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)
Forward Spectrometer: $\Delta p/p = \pm 0.5$, $\theta = \pm 8\text{mr}$

Compton Polarimeter Chicane & $0^\circ e^-$ Tagger
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 $10\sigma_L\otimes T$ beam emittance
  - Momentum resolution = beam rms = $\delta p/\rho \approx 3\cdot10^{-4}$ (L&T)
  - Large angular acceptance ($\pm 8$ mrad)
  - Dispersion $\sim 1000$ mm/100% at secondary focus, Magnification = $-0.5$
  - $10\sigma$ Beam-Stay-Clear (BSC) (Roman Pots!)
    - 100 GeV/c: 3 mm radius
    - 20 GeV/c: 7 mm radius
  - Desired (position, angle resolution) $\leq (0.3$ mm, $0.3$ mrad)
FORWARD DETECTION REGIONS After FFQ Triplet

• Far-Forward: Dipole2 < z < Dipole3 \(\rightarrow z > 20 \text{ m}\)

  • \(e^-p \rightarrow e^-p \gamma\) for \(x_B > 0.1\)

  • Neutron structure and dynamics: \(e^-D \rightarrow e^-p X\), \(e^-D \rightarrow e^-p n X\), ...
    
    • \(p, n\) each have momentum \(\approx P_D/2 = 50 \text{ GeV/c}\)

    • Large aperture \(D_2\) (40 cm radius = HMS Dipole)

    • Large aperture \(0^\circ\) Line-of-sight to ZDC for neutron detection
      
      • Desired ZDC Hcal resolution 30\%\([1\text{GeV}/E_n]^{1/2}\) \(\oplus\) 1 cm transverse

• Estimated nominal beam pipe size = 4 cm radius

  • Roman Pot Detectors to achieve full acceptance post tuning/cooling

  • Single stations \(~2 \text{ m long}\) ?

  • Paired stations each \(\leq 20 \text{ cm long}\)?
FAR-FORWARD REGION: SAMPLE TRACKING

\( P_0 = 100 \text{ GeV/c} \)

- \( \delta = -0.1 \)
  - \( P = 90 \text{ GeV/c} \)
  - \( \delta = -0.5 \)
  - \( P = 50 \text{ GeV/c} \)

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

Roman Pots required

Focus @ 26m

Focus @ Q3 exit

nZDC

iDipole 2

Fixed Trackers + RP

iDipole 3
FORWARD REGION: DIPOLE-1

2Tesla•m

- Projectile Fragmentation Region
  - $ep \rightarrow eX, \; ep \rightarrow epX, \; ep \rightarrow eN^*X$
    - $N^* \rightarrow N\pi, \; p_\pi \approx P_0 \frac{m_\pi}{M_p} \approx P_0/7,$
    - $p_{\pi,T}/p_\pi \approx (0.3 \; GeV)/(15 \; GeV ) = 20 \; mrad \; (\text{outside FFQ acceptance})$
    - Track deflection in Dipole-1 (6mrad)$\cdot 7 \approx 42 \; mrad$
PERFORMANCE CHARACTERISTICS OF FAR/ULTRA FORWARD ROMAN-POT TRACKERS

• Assumptions:
  • Vacuum window 1mm Al
    • $X_0(\text{Al}) = 8.9$ cm
  • Two stations, 2m apart, each 20 cm long with 4 μstrip layers
    • Each layer is 300 μm Si (DEPFET could be 50 μm)
    • $X_0(\text{Si}) = 9.4$ cm
MULTIPLE SCATTERING AND RESOLUTION

• Roman Pot Thickness:

\[ \frac{X}{X_0} = \frac{1.2 \text{ mm(Si)}}{94 \text{ mm}} + \frac{2.0 \text{ mm(Al)}}{88 \text{ mm}} = 3.5\% \]

• Multiple Scattering

\[ \frac{X}{X_0} = \frac{1.2 \text{ mm(Si)}}{94 \text{ mm}} + \frac{2.0 \text{ mm(Al)}}{88 \text{ mm}} = 3.5\% \]

\[ \theta_{ms} = \frac{14 \text{ MeV/c}}{p} \sqrt{\frac{X}{X_0}} \]

\[ = \begin{cases} 
30 \mu\text{rad} & \text{for } p = 100 \text{ GeV/c} \\
130 \mu\text{rad} & \text{for } p = 20 \text{ GeV/c} 
\end{cases} \]

• Resolution at IP: \( \theta_{ms}/M \approx 2\theta_{ms} < \sigma_\theta(\text{emittance}) = 300 \mu\text{rad} \)

• Momentum Resolution:

\( \sigma(p)/p \approx L \theta_{ms}/D \approx 2\theta_{ms} < 3 \times 10^{-4} = \text{beam rms momentum spread} \)
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 $^3\text{He}$ ($\delta=-66\%$)
• Currently, there is a gap in acceptance for $\delta<-50\%$ if $\theta<10$ 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 $\theta_{\text{Normal}} < 60^\circ$

• All particles in ion EndCap exit central Be pipe

• Minimal beam pipe radii 2 cm
BEAM PIPE DESIGN STUDY

  - 4/6/2016: Revised beam pipe with 0 synchronization offsets
    - [https://eic.jlab.org/internal/images/8/85/RevisedBeamPipe_Synch=0.png](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](https://eic.jlab.org/internal/images/9/97/BeamPipe_EIC@40JLab-IP.pdf)
  - 10/14/2015: Beam Pipe design after feedback from M. Sullivan
  - 6/24/2015: Ideas and Constraints for a beam pipe design
    - [https://eic.jlab.org/internal/images/2/23/BeamPipe_MEIC-IP.pdf](https://eic.jlab.org/internal/images/2/23/BeamPipe_MEIC-IP.pdf)
VERTEX BEAM PIPE

• Central cylinder radius = 2.71 cm,
  • $z \in [-28.5\text{cm}, 28.5\text{cm}]$ (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 $\geq 2$ cm radius and accept full $\sim 10$ 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:
    • $^{208}\text{Pb}(e,e'\gamma)^{208}\text{Pb}^*$ $^{208}\text{Pb}^* \rightarrow \gamma\ldots^{208}\text{Pb}$
    • $E_\gamma \geq 2.6$ MeV $\rightarrow$ Boosted to Detector frame, 50% $> 144$ MeV
  • 1$m^3$ high granularity (1x1x100 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 $= 30\% \times \sqrt{50\text{GeV}^2} = 2\text{GeV}$