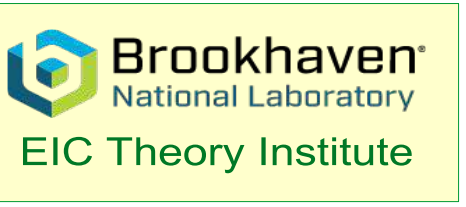
xFitter Opportunities at the EIC

...

SURGE, HEFTY, & EIC Theory Initiative

Fred Olness
SMU

Thanks for substantial input
from my friends & colleagues



xFitter Workshop
CERN
2-5 May 2023

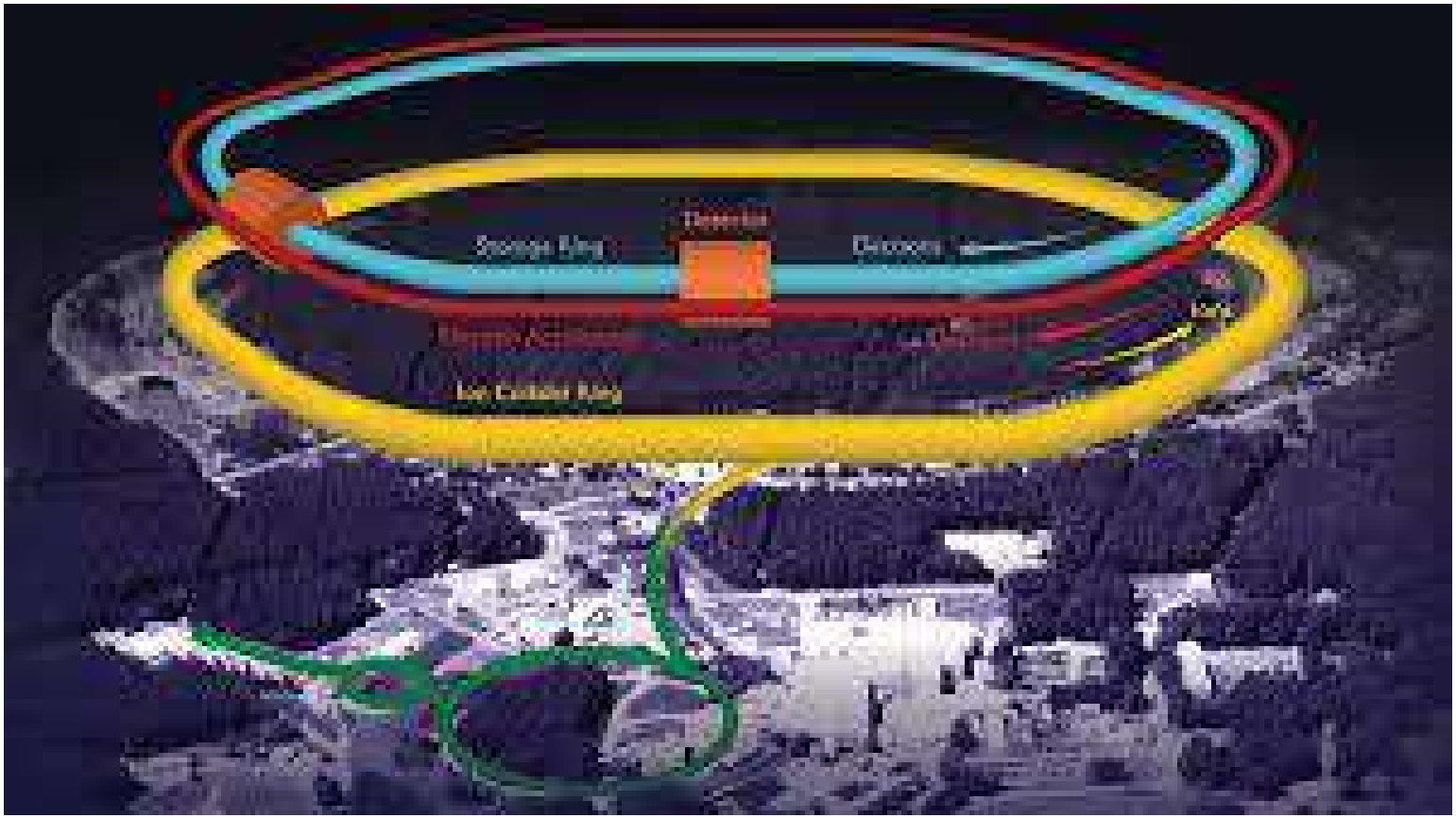
https://www.bnl.gov/physics/surge/

https://hefty.tamu.edu/

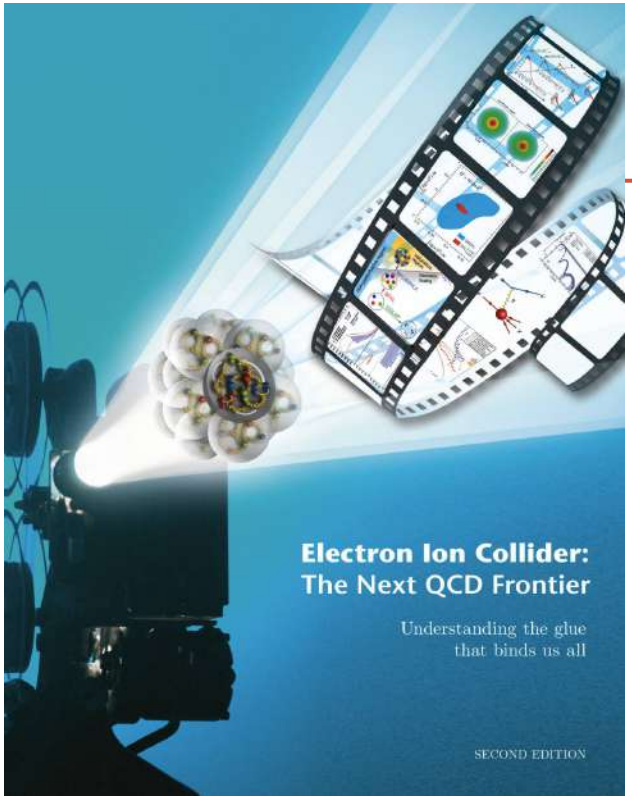
EIC Theory Institute

https://www.bnl.gov/eic-theory/

EIC UPDATE

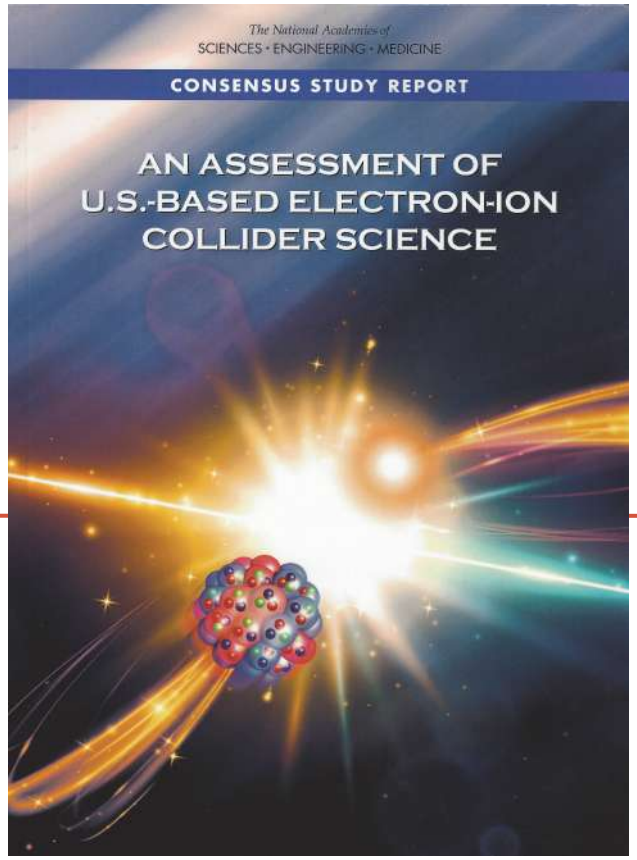


2016



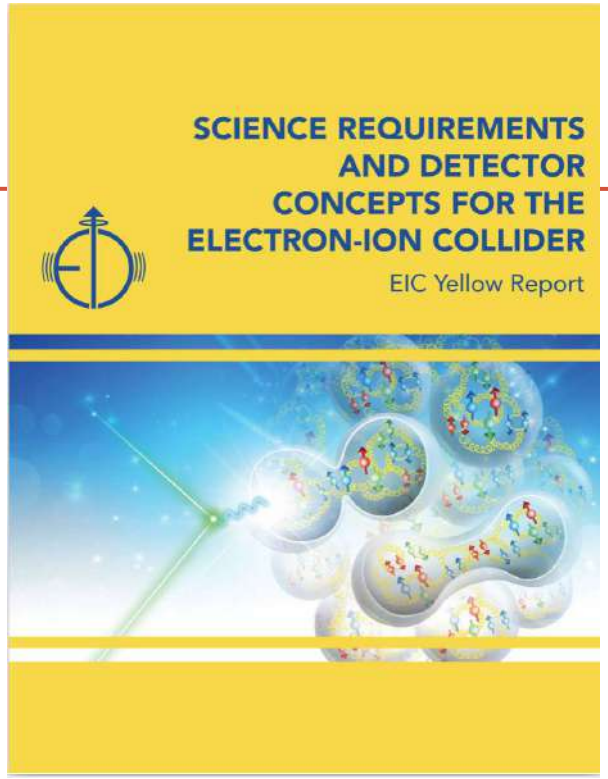
EIC Physics at-a-Glance
Eur. Phys. J. A 52 (2016) 9, 268
arXiv:1212.1701 (nucl-ex)

2018



National Academy of Science, Engineering and Medicine

2022

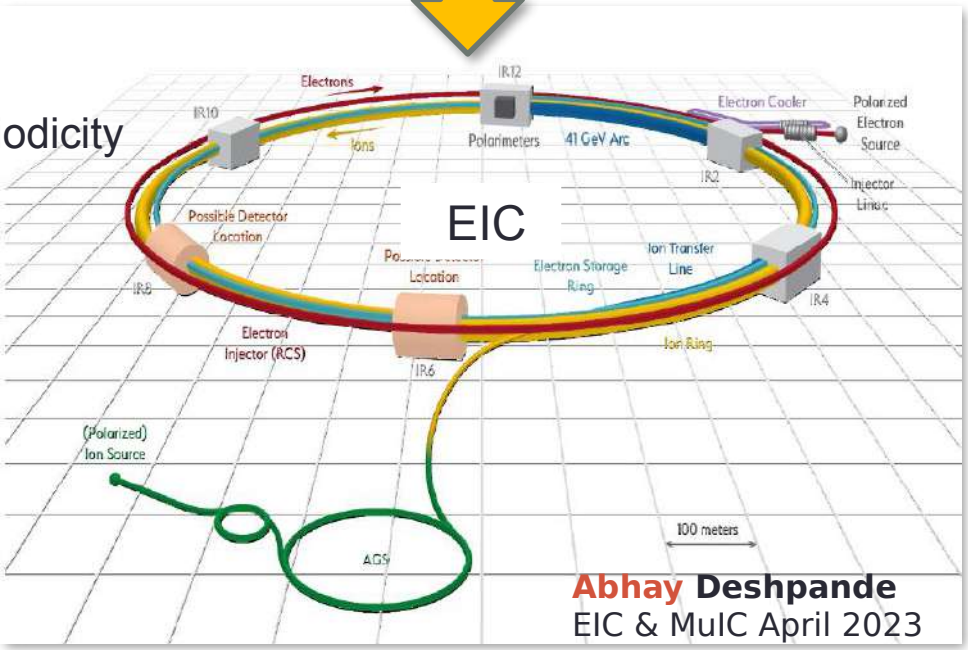


EIC Yellow Report 2022
https://arxiv.org/abs/2103.05419

https://nap.nationalacademies.org/catalog/25171/an-assessment-of-us-based-electron-ion-collider-science

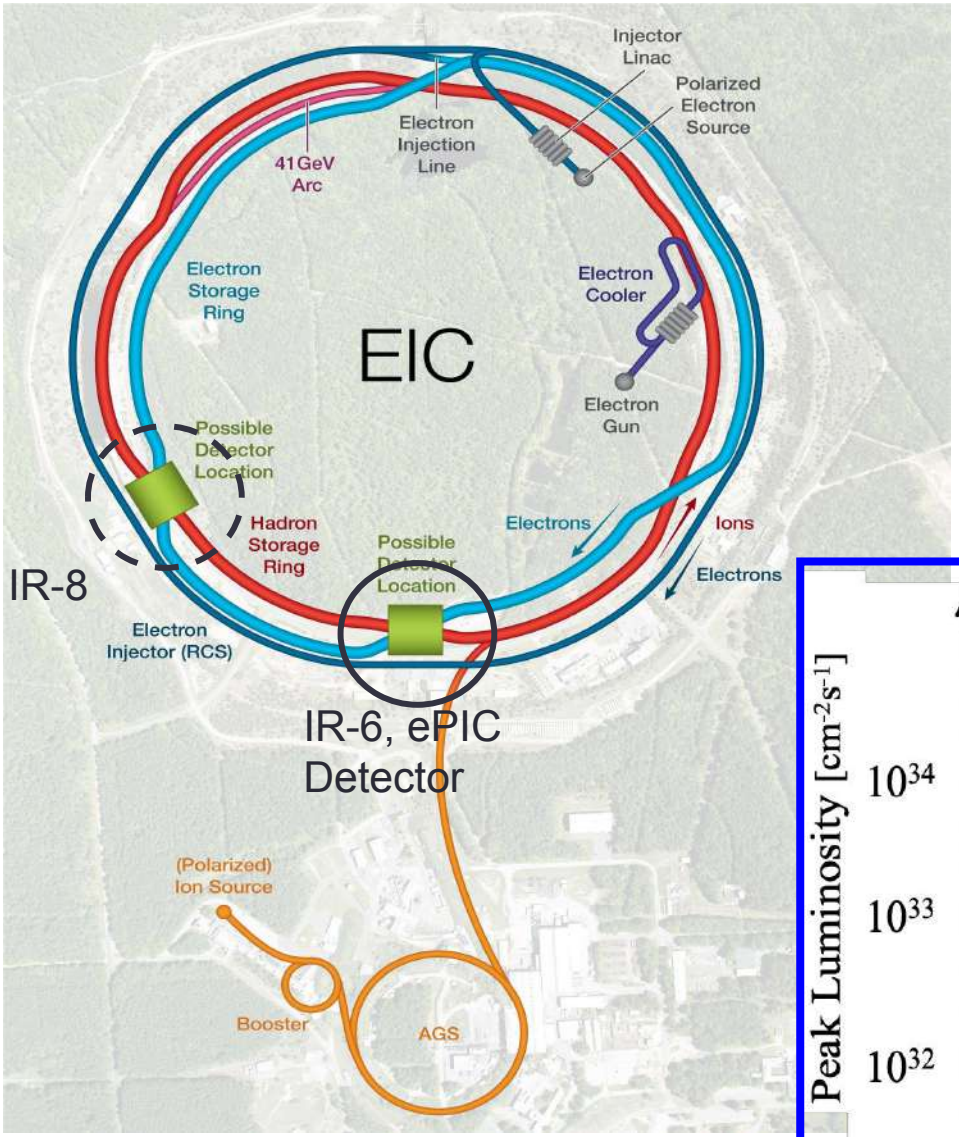
EIC Accelerator Design Overview

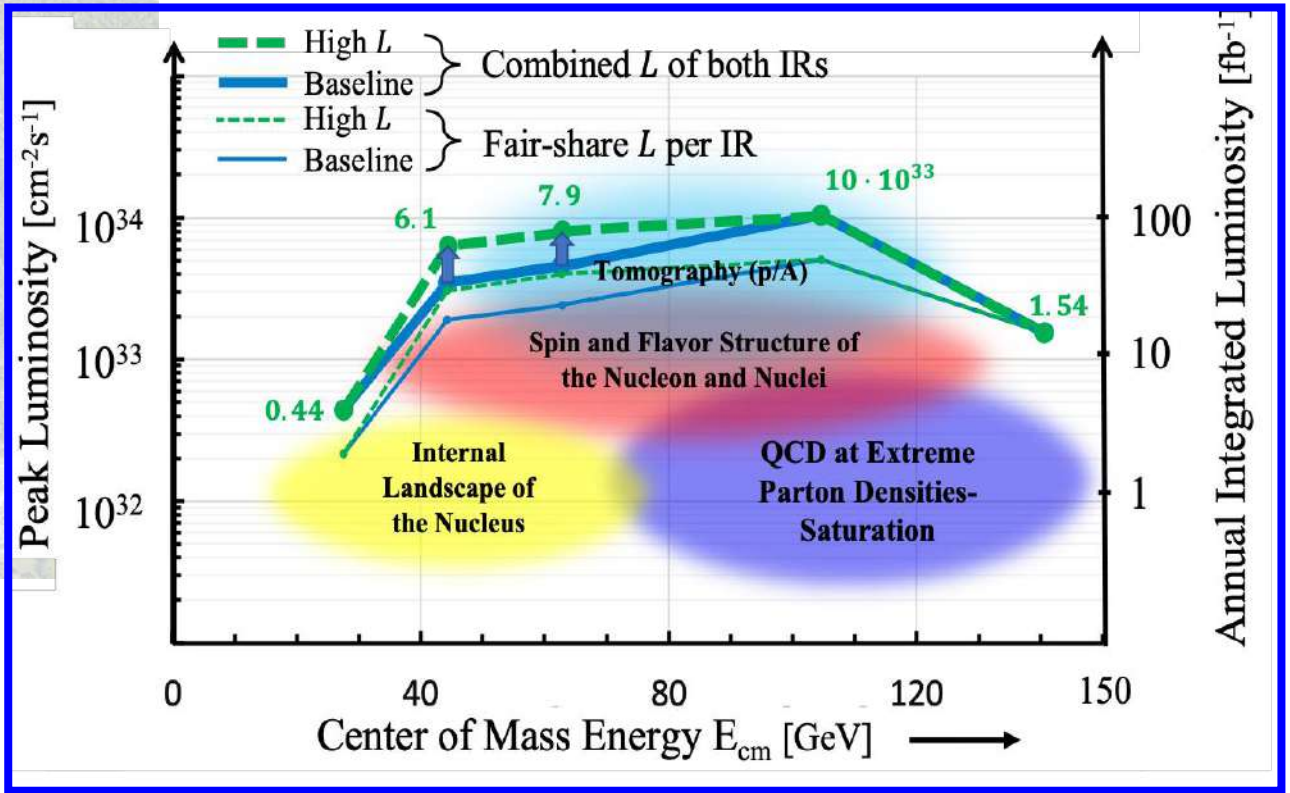
- **Hadron storage ring (HSR): 41-275 GeV (based on RHIC)**
  - up to 1160 bunches, 1A beam current (3x RHIC)
  - bright vertical beam emittance (1.5 nm)
  - strong cooling (coherent electron cooling, ERL)
- **Electron storage ring (ESR): 2.5–18 GeV (new)**
  - up to 1160 polarized bunches
    - high polarization by continual reinjection from RCS
  - large beam current (2.5 A) $\doteq$ 9 MW SR power
  - superconducting RF cavities
- **Rapid cycling synchrotron (RCS): 0.4-18 GeV (new)**
  - 2 bunches at 1 Hz; spin transparent due to high periodicity
- **High luminosity interaction region(s) (new)**
  - L = 10^{34} $cm^{-2}s^{-1}$
  - superconducting magnets
  - 25 mrad crossing angle with crab cavities
  - spin rotators (produce longitudinal spin at IP)



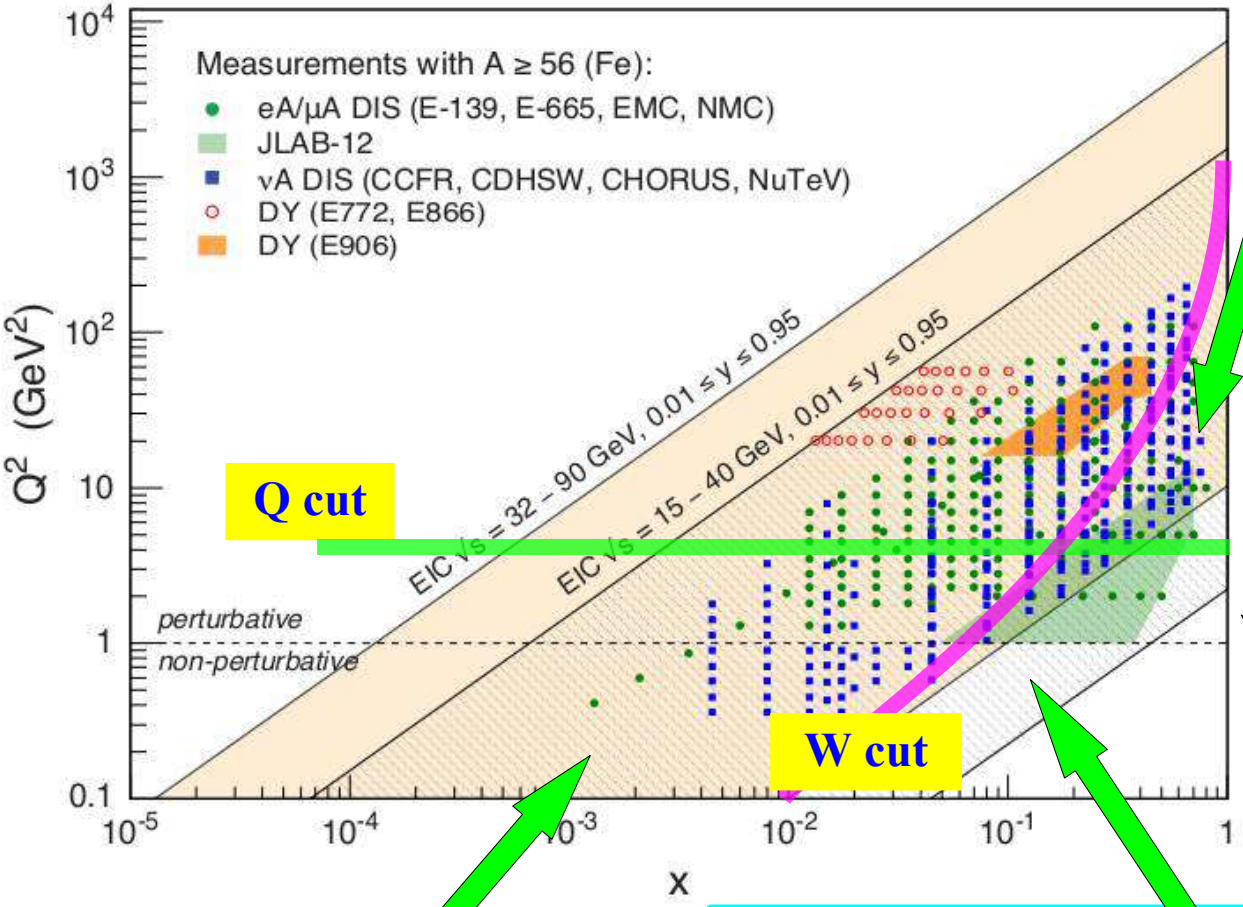
EIC Accelerator Design

Center of Mass Energies:	20GeV - 140GeV
Luminosity:	10^{33} - 10^{34} $cm^{-2}s^{-1}$ / 10-100fb^{-1} / year
Highly Polarized Beams:	70%
Large Ion Species Range:	p to U
Number of Interaction Regions:	Up to 2!





nPDFs: Extend Kinematic Reach in {x,Q^2}



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-x:

Shadowing
Recombination
Resummation
BFKL
Saturation

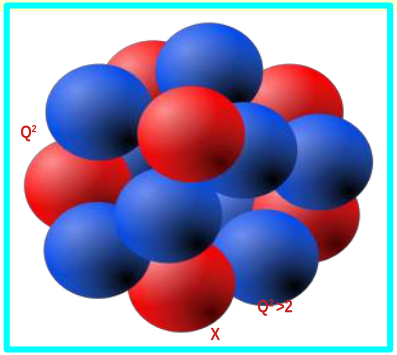
Low-Q^2:

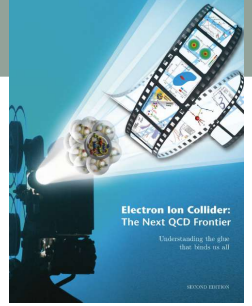
Non-Perturbative inteface
collective effects

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

JLab Data @ Hi-X Low-Q^2
extend nCTEQ framework for this region
& prepare for EIC





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Eur. Phys. J. A 52 (2016) 9, 268
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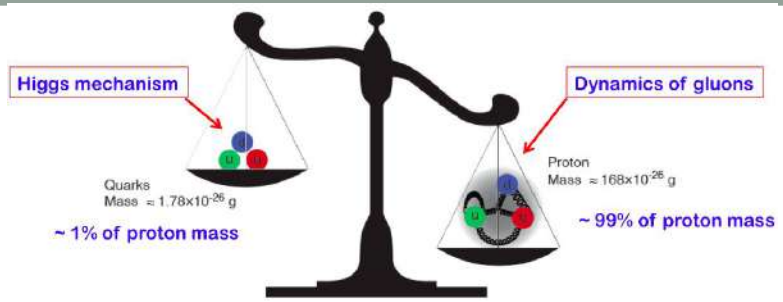
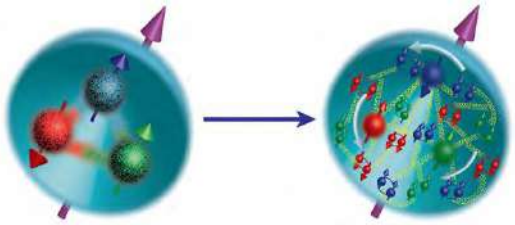
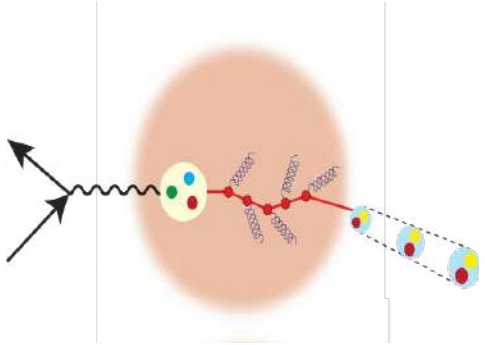


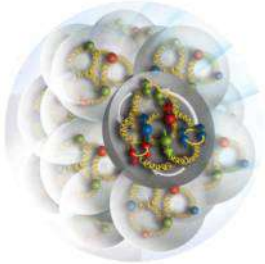
NUCLEAR TOMOGRAPHY: How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon? How do the nucleon properties (mass & spin) emerge from their interactions?





NUCLEAR MEDIUM: How do color-charged quarks and gluons, and colorless jets, interact with a nuclear medium? How do the confined hadronic states emerge from these quarks and gluons? How do the quark-gluon interactions create nuclear binding?

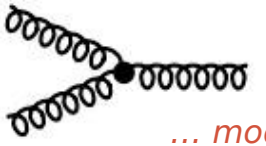
DENSE NUCLEAR MATTER: How does a dense nuclear environment affect the quark- and gluon- distributions? What happens to the gluon density in nuclei? Does it saturate at high energy, giving rise to a gluonic matter with universal properties in all nuclei, even the proton?



gluon emission

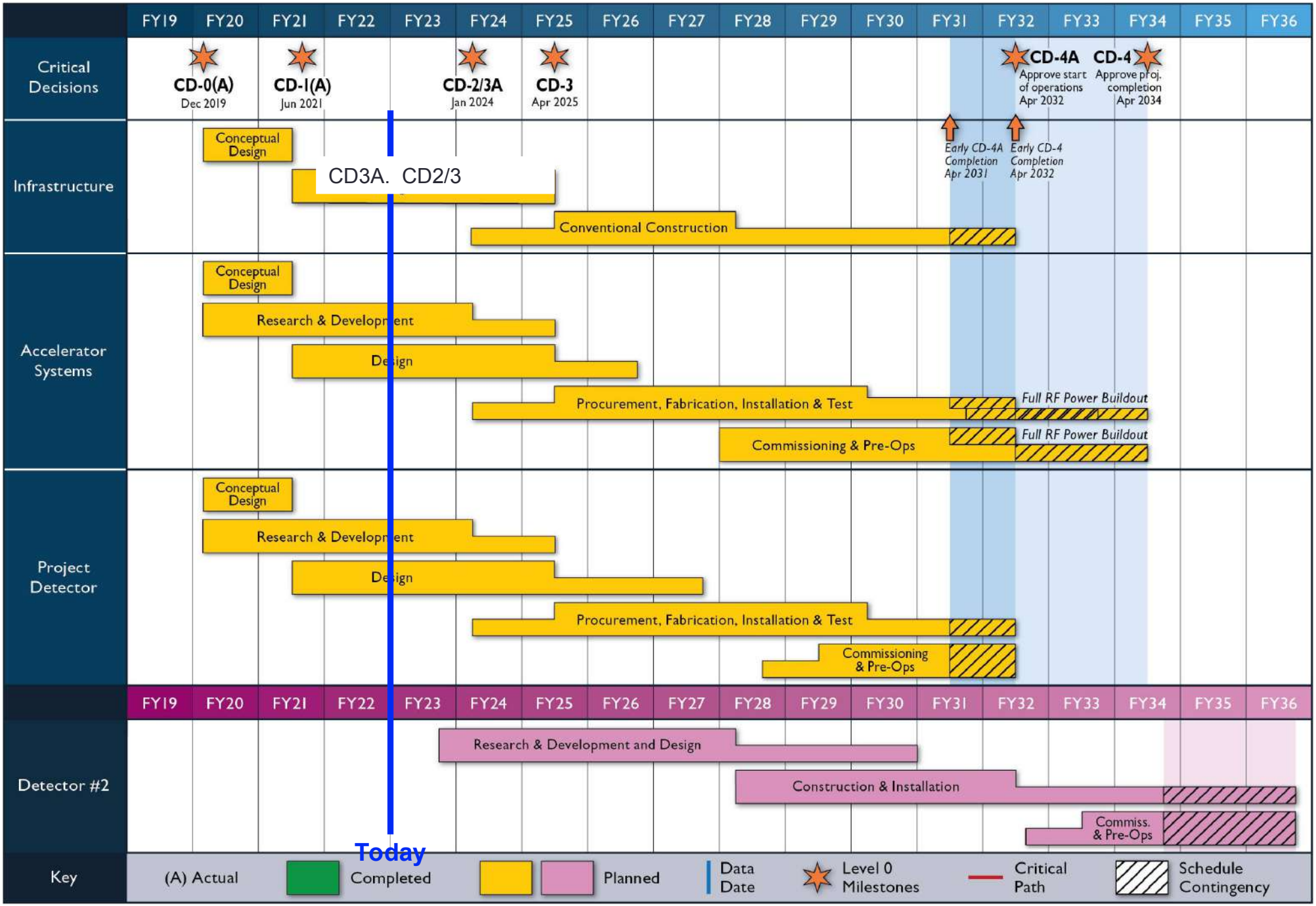
?

gluon recombination



... modified from
Abhay Deshpande
EIC & MuIC April 2023

Overall Schedule



2nd Detector

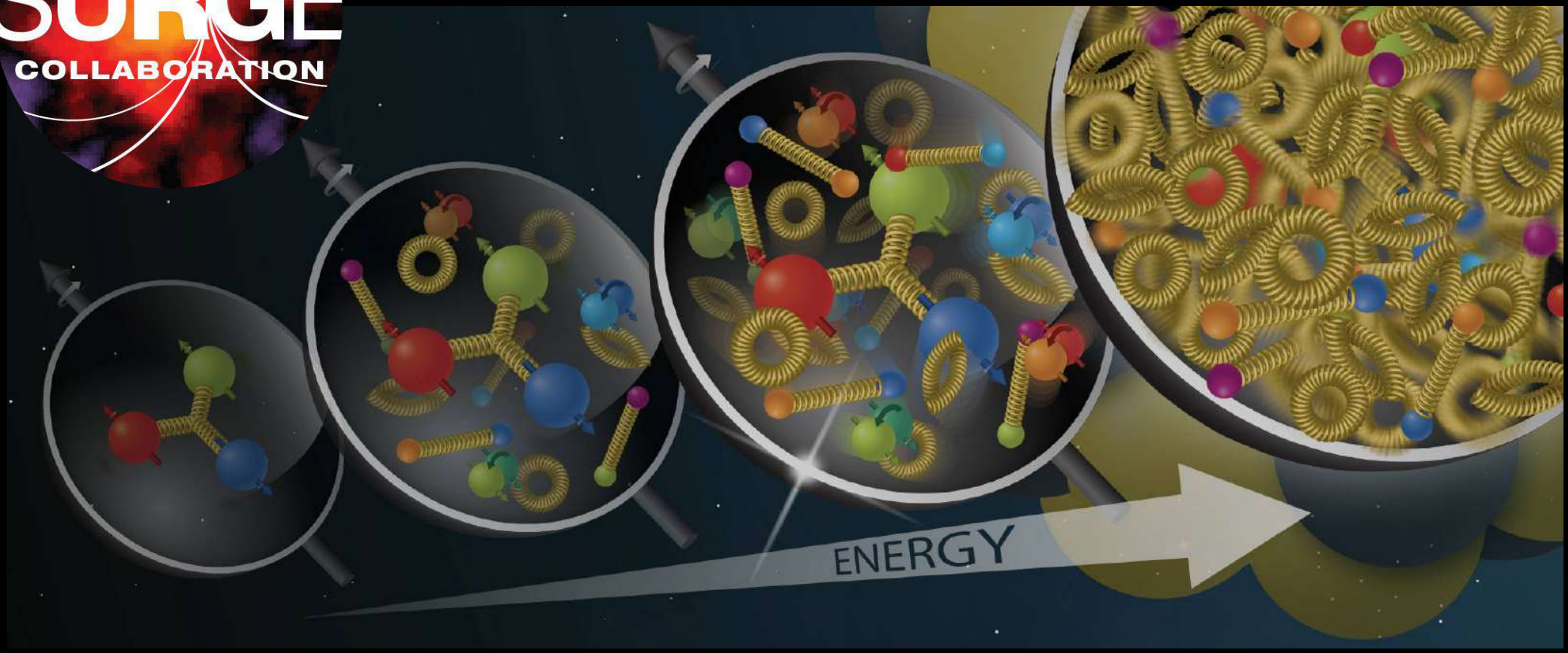
- Current assumption realization trailing ~ 5 years behind Detector-1
- focus on complementary IR/physics & technologies

SURGE

https://www.bnl.gov/physics/surge/

https://www.bnl.gov/physics/surge/

SURGE COLLABORATION



Mission statement: Discover and explore the gluon saturation regime of quantum chromodynamics by advancing calculations to high precision and developing a comprehensive framework to compute observables and compare to a wide range of experimental data, including predictions for the Electron Ion Collider (EIC).

Members

Brookhaven National Laboratory
Y. Hatta, D. Kharzeev, Y. Mehtar-Tani, S. Mukherjee, P. Petreczky, R. Venugopalan

Old Dominion University / Thomas Jefferson Laboratory I. Balitsky

McGill University
S. Caron-Huot

CUNY, Baruch College
A. Dumitru, J. Jalilian-Marian

University of California, Los Angeles
Z. Kang

The Ohio State University
Y. Kovchegov

University of Connecticut
A. Kovner

University of Illinois at Urbana Champaign
J. Noronha-Hostler

Southern Methodist University
F. Olness

Lebanon Valley College
D. Pitonyak

New Mexico State University
M. Sievert

North Carolina State University
V. Skokov

Penn State University
A. Stasto

University of California Berkeley / Lawrence Berkeley National Laboratory
X.-N. Wang

Steering Committee

Björn Schenke

Anna Stasto

Zhongbo Kang

Jaki Noronha-Hostler

Matt Sievert

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.

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
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.

- Initial state **(Vladi Skokov)**
- Small x evolution + NLO calculations **(Zhongbo Kang)**
- Spin **(Yuri Kovchegov)**
- Framework and global analysis **(Fred Olness)**
- Final state **(Xin-Nian Wang)**

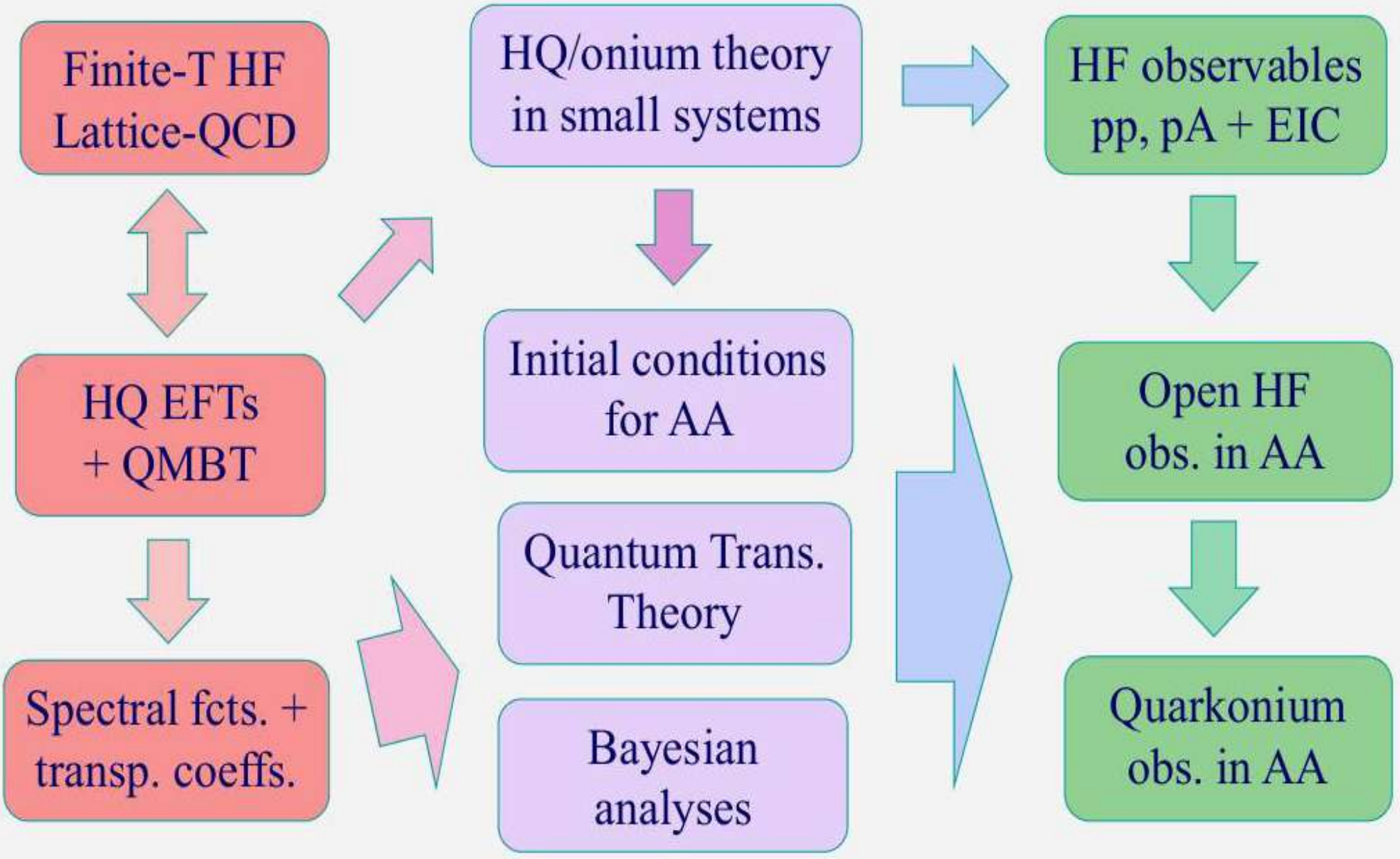




HEFTY

https://hefty.tamu.edu/

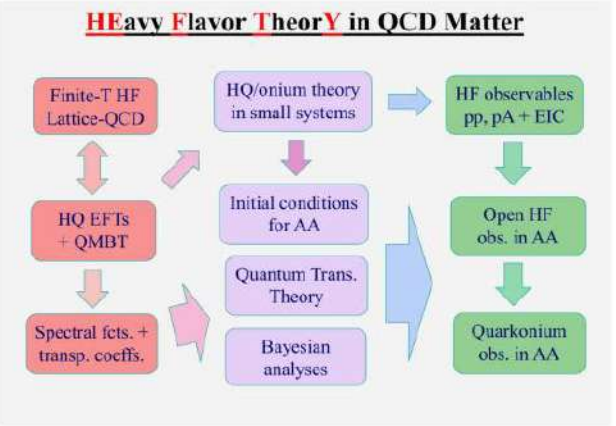
HEavy Flavor TheorY in QCD Matter



WG2: Heavy-Flavor Production in pp, pA, ep and eA Collisions

Co-PIs: Xin Dong, Anthony Frawley, Thomas Mehen, Ivan Vitev (convener), Ramona Vogt

Affiliates: Vincent Cheung, Weiyao Ke, Haitao Li, Frederick Olness



- Close collaboration within the WG2
- We push the boundaries of HF theory in small systems
- We provide baseline cross sections and CNM effects for other WGs

Tasks and Milestones

Perform resummed NLO calculations for HQ production and analyze HF jet observables in ep and pp reactions to obtain novel constraints on parton fragmentation and intrinsic charm in the proton (LLNL-PD+JLab-PD)

MS-2: Comprehensive theory of open HF production + hadronization in pp and ep

Analyze quarkonium and open HF production in pA and eA, combining EFTs, nuclear PDFs, and inelastic break-up reactions (LANL-PD+Duke-GS)

MS-8: Microscopic theory of quarkonia and open HF production on nuclear targets

HEFTY COLLABORATION

Physics Letters B 795 (2019) 502–510

ELSEVIER

A complete set of in-medium splitting functions to any order opacity

Matthew D. Sievert [a,*], Ivan Vitev [b], Boram Yoon [c]

www.elsevier.com/locate/physletb

XFITTER

DESY xFitter

xFitter/xFitterTalks » xFitter/../xFitterDevel.. »

xFitter

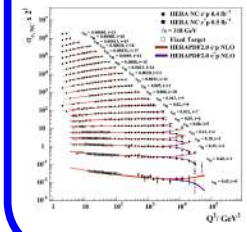
Features & Recent Updates:

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

Sample data files:

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

Experimental Data



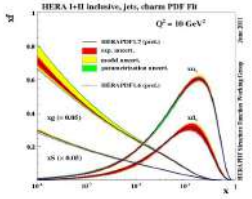
Data: HERA, Tevatron, LHC, fixed target experiments

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

xFitter 2.2.0
Future Freeze

Date	Version
02/2020	2.0.1N Nuclear Daiquiri

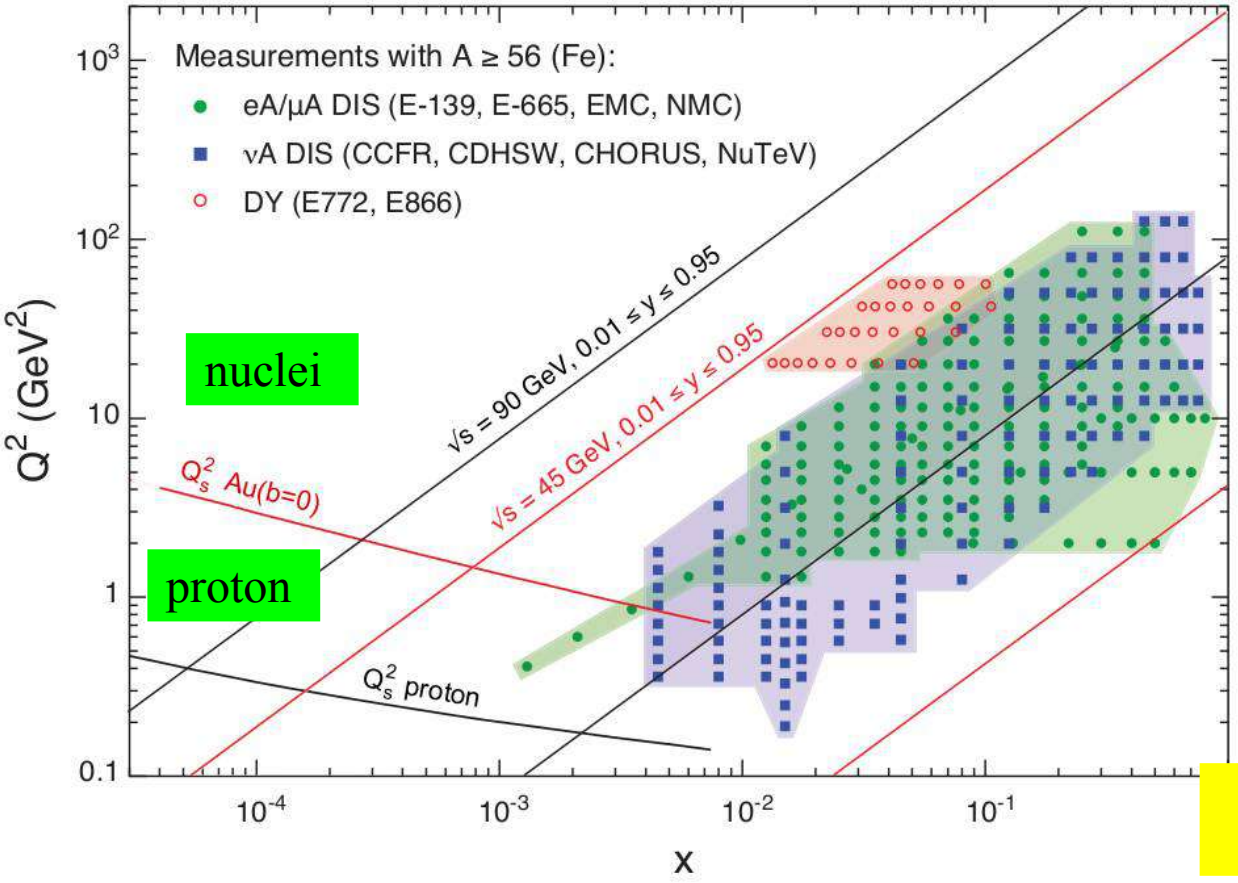
xFitter Collaboration Meeting February 2020, DESY

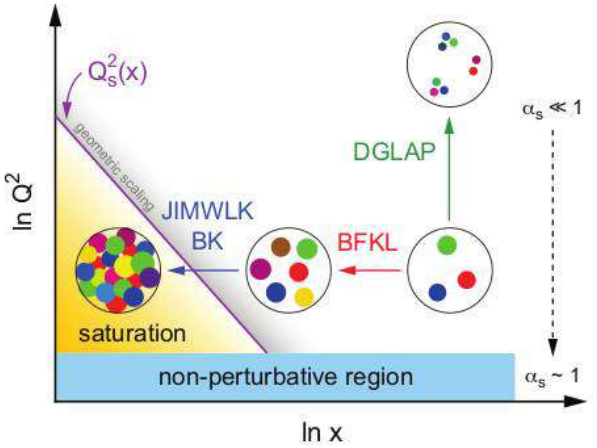
www.xFitter.org

Saturation, BFKL, recombination, ...

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:

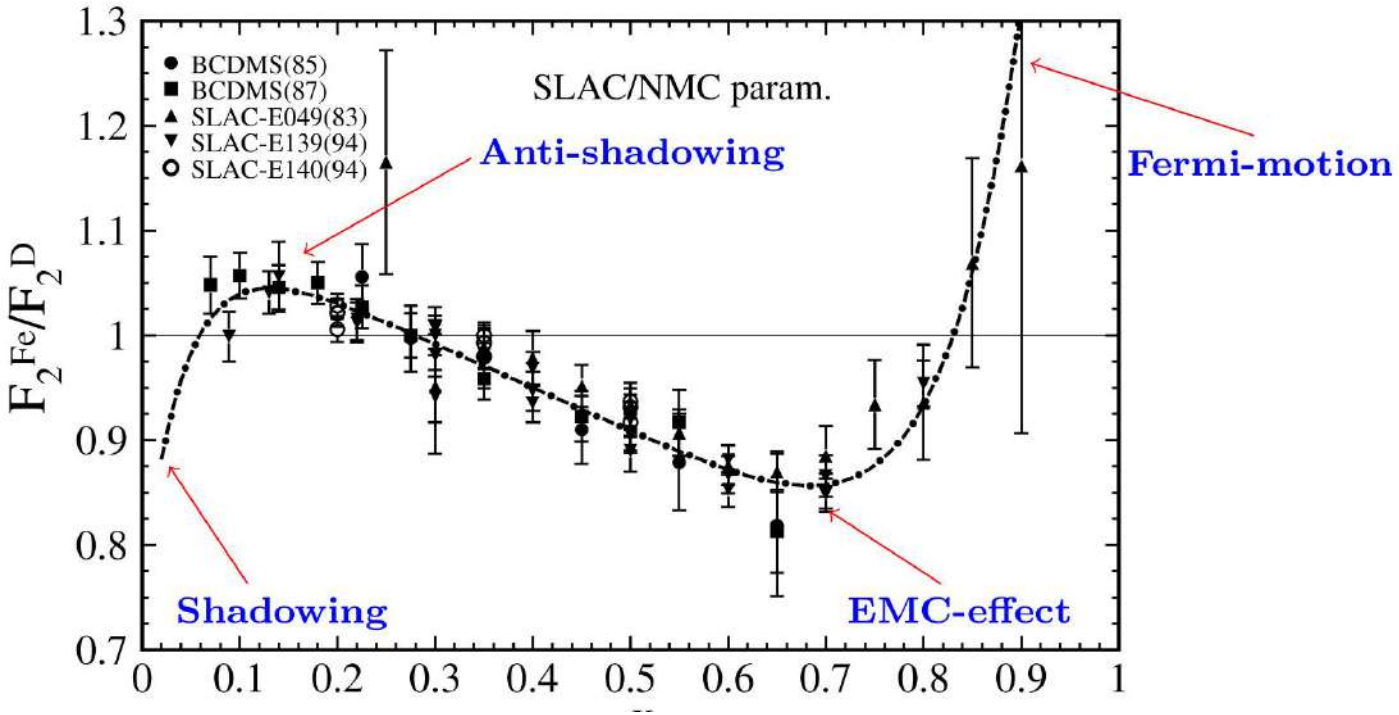


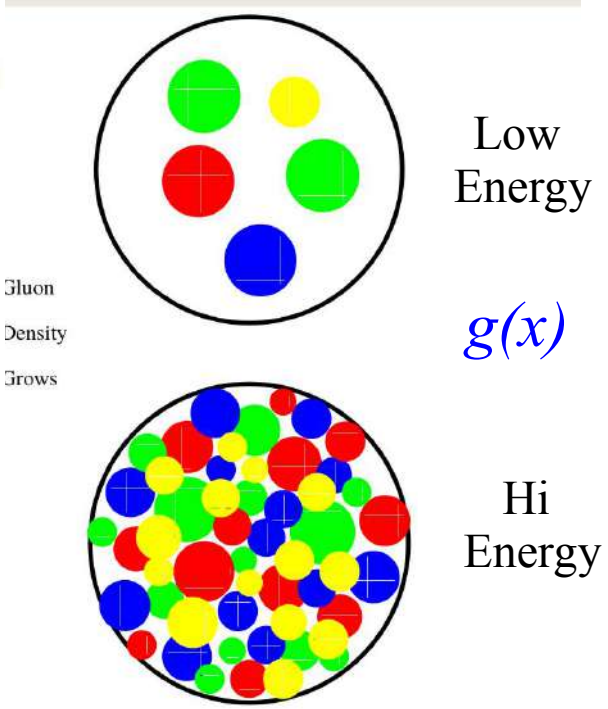


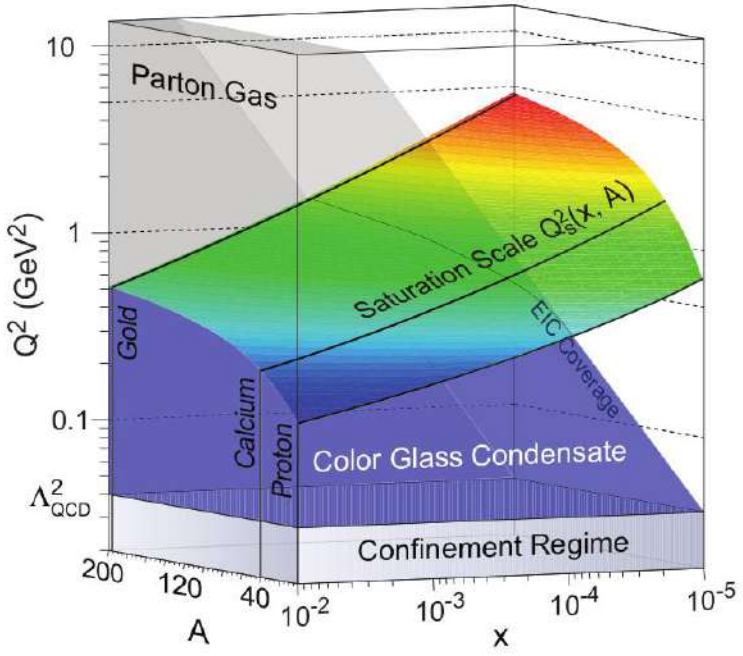
Yuri Kovchegov (OSU)

MC4EIC: Monte Carlo event simulation for the EIC

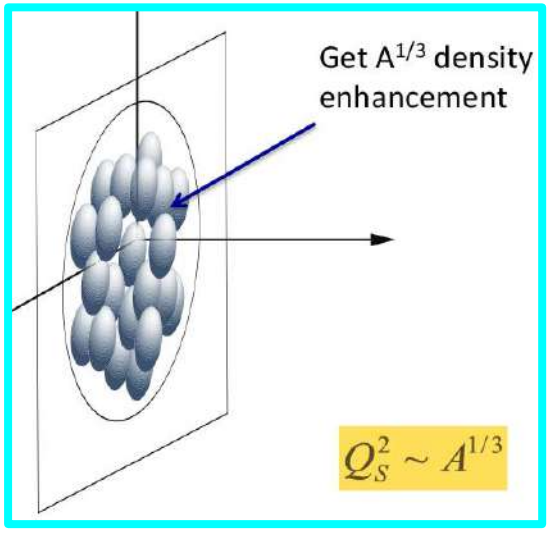
Nuclear Modifications: Expected $A^{1/3}$ Enhancement







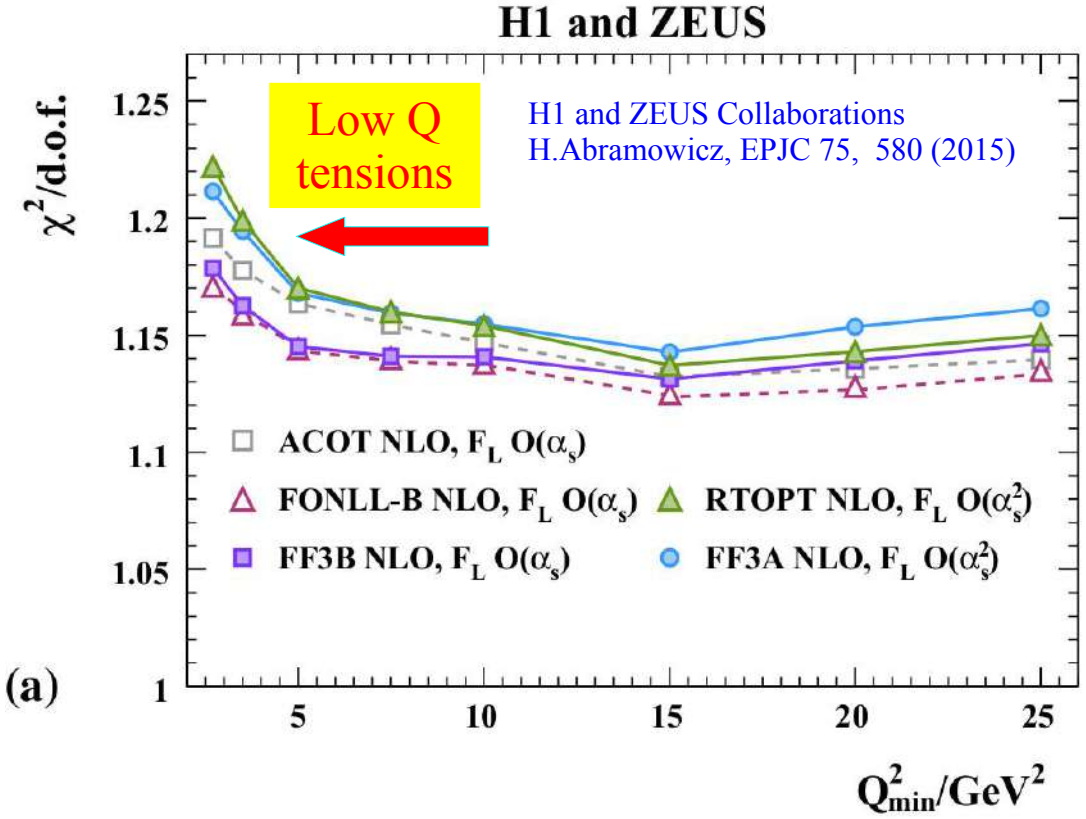
We gain a geometric factor of $A^{1/3}$



Review: Edmond Iancu & Raju Venugopalan: arXiv:0303204

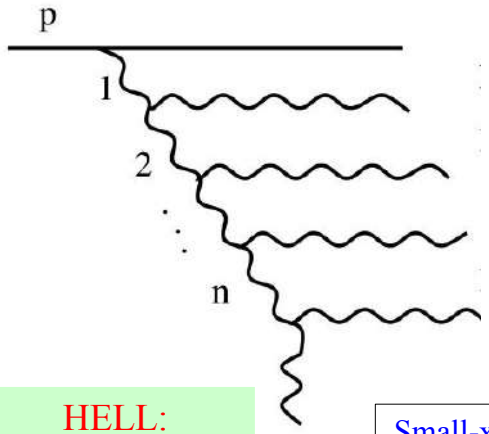
Motivation for Improved Treatment

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 $Q^2 = 15\,\text{GeV}^2$, and at high Q^2, i.e. above $Q^2 = 150\,\text{GeV}^2$. 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

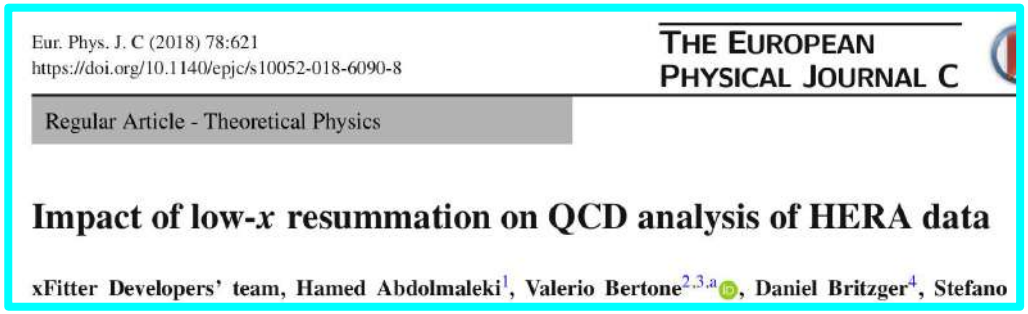


resum logs

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

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

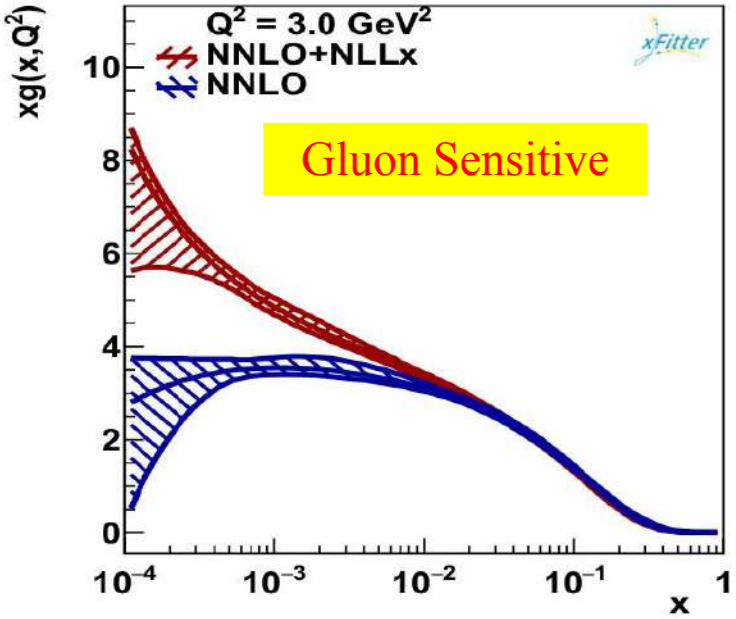
THE EUROPEAN PHYSICAL JOURNAL C

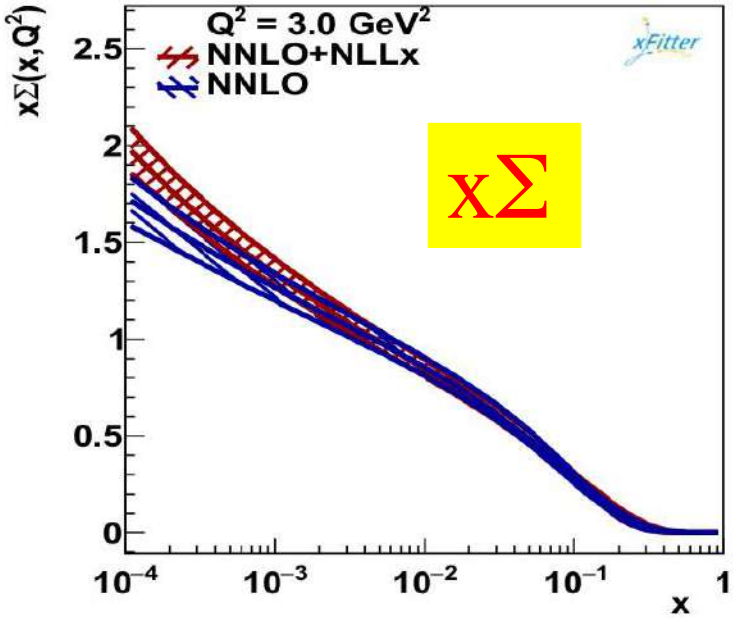
Regular Article - Theoretical Physics

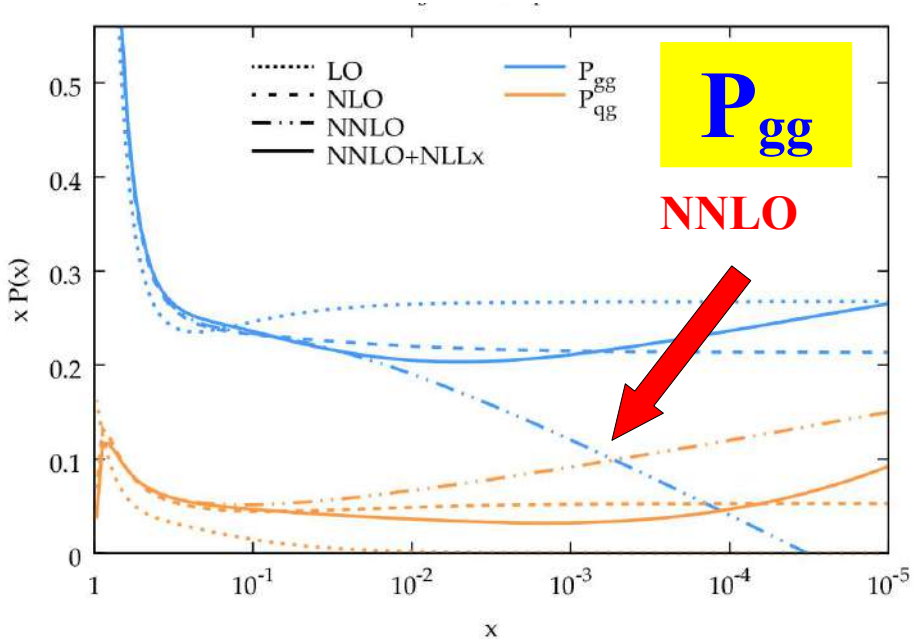
Impact of low-x resummation on QCD analysis of HERA data

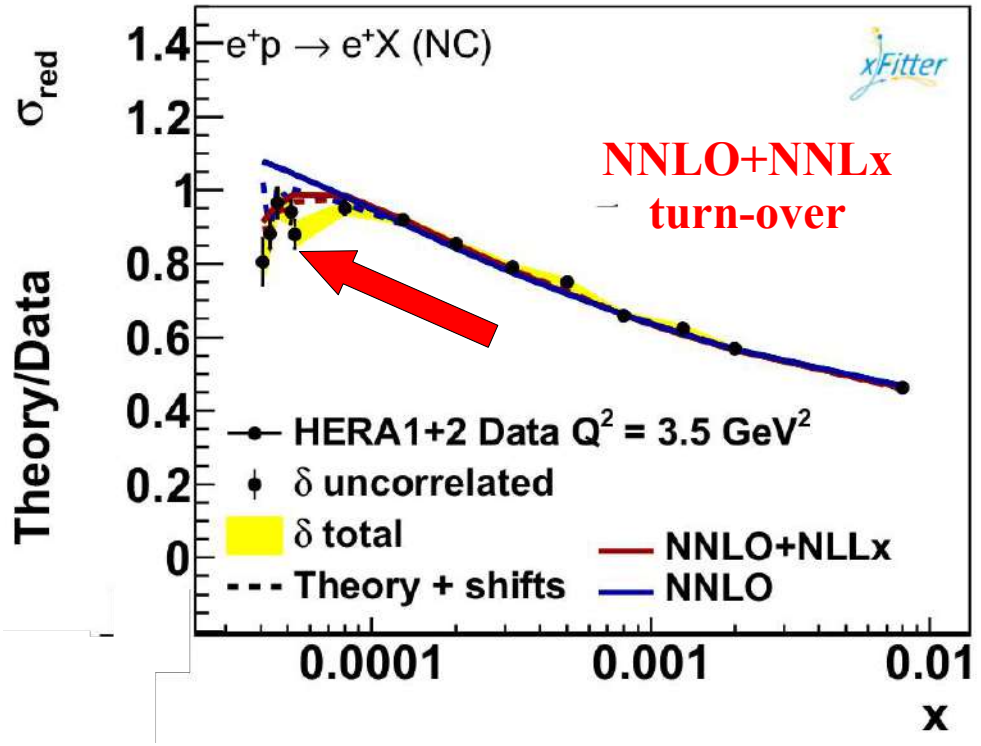
xFitter Developers' team, Hamed Abdolmaleki[1], Valerio Bertone[2,3,a], Daniel Britzger[4], Stefano

xFitter Resummation Study









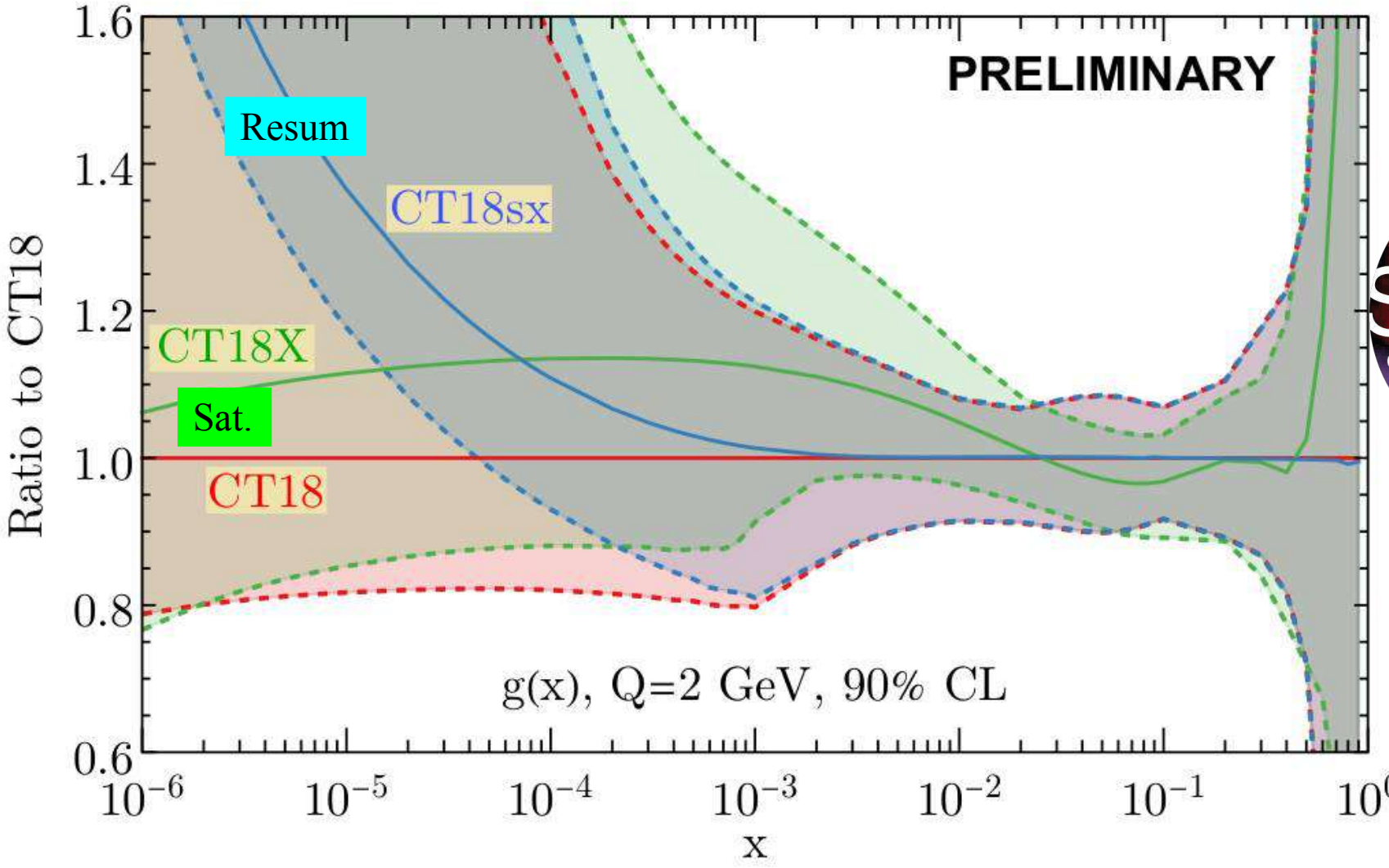
Impact of low-x resummation on QCD analysis of HERA data
xFitter Developers' Team: Eur.Phys.J.C 78 (2018) 8, 621

Gluon is sensitive to small-x treatment

CT18x: Saturation inspired μ modification
CT18sx: w/ HELL small-x resummation code

Saturation inspired x-dependent

$$\mu^2 = a_1\left(Q^2 + \frac{a_2}{x^{a_3}}\right)$$



BFKL & Saturation differ at very small x

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

CT Collaboration: 2108.06596 [hep-ph]

F_L is senstive to Gluon and Small-x Treatments

F_L driven by gluon

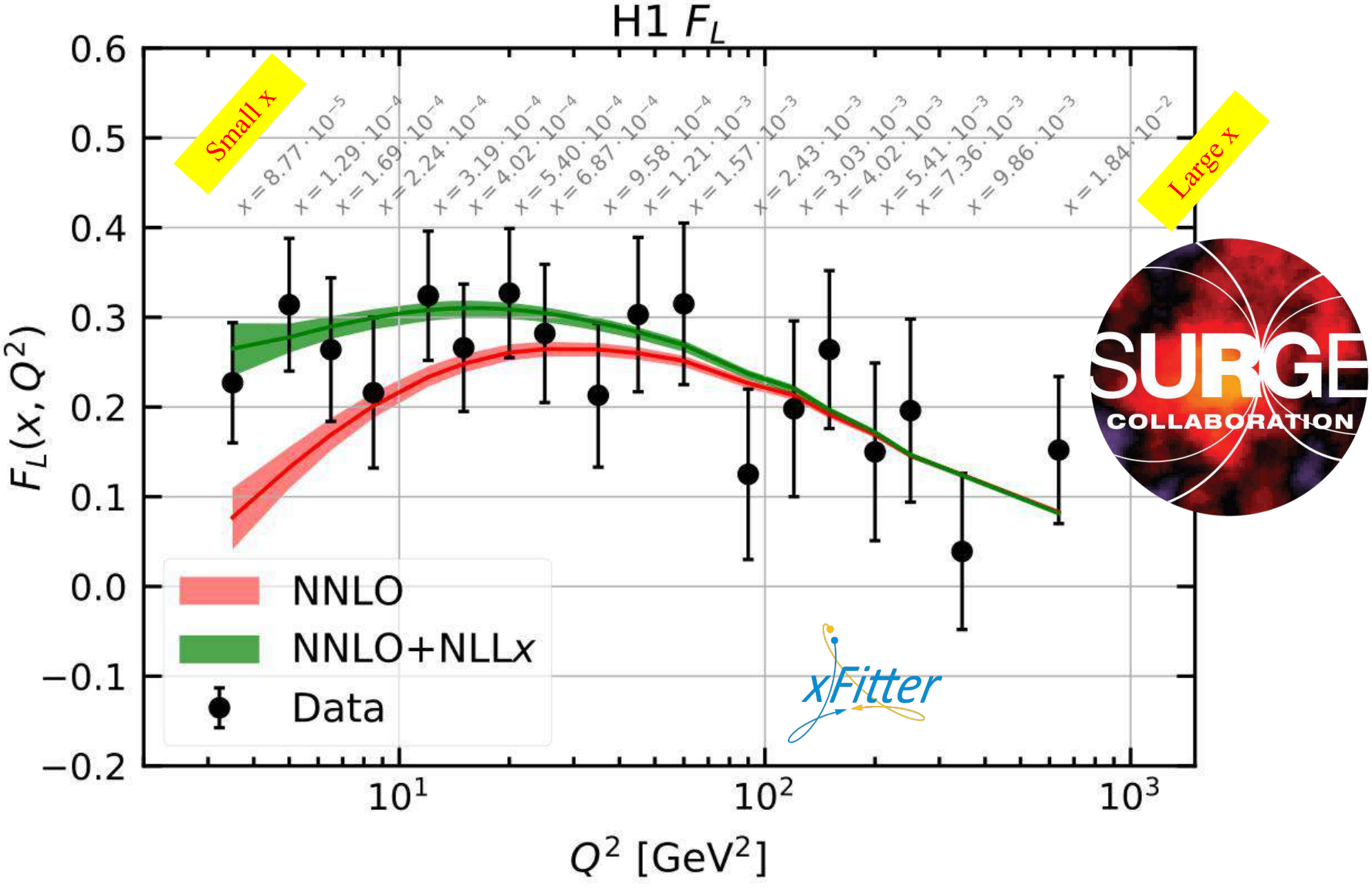


Fig. 8 The H1 extraction of F_L compared to the predictions with and without $\ln(1/x)$ resummation

focus on gluon

Gluon PDF

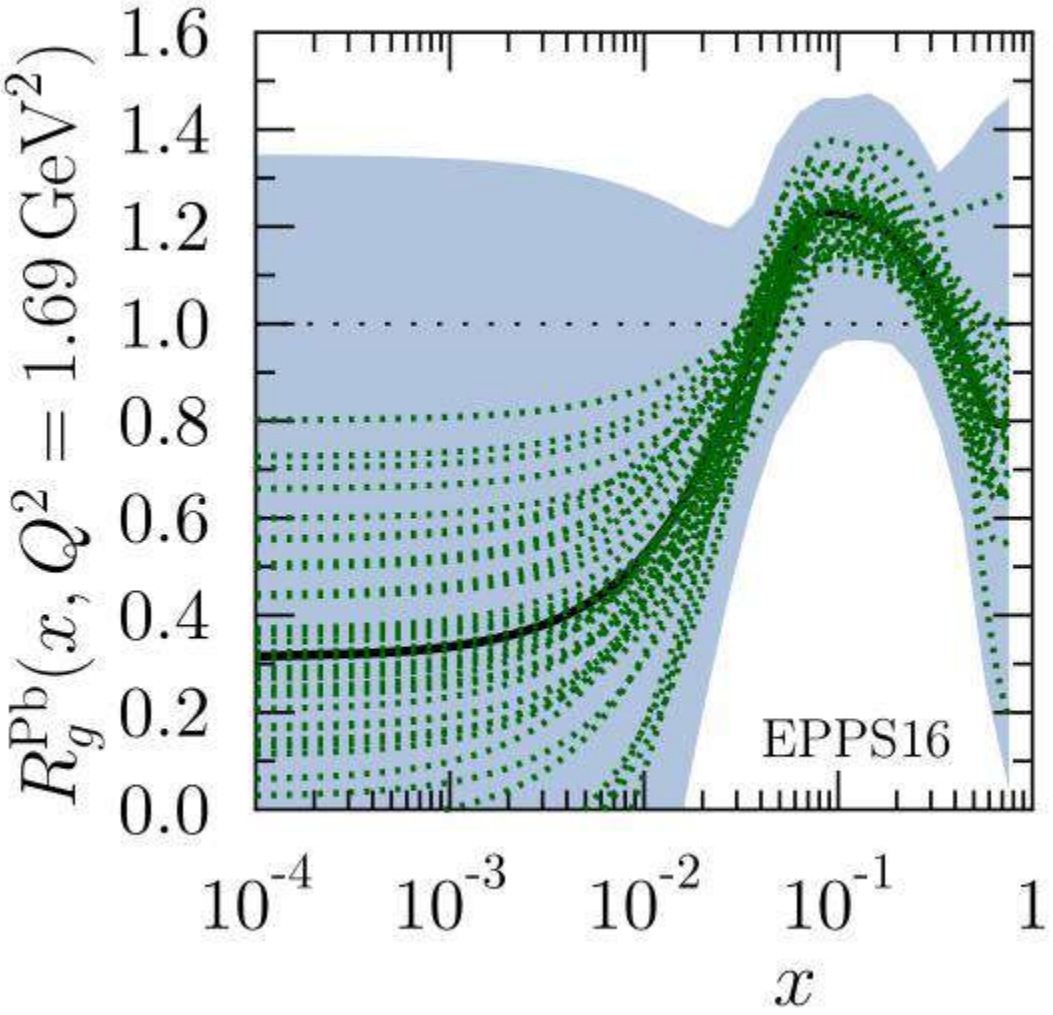
1) J/Psi Production

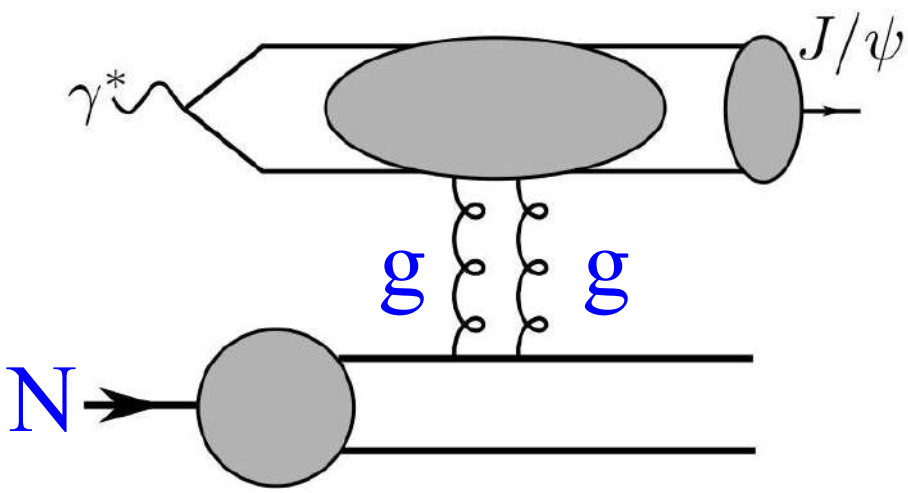
&

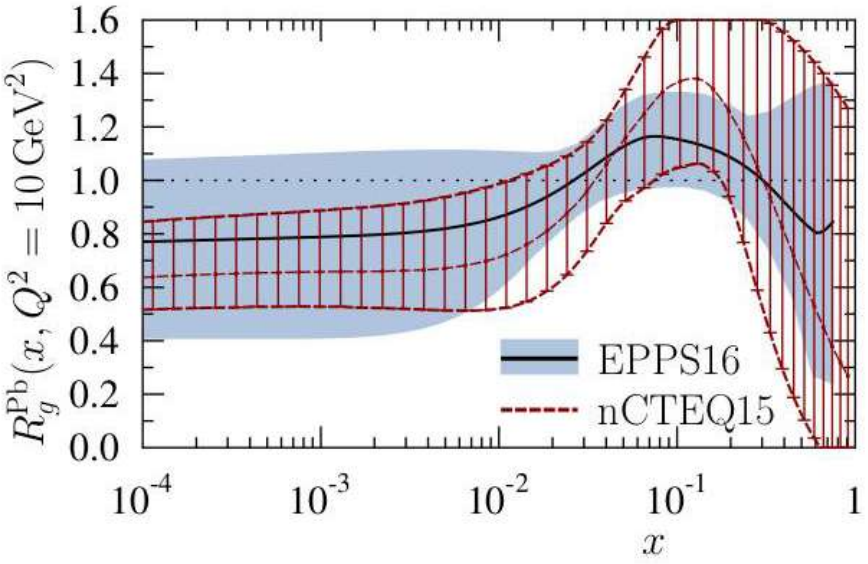
2) Semi-Inclusive Hadron Production

Heavy FlavorProduction: Effective Probe of Gluon PDF

Nuclear Gluon PDF
Large uncertainties
Strong shadowing at small x







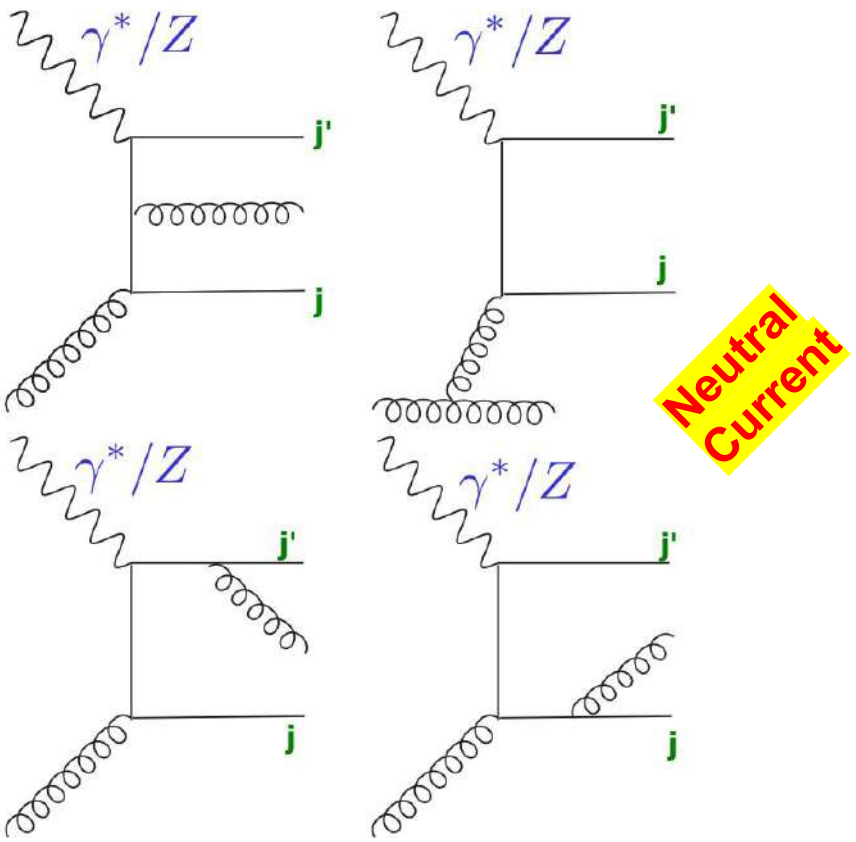
Caution: EPPS16 errors are probably more realistic at small x than nCTEQ15

nNNPDF provide complementary approach

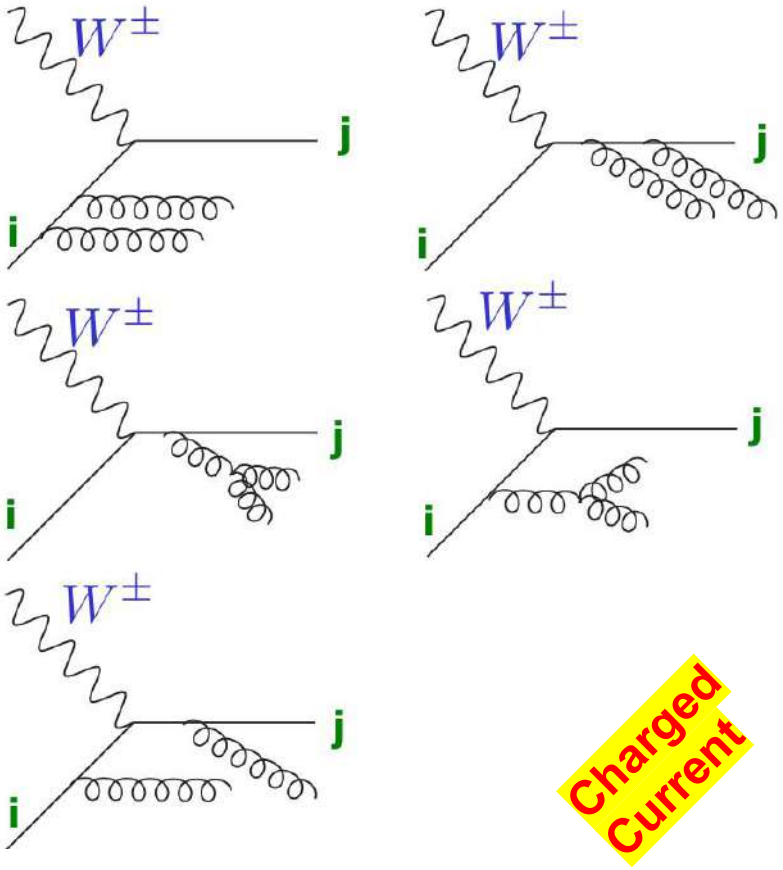
Heavy Quark Production

sACOT-χ – NNLO gluon

Stavreva *et al*, arXiv:1203.0282



sACOT-χ – NNLO non-singlet



Precompute observables

$$F_\lambda(x,Q^2) = \sum_k \sum_\alpha \underbrace{\int_\chi^1 \frac{\mathrm{d}\xi}{\xi} C_k^\lambda \left(\frac{\chi}{\xi}, \frac{Q}{mu}, \frac{M_i}{\mu}, \alpha_s(\mu)\right) w_\alpha(\xi)}_{\text{Precompute}} f_k(\xi_\alpha, \mu)$$

APFEL++ – A PDF evolution library in c++

Bertone, arXiv:1708.00911

- main author: **V. Bertone**
- rewrite of the Fortran APFEL code
  - used by the NNPDF collaboration

Available schemes in APFEL++

scheme	$\mathcal{O}(\alpha_s)$		NC: F_2	NC: F_3	NC: F_L		CC: F_2	CC: F_3	CC: F_L
ZM	N2LO		✓	✓	✓		✓	✓	✓
FONLL-C	N2LO		✓	✗	✓		✗	✗	✗
ACOT	NLO		✓	✓	✓		✗	✗	✗
sACOT-χ	NLO		✓	✓	✓		✓	✓	✓
approx. sACOT-χ	N2LO		✓	✓	✓		✓	✓	✓

No time for …

TMDs

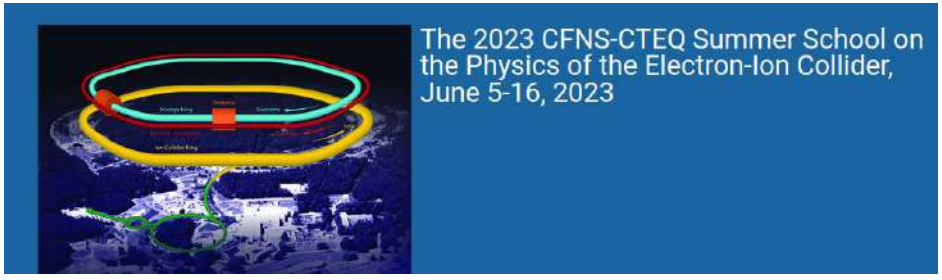
GPDs

Spin

…

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

Minor issue: Ubuntu 22 bug in logo

Resolved with:

./bin/xfitter-draw ./output --no-logo

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

Low Priority

DrawLogo.cc

```
 83        }
 84      logo->DrawText(170, 510, ver.c_str(), 80, 0,
 85                     font, TImage::kShadeBelow);
 86    }
 87
 88   float dx = 0.0768 * 1.5;
```

Program received signal SIGSEGV, Segmentation fault.
XFindOnExtensionList () from /lib/x86_64-linux-gnu/libX11.so.6

```
vboxuser@Ubuntu22:~/xfit/xfitter-2.2.0_Future_Freeze$ ./bin/xfitter-draw  ./output

 *** Break *** segmentation violation

==========================================================
There was a crash.
This is the entire stack trace of all threads:
==========================================================
#0  0x00007f1cda4ea45a in __GI___wait4 (pid=2161, stat_loc=stat_loc
entry=0x7ffe202b4e58, options=options
entry=0, usage=usage
entry=0x0) at ../sysdeps/unix/sysv/linux/wait4.c:30
#1  0x00007f1cda4ea41b in __GI___waitpid (pid=<optimized out>, stat_loc=stat_loc
entry=0x7ffe202b4e58, options=options
entry=0) at ./posix/waitpid.c:38
#2  0x00007f1cda450bcb in do_system (line=<optimized out>) at ../sysdeps/posix/system.c:171
#3  0x00007f1cdbd1a164 in TUnixSystem::StackTrace() () from /home/vboxuser/opt/lib/libCore.so.6.28
#4  0x00007f1cdbd17495 in TUnixSystem::DispatchSignals(ESignals) () from /home/vboxuser/opt/lib/libCore.so.6.28
#5  <signal handler called>
#6  0x00007f1cabc454e4 in XFindOnExtensionList () from /lib/x86_64-linux-gnu/libX11.so.6
#7  0x00007f1cabc3fee1 in ?? () from /lib/x86_64-linux-gnu/libX11.so.6
#8  0x00007f1cabc4051d in XLoadQueryFont () from /lib/x86_64-linux-gnu/libX11.so.6
#9  0x00007f1cabda1d3f in get_asfont () from /home/vboxuser/opt_root_6.28_ubuntu22/lib/libASImage.so.6.28.00
#10 0x00007f1cabd92021 in TASImage::DrawText(int, int, char const*, int, char const*, char const*, TImage::EText3DType, char const*, float) () from
/home/vboxuser/opt_root_6.28_ubuntu22/lib/libASImage.so.6.28.00
#11 0x000056394f78b8a3 in DrawLogo (pos="ul") at /home/vboxuser/xfit/xfitter-2.2.0_Future_Freeze/tools/draw/src/DrawLogo.cc:84
#12 0x000056394f7cd0e8 in PdfsPainter (q2=1.8999999761581421, ipdf=uv) at /home/vboxuser/xfit/xfitter-2.2.0_Future_Freeze/tools/draw/src/PdfsPainter.cc:364
#13 0x000056394f7d7b15 in main (argc=2, argv=0x7ffe202b8e48) at /home/vboxuser/xfit/xfitter-2.2.0_Future_Freeze/tools/draw/src/xfitter-draw.cc:75
==========================================================

The lines below might hint at the cause of the crash. If you see question
marks as part of the stack trace, try to recompile with debugging information
enabled and export CLING_DEBUG=1 environment variable before running.
You may get help by asking at the ROOT forum https://root.cern/forum
Only if you are really convinced it is a bug in ROOT then please submit a
report at https://root.cern/bugs Please post the ENTIRE stack trace
from above as an attachment in addition to anything else
that might help us fixing this issue.
==========================================================
#6  0x00007f1cabc454e4 in XFindOnExtensionList () from /lib/x86_64-linux-gnu/libX11.so.6
#7  0x00007f1cabc3fee1 in ?? () from /lib/x86_64-linux-gnu/libX11.so.6
#8  0x00007f1cabc4051d in XLoadQueryFont () from /lib/x86_64-linux-gnu/libX11.so.6
#9  0x00007f1cabda1d3f in get_asfont () from /home/vboxuser/opt_root_6.28_ubuntu22/lib/libASImage.so.6.28.00
#10 0x00007f1cabd92021 in TASImage::DrawText(int, int, char const*, int, char const*, char const*, TImage::EText3DType, char const*, float) () from
/home/vboxuser/opt_root_6.28_ubuntu22/lib/libASImage.so.6.28.00
#11 0x000056394f78b8a3 in DrawLogo (pos="ul") at /home/vboxuser/xfit/xfitter-2.2.0_Future_Freeze/tools/draw/src/DrawLogo.cc:84
#12 0x000056394f7cd0e8 in PdfsPainter (q2=1.8999999761581421, ipdf=uv) at /home/vboxuser/xfit/xfitter-2.2.0_Future_Freeze/tools/draw/src/PdfsPainter.cc:364
#13 0x000056394f7d7b15 in main (argc=2, argv=0x7ffe202b8e48) at /home/vboxuser/xfit/xfitter-2.2.0_Future_Freeze/tools/draw/src/xfitter-draw.cc:75
==========================================================
```

Minor issue: Ubuntu 22 bug in logo

Resolved with:

./bin/xfitter-draw ./output --no-logo

Old version: xFitter 2.1 Docker / Singularity

JBrandonS / xfitter-docker

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

<> Code | Issues 0 | Pull requests 0 | Actions | Projects 0 | Wiki | Security | Insights

A WIP docker contatiner 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 b103aaf 10 hours ago

.gitignore	Added run dir for steering files. Updated Readme. Fixed issues with S...	5 days ago
Dockerfile	Handeling 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	Handeling 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

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

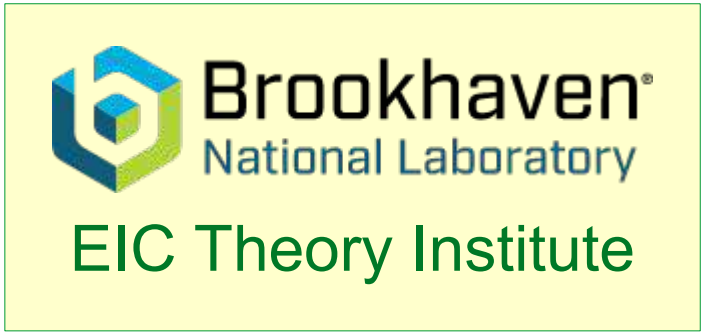
Your **$pwd** will be mounted to **/run** so you have local access to output
Launch singularity; you'll drop into a bash shell.
xfitter and **xfitter-draw** are in your image path.

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

CONCLUSIONS

https://www.bnl.gov/physics/surge/

https://hefty.tamu.edu/



https://www.bnl.gov/eic-theory/

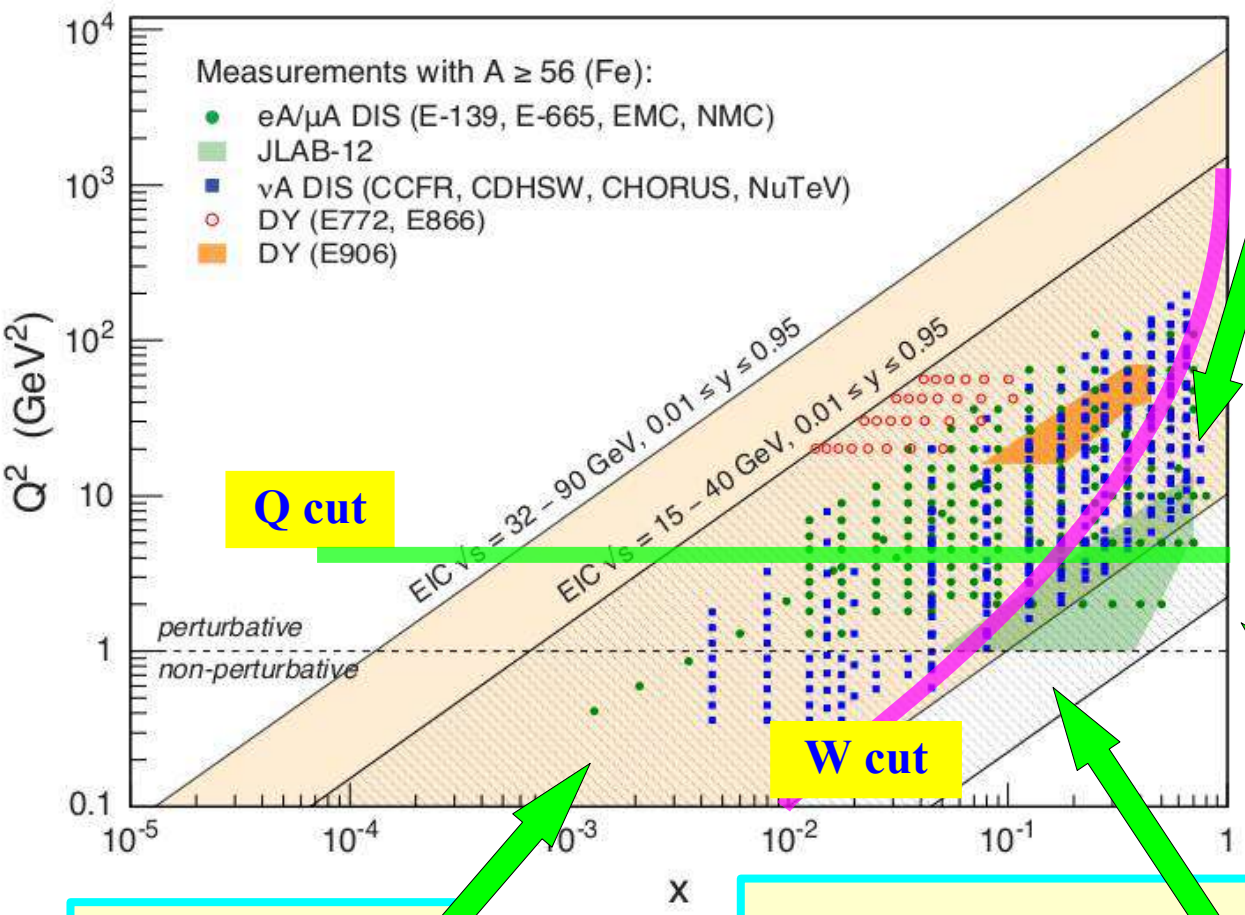
EIC Theory Institute

Come Visit

- EIC related activities ramping up in the US
- Past xFitter projects serve as "seeds" for EIC extension
- **My TO DO List:**
  - Finish integrating the S-ACOT N2LO and N3LO codes
  - Work with Peter & Valerio to get grid code into xFitter
  - Provide VirtualBox & Docker images for general use
  - **Students:**
    - Re-do some of past projects
    - Possibly document exercises for future tutorials

Bottom line: the xFitter tool is valuable to the EIC community

Leverage this into contributions and projects



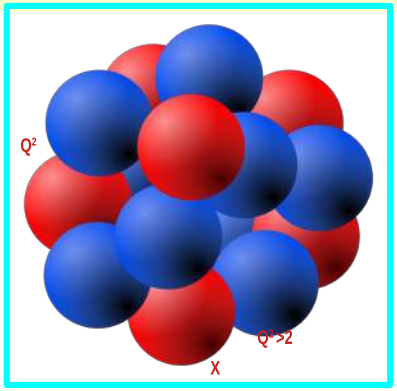
High-x:

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-Q²
extend nCTEQ framework for this region
& prepare for EIC



Low-x:

Shadowing
Recombination
Resummation
BFKL
Saturation

Low-Q²:

Non-Perturbative inteface
collective effects

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

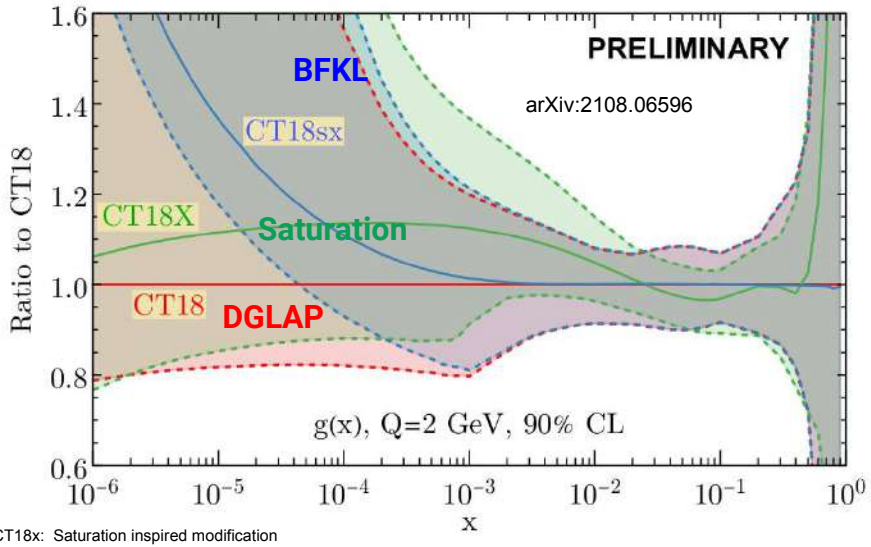
F_L at low Q^2 access to g(x)
Run at multiple energies

… combine with complementary approaches (3D-PDFs, Lattice QCD) ⇒ **"solve" QCD**

BACKUP

Global analysis: Selected Examples: g(x), F_L

Gluon Parton Distribution Function g(x)

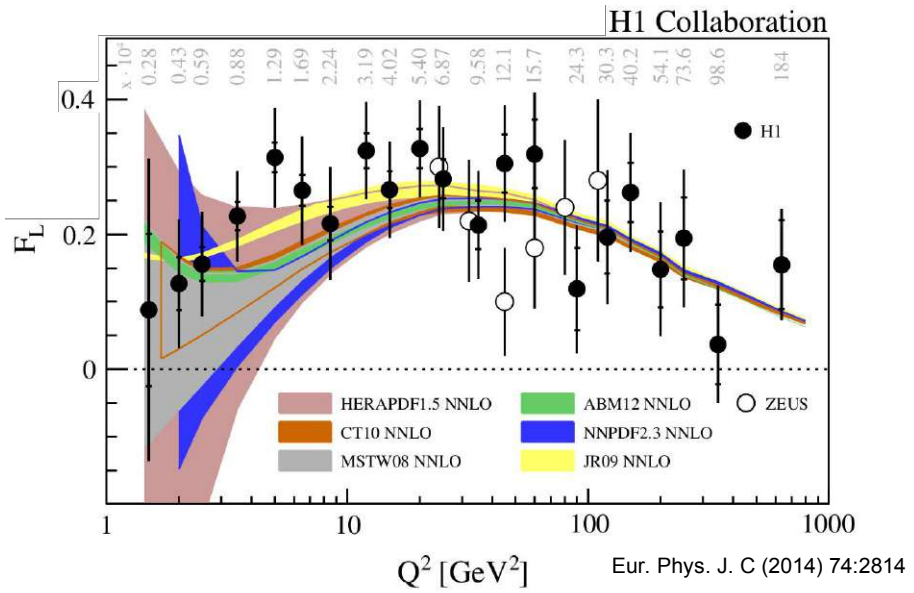


CT18x: Saturation inspired modification
CT18sx: w/ HELL small-x resummation code

Gluon PDF:

- Differences: DGLAP, BFKL, Saturation
- Different {x, Q^2, **A**} dependence
- Large Uncertainties: EIC can improve

Longitudinal Structure Function F_L



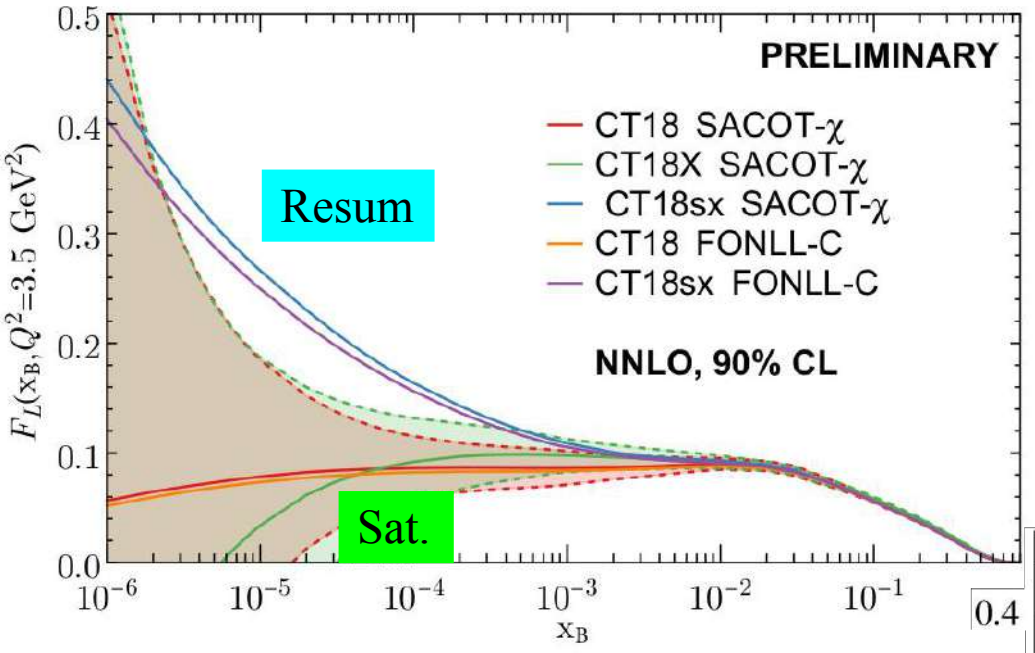
Eur. Phys. J. C (2014) 74:2814

Longitudinal Structure Function F_L:

- Current theory is challenged
- Gluon strongly influences F_L
- Large Uncertainties: EIC can improve

F_L is senstive to Gluon and Small-x Treatments

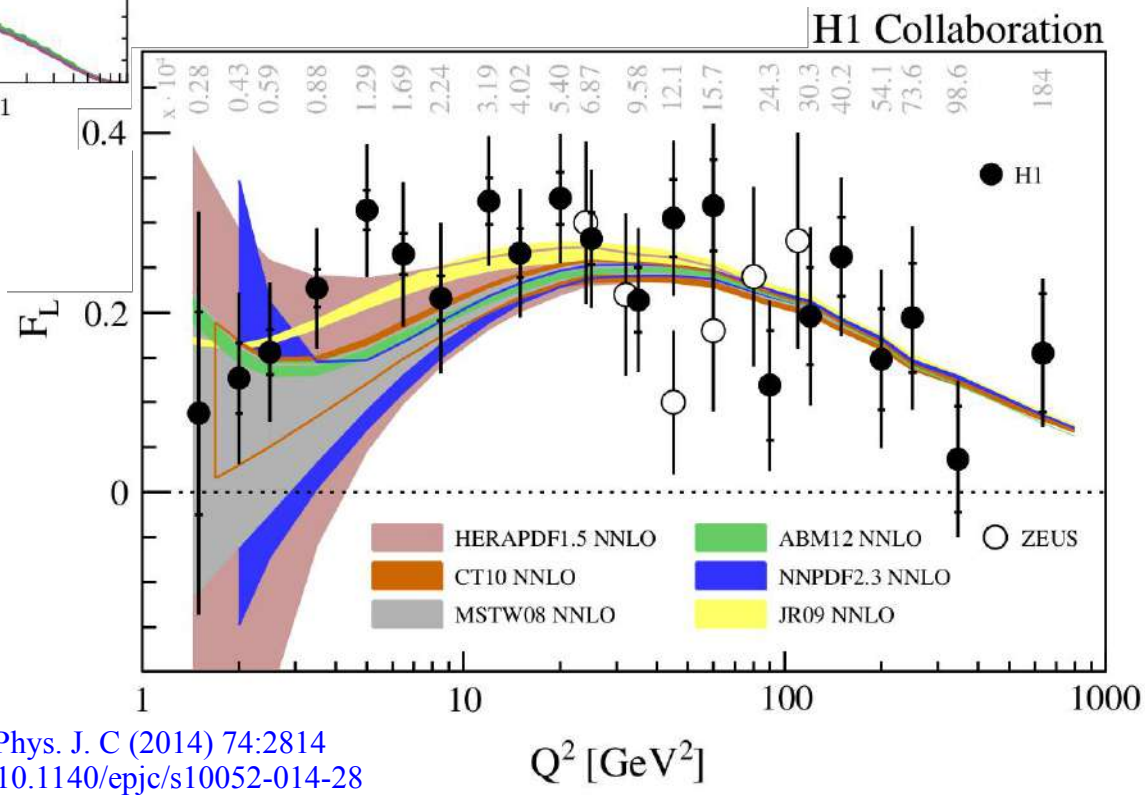
Still, large uncertainty at small x *(low Q^2)*



CT Collaboration: 2108.06596 [hep-ph]

Saturation & Resummation:

again
different behavior
at very small x



F_L Challenge:

Large Uncertainties at small x

Eur. Phys. J. C (2014) 74:2814
DOI 10.1140/epjc/s10052-014-28

Physics @ the US EIC beyond the EIC's core science

Of HEP/LHC-HI interest to Snowmass 2021 (EF 05, 06, and 07 and possibly also EF 04)

New Studies with proton or neutron target:

- Impact of precision measurements of unpolarized PDFs at high x/Q^2, on LHC-Upgrade results(?)
- Precision calculation of α_S : higher order pQCD calculations, twist 3
- Heavy quark and quarkonia (c, b quarks) studies with **100-1000 times lumi of HERA and with polarization**
- Polarized light nuclei in the EIC

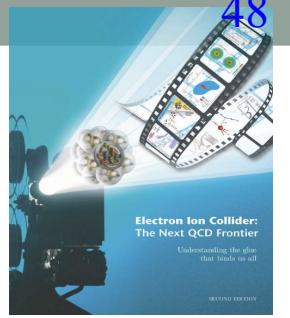
Physics with nucleons and nuclear targets:

- Quark Exotica: 4,5,6 quark systems…? Much interest after recent **LHCb** led results.
- Physic of and with jets with EIC as a precision QCD machine:
  - Jets as probe of nuclear matter & Internal structure of jets : novel new observables, energy variability
  - Entanglement, entropy, connections to fragmentation, hadronization and confinement

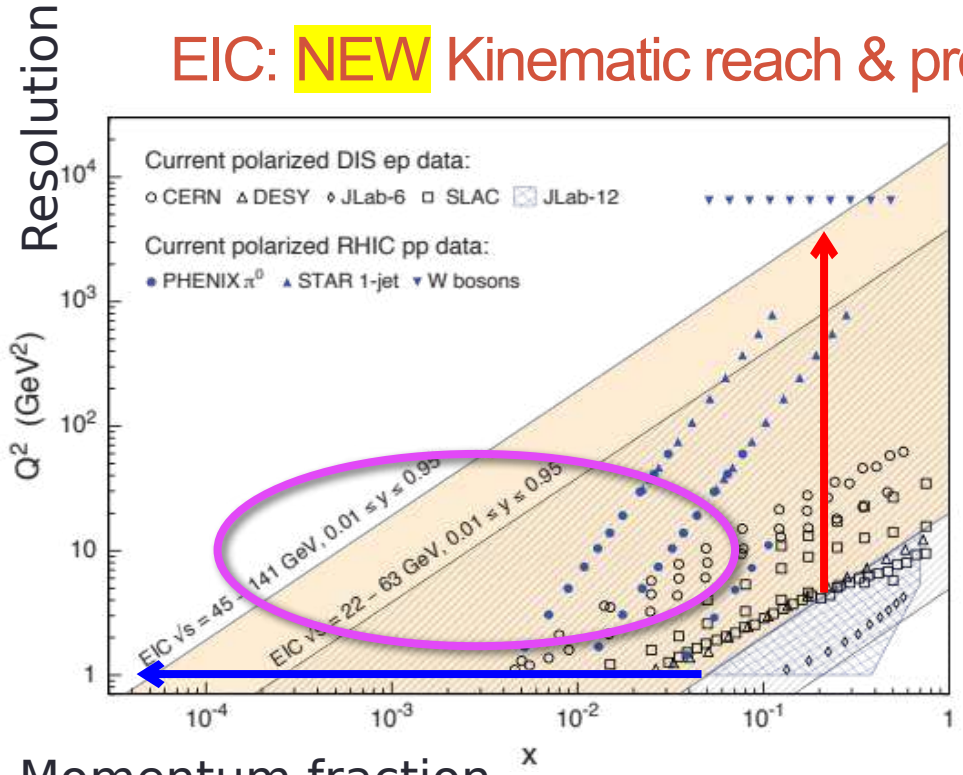
Precision electroweak and BSM physics:

- Electroweak physics & searches beyond the SM: Parity, charge symmetry, lepton flavor violation
- LHC-EIC Synergies & complementarity

Study of universality: e-p/A vs. p-A, d-A, A-A at RHIC and LHC



EIC: NEW Kinematic reach & properties

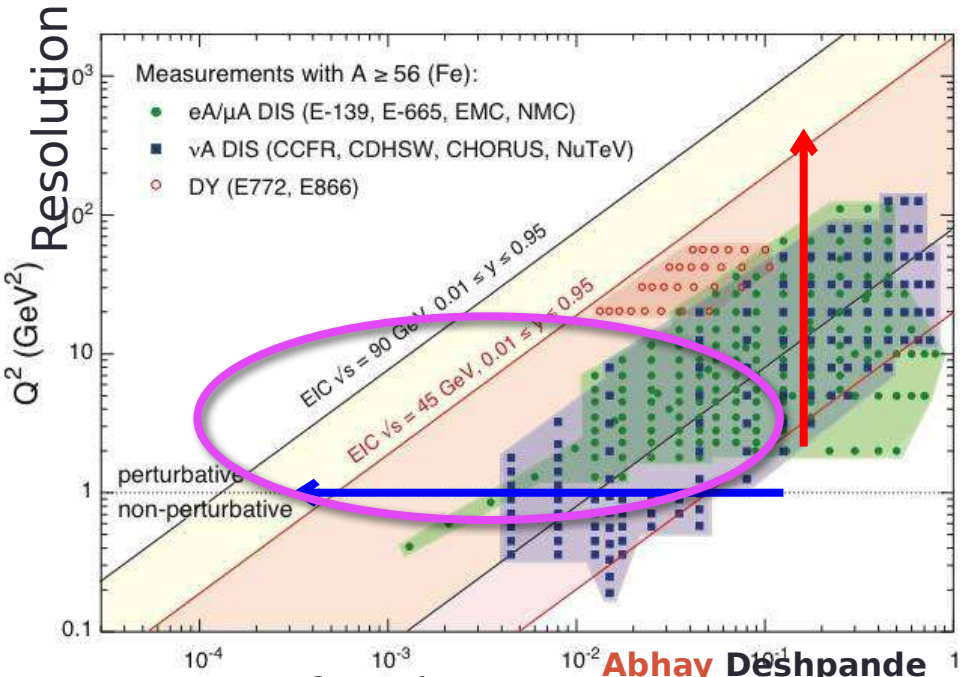


For e-N collisions at the EIC:

- ✓ Polarized beams: e, p, d/^{3}He
- ✓ Variable center of mass energy
- ✓ Wide Q^2 range → evolution
- ✓ Wide x range → spanning valence to low-x

For e-A collisions at the EIC:

- ✓ Wide range in nuclei
- ✓ Luminosity per nucleon same as e-p
- ✓ Variable center of mass energy
- ✓ Wide x range (evolution)
- ✓ Wide x region (reach high gluon densities)



PDF profiling using the forward-backward asymmetry in Neutral Current Drell-Yan production

Elena Accomando,[a,b] Juri Fiaschi,[c,a,b] Francesco Hautmann,[b,d,e,f,g] Stefano Moretti,[a,b]
the xFitter Developers' team: Hamed Abdolmaleki,[h] Valerio Bertone,[i]
Francesco Giuli,[j] Alexander Glazov,[k] Agnieszka Luszczak,[l] Ivan Novikov,[m]
Fred Olness[n] and Oleksandr Zenaiev[o]

Eur. Phys. J. C (2019) 79:864
https://doi.org/10.1140/epjc/s10052-019-7362-7

THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Theoretical Physics

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,a], Andrey Sapronov[9], Oleksandr Zenaiev[11]

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]