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Towards the Electron Ion Collider: polarimeter, LQ simulation, and GPD with PARTONS

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Outline

I. Compton Polarimeter for electron beam (with PREX/CREX Compton group)

II. EIC Simulation: Search for charged lepton flavor violation at EIC (with A. Deshpande, J. Huang, K. Kumar and Y.-X. Zhao)

III. Impact studies of GPD with PARTONS framework (with PARTONS team, locally with A. Deshpande and S. Fazio)

I. Compton Polarimeter

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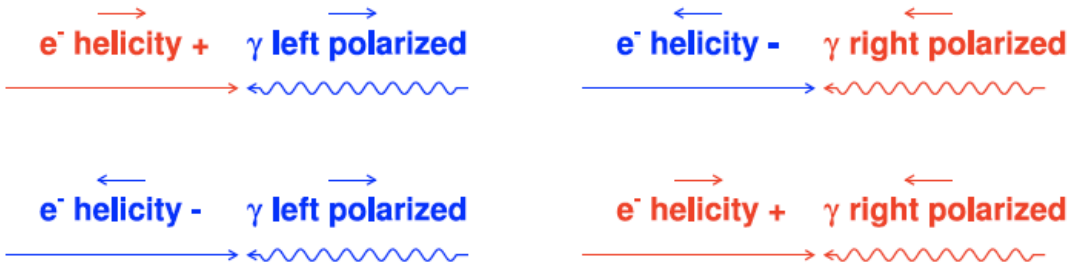
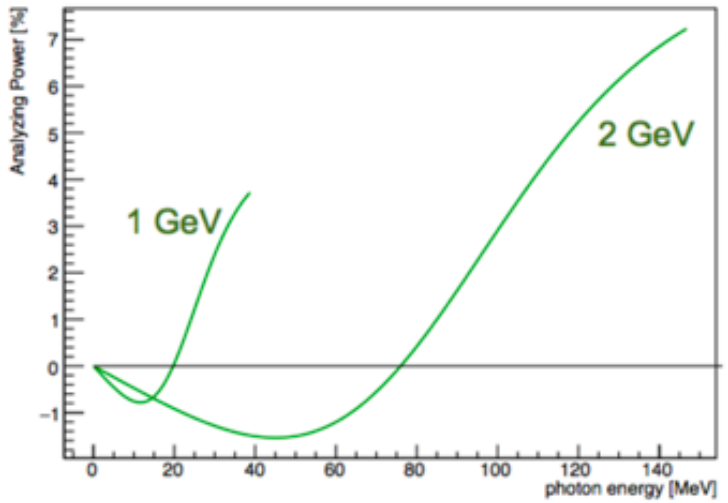
Compton Polarimeter



$$\left(\frac{d\sigma}{d\rho}\right)_{Compton} = \left(\frac{d\sigma}{d\rho}\right)_{Unpolarized}[1 + P_\gamma P_e A_l(\rho)]$$

$$P_e = \frac{A_{measured}}{P_\gamma A_l}$$

Analyzing power of polarized Compton scattering



- QED process with significant analyzing power
- Non-invasive to the beam with laser "target"
- Spin (-related) program at the high luminosity EIC requires high precision and non-invasive polarimeter

→ Strong candidate for EIC polarimetry

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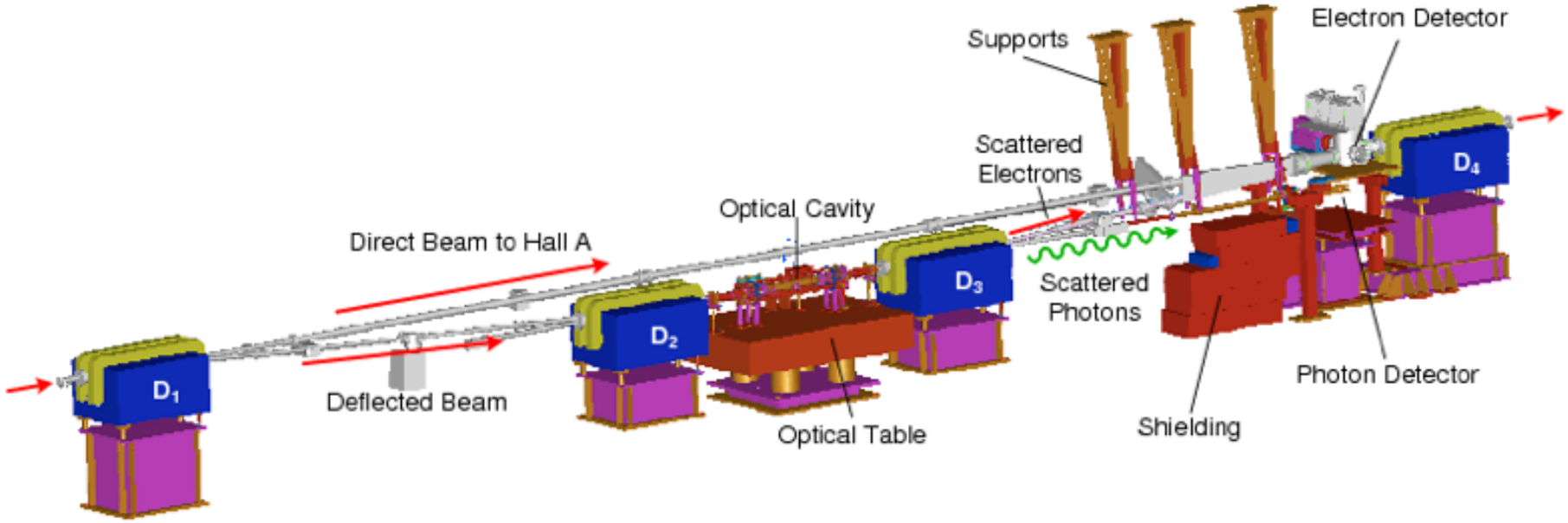
Compton polarimeter at JLab Hall A

- One of the three types of polarimeter at Jefferson Lab (together with Mott and Moller)
- Have been and is being developed to push to the high precision.



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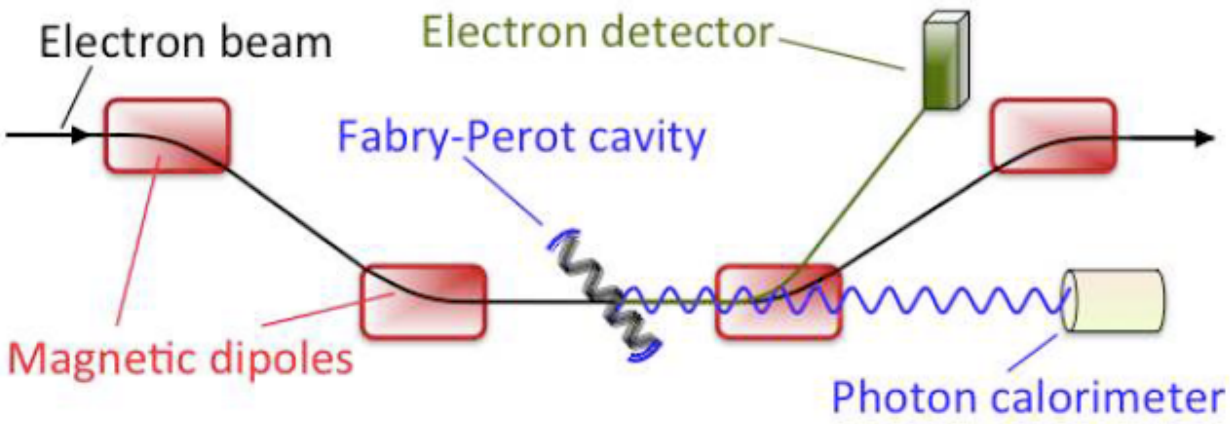
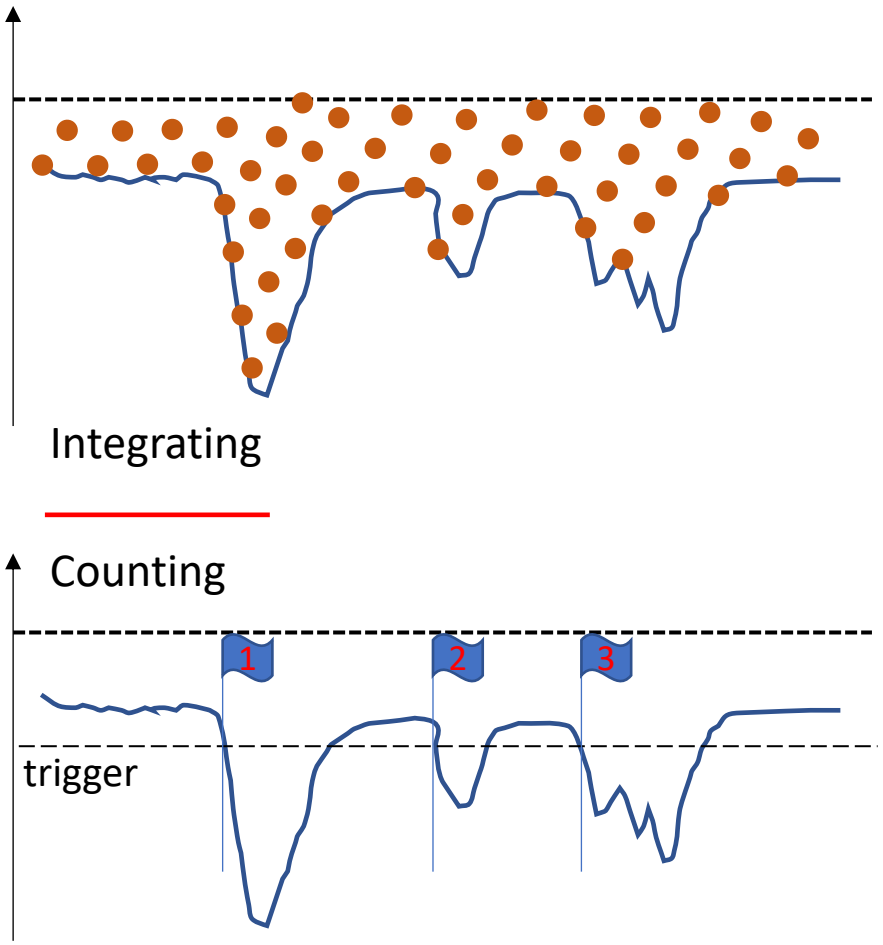
Compton polarimeter at JLab Hall A

1. Four-dipole chicane, bending electron beam to laser table.
2. High power laser in Fabry-Perot Cavity
3. Back-scattering photons detected by photon detector (GSO)
4. Scattered electron bended away by D3 toward to electron detector (Silicon strip)



- Continuous monitoring electron beam polarization
- ~1% precision for PREX/CREX; aim for ~0.5% for MOLLER
- Technology preparation for EIC spin (-related) physics

Data Acquisition: Integrating vs counting



- Photon side: integrating mode is used
  - GSO Calorimeter
  - Higher energy photons with large analyzing power are enhanced
  - “Zero” dead-time
  - Without trigger threshold effect

- Electron side: counting mode is used
  - Silicon strips: position -> momentum
  - Compton spectrums

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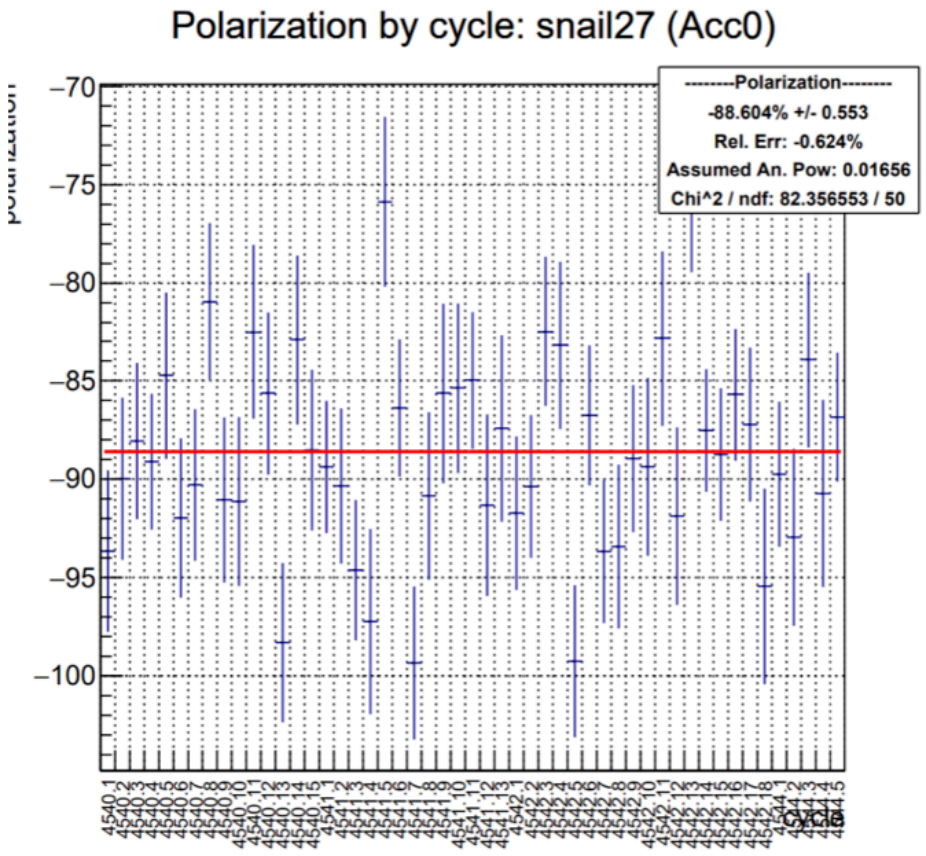
Compton polarimeter Status for PREX/CREX



Just an example, not public

- PREX data is on tape and being analyzed

  ← example of polarization data by laser cycle

- CREX is starting this week
  - Photon side will continue the successful operation with adjustment
  - Electron detector with counting DAQ is commissioning; critical for MOLLER and SoLID

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II. Leptoquark Search at EIC

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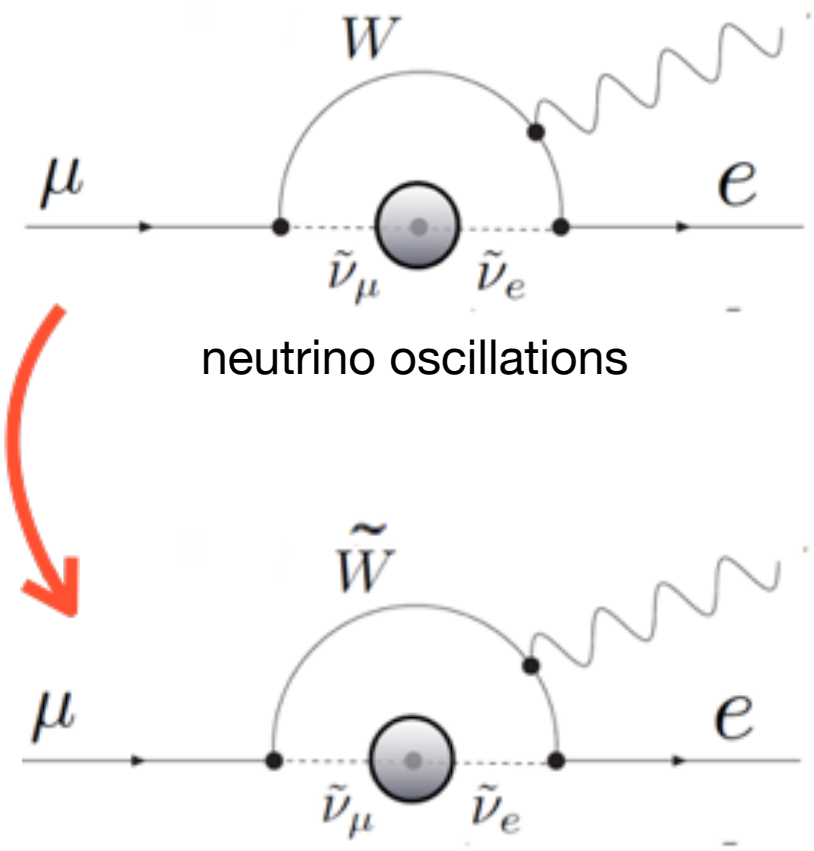
Charged lepton flavor violation

- Lepton Flavor (generation) is not conserved, neutrino oscillations observed. (2015 Nobel Prize)
- Charged lepton flavor violations (CLFV) should also be allowed within the SM; but extremely low rate, e.g. BR($\mu \to e\gamma$) < 10^{-54}
- Many BSM models predict significantly higher rate of CLFV, e.g. SUSY slepton mixing BR($\mu \to e\gamma$) < 10^{-15}

Experimental observation will be a signature of new physic.



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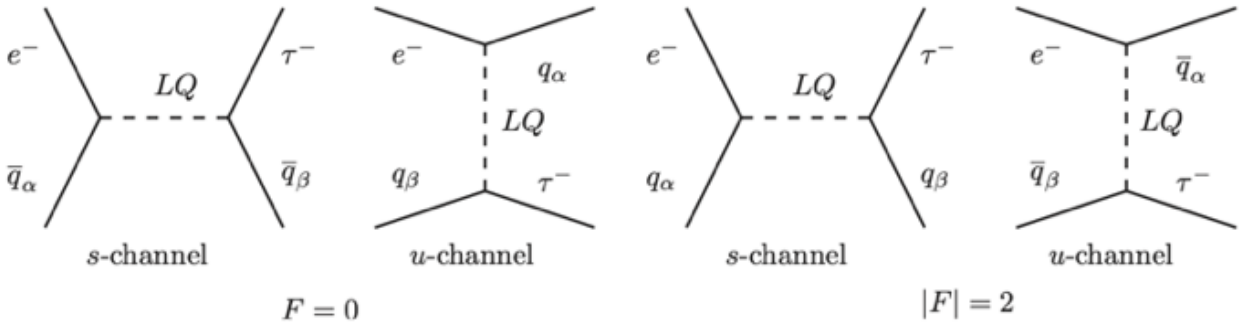
Discovery Space at EIC? Yes

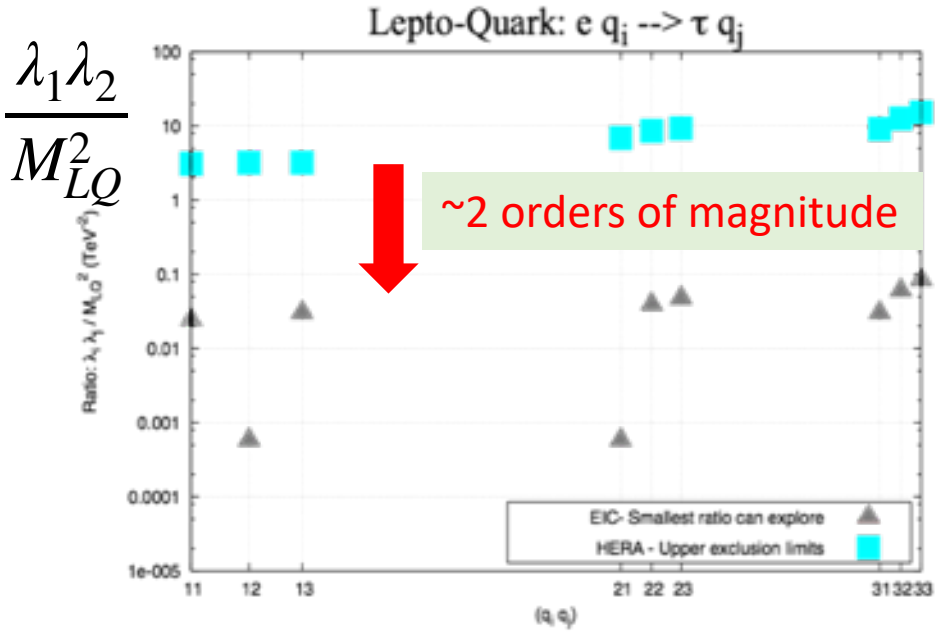
Experimentally, $e \leftrightarrow \mu$ conversion upper limits < 10^{-13}

But various models predict enhanced sensitivity for LFV(1,3) while suppressing LFV(1,2)

Leptoquark model provides a good benchmark to study sensitivity (Gonderinger, Ramsey-Musolf, 2010)

- CLFV at tree level, likely enhanced rates than loop level processes in other models





- Current limits set by HERA in *coupling-mass* space
- With much higher luminosity, ~2 orders of magnitude improvement of the sensitivity is expected at EIC

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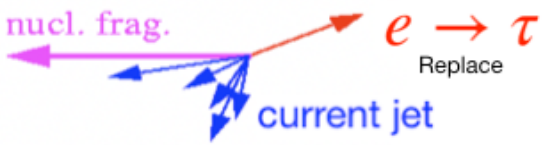
Goal of this Study

HERA Efficiency *~2.5%*

EIC, benefit from improved vertex and jet detection, aim to greater than *10%* efficiency with negligible background in a *100 fb^{-1}* data sample



- Replace electron with tau
- Tau back-to-back with current jet
- Primary vertex reconstructed from tracks of current jets
- 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

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%

- LQGENEP 1.0 for Leptoquark events (L. Bellagamba, 2001)
- DJANGOH 4.6.8 for DIS (NC + CC) events (H. Spiesberger 2005)

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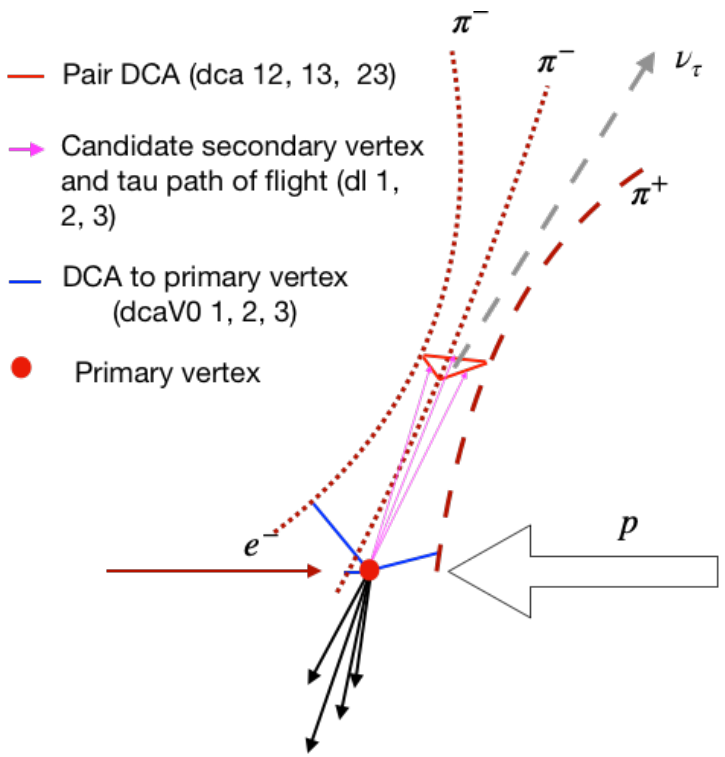
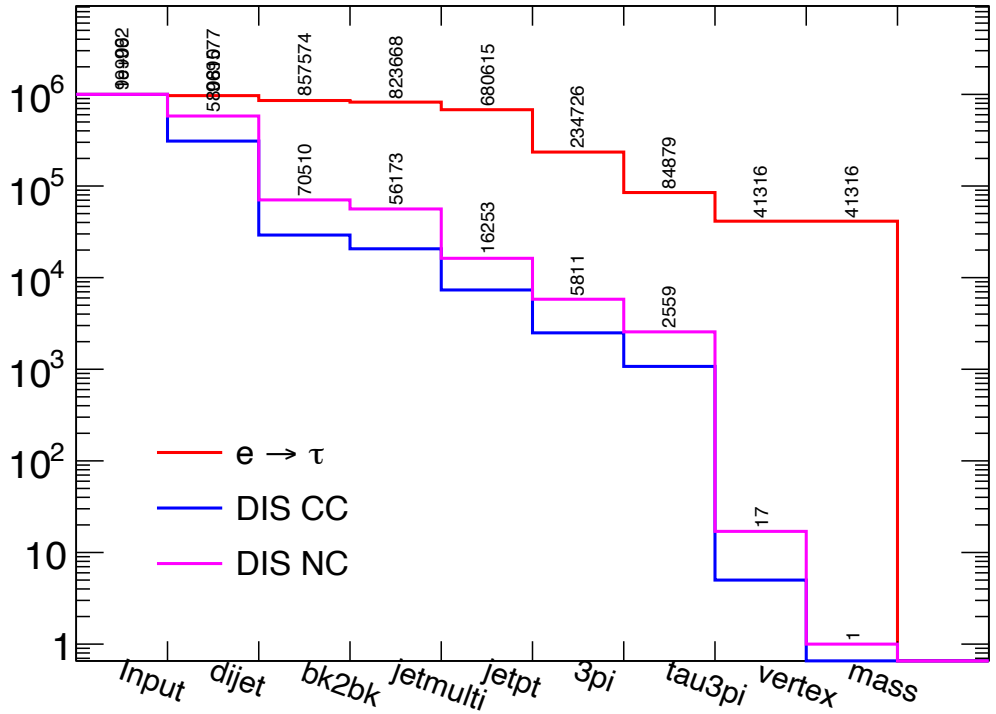
Preliminary Result of three prong





- di-jet: number of jets >= 2
- bk2bk: cos $\Delta\phi_{jet1-jet2}$ < -0.7
- jetmulti: number of particles < 5 for at least one of the jets
- jetpt: pT (1) > 4.0 and pT (2) > 2.5
- 3pi: jet contain 3pi
- tau3pi: 3pi jet aligns with missing pT
- Decay length > 0.2mm
- Corrected mass < 1.8GeV

$$\sqrt{M_{3\pi}^2 + p_{3\pi}^2 sin^2\theta} + p_{3\pi} sin\theta$$

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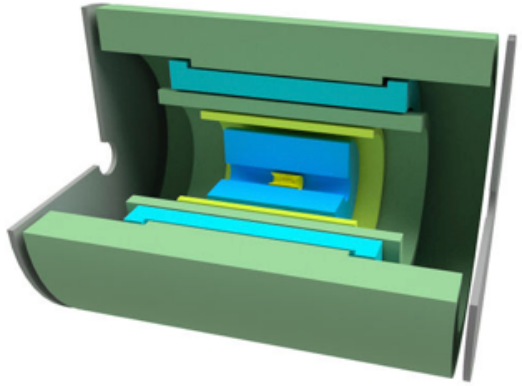
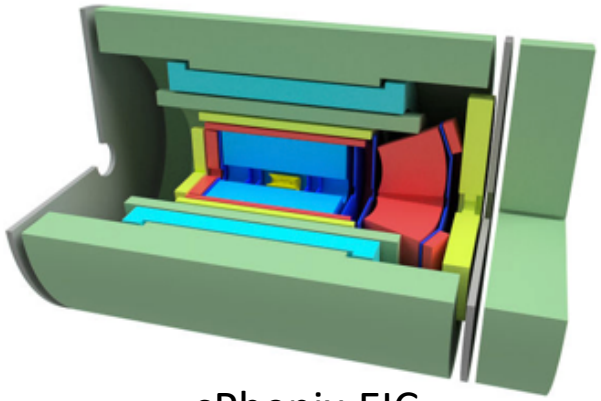
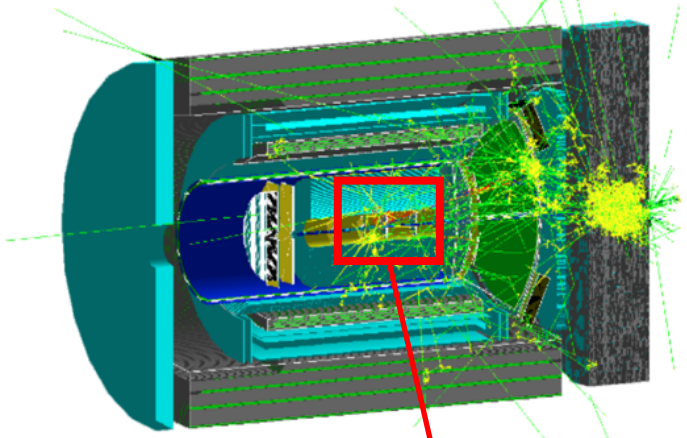
Full detector simulation with sPhenix(-EIC) framework



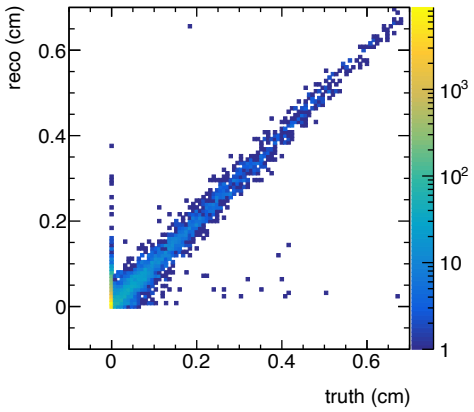
sPHENIX

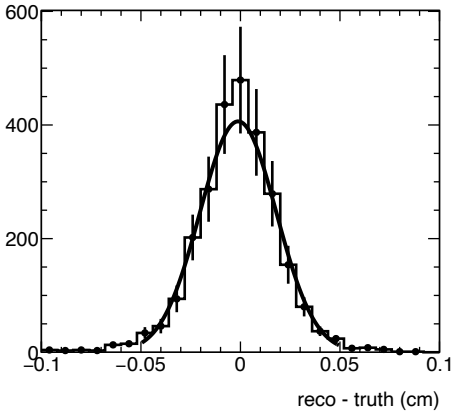


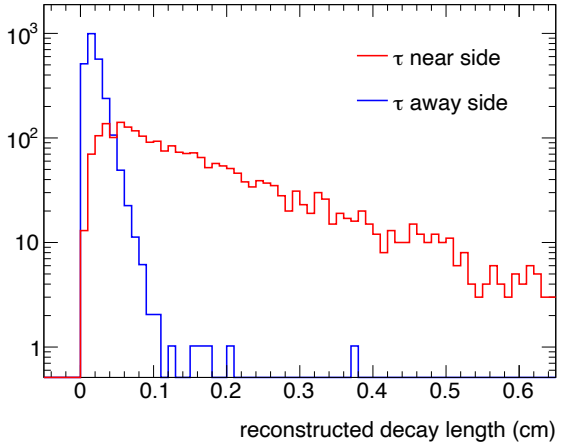
sPhenix-EIC



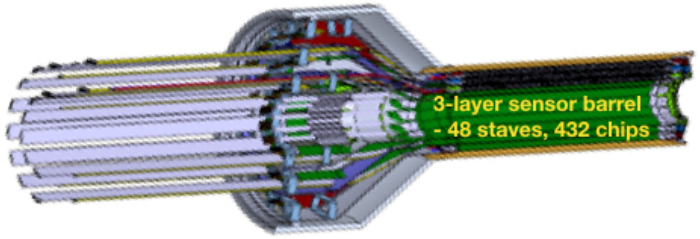
Leptoquark event







MVTX — Monolithic-Active-Pixel-Sensor-based Vertex Detector



Service cone: signal, power, cooling and mechanical support

state-of-the-art vertex detector

~1.4% (**~9.3%** out ~15% 3-prong) signal efficiency from sPHENIX detector simulation

Still a lot to do, but promising

III. Impact Studies of GPD with PARTONS

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PARTONS

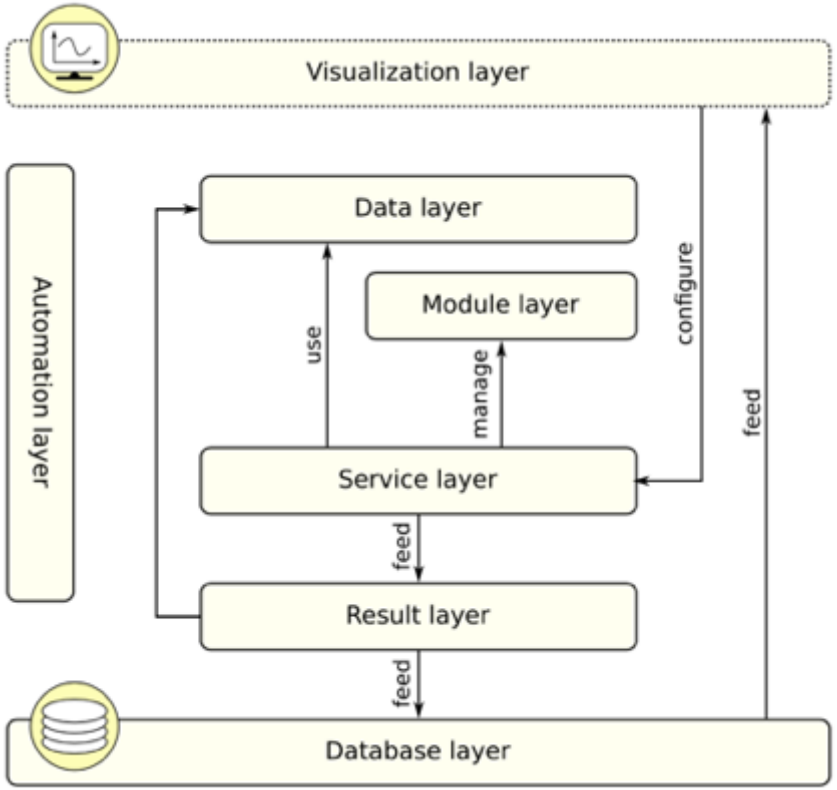
PARtonic **T**omography Of **N**ucleon **S**oftware

- Software framework dedicated to GPD phenomenology
- *Useful* to theorists to develop new models, to phenomenologists to interpret existing measurements, and to experimentalists to design new experiments.

Layered framework, benefiting from the GPD factorization

- One layer = collection of objects designed for common purpose
- One module = one physical development

GPD: GK, VGG, Vinnikov, MPSSW, MMS, HM
Evolution: Vinnikov's code
CFF (DVCS only): LO, NLO (gluons and light (+heavy) quarks)
Cross Section (DVCS only): VGG, BMJ, GV



Berthou et al, Eur. Phys. J. C78 (2018) 478
http://partons.cea.fr

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Status and Perspective

Generic software framework is important for GPD community:

- Global analysis of existing and upcoming data from HERA, JLab, and COMPASS
- **Impact studies and physics program design for EIC**

Current focus:

- Update MILOU CFF grid file with PARTONS
- Study the sensitivity to D-term at EIC

Long term development direction:

- Implementation of TCS and DVMP, demonstration of multi-channel capability
- PARTONS-based MC generator

Summary

Compton polarimeter at JLab:

- DAQ setup and data analysis for ongoing experiments PREX/CREX; -> EIC

Simulation on sensitivity to CLFV: BSM@EIC

- e → τ event searching with generator + full G4 detector

GPD impact study:

- Joined PARTONS collaboration recently; will actively work on in following year

Potential H1 analysis topics in discussion with our local group:

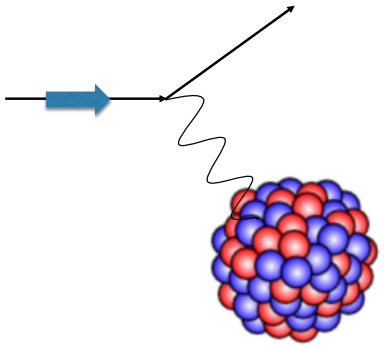
- DVCS, Spin transfer to Lambda in DIS

Publications and talks in 2019:

- *One STAR PA paper published: PRD 99 (2019) 051102(R)*
- *Four invited talks: RHIC&AGS User Meeting2019, HadronChina2019, DNP2019, and LPC LHC-EIC Workshop*

Backup

PREX/CREX



Measurements of neutron radii of 208Pb and 48Ca

- *Clean and model independent*: parity violating electron elastic scattering -> weak form factor -> weak radii -> neutron radii
- *Challenging*: part-per-million level signal with percent level precision
  - Need to control systematics from every possible source;
  - Beam polarization is one of the leading factors;
  - Three types of polarimeters at JLab: Compton, Moller, and Mott.
- My contribution is mainly on Compton polarimeter

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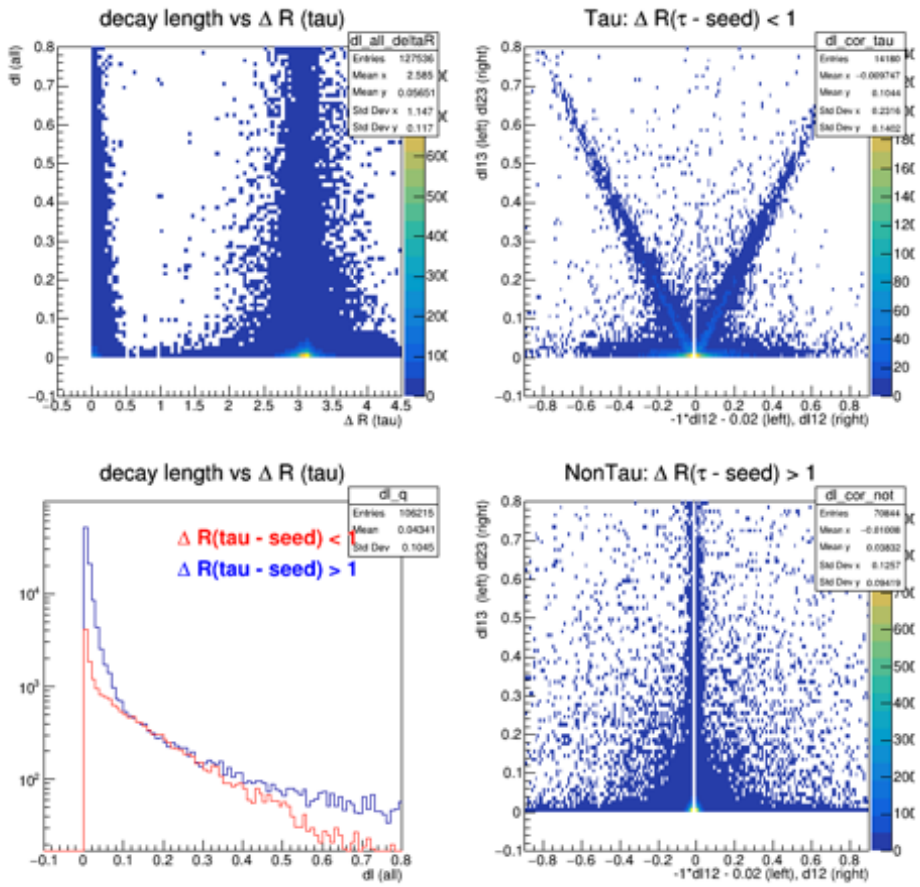
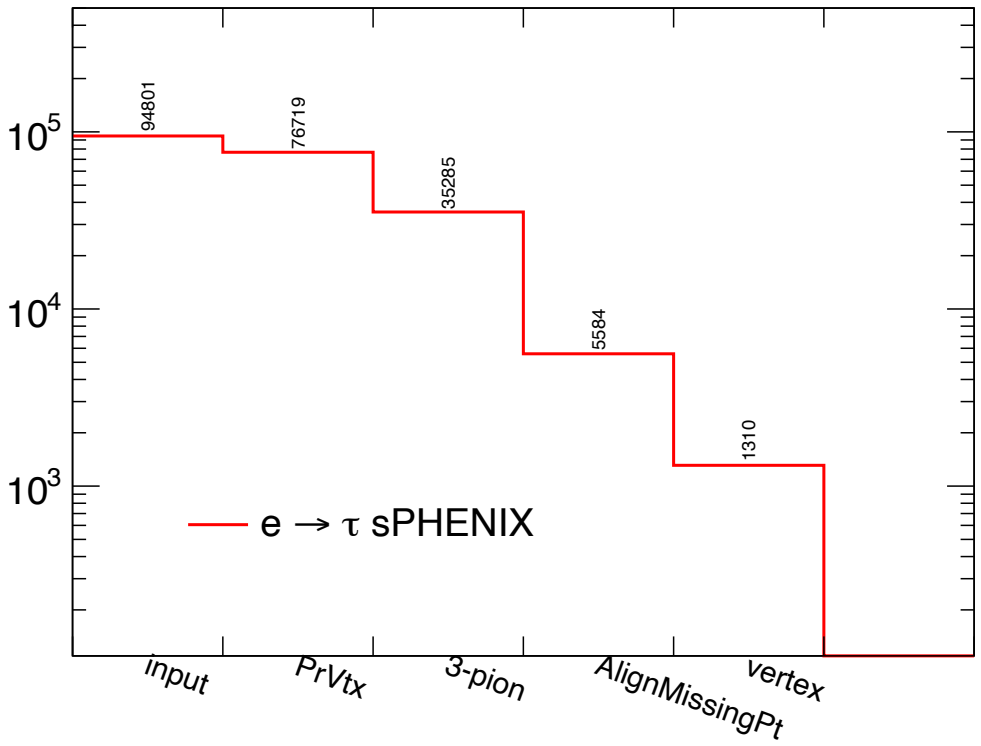
LQ in sPHENIX





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