Meson electroproduction & imaging with EIC

Tanja Horn

THE
CATHOLIC UNIVERSITY
of AMERICA

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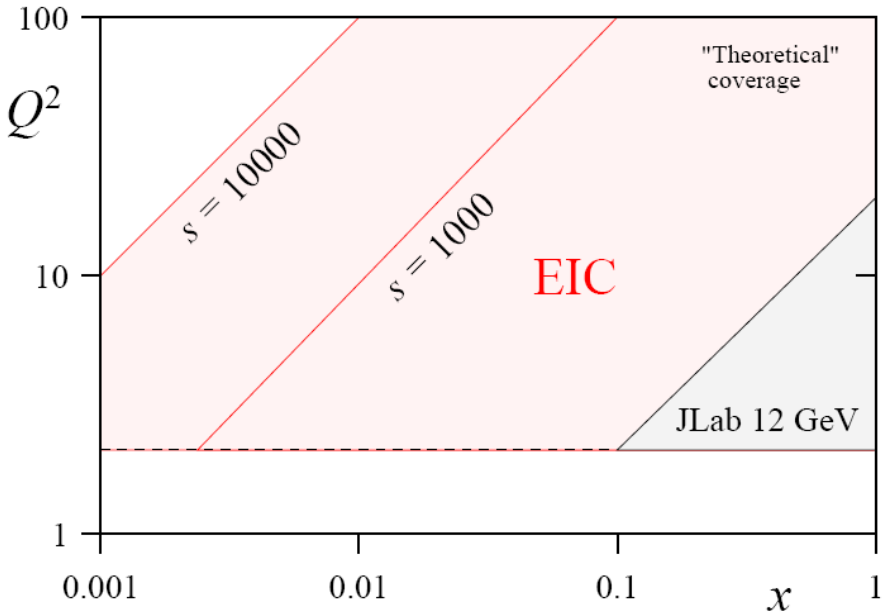
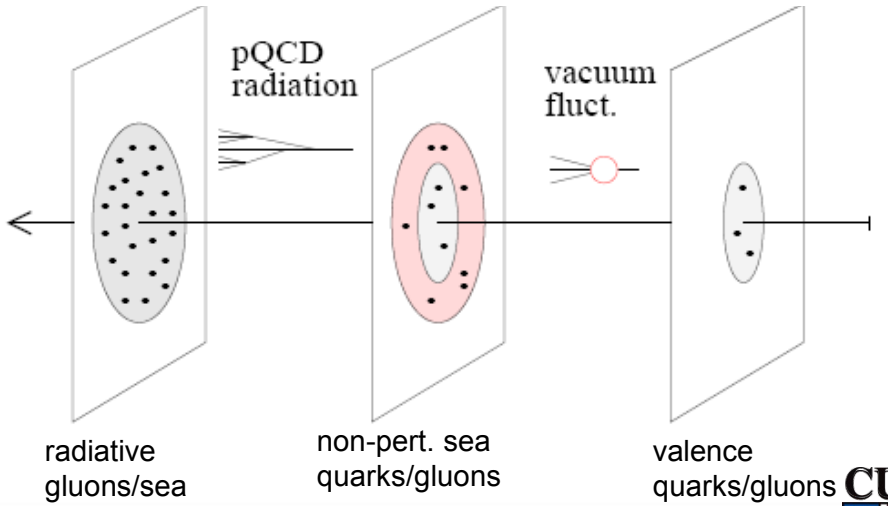
Nucleon Structure: landscape

- Hadrons in QCD are relativistic many-body systems
  - Fluctuating number of elementary quark/gluon constituents
  - Rich structure of the wave function

- Components probed in *ep* scattering:
  - JLab 12 GeV: valence region
  - EIC: sea quarks, gluons, Q^2 dependence

- Physical properties
  - Transverse imaging
  - Correlations: transverse, longitudinal, and nuclear modifications
  - Tests of reaction mechanism



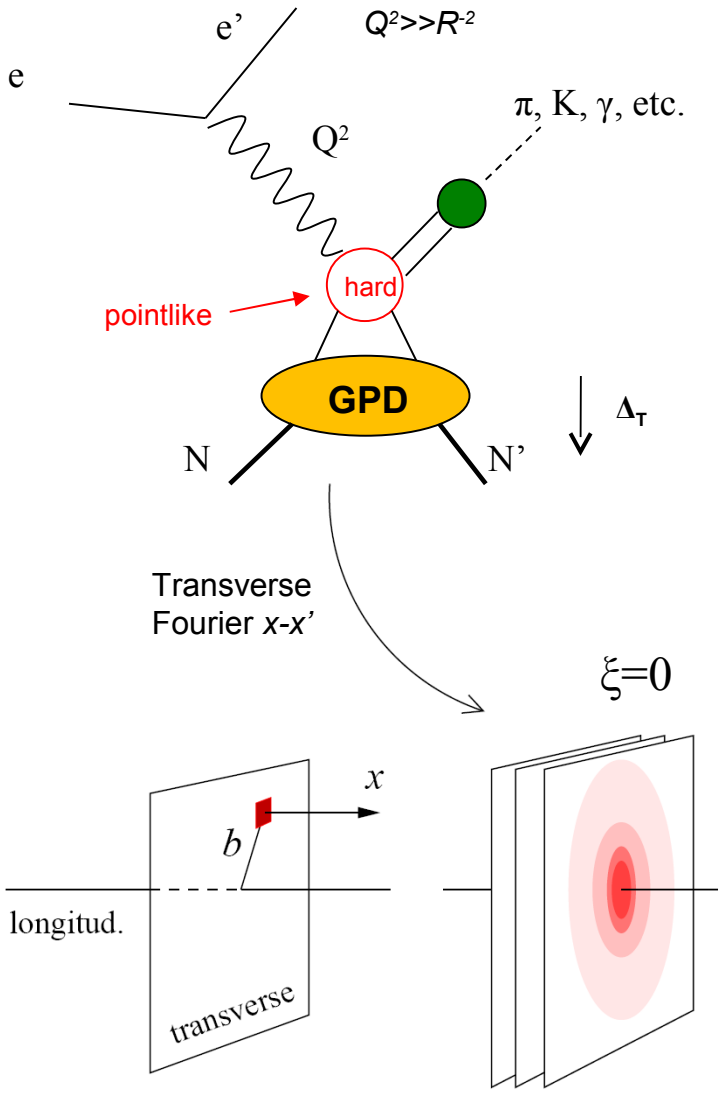


Nucleon Structure: exclusive processes

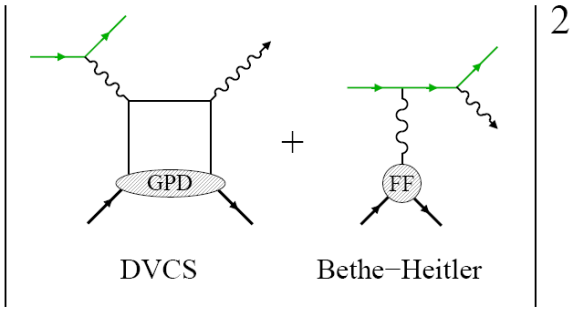
- Exclusive processes at sufficiently high Q^2 should be understandable in terms of the "handbag" diagram
  - The non-perturbative (soft) physics is represented by the GPDs
    - Shown to factorize from QCD perturbative processes for longitudinal photons *[Collins, Frankfurt, Strikman 97]*

- Physical interest in GPDs
  - **Transverse spatial distribution of partons with longitudinal momentum x:** transverse imaging of nucleon *[Burkhardt 00]*
  - Correlations in wave function
  - Moment x^{n-1} Form factor of local twist-2 spin-n operator: EM tensor, angular momentum *[Ji 96, Polyakov 02]*

- Tests of reaction mechanism
  - Model-independent features of small-size regime? Finite-size corrections?



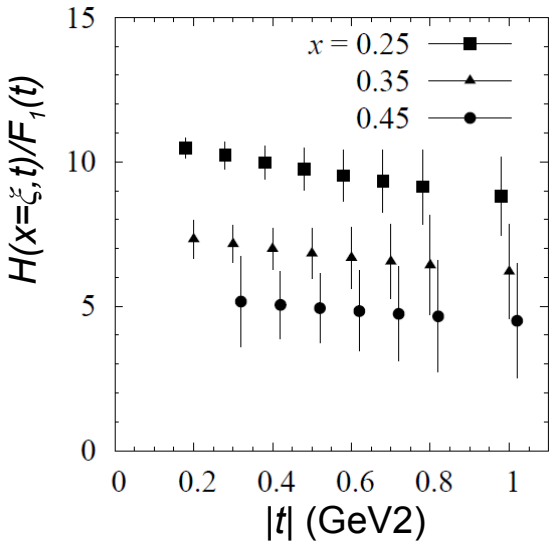
Valence Quark Imaging: DVCS at JLab 12 GeV



Interference with BH gives access to DVCS amplitude

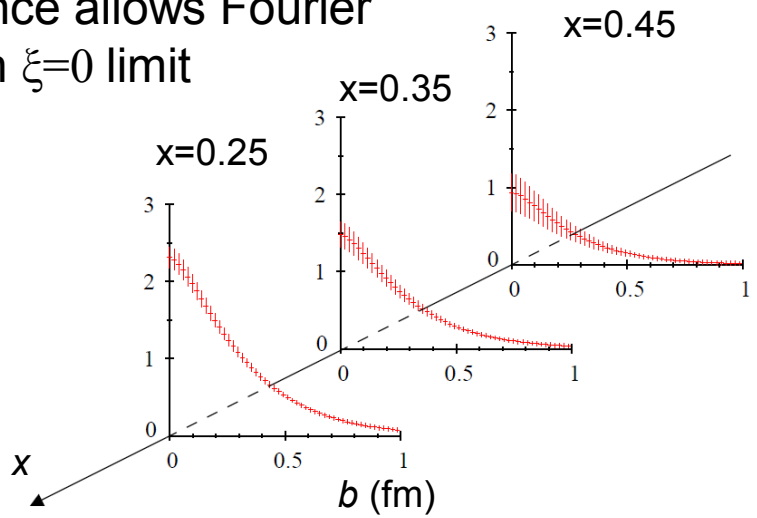
$$\mathrm{Im(DVCS)} \overset{LT}{\sim} H(x=\xi,\xi;t)$$

$$\mathrm{Re(DVCS)} \sim \int dx \frac{H(x,\xi;t)}{x-\xi}$$



Projected results for GPD H(ξ,x=ξ,t) extracted from beam spin asymmetry

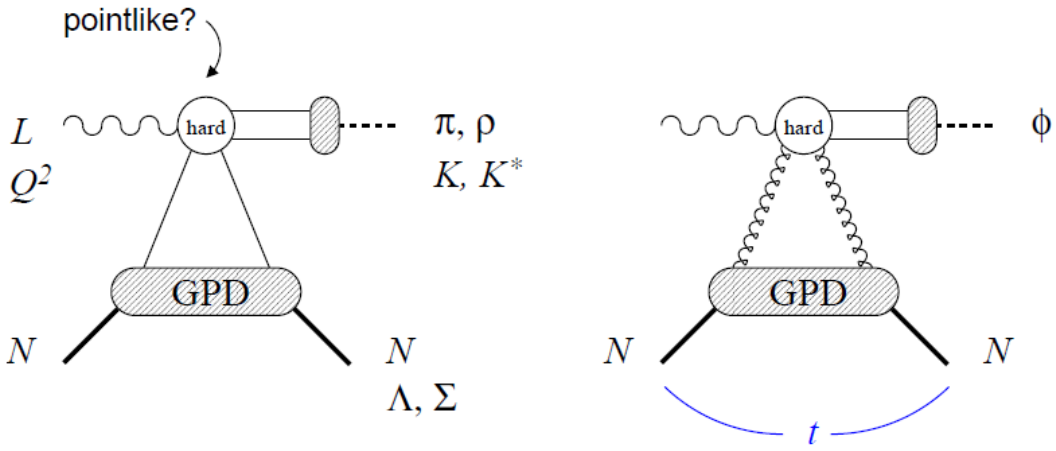
t- dependence allows Fourier transform in ξ=0 limit



Transverse spatial image of proton obtained by Fourier transforming the measured GPD

Nucleon GPDs: spin-flavor

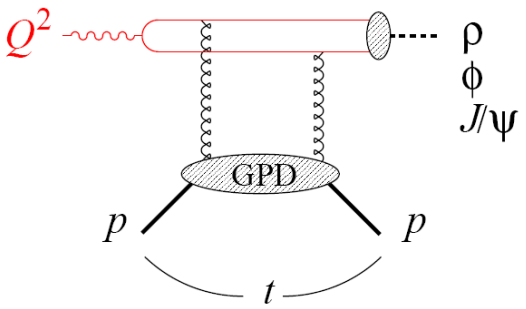
Deep Virtual Meson Production (DVMP)

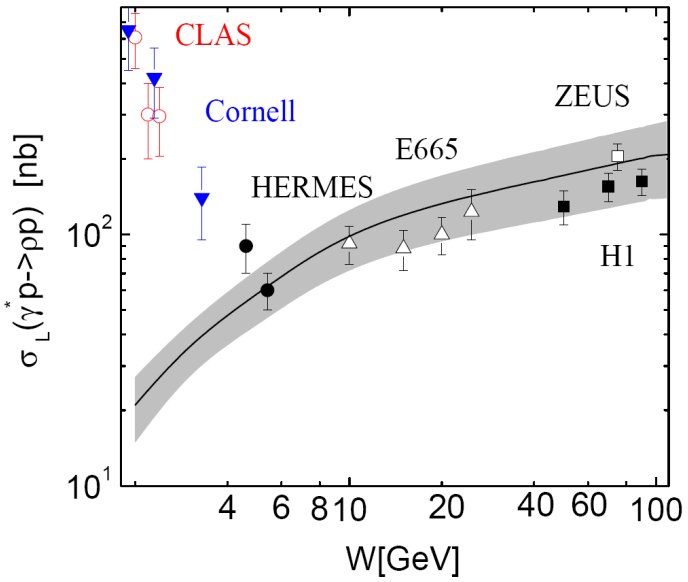


- Nucleon structure described by 4 GPDs:
  - H, E (unpolarized), $\tilde{H}$, $\tilde{E}$ (polarized)
- Quantum numbers probe individual GPD components more selectively
  - $\rho^o/\rho+/K^*$ select H, E for u/d flavors
  - π,η,K select $\tilde{H}$, $\tilde{E}$
- Need good understanding of reaction mechanism
  - QCD factorization for mesons is complex (additional interaction of the produced meson)

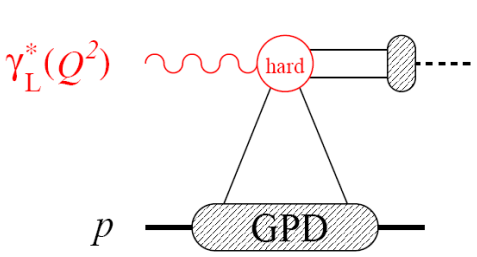
Valence Quark Imaging: JLab 12 GeV Mesons

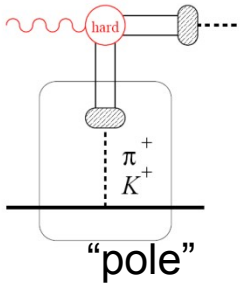
Vector Mesons

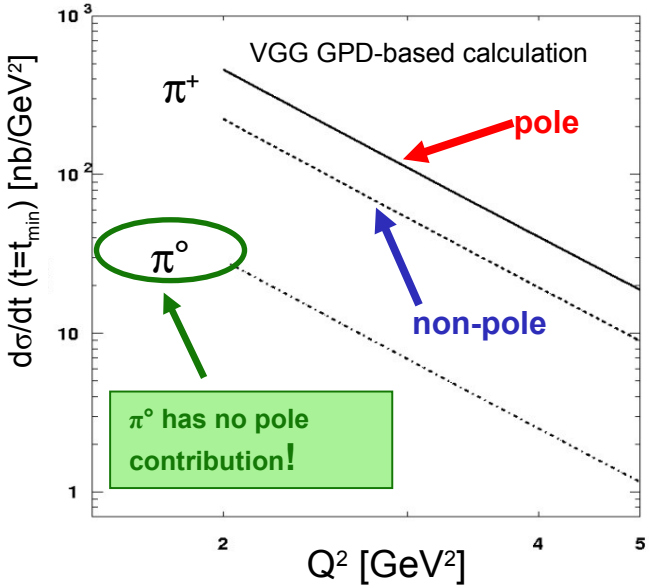




Pseudoscalar Mesons



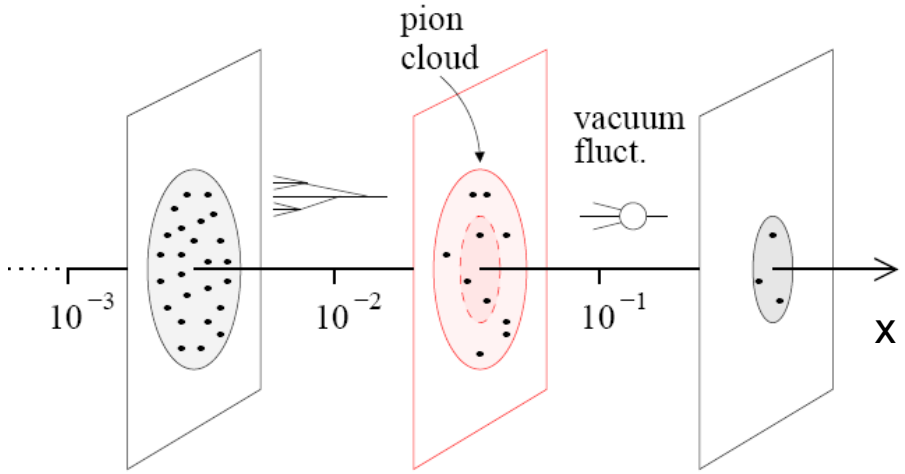




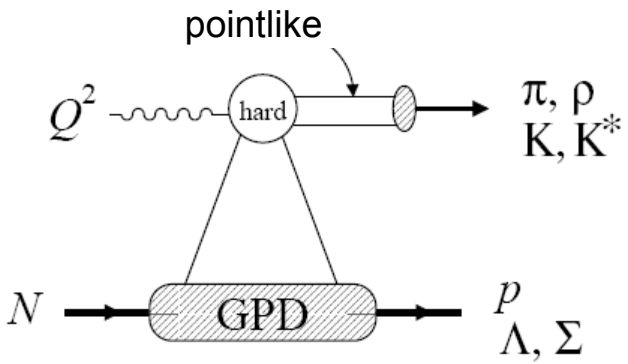
- Understanding of reaction mechanism
  - Role of qqbar pair knockout
  - Finite-size corrections

- Feature: pole term in GPD
- Understand relative importance of "pole and "non-pole" contributions

EIC: Quark Imaging through Meson Production



radiative sea | Non-perturbative sea quarks | valence quarks



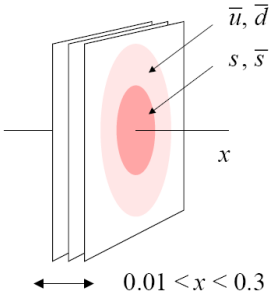
- Transverse distribution of non-perturbative sea quarks
- Flavor structure and longitudinal polarization
  - QCD vacuum structure
  - Chiral dynamics, "pion cloud"
- Exclusive meson production

$$\gamma^* N \rightarrow M + B$$

  - Requires Q^2>10GeV^2 for dominance of "pointlike" configurations -> pQCD
  - Meson quantum numbers select spin/flavor component of GPD
  - Information about meson wavefunction: size flavor structure

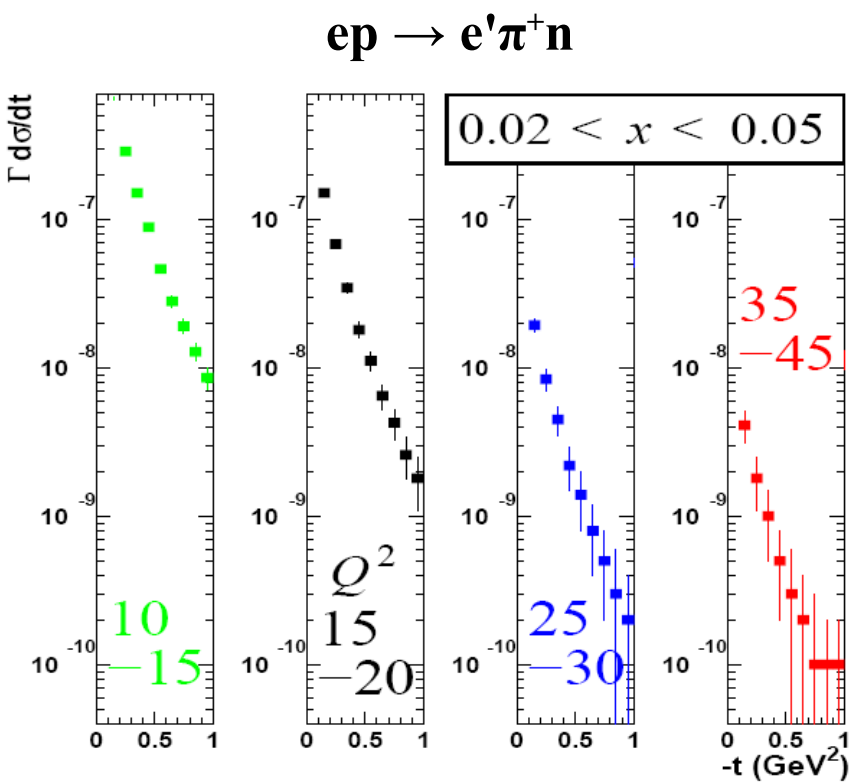
EIC: Transverse sea quark imaging

- New territory for collider!



- Spatial structure of *non-perturbative sea*
  - Closely related to Jlab 6/12 GeV
    - Quark spin/flavor separations
    - Nucleon/meson structure

- Simulation for π^+ production assuming 100 days at a luminosity of 10^{34} with 5 on 50 GeV (s=1000 GeV^2)
  - V. Guzey, C. Weiss: Regge model
  - T. Horn: empirical π^+ parameterization



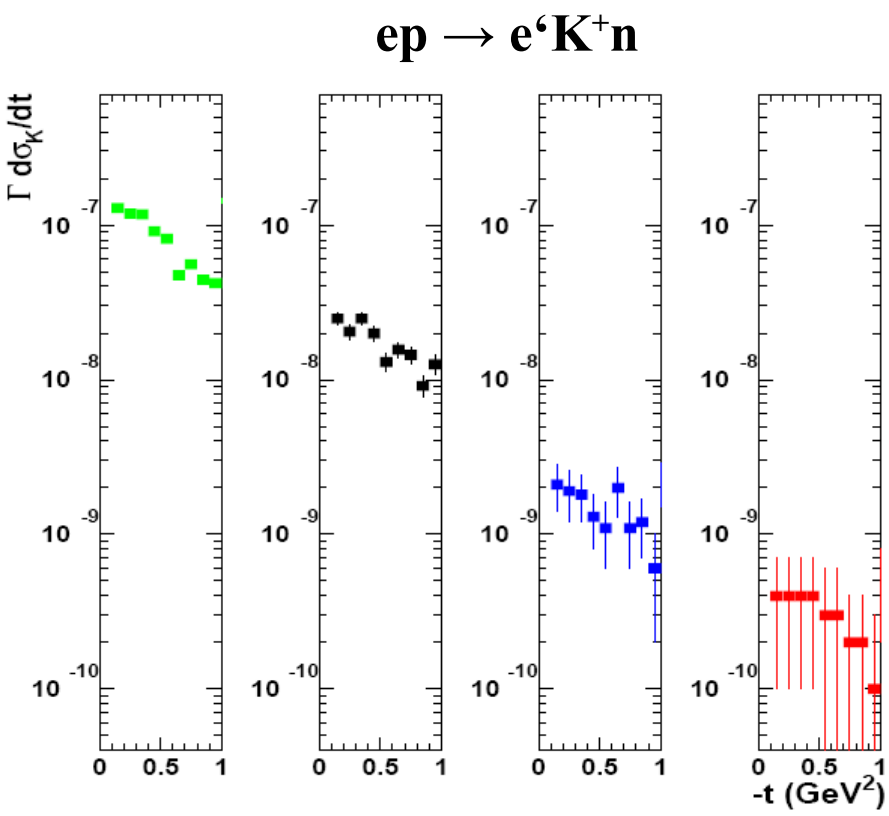
Tanja Horn, Antje Bruell, Christian Weiss

- Lower and more symmetric energies essential to ensure exclusivity

EIC: Transverse *strange* 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
- Rate estimate for $K\Lambda$ using an empirical fit to kaon electroproduction data from DESY and JLab assuming 100 days at a luminosity of 10^{34} with 5 on 50 GeV (s=1000 GeV^2)
- Lower and more symmetric energies essential to ensure exclusivity

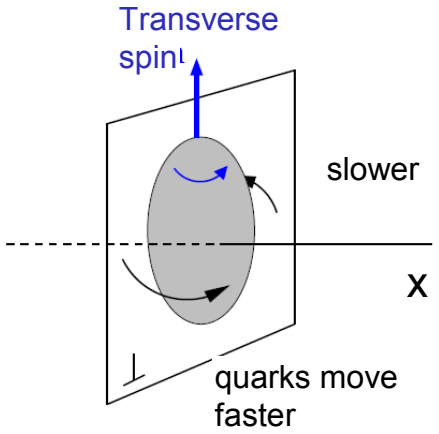
Pushes **luminosity > 10^{34}**

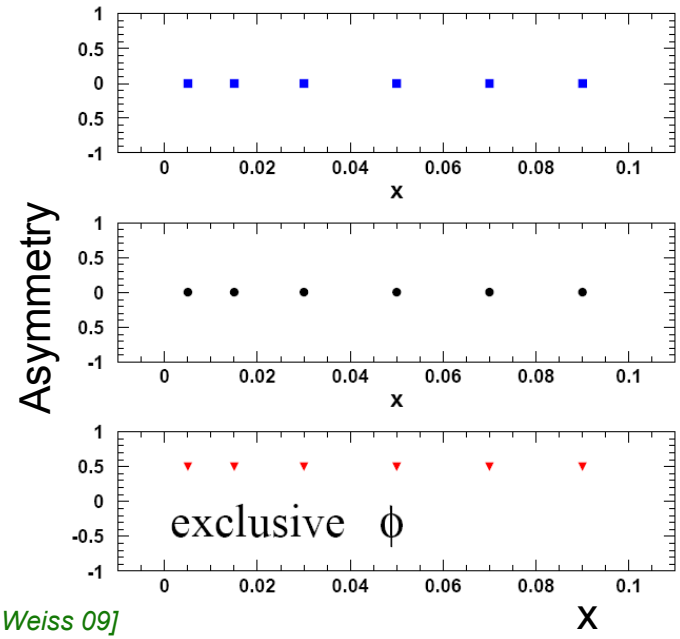


Tanja Horn, David Cooper

Consistent with back-of-the-envelope scaling arguments

Transverse polarization example





[Horn, Weiss 09]

- Deformation of transverse distribution by transverse polarization of nucleon
  - Helicity flip GPD *E*, cf. Pauli ff
- EIC: exclusive ρ and φ production with transversely polarized beam
  - Excellent statistics at $Q^2>10$ GeV^2
  - Transverse polarization natural for collider

$$\frac{\sigma\uparrow - \sigma\downarrow}{\sigma\uparrow + \sigma\downarrow} \propto \frac{\mathrm{Im}(\mathcal{H}\mathcal{E}^*)}{|\mathcal{H}|^2 + \mathrm{corr.}}$$

Beyond transverse imaging

- Longitudinal correlations in nucleon
  - GPDs at $x' \neq x$: correlated qqbar pairs in nucleon
    - QCD vacuum structure, relativistic nature of nucleon
  - EIC: reveal correlations through exclusive meson, γ at $x>0.1$, Q^2 dependence

…needs kinematic coverage way beyond JLab 12 GeV

- Orbital motion of quarks/gluons
  - TMD and orbital motion from SIDIS
    - Major component of the EIC program
  - Connection with GPDs
    - Unintegrated distributions, Ji sum rule

…should be discussed together

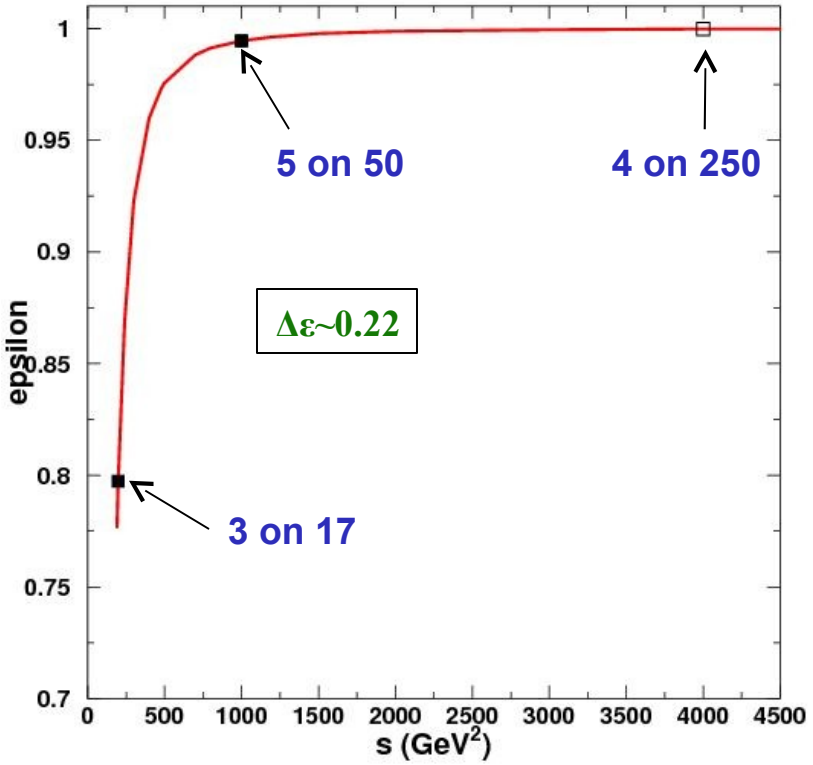
L/T separations in exclusive K^+/π^+ production

[Horn 08]

- L/T separated cross sections require:
  - Data taken at *different beam energies* (Rosenbluth)
  - *Sufficiently large Δε* (to avoid magnification of the systematic uncertainty in the separation)

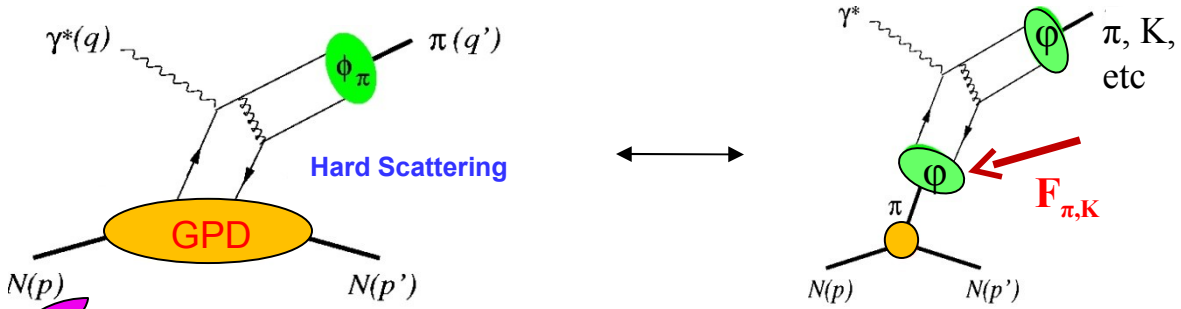
- Virtual photon polarization, ε, goes to unity at high √s

Q^2=10 GeV^2, x=0.1, -t=0.1



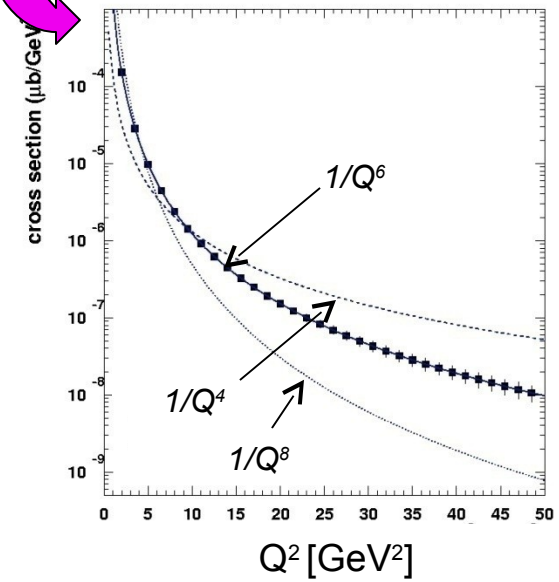
Requires special low energies for at least one ε point

L/T separation examples



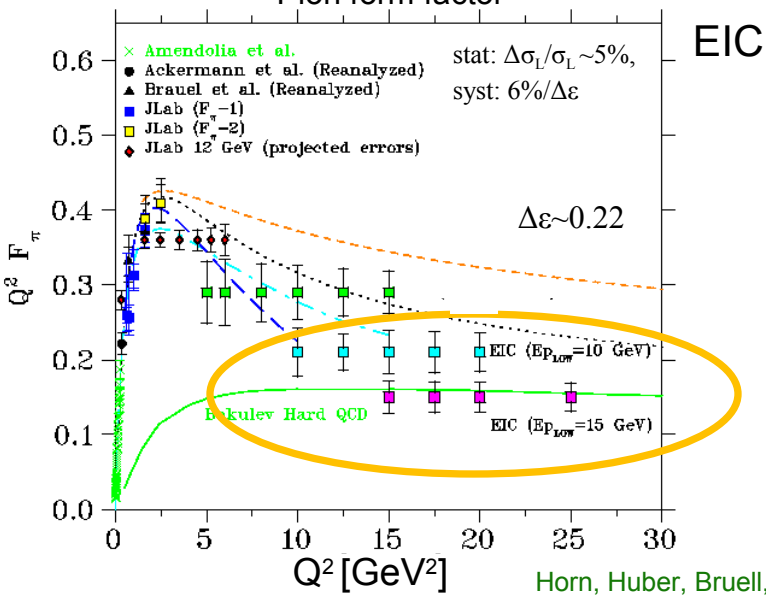
- In exclusive reactions we can study both nucleon GPDs *and* meson form factors

Pion factorization



$ep \rightarrow e'\pi^+n$

Pion form factor



EIC: E_e=5 GeV, E_p=50 GeV

s=1000 GeV²

100 days

Luminosity 10^{34}

Horn, Huber, Bruell, Weiss [EICC 2008 HU]

Excellent potential to study the QCD transition nearly over the whole range from the strong QCD regime to the hard QCD regime.

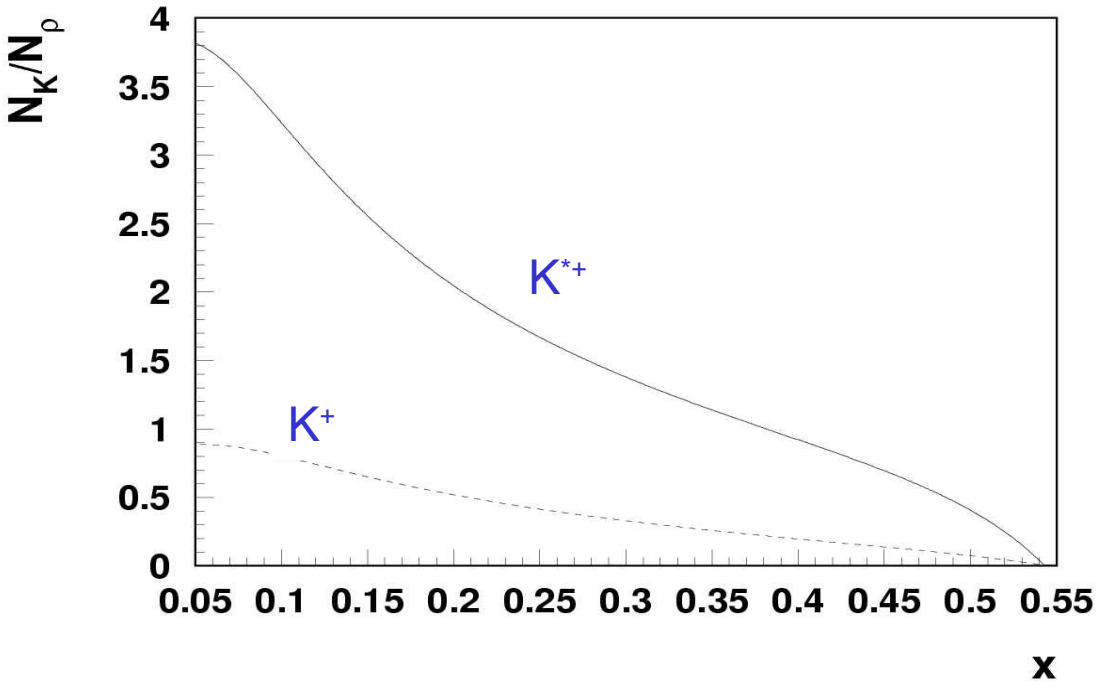
Spin-flavor beyond transverse imaging

$$\rho^+ n \propto [2H^u - H^d] - [H^{\bar{u}} - H^{\bar{d}}])$$

$$K^+\Lambda \propto -\frac{1}{\sqrt{6}}(2[2\tilde{H}^u - \tilde{H}^d - \tilde{H}^s] + [2\tilde{H}^{\bar{u}} - \tilde{H}^{\bar{d}} - \tilde{H}^{\bar{s}}])$$

$$K^{*+}\Lambda \propto -\frac{1}{\sqrt{6}}(2[2H^u - H^d - H^s] - [2H^{\bar{u}} - H^{\bar{d}} - H^{\bar{s}}])$$

[Avakian, Milos 09]



M.Diehl et al. hep-ph/0506171

- L/T separation from $K^* \to K\pi$ decay + SCHC

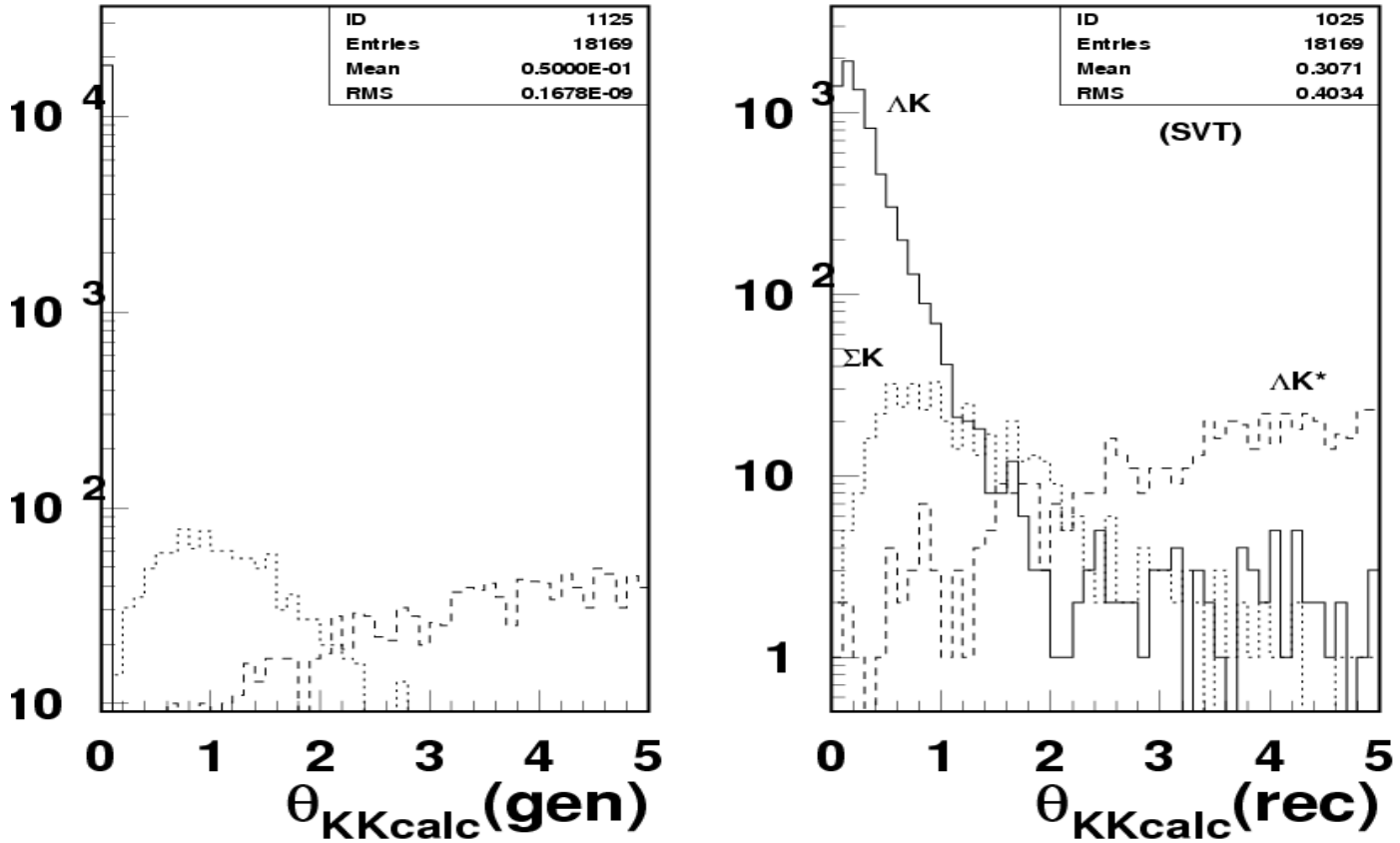
•Study ratio observables: K/K*/ρ+,polarization transfer

•Different final state mesons filter out different combinations of unpolarized (H,E) and polarized (H,E) GPDs.

Spin-flavor beyond transverse imaging

K/K* and Λ/Σ separations

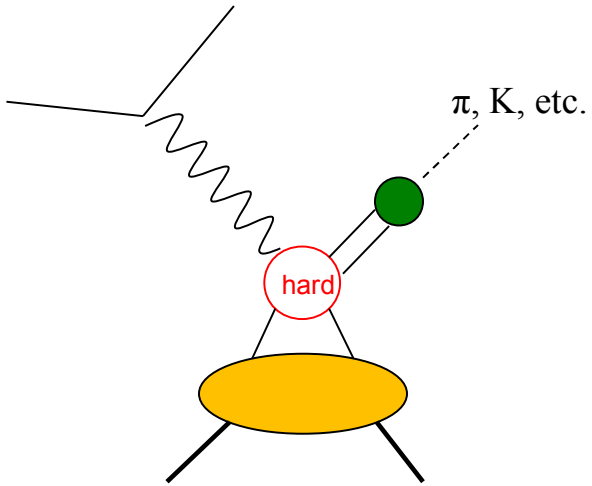
[Avakian, Milos 09]



Detection of K+ crucial for separation of different final states (Λ,Σ,K*)

Experimental Perspectives

- Exclusivity (channel selection)
- Particle identification
- Luminosity

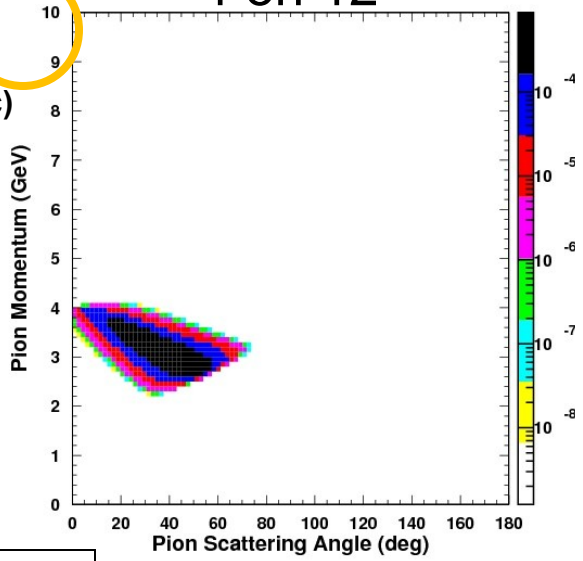


⟹ Design of detector/Interaction Region (IR)

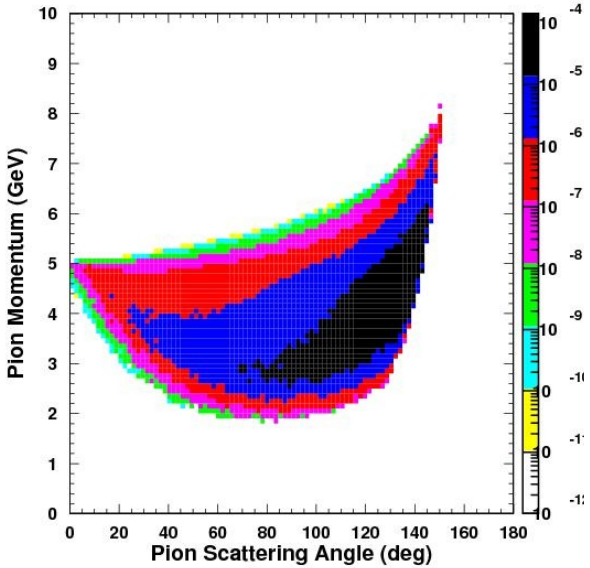
⟶ P. Nadel-Turonski talk

Deep Exclusive – meson kinematics

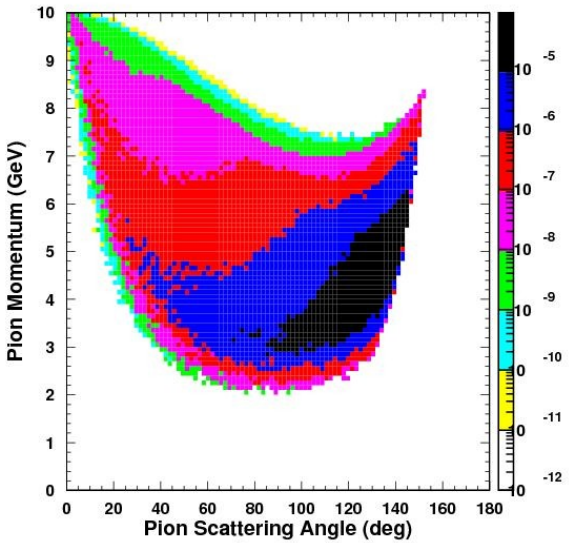
4 on 12



5 on 50



10 on 50



P (GeV/c)

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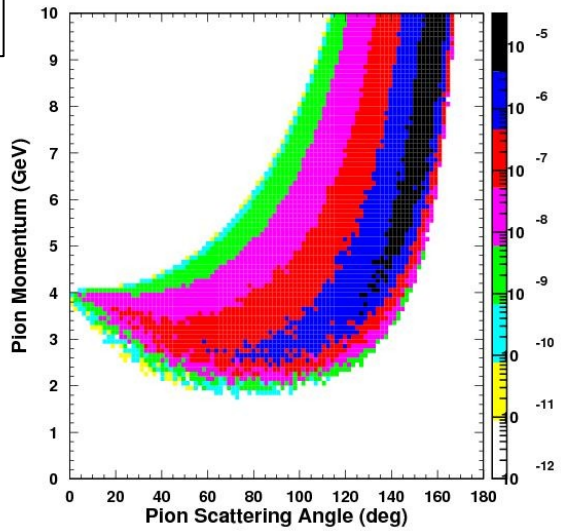
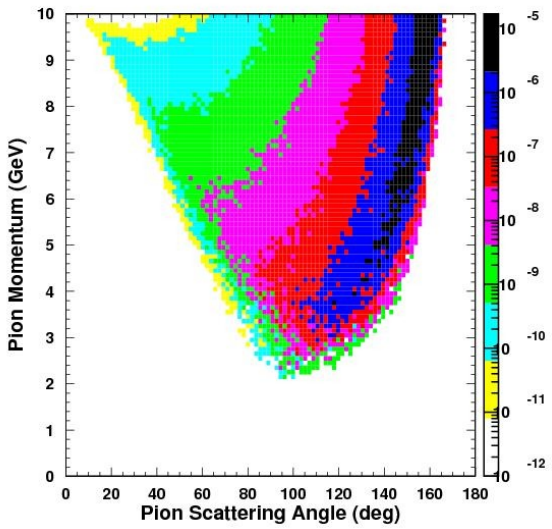
$ep \rightarrow e'\pi^+n$

4 on 250



10 on 250

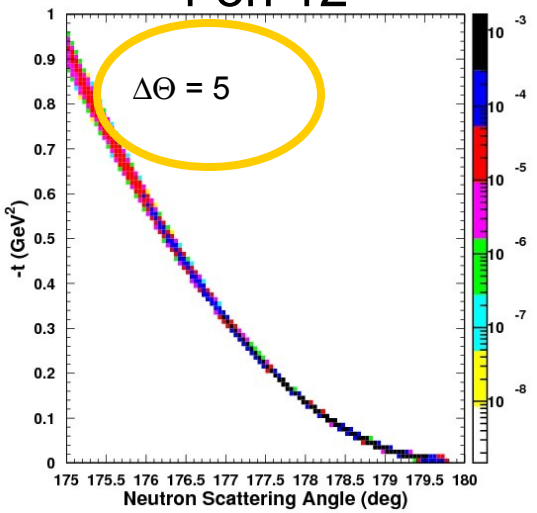


P (GeV/c)

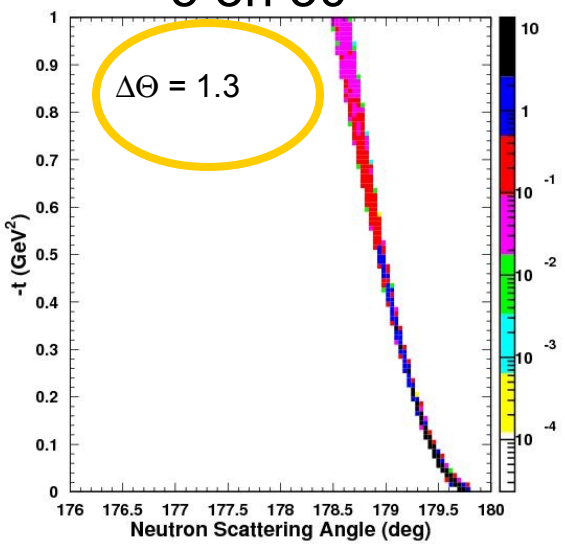
More symmetric kinematics improve detector *acceptance* (hermeticity), particle identification, and resolution (momentum and angular).

Deep Exclusive – recoil baryon kinematics

4 on 12



5 on 50



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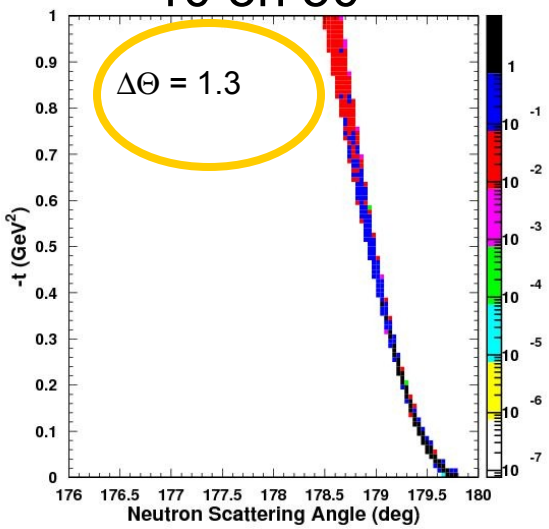
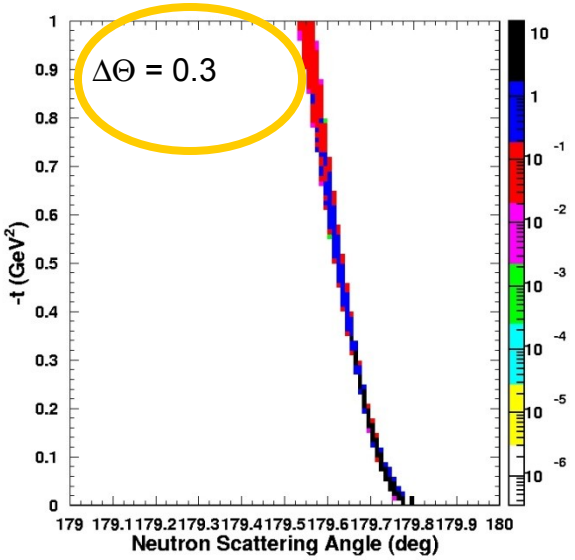


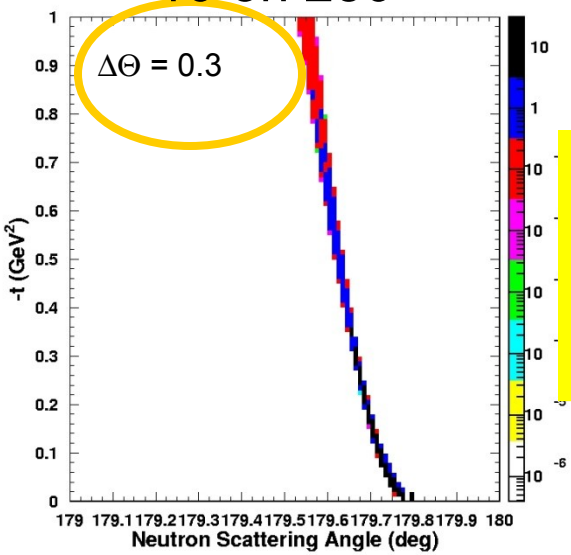
Want 0 < t < 1 GeV

$ep \rightarrow e'\pi^+n$

4 on 250



10 on 250



$\delta t/t \sim t/E_p$
→ lower E_p better

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Exclusive Meson Production Perspectives

- Energies
  - More symmetric energies favorable, 5 on 50 seems to be a sweet spot for exclusive meson production
  - Lower energies essential for ε range in pseudoscalar L/T separations (pion form factor)
- Kinematic reach
  - Need Q^2>10 GeV^2 (pointlike configurations)
  - *x* range between 0.001 and 0.1 overlapping with HERA and JLab12 GeV
  - *s*-range between 200 and 1000 GeV^2
- Luminosity
  - Non-diffractive proceses (exclusive π and *K* production) require high luminosity for low rates, differential measurements in *x, t, Q*^{2}
  - Kaons push luminosity >10^{34}
- Detection
  - Recoil detection for exclusivity, *t*-range

Summary

- The EIC is an excellent tool to access nucleon structure

- JLab 12 GeV
  - Main focus: valence quark imaging with DVCS
  - Also initial deep exclusive meson production studies

- EIC: gluon and sea quarks
  - Transverse gluon and sea quark imaging through deep exclusive meson production