EIC JLab users workshops: An update

Organized by Users Group and Sponsored by JLab and JSA Initiative funds

Z.-E. Meziani

Meetings discussing various EIC options have been going on for over a decade

Natural interest, but limited involvement of JLab users, in collider eA +eN program

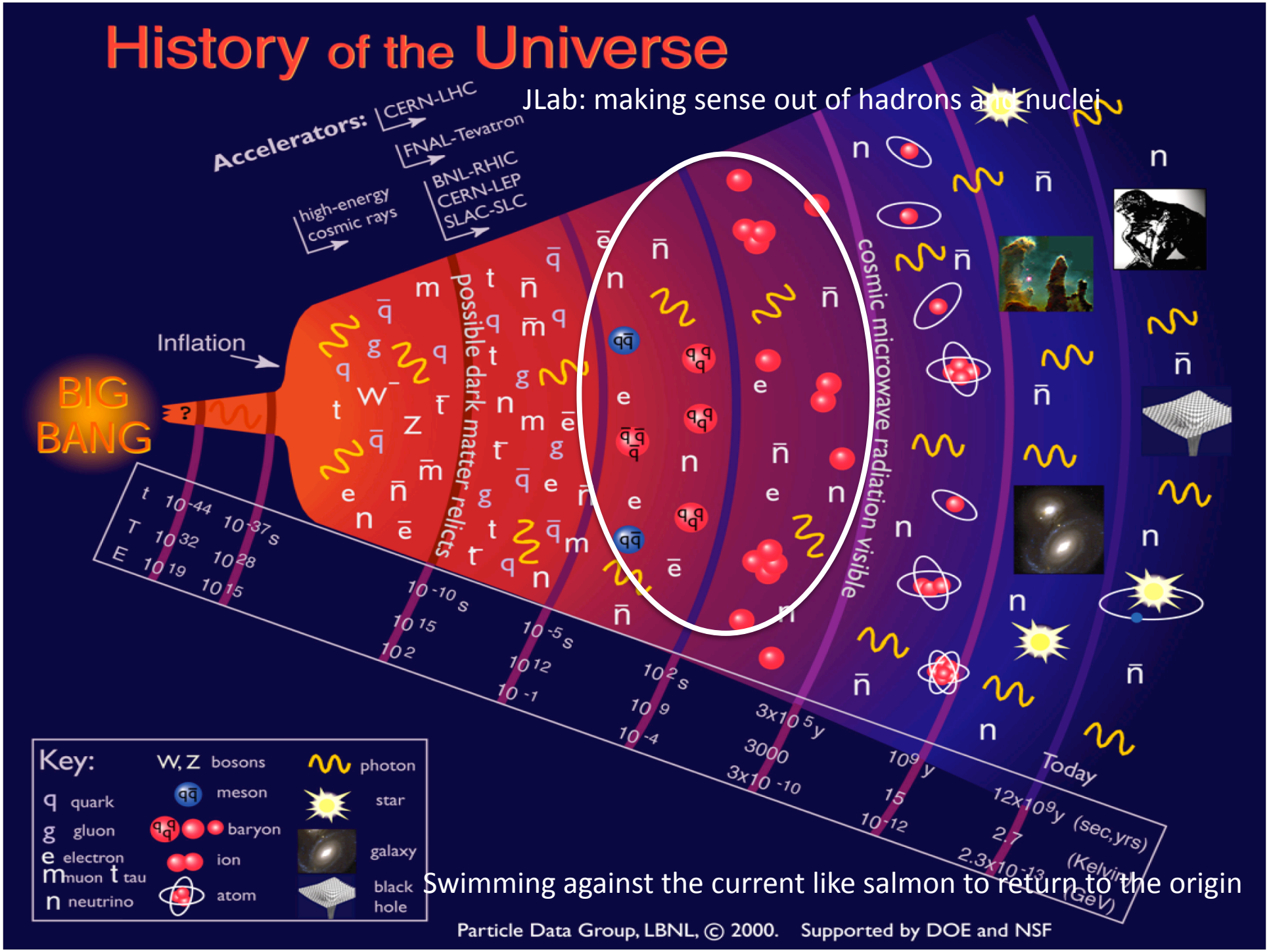
2007 Long Range Plan:

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.

Expected 2012 (?) LRP

12-GeV upgrade underway, "2013" start

JLab UGBoD decides to try to help "kick-start" greater user involvement by sponsoring series of workshops



Swimming against the current like salmon to return to the origin

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?

The Tools

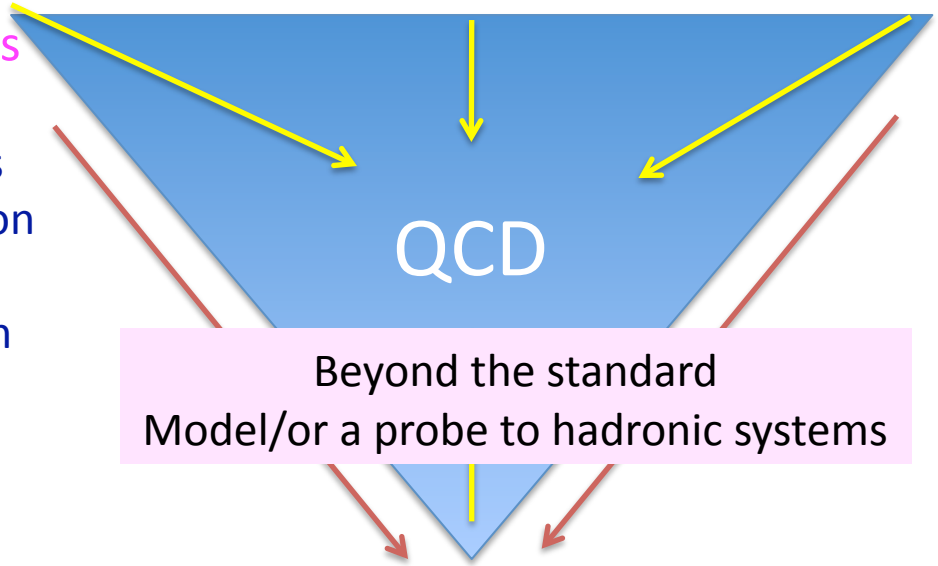
Generalized Parton Distributions

Since 1998

Exclusive reactions

Elastic form factors
Deep Virtual Compton Scattering
Deep Virtual Meson Production

Inclusive
Sum rules and polarizabilities



Transverse Momentum Distributions

Since 2002

Semi-Inclusive DIS

Distributions and Fragmentation functions

Beyond the standard Model/or a probe to hadronic systems

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

Why mEIC/ELIC?

- A natural extension of the 12 GeV physics program of hadron structure in free space and in nuclei/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 adequate center of mass energy
  - ➥ Luminosity is key for probing the system using known processes with higher precision or exploring rare processes
  - ➥ Energy reach key for providing a clean interpretation through rigorous tests in some case

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 et al.

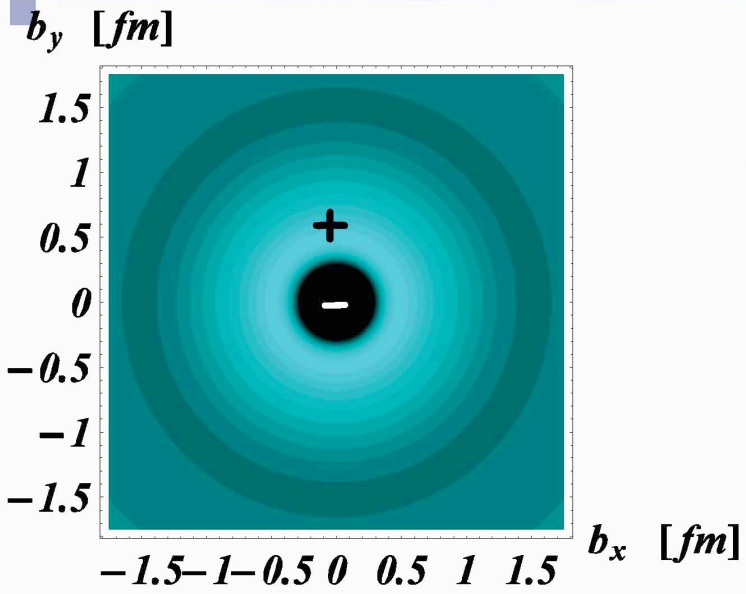
  https://eic.jlab.org/wiki/index.php/Electroweak_Working_Group

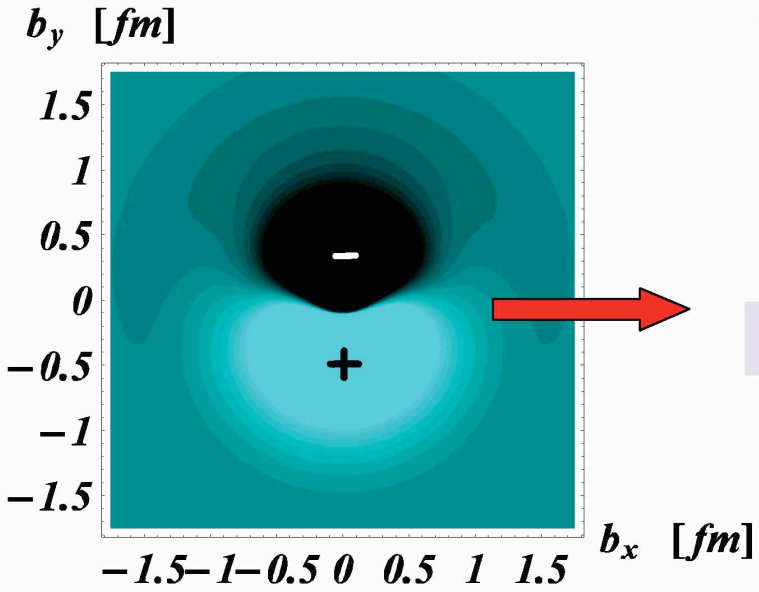
- Study group on interaction region and detectors
  - EIC Detectors/Instrumentation
    (workshop at JLab, June 03-04, 2010)

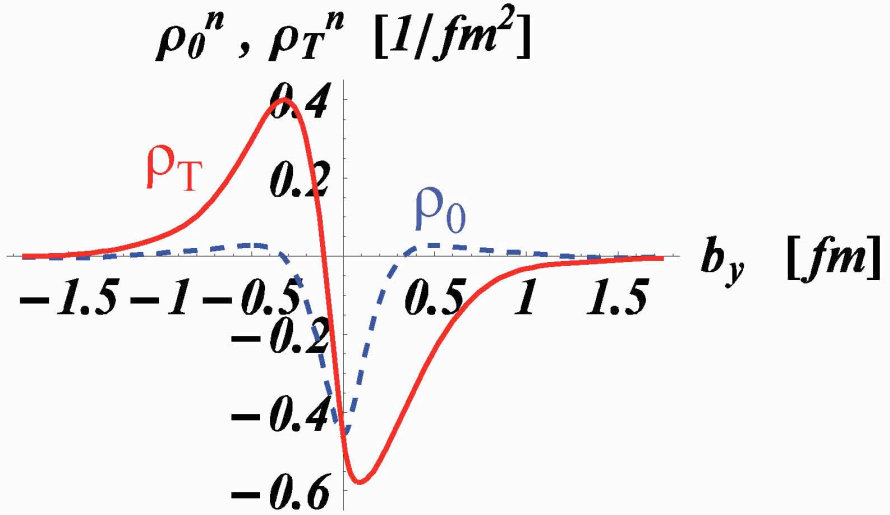
  C. Hyde et al.

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

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)

Rutgers University / Jefferson Lab Electron-Ion Collider Workshop: Electron-Nucleon Exclusive Reactions

Organizing Committee:
Ronald Gilman (Rutgers)
Tanja Horn (Catholic University)
Pawel Nadel-Turonski (JLab)
Christian Weiss (JLab)

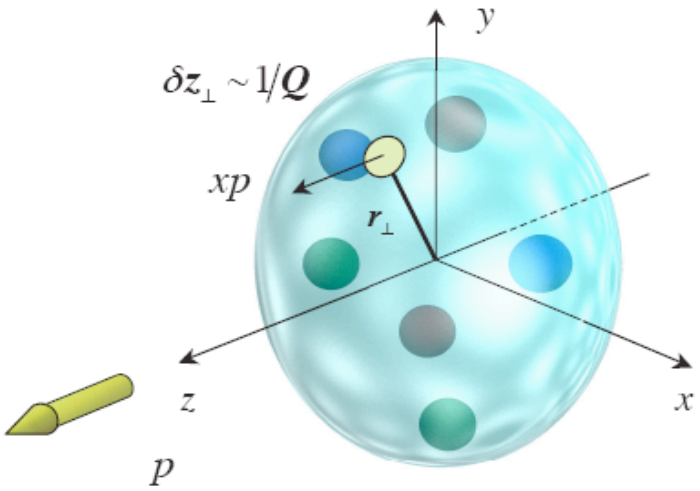
A follow mini-workshop at the INT

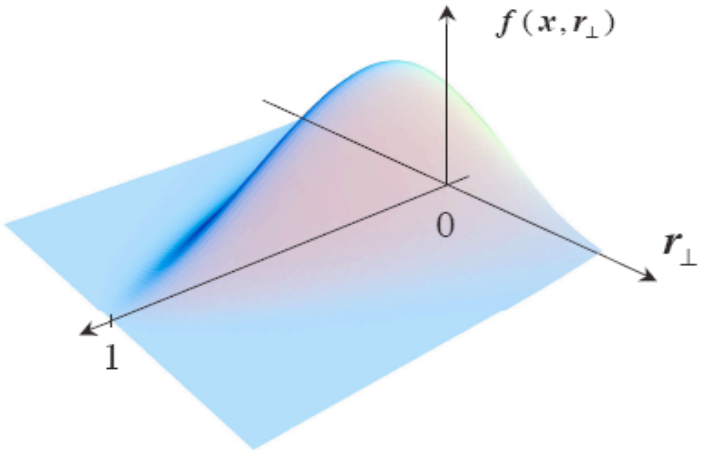
Orbital Angular Momentum in QCD (12-49W)
February 6 - 17, 2012
L. C. Bland, Z-E. Meziani, G. A. Miller, M. Vanderhaeghen, C. Weiss, F. Yuan

http://www.int.washington.edu/PROGRAMS/12-49w/

3-D quark imaging of the nucleon

Tool: Generalised Parton Distributions

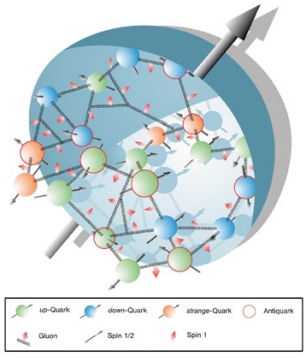




Generalized description in 2+ 1 dimensions

Valence quark imaging of the nucleon is one goal of JLab at 12 GeV.

- Gluon imaging is still missing
- Sea Quarks imaging is also missing
- Total Spin of the nucleon in terms of all of its constituents.



Nucleon Angular Momentum

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

Ji Sum rule (1997)

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

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

Total angular momentum of gluons

$$J^q(\mu) = \frac{1}{2}\Delta\Sigma + L^q(\mu)$$

Spin of quarks Contribution: Measured in DIS

Orbital angular momentum of quarks: Input from Lattice and measurements at JLab 12 GeV

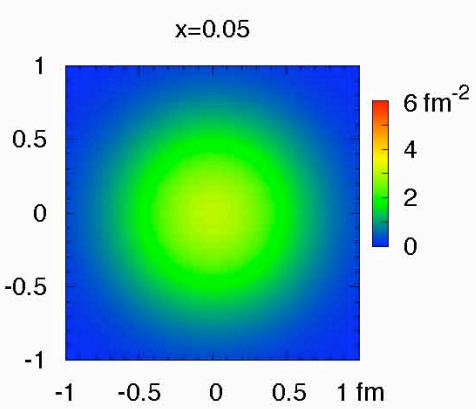
- Through the momentum sum rule and HERA DVMP with J/Psi data we have a glimpse on GPD H^g
- Nothing is known about GPD E^g

What can we do with the GPDs?

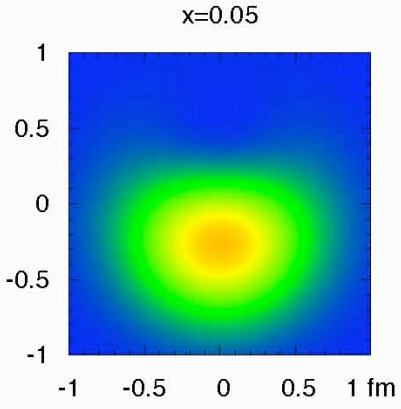
evaluate parton angular momenta from Ji's sum rule

$J^u = 0.25 \pm 0.03 \qquad J^d = 0.02 \pm 0.03 \qquad J^s = 0.02 \pm 0.03 \qquad J^g = 0.21 \pm 0.06$

work out transverse localization of partons



unpolarized



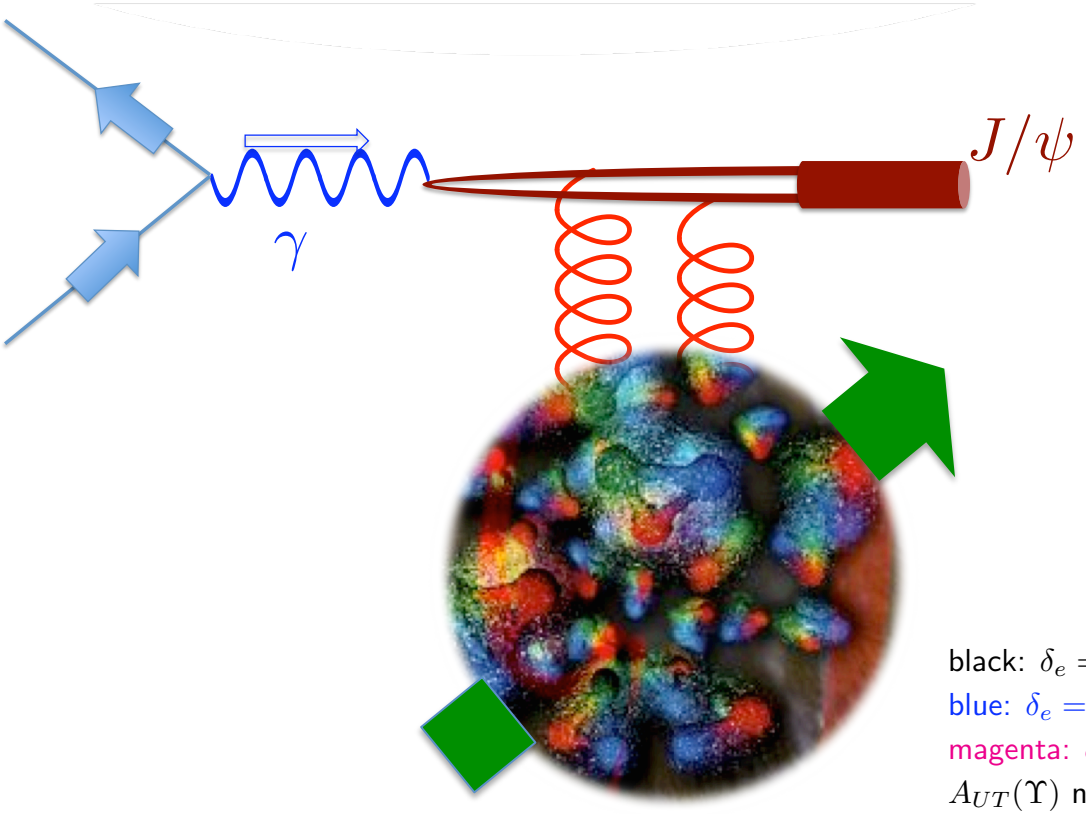
polarized proton

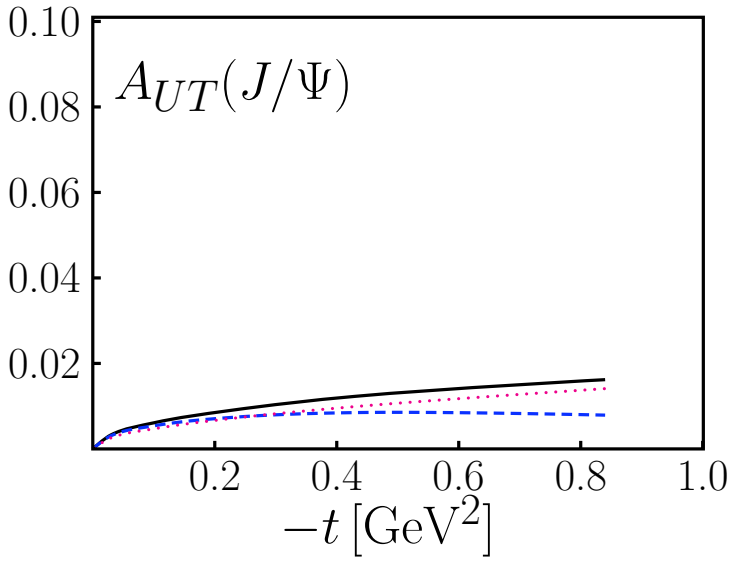
for d quarks

$$q_v^X(x,\mathbf{b}) = q_v(x,\mathbf{b}) - \frac{b^y}{m}\frac{\partial}{\partial \mathbf{b}^2} e_v^q(x,\mathbf{b})$$

Peter Kroll

"My" Golden Experimental Program





black: $\delta_e = 0.0,\ \alpha'_e = 0.25$ $\sqrt{s} = 55\,\mathrm{GeV}$

blue: $\delta_e = -0.1 + \ln(m_c/\mathrm{GeV}),\ \alpha'_e = 0.45$

magenta: $\delta_e = 0.1,\ \alpha'_e = 0.15$

$A_{UT}(\Upsilon)$ nearly twice as large

- Glue imaging using unpolarized targets and accessing gluon GPD H through exclusive meson production in the valence region
- Transversely polarized nucleon to access gluon GPD E and the Spin Sum Rule.

Duke/JLab Workshop on Partonic Transverse Momentum in Hadrons: Quark Spin-Orbit Correlations and Quark-Gluon Interactions, March 2010

Workshop summary paper:
M. Anselmino *et al.* EPJA 47, 35 (2011)

Transverse Spin Structure: Leading Twist TMDs

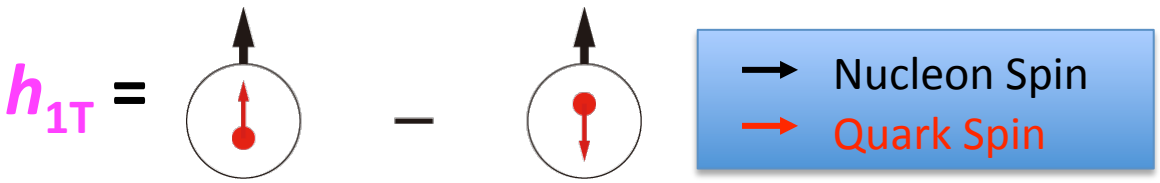
Nucleon Spin

Quark Spin

Quark / Nucleon		Quark polarization: Un-Polarized	Quark polarization: Longitudinally Polarized	Quark polarization: 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**

Transversity and the Tensor Charge

- Quark transverse polarization in a transversely polarized nucleon:



  - Can be probed in Semi-Inclusive DIS, Drell-Yan processes.
  - Does not mix with gluons, has valence like behavior.
  - Nucleon tensor charge can be extracted from the lowest moment of h_1 and compared to LQCDcalculations

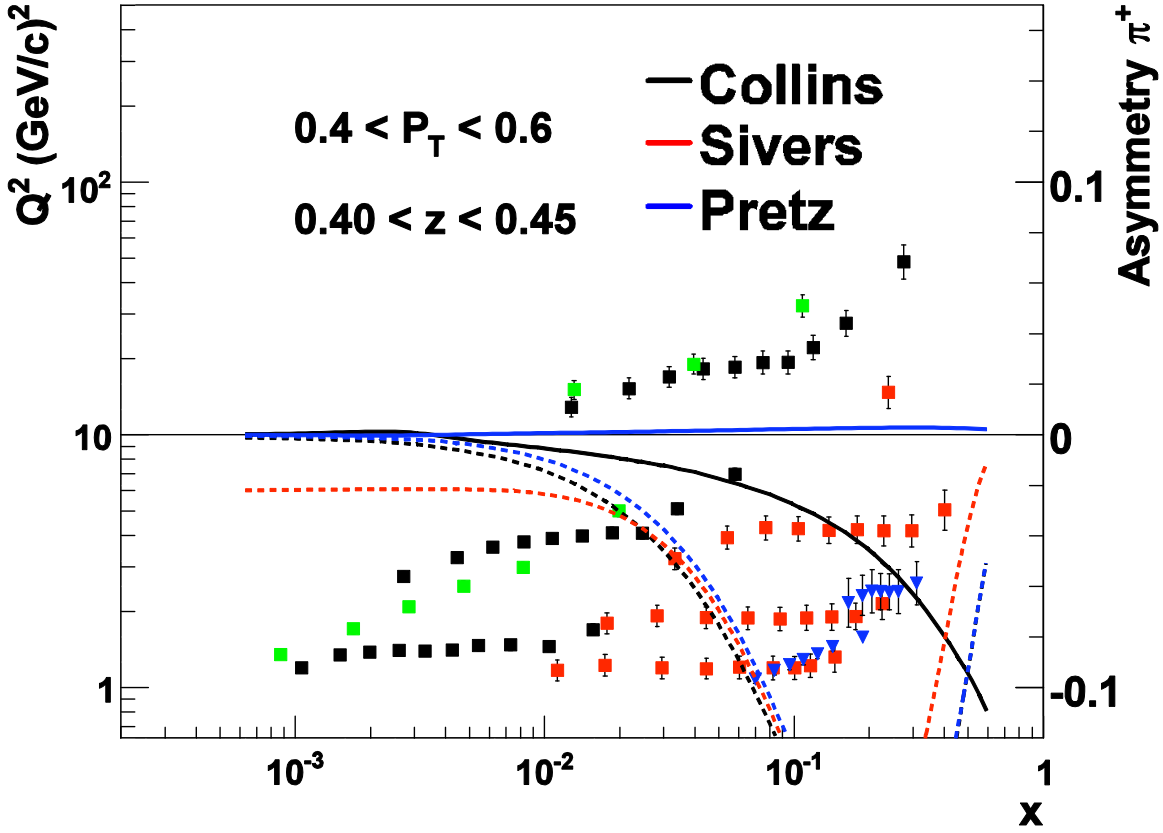
Tensor Charge

$$\langle PS\bar{\psi}\sigma^{\mu\nu}\psi PS\rangle = \int_0^1 dx\,[\delta q(x) - \delta\bar{q}(x)]$$

Projections with ^{3}He (neutron)

- 11 + 60 GeV
  72 days
- 3 + 20 GeV
  36 days
- 11 + 100 GeV
  72 days
- 12 GeV SoLid

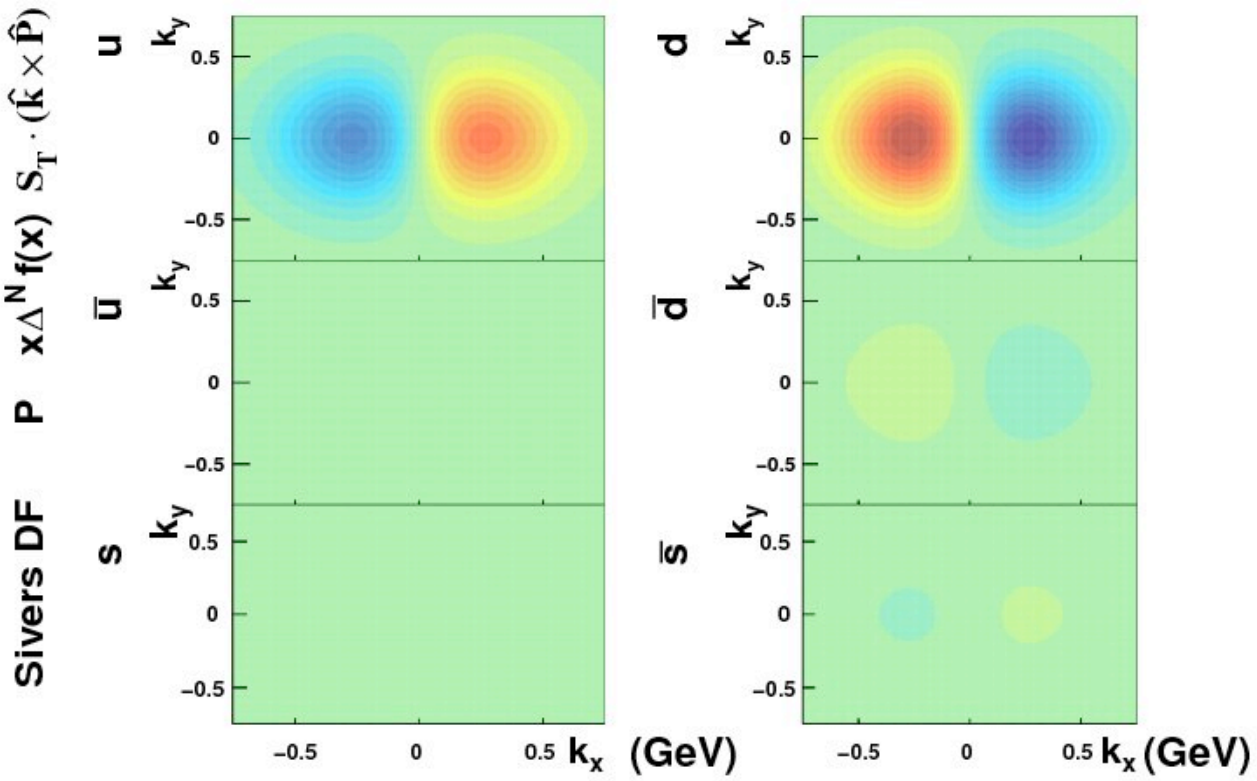
^{3}He: 87% effective polarization



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

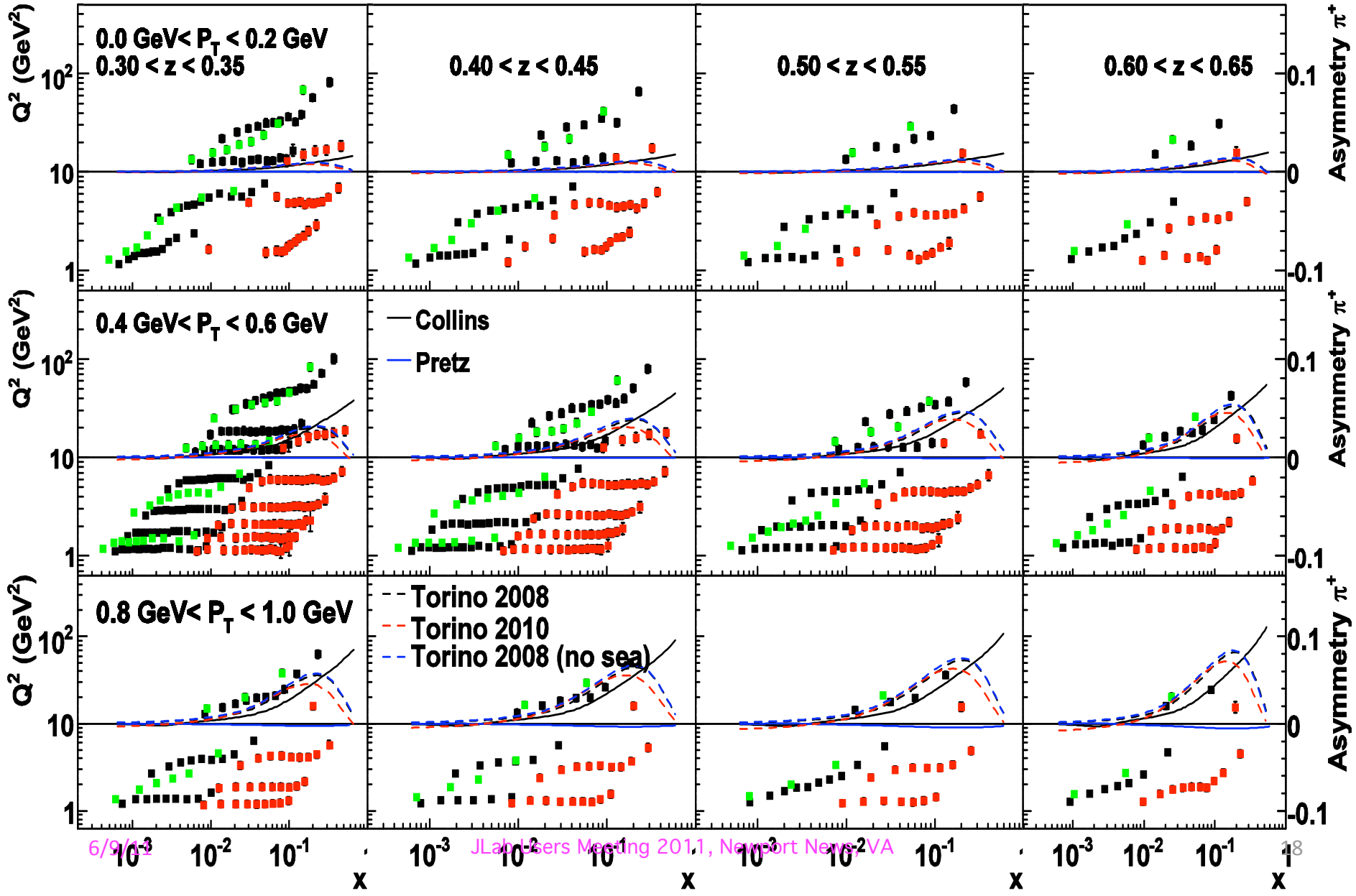
	11 + 60 GeV	11 + 100 GeV	3+20 GeV
P	36 d (3×10^{34}/cm^2/s)	36 d (1×10^{34}/cm^2/s)	36 d (1×10^{34}/cm^2/s)
D	72 d	72 d	72 d
^{3}He	72 d	72 d	72 d

3-D momentum structure the nucleon: Dipole pattern due to Sivers effect



(Plot from Prokudin; red: positive effect, blue: negative effect)

Proton π^+ (z = 0.3-0.7)



Workshop on Nuclear Chromo-Dynamic Studies with a Future Electron Ion Collider

Argonne National Laboratory, April 7 - 9, 2010

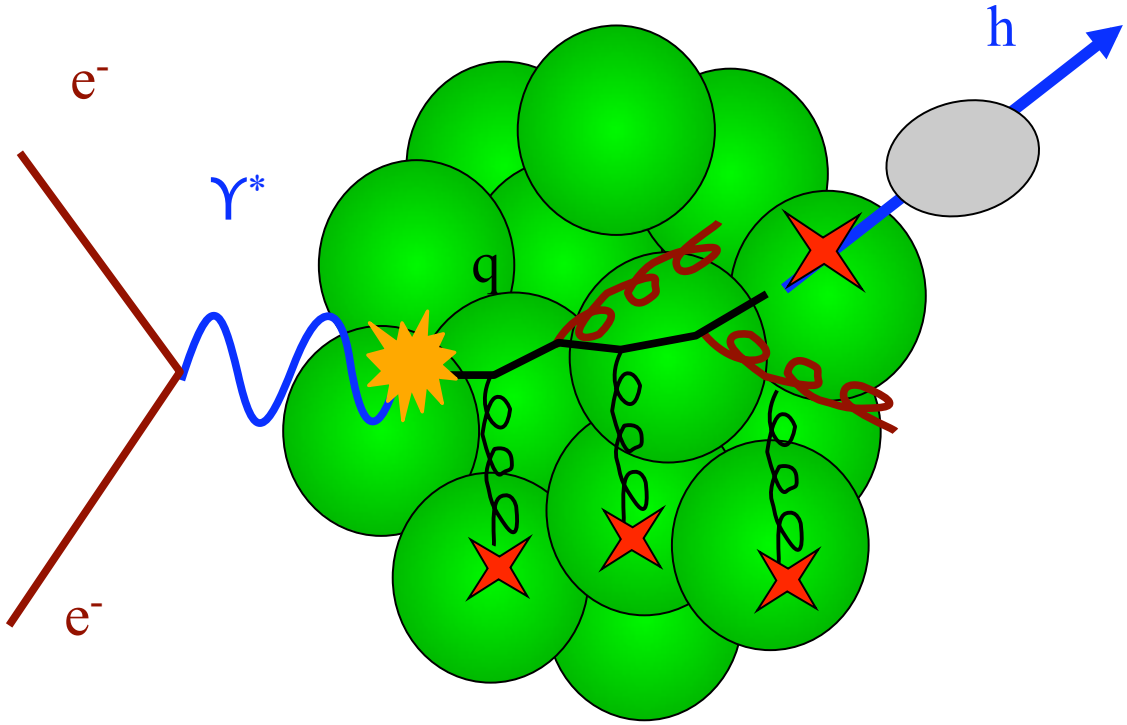
- **Topics:**

  Nuclear DVCS, shadowing and anti-shadowing -- Color Transparency -- EMC effect -- short range correlations -- nuclear form factors -- Hadronization -- Bose-Einstein correlations -- hidden colors

- **Organizing committee:**

  Alberto Accardi, Hampton University and Jefferson Lab
  William Brooks, Universidad Técnica Federico Santa María, Chile
  Claudio Ciofi Degli Atti, University of Perugia, Italy
  Dave Gaskell, Jefferson Lab
  Vadim Guzey, Jefferson Lab
  Kawtar Hafidi, Argonne National Lab
  Paul Hoyer, University of Helsinki, Finland

Parton propagation and fragmentation



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

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
- **Heavy quark detection requires a vertex determination** of at least 100 μm and high luminosity especially bottom quarks of at least few 10^{34}

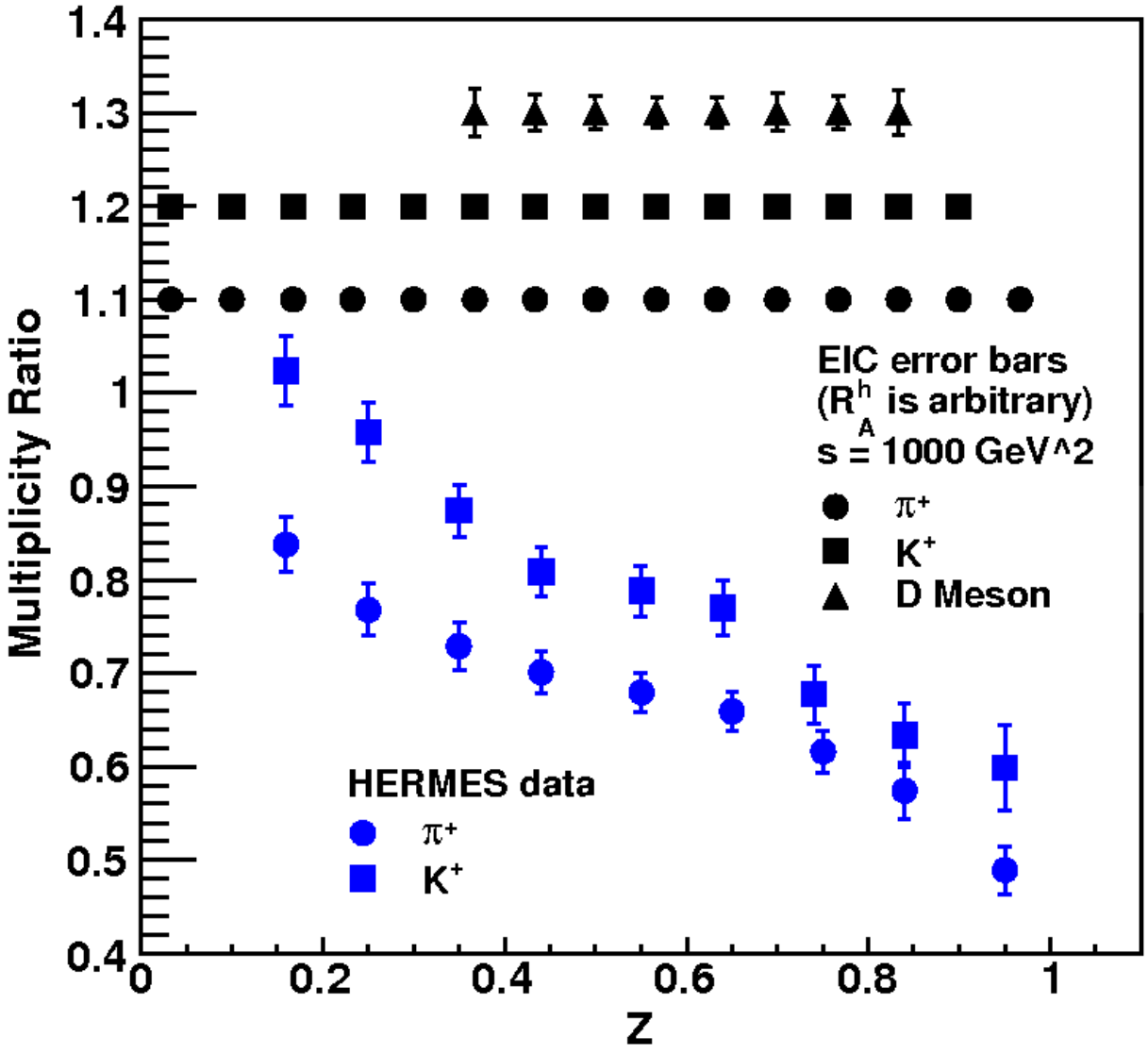
Multiplicity ratio for 100 GeV < ν < 130 GeV

Luminosity: 200 fb^{-1}

or 115 days at 2.10^{34} $cm^{-2}s^{-1}$ per target

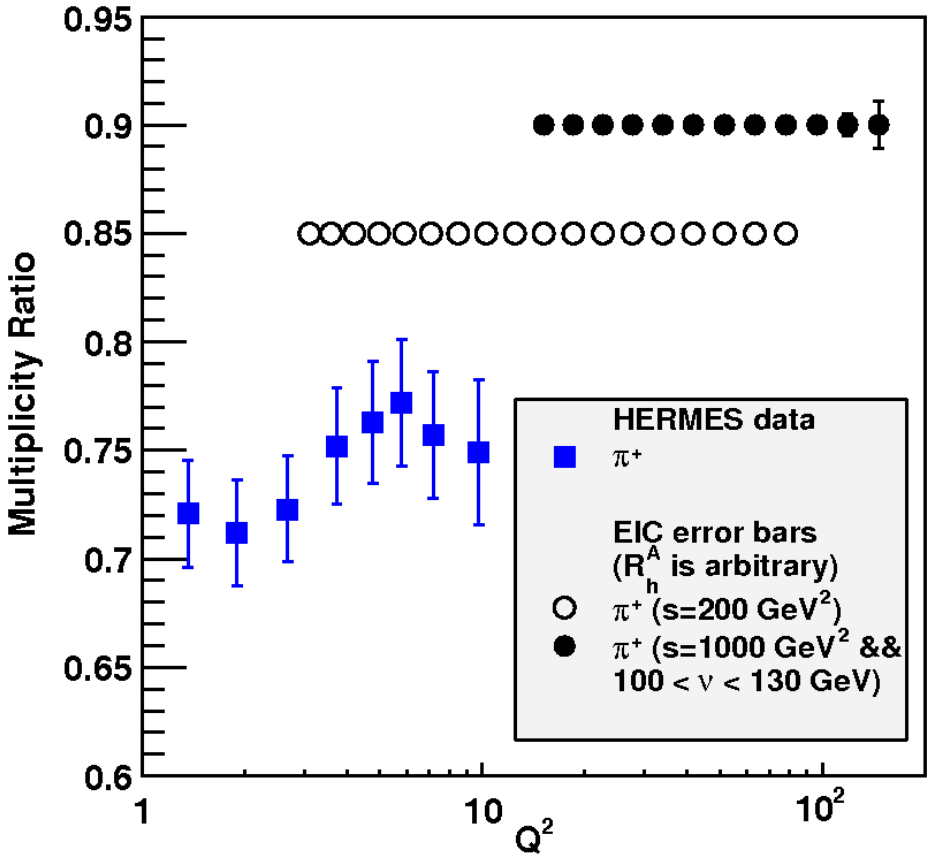
s = 1000 GeV^2

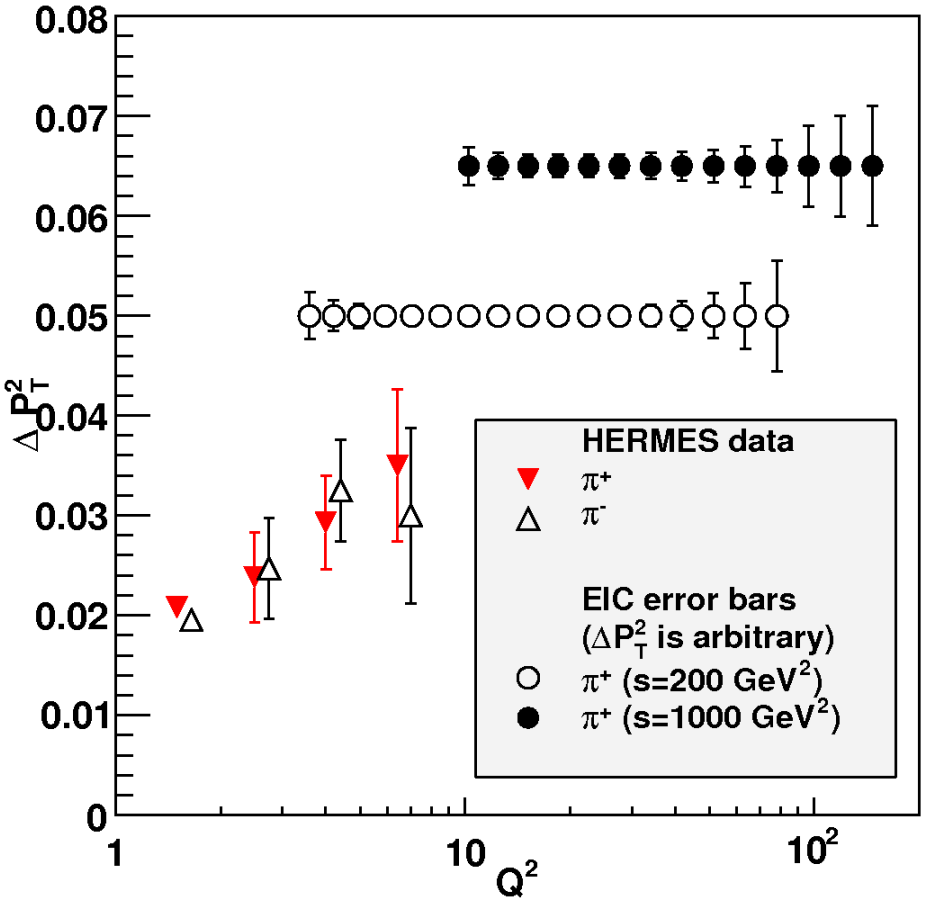
$X_{Bj} > 0.1$



Q^2 evolution

100 GeV < ν < 130 GeV





Luminosity: 200 fb^{-1}

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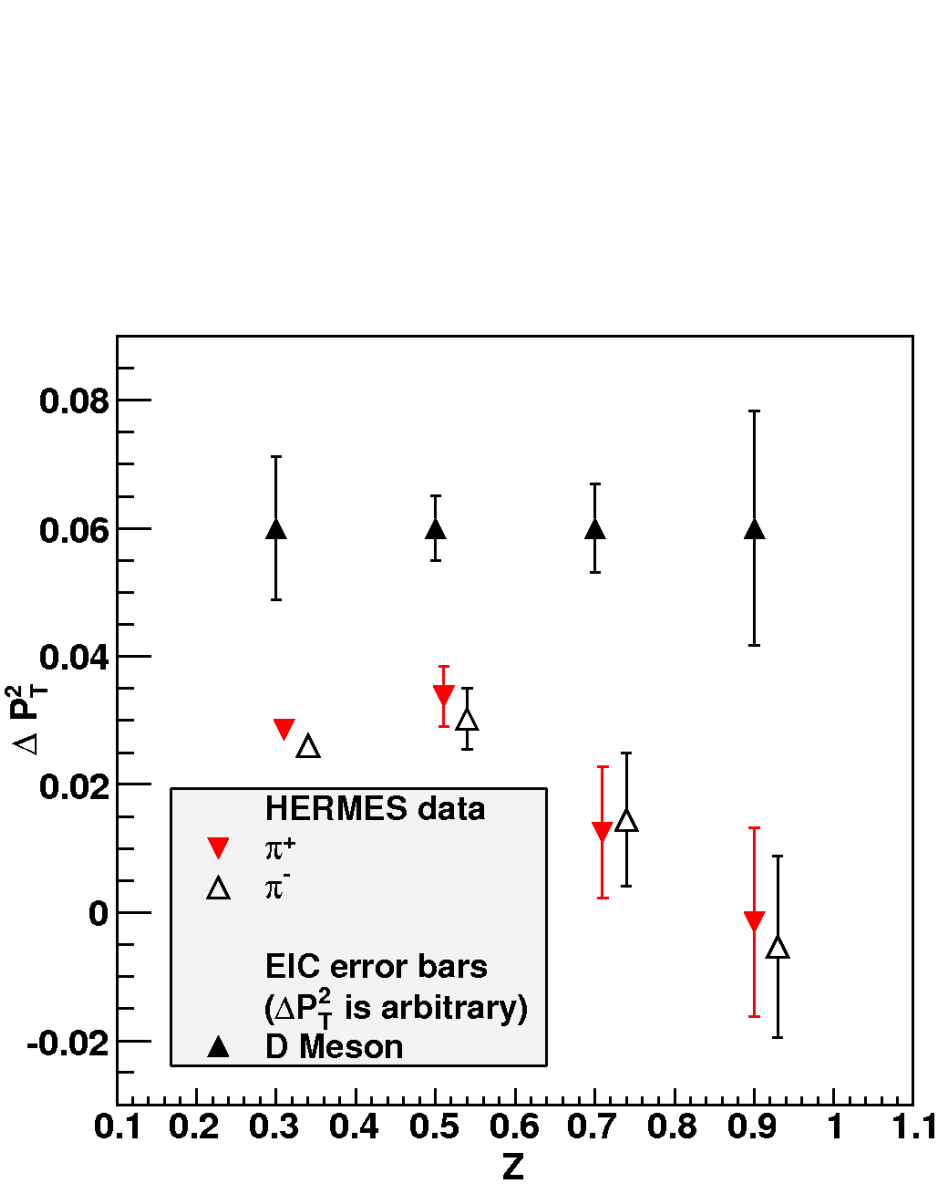
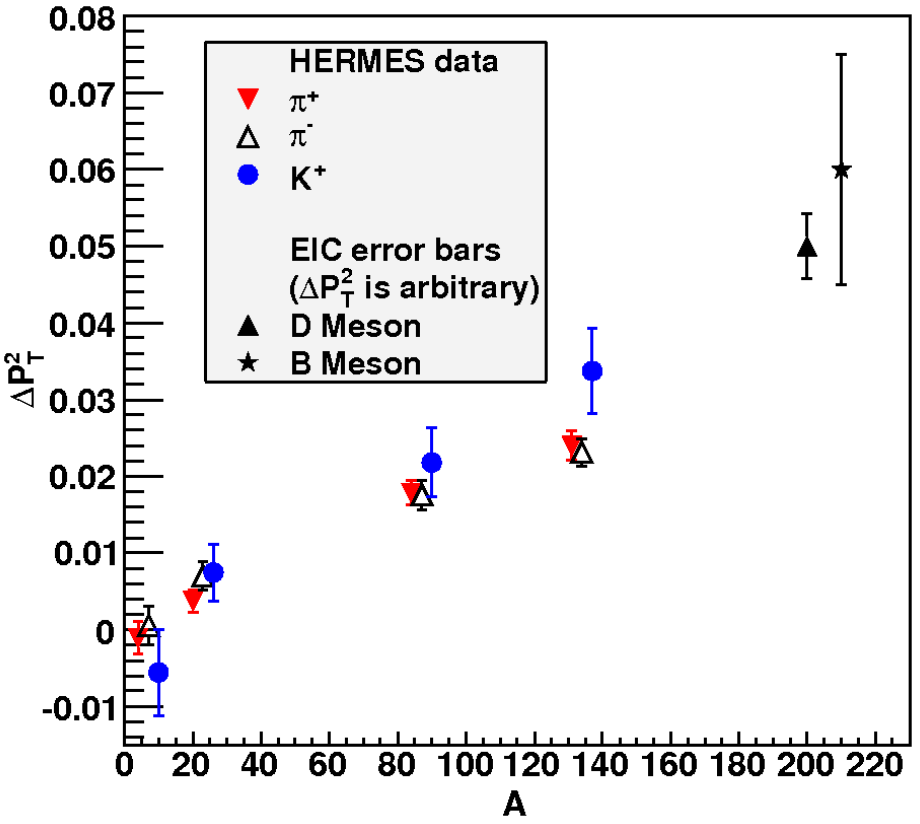
Heavy quark energy loss





Electroweak Workshop Outcome: Physics Topics

- Studies of the Electroweak Interaction (BSM Physics)
  - Search for Lepton-Flavor-Violation $e \rightarrow \tau$
  - Precision $\sin^2\theta_W$ at $10\ \text{GeV}^2 < Q^2 < 60\ \text{GeV}^2$
- Studies using the Electroweak Interaction (Nucleon Structure)
  - New spin structure functions using charged and neutral currents
  - Aid six-flavor separation of quark polarizations

All topics except EW structure functions need high integrated luminosity (~ 100 fb^{-1})

(A bit less integrated luminosity required at higher center of mass energy)

Progress since June '10

- INT workshop (3 days dedicated to EW physics, Oct 25-27 2010)
  - organizers: Yingchuan Li, W. Marciano, K. Kumar
  - Experiment and theory talks on all three topics
- Physics Effort
  - MC simulations of e-tau process to explore cuts & background (SUNY Stony Brook)
  - Theory developed and published on e-tau reach (U Wisconsin)
  - Spin structure function sensitivity explored (UMass)
  - Weak mixing angle sensitivity studies (BNL)
- INT Science Document contributions on all three topics
  - e-tau: A. Deshpande, C. Faroughy, M. Gonderinger, K. Kumar, S. Taneja
  - weak mixing angle: Y. Li, W. Marciano, K. Kumar
  - spin structure functions: A. Deshpande, K. Kumar, S. Riordan, S. Taneja, W. Vogelsang

Looking Forward

- EIC Science White Paper will have an Electroweak Physics section
  - Editors: M. Ramsey-Musolf and K. Kumar
- A joint publication is being developed with all three subtopics with a combined author list
  - "Electroweak Physics Potential of an EIC"
- Experimental Studies
  - Detector Simulations and Background Studies for e-tau
  - Combined Global Fitting of EW Structure Functions

Interested? Please contact S. Riordan (UMass) or S. Taneja (SUNY Stony Brook)

Summary

- A high polarized luminosity EIC with variable energy will be important for the future of Hadronic and Nuclear Physics and QCD.

- More than one interaction region is important for complementarity of explored physics (exclusive vs semi-inclusive) and confirmation of discoveries.

A range from a s from 200 to 4000 GeV^2 would be desirable

A luminosity above $10^{34} cm^{-2} s^{-1}$

- We welcome you to join this physics effort and help with new physics ideas and experimental simulations. The work is still in progress.