PDFs Flavor Determination

Nuclear PDFs

Challenges and Opportunities for QCD

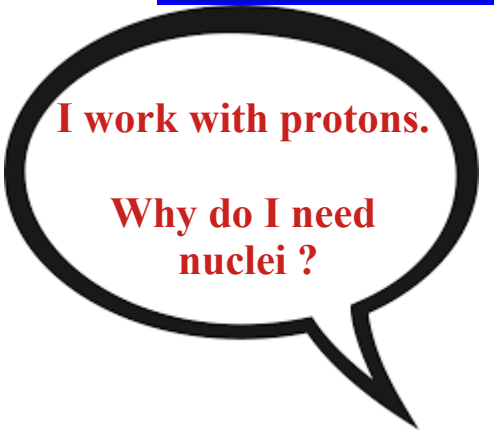
Fred Olness
SMU

Thanks for substantial input
from my friends & colleagues

CTEQ

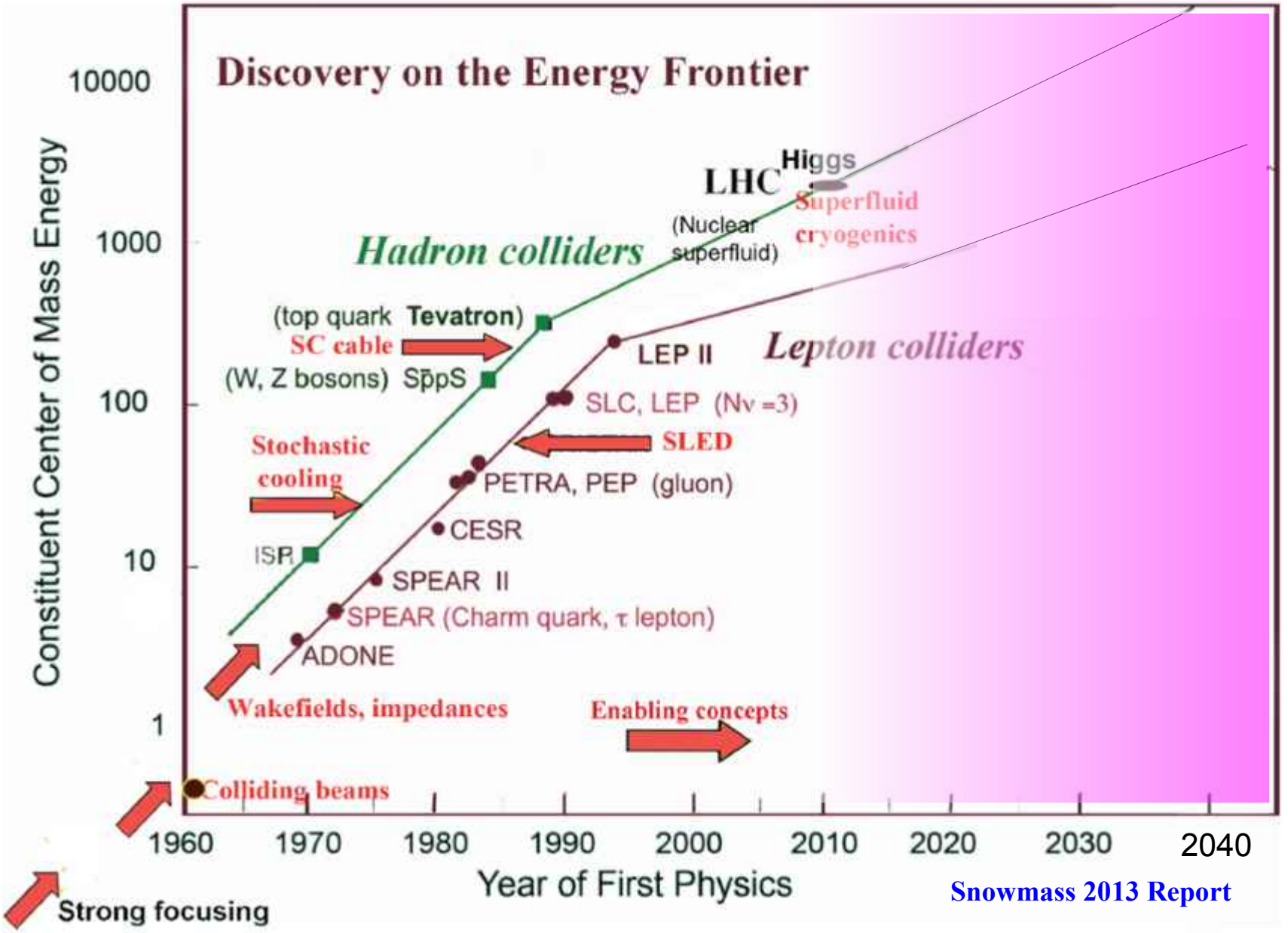
xFitter

nCTEQ
nuclear parton distribution functions



LPC Workshop
Physics Connections between the LHC and EIC
13-15 November 2019

Landscape of the Energy Frontier & New Physics Searches



We've reached the peak energy. Future searches require precision!!!

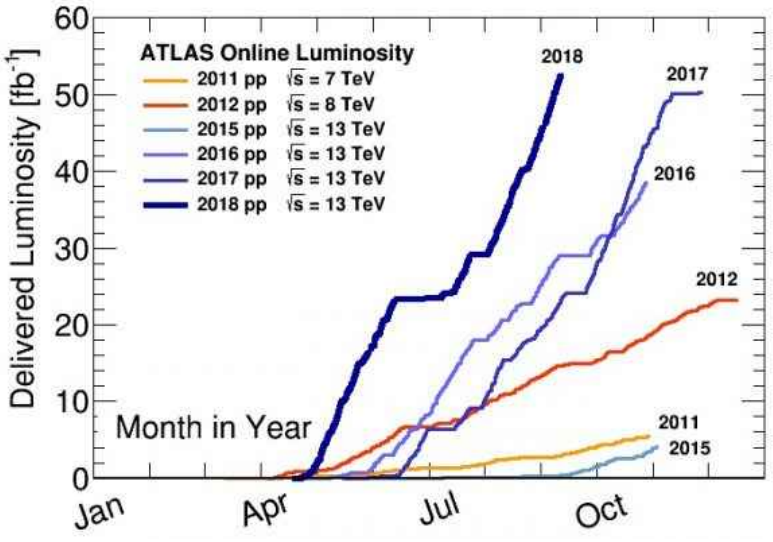
The Key to Understanding: The Parton Model and Factorization

$$\sigma_{N\gamma\to c} = f_{N\to a} \otimes \hat{\sigma}_{a\gamma\to c}$$

Experimental Observables

WHAT ABOUT PDF'S ???

Theoretical Calculations



Sergo Jindariani

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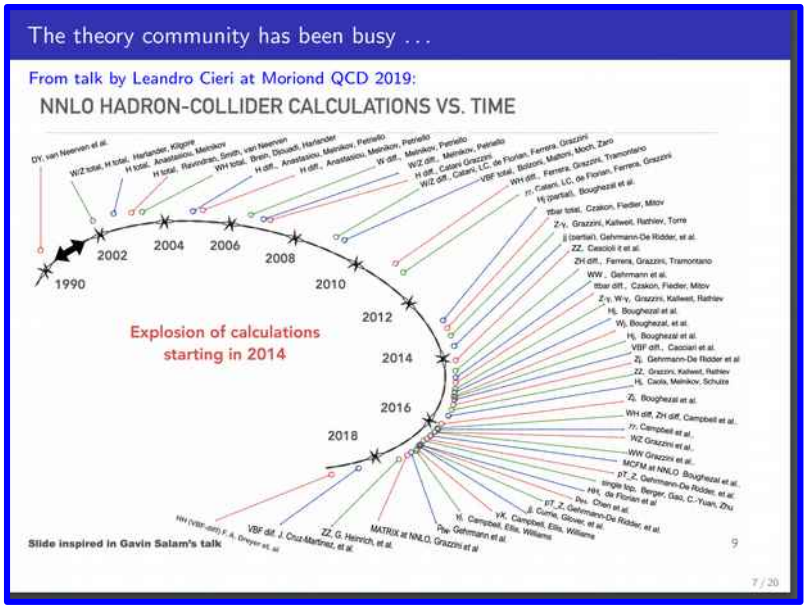
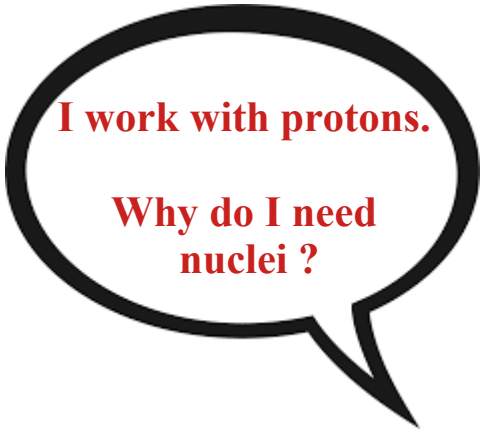


John Campbell

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

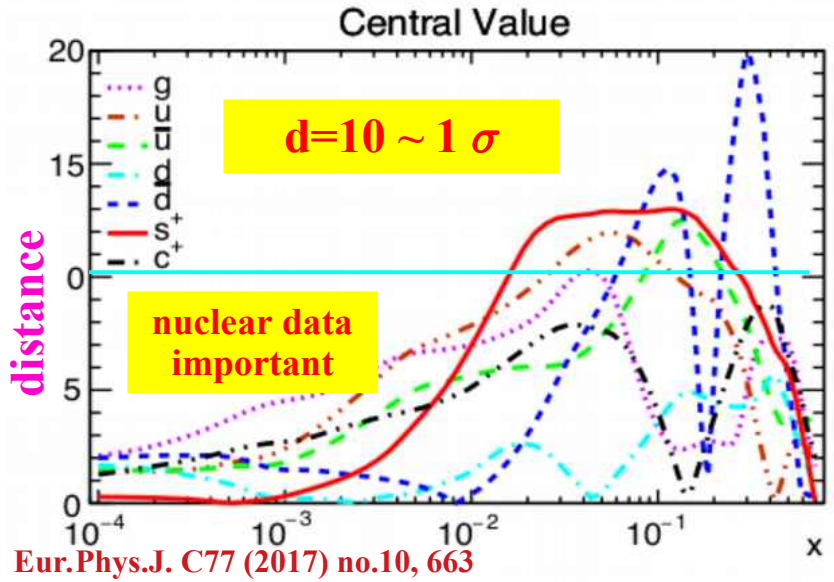
... what's this got to do with

Nuclear PDFs



Impact of Nuclear Corrections on Flavor Decomposition *(including Proton)*

NNPDF3.1 NNLO, Impact of nuclear+deuteron fixed-target data , Q = 100 GeV



Eur.Phys.J. C77 (2017) no.10, 663

$$F_2^{\nu} \sim [d + s + \bar{u} + \bar{c}]$$

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$$F_3^{\nu} = 2[d + s - \bar{u} - \bar{c}]$$

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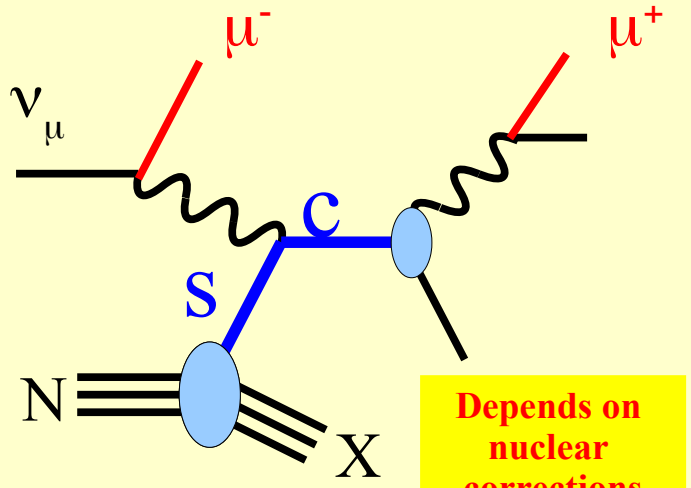
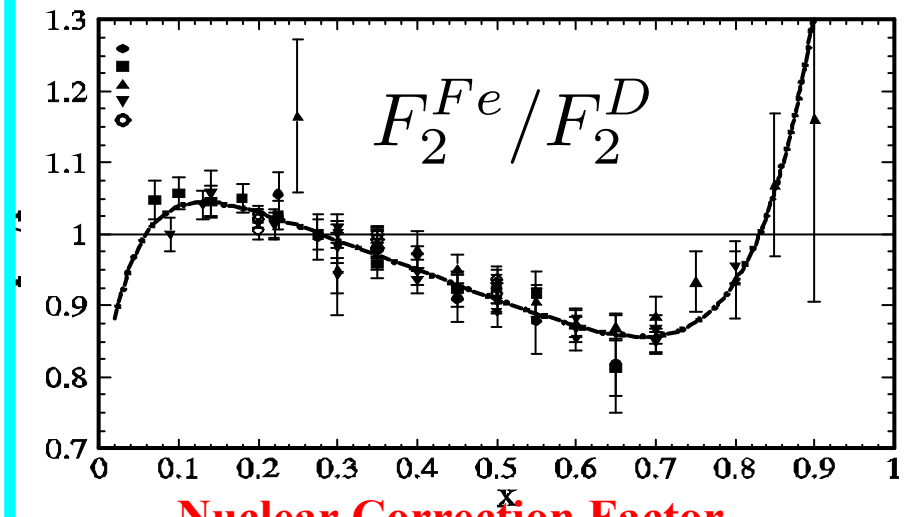
Neutrino DIS



Depends on nuclear corrections

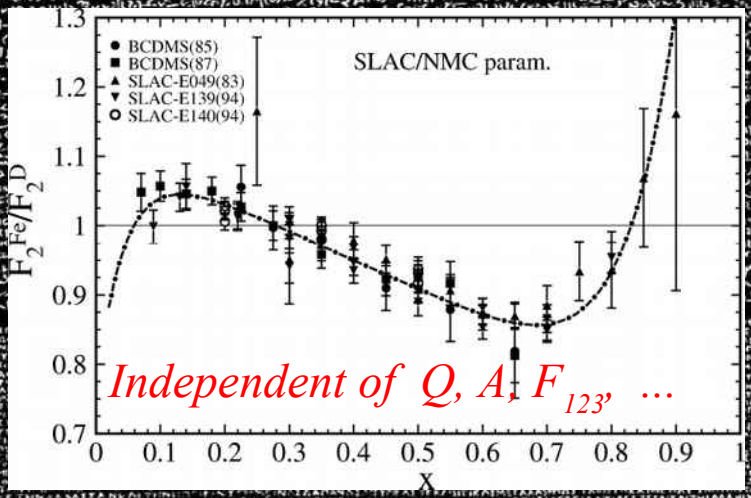


Nuclear Correction Factor

Extraction of Proton PDF flavors is inextricably linked to the nuclear degrees of freedom

Where do nuclear corrections come from ????

We need to deal with the Nuclei

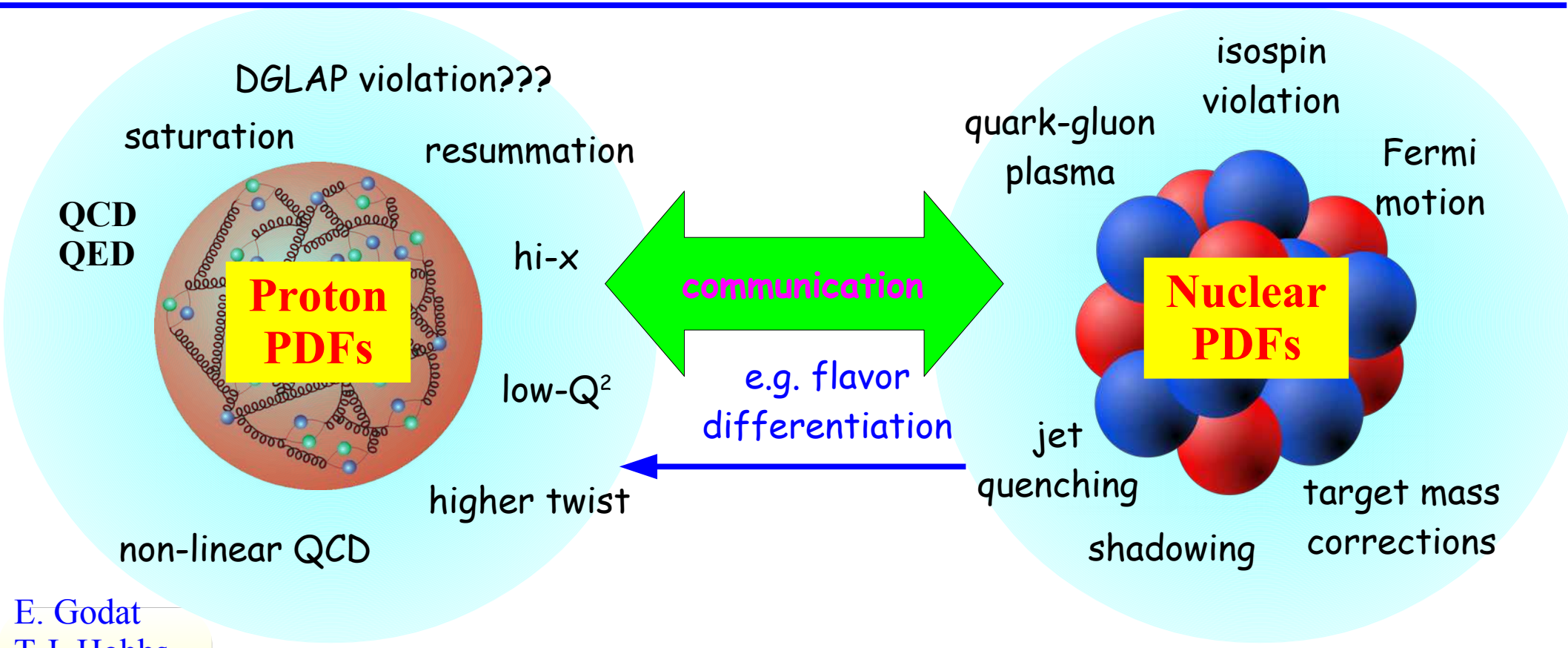


The ratio of iron (Fe) to Deuterium (D)

$$\frac{F_2^{Fe}}{F_2^D}$$

Discovered by the French in 1799 at Rosetta, a harbor on the Mediterranean coast in Egypt. Comparative translation of the stone assisted in understanding many previously undecipherable examples of hieroglyphics.

… the motivation for nCTEQ



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T.J. Hobbs
T. Jezo,
M. Klasen
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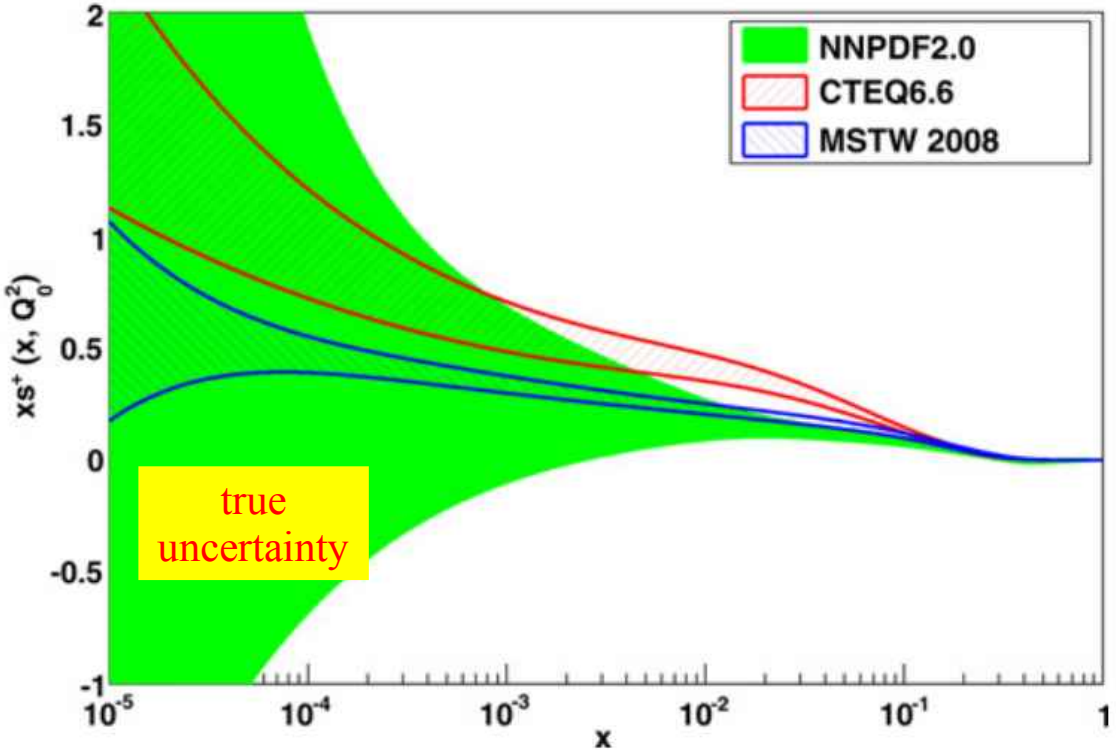
K. Kovarik
A Kusina,
F. Lyonnet,
J. Morfin,
F. Olness
J. Owens,
I. Schienbein,
J. Yu

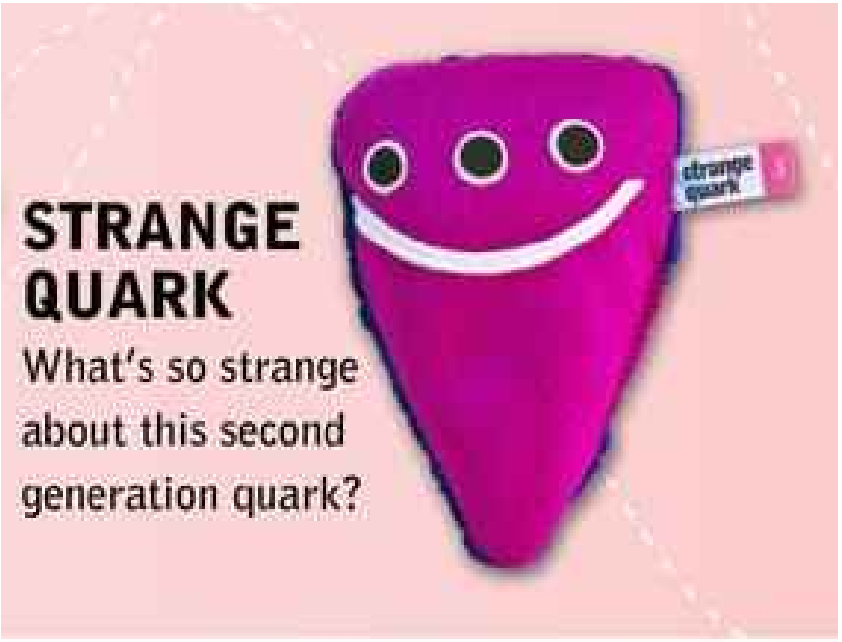
Data from nuclear targets play a key role in the flavor differentiation

nCTEQ

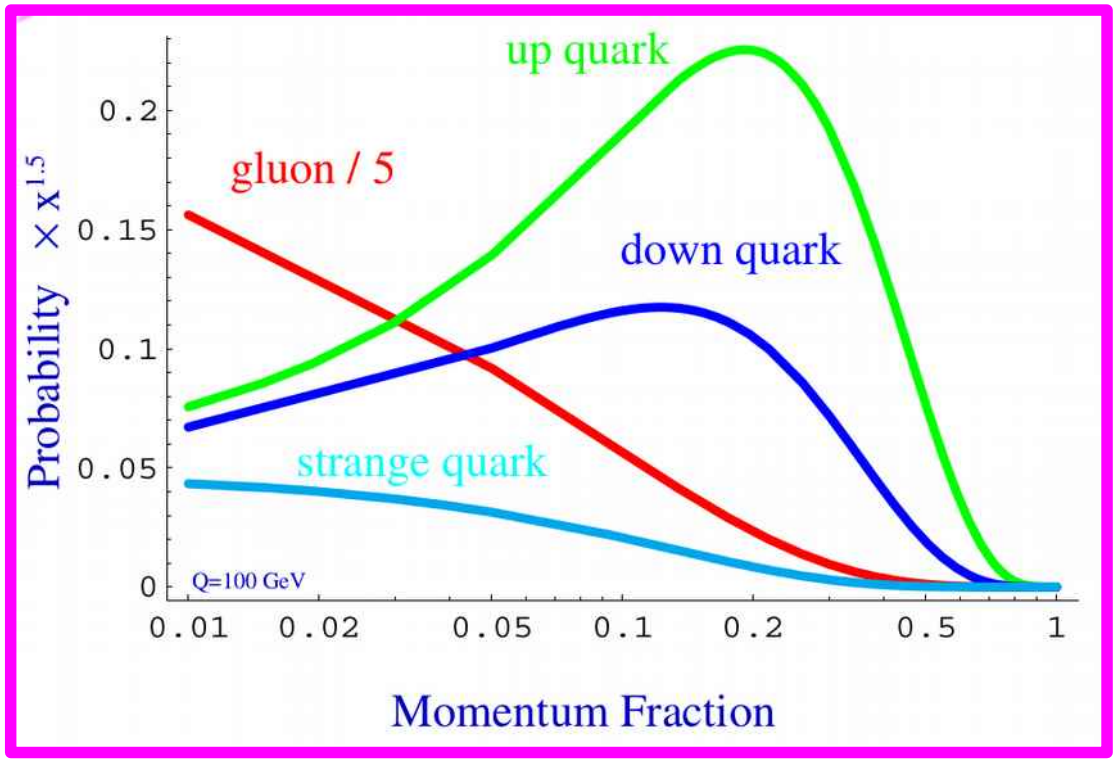
nuclear parton distribution functions

Case Study: The Strange PDF



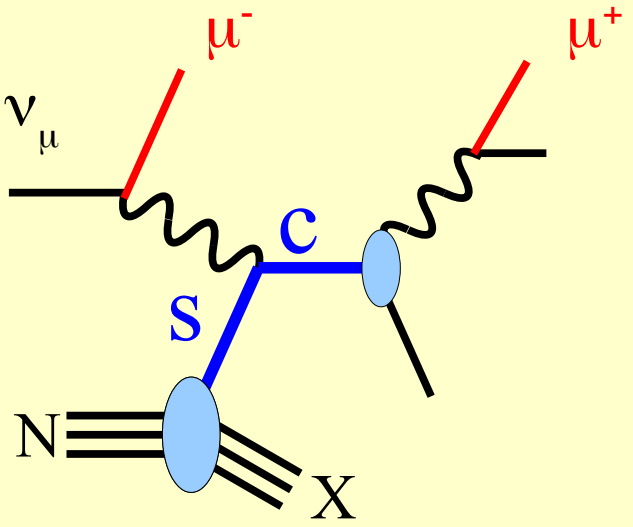


Strange PDF: ν N di-muon Production

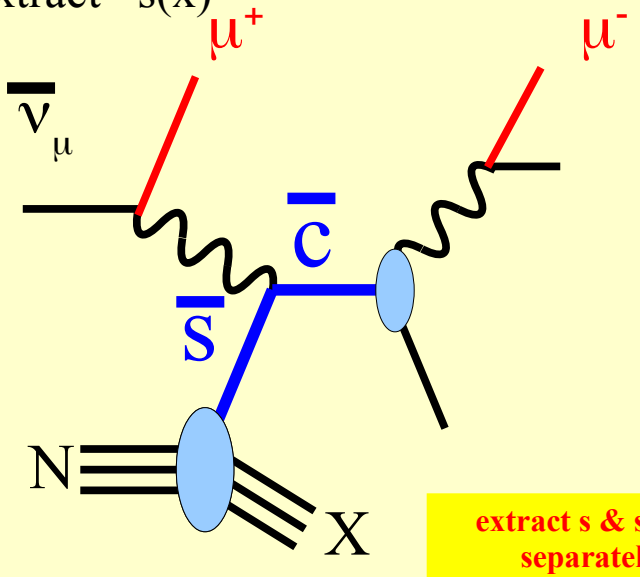


Need to "dig out" s(x) underneath d(x)

Extract s(x)

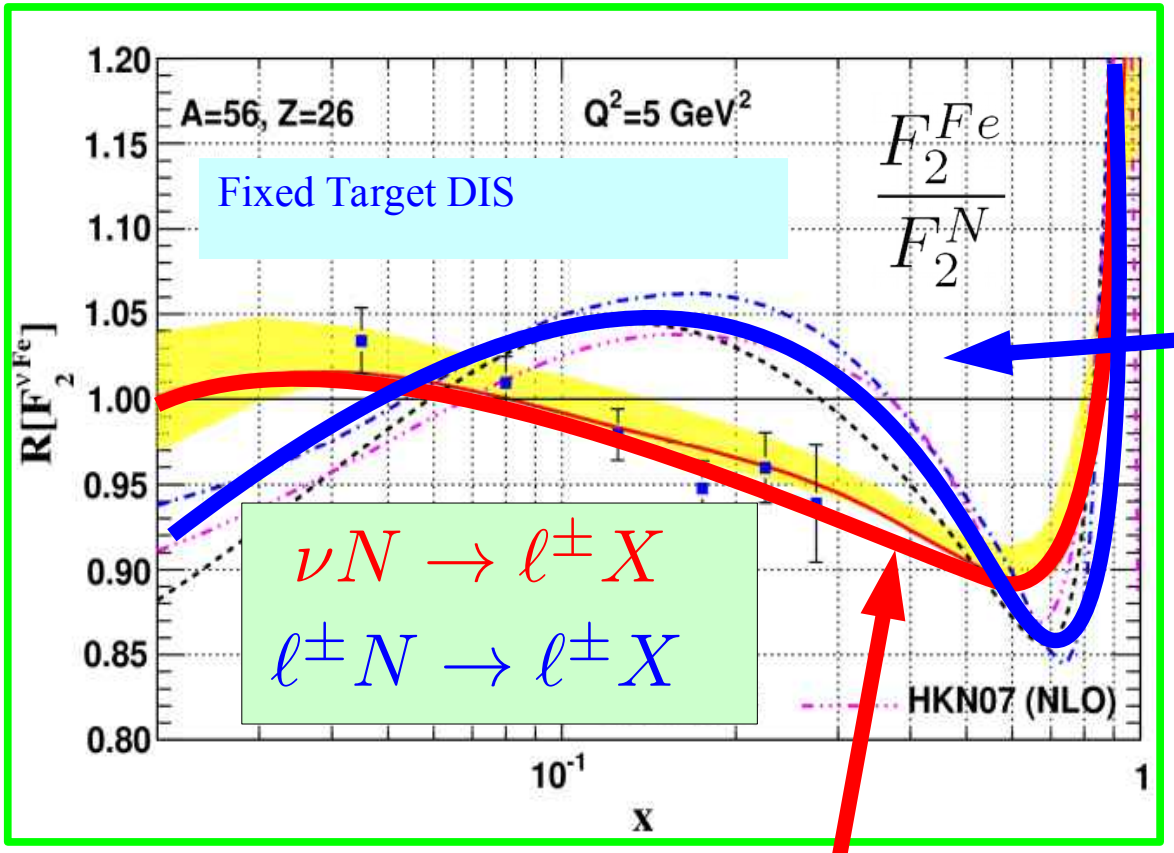


Extract $\bar{s}(x)$

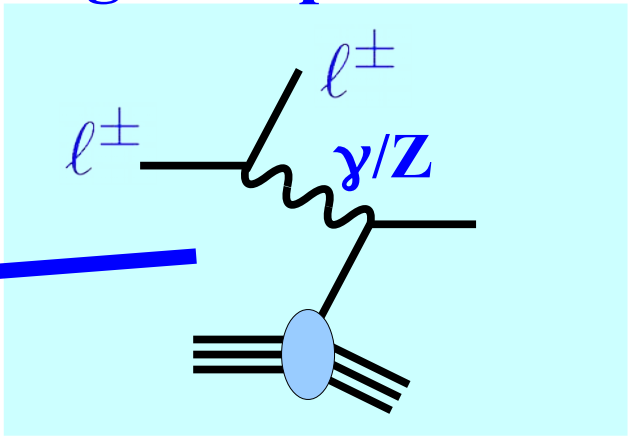


extract s & s-bar separately

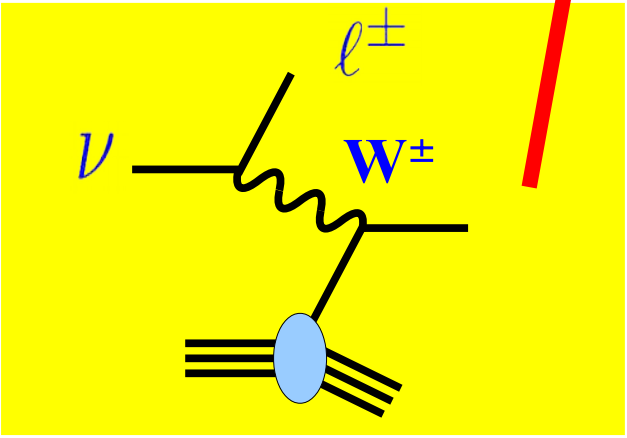
Puzzle: What is the Nuclear Correction



Charged Lepton DIS

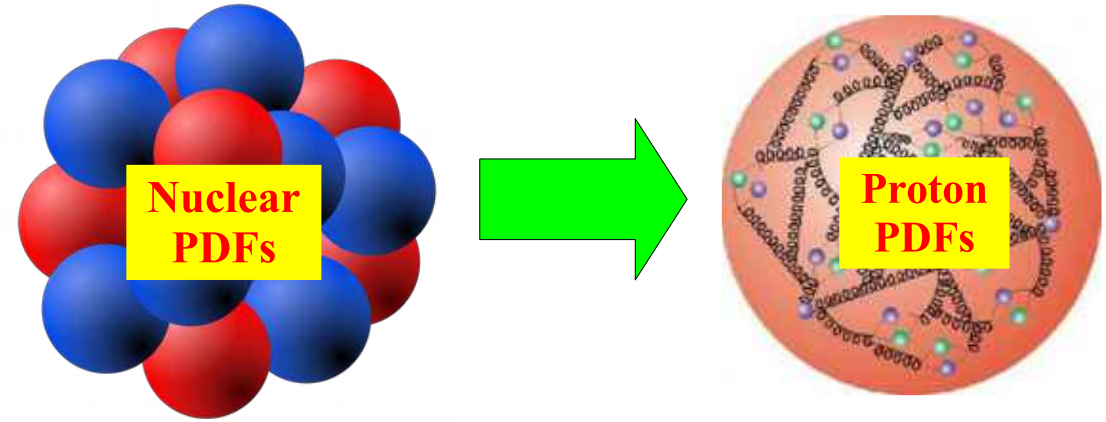


some caveats
... correlated errors



Neutrino DIS

Depends on nuclear corrections



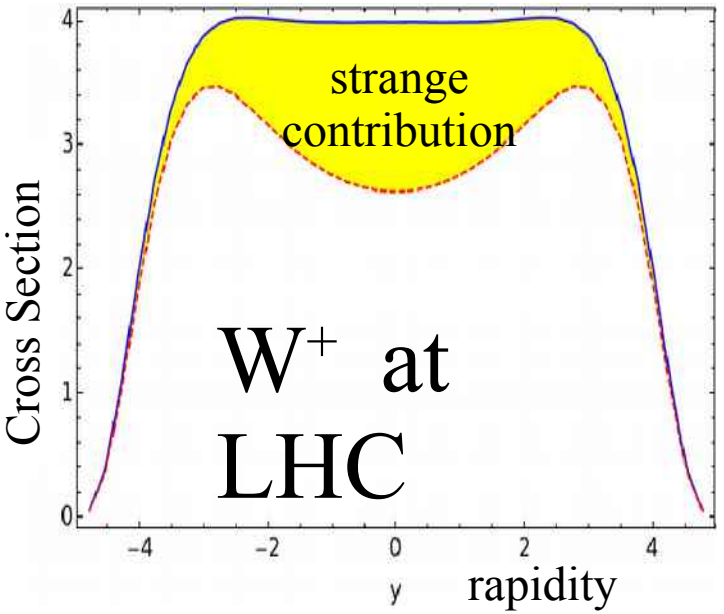
Propagation of γ/W thru nuclei

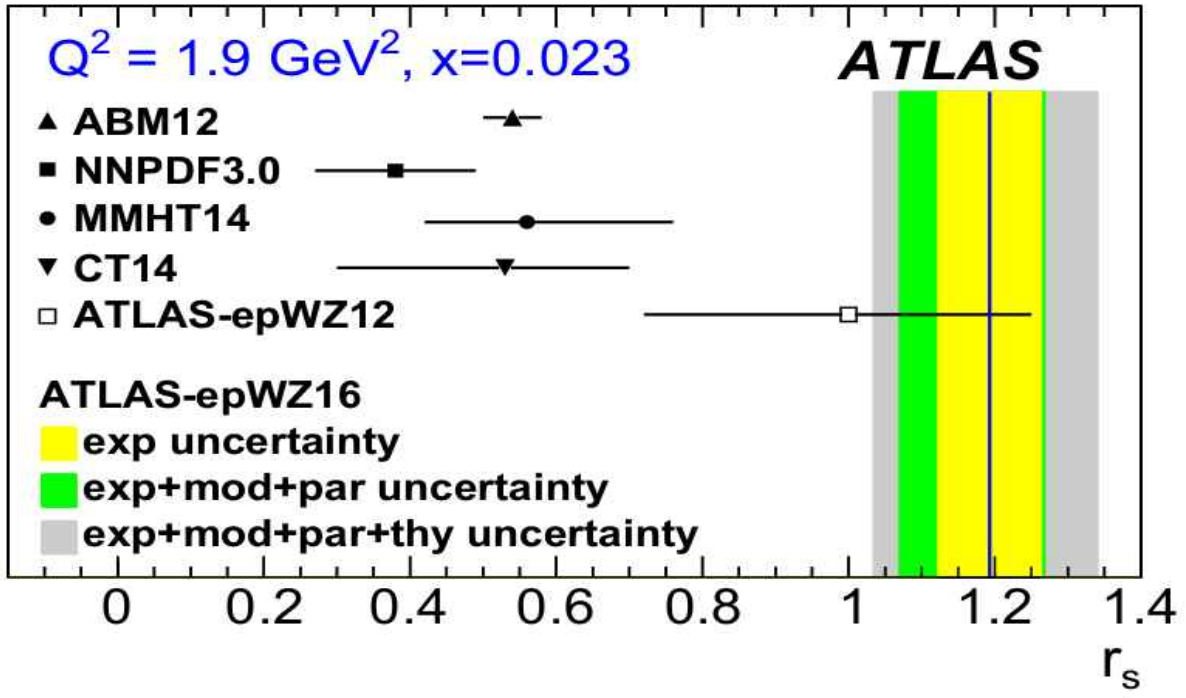
Just use protons

and

go to high energy !!!

$$u\bar{d} + u\bar{\mathbf{s}} + \mathbf{c}\bar{d} + \mathbf{c}\bar{\mathbf{s}} \rightarrow W^+$$
$$\bar{u}d + \bar{u}\mathbf{s} + \bar{\mathbf{c}}d + \bar{\mathbf{c}}\mathbf{s} \rightarrow W^-$$
$$u\bar{u} + d\bar{d} + \mathbf{s}\bar{\mathbf{s}} + \mathbf{c}\bar{\mathbf{c}} \rightarrow Z$$





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

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

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

CTEQ School Tutorial

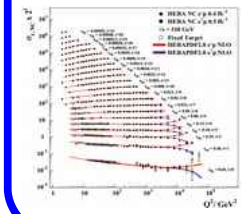
xFitter release xfitter-2.0.0

www.xFitter.org

Sample data files:

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

Experimental Data



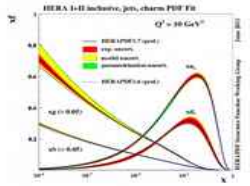
Data: HERA, Tevatron, LHC, fixed target experiments

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)

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

How can we resolve proton structure and nuclear corrections

Ideally suited to " ... glean the fundamental insights into QCD"

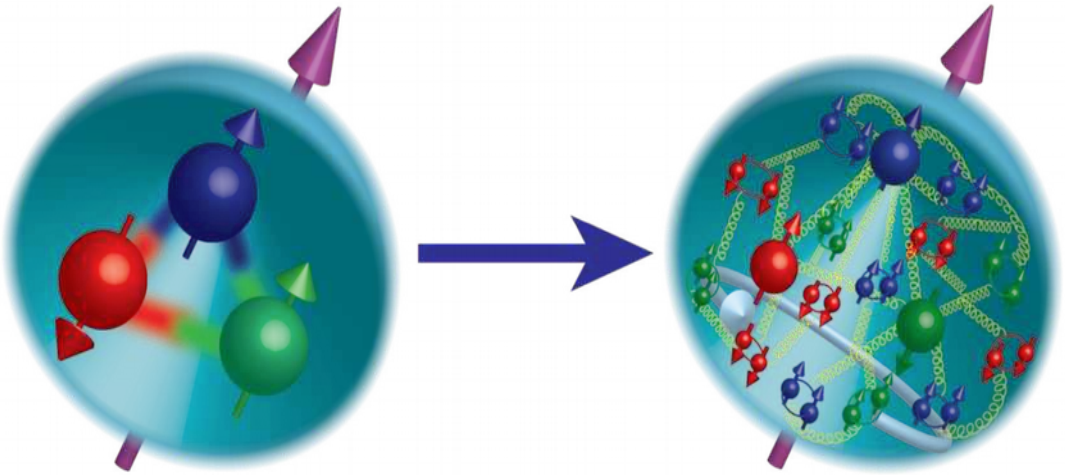
A few thoughts:

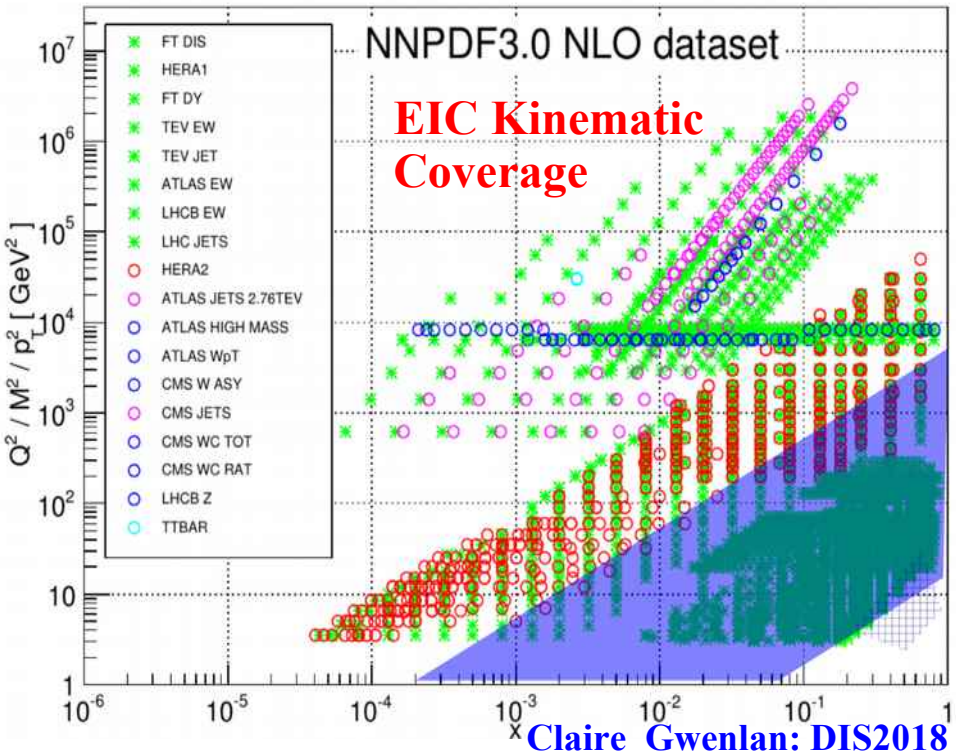
Nucleon Structure:

protons, hadrons, nuclear tomography, …

Hadron/Parton Transition:

Higher Twist, many body, duality, ...



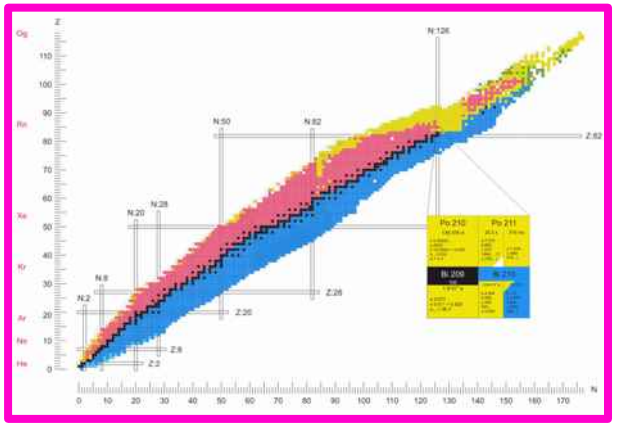


nCTEQ PDF Update

What are the challenges & opportunities with an EIC

It will have high statistics for a wide variety of NUCLEI

Nuclear corrections are inextricably linked
to the PDF flavor differentiation

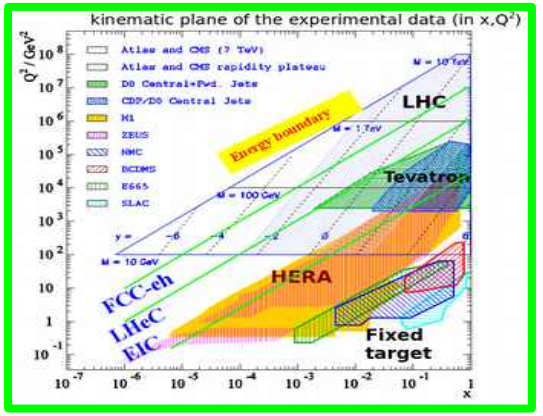


It allows us to push to HI-X

W cuts eliminate much of this region
Higher-twist, factorization violations, …
Test models in x→1 limit, e.g., d/u, …

It allows us to push to low Q

Q cuts eliminate much of this region
Explores the parton/hadron transition
Study non-perturbative collective phenomena



These are hard problems

...

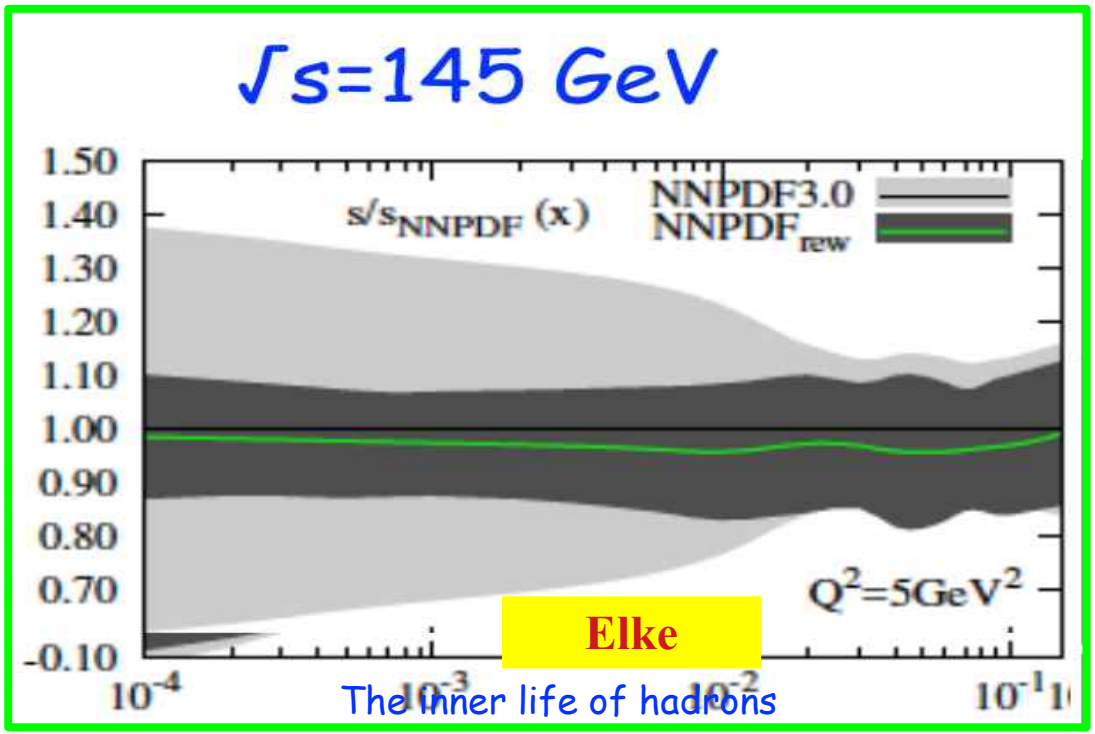
we need good ideas

What's the Solution???

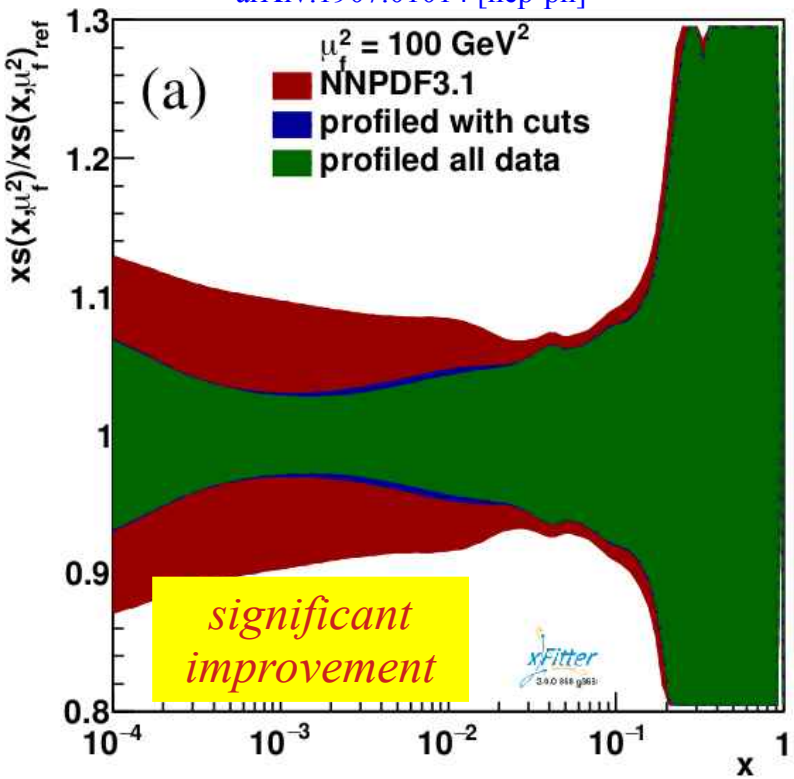
This is an area where EIC & LHeC are particularly suited to help

Combined Effort to Decipher

EIC can expand our knowledge of the nuclear A dimension

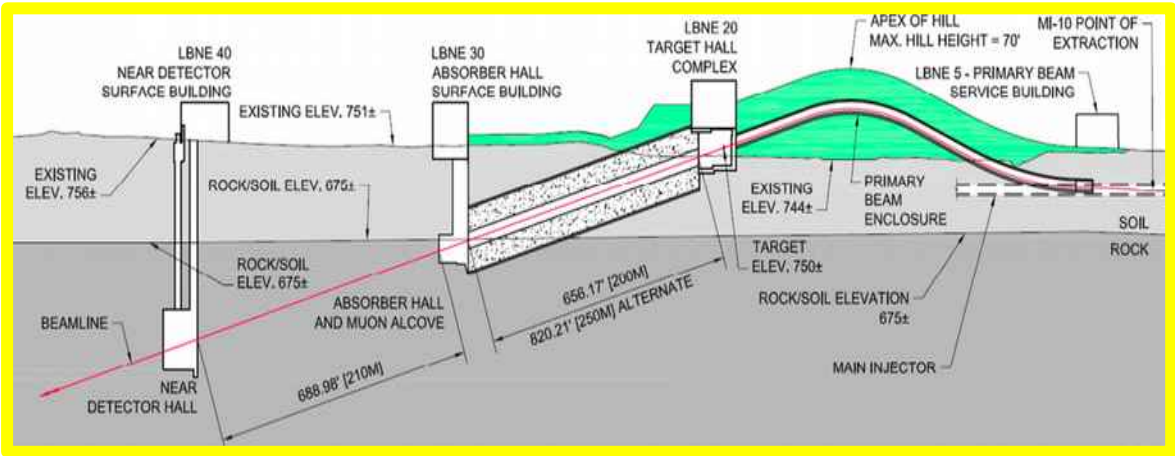


LHeC Study: xFitter Developers' Team;
arXiv:1907.01014 [hep-ph]



DUNE:

Nuclei σ needed for beam profile



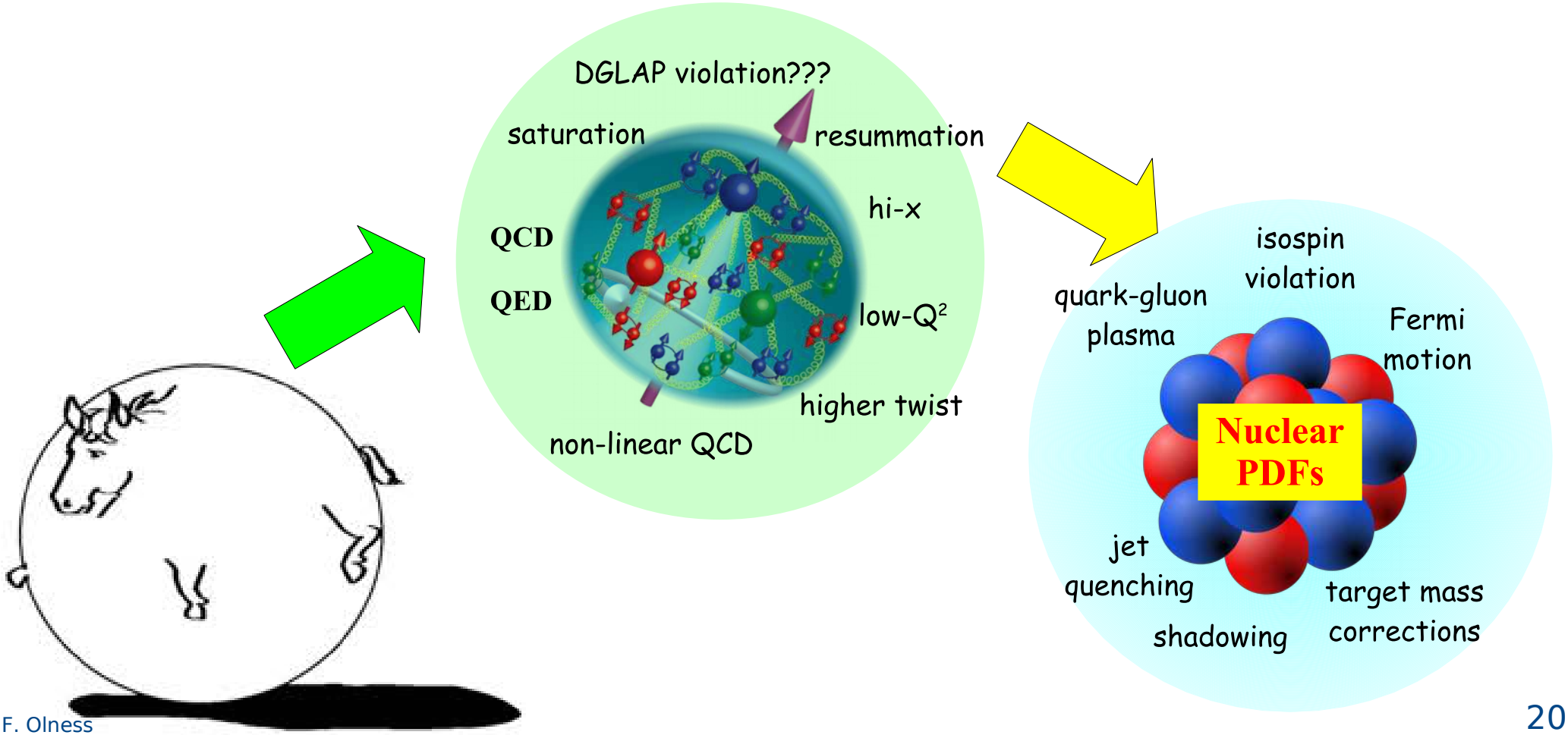
Conclusion

an ideal QCD Laboratory

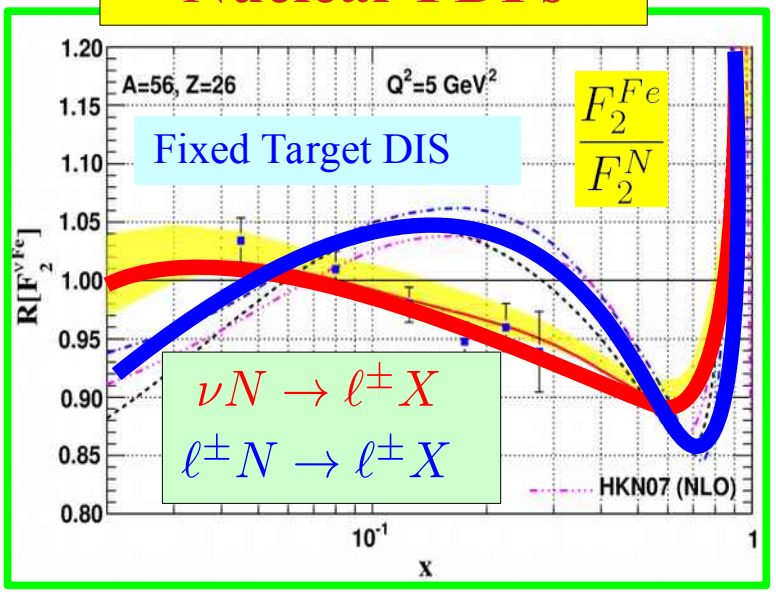
"QCD is our most perfect physical theory" ***Frank Wilczek***

"EIC would unlock scientific mysteries" ***NAP Report***

Ideally suited to " ... glean the fundamental insights into QCD"



Nuclear PDFs



I work with protons.

Why do I need nuclei ?

Flavor Differentiation

$$F_2^\nu \sim [d + s + \bar{u} + \bar{c}]$$

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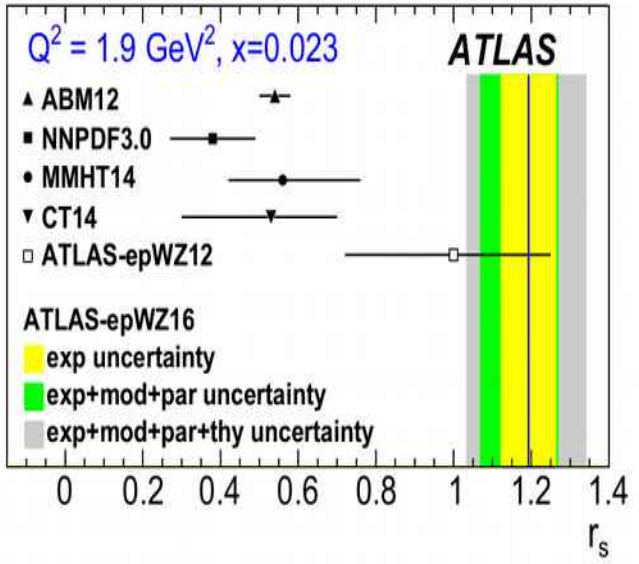
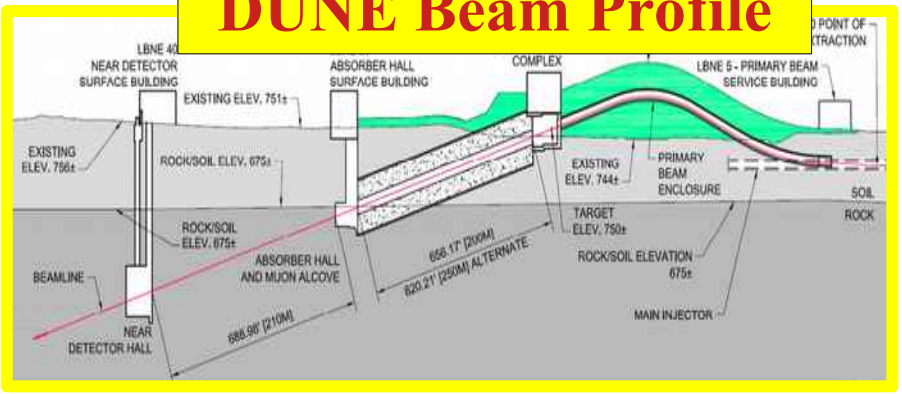


Precision QCD

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

DUNE Beam Profile



Input on the Snowmass Community Planning Process

Your contributions and participation will naturally occur as part of one or more working groups. However, as we put together the process, you are also welcome to provide input and suggestions through this form. Please fill out the form by November 15.

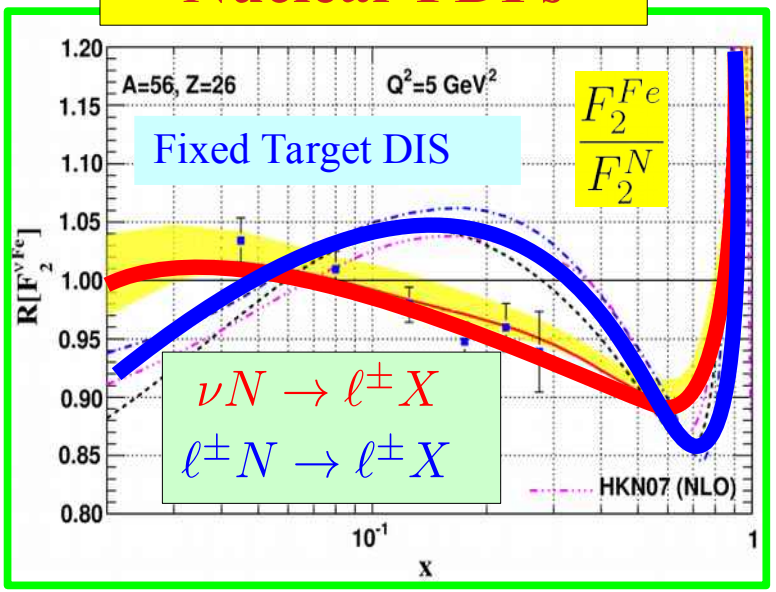
* Required

Email address *

Your email

First and Last Name

Nuclear PDFs



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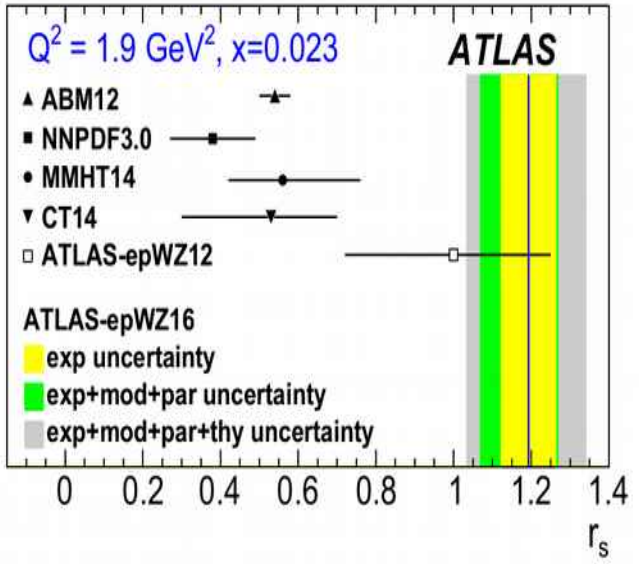

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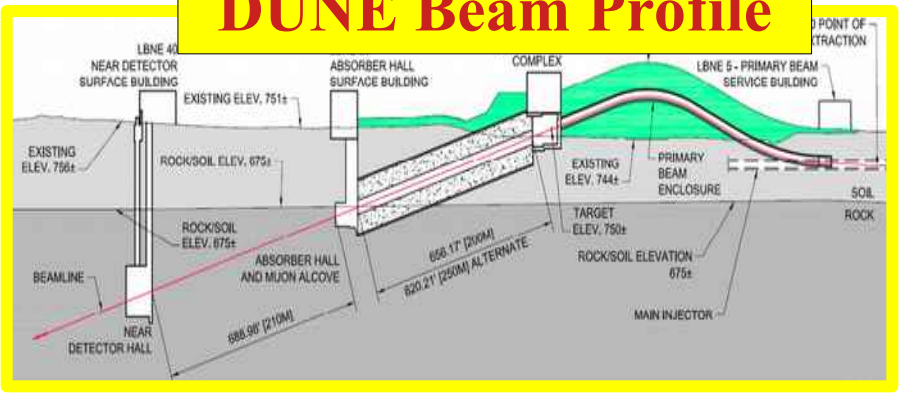
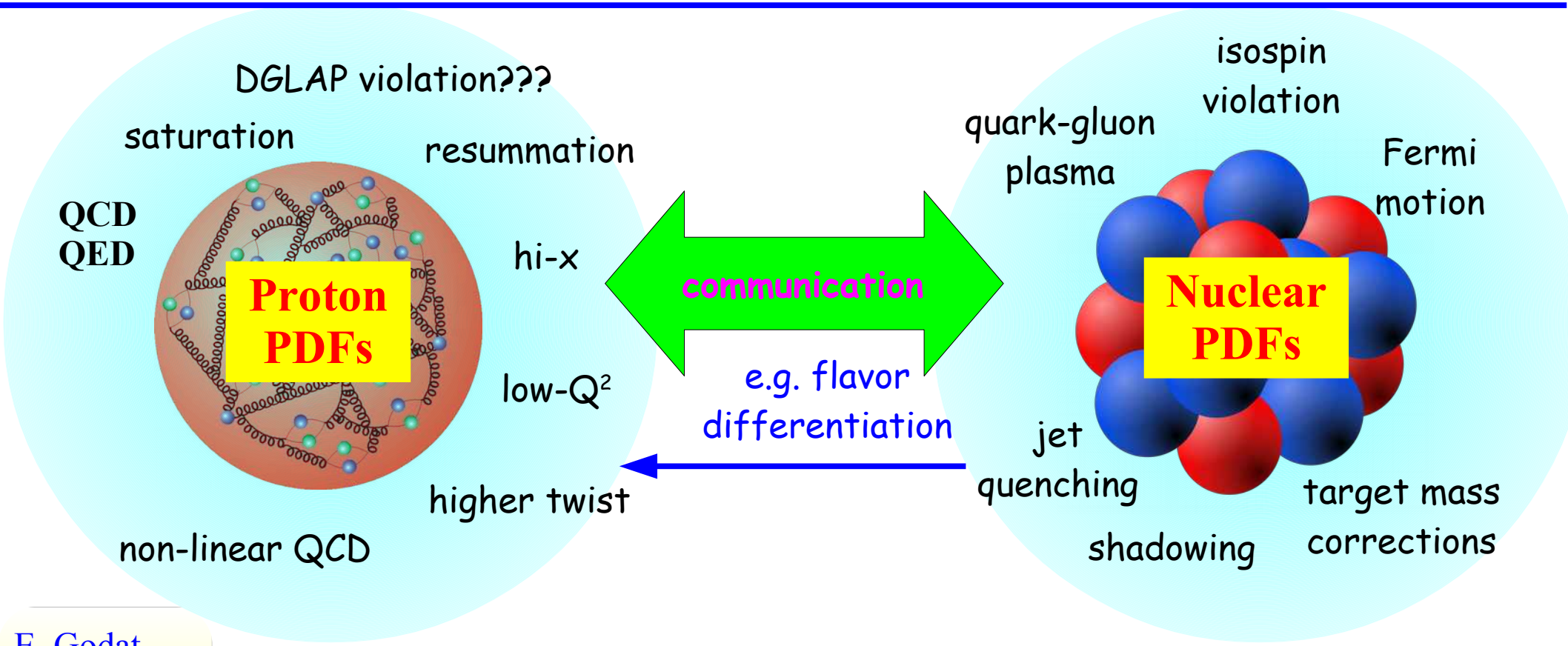


… the motivation for nCTEQ



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