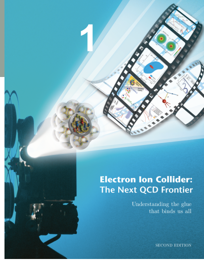
Electroweak and Beyond The Standard Model Physics with the Electron Ion Collider

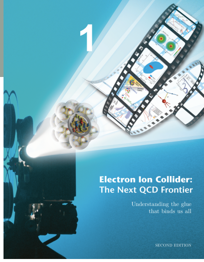
Stony Brook University
Abhay Deshpande



Electroweak and Beyond The Standard Model Physics with the Electron Ion Collider

Physics Possibilities *Beyond* EIC's Core Physics Goals

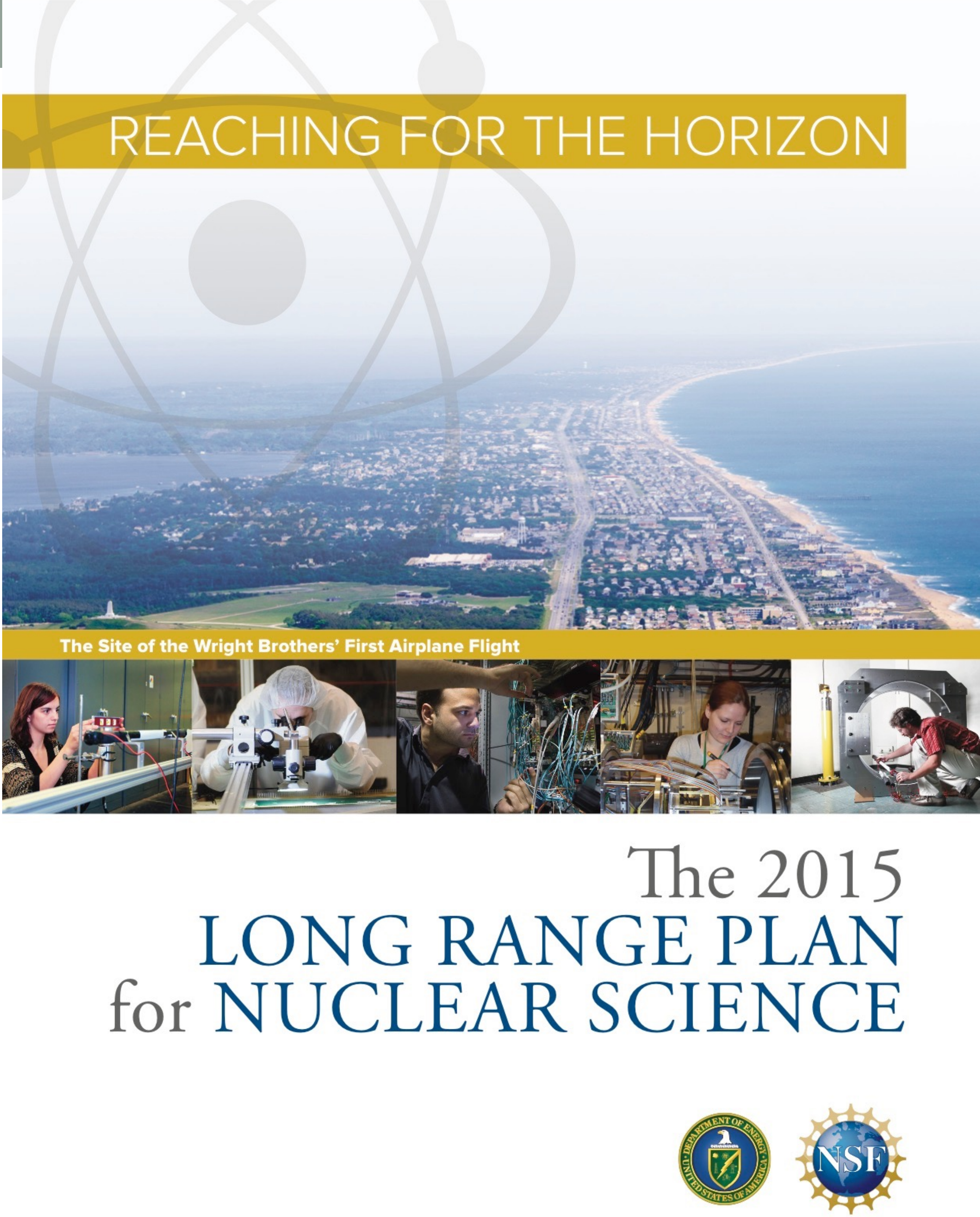
Stony Brook University
Abhay Deshpande



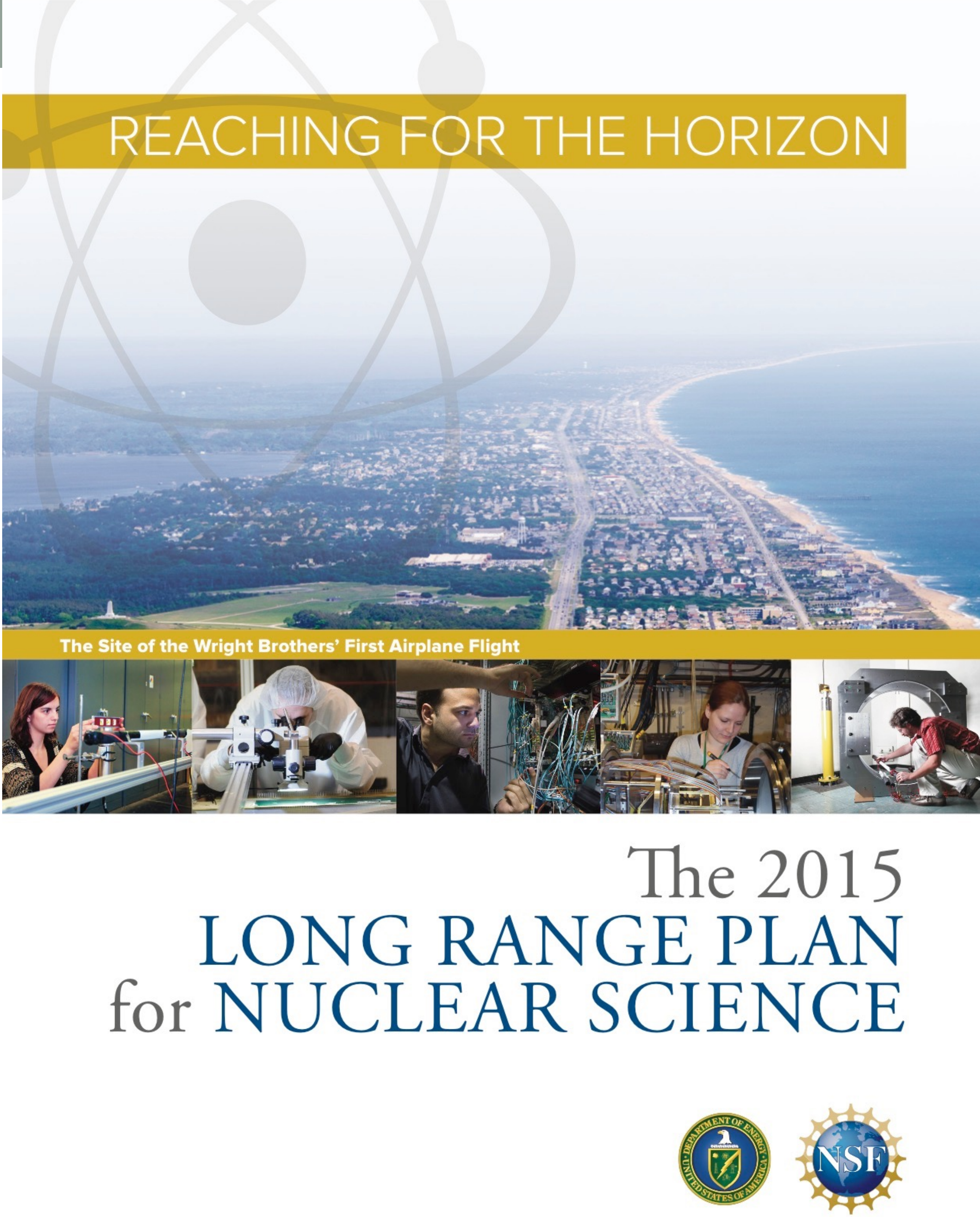
Electroweak and Beyond The Standard Model Physics with the Electron Ion Collider

Physics Possibilities *Beyond* EIC's Core Physics Goals

(See R. Yoshida's Talk Saturday AM for the Science of EIC, Overview)



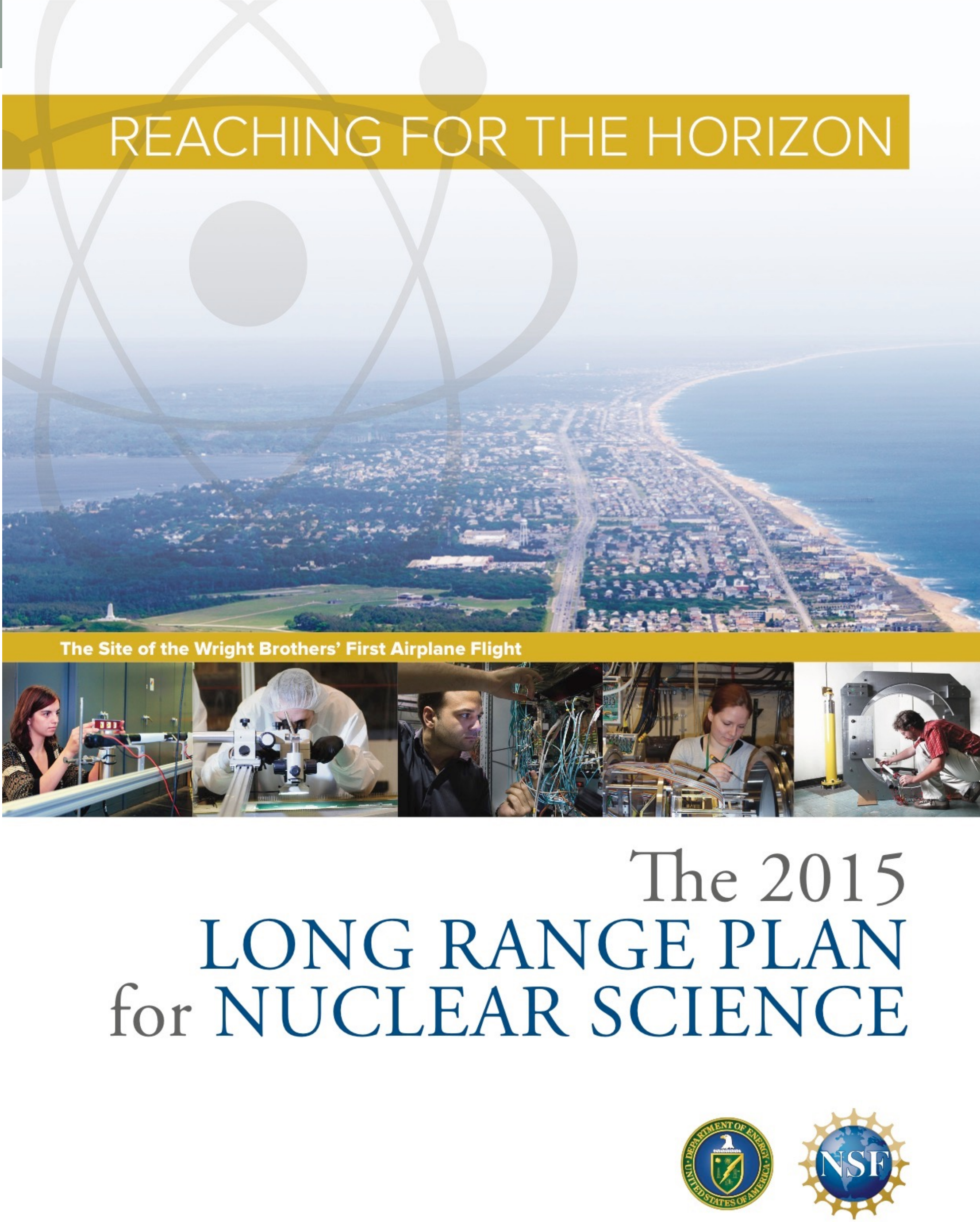
http://science.energy.gov/np/reports



RECOMMENDATION:

We recommend a high-energy high-luminosity polarized EIC as the highest priority for new facility construction following the completion of FRIB.

http://science.energy.gov/np/reports



http://science.energy.gov/np/reports

<u>RECOMMENDATION:</u>

We recommend a high-energy high-luminosity polarized EIC as the highest priority for new facility construction following the completion of FRIB.

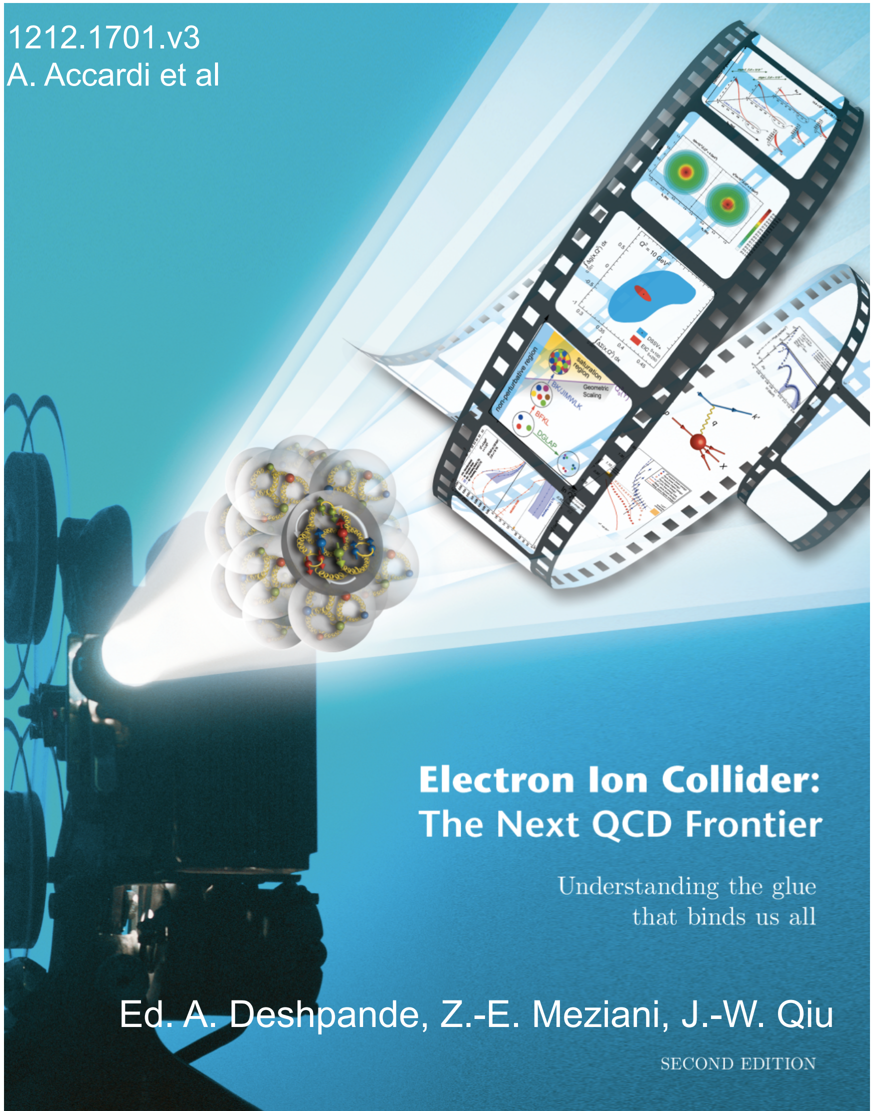
<u>Initiatives:</u>

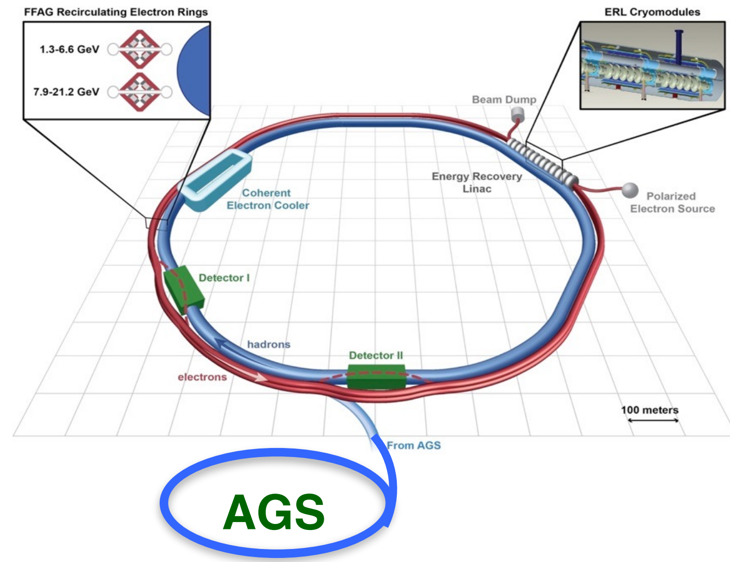
Theory

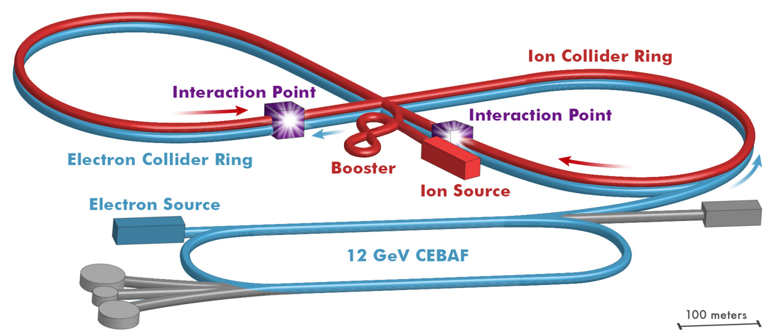
Detector & Accelerator R&D

The Electron Ion Collider

Two options of realization!





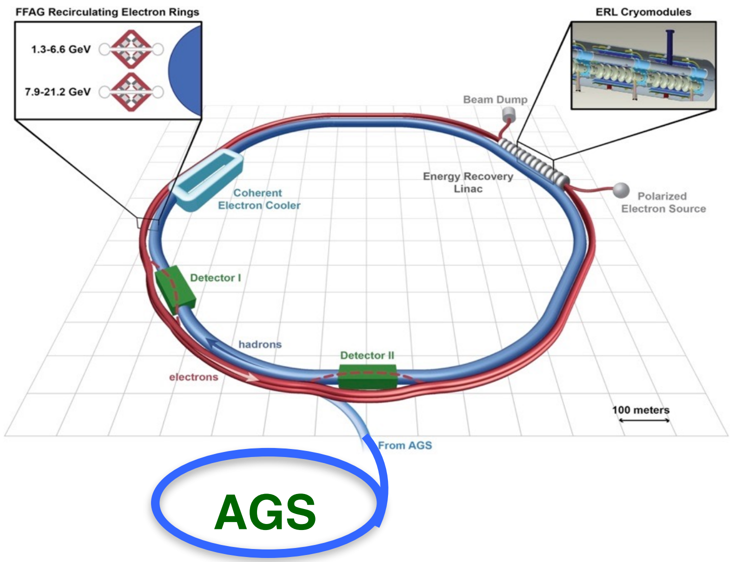


The Electron Ion Collider

Two options of realization!

For e-N collisions at the EIC:

- ✓ Polarized beams: e, p, d/^{3}He
- ✓ e beam 5-10(20) GeV
- ✓ Luminosity L_{ep} ~ 10^{33-34} cm^{-2}sec^{-1}
  100-1000 times HERA
- ✓ 20-100 (140) GeV Variable CoM

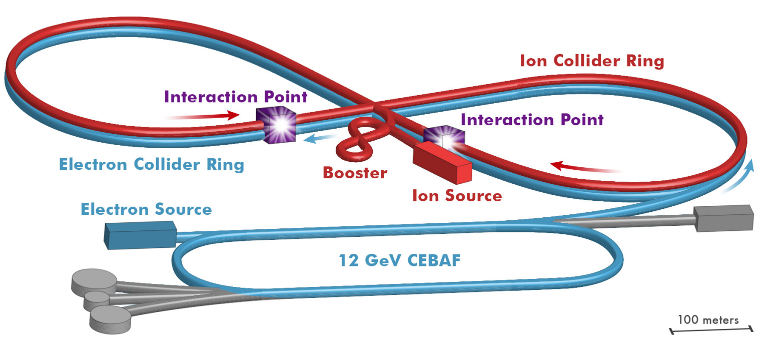


For e-A collisions at the EIC:

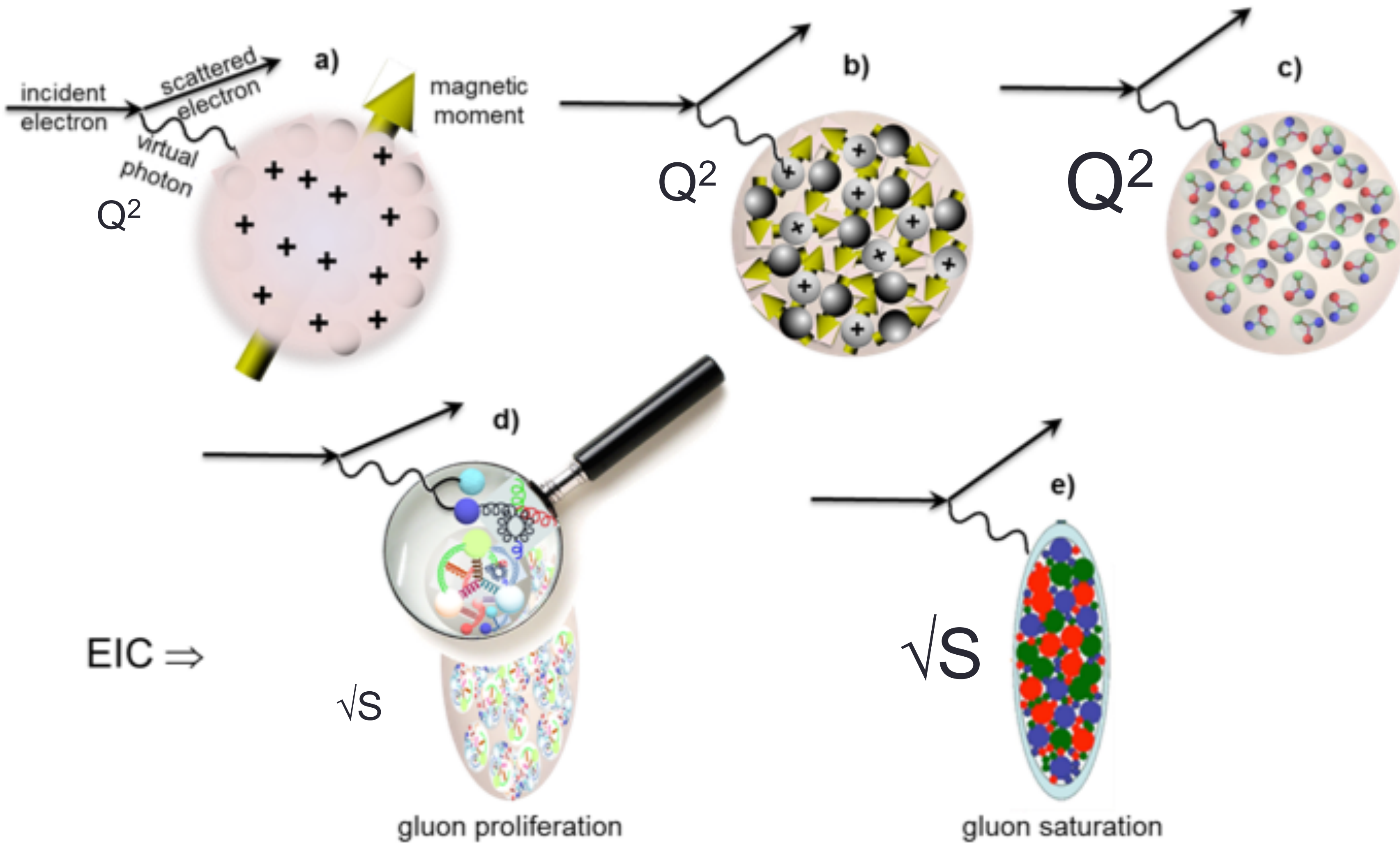
- ✓ **Wide range in nuclei**
- ✓ Luminosity per nucleon same as e-p
- ✓ Variable center of mass energy

World's first
Polarized electron-proton/light ion
and electron-Nucleus collider

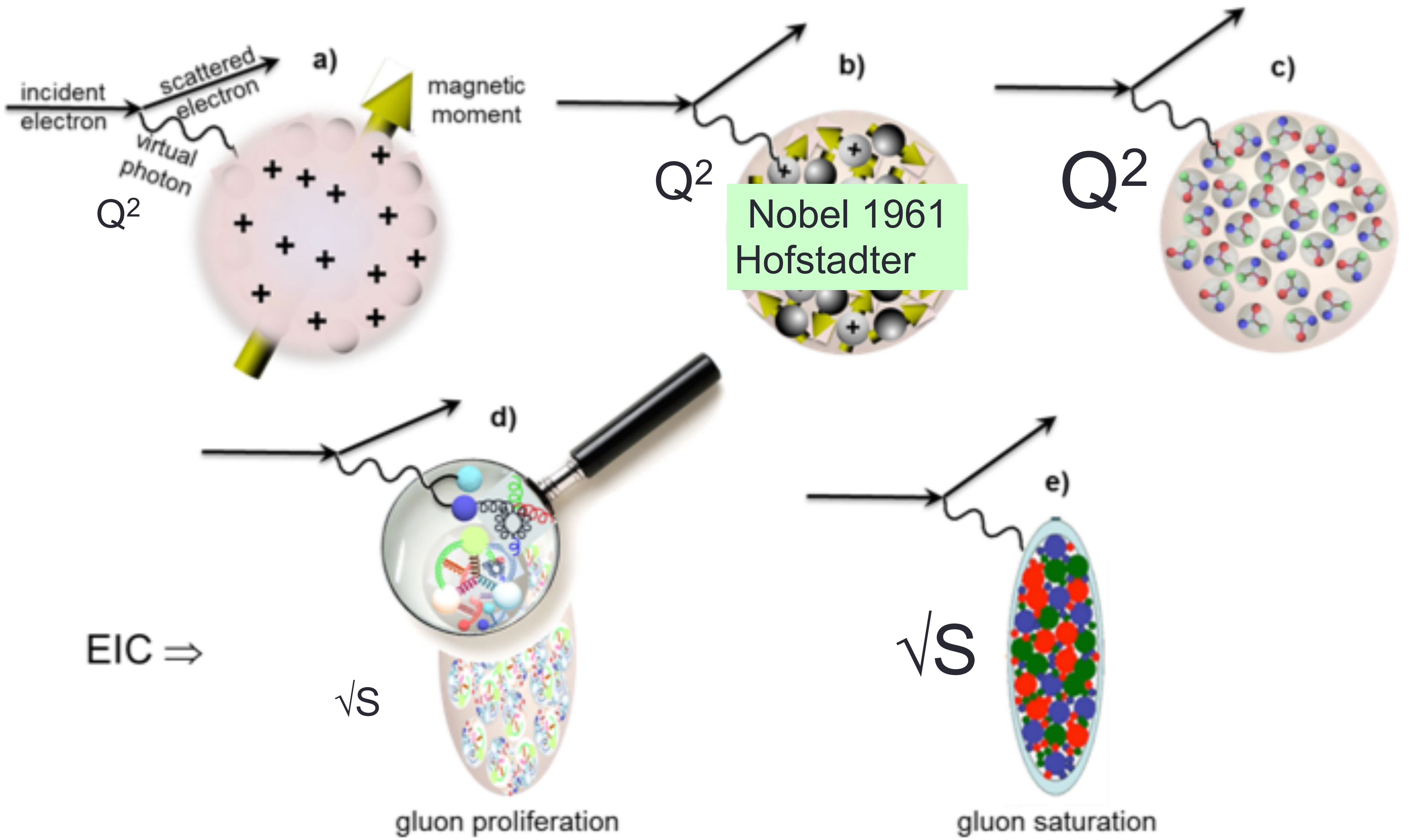
Both designs use DOE's significant investments in infrastructure



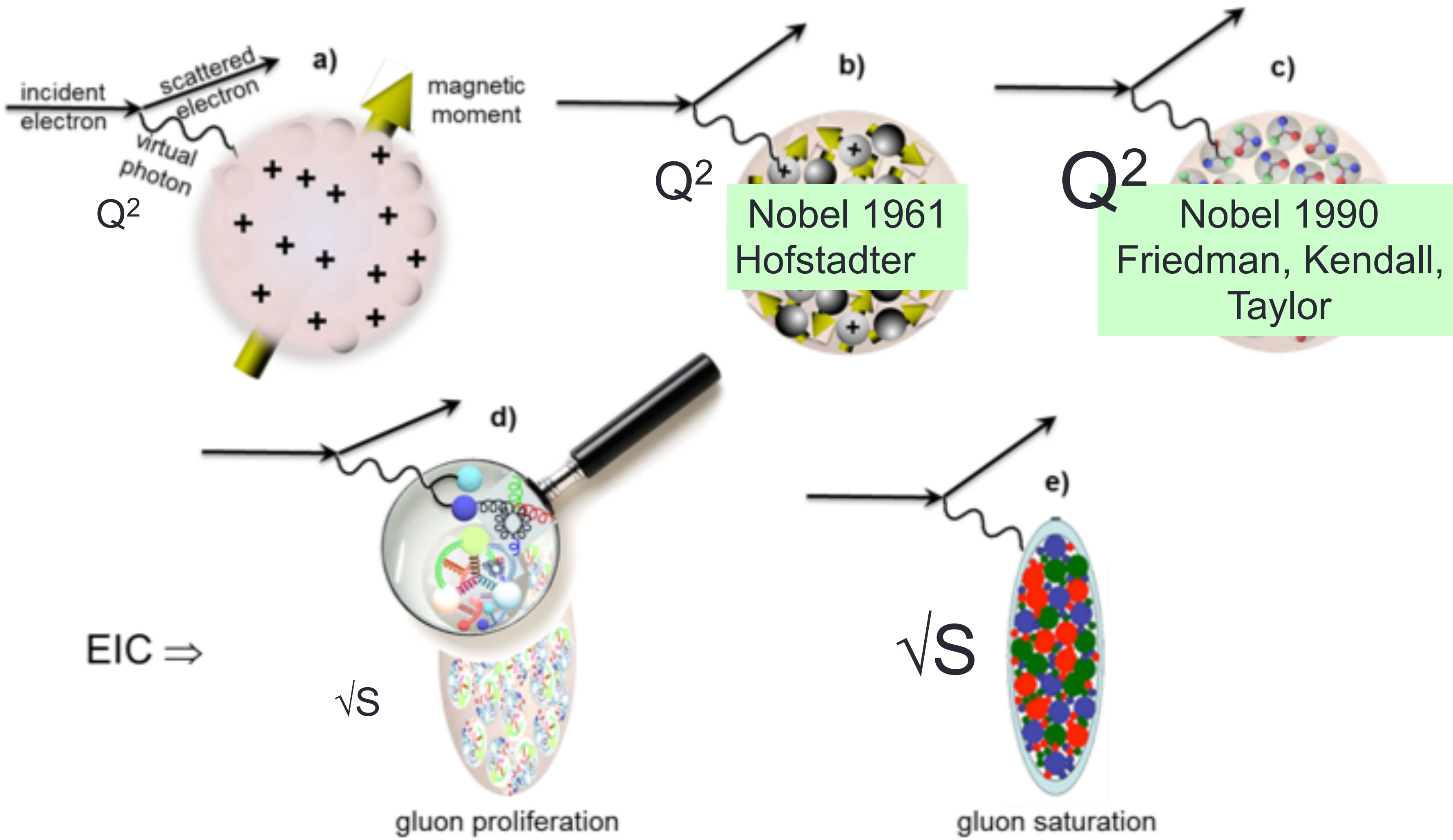
Deep Inelastic Scattering allows the Ultimate Experimental Control



Deep Inelastic Scattering allows the Ultimate Experimental Control



Deep Inelastic Scattering allows the Ultimate Experimental Control

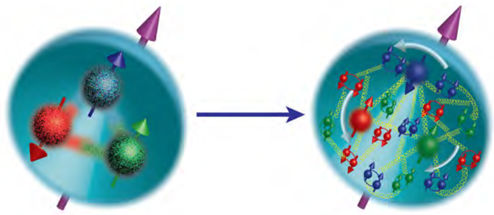


Puzzles and challenges in understanding these QCD many body emergent dynamics

How are the gluons and sea quarks, and their intrinsic spins distributed in space & momentum inside the nucleon?

Role of Orbital angular momentum?

How do they constitute the nucleon Spin?

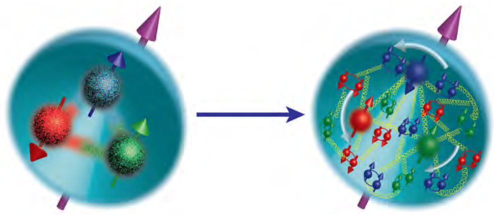


Puzzles and challenges in understanding these QCD many body emergent dynamics

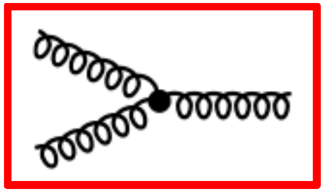
How are the gluons and sea quarks, and their intrinsic spins distributed in space & momentum inside the nucleon?

Role of Orbital angular momentum?

How do they constitute the nucleon Spin?



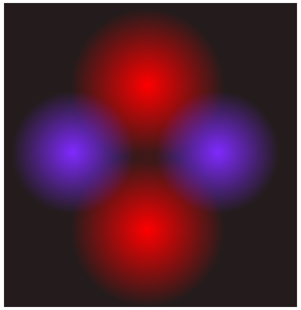
What happens to the gluon density in nuclei at high energy? Does it saturate in to a gluonic form of matter of universal properties?



?

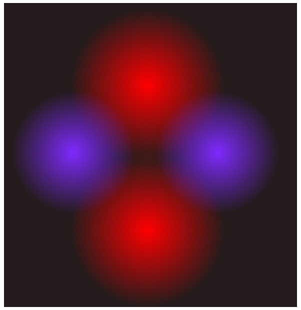
Puzzles and challenges….

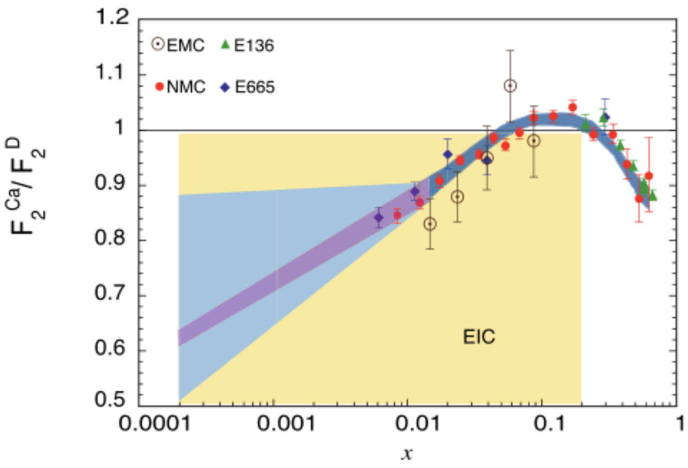
How do gluons and sea quarks contribute to the nucleon-nucleon force?



Puzzles and challenges….

How do gluons and sea quarks contribute to the nucleon-nucleon force?

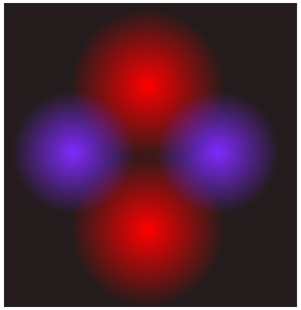


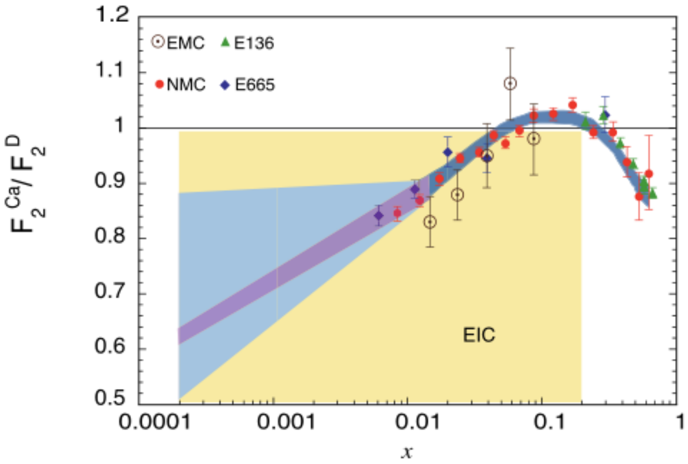


How does the nuclear environment affect the distributions of quarks and gluons and their interactions inside nuclei?

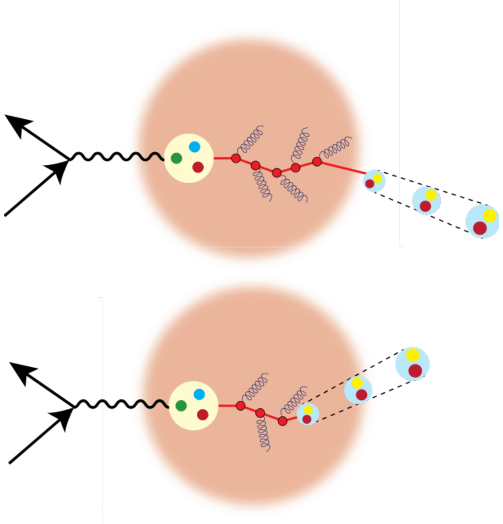
Puzzles and challenges….

How do gluons and sea quarks contribute to the nucleon-nucleon force?



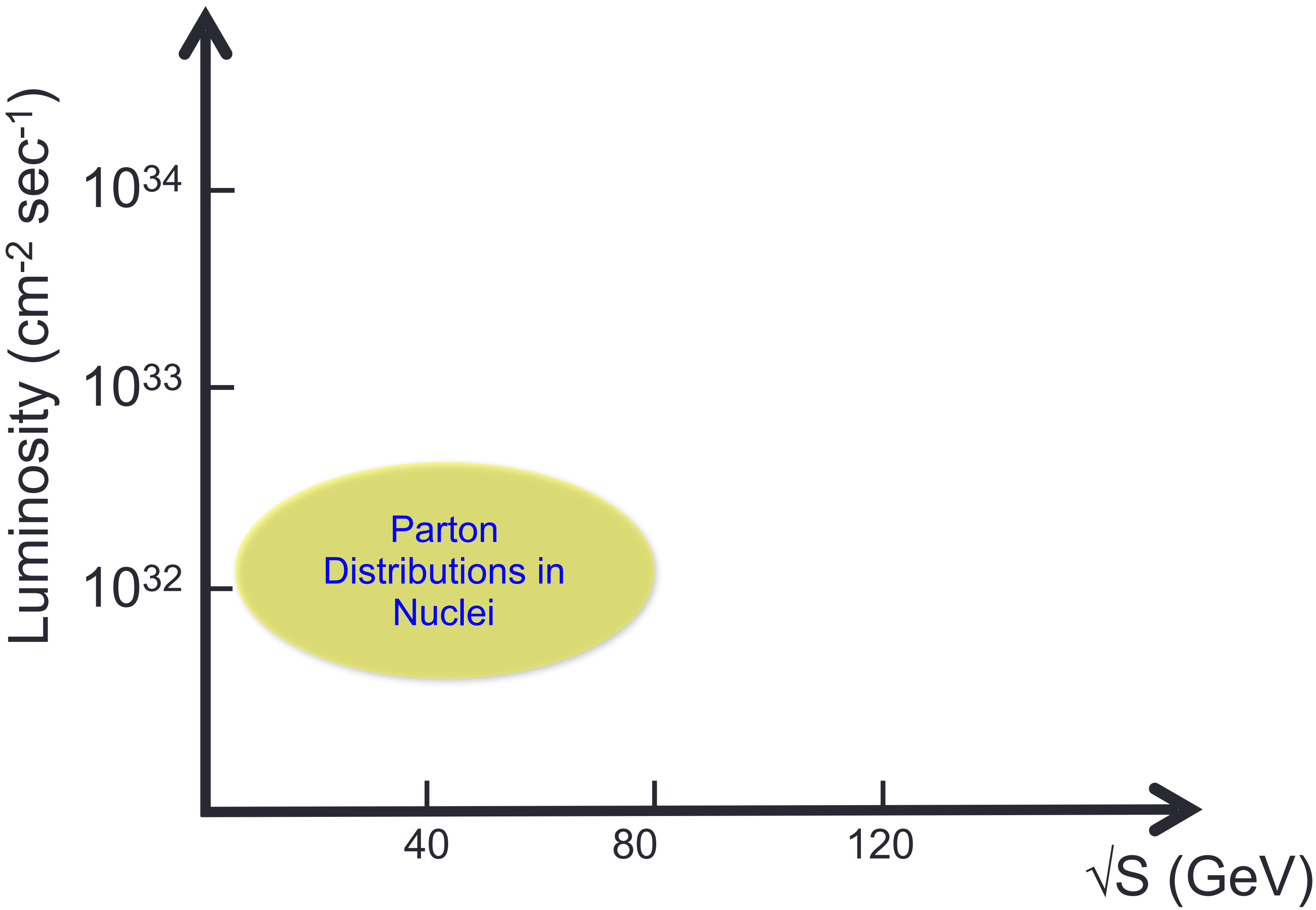


How does the nuclear environment affect the distributions of quarks and gluons and their interactions inside nuclei?

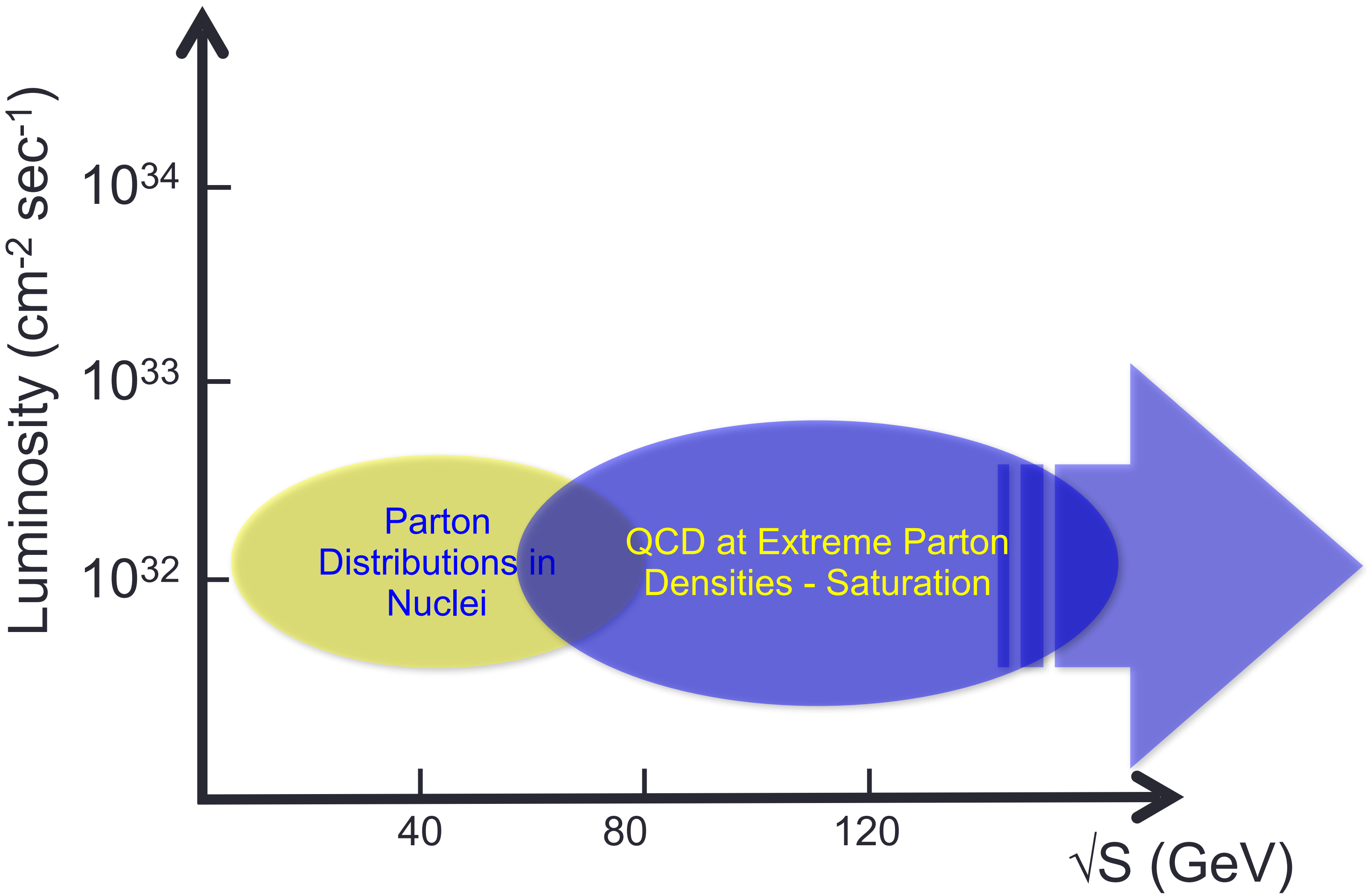


How does nuclear matter respond to fast moving color charge passing through it? (hadronization…. confinement?)

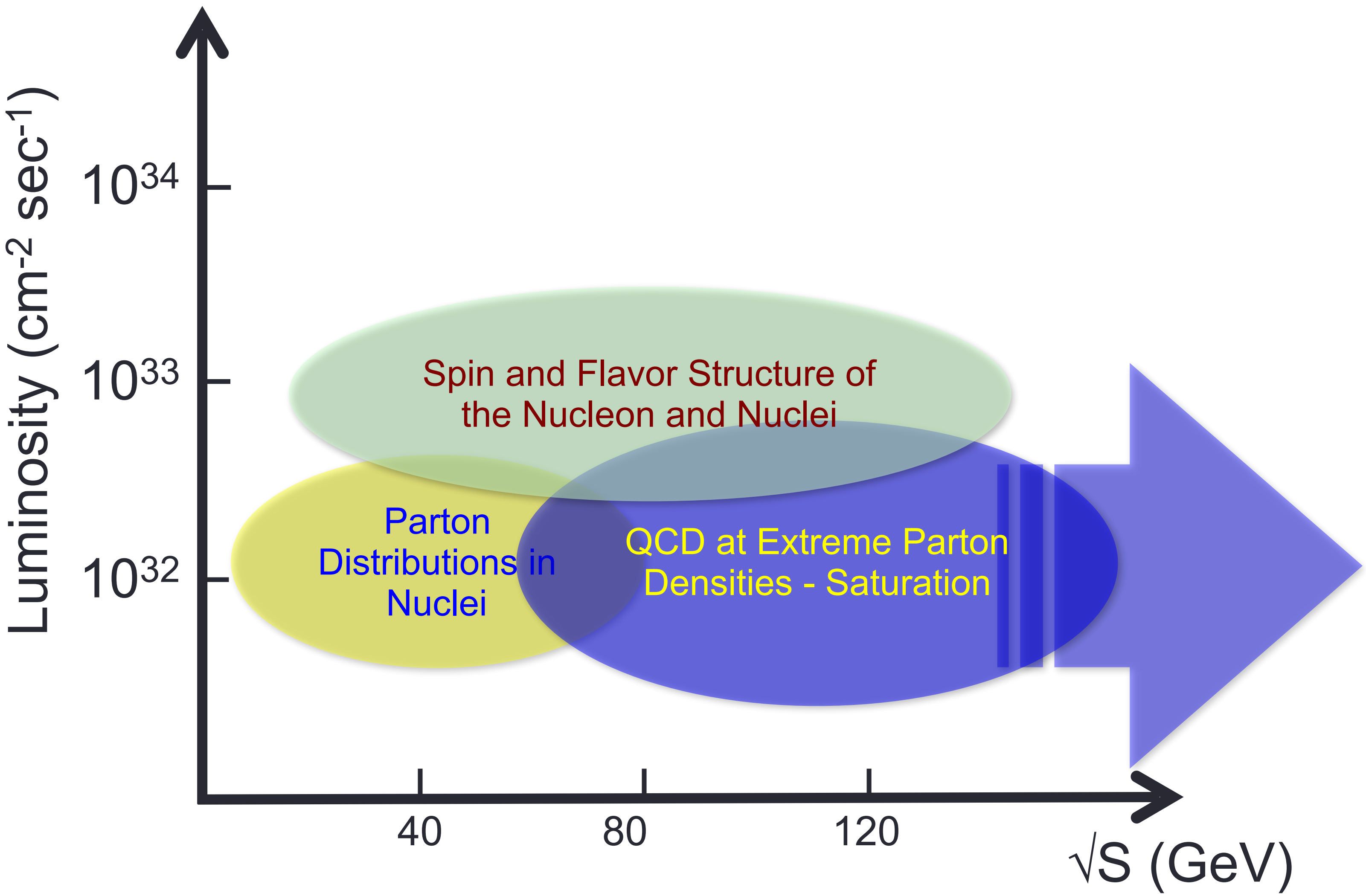
Physics vs. Luminosity & Energy



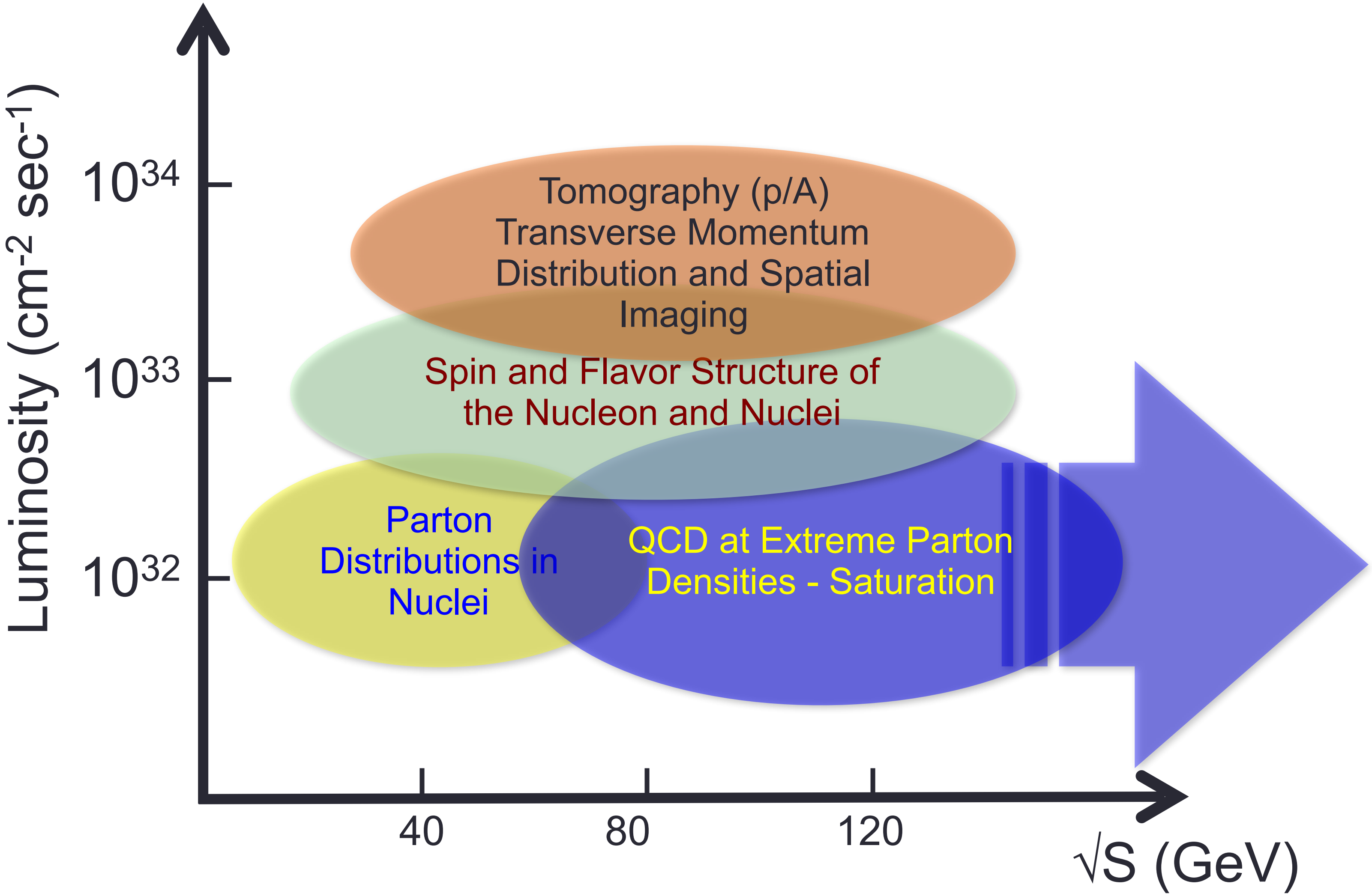
Physics vs. Luminosity & Energy



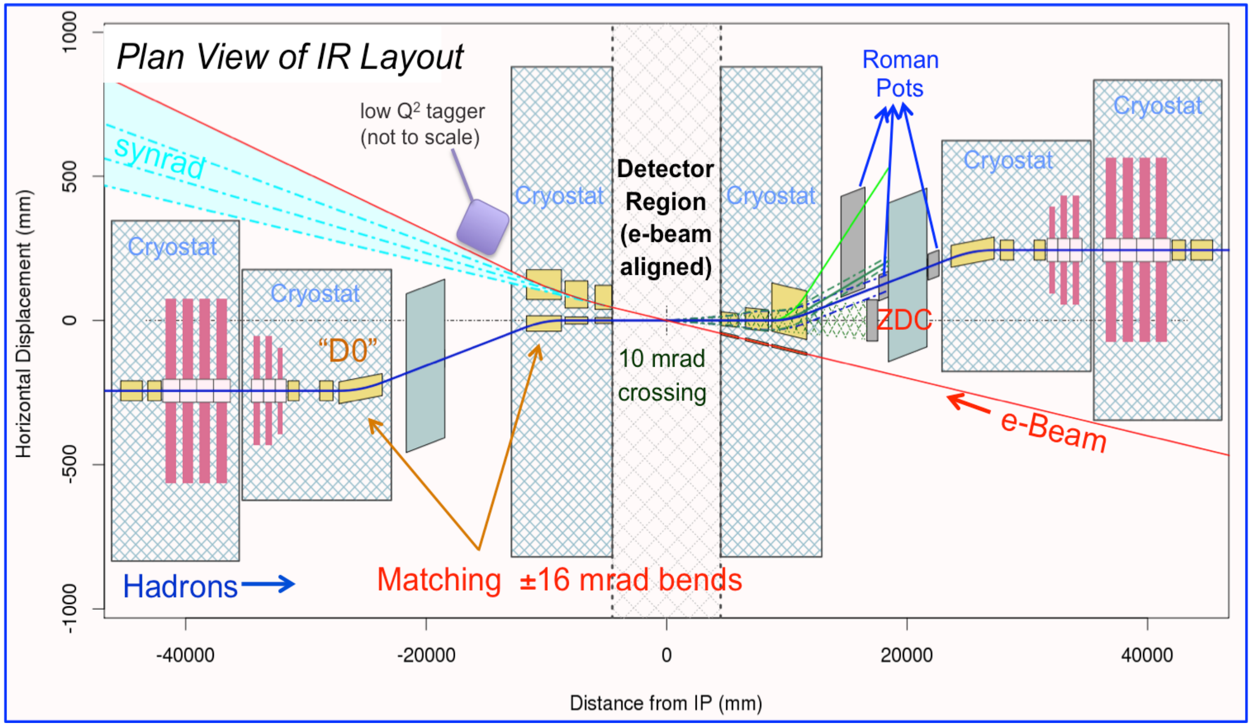
Physics vs. Luminosity & Energy



Physics vs. Luminosity & Energy

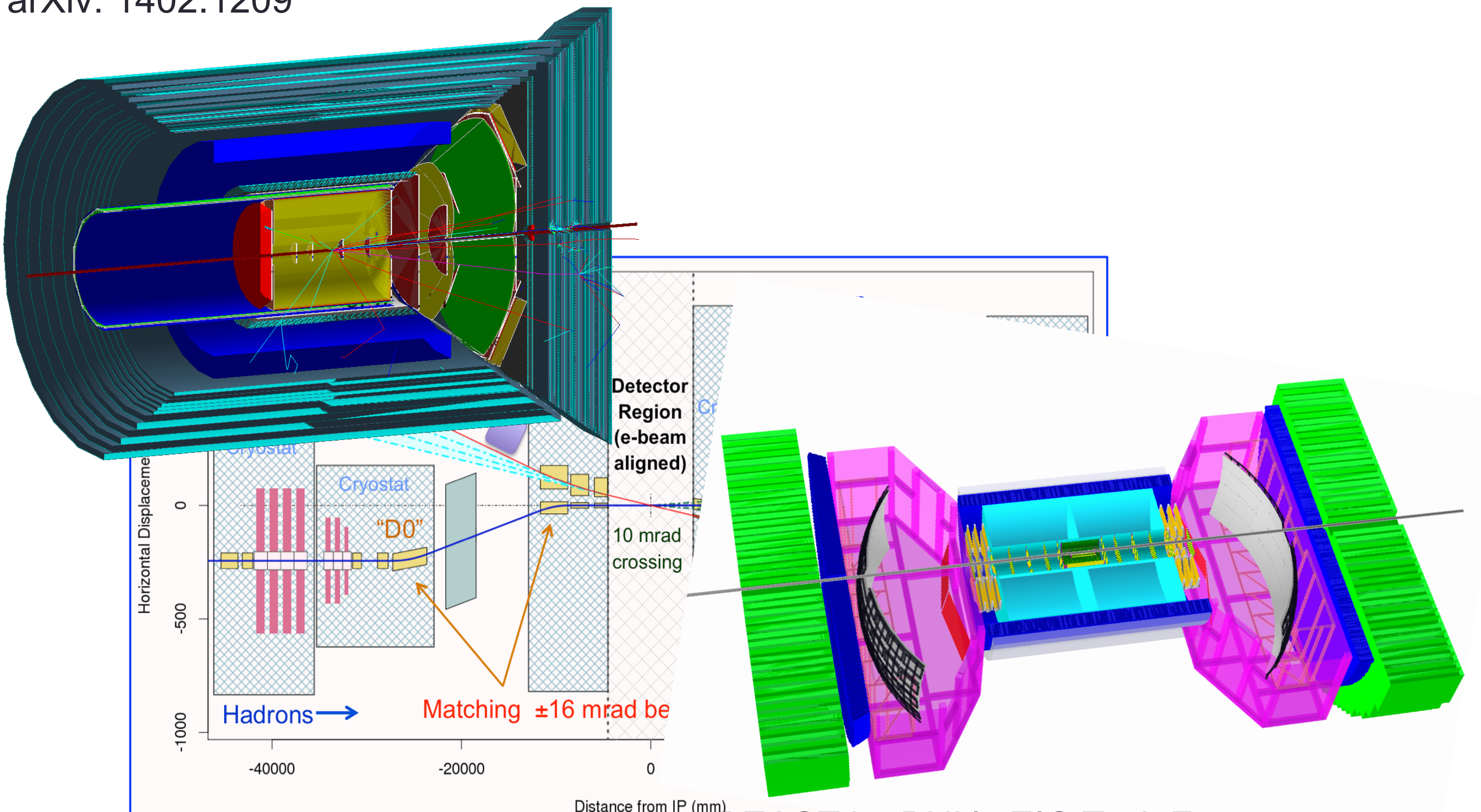


EIC IR & Detector Plan both at eRHIC & JLEIC



EIC IR & Detector Plan both at eRHIC & JLEIC

Day-1 Detector: CELESTE
A.K.A. “ePHENIX” with BaBar Solenoid
arXiv: 1402.1209

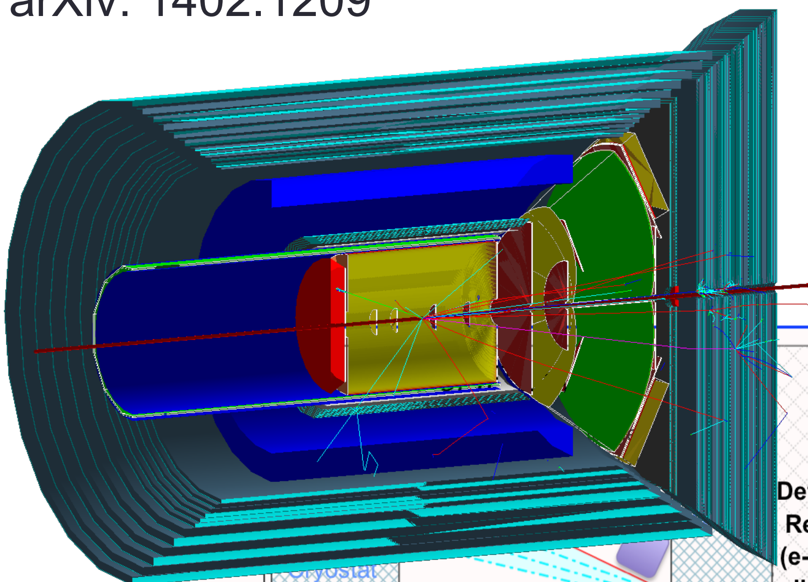


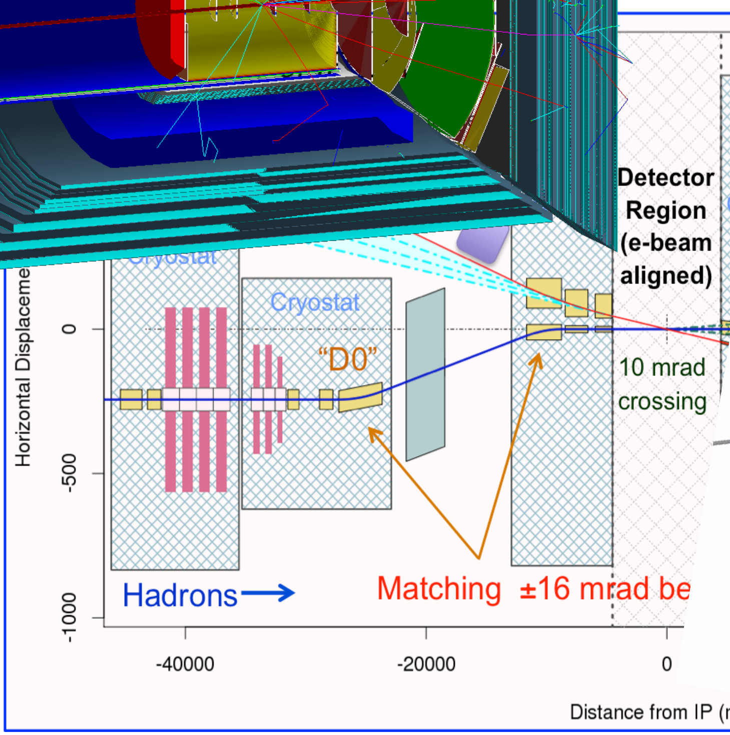
BEAST by BNL’s EIC Task Force
arXiv: 1409.1633

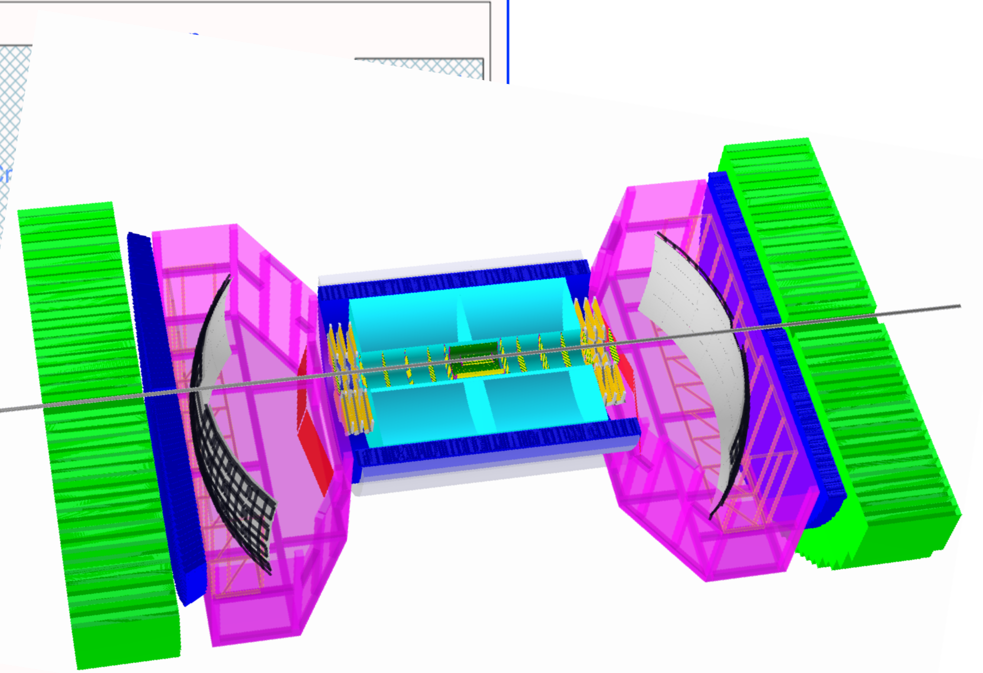
EIC IR & Detector Plan both at eRHIC & JLEIC

Day-1 Detector: CELESTE
A.K.A. “ePHENIX” with BaBar Solenoid
arXiv: 1402.1209

Detector: Low mass tracking technology, particle ID, asymmetric collisions (moving CM) are all in! Opportunities for HQ and Quarkonium physics.

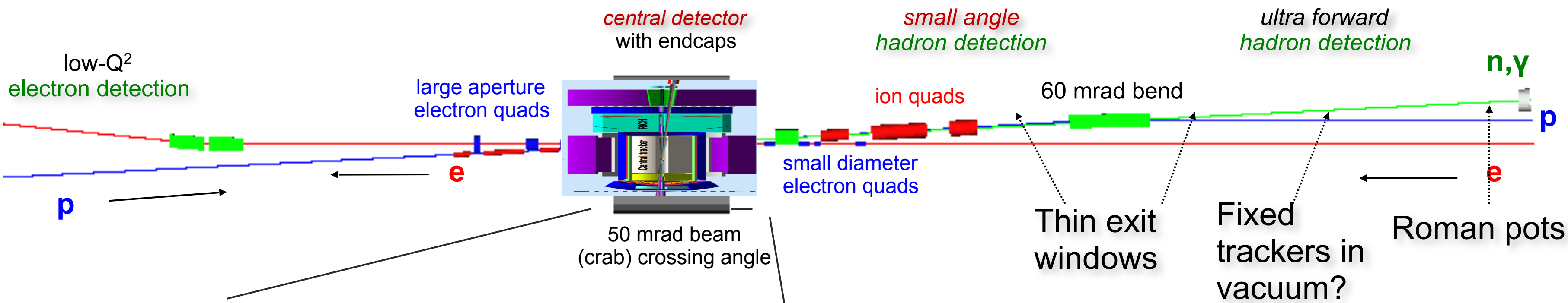


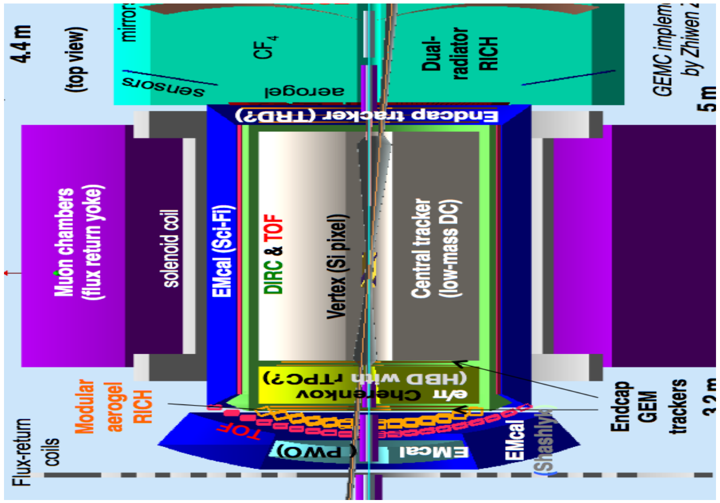




BEAST by BNL’s EIC Task Force
arXiv: 1409.1633

EIC at JLab: Integrated IR & Detector

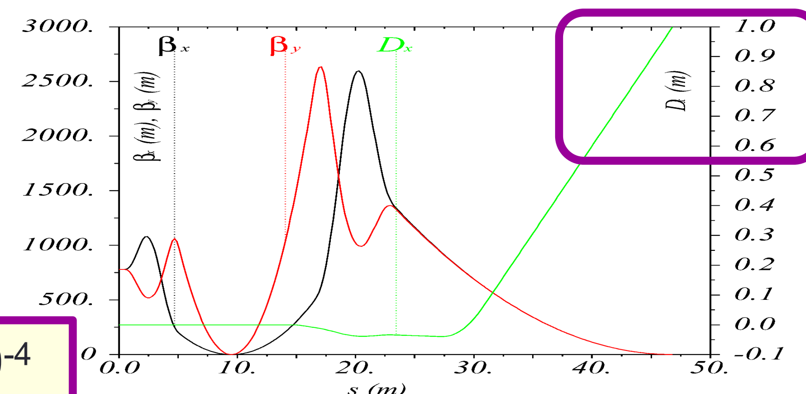




Cartoon of central detector based on dual solenoid a la ILC4 detector, but using the previous iteration interaction region design.

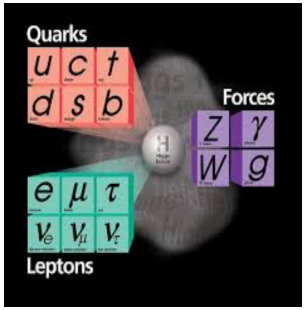
Hadron/Ion detection in 3 stages

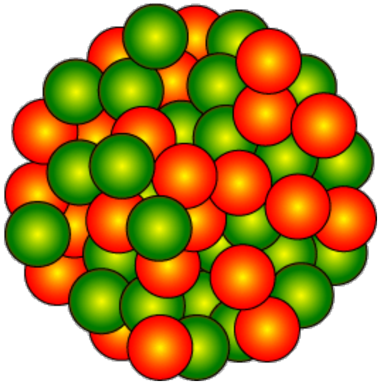
- Endcap with 50 mrad crossing angle
- Small dipole covering angles to a few degrees
- Ultra-forward up to one degree, for particles passing accelerator quads



Beamline functions as spectrometer: $dp/p < 3\times10^{-4}$

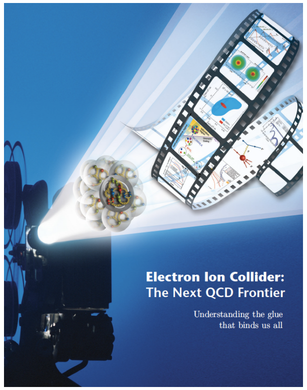
The QCD physics summarized so far will be discussed in the talk by Rik Yoshida tomorrow morning (plenary session)



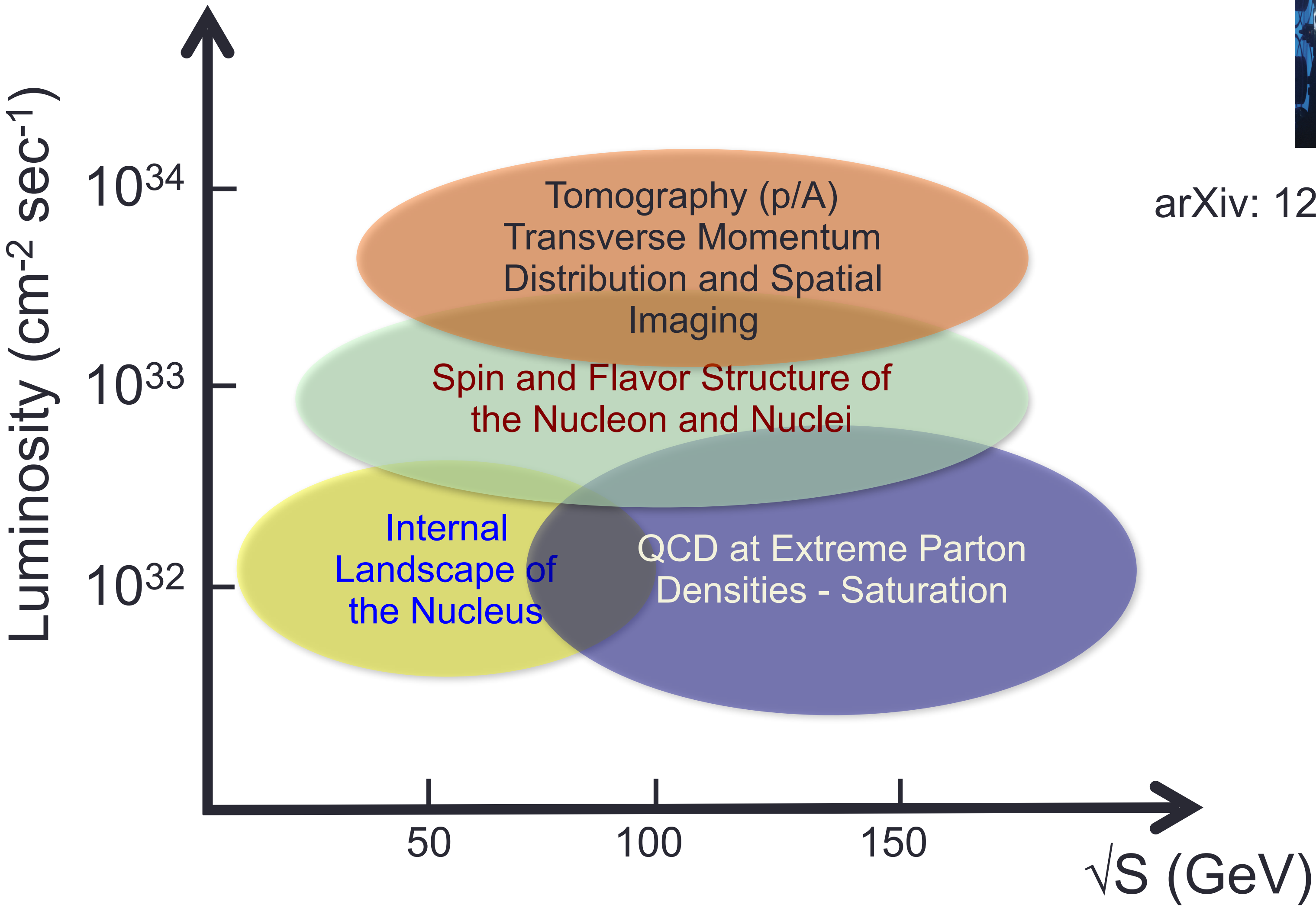


The QCD physics summarized so far will be discussed in the talk by Rik Yoshida tomorrow morning (plenary session)

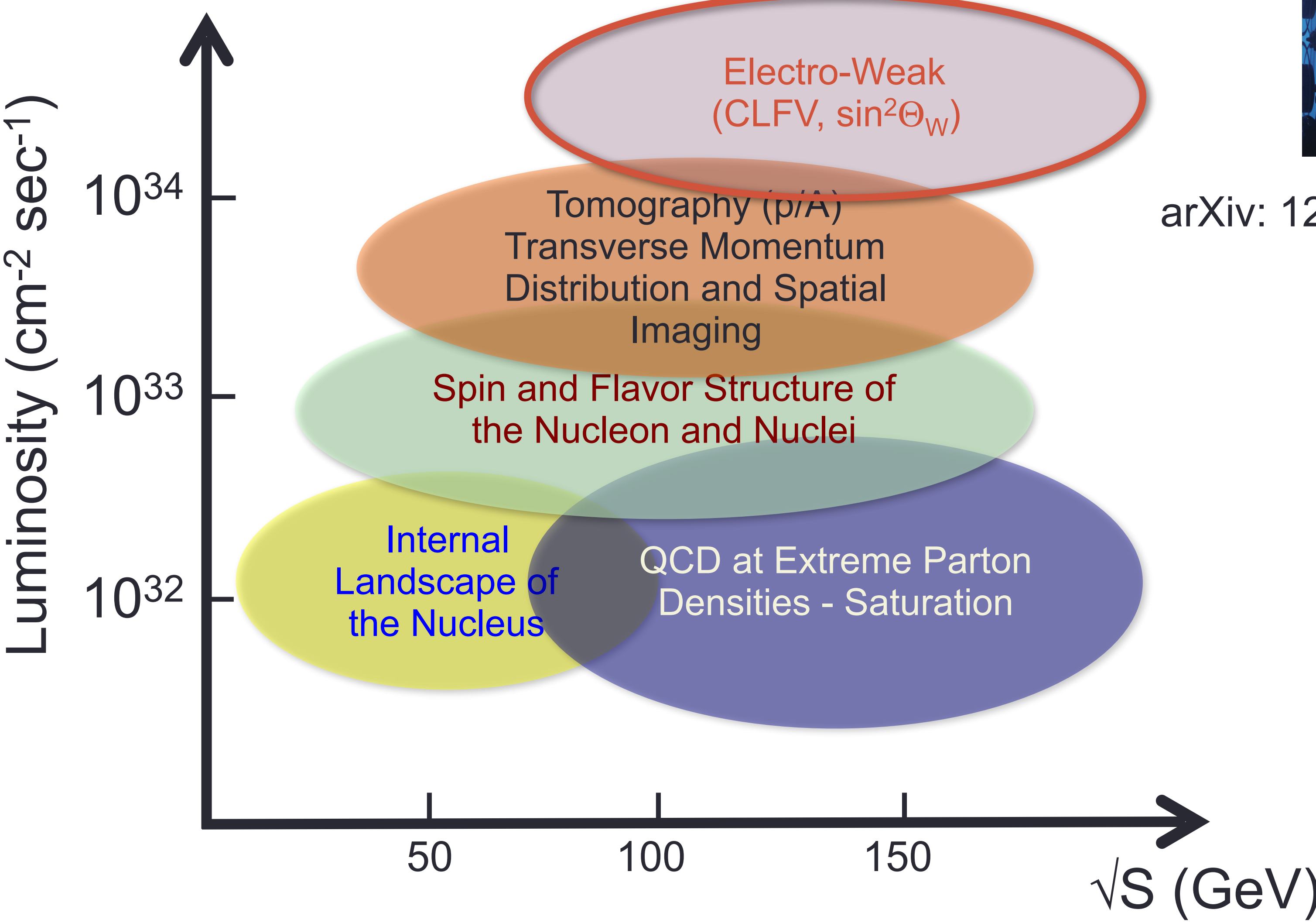
Physics vs. Luminosity & Energy

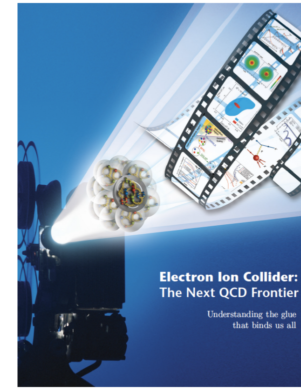


arXiv: 1212.1701.v3



Physics vs. Luminosity & Energy





arXiv: 1212.1701.v3

QCD Physics at the EIC:

- Pushes the luminosity requirements ~ few x 10^{34} $cm^{-2}s^{-1}$
  - Recall that although lower in luminosity than fixed target experiments, the collider is at (high) 100-140 GeV in CM Energy
- Push the polarimetry and beam quality requirements to the extreme:
  - (dPol/Pol) ~ 1%
  - Ultra low beam divergence for DVCS/Diffraction…

Why not consider using this machine for precision EW & BSM Physics?

Electroweak & beyond….(?)

BNL LDRD: Deshpande, Marciano, Kumar & Vogelsang

Electroweak & beyond….(?)

BNL LDRD: Deshpande, Marciano, Kumar & Vogelsang

- 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*

Electroweak & beyond….(?)

BNL LDRD: Deshpande, Marciano, Kumar & Vogelsang

- 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*

Electroweak & beyond….(?)

BNL LDRD: Deshpande, Marciano, Kumar & Vogelsang

- 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 $\mathrm{Sin}^2\Theta_W$

$$e^- + p \to \tau^- + X$$

Electroweak & beyond….(?)

BNL LDRD: Deshpande, Marciano, Kumar & Vogelsang

- 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 $\mathrm{Sin}^2\Theta_W$

$$e^- + p \rightarrow \tau^- + X$$

Electroweak & beyond….(?)

BNL LDRD: Deshpande, Marciano, Kumar & Vogelsang

- 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 through LFV search M. Gonderinger & M. Ramsey-Musolf, JHEP 1011 (045) (2010); arXive: 1006.5063 [hep-ph]

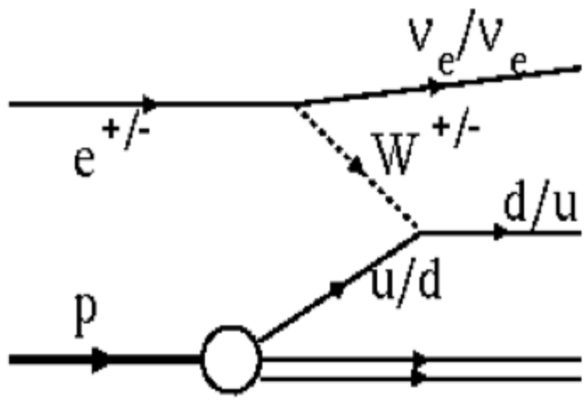
$$e^- + p \to \tau^- + X$$

Exploring Nucleon Spin Using E-W Probes

Charged Vector Boson (W) exchange allows access to quark and anti-quark distributions separately….

-- Something a virtual photon can not do.

Weak probes of nucleon helicity



$$a = 2(y^2 - 2y + 2); \quad b = y(2-y); \quad \lambda = \pm 1 \text{ for } e^{\pm}$$

$$\delta = \pm 1 \text{ for } \uparrow\downarrow \text{ and } \uparrow\uparrow \text{ spin orientations}$$

$$A_{cc}^{W^+} = \frac{-2bg_1 + ag_5}{aF_1 - bF_3} \qquad A_{cc}^{W^-} = \frac{+2bg_1 + ag_5}{aF_1 + bF_3}$$

Experimental signature is a large asymmetry (due to missing neutrino)

$$= 2(y^2 - 2y + 2); \quad b = y(2-y); \quad \lambda = \pm 1 \text{ for } e$$

$$= \pm 1 \text{ for } \uparrow\downarrow \text{ and } \uparrow\uparrow \text{ spin orientations}$$

HERA used this to probe $xF_{3,}$ ➔ combination of quark, anti-quark Distributions, using electron and positron beams

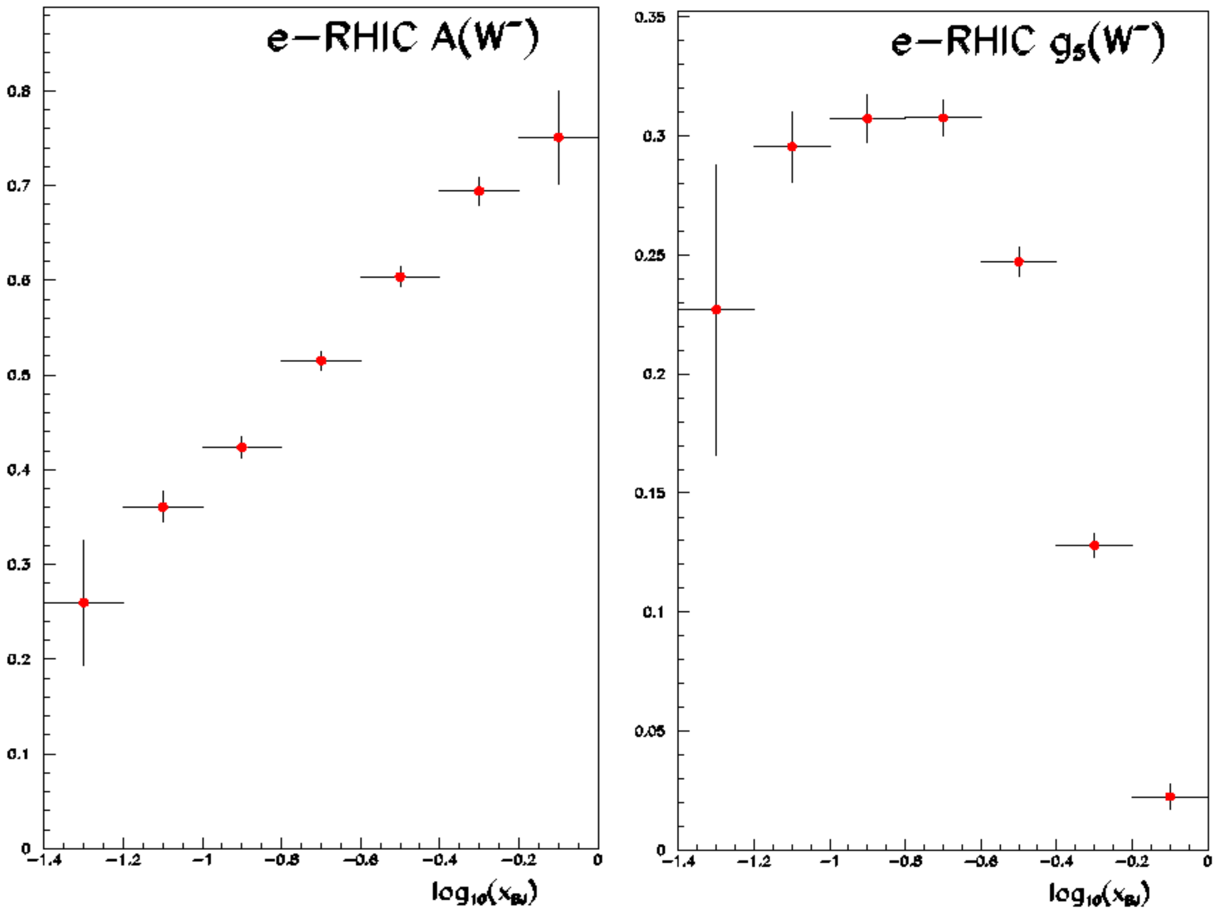
$$\left[a\left[F_1 - \lambda bF_3\right] + \delta\left[ag_5 - \lambda^2 bg_1\right]\right\}$$

EIC's Polarized beam ➔ $g_5^{W+/-}$

First studied: J. Contreras & A. De Roeck 2002

J. Contreras & A. De Roeck, A. Deshpande
Yale eRHIC Meeting 2000

Sensitivity to g_5^{W-}: with polarized e- beam



Needs good measurement of xF_3

Simulation assuming 4 fb^{-1} (about 1 month operation)

In a Ring-Ring design e+/e- both possible ➔ g_5^{W+} also possible for full flavor separation: Delta (ubar, dbar….)

A more recent study: Global analysis of existing and future EIC data

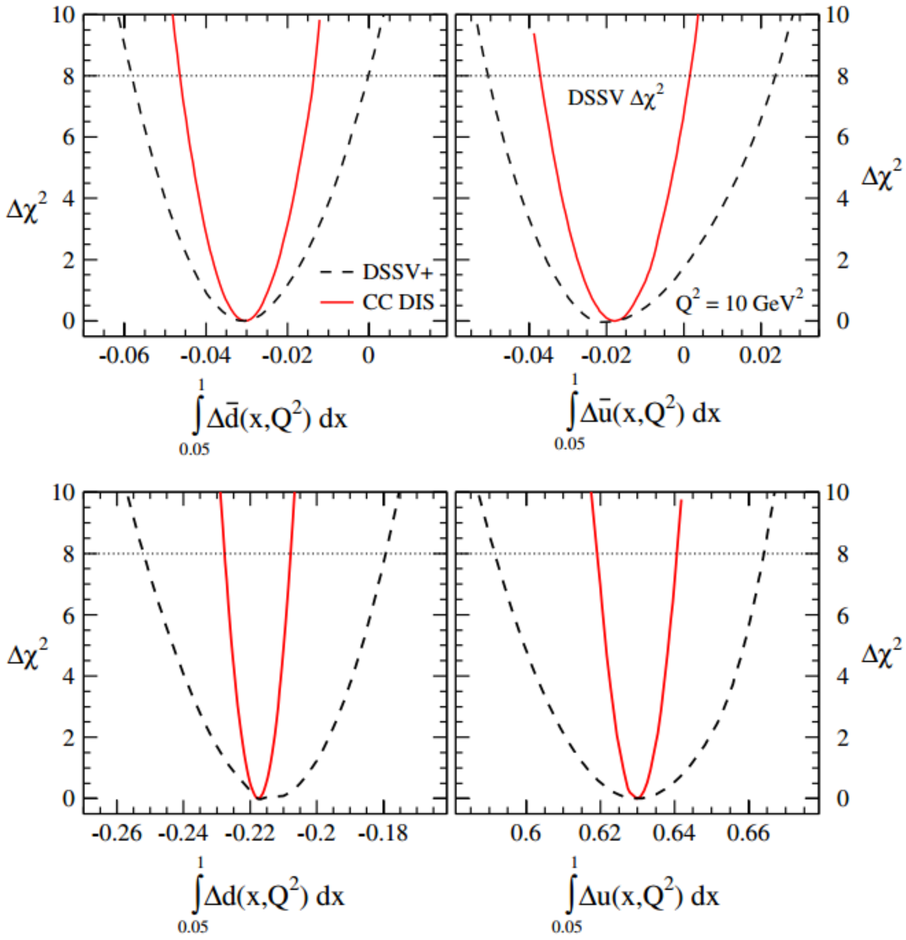
E. Aschanauer , et al. PRD 88 114025 (2013)

$$g_1^{W^-,p}(x) = \Delta u(x) + \Delta \bar{d}(x) + \Delta c(x) + \Delta \bar{s}(x),$$

$$g_5^{W^-,p}(x) = -\Delta u(x) + \Delta \bar{d}(x) - \Delta c(x) + \Delta \bar{s}(x)$$

$$g_1^{W^+,p}(x) = \Delta \bar{u}(x) + \Delta d(x) + \Delta \bar{c}(x) + \Delta s(x),$$

$$g_5^{W^+,p}(x) = \Delta \bar{u}(x) - \Delta d(x) + \Delta \bar{c}(x) - \Delta s(x)$$



A full unfolding of Q and Qbars will require polarized electron and positron beams at high luminosity.

High luminosity positron beams is a challenge in LINAC based EICs.

EIC provides independent weak probes of the nucleon spin constitution, Including separation between quarks and anti-quarks

A more recent study: Global analysis of existing and future EIC data

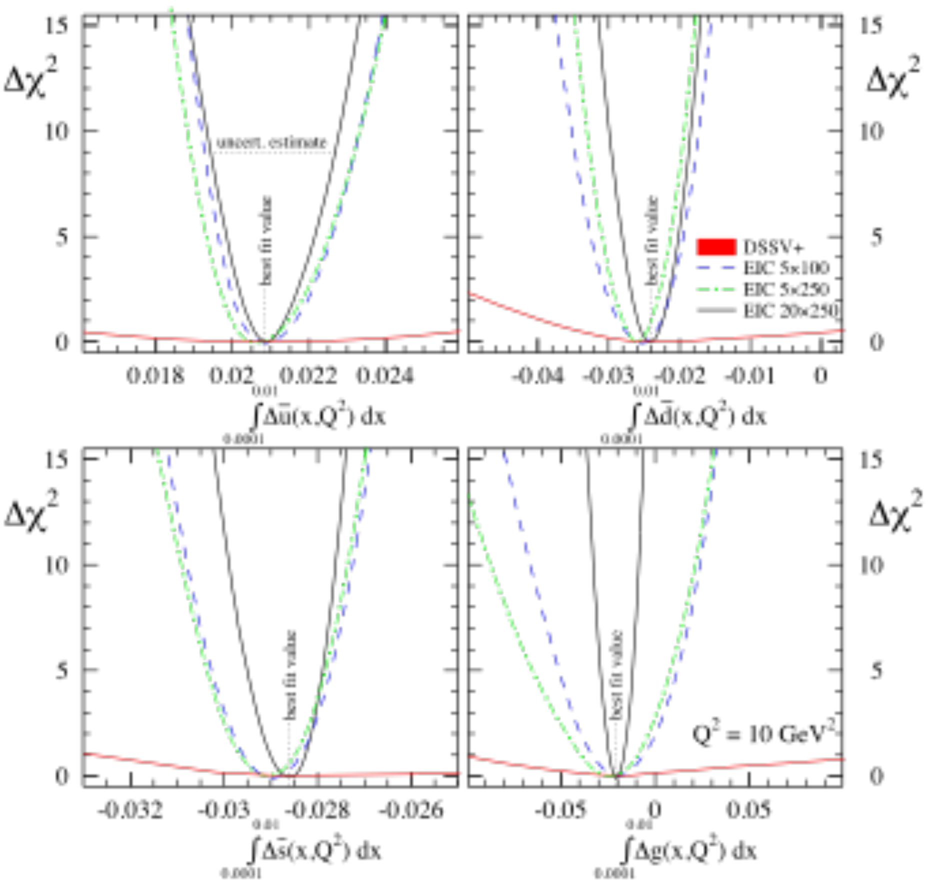
E. Aschanauer , et al. PRD 88 114025 (2013)

$$g_1^{W^-,p}(x) = \Delta u(x) + \Delta\bar{d}(x) + \Delta c(x) + \Delta\bar{s}(x),$$

$$g_5^{W^-,p}(x) = -\Delta u(x) + \Delta\bar{d}(x) - \Delta c(x) + \Delta\bar{s}(x)$$

$$g_1^{W^+,p}(x) = \Delta\bar{u}(x) + \Delta d(x) + \Delta\bar{c}(x) + \Delta s(x),$$

$$g_5^{W^+,p}(x) = \Delta\bar{u}(x) - \Delta d(x) + \Delta\bar{c}(x) - \Delta s(x)$$



A full unfolding of Q and Qbars will require polarized electron and positron beams at high luminosity.

High luminosity positron beams is a challenge in LINAC based EICs.

EIC provides independent weak probes of the nucleon spin constitution, Including separation between quarks and anti-quarks

PV DIS and $\mathrm{Sin}^2(\Theta_W)$

Measurement of Weinberg Angle at high Q, but still below the Z mass….

Deviation from the running of the expectd curve would indicatae existance of physics beyond the SM

Prospects: near and far future….

Jefferson Laboratory:

- 6 GeV DIS eD→ eX recently completed
- 12 GeV SoLID experiment at JLab12 in future (2020-2025)
  - Measure C_{2q}'s New Physics, Charge Symmetry violation
  - Effective luminosity (fixed target) 10^{38} $cm^{-2}sec^{-1}$

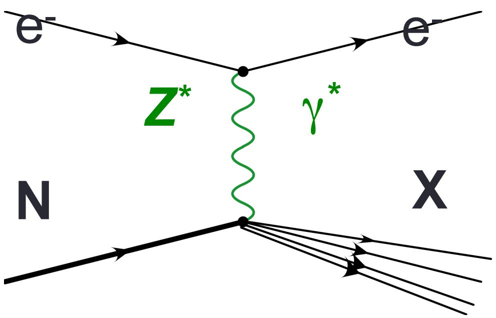
Future ep, eD → Electron Ion Collider:

- Asymmetry: FOM ~ A^2N; **$A \sim Q^2$ & $N \sim 1/Q^2$,** Acceptance
- **Collider: higher Q^2 but luminosity(?)**
- **Need accumulate > 100 fb^{-1} (possible with 10^{34} $cm^{-2}sec^{-1}$)**

Y. Li & W. Marciano first studied this at Sqrt(s) = 140 GeV (eD)

Yuxiang Zhang, AD & Krishna Kumar, a more recent estimate

A_{PV} in Deep Inelastic Scattering



A_{PV} in e-N DIS:

$$A_{PV} = \frac{G_F Q^2}{\sqrt{2}\pi\alpha}\left[a(x) + f(y)b(x)\right]$$

$$a(x) = \frac{\sum_i C_{1i} Q_i f_i(x)}{\sum_i Q_i^2 f_i(x)} \qquad b(x) = \frac{\sum_i C_{2i} Q_i f_i(x)}{\sum_i Q_i^2 f_i(x)}$$

For a ^{2}H target, assuming charge symmetry, structure functions largely cancel in the ratio

$$\boxed{a(x) = \frac{3}{10}\left[(2C_{1u} - C_{1d})\right] + \cdots} \qquad \boxed{b(x) = \frac{3}{10}\left[(2C_{2u} - C_{2d})\frac{u_v(x) + d_v(x)}{u(x) + d(x)}\right] + \cdots}$$

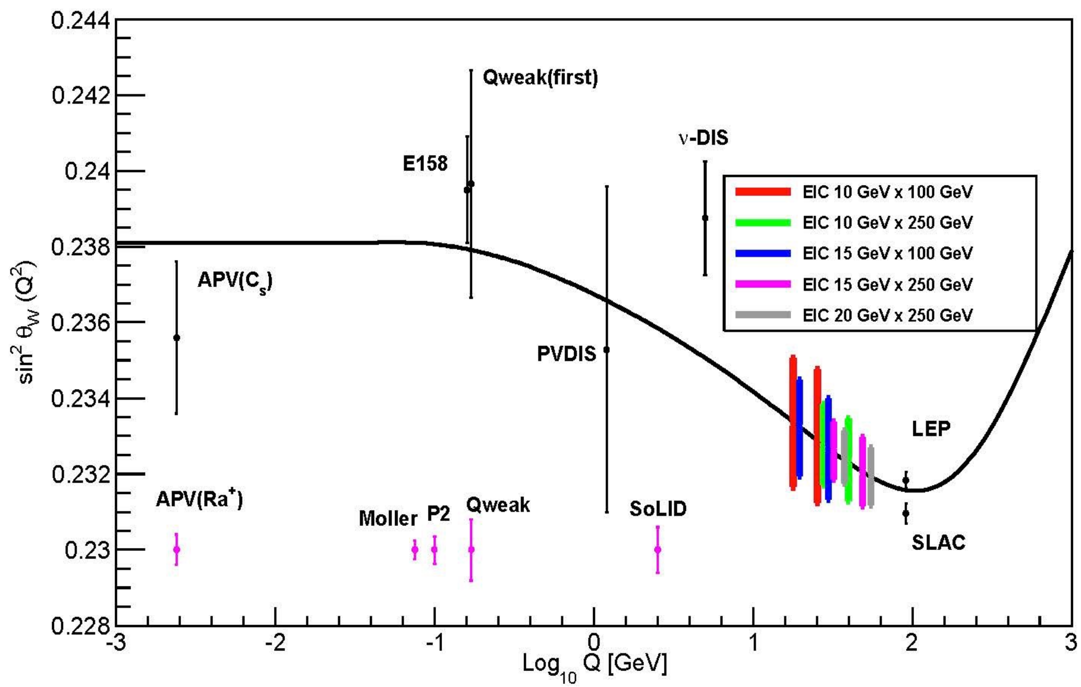
$$C_{1u} = (1 - 8\sin^2\theta_W/3)/2 \sim 0.20 \text{ Hadronic}$$
$$C_{1d} = (1 - 4\sin^2\theta_W/3)/2 \sim -0.32 \text{ Hadronic}$$
$$C_{2u} = (1 - 4\sin^2\theta_W)/2 \sim 0.04 \text{ Leptonc}$$
$$C_{2d} = -(1 - 4\sin^2\theta_W)/2 \sim -0.04 \text{ Leptonc}$$

C_{2q} sensitive to RC & New Physics

Measure A_{PV} (C_{2q}) to better than 0.5% (1-2%)

$Sin^2\Theta_W$ with the EIC: Physics Beyond SM

- Precision parity violating asymmetry measurements e/D or e/p
- Deviation from the "curve" may be hints of BSM scenarios including: Lepto-Quarks, RPV SUSY extensions, E_6/Z' based extensions of the SM

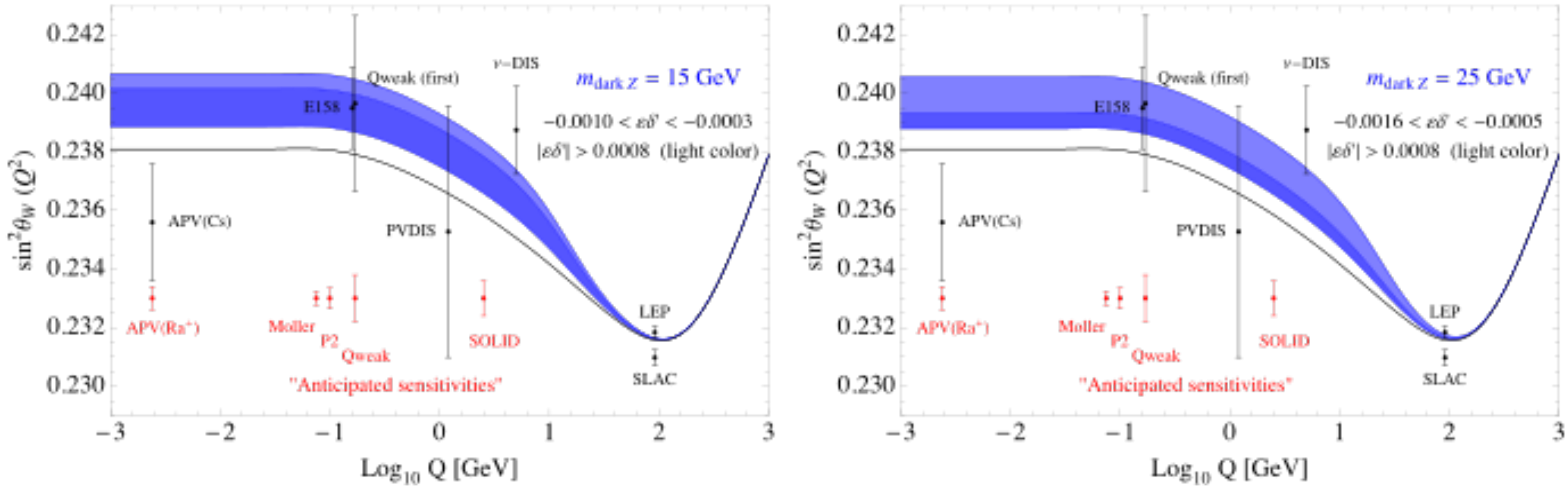


Black: measurements

Blue: near future measurements

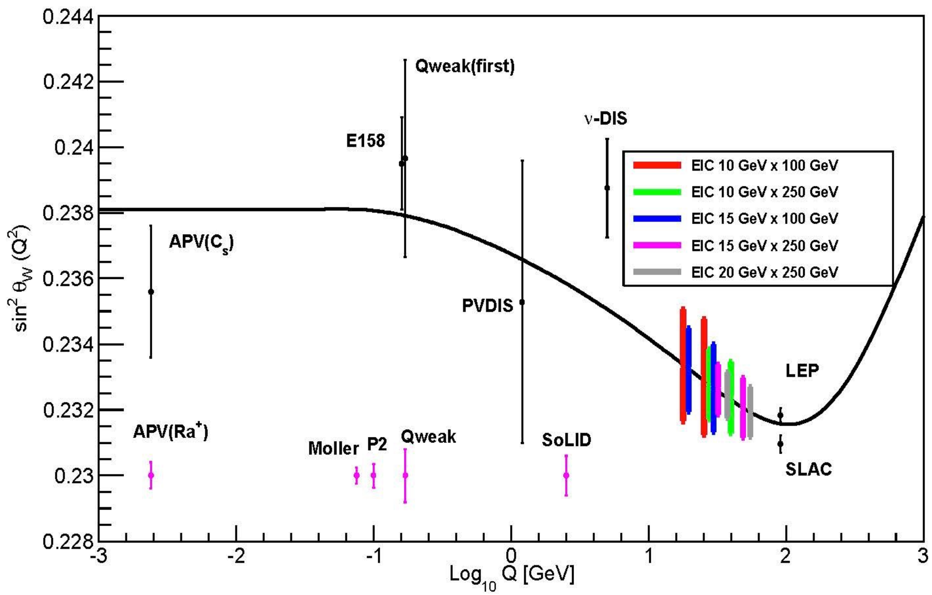
Red: US EIC projections

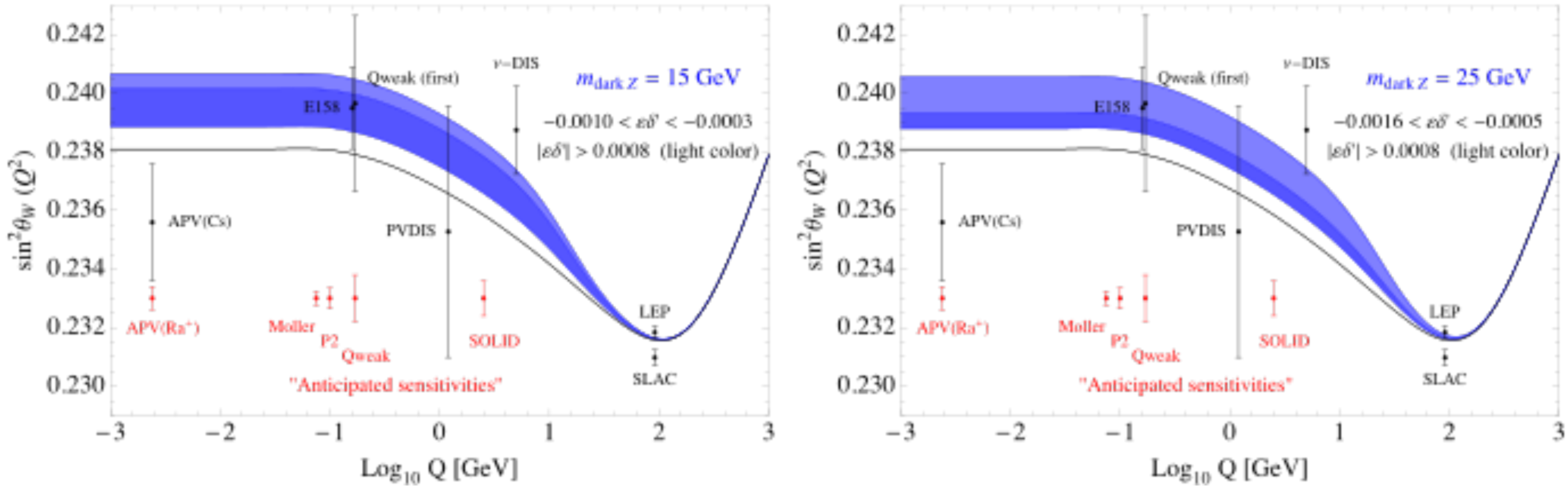
Yuxiang Zhao, A. Deshpande & K. Kumar



Low Q^2 Weak Mixing Angle Measurements and Rare Higgs Decays

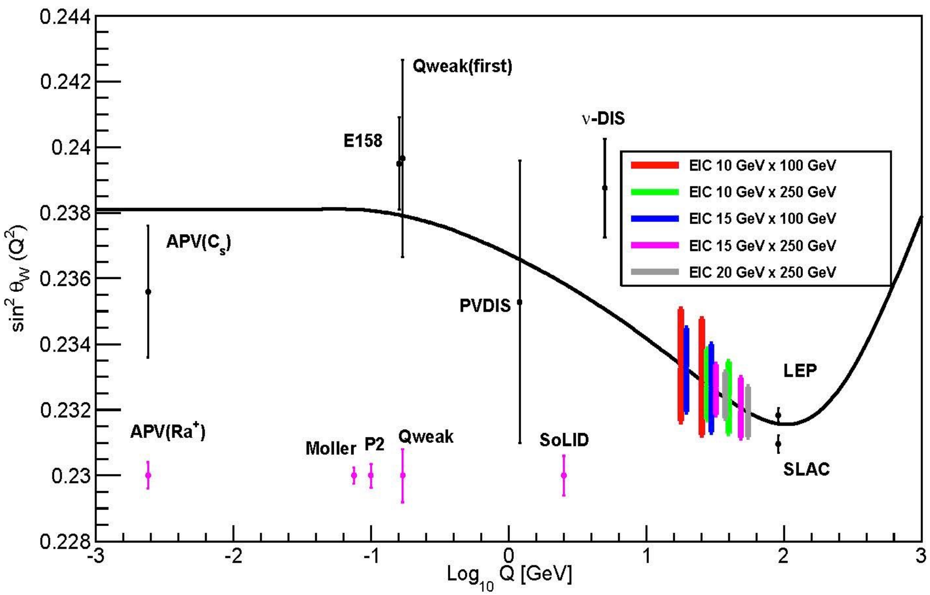
and William J. Marciano[1]





Low Q^2 Weak Mixing Angle Measurements and Rare Higgs Decays

and William J. Marciano[1]



Dark Z Study: arXiv:1507.00352

EIC Study .

Y. Zhao, *A. Deshpande & K. Kumar et al.*

Search for Charged Lepton Flavor Violation with the EIC

Why search for Lepton Flavor Violation?

Why search for Lepton Flavor Violation?

- Every conservation law in the SM of Physics is anticipated to have a “symmetry” associated with it

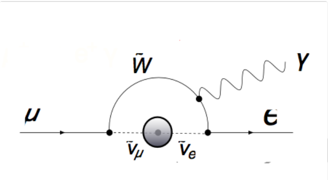
Why search for Lepton Flavor Violation?

- Every conservation law in the SM of Physics is anticipated to have a “symmetry” associated with it
- We have no knowledge of a symmetry that asserts Lepton Flavor Conservation, and yet its violation has not been seen

Why search for Lepton Flavor Violation?

- Every conservation law in the SM of Physics is anticipated to have a "symmetry" associated with it
- We have no knowledge of a symmetry that asserts Lepton Flavor Conservation, and yet its violation has not been seen

Although neutrino oscillation implies charged lepton flavor violation within the SM, observation of processes such as $\mu \rightarrow e\gamma$, very challenging due to small neutrino mass

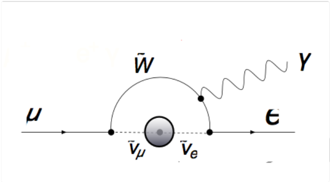


$$\mathrm{BR}(\mu \to \mathbf{e}\gamma) = \frac{3\alpha}{32\pi}\left|\sum_{i=2,3} U^*_{\mu i} U_{ei} \frac{\Delta m^2_{1i}}{M^2_W}\right|^2 < 10^{-54}$$

Why search for Lepton Flavor Violation?

- Every conservation law in the SM of Physics is anticipated to have a "symmetry" associated with it
- We have no knowledge of a symmetry that asserts Lepton Flavor Conservation, and yet its violation has not been seen

Although neutrino oscillation implies charged lepton flavor violation within the SM, observation of processes such as $\mu \rightarrow e\gamma$, very challenging due to small neutrino mass



$$\mathrm{BR}(\mu \to \mathrm{e}\gamma) = \frac{3\alpha}{32\pi}\left|\sum_{i=2,3} U^*_{\mu i} U_{ei} \frac{\Delta m^2_{1i}}{M^2_W}\right|^2 < 10^{-54}$$

Many models of physics beyond the SM predict rates of charged LFV larger than those within the SM and within reach of existing and near-future experiments.

LVF is hence an important probe of physics beyond the SM

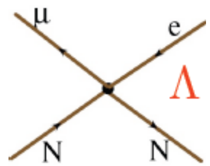
Experimental Studies of LFV

$$L_{\mathrm{CLFV}} = \frac{m_\mu}{(\kappa+1)\Lambda^2}\bar{\mu}_R \sigma_{\mu\nu} e_L F^{\mu\nu} + \frac{\kappa}{(\kappa+1)\Lambda^2}\bar{\mu}_L \gamma_\mu e_L \left(\sum \bar{q}_L \gamma^\mu q_L\right)$$

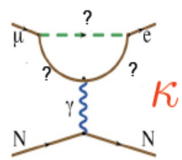
- Lepton flavor violation searches have predomina and 2nd generation leptons (μ,e) → "LFV(1,2)"

- SINDRUM (μ→3e)
- SINDRUM II (μ→e)

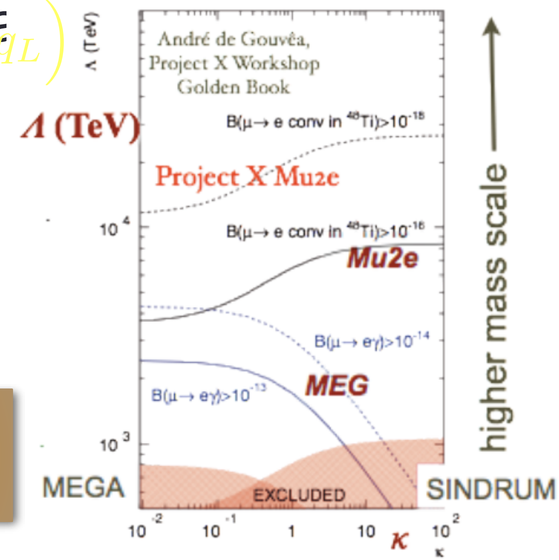
- MEGA (μ→eγ)



Contact Interactions



SUSY & heavy neutrinos



Project X

- LFV(1,3) limits few orders of magnitudes **weaker** than LVF(1,2)
  - BaBar (τ→eγ)
  - BELLE (τ→3e)
- Future measurements at Mu2e@FNAL, MEG@PSI also focus on LFV(1,2)

Opportunity for EIC

Opportunity for EIC

- Limits on **LFV(1,3)** experimental searches are significantly worse than those for LFV(1,2)

Opportunity for EIC

- Limits on **LFV(1,3)** experimental searches are significantly worse than those for LFV(1,2)
- 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)

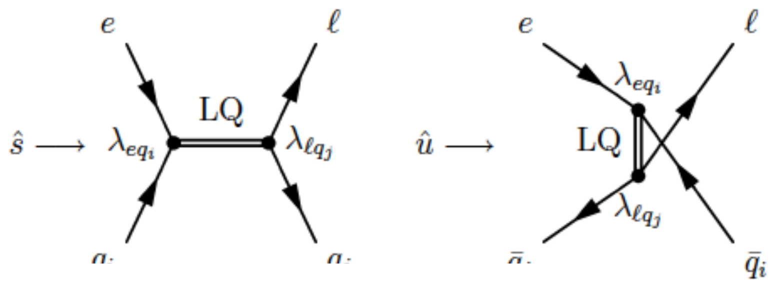
Opportunity for EIC

- Limits on **LFV(1,3)** experimental searches are significantly worse than those for LFV(1,2)
- 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%

Opportunity for EIC

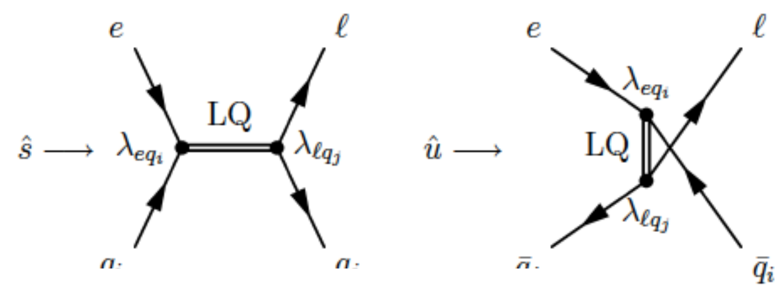
- Limits on **LFV(1,3)** experimental searches are significantly worse than those for LFV(1,2)
- There are BSM models which specifically allow and enhance LFV(1,3) over LFV(1,2)
  - Minimal Super-symmetric Seesaw model:J. Ellis et al. Phys. Rev. D66 115013 (2002)
  - SU(5) GUT with leptoquarks: I. Dorsner 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%
- Clearly there is an opportunity for EIC: “icing on the cake”

LFV phenomenology



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

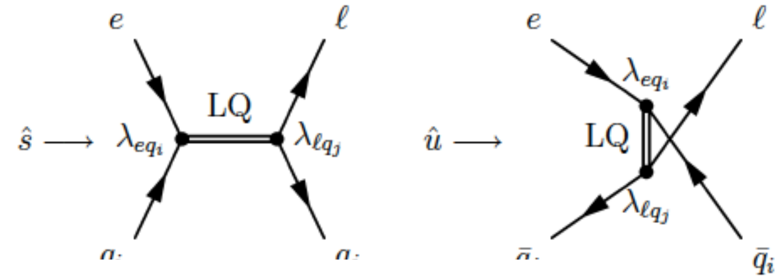
LFV phenomenology



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

- 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

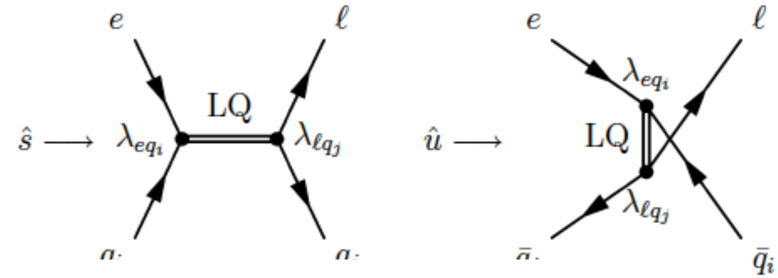
LFV phenomenology



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

- 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, $\lambda = 0.3$ (for example one particular LQ…)
  - **Then go over various values of M_{LQ} i.e. ratios: z = $\lambda i \lambda j / M_{LQ}^2$**

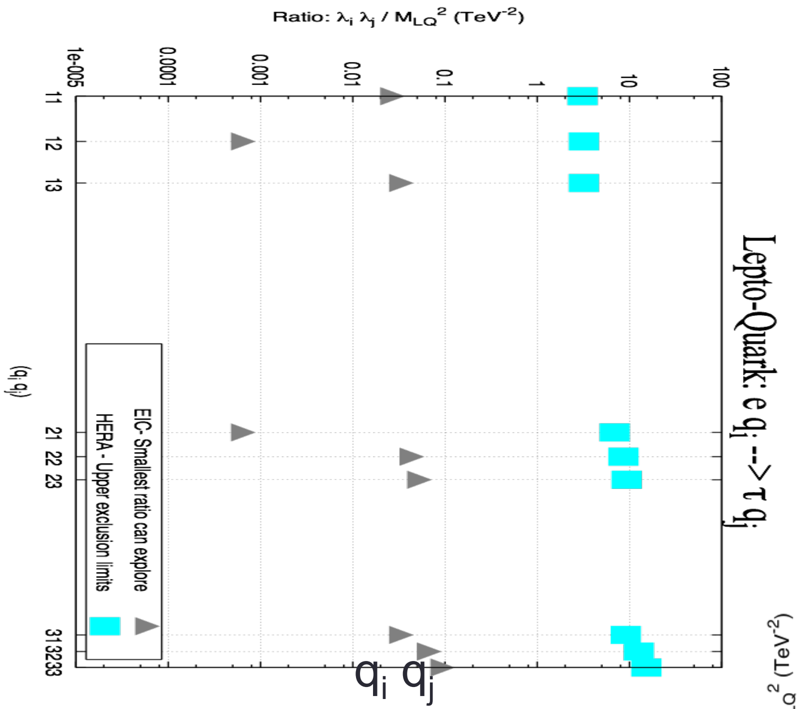
LFV phenomenology



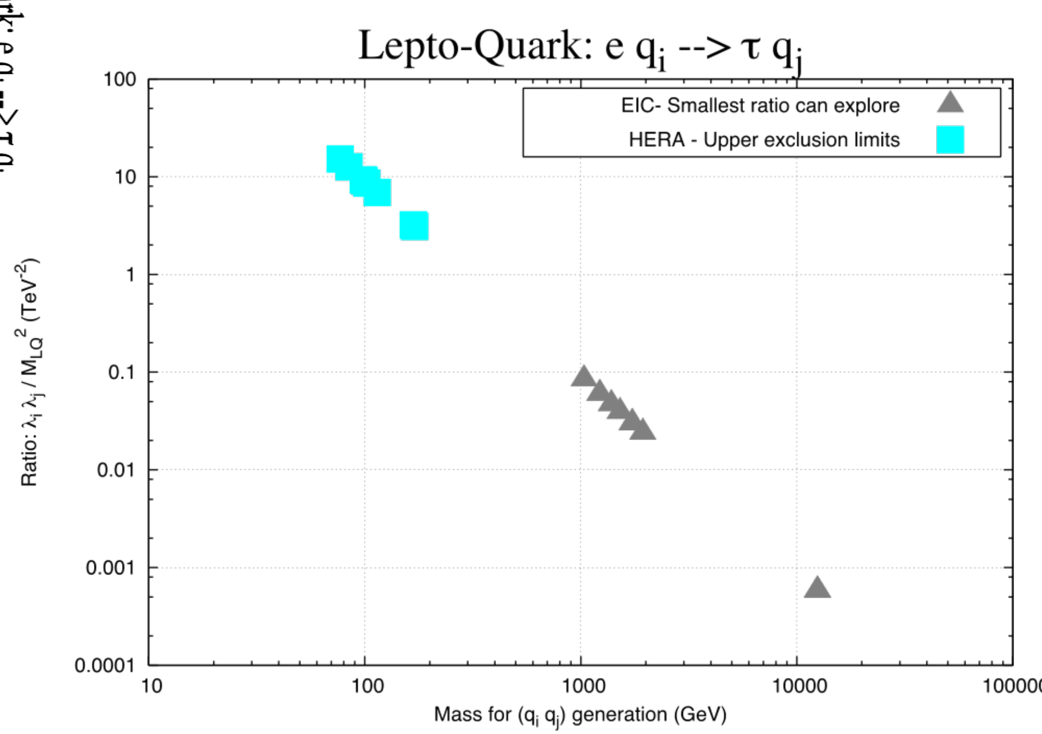
$$\frac{d^2\sigma_s}{dx\,dy} = \underbrace{\frac{1}{32\pi\hat{s}}}_{\text{phase space}} \cdot \underbrace{\frac{\lambda_{eq}^2\lambda_{\ell q}^2\hat{s}^2}{(\hat{s}^2 - m_{\mathrm{LQ}}^2)^2 + m_{\mathrm{LQ}}^2\Gamma_{\mathrm{LQ}}^2}}_{\text{Breit-Wigner LQ propagator term}} \cdot \underbrace{q_i(x,\hat{s})}_{\text{parton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

- 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, $\lambda = 0.3$ (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 mom.) with **different angular correlations i** SM vs. LQ

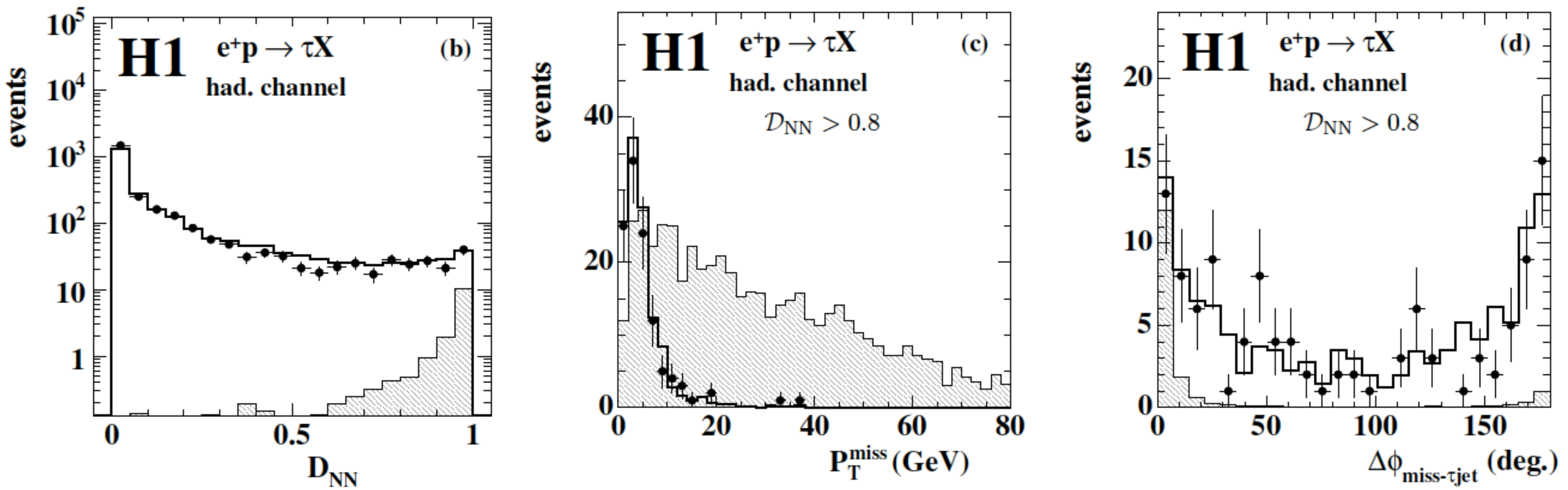
How does EIC compare with HERA?



Private communications: M. Gonderinger



Tau Jet identifiers and selections



- Reconstructed D_{NN} variable for Tau into hadronic channel
- $P_{T(miss)}$ distribution
- $\Delta\phi_{miss\text{-}TauJet}$

H1 Collaboration, F. D. Aaron et al., Phys. Lett. B 701 20 (2011)

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 identification 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.

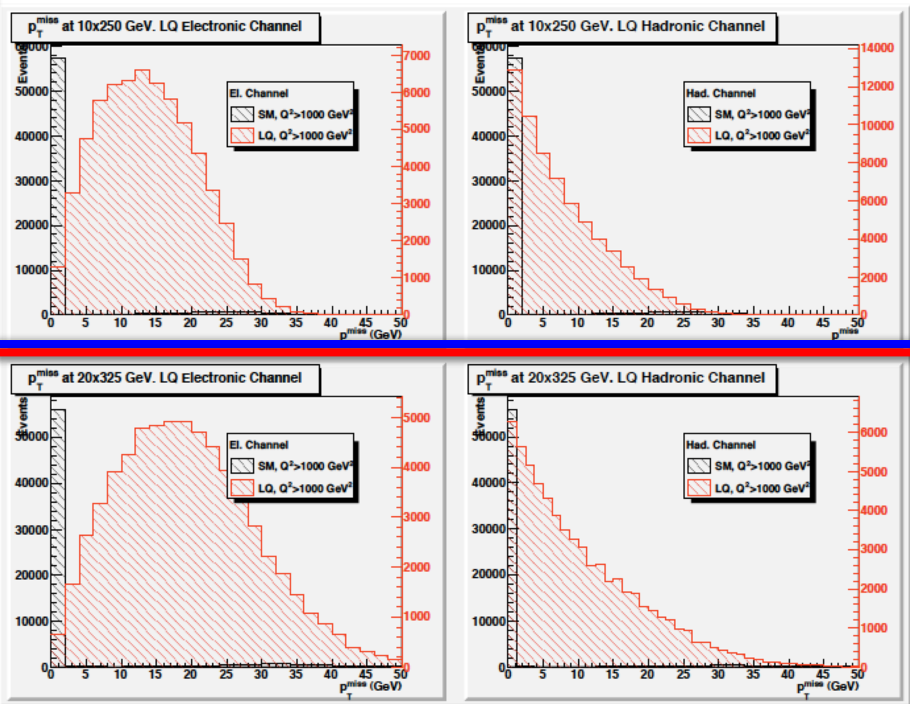
C. Faroughy (UG Researcher now at U. Maryland),
+S.Teneja (post doc, now a research faculty in Canada) & AD

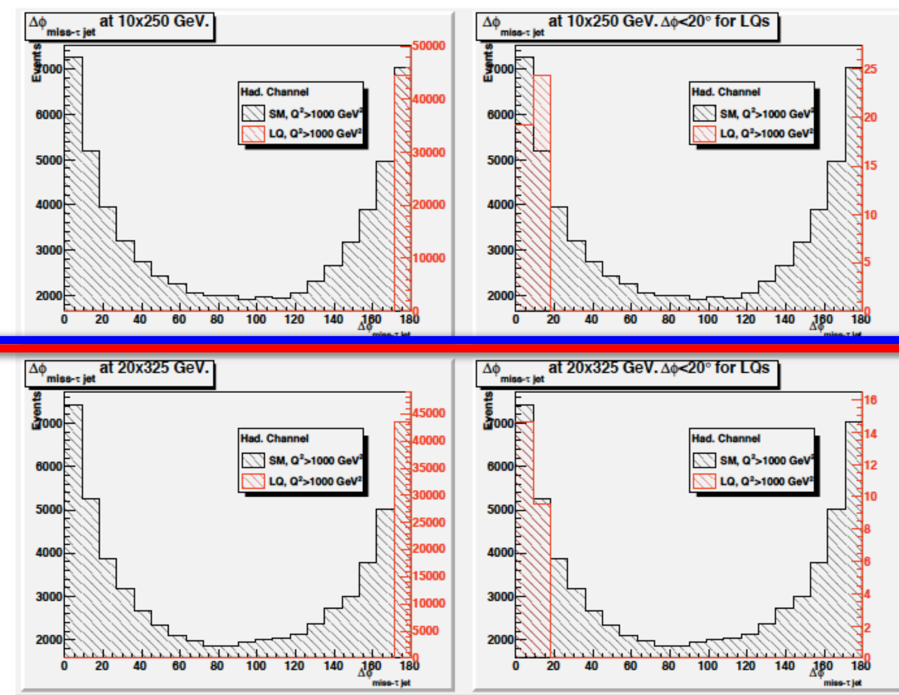
SM vs. LPQ

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

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

10 x 250





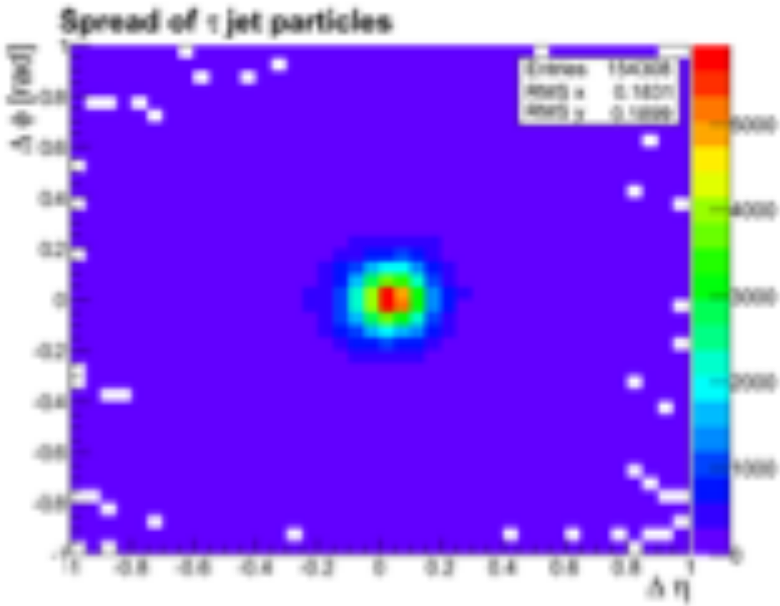
20 x 325

Based on similar studies at HERA:

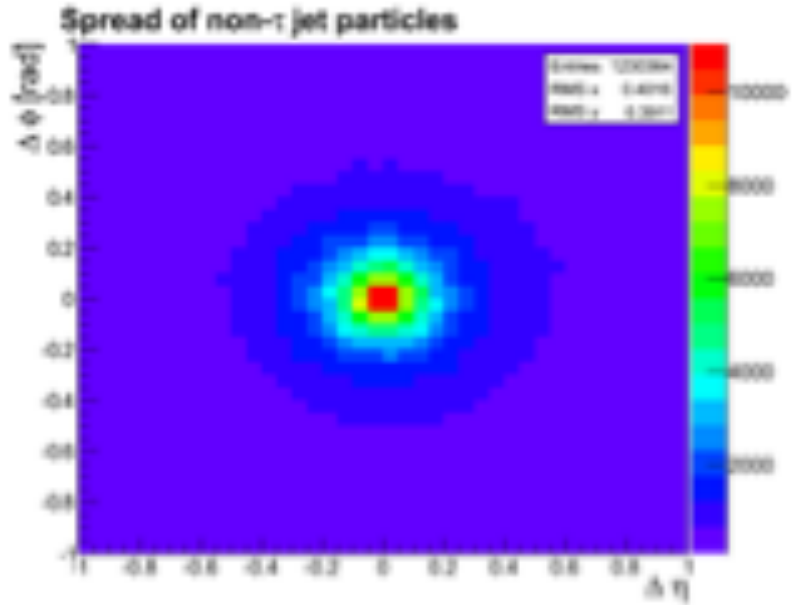
H1 Collaboration, F. D. Aaron et al., Phys. Lett. B 701 20 (2011)

ZEUS Collaboration, S. Chekanov et al., Eur. Phys. J. C44 463 (2005)

Jets at Generator Level (first look)



τ decay jet

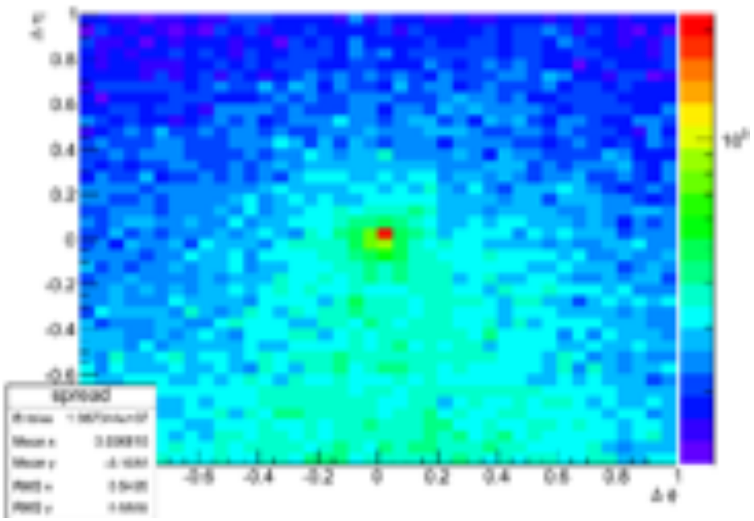


Normal hadronic jet in DIS

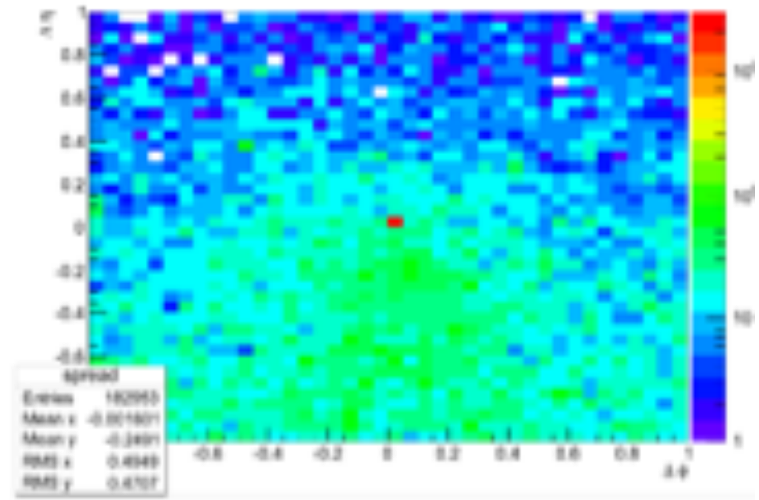
DIS Jet width seems to be about 2 times the τ-jet width

Through G4 Calorimeter Detector

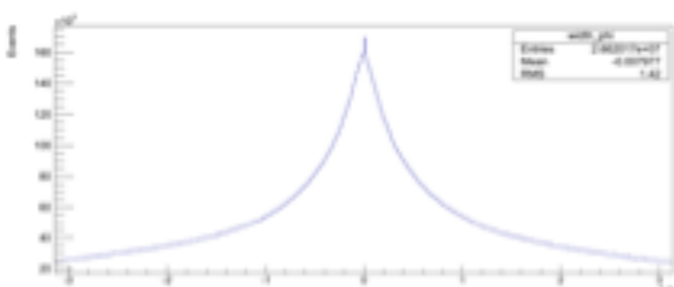
Jet width seems narrower in “pencil-like” jets, compared to “hadronic jets”

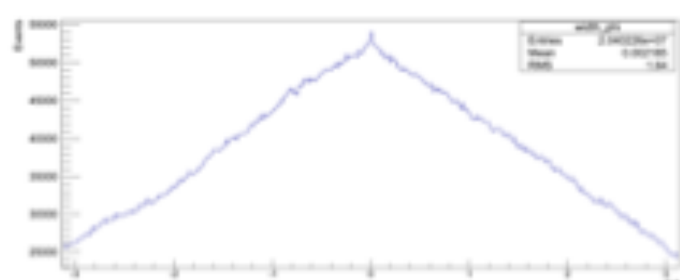


τ decay jet



Normal hadronic jet in DIS





To Do (e-τ studies)

Geant4 simulations for future EIC collider detectors now becoming available, we plan to do detailed signal searches using those.

Jets studies:

- What effect of Collider CM Energy variation
- What definitions of jets at 100-140 GeV Center of Mass?
- What PID/Tracking on hadronic final states and hence jets
- …

Eventually, would have a full feasibility study

Study underway….

Summary & prospects:

- Although EIC is primarily a QCD-Machine, opportunities in EW & BSM physics searches have been identified

- EW structure function measurements: could begin with the 1st Stage of the EIC (asymmetries are large)
- $\mathrm{Sin}^2\Theta_W$ ➔ High luminosity, precision polarimetry
- Lepto-Quark searches ➔ High luminosity & 4π detector: detailed and quantitative estimates need to be made.

- Core Physics of EIC will be presented by R. Yoshida (Saturday)

- Invitation: Other-ideas welcome. Please join us in the effort to define, finalize and realize the EIC Physics program