PDF Flavor Determination

Updates from xFitter & nCTEQ

Fred Olness
SMU

Thanks to

my xFitter colleagues

V. Bertone, M. Botje, D. Britzger, S. Camarda, A. Cooper-Sarkar, F. Giuli,
A. Glazov, A. Luszczak, R. Placakyte, V. Radescu, W. Slominksi, O. Zenaiev

my nCTEQ colleagues

B. Clark, E. Godat, T. Jezo, C. Keppel, A. Kusina, F. Lyonnet, J.G. Morfin,
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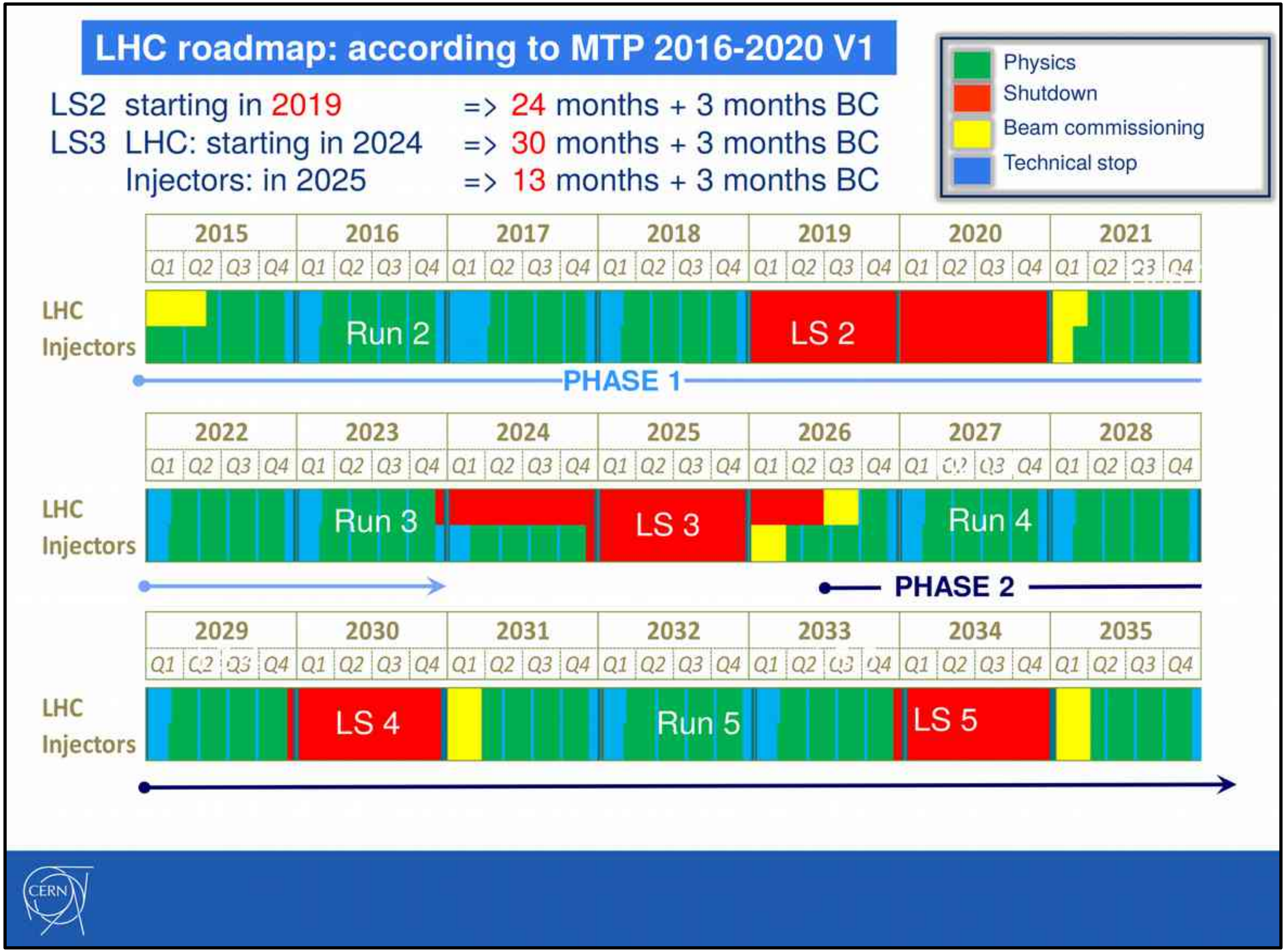
and also

C. Bertulani, A. Geiser, M. Guzzi, P. Nadolsky, Emanuele R. Nocera,
Huey-Wen Lin, Kostas Orginos, Juan Rojo, J. Thomas

LHeC & FCC-eh Workshop
CERN 11-13 September 2017

LHC Roadmap to the Future:



Precision is the Key!

Precise knowledge of the PDFs are essential for predictions of new physics

QCD factorization:

$$\sigma = \hat{\sigma} \otimes PDF$$

Experimental Data:

→ **requires** a large variety of data from fixed-target and collider experiments

Theory:

→ intense theoretical developments

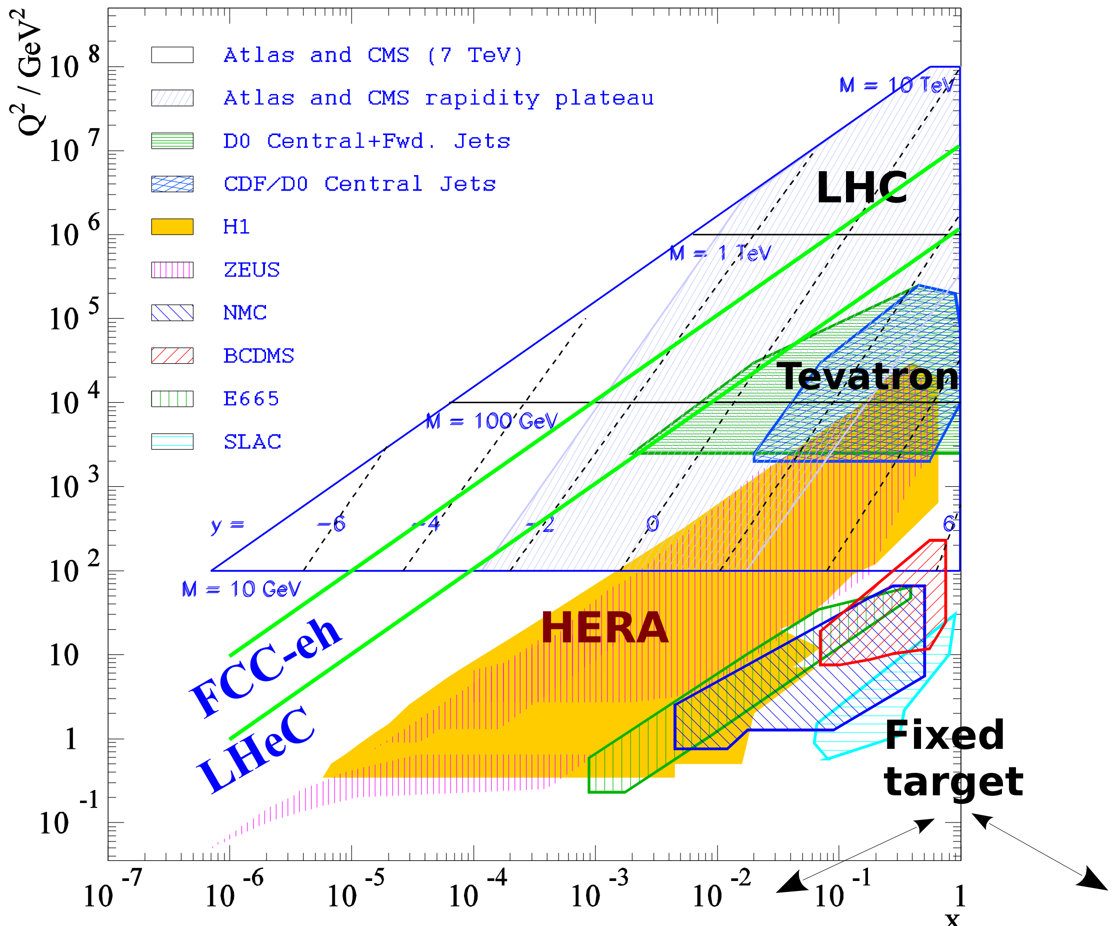
Tevatron + HERA
essential complementary components

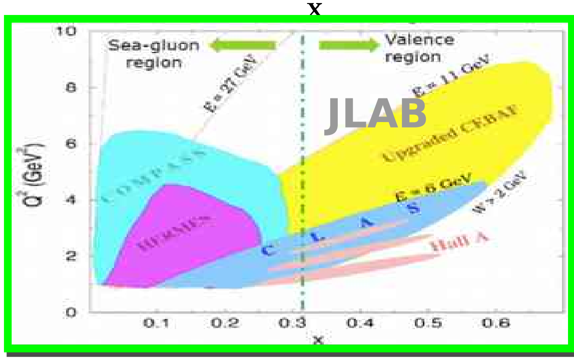
LHC alone cannot maximize PDF precision

LHeC
also essential
… including nuclear

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

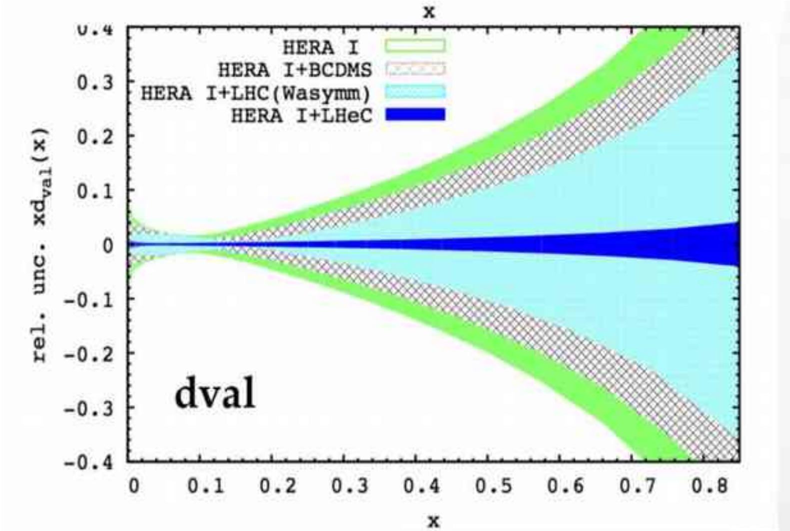
kinematic plane of the experimental data (in x,Q^2)



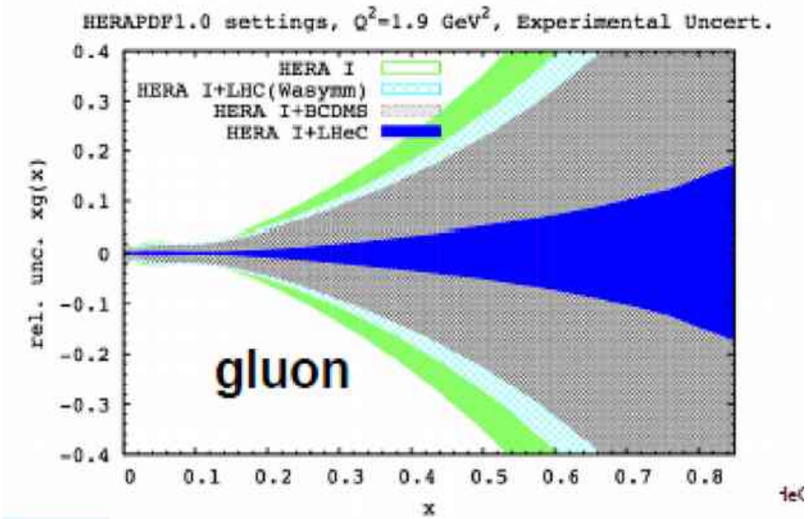


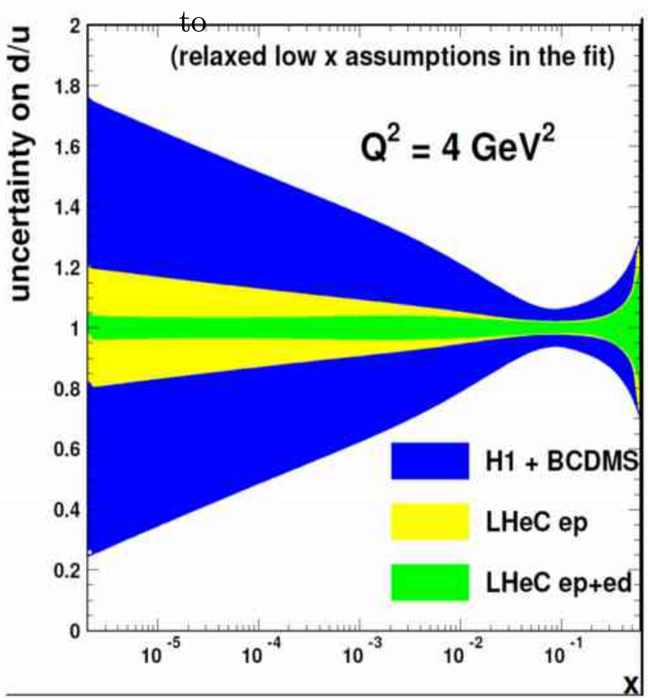
LHeC & FCC-eh PDF Precision Studies via xFitter

→ Compute PDFs for future facilities
→ Determine discovery reach



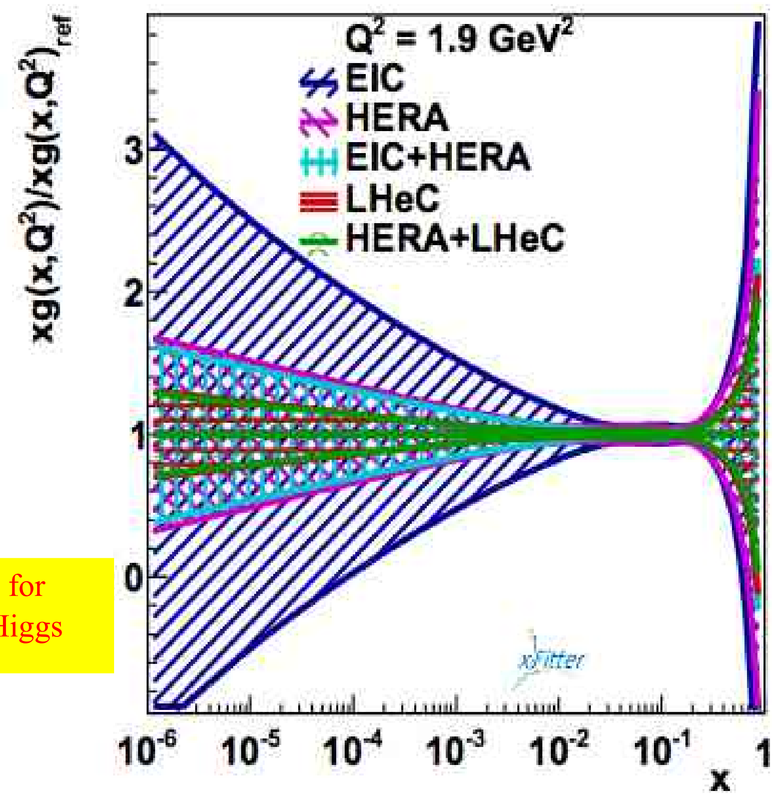
pseudo data available in xFitter





Precision d(x)

EW corrections violate isospin



N3LO for gg → Higgs

Thanks to Voica Radescu

NEW xFitter release xfitter-2.0.0

www.xFitter.org

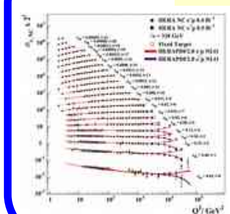
DESY xFitter

xFitter/xFitterTalks » xFitter/../xFitterDevel.. » xFitter/../Meeting2017-.. » xFitter » xFitter/DownloadPage

Sample data files:

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

Experimental Data



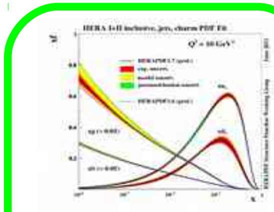
Data: HERA, Tevatron, LHC, fixed target experiments

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)

xFitter 2.0.0 FrozenFrog

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*

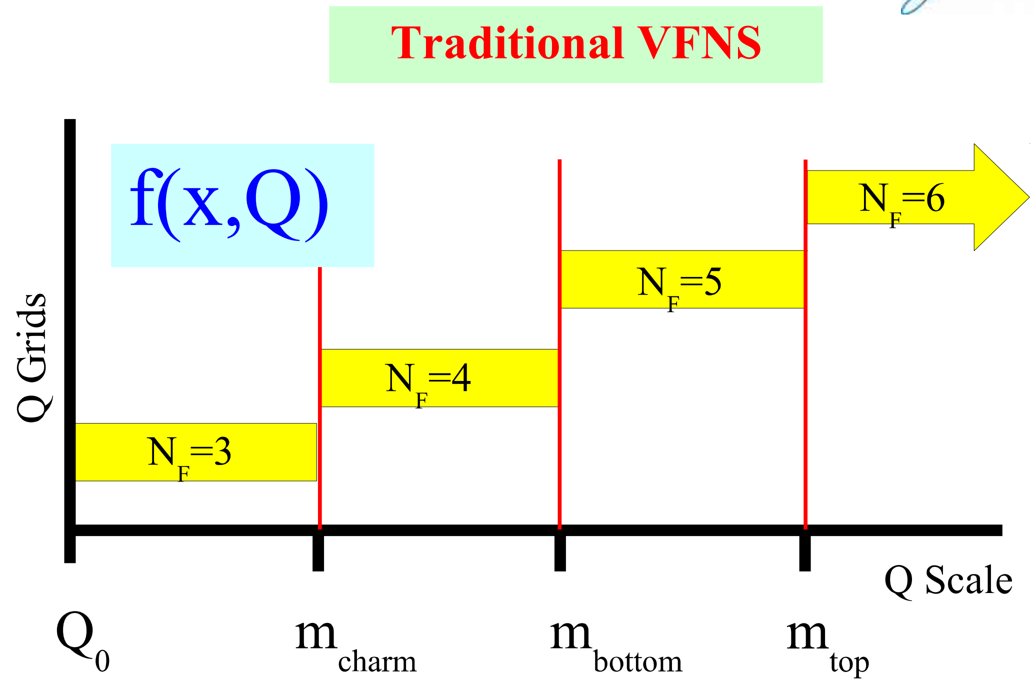
Progress on heavy quarks charm & bottom

"Turn on" heavy quarks (c,b) at an arbitrary scale $\mu_{c,b}$

APFEL has a new feature

included in xFitter

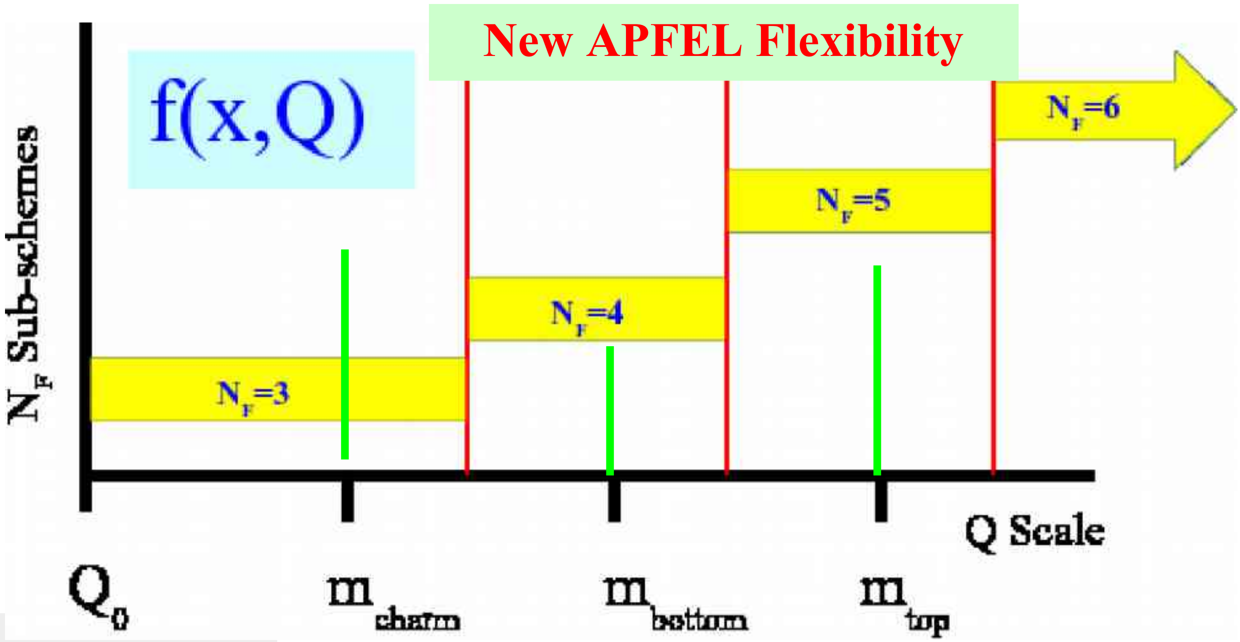
We can adjust the matching scale for the heavy quark PDF transition



What are the benefits?

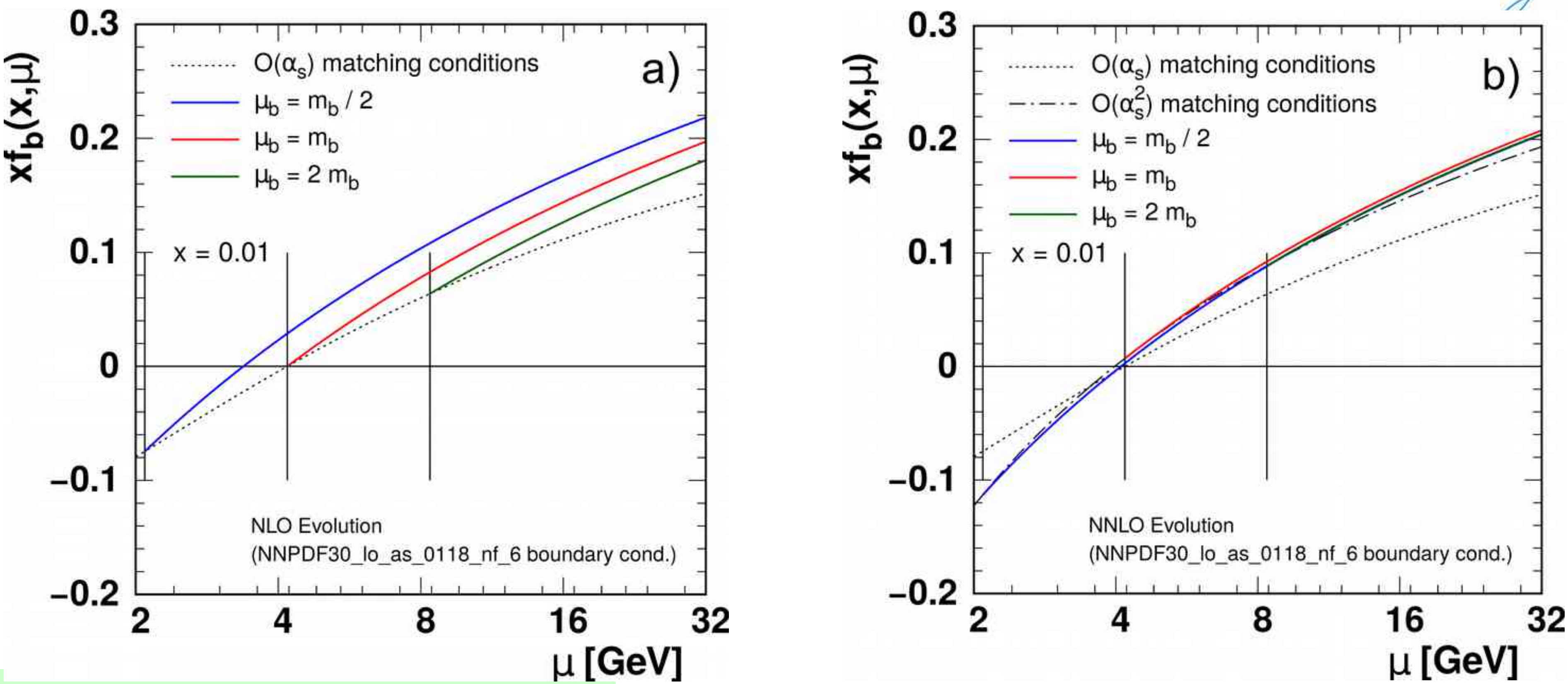
1) **avoid discontinuities in the middle of data sets**

2) **avoid delicate matching in region $\mu \sim m_{c,b}$**



Impact of the heavy quark matching scales in PDF fits
The xFitter Developers Team: V. Bertone, et al., arXiv:1707.05343

The matching conditions are non-trivial, especially at NNLO



NLO Matching Condition

$$f_b^5(x,\mu) = \left(\frac{\alpha_S}{2\pi}\right)\left[P_{1,0} + P_{1,1}\log\left(\frac{\mu^2}{m_b^2}\right)\right] \otimes f_g^4(x,\mu)$$

Zero at Leading Order ($P_{1,0}$)

DGLAP contribution ($P_{1,1}$)

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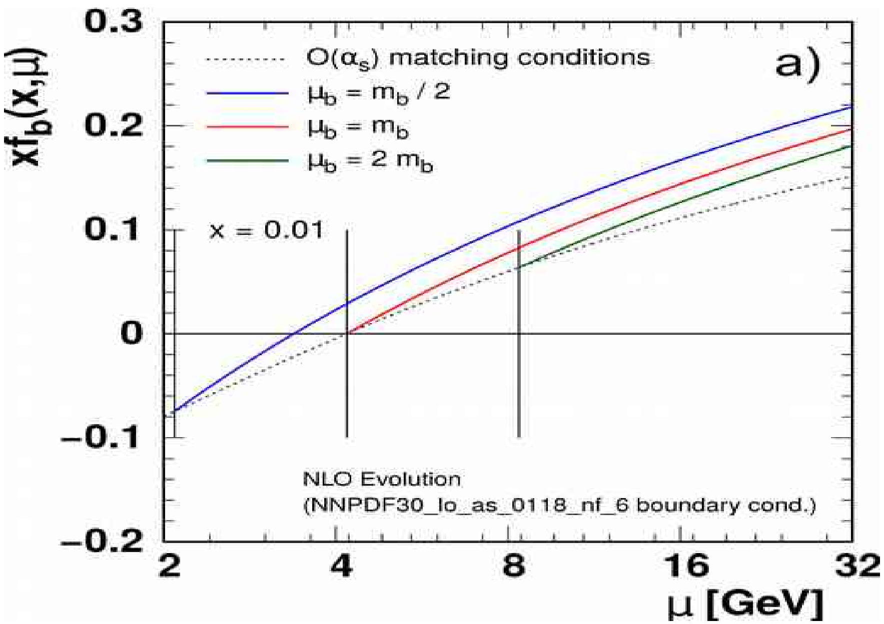
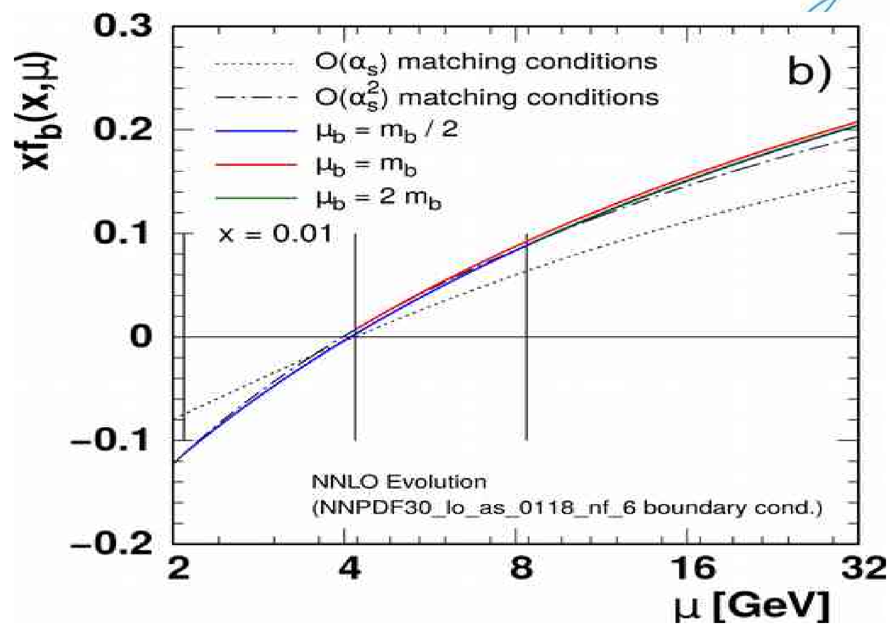
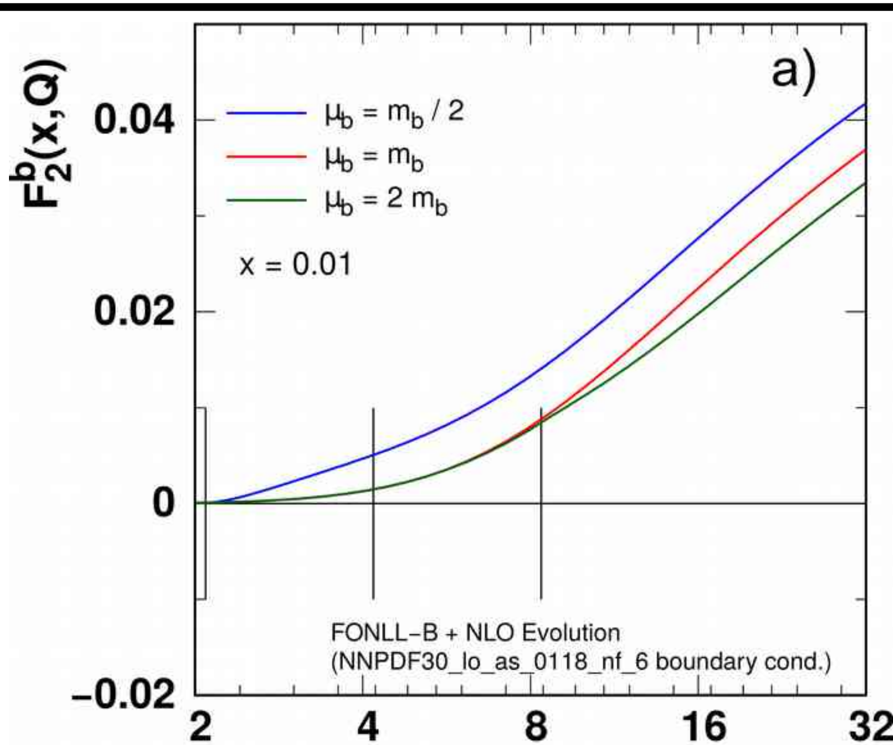
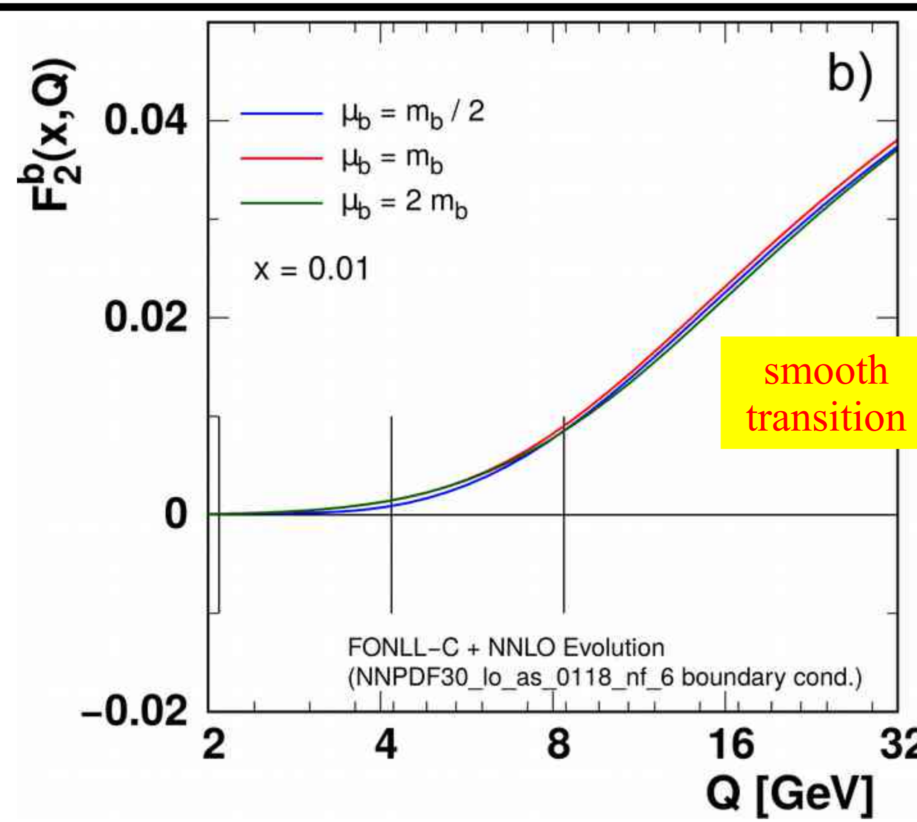






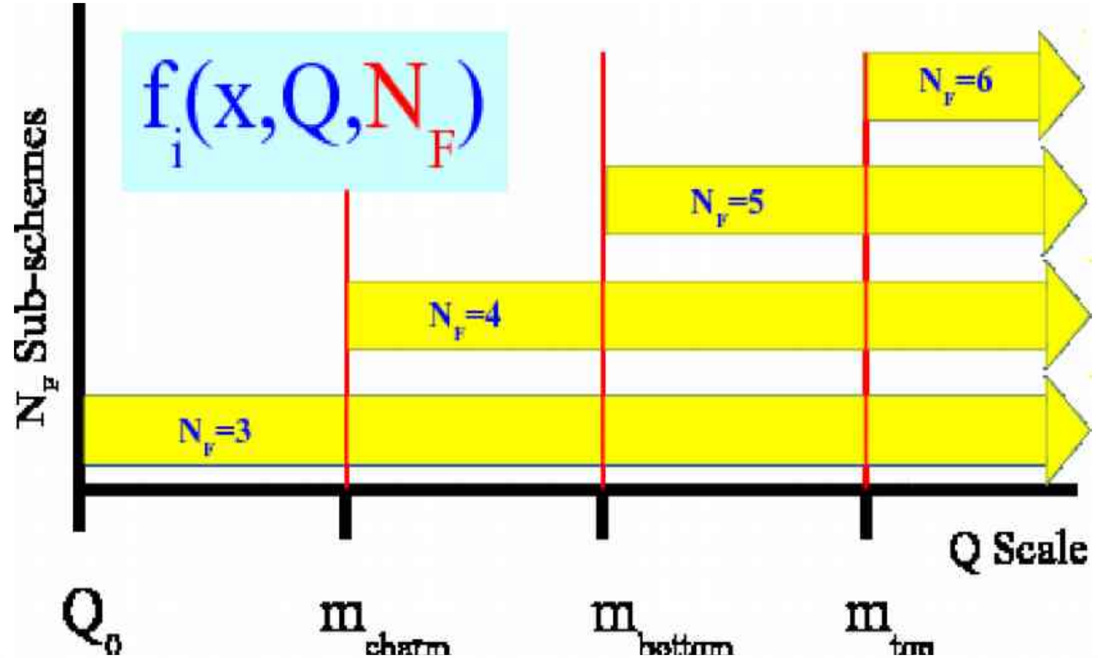


Impact of the heavy quark matching scales in PDF fits
The xFitter Developers Team: V. Bertone, et al., arXiv:1707.05343

A proposal: **Consider N_F dependent PDF**

Provides some of the benefits & flexibility of flexible matching,

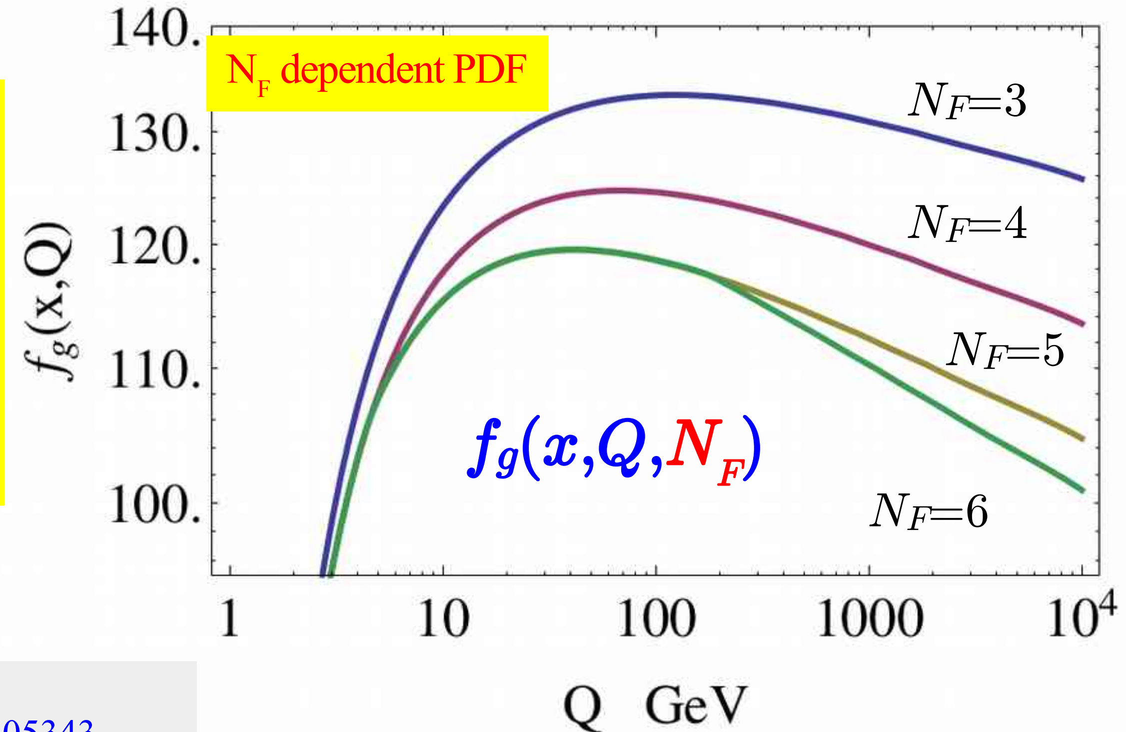
Advantages:
* avoid discontinuities in data
* avoid delicate cancellations
* minimal set of PDF grids



… for example, simultaneously

1) analyze HERA in N_F=4

2) analyze LHC in N_F=5



Impact of the heavy quark matching scales in PDF fits
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Progress on strange PDF

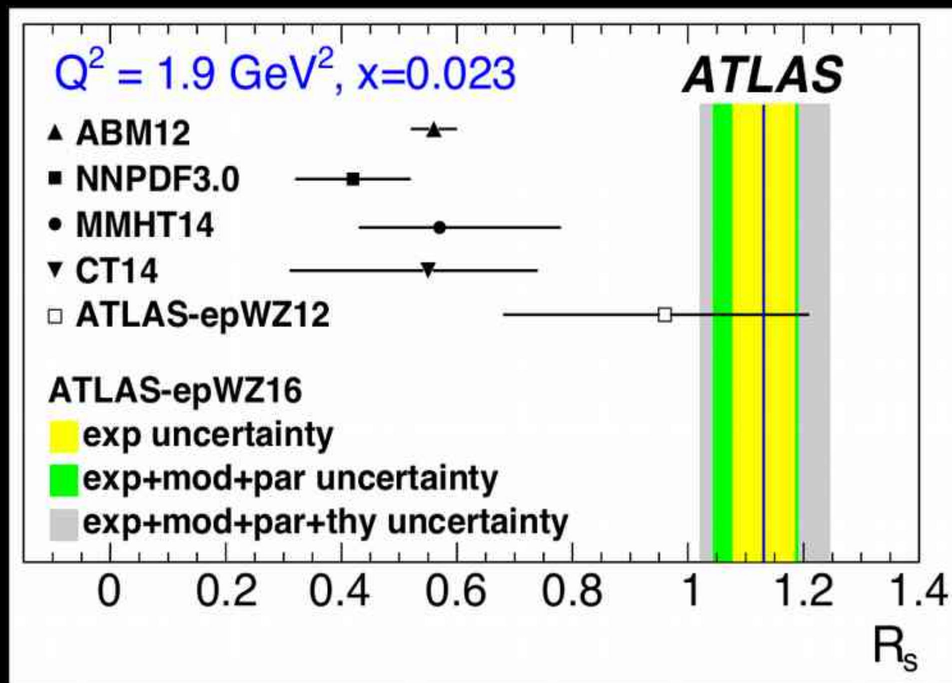
… at DIS2017 we heard ...

Electroweak and QCD Measurements at the Large Hadron Collider

DIS 17

Strangeness in the Proton

arXiv:1612.03016



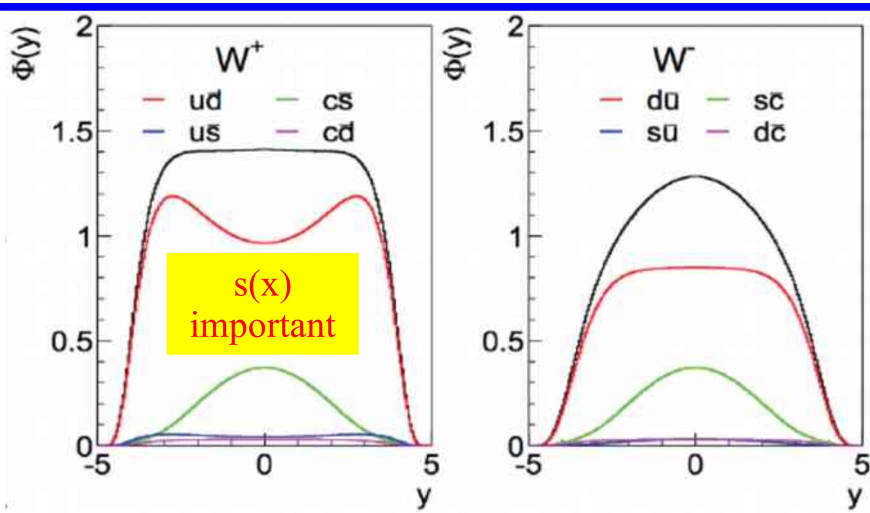
$$R_s = \frac{s+\bar{s}}{\bar{u}+\bar{d}} = 1.13 \pm 0.05\,(\text{exp}) \pm 0.02\,(\text{mod})\ ^{+0.01}_{-0.06}\,(\text{par})$$

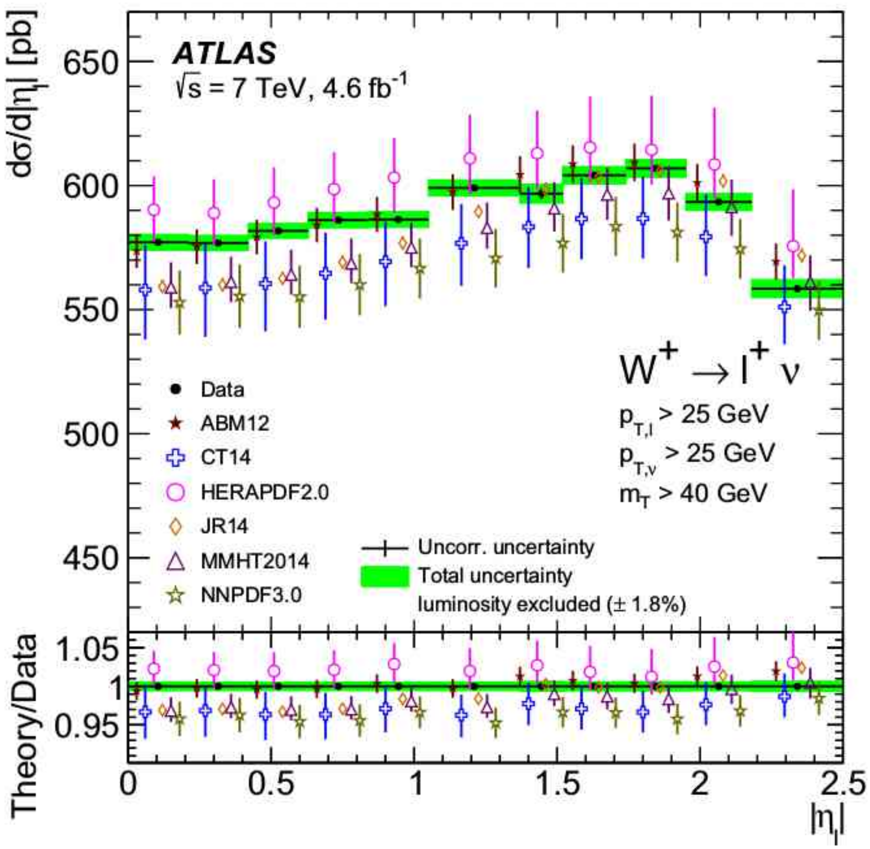
João Guimarães da Costa
IHEP, Chinese Academy of Sciences

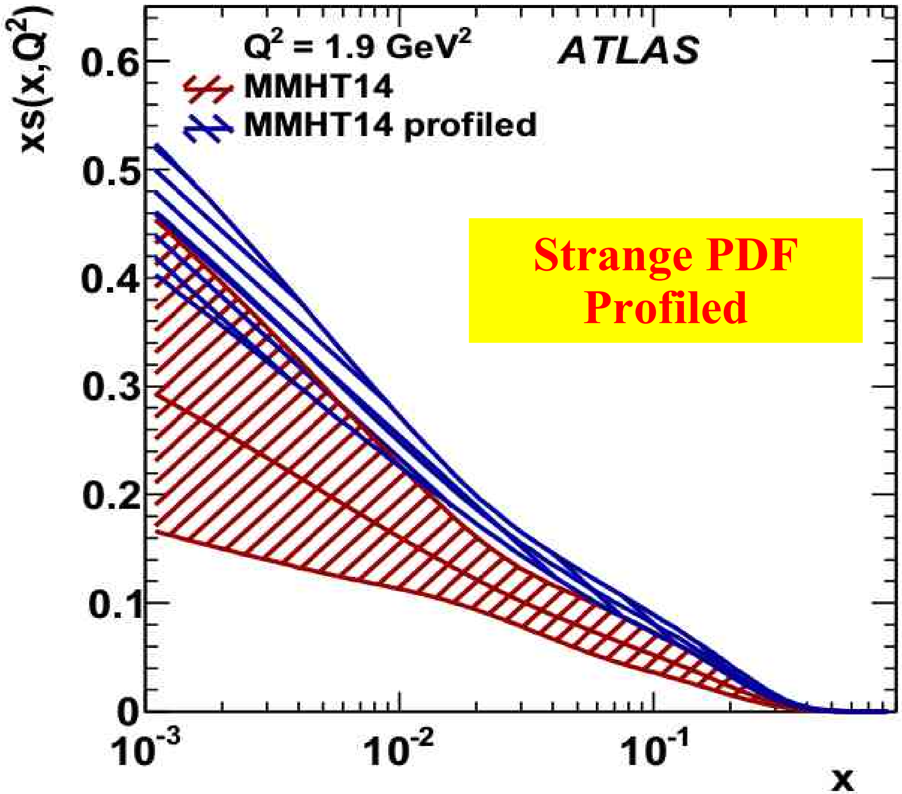
Birmingham, 3 April 2017

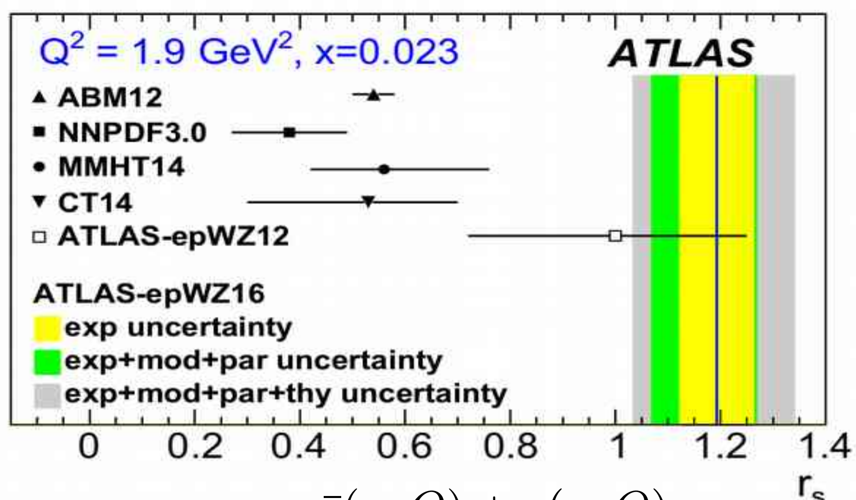
Do it yourself!!!
Try **xFitter**

W/Z Production at LHC and the strange PDF







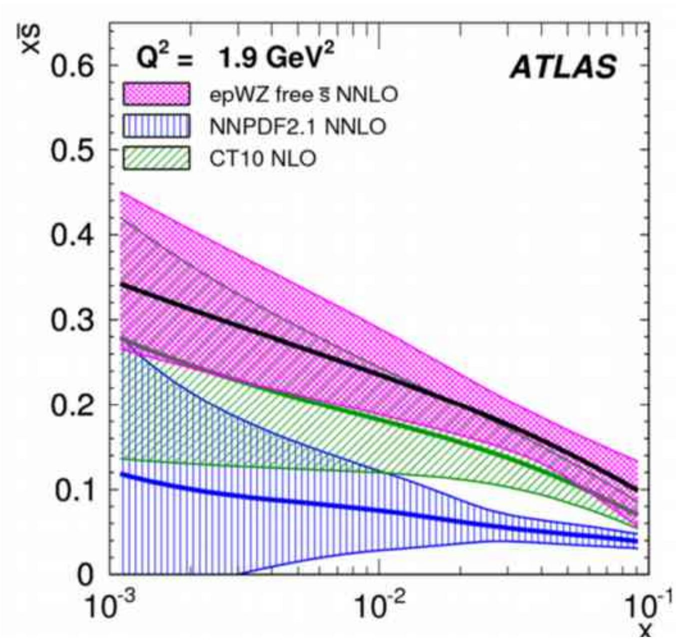


$$r^s(x,Q) = \frac{\bar{s}(x,Q) + s(x,Q)}{2\bar{d}(x,Q)}$$

ATLAS: Eur. Phys. J. C 77 (2017) 367

… do we know what the strange PDF is ???

$$\kappa(Q) = \frac{\int_0^1 x\,[s(x,Q)+\bar{s}(x,Q)]\,dx}{\int_0^1 x\,[\bar{u}(x,Q)+\bar{d}(x,Q)]\,dx} \qquad r^s(x,Q) = \frac{\bar{s}(x,Q)+s(x,Q)}{2\bar{d}(x,Q)} \qquad R^s(x,Q) = \frac{s(x,Q)+\bar{s}(x,Q)}{\bar{u}(x,Q)+\bar{d}(x,Q)}$$

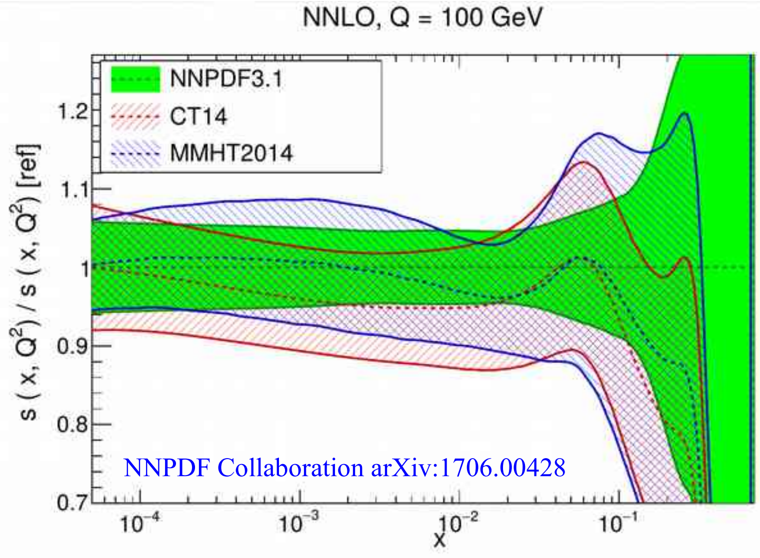


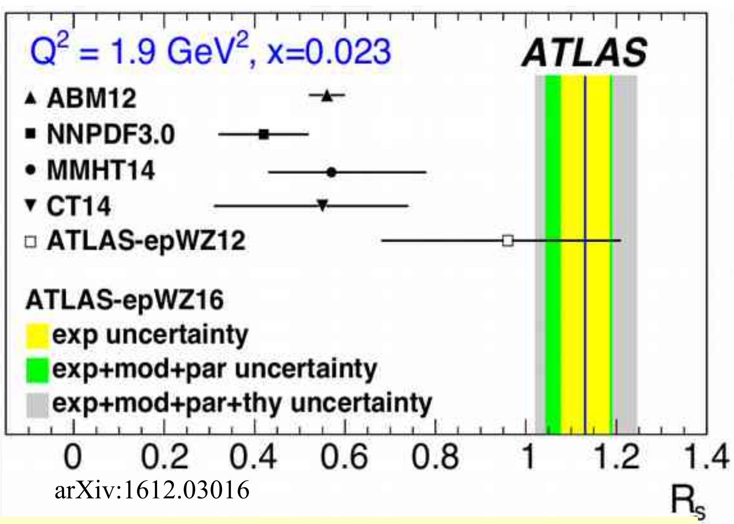
HERAFitter, Open Source QCD Fit Project
Eur. Phys. J. C (2015) 75: 304.

$$\kappa^s_{CT14NNLO} = 0.62 \pm 0.14$$
$$\kappa^s_{CT10NNLO} = 0.73 \pm 0.11$$

Carl Schmidt October 2015: INT Workshop

… whatever you want it to be





arXiv:1612.03016

… yes, details depend on {x,Q^2}

$$\text{NuTeV}\ \kappa = 0.477^{+0.063}_{-0.053}$$ Z.Phys.C65:189-198,1995

$$\text{NOMAD}\ \kappa = 0.591 \pm 0.019$$ arXiv:1308.4750

$$\text{CMS}\ \kappa = 0.52^{+0.12}_{-0.10}{}^{+0.05}_{-0.06}{}^{+0.13}_{-0.10}$$ Q^2=20 GeV^2

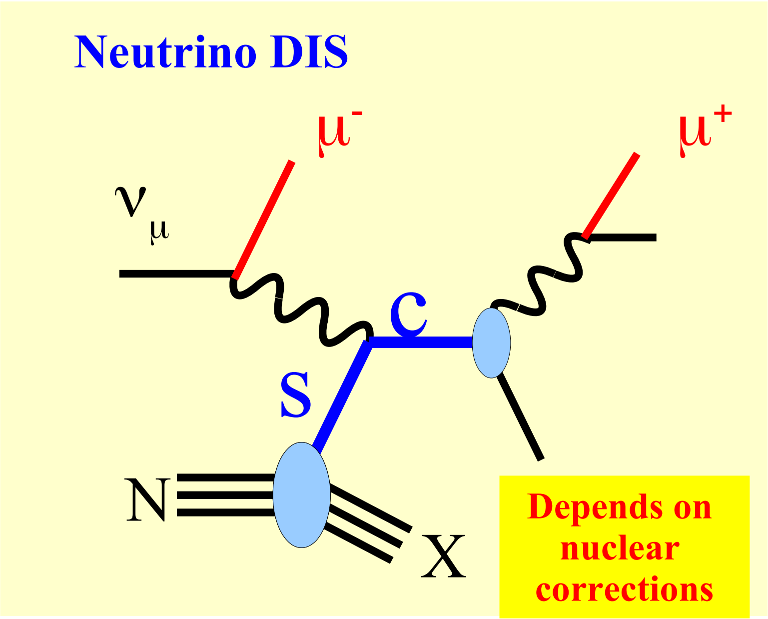
PhysRevD.90.032004
(exp)(model)(param)

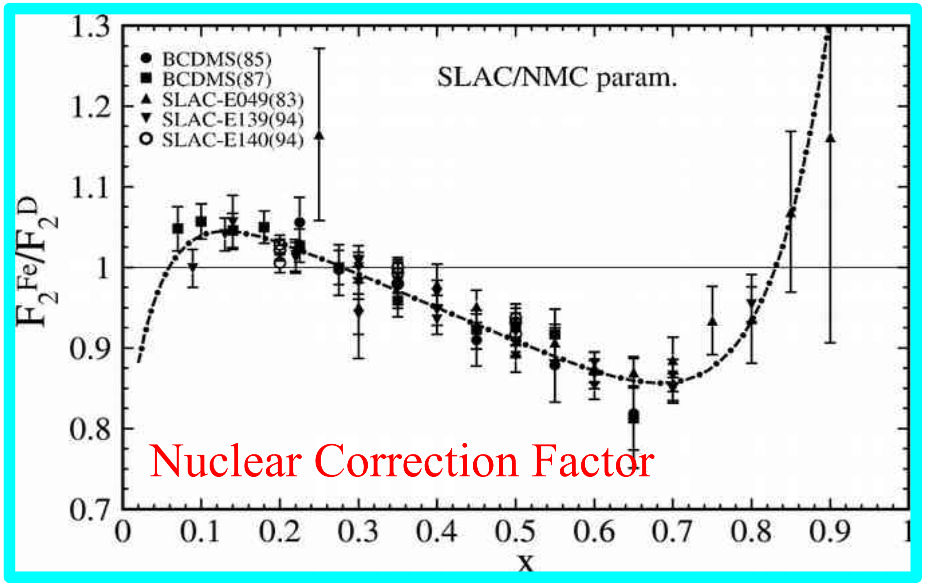
$$\text{ATLAS}\ r_s = 1.19 \pm 0.07 \pm 0.02^{+0.02}_{-0.10}$$

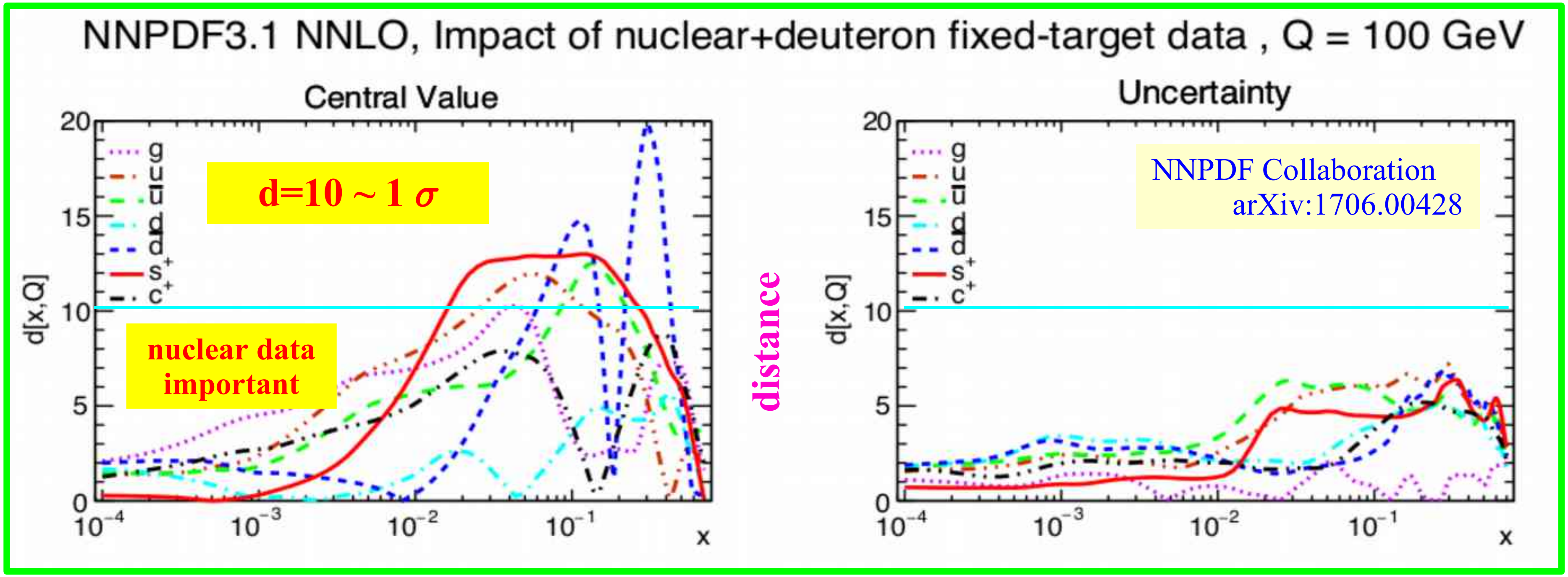
Q_0^2=1.9 GeV^2 at x=0.023

EPJC (2107) 77:367
(exp)(model)(param)

Impact of Nuclear Corrections on Proton PDF

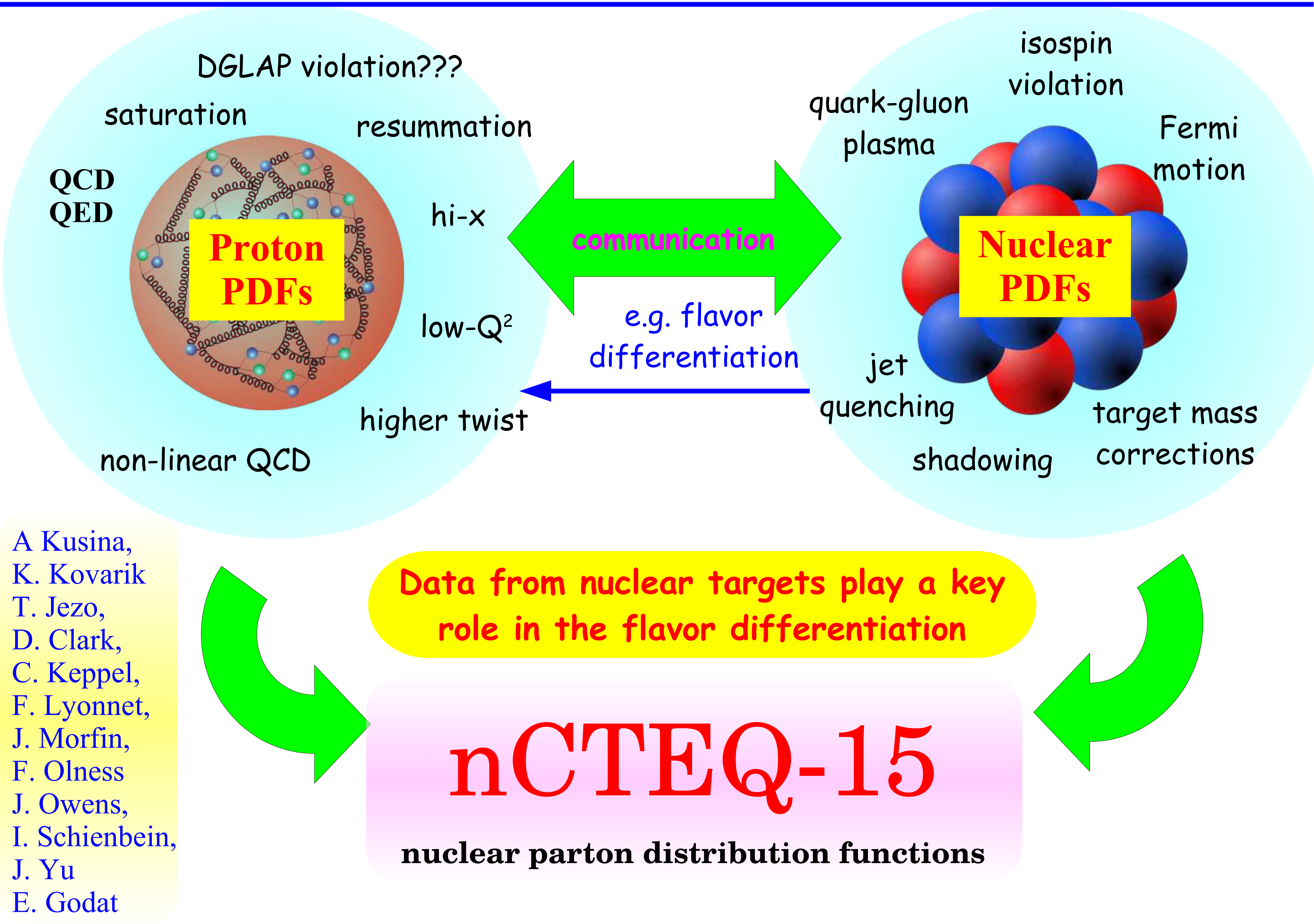






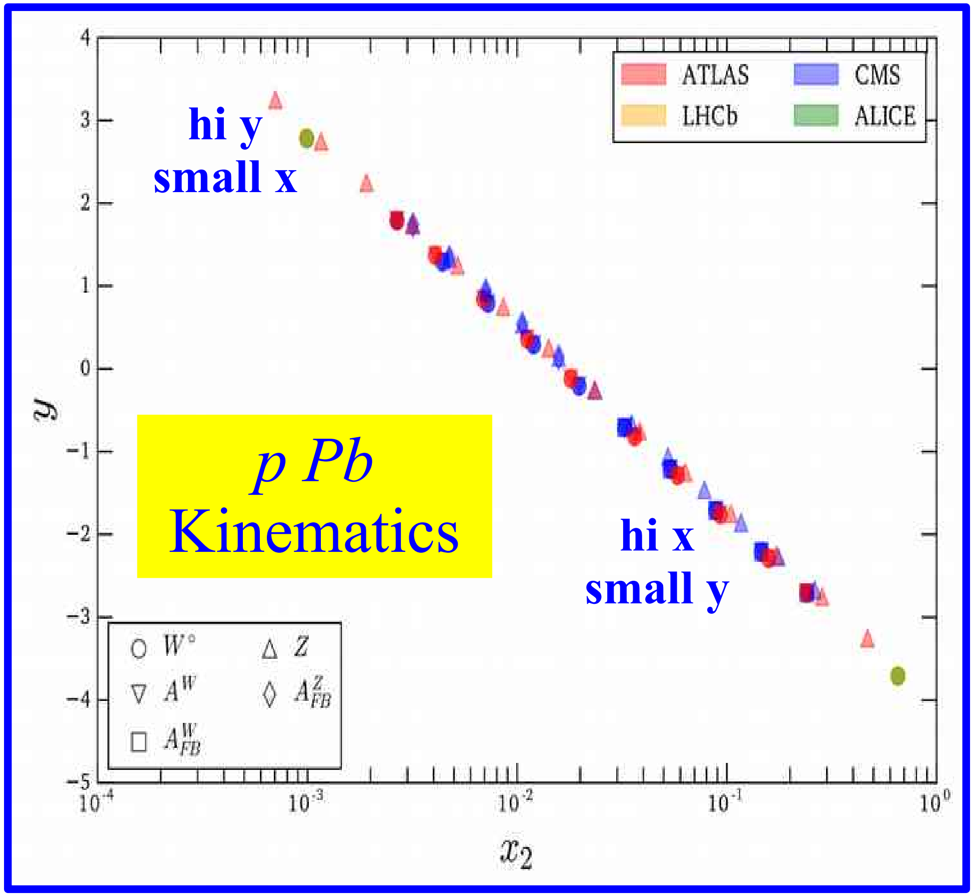
"... for the time being it is still appears advantageous to retain nuclear target data in the global dataset for general-purpose PDF determination"

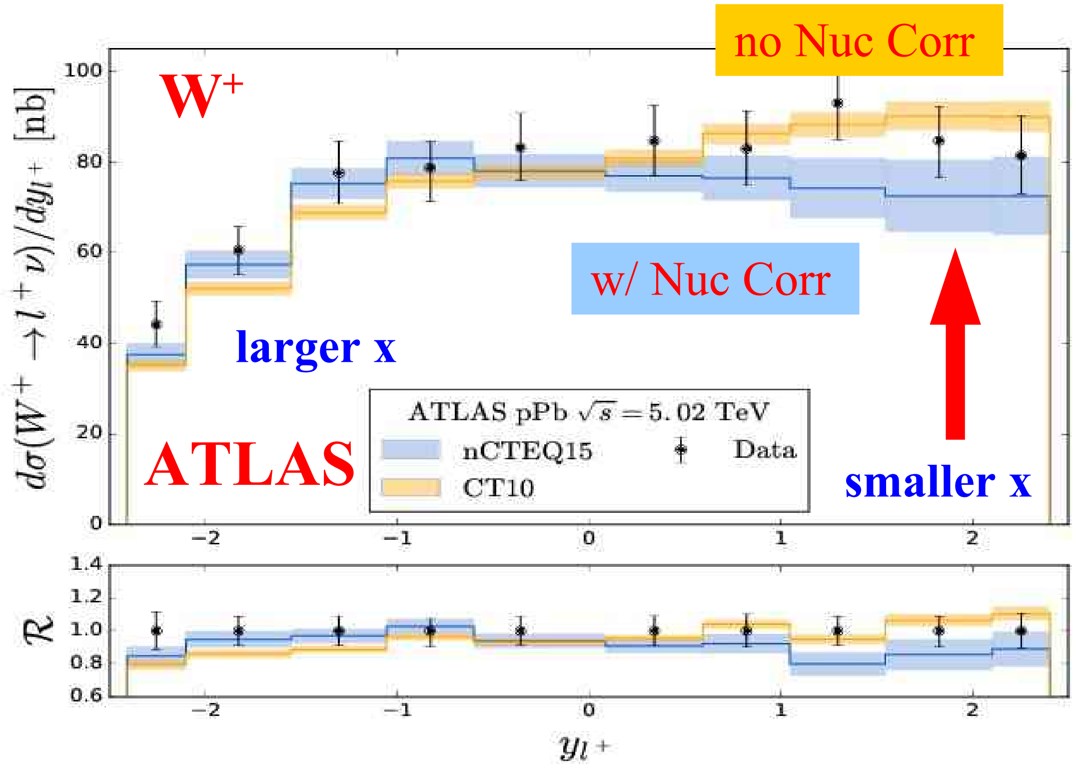
… the original motivation for nCTEQ



$p\,Pb \rightarrow W/Z$ and Nuclear Corrections

$$\frac{d\sigma(p\,Pb \rightarrow W^+)}{dy}$$





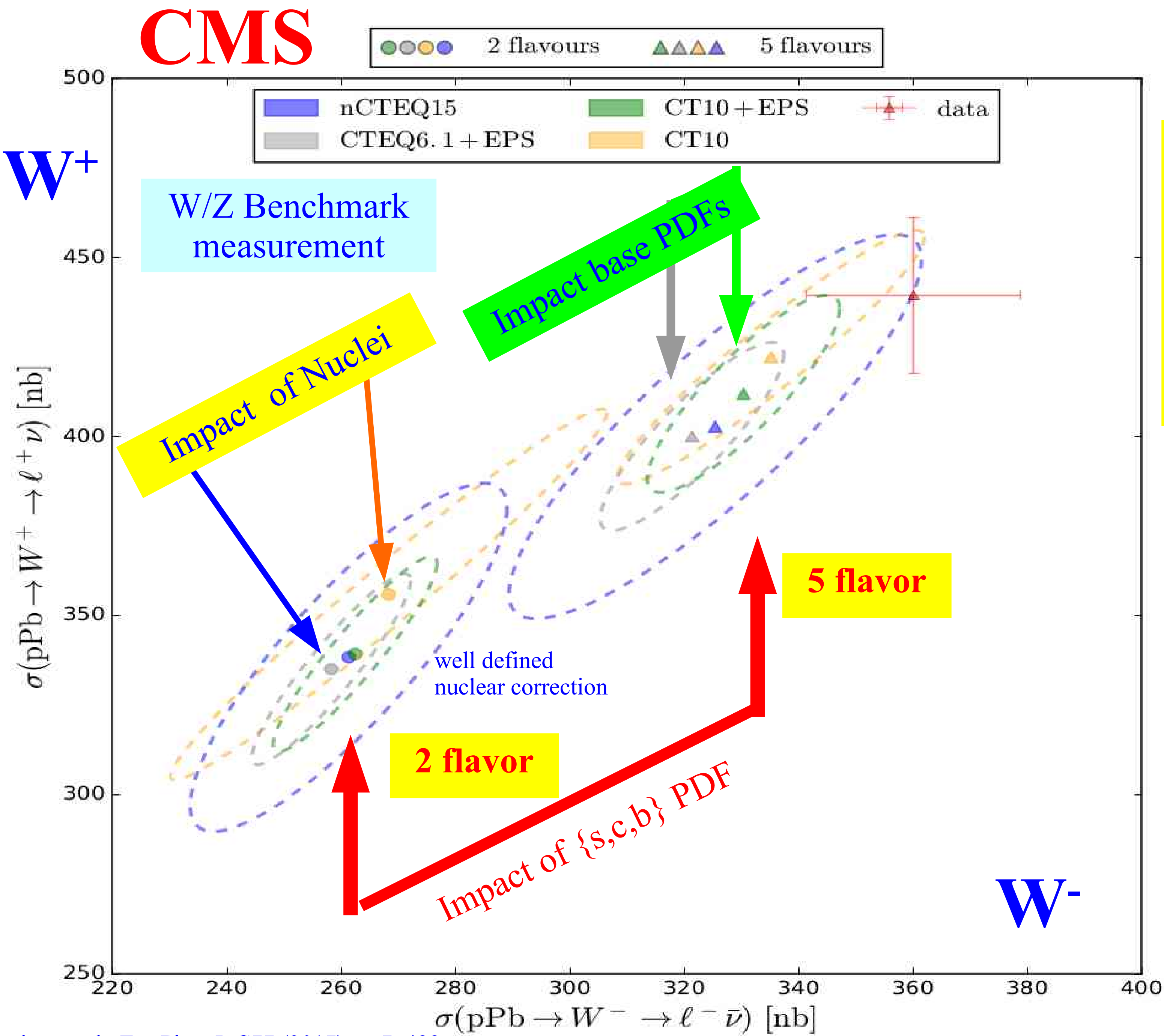
lead kinematics

larger x ⟷ **smaller x**

"OK" nuclear correction	**too much suppression**
previous data constraints	**minimal data constraints**

Vector boson production in pPb & PbPb
A. Kusina, F. Lyonnet, D. B. Clark, E. Godat, T. Jezo, K. Kovarik, F. I. Olness, I. Schienbein, J. Y. Yu,
Eur.Phys.J. C77 (2017) no.7, 488

Impact of {s,c,b} PDF



Entangled:

- Nuc Corrections
- Base PDF
- PDF Flavors

This is an area where LHeC is particularly suited to help

A. Kusina, et al., Eur.Phys.J. C77 (2017) no.7, 488

Thanks to my xFitter & nCTEQ colleagues

xFitter Meeting: Oxford March 2017

A special thanks to
former xFitter conveners:
Ringaile Placakyte & Voica Radescu

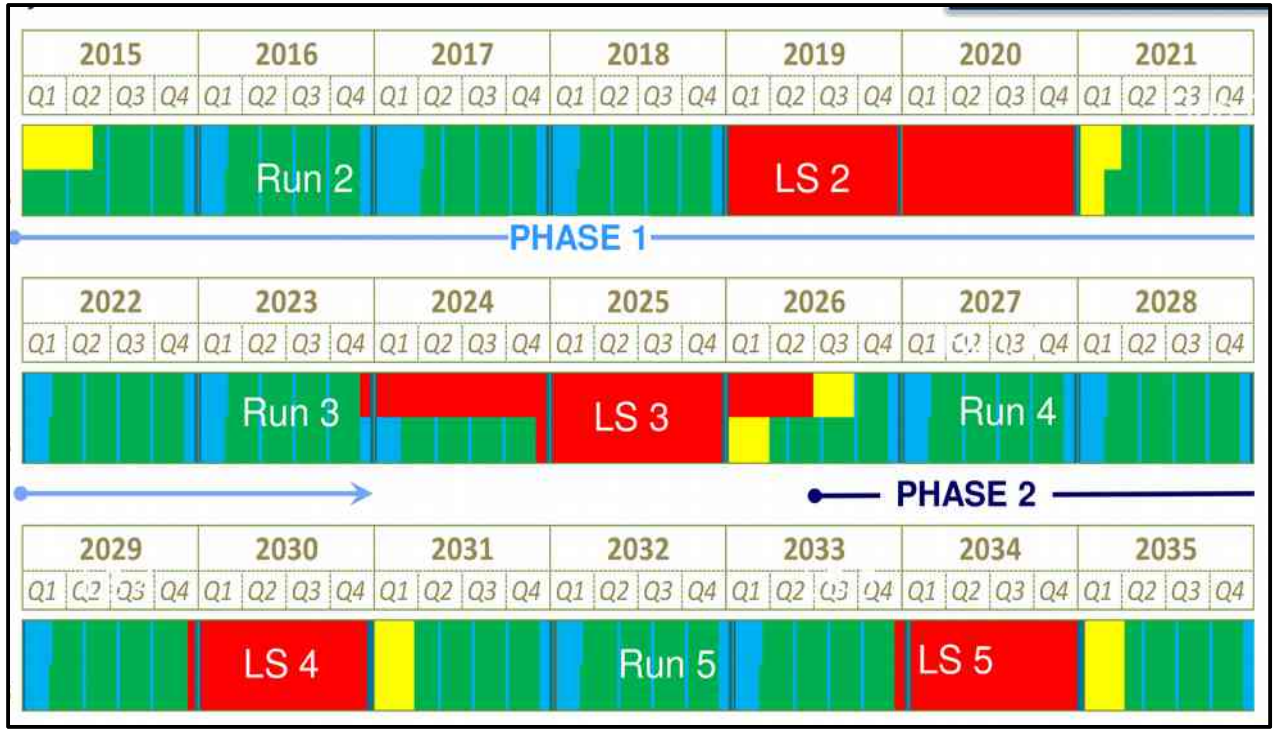
nCTEQ
nuclear parton distribution functions

nCTEQ & friends @ Grenoble

The coming decades: maximize precision for discovery reach

xFitter

nCTEQ
nuclear parton distribution functions



Our discovery reach will be limited by our precision

$\hat{\sigma}$: improved calculations, higher ordered, mass effects, …

PDF: improved uncertainties, QED, heavy quarks, nuclear …

LHeC: can maximize precision for maximum reach

s(x) puzzle, d(x) precision, heavy quarks, QED, nuclear corrections