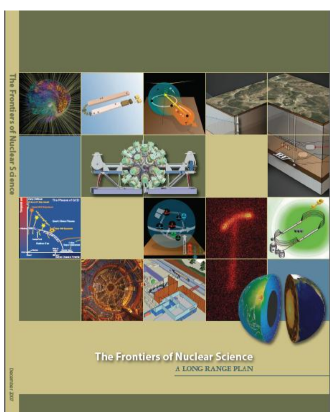
Detector Design and Physics at an Electron-Ion Collider

(√s =20-70 GeV)

Rolf Ent - Jefferson Lab

Future Directions in High Energy QCD,
Workshop at RIKEN,
October 20-22, 2011



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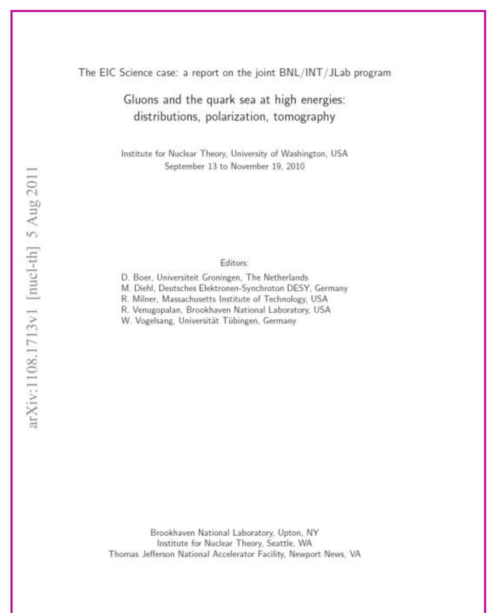
Transverse-momentum–dependent parton distribution/fragmentation functions at an electron-ion collider

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

EDP Sciences · Società Italiana di Fisica · Springer



The EIC Science case: a report on the joint BNL/INT/JLab program

Gluons and the quark sea at high energies: distributions, polarization, tomography

Institute for Nuclear Theory, University of Washington, USA
September 13 to November 19, 2010

arXiv:1108.1713v1 [nucl-th] 5 Aug 2011

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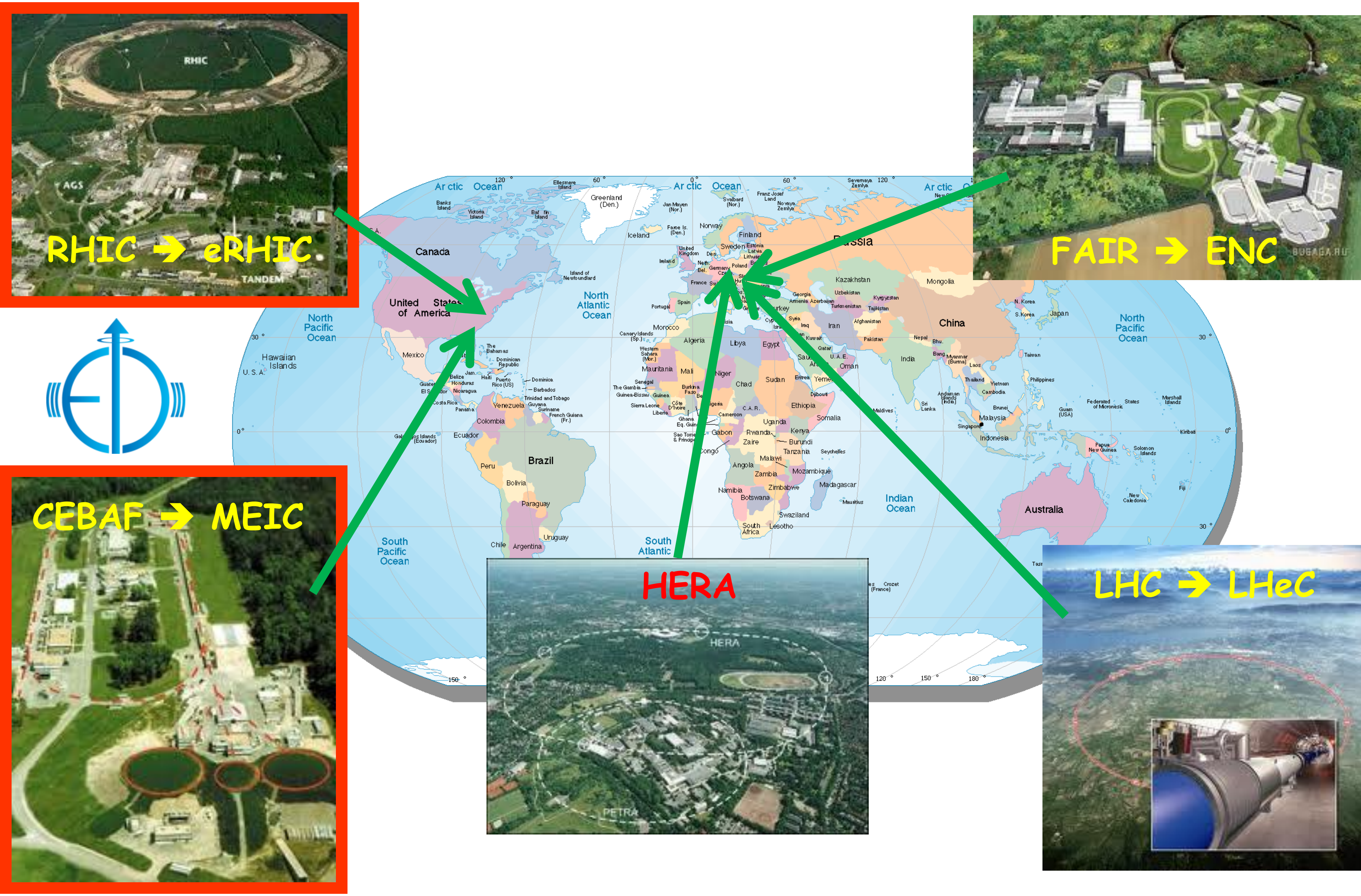
Electron Ion Colliders on the World Map



EIC: Critical Capabilities

- EIC is the generic name for the Nuclear Science-driven Electron-Ion Collider, presently considered in the US
- eRHIC and MEIC implement the base EIC requirements into the actual designs at BNL and JLab, respectively.

- Base EIC Requirements *per Executive Summary INT Report*:
    - range in energies from **$\sqrt{s}$ ~ 20 to $\sqrt{s}$ ~ 70 & variable**
    - fully-polarized (>70%), longitudinal and transverse
    - ion species up to A = 200 or so
    - high luminosity: **about 10^{34}** e-nucleons cm^{-2} s^{-1}
    - multiple interaction regions
    - upgradable to higher energies ($\sqrt{s}$ ~ 150 GeV)
- Philosophy of integration of Detectors in extended Interaction Region similar at both eRHIC and MEIC
- Base EIC requirements have converged, but we still argue (quite a bit) on how to go from base EIC requirements to accelerator design and on where high luminosity is needed, how variable the energies need to be.

EICAC Report Excerpts (3rd EICAC meeting, April 10)

• *one-day meeting … provided for limited, and in many respects insufficient, time for discussions and Committee deliberations.*

• significant progress, in particular on the theory side, has been made in consolidating key areas and some potential golden experiments have been addressed: Spin, flavor and 3D structure of the nucleon, saturation and high-density gluonic matter, and recent studies into electro-weak physics …

• the EICAC found that considerable work has been done by both JLab and BNL on the EIC facility designs. JLab has made significant advances in the design of the hadron injector and storage ring …

• both laboratories have done excellent work in moving forward on facility design and R&D issues. Performance deliverables in terms of energies and luminosities have converged. However, we note that both machine designs remain very challenging …

• Good progress has been made on the detector – machine interface, and in defining the physics case such that benchmark processes can now be selected for detector parameter optimizations.

• **the EIC collaboration will need to speak with a single voice to the rest of the nuclear physics community in order to generate support for the project in the next LRP.**

The Physics Program of an EIC

I) Map the spin and spatial structure of quarks and gluons in nucleons

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

Needs high luminosity and range of energies

II) Discover the collective effects of gluons in atomic nuclei

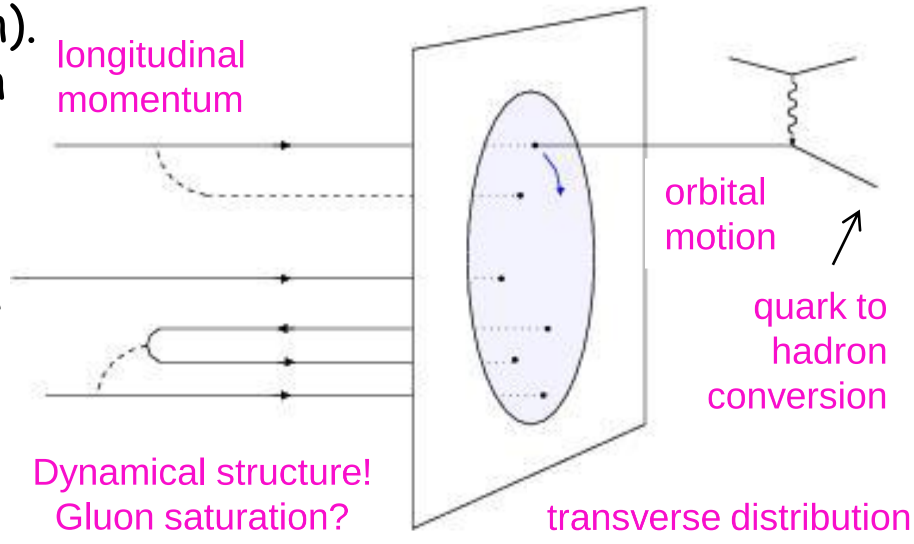
- Color transparency: Small-size configurations
- Nuclear gluons: EMC effect, shadowing
- Strong color fields: Unitarity limit, saturation
- Fluctuations: Diffraction

III) Understand the emergence of hadronic matter from color charge

- Materialization of color: Fragmentation, hadron breakup, color correlations
- Parton propagation in matter: Radiation, energy loss

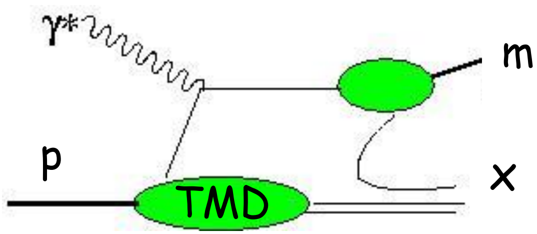
Why a New-Generation EIC? Why not HERA?

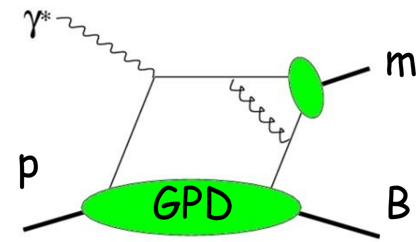
- Obtain detailed differential **transverse quark and gluon images**
  (derived directly from the t dependence with good t resolution!)
  - Gluon size from J/Ψ and ϕ electroproduction
  - Singlet quark size from deeply virtual compton scattering (DVCS)
  - Strange and non-strange (sea) quark size from π and K production
- Determine the **spin-flavor decomposition of the light-quark sea**
- Constrain the **orbital motions** of quarks & anti-quarks of different flavor
  - The difference between π^+, π^-, and K^+ asymmetries reveals the orbits
- Map both the **gluon momentum distributions of nuclei** (F_2 & F_L measurements) and the **transverse spatial distributions of gluons on nuclei** (coherent DVCS & J/Ψ production).
- At high gluon density, the recombination of gluons should compete with gluon splitting, rendering **gluon saturation**. Can we reach such state of saturation?
- Explore the interaction of color charges with matter and understand the **conversion of quarks and gluons to hadrons** through fragmentation and breakup.



Towards a "3D" spin-flavor landscape

$W^u(x,\mathbf{k},\mathbf{r})$ (Wigner Function)





d^3r

d^2k_T

Link to Orbital Momentum

$TMD^u(x,k_T)$

$f_1, g_1, f_{1T}^{\perp}, g_{1T}$

$h_1, h_{1T}^{\perp}, h_{1L}^{\perp}, h_1^{\perp}$

$GPD^u(x,\xi,t)$

$H^u, E^u, \tilde{H}^u, \tilde{E}^u$ + 4 "T"s

Link to Orbital Momentum

Want $P_T > \Lambda$ but not too large!

d^2k_T

$\xi = 0, t = 0$

dx

$f_1(x)$

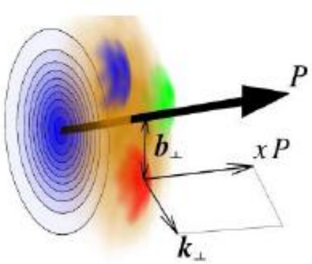
g_1, h_1

$u(x)$

$\Delta u, \delta u$

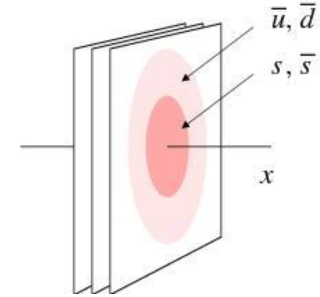
$F_1^u(t)$

F_2^u, G_A^u, G_P^u



Parton Distributions

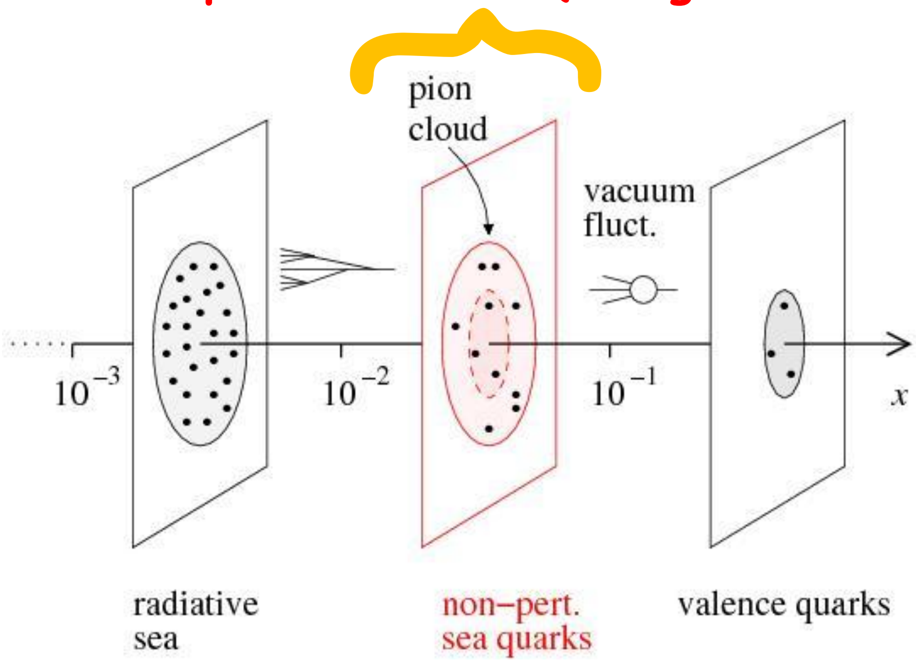
Form Factors



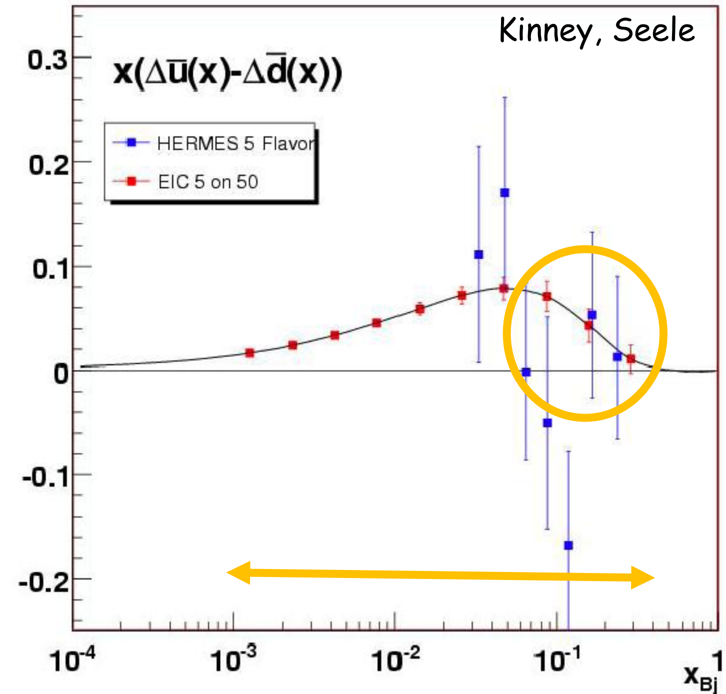
Sea Quark Polarization

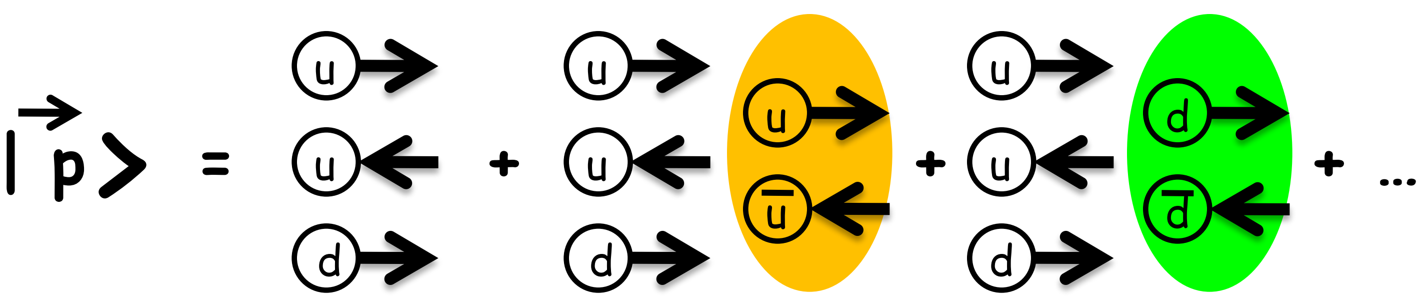
- Spin-Flavor Decomposition of the Light Quark Sea

  Access requires $\sqrt{s}$ ~ 30 (and good luminosity)



100 days, L =10^{33}, $\sqrt{s}$ ~ 30





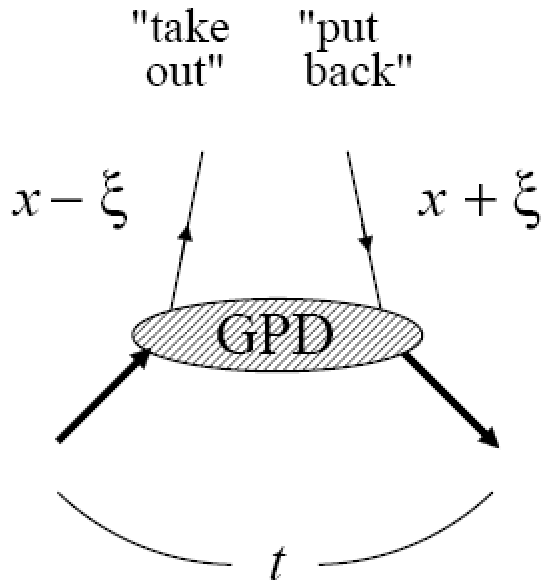
Many models predict

$\Delta\bar{u} > 0$, $\Delta\bar{d} < 0$

Transverse Quark & Gluon Imaging

Deep exclusive measurements in ep/eA with an EIC:

diffractive:	transverse gluon imaging	J/ψ, ϕ, ρ^o, γ (DVCS)
non-diffractive:	quark spin/flavor structure	π, K, ρ^+, …



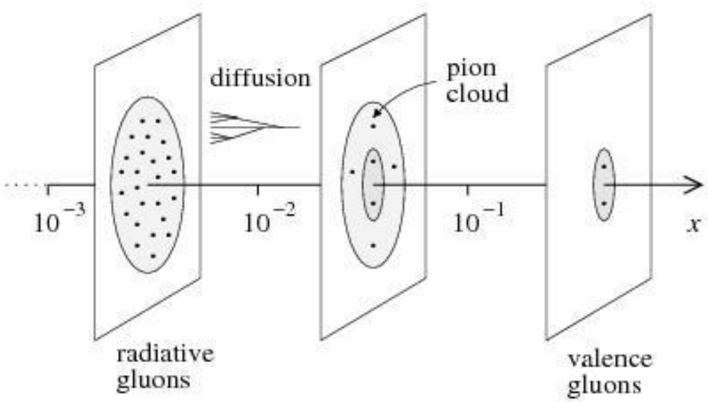
Are gluons uniformly distributed in nuclear matter or are there small clumps of glue? Are gluons & various quark flavors similarly distributed?

(some hints to the contrary)

Describe correlation of longitudinal momentum and transverse position of quarks/gluons →

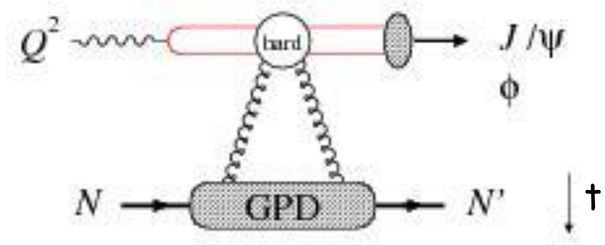
Transverse quark/gluon imaging of nucleon ("tomography")

Detailed differential images from nucleon's partonic structure



Weiss, Hyde, Horn

EIC: Gluon size from J/Ψ and ϕ electroproduction (Q^2 > 10 GeV^2)



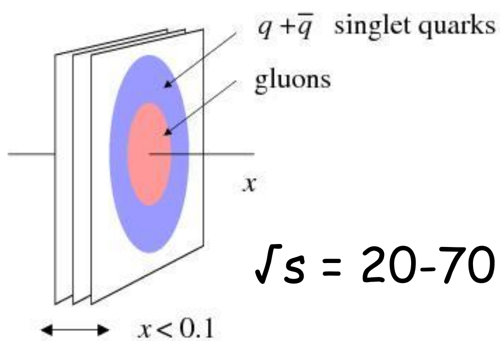
[Transverse distribution derived directly from t dependence]

Hints from HERA:

Area ($q + \bar{q}$) > Area (g)

Dynamical models predict difference:

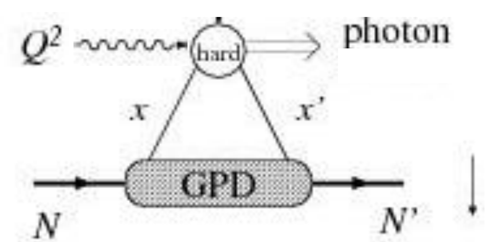
pion cloud, constituent quark picture



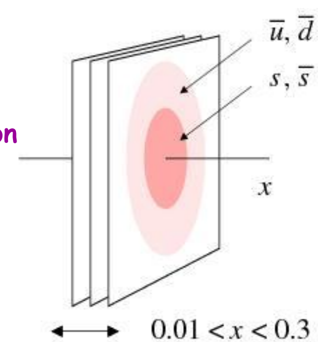
Fazio

$\sqrt{s}$ = 20-70

EIC: singlet quark size from deeply virtual compton scattering



- Q^2 > 10 GeV^2 for factorization
- Statistics hungry at high Q^2!



Horn

$\sqrt{s}$ = 30

EIC: strange and non-strange (sea) quark size from π and K production

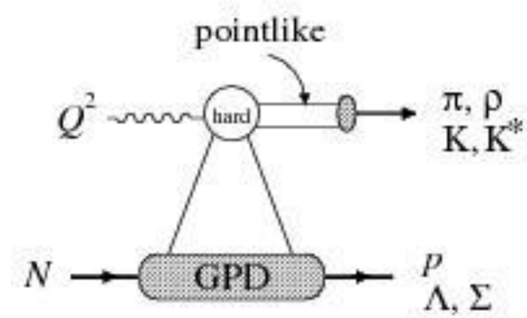
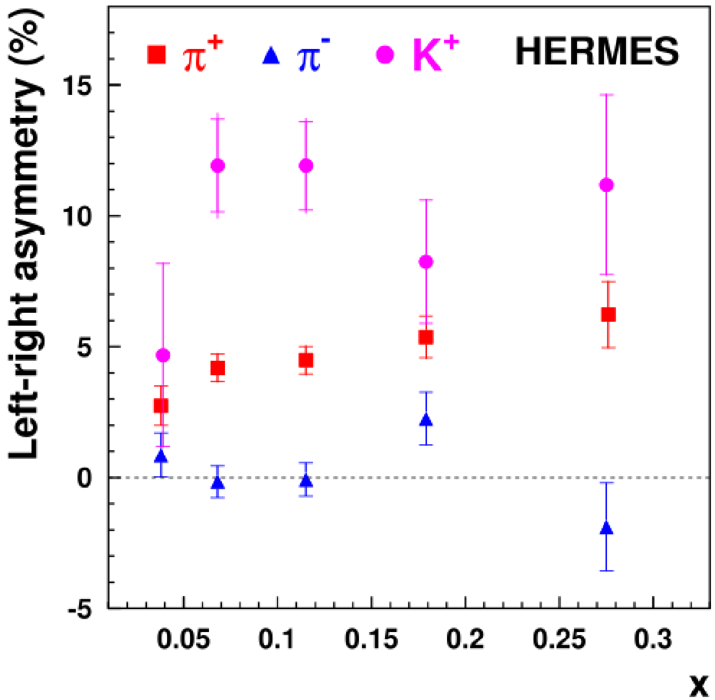


Image the Transverse Momentum of the Quarks

Swing to the left, swing to the right:
A surprise of transverse-spin experiments



The difference between the π^+, π^-, and K^+ asymmetries reveals that quarks and anti-quarks of different flavor are **orbiting in different ways** within the proton.

$$d\sigma^h \sim \Sigma e_q^2 q(x)\ d\sigma_f\ D_f^h(z)$$

Sivers distribution

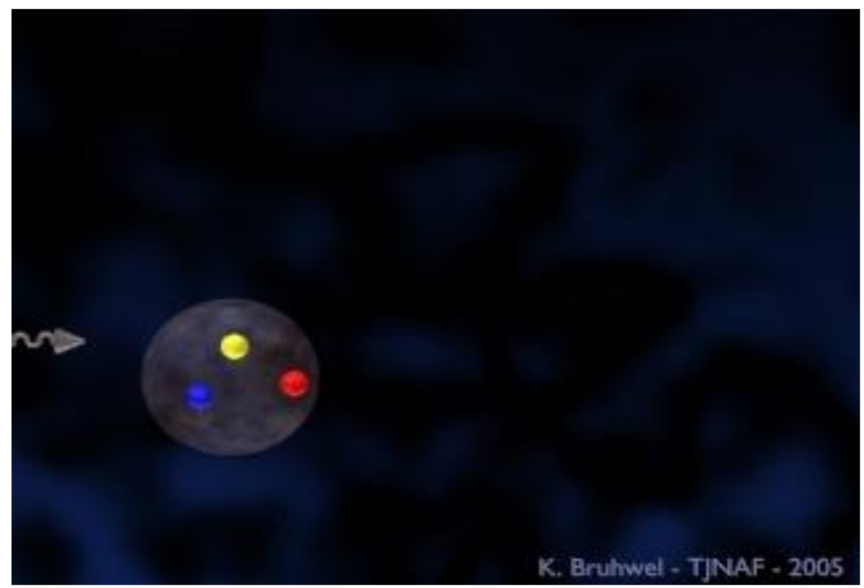
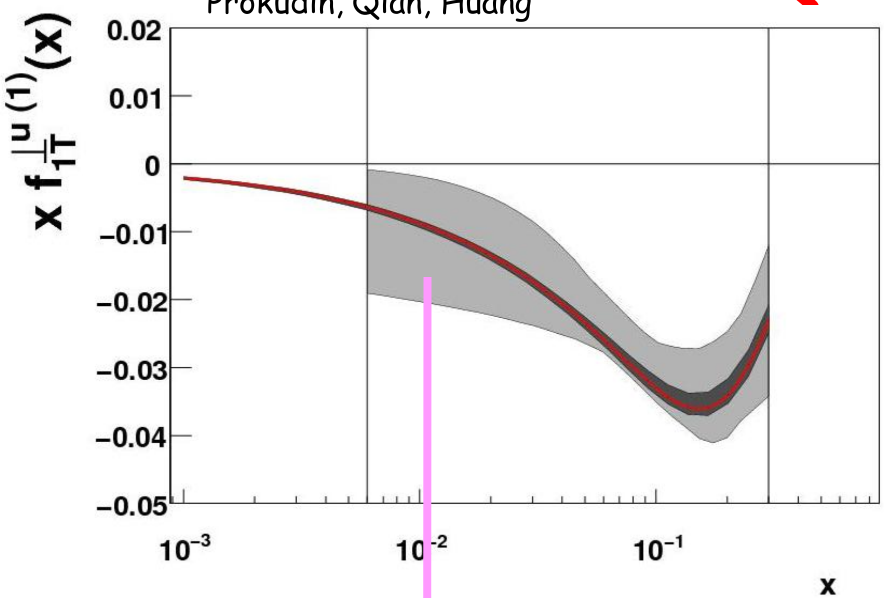
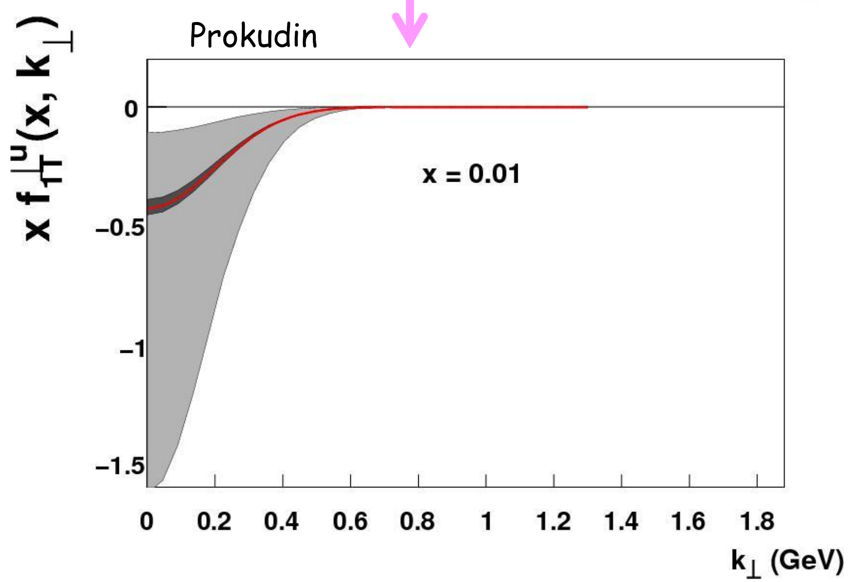


Image the Transverse Momentum of the Quarks

Prokudin, Qian, Huang



Prokudin



Only a small subset of the (x,Q^2) landscape has been mapped here:

terra incognita

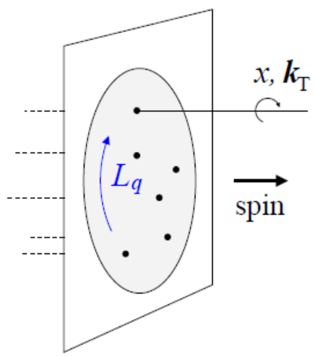
Gray band: present "knowledge"
Red band: EIC (1σ)
(dark gray band: EIC (2σ))

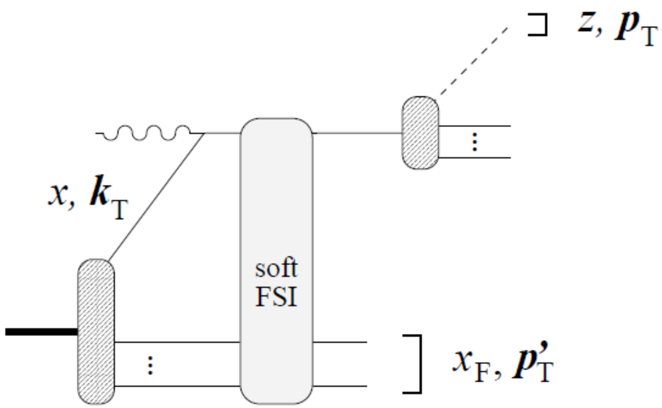
Exact k_T distribution unknown!
"Knowledge" of k_T distribution at large k_T is artificial!
(but also perturbative calculable limit at large k_T)

An EIC with good luminosity & high transverse polarization is the optimal tool to to study this!

Nucleon Structure: Orbital Motion

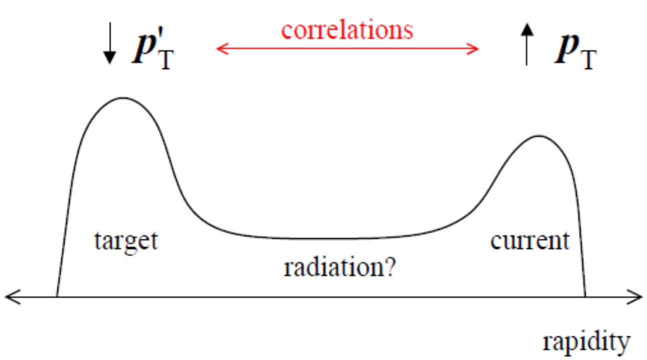
Goal: explore quark/gluon orbital motion and its **polarization dependence** through both deep exclusive and semi-inclusive multi-dimensional processes





Semi-inclusive DIS with p_T dependence? But, can not separate intrinsic k_T in wave function from soft final-state interactions and fragmentation: TMDs combine intrinsic k_T and FSI.

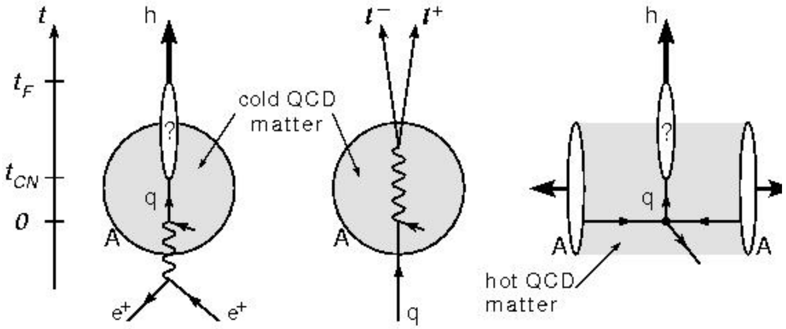
Potential new insight from jets or p'_T of target fragmentation?



EIC: wide kinematic range
low to high p_T

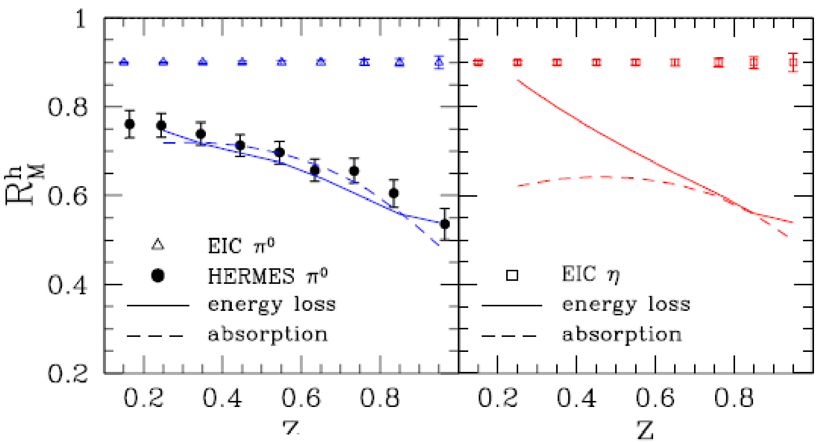
Can we learn about **orbital motion** from a comprehensive approach based on TMDs, GPDs, etc., even if model-dependent?

Hadronization: Parton propagation in matter

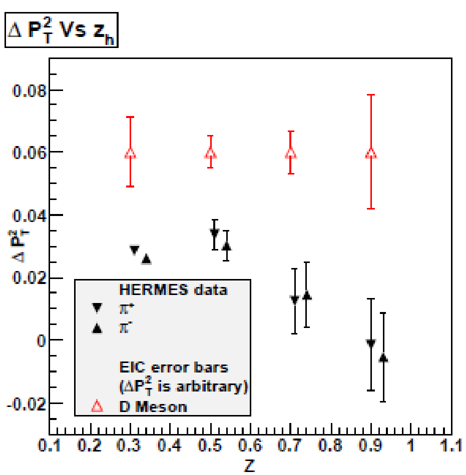


EIC: Explore the interaction of fast color charges with matter

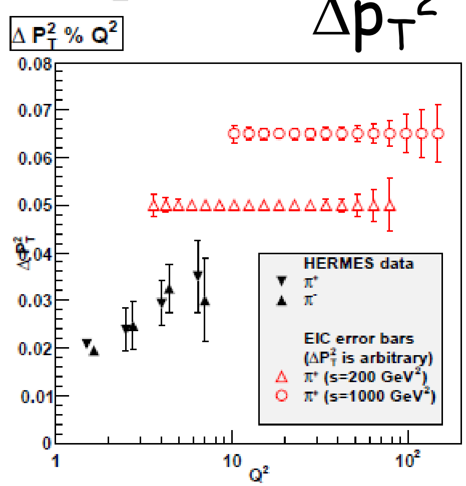
- Time scales for color neutralization t_{CN} and hadron formation t_F
- $eA/\gamma A$ complementary to jets in AA: cold vs. hot matter



EIC: Understand the conversion of color charge to hadrons through fragmentation and breakup



Δp_T^2



Comprehensive studies possible:

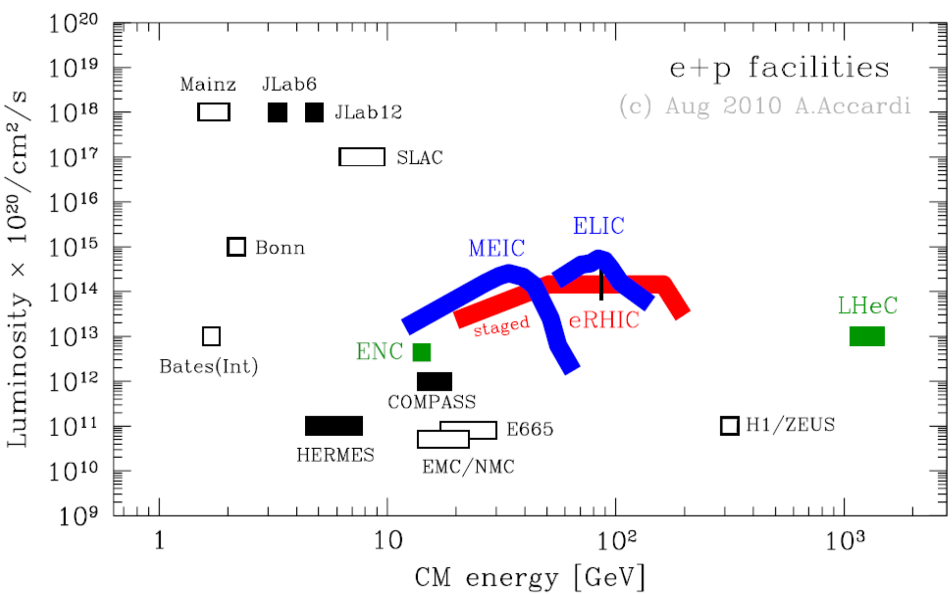
- wide range of energy ν = 10-100 GeV
  → move hadronization inside/outside nucleus, distinguish energy loss and attenuation
- wide range of Q^2: QCD evolution of fragmentation functions and medium effects
- Hadronization of charm, bottom
  → Clean probes with definite QCD predictions
- High luminosity
  → Multi-dimensional binning and correlations
- $\sqrt{s}$ > 30: jets and their substructure in eA

[Accardi, Dupre INT10-03 Report]

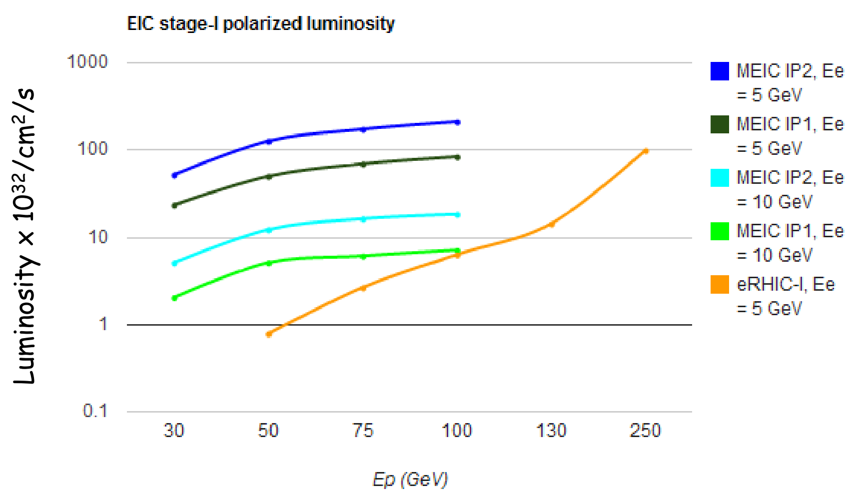
EIC: Critical Capabilities

- Base EIC Requirements *per Executive Summary INT Report*:
  - range in energies from **√s ~ 20 to √s ~ 70 & variable**
  - fully-polarized (>70%), longitudinal and transverse
  - ion species up to A = 200 or so
  - high luminosity: **about 10^{34}** e-nucleons cm^{-2} s^{-1}
  - multiple interaction regions
  - upgradable to higher energies (√s ~ 150 GeV)

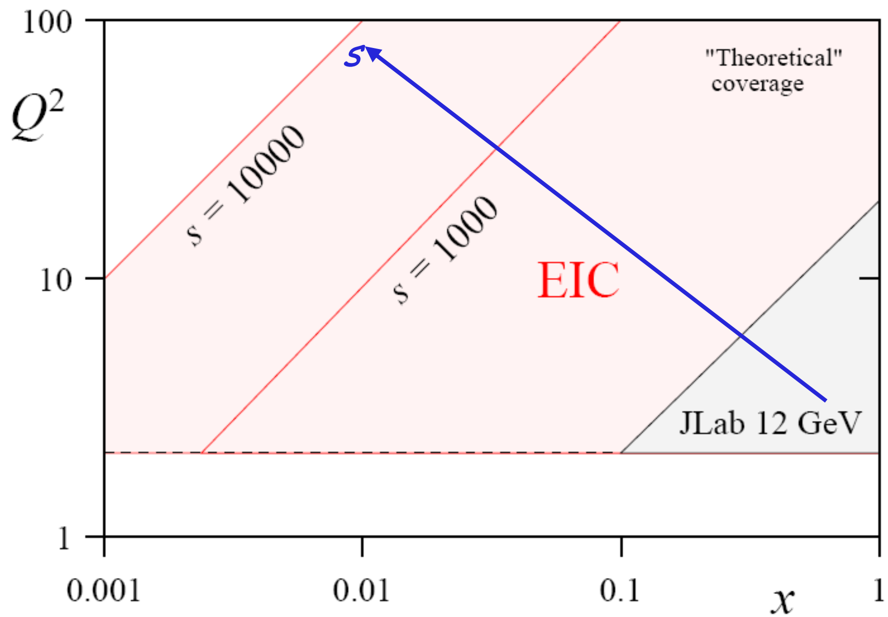
Input passed on to INT10-03 program:

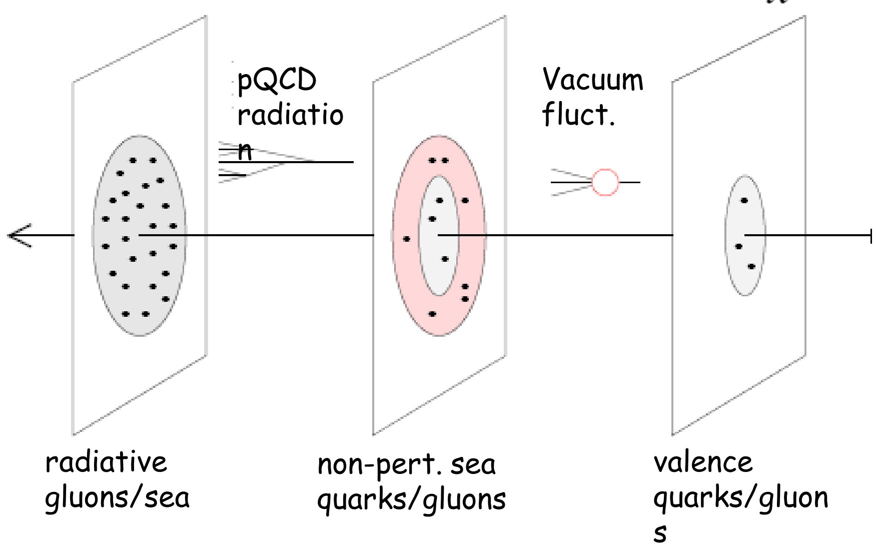


But we get there in different ways:



To cover the physics we need…





$$x = Q^2/ys$$

Range in y

- For large or small y, uncertainties in kinematic variables become large
- Detecting the electron $y_{max} / y_{min} \sim 10$
- Also detecting hadrons $y_{max} / y_{min} \sim 100$
  - Requires hermetic detector (no holes)

Range in s

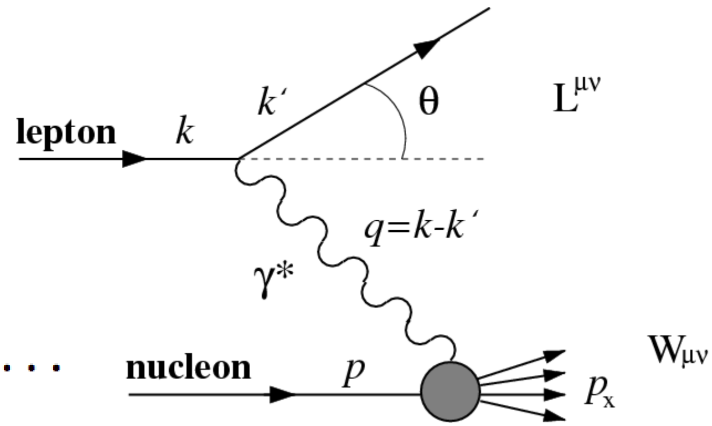
- Accelerator considerations limit s_{min}
  - Depends on s_{max} (dynamic range)

Range of kinematics

- At fixed s, changing the ratio E_e / E_{ion} can for some reactions improve resolution, particle identification (PID), and acceptance

Range of energies & variable

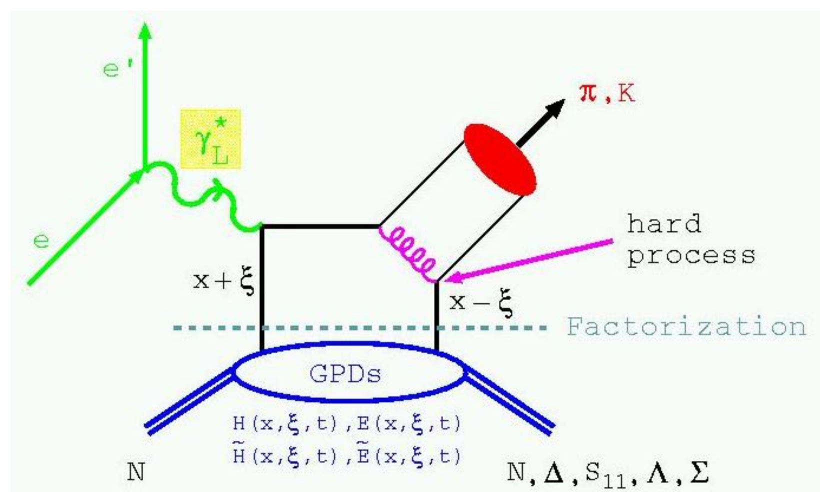
1. Important for L/T separations
   a. Deep Inelastic Scattering:
      σ_L/F_L gives access to gluons



$$\propto \frac{\alpha_s}{2\pi} x \int_x^1 \frac{d\xi}{\xi} \xi(1-\xi)\, g\left(\frac{x}{\xi}, Q^2\right) + \ldots$$

$$\frac{d^2\sigma^{ep\to eX}}{dx dQ^2} = \frac{4\pi\alpha_{e.m.}^2}{xQ^4}\left[\left(1-y+\frac{y^2}{2}\right)F_2(x,Q^2) - \frac{y^2}{2}F_L(x,Q^2)\right]$$

   b. Deep Exclusive Scattering:
      Factorization proven for Deep-Virtual Meson Production for Longitudinal cross section only
      → Need to isolate σ_L (but @ finite Q^2)



Range of energies & variable

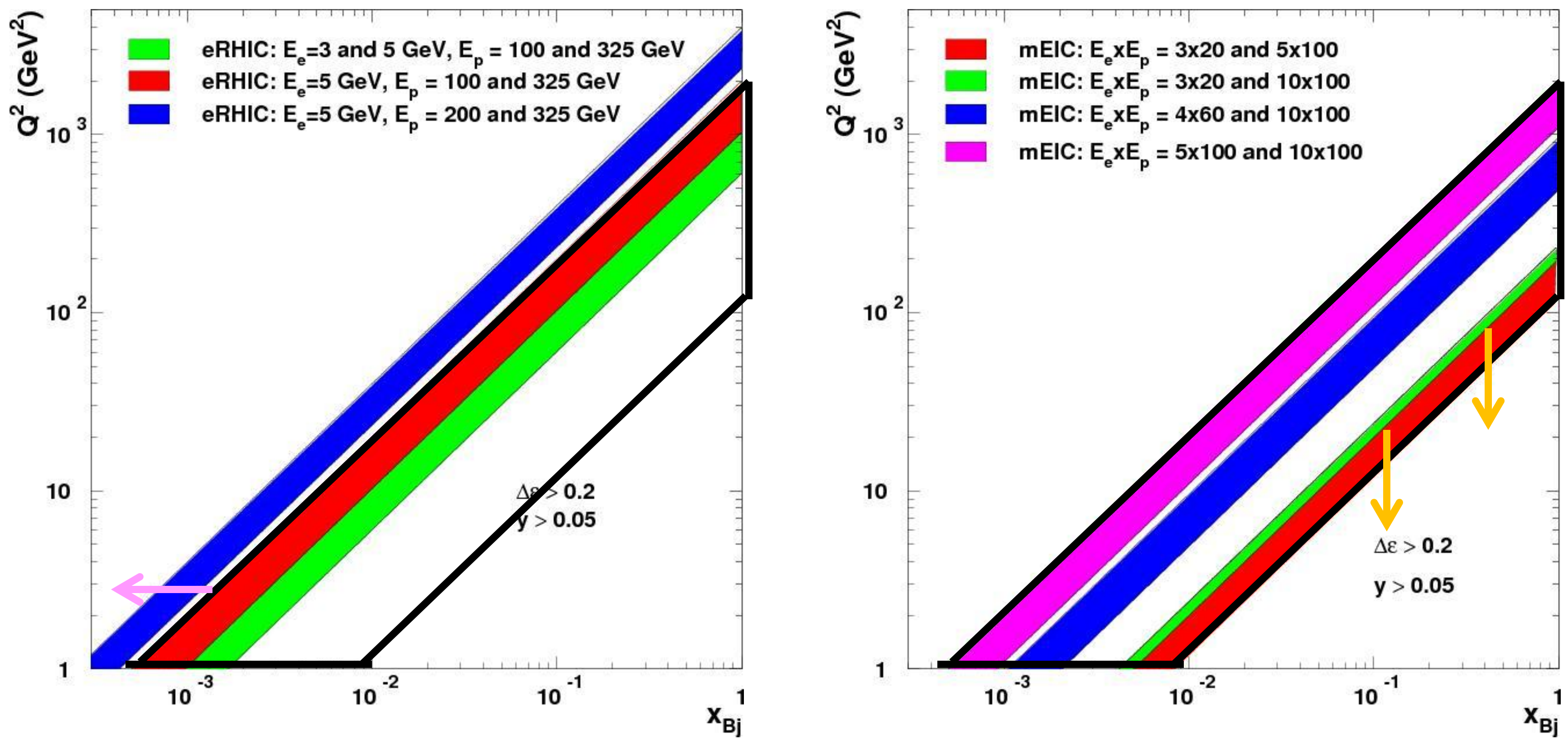
1. Important for L/T separations

   Typical rule of thumb: $\Delta\varepsilon > 0.2$ (ε = virtual-photon polarization = f(y))

   inclusive/saturation: (x,Q^2) down to small-x, $Q^2 \sim 1$

   deep exclusive: need σ_L @ Q^2 =10-100 for flavor decomposition

   in region of non-perturbative nucleon structure



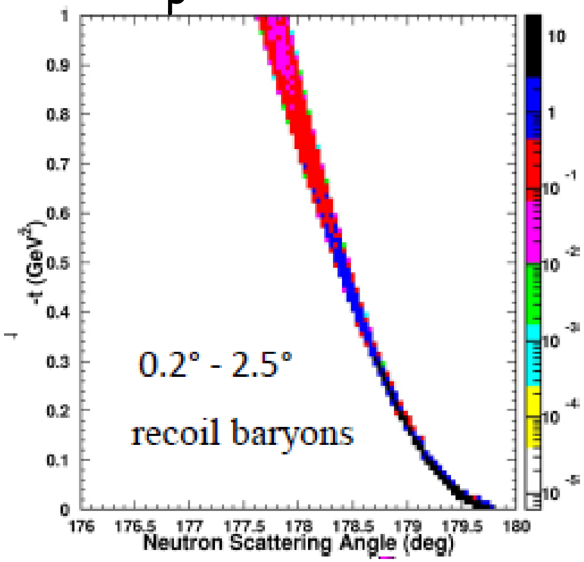
* Can fill white areas between colored areas by choice of intermediate energies

Range of energies & variable

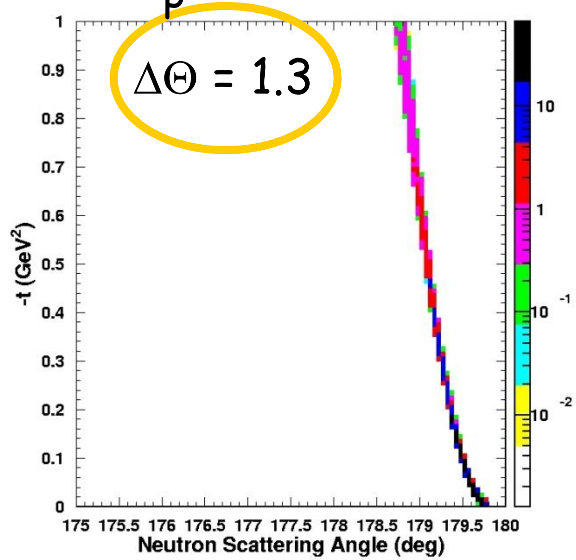
2. Issue of resolution & particle identification

$t \sim E_p^2\Theta^2 \rightarrow$ Angle recoil baryons = $t^{\frac{1}{2}}/E_p$

E_p = 30 GeV



E_p = 60 GeV



At E_p = 250 GeV:
$\Delta\Theta$ = 0.3 degrees

t resolution
~ $\delta\Theta$ ~ 1 mr?

Nuclear Science: Map t between ~t_{min} and 1 (2?) GeV

→ Must cover between ~0.5 and ~5 degrees	E_p = 30 GeV
→ Must cover between ~0.2 and ~2 degrees	E_p = 100 GeV
→ Must cover between ~0.1 and ~0.5 degrees	E_p = 250 GeV

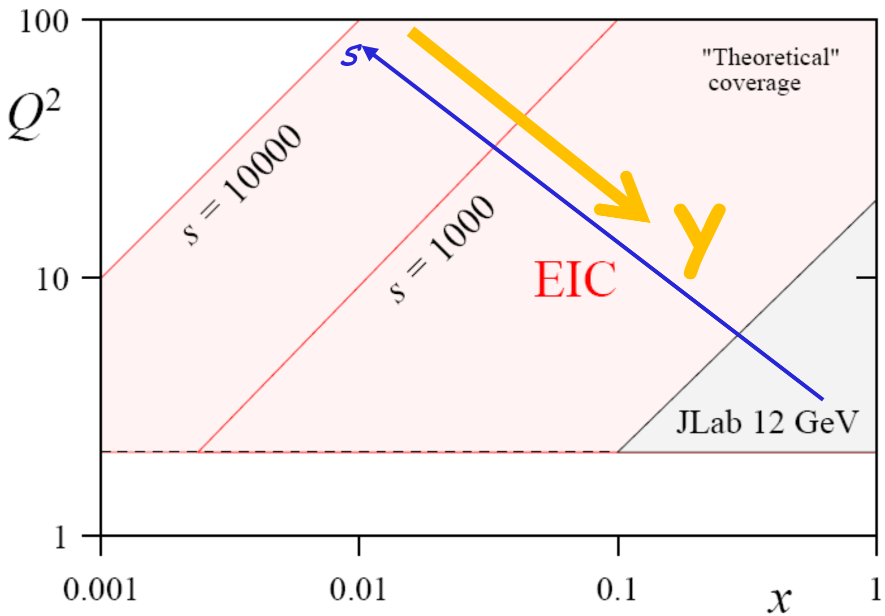
But, DVCS versus DVCS & DVMP give somewhat different requirements

Range of energies & variable

3. Access to TMDs through Semi-Inclusive DIS

What resolutions are needed? Can we use hadronic detection method?

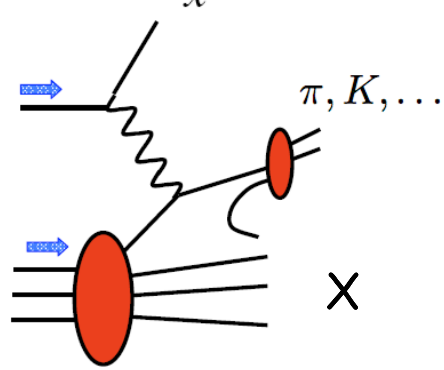
Simpler?: get large range of Q^2 at fixed x by varying s



HERA experience for ep DIS:
- e⁻ detection to constrain DIS kinematics for ~0.05 < y < 0.8 (y and x resolution diverge for y → 0)
- hadronic methods allowed to reach y ~ 0.004 in ep DIS

$x = Q^2/ys$

SIDIS/TMDs



Sivers needs angle info between h and q vectors
- Kinematic info on X & π,K … → determines the q vector
- then need π, K, … w.r.t. q
- check impact on resolutions from e⁻/hadronic method

Where do particles go - general

p or A $\longrightarrow \longleftarrow$ e

Several processes in e-p:

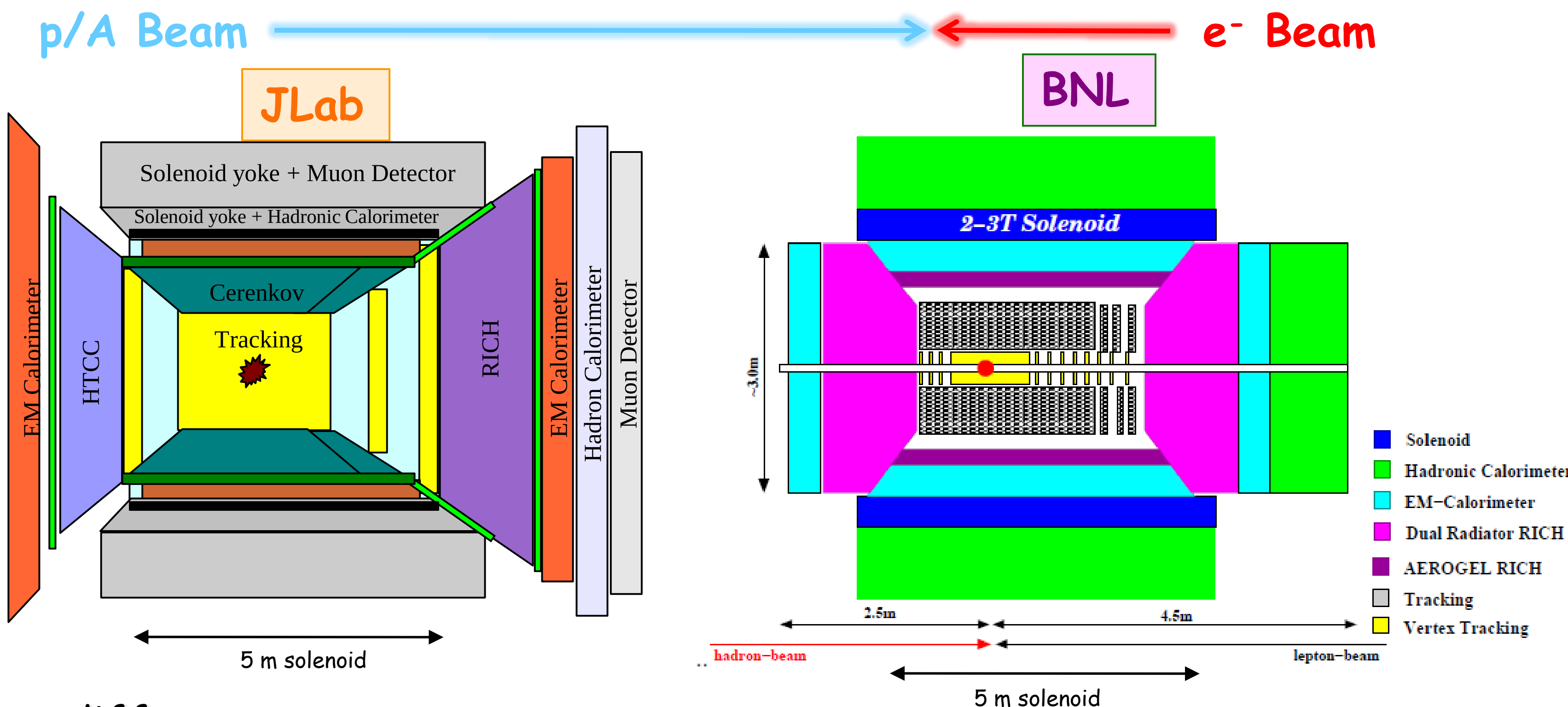
1) "DIS" (electron-quark scattering)	$e + p \rightarrow e' + X$
2) "Semi-Inclusive DIS (SIDIS)"	$e + p \rightarrow e' + \text{meson} + X$
3) "Deep Exclusive Scattering (DES)"	$e + p \rightarrow e' + \text{photon/meson} + \text{baryon}$
4) Diffractive Scattering	$e + p \rightarrow e' + p + X$
5) Target fragmentation	$e + p \rightarrow e' + \text{many mesons} + \text{baryons}$

Even more processes in e-A:

1) "DIS"	$e + A \rightarrow e' + X$
2) "SIDIS"	$e + A \rightarrow e' + \text{meson} + X$
3) "Coherent DES"	$e + A \rightarrow e' + \text{photon/meson} + \text{nucleus}$
4) Diffractive Scattering	$e + A \rightarrow e' + A + X$
5) Target fragmentation	$e + A \rightarrow e' + \text{many mesons} + \text{baryons}$
6) Evaporation processes	$e + A \rightarrow e' + A' + \text{neutrons}$

In general, e-p and even more e-A colliders have a large fraction of their science related to the detection of what happens to the ion beams. The struck quark remnants can be guided to go to the central detector region with Q^2 cuts, but the spectator quark or struck nucleus remnants will go in the forward (ion) direction.

JLab and BNL detector layouts similar



Minor differences

- JLab layout has *conical* rather than *cylindrical forward / backward trackers*
- JLab envisions *DIRC/LTCC in central barrel* for high-momentum PID, BNL an aerogel RICH
- JLab interaction region has a *larger ion beam crossing angle 50-60 mrad* vs *10 mrad*

(In ion beam to prevent synchrotron backgrounds!)

- JLab interaction region allocates 7 meter detector space before the final-focus ion quad to detect particles down to 0.5 degrees, BNL allocates 4.5 meter in staged approach but has also shown a 7 meter version for a dedicated EIC detector.

JLAB/users Detector R&D projects

BNL/users Detector R&D projects

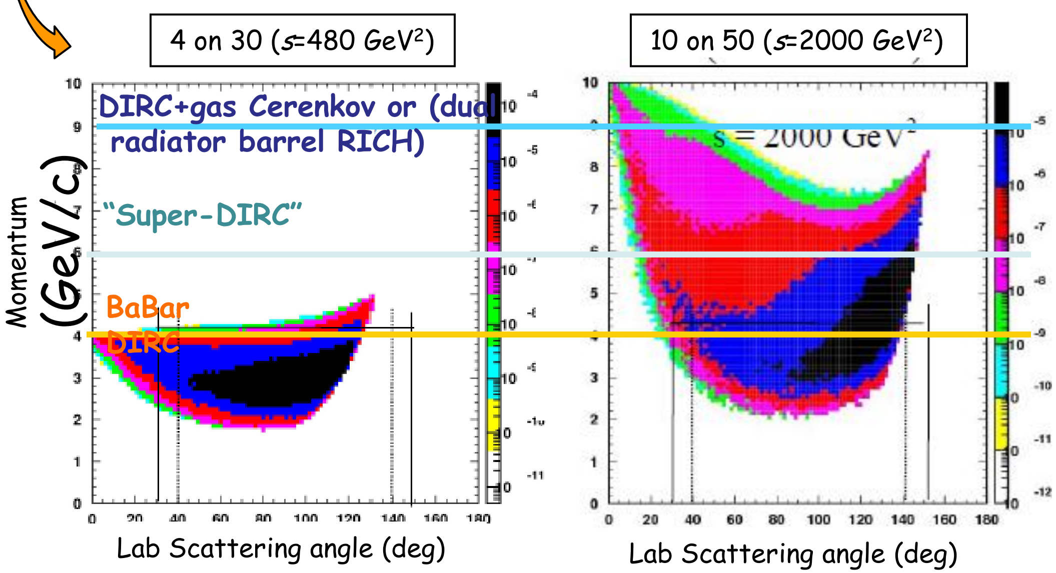
Central Detector

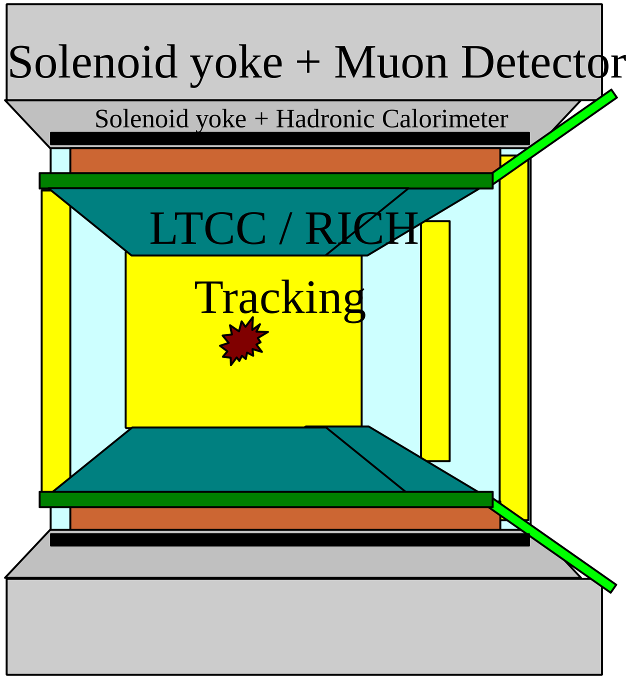
Solenoid Yoke, Hadron Calorimeter, Muons

- 3-4 T solenoid with about 4 m diameter

Particle Identification

- TOF for low momenta
- π/K separation
- p/K: DIRC up to 7 GeV
- e/π: C_4F_8O LTCC up to 3 GeV





Tracking

- Low-mass vertex tracker
- GEM-based central tracker
- Conical endcap trackers
  - precise vertex reconstruction (< 10 μm) → separate Beauty and Charmed Meson
  - low radiation length extremely critical → low lepton energies

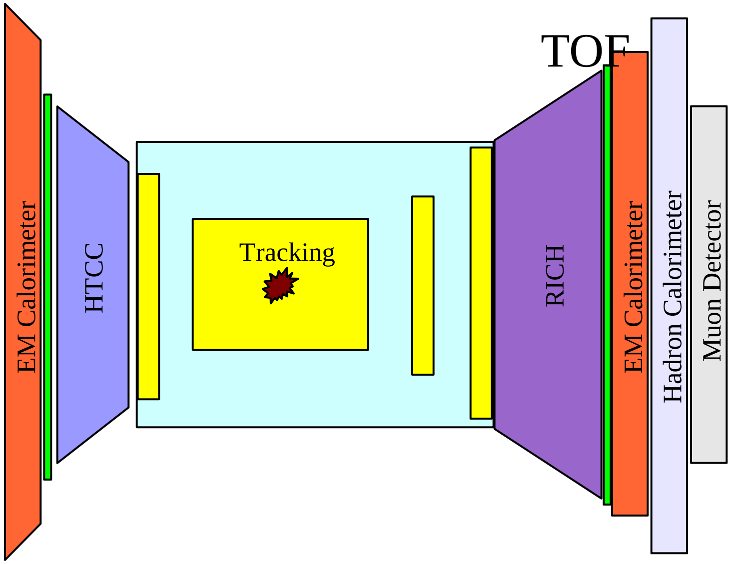
JLAB/users Detector R&D projects

BNL/users Detector R&D projects

Detector Endcaps

Electron side (left)

- Bore angle: ~45° (line-of-sight from IP)
- High-Threshold Cerenkov (e/π)
- Time-of-Flight Detectors
  - Hadrons, event reconstruction, trigger
- Electromagnetic Calorimeter (e/π)



Ion side (right)

- Bore angle: 30-40° (line-of-sight from IP)
- Ring-Imaging Cerenkov (RICH)
- Time-of-Flight Detectors (event recon., trigger)
- Electromagnetic Calorimeter
  - Pre-shower for $\gamma/\pi^\circ \rightarrow \gamma\gamma$ (very small opening angle at high p)
- Hadronic Calorimeter (jets)
- Muon detector (J/Ψ production at low Q^2)

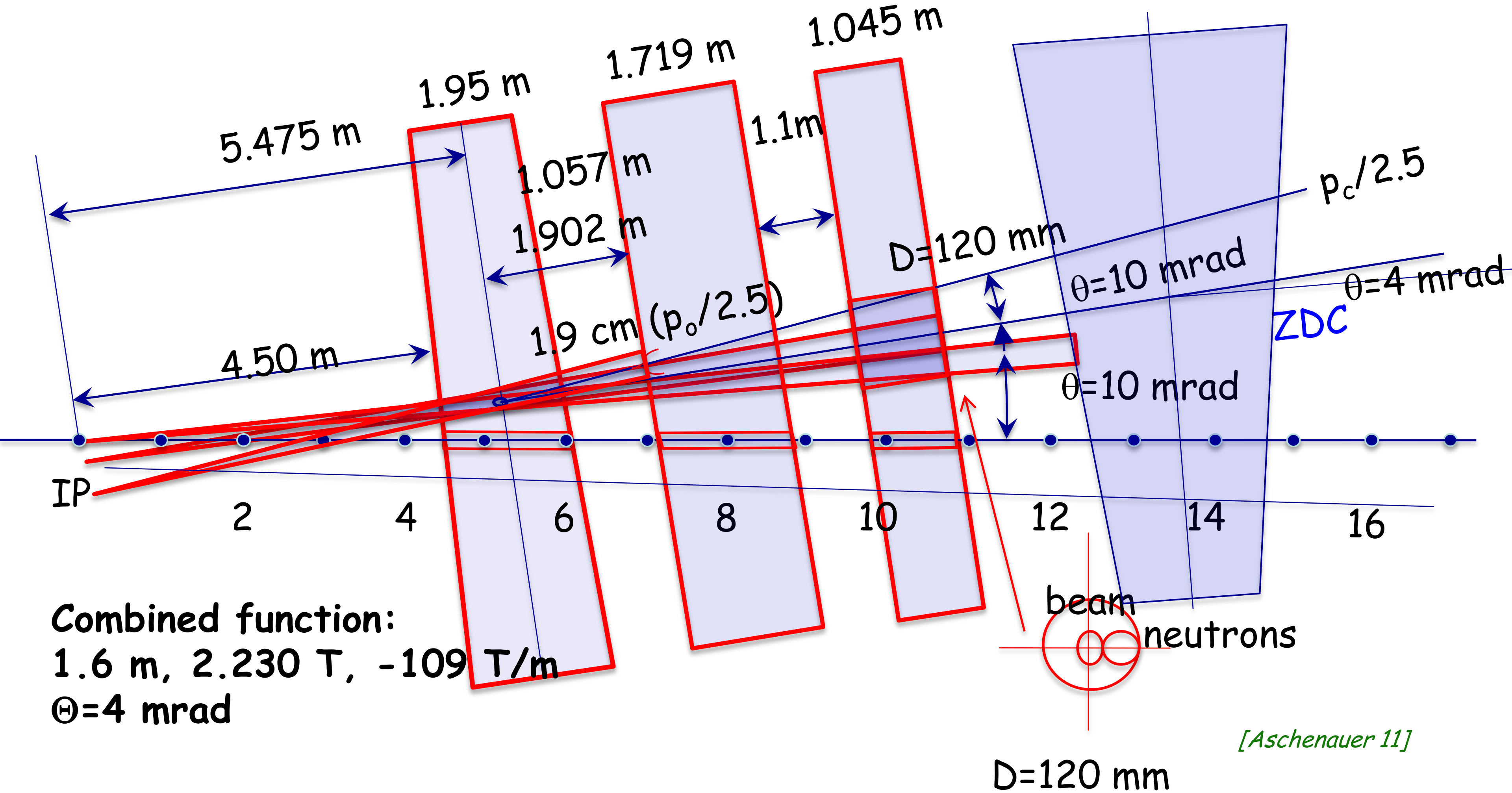
Space constraints

- Electron side has a lot of space
- Ion side limited by distance to FFQ quads

  (7 m @ MEIC, eRHIC similar)

Interaction Region configuration for eRHIC

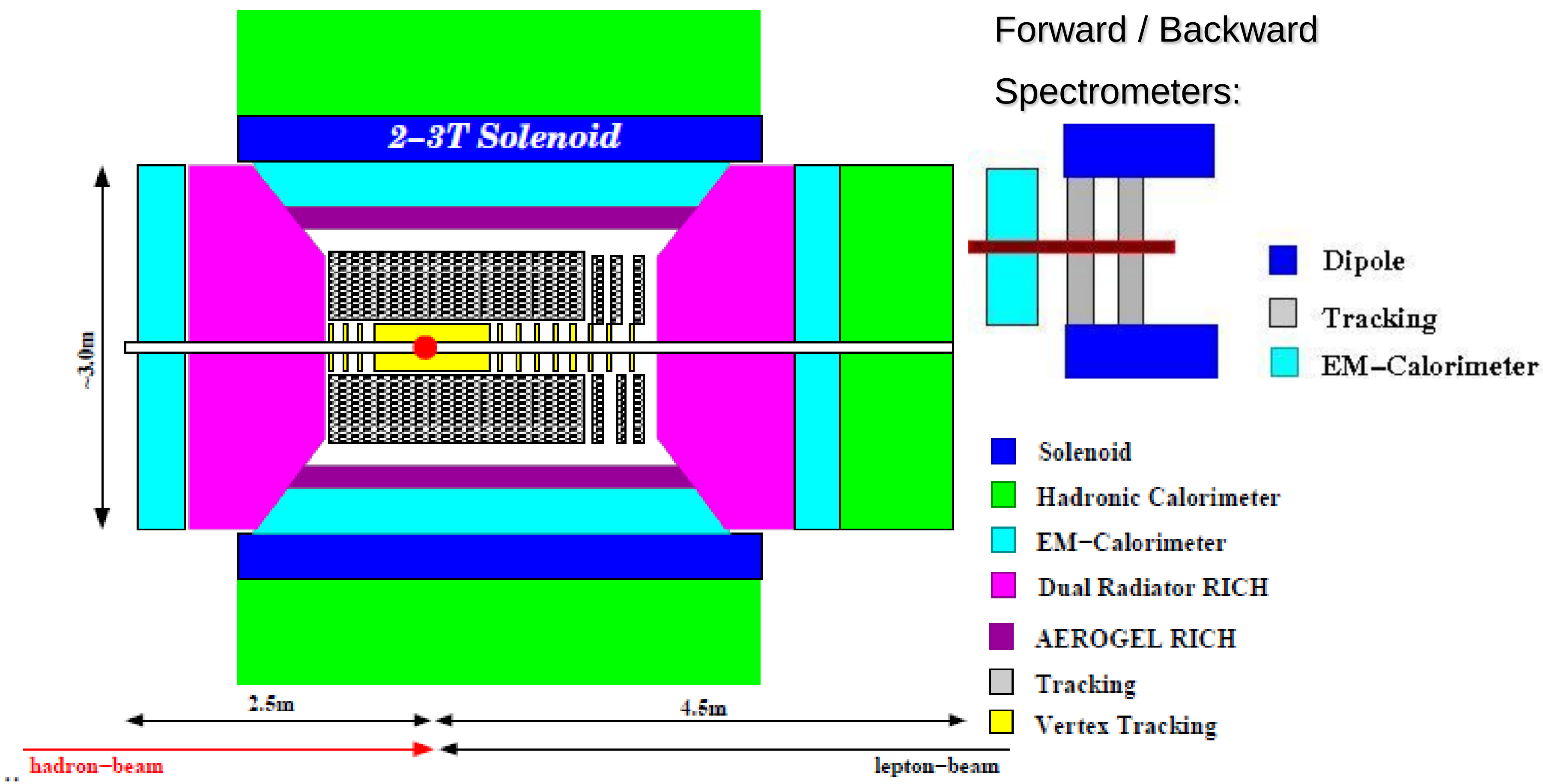
eRHIC - Geometry high-lumi IR with β*=5 cm, l*=4.5 m and 10 mrad crossing angle



Combined function:
1.6 m, 2.230 T, -109 T/m
Θ=4 mrad

[Aschenauer 11]

eRHIC: Forward Detection - 2Tm dipole

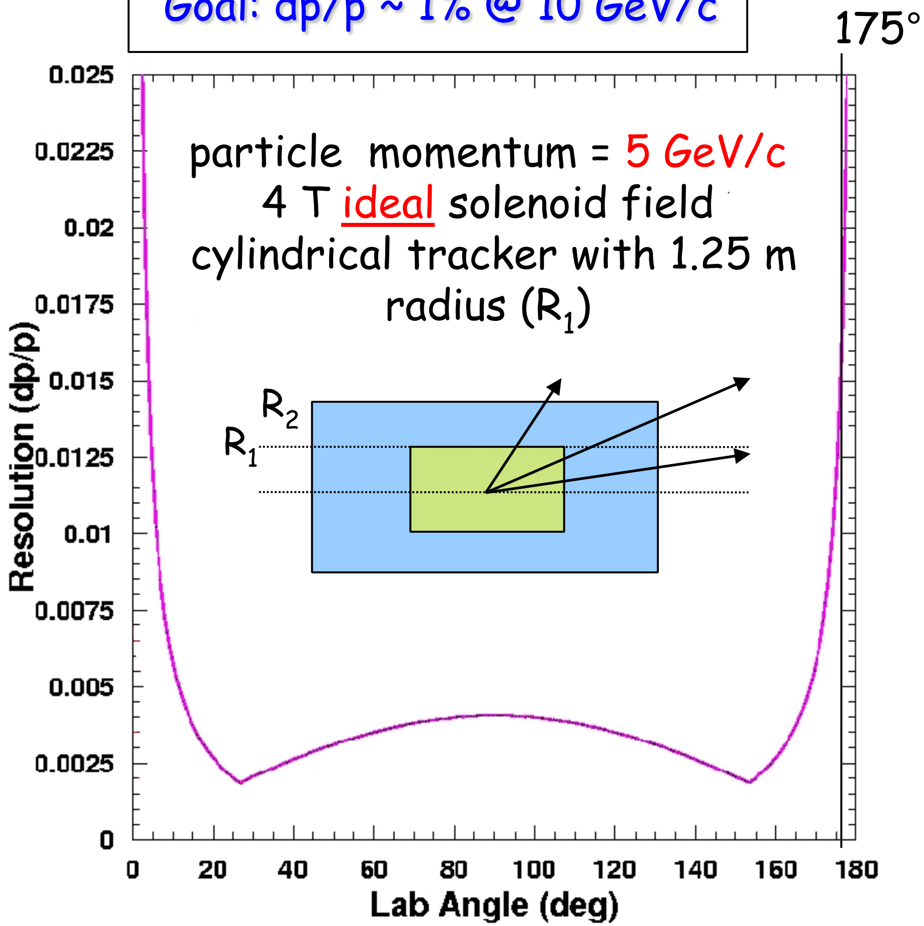


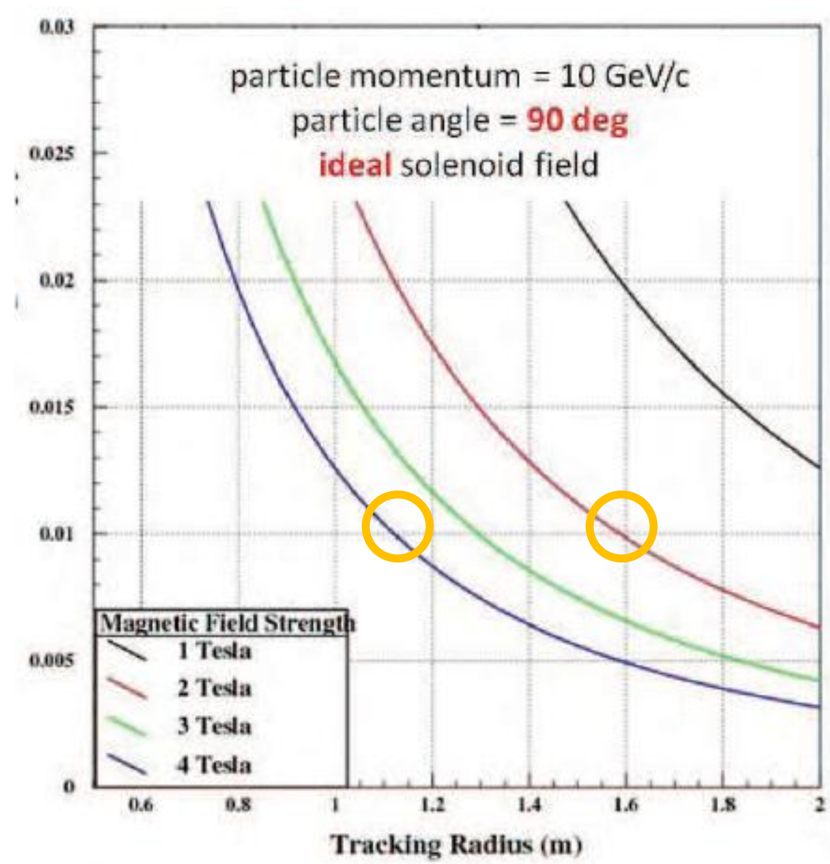
Dipoles needed to have good forward momentum resolution and acceptance

MEIC: Resolution dp/p in solenoid

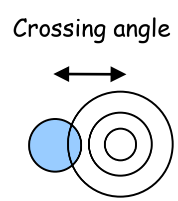
Goal: dp/p ~ 1% @ 10 GeV/c

$\Delta p/p \sim \sigma p \,/\, BR^2$ (@ 90°)





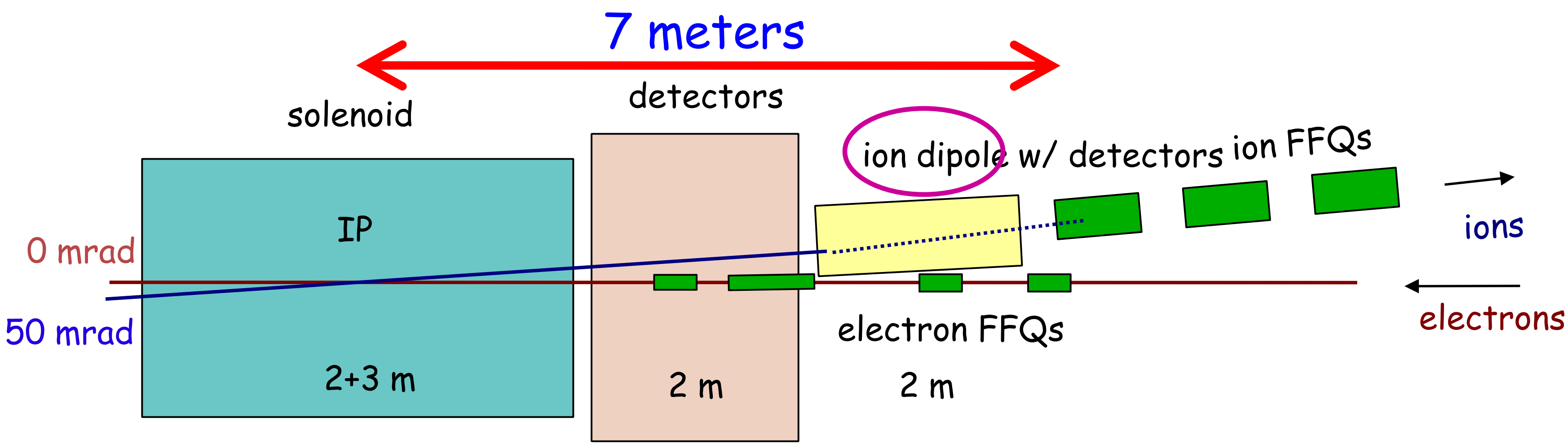
- A 2 Tm dipole covering 3-5° eliminates divergence at small angles
- A 50 mr or 3° beam crossing angle moves the region of poor resolution .
  - 2D problem!

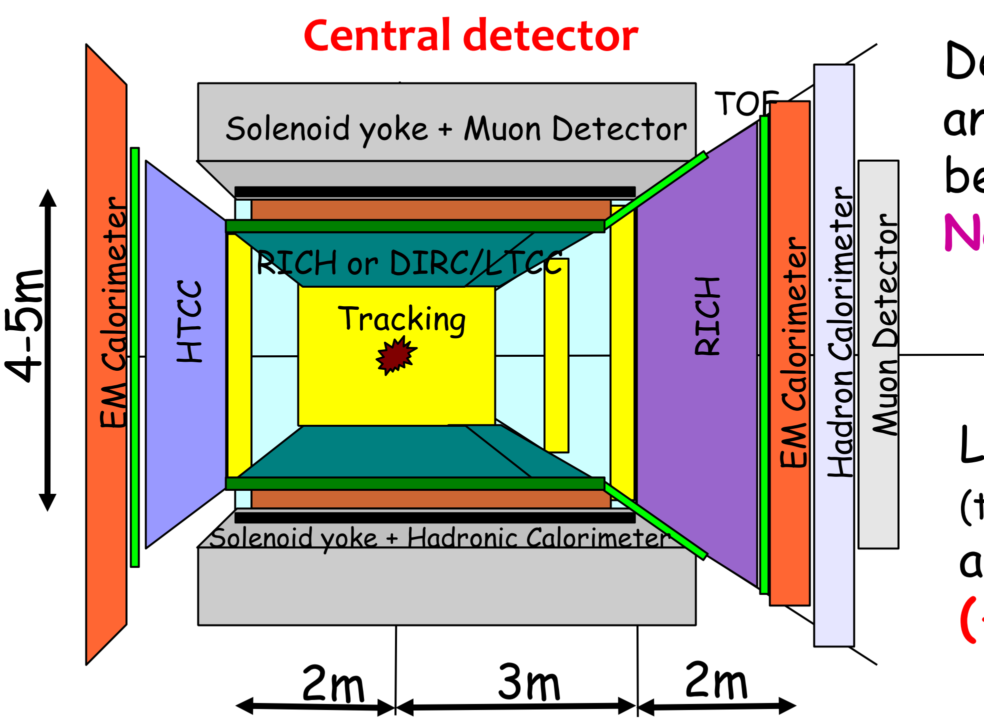


Tracker (not magnet!) radius R is important at central rapidities

- Likely better to aim for 2-3 T solenoid rather than 4 T and increase tracker radius

MEIC: Full Acceptance Detector





Detect particles with angles down to 0.5° before ion FFQs.
Need 1-2 Tm dipole.

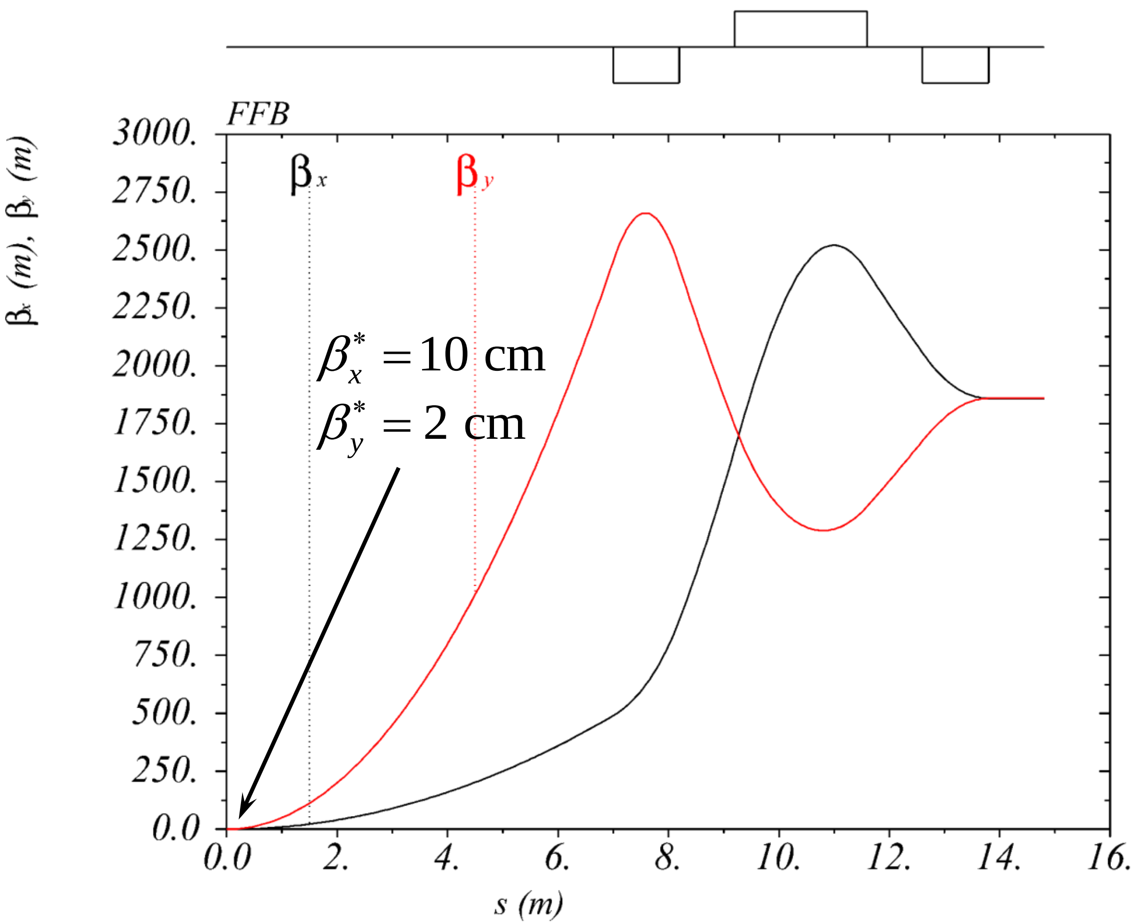
Detect particles with angles below 0.5° beyond ion FFQs and in arcs.

Very-forward detector

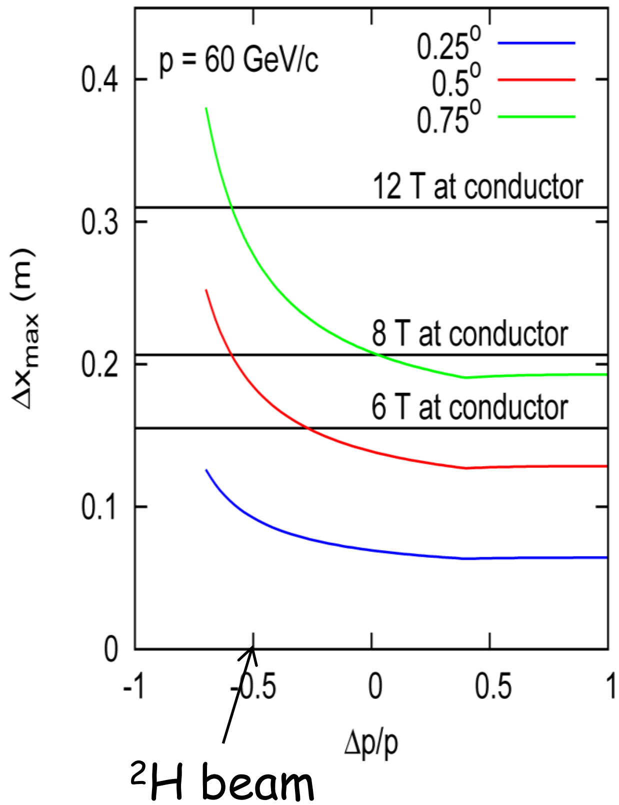
Large dipole bend @ 20 meter from IP (to correct the 50 mr ion horizontal crossing angle) allows for **very-small angle detection (<0.3°)**

MEIC: "Optimized" Final Focusing Block

- Distance from the IP to the first quad = 7 m
- Quadrupole lengths: L_1 = 1.2 m, L_2 = 2.4 m, L_3 = 1.2 m
- Quad strengths @ 100 GeV/c: Q_1 = -79.7 T/m, Q_2 = 41.3 T/m, Q_3 = -23.6 T/m



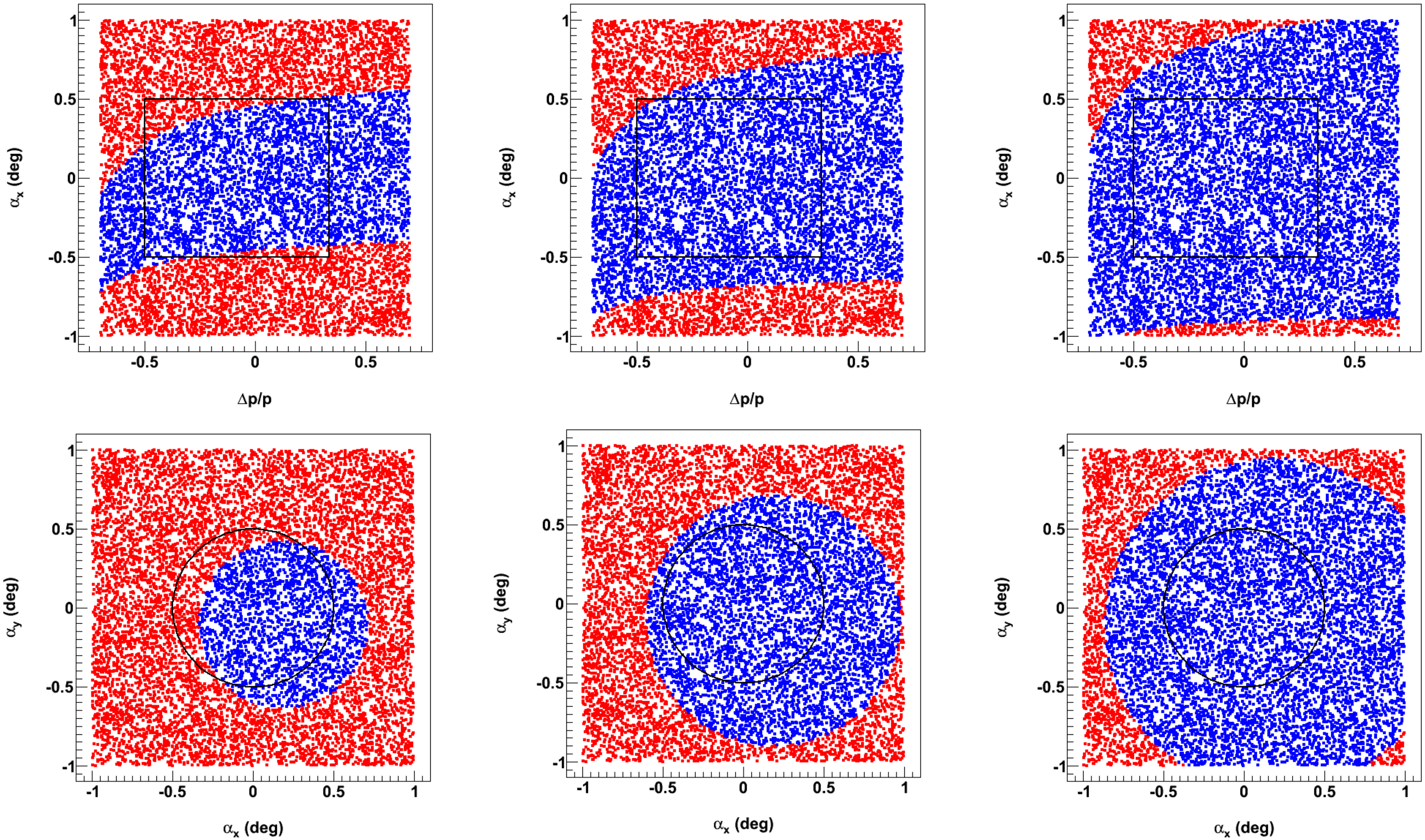
Quad aperture = Field at the pole tip / maximum field gradient (@ 100 GeV)



MEIC: “Optimized” FFB Acceptance

Blue region corresponds to angles smaller than 0.5 (1.0) degrees for 60 GeV protons, top (neutrons, bottom) and large momentum spread to account for e-A. If no red in square/circle, we have full acceptance

6 T max **9 T max** **12 T max**

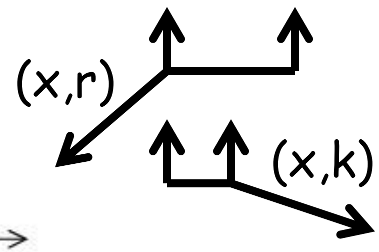


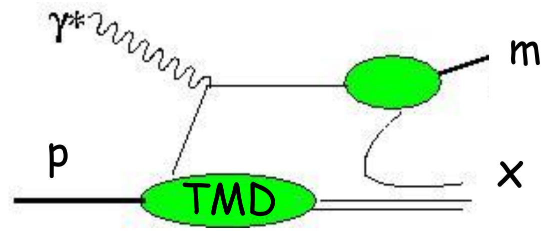
Summary

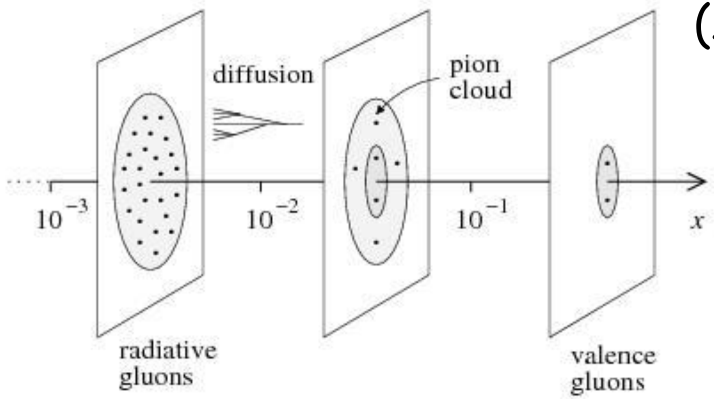
- Close and frequent collaboration between accelerator and nuclear physicists regarding the machine, interaction region and detector requirements has taken place. The MEIC detector/IR design has concentrated on *maximizing acceptance* for deep exclusive processes and processes associated with very-forward going particles, over a wide range of proton energies (20-100 GeV). The eRHIC design has concentrated on compatibility with the 250 GeV operations, planning to make use of advances in focusing SC magnet technology to achieve *good acceptance for deep exclusive and diffractive processes*.
- We have **unique opportunities** to make a (future textbook) breakthrough in nucleon structure and QCD dynamics, including:
  - the possibility to truly **explore and image the nucleon**
  - the possibility to discover the role of **gluons in structure and dynamics**
  - the possibility to understand the emergence of hadrons from color charge
- BNL and JLab managements and the EIC community closely collaborate, and some convergence has occurred on performance deliverables in terms of energy and luminosity, detector design, and the EIC realization timeline. Nonetheless, differences remain in design approach, interaction region integration, and the benchmark processes.
- Urgency of simulation work to understand the relation between detector performance and quality of physics results, in order to understand trade-offs.

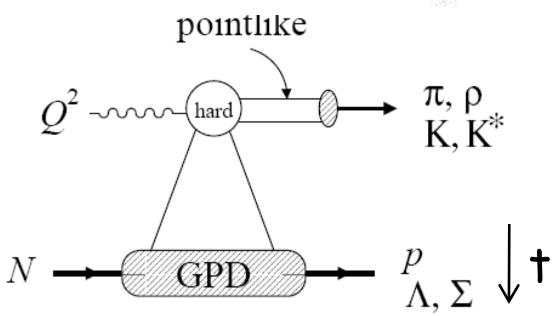
Towards a "3D" spin-flavor landscape

$W^u(x,\mathbf{k},\mathbf{r})$ (Wigner Function)









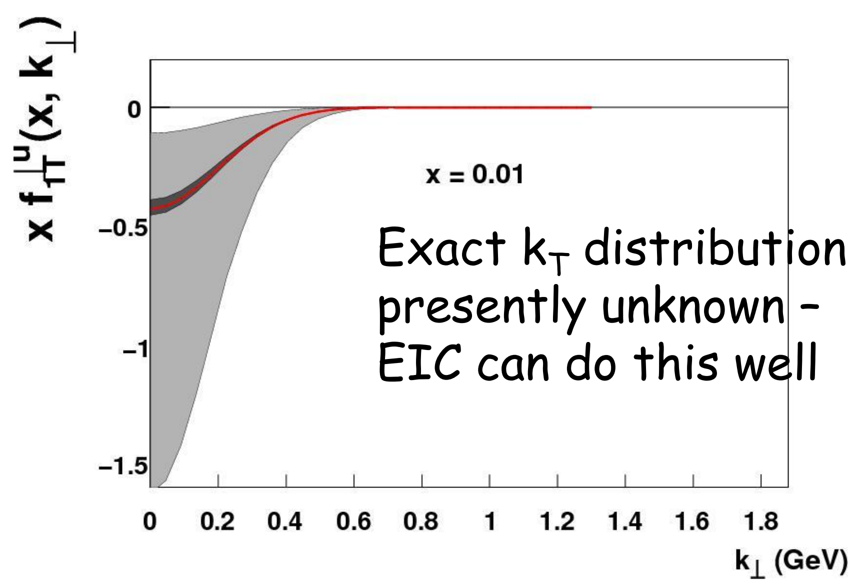
EIC: Transverse spatial distribution derived directly from t dependence:

- Gluon size from J/Ψ and ϕ
- Singlet quark size from γ
- Strange and non-strange (sea) quark size from π and K production

Hints from HERA:

Area $(q + \bar{q})$ > Area (g)

EIC: Transverse momentum distribution derived directly from semi-inclusive measurements, plus large gain in our knowledge of transverse momentum effects as function of x.

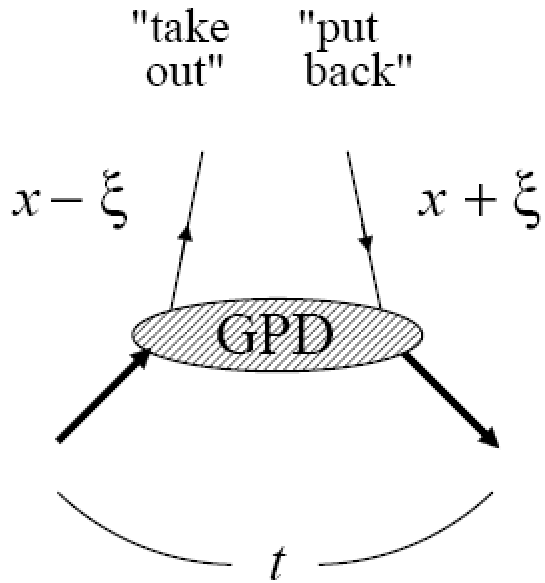


Exact k_T distribution presently unknown – EIC can do this well

Transverse Quark & Gluon Imaging

Deep exclusive measurements in ep/eA with an EIC:

diffractive:	transverse gluon imaging	J/ψ, ϕ, ρ^o, γ (DVCS)
non-diffractive:	quark spin/flavor structure	π, K, ρ^+, …



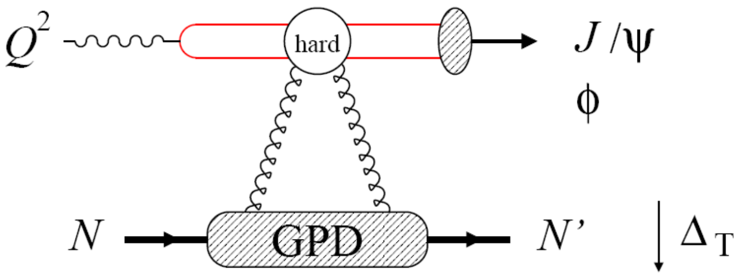
Are gluons uniformly distributed in nuclear matter or are there small clumps of glue? Are gluons & various quark flavors similarly distributed?

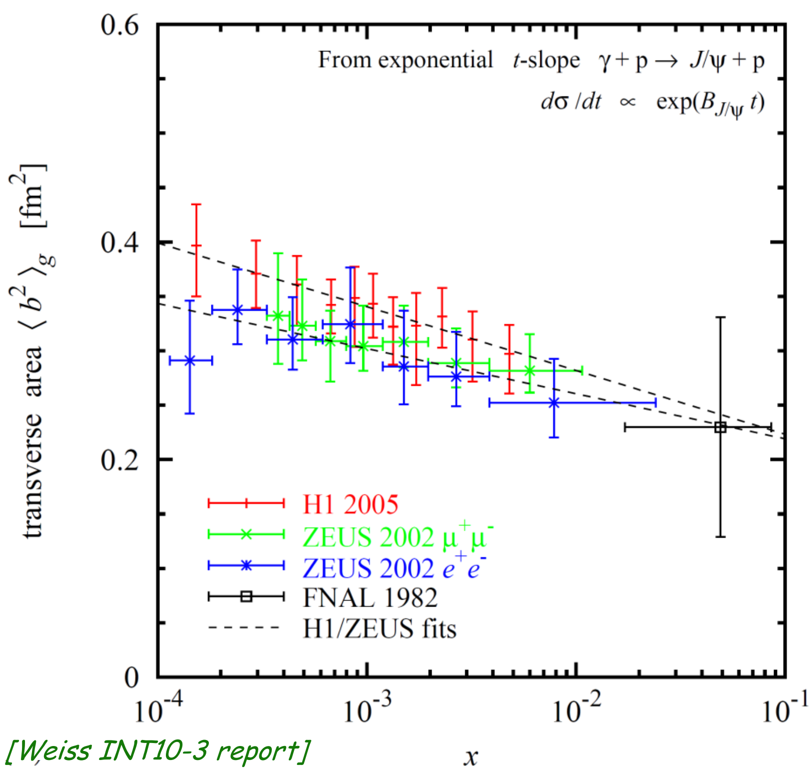
(some hints to the contrary)

Describe correlation of longitudinal momentum and transverse position of quarks/gluons →

Transverse quark/gluon imaging of nucleon ("tomography")

Gluon Imaging with J/Ψ (or ϕ)



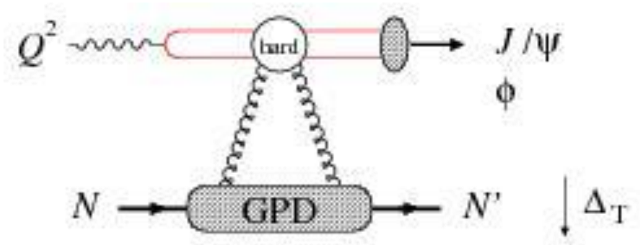


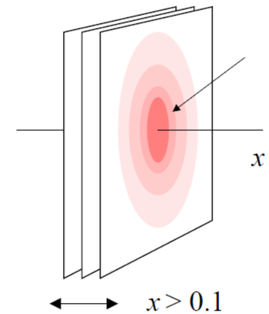
[Weiss INT10-3 report]

- Transverse spatial distributions from exclusive J/ψ, and ϕ at Q^2>10 GeV^2
  - –Transverse distribution *directly* from Δ_T dependence
  - –Reaction mechanism, QCD description studied at HERA [H1, ZEUS]
- Physics interest
  - –Valence gluons, dynamical origin
  - –Chiral dynamics at $b \sim 1/M_\pi$ *[Strikman, Weiss 03/09, Miller 07]*
  - –Diffusion in QCD radiation
- Existing data
  - –Transverse area x < 0.01 *[HERA]*
  - –Larger x poorly known *[FNAL]*

Gluon Imaging: Valence-like Gluons

EIC: Precise Gluon imaging through exclusive J/Ψ and ϕ (Q^2 > 10 GeV^2)



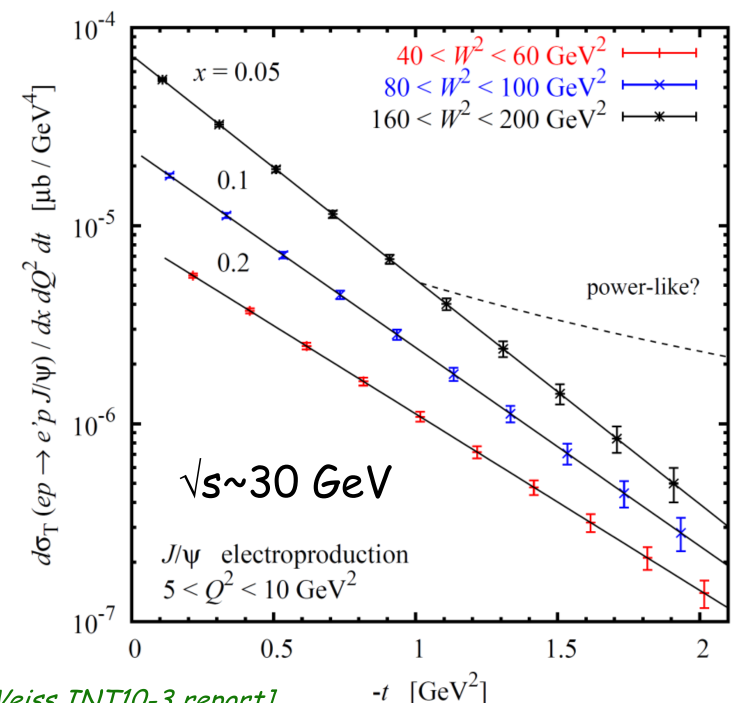


Transverse distribution derived directly from Δ_T-dependence

- EIC: Map unknown region of non-perturbative gluons at x > 0.01
- Needed for imaging
  - -Full t-distribution to allow Fourier transform, and distinguish e.g. between exponential (solid) and power-like (dashed) fall-off
  - $Q^2 > 10$ GeV^2, various channels

1st gluonic images of nucleon @ large x

~100 days, ε=1.0, $\mathcal{L}$=10^{34} $s^{-1}cm^{-2}$



[Weiss INT10-3 report]

Gluon Imaging: Gluon vs Quark Size

• Do singlet quarks and gluons have the same transverse distribution?

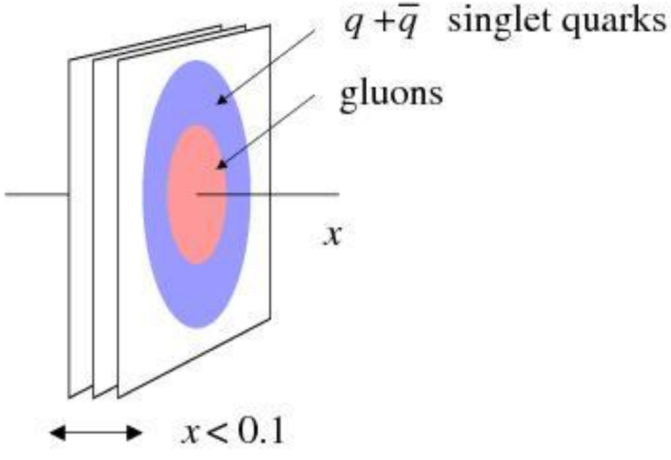
Hints from HERA:

Area ($q + \bar{q}$) > Area (g)

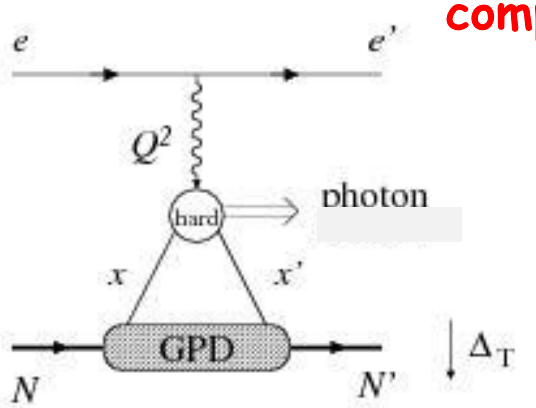
Dynamical models predict difference:

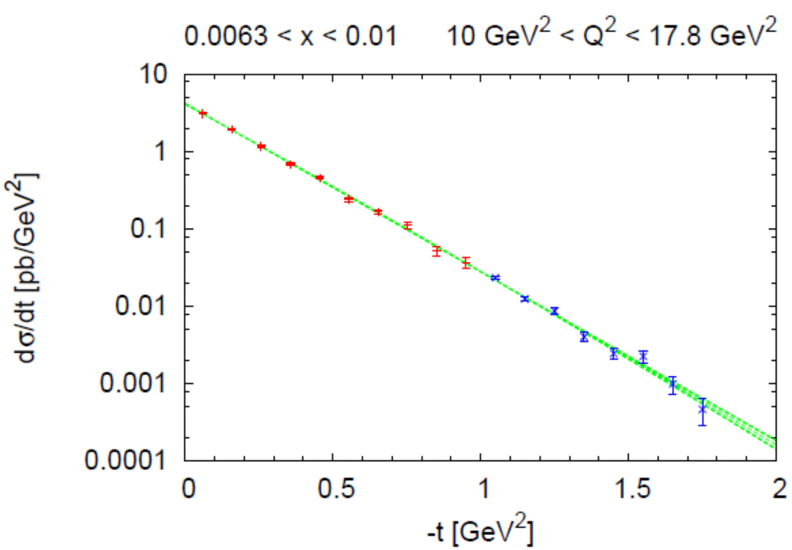
pion cloud, constituent quark picture

EIC: Gluon size from J/Ψ electroproduction, singlet quark size from deeply virtual compton scattering



~12 and 150 fb^{-1}, respectively





[Fazio, Aschenauer INT10-03 Report]

Gluon Imaging: Gluon vs Quark Size

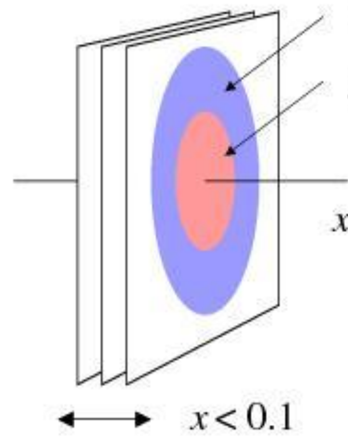
- Do singlet quarks and gluons have the same transverse distribution?

Hints from HERA:

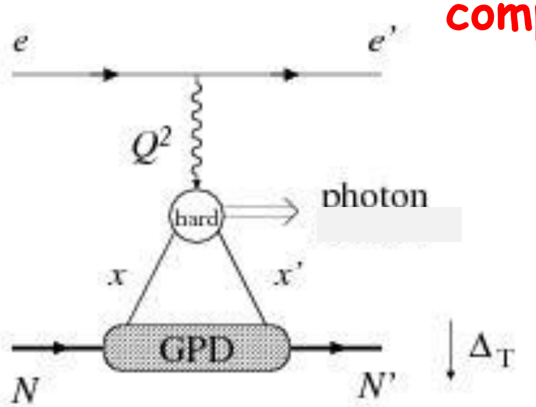
Area ($q + \bar{q}$) > Area (g)

Dynamical models predict difference:

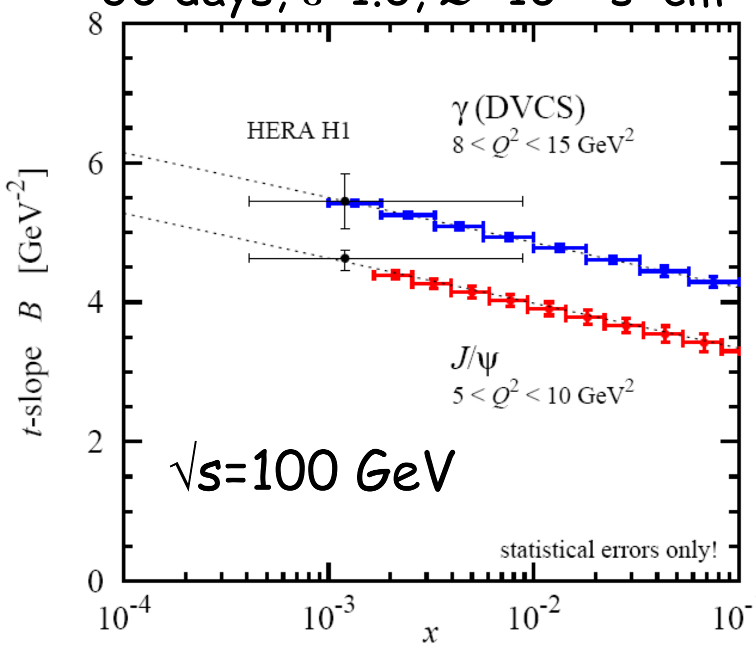
pion cloud, constituent quark picture



EIC: **Gluon size from J/Ψ electroproduction, singlet quark size from deeply virtual compton scattering**



~30 days, ε=1.0, $\mathcal{L}$ =10^{34} $s^{-1}cm^{-2}$

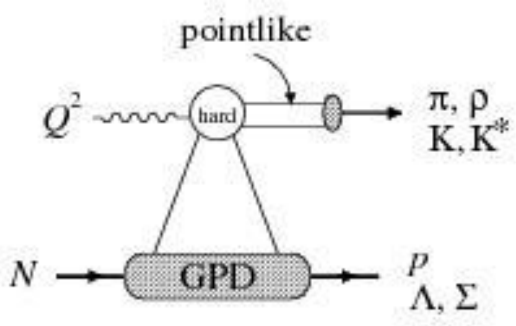


[Sandacz, Hyde, Weiss 08+]

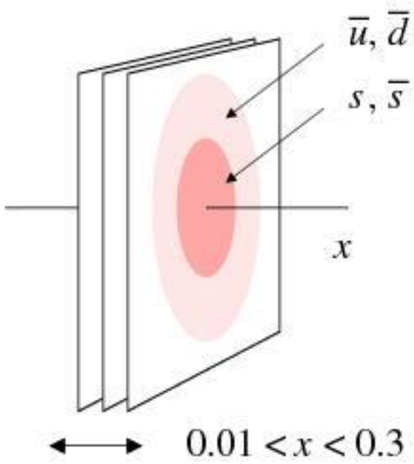
Detailed differential images of nucleon's partonic structure

Sea Quark Imaging

- Do strange and non-strange sea quarks have the same spatial distribution?

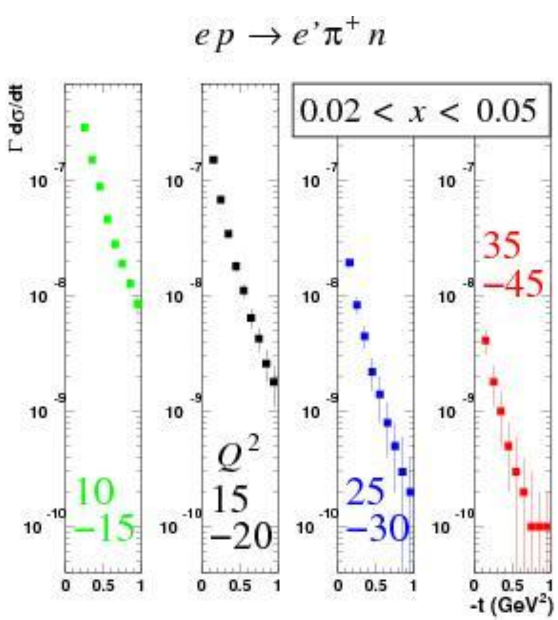


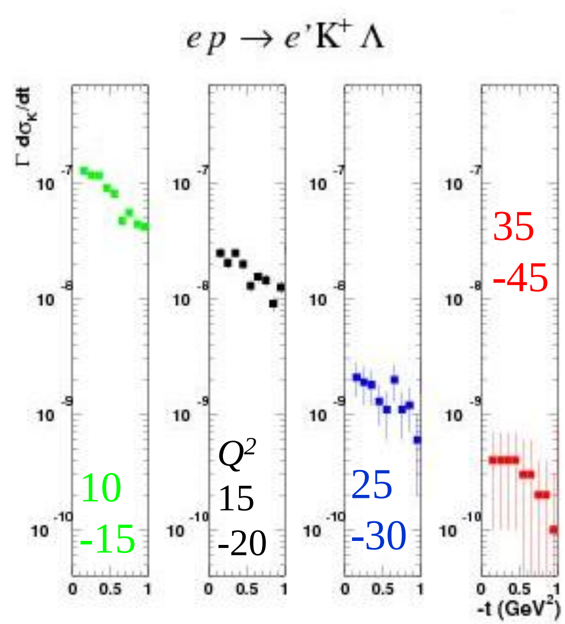
–πN or $K\Lambda$ components in nucleon
–QCD vacuum fluctuations
–Nucleon/meson structure



~100 days, ε=1.0, $\mathcal{L}$=10^{34} $s^{-1}cm^{-2}$

- Accessible with exclusive π and K production!
- $Q^2 > 10(?)$ GeV^2 relevant for application of factorization
- Statistics hungry



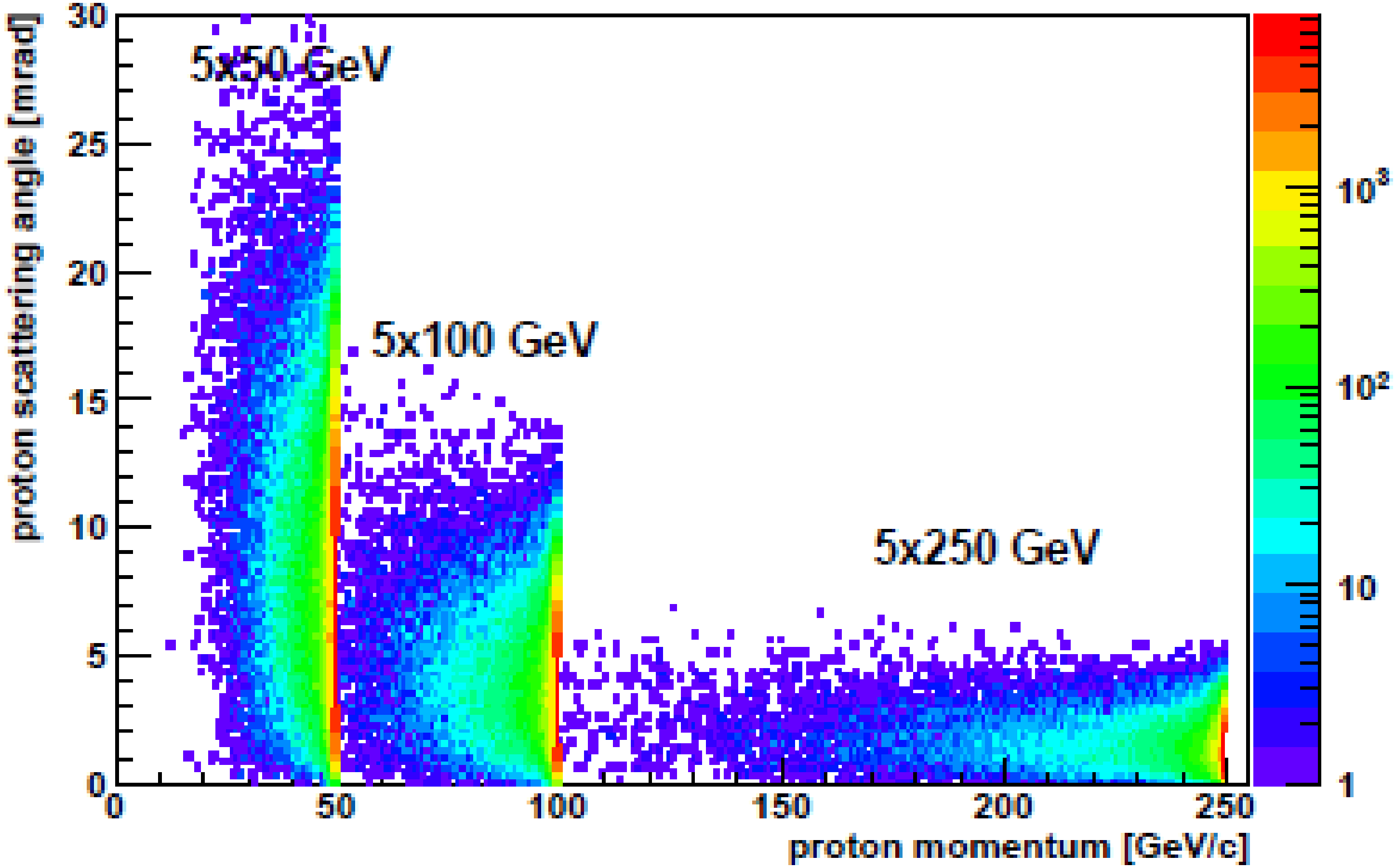


Imaging of *strange* sea quarks!

$\sqrt{s}$~30 GeV

[Horn et al. 08+, INT10-3 report]

Example: DVCS proton measurement @ eRHIC



IR region optimization → ~70% detection fraction at 250 GeV protons

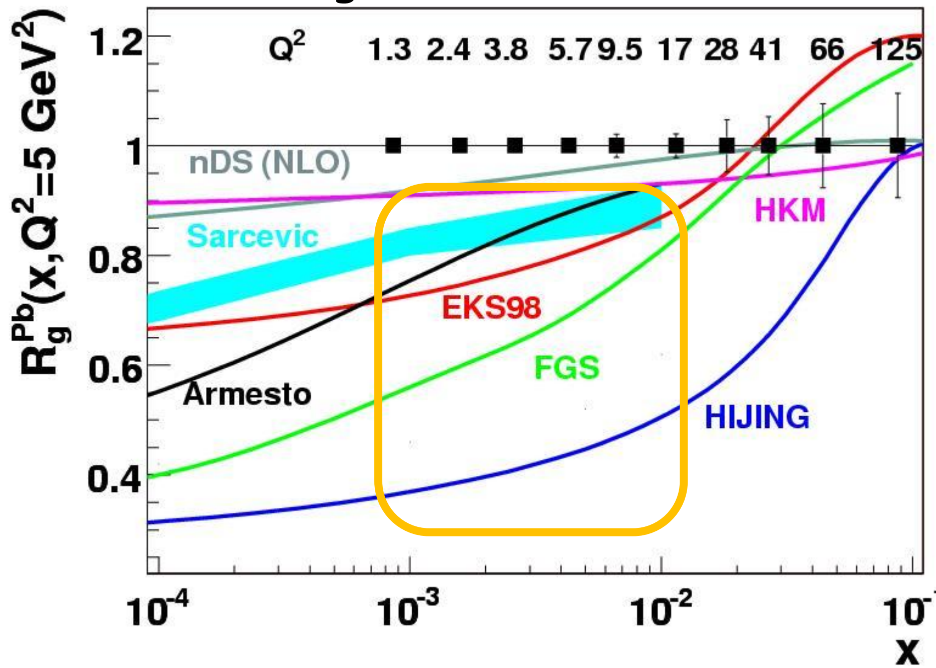
Gluons in Nuclei

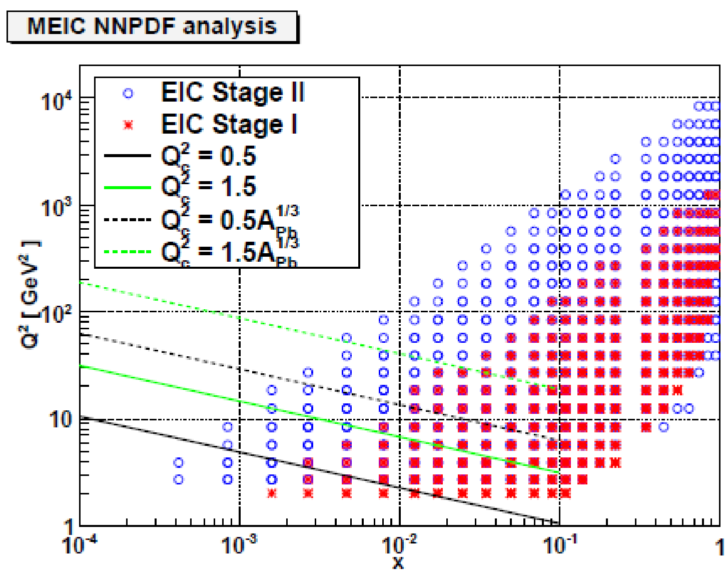
- What do we know about gluons in a nucleus?

NOTHING!!!

- Large uncertainty in gluon distributions
- need range of Q^2 in shadowing region,
  → $x \sim 10^{-2}$-10^{-3} → $s_{EIC} = 1000+$

Ratio of gluons in lead to deuterium

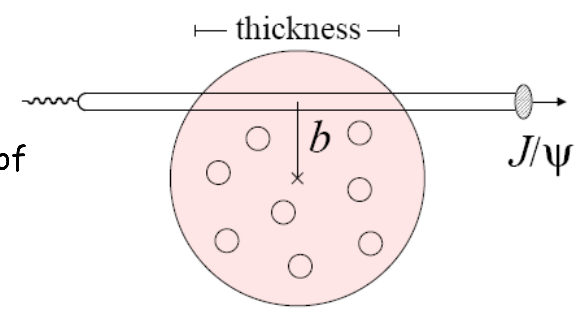




Kinematic coverage in eA ($A = 208$).

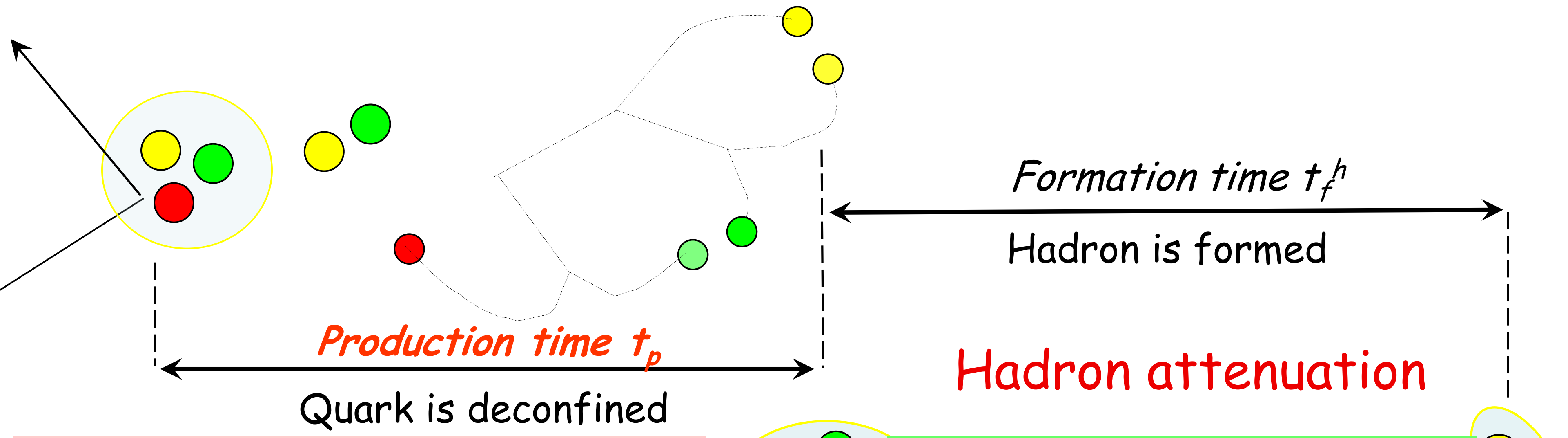
[Rojo, Guzey, Accardi]

+ Transverse distribution of gluons on light nuclei from coherent Deep-Virtual Compton Scattering and coherent J/Ψ production



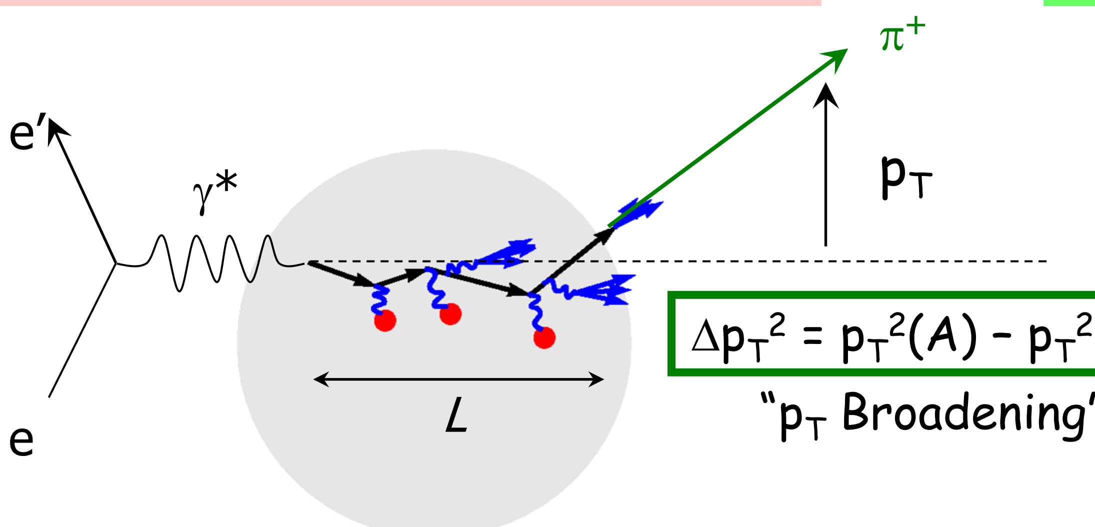
→ **Gluon radius of a nucleus?**

Using the nuclear arena



Time required to produce colorless "pre-hadron", signaled by medium-stimulated energy loss via gluon emission

Time required to produce fully-developed hadron, signaled by CT and/or usual hadronic interactions



$$\boxed{\Delta p_T^2 = p_T^2(A) - p_T^2(^2H)}$$

"p_T Broadening"

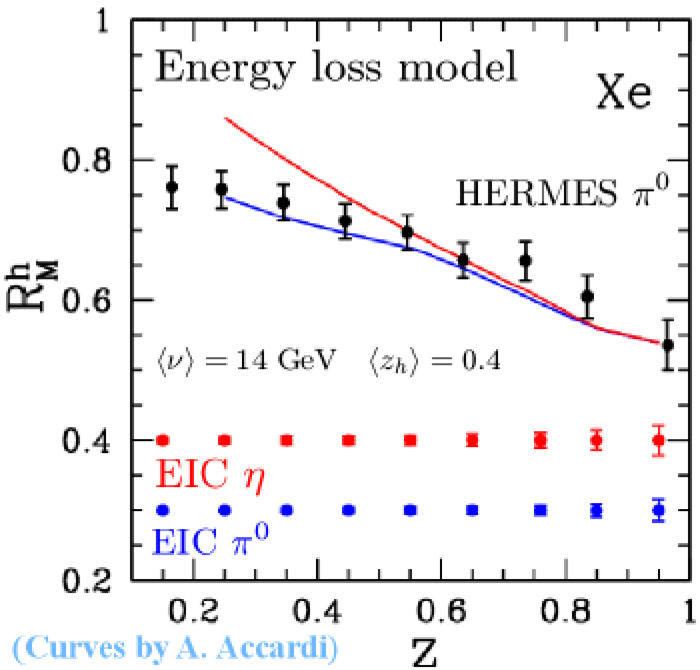
$dE/dx \sim \langle p_T^2 \rangle_L$

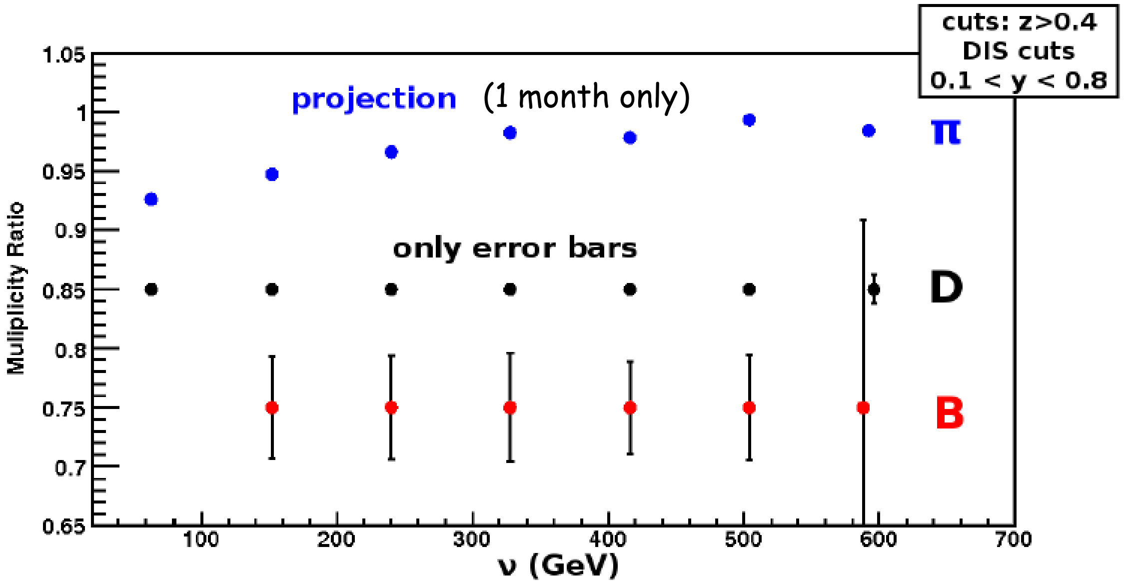
$\Delta E \sim L$ (QED)

$\sim L^2$ (QCD)?

Hadronization

EIC: Explore the interaction of color charges with matter



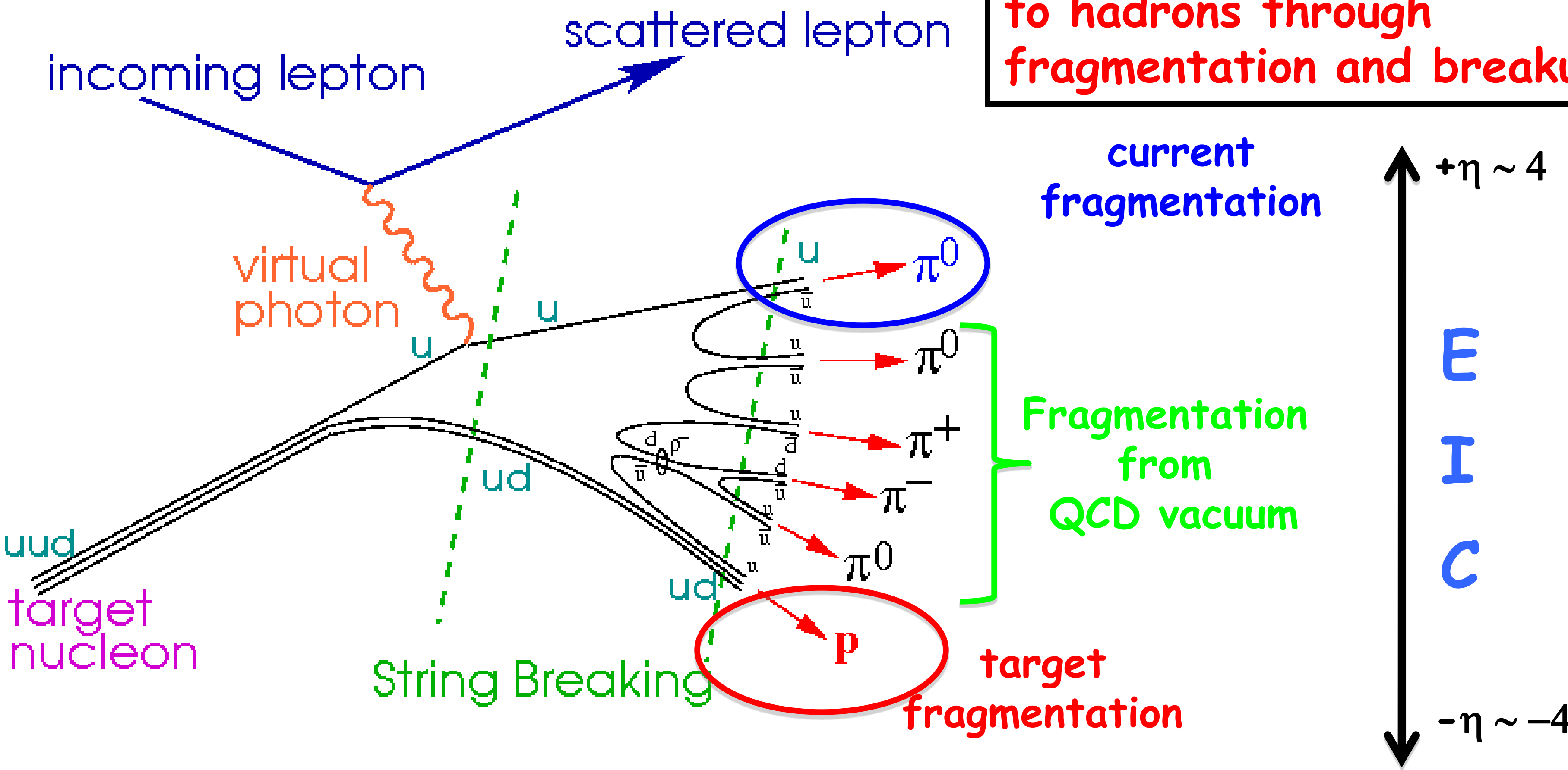


EIC: Understand the conversion of color charge to hadrons through fragmentation and breakup

Hadronization

- un-integrated parton distributions

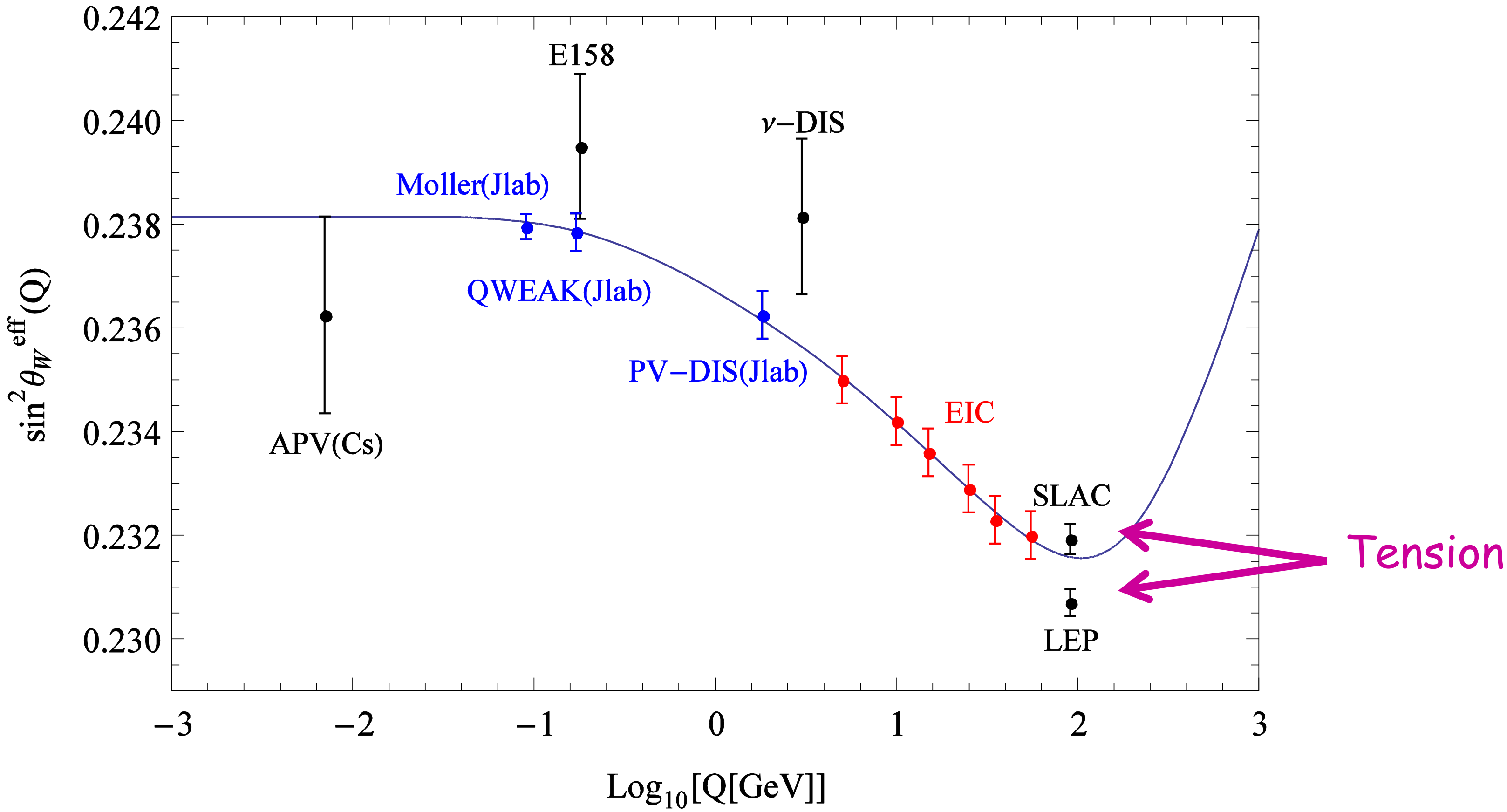
EIC: Understand the conversion of color charge to hadrons through fragmentation and breakup



EIC: Explore the interaction of color charges with matter

Completed, planned, and possible EIC measurements

"Hunting for the unseen forces of the universe"



→ EIC allows to probe the electro-weak mixing angle over a wide range of Q

Accelerator Team's Roadmap

Major Events/Accomplishments

- Held an internal machine design review (Sep. 15 & 16, 2010)
- Held an internal Workshop on the choice of RF → SRF/750 MHz
- Received a grant ($900K) from DOE/NP for MEIC R&D (Nov. 2010)
- Held an internal MEIC Ion Complex Design Workshop (Jan. 29 & 30, 2011)
- Reported the MEIC machine design in the EICAC Meeting (April 10, 2011)
- Completed extended interaction region recertification for Full Acceptance (Sep. 2011)
- Ongoing priority: electron cooling design
- Planning for 2nd MEIC Internal Accelerator Design Review and 1st Cost Review this Fall