PDFs in the EIC Era

Challenges and Opportunities for QCD

Fred Olness
SMU

Thanks for substantial input
from my friends & colleagues

C T E Q

xFitter

nCTEQ
nuclear parton distribution functions

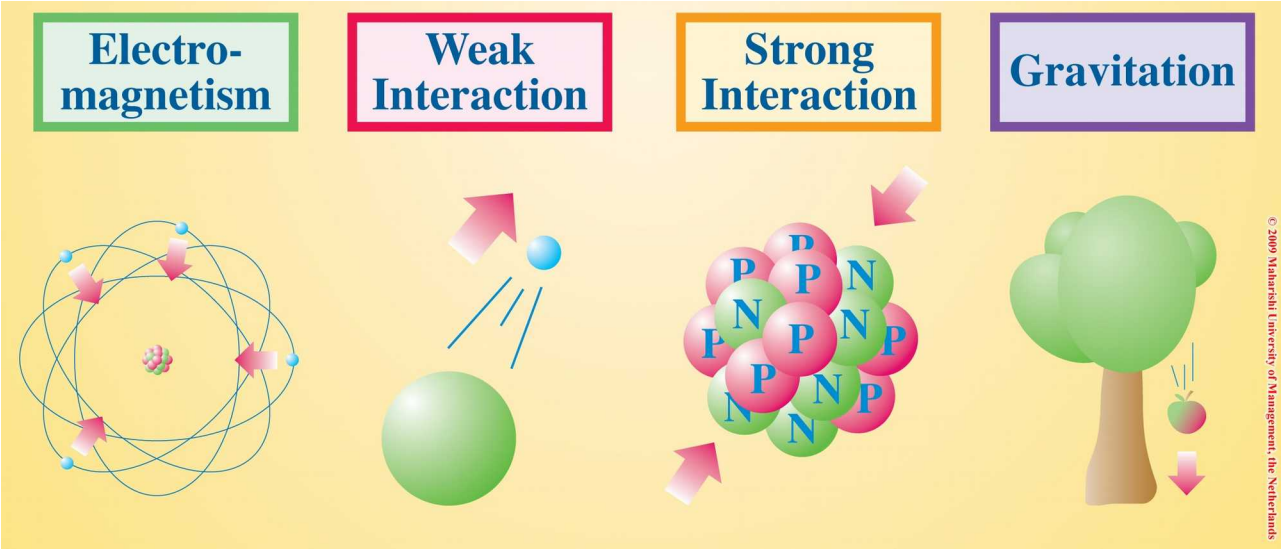
EIC Users Group Meeting
Washington DC
July 30 – Aug 1, 2018

… an important step

On July 23, the National Academies released a study report backing the scientific case for building a U.S.-based electron-ion collider (EIC).

FYI AIP.org

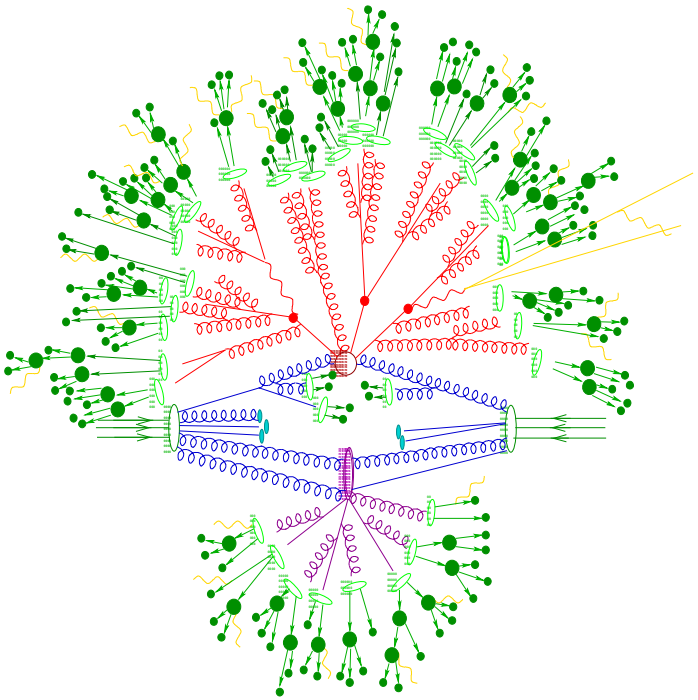
EIC: An Ideal QCD Laboratory



QCD is our most perfect physical theory

What QCD Tells Us About Nature – and Why We Should Listen. *Frank Wilczek*

In many respects, our most complex
- asymptotic freedom
- strong color confinement
- … associated manifestations



Lessons: The Nature of Nature

"… alien, simple, beautiful, weird, & comprehensible"

"EIC would unlock scientific mysteries" *NAP Report*

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

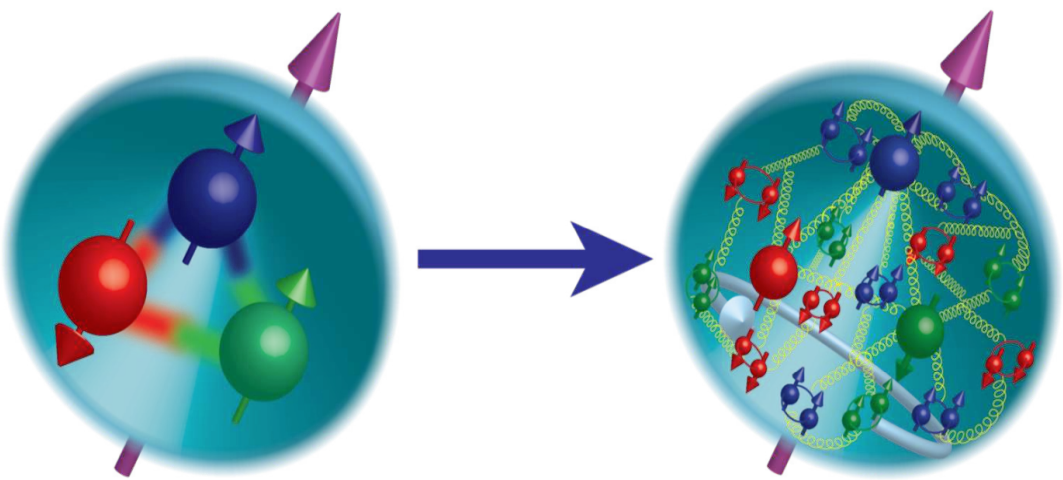
A few thoughts:

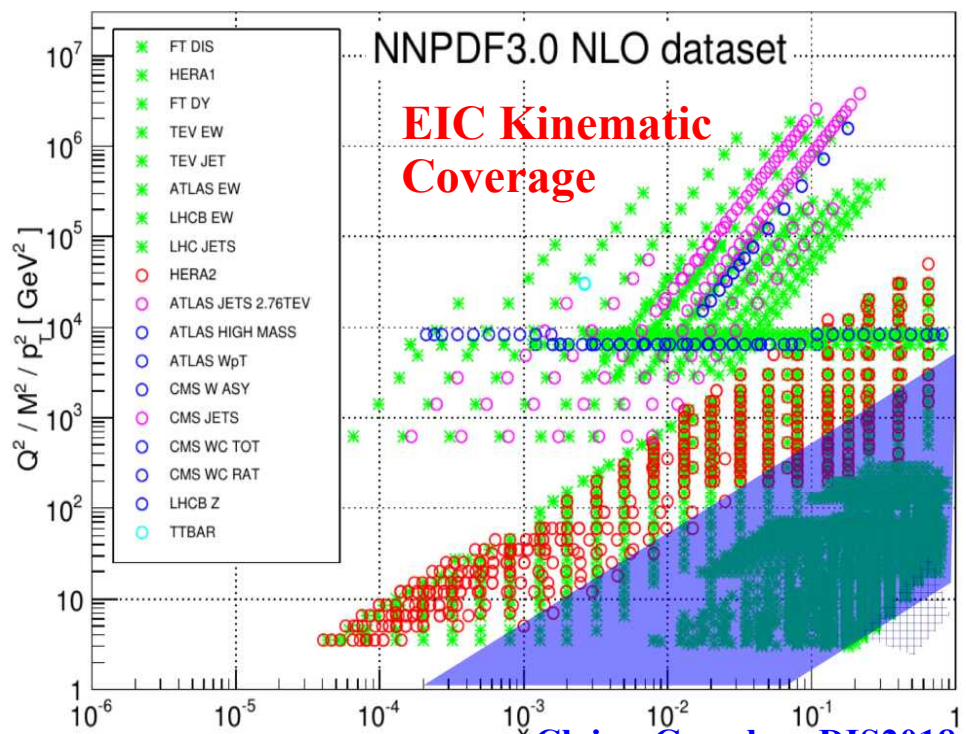
Nucleon Structure:

protons, hadrons, nuclear tomography, …

Hadron/Parton Transition:

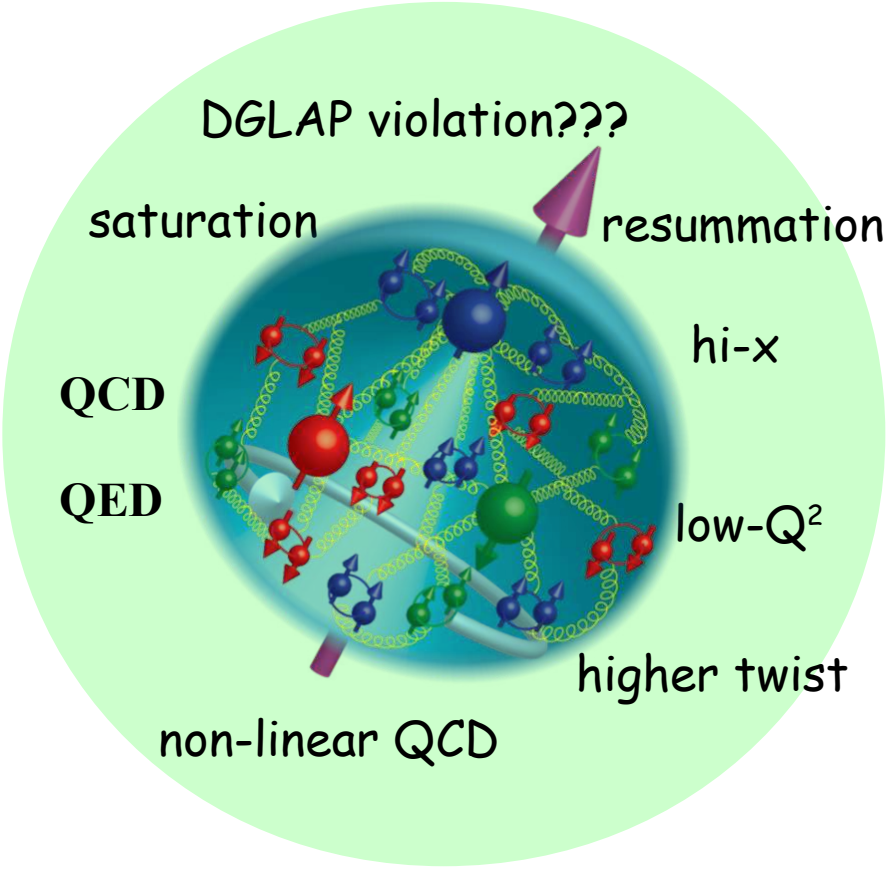
Higher Twist, many body, duality, ...

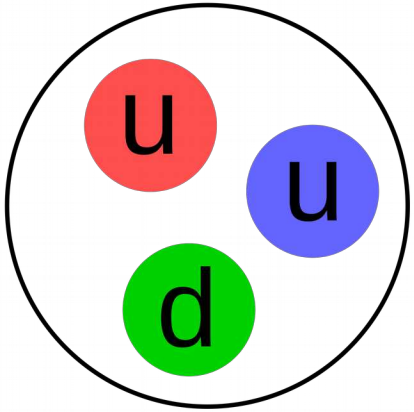


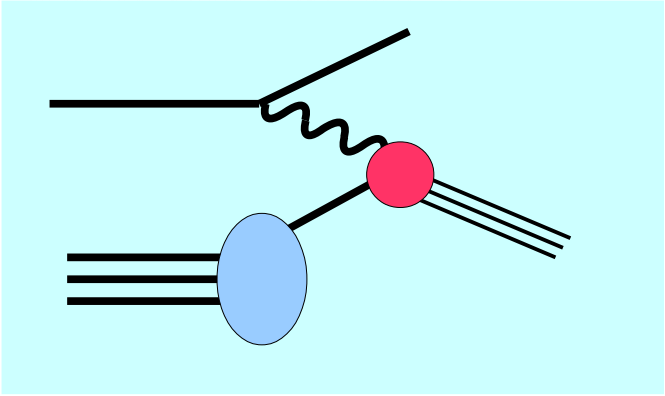


Claire Gwenlan: DIS2018

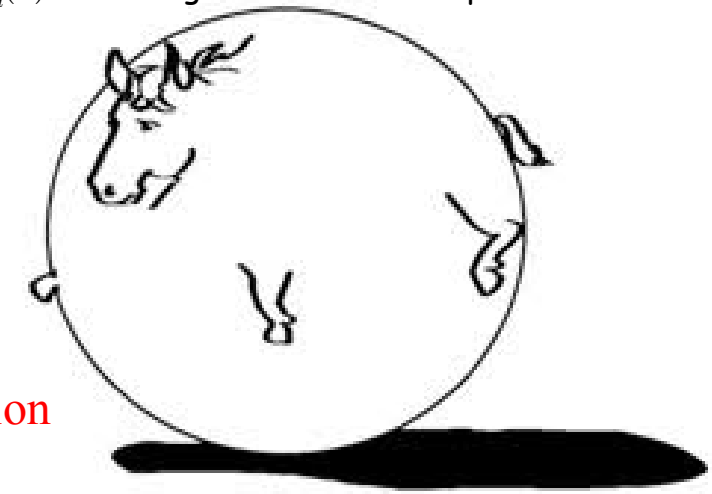
PDFs & the Parton Model … *a few simpifications*







$f_a(x)$ … working in the limit of a spherical horse …



The QCD Parton Model

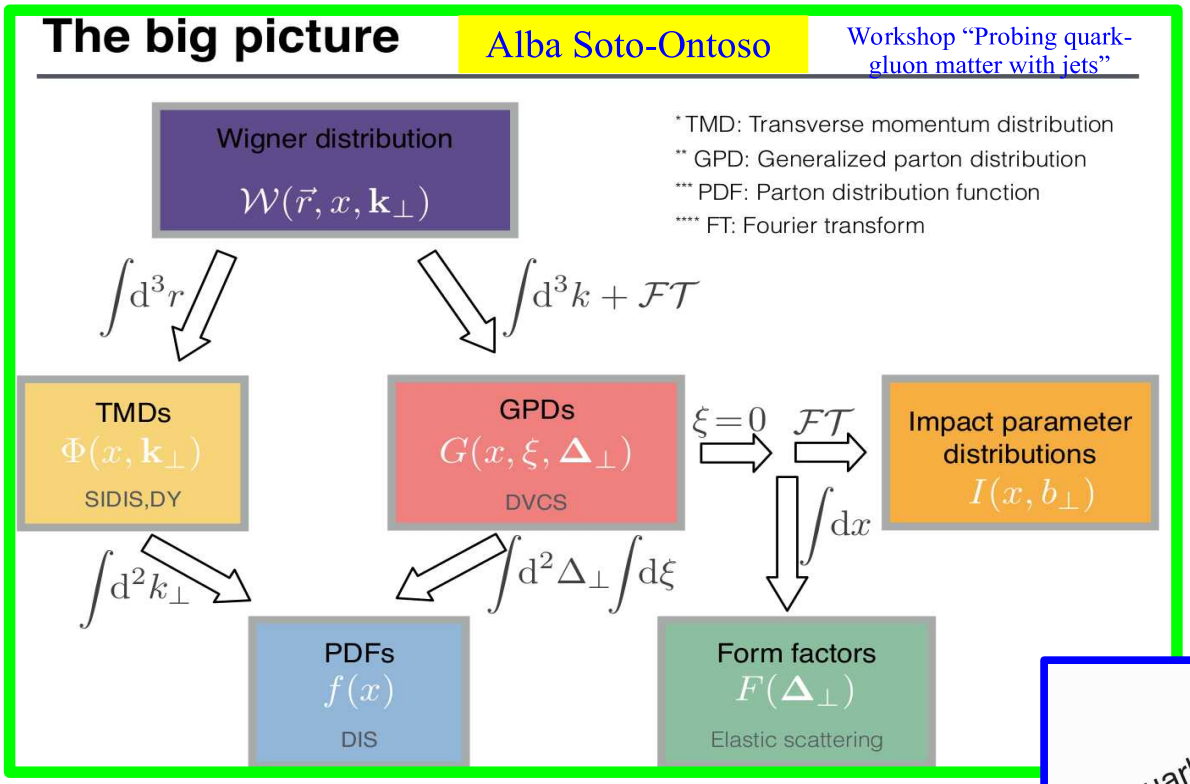
$$d\sigma = f_a(x) \otimes \hat{\sigma}$$

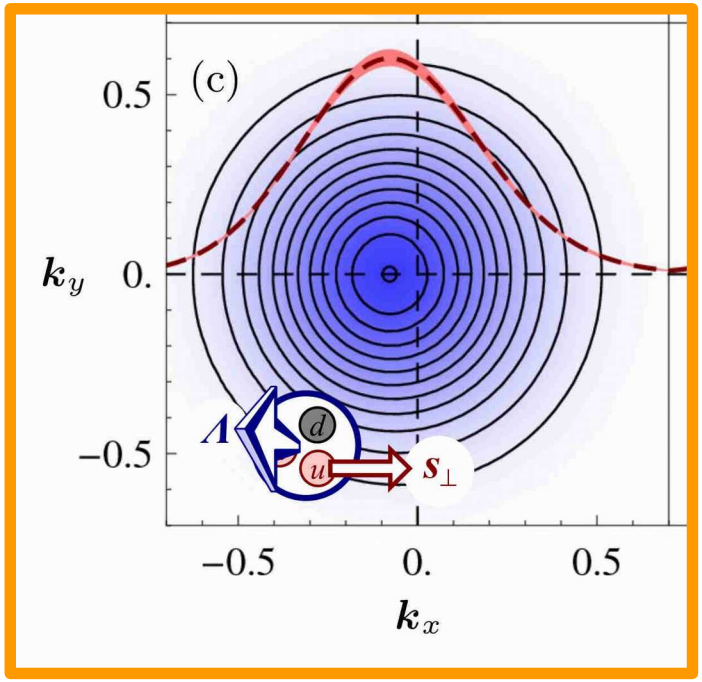
Parameterized in terms of a single variable x, the momentum fraction

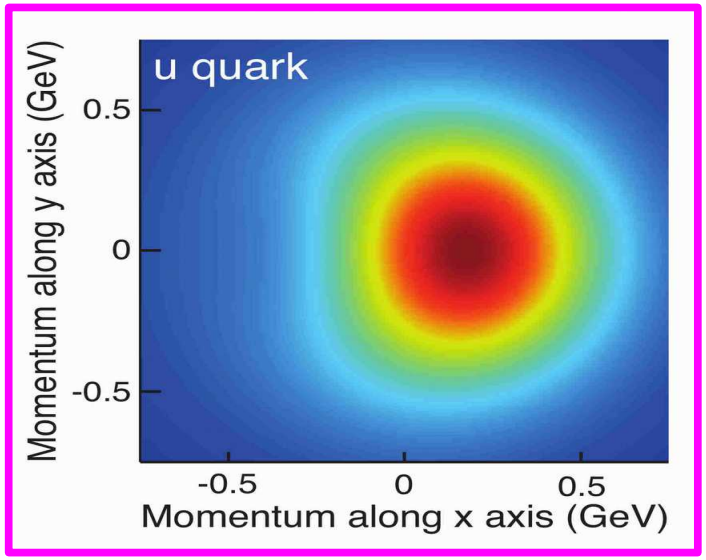
… use DGLAP to determine μ dependence

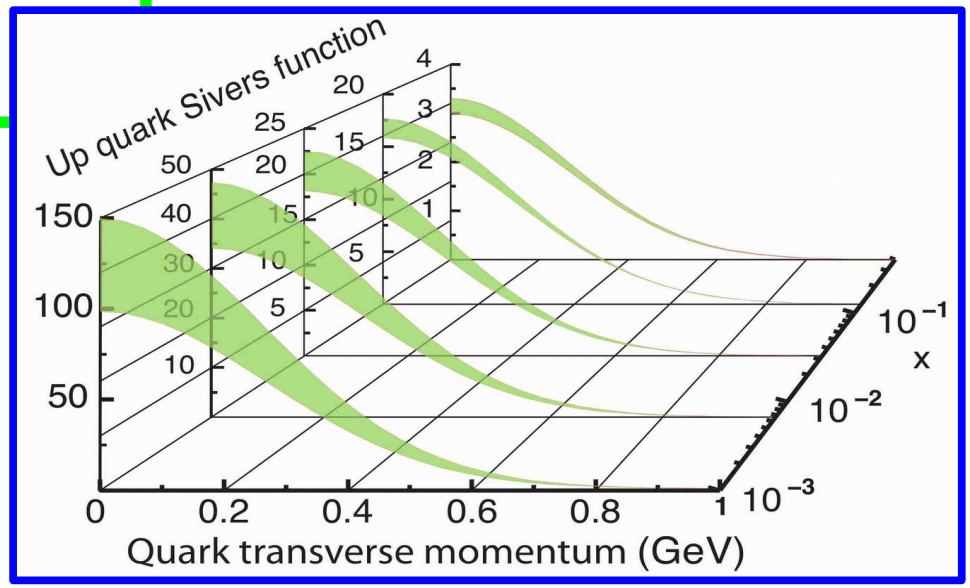
Nuclear Structure

Hadron structure is much richer than f(x) conveys





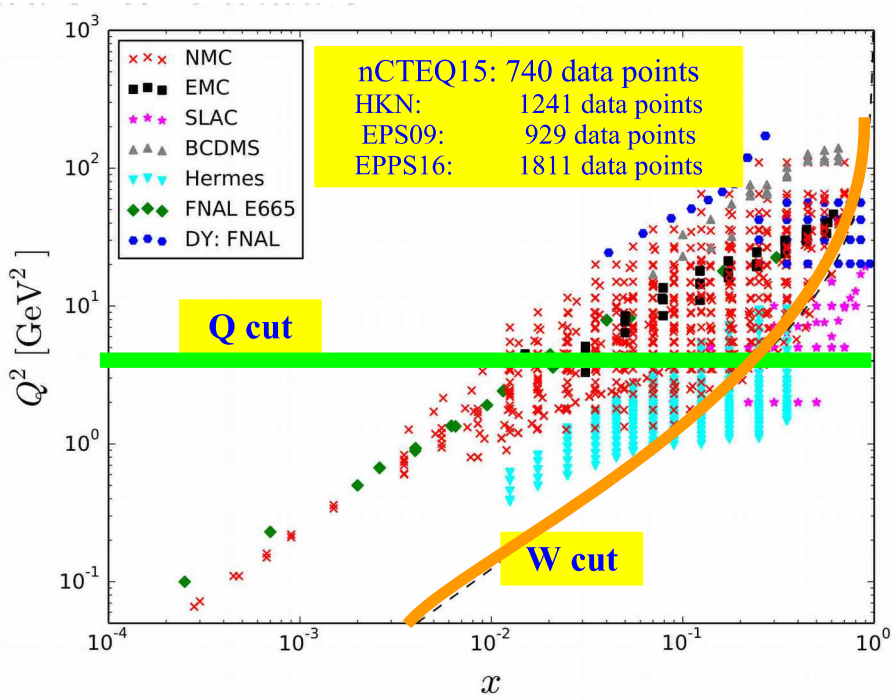


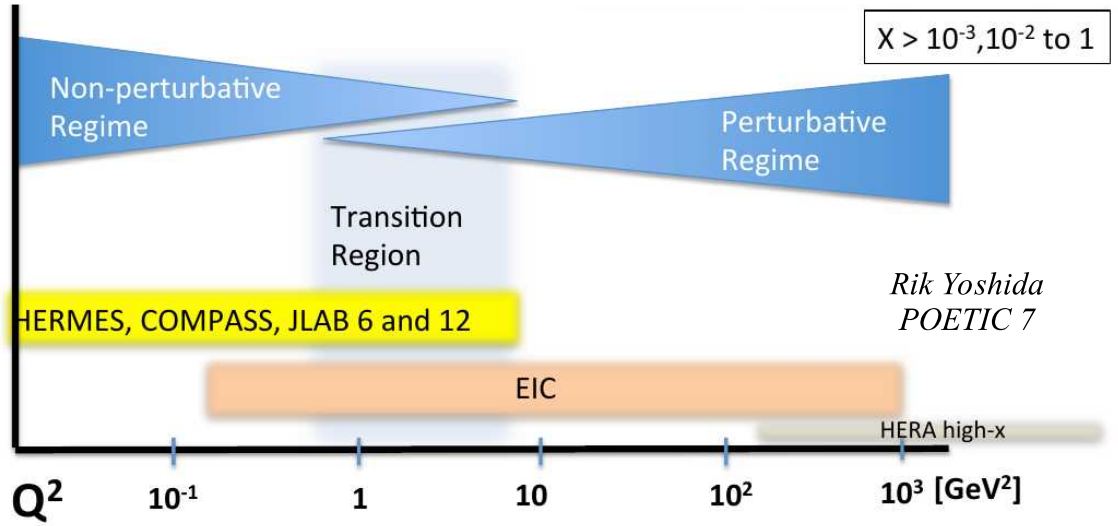


Conventional PDFs f(x) are the Boundary Conditions

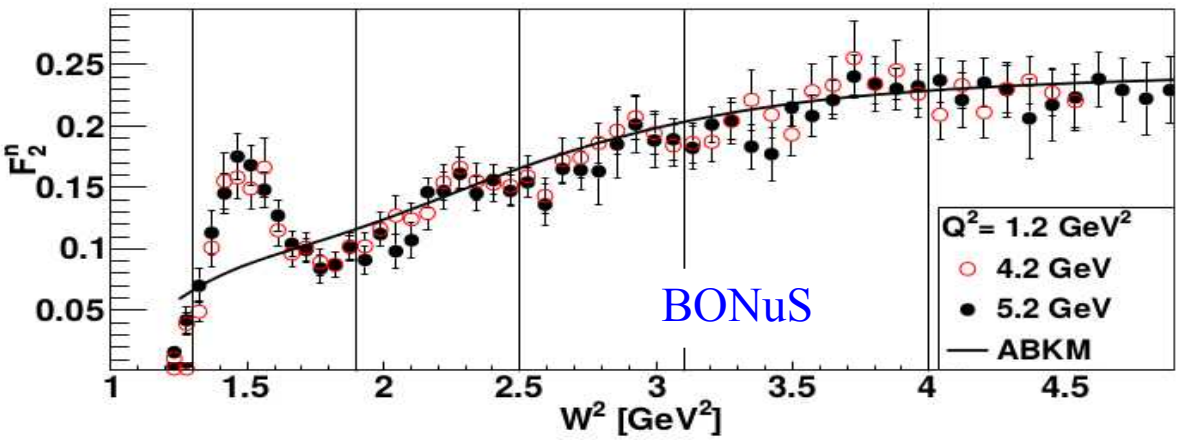
Hadron / Parton Transition:

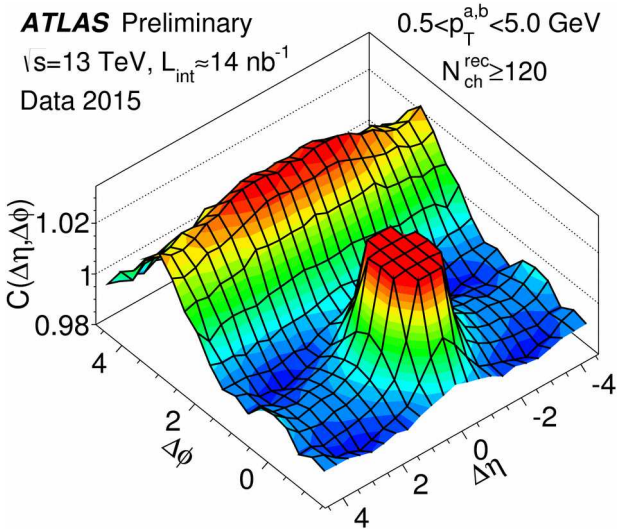
Higher Twist, many body problem, duality, hi-x, mass corrections ...





Rik Yoshida
POETIC 7





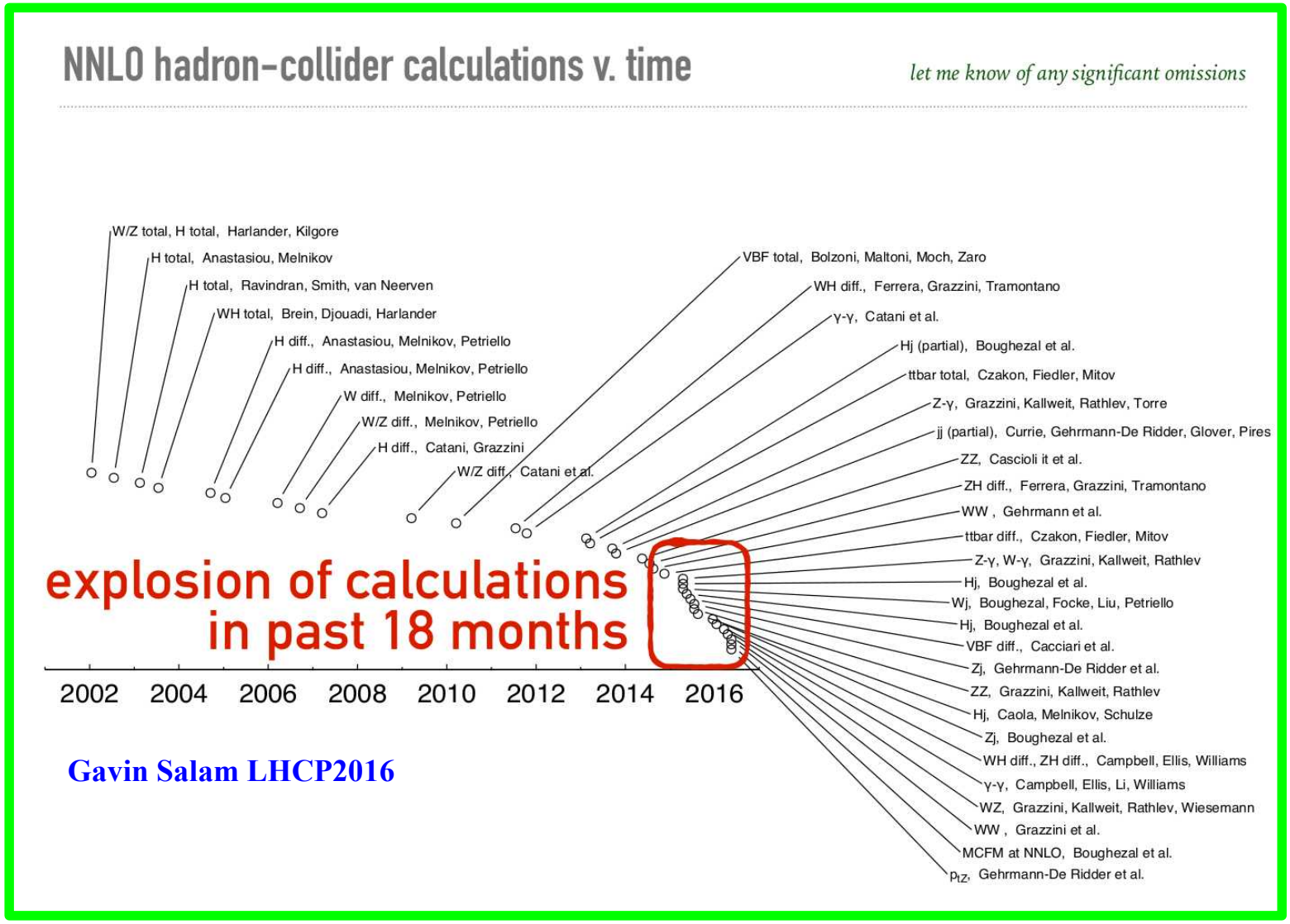
EIC can push these boundaries

These are hard problems

...

we need good ideas

Some Inspiration

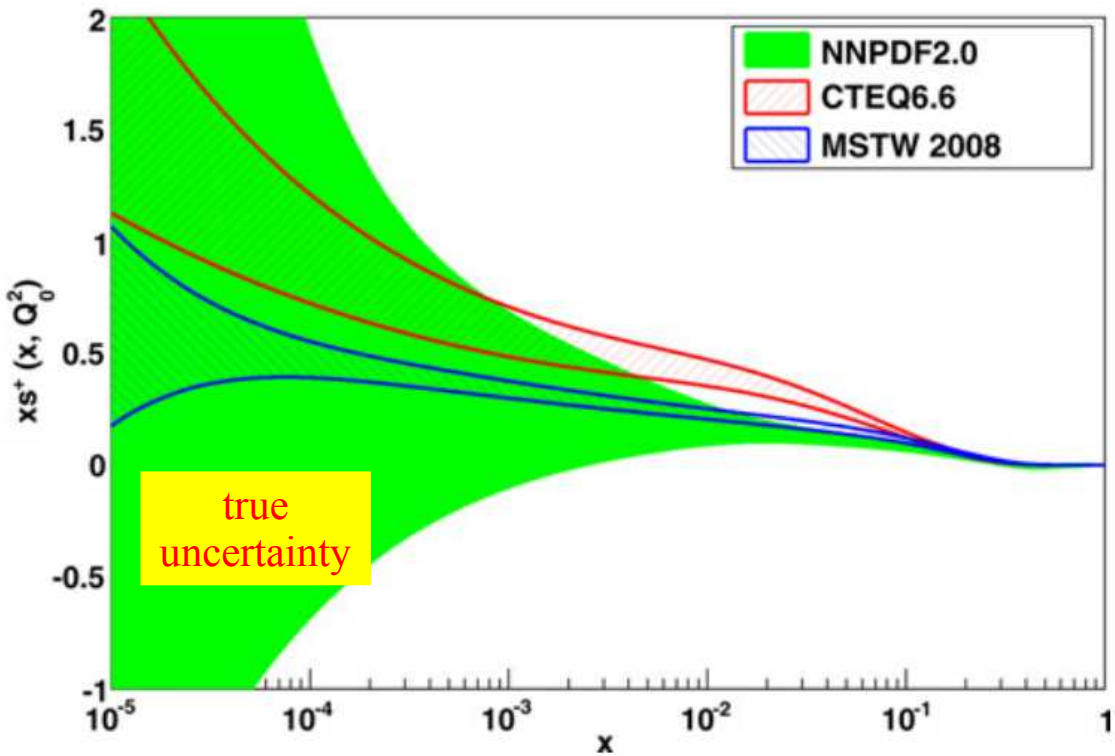


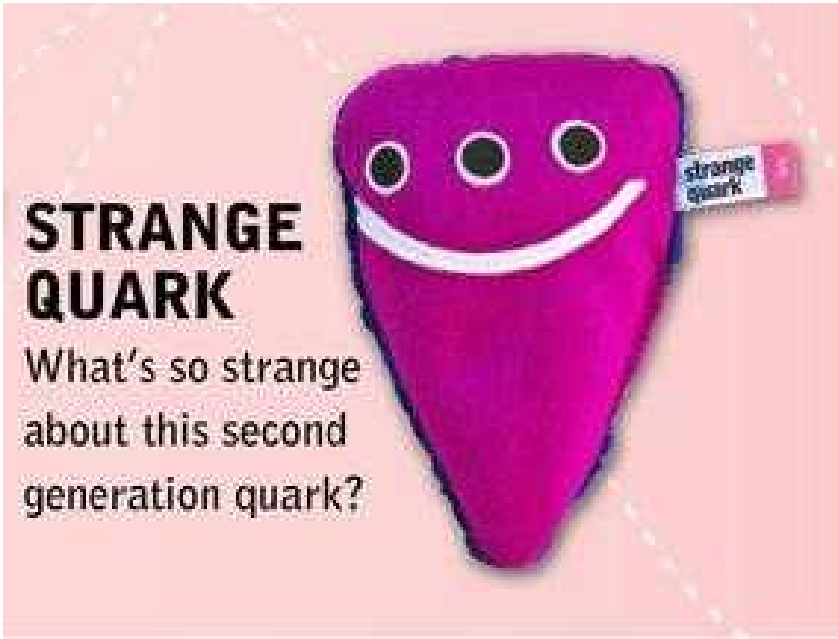
Gavin Salam LHCP2016

"Data Make You Smarter"

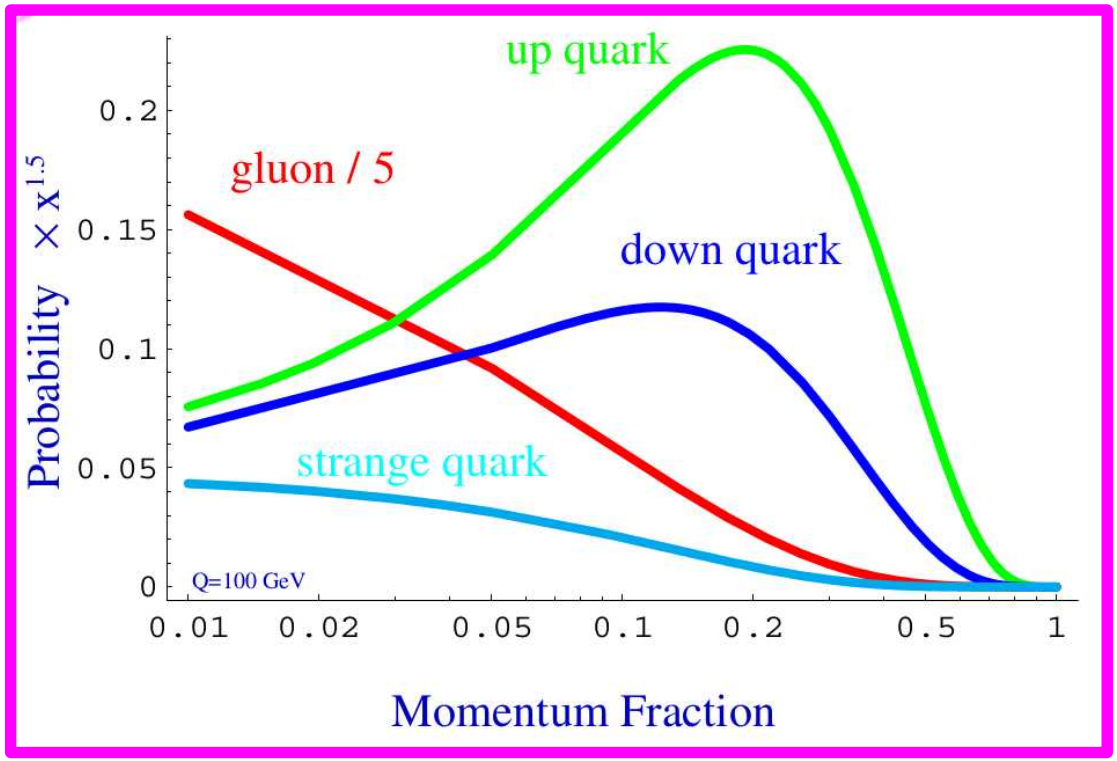
Dan Amidei (UM) & Chip Brock (MSU)
FermiNews January 17, 2003

Case Study: The Strange PDF



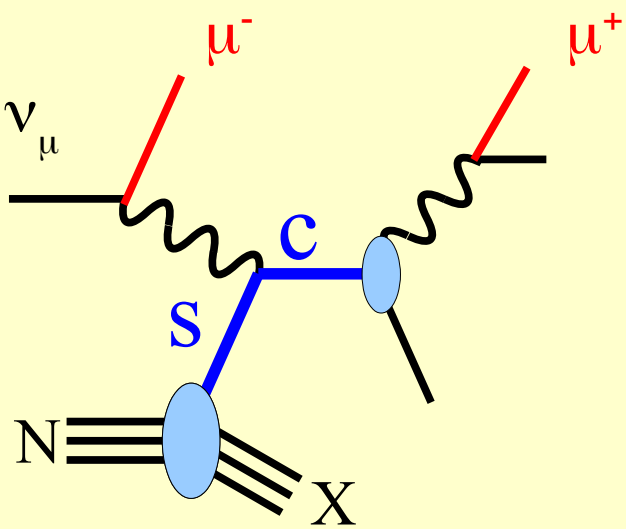


Strange PDF: ν N di-muon Production

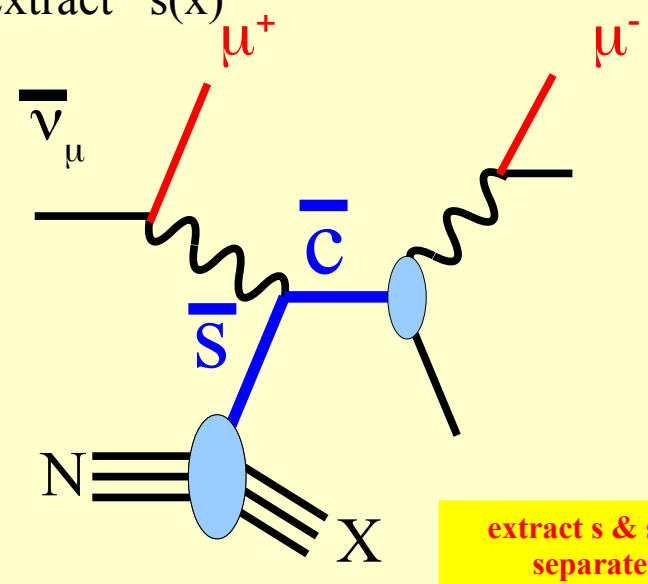


Need to "dig out" s(x) underneath d(x)

Extract s(x)

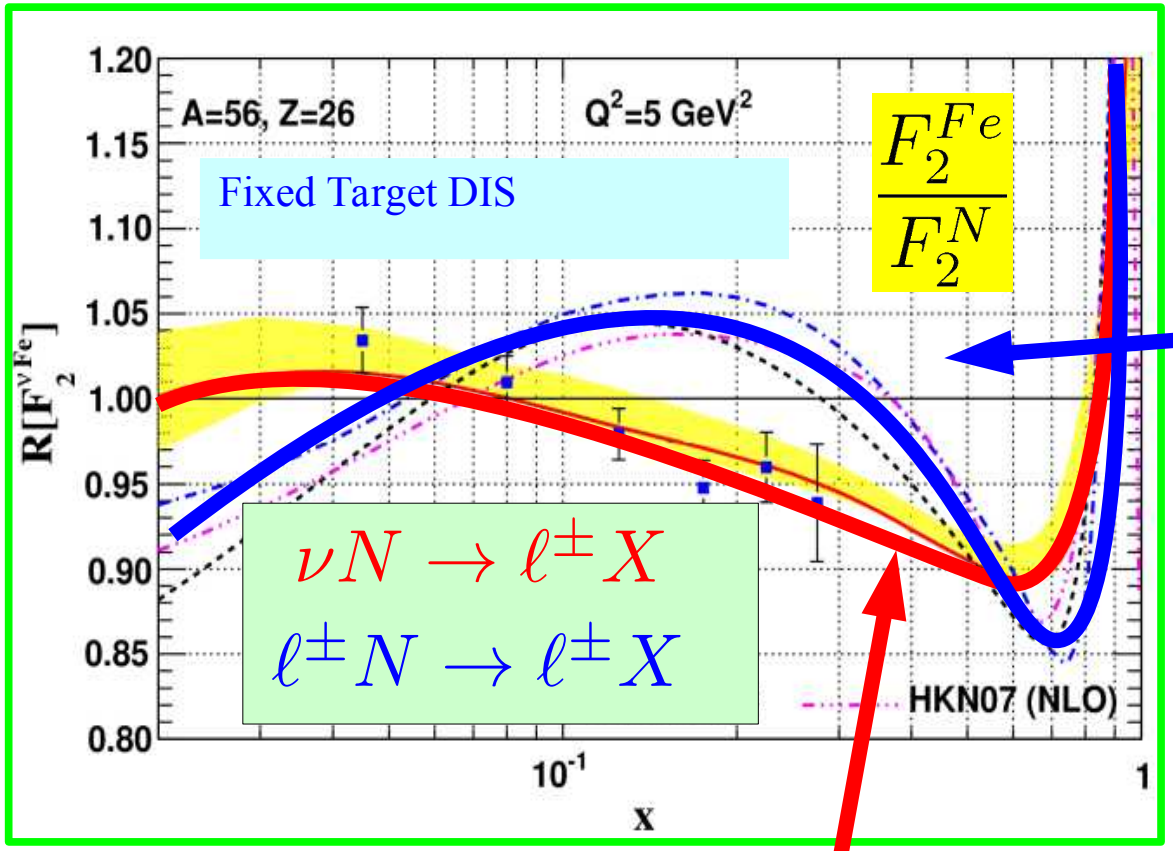


Extract $\bar{s}(x)$

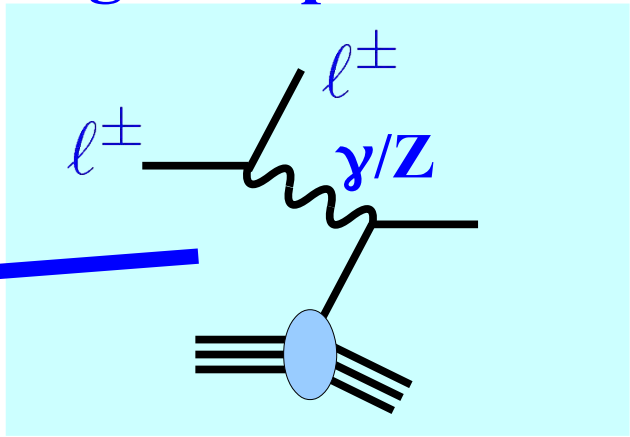


extract s & s-bar separately

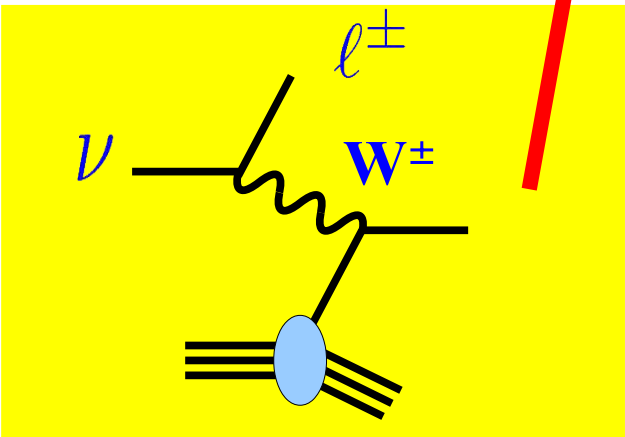
Puzzle: What is the Nuclear Correction



Charged Lepton DIS

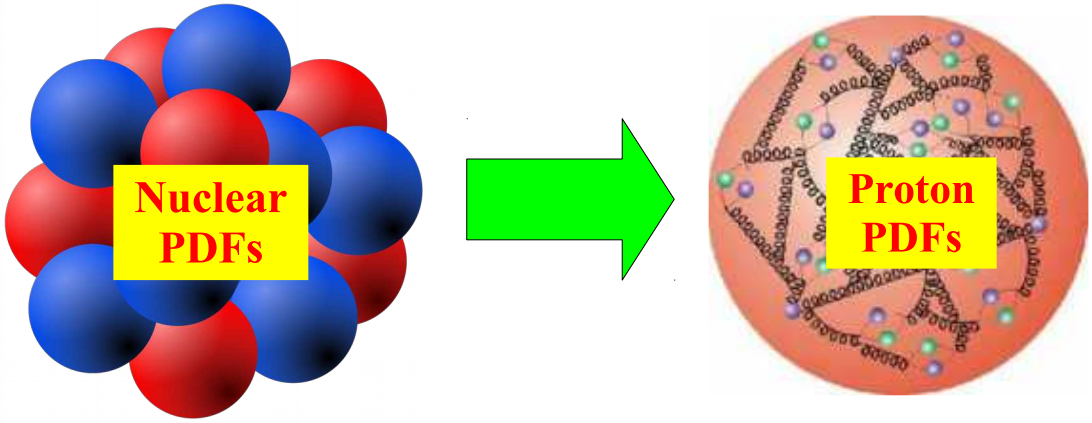


some caveats
... correlated errors



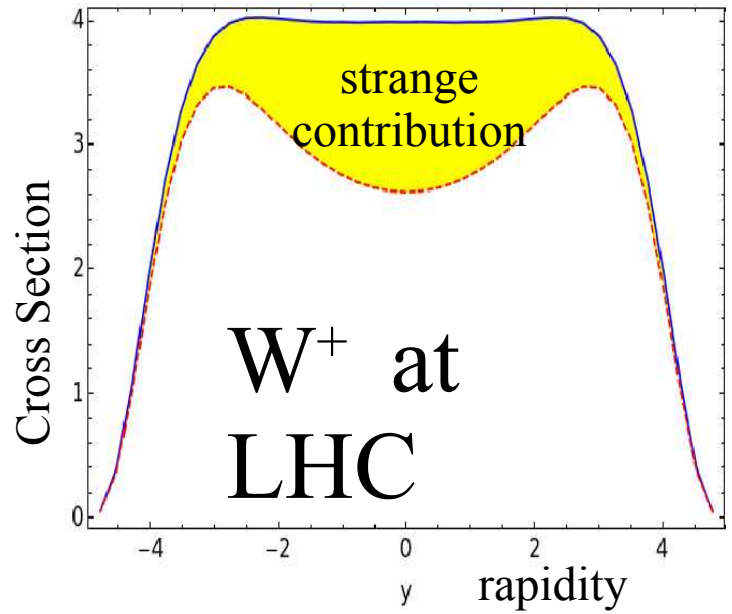
Neutrino DIS

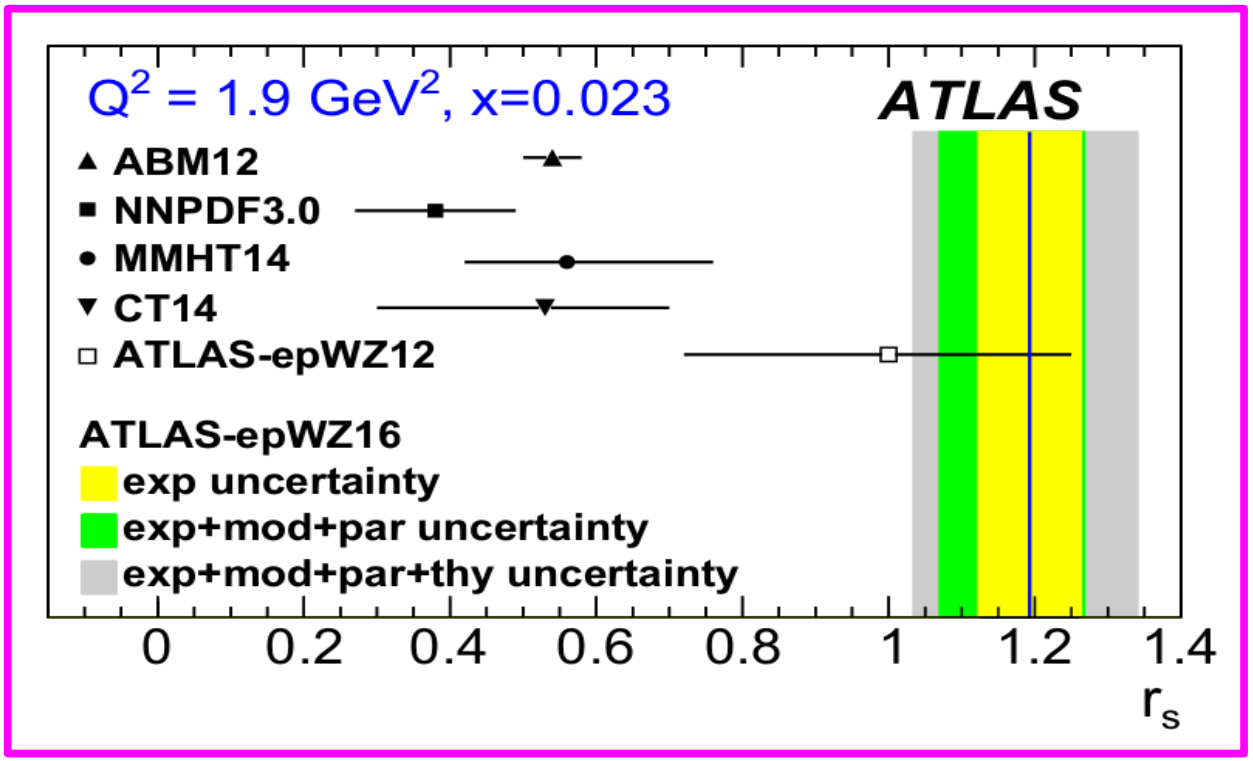
Depends on nuclear corrections



Propagation of γ/W thru nuclei

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



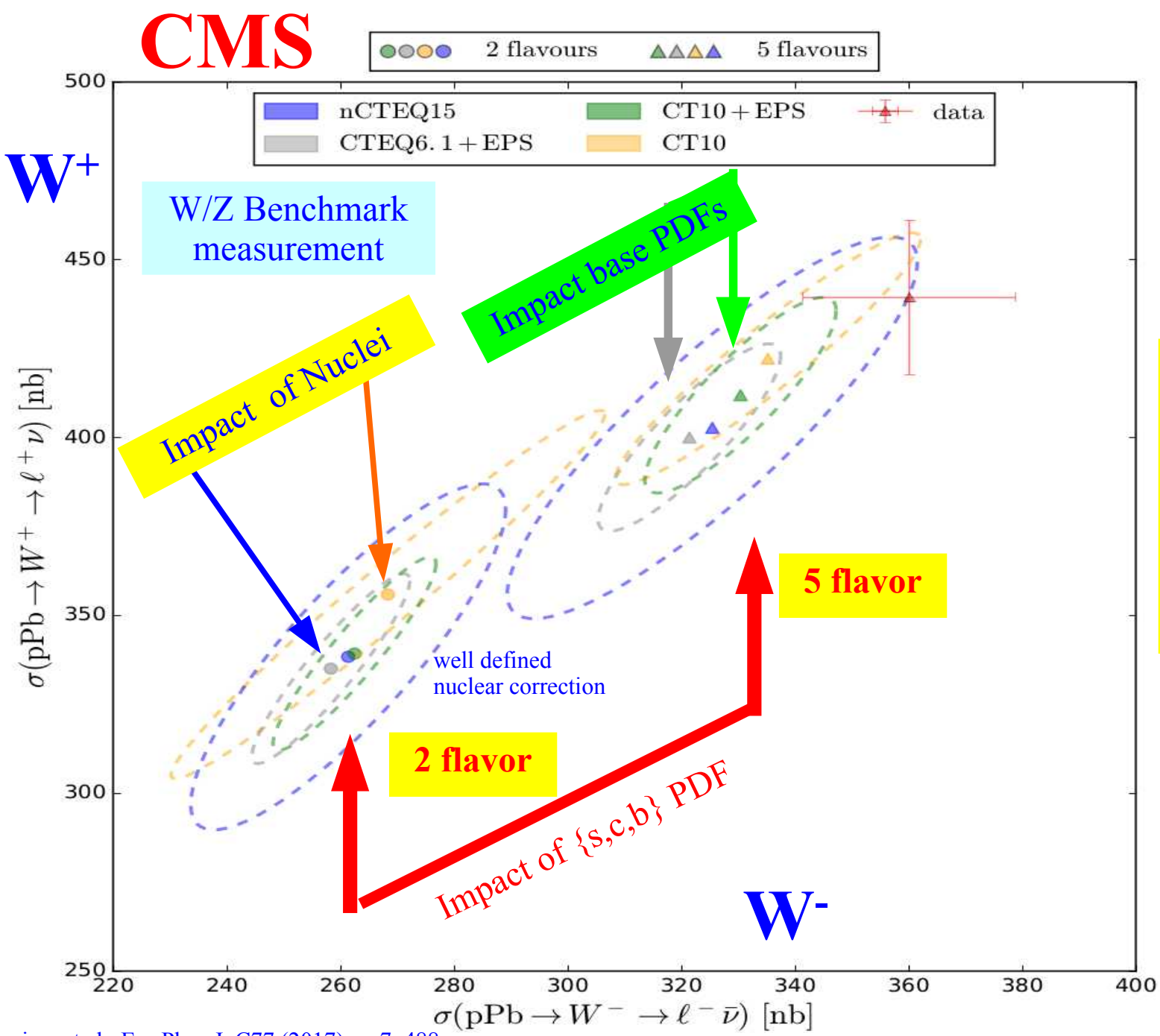


$$r^s(x,Q) = \frac{\bar{s}(x,Q) + s(x,Q)}{2\bar{d}(x,Q)}$$

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

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

Add LHC Heavy Ion: $p\,Pb \rightarrow W/Z$

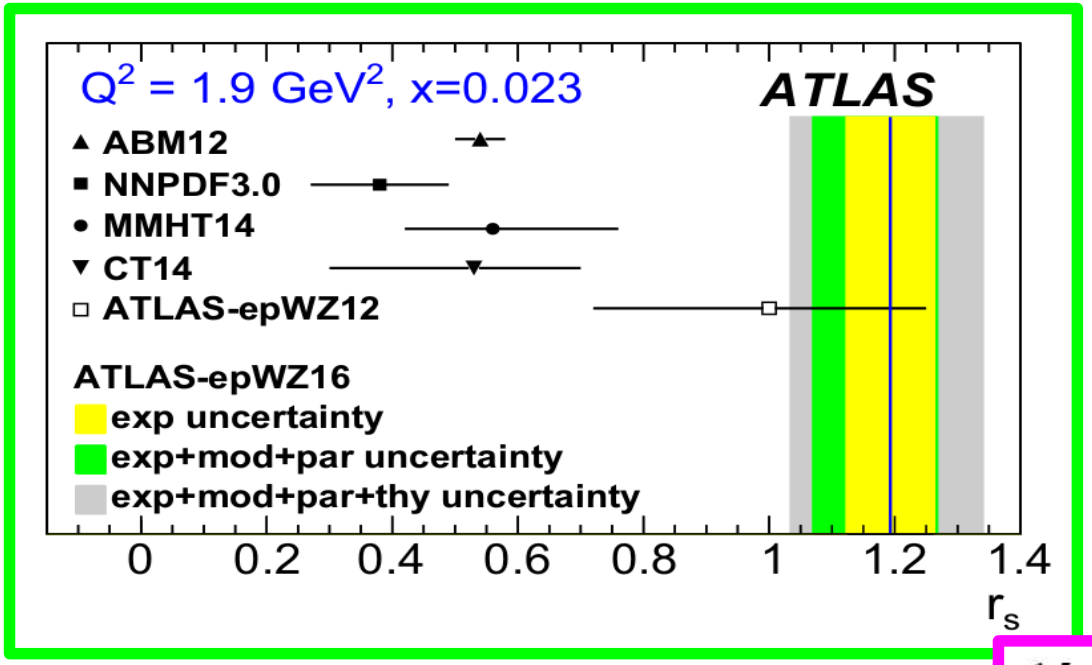


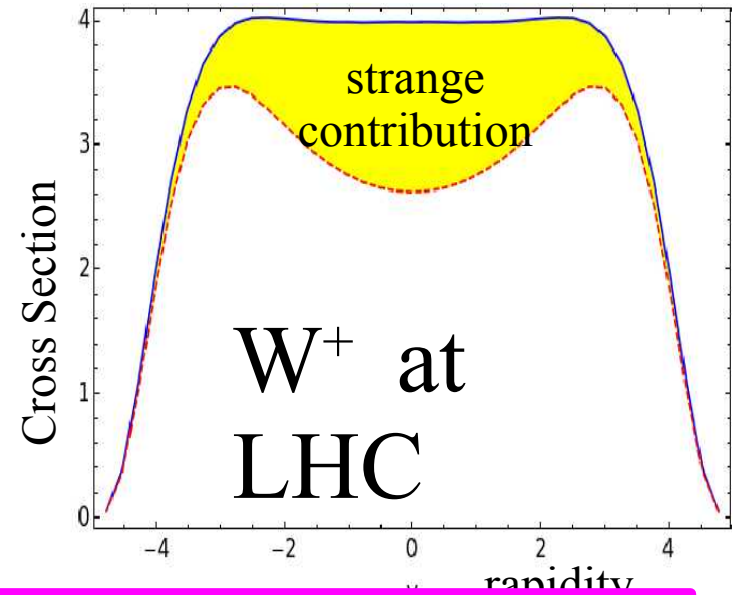
Entangled:

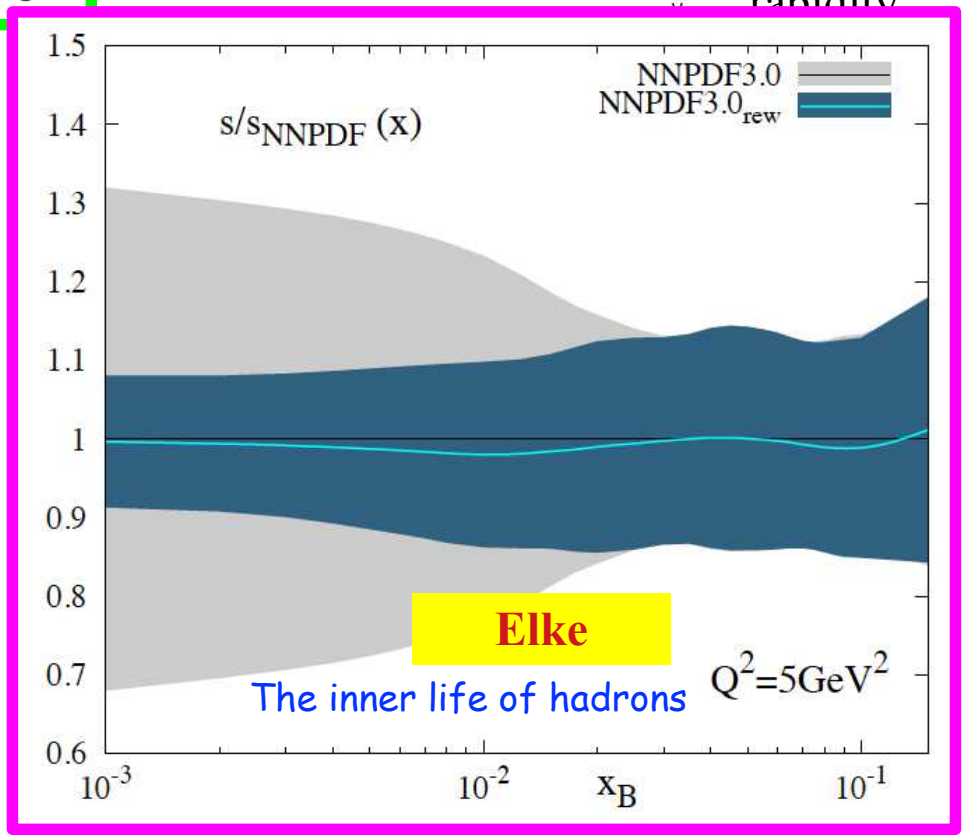
- Nuc Corrections
- Base PDF
- PDF Flavors

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

What's the Solution???







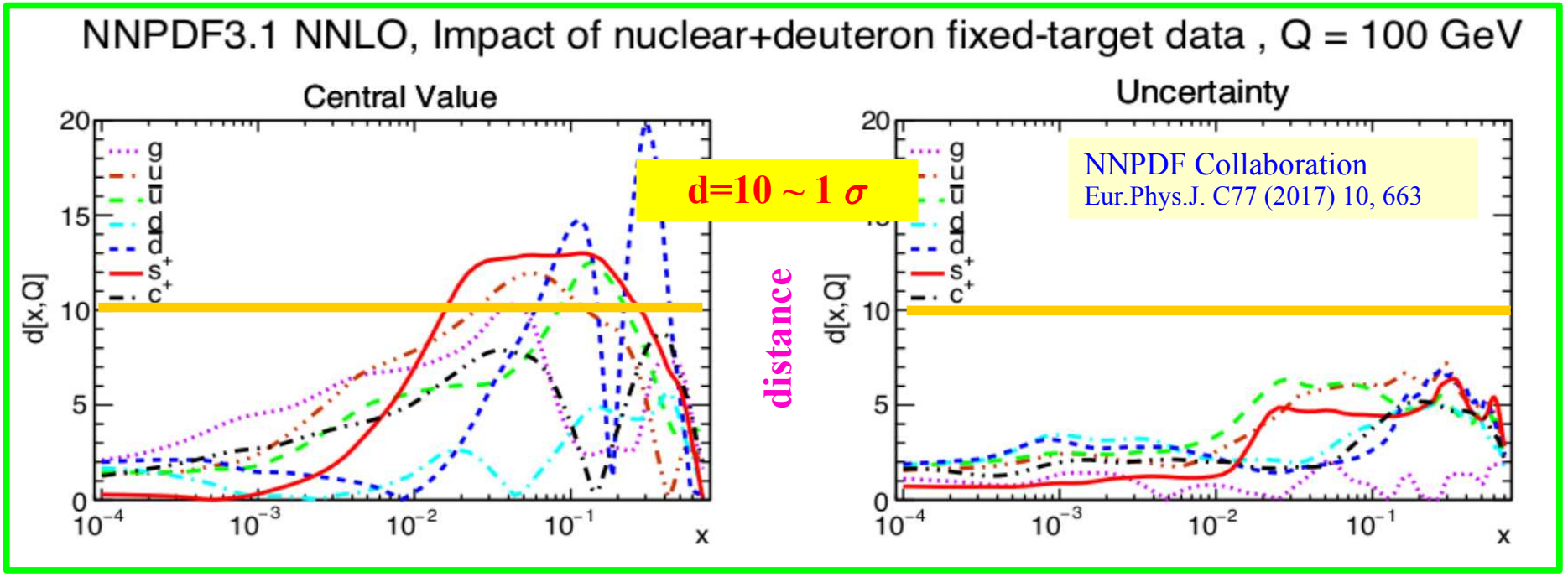
This is an area where EIC & LHeC are particularly suited to help

Combined Effort to Decipher

EIC can expand our knowledge of the nuclear A dimension

Impact of Nuclear Corrections on Proton PDF

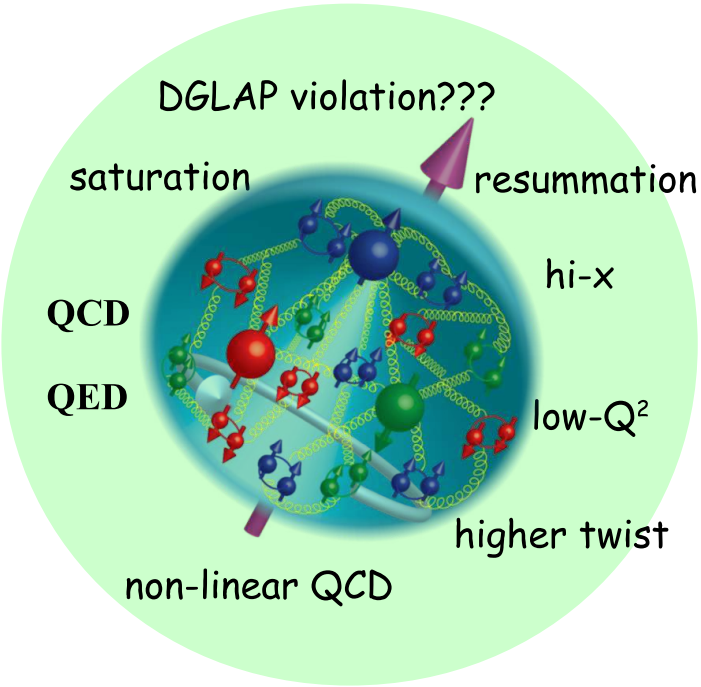
"... for the time being it is still appears advantageous to retain nuclear target data in the global dataset for general-purpose PDF determination"

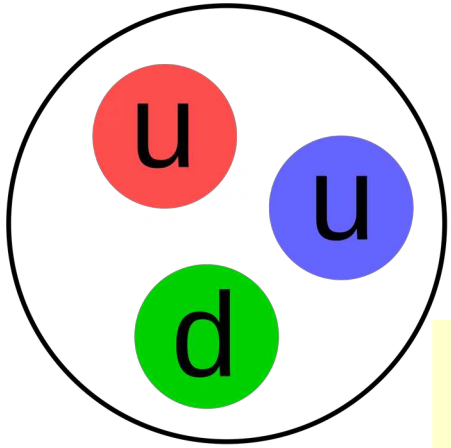


Nuclear PDFs are ESSENTIAL for proton PDFs

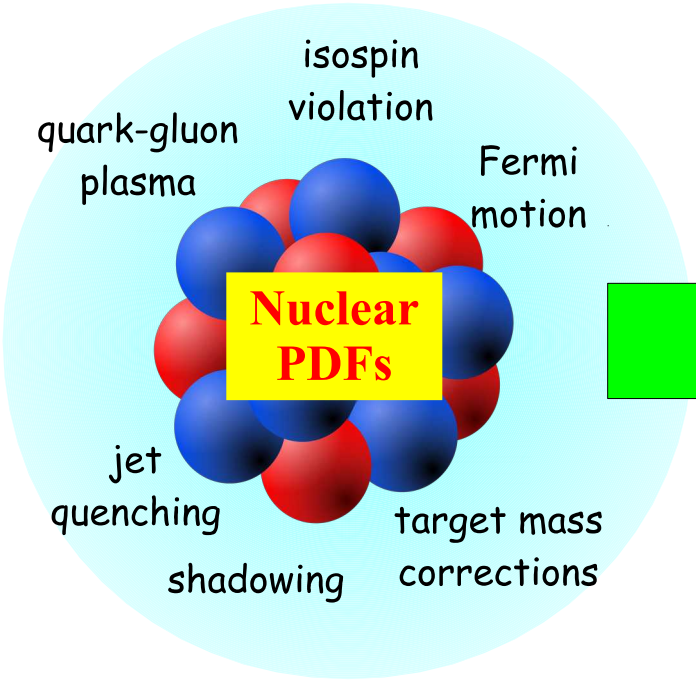
Nuclear PDFs

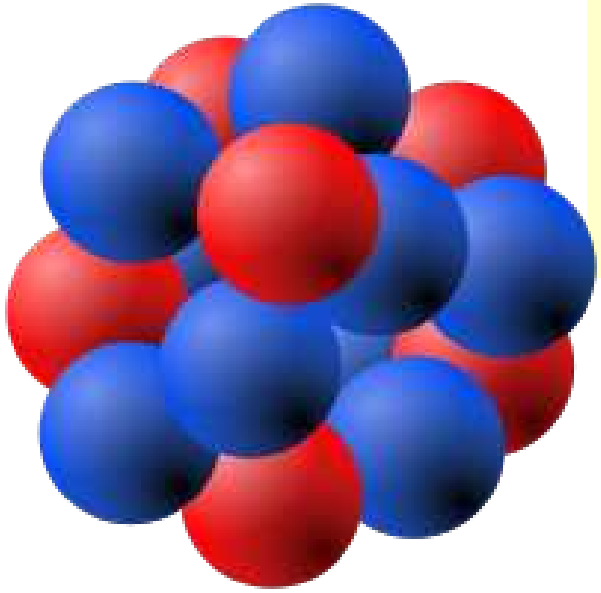
Nuclear PDFs & the Parton Model … *a few simpifications*





Limited data in nuclear dimension





This is where EIC can contribute!!!

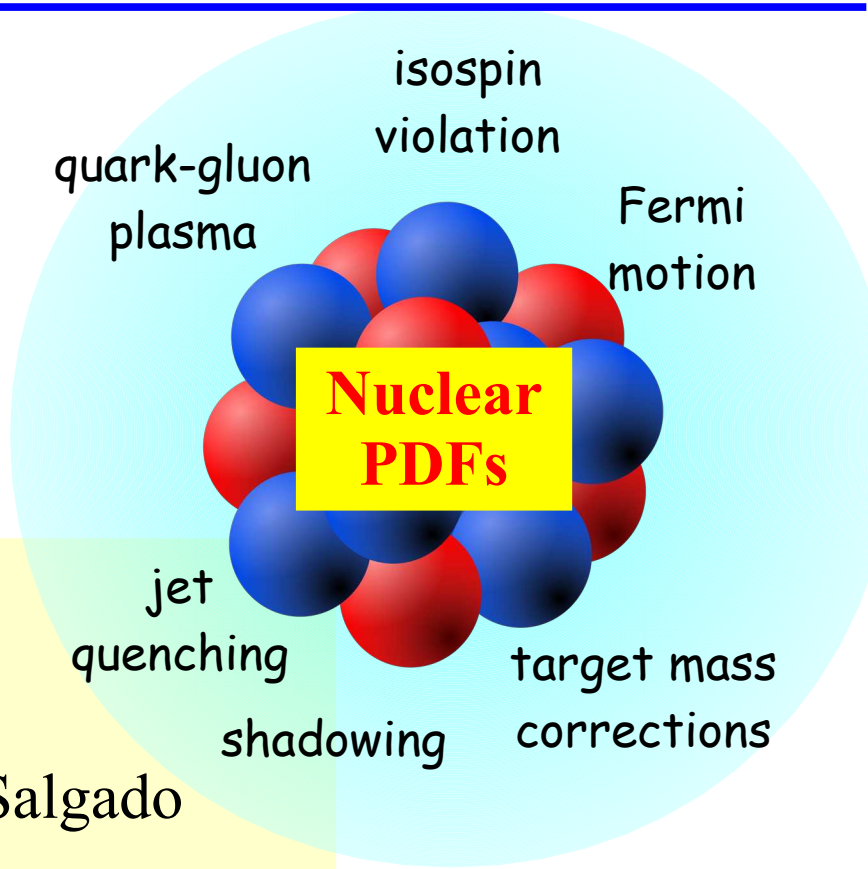
Nuclear PDF

The Players
The Ingredients

… selected NLO Nuclear PDF Fits

nPDFs

nuclear parton distribution functions



HKN'07: Hirai, Kumano, Nagai
[PRC 76, 065207 (2007)]

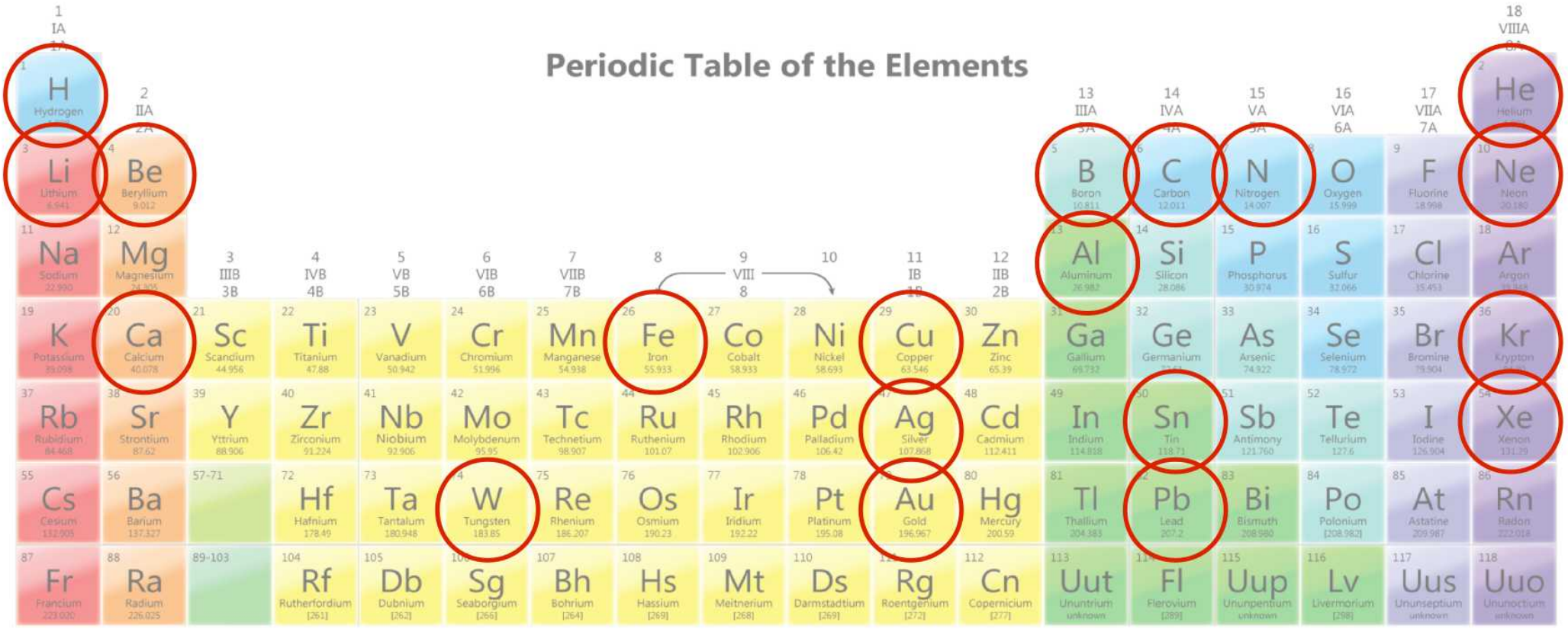
EPPS'16: Eskola, Paakkinen, Paukkunen, Salgado
Eur.Phys.J. C77 (2017) no.3, 163
(supersedes EPS'09)

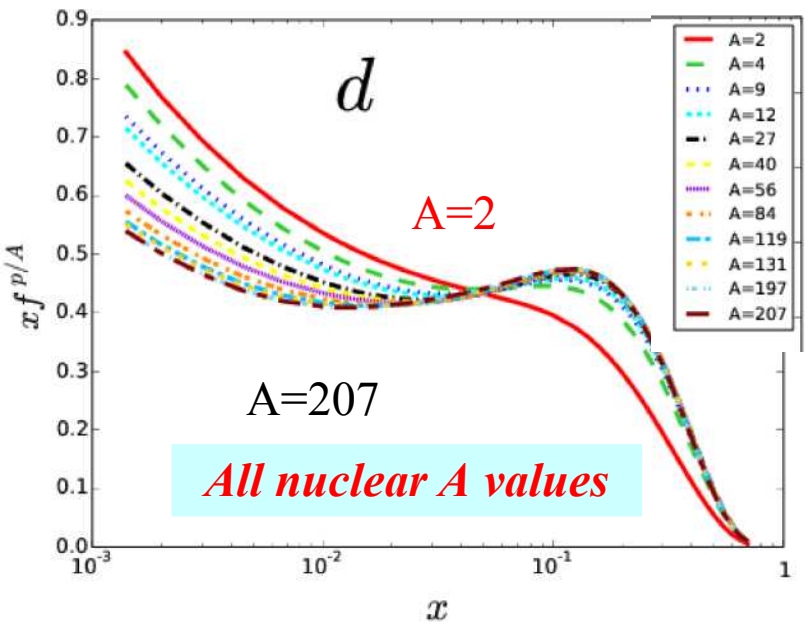
EPS'09: Eskola, Paukkunen, Salgado
[JHEP 04 (2009)]

DSSZ'11: de Florian, Sassot, Stratmann, Zurita
[PRD 85, 074028 (2012)]

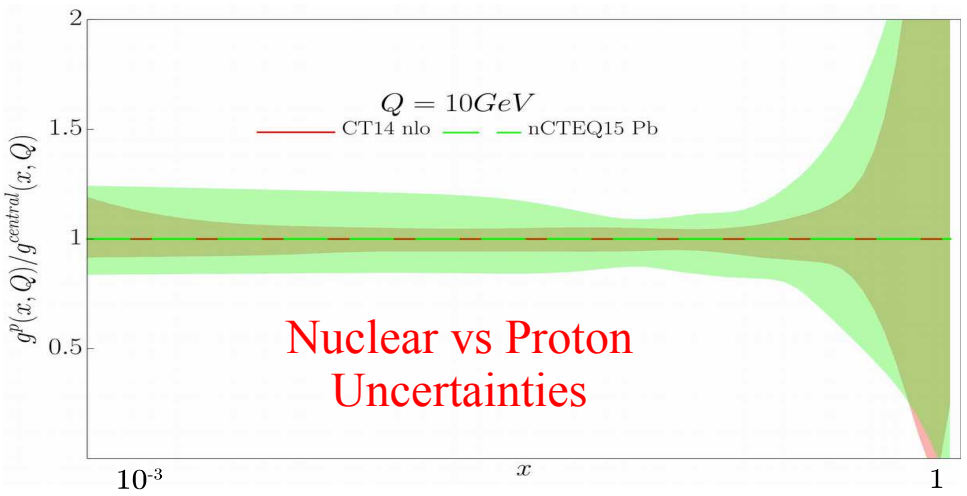
nCTEQ'15: nCTEQ Collaboration
[PRD 93, 085037 (2016)]

Nuclear PDFs: DIS, DY, π Prod, *(new)* Di-Jet





All nuclear A values



Nuclear vs Proton Uncertainties

EIC can expand our knowledge of the nuclear A dimension

Data sets & cuts for nPDF fits

NC DIS & DY

SLAC E-139 & E-049
N = (D, Ag, Al, Au, Be,C, Ca, Fe, He)

CERN BCDMS & EMC & NMC
N = (D, Al, Be, C, Ca, Cu, Fe, Li, Pb, Sn, W)

DESY Hermes
N = (D, He, N, Kr)

FNAL E-665
N = (D, C, Ca, Pb, Xe)

FNAL E-772 & E-886
N = (D, C, Ca, Fe,W)

Neutrino DIS*

NuTeV CHORUS CCFR & NuTeV
N = Pb & Fe

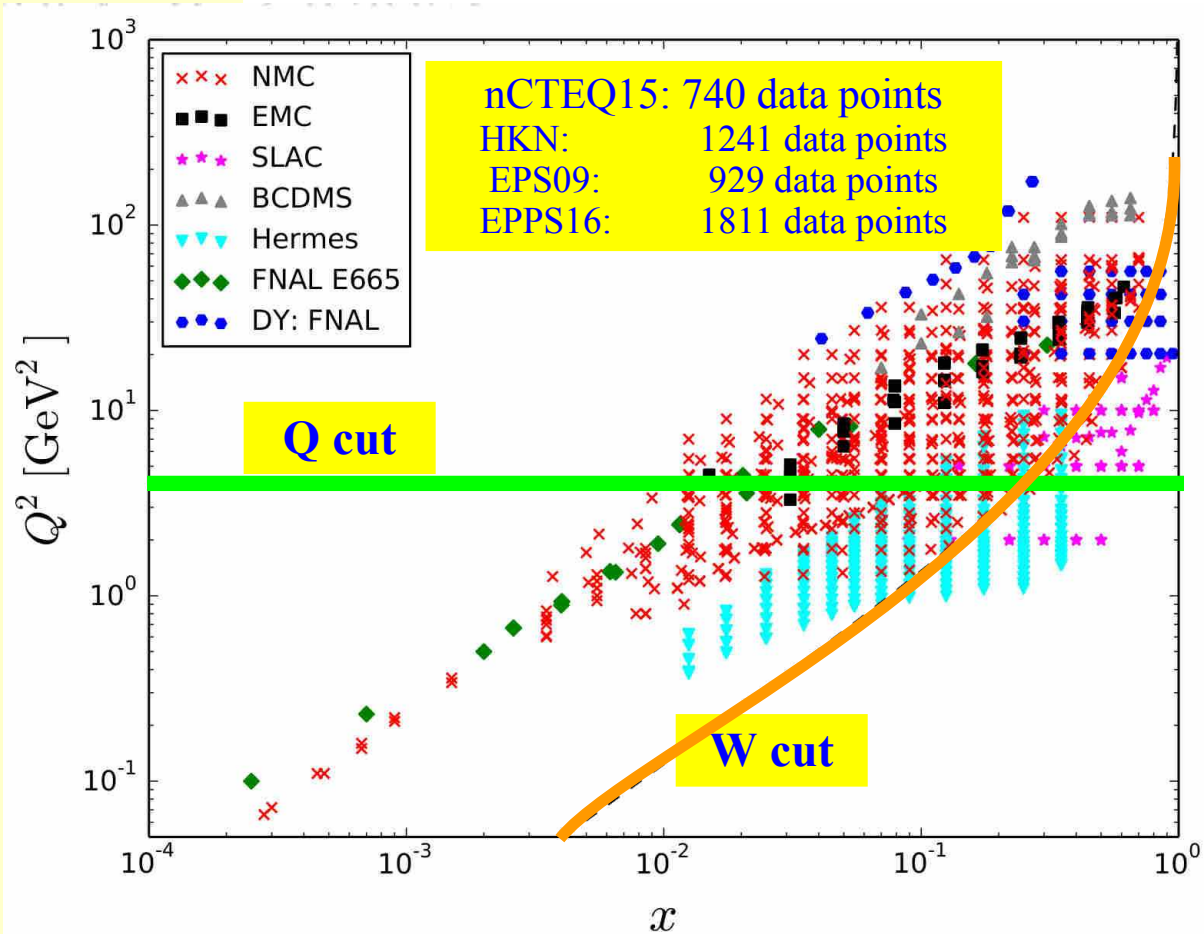
Pion Production:

RHIC: PHENIX & STAR
N = Au

will show comparision w/ LHC pPb

DIS Cuts:

nCTEQ:	Q>2.0 & W>3.5
EPPS16:	Q>2.0 & W>3.5
EPS09:	Q>1.3
HKN:	Q>1.0
DSSZ:	Q>1.0



proton vs nuclear: fewer data and more DOF … impose assumptions on nPDFs

Mechanics of nPDFs

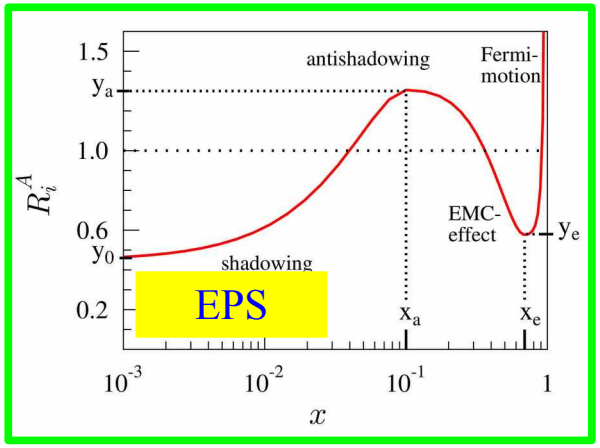
1) Multiplicative nuclear correction factors (HKN, EPPS, DSSZ)

$$f_i^{p/A}(x_N, Q_0) = R_i(x_N, Q_0, A)\ f_i^{free\ proton}(x_N, Q_0)$$

... for example

HKN

$$R_i(x, Q_0, A) = 1 + \left(1 - \frac{1}{A^\alpha}\right) \frac{a_i + b_i x + c_i x^2 + d_i x^3}{(1-x)^{\beta_i}}$$



2) Generalized A-parameterization (nCTEQ)

$$f_i^{p/A}(x_N, \mu_0) = f_i(x_N, A, \mu_0)$$

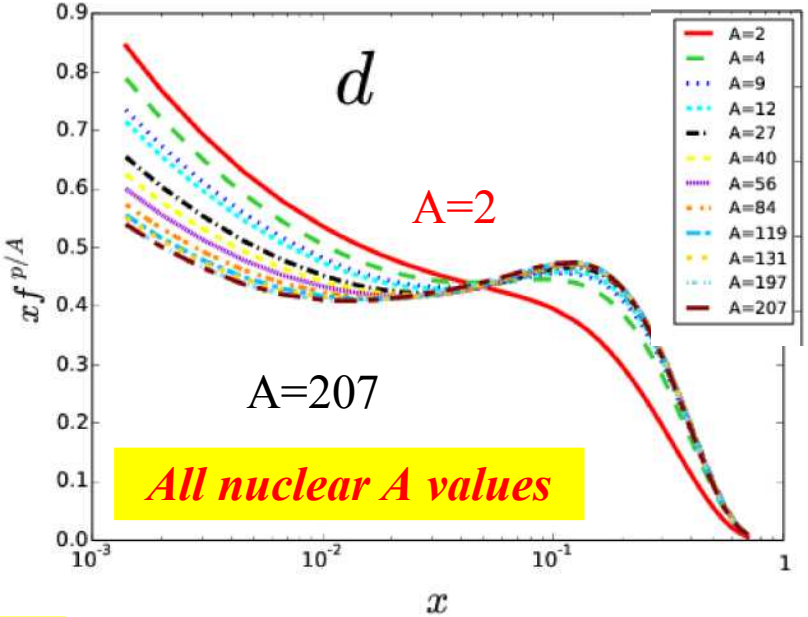
$$f \sim \ldots x^{c_1(A)}(1-x)^{c_2(A)} \ldots$$

$$c_k \sim c_{k,0} + c_{k,1}\left(1 - A^{-c_{k,2}}\right)$$

Proton

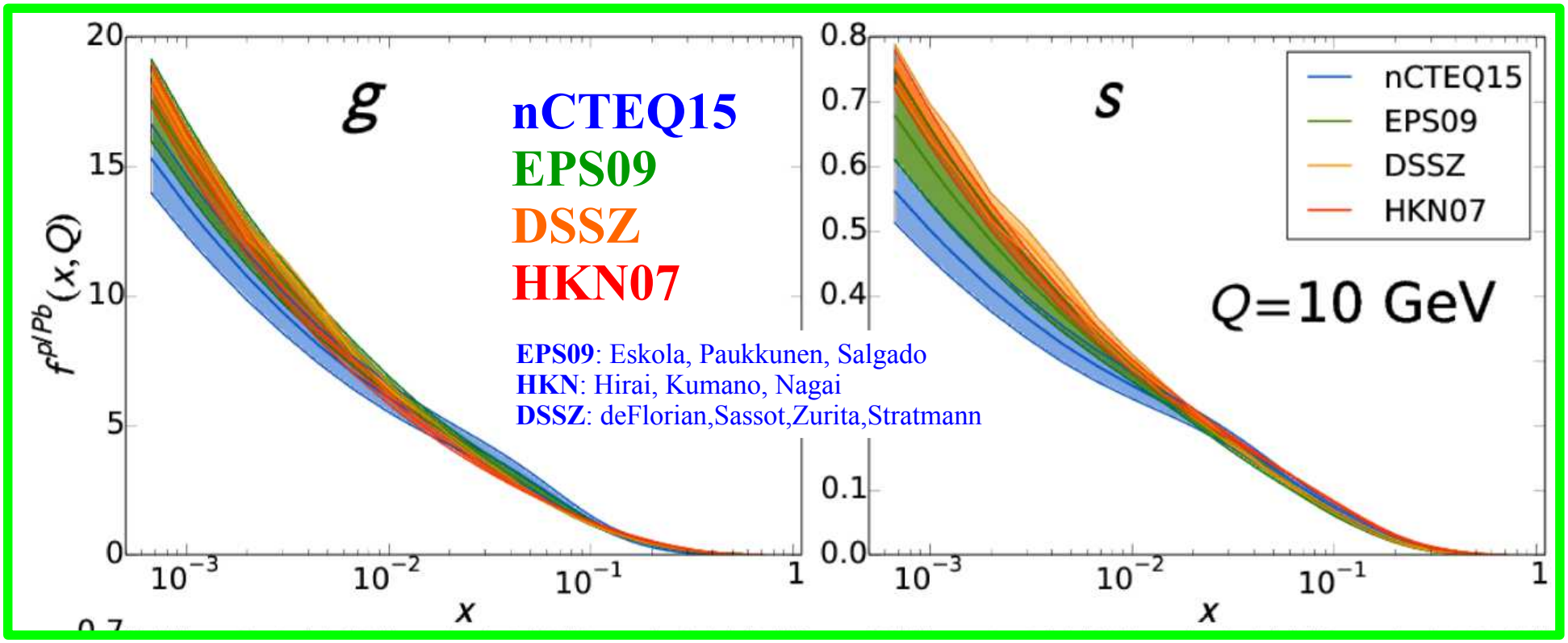
Nuclear

use proton as a Boundary Condition



All nuclear A values

Nuclear PDFs: Complementary efforts in general agreement

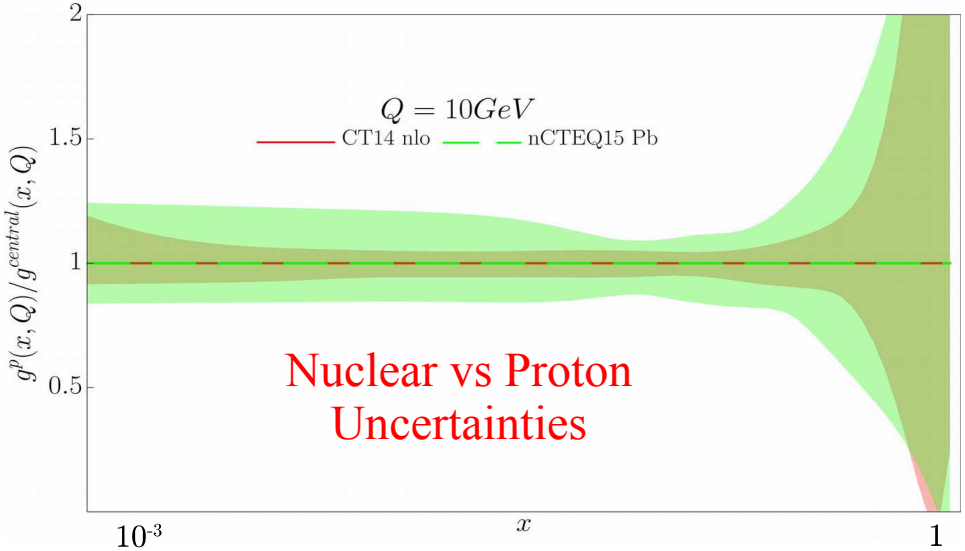


Nuclear PDFs are more complex

more DOF than Proton case

more "issues" to consider

more work to do ...

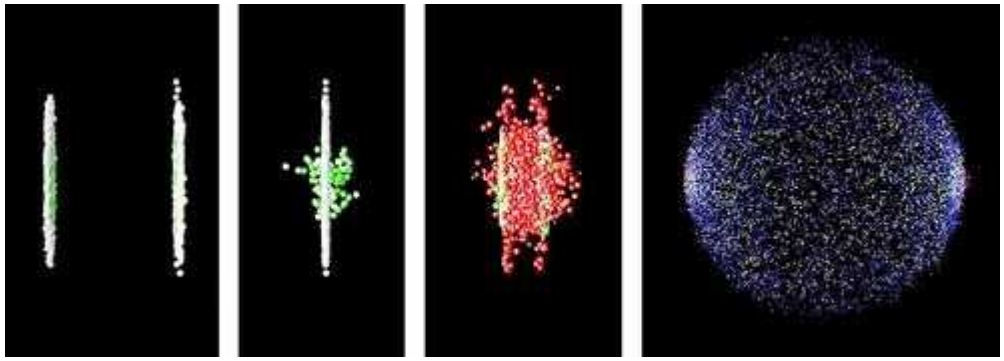


Motivation for nPDFs???

Make predictions for heavy ion collisions at:

RHIC (Al, Au, Cu, U, ...)

LHC (pPb, PbPb)



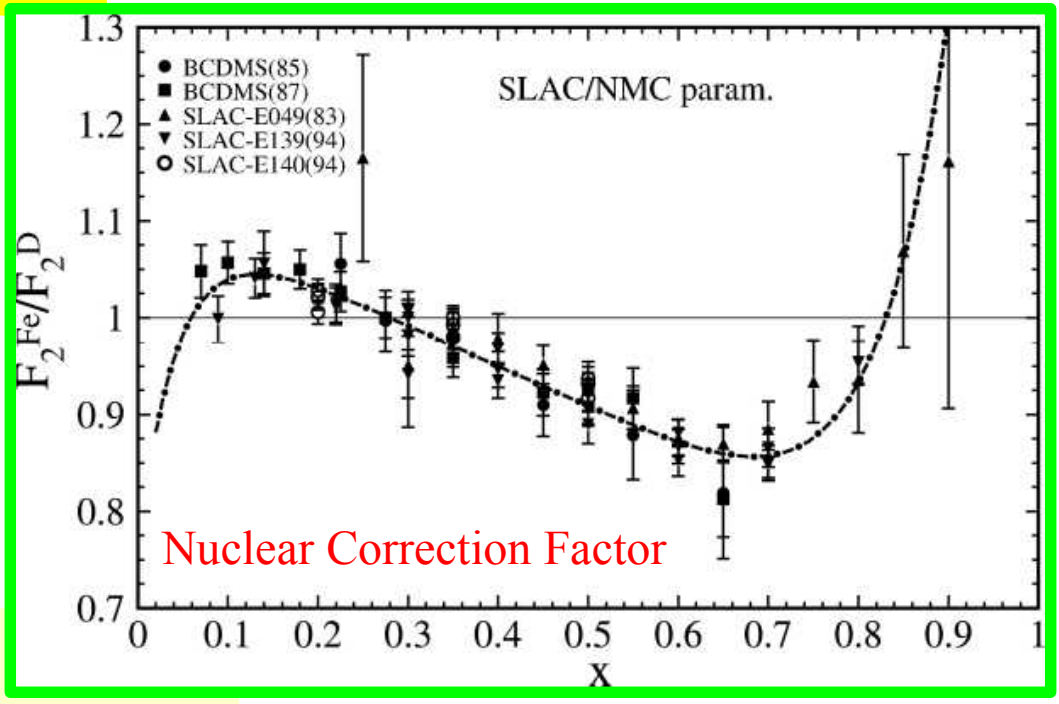
Differentiate flavors of free-proton PDFs:

neutrino DIS

$$F_2^{\nu} \sim \left[d + s + \bar{u} + \bar{c}\right]$$
$$F_2^{\bar{\nu}} \sim \left[\bar{d} + \bar{s} + u + c\right]$$
$$F_3^{\nu} \sim 2\left[d + s - \bar{u} - \bar{c}\right]$$
$$F_3^{\bar{\nu}} \sim 2\left[u + c - \bar{d} - \bar{s}\right]$$

charged lepton DIS

$$F_2^{l^{\pm}} \sim \left(\tfrac{1}{3}\right)^2 [d + s] + \left(\tfrac{2}{3}\right)^2 [u + c]$$



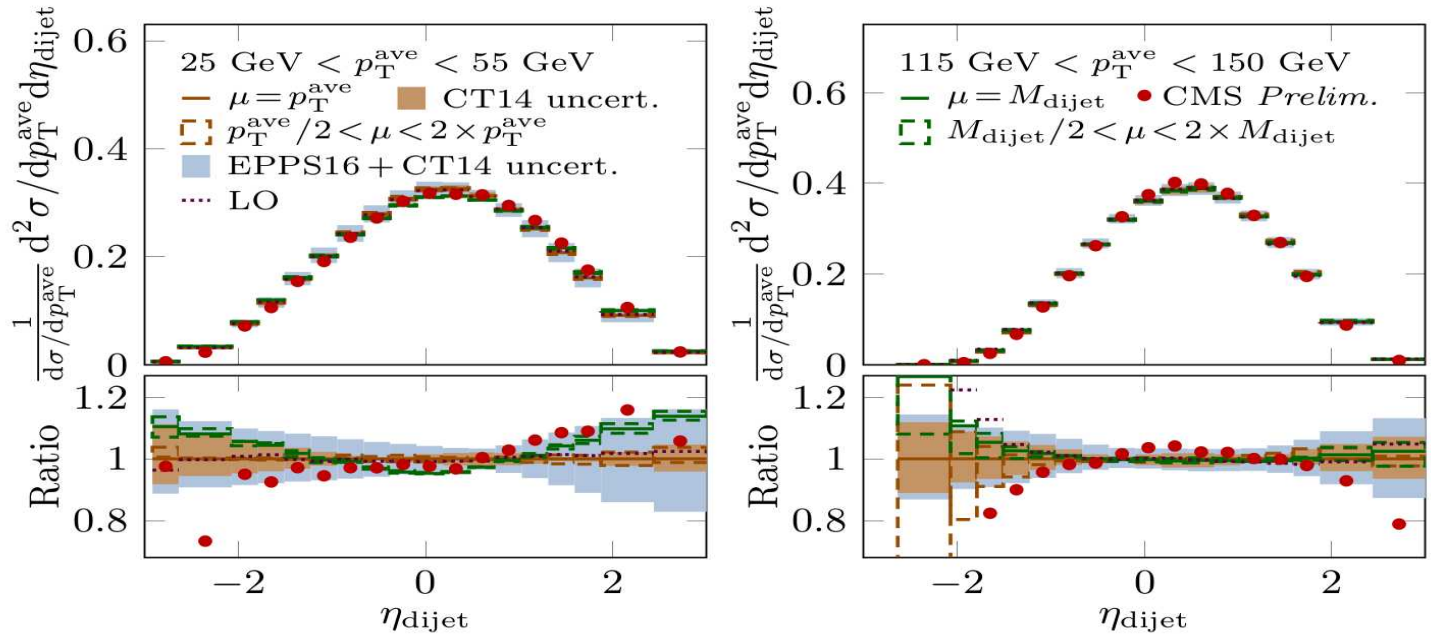
Di-Jets

EPPS16

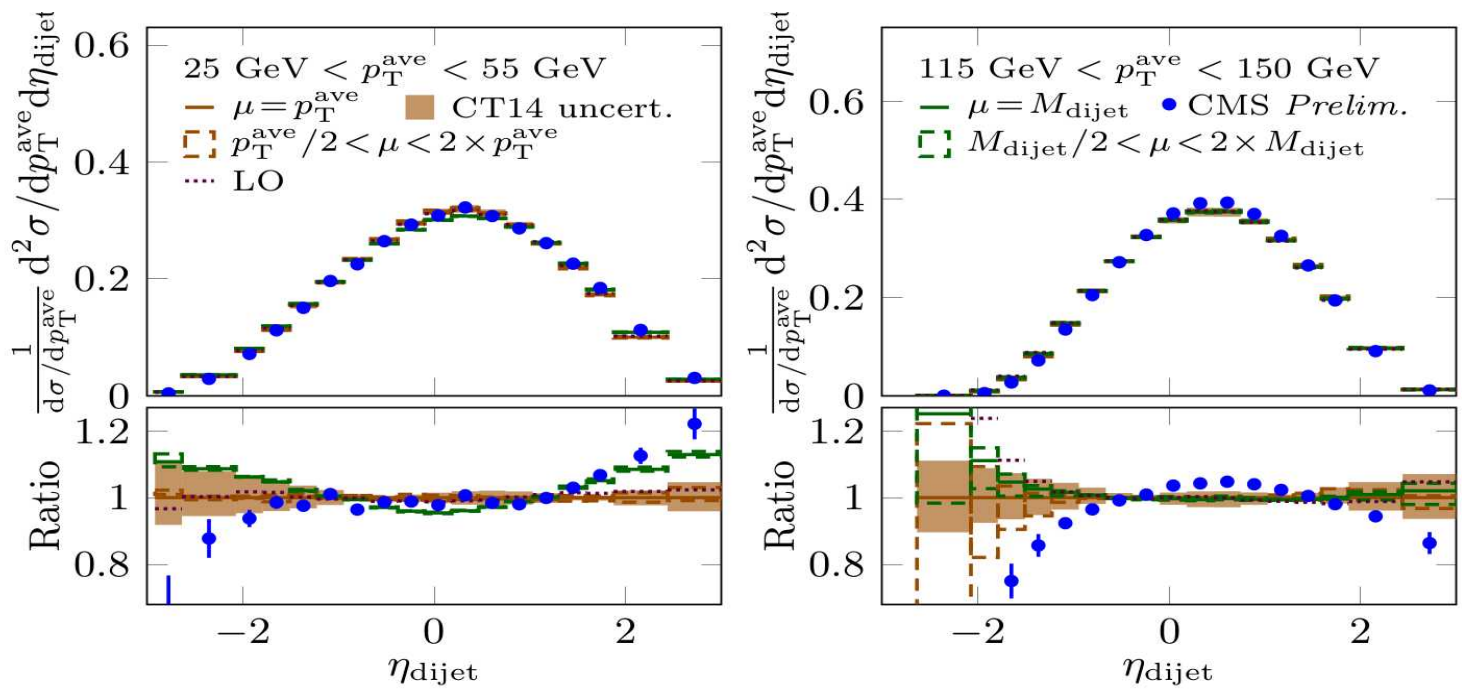
pp & pPb

EPPS16: Di-Jet Production

CMS
pPp



CMS
pp



See Talk By:
Petja Paakkinen
(University of Jyväskylä)

Impact of CMS 5.02 TeV dijet measurements on gluon PDFs – a preliminary view
Kari J. Eskola, Petja Paakkinen, Hannu Paukkunen. 1806.08208

Hi-x

Higher twist
mass effects
limit $x \to 1$

CJ Project

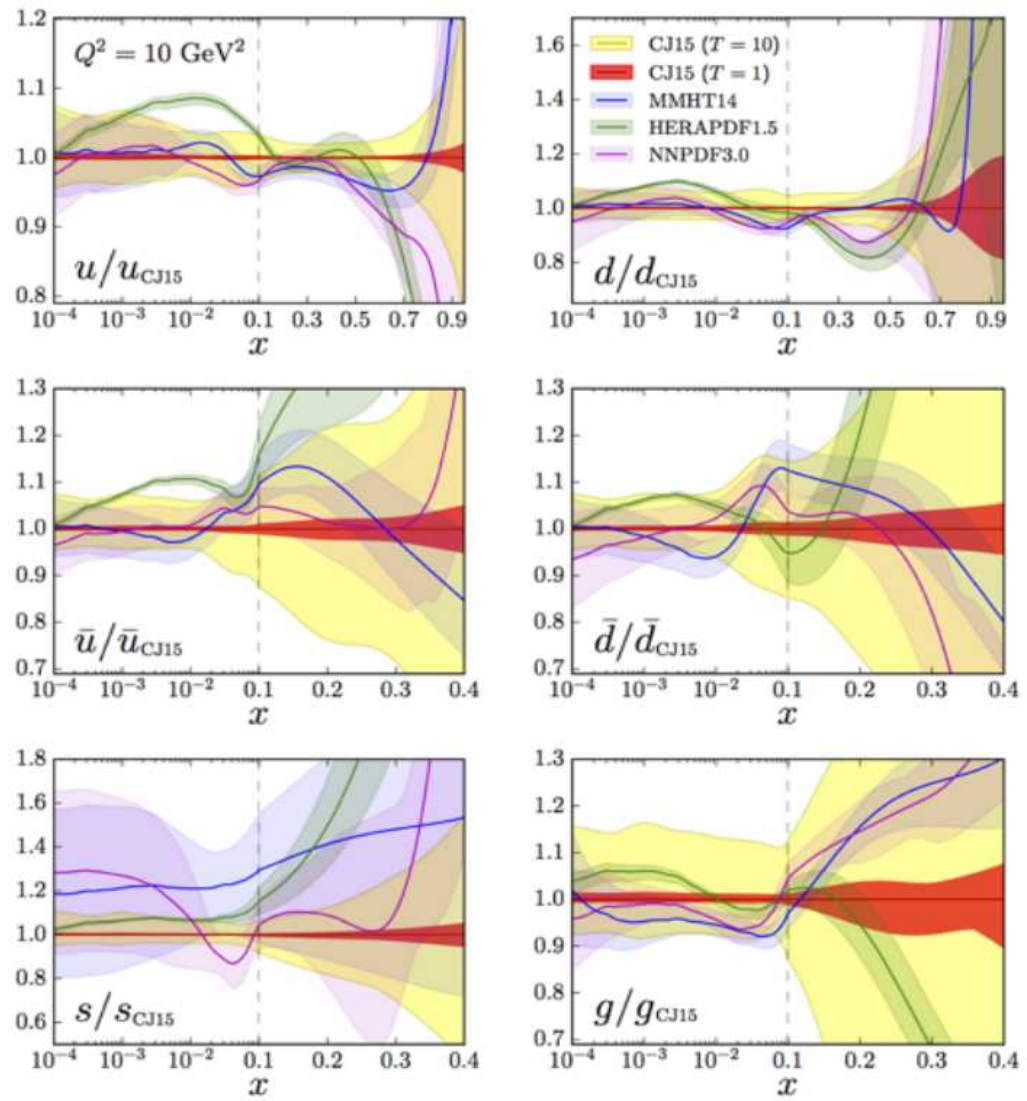
Partonic structure at high-x

- Partonic structure of nucleons/nuclei at high-x (x>0.5) poorly known:
  - >50% uncertainty on d(x) at x>0.6
  - >50% uncertainty on g(x) at x>0.2
  - very large uncertainties on quark sea
- Better understanding provides tests of models of hadron structure
  - d/u→1/2 : SU(6) Spin-Flavor symmetry
  - d/u→0 : Scalar diquark dominance
  - d/u→1/5 : pQCD power counting
  - Local quark hadron duality:

$$\mathrm{d/u} \to \frac{4\mu_n^2/\mu_p^2 - 1}{4 - \mu_n^2/\mu_p^2} \simeq 0.42$$

- Better understanding important for BSM searches of new heavy states

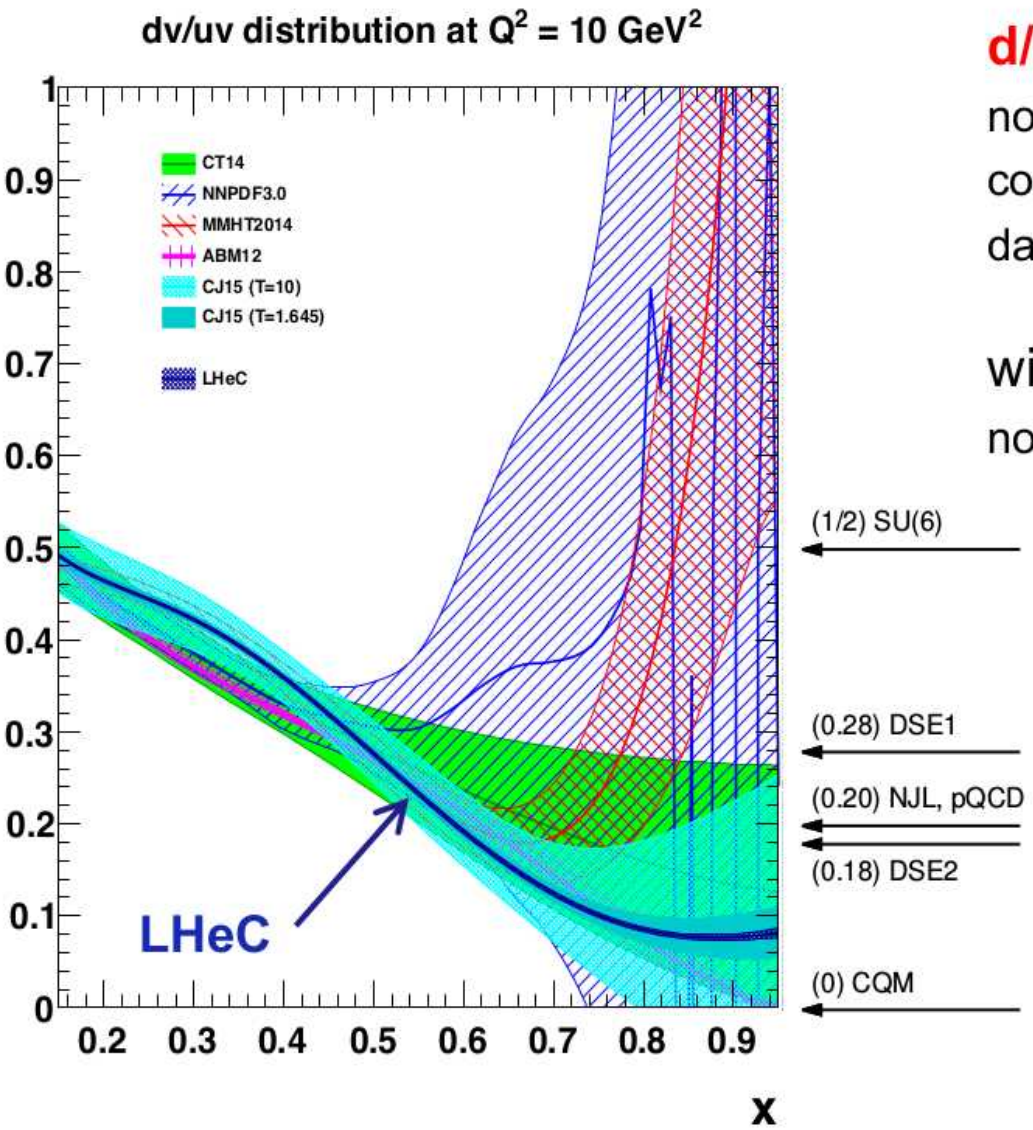
CJ15 global fit, PRD93(2016)114017



Ingo Schienbein
2018 Trento Workshop

Claire Gwenlan: DIS2018

d/u at large x

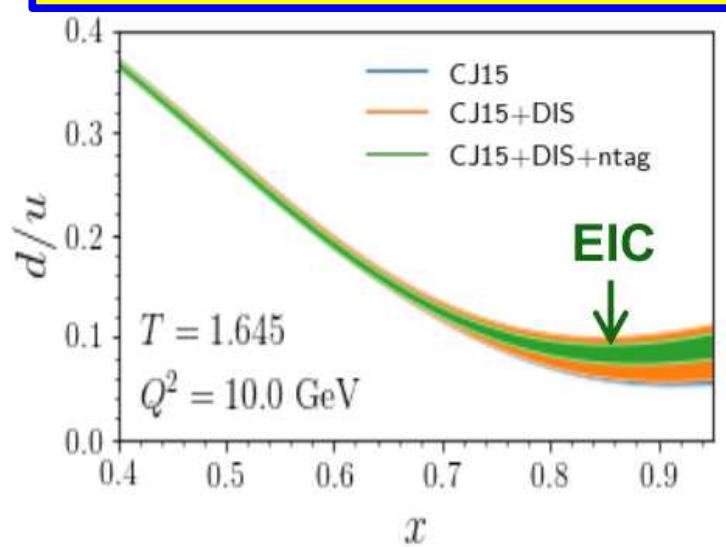


d/u essentially unknown at large x

no predictive power from current pdfs;
conflicting theory pictures;
data inconclusive, large nuclear uncerts.

with precision ep (n) data to v. large x:
no nuclear corrections; relax assumptions

CJ: Meaningful parameterization at large x



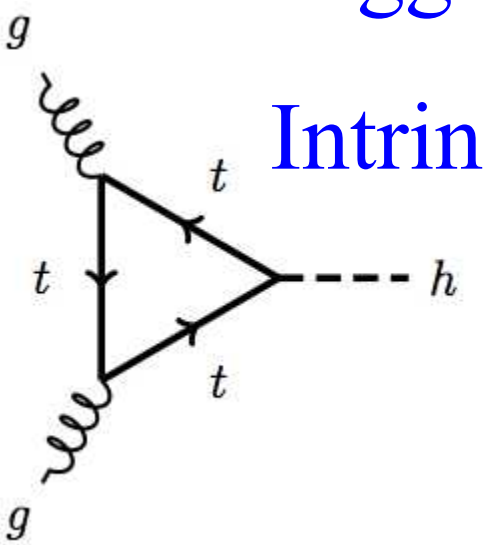
resolve long-standing mystery of d/u ratio at large x

Heavy Quarks

$$\alpha_S \ln\left(\frac{m}{Q}\right)$$

Multi-Scale Problem: {m, Q}

Higgs coupling proportional to mass



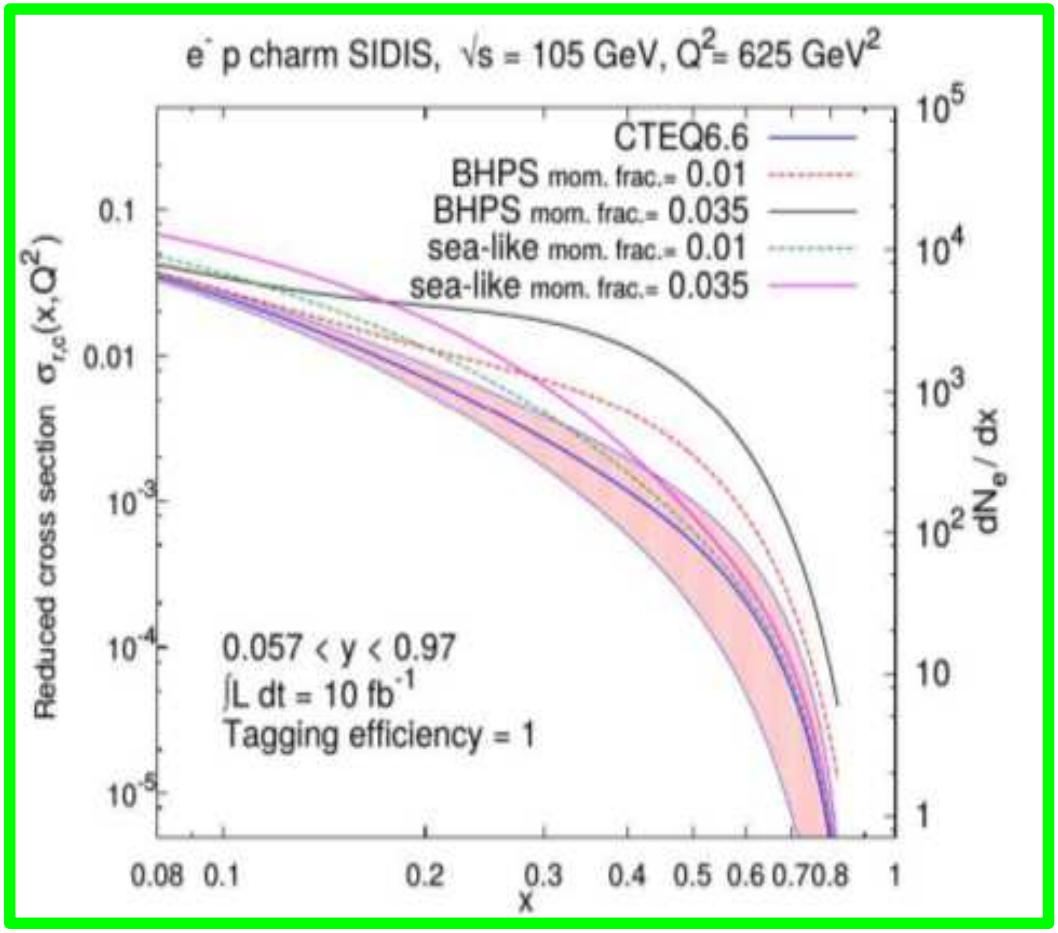
Intrinsic & Fitted Charm, F_2^c, F_L^c …

FFNS & VFNS (see afternoon talk)

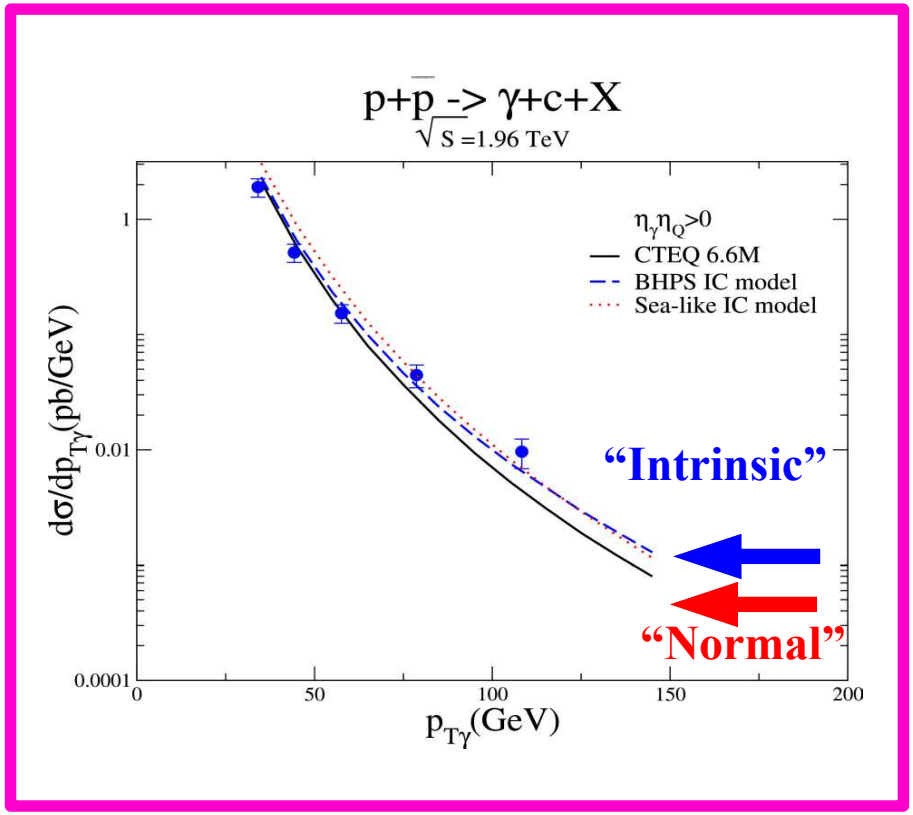
Intrinsic Charm (IC)

also F_2^c for charm PDF...

Probe IC via charm contributions to DIS σ, F_L^C, or angular distributions



… Tevatron excesss in γ c Production



Gluons and the quark sea at high energies: distributions, polarization, tomography, D.Boer, et al., arXiv:1108.1713.

T. Stavreva, I. Schienbein, F. Arleo, K. Kovarik, F. Olness, J.Y. Yu, J.F. Owens, JHEP 1101 (2011) 152

Lattice QCD

Lattice QCD input & constraints to PDFs

ELSEVIER

Progress in Particle and Nuclear Physics

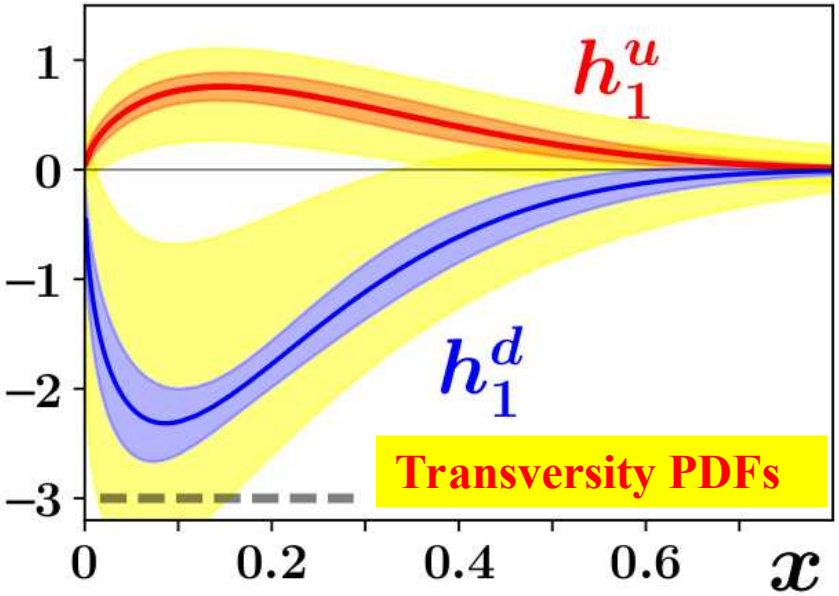
Volume 100, May 2018, Pages 107-160

Review

Workshop March 2017

Parton distributions and lattice QCD calculations: A community white paper

Huey-Wen Lin [1, 2], Emanuele R. Nocera [3, 4], Fred Olness [5], Kostas Orginos [6, 7], Juan Rojo ((editors)) [8, 9], Alberto Accardi [7, 10], Constantia Alexandrou [11, 12], Alessandro Bacchetta [13], Giuseppe Bozzi [13], Jiunn-Wei Chen [14], Sara Collins [15], Amanda Cooper-Sarkar [16], Martha Constantinou [17], Luigi Del Debbio [4], Michael Engelhardt [18], Jeremy Green [19], Rajan Gupta [20], Lucian A. Harland-Lang [3, 21] … James Zanotti [32]



First Monte Carlo Global Analysis of Nucleon Transversity with Lattice QCD Constraints

Huey-Wen Lin, W. Melnitchouk, Alexei Prokudin, N. Sato, H. Shows,

Phys.Rev.Lett. 120 (2018) no.15, 152502

xFitter

xFitter release xfitter-2.0.0

www.xFitter.org

xFitter

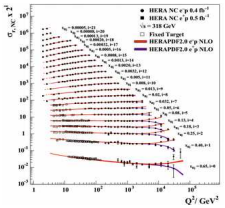
DESY xFitter

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



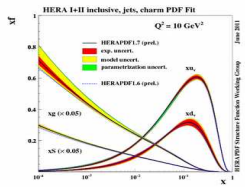
Data: HERA, Tevatron, LHC, fixed target experiments

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:

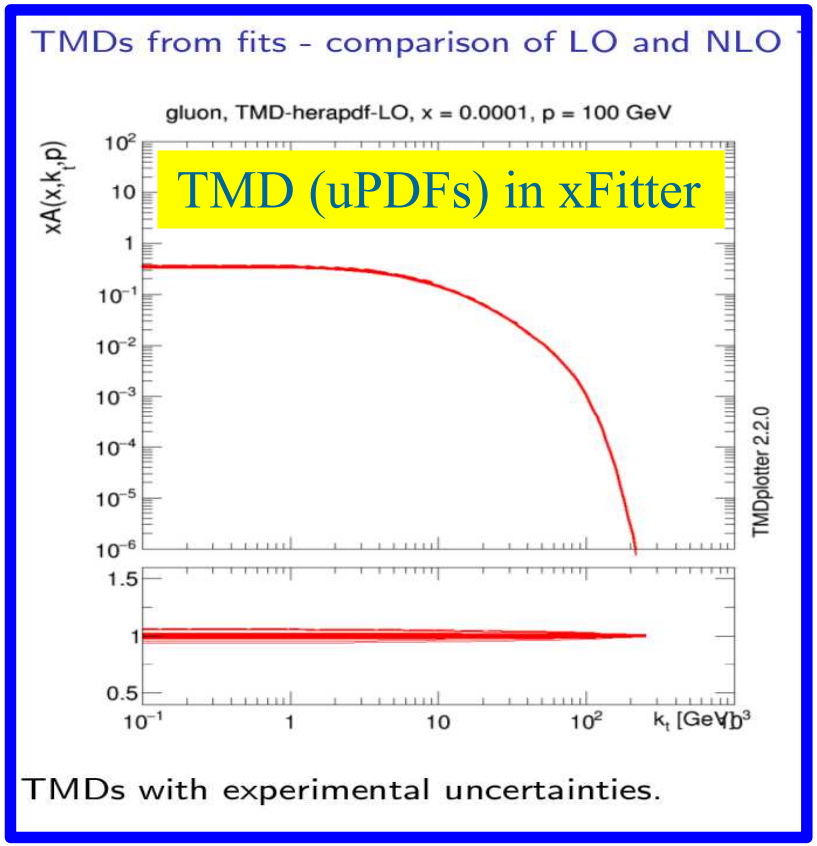
Photon PDF & QED
Pole & MS-bar masses
Profiling and Re-Weighting

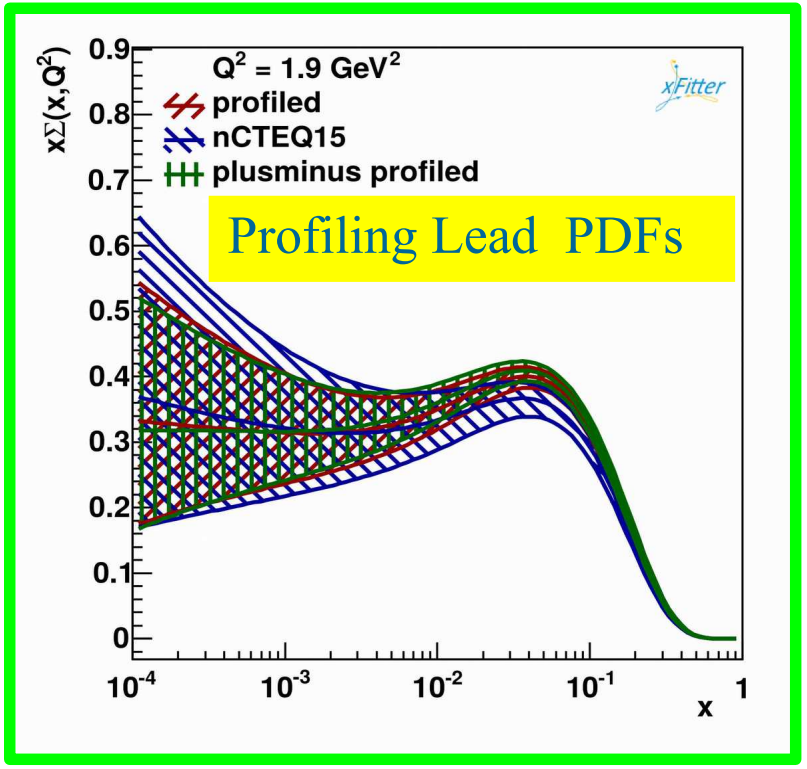
Heavy Quark Variable Treshold
Improvements in χ^2 and correlations
TMD PDFs (uPDFs)
... and many other

Versatility of xFitter

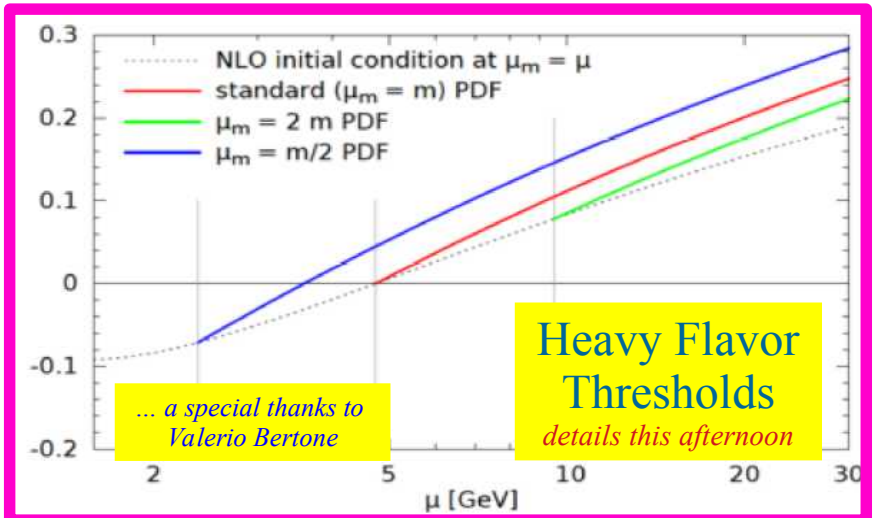
xFitter Meeting: Krakow March 2018

www.xFitter.org





xFitter



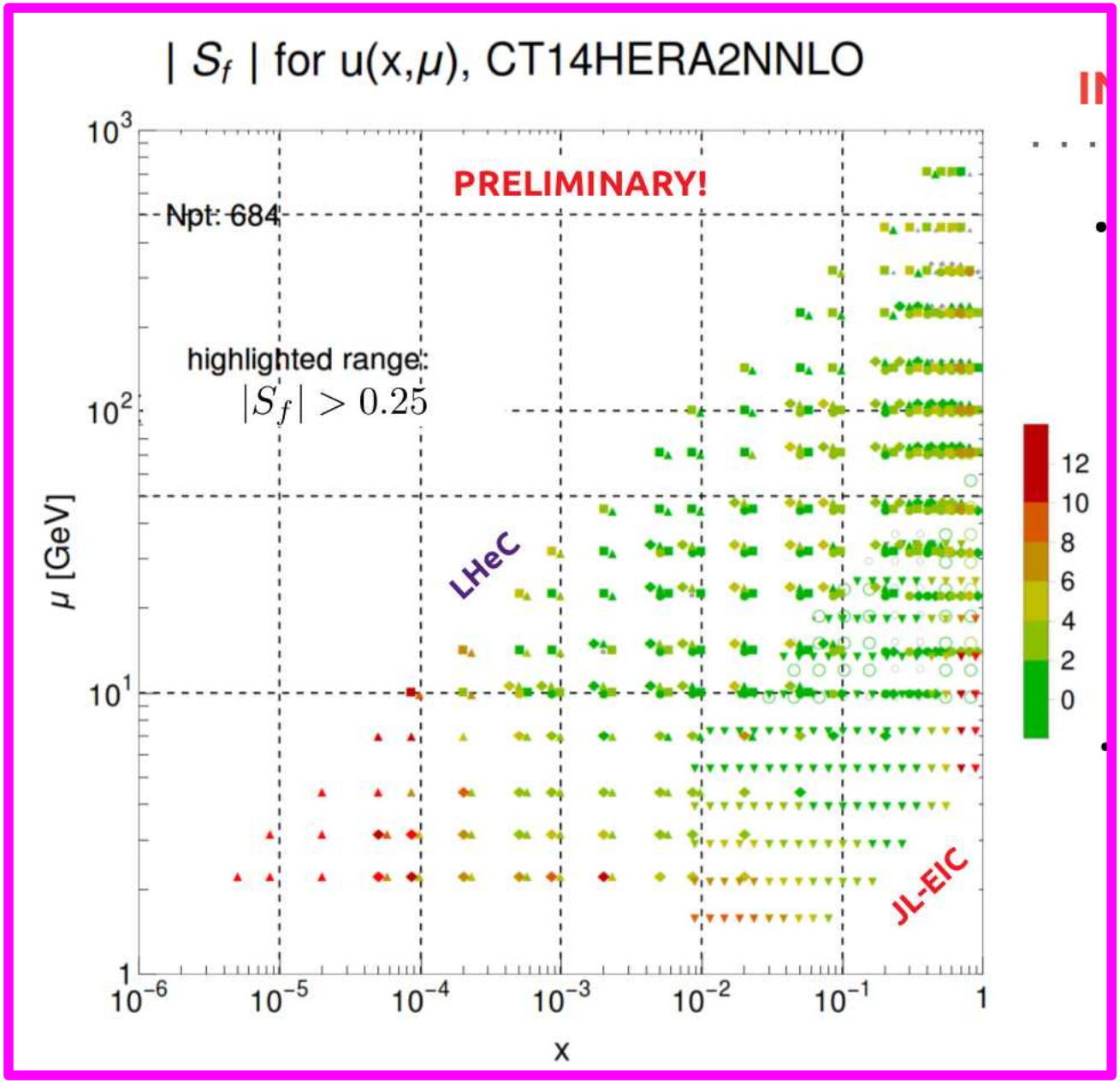
nPDFs with xFitter
Marina Walt
U. Tuebingen

New Tools

PDFSense

&

… borrowing from AI



A new measure:

Sensitivity S_f

Extend concept of correlation (C) to include both pull and precision of experiment.

(Technically, weight by scaled residual.)

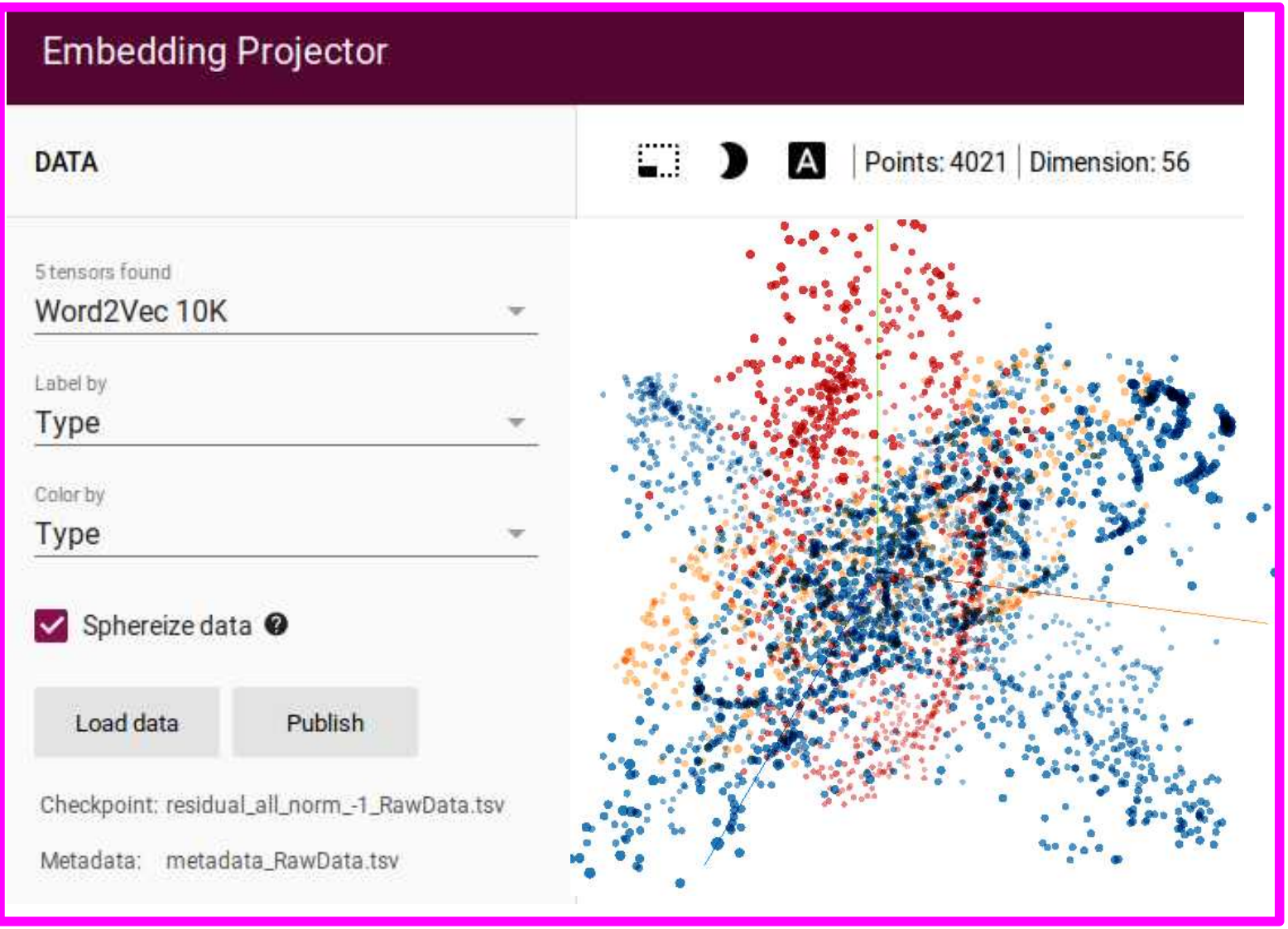
New insights on experimental impacts

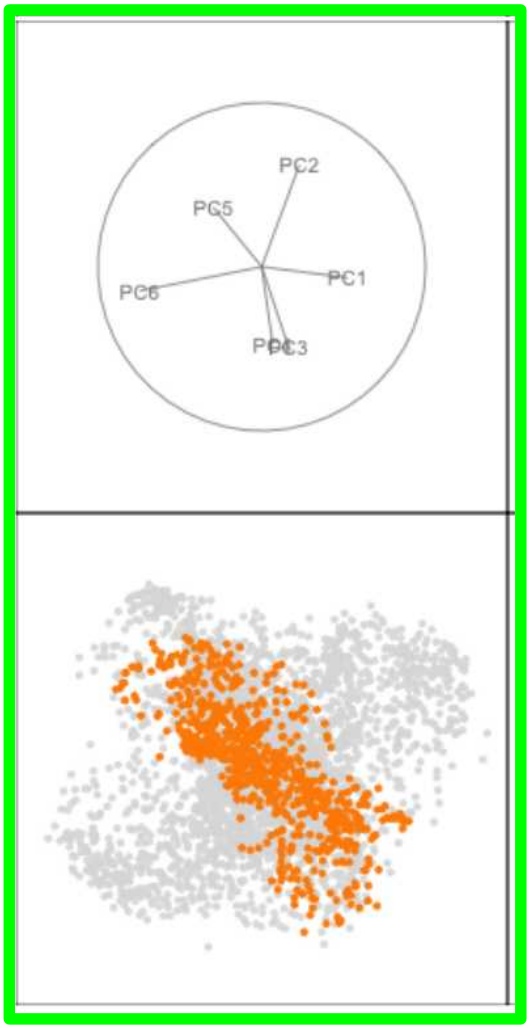
See Talk By: Tim Hobbs (SMU)

Linked from: https://metapdf.hepforge.org/

Applications of PDFSense:

Artificial Intelligence Tools: Projector tool of Google TensorFlow



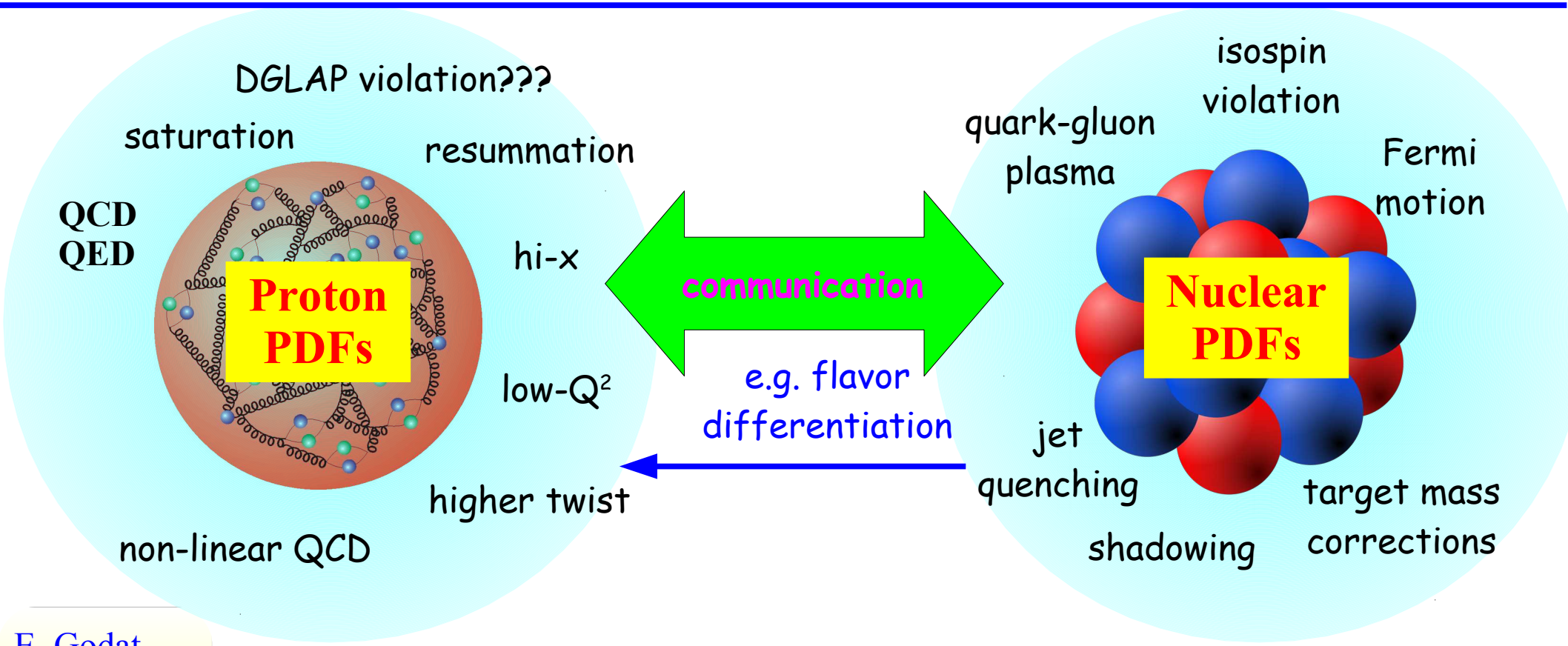


Dynamical projections for the visualization of PDFSense data

Dianne Cook, Ursula Laa, German Valencia arXiv:1806.09742

nCTEQ++

… the motivation for nCTEQ



E. Godat
T.J. Hobbs
T. Jezo,
C. Keppel,
K. Kovarik
A Kusina,
F. Lyonnet,
J. Morfin,
F. Olness
J. Owens,
I. Schienbein,
J. Yu

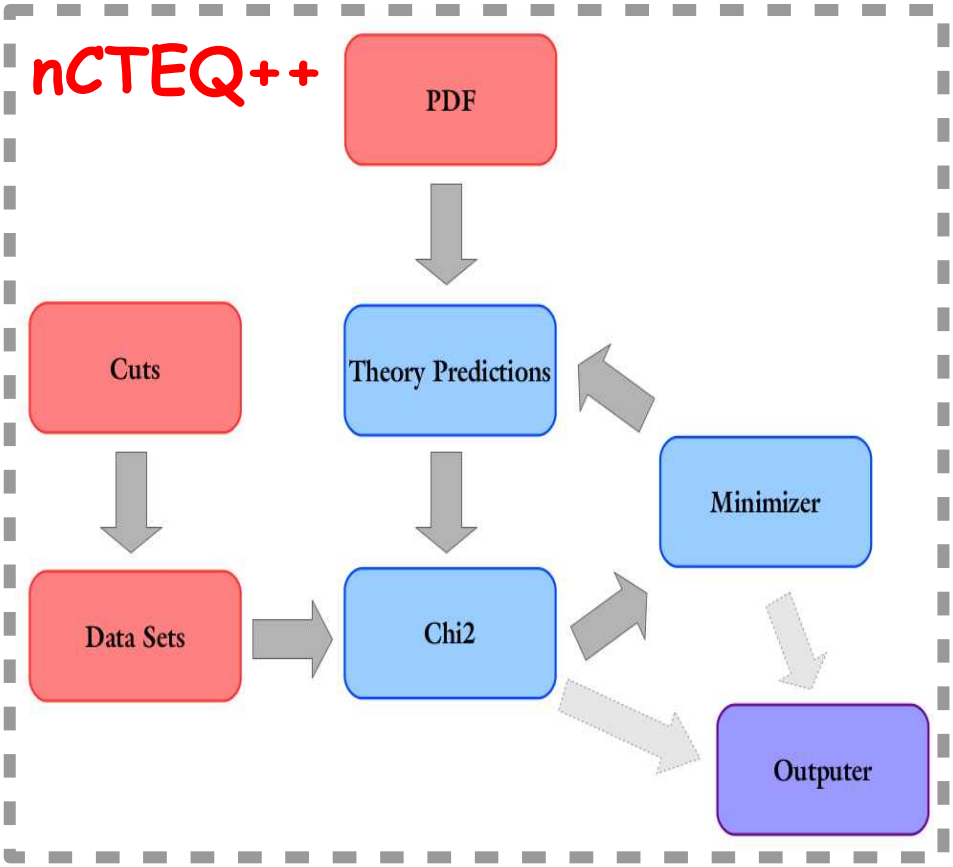
Data from nuclear targets play a key role in the flavor differentiation

nCTEQ

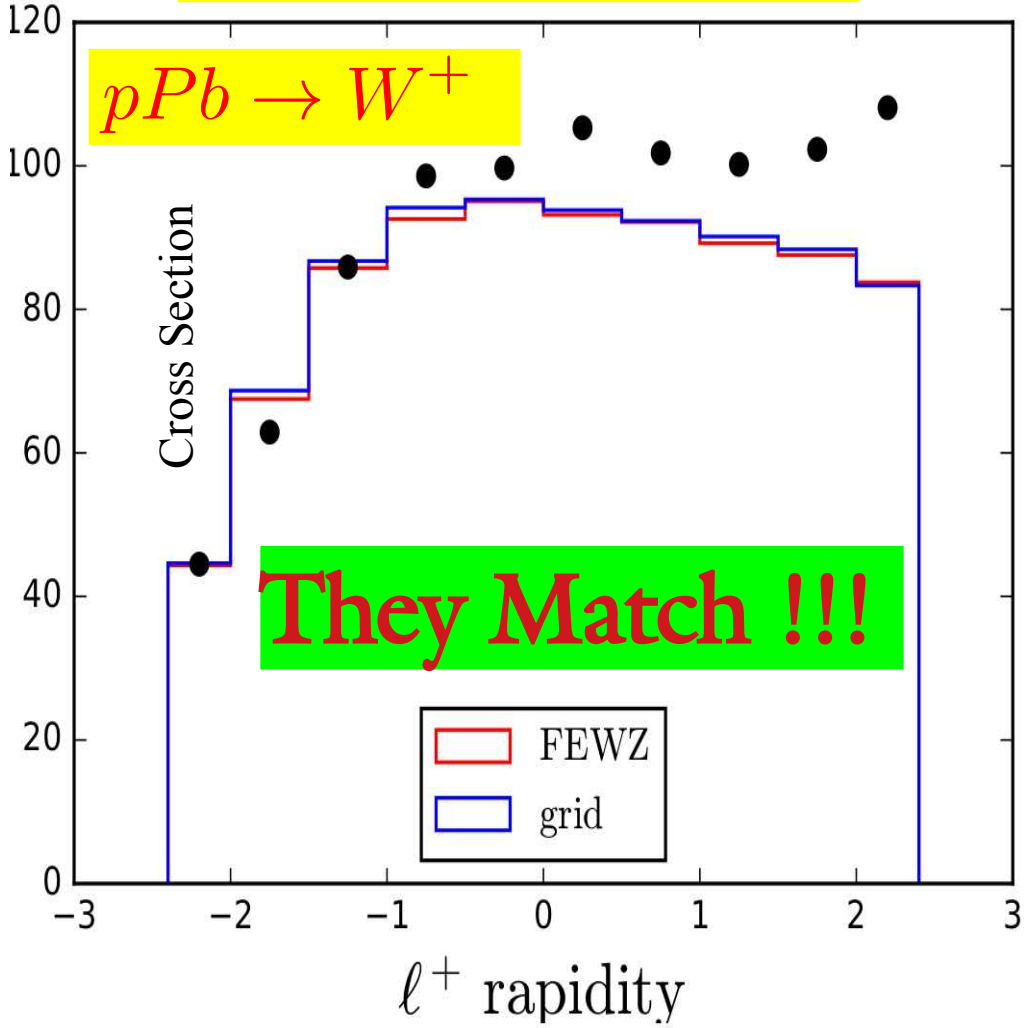
nuclear parton distribution functions

nCTEQ++ … a complete rewrite in C++

Top level C++, modular structure, output to YAML & Python scripts
Use external programs: Minuit, HOPPET, MCFM, APPLgrid, ...



LHC Heavy Ion Data:
Grids generated for pp
can be used for pPb !!!



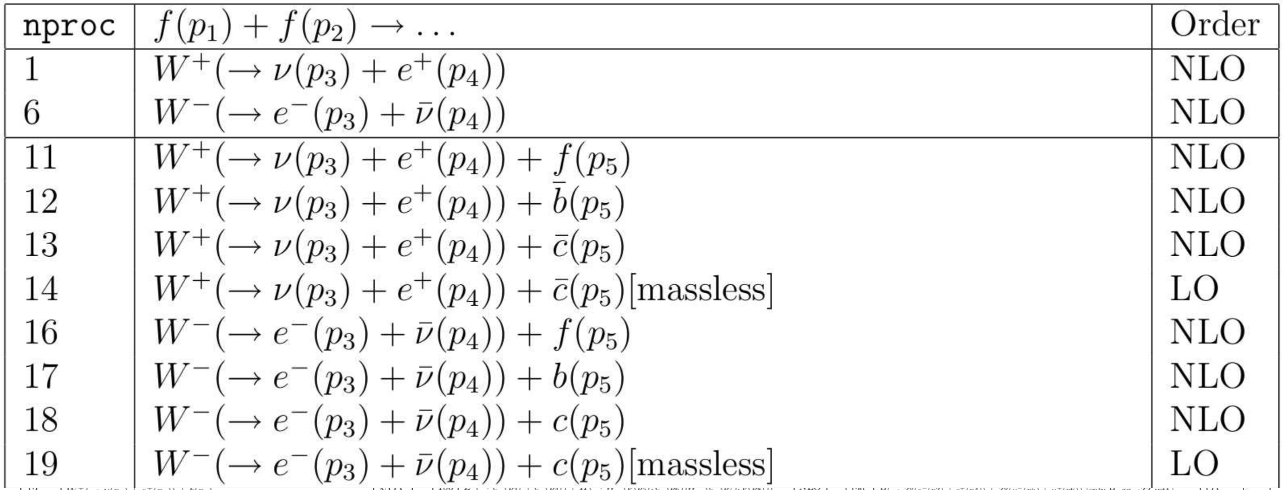
Special thanks to:
Eric Godat
Florian Lyonnet
Tomas Jezo
Aleksander Kusina

nCTEQ++ … can now access all MCFM Processes

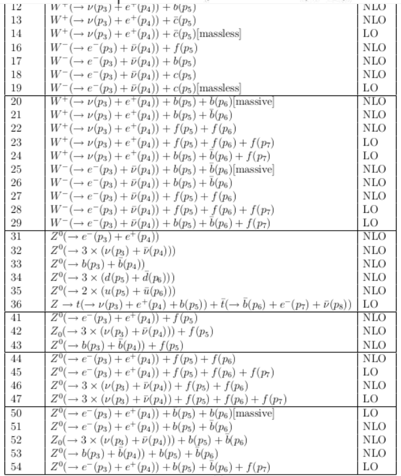
MCFM Processes Library (v6.8)

MCFM: Vector boson pair production at the LHC, J. M.Campbell, R. K.Ellis and C.Williams, JHEP 1107, 018 (2011)

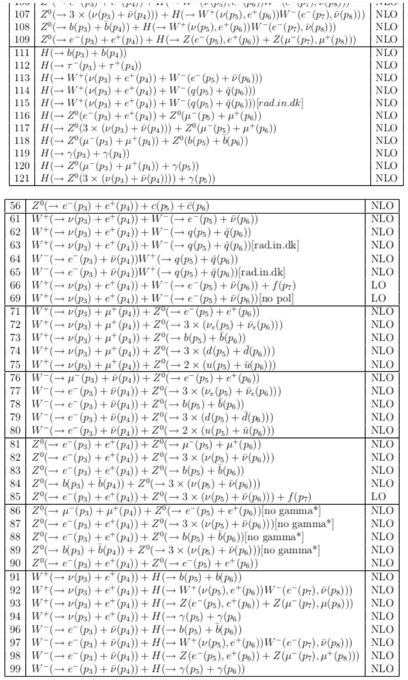
The APPLGRID Project: Tancredi Carli, Dan Clements, Amanda Cooper-Sarkar, Claire Gwenlan, Gavin P. Salam, Frank Siegert, Pavel Starovoitov, Mark Sutton. Eur.Phys.J. C66 (2010) 503-524



nproc	$f(p_1)+f(p_2)\to\dots$	Order
1	$W^+(\to\nu(p_3)+e^+(p_4))$	NLO
6	$W^-(\to e^-(p_3)+\bar\nu(p_4))$	NLO
11	$W^+(\to\nu(p_3)+e^+(p_4))+f(p_5)$	NLO
12	$W^+(\to\nu(p_3)+e^+(p_4))+\bar b(p_5)$	NLO
13	$W^+(\to\nu(p_3)+e^+(p_4))+\bar c(p_5)$	NLO
14	$W^+(\to\nu(p_3)+e^+(p_4))+\bar c(p_5)$[massless]	LO
16	$W^-(\to e^-(p_3)+\bar\nu(p_4))+f(p_5)$	NLO
17	$W^-(\to e^-(p_3)+\bar\nu(p_4))+b(p_5)$	NLO
18	$W^-(\to e^-(p_3)+\bar\nu(p_4))+c(p_5)$	NLO
19	$W^-(\to e^-(p_3)+\bar\nu(p_4))+c(p_5)$[massless]	LO

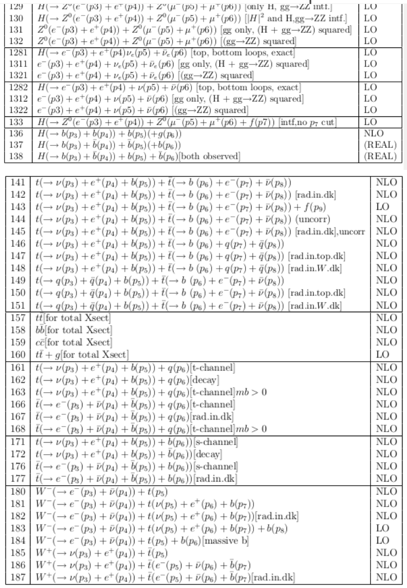


12	$W^+(\to\nu(p_3)+e^+(p_4))+b(p_5)$	NLO
13	$W^+(\to\nu(p_3)+e^+(p_4))+\bar c(p_5)$	NLO
14	$W^+(\to\nu(p_3)+e^+(p_4))+\bar c(p_5)$[massless]	LO
16	$W^-(\to e^-(p_3)+\bar\nu(p_4))+f(p_5)$	NLO
17	$W^-(\to e^-(p_3)+\bar\nu(p_4))+b(p_5)$	NLO
18	$W^-(\to e^-(p_3)+\bar\nu(p_4))+c(p_5)$	NLO
19	$W^-(\to e^-(p_3)+\bar\nu(p_4))+c(p_5)$[massless]	LO
20	$W^+(\to\nu(p_3)+e^+(p_4))+b(p_5)+\bar b(p_6)$[massive]	NLO
21	$W^+(\to\nu(p_3)+e^+(p_4))+b(p_5)+\bar b(p_6)$	NLO
22	$W^+(\to\nu(p_3)+e^+(p_4))+f(p_5)+f(p_6)$	NLO
23	$W^+(\to\nu(p_3)+e^+(p_4))+f(p_5)+f(p_6)+f(p_7)$	LO
24	$W^+(\to\nu(p_3)+e^+(p_4))+b(p_5)+\bar b(p_6)+f(p_7)$	LO
25	$W^-(\to e^-(p_3)+\bar\nu(p_4))+b(p_5)+\bar b(p_6)$[massive]	NLO
26	$W^-(\to e^-(p_3)+\bar\nu(p_4))+b(p_5)+\bar b(p_6)$	NLO
27	$W^-(\to e^-(p_3)+\bar\nu(p_4))+f(p_5)+f(p_6)$	NLO
28	$W^-(\to e^-(p_3)+\bar\nu(p_4))+f(p_5)+f(p_6)+f(p_7)$	LO
29	$W^-(\to e^-(p_3)+\bar\nu(p_4))+b(p_5)+\bar b(p_6)+f(p_7)$	LO
31	$Z^0(\to e^-(p_3)+e^+(p_4))$	NLO
32	$Z^0(\to 3\times(\nu(p_3)+\bar\nu(p_4)))$	NLO
33	$Z^0(\to b(p_3)+\bar b(p_4))$	NLO
34	$Z^0(\to 3\times(d(p_5)+\bar d(p_6)))$	NLO
35	$Z^0(\to 2\times(u(p_5)+\bar u(p_6)))$	NLO
36	$Z\to t(\to\nu(p_3)+e^+(p_4)+b(p_5))+\bar t(\to\bar b(p_6)+e^-(p_7)+\bar\nu(p_8))$	LO
41	$Z^0(\to e^-(p_3)+e^+(p_4))+f(p_5)$	NLO
42	$Z_0(\to 3\times(\nu(p_3)+\bar\nu(p_4)))+f(p_5)$	NLO
43	$Z^0(\to b(p_3)+\bar b(p_4))+f(p_5)$	NLO
44	$Z^0(\to e^-(p_3)+e^+(p_4))+f(p_5)+f(p_6)$	NLO
45	$Z^0(\to e^-(p_3)+e^+(p_4))+f(p_5)+f(p_6)+f(p_7)$	LO
46	$Z^0(\to 3\times(\nu(p_3)+\bar\nu(p_4))+f(p_5)+f(p_6)$	NLO
47	$Z^0(\to 3\times(\nu(p_3)+\bar\nu(p_4))+f(p_5)+f(p_6)+f(p_7)$	LO
50	$Z^0(\to e^-(p_3)+e^+(p_4))+\bar b(p_5)+b(p_6)$[massive]	LO
51	$Z^0(\to e^-(p_3)+e^+(p_4))+b(p_5)+\bar b(p_6)$	NLO
52	$Z_0(\to 3\times(\nu(p_3)+\bar\nu(p_4)))+b(p_5)+\bar b(p_6)$	NLO
53	$Z^0(\to b(p_3)+\bar b(p_4))+b(p_5)+\bar b(p_6)$	NLO
54	$Z^0(\to e^-(p_3)+e^+(p_4))+b(p_5)+\bar b(p_6)+f(p_7)$	LO



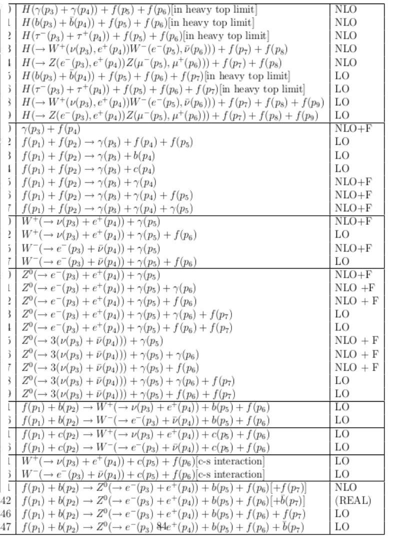
107	$Z^0(\to 3\times(\nu(p_3)+\bar\nu(p_4)))+H(\to W^+(\nu(p_5),e^+(p_6))W^-(e^-(p_7),\bar\nu(p_8)))$	NLO
108	$Z^0(\to b(p_3)+\bar b(p_4))+H(\to W^+(\nu(p_5),e^+(p_6))W^-(e^-(p_7),\bar\nu(p_8)))$	NLO
109	$Z^0(\to e^-(p_3)+e^+(p_4))+H(\to Z(e^-(p_5),e^+(p_6))+Z(\mu^-(p_7),\mu^+(p_8)))$	NLO
111	$H(\to b(p_3)+b(p_4))$	NLO
112	$H(\to\tau^-(p_3)+\tau^+(p_4))$	NLO
113	$H(\to W^+(\nu(p_3)+e^+(p_4))+W^-(e^-(p_5)+\bar\nu(p_6)))$	NLO
114	$H(\to W^+(\nu(p_3)+e^+(p_4))+W^-(q(p_5)+\bar q(p_6)))$	NLO
115	$H(\to W^+(\nu(p_3)+e^+(p_4))+W^-(q(p_5)+\bar q(p_6)))[rad.in.dk]$	NLO
116	$H(\to Z^0(e^-(p_3)+e^+(p_4))+Z^0(\mu^-(p_5)+\mu^+(p_6))$	NLO
117	$H(\to Z^0(3\times(\nu(p_3)+\bar\nu(p_4)))+Z^0(\mu^-(p_5)+\mu^+(p_6))$	NLO
118	$H(\to Z^0(\mu^-(p_3)+\mu^+(p_4))+Z^0(b(p_5)+\bar b(p_6))$	NLO
119	$H(\to\gamma(p_3)+\gamma(p_4))$	NLO
120	$H(\to Z^0(\mu^-(p_3)+\mu^+(p_4))+\gamma(p_5))$	NLO
121	$H(\to Z^0(3\times(\nu(p_3)+\bar\nu(p_4))))+\gamma(p_5))$	NLO

56	$Z^0(\to e^-(p_3)+e^+(p_4))+c(p_5)+\bar c(p_6)$	NLO
61	$W^+(\to\nu(p_3)+e^+(p_4))+W^-(\to e^-(p_5)+\bar\nu(p_6))$	NLO
62	$W^+(\to\nu(p_3)+e^+(p_4))+W^-(\to q(p_5)+\bar q(p_6))$	NLO
63	$W^+(\to\nu(p_3)+e^+(p_4))+W^-(\to q(p_5)+\bar q(p_6))$[rad.in.dk]	NLO
64	$W^-(\to e^-(p_3)+\bar\nu(p_4))W^+(\to q(p_5)+\bar q(p_6))$	NLO
65	$W^-(\to e^-(p_3)+\bar\nu(p_4))W^+(\to q(p_5)+\bar q(p_6))$[rad.in.dk]	NLO
66	$W^+(\to\nu(p_3)+e^+(p_4))+W^-(\to e^-(p_5)+\bar\nu(p_6))+f(p_7)$	LO
69	$W^+(\to\nu(p_3)+e^+(p_4))+W^-(\to e^-(p_5)+\bar\nu(p_6))$[no pol]	LO
71	$W^+(\to\nu(p_3)+\mu^+(p_4))+Z^0(\to e^-(p_5)+e^+(p_6))$	NLO
72	$W^+(\to\nu(p_3)+\mu^+(p_4))+Z^0(\to 3\times(\nu_e(p_5)+\bar\nu_e(p_6)))$	NLO
73	$W^+(\to\nu(p_3)+\mu^+(p_4))+Z^0(\to b(p_5)+\bar b(p_6))$	NLO
74	$W^+(\to\nu(p_3)+\mu^+(p_4))+Z^0(\to 3\times(d(p_5)+\bar d(p_6)))$	NLO
75	$W^+(\to\nu(p_3)+\mu^+(p_4))+Z^0(\to 2\times(u(p_5)+\bar u(p_6)))$	NLO
76	$W^-(\to\mu^-(p_3)+\bar\nu(p_4))+Z^0(\to e^-(p_5)+e^+(p_6))$	NLO
77	$W^-(\to e^-(p_3)+\bar\nu(p_4))+Z^0(\to 3\times(\nu_e(p_5)+\bar\nu_e(p_6)))$	NLO
78	$W^-(\to e^-(p_3)+\bar\nu(p_4))+Z^0(\to b(p_5)+\bar b(p_6))$	NLO
79	$W^-(\to e^-(p_3)+\bar\nu(p_4))+Z^0(\to 3\times(d(p_5)+\bar d(p_6)))$	NLO
80	$W^-(\to e^-(p_3)+\bar\nu(p_4))+Z^0(\to 2\times(u(p_5)+\bar u(p_6)))$	NLO
81	$Z^0(\to e^-(p_3)+e^+(p_4))+Z^0(\to\mu^-(p_5)+\mu^+(p_6))$	NLO
82	$Z^0(\to e^-(p_3)+e^+(p_4))+Z^0(\to 3\times(\nu(p_5)+\bar\nu(p_6)))$	NLO
83	$Z^0(\to e^-(p_3)+e^+(p_4))+Z^0(\to b(p_5)+\bar b(p_6))$	NLO
84	$Z^0(\to b(p_3)+\bar b(p_4))+Z^0(\to 3\times(\nu(p_5)+\bar\nu(p_6)))$	NLO
85	$Z^0(\to e^-(p_3)+e^+(p_4))+Z^0(\to 3\times(\nu(p_5)+\bar\nu(p_6)))+f(p_7)$	LO
86	$Z^0(\to\mu^-(p_3)+\mu^+(p_4))+Z^0(\to e^-(p_5)+e^+(p_6))$[no gamma*]	NLO
87	$Z^0(\to e^-(p_3)+e^+(p_4))+Z^0(\to 3\times(\nu(p_5)+\bar\nu(p_6)))$[no gamma*]	NLO
88	$Z^0(\to e^-(p_3)+e^+(p_4))+Z^0(\to b(p_5)+\bar b(p_6))$[no gamma*]	NLO
89	$Z^0(\to b(p_3)+\bar b(p_4))+Z^0(\to 3\times(\nu(p_5)+\bar\nu(p_6)))$[no gamma*]	NLO
90	$Z^0(\to e^-(p_3)+e^+(p_4))+Z^0(\to e^-(p_5)+e^+(p_6))$	NLO
91	$W^+(\to\nu(p_3)+e^+(p_4))+H(\to b(p_5)+\bar b(p_6))$	NLO
92	$W^+(\to\nu(p_3)+e^+(p_4))+H(\to W^+(\nu(p_5),e^+(p_6))W^-(e^-(p_7),\bar\nu(p_8)))$	NLO
93	$W^+(\to\nu(p_3)+e^+(p_4))+H(\to Z(e^-(p_5),e^+(p_6))+Z(\mu^-(p_7),\mu(p_8)))$	NLO
94	$W^+(\to\nu(p_3)+e^+(p_4))+H(\to\gamma(p_5)+\gamma(p_6)$	NLO
96	$W^-(\to e^-(p_3)+\bar\nu(p_4))+H(\to b(p_5)+\bar b(p_6))$	NLO
97	$W^-(\to e^-(p_3)+\bar\nu(p_4))+H(\to W^+(\nu(p_5),e^+(p_6))W^-(e^-(p_7),\bar\nu(p_8)))$	NLO
98	$W^-(\to e^-(p_3)+\bar\nu(p_4))+H(\to Z(e^-(p_5),e^+(p_6))+Z(\mu^-(p_7),\mu^+(p_8)))$	NLO
99	$W^-(\to e^-(p_3)+\bar\nu(p_4))+H(\to\gamma(p_5)+\gamma(p_6))$	NLO

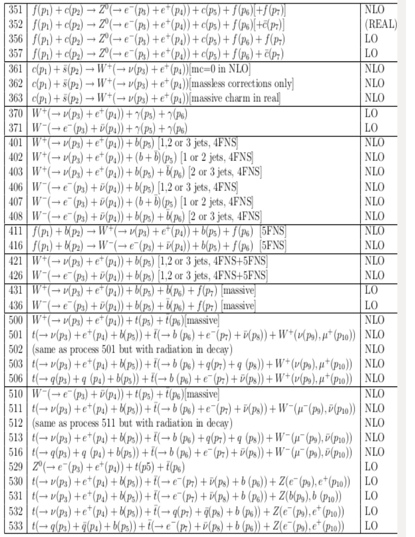


129	$H(\to Z^0(e^-(p3)+e^+(p4))+Z^0(\mu^-(p5)+\mu^+(p6))$ [only H, gg→ZZ intf.]	LO
130	$H(\to Z^0(e^-(p3)+e^+(p4))+Z^0(\mu^-(p5)+\mu^+(p6))$ [$\vert H\vert^2$ and H,gg→ZZ intf.]	LO
131	$Z^0(e^-(p3)+e^+(p4))+Z^0(\mu^-(p5)+\mu^+(p6))$ [gg only, (H + gg→ZZ) squared]	LO
132	$Z^0(e^-(p3)+e^+(p4))+Z^0(\mu^-(p5)+\mu^+(p6))$ [(gg→ZZ) squared]	LO
1281	$H(\to e^-(p3)+e^+(p4)\nu_e(p5)+\bar\nu_e(p6)$ [top, bottom loops, exact]	LO
1311	$e^-(p3)+e^+(p4)+\nu_e(p5)+\bar\nu_e(p6)$ [gg only, (H + gg→ZZ) squared]	LO
1321	$e^-(p3)+e^+(p4)+\nu_e(p5)+\bar\nu_e(p6)$ [(gg→ZZ) squared]	LO
1282	$H(\to e^-(p3)+e^+(p4)+\nu(p5)+\bar\nu(p6)$ [top, bottom loops, exact]	LO
1312	$e^-(p3)+e^+(p4)+\nu(p5)+\bar\nu(p6)$ [gg only, (H + gg→ZZ) squared]	LO
1322	$e^-(p3)+e^+(p4)+\nu(p5)+\bar\nu(p6)$ [(gg→ZZ) squared]	LO
133	$H(\to Z^0(e^-(p3)+e^+(p4))+Z^0(\mu^-(p5)+\mu^+(p6)+f(p7))$ [intf,no p_7 cut]	LO
136	$H(\to b(p_3)+b(p_4))+b(p_5)(+g(p_6))$	NLO
137	$H(\to b(p_3)+\bar b(p_4))+\bar b(p_5)(+b(p_6))$	(REAL)
138	$H(\to b(p_3)+\bar b(p_4))+b(p_5)+\bar b(p_6)$[both observed]	(REAL)

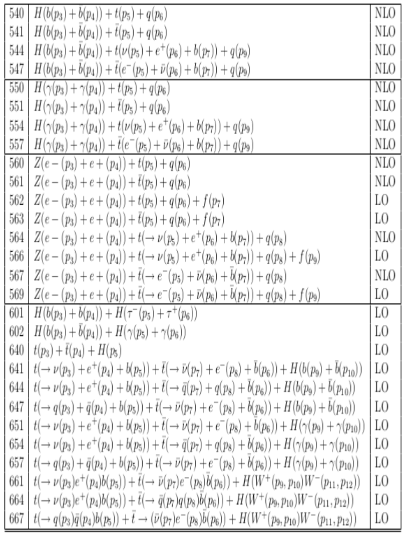
141	$t(\to\nu(p_3)+e^+(p_4)+b(p_5))+\bar t(\to b\,(p_6)+e^-(p_7)+\bar\nu(p_8))$	NLO
142	$t(\to\nu(p_3)+e^+(p_4)+b(p_5))+\bar t(\to b\,(p_6)+e^-(p_7)+\bar\nu(p_8))$ [rad.in.dk]	NLO
143	$t(\to\nu(p_3)+e^+(p_4)+b(p_5))+\bar t(\to b\,(p_6)+e^-(p_7)+\bar\nu(p_8))+f(p_9)$	LO
144	$t(\to\nu(p_3)+e^+(p_4)+b(p_5))+\bar t(\to b\,(p_6)+e^-(p_7)+\bar\nu(p_8))$ (uncorr)	NLO
145	$t(\to\nu(p_3)+e^+(p_4)+b(p_5))+\bar t(\to b\,(p_6)+e^-(p_7)+\bar\nu(p_8))$ [rad.in.dk],uncorr	NLO
146	$t(\to\nu(p_3)+e^+(p_4)+b(p_5))+\bar t(\to b\,(p_6)+q(p_7)+\bar q(p_8))$	NLO
147	$t(\to\nu(p_3)+e^+(p_4)+b(p_5))+\bar t(\to b\,(p_6)+q(p_7)+\bar q(p_8))$ [rad.in.top.dk]	NLO
148	$t(\to\nu(p_3)+e^+(p_4)+b(p_5))+\bar t(\to b\,(p_6)+q(p_7)+\bar q(p_8))$ [rad.in.W.dk]	NLO
149	$t(\to q(p_3)+\bar q(p_4)+b(p_5))+\bar t(\to b\,(p_6)+e^-(p_7)+\bar\nu(p_8))$	NLO
150	$t(\to q(p_3)+\bar q(p_4)+b(p_5))+\bar t(\to b\,(p_6)+e^-(p_7)+\bar\nu(p_8))$ [rad.in.top.dk]	NLO
151	$t(\to q(p_3)+\bar q(p_4)+b(p_5))+\bar t(\to b\,(p_6)+e^-(p_7)+\bar\nu(p_8))$ [rad.in.W.dk]	NLO
157	$t\bar t$[for total Xsect]	NLO
158	$b\bar b$[for total Xsect]	NLO
159	$c\bar c$[for total Xsect]	NLO
160	$t\bar t+g$[for total Xsect]	LO
161	$t(\to\nu(p_3)+e^+(p_4)+b(p_5))+q(p_6)$[t-channel]	NLO
162	$t(\to\nu(p_3)+e^+(p_4)+b(p_5))+q(p_6)$[decay]	NLO
163	$t(\to\nu(p_3)+e^+(p_4)+b(p_5))+q(p_6)$[t-channel]$mb>0$	NLO
166	$\bar t(\to e^-(p_3)+\bar\nu(p_4)+\bar b(p_5))+q(p_6)$[t-channel]	NLO
167	$\bar t(\to e^-(p_3)+\bar\nu(p_4)+\bar b(p_5))+q(p_6)$[rad.in.dk]	NLO
168	$\bar t(\to e^-(p_3)+\bar\nu(p_4)+\bar b(p_5))+q(p_6)$[t-channel]$mb>0$	NLO
171	$t(\to\nu(p_3)+e^+(p_4)+b(p_5))+\bar b(p_6))$[s-channel]	NLO
172	$t(\to\nu(p_3)+e^+(p_4)+b(p_5))+\bar b(p_6))$[decay]	NLO
176	$\bar t(\to e^-(p_3)+\bar\nu(p_4)+\bar b(p_5))+b(p_6))$[s-channel]	NLO
177	$\bar t(\to e^-(p_3)+\bar\nu(p_4)+\bar b(p_5))+b(p_6))$[rad.in.dk]	NLO
180	$W^-(\to e^-(p_3)+\bar\nu(p_4))+t(p_5)$	NLO
181	$W^-(\to e^-(p_3)+\bar\nu(p_4))+t(\nu(p_5)+e^+(p_6)+b(p_7))$	NLO
182	$W^-(\to e^-(p_3)+\bar\nu(p_4))+t(\nu(p_5)+e^+(p_6)+b(p_7))$[rad.in.dk]	NLO
183	$W^-(\to e^-(p_3)+\bar\nu(p_4))+t(\nu(p_5)+e^+(p_6)+b(p_7))+b(p_8)$	LO
184	$W^-(\to e^-(p_3)+\bar\nu(p_4))+t(p_5)+b(p_6)$[massive b]	LO
185	$W^+(\to\nu(p_3)+e^+(p_4))+\bar t(p_5)$	NLO
186	$W^+(\to\nu(p_3)+e^+(p_4))+\bar t(e^-(p_5)+\bar\nu(p_6)+\bar b(p_7)$	NLO
187	$W^+(\to\nu(p_3)+e^+(p_4))+\bar t(e^-(p_5)+\bar\nu(p_6)+\bar b(p_7)$[rad.in.dk]	NLO



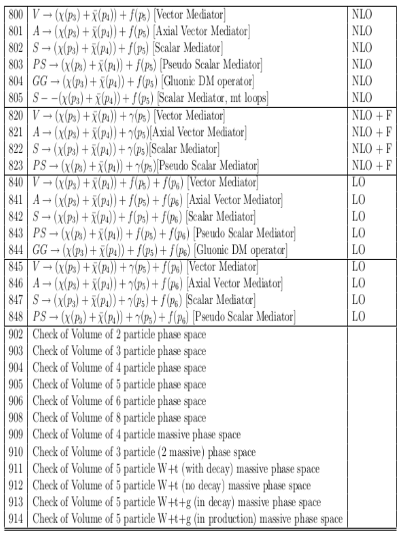
	$H(\gamma(p_3)+\gamma(p_4))+f(p_5)+f(p_6)$[in heavy top limit]	NLO
	$H(b(p_3)+\bar b(p_4))+f(p_5)+f(p_6)$[in heavy top limit]	NLO
	$H(\tau^-(p_3)+\tau^+(p_4))+f(p_5)+f(p_6)$[in heavy top limit]	NLO
	$H(\to W^+(\nu(p_3),e^+(p_4))W^-(e^-(p_5),\bar\nu(p_6)))+f(p_7)+f(p_8)$	NLO
	$H(\to Z(e^-(p_3),e^+(p_4))Z(\mu^-(p_5),\mu^+(p_6)))+f(p_7)+f(p_8)$	NLO
	$H(b(p_3)+\bar b(p_4))+f(p_5)+f(p_6)+f(p_7)$[in heavy top limit]	LO
	$H(\tau^-(p_3)+\tau^+(p_4))+f(p_5)+f(p_6)+f(p_7)$[in heavy top limit]	LO
	$H(\to W^+(\nu(p_3),e^+(p_4))W^-(e^-(p_5),\bar\nu(p_6)))+f(p_7)+f(p_8)+f(p_9)$	LO
	$H(\to Z(e^-(p_3),e^+(p_4))Z(\mu^-(p_5),\mu^+(p_6)))+f(p_7)+f(p_8)+f(p_9)$	LO
	$\gamma(p_3)+f(p_4)$	NLO+F
	$f(p_1)+f(p_2)\to\gamma(p_3)+f(p_4)+f(p_5)$	LO
	$f(p_1)+f(p_2)\to\gamma(p_3)+b(p_4)$	LO
	$f(p_1)+f(p_2)\to\gamma(p_3)+c(p_4)$	LO
	$f(p_1)+f(p_2)\to\gamma(p_3)+\gamma(p_4)$	NLO+F
	$f(p_1)+f(p_2)\to\gamma(p_3)+\gamma(p_4)+f(p_5)$	NLO+F
	$f(p_1)+f(p_2)\to\gamma(p_3)+\gamma(p_4)+\gamma(p_5)$	NLO+F
	$W^+(\to\nu(p_3)+e^+(p_4))+\gamma(p_5)$	NLO+F
	$W^+(\to\nu(p_3)+e^+(p_4))+\gamma(p_5)+f(p_6)$	LO
	$W^-(\to e^-(p_3)+\bar\nu(p_4))+\gamma(p_5)$	NLO+F
	$W^-(\to e^-(p_3)+\bar\nu(p_4))+\gamma(p_5)+f(p_6)$	LO
	$Z^0(\to e^-(p_3)+e^+(p_4))+\gamma(p_5)$	NLO+F
	$Z^0(\to e^-(p_3)+e^+(p_4))+\gamma(p_5)+\gamma(p_6)$	NLO +F
	$Z^0(\to e^-(p_3)+e^+(p_4))+\gamma(p_5)+f(p_6)$	NLO + F
	$Z^0(\to e^-(p_3)+e^+(p_4))+\gamma(p_5)+\gamma(p_6)+f(p_7)$	LO
	$Z^0(\to e^-(p_3)+e^+(p_4))+\gamma(p_5)+f(p_6)+f(p_7)$	LO
	$Z^0(\to 3(\nu(p_3)+\bar\nu(p_4)))+\gamma(p_5)$	NLO + F
	$Z^0(\to 3(\nu(p_3)+\bar\nu(p_4)))+\gamma(p_5)+\gamma(p_6)$	NLO + F
	$Z^0(\to 3(\nu(p_3)+\bar\nu(p_4)))+\gamma(p_5)+f(p_6)$	NLO + F
	$Z^0(\to 3(\nu(p_3)+\bar\nu(p_4)))+\gamma(p_5)+\gamma(p_6)+f(p_7)$	LO
	$Z^0(\to 3(\nu(p_3)+\bar\nu(p_4)))+\gamma(p_5)+f(p_6)+f(p_7)$	LO
	$f(p_1)+b(p_2)\to W^+(\to\nu(p_3)+e^+(p_4))+b(p_5)+f(p_6)$	LO
	$f(p_1)+b(p_2)\to W^-(\to e^-(p_3)+\bar\nu(p_4))+b(p_5)+f(p_6)$	LO
	$f(p_1)+c(p_2)\to W^+(\to\nu(p_3)+e^+(p_4))+c(p_5)+f(p_6)$	LO
	$f(p_1)+c(p_2)\to W^-(\to e^-(p_3)+\bar\nu(p_4))+c(p_5)+f(p_6)$	LO
	$W^+(\to\nu(p_3)+e^+(p_4))+c(p_5)+f(p_6)$[c-s interaction]	LO
	$W^-(\to e^-(p_3)+\bar\nu(p_4))+c(p_5)+f(p_6)$[c-s interaction]	LO
	$f(p_1)+b(p_2)\to Z^0(\to e^-(p_3)+e^+(p_4))+b(p_5)+f(p_6)[+f(p_7)]$	NLO
342	$f(p_1)+b(p_2)\to Z^0(\to e^-(p_3)+e^+(p_4))+b(p_5)+f(p_6)[+\bar b(p_7)]$	(REAL)
346	$f(p_1)+b(p_2)\to Z^0(\to e^-(p_3)+e^+(p_4))+b(p_5)+f(p_6)+f(p_7)$	LO
347	$f(p_1)+b(p_2)\to Z^0(\to e^-(p_3)+e^+(p_4))+b(p_5)+f(p_6)+\bar b(p_7)$	LO



351	$f(p_1)+c(p_2)\to Z^0(\to e^-(p_3)+e^+(p_4))+c(p_5)+f(p_6)[+f(p_7)]$	NLO
352	$f(p_1)+c(p_2)\to Z^0(\to e^-(p_3)+e^+(p_4))+c(p_5)+f(p_6)[+\bar c(p_7)]$	(REAL)
356	$f(p_1)+c(p_2)\to Z^0(\to e^-(p_3)+e^+(p_4))+c(p_5)+f(p_6)+f(p_7)$	LO
357	$f(p_1)+c(p_2)\to Z^0(\to e^-(p_3)+e^+(p_4))+c(p_5)+f(p_6)+\bar c(p_7)$	LO
361	$c(p_1)+\bar s(p_2)\to W^+(\to\nu(p_3)+e^+(p_4))$[mc=0 in NLO]	NLO
362	$c(p_1)+\bar s(p_2)\to W^+(\to\nu(p_3)+e^+(p_4))$[massless corrections only]	NLO
363	$c(p_1)+\bar s(p_2)\to W^+(\to\nu(p_3)+e^+(p_4))$[massive charm in real]	NLO
370	$W^+(\to\nu(p_3)+e^+(p_4))+\gamma(p_5)+\gamma(p_6)$	LO
371	$W^-(\to e^-(p_3)+\bar\nu(p_4))+\gamma(p_5)+\gamma(p_6)$	LO
401	$W^+(\to\nu(p_3)+e^+(p_4))+b(p_5)$ [1,2 or 3 jets, 4FNS]	NLO
402	$W^+(\to\nu(p_3)+e^+(p_4))+(b+\bar b)(p_5)$ [1 or 2 jets, 4FNS]	NLO
403	$W^+(\to\nu(p_3)+e^+(p_4))+b(p_5)+\bar b(p_6)$ [2 or 3 jets, 4FNS]	NLO
406	$W^-(\to e^-(p_3)+\bar\nu(p_4))+b(p_5)$ [1,2 or 3 jets, 4FNS]	NLO
407	$W^-(\to e^-(p_3)+\bar\nu(p_4))+(b+\bar b)(p_5)$ [1 or 2 jets, 4FNS]	NLO
408	$W^-(\to e^-(p_3)+\bar\nu(p_4))+b(p_5)+\bar b(p_6)$ [2 or 3 jets, 4FNS]	NLO
411	$f(p_1)+b(p_2)\to W^+(\to\nu(p_3)+e^+(p_4))+b(p_5)+f(p_6)$ [5FNS]	NLO
416	$f(p_1)+b(p_2)\to W^-(\to e^-(p_3)+\bar\nu(p_4))+b(p_5)+f(p_6)$ [5FNS]	NLO
421	$W^+(\to\nu(p_3)+e^+(p_4))+b(p_5)$ [1,2 or 3 jets, 4FNS+5FNS]	NLO
426	$W^-(\to e^-(p_3)+\bar\nu(p_4))+b(p_5)$ [1,2 or 3 jets, 4FNS+5FNS]	NLO
431	$W^+(\to\nu(p_3)+e^+(p_4))+b(p_5)+\bar b(p_6)+f(p_7)$ [massive]	LO
436	$W^-(\to e^-(p_3)+\bar\nu(p_4))+b(p_5)+\bar b(p_6)+f(p_7)$ [massive]	LO
500	$W^+(\to\nu(p_3)+e^+(p_4))+t(p_5)+\bar t(p_6)$[massive]	NLO
501	$t(\to\nu(p_3)+e^+(p_4)+b(p_5))+\bar t(\to b\,(p_6)+e^-(p_7)+\bar\nu(p_8))+W^+(\nu(p_9),\mu^+(p_{10}))$	NLO
502	(same as process 501 but with radiation in decay)	NLO
503	$t(\to\nu(p_3)+e^+(p_4)+b(p_5))+\bar t(\to b\,(p_6)+q(p_7)+q\,(p_8))+W^+(\nu(p_9),\mu^+(p_{10}))$	NLO
506	$t(\to q(p_3)+q\,(p_4)+b(p_5))+\bar t(\to b\,(p_6)+e^-(p_7)+\bar\nu(p_8))+W^+(\nu(p_9),\mu^+(p_{10}))$	NLO
510	$W^-(\to e^-(p_3)+\bar\nu(p_4))+t(p_5)+\bar t(p_6)$[massive]	NLO
511	$t(\to\nu(p_3)+e^+(p_4)+b(p_5))+\bar t(\to b\,(p_6)+e^-(p_7)+\bar\nu(p_8))+W^-(\mu^-(p_9),\bar\nu(p_{10}))$	NLO
512	(same as process 511 but with radiation in decay)	NLO
513	$t(\to\nu(p_3)+e^+(p_4)+b(p_5))+\bar t(\to b\,(p_6)+q(p_7)+q\,(p_8))+W^-(\mu^-(p_9),\bar\nu(p_{10}))$	NLO
516	$t(\to q(p_3)+q\,(p_4)+b(p_5))+\bar t(\to b\,(p_6)+e^-(p_7)+\bar\nu(p_8))+W^-(\mu^-(p_9),\bar\nu(p_{10}))$	NLO
529	$Z^0(\to e^-(p_3)+e^+(p_4))+t(p5)+\bar t(p_6)$	LO
530	$t(\to\nu(p_3)+e^+(p_4)+b(p_5))+\bar t(\to e^-(p_7)+\bar\nu(p_8)+b\,(p_6))+Z(e^-(p_9),e^+(p_{10}))$	LO
531	$t(\to\nu(p_3)+e^+(p_4)+b(p_5))+\bar t(\to e^-(p_7)+\bar\nu(p_8)+b\,(p_6))+Z(b(p_9),b\,(p_{10}))$	LO
532	$t(\to\nu(p_3)+e^+(p_4)+b(p_5))+\bar t(\to q(p_7)+\bar q(p_8)+b\,(p_6))+Z(e^-(p_9),e^+(p_{10}))$	LO
533	$t(\to q(p_3)+\bar q(p_4)+b(p_5))+\bar t(\to e^-(p_7)+\bar\nu(p_8)+b\,(p_6))+Z(e^-(p_9),e^+(p_{10}))$	LO



540	$H(b(p_3)+\bar b(p_4))+t(p_5)+q(p_6)$	NLO
541	$H(b(p_3)+\bar b(p_4))+\bar t(p_5)+q(p_6)$	NLO
544	$H(b(p_3)+\bar b(p_4))+t(\nu(p_5)+e^+(p_6)+b(p_7))+q(p_9)$	NLO
547	$H(b(p_3)+\bar b(p_4))+\bar t(e^-(p_5)+\bar\nu(p_6)+b(p_7))+q(p_9)$	NLO
550	$H(\gamma(p_3)+\gamma(p_4))+t(p_5)+q(p_6)$	NLO
551	$H(\gamma(p_3)+\gamma(p_4))+\bar t(p_5)+q(p_6)$	NLO
554	$H(\gamma(p_3)+\gamma(p_4))+t(\nu(p_5)+e^+(p_6)+b(p_7))+q(p_9)$	NLO
557	$H(\gamma(p_3)+\gamma(p_4))+\bar t(e^-(p_5)+\bar\nu(p_6)+b(p_7))+q(p_9)$	NLO
560	$Z(e-(p_3)+e+(p_4))+t(p_5)+q(p_6)$	NLO
561	$Z(e-(p_3)+e+(p_4))+\bar t(p_5)+q(p_6)$	NLO
562	$Z(e-(p_3)+e+(p_4))+t(p_5)+q(p_6)+f(p_7)$	LO
563	$Z(e-(p_3)+e+(p_4))+\bar t(p_5)+q(p_6)+f(p_7)$	LO
564	$Z(e-(p_3)+e+(p_4))+t(\to\nu(p_5)+e^+(p_6)+b(p_7))+q(p_8)$	NLO
566	$Z(e-(p_3)+e+(p_4))+t(\to\nu(p_5)+e^+(p_6)+b(p_7))+q(p_8)+f(p_9)$	LO
567	$Z(e-(p_3)+e+(p_4))+\bar t(\to e^-(p_5)+\bar\nu(p_6)+\bar b(p_7))+q(p_8)$	NLO
569	$Z(e-(p_3)+e+(p_4))+\bar t(\to e^-(p_5)+\bar\nu(p_6)+\bar b(p_7))+q(p_8)+f(p_9)$	LO
601	$H(b(p_3)+\bar b(p_4))+H(\tau^-(p_5)+\tau^+(p_6))$	LO
602	$H(b(p_3)+\bar b(p_4))+H(\gamma(p_5)+\gamma(p_6))$	LO
640	$t(p_3)+\bar t(p_4)+H(p_5)$	LO
641	$t(\to\nu(p_3)+e^+(p_4)+b(p_5))+\bar t(\to\bar\nu(p_7)+e^-(p_8)+\bar b(p_6))+H(b(p_9)+\bar b(p_{10}))$	LO
644	$t(\to\nu(p_3)+e^+(p_4)+b(p_5))+\bar t(\to\bar q(p_7)+q(p_8)+\bar b(p_6))+H(b(p_9)+\bar b(p_{10}))$	LO
647	$t(\to q(p_3)+\bar q(p_4)+b(p_5))+\bar t(\to\bar\nu(p_7)+e^-(p_8)+\bar b(p_6))+H(b(p_9)+\bar b(p_{10}))$	LO
651	$t(\to\nu(p_3)+e^+(p_4)+b(p_5))+\bar t(\to\bar\nu(p_7)+e^-(p_8)+\bar b(p_6))+H(\gamma(p_9)+\gamma(p_{10}))$	LO
654	$t(\to\nu(p_3)+e^+(p_4)+b(p_5))+\bar t(\to\bar q(p_7)+q(p_8)+\bar b(p_6))+H(\gamma(p_9)+\gamma(p_{10}))$	LO
657	$t(\to q(p_3)+\bar q(p_4)+b(p_5))+\bar t(\to\bar\nu(p_7)+e^-(p_8)+\bar b(p_6))+H(\gamma(p_9)+\gamma(p_{10}))$	LO
661	$t(\to\nu(p_3)e^+(p_4)b(p_5))+\bar t(\to\bar\nu(p_7)e^-(p_8)\bar b(p_6))+H(W^+(p_9,p_{10})W^-(p_{11},p_{12}))$	LO
664	$t(\to\nu(p_3)e^+(p_4)b(p_5))+\bar t(\to\bar q(p_7)q(p_8)\bar b(p_6))+H(W^+(p_9,p_{10})W^-(p_{11},p_{12}))$	LO
667	$t(\to q(p_3)\bar q(p_4)b(p_5))+\bar t\to(\bar\nu(p_7)e^-(p_8)\bar b(p_6))+H(W^+(p_9,p_{10})W^-(p_{11},p_{12}))$	LO



800	$V\to(\chi(p_3)+\bar\chi(p_4))+f(p_5)$ [Vector Mediator]	NLO
801	$A\to(\chi(p_3)+\bar\chi(p_4))+f(p_5)$ [Axial Vector Mediator]	NLO
802	$S\to(\chi(p_3)+\bar\chi(p_4))+f(p_5)$ [Scalar Mediator]	NLO
803	$PS\to(\chi(p_3)+\bar\chi(p_4))+f(p_5)$ [Pseudo Scalar Mediator]	NLO
804	$GG\to(\chi(p_3)+\bar\chi(p_4))+f(p_5)$ [Gluonic DM operator]	NLO
805	$S--(\chi(p_3)+\bar\chi(p_4))+f(p_5)$ [Scalar Mediator, mt loops]	NLO
820	$V\to(\chi(p_3)+\bar\chi(p_4))+\gamma(p_5)$ [Vector Mediator]	NLO + F
821	$A\to(\chi(p_3)+\bar\chi(p_4))+\gamma(p_5)$[Axial Vector Mediator]	NLO + F
822	$S\to(\chi(p_3)+\bar\chi(p_4))+\gamma(p_5)$[Scalar Mediator]	NLO + F
823	$PS\to(\chi(p_3)+\bar\chi(p_4))+\gamma(p_5)$[Pseudo Scalar Mediator]	NLO + F
840	$V\to(\chi(p_3)+\bar\chi(p_4))+f(p_5)+f(p_6)$ [Vector Mediator]	LO
841	$A\to(\chi(p_3)+\bar\chi(p_4))+f(p_5)+f(p_6)$ [Axial Vector Mediator]	LO
842	$S\to(\chi(p_3)+\bar\chi(p_4))+f(p_5)+f(p_6)$ [Scalar Mediator]	LO
843	$PS\to(\chi(p_3)+\bar\chi(p_4))+f(p_5)+f(p_6)$ [Pseudo Scalar Mediator]	LO
844	$GG\to(\chi(p_3)+\bar\chi(p_4))+f(p_5)+f(p_6)$ [Gluonic DM operator]	LO
845	$V\to(\chi(p_3)+\bar\chi(p_4))+\gamma(p_5)+f(p_6)$ [Vector Mediator]	LO
846	$A\to(\chi(p_3)+\bar\chi(p_4))+\gamma(p_5)+f(p_6)$ [Axial Vector Mediator]	LO
847	$S\to(\chi(p_3)+\bar\chi(p_4))+\gamma(p_5)+f(p_6)$ [Scalar Mediator]	LO
848	$PS\to(\chi(p_3)+\bar\chi(p_4))+\gamma(p_5)+f(p_6)$ [Pseudo Scalar Mediator]	LO
902	Check of Volume of 2 particle phase space	
903	Check of Volume of 3 particle phase space	
904	Check of Volume of 4 particle phase space	
905	Check of Volume of 5 particle phase space	
906	Check of Volume of 6 particle phase space	
908	Check of Volume of 8 particle phase space	
909	Check of Volume of 4 particle massive phase space	
910	Check of Volume of 3 particle (2 massive) phase space	
911	Check of Volume of 5 particle W+t (with decay) massive phase space	
912	Check of Volume of 5 particle W+t (no decay) massive phase space	
913	Check of Volume of 5 particle W+t+g (in decay) massive phase space	
914	Check of Volume of 5 particle W+t+g (in production) massive phase space	

Conclusion

EIC *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"