Electron Ion Collider:
(a limited personal view on the) Science Case

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Outline

Presentation

Presentation

François-Xavier Girod

- 12/2006 PhD (Saclay)
  Deeply Virtual Compton Scattering Beam Spin Asymetries at CLAS for a study of Generalized Parton Distributions
- Feb. 2007 - Oct. 2011 : Post-doc in Hall-B at JLab
- 2011 Staff scientist in Hall-B
- Continued program support on DVCS, DVMP, and SIDIS studies
- Focus on Exclusive Reaction program on (polarized) Hydrogen and Nuclei (He)
- Polarized Positron Beam proposal
- Detector operation: CLAS12 beamline, calorimeters
- Heavy Photon Search
- 2020 switch to Electron Collider Science

Suggested Reading

Electron Ion Collider specific references

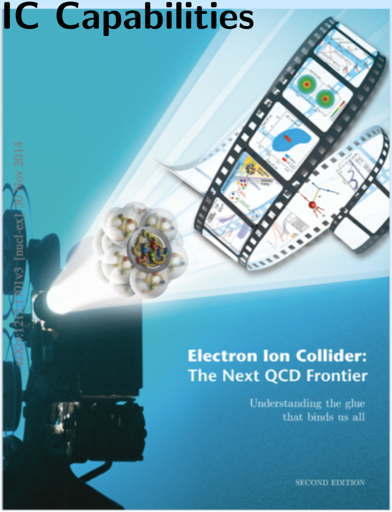
- "Yellow Report" EIC community, Nucl. Phys. A 1026 (2022) 122447
- "An Assessment of U.S.-Based Electron-Ion Collider Science"
  National Academies of Science (2018)
- "White Paper" Eur. Phys. J. A52 (2016) 268
- "HERA Physics" G. Wolf, DESY-94-22 (1994)

Some **personal** recommendations

- "The Quark Structure of Hadrons" C. Amsler
  Springer Lecture Notes in Physics Vol 949 (2018)
- "High-Energy Particle Diffraction" V. Barone E. Predazzi
  Springer Texts and Monographs in Physics (2002)
- "The Structure of the Nucleon" A.W. Thomas W. Weise
  Wiley VCH (2001)
- "Deep Inelastic Positron-Proton Scattering at High-p Transfer at HERA" U.F. Katz
  Springer Tracts in Modern Physics (2000)
- "QCD at HERA" M. Kuhlen
  Springer Tracts in Modern Physics (1999)

General Introduction

EIC Capabilities



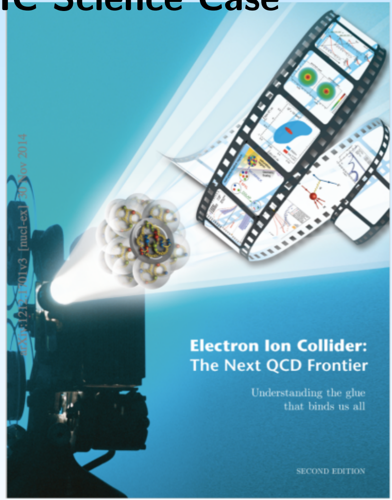
Eur. Phys. J. A52 (2016) no.9, 268

See also Rept.Prog.Phys. 82 (2019) 024301

- *A collider to provide kinematic reach well into the gluon dominated regime,*
- *Electron beams provide the unmatched precision of the electromagnetic interaction as a probe,*
- *Polarized nucleon beams to determine the correlations of sea quark and gluon distributions with the nucleon spin,*
- *Heavy Ion beams to access the gluon-saturated regime and as a precise dial to study propagation of color charges in nuclear matter.*
- *Facility concepts at BNL and at JLab, re-use of existing, significant investment (BNL has since been site-selected).*

E. Sichtermann (LBNL) CNFS-CTEQ23

EIC Science Case



Eur. Phys. J. A52 (2016) no.9, 268

See also Rept.Prog.Phys. 82 (2019) 024301

- *How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleus?*
- *Where does the saturation of gluon densities set in?*
- *How does the nuclear environment affect the distribution of quarks and gluons and their interactions in nuclei?*

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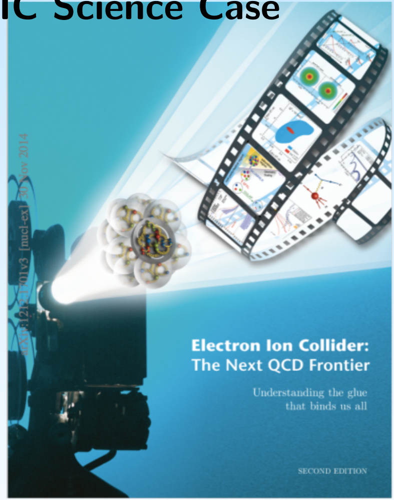
EIC Science Case



Eur. Phys. J. A52 (2016) no.9, 268

See also Rept.Prog.Phys. 82 (2019) 024301

Organized around four themes:

- *Proton spin,*
  quark and gluon helicity distributions,
  orbital motion
- *Imaging of nucleons and nuclei*
  TMDs, GPDs, Wigner functions
- *Saturation*
  Non-linear evolution,
  Color-glass condensate,
- *Hadronization and fragmentation,*
  in-medium propagation,attenuation

Identified measurements and impact.

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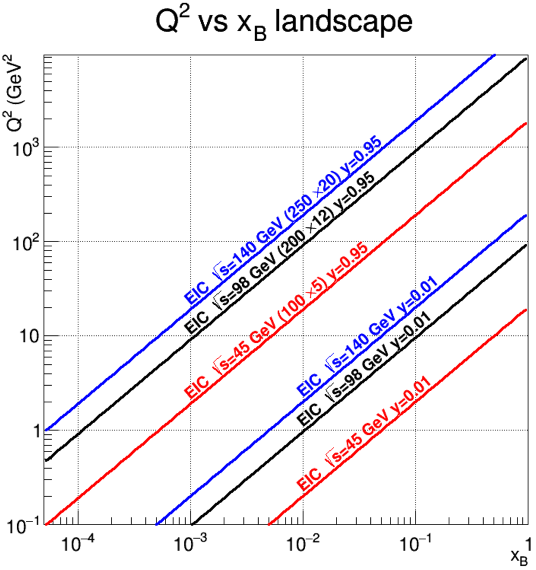
Collider Energy Scenarios



Build on knowledge from

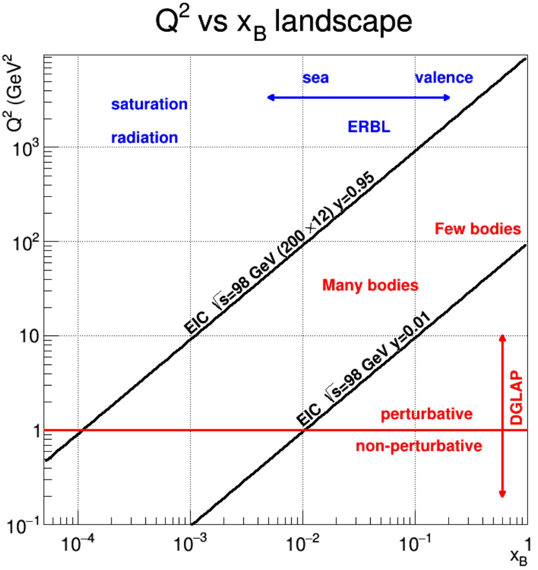
other colliders
HERA, RHIC, LHC

Fixed targets
SLAC, HERMES, COMPASS, JLab

Crucial ingredients:
polarizations
luminosity

Complementarity of energy runs

Kinematic reach and QCD Landscape



Rich physics program

Position, Spin, Energy, Momentum distributions of quarks and gluons

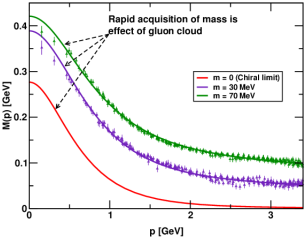
Origin Mass, Confinement, χSM QCD and Gravity

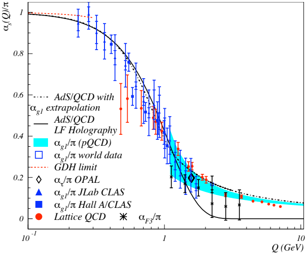
Gluon saturation, jet radiophysics QCD Bremsstrahlung

Nuclear Modifications EMC Effect, SRC

Confinement Mechanism(s?)

Hadrons are singlets under $SU(3)_{color}$: No net color charge in asymptotic particle states





- **Linear growth of the static quark-antiquark pair**
  Area-law falloff for the Wilson loop
- **Gribov Confinement for light quarks**
  Analytical properties of the propagators in the infrared
  Instability of the vacuum above a supercritical charge

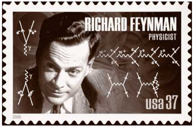
$$\alpha_{\text{QED}}^{\text{crit}} = 137 \text{ for a point-like nucleus}$$
$$\approx 180 \text{ for a finite size nucleus}$$
$$\frac{\alpha_{\text{QCD}}^{\text{crit}}}{\pi} = C_F^{-1}\left[1 - \sqrt{\frac{2}{3}}\right] \approx 0.137$$

- **Light-Front AdS/QCD**
  quark and gluon chiral condensates confined!
  →condensates contribution to the cosmological constant already included in hadron mass
- Mass-Gap Millenium problem and Yang-Mills existence
  $1M from the Clay Mathematical Institute

Gravity and QCD

In some fundamental sense a *graviton* can be thought of as a *pair of vector bosons*: Gravity amplitudes appear as squared Yang-Mills amplitudes in the *Color-Kinematics Duality*

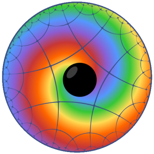
Z. Bern *et al.*
Gravity as the Square of Gauge Theory
*Phys. Rev. D***82** 065003 (2010)



Understanding the deeper origin of these dualities is at the heart of string theory. Here a graviton (closed string) happens naturally as a pair of vector bosons (open strings). The **duality** between Gravity in the bulk and QCD on the boundary of AdS space, also called **holographic principle** is the currently the all time most cited high energy physics publication

J. Maldacena
The Large N limit of superconformal field theories and supergravity
*Int. J. Theor. Phys.***38** 1113 (1999)
(13k citations as of June 2018)

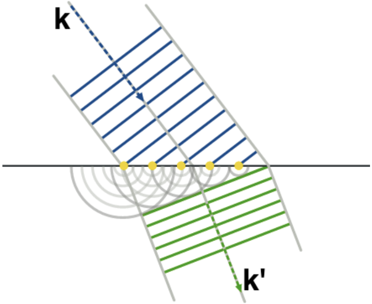
Gravitational Form Factors from QCD bound states are observables of choice to test these dualities. Most promising avenue to understand the non-perturbative structure of gauge theories.



EIC Science Case

Diffraction and Imaging

Huygens-Kirchhoff-Fresnel principle

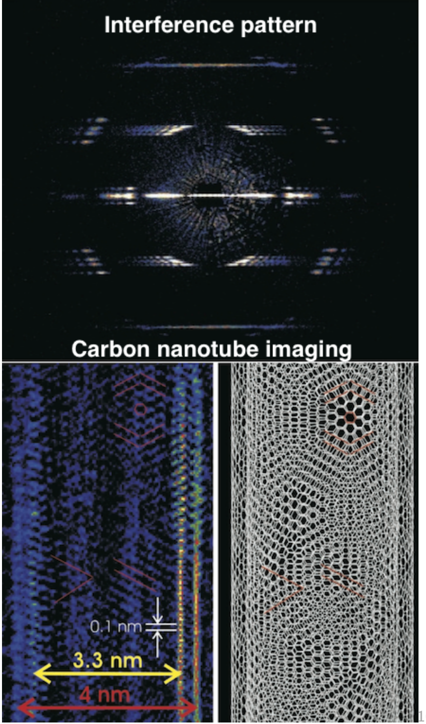


$\vec{q} = \vec{k} - \vec{k'}$

The interference pattern is given by the superposition of spherical wavelets

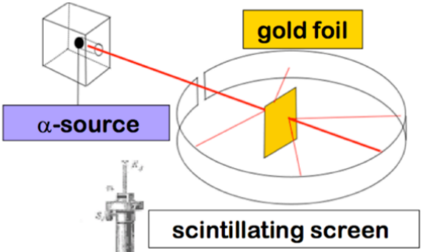
$$f(\Omega_{\vec{q}}) = \int \frac{\mathrm{d}^3\vec{r}}{(2\pi)^3} F(\vec{r}) \mathrm{e}^{i\vec{q}\cdot\vec{r}}$$

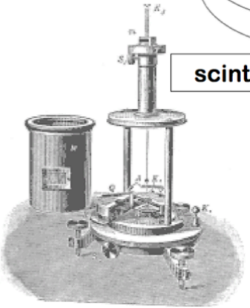
Fourier imaging



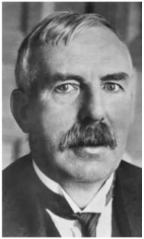
Rutherford Scattering

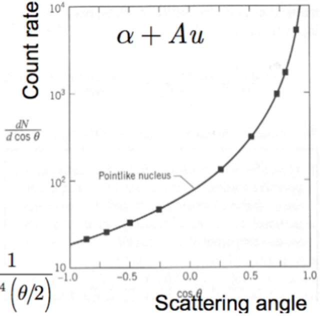
~5 MeV





Ernest Rutherford, Nobel Prize 1908





$$\frac{d\sigma}{d\Omega} = (zZ\alpha)^2 \left(\frac{\hbar c}{4E_{\text{kin}}}\right)^2 \frac{1}{\sin^4(\theta/2)}$$

Scattering off a hard sphere; $r_{\text{nucleus}} \sim (10^{-4} \cdot r_{\text{atom}}) \sim 10^{-14}$ m

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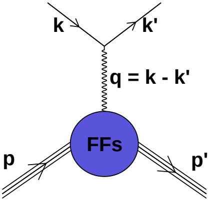
Elastic scattering

Form Factors

Probing deeper using virtual photons



$$J^{\mu}_{\text{EM}} = F_1 \gamma^{\mu} + \frac{\kappa}{2M} F_2 i \sigma^{\mu\nu} q_{\nu}$$

$$\frac{d\sigma}{d\Omega} = \frac{\sigma_{\text{Mott}}}{\epsilon(1+\tau)} \left[\tau G_M^2 + \epsilon G_E^2\right]$$

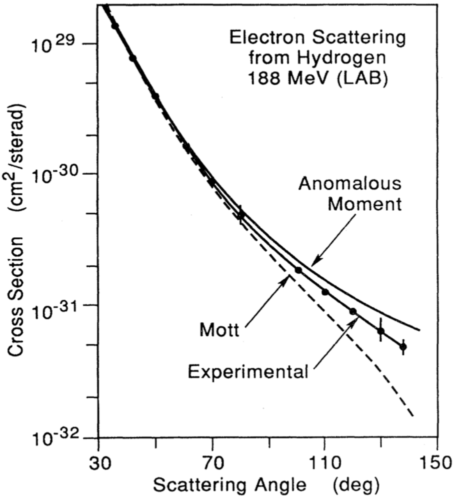
$$\tau = \frac{Q^2}{4M^2}$$

$$Q^2 = -\left(k - k'\right)^2 = -m^2_{\gamma*}$$

$$\frac{1}{\epsilon} = 1 + 2(1+\tau)\tan^2 \frac{\theta_e}{2}$$

$$G_E = F_1 - \tau F_2$$

$$G_M = F_1 + F_2$$



Hofstadter Nobel prize 1961

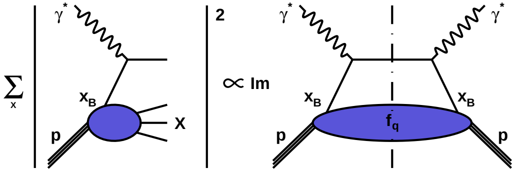
"The best fit in this figure indicates an rms radius close to $0.74 \pm 0.24 \times 10^{-13}$ cm."

Imaging in transverse impact parameter space

Deeply Inelastic Scattering

Parton Distributions

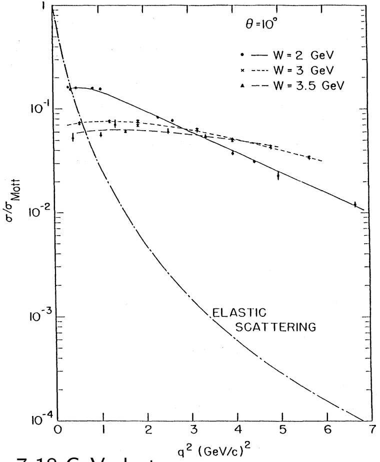
Optical theorem



The total cross section is given by
the imaginary part of the forward amplitude

$$\nu = E_{\gamma^*} \quad , \quad x_B = \frac{Q^2}{2M\nu}$$

$\sigma_{\text{DIS}}(x_B, \cancel{Q^2}) \rightarrow$ scaling, point-like constituents



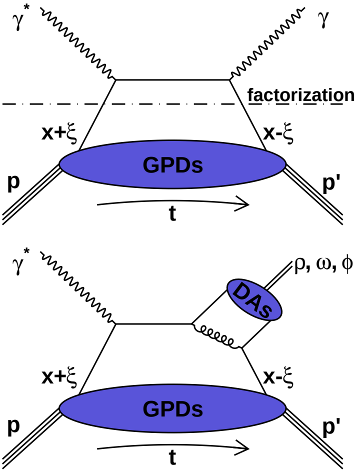
Discovery of quarks, SLAC-MIT group, 7-18 GeV electron
Friedman, Kendall, Taylor, Nobel prize 1990

$$\lim_{Q^2 \to \infty} \sigma_{\text{DIS}}(x_B) = \int_{x_B}^{1} \frac{d\xi}{\xi} \sum_a f_a(\xi, \mu) \hat{\sigma}^a \left(\frac{x_B}{\xi}, \frac{Q}{\mu} \right)$$

1-D distribution in longitudinal momentum space

Deep Exclusive Scattering

Generalized Parton Distributions



$$\gamma^* p \to \gamma p', \ \gamma^* p \to \begin{cases} \rho p' \\ \omega p' \\ \phi p' \end{cases}$$

Bjorken regime :
$Q^2 \to \infty$, x_B fixed

t fixed $\ll Q^2$, $\xi \to \frac{x_B}{2-x_B}$

$$\frac{P^+}{2\pi} \int dy^- \, e^{ixP^+y^-} \langle p' | \bar{\psi}_q(0) \gamma^+ (1+\gamma^5) \psi(y) | p \rangle$$

$$= \bar{N}(p') \left[H^q(x,\xi,t)\gamma^+ + E^q(x,\xi,t) i\sigma^{+\nu} \frac{\Delta_\nu}{2M} \right.$$

$$\left. + \tilde{H}^q(x,\xi,t)\gamma^+\gamma^5 + \tilde{E}^q(x,\xi,t)\gamma^5 \frac{\Delta^+}{2M} \right] N(p)$$

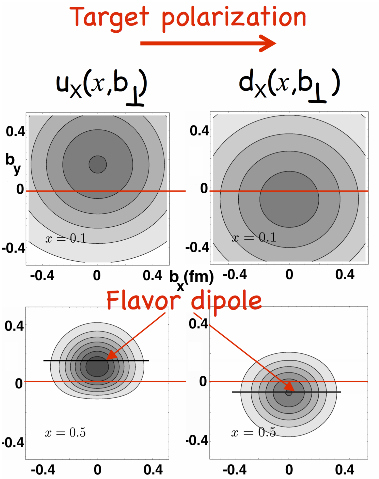
spin	N no flip	N flip
q no flip	H	E
q flip	$\tilde{H}$	$\tilde{E}$

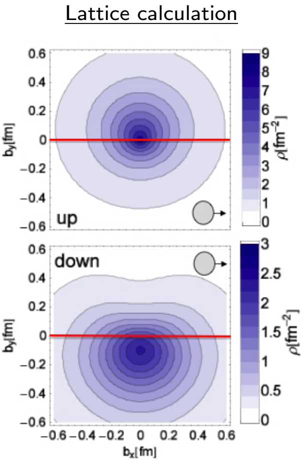
3-D Imaging conjointly in transverse impact parameter and longitudinal momentum

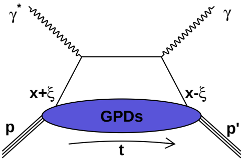
GPDs and Transverse Imaging

(x_B, t) correlations

$$q_X(x, \vec{b}_\perp) = \int \frac{d^2\vec{\Delta}_\perp}{(2\pi)^2}\left[H(x,0,t) - \frac{E(x,0,t)}{2M}\frac{\partial}{\partial b_y}\right] e^{-i\vec{\Delta}_\perp\cdot\vec{b}_\perp}$$





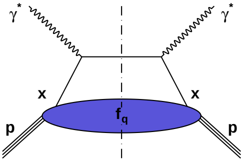


Generalized Parton Distributions

$$\frac{P^+}{2\pi}\int dy^- \, e^{ixP^+y^-}\langle p'|\bar{\psi}_q(0)\gamma^+(1+\gamma^5)\psi(y)|p\rangle$$

$$= \bar{N}(p')\left[H^q(x,\xi,t)\gamma^+ + E^q(x,\xi,t)i\sigma^{+\nu}\frac{\Delta_\nu}{2M}\right.$$

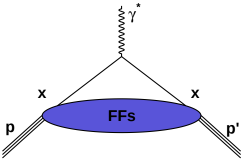
$$\left. + \tilde{H}^q(x,\xi,t)\gamma^+\gamma^5 + \tilde{E}^q(x,\xi,t)\gamma^5\frac{\Delta^+}{2M}\right]N(p)$$



Parton longitudinal momentum fraction distributions

$$\frac{1}{4\pi}\int dy^- \, e^{ixp^+y^-}\langle p|\bar{\psi}_q(0)\gamma^+\psi(y)|p\rangle = f_q(x)$$

$$H^q(x,\xi=0,t=0) = f_q(x)$$



Form Factors - Fourier transform of transverse spatial distributions

$$\langle p'|\bar{\psi}_q(0)\gamma^+\psi(0)|p\rangle = \bar{N}(p')\left[F_1^q(t)\gamma^+ + F_2^q(t)i\sigma^{+\nu}\frac{\Delta_\nu}{2M}\right]N(p)$$

$$\int_{-1}^{1} dx\, H^q(x,\xi,t) = F_1^q(t) \qquad \text{First x-moment}$$

$$\int_{-1}^{1} dx\, E^q(x,\xi,t) = F_2^q(t)$$

GPDs and Energy Momentum Tensor

(x, ξ) correlations

Form Factors accessed *via* second x-moments :

$$\langle p'|\hat{T}^q_{\mu\nu}|p\rangle = \bar{N}(p')\left[M_2^q(t)\,\frac{P_\mu P_\nu}{M} + J^q(t)\,\frac{\imath(P_\mu\sigma_{\nu\rho}+P_\nu\sigma_{\mu\rho})\Delta^\rho}{2M} + d_1^q(t)\,\frac{\Delta_\mu\Delta_\nu - g_{\mu\nu}\Delta^2}{5M}\right] N(p)$$

Angular momentum distribution

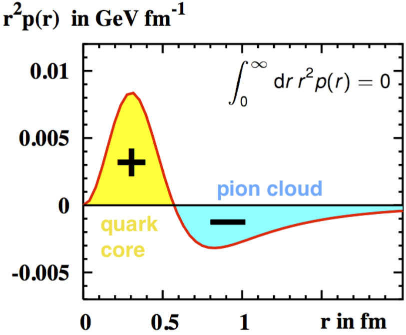
$$J^q(t) = \frac{1}{2}\int_{-1}^{1} \mathrm{d}x\, x\,[H^q(x,\xi,t) + E^q(x,\xi,t)]$$

Mass and force/pressure distributions

$$M_2^q(t) + \frac{4}{5}d_1(t)\xi^2 = \frac{1}{2}\int_{-1}^{1}\mathrm{d}x\, xH^q(x,\xi,t)$$

$$d_1(t) = 15M\int \mathrm{d}^3\vec{r}\,\frac{j_0(r\sqrt{-t})}{2t}\,p(r)$$

Distribution of pressure



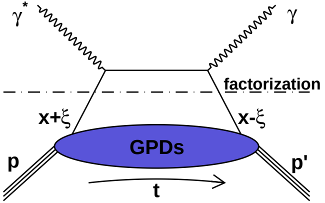
Deeply Virtual Compton Scattering

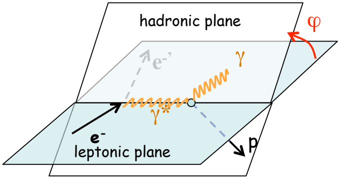
The cleanest GPD probe at low and medium energies

$$\gamma^* p \to \gamma p'$$

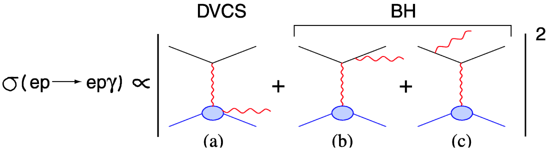
Bjorken regime :
$Q^2 \to \infty$, $\nu \to \infty$, x_B fixed

$$\xi \to \frac{x_B}{2 - x_B}$$





$$ep \to ep\gamma$$



Diehl, Gousset, Pire, Ralston (1997)
Belitsky, Müller, Kirchner (2002, 2010)

$$A_{\mathrm{LU}} = \frac{d^4\sigma^{\rightarrow} - d^4\sigma^{\leftarrow}}{d^4\sigma^{\rightarrow} + d^4\sigma^{\leftarrow}} \overset{\text{twist-2}}{\approx} \frac{\alpha \sin\phi}{1 + \beta\cos\phi}$$

$$\alpha \propto \mathcal{I}\mathrm{m}\left(F_1 \mathcal{H} + \xi G_M \tilde{\mathcal{H}} - \frac{t}{4M^2} F_2 \mathcal{E}\right)$$

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

$$A_{\mathrm{UL}} \propto \mathcal{I}\mathrm{m}\left(F_1 \tilde{\mathcal{H}} + \xi G_M \mathcal{H} + G_M \frac{\xi}{1+\xi} \mathcal{E} + \cdots\right) \sin\phi$$

Deeply Virtual Compton Scattering

The cleanest GPD probe at low and medium energies

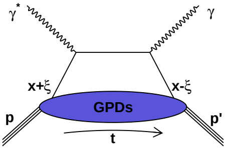
$$
\begin{aligned}
A_{\mathrm{UT}} &= \frac{d^4\sigma^{U\uparrow}(\phi_S-\phi) - d^4\sigma^{U\downarrow}(\phi_S-\phi+\pi)}{d^4\sigma^{U\uparrow}(\phi_S-\phi) + d^4\sigma^{U\downarrow}(\phi_S-\phi+\pi)} \\
&\overset{\text{twist-2}}{\propto} A_{\mathrm{UT}}^{\sin(\phi_S-\phi)\cos\phi}\sin(\phi_S-\phi)\cos\phi \\
&\quad + A_{\mathrm{UT}}^{\cos(\phi_S-\phi)\sin\phi}\cos(\phi_S-\phi)\sin\phi \\
A_{\mathrm{UT}}^{\sin(\phi_S-\phi)\cos\phi} &= \frac{1}{\pi}\int_0^{2\pi} \mathrm{d}\phi\,\cos(\phi) A_{\mathrm{UT}}^{\sin(\phi_S-\phi)} \\
A_{\mathrm{UT}}^{\sin(\phi_S-\phi)} &\propto \frac{1-x}{2-x}\frac{t}{Q^2}F_2\mathcal{H} + \frac{t}{4M^2}(2-x)F_1\mathcal{E}
\end{aligned}
$$

Deeply Virtual Compton Scattering

The cleanest GPD probe at low and medium energies

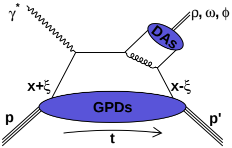
$$
\begin{aligned}
A_{\mathrm{LT}} &= \frac{(d^4\sigma^{\rightarrow\uparrow} + d^4\sigma^{\leftarrow\downarrow}) - (d^4\sigma^{\rightarrow\downarrow} + d^4\sigma^{\leftarrow\uparrow})}{(d^4\sigma^{\rightarrow\uparrow} + d^4\sigma^{\leftarrow\downarrow}) + (d^4\sigma^{\rightarrow\downarrow} + d^4\sigma^{\leftarrow\uparrow})} \\
A_{\mathrm{LT}}^{\sin(\phi_S-\phi)\sin\phi} &= \frac{1}{\pi}\int_0^{2\pi} \mathrm{d}\phi\, \sin(\phi) A_{\mathrm{LT}}^{\sin(\phi_S-\phi)} \\
A_{\mathrm{LT}}^{\sin(\phi_S-\phi)} &\propto A_{\mathrm{LT,BH}}^{\sin(\phi_S-\phi)} + \frac{1}{2-x}\left(x^2 F_1 - (1-x)\frac{t}{M^2}F_2\right)\mathcal{H} \\
&+ \left\{\frac{t}{4M^2}\left(\frac{x}{\xi}F_1 + x\xi F_2\right) + x\xi F_1\right\}\mathcal{E}
\end{aligned}
$$

Observables sensitivities to GPD



DVCS

	$\mathcal{I}$m	$\mathcal{R}$e
$\mathcal{H}$	A_{LU}	σ
$\tilde{\mathcal{H}}$	A_{UL}	A_{LL}, A_{LT}
$\mathcal{E}$	A_{UT}	



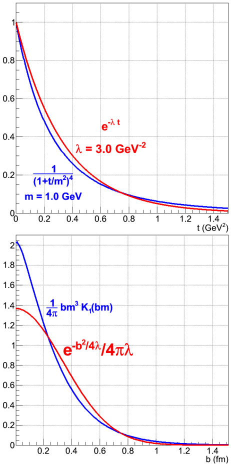
DVMP

	Meson	Flavor
$\tilde{\mathcal{H}}$,$\tilde{\mathcal{E}}$	π^+	$\Delta u - \Delta d$
	π^0	$2\Delta u + \Delta d$
	η	$2\Delta u - \Delta d + 2\Delta s$
$\mathcal{H}$,$\mathcal{E}$	ρ^+	$u - d$
	ρ^0	$2u + d$
	ω	$2u - d$
	ϕ	s

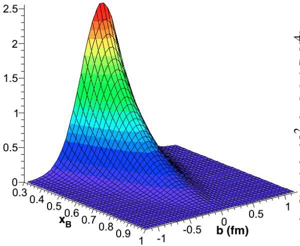
A global analysis is needed to fully disentangle GPDs

Electron-Ion Collider

J/Ψ electroproduction as a probe of the glue distribution



Glue tomography

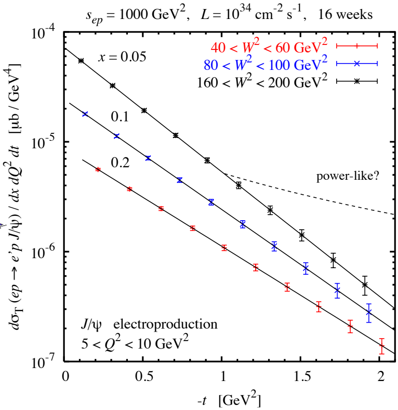


t-dependence

$\leftrightarrow$

spatial distribution

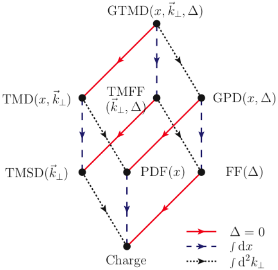
unknown below $b < 0.2$ fm



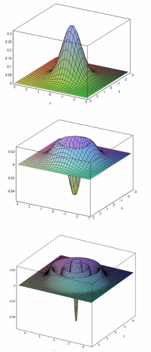
Unified view of hadron structure

Wigner Distributions

FFs, PDFs, GPDs, TMDs, inflation of acronyms all related to the same Wigner distribution



- Most general one-parton density matrix
- Not known how to measure
- Provides a unifying description
- Constraints for model building

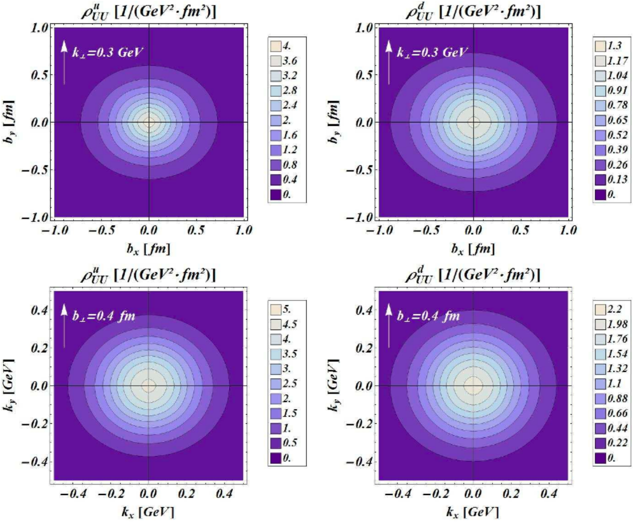


Unified framework for GPDs and TMDs within a 3Q LC picture of the nucleon

C. Lorcé *et al*, arXiv:1102.4704, JHEP 1105:041,2011

Overview of the nucleon structure

Unpolarized quark in unpolarized nucleon



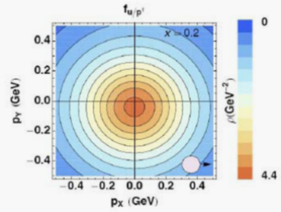
Quadrupole deformation of transverse position for quarks at large transverse momentum
Intuitive from a semi-classical picture of confinement

C. Lorcé *et al*, arXiv:1106.0139

Two Approaches to Imaging

TMDs

2+1 D picture in **momentum space**

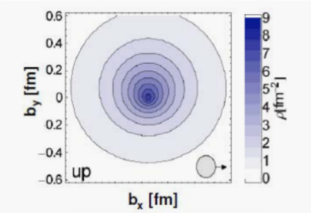


Bacchetta, Conti, Radici

- intrinsic transverse motion
- spin-orbit correlations = indicator of OAM
- non-trivial factorization
- accessible in SIDIS, DY (and at RHIC)

GPDs

2+1 D picture in **impact-parameter space**



QCDSF collaboration

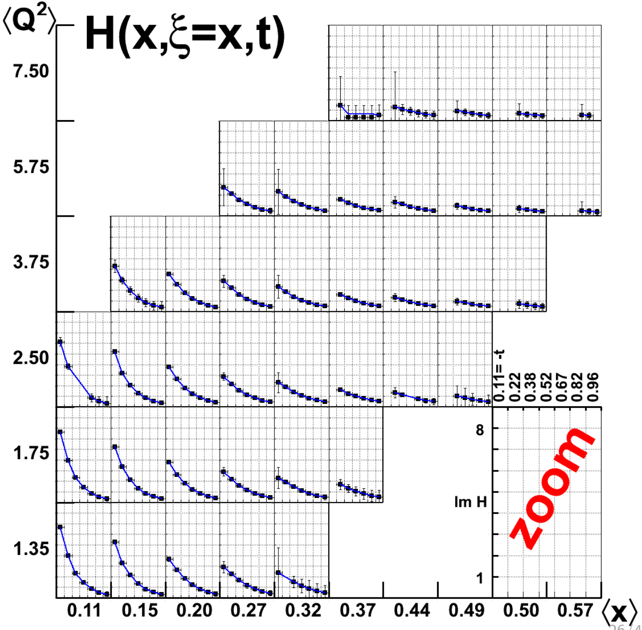
- collinear but long. momentum transfer
- indicator of OAM; access to Ji's total $J_{q,g}$
- existing factorization proofs
- DVCS, exclusive vector-meson production

currently no direct, model-independent relation known between TMDs and GPDs

CLAS12 CFF Impact Projections

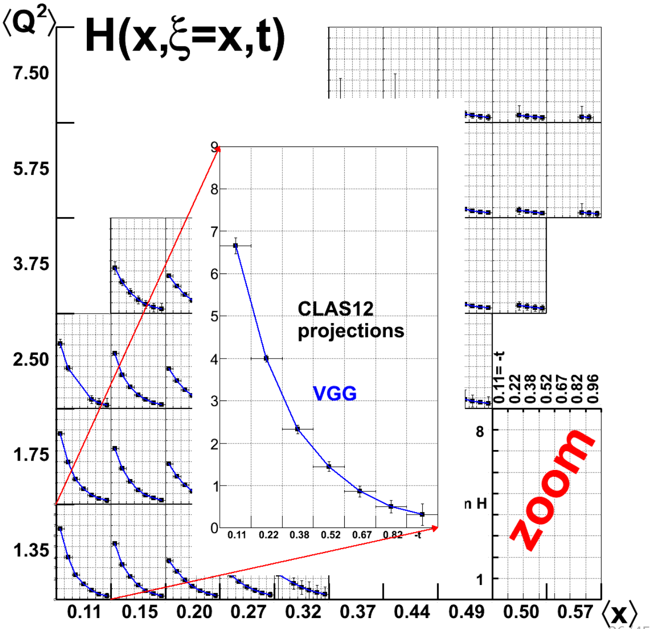
Projected CLAS12 impact on CFFs

Using simulated data based on VGG model. Input GPD H extracted with good accuracy



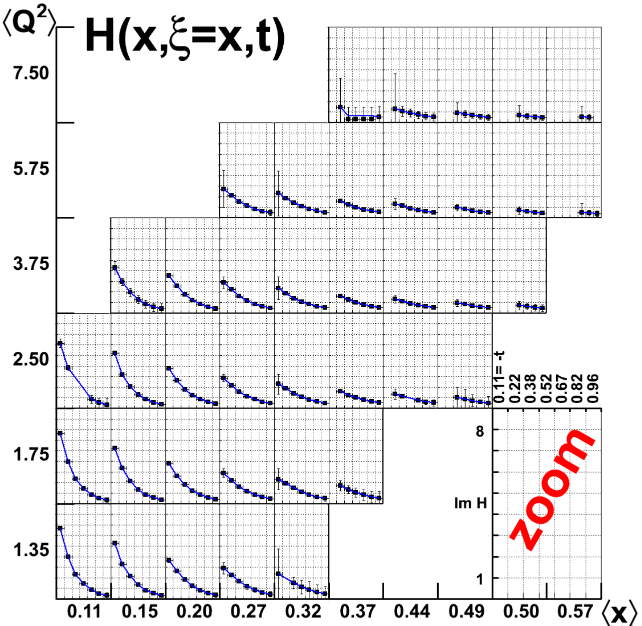
Projected CLAS12 impact on CFFs

Using simulated data based on VGG model. Input GPD H extracted with good accuracy



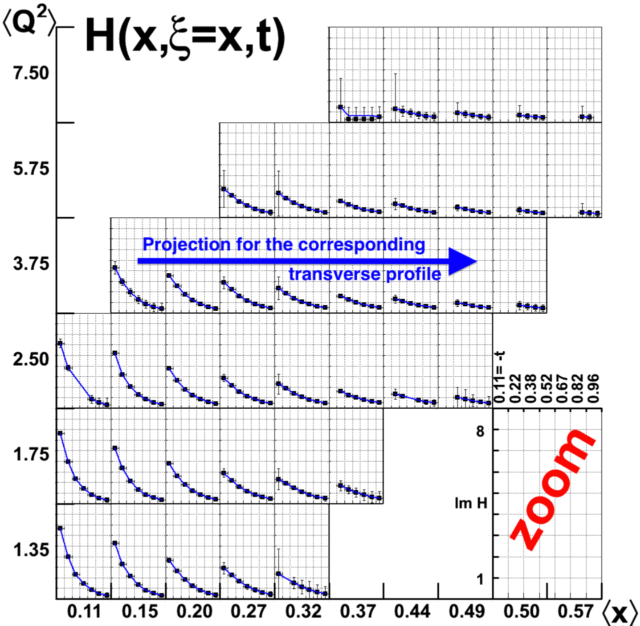
Projected CLAS12 impact on CFFs

Using simulated data based on VGG model. Input GPD H extracted with good accuracy

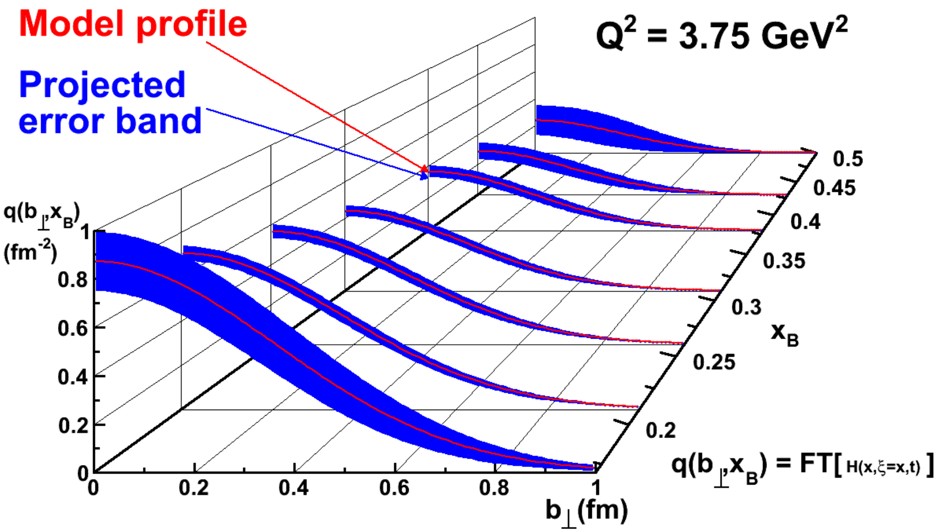


Projected CLAS12 impact on CFFs

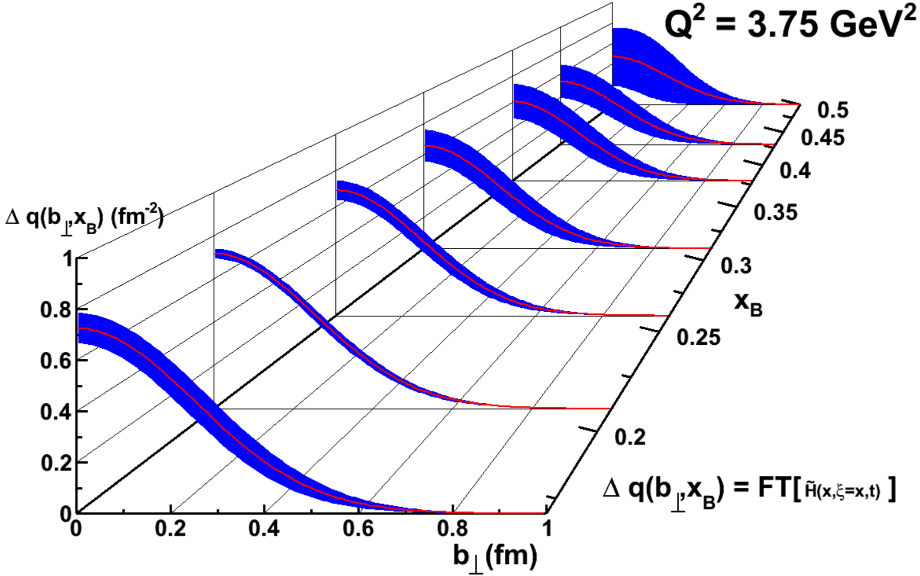
Using simulated data based on VGG model. Input GPD H extracted with good accuracy



Projection for the Nucleon transverse profile

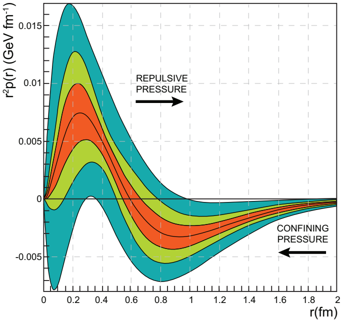


Precision tomography in the valence region



Precision tomography in the valence region

Proton Pressure distribution results



The pressure at the core of the proton is $\sim 10^{35}$ Pa
About 10 times the pressure at the core of a neutron star

Positive pressure in the core (repulsive force)
Negative pressure at the periphery: pion cloud
Pressure node around $r \approx 0.6$ fm

Stability condition : $\int_0^\infty \mathrm{d}t\, r^2 p(r) = 0$

Rooted into Chiral Symmetry Breaking

World data fit

CLAS 6 GeV data

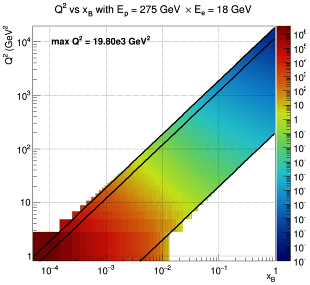
Projected CLAS12 data E12-16-010B

CFF local Fits at EIC

EIC proton DVCS Observables

	$\int \mathcal{L}$	Observables	$A_{e,p}$		
unpolarized	200 fb^{-1}	σ	A_{LU}		
L polarized	100 fb^{-1}	A_{UL}	A_{LL}		
T polarized	100 fb^{-1}	A_{UTx}	A_{UTy}	A_{LTx}	A_{LTy}
e^+	100 fb^{-1}	A^C	A^C_{LU}		

$$N_{events} = \int \mathcal{L} \times \sigma \times KPS$$
$$KPS = \Delta x_B \Delta Q^2 \Delta t \Delta \phi$$



$$\frac{\Delta\sigma}{\sigma} = \frac{1}{\sqrt{N_{events}}} \oplus 5\%$$

$$\Delta A_{LU} = \frac{1}{P_e}\sqrt{\frac{1-P_e^2 A_{LU}^2}{N}} \oplus 3\%_{relative} \qquad P_e = 70\%$$

$$\Delta A_{UL} = \frac{1}{P_p}\sqrt{\frac{1-P_p^2 A_{UL}^2}{N}} \oplus 3\%_{relative} \qquad P_p = 70\%$$

$$\Delta A_{LL} = \frac{1}{P_e P_p}\sqrt{\frac{1-P_e^2 P_p^2 A_{LL}^2}{N}} \oplus 3\%_{relative} \oplus 3\%_{relative}$$

$$\Delta A_C = \sqrt{\frac{1-A_C^2}{N}} \oplus 3\%_{relative}$$

$$\Delta A_{LC} = \frac{1}{P_{e+}}\sqrt{\frac{1-P_{e+}^2 A_{LC}^2}{N}} \oplus 3\%_{relative} \qquad P_{e+} = 70\%$$

N.B. assumption on the luminosity

$$1 \text{ year} = 365 \text{ days} \times 24 \text{ hours/day} \times 3600 \text{ s/hour} = 3.15 \times 10^7 \text{ s} \approx \frac{1}{3} \times 10^8 \text{ s}$$

$$\mathcal{L} = 10^{34} \text{ cm}^{-2}\text{s}^{-1} = 10^{38} \text{ m}^{-2}\text{s}^{-1}$$

$$\int \mathcal{L} = 10^{34} \text{ cm}^{-2}\text{s}^{-1} \times 1 \text{ year} \approx \frac{1}{3} \times 10^{46} \text{ m}^{-2}$$

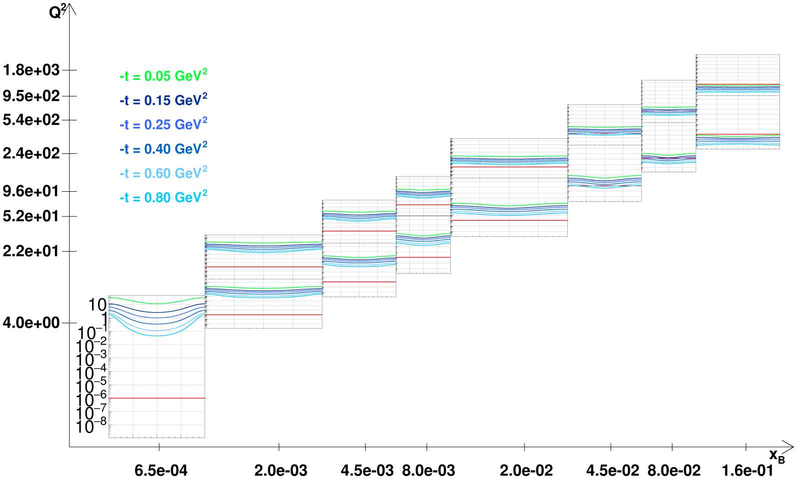
$$\begin{aligned} 1 \text{ barn} &= 10^{-28} \text{ m}^2 \\ 1 \text{ fb} &= 10^{-43} \text{ m}^2 \\ 1 \text{ fb}^{-1} &= 10^{43} \text{ m}^{-2} \\ 100 \text{ fb}^{-1} &= 10^{45} \text{ m}^{-2} \end{aligned}$$

100 fb^{-1} $\Longleftrightarrow$ 1 year at 10^{34} cm^{-2}s^{-1} with contingency (≈ 3)

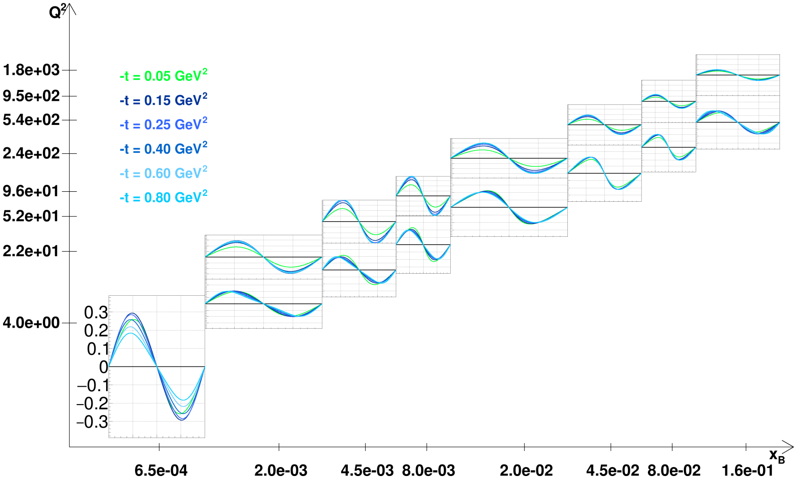
$\Longleftrightarrow$ 10 years at 10^{33} cm^{-2}s^{-1}

Luminosity is a potential challenge for exclusive reactions

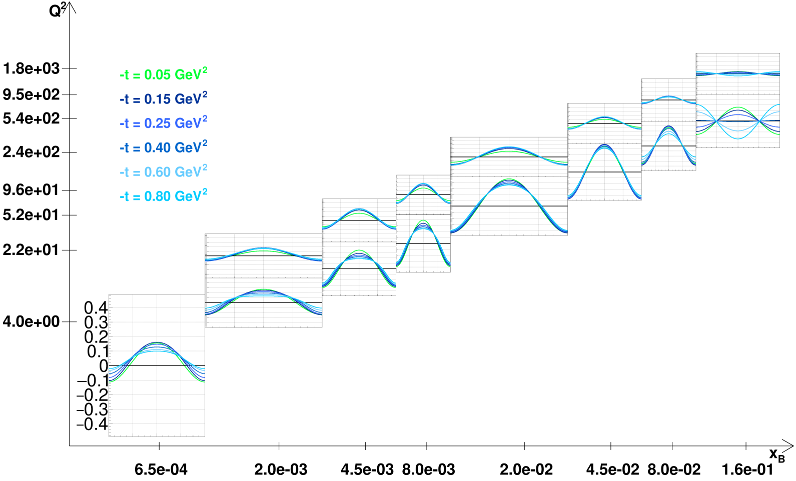
275 GeV × 18 GeV σ



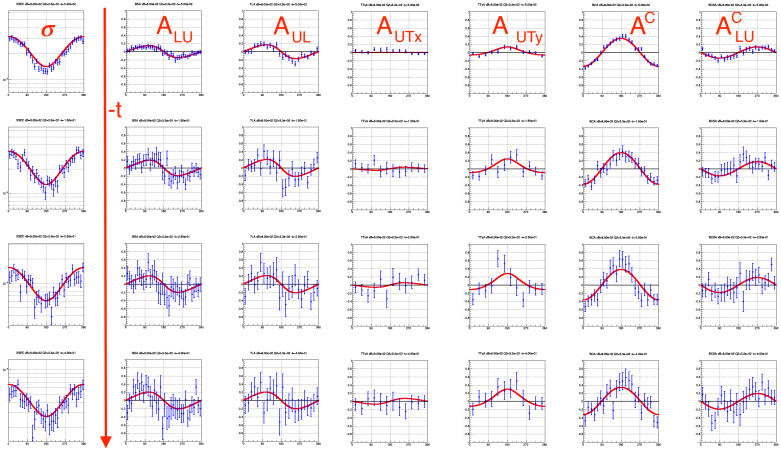
275 GeV × 18 GeV A_{LU}



275 GeV × 18 GeV A^C

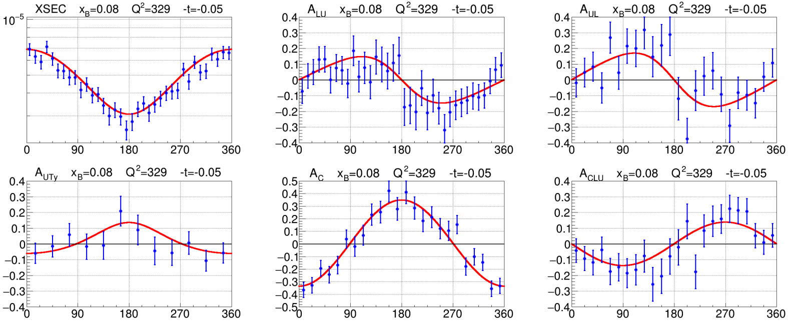


275 **GeV** × 18 **GeV** $x_B = 0.08 \pm 0.02$ $Q^2 = 329 \pm 175$ **GeV**^{2}



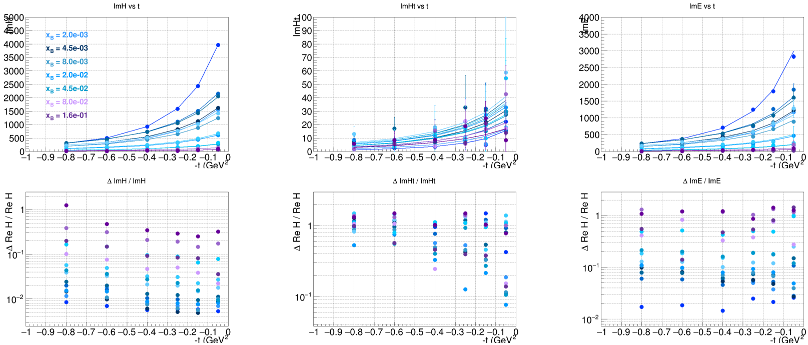
Not shown here: A_{LL} A_{LTx} A_{LTy} are small

275 **GeV** $\times$ 18 **GeV** $x_B = 0.08 \pm 0.02$ $Q^2 = 329 \pm 175$ **GeV**^{2} $-t = 0.05 \pm 0.05$ **GeV**^{2}

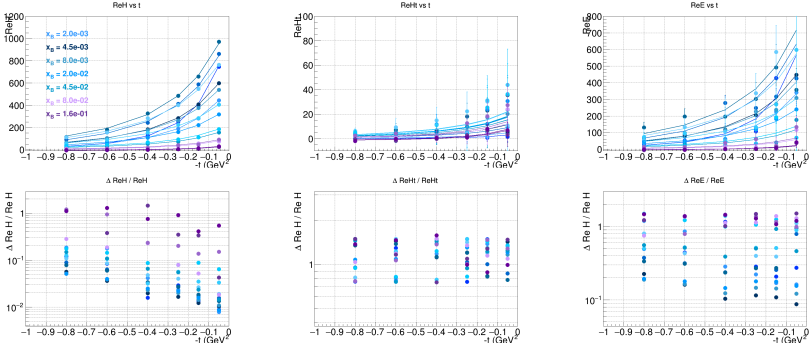


note: statistics and systematics included

Locally extracted Im CFF 275×18 GeV^2



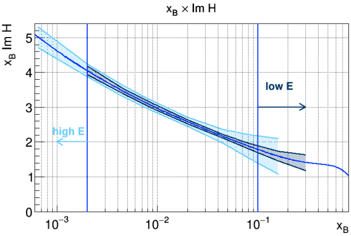
Locally extracted Re CFF 275×18 GeV^2

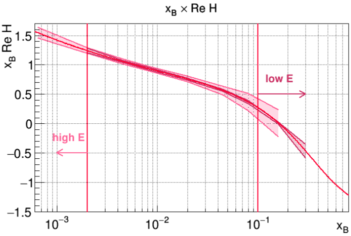


High and Low energies runs

Kinematical coverage complementarity

Local extraction results:





Better Strategy:

global fit using DR and parameterizations for $\mathcal{I}m\mathcal{H}$ and $D(t)$

note: subtraction constant: same for $\mathcal{H}$ and $\mathcal{E}$, none for $\tilde{\mathcal{H}}$ and $\tilde{\mathcal{E}}$

Towards Ji's sum rule

$$J^q(t) = \frac{1}{2}\int_{-1}^{1} \mathrm{d}x\, x\, [H^q(x,\xi,t) + E^q(x,\xi,t)]$$

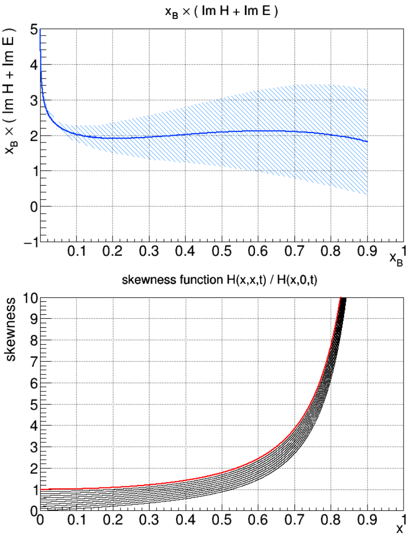
independent of ξ but at fixed ξ

DVCS measures

$$\mathcal{I}m\mathcal{H}(\xi,t) = \pi H(\xi,\xi,t)$$

need another process to access the skewness
$\rightarrow$ especially crucial at large x_B

DDVCS?
JLab 12 luminosity upgrade?

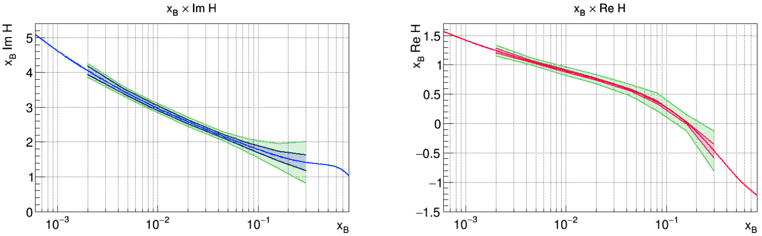


Impact of the positron beam

Enhanced sentivity to the Real part of the amplitude

Local extraction results:

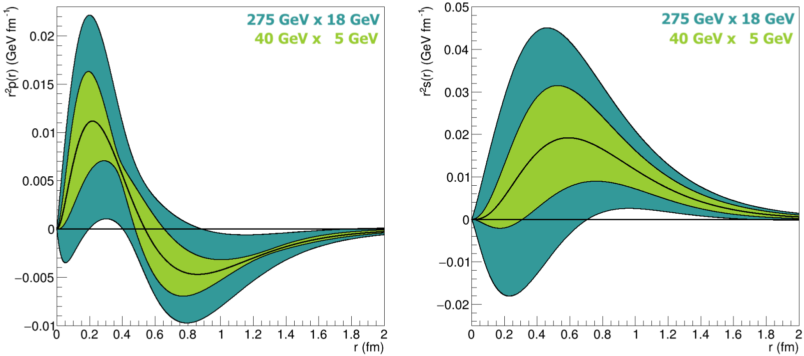
low E: 40 GeV $\times$ 5 GeV



Improved sensitivity, and systematic checks
Also, in general opens up access to new physics ($\cdots$)

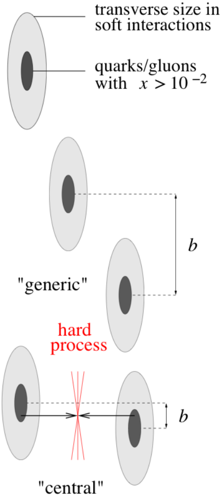
Pressure and Shear Sensitivities

Propagate uncertainties estimated with local fits using dispersion relation

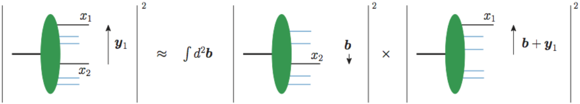


Relevance of the large x_B region to the dispersion analysis

Nucleon structure for hadron-hadron colliders



- MultiParton Interaction first suggested in 1975 (Landshoff & Polkinghorne)
- Evidence in :
  - high p_T at the CERN/ISR and Tevatron
  - intermediate p_T : underlying event in Dijet and Drell-Yann at CFD Run I and II, and at CMS
  - Found to be necessary to tune low p_T Pythia and Herwig
- MPI more important at LHC is expected to challenge many new physics search
- MPI can also be better studied at LHC for itself !

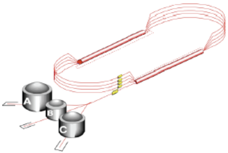


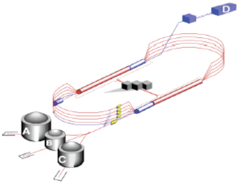
C. Weiss, L. Frankfurt, M. Strikman, Ann.Rev.Nucl.Part.Sci. 55 (2005) 403-465
Diehl, Ostermeier, Schäfer, "Elements of MPI in QCD", DESY 11-196

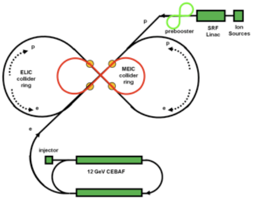
Summary

Summary

- A unified framework for nucleon tomography
- The first 6 GeV results suggested precocious dominance of small configurations
- Accuracy of 12 GeV era in the valence region at moderate momentum transfer
- Long range plan extends naturally to EIC
- Interplay between spin and flavor decompositions requires all reactions
- The EIC will expand the reach and probe the sea and gluons
- Other future measurements planned at CERN/Compass and DESY/Panda
- EIC will be essential for QCD backgrounds at LHC and beyond
- Complementarity







Outlook
Supplementary slides

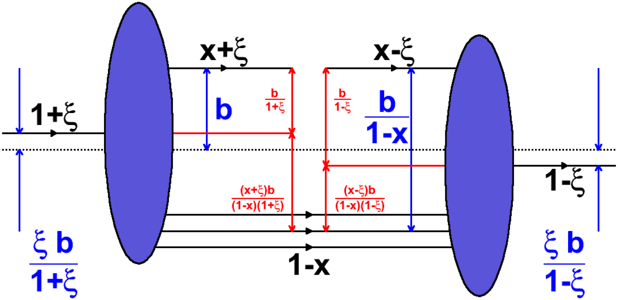
Impact parameter space

$$\text{GPD} \quad \propto \quad e^{Bt}$$

$$-t \quad = \quad \frac{x_B^2 M^2 + \Delta_\perp^2}{1 - x_B}$$

$$\text{GPD} \quad \propto \quad e^{-B_\perp \Delta_\perp^2}$$

$$B_\perp \quad = \quad \frac{1}{1 - x_B} B$$



GPD modelling and Dispersion relations

$$\begin{aligned}
\mathrm{CFF}(x_B, Q^2, t) &= \int_{-1}^{1} \mathrm{d}x \frac{2x}{\xi^2 - x^2 - i\epsilon} \mathrm{GPD}(x, \xi, t, Q^2) \\
\mathcal{I}\mathrm{m}\ \mathrm{CFF}(x_B, Q^2, t) &= \pi \mathrm{GPD}(\xi, \xi, t, Q^2) \\
\mathcal{R}\mathrm{e}\ \mathrm{CFF}(x_B, Q^2, t) &= \int_{0}^{1} \mathrm{d}x \frac{2x}{\xi^2 - x^2} \mathrm{GPD}(x, x, t, Q^2) \pm \mathcal{D}(t, Q^2)
\end{aligned}$$

"Holographical" models for global fitting strategies
Parameters are direct observables

Model dependent extraction of J_u and J_d