Experience and Thoughts from HERMES

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- Introduction
- The HERMES Experiment
- Inclusive Measurements from Nuclei
- Semi-inclusive? More information but at a cost.
- Closing “Thoughts”

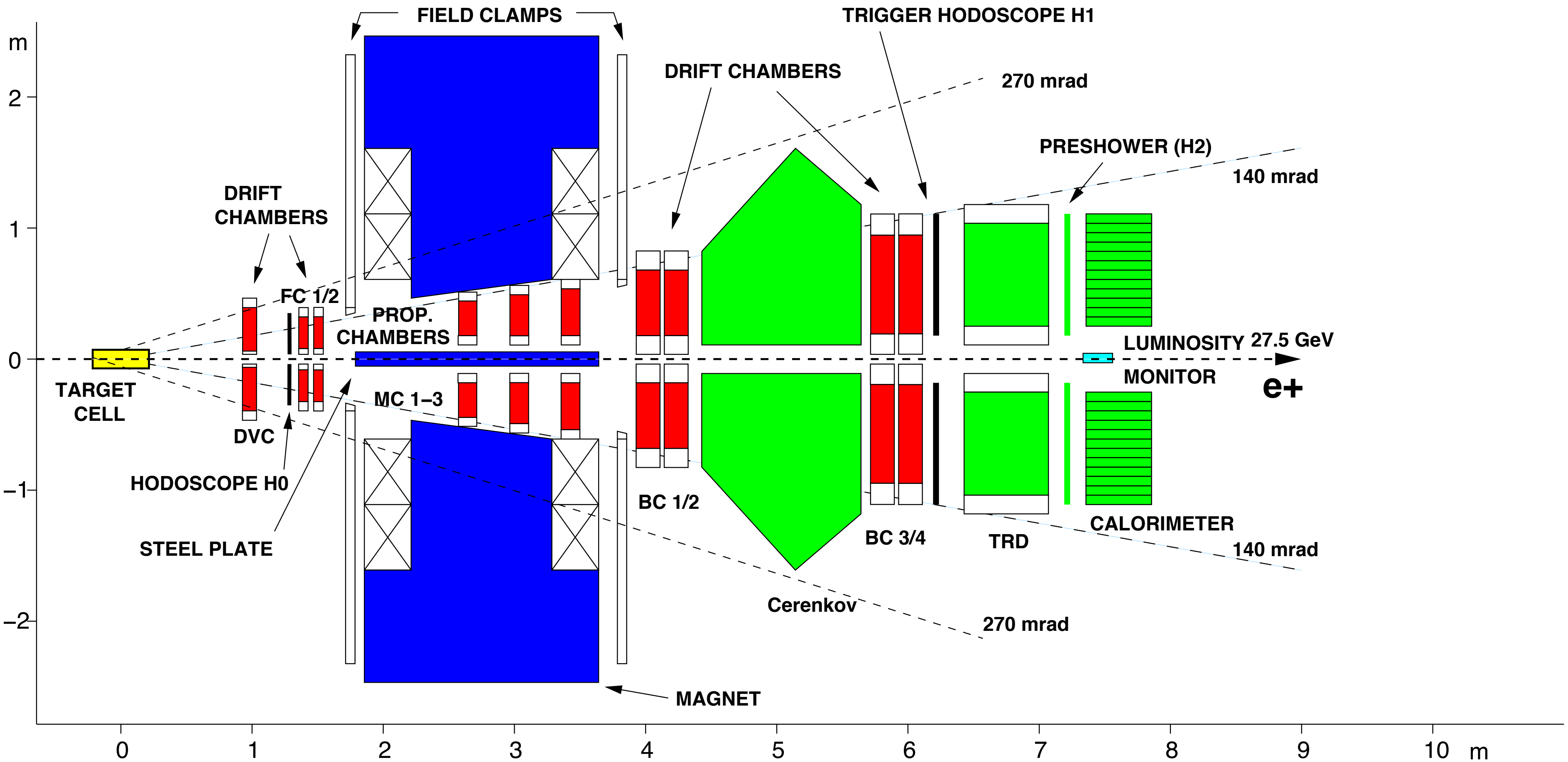
Introduction

- Main Goal: Review inclusive measurements of HERMES
- Brief reminder of the basic aspects of the experiment
- Inclusive DIS in nuclei (EMC)
- Extraction of R_A/R_D
- SIDIS and Nuclear Attenuation
- Whither EMC?

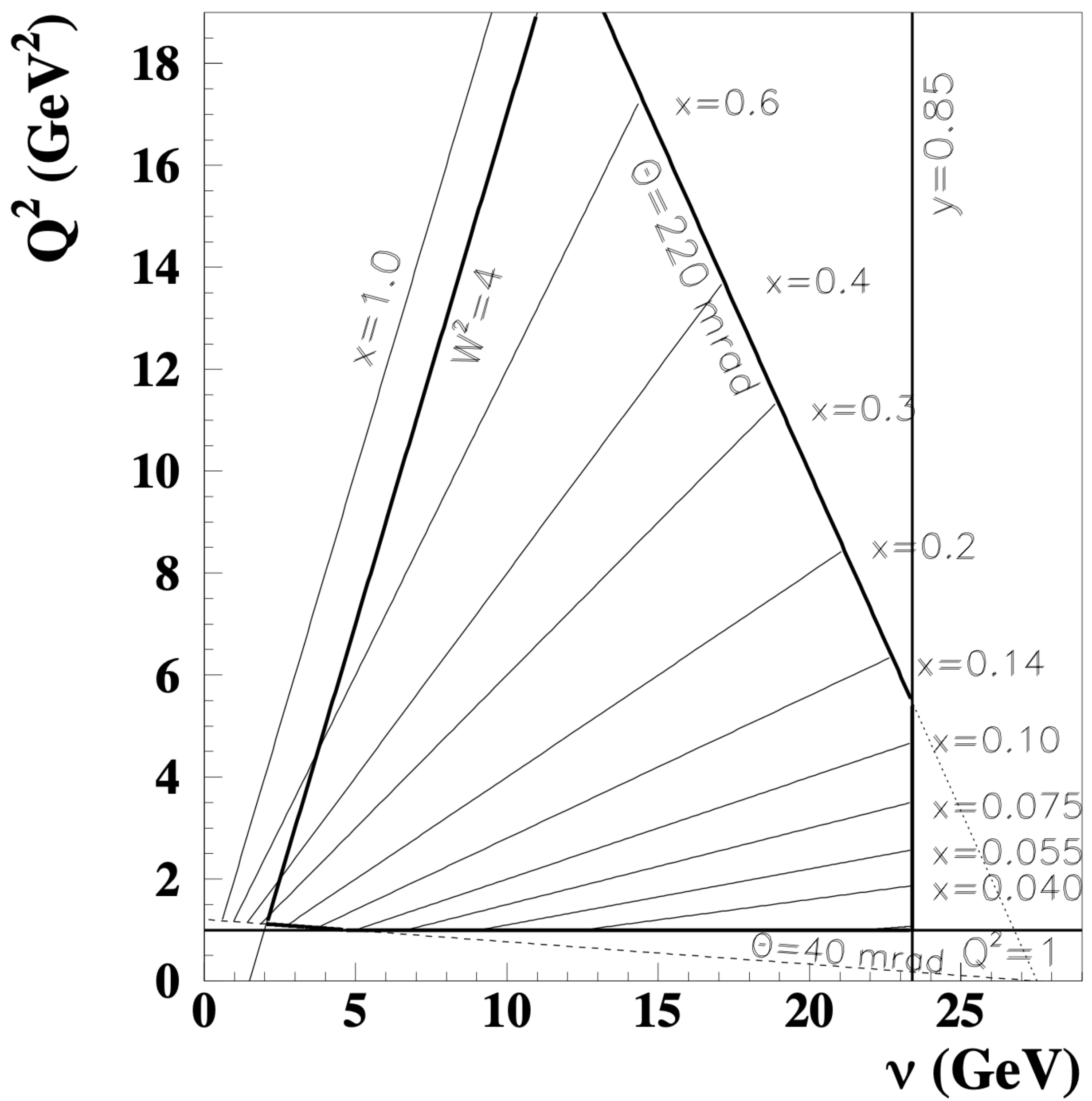
The HERMES Experiment

- Fixed target experiment with 27.5 GeV polarized positron (electron) beam
- Internal gas target in HERA storage ring (polarized H,D,^{3}He or unpolarized H,D,^{14}N, ^{20}Ne, ^{86}Kr)
- "Open" geometry spectrometer
- Luminosities ranging from 10^{31}-10^{33}
- Initial focus: Inclusive polarized DIS (g1 structure function)
- Eventually a broad range of topics including azimuthal asymmetries and exclusive reactions in addition to polarized SIDIS

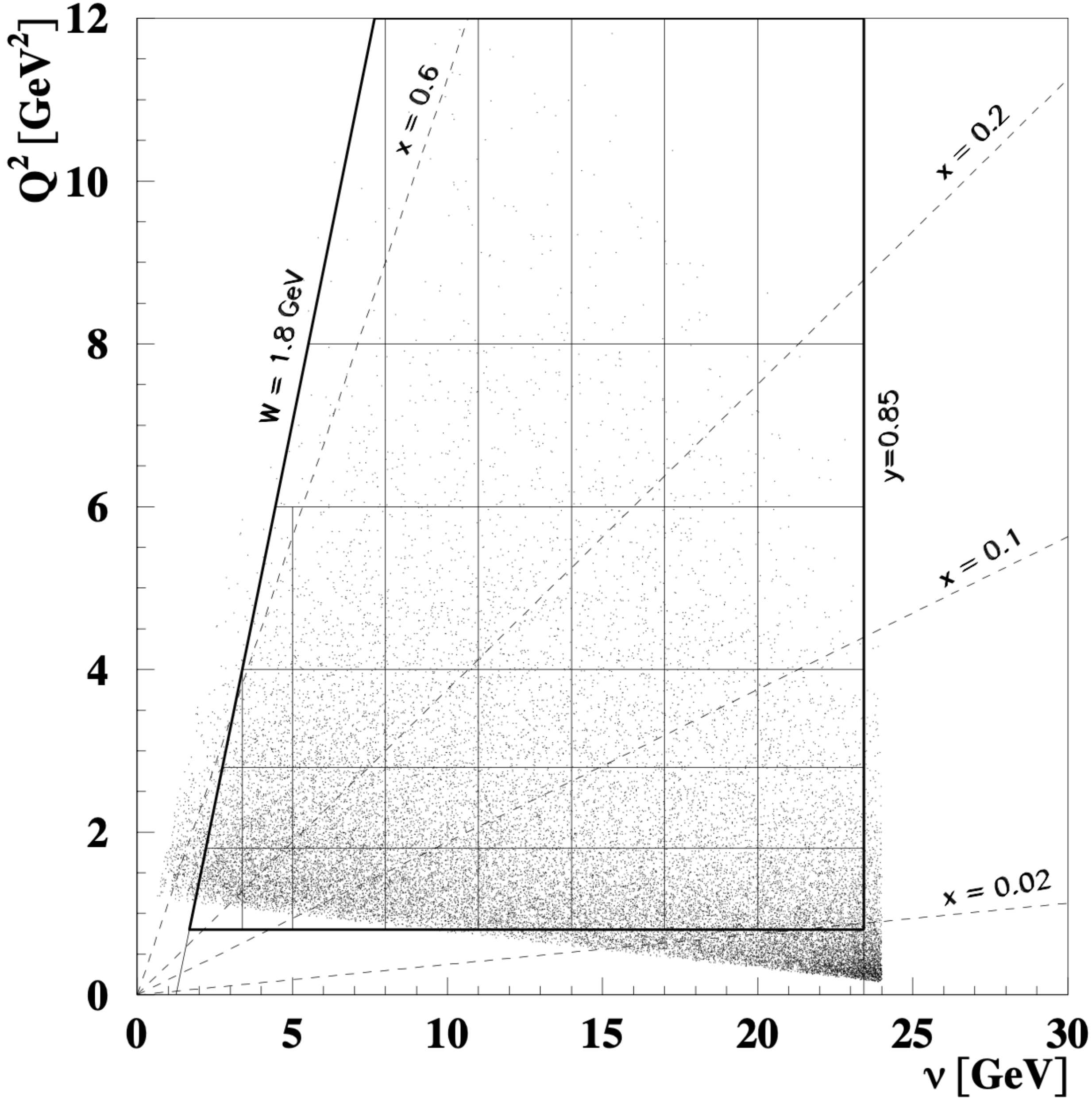
The HERMES Spectrometer



The HERMES Kinematic Acceptance



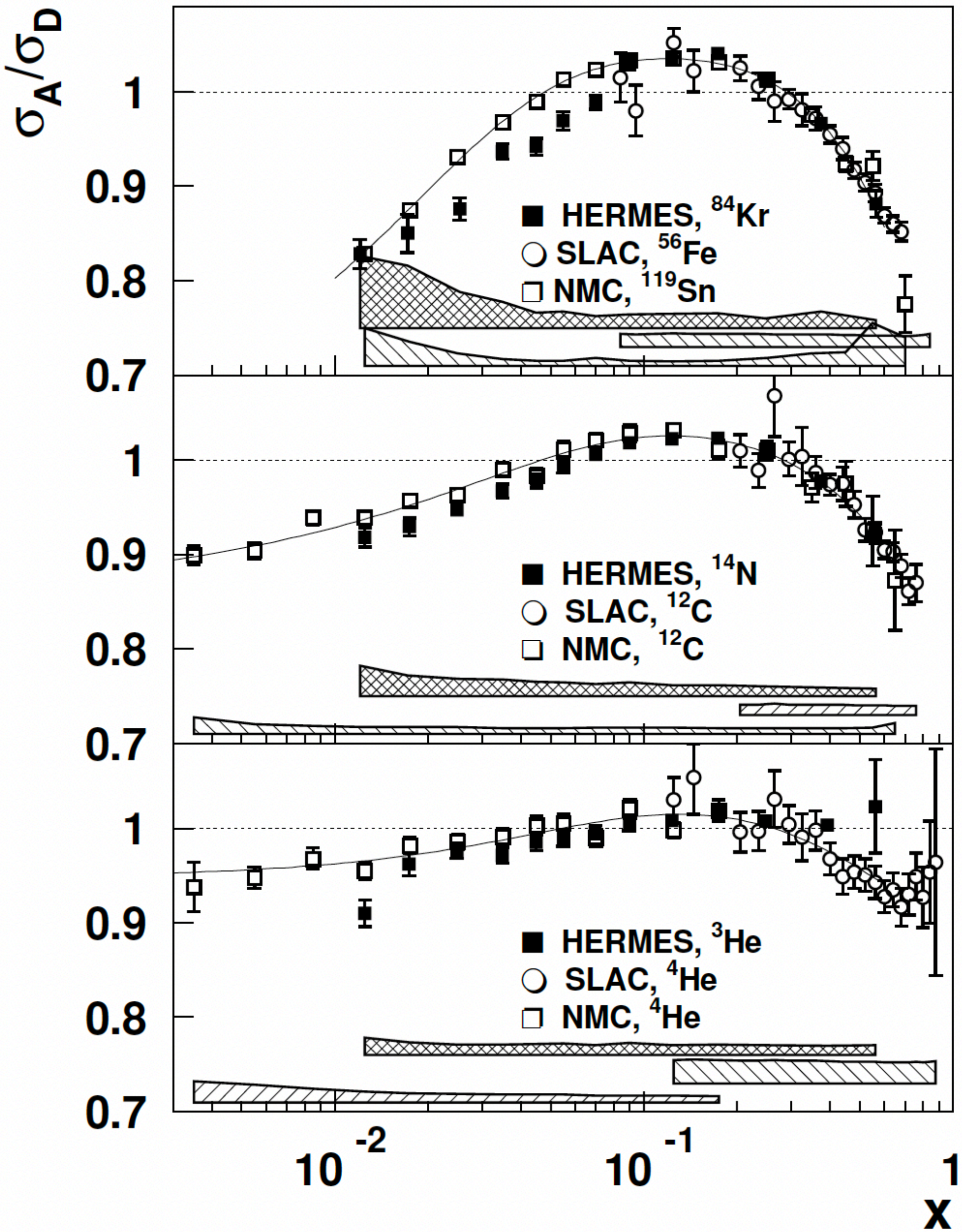
The HERMES Kinematic Acceptance&Events



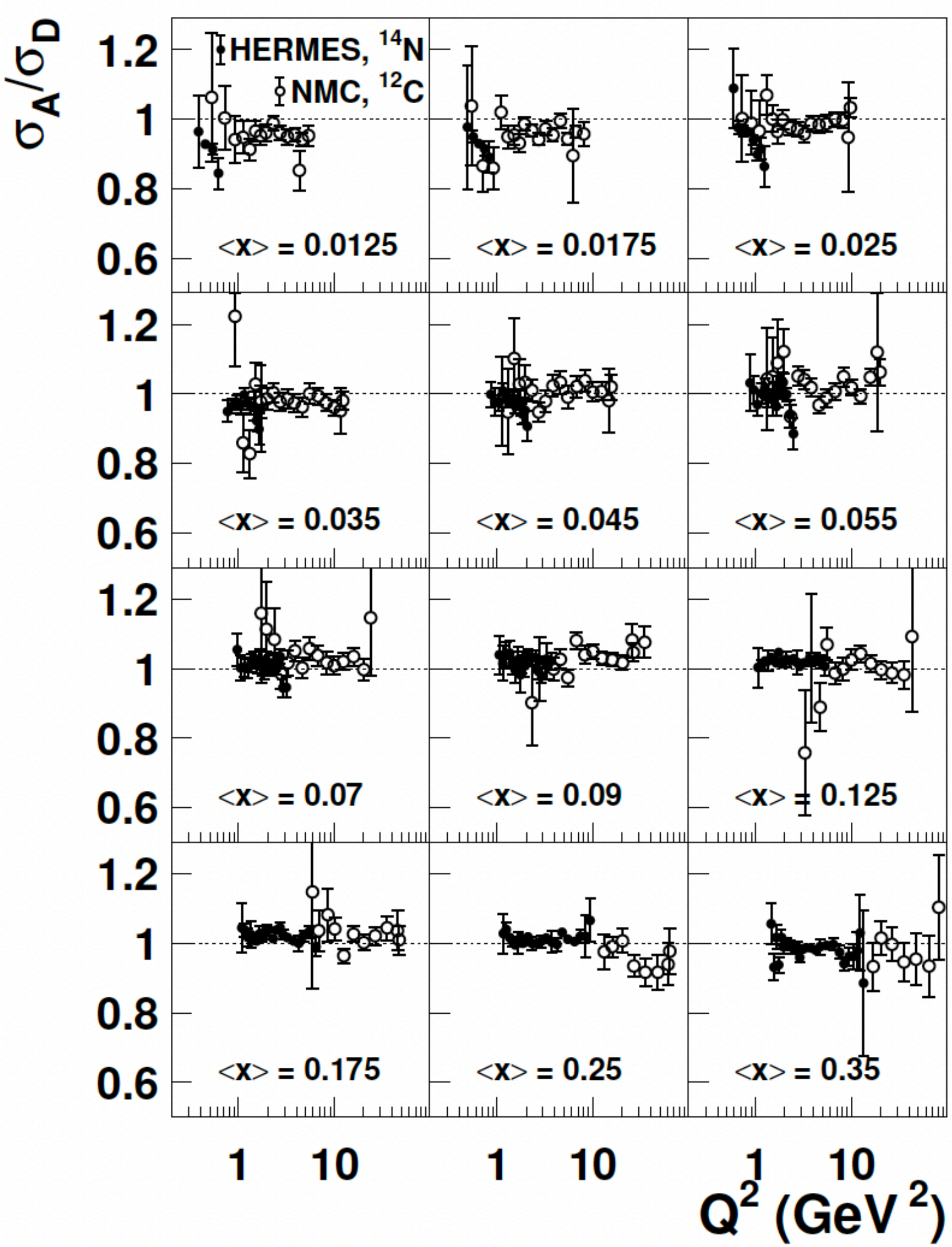
Inclusive DIS on Nuclei

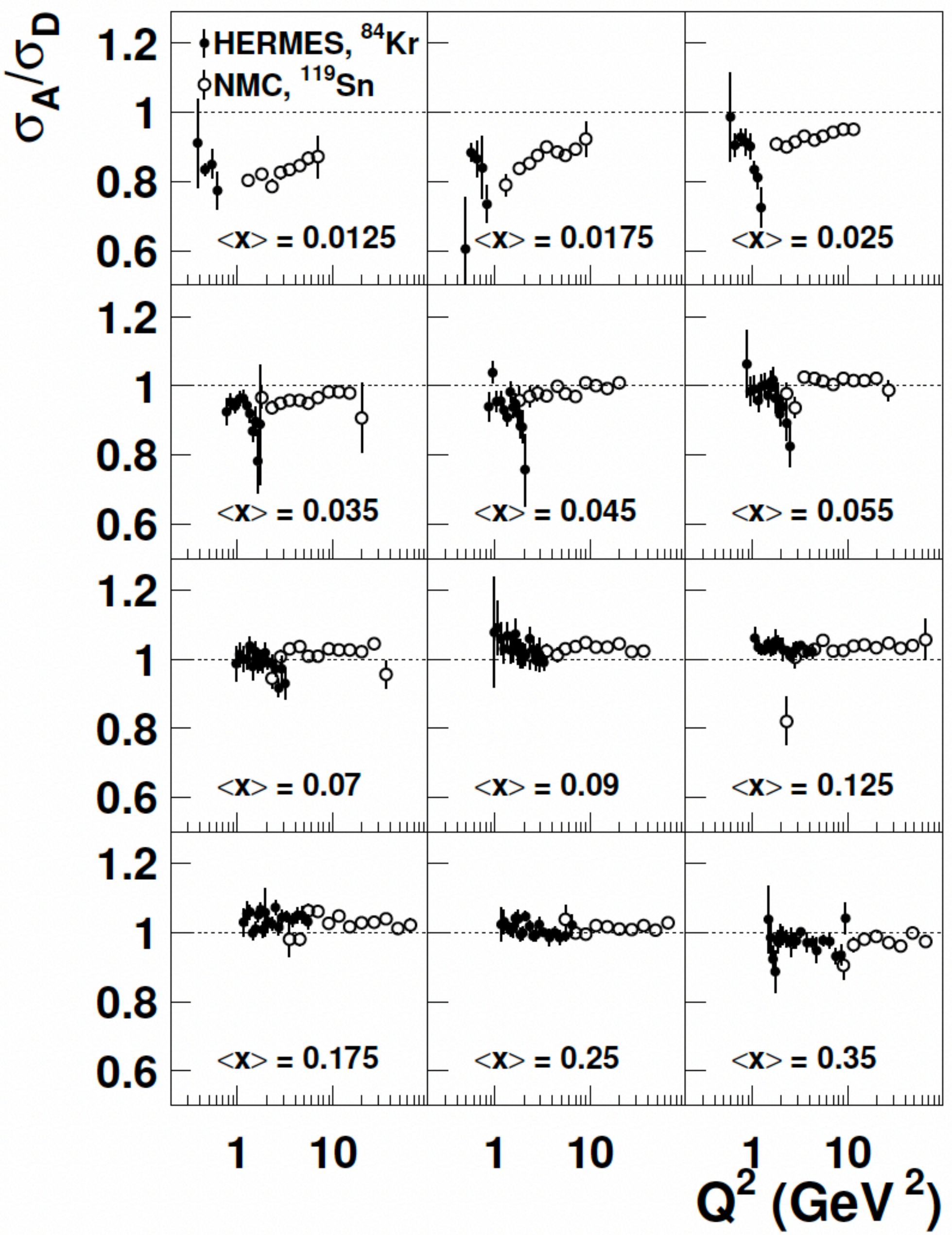
- Original publication was plagued by a large, unforeseen, kinematically correlated tracking inefficiency! Eventually this was discovered and corrected.
- The essential observable (in which many factors cancel) is the cross section ratio (with a factor to make it isoscalar)
- As always, bear in mind the strong correlation between x and Q^2
- Most of these results taken from Erica Garutti's PhD thesis and also some from Beni Zihlmann

Cross Section Ratios - x dependence



Cross Section Ratios - Q^2 dependence





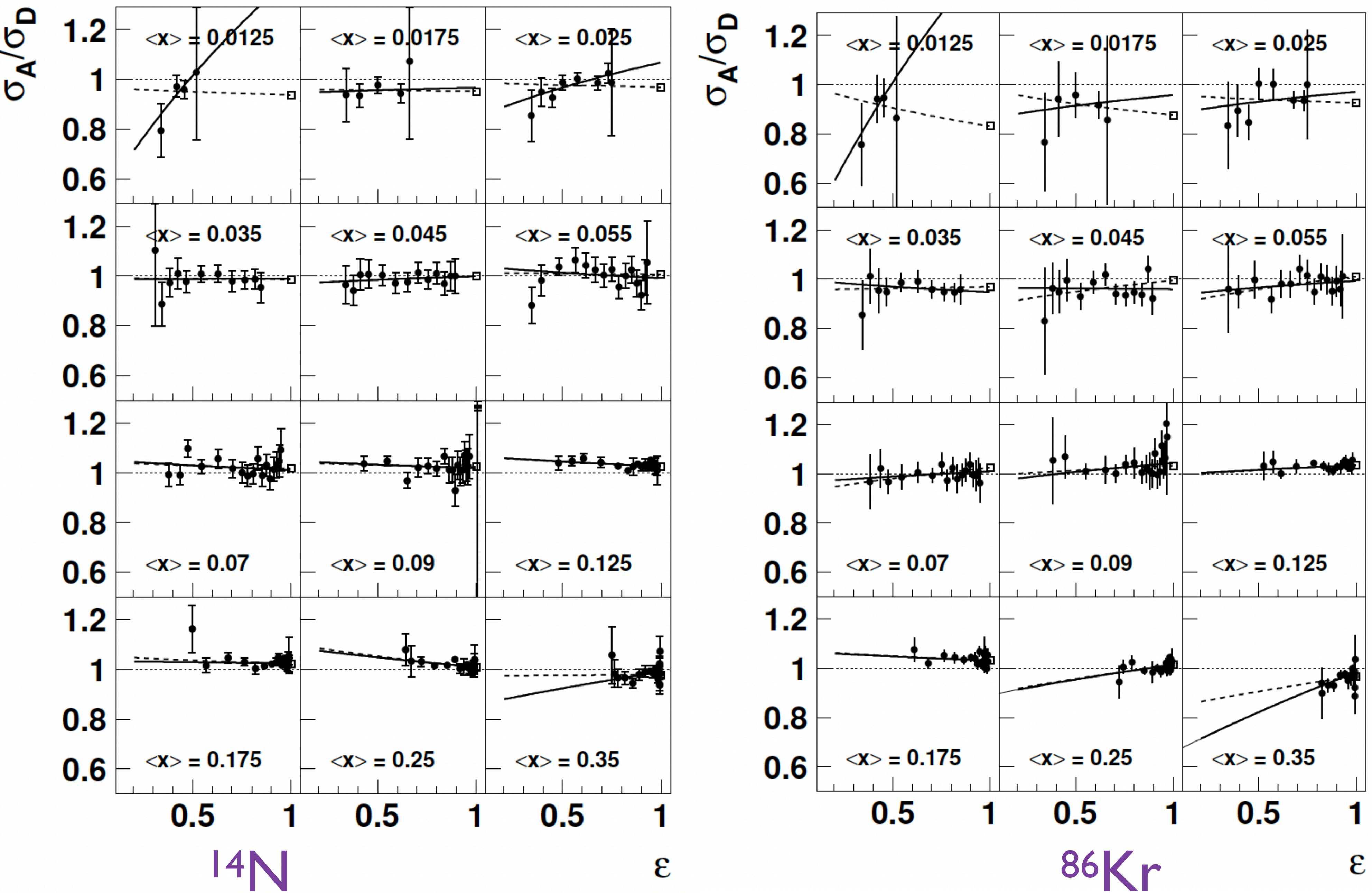
Fit to find R_A/R_D

- Using the relation below and taking R_D (i.e., σ_L/σ_T) as a given from another experiment (Whitlow), one can fit the cross section ratio's epsilon dependence to find F_2^A/F_2^D and R_A/R_D

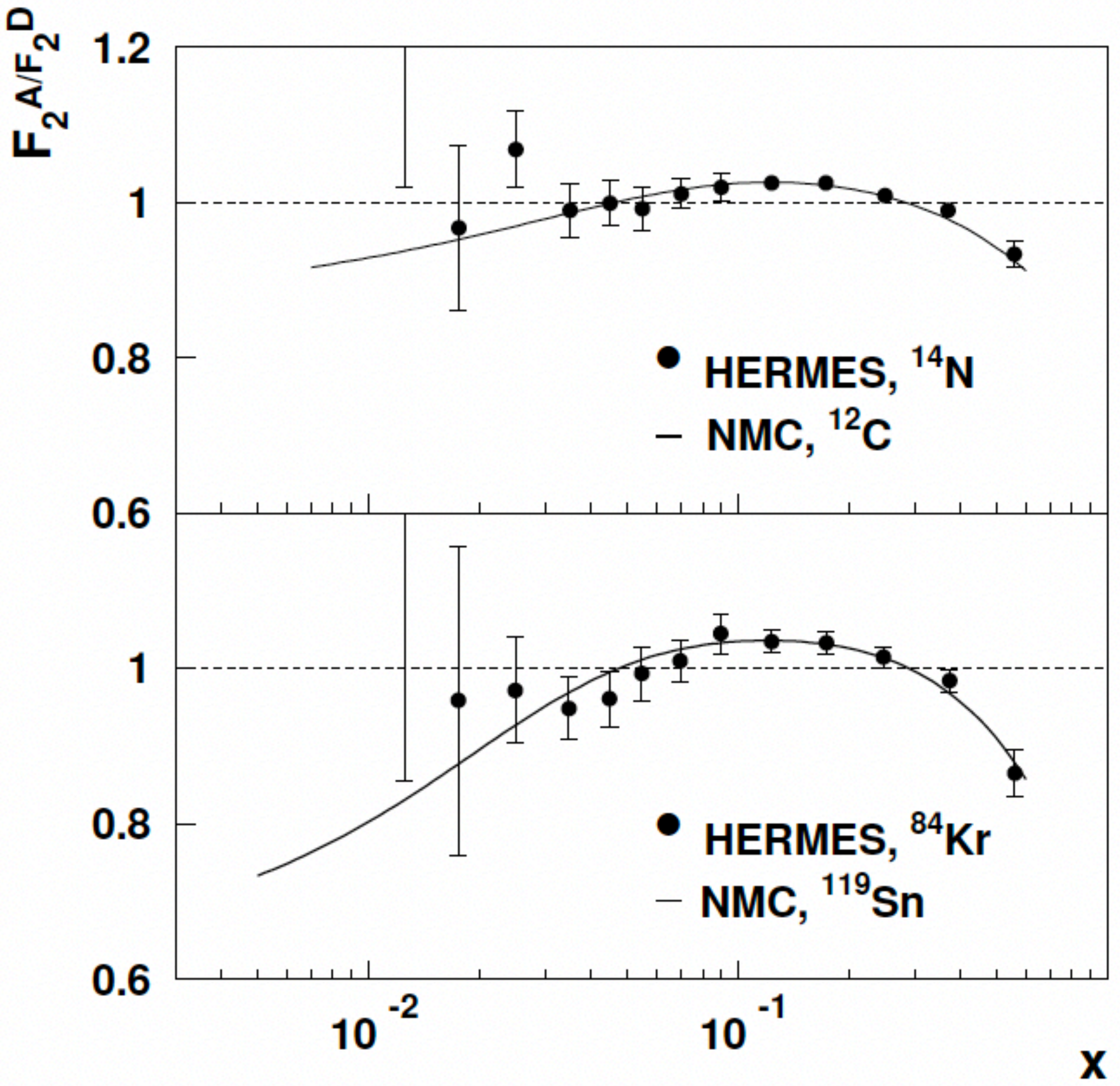
- Relative to EMC/NMC

$$\frac{\sigma_A}{\sigma_D} = \frac{F_2^A}{F_2^D} \frac{(1 + \epsilon R_A)(1 + R_D)}{(1 + R_A)(1 + \epsilon R_D)}$$

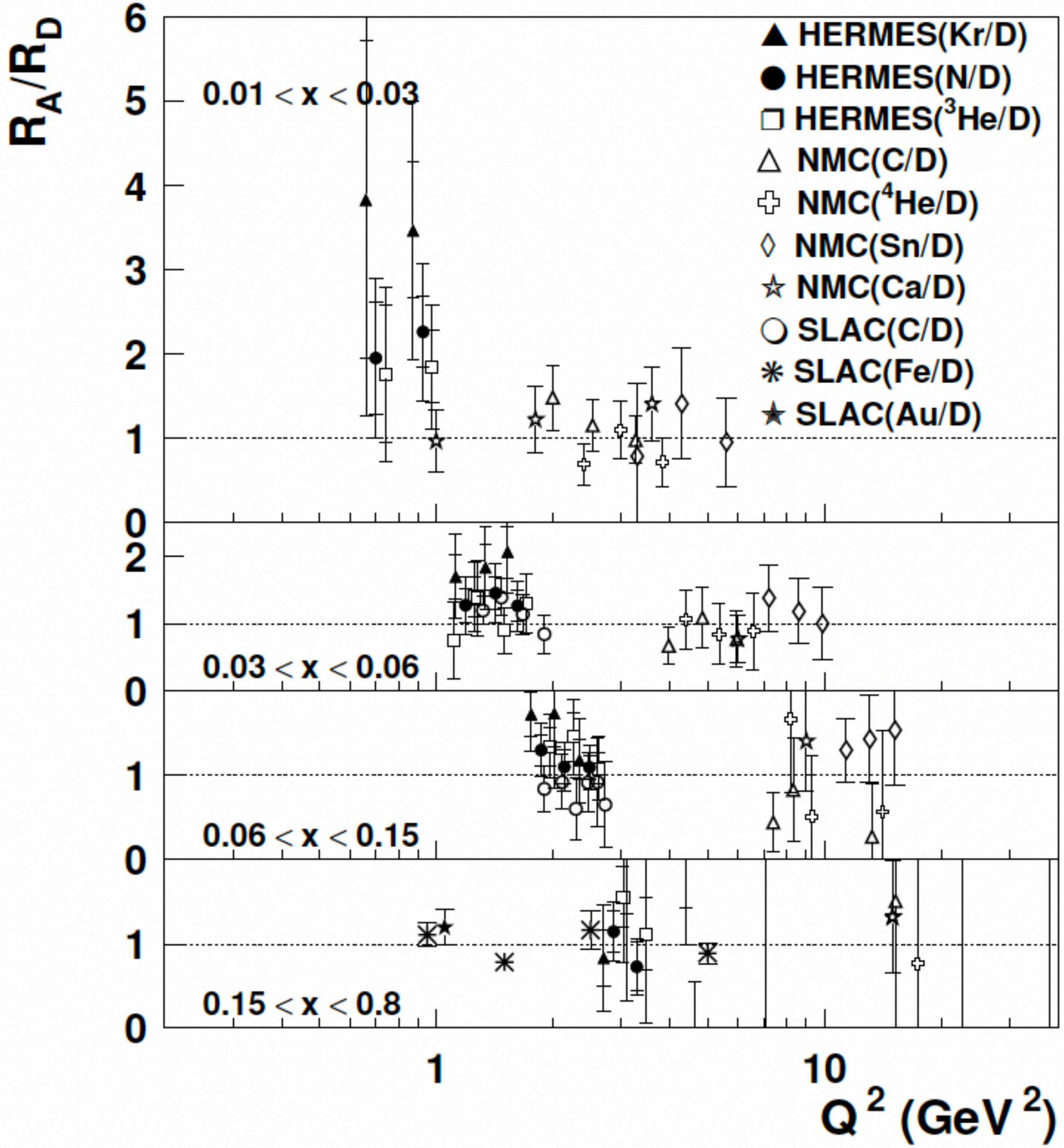
R_A/R_D - Fits to ε Dependence



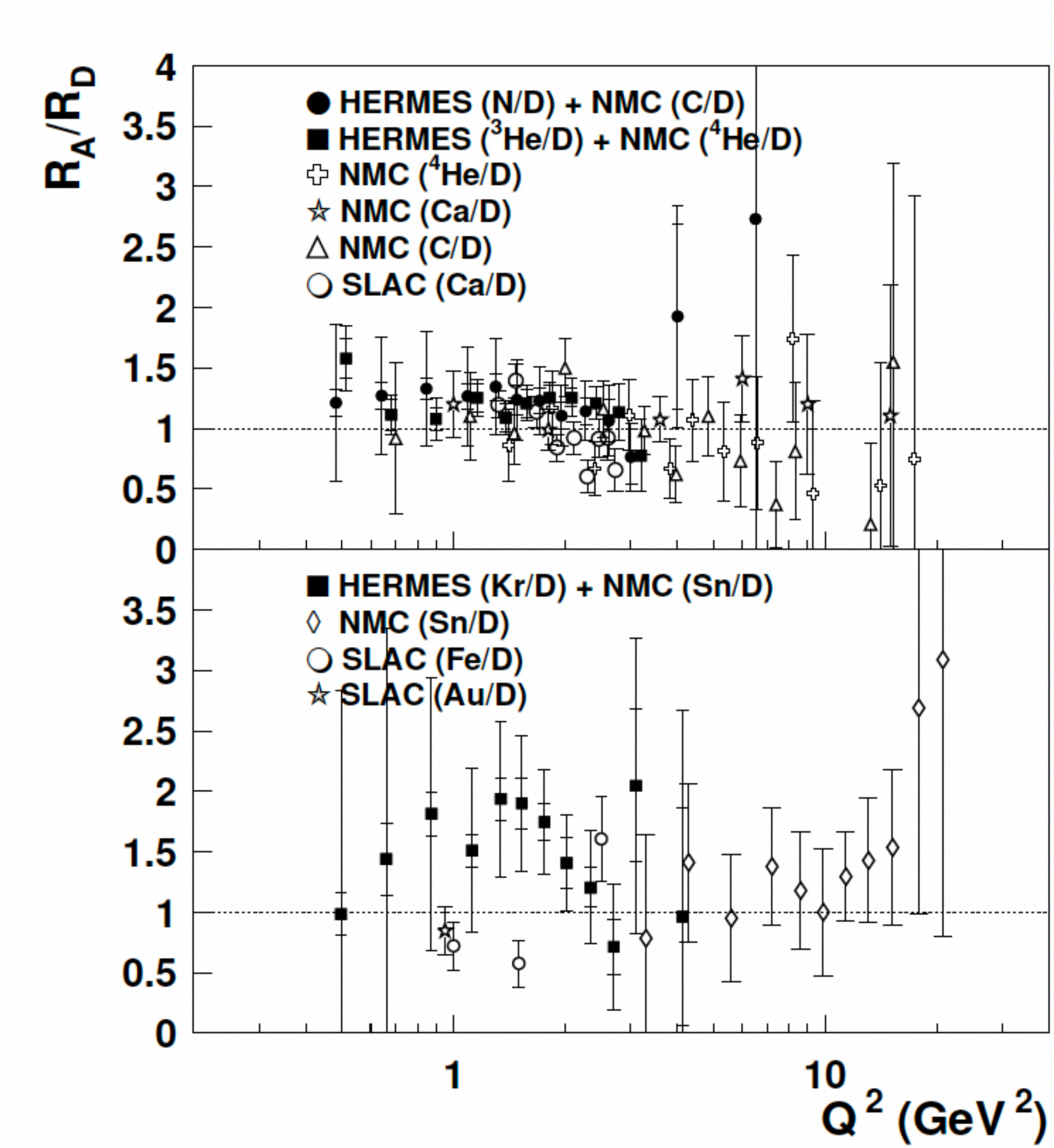
Results for F_2^A/F_2^D



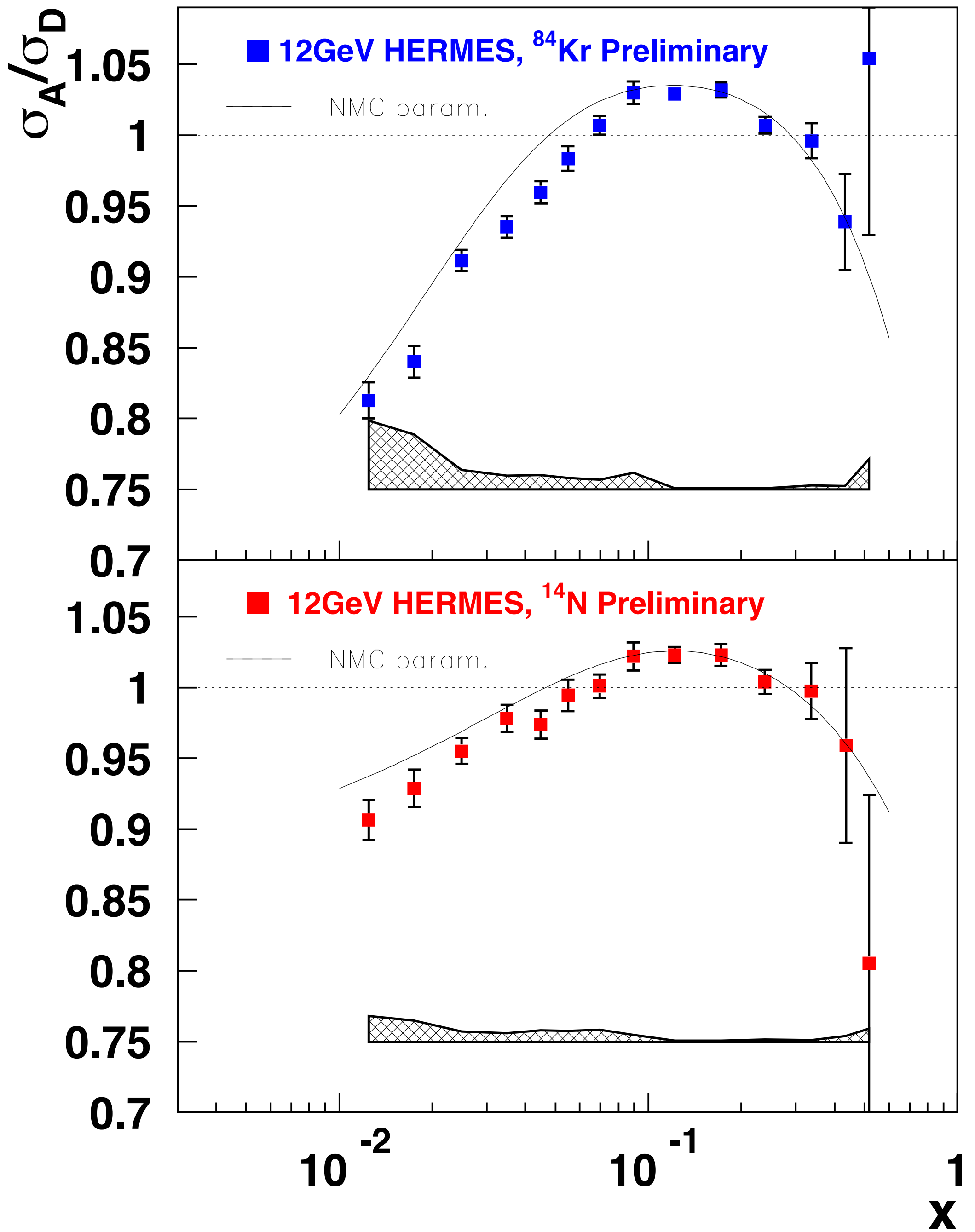
Results for R_A/R_D



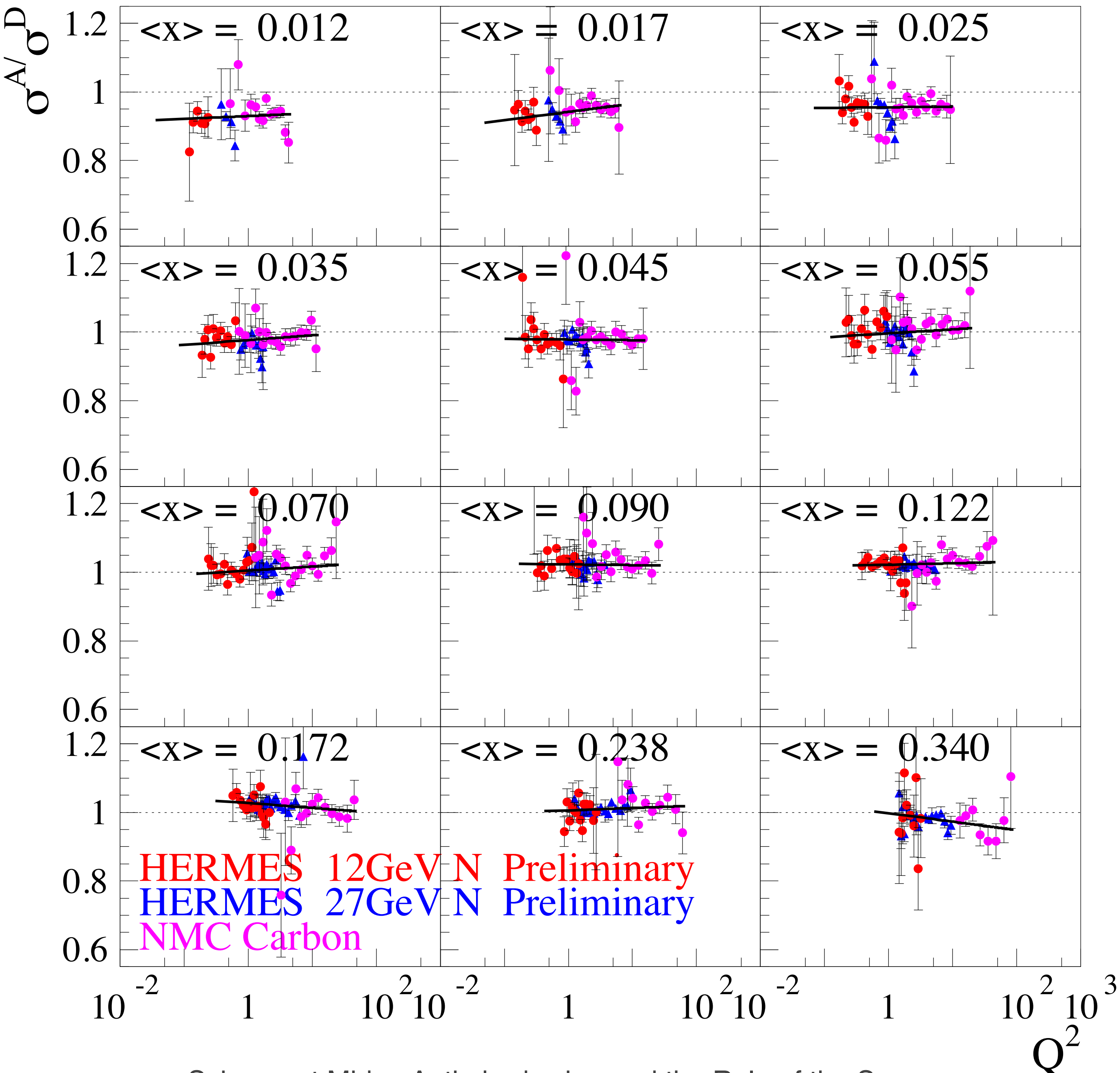
Results for R_A/R_D with NMC F_2^A/F_2^D



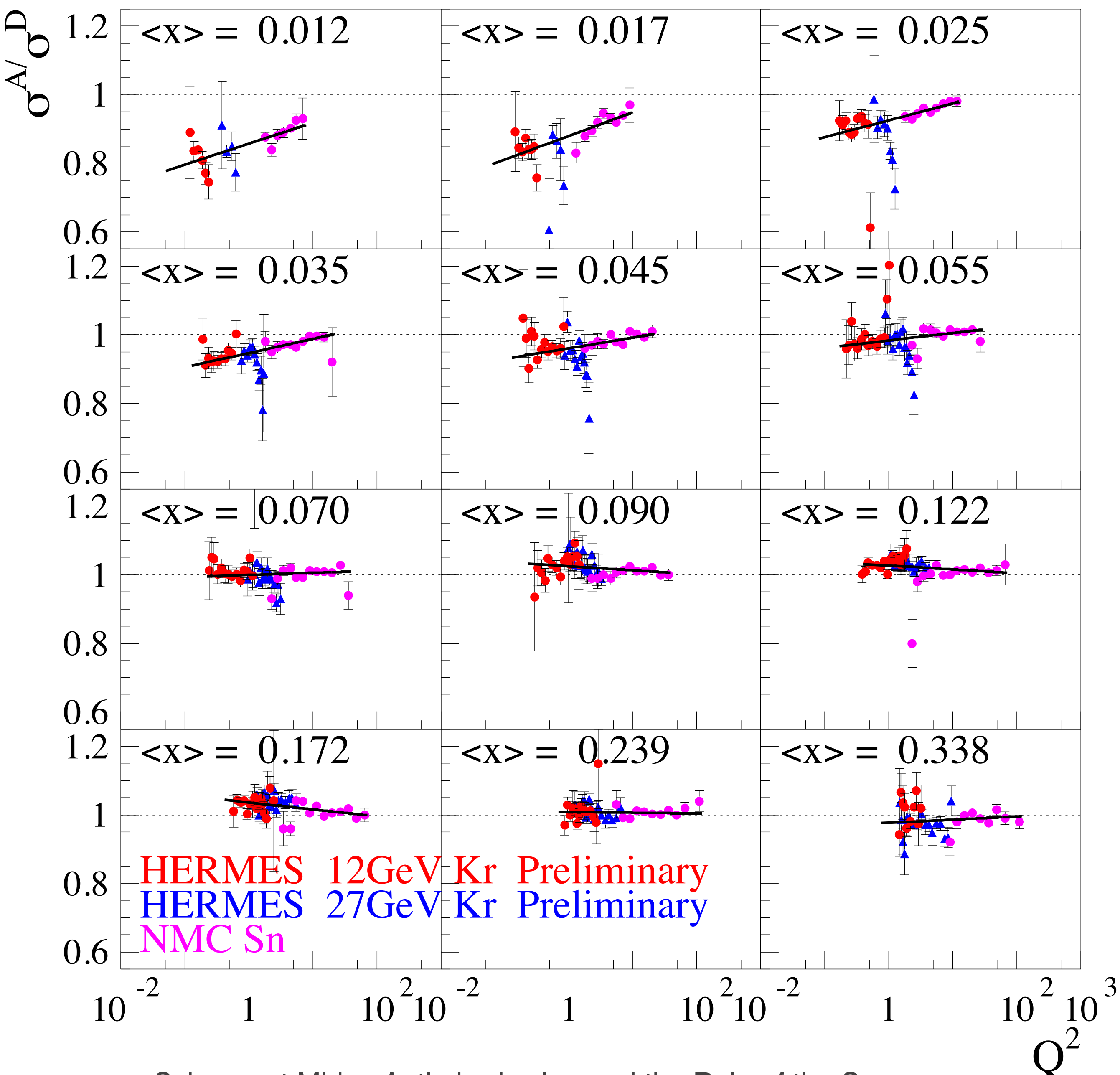
Cross Section Ratios - x dependence at 12 GeV



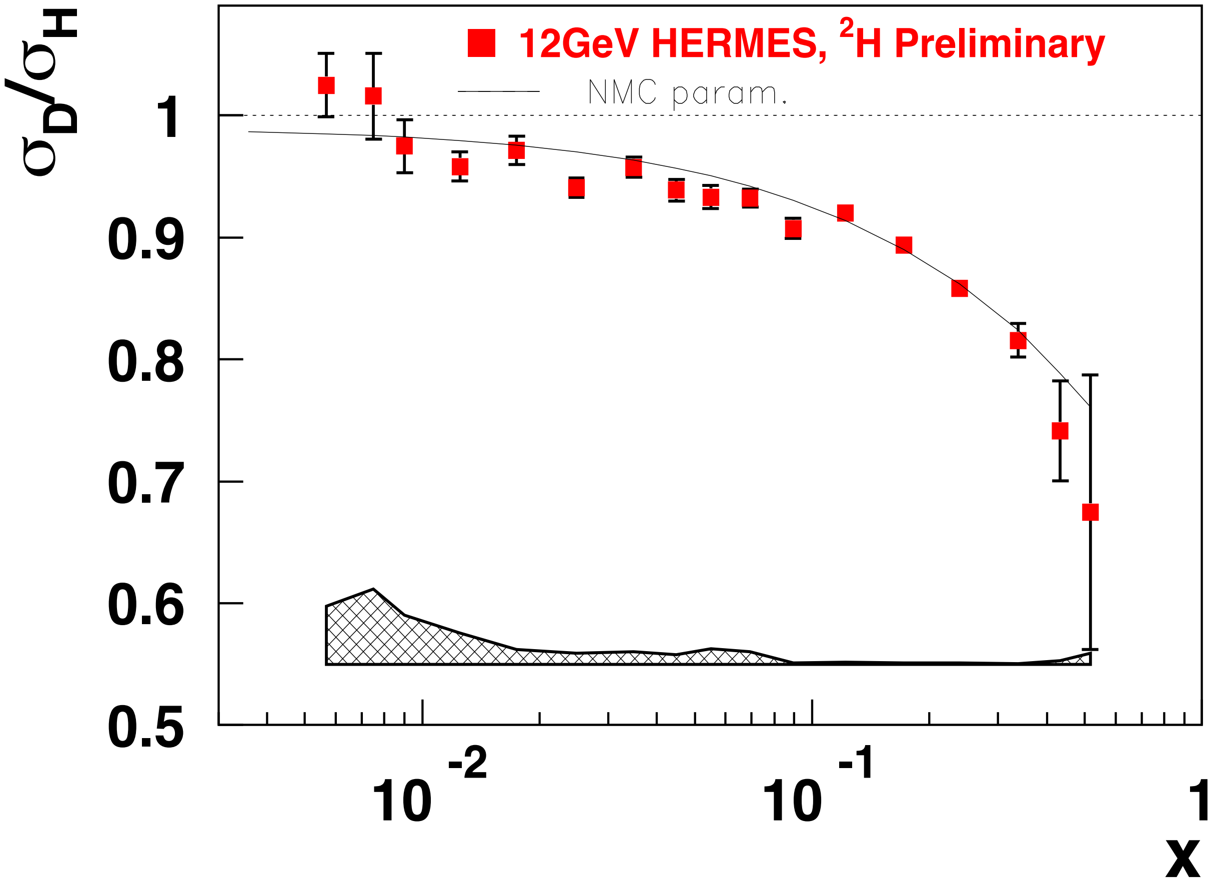
N Cross Section Ratios - Q^2 dependence at 12 GeV



Kr Cross Section Ratios - Q² dependence at 12 GeV



D/H Cross Section Ratios - x dependence at 12 GeV



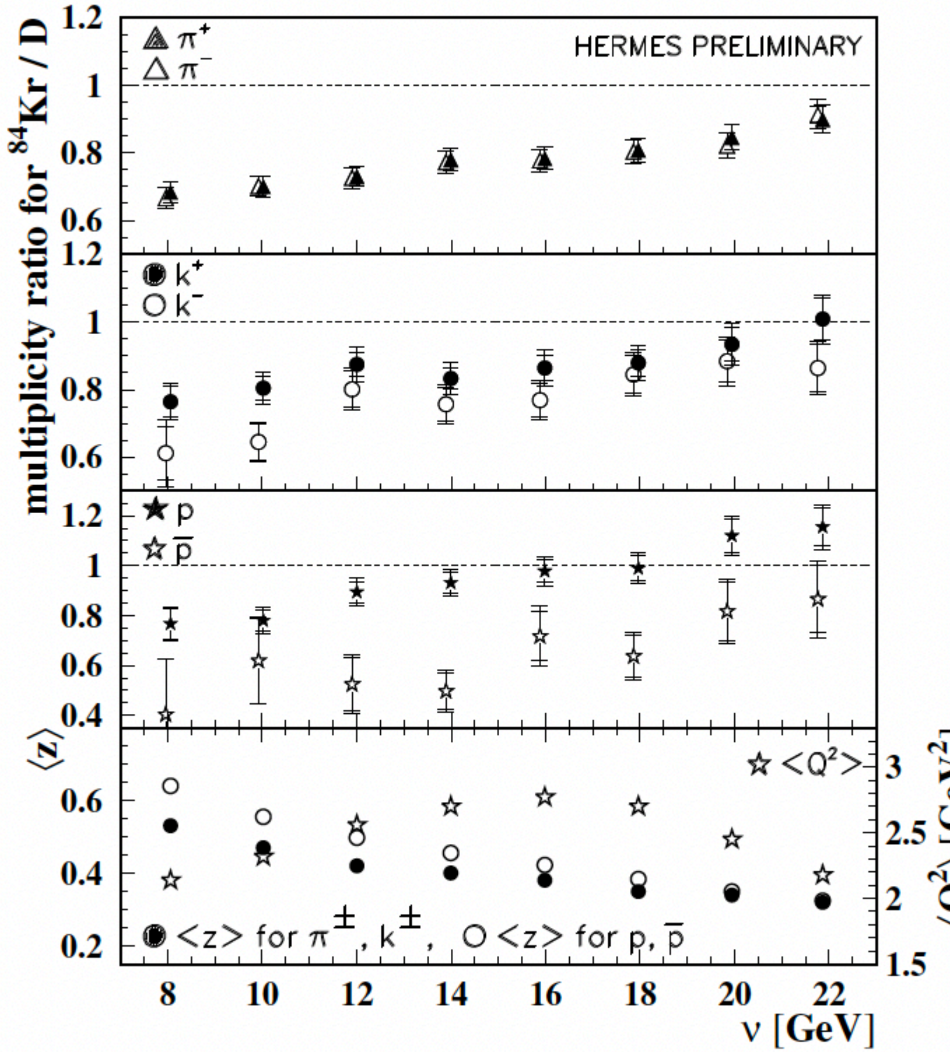
Conclusions from Inclusive DIS

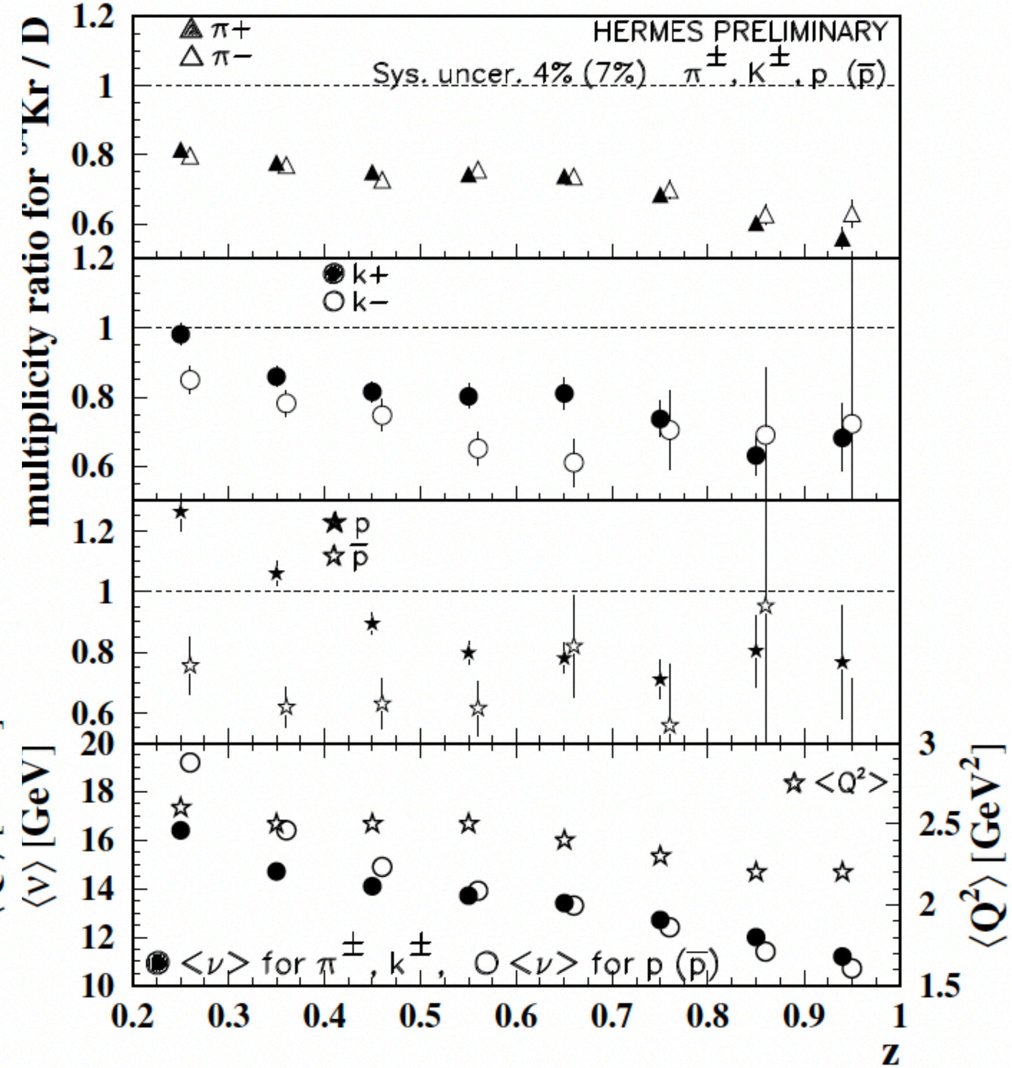
- Cross section ratios mostly in agreement with NMC/SLAC, evidence of Q^2 dependence confirmed (largest at low x)
- R_A/R_D agrees with earlier experiment, no strong Q^2 dependence, but rather large uncertainties!
- How well is R_D known now (as opposed to 2004)?

HERMES Semi-Inclusive DIS in Nuclei

- Focuses on nuclear attenuation of hadrons (relative to D)
- Lots of data for pions, kaons, and even protons
- Difficult to relate to anti-shadowing region - knowing more about the final state forces one to have to understand hadronization AND nuclear interactions

HERMES Semi-Inclusive DIS in Nuclei - Results

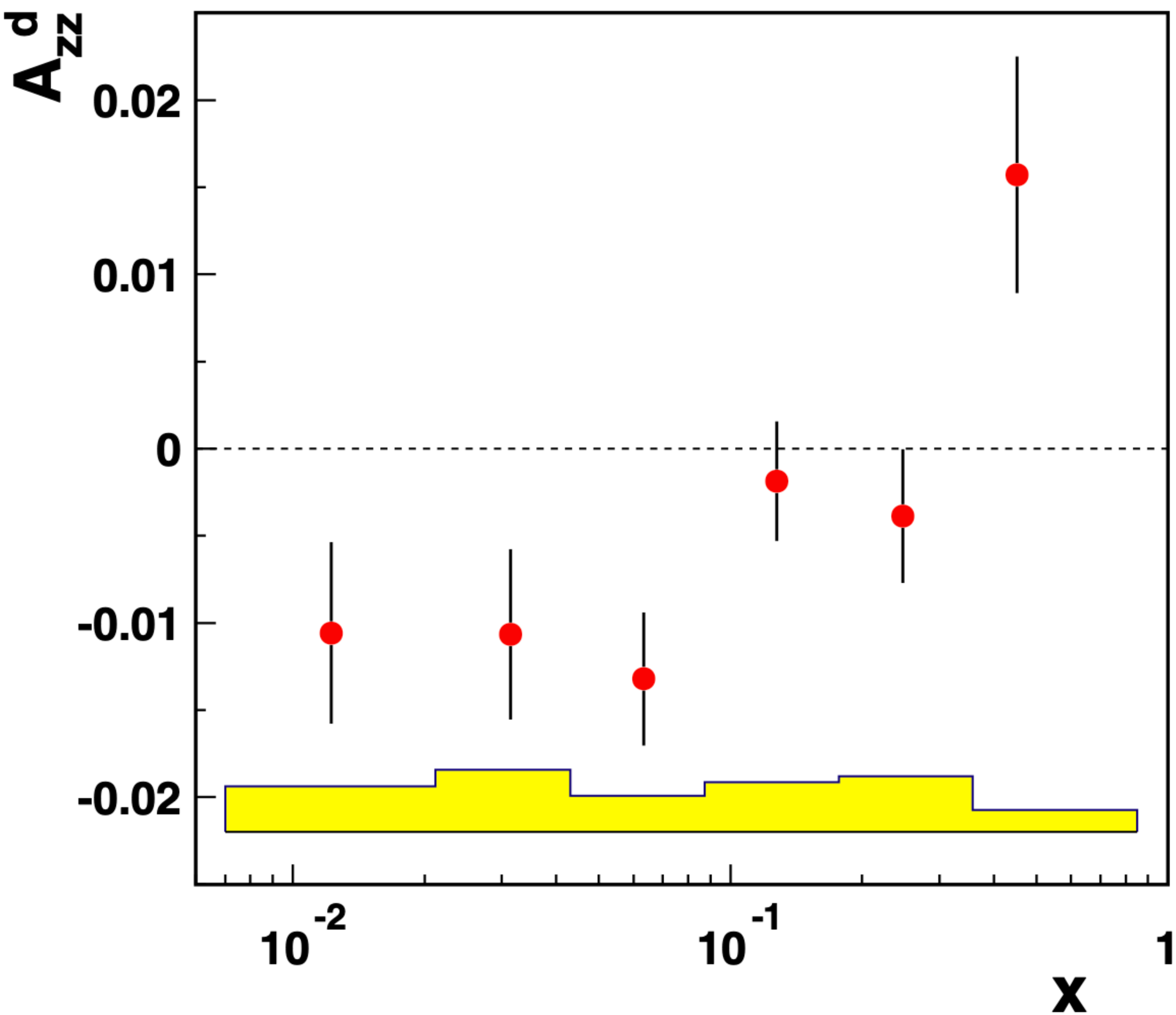




Wither EMC at higher energy?

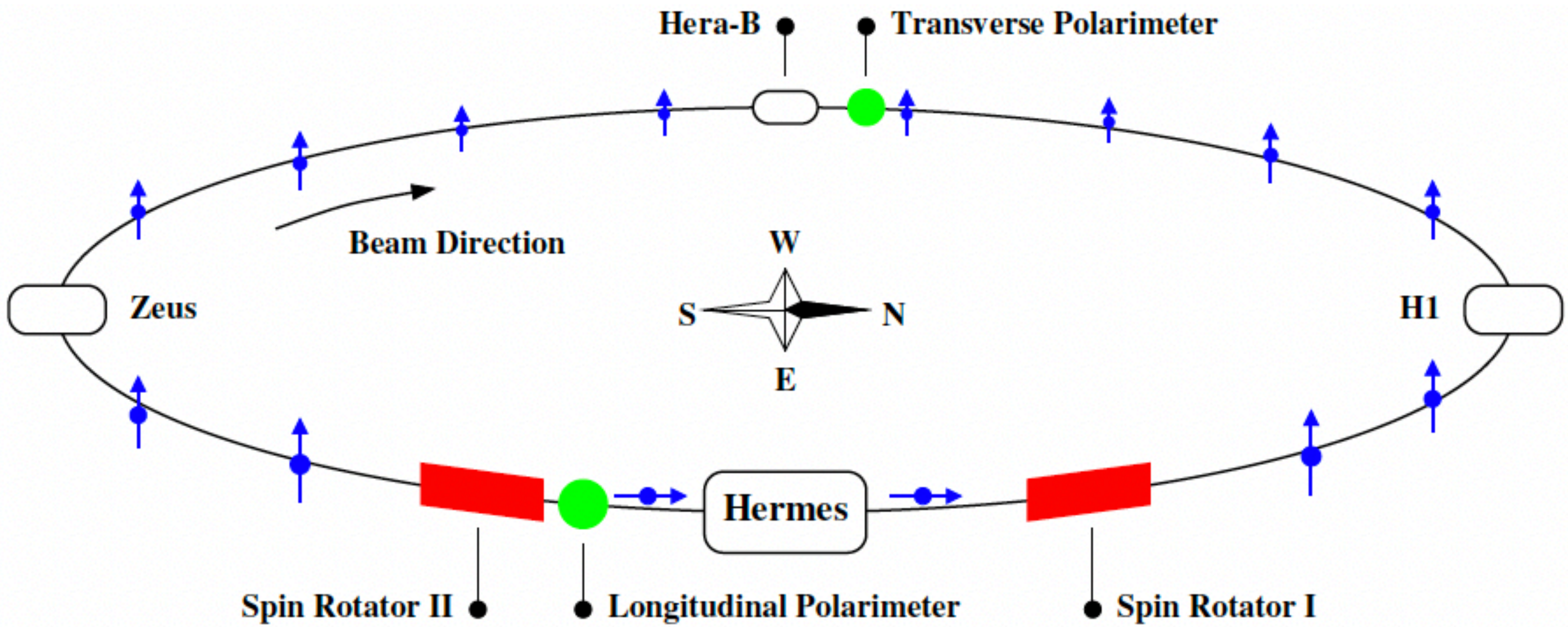
- Relatively broad Q^2 range covered by now; probably no surprises in cross section ratio
- R_A/R_D can be more precisely measured certainly!
- Ongoing JLab program going after nuclei with varying connection to nuclear mean field, SRC pairs and their possible effects
- Does looking at the resonance region give us a new handle?
- Maybe focus should be on D instead of A; does tensor polarization help?

Tensor Structure Function b_1

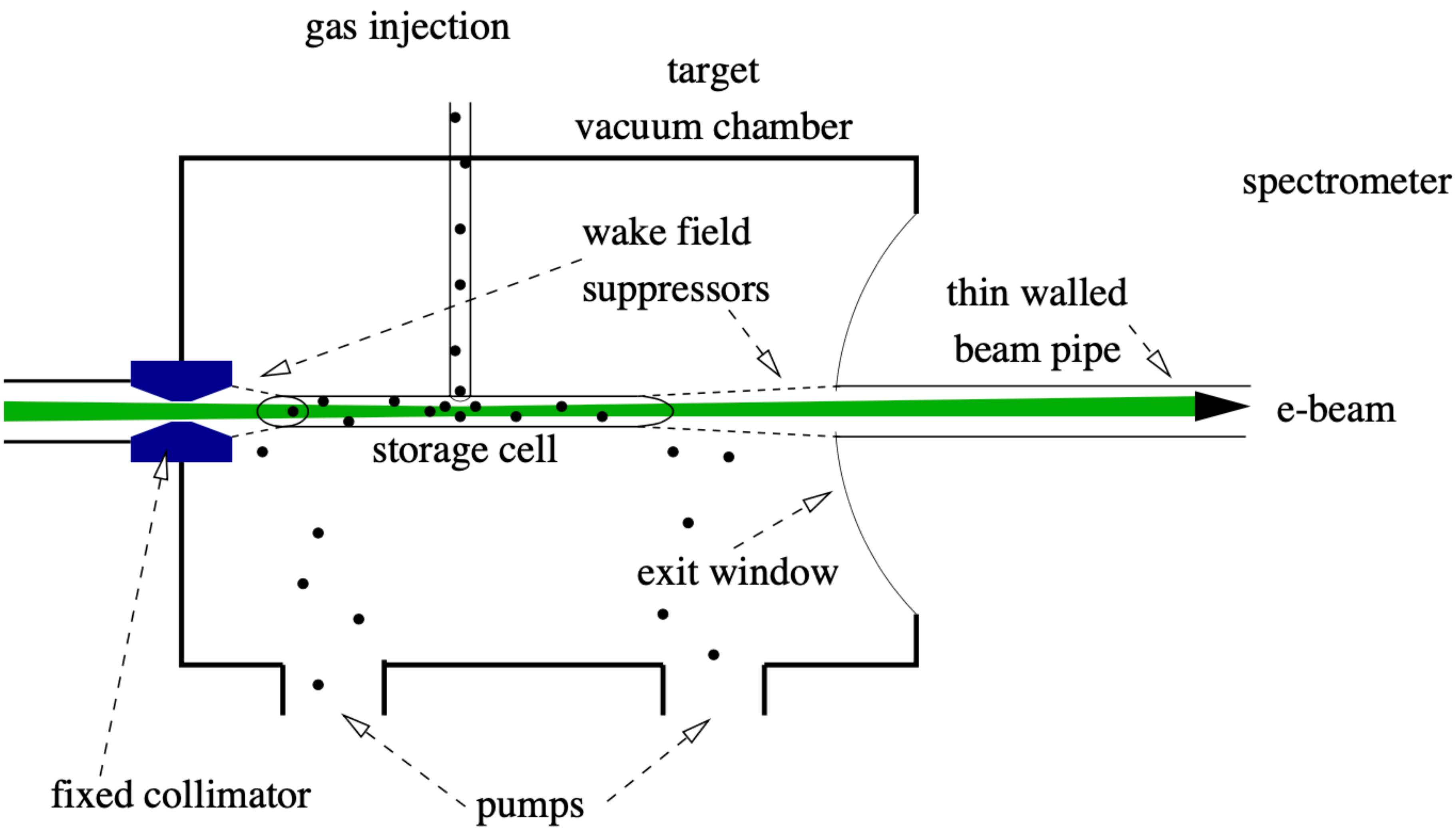


Backup

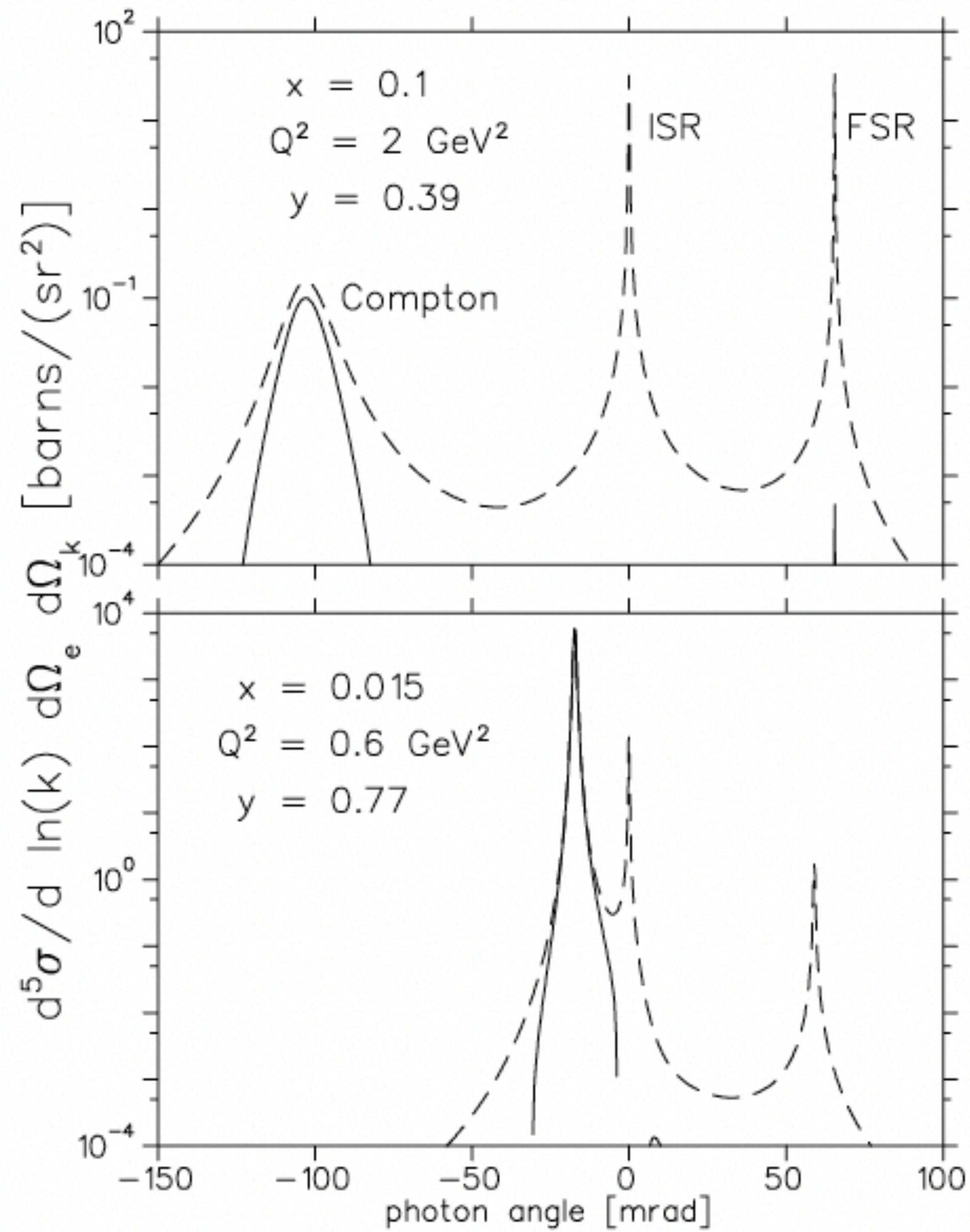
HERA Positrons



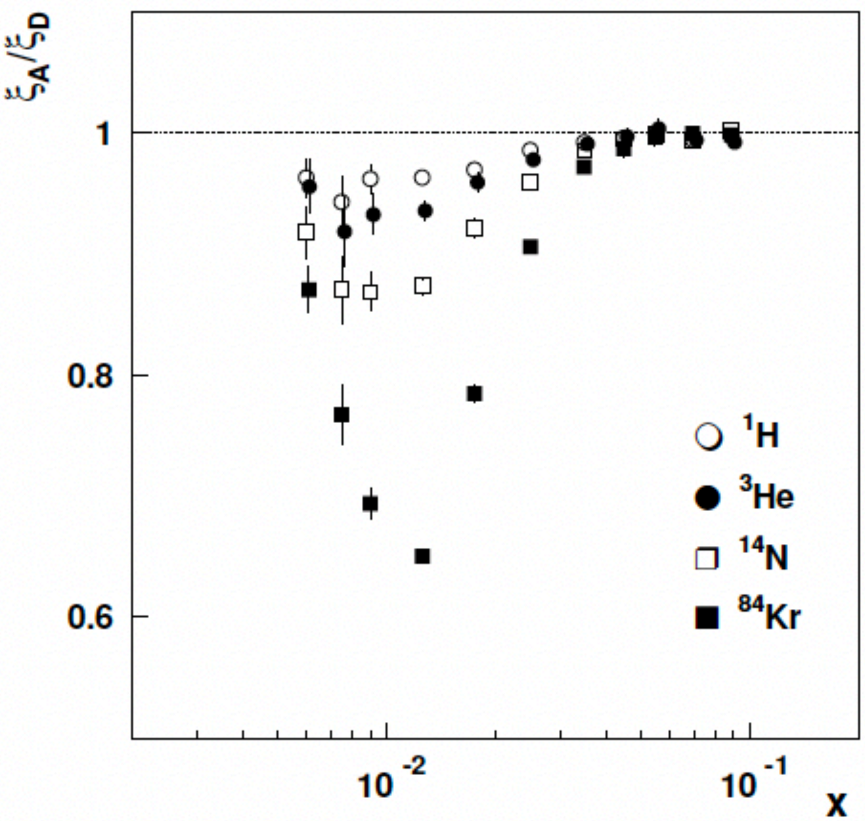
HERMES Internal Gas Target

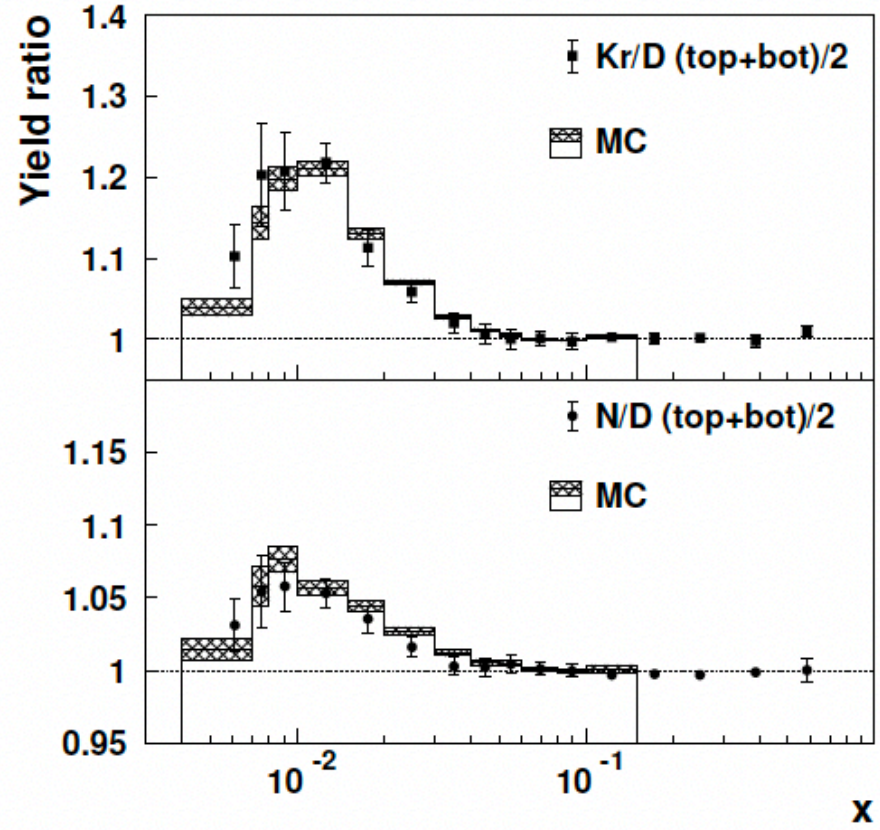


Bethe-Heitler at HERMES

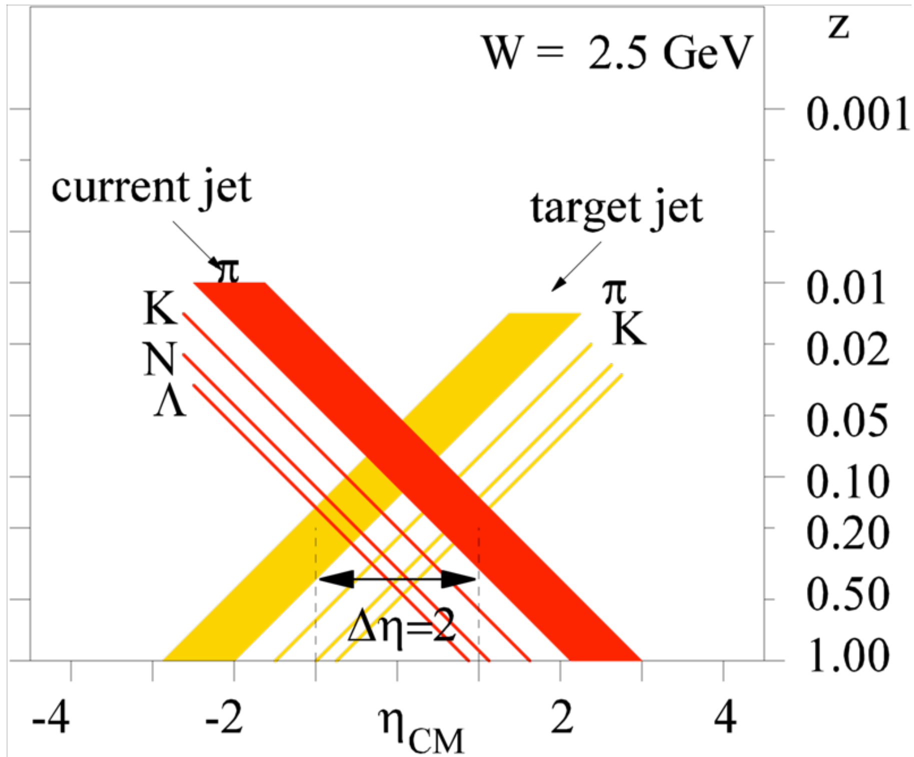


Tracking Correction for BH Showers





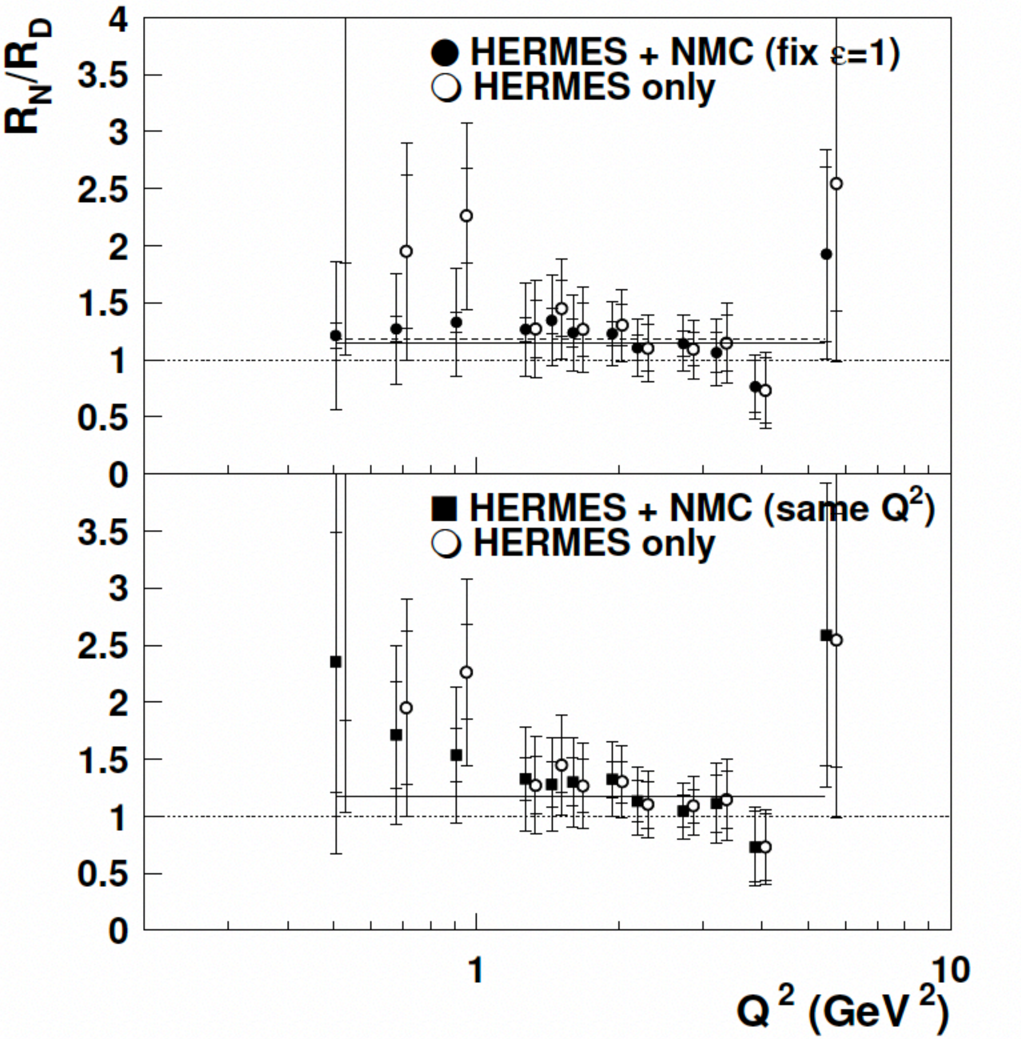
Current vs Target?

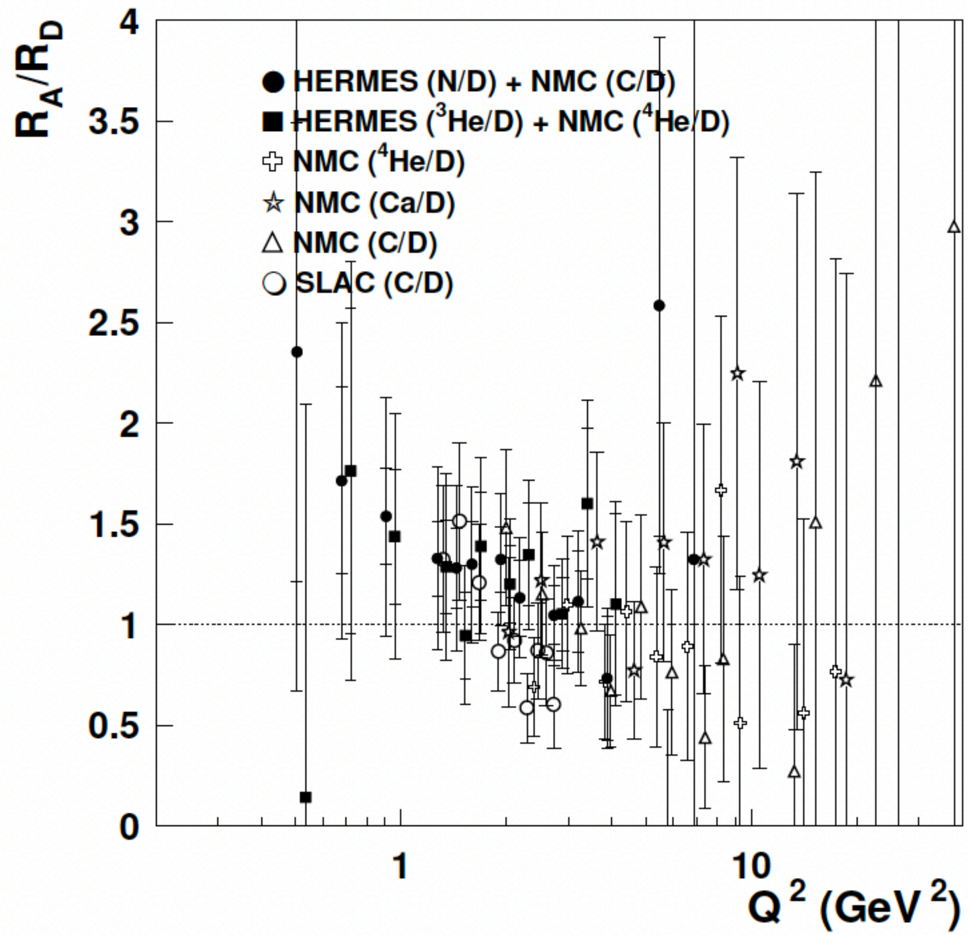


P.J. Mulders, hep-ph/0010199 (EPIC Workshop, MIT, 2000)

- Strict application of Berger "criterion" will limit useful range of kinematics; can we push our understanding to develop a more sophisticated measure?
- How do we expand this picture to handle large p_T?

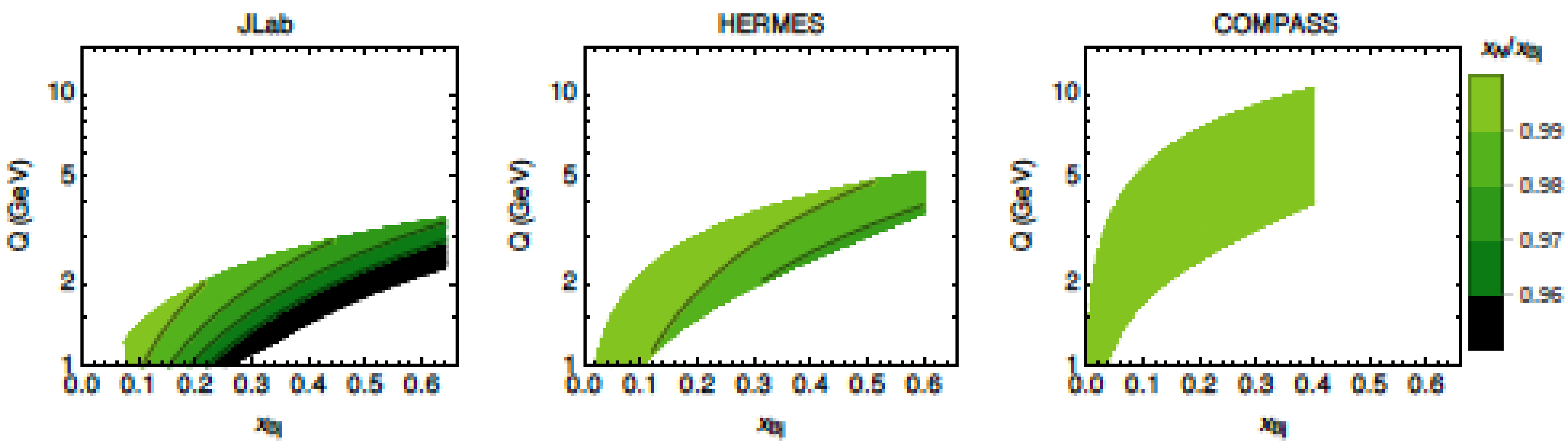
Alternate Rosenbluth Separation (HERMES + NMC)





New Theoretical Guidance

Mapping the Kinematical Regimes of Semi-Inclusive Deep Inelastic Scattering,
M. Boglione, A. Dotson, L. Gamberg, S. Gordon, J.O. Gonzalez-Hernandez, A. Prokudin, T.C. Rogers, and N. Sato, (2019), ArXiv:1904.12882

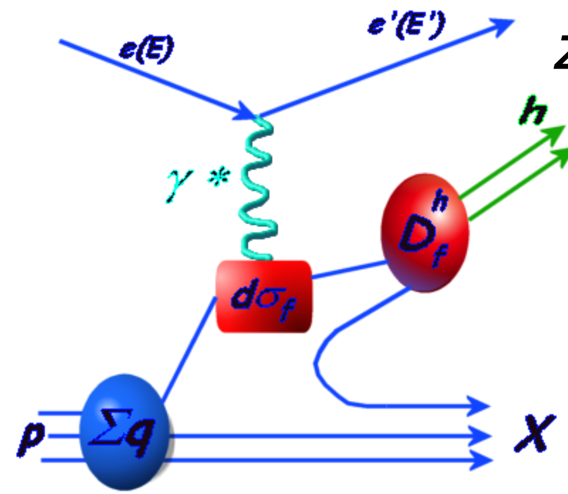


Example: Study of kinematic deviation between Nachtmann and Bjorken x

Do parton distributions and fragmentation functions factorize at Jefferson Lab energies?

Flavor Decomposition of SIDIS

$$\frac{1}{\sigma_{(e,e')}}\frac{d\sigma}{dz}(ep \to hX) = \frac{\sum_q e_q^2 f_q(x) D_q^h(z)}{\sum_q e_q^2(x) f_q(x)}$$



$z = E_h/\nu$

$f_q(x)$: parton distribution function

$D_q^h(z)$: fragmentation function

$M_x^2 = W'^2 \sim M^2 + Q^2\,(1/x - 1)(1 - z)$

- Leading-Order (LO) QCD
- after integration over $p_{h\perp}$ and Φ_h
- NLO: gluon radiation mixes
  x and z dependences
- Target-Mass corrections at large z
- ln(1-z) corrections at large z

With p_T and k_T dependences, some kind of convolution is necessary to obtain final $P_{h\perp}$

SIDIS Cross Section

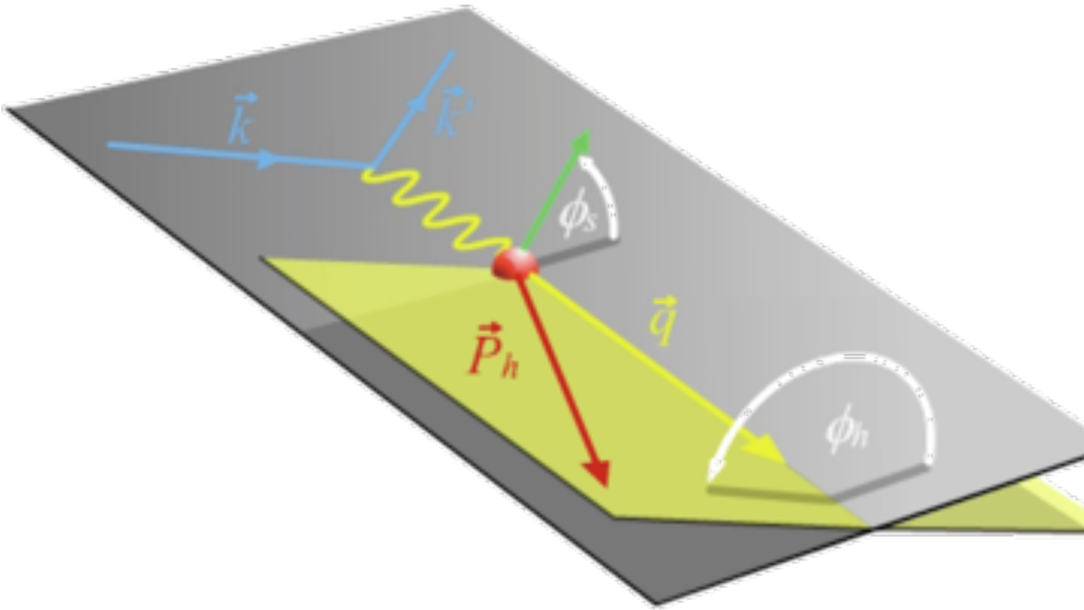
$$\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h,t}^2} = \frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Big\{F_{UU,T} + \varepsilon F_{UU,L} +$$

$$\sqrt{2\varepsilon(1+\varepsilon)}\cos\phi_h F_{UU}^{\cos\phi_h} + \varepsilon\cos(2\phi_h)F_{UU}^{\cos(2\phi_h)} + \lambda_e\sqrt{2\varepsilon(1+\varepsilon)}\sin\phi_h F_{LU}^{\sin\phi_h}\Big\}$$

Q^2 = Virtual Photon Mass

ε = Virtual Photon Polarization

λ = Long. Beam Polarization



General formalism for (e,e'h) coincidence reaction w. polarized beam: [A. Bacchetta et al., JHEP 0702 (2007) 093]

(Ψ = azimuthal angle of e' around the electron beam axis w.r.t. an arbitrary fixed direction)