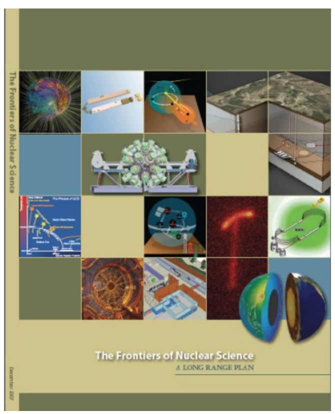
Medium-energy Electron-Ion Collider (MEIC) Physics

A. Accardi, R. Ent, V. Guzey, T. Horn, C. Hyde,
P. Nadel-Turonski, A. Prokudin, C. Weiss, ...

+ CASA / accelerator team

+ lots of JLab of users!

JLab S&T review, May 9, 2012



2007 Long-Range Plan
EIC: "half" recommendation


EPJ A
Hadrons and Nuclei

Eur. Phys. J. A (2011) 47: 35 DOI: 10.1140/epja/i2011-11035-2

Transverse-momentum–dependent parton distribution/fragmentation functions at an electron-ion collider

M. Anselmino, H. Avakian, D. Boer, F. Bradamante, M. Burkardt, J.P. Chen, E. Cisbani, M. Contalbrigo, D. Crabb, D. Dutta, L. Gamberg, H. Gao, D. Hasch, J. Huang, M. Huang, Z. Kang, C. Keppel, G. Laskaris, Z.-T. Liang, M.X. Liu, N. Makins, R.D. Mckeown, A. Metz, Z.-E. Meziani, B. Musch, J.-C. Peng, A. Prokudin, X. Qian, Y. Qiang, J.W. Qiu, P. Rossi, P. Schweitzer, J. Soffer, V. Sulkosky, Y. Wang, B. Xiao, Q. Ye, Q.-J. Ye, F. Yuan, X. Zhan, Y. Zhang, W. Zheng and J. Zhou

2010 JLab User
Workshops

INT10-3 program
>500 page report

The physics program of an EIC (sea quarks and gluons)

Map the *spin and spatial structure* of *sea quarks and gluons* in nucleons

- Sea quark and gluon polarization
- Transverse spatial distributions
- Orbital motion of sea quarks / gluons
- Parton correlations: beyond one-body densities

Discover the collective effects of *gluons in nuclei*

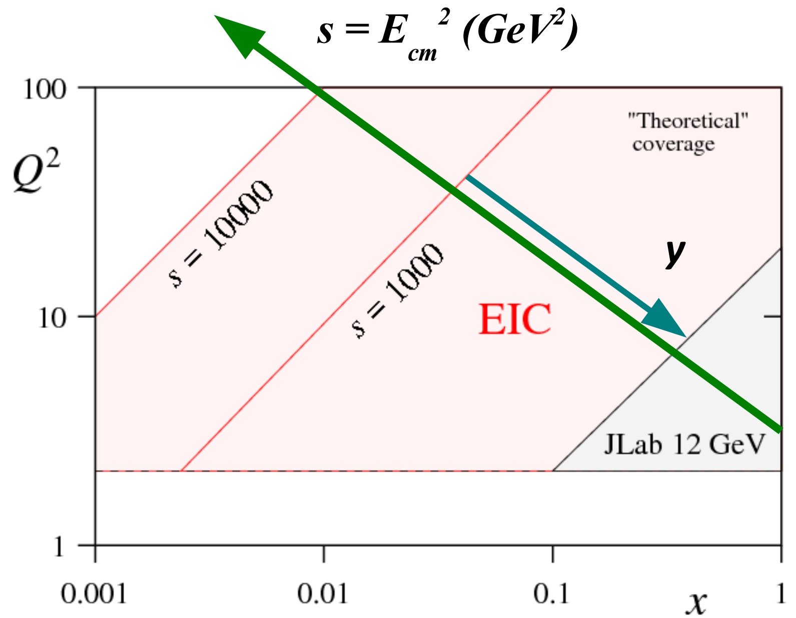
- Color transparency: small-size configurations
- Nuclear gluons: EMC effect, shadowing
- Strong color fields: unitarity limit, saturation
- Fluctuations: diffraction

Understand the emergence of *hadronic matter from color charge*

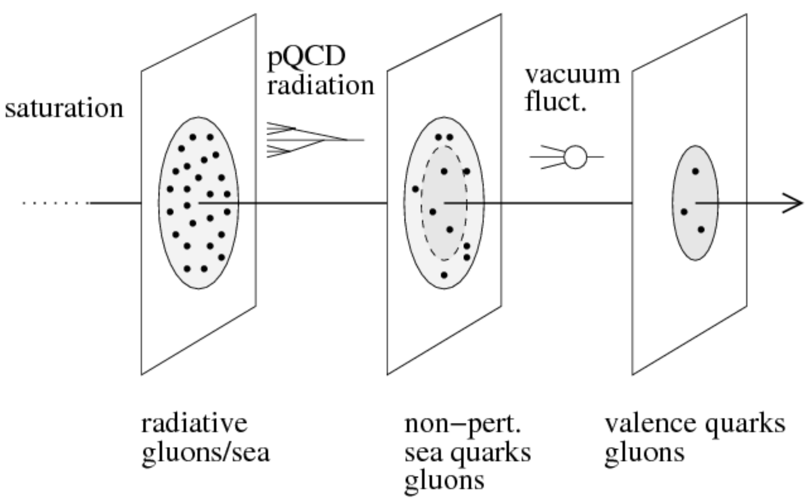
- Materialization of color: fragmentation, hadron breakup, color correlations
- Parton propagation in matter: radiation, energy loss

Opportunities for fundamental symmetry measurements?

EIC – why a collider?



C. Weiss



LHeC ?

EIC Stage II (ELIC) **EIC Stage I (MEIC)** **JLab 12 GeV**

$Q^2 \sim ysx$

Medium-energy EIC

- $s = 4\, E_e E_p = 4 \times 11 \times 100 = 4400$ GeV^2

Fixed-target experiments

- $s = 2\, E_e M_p = 2 \times 11 \times 0.938 = 20$ GeV^2
- $s = 2\, E_e M_p = 2 \times 2345 \times 0.938 = 4400$ GeV^2

Range in the inelasticity y determines the coverage at each energy setting

EIC – consensus on many global requirements

The EIC project is pursued jointly by BNL and JLab, and both labs work towards implementing a common set of goals

- Polarized electron, nucleon, and light ion beams
  - Electron and nucleon polarization > 70%
  - Transverse polarization at least for nucleons
- Ions from hydrogen to A > 200
- Luminosity reaching 10^{34} $cm^{-2}s^{-1}$
- Stage I energy: $\sqrt{s}$ = 20 – 70 GeV (variable) (MEIC)
- Stage II energy: $\sqrt{s}$ up to about 150 GeV (ELIC)

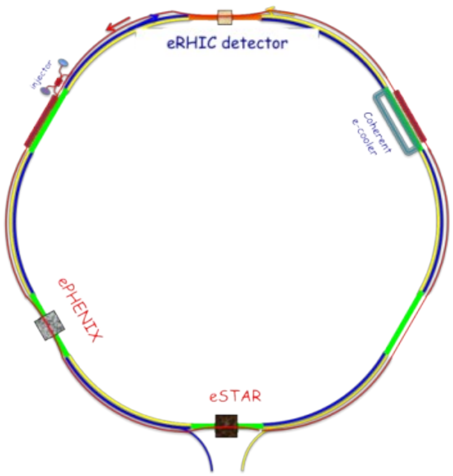
From base EIC requirements in the INT report

EIC – similar energies at both BNL and JLab

Stage I

Stage II

eRHIC @ BNL



Stage I:

$\sqrt{s}$ = 25 – 71 GeV

E_e = 3 – 5 GeV

E_p = 50 – 250 GeV

E_{Pb} = up to 100 GeV/A

Stage II:

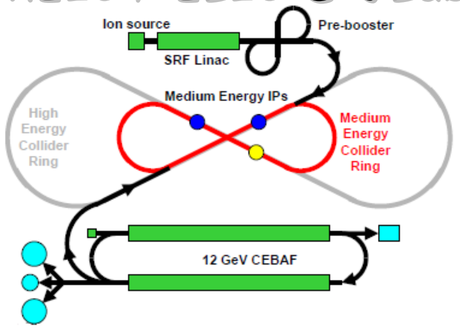
$\sqrt{s}$ = up to ~180 GeV

E_e = up to ~30 GeV

E_p = up to 275 GeV

E_{Pb} = up to 110 GeV/A

MEIC / ELIC @ JLab



Stage I:

$\sqrt{s}$ = 15 – 66 GeV

E_e = 3 – 11 GeV

E_p = 20 – 100 GeV

E_{Pb} = up to 40 GeV/A

(MEIC)

Stage II:

$\sqrt{s}$ = up to ~140 GeV

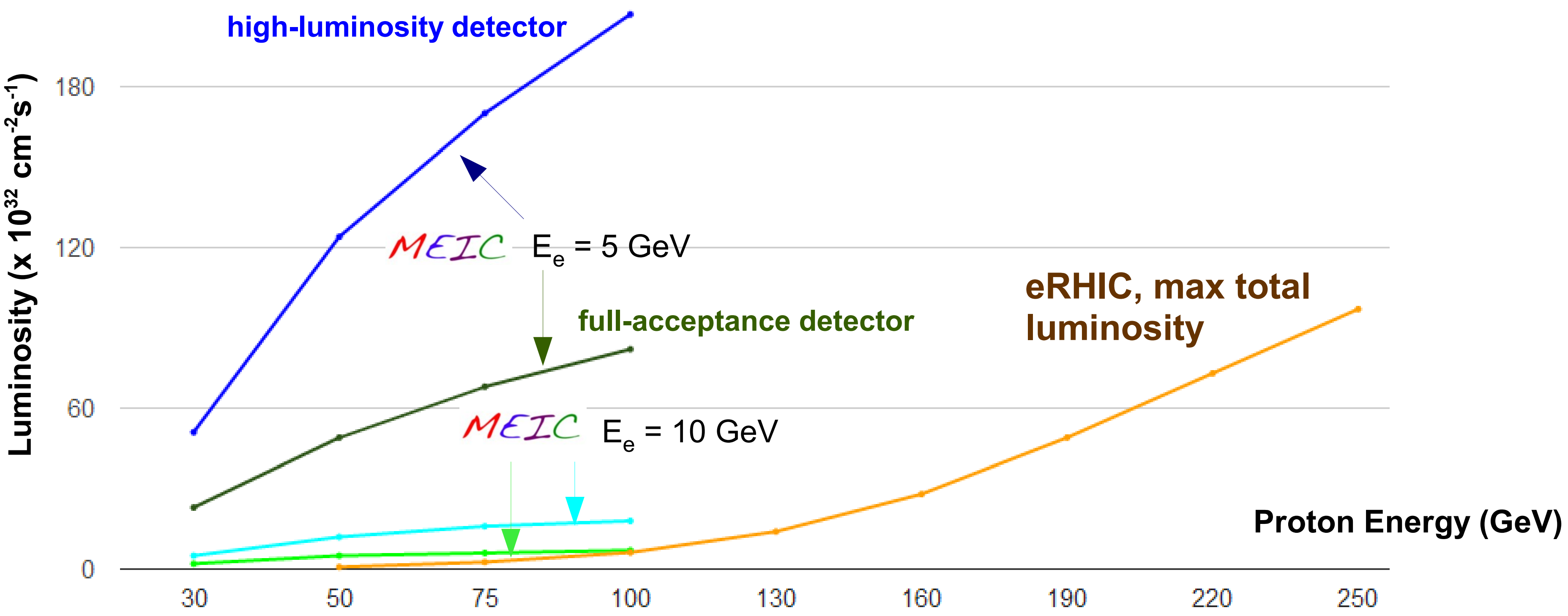
E_e = up to ~20 GeV

E_p = up to at least 250 GeV

E_{Pb} = up to at least 100 GeV/A

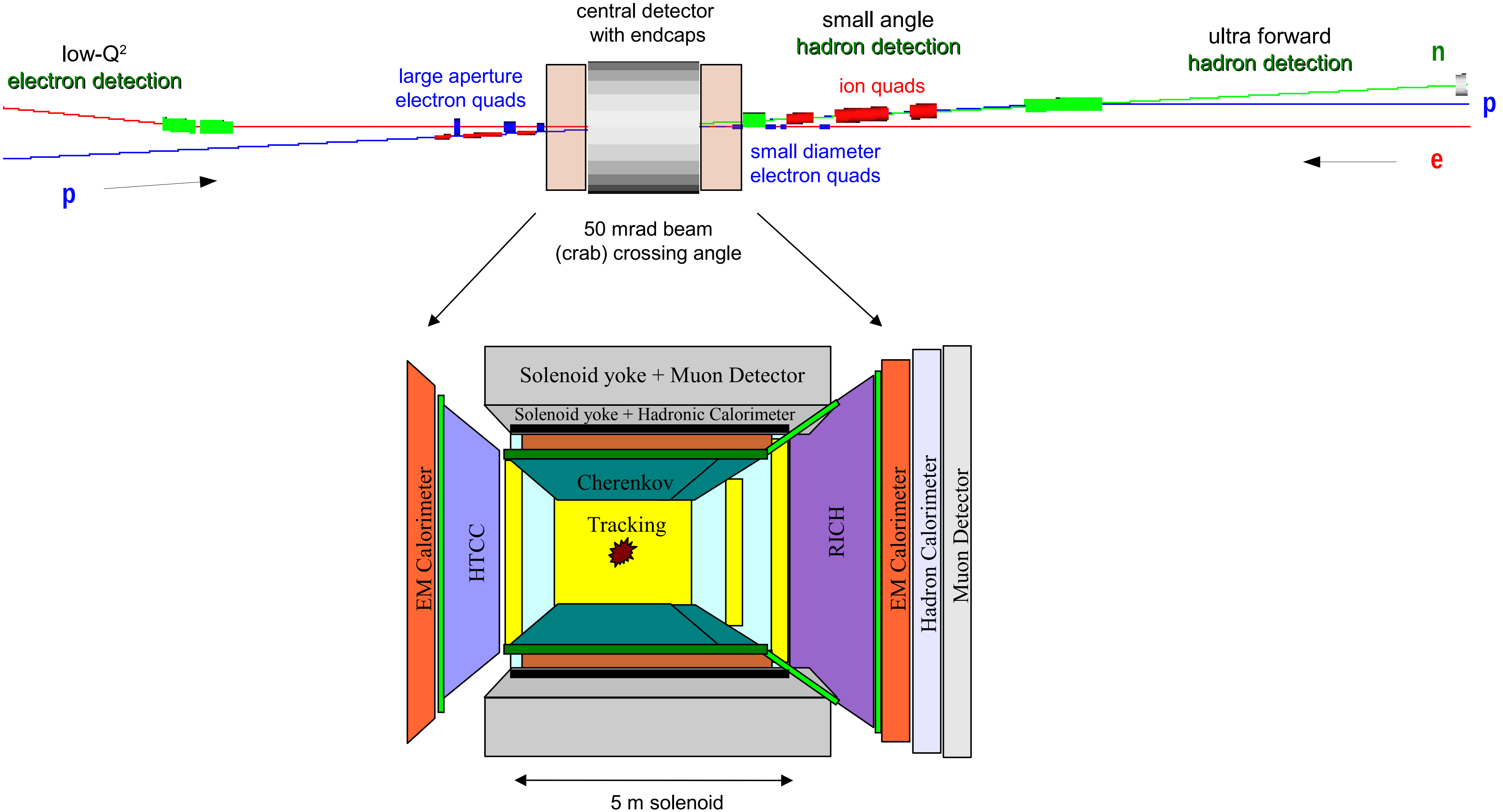
(ELIC)

EIC – different luminosity profiles



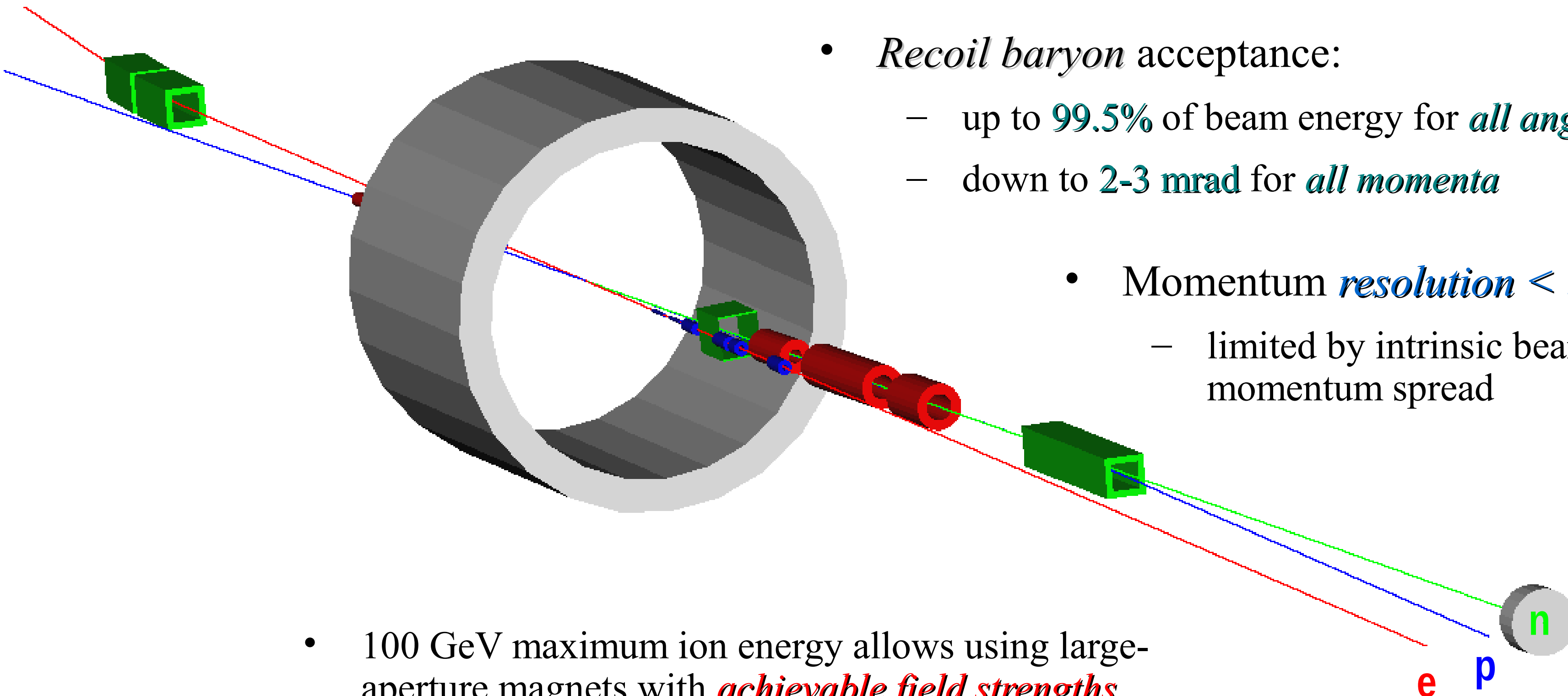
- MEIC luminosity is optimized for mid-range (4-8 GeV) electron energies over a wide range of proton energies.
  - Luminosities are listed *per detector*. All can be used simultaneously.
- eRHIC offers a high luminosity at a high proton energy.
  - Luminosity is given for *all detectors*. Only one can be used at a time.

MEIC – the full-acceptance detector



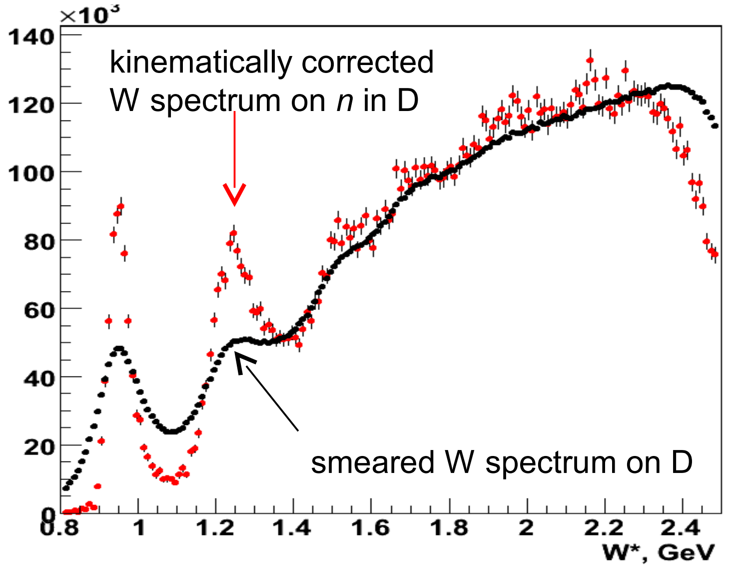
MEIC – small-angle detection in GEANT4

- *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 < $3x10^{-4}$***
  - limited by intrinsic beam momentum spread



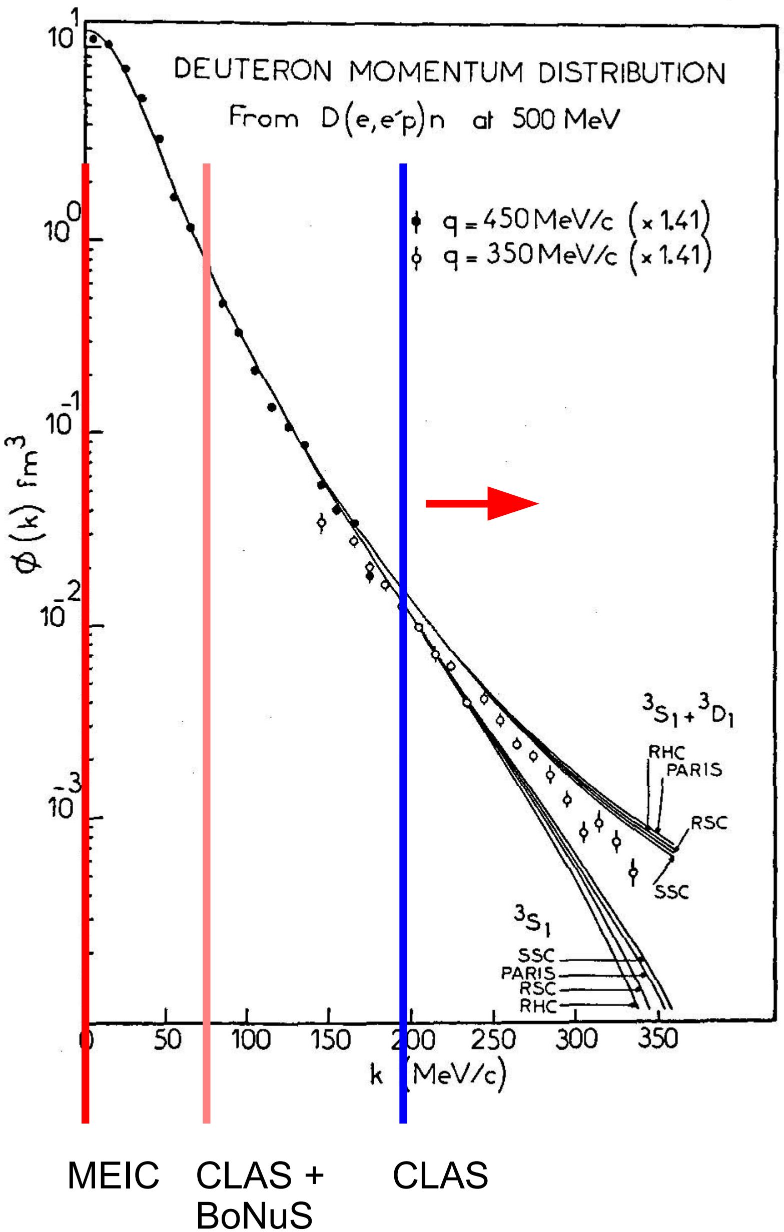
- 100 GeV maximum ion energy allows using large-aperture magnets with ***achievable field strengths***

Spectator tagging

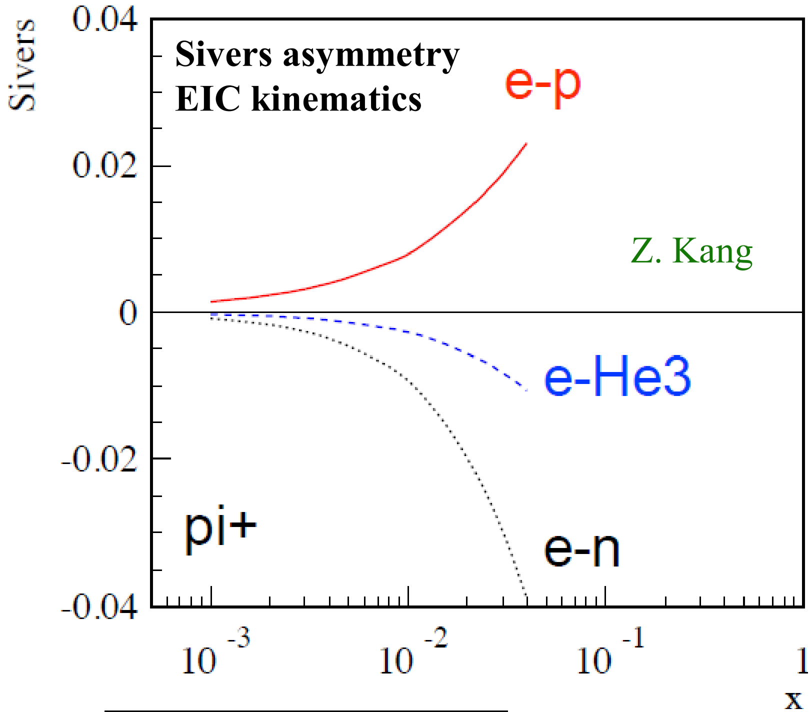


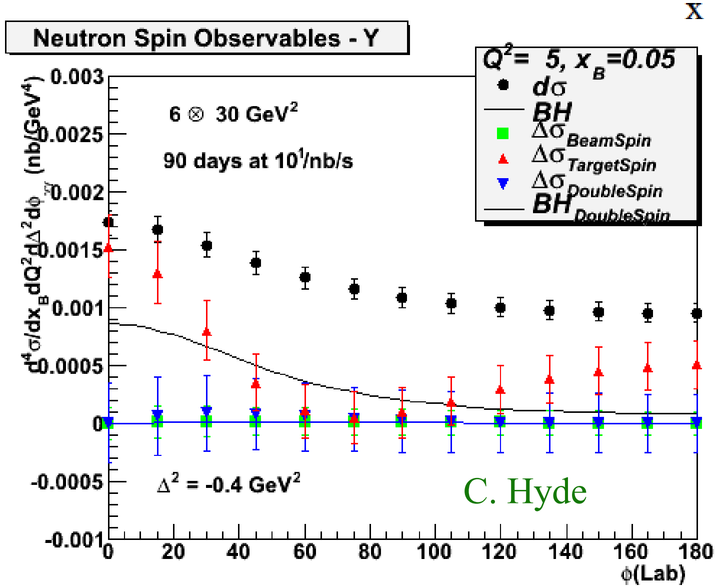
CLAS BoNuS data with tagged spectators

- In fixed-target experiments, scattering on *bound neutrons* is complicated
  - Fermi motion, nuclear effects
  - Low-momentum spectators
- The MEIC allows easy tagging of *spectators* and *all nuclear fragments*



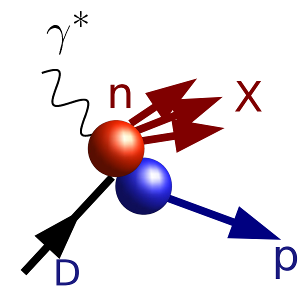
Spectator tagging – polarized deuterium





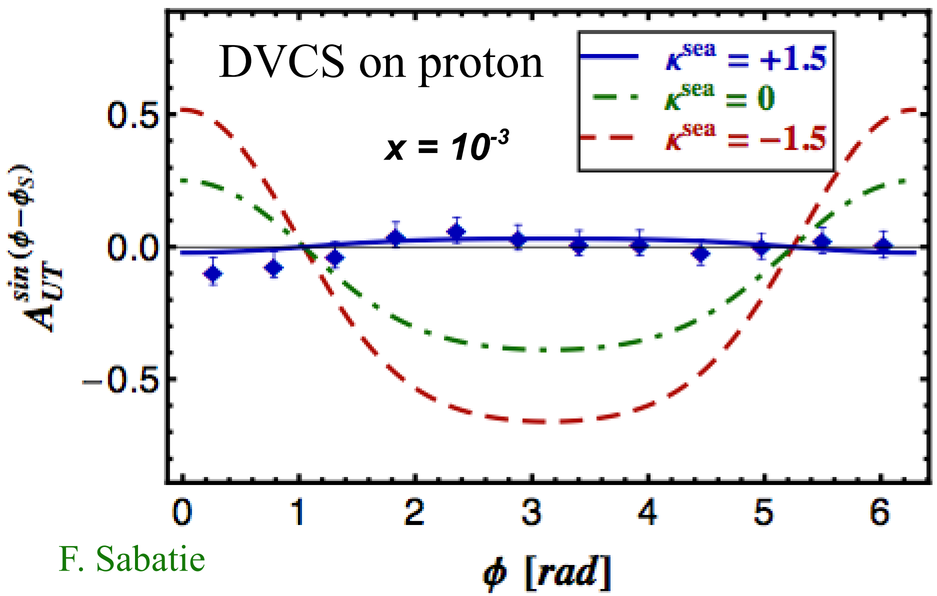
„If one could tag neutron, it typically leads to larger asymmetries“

Z. Kang



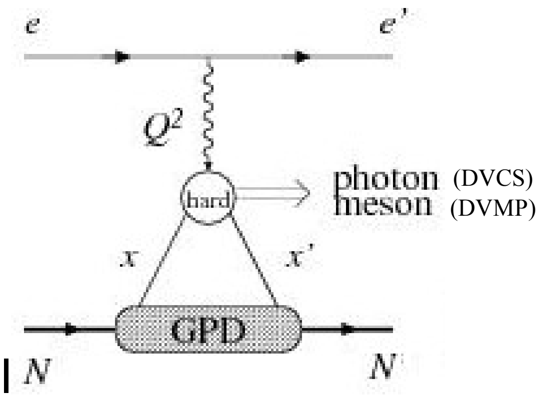
- MEIC will provide longitudinal and *transverse* polarization for d, ^{3}He, and other light ions
- Polarized *neutrons* are important for probing d-quarks through SIDIS
- Exlusive reactions like DVCS greatly benefit from polarized *neutron* “targets“
  - *c.f.* Hall A and B programs

Exclusive reactions with transverse “target“



F. Sabatie

Model

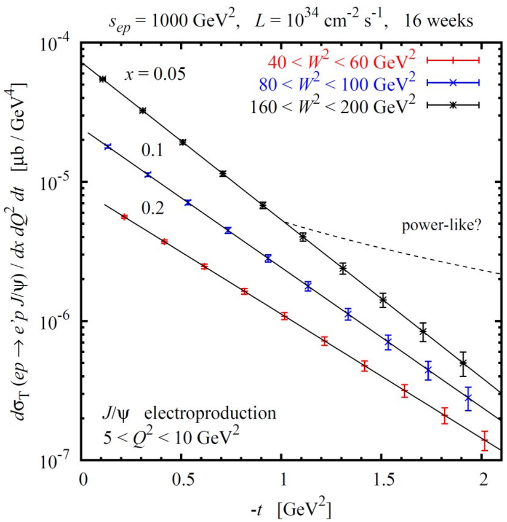


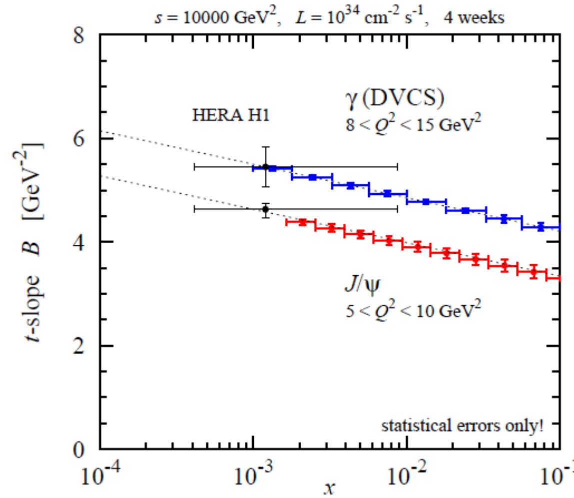
$$E^i(x, \xi, t) = \kappa^i(t)\, H^i(x, \xi, t)$$

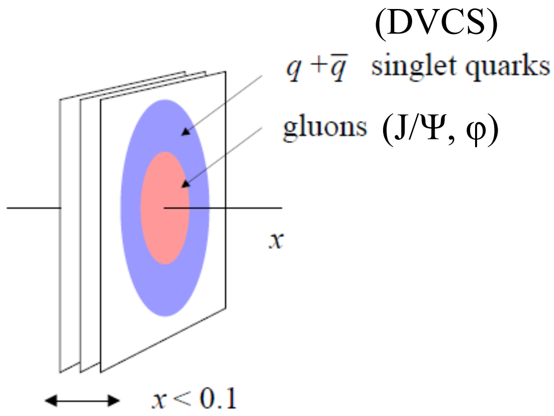
Error bars shown only for $\kappa^{sea} = +1.5$

- 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/Ψ sensitive to corresponding ***gluon GPDs***
- Colliders provide an excellent Figure-Of-Merit (FOM)
  - ***FOM*** = Cross section x Luminosity x Acceptance x ***(Polarization)^2 x (Target dilution)^2***

Transverse spatial imaging of sea quarks and gluons

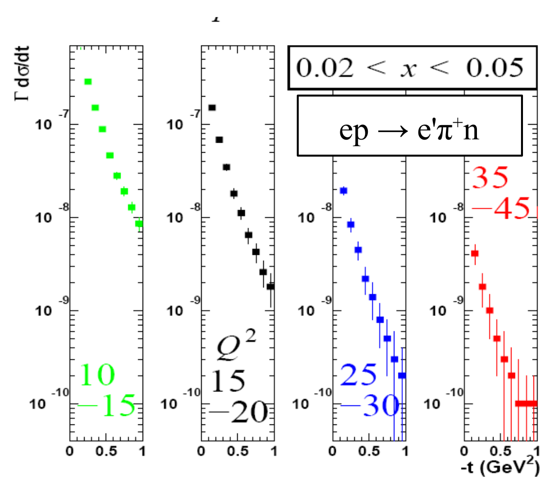


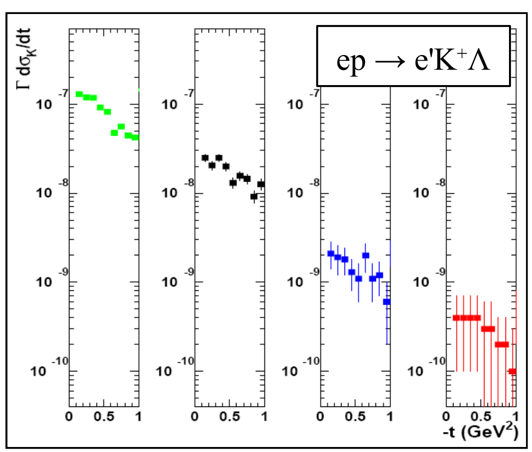


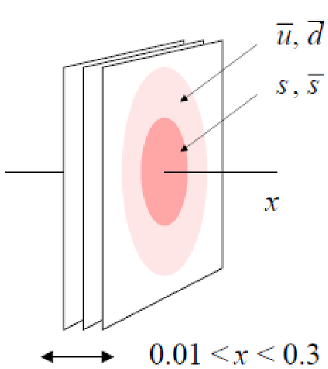


Weiss et al, INT 10-3

- 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.

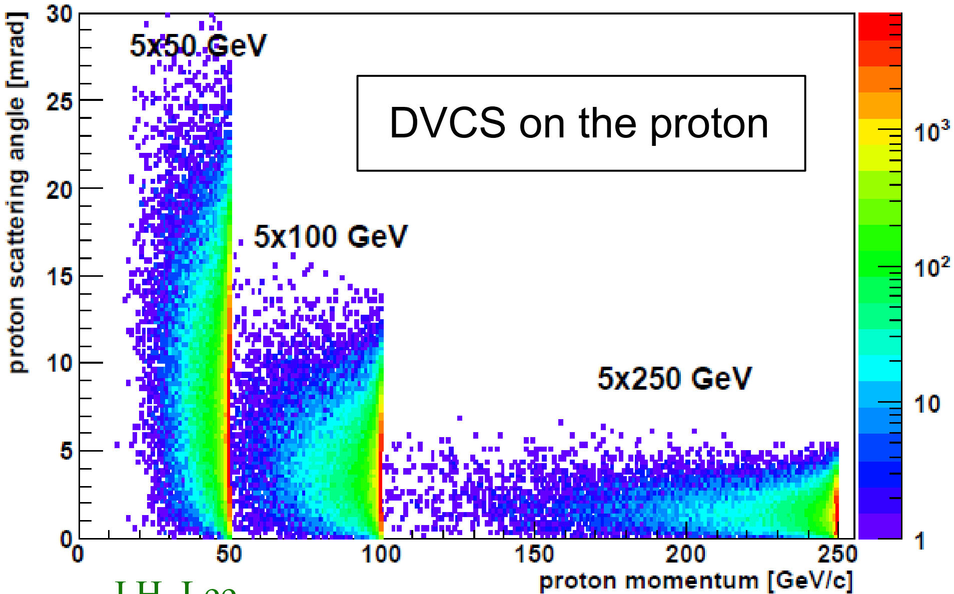




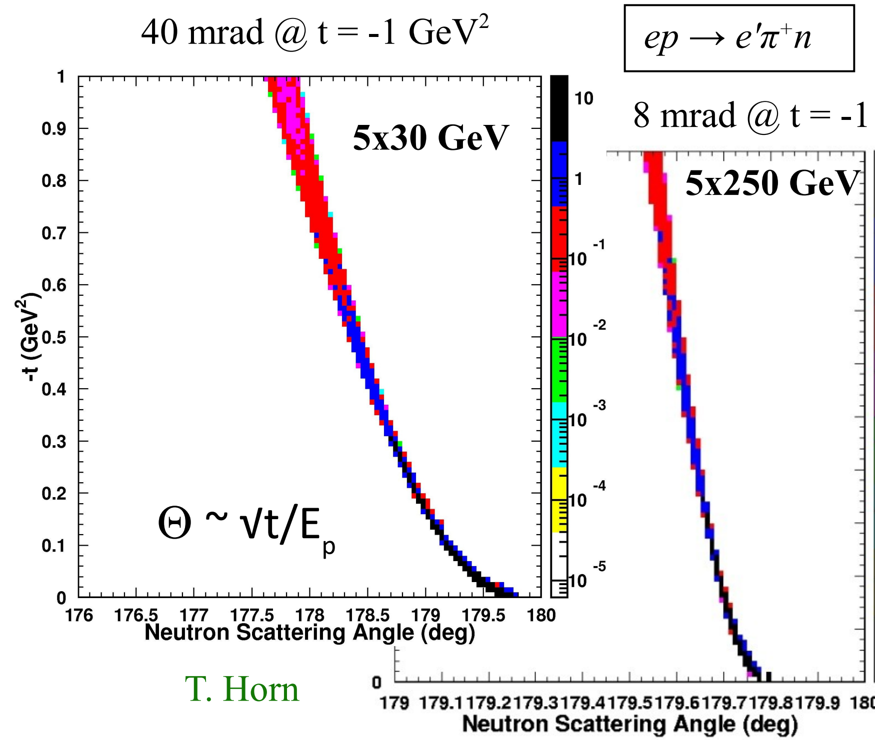


Horn et al. 08+, INT10-3

Transverse spatial imaging – recoil baryons



J.H. Lee



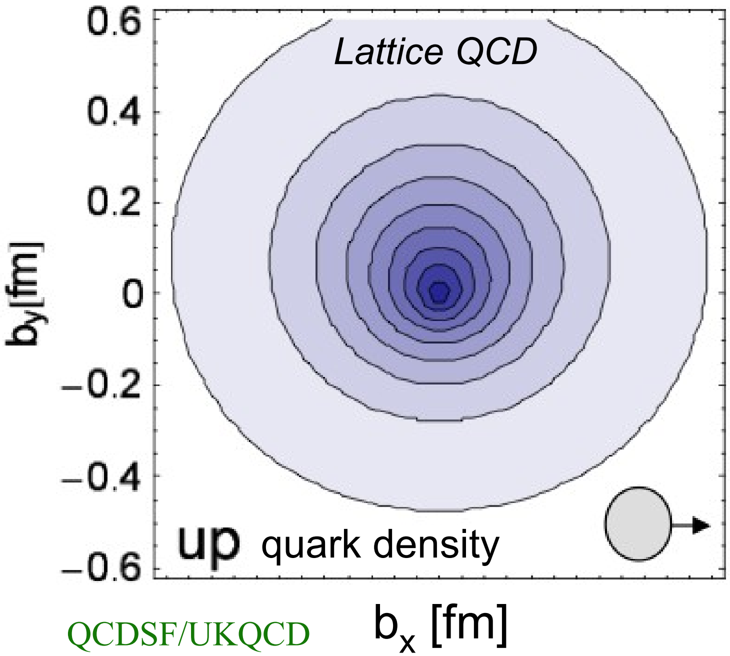
T. Horn

- At high proton energies, recoil baryons are scattered at small angles
  - Lower energies give better *resolution* in *-t*
- The MEIC is a perfect tool for imaging of the nucleon
  - High luminosity over a wide range of proton (deuteron) energies
  - Excellent small-angle detection

Imaging in coordinate and momentum space

<u>GPDs</u>

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

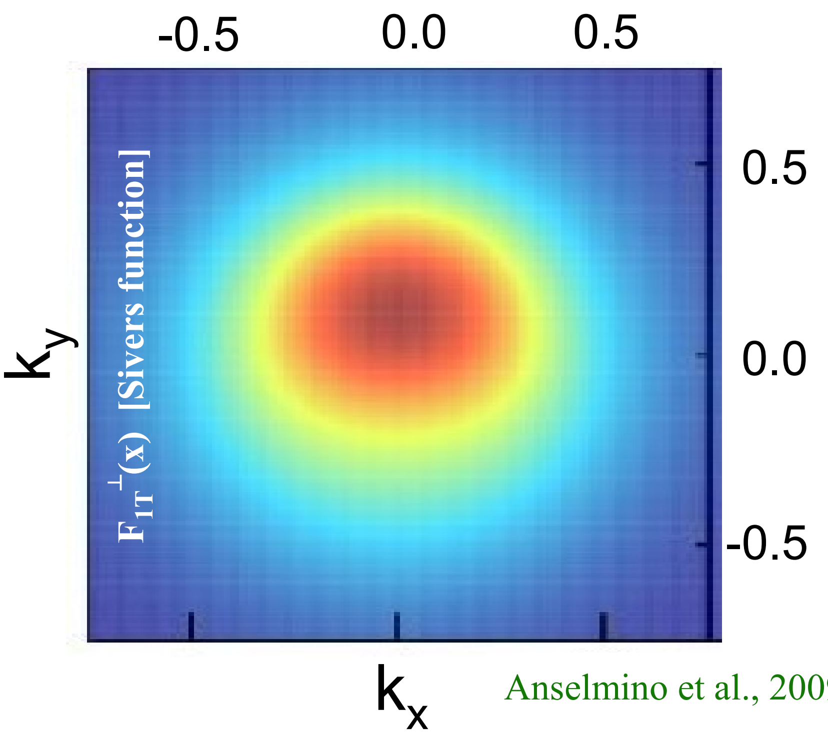


QCDSF/UKQCD Coll., 2006

- Accessed through *exclusive* processes
- Existing factorization theorems
- Ji sum rule for nucleon spin

<u>TMDs</u>

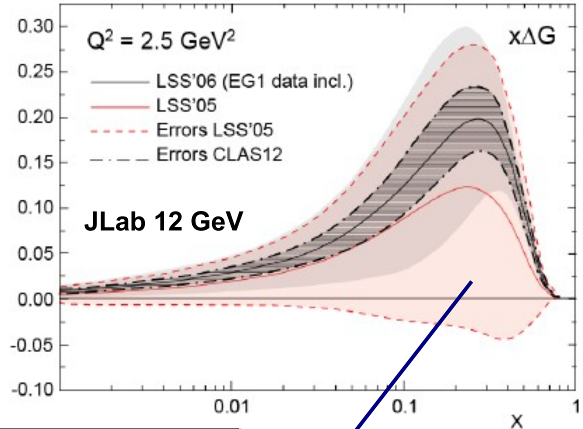
2+1 D picture in **momentum space**

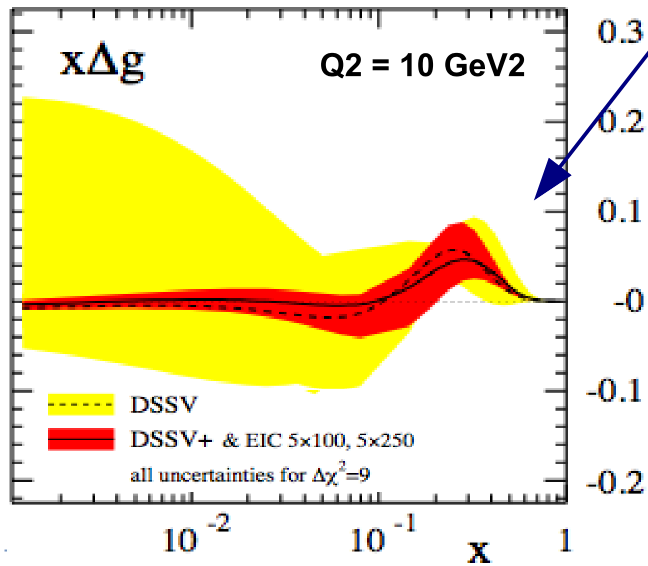


Anselmino et al., 2009

- Accessed through *Semi-Inclusive* DIS
- Non-trivial factorization
- OAM through spin-orbit correlations?

Longitudinal spin – ΔG



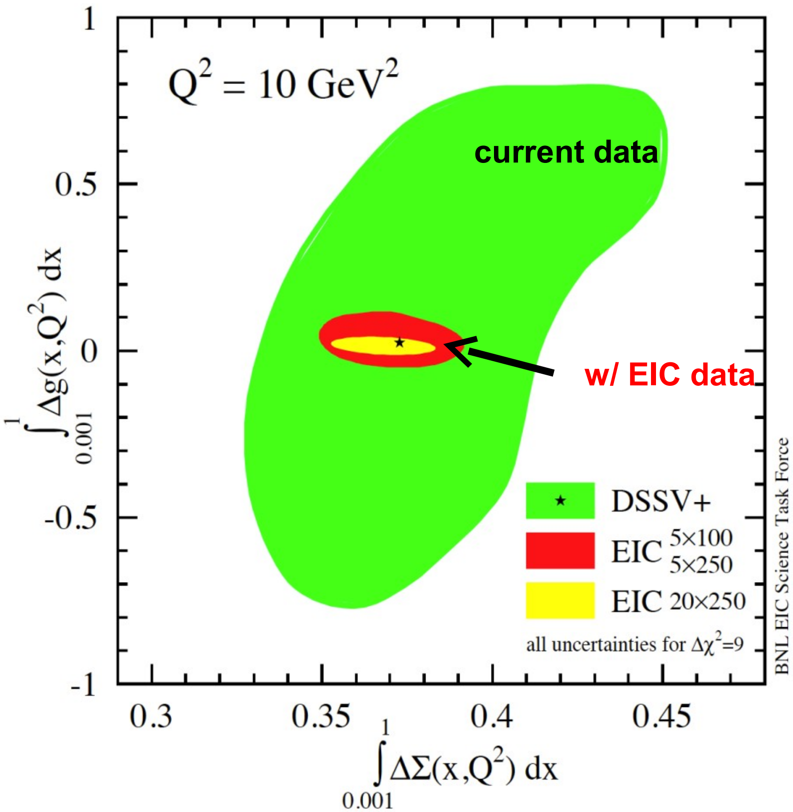


M. Stratmann

Green: RHIC spin, etc

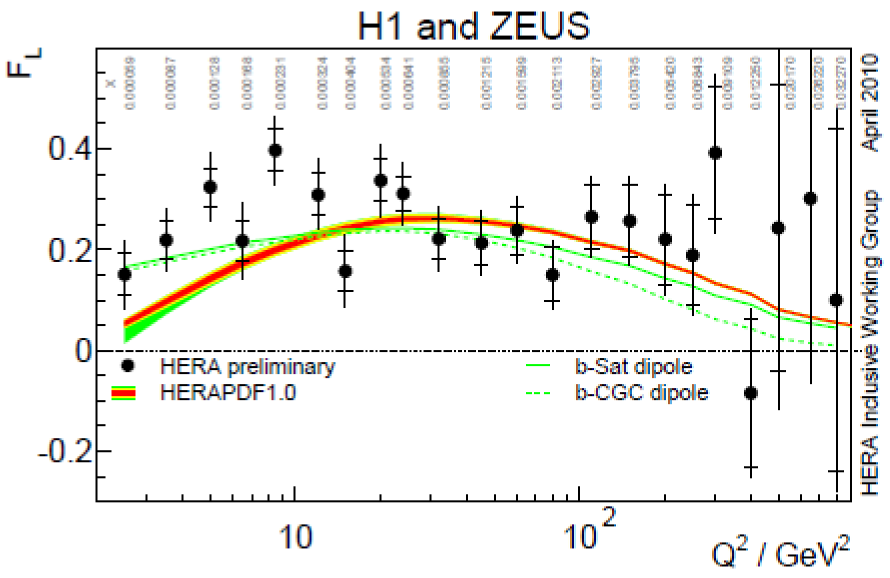
Red: EIC Stage I: MEIC or eRHIC

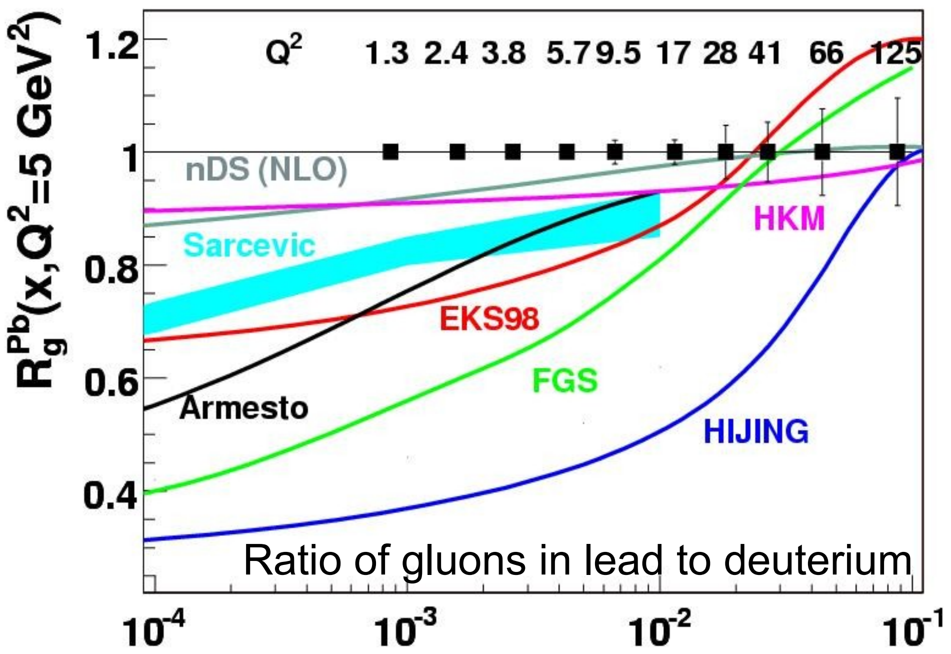
Yellow: EIC Stage II: ELIC or eRHIC



- EIC stage I will greatly improve our understanding of ΔG
  - Stage II will eventually further reduce the uncertainty somewhat

Gluons in nuclei

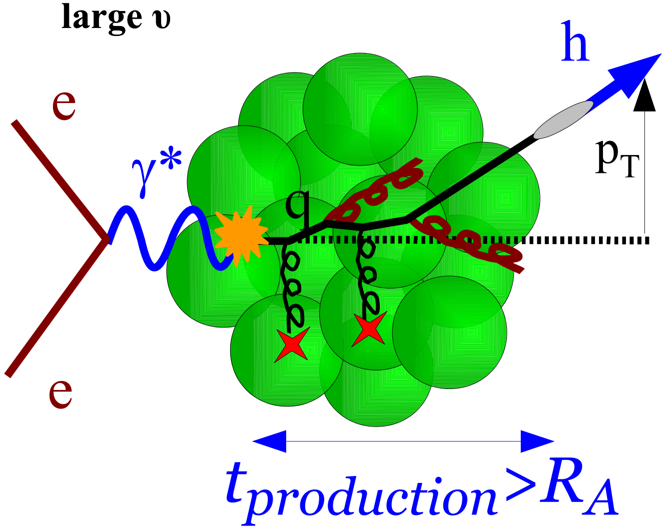


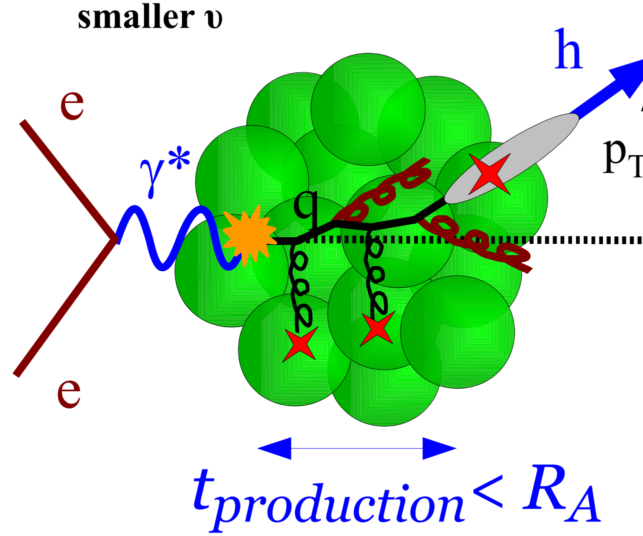


Guzey et al., Phys.Rept. 512 (2012) 255-393

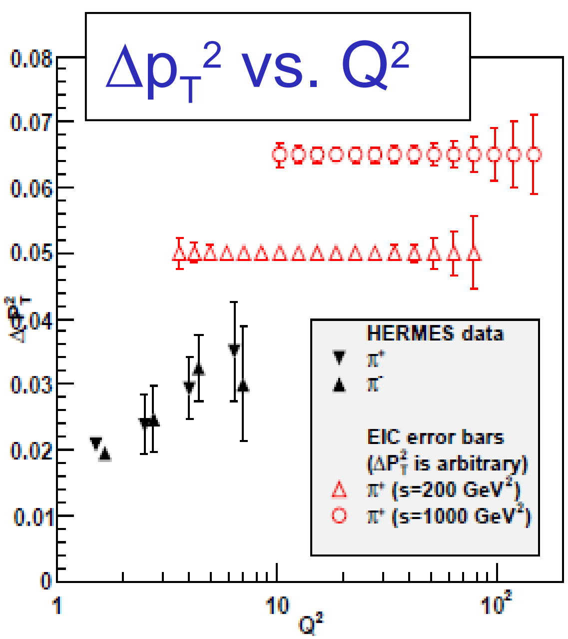
- HERA measured the longitudinal gluon distributions in the *nucleon*
  - F_L and $dF_2/dln(Q^2)$
- Very little is known about gluons in *nuclei* for all x
- New discoveries awaiting the MEIC?

Hadronization – parton propagation in matter

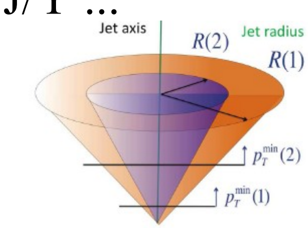




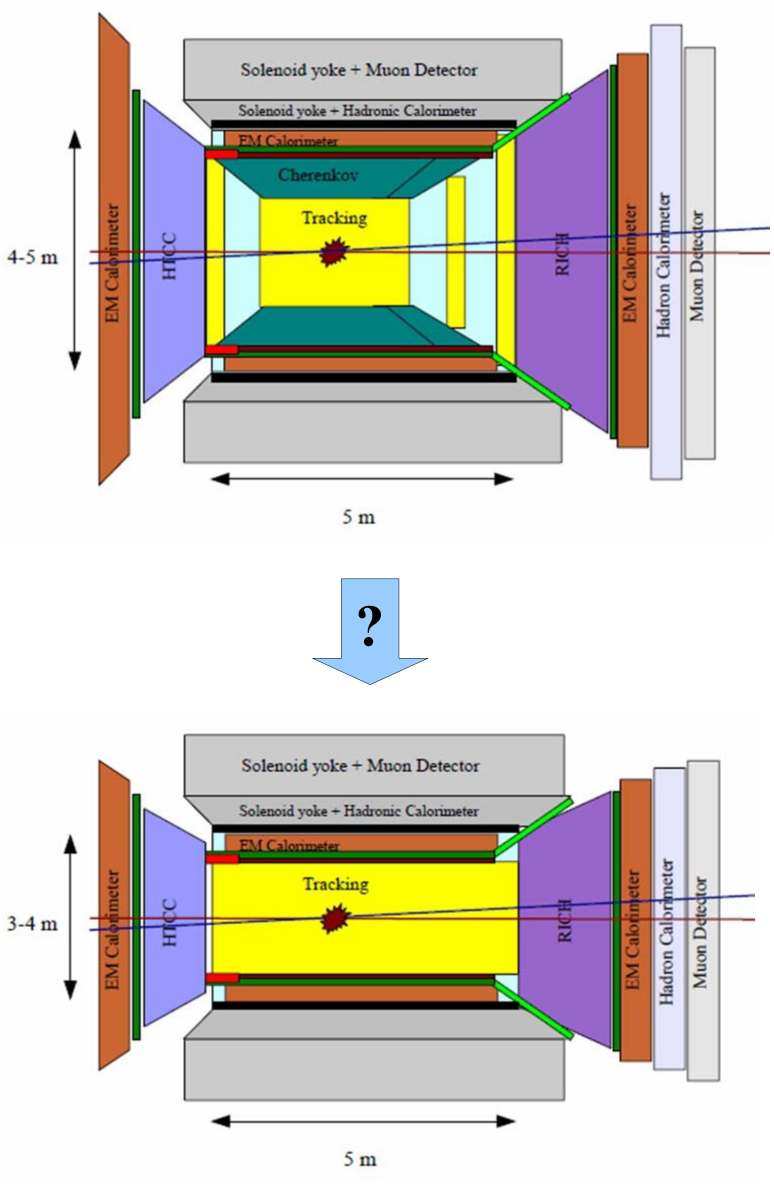
Accardi, Dupre



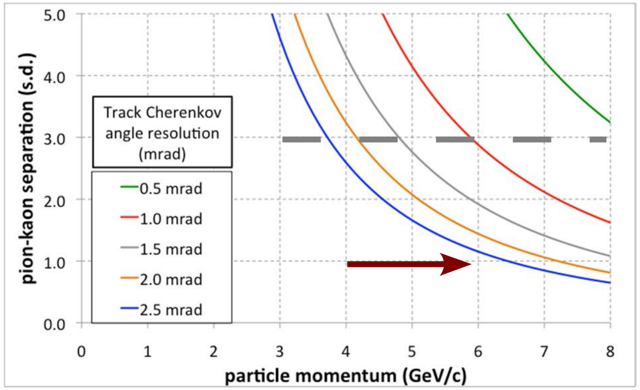
- p_T broadening strongly constrains theory
  - Large range in υ at a collider allows
    - Isolation of pQCD energy loss (large υ)
    - Study of (pre)hadronization (smaller υ)
  - Heavy flavors: B, D mesons, J/Ψ ...
  - Jets above s = 1000 GeV^2
    - „real“ pQCD, IR safe



R&D – DIRC-based PID for the central detector



- Can we build a radially compact detector?
  - Driven by particle identification
- Generic EIC detector R&D grant
  - \$0.4M over three years
  - JLab, GSI (PANDA), ODU, CUA, USC
- DIRC – a compact imaging Cherenkov
  - Reduces radial space from ~1 m to ~0.1 m
  - Possible to improve Cherenkov angle resolution beyond BaBar?



Generic detector R&D for an EIC

Funded at an annual level of $1.0M-1.5M, subject to availability of funds from DOE NP

Funded JLab-related proposals (and LOI with BNL) from 1st and 2nd calls

- Proposal to test improved radiation tolerant silicon photomultipliers
  - JLab

  $60k,1 year
- DIRC-based PID for the EIC central detector
  - JLab, GSI (PANDA), Old Dominon U., Catholic U. of America, U. of South Carolina

  $400k, 3 years
- Design and Assembly of fast and lightweight barrel and forward tracking prototype for an EIC
  - CEA Saclay, MIT, Temple U.

  $150k, 2 years
- Letter of Intent for Detector R&D towards an EIC detector
  - U. Virginia, Temple U, BNL, FIT, Iowa State U., LBNL, MIT, Riken, Stony Brook U., Yale U.

  $200k

JLab-related proposals submitted in response to 3rd call

- Development of a Spin Light Polarimeter for the EIC
  - JLab, Mississippi State U., William & Mary, U. Virginia, Mainz, Stony Brook U., Argonne
- R&D of a Silicon-based Tracker System for the Detector of the EIC
  - JLab, U. New Hapmshire, Moscow State U.
- A pre-shower detector for forward electromagnetic calorimeters
  - UTFSM Valparaiso
- RICH detector for the forward EIC detector
  - JLab, INFN Frascati, INFN Ferrara, CNU, UTFSM

Summary

EIC is the ultimate tool for studying sea quarks and gluons

- An EIC is required to fully understand nucleon structure and the role of gluons in nuclei

Collider environment offers tremendous advantages

- Kinematic coverage (high center-of-mass energy)
- Polarization measurements with excellent figure of merit
- Straightforward detection of recoil baryons, spectators, and target fragments

EIC is a maturing project

- Designs ongoing at JLab and BNL
- Funds for joint detector R&D projects and accelerator R&D have been allocated
- White paper (summary of INT report) in progress