
non-perturbative

High-x:

Nuclear PDFs: x>1 allowed;
impacts F_2^{Nuc}/F_2^{Iso} in Fermi region

Target Mass Corrections
pick up M^2/Q^2 higher twist

Deuteron Corrections
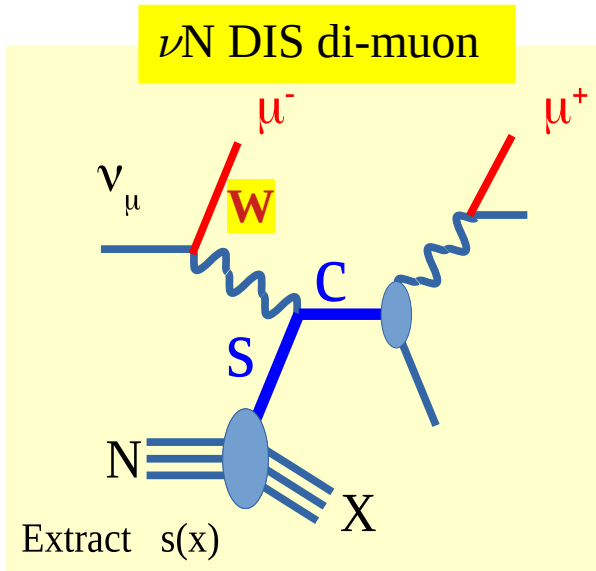impacts $F_2^{Nuc}/F_2^{Deuteron}$ ratio

Low-Q²:

Non-Perturbative inteface
collective effects

Target Mass Corrections
pick up M^2/Q^2 higher twist

F_L at low Q^2 access to g(x)
Run at multiple energies

Warm-up:

JLab Data @ Hi-X Low-Q²
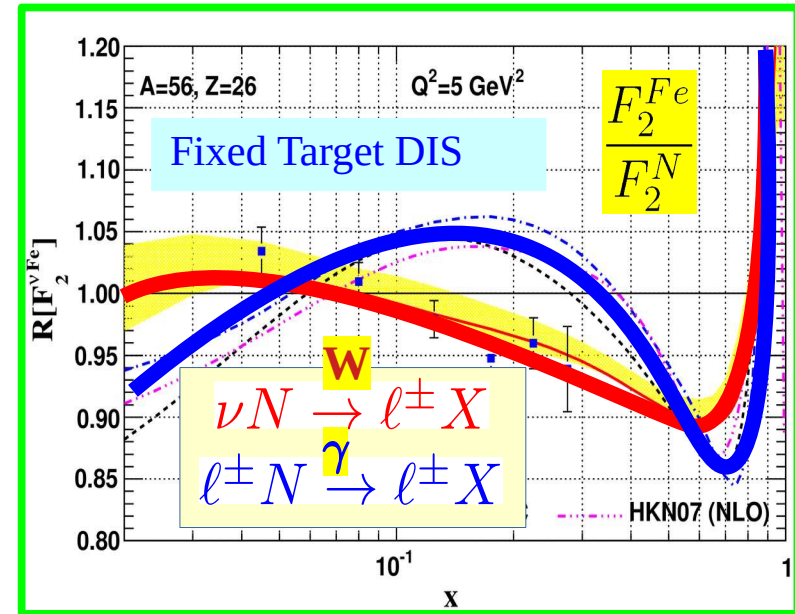
extend nCTEQ framework for this region
& prepare for EIC
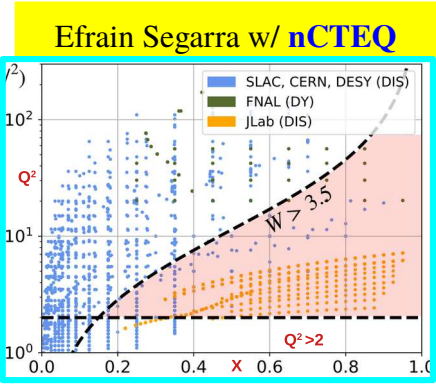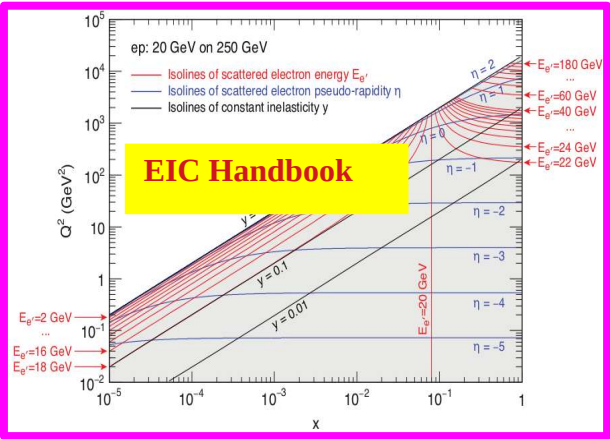
EIC Handbook

ep: 20 GeV on 250 GeV
- Isolines of scattered electron energy $E_{e'}$
- Isolines of scattered electron pseudo-rapidity η
- Isolines of constant inelasticity y

Efrain Segarra w/ nCTEQ

- SLAC, CERN, DESY (DIS)
- FNAL (DY)
- JLab (DIS)

W > 3.5
Q^2 >2

Fixed Target

νN DIS di-muon

μ^- μ^+

ν_μ

W

C

S

N

X

Extract s(x)

propagation through nuclear medium

Fixed Target DIS

A=56, Z=26 Q^2=5 GeV^2

$\dfrac{F_2^{Fe}}{F_2^N}$

$R[F_2^{\nu Fe}]$

W

$\nu N \rightarrow \ell^\pm X$

γ

$\ell^\pm N \rightarrow \ell^\pm X$

HKN07 (NLO)

x

LHC

Large s(x) preferred ...
similar in heavy ion p-Pb

$R_s = \dfrac{s + \bar{s}}{\bar{u} + \bar{d}}$

Q^2 = 1.9 GeV^2, x=0.023   **ATLAS**

▲ ABM12
■ NNPDF3.0
● MMHT14
▼ CT14
□ ATLAS-epWZ12

ATLAS-epWZ16
  exp uncertainty
  exp+mod+par uncertainty
  exp+mod+par+thy uncertainty

0   0.2   0.4   0.6   0.8   1   1.2   1.4
R_s
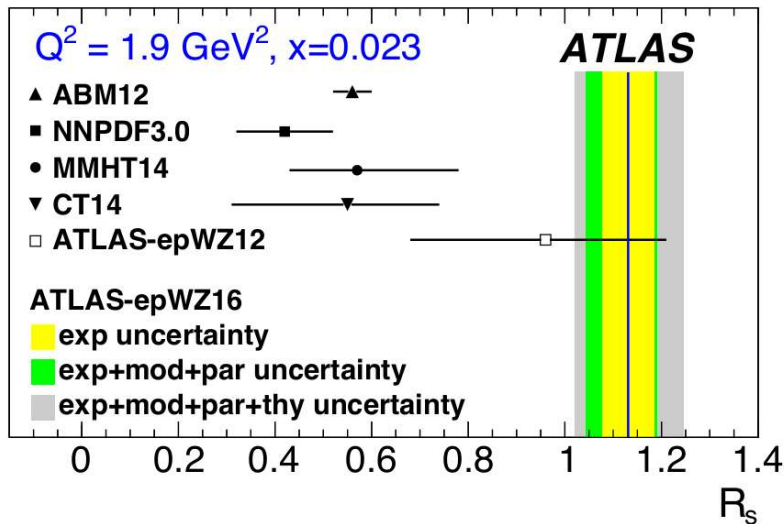
*also see Cooper-Sarkar & Wichmann.
PRD98 (2018) 014027*

○○○○ 2 flavours   ▲▲▲▲ 5 flavours

nCTEQ15   CT10+EPS   data
CTEQ6.1+EPS   CT10

W$^+$

W/Z Benchmark measurement

Impact base PDFs

Impact of Nuclei

$\sigma(pPb \rightarrow W^+ \rightarrow \ell^+ \nu)$ [nb]

well defined nuclear correction

5 flavor

2 flavor

*LHC pPb
W/Z production*

Impact of {s,c,b} PDF

W$^-$

$\sigma(pPb \rightarrow W^- \rightarrow \ell^- \bar{\nu})$ [nb]
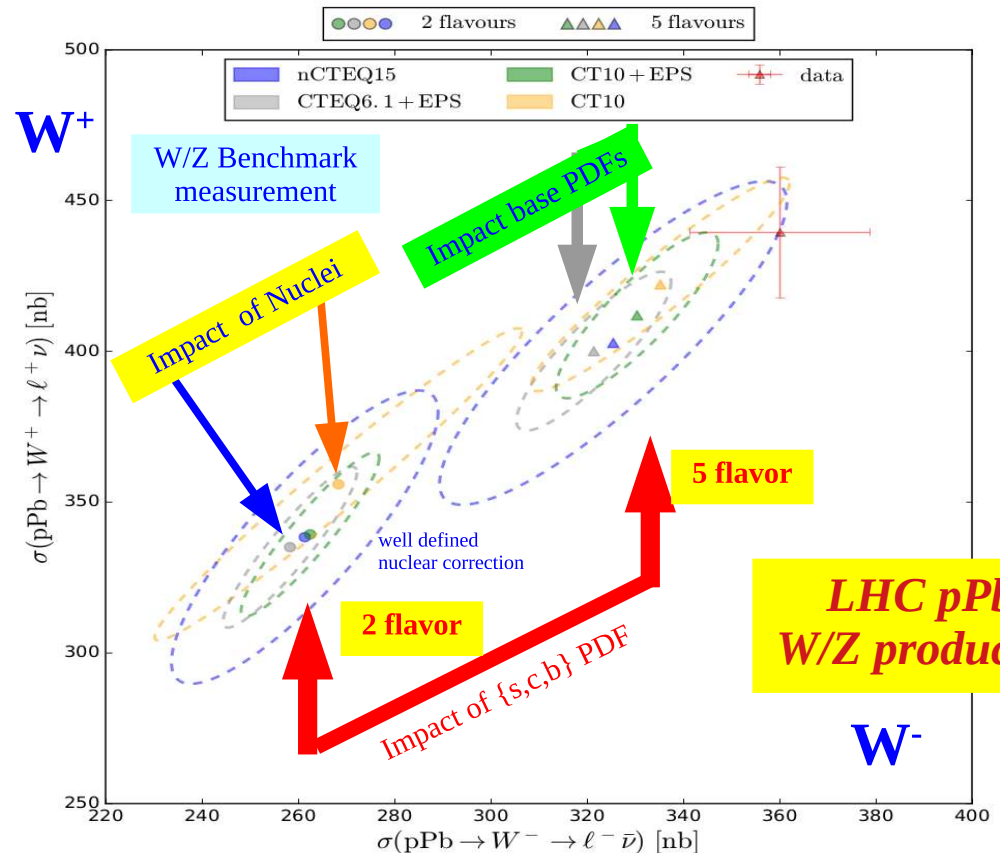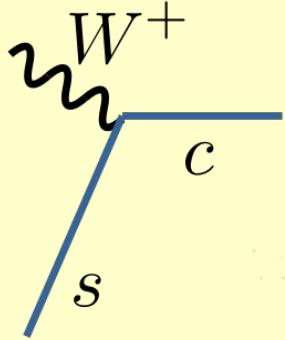
PDFSense: Visualizing sensitivity of hadronic experiments to the nucleon structure

Phys.Rev.D 98 (2018) 9, 094030 arXiv:1803.02777

Sensitivity: Combination of the PDF correlation (~C) and the scaled residual ~(D-T)/σ
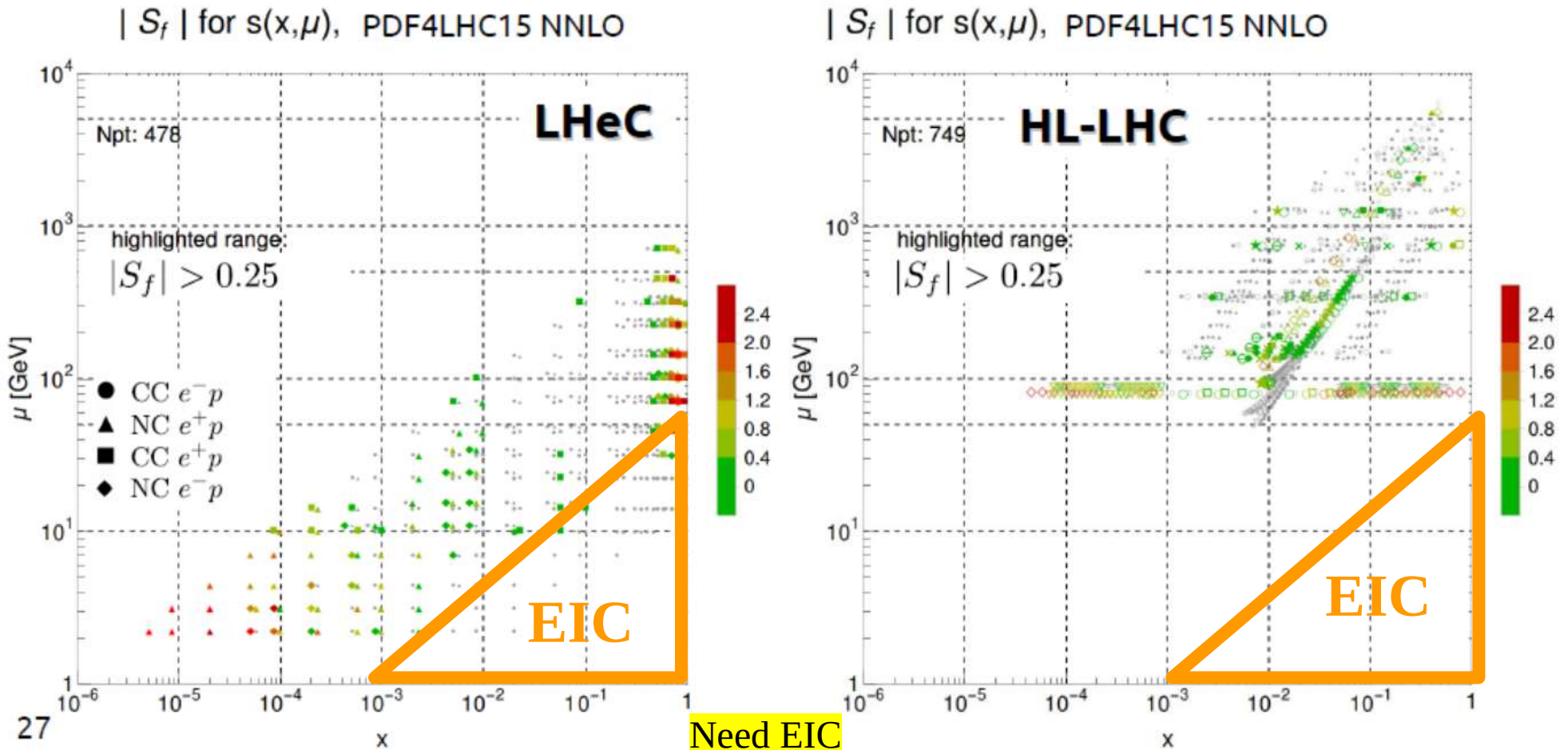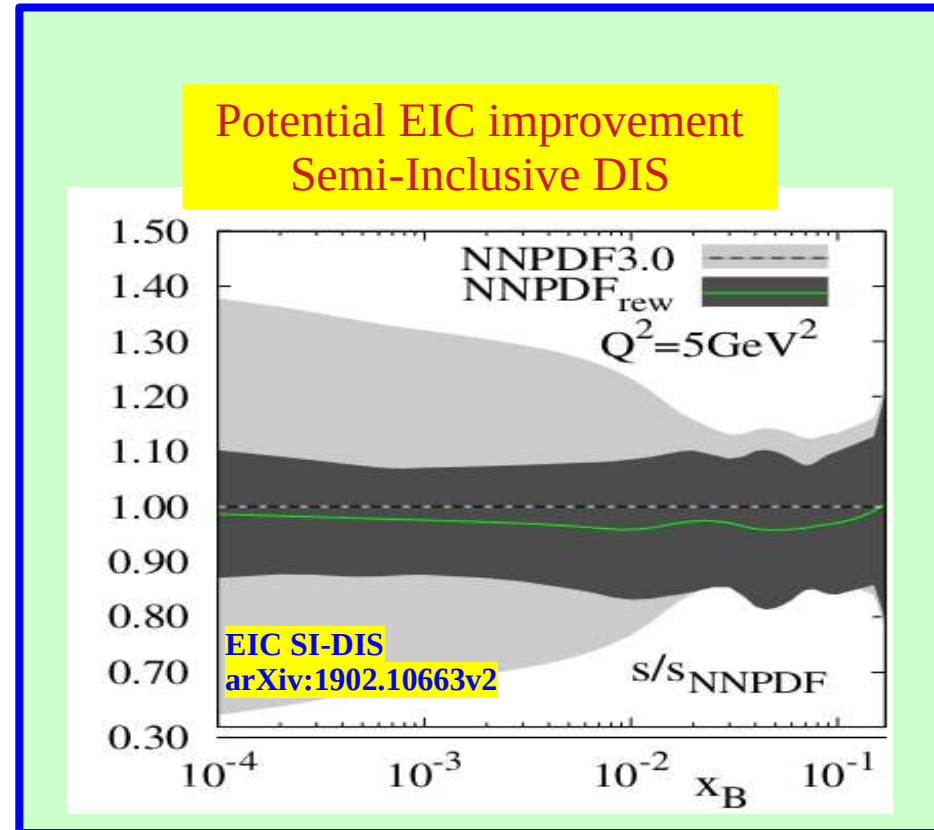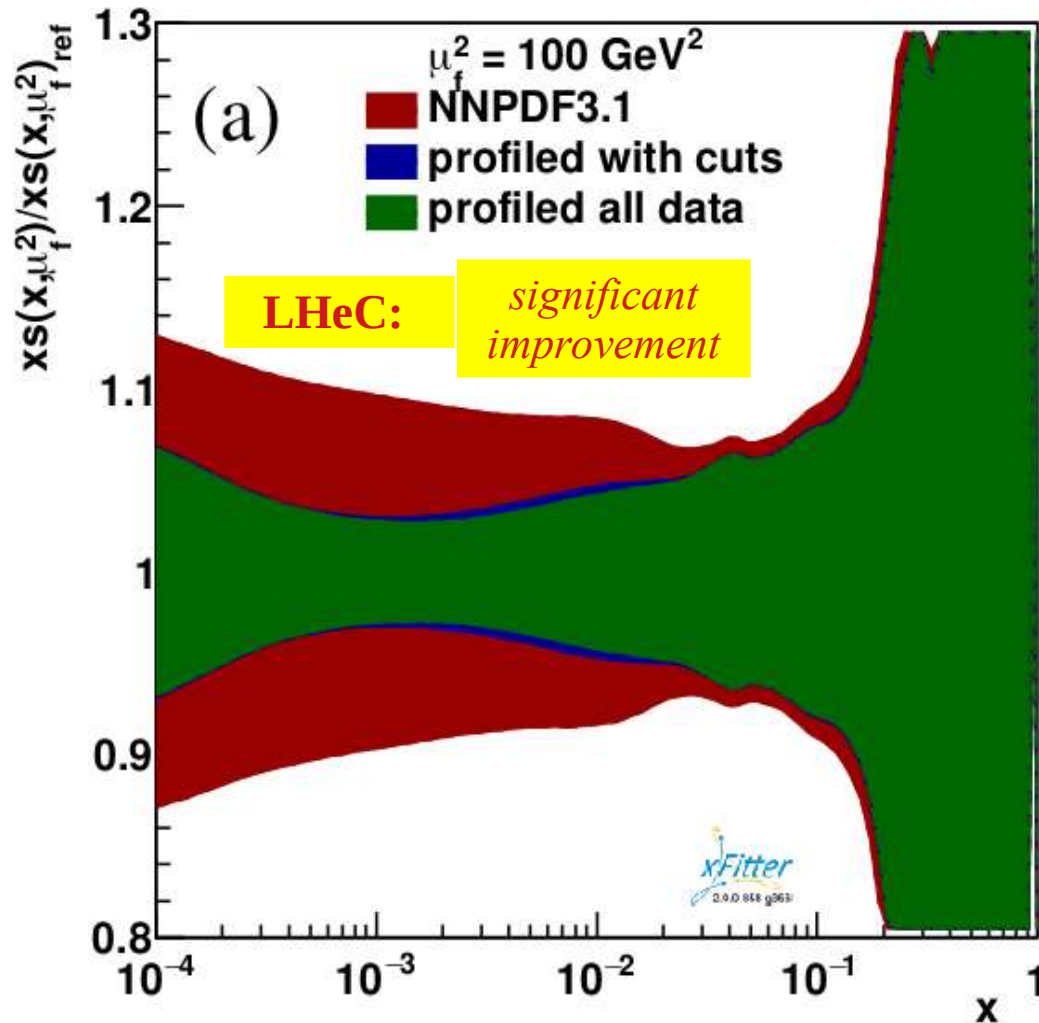

Need EIC pseudo-data

W^+

c

s

Probing the strange content of the proton with charm production in charged current at LHeC

xFITTER Developers' team: Hamed Abdolmaleki[1], Valerio Bertone[2], Daniel Britzger[3], Stefano Camarda[4], Amanda Cooper-Sarkar[5], Achim Geiser[6], Francesco Giuli[7], Alexander Glazov[6], Agnieszka Luszczak[8], Ivan Novikov[9], Fred Olness[10], Andrey Sapronov[9], Oleksandr Zenaiev[11]
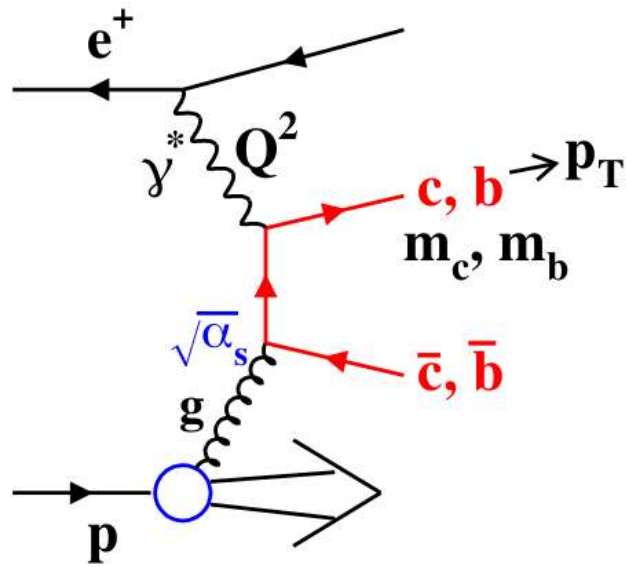
xFitter Developers' Team;
arXiv:1907.01014 [hep-ph]

xFitter:
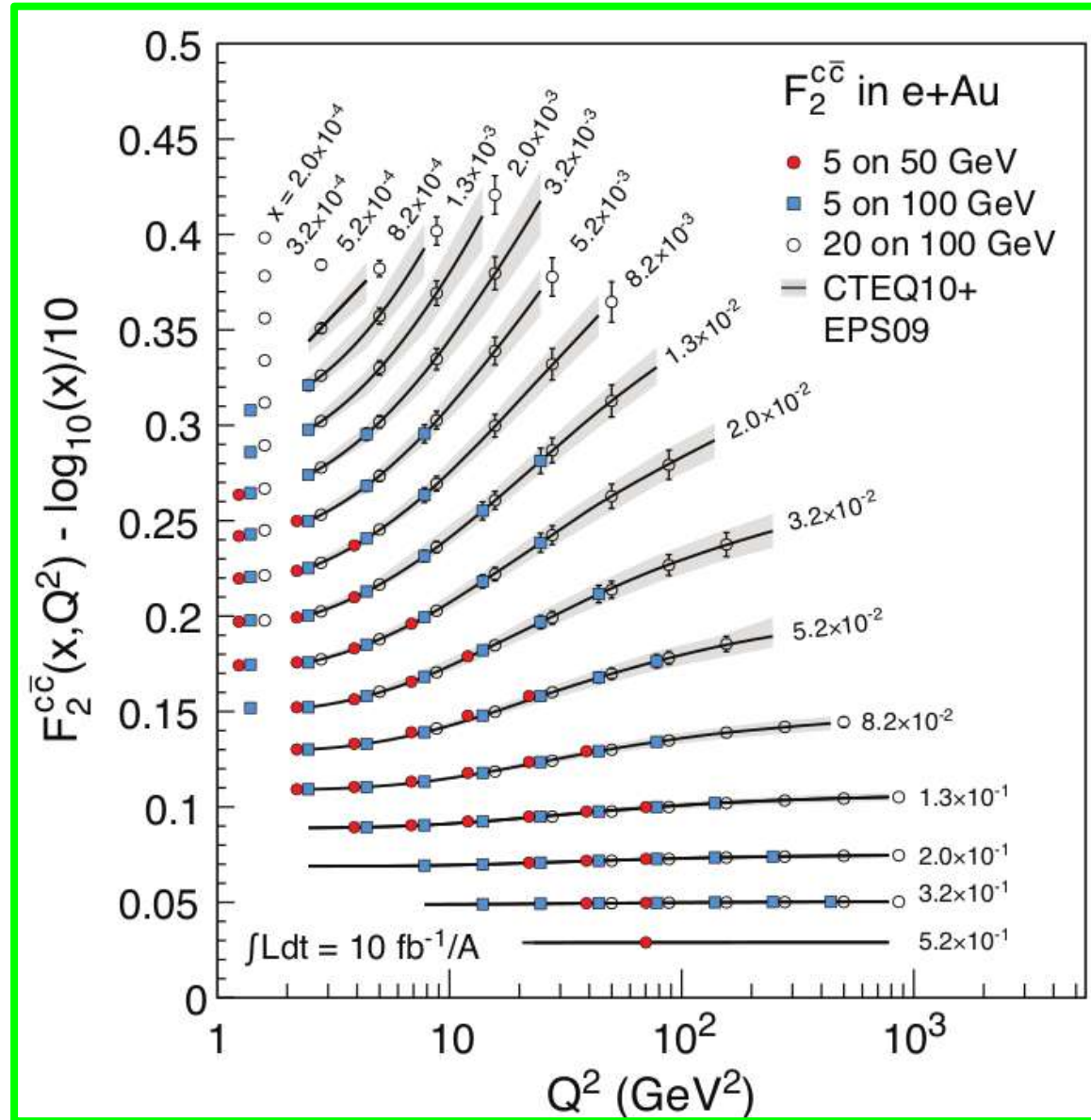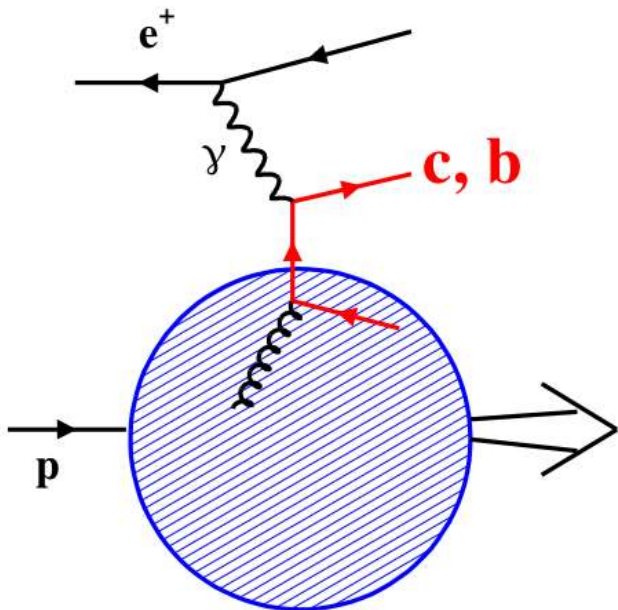Docker & Singularity
images available
details in extra slides

$\mu_f^2 = 100$ GeV^2
NNPDF3.1
profiled with cuts
profiled all data

(a)

LHeC: *significant improvement*

Potential EIC improvement
Semi-Inclusive DIS

NNPDF3.0
NNPDF$_{rew}$

$Q^2 = 5$ GeV^2

EIC SI-DIS
arXiv:1902.10663v2

s/s_{NNPDF}

… how can we nail this!
would also elucidate LHC issues

R.A. Khalek, S. Bailey, J.Gao, L. Harland-Lang, J. Rojo, arXiv:1906.10127 [hep-ph] *w/ additional channels*

Fixed Flavor Number Scheme (FFNS)

Variable Flavor Number Scheme (VFNS)

xFitter implements a unification of these two

Multi-Scale problem: Q, $m_{c,b}$

… and J/Psi, D, production ...

Tim Hobbs et al., PRD**89**, 074008 (2014).

$F_2^{c\bar{c}}$

- $\langle x \rangle = 0.0035$
- $\langle x \rangle = 0.001$
- extrinsic

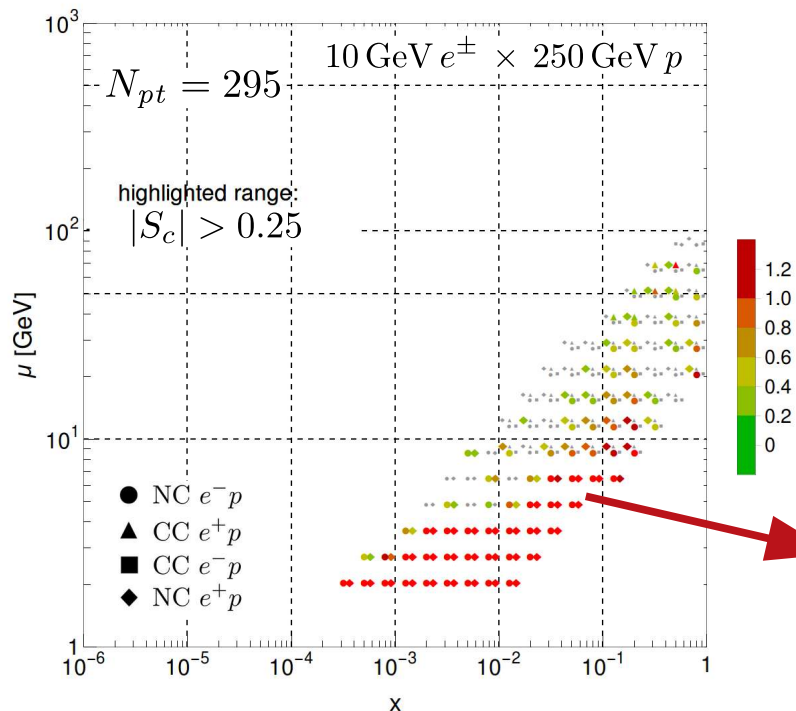NLO DGLAP

$Q^2 = 20$ GeV^2

x

An EIC can finally resolve the **NP nucleon charm** question

- various models predict a nonpertubative (intrinsic) component to the nucleon structure function, but the normalization is small and undetermined

$$\langle x \rangle_{\rm IC} = \int_0^1 dx \, x \, [c + \bar{c}](x, m_c^2)$$

$$\lesssim 1 - 2\%$$

- the presence of a NP charm component has consequences for **heavy quark schemes**, **masses**, and global analyses

$| S_f |$ for c(x,μ), CT14 HERA2 NNLO

$N_{pt} = 295$

$10 \, {\rm GeV} \, e^{\pm} \times 250 \, {\rm GeV} \, p$

highlighted range:
$|S_c| > 0.25$

- NC $e^- p$
- CC $e^+ p$
- CC $e^- p$
- NC $e^+ p$

μ [GeV]

x
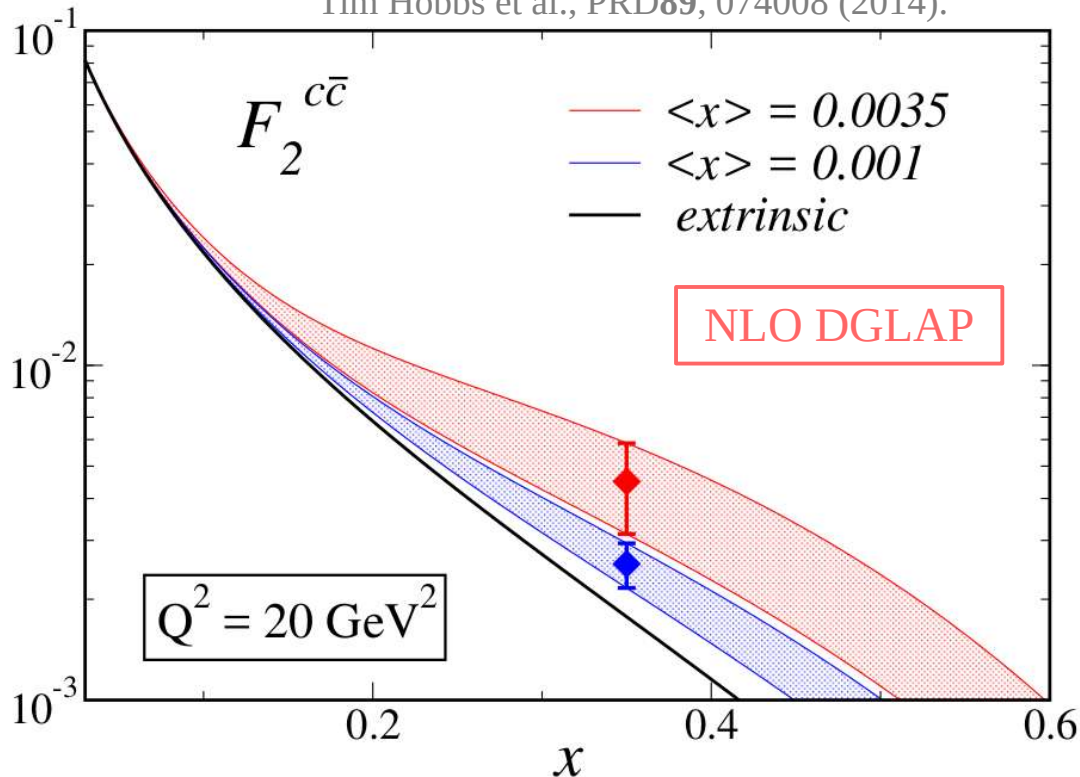
J-EIC pseudo-data
Yulia Furletova

an EIC will measure very precisely in the ~few GeV, high x region in which typical NP charm signals are to be expected, à la EMC
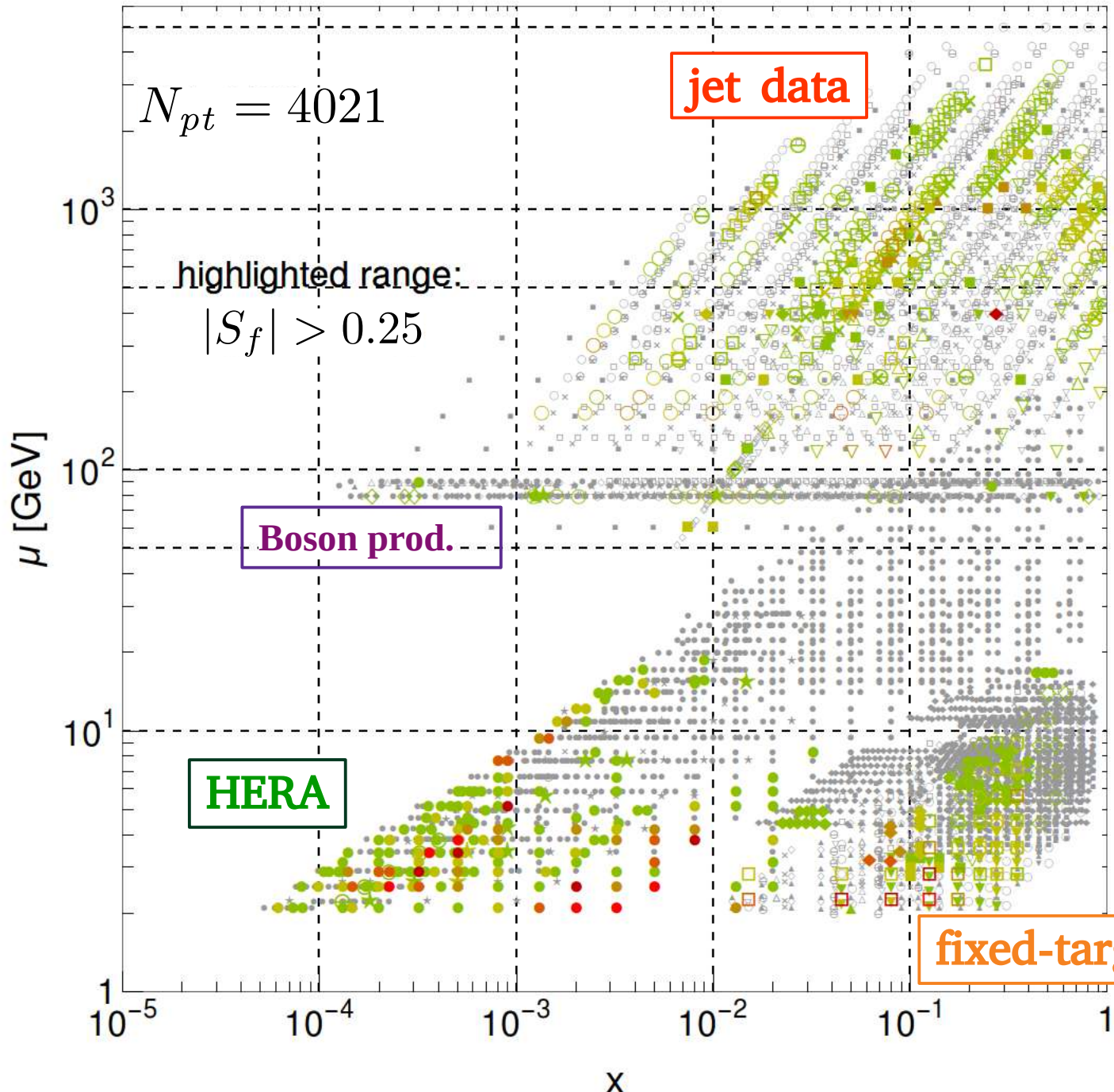

Tim Hobbs

$|S_f|$ for $g(x,\mu)$, CT14 HERA2 NNLO

II) visualizing impacts with `PDFSense`

Phys.Rev. D98 (2018) 094030

$N_{pt} = 4021$

highlighted range:

$|S_f| > 0.25$

jet data

Boson prod.

HERA

fixed-target

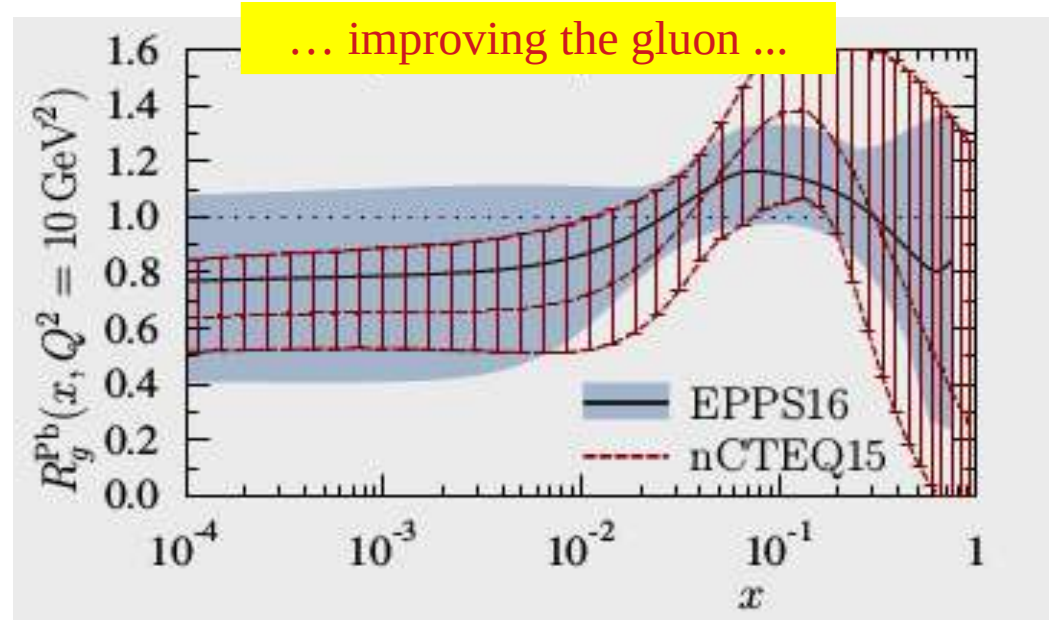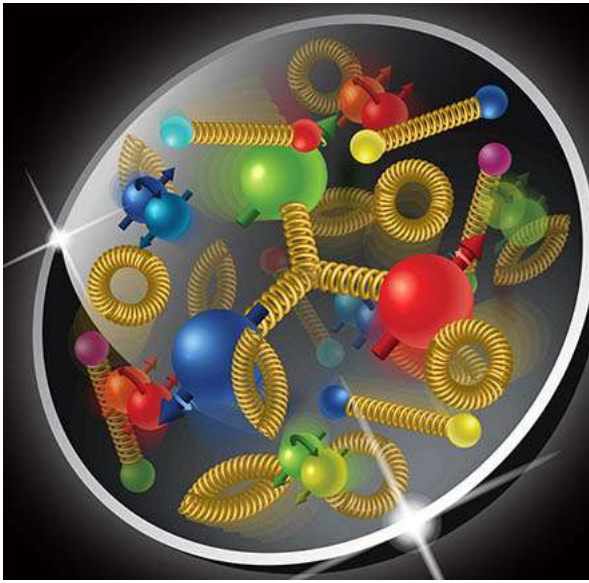the PDF *sensitivity*

$|S_f|$

1.2
1.0
0.8
0.6
0.4
0.2
0

(magnitude of PDF pull of each datum)

→ measurements with strong PDF correlations <u>AND</u> high precision have high $|S_f|$

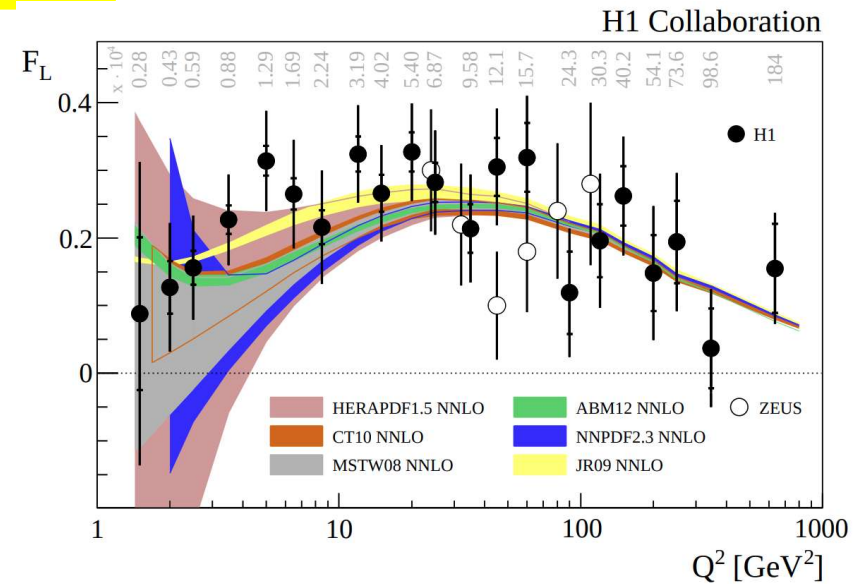▪ used to identify high-impact data for CT18

F_L: Might require multiple energy run

… improving the gluon …

EPPS16
nCTEQ15

$$F_L \sim \frac{m^2}{Q^2}\, q(x) + \alpha_S \{ c_g \otimes g(x) + c_q \otimes q(x) \}$$

F_L sensitive to NLO terms (gluon)
& helicity violating terms (masses)

HERA used low energy run
to explore low-Q region

… *other handles on g(x)*
Heavy Quark Production: g→ cc

H1 Collaboration

HERAPDF1.5 NNLO   ABM12 NNLO   ○ ZEUS
CT10 NNLO   NNPDF2.3 NNLO
MSTW08 NNLO   JR09 NNLO

key to understanding strong interactions

Fred Olness w/ help from: Tim Hobbs, Aleksander Kusina Pavel Nadolsky, Tomas Jezo, Thia Keppel, Michael Klasen, Karol Kovarik, Jorge Morfin, Ingo Schienbein, Efrain Segarra, Steve Sekula

nCTEQ
nuclear parton distribution functions

C T E Q

… how do we make sure the EIC can cover all we want/need

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"Inclusive Reactions
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Hi-x:

TMC, Nuclear x>1, …

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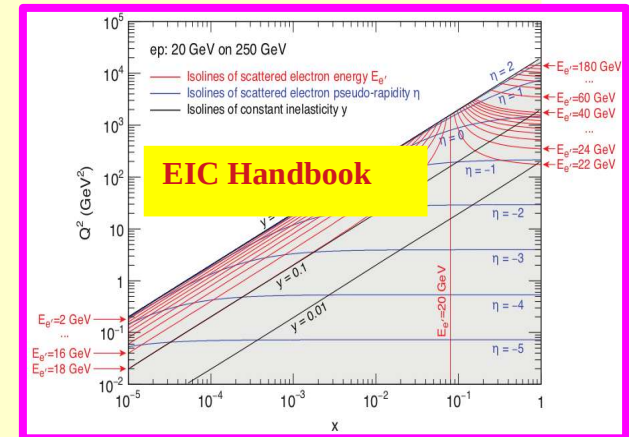
2) nuclear corrections

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Gluon (& Charm+Bottom):

Improve R_G via F_L: window on NLO and mass effects

Nuclear A:

Map out A dependence … and maybe beyond

EIC Handbook

EIC Yellow Report:
Jets and Heavy
Flavor Physics
20 April 2020

Instructions for xFitter Docker & Singularity Images

UPDATE:
xFitter in
Docker & Singularity
notes

Fred Olness
22 April 2020

JBrandonS / **xfitter-docker**

<> Code ⊙ Issues 0 ⌥ Pull requests 0 ⊙ Actions ⊞ Projects 0 ⊞ Wiki ⊙ Security ⊞ Insights

A WIP docker container featuring xFitter

○ 14 commits | ⌥ 1 branch | ⊡ 0 packages | ◇ 0 releases | ⊥ 1 contributor | ⚖ GPL-3.0

Branch: master ▾ | New pull request | | Create new file | Upload files | Find file | Clone or download ▾

JBrandonS Updated README.md | ✓ Latest commit b1o3aaf 10 hours ago

.gitignore	Added run dir for steering files. Updated Readme. Fixed issues with S…	5 days ago
Dockerfile	Handling PDF data correctly. Updated readme.	4 days ago
LICENSE	Initial commit	7 days ago
README.md	Updated README.md	10 hours ago
docker-entrypoint.sh	Handling PDF data correctly. Updated readme.	4 days ago
install-xfitter-master	Initial commit	7 days ago

⊞ README.md

xFitter-Docker

xFitter-Docker is a docker container featuring the latest version of xFitter, from the master branch for the main repo, and as well as many standard HEP software packages needed for processing.
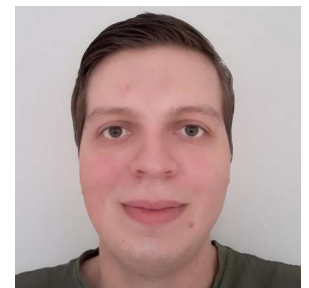
This allows for easy use of an up-to-date xFitter across all systems and configurations.

Installation

Prebuilt images for this project are available in docker-hub under jbrandons/xfitter. You can pull this project from any internet connected PC with

Brandon
Stevenson

Lucas
Kotz

DOCKER

```
docker pull jbrandons/xfitter
```

```
docker run -it -u $(id -u ${USER}):$(id -g ${USER})  -v $(pwd):/run
    -v /users/olness/xfit/DATA/datafiles:/data
    -v /usr/local/share/LHAPDF:/pdfdata   jbrandons/xfitter bash
```

xfitter and **xfitter-draw** are installed in the path, so a plain "**xfitter**" command should run the test.
The `-u $(id -u ${USER}):$(id -g ${USER})` command mounts as the user instead of root.
The `-v $(pwd):/run` command mounts the current directory as **/run**; this is the working
directory.
The `-v /users/olness/xfit/DATA/datafiles:/data` command mounts your local set of
data files. The `-v /usr/local/share/LHAPDF:/pdfdata` command mounts your local set of
lhapdf files.
        (This keeps the docker image lightweight)
The `bash` command drops to a bash shell.

In the above example, the **pwd** is mounted at **/run**, so if you place
" `constants.yaml    parameters.yaml    steering.txt` "
locally, you can then run the xfitter example.

SINGULARITY

```
singularity run -B $(pwd)/datafiles:/data
     -B $(pwd)/lhafiles:/pdffiles   -B $(pwd):/run
     docker://jbrandons/xfitter bash
```

* user runs as **non-root**

* **image is mounted read-only** *(not a problem)*

SETUP: In your working dir $(pwd) make 2 symlinks:
   1) Symlink **./datafiles** to your local xFitter data file
   2) Symlink **./lhafiles** to your local LHAPDF data files

Your **$pwd** will be mounted to **/run** so you have local access to output
Launch singularity; you'll drop into a bash shell.
**xfitter** and **xfitter-draw** are in your image path.

In your local working directory, you will need: `constants.yaml parameters.yaml steering.txt`

Leftovers

Heavy Flavor

Physics goals + channel	Workforce + overlaps	Money plots	Bonus plots	Detector requirements
Charm and bottom content of nucleons and nuclei Heavy-flavor tagged jet cross section	Vitev, Furletova, Olness, Nadolsky, Hobbs, Li, Durham, Wong, Sichtermann Inclusive, Tracking, Calorimetry, Software	Charm - tagged jet cross sections vs p_T, Charm F_2 (vs x Q^2)	Bottom tagged jet cross sections vs p_T, Bottom F_2 (vs x Q^2)	Tracking, Forward and backward coverage, Calorimetry

4. D and B meson cross sections, modification in e+A [energy loss, hadronization]

5. Heavy flavor jet cross sections, modification and substructure in e+A, charm F_2 [transport properties of nuclei, charm content, QCD in matter]

F_2^A/F_2^D

SLAC/NMC param.

- BCDMS(85)
- BCDMS(87)
- SLAC-E049(83)
- SLAC-E139(94)
- SLAC-E140(94)
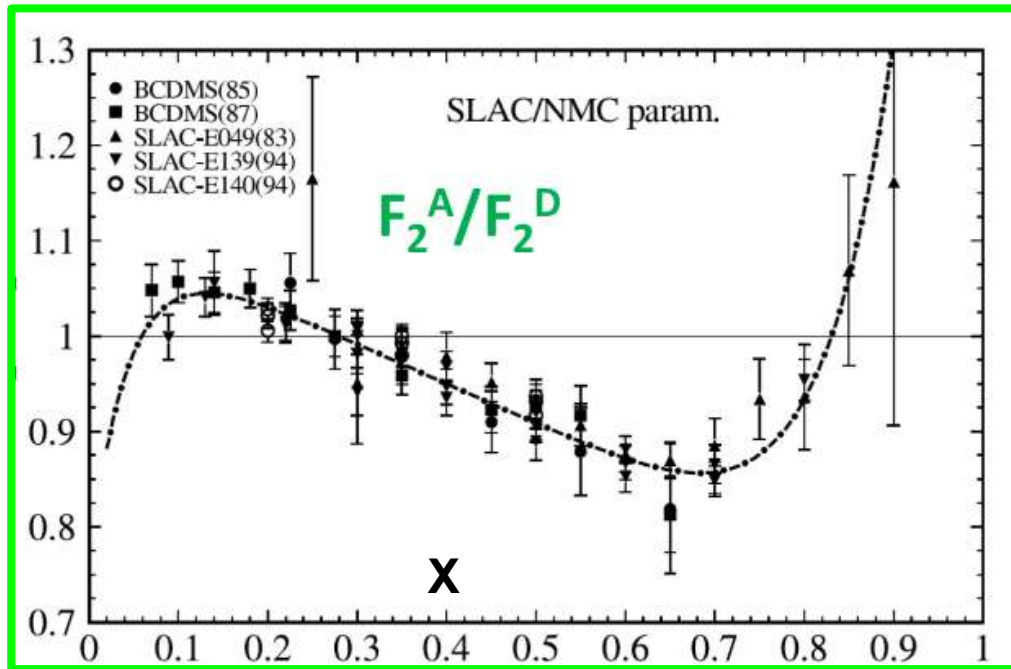
Nuclear PDFs: x>1 allowed;
impacts F_2^{Nuc}/F_2^{Iso} in Fermi region
Higher Twist
Isospin violation: u⇔d
d/u limits as x➔1

Efrain Segarra
Or Hen

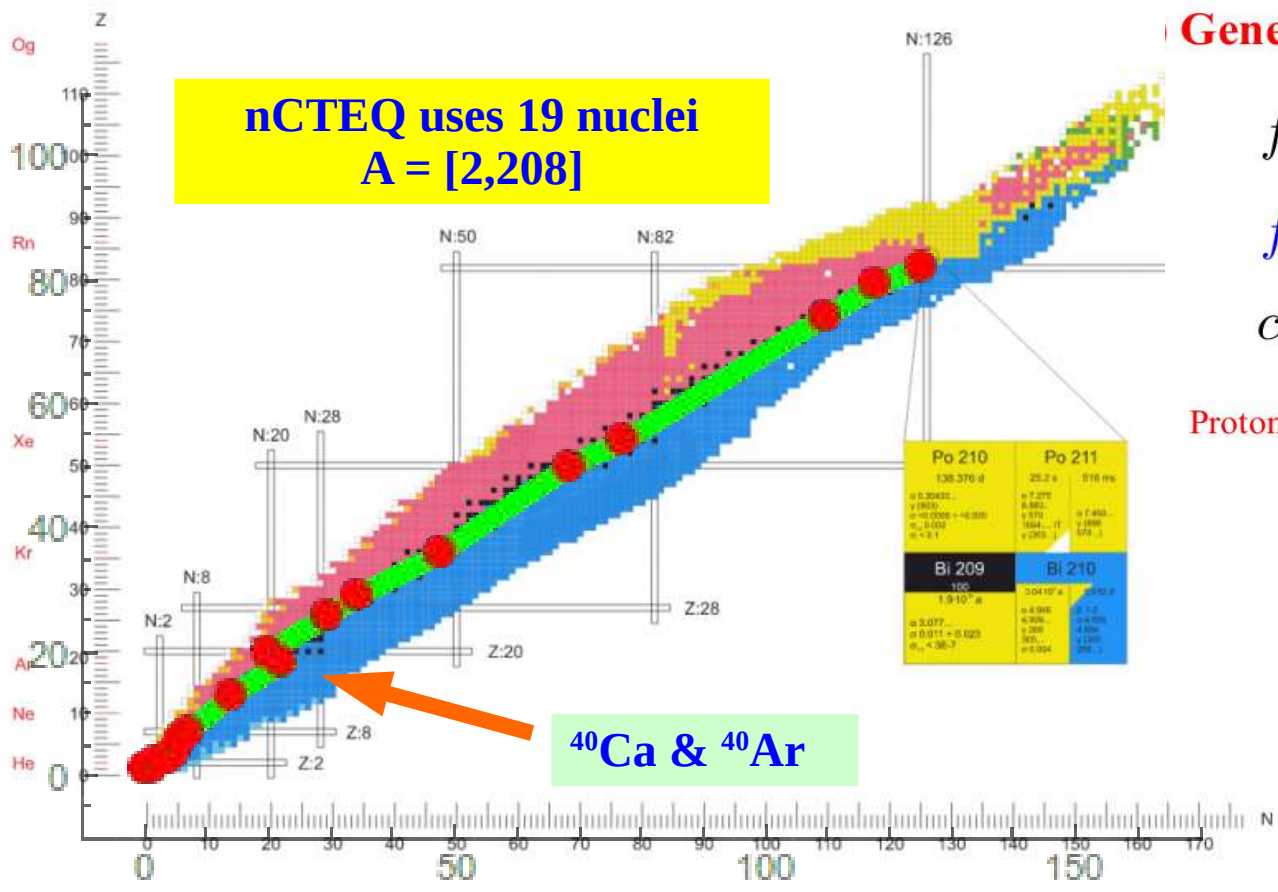SLAC, CERN, DESY (DIS)
FNAL (DY)
JLab (DIS)

Q^2

$W > 3.5$

10^1

10^0

$Q^2 > 2$

X

JLab Data @ Hi-X Low-Q²

Current nCTEQ framework
must be extended
to accommodate this region

lots of work to do ...

nCTEQ uses 19 nuclei
A = [2,208]

Po 210 Po 211
Bi 209 Bi 210

^{40}Ca & ^{40}Ar
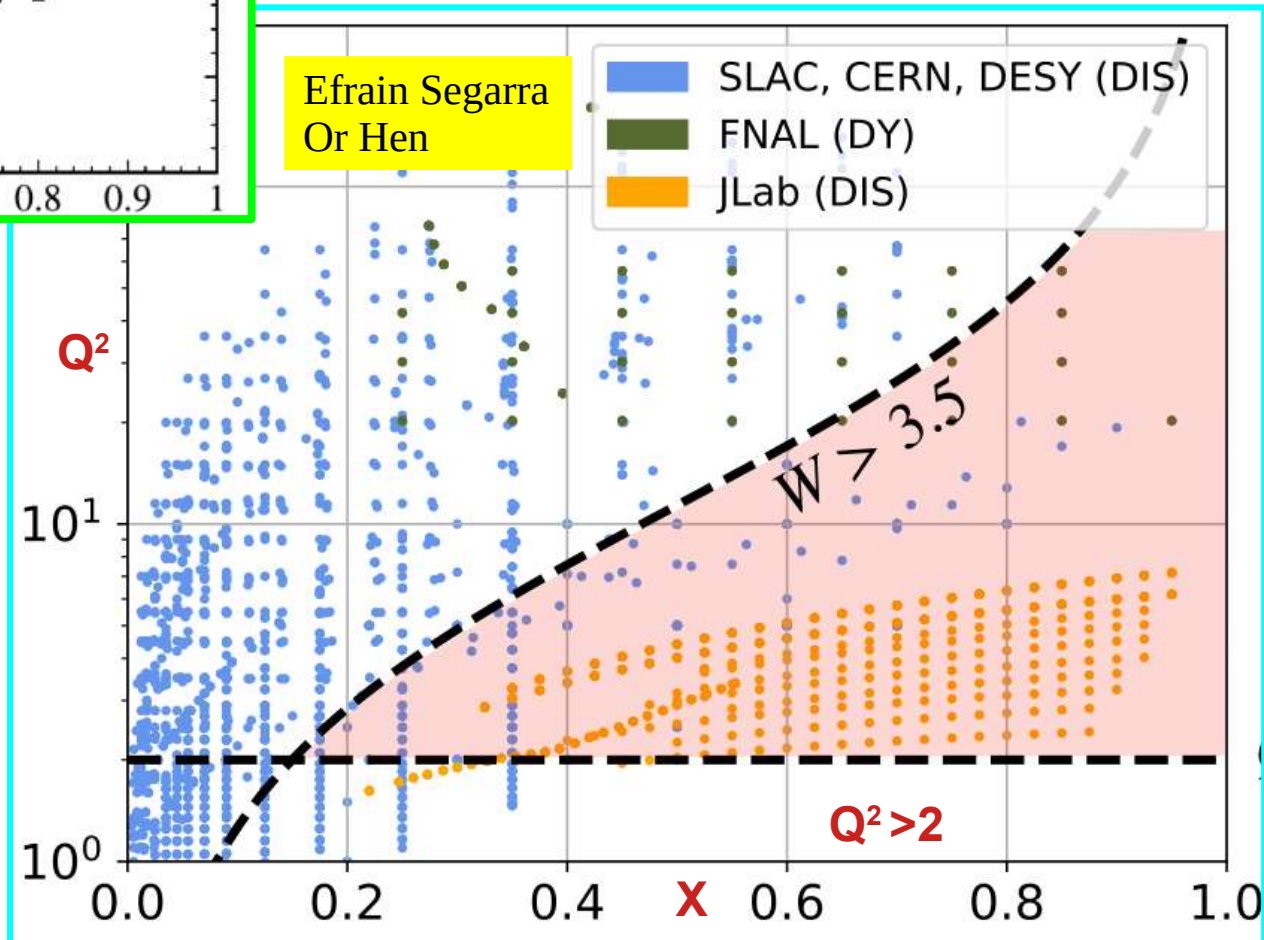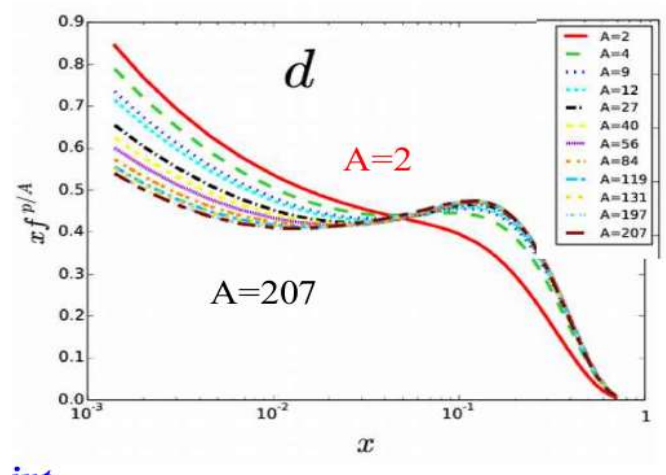
Generalized A-parameterization (nCTEQ)

$$f_i^{p/A}(x_N, \mu_0) = f_i(x_N, A, \mu_0)$$

$$f \sim ...x^{c_1(A)}(1-x)^{c_2(A)}...$$
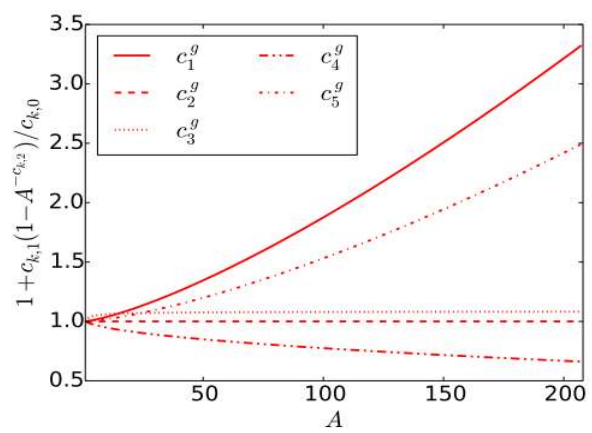
$$c_k \sim c_{k,0} + c_{k,1}\left(1 - A^{-c_{k,2}}\right)$$
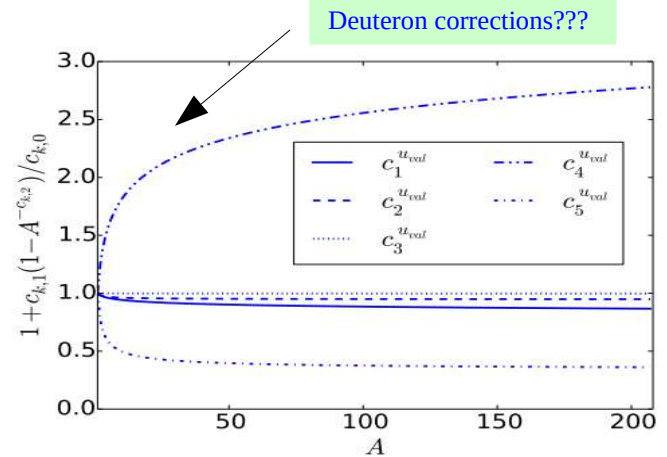
Proton

Nuclear

d

A=2

A=207

A=2
A=4
A=9
A=12
A=27
A=40
A=56
A=84
A=119
A=131
A=197
A=207

$xf^{p/A}$

x

A-dependence
of coefficients

Fill out A spectrum with
high-stats data

Deuteron corrections???

c_1^g c_4^g
c_2^g c_5^g
c_3^g

$1 + c_{k,1}(1-A^{-c_{k,2}})/c_{k,0}$

A

(a) Gluon

$c_1^{u_{val}}$ $c_4^{u_{val}}$
$c_2^{u_{val}}$ $c_5^{u_{val}}$
$c_3^{u_{val}}$

$1 + c_{k,1}(1-A^{-c_{k,2}})/c_{k,0}$

A

(c) u-valence