Istituto Nazionale
di Fisica Nucleare

Electron Ion Collider User Group Meeting 2017

18-22 July 2017

Parallel Session 4: 3D nucleon and nucleus structure

A. Martin/ B. Pasquini

Nucleon and Nucleus GPDs N. D'Hose S. Niccolai S. Scopetta A. Manashov

Nucleon TMDs I. Cloet A. Schäfer Z. Kang C. Pisano F. Bradamante
A. Vladimirov D. Gutierrez U. D'Alesio

Fragmentation Functions M. Diefenthaler O. Gonzalez Hernandez

Thank you to all the speakers

Our apologies where we omitted your favorite topic…….

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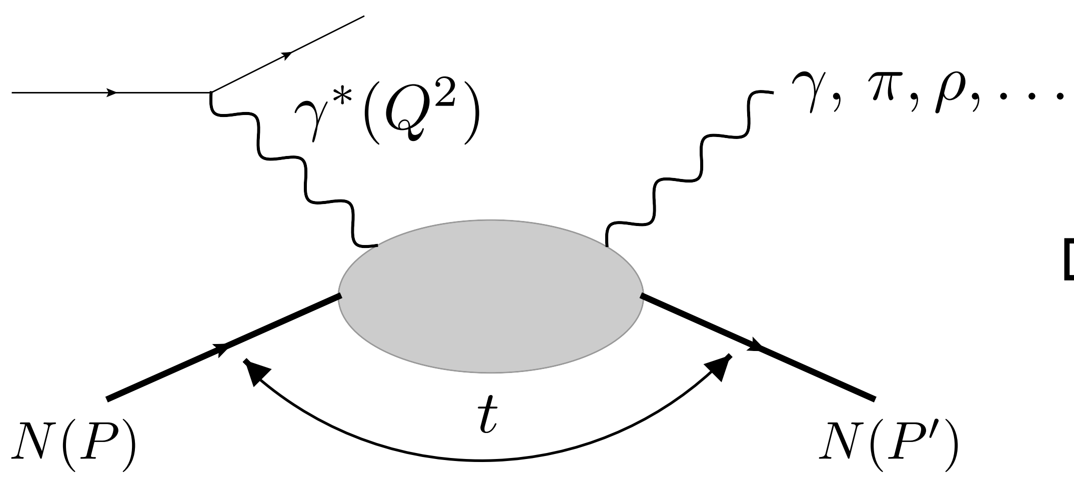
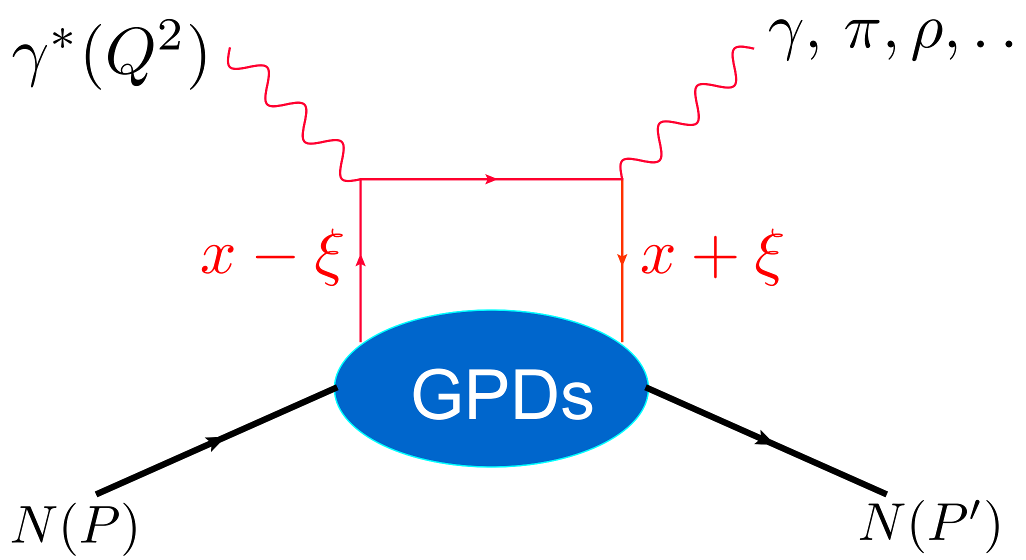
How to access GPDs

N. D'Hose, S. Niccolai





factorization for large Q^2, |t|<< Q^2 , s

$\mathcal{M}$ =[parton Ampl.] $\otimes$ [GPDs]

$P \neq P' \Rightarrow$ GPDs depend on two momentum fractions x, ξ, and t

$$x = \frac{(k+k')^+}{(P+P')^+} = \frac{\bar{k}^+}{\bar{P}^+}$$

average fraction of the longitudinal momentum carried by partons

$$\xi = \frac{(P-P')^+}{(P+P')^+} = -\frac{\Delta^+}{2\bar{P}^+}$$

skewness parameter: fraction of longitudinal momentum transfer

$$t = (P-P')^2 \equiv \Delta^2$$

t-channel momentum transfer squared

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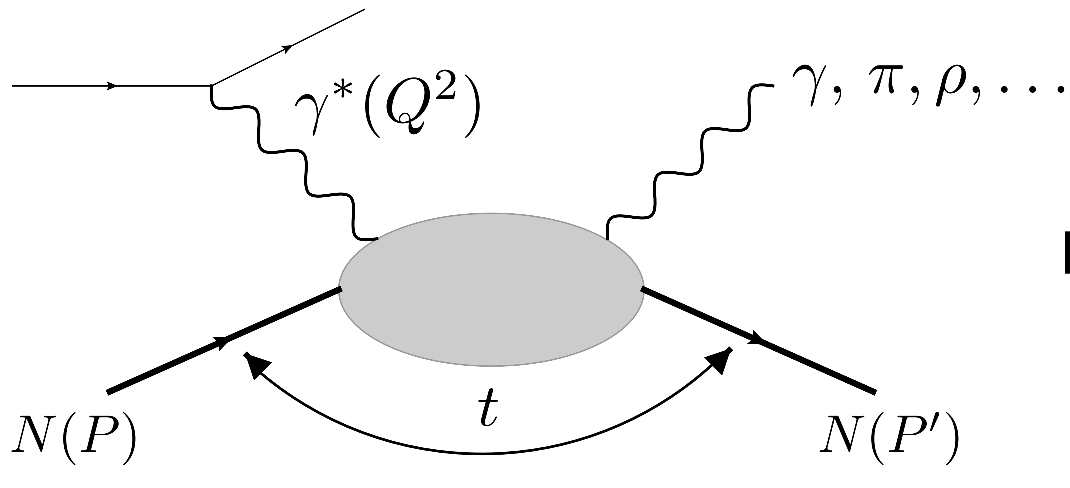

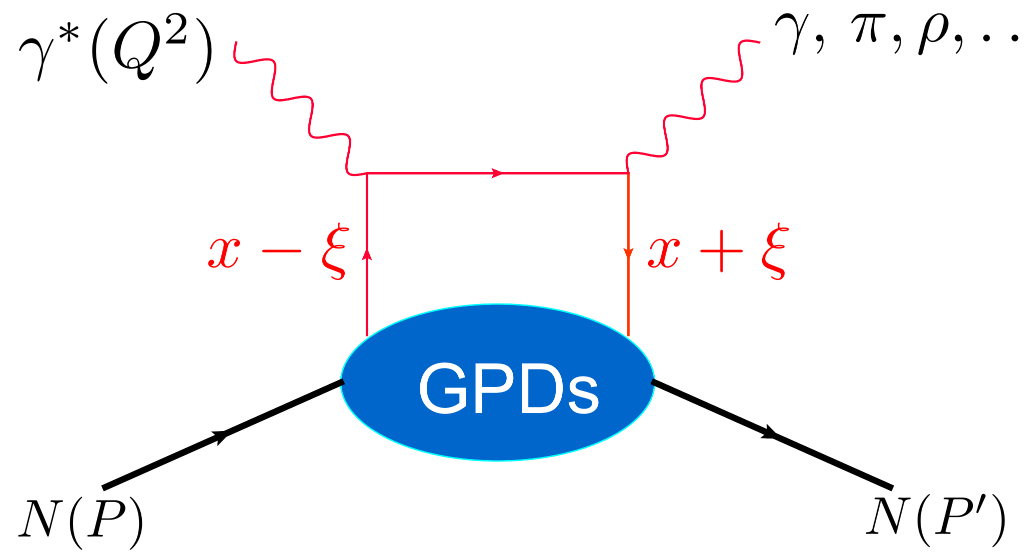

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8 GPDs at LO and leading-twist

$H(x,\xi,t),\ \tilde{H}(x,\xi,t),\ E(x,\xi,t),\ \tilde{E}(x,\xi,t)$

Chiral even

$H_T(x,\xi,t),\ \tilde{H}_T(x,\xi,t),\ E_T(x,\xi,t),\ \tilde{E}_T(x,\xi,t)$

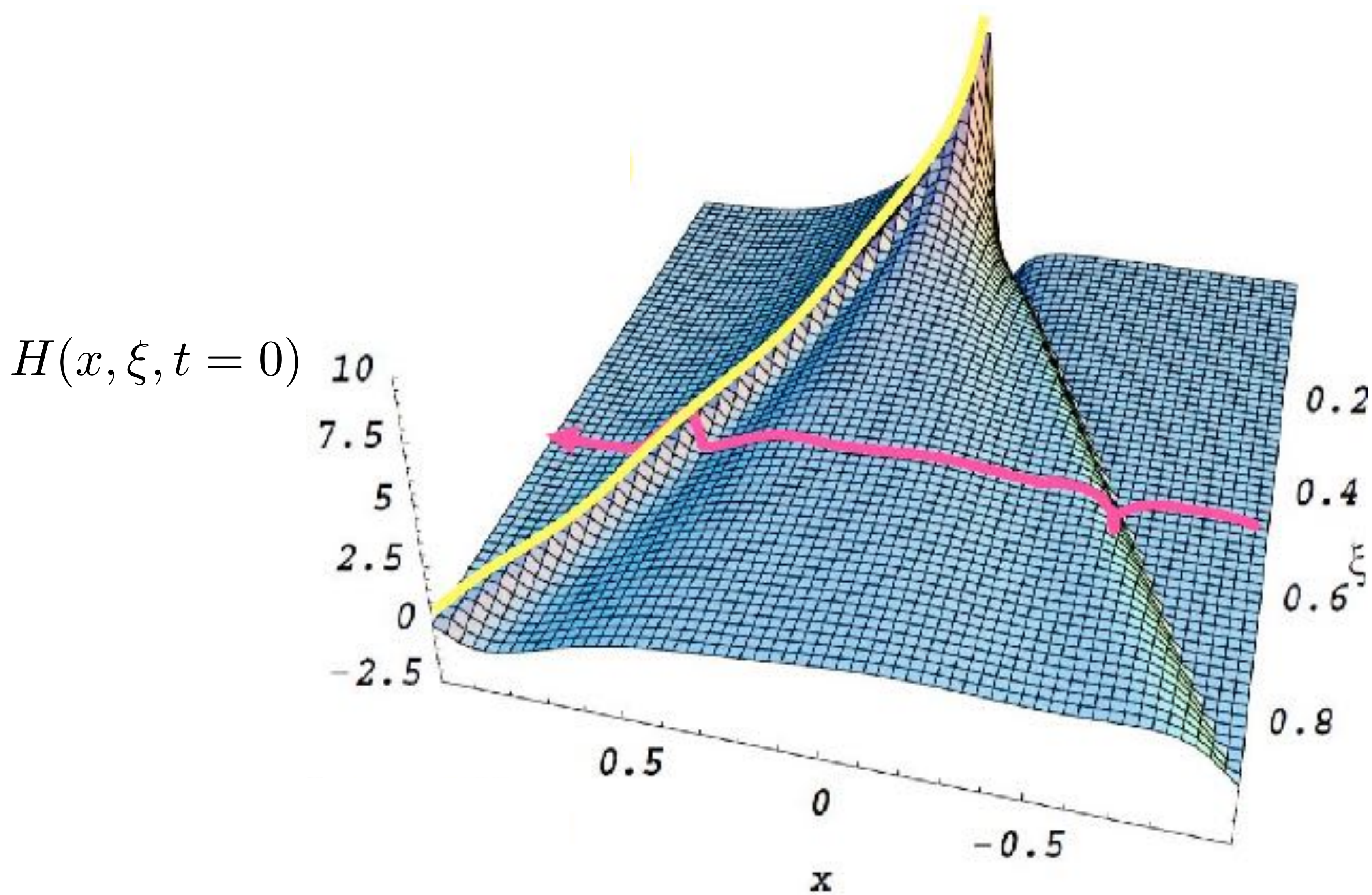
Chiral odd

Compton form factors

$$\int_{-1}^{+1} \mathrm{d}x \frac{H(x,\xi,t)}{x-\xi+i\epsilon} = \mathcal{P}\int_{-1}^{+1} \mathrm{d}x \frac{H(x,\xi,t)}{x-\xi} - i\pi H(\xi,\xi,t)$$

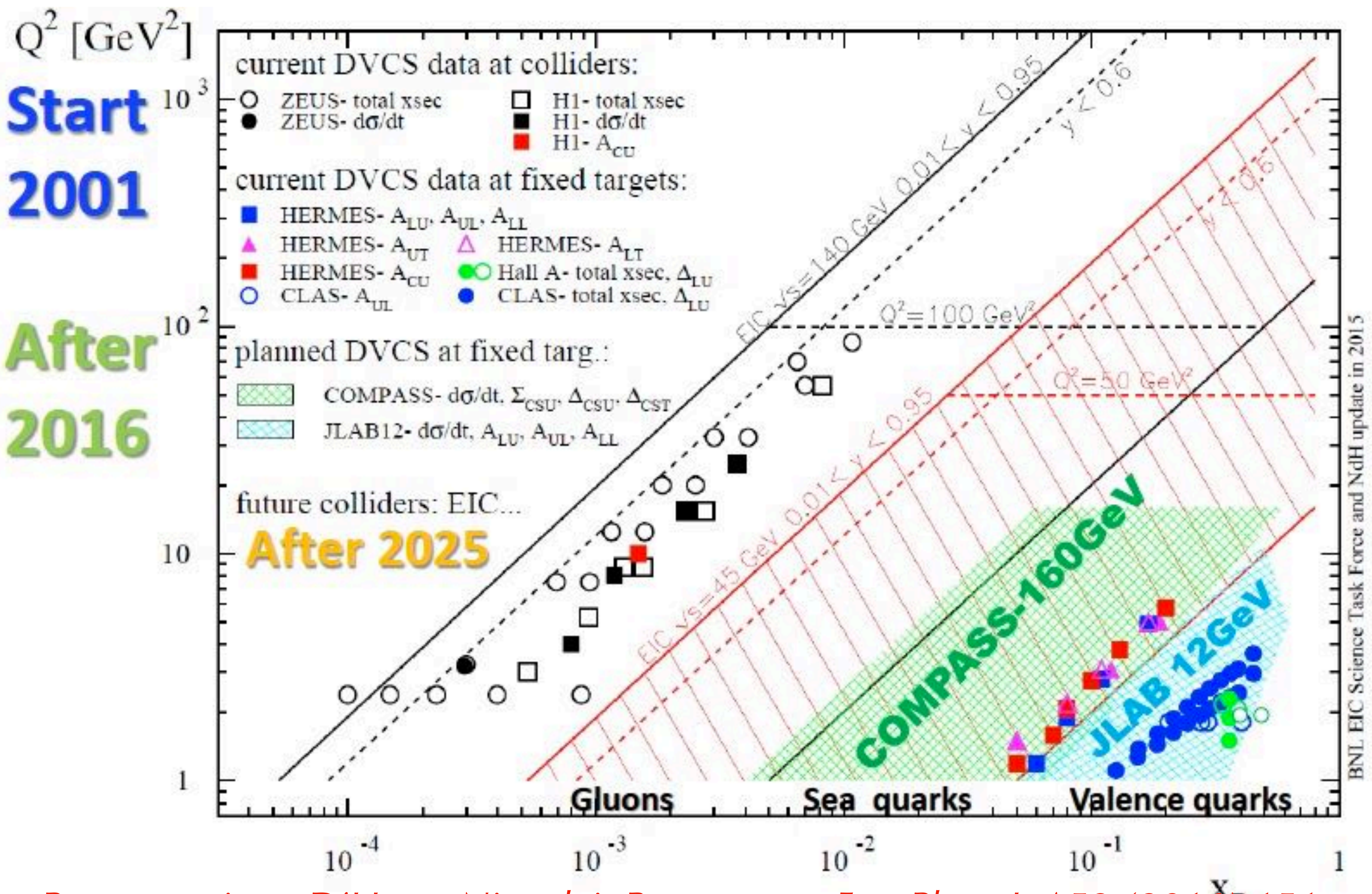
x is mute variable (integrated over), needs deconvolution

$\longrightarrow$ apart from `cross-over' trajectory ($x = \pm\xi$) GPDs non directly accessible



DVCS: past, present and future

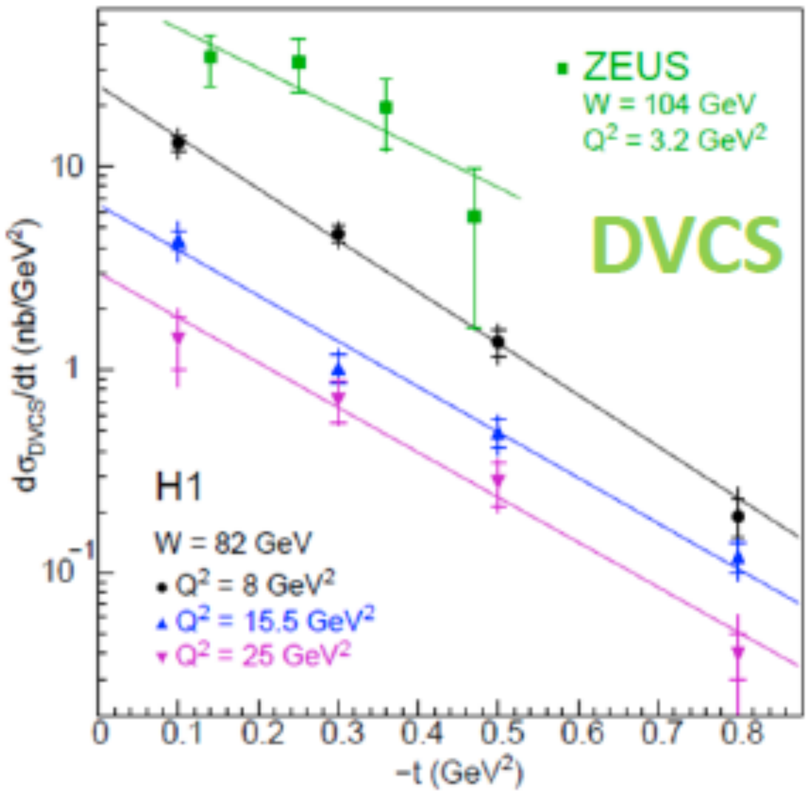
N. D'Hose



Recent review: D'Hose, Niccolai, Rostomyan, Eur. Phys. J. A52 (2016) 151

Gluon and sea quark imaging at HERA and COMPASS

Aaron et al., H1 Coll, PLB659 (2008)



$$\mathrm{d}\sigma^{\mathrm{DVCS}}/\mathrm{d}t \propto e^{-B|t|}$$

$$\langle r_\perp^2 \rangle \approx 2B$$

$$\sqrt{\langle r_\perp^2 \rangle} = 0.65 \pm 0.02 \ \mathrm{fm}$$

To be compared with

$$\sqrt{4 \frac{d}{dt} F_1^p}|_{t=0} = 0.67 \pm 0.01 \ \mathrm{fm}$$

N. D'Hose

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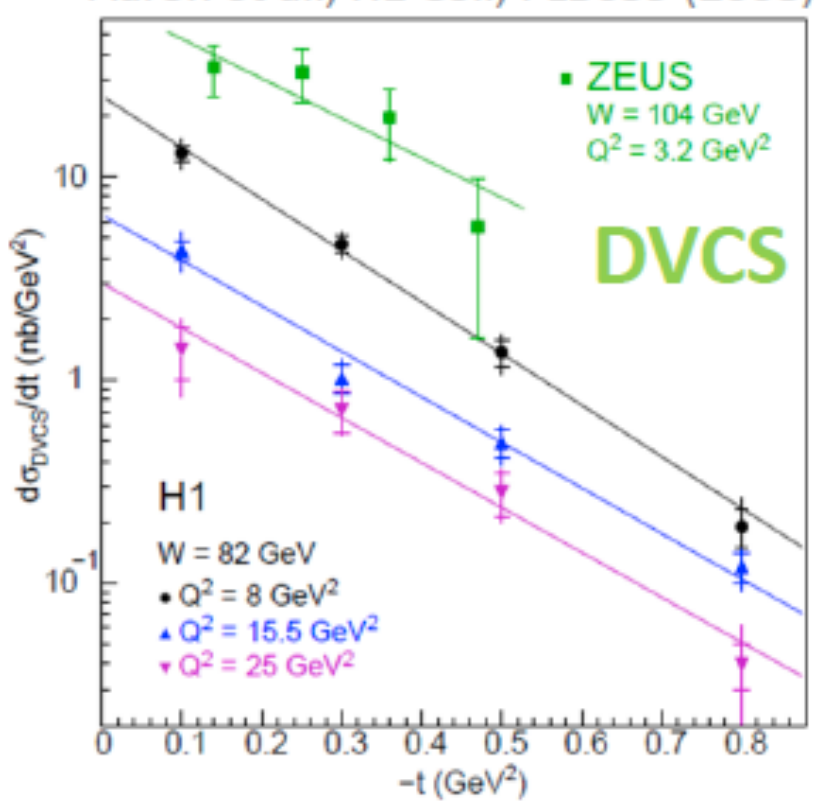

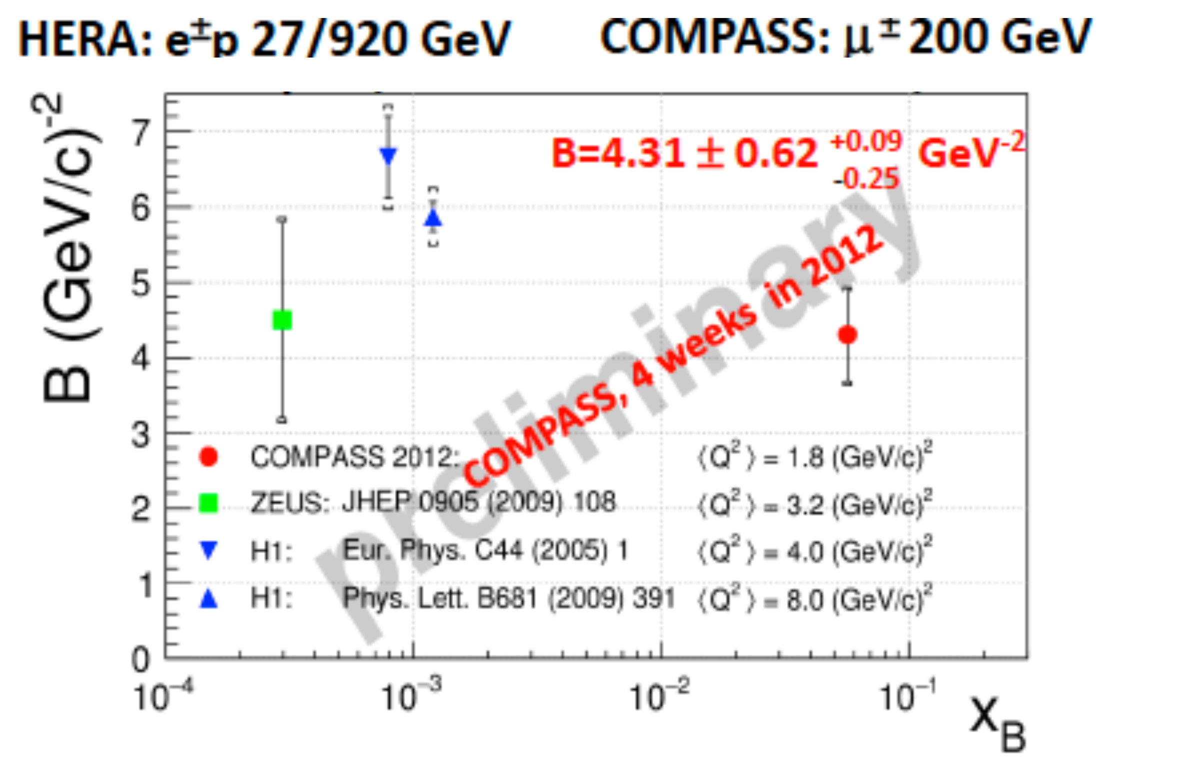

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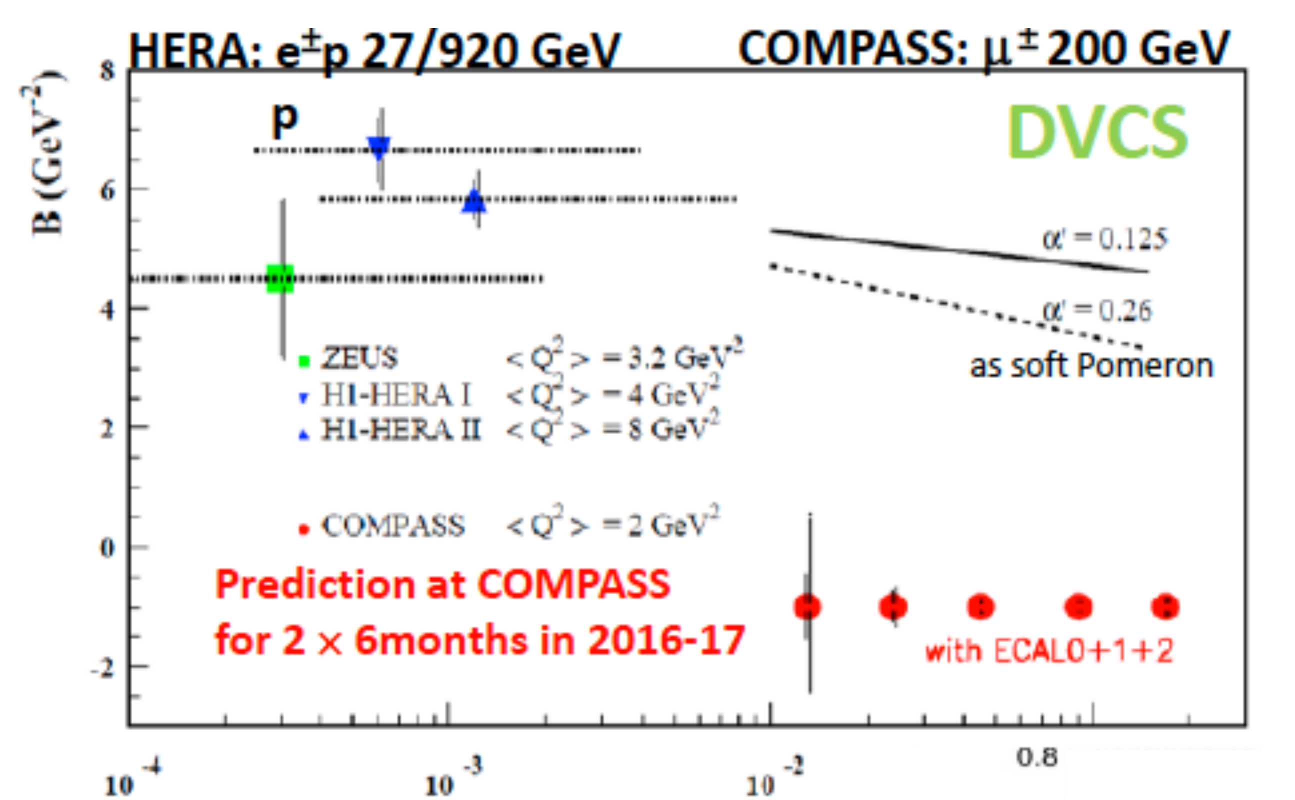
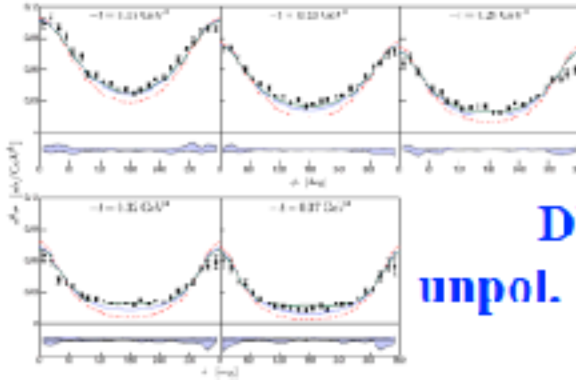


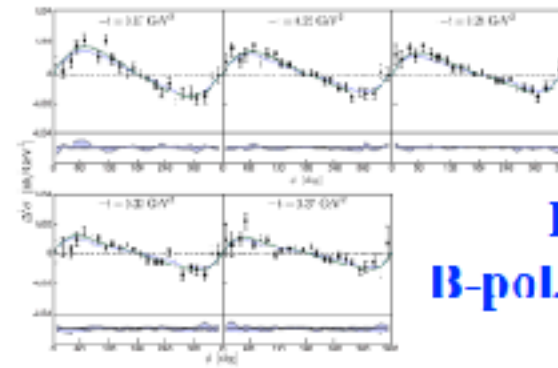
N. D'Hose

S. Niccolai

JLab
Hall A



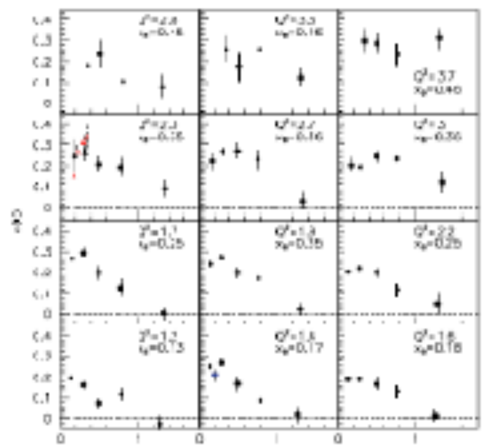
DVCS
unpol. X-section

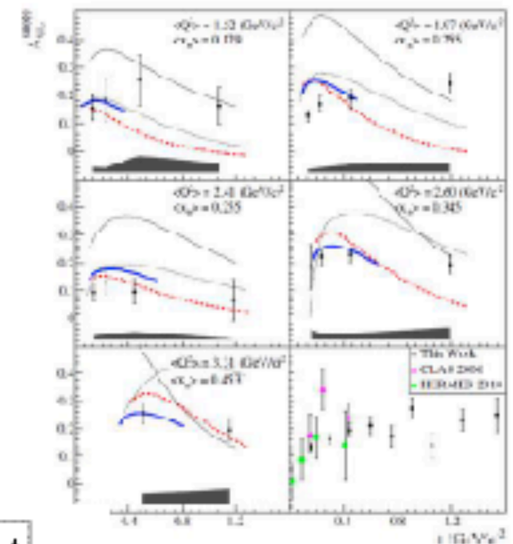


DVCS
B-pol. X-section

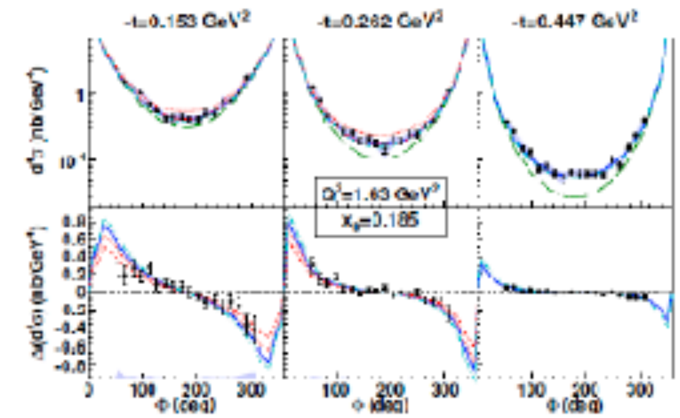
JLab
CLAS

DVCS
BSA



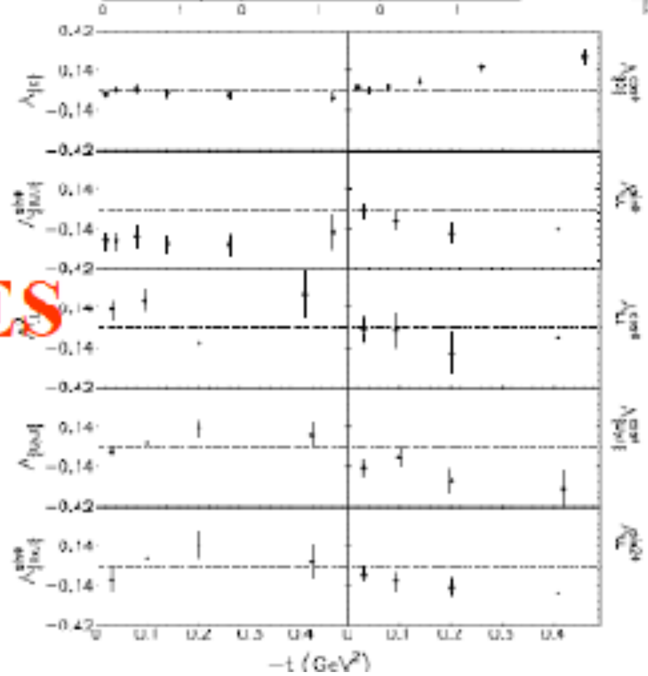


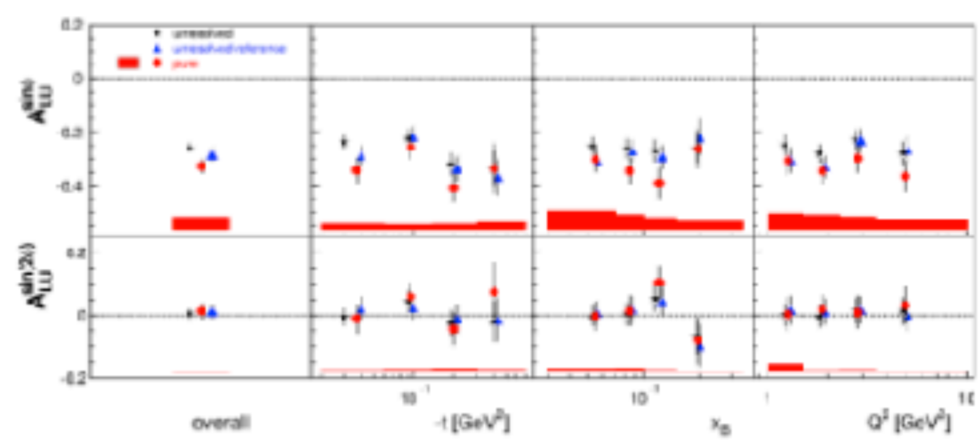
DVCS
lTSA



DVCS unpol. and
B-pol. X-sections

HERMES





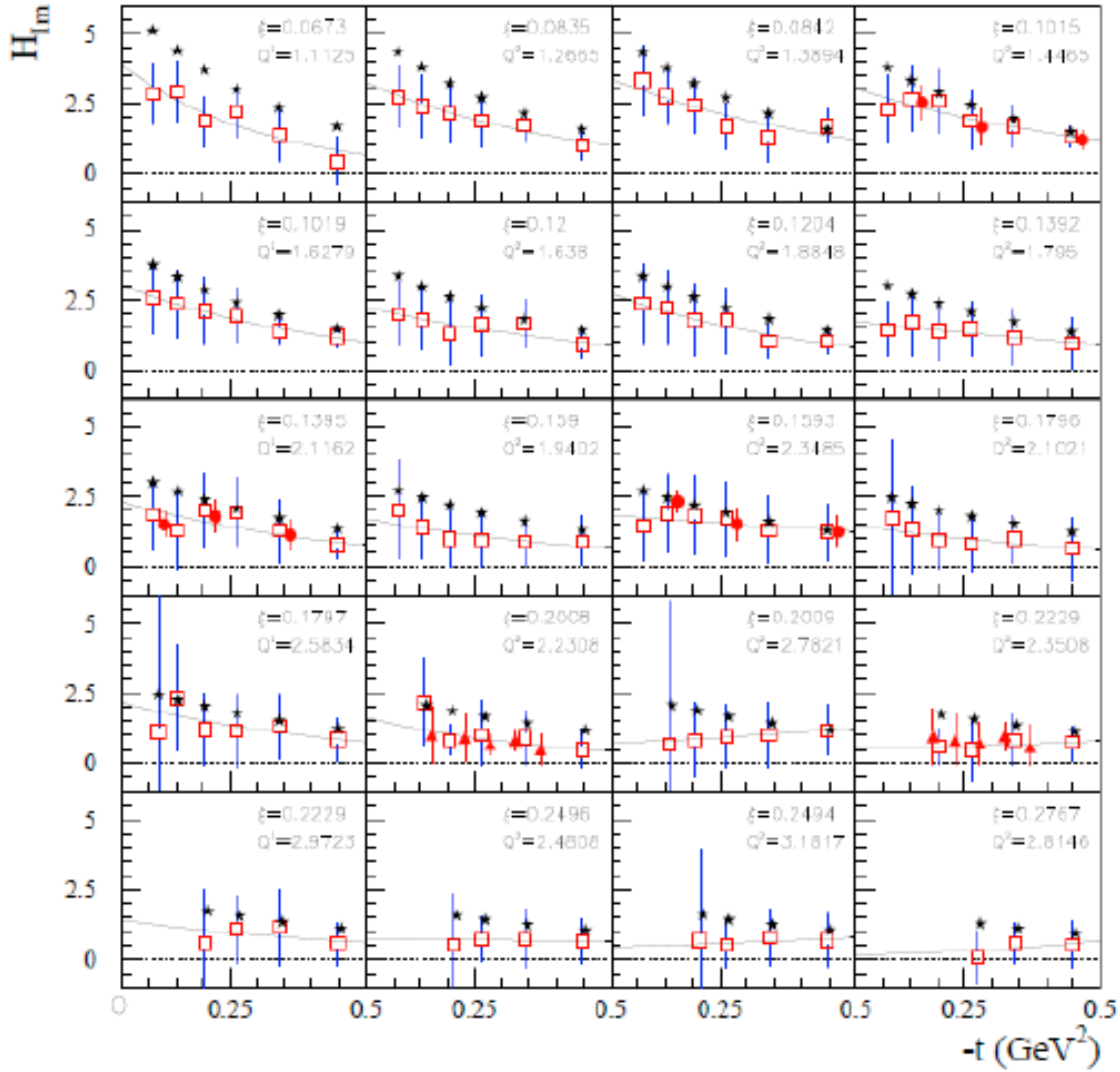
DVCS
BSA,lTSA,tTSA,BCA

- `Brute force' fitting: χ^2 minimization (MINUIT+MINOS) at given x, t and Q^2 point by varying 8 CFFs in a limited hyperspace

- Constraints on $\mathcal{H}_{Im}, \mathcal{H}_{Re}, \tilde{\mathcal{H}}_{Im}$

From Compton FFs to proton tomography

S. Niccolai



$$\mathcal{H}_{Im}(\xi,t) = A(\xi)e^{B(\xi)t}$$

$$\Big\downarrow \text{“deskewness”}$$

$$\xi = 0$$

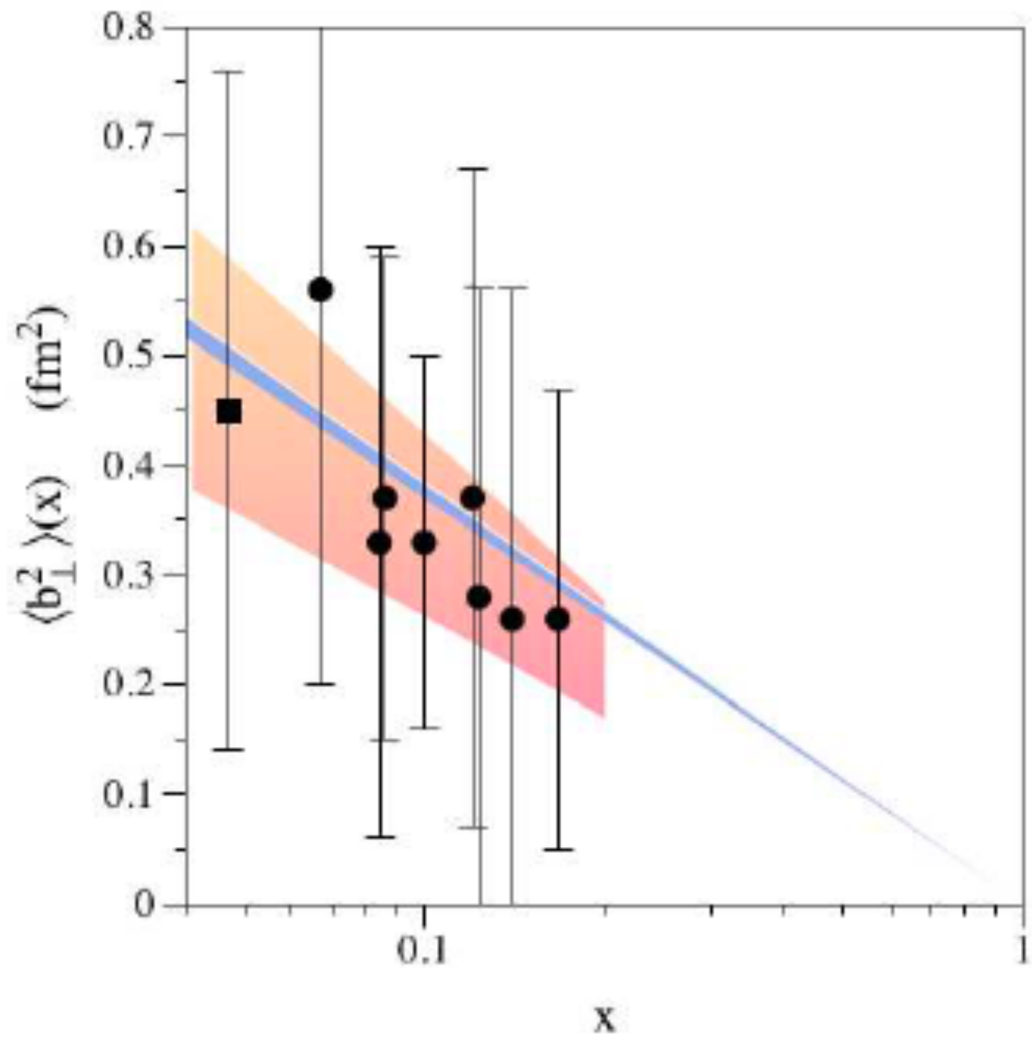
$$H(x,0,\vec{b}_\perp) = \int \mathrm{d}^2\Delta_\perp \, H(x,0,t)\, e^{-i\vec{\Delta}_\perp\cdot\vec{b}_\perp}$$

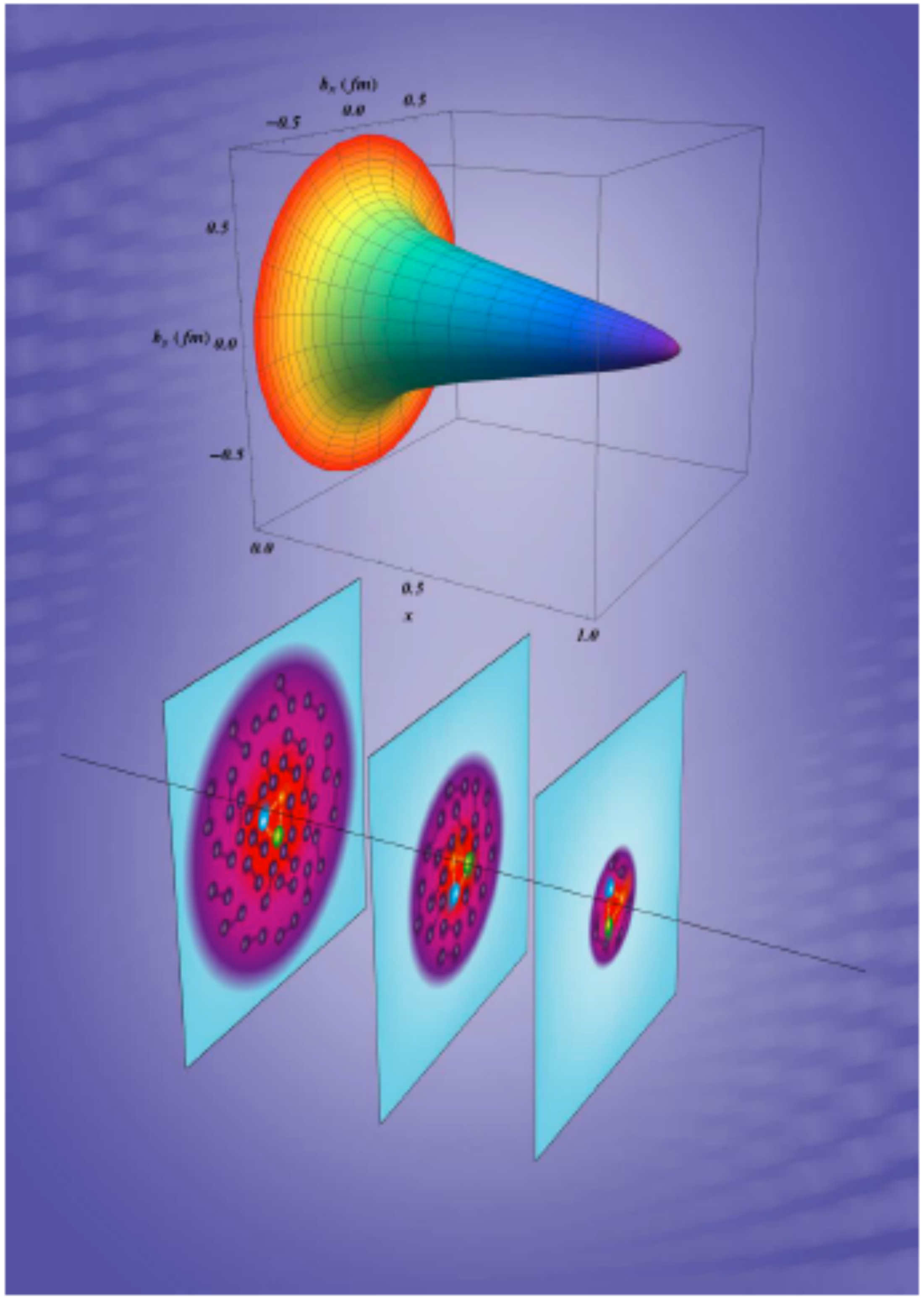
$$\langle \vec{b}_\perp^2(x)\rangle = \frac{\int \mathrm{d}^2\vec{b}_\perp\, \vec{b}_\perp^2\, H(x,0,b_\perp)}{\int \mathrm{d}^2\vec{b}_\perp H(x,0,b_\perp)}$$

Dupré, Guidal, Niccolai, Vanderhaeghen, arXiv: 1704.07330

From Compton FFs to proton tomography

$$\langle \vec{b}_\perp^{\,2}(x) \rangle = \frac{\int d^2\vec{b}_\perp \, \vec{b}_\perp^{\,2} \, H(x,0,b_\perp)}{\int d^2\vec{b}_\perp \, H(x,0,b_\perp)}$$





Dupré, Guidal, Niccolai, Vanderhaeghen, arXiv: 1704.07330

Finite t and target mass corrections in DVCS

A. Manashov

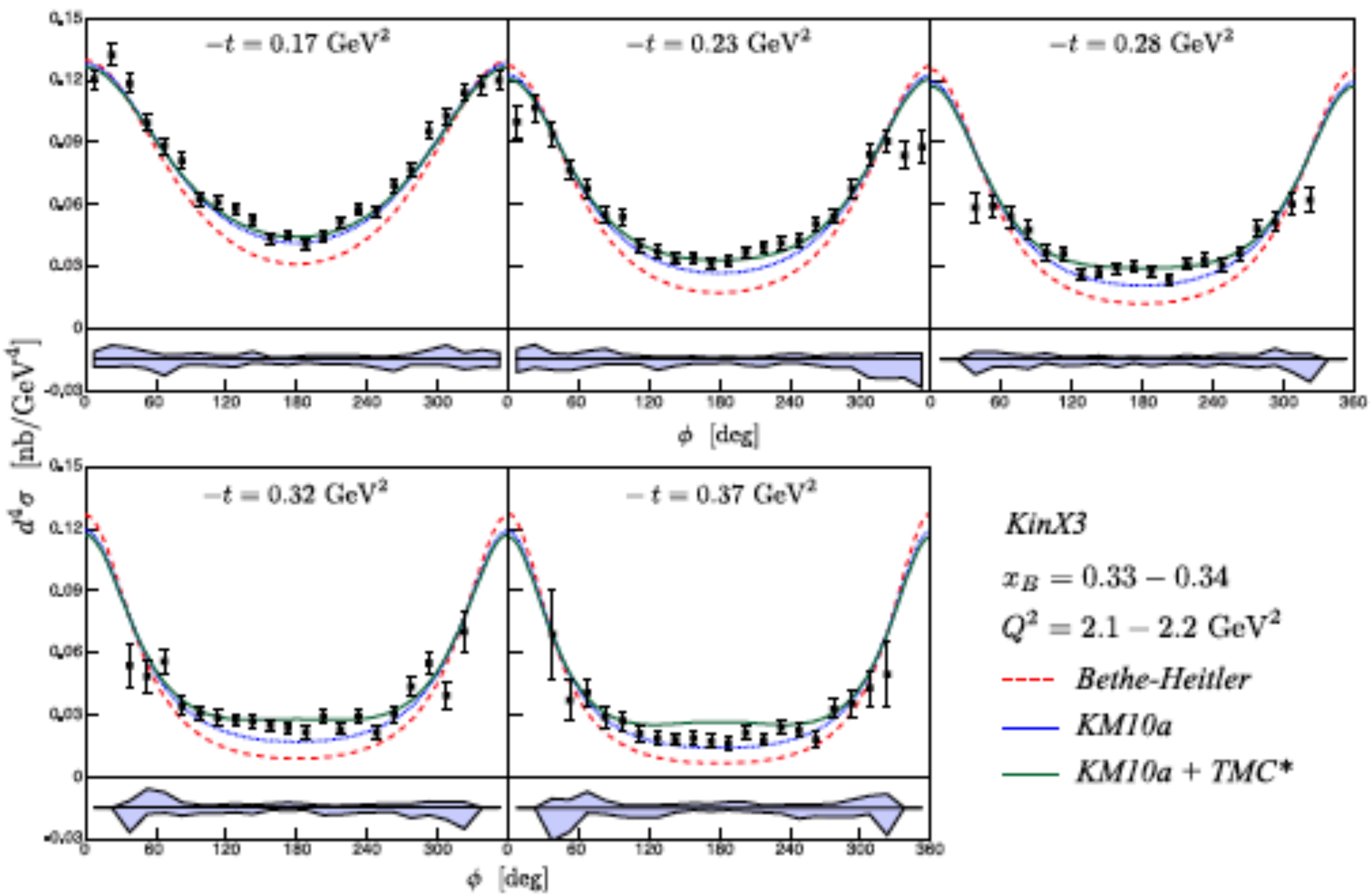
- Kinematic power corrections at twist-4: t/Q^2, M^2/Q^2

⟶ restore gauge- and translation-invariance of twist-2 DVCS amplitude

- They can become important in the Q^2 range of present experiments

⟶ large effects for the total cross section, small moderate effects for asymmetries

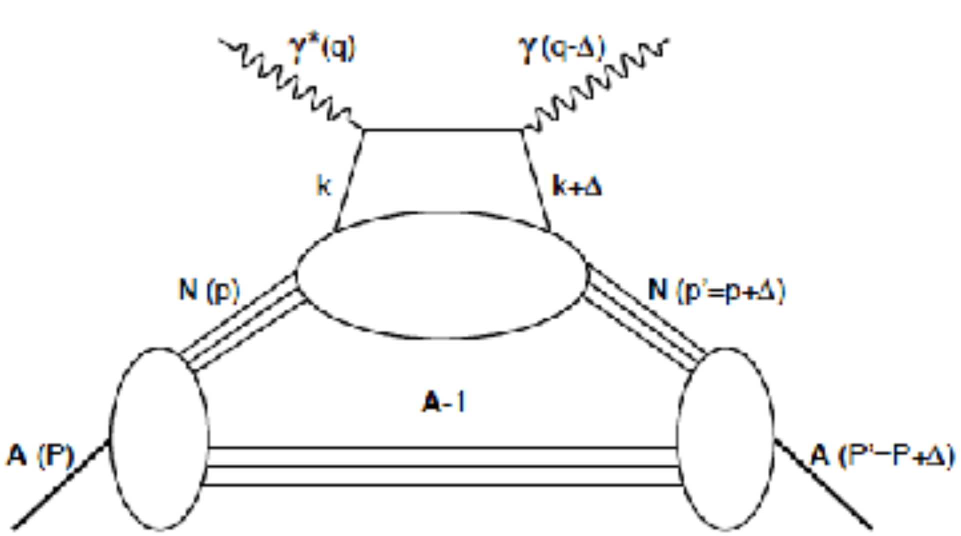
M. Defurne *et al.* [Hall A Collaboration] arXiv:1504.05453



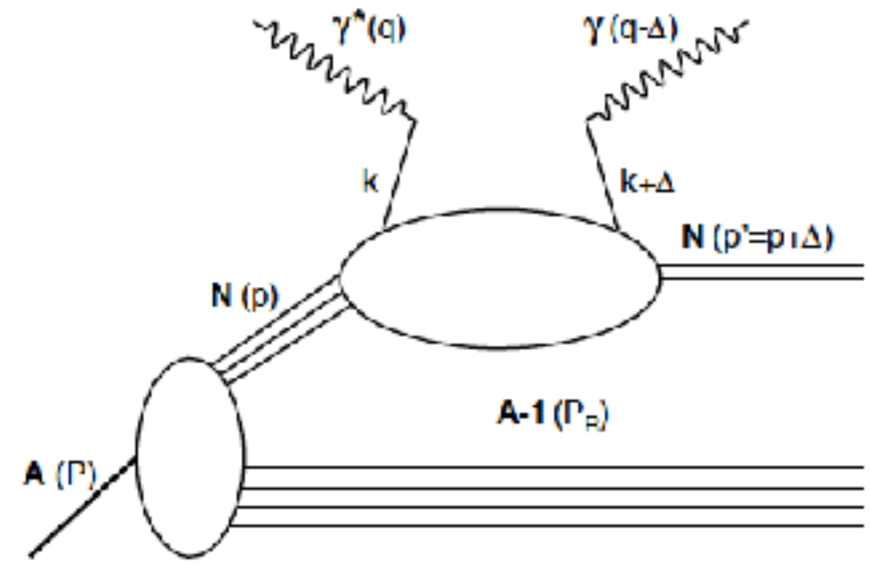
Braun, Manashov, Müller, Pirnay, PRD89 (2014) 074022

DVCS with Nuclear Targets

S. Scopetta



Coherent DVCS:
nuclear tomography



Incoherent DVCS:
tomography of bound nucleons

- Large energy gap between the high-energy photons and the slow recoiling nuclei: very different detector systems to be measured in coincidence
- Very difficult to distinguish coherent and incoherent channels (for example, in HERMES data, Airapetian et al., PRC2011)

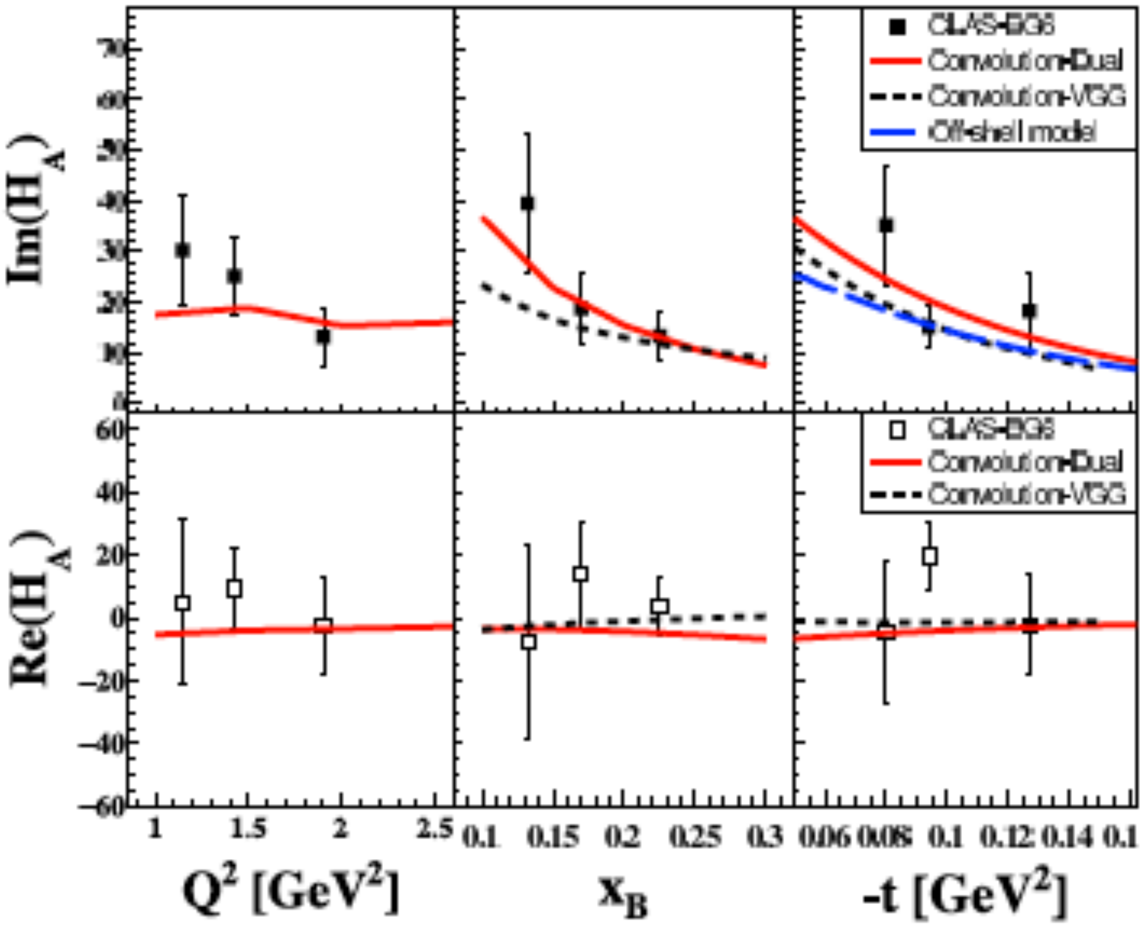
Difficult but possible! Just released from CLAS!

S. Scopetta

(M. Hattawy et al., arXiv: 1707.03361v1 [nucl-ex])

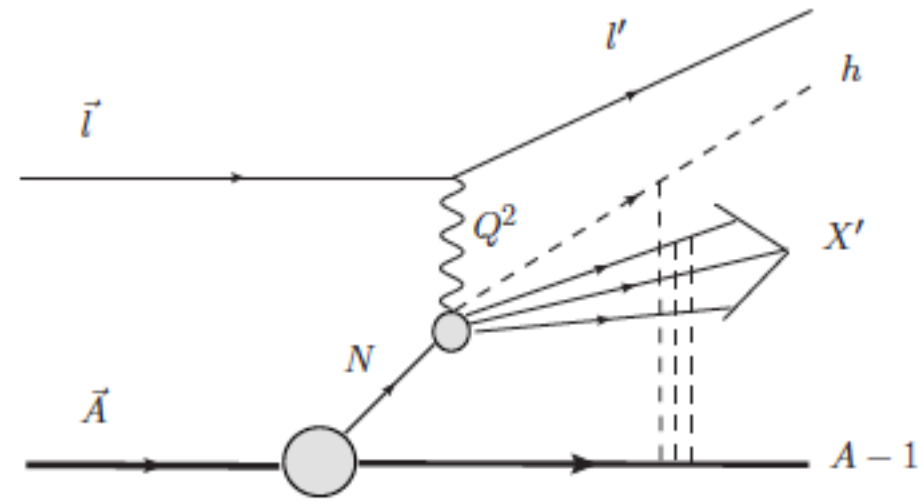
off-shell model by
Gonzalez, Liuti, Goldstein, Kathuria
(blue dashed)
(**PRC 88, 065206 (2013)**)

IA calculation, Guzey
(full, dashed, different GPD models)
(**PRC 78, 025211 (2008)**)



- ^{4}He: $J = 0, I = 0$, easy *formal* description (1 chiral-even twist-2 GPD); but a true nucleus (deeply bound, dense...)
- Next generation of experiments (ALERT run-group), just approved (A-rate), will distinguish models: precisely what is needed to understand nuclei at parton level!
- **Good prospects for the EIC at low x_B, easy recoil detection...**

TMDs of Nuclei



He^3 is the ideal target to study the polarized neutron
and it was used in a series of experiments at JLab HallA and will be used at JLab12

TMDs of Nuclei

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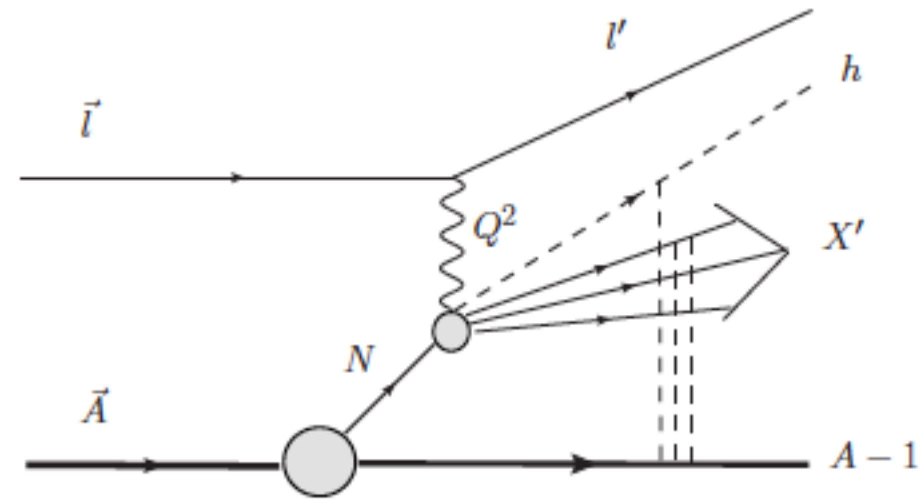

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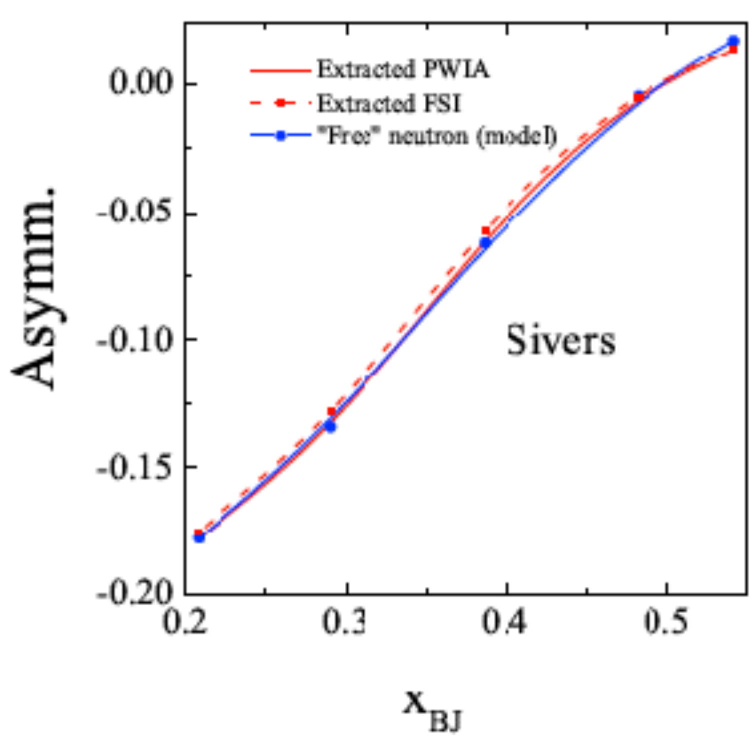
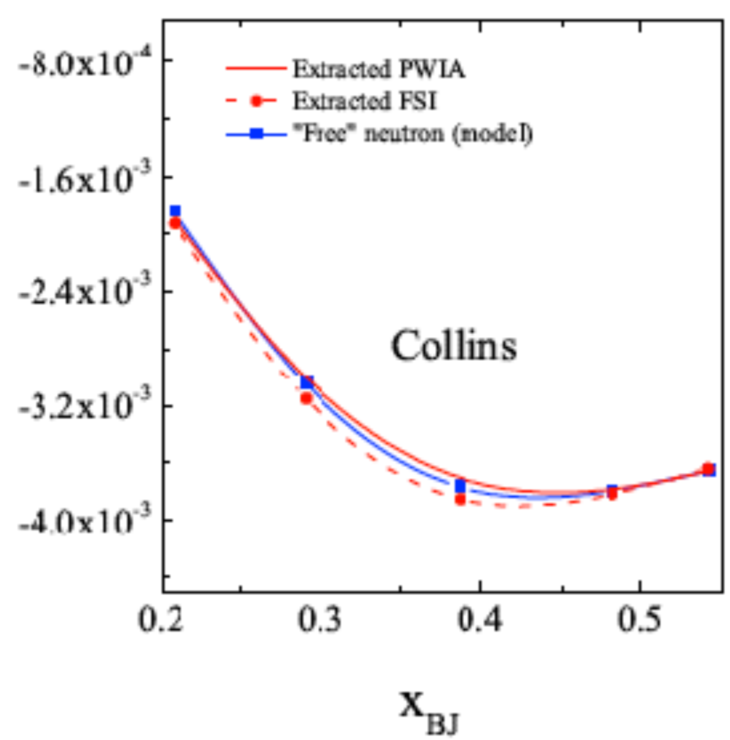
Dynamical nuclear effects and effects of FSI properly taken into account
in dilution factors and effective polarizations:
Del Dotto, Kaptari, Pace, Salmè, Scopetta: arXiv:1704.06182 [nucl-th]



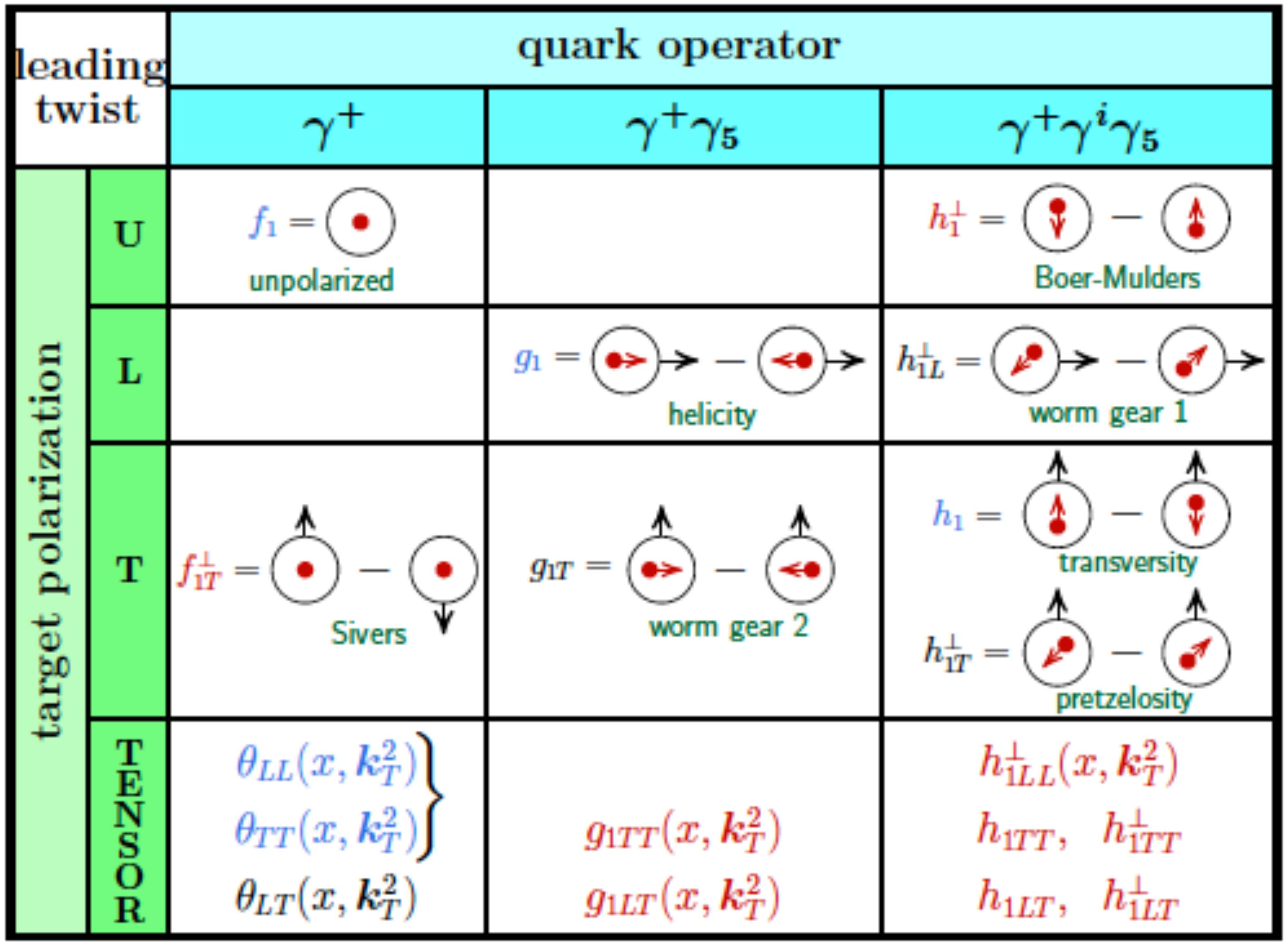


$$A_n \approx \frac{1}{p_n^{FSI} f_n^{FSI}} \left(A_3^{exp} - 2 p_p^{FSI} f_p^{FSI} A_p^{exp} \right)$$
$$\approx \frac{1}{p_n f_n} \left(A_3^{exp} - 2 p_p f_p A_p^{exp} \right)$$

TMDs of a spin-one targets

I. Cloet

3 additional T-even and 7 additional T-odd quark TMDs compared to nucleon



- Very challenging experimentally:

-need longitudinal and tensor polarized spin 1 targets, e.g. deuteron and Li^6

-for SIDIS there are 41 structure functions (23 associated with tensor polarization + 18 for U+L)

-for DY there are 108 structure functions (60 associated with tensor polarization)

-could be studied at EIC

- Exploratory study of rho meson TMDs in the Nambu-Jona Lasinio model

I. Cloet

- Tensor polarized TMDs have a number of surprising features

  - $\theta_{LL}(x,k_T^2)$ and $\theta_{LT}(x,k_T^2)$ identically vanishes at x=1/2

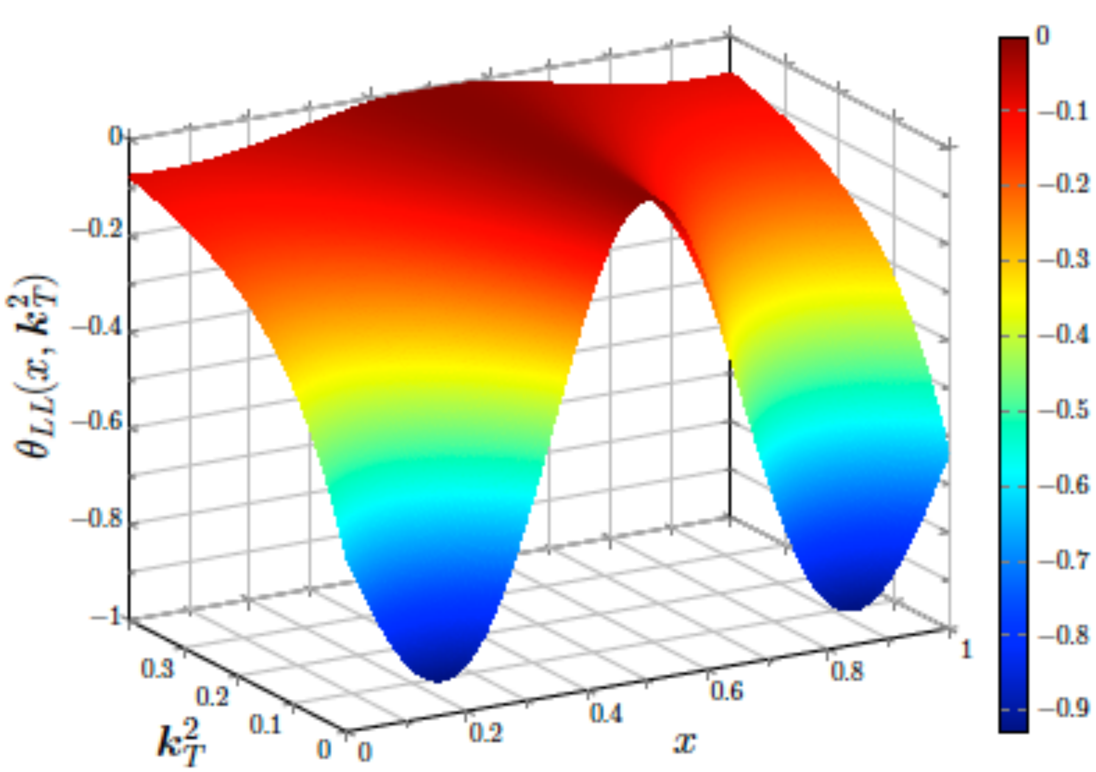
  -x=1/2 corresponds to zero relative momentum between the two constituents

  $\longrightarrow$ S-wave contributions

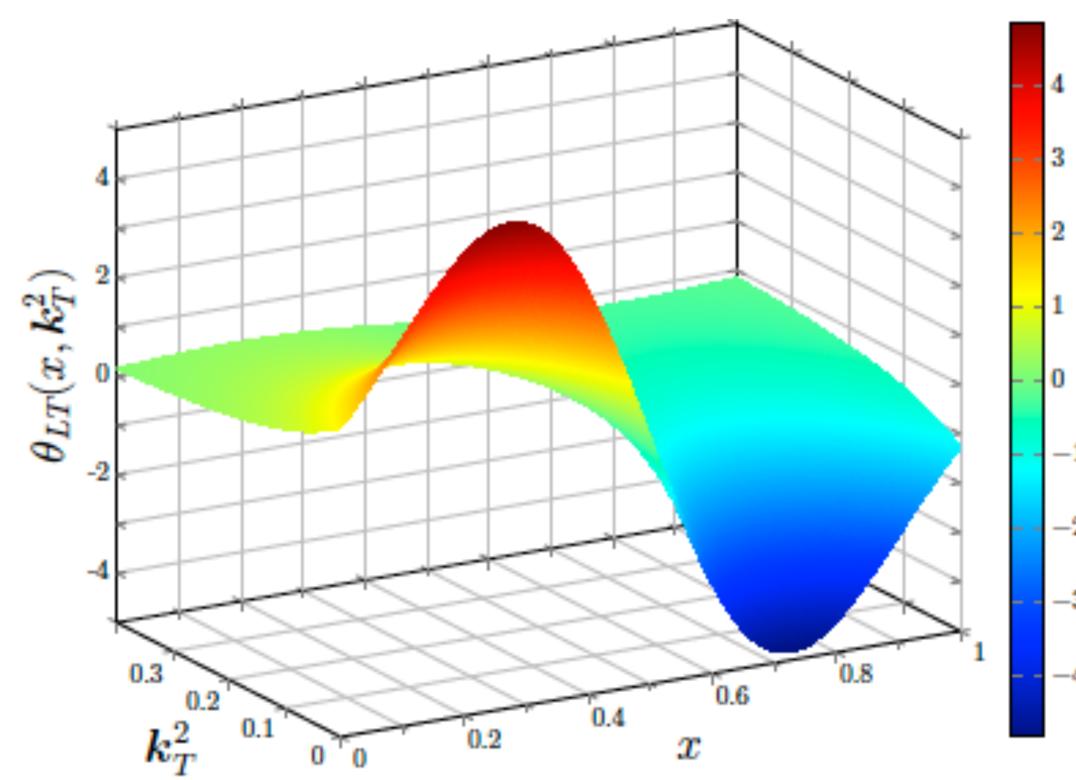
  -contributions only from $L \geq 1$ components of the wave function

  $\longrightarrow$ sensitive measure of orbital angular momentum

$\theta_{LL}(x,k_T^2)$



$\theta_{LT}(x,k_T^2)$



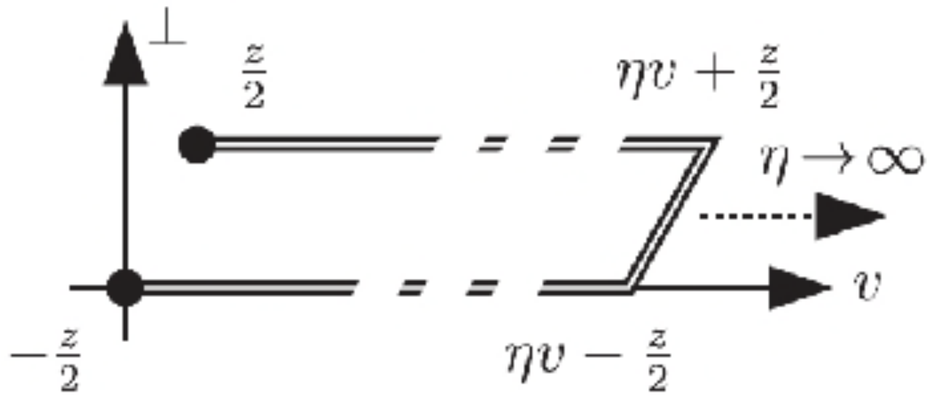
Ninomiya, Cloet, Bentz, arXiv: 1707.03787 [nucl-th]

TMDs on the lattice

- Calculation with two different ensembles (domain-wall fermions and Wilson-clover fermions) with comparable pion masses $(m_\pi \approx 300 \text{ MeV})$ but very different discretisation schemes

$\longrightarrow$ test of discretisation effects and renormalisation of the quark bilocal operator

$$\widetilde{\Phi}^{[\Gamma]}_{\text{unsubtr.}}(b, P, S, \ldots) \equiv \frac{1}{2}\langle P, S|\ \bar{q}(0)\,\Gamma\,\mathcal{U}[0, \eta v, \eta v+b, b]\ q(b)\,|P, S\rangle$$



η :length of the staple

v :staple direction taken off the light-cone to regulate rapidity divergences

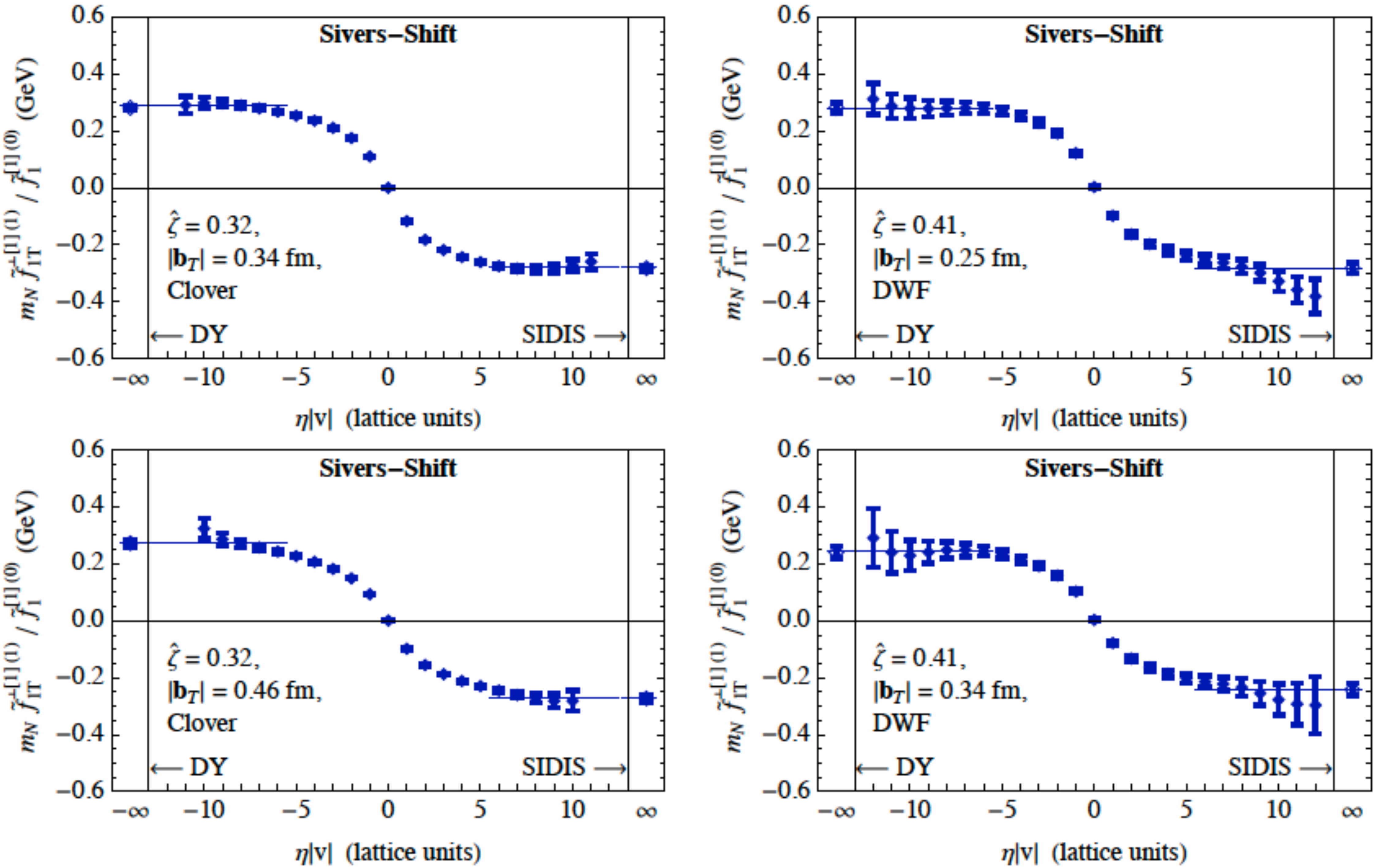
$$\hat{\zeta} = \frac{v \cdot P}{\sqrt{|v^2|}\sqrt{P^2}}$$ Collin-Soper type parameter

$\hat{\zeta} \to \infty$ light-cone limit

Yoon, Engelhardt, Gupta,Bhattacharya, Green, Musch, Negele, Pochinsky, Schäfer, Syritsy, arXiv: 1706.03406 [hep-lat]

Moments of TMDs

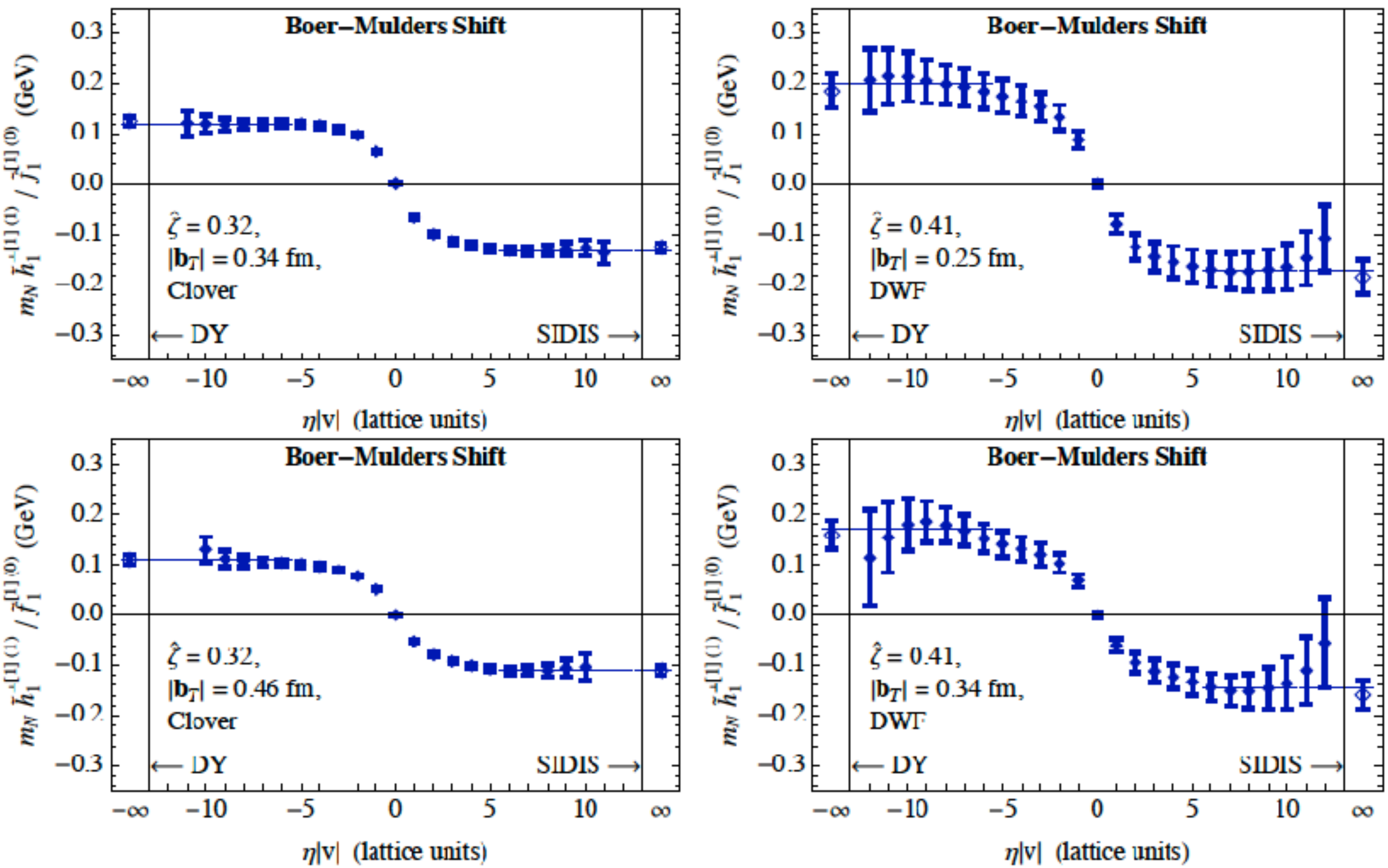
A. Schäfer



Sivers shift

Yoon, Engelhardt, Gupta,Bhattacharya, Green, Musch, Negele, Pochinsky, Schäfer, Syritsy, arXiv: 1706.03406 [hep-lat]

Moments of TMDs



Boer-Mulders shift

Yoon, Engelhardt, Gupta,Bhattacharya, Green, Musch, Negele, Pochinsky, Schäfer, Syritsy, arXiv: 1706.03406 [hep-lat]

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