“Other” EW/BSM Physics with SoLID

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Neutral Current Inclusive Physics

Inclusive NC cross sections:

$$\frac{d^2\sigma}{dxdy}=\frac{d^2\sigma_0}{dxdy}+P_e\frac{d^2\sigma_e}{dxdy}+P_p\frac{d^2\sigma_p}{dxdy}+P_eP_p\frac{d^2\sigma_{ep}}{dxdy}$$

$$\left[F_2^{\gamma},F_2^{\gamma Z},F_2^{Z}\right] = x\sum_q\left[e_q^2,2e_qg_V^q,g_V^{q\,2}+g_A^{q\,2}\right](q+\bar{q}),$$

$$\left[F_3^{\gamma},F_3^{\gamma Z},F_3^{Z}\right] = \sum_q\left[0,2e_qg_A^q,2g_V^qg_A^q\right](q-\bar{q}),$$

$$\left[g_1^{\gamma},g_1^{\gamma Z},g_1^{Z}\right] = \frac{1}{2}\sum_q\left[e_q^2,2e_qg_V^q,g_V^{q\,2}+g_A^{q\,2}\right](\Delta q+\Delta\bar{q}),$$

$$\left[g_5^{\gamma},g_5^{\gamma Z},g_5^{Z}\right] = \sum_q\left[0,e_qg_A^q,g_V^qg_A^q\right](\Delta q-\Delta\bar{q}),$$

Neglecting target-mass corrections:

$$\frac{d^2\sigma_0}{dxdy} = \frac{4\pi\alpha^2}{xyQ^2}\Big\{(1-y)\left[F_2^{\gamma}-g_V^e\eta_{\gamma Z}F_2^{\gamma Z}+(g_V^{e\,2}+g_A^{e\,2})\eta_ZF_2^Z\right]$$
$$+xy^2\left[F_1^{\gamma}-g_V^e\eta_{\gamma Z}F_1^{\gamma Z}+(g_V^{e\,2}+g_A^{e\,2})\eta_ZF_1^Z\right]-\frac{xy}{2}(2-y)\left[g_A^e\eta_{\gamma Z}F_3^{\gamma Z}-2g_V^eg_A^e\eta_ZF_3^Z\right]\Big\}\quad(2)$$

$$\frac{d^2\sigma_e}{dxdy} = \frac{4\pi\alpha^2}{xyQ^2}\Big\{(1-y)\left[g_A^e\eta_{\gamma Z}F_2^{\gamma Z}-2g_V^eg_A^e\eta_ZF_2^Z\right]+xy^2\left[g_A^e\eta_{\gamma Z}F_1^{\gamma Z}-2g_V^eg_A^e\eta_ZF_1^Z\right]$$
$$+\frac{xy}{2}(2-y)\left[g_V^e\eta_{\gamma Z}F_3^{\gamma Z}-(g_V^{e\,2}+g_A^{e\,2})\eta_ZF_3^Z\right]\Big\},\quad(3)$$

$$\frac{d^2\sigma_p}{dxdy} = \frac{4\pi\alpha^2}{xyQ^2}\Big\{y(2-y)\left[g_A^e\eta_{\gamma Z}g_1^{\gamma Z}-2g_V^eg_A^e\eta_Zg_1^Z\right]+(1-y)\left[-g_V^e\eta_{\gamma Z}g_4^{\gamma Z}+(g_V^{e\,2}+g_A^{e\,2})\eta_Zg_4^Z\right]$$
$$+xy^2\left[-g_V^e\eta_{\gamma Z}g_5^{\gamma Z}+(g_V^{e\,2}+g_A^{e\,2})\eta_Zg_5^Z\right]\Big\},\quad(4)$$

$$\frac{d^2\sigma_{ep}}{dxdy} = \frac{4\pi\alpha^2}{xyQ^2}\Big\{y(2-y)\left[g_1^{\gamma}-g_V^e\eta_{\gamma Z}g_1^{\gamma Z}+(g_V^{e\,2}+g_A^{e\,2})\eta_Zg_1^Z\right]$$
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fermion	Q_f	g_A^f	g_V^f
ν_e,ν_μ,ν_τ	0	$\frac{1}{2}$	$\frac{1}{2}$
e^-,μ^-,τ^-	-1	$-\frac{1}{2}$	$-\frac{1}{2}+2\sin^2\theta_W\approx-0.03$
u,c,t	$\frac{2}{3}$	$\frac{1}{2}$	$\frac{1}{2}-\frac{4}{3}\sin^2\theta_W\approx0.19$
d,s,b	$-\frac{1}{3}$	$-\frac{1}{2}$	$-\frac{1}{2}+\frac{2}{3}\sin^2\theta_W\approx-0.34$

$$\eta_{\gamma Z}=\left(\frac{G_FM_Z^2}{2\sqrt{2}\pi\alpha}\right)\left(\frac{Q^2}{Q^2+M_Z^2}\right)$$

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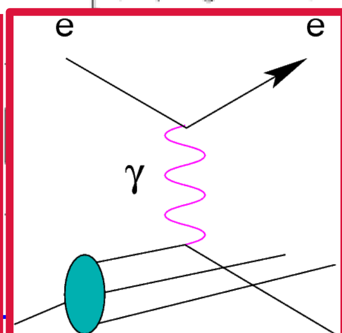
$$\frac{d^2\sigma_e}{dxdy} = \frac{4\pi\alpha^2}{xyQ^2}\Big\{(1-y)\left[g_A^e\eta_{\gamma Z}F_2^{\gamma Z}-2g_V^e g_A^e\eta_Z F_2^Z\right]+xy^2\left[g_A^e\eta_{\gamma Z}F_1^{\gamma Z}-2g_V^e g_A^e\eta_Z F_1^Z\right]$$
$$+\frac{xy}{2}(2-y)\left[g_V^e\eta_{\gamma Z}F_3^{\gamma Z}-(g_V^{e\,2}+g_A^{e\,2})\eta_Z F_3^Z\right]\Big\}, \quad (3)$$

$$\frac{d^2\sigma_p}{dxdy} = \frac{4\pi\alpha^2}{xyQ^2}\ \ldots\ g_A^e\eta_Z g_1^Z\ \ldots\ (g_V^{e\,2}+g_A^{e\,2})\eta_Z g_4^Z\Big] \ \ldots\ xy^2 \ \ldots\ \Big\}, \quad (4)$$

$$\frac{d^2\ldots}{dxdy} = \frac{\ldots\alpha^2}{xyQ^2}\ \ldots\ +(g_V^{2}+\ldots \quad +(1-\ldots\ g^Z\Big]+xy^2\Big[\ \ldots\ , \quad (5)$$

$A_{NC} =$



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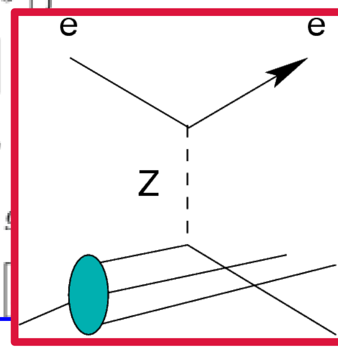

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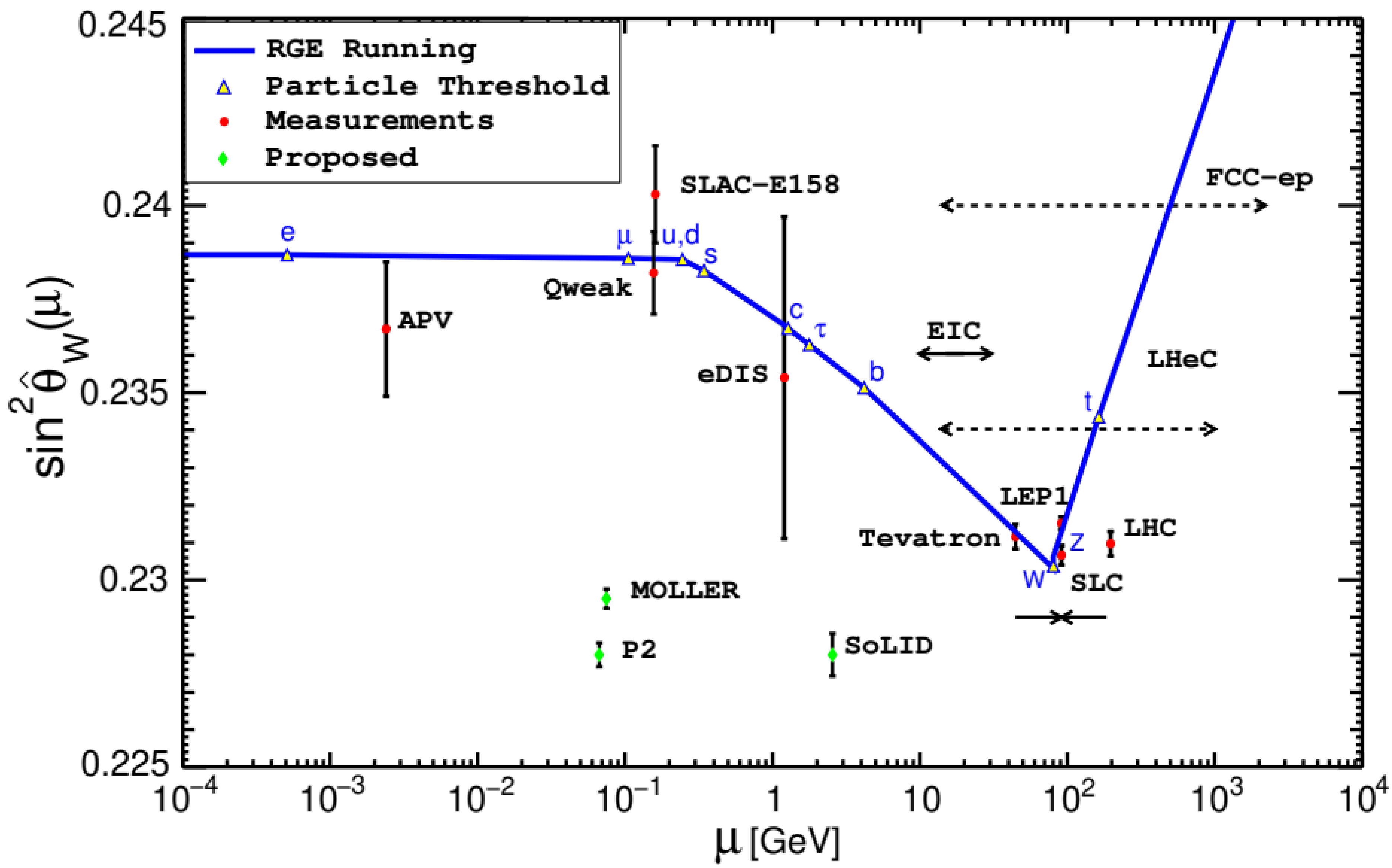
$$\eta_{\gamma Z}=\left(\frac{G_F M_Z^2}{2\sqrt{2}\pi\alpha}\right)\left(\frac{Q^2}{Q^2+M_Z^2}\right)$$

PVDIS Apv(e) asymmetry

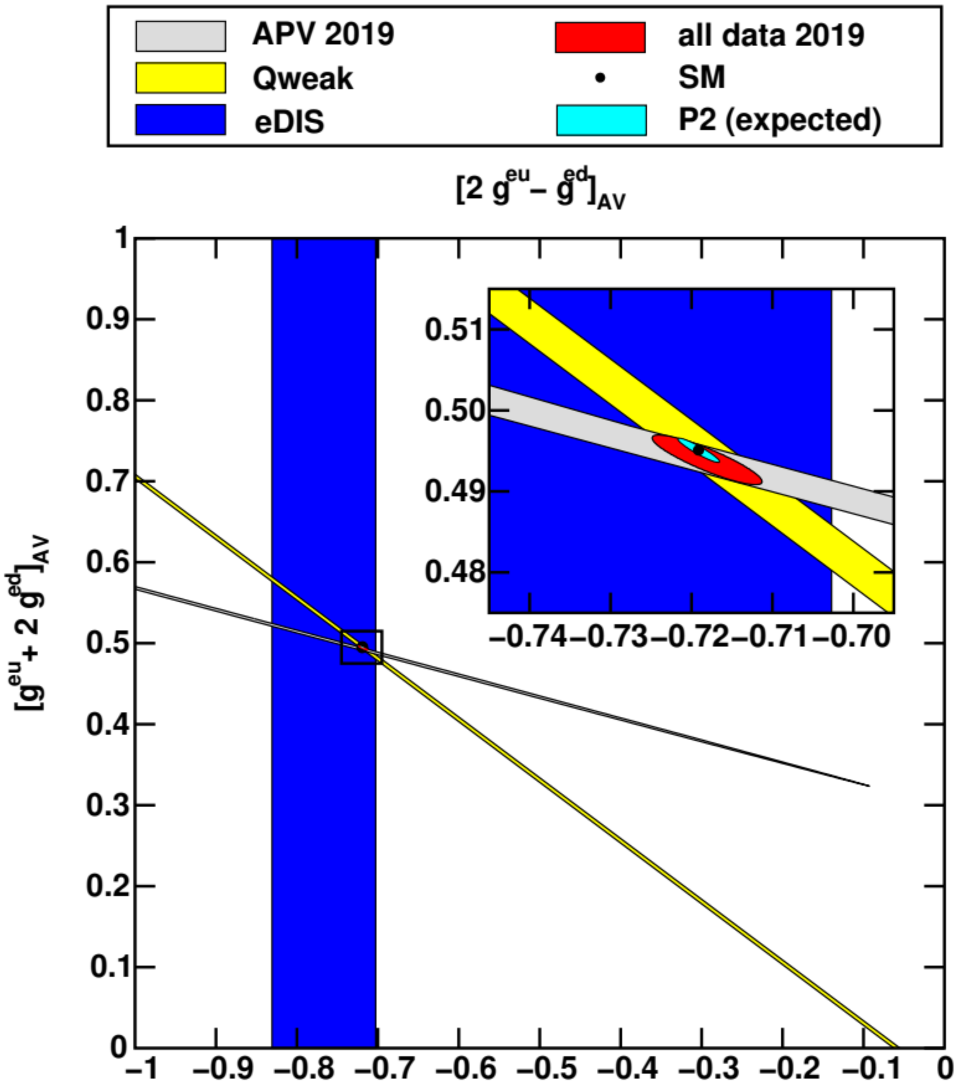
$$A_{RL}^{e^-}=\frac{\eta_{\gamma Z}\left[g_A^e 2yF_1^{\gamma Z}+g_A^e F_2^{\gamma Z}\left(\frac{2}{xy}-\frac{2}{x}-\frac{2M^2xy}{Q^2}\right)+g_V^e(2-y)F_3^{\gamma Z}\right]}{2yF_1^\gamma+\left(\frac{2}{xy}-\frac{2}{x}-\frac{2M^2xy}{Q^2}\right)F_2^\gamma-\eta_{\gamma Z}\left[g_V^e 2yF_1^{\gamma Z}+g_V^e\left(\frac{2}{xy}-\frac{2}{x}-\frac{2M^2xy}{Q^2}\right)F_2^{\gamma Z}+g_A^e(2-y)F_3^{\gamma Z}\right]}$$

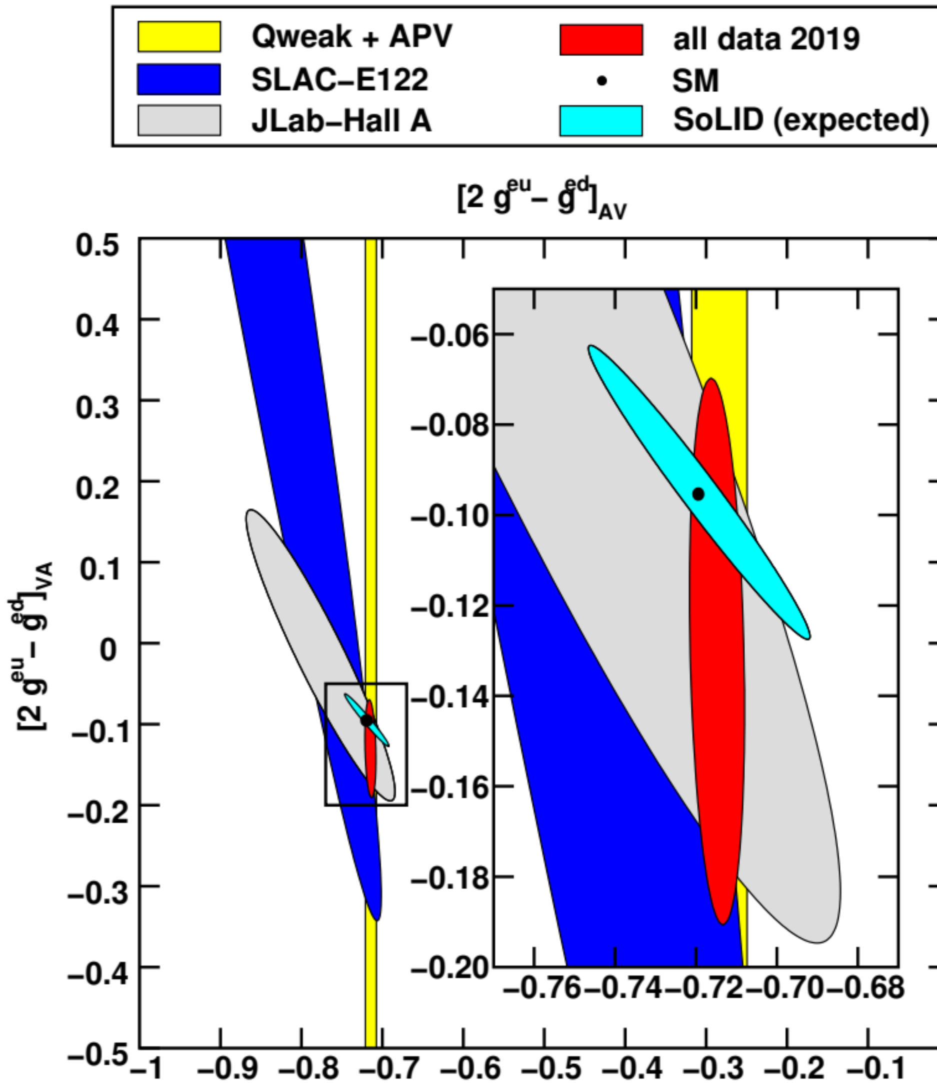
Weak Mixing Angle – Near and Far Future



Current Knowledge on $C_{1q,2q}$

all are 68% C.L. limit





CERN for muon: $2C_{3u}^{\mu q} - C_{3d}^{\mu q} = 1.57 \pm 0.38$

Argento et al., PLB120B, 245 (1983)

https://arxiv.org/abs/2103.12555

Other/Future EW/BSM Physics

- Polarized PVDIS – LOI12-06-007 PAC44
- Lepton-charge asymmetry (C_{3q}) – PR12-21-006 deferred by PAC49 (July 2021)

Ideas:

- Study QED NLO (TPE) Ae+e- at 11 GeV, then C_{3q} at 22 GeV.
- Beam-normal asymmetry (A_n) DIS
- Quark-hadron duality in PVES
- PVDIS with 22 GeV

LOI12-06-007 Polarized PVDIS

$$\frac{d^2\sigma_0}{dxdy} = \frac{4\pi\alpha^2}{xyQ^2}\Big\{(1-y)\left[F_2^\gamma - g_V^e\eta_{\gamma Z}F_2^{\gamma Z} + ({g_V^e}^2+{g_A^e}^2)\eta_Z F_2^Z\right]$$
$$+xy^2\left[F_1^\gamma - g_V^e\eta_{\gamma Z}F_1^{\gamma Z} + ({g_V^e}^2+{g_A^e}^2)\eta_Z F_1^Z\right] - \frac{xy}{2}(2-y)\left[g_A^e\eta_{\gamma Z} \ldots\right.$$

$$\frac{d^2\sigma_e}{dxdy} = \frac{4\pi\alpha^2}{xyQ^2}\Big\{(1-y)\left[g_A^e\eta_{\gamma Z}F_2^{\gamma Z} - 2g_V^e g_A^e\eta_Z F_2^Z\right] + xy^2\left[g_A^e\eta_{\gamma Z}F_1^{\gamma Z} \ldots\right.$$
$$+\frac{xy}{2}(2-y)\left[g_V^e\eta_{\gamma Z}F_3^{\gamma Z} - ({g_V^e}^2+{g_A^e}^2)\eta_Z F_3^Z\right]\Big\},$$

$$\frac{d^2\sigma_p}{dxdy} = \frac{4\pi\alpha^2}{xyQ^2}\Big\{y(2-y)\left[g_A^e\eta_{\gamma Z}g_1^{\gamma Z} - 2g_V^e g_A^e\eta_Z g_1^Z\right] + (1-y)\left[-g_V^e\eta_{\gamma Z}g_4^{\gamma Z} + ({g_V^e}^2+{g_A^e}^2)\eta_Z g_4^Z\right]$$
$$+xy^2\left[-g_V^e\eta_{\gamma Z}g_5^{\gamma Z} + ({g_V^e}^2+{g_A^e}^2)\eta_Z g_5^Z\right]\Big\}, \qquad (4)$$

$$\frac{d^2\sigma_{ep}}{dxdy} = \frac{4\pi\alpha^2}{xyQ^2}\Big\{y(2-y)\left[g_1^\gamma - g_V^e\eta_{\gamma Z}g_1^{\gamma Z} + ({g_V^e}^2+{g_A^e}^2)\eta_Z g_1^Z\right]$$
$$+(1-y)\left[g_A^e\eta_{\gamma Z}g_4^{\gamma Z} - 2g_V^e g_A^e\eta_Z g_4^Z\right] \ldots$$

$$\left[F_2^\gamma, F_2^{\gamma Z}, F_2^Z\right] = x\sum_q\left[e_q^2, 2e_q g_V^q, {g_V^q}^2 + {g_A^q}^2\right](q+\bar{q}),$$
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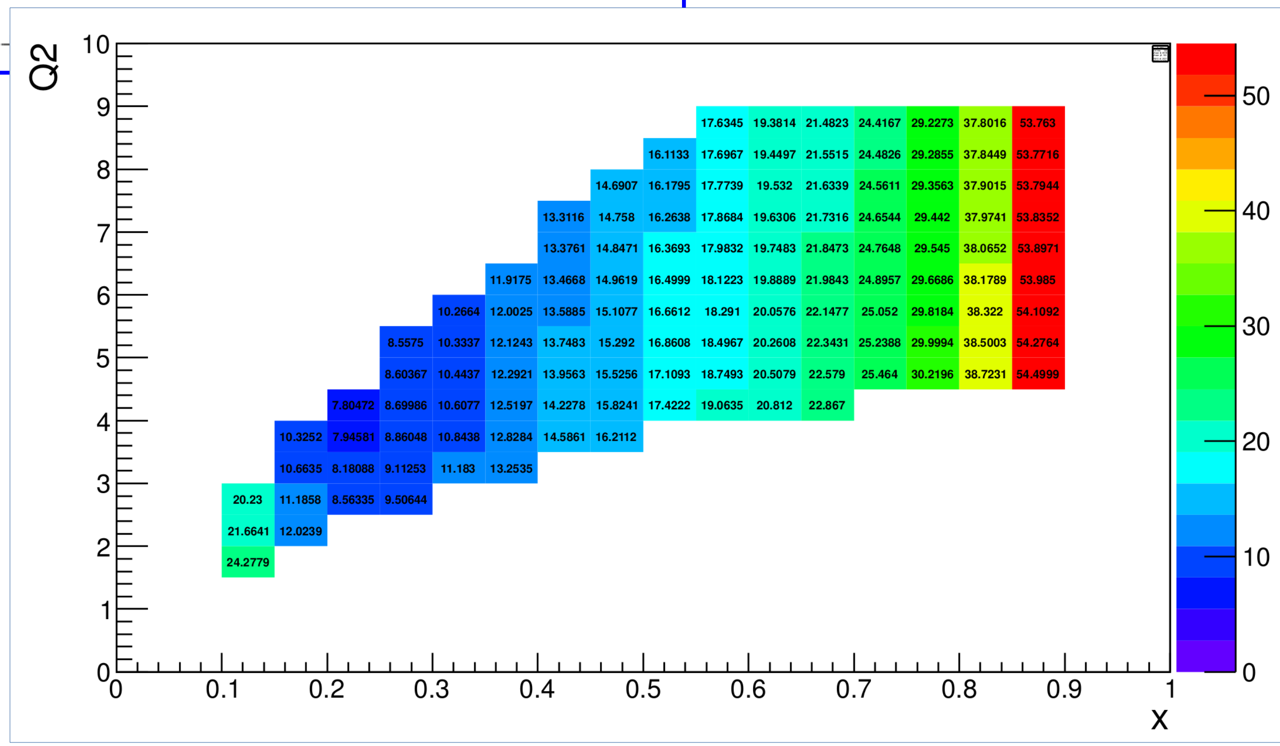
$$\eta_{\gamma Z} = \left(\frac{G_F M_Z^2}{2\sqrt{2}\pi\alpha}\right)\left(\frac{Q^2}{Q^2+M_Z^2}\right)$$

$$f(y) = \frac{1-(1-y)^2}{1+(1-y)^2}$$

PVDIS Apv(N) asymmetry

$$A_{RL}^N \approx \frac{\eta_{\gamma Z}\left[g_A^e f(y)\, g_1^{\gamma Z} + g_V^e g_5^{\gamma Z}\right]}{F_1^\gamma}$$

- 180 PAC days
- stage-II polarized 3He target, 60cm, 60uA, upgraded to 160 amg
- have not looked into SMEFT potentials



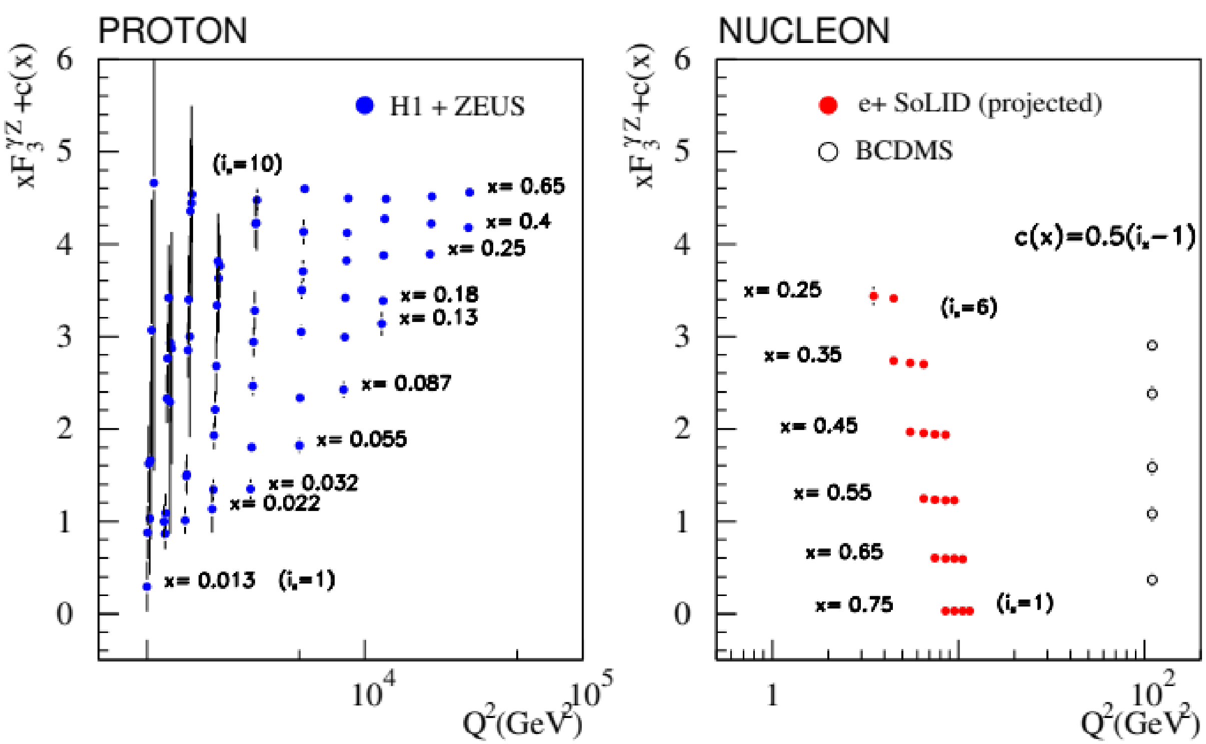
PR12-21-006 Lepton Charge Asymmetry

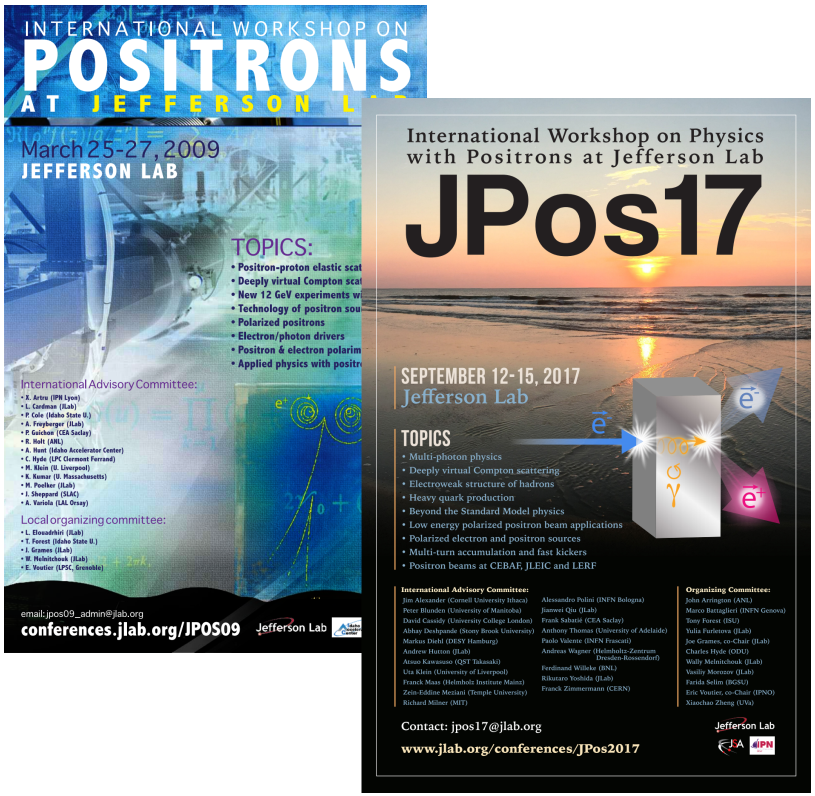
Eur. Phys. J. A manuscript No.
(will be inserted by the editor)

An experimental program with high duty-cycle polarized and unpolarized positron beams at Jefferson Lab

- 104 PAC days
- positron beam 3uA unpolarized
- beam control (1E-4 beam energy, ? beam position, “fast (week-wise)” switch)

$$\Delta\left(2C_{3u}-C_{3d}\right)_{\text{total}}=\pm0.053(\exp)\pm0.009(1\%\ \text{QED})$$
$$+0.000-0.035(\text{HT, CJ15})\approx\pm0.060$$





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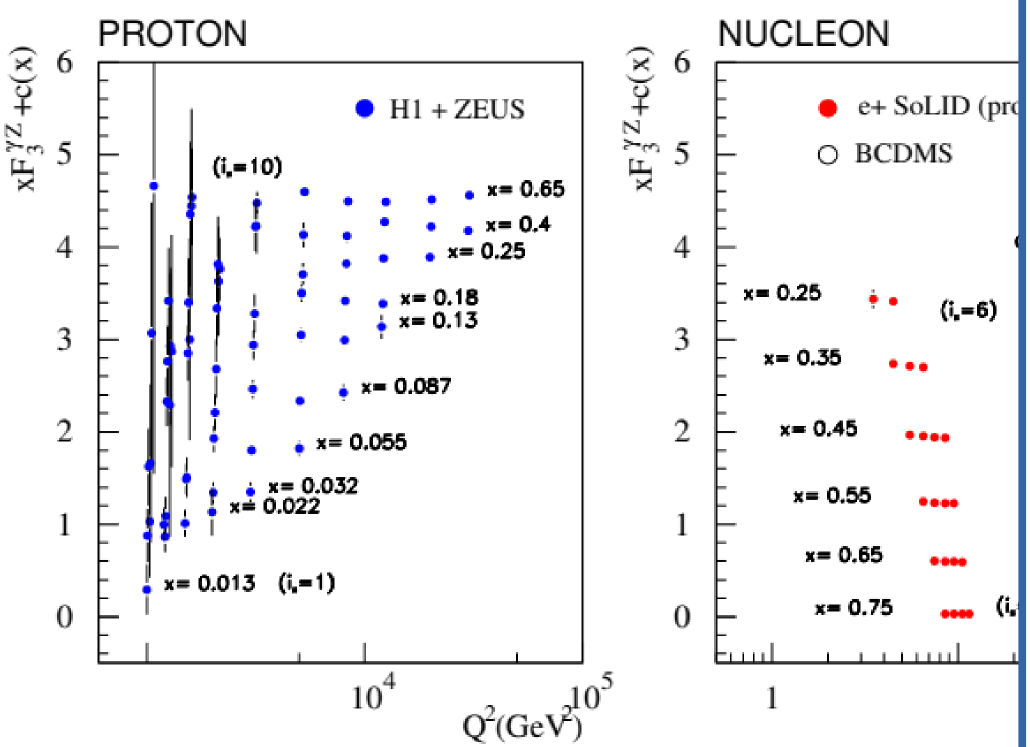


PAC49 report:

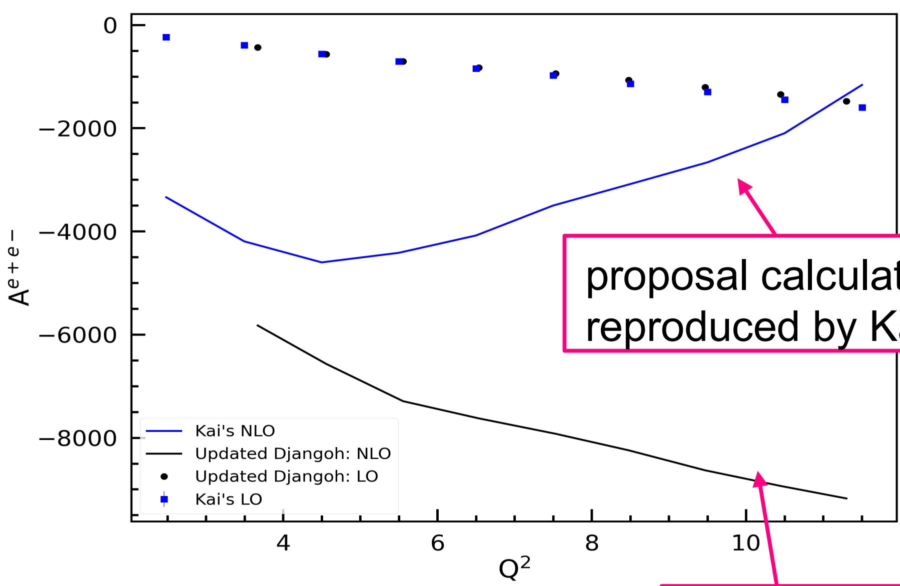
Issues: The PAC is pleased to see such an interesting and far-reaching proposal. … ...At the same time, the requirements on the accelerator and theory are both daunting.

Summary: This proposal will require a tour-de-force effort, and the PAC encourages the group to proceed with development. To allow the community better usage of the results, the proposal should include estimates of asymmetry and cross section uncertainties. At this time, our concerns about the details of having the proper beam and the optimal theory extraction of the electron-quark couplings leads us to defer the proposal in its present form.

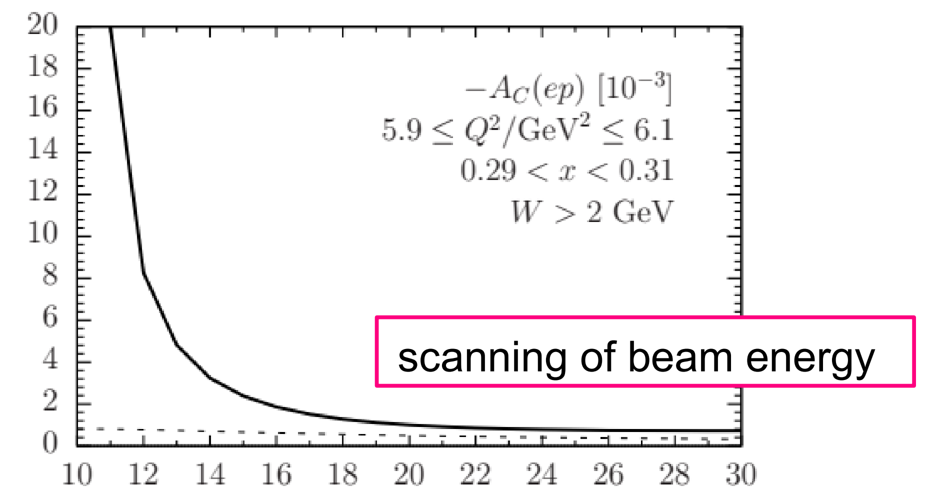
Idea: with positron beam, study TPE DIS (QED NLO) first

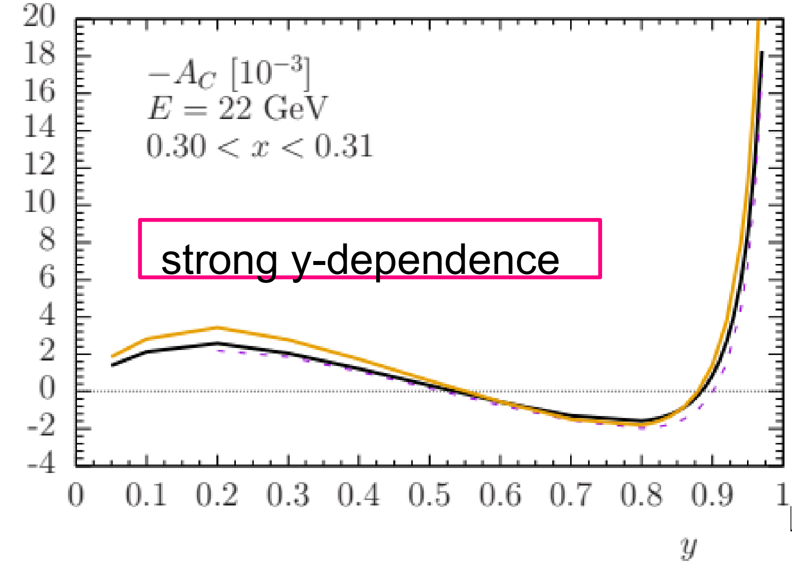
- TPE in DIS using positrons:
  - New calculation shows that NLO asymmetry is larger now for 11 GeV (than in the proposal), but at least 20 times much smaller at 22 GeV. Djangoh author (Hubert S.) also suggested lower y settings;

Djangoh 4.6.16 vs. 4.6.19
(lepton-charge for deuteron fixed)



H. Spiesberger, DJANGOH.4.6.19 16.10.2021





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  - New calculation shows that NLO asymmetry is larger now for 11 GeV (than in the proposal), but at least 20 times much smaller at 22 GeV. Djangoh author (Hubert S.) also suggested lower y settings;
  - We now have the tool for calculation, can do **FOM study** [target position/ scattering angle/ (x,Q2,y)]:
    - develop the physics case (TPE in DIS, relating to GPD, etc?); multi-stage approach?
    - calculation of A^{e+e-} LO and NLO over a wide range of (x,Q^2), optimize kinematics separately for:
      - TPE study (test NLO calculations, need NLO>>LO)
      - electroweak study (need NLO<<LO), measure C_{3q} ;
      - possibly study NLO at 11 GeV and C_{3q} at 22 GeV?
  - Proposal focusing on testing TPE DIS calculation possible (2024?), and e+@22 GeV in the (far) future.

Idea: Beam-normal SSA (A_n) in DIS

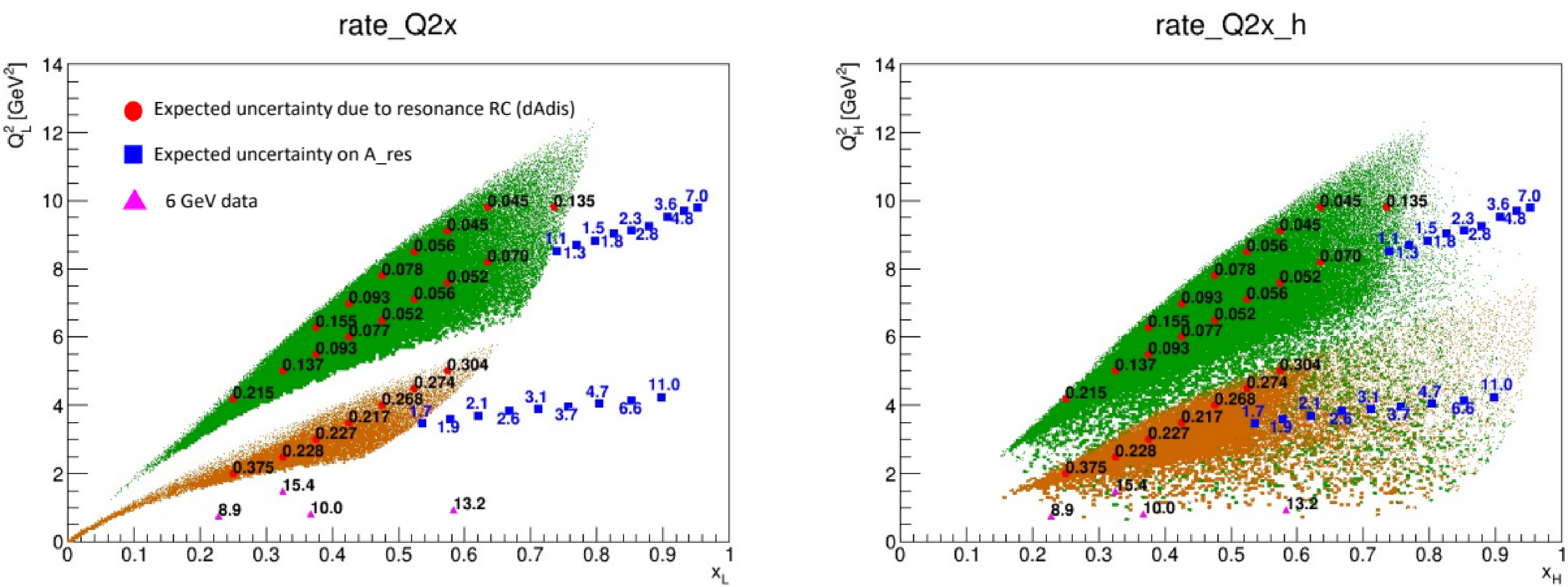
- Beam-normal single spin asymmetry (A_n) in DIS
  - A_n in elastic measured in all previous PVES, interesting results; A_n in DIS measured only at 6 GeV
  - **TPE physics**, PVDIS setup, beam **transverse spin** (horizontal plane, non-invasive), could impact positron C_{3q} and $F_3^{\gamma Z}$ study.
  - What needs to be done:
    - review of existing data – mostly elastic PVES
    - comprehensive review of TPE physics, relation to other observables
    - contact theorists for developing the physics case and acquire predictions: A. Afanasev, A. Metz, Marc Vanderhaegen, Wally Melnitchouk
  - **Possible proposal PAC50** (summer 2022)?
    - 5ppm precision "would be very good" (A. Afanasev).
    - Michael Nycz, William Henry, +?

Ideas: quark-hadron duality in PVES

- resonance PV measured to 10% with 6 GeV, parasitic data from SoLID 11+6.6 GeV PVDIS will improve this to ~2% for a broad Q^2 and W region;
- Physics would be **resonance PVES asymmetry and duality**;
- Modeling the low Q^2 region useful for controlling PVDIS radiative corrections;
- What needs to be done:
  - Projection of data and precision – Weizhi X.→? ; Study previous proposals (PR06-005, PR07-010)
  - acquire duality model for unpolarized and polarized structure functions and come up with some model for PVES asymmetry; comprehensive review of duality
- **possible rungroup proposal PAC50** (summer 2022)

- Using F1F2 21
- 120 days of running with 11 GeV, 10 days of running with 6.6 GeV
- All numbers in percentage

Weizhi X



PVDIS with 24 GeV

$$A_{PV}^{fit} = A_{PV}(C_1, C_2)^{EW\,SM}\left(1+\beta_{HT}\frac{1}{(1-x)^3 Q^2}+\beta_{CSV}\,x^2\right)$$

Generator level study (A. Emmert/UVA)
blue = 11 GeV
black = 22 GeV target at z=0
red = 22 GeV target at z=-50cm
orange = 22 GeV target at z=-100cm

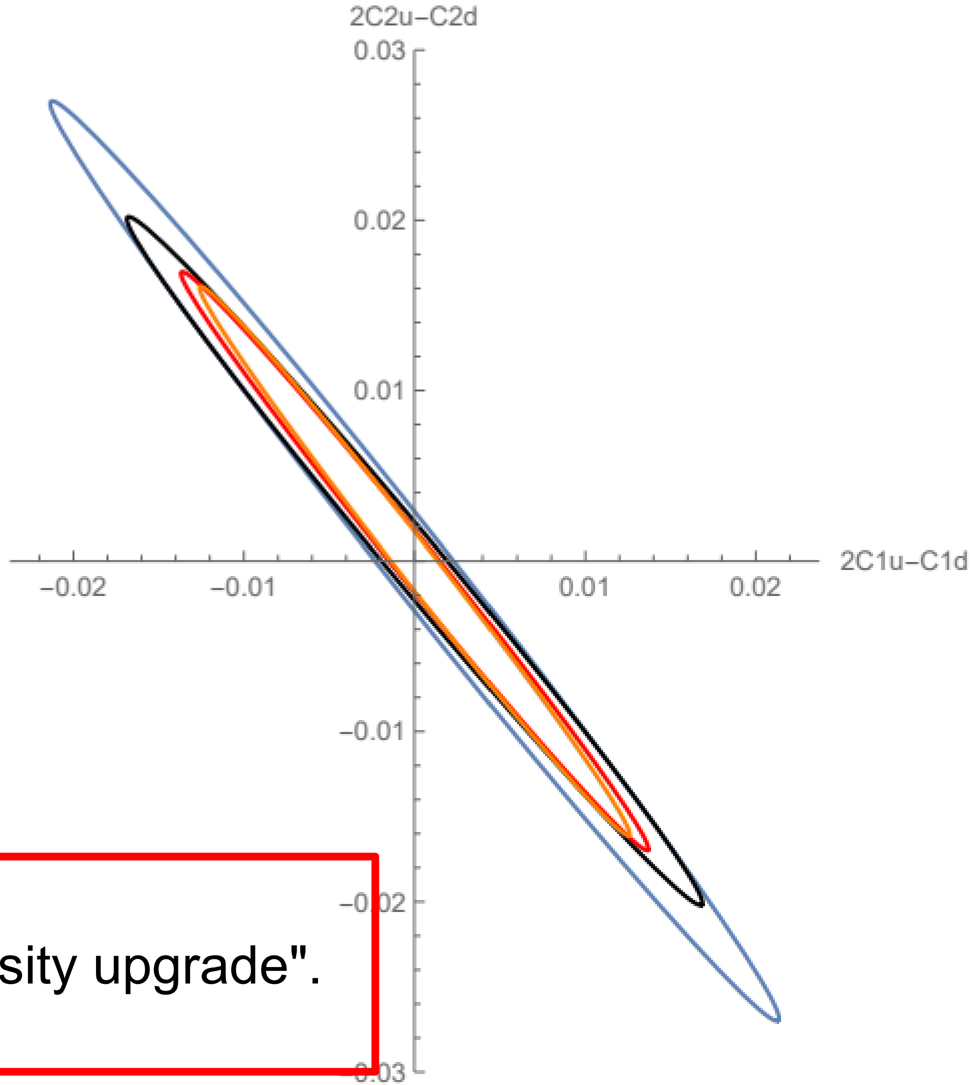
12 GeV full sim:
PARAMETER CORRELATION COEFFICIENTS

NO.	GLOBAL	1	2	3	4
1	0.99865	1.000	-0.990	**0.246**	**-0.042**
2	0.99860	-0.990	1.000	**-0.315**	**0.157**
3	0.96522	**0.246**	**-0.315**	1.000	-0.880
4	0.98216	**-0.042**	**0.157**	-0.880	1.000

(if it's 0.3, one starts to worry – Jens)

22 GeV: expect less correlation

- **Goal**
  - realistic trigger cuts and baffles;
  - expect smaller C_2 uncertainty and less EW/hadronic correlation



ECT Workshop*
"Opportunities with JLAB energy and luminosity upgrade".
September 26-30, 2022