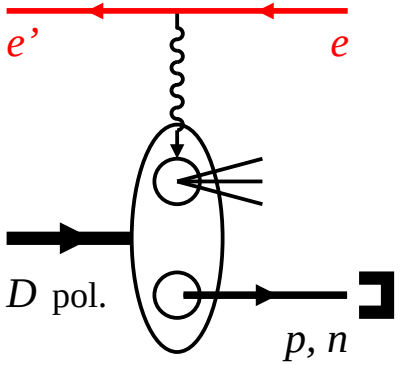
Simulating spectator nucleon tagging with EIC

C. Weiss (JLab), EIC Software Meeting, JLab, 24–Sep–15

Jefferson Lab

- High-energy eD scattering with detection of forward proton/neutron



Identify active nucleon, control quantum state

Spectator momentum $\sim$ few 10 MeV in nucleus rest frame, boosted longitudinally in collider

Unique for collider: No target material, forward detectors, deuteron polarization longitudinal & transverse
Fixed target CLAS BONUS limited to recoil momenta $>$ 100 MeV

Great potential: Neutron spin structure, nuclear modification of quark/gluon structure, coherent effects at small x

- R&D project to develop physics potential
https://www.jlab.org/theory/tag/

FY14/15 LDRD Project: W.Cosyn, V.Guzey, D.Higinbotham, Ch.Hyde, K.Park, P.Nadel–Turonski, M.Sargsian, C.Weiss. Open for collaboration with users!

Develop **physics models, event generators, and analysis tools** for spectator tagging. Perform process simulations with schematic modeling of MEIC beam and detector chars. Quantify physics impact.

Physics models

- Unpolarized $e+D \to e'+N+X$: Nuclear binding in impulse approximation. Final-state interaction theory & implementation in progress.
- Longitudinally polarized $e+D \to e'+N+X$: Minimal implementation. General deuteron polarization (transverse, tensor) in progress.
- Diffractive $e+D \to e'+p+X(\mathrm{diff})$: Minimal implementation including diffraction/shadowing at $x \ll 0.1$. Full theory & implementation in prog.

  Codes & documentation available at: https://www.jlab.org/theory/tag/

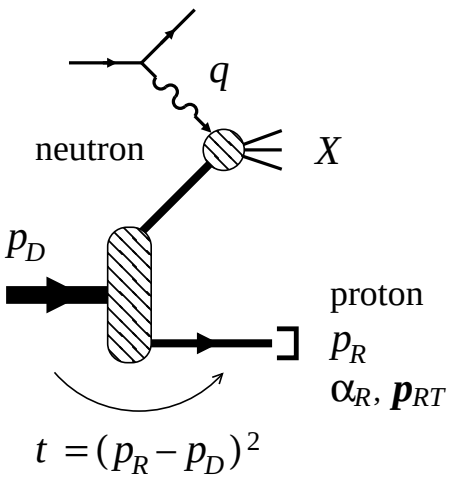
Event generators and analysis tools

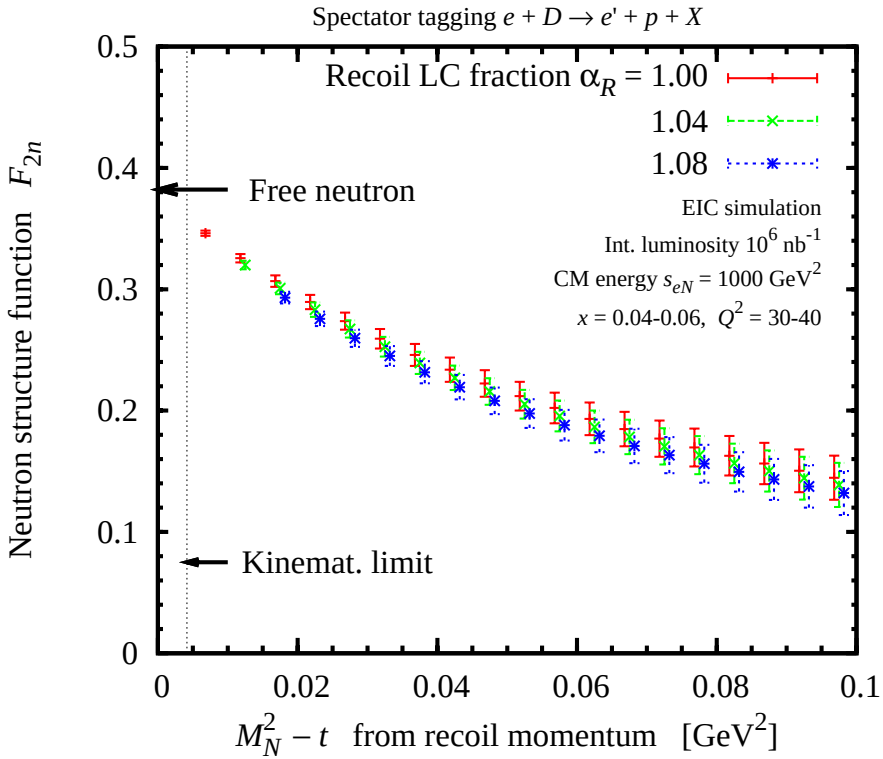
→ Talk K. Park

- $e+D \to e'+p+X$ event generator: 4–vectors generated in collider frame. Includes crossing angle and intrinsic momentum spread in ion beam.
- Output in GEMC format, allows studies of tracking, acceptance.
- Fixed-target applications possible; tested against FSGEN-based generator.
- Analysis tools: Neutron structure, on-shell extrapolation

  Codes & docu available at: https://github.com/JeffersonLab/LightIonEIC

Applications: Unpolarized neutron structure





- On-shell extrapolation

  Recoil momentum defines/controls neutron off-shellness $t - M_N^2$

  Free neutron at pole $t - M_N^2$: On-shell extrapolation

  Model-independent method! Eliminates nuclear binding effects and FSI Sargsian, Strikman 05

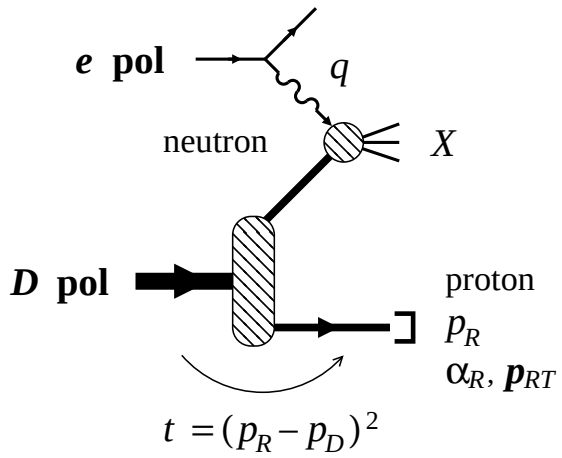
- Detection requirements

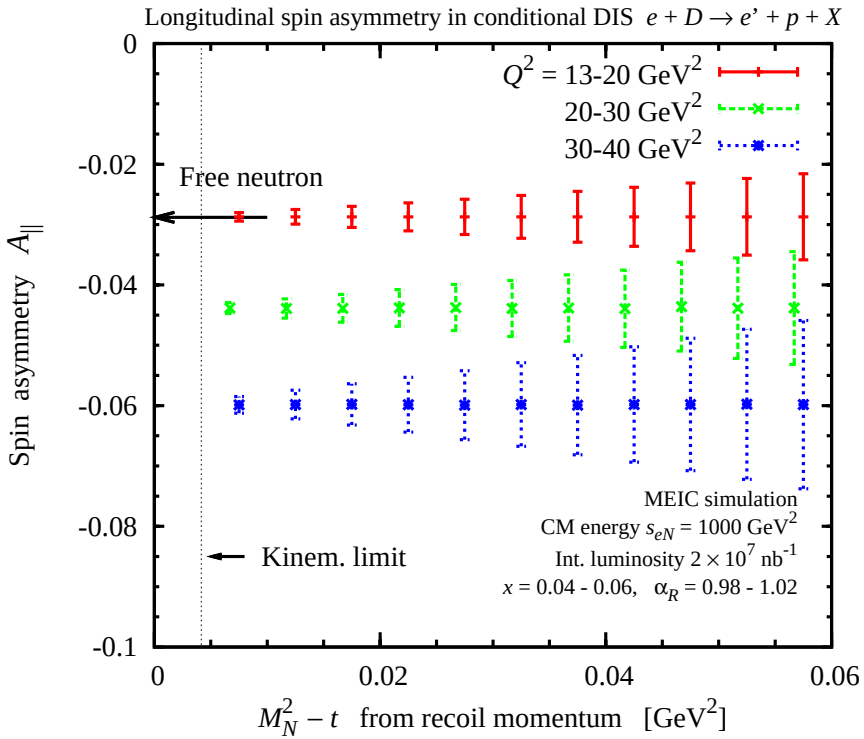
  Coverage for forward protons:
  Transv. $p_{RT} = [0, 200\,\mathrm{MeV}]$
  Longitud. $p_{RL} = [0.9, 1.1] \times p_D/2$

  Resolution in proton momentum:
  Transverse $\delta p_{RT} \sim 20\,\mathrm{MeV}$
  Longitudinal $\delta p_{RL}/p_{RL} < 10^{-3}$

  Momentum uncertainty from beam momentum spread and detector resolution

Applications: Polarized neutron structure





- Neutron spin structure with polarized D and proton tagging

  On-shell extrapolation of asymmetry

  D–wave suppressed at on-shell point: Neutron 100% polarized

- Systematic uncertainties reduced

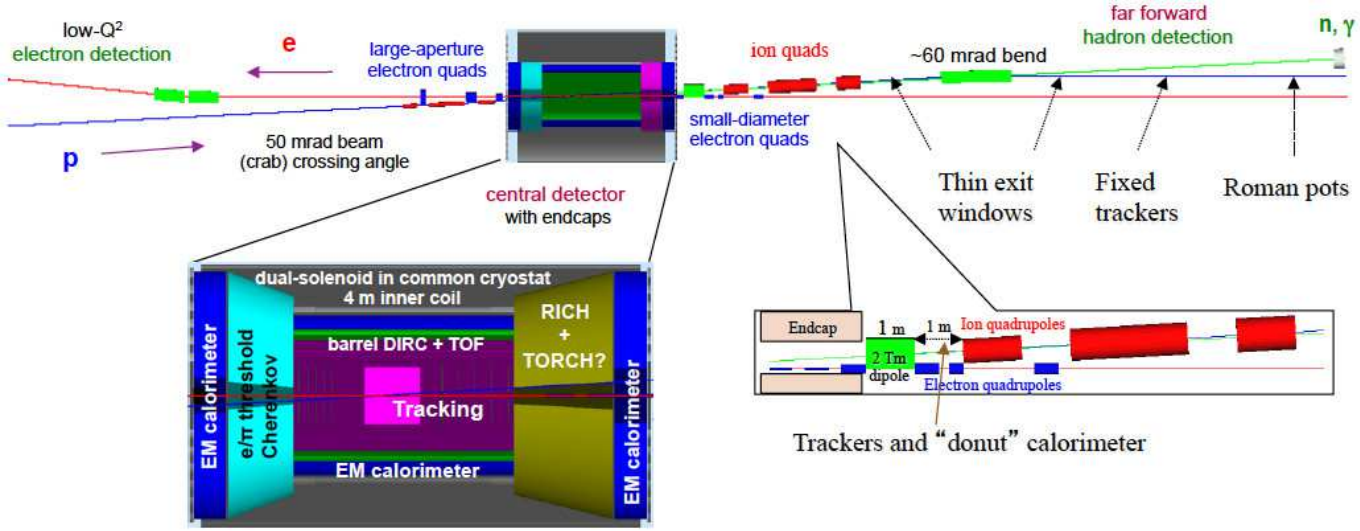
  Weak off-shell dependence of asymmetry

  Momentum smearing/resolution effects largely cancel in asymmetry

- Physics impact

  → arXiv:1409.5768

MEIC forward detector



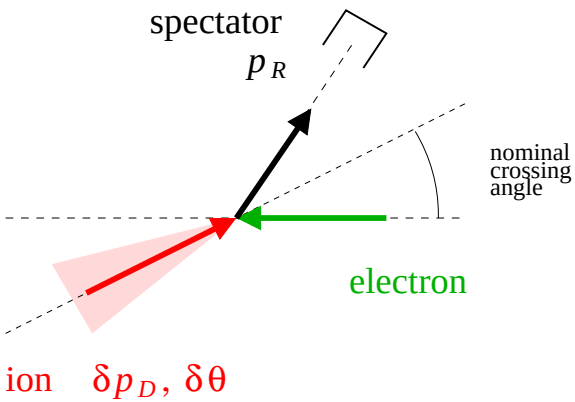
P. Nadel-Turonski et al.

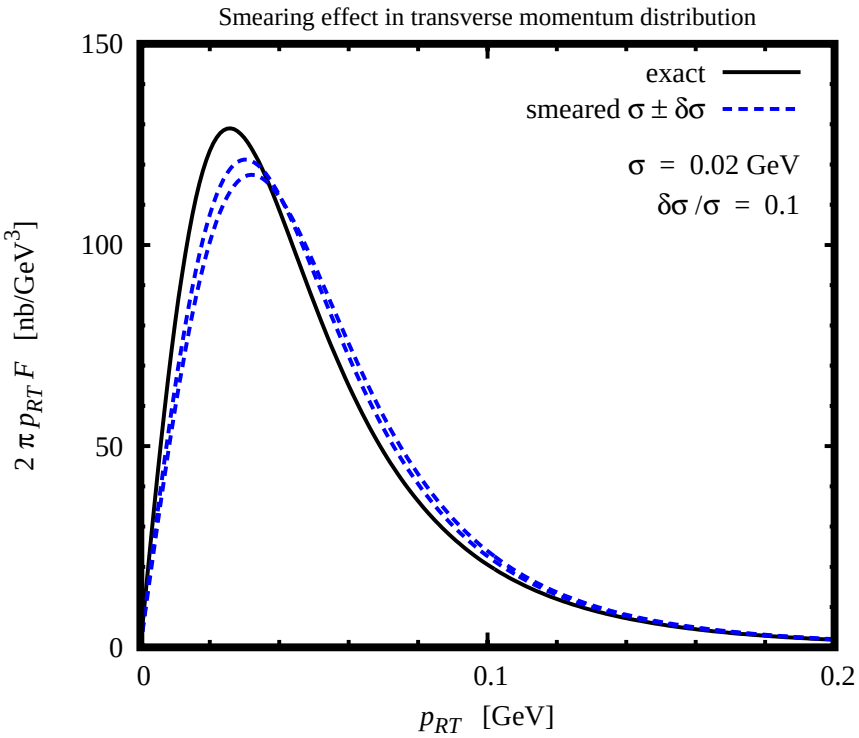
- Good acceptance for spectators and ion fragments (rigidity $\neq$ beam)
  Large magnet apertures, small gradients

- Good acceptance for elastic recoil (rigidity $=$ beam)
  Large dispersion generated *after* IP
  Longitudinal momentum up to 99.5% of beam, angles down to 2 mrad (10 σ)

- Good momentum and angular resolution
  Magnetic field as analyzer.
  Longitudinal $\delta p_{RL}/p_{RL} \sim$ few $\times\, 10^{-4}$, angular $\delta\theta \sim 0.3$ mrad
  $p_{RT} \sim 15\,\mathrm{MeV}/c$ resolution for tagged 50 GeV/A deuterium beam

MEIC ion beam momentum spread





- Intrinsic momentum spread in ion beam

  Ion beam has transverse momentum spread with width $\sigma \approx 20$ MeV

  Smearing effect
  $\boldsymbol{p}_{RT}(\text{vertex}) \neq \boldsymbol{p}_{RT}(\text{measured})$

  Width known only to $\delta\sigma/\sigma \sim 10\%$

  Results in systematic uncertainty:
  Correlated, x and Q^2–indpendent

  Does not compromise PDF fits!
  Cf. normalization uncertainty

- Dominant syst error in neutron structure measurements at MEIC

  Detector resolution much better than beam momentum spread
  Different for eRHIC!

Physics model codes

- Written/maintained by individual theorists. Free format, no standardization at software level

- Unpolarized/polarized tagged DIS model [CW 14/15]

  FORTRAN77 package

  Design goals: Simple, fast, adaptable, extensible

  Three levels of functionality:

Core	General physics functions, e.g. cross secn formulas	Subroutine
User	User-defined model input, e.g. PDFs, deuteron wave fn	Subroutine
App	Application programs for specific tasks, e.g., tabulating cross secn	Program

  Configuration at compile/link stage through selection of user-defined input routines. Avoids loading code with large number of options.

  Open source: No use of restricted or proprietary routines

  Fully documented: https://www.jlab.org/theory/tag/weiss/tag.pdf