Long Term Future: EIC

Zein-Eddine Meziani
Temple University

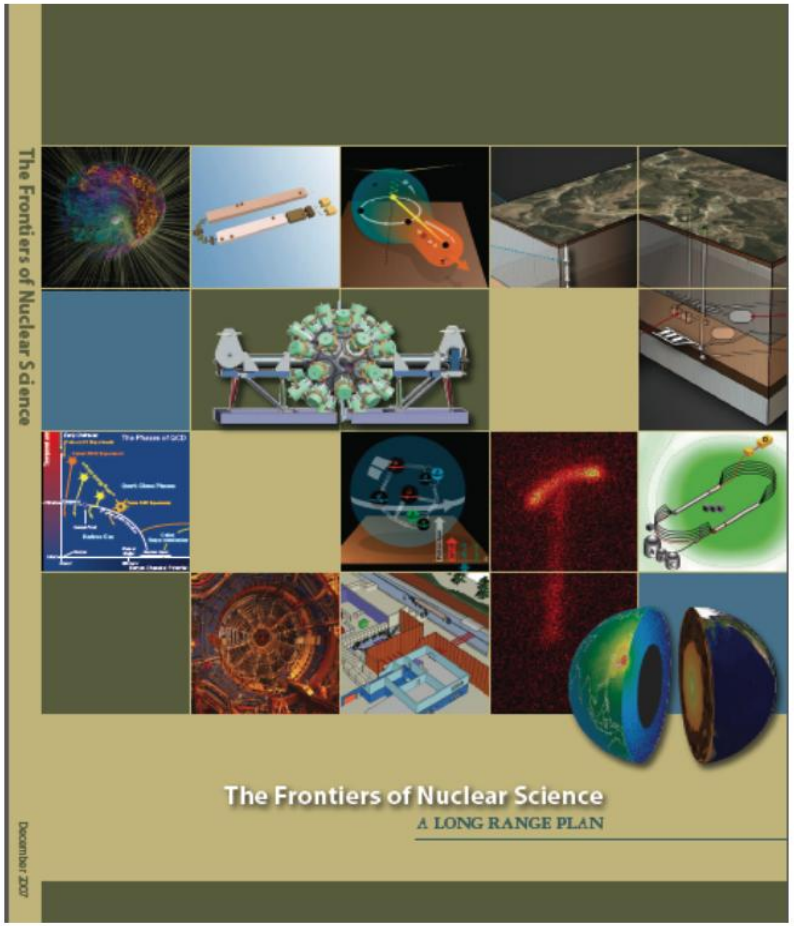
Outline:

- Introduction
- EIC at JLab
- Physics examples
- Conclusion

NSAC 2007 Long Range Plan

"An **Electron-Ion Collider (EIC)** with polarized beams has been **embraced by the U.S. nuclear science community** as embodying the vision for **reaching the next QCD frontier**. EIC would provide unique capabilities for the study of QCD well beyond those available at existing facilities worldwide and complementary to those planned for the next generation of accelerators in Europe and Asia. In support of this new direction:

We recommend the allocation of resources to develop accelerator and detector technology necessary to lay the foundation for a polarized Electron Ion Collider. The EIC would explore the new QCD frontier of strong color fields in nuclei and precisely image the gluons in the proton."



Some of the NSAC LRP Overarching QCD questions (December 2007)

- What is the internal spin and flavor landscape of hadrons?
- What is the role of gluons and gluons self interactions in nucleon and nuclei?
- What governs the transition of quarks and gluons into pions and nucleons?

EIC; a natural extension of studies planned for JLab but to probe the glue and the sea

Generalized Parton Distributions

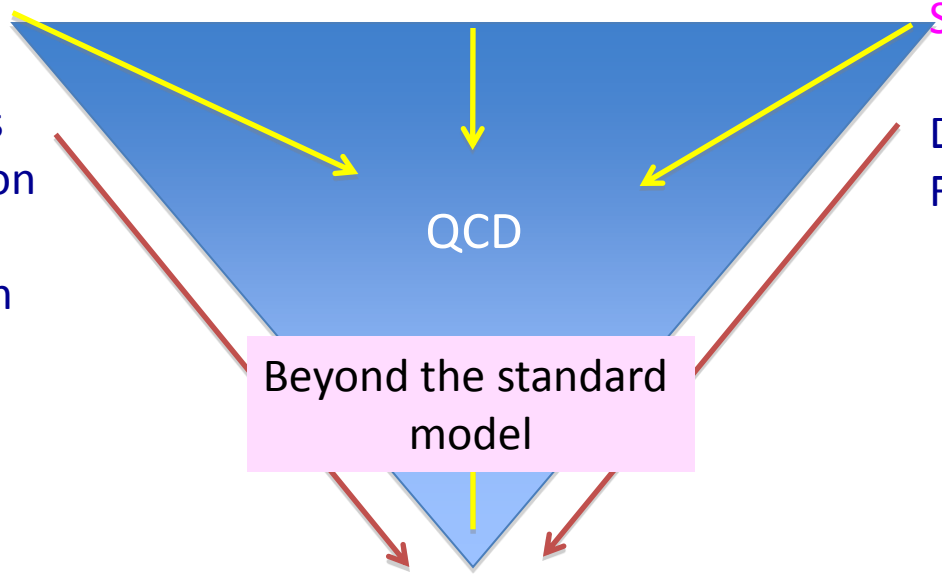
Inclusive

Sum rules and polarizabilities

Transverse Momentum Distributions

Exclusive reactions

Semi-Inclusive DIS



Elastic form factors
Deep Virtual Compton Scattering
Deep Virtual Meson Production

Since 1998

Distributions and Fragmentation functions

Since 2000

GPDs and TMDs in Nuclei
Exclusive
Semi-inclusive
Initial and final medium effects

Why ELIC/mEIC?

- A natural extension of the 12 GeV physics program of hadron structure/QCD

However, the emphasis is not the valence quarks but

Gluons and Sea Quarks in the valence region and beyond

- This requires high luminosity and good center of mass energy
  - ➥Luminosity is key for probing rare processes
  - ➥Energy reach key for clean interpretation

JLab beyond the 12 GeV upgrade

- Jlab community hopes to articulate a comprehensive physics program using an electron ion collider that will complement, extend, and complete (?) our current physics program and our plans for 12 GeV.

- The community, together with the Lab had a series of workshops to assess the physics potential of such a facility (all are welcome to participate in this endeavor).

- An important part of this effort will be a clarification of the machine and detector specifications that are optimal for completing this program.

Physics Areas Under Investigation and Workshops

- Study group on Hadronic Physics
  - Nucleon spin and quark-gluon correlations: Transverse spin, quark and gluon orbital motion, semi-inclusive processes
    (Partonic Transverse Momentum in Hadrons: Quark Spin-Orbit Correlations and Quark Gluons Interactions: workshop at Duke U., March 12-13, 2010)

  H. Gao et al.

  http://michael.tunl.duke.edu/workshop

  - 3D mapping of the glue and sea quarks in the nucleon
    (Electron-Nucleon Exclusive Reactions: workshop at Rutgers U., March 14-15, 2010)

  R. Gilman et al.

  http://www.physics.rutgers.edu/np/2010rueic-home.html

- Study group on Nuclear Physics
  - 3D tomography of nuclei, quark/gluon propagation and the gluon/sea quark EMC effect
    (EIC Nuclear Chromodynamics: workshop at Argonne National Lab, April 7-9, 2010)

  K. Hafidi, et al.

  http://www.phy.anl.gov/mep/EIC-NUC2010/

- Study group on Electroweak Physics
  - Electroweak structure of the nucleon and tests of the Standard Model
    (workshop at the College of W&M , May 17-18, 2010)

  K. Kumar, D. Armstrong et al.

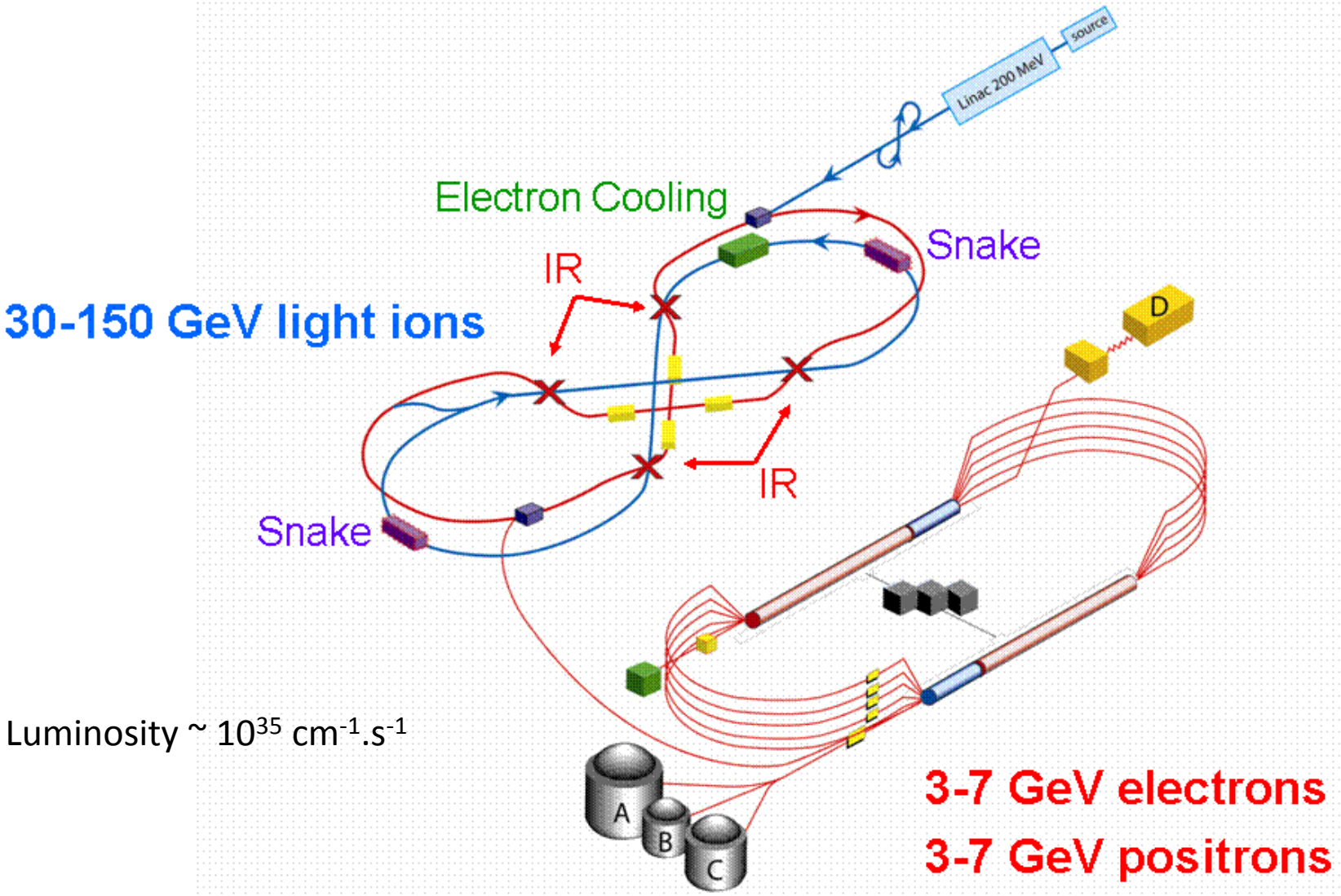
  https://eic.jlab.org/wiki/index.php/Electroweak_Working_Group

- Study group on interaction region and detectors
  - EIC Detectors/Instrumentation
    (workshop at JLab, June 03-04, 2010)

  C. Hyde et al.

  http://conferences.jlab.org/eic2010/program.html

ELIC presented at the LRP



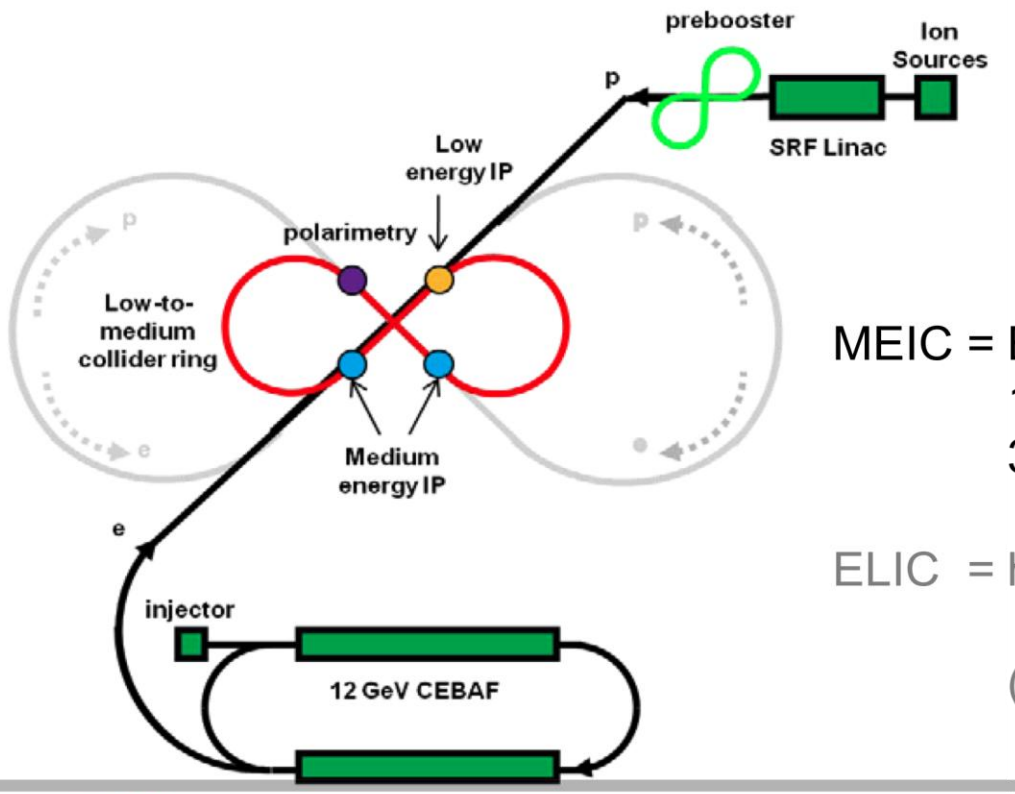
Luminosity ~ 10^{35} $cm^{-1}.s^{-1}$

Medium Energy Electron Ion Collider

Map the spin and 3D quark-gluon structure of protons

Discover the role of gluons in atomic nuclei

Understand the creation of the quark-gluon matter around us

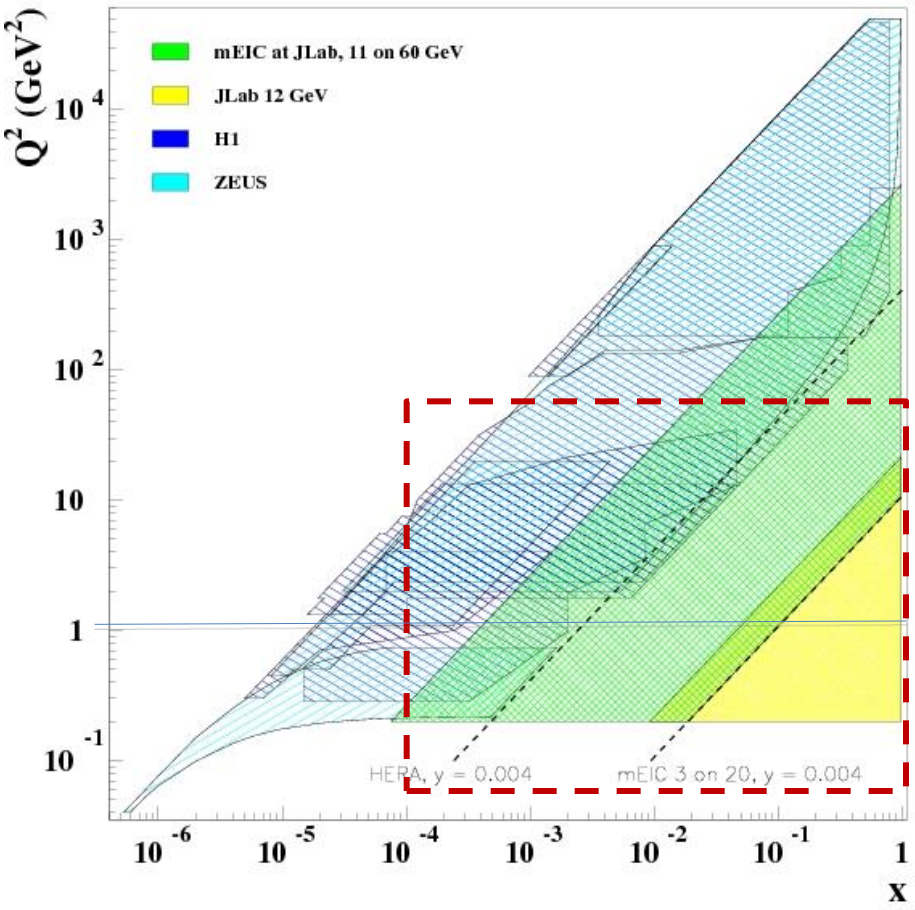


Luminosity~ few 10^{34} $cm^{-1}s^{-1}$

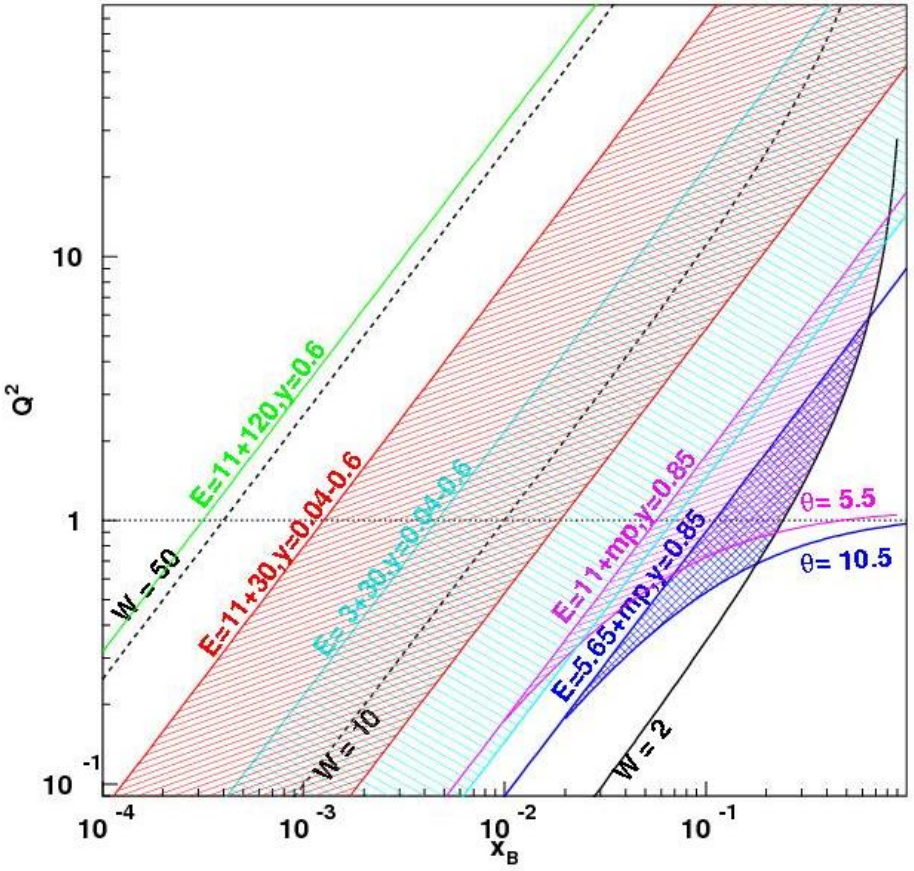
MEIC = EIC@JLab
1 low-energy IR (s ~ 200)
3 medium-energy IRs
(s < 2600)

ELIC = high-energy EIC@JLab
(s = 11000)
(limited by JLab site)

EIC Kinematic Coverage



ep mEIC: 11+60



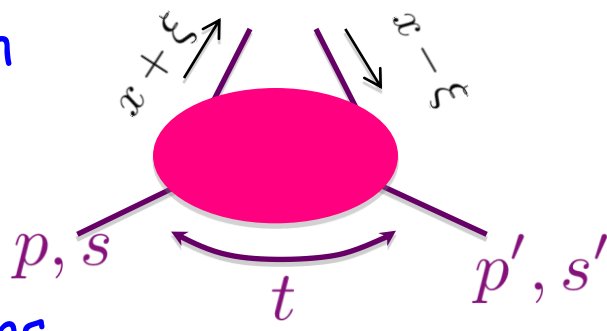
eA mEIC: 3+30/11+30 (0.04<y<0.6)
eA eLIC: 11+120 (y=0.6)

EIC connects JLab and HERA kinematic region

Theoretical Framework within QCD

- Generalized Parton Distributions
  - Matrix elements of non-local operators with quarks and gluon field

$$\langle p|\mathcal{O}|p\rangle$$



  - Depend on two longitud. momentum fractions

$$x,\ \xi \text{ and } t = (p-p')^2$$

  - For unpolarized quarks we have two distributions:

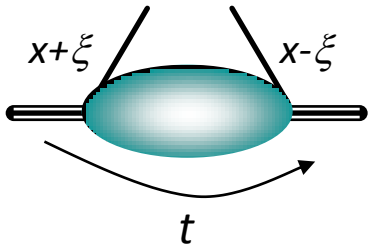
H^q *conserves proton helicity*

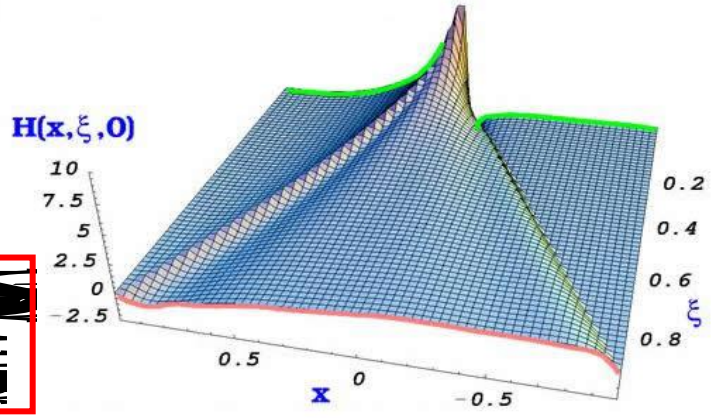
E^q *flips proton helicity*

$$p = p' \Longrightarrow$$

$$H^q(x,0,0) = \begin{cases} q(x) & \text{for } x > 0 \\ -\bar{q}(x) & \text{for } x < 0 \end{cases}$$

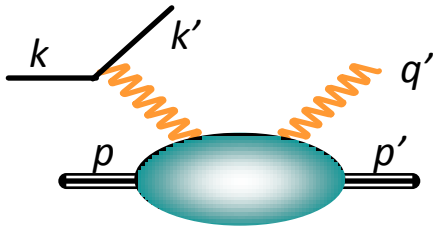
Generalized Parton Distributions, Deeply Virtual Compton Scattering





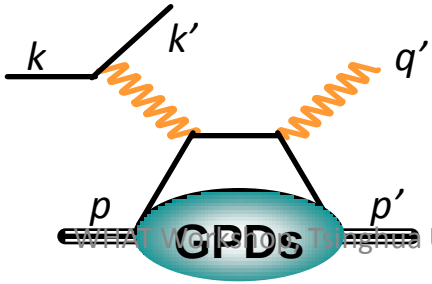
Model by Goeke, Polyakov, Vanderhaeghen

Deeply Virtual Compton Scattering is the simplest hard exclusive process involving GPDs

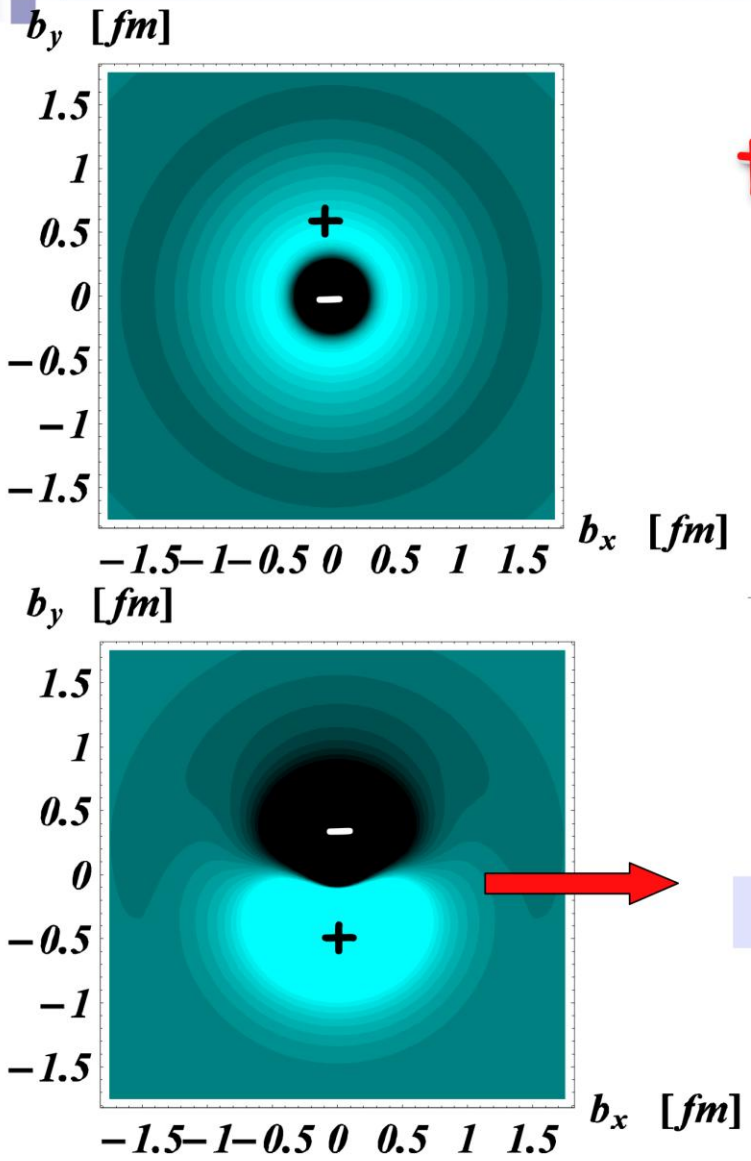


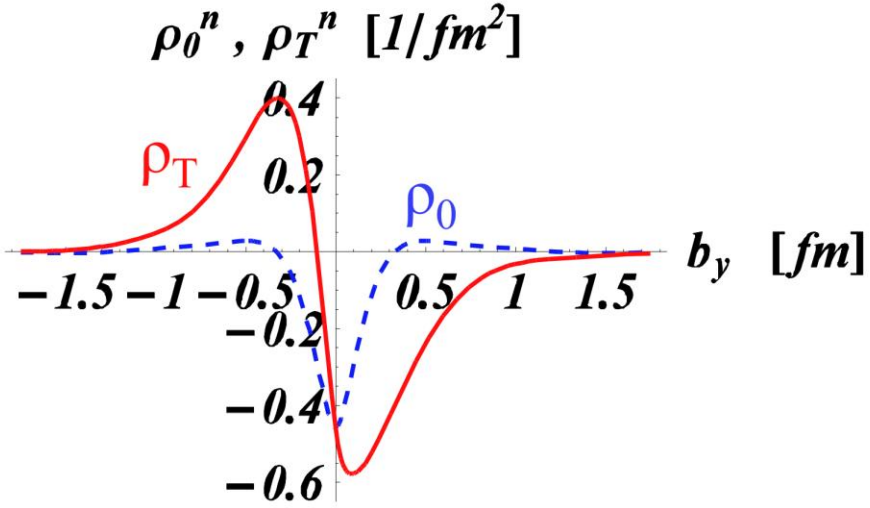
The handbag dominance:

Factorization Theorem



empirical quark transverse densities in neutron





induced EDM : $d_y = F_{2n}(0) \cdot e / (2 M_N)$

data: Bradford, Bodek, Budd, Arrington (2006)

densities : Miller (2007); Carlson, Vdh (2007)

Angular Momentum Sum Rule

$$\frac{1}{2} = J^q(\mu) + J^g(\mu)$$

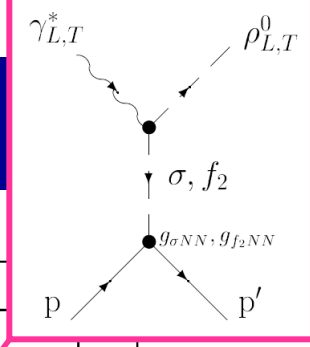
Ji Sum rule

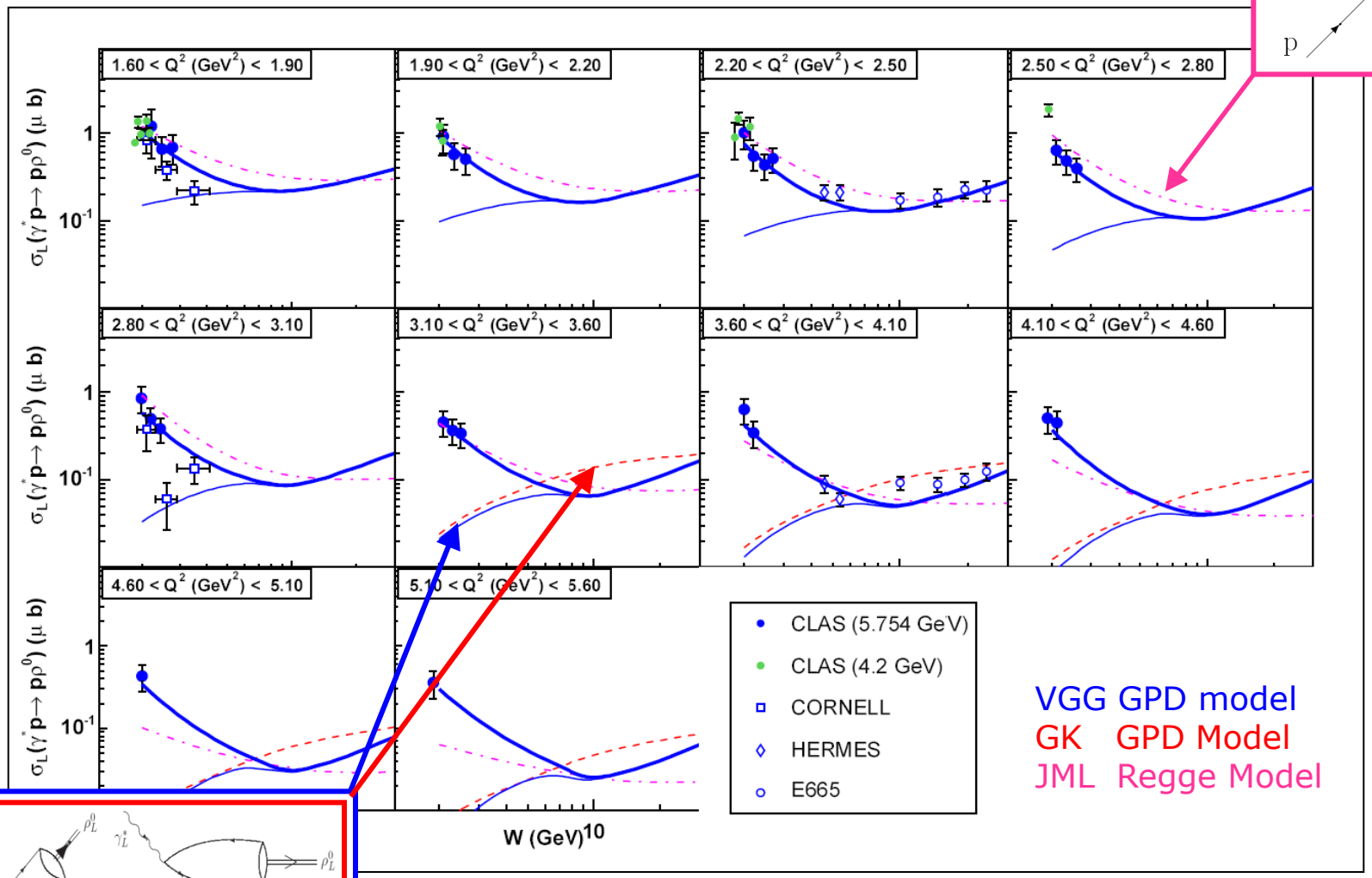
$$J^q(\mu) = \frac{1}{2}\Delta\Sigma + L^q(\mu) \qquad J^q = \int dx x \left[H^q + E^q\right]$$

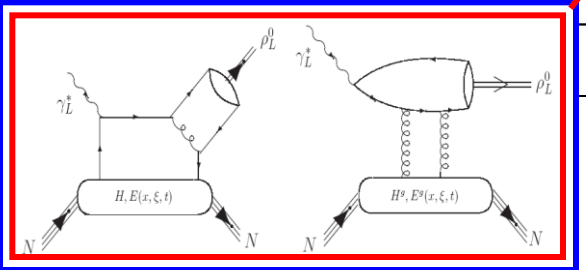
$$J^g = \int dx \left[H^g + E^g\right]$$

- A goal is to determine the glue GPDs H^g and E^g
- The momentum sum rule put constraints on GPD H^g . Data come mainly from HERA exclusive measurements of J/Psi production
- However nothing is known about GPD E^g
- If the quark angular momentum is small like some Lattice QCD is suggesting than J^g is large.

ρ^0 electroproduction







CLAS Deeply Virtual ρ^0, ρ^+ production and GPDs

E-99-105

Exploration of GPD application in meson sector.

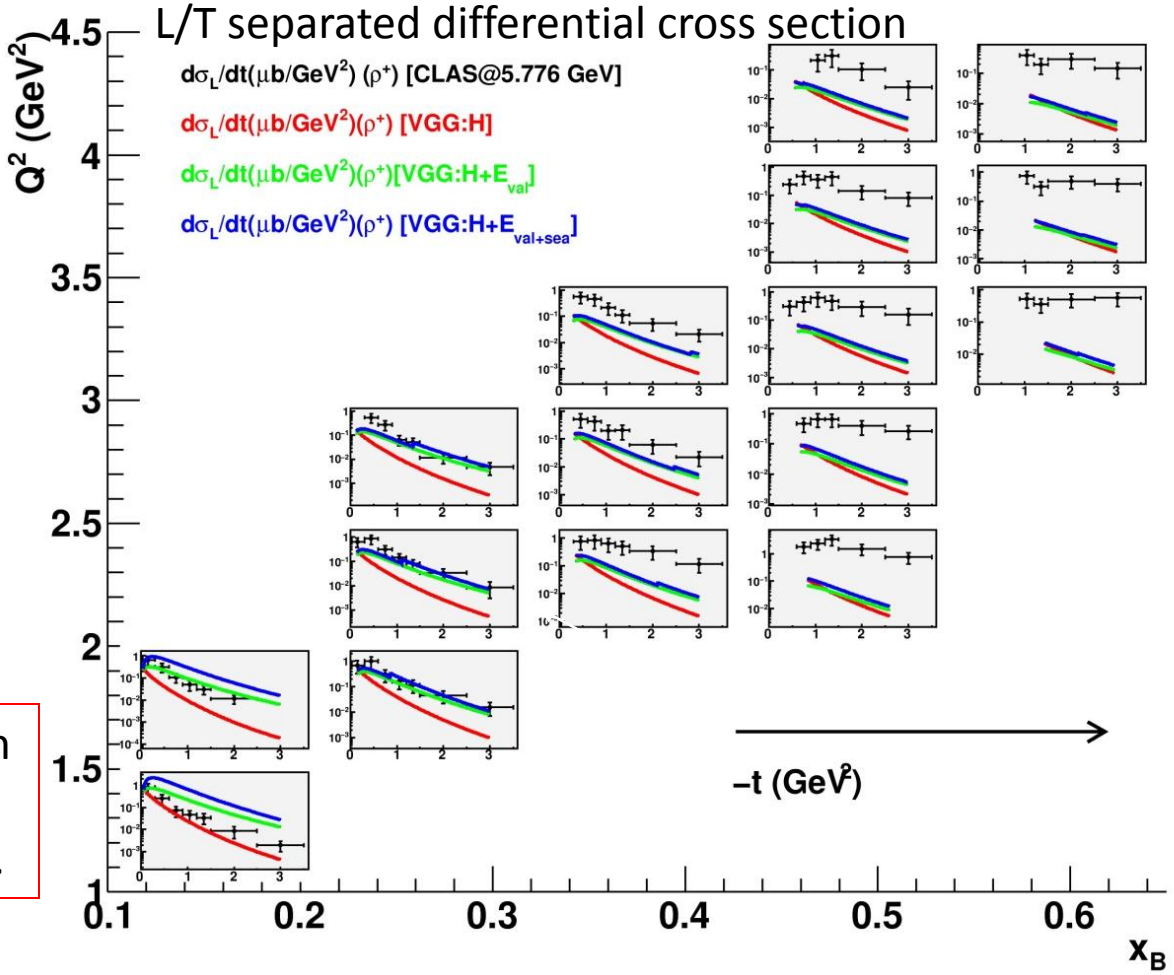
ρ^0: Eur.Phys.J.A39:5-31 ,2009
ρ^+: In preparation

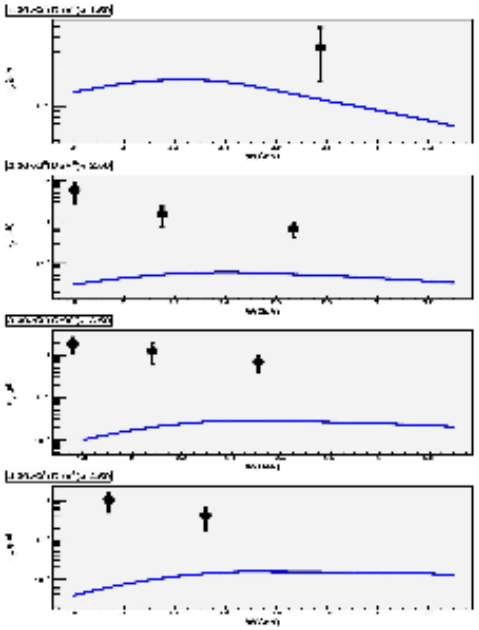
GPDs model agrees fairly with the data at low x_B (high W)

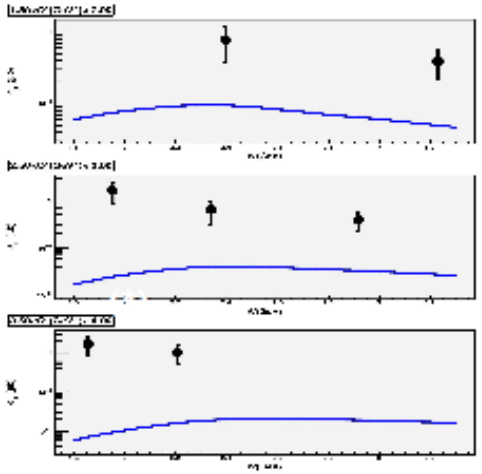
Hint of GPD E dominance at low x_B (high W)

Differences of GPD prediction and measurements shrink with increasing Q^2 at fixed x_B.

L/T separated differential cross section







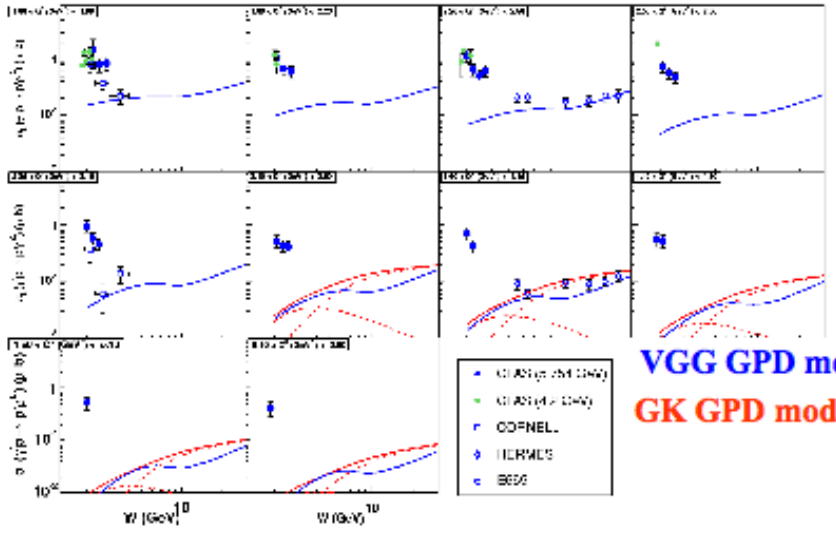
$\sigma_T(\rho^+)$ [CLAS@5.776 GeV]

$\sigma_L(\rho^+)$ [VGG]

"Partonic approach": GPDs

ρ^+

ρ^0



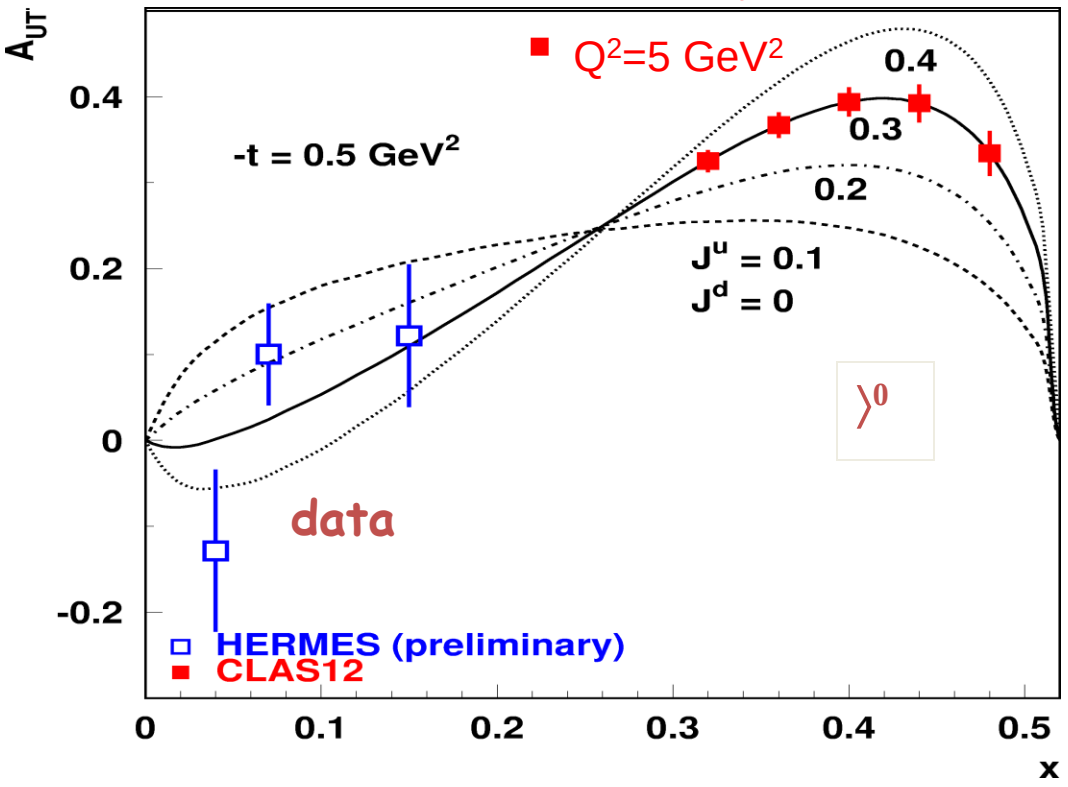
VGG GPD model

GK GPD model

exclusive ρ^0 production on *transverse* target

$$A_{UT} = - \frac{2\otimes (\mathrm{Im}(AB^*))/\square}{|A|^2(1-\xi^2) - |B|^2(\xi^2+t/4m^2) - \mathrm{Re}(AB^*)2\xi^2}$$

Projected results



$\rangle^0$

A ~ $2H^u + H^d$

B ~ $2E^u + E^d$

$\rangle^+$

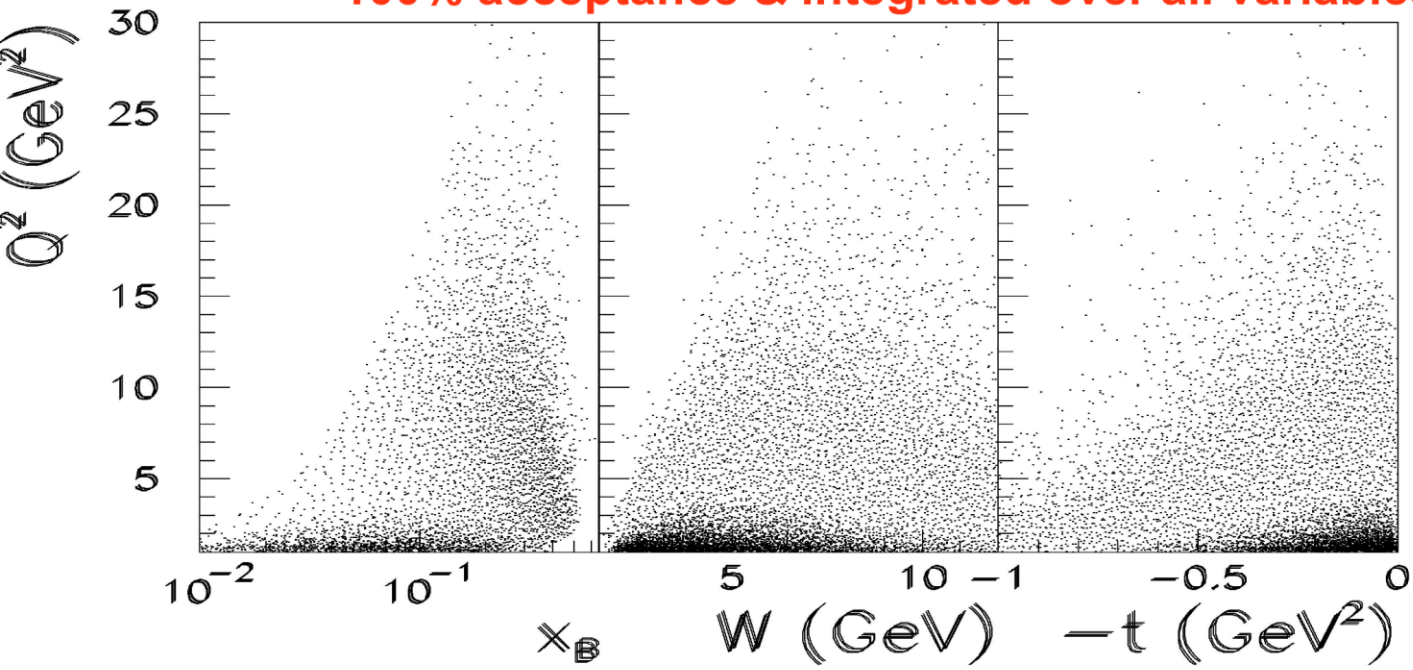
A ~ $H^u - H^d$

B ~ $E^u - E^d$

E^u, E^d needed for angular momentum sum rule.

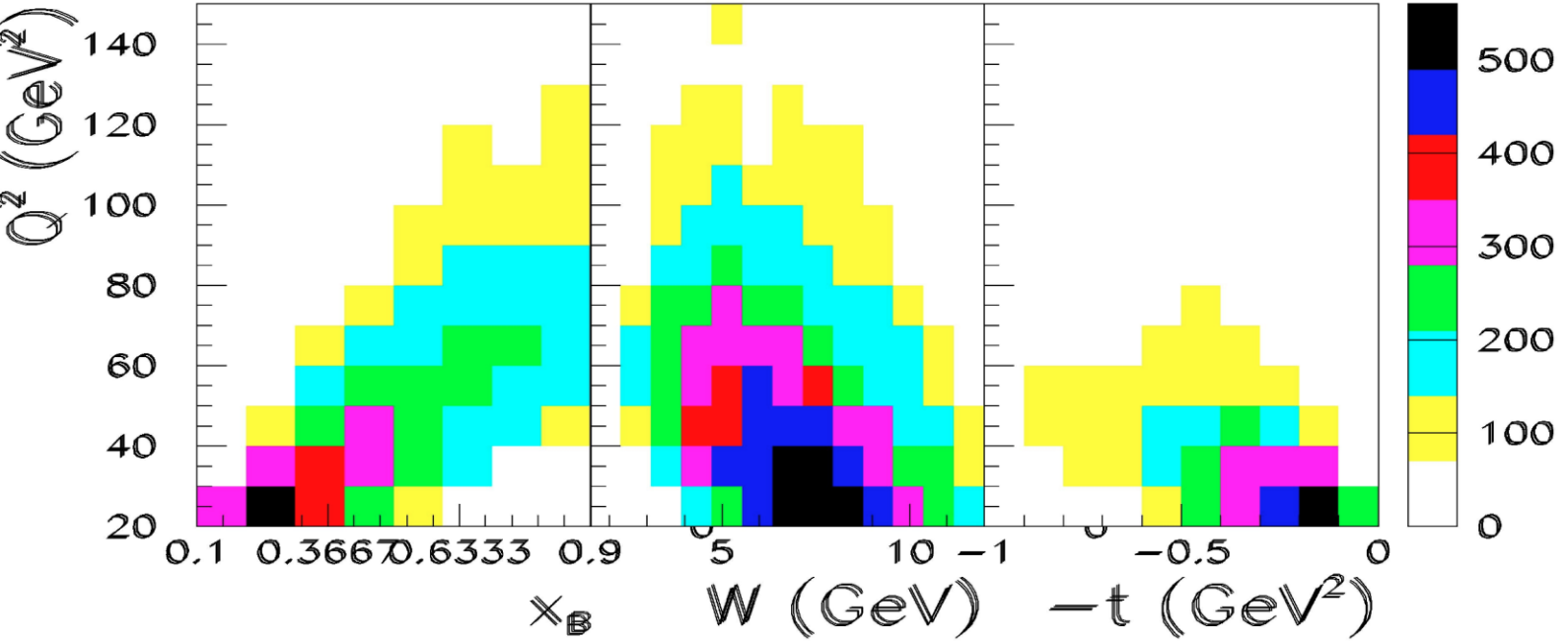
Goeke, Polyakov, Vanderhaegen (2001)

100% acceptance & integrated over all variables but (x_B,Q^2)



M. Guidal

11 GeV e
60 GeV p

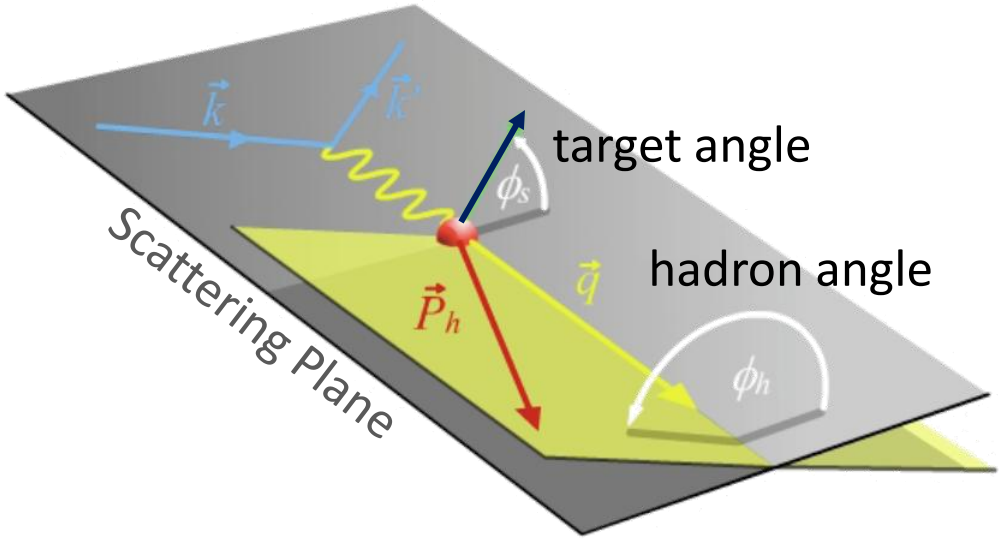


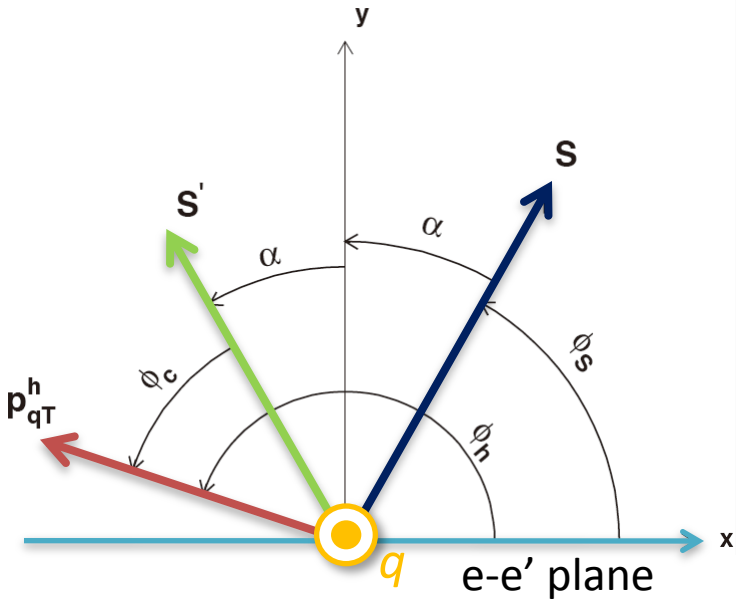
Counting ra
for 1000 hou
at 10^{34} cm^{-2}s

Limitation co
from luminos

SIDIS electroproduction of pions

- Separate Sivers and Collins effects





- **Sivers** angle, effect in distribution function:
  - $(\phi_h - \phi_s)$ = angle of hadron relative to *initial* quark spin
- **Collins** angle, effect in fragmentation function:
  - $(\phi_h + \phi_s) = \pi + (\phi_h - \phi_{s'})$ = angle of hadron relative to *final* quark spin

Leading Twist Transverse Momentum Distributions

Nucleon Spin

Quark Spin

Quark /Nucleon		Quark polarization		
		Un-Polarized	Longitudinally Polarized	Transversely Polarized
Nucleon Polarization	U	f_1 =		$h_1^{\perp}$ = **Boer-Mulder**
	L		g_1 = **Helicity**	$h_{1L}^{\perp}$ =
	T	$f_{1T}^{\perp}$ = **Sivers**	$g_{1T}^{\perp}$ =	h_{1T} = **Transversity** $h_{1T}^{\perp}$ = **Pretzelosity**

Simulations of Transverse SSA from SIDIS @ EIC

Workshop on Partonic Transverse Momentum in Hadrons: Quark Spin-Orbit Correlations and Quark-Gluon Interactions

Min Huang Xin Qian
Duke University / TUNL
Advisor: Haiyan Gao

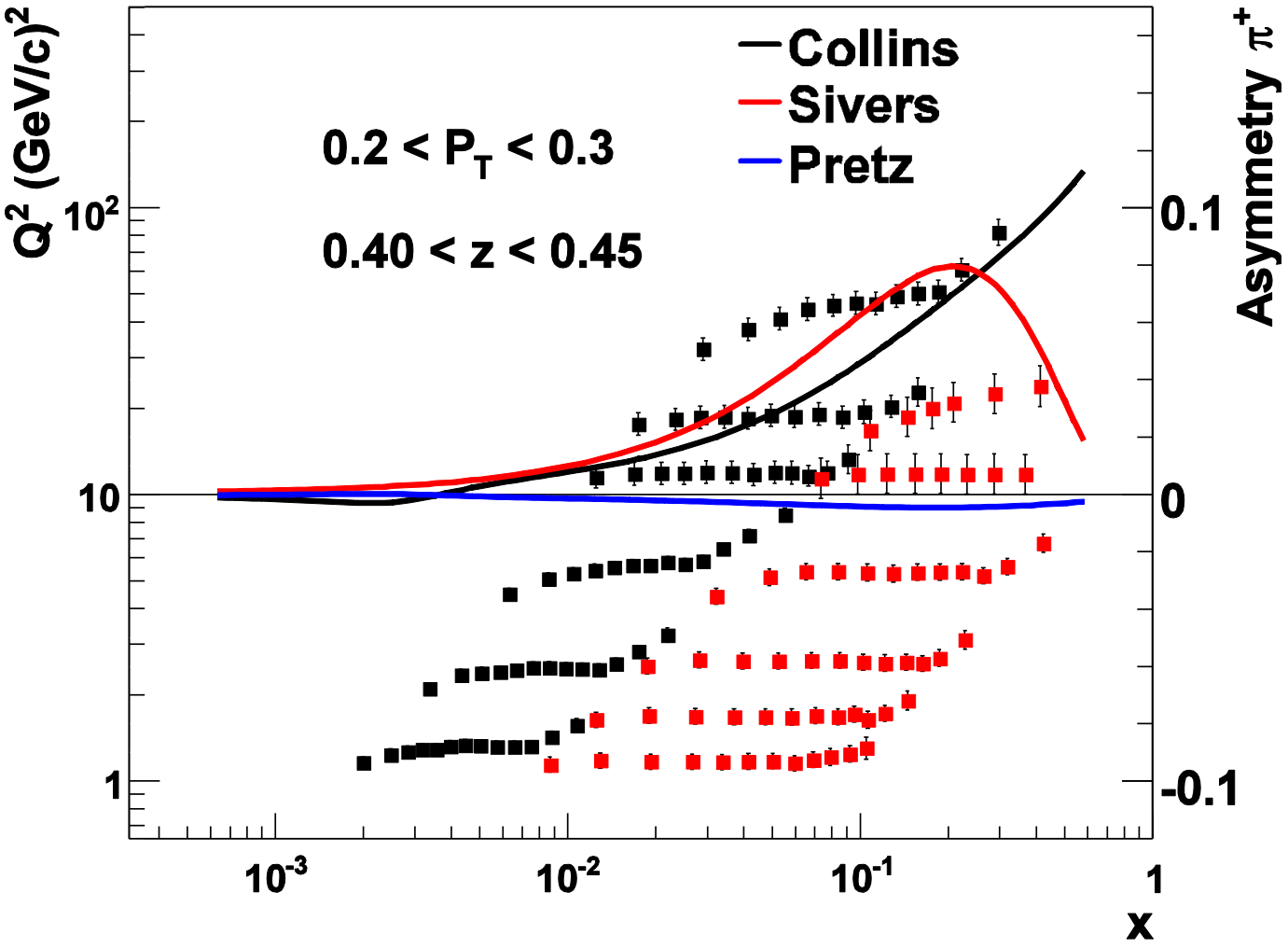
Projection with Proton

- 11 + 60 GeV
  36 days
  L = 3×10^{34} /cm^2/s
  2×10^{-3} $Q^2<10$ GeV^2
  4×10^{-3} $Q^2>10$ GeV^2

- 3 + 20 GeV
  36 days
  L = 1×10^{34}/cm^2/s
  3×10^{-3} $Q^2<10$ GeV^2
  7×10^{-3} $Q^2>10$ GeV^2

Polarization 80%
Overall efficiency 70%

z: 12 bins 0.2 - 0.8
P_T: 5 bins 0-1 GeV



ϕ_h angular coverage considered
Show the average of Collins/Sivers/Pretzlosity projections

Also π^-

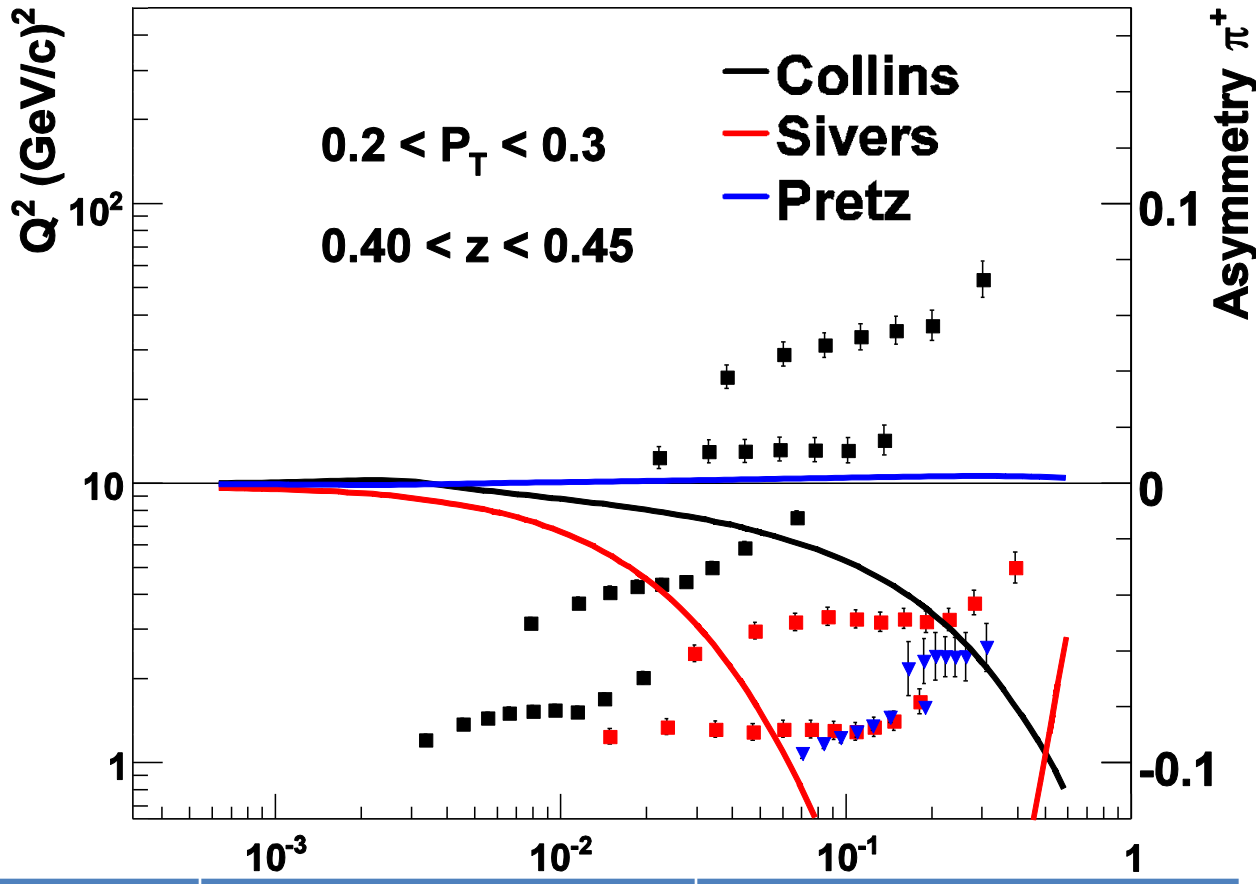
Projection with ^{3}He (neutron)

- 11 + 60 GeV
  72 days
- 3 + 20 GeV
  72 days
- 12 GeV SoLid

^{3}He: 86.5% effective polarization
Dilution factor: 3

D: 88% effective polarization
Effective dilution $\sqrt{8}$

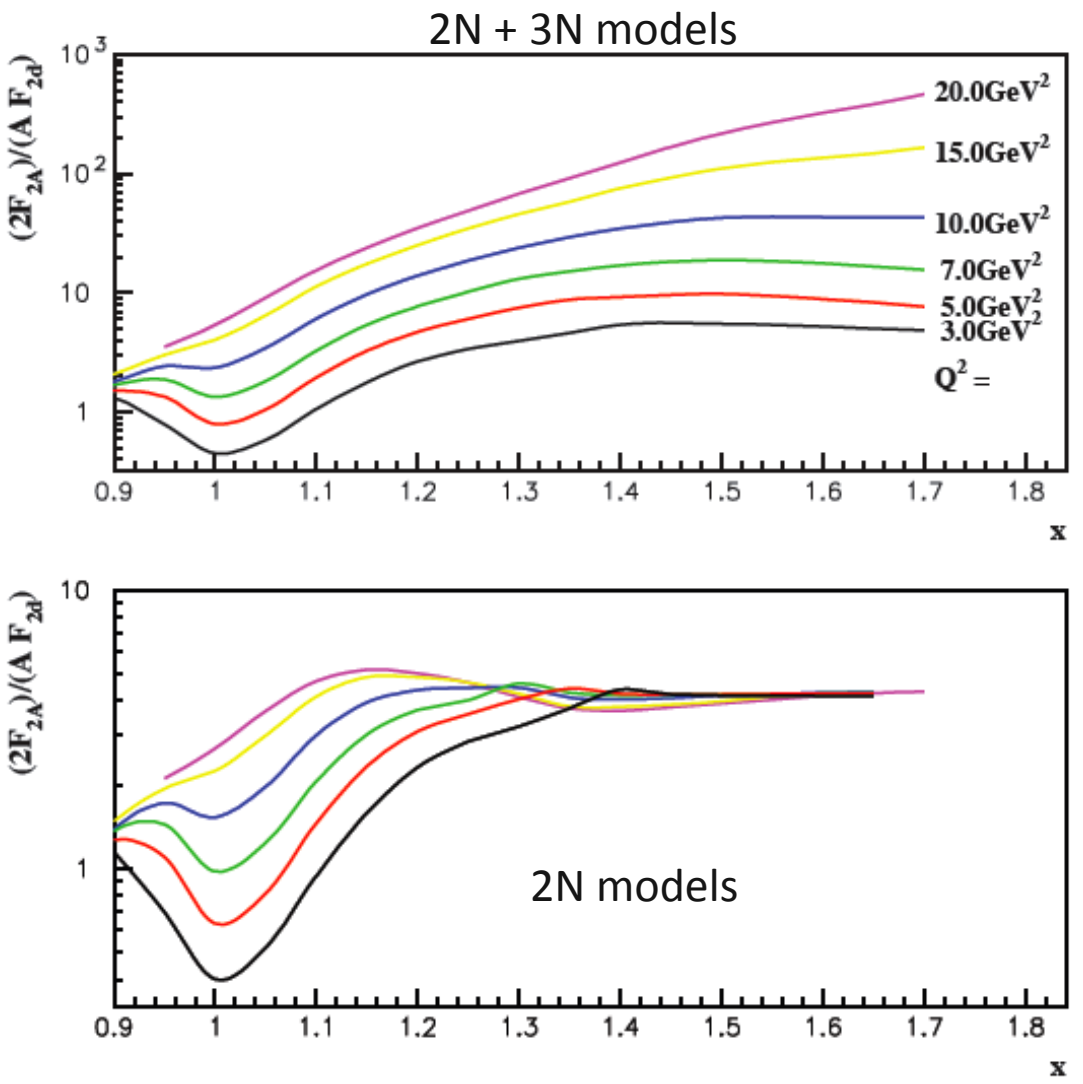
Equal stat. for proton and neutron (combine ^{3}He and D)



	11 + 60 GeV	3 + 20 GeV
P	36 d ($3x10^{34}/cm^2/s$)	36 d ($1x10^{34}/cm^2/s$)
D	72 d	72 d
^{3}He	72 d	72 d

Superfast quarks – Short range correlations @ larger Q^2

- **EIC is limited by cross section**
- **For s=1000, L ≈ 10^{34}, statistics running out for x ≈ 0.85**
- **Might be possible to reach interesting x range**
  - *Need factor of 10, 100, 1000 to reach x ≈ 1.0, 1.15, 1.30*
  - *Need to evaluate statistics for lower s*
  - *Not clear just how high in x required to isolate short-range structure that we're interested in*



Nuclear Chromo-Dynamics Workshop @ANL Report

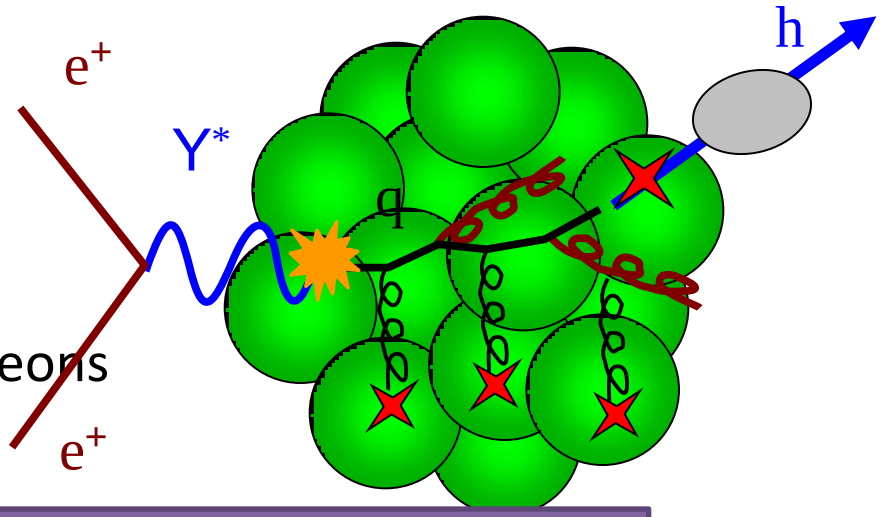
JLab users group annual meeting

June 8th, 2010

Kawtar Hafidi

Parton propagation and fragmentation

- **Nuclei as space-time analyzers**
- **Non perturbative aspects**
  - Color confinement dynamics
  - Probe nuclear gluons
  - new look at TMDs in “bound” nucleons
  - novel access to gluon GPDs

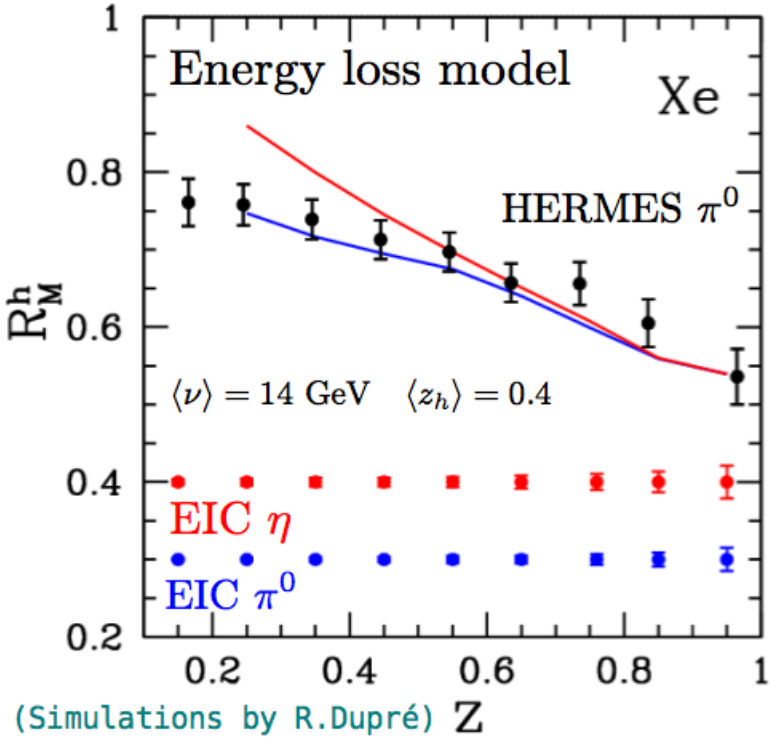


Partons created in the medium could be used as a color probe of the gluon density in a nucleus when parton lifetime and energy loss mechanisms are under theoretical control

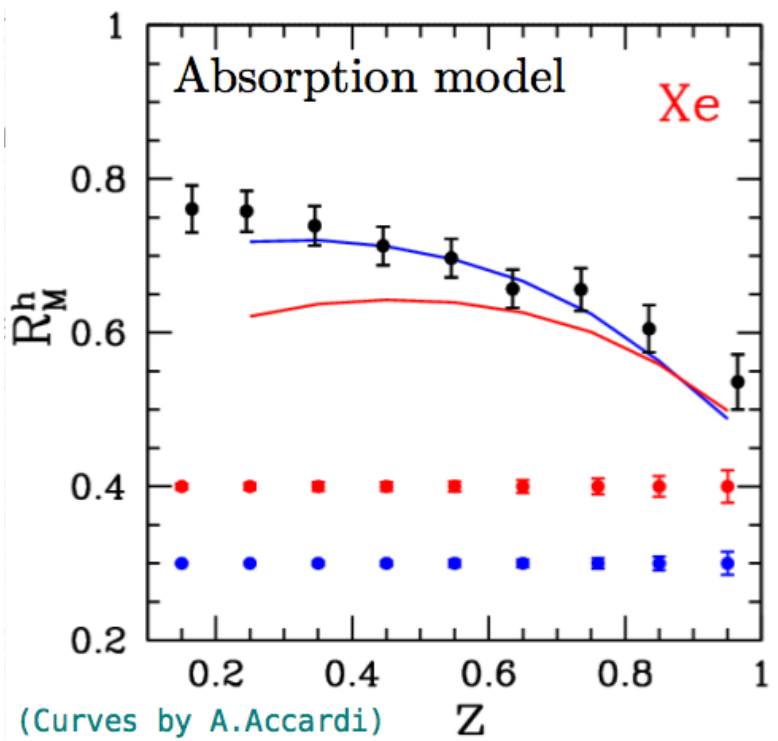
- **Connection to other fields**
  - Quark-Gluon Plasma at RHIC: medium unknown and rapidly expanding
  - Neutrino experiments: nucleus increases cross section

Hadronization in cold nuclear matter

- Observables to measure are multiplicity ratios and transverse momentum broadening
- For the EIC @ s = 1000 GeV^2, one can isolate parton energy loss in cold nuclear medium when fragmentation starts outside the nucleus
- For lower energies when hadronization is expected to occur inside the nucleus, one would be able to study pre-hadron absorption
- Compare π^0 and η for energy loss versus pre-hadron absorption



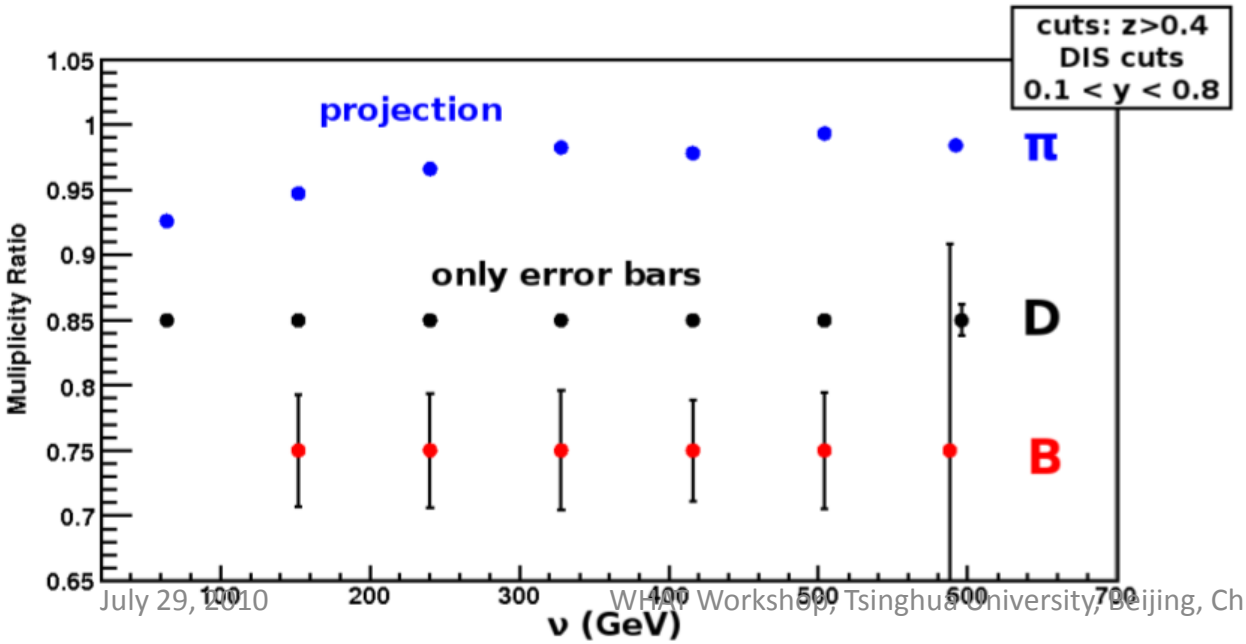
(Simulations by R.Dupré)



(Curves by A.Accardi)

Heavy flavors

- EIC offers a unique opportunity to study heavy quark propagation and fragmentation in a medium with known properties
- Large mass of charm and bottom allow in principle to **calculate fragmentation in perturbative QCD**
- **Heavy quarks** are expected to have **reduced energy loss** compared to light quark not observed in RHIC
- **Heavy quark detection requires a vertex determination** of at least 100 μm and high luminosity especially bottom quarks of at least few 10^{34}



11 + 30 GeV/A
L = 0.4 10^{33} cm^{-2} s^{-1}
1 month 100% running

Summary

- A high polarized luminosity EIC with variable energy will be important for the future of Hadron Physics and QCD.
- More than one interaction region is important for complementarity of explored physics (exclusive vs semi-inclusive) and confirmation of discoveries.
- The JLab community started to explore further the physics of this new generation of machine in preparation for the next Long Range Plan.
- We welcome you to join this physics effort help with new physics ideas and experimental simulations.