EW/BSM Physics Working Group Update

Yulia Furletova, Ciprian Gal, Sonny Mantry, Xiaochao Zheng

Main page
Collaboration Info

Detector
Tracking
Cherenkov PID
TOF PID
Calorimetry
Far Forward
Far Backward
Experimental Solenoid

Physics
Inclusive
SIDIS
Exclusive, Diffraction and Tagging
BSM&Precision EW
Jets/HF

Integration
Global Detector/Integration

DAQ
Main DAQ Page

Software
Simulation

BSMEW

Working group meetings

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will be held every 2 weeks on Tue at 9AM (NY time). The indico page for these meetings is:
https://indico.bnl.gov/category/421/
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Working Group Conveners:

- Xiaochao Zheng: xiaochao@jlab.org
- Sonny Mantry: Sonny.Mantry@ung.edu
- Yulia Furletova: yulia@jlab.org
- Ciprian Gal: ciprian@jlab.org

Physics topics:

CLFV search

Weak mixing angle

Dark Z_d effect on weak mixing angle

Dark Photon

Leptophobic Z'

SMEFT analysis

CC DIS W_R

CC DIS s to c

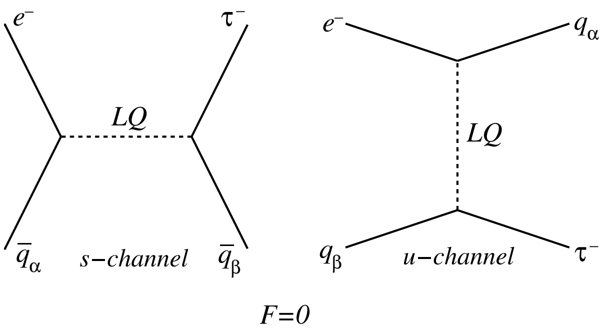
NC structure functions from unpolarized and polarized cross sections

Exotic decays

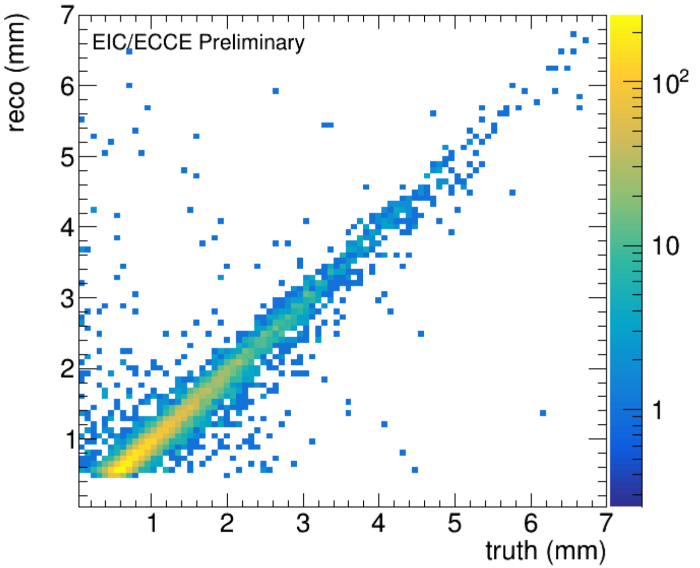
EW/BSM Physics Working Group To do List

1. CLFV(1,3) search:
   - build upon existing work, adding one-prong channel, detector-based PID, and high statistics for background study
   - *leptoquarks*, axion-like particles (?)
   - good vertex reconstruction – collaborating with tracking and HF WGs
2. Projection for weak mixing angle (NC DIS), expanding theory projections
   - dark Z_d, dark photon, leptophobic Z', and SMEFT analysis
   - generator with fast smearing (electron ID, acceptance, photoprod background, Inclusive PWG)
   - unfolding precision?
3. CC DIS – longitudinally polarized hadron asymmetry, flavor separation of helicity PDFs
   - JB method of kinematics reconstruction – (with jet/HF, incl, and SIDIS PWG)
   - longitudinally polarized hadron asymmetry, flavor separation of helicity PDFs
   - W_R boson study
4. NC structure function: $F_1^{\gamma Z}$, $g_1^{\gamma Z}$ (but probably not $F_3^{\gamma Z}$ and $g_4^{\gamma Z}$)
5. Rare decays – with other PWGs

CLFV(1,3) (e→ τ transition)



- **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



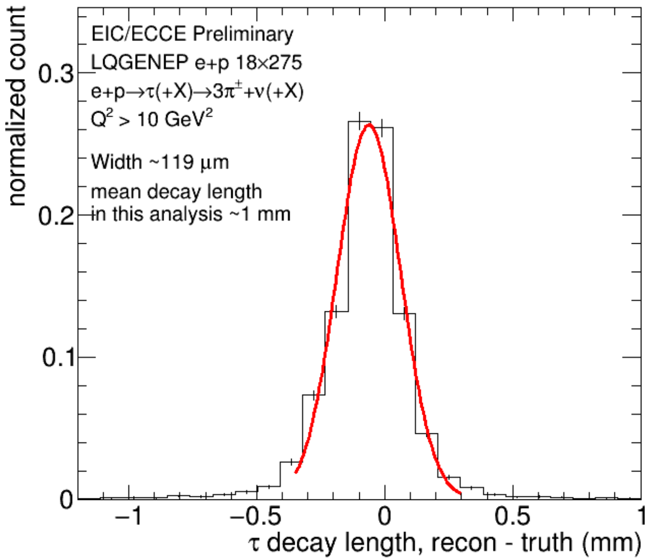
Tau decay mode and branching ratio

- **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%

- Existing study based on ECCE detector design
  - ➔ 3-prong mode only
  - ➔ vertex resolution important
  - ➔ limited by background statistics

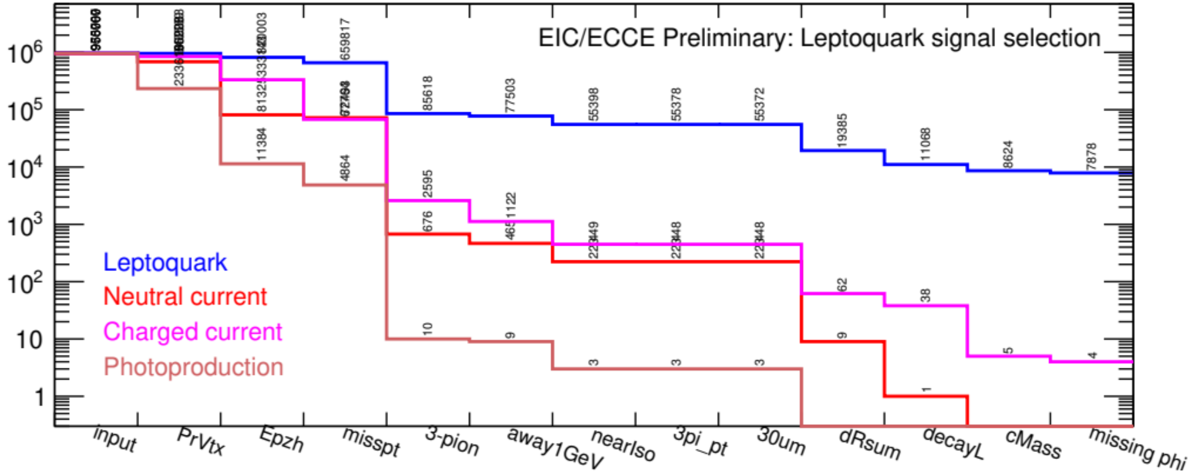
  https://arxiv.org/abs/2207.10261

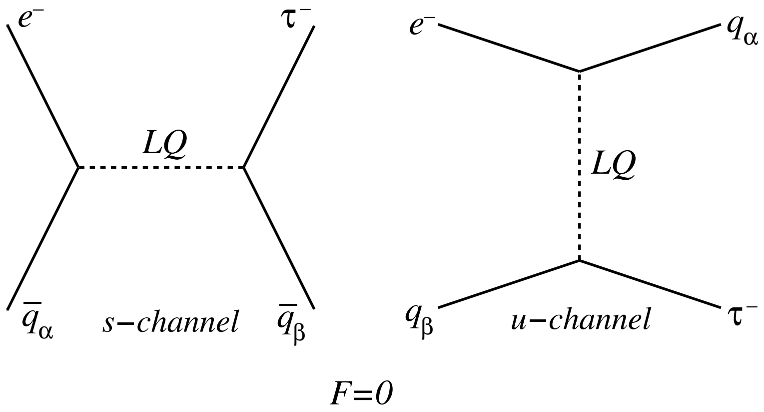
- migrating to Det#1

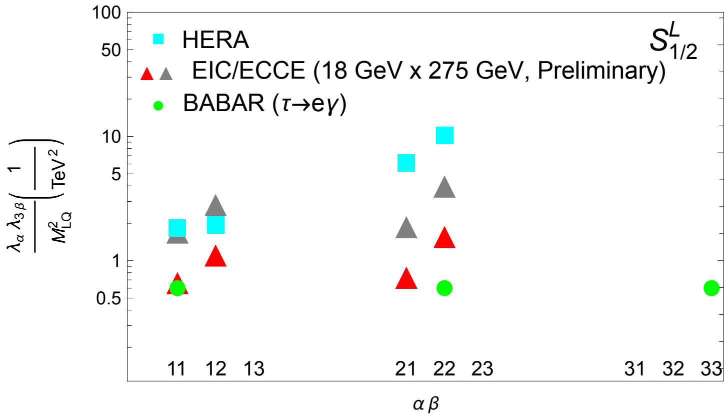


CLFV(1,3) ($e\to\tau$ transition)

https://arxiv.org/abs/2207.10261







Working on:

- reproducing 3-prong analysis with Det #1
- adding 1-prong analysis
- higher statistics NC and photoproduction backgrounds

(red: assuming no NC and photoproduction background)

Neutral Current Electroweak Physics and SMEFT Studies at the EIC

https://arxiv.org/abs/1612.06927

https://arxiv.org/abs/2204.07557

DIS cross sections: $d\sigma = d\sigma_0 + P_e d\sigma_e + P_H d\sigma_H + P_e P_H d\sigma_{eH}$

Parity-Violating asymmetries:

$$A_{PV}^{(e)} \equiv \frac{d\sigma_e}{d\sigma_0} \qquad A_{PV}^{(H)} \equiv \frac{d\sigma_H}{d\sigma_0}$$

Double-spin asymmetries:

$$A_{PV}^{(eH)} \equiv \frac{d\sigma_{eH}}{d\sigma_0}$$

Lepton-charge asymmetries:

$$A_{LC,H} \equiv \frac{d\sigma_0^{e+} - d\sigma_0^{e-}}{d\sigma_0^{e+} + d\sigma_0^{e-}}$$

("complete" DIS xsection derivation in progress)

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

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

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

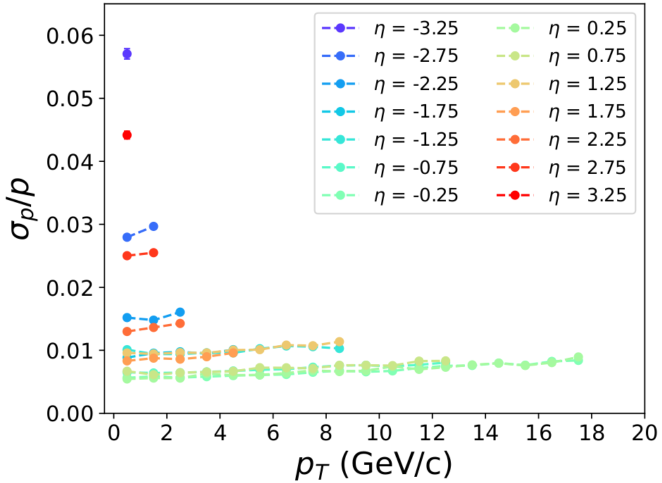
$$\frac{d^2\sigma_{eH}}{dxdy} = \frac{4\pi\alpha^2}{xyQ^2}\Big\{(2-y)\,xy\left[g_1^\gamma - g_V^e\eta_{\gamma Z}g_1^{\gamma Z} + (g_V^{e\,2} + g_A^{e\,2})\eta_Z g_1^Z\right] - (1-y)\left[g_A^e\eta_{\gamma Z}g_4^{\gamma Z} - 2g_V^e g_A^e\eta_Z g_4^Z\right] + xy^2\left[g_A^e\eta_{\gamma Z}g_5^{\gamma Z}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

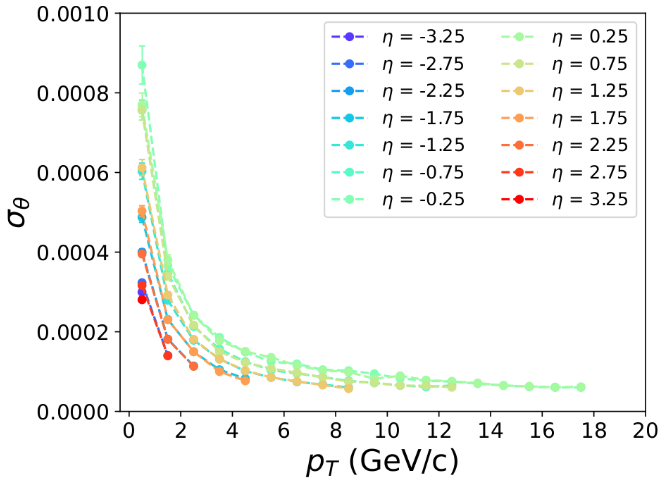
Existing Work using ECCE

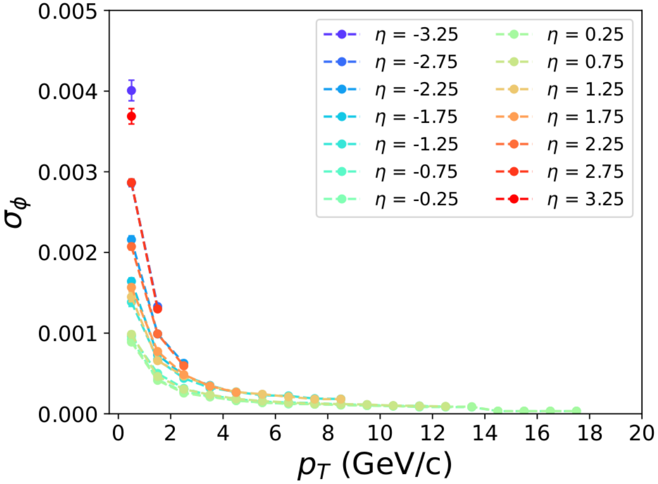
https://arxiv.org/abs/2204.07557

Simulation:

- Djangoh 4.6.16 combined with fast smearing from single-electron gun simulation
- Modified user routine of Djangoh to calculate counts and size of Apv
- Events unfolded to leptonic truth using R-matrix inversion method
- 20M events per energy/beam setting





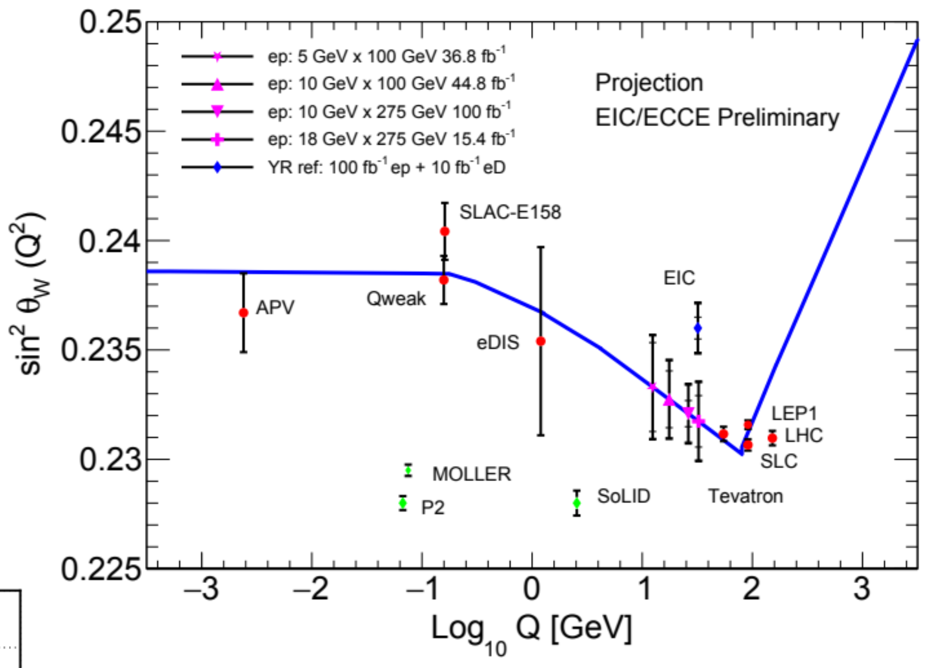


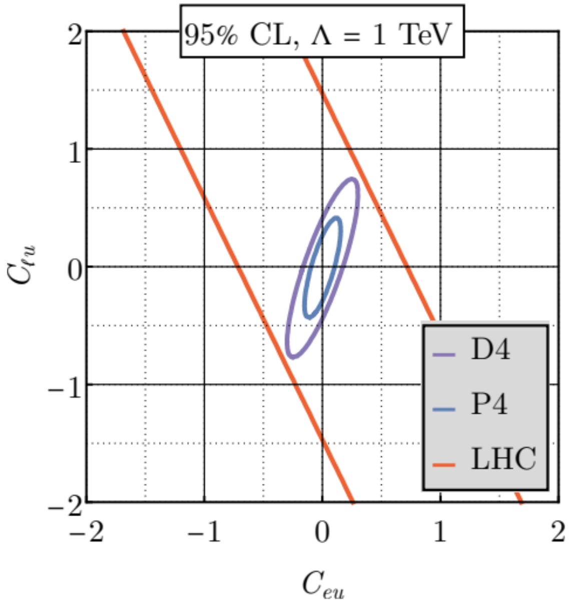
Existing Work using ECCE

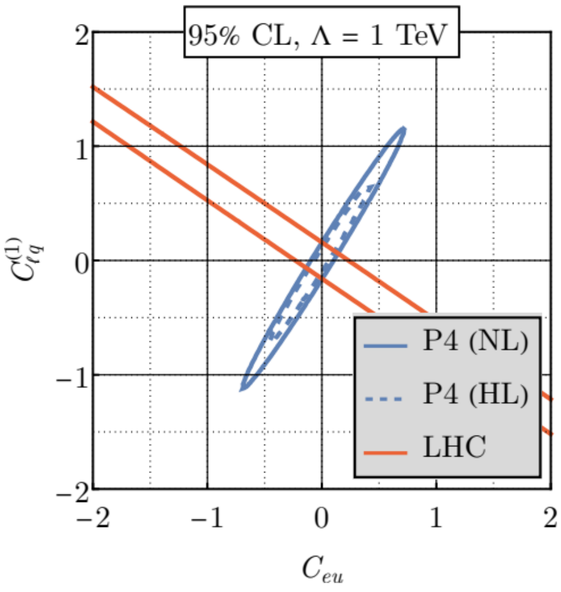
Analysis:

- Fitting weak mixing angle using Apv(e)
- 2D Wilson coefficient fits

https://arxiv.org/abs/2204.07557







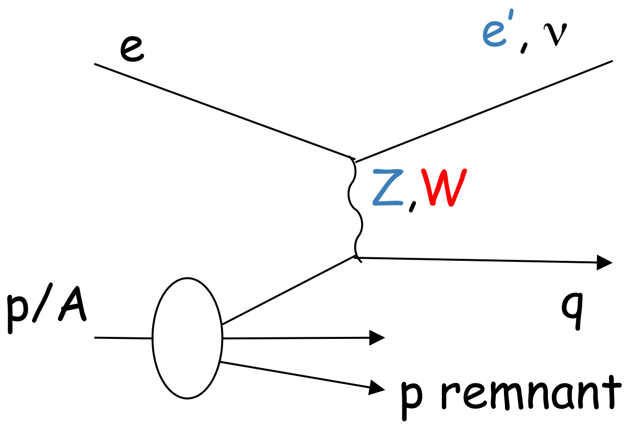
For Detector #1:

- Single-electron gun/fast smearing available
- Need looking into unfolding uncertainty

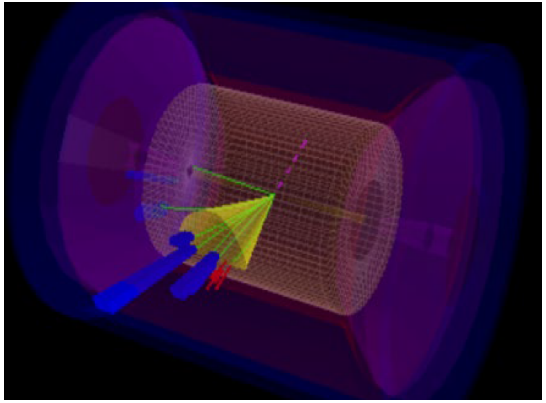
Charged Current at EIC

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

CFNS Annual Review (2 Feb 2021)



- Explore the high-x frontier
- flavor separation

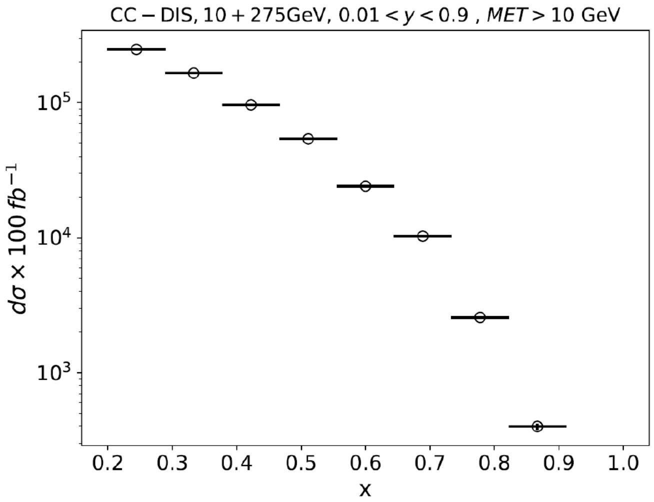


NC background rejection: need 4pi coverage for HCAL

Jacquet-Blondel method for kinematic reconstruction

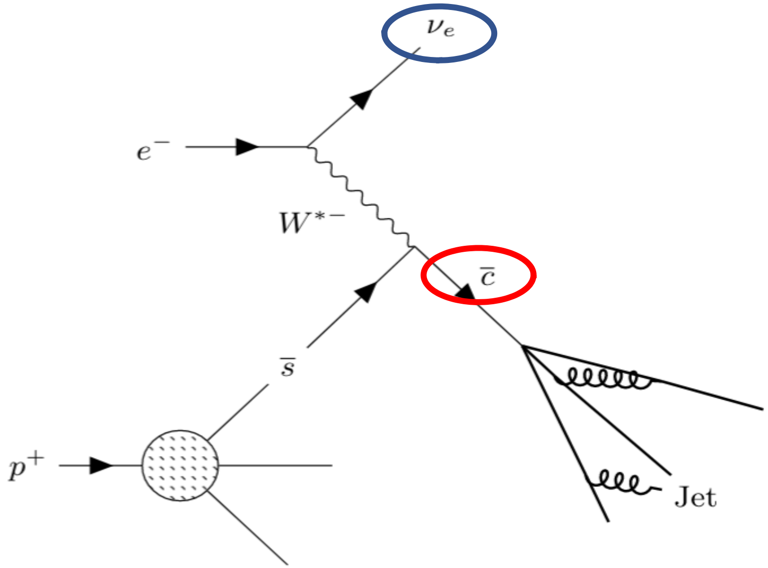
$$Q^2_{JB} = \frac{p_T^2}{1-y_{JB}} \qquad y_{JB} = \frac{(E-p^z)}{2E} \qquad x_{JB} = \frac{Q^2_{JB}}{s y_{JB}}$$

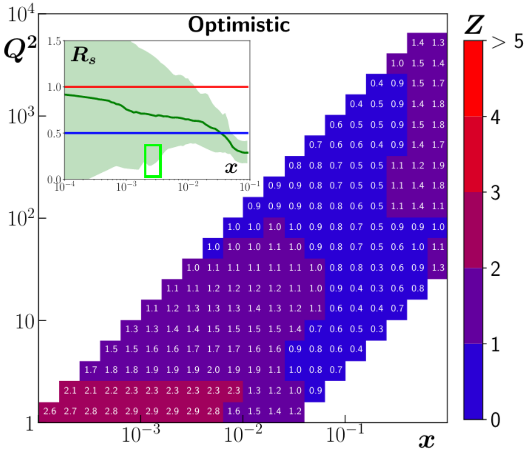
where $p_T^2 = (\sum_h P_h^x)^2 + (\sum_h P_h^y)^2$ and $(E-p^z) = \sum_h (E_h - p_h^z)$

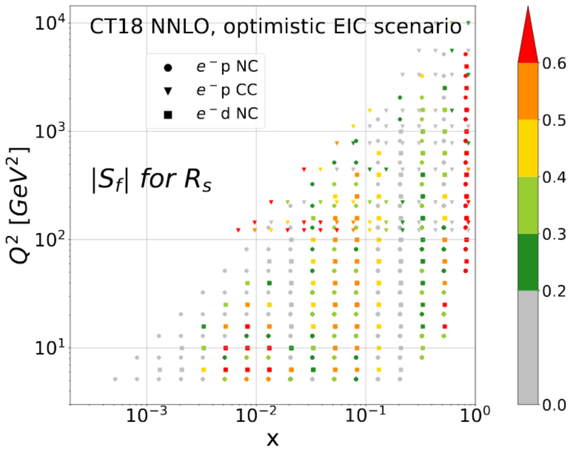


Charm as probe for strangeness in CC

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







Charm jets as a probe for strangeness at the future Electron-Ion Collider

Authors: Miguel Arratia, Yulia Furletova, T. J. Hobbs, Fredrick Olness, Stephen J. Sekula

$$R_S = \frac{s+\bar{s}}{\bar{u}+\bar{d}}$$

Phys. Rev. D **103**, 074023 – Published 29 April 2021
10.1103/PhysRevD.103.074023

Need to re-do analysis with Det-1

Chiral Structure of CC Physics

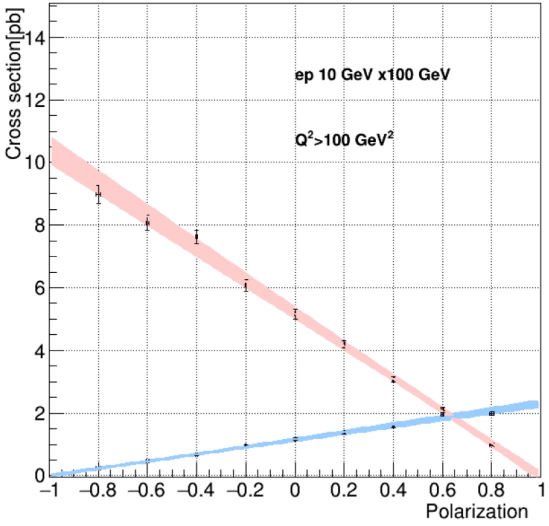
- Clear linear dependence:

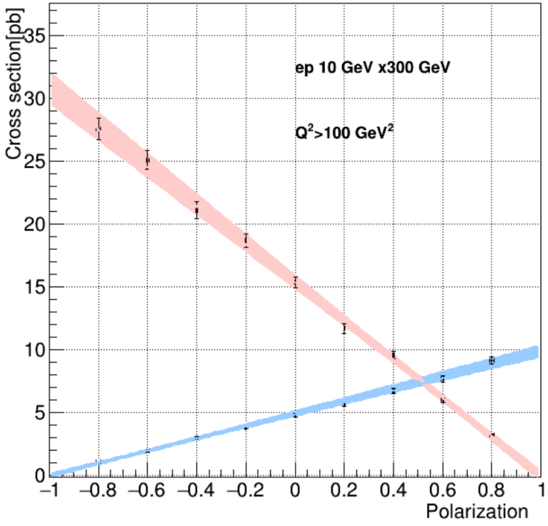
$$\sigma_{CC}^{e^{\pm}p}(P_e) = (1 \pm P_e) \cdot \sigma_{CC}^{e^{\pm}p}(P_e = 0)$$

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

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

Extrapolation to P=±1 → limits on W_R





https://doi.org/10.1063/1.5040210

Simulation

1. LQGENEP
2. Dark-photon
3. Pythia,Herwiq Djangoh for NC/CC
4. Single-particle gun for fast smearing, combine with Djangoh

Request was sent to Simulation WG.

Summary

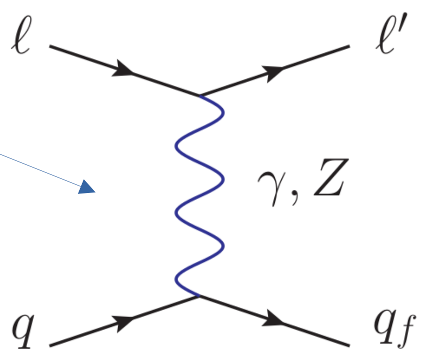
- Limited person-power for this WG
- Focusing on the main topics but planning to extend to other topics
- Simulation is ongoing (request sent to Sim/Comp WG)
- We welcome all scientists/students who are interested in BSM topic
- Please subscribe to our mailing list

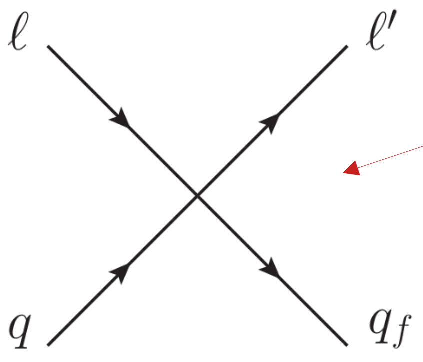
  https://lists.bnl.gov/mailman/listinfo/eic-projdet-bsmew-l
- Meetings every other Tuesday at 9am ET

  https://indico.bnl.gov/category/421/

Neutral Current Electroweak Physics and SMEFT Studies at the EIC

SM (one-boson exchange)





SMEFT

("effective" dimension-6 operators)

$$\mathcal{L}_{\mathrm{SMEFT}} = \frac{1}{\Lambda^2}\sum_r C_r \mathcal{O}_r + \cdots$$

Note: all Lagragians should be dimension-4

To facilitate communication, we also "translated" all SMEFT operators to the language of hadronic tensor and structure functions

$$\mathcal{L}_{\mathrm{SMEFT}} = \frac{1}{\Lambda^2}\sum_r \tilde{C}_r\Big\{\sum_f \bar{e}\gamma^\mu(c^e_{V_r} - c^e_{A_r}\gamma_5)e\,\bar{q}_f\gamma^\mu(c^f_{V_r} - c^f_{A_r}\gamma_5)q_f\Big\} + \cdots,$$

$$\frac{d^2\sigma}{dxdy} = \frac{2\pi y\alpha^2}{Q^4}L^\gamma_{\mu\nu}\Big\{\eta^\gamma W^{\mu\nu}_\gamma - \eta^{\gamma Z}(g^e_V - \lambda_e g^e_A)W^{\mu\nu}_{\gamma Z} + \eta^Z(g^e_V - \lambda_e g^e_A)^2 W^{\mu\nu}_Z$$
$$-\sum_r \xi^{\gamma r}(c^e_{V_r} - \lambda_e c^e_{A_r})W^{\mu\nu}_{\gamma r} + \sum_r \xi^{Zr}(c^e_{V_r} - \lambda_e c^e_{A_r})(g^e_V - \lambda_e g^e_A)W^{\mu\nu}_{Zr}\Big\}.$$

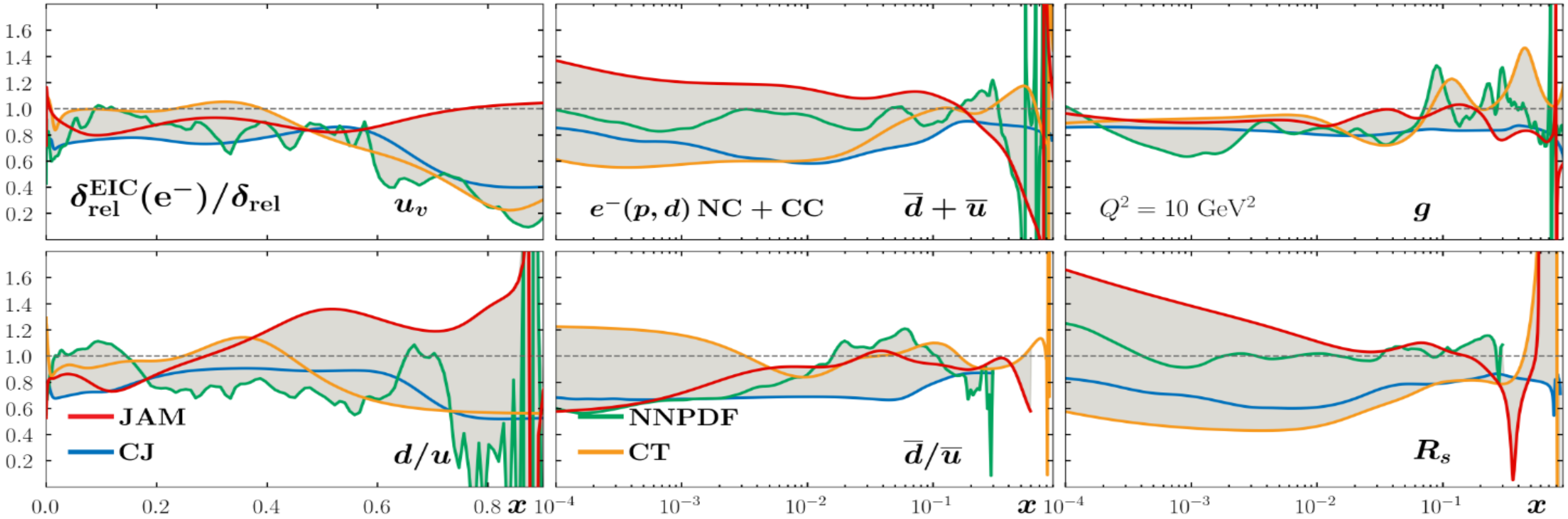
PDF fits

Timothy Hobbs

CFNS Annual Review (2 Feb 2021)

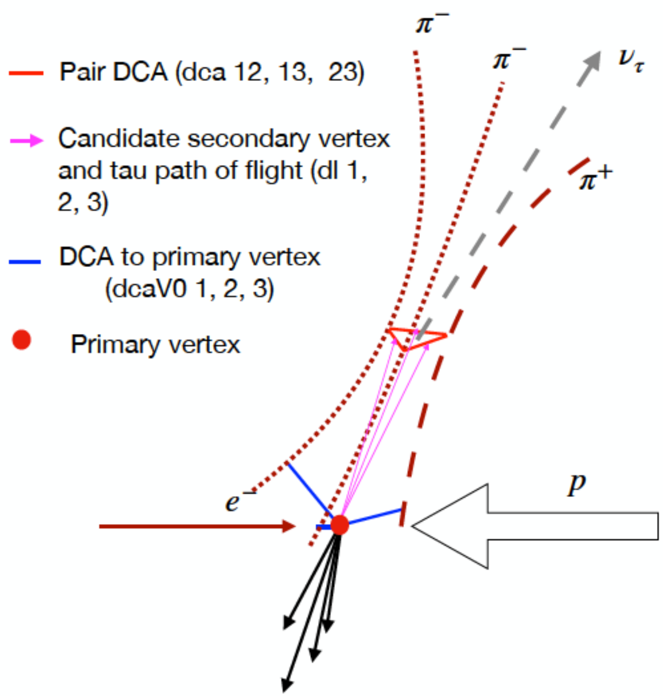
Our knowledge of unpolarized collinear parton distribution functions (PDFs) driven by inclusive neutral current (NC) and charged current (CC) deep inelastic scattering(DIS) cross section.

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

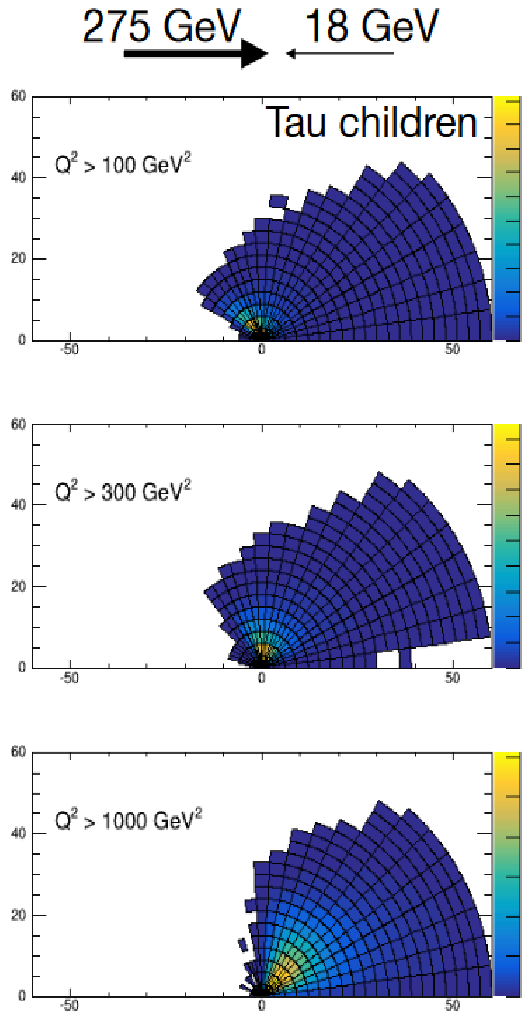


100 fb-1 ~ 28.6, 44.7, 63.3, 140.7 GeV for NC and 140.7 GeV for CC
and deuteron beams L= 10fb−1 and consider only NC at √s= 28.6, 66.3, 89.0 GeV

CLFV: e to tau (leptoquarks)

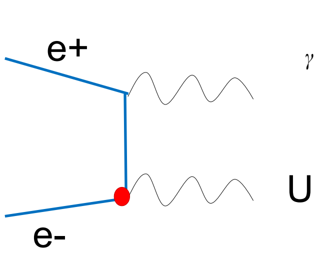


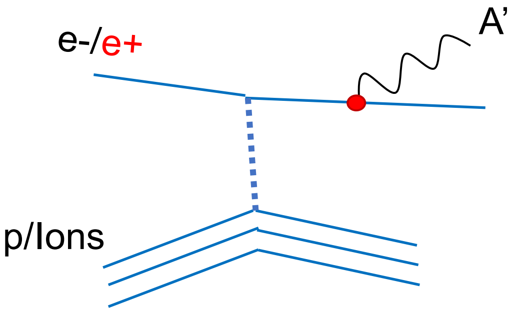
- Assumes hadron calorimetry in the central barrel
- 1-prong analysis is actively being worked on and should have results by January workshop



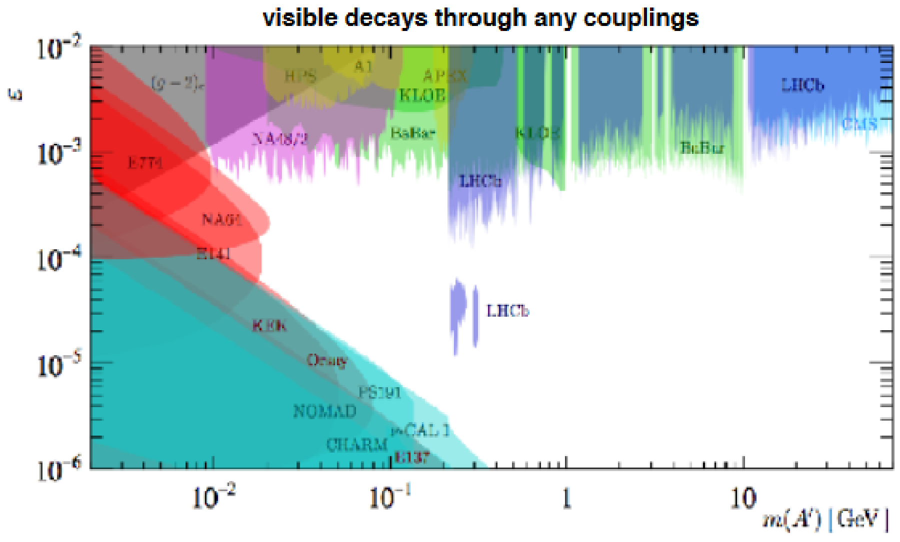
Angle for theta, radius for momentum

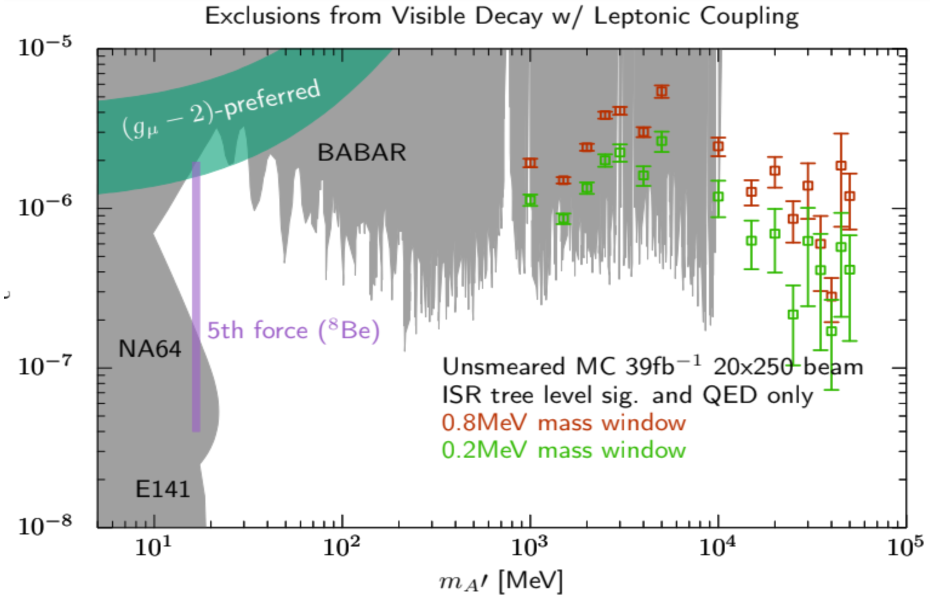
Dark Photon Searches



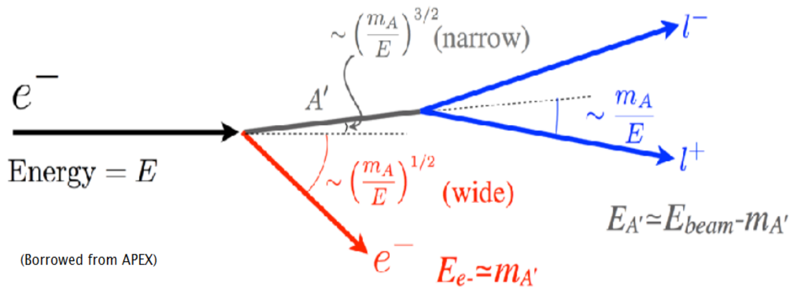


- Dark Photon (U,A'): new mediator to a sector of Dark Matter particles (MeV-GeV mass)
- Weakly coupled to Standard Model through kinetic mixing with ordinary photon → production in e^+e^- annihilation.
- A' can be probed with $e^{+/-}$ p(Ions) (e.g. target experiments PADME at LNF, Adv. High Energy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

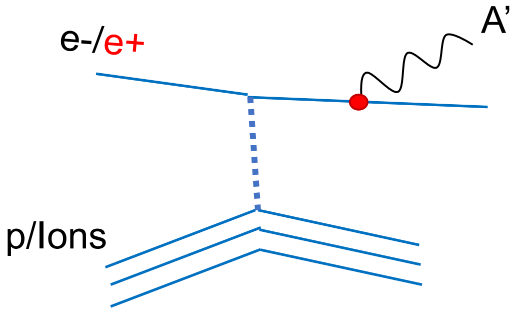


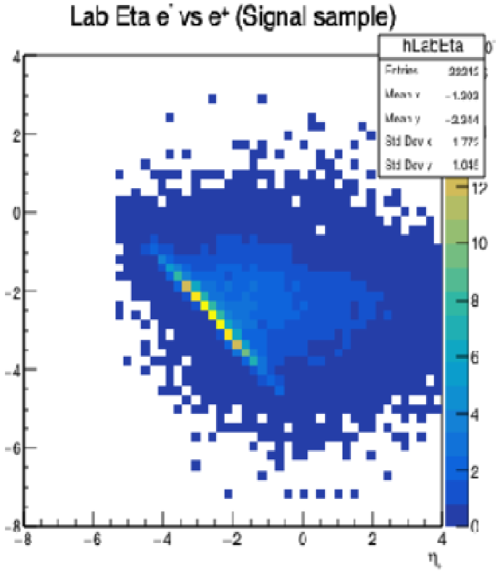


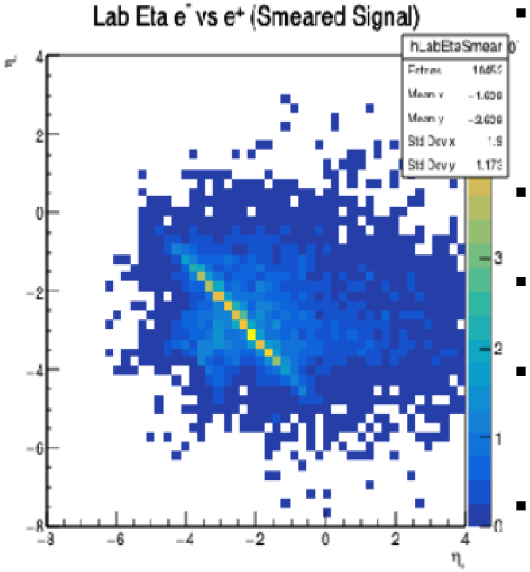
Dark Photon Searches



(Borrowed from APEX)







- 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
  - Handbook detector used for initial smearing studies
- 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
- Ross discussed with Stefan Prestel about moving event generation from madgraph to pythia and they plan to have analysis ready by January workshop