Stony Brook University

PVDIS with a polarized ^{3}He target

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SoLID Collaboration meeting (2016-5-7)

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Outline

- Physics of PVDIS with a longitudinally polarized target and unpolarized electron beam
- Simulations and expected results
- Discussions

Physical motivations

- With purely electromagnetic scattering in DIS process
  - F_1^{γ}, F_2^{γ}, g_1^{γ}, g_2^{γ}

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- Taking into account γ-Z mixing, with parity violation
  - Additional interference structure functions: $F_1^{\gamma Z}$, $F_3^{\gamma Z}$, $g_1^{\gamma Z}$, $g_5^{\gamma Z}$

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  - ➢ Additional interference structure functions: $F_1^{\gamma Z}$, $F_3^{\gamma Z}$, $g_1^{\gamma Z}$, $g_5^{\gamma Z}$
- At JLab energy scale, $Q^2 \ll M_Z^2$

Pol. beam & unpol. Target: $$A_{beam} = \frac{G_F Q^2}{2\sqrt{2}\pi\alpha}\left[g_A^e \frac{F_1^{\gamma Z}}{F_1^{\gamma}} + g_V^e \frac{Y_-}{2Y_+}\frac{F_3^{\gamma Z}}{F_1^{\gamma}}\right]$$

$$g_A^e = -0.5, \quad g_V^e = -0.5 + 2sin^2(\theta_W)$$

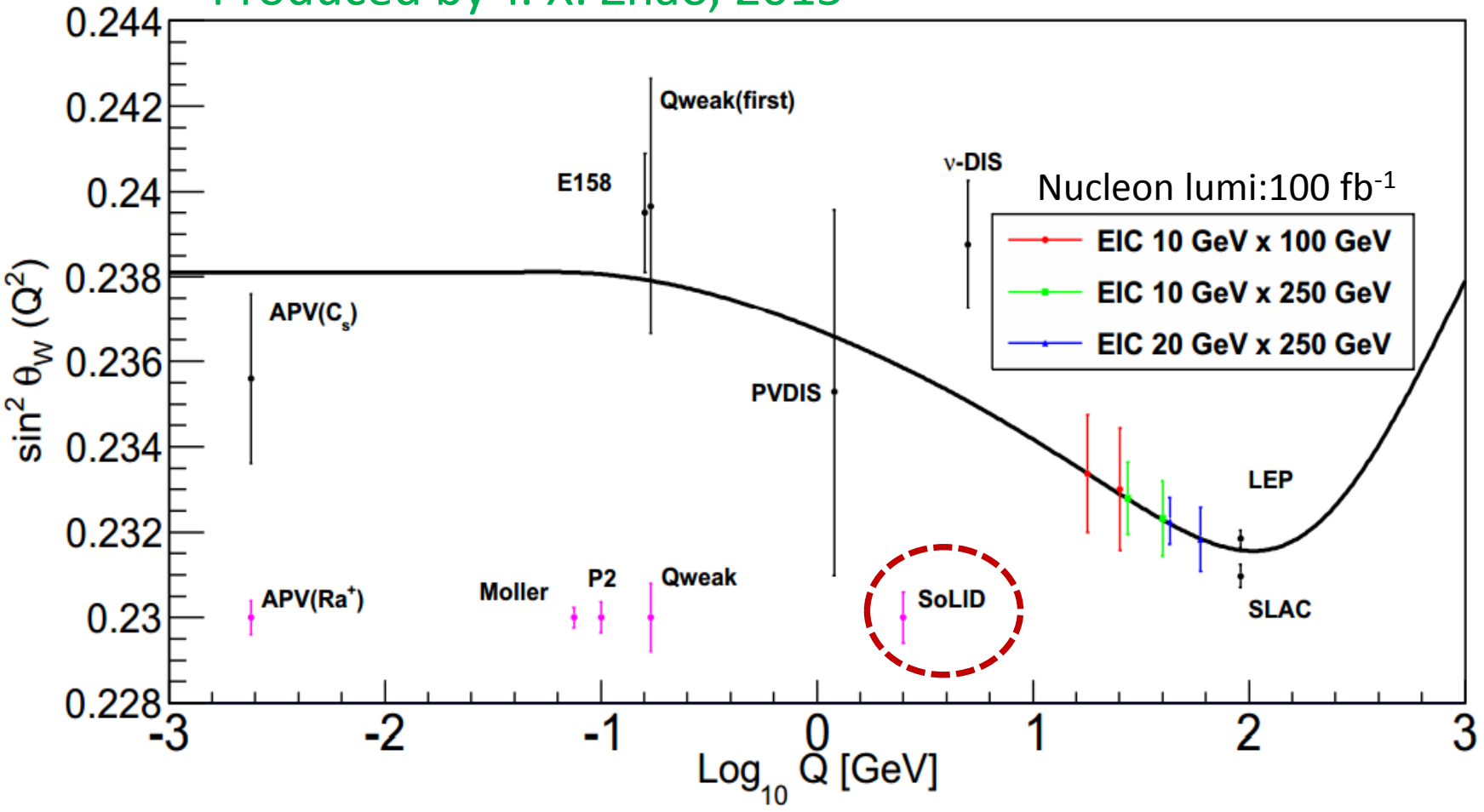
$$Y_- = 2y - y^2, \quad Y_+ = y^2 - 2y + 2.$$

$$F_1^{\gamma Z} = \sum_f e_{q_f}(g_V)_{q_f}(q_f + \bar{q}_f)$$

$$F_3^{\gamma Z} = 2\sum_f e_{q_f}(g_A)_{q_f}(q_f - \bar{q}_f)$$

Physical motivations

Produced by Y. X. Zhao, 2015



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  - ➢ F_1^{γ}, F_2^{γ}, g_1^{γ}, g_2^{γ}
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Unpol. beam & pol. Target:

$$A_L = \frac{G_F Q^2}{2\sqrt{2}\pi\alpha}\left[g_V^e \frac{g_5^{\gamma Z}}{F_1^{\gamma}} + g_A^e \frac{Y_-}{Y_+}\frac{g_1^{\gamma Z}}{F_1^{\gamma}}\right]$$

Physical motivations

Unpol. beam & pol. Target:

$$A_L = \frac{G_F Q^2}{2\sqrt{2}\pi\alpha}\left[g_V^e \frac{g_5^{\gamma Z}}{F_1^\gamma} + g_A^e \frac{Y_-}{Y_+}\frac{g_1^{\gamma Z}}{F_1^\gamma}\right]$$

$$g_1^{\gamma Z} = \sum_f e_{q_f}(g_V)_{q_f}(\Delta q_f + \Delta\bar{q}_f) \qquad g_5^{\gamma Z} = \sum_f e_{q_f}(g_A)_{q_f}(\Delta q_f - \Delta\bar{q}_f)$$

$$g_1^{n,\gamma Z} = \frac{1}{9}\left(\Delta u + \Delta\bar{u} + \Delta c + \Delta\bar{c} + \Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s}\right) = g_1^{p,\gamma Z}$$

$$g_5^{n,\gamma Z} = \left[\frac{1}{3}\left(\Delta d_V + \Delta s - \Delta\bar{s}\right) + \frac{1}{6}\left(\Delta u_V + \Delta c - \Delta\bar{c}\right)\right]$$

$$g_5^{p,\gamma Z} = \left[\frac{1}{3}\left(\Delta u_V + \Delta c - \Delta\bar{c}\right) + \frac{1}{6}\left(\Delta d_V + \Delta s - \Delta\bar{s}\right)\right]$$

- Unique linear combinations of the quark polarization
- Never been measured before

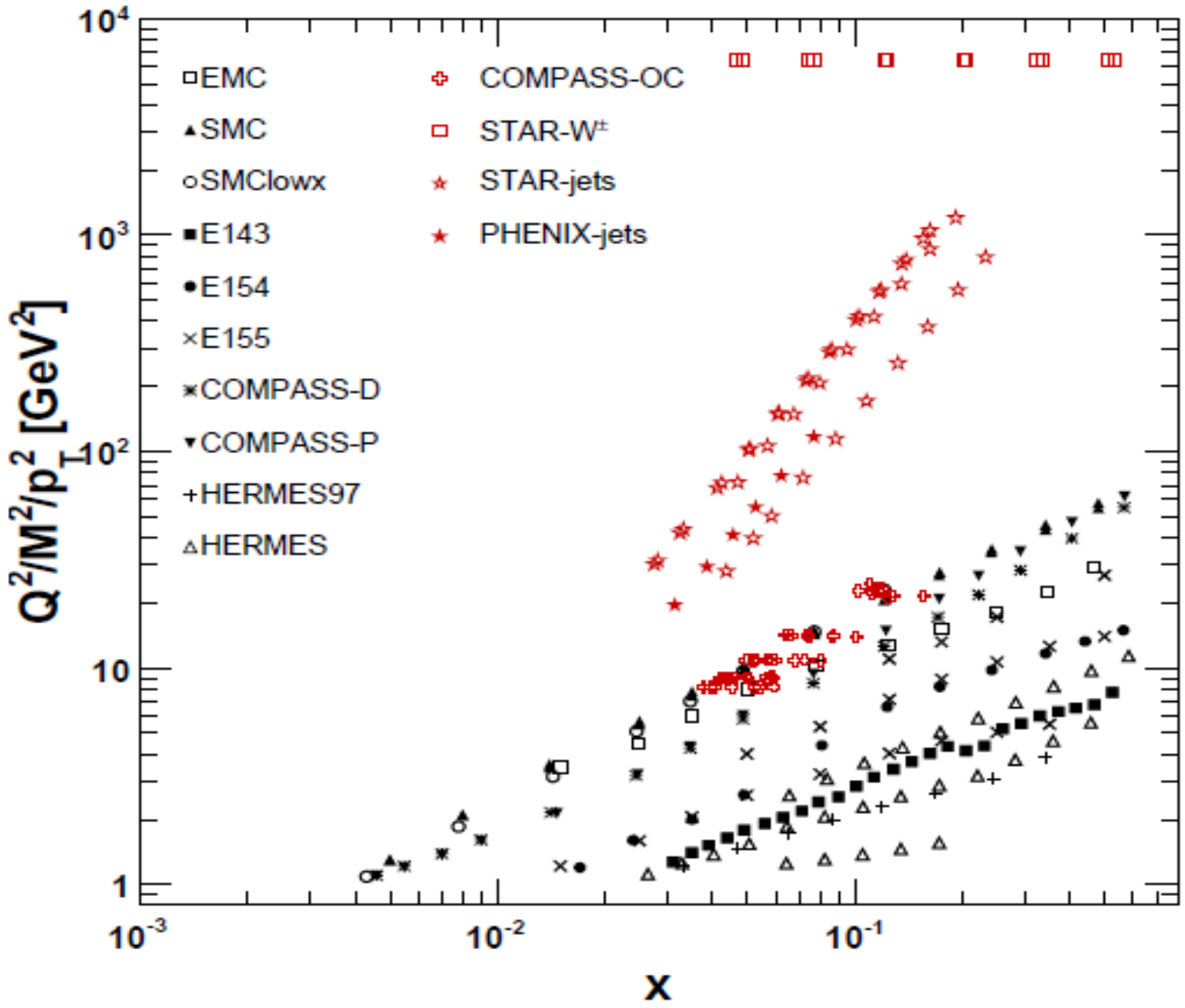
^{3}He asymmetry calculations using World PDF fits

$$A_{^3\mathrm{He}} = P_n(1 - f_p)A_n + P_p f_p A_p,$$

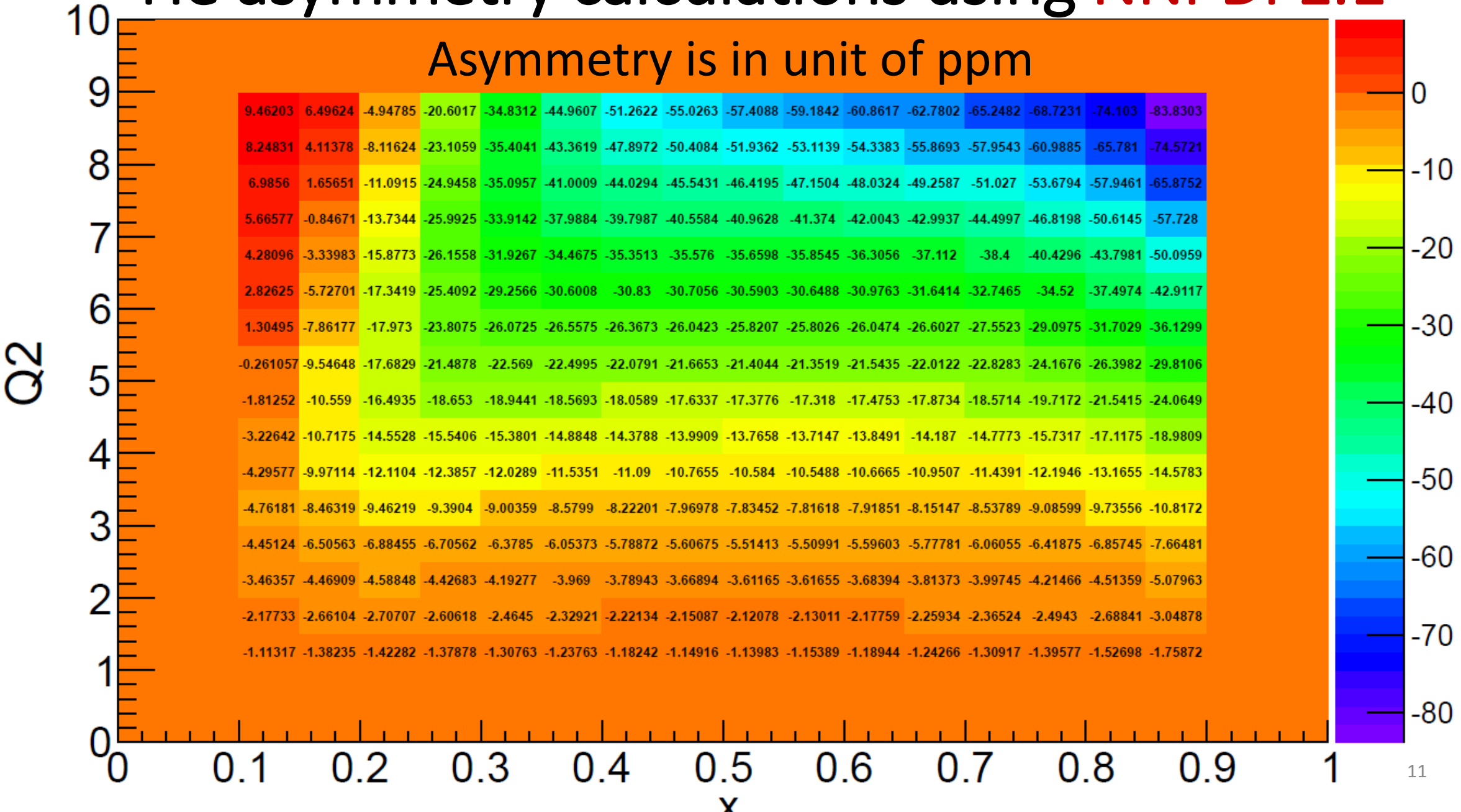
$P_n = 0.86^{+0.036}_{-0.02}$ and $P_p = -0.028^{+0.009}_{-0.004}$ $\qquad f_p = \frac{2\sigma_p}{\sigma_{^3\mathrm{He}}}$

- Using LHAPDF6 (Released on Dec 22, 2015)
  - A C++ interface to access both unpolarized and polarized pdfs
    - Pdf sets: https://lhapdf.hepforge.org/pdfsets.html
    - Unpolarized pdfs: CT, MRST, MSTW, MMHT, etc
    - Polarized pdfs: only NNPDF (global data fit up to 2014)

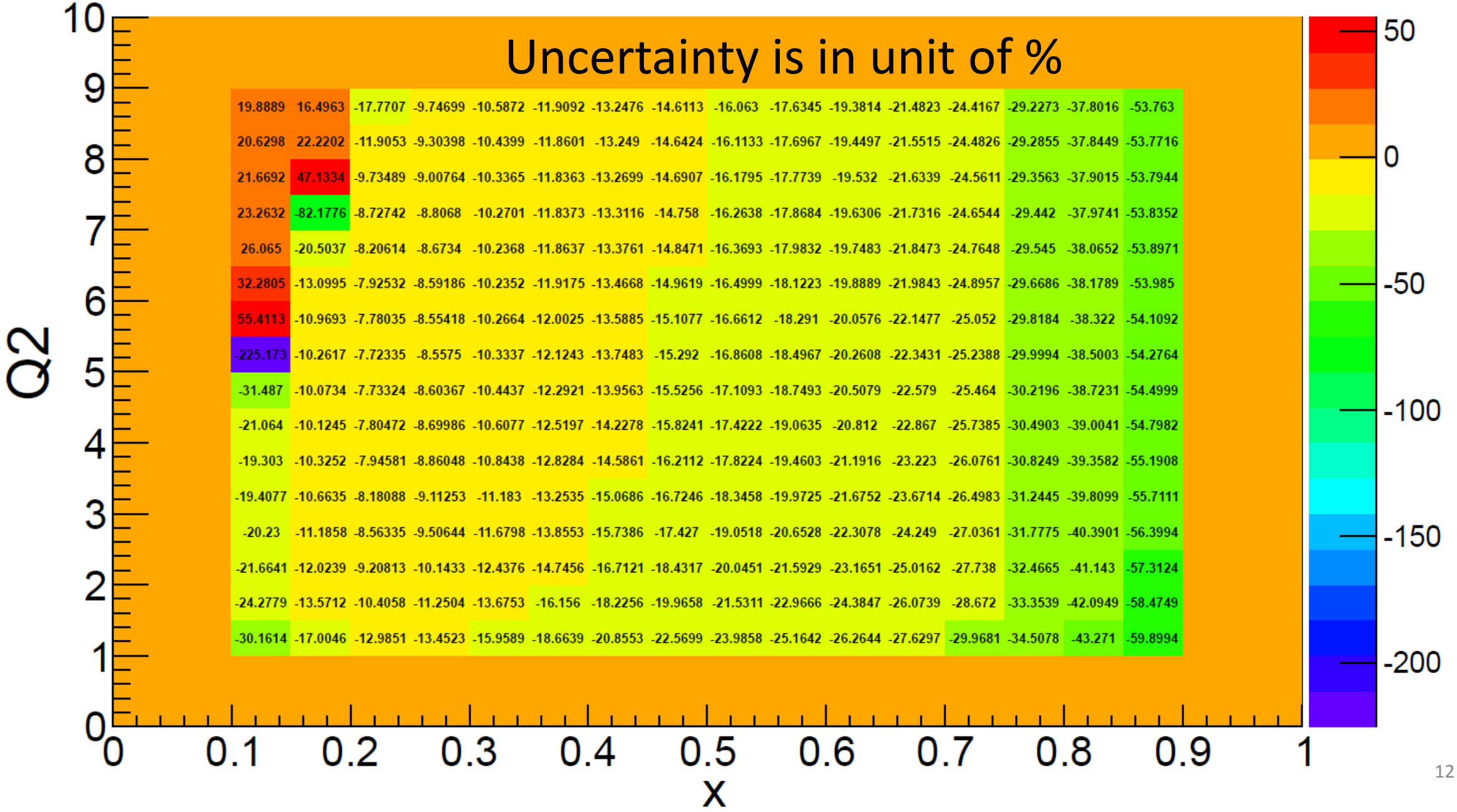
NNPDFpol1.1 data set



^{3}He asymmetry calculations using NNPDF1.1



^{3}He asymmetry uncertainty using NNPDF1.1



^{3}He asymmetry calculations using World PDF fits

X

Q^2

	0.125	0.175	0.225	0.275	0.325	0.375	0.425	0.475	0.525	0.575	0.625	0.675	0.725	0.775	0.825	0.875
asymmetry uncertainty (%) from DSSV2008:																
8.750	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(5.8%)	(7.1%)	(8.8%)	(10.9%)	(13.6%)	(17.2%)	(22.3%)
8.250	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(4.8%)	(5.8%)	(7.1%)	(8.8%)	(10.9%)	(13.6%)	(17.2%)	(22.3%)
7.750	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(4.1%)	(4.8%)	(5.8%)	(7.1%)	(8.8%)	(10.9%)	(13.6%)	(17.3%)	(22.4%)
7.250	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(4.1%)	(4.8%)	(5.8%)	(7.1%)	(8.8%)	(10.9%)	(13.7%)	(17.3%)	(22.4%)
6.750	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(3.6%)	(4.1%)	(4.8%)	(5.8%)	(7.2%)	(8.8%)	(11.0%)	(13.7%)	(17.4%)	(22.5%)
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4.750	(0.0%)	(0.0%)	(0.0%)	(3.4%)	(3.3%)	(3.4%)	(3.7%)	(4.2%)	(4.9%)	(6.0%)	(7.3%)	(9.0%)	(11.2%)	(14.0%)	(17.7%)	(22.9%)
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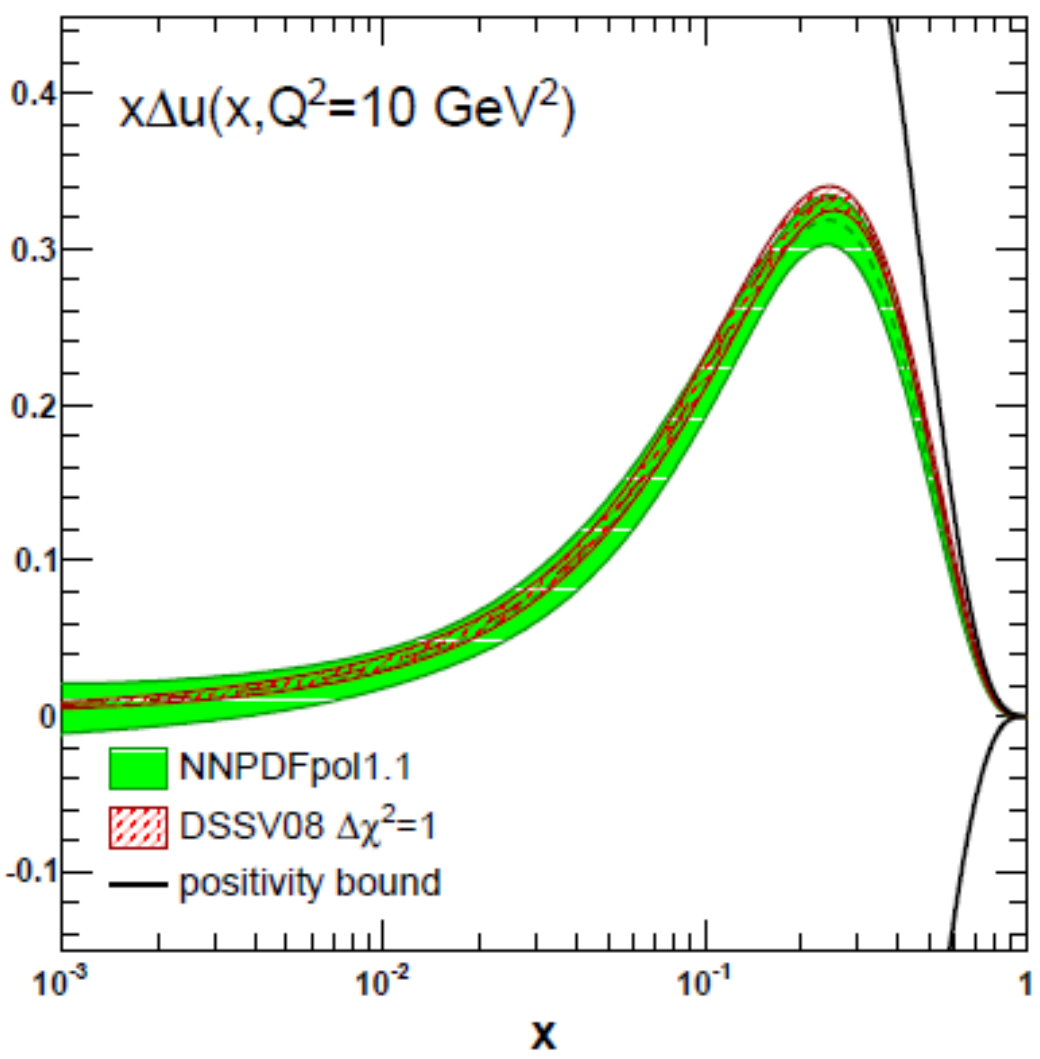
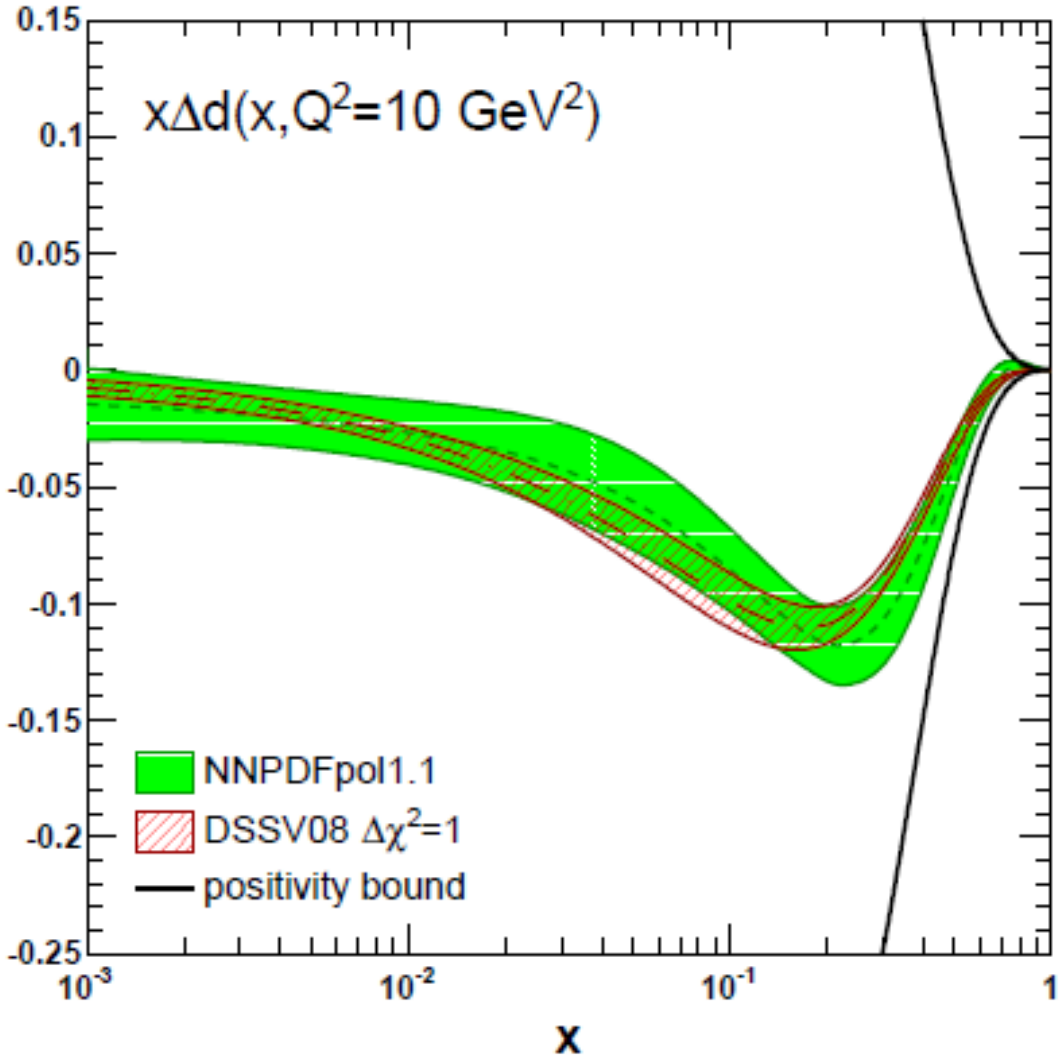
3.750	(0.0%)	(0.0%)	(4.1%)	(3.6%)	(3.4%)	(3.5%)	(3.8%)	(4.3%)	(5.1%)	(6.1%)	(7.5%)	(9.2%)	(11.4%)	(14.2%)	(17.9%)	(23.3%)
3.250	(0.0%)	(5.9%)	(4.3%)	(3.7%)	(3.5%)	(3.6%)	(3.9%)	(4.4%)	(5.2%)	(6.2%)	(7.6%)	(9.3%)	(11.5%)	(14.3%)	(18.1%)	(23.5%)
2.750	(0.0%)	(6.2%)	(4.6%)	(4.0%)	(3.7%)	(3.7%)	(4.0%)	(4.6%)	(5.3%)	(6.4%)	(7.7%)	(9.5%)	(11.7%)	(14.6%)	(18.4%)	(23.8%)
2.250	(11.3%)	(6.9%)	(5.2%)	(4.4%)	(4.0%)	(4.0%)	(4.2%)	(4.7%)	(5.5%)	(6.6%)	(7.9%)	(9.7%)	(11.9%)	(14.8%)	(18.7%)	(24.2%)
1.750	(12.9%)	(8.3%)	(6.2%)	(5.1%)	(4.5%)	(4.3%)	(4.6%)	(5.1%)	(5.8%)	(6.9%)	(8.2%)	(10.0%)	(12.3%)	(15.2%)	(19.1%)	(24.7%)
1.250	(16.7%)	(11.4%)	(8.5%)	(6.6%)	(5.5%)	(5.1%)	(5.1%)	(5.6%)	(6.3%)	(7.4%)	(8.7%)	(10.5%)	(12.8%)	(15.7%)	(19.7%)	(25.4%)
asymmetry uncertainty (%) among all 4 PDFs:																
8.750	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(5.1%)	(7.6%)	(11.1%)	(15.8%)	(22.9%)	(33.7%)	(51.3%)
8.250	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(3.1%)	(5.0%)	(7.6%)	(11.0%)	(15.7%)	(22.7%)	(33.5%)	(51.0%)
7.750	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(2.7%)	(3.1%)	(5.0%)	(7.5%)	(11.0%)	(15.6%)	(22.5%)	(33.2%)	(50.6%)
7.250	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(2.8%)	(3.0%)	(4.9%)	(7.5%)	(10.9%)	(15.6%)	(22.3%)	(33.0%)	(50.3%)
6.750	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(3.0%)	(2.8%)	(3.0%)	(4.9%)	(7.5%)	(10.9%)	(15.5%)	(22.2%)	(32.8%)	(50.1%)
6.250	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(3.6%)	(3.1%)	(2.9%)	(3.0%)	(4.9%)	(7.5%)	(10.9%)	(15.5%)	(22.1%)	(32.6%)	(49.9%)
5.750	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(4.3%)	(3.7%)	(3.2%)	(3.0%)	(2.9%)	(4.8%)	(7.3%)	(10.6%)	(15.2%)	(21.7%)	(31.9%)	(48.9%)
5.250	(0.0%)	(0.0%)	(0.0%)	(4.8%)	(4.4%)	(3.8%)	(3.3%)	(3.1%)	(2.9%)	(4.7%)	(7.1%)	(10.4%)	(14.9%)	(21.3%)	(31.2%)	(48.0%)
4.750	(0.0%)	(0.0%)	(0.0%)	(5.0%)	(4.6%)	(4.0%)	(3.5%)	(3.3%)	(3.0%)	(4.7%)	(7.1%)	(10.4%)	(14.9%)	(21.3%)	(31.0%)	(47.7%)
4.250	(0.0%)	(0.0%)	(5.4%)	(5.1%)	(4.7%)	(4.1%)	(3.6%)	(3.4%)	(3.2%)	(4.7%)	(7.1%)	(10.4%)	(14.9%)	(21.2%)	(30.7%)	(47.4%)
3.750	(0.0%)	(0.0%)	(5.6%)	(5.3%)	(4.8%)	(4.2%)	(3.8%)	(3.6%)	(3.4%)	(4.6%)	(7.0%)	(10.2%)	(14.6%)	(20.9%)	(30.3%)	(46.5%)
3.250	(0.0%)	(6.5%)	(5.8%)	(5.5%)	(5.0%)	(4.4%)	(4.0%)	(3.8%)	(3.6%)	(4.5%)	(6.8%)	(10.0%)	(14.3%)	(20.4%)	(29.5%)	(45.0%)
2.750	(0.0%)	(7.0%)	(6.1%)	(5.7%)	(5.2%)	(4.6%)	(4.3%)	(4.1%)	(3.9%)	(4.5%)	(6.8%)	(9.9%)	(14.2%)	(20.3%)	(29.3%)	(44.4%)
2.250	(9.4%)	(7.7%)	(6.6%)	(6.0%)	(5.5%)	(5.0%)	(4.7%)	(4.5%)	(4.3%)	(4.4%)	(6.7%)	(9.7%)	(13.9%)	(19.8%)	(28.6%)	(43.4%)
1.750	(11.1%)	(9.0%)	(7.6%)	(6.7%)	(6.0%)	(5.6%)	(5.2%)	(4.9%)	(4.6%)	(4.2%)	(5.5%)	(8.2%)	(11.9%)	(17.2%)	(25.3%)	(38.7%)
1.250	(14.9%)	(11.7%)	(9.6%)	(8.2%)	(7.2%)	(6.5%)	(5.9%)	(5.5%)	(5.0%)	(4.6%)	(5.3%)	(7.8%)	(11.4%)	(16.6%)	(24.5%)	(37.6%)

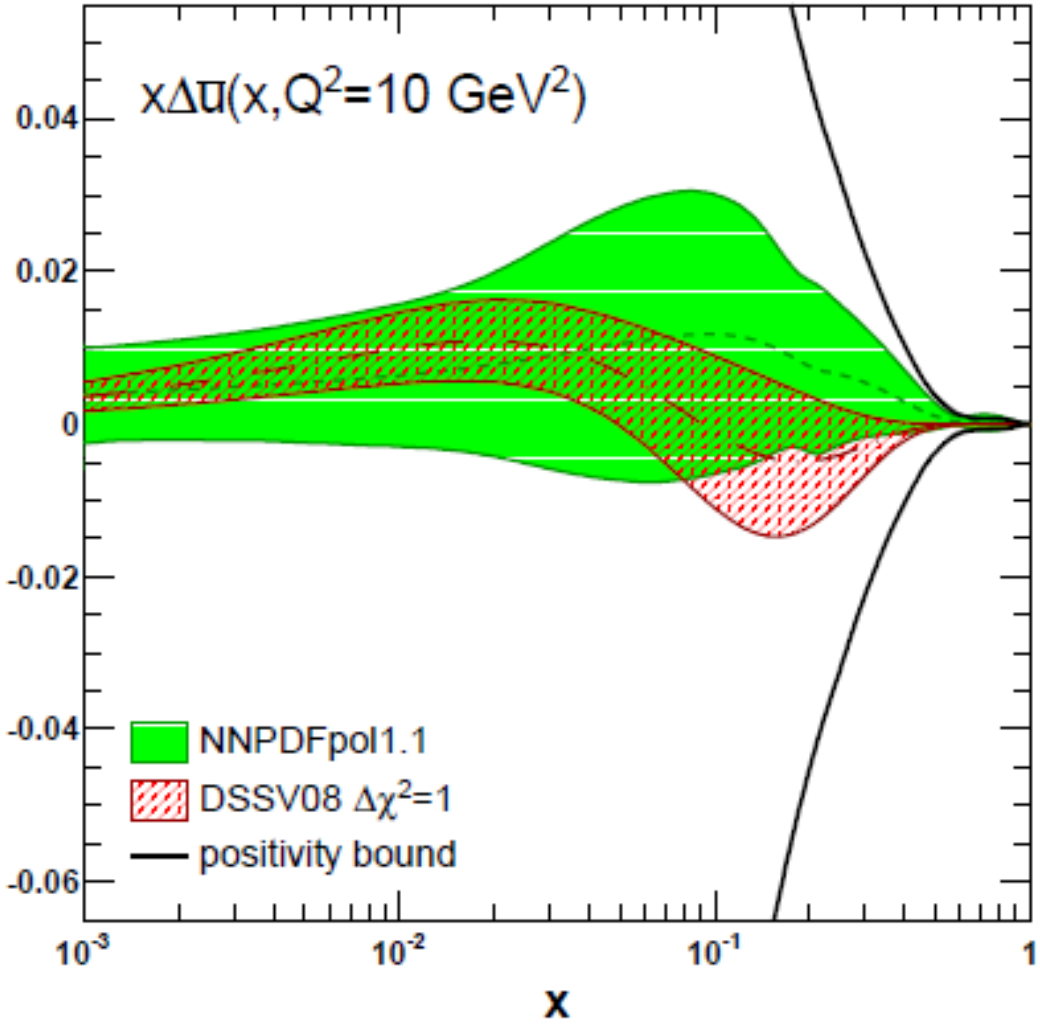
Calculated by Xiaochao Zheng

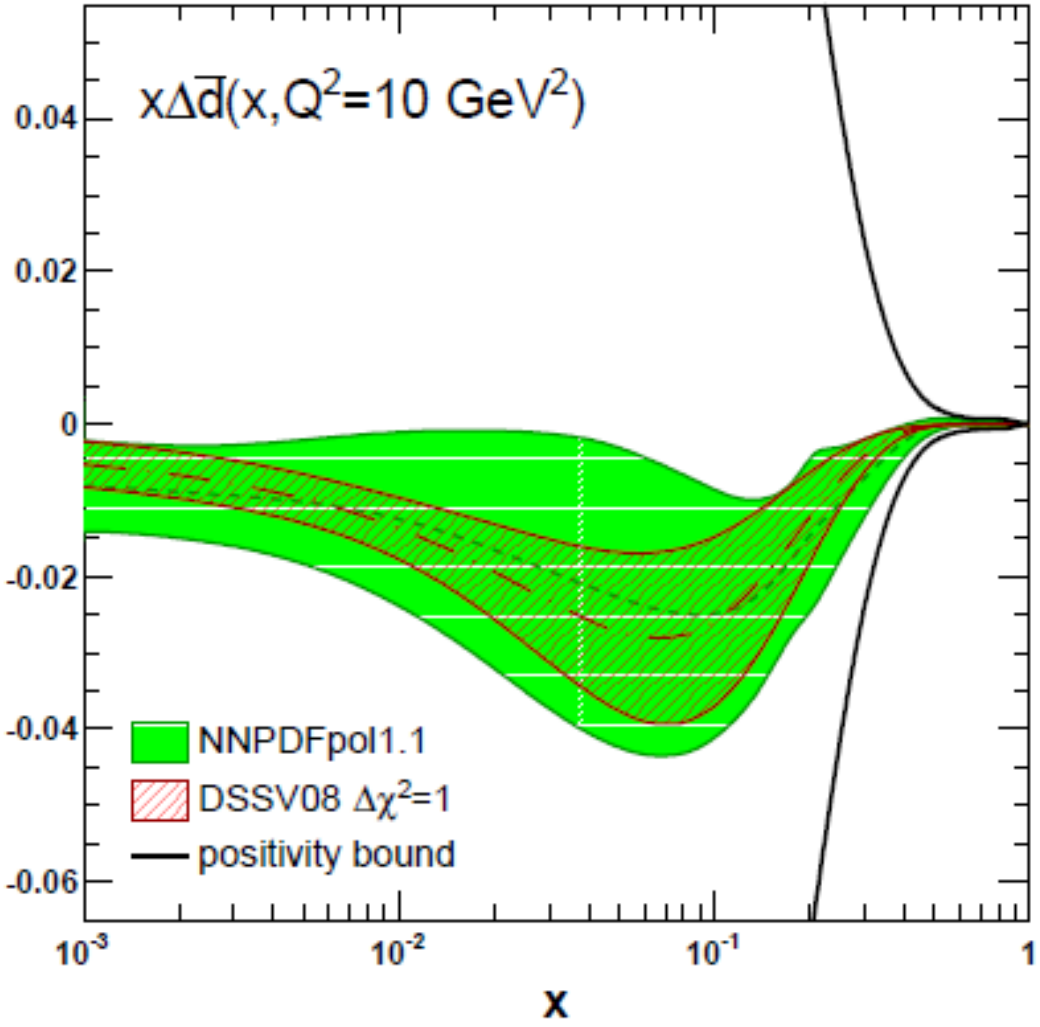
Δq world data (Δu and Δd)



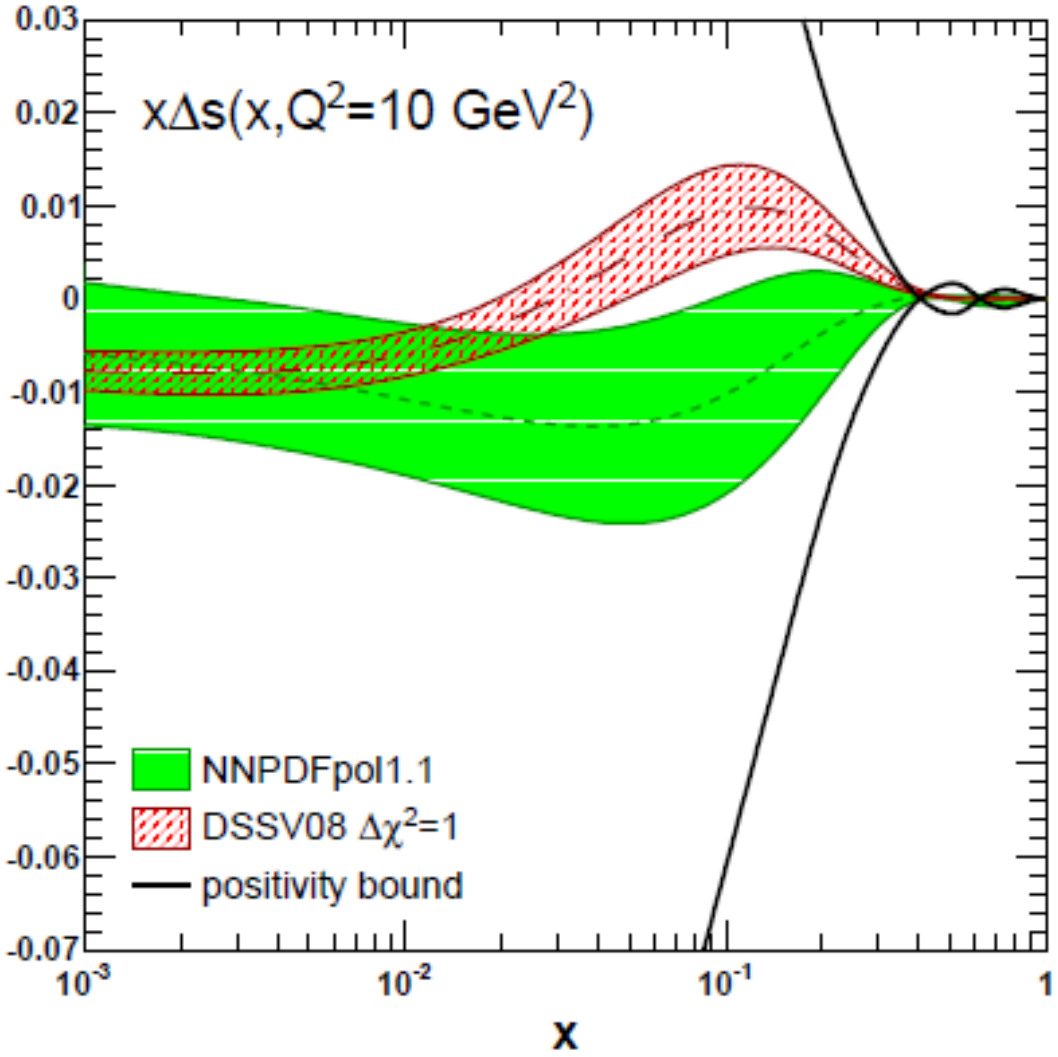


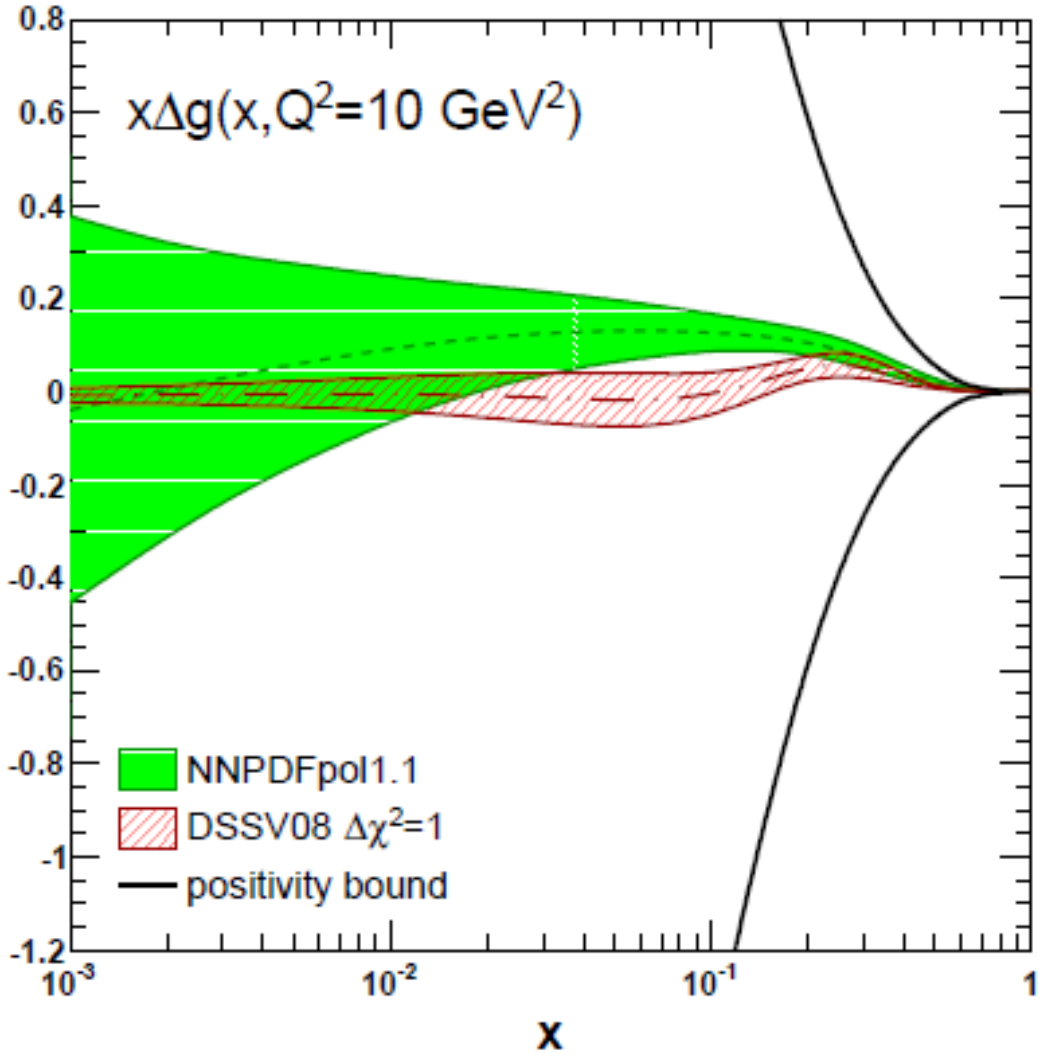
Δq world data (Δubar and Δdbar)



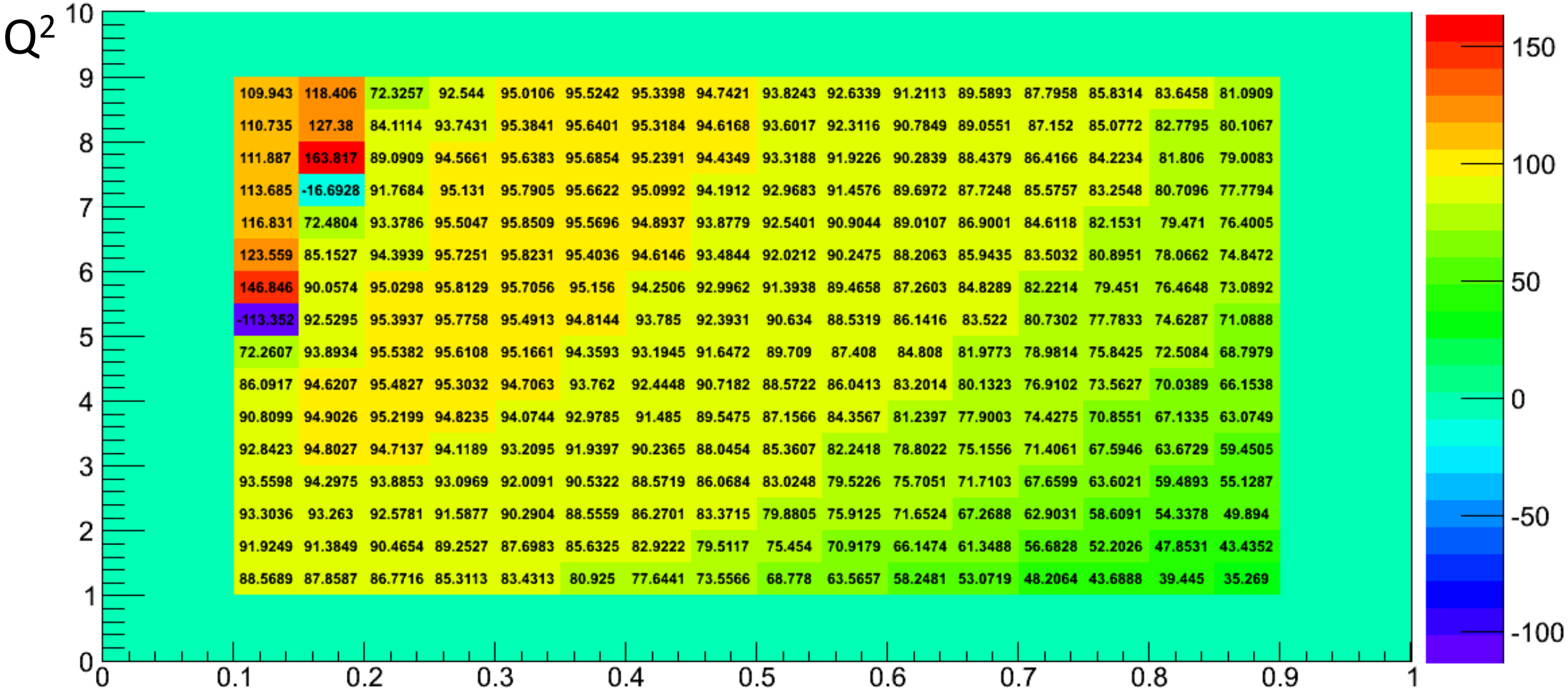


Δq world data (Δs and Δg)





Asymmetry contribution from g1gz



G1gz dominates the asymmetry (> 90%)

Simulations using GEMC

- Beam current: 60 μA (2nd stage of target upgrade plan)

- 3He target requirements:
  - ✓Length: 60cm (2nd stage of target upgrade plan)
  - ✓Polarization: 60%
  - ✓Density: 12 amg **X 12**

- Beam time: 200 days

Goal at ~10% precision on the ^{3}He asymmetry measurement

Projections of the asymmetry measurement

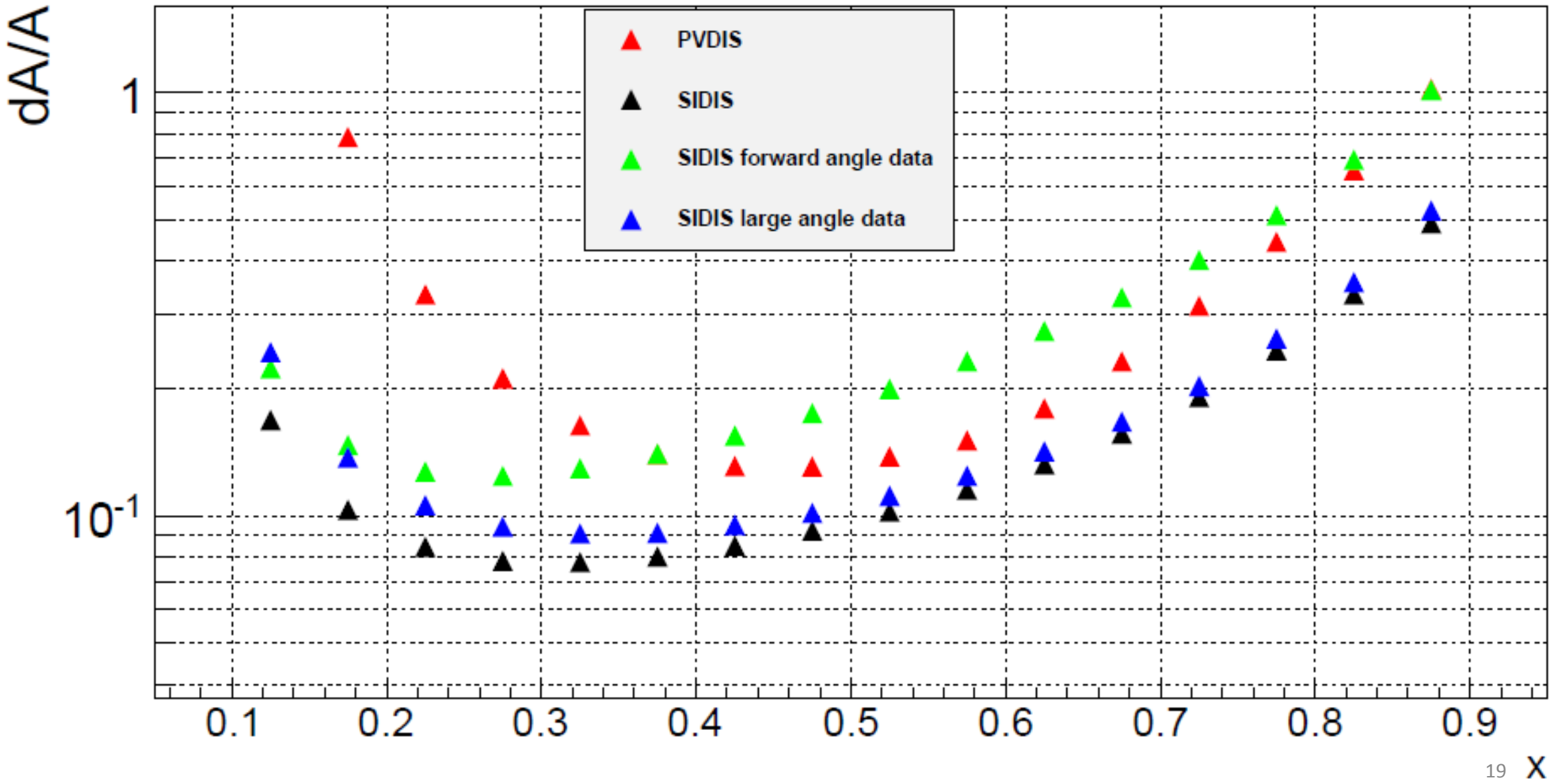
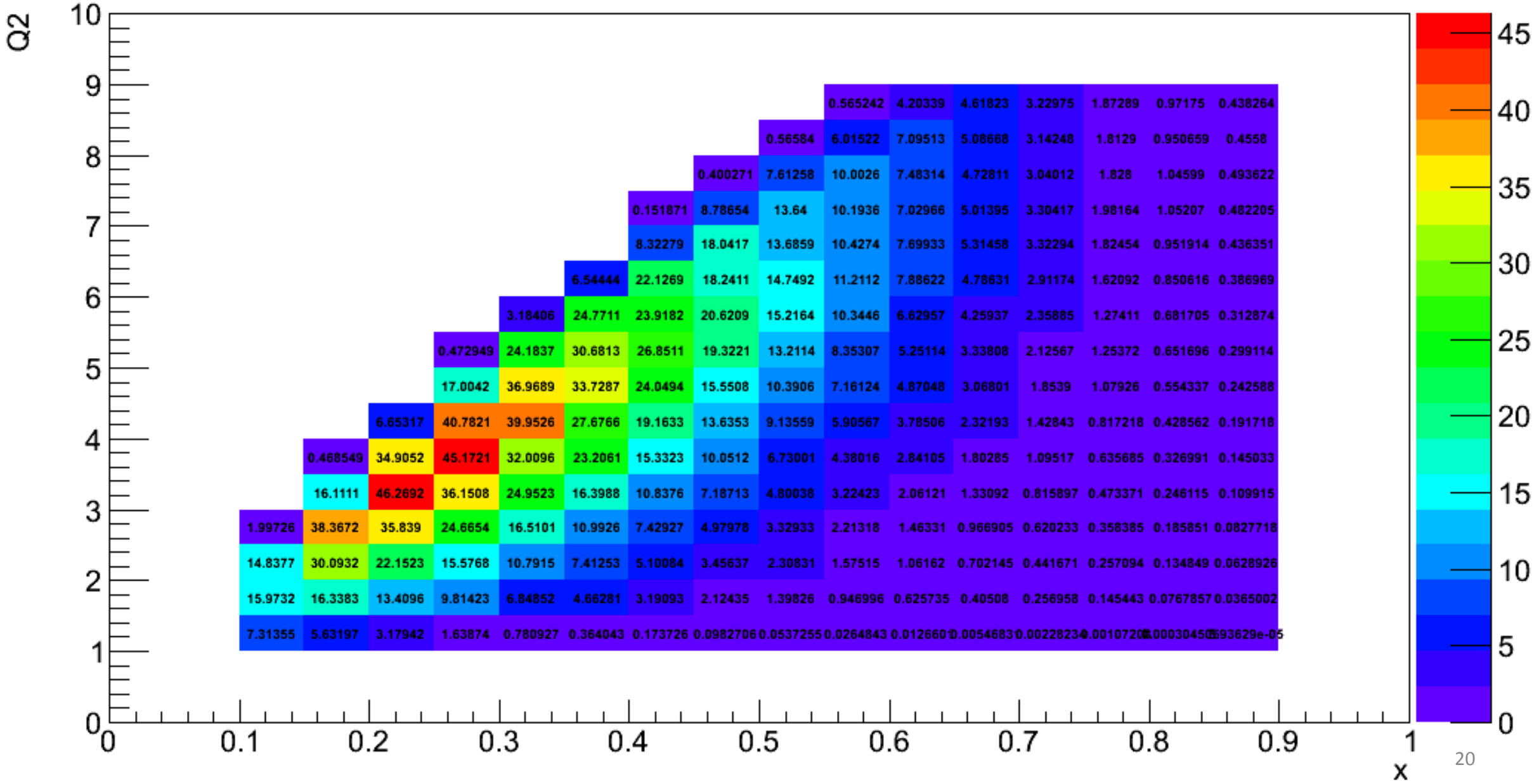
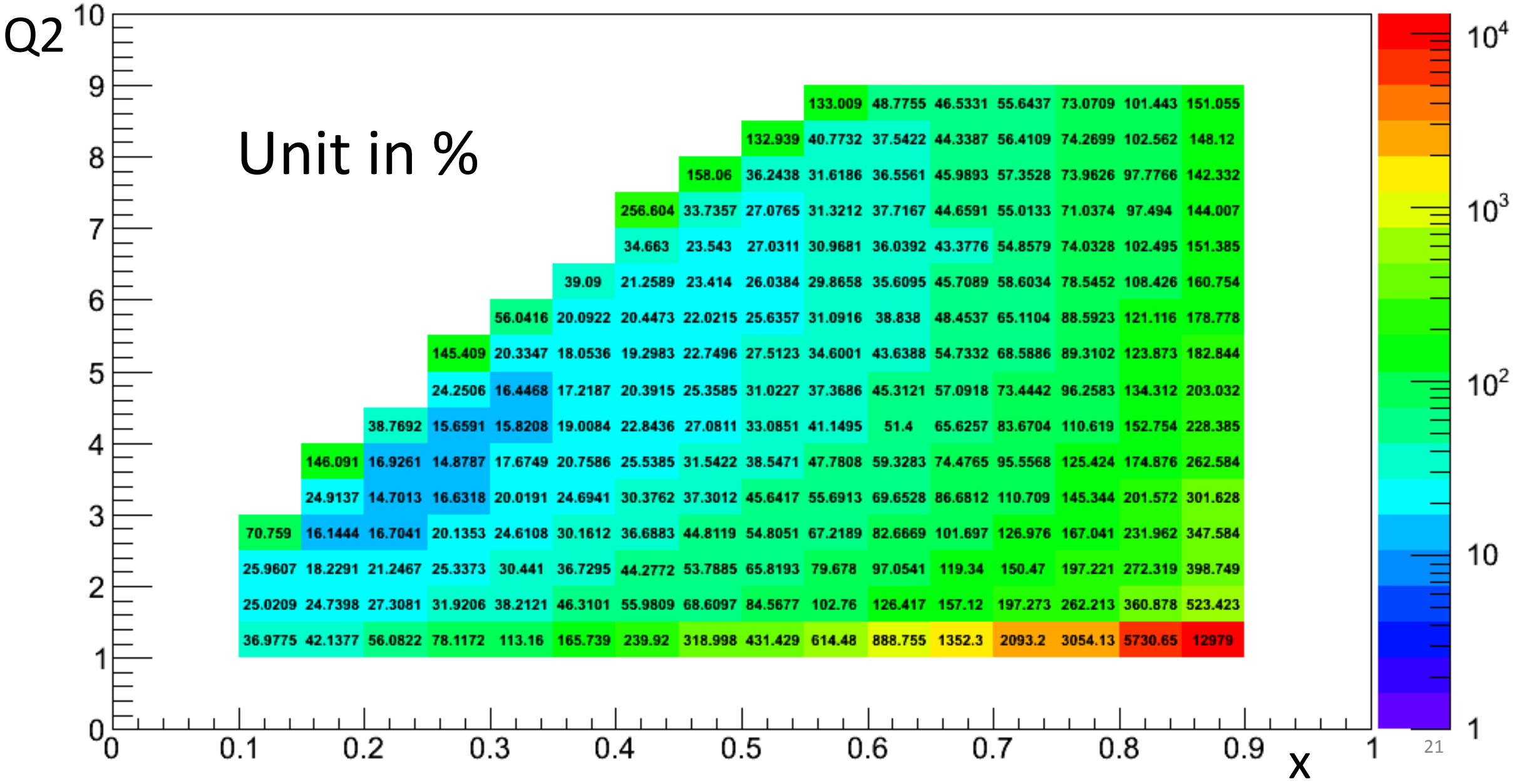


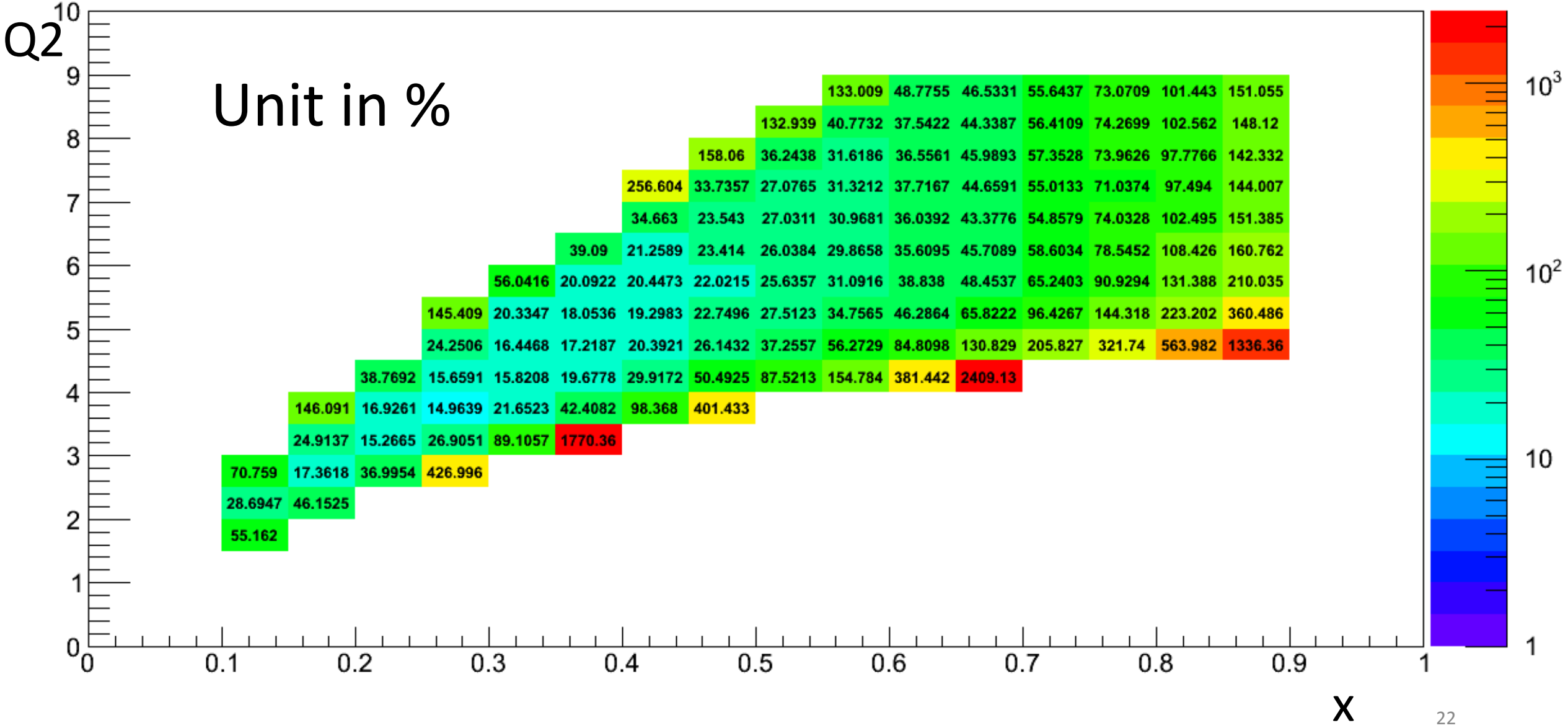
Figure-of-merit (A*A*rate) for SIDIS configuration



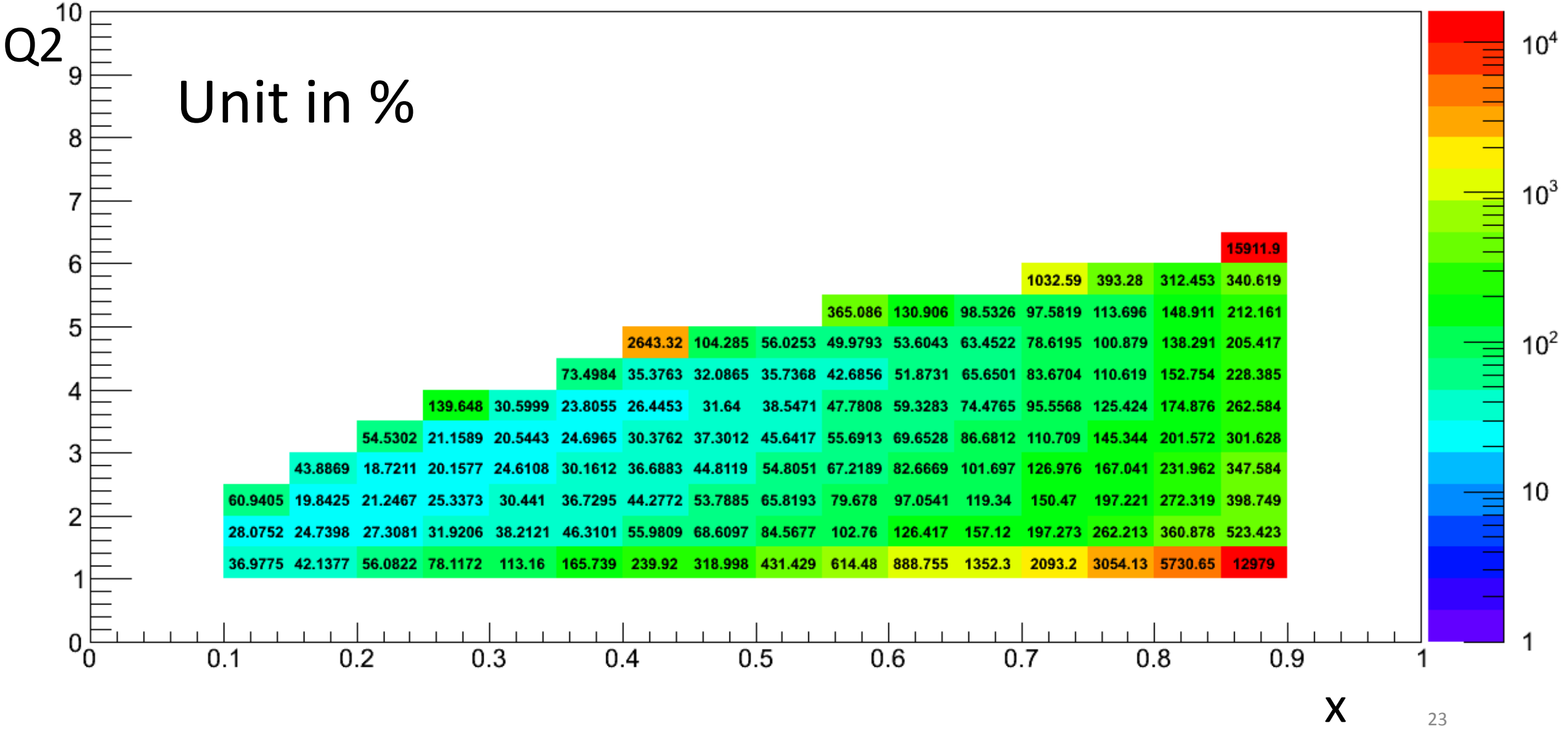
dA/A projections using SIDIS configuration



dA/A projections for large angle data only



dA/A projections for forward angle data only



Trigger rate

- Follow closely with SIDIS electron trigger design
  - Large angle electron rate: 2.2 MHz
  - Forward angle electron rate: 11.2MHz

- Large angle detector is sufficient to reach ~10% measurement
  - With 30 sectors, trigger rate is 73KHz/sector

- Forward angle
  - Can put tight trigger cut to lower down trigger rate
  - Bonus for our measurement

Conclusions and discussions

- With proposed luminosity and beam time, we can access a new structure function g1gz at ~10% level in x<0.5 region
  - Only large angle data in SIDIS configuration is sufficient
- Provide a linear combination of Δu+Δd+Δs with even weight
  - In g1-gamma structure function, Δd is only 1/4 of Δu
  - Inclusive electron detection, without complication of fragmentation or hadronic processes
- We will further investigate the impact of our new data to the world polarized PDF fit

Backups

^{3}He asymmetry calculations using DSSV2008

X

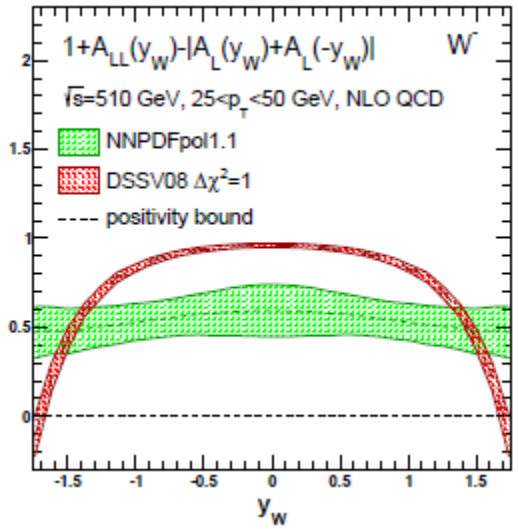
Q^2

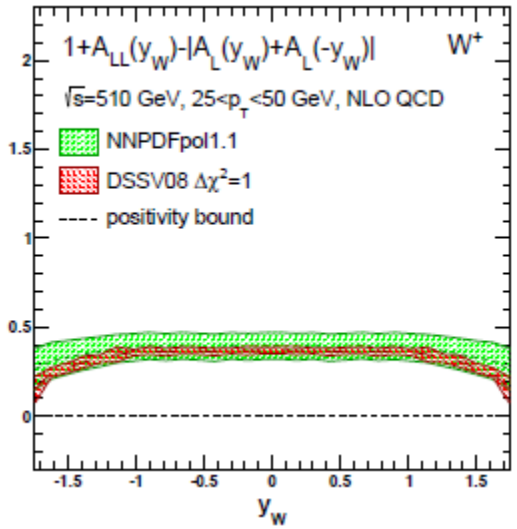
DSSV2008 :

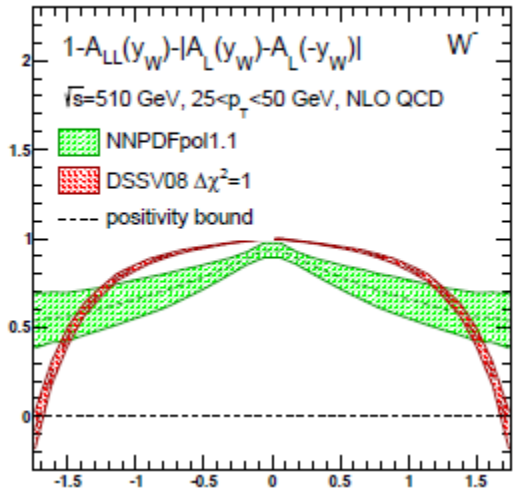
	0.125	0.175	0.225	0.275	0.325	0.375	0.425	0.475	0.525	0.575	0.625	0.675	0.725	0.775	0.825	0.875
8.750	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-56.96	-55.93	-54.47	-52.66	-50.42	-47.56	-43.57
8.250	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-51.99	-51.28	-50.15	-48.72	-47.03	-45.01	-42.45	-38.89
7.750	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-46.94	-46.55	-45.68	-44.52	-43.17	-41.63	-39.83	-37.56	-34.43
7.250	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-41.82	-41.16	-40.22	-39.10	-37.87	-36.50	-34.91	-32.94	-30.20
6.750	0.00	0.00	0.00	0.00	0.00	0.00	-37.12	-36.69	-35.91	-34.97	-33.95	-32.85	-31.66	-30.28	-28.58	-26.21
6.250	0.00	0.00	0.00	0.00	0.00	-32.53	-32.33	-31.71	-30.91	-30.04	-29.14	-28.19	-27.18	-26.01	-24.57	-22.54
5.750	0.00	0.00	0.00	0.00	-27.94	-28.12	-27.65	-26.98	-26.24	-25.48	-24.73	-23.95	-23.12	-22.17	-20.98	-19.28
5.250	0.00	0.00	0.00	-23.29	-23.98	-23.73	-23.16	-22.52	-21.88	-21.26	-20.65	-20.03	-19.37	-18.60	-17.64	-16.23
4.750	0.00	0.00	0.00	-19.91	-19.95	-19.52	-18.96	-18.41	-17.89	-17.39	-16.92	-16.44	-15.92	-15.33	-14.56	-13.41
4.250	0.00	0.00	-15.83	-16.33	-16.05	-15.59	-15.11	-14.68	-14.28	-13.91	-13.56	-13.20	-12.81	-12.36	-11.75	-10.84
3.750	0.00	0.00	-12.83	-12.80	-12.45	-12.07	-11.70	-11.39	-11.11	-10.86	-10.62	-10.37	-10.10	-9.77	-9.32	-8.62
3.250	0.00	-9.32	-9.74	-9.55	-9.26	-8.98	-8.74	-8.54	-8.37	-8.22	-8.07	-7.92	-7.74	-7.52	-7.21	-6.71
2.750	0.00	-6.84	-6.89	-6.72	-6.52	-6.36	-6.22	-6.12	-6.03	-5.95	-5.87	-5.78	-5.68	-5.54	-5.33	-4.98
2.250	-4.06	-4.49	-4.48	-4.38	-4.29	-4.22	-4.16	-4.12	-4.09	-4.06	-4.04	-4.00	-3.96	-3.88	-3.75	-3.52
1.750	-2.38	-2.57	-2.59	-2.57	-2.55	-2.54	-2.54	-2.55	-2.56	-2.57	-2.58	-2.58	-2.57	-2.54	-2.48	-2.35
1.250	-1.09	-1.21	-1.25	-1.27	-1.29	-1.32	-1.34	-1.37	-1.40	-1.42	-1.45	-1.47	-1.48	-1.48	-1.46	-1.40

Calculated by Xiaochao Zheng

Asymmetry comparison between DSSV08 and NNPDF







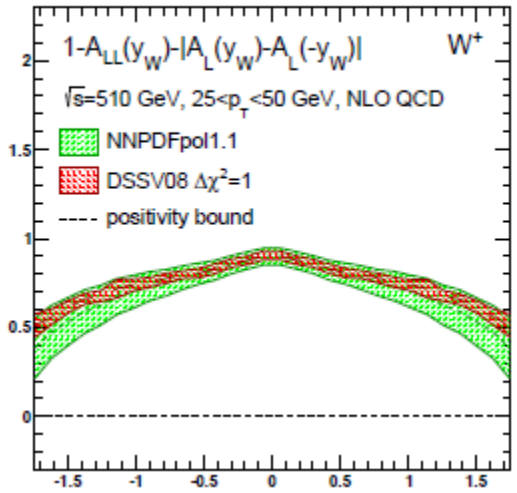


Figure-of-merit numbers in (x,Q2) grid

8.75	0	0	0	0	0	0	0	0	0.565	4.2	4.62	3.23	1.87	0.972	0.438
8.25	0	0	0	0	0	0	0	0	0.566	6.02	7.1	5.09	3.14	1.81	0.951	0.456
7.75	0	0	0	0	0	0	0	0.4	7.61	10	7.48	4.73	3.04	1.83	1.05	0.494
7.25	0	0	0	0	0	0	0.152	8.79	13.6	10.2	7.03	5.01	3.3	1.98	1.05	0.482
6.75	0	0	0	0	0	0	8.32	18	13.7	10.4	7.7	5.31	3.32	1.82	0.952	0.436
6.25	0	0	0	0	0	6.54	22.1	18.2	14.7	11.2	7.89	4.79	2.91	1.62	0.851	0.387
5.75	0	0	0	0	3.18	24.8	23.9	20.6	15.2	10.3	6.63	4.26	2.36	1.27	0.682	0.313
5.25	0	0	0	0.473	24.2	30.7	26.9	19.3	13.2	8.35	5.25	3.34	2.13	1.25	0.652	0.299
4.75	0	0	0	17	37	33.7	24	15.6	10.4	7.16	4.87	3.07	1.85	1.08	0.554	0.243
4.25	0	0	6.65	40.8	40	27.7	19.2	13.6	9.14	5.91	3.79	2.32	1.43	0.817	0.429	0.192
3.75	0	0.469	34.9	45.2	32	23.2	15.3	10.1	6.73	4.38	2.84	1.8	1.1	0.636	0.327	0.145
3.25	0	16.1	46.3	36.2	25	16.4	10.8	7.19	4.8	3.22	2.06	1.33	0.816	0.473	0.246	0.11
2.75	2	38.4	35.8	24.7	16.5	11	7.43	4.98	3.33	2.21	1.46	0.967	0.62	0.358	0.186	0.082
2.25	14.8	30.1	22.2	15.6	10.8	7.41	5.1	3.46	2.31	1.58	1.06	0.702	0.442	0.257	0.135	0.062
1.75	16	16.3	13.4	9.81	6.85	4.66	3.19	2.12	1.4	0.947	0.626	0.405	0.257	0.145	0.0768	0.036
1.25	7.31	5.63	3.18	1.64	0.781	0.364	0.174	0.0983	0.0537	0.0265	0.0127	0.00547	0.00228	0.00107	0.000305	5

.94e-05

Physical motivations

- With purely electromagnetic scattering in DIS process
  - F_1^{γ}, F_2^{γ}, g_1^{γ}, g_2^{γ}
- Taking into account γ-Z mixing, with parity violation
  - Additional interference structure functions: $F_1^{\gamma Z}$, $F_3^{\gamma Z}$, $g_1^{\gamma Z}$, $g_5^{\gamma Z}$
- At JLab energy scale, $Q^2 \ll M_Z^2$

Pol. beam & unpol. Target:

$$A_{beam} = \frac{G_F Q^2}{2\sqrt{2}\pi\alpha}\left[g_A^e \frac{F_1^{\gamma Z}}{F_1^{\gamma}} + g_V^e \frac{Y_-}{2Y_+}\frac{F_3^{\gamma Z}}{F_1^{\gamma}}\right]$$

Unpol. beam & pol. Target:

$$A_L = \frac{G_F Q^2}{2\sqrt{2}\pi\alpha}\left[g_V^e \frac{g_5^{\gamma Z}}{F_1^{\gamma}} + g_A^e \frac{Y_-}{Y_+}\frac{g_1^{\gamma Z}}{F_1^{\gamma}}\right]$$