EIC at JLab - design considerations and detector overview

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Outline

1. Introduction

2. Exclusive kinematics and Detector Requirements

3. Interaction Region and Detector Concepts

Why a collider?

Easier to reach high CM energies ($E_{cm}^2 = s$)

- $s = 4E_eE_p$ for colliders (*e.g.*, 4 x **9** x **60** = 2160 GeV^2)
- $s = 2E_eM_p$ for fixed target experiments (*e.g.*, 2 x **11** x 0.938 = 20 GeV^2)

Spin physics with high figure of merit

- Unpolarized FOM = ***Rate = Luminosity · Cross Section · Acceptance***
- Polarized FOM = ***Rate* · (*Target Polarization*)^2 · (*Target Dilution*)^2**
- No *dilution* and high ion polarization (also *transverse*)
- No current (*luminosity*) limitations, no holding fields (*acceptance*)
- No *backgrounds* from target (Møller electrons)

Easier detection of reaction products

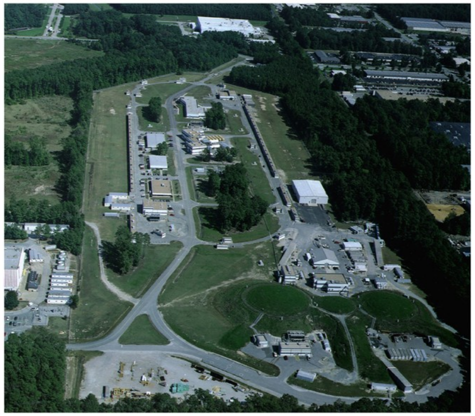
- Can optimize kinematics by adjusting beam energies
  - Laws of physics do not depend on reference frame, but measured uncertainties do!
- More symmetric kinematics improve acceptance, resolution, particle identification, etc
- Access to neutron structure with deuteron beams through spectator tagging ($p_p \neq 0$)

Past and future e-p and e-A colliders

HERA, Hamburg, 1992-2007

27 GeV e on 920 GeV p, L = 5 x 10^{31}

LHeC, CERN, Geneva



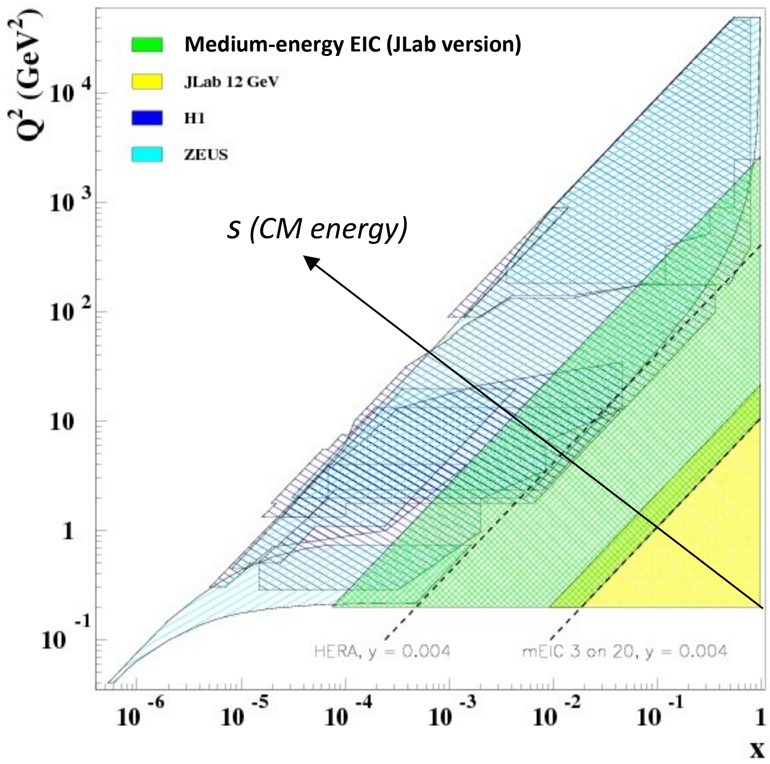
Jefferson Lab, Newport News, VA

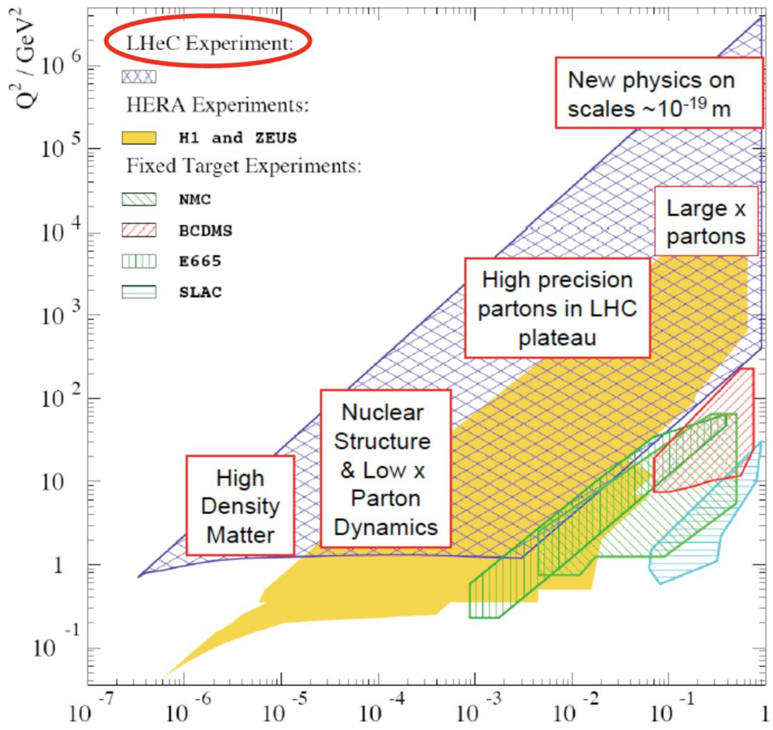
EIC

Brookhaven, Upton, NY

Kinematic coverage

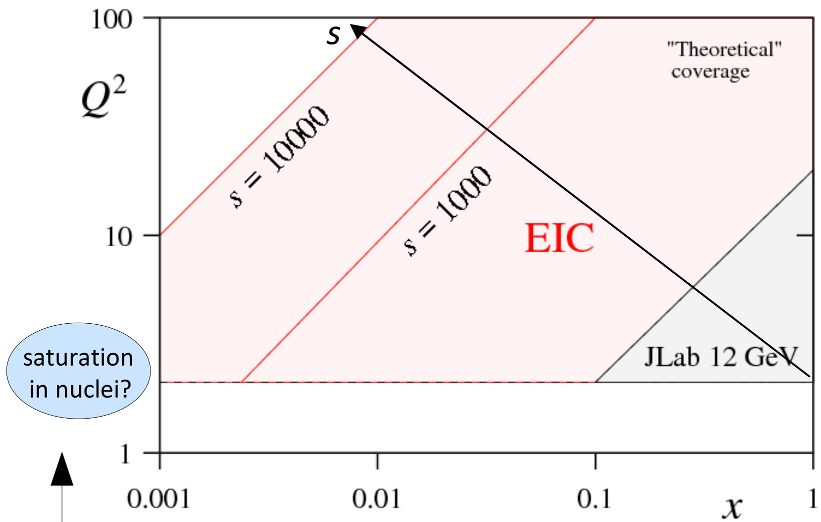
$Q^2 \sim xys$



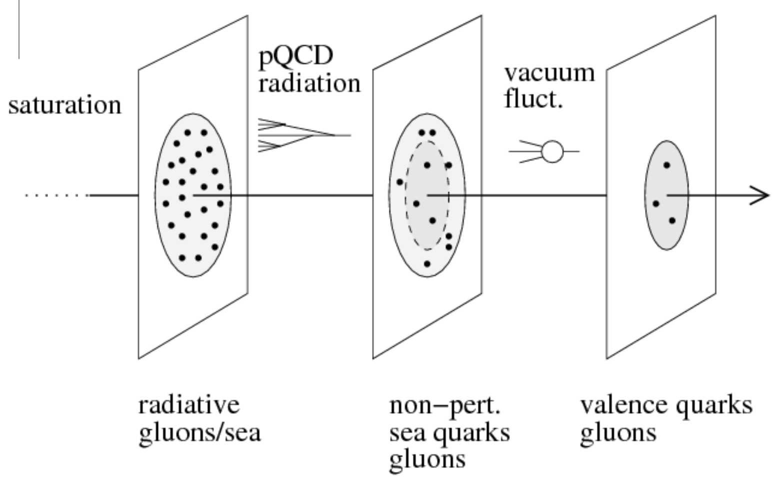


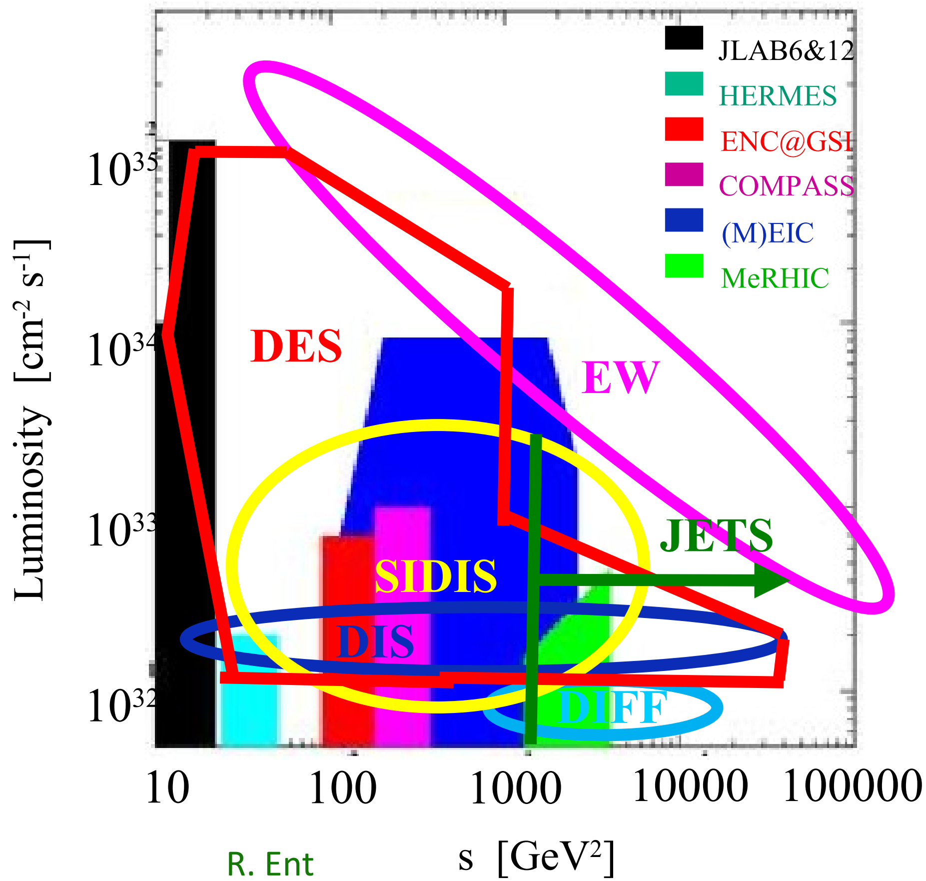
- Medium-energy EIC
  - Overlaps with and is complementary to the LHeC (both JLab and BNL versions)
  - Overlaps with JLab 12 GeV (JLab version)
  - Provides high luminosity and excellent polarization for the range in between
    - Currently only low-statistics fixed-target data available in this region

Physics, kinematic coverage, and luminosity



C. Weiss

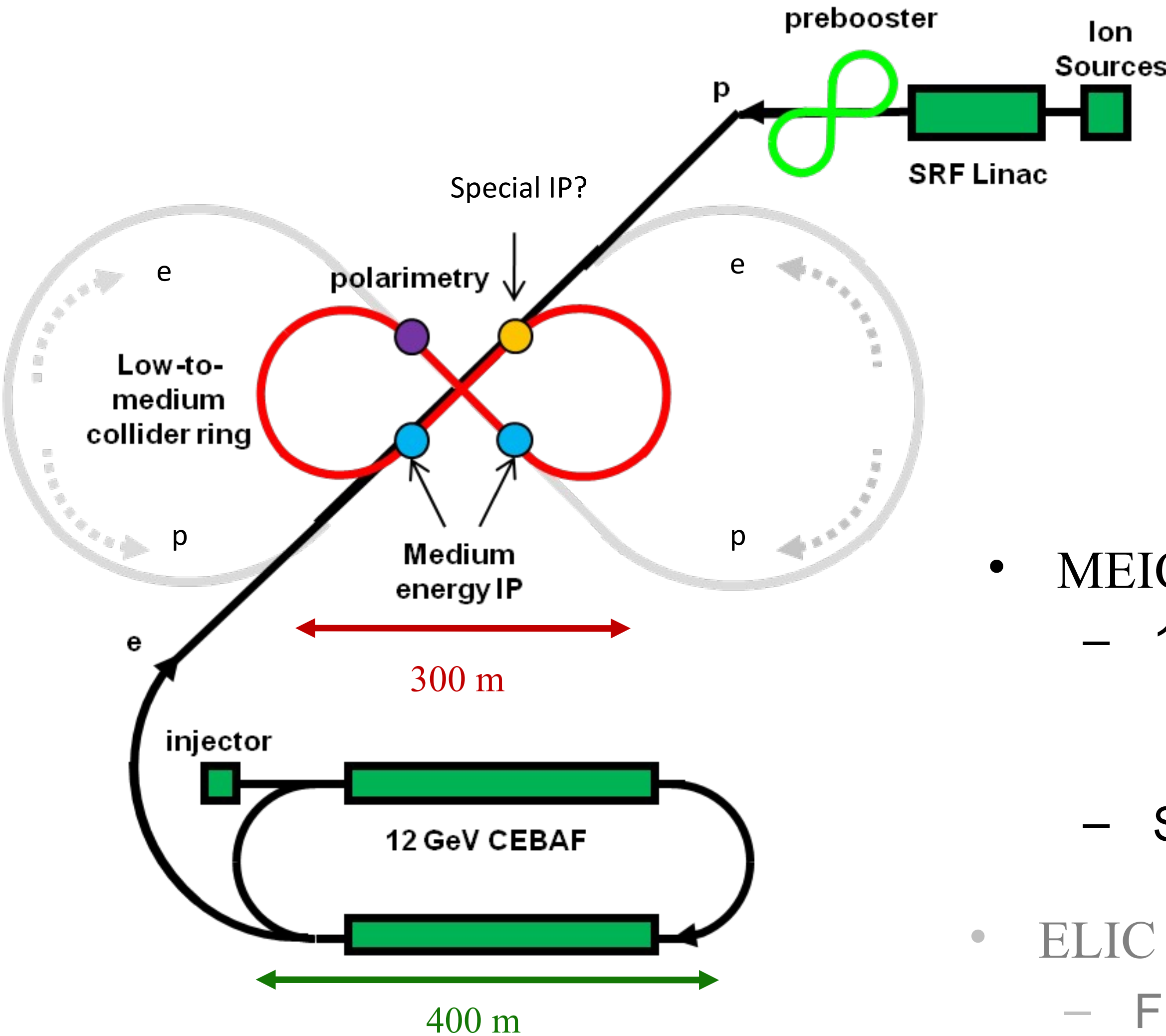




R. Ent

- Right plot (L vs. s) is a projection on the diagonal of the left one (Q^2 vs. x)

MEIC@JLab – Detector Layout



Electron energy: 3-11 GeV

Proton energy: 20-60 GeV

$s = 250 - 2650\ \text{GeV}^2$

Can operate in parallel with fixed-target program

- MEIC = EIC@JLAB
  - 1-2 high-luminosity detectors
    - Luminosity ~ $10^{34}\ \text{cm}^{-2}\text{s}^{-1}$
    - Low backgrounds
  - Special detector?
- ELIC = high-energy EIC@JLab
  - Future upgrade?

Hadronic background – comparison with HERA

Random background

- Dominated by interaction of beam ions with residual gas
- Worst case at maximum energy

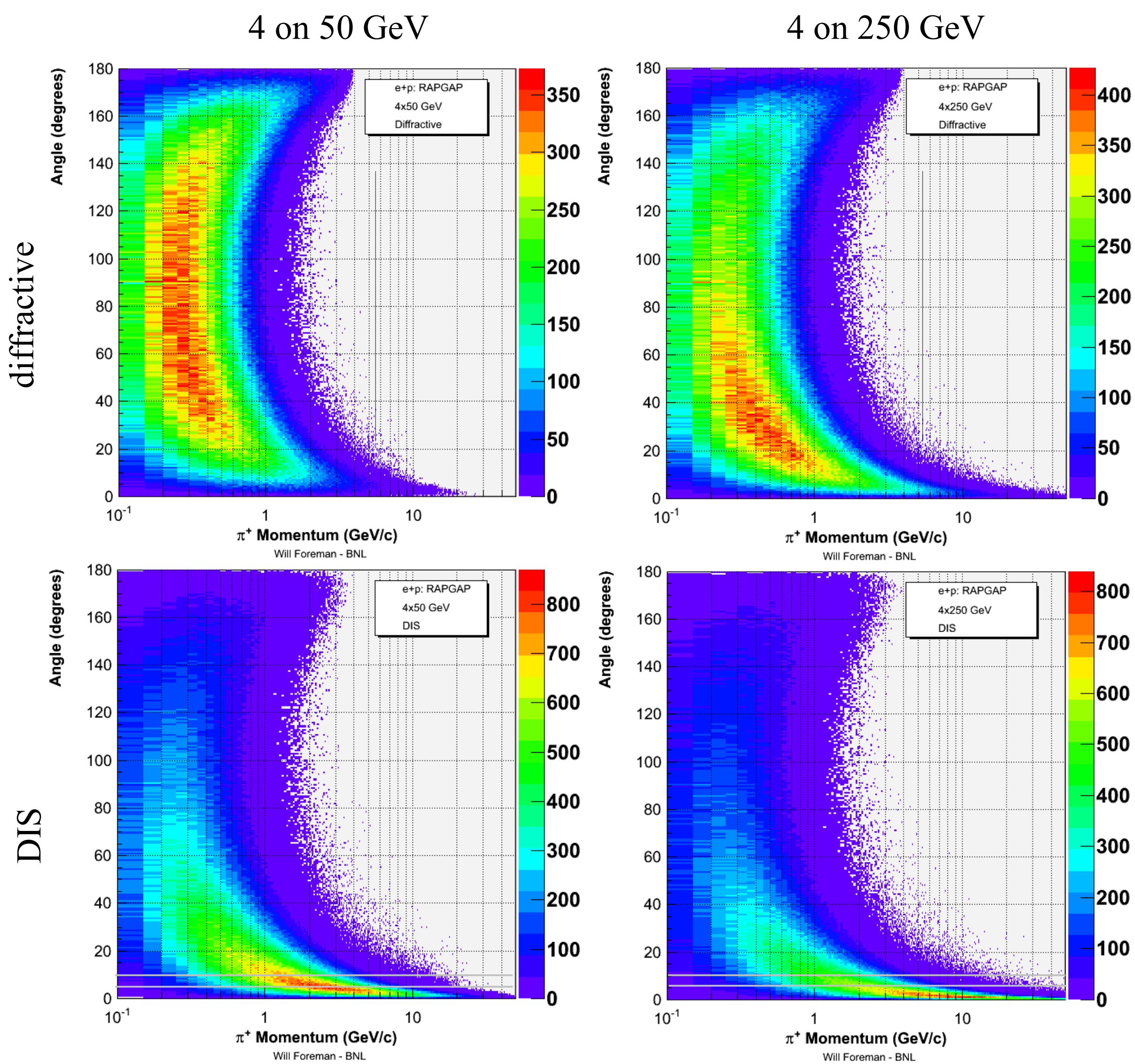
Comparison of MEIC (11 on 60 GeV) and HERA (27 on 920 GeV)

- Distance from arc to IP: 30 m / 120 m = 0.25
- Average hadron multiplicity: $(2640 / 100000)^{1/4} = 0.4$
- p-p cross section (fixed target): $\sigma(60\text{ GeV}) / \sigma(920\text{ GeV}) = 0.7$
- At the same current and vacuum, MEIC background is 7% of HERA

Hadronic background is not a problem for the MEIC

- At constant vacuum the MEIC can run 1.4 A with comparable background
- Vacuum is much easier to maintain in a short section of a small ring
- MEIC luminosity is more than 100 times higher (depending on kinematics)
- Signal-to-background will be considerably better at the MEIC

Diffractive and SIDIS mesons



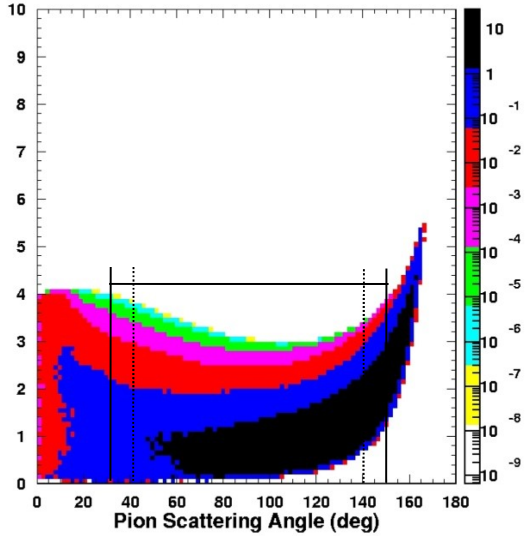
- Both reactions produce high-momentum mesons at small angles

- For exclusive reactions, this constitutes our background!

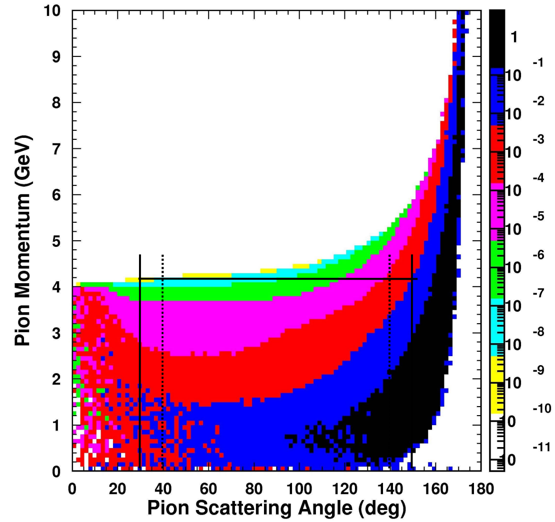
Exclusive meson kinematics

$ep \rightarrow e'\pi^+ n$

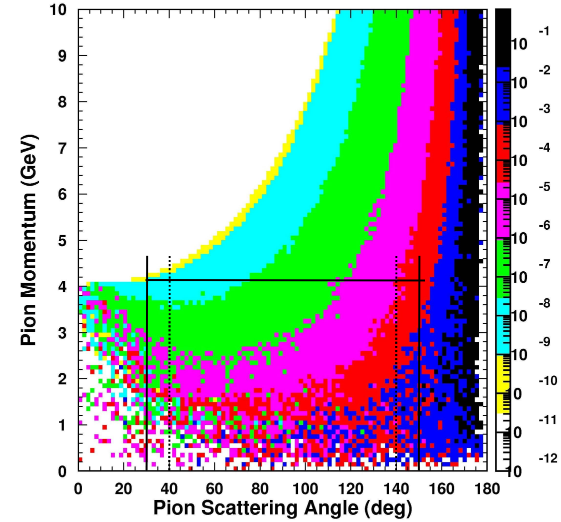
4 on 12 GeV

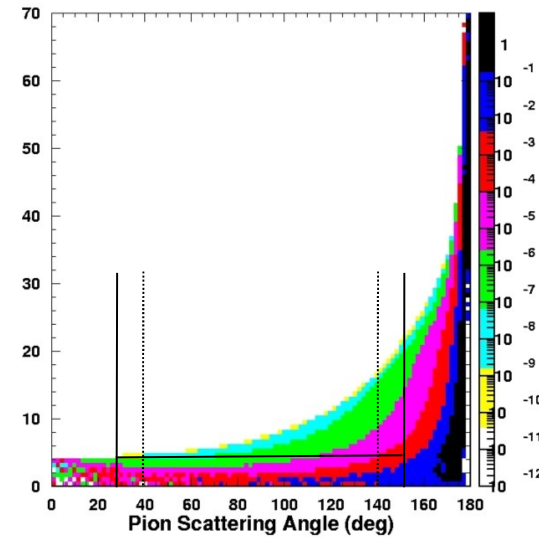


4 on 30 GeV



4 on 250 GeV

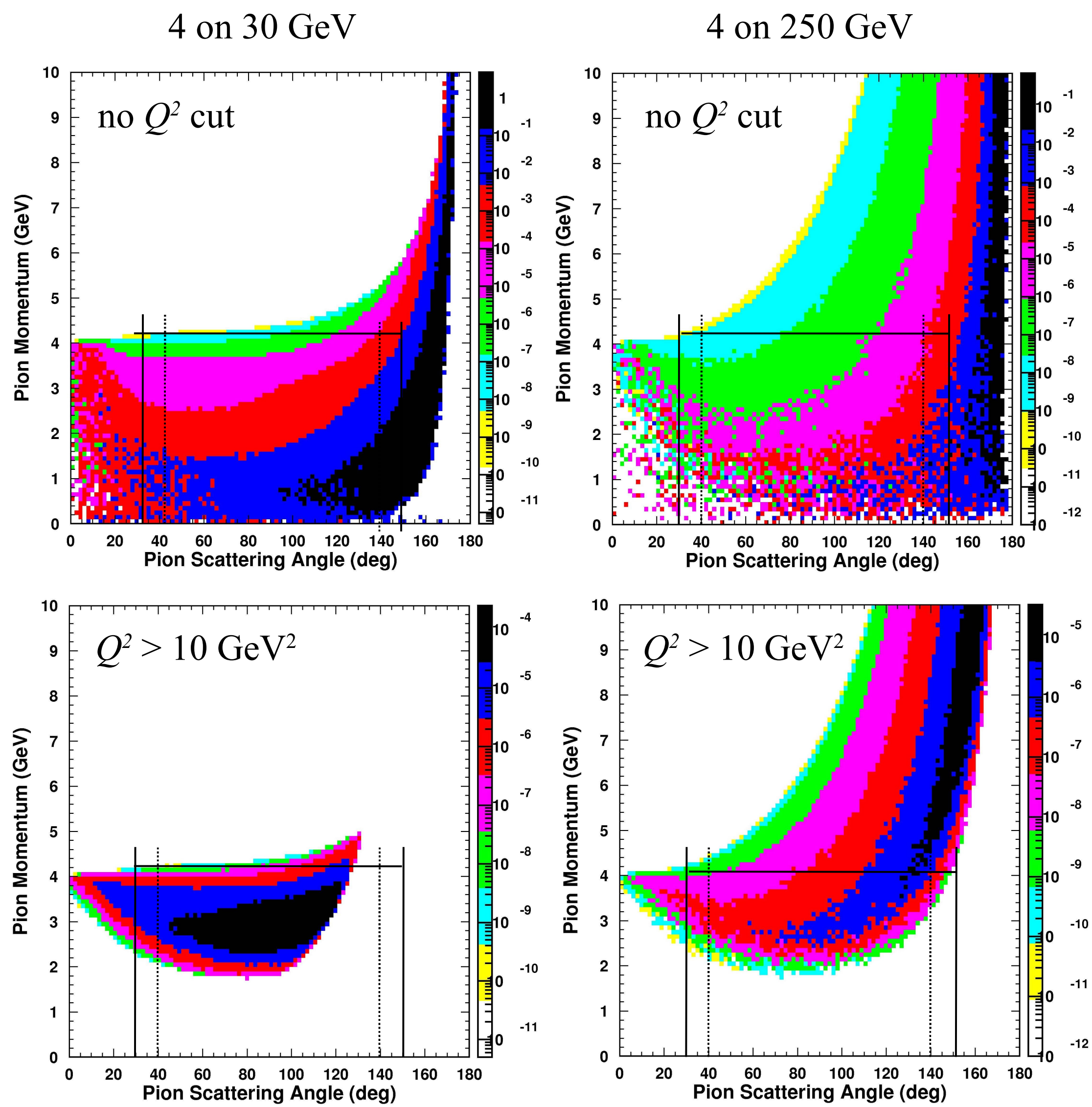




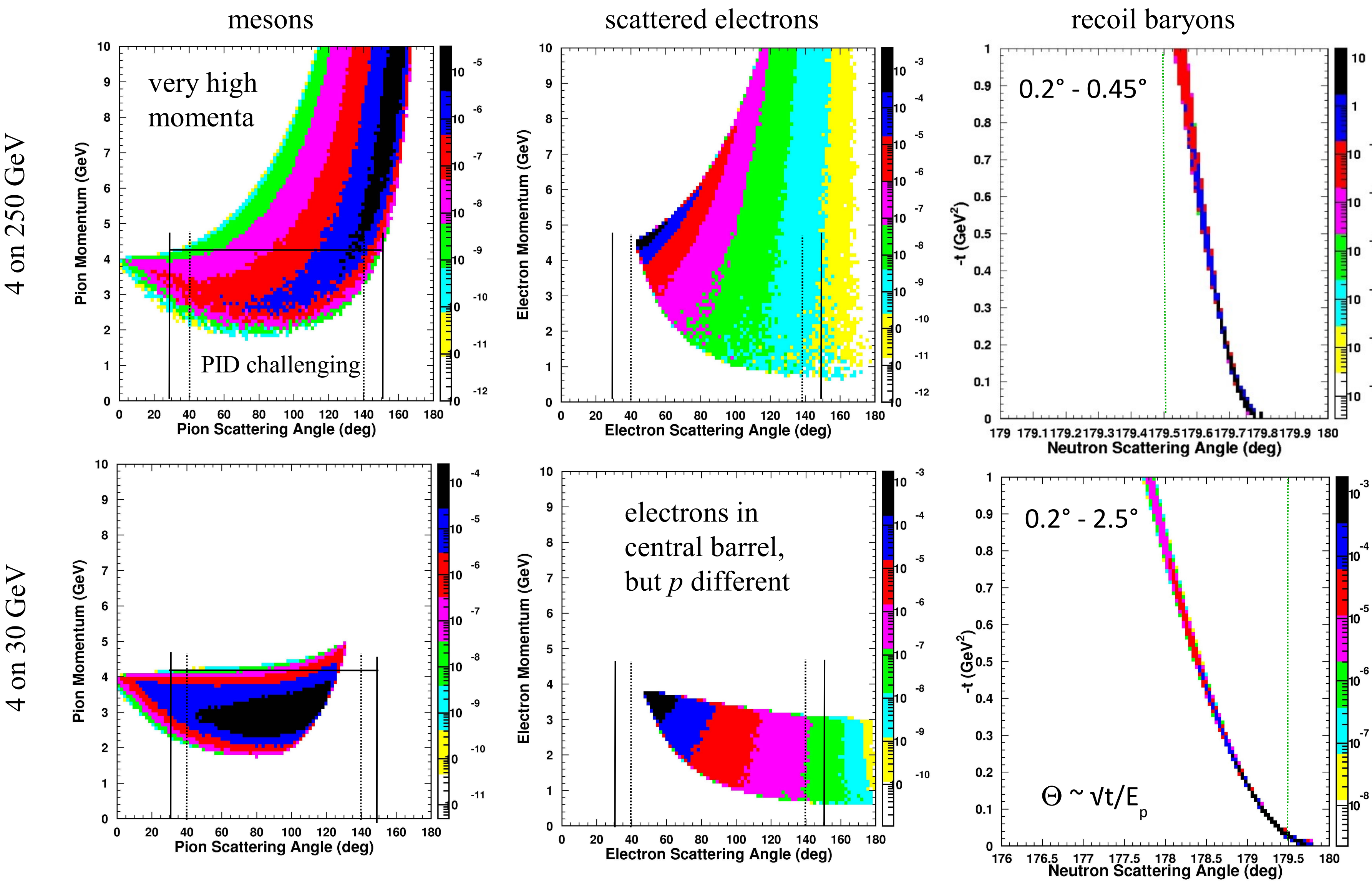
- Meson kinematics integrated over all Q^2
  - Vertical lines at 30° (possibly up to 40°) indicate transition from central barrel to endcaps
  - Horizontal line indicates maximum meson momentum for π/K separation with a DIRC
- Problem: cross section falls rapidly with Q^2
  - Higher Q^2 is needed due to factorization requirements for GPD determination, but plots shown are dominated by photoproduction.

Exclusive meson kinematics at higher Q^2

- The meson momentum distribution has a strong Q^2-dependence
- No mesons at small angles where solenoid resolution is poor (both kinematics).
- Momentum resolution ($dp/p \sim p$ from tracking), a challenge at 250 GeV
- DIRC not useful at 250 GeV.



Exclusive light meson kinematics ($Q^2 > 10$ GeV^2)

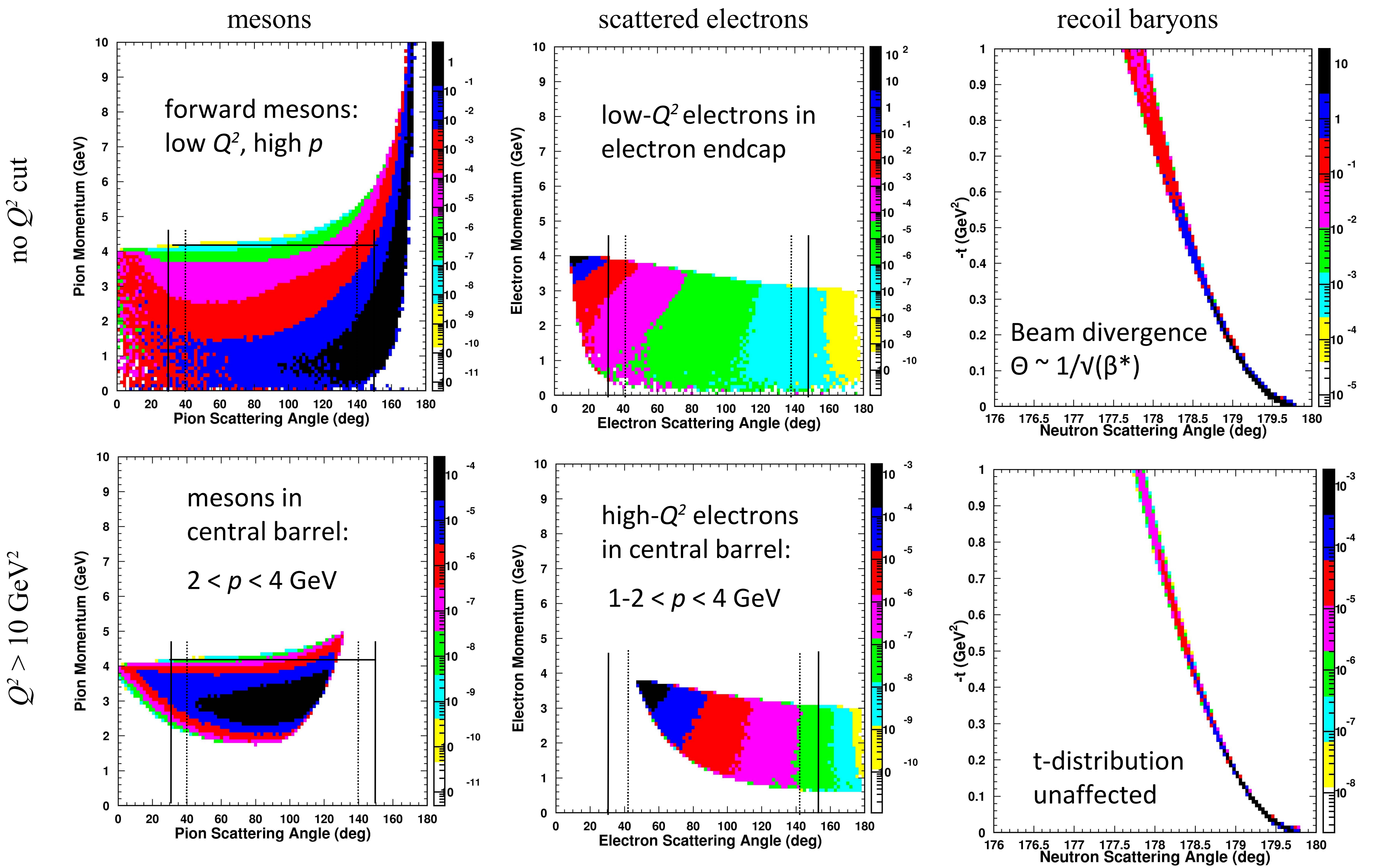


$ep \rightarrow e'\pi^+ n$

Tanja Horn

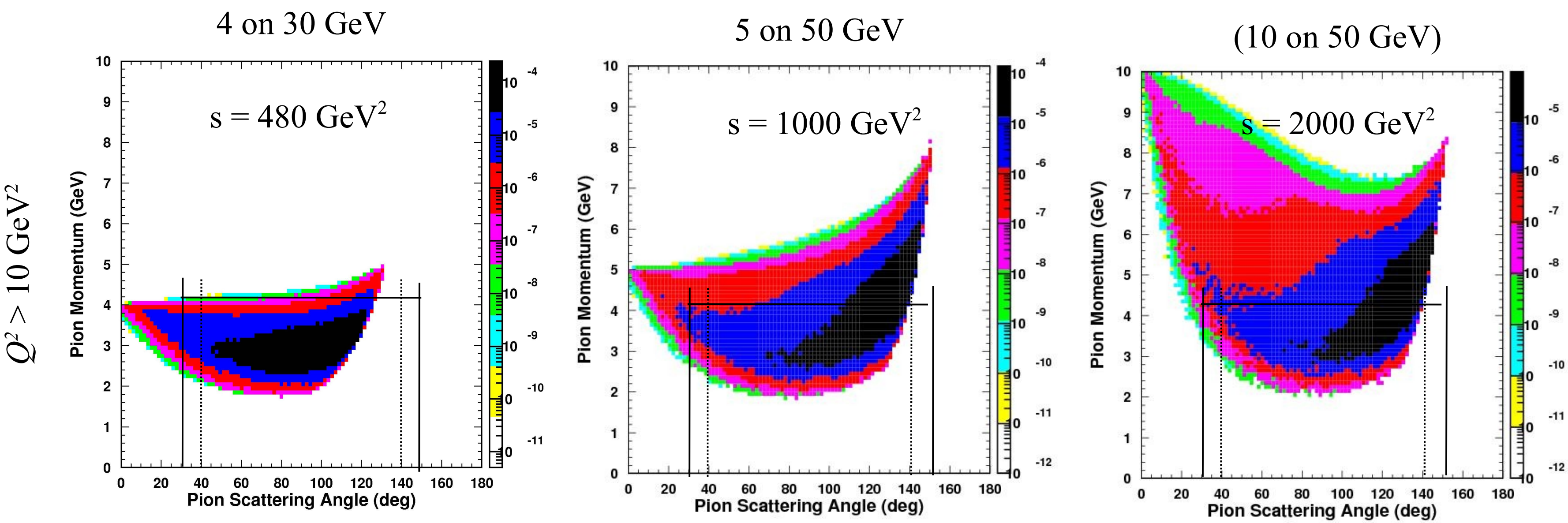
“Symmetric” kinematics – 4 on 30 GeV

$ep \to e'\pi^+ n$



Tanja Horn

DES at higher electron energies



- With 12 GeV CEBAF, MEIC@JLab has the option of using higher electron energies
  - DIRC no longer sufficient for π/K separation
- RICH based on ALICE design might push the limit from 4 to 7 GeV
  - Requires a more detailed study
- RICH would extend the minimum diameter of solenoid from approximately 3 to 4 m
  - Main constraint since bore angle is not an issue in JLab kinematics

DES detector and Interaction Region concepts

1. (Crab) crossing angle and symmetric kinematics

- Allow a compact, hermetic forward ion detector
- Can be used to eliminate synchrotron radiation
- Produce electron and meson momenta comparable to CLAS
  - Good momentum resolution
  - Good particle identification

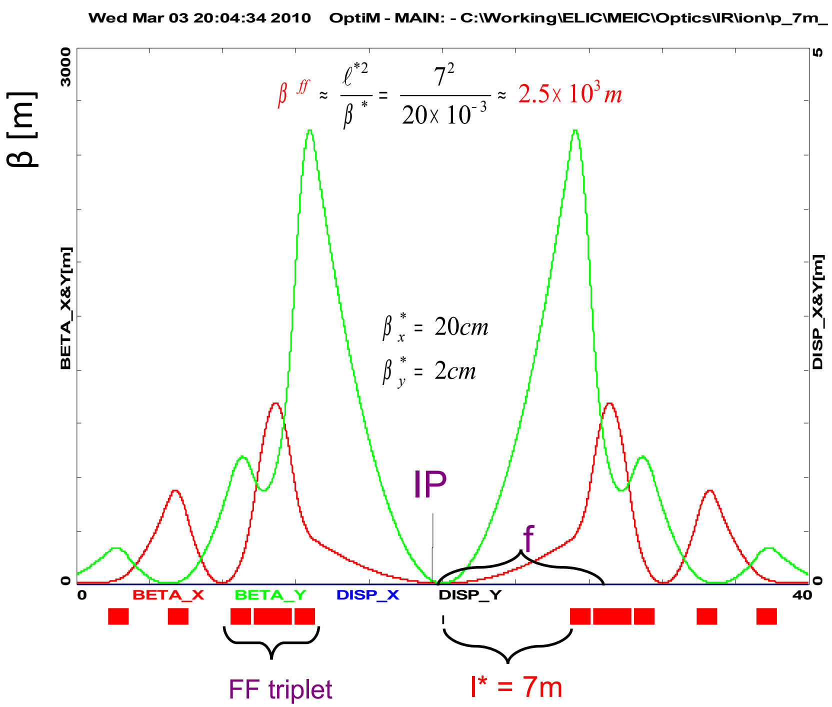
2. Detector Challenges

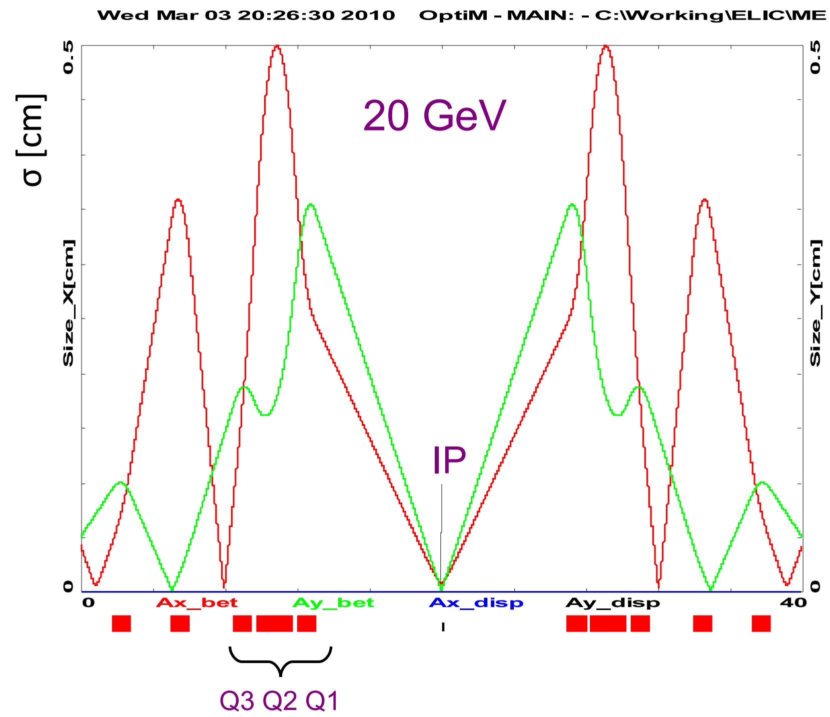
- Optimization of forward ion detection
- PID at higher electron energies (5-10 GeV)
- Beam divergence and transverse momentum spread

3. Interaction Region challenges

- Quad gradients and apertures
- Chromatic corrections (~ f/β^*) limit β^{max} to ~ 2.5 km

Ion quadrupole apertures (preliminary optics)





- Beam size: σ = √(ε β m / p)
- Focal length: f = √(β* β^max)
- Quad gradient: G ~ p / f
- Peak field: rG

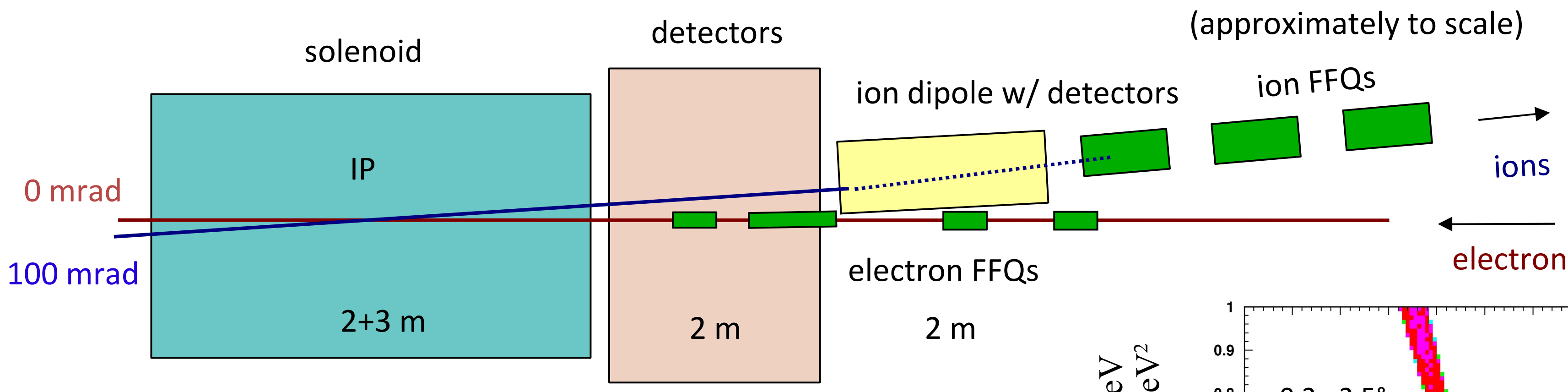
Gradients: 20 - 60 GeV

Q1 G[T/m] =	-38 to -115
Q2 G[T/m] =	33 to 99
Q3 G[T/m] =	-33 to -100

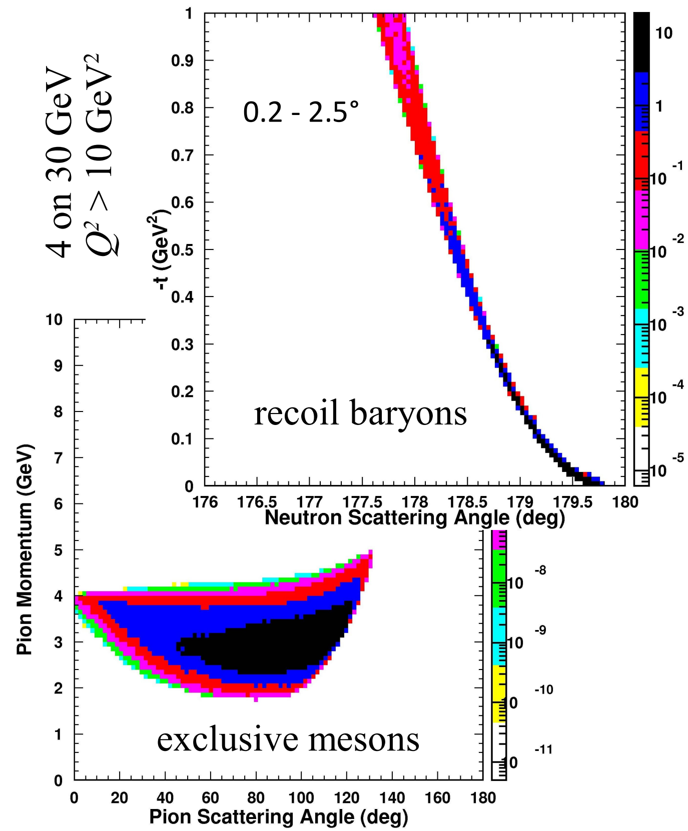
Beam size (σ): up to 5 mm
Aperture (r): 10-15 σ
Peak field (rG): up to 7T

- IP quad gradients limits the size of apertures, imposing a low-energy cut-off
- Covering a wide ion energy range (for acceleration and experiment) requires larger β^* and focal length

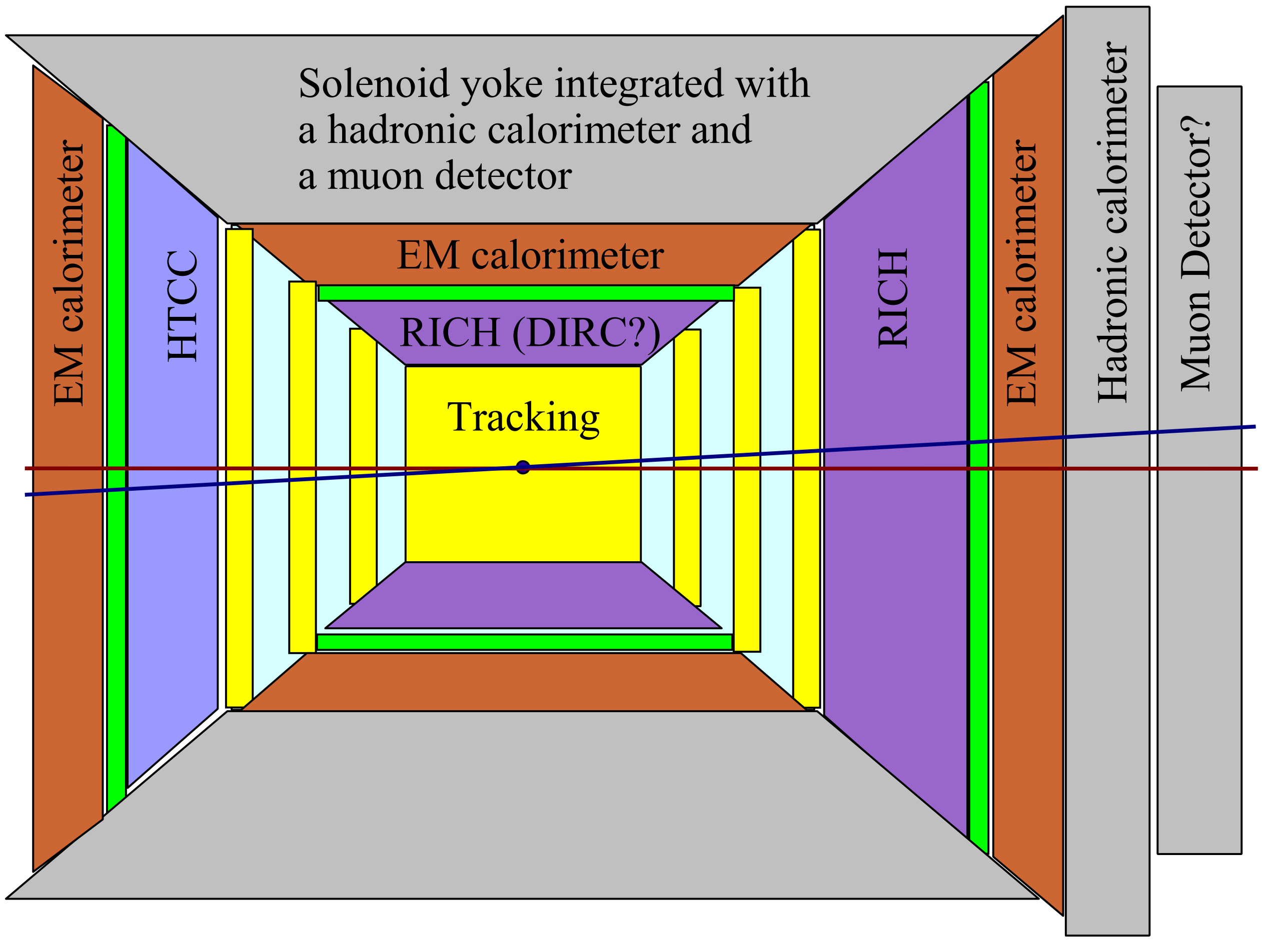
Forward detection with crossing angle



- Downstream dipole on ion beam line has several advantages
  - No synchrotron radiation
  - Electron quads can be placed close to IP
  - Dipole field not determined by electron energy
  - Positive particles are bent *away* from the electron beam
  - Long recoil baryon flight path gives access to low *-t*
  - Dipole does not interfere with RICH and forward calorimeters
    - Excellent acceptance (hermeticity)



Overview of central detector layout



(not to scale)

Time-of-flight detectors shown in green

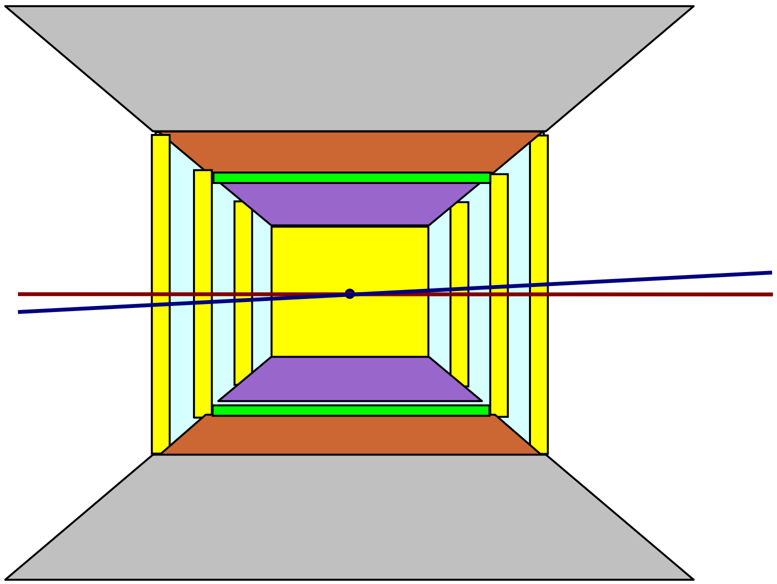
ions

electrons

DIRC would have thin bars arranged in a cylinder with readout after the EM calorimeter on the left

- IP is shown at the center, but can be shifted left
  - Determined by desired bore angle and forward tracking resolution

Central detector



Solenoid Yoke, Hadron Calorimeter, Muons

- 4T solenoid with 3-4 m diameter
- Hadronic calorimeter and muon detector integrated with the return yoke (*c.f.* CMS)

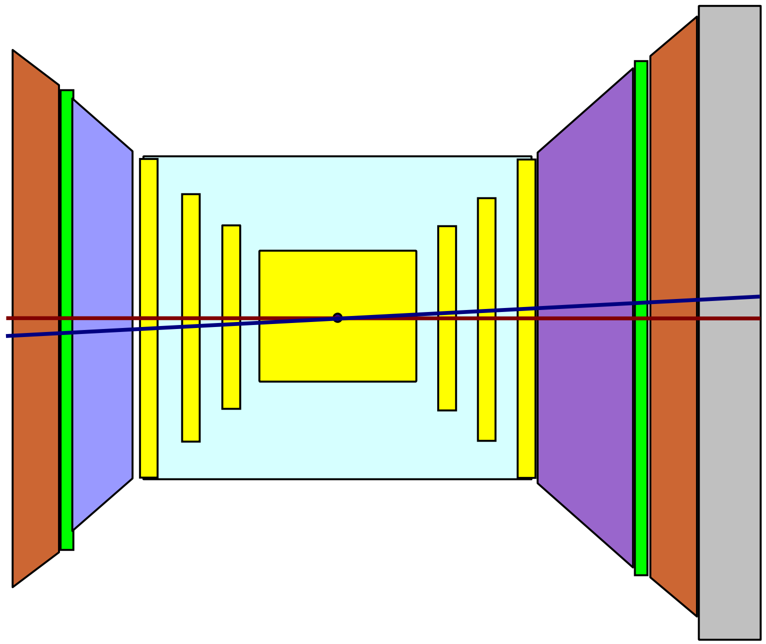
Particle Identification

- TOF for low momenta
- π/K separation options
  - DIRC (BaBar) up to 4 GeV
  - RICH (ALICE) up to 7 GeV?
- e/π separation options
  - Lead-tungsten
    - Very good resolution
  - Tungsten powder / scintillating fiber
    - Very compact, 6% resolution

Tracking

- Central Tracker
  - Microchannel or silicon detectors?
    - CLAS12 experience?
  - Integrated vertex tracker

Detector endcaps



Tracking

- Forward / Backward
  - IP may be shifted to electron side
  - 3 regions of drift chambersg

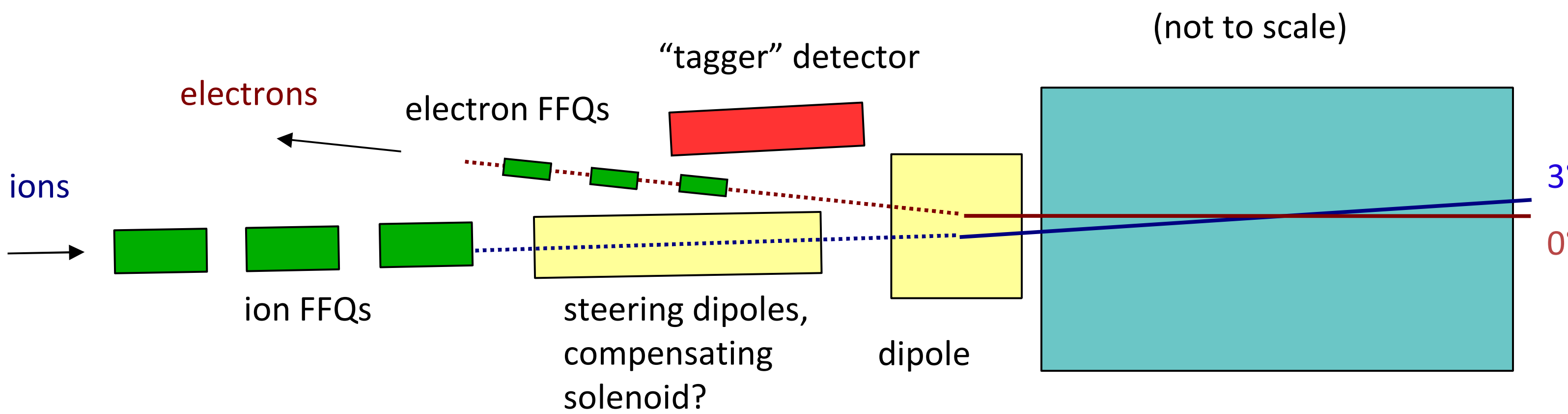
Electron side (left)

- Bore angle: ~45° (line-of-sight from IP)
- High-Threshold Cerenkov
- Time-of-Flight Detectors
- Electromagnetic Calorimeter

Ion side (right)

- Bore angle: 30-40° (line-of-sight from IP)
- Ring-Imaging Cerenkov (RICH)
- Time-of-Flight Detectors
- Electromagnetic Calorimeter
- Hadronic Calorimeter
- Muon detector (at least small angles)
  - Important for J/Ψ photoproduction

Low-Q^2 tagging? – very conceptual!



- Synchrotron radiation is not an issue for outgoing electrons
  - Can use strong dipole to cover small scattering angles
- Still need steering dipole on *either* the electron or ion beam line to compensate for independently adjustable beam energies
- Ion quads can be placed closer on electron side.

Summary

- A medium energy EIC overlaps with HERA and JLab 12 GeV
  - Complementary to proposed LHeC
- Placement and design of the Interaction Regions allow running at high currents with small backgrounds.
- For any given *s*, the MEIC can provide a choice of kinematics
- A concept for a detector taking advantage of a beam crossing angle and “symmetric kinematics” has been developed.
- Need input from users on wide range of processes for optimization
- Detector workshop at JLab (late April)!

Backup

Multiplicity for High-Energy Hadron Interactions

F. Braccella and L. Popova, J. Phys. G 21 (1995) 1379

Simple fit to data in article: total multiplicity ~ 2s1/4

s1/2 (GeV)	n (article)	2s1/4
20 (ISR/FNAL)	9	9
540 (SPS)	45	46
1800	82	86

CLAS (L = 2 x 1034) n = 3.7 (close to empirical observation in CLAS)

CLAS12 (L = 1 x 1035) n = 4.2

Factor of 2-4

EIC Ecm = 12 (MEIC-Low E) 7

51 (MEIC-Hi E) 14

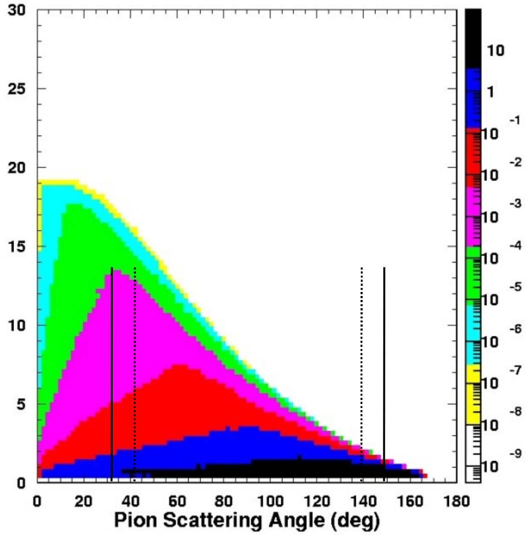
100 (ELIC) 20

HERA 319 35

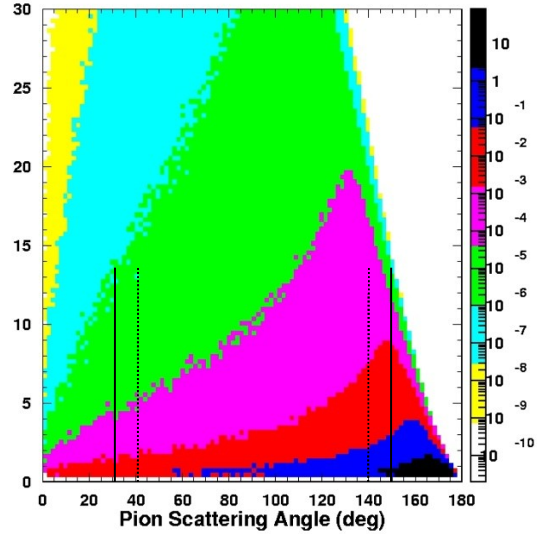
Exclusive meson kinematics – Q^2

$ep \rightarrow e'\pi^+ n$

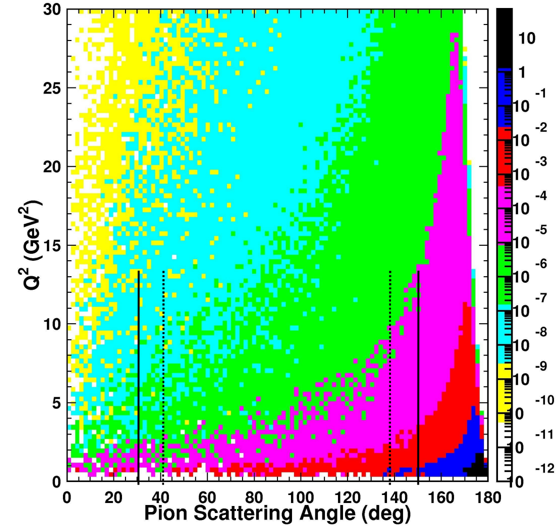
4 on 12 GeV

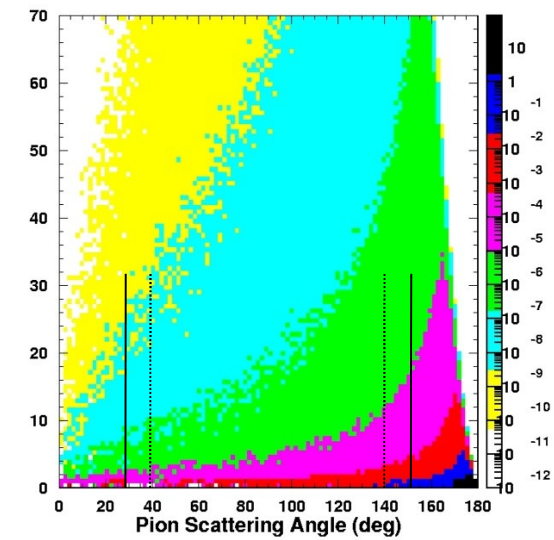


4 on 60 GeV



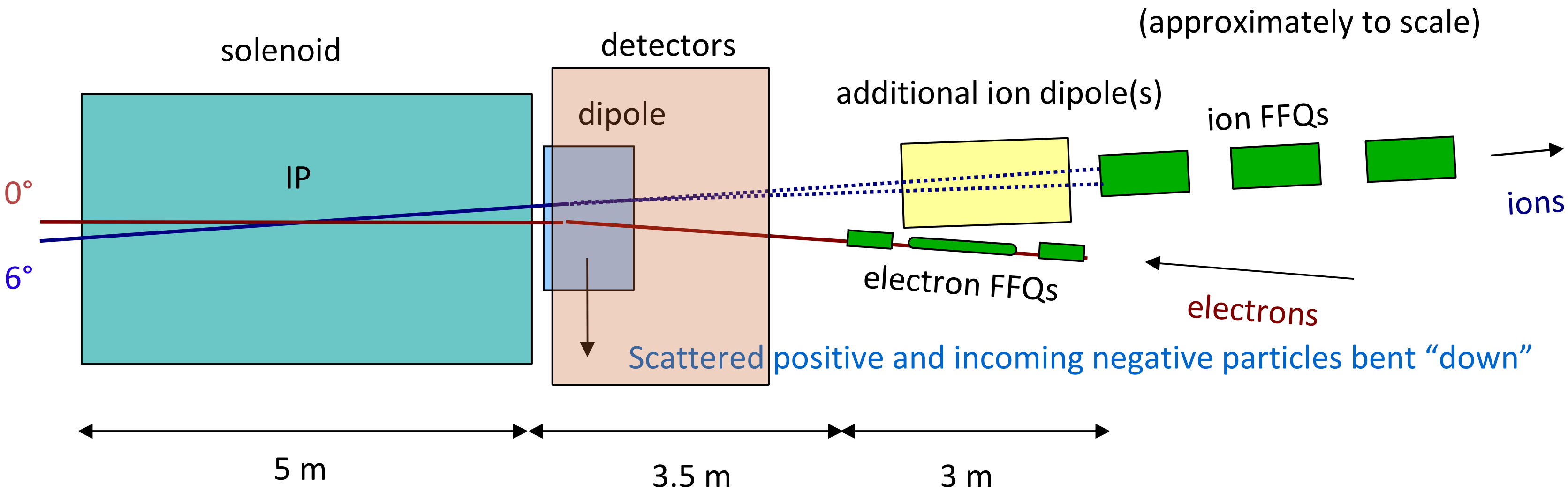
4 on 250 GeV





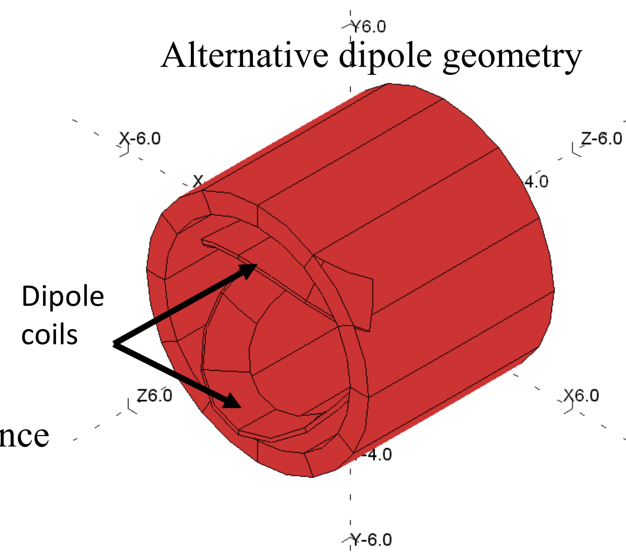
- "Symmetric" kinematics: 12 - 60 GeV protons
  - high Q^2 mesons are detected in the central barrel
- "Asymmetric" kinematics: 250 GeV protons
  - high Q^2 mesons are detected in ion side endcap
- May suggests slightly different optimizations, but no major differences

Forward detection with crossing angle

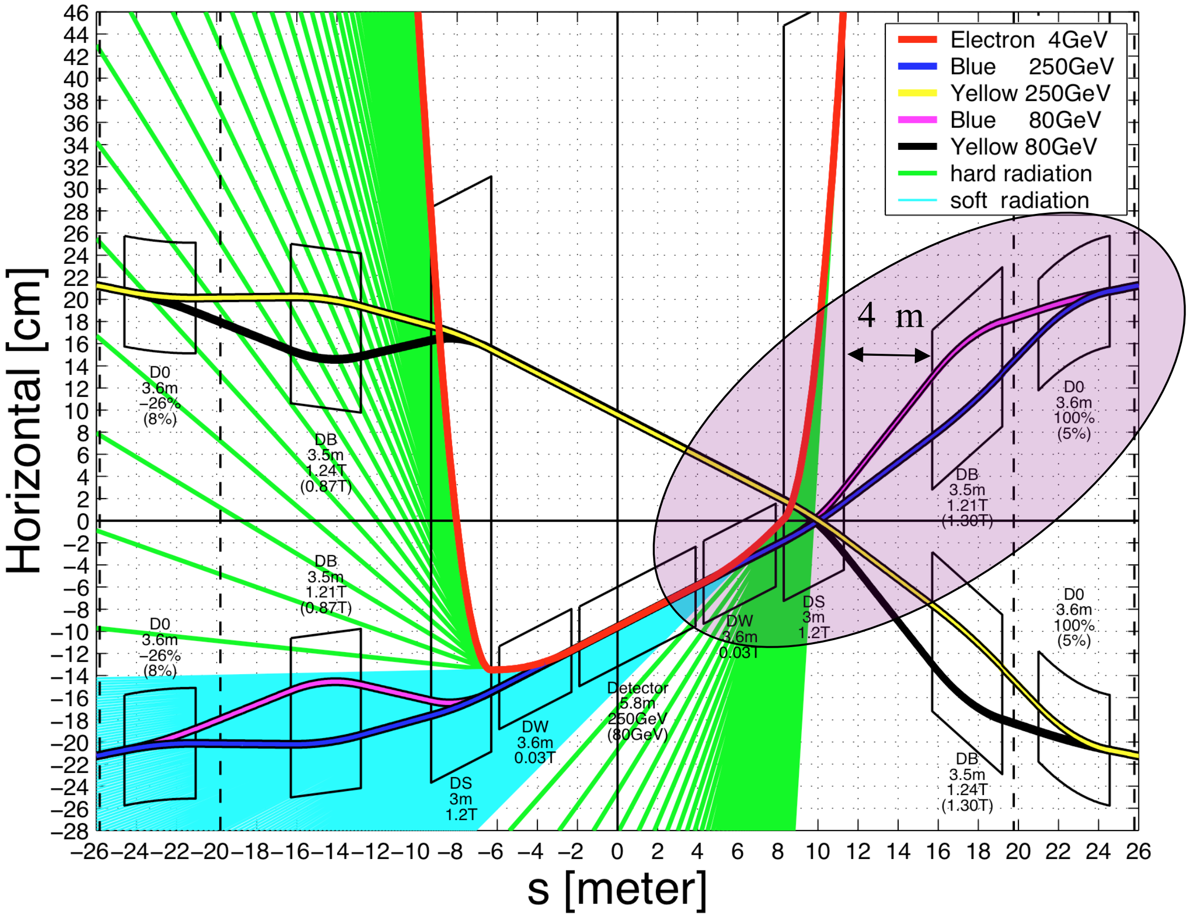


- Electrons on solenoid axis, ions cross at 6° (100 mrad)
  - Improves hadron tracking at small angles, also in solenoid (v x B = 0 on axis)
  - Outer radius of electron FFQs about 10 cm if 3-4 m from IP
- Common forward dipole has some disadvantages
  - Produces synchrotron radiation (field exclusion plates?)
  - Field settings according to electron energy, not ion energy
  - Requires downstream steering for ions before FFQs
  - Introduces a large amount of dead material close to bore
  - Even a 1 m diameter aperture offers only 9° *incoming* acceptance

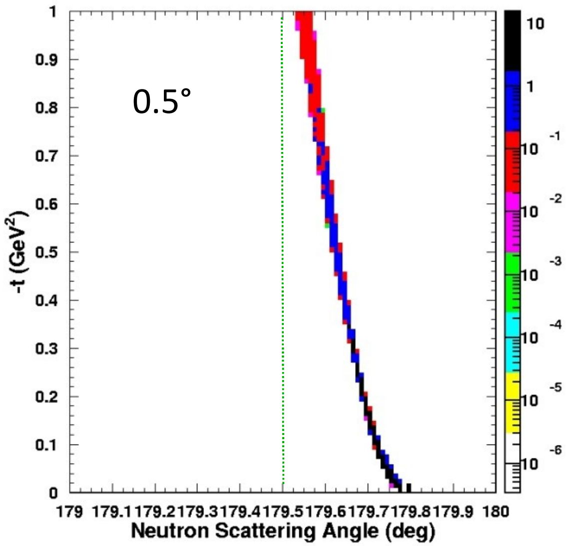
Alternative dipole geometry



Forward ion (proton) detection at 250 GeV

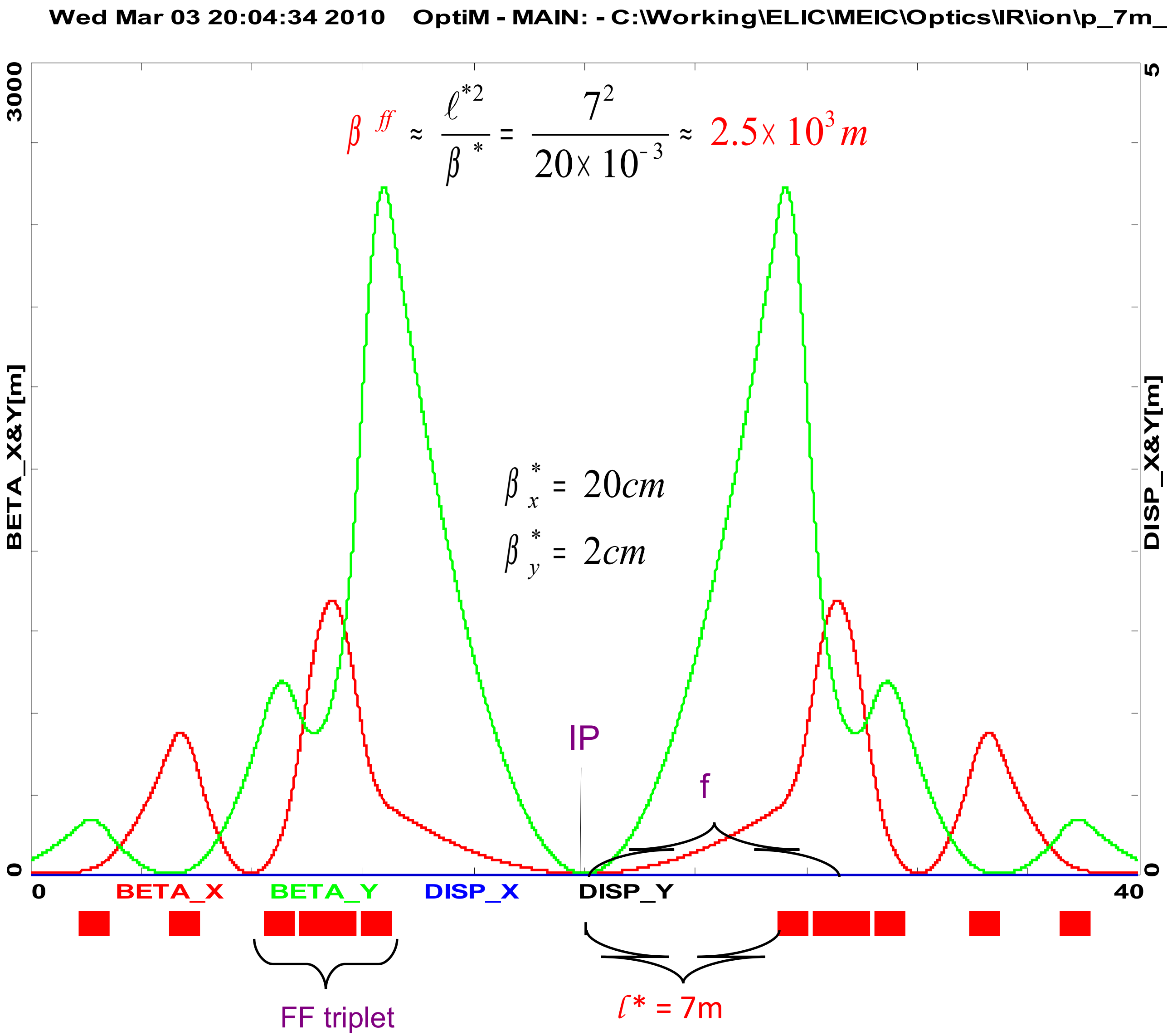


recoil baryons



- If luminosity is only high at max ion energy, asymmetric kinematics may be unavoidable
- Achieving low-*t* coverage comparable to symmetric kinematics will require long unobstructed flight paths
  - 45 m vs. 9 m (for neutrons; for protons only taking geometry into account)

‘Relaxed’ IR Optics (ions)



$$\beta(\ell) = \beta^* + \frac{\ell^2}{\beta^*}$$

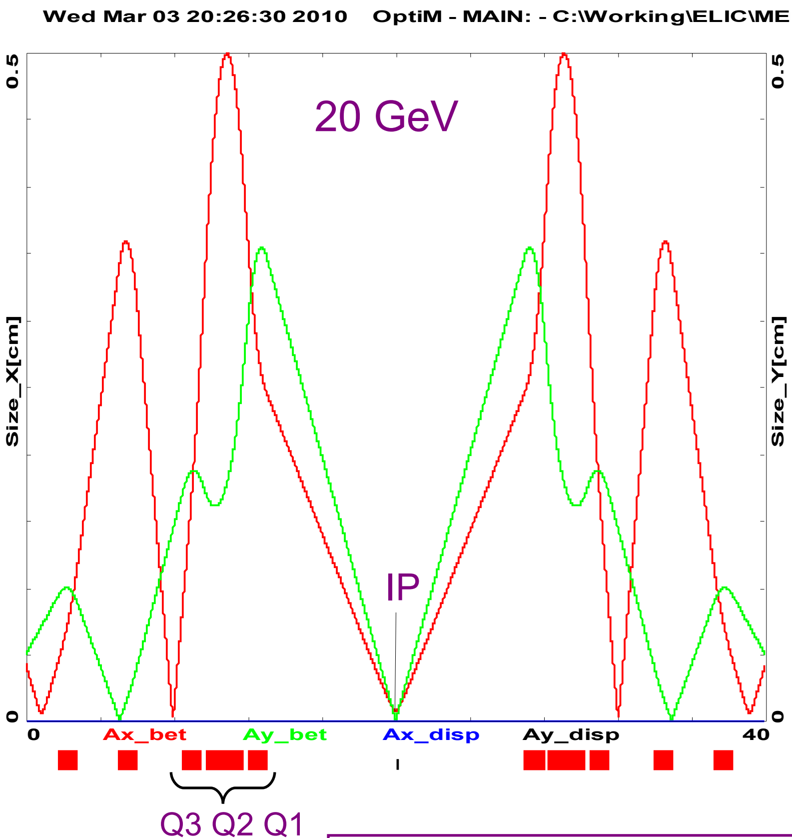
$$\sigma_\theta(\ell) = \sqrt{\frac{\varepsilon_N}{\gamma\beta^*}}$$

$$\zeta_{IR} : \frac{f^2}{\beta^*}\frac{1}{f} = \frac{f}{\beta^*}$$

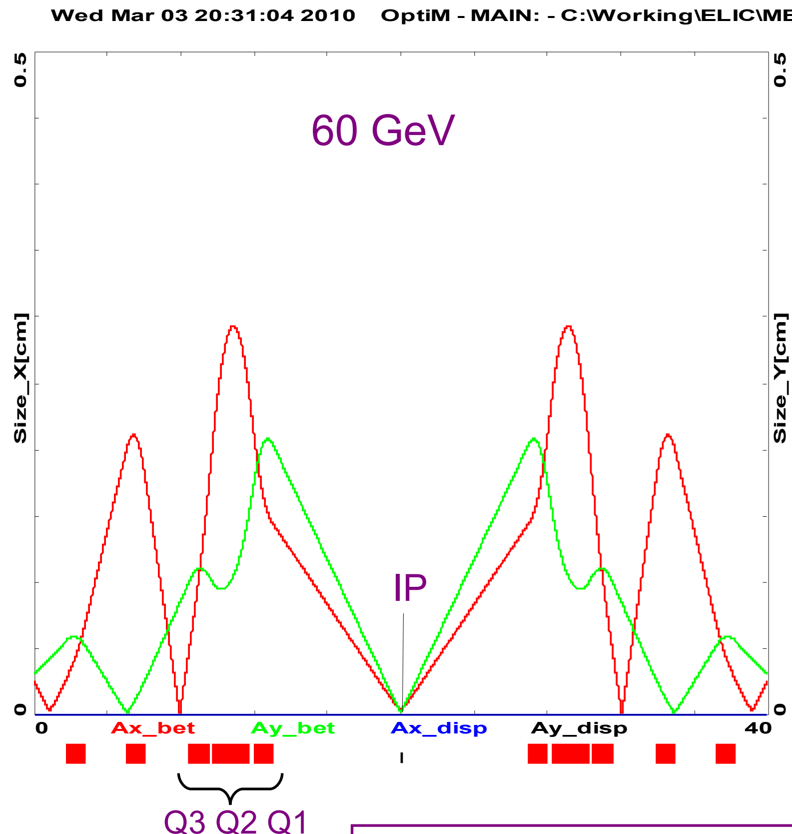
'Relaxed' IR Optics (ions)

$$\varepsilon_N^x = 0.55 \times 10^{-6} m \qquad \beta_x^* = 20cm$$

$$\varepsilon_N^y = 0.11 \times 10^{-6} m \qquad \beta_y^* = 2cm$$

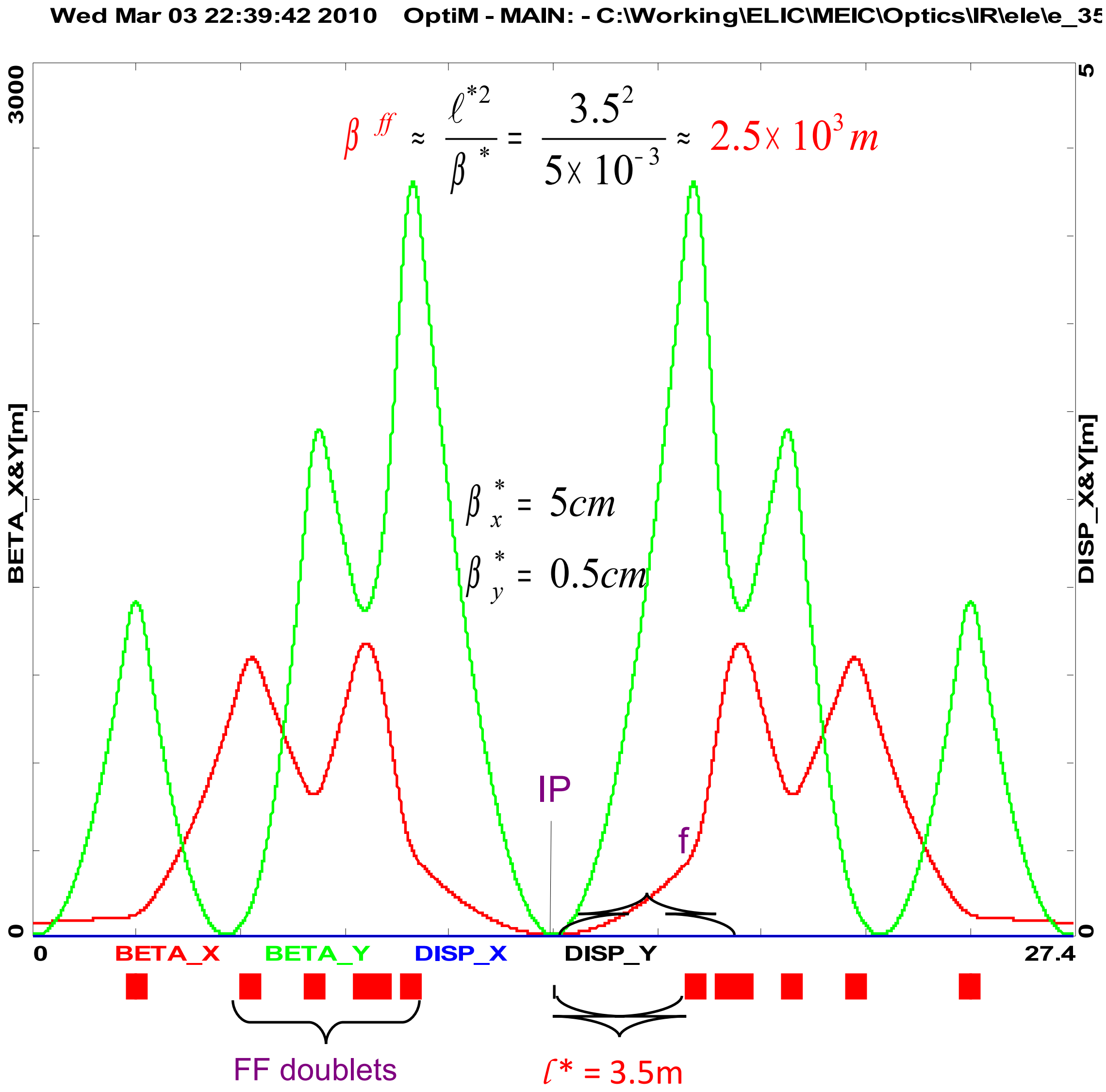


Q1	G[kG/cm] = -3.8
Q2	G[kG/cm] = 3.3
Q3	G[kG/cm] = -3.3



Q1	G[kG/cm] = -11.5
Q2	G[kG/cm] = 9.9
Q3	G[kG/cm] = -10

‘Relaxed’ IR Optics (electrons)



$$\beta(\ell) = \beta^* + \frac{\ell^2}{\beta^*}$$

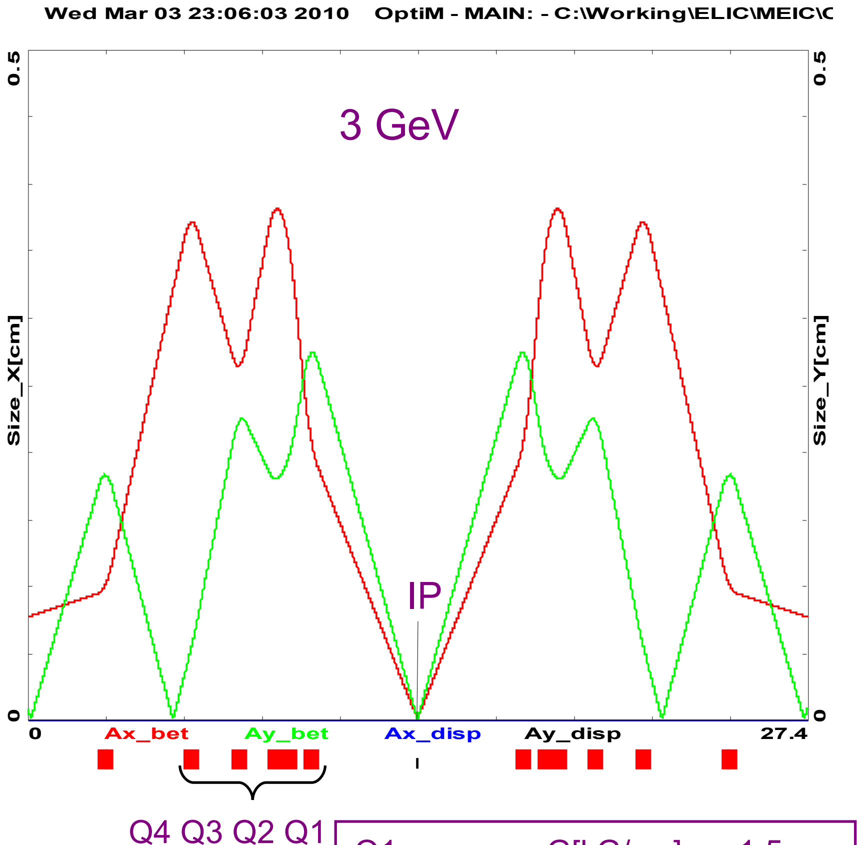
$$\sigma_\theta(\ell) = \sqrt{\frac{\varepsilon_N}{\gamma\beta^*}}$$

$$\zeta_{IR} : \frac{f^2}{\beta *}\frac{1}{f} = \frac{f}{\beta *}$$

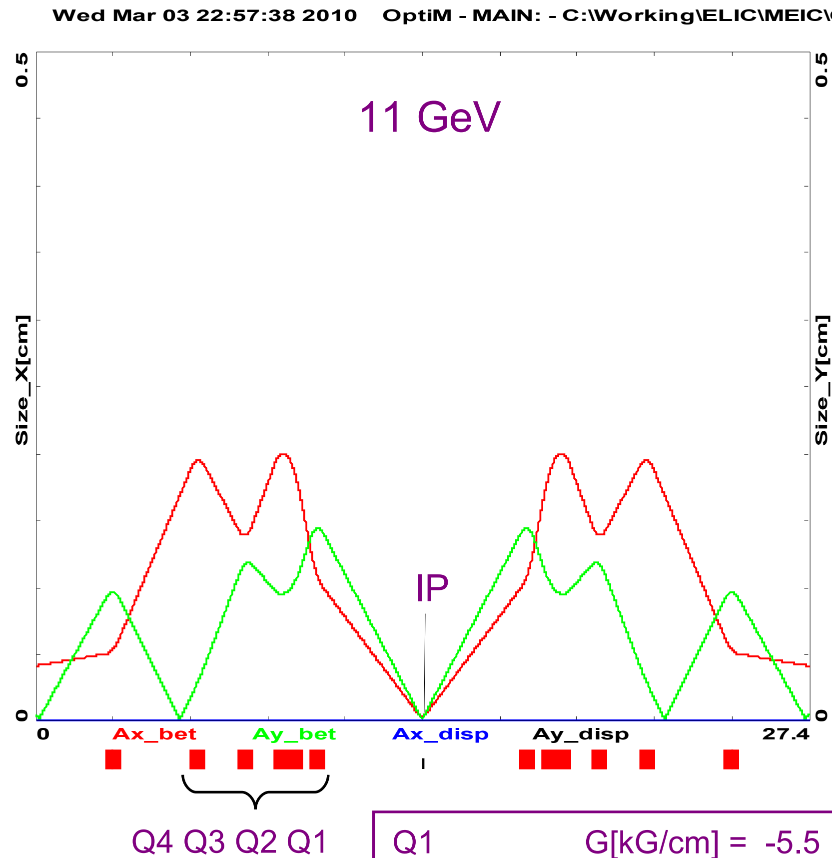
‘Relaxed’ IR Optics (electrons)

$$\varepsilon_N^x = 85 \times 10^{-6} m \qquad \beta_x^* = 5cm$$

$$\varepsilon_N^y = 17 \times 10^{-6} m \qquad \beta_y^* = 0.5cm$$

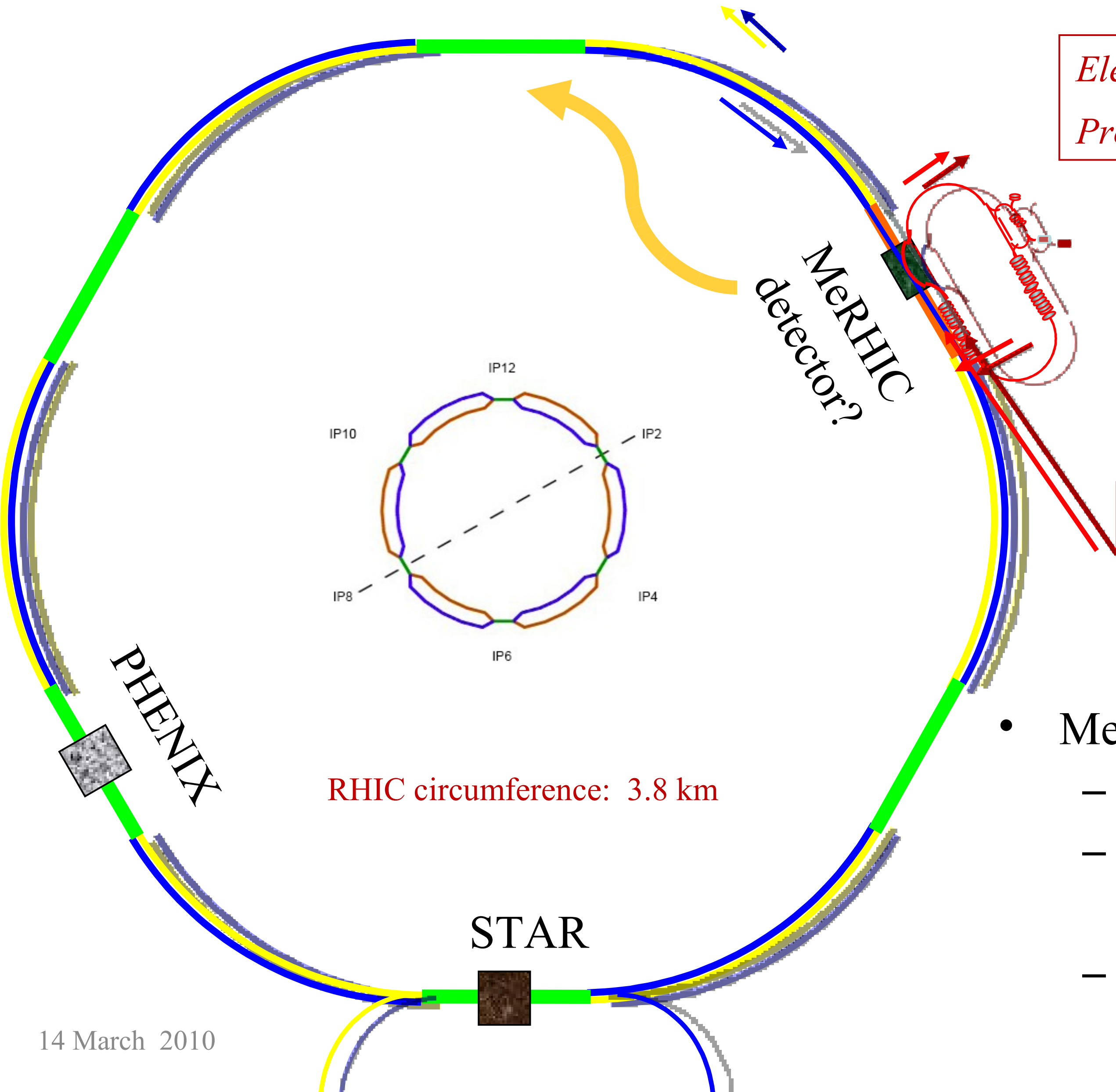


Q1	G[kG/cm] = -1.5
Q2	G[kG/cm] = 0.9
Q3	G[kG/cm] = -1.4
Q4	G[kG/cm] = 0.9



Q1	G[kG/cm] = -5.5
Q2	G[kG/cm] = 3.3
Q3	G[kG/cm] = -5.1
Q4	G[kG/cm] = 3.4

MeRHIC@BNL (ERL-Ring) – an overview



Electron energy: 2-4 GeV

Proton energy: up to 250 GeV

$s = 1200 - 4000\ GeV^2$

3 pass, 4 GeV ERL

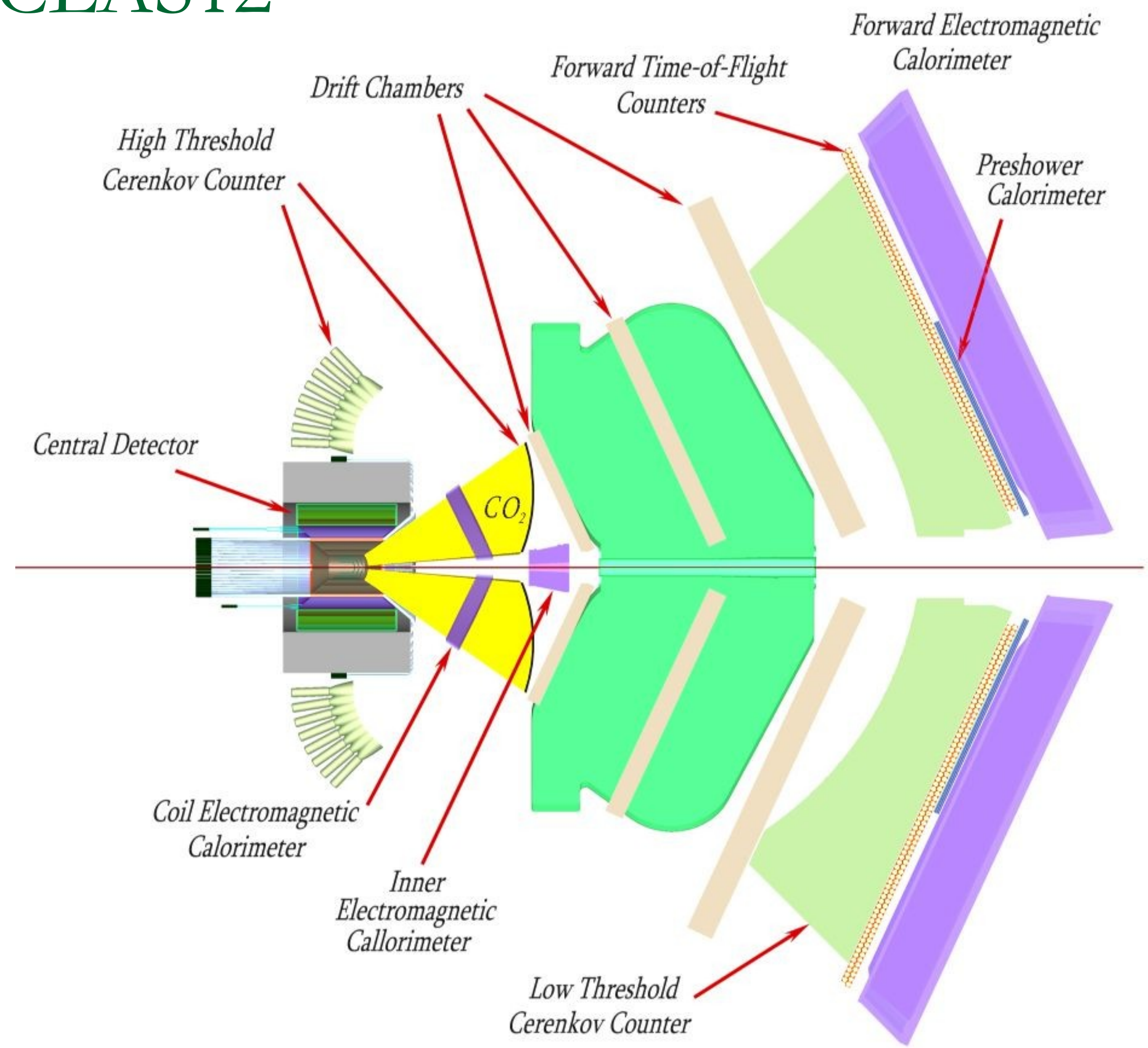
- MeRHIC
  - 1 (2 ?) detector(s)
  - Max Luminosity:
    10^{32}-10^{33} $cm^{-2}s^{-1}$
  - 90% of hardware can be reused for eRHIC.

Summary of current e-p/e-A collider ideas

Design Goals for Colliders Under Consideration World-wide

	Max e/p Energies	s	Max Luminosity
ENC@GSI	3 x 15	180	Few x 10^{32}
MEIC@JLab	11 x 60	250-2650	Few x 10^{34}
MeRHIC@BNL	4 x 250	1200-4000	Close to 10^{33}
ELIC@JLab	11 x 250	11000	Close to 10^{35}
eRHIC@BNL	20 x 325	26000	Few x 10^{33}
LHeC@CERN	70 x 1000	280000	10^{33}

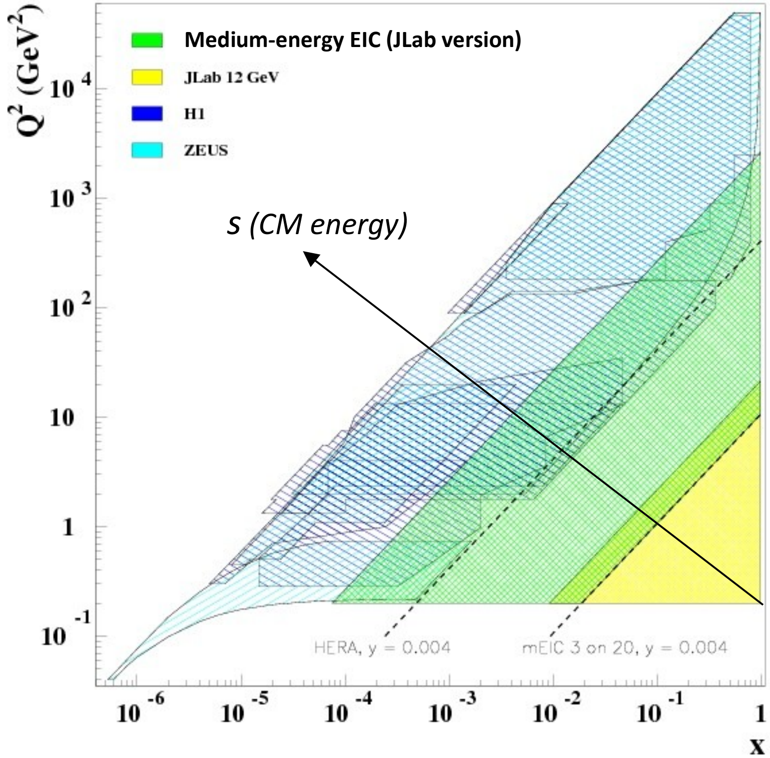
JLab CLAS12

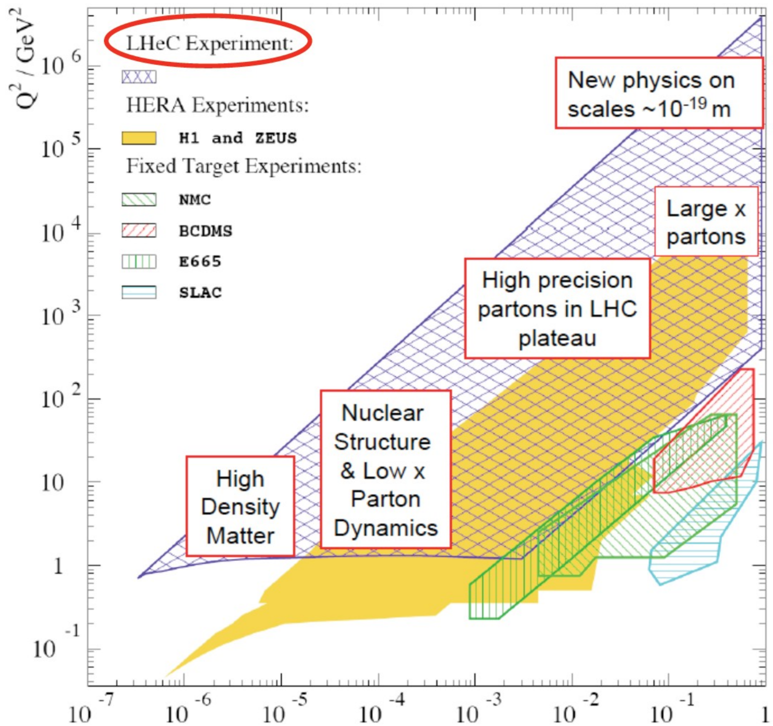


Forward Electromagnetic Calorimeter
Forward Time-of-Flight Counters
Drift Chambers
High Threshold Cerenkov Counter
Preshower Calorimeter
Central Detector
CO_2
Coil Electromagnetic Calorimeter
Inner Electromagnetic Callorimeter
Low Threshold Cerenkov Counter

Kinematic coverage

$Q^2 \sim xys$





- High-energy EIC (not shown)
  - Will move higher into the region covered by HERA (and LHeC)
  - Will provide good polarization and heavy ions (which HERA did not have)
  - If LHeC is not build, may be only machine that can see gluon saturation in *e-A* collisions