MEIC detector design

Pawel Nadel-Turonski

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Outline

Detection requirements and opportunities

Full-acceptance detector (primary)

High-luminosity detector (secondary)
Imaging in coordinate and momentum space

**GPDs**

2+1 D picture in **impact-parameter space**

![Diagram showing Lattice QCD up quark density](image)

- Accessed through *exclusive* processes
- Image above for polarized nucleon
- Ji sum rule for nucleon spin

**TMDs**

2+1 D picture in **momentum space**

![Diagram showing $F_1^T(x)$](image)

- Accessed through *Semi-Inclusive* DIS
- Requires transverse nucleon polarization
- OAM through spin-orbit correlations?
TMDs and Orbital Angular Momentum

- Do up and down quarks orbit in opposite directions? How about other quarks?

- Need to detect hadron(s) from struck quark

- How is this balanced by the fragmenting nucleon?
Transverse spatial imaging of sea quarks and gluons

- Are the radii of quarks and gluons, or strange and light sea quarks, different at a given $x$?
- Full image of the proton can be obtained by mapping $t$-distributions for different processes.

Horn et al. 08+, INT10-3
Recoil baryon detection

- At high proton energies, recoil baryons are scattered at small angles
  - Lower proton energies give better small-\( t \) acceptance and resolution in \( -t \)
  - Higher proton energies give better large-\( t \) acceptance for a given maximum ring energy
    - Lower maximum energy gives better acceptance at the actual running energy

- Good recoil baryon detection requires
  - Wide range of proton (deuteron) energies
  - Small beam size to reach low \( -t \)
GPDs with transversely polarized “targets“

- DVCS on a transversely polarized target is sensitive to the GPD $E$
  - GPD $H$ can be measured through the beam spin asymmetry

- Meson production is more selective: $J/\Psi$ sensitive to corresponding gluon GPDs

- GPD program requires good resolution and acceptance in $-t$, but also transversely polarized proton and neutron targets

$$E' (x, \zeta, t) = \kappa^c (t) \, H^i (x, \zeta, t)$$

Error bars shown only for $\kappa^{sea} = +1.5$
Spectator tagging with polarized deuterium

"If one could tag neutron, it typically leads to larger asymmetries" - Z. Kang

- Deeply Virtual Compton Scattering (DVCS) on a neutron target
- Tagged, polarized neutrons are essential for the GPD program

Polarized neutrons are important for probing d-quarks through SIDIS

C. Hyde

Z. Kang
Neutron structure through spectator tagging

- In fixed-target experiments, scattering on *bound neutrons* is complicated
  - Fermi motion, nuclear effects
  - Low-momentum spectators
  - No polarization

- The MEIC is designed from the outset to tag spectators, and all nuclear fragments.
Spectator (and fragment) detection / tagging

**Quasi-free neutron**
- Target: $^3\text{H}$
- Spect.: $D$

**(Quasi)-free proton**
- Target: $p$
- Spect.: $D$

A. Accardi
Quark propagation in matter (hadronization)

Accardi, Dupre

- Broadening of $p_T$ distribution
- Heavy flavors: B, D mesons, J/$\Psi$ ...
- Hadron jets at $s > 1000$ GeV$^2$
- What happens to the nucleus?
  - Does it disintegrate to nucleons or fragments?
**Full-acceptance detector – strategy**

No other magnets or apertures between IP and FP!

Central detector, more detection space in ion direction as particles have higher momenta.

Detect particles with angles down to ~0.5° before ion FFQs. Need up to 2 Tm dipole in addition to central solenoid.

Make use of the (50 mrad) crossing angle for ions!
Hadron detection prior to ion quadrupoles

- Large crossing angle (50 mrad)
  - Moves spot of poor resolution along solenoid axis into the periphery
  - Minimizes shadow from electron FFQs

- Large-acceptance dipole further improves resolution in the few-degree range
Ultra-forward hadron detection – requirements

1. **Good acceptance for ion fragments** (rigidity different from beam)
   - Large downstream magnet apertures
   - Small downstream magnet gradients (realistic peak fields)

2. **Good acceptance for recoil baryons** (rigidity similar to beam)
   - Small beam size at second focus (to get close to the beam)
   - Large dispersion (to separate scattered particles from the beam)

3. **Good momentum- and angular resolution**
   - Large dispersion (*e.g.*, 60 mrad bending dipole)
   - Long, instrumented magnet-free drift space

4. **Sufficient separation between beam lines (~1 m)**
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Ultra-forward hadron detection – summary

- Neutron detection in a 25 mrad cone down to zero degrees
- Excellent acceptance for all ion fragments
- Recoil baryon acceptance:
  - up to 99.5% of beam energy for all angles
  - down to 2-3 mrad for all momenta
- Momentum resolution < $3 \times 10^{-4}$
  - limited by intrinsic beam momentum spread
- 100 GeV maximum ion energy allows using large-aperture magnets with achievable field strengths
Other interaction regions

**Space for 3 Interaction Points (IP)**

- Main IPs located close to outgoing ion arc to reduce backgrounds

**Full-acceptance detector (primary)**

- 7 m from IP to ion final-focus quads

**High-luminosity detector (secondary)**

- 4.5 m from IP to ion final-focus quads

**Special IP**

- Space reserved for future needs
Momentum resolution at different rapidities

particle momentum = 5 GeV/c
4 T ideal solenoid field
cylindrical tracker with 1.25 m radius ($R_1$)

\[ \Delta p/p \sim \sigma p / BR^2 \]

- Tracker (not magnet!) radius $R$ is important at central rapidities (i.e., scattering angles)
- Only solenoid field $B$ matters at forward rapidities
- Full-acceptance detector benefits from high field for uniform resolution
- High-luminosity detector solenoid could have a lower field and larger radius, focusing on transverse physics
- High-luminosity IP could give up the intermediate detection stage to save space, but keep the crossing angle and a simplified ultra-forward detection
Detector radius also useful for particle identification

- Small differences in the desired momentum range ($p_{lab}$) for π/K separation has a huge impact on detector layout

- If you need 8-9 GeV, the detector may look like on the left (1 m radial space for PID)
  - High luminosity detector?

- If 5-6 GeV is enough, the detector may look like this instead (0.1 m radial space for PID)
  - Full acceptance detector?

- TOF
- DIRC bar
- DIRC expansion volume