Connections between EW&BSM physics @EIC and Snowmass planning

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(with slides stolen from many others)

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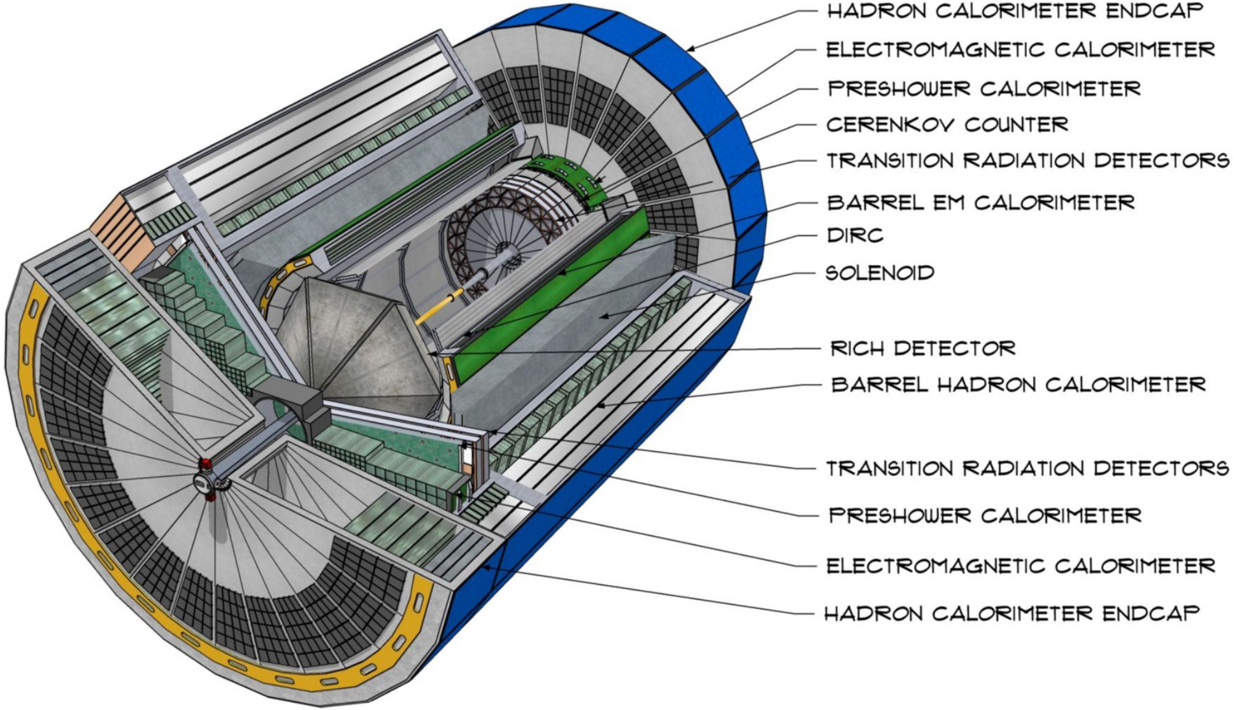
The EIC community YR effort

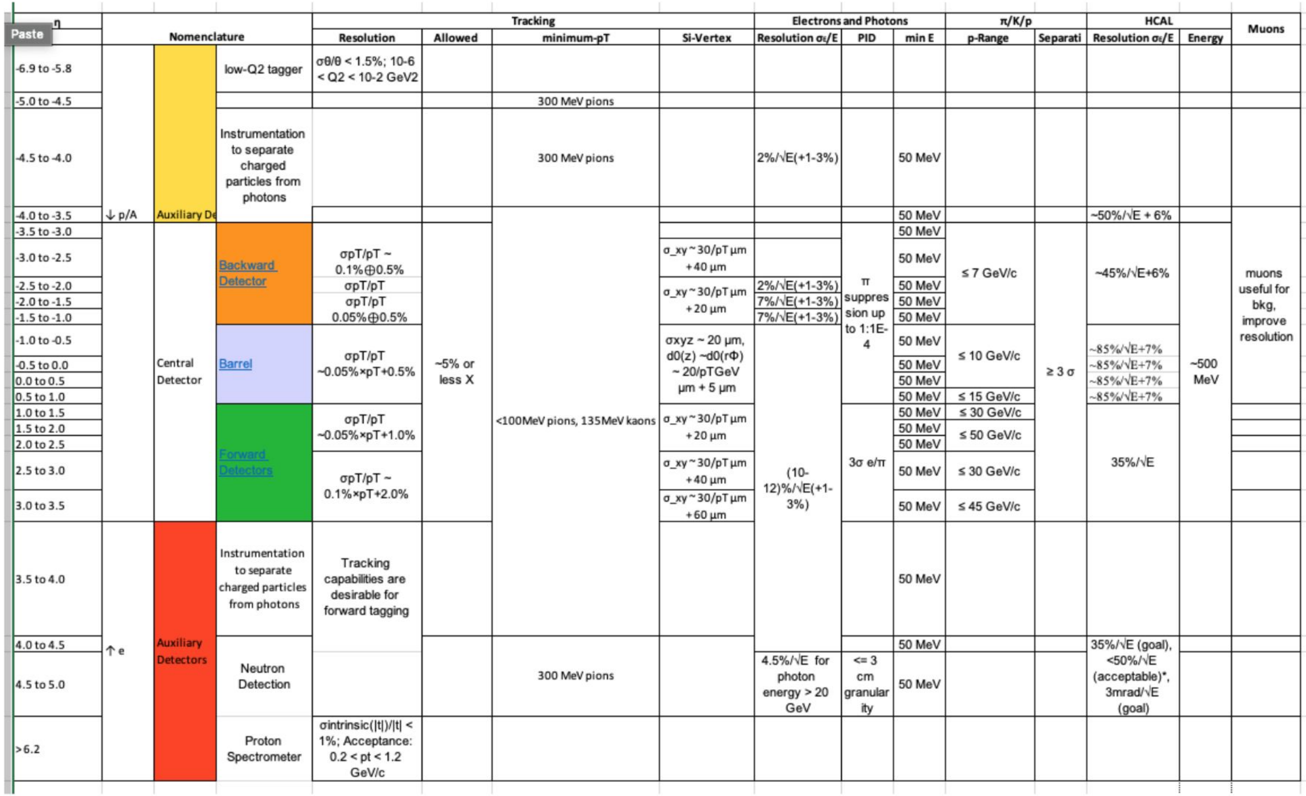
- The YR effort crystalised the main physics thrusts of the EIC and allowed the community to determine the best possible detector for that physics
- Some of the studies that are being worked on for the Snowmass LOI have already made some contributions/constraints through this process



Detector requirements

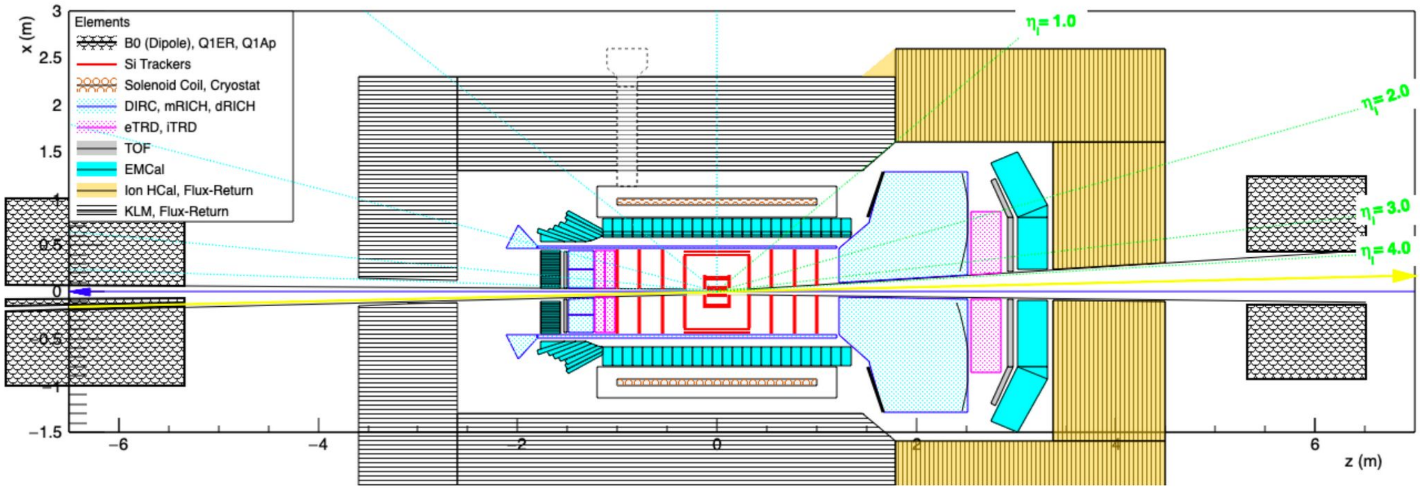
- The detector requirements have been compiled in several tables with feedback from detector groups as to what is actually achievable in terms of construction
- Detailed detector models exist at different levels which should enable quick progress for studies that we are considering for the Snowmass process

Table 10.5: This matrix summarizes the high level requirements for the detector performance. The interactive version of this matrix can be obtained through the Yellow Report Physics Working Group WIKI page (https://wiki.bnl.gov/eicug/index.php/Yellow_Report_Physics_Common).



η	Nomenclature			Tracking				Electrons and Photons			π/K/p		HCAL		Muons
				Resolution	Allowed	minimum-pT	Si-Vertex	Resolution σE/E	PID	min E	p-Range	Separati	Resolution σE/E	Energy	
-6.9 to -5.8	↓ p/A	Auxiliary De	low-Q2 tagger	σθ/θ < 1.5%; 10-6 < Q2 < 10-2 GeV2											
-5.0 to -4.5						300 MeV pions									
-4.5 to -4.0			Instrumentation to separate charged particles from photons			300 MeV pions		2%/√E(+1-3%)		50 MeV					
-4.0 to -3.5						<100MeV pions, 135MeV kaons				50 MeV			~50%/√E + 6%		muons useful for bkg, improve resolution
-3.5 to -3.0		Central Detector	Backward Detector	σpT/pT ~ 0.1%⊕0.5%	~5% or less X				π suppression up to 1:1E-4	50 MeV	≤ 7 GeV/c	≥ 3 σ	~45%/√E+6%	~500 MeV	
-3.0 to -2.5							σ_xy~30/pT µm +40 µm			50 MeV					
-2.5 to -2.0				σpT/pT			σ_xy~30/pT µm +20 µm	2%/√E(+1-3%)		50 MeV					
-2.0 to -1.5				σpT/pT 0.05%⊕0.5%				7%/√E(+1-3%)		50 MeV					
-1.5 to -1.0								7%/√E(+1-3%)		50 MeV					
-1.0 to -0.5			Barrel	σpT/pT ~0.05%×pT+0.5%			σxyz ~ 20 µm, d0(z) ~d0(rΦ) ~ 20/pTGeV µm + 5 µm	(10-12)%/√E(+1-3%)		50 MeV	≤ 10 GeV/c		~85%/√E+7%		
-0.5 to 0.0										50 MeV			~85%/√E+7%		
0.0 to 0.5										50 MeV			~85%/√E+7%		
0.5 to 1.0										50 MeV	≤ 15 GeV/c		~85%/√E+7%		
1.0 to 1.5			Forward Detectors	σpT/pT ~0.05%×pT+1.0%			σ_xy~30/pT µm +20 µm		3σ e/π	50 MeV	≤ 30 GeV/c		35%/√E		
1.5 to 2.0										50 MeV	≤ 50 GeV/c				
2.0 to 2.5										50 MeV					
2.5 to 3.0				σpT/pT ~ 0.1%×pT+2.0%			σ_xy~30/pT µm +40 µm			50 MeV	≤ 30 GeV/c				
3.0 to 3.5							σ_xy~30/pT µm +60 µm			50 MeV	≤ 45 GeV/c				
3.5 to 4.0	↑ e	Auxiliary Detectors	Instrumentation to separate charged particles from photons	Tracking capabilities are desirable for forward tagging						50 MeV					
4.0 to 4.5			Neutron Detection			300 MeV pions				50 MeV			35%/√E (goal), <50%/√E (acceptable)*, 3mrad/√E (goal)		
4.5 to 5.0								4.5%/√E for photon energy > 20 GeV	<= 3 cm granularity	50 MeV					
>6.2			Proton Spectrometer	σintrinsic(|t|)/|t| < 1%; Acceptance: 0.2 < pt < 1.2 GeV/c											

Detector concepts

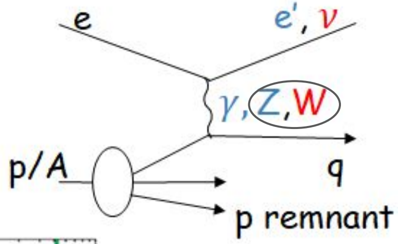


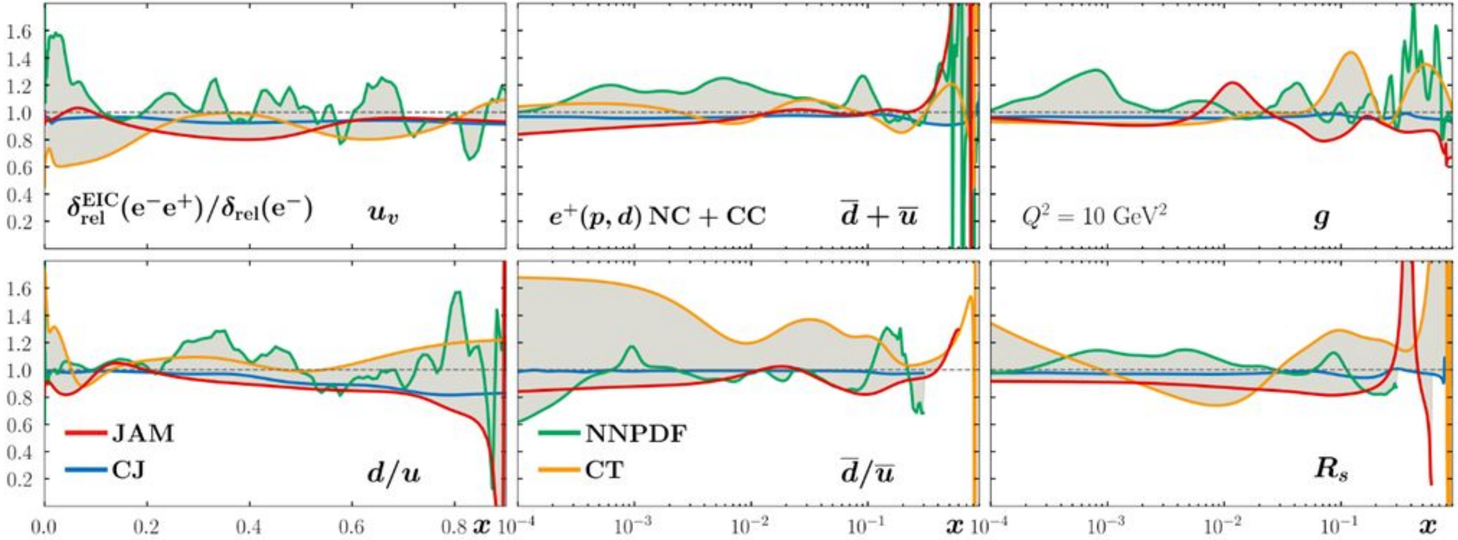
- Additional detector concepts are being worked on within the community
    - As all this is in the design phase we should try to quickly give feedback to the proponents to see if it is possible to enhance capability for this type of physics or at the very least ensure we don't significantly lose capability with new designs

PDF fits

Tim Hobbs

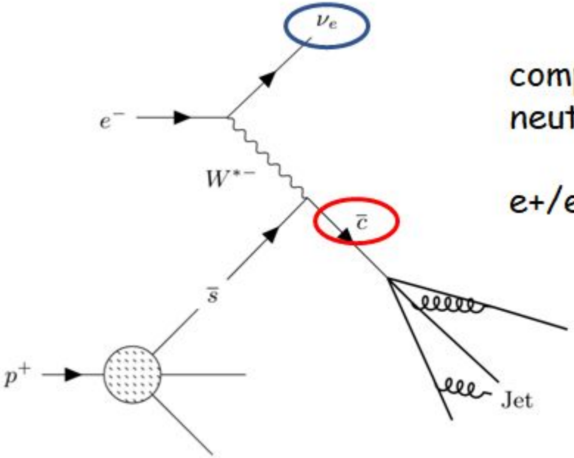
- EIC will provide high precision data on proton PDFs on a large kinematic range
- differing charge of the exchanged W+/- boson is such that positron CC interactions are capable of probing a unique combination of flavor currents inside the target hadron relative to an electron beam.





Charm jets in the CC reactions

Yulia Furletova

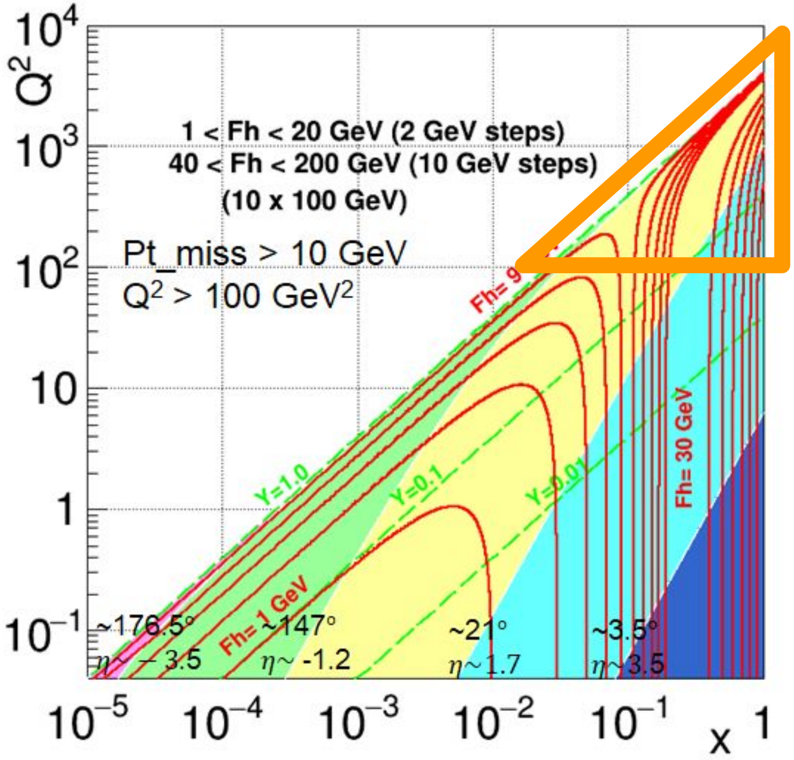


complementary to
neutrino facilities (νN).

e+/e- beams => s/s-bar

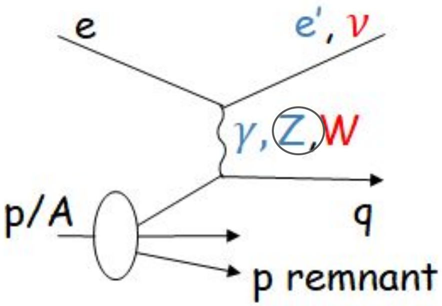
$$s' = |V_{cs}|^2 s + |V_{cd}|^2 d + |V_{cb}|^2 b.$$

$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \approx \begin{pmatrix} 0.97 & 0.22 & 0.0037 \\ 0.22 & 0.97 & 0.042 \\ 0.094 & 0.040 & 1.0 \end{pmatrix}$$



NC extractions

Yuxiang Zhao



With parity violation and $Q^2 << Z^2$

Inclusive electron measurements

pol. electron & unpol. nucleon:

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

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

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

unpol. electron & pol. nucleon:

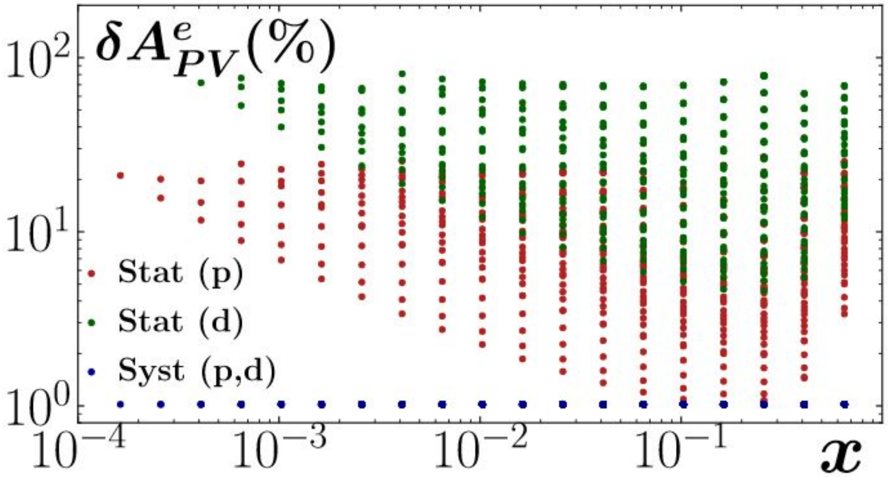
$$A_L = \frac{G_F Q^2}{2\sqrt{2}\pi\alpha}\left[g_V^e \frac{g_5^{\gamma Z}}{F_1^{\gamma}} + g_A^e \frac{Y_-}{Y_+}\frac{g_1^{\gamma Z}}{F_1^{\gamma}}\right]$$

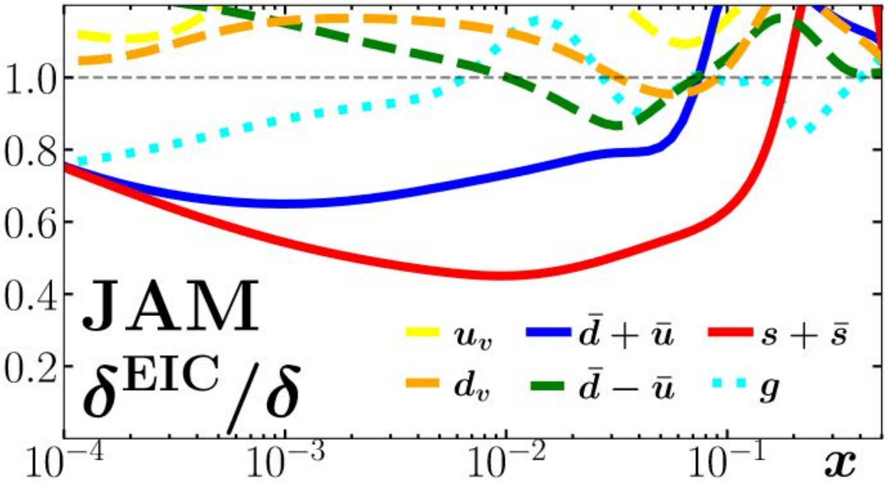
$$g_1^{\gamma Z} = \sum_f e_{q_f}(g_V)_{q_f}(\Delta q_f + \Delta\bar{q}_f)$$

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

NC extractions

Nobuo Sato

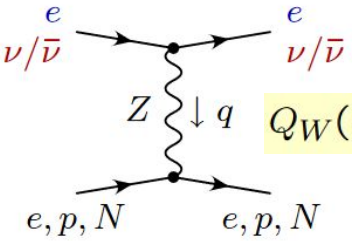




- With 100 inverse fb of ep data the EIC can put significant constraints on the unpolarized strange contributions
- While the eD statistics simulated for the YR has been only 10 inverse fb it is still very important data to have (the potential to run more would bring a pretty large benefit)

Weak mixing angle extractions

Ayres Freitas



$$Q_W(e) = Q_W(p) = 1 - 4\sin^2\theta_W$$

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

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

Need precise knowledge of PDFs for
100 GeV^2 < Q2 < 5000 GeV^2

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

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

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

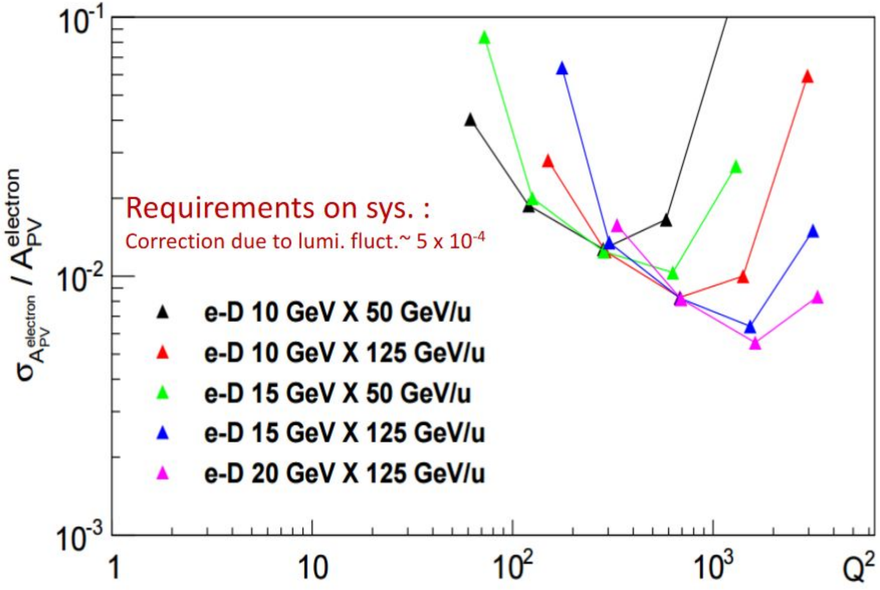
$$A_{LR}^{ep} \approx \frac{G_\mu(-q^2)}{4\sqrt{2}\pi\alpha}\left[\frac{9}{5} - \sin^2\theta_W + \frac{9}{5}(1 - 4\sin^2\theta_W)\frac{y(1-y)}{1+(1-y)^2}\right]$$

- Current studies suggest that PDF uncertainties will be small enough for weak mixing angle extractions to be precisely obtained from ep data

NC extractions

Yuxiang Zhao

Eur. Phys. J. A, 53 3 (2017) 55



Requirements on sys. :

Correction due to lumi. fluct.~ 5 x 10^{-4}

e-D collisions	10x50,10x125,15x50,15x125,20x125 GeV/u
Integrated luminosity	**267 fb^{-1}**
Electron beam polarization	80%

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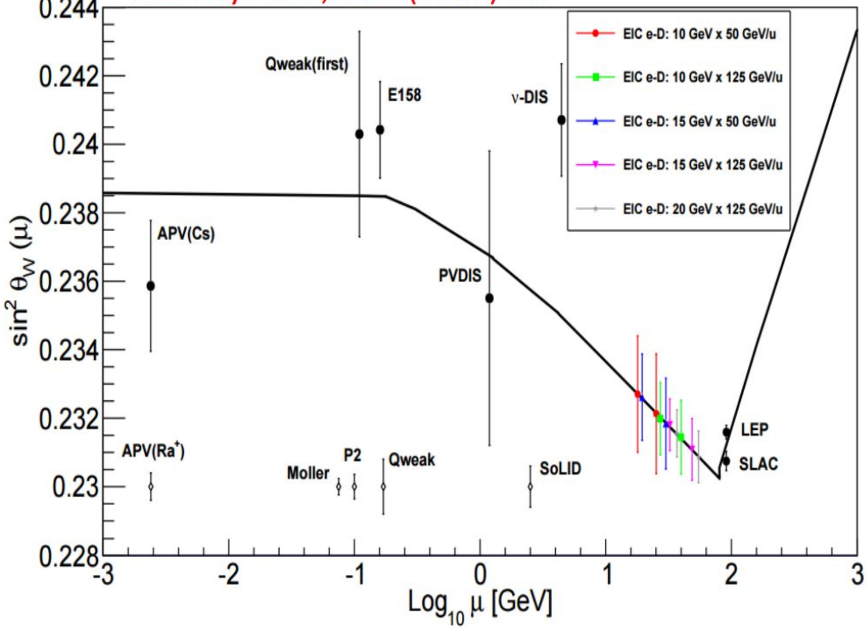
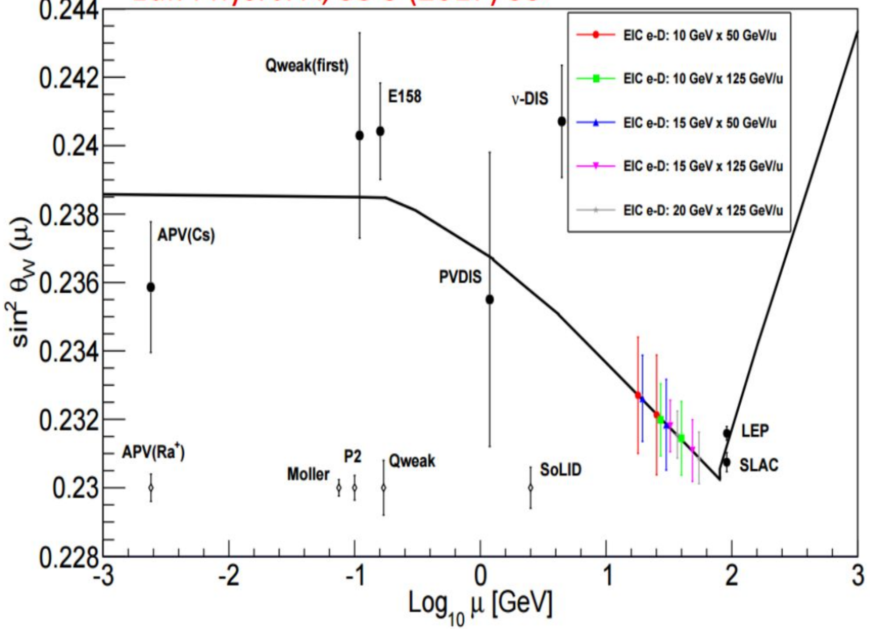


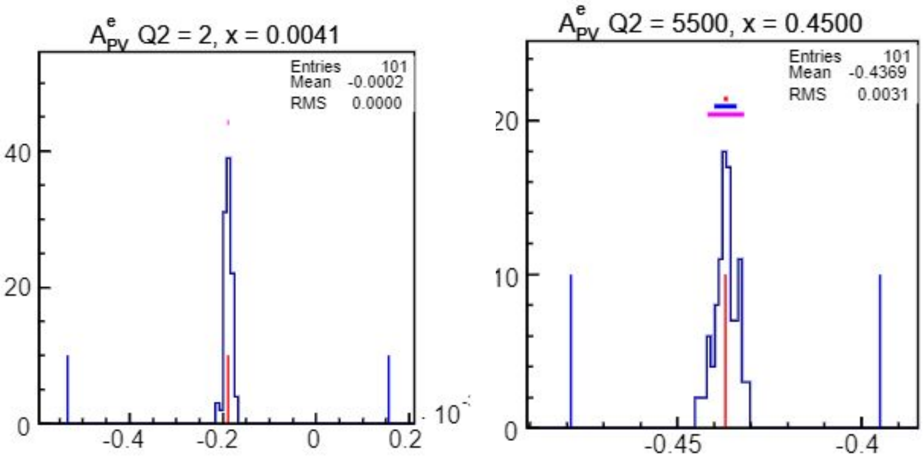
- The weak mixing angle extractions are in a region that has not been probed before and overall reach similar precisions as SoLID
- Beyond the weak mixing angle extractions if we use the CC current measurements on deuteron we can obtain similar if not better precision than with positron beams for flavour decomposition

NC extractions

Jinlong Zhang

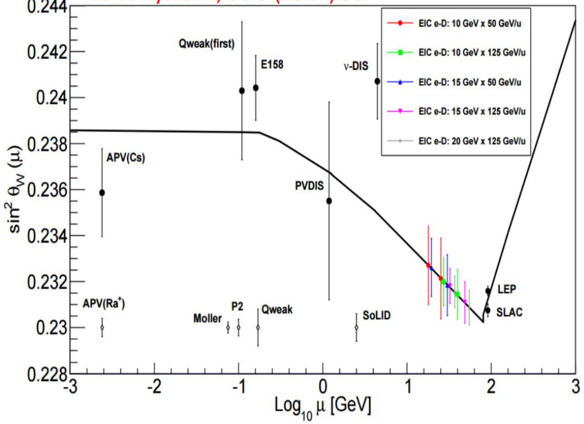
Eur. Phys. J. A, 53 3 (2017) 55





- PDF uncertainties are fairly small compared to the statistical precision of the data
- We are working to understand if we can use the proton data to extract the weak mixing angle on top of the deuteron result published by Yuxiang
- This data should allow us to get larger statistical precision and have a larger reach in Q

Weak mixing angle extractions



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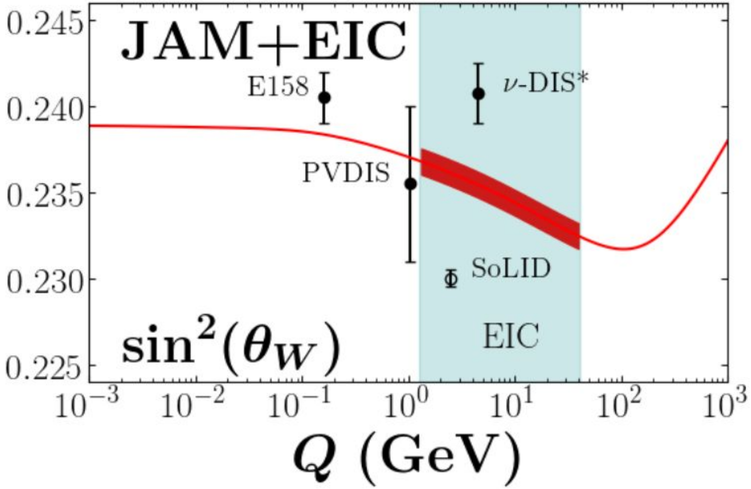
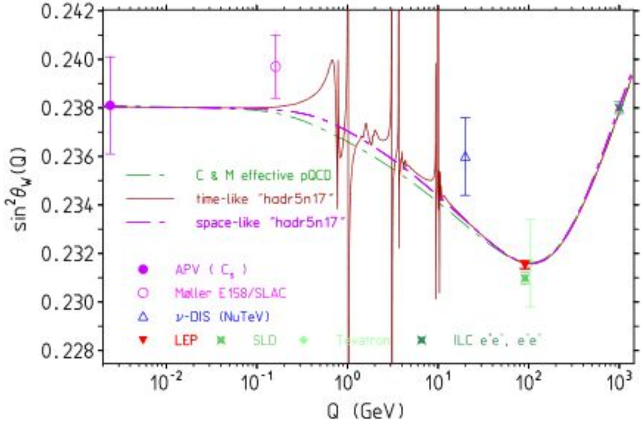
Christopher Cocuzza



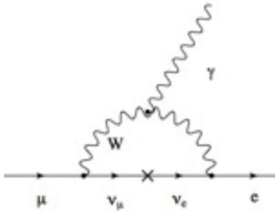


- EIC kinematic region is unexplored and has the potential to constrain some theoretical uncertainties
- Clear analysis pathway for the eD data
    - This will require quite high statistics for it to be meaningful
- ep data is proving to be quite useful in initial studies

Charged Lepton Flavor Violation

Sonny Mantry

- LFV in the neutrinos also implies Charged Lepton Flavor Violation (CLFV):



$$\mathrm{BR}(\mu \to e\gamma) < 10^{-54}$$

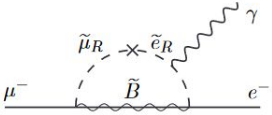
However, SM rate for CLFV is tiny due to small neutrino masses

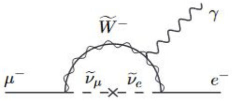
- No hope of detecting such small rates for CLFV at any present or future planned experiments!

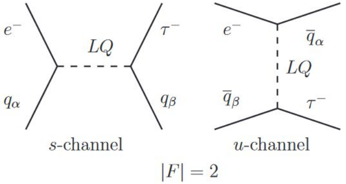
LFV transitions	LFV Present Bounds (90%CL)	Future Sensitivities
$\mathrm{BR}(\mu \to e\gamma)$	4.2×10^{-13} (MEG 2016)	4×10^{-14} (MEG-II)
$\mathrm{BR}(\tau \to e\gamma)$	3.3×10^{-8} (BABAR 2010)	10^{-9} (BELLE-II)
$\mathrm{BR}(\tau \to \mu\gamma)$	4.4×10^{-8} (BABAR 2010)	10^{-9} (BELLE-II)
$\mathrm{BR}(\mu \to eee)$	1.0×10^{-12} (SINDRUM 1988)	10^{-16} Mu3E (PSI)
$\mathrm{BR}(\tau \to eee)$	2.7×10^{-8} (BELLE 2010)	$10^{-9,-10}$ (BELLE-II)
$\mathrm{BR}(\tau \to \mu\mu\mu)$	2.1×10^{-8} (BELLE 2010)	$10^{-9,-10}$ (BELLE-II)
$\mathrm{BR}(\tau \to \mu\eta)$	2.3×10^{-8} (BELLE 2010)	$10^{-9,-10}$ (BELLE-II)
$\mathrm{CR}(\mu - e, \mathrm{Au})$	7.0×10^{-13} (SINDRUM II 2006)	
$\mathrm{CR}(\mu - e, \mathrm{Ti})$	4.3×10^{-12} (SINDRUM II 2004)	10^{-18} PRISM (J-PARC)
$\mathrm{CR}(\mu - e, \mathrm{Al})$		3.1×10^{-15} COMET-I (J-PARC)

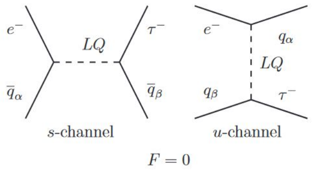
[taken from a talk by Y. Furletova]

- However, many BSM scenarios predict enhanced CLFV rates:
  - SUSY (RPV)
  - SU(5), SO(10) GUTS
  - Left-Right symmetric models
  - Randall-Sundrum Models
  - LeptoQuarks
  - ...









F= 3B+L

- With electron beams, LQs couple to:

|F|= 2:
-quarks in s-channel
-antiquarks in u-channel

F= 0:
-antiquarks in s-channel
-quarks in the u-channel

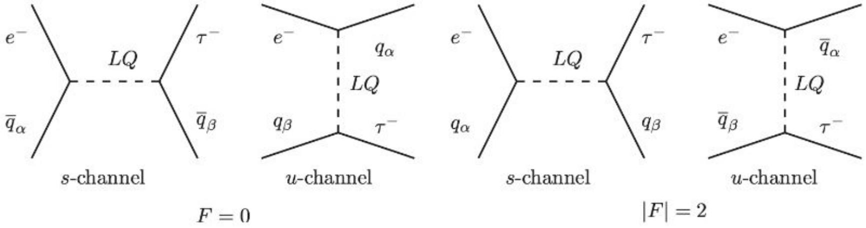
- With positron beams, LQs couple to:

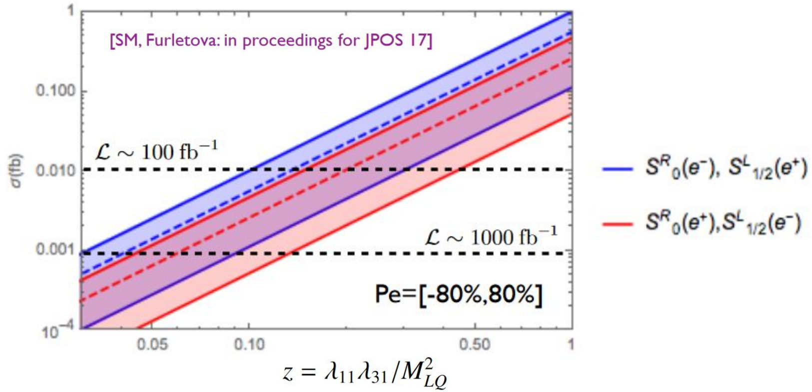
|F|= 2:
-antiquarks in s-channel
-quarks in u-channel

F= 0:
-quarks in s-channel
-antiquarks in the u-channel

CLFV: e to tau (lepto-quarks)

Jinlong Zhang



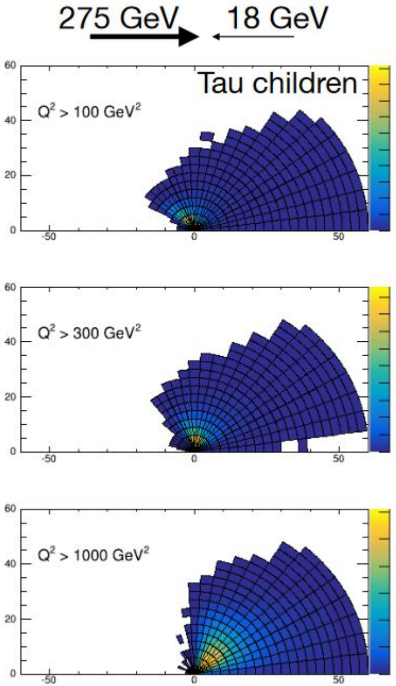


- Sensitivities to the CLFV(1,3) would be enhanced with positron beams (can search for specific LQ)
- Current limits set by HERA sitting at sensitivities of a few fb
  - The high luminosity of the EIC will gain us 2 orders of magnitude

Tau decay mode and branching ratio

- **3-prong**	**15.21 (0.06)%**
- $\pi^-\pi^+\pi^-\nu_\tau$	9.31 (0.05)%
- $\pi^-\pi^+\pi^-\pi^0\nu_\tau$	4.62 (0.05)%
- others (kaon, etc)	1.28%
- **1-prong**	**84.58 (0.06)%**
- $\mu^-\bar{\nu}_\mu\nu_\tau$	17.39 (0.04)%
- $e^-\bar{\nu}_e\nu_\tau$	17.82 (0.04)%
- $\pi^-\nu_\tau$	10.82 (0.05)%
- $\pi^-\pi^0\nu_\tau$	25.49 (0.09)%
- $\pi^-2\pi^0\nu_\tau$	9.26 (0.10)%
- $\pi^-3\pi^0\nu_\tau$	1.04 (0.07)%
- others (kaon, etc)	3.24%
- others	0.21%

- **Tau vertex displaced at cm level**
  - 3-prong tau jet; decay topology important for τ jet ID
  - 1-prong: recovering higher branching ratios; but background control is much more demanding

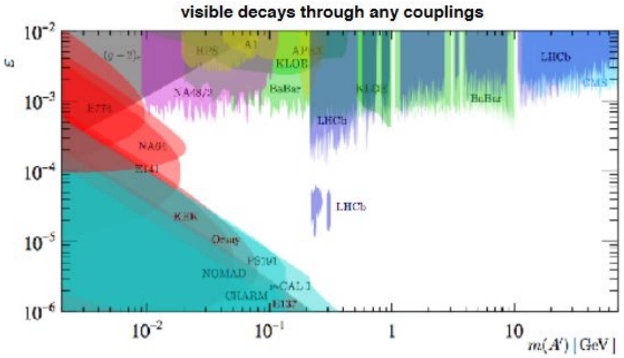


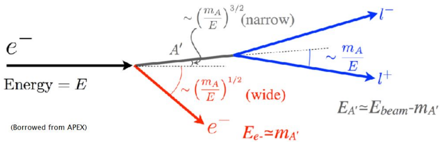
Angle for theta, radius for momentum

- Assumes hadron calorimetry in the central barrel

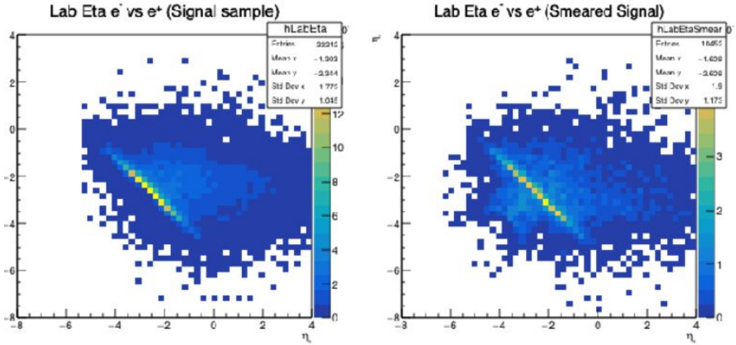
Dark photons

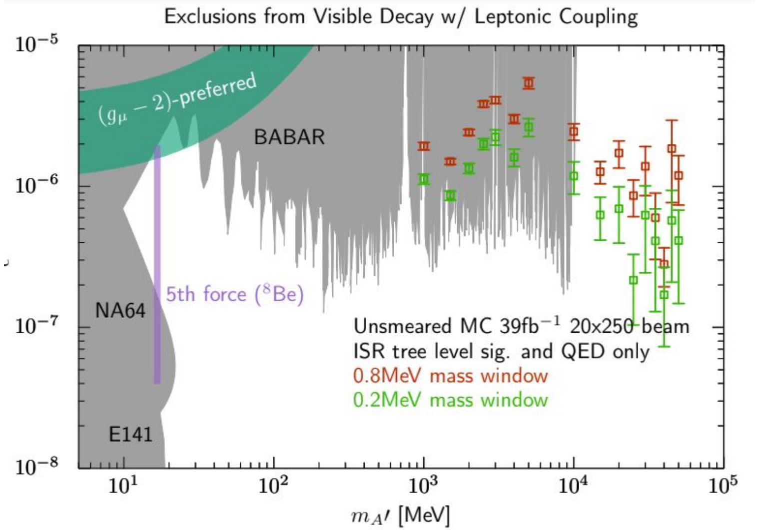
Ross Corliss





(Borrowed from APEX)



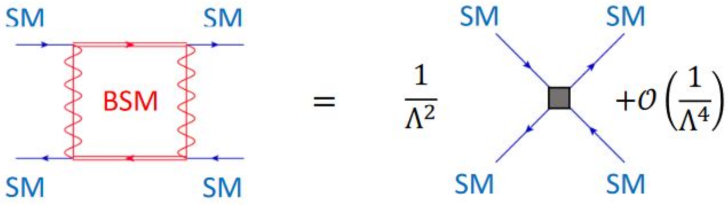


$$\alpha_D = S\frac{\alpha_{D0}}{\sqrt{L}}\frac{\sqrt{\sigma_{QED}}}{\sigma_{A0}}$$

- First analysis looks at e+e- decay, but hadronic final states could be investigated as well
- The boosted kinematics significantly opens up the angle between the decay leptons creating a specific topology
- Only consider QED background for now
- With 6 months of running 25 on 250 (~39 fb^{-1}) we could reach similar sensitivities than BABAR but in a wider mass range
- Measurement would benefit from improved charge sign reconstruction (PID)
- Higher eta coverage would lead to access to lower mass dark photons
- There is still the possibility that the muon g-2 anomaly could be explained by a dark photon with a purely leptonic coupling

SMEFT

Daniel Wiegand



$$= \frac{1}{\Lambda^2} \; + \mathcal{O}\left(\frac{1}{\Lambda^4}\right)$$

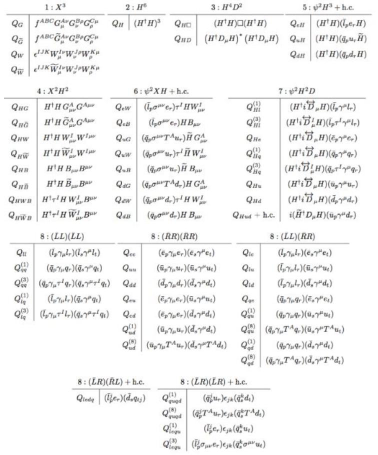
Non-SM operators **suppressed by powers of** $\frac{1}{\Lambda}$:

- Higher dimensional operators built from SM fields
- Modification of SM couplings/EWSB/…

Quantify deviation from SM through comparison with data

- **Model independent constraints** on new physics
- Maximal gain from data
- Part of the **LHC legacy**

Boughezal/Petriello/DW - (arXiv: 2004.00748)



$1: X^3$	
Q_G	$f^{ABC}G_\mu^{A\nu}G_\nu^{B\rho}G_\rho^{C\mu}$
$Q_{\widetilde{G}}$	$f^{ABC}\widetilde{G}_\mu^{A\nu}G_\nu^{B\rho}G_\rho^{C\mu}$
Q_W	$\epsilon^{IJK}W_\mu^{I\nu}W_\nu^{J\rho}W_\rho^{K\mu}$
$Q_{\widetilde{W}}$	$\epsilon^{IJK}\widetilde{W}_\mu^{I\nu}W_\nu^{J\rho}W_\rho^{K\mu}$

$2: H^6$	
Q_H	$(H^\dagger H)^3$

$3: H^4D^2$	
$Q_{H\Box}$	$(H^\dagger H)\Box(H^\dagger H)$
Q_{HD}	$\left(H^\dagger D_\mu H\right)^*\left(H^\dagger D_\mu H\right)$

$5: \psi^2H^3 + \text{h.c.}$	
Q_{eH}	$(H^\dagger H)(\bar{l}_p e_r H)$
Q_{uH}	$(H^\dagger H)(\bar{q}_p u_r \widetilde{H})$
Q_{dH}	$(H^\dagger H)(\bar{q}_p d_r H)$

$4: X^2H^2$	
Q_{HG}	$H^\dagger H\, G^A_{\mu\nu}G^{A\mu\nu}$
$Q_{H\widetilde{G}}$	$H^\dagger H\, \widetilde{G}^A_{\mu\nu}G^{A\mu\nu}$
Q_{HW}	$H^\dagger H\, W^I_{\mu\nu}W^{I\mu\nu}$
$Q_{H\widetilde{W}}$	$H^\dagger H\, \widetilde{W}^I_{\mu\nu}W^{I\mu\nu}$
Q_{HB}	$H^\dagger H\, B_{\mu\nu}B^{\mu\nu}$
$Q_{H\widetilde{B}}$	$H^\dagger H\, \widetilde{B}_{\mu\nu}B^{\mu\nu}$
Q_{HWB}	$H^\dagger\tau^I H\, W^I_{\mu\nu}B^{\mu\nu}$
$Q_{H\widetilde{W}B}$	$H^\dagger\tau^I H\, \widetilde{W}^I_{\mu\nu}B^{\mu\nu}$

$6: \psi^2XH + \text{h.c.}$	
Q_{eW}	$(\bar{l}_p\sigma^{\mu\nu}e_r)\tau^I H W^I_{\mu\nu}$
Q_{eB}	$(\bar{l}_p\sigma^{\mu\nu}e_r)H B_{\mu\nu}$
Q_{uG}	$(\bar{q}_p\sigma^{\mu\nu}T^A u_r)\widetilde{H}\, G^A_{\mu\nu}$
Q_{uW}	$(\bar{q}_p\sigma^{\mu\nu}u_r)\tau^I\widetilde{H}\, W^I_{\mu\nu}$
Q_{uB}	$(\bar{q}_p\sigma^{\mu\nu}u_r)\widetilde{H}\, B_{\mu\nu}$
Q_{dG}	$(\bar{q}_p\sigma^{\mu\nu}T^A d_r)H\, G^A_{\mu\nu}$
Q_{dW}	$(\bar{q}_p\sigma^{\mu\nu}d_r)\tau^I H\, W^I_{\mu\nu}$
Q_{dB}	$(\bar{q}_p\sigma^{\mu\nu}d_r)H\, B_{\mu\nu}$

$7: \psi^2H^2D$	
$Q_{Hl}^{(1)}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{l}_p\gamma^\mu l_r)$
$Q_{Hl}^{(3)}$	$(H^\dagger i\overleftrightarrow{D}^I_\mu H)(\bar{l}_p\tau^I\gamma^\mu l_r)$
Q_{He}	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{e}_p\gamma^\mu e_r)$
$Q_{Hq}^{(1)}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{q}_p\gamma^\mu q_r)$
$Q_{Hq}^{(3)}$	$(H^\dagger i\overleftrightarrow{D}^I_\mu H)(\bar{q}_p\tau^I\gamma^\mu q_r)$
Q_{Hu}	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{u}_p\gamma^\mu u_r)$
Q_{Hd}	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{d}_p\gamma^\mu d_r)$
Q_{Hud} + h.c.	$i(\widetilde{H}^\dagger D_\mu H)(\bar{u}_p\gamma^\mu d_r)$

$8: (\bar{L}L)(\bar{L}L)$	
Q_{ll}	$(\bar{l}_p\gamma_\mu l_r)(\bar{l}_s\gamma^\mu l_t)$
$Q_{qq}^{(1)}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{q}_s\gamma^\mu q_t)$
$Q_{qq}^{(3)}$	$(\bar{q}_p\gamma_\mu\tau^I q_r)(\bar{q}_s\gamma^\mu\tau^I q_t)$
$Q_{lq}^{(1)}$	$(\bar{l}_p\gamma_\mu l_r)(\bar{q}_s\gamma^\mu q_t)$
$Q_{lq}^{(3)}$	$(\bar{l}_p\gamma_\mu\tau^I l_r)(\bar{q}_s\gamma^\mu\tau^I q_t)$

$8: (\bar{R}R)(\bar{R}R)$	
Q_{ee}	$(\bar{e}_p\gamma_\mu e_r)(\bar{e}_s\gamma^\mu e_t)$
Q_{uu}	$(\bar{u}_p\gamma_\mu u_r)(\bar{u}_s\gamma^\mu u_t)$
Q_{dd}	$(\bar{d}_p\gamma_\mu d_r)(\bar{d}_s\gamma^\mu d_t)$
Q_{eu}	$(\bar{e}_p\gamma_\mu e_r)(\bar{u}_s\gamma^\mu u_t)$
Q_{ed}	$(\bar{e}_p\gamma_\mu e_r)(\bar{d}_s\gamma^\mu d_t)$
$Q_{ud}^{(1)}$	$(\bar{u}_p\gamma_\mu u_r)(\bar{d}_s\gamma^\mu d_t)$
$Q_{ud}^{(8)}$	$(\bar{u}_p\gamma_\mu T^A u_r)(\bar{d}_s\gamma^\mu T^A d_t)$

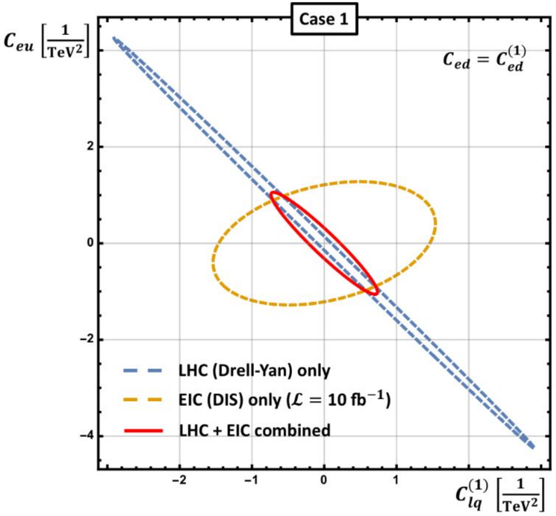
$8: (\bar{L}L)(\bar{R}R)$	
Q_{le}	$(\bar{l}_p\gamma_\mu l_r)(\bar{e}_s\gamma^\mu e_t)$
Q_{lu}	$(\bar{l}_p\gamma_\mu l_r)(\bar{u}_s\gamma^\mu u_t)$
Q_{ld}	$(\bar{l}_p\gamma_\mu l_r)(\bar{d}_s\gamma^\mu d_t)$
Q_{qe}	$(\bar{q}_p\gamma_\mu q_r)(\bar{e}_s\gamma^\mu e_t)$
$Q_{qu}^{(1)}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{u}_s\gamma^\mu u_t)$
$Q_{qu}^{(8)}$	$(\bar{q}_p\gamma_\mu T^A q_r)(\bar{u}_s\gamma^\mu T^A u_t)$
$Q_{qd}^{(1)}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{d}_s\gamma^\mu d_t)$
$Q_{qd}^{(8)}$	$(\bar{q}_p\gamma_\mu T^A q_r)(\bar{d}_s\gamma^\mu T^A d_t)$

$8: (\bar{L}R)(\bar{R}L) + \text{h.c.}$	
Q_{ledq}	$(\bar{l}_p^j e_r)(\bar{d}_s q_{tj})$

$8: (\bar{L}R)(\bar{L}R) + \text{h.c.}$	
$Q_{quqd}^{(1)}$	$(\bar{q}_p^j u_r)\epsilon_{jk}(\bar{q}_s^k d_t)$
$Q_{quqd}^{(8)}$	$(\bar{q}_p^j T^A u_r)\epsilon_{jk}(\bar{q}_s^k T^A d_t)$
$Q_{lequ}^{(1)}$	$(\bar{l}_p^j e_r)\epsilon_{jk}(\bar{q}_s^k u_t)$
$Q_{lequ}^{(3)}$	$(\bar{l}_p^j\sigma_{\mu\nu}e_r)\epsilon_{jk}(\bar{q}_s^k\sigma^{\mu\nu}u_t)$

Warsaw Basis: 59 Operators $(\delta B = 0, \delta L = 0)$

Grzadkowski/Iskrzynski/Misiak/Rosiek (1008.4884)



SMEFT suffers from a large number of flat directions

- We presented a strategy to lift 4-Fermi **flat directions**

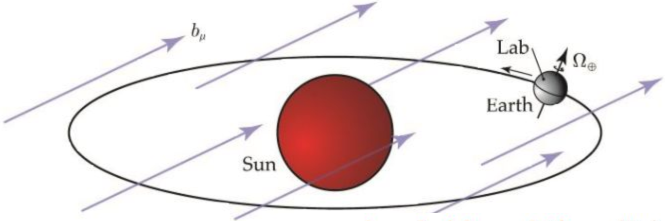
The future **EIC** will complement LHC data

- Combine EIC observables with **different polarizations** additionally to LHC measurements
- Interplay of different measurements improve bounds significantly

Lorentz violating effects

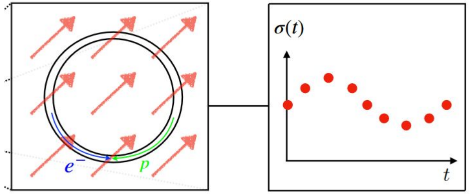
Based on:
A. Kostelecky, E.L. and A. Vieira [1610.09318]
E.L. and N. Sherrill [1805.11684]
A. Kostelecky, E.L., N. Sherrill and A. Vieira [1911.04002]

Enrico Lunghi

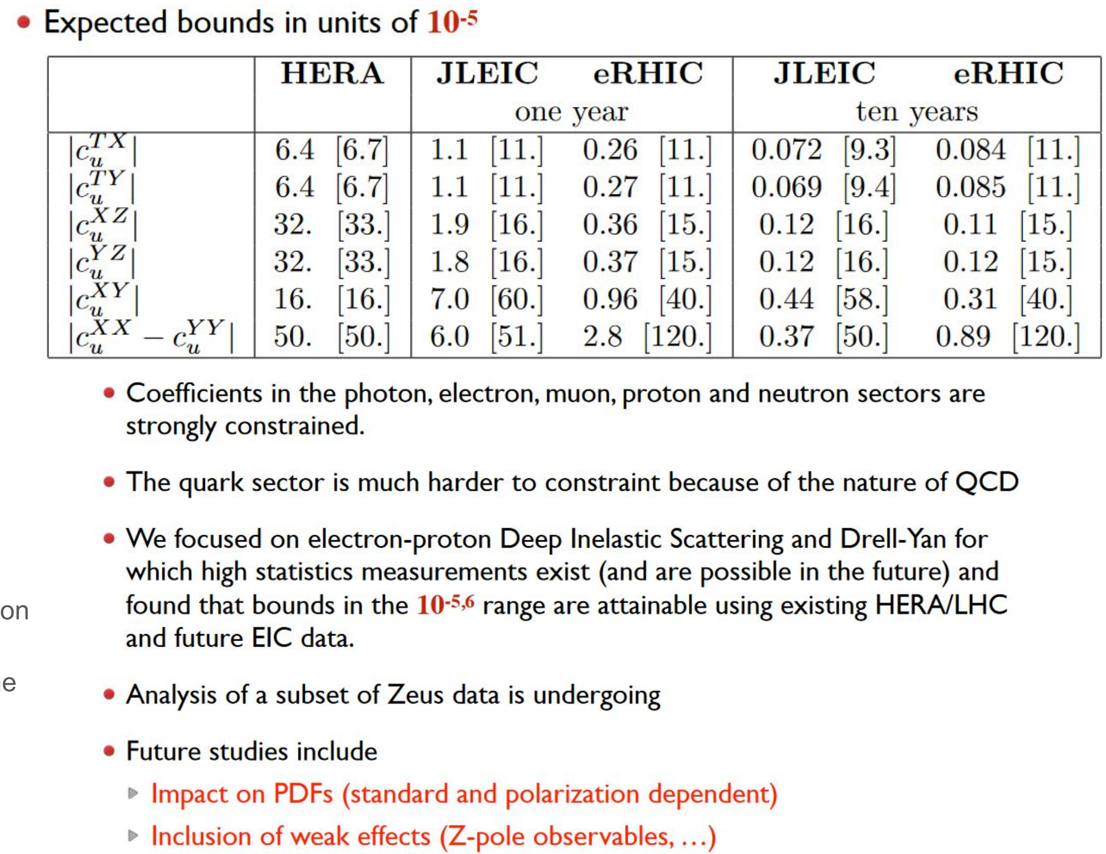


- **local sidereal time** ($T_\oplus$)

$$\sigma(T_\oplus) \sim \sigma_{\rm SM}\left(1 + c_0 + c_1\cos(\omega_\oplus T_\oplus) + c_2\cos(2\omega_\oplus T_\oplus) + \cdots\right)$$



- Construct an extension to the SM where the vacuum expectation of a constant background field is not Lorentz invariant
    - For example: the lifetime of a boosted muon and the lifetime of a muon at rest but measured in a boosted frame would differ
- This would lead measurements varying with sidereal time



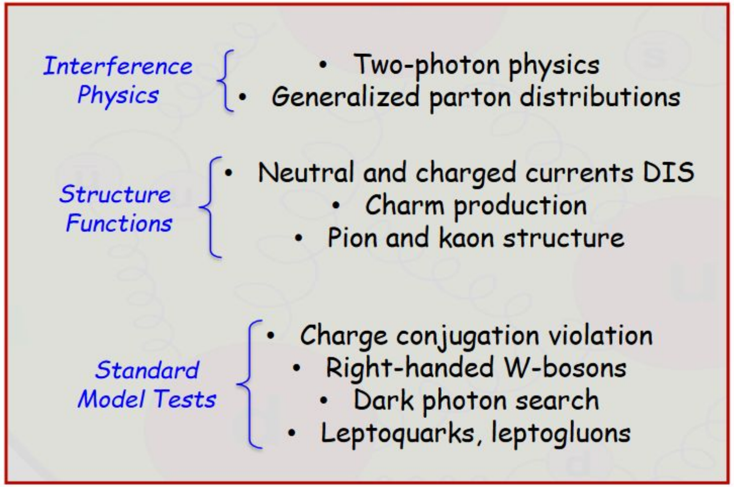
- Expected bounds in units of 10^{-5}

	HERA	JLEIC	eRHIC	JLEIC	eRHIC
		one year		ten years	
$\lvert c_u^{TX}\rvert$	6.4 [6.7]	1.1 [11.]	0.26 [11.]	0.072 [9.3]	0.084 [11.]
$\lvert c_u^{TY}\rvert$	6.4 [6.7]	1.1 [11.]	0.27 [11.]	0.069 [9.4]	0.085 [11.]
$\lvert c_u^{XZ}\rvert$	32. [33.]	1.9 [16.]	0.36 [15.]	0.12 [16.]	0.11 [15.]
$\lvert c_u^{YZ}\rvert$	32. [33.]	1.8 [16.]	0.37 [15.]	0.12 [16.]	0.12 [15.]
$\lvert c_u^{XY}\rvert$	16. [16.]	7.0 [60.]	0.96 [40.]	0.44 [58.]	0.31 [40.]
$\lvert c_u^{XX} - c_u^{YY}\rvert$	50. [50.]	6.0 [51.]	2.8 [120.]	0.37 [50.]	0.89 [120.]

- Coefficients in the photon, electron, muon, proton and neutron sectors are strongly constrained.
- The quark sector is much harder to constraint because of the nature of QCD
- We focused on electron-proton Deep Inelastic Scattering and Drell-Yan for which high statistics measurements exist (and are possible in the future) and found that bounds in the $10^{-5,6}$ range are attainable using existing HERA/LHC and future EIC data.
- Analysis of a subset of Zeus data is undergoing
- Future studies include
    - Impact on PDFs (standard and polarization dependent)
    - Inclusion of weak effects (Z-pole observables, …)

Positron beams

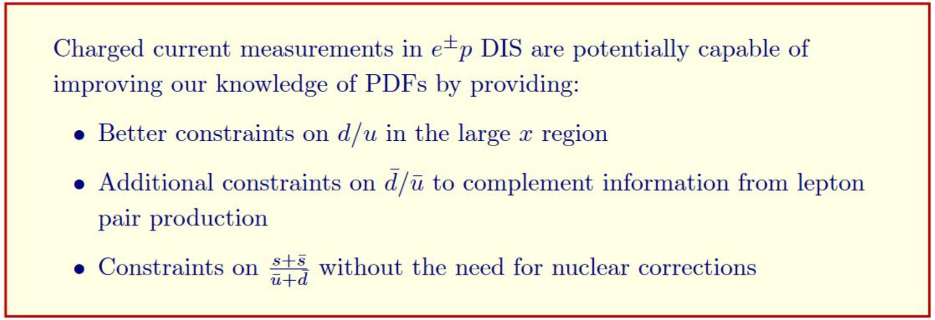
Wally Melnitchouk



Interference Physics
- Two-photon physics
- Generalized parton distributions

Structure Functions
- Neutral and charged currents DIS
- Charm production
- Pion and kaon structure

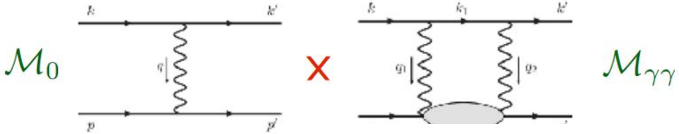
Standard Model Tests
- Charge conjugation violation
- Right-handed W-bosons
- Dark photon search
- Leptoquarks, leptogluons



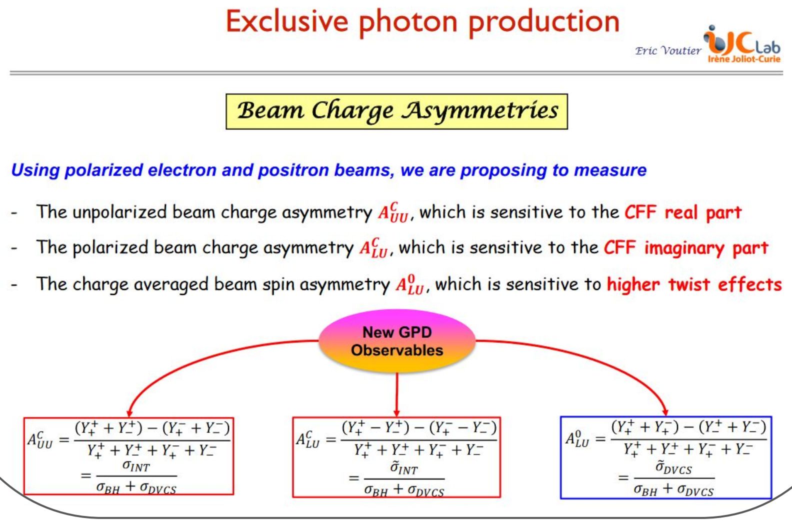
Charged current measurements in $e^{\pm}p$ DIS are potentially capable of improving our knowledge of PDFs by providing:

- Better constraints on d/u in the large x region
- Additional constraints on $\bar{d}/\bar{u}$ to complement information from lepton pair production
- Constraints on $\frac{s+\bar{s}}{\bar{u}+\bar{d}}$ without the need for nuclear corrections

Two photon exchange contribution changes sign for e+ and e-



$$R_{2\gamma} = \frac{\sigma^{e^+}}{\sigma^{e^-}} \approx 1 - 2\delta_{\gamma\gamma} \qquad \delta^{(2\gamma)} = \frac{2\mathcal{R}e\left\{\mathcal{M}_0^\dagger\, \mathcal{M}_{\gamma\gamma}\right\}}{|\mathcal{M}_0|^2}$$



Exclusive photon production

Eric Voutier
IJCLab Irène Joliot-Curie

Beam Charge Asymmetries

Using polarized electron and positron beams, we are proposing to measure

- The unpolarized beam charge asymmetry A^C_{UU}, which is sensitive to the **CFF real part**
- The polarized beam charge asymmetry A^C_{LU}, which is sensitive to the **CFF imaginary part**
- The charge averaged beam spin asymmetry A^0_{LU}, which is sensitive to **higher twist effects**

New GPD Observables

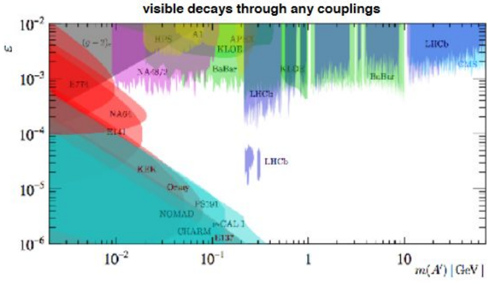
$$A^C_{UU} = \frac{(Y^+_+ + Y^+_-) - (Y^-_+ + Y^-_-)}{Y^+_+ + Y^+_- + Y^-_+ + Y^-_-} = \frac{\sigma_{INT}}{\sigma_{BH} + \sigma_{DVCS}}$$

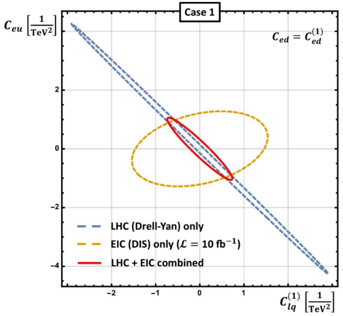
$$A^C_{LU} = \frac{(Y^+_+ - Y^+_-) - (Y^-_+ - Y^-_-)}{Y^+_+ + Y^+_- + Y^-_+ + Y^-_-} = \frac{\tilde{\sigma}_{INT}}{\sigma_{BH} + \sigma_{DVCS}}$$

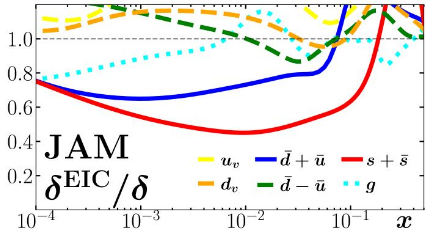
$$A^0_{LU} = \frac{(Y^+_+ + Y^-_+) - (Y^+_- + Y^-_-)}{Y^+_+ + Y^+_- + Y^-_+ + Y^-_-} = \frac{\tilde{\sigma}_{DVCS}}{\sigma_{BH} + \sigma_{DVCS}}$$

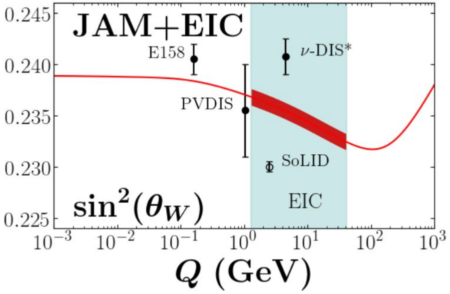
Conclusions

- The high luminosity and polarization at the EIC opens doors to physics that are not normally associated with nuclear physics
- Many of the BSM studies that are being investigated are fully complementary to searches being done or planned at other facilities around the world
- The addition of capabilities to the detector or the machine (positrons, mirror nuclei) would make it a truly unprecedented machine in it’s physics reach









Backup

Impact on HEP extractions

ATLAS, 1701.07240

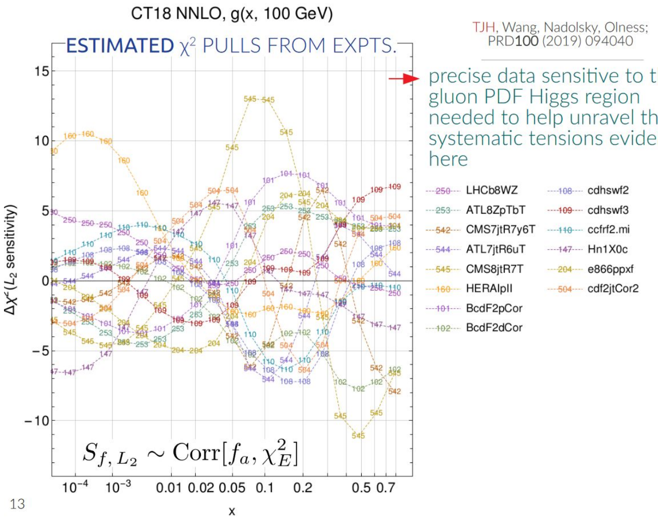
for example:

Channel	$m_{W^+} - m_{W^-}$ [MeV]	Stat. Unc.	Muon Unc.	Elec. Unc.	Recoil Unc.	Bckg. Unc.	QCD Unc.	EW Unc.	PDF Unc.	Total Unc.
$W \to e\nu$	−29.7	17.5	0.0	4.9	0.9	5.4	0.5	0.0	24.1	30.7
$W \to \mu\nu$	−28.6	16.3	11.7	0.0	1.1	5.0	0.4	0.0	26.0	33.2
Combined	−29.2	12.8	3.3	4.1	1.0	4.5	0.4	0.0	23.9	28.0

- The limitations on HEP extractions are mostly coming from PDF uncertainties
- We have reached a limit on extractions using the current data as they pull in different directions
  - The EIC would play the vital role as a arbiter (particularly with high precision dataset)
- Measuring both NC and CC for electron and positron beams allows for a simple deconvolution without nuclear effects

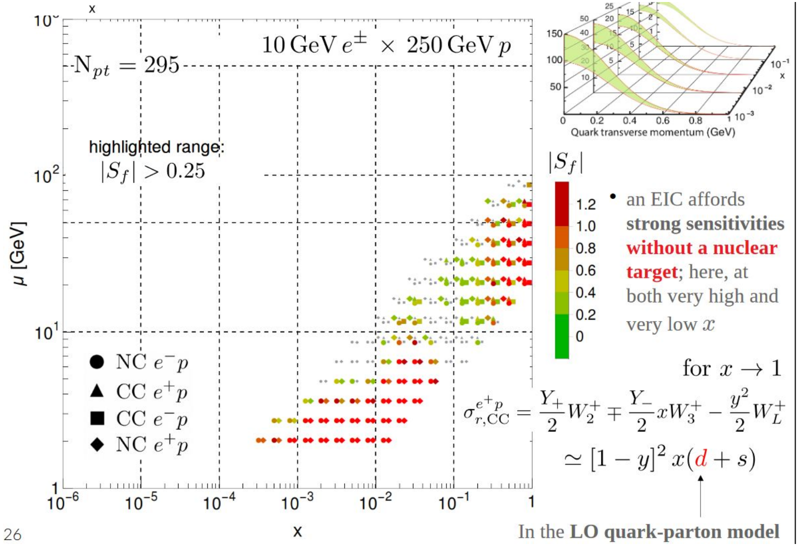
Tim Hobbs

EIC and LHC workshop



precise data sensitive to the gluon PDF Higgs region needed to help unravel the systematic tensions evident here

TJH, Wang, Nadolsky, Olness; PRD100 (2019) 094040



- an EIC affords **strong sensitivities** **without a nuclear target**; here, at both very high and very low x

for $x \to 1$

$$\sigma^{e^+p}_{r,\mathrm{CC}} = \frac{Y_+}{2}W_2^+ \mp \frac{Y_-}{2}xW_3^+ - \frac{y^2}{2}W_L^+$$

$$\simeq [1-y]^2\, x(d+s)$$

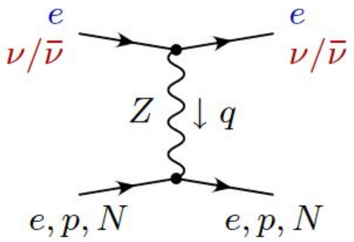
In the **LO quark-parton model**

Stony Brook University

Ciprian Gal

Weak mixing angle extractions

Ayres Freitas



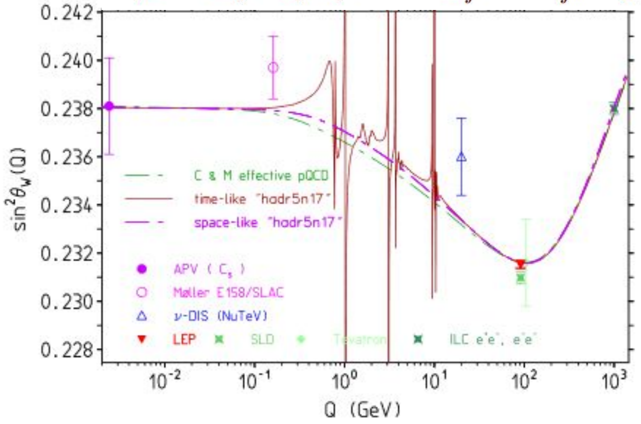
$$A_{\mathrm{LR}}^{ep} \approx \frac{\sigma_{\mathrm{L}} - \sigma_{\mathrm{R}}}{\sigma_{\mathrm{L}} + \sigma_{\mathrm{R}}} = \frac{G_\mu(-q^2)}{4\sqrt{2}\pi\alpha} Q_{\mathrm{W}}(p)$$

$$y \approx \tfrac{1}{2}(1 - \cos\theta_{\mathrm{CM}})$$

$$Q_W(e) = Q_W(p) = 1 - 4\sin^2\theta_{\mathrm{W}}$$

- Radiative corrections must be included:
  $1 - 4\sin^2\theta_{\mathrm{W}} \quad \rightarrow \quad [1 - 4\kappa(\mu)\sin^2\bar{\theta}(\mu)] + \Delta Q(\mu)$

$$\Delta_{\gamma Z} = \textstyle\sum_f (I_{3f}Q_f - 2s^2Q_f^2) \ln m_f^2/M_Z^2$$



At the EIC

$$A_{\mathrm{LR}}^{ep} \approx \frac{\sigma_{\mathrm{L}} - \sigma_{\mathrm{R}}}{\sigma_{\mathrm{L}} + \sigma_{\mathrm{R}}} = \frac{G_\mu(-q^2)}{4\sqrt{2}\pi\alpha}\left[\frac{F_1^{\gamma Z}}{F_1^{\gamma}} + (1 - 4\sin^2\theta_{\mathrm{W}})\frac{y(1-y)}{1+(1-y)^2}\frac{F_3^{\gamma Z}}{F_1^{\gamma}}\right]$$

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

Need precise knowledge of PDFs for 100 GeV^2 < Q2 < 5000 GeV^2

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

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

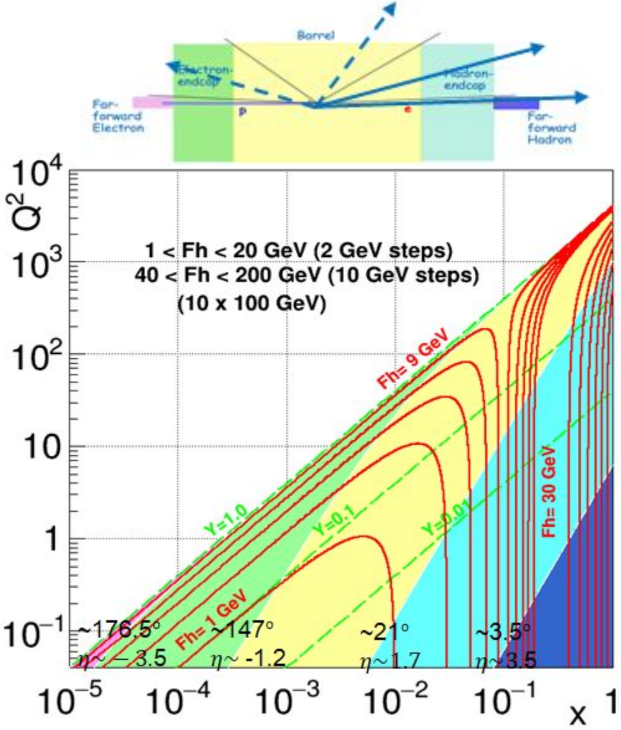
$$f_u \approx f_d,$$
$$f_{\bar{u}} \approx f_{\bar{d}} \approx f_{s,c,b} \approx f_{\bar{s},\bar{c},\bar{b}} \approx 0$$

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

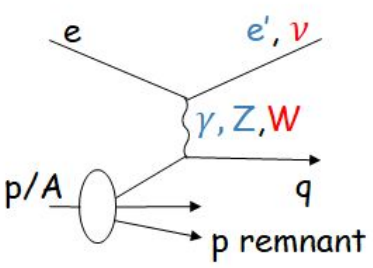
- Extractions from different ion will need a more complicated analysis

EIC kinematics

Yulia Furletova



Other methods would require a good knowledge of hadronic final state :



Hadron energy => x

b) Jacquet -Blondel method (only method for CC)

$$y_{\mathrm{JB}} = \frac{1}{2E_e}\sum_h (E_h - p_{z,h}),$$

$$Q^2_{\mathrm{JB}} = \frac{1}{1-y_{\mathrm{JB}}}\left[\left(\sum_h p_{x,h}\right)^2 + \left(\sum_h p_{y,h}\right)^2\right].$$

c) Double angle method

$$Q^2_{\mathrm{DA}} = \frac{4E_e^2 \sin\gamma_h\,(1+\cos\theta_{e'})}{\sin\gamma_h + \sin\theta_{e'} - \sin(\theta_{e'}+\gamma_h)},$$

$$y_{\mathrm{DA}} = \frac{\sin\theta_{e'}\,(1-\cos\gamma_h)}{\sin\gamma_h + \sin\theta_{e'} - \sin(\theta_{e'}+\gamma_h)},$$

$$\cos\gamma_h = \frac{P^2_{T,h} - \left(\Sigma_h\,(E_h - p_{z,h})\right)^2}{P^2_{T,h} + (\Sigma_h\,(E_h - p_{z,h}))^2}$$

d) Sigma method

$$y_{e\Sigma} = \frac{\Sigma_h\,(E_h - p_{z,h})}{E - P_z},$$

$$Q^2_{e\Sigma} = \frac{(E_{e'}\sin\theta_{e'})^2}{1-y}.$$

Note: Does not depend on initial electron beam energy, **less influenced by a initial state radiation**

And many other methods ....