Extracting the weak mixing angle from ep data

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Weak mixing angle extraction at the EIC

- Polarized e^- on d for $Q^2 \gg \Lambda_{\rm QCD}$
- d is iso-singlet $\longrightarrow$ PDF dependence approximately cancels in LR asymmetry:
- Assuming valence quark dominance and charge symmetry:

$$f_u \approx f_d,$$
$$f_{\bar u} \approx f_{\bar d} \approx f_{s,c,b} \approx f_{\bar s,\bar c,\bar b} \approx 0$$

$$A_{\rm LR}^{ep} \approx \frac{G_\mu(-q^2)}{4\sqrt{2}\pi\alpha}\left[\frac{9}{5} - \sin^2\theta_{\rm W} + \frac{9}{5}(1-4\sin^2\theta_{\rm W})\frac{y(1-y)}{1+(1-y)^2}\right]$$

$\longrightarrow$ Reduced need for precision PDF input

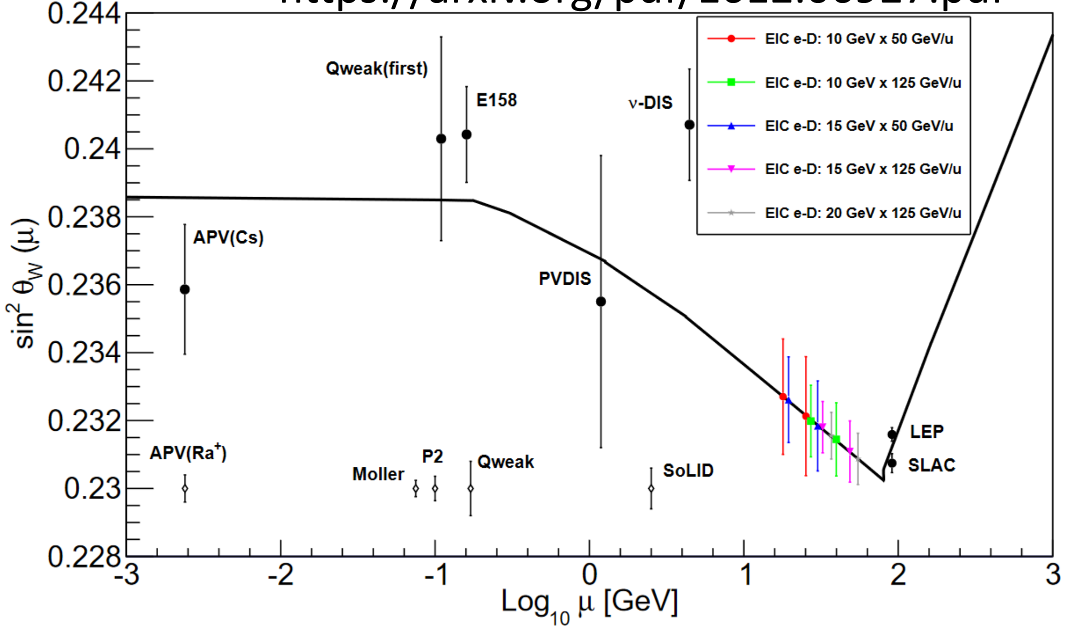
Ayres Freitas

- For the extraction of the weak mixing angle the main focus so far has been the e-d collisions due to their reduced PDF uncertainties and simple theoretical interpretation of any possible measurements

- Indeed Yuxiang Z and collaborators published an initial study looking at very high luminosity (267 fb^{-1}) at collisions energies close to the EIC design
  - Such a luminosity will certainly require quite an investment in time
- The study focuses on the high Q^2 region that provides most of the constraint on the running

Y. X. Zhao *et al.*: Neutral Weak Interactions at an EIC

https://arxiv.org/pdf/1612.06927.pdf



Weak mixing angle extraction at the EIC

Ayres Freitas

- Polarized e^- on p for $Q^2 \gg \Lambda_{QCD}$
- LR asymmetry:

$$A_{LR}^{ep} \approx \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = \frac{G_\mu(-q^2)}{4\sqrt{2}\pi\alpha}\left[\frac{F_1^{\gamma Z}}{F_1^{\gamma}} + (1 - 4\sin^2\theta_W)\frac{y(1-y)}{1+(1-y)^2}\frac{F_3^{\gamma Z}}{F_1^{\gamma}}\right]$$

$$y = 1 - E'_e/E_e$$

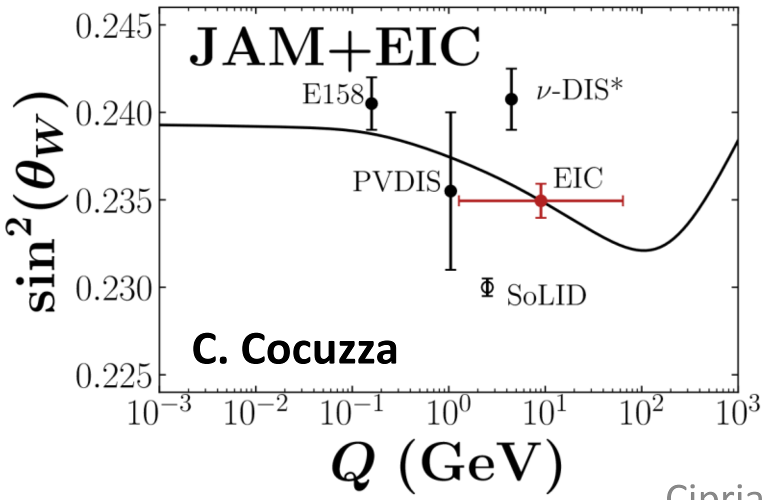
- DIS regime (rather than point-like as at P2):

$$F_1^{\gamma} = \sum_q q_q(f_q + f_{\bar{q}})$$

$$F_1^{\gamma Z} = \sum_q q_q\, g_V^q(f_q + f_{\bar{q}})$$

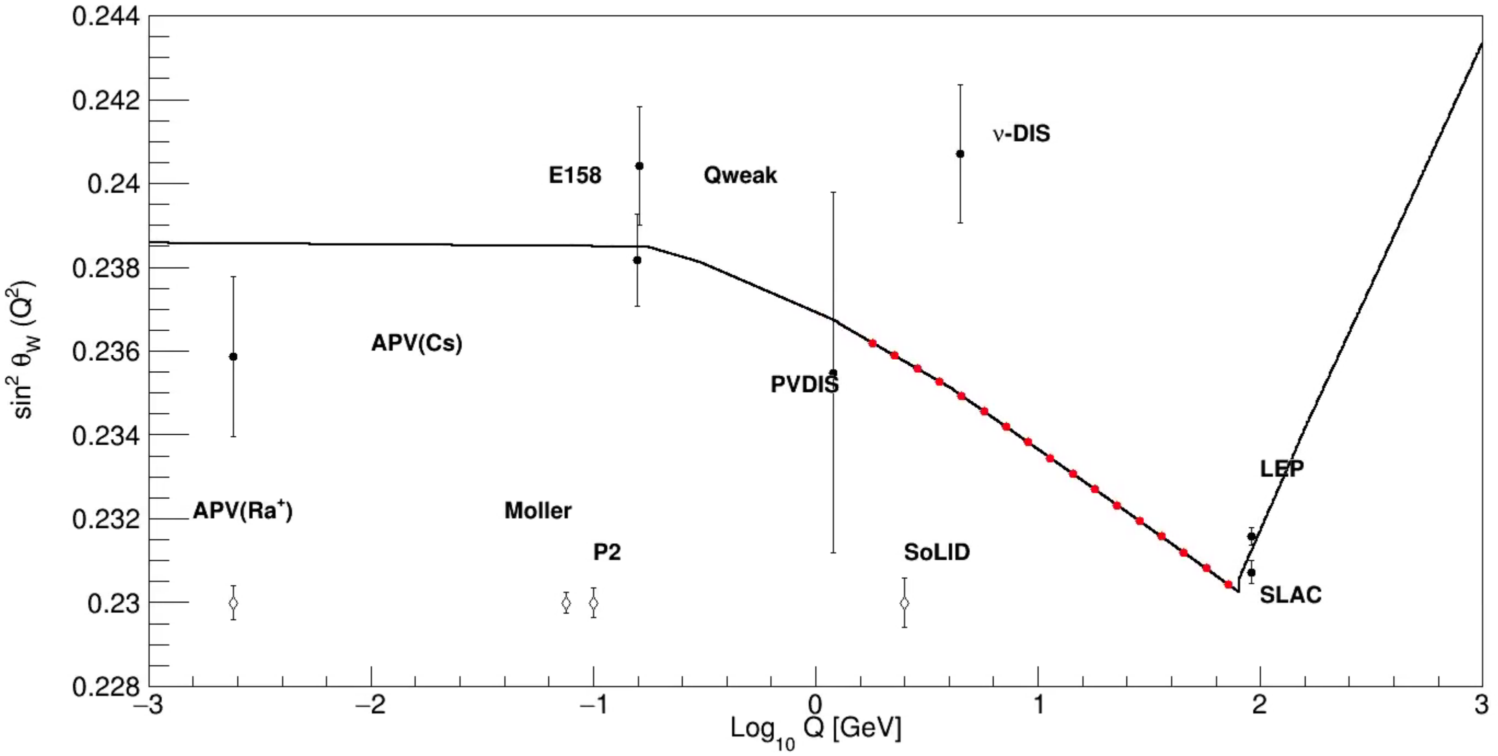
$$F_1^{\gamma Z} = 2\sum_q q_q\, g_A^q(f_q + f_{\bar{q}})$$

$\rightarrow$ Need precise knowledge of PDFs for $100\ \text{GeV}^2 \lesssim Q^2 \lesssim 5000\ \text{GeV}^2$



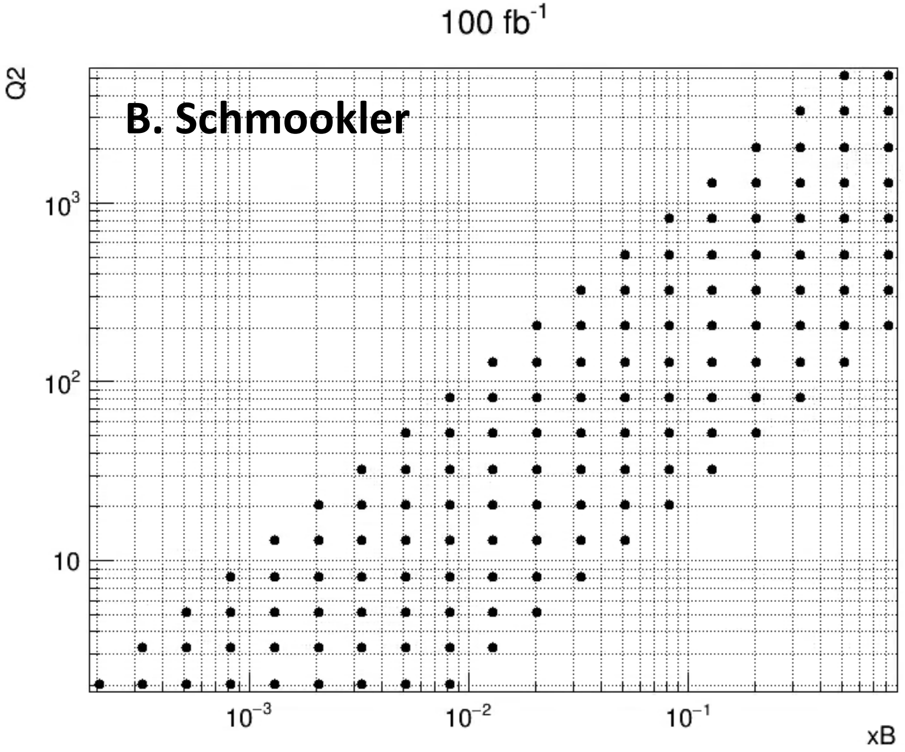
- The EIC will focus on ep collisions with ~100 fb-1 for each sqrt{s} regime
- Ayres pointed out in a talk last year the constraints on the mixing angle are harder to resolve in ep DIS collisions without significant improvement of the PDFs
- Chris and Nobuo did a statistical analysis of the impact on the s2tw extraction using this data for the Yellow Report
  - More work needs to be put in to convince everyone – especially in the procedure for the extraction of the uncertainty on the mixing angle

EIC weak mixing angle kinematical reach



- The first thing to confirm is the kinematical reach of the EIC
  - The red points here show the Q^2s that can be reasonable reached by the EIC
  - Still working on the extraction of the uncertainty on the mixing angle for each one (hope to get that in a couple of weeks)

Statistical analysis of 100 fb^{-1} (e)18x(p)275 GeV



- The observable is the NC parity violating asymmetry
  - To get at the mixing angle we need information on both the electromagnetic structure function but also on the interference structure function
- Using the inclusive NC tables generated for the YR by Barak to confirm some of the work that Chris has already done
  - Here I select all the Q^2>2 GeV data and 0.01<y<0.95

$$A_{PV}^{\text{electron}} = \frac{\sigma^R - \sigma^L}{\sigma^R + \sigma^L} = \frac{G_F Q^2}{2\sqrt{2}\pi\alpha}[g_A^e \frac{F_1^{\gamma Z}}{F_1^\gamma} + g_V^e \frac{Y_-}{2Y_+}\frac{F_3^{\gamma Z}}{F_1^\gamma}],$$

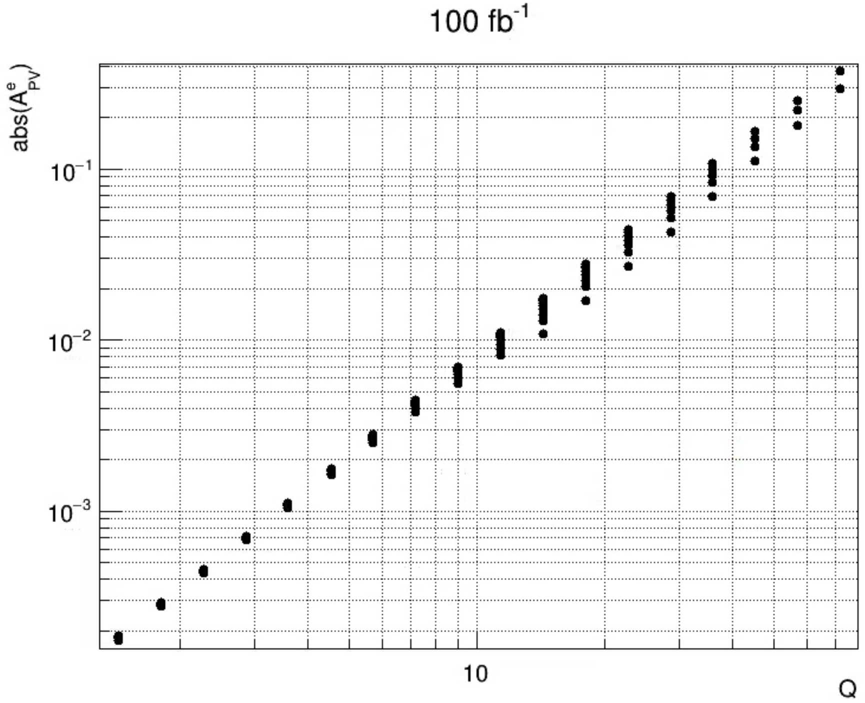
$$F_1^{\text{proton},\ \gamma Z} \approx \frac{1}{9}(u+\bar{u}+d+\bar{d}+s+\bar{s}+c+\bar{c}), \quad (11)$$

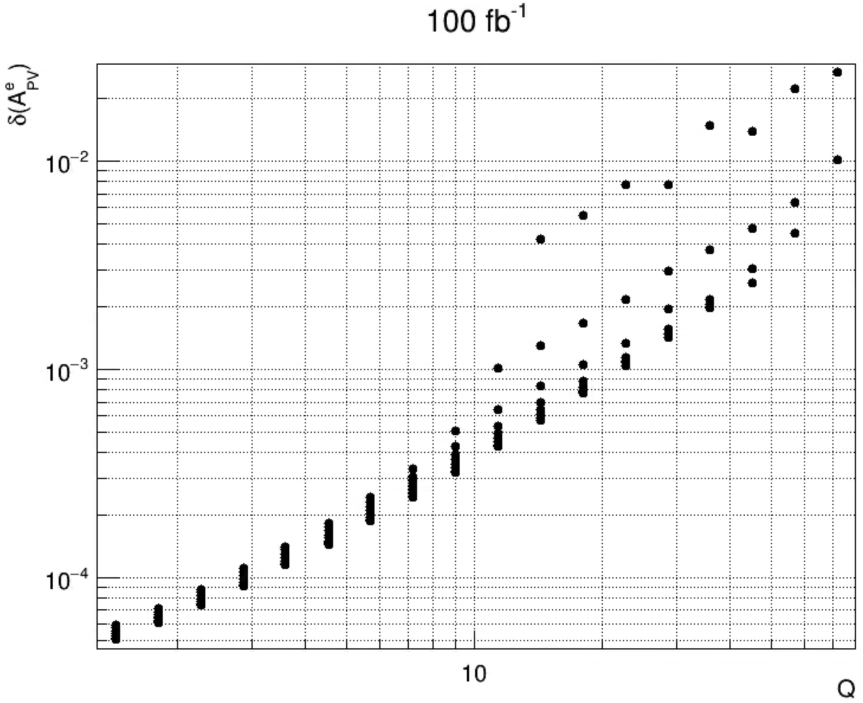
$$F_3^{\text{proton},\ \gamma Z} = \frac{2}{3}(u_V + c - \bar{c}) + \frac{1}{3}(d_V + s - \bar{s}), \quad (12)$$

$$g_1^{\text{proton},\ \gamma Z} \approx \frac{1}{9}(\Delta u+\Delta\bar{u}+\Delta d+\Delta\bar{d}+\Delta s+\Delta\bar{s}+\Delta c+\Delta\bar{c}), \quad (13)$$

$$g_5^{\text{proton},\ \gamma Z} = \frac{1}{3}(\Delta u_V + \Delta c - \Delta\bar{c}) + \frac{1}{6}(\Delta d_V + \Delta s - \Delta\bar{s}), \quad (14)$$

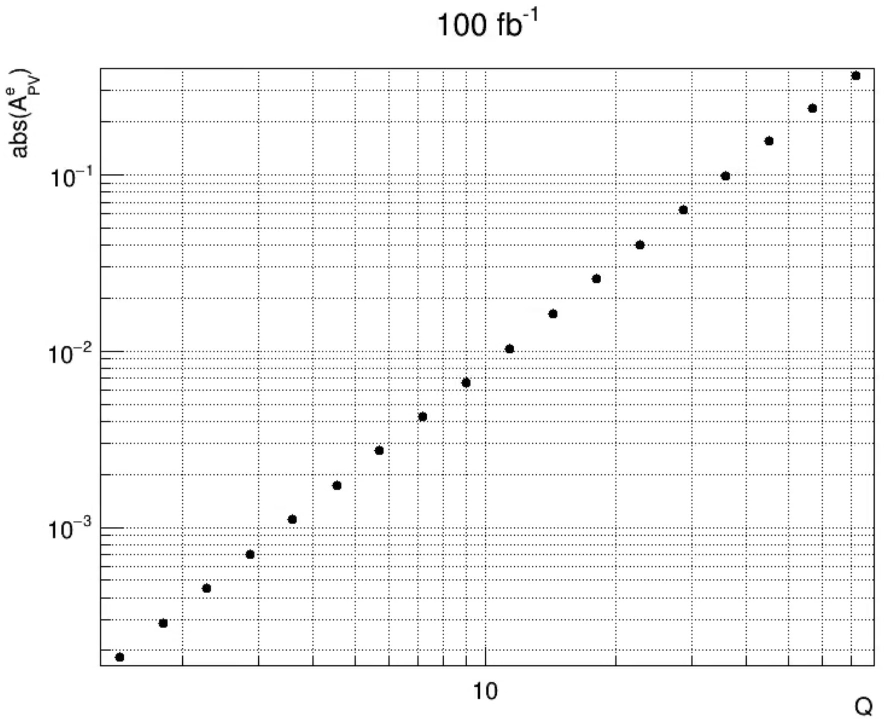
Obtaining $A^{PV}e$ for each (x,Q^2) bin

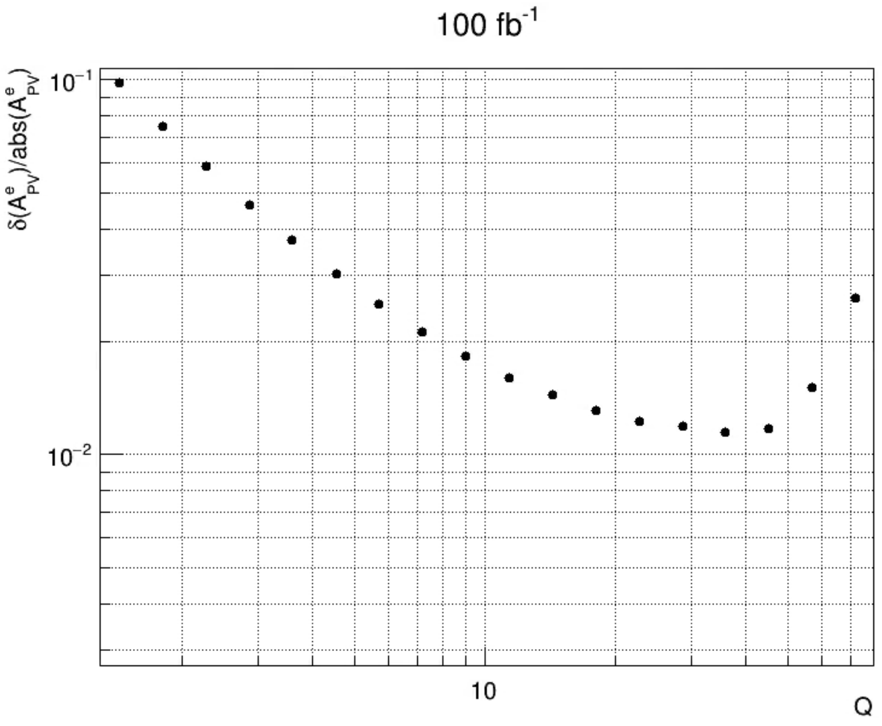




- I make use of the NNPDF framework to calculate the parity violating asymmetry for each (x,Q^2) bin and using the uncertainty for the unpolarized inclusive x-section (from Barak) one can determine the uncertainty for each of those bins
  - Note that at low Q^2 the asymmetry for all x is very similar so all the points are stacked on top of each other
- For now I preserve the Q^2 binning that Barak used in his grids for convenience

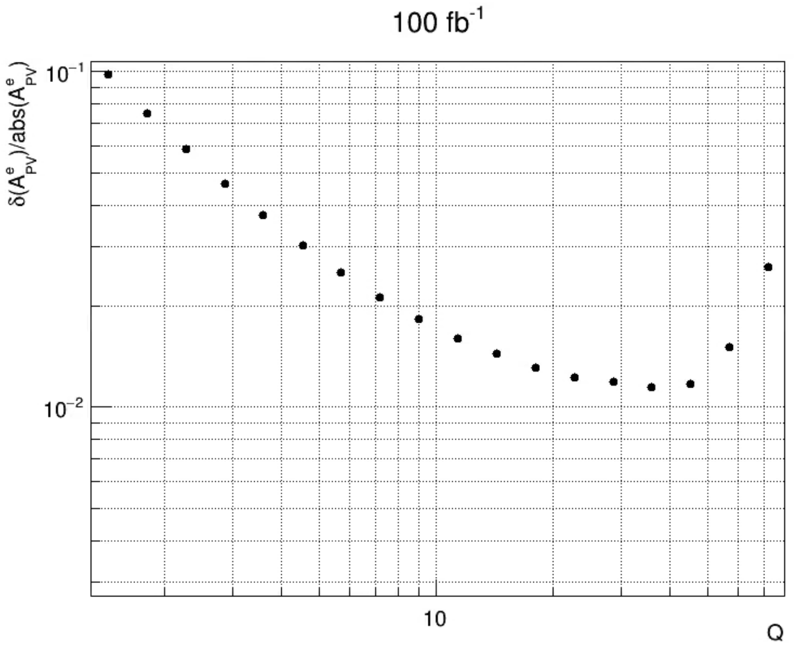
Obtaining $A^{PV}e$ for each (Q) bin

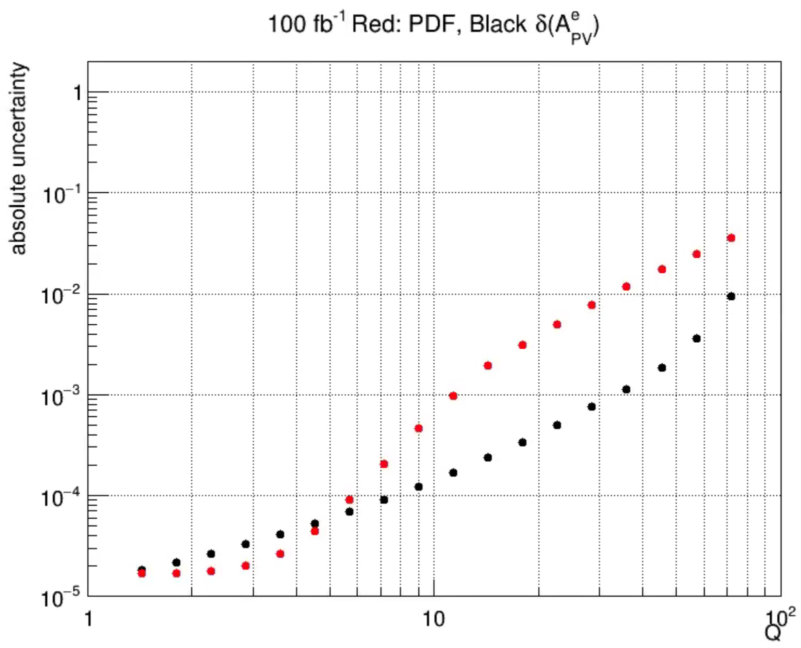




- A simple statistical average for each Q^2 bin can give us the average asymmetry and relative uncertainty
- We can see that in some bins the statistical precision is getting "dangerously" close to 1%
  - This would make this one of the most (experimentally) precise measurements we can perform using all the luminosity that the EIC is slated to accumulate

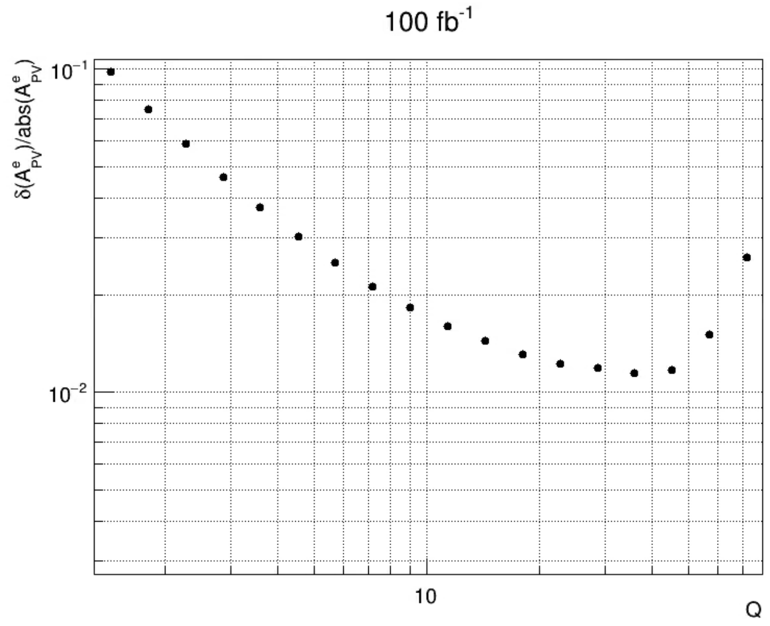
What about that theoretical uncertainty?

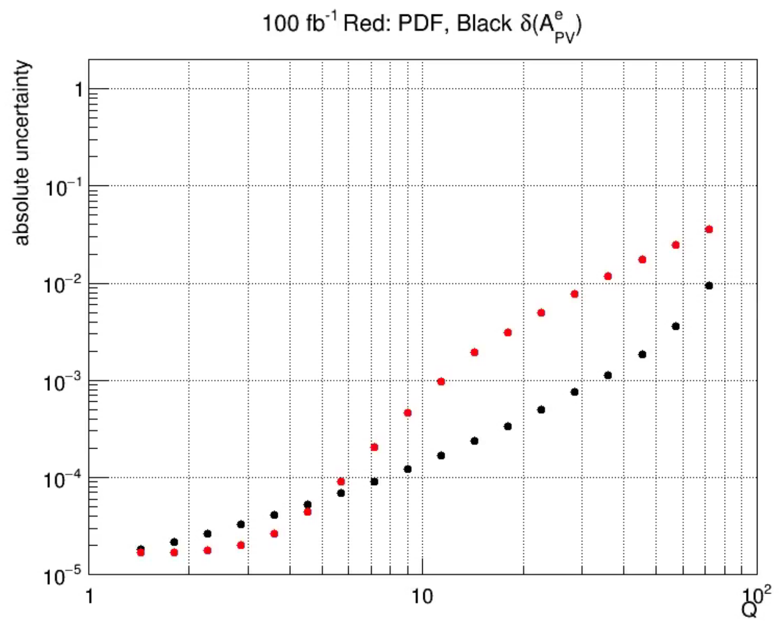




- All of this would be useless if the theoretical uncertainties completely eclipse the statistical precision
- I looked over the range of 100 NNPDF replicas at the variation of the parity violating asymmetry plot the absolute statistical uncertainty (black points on the right) together with the standard deviation for the replica variation (red points)
  - Indeed we see that for the bins where we have most of our statistics the PDF uncertainty if a factor of 10 larger
  - However, we should take into account that the EIC itself with bring significant improvements in these PDFs, so much so that we may easily end up with a statistically limited measurement

Not a Golden Channel, but ..



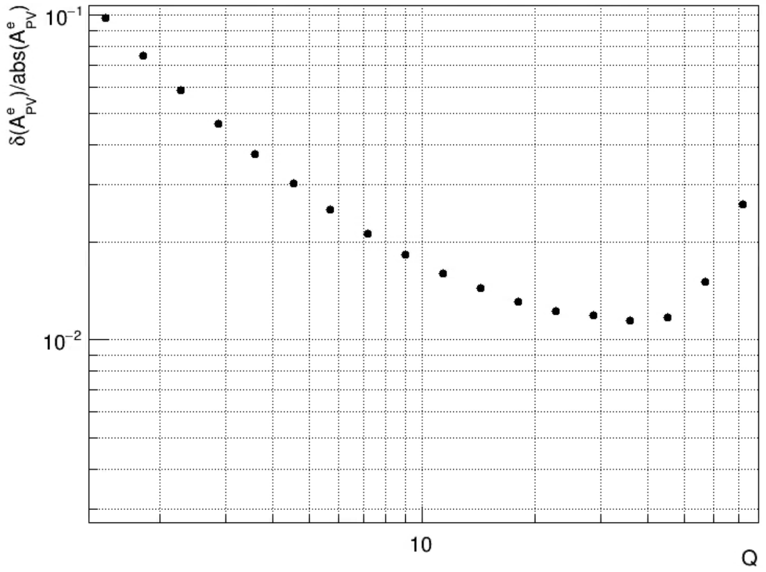


- While certainly the parity violating asymmetry is NOT one of the main pillars on which the EIC project has been proposed it certainly seems to be one of the most demanding measurements (due to the high statistical precision)
- I would argue that such a measurement could be the "golden differentiator" between different detector proposals highlighting the systematic control one can reach

Steps needed to get this to completion

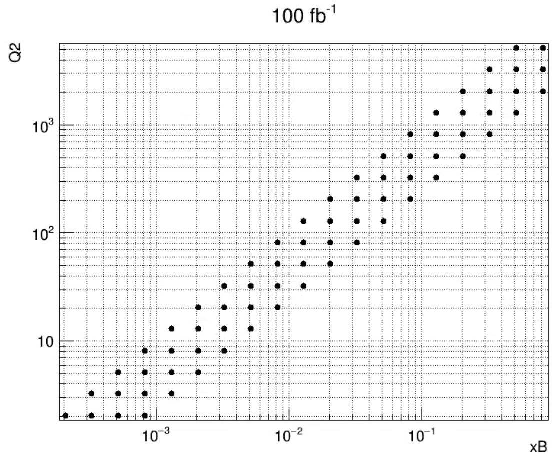
- Add the other sqrt{s} statistical data into the mix to see what the overall uncertainty will be for each Q^2 bin
- Use the DD4HEP particle simulation to evaluate proper acceptances and systematic uncertainties for this measurement
    - This would have significant overlap with the inclusive group
- Evaluate the proper way to propagate the precision of the asymmetry to the weak mixing angle precision
    - In my opinion this is not really needed for the proposal since we want to show that we can make a difficult measurement well, but certainly would be nice

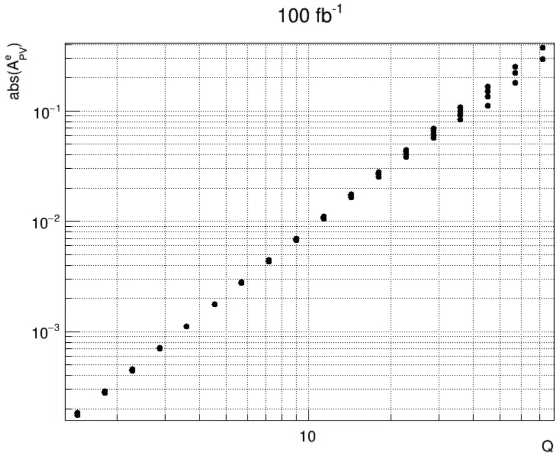
- Question/discussion: if we reach the point where we can add realistic statistical (from acceptance loss) and systematic (from detector effects) points on this plot, should we consider putting it into the proposal?

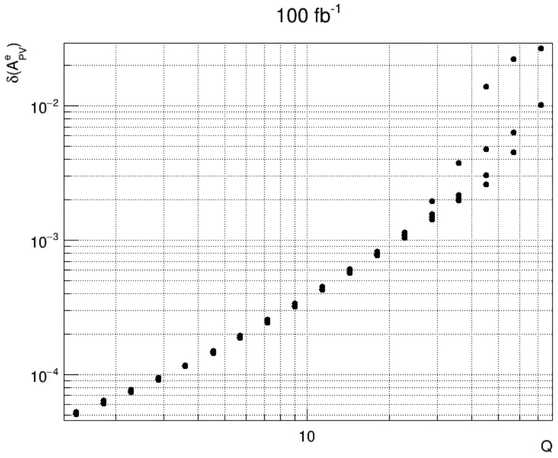


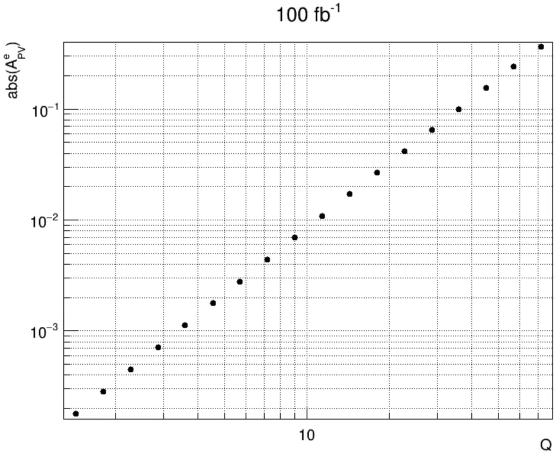
Backups

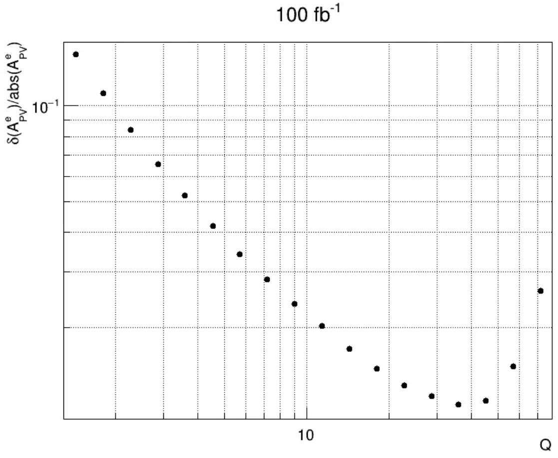
100 fb^-1 18x275 GeV

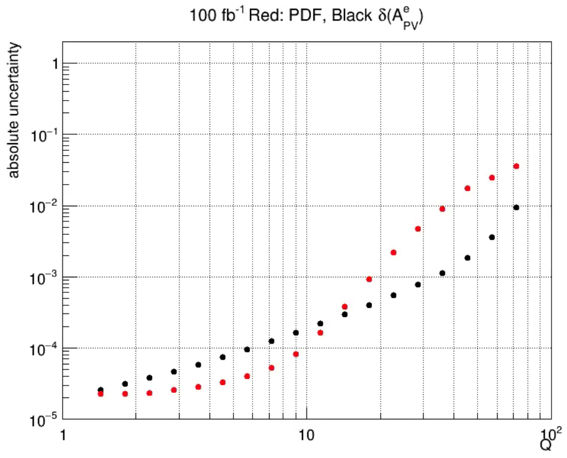












- $0.1<y<0.95$
- Q2>=2
- NNPDFpol11 (red points)