Neutral current weak interaction at EIC

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Reference:

1. Y.X. Zhao *et al.,* Eur. Phys. J. A 53 (2017) 55
2. K.S. Kumar *et al.,* EPJ Web of Conferences 112, 03004 (2016)

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Outline

- The weak neutral current interaction allows us to access the ɣ - Z interference structure functions by measuring the PVDIS asymmetries ($Q^2 < M_Z^2$)
  - $F_1^{\gamma Z}, F_3^{\gamma Z}$: polarized electron and unpolarized nucleon
  - $g_1^{\gamma Z}, g_5^{\gamma Z}$: unpolarized electron and polarized nucleon
- The parity violating asymmetry for the longitudinally polarized electron scattering off unpolarized nucleon can be expressed as;
  - $A_{PV}^{electron} = \frac{G_F Q^2}{2\sqrt{2}\pi\alpha}\left[\, g_A^e \frac{F_1^{\gamma Z}}{F_1^{\gamma}} + g_V^e \frac{Y_-}{2Y_+} \frac{F_3^{\gamma Z}}{F_1^{\gamma}} \,\right]$
- Similarly, it can be written for the unpolarized electron scattering off longitudinally polarized hadron
  - $A_{PV}^{hadron} = \frac{G_F Q^2}{2\sqrt{2}\pi\alpha}\left[\, g_V^e \frac{g_5^{\gamma Z}}{F_1^{\gamma}} + g_A^e \frac{Y_-}{Y_+} \frac{g_1^{\gamma Z}}{F_1^{\gamma}} \,\right]$
- The ɣ - Z interference structure functions can be expressed as a linear combination of the unpolarized and polarized parton distribution functions
  - $F_1^{\gamma Z} = \sum_f e_{qf} (g_v)_{qf} \, (q_f + \overline{q_f})$
  - $F_3^{\gamma Z} = 2\sum_f e_{qf} (g_A)_{qf} \, (q_f - \overline{q_f})$
  - $g_1^{\gamma Z} = \sum_f e_{qf} (g_v)_{qf} \, (\Delta q_f + \Delta\overline{q_f})$
  - $g_5^{\gamma Z} = \sum_f e_{qf} (g_A)_{qf} \, (\Delta q_f - \Delta\overline{q_f})$

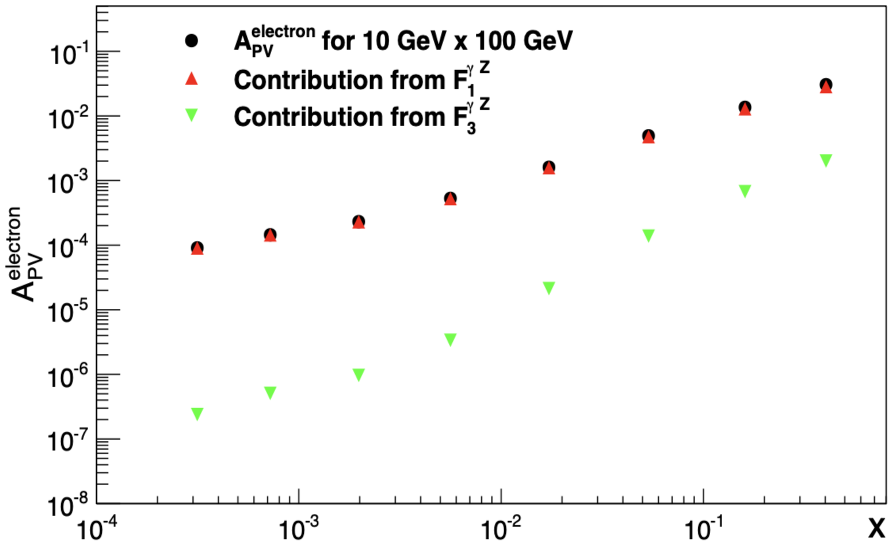
Existing work (Y.X. Zhao *et al.*, Eur. Phys. J. A 53 (2017) 55)

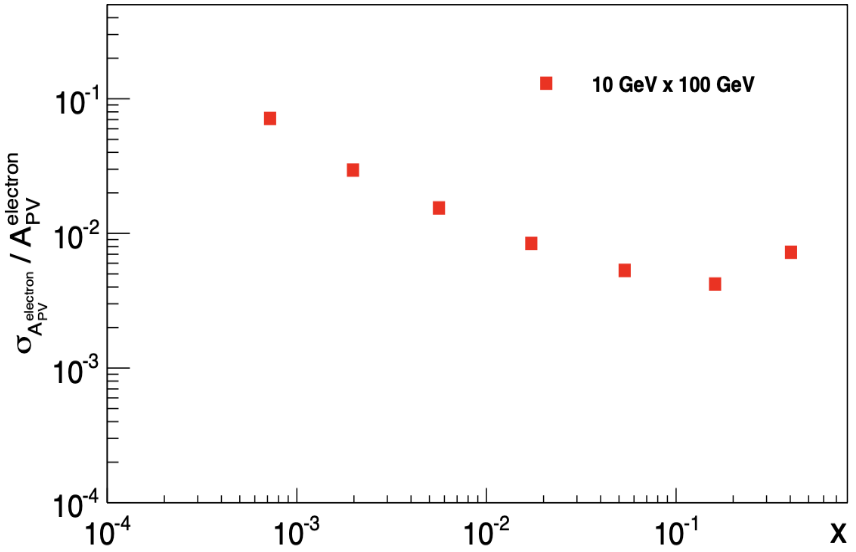
- Within the approximation of $sin^2_{\theta_W} \approx {}^1/_4$ the interference structure functions can be expressed as
  - $F_1^{proton,\gamma Z} \approx \frac{1}{9}\,(u+\overline{u}+d+\overline{d}+s+\overline{s}+c+\overline{c})$
  - $F_3^{proton,\gamma Z} = \frac{2}{3}\,(u_V+c-\overline{c})+\frac{1}{3}\,(d_V+s-\overline{s})$
  - $g_1^{proton,\gamma Z} \approx \frac{1}{9}\,(\Delta u+\Delta\overline{u}+\Delta d+\Delta\overline{d}+\Delta s+\Delta\overline{s}+\Delta c+\Delta\overline{c})$
  - $g_5^{proton,\gamma Z} = \frac{1}{3}\,(\Delta u_V+\Delta c-\Delta\overline{c})+\frac{1}{6}\,(\Delta d_V+\Delta s-\Delta\overline{s})$

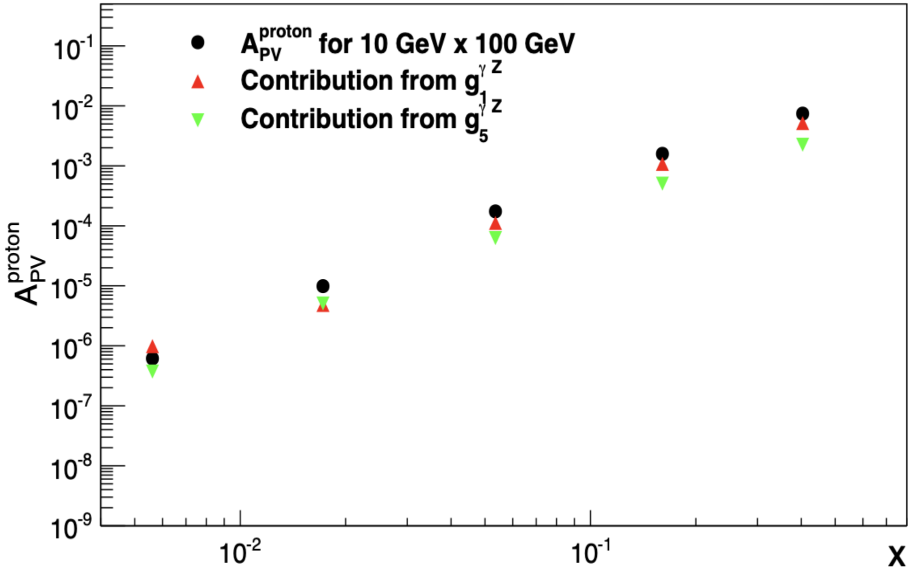
  Where u_V and d_V represents the valence quark contributions
- **Event generator used :** DJANGOH
- **PDFs used :** CTEQ61M (unpolarized structure functions) & DSSV08 (polarized structure functions)
- **Systems simulated :** 10 GeV (electron) ×100 GeV (proton), 10 GeV × 250 GeV, 15 GeV × 100 GeV, 15 GeV × 250 GeV
- **Integrated luminosity :** 500 fb^{-1} & **Polarization :** 70 % (proton) & 80 % (electron)
- **Detector effects :**

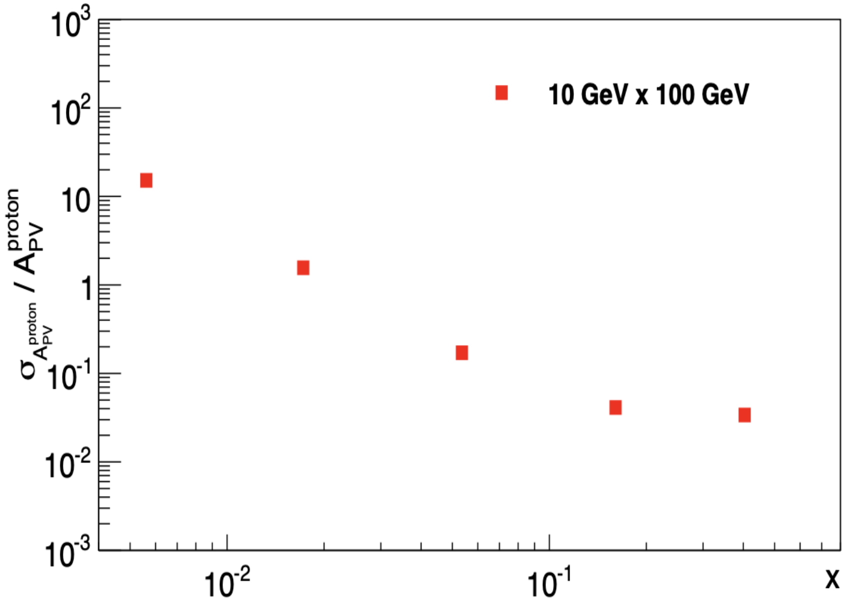
	-1.1< η <1.1 sPHENIX	$\lvert\eta\rvert > 1.1$ ePHENIX
$d\theta$ (mrad)	10	1
$d\phi$ (mrad)	0.3	0.3
$\frac{dp_T}{p_T}$	$0.65\% \oplus 0.09\% * p_T$	$0.65\% \oplus 1\% * p_T$
$\frac{dE}{E}$	$3\% \oplus 11.7\%/\sqrt{E}$	$1\% \oplus 2.5\%/\sqrt{E}$

Existing work (Y.X. Zhao *et al.*, Eur. Phys. J. A 53 (2017) 55)



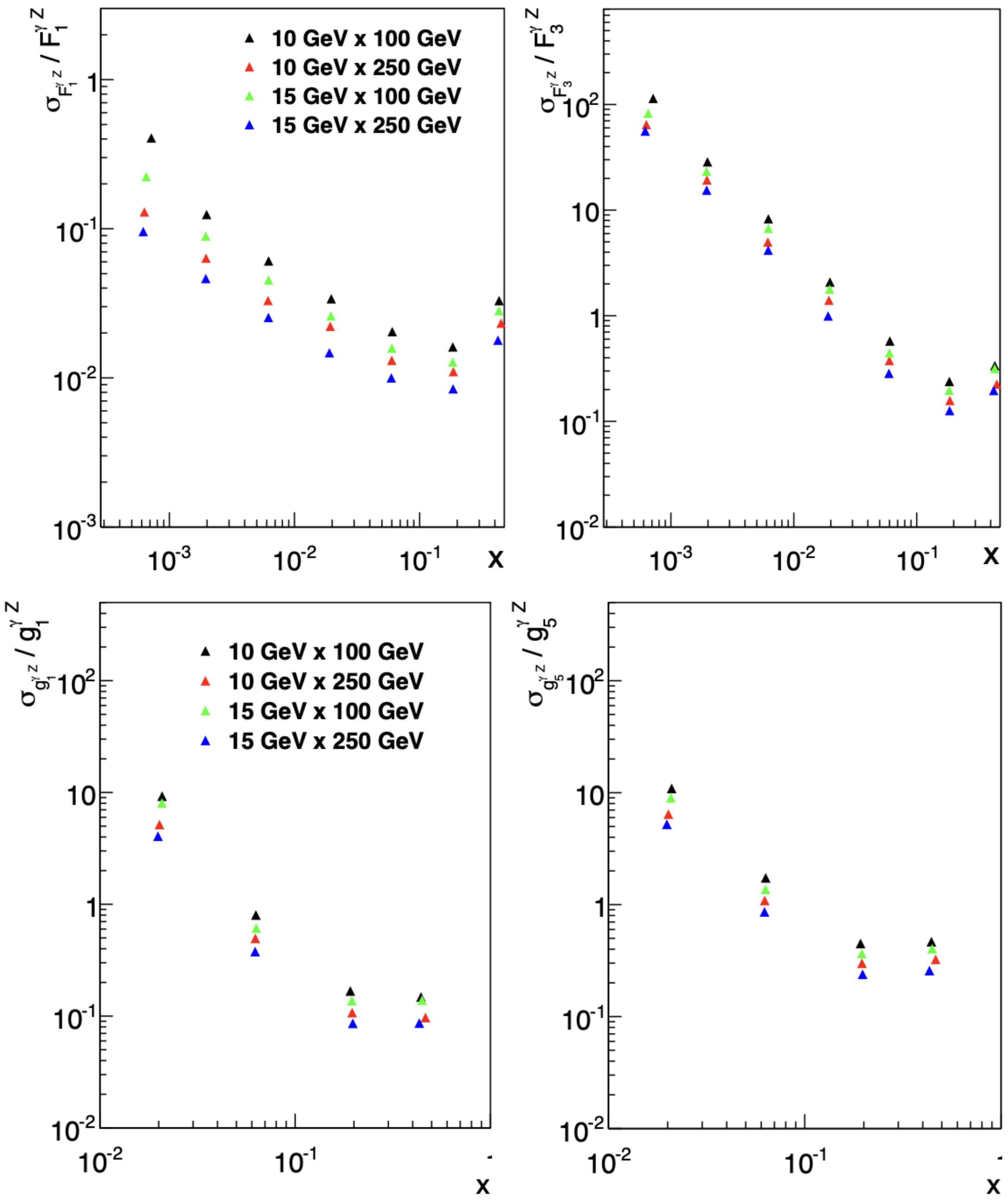






- The data is binned in (x, Q^2) two dimensions
- The predicted value of the $A_{PV}^{electron}$ and A_{PV}^{proton} and their relative uncertainties with assumed luminosity and beam polarization
- Found out that $F_1^{\gamma Z}$ dominates the asymmetry

Existing work (Y.X. Zhao *et al.*, Eur. Phys. J. A 53 (2017) 55)



- Projected relative uncertainties as a function of x

$\log_{10}(Q^2)$ bin	$\log_{10}(x)$ bin	$\langle Q^2\rangle$ (GeV^2)	$\langle x\rangle$	y coverage	$\frac{\sigma_{F_3^{\gamma Z}}}{F_3^{\gamma Z}}$	$\langle F_3^{\gamma Z}\rangle$	$\frac{\sigma_{F_1^{\gamma Z}}}{F_1^{\gamma Z}}$	$\langle F_1^{\gamma Z}\rangle$
(0.0, 0.4)	(-3.5, -3.0)	1.6e+00	7.2e-04	(0.25, 0.81)	1.1e+02	3.8e+01	4.1e-01	2.8e+02
(0.0, 0.4)	(-3.0, -2.5)	1.8e+00	1.9e-03	(0.10, 0.63)	5.8e+01	2.6e+01	1.8e-01	9.8e+01
(0.0, 0.4)	(-2.5, -2.0)	2.1e+00	4.1e-03	(0.10, 0.20)	5.1e+02	1.8e+01	1.1e+00	4.0e+01
(0.4, 0.8)	(-3.5, -3.0)	2.8e+00	9.2e-04	(0.63, 0.81)	2.0e+03	3.6e+01	9.4e+00	2.5e+02
(0.4, 0.8)	(-3.0, -2.5)	4.2e+00	2.1e-03	(0.20, 0.82)	3.4e+01	2.7e+01	1.8e-01	1.3e+02
(0.4, 0.8)	(-2.5, -2.0)	4.6e+00	5.8e-03	(0.10, 0.50)	2.8e+01	1.8e+01	1.1e-01	4.4e+01
(0.4, 0.8)	(-2.0, -1.5)	5.5e+00	1.2e-02	(0.10, 0.16)	1.4e+03	1.3e+01	4.0e+00	1.9e+01
(0.8, 1.2)	(-3.0, -2.5)	7.6e+00	2.7e-03	(0.50, 0.83)	1.5e+02	2.6e+01	1.1e+00	1.2e+02
(0.8, 1.2)	(-2.5, -2.0)	1.1e+01	6.3e-03	(0.16, 0.84)	9.8e+00	1.9e+01	7.7e-02	5.3e+01
(0.8, 1.2)	(-2.0, -1.5)	1.2e+01	1.7e-02	(0.10, 0.40)	1.5e+01	1.2e+01	8.0e-02	1.6e+01
(0.8, 1.2)	(-1.5, -1.0)	1.5e+01	3.4e-02	(0.10, 0.13)	9.2e+03	8.4e+00	4.7e+01	6.6e+00
(1.2, 1.6)	(-2.5, -2.0)	2.2e+01	8.1e-03	(0.40, 0.89)	1.9e+01	1.8e+01	2.5e-01	4.2e+01
(1.2, 1.6)	(-2.0, -1.5)	2.8e+01	1.9e-02	(0.13, 0.90)	3.3e+00	1.2e+01	4.3e-02	1.7e+01
(1.2, 1.6)	(-1.5, -1.0)	3.0e+01	5.0e-02	(0.10, 0.31)	8.1e+00	7.3e+00	7.2e-02	4.9e+00
(1.6, 2.0)	(-2.0, -1.5)	6.4e+01	2.3e-02	(0.32, 1.0)	2.8e+00	1.1e+01	7.3e-02	1.4e+01
(1.6, 2.0)	(-1.5, -1.0)	6.9e+01	5.9e-02	(0.10, 0.79)	1.1e+00	6.8e+00	2.7e-02	4.4e+00
(1.6, 2.0)	(-1.0, -0.5)	7.8e+01	1.4e-01	(0.10, 0.25)	6.7e+00	3.5e+00	9.9e-02	1.3e+00
(2.0, 2.4)	(-2.0, -1.5)	1.1e+02	2.9e-02	(0.79, 1.0)	8.3e+01	9.9e+00	3.2e+00	9.7e+00
(2.0, 2.4)	(-1.5, -1.0)	1.6e+02	6.4e-02	(0.25, 1.0)	6.8e-01	6.5e+00	3.5e-02	3.9e+00
(2.0, 2.4)	(-1.0, -0.5)	1.7e+02	1.8e-01	(0.10, 0.63)	6.7e-01	2.8e+00	2.4e-02	9.6e-01
(2.0, 2.4)	(-0.5, 0.0)	2.0e+02	3.8e-01	(0.10, 0.20)	2.3e+01	6.8e-01	4.4e-01	1.7e-01
(2.4, 2.8)	(-1.5, -1.0)	3.0e+02	8.5e-02	(0.63, 1.0)	4.7e+00	5.1e+00	3.7e-01	2.4e+00
(2.4, 2.8)	(-1.0, -0.5)	4.2e+02	1.8e-01	(0.20, 1.0)	2.6e-01	2.6e+00	2.2e-02	8.5e-01
(2.4, 2.8)	(-0.5, 0.0)	4.4e+02	4.2e-01	(0.10, 0.49)	1.1e+00	5.3e-01	5.3e-02	1.3e-01
(2.8, 3.2)	(-1.0, -0.5)	8.2e+02	2.5e-01	(0.50, 1.0)	1.0e+00	1.5e+00	1.3e-01	4.3e-01
(2.8, 3.2)	(-0.5, 0.0)	1.1e+03	4.2e-01	(0.20, 1.0)	3.5e-01	4.6e-01	4.1e-02	1.1e-01
(3.2, 3.6)	(-0.5, 0.0)	1.9e+03	5.3e-01	(0.54, 1.0)	2.1e+00	1.7e-01	3.2e-01	3.9e-02

Available data from the paper …

Motivation

- Zhao *et al.*, reported on the detailed simulation study of the γ–Z structure functions at the EIC using realistic detector simulations and beam energy configurations available at that time
  - They suggested a natural extension of the work by performing a comprehensive PDF fit study that would quantify how these measurements translate into constraints on individual quark distributions, and specifically whether s(x) and Δs(x) could be constrained without semi-inclusive data.

Proposal

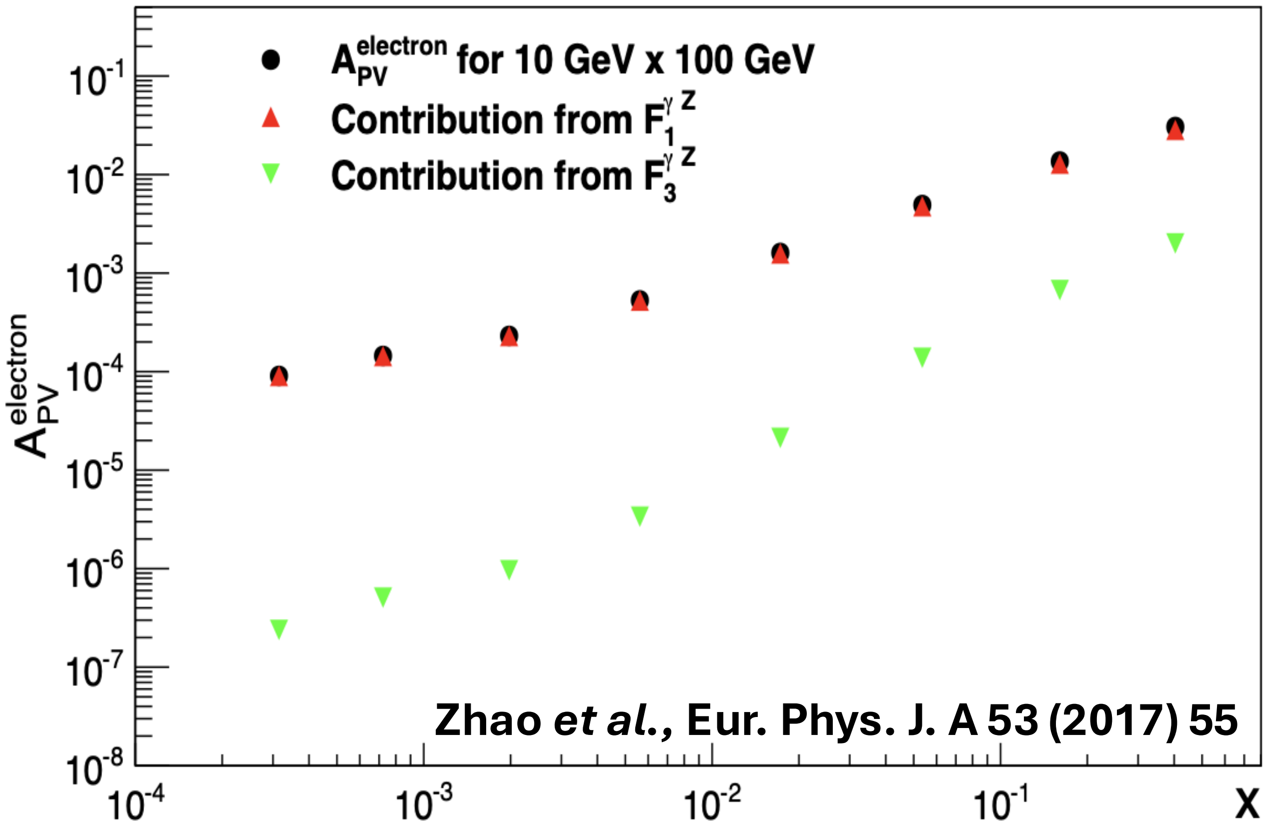
- Repeat the work with updated EIC detector setup and with realistic collision system and energy;

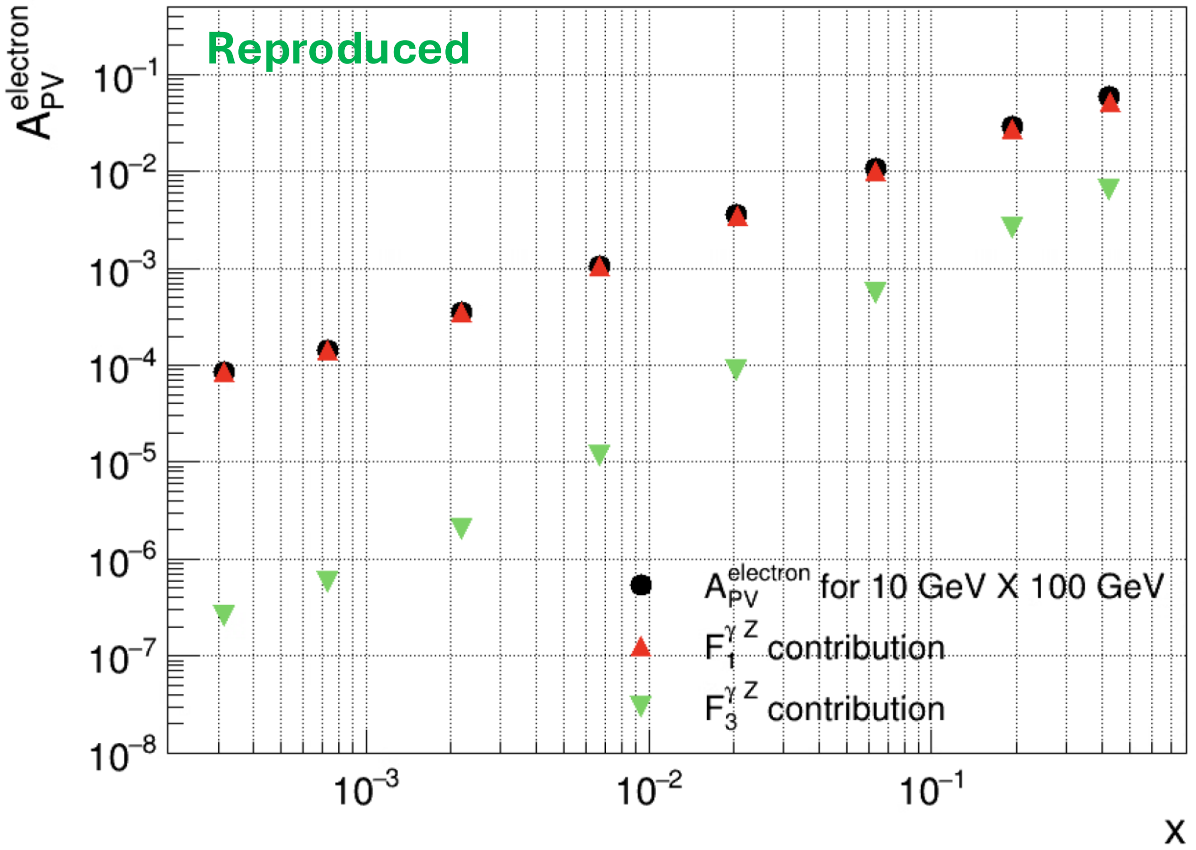
Species	Beam energy (GeV)	Integrated luminosity	Electron-beam polarization	Hadron-beam polarization
e+Ag	9×115	1.0 fb^{-1}	NO	N/A
e+D	9×130	1.5 fb^{-1}	LONG	NO
$e+p$	9×130	1.0 fb^{-1}	LONG	TRANS and/or LONG
$e+p$	9×275	2.5 fb^{-1}	LONG	TRANS and/or LONG
e+Au	9×100	1.0 fb^{-1}	LONG	N/A
$e+{}^3$He	9×166	1.5 fb^{-1}	LONG	TRANS and/or LONG

- Using the projected structure function uncertainties from Zhao et al. as pseudo-data inputs and profile them against current baseline PDF sets in a global fit framework (use different PDFs and add that as the systematic uncertainty)
- How does the constraining power of the γ–Z channel compliment the charged current DIS channel?
- Which beam energy configuration delivers the most improvement in strange PDF uncertainty, and in which x range?

Current status

- Reproducing the plots from Zhao's paper as a sanity check



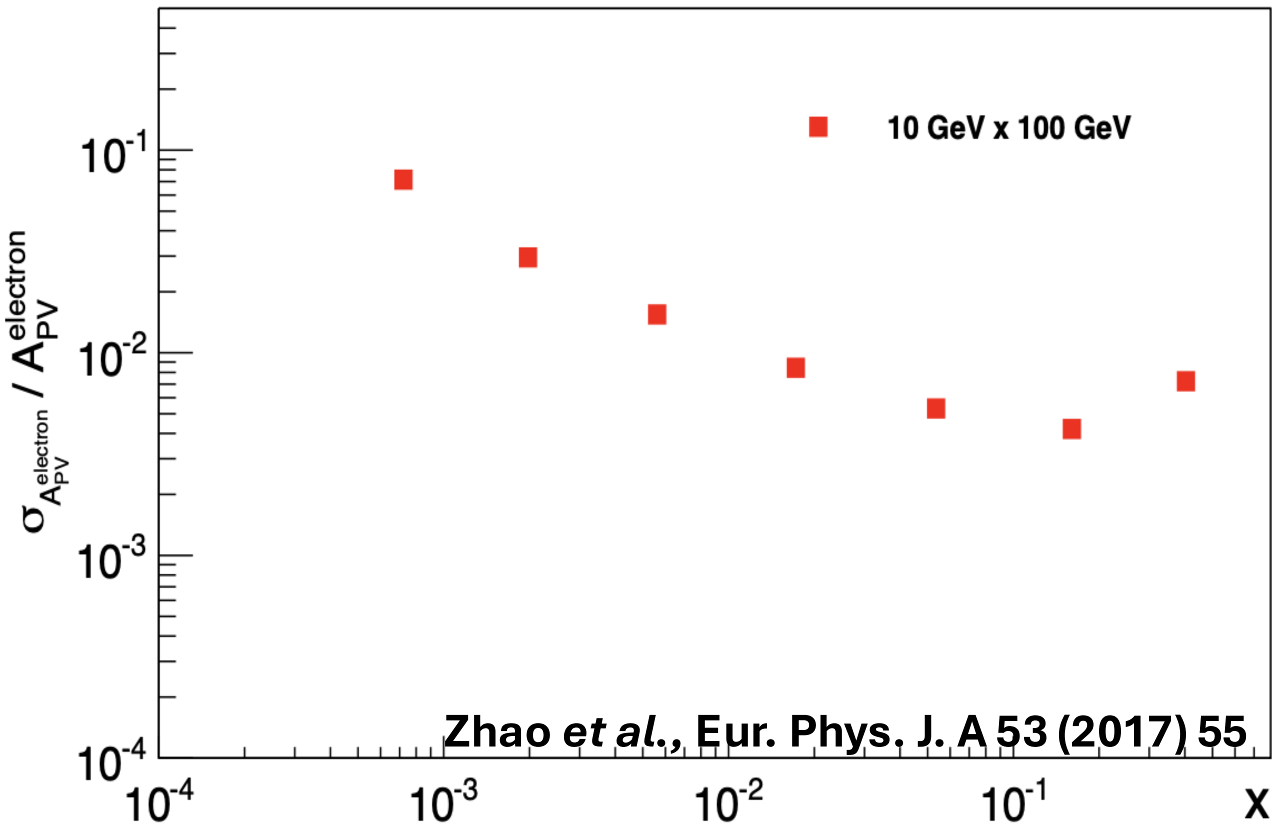


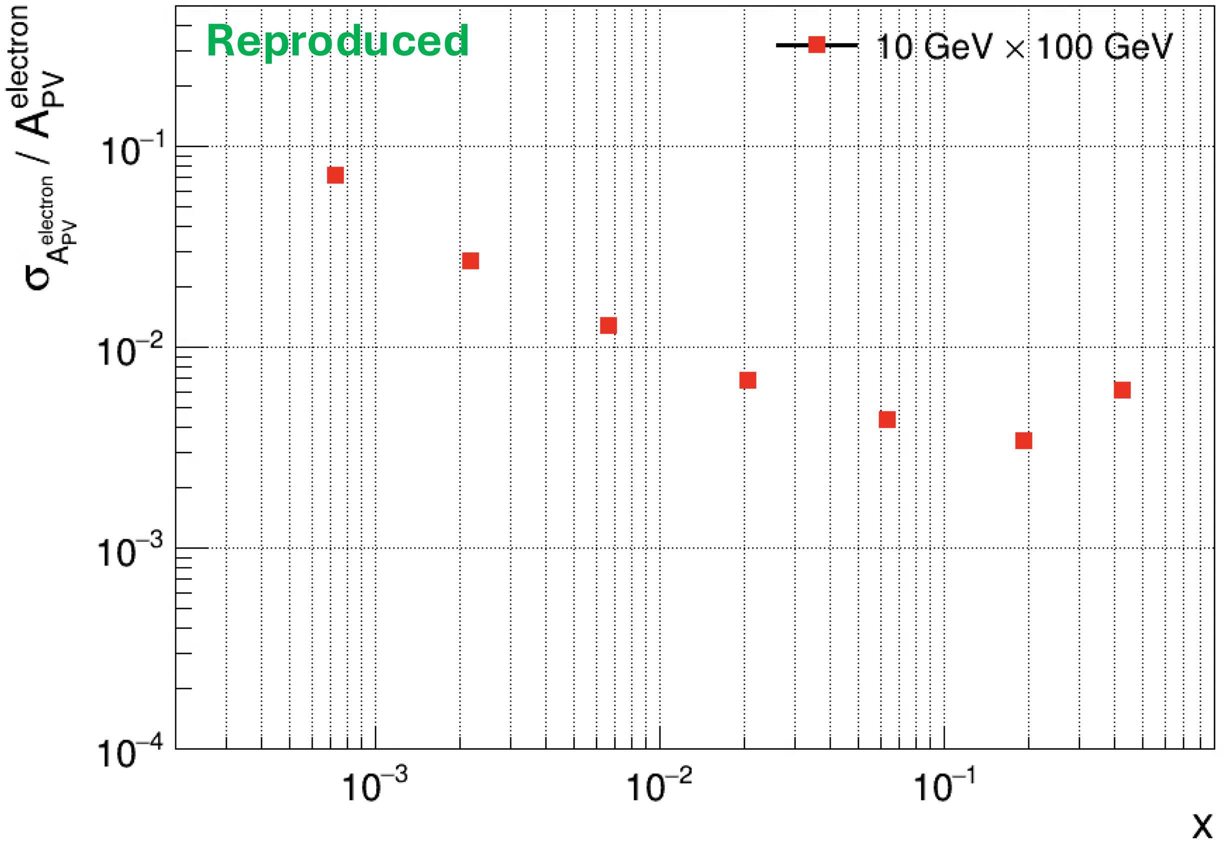
Cuts: $1 < Q^2 < 80\ \mathrm{GeV}^2$, $W_h > 2$ GeV, $y > 0.1$, $p_{e'} > 2$ GeV

PDF: CTEQ61M (unpolarised case)

Current status

- Reproducing the plots from Zhao's paper as a sanity check





Cuts: $1 < Q^2 < 80$ GeV^2, $W_h > 2$ GeV, $y > 0.1$, $p_{e'} > 2$ GeV

Immediate next steps

- Reproduce all the plots from Zhao's paper as a sanity check
- Convert the DJANGOH input file to HepMC format so that the entire EIC simulation chain can be performed
- Validate the reconstructed output (reco vs truth)
- Submit request to the simulation campaign for generating large scale data set
- Extract the observables and compare with the old paper to understand the effects of realistic detector effects
- **Anything else?**