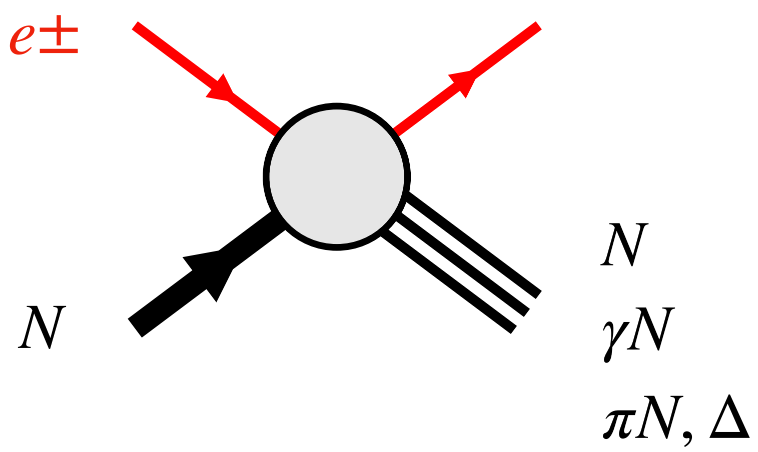
Chiral dynamics in low-energy e+/e- N scattering

C. Weiss (JLab) [weiss@jlab.org],
Low energy electron positron physics at Jefferson Lab, JLab, 23-27 March 2026 [Webpage]



Here: $E_{e\pm} \lesssim$ 300 MeV

What hadronic structure and dynamics can be explored in low-energy electron/positron-nucleon scattering?

What specific/unique measurements can be done with positrons?

Long-distance dynamics in baryon sector

Chiral symmetry breaking and EFT methods

Δ baryon and $1/N_c$ expansion of QCD

Physics in low-energy e+/e- N scattering

Low Q^2 elastic form factors $\rightarrow$ chiral dynamics

Single-spin asymmetries $\rightarrow$ two-photon exchange

Virtual Compton scattering $\rightarrow$ Re/Im, contact, polarizabilities

Complementarity JLab $e^\pm \leftrightarrow$ MUSE $\mu^\pm, e^\pm$

This presentation

- Key measurements, not a complete inventory
- Focus on physics potential, not a review of literature
- Intended to start discussions

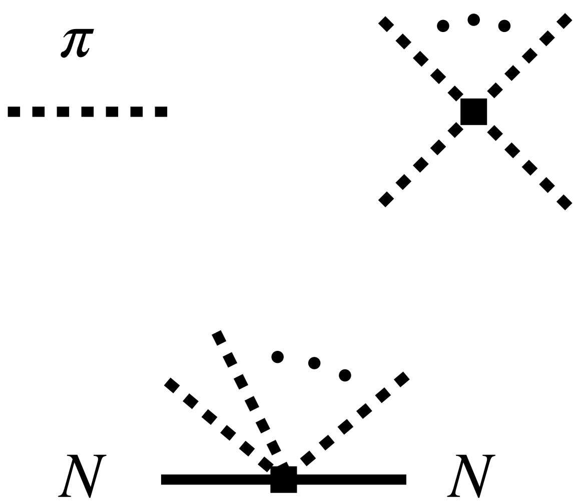
Also interesting (not covered here):

e+/e- scattering on nuclei A > 1

Nuclear form factors, radii, two-photon exchange in elastic scattering

Nuclear excitations 1-10 MeV in inelastic scattering

Long-distance dynamics in baryon sector



Chiral dynamics

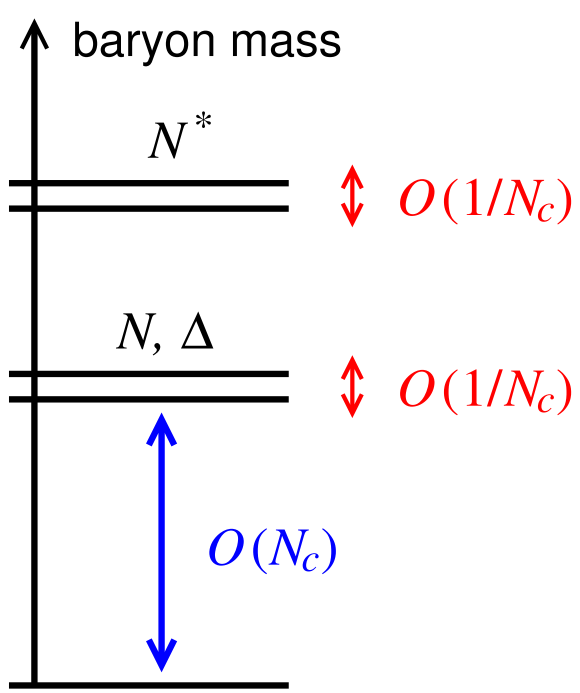
Chiral symmetry breaking in QCD $\langle \bar{\psi}\psi \rangle \neq 0$

Pion as phase fluctuation of condensate $\langle \bar{\psi}^a \psi^b \rangle \sim C\, U^{ab}(x)$

Quasi-massless excitation

Interactions $\propto p^\mu$, coupling to baryons

Dynamics constructed and solved using EFT methods
Gasser, Leutwyler 1984; Weinberg 1990; Bernard, Kaiser, Meissner 1990s, ...



Baryon resonances $\Delta(1232)$

$1/N_c$ expansion of QCD: Semiclassical limit, dynamics simplifies
'tHooft 1974, Witten 1979, Gervais, Sakita 1984, Dashen, Jenkins, Manohar 1990s

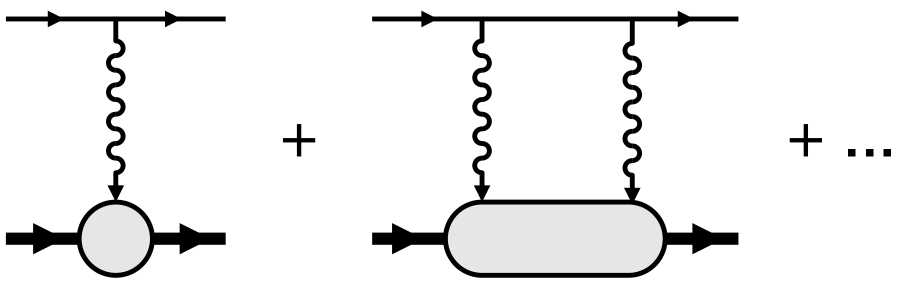
Dynamical spin-flavor symmetry in baryon sector

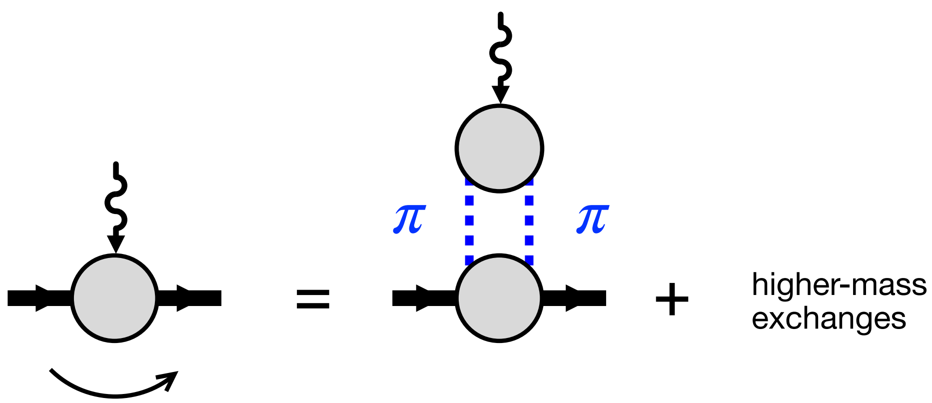
N and Δ in ground-state multiplet $I = J = 1/2$

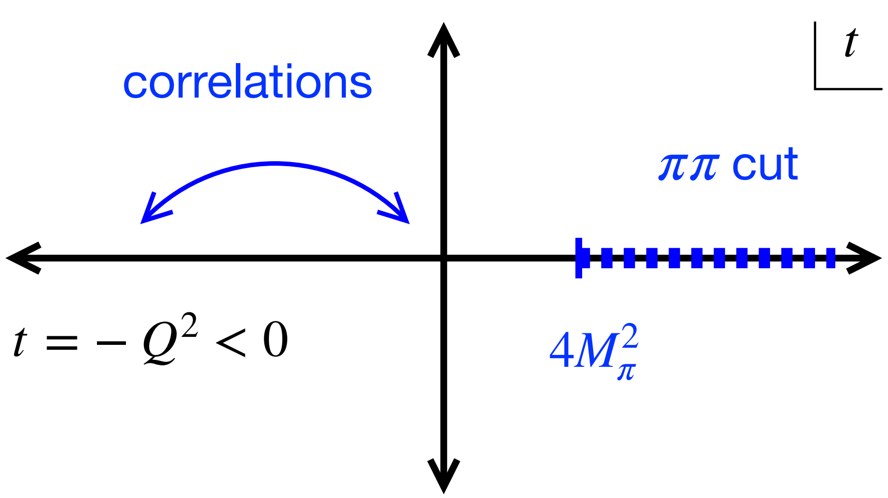
Transitions governed by symmetry $\langle \Delta | .. | N \rangle \leftrightarrow \langle N | .. | N \rangle$

EFT methods: Combine chiral $\times\, 1/N_c$ expansions
Goity, Calle Cordon, Fernando, Jayakodige 2013+

Low-Q^2 elastic form factors







Elastic scattering $e^{\pm}N \rightarrow e^{\pm}N$

TPE + other radiative corrections

Extract electric/magnetic form factors $G_{E,M}(t)$

Charge radius $\langle r^2 \rangle_E = 6\, G'_E(0)$

Long-distance dynamics

$\pi\pi$ cut in analytic functions $G_{E,M}(t > 0)$

Calculated using unitarity + dynamical input
Frazer, Fulco 1960; Hoehler et al 1970s; ...; Hoferichter et al 2016

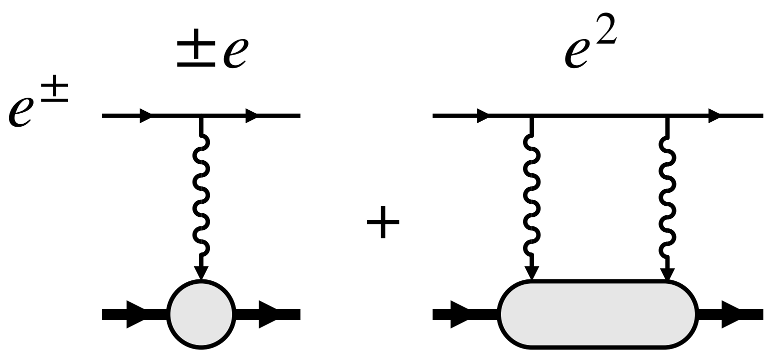
Encoded in low-Q^2 behavior of spacelike form factors:
Higher derivatives G''_E, moments $\langle r^4 \rangle$ etc.
see e.g. Alarcon, Weiss, PRC 97 (2018) 055203 [INSPIRE]

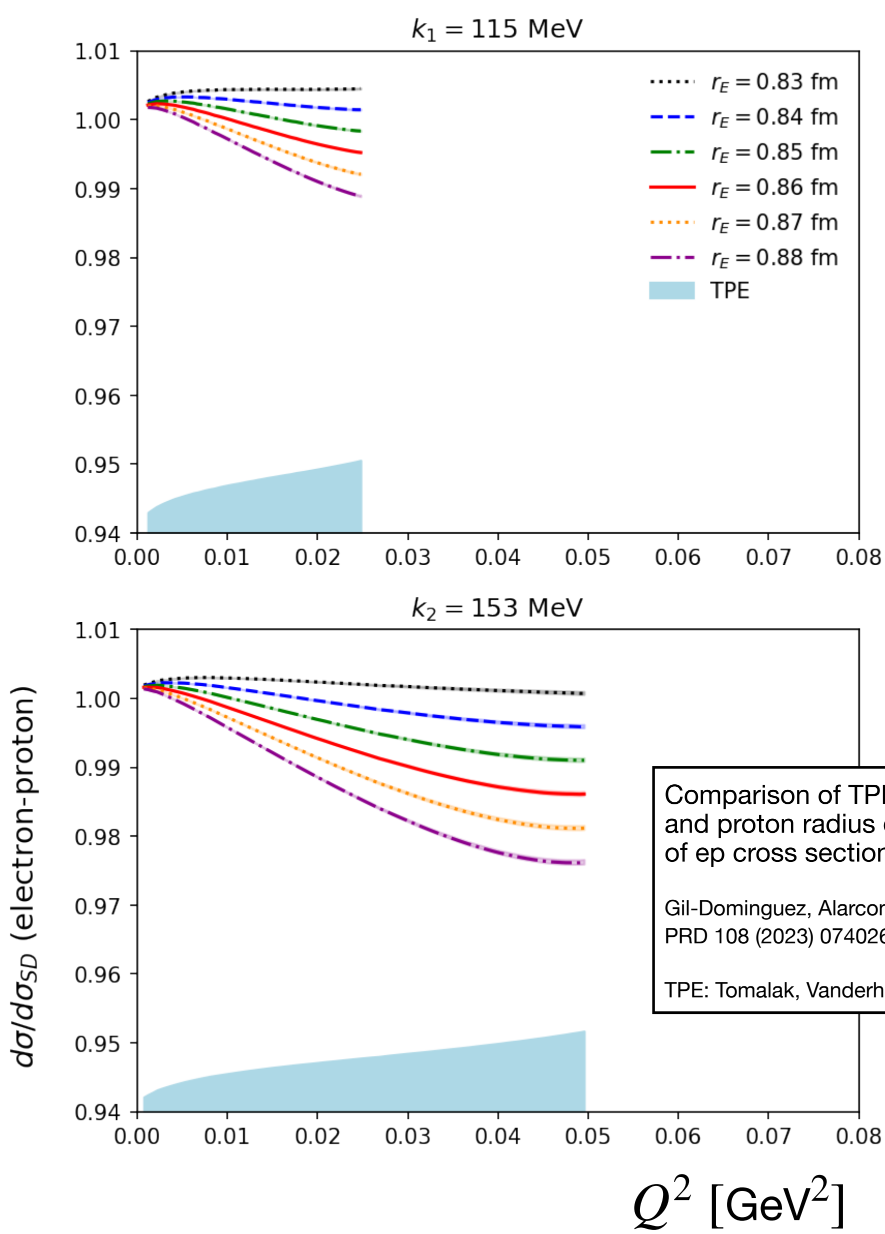
To explore it, need to measure Q^2-dependence over finite range, not just $Q^2 \rightarrow 0$

Basic feature of long-distance hadron structure

Controls systematics in nucleon radius extraction

Low-Q^2 elastic form factors





Comparison of TPE effect and proton radius dependence of ep cross section.

Gil-Dominguez, Alarcon, Weiss PRD 108 (2023) 074026 [INSPIRE]

TPE: Tomalak, Vanderhaeghen 2016

Positrons

Two-photon exchange correction changes sign TPE × OPE

Validate calculations of TPE + other radiative corrections
Blunden, Melnitchouk, Tjon 2003; Guichon, Vanderhaeghen 2003, many authors...
Review Arrington, Blunden, Melnitchouk PPNP 66 (2011) 782

Improve low-Q^2 G_E measurements and radius extraction:
Major source of uncertainty

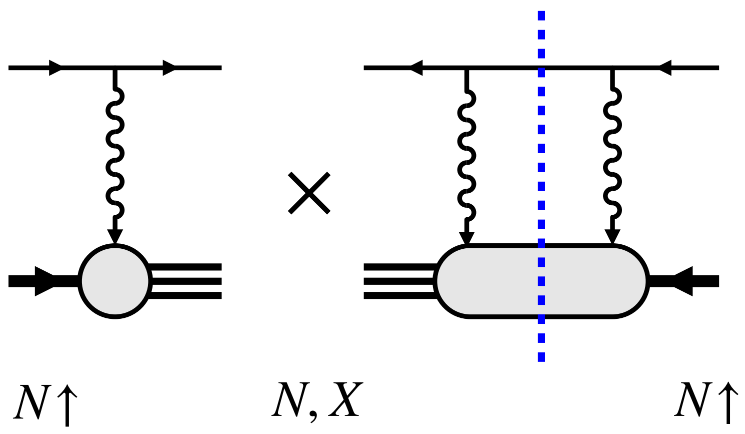
Also: Improve sensitivity to G_M at low-Q^2
Alarcon, Higinbotham, Weiss, PRC 102 (2020) 035203 [INSPIRE]

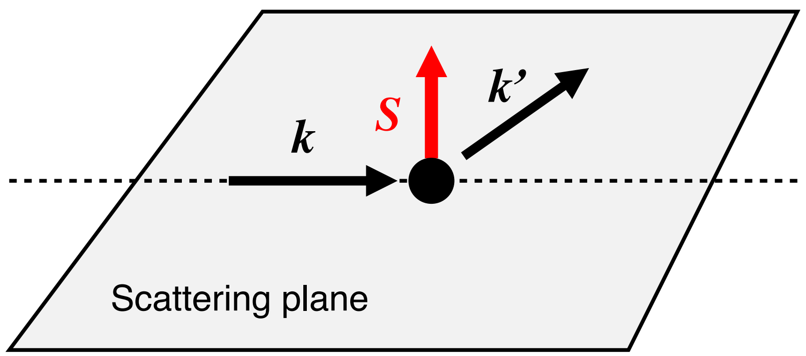
Complementarity with PSI MUSE

$\mu^\pm p$ scattering at incident momenta 115-210 MeV

Also $e^\pm p$ scattering in similar kinematics

DESY OLYMPUS: $e^\pm p$ scattering at $E_e =$ 1-2 GeV





Target normal single-spin asymmetry

$$A_N = \frac{\sigma\uparrow - \sigma\downarrow}{\sigma\uparrow + \sigma\downarrow}$$ spin normal to scattering plane

$eN \to e'N$ elastic

$\to e'X$ inclusive

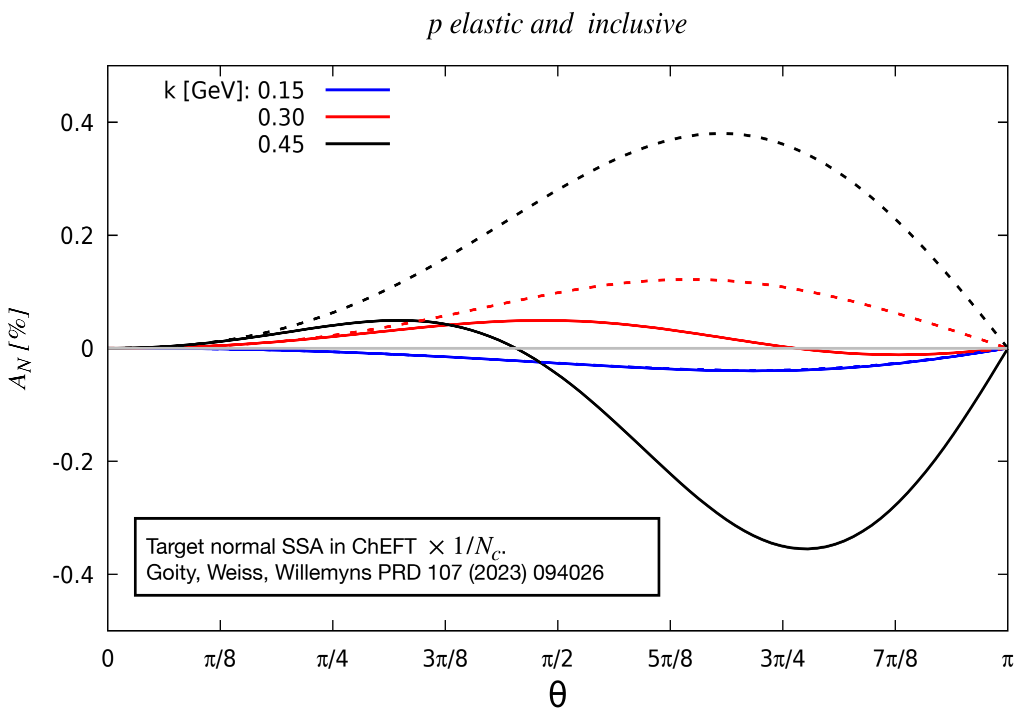
Asymmetry zero in OPE
Christ, Lee 1966

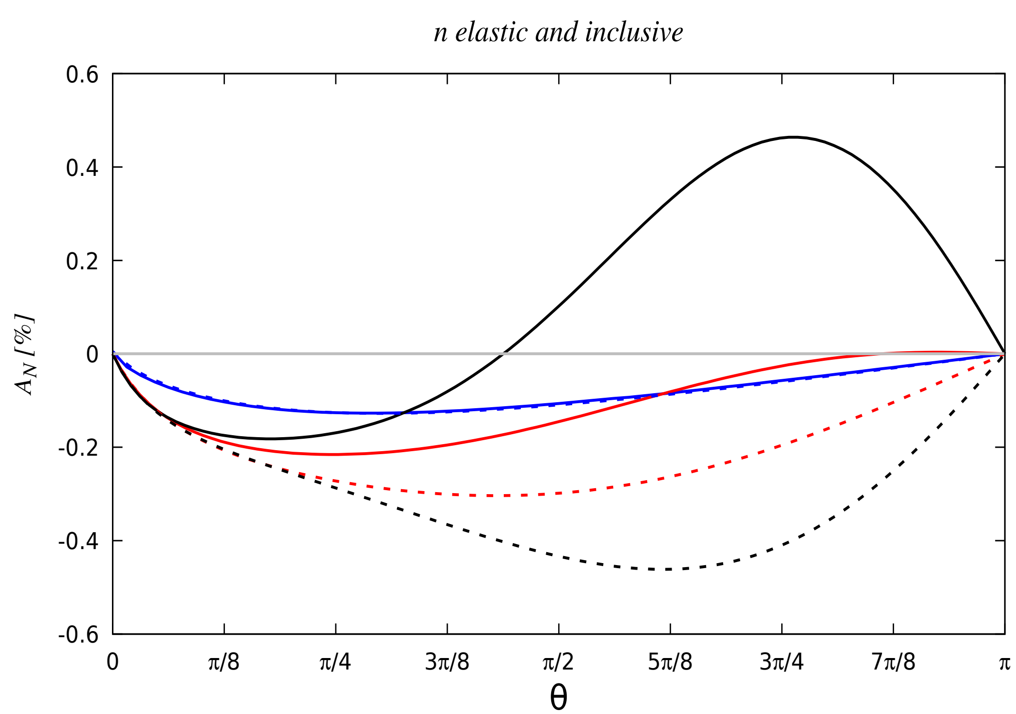
Pure TPE effect, arises from interference OPE × TPE
Barut, Fronsdal 1960

Involves imaginary part Im(TPE), IR-finite

[Also: Beam normal single-spin asymmetry → following]

Single-spin asymmetries





Long-distance dynamics

A_N calculated in ChEFT $\times\ 1/N_c$ expansion

Goity, Weiss, Willemyns PLB 835 (2022) 137580 [INSPIRE], PRD 107 (2023) 094026 [INSPIRE]

Includes Δ in intermediate/final states where allowed

$A_N \sim 10^{-2}$ in low-energy regime

Elastic and inclusive scattering

See also: Koshchii, Afanasev 2018; Ahmed, Blunden, Melnitchouk 2023

Positrons

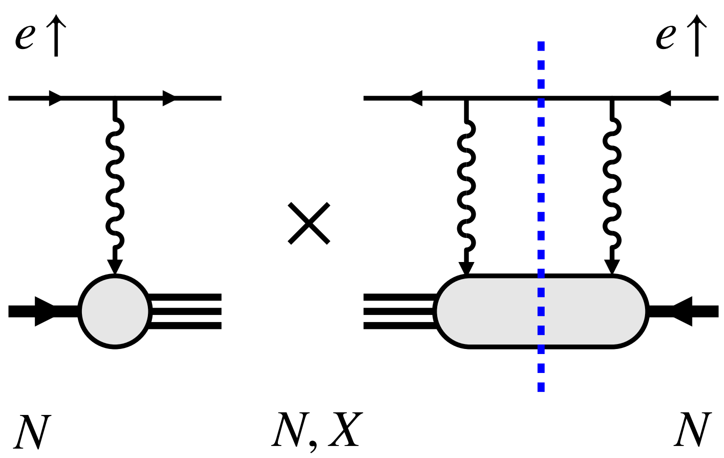
$A_N(e^+N) = -\,A_N(e^-N)$ odd in beam charge

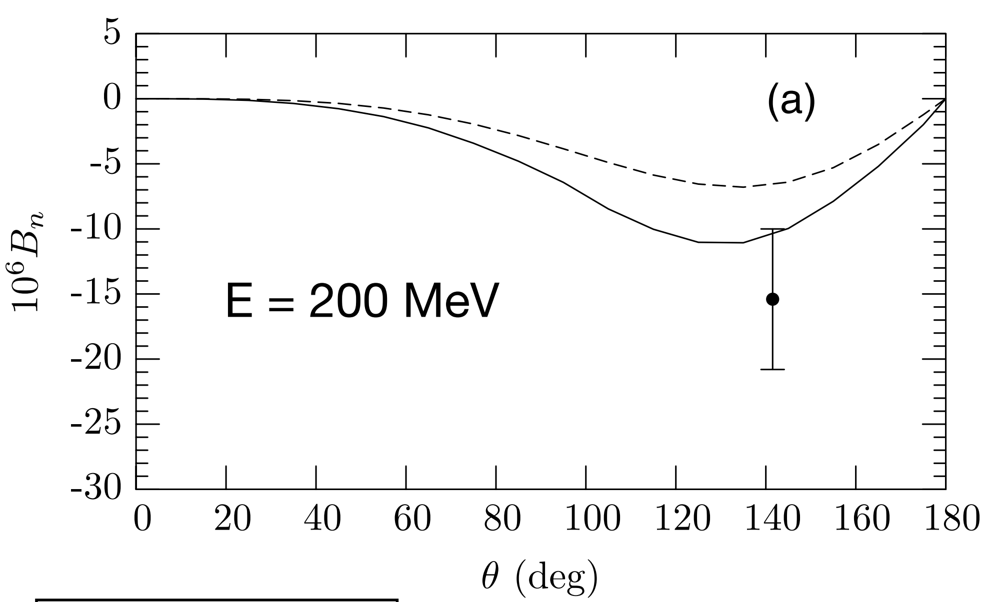
Test universality, validate EFT calculations

HERMES: $A_N(e^+N)$ measured in DIS kinematics

Theory: Metz, Schlegel, Goeke 2006;
Afanasev, Strikman, Weiss, *Phys.Rev.D* 77 (2008) 014028 [INSPIRE]

Single-spin asymmetries





Beam normal SSA
Borisyuk, Kobushkin 2006

Beam normal single-spin asymmetry

$$B_N = \frac{\sigma\uparrow - \sigma\downarrow}{\sigma\uparrow + \sigma\downarrow}$$ lepton spin normal to scattering plane

Asymmetry proportional to electron mass m_e

Enhanced by $\log^2(m_e^2/Q^2)$ and $\log(m_e^2/Q^2)$ due to collinear photons in TPE
Afanasev, Merenkov 2004; Borisyuk, Kobushkin 2006

$B_N \sim 10^{-5}$ in low-energy regime

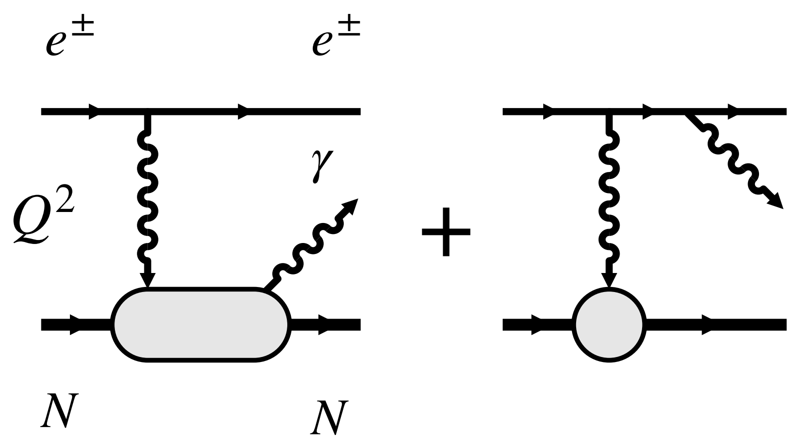
Calculations based on empirical input
Koshchii, Afanasev 2019; Ahmed, Blunden, Melnitchouk 2023

Positrons

Would require polarized positron beam.
Challenging measurement

Larger asymmetries in μN scattering

Virtual Compton scattering



VCS BH

Real photon production $e^{\pm}N \to e^{\pm}\gamma N$

Bethe-Heitler + Virtual Compton Scattering

Amplitudes interfere

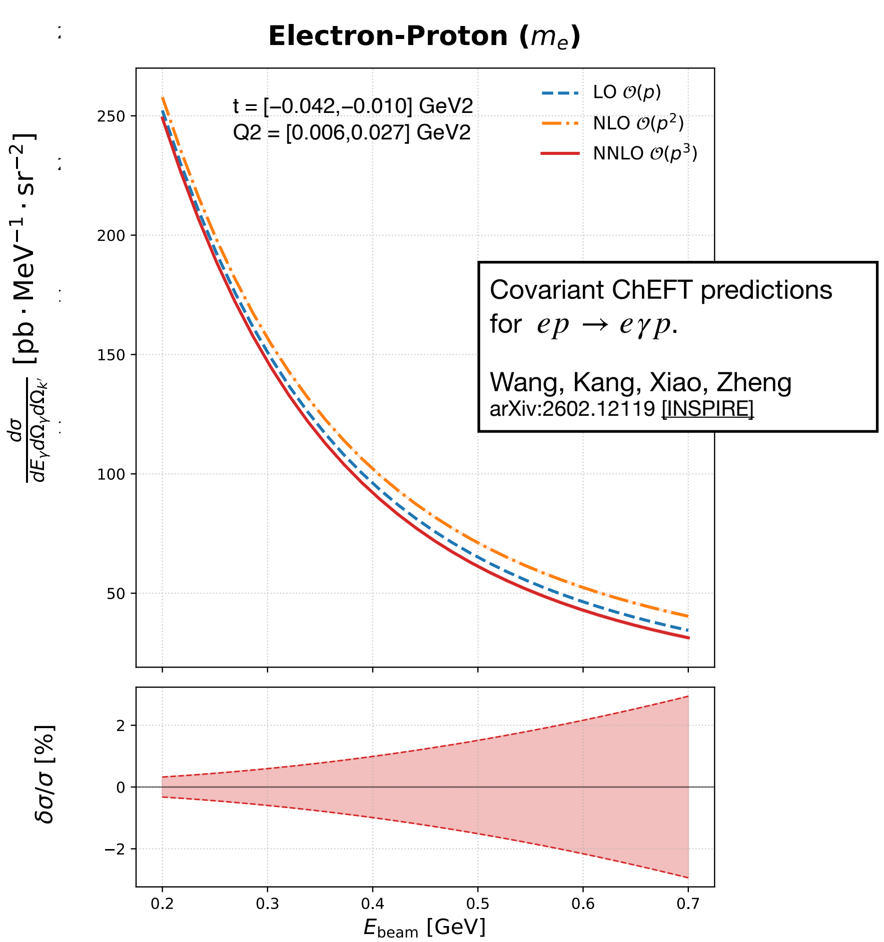
Long-distance dynamics

Dispersion relations for real/virtual Compton amplitude

Schumacher, Lvov, Petrunkin 1997; Drechsel, Pasquini, Vanderhaeghen, Gorchtein 1999+, ...

Chiral EFT calculations

Gellas, Hemmert, Meissner 2000; Griesshammer et al 2012; Hagelstein, Miskimen, Pascalutsa 2016, Lensky et al. 2017...



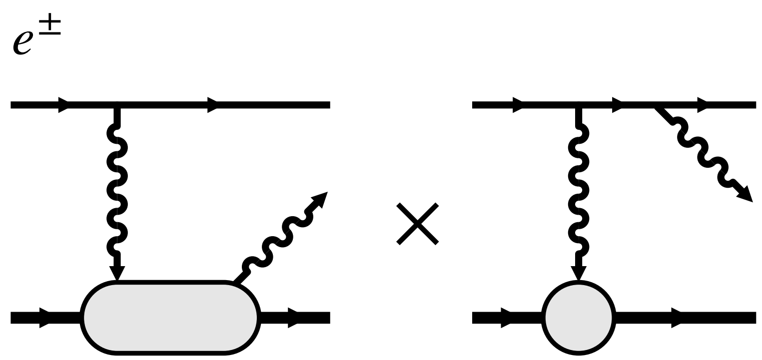
Nucleon generalized polarizabilities

Coefficients of low-energy expansion of virtual Compton amp

$\alpha_E(Q^2), \beta_M(Q^2)$ depend on Q^2

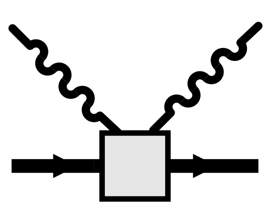
Describe deformation of charge/magnetization distributions in hadron by external EM field

Virtual Compton scattering



VCS BH

$$\mathrm{Re}\,A(\nu,..) = \frac{\nu}{\pi}\int d\nu' \frac{\mathrm{Im}\,A(\nu,..)}{\nu'(\nu'-\nu)} + \mathrm{Re}\,A(0,..)$$



Positrons

$$A_{UU}^{C} = \frac{\sigma_{UU}(e^+) - \sigma_{UU}(e^-)}{\sigma_{UU}(e^+) + \sigma_{UU}(e^-)}$$

beam charge asymmetry (unpolarized diff cross secn)

Arises from interference BH × VCS

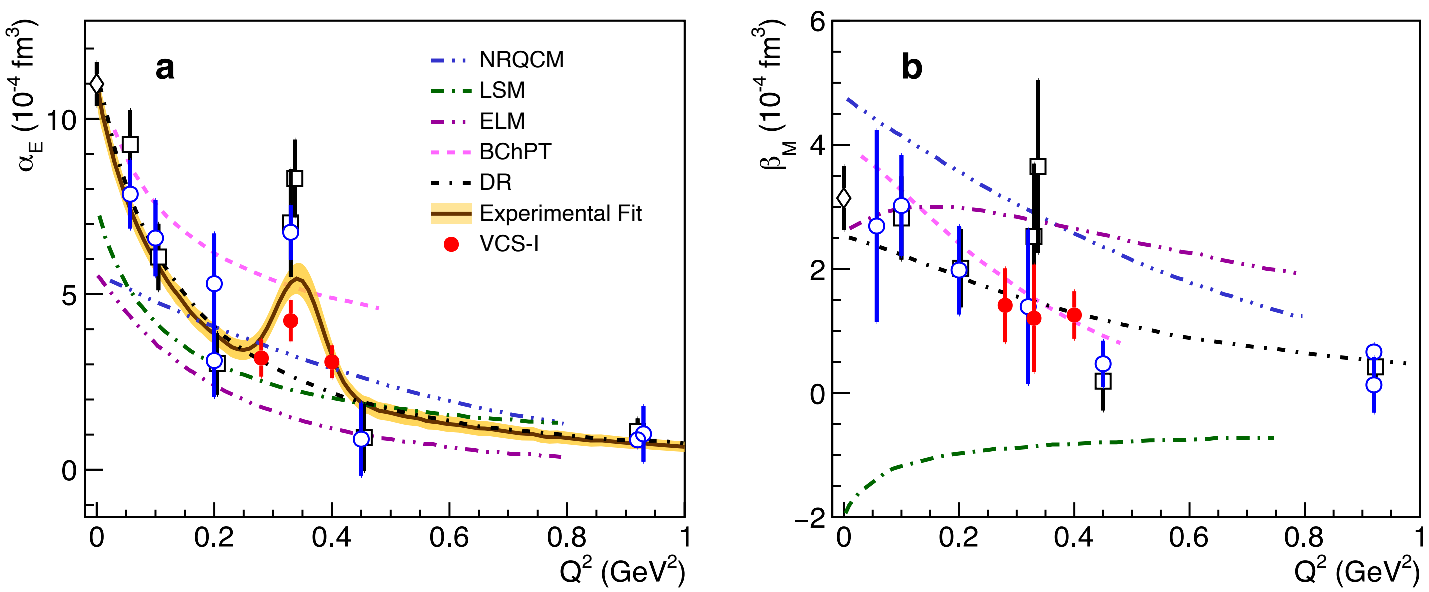
Probes directly real part Re(VCS)

Dispersion theory: Subtraction constant $\mathrm{Re}\,A(0,..)$, depends on t, Q^2

Chiral EFT: Low-energy constant describing local $\gamma\gamma NN$ coupling (induced by high-energy DoF)

Improves extraction of generalized polarizabilities

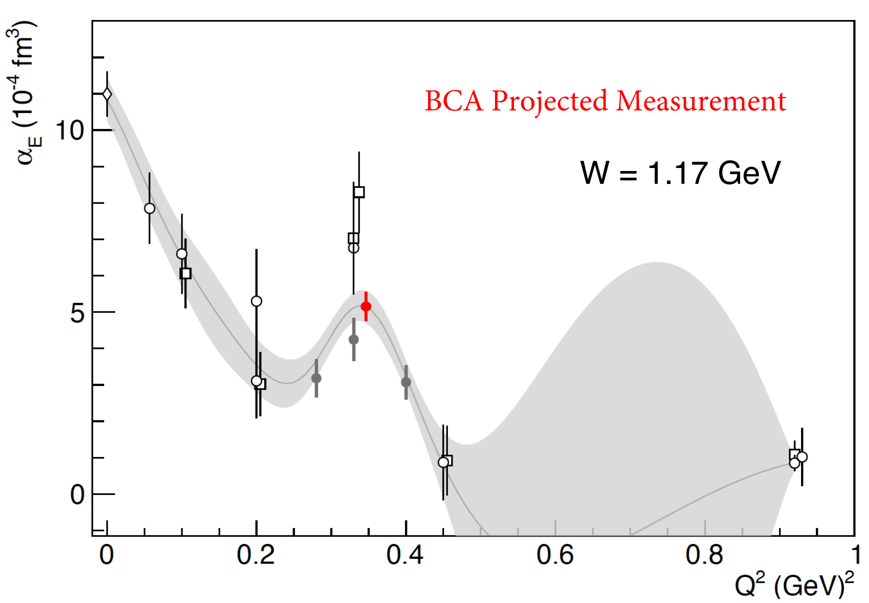
Virtual Compton scattering



Higher energies $\gtrsim$ 1 GeV

Status of generalized polarizabilities:
World data, different extraction methods

From N. Sparveris, Chiral Dynamics 2024 [INSPIRE]



Projected extraction of electric polarizability
using beam charge asymmetry

Summary

Long-distance dynamics emerging from QCD can be constructed/solved using systematic EFT methods

Physics with positrons at energies $E_{e\pm} \lesssim$ 300 MeV

- TPE in elastic eN scattering: Low-Q^2 form factors, $\pi\pi$ cut, peripheral nucleon structure

- Single-spin asymmetries in elastic or inclusive eN scattering: Pure TPE effects, could be validated through beam charge dependence

- Virtual Compton scattering: Re(VCS), LECs, improved determination of polarizabilities

Discuss complementarity with MUSE $\mu^{\pm}/e^{\pm}$