Hard Exclusive Diphoton Photoproduction

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with help from
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01.

Describing the Nucleon Structure

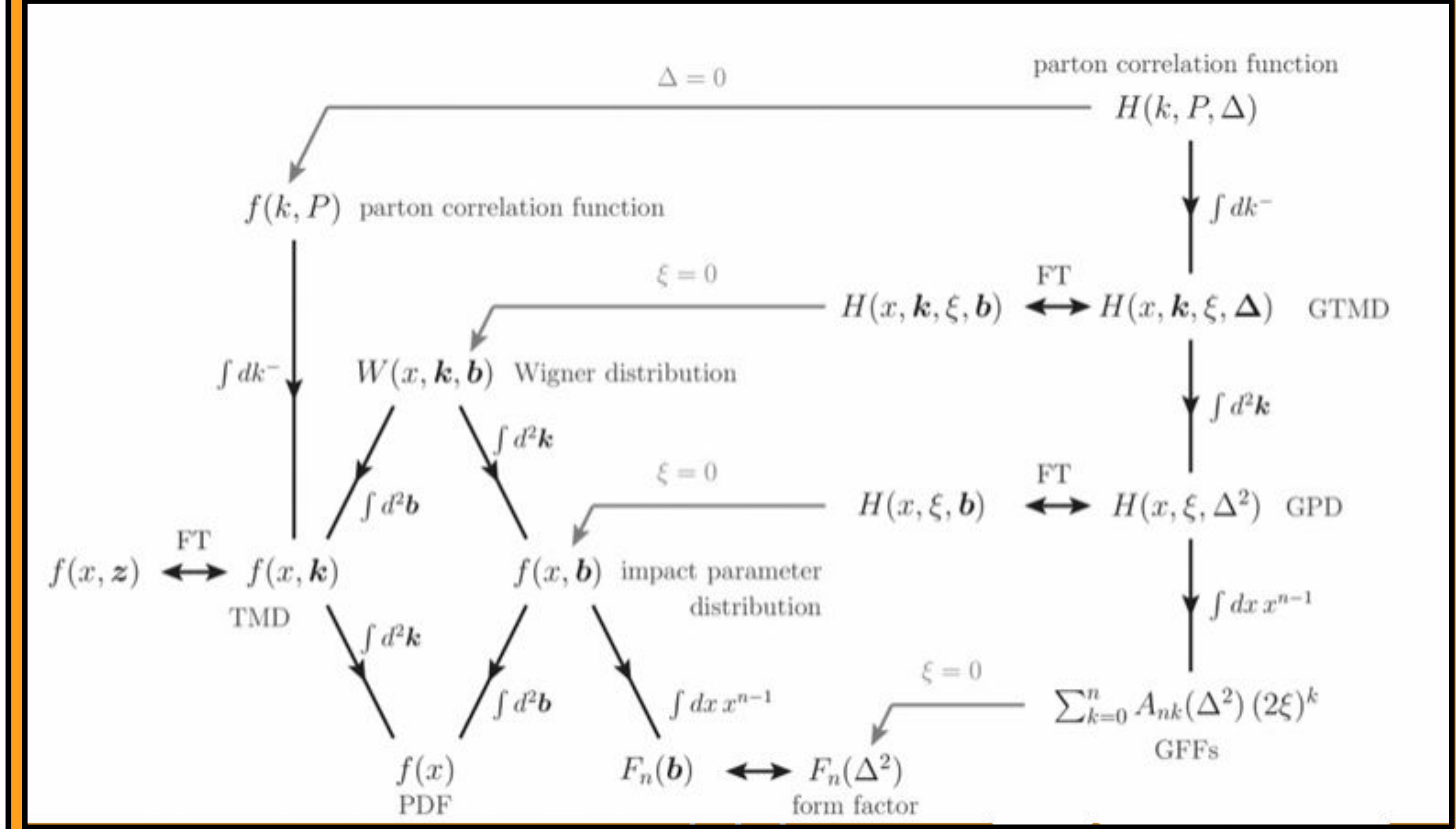
Generalized Transverse Momentum Distribution

Transverse Momentum Distributions + Generalized Parton Distributions* = Generalized Transverse Momentum Distributions

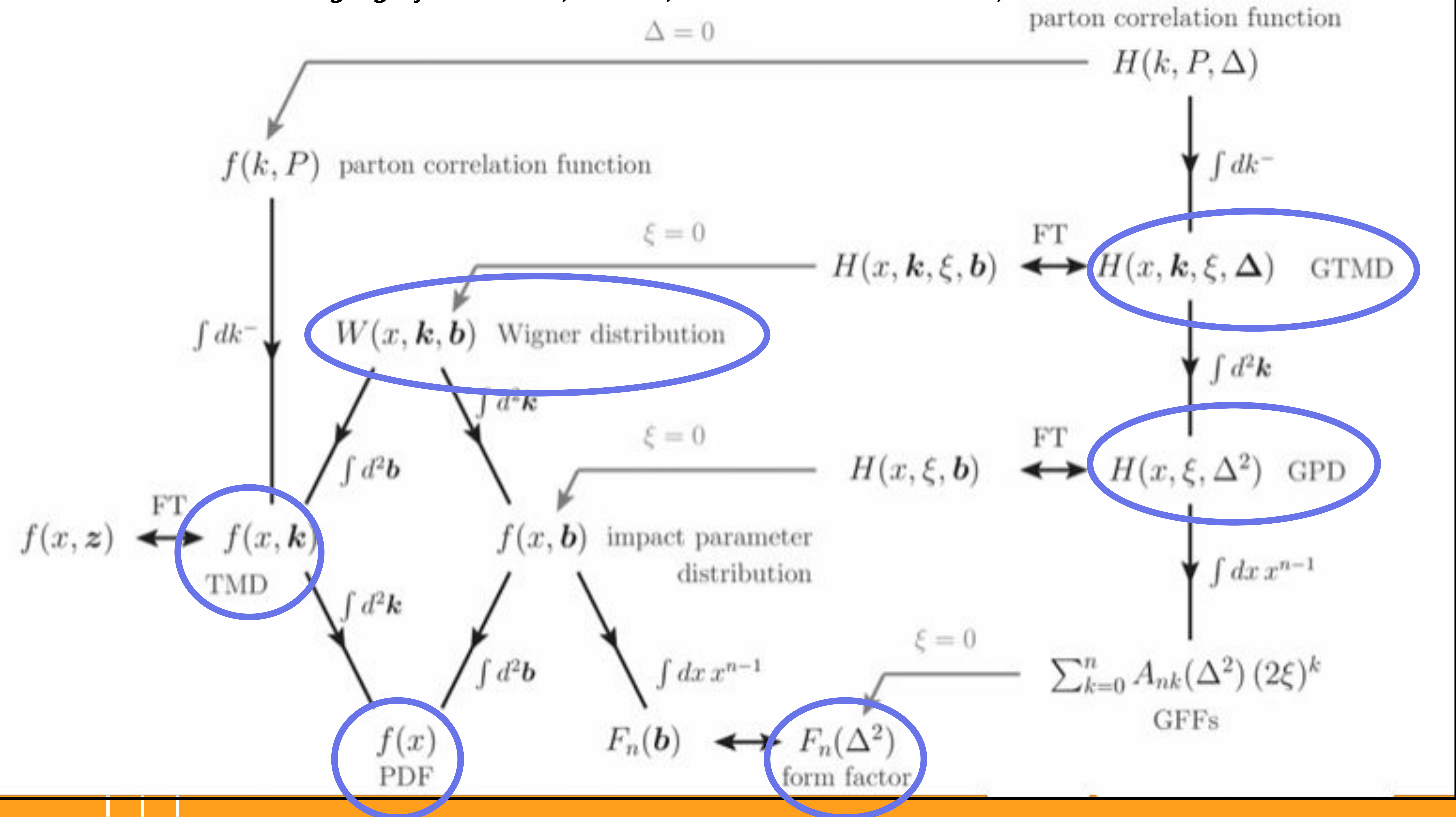
Combining these two distinct distributions allows for a “unified framework” that simultaneously models multiple aspects of the final distributions[1]

*This will be covered later in the presentation

Photo: *Multi-Dimensional Imaging of Nucleons, Nuclei, and Mesons at the EIC,* A. Vossen



Multi-Dimensional Imaging of Nucleons, Nuclei, and Mesons at the EIC, A. Vossen



02.

Form Factors and Elastic Scattering

What Are Form Factors?

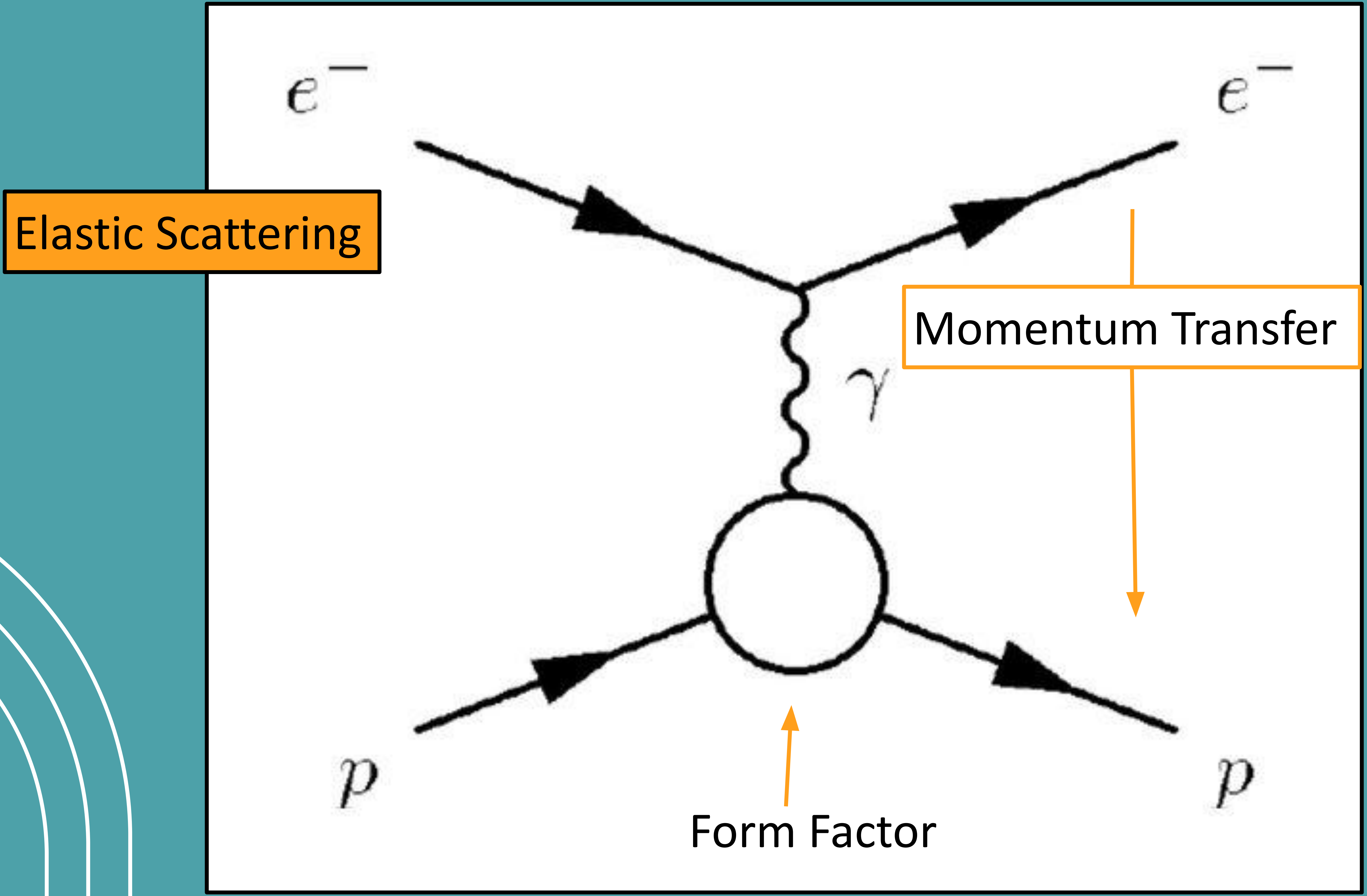
<u>Form factors</u> "[take] into account the shape of the scattering particle in the observed cross-section"[2] to give an approximation for spatial charge density.[3] It is dependent on the momentum transfer.

Note: A cross-section (σ) is the probability of an interaction occurring.

$\sigma_{pointlike}$ *depends on* E_{e^-}, θ

If σ_{proton} *= pointlike, then charge = +1.*

If σ_{proton} *= non-pointlike, then* $\sigma_{pointlike}$ ** (Form Factor)*



Elastic Scattering
e^-
e^-
Momentum Transfer
γ
p
p
Form Factor

Fourier Transform of Form Factor

$F(Q^2) = F(t)$ where Q is the virtual mass and t is the momentum transfer.

$$Q^2 = t = (P_{\text{proton final}} - P_{\text{proton inital}})^2$$

This gives the transverse position, which goes to zero as $F(\Delta^2_{\perp}) + F(\Delta_L) \rightarrow 0$.

Performing a Fourier Transform on the form factor yields the position distribution of intransverse (2D charge/quark distribution) space:

$$F(\Delta^2_{\perp}) \xrightarrow{\text{Fourier Transform}} f(b_{\perp})$$

03.

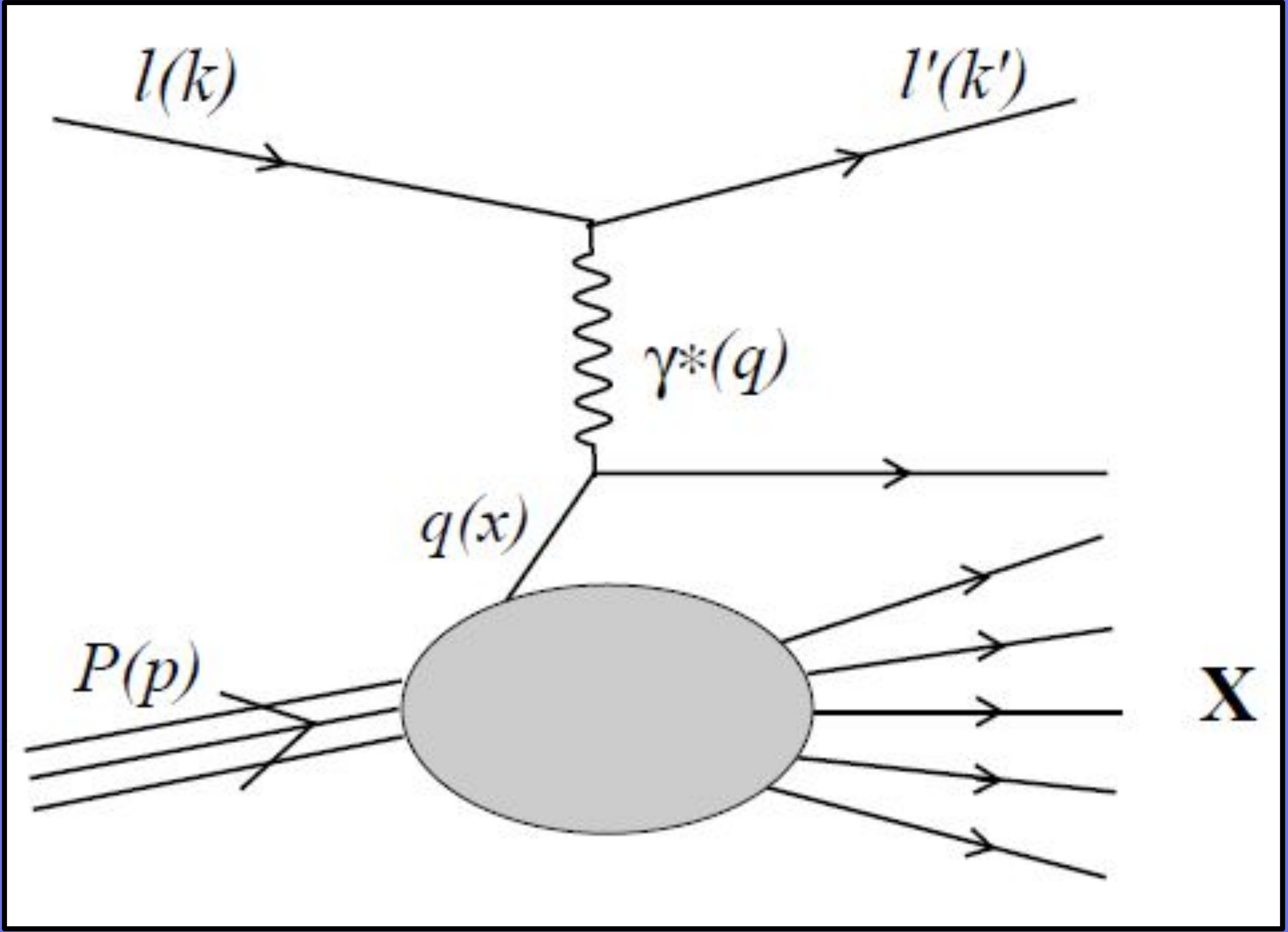
PDF & Deep Inelastic Scattering

Deep Inelastic Scattering

- "Inelastic" refers to the target's absorption of energy
  - At high energies, the target "shatters", releasing new particles due to the intake of energy

- "Deep*" refers to the high energy required to affect the quarks within the target

*Deep is also referred to as hard



Parton Distribution Function

Partons = Quarks and Gluons

PDFs “give the probability to find partons [...] in a hadron as a function of the fraction [Ψ] of the proton's momentum carried by the parton.”[4]

PDFs are “determined from experimental results of short distance scattering of the partons.”[4]

04.

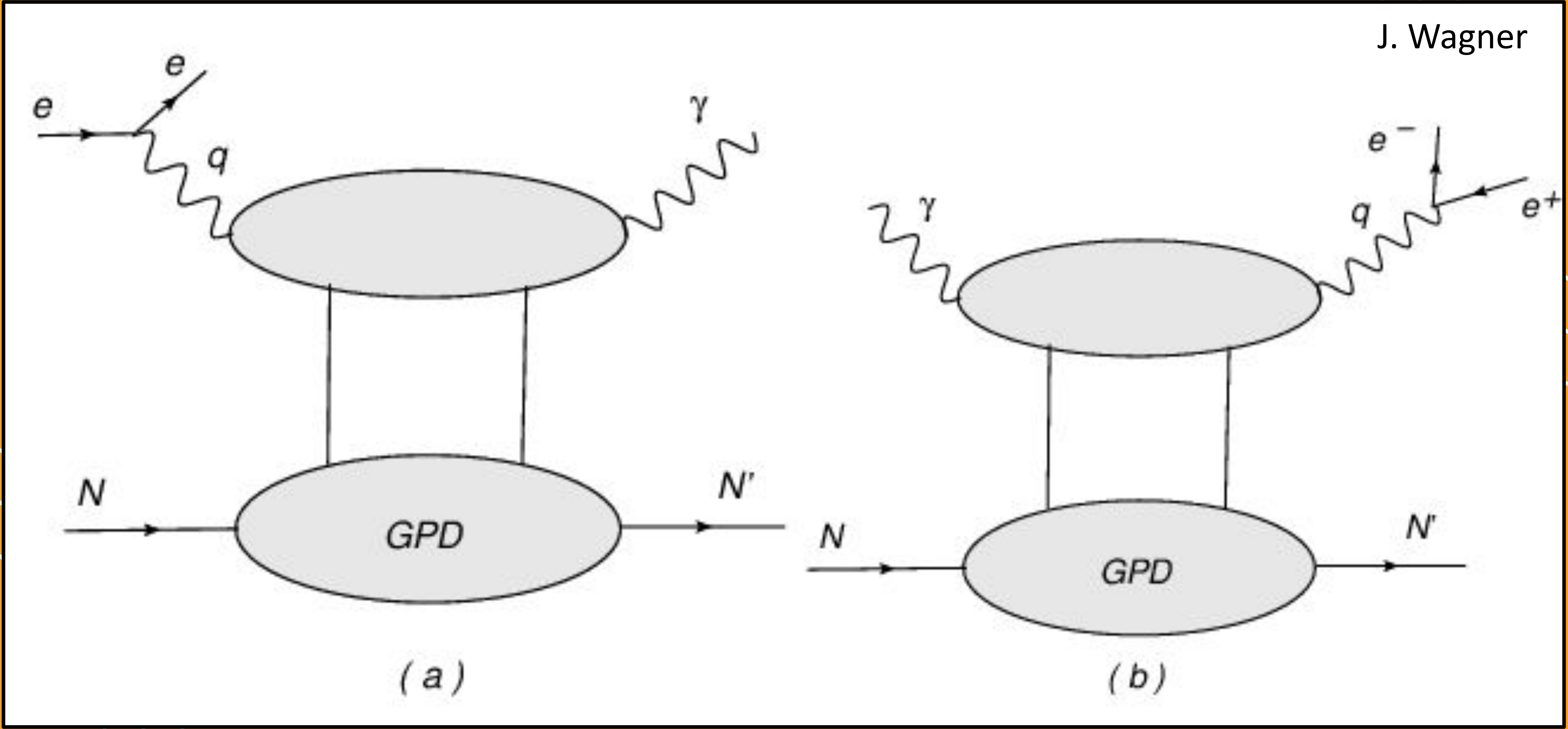
GPD & Timelike Compton Scattering

Relating Form Factors and PDFs

Recall that Generalized Parton Distribution (GPD) combines the concepts of parton distributions and Form Factors.

The elastic scattering in Form Factors and the inelastic scattering in PDFs relate to correlate parallel momentum with perpendicular momentum.

To do this, our experiments must create at least one new particle to get x, detect the final state to get t, and have $Q^2 > 1$ GeV^2 to get a “deep” regime so that we can see quarks as pointlike ($t = [p - p']^2$).

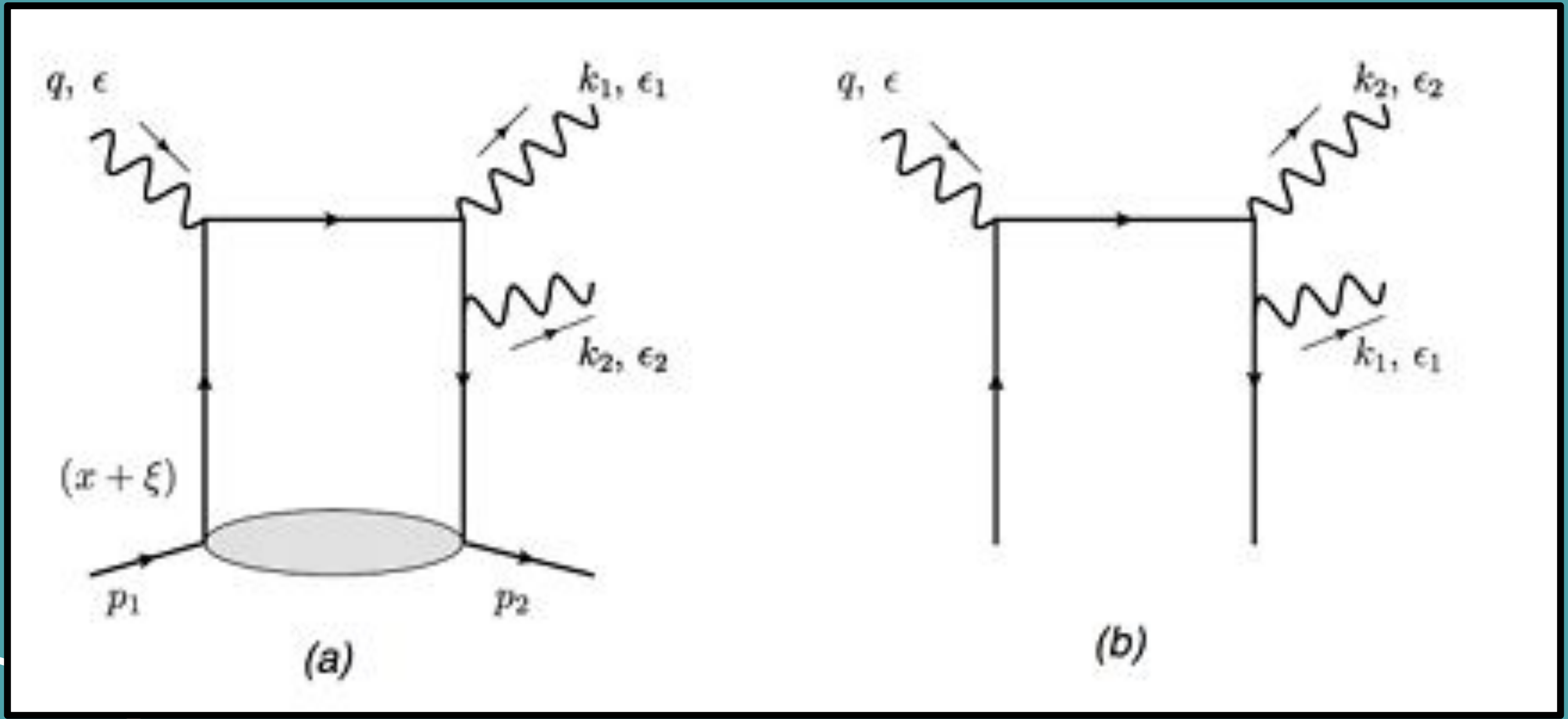


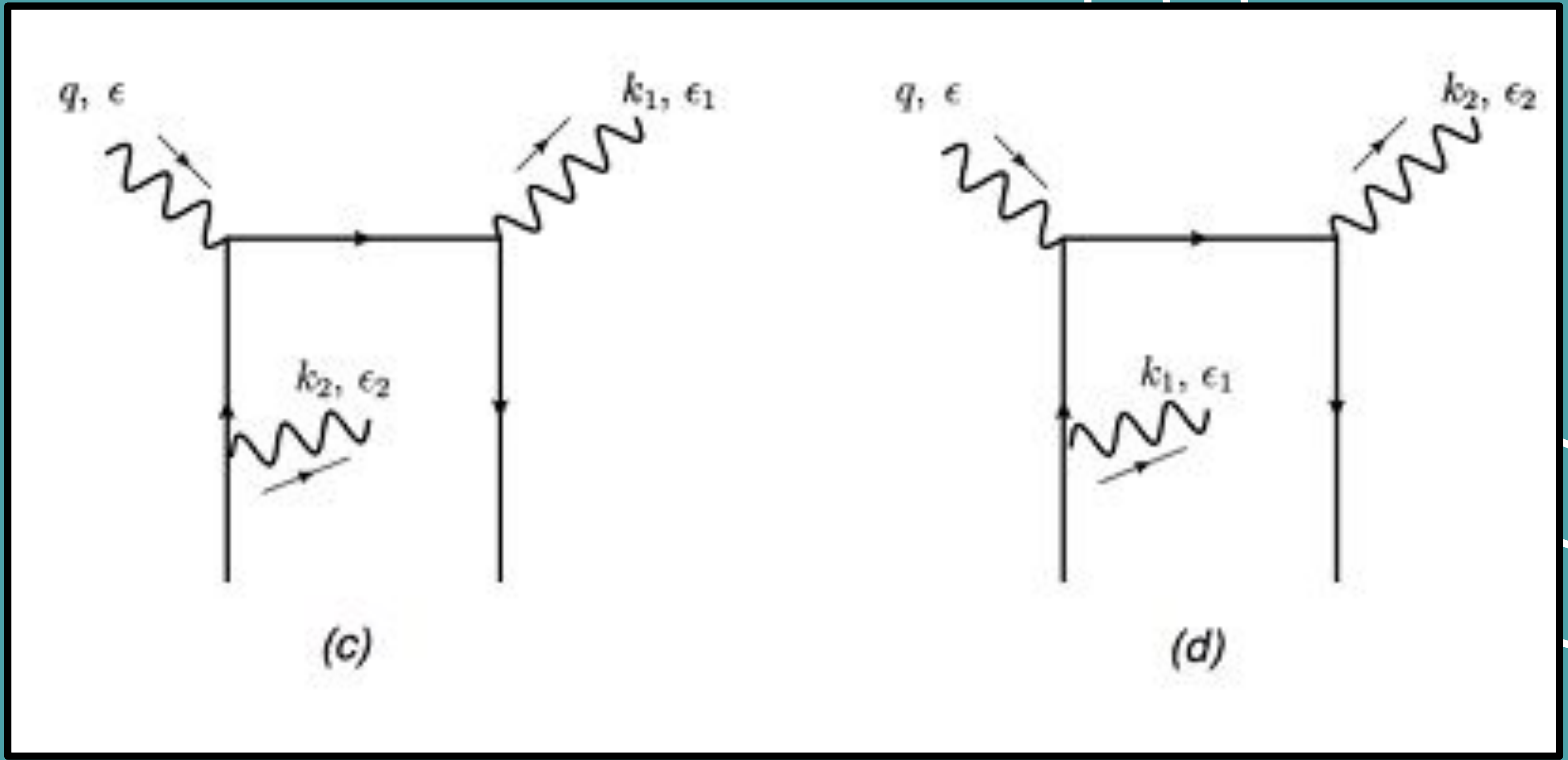
(a) Deeply Virtual Compton Scattering
(b) Timelike Compton Scattering

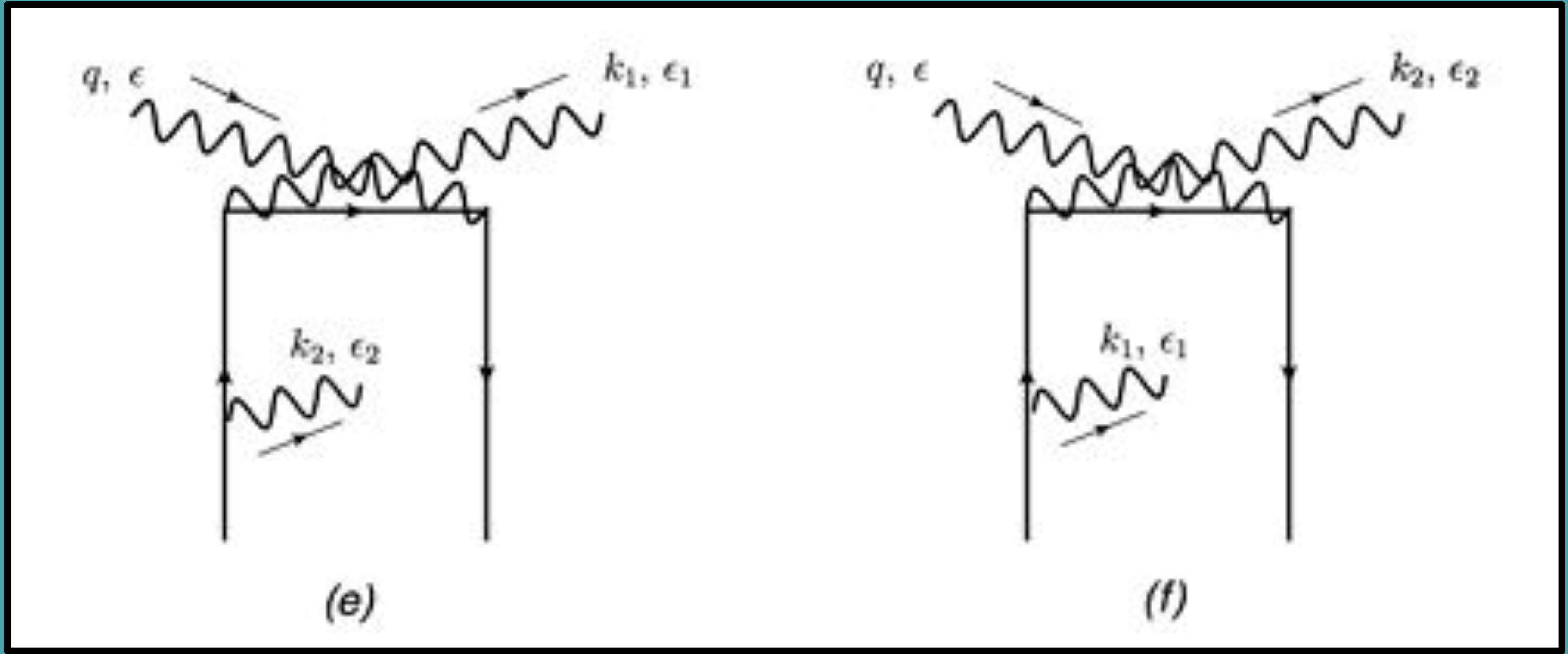
05.

Hard Exclusive Diphoton Photoproduction

Hard Exclusive Diphoton Photoproduction







A. Pedrak and B. Pire and L. Szymanowski and J. Wagner

The Whys, Hows, & Whats

Why is Hard Exclusive Diphoton Photoproduction important?

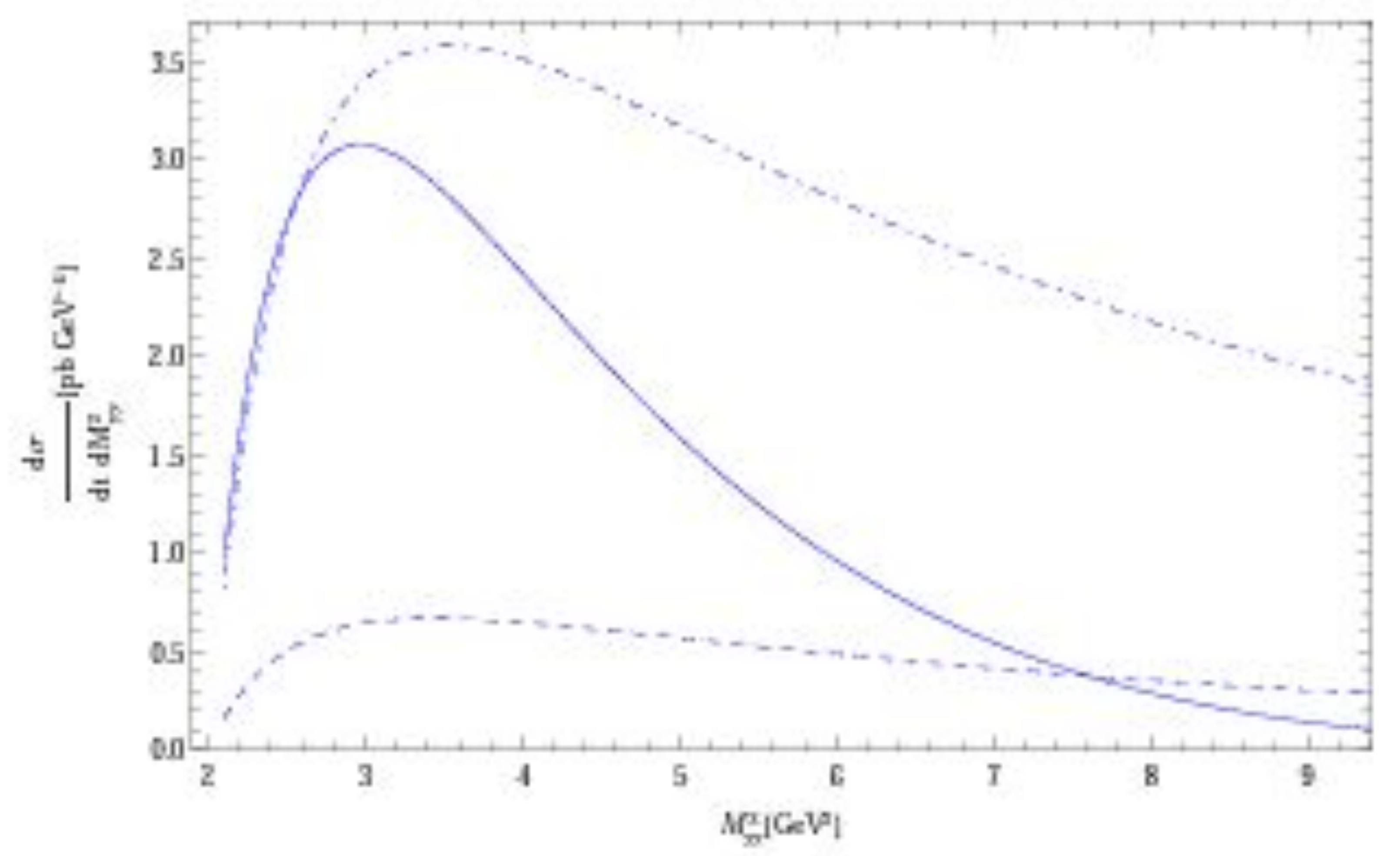
"...this reaction may help us to progress in the understanding of hard exclusive scattering in the framework of the QCD collinear factorization of hard amplitudes in terms of [...] GPDs and hard perturbatively calculable coefficient functions"[5]

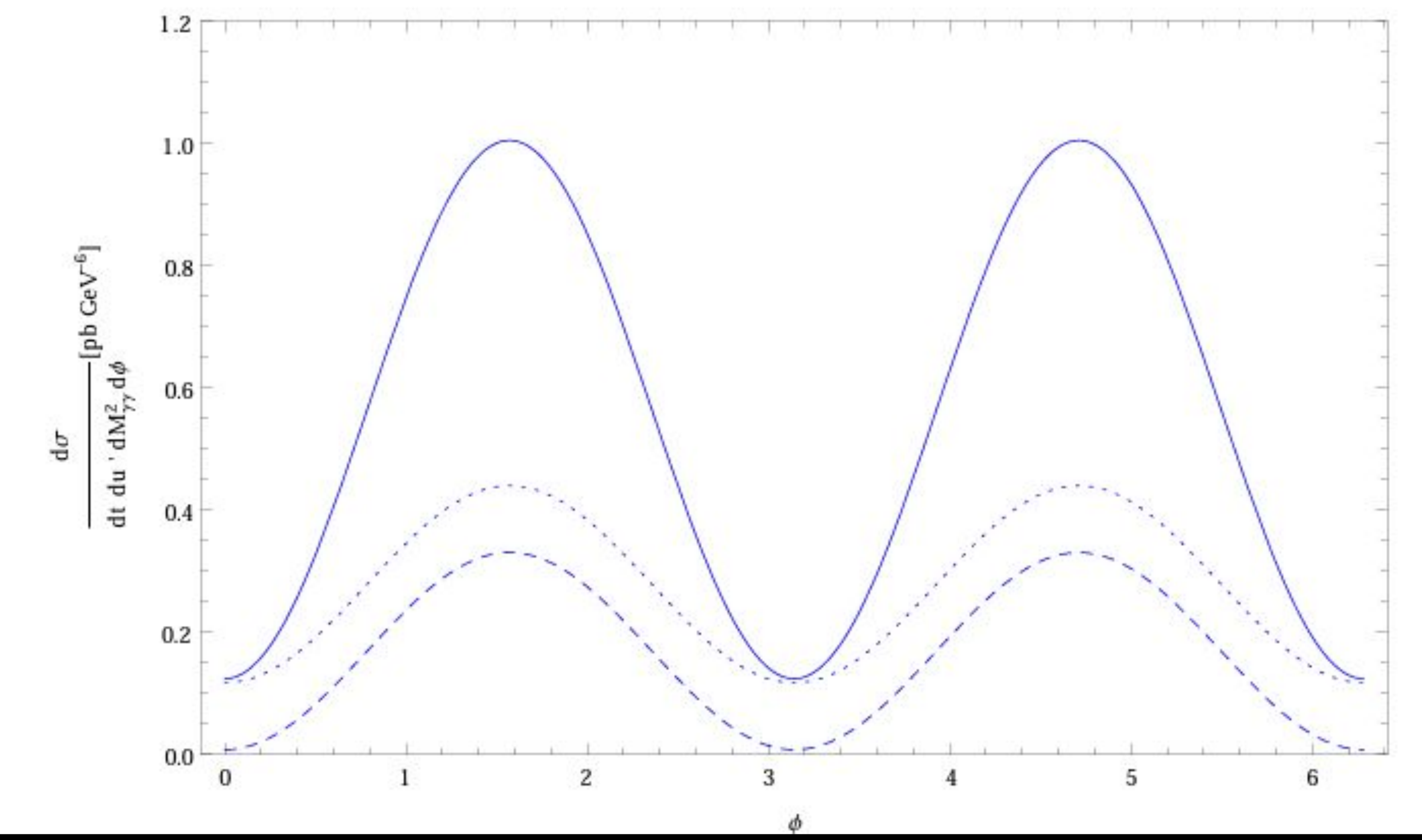
How will we study this phenomenon?

Currently running simulations comparing the use of 11 GeV and 8.5 GeV electron beams, as well as real versus quasi real photon beams. Future research would possibly involve real iterations of the projections.

What outcomes do we expect?

Graphs to follow!

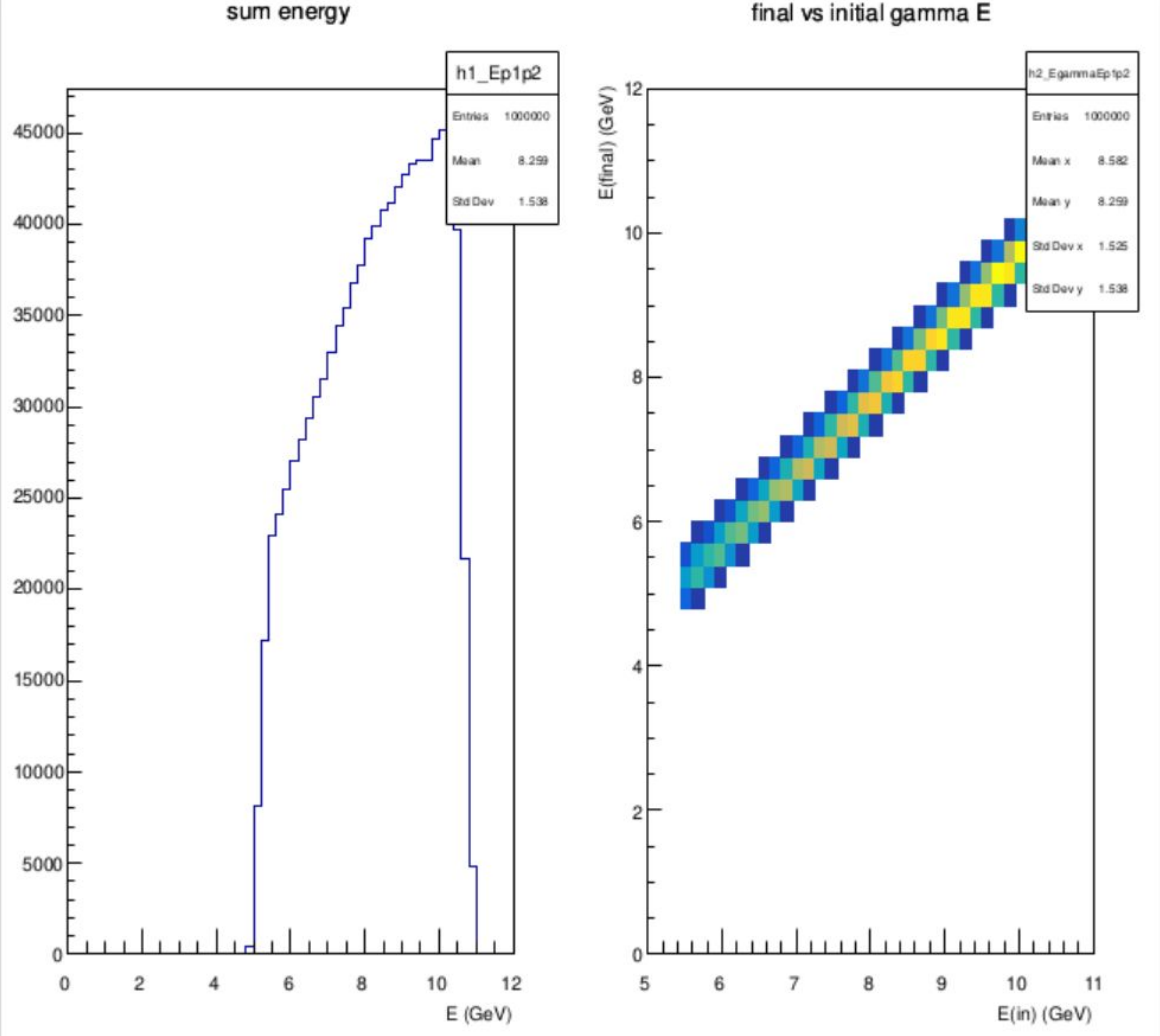




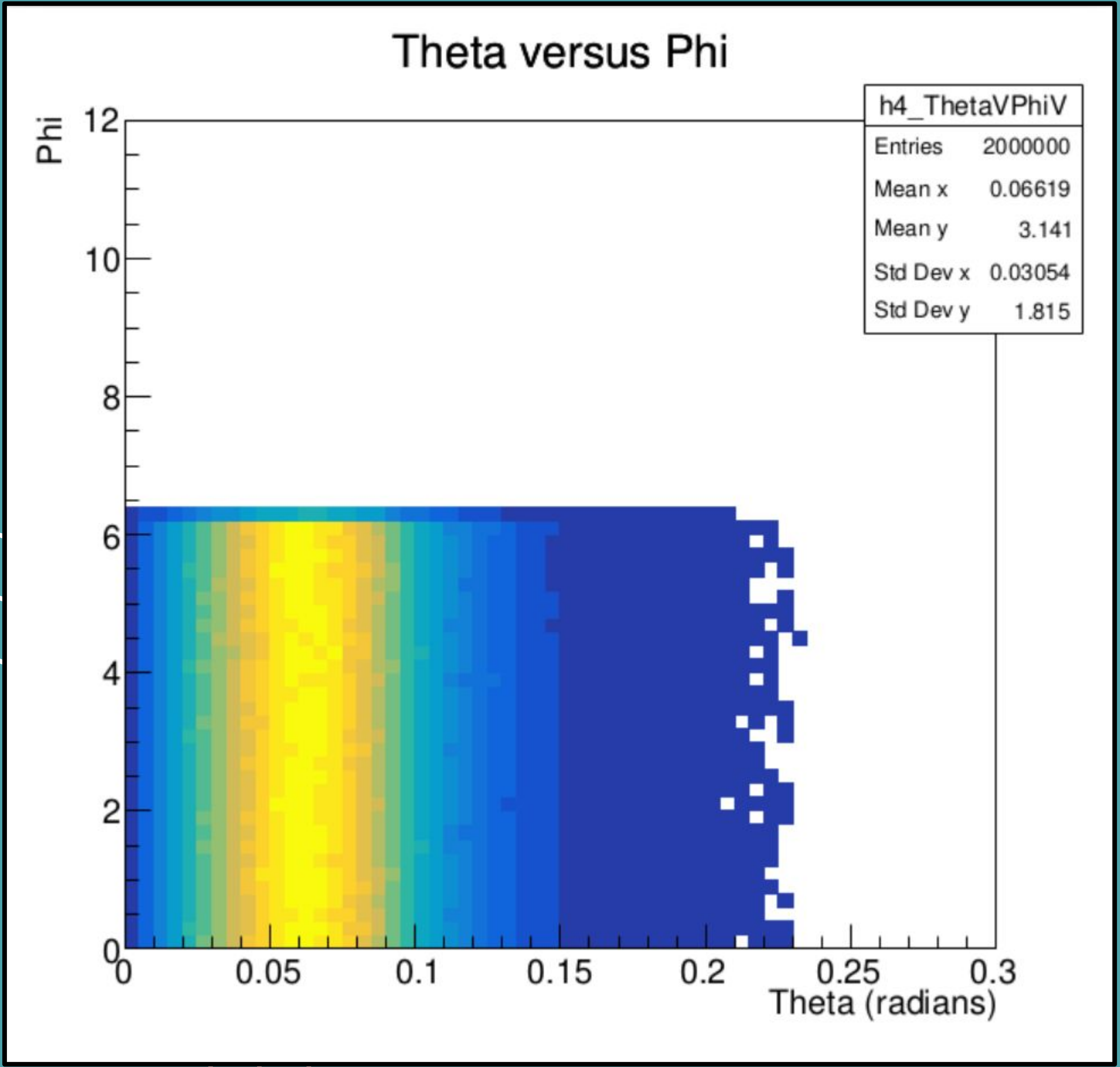
Top: The diphoton mass dependence of the unpolarized cross section on a proton. 20 GeV^2 (full curves), 100 GeV^2 (dashed curve), 10^6 GeV^2 (dot-dashed curve).

Bottom: The azimuthal dependence of the differential cross section. (3, -2) GeV^2 (solid line), (4, -1) GeV^2 (dotted line), (4, -2) GeV^2 (dotted line).

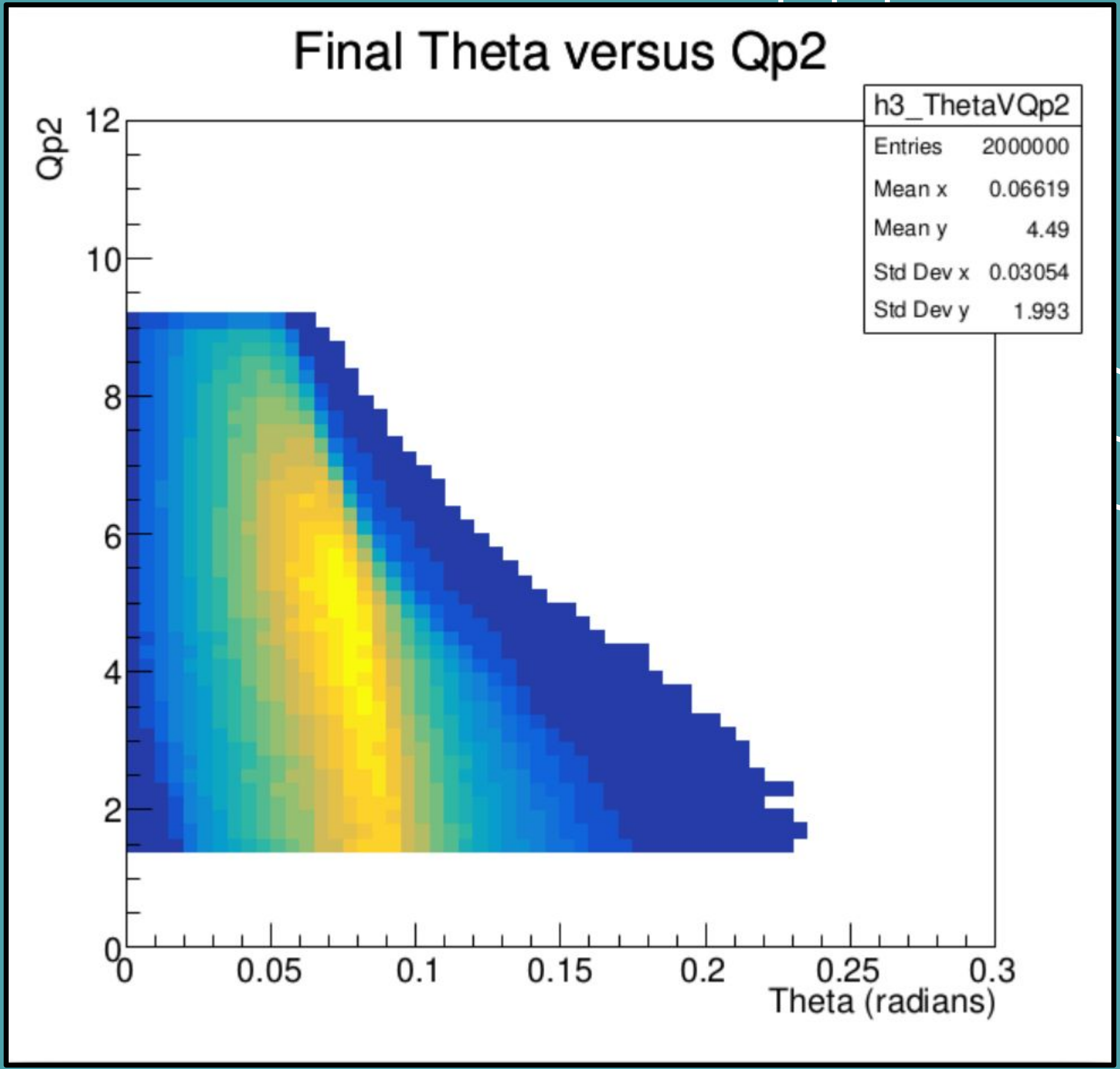
A. Pedrak and B. Pire and L. Szymanowski and J. Wagner



sum energy
h1_Ep1p2
Entries 1000000
Mean 8.259
Std Dev 1.538
E (GeV)
final vs initial gamma E
h2_EgammaEp1p2
Entries 1000000
Mean x 8.582
Mean y 8.259
Std Dev x 1.525
Std Dev y 1.538
E(final) (GeV)
E(in) (GeV)



Theta versus Phi
h4_ThetaVPhiV
Entries 2000000
Mean x 0.06619
Mean y 3.141
Std Dev x 0.03054
Std Dev y 1.815
Phi
0
2
4
6
8
10
12
0.05
0.1
0.15
0.2
0.25
0.3
Theta (radians)



Final Theta versus Qp2
h3_ThetaVQp2
Entries 2000000
Mean x 0.06619
Mean y 4.49
Std Dev x 0.03054
Std Dev y 1.993
Qp2
0
2
4
6
8
10
12
0.05
0.1
0.15
0.2
0.25
0.3
Theta (radians)

Previous Theoretical Work with Hard Exclusive Diphotons ("Paris/Warsaw team")

Hard photoproduction of a diphoton with a large invariant mass

A. Pedrak,[1] B. Pire,[2] L. Szymanowski,[1] and J. Wagner[1]

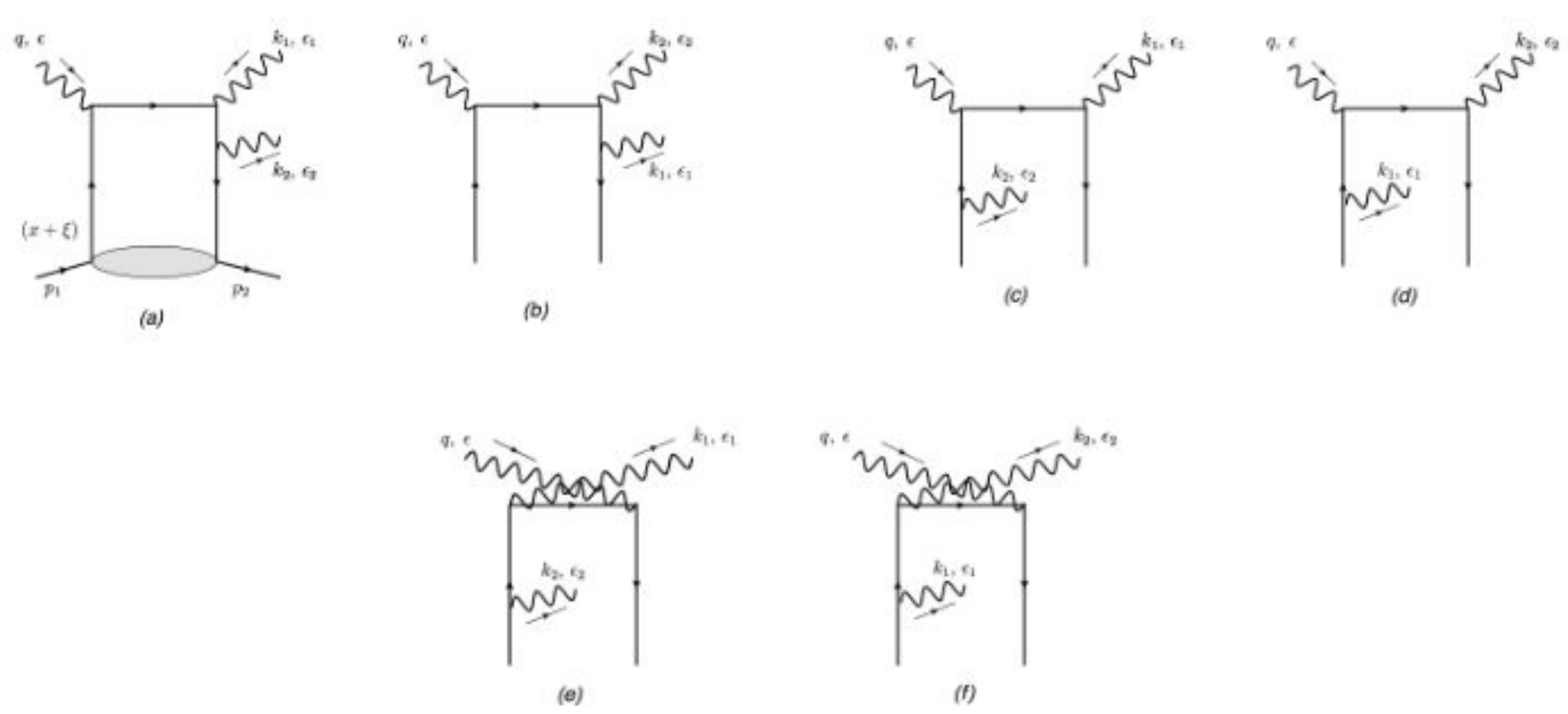


FIG. 1: Feynman diagrams contributing to the coefficient functions of the process $\gamma N \to \gamma\gamma N'$

Cancellation of NLO contributions / higher twist

- GPD universality (versus DVCS and TCS)
- Different structure: using invariant mass of the pair rather than virtuality
- Studies and understanding of NLO and higher twist effects in DVCS or TCS in a comparative or a multichannel CFF fits approach

=> Marie implementing this framework into her code for our analysis / now using unweighted data
=> impact studies for potential measurements in Hall C or Hall D

Recent JLab LDRD on this project (theory group) to study the x-dependence of GPDs from γγ and γπ photoproduction

Extraction of the x-dependence of generalized parton distributions from exclusive photoproduction

Jian-Wei Qiu[1,2,*] and Zhite Yu[3,†]

Experimental Application: we started discussions with GlueX.

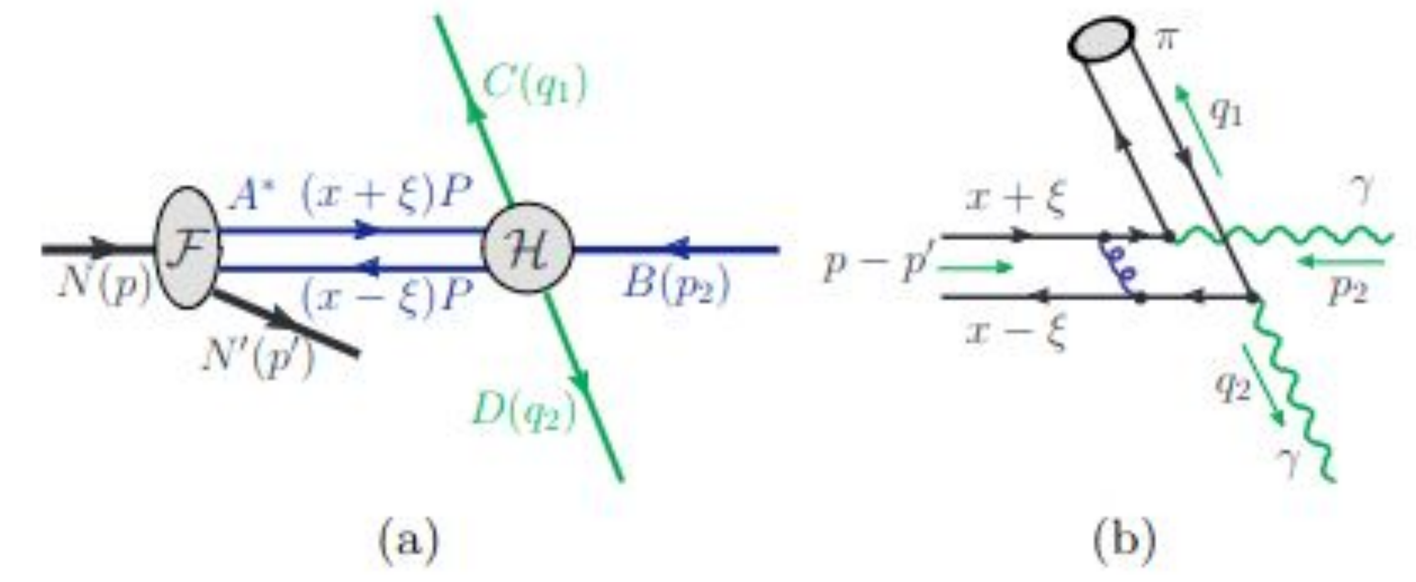
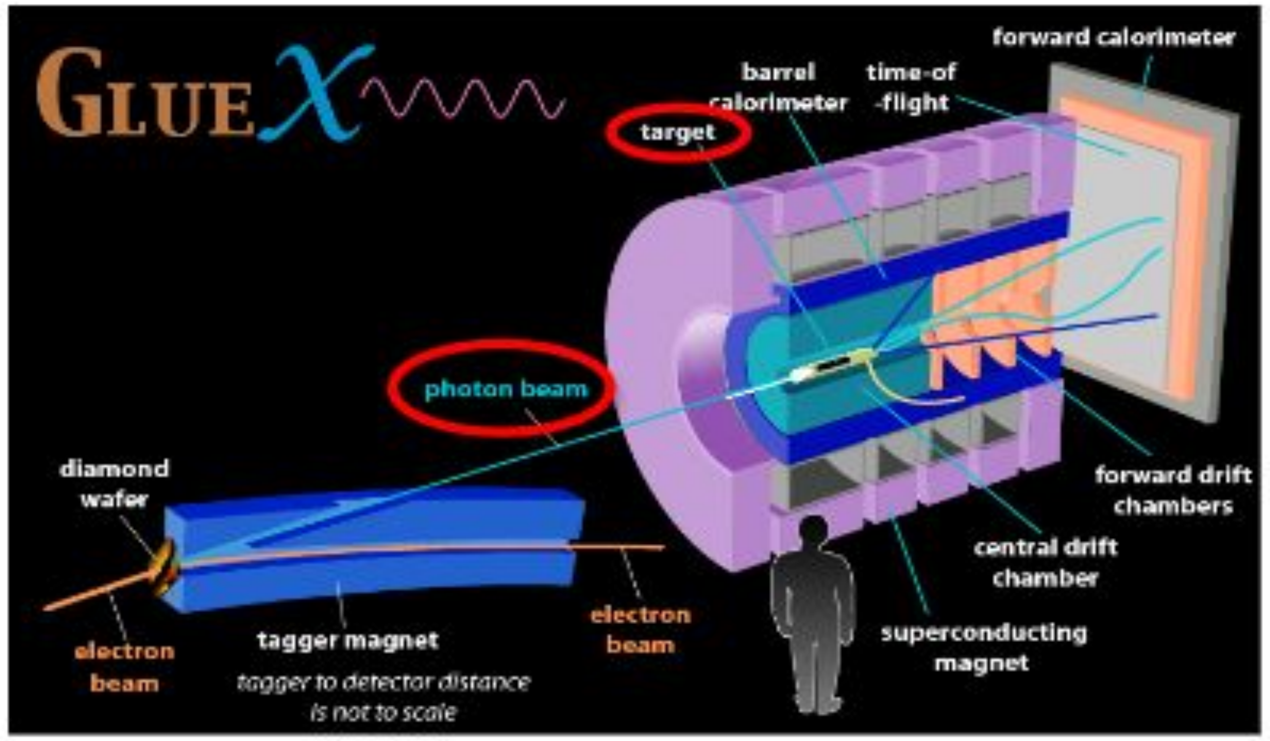
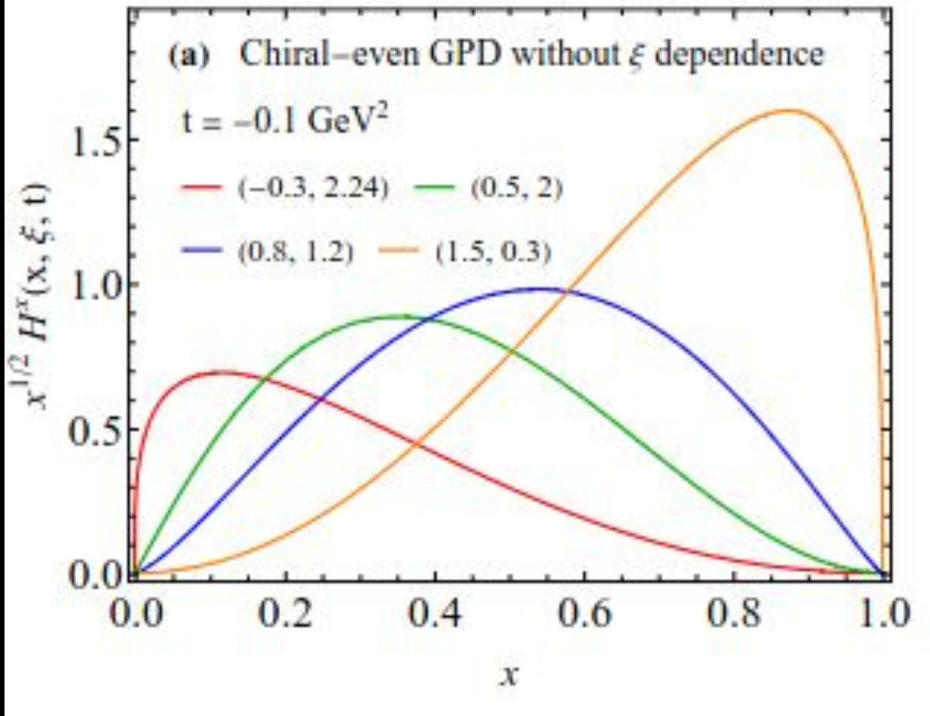
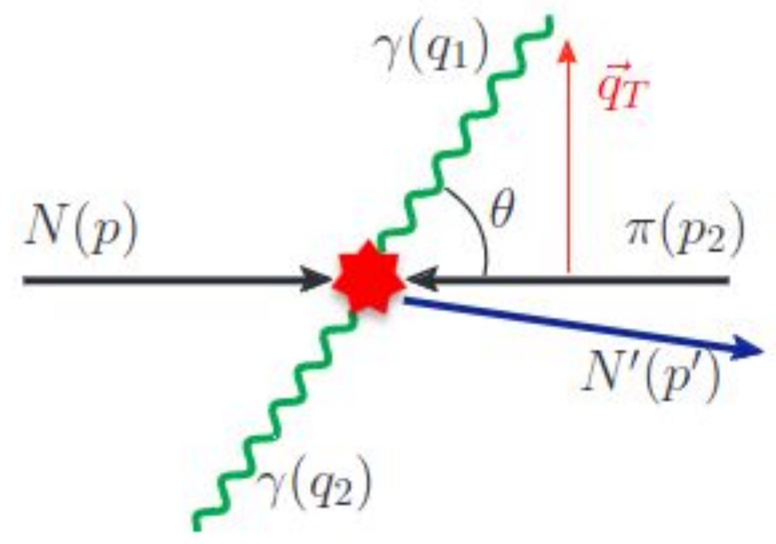


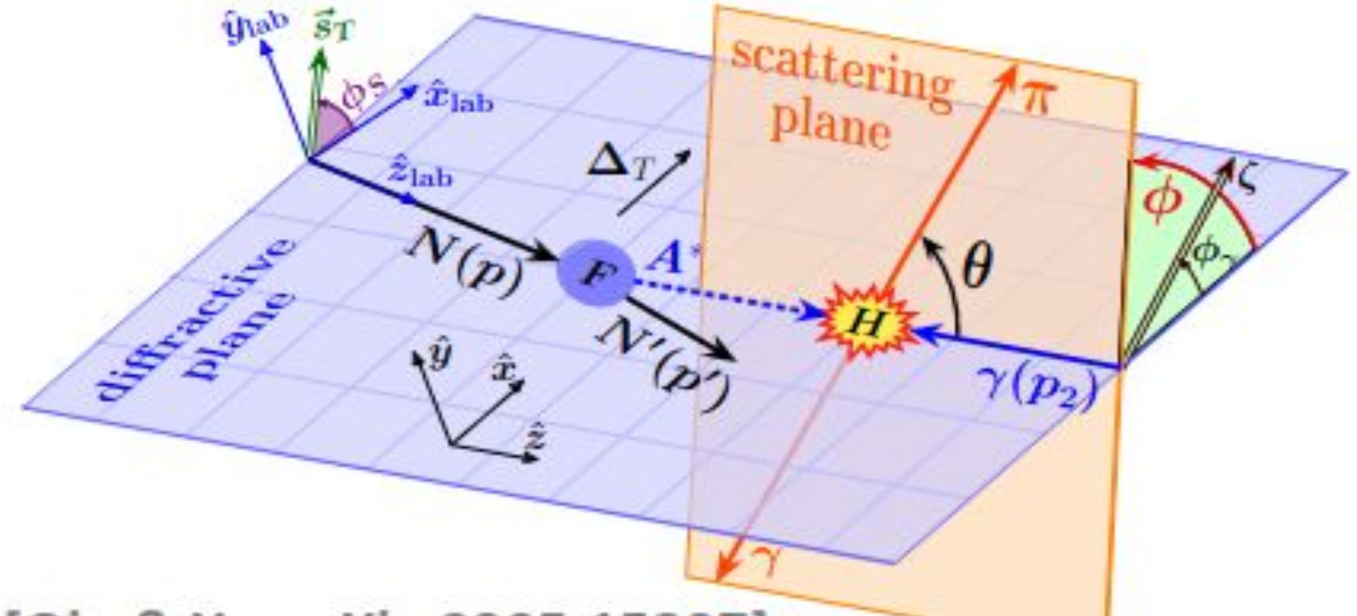
Fig. 1. (a) Sketch of 2 → 3 SDHEP needed for extracting GPDs. (b) Sample diagram for the SDHEP in Eq. (1).





[Qiu & Yu, JHEP 08 (2022) 103]





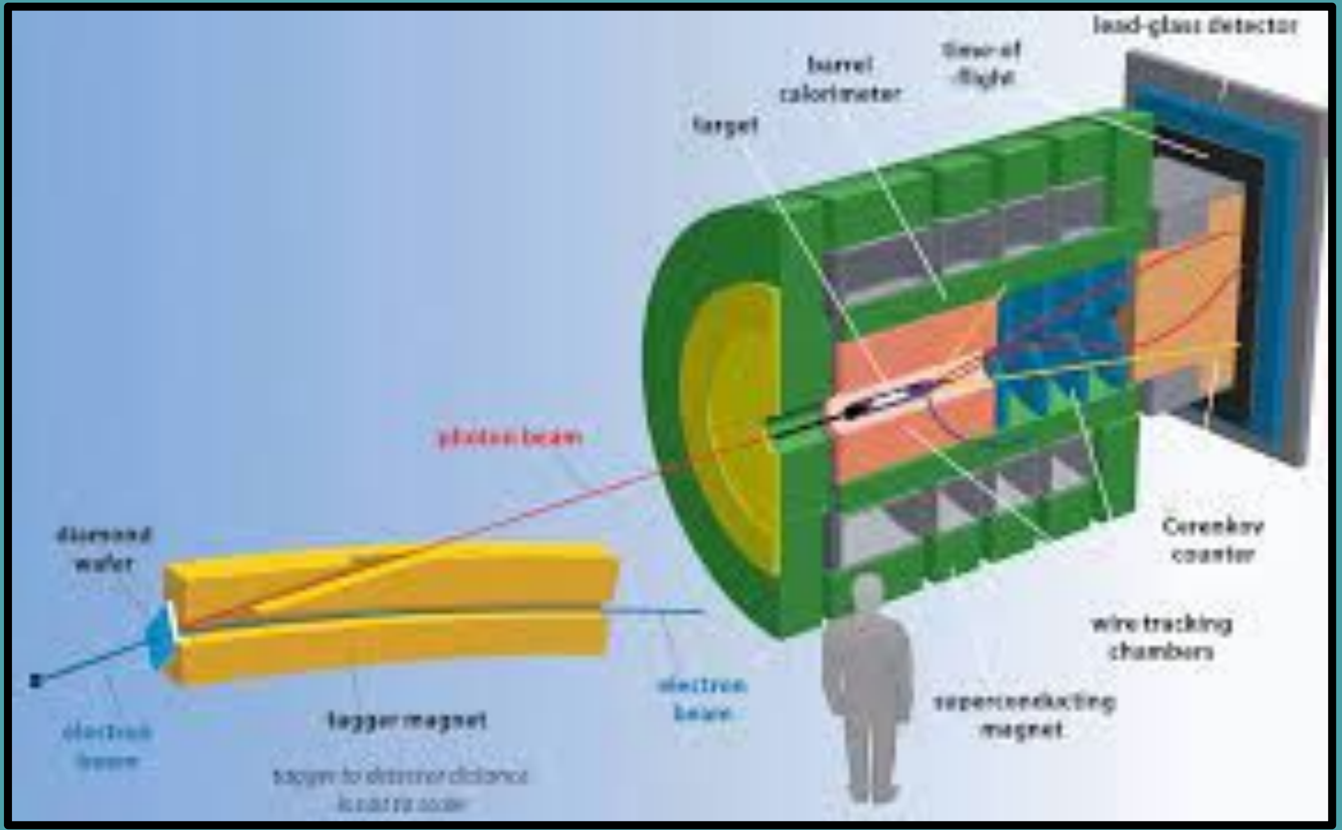
[Qiu & Yu, arXiv:2305.15397]

1) GlueX (Hall D)

Pros:
- large acceptance
- tagged photon beam
- linearly polarized photon beam
  => access real part of CFFs

Cons:
- lower intensity

Goal: **beam asymmetry,** maybe cross section



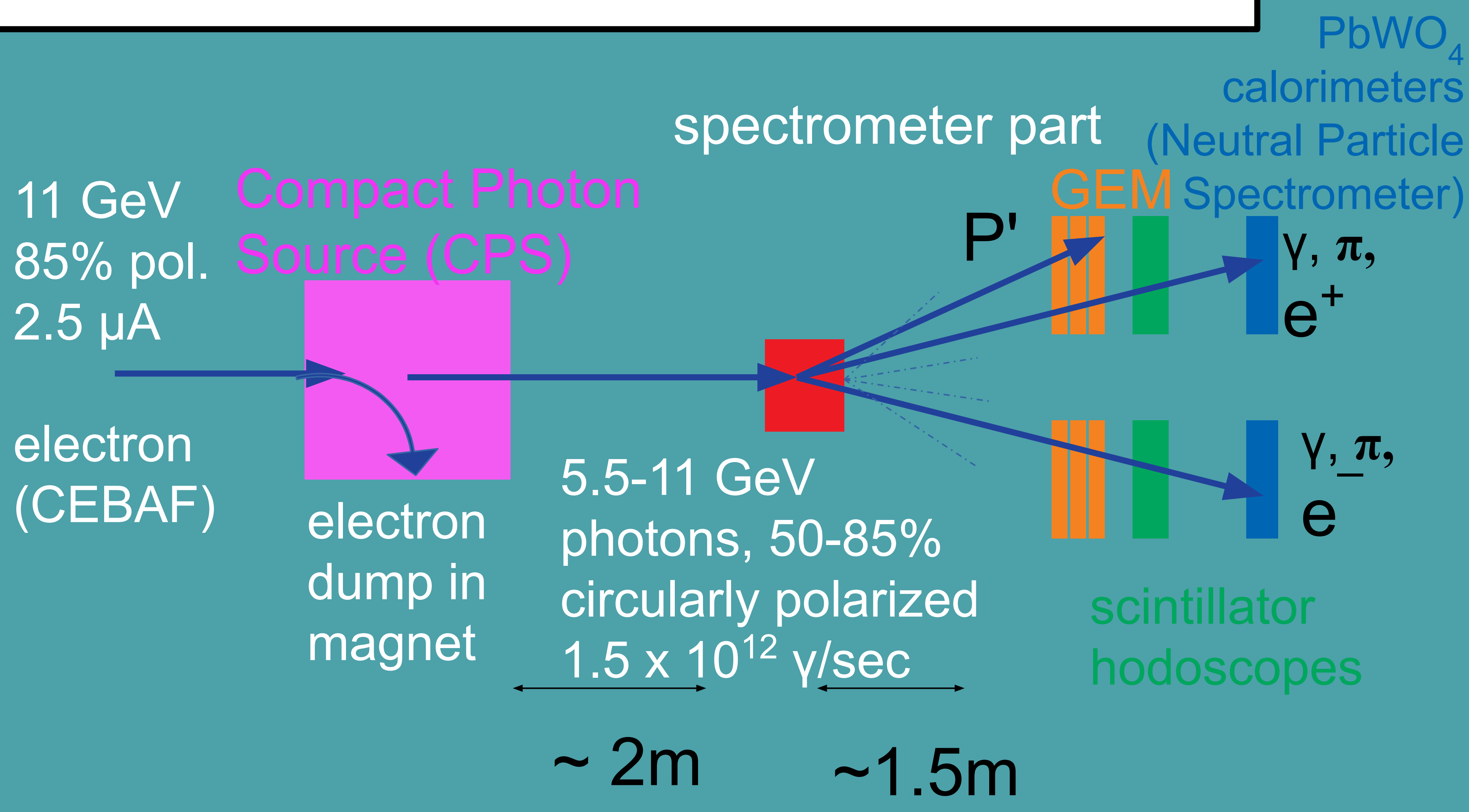
(we requested to join the collaboration, Gyang may work on it)

2) Hall C dedicated, based on proposed TCS

Pros:
- dedicated setup, lower background
- higher resolution
- Compact Photon Source: high intensity real photon

Cons:
- untagged photon (energy from "missing" technique)
- limited acceptance

Goal: **Unpolarized cross section** (no asymmetry)



Trigger: GEMs, hodoscopes, calorimeters (all 3 particles)

(Deb is working on GEANT4 / we are working on analysis)

Summary

1. Form Factors and PDFs to GPDs
2. Showed the GPD process
3. Our work with diphotons
4. Research potential for JLabs (theoretical and experimental approaches)

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3. Barr, J. (2013, March 31). What does the Atomic Form Factor mean? *Physics StackExchange*. https://physics.stackexchange.com/questions/57463/what-does-the-atomic-form-factor-mean.

4. Davison E. Soper, Parton distribution functions, *Nuclear Physics B - Proceedings Supplements*, Volume 53, Issues 1–3, 1997, Pages 69-80, ISSN 0920-5632, https://doi.org/10.1016/S0920-5632(96)00600-7.

5. A. Pedrak and B. Pire and L. Szymanowski and J. Wagner. Exclusive production of a large mass photon pair. 2019. https://arxiv.org/abs/1907.08431

Acronyms

GTMD	Generalized Transverse Momentum Distribution
TMD	Transverse Momentum Distribution
GPD	Generalized Parton Distribution
PDF	Parton Distribution Function
DVCS	Deeply Virtual Compton Scattering
TCS	Timelike Compton Scattering