EW/BSM workshop

6-7 May 2020

Y. Furletova (on behalf of workshop organizes)

U.S. DEPARTMENT OF ENERGY JSA Jefferson Lab EIC² EIC Center at Jefferson Lab

EW/BSM workshop motivations:

- EW/BSM physics is a part of the EIC White Paper. NAS report did not include EW/BSM. Now, as project had been approved, it is a right time to come back and summarize key measurements.
- Yellow Report process was on the way: how EW/BSM topics best fit into the structure…
- Synergies with HEP/LHC communities through SnowMass2021 long range planning process .
- Accelerator/Detector:
  - Polarized positrons (possible ?)
  - Two IRs (could run simultaneously? Yes, but will be less efficient, ~ 30% less each)
  - Detector requirements for EW/BSM physics (or complementarity in case of two IRs)

Electroweak and BSM physics at the EIC

https://indico.bnl.gov/event/8110/timetable/

Center for Frontiers in Nuclear Science
Workshop series

6-7 May 2020
Online
US/Eastern timezone

- Overview
- Call for Abstracts
- Timetable
- Contribution List
- Registration
- Participant List
- Remote Connection (via ZOOM)

Contact

- cfns_contact@stonybroo...
- ciprian.gal@stonybrook....
- mgericke@physics.uma...
- wouter.deconinck@uma...
- yulia@jlab.org

As part of the third physics pillar ("Physics at the Luminosity Frontier") of the original Electron-Ion Collider (EIC) white paper, Electroweak Physics gives us the possibility to study topics that have a much broader appeal in the Physics community.

Nearly a decade ago at a workshop at William & Mary, the opportunities for studying electroweak physics at the EIC were explored. At that time the parameters of the collider were still in flux and the detector design still in early stages. Since then the focus of the EIC community has largely been on QCD and nuclear processes. Now is an opportune time to re-evaluate the prospects for studying electroweak processes at the EIC. The goal of the
proposed adhoc meeting would be to reinvigorate the efforts of the electroweak community in the detector development for the electron-ion collider and to re-engage with the broader EIC community so that we can take full advantage of the recent developments (in particular in simulations working group).

Due to the COVID-19 virus, we will hold the workshop online using Zoom (password via email to registered participants).

This event is part of the CFNS workshop/ad-hoc meeting series. See the CFNS conferences page for other events.

Starts May 6, 2020, 8:00 AM
Ends May 7, 2020, 7:00 PM
US/Eastern

Online

Ciprian Gal
Michael Gerike
Wouter Deconinck
Yulia Furletova

There are no materials yet.

Two days workshop

Due to the COVID-19, we had to hold the workshop online using ZOOM

Ciprian Gal
Michael Gericke
Wouter Deconinck
Yulia Furletova

Diversity

81 Participants !

16%

Male	68		
Female	13		
	US	53	
	Armenia	5	
	Saudi-Arabia	1	
	Canada	11	
	Germany	2	
	Italy	2	
	India	2	
	Mexico	2	
	Russa	1	
	Taiwan	1	
	China	1	
		Faculty	43
		Scientist	25
		Grad student	9
		Postdoc	4

16%

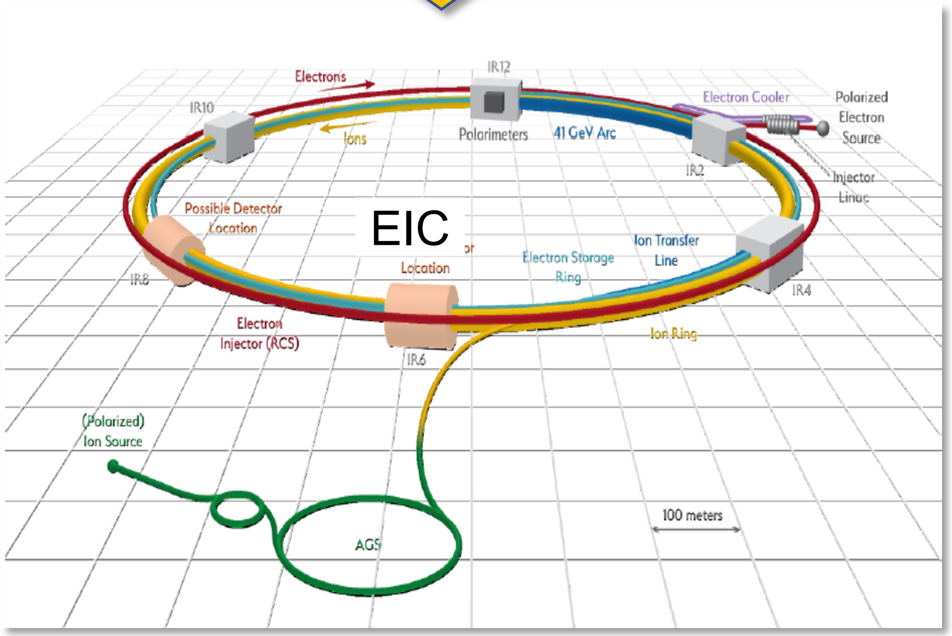
Introduction to the EIC

Welcome
Abhay Deshpande (Stony Brook University)

Broad overview of EIC
Douglas Higinbotham (Jefferson Lab)

EIC accelerator overview
Christoph Montag (BNL)

Polarimetry Overview
Dave Gaskell (Jefferson Lab)

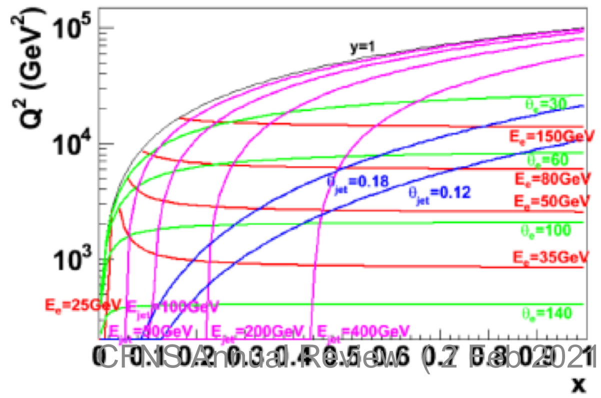


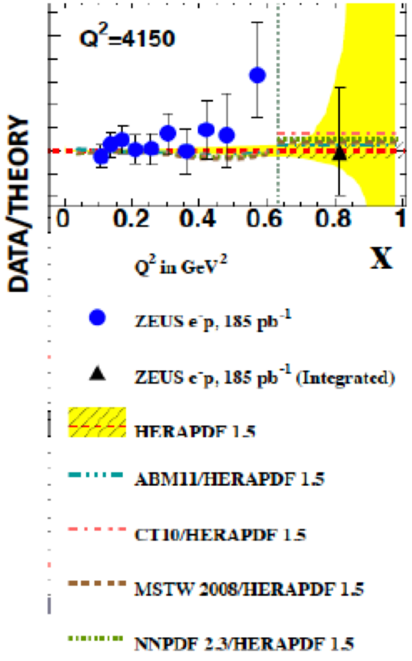
Lessons learned at HERA

Very very high-x

- Let's suppose to have a very high Q^2 electron (reconstructed in the detector) and very high x, so that the jet disappears in the fwd region
- Reconstruct Q^2 from the electron and integrate cross section in x- from edge up to x=1

A. Caldwell
https://indico.desy.de/indico/event/10523





Phys. Rev. D 89 (2014) 072207

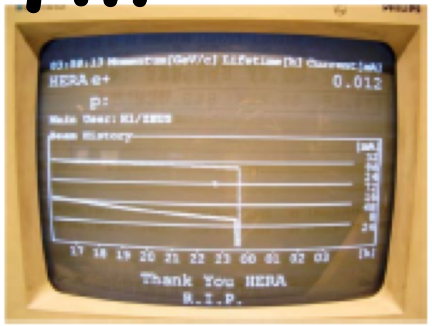
Uncertainties in PDFs at high-x still very high, these data at x>0.6

Experience of EW and BSM physics at HERA and lessons for the EIC
Elisabetta Gallo (DESY and University of Hamburg)
Stefan Schmitt (H1, DESY)

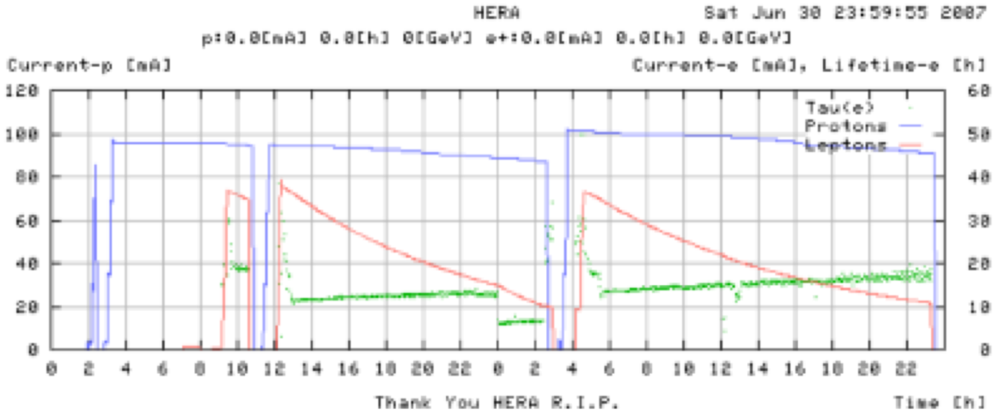
- ➢ Combination of H1-ZEUS data was fundamental for precision PDFs and electroweak measurements in particular (first one in 2006 for xF3 !)
- ➢ Very high x still very unknown region (crucial for searches at the LHC)
- ➢ Strong attention to PDFs from LHC community

Last HERA fill

Last fill 30/6/2007 at 23:30



Elisabetta Gallo



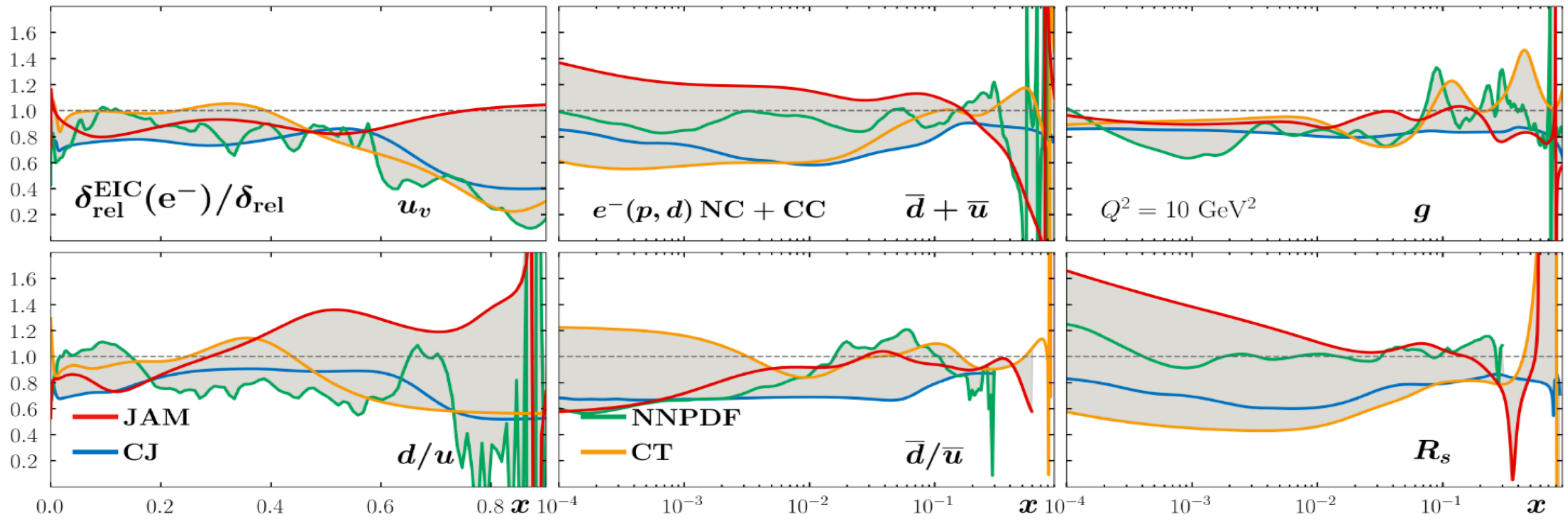
- Picture taken at the party after the last fill
- You have all a new project to start in DIS

PDF fits

Impact of EIC on LHC
Speaker: Timothy Hobbs

Our knowledge of unpolarized collinear parton distribution functions (PDFs) driven by inclusive neutral current (NC) and charged current (CC) deep inelastic scattering(DIS) cross section.

The potential impact of EIC's NC and CC with incident electron beam colliding with **proton and deuterium beams** from a selection of PDF global analyzers

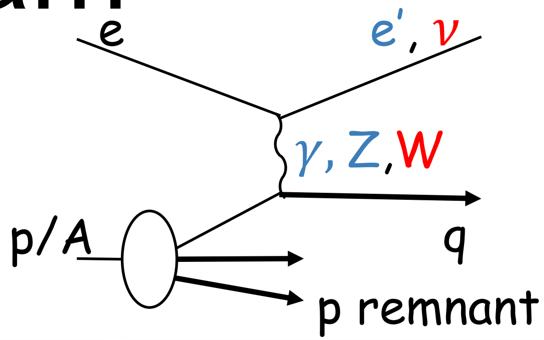


100 fb-1 $\sqrt{s}$ ~ 28.6, 44.7, 63.3, 140.7 GeV for NC and 140.7 GeV for CC
and deuteron beams L= 10fb−1 and consider only NC at √s= 28.6, 66.3, 89.0 GeV

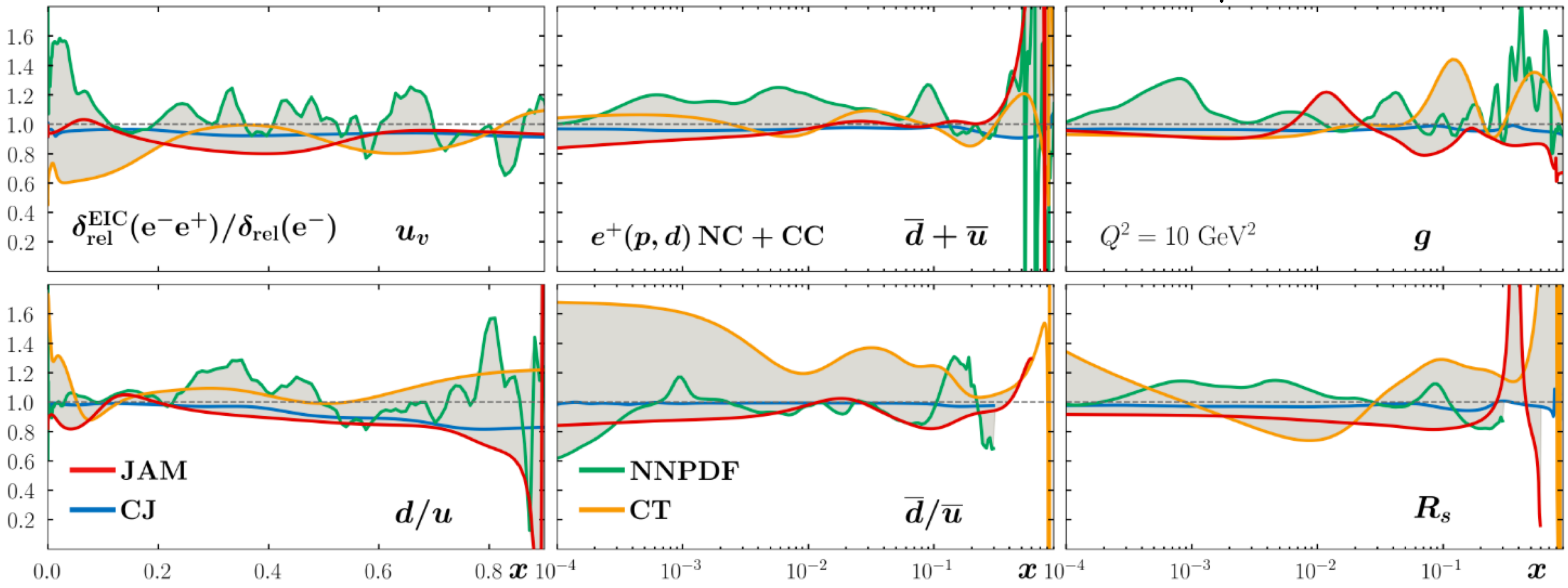
T. Hobbs

PDF fits with positron beam

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.

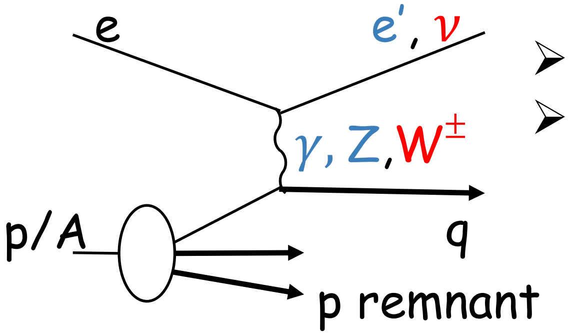


BSM and EW with positrons at EIC
Wally Melnitchouk
(Jefferson Lab)



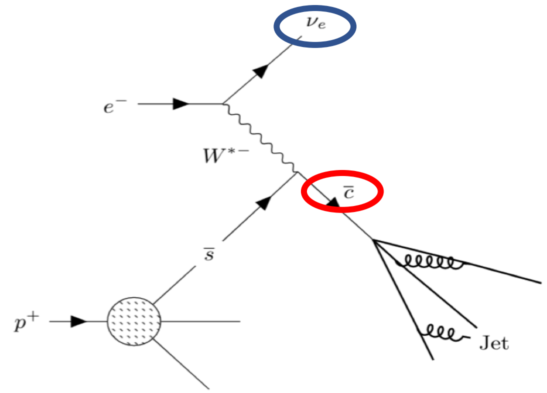
Charged Current at EIC

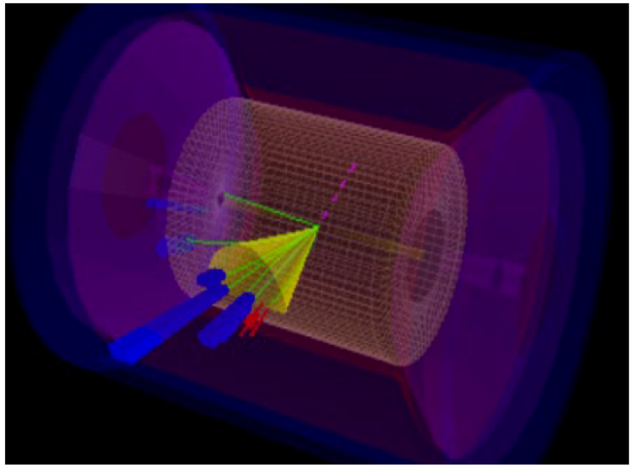
Charge-current jet measurements
Miguel Arratia (University of California, Riverside)

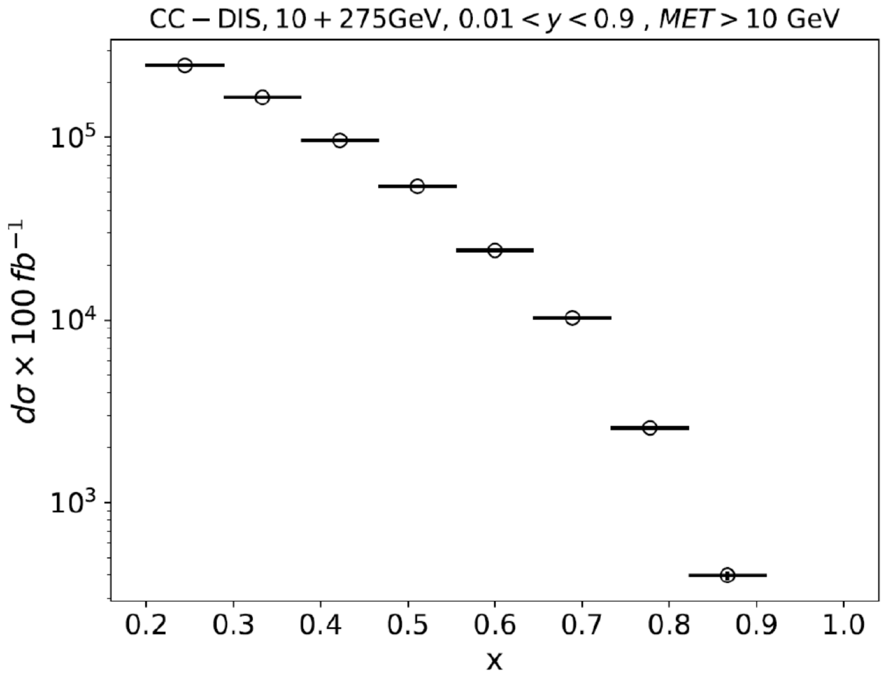


- **Explore the high-x frontier**
- **flavor separation**

NC background rejection: need 4pi coverage for HCAL
-> Probing Strangeness with charm jets.

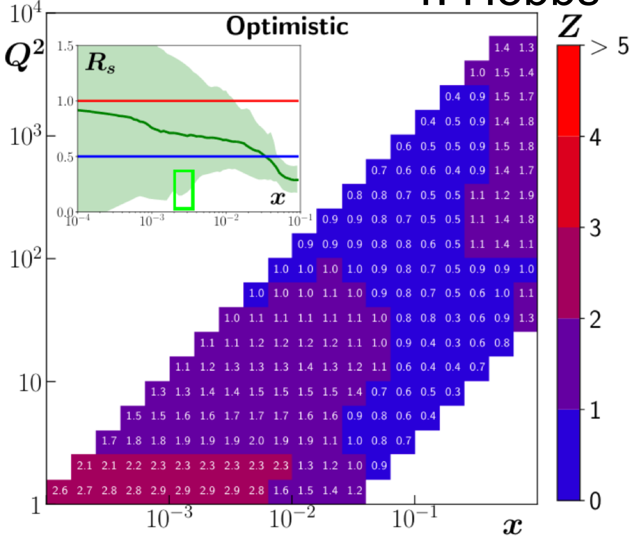




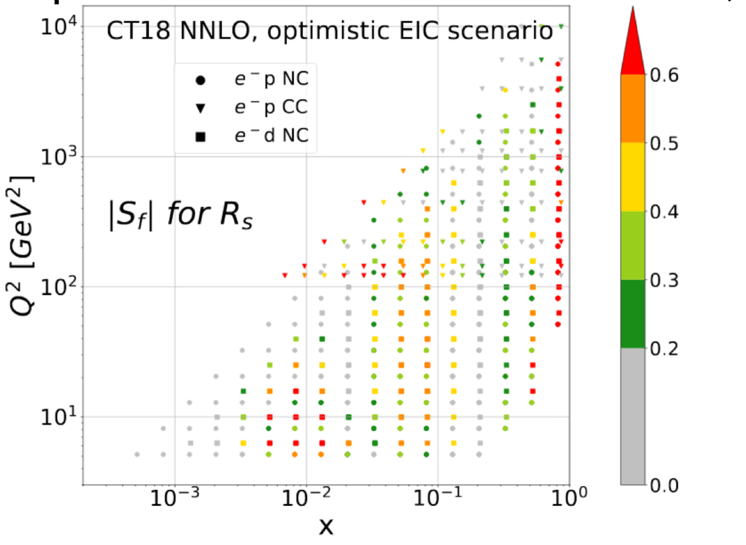


Rs= $(s+\bar{s})/(\bar{u}+\bar{d})$

T. Hobbs



The sensitivity,|Sf|, of the EIC e−pseudodata to the Rs PDF ratio;



Parity violation at EIC

Yuxiang Zhao

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

$$A_{PV} = \frac{d\sigma_L - d\sigma_R}{d\sigma_L + d\sigma_R}.$$

Since both beams are polarized, parity violating measurements can be obtained for polarized electrons or polarized protons

With parity violation and $Q^2 \ll Z^2$

Inclusive electron measurements

pol. electron & unpol. nucleon:

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

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

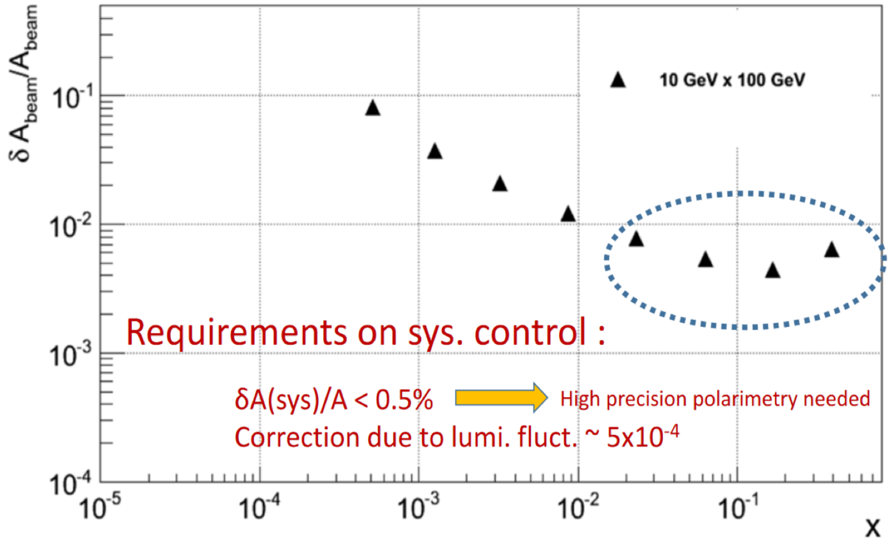
$$F_3^{\gamma Z} = 2\sum_f e_{q_f}(g_A)_{q_f}(q_f - \bar{q}_f)$$

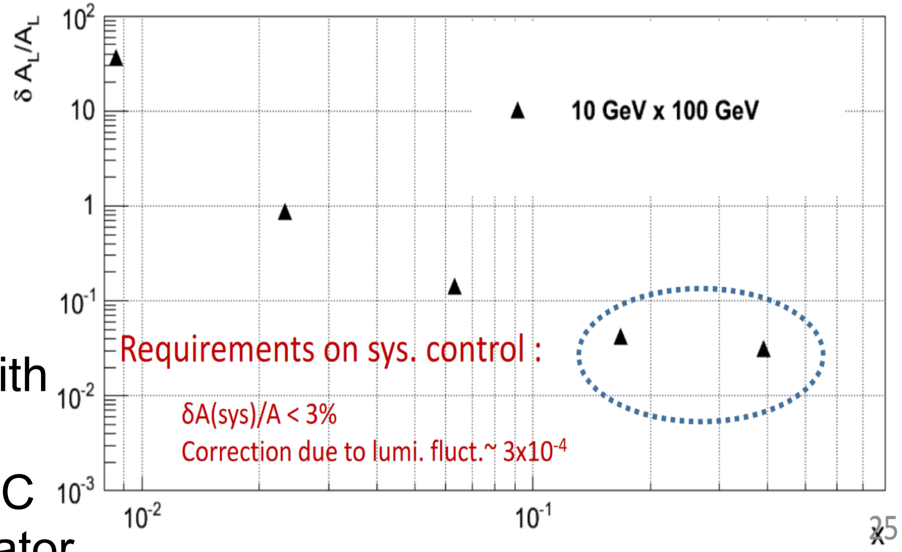
unpol. electron & pol. nucleon:

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

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

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





the deuteron beam would allow an extraction of the weak mixing angle with little PDF uncertainty

comparisons of Ae PV measurements on heavy nuclei available at the EIC with the deuteron result would allow to test EMC effect with a weak mediator.

Weak mixing angle extractions

Ayres Freitas
Yuxiang Zhao

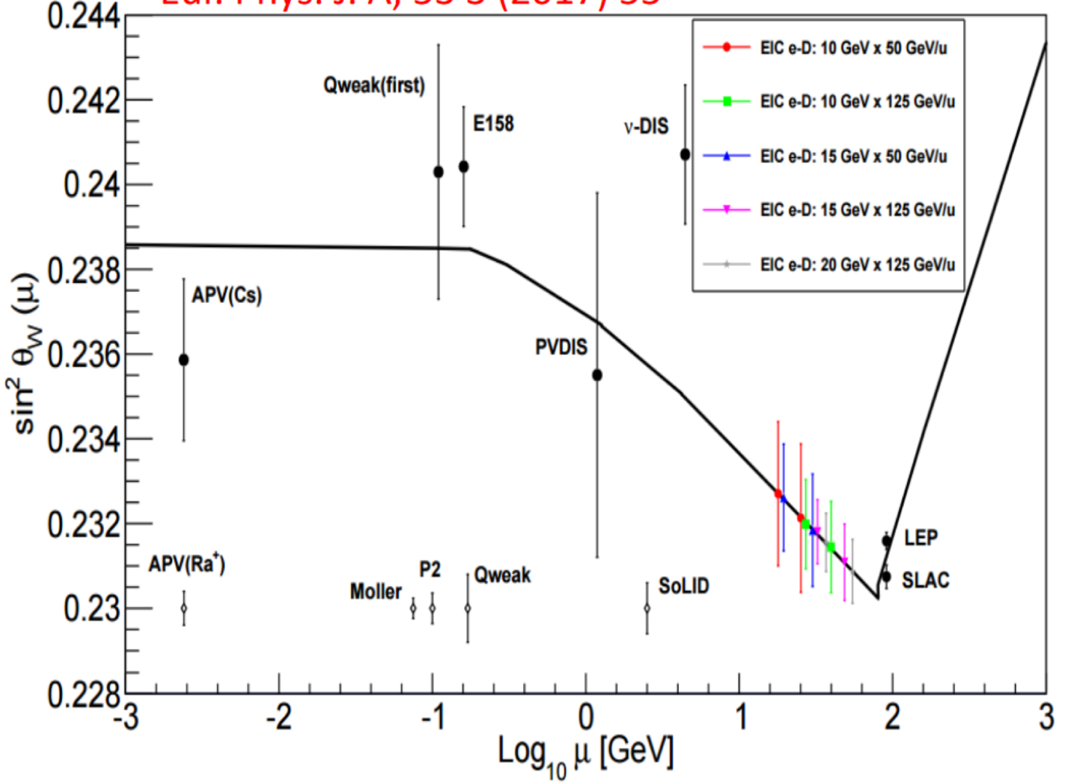
In the $Q^2 << M^2_Z$ limit, the weak neutral current contribution to DIS can be parameterized in terms of contact interactions

$$\mathcal{L} = \frac{G_F}{\sqrt{2}} \sum_{\ell,q} \Big[C_{1q}\, \bar{\ell}\gamma^\mu \gamma_5 \ell \bar{q}\gamma_\mu q + C_{2q}\, \bar{\ell}\gamma^\mu \ell \bar{q}\gamma_\mu \gamma_5 q + C_{3q}\, \bar{\ell}\gamma^\mu \gamma_5 \ell \bar{q}\gamma_\mu \gamma_5 q \Big],$$

where C_{iq} denote the weak neutral current couplings.
A comparison of the measured values of the C_{iq} couplings with the SM predictions can be used to set limits on the new physics scale Λ.

the C_{1q} and C_{2q} couplings are functions of the weak mixing angle θ_W

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



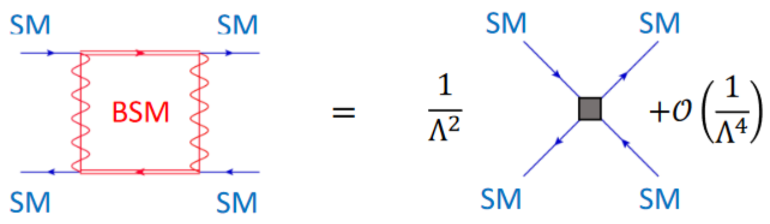
$$A^{ep}_{\mathrm{LR}} \approx \frac{\sigma_{\mathrm{L}} - \sigma_{\mathrm{R}}}{\sigma_{\mathrm{L}} + \sigma_{\mathrm{R}}} = \frac{G_\mu(-q^2)}{4\sqrt{2}\pi\alpha} Q_{\mathrm{W}}(p)$$

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

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

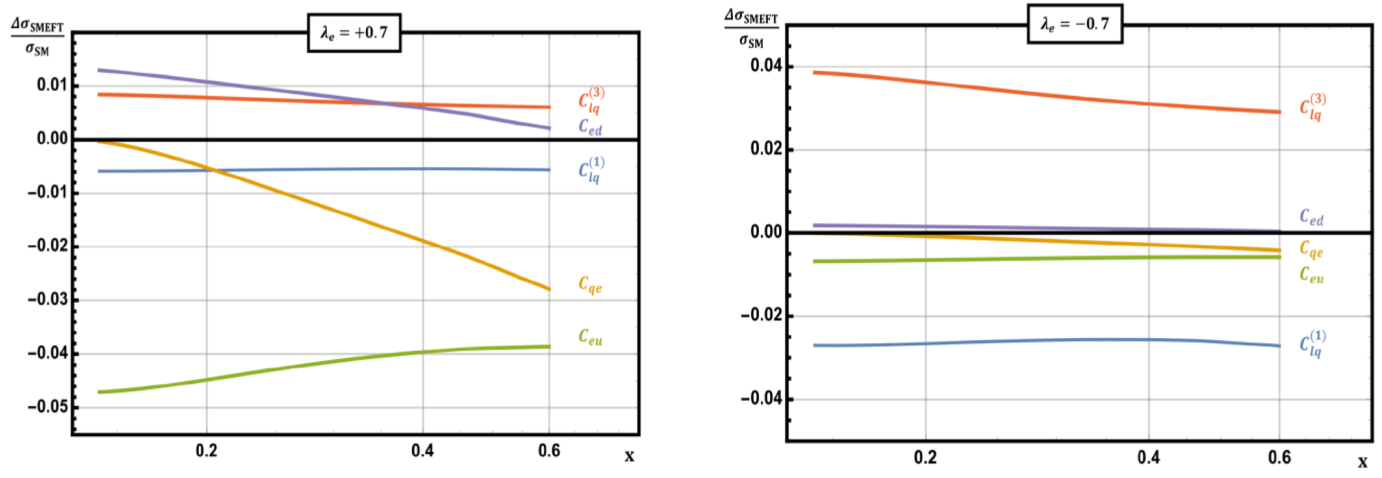
Complementarity of EIC and LHC probes of the SMEFT

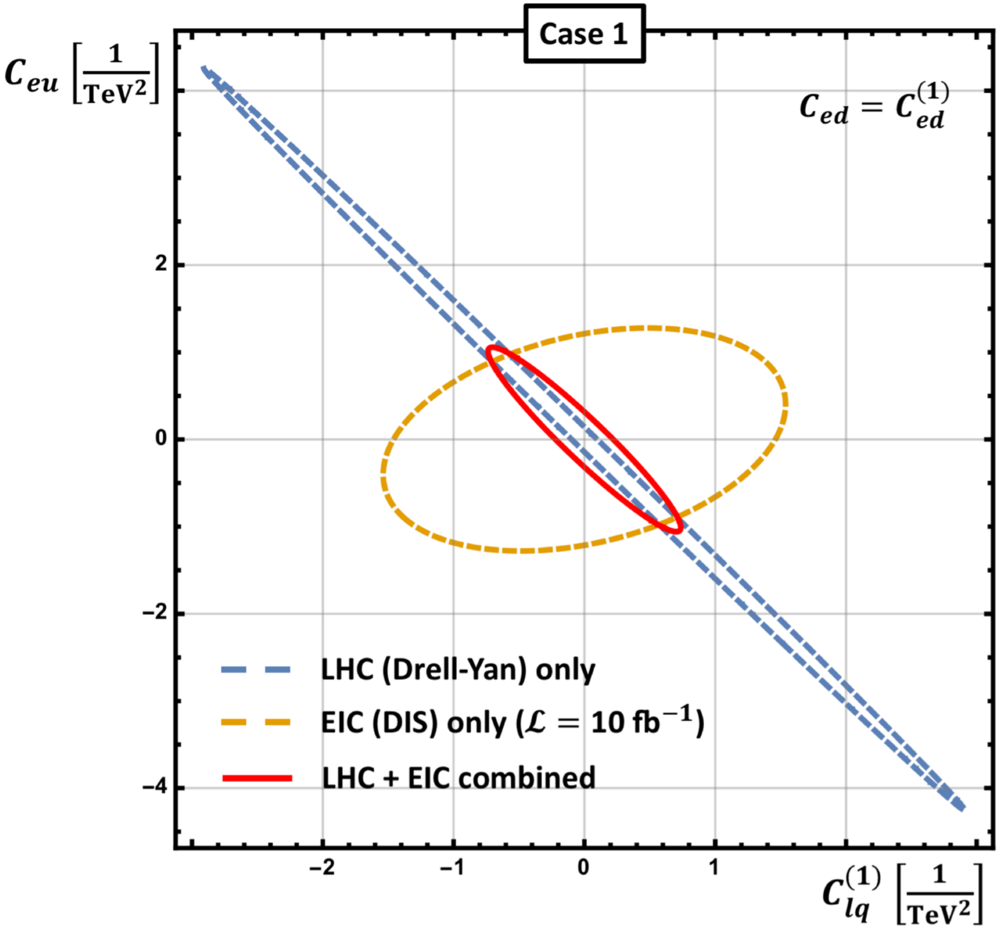
Daniel Wiegand



The SM effective field theory (SMEFT) provides a convenient theoretical framework for investigating indirect signatures of heavy new physics without associated new particles at low energies. Considerable effort has been devoted to performing global analyses of the available data within the SMEFT and other frameworks.

Simultaneous fit of PDFs AND Wilson Coefficients





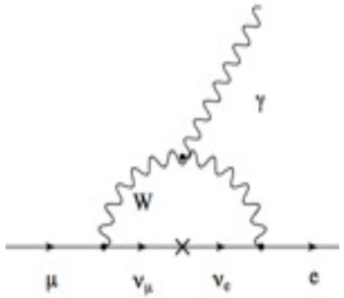
Different Wilson coefficients contribute for different electron polarizations

Charged Lepton Flavor Violation

Theory of lepton flavor violation
Sonny Mantry (University of North Georgia)

Charged lepton flavor and number violation
Jinlong Zhang (Stony Brook University)

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



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

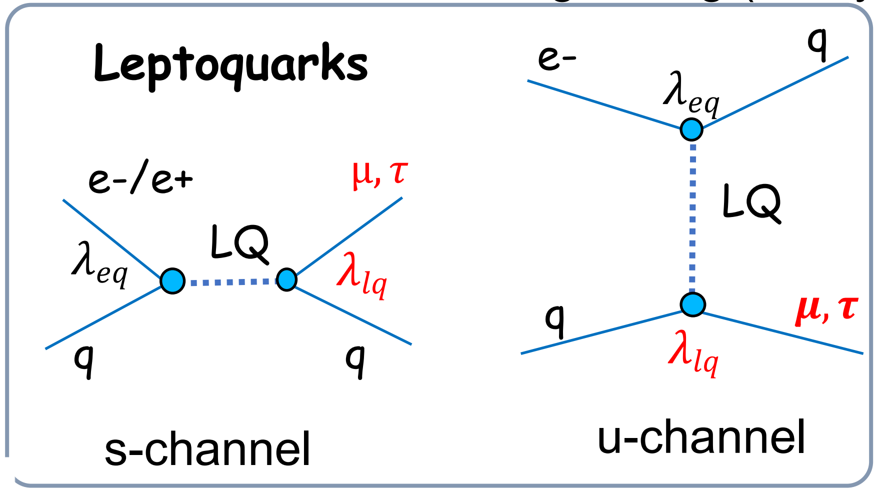
However, SM rate for CLFV is tiny due to small neutrino masses

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

However, many BSM scenarios predict enhanced CLFV rate (LQ, RPV-SUSY , SU(5) etc.…

Type	J	F	Q	ep dominant process	Coupling	Branching ratio β_ℓ
S_0^L	0	2	$-1/3$	$e_L^- u_L \to \ell^- u$	λ_L	1/2
				$\to \nu_\ell d$	$-\lambda_L$	1/2
S_0^R	0	2	$-1/3$	$e_R^- u_R \to \ell^- u$	λ_R	1
$\tilde{S}_0^R$	0	2	$-4/3$	$e_R^- d_R \to \ell^- d$	λ_R	1
S_1^L	0	2	$-1/3$	$e_L^- u_L \to \ell^- u$	$-\lambda_L$	1/2
				$\to \nu_\ell d$	$-\lambda_L$	1/2
			$-4/3$	$e_L^- d_L \to \ell^- d$	$-\sqrt{2}\lambda_L$	1
$V_{1/2}^L$	1	2	$-4/3$	$e_L^- d_R \to \ell^- d$	λ_L	1
$V_{1/2}^R$	1	2	$-1/3$	$e_R^- u_L \to \ell^- u$	λ_R	1
			$-4/3$	$e_R^- d_L \to \ell^- d$	λ_R	1
$\tilde{V}_{1/2}^L$	1	2	$-1/3$	$e_L^- u_R \to \ell^- u$	λ_L	1

Type	J	F	Q	ep dominant process	Coupling	Branching ratio β_ℓ
V_0^L	1	0	$+2/3$	$e_R^+ d_L \to \ell^+ d$	λ_L	1/2
				$\to \bar{\nu}_\ell u$	λ_L	1/2
V_0^R	1	0	$+2/3$	$e_L^+ d_R \to \ell^+ d$	λ_R	1
$\tilde{V}_0^R$	1	0	$+5/3$	$e_L^+ u_R \to \ell^+ u$	λ_R	1
V_1^L	1	0	$+2/3$	$e_R^+ d_L \to \ell^+ d$	$-\lambda_L$	1/2
				$\to \bar{\nu}_\ell u$	λ_L	1/2
			$+5/3$	$e_R^+ u_L \to \ell^+ u$	$\sqrt{2}\lambda_L$	1
$S_{1/2}^L$	0	0	$+5/3$	$e_R^+ u_R \to \ell^+ u$	λ_L	1
$S_{1/2}^R$	0	0	$+2/3$	$e_L^+ d_L \to \ell^+ d$	$-\lambda_R$	1
			$+5/3$	$e_L^+ u_L \to \ell^+ u$	λ_R	1
$\tilde{S}_{1/2}^L$	0	0	$+2/3$	$e_R^+ d_R \to \ell^+ d$	λ_L	1

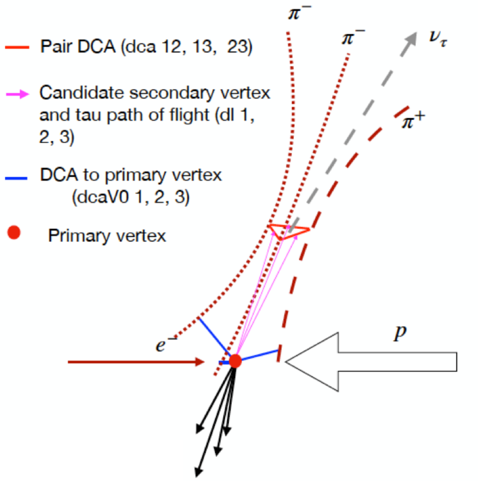


- ➢ High luminosity (~100-1000 higher then HERA)
- ➢ Electron and positron beam will probe different types of LQs
  - -electron-proton collisions, mainly F=2 LQs produced
  - -positron-proton collisions, mainly F=0 LQs produced
- ➢ eD (deuterium) vs ep collisions
- ➢ LQs are chiral particles, gain in sensitivity due to polarized beams

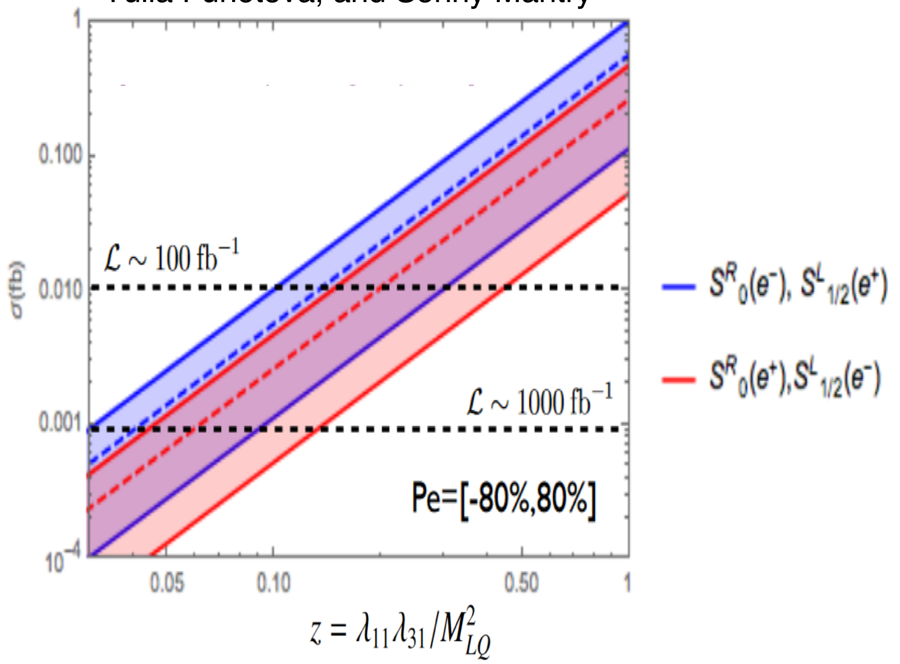
CLFV: e to tau (leptoquarks)

Jinlong Zhang

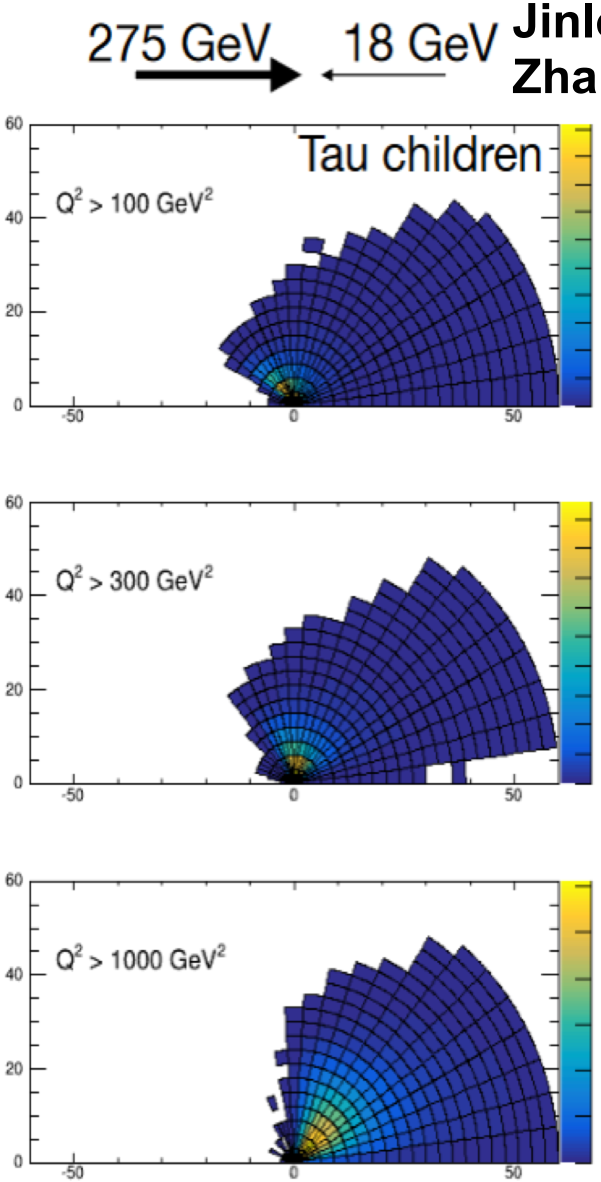
- **Tau vertex displaced at cm level**
  - 3-prong tau jet; decay topology important for τ jet ID
  - 1-prong: recovering higher branching ratios; but background control is much more demanding



Yulia Furletova, and Sonny Mantry

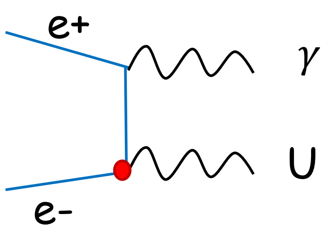


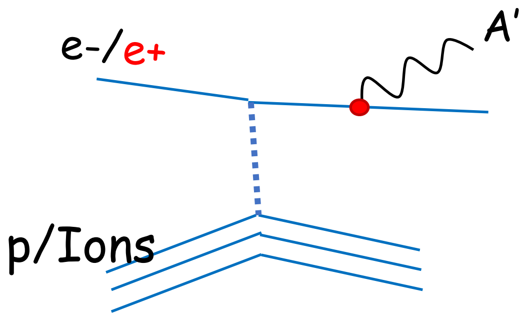
- Isolated tau, Pt balance with q-jet.
- Tau-Jet identification (narrow cone, displaced vertex)
- Precise measurements of vertex (tau vertex displacements 200 to 3000 microns)
- Current limits set by HERA sitting at sensitivities of a few fb
  - The high luminosity of the EIC will gain us 2 orders of magnitude

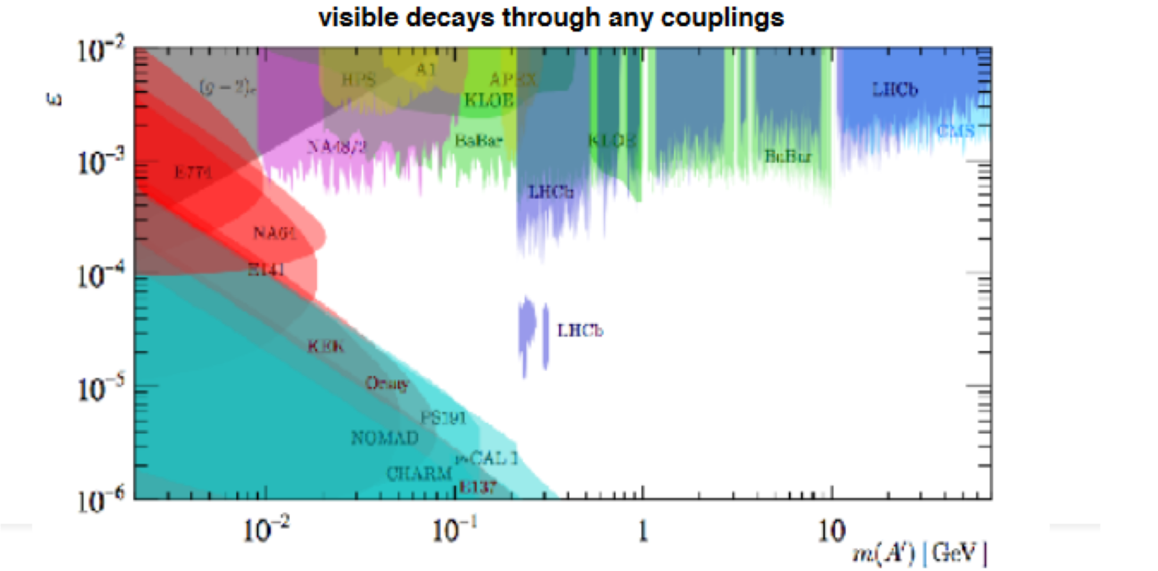


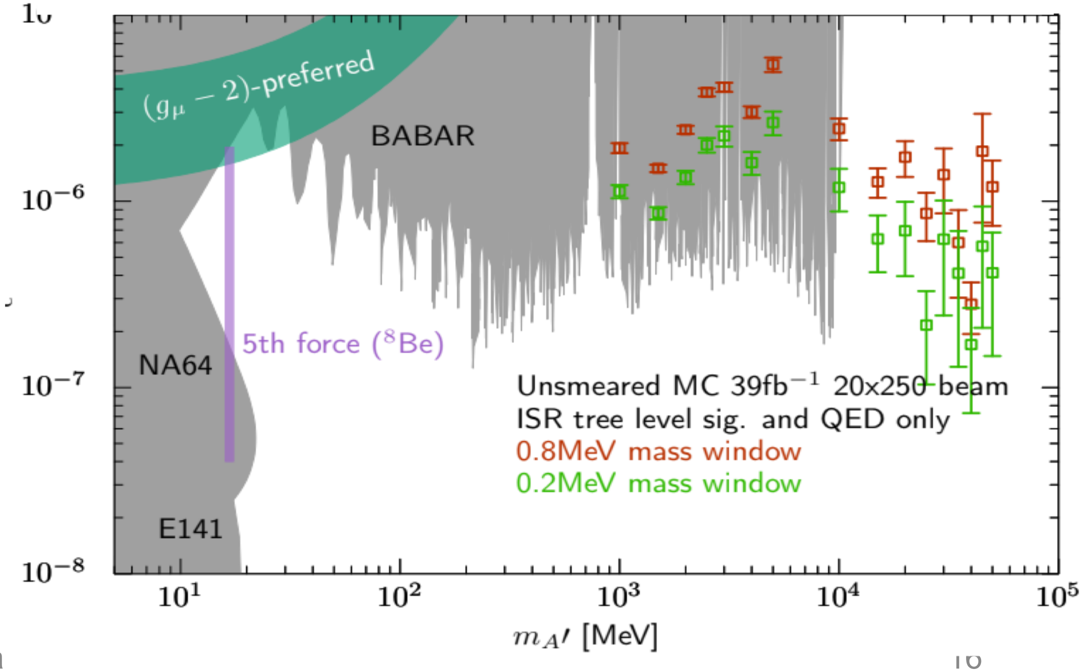
Angle for theta, radius for momentum

Dark Photon Searches





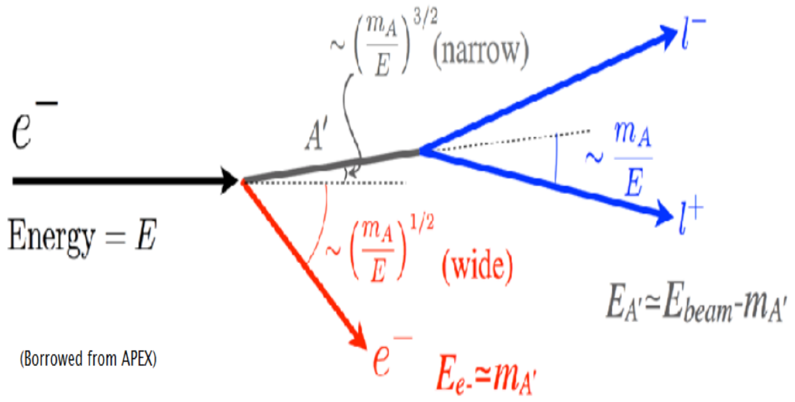


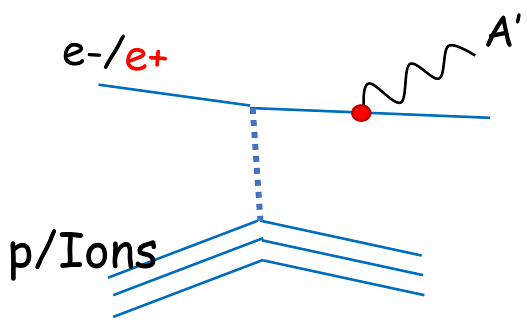


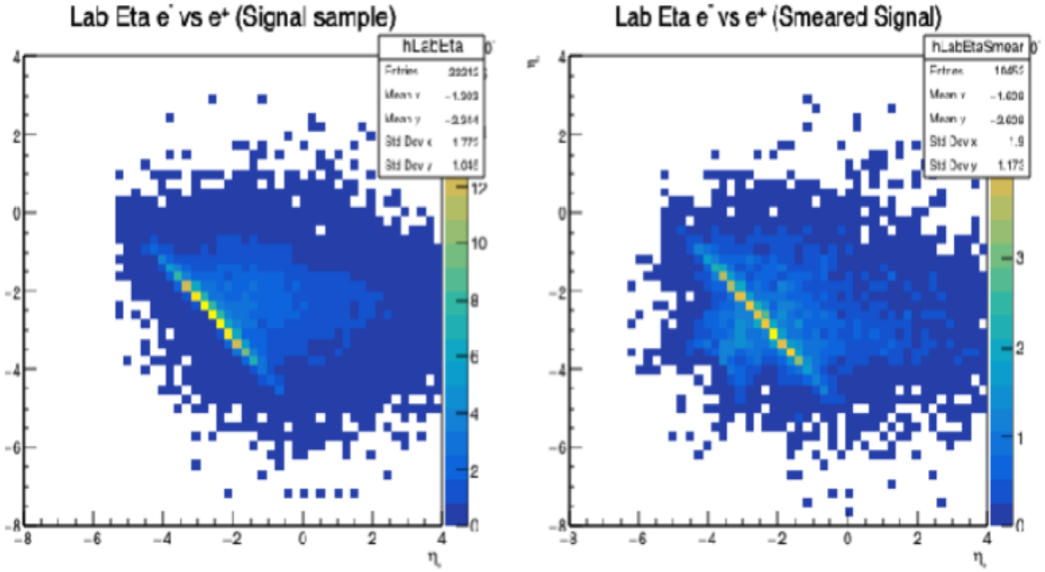
- Dark Photon (U,A'): new mediator to a sector of Dark Matter particles (MeV-GeV mass)
- Weakly coupled to Standard Model through kinetic mixing with ordinary photon → production in e^+e^- annihilation.
- A′ can be probed with $e^{+/-}$ p(Ions) (e.g. target experiments PADME at LNF, Adv. High Energy Phys. 2014:959802; VEPP-3, arXiv:1207.5089 [hep-ex])
- Detection via decay into SM particles (e+/e-)
- High luminosity is needed

Dark Photon Searches

Ross Corliss







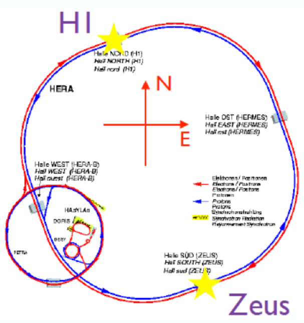
- First analysis looks at e+e- decay, but hadronic final states could be investigated as well
- The boosted kinematics significantly opens up the angle between the decay leptons creating a specific topology
- Measurement would benefit from improved charge sign reconstruction and good lepton PID (e/pi rejection)
- Higher eta coverage would lead to access to lower mass dark photons

- With 6 months of running 25 on 250 (~39 fb^{-1}) we could reach similar sensitivities than BABAR but in a wider mass range

Lorentz violating effects

Enrico Lunghi

HERA

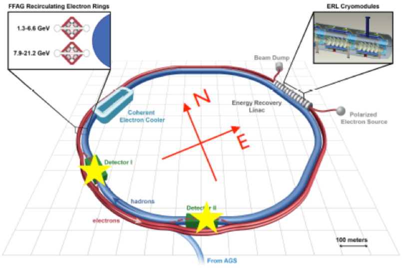


χ=36.4°

φ_{ZEUS}=20° NoE

φ_{H1}=-20° NoE

eRHIC

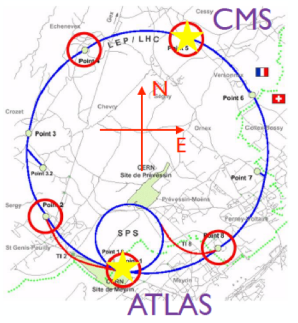


χ=49.1°

φ_{eRHIC1}=-78.5° NoE

φ_{eRHIC2}=-16.8° NoE

LHC

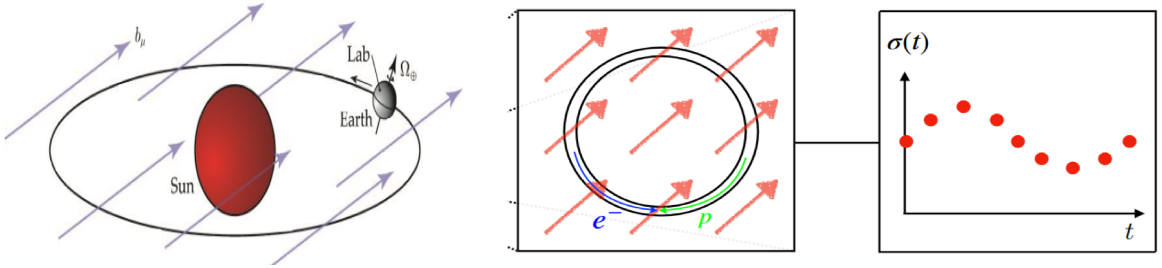


χ=46°

φ_{ATLAS}=-14° NoE

φ_{CMS}=-14° NoE

- Lorentz and CPT symmetry are among the most well established symmetries in physics.
- However, many BSM theories admit regimes where one or both of these symmetries can be spontaneously broken.



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

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

Recent studies suggest differential cross section measurements at the EIC will allow for precision tests of Lorentz and CPT symmetry in the quark sector and could increase bounds on quark sector coefficients by two orders of magnitude over data taken at HERA.

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

	HERA	JLEIC (one year)	eRHIC (one year)	JLEIC (ten years)	eRHIC (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.]

Summary

- EW (Charged current) physics is essential for PDF flavor decompositions.
- High luminosity at EIC will offer precision measurements and access to rare physics;
- Polarization is essential for EW/BSM physics
- Preliminary estimates on BSM physics at EIC looks promising.
- Next generation of detectors: control under systematics, efficiency.
- Yellow report, SnowMass process
- Looking forward for new EW/BSM physics studies at EIC !

  and to the new EW/BSM Workshop! ;-)

➢ Increase informal discussion time to compensate coffee breaks

Thanks, CFNS, for support!

Testing the chiral structure of the week interaction with Charged Current DIS at EIC

Yulia Furletova, and Sonny Mantry

- linear dependence from lepton polarization:

$$\sigma_{CC}^{e^{\pm}p}(P_e) = (1 \pm P_e) \cdot \sigma_{CC}^{e^{\pm}p}(P_e = 0)$$

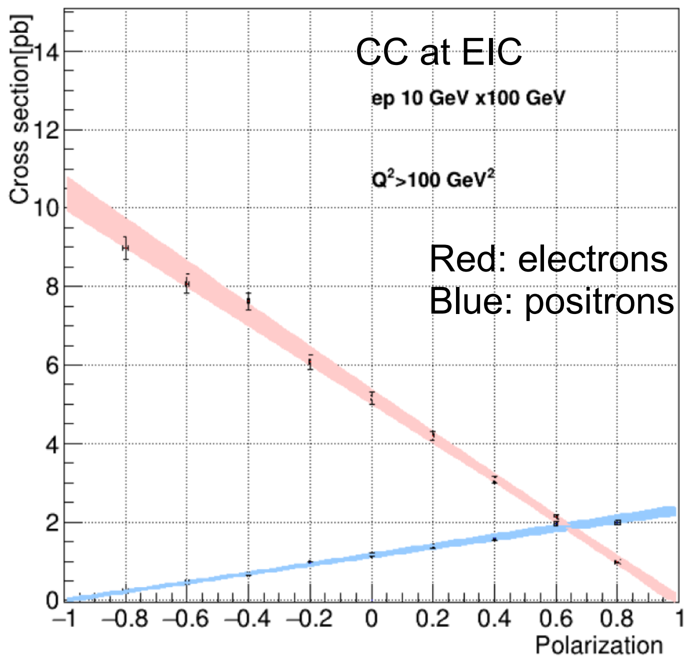
Clear left-handed nature of weak currents (W_L):
At HERA:

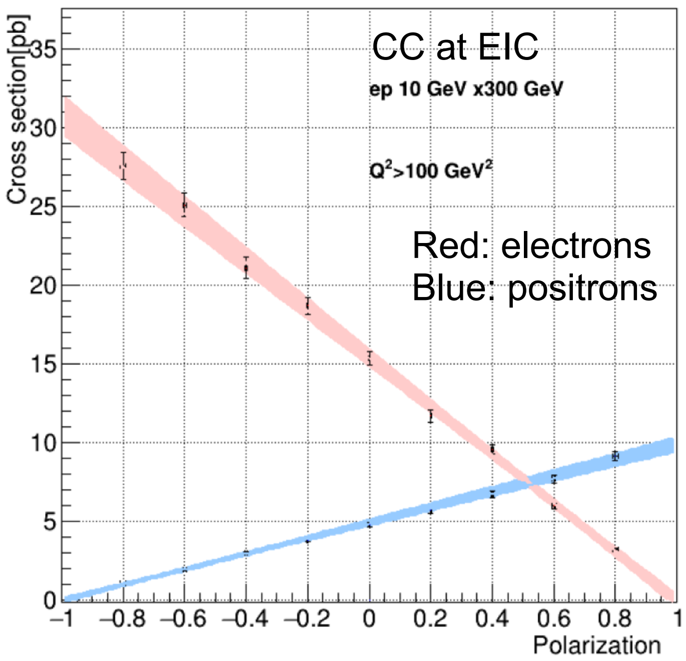
extrapolation to $P_{e^+} = -1$:

- $\sigma_{CC}^{tot} = -1.0 \pm 1.8_{stat} \pm 1.1_{sys}$ pb

If not 0 for e- @P=1 or e+@ P=-1
=> new physics

Extrapolation to P=±1 => limits on W_R





- High energy, high luminosity and high polarization are needed
- High control under systematic uncertainties for lepton polarization (~1%)

https://doi.org/10.1063/1.5040210