JLEIC Detector Study Group
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FORWARD (ION-SIDE) TAGGING: MOTIVATIONS, CONCEPT, PERFORMANCE

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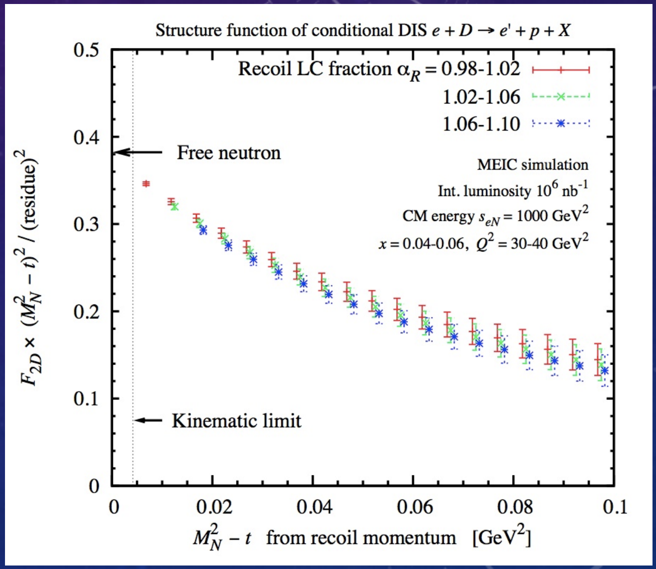
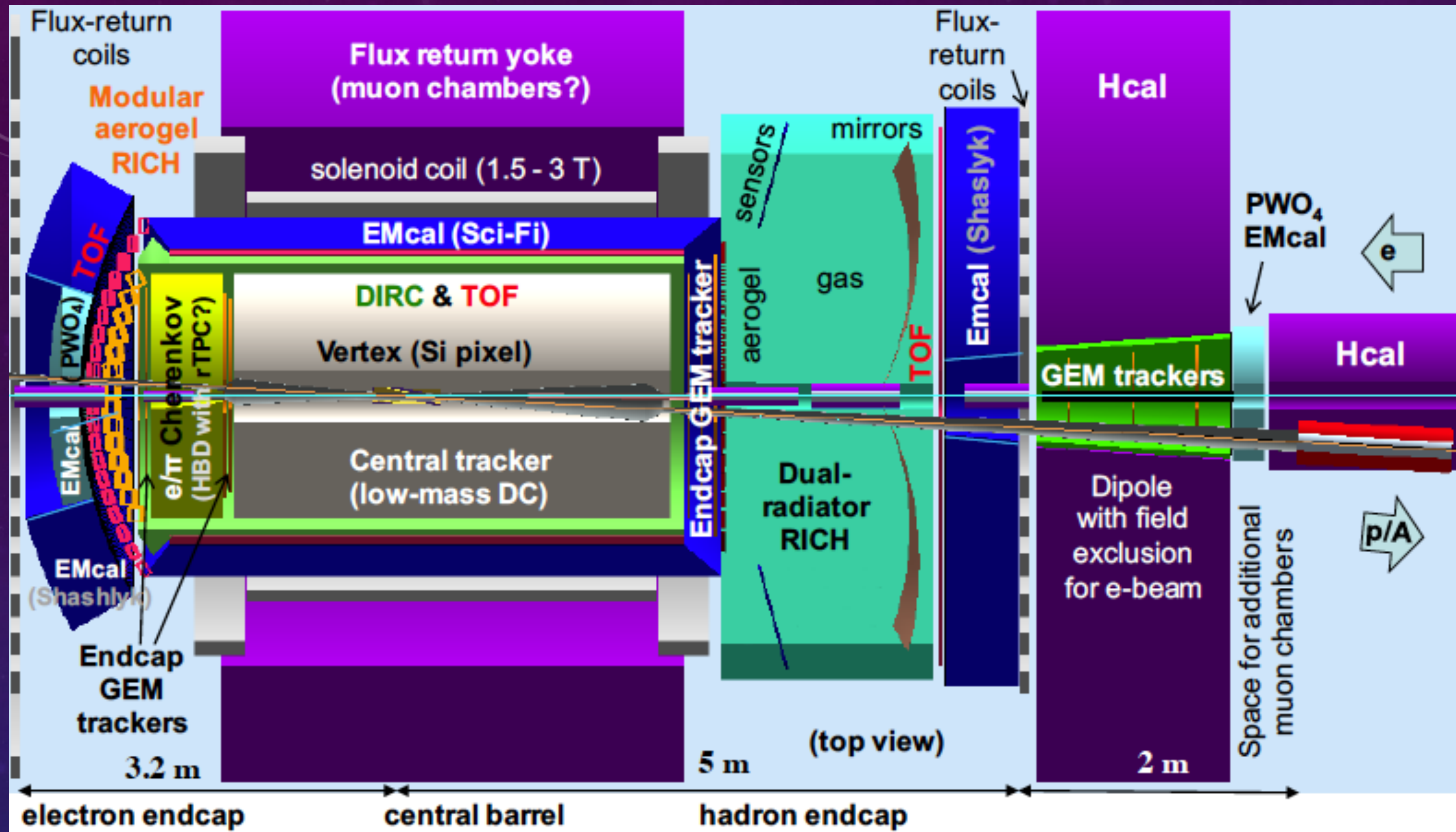
FORWARD DETECTION PHYSICS PROJECTS

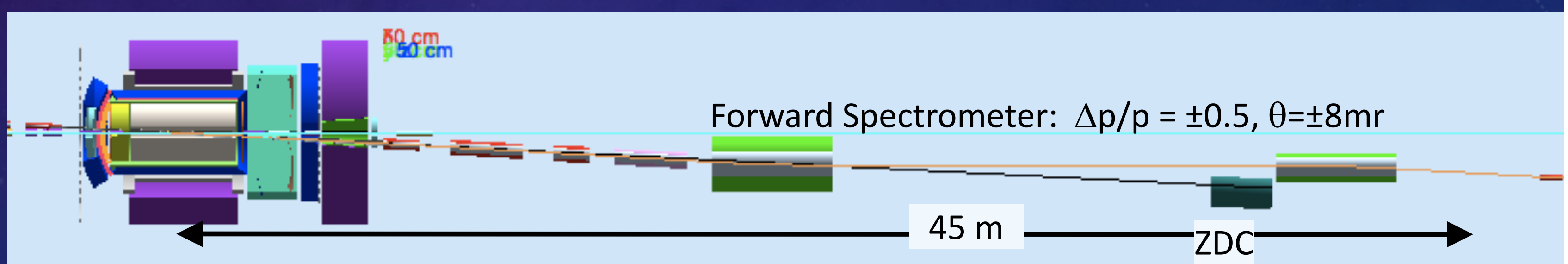
- Neutron Structure and the quark-gluon dynamics of the NN force
  - JLab LDRD FY2014/2015 (Ch.Weiss)
  - https://www.jlab.org/theory/tag/
  - 4 Conference Proceedings /Technical Reports
  - 35 Conference presentations
  - Publicly released simulation code

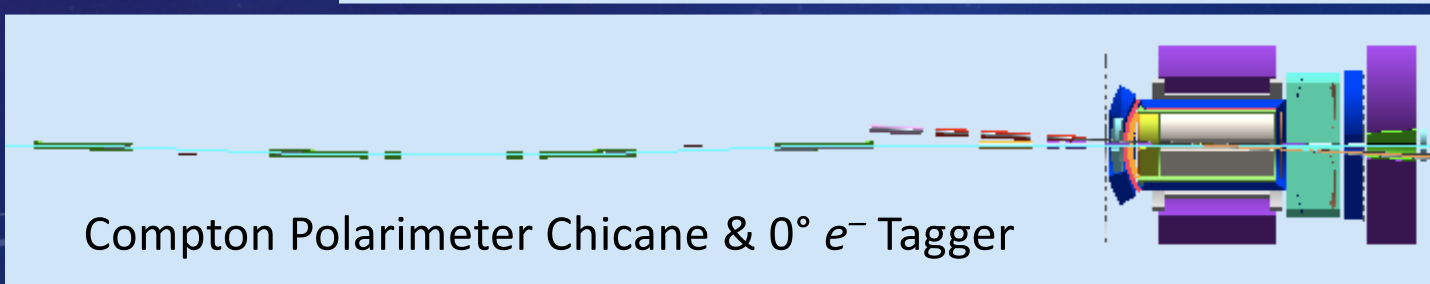


- Geometrical Tagging in eA Deep Inelastic Scattering
  - LDRD FY2017 (V. Morozov)

JLEIC FULL ACCEPTANCE DETECTOR

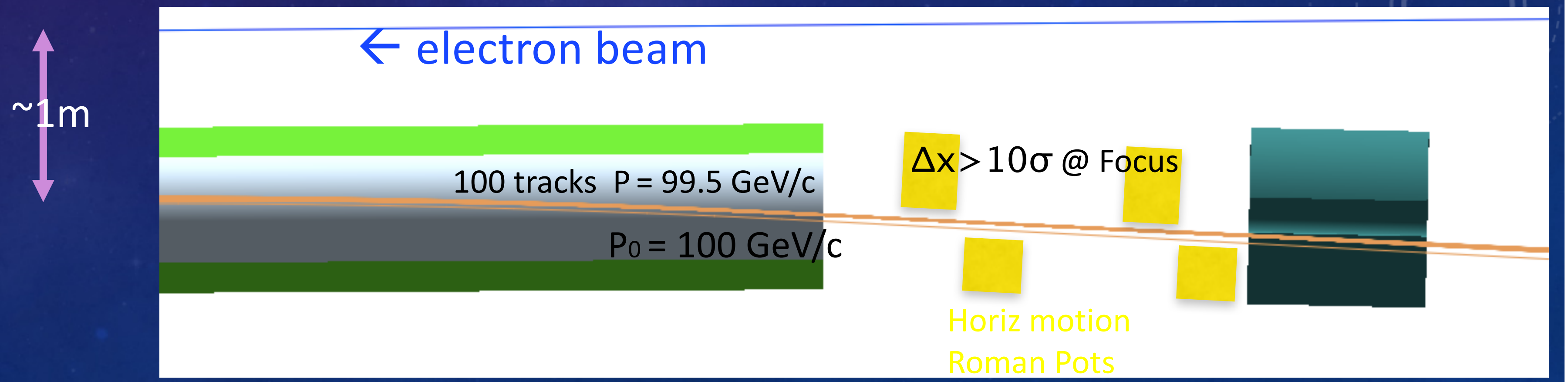






FORWARD DETECTION REGIONS: After iFFQ

- Ultra-Forward: Dipole3 < z → 43m < z < 47m (approx)
  - 3-D imaging of proton: ep→ epγ. Goals:
    - Hermetic detection for protons outside 10σ L⊗T beam emittance
    - Momentum resolution = beam rms = $\delta p/p \approx 3 \bullet 10^{-4}$ (L&T)
    - Large angular acceptance (±8 mrad)
    - Dispersion ~1000 mm/100% at secondary focus, Magnification = –0.5
    - 10σ Beam-Stay-Clear (BSC) (Roman Pots!)
      - 100 GeV/c: 3 mm radius
      - 20 GeV/c: 7 mm radius
    - Desired (position, angle resolution) ≤ (0.3 mm, 0.3 mrad)



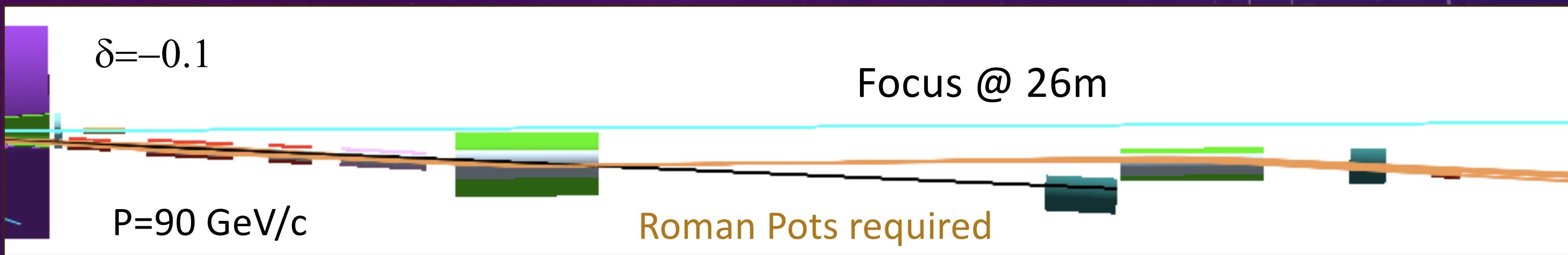
C.Hyde

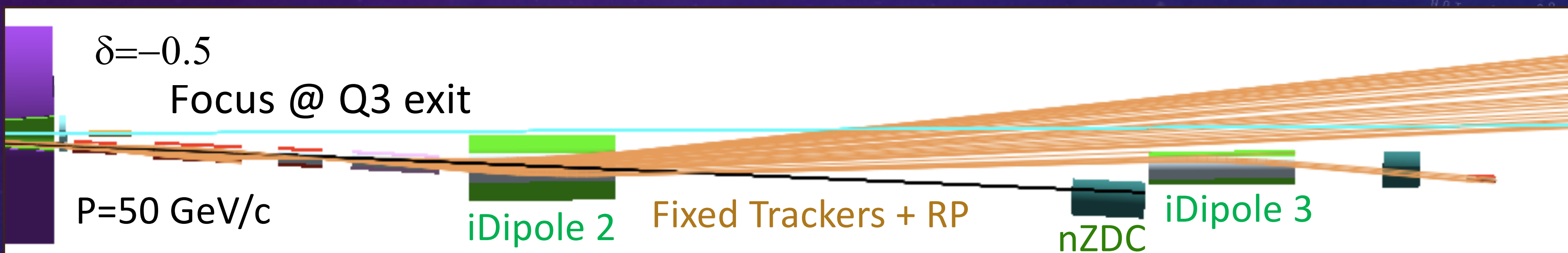
FORWARD DETECTION REGIONS After FFQ Triplet

- Far-Forward: Dipole2< z < Dipole3 ➔ z>20 m
  - ep→ epγ for x_B >0.1
  - Neutron structure and dynamics: eD→ epX, eD→ epnX…
    - p, n each have momentum ≈ $P_D/2$ = 50 GeV/c
    - Large aperture D2 (40 cm radius = HMS Dipole)
    - Large aperture 0° Line-of-sight to ZDC for neutron detection
      - Desired ZDC Hcal resolution $30\%[1\mathrm{GeV}/E_n]^{1/2} \oplus$ 1 cm transverse
- Estimated nominal beam pipe size = 4 cm radius
  - Roman Pot Detectors to achieve full acceptance post tuning/cooling
  - Single stations ~2 m long ?
  - Paired stations each ≤ 20 cm long?

FAR-FORWARD REGION: SAMPLE TRACKING

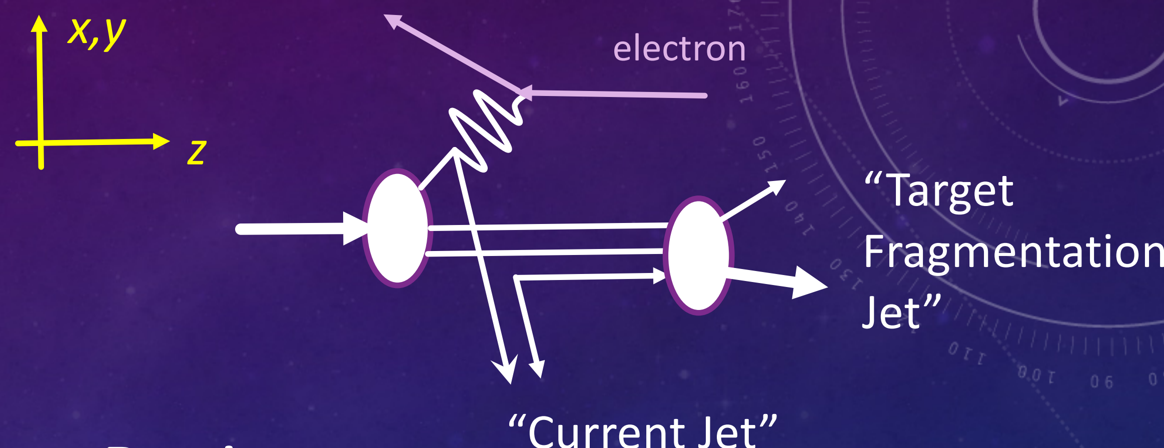
$P_0 = 100$ GeV/c





- $\delta > -1\%$ tracks converging towards downstream focus:
  - Detect large angle tracks before focal point
- $-0.5 < \delta < 0.05$: Focal point moves through drift space

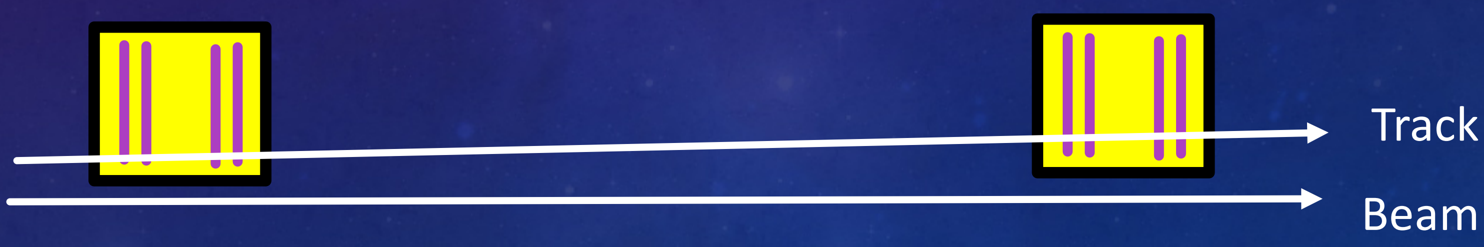
FORWARD REGION: DIPOLE-1 2Tesla•m



- Projectile Fragmentation Region
  - ep→ eX,   ep→ epX,   ep→ eN*X
    - N*→ Nπ, $p_\pi \approx P_0\, m_\pi / M_p \approx P_0/7$,
    - $p_{\pi,T} / p_\pi \approx$ (0.3 GeV)/(15 GeV) = 20 mrad (outside FFQ acceptance)
    - Track deflection in Dipole-1 (6mrad)•7 ≈ 42 mrad

PERFORMANCE CHARACTERISTICS OF FAR/ULTRA FORWARD ROMAN-POT TRACKERS

- Assumptions:
  - Vacuum window 1mm Al
    - X_0(Al) = 8.9 cm
  - Two stations, 2m apart, each 20 cm long with 4 µstrip layers
    - Each layer is 300 µm Si (DEPFET could be 50 µm)
    - X_0(Si) = 9.4 cm



MULTIPLE SCATTERING AND RESOLUTION

- Roman Pot Thickness:

$$\frac{X}{X_0} = \frac{1.2\ \mathrm{mm(Si)}}{94\ \mathrm{mm}} + \frac{2.0\ \mathrm{mm(Al)}}{88\ \mathrm{mm}} = 3.5\%$$

- Multiple Scattering

$$\theta_{ms} = \frac{14\ \mathrm{MeV/c}}{p}\sqrt{\frac{X}{X_0}} = \begin{cases} 30\ \mu\mathrm{rad} & \text{for} \quad p = 100\ \mathrm{GeV/c} \\ 130\ \mu\mathrm{rad} & \text{for} \quad p = 20\ \mathrm{GeV/c} \end{cases}$$

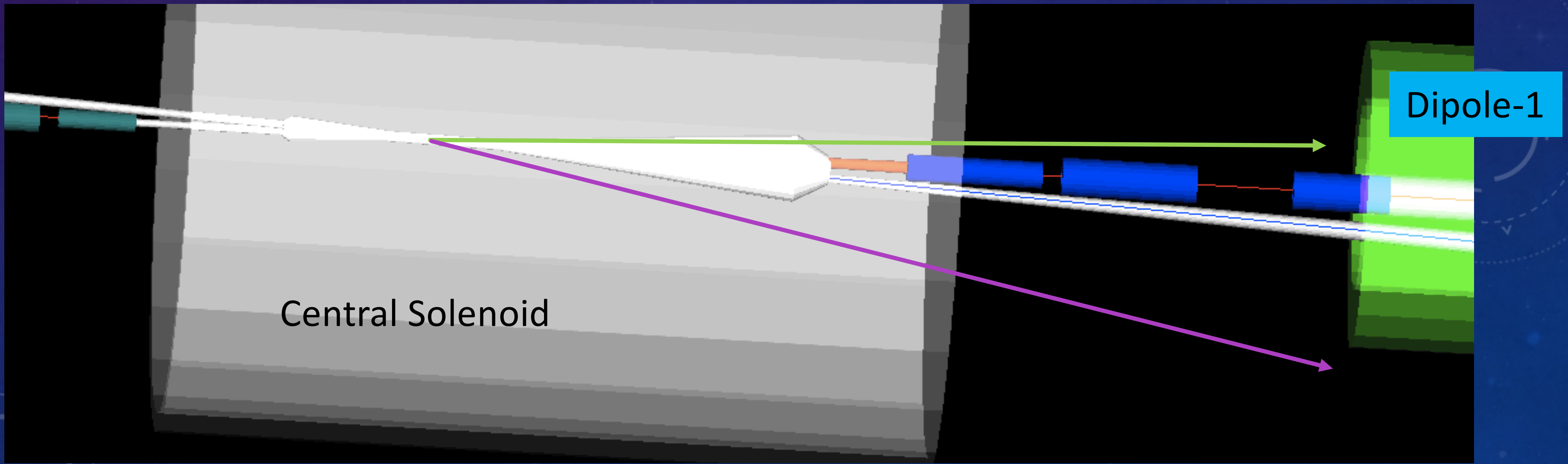
  - Resolution at IP: θ_{ms} /M ≈ $2\theta_{ms}$ < σ_{ϑ}(emittance) = 300 μrad
- Momentum Resolution:
  - $\sigma(p)/p \approx L\,\theta_{ms}/D \approx 2\theta_{ms} < 3 \bullet 10^{-4}$ = beam rms momentum spread

ACCEPTANCE GAPS

- Roman Pots:
  - The beam-facing edges of the Roman Pots will create dead-areas of large multiple scattering
  - The gap between the Si μStrip and the RP window creates a gap in the acceptance
  - These need to be optimized with optics and realistic RP designs.
- We have done acceptance studies for protons from ^{3}He (δ=-66%)
- Currently, there is a gap in acceptance for δ<–50% if θ<10 mrad (relative to ion beam)

CENTRAL BEAM PIPE DESIGN

- All particles in FFQ acceptance stay in vacuum
- All particles in Dipole-1 Tracker acceptance exit thin window at $\theta_{Normal} < 60°$
- All particles in ion EndCap exit central Be pipe
- Minimal beam pipe radii 2 cm



BEAM PIPE DESIGN STUDY

- https://eic.jlab.org/internal/index.php/Detector_Working_Group_Meetings
  - 4/6/2016: Revised beam pipe with 0 synchronization offsets
    - https://eic.jlab.org/internal/images/8/85/RevisedBeamPipe_Synch=0.png
  - 12/30/2015: Beam Pipe Concept in IP region
    - https://eic.jlab.org/internal/images/9/97/BeamPipe_EIC@40JLab-IP.pdf
  - 10/14/2015: Beam Pipe design after feedback from M. Sullivan
    - https://eic.jlab.org/internal/images/b/b2/VacuumPipe_14Oct2015.pdf
  - 6/24/2015: Ideas and Constraints for a beam pipe design
    - https://eic.jlab.org/internal/images/2/23/BeamPipe_MEIC-IP.pdf

VERTEX BEAM PIPE

- Central cylinder radius = 2.71 cm,
  - z ∈ [-28.5cm, 28.5cm] (at -0.025 rad)
- Total length from z = -84 cm to +200 cm
  - Flare angle (adjust to Dipole-1 aperture)
  - Endcap taper = 30° from -0.025 rad axis
  - Length constrained by requirement that separate beam pipes are ≥ 2 cm radius and accept full ~10 mrad acceptance of FFQ:
    - 20 mm = (2.0 m) • (10 mrad)
    - 16 mm = (2.0 m) • (8 mrad) (with 6T max field FFQ)

OUTLOOK

- The present design is well matched to our physics goals
- We need engineering constraints on Roman Pot designs, Beam Pipe materials and thickness
  - This will enable more quantitative evaluation of realistic resolution and acceptance.

MORE PHYSICS SPECULATIONS

- High Resolution EMCal in front of ZDC
  - Measure boosted decay gamma-rays from nuclear bound state:
  - $^{208}Pb(e,e'\gamma)^{208}Pb^*$ $^{208}Pb^* \rightarrow \gamma \ldots {}^{208}Pb$
  - $E_\gamma \geq 2.6$ MeV → Boosted to Detector frame, 50% > 144 MeV
- $1m^3$ high granularity ($1 \times 1 \times 100$ cm^3) scintillator array
  - Measure polarized neutron electron elastic scattering:
  - $\vec{e}\, \vec{d} \rightarrow (e)\, p\, \vec{n}$ tag proton
    - Measure neutron scattering off atomic electron, with detection of forward neutron and recoil electron
    - $Q^2 \leq 10^{-3}$ GeV^2, $E_e' < 10$ GeV
    - Neutron energy resolution = 30%*sqrt(50GeV^2) = 2GeV