Opportunities in Electroweak Physics and **Beyond** at a future Electron Ion Collider (EIC)

1. Why an Electron Ion Collider?

Mainly for QCD studies (see: **arXiv:1108.1713 & arXiv:1212.1701**)

2. EIC Machine Concepts

Two options under consideration: at BNL using RHIC and at Jefferson Lab using the 12 GeV upgraded CEBAF

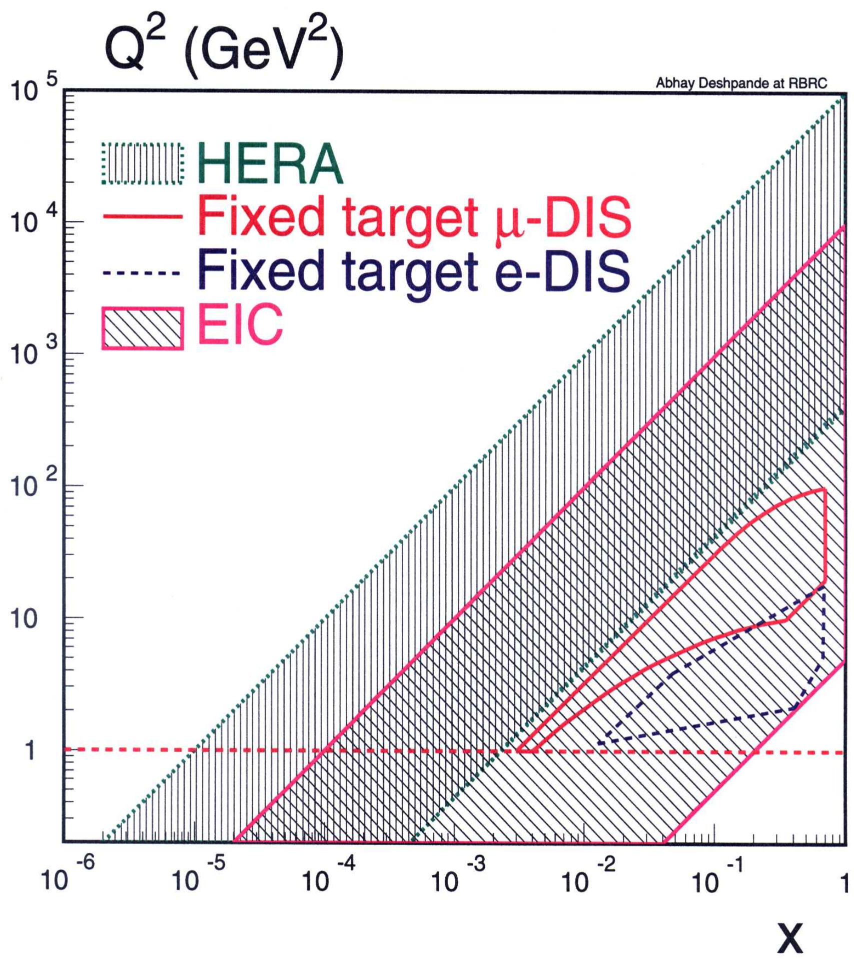
*3. **Ideas & preliminary studies of possibilities of EW, BSM Physics at the EIC***

High luminosity, and full acceptance modern detector may allow in addition, studies of physics beyond Standard Model

Stony Brook University

Abhay Deshpande

EIC: Basic Parameters

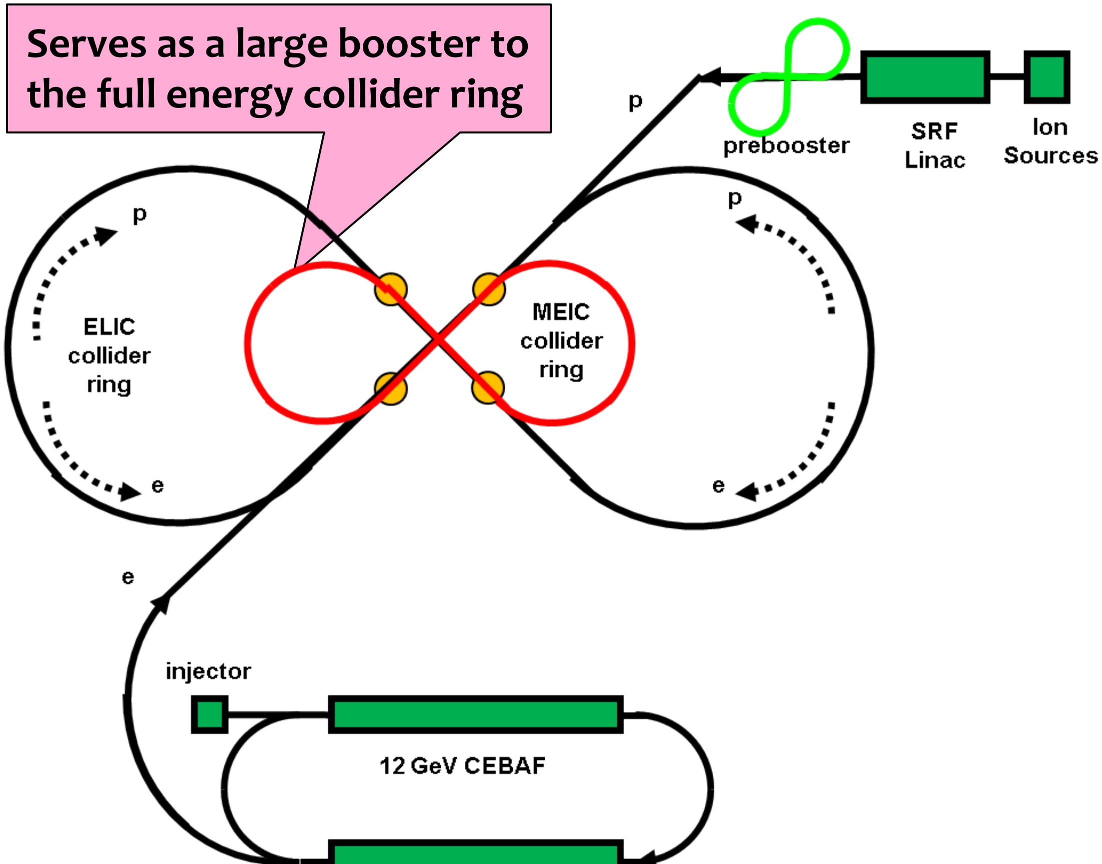


- E_e=10 GeV (5-30 GeV variable)
- E_p=250 GeV (50-325 GeV Variable)
- Sqrt(S_{ep}) = 100 (30-200) GeV
- $X_{min} = 10^{-4}$; $Q^2_{max} = 10^4$ GeV
- Beam pol. ~ 70% for e,p,D,^{3}He
- Luminosity $L_{ep} = 10^{33\text{-}34}$ cm^{-2}s^{-1}
- Minimum Integrated luminosity:
  - 50 fb^{-1} in 10 yrs (100 x HERA)
  - Possible with 10^{33} cm^{-2}s^{-1}
  - Recent projections *much higher*

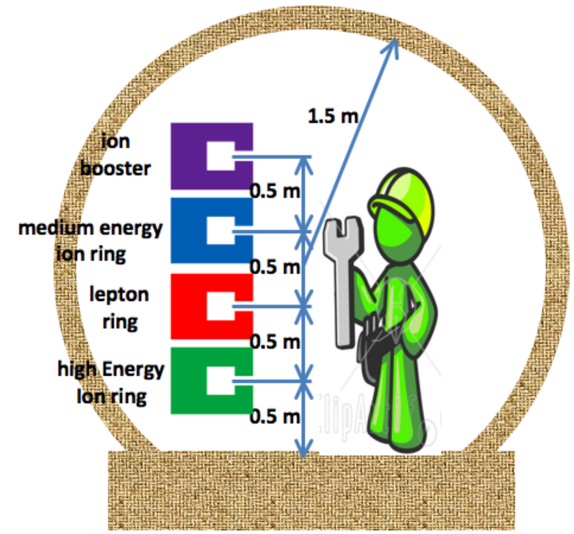
Nuclei:

- **p->U; E_A=20-100 (140) GeV/N**
- **Sqrt(S_{eA}) = 12-63 (75) GeV**
- **L_{eA}/N = 10^{33} cm^{-2}s^{-1}**

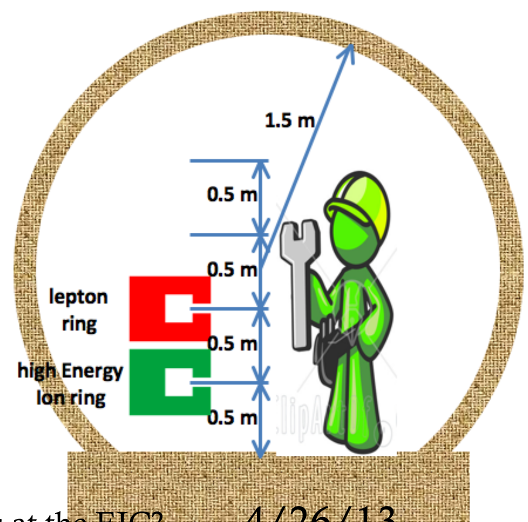
ELIC: High Energy & Staging



Straight section



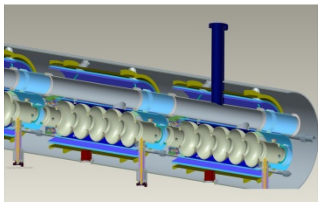
Arc

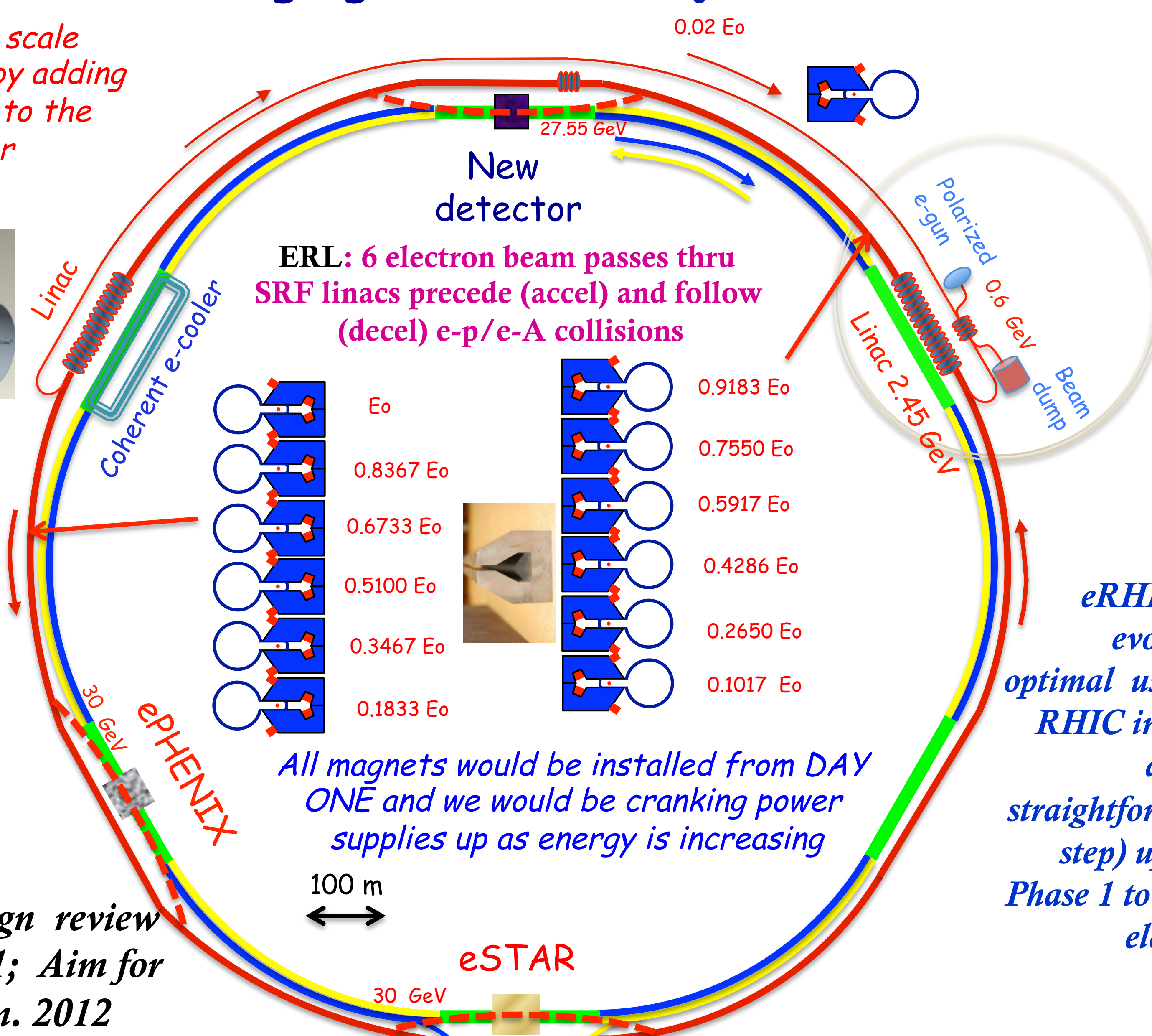


Stage	Max. Energy (GeV/c)		Ring Size (m)	Ring Type		IP #
	p	e		p	e	
Medium	96	11	1000	Cold	Warm	3
High	250	20	2500	Cold	Warm	4

Staging of eRHIC: E_o : 5 -> 30 GeV

All energies scale proportionally by adding SRF cavities to the injector





E/Eo
0.0200
0.1017
0.1833
0.2650
0.3467
0.4283
0.5100
0.5917
0.6733
0.7550
0.8367
0.9183
1.0000

eRHIC design has evolved to make optimal use of existing RHIC infrastructure, and to permit straightforward (multi-step) upgrades from Phase 1 to eventual full electron energy

Technical design review Aug. 1-3, 2011; Aim for cost review Jan. 2012

Electroweak & beyond….(?)

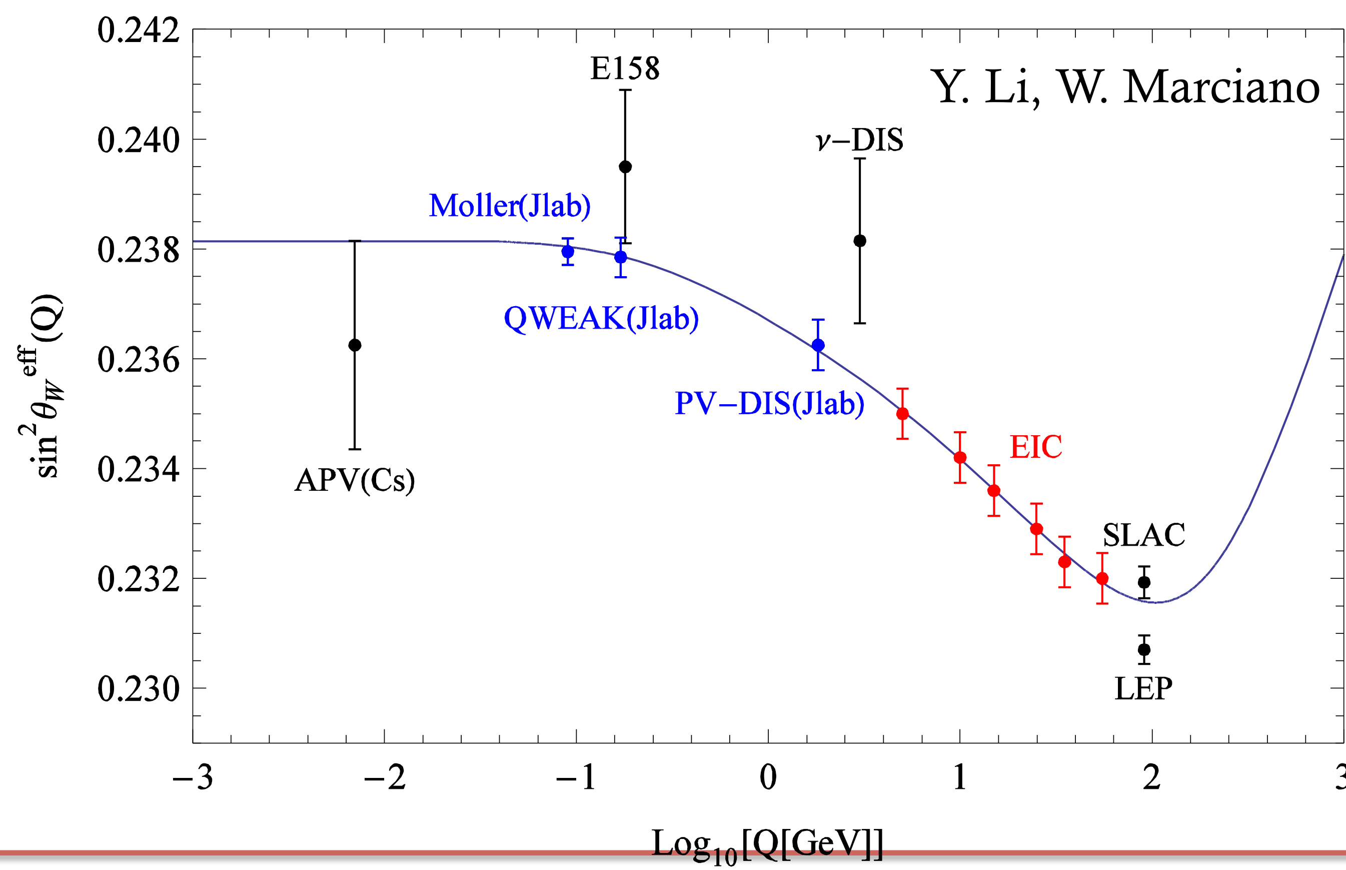
A. Deshpande, W. Marciano, K. Kumar & W. Vogelsang

- High energy collisions of polarized electrons and protons and nuclei afford a unique opportunity to study electro-weak deep inelastic scattering
  - **Electroweak structure functions (including spin)**
  - Significant contributions from W and Z bosons which have different couplings with ***quarks and anti-quarks***
- **Parity violating DIS**: a probe of beyond TeV scale physics
  - Measurements at higher Q^2 than the PV DIS 12 GeV at Jlab
  - Precision measurement of $\mathrm{Sin}^2\Theta_W$
- **New window for physics beyond SM?**
  - Lepton flavor violation search $e^- + p \to \tau^- + X$

arXiv: 006.5063v1 [hep-ph]
M. Gonderinger et al.

$Sin^2\Theta_W$ with the EIC

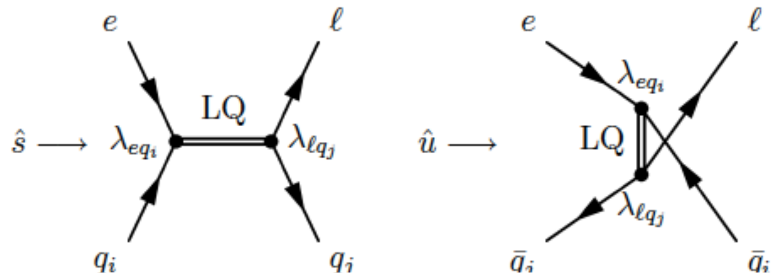
- Deviation from the "curve" may be hints of BSM scenarios including: Lepto-Quarks, RPV SUSY extensions, E_6/Z' based extensions of the SM



Opportunity for EIC

- Limits on **LFV(1,3)** experimental searches are significantly worse than those for LFV(1,2)
- Especially if there are BSM models which specifically allow and enhance LFV(1,3) over LFV(1,2)
  - Minimal Super-symmetric Seesaw model
    - J. Ellis et al. Phys. Rev. D66 115013 (2002)
  - SU(5) GUT with leptoquarks
    - I. Dorsner et al., Nucl. Phys. B723 53 (2005)
    - P. Fileviez Perez et al., Nucl. Phys. B819 139 (2009)
- M. Gonderinger & M.Ramsey Musolf, JHEP 1011 (045) (2010); arXive: 1006.5063 [hep-ph]
  - 10 fb^{-1} e-p luminosity @ 90 GeV CM would have potential
  - Detector & analysis efficiencies assumed 100%
  - HERA experience: effective efficiencies 5-15%
  - *See: H1 Collaboration, F. D. Aaron et al., Phys. Lett. B 701 20 (2011)*
- Clearly there is an opportunity for EIC: "icing on the cake"

LFV phenomenology



$$\frac{d^2\sigma_s}{dxdy} = \underbrace{\frac{1}{32\pi\hat{s}}}_{\text{phase space}} \cdot \underbrace{\frac{\lambda_{eq}^2\lambda_{\ell q}^2\hat{s}^2}{(\hat{s}^2 - m_{\rm LQ}^2)^2 + m_{\rm LQ}^2\Gamma_{\rm LQ}^2}}_{\text{Breit-Wigner LQ propagator term}} \cdot \underbrace{q_i(x,\hat{s})}_{\text{parton density}} \times \begin{cases} \frac{1}{2} & \text{scalar LQ} \\ 2(1-y)^2 & \text{vector LQ} \end{cases}$$

- Leptoquark (LQ) event topologies studied with:
  - LFV MC generator: LQGENEP (L. Bellagamba, Comp. Phys. Comm. 141, 83 (2001)
  - LQ generator for e-p processes using BRW effective model
- In this study to increase efficiency: BW-LO propagator replaced with a constant.
  - m_{LQ} = 200 GeV, λ = 0.3 (for example one particular LQ…)
  - **Then go over various values of M_{LQ} i.e. ratios: $z = \lambda i \lambda j / M_{LQ}^2$**
- τ has a clean characteristic decay signature:
  - 3π decay in a **narrow pencil like jet**
  - Leptonic decays with neutrinos (missing momentum) with **different angular correlations** in SM vs. LQ

MC generator level studies…. So far

- **Standard model backgrounds generated**: Neutral & Charged current DIS, photo-production, lepton-pair production & W production…. *Compare event topologies* with the LQ events

- τ has a clean signature: Analyses similar to those performed for such analyses in H1 and ZEUS analyses at HERA: **Indicates that reliable dentification of Tau is certainly possible both for**
  – Leptonic Decays of τ
  – Hadronic Decays: Narrow "pencil" like jets with 1-3 pions

- Very clear differences in topologies of SM and LQ events established. GEANT detector simulations now underway.

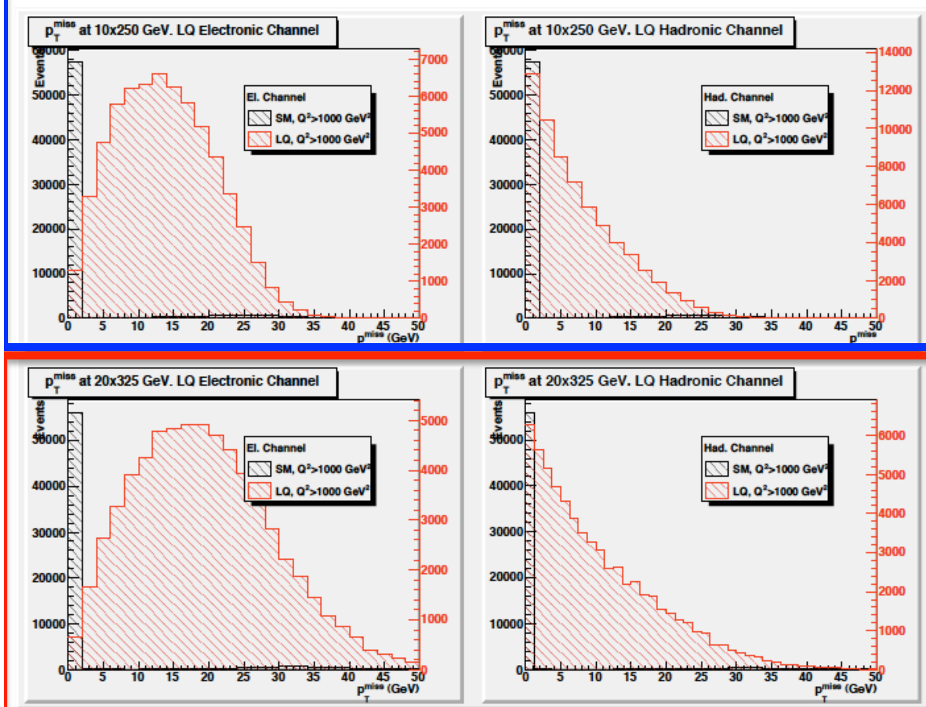
C. Faroughy (UG Research Project),
+S. Teneja & AD

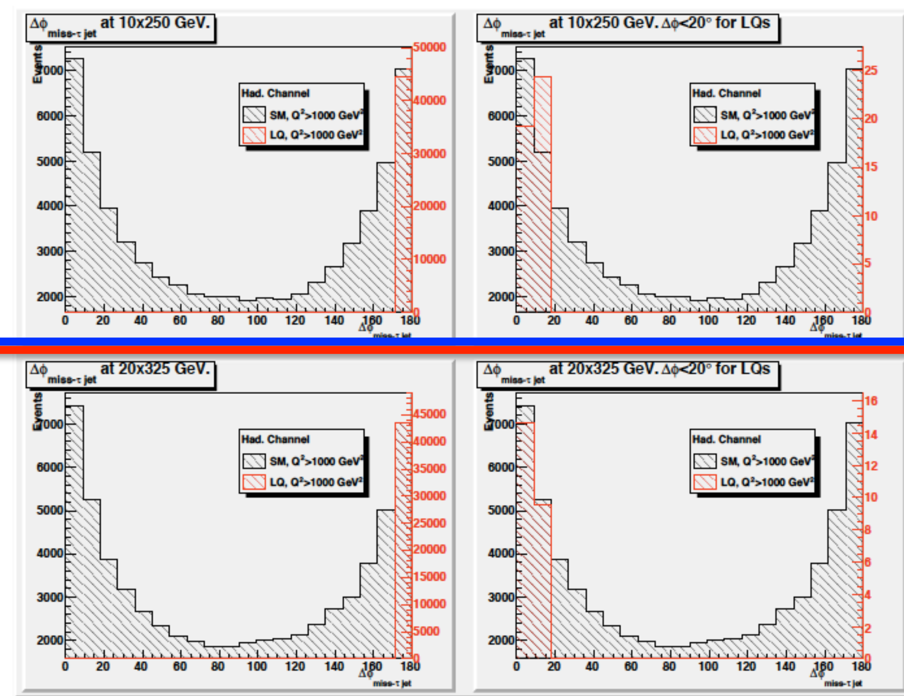
SM vs. LPQ

$$p_T^{miss} = \sqrt{(\sum P_{x,i})^2 + (\sum P_{y,i})^2}$$

Acoplanarity: $\Delta\phi_{miss}$-τ_{jet}

10 x 250

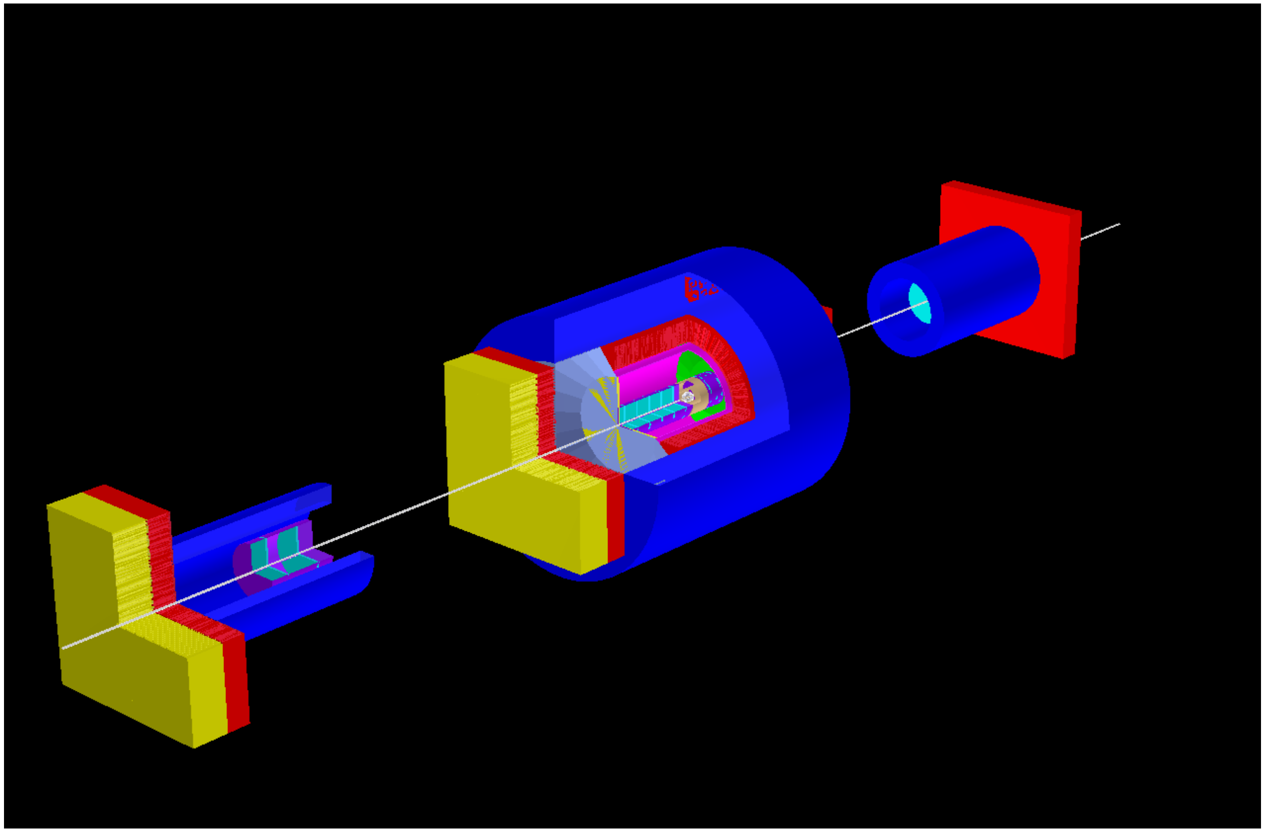




20 x 325

Based on similar studies at HERA:
H1 Collaboration, F. D. Aaron et al., Phys. Lett. B 701 20 (2011)
ZEUS Collaboration, S. Chekanov et al., Eur. Phys. J. C44 463 (2005)

EIC Detector in FAIRRoot

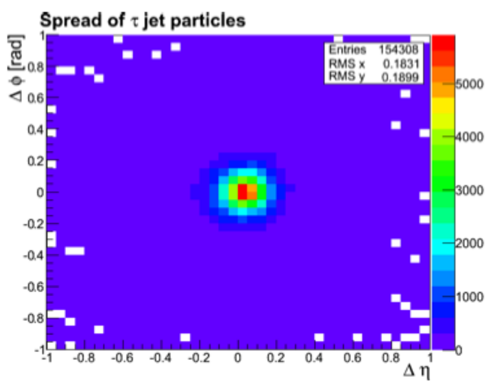


Events generated: step 1:

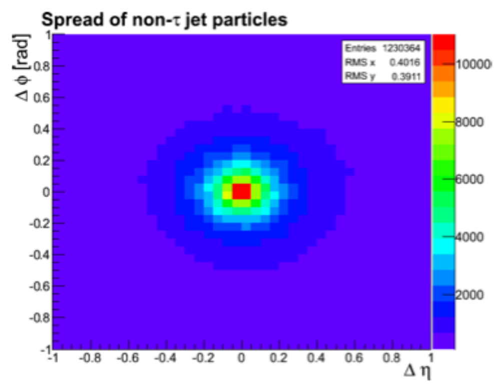
Study how the jets look at the generator level vs. detector

Various Jet Clustering Algorithms: Iterative Cone (JetClu, ILCA/Midpoint ; Sequential Combination (k_t, Cambridge/Achen, Anti-k_t)

Jets at Generator Level (first look)



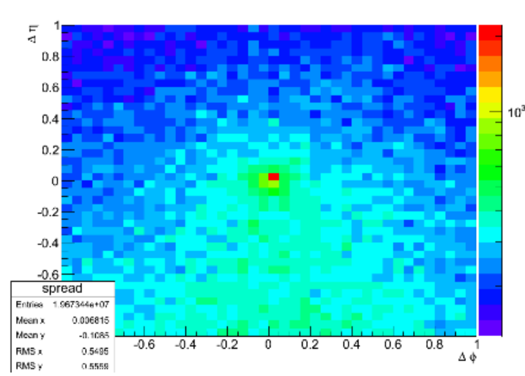
τ decay jet



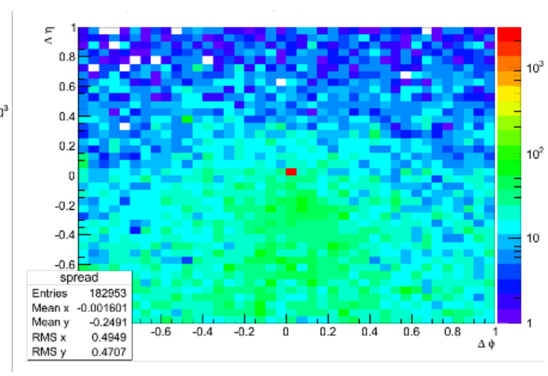
Normal hadronic jet

Jet width seems to be about 2 times the τ-jet width

Through a G4 Calorimeter Width/Shape difference remains



τ decay jet



hadronic jet

To Do (e-τ)

Jets:

- Put in more detector details and see what else could be used
- Energy variation of the center of mass (limited range, but may have an effect on jet-width within that range)

Any other idea suggestion welcome….

THANK YOU!

This work has been done mainly by

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***SBU Post Doctoral Fellow**: Dr. Swadhin Taneja (now at Dalhousie University)*

***Advisors:** K. Kumar, M. Gonderinger & M. Ramsey-Musolf*

H. Montgomery, Jeff. Laboratory Director

EIC at JLab Realization Imagined

Time line at BNL not ***too*** different