Preliminary Detector Design for the EIC at JLab

Pawel Nadel-Turonski

Jefferson Lab, Newport News, VA

EIC Detector Workshop at JLab, 4-5 June 2010
Outline

1. Introduction

2. Interaction Region

3. Detector Requirements and Challenges

4. Brief Overview of Current Detector Ideas
Why a collider?

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

- $s = 4E_e E_p$ for colliders (e.g., $4 \times 9 \times 60 = 2160$ GeV$^2$)
- $s = 2E_e M_p$ for fixed target experiments (e.g., $2 \times 11 \times 0.938 = 20$ GeV$^2$)

Spin physics with high figure of merit

- Unpolarized FOM = $Rate = Luminosity \cdot Cross\; Section \cdot Acceptance$
- Polarized FOM = $Rate \cdot (Target\; Polarization)^2 \cdot (Target\; Dilution)^2$
- 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

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

LHeC, CERN, Geneva

Jefferson Lab, Newport News, VA

Brookhaven, Upton, NY

EIC
Kinematic coverage

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

- 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 $\sim 10^{34} \text{ cm}^{-2}\text{s}^{-1}$
    - Low backgrounds
  - Special detector?

- ELIC = high-energy EIC@JLab
  - Future upgrade?

< 1 km circumference
Note: RHIC is 3.8 km

1.4 km circumference

< 1 km circumference
Note: RHIC is 3.8 km

12 GeV CEBAF

Medium energy IP

Low-to-medium collider ring

polarimetry

Special IP?

prebooster

Ion Sources

SRF Linac
Hadronic background – a 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: 40 m / 120 m = 0.33
- 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 10% of HERA

**Hadronic background not a major problem for the MEIC**

- With HERA vacuum, the MEIC would at 60 GeV and 1 A have backgrounds like HERA at 0.1 A
  - But good vacuum is much easier to maintain in a short section of a small ring!
- MEIC luminosity is also about 100 times higher (depending on kinematics)
- Signal-to-background will be considerably better at the MEIC
Ion quadrupole apertures and the minimum energy

$$\beta = \frac{\beta^*}{\beta^*_{max}} = \frac{7^2}{20 \times 10^{-3}} = 2.5 \times 10^3 m$$

$\beta^*_{max} = 20 cm$

$\beta^* = 2 cm$

• Beam size: $\sigma = \sqrt{\left(\epsilon \beta m / p\right)}$
• Focal length: $f = \sqrt{\left(\beta^* \beta_{max}\right)}$
• Quad gradient: $G \sim p / f$
• Peak field: $rG$

• Max aperture size $\sim 1 / G \sim 1 / E_{max}$
• Max beam size $\sim 1 / \sqrt{\left(\beta^* E_{min}\right)}$

$E_{min} \sim \sqrt{E_{max}} / \beta^*$

Gradients: 20 - 60 GeV

Q1 $G[T/m] = -32$ to $-97$
Q2 $G[T/m] = 22$ to $67$
Q3 $G[T/m] = -21$ to $-63$

Beam size ($\sigma$): up to 5 mm
Aperture ($r$): 10-15 $\sigma$
Peak field ($rG$): up to 5-7T
Trigger, accelerator RF, and luminosity

1. Luminosity at high energy

- Naïve scaling:
  \[ \text{Luminosity} \sim I_e I_p / \beta^* \]
- \( E_p \) scaling due to Lorentz boost is often shown, but is not always a good approximation

2. Luminosity at low energy

- “Hourglass effect” requires that the bunch length \( L = \beta^* \)
- Due to “space charge”, in rings with large circumference \( C \) one has:
  \[ I_p \sim f_{RF} L / C = f_{RF} \beta^* / C, \text{ and } I_e = \text{constant} \]
- \text{Luminosity} \sim f_{RF} / C

3. Effective low-energy operation requires \( f_{RF} \sim 1 \text{ GHz} \)

- Cannot trigger on each bunch crossing as in hadron machines!
- The solution is an asynchronous electron trigger
Detector requirements

1. Mainly driven by exclusive physics
   - Hermeticity (also for hadronic reconstruction methods in DIS)
   - Particle identification (also SIDIS)
   - Momentum resolution (kinematic fitting to ensure exclusivity)
   - Forward detection of recoil baryons (also baryons from nuclei)
   - Muon detection (J/Ψ)
   - Photon detection (DVCS)

2. But not only ...
   - Very forward detection (spectator tagging, diffractive, coherent nuclear, etc)
   - Vertex resolution (charm, strangeness)
   - Hadronic calorimetry (jet reconstruction)

3. More details in workshop reports tomorrow!
Diffractive and (SI)DIS mesons

Both reactions produce high-momentum mesons at small angles

This constitutes the background for exclusive reactions!
Low $Q^2 (J/\Psi)$ vs high $Q^2$ (light mesons) – 4 on 30 GeV

4-5 June 2010

EIC Detector Workshop at JLab

Tanja Horn
Exclusive light meson kinematics ($Q^2 > 10 \text{ GeV}^2$)

**Recent results**

- Exit of exclusive light meson kinematics
- $Q^2 > 10 \text{ GeV}^2$
- $ep \rightarrow e'\pi^+n$

**Plots**

- Mesons
  - Very high momenta
  - PID challenging
- Scattered electrons
  - Electrons in central barrel, but $p$ different
- Recoil baryons
  - $0.2^\circ - 0.45^\circ$
  - $0.2^\circ - 2.5^\circ$
  - $\Theta \sim \sqrt{t/E_p}$

**Notes**

- 4-5 June 2010
- EIC Detector Workshop at JLab
Main detector challenges

1. **Central Detector**
   - Particle ID (e/π/K/p)
   - Momentum resolution (tracker radius / layout)

2. **Forward hadron detection**
   - Acceptance (3 stages needed)
   - Momentum resolution at intermediate angles (0.5-5°)

3. **Low-Q² electron tagging**
   - Endcap design (DIRC readout?)
   - Common dipole for both beams?

4. **Integration with accelerator**
Three stage forward detection strategy

- Charged particle tracking resolution in a solenoidal field becomes very poor at small angles (up to 5-10°)
  - \[ F = v \times B \]
- A crossing angle of 3-5° between the ion beam and solenoid axis moves this spot to a peripheral point in \( \phi \)
  - Good place for (very small) electron quads
- A crossing angle also allows a downstream analyzing magnet with comparable aperture (3-5°)
- High-momentum particles scattered at angles < 0.5° can be detected after passing through the ion quads
Analyzing magnet - dipole

- Analyzing magnet for high-momentum mesons and recoil baryons
  - Critical to ensure exclusivity and give access to full range in $-t$

- A 1-2 Tm dipole bypassed by the electron beam is very advantageous
  - No synchrotron radiation
  - Electron quads can be placed close to IP
  - Dipole field is not determined by electron energy
  - Positive particles are bent away from the electron beam
  - Dipole does not interfere with RICH and forward calorimeters
    - Excellent hermeticity

4-5 June 2010
EIC Detector Workshop at JLab
Analyzing magnets - quadrupoles?

- By bending all charged particles, a dipole on the ion beam line
  - provides excellent resolution at small angles and does not interfere with optics
  - will bent away low-momentum particles scattered at small angles prior to quads
  - may limit very forward acceptance for neutrals within the quad aperture if field is too strong

- Weak, large-aperture quads would not bend the ion beam and may impact forward detection less, but
  - a single quad, even if weak, will defocus the beam, reducing luminosity
  - a doublet will not affect the optics adversely, but makes tracking more complicated
  - a quad solution will provide less resolution, in particular at small angles
  - Would needs to be explored.
Very forward detection (< 0.5°)

- Diffractive processes
- Spectator tagging
- Coherent processes

The ion beam has a 3-5° horizontal crossing angle

Very forward detection (0.5°)

Diffractive recoil protons for 4 on 50

• Diffractive processes
• Spectator tagging
• Coherent processes

- Quad gradient and aperture scale with distance
- Aperture angle depends only on $E_{\text{max}}$ and quad length

~ 20 meters

20-40 Tm dipole
The IP is offset within the solenoid towards the electron endcap to provide more tracking space.

Only active elements are shown. Detector can be “closed” magnetically.

- Crossing angle: 3-5°
- Magnet apertures for small-angle ion and electron detection not shown
- TOF (5-10 cm)
- DIRC (10 cm)
Identification of exclusive mesons at higher energies

- At higher ion energies a DIRC alone is no longer sufficient for $\pi/K$ separation
- Need to cover meson momenta up to 7-9 GeV/c for operations at 60 GeV
- Two options
  - Supplement the DIRC with a gas Cerenkov (threshold or RICH)
  - Replace it with a dual radiator (aerogel / gas) RICH
Central Detector

Solenoid Yoke, Hadron Calorimeter, Muons

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

Particle Identification

- TOF for low momenta
  - Precise timing also important for trigger
- p/K separation
  - DIRC or dual radiator (aerogel) RICH
- π/K separation options
  - DIRC + LTCC up to 9 GeV (higher if RICH)
  - dual radiator RICH up to ~8 GeV (?)
- e/π separation
  - $C_4F_8O$ LTCC / RICH up to 3 / 5 GeV
  - EC: Tungsten powder / scintillating fiber?

Tracking

- Vertex tracker (silicon pixel?)
- Central tracker (DC, micropattern?)
- Tracking planes (DC)
  - Configuration to be optimized

EIC Detector Workshop at JLab
Detector Endcaps

**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)
- Dual-radiator RICH (HERMES / LHCb ?)
- Time-of-Flight Detectors
- Electromagnetic Calorimeter
- Hadronic Calorimeter
- Muon detector (at least at small angles)
  - Important for J/Ψ photoproduction (at low $Q^2$)

**Tracking**
- Forward / Backward
  - IP shifted to electron side (2+3 m)
  - Vertical planes in central tracker
  - Drift chambers on either side
Low-$Q^2$ tagging – very conceptual!

- Synchrotron radiation is not an issue for outgoing electrons
  - Can use dipole covering small scattering angles
  - Effect on electron emittance of strong dipole in high-$\beta$ region?

- Common dipole requires additional steering to allow independently adjustable beam energies

- Endcap layout required for detailed design!
Electron endcap options

- The exact endcap configuration will to a large extent depend on the readout for the DIRC
- The alternative configuration on the right provides easier access to the DIRC
Summary - main detector challenges

1. **Central Detector**
   - Particle ID (e/π/K/p)
   - Momentum resolution (tracker radius / layout)

2. **Forward hadron detection**
   - Acceptance (3 stages needed)
   - Momentum resolution at intermediate angles (0.5-5°)

3. **Low-\(Q^2\) electron tagging**
   - Endcap design (DIRC readout?)
   - Common dipole for both beams?

4. **Integration with accelerator**