Tools for PDF and Structure Functions

... LHAPDF Grids, Mathematica Notebooks ...

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Jefferson Lab, & Southern Methodist University

Thanks for substantial input
from our friends & colleagues

- Nuclear PDF Structure Function Grids
- ManeParse w/ Mathematica
- Structure Functions: Proton & Nuclear PDFs
- Uncertainties: Proton & Nuclear
- Cross Sections w/ cuts

Lucas

Brandon

Tim

Pavel

Fred

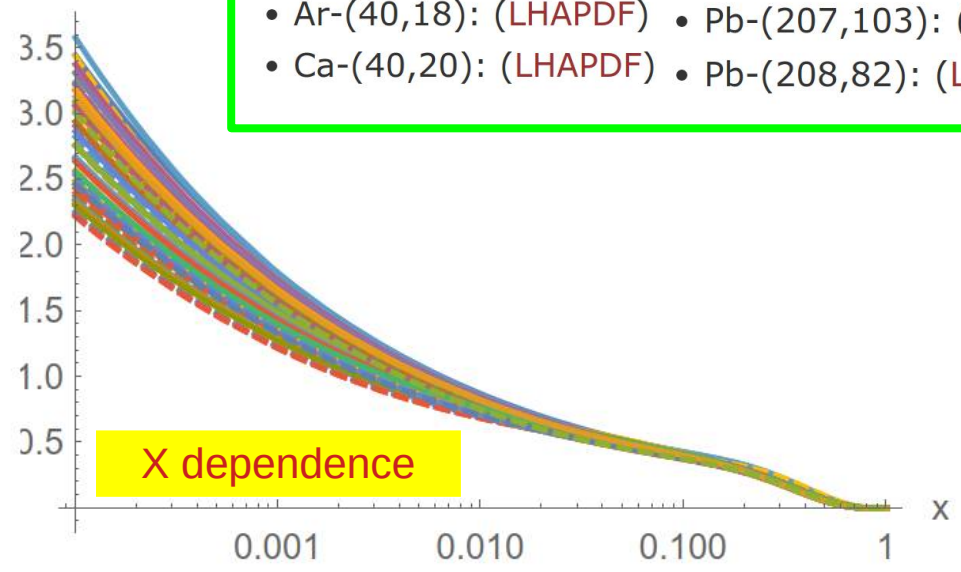
04 August 2020
IR4YR Virtual Meeting

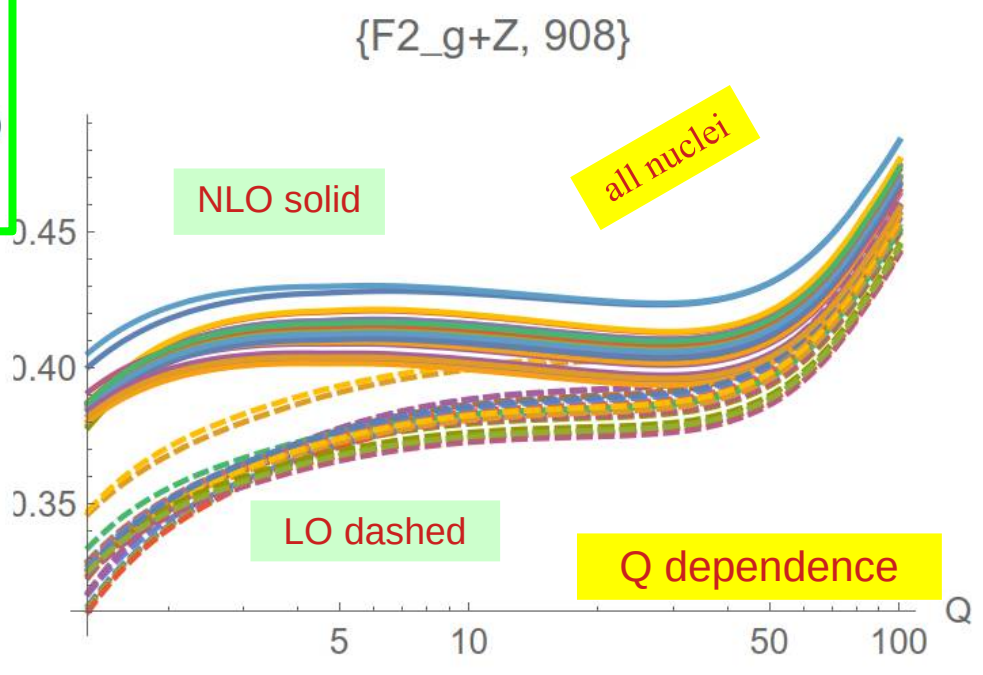
nCTEQ15 Structure Function Tables with Nuclear PDFs

22 available nuclei

- He-(3,2): (LHAPDF)
- He-(4,2): (LHAPDF)
- Li-(6,3): (LHAPDF)
- Li-(7,3): (LHAPDF)
- Be-(9,4): (LHAPDF)
- C-(12,6): (LHAPDF)
- N-(14,7): (LHAPDF)
- Ne-(20,10): (LHAPDF)
- Al-(27,13): (LHAPDF)
- Ar-(40,18): (LHAPDF)
- Ca-(40,20): (LHAPDF)
- Fe-(56,26): (LHAPDF)
- Cu-(64,32): (LHAPDF)
- Kr-(84,42): (LHAPDF)
- Ag-(108,54): (LHAPDF)
- Sn-(119,59): (LHAPDF)
- Xe-(131,54): (LHAPDF)
- W-(184,74): (LHAPDF)
- Au-(197,79): (LHAPDF)
- Au-(197,98): (LHAPDF)
- Pb-(207,103): (LHAPDF)
- Pb-(208,82): (LHAPDF)

$$f_i^{(A,Z)}(x,Q) = \frac{Z}{A} f_i^{p/A}(x,Q) + \frac{A-Z}{A} f_i^{n/A}(x,Q)$$





48 Structure Functions per Nuclei

		F123L	ID #	Name
W-	TOT	F1	-930	F1_wm
W-	TOT	F2	930	F2_wm
W-	TOT	F3	932	F3_wm
W-	TOT	FL	931	FL_wm
gamma	TOT	F1	-900	F1_gam
gamma	TOT	F2	900	F2_gam
gamma	TOT	F3	-901	F3_gam
gamma	TOT	FL	901	FL_gam
W+	TOT	F1	-940	F1_wp
W+	TOT	F2	940	F2_wp
W+	TOT	F3	942	F3_wp
W+	TOT	FL	941	FL_wp
gamma+Z	TOT	F1	-908	F1_g+Z
gamma+Z	TOT	F2	908	F2_g+Z
gamma+Z	TOT	F3	910	F3_g+Z
gamma+Z	TOT	FL	909	FL_g+Z
W-	Charm	F1	-933	F1c_wm
W-	Charm	F2	933	F2c_wm
W-	Charm	F3	935	F3c_wm
W-	Charm	FL	934	FLc_wm
gamma	Charm	F1	-911	F1c_gam
gamma	Charm	F2	911	F2c_gam
gamma	Charm	F3	913	F3c_gam
gamma	Charm	FL	912	FLc_gam

		F123L	ID #	Name
W+	Charm	F1	-943	F1c_wp
W+	Charm	F2	943	F2c_wp
W+	Charm	F3	945	F3c_wp
W+	Charm	FL	944	FLc_wp
gamma+Z	Charm	F1	-914	F1c_g+Z
gamma+Z	Charm	F2	914	F2c_g+Z
gamma+Z	Charm	F3	916	F3c_g+Z
gamma+Z	Charm	FL	915	FLc_g+Z
W-	Bottom	F1	-936	F1b_wm
W-	Bottom	F2	936	F2b_wm
W-	Bottom	F3	938	F3b_wm
W-	Bottom	FL	937	FLb_wm
gamma	Bottom	F1	-917	F1b_gam
gamma	Bottom	F2	917	F2b_gam
gamma	Bottom	F3	919	F3b_gam
gamma	Bottom	FL	918	FLb_gam
W+	Bottom	F1	-946	F1b_wp
W+	Bottom	F2	946	F2b_wp
W+	Bottom	F3	948	F3b_wp
W+	Bottom	FL	947	FLb_wp
gamma+Z	Bottom	F1	-920	F1b_g+Z
gamma+Z	Bottom	F2	920	F2b_g+Z
gamma+Z	Bottom	F3	922	F3b_g+Z
gamma+Z	Bottom	FL	921	FLb_g+Z

ID #'s Yellow Non-standard

gamma+Z is full NC

Mathematica: ManeParse

www.ncteq.org

nCTEQ

nuclear parton distribution functions

ManeParse: A Mathematica Interface to the PDFs

ManeParse is a modular Mathematica package that provides access to PDFs for hadronic calculations. It allows LHAPDF6 files and estimates PDF errors for Hessian and MC releases.

ManeParse Publication:

Download the publication here:

- **ManeParse : A Mathematica reader for Parton Distribution Functions**
  D.B. Clark, E. Godat, F.I. Olness.
  Comput.Phys.Commun. 216 (2017) 126-137.
  or: arXiv:1605.08012 [hep-ph] .

ManeParse version 3.0, Mathematica package:

An SIMPLE example using LHAPDF Tables for PDFs:

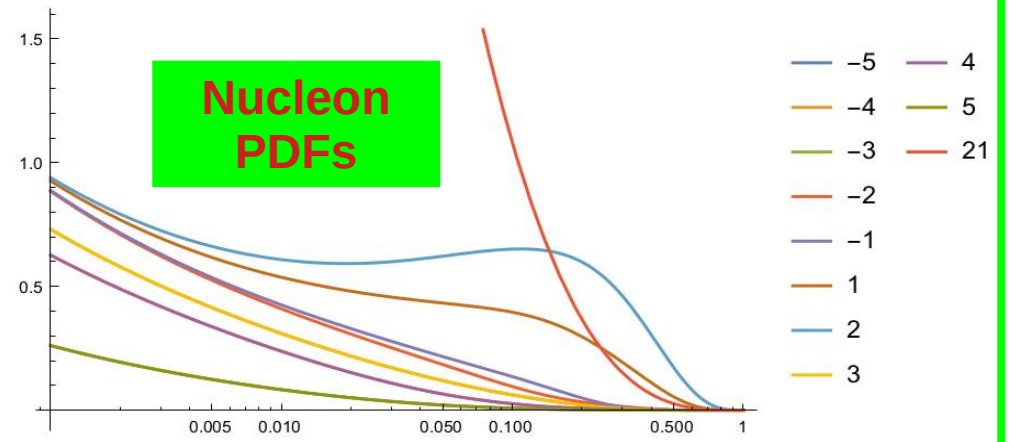
This is an self-contained example that reads PDF tables in LHAPDF format.
PDF_DEMO_v01.zip
(850Kb, Version May 2020).
Includes PDF Grid files needed for demo.

A SIMPLE example using Structure Function Tables:

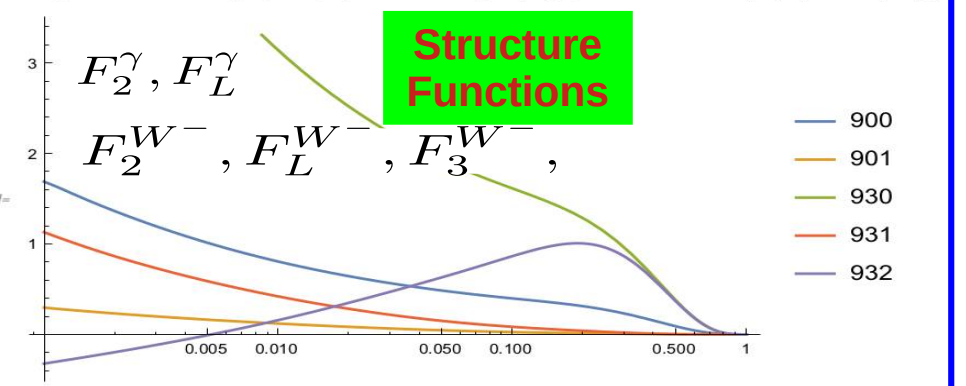
This is an self-contained example that reads Structure Function tables in LHAPDF format.
SF_DEMO_v01.zip
(460Kb, Version May 2020).
Includes Structure Function Grid files needed for demo.
Thanks to Tim Hobbs for supplying the sample tables.

Tim Hobbs
23 June

```
q0 = 10. ;
LogLinearPlot [ x pdf[1, flavors , x, q0] // Evaluate , {x, 10^-3, 1}, Plo
```

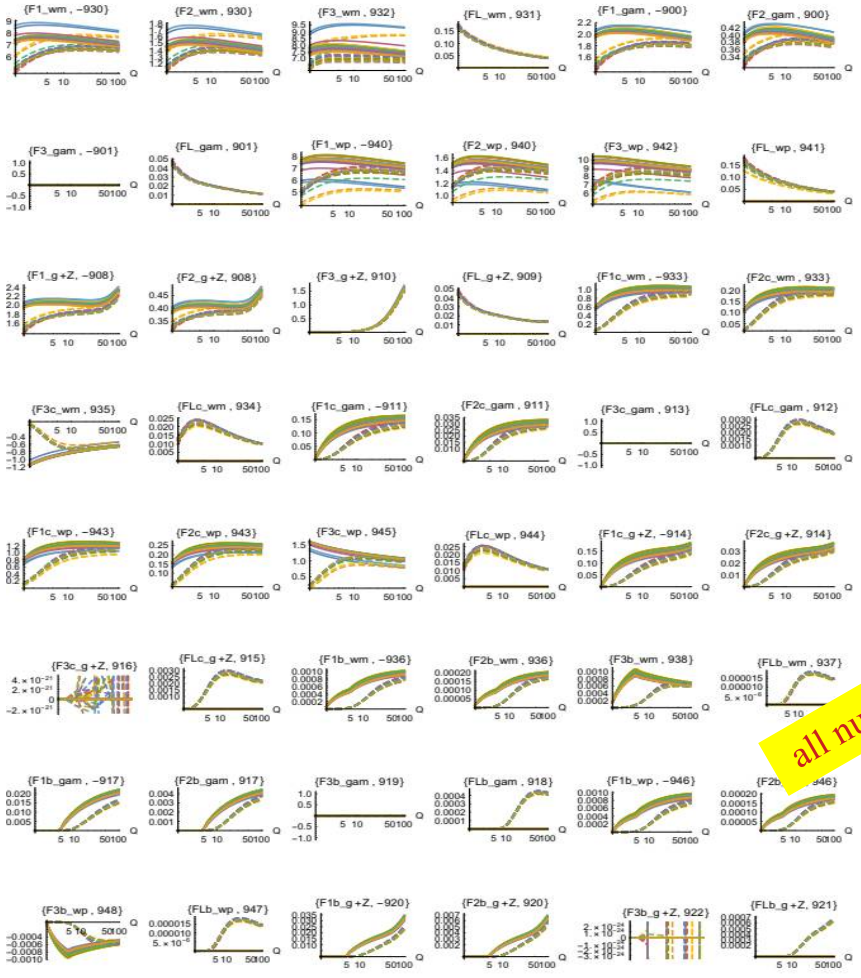



```
q0 = 10. ;
LogLinearPlot [ x pdf[1, flavors , x, q0] // Evaluate , {x, 10^-3, 1},
```



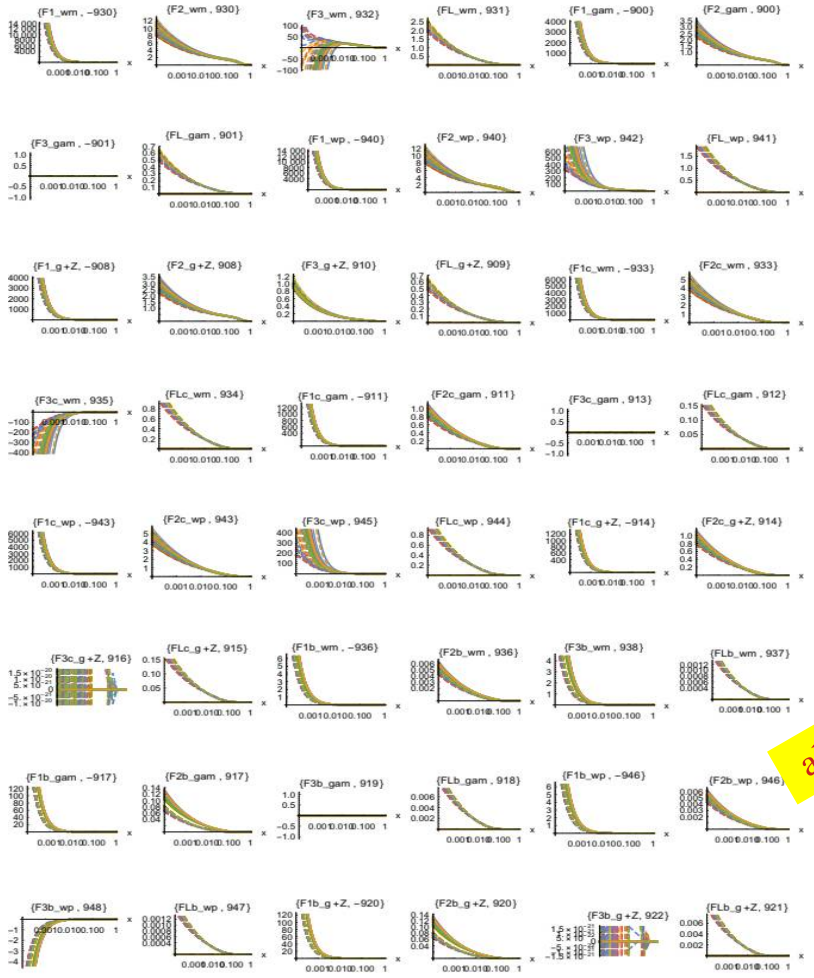
48 Structure Functions per Nuclei × ~22 Nuclei

Q dependence



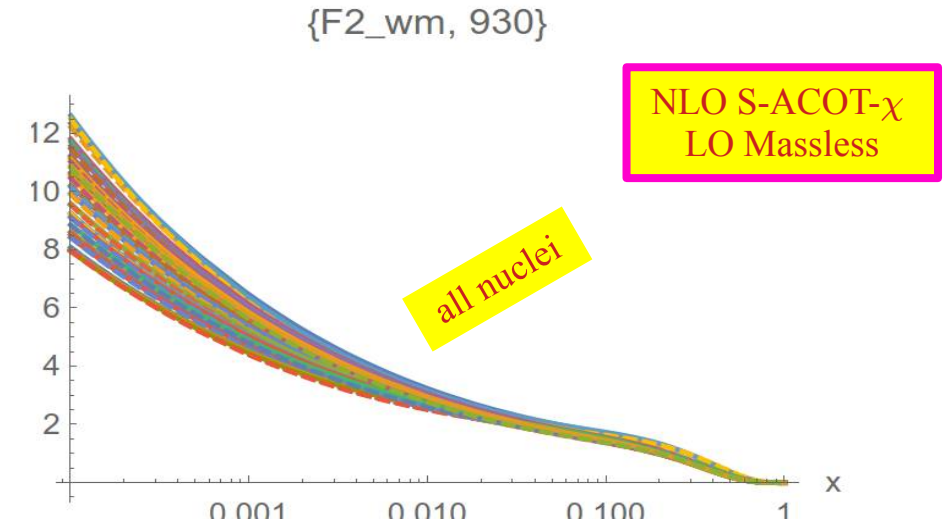
all nuclei

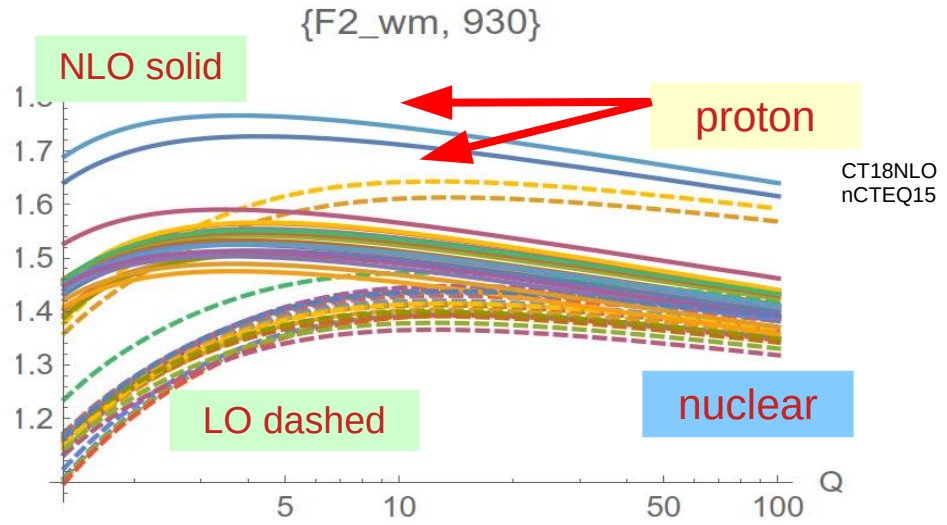
X dependence

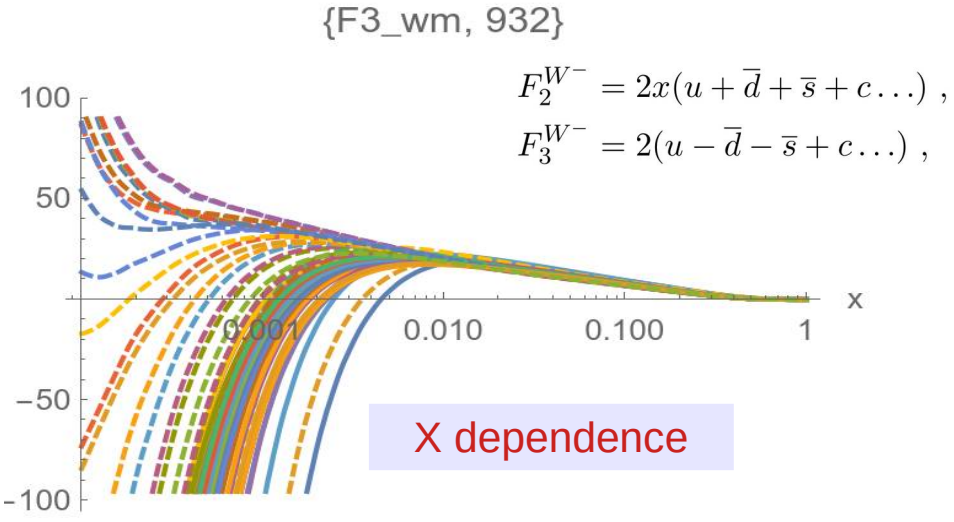


all nuclei

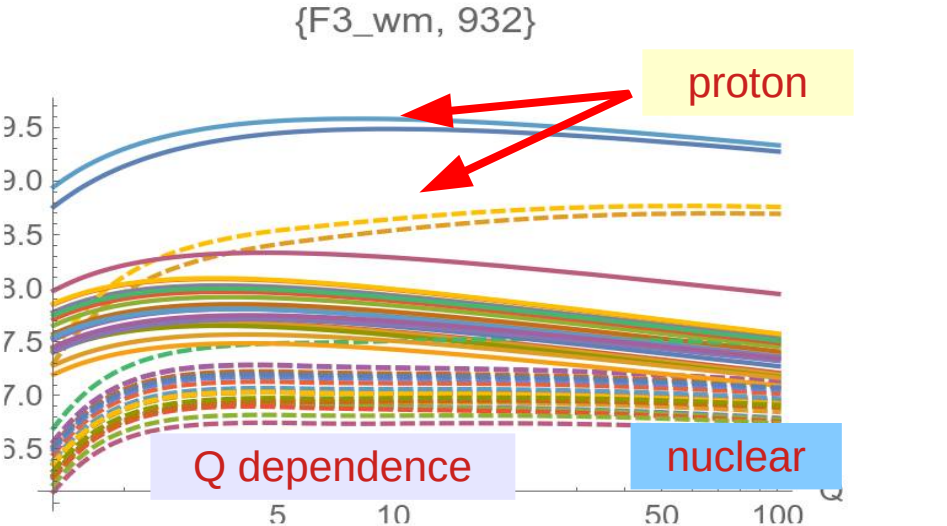
Sample Structure Functions: F_2^{W-}



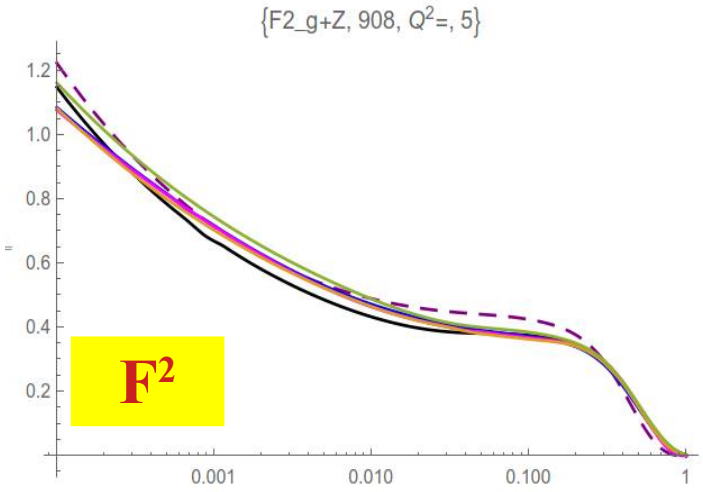


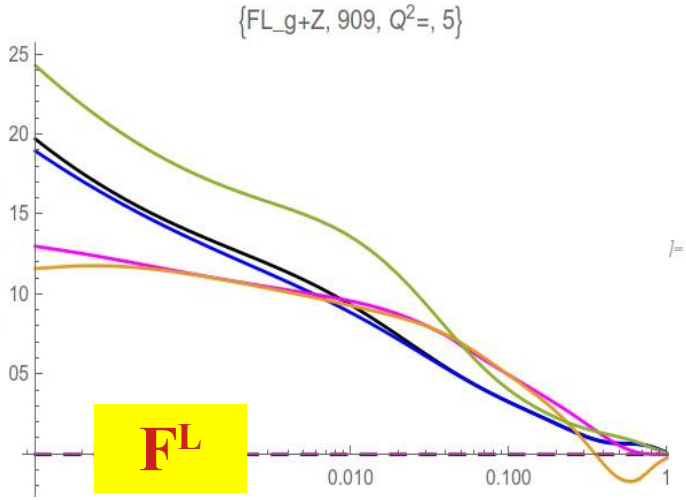


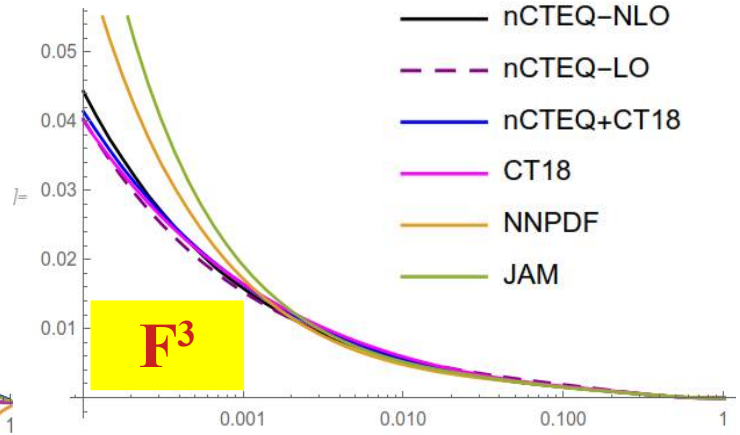
$$F_2^{W^-} = 2x(u + \bar{d} + \bar{s} + c \ldots) \ ,$$
$$F_3^{W^-} = 2(u - \bar{d} - \bar{s} + c \ldots) \ ,$$

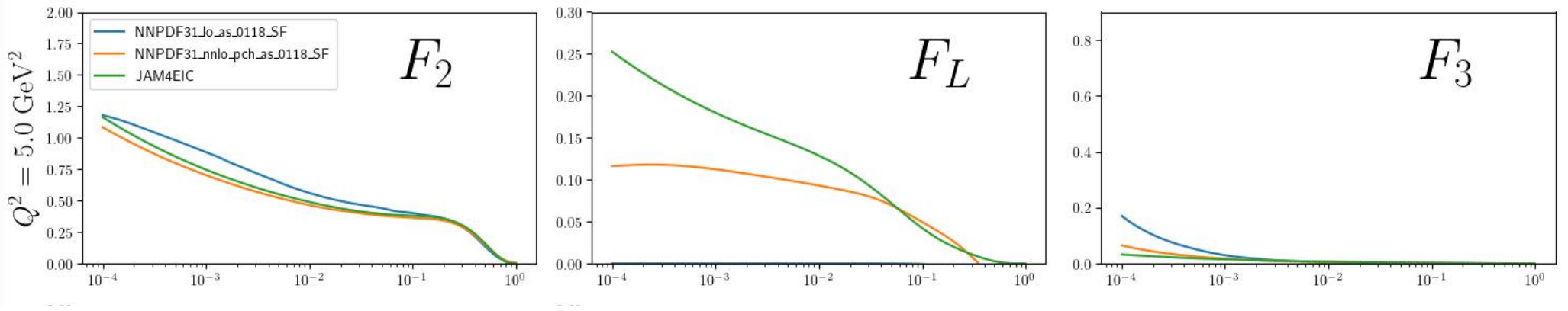


Cross Check: EIC Benchmark Plots *Neutral Current: γ+Z=NC*



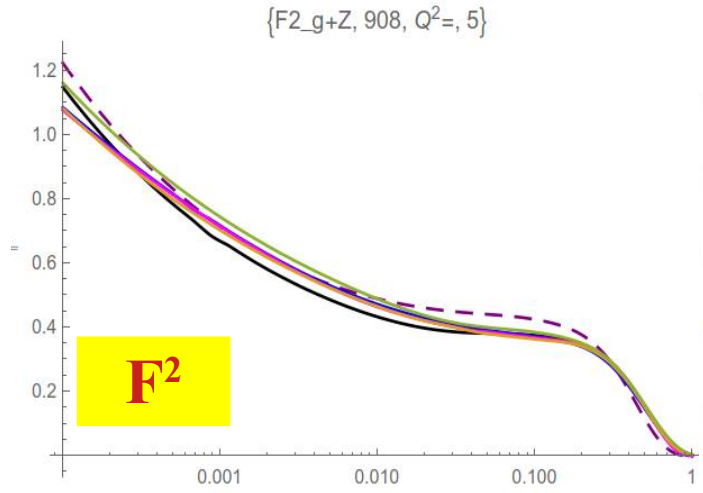


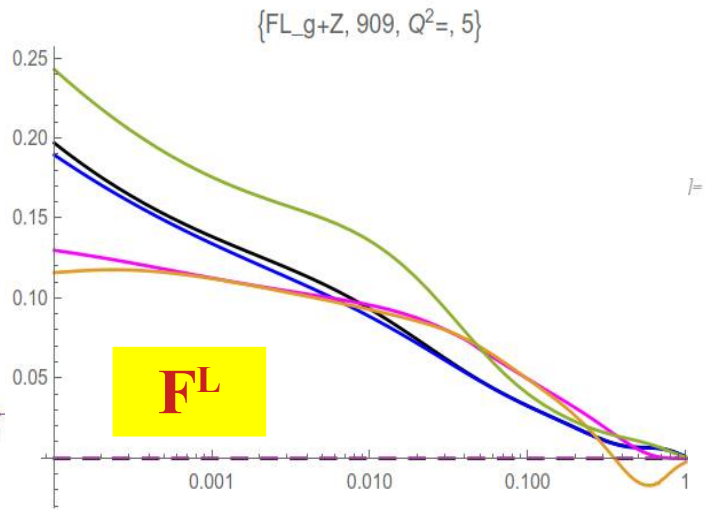


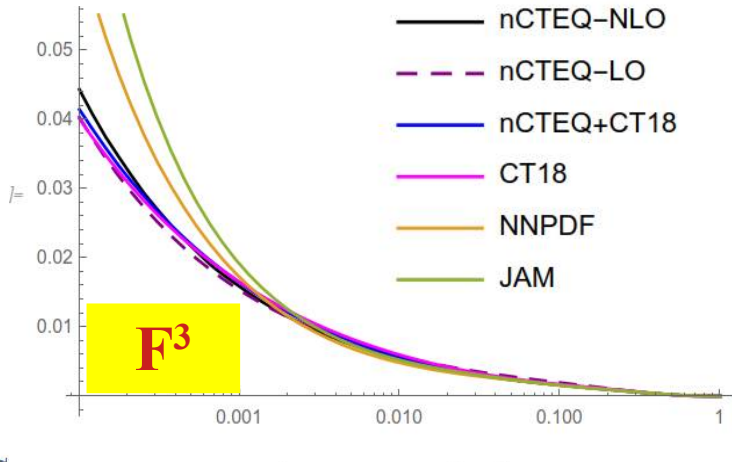


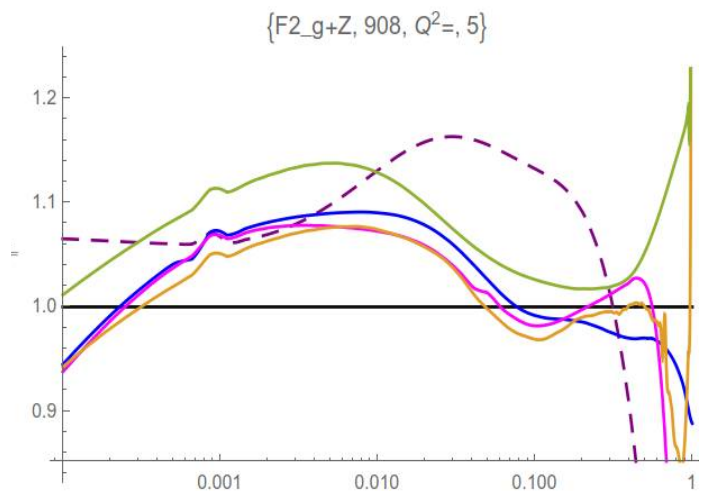
Cross Check: EIC Benchmark Plots

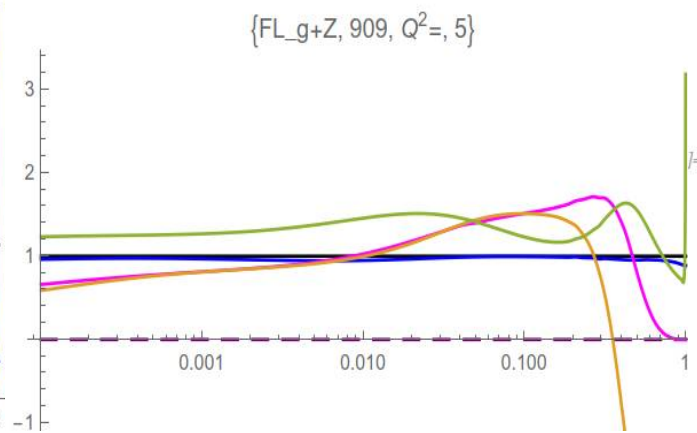
Neutral Current: γ+Z=NC

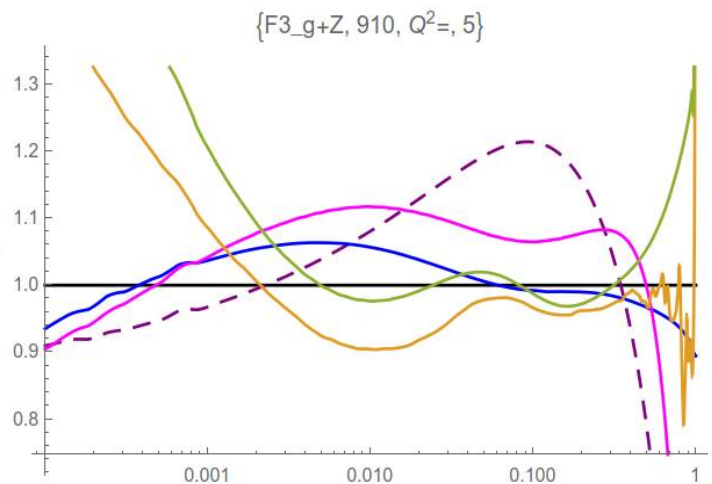




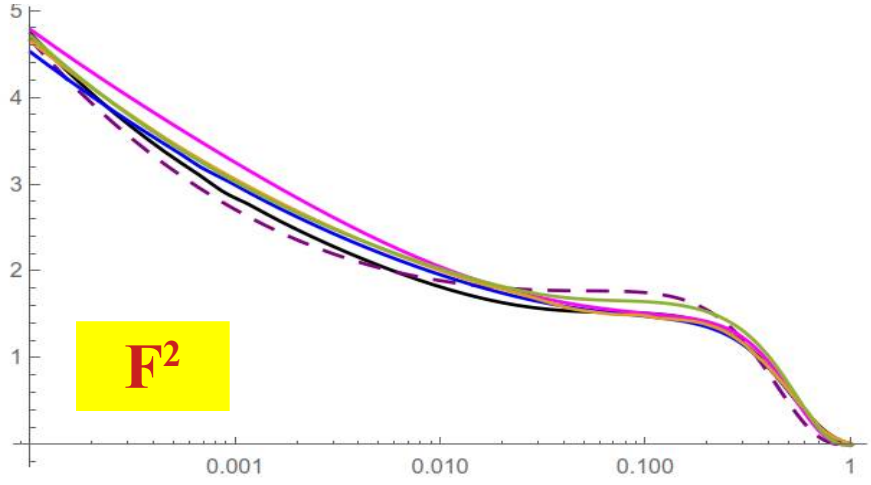


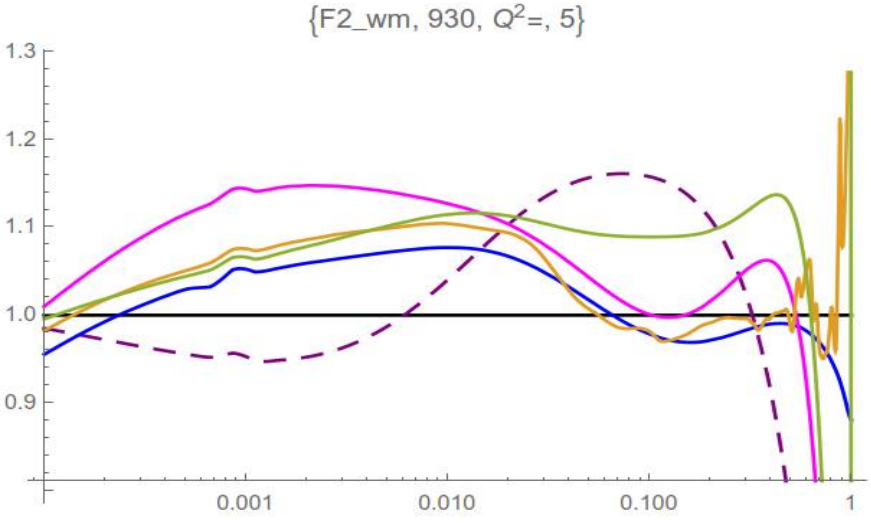


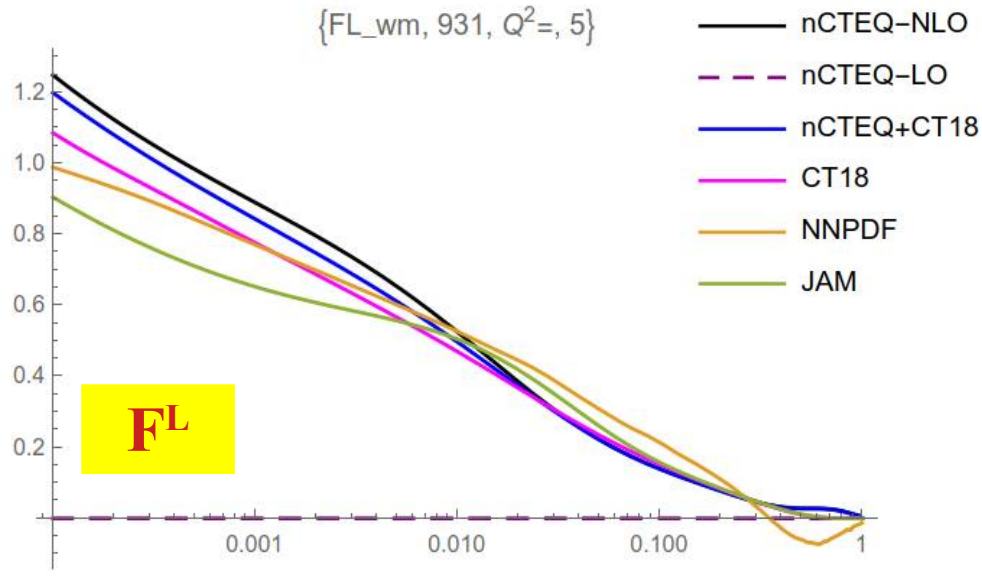


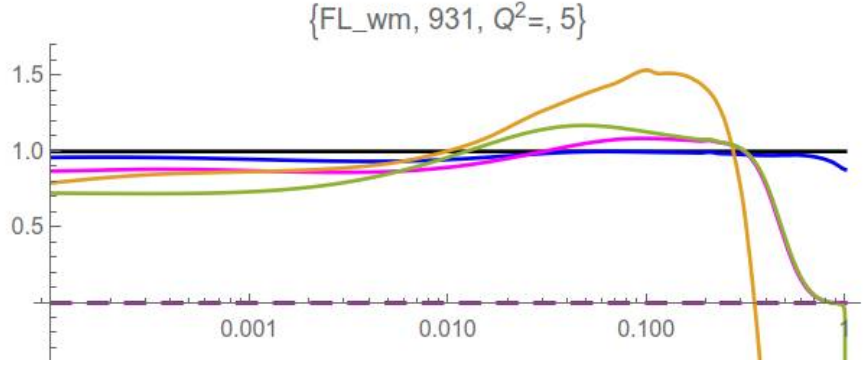


Cross Check: Charged Current W^-

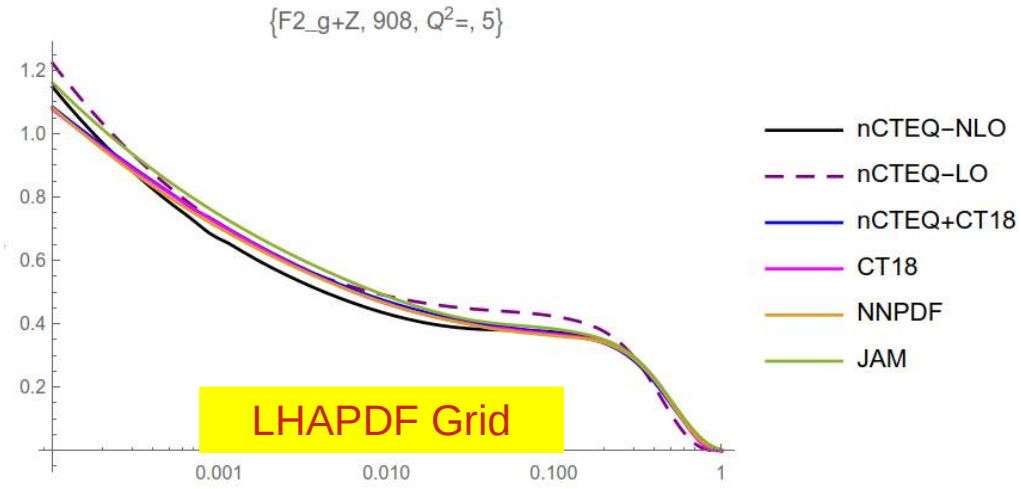




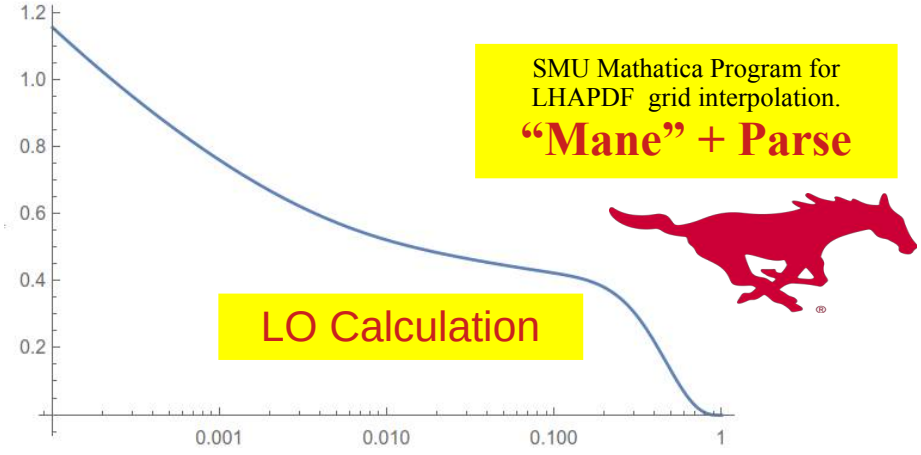




Mathematica Notebook w/ LO Calculations: *… provides flexibilty*




```
LogLinearPlot[ f2nc[1, x, Sqrt[5.0]], {x, 10^-4, 1}]
```



SMU Mathatica Program for LHAPDF grid interpolation.

"Mane" + Parse

- **Simple Cross Check**
- **PDF/SF Uncertainties**
- **Cross Sections $d\sigma$**
  - **w/ cuts (*e.g.* y_{min})**
  - **integrate $d\sigma$ & stats**
  - **Total, charm, bottom ...**

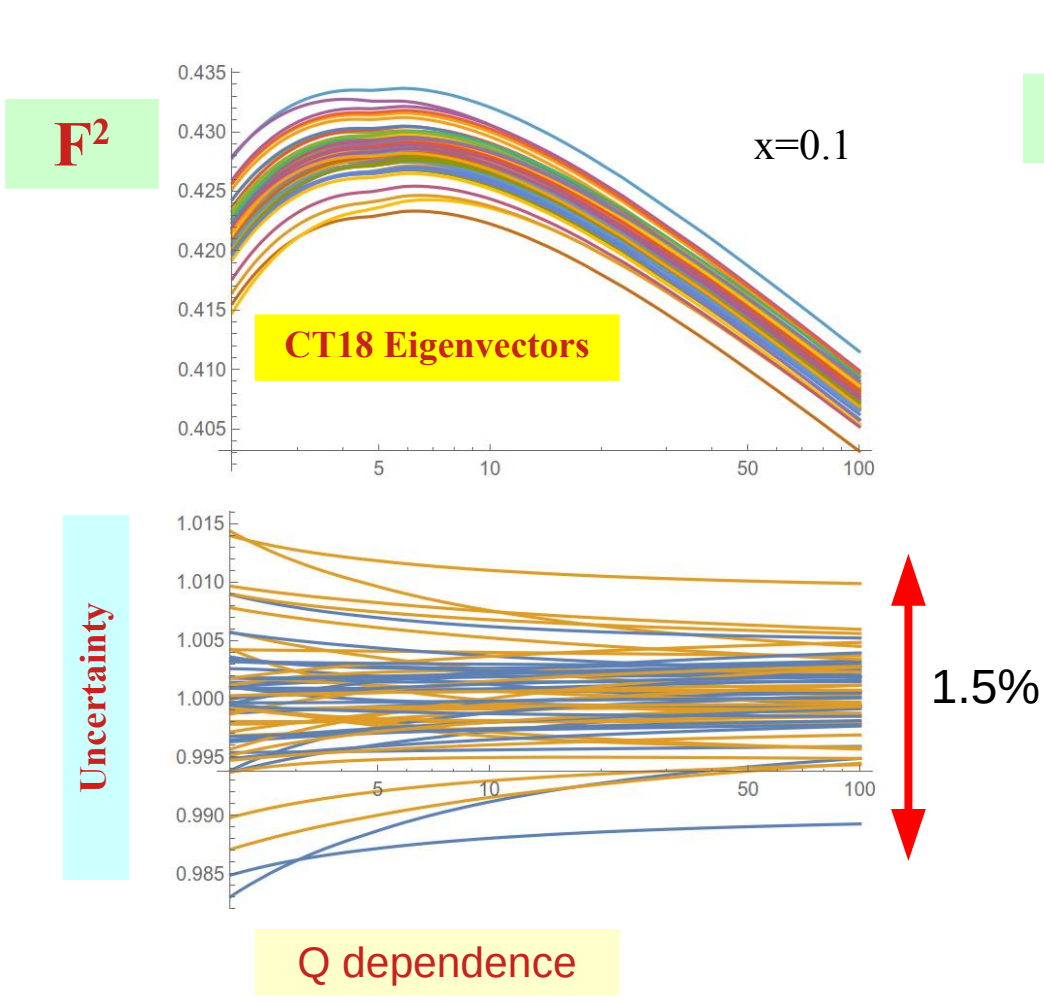
$$F_2^{NC} = x \sum_q e_q^2 (q + \bar{q})$$

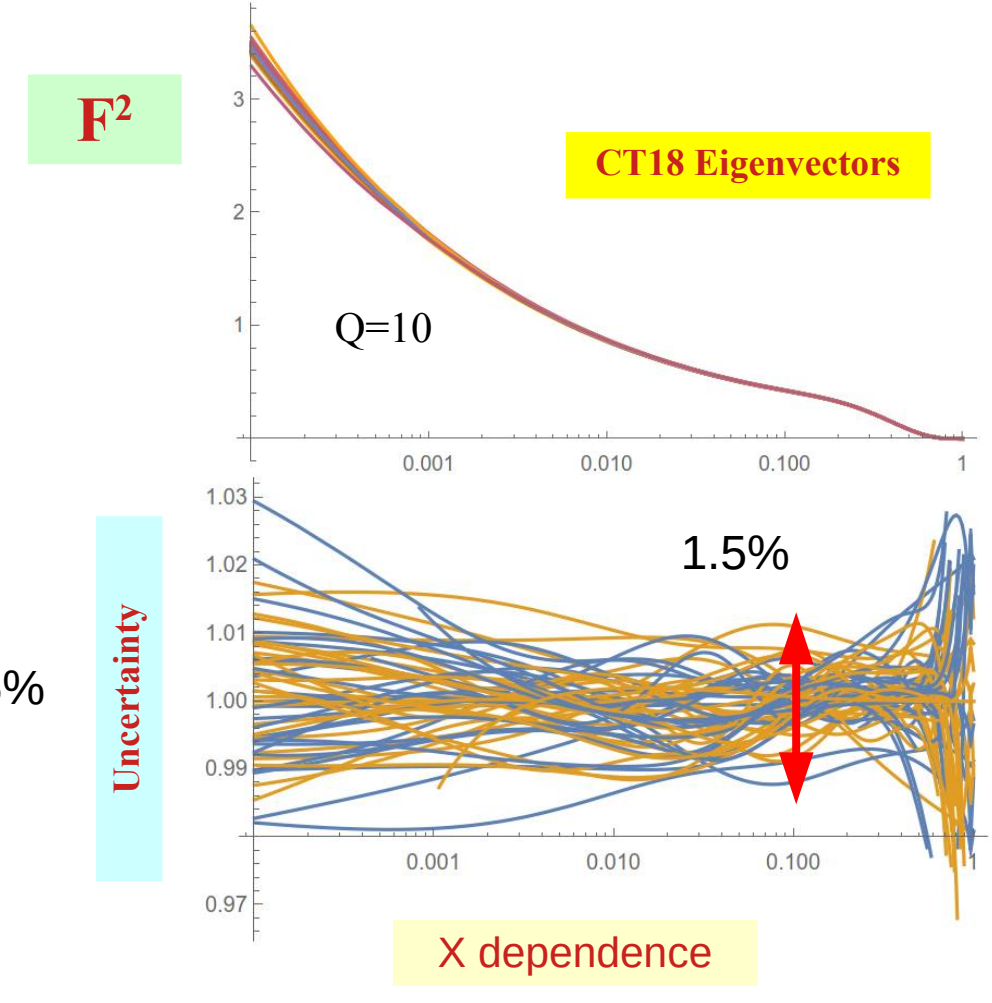
$$F_2^{W^-} = 2x(u + \bar{d} + \bar{s} + c \ldots) \ ,$$

$$F_3^{W^-} = 2(u - \bar{d} - \bar{s} + c \ldots) \ ,$$

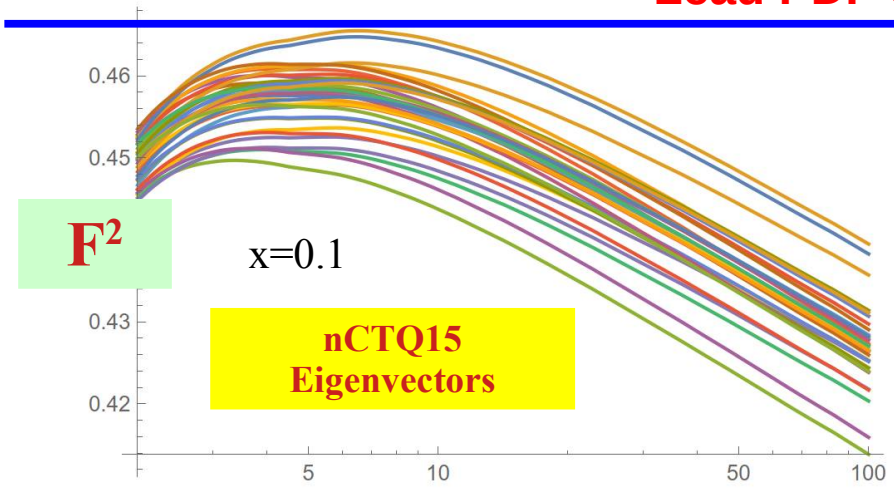
$$\frac{d^2\sigma_{Born}}{dx dQ^2}$$

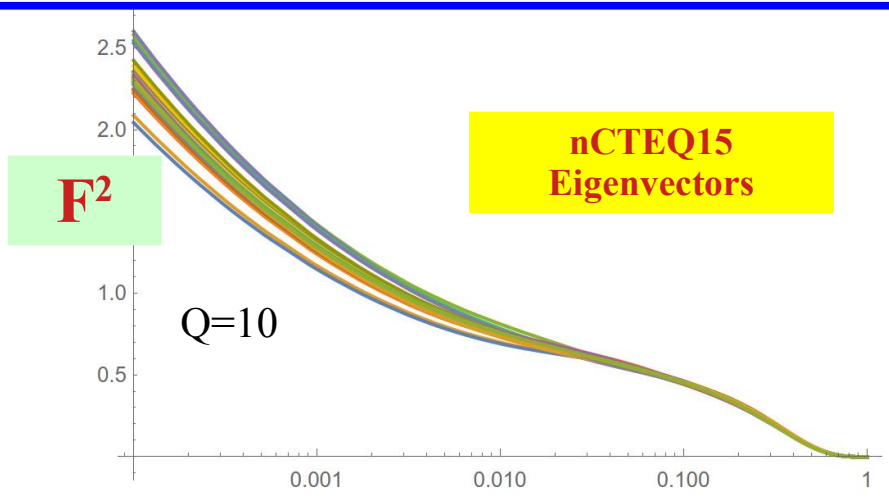
Proton PDF Uncertainty Eigenvectors

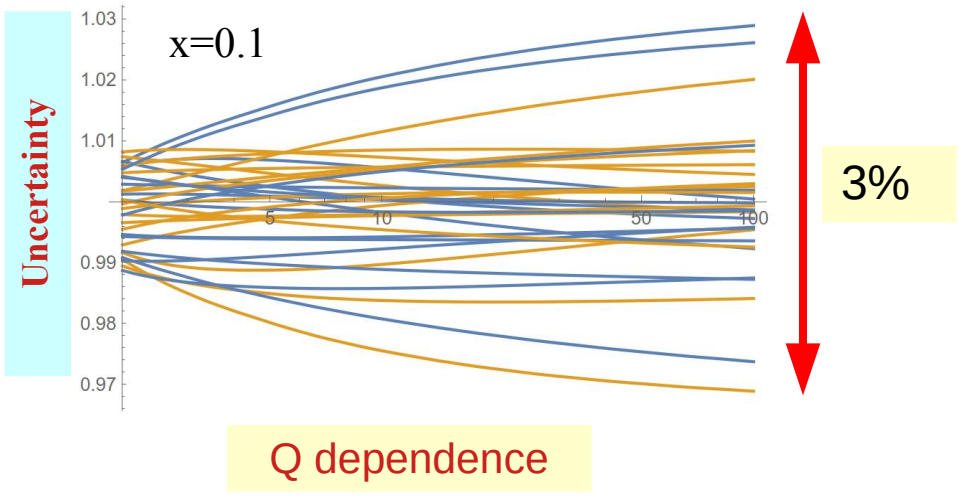


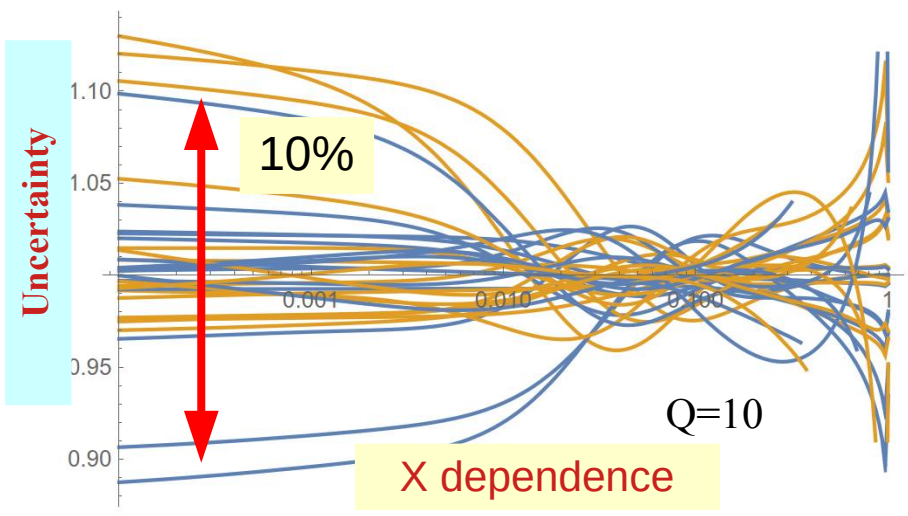


Lead PDF Uncertainty Eigenvectors









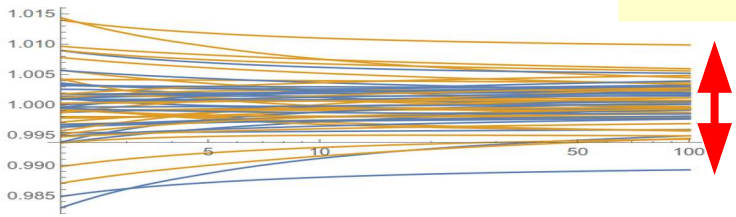
Compare Proton & Lead PDF Uncertainty

Proton

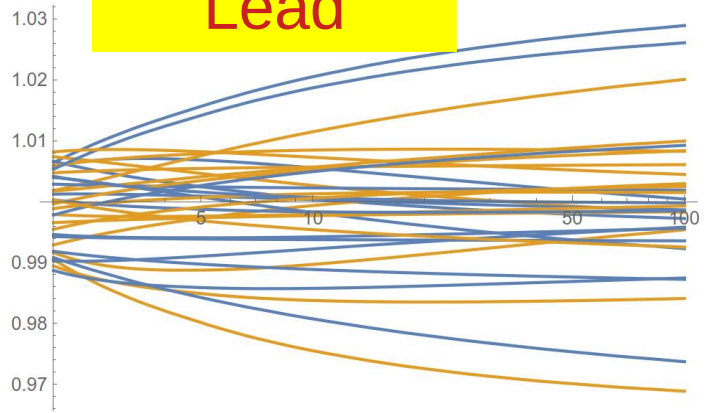
Lead

Uncertainty

1%



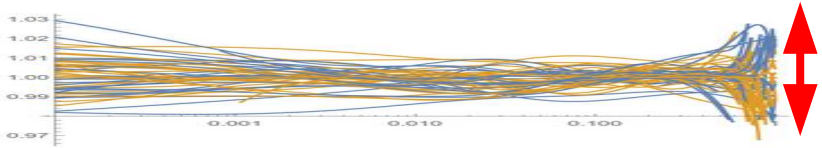
Q dependence



3%

Uncertainty

3%



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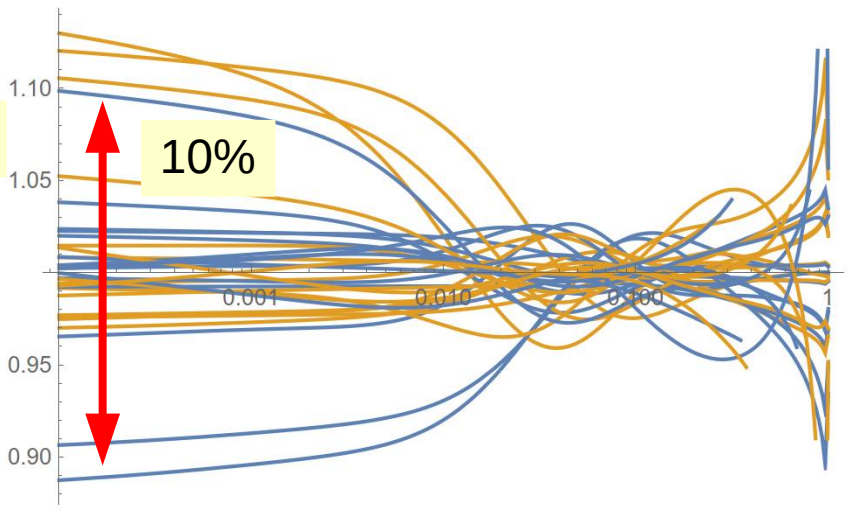


X dependence

Integrated Events: {x,Q} bins Proton & Nuclei

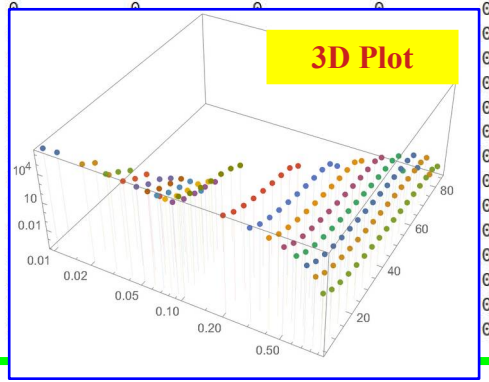
DIS Events per fb^{-1}

$$\frac{d^2\sigma^i}{dxdy} = \frac{4\pi\alpha^2}{xyQ^2}\,\eta^i\left\{\left(1 - y - \frac{x^2y^2M^2}{Q^2}\right)F_2^i + y^2xF_1^i \mp \left(y - \frac{y^2}{2}\right)xF_3^i\right\},$$

x

Q

	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
5	3 723 822	2 018 319	1 344 277	991 027	776 611	633 941	532 747	457 456	399 368	2 366 831	1 074 077	531 514	252 369	108 360	39 438	10 871	1750	72
10	566 494	333 857	229 844	171 984	135 727	111 147	93 506	80 276	70 015	410 721	181 168	87 012	40 093	16 687	5870	1554	237	9
15	70 604	94 750	67 664	52 203	42 068	34 952	29 710	25 699	22 540	133 658	59 016	28 078	12 779	5244	1814	471	70	3
20	0	19 137	25 889	20 254	16 618	14 041	12 101	10 584	9366	56 779	25 472	12 117	5487	2235	766	196	29	1
25	0	0	3463	8400	7713	6535	5683	5019	4483	27 937	12 856	6152	2785	1130	385	114	14	0
30	0	0	0	309	2642	3457	2992	2639	2365	15 104	7163	3463	1572	638	217	55	8	0
35	0	0	0	0	0	366	1266	1531	1367	8764	4271	2092	955	388	132	33	5	0
40	0	0	0	0	0	0	0	188	558	5360	2677	1331	612	250	85	21	3	0
45	0	0	0	0	0	0	0	0	0	2838	1747	881	409	167	57	14	2	0
50	0	0	0	0	0	0	0	0	0	1216	1182	601	281	116	39	10	1	0
55	0	0	0	0	0	0	0	0	0	424	830	422	199	82	28	7	1	0
60	0	0	0	0	0	0	0	0	0	44	600	304	144	60	21	5	1	0
65	0	0	0	0	0	0	0	0	0	0	283	224	106	44	15	4	1	0
70	0	0	0	0	0	0	0	0	0	0	91	170	80	33	12	3	0	0
75	0	0	0	0	0	0	0	0	0	0	5	117	61	26	9	2	0	0
80	0	0	0	0	0	0	0	0	0	0	0	46	48	20	7	2	0	0
85	0	0	0	0	0	0	0	0	0	0	0	7	38	16	5	1	0	0
90	0	0	0	0	0	0	0	0	0	0	0	0	18	13	4	1	0	0
95	0	0	0	0	0	0	0	0	0	0	0	0	3	10	4	1	0	0
100	0	0	0	0	0	0	0	0	0	0	0	0	0	5	3	1	0	0



Proton: $\sqrt{s}$ = 140 GeV

y_{min} cut

	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
5	3 012 451	1 769 246	1 222 710	920 451	731 027	602 305	509 629	439 898	385 628	2 310 229	1 059 438	526 418	250 502	107 708	39 238	10 823	1743	71
10	116 843	224 448	176 815	138 390	113 059	95 011	81 526	71 082	62 769	380 597	173 441	84 379	39 151	16 367	5774	1532	234	9
15	0	1220	22 091	34 086	30 971	26 367	23 004	20 376	18 243	114 948	54 046	26 383	12 177	5041	1755	477	68	2
20	0	0	0	15	3342	6935	7792	7698	6895	44 825	22 030	10 923	5062	2092	724	197	27	1
25	0	0	0	0	0	0	68	1201	1975	20 452	10 412	5275	2469	1024	354	91	13	0
30	0	0	0	0	0	0	0	0	0	6858	5441	2809	1332	556	193	49	7	0
35	0	0	0	0	0	0	0	0	0	1370	3110	1606	770	324	113	29	4	0
40	0	0	0	0	0	0	0	0	0	0	1611	977	470	199	70	18	3	0
45	0	0	0	0	0	0	0	0	0	0	247	629	301	128	45	12	2	0
50	0	0	0	0	0	0	0	0	0	0	0	239	203	85	30	8	1	0
55	0	0	0	0	0	0	0	0	0	0	0	13	127	59	21	5	1	0
60	0	0	0	0	0	0	0	0	0	0	0	0	17	43	15	4	1	0
65	0	0	0	0	0	0	0	0	0	0	0	0	0	10	11	3	0	0

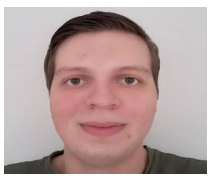
Nuclei: $\sqrt{s}$ = 90 GeV

y_{min} cut

Tools for PDF and Structure Functions

... LHAPDF Grids, Mathematica Notebooks ...

- Nuclear PDF Structure Function Grids
- ManeParse w/ Mathematica
- Structure Functions: Proton & Nuclear PDFs
  - Uncertainties: Proton & Nuclear
  - Cross Sections w/ cuts


Lucas

Brandon

Tim

Pavel

Fred

Link to test files:

https://smu.box.com/s/pqbo21a6wa4bh4w7e7fvshfhmvf9hjxt

xFitter

EIC² EIC Center at Jefferson Lab

C T E Q

nCTEQ nuclear parton distribution functions