Precision QCD at future DIS facilities

with focus on PDFs at LHeC, FCC-he, …

Fred Olness
(SMU)

Thanks to the LHeC Study Group
C. Gwenlan, G. Pownall, M. Klein, N. Armesto, P. Newman, A. Stasto,
D. Britzger, J. Rojo, U. Klein, … *LHeC PDF & Low x Working Group*

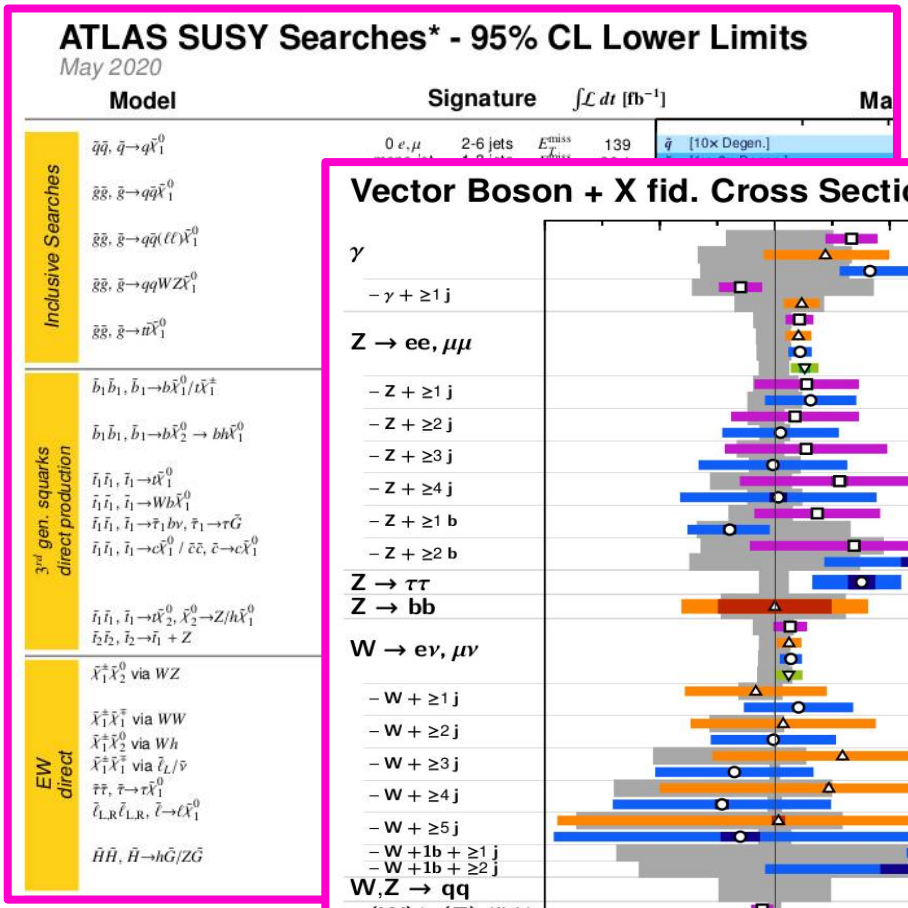
and my xFitter colleagues

LHeC Study Group

CERN-ACC-Note-2020-0002

Snowmass 2021
Energy Frontier
7-8 July 2020

Improved PDFs are Key to Precision Measurements



Key for BSM

Much of theory error from PDFs.

E.g., N^{3}LO gg → H (PDF is dominant)

" PDF uncertainties are among the leading uncertainties in the first LHC precision measurements by CMS"

DIS2018 Plenary

Fundamental SM Parameters limited by PDFs

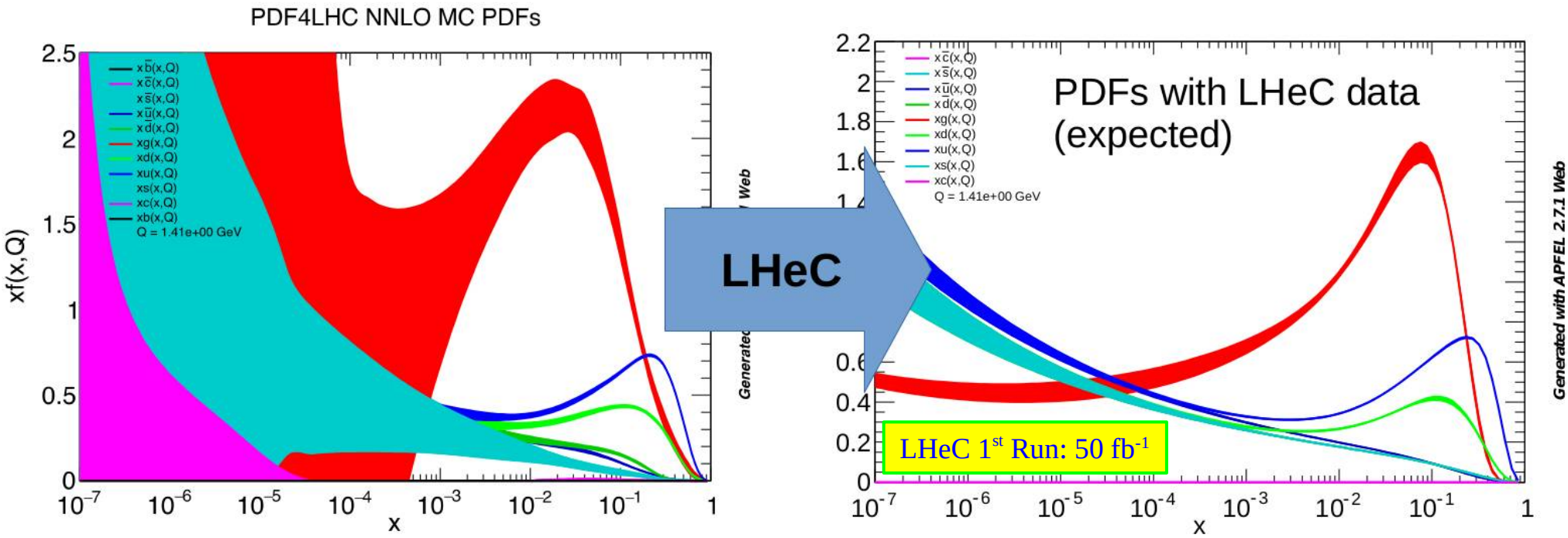
Measurement of m_W at LHC

[EPJC 78 (2018) 110, ATL-PHYS-PUB-2018-004]

	Stat. Unc.	Muon Unc.	Elec. Unc.	Recoil Unc.	Bckg. Unc.	QCD Unc.	EW Unc.	PDF Unc.	Total Unc.
W^+	8.9	6.6	8.2	3.1	5.5	8.4	5.4	14.6	23.4
W^-	9.7	7.2	7.8	3.3	6.6	8.3	5.3	13.6	23.4
$W^\pm$	6.8	6.6	6.4	2.9	4.5	8.3	5.5	9.2	18.5

[MeV]

Improved PDFs are Key to Precision Measurements



LHeC: A Game Changer

- First Run (3 Years, ~50 fb^{-1}) ≡ **×50 HERA**
- Complete PDF unfolding in a single experiment
- Precision resolution of parton dynamics
- Extend {x,Q^2} kinematic reach by decades
- PDF Extraction free of: i) Nuclear effects,
  ii) Hadronization iii) higher twist, iv) …

Unique potential to revolutionize PDFs

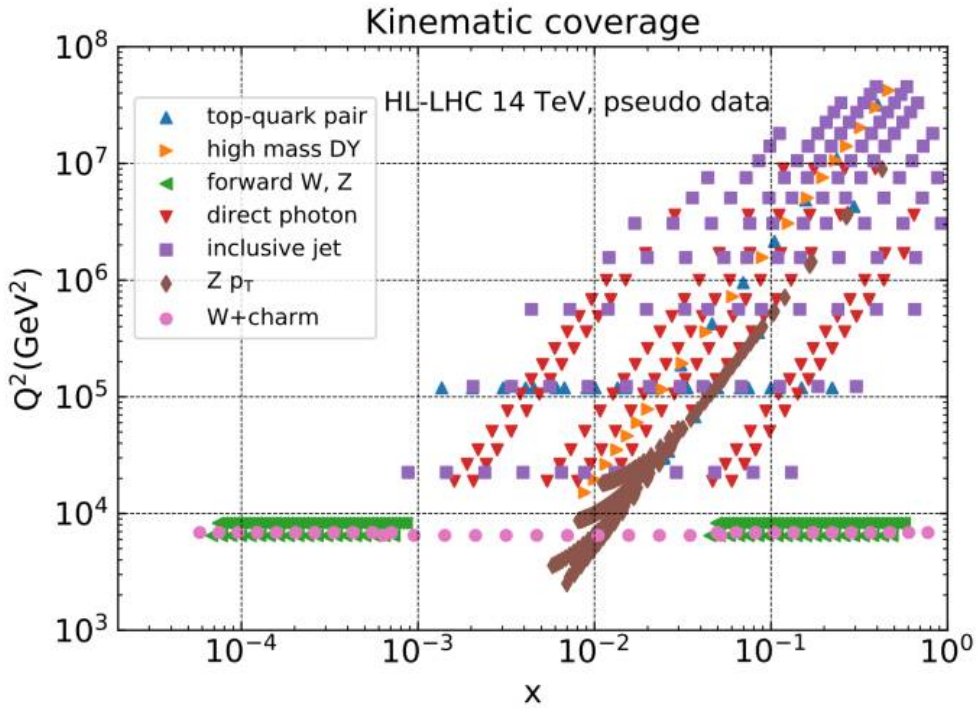
LHeC

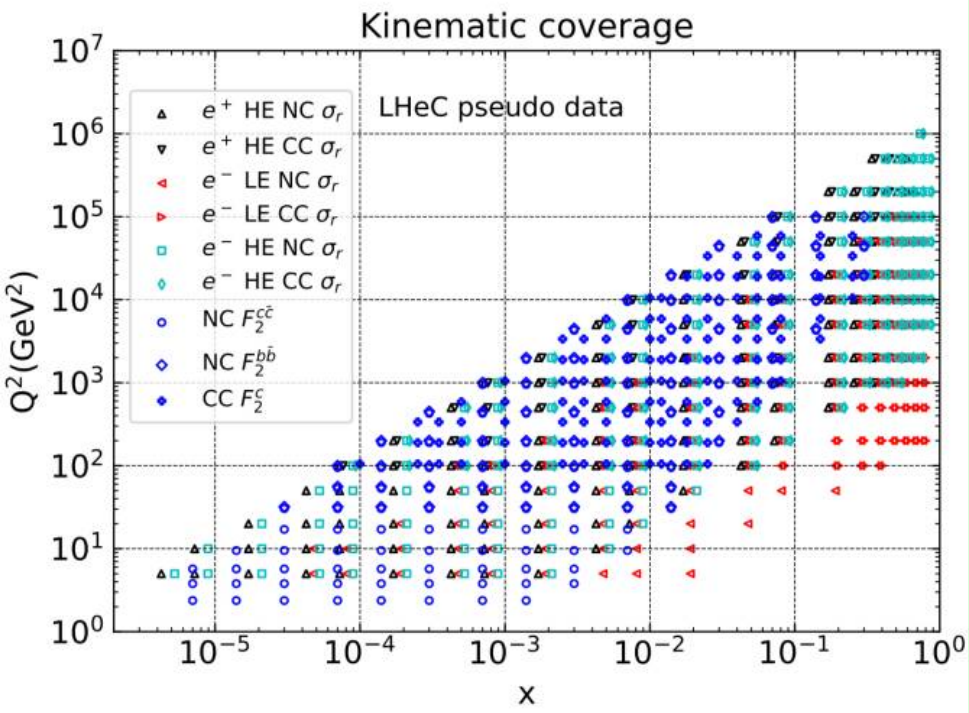
Also Provides Access to Unique Kinematic Regions

Towards ultimate PDFs at the HL-LHC and LHeC

Exploit **novel facilities** for precision studies of the proton structure

Juan Rojo





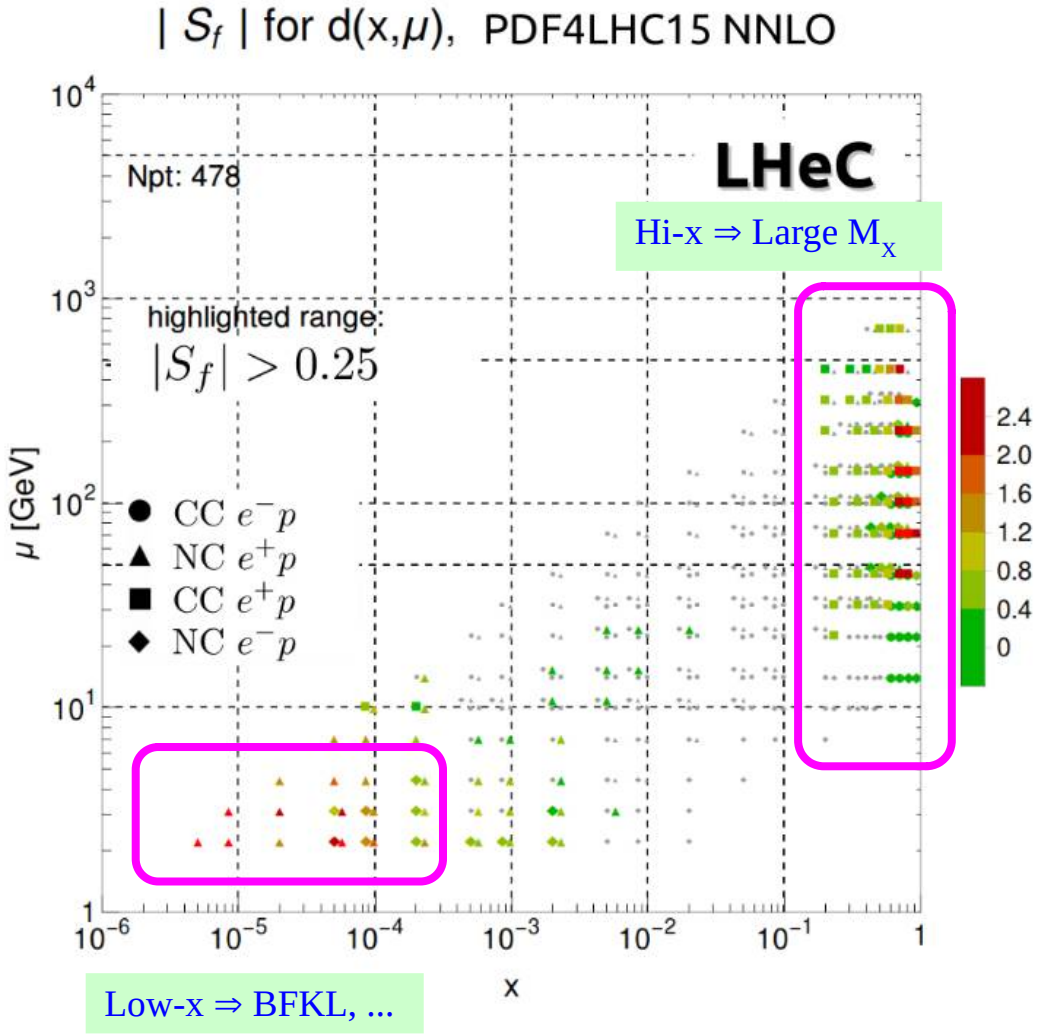
Fully **complementary** in terms of PDF constraints, possible synchronous operation

Complementary: … add a dimension, Sensitivity: S^F

Sensitivity S^F:

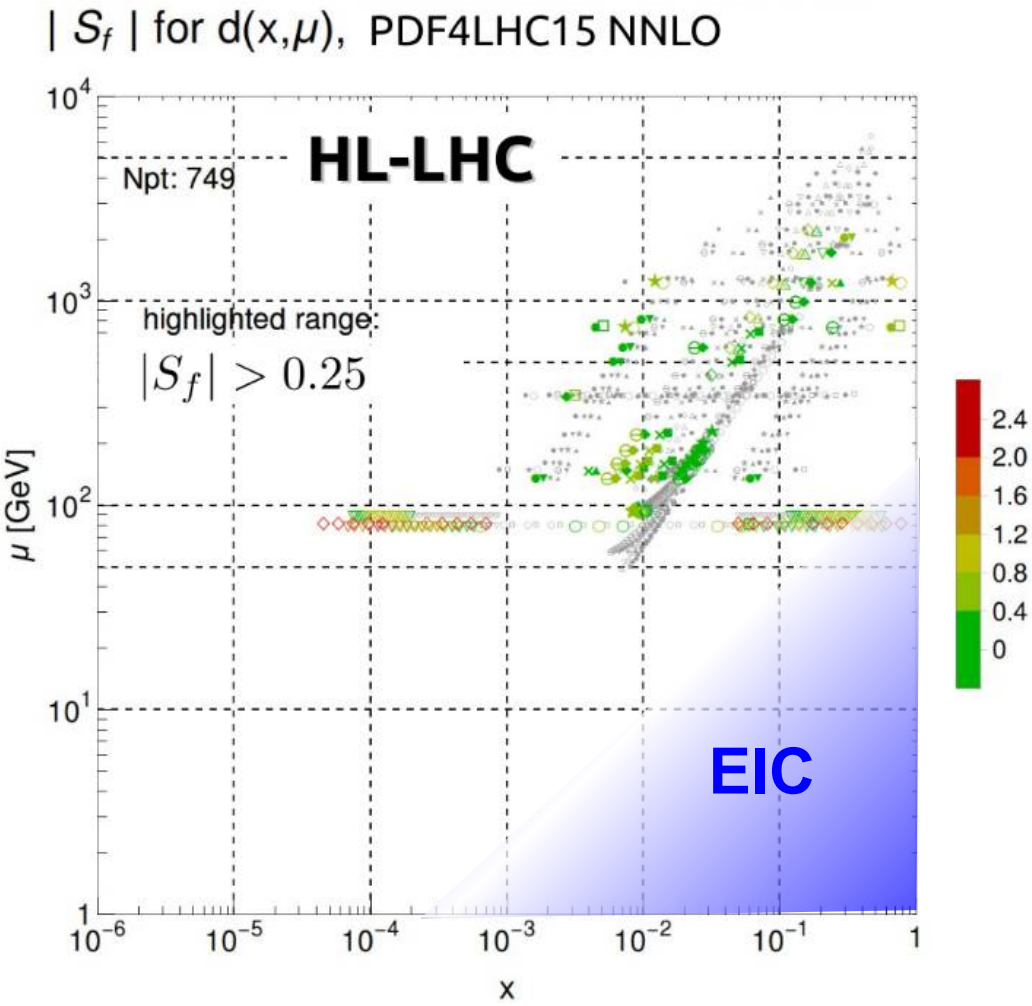
Correlation times the scaled residual:

$$S_F \sim C_f \frac{\delta r}{\langle r \rangle_{exp}} \qquad \delta r \sim \frac{T - D}{\sigma}$$



Hi-x ⇒ Large M_x

Low-x ⇒ BFKL, ...



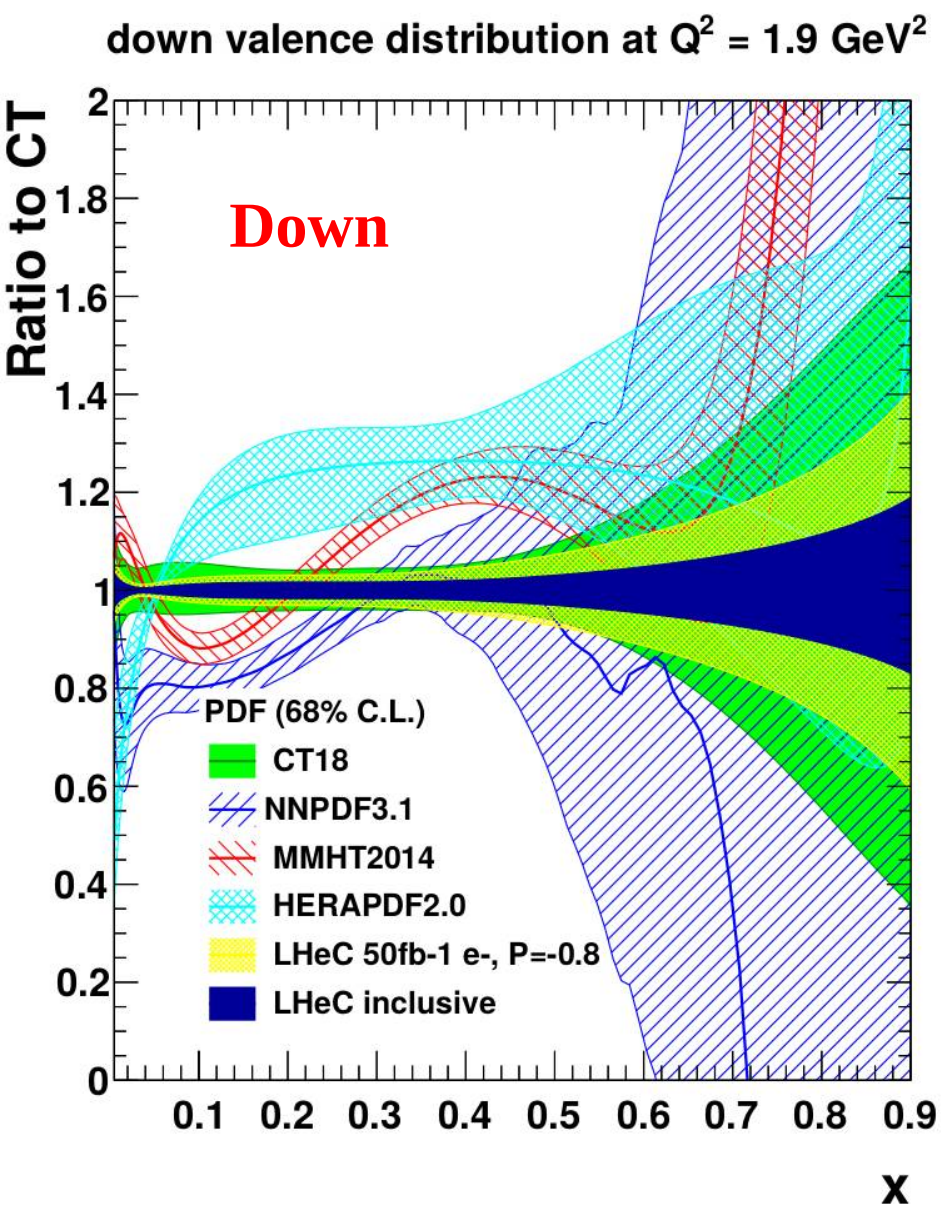
PDFSense: B.-T. Wang, et al., Phys.Rev. D98 (2018) no.9, 094030

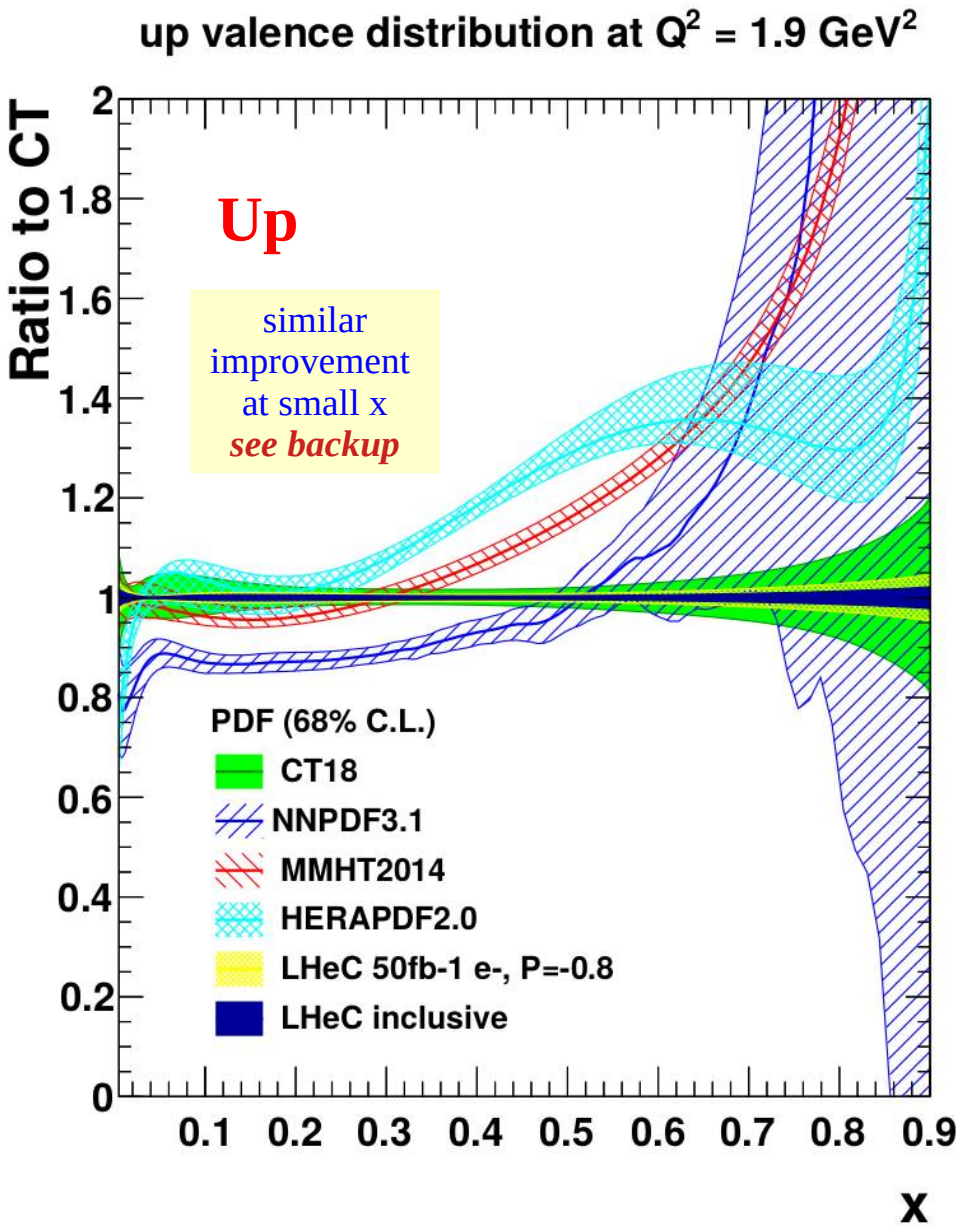
LHeC provides unique information

thanks to Tim Hobbs & Pavel Nadolsky for figs

A very brief tour of the flavors

Up and Down PDFs at Large x



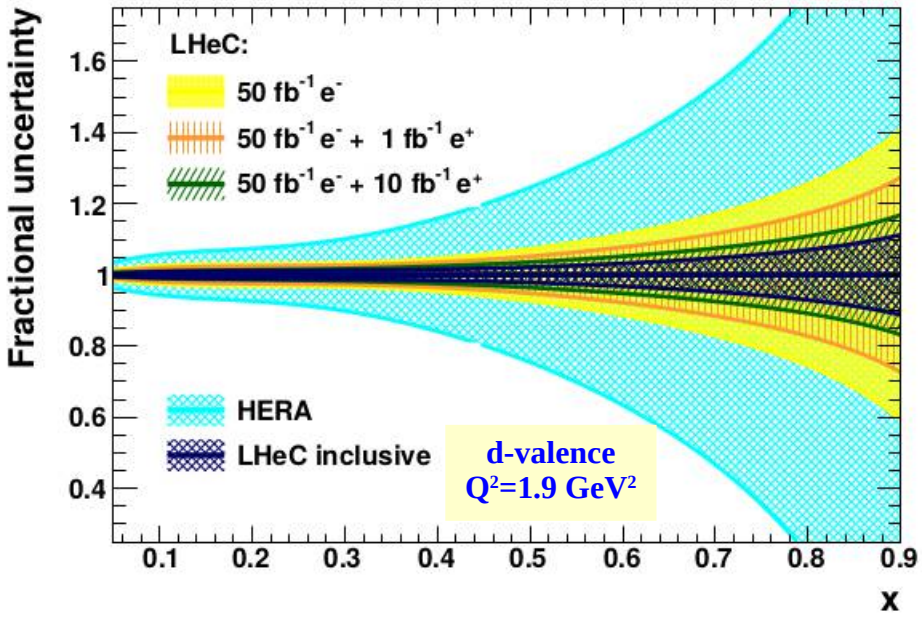


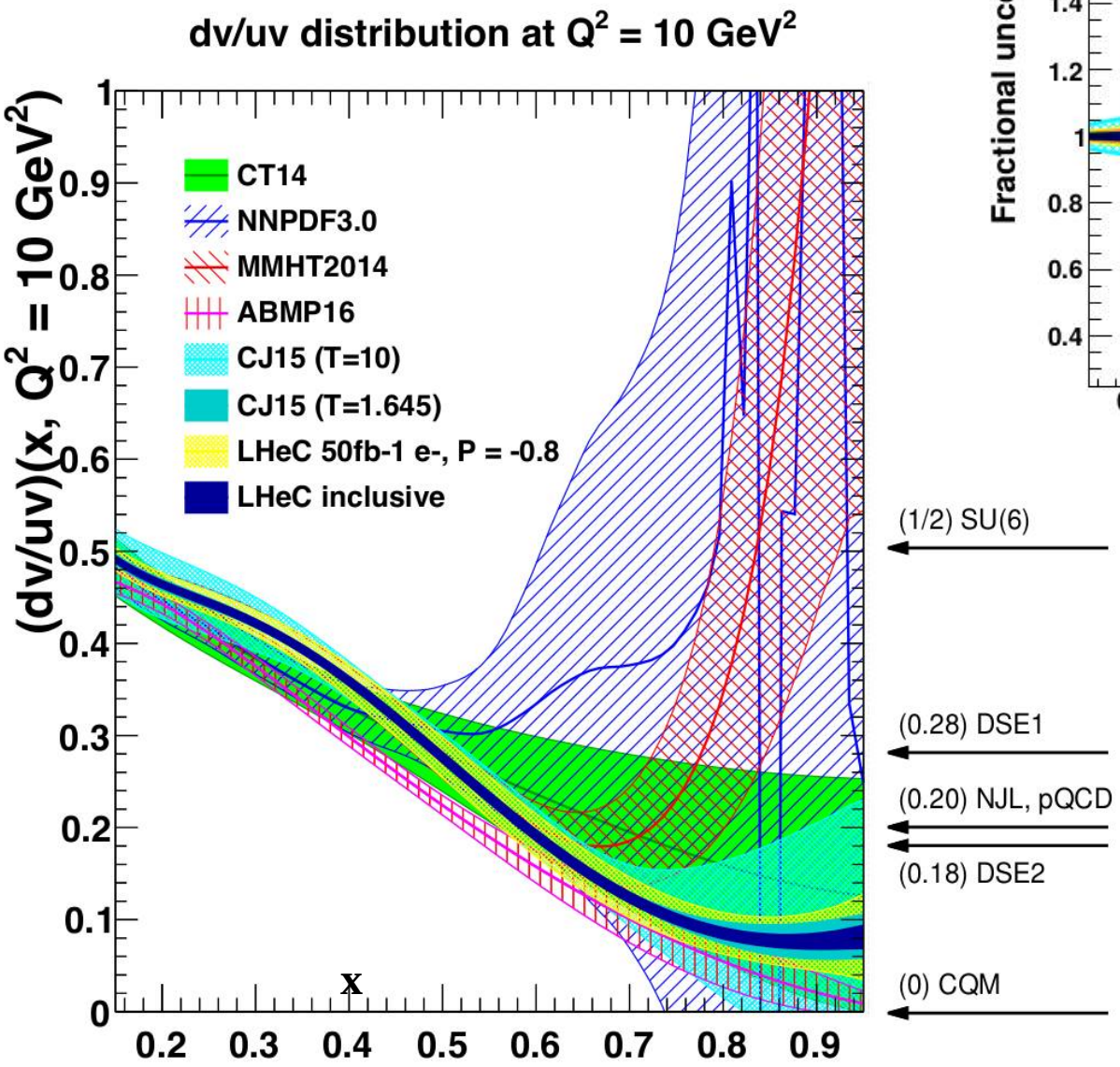
Precision Determination:
free from higher twist corrections and nuclear uncertainties

Large x
crucial for HL/HE–LHC & FCC searches
Also relevant for DY, M_W etc.

Resolve the long-standing mystery of d/u as x → 1

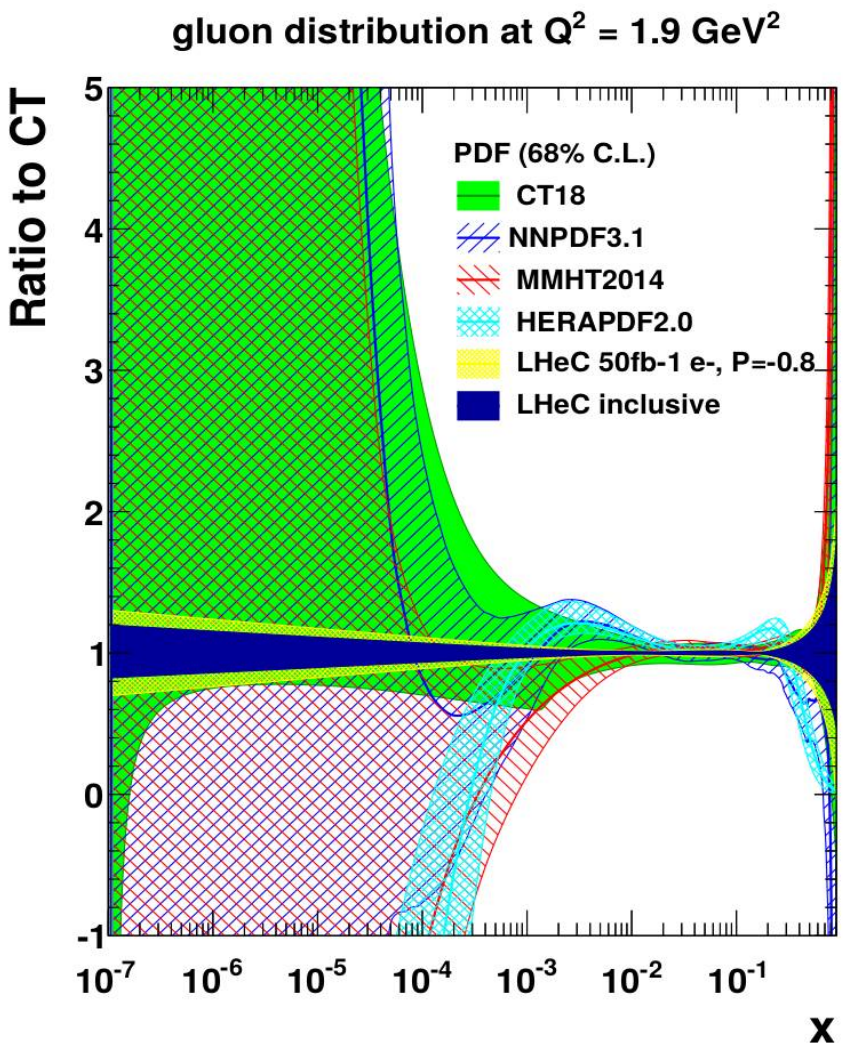
Positron (e^+) Sensitive to d-valence

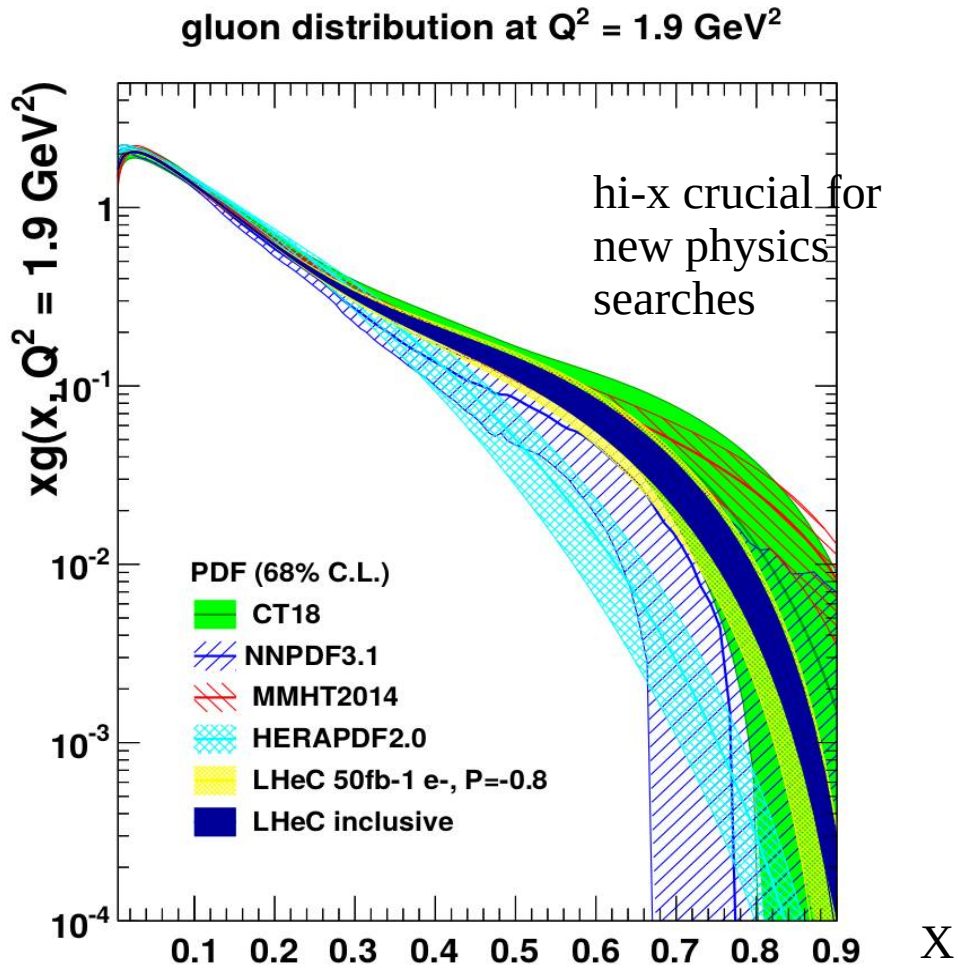




Wide range of model predictions

Gluon PDF and α_s





Explore small x QCD

- DGLAP vs BFKL
- non-linear evolution
- gluon saturation
- implications for ultra high energy neutrino cross sections

Gluon and sea PDFs intimately related.

LHeC can disentangle sea from valence quarks at large x, with precision measurements of CC and NC $F_2^{\gamma Z}$ & $xF_3^{\gamma Z}$

High precision alpha-s

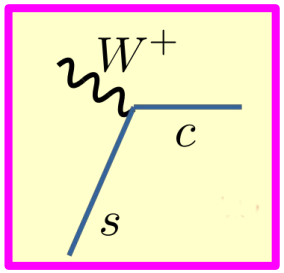
c.f., Daniel Britzger presentation last week

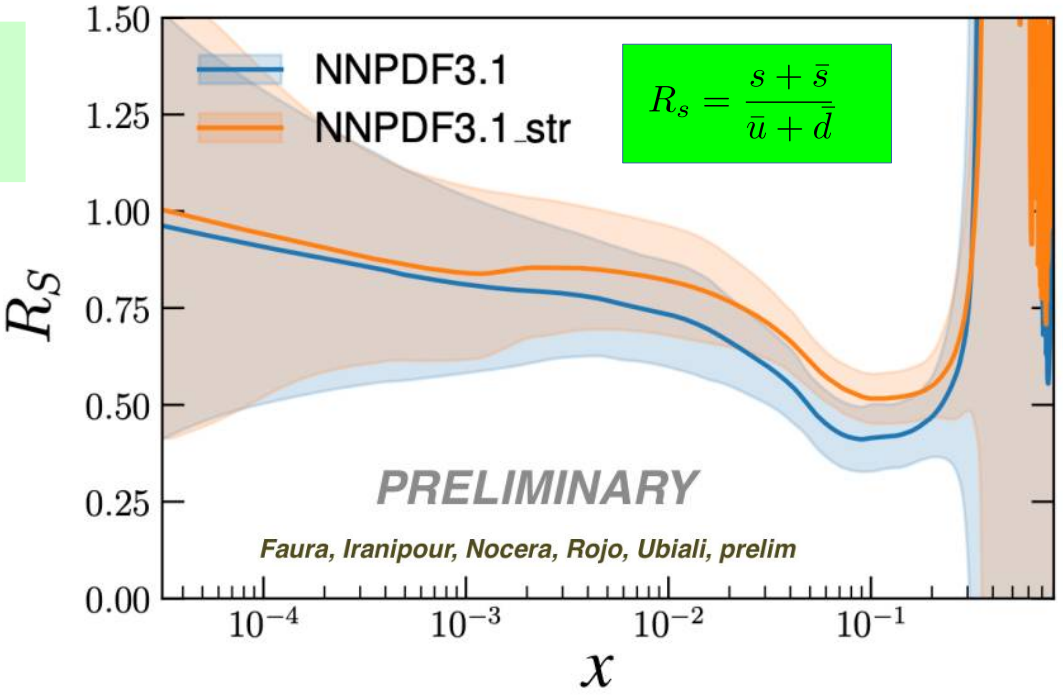
$$\Delta\alpha_s(M_Z)(\text{incl. DIS \& jets}) = \pm 0.00018_{(\text{exp+PDF})}$$

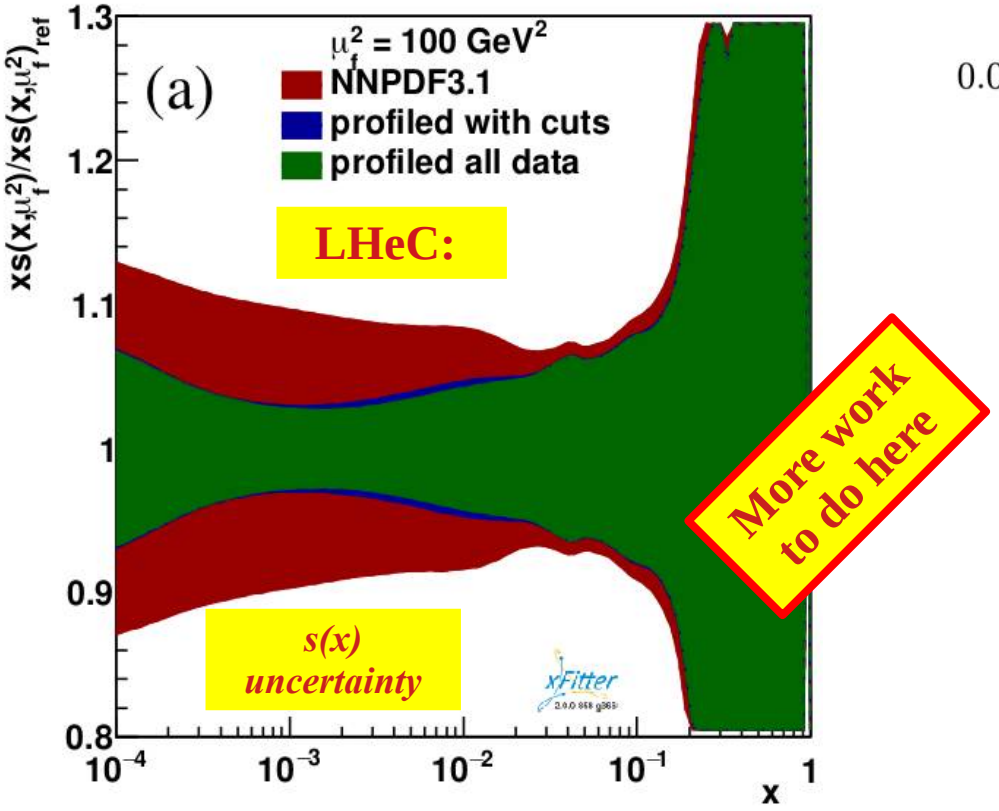
The "Strange" Strange PDF:

Strange PDF
Large Uncertainty

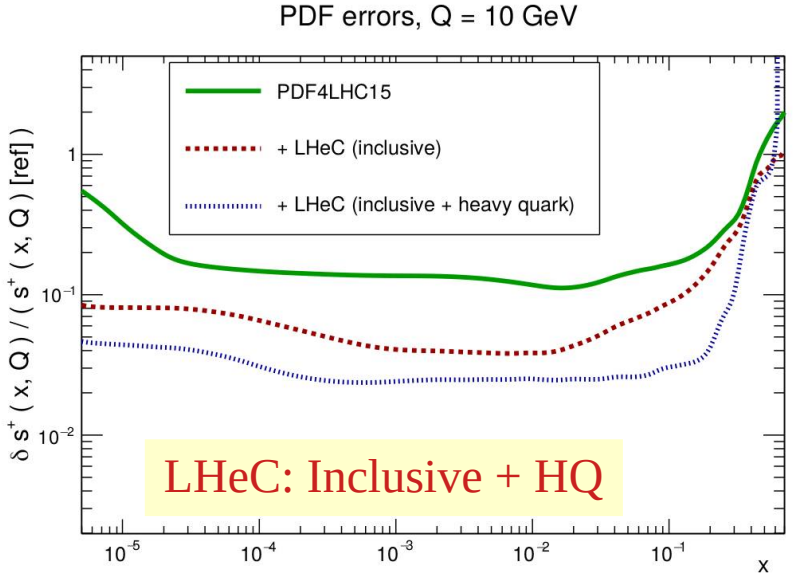
Charged Current Charm Production







More work to do here

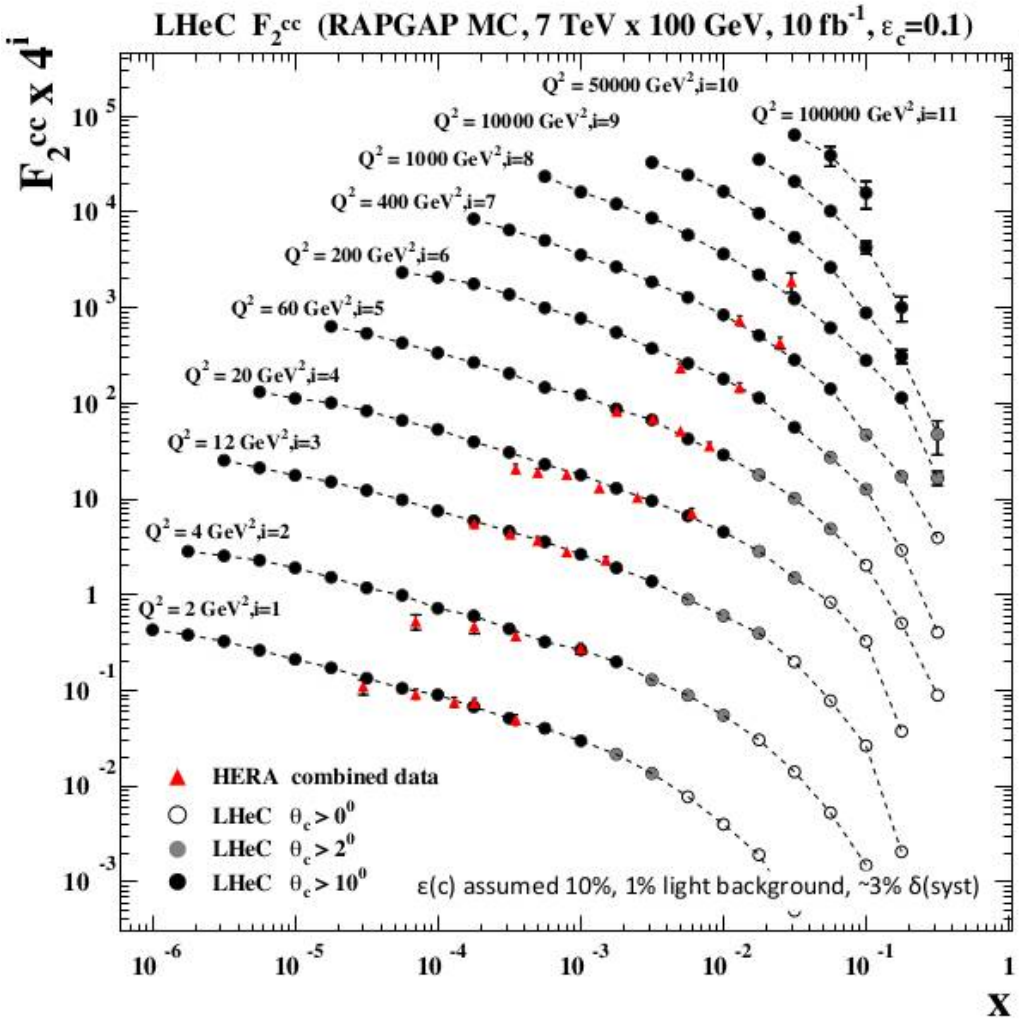


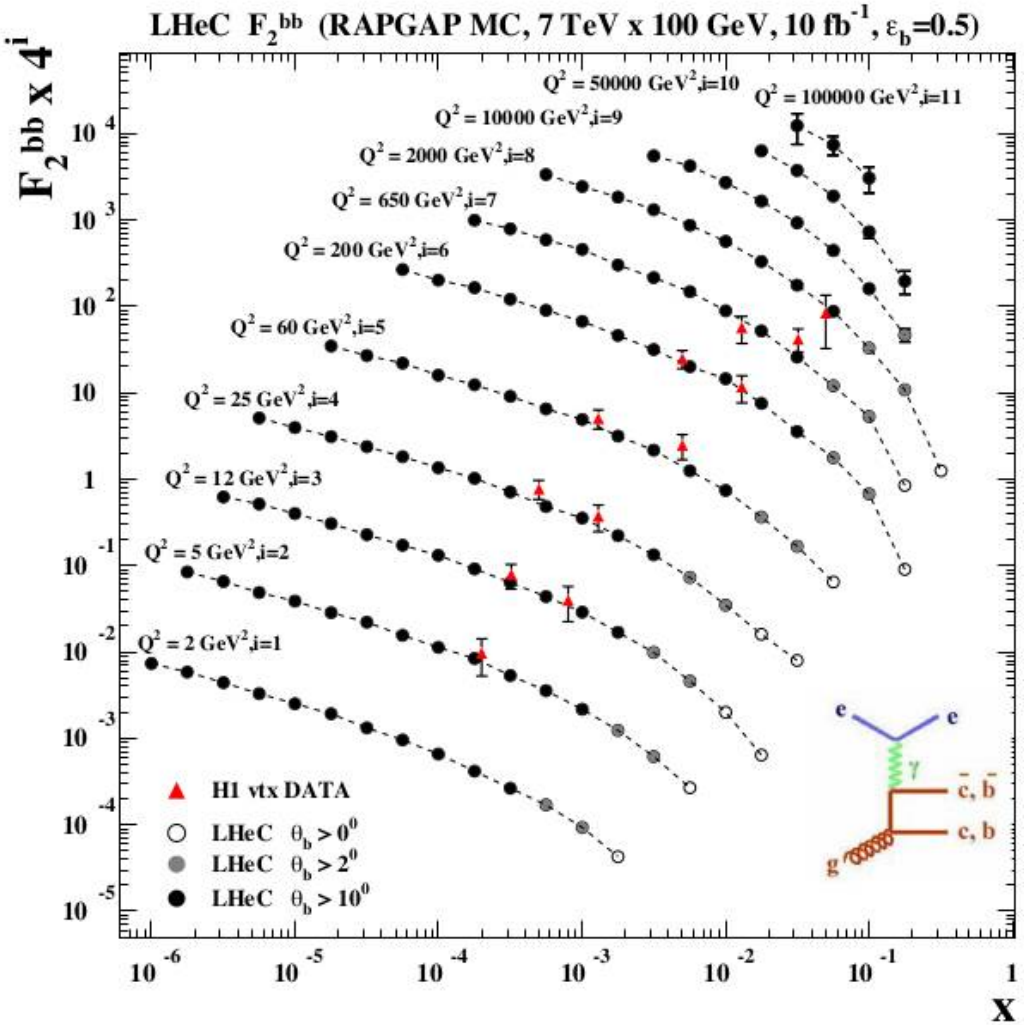
xFitter Developers' Team
Eur.Phys.J.C 79 (2019) 10, 864

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

Charm and Bottom

Multi-scale problem, HQ PDFs and resummation, … theory improvements ongoing





LHeC: enormously extended range and much improved precision c.f. HERA

- **δMc = 50 (HERA)** to **3 MeV**: impacts on αs, regulates ratio of charm to light, crucial for precision t, H
- **δMb** to **10 MeV**; MSSM: Higgs produced dominantly via $b\bar{b} \rightarrow A$

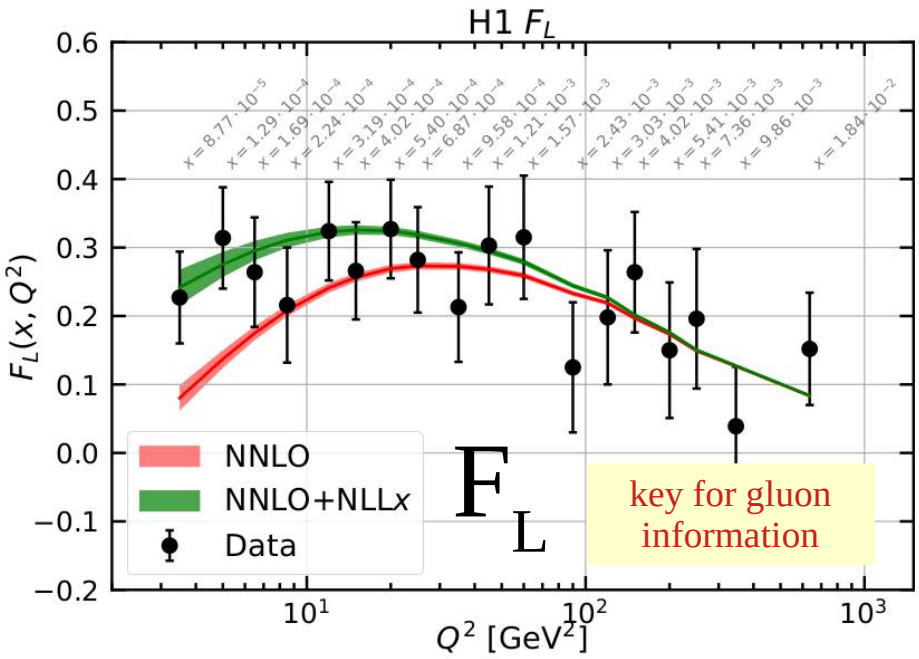
Tip of the iceberg

Two Sample Topics

Small x Physics
&
Nuclear PDFs

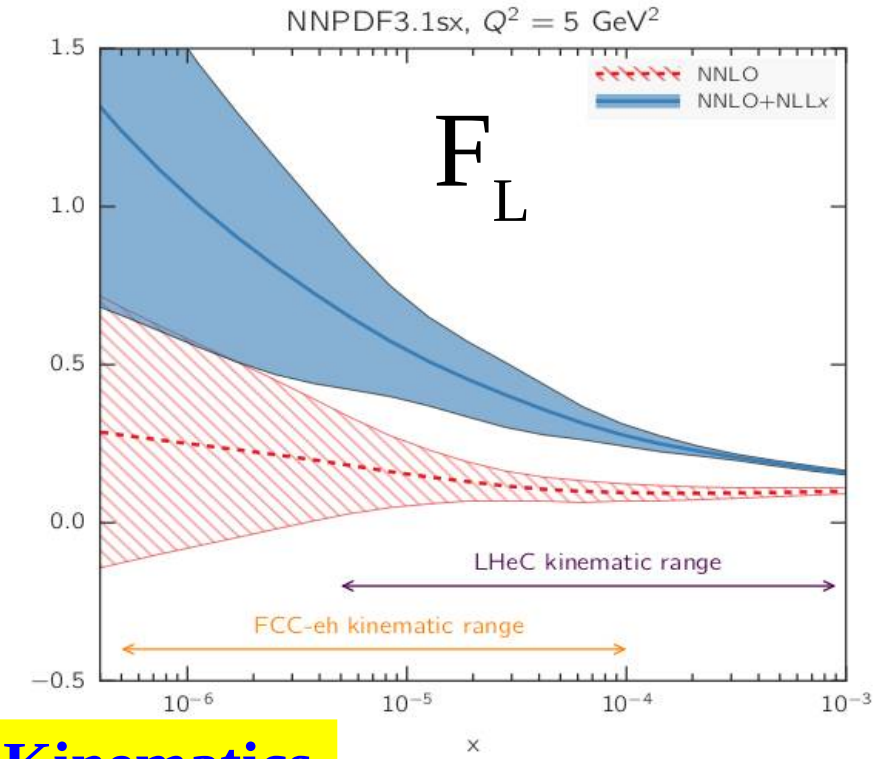
Small x region: Effects of Resummation F_L

Resummation Effects at HERA

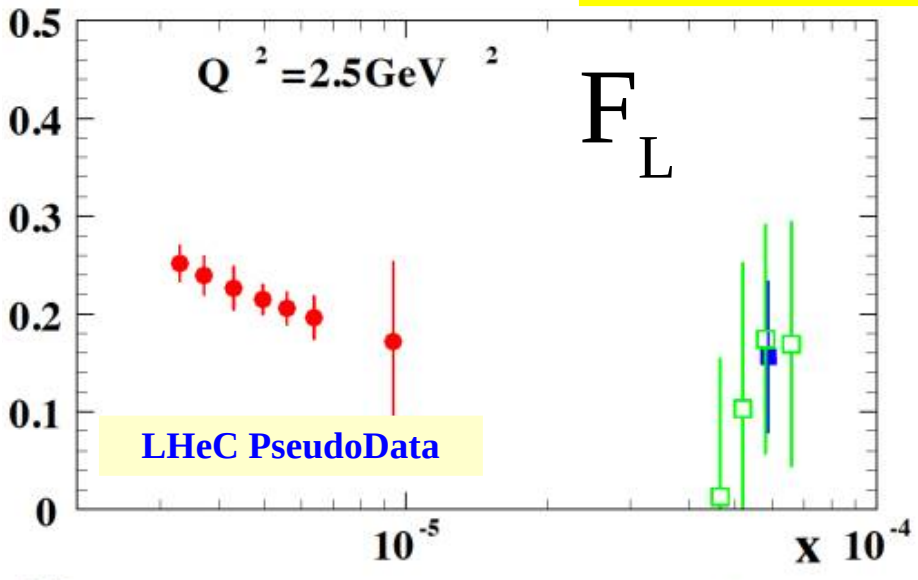


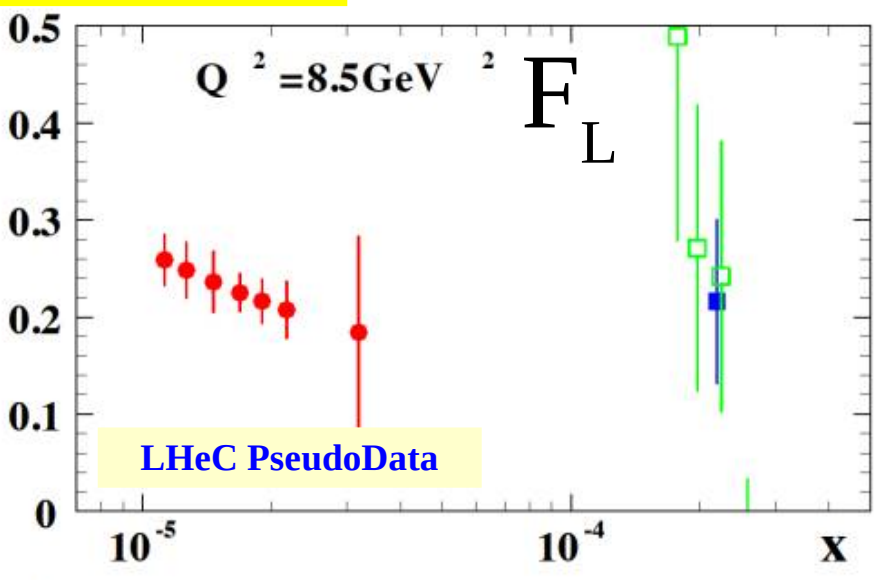
key for gluon information

Resummation at LHeC

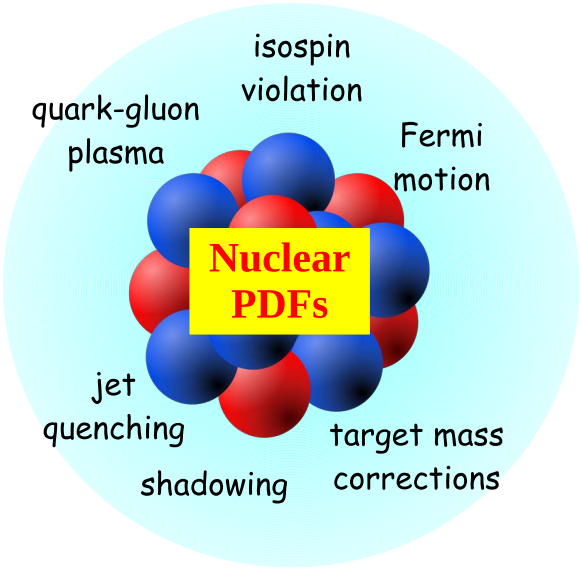


Ultra-Low x Kinematics

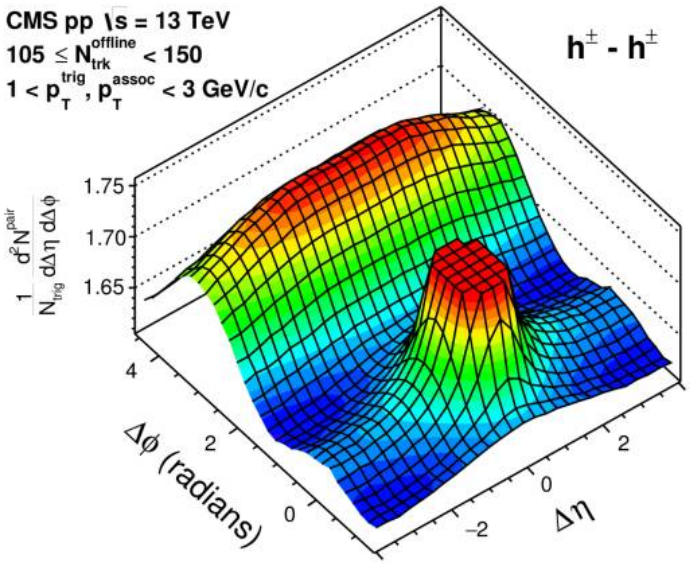




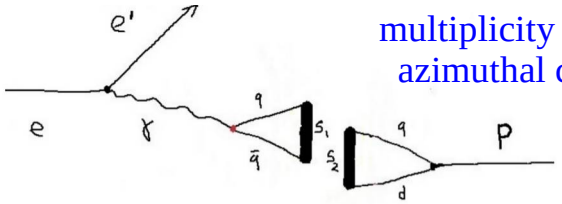
Nuclear PDFs & Collective Phenomena



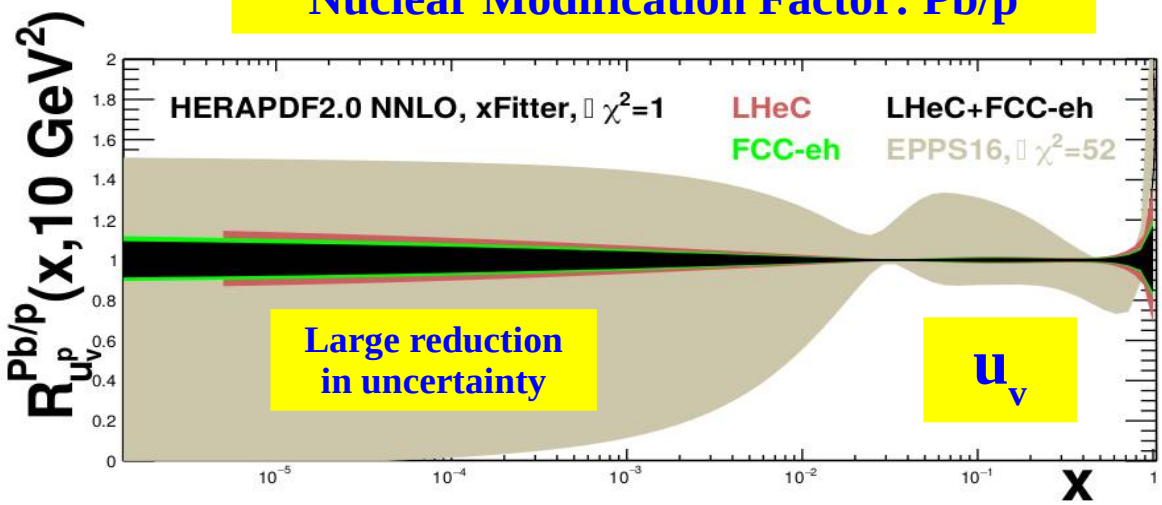
Collective Effects

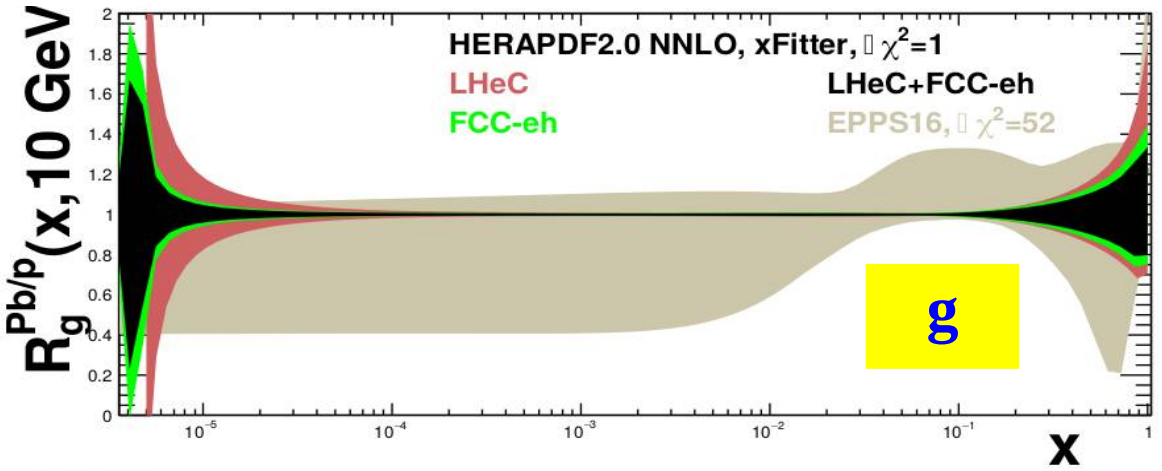


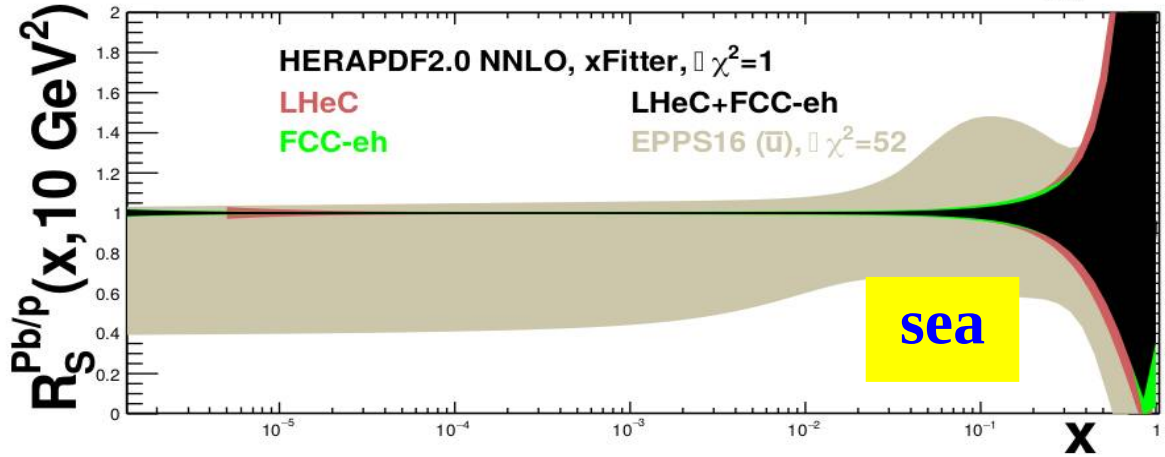
Collective effects seen in high-multiplicity two-particle azimuthal correlation,



Nuclear Modification Factor: Pb/p







Work ongoing

Contributions welcome

DESY xFitter

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

xFitter

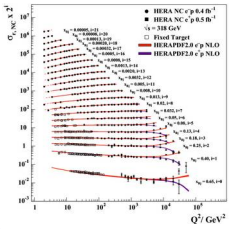
Features & Recent Updates:

- 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



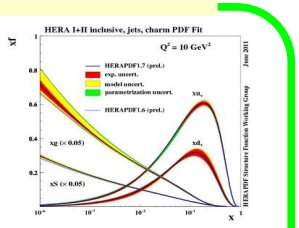
Data: HERA, Tevatron, LHC, fixed target experiments

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 2.0.1
Old Fashioned

Date	Version
 02/2020	2.0.1N Nuclear Daiquiri

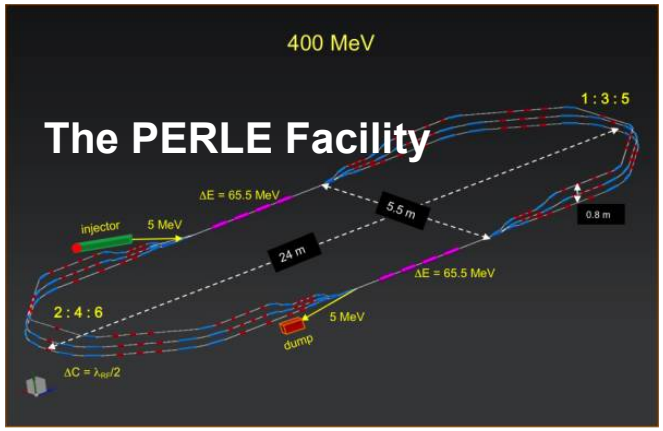
xFitter Collaboration Meeting February 2020, DESY

www.xFitter.org

CERN-ACC-Note-2020-0002
Version v2.0
Geneva, June 18, 2020

The Large Hadron-Electron Collider at the HL-LHC

LHeC Study Group



OPEN ACCESS
IOP Publishing
Journal of Physics G: Nuclear and Particle Physics
J. Phys. G: Nucl. Part. Phys. 45 (2018) 065003 (71pp)
https://doi.org/10.1088/1361-6471/aaa171

PERLE. Powerful energy recovery linac for experiments. Conceptual design report

D Angal-Kalinin[1], G Arduini[2], B Auchmann[2], J Bernauer[3], A Bogacz[4], F Bordry[2], S Bousson[5], C Bracco[2], O Brüning[2], R Calaga[2], K Cassou[6], V Chetvertkova[2], E Cormier[7], E Daly[4], D Douglas[4], K Dupraz[6], B Goddard[2], J Henry[4], A Hutton[4], E Jensen[2], W Kaabi[6], M Klein[8,11], P Kostka[8], N Lasheras[2], E Levichev[9], F Marhauser[4], A Martens[6], A Milanese[2], B Militsyn[1], Y Peinaud[6], D Pellegrini[2], N Pietralla[10], Y Pupkov[9], R Rimmer[4], K Schirm[2], D Schulte[2], S Smith[1], A Stocchi[6], A Valloni[2], C Welsch[8], G Willering[2], D Wollmann[2], F Zimmermann[2] and F Zomer[6]

[1] ASTeC, STFC, Daresbury, United Kingdom
[2] CERN, Geneva, Switzerland
[3] Massachusetts Institute of Technology, Cambridge, MA, United States of America
[4] Jefferson Lab, Newport News, VA, United States of America
[5] Institute de Physique Nucleaire Orsay, France
[6] LAL, CNRS-IN2P3, Université Paris-Sud, Centre Scientifique d'Orsay, France
[7] CELIA, University of Bordeaux 1, CNRS UMR 5107, Talence, France
[8] University of Liverpool, United Kingdom
[9] BINP, Novosibirsk, Russia
[10] Institut für Kernphysik Technische Universität Darmstadt, Germany

E-mail: mklein@hep.ph.liv.ac.uk

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Published 3 May 2018

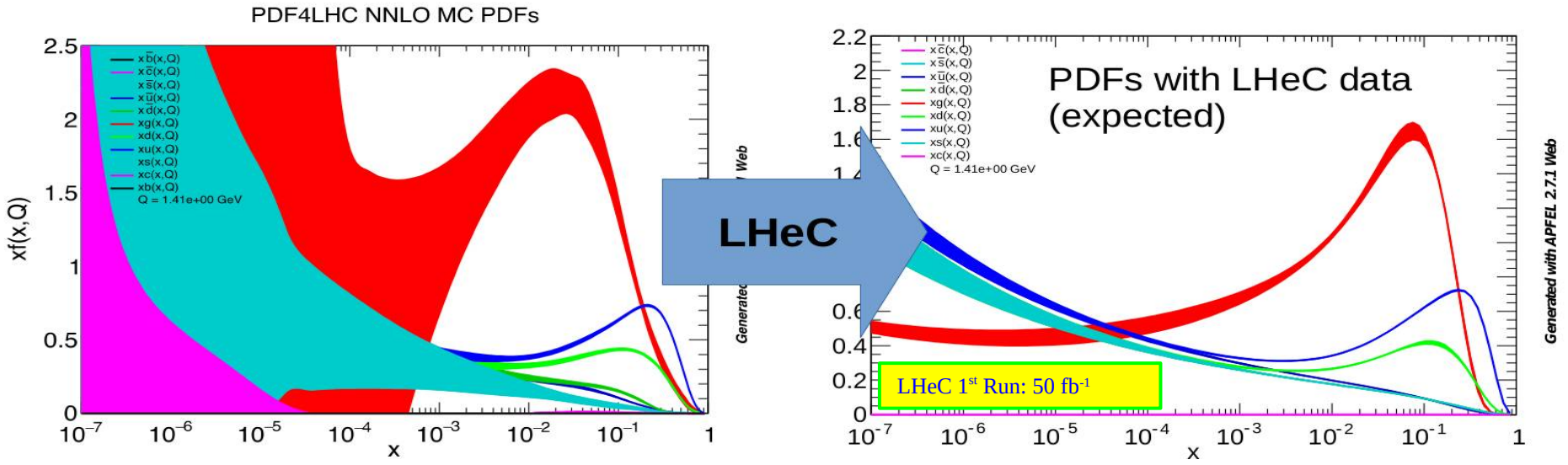
CrossMark

Abstract
A conceptual design is presented of a novel energy-recovering linac (ERL) facility for the development and application of the energy recovery technique to linear

CERN-ACC-Note-2020-0002

J. Phys. G: Nucl. Part. Phys. 45 (2018) 065003

Conclusions



LHeC: A Game Changer

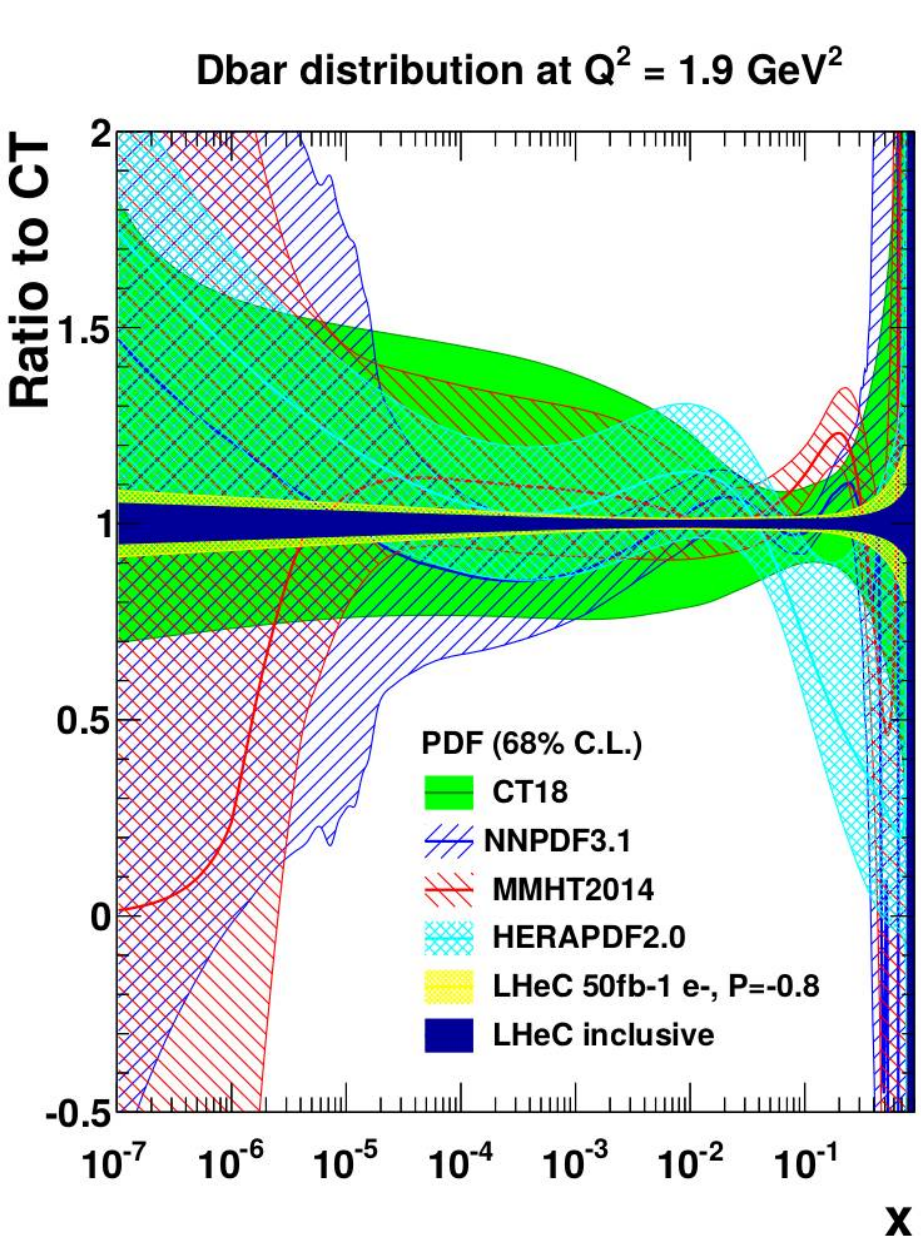
to boldy go where no experiment has gone before

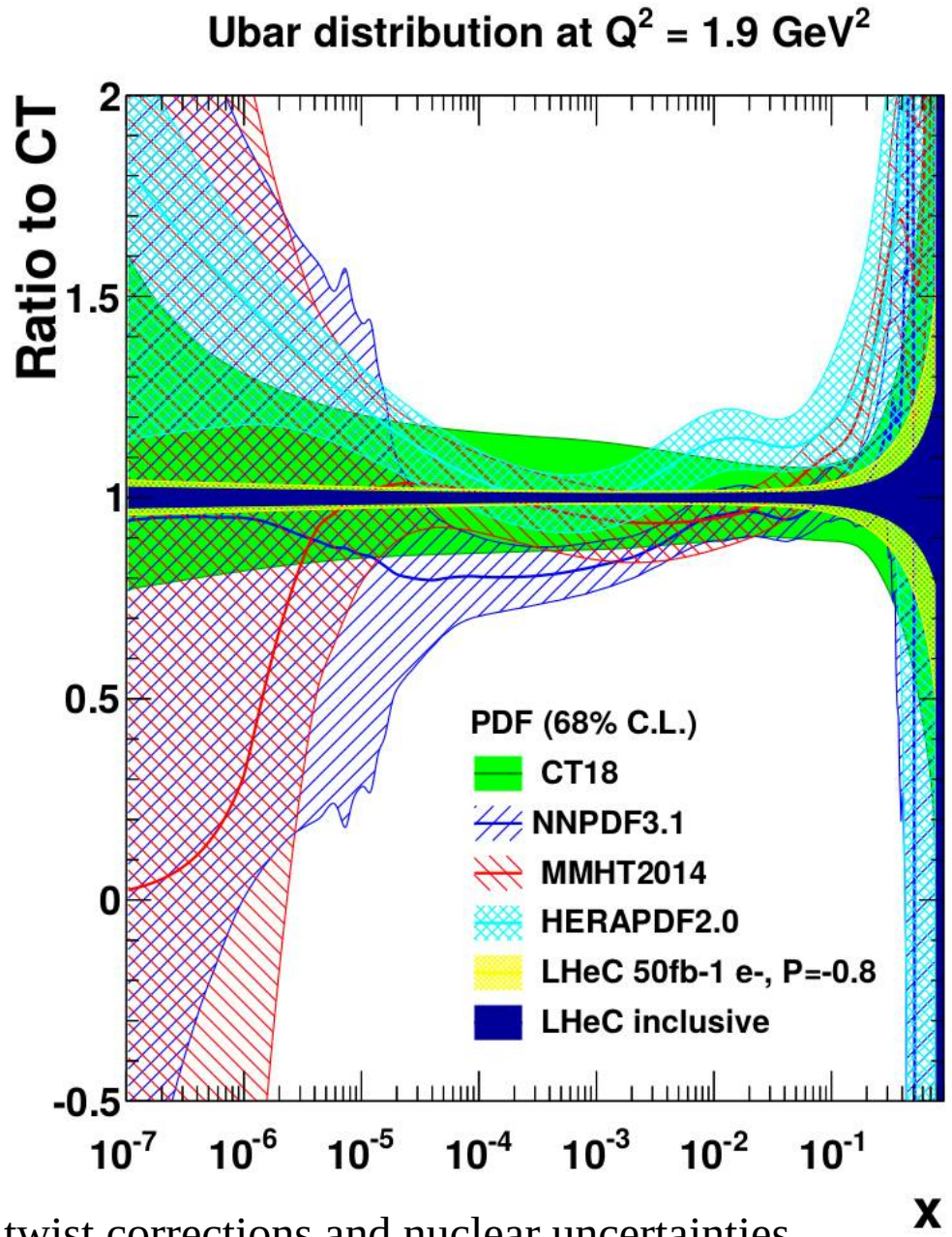
- First Run (3 Years, ~50 fb^{-1}) ≡ **×50 HERA**
- Complete PDF unfolding in a single experiment
- Hi resolution of parton dynamics: **a new era of precision QCD**
- Explore new {x,Q^2} kinematic regions: hi-x & low-x
- Fundamental for hadron collider physics, both SM (Higgs) & BSM, …

no other facility can match

Unique potential to revolutionize PDFs

Up and Down PDFs at Small x





precision determination, free from higher twist corrections and nuclear uncertainties