Overview of Global Analysis WG

... developing a "To Do" list

Fred Olness
SMU

Thanks for substantial input
from my friends & colleagues

nCTEQ
nuclear parton distribution functions

xFitter

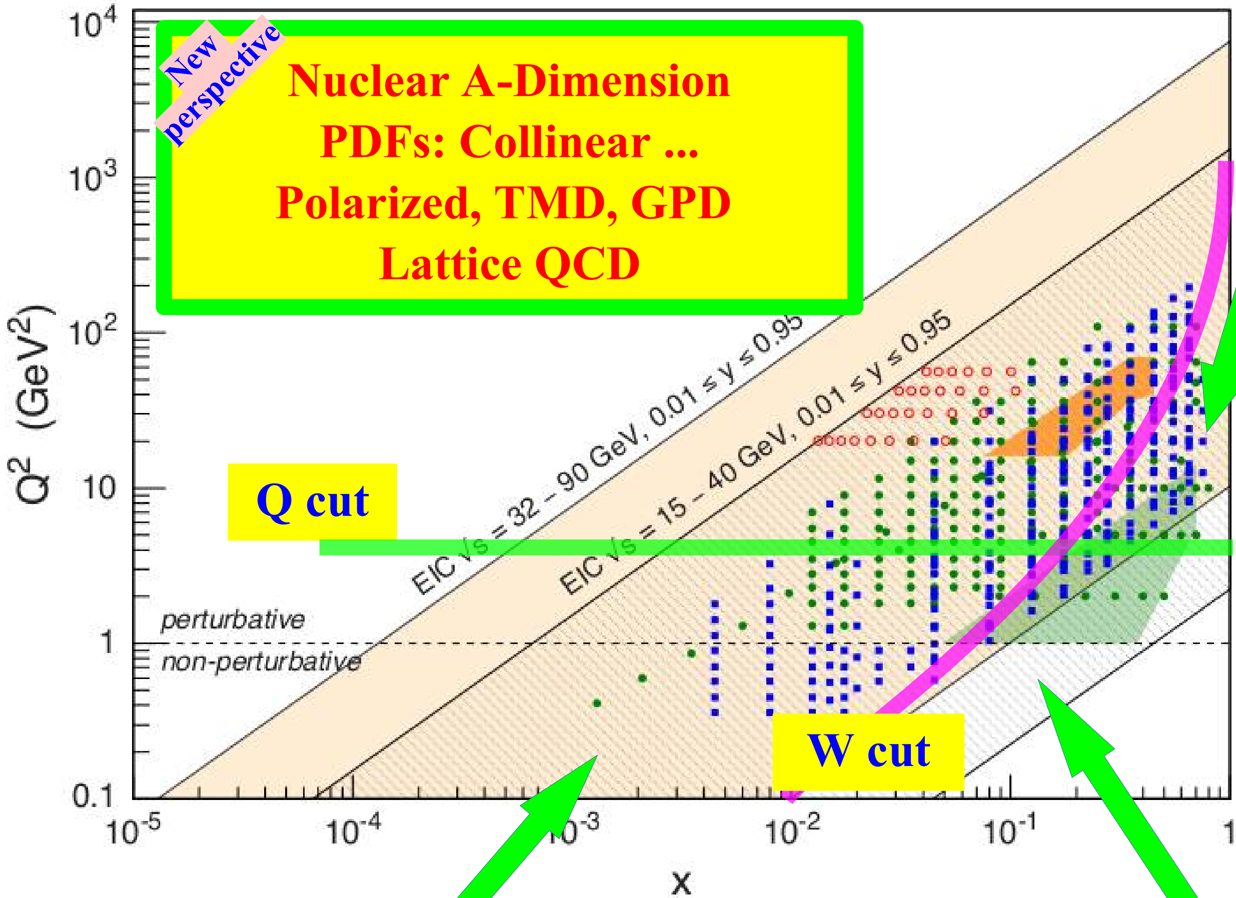
SURGE COLLABORATION

CTEQ

SURGE Meeting
BNL
28 June 2023

Preparing for the EIC

... and exploiting the advantages



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

JLab Data @ Hi-X Low-Q^2

extend nCTEQ framework for this region

Prepare for EIC

Low-x:

Shadowing

Recombination

Resummation

BFKL

Saturation

Low-Q^2:

Non-Perturbative interface

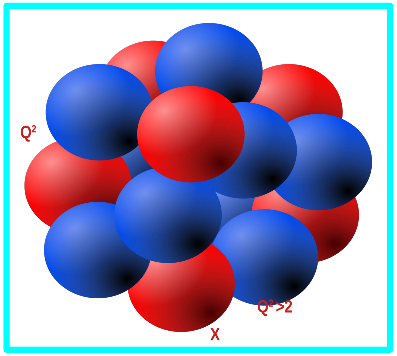
collective effects

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



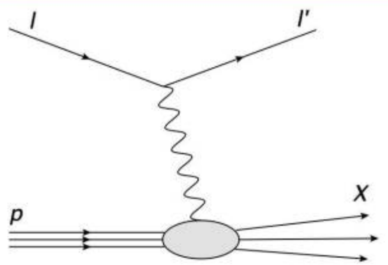
Physics questions

- **Initial conditions:** How to parametrize and/or compute initial conditions for the evolution ?
- **Small x evolution:** LO evolution is not sufficient for accuracy. Need the NLO and beyond. How to consistently implement resummation in non-linear evolution and match small with large x, relevant for EIC kinematic regime ?
- **Impact factors:** Need impact factors at NLO for accuracy. For many observables analytical and numerical implementations are missing.
- **Spin:** How proton spin emerges from spins and angular orbital momenta of quarks and gluons? What is the contribution of the small x region to the proton spin ?
- **Hadronization:** How hadronization is affected by the presence of saturated gluons ?
- **Global analysis:** Much progress made in increasing accuracy of cross sections in the collinear approach. Need to increase accuracy of predictions based on high energy factorization.

Physics questions

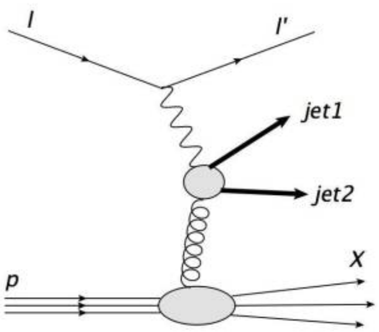
- **Global analysis:** Much progress made in increasing accuracy of cross sections in the collinear approach. Need to increase accuracy of predictions based on high energy factorization.

Observables

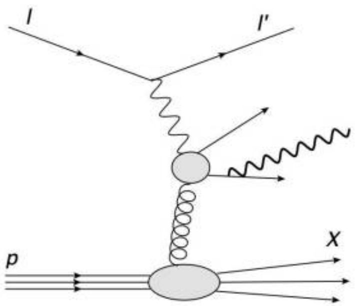


DIS inclusive

Inclusive: structure functions for protons and nuclei, F_2,F_L also for charm F_2^c, inclusive polarized g_1

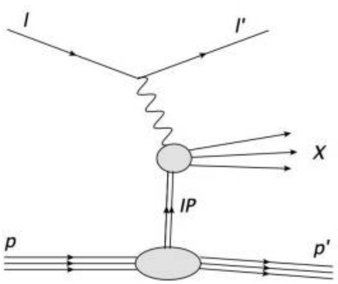


Dijets



Photon in DIS

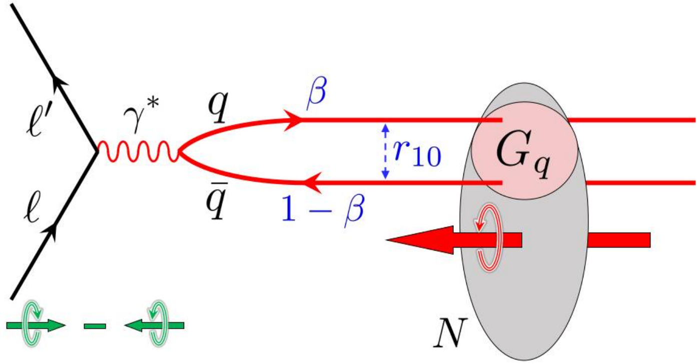
Less inclusive: dihadron and dijets in pA and ep/eA, photons in pA and ep/eA, polarized SIDIS, hadrons in polarized pp

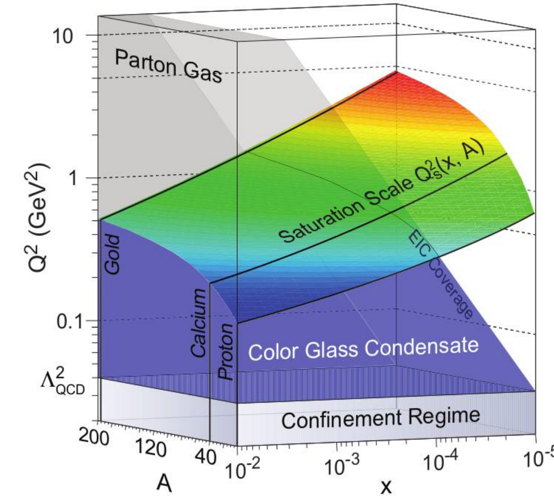


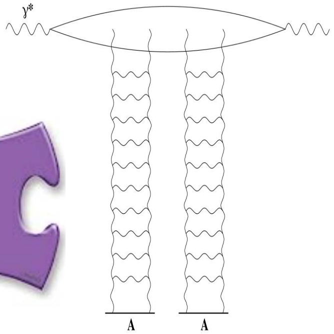
Diffraction

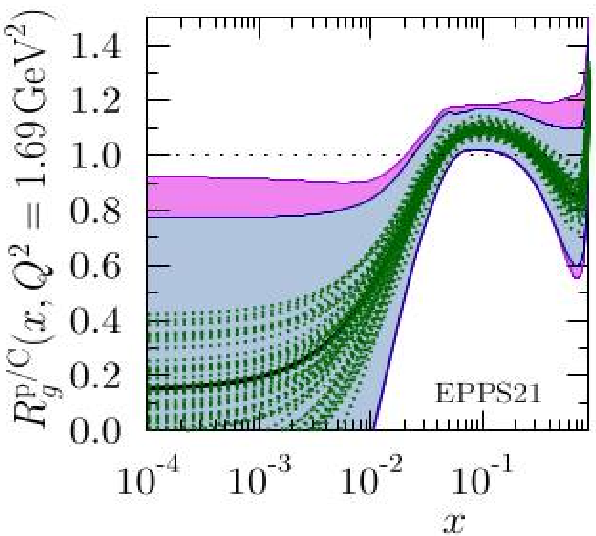
Diffractive: inclusive diffractive structure functions, exclusive diffractive vector mesons

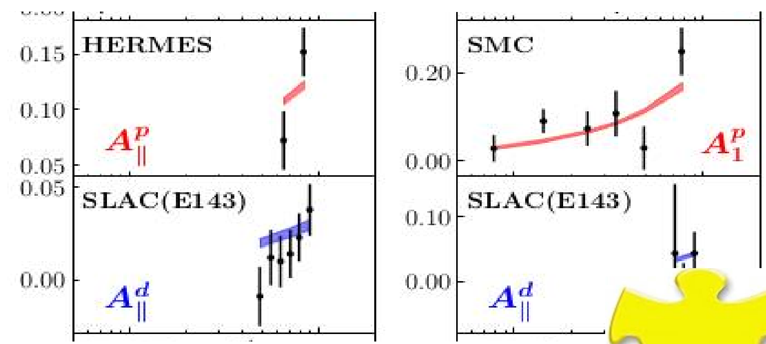
Many pieces to the puzzle ...

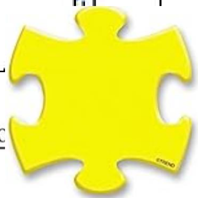


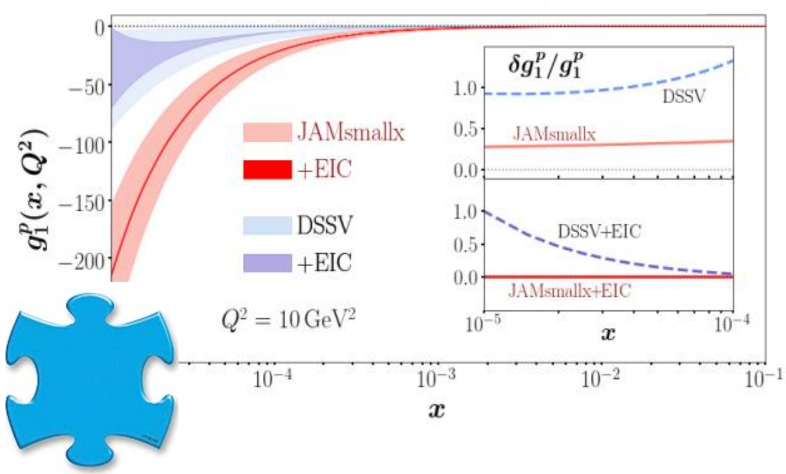


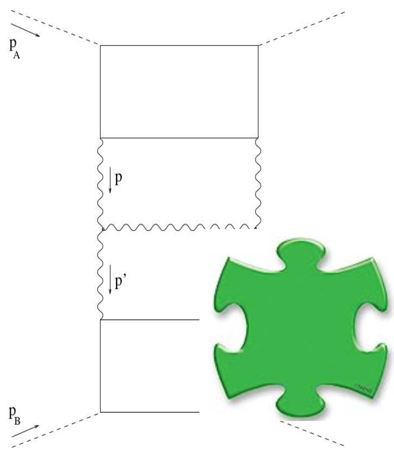


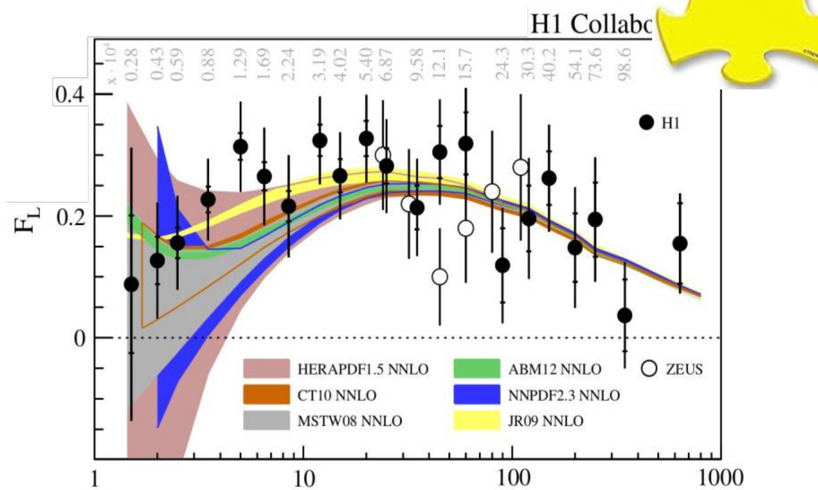






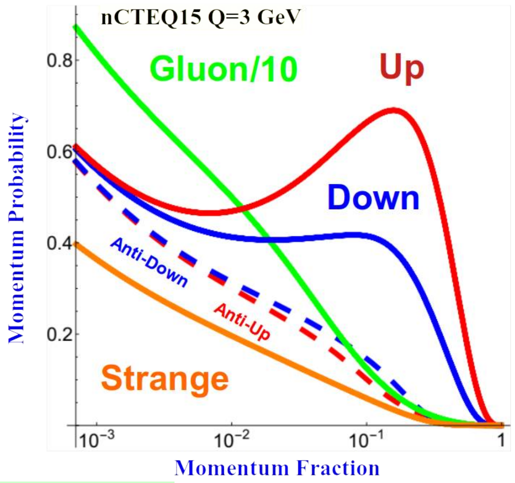




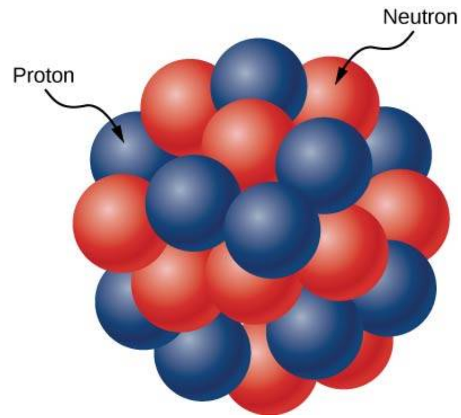


Eur. Phys. J. C (2014) 74:2814

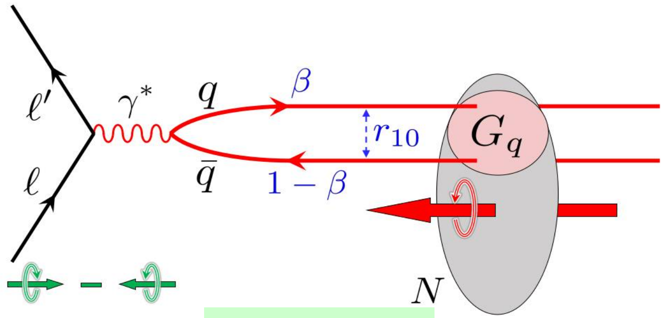
Putting the pieces all together in a unified framework



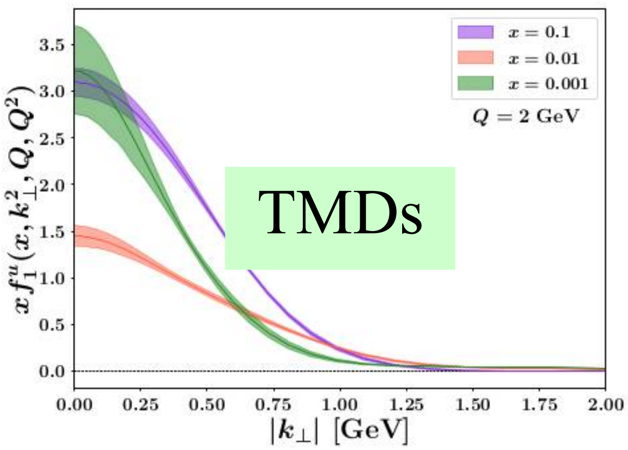
PDFs



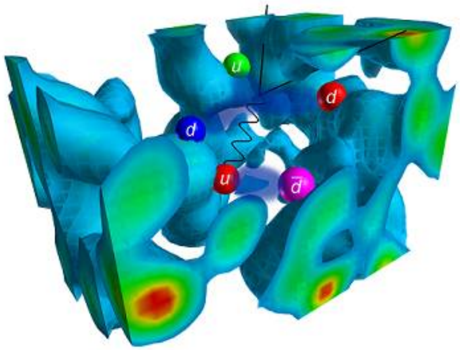
Nuclear



Spin



TMDs



Lattice QCD

we have the experts here

Enhancing open access research: The SURGE Collaboration will make software developed as part of the proposal, ranging from initial state, small-x evolution, and hadronization implementations, and data used in publications publicly available. This way the SURGE Collaboration will generate a lasting impact on the future of the high energy nuclear physics program in general, and the theory and phenomenology efforts focused on the upcoming EIC specifically.

Topics and working groups

Initial state WG
Improve the initial conditions for evolution for unpolarized and polarized observables.

Small x evolution + NLO calculations WG
Non-linear evolution at NLO and beyond, computation and implementation of impact factors

Spin WG
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To establish saturation, perform comprehensive global analysis quantifying and minimizing uncertainties, extracting universal building blocks of high energy factorization.

Our first "in person" meeting

I have more questions than answers

Will "float" some directions and plans … follow up with discussion

… an example for your consideration

… is xFitter the right tool?

Eur. Phys. J. C (2018) 78:621
https://doi.org/10.1140/epjc/s10052-018-6090-8

THE EUROPEAN PHYSICAL JOURNAL C

CrossMark

Regular Article - Theoretical Physics

Impact of low-x resummation on QCD analysis of HERA data

xFitter Developers' team, Hamed Abdolmaleki[1], Valerio Bertone[2,3,a], Daniel Britzger[4], Stefano Camarda[5], Amanda Cooper-Sarkar[6], Francesco Giuli[6], Alexander Glazov[7], Aleksander Kusina[8], Agnieszka Luszczak[7,9], Fred Olness[10], Andrey Sapronov[11], Pavel Shvydkin[11], Katarzyna Wichmann[7], Oleksandr Zenaiev[7], Marco Bonvini[12]

xFitter Collaboration Meeting February 2020, DESY

www.xFitter.org

xFitter

PROTON

NUCLEON

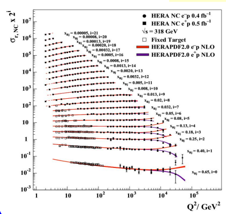
MESON

www.xFitter.org

Sample data files:

- **LHC:** ATLAS, CMS, LHCb
- **Tevatron:** CDF, D0
- **HERA:** H1, ZEUS, Combined
- **Fixed Target:** …
- **User Supplied:** …

Experimental Data



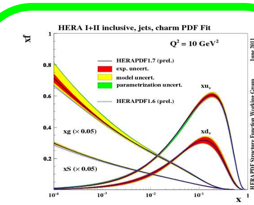
Data: HERA, Tevatron, LHC, fixed target experiments

Processes: Inclusive DIS, Jets, Drell-Yan, Diffraction, Top production, W and Z production

Theory Calculations

HQ Schemes:	MSTW, NNPDF, ABM, ACOT
Jets, W, Z:	FastNLO, ApplGrid
Top:	Hathor
Evolution:	QCDNUM, APFEL, k_T
Other:	NNPDF reweighting TMDs, Dipole Model, ...

xFitter



Parton Distribution Functions: PDF, Updf, TMD

$\alpha_S(M_Z)$, m_c, m_b, m_t ...

Theoretical Cross Sections

Comparisons to other PDFs (LHAPDF)

extensions include nuclear PDFs

Features & Recent Updates:

- Photon PDF & QED
- Pole & MS-bar masses
- Profiling and Re-Weighting
- Heavy Quark Variable Treshold
- Improvements in χ^2 and correlations
- TMD PDFs (uPDFs)
- *... and many other*

xFitter 2.2.0
Future Freeze

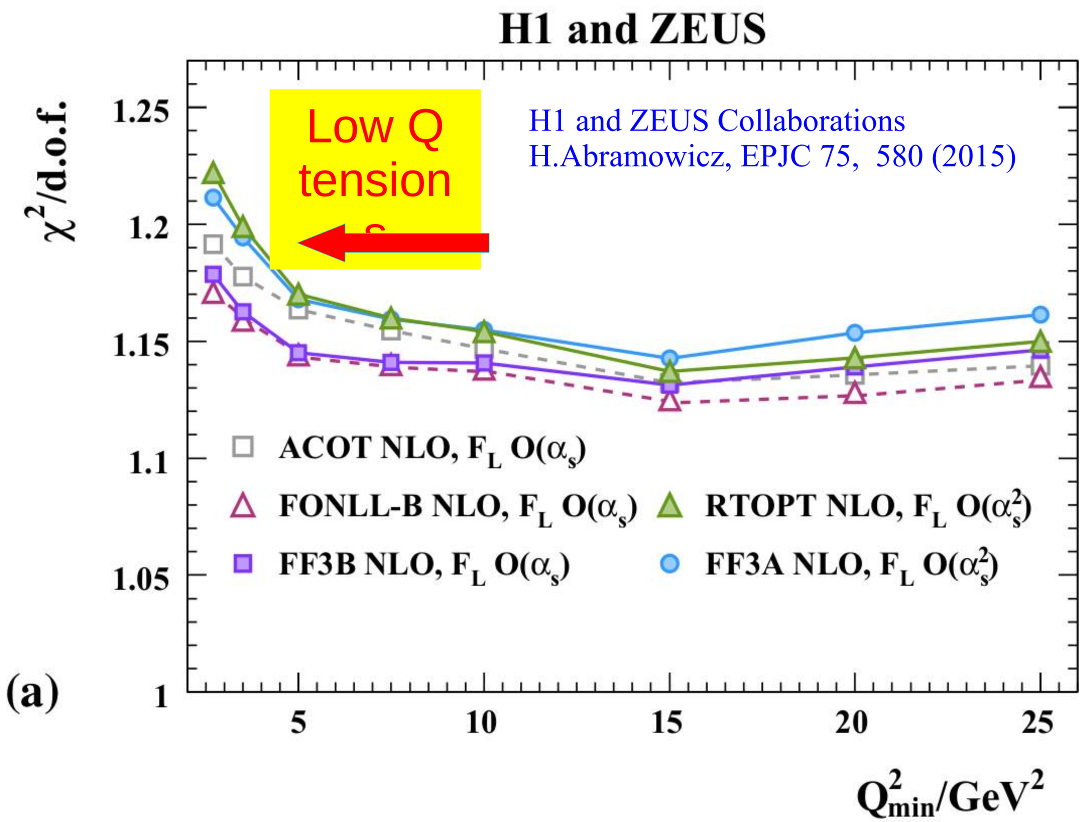
Example

plug in ...
BFKL w/ HELL

This can be replace by
BK, CGC EFT,
JIMWLK, B-JIMWLK,
BBGKY, ...

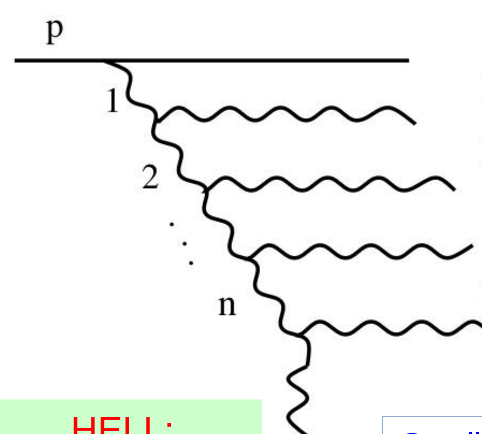
Motivation for Improved Treatment at Small x

Small x *(Low Q)*: need to improve fits
NNLO: "fits at NNLO do not improve agreement"



HERAPDF2.0 shows tensions between data and fit, independent of the heavy-flavour scheme used, at low Q^2, i.e. below $Q^2 = 15\,\mathrm{GeV}^2$, and at high Q^2, i.e. above $Q^2 = 150\,\mathrm{GeV}^2$. Comparisons between the behaviour of the fits with different Q^2_{min} values indicate that the NLO theory evolves faster than the data towards lower Q^2 and x. Fits at NNLO do not improve the agreement. HERAPDF2.0 NNLO and NLO have a similar fit quality.

NNLO vs. NLO



resum logs

$$\alpha_S^n \frac{\ln^k(x)}{x}$$

HELL:
High Energy
Leading Logs

Small-x resummation from HELL
Marco Bonvini, et al.,
Eur.Phys.J.C 76 (2016) 11, 597

Eur. Phys. J. C (2018) 78:621
https://doi.org/10.1140/epjc/s10052-018-6090-8

THE EUROPEAN PHYSICAL JOURNAL C

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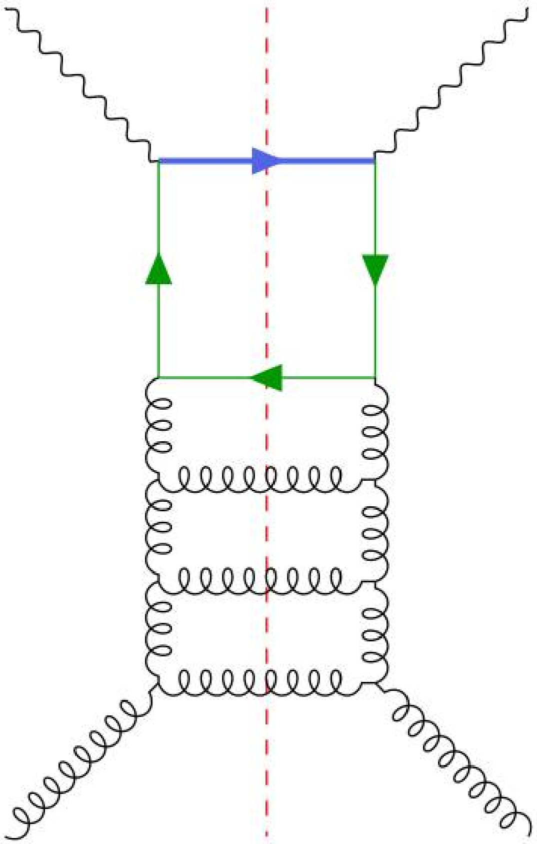
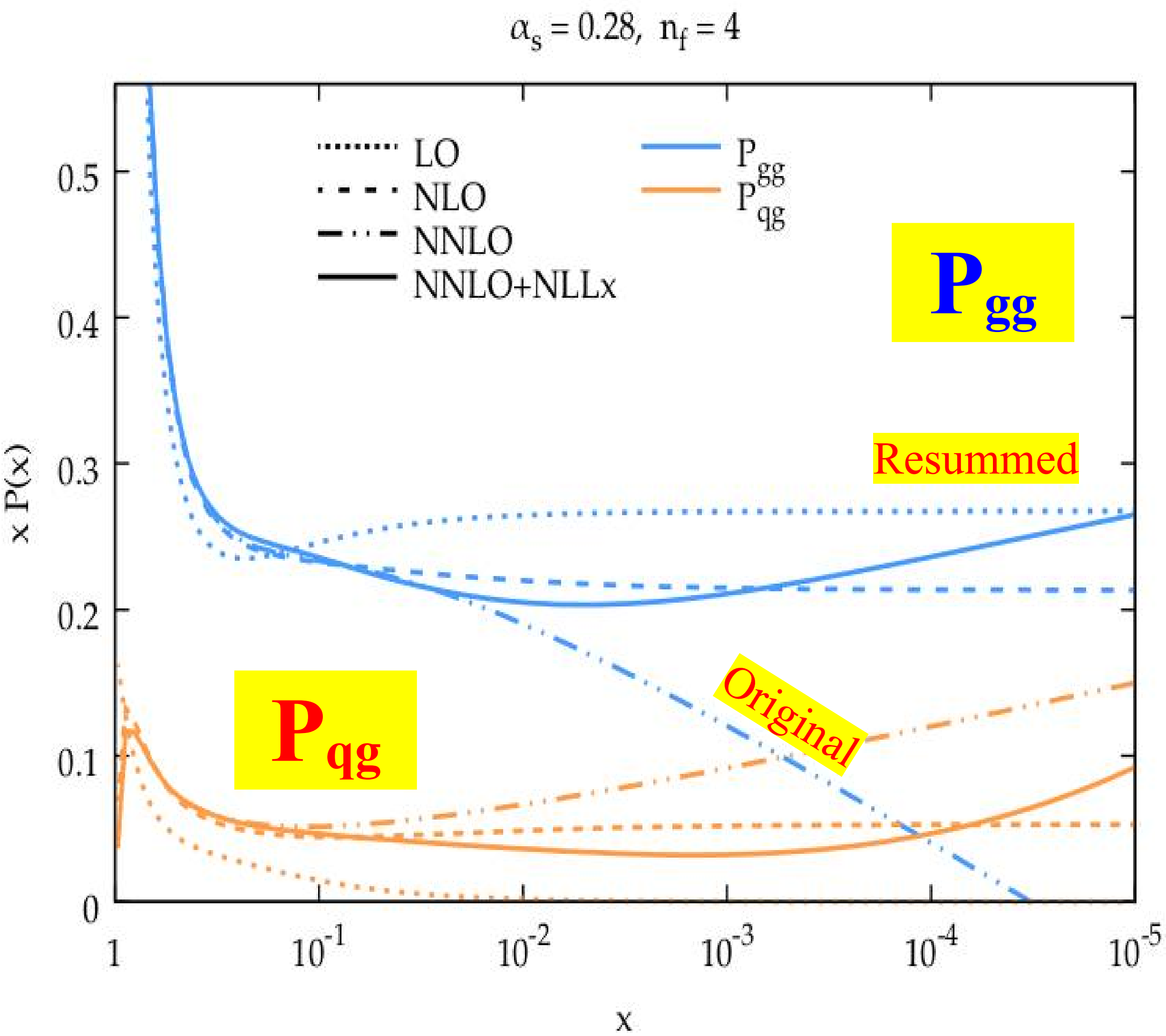
HELL (High-Energy Large Logarithms) Program

next-to-leading logarithmic (NLL) accuracy &
next-to-next-to-leading order (NNLO)

Resum small-x logs

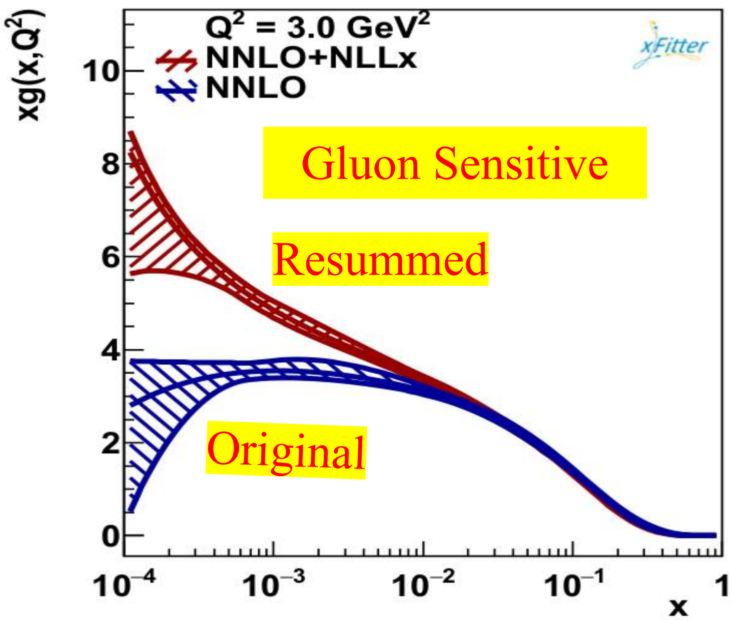


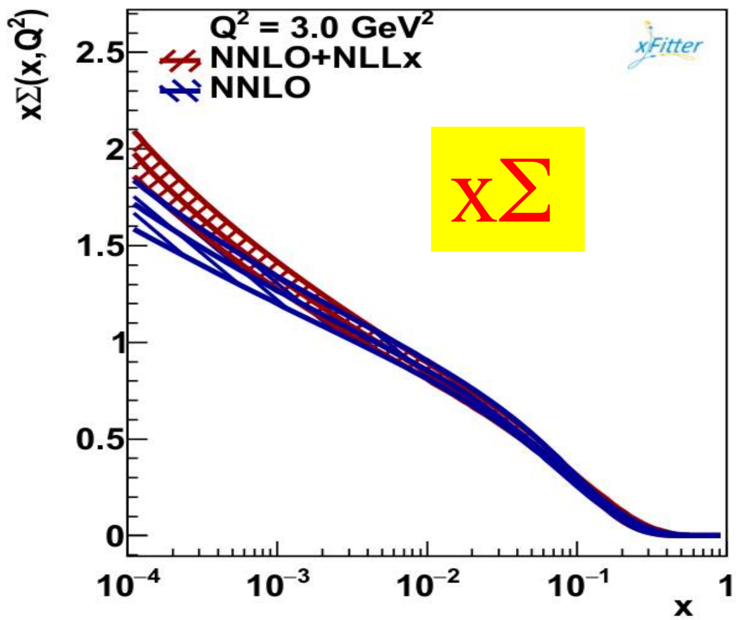


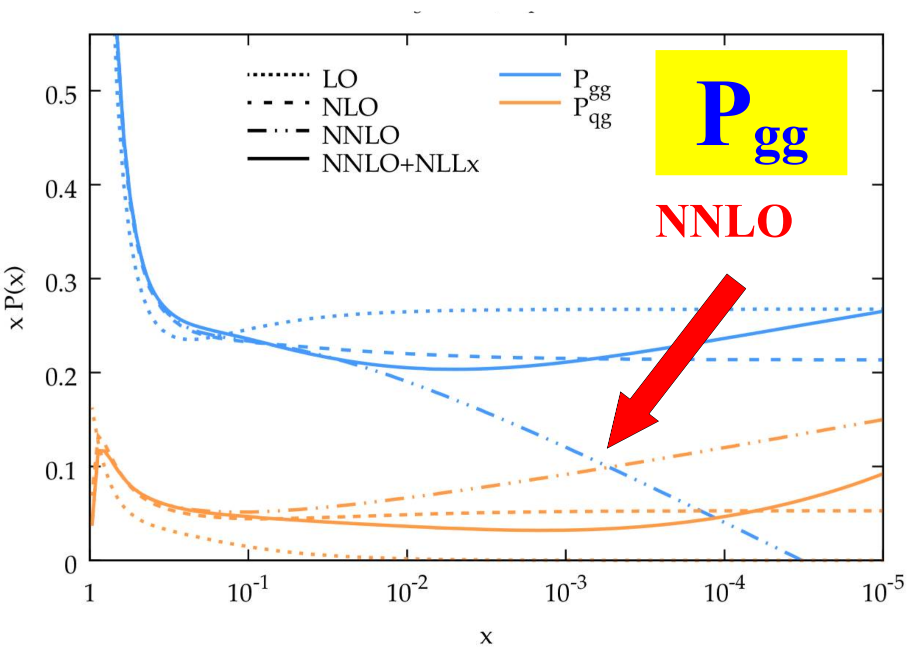
Towards parton distribution functions with small-x resummation: HELL 2.0
Marco Bonvini, Simone Marzani, Claudio Muselli
JHEP 12 (2017) 117

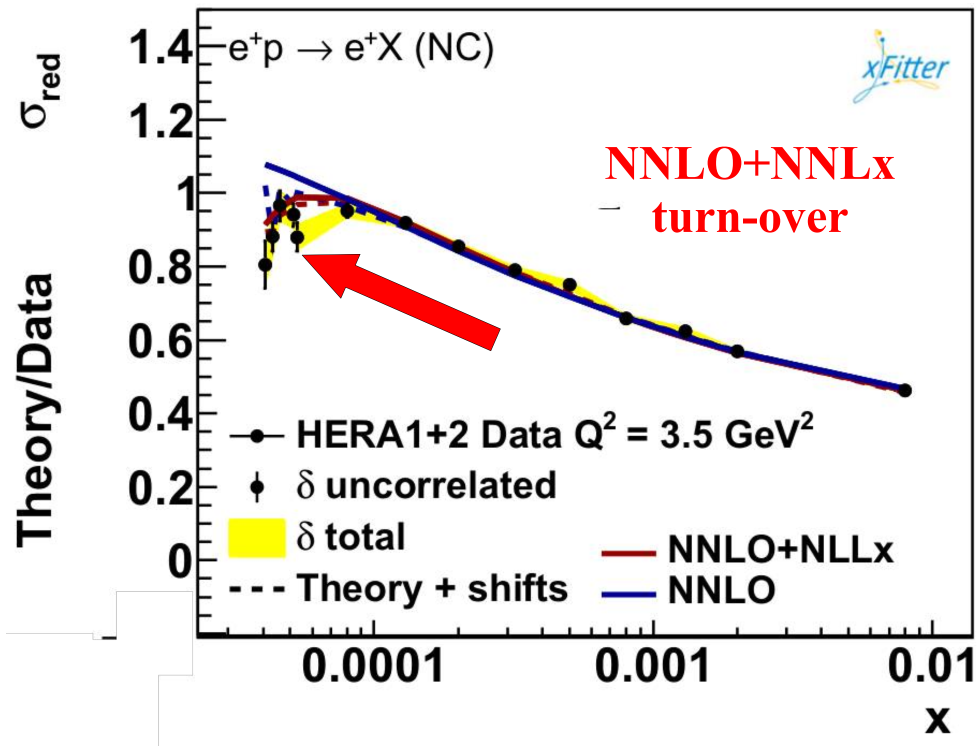
Small-x resummation from HELL
Marco Bonvini, Simone Marzani, Tiziano Peraro
Eur. Phys. J. C (2016) 76: 597

xFitter Resummation Study









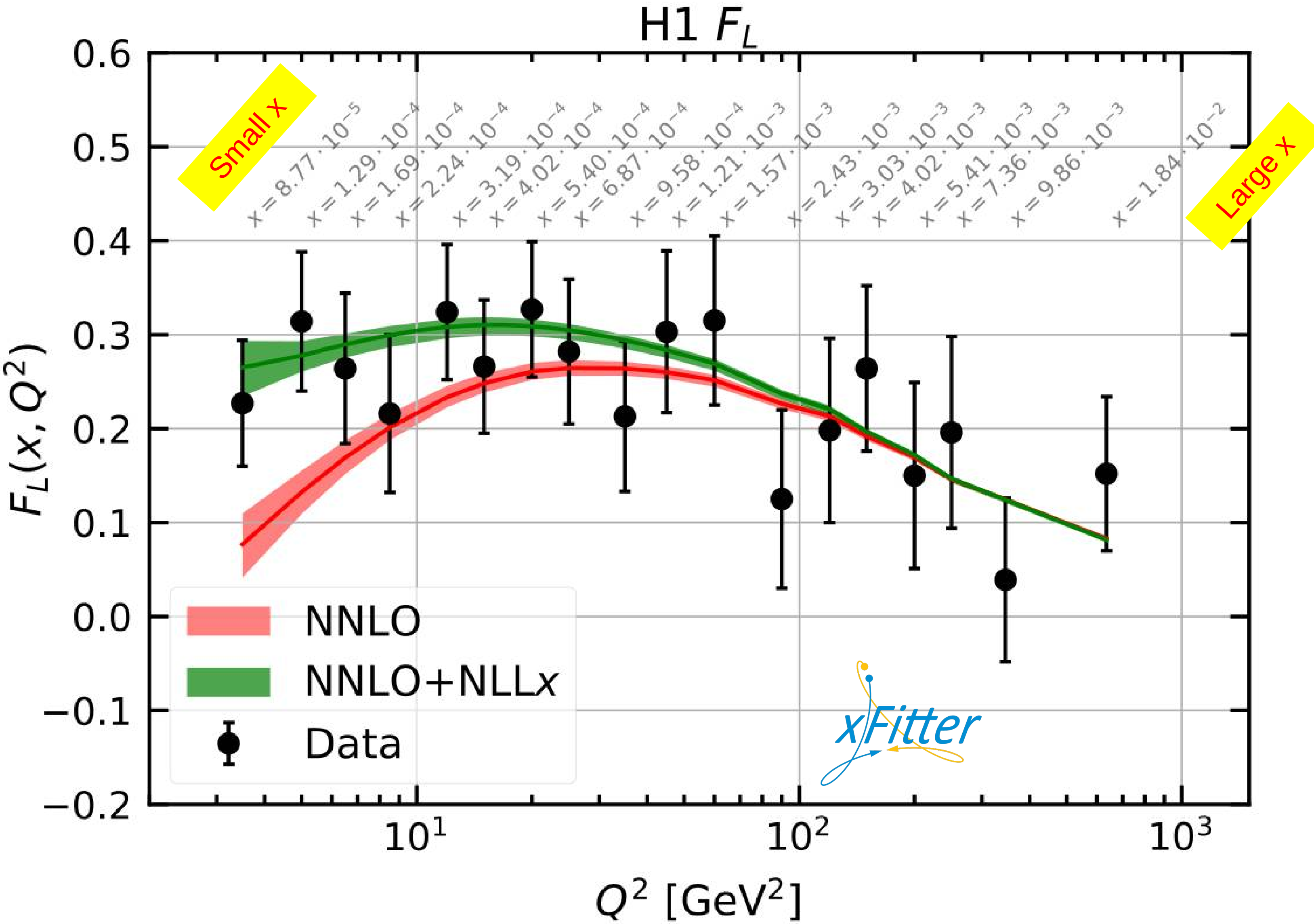
Impact of low-x resummation on QCD analysis of HERA data

xFitter Developers' Team: Eur.Phys.J.C 78 (2018) 8, 621

F_L is senstive to Gluon and Small-x Treatments

F_L driven by gluon

$$F_L = ... + \alpha_S \; c_g \otimes g(x) + c_q \otimes q(x)$$

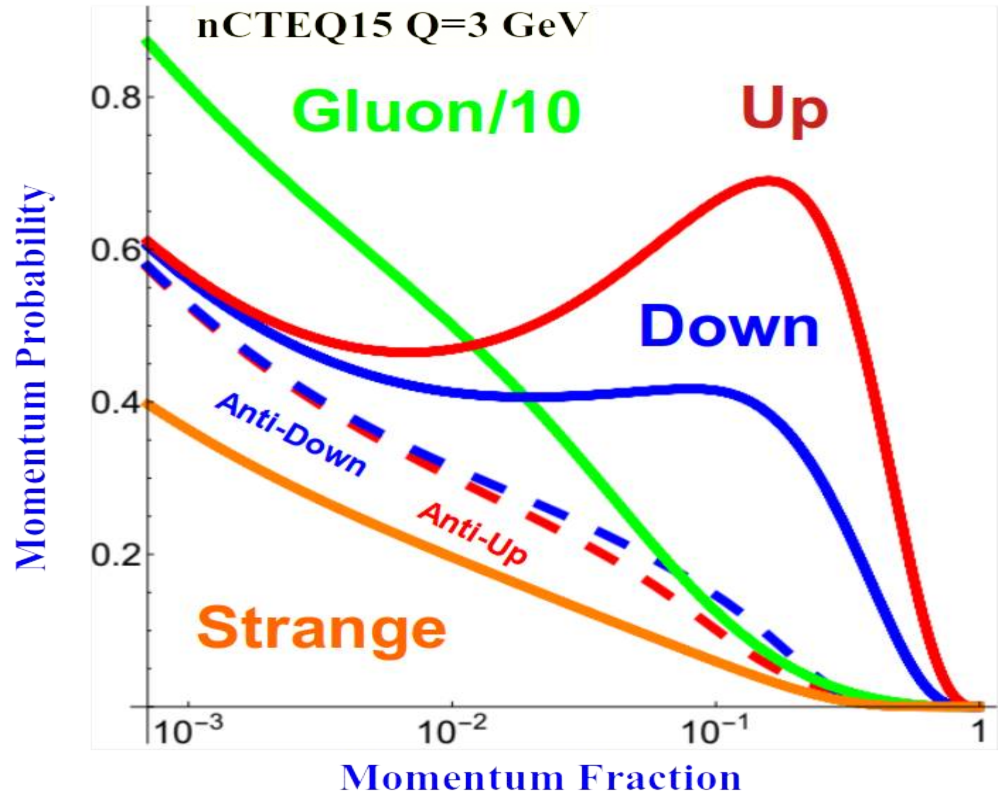


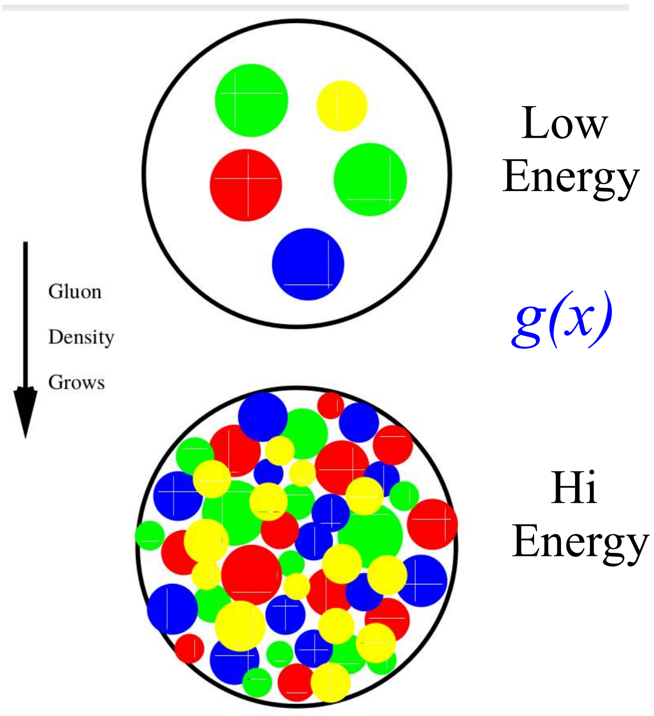
focus on gluon

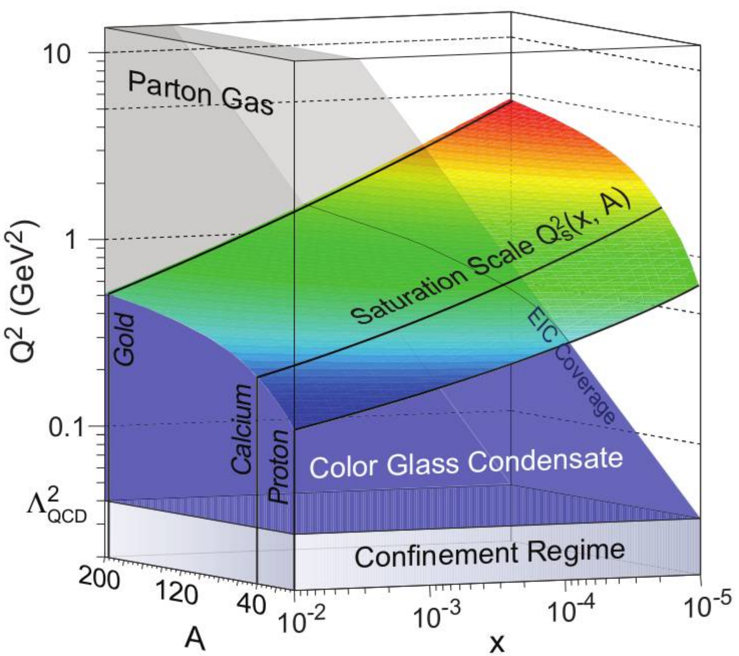
Gluon PDF

… key role in small-x region

Gluon: Nuclear Medium Effects at small momentum fraction (x)

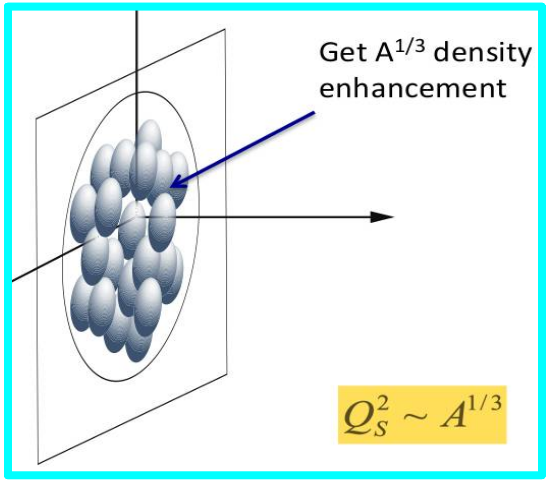






Nuclear medium effects:
- Quark Gluon Plasma
- Color Glass Condensate
- Recombination
- Saturation
- Resummation
- … *your theory here*

We gain a geometric factor of $A^{1/3}$



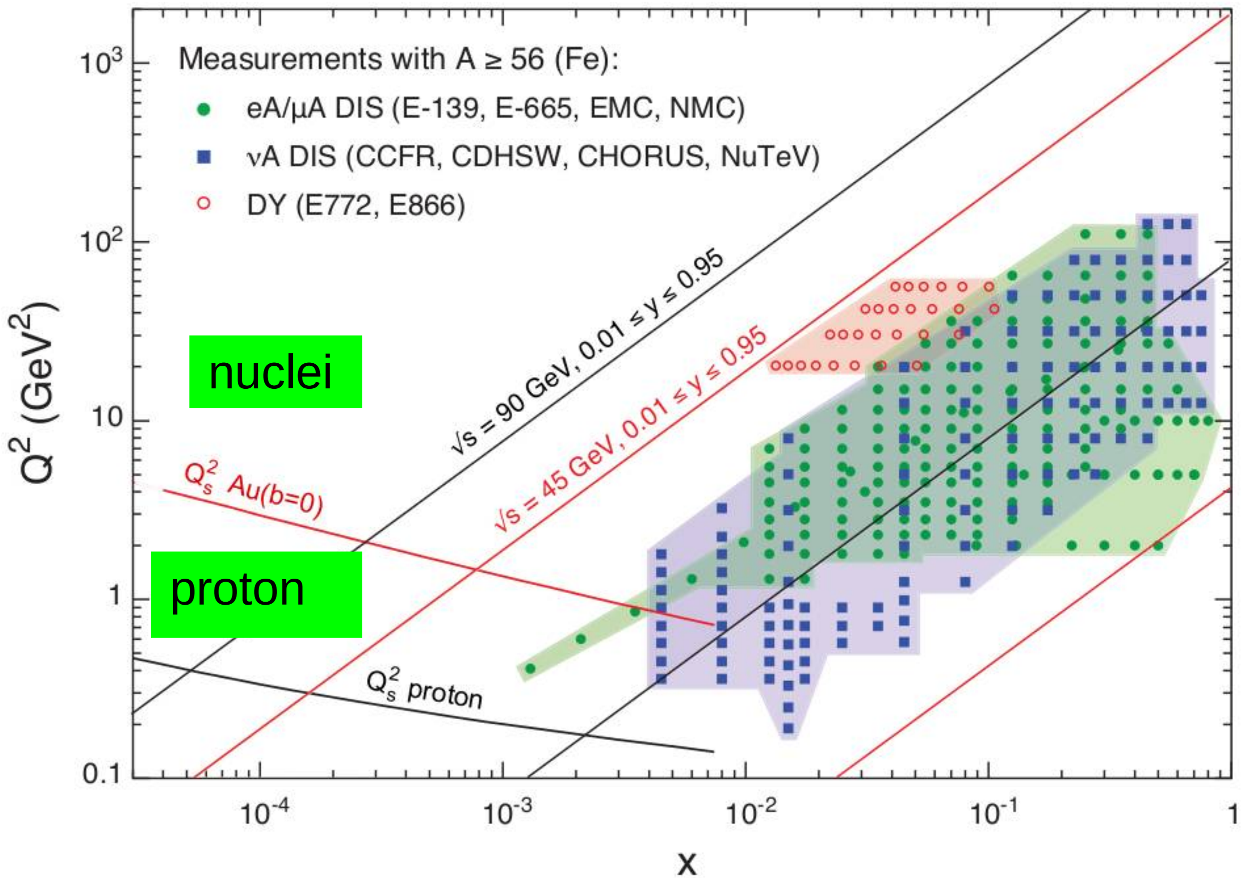
Review: Edmond Iancu & Raju Venugopalan: arXiv:0303204

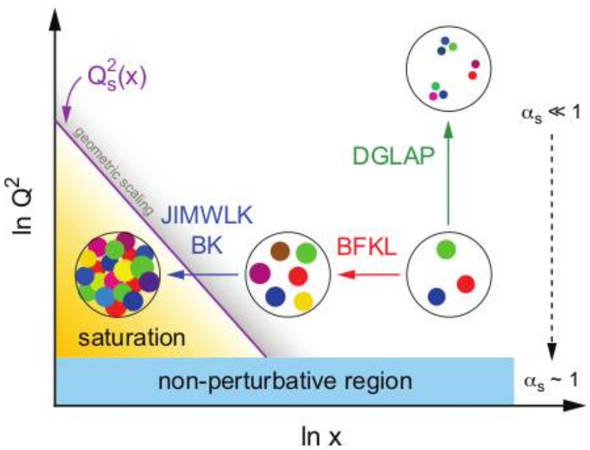
Saturation, BFKL, recombination, ...

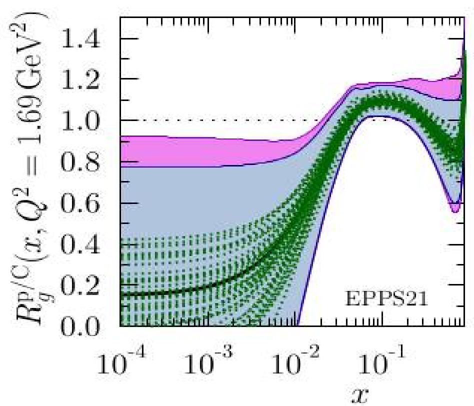
Yuri Kovchegov (OSU)
MC4EIC: Monte Carlo event simulation for the EIC

Can Saturation be Discovered at EIC?

EIC has an unprecedented small-x reach for DIS on large nuclear targets, allowing to seal the discovery of saturation physics and study of its properties:

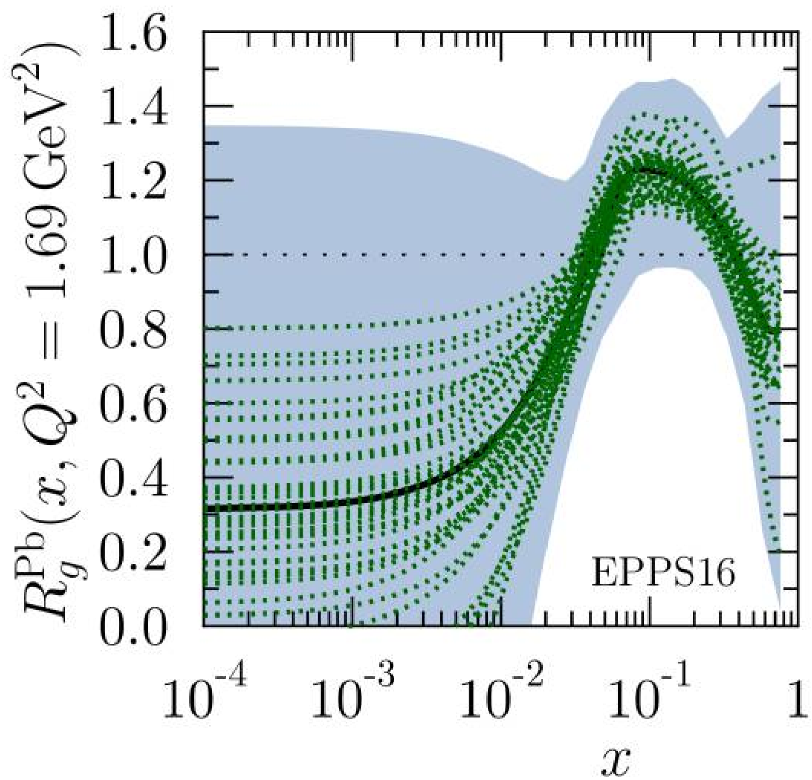


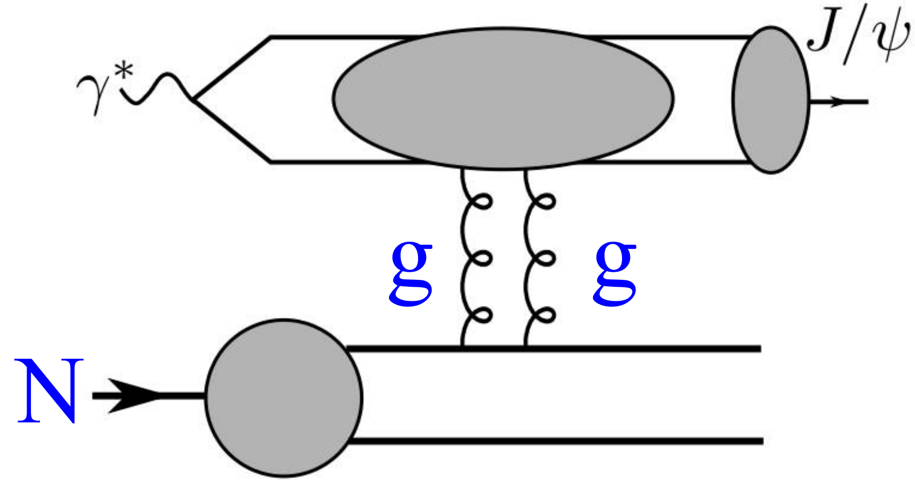




Heavy FlavorProduction: Effective Probe of Gluon PDF

Nuclear Gluon PDF
Large uncertainties
Strong shadowing at small x





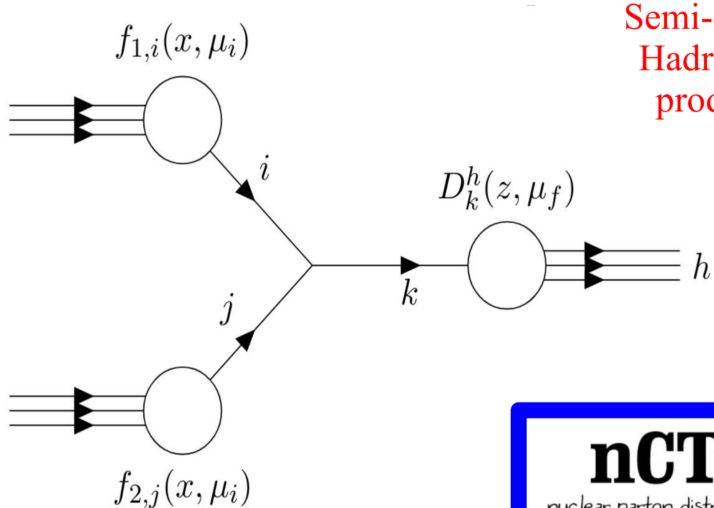
HEFTY
COLLABORATION

nCTEQ
nuclear parton distribution functions

Precision Gluon can help study nuclear medium effects

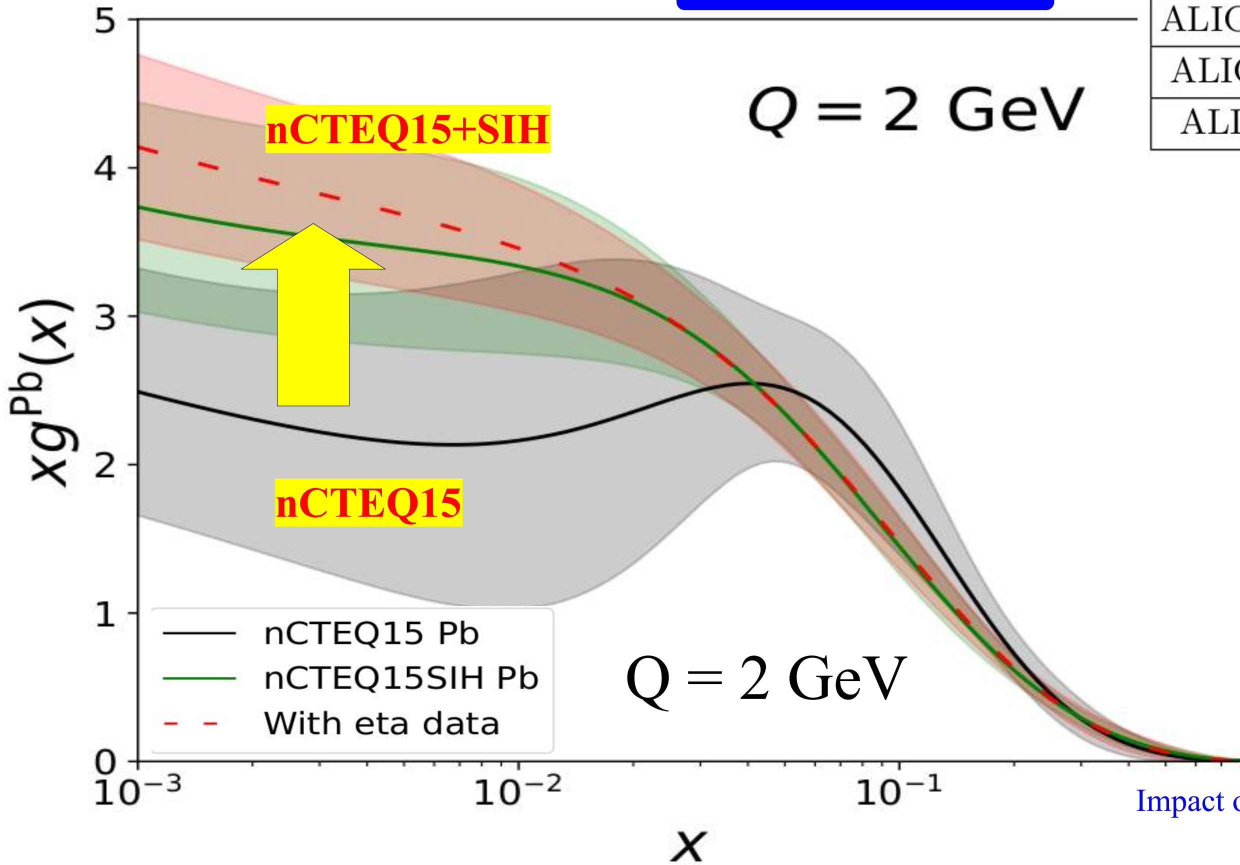
nCTEQ: Pit Duwentaster, Michael Klasen, ...

Semi-Inclusive Hadron (SIH) production



nCTEQ
nuclear parton distribution functions

Data set	$\sqrt{s_{NN}}$ [GeV]	Observ.	No. points
PHENIX π^0	200	R_{dAu}	21
PHENIX η	200	R_{dAu}	12
PHENIX $\pi^\pm$	200	R_{dAu}	20
PHENIX $K^\pm$	200	R_{dAu}	15
STARπ^0	200	R_{dAu}	13
STAR η	200	R_{dAu}	7
STAR $\pi^\pm$	200	R_{dAu}	23
ALICE 5 TeV π^0	5020	R_{pPb}	31
ALICE 5 TeV η	5020	R_{pPb}	16
ALICE 5 TeV $\pi^\pm$	5020	R_{pPb}	58
ALICE 5 TeV $K^\pm$	5020	R_{pPb}	58
ALICE 8 TeV π^0	8160	R_{pPb}	30
ALICE 8 TeV η	8160	R_{pPb}	14



Semi-Inclusive Hadron (SIH) production

Determines gluon in small x region

Impact of inclusive hadron production data on nuclear gluon PDFs
nCTEQ: P. Duwentäster, et al., PRD104 (2021) 094005.

Possible directions

... moving forward ...

Topics and working groups

Initial state WG
Improve the initial conditions for evolution for unpolarized and polarized observables.

Small x evolution + NLO calculations WG
Non-linear evolution at NLO and beyond, computation and implementation of impact factors

Spin WG
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I have more questions than answers

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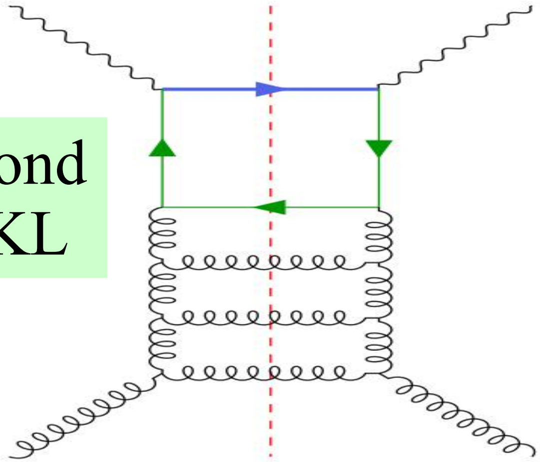
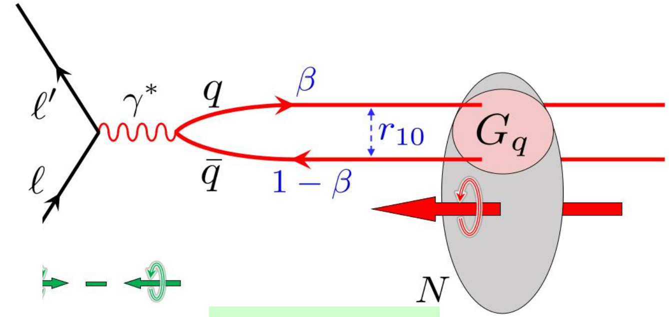
Possible direction … *for discussion* ...

we have the experts here

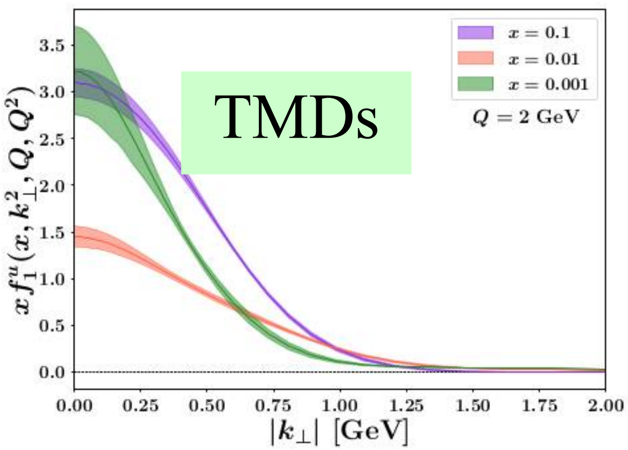
Beyond BFKL

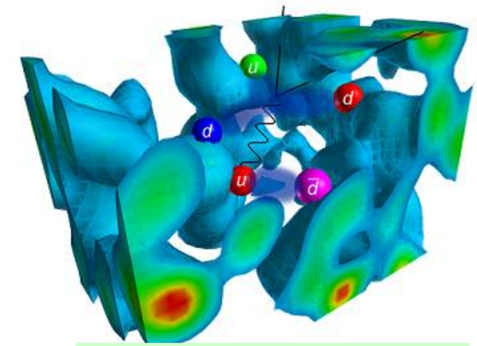




Spin

TMDs





Lattice QCD

Question: is xFitter the best framework?

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APPENDIX

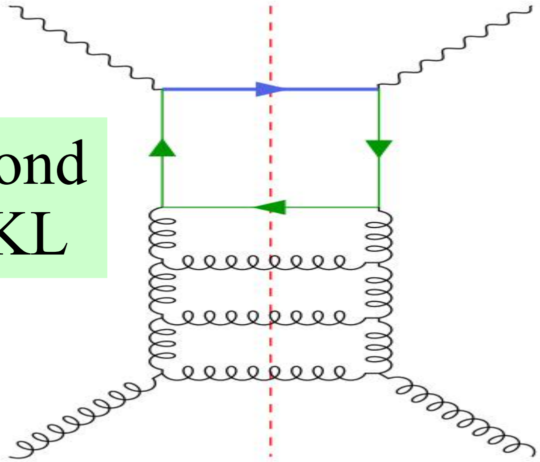
- **xFitter Material & Examples :**
  - Snowmass xFitter reference document
  - Pion PDF & Fragmentation functions
  - Selected example plots
  - ApplGrid Interface (Including Nuclear PDFs)

- **Fantomas**:
  - Using Bezier curves for PDF parameterization

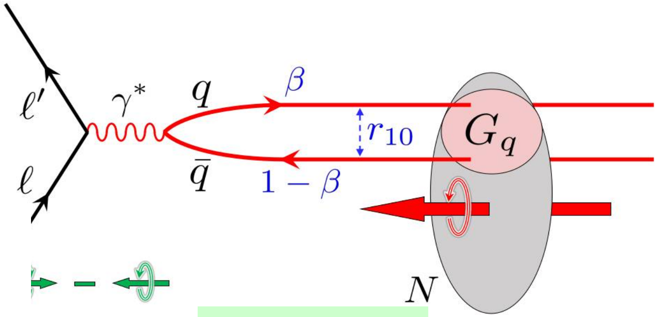
- **xFitter Tutorials:**
  - xFitter VirtualBox downloads
  - xFitter Docker & Singularity

Possible direction … *for discussion* ...

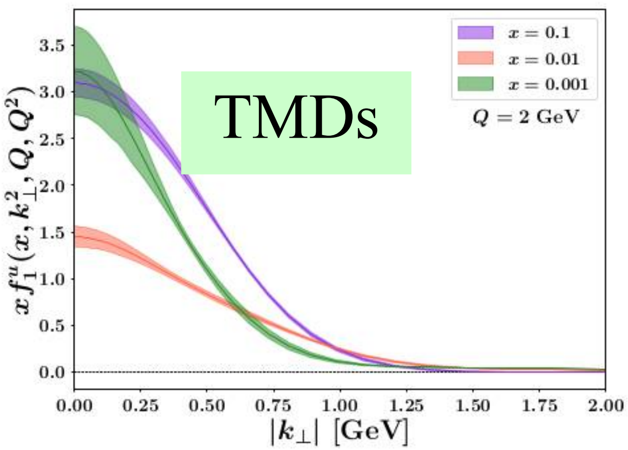
we have the experts here



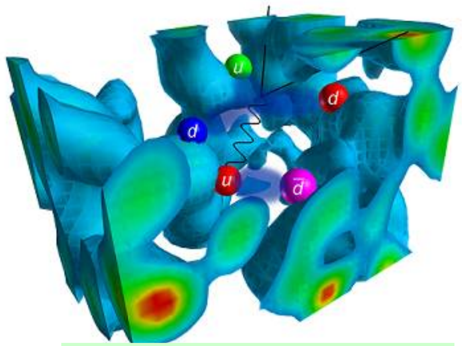
Beyond BFKL



Spin



TMDs



Lattice QCD

Question: is xFitter the best framework?

Initial state WG
Improve the initial conditions for evolution for unpolarized and polarized observables.

Small x evolution + NLO calculations WG
Non-linear evolution at NLO and beyond, computation and implementation of impact factors

Spin WG
Analyze role saturation in the polarized observables. Elucidate the role of chiral anomaly in small x helicity evolution.

Final states WG
Construct a framework for hadronization in a saturated environment, including development of MC generator based on CGC calculations

Global analysis WG
To establish saturation, perform comprehensive global analysis quantifying and minimizing uncertainties, extracting universal building blocks of high energy factorization.

APPENDIX

xFitter

Resources

xFitter: An Open Source QCD Analysis Framework

A resource and reference document for the Snowmass study

(xFitter Collaboration)*

The xFitter Developers' Team:, H. Abdolmaleki, S. Amoroso, V. Bertone, M. Botje, D. Britzger, S. Camarda, A. Cooper-Sarkar, J. Fiaschi, F. Giuli, A. Glazov, C. Gwenlan, F. Hautmann, H. Jung, A. Kusina, A. Luszczak, T. Mäkelä, I. Novikov, F. Olness, R. Sadykov, P. Starovoitov, M. Sutton, and O. Zenaiev

https://arxiv.org/abs/2206.12465

We provide an overview of the xFitter open-source software package, review the general capabilities of the program, and highlight applications relevant to the Snowmass study. An updated version of the program (2.2.0) is available on CERN GitLab, a and this has been updated to a C++ codebase with enhanced and extended features. We also discuss some of the ongoing and future code developments that may be useful for precision studies. We survey recent analyses performed by the xFitter developers' team including: W and Z production, photon PDFs, Drell-Yan forward-backward asymmetry studies, resummation of small-x contributions, heavy quark production, constraints on the strange PDF, determination of the pion PDF, and determination of the pion Fragmentation Functions. Finally, we briefly summarize selected applications of xFitter in the literature. The xFitter program is a versatile, flexible, modular

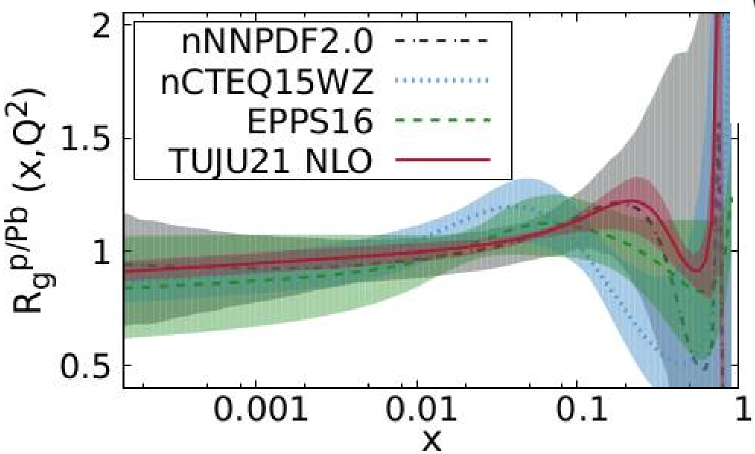
xFitter Nuclear Code

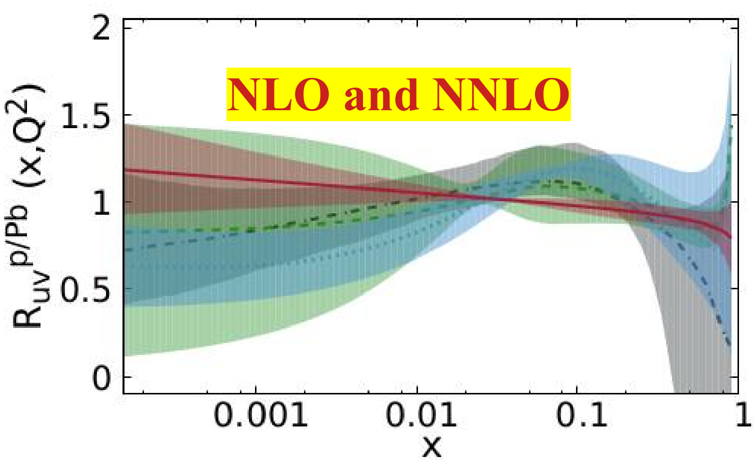
Nuclear xFitter: *(Daiquiri)*

PHYSICAL REVIEW D **100**, 096015 (2019)

Open-source QCD analysis of nuclear parton distribution functions at NLO and NNLO

Marina Walt[1,*] Ilkka Helenius[2,3,†] and Werner Vogelsang[1,‡]





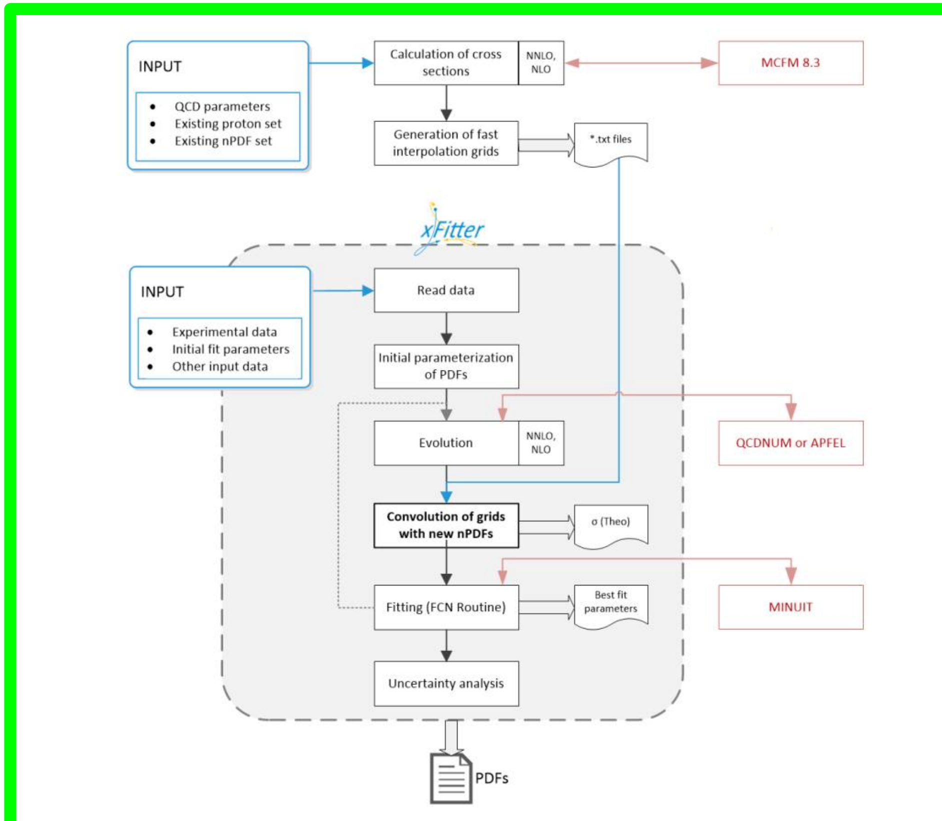


FIG. 1: Schematic view of the high-level xFITTER functionalities as relevant for Drell-Yan and $W^{\pm}$, Z boson production processes, with the newly implemented convolution routine in xFITTER as used for the nPDF fit TUJU21. xFITTER logo credited from [60].

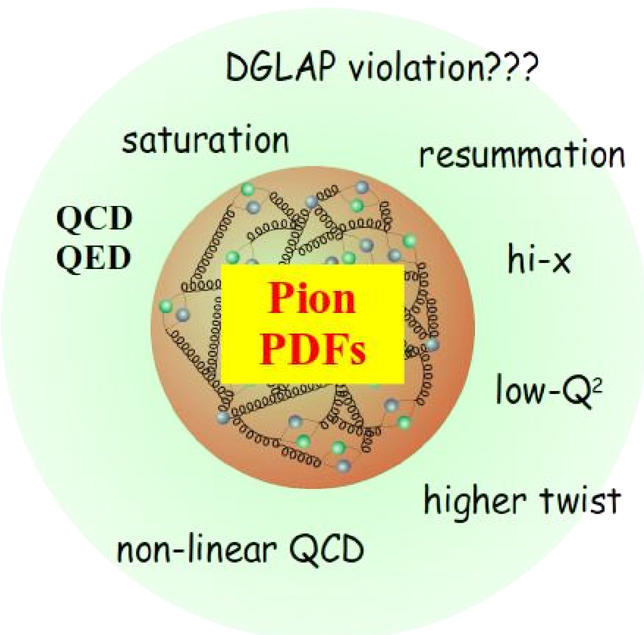
DESY. xFitter

Volunteers Welcome

Date	Version	Files	Remarks
 02/2020	**2.0.1N Nuclear Daiquiri**	xfitter-2.0.1N.tgz	Nuclear xFitter based on OldFashioned 2.0.1

xFitter Pion Fit

Phys.Rev.D 102 (2020) 1, 014040



Special thanks to: Ivan Novikov, Alexander Glazov, Oleksandr Zenaiev

Parton Distribution Functions of the Charged Pion Within The xFitter Framework

xFitter Developers' team: Ivan Novikov,[1,2,*] Hamed Abdolmaleki,[3] Daniel Britzger,[4] Amanda Cooper-Sarkar,[5] Francesco Giuli,[6] Alexander Glazov,[2,†] Aleksander Kusina,[7] Agnieszka Luszczak,[8] Fred Olness,[9] Pavel Starovoitov,[10] Mark Sutton,[11] and Oleksandr Zenaiev[12]

xFitter: Phys.Rev.D 102 (2020) 1, 014040

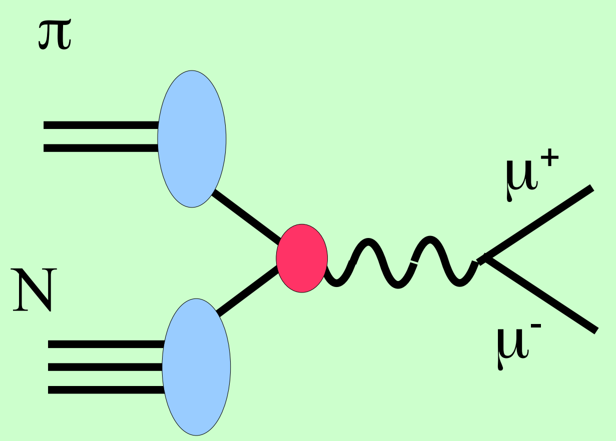
xFitter Meson PDFs

xFitter: open-source framework for global fits to meson PDFs

https://www.xfitter.org/

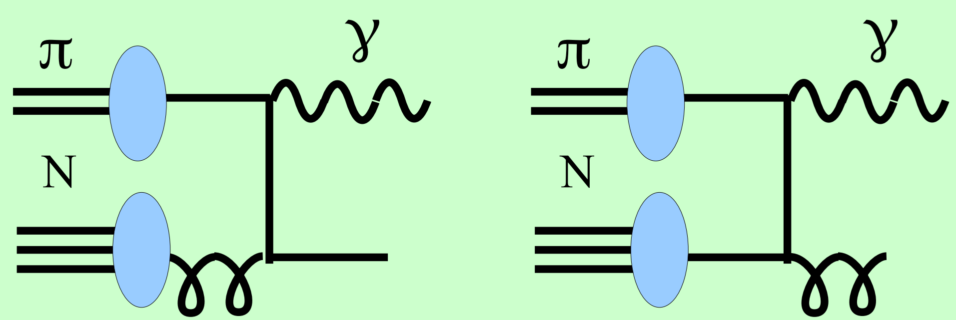
DESY. xFitter

Experiment	χ^2/N_{points}
E615	206/140
NA10 (194 GeV)	107/67
NA10 (286 GeV)	95/73
WA70	64/99



E615 & NA10

Pions on Tungsten



WA70

Pions on Proton

Parton Distribution Functions of the Charged Pion Within The xFitter Framework

xFitter Developers' team: Ivan Novikov,[1,2,*] Hamed Abdolmaleki,[3] Daniel Britzger,[4] Amanda Cooper-Sarkar,[5] Francesco Giuli,[6] Alexander Glazov,[2,†] Aleksander Kusina,[7] Agnieszka Luszczak,[8] Fred Olness,[9] Pavel Starovoitov,[10] Mark Sutton,[11] and Oleksandr Zenaiev[12]

e-Print: 2002.02902 [hep-ph]

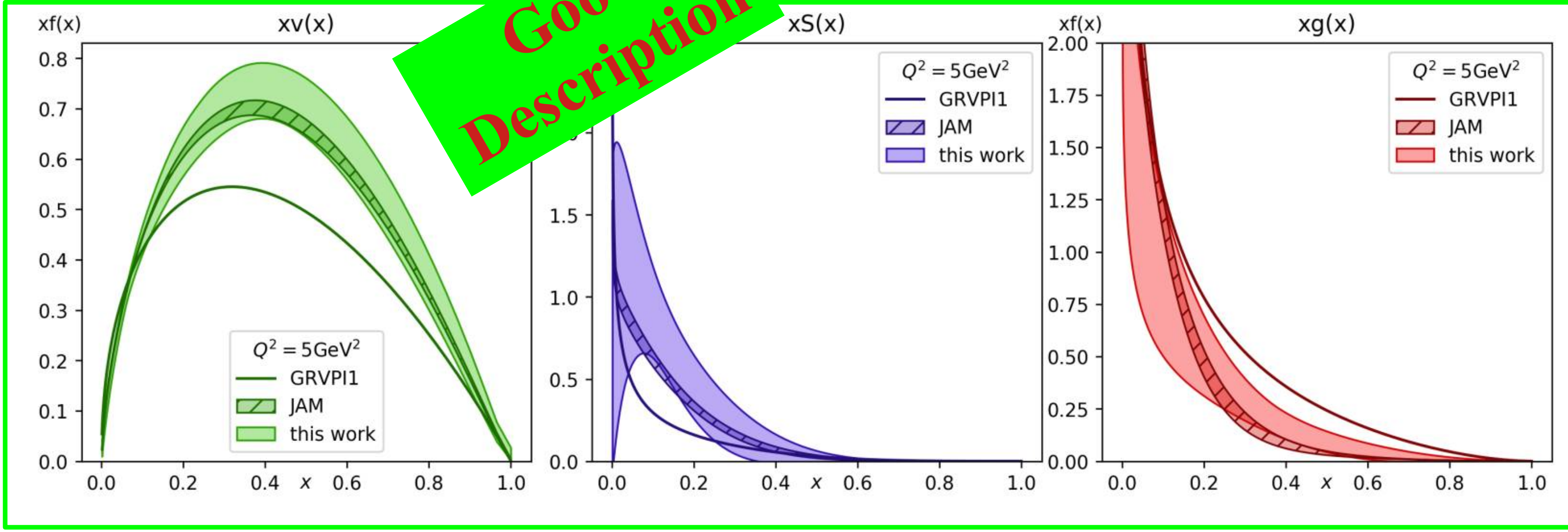
xFitter Pion PDFs

Experiment	Normalization uncertainty	χ^2/N_{points}
E615	15 %	206/140
NA10 (194 GeV)	6.4%	107/67
NA10 (286 GeV)	6.4%	95/73
WA70	32%	64/99

$$xv(x) = A_v x^{B_v}(1-x)^{C_v}(1+D_v x^{\alpha}),$$
$$xS(x) = A_S x^{B_S}(1-x)^{C_S}/\mathcal{B}(B_S+1, C_S+1),$$
$$xg(x) = A_g(C_g+1)(1-x)^{C_g},$$

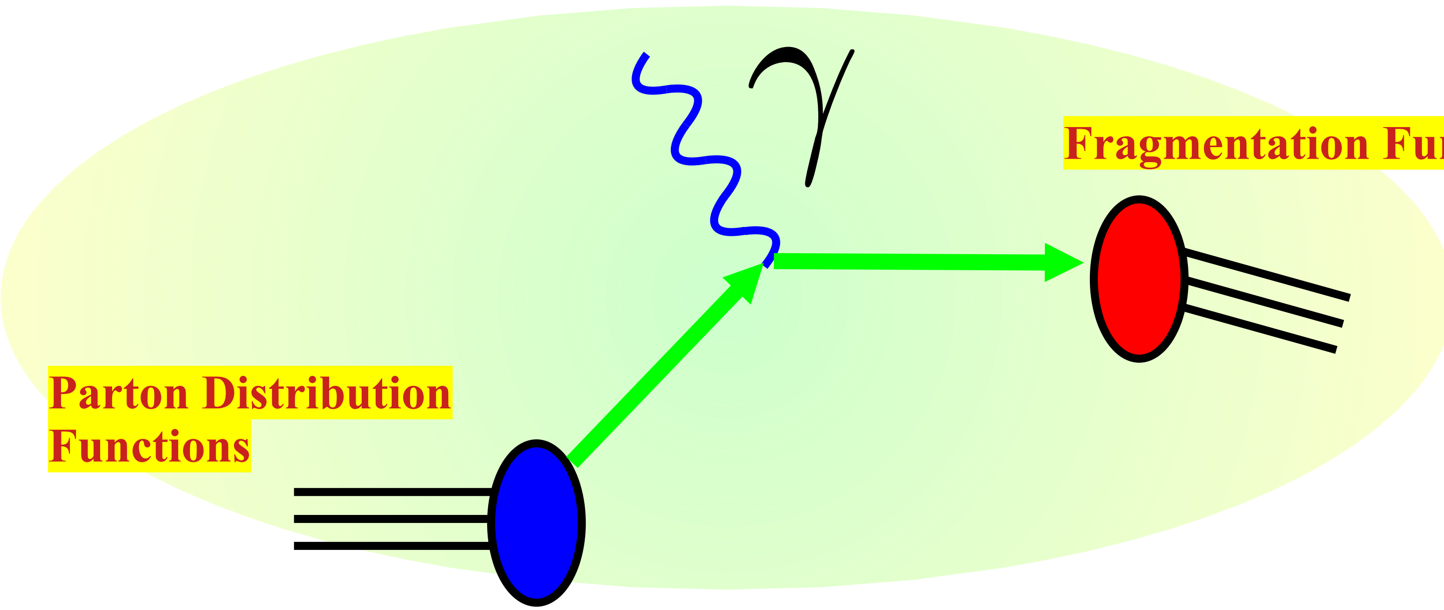
	$\langle xv\rangle$	$\langle xS\rangle$	$\langle xg\rangle$	Q^2 (GeV^2)
JAM [31]	0.54 ± 0.01	0.16 ± 0.02	0.30 ± 0.02	1.69
JAM (DY)	0.60 ± 0.01	0.30 ± 0.05	0.10 ± 0.05	1.69
this work	0.55 ± 0.06	0.26 ± 0.15	0.19 ± 0.16	1.69
Lattice-3 [18]	0.428 ± 0.030			4
SMRS [25]	0.47			4
Han et al. [44]	0.51 ± 0.03			4
GRVPI1 [27]	0.39	0.11	0.51	4
Ding et al. [11]	0.48 ± 0.03	0.11 ± 0.02	0.41 ± 0.02	4
this work	0.50 ± 0.05	0.25 ± 0.13	0.25 ± 0.13	4
JAM	0.48 ± 0.01	0.17 ± 0.01	0.35 ± 0.02	5
this work	0.49 ± 0.05	0.25 ± 0.12	0.26 ± 0.13	5
Lattice-1 [16]	0.558 ± 0.166			5.76
Lattice-2 [17]	0.48 ± 0.04			5.76
this work	0.48 ± 0.05	0.25 ± 0.12	0.27 ± 0.13	5.76
WRH [26]	0.434 ± 0.022			27
ChQM-1 [13]	0.428			27
ChQM-2 [15]	0.46			27
this work	0.42 ± 0.04	0.25 ± 0.10	0.32 ± 0.10	27
SMRS [25]	0.49 ± 0.02			49
this work	0.41 ± 0.04	0.25 ± 0.09	0.34 ± 0.09	49

Good Description



Pion Fragmentation Functions

Phys.Rev.D 104 (2021) 5, 056019



xFitter

Hamed Abdolmaleki, Maryam Soleymaninia, Hamzeh Khanpour

PHYSICAL REVIEW D **104,** 056019 (2021)

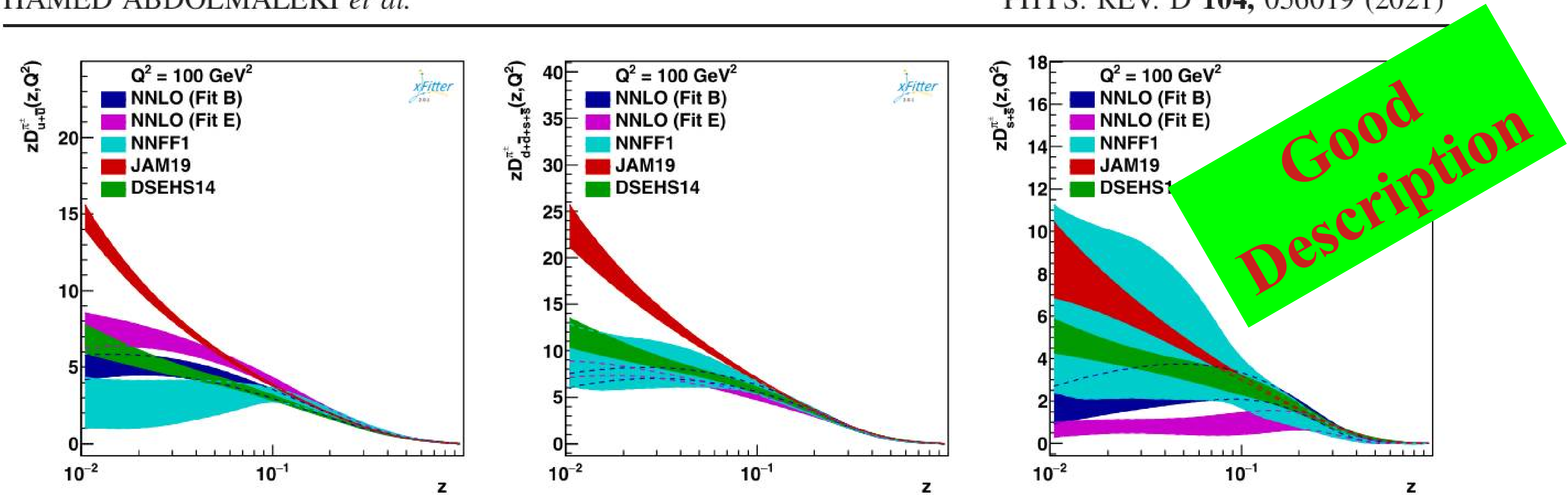
QCD analysis of pion fragmentation functions in the xFitter framework

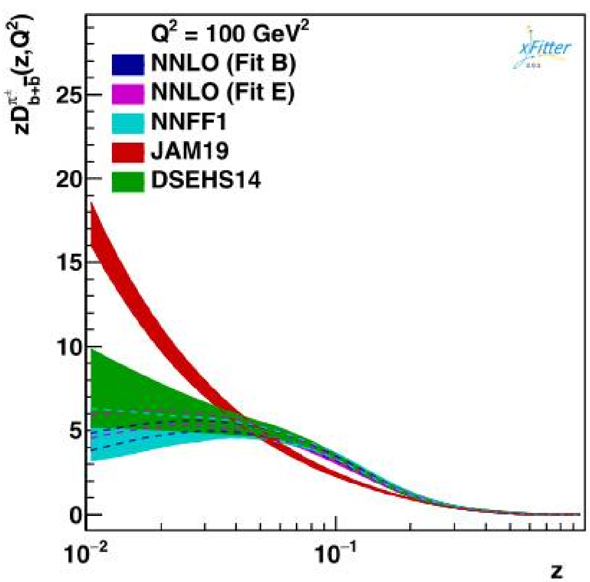
Hamed Abdolmaleki,[1,*] Maryam Soleymaninia,[1,†] Hamzeh Khanpour,[1,2,3,‡] Simone Amoroso,[4,§] Francesco Giuli,[5,∥] Alexander Glazov,[4,¶] Agnieszka Luszczak,[6,**] Fredrick Olness,[7,††] and Oleksandr Zenaiev[8,‡‡]

(xFITTER Developers' Team:)

xFitter: Comparisons: … good overall … *more work needed*

HAMED ABDOLMALEKI *et al.* PHYS. REV. D **104,** 056019 (2021)





Good description of the data in general

Deviations in the low-z region

BELLE and BaBar data pull in opposite directions

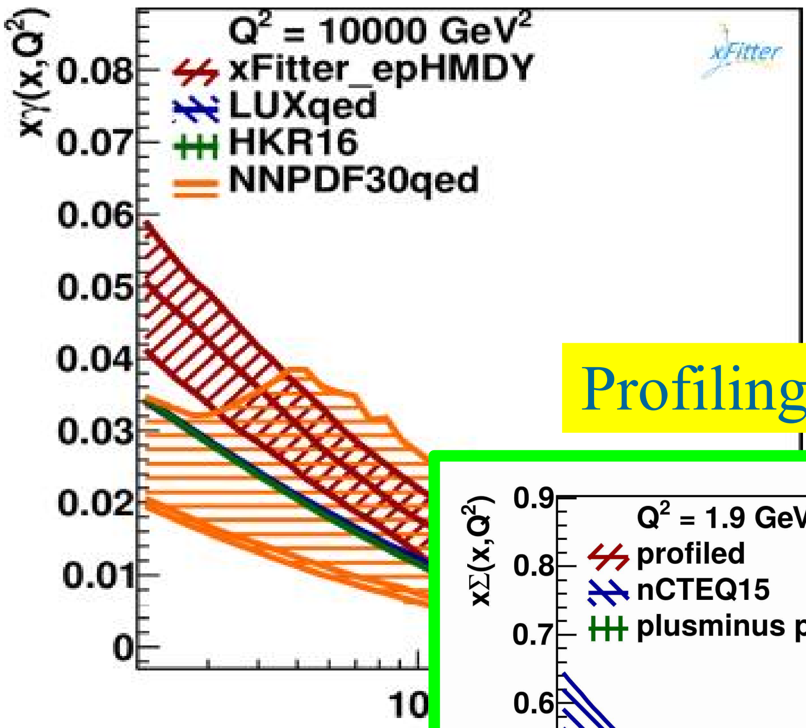
Clearly further investigation is warranted

xFitter Selected Examples

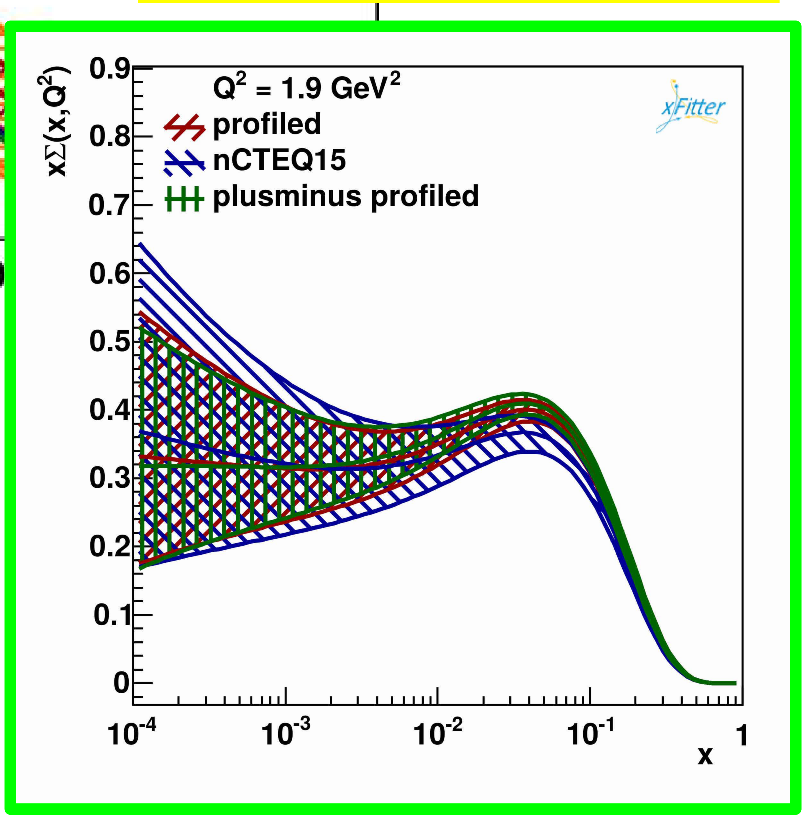
xFitter Capabilities

www.xFitter.org

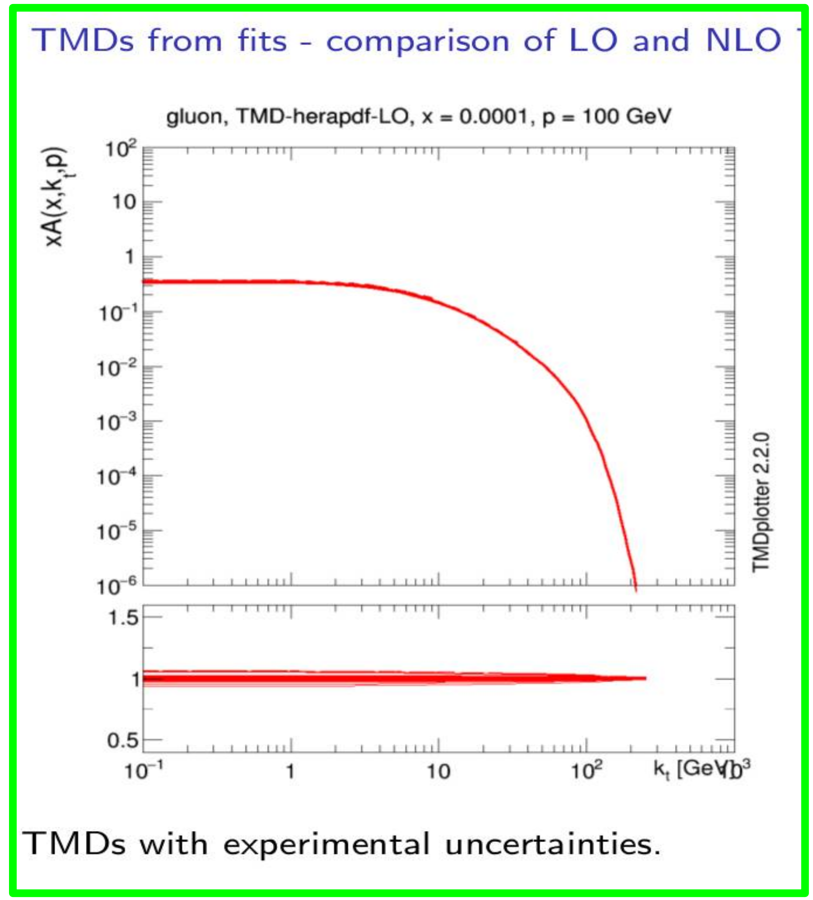
Photon PDF



Profiling Lead PDFs

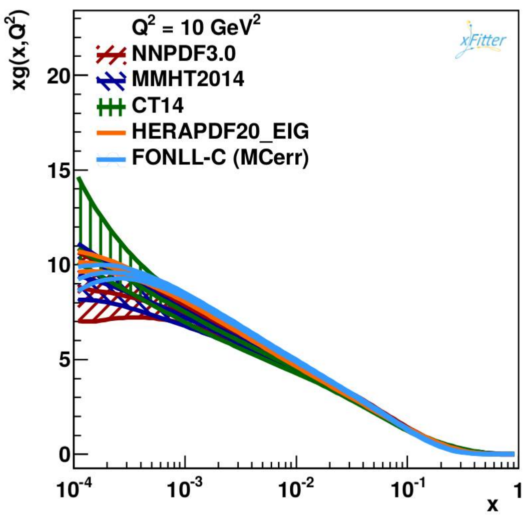


TMD (uPDFs) in xFitter

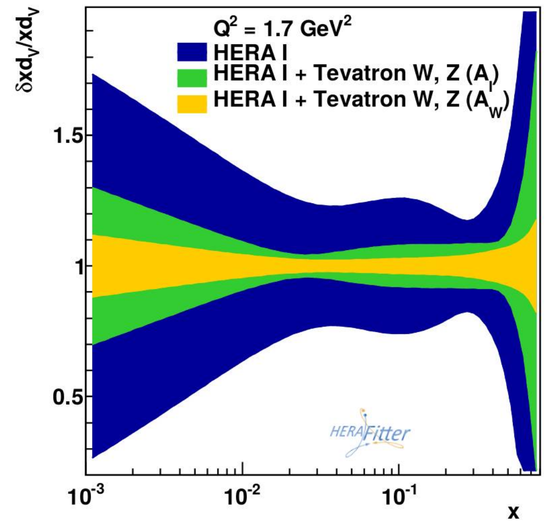


more xFitter Capabilities

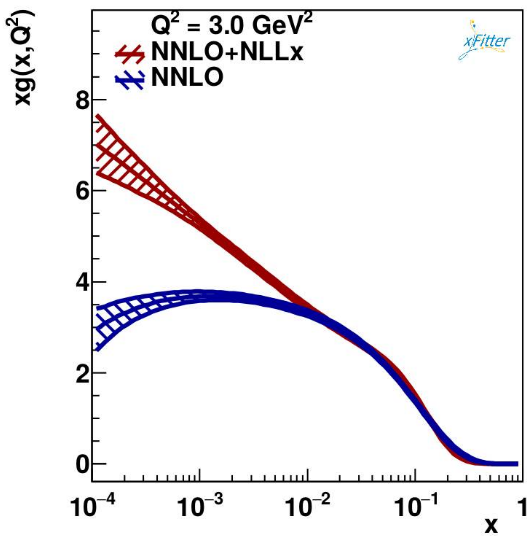
www.xFitter.org



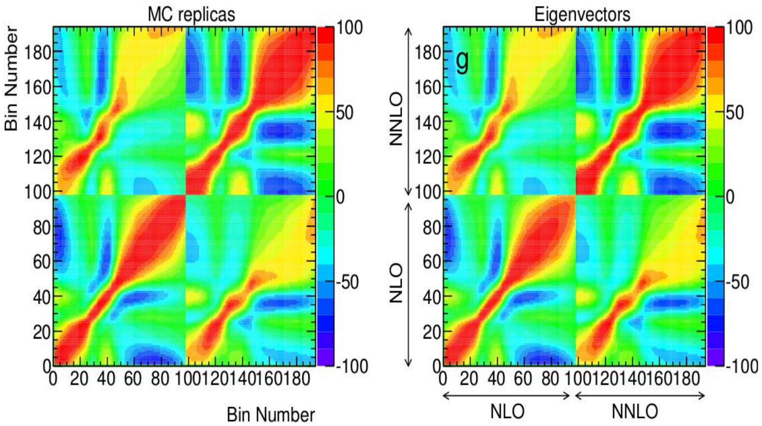
Multiple Heavy Quark Models



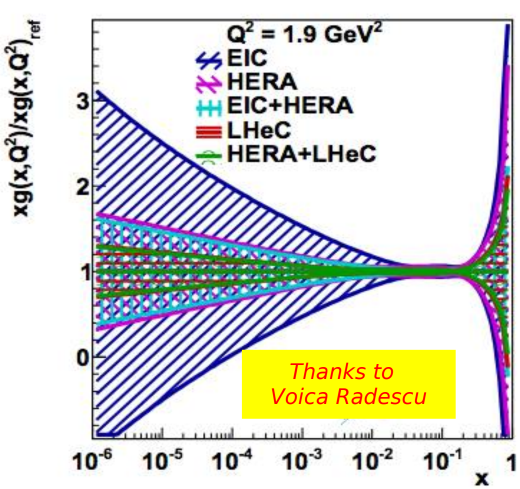
Profiling of W/Z Data



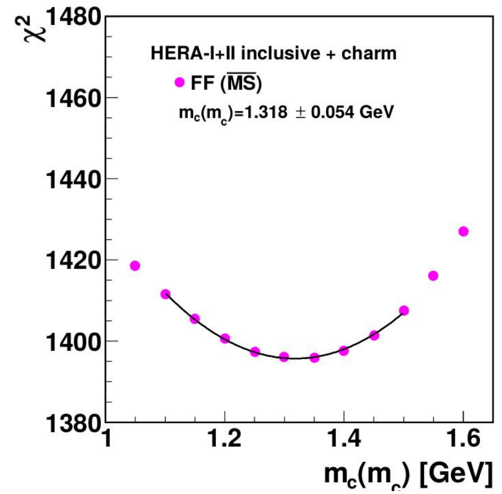
NNLx Resummation @ Small x



Correlation Coefficients



Sensitivity Studies

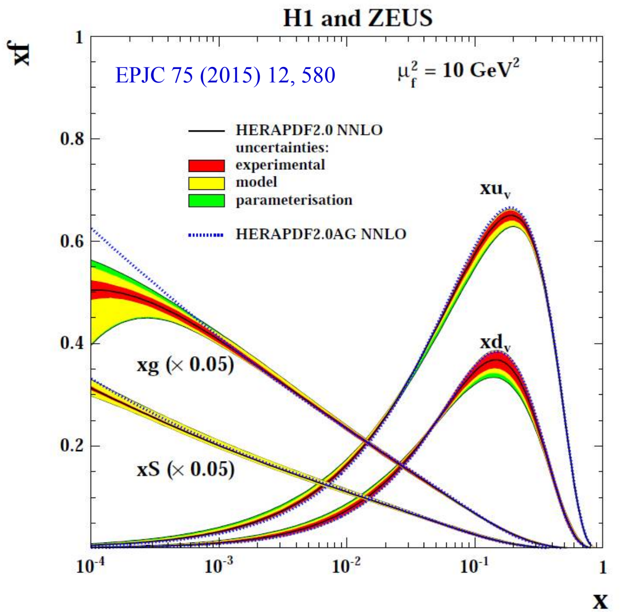


Pole & MS-Bar Running Mass

more xFitter Capabilities

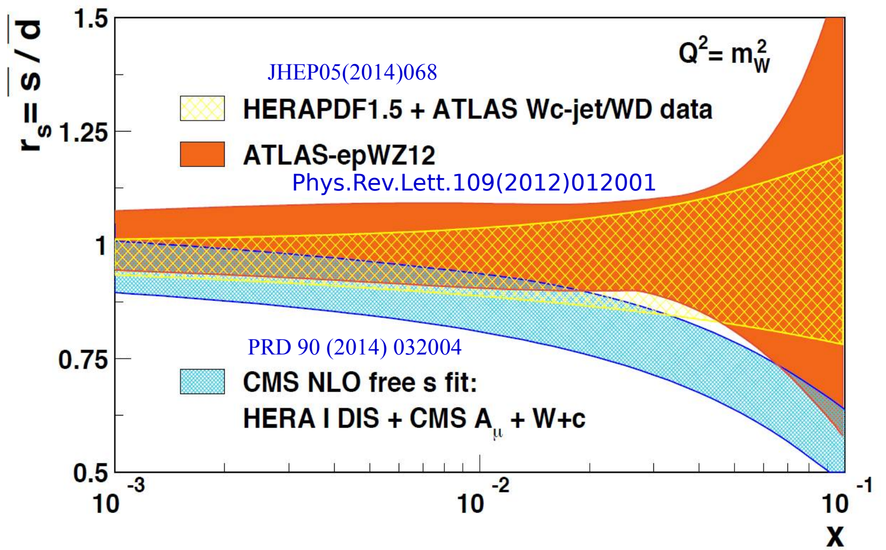
www.xFitter.org

DIS inclusive processes in *ep*

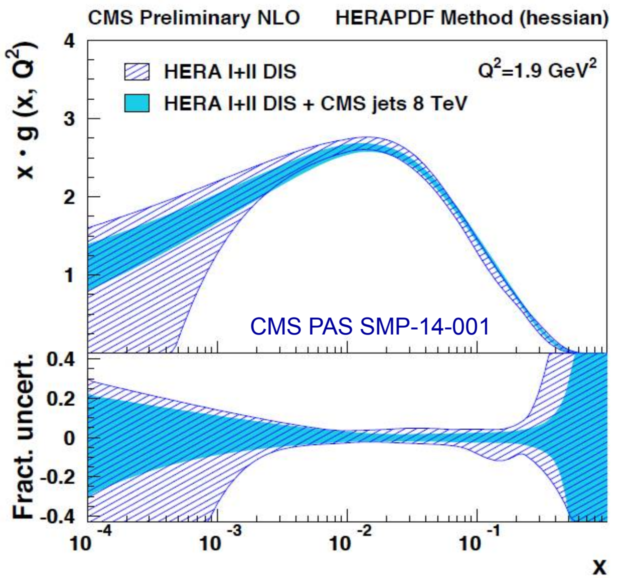


Drell-Yan processes (*pp, ppbar*)

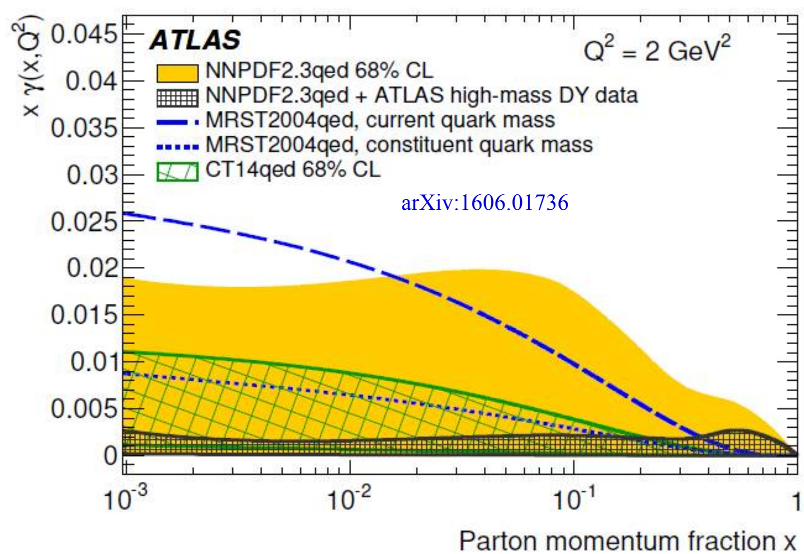
→ strange quark density determination



Jet production (*ep, pp, ppbar*)



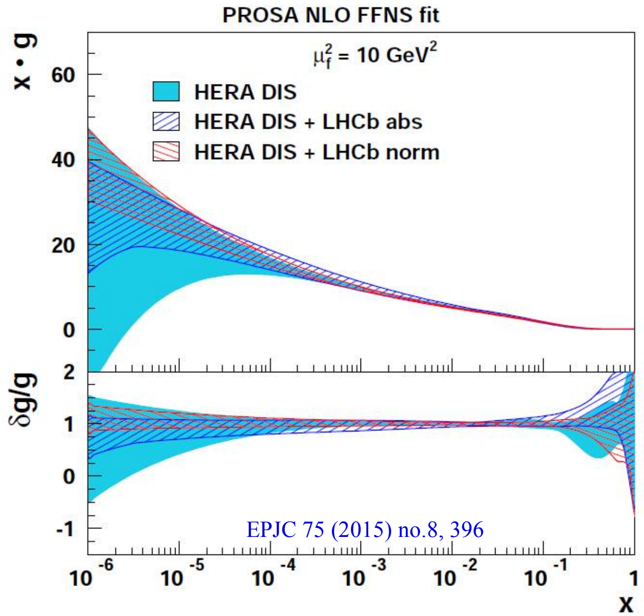
DY data sensitivity to photon PDF



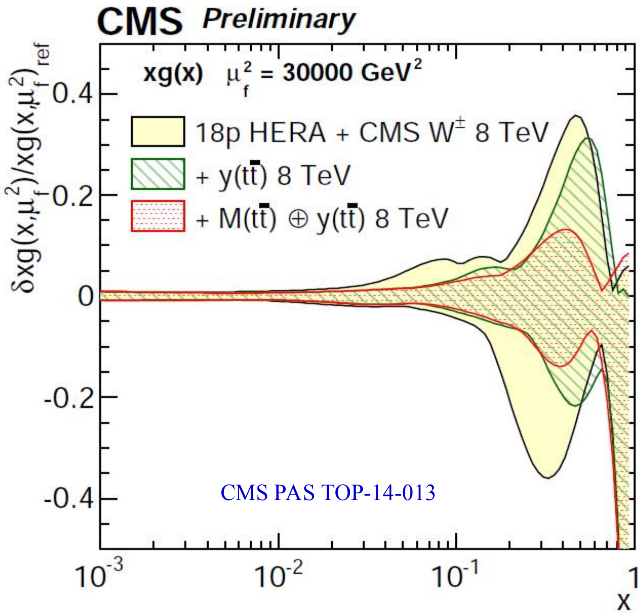
more xFitter Capabilities

www.xFitter.org

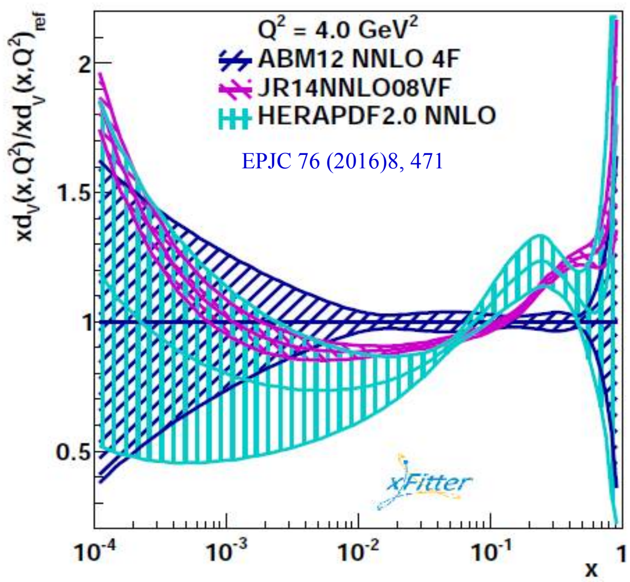
Heavy Quark production (*ep, pp, ppbar*)



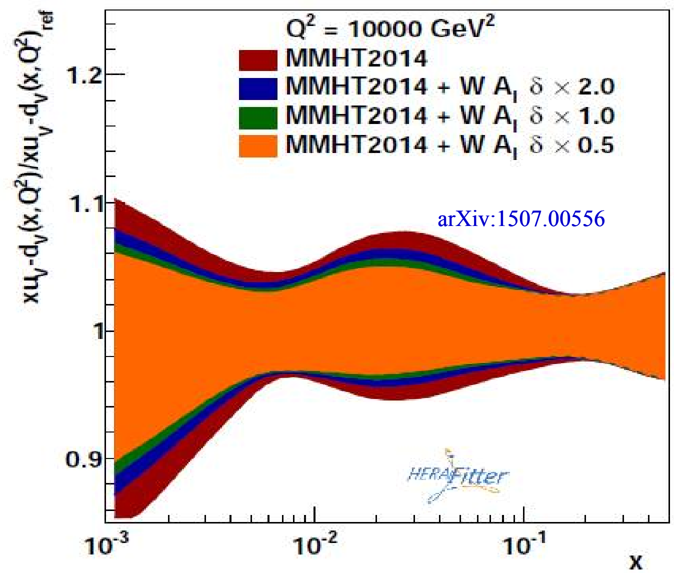
Top-quark production (*pp, ppbar*)



Evaluation of modern PDFs (benchmarking)



PDF4LHC report (benchmarking)



xFitter
Interface to
ApplGrid
Grid Technology

special thanks to Mark Sutton

APPLGRID: Grid Technology: … to NLO and Beyond ...

APPLGRID method

Eur.Phys.J.C66:503-524,2010.

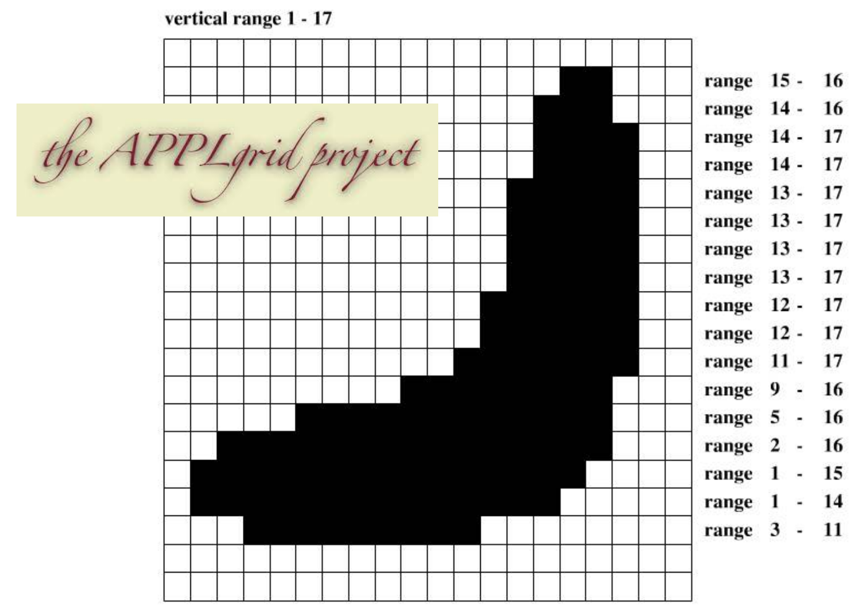
- Step 1 (long run): Collect perturbative weights to grids .
  - binning (x_1, x_2, Q^2)
  - interpolation
  - initial flavours decomposition : $13 \times 13 \to \mathcal{L}$ $(\mathcal{L} \sim 10)$

$$\frac{d\hat{\sigma}^{ij}_{(p)}}{dX}(x_1, x_2, Q^2_F, Q^2_R;\ S) \xrightarrow{3D-grid} w^{(p)(l)}(x_1^m, x_2^n, Q^{2^k})\ (Q^2_R \equiv Q^2_F)$$

- Step 2 ($\sim$ 10–100 ms): Convolute grid with PDF's .
  - integral $\to$ sum
  - any coupling, PDF

$$\frac{d\sigma}{dX} = \sum_p \sum_{l=0}^{L} \sum_{m,n,k} w^{(p)(l)}_{m,n,k} \left(\frac{\alpha_s(Q^2_k)}{2\pi}\right)^{p_l} F^{(l)}\left(x_{1\,m}, x_{2\,n}, Q^2_k\right)$$

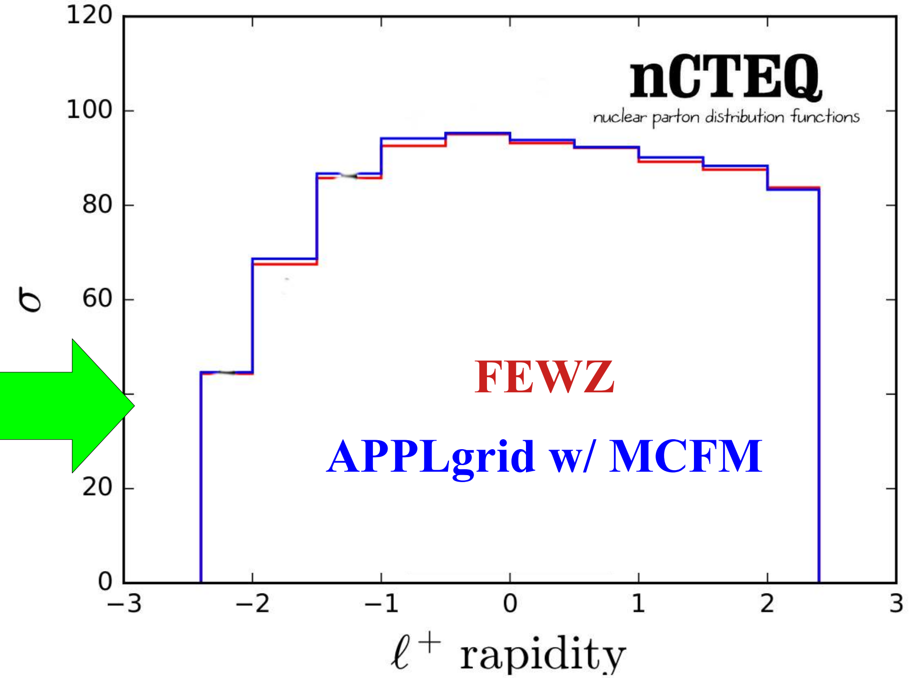
Pavel Starovoitov (Kirchhof-Institut für Physik) APPLGRID project zFitter@JINR 4 / 18



Validation:

Compare Grid to Full Calculation

Works for both proton & **nuclear**



nCTEQ Collaboration
Eur.Phys.J.C 80 (2020) 10, 968

TUTORIALS

VirtualBox & Docker

Past tutorials and VirtualBox images

https://smu.box.com/s/alwdhtjsl6dn23o4j9112oyomea5mog5

All Files › XFITTER › VBOX

NAME ↑

2016 Tutorial — 2016 CTEQ-DESY School Tutorials

2018 Tutorial — 2018 CTEQ School Tutorials (Based on 2016)

VBox Ubuntu18 — VirtualBox with v.2.2

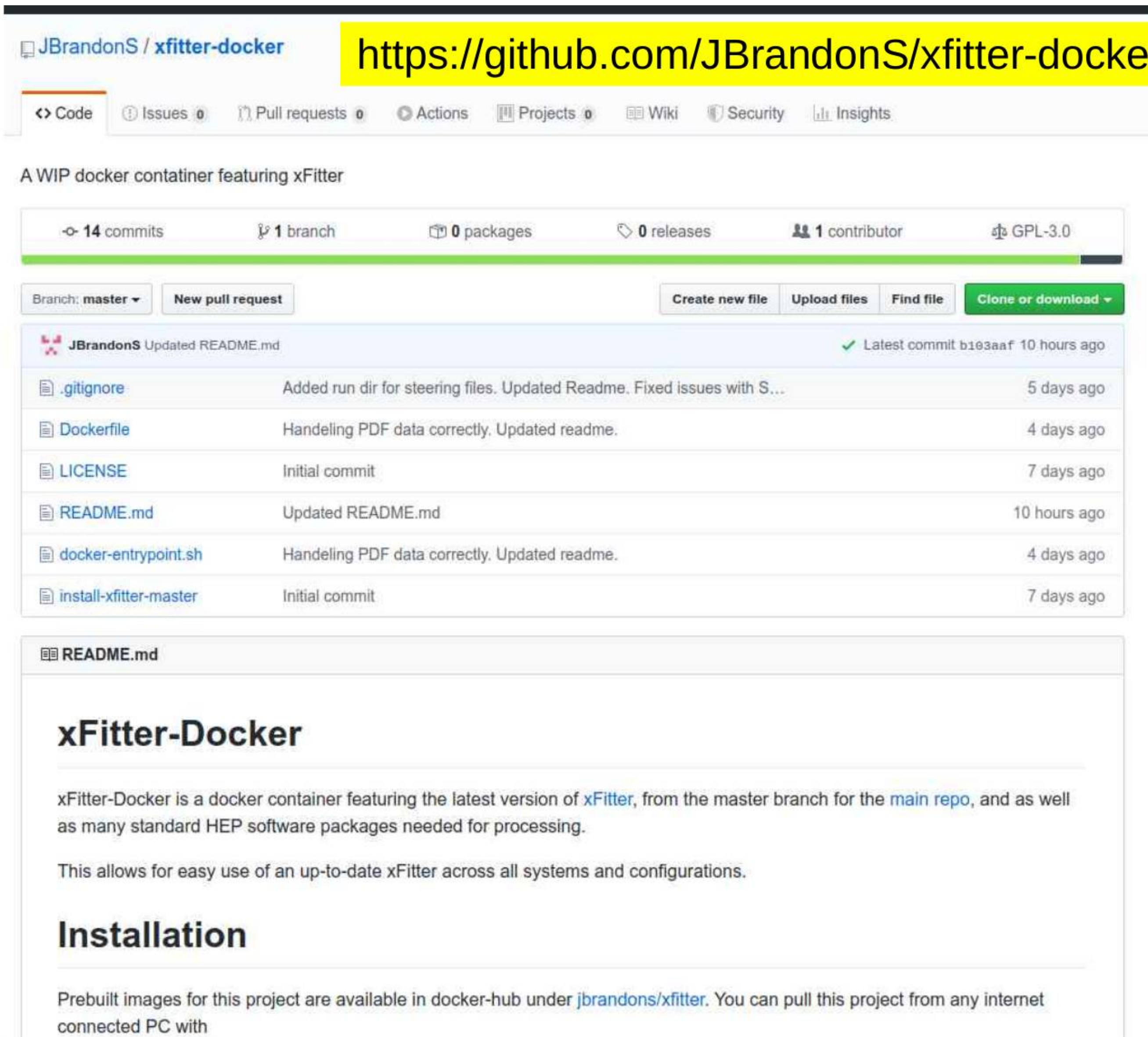
VBox Ubuntu22 — VirtualBox with v.2.2

bug: ./bin/xfitter-draw ./output **--no-logo**

pw: xfitter2023

Old version: xFitter 2.1 Docker / Singularity

https://github.com/JBrandonS/xfitter-docker



UPDATE:
xFitter in
Docker & Singularity
notes

Fred Olness
22 April 2020

Brandon
Stevenson

Lucas
Kotz

Old version: xFitter 2.1 Docker / Singularity

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.

Old version: xFitter 2.1 Docker / Singularity

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`

Fantomas Project

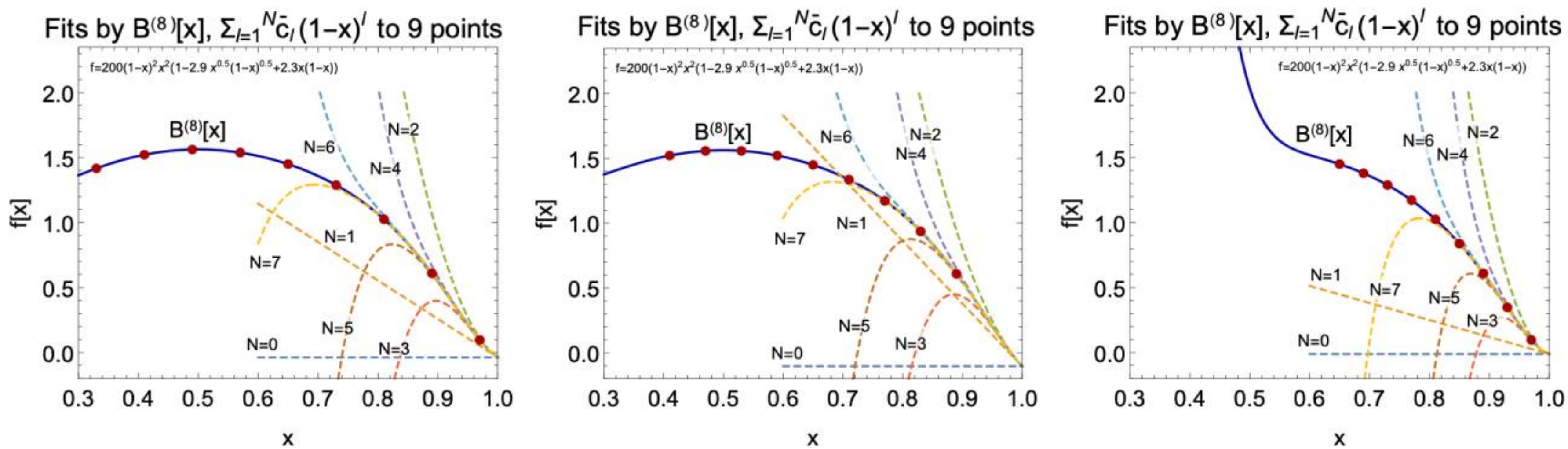
Using a Bezier curve for the PDF parameterization in xFitter

Fantômas4QCD: advanced polynomial parametrisations

L. Kotz, M. Chavez, A. Courtoy, P. Nadolsky, F. Olness, V. Purohit, 2023

Parametrize PDFs using **Bézier curves** $B^{(n)}(x;a) = \sum_{k=0}^{n} a_{k+2} \binom{n}{k} x^k (1-x)^{n-k}$

A metamorph $f(x) \equiv a_0 \underbrace{x^{a_1}(1-x)^{a_2}}_{\text{carrier}} B^{(n)}(x^{\alpha_x};a)$



Main idea: **<u>New parameterization methods for mesons PDF fits</u>**

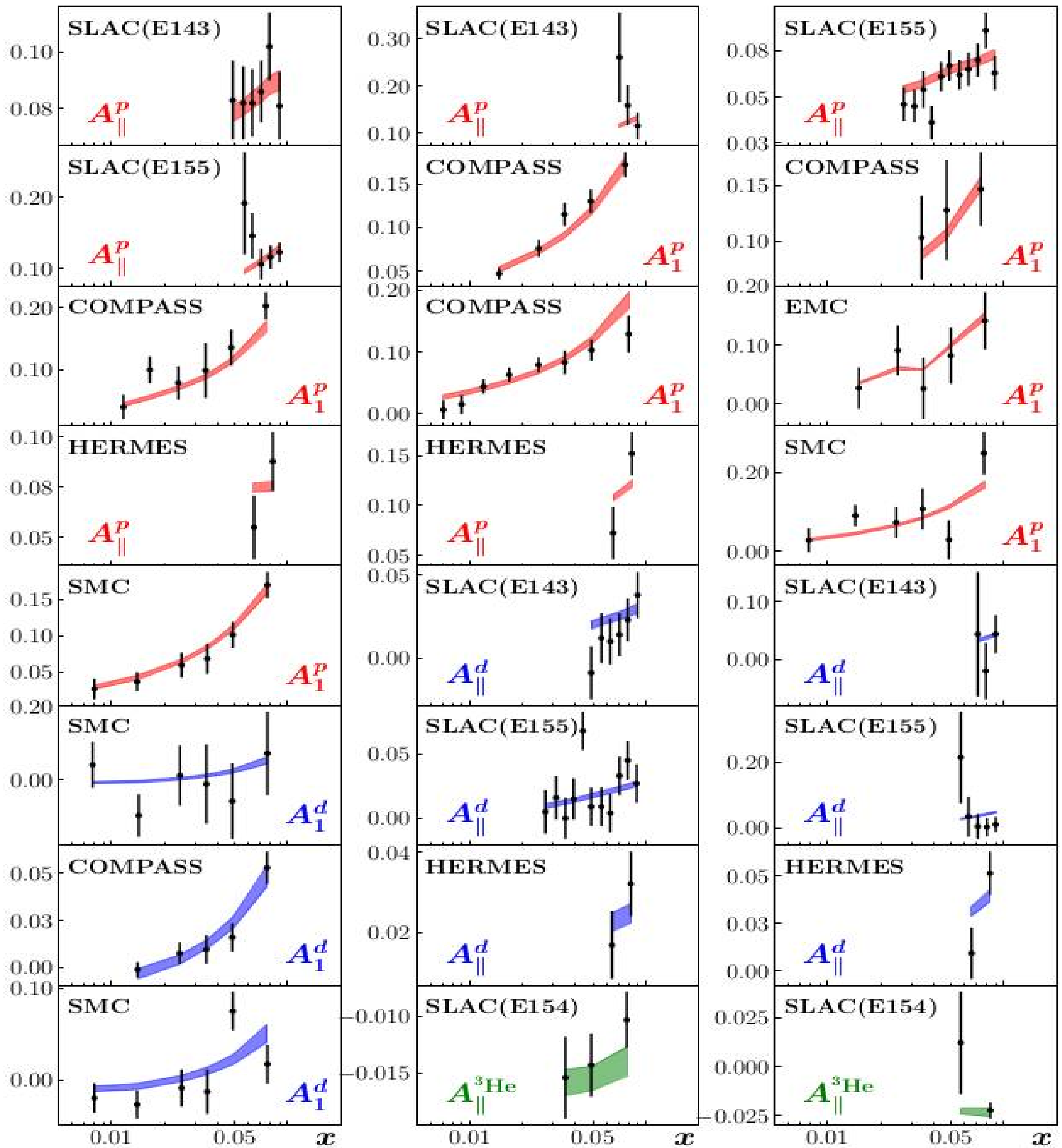
The new modular xFitter 2.2 version was a HUGE help for this project

Backup

First analysis of world polarized DIS data with small-x helicity evolution

Daniel Adamiak,[1,*] Yuri V. Kovchegov,[1,†] W. Melnitchouk,[2]
Daniel Pitonyak,[3,‡] Nobuo Sato,[2,§] and Matthew D. Sievert[4,¶]

JLAB-THY-21-3318



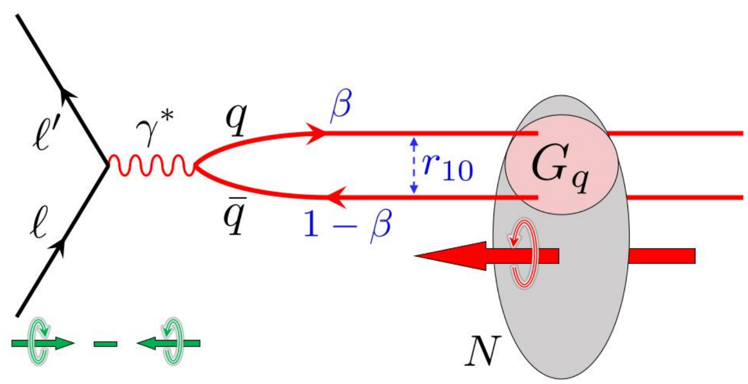
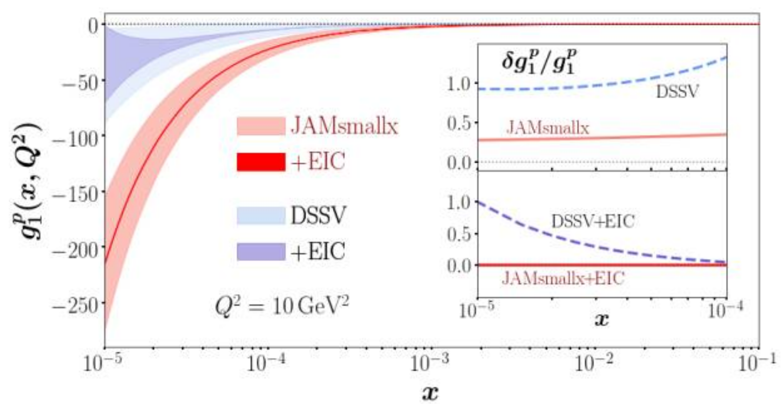
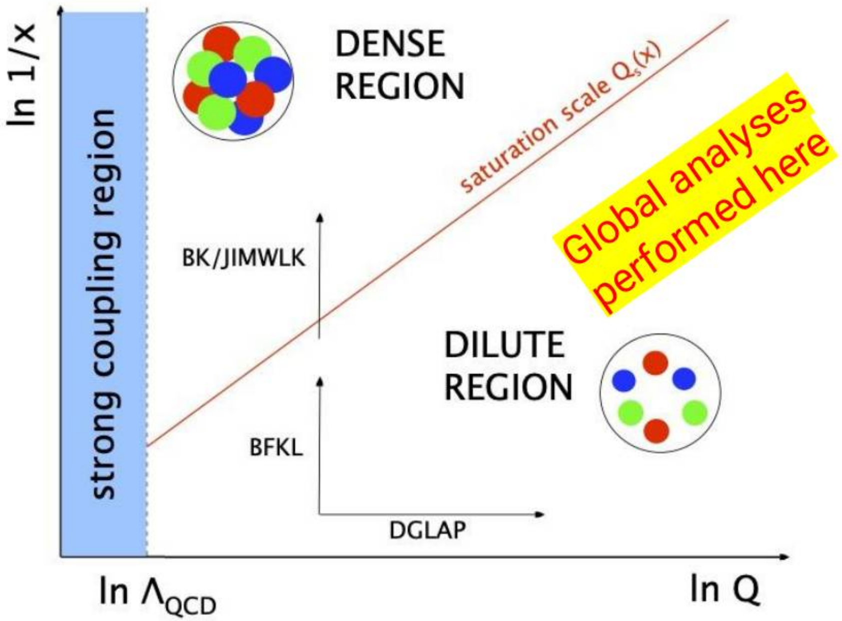


Illustration of polarized DIS at small x.



Jefferson Lab Angular Momentum (JAM) Collaboration

Global analysis: Exploring QCD in extreme limits



Challenge:

- Current PDF analyses use "standard" DGLAP
- Extend analyses into extreme limits of QCD
- Include additional effects into PDF fit

Method:

xFitter: open-source,
modular PDF framework

Goal:

To unequivocally establish saturation, perform comprehensive global analysis quantifying and minimizing uncertainties, extracting universal building blocks of high energy factorization.

Small-x evolution of the gluon GPD E_g

Yoshitaka Hatta[1,2] and Jian Zhou[3]

[1] *Physics Department, Building 510A, Brookhaven National Laboratory, Upton, NY 11973, USA*
[2] *RIKEN BNL Research Center, Brookhaven National Laboratory, Upton, NY 11973, USA*
[3] *Key Laboratory of Particle Physics and Particle Irradiation (MOE), Institute of Frontier and Interdisciplinary Science, Shandong University (QingDao), 266237, China*

We study the small-x evolution equation for the gluon generalized parton distribution (GPD) E_g of the nucleon. It is shown that E_g at vanishing skewness exhibits the Regge behavior identical to the BFKL Pomeron despite its association with nucleon helicity-flip processes. We also consider the effect of gluon saturation and demonstrate that E_g gets saturated in the same way as its helicity-nonflip counterpart H_g. Our result has a direct impact on the modeling of E_g as well as the small-x contribution to nucleon spin sum rules.

PROCEEDINGS OF SCIENCE

Global extraction of unpolarized quark TMDs at N^{3}LL

Alessandro Bacchetta,[a,b] Valerio Bertone,[c] Chiara Bissolotti,[a,d] Giuseppe Bozzi,[e,f,*] Matteo Cerutti,[a,b] Fulvio Piacenza,[a] Marco Radici[b] and Andrea Signori[g,h]

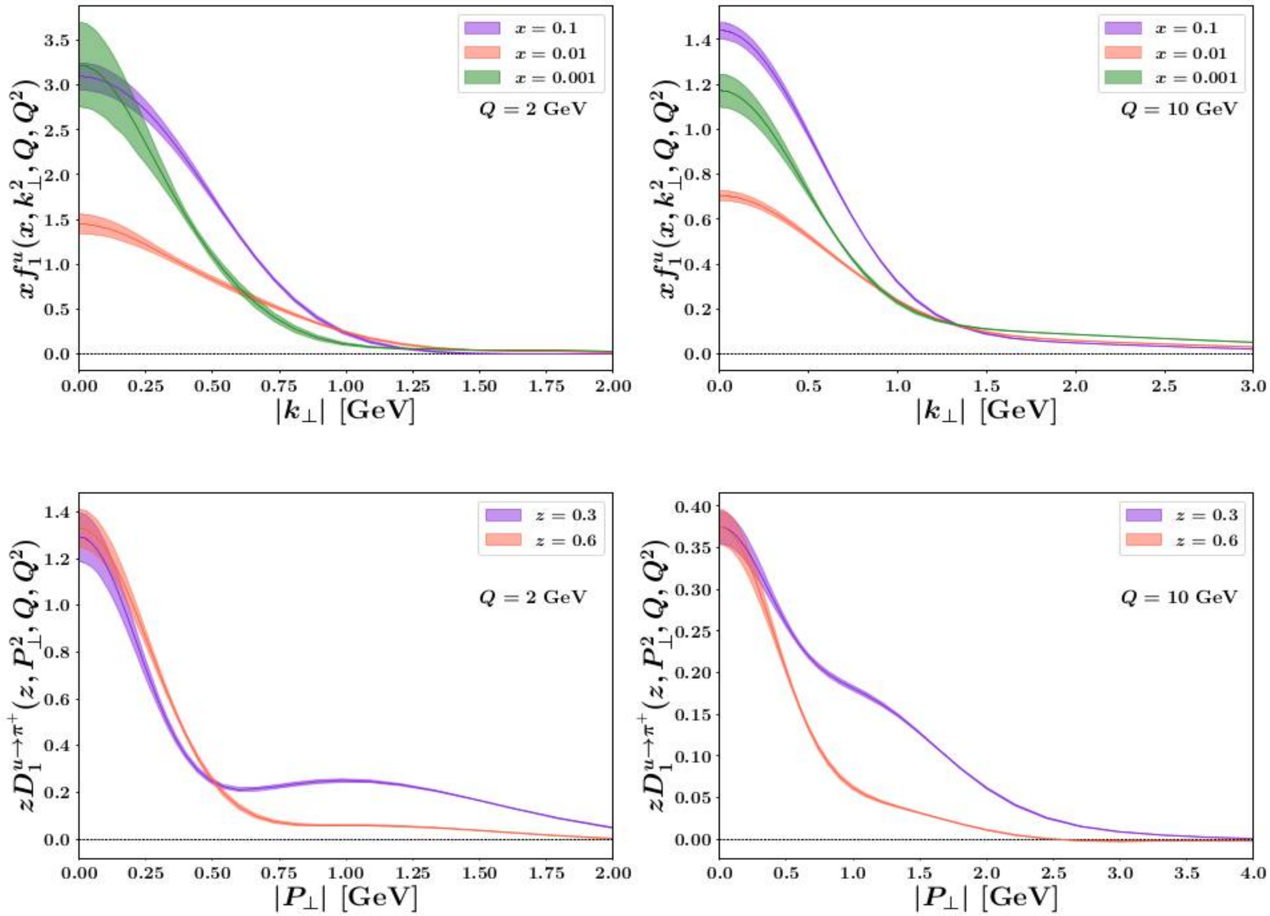
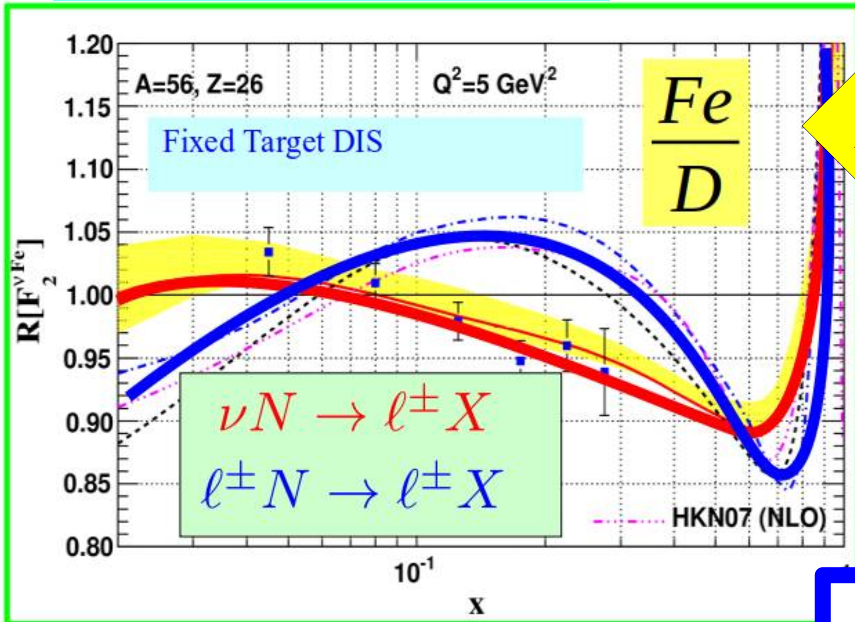


Figure 2: *Upper plots:* the TMD PDF of the up quark in a proton at $Q = 2$ GeV (left panel) and 10 GeV (right panel) as a function of the partonic transverse momentum $|k_\perp|$ for $x = 0.001$, 0.01 and 0.1.
Lower plots: the TMD FF for an up quark fragmenting into a π^+ at $Q = 2$ GeV (left panel) and 10 GeV (right panel) as a function of the hadron transverse momentum $|P_\perp|$ for $z = 0.3$ and 0.6.
The uncertainty bands in all plots represent the 68%CL.

nCTEQ15ν

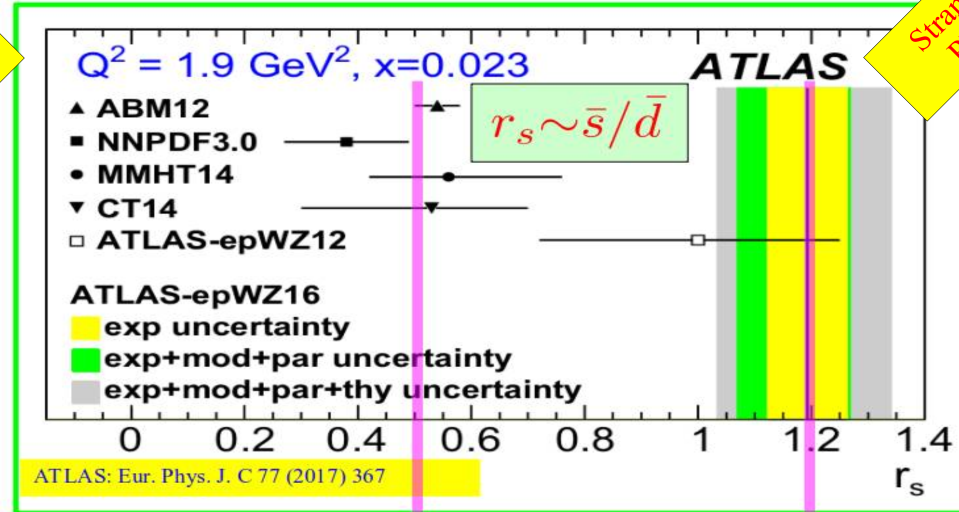
Split Personality



nCTEQ: arXiv: 2204.13157

nCTEQ15WZ

Strange PDF



We expect: At the LHC:

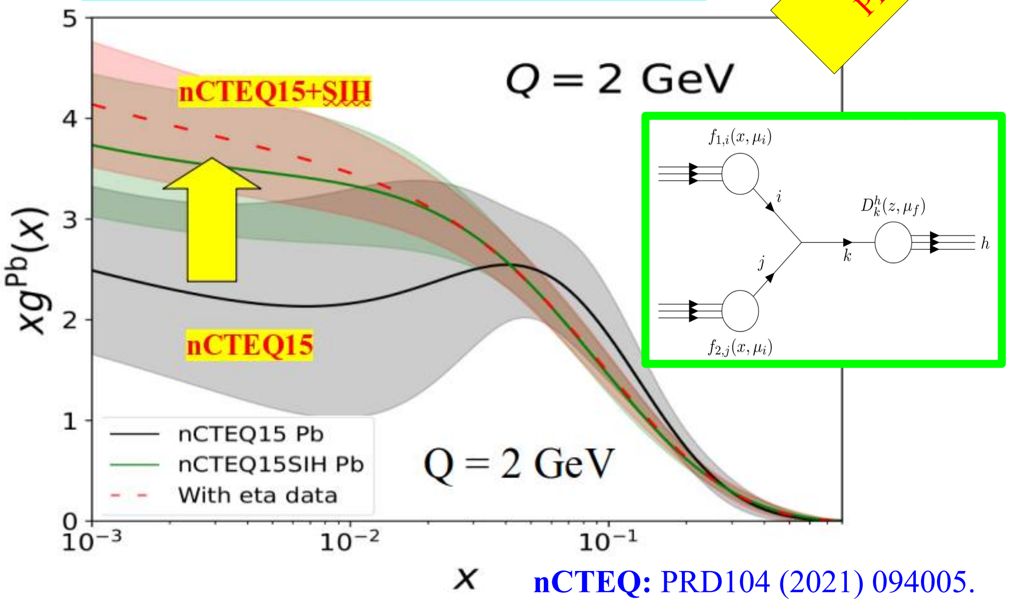
nCTEQ: Phys.Rev.D 104 (2021) 094005

nCTEQ

nuclear parton distribution functions

nCTEQ15WZ+SIH

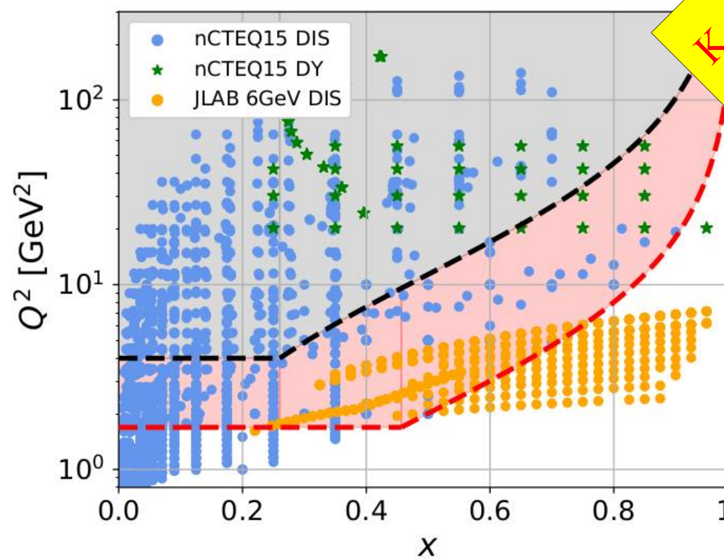
Gluon PDF



nCTEQ: PRD104 (2021) 094005.

nCTEQ15HIX

Key for EIC



nCTEQ: Phys.Rev.D 103 (2021) 11, 114015

precision $f_A(x,Q)$ can serve as Boundary Condition for $f_A(x,Q,k_T,b_T,\sigma)$

QCD: From PDFs to the underlying QCD