Multichannel approach to access GPDs with experiments at JLab

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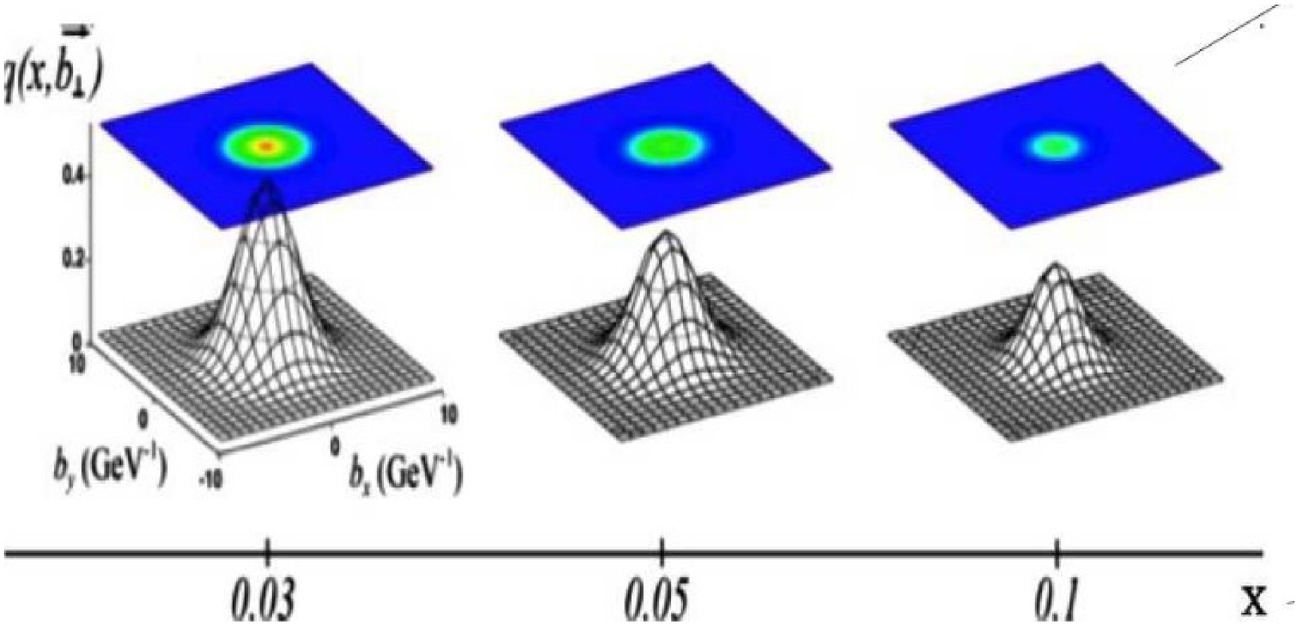
REVSTRUCTURE workshop, Zagreb, July 12th, 2023

PARTONIC STRUCTURE OF THE HADRONS

Goal: accessing Generalized Parton Distributions

Among outstanding questions: tomographic imaging of the nucleon
Other interpretations: spin, angular momentum, “pressure”…

Momentum dependent impact parameter distributions
Quarks and gluons transverse position versus their longitudinal momentum



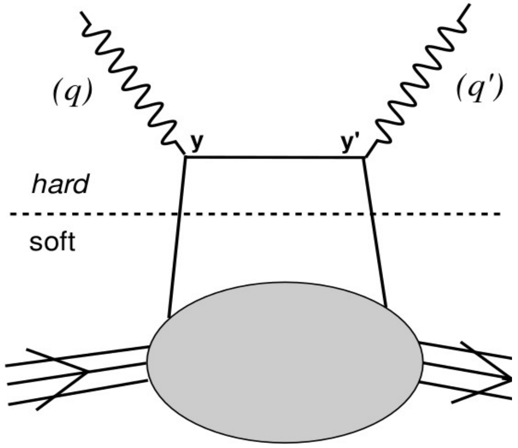
gluons dominate

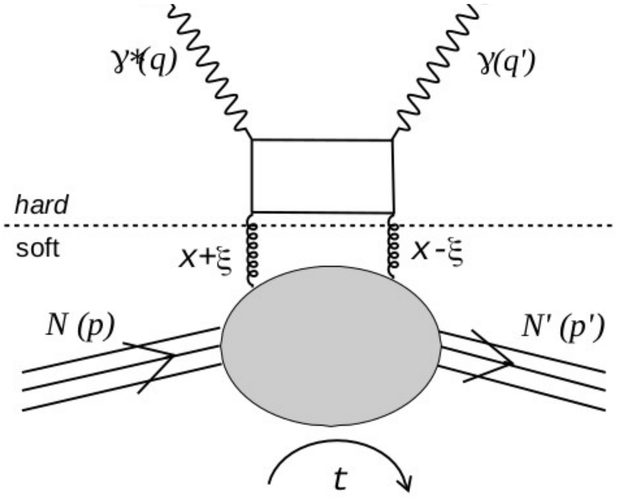
gluons, sea quarks
"meson cloud"

valence quarks region

Hard Exclusive Reactions

GPDs with Compton-like reactions **γ (*) N → γ'(*) N'**





Leading order / leading twist generic handbag diagram

DVCS: final photon is real, incoming is spacelike (Spacelike Deeply Virtual Compton Scattering)

TCS: incoming is real, final is timelike (Timelike Deeply Virtual Compton Scattering)

DDVCS: incoming is spacelike, outgoing is timelike Double Deeply Virtual Compton Scattering

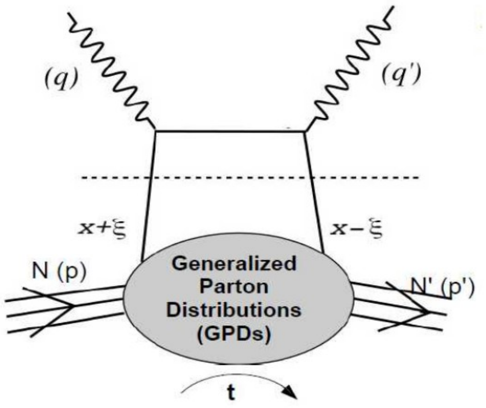
Other: multi-photons, photon+meson, ...

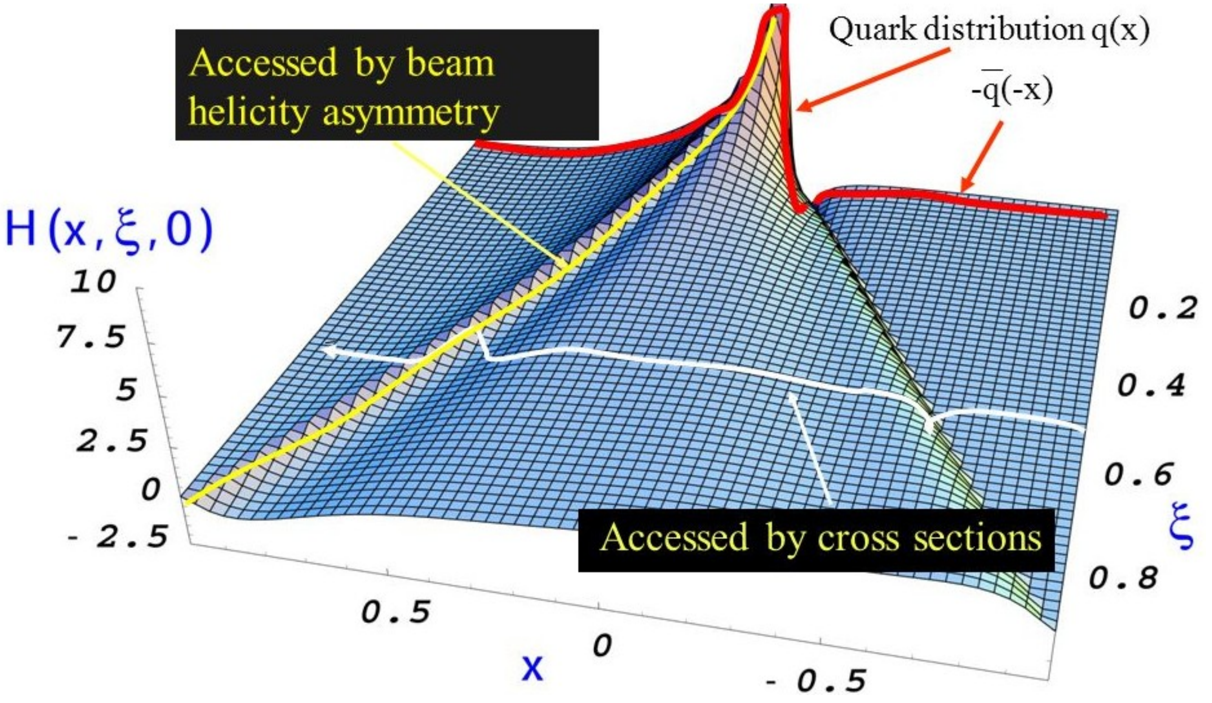
Quark GPDs; as function of x (// momentum fraction), ξ (skewness), t (squared momentum transfer)
+ Q^2, Q'^2: evolution not being taken into account in this work. Q^2/Q'^2 relevant for DDVCS

Can be seen as the "cleanest" way to access GPDs, no meson DA

Most measurements = DVCS; What can we learn with other reactions?

Generalized Parton Distributions (DVCS or TCS, "diagonal")



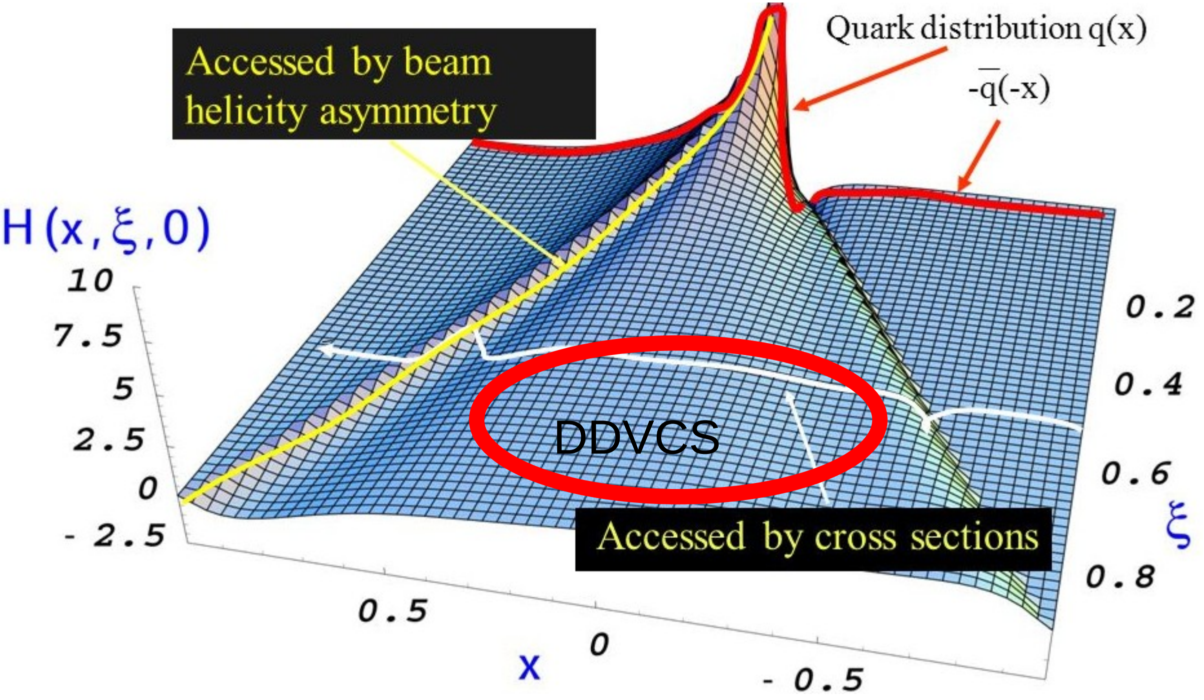


Extracted at ξ (skewness // momentum)
and t (momentum transfer ²)
from experimental data [can't access x]

Various "parts" of the GPD accessible via different reactions or observables

$$T^{DVCS} \sim \int_{-1}^{+1} \frac{H(x,\xi,t)}{x \pm \xi + i\varepsilon} dx + \ldots \sim \underbrace{P\int_{-1}^{+1} \frac{H(x,\xi,t)}{x \pm \xi} dx}_{\mathrm{Re}(\mathcal{H})} - \underbrace{i\pi H(\pm\xi,\xi,t)}_{\mathrm{Im}(\mathcal{H})} + \ldots$$

Generalized Parton Distributions: "off diagonal"



"diagonal": $T^{DVCS} \sim \int_{-1}^{+1} \frac{H(x,\xi,t)}{x \pm \xi + i\varepsilon} dx + \ldots \sim P\int_{-1}^{+1} \frac{H(x,\xi,t)}{x \pm \xi} dx - i\pi H(\pm\xi,\xi,t) + \ldots$

Re $(\mathcal{H})$ Im $(\mathcal{H})$

"off diagonal": $T^{DDVCS} \sim \int_{-1}^{+1} \frac{H(x,\xi,t)}{x - (2\xi' - \xi) + i\varepsilon} dx + \ldots \sim P\int_{-1}^{+1} \frac{H(x,\xi,t)}{x - (2\xi' - \xi)} dx - i\pi H(2\xi' - \xi, \xi, t) + \ldots$

Advantages of TCS and DDVCS

TCS and DVCS access Im(CFFs) at $x = \pm\xi$

=> complementary measurements, **access same CFFs**,

- GPD **universality** studies with independent TCS data set
- higher twist/order studies in comparison, can help understanding “effects” seen in DVCS
- combined data set for additional constraints to GPDs

DDVCS (and meson masses but some extra steps) give a lever arm for going “off diagonal”, needed to **extrapolate to zero skewness**

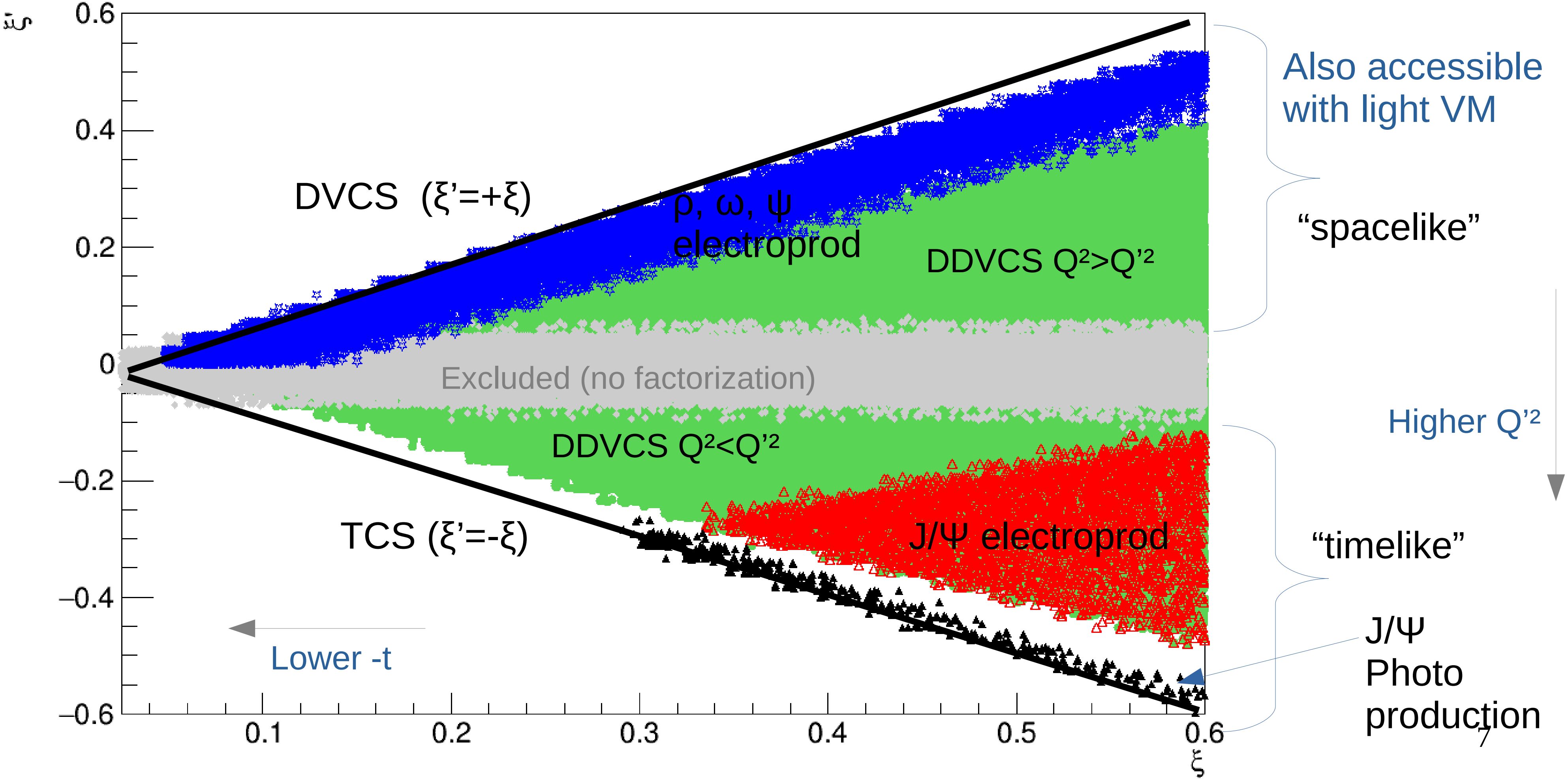
- tomographic interpretations
- can move from “timelike” to “spacelike” region
- complementary observables for GPD data sets in multichannel approach

Vector mesons: can “play” with the mass

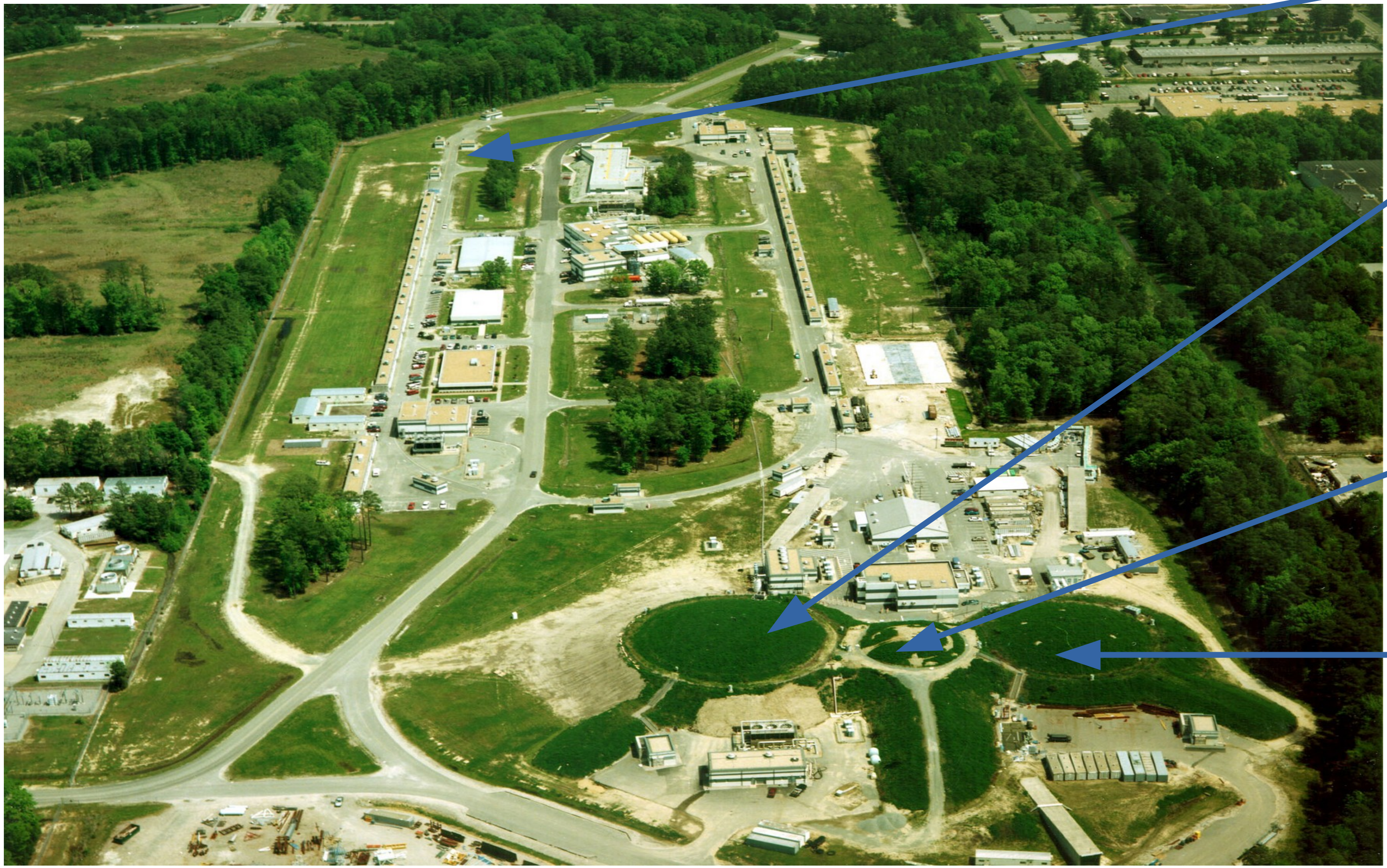
Other reactions: see other talks in this workshop

Using DDVCS Q’² and meson masses to go “off-diagonal”

11 GeV beam, -t<1 GeV², W²<2 GeV², Q’² (TCS, DDVCS>2 GeV²), Q² (electroprod. > 1 GeV²)



Jefferson Lab / CEBAF experimental Halls



Hall D: GlueX…
Photoproduction
Large acceptance

Hall A
DVCS (see Carlos talk)
SBS: small acceptance
SoLID: future, large accept

Hall B
DVCS, TCS, mesons
CLAS/CLAS12
Large acceptance

Hall C
DVCS (see Carlos talk)
Potential for new dedicated
High precision measurement,
Small acceptance


Hall A


Hall B


Hall C


Hall D

- DVCS programs in Hall A and Hall C: see Carlos talk this morning

Recent overview of hard exclusive measurements in Hall B, see Pierre Chatagnon’s talk:
(and next few slides I stole from him)

https://indico.jlab.org/event/714/contributions/12546/attachments/9928/14653/JLUO_Exclusive_CLAS12_Chatagnon.pdf

- This talk: potential for future measurements for TCS, DDVCS, mesons at JLab Hall A, C, D

Deep exclusive reactions program of CLAS12

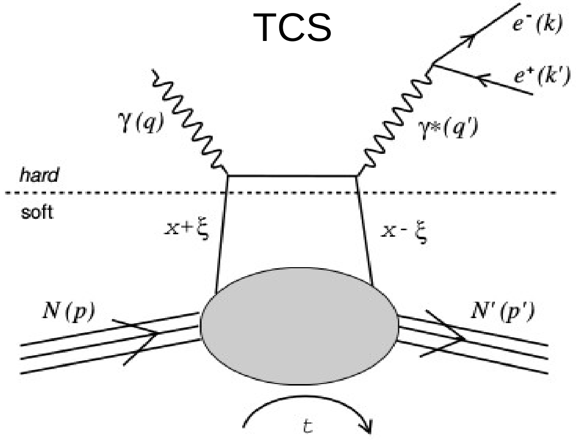
Slide credit: Pierre Chatagnon

Reaction	Observable	Experimental configuration	Lead analyzer (Affiliation)	Status
DVCS on proton	BSA	RG-A (Proton target)	G.Christiaens/M. Defurne (CEA Saclay)	Published (PRL)
DVCS on proton	Cross-section	RG-A	S. Lee (ANL)	Internal review
DVCS on bound neutron	BSA	RG-B (Deuterium target)	A. Hobart/S. Niccolai (IJCLab Orsay)	Internal review
DVCS on bound proton	BSA	RG-B	A. Hobart/S. Niccolai (IJCLab Orsay)	Internal review
Coherent DVCS on deuterium	BSA	RG-B	A. Biselli (Fairfield U.)	Ongoing
DVCS on proton	BSA	RG-K (Proton target, 6.5 and 7.5 GeV beam)	J.A. Tan (Kyungpook National U.)	Ongoing
DVCS on proton	BSA/TSA/DSA	RG-C (Longitudinally polarized target)	S. Polcher (CEA Saclay)	Ongoing
DVCS on neutron	BSA/TSA/DSA	RG-C	N. Pilleux (IJCLab Orsay)	Ongoing
Tagged DVCS on neutron	BSA	RG-F (BONuS12)	M. Ouillon (IJCLab) / M.Hattawy (ODU)	Ongoing
TCS on proton	BSA/AFB	RG-A	P. Chatagnon (JLab)	Published (PRL)
TCS on proton	BSA/TSA/DSA	RG-C	K. Gates (Glasgow)	Ongoing
DVMP π^0	BSA	RG-A	A. Kim (UConn)	To be submitted to PLB
DVMP π^0	Cross-section	RG-A	R. Johnston (MIT)	Ongoing
DVMP π^+	BSA	RG-A	S. Diehl (Giessen/UConn)	Published (PLB)
DVMP ρ	BSA	RG-A	N. Trotta (UConn)	Ongoing
DVMP ϕ	Cross-section	RG-A	P. Moran (MIT)	Ongoing
DVMP ϕ	BSA	RG-B	N. Ram (CEA Saclay)	Ongoing
DVMP π^- on Δ^{++}	BSA	RG-A	S. Diehl (Giessen/UConn)	Just accepted in PRL
J/ψ photoproduction on proton	Cross-section	RG-A	P. Chatagnon (JLab)	Ongoing
J/ψ photoproduction on neutron	Cross-section	RG-A	R. Tyson (Glasgow)	Ongoing
Tagged J/ψ photoproduction on proton	Cross-section	RG-A	M. Tenorio Pita (ODU)	Ongoing

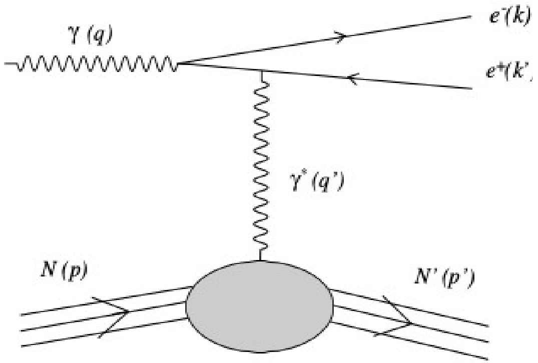
Timelike Compton Scattering

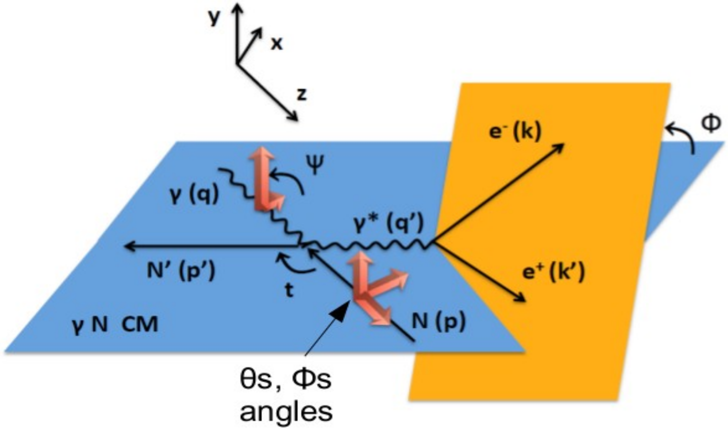
$\gamma N \rightarrow e^+e^- N' = TCS + BH$

TCS



Bethe-Heitler

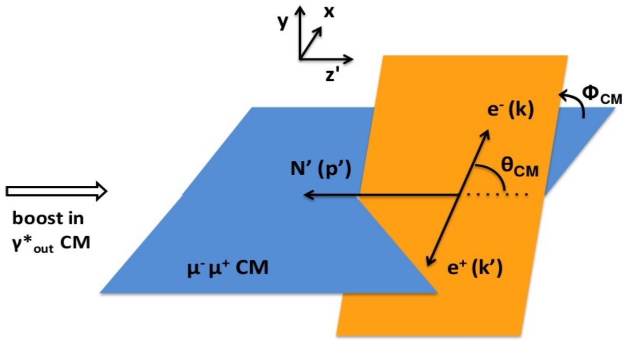




5-differential unpolarized
6-differential perp target

Choice in presented work:
Q'^2, t, Eγ, φ, θ or Q'^2, t, ξ, φ, θ

Ψ: (reaction plane, γ spin)
φ: (hadronic plane, e^+e^- pair)
θ: (γ^*, e^-)
θs, Φs: (target spin vector orientation)



Notations: σ = unpolarized cross section, Axx = asymmetry
A⊙u = circularly polarized beam, unpolarized target / ALu = linearly polarized beam
Aui (i=x, y, z) = unpolarized beam, polarized target along i axis.

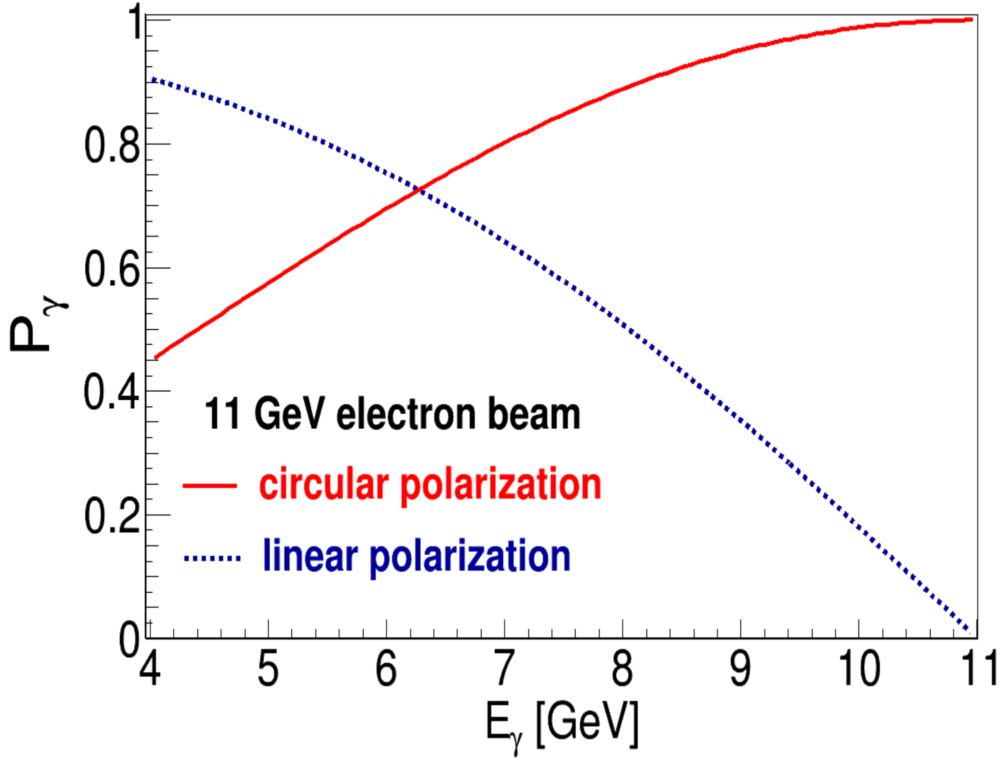
Photon beam for TCS or other channels

- Quasi-real photon beam for Hall A and B
- Real photon beam for Hall C and D

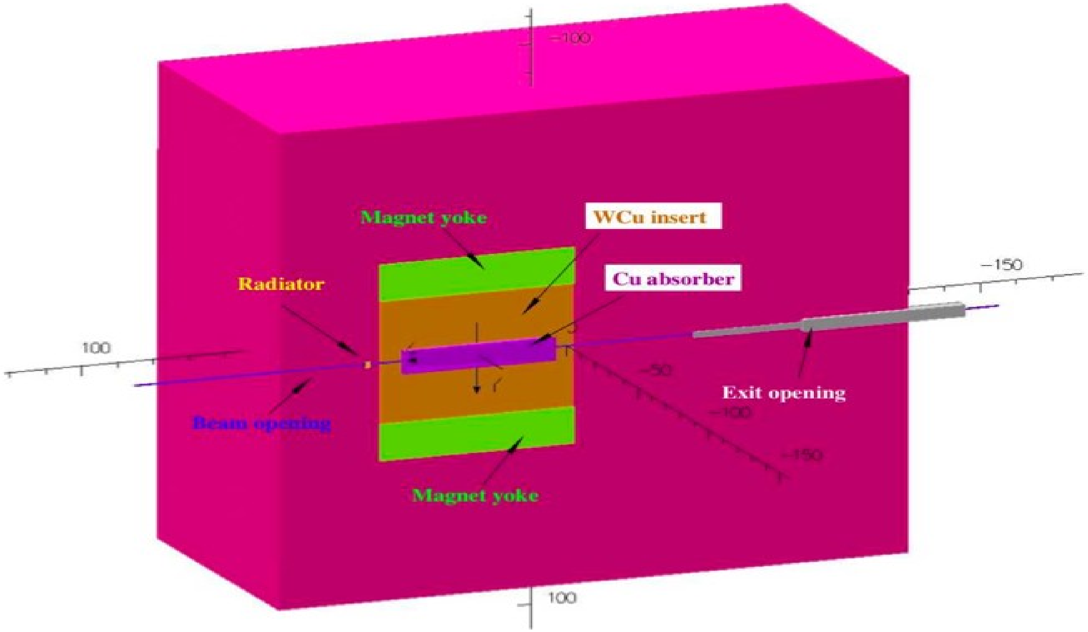
- Circularly polarized in Hall A, B, C
- Linearly polarized in Hall D

- Potential for polarized target in all Hall, but limitations for intensity / space and material (high density vs dilution factor)

Photon beam polarization for a 100% polarized 11 GeV electron beam (JLab)



Radiator: Compact Photon Source



- 10% Cu radiator
- used for beam dump with 3.2 T warm magnet
- W/Cu shielding: minimal radiation, negligible interference with target field
- 1.5e12 γ/s at 2.5 μA, 5.5 to 11 GeV (5.8e5 pb^{-1} integrated luminosity)
- ~1 mm spot size at 2m

Available to Hall C, potentially to Hall A (will be built soon)

TCS current and future at JLab

Observable (proton target)	Experimental challenge	Main interest for GPDs	JLab experiments
Unpolarized cross section	1 or 2 order of magnitude lower than DVCS, require high luminosity	Im + Re part of amplitude. Re(H), Im(H)	CLAS 12, SoLID approved Hall C proposing
Circularly polarized beam	Easiest observable to measure at JLab	Im(H), Im(H) Sensitivity to quark angular momenta, in particular for neutron	CLAS 12, SoLID approved Hall C proposing
Linearly polarized beam	Need high luminosity, at least 10x more than for circular beam, and electron tagging	Re(H), D-term. Good to discriminate models and very important to bring constrains to real part of CFF	GlueX (?)
Longitudinaly polarized target	Polarized target	Im(H)	Hall B ongoing
Transversely polarized target	Polarized target, and high luminosity: binning in θs, φs	Im(H), Im(E)	Hall C proposing
Double spin asymmetry with circularly polarized beam	Polarized target, very high luminosity, precision measurement	Real part of all CFF	maybe
Double spin asymmetry with longitudinally polarized beam	Polarized target, electron tagging, very high luminosity and precision	Not the most interesting, Im(CFFs) but difficult to measure	maybe

TCS off the neutron

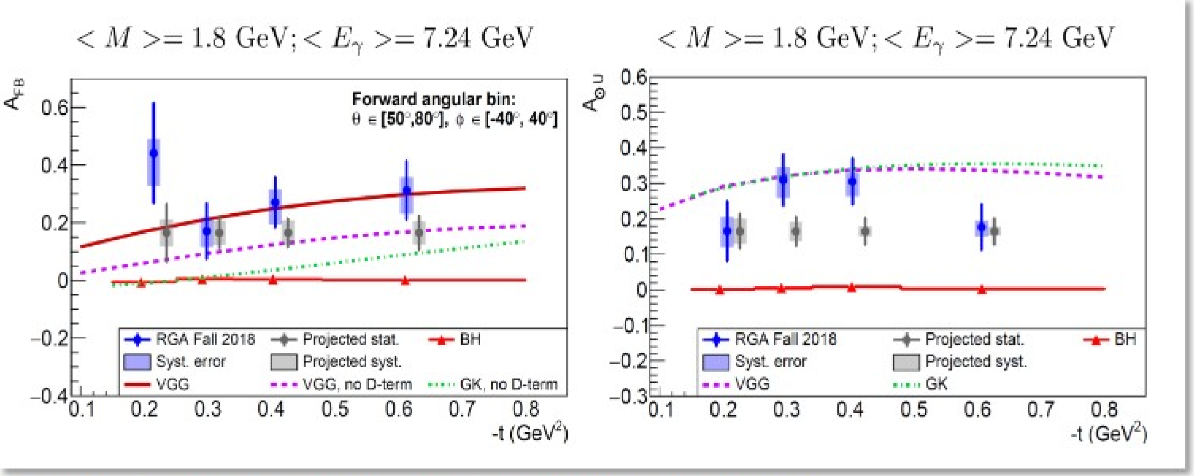
- similar, need higher luminosity and proton or neutron tagging
- target spin asymmetries are expected to be larger, and beam spin asymmetries are smaller

TCS measurements in Hall B (CLAS12)

- Use quasi-photoproduction events: $ep \rightarrow (e')p'e^+e^-$

Projections for the full proton target dataset (RG-A)

- Only a fraction of RG-A dataset was used for in the PRL article (1/3)
- New significant improvement on the tracking software have been done since 2020 → 50% more efficiency for the 3-particle final state



Results from First Measurement of Timelike Compton Scattering, P. Chatagnon *et al.* (CLAS Collaboration), Phys. Rev. Lett. 127, 262501 (2021)

- Test of the GPD universality, via the BSA measurement

$$A_{\odot U} = \frac{d\sigma^+ - d\sigma^-}{d\sigma^+ + d\sigma^-} \propto \frac{\frac{L_0}{L}\sin\phi \frac{(1+\cos^2\theta)}{\sin(\theta)} \mathrm{Im}\mathcal{H}}{d\sigma_{BH}}$$

- Access to Re($\mathcal{H}$), via the forward/backward asymmetry

$$A_{FB}(\theta_0,\phi_0) = \frac{d\sigma(\theta_0,\phi_0) - d\sigma(180^\circ-\theta_0, 180^\circ+\phi_0)}{d\sigma(\theta_0,\phi_0) + d\sigma(180^\circ-\theta_0, 180^\circ+\phi_0)}$$

$$\propto \frac{\frac{L_0}{L}\cos\phi_0 \frac{(1+\cos^2\theta_0)}{\sin(\theta_0)} \mathrm{Re}\mathcal{H}}{d\sigma_{BH}(\theta_0,\phi_0) + d\sigma_{BH}(180^\circ-\theta_0, 180^\circ+\phi_0)}$$

Slide credit: Pierre Chatagnon

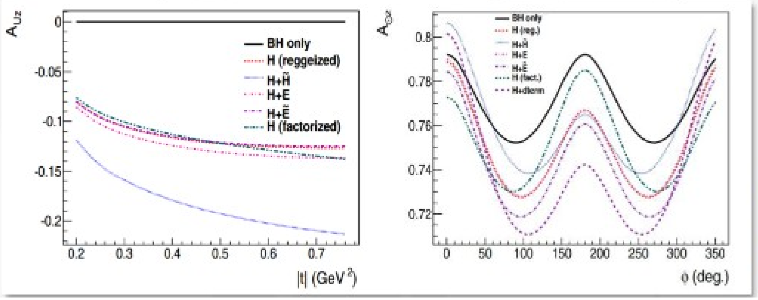
TCS measurements in Hall B (CLAS12)

Slide credit: Pierre Chatagnon

Lead analyzer: K. Gates (Glasgow)

Motivations

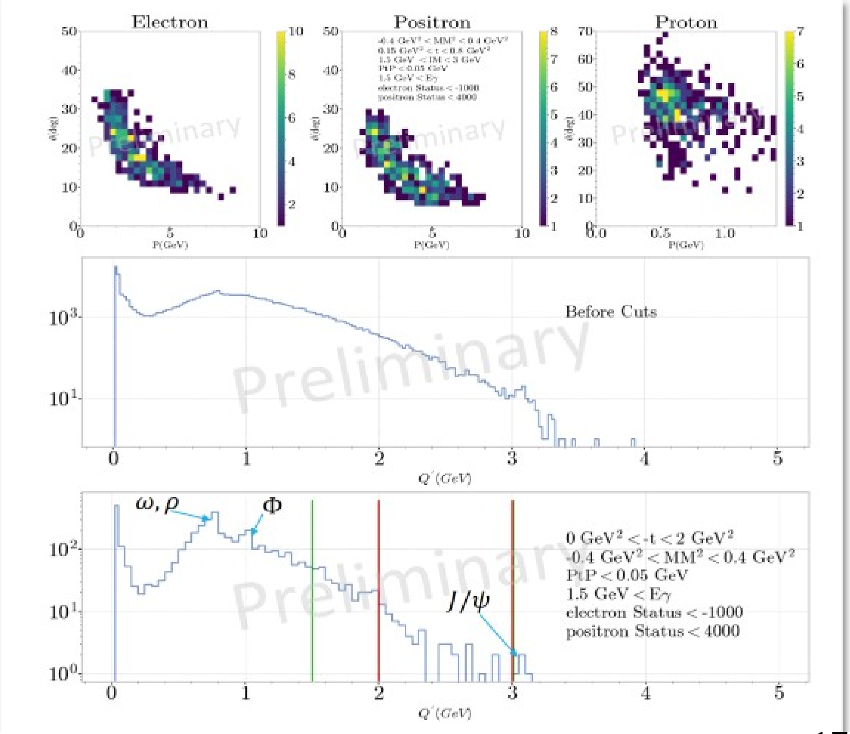
- TCS spin asymmetries provide a complementary way to access CFFs to DVCS
- RG-C data will allow to access 3 spin-polarization observables of TCS
  - BSA: $A_{\odot U} \propto \mathrm{Im}\mathcal{H}$
  - TSA: $A_{UL} \propto \mathrm{Im}\tilde{\mathcal{H}}$
  - DSA: $A_{LL} \propto \mathrm{Re}\tilde{\mathcal{H}}, \mathrm{Re}\mathcal{H}$
- Model predictions show significant asymmetries:



Figures in Boër, M., Guidal, M., Vanderhaeghen, M. Timelike Compton scattering off the proton and generalized parton distributions. Eur. Phys. J. A 51, 103 (2015)

Very preliminary results

- Use quasi-photoproduction event: $ep \to (e')p'e^+e^-$
- Only ~6% of the total dataset shown



Timelike Compton Scattering: status in other Halls

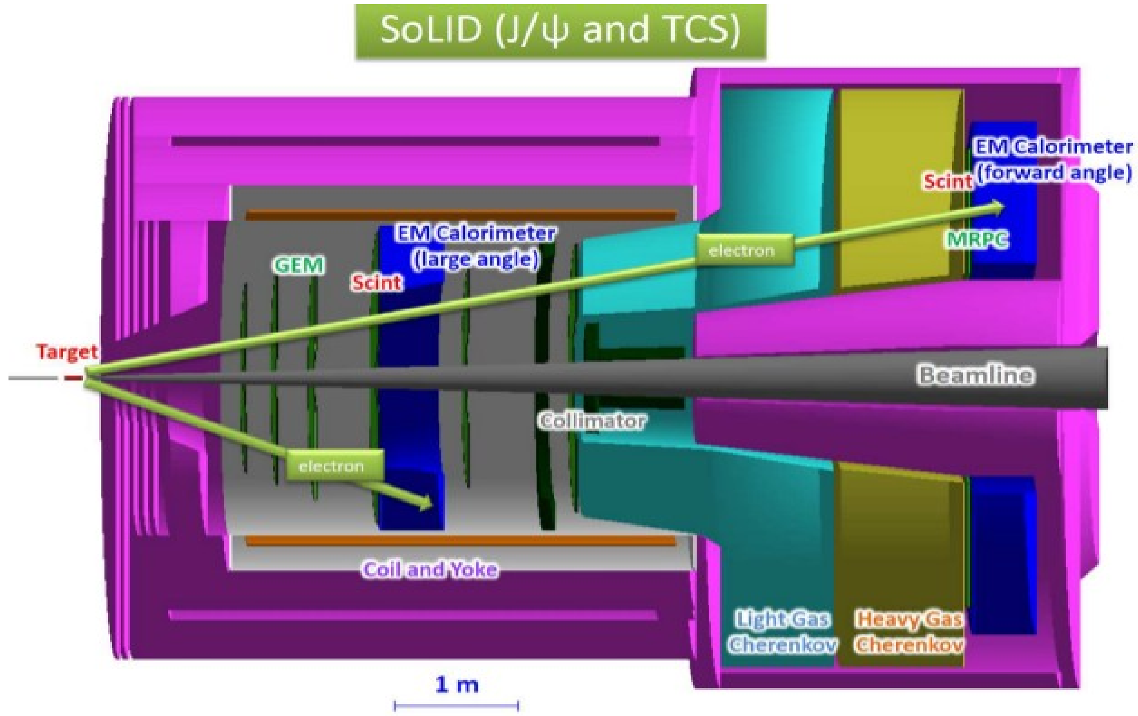
- Hall D: currently analyzing TCS in same region as Hall B (no public results yet)

Future:

- Hall A SoLID: large acceptance spectrometer, should be in ~10 years
Unpolarized TCS experiment approved – cross sections and beam spin asymmetries with significantly more statistics than Hall B/D – Q'^2 dependence, fine binning...

- Hall C: kinematic range coverage not the same as Hall B and D, significantly higher Q'^2,
Higher intensity but narrower acceptance, potential for dedicated experiments

Timelike Compton Scattering with SoLID



SoLID setup for J/ψ approved exp.
50 days at flux 10^37 $cm^{-2}s^{-1}$
LH2 unpolarized target

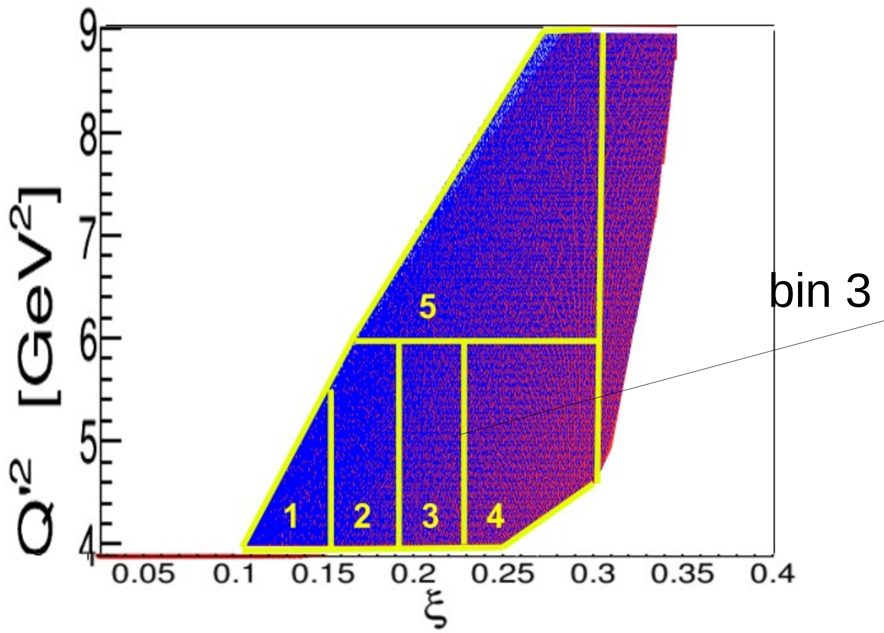
x-sec and BSA with high statistic
→ binning in Q'^2: evolution...
→ studies of GPD universality by comparing H extracted from TCS and DVCS

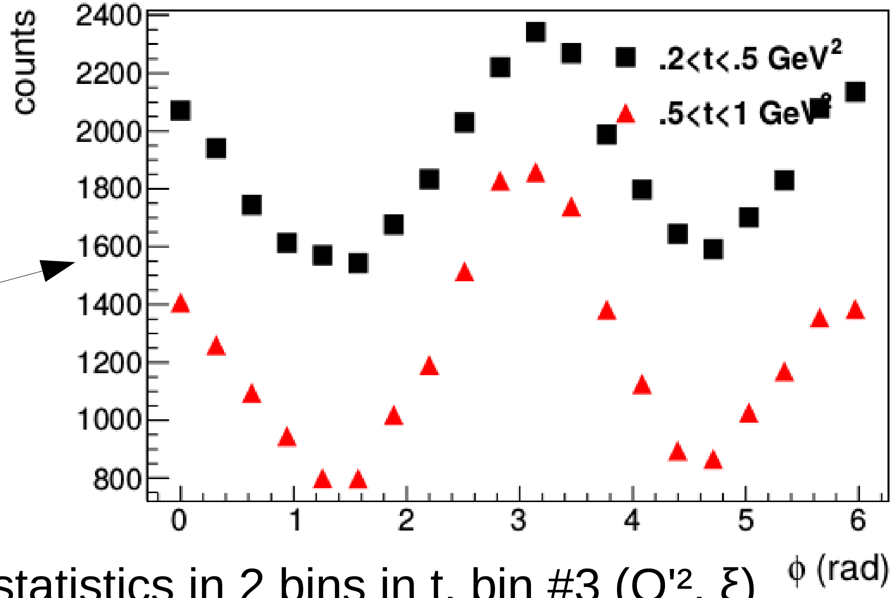
- from electron beam

E12-12-006A
PAC43

Other TCS measurements possible, in particular with polarized targets.
no dedicated measurements planned yet, quasi-real photon

Timelike Compton Scattering with SoLID





statistics in 2 bins in t, bin #3 (Q'^2, ξ)

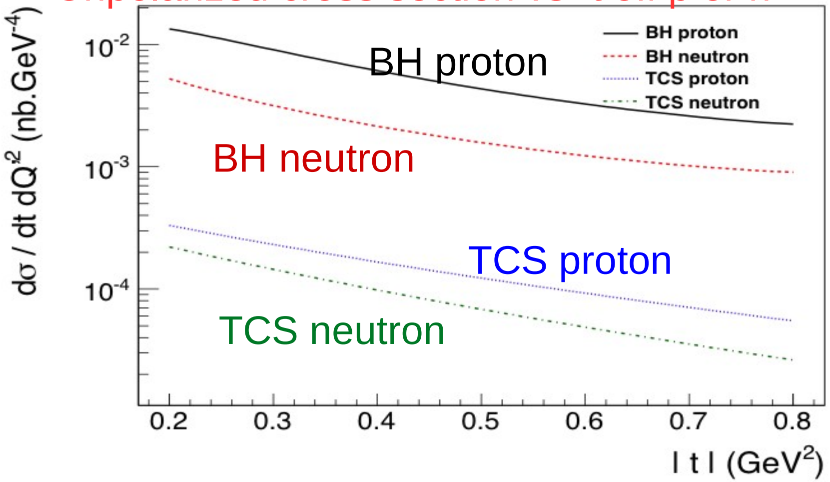
(in progress) Unpolarized TCS with Hall C off proton and neutron

Needs for GPD universality studies+multichannel fits: precision unpolarized cross sections

- Measurement off the proton: requires another magnet & LH2 target
- Off neutron: needed for flavor separation, comparision DVCS/TCS from quark GPDs
  requires neutron detector and/or proton tagging (looking at options)

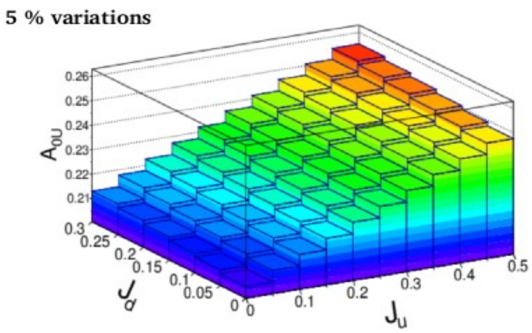
- **Neutron: flavor separation and spin**

Unpolarized cross section vs -t off p or n

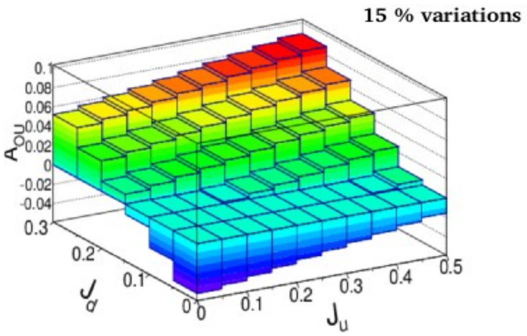


- σ off neutron not suppressed, sizeable asymmetries
- similar sensitivities to GPDs expected
- strong sensitivity to J_u, J_d

BSA proton



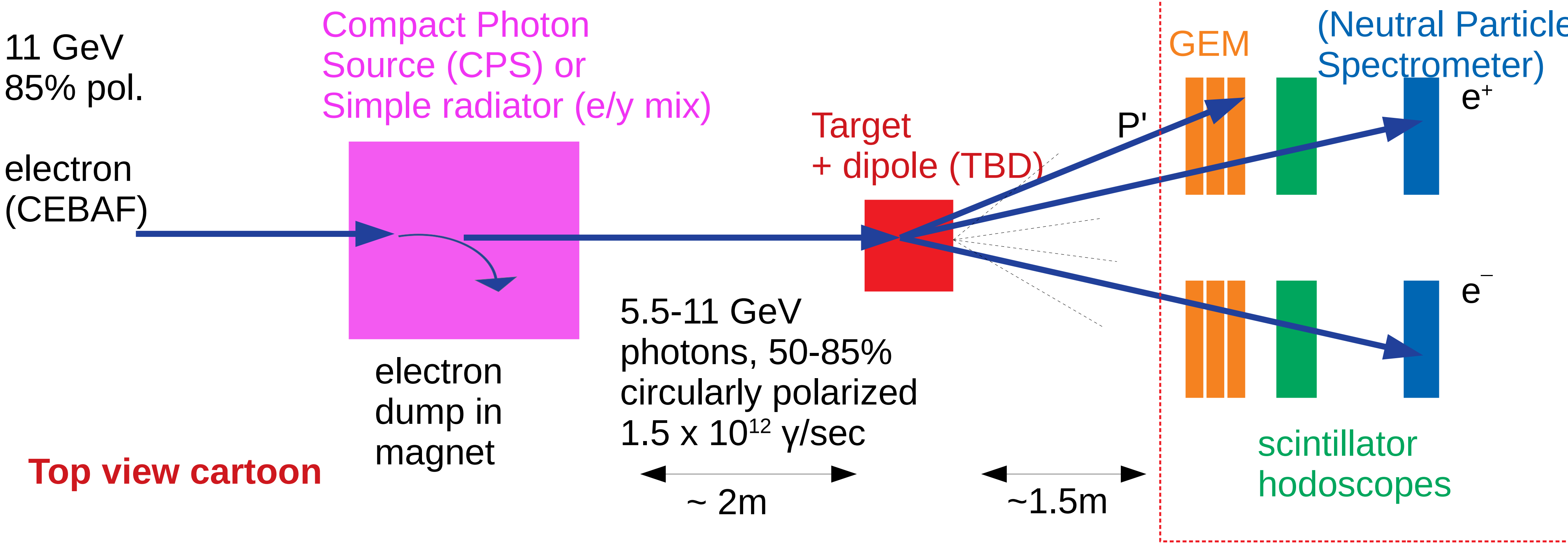
BSA neutron



Experimental setup possible for unpolarized TCS

γ P → e⁺ e⁻ P'

All 3 final particles in coincidence detected



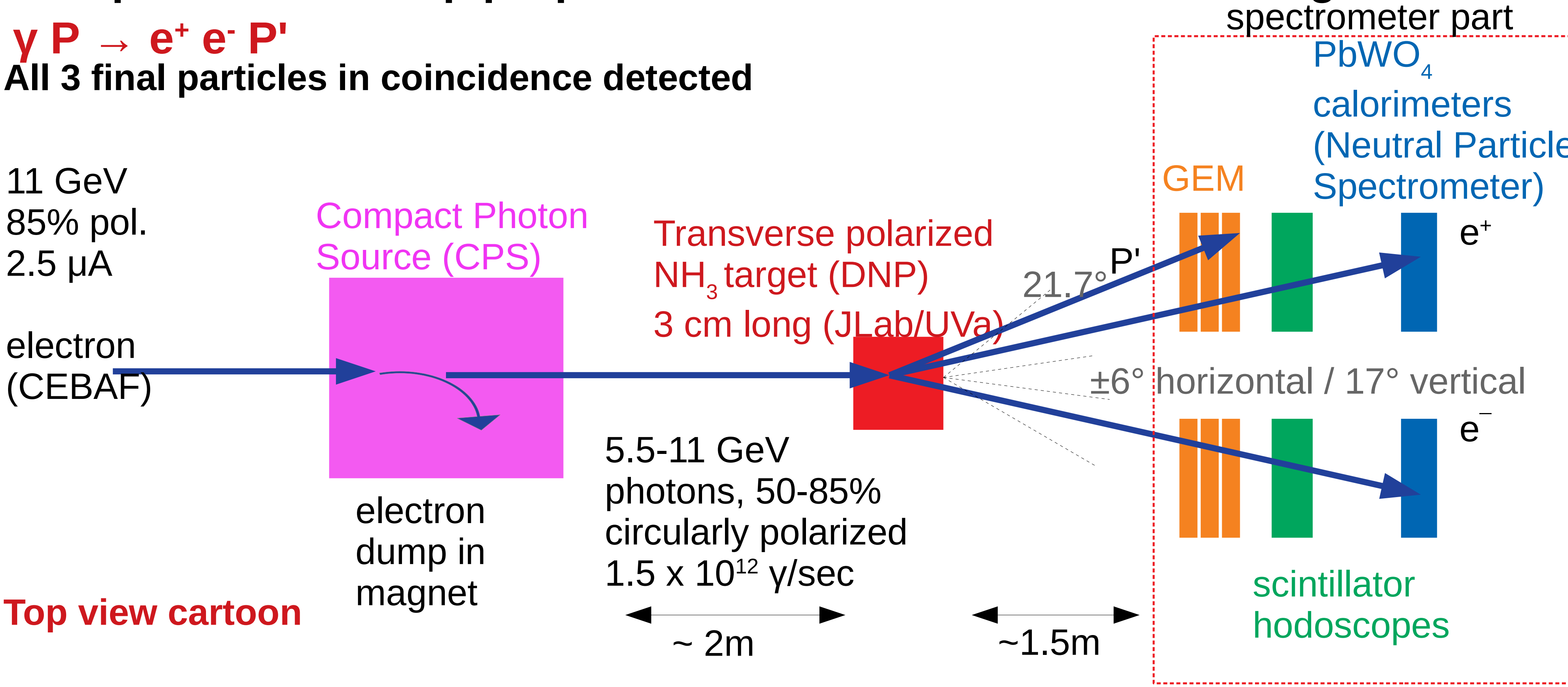
Top view cartoon

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

Experimental setup proposed for Hall C with transverse target

$\gamma P \rightarrow e^+ e^- P'$

All 3 final particles in coincidence detected



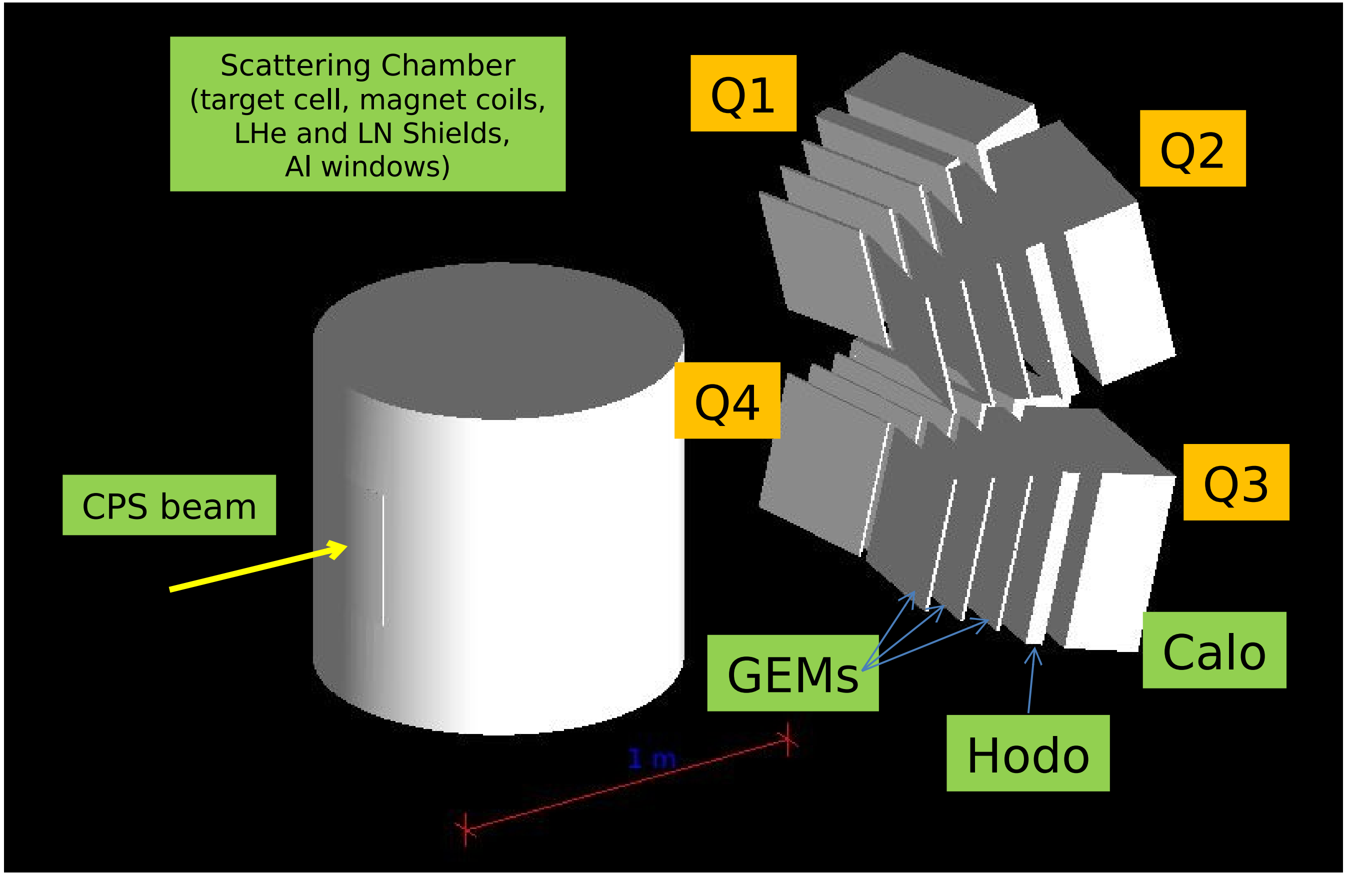
Top view cartoon

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

Integrated luminosity: 5.85×10^5 pb^{-1} for 30 PAC days of "physics"
PAC requested further background simulations & other aspects

Setup: Transversely polarized TCS in Hall C

$\gamma P \rightarrow e^+ e^- P'$



1. High intensity photon source
1.5×10^{12} γ/sec (CPS)

2. Target chamber: NH_3, 3cm
Polarized via DNP

3. Tracking: GEM+hodoscopes,
4 symmetric quadrants

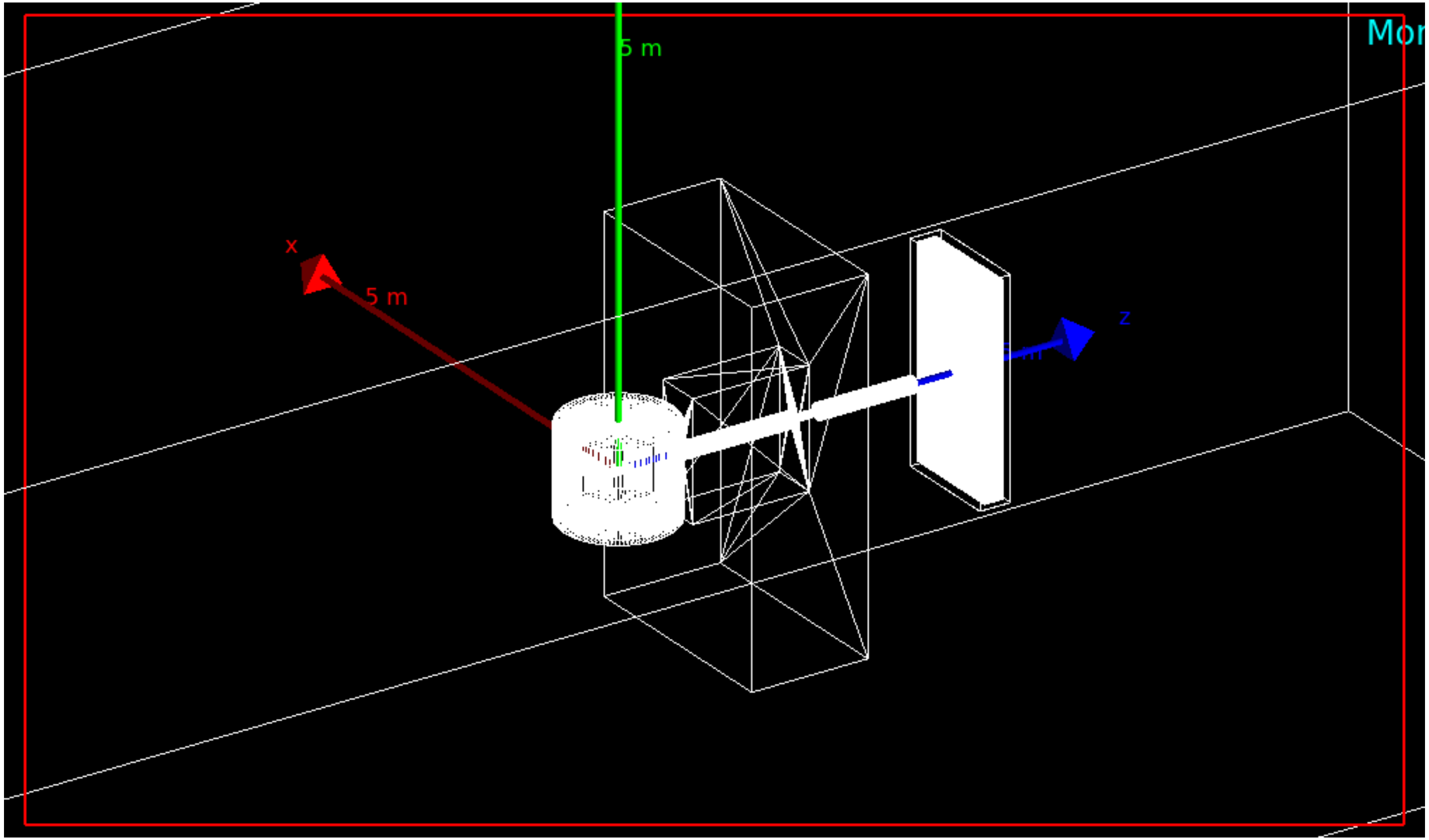
4. Calorimeters: 4 symmetric
quadrants, equivalent of 2 NPS

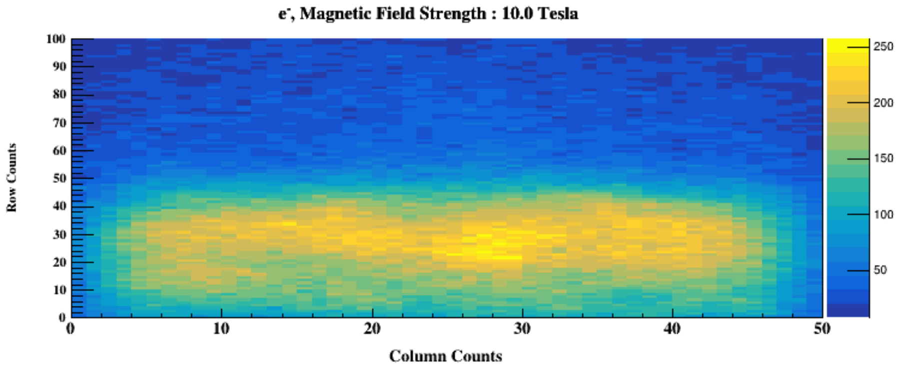
~ 6° to 27° aperture
Lumi request: 5.85×10^5 pb^{-1}

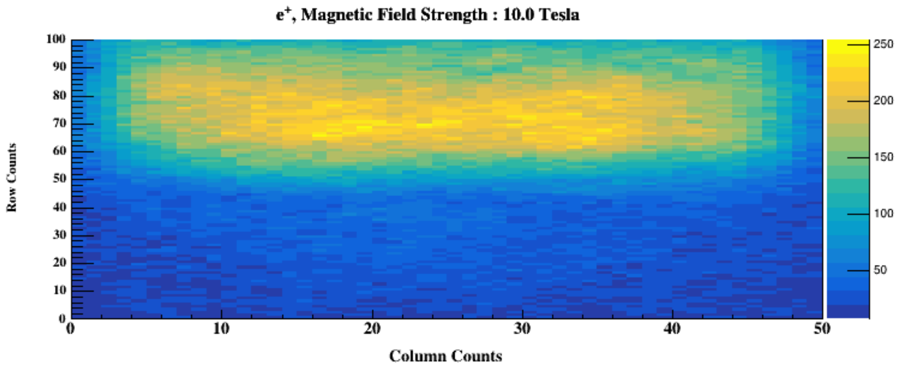
Setup: (not proposed yet) Unpolarized TCS in Hall C

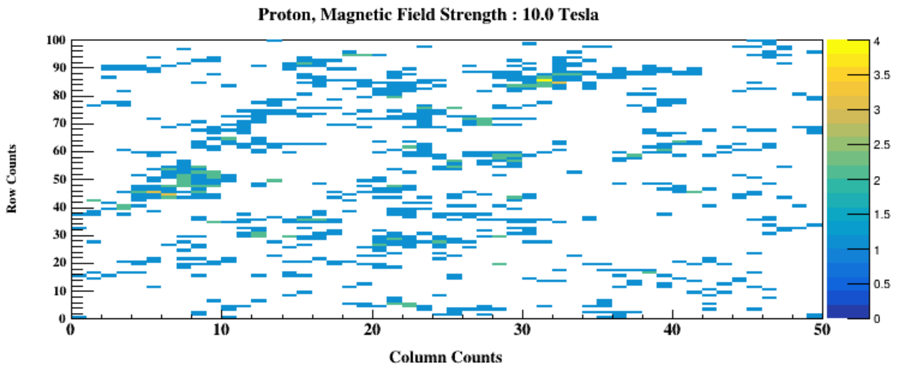
- High intensity with real photon: dedicated photon source or radiator
- Dedicated experiment, high resolution

Goal: universality studies (cross section + BSA), complement polarized measurements









Work in progress for unpolarized TCS in Hall C
Credit: Debaditya Biswas

- need to find the right setup
- which magnet to use...

- open opportunities for other reactions, such as diphotons, photon+meson…
(also work in progress)

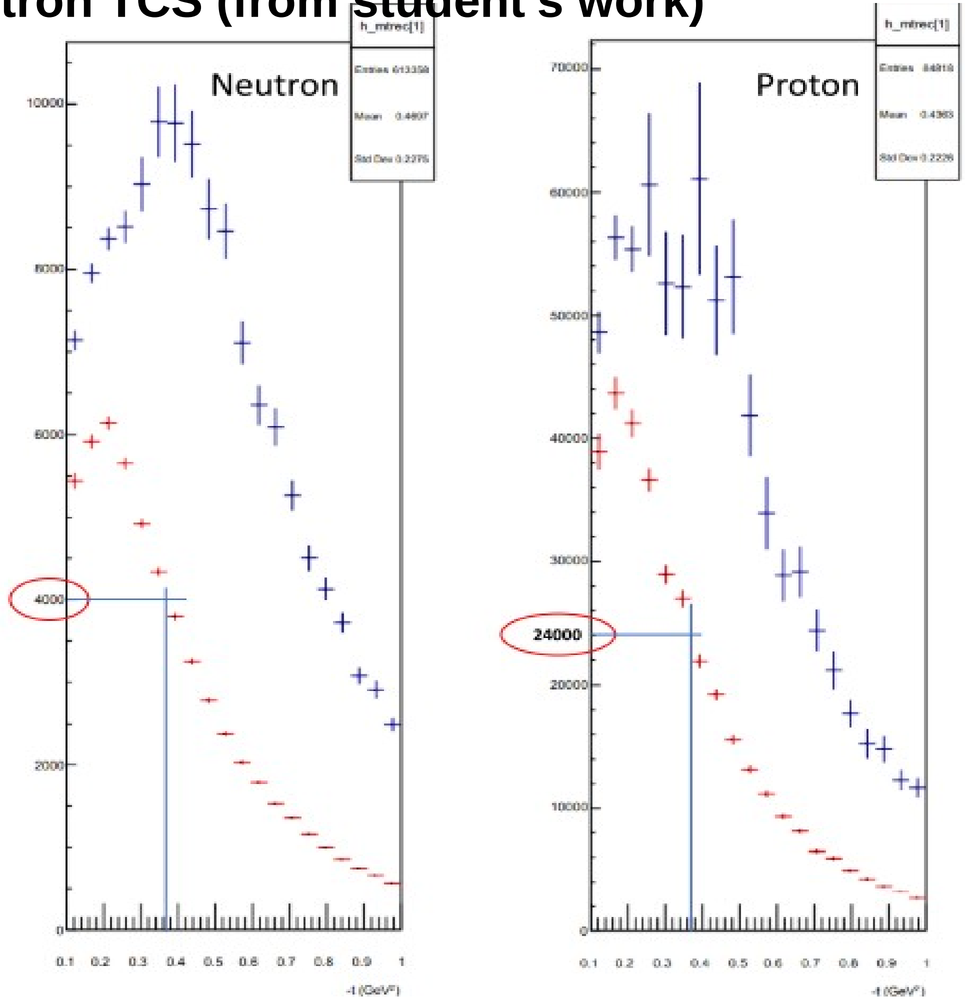
Projections for unpolarized proton and neutron TCS (from student's work)

Number of reconstructed events measured for the TCS reaction depending on $-t$ weighted by the cross section

The data are normalized.

Difference between proton and neutron:

- Measured : x6



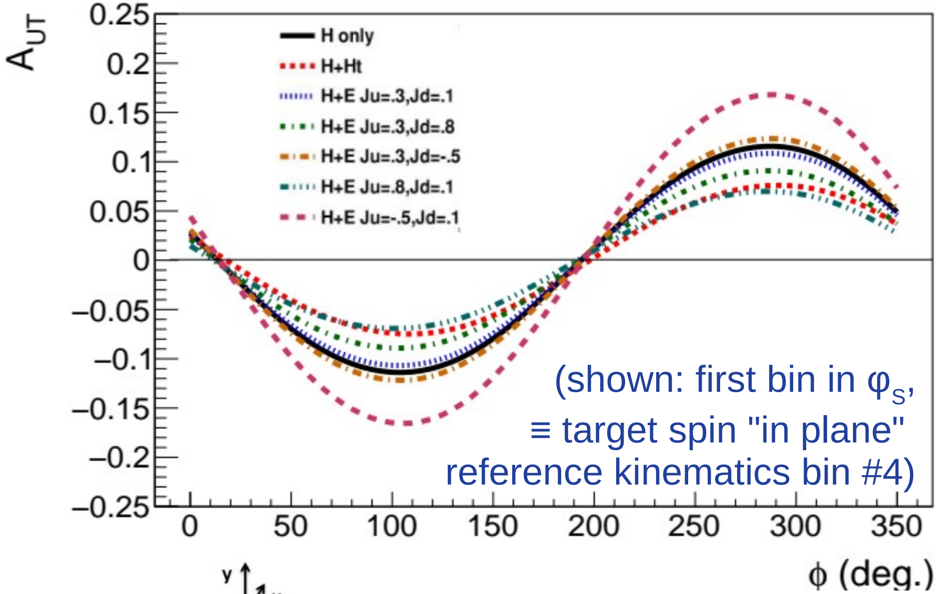
Camille's projection demonstrate

1) feasibility of measuring unpolarized proton TCS off LH2 (in terms of counting rates & impact)

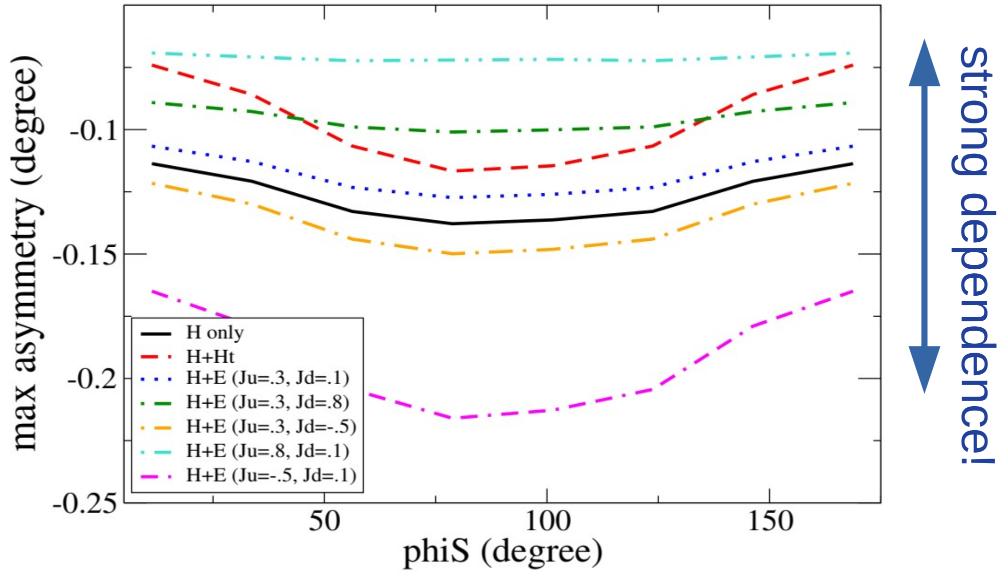
2) feasibility of measuring unpolarized neutron TCS off LD2

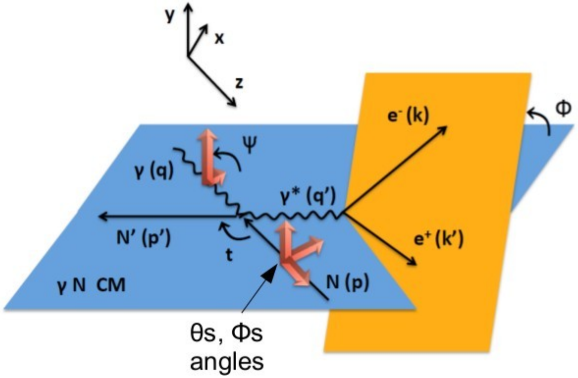
Physics case for proposed experiment: TSA dependencies, GPD E and proton spin decomposition

Dependence in GPD parametrization and J_u, J_d (VGG model) vs φ and $φ_S$



Sin(φ) moment of transverse spin asymmetry vs $φ_S$, Dependence in GPD E and $J^{u,d}$ (VGG model)



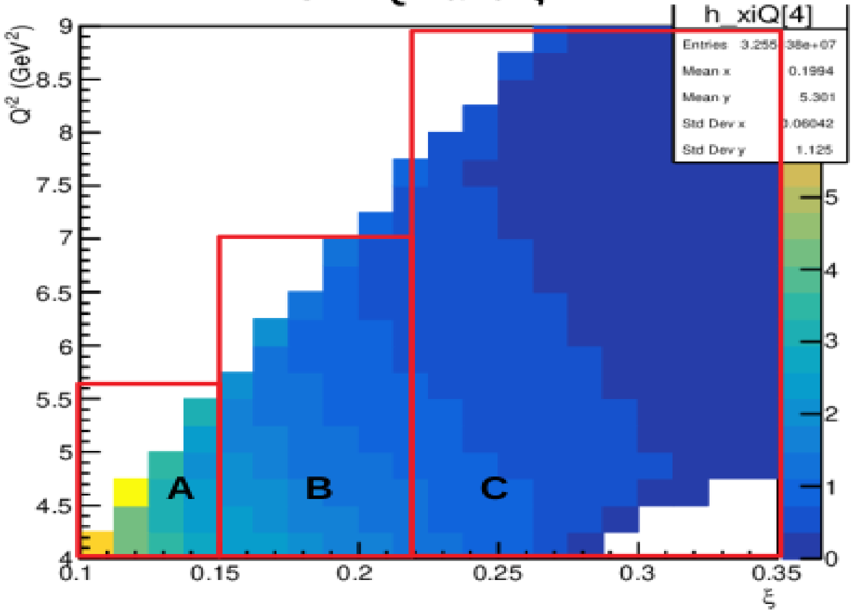


Extraction of CFFs from azimuthal dependence in φ (reaction plane vs lepton pair) and $φ_S$ (proton spin) angles

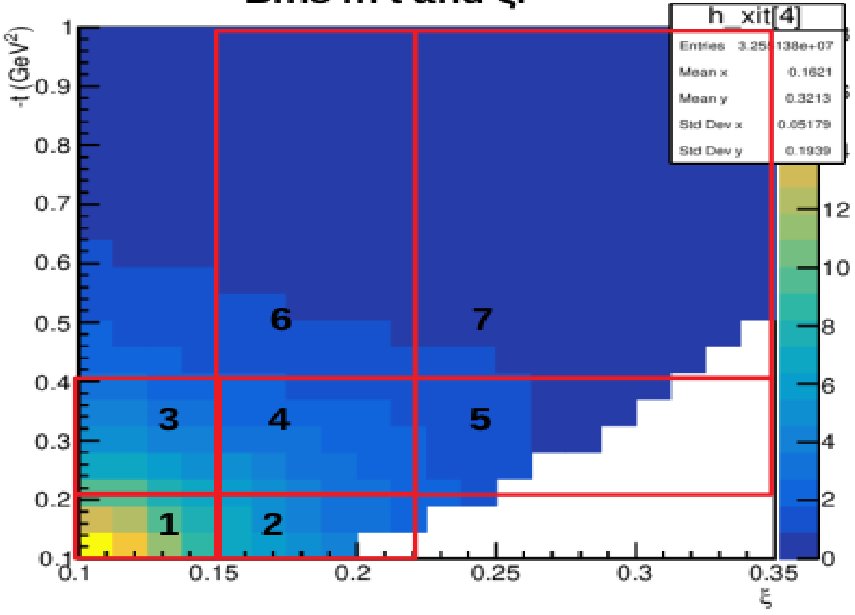
Here: projection vs φ and $φ_S$ using different version of VGG model

Phase Space for TCS (Hall C, NPS experiment)

Bins in Q'² and ξ:



Bins in t and ξ:



A: $.10 < \xi < .15$; $4 < Q'^2 < 5.5$ GeV²
B: $.15 < \xi < .22$; $4 < Q'^2 < 7$ GeV²
C: $.22 < \xi < .35$; $4 < Q'^2 < 9$ GeV²

1, 2: $.1 < -t < .2$ GeV²
3, 4, 5: $.2 < -t < .35$ GeV²
6, 7: $.35 < -t < .7$ GeV²

x 16 bins in φ x 16 bins in φ_s, integrated over θ

Main cuts:

- Physics: regions near BH peaks by (E, θ, φ) cut
- Trigger thresholds:
- Exclusivity

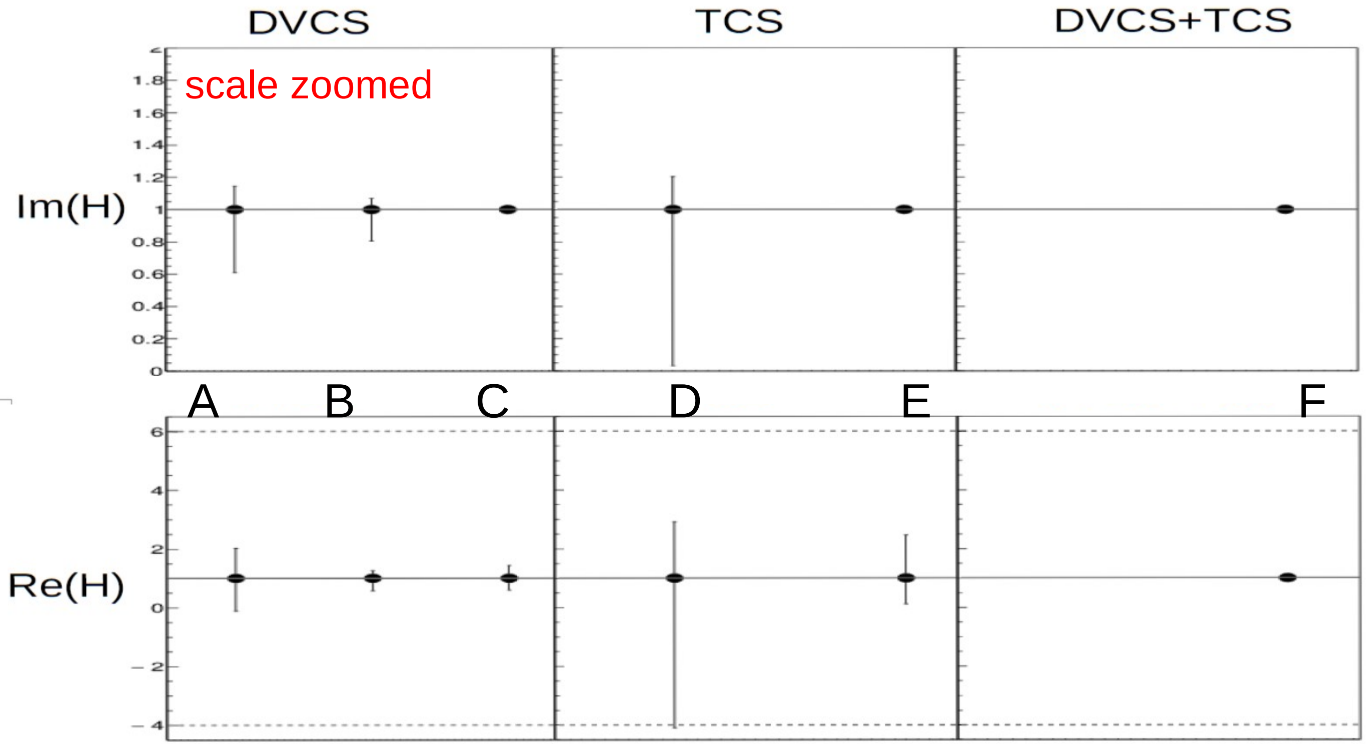
CFF extraction from future JLab DVCS and TCS experiments

GPD H

Legend
___ generated CFF value = 1
--- limits of CFF variation during fit
[1] approved experiments
[2] conditionally approved
[3] proposal in progress
# of independent parameters: 7
Assumed uncertainties: 5% with 20 points for each observable

Configuration of observables

A. DVCS $\sigma + \Delta\sigma_{LU}$ (Hall A, B, C)[1]
B. DVCS $\sigma + \Delta\sigma_{LU} + \Delta\sigma_{Uz} + \Delta\sigma_{Lz}$ (Hall B)[1]
C. DVCS $\sigma + \Delta\sigma_{LU} + \Delta\sigma_{Uz} + \Delta\sigma_{U\perp}$ (+Hall B)[2]
D. TCS $\sigma + \Delta\sigma_{OU}$ (Hall A, B)[1]
E. TCS $\sigma + \Delta\sigma_{OU} + \Delta\sigma_{U\perp}$ (+Hall C)[3]
F. DVCS $\sigma + \Delta\sigma_{LU} + \Delta\sigma_{Uz} + \Delta\sigma_{Lz}$ + TCS $\sigma + \Delta\sigma_{OU} + \Delta\sigma_{U\perp}$



- Future experiments: GPD H with TCS and DVCS. Comparison to confirm GPDs universality. Possible evaluation of NLO / higher twist effects, different in spacelike vs timelike.

- Small uncertainty on Im(H). Other CFF more difficult to extract. Re(E) is the most difficult one from DVCS and TCS: comes only through correlations from many observables once other CFFs are constrained.

- Combined fits: improve uncertainty vs DVCS-only (need some assumptions). Bring more constrains in multi-observables, multi-CFF fits.

CFF extraction from future JLab DVCS and TCS experiments

GPD E

Legend
___ generated CFF value = 1
--- limits of CFF variation during fit
[1] approved experiments
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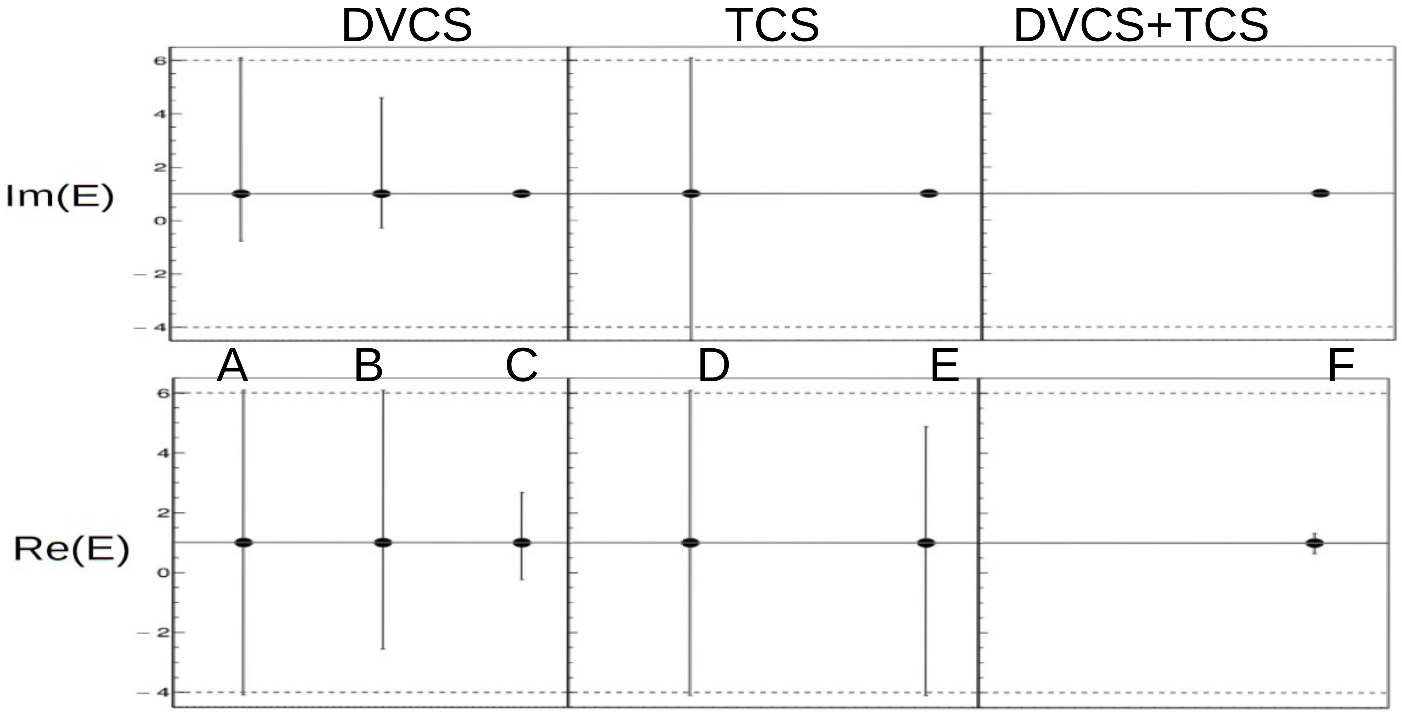
C. DVCS $\sigma + \Delta\sigma_{LU} + \Delta\sigma_{Uz} + \Delta\sigma_{U\perp}$ (+Hall B)
D. TCS $\sigma + \Delta\sigma_{OU}$ (Hall A, B)[1]
E. TCS $\sigma + \Delta\sigma_{OU} + \Delta\sigma_{U\perp}$ (+Hall C)[3]
F. DVCS $\sigma + \Delta\sigma_{LU} + \Delta\sigma_{Uz} + \Delta\sigma_{Lz}$ + TCS $\sigma + \Delta\sigma_{OU} + \Delta\sigma_{U\perp}$



- Im(E) needs transversely polarized target experiments to be constrained. Similar sensitivity to Im(E) using DVCS or TCS asymmetries.

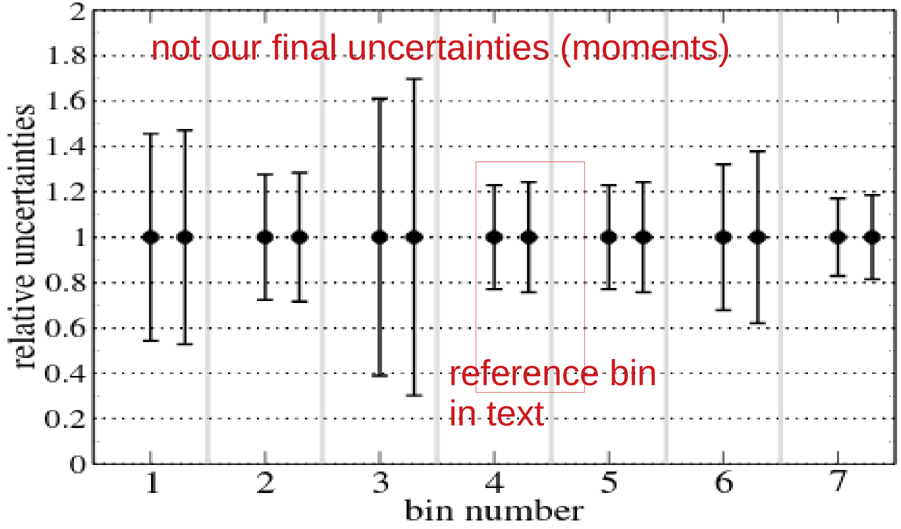
- Re(E) cannot be constrained with DVCS-only nor TCS-only. But by correlations, combined fits show that Re(E) can be extracted with enough independent observables in the fitting procedure. It is essential for GPD E and its interpretations.

Note: fits from long ago, will soon come back to this work

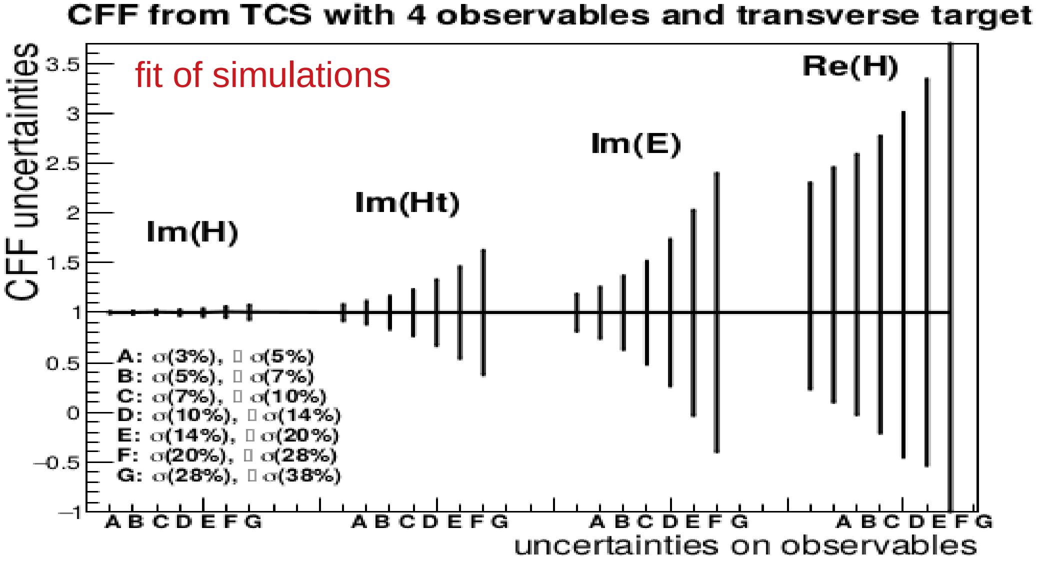
Uncertainty propagation to CFFs

Error mostly dominated by unpolarized experiment precision (GPD H dominant)

1) uncertainties for polarized target experiment (illustration) **combined errors** on 2 orthogonal ⊥ asymmetries for first sinus moment, for all bins (to be compared with size of asymmetries vs φ_S)



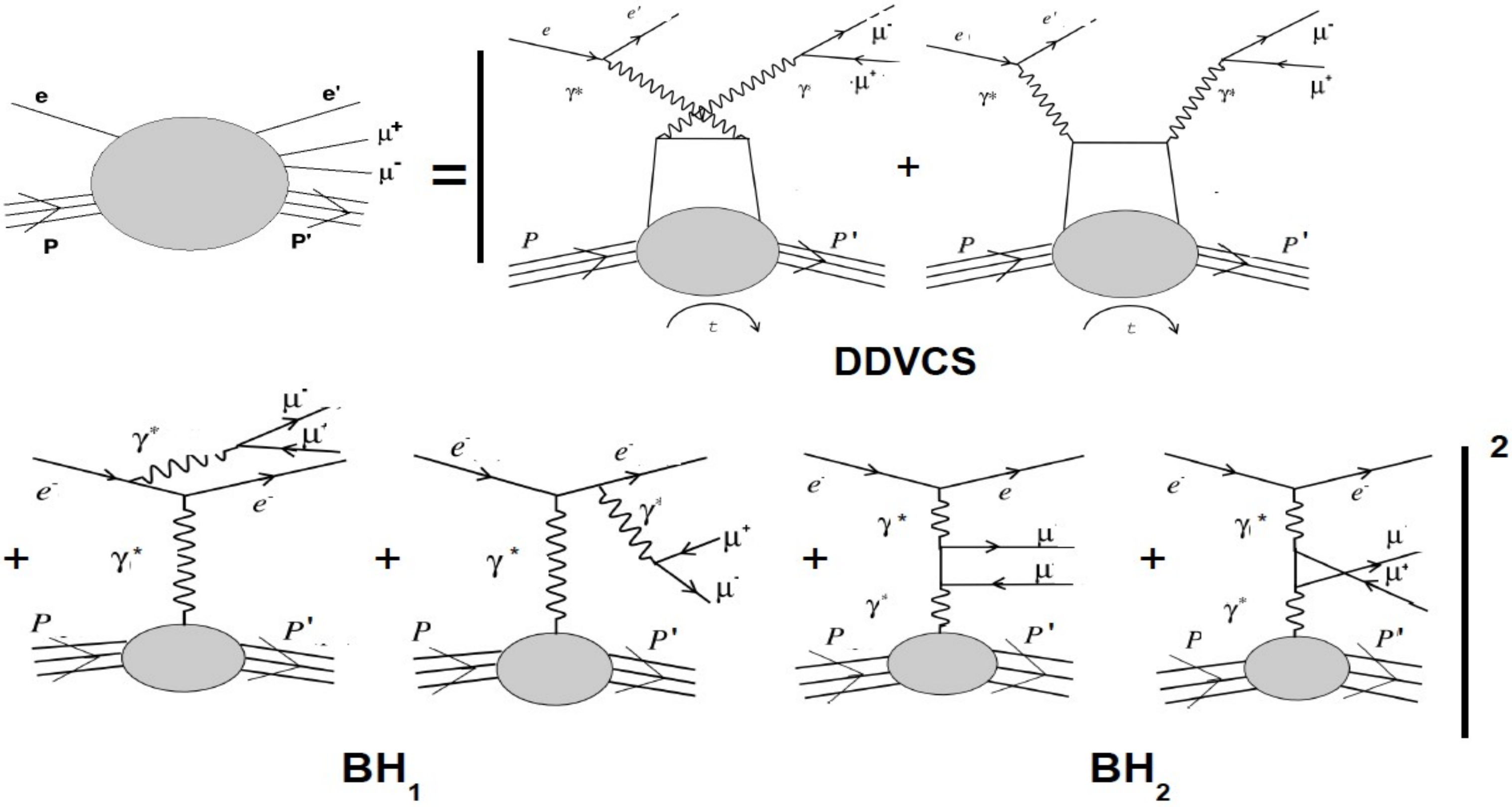
CFFs uncertainties vs experimental errors
For different scenarios having unpolarized/polarized x-secs
fits on simulations using VGG parametrization



- **Im(H), Re(H), Im(H̃), Im(E) extracted even with very large experimental uncertainties (E, F, G)**
- **Results mostly depend on unpolarized cross section errors / importance of precision measurement, not only polarized**
- **Transverse target Hall C experiment will put constraints on GPD E, J_u & J_d, and reduce errors on Im+Re(H)**
- **Unpolarized experiment will enable these fits and universality studies**

Double Deeply Virtual Compton Scattering

Interest: access the off diagonal part of (x, ξ) distribution of CFF

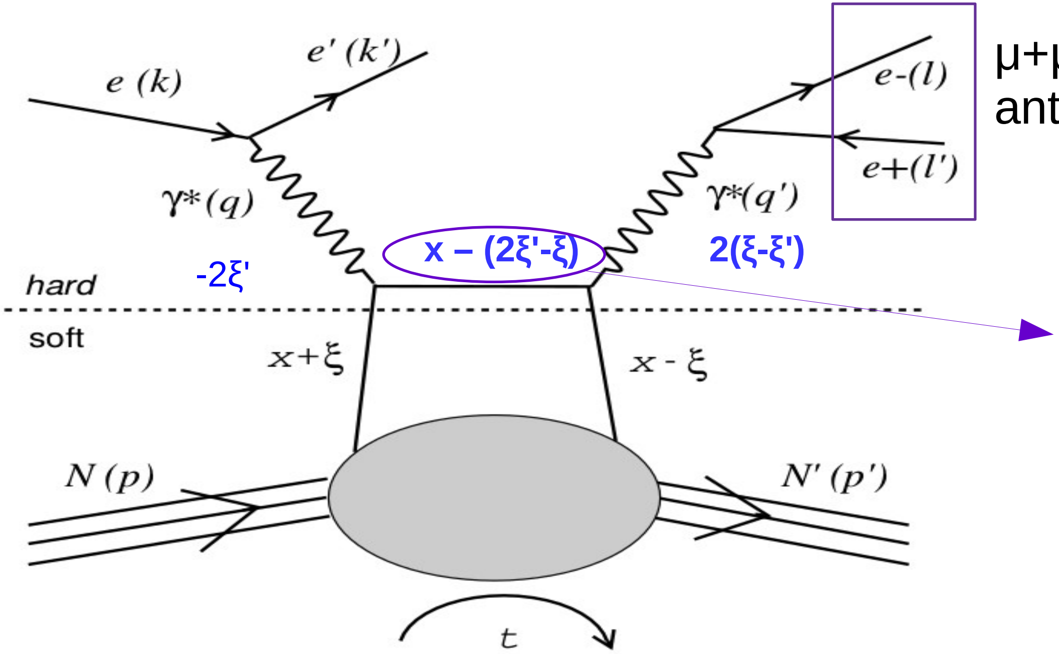


behaves like DVCS-like BH

behaves like TCS-like BH

DDVCS from e- beam, decaying in dimuons to avoid anti-symetrization and experimental challenges

Double Deeply Virtual Compton Scattering (notations)



μ+μ- → avoid antisymmetrisation

- ξ = + component of P=(p+p') in light cone frame. GPDs depend on it. "skewness"
- ξ' = + component of $\bar{q}$=(q+q')/2 in light cone frame. quark propagator can be related to x_{bj}

Special cases (at asymp. limit):
DVCS: ξ'=ξ; TCS: ξ'=-ξ

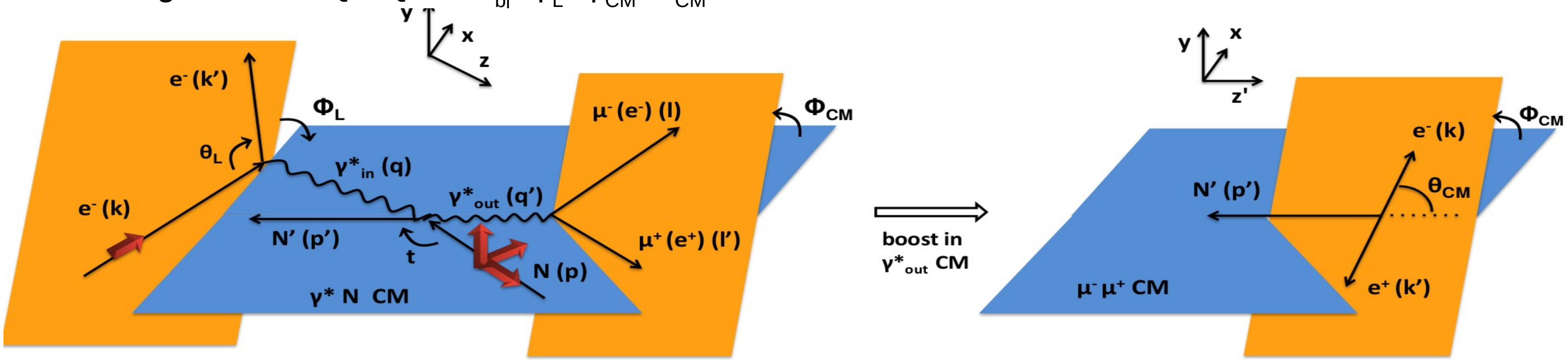
Mesons: fixing Q'² at meson mass squared

Lever arm to go “off diagonal”
Provided by relative virtuality of the photons

Notations for Bethe-Heitler + DDVCS reaction

BH+DDVCS = e P → e' μ+ μ- P'

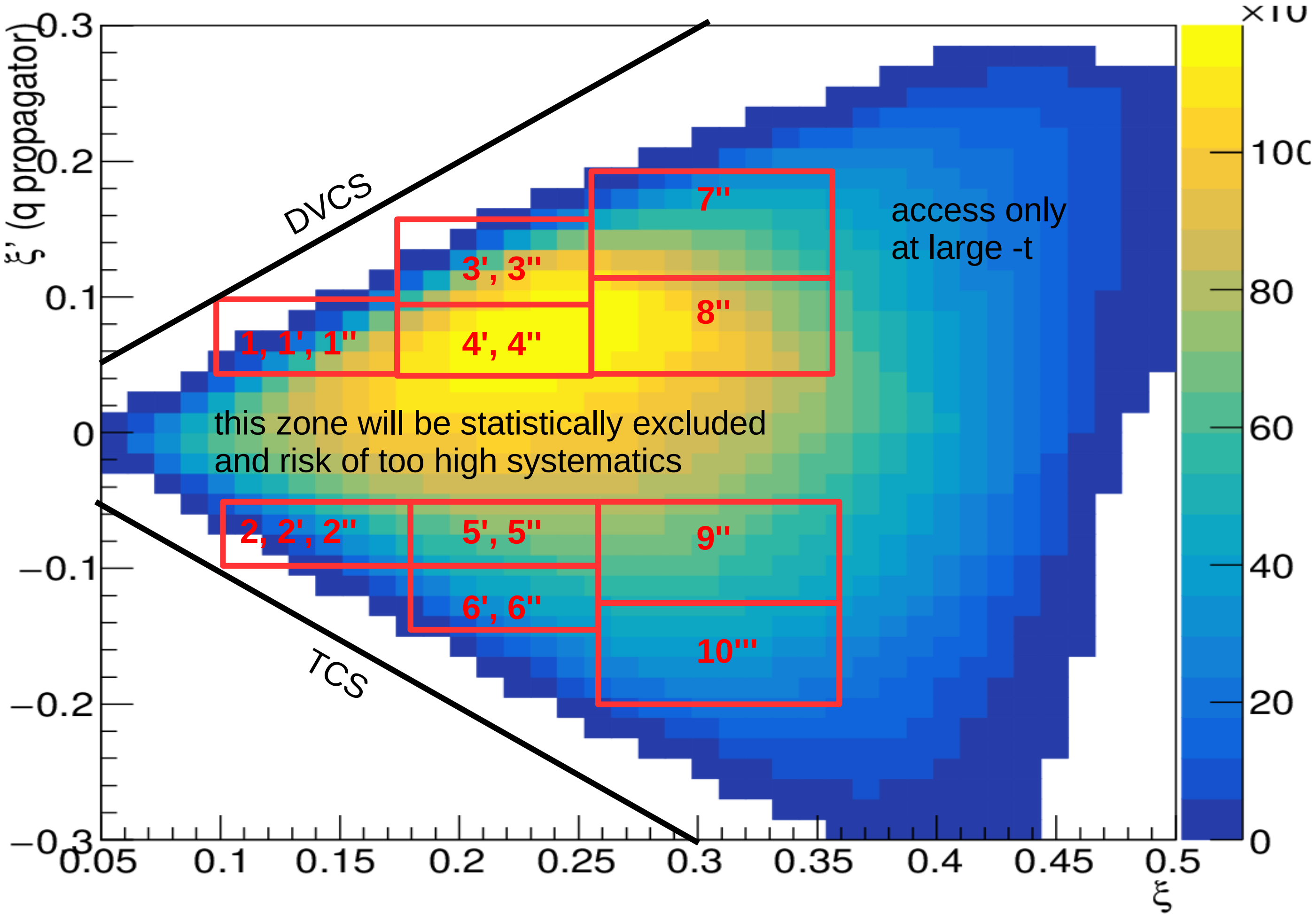
• 7 independent variables for unpolarized cross section.
Choice for the generator: Q^2, Q'^2, t, x_{bj}, φ_L, φ_{CM}, θ_{CM}



With the generator:
unpolarized cross section, beam polarized cross section, asymmetry.

Notation of the angles in generator files:
φ_{CM}= Phi_CMV
θ_{CM} = Theta_CMV
φ_L = Phi_LH
φ_{beam}, θ_{beam} = theta_beam, phi_beam

Binning in ξ, ξ', all t: going "off-diagonal" (some scenarios under studies)



Bin in ξ	code # large/low t
A) .1 < ξ < .18 (all t bins)	
1) .05 < ξ' < .1	1, 7, 17
2) -.05 > ξ' >-.1	2, 8, 18
B) .18 < ξ < .26 (t bins 2 and 3)	
3) .1 < ξ' < .15	3, 9
4) .05 < ξ' < .1	4, 10
5) -.05 > ξ' > -.1	5, 11
6) -.1 > ξ' > -.15	6, 12
C) .26 < ξ < .36 (t bin 3)	
7) .12 < ξ < .2	13
8) .05 < ξ < .12	14
9) -.05 > ξ > -.12	15
10) -.12 > ξ > -.2	16

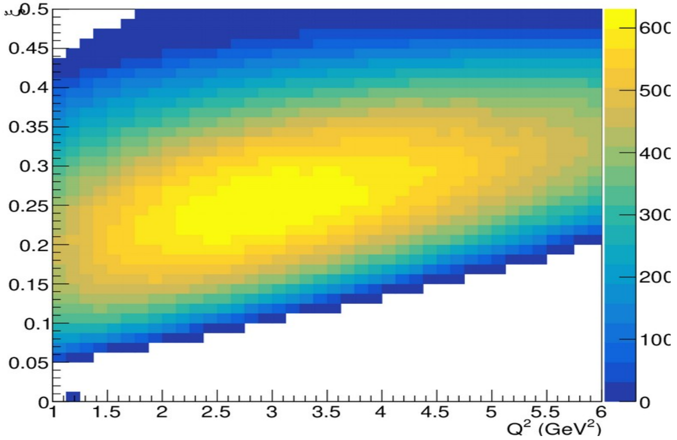
Bins in t: (1) 0 < -t < 0.15 GeV², (2) 0.15 < -t < 0.35 GeV², (3) 0.35 < -t < 0.55 GeV² (indicated ', '')

Phase space coverage for JLab 11 GeV

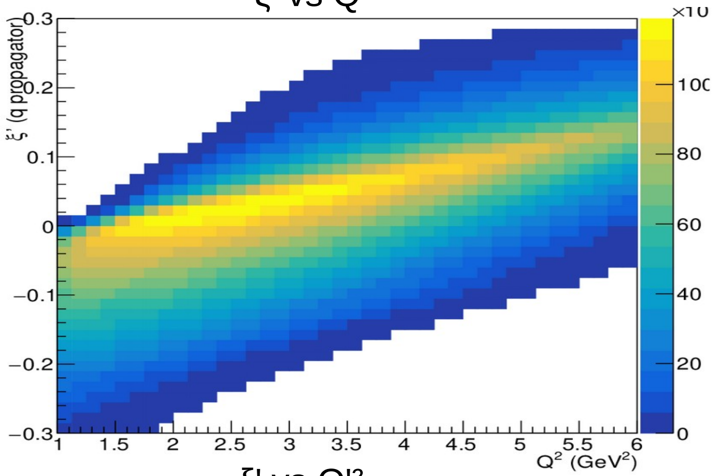
values of skewness and quark propagator accessible vs Q^2 and Q'^2

Q^2 and Q'^2 not correlated
correlation with other kinematic variables

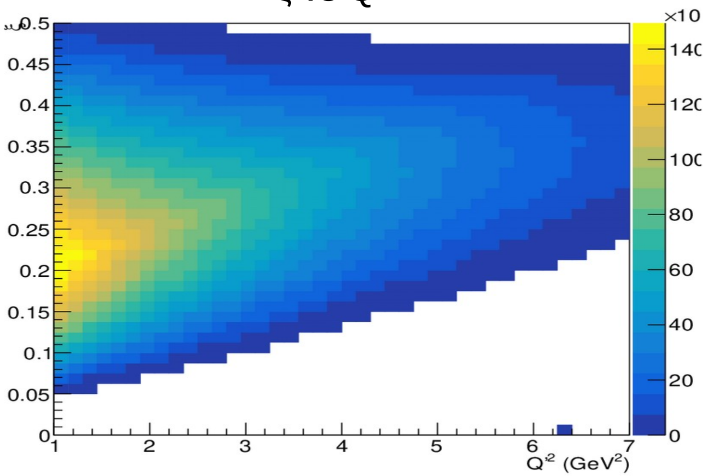
ξ vs Q^2



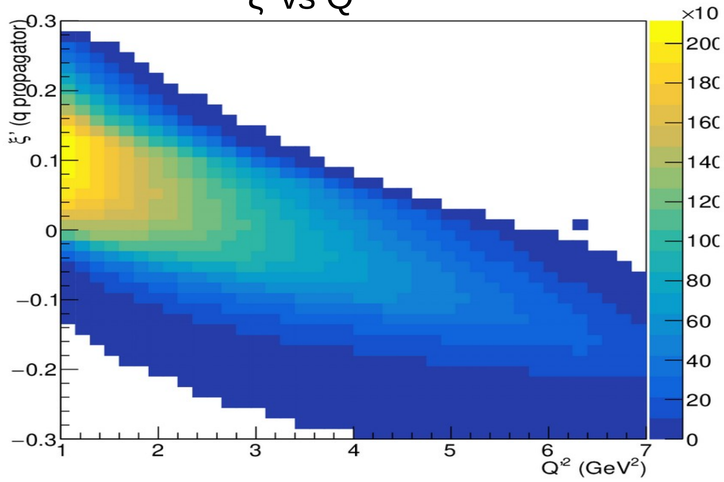
ξ' vs Q^2



ξ vs Q'^2

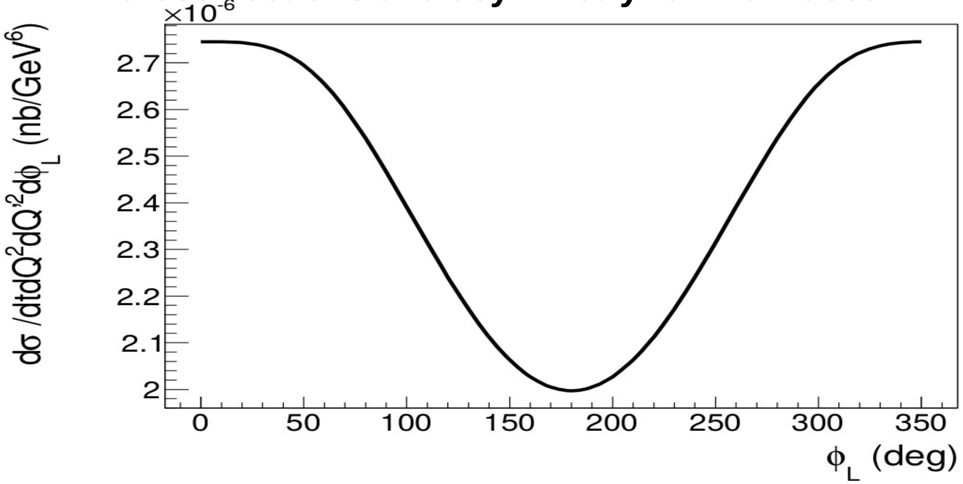


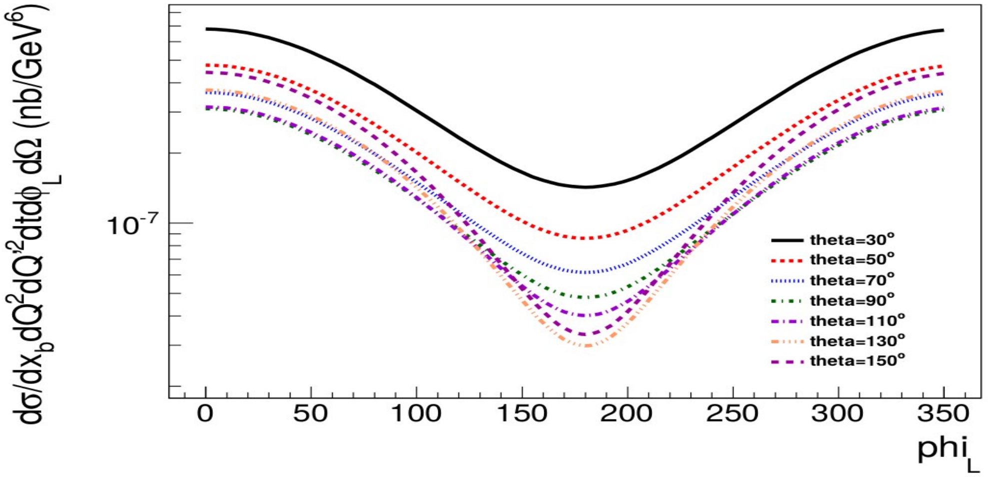
ξ' vs Q'^2

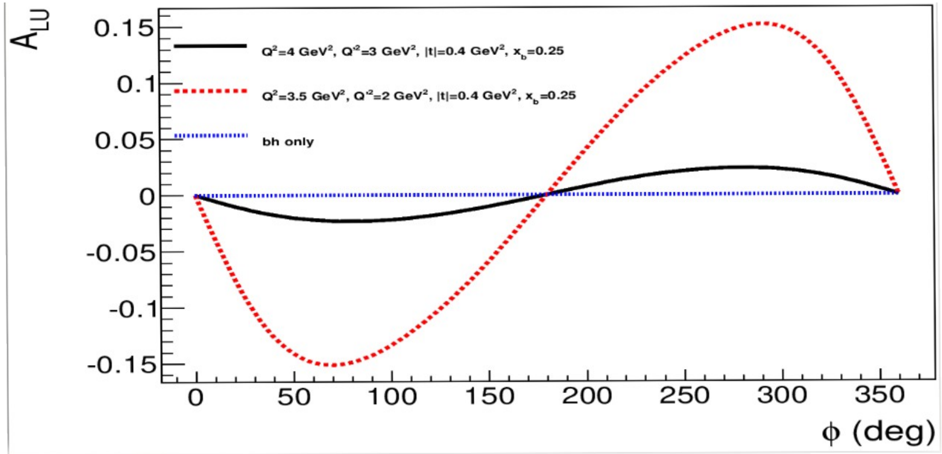


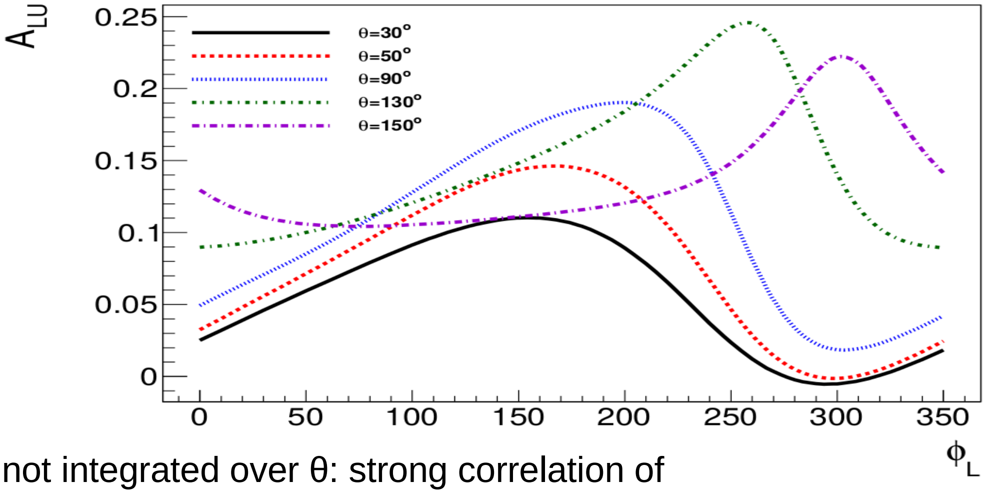
φ_L behavior. similar than DVCS; but correlations with final angles and “BH2”

cross sections and asymmetry for 1 bin used in 2015 SoLID LOI







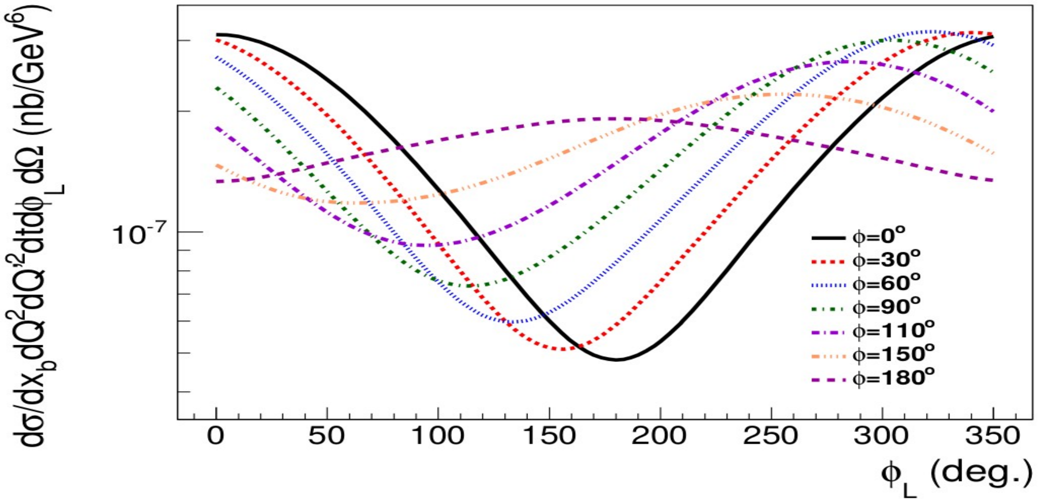


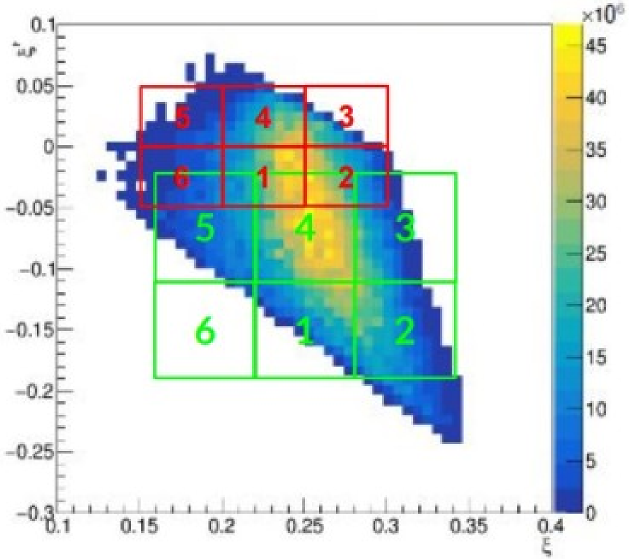
left= integrated over θ, right=not integrated

if not integrated over θ: strong correlation of A_{LU} with θ, this variable need to be well defined

θ propto rate of “BH2” vs other diagrams

correlation between the azymutal angles in DDVCS





- To extract CFFs: 2D fits in φ_{CM}, φ_{LH}, as a function of ξ, ξ', t
or ξ' replaced by <Q²/Q'²> (bin), but loose precision taking just the ratio
integrated over θ for statistics (as for TCS, there is a systematic associated to that)

Projections for potential experiment
In Hall C (in progress)

- only Im(ℋ) (ξ', ξ, t) will be possible to extract with unpolarized cross section and beam asym.

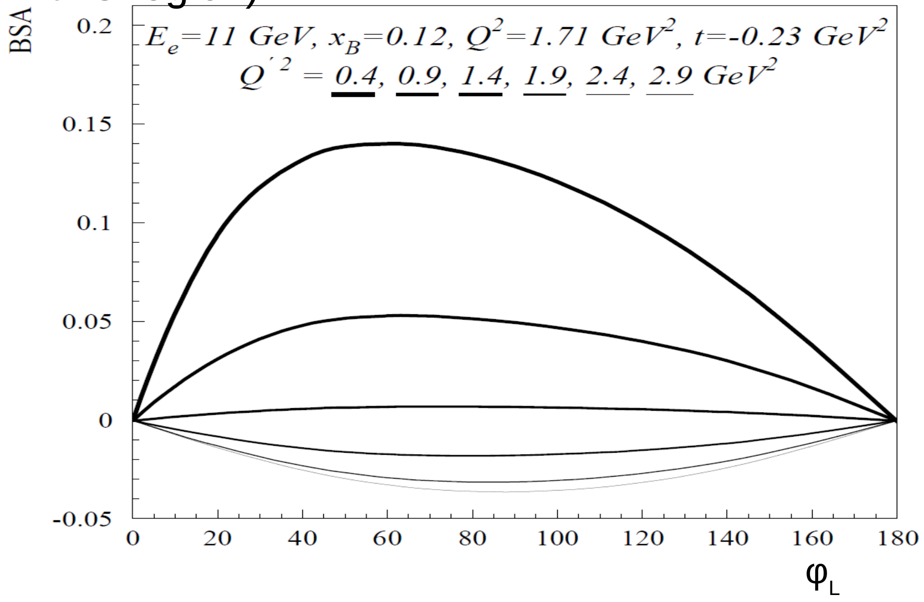
GPDs from DDVCS can be extracted, but one need to
1) take angular correlation into account, similar than TCS
2) 2 or 3D fits of angles

Nucleon tomography and sign change in DDVCS beam spin asymmetry

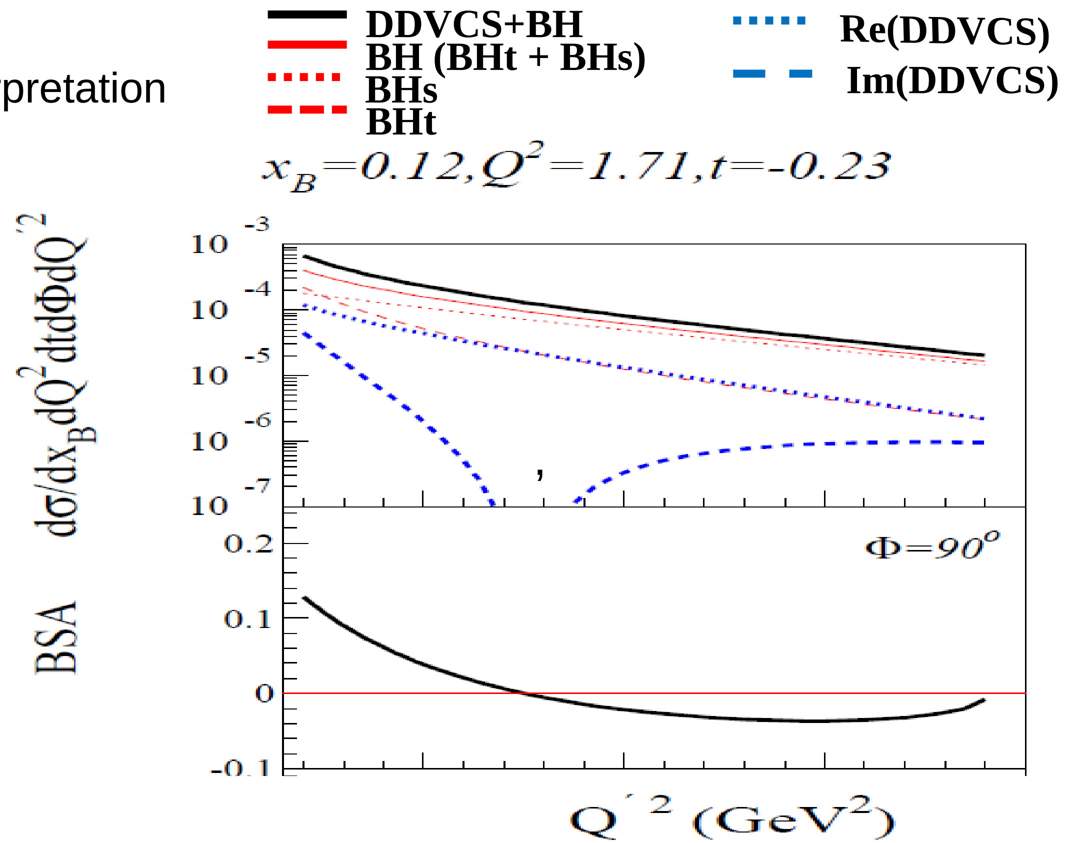
Calculations and figures from M. Guidal

→ scan in Q'² at fixed Q²

→ sign change in BSA when Q'² ≈ Q² (no GPD interpretation in this region)



cross section and asymmetry Q² scan



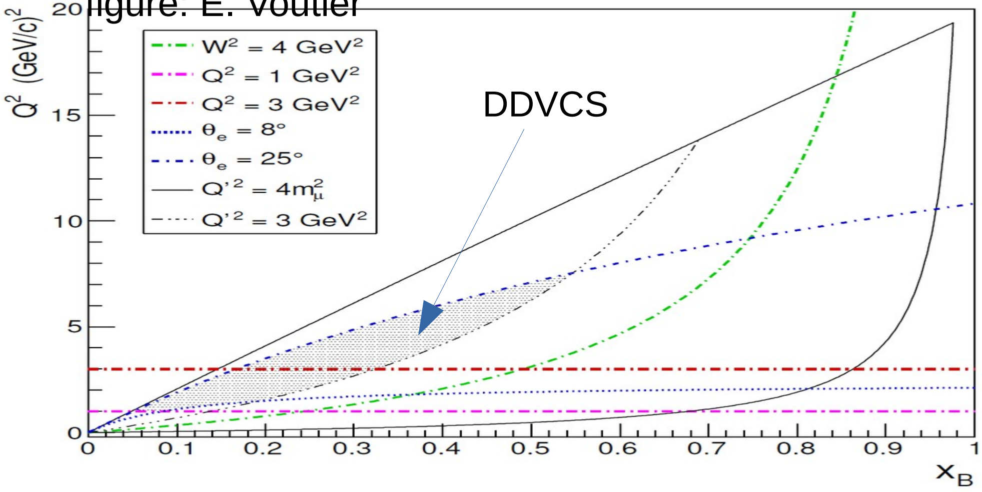
- Expectation of sign change when moving from « spacelike » to « timelike » region in asymmetry. This reaction is unique for probing effects between these 2 regions.

- Interpretation with Q² ~ Q'²???

- Need more theorists to look at it!

DDVCS JLab Hall A SoLID projections

Phase space and counting rates for SoLID
figure: E. Voutier



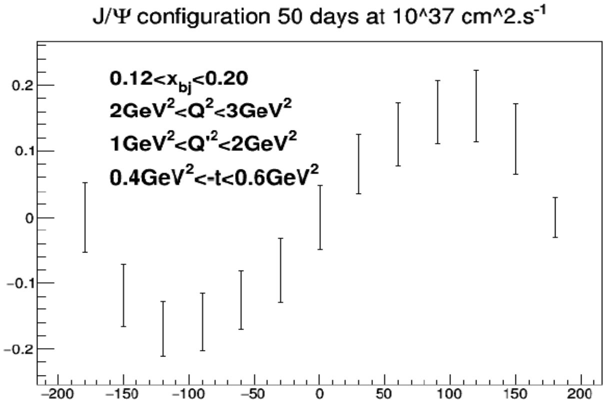
Cross section and beam spin asymmetry

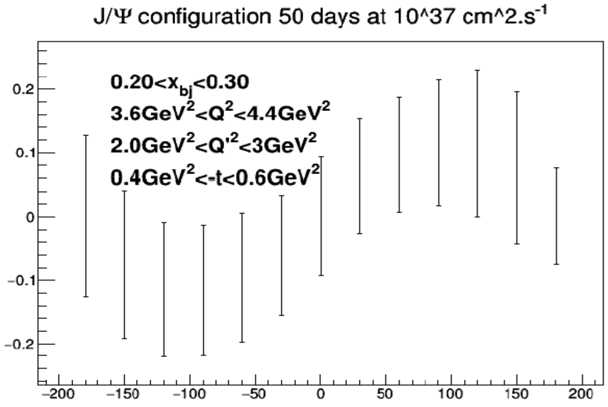
Plans: exploratory measurements with the goal of a future dedicated experiment at very high luminosity (SoLID?)

SoLID: LOI this year, update from 2015 one

CLAS12: LOI PAC 44 (2016)

Hall C: in progress, need manpower!

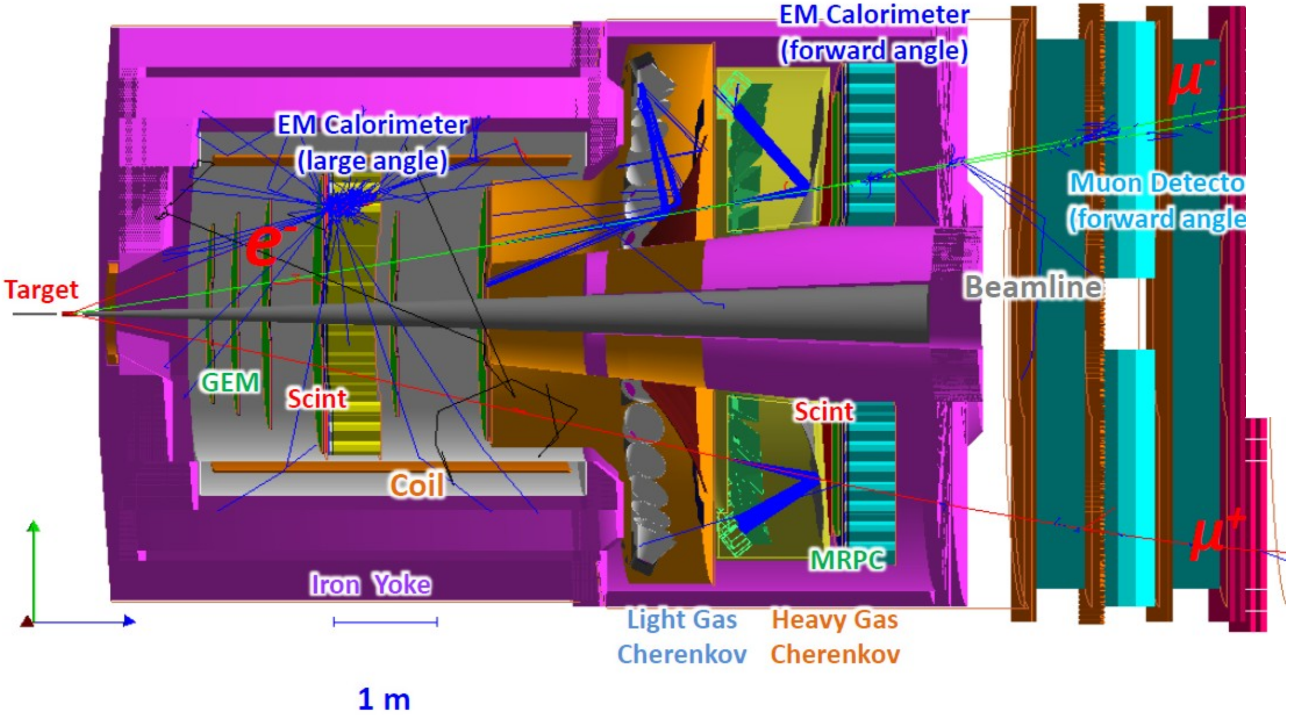


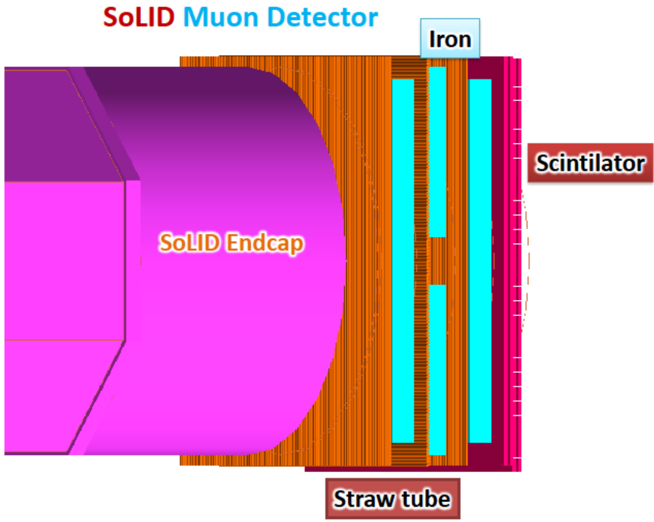


DDVCS JLab Hall A with SoLID

Using similar setup as J/psi experiment E12-12-006, with additional muon detector

SoLID DDVCS





3 layers iron (shielding)
3 layers straw tubes (tracking)
2 layers scintillators (trigger)

Muon detector

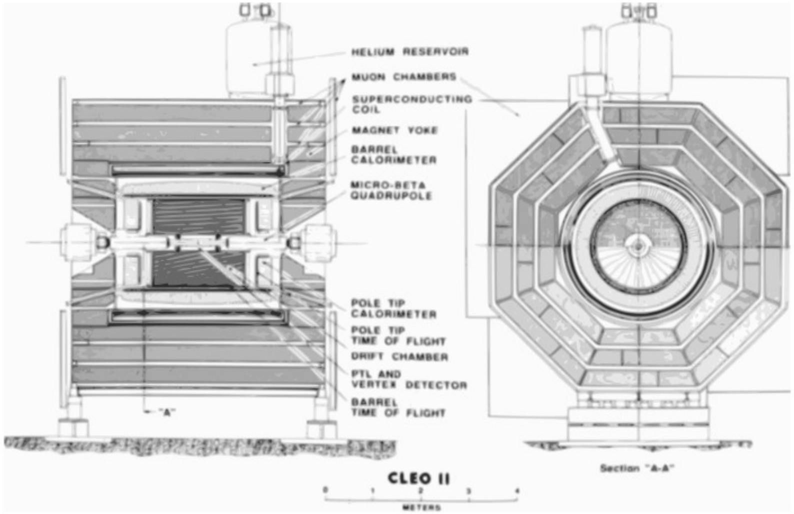
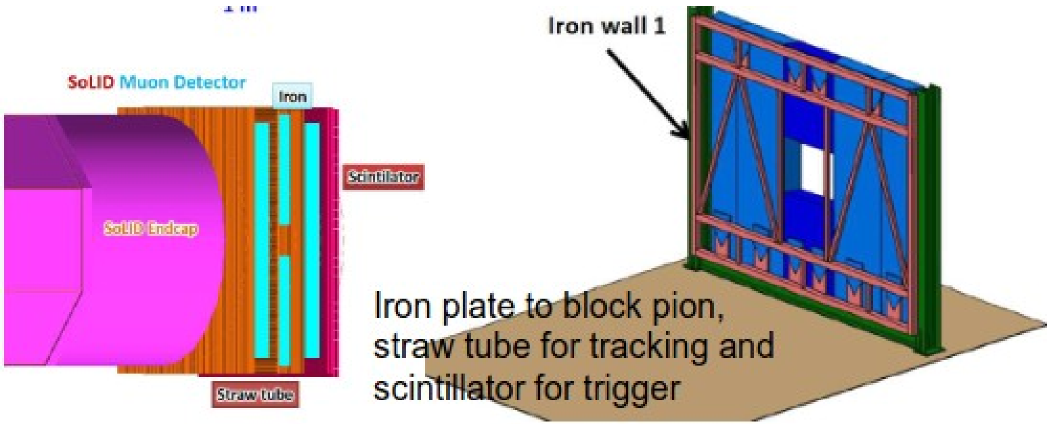


Figure 10: CLEO II setup with muon chambers installed inside the iron yoke.

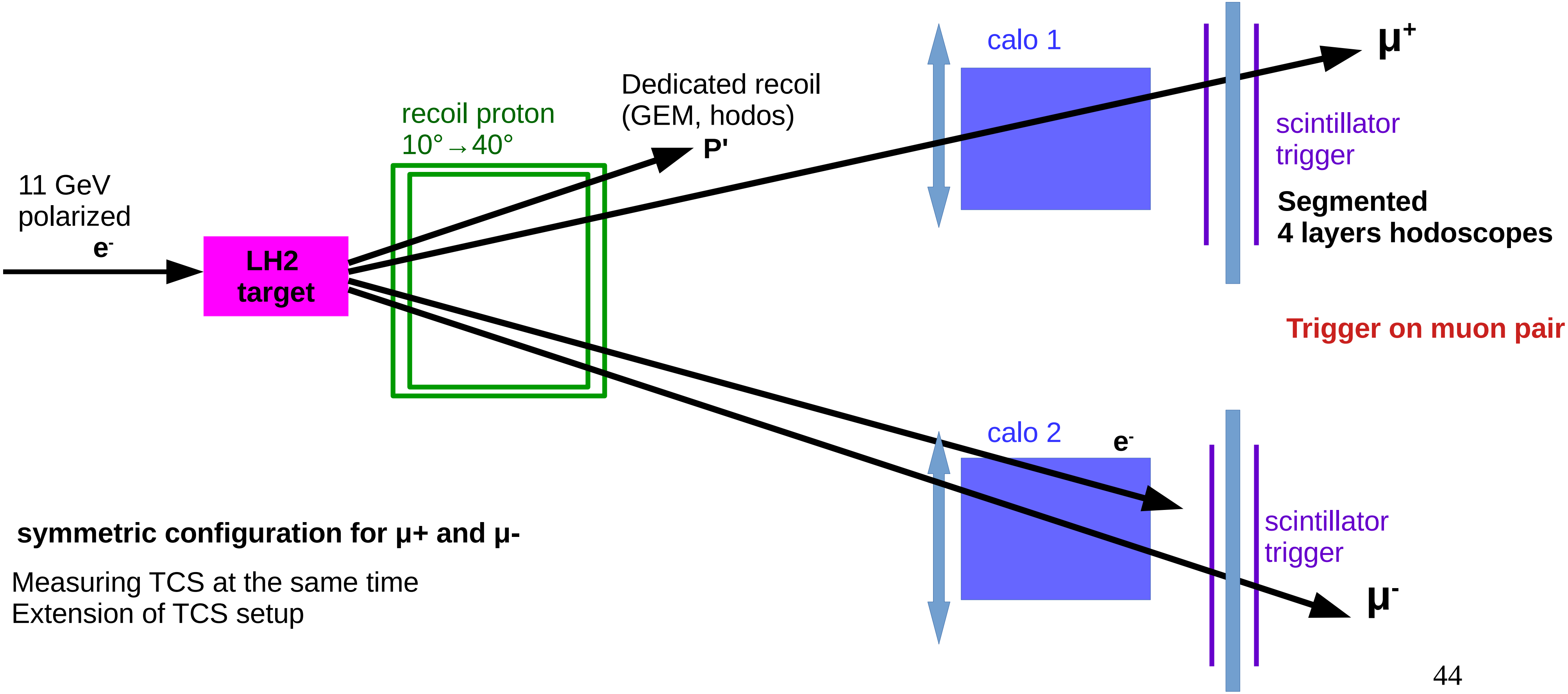


Reuse muon chambers from CLEO,
Straw tubes + scintillators

Simulations in progress and will do testing at VT
LOI submitted this year: SoLID collaboration supportive, but current problem is the cost

Looking at similar things for Hall C, but will not be same technology

DDVCS JLab Hall C: some possibilities

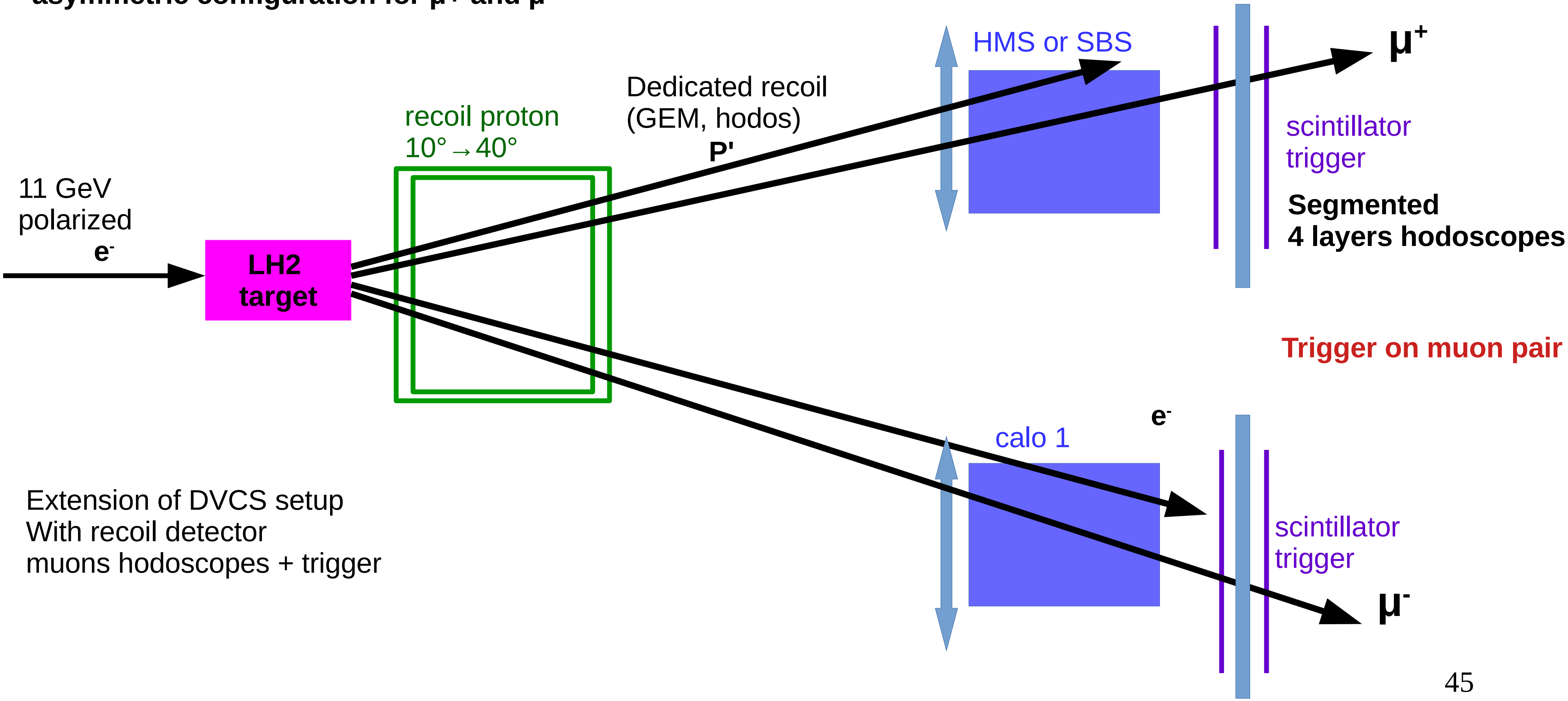


symmetric configuration for μ+ and μ-

Measuring TCS at the same time
Extension of TCS setup

DDVCS JLab Hall C: some possibilities

asymmetric configuration for μ+ and μ-



Extension of DVCS setup
With recoil detector
muons hodoscopes + trigger

DDVCS JLab Hall B (in progress)

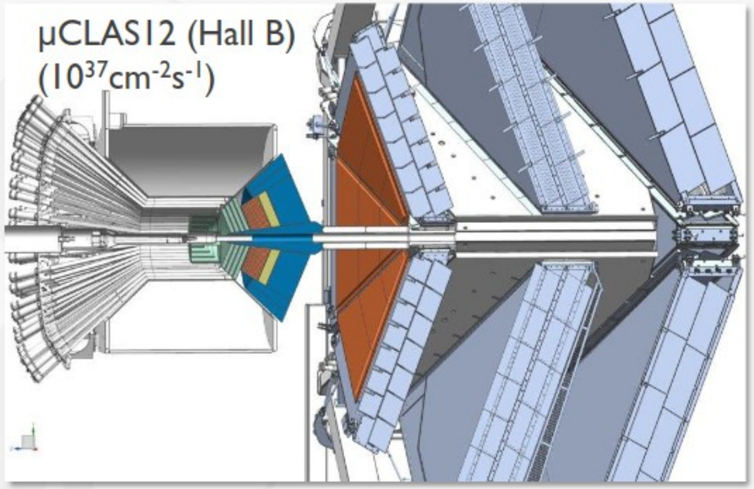
Slide credit
Pierre Chatagnon

$$ep \to e'\mu^+\mu^-p$$

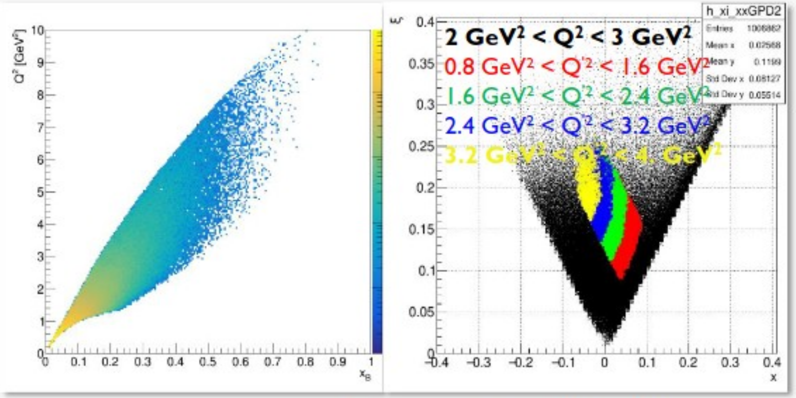
- Two main challenges for DDVCS measurement:
  1. Low x-section: requires high-luminosity
  2. Muon detection needed

A potential solution: μCLAS12

- Luminosity increase by a factor 100
- Shielding to reduce DC occupancy and pion background
- Additional calorimeter for electron ID
- New tracking system around the target



Kinematic reach for DDVCS with μCLAS12



Figures courtesy of Rafayel Paremuzyan

Material from LOI-12-16-004 (Stepanyan, Paremuzyan, Baltzell, De Vita,Ungaro et al.)

Jefferson Lab clas

What else? Group contributions and need of more collaborators!

Grad students (since 8/2022):
Mahmoud Gomina,
Gyang Chung

SoLID DDVCS
(+ other topic)

GlueX TCS/diphotons
(+ other topic)

Debaditya Biswas
Started as postdoc in 2022
Unpolarized TCS, DDVCS
Hall C (+ mesons?)

This summer students (2023): impact studies for diphotons [based on Jakub's et al work]
Goal: complementary measurements Compton-like + VM for multichannel fits

Tons of work to do, But need more collaborators and manpower!

Undergraduates working on these things

Here:
Erik W., Melinda Y., Jocelyn R., Kevin S.
Bobby D., Tzu-Yun H., Tyler S., Brannon S.

Also:
Alexander H. Barbara S., Ben P.,
Brandon L., Camille Z., Cesar I., Keirsten K., Mary C., May H., Mitchell C., Nathan S., Nicholas R., Seth S., Tristan A., Zeyu G.

Some advertisement…

Towards improved hadron femtography with hard exclusive reactions
August 7-11th, 2023. "2nd edition", Jefferson Lab, Newport News, USA

https://indico.phys.vt.edu/event/58/

- Hard Exclusive Compton-like Reactions
- Hard Exclusive Meson Production
- Meson Structure
- Nuclei and transition GPDs
- Theoretical progresses
- Models and Interpretations
- Current and future experiments
- Computing and AI/ML techniques
- Hardware for exclusive measurements

70+ participants in 2022, group picture:

PLEASE COME OR JOIN ONLINE

Postdoctoral advertisement

Will soon be announced

- Good for experimentalist or theorist with interest in phenomenology and computing
- With EXCLAIM collaboration: see Simonetta’s talk

UVA (S. Liuti, C.W. Chern), NMSU (M. Engelhart, M. Sievert), MSU (HW Lin), ODU (Y. Li), Tufts (G. Goldstein)

The experimental nuclear physics group of Prof. M. Boër at Virginia Tech is inviting applications for a postdoctoral research associate position. The successful candidate will work with the EXCLAIM collaboration, including scientists from UVA, ODU, MSU, NMSU, Tufts, and other universities, who are active in theory, lattice QCD, data science, and aim at developing together new techniques with AI/ML for novel studies of the nucleon’s multidimensional partonic structure.

Our group is particularly active in studies of Generalized Parton Distributions (GPDs) and is developing experiments at Jefferson Lab aiming at accessing new information on GPDs from novel hard exclusive reactions such as Timelike Compton Scattering or Double Deeply Virtual Compton Scattering. The successful candidate is expected to work closely with the theorists of the collaboration and work on event generators and analysis techniques, fits, databases, and impact studies. They will also be invited to work with students and other postdocs. Good communication skills are required. The nature of the work makes this position suitable for candidates with an experimental or a theoretical background, with good computing skills and experience with software, and with an interest in phenomenology and computing techniques.

The position will be primarily based at Jefferson Lab, Newport News, VA. Travel to the university in Blacksburg, VA may be required. More information about our activities and group composition can be found on the group’s webpage: https://boer.phys.vt.edu

The initial appointment is for one year, with possible extension for up to 3 years contingent upon funding availability and satisfactory performance. Review of applications will start July 24th, 2023 and the position will remain open until filled. Applications received by July 24h will receive full consideration. The expected start date is September 2023.

New ideas and collaboration

- Of course time dependent, but if you have ideas of reactions with interest or bringing something new, let discuss!

- Fit from multichannels: also very interested to discuss, collaborate...

Simulations/generator:
Can integrate any model in format of equations (if fast enough), tables…

Currently: DVCS, TCS, DDVCS, some mesons and some other channels
- some public version but not yet a “wide spread” version, planning to distribute it soon

SUMMARY

- Multichannel fits of CFFs / GPDs for complementary informations, universality studies, Zero skewness, …

- Need to develop new experimental programs beyond DVCS and “high precision”

- Potential in Hall C and D for new measurements (of course other places too)

    Hall C: precision, dedicated / Hall D: photon beam, large acceptance, more data

- Priority on TCS and DDVCS, looking towards VM and diphotons / photon-meson

- Need collaborators on both theory and experimental side!

    - Join the workshop in-person if you can or online

    - Tell your students/postdocs about the job opportunity