Generalized Parton Distributions with timelike photons

What measurements can we do at JLab and beyond, and why is it important to complement DVCS programs?

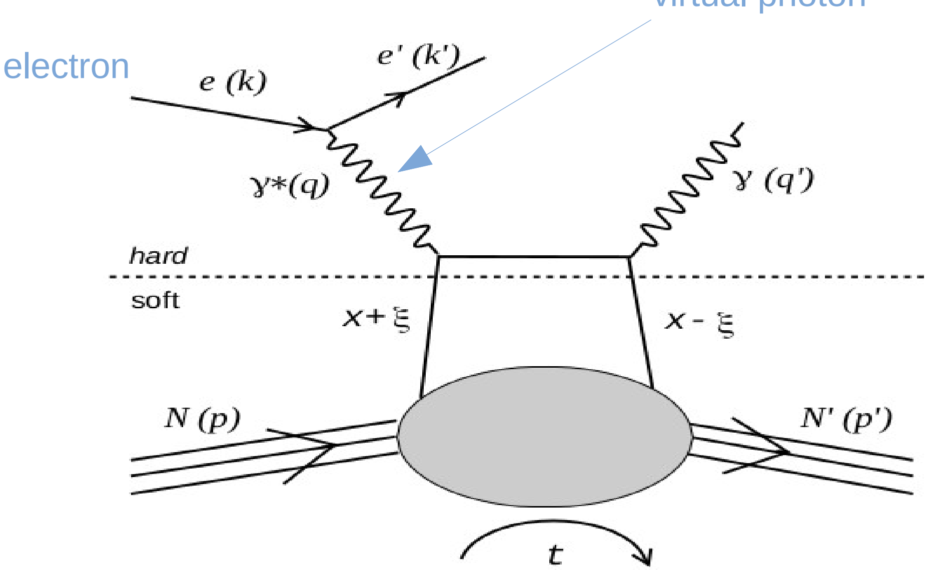
Marie Boër, Virginia Tech

QCD Evolution workshop

UVA, Charlottesville, VA, May 10th, 2022

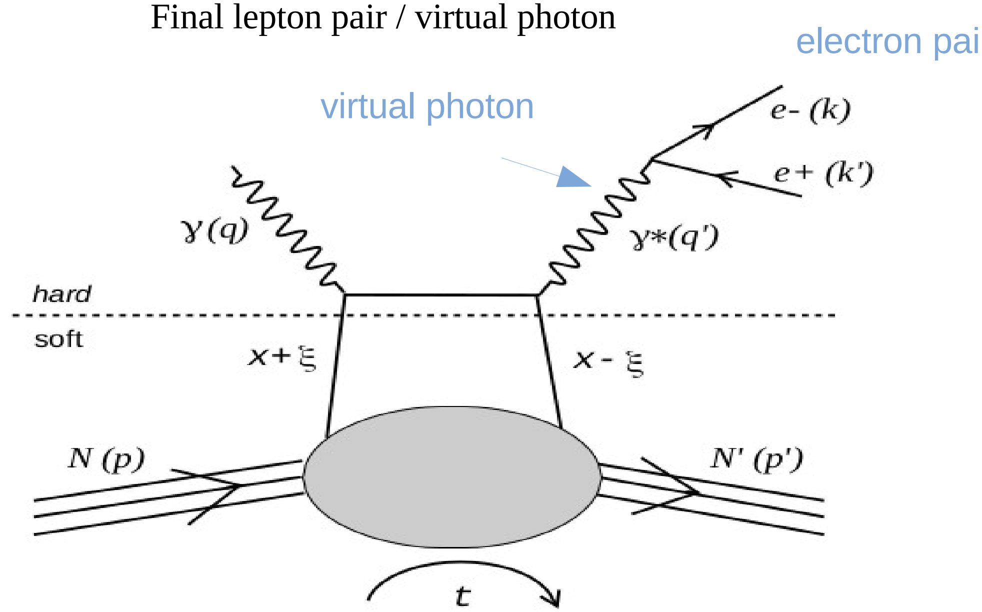
Hard exclusive Deep Virtual Compton Scattering

Initial lepton beam / virtual photon



Deeply Virtual Compton Scattering (DVCS)

Final lepton pair / virtual photon



Timelike Compton Scattering (TCS)

Both reactions access same Generalized Parton Distributions,

same kinematics Leading order, leading twist

⇒ **Many experiments measuring spacelike DVCS, Need data for Timelike Compton Scattering**

Goal: GPDs universality, complementary measurements of polarization observables to constrain all GPDs, understanding higher twist/order...

Extraction of GPDs from Compton Form Factors with DVCS & TCS

DVCS amplitude decomposition into Compton Form Factors (TCS similar):

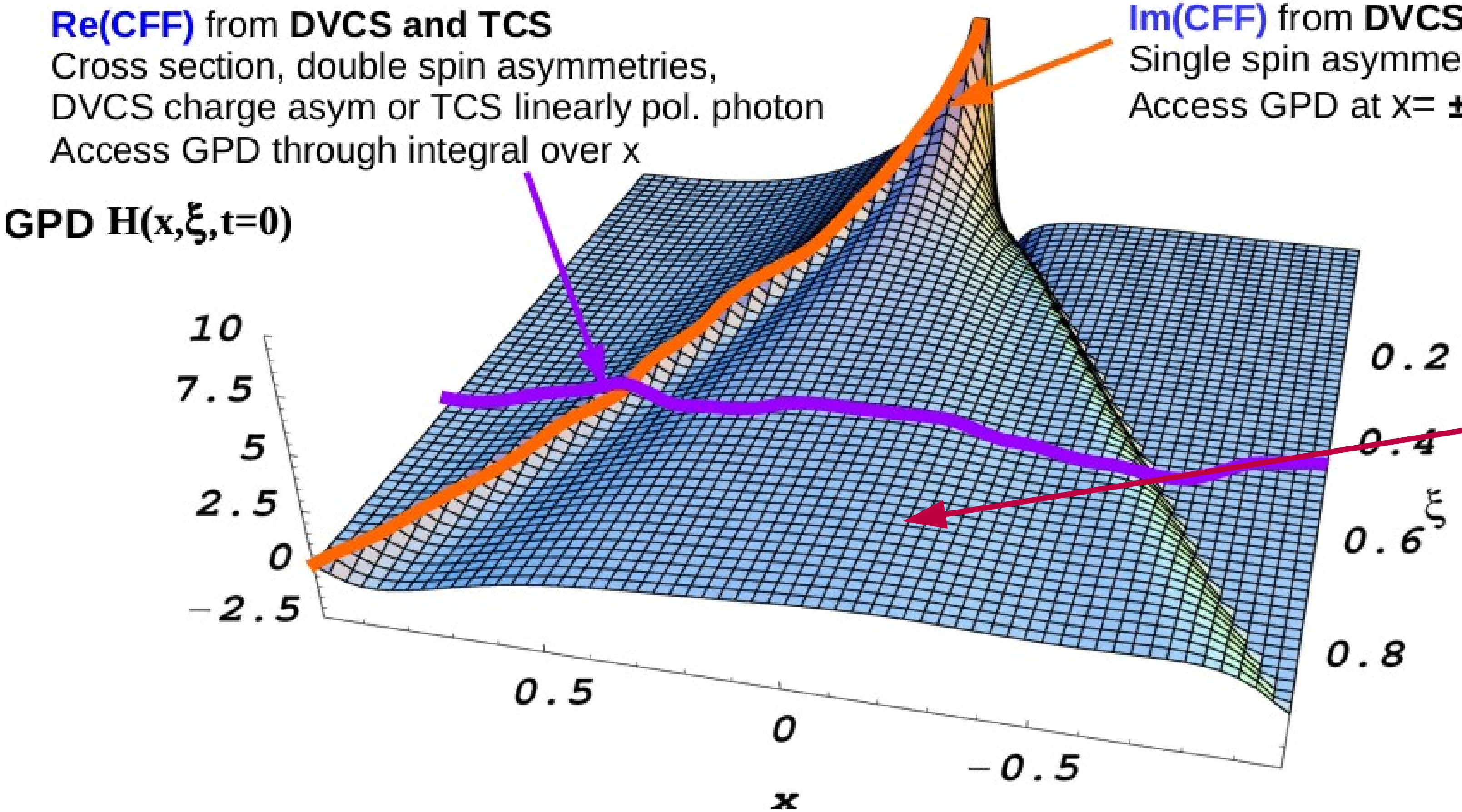
ξ, t = measurable
x = integrals

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

Probing GPD x vs ξ dependence with experimental observables:

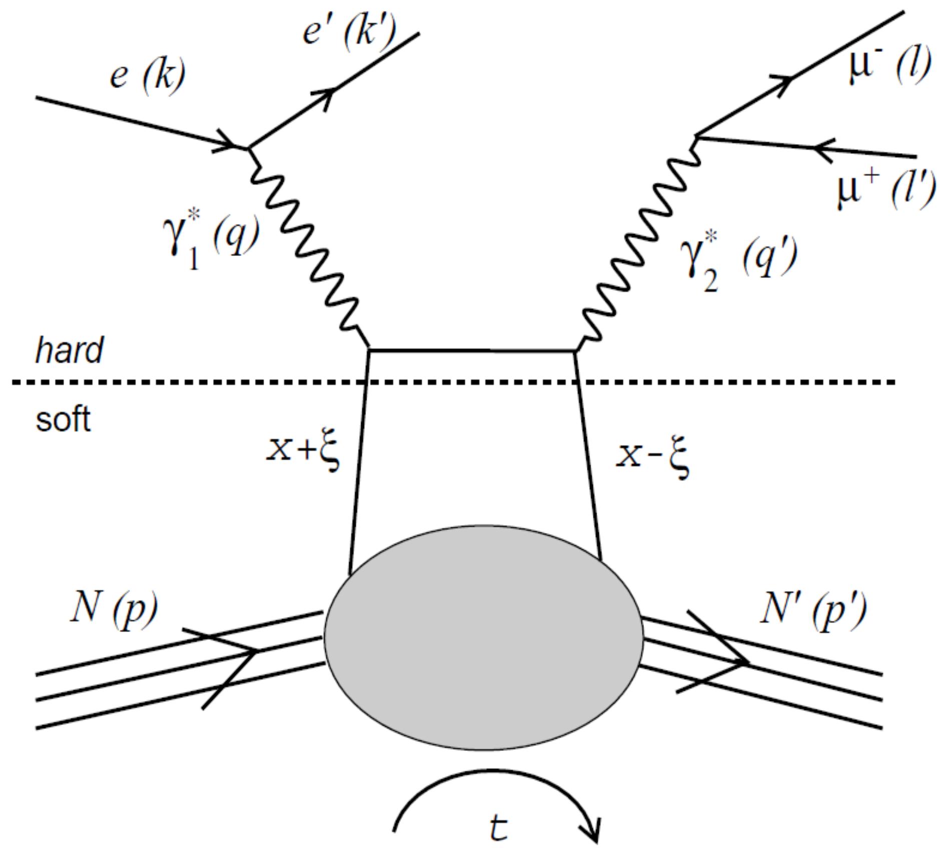
Re(CFF) from **DVCS and TCS**
Cross section, double spin asymmetries,
DVCS charge asym or TCS linearly pol. photon
Access GPD through integral over x

Im(CFF) from **DVCS and TCS**
Single spin asymmetries, cross section
Access GPD at x= **±ξ**



DDVCS
ERBL region
“off diagonal”

Access non-diagonal part with DDVCS
Double Deeply Virtual Compton Scattering



Lever arm in q/q' will access the off-diagonal region
Essential for tomographic interpretations for x vs xi decorrelation and extrapolation to 0

Access non-diagonal part with DDVCS

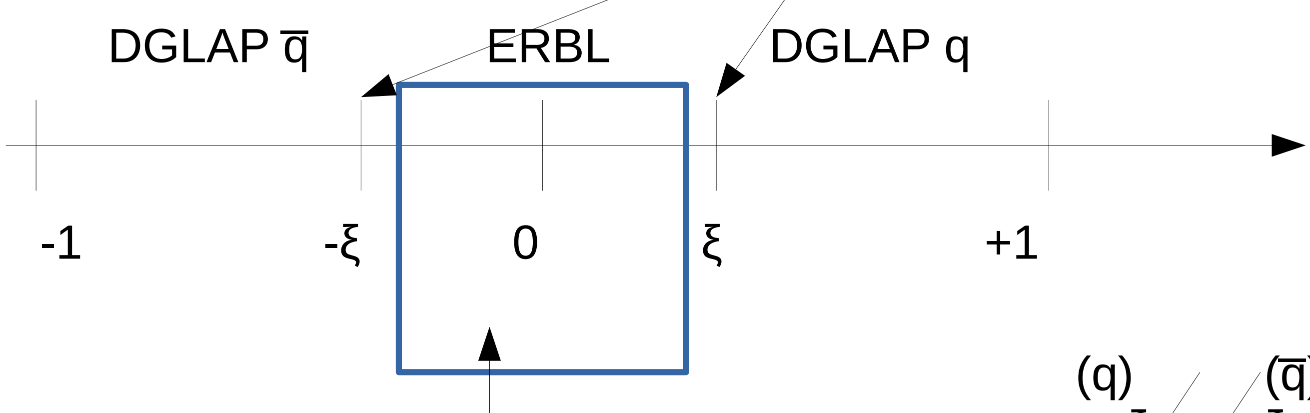
DVCS and TCS get GPDs at the limit between DGLAP and ERBL regions
ERBL region need constraints: DDVCS better than mesons

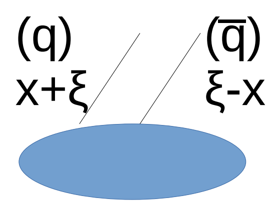
$\xi>|\xi'|$: ERBL region; $\xi<|\xi'|$ DGLAP region

Quark propagator normalized to ξ at asymtotic limit: $(1-Q'^2/Q^2)$ / $(1+ Q'^2/Q^2)$
→ up to t/Q^2 factor, we play with respective value of Q^2 and Q'^2 to go "out of diagonal" for GPD
→ neglecting t, we are restricted to $\xi>|\xi'|$

M. Diehl's representations:

limit between the 2 regions:
Im(CFFs) from DVCS and TCS



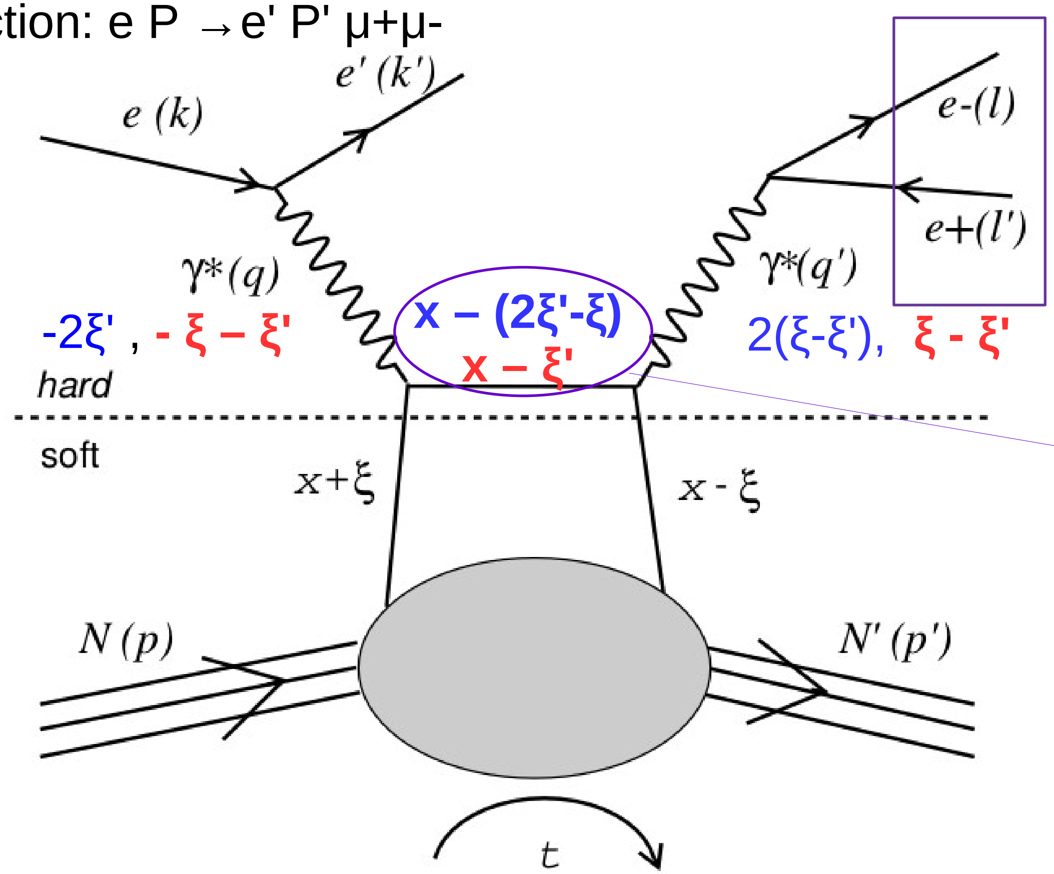


partonic interpretation from M. Diehl in ERBL region

need to map this region for GPD models and extrapolations needed for tomographic interpretations at $\xi=0$; GPD extrapolated from $\xi\to 0$

DDVCS Compton amplitude and definitions/notations

Reaction: e P → e' P' μ+μ-



μ+μ- → avoid antisymmetrisation

propagator for coefficient function
red, blue= 2 sets of definitions
blue = Guidal, Vanderhaeghen (& me)
red = others (Muller, Diehl, Wallon...)

GPD from Im (CFF) extracted at this value

ξ = + component of P=(p+p') in light cone frame. GPDs depend on it. "skewness"
$\xi = -\Delta.\bar{q} / P.\bar{q} = (Q^2+Q'^2) / (2s + Q^2 – Q'^2 – 2m^2 + t)$
with $\Delta = (p'-p) = (q-q')$ and $t = \Delta^2$; $\bar{q} = (q+q')/2$, $P = (p+p')$ (standard in litterature)
notations: η in Belitski, Muller; ξ in Guidal, Vanderhaeghen; Wallon; Diehl (articles ref. next slide)

ξ' = + component of $\bar{q}=(q+q')/2$ in light cone frame. quark propagator depend on it (red notations)
can be related to x_{bj}
$\xi' = - \bar{q}^2 / 2P.\bar{q} = (Q^2 -Q'^2 + t/2)/ (2s + Q^2 – Q'^2 – 2m^2 + t)$ → Im(CFF) at $x = \pm\xi' \neq \xi$
notations: ξ in Belitski, Muller; ρ in Diehl; not explicited in Wallon; 2ξ-ξ' in Guidal, Vanderhaeghen

at asymptotic limits and q^2 or $q'^2 = 0$ → DVCS: ξ'=ξ; TCS: ξ'=-ξ. Im(CFFs) at $x = \pm\xi = \pm\xi'$

References for previous slide

Theory:

A. Belitsky, S. Muller, PRL 90 n2, 022001-1, 2003

M. Guidal, M. Vanderhaeghen, PRL 90 n1, 022001-1, 2003

M. Diehl, Generalized Parton Distributions, physics report 388 (2003) 41-277
see around page 164, + other parts before and after

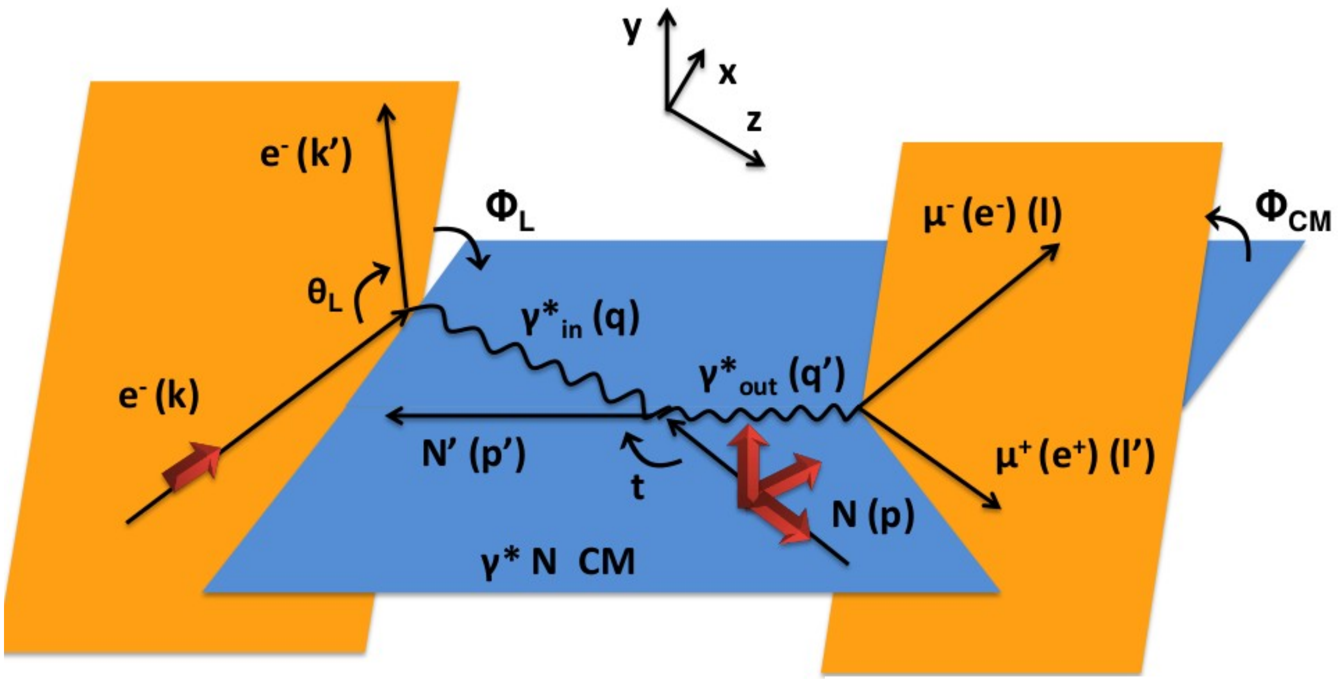
S. Wallon, Hard exclusive processes in perturbative QCD, from medium to asymptotical energies (updated 2017) see after page 109 + other parts after

Some past experimental studies:

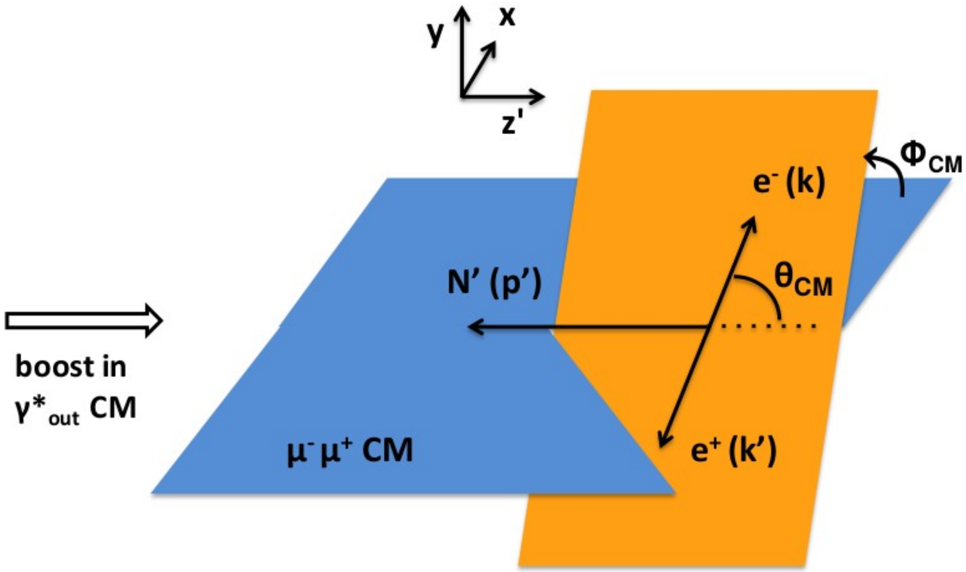
LOI 2015 SoLID
LOI 2016 CLAS12
Shenying Zhao SPIN conference 2018

Slide, diagram, studies in this talk: MB

Other notations used here for DDVCS observables

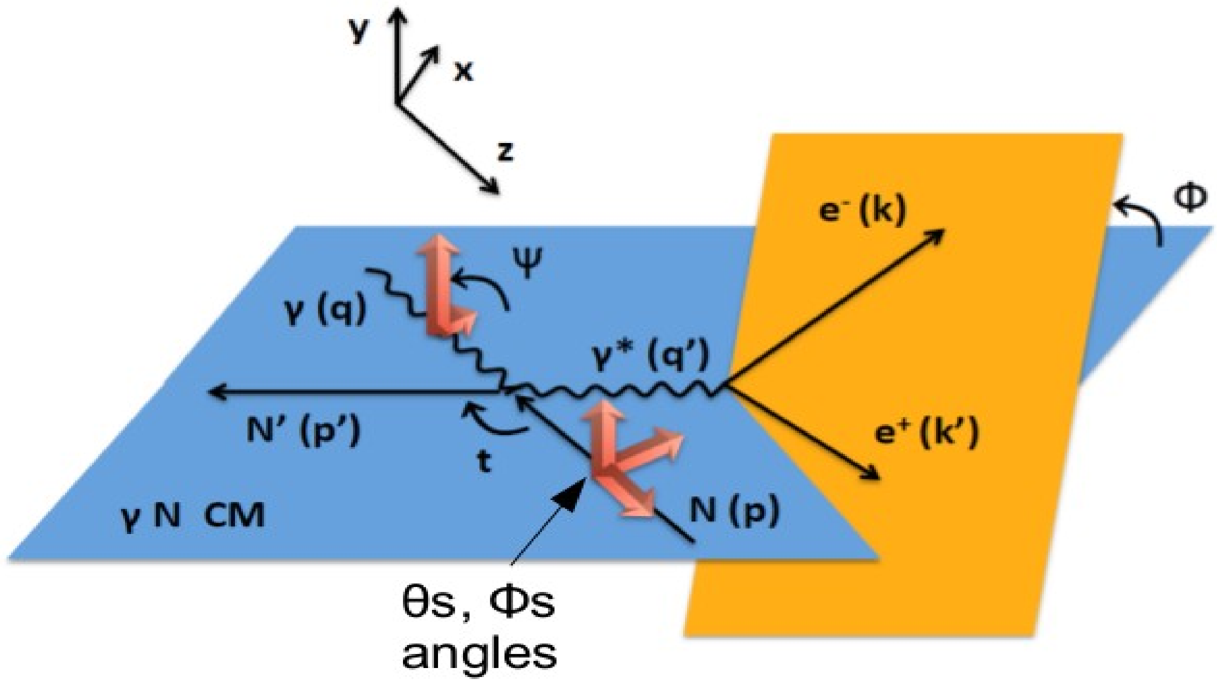


7 independent variables
For unpolarized x-sec



notation:
φ_L or φ_{LH} for "initial" angle
and φ, θ or φ_{CM}, θ_{CM} for "final" angles
cross section unpolarized=σ
beam spin asymmetry=A_{LU}

Other notations used here for TCS observables



5 independent variables
For unpolarized x-sec

TCS+BH in γ P → e+ e- P: 6 independent variables for polarized cross sections

Choice: 3 kinematics (ξ, t, Q'²), 3 angles (φ_{CM}, θ_{CM}, φ_S)
Transversally polarized target: θ_S=90°, eventual corrections at % level if small rotation of axis

A_{UT} = single target (transverse) spin asymmetry,
$A_{\odot T}$ = double beam (circular) and target (transverse) spin asymmetry

Simulations and studies of TCS and DDVCS

Impact studies for new experiments at JLab

1) **Understanding angular correlations**

2) Kinematics for JLab 11 GeV

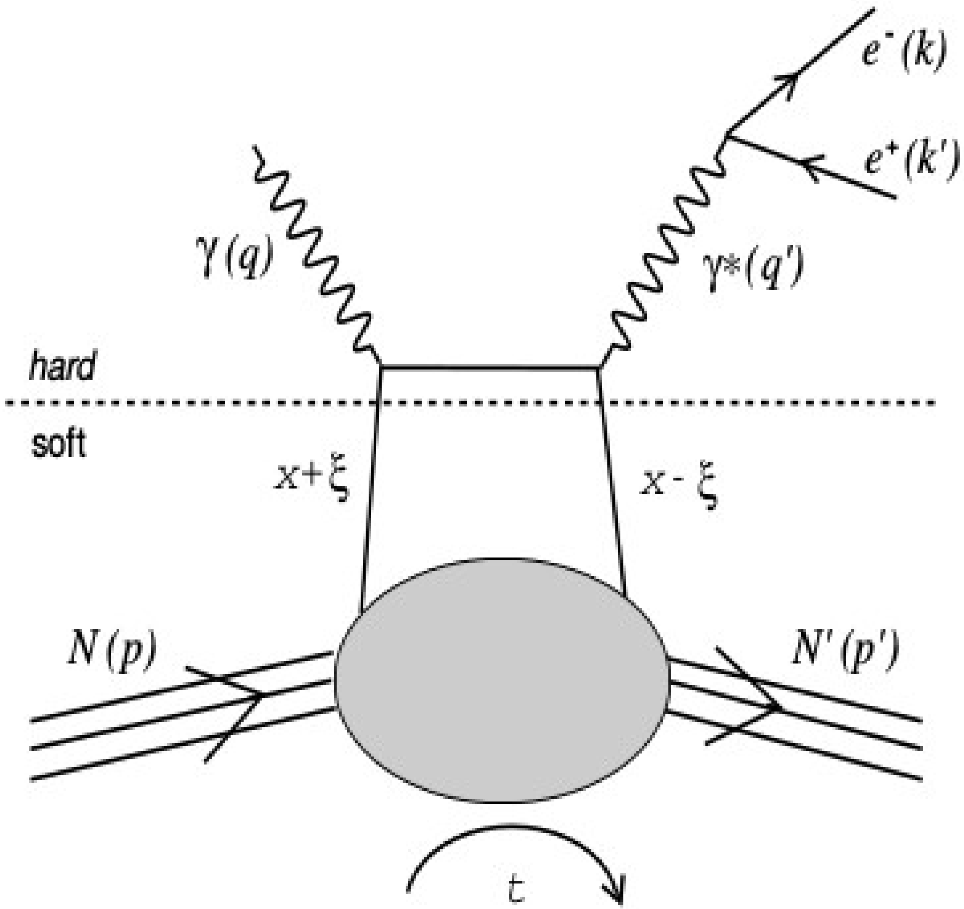
3) Observables, what can be measured

4) Future and potential experiments

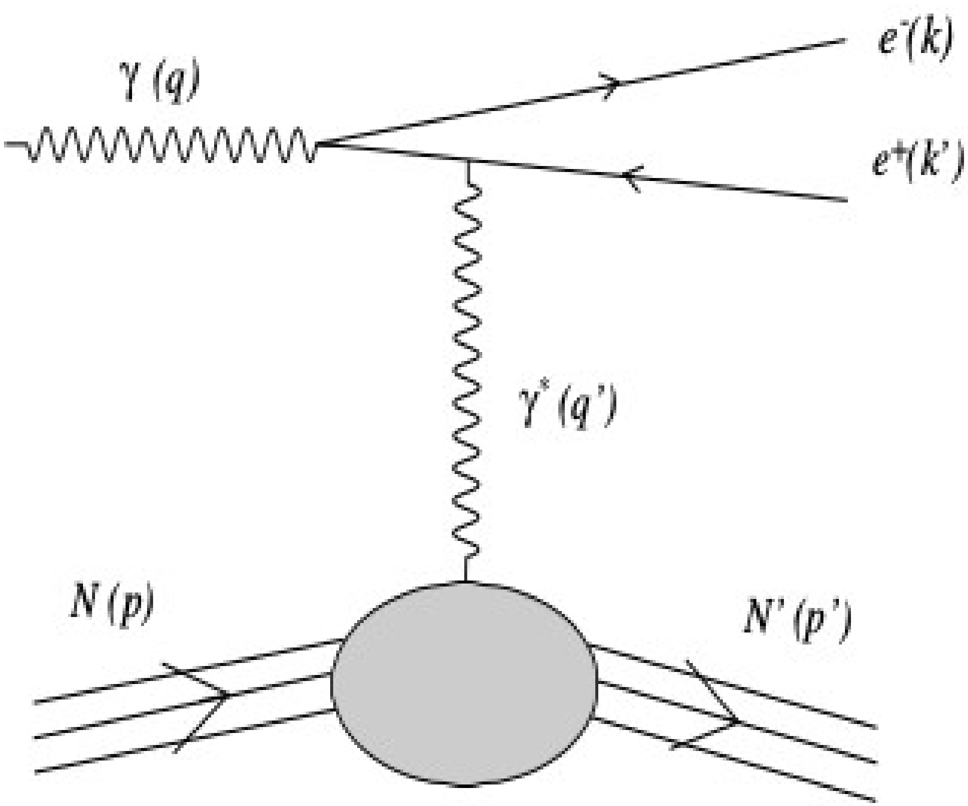
Timelike Compton Scattering and Bethe Heitler

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

TCS

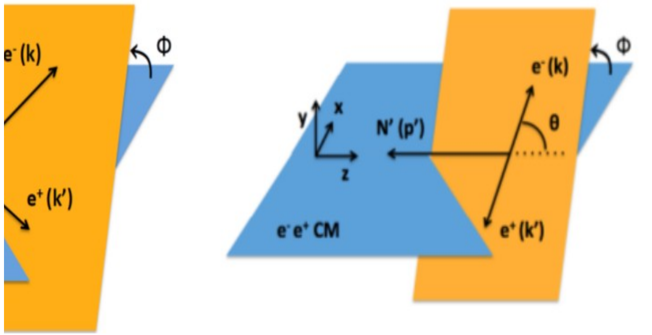


Bethe-Heitler

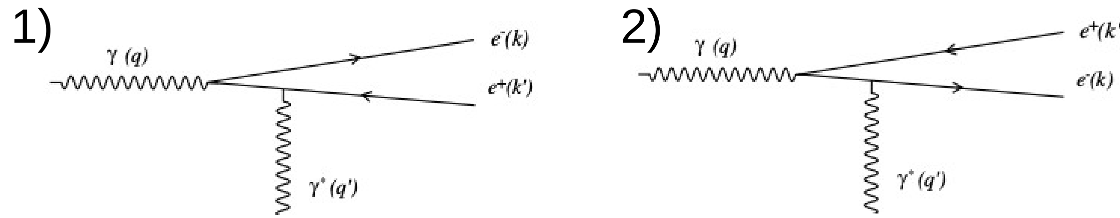


Angular correlations (CM)

CM angles



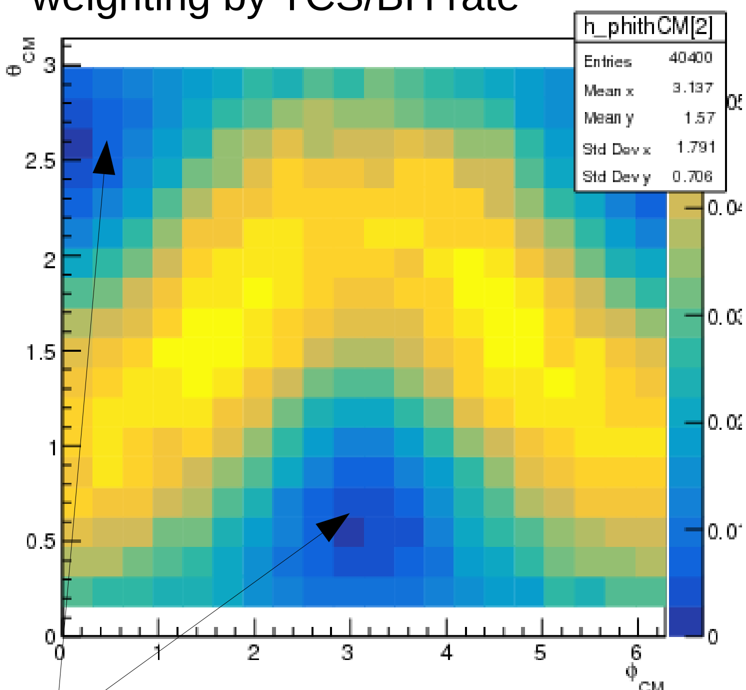
BH propagators



- quasi singularities when e- or e+ collinear to incoming γ
- strong kinematic dependence at JLab energy
- one diagram becomes largely dominant / very asymmetric decays

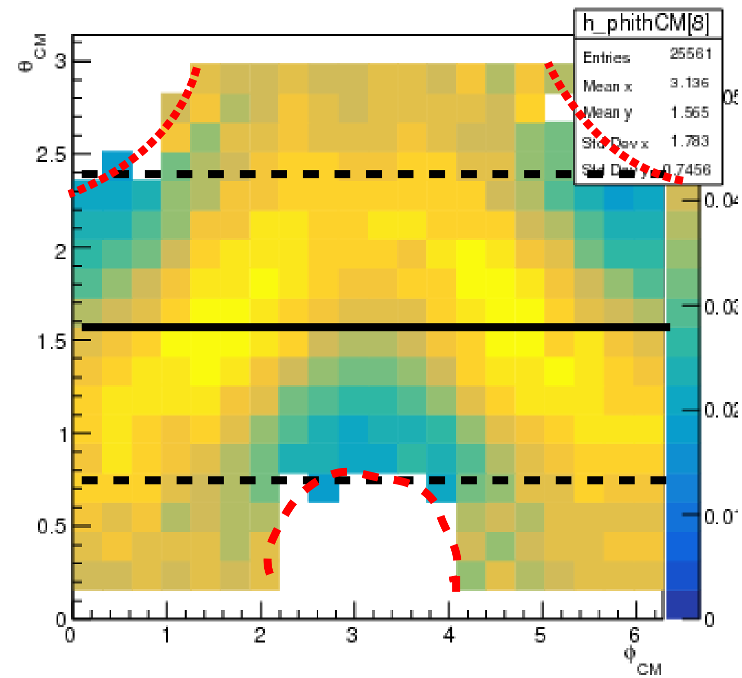
θ_{CM} vs φ_{CM} weighted distributions

weighting by TCS/BH rate



regions next to BH singularities
very large cross section
low TCS/BH rate, low A_{UT}

same with 0.2 GeV momentum cuts & θ_{lab}>6°



-- cut at 45°; 135°
-- acceptance cut
not included: cut of some bins next to singularities if not experimentaly "solvable" due to limited statistics (example 2 orders of magnitude increase of σ within a bin)

quasi-singularities: lepton 1 to beam direction, other almost "at rest"
⇒ momentum threshold and geometrical acceptance mostly prevent for too high rates and singularitie regions.
Angular + momentum acceptance is important

2D kinematic cut
Peaks position in theta vs kinematics

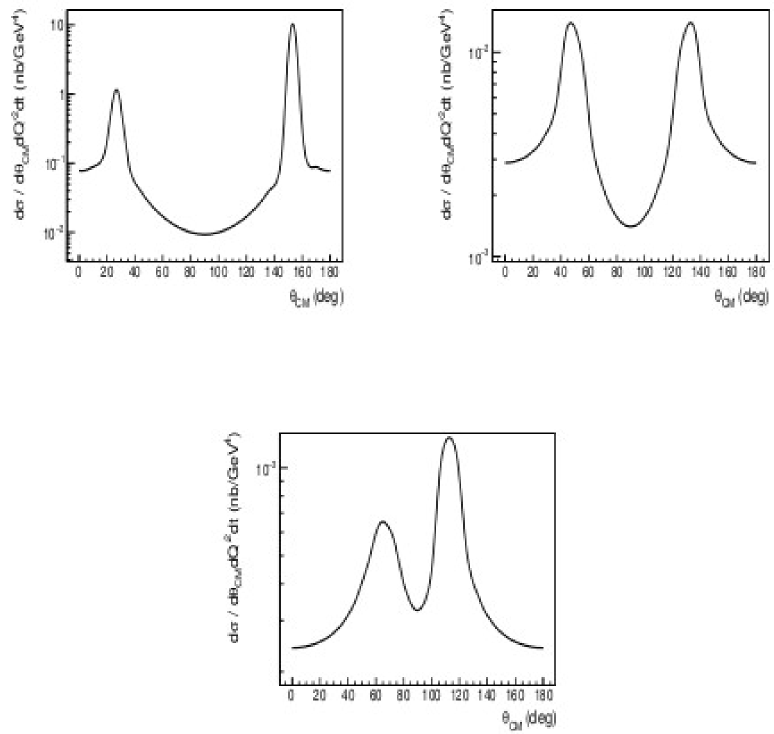
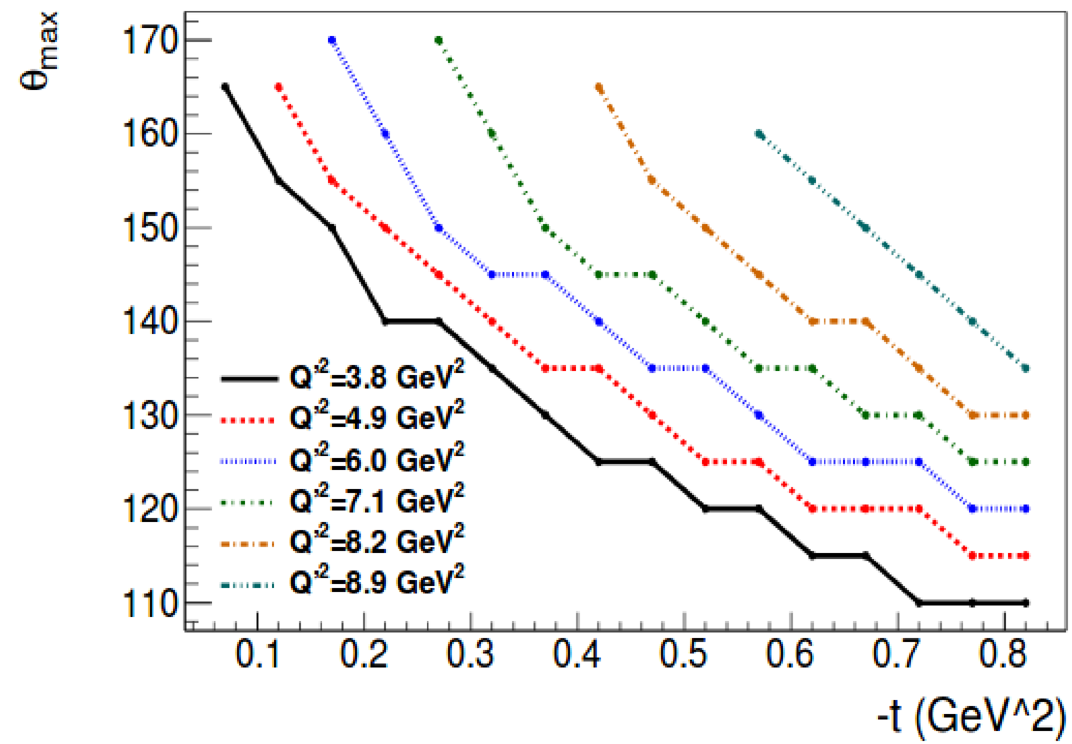
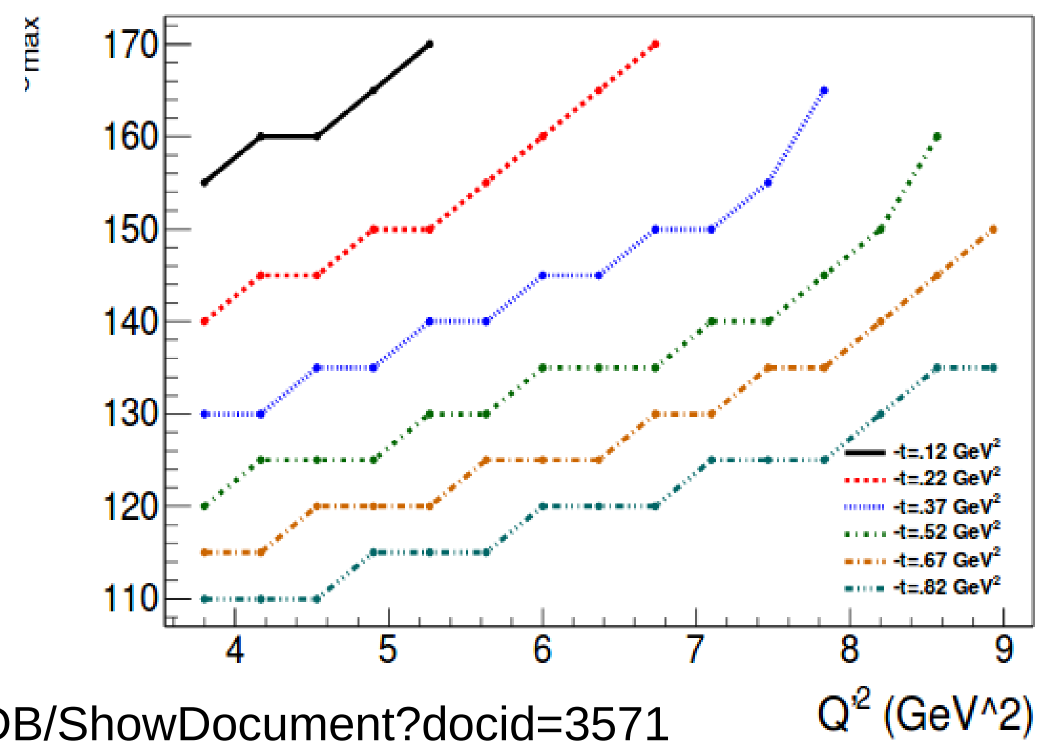


Figure 10: BH cross section as a function of θ_{CM} for E_γ=9.5 GeV, Q'^2 = 5 GeV^2, $0 < \phi_{CM} < 360°$ and -t=0.3 GeV^2 (top left panel), -t=0.8 GeV^2 (top right panel), -t=1.5 GeV^2 (bottom panel).





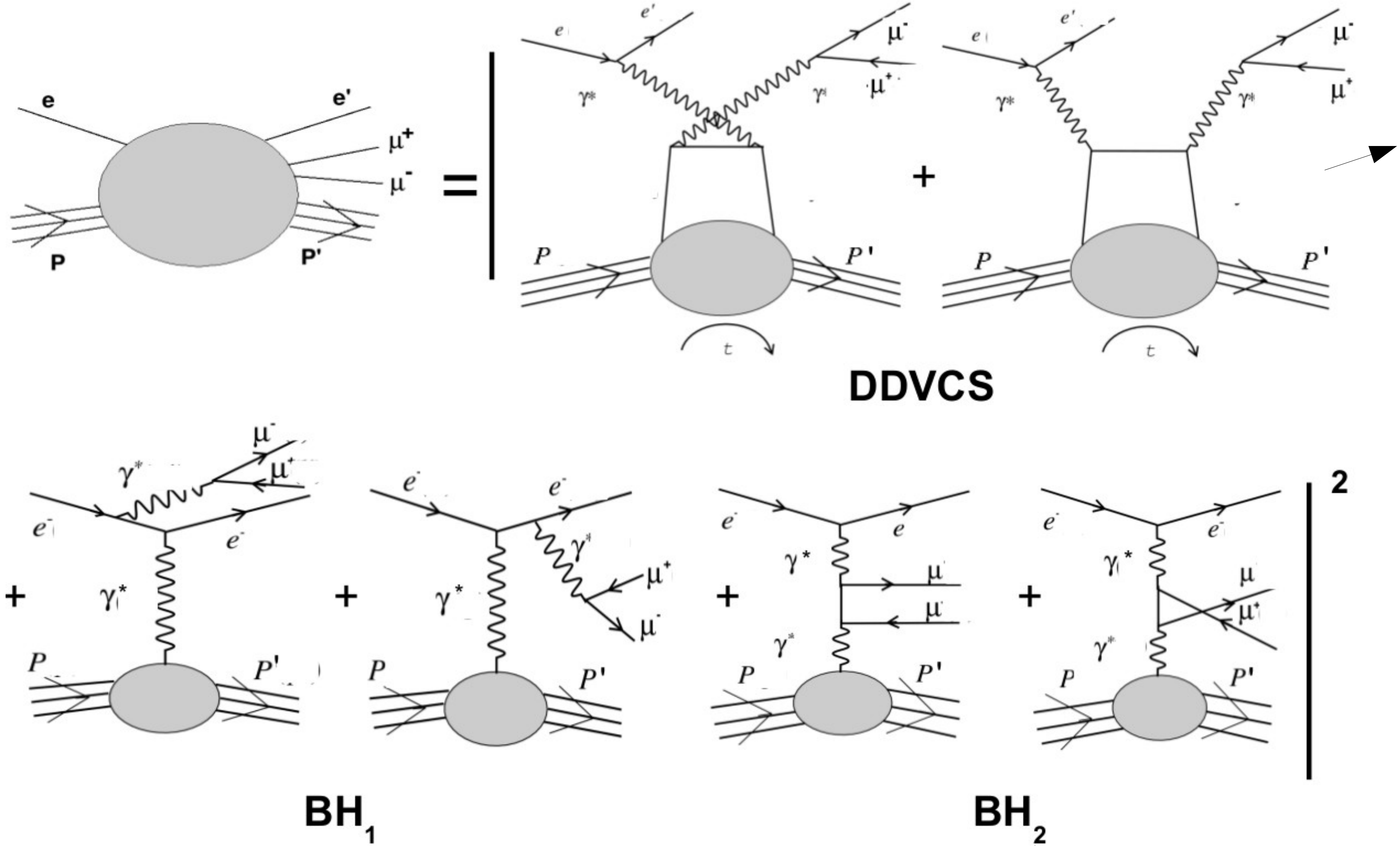
* asymmetric peaks = “voluntary artifact”
But not measurable

cut as a function of (E, Q'², t)

2 figs on right: θmax cut, all what is above is rejected in case φ=0±30° or φ=180°±30°

note: https://halldweb.jlab.org/doc-public/DocDB/ShowDocument?docid=3571

DDVCS leading order diagrams and angular behavior



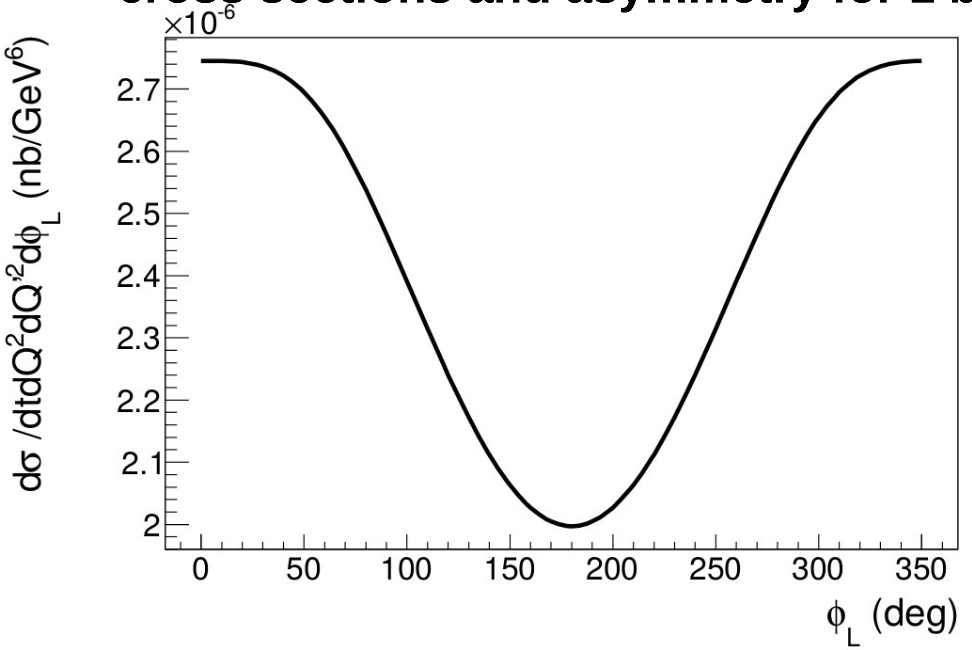
no favored direction for γ* emission or decay leptons

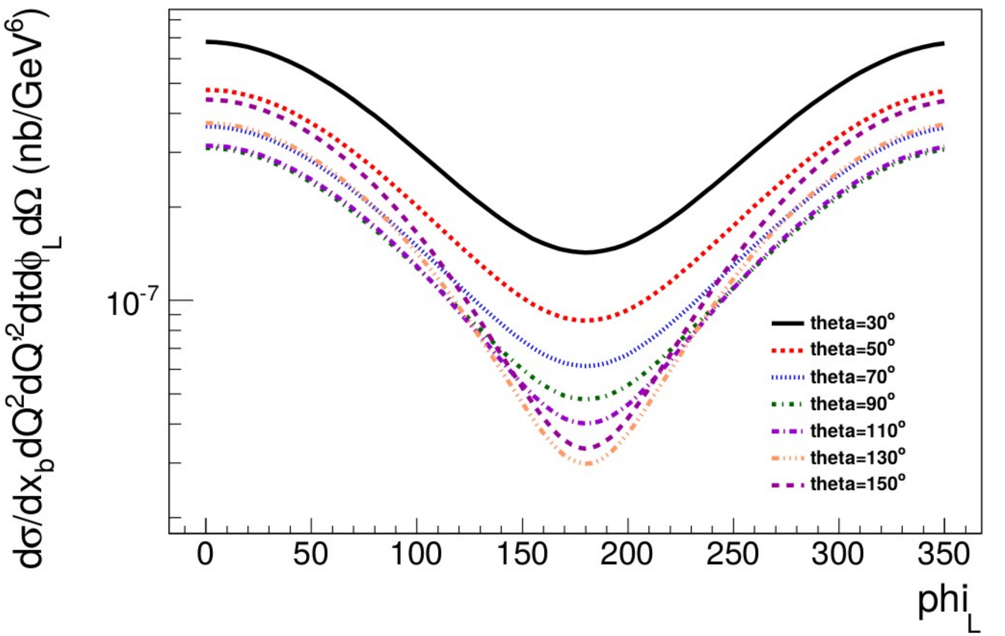
peak when γ' becomes collinear to e
related to φ_{LH}=0,
and depends $\cos\theta_{\gamma\gamma}$ (kinematics)
and "γ" → e' angle

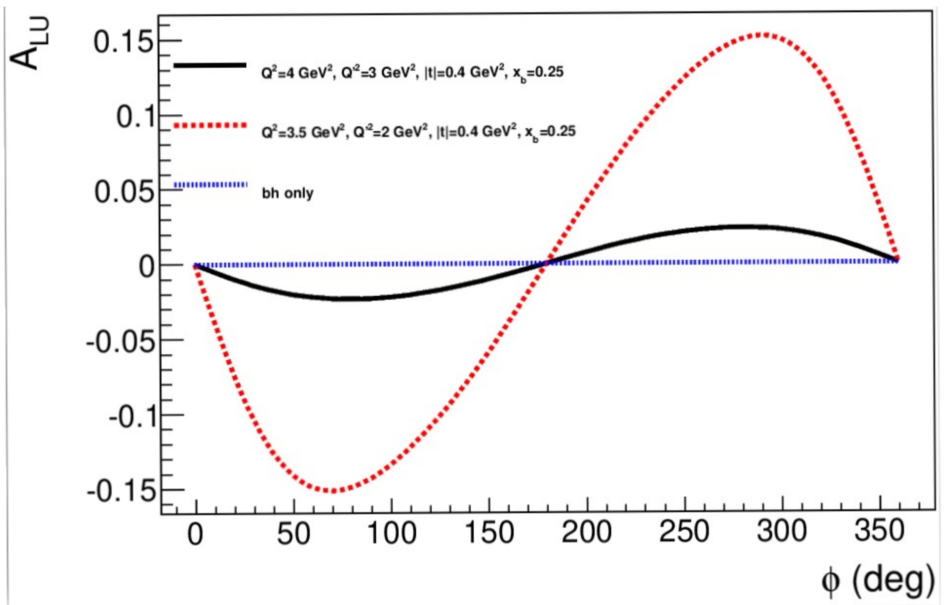
2 peaks when μ+ or μ- become collinear to γ
related to φ_{LH}=0 and 180°,
and depends $\cos\theta_{\gamma\gamma}$ (kinematics) which position the value of θ_{CM} for the peaks

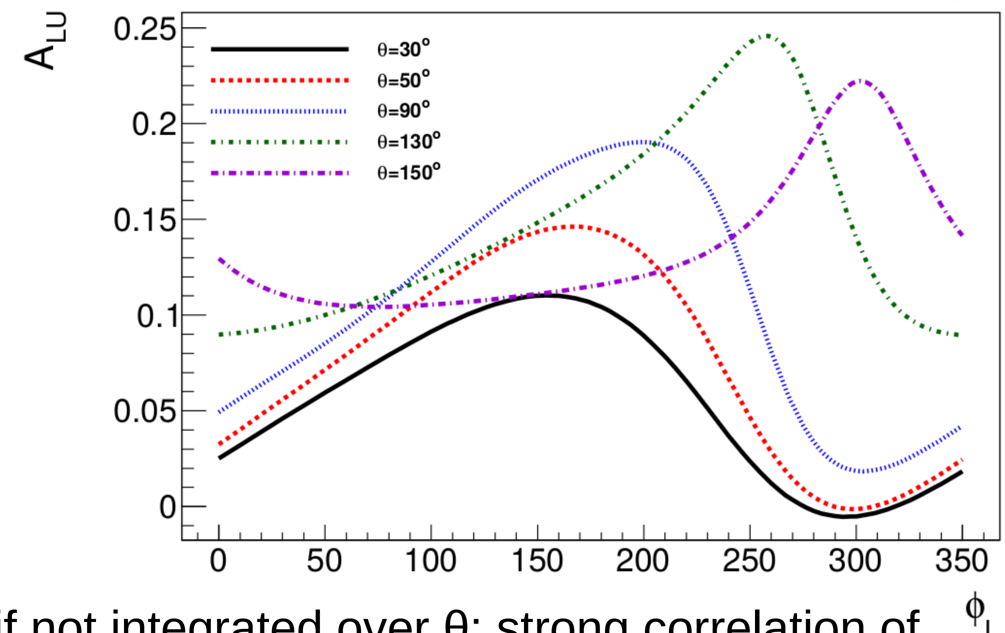
φ_L behavior. similar than DVCS; but correlations with final angles and “BH2”

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







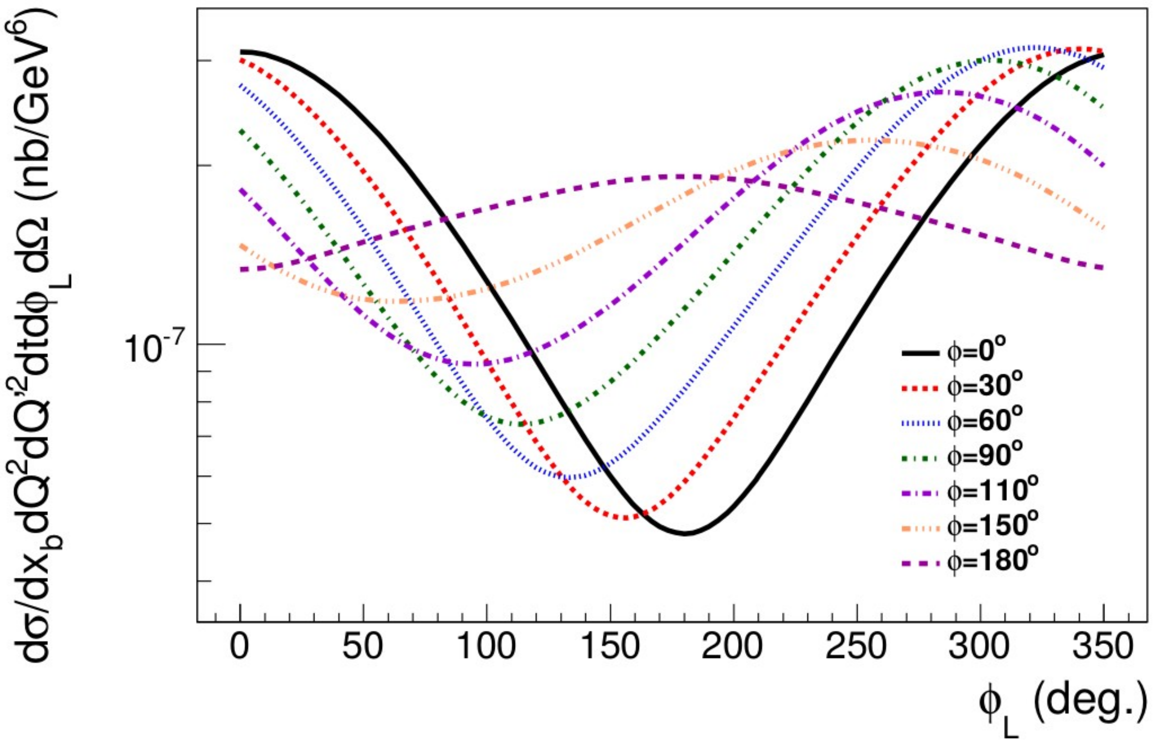


left= integrated over θ, right=not integrated

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 $<Q^2/Q'^2>$ (bin), but loose precision taking just the ratio
integrated over θ for statistics (as for TCS, there is a systematic associated to that)

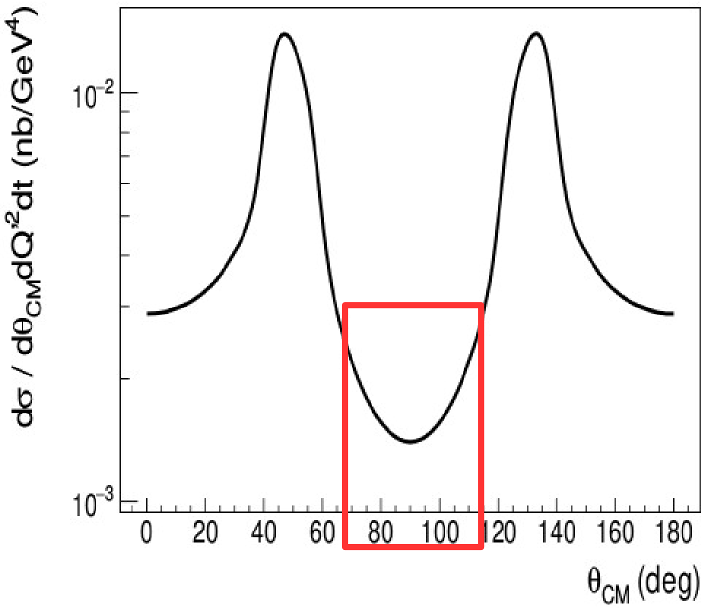
- only Im($\mathcal{H}$) (ξ', ξ, t) will be possible to extract with unpolarized cross section and beam asym.

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

Angular behavior and what to be careful at

- Compton process flat at first order in φ_{CM} (final lepton pair) and φ_{LH} (scattered electron)
- BH: 2 kind, present "quasi-singularities". depending the kinematics, BH1 or BH2 is more important. BH1 behaves like the one associated to DVCS and BH2 like the one associated to TCS
- in DVCS+BH → call it "BH1". the rate BH1/DDVCS driven by "y". BH1 can be small at large y
- in TCS+BH → BH2, rate BH2/DDVCS always large in particular for larger θ

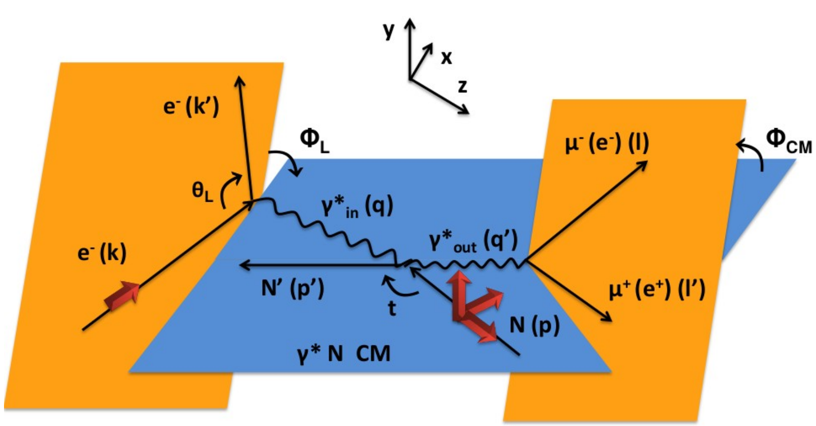
• expected behavior in θ, from BH2 (2 quasi-singularities coming from e+ or e- becomes collinear to the beam)

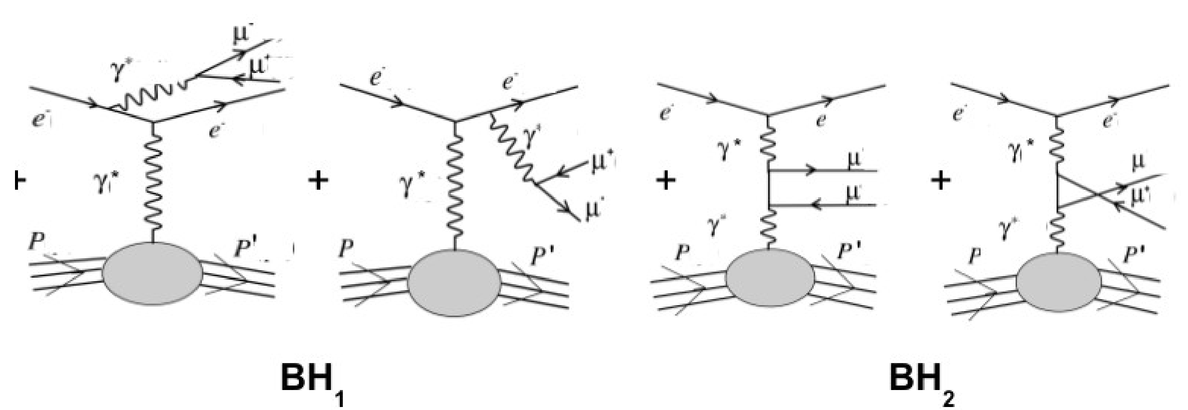


γP → γ'P' kinematics positions the peaks, at asymtotic limit: 0° and 180°. larger θγγ: peaks close to 90°

each peak associated to 1 diagram (l+ or l-): important to have a symmetric spectrometer configuration to detect the muons if we want to get the whole range around 90° and avoid favoring one diagram vs the other

⇒ table of cuts in θ vs (t, xbj, Q², Q'²) then, BH2 can be under control. peaks (solvable) at 0° and 180° in the φCM distribution



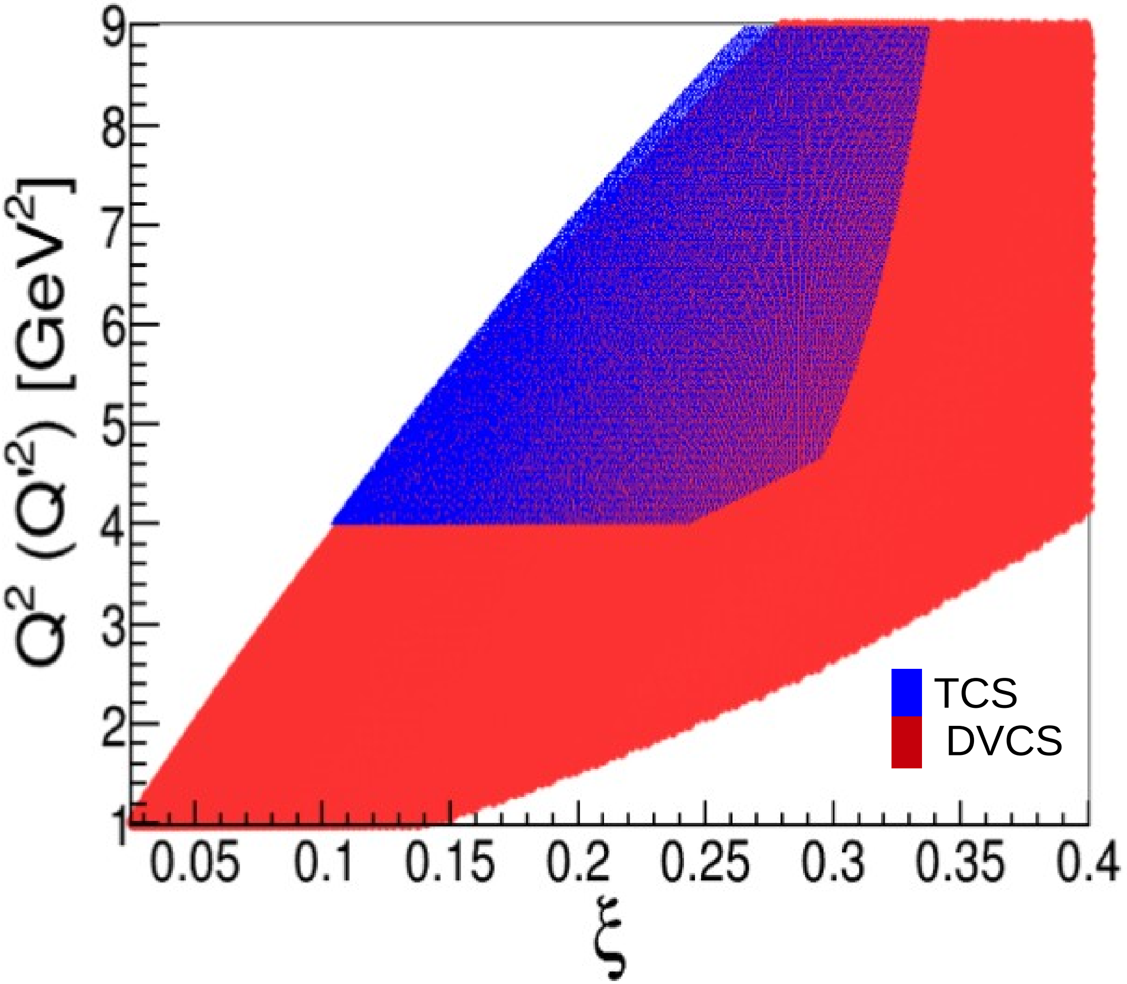


Simulations and studies of TCS and DDVCS

Impact studies for new experiments at JLab

1) Understanding angular correlations
2) **Kinematics for JLab 11 GeV**
3) Observables, what can be measured
4) Future and potential experiments

Comparing DVCS and TCS in CFF extraction



ξ vs Q^2 (Q'^2) for DVCS and TCS
"JLab-like" phase-space
$0 < -t < 1$ GeV²
$s > 4$ GeV², E= 11 GeV for DVCS
$5 < E_\gamma < 11$ GeV for TCS
mass cut: out of resonences region

Fits of CFFs from DVCS and TCS observables at same (ξ, t) points

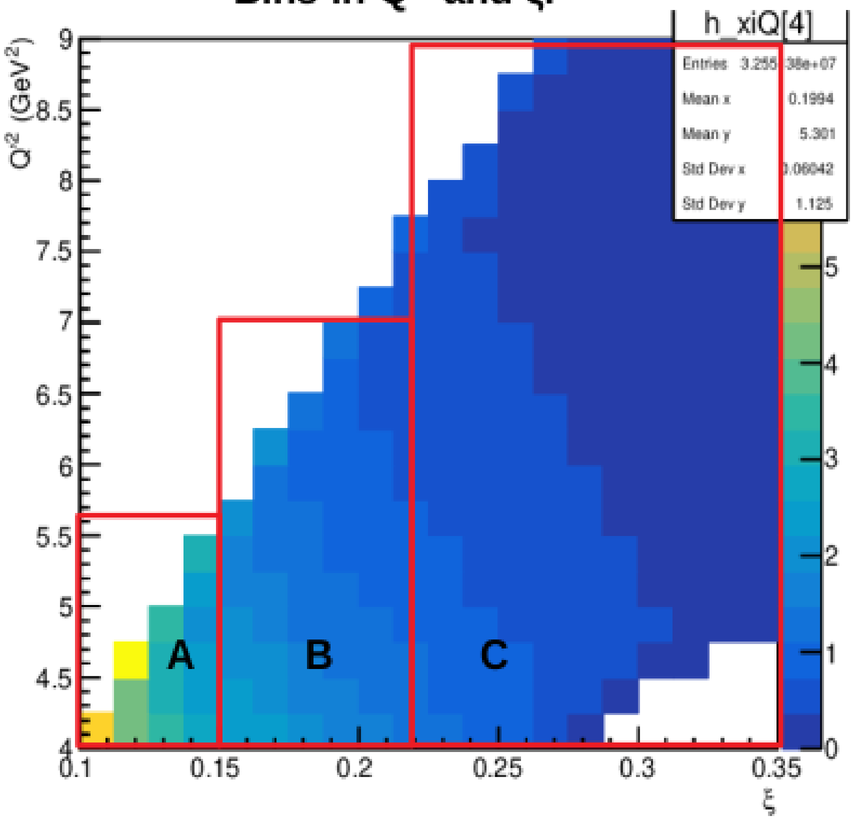
CFF extraction from twist 2 and LO DVCS and TCS independently and combined

Interpretations, depending on size of NLO and higher twist

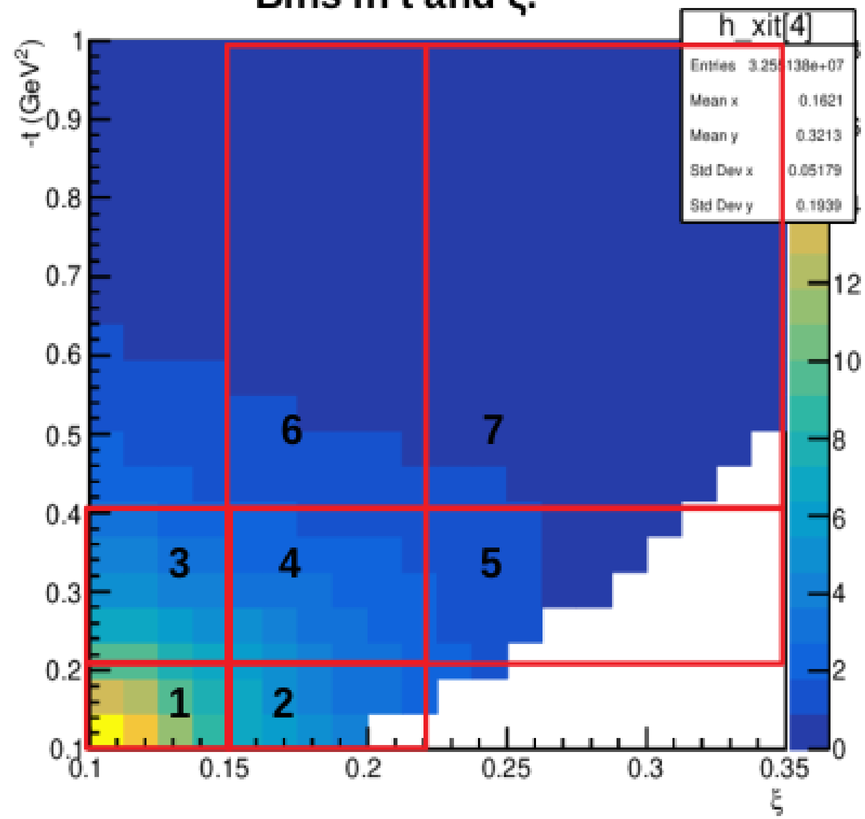
- small effects: combine DVCS+TCS observables → global fits
- small/moderate effects: independent analysis → constraint on GPD universality
- large effects: observation of higher twist in spacelike (DVCS) vs timelike (TCS)

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

Analysis:

Kinematics for DDVCS

What I had to take into account:

- we want to scan over ξ' at fix ξ and t. Q^2 and Q'^2 can be integrated in LO approximation (need statistics)

- perturbative QCD limit: stay at low $|t-t_{min}|<0.5$ GeV², high $Q^2 > 1$ GeV², $|Q^2-Q'^2+t/2| > 1$ GeV²

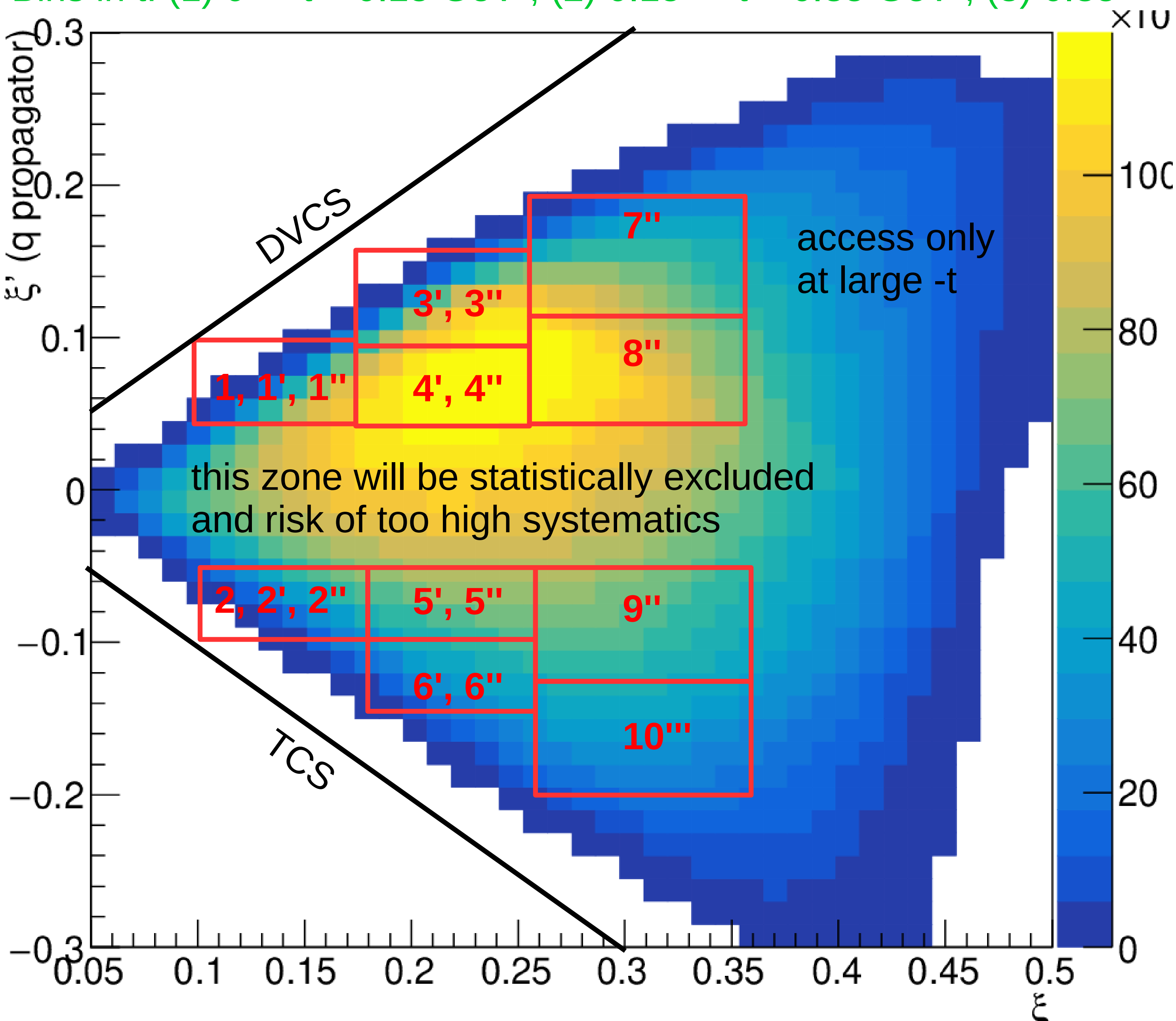
- resolution in t, ξ, ξ' important. $\delta t(\text{bin})/2 < 100$ MeV to avoid misidentification of ξ' bin (~10% of lower Q^2-Q'^2 limit)

⇒ the most important is the binning in t, ξ, ξ'
- we can integrate over Q^2 and Q'^2, however it is strongly correlated with ξ and ξ' (no need to bin)

⇒ this study integrate over final muons and electron azimuthal and polar angle.
- will need to bin in φ_{LH} and φ_{CM} → in principle 16*16 is OK. what is needed to fit CFF and deconvolute DDVCS from BH_1 and BH_2
- can integrate from θ_{min} to θ_{max} (away of quasi-singularities of BH_2) → similar than TCS

Binning in ξ, ξ', all t

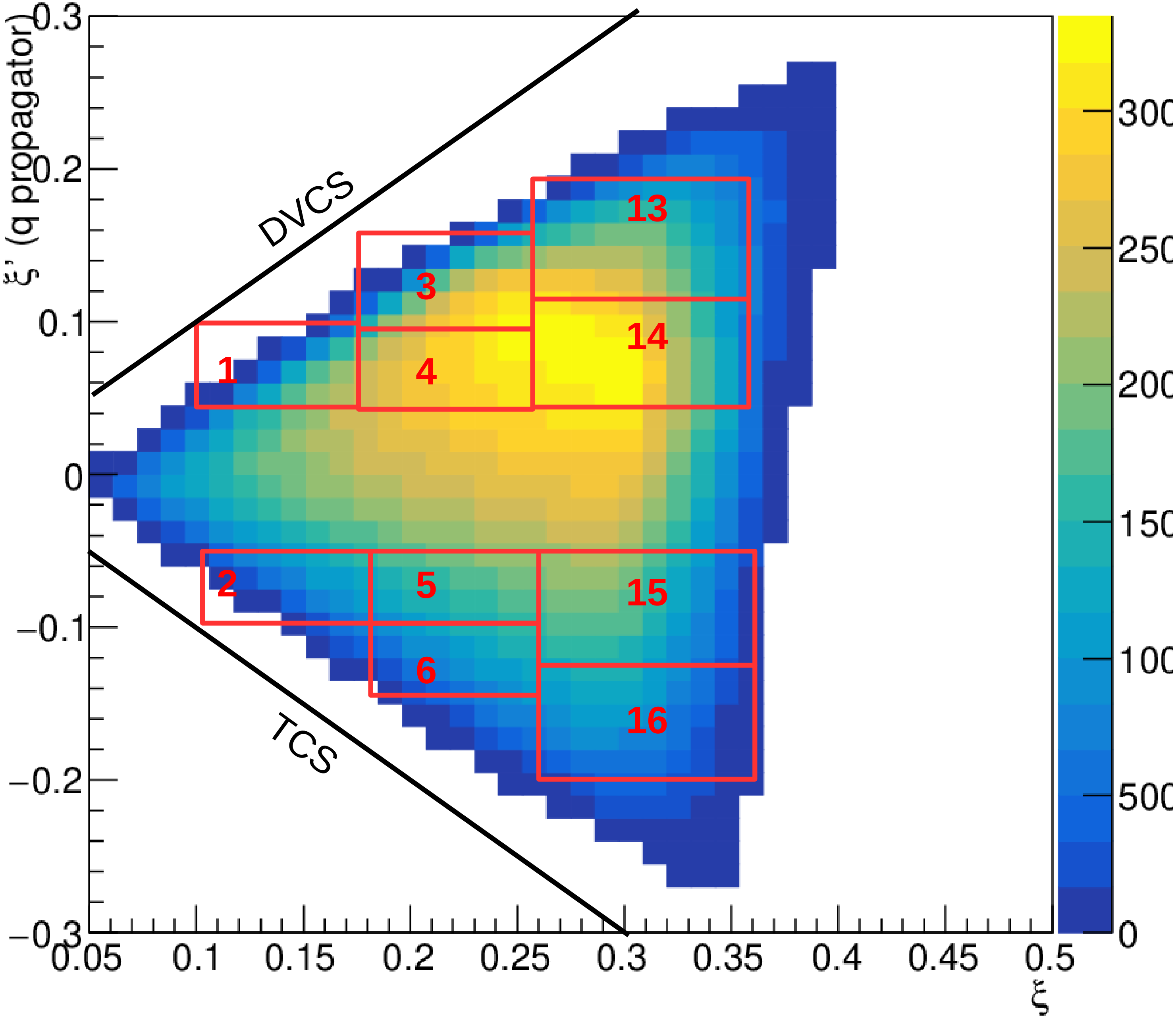
Bins in t: (1) $0 < -t < 0.15$ GeV², (2) $0.15 < -t < 0.35$ GeV², (3) $0.35 < -t < 0.55$ GeV² (indicated ', '')



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

- choice of limited acceptance: few bins, high intensity → some bins may be empty or limited statistic
- no binning in Q² and Q'²: the above selections are cutting bands in the Q² vs Q'² distribution
- next 3 slides: same figure ξ' vs ξ, separated for the 3 bins in t

Binning in ξ, ξ', at large -t (3) 0.35 < -t < 0.55 GeV²



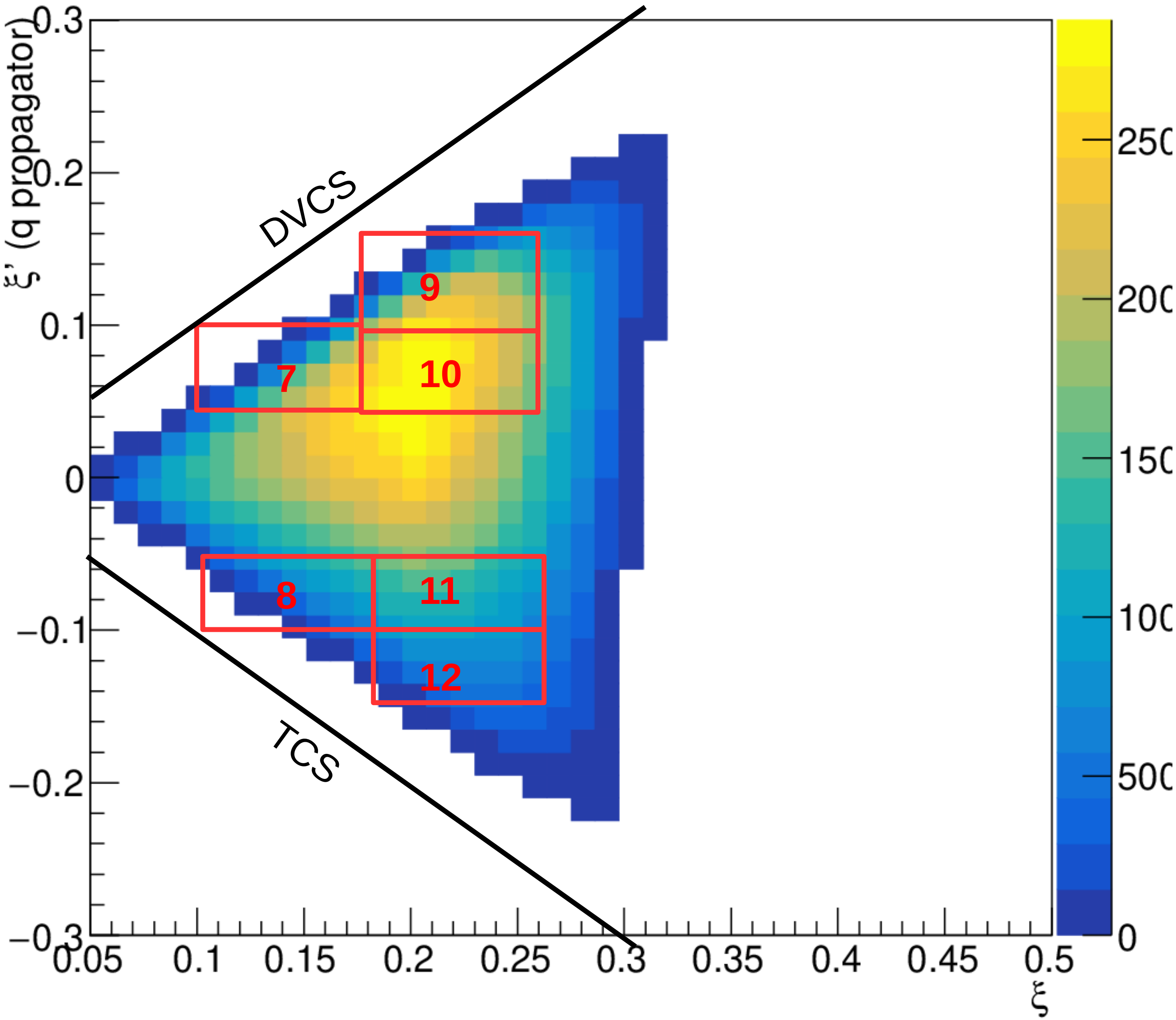
Bin in ξ

A) .1 < ξ < .18
- 1) .05 < ξ' < .1
- 2) -.05 > ξ' >-.1

B) .18 < ξ < .26
- 3) .1 < ξ' < .15
- 4) .05 < ξ' < .1
- 5) -.05 > ξ' > -.1
- 6) -.1 > ξ' > -.15

C) .26 < ξ < .36
- 13) .12 < ξ < .2
- 14) .05 < ξ < .12
- 15) -.05 > ξ > -.12
- 16) -.12 > ξ > -.2

Binning in ξ, ξ', at medium -t (2) 0.15 < -t < 0.35 GeV²

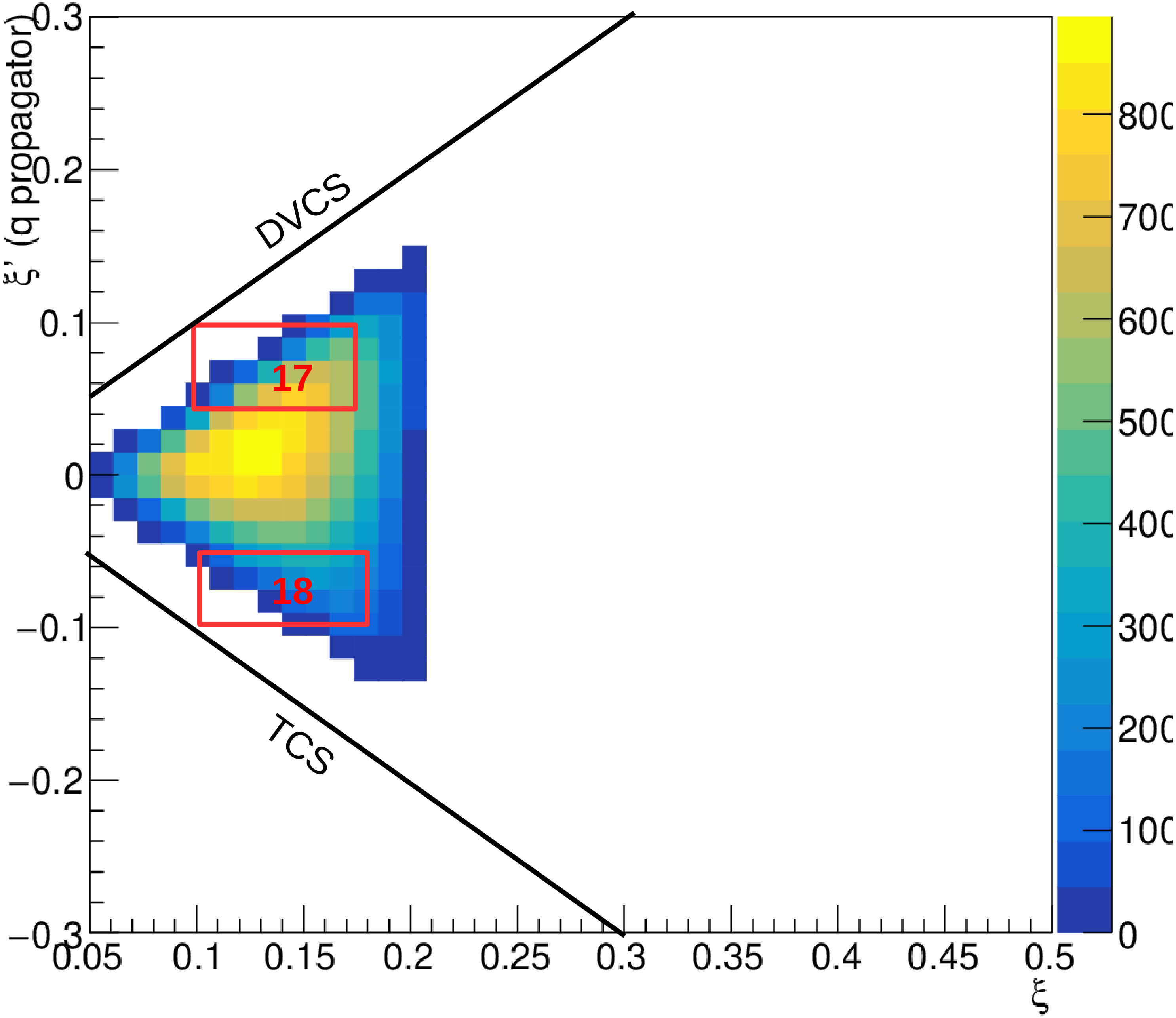


Bin in ξ

A) .1 < ξ < .18
- 7) .05 < ξ' < .1
- 8) -.05 > ξ' >-.1

B) .18 < ξ < .26
- 9) .1 < ξ' < .15
- 10) .05 < ξ' < .1
- 11) -.05 > ξ' > -.1
- 12) -.1 > ξ' > -.15

Binning in ξ, ξ', at low -t (1) tmin < -t < 0.15 GeV²



Bin in ξ

A) .1 < ξ < .18

17) .05 < ξ' < .1

18) -.05 > ξ' >-.1

DDVCS kinematics

• Generated phase space limits in these studies (unweighted):

E(beam) = 11 GeV

$0<-t<1$ GeV^2

$0<x_{bj}<0.5$

$1<Q^2<6$

$1<Q'^2<7$

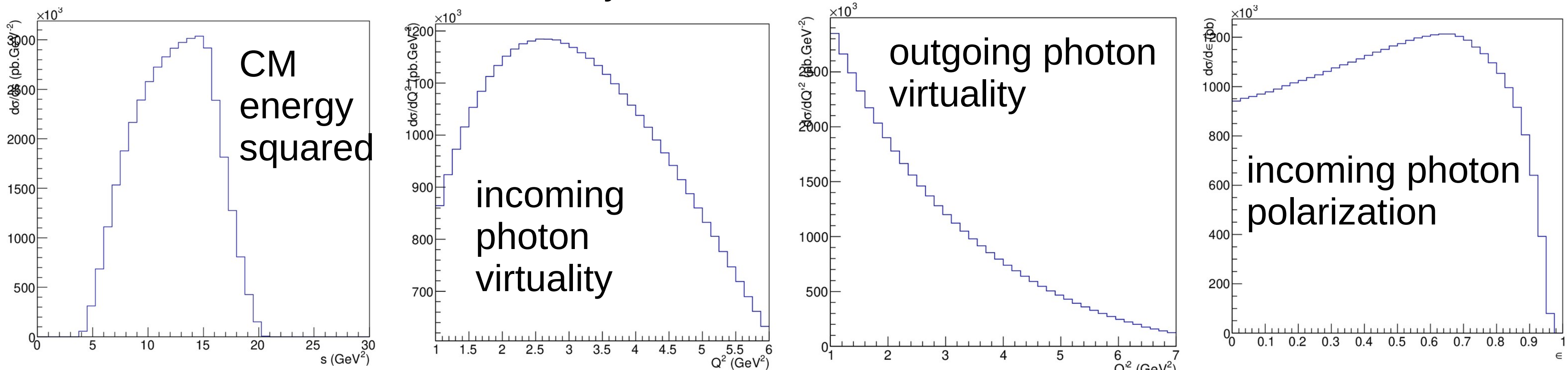
$\pi/4<\theta_{CM}<3\pi/4$

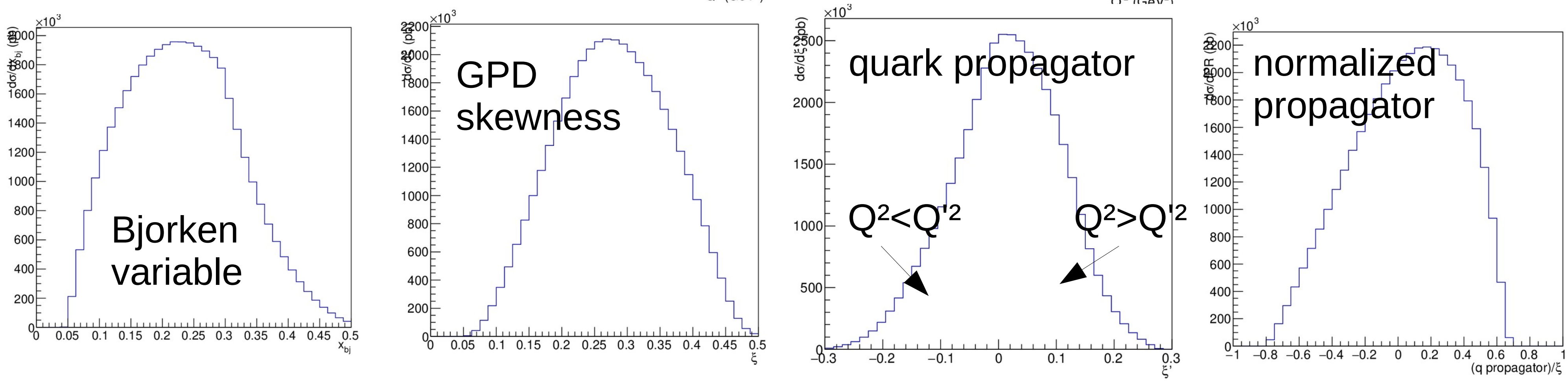
$\varphi_L,\varphi_{CM}<2\pi$

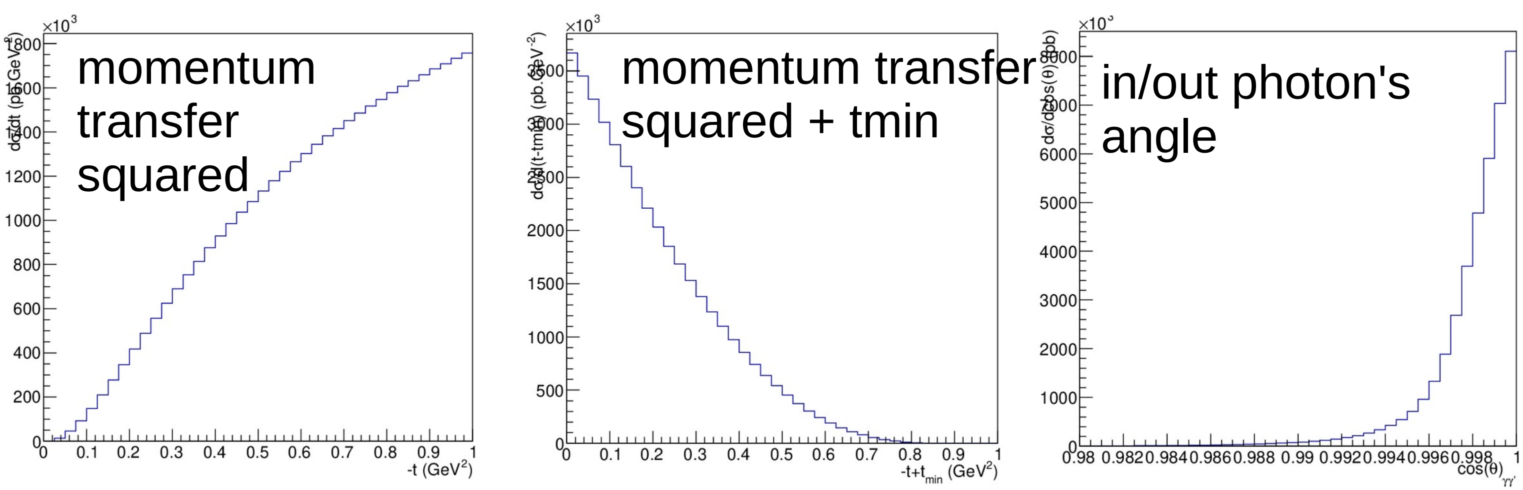
look at extended phase space ideally accessible from various experiments at JLab

1) maximal kinematic limits with 11 GeV beam
2) momentum and angular acceptance needed
3) physics regions

kinematics arbitrary normalization, does not follow x-sec







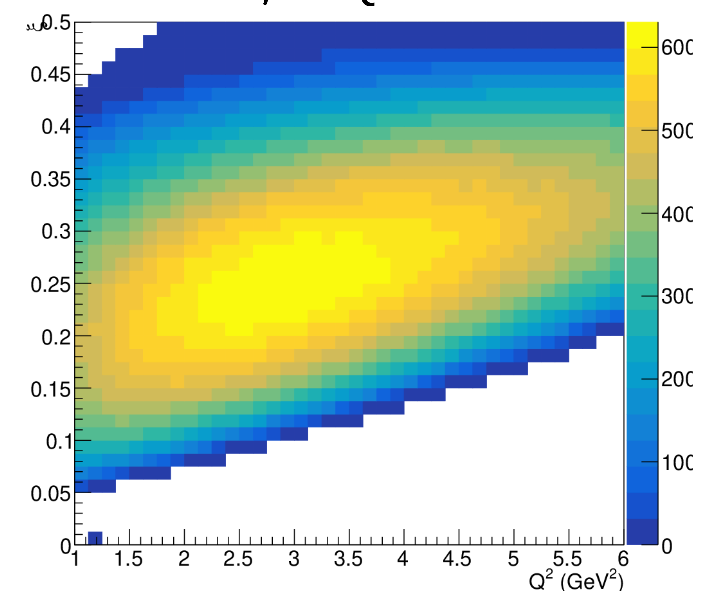
- access ERBL region of GPD
- "medium" skewness: valence region
- forward angles, momentum

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

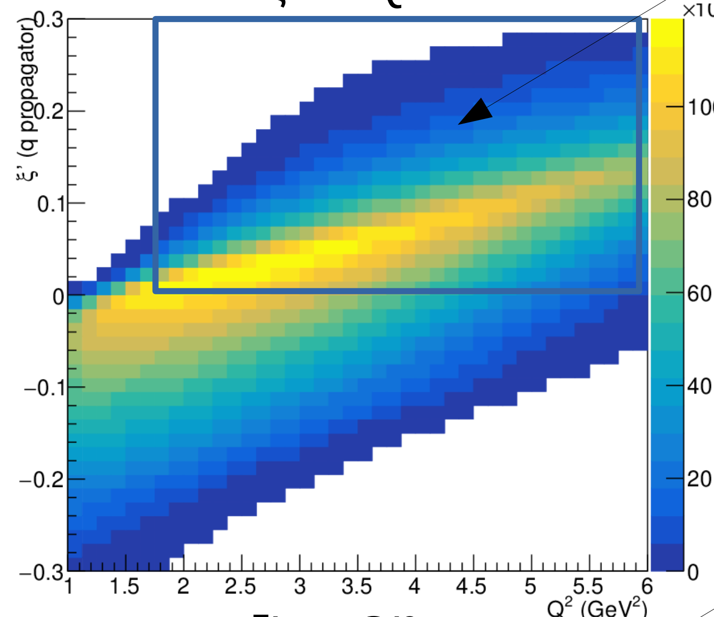
Q^2 and Q'^2 not correlated
correlation with other kinematic variables

Q²>2 GeV² if we want to stay at ξ'>0

ξ vs Q²

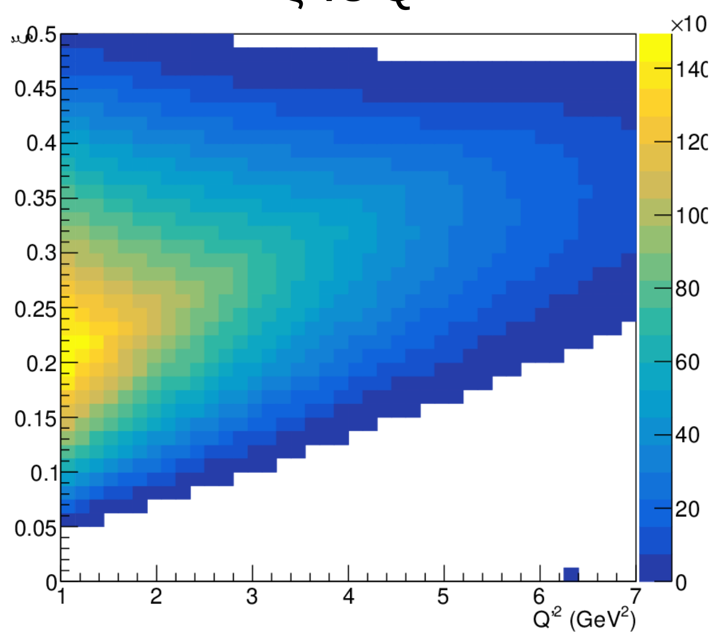


ξ' vs Q²

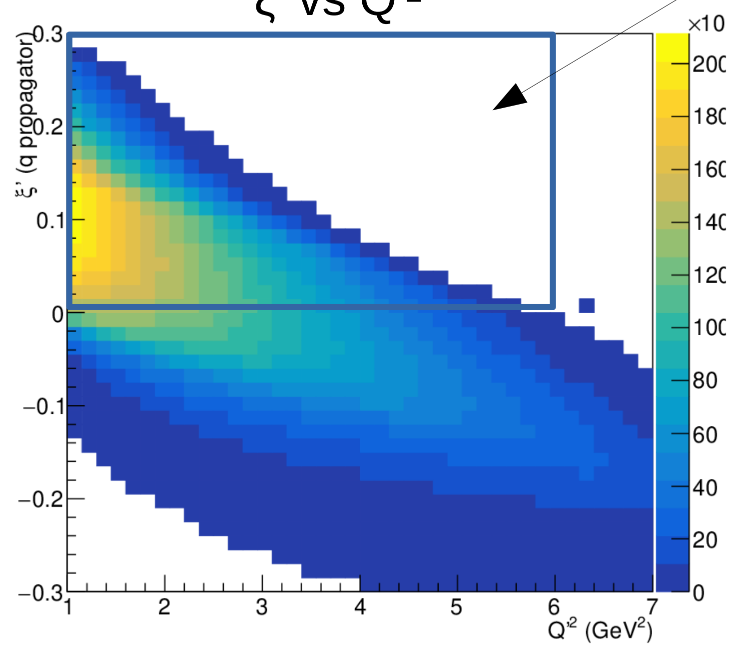


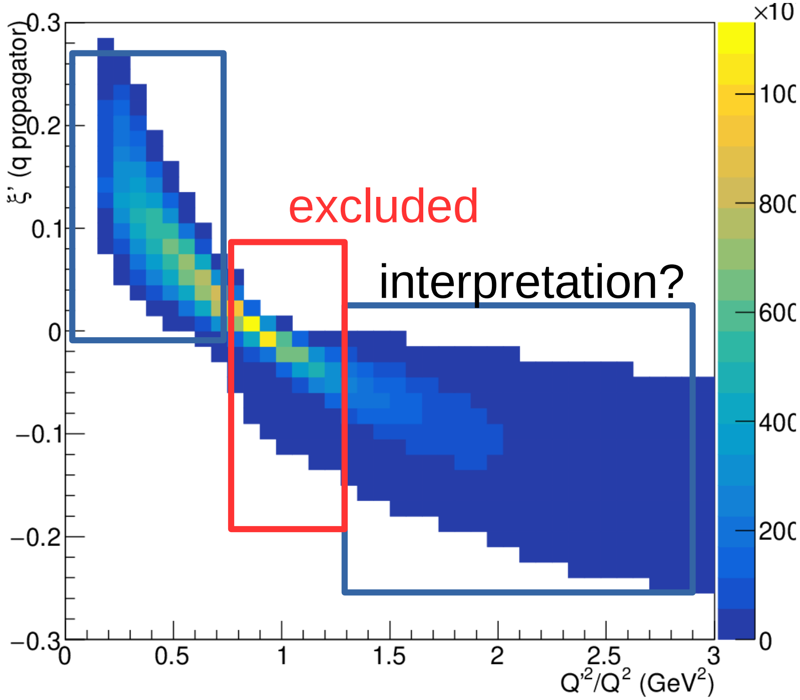
in this case, Q'²<6 GeV²
question about resonances and interferences

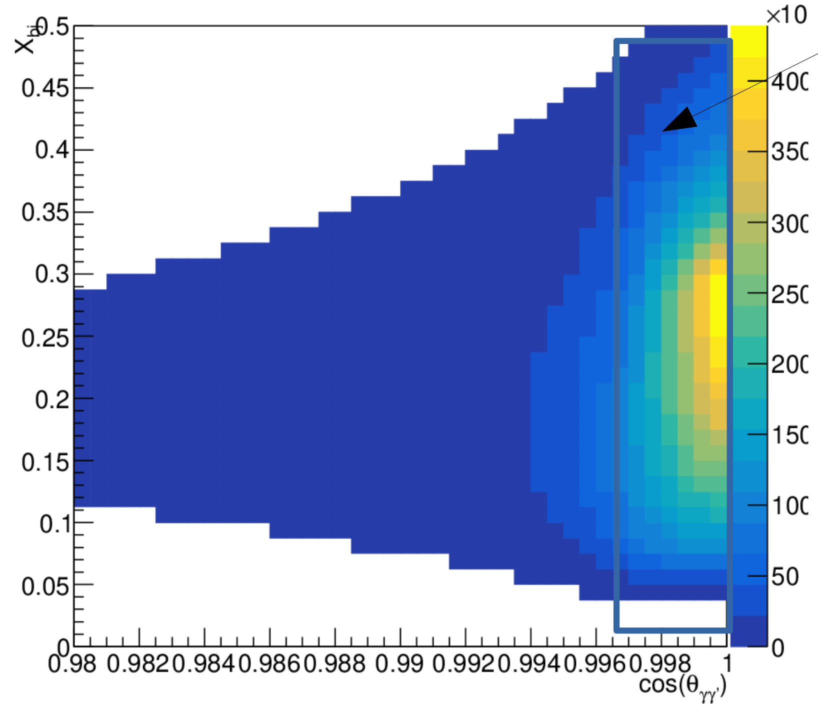
ξ vs Q'²



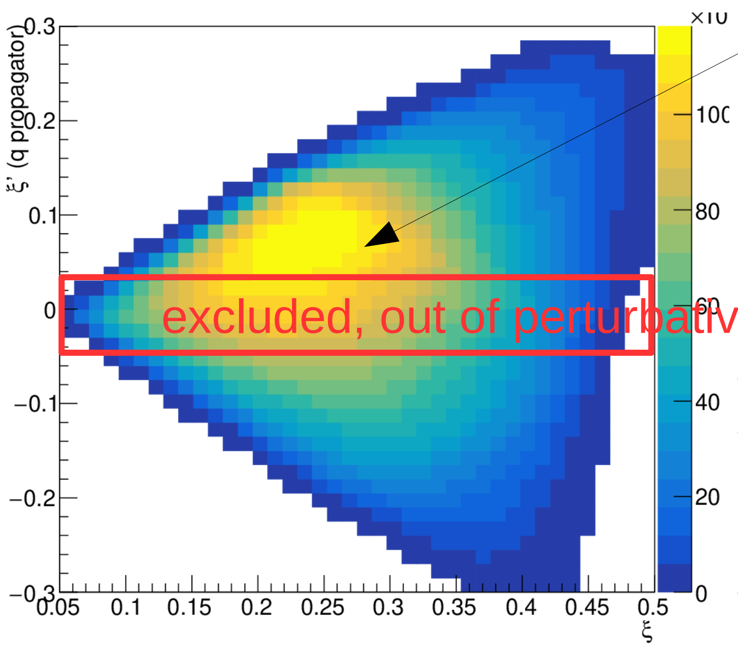
ξ' vs Q'²







we want to stay here → forward region



where do we want to have measurement?
this show how much "out of diagonal" we can go

excluded, out of perturbative handbag approach (assuming small t)

→ playing with larger t could get data in this region?

→ but in this case all approximations need to be waved and must be very carefull about interpretations

→ also need to be very carefull in this region: resolution in t !!!

outgoing particle lab momentum and correlation with physics and kinematics

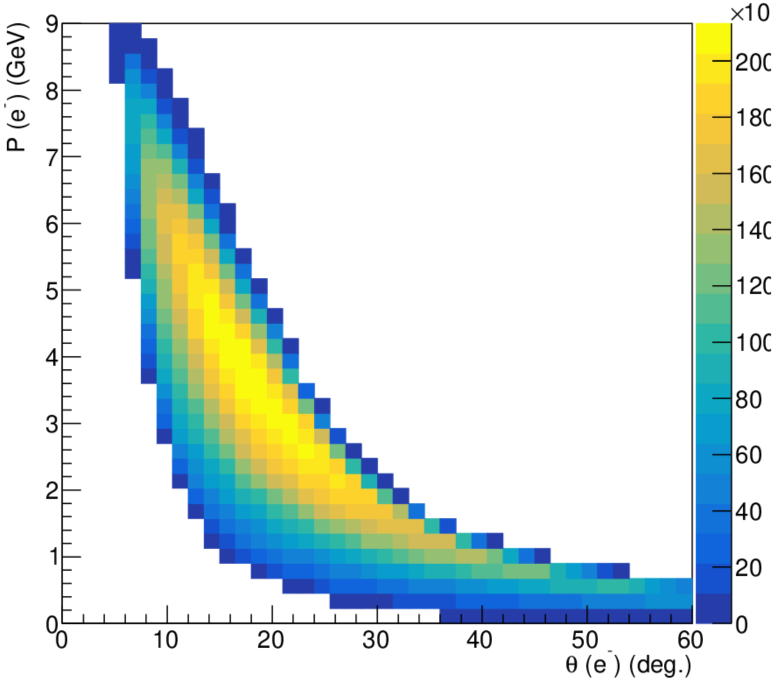
electron: .5→9 GeV, best below 5 GeV, 10°<θ<50°

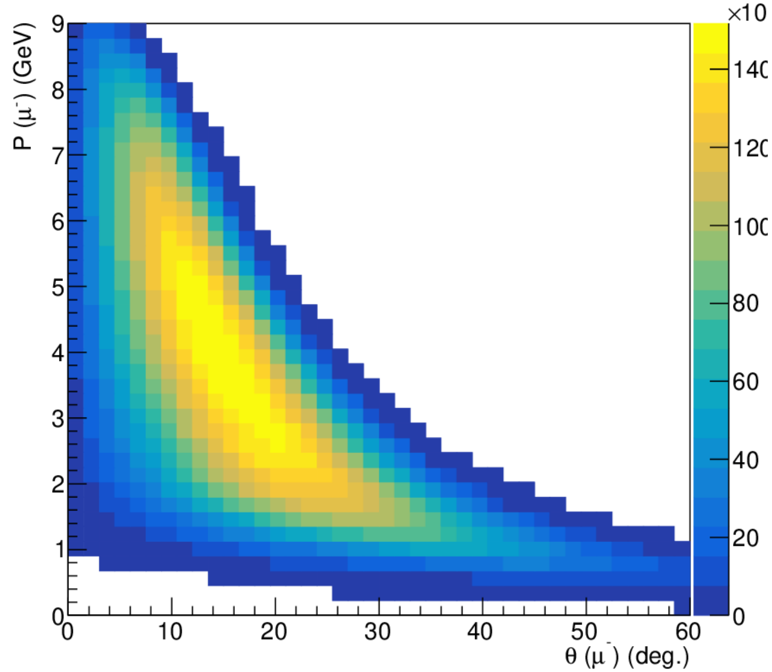
muon: .5→9 GeV, 0°<θ<50°

proton: .2→1.1 GeV, 0°<θ<50°

vs quarks propagator value,
no strong correlation without cuts

need to see with cuts and FOM





- outgoing particles are scattered in accessibles regions for JLab halls
- best measurements will be at smaller angles: statistics, lower t-tmin...
- need muon detection, not possible to just get "charged particle", need to distinguish μ- and e-

If dedicated setup: at least e' and μ+μ-, but P is very important due to the strong sensitivity of the value of the propagator to t. resolution is essential!

Simulations and studies of TCS and DDVCS

Impact studies for new experiments at JLab

1) Understanding angular correlations
2) Kinematics for JLab 11 GeV
3) **Observables, what can be measured**
4) Future and potential experiments

DDVCS: never measured, a first measurements would get beam spin asymmetries and unpolarized cross section off LH2

TCS: first measurement (published 2021) in Hall B JLab
Dedicated experiments Hall A (SoliD), Hall C with transversely polarized target
Future opportunities with Hall C: LH2, LD2 (neutron), other targets…
Program is in progress

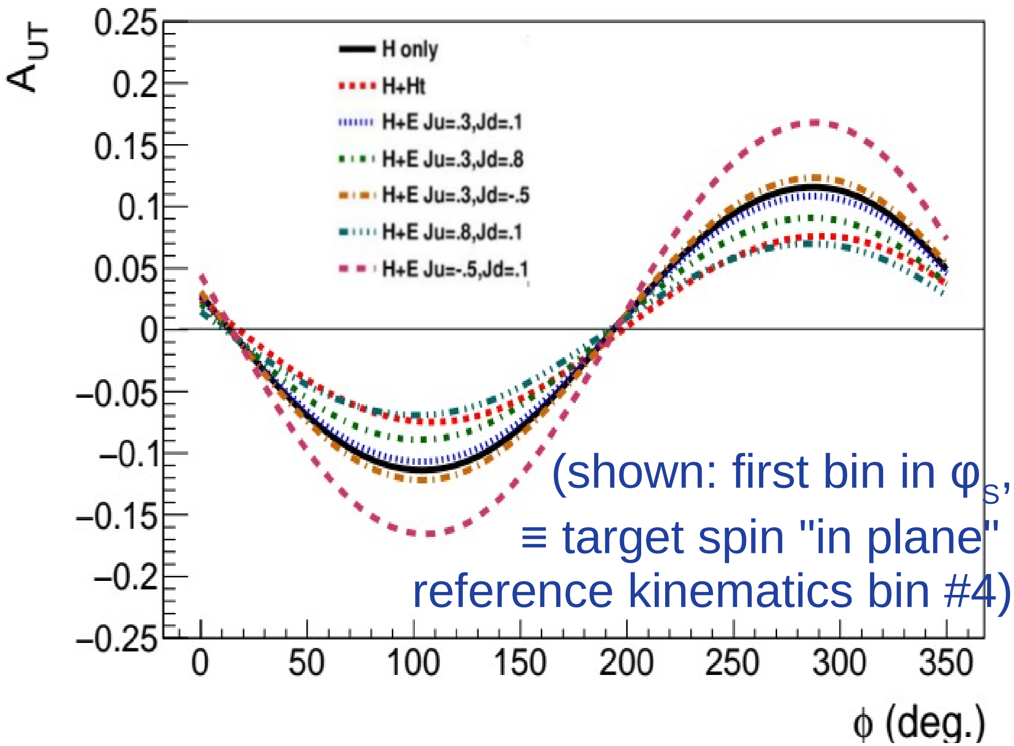
TCS observables, interests and plans at JLab

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 NPS proposed
Circularly polarized beam	Easiest observable to measure at JLab	Im(H), Im($\widetilde{H}$) Sensitivity to quark angular momenta, in particular for neutron	CLAS 12, SoLID approved NPS proposed
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($\widetilde{H}$)	no
Transversely polarized target	Polarized target, and high luminosity: binning in θs, φs	Im($\widetilde{H}$), Im(E)	NPS proposed
Double spin asymmetry with circularly polarized beam	Polarized target, very high luminosity, precision measurement	Real part of all CFF	no / "for free"?
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	no

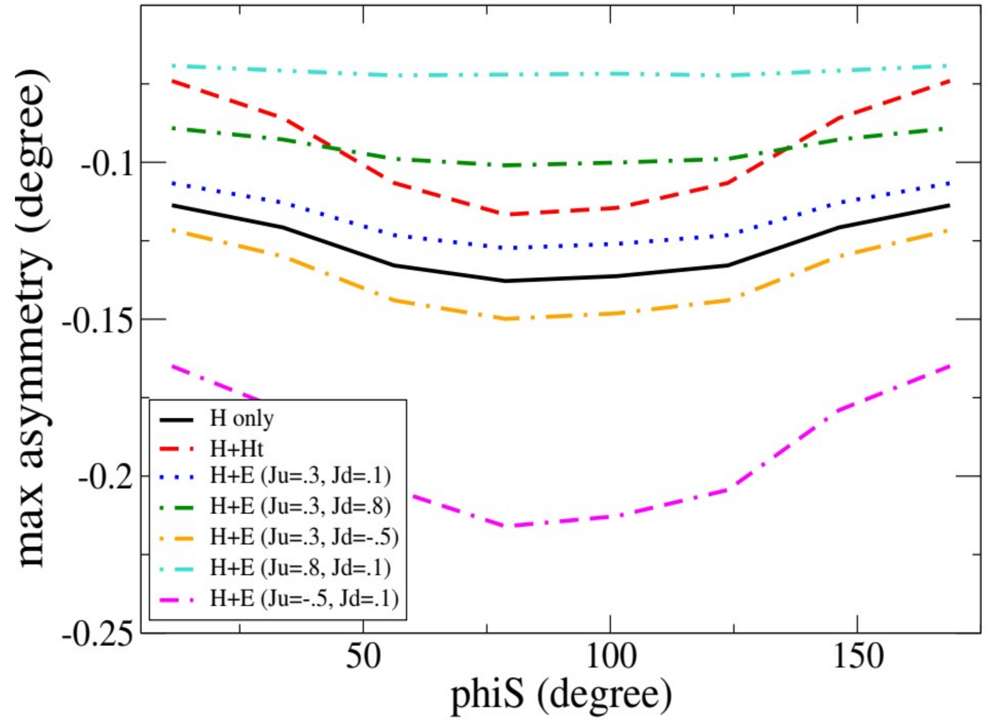
TCS off the neutron
- similar conclusion, need 10 to 100x higher luminosity.
- target spin asymmetries are expected to be larger, and beam spin asymmetries are smaller
- important measurement for GPDs flavor separation, and its sensitivity to quark angular momenta

Transverse target spin asymmetries

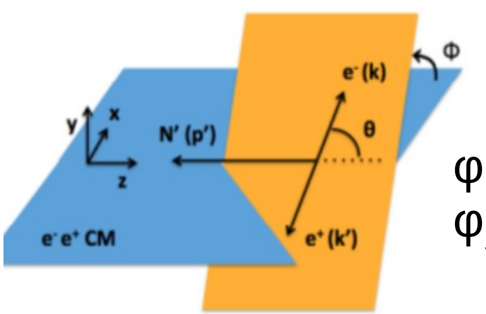
Dependence in GPD parametrization and J_u, J_d (VGG model) vs φ and φ_S



(shown: first bin in φ_S, ≡ target spin "in plane" reference kinematics bin #4)



strong dependence!



φ: e^- vs reaction plane
φ_S: P spin vs reaction plane

θ: polar angle (integrated)
E_γ ($\rightarrow$ ξ), t, Q'^2

- **TCS contribution through interference**
  → purely imaginary, BH cancels
- **Sensitive to GPD parametrization**
- **Angular momenta J_u, J_d and GPD E**

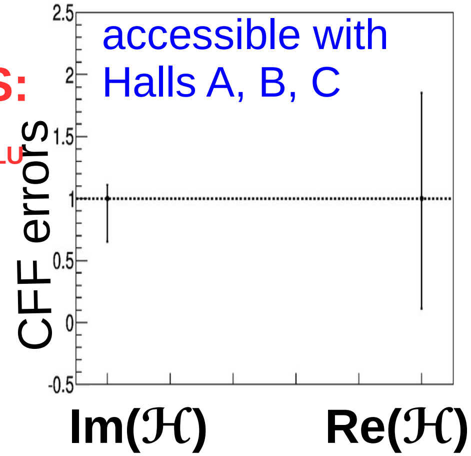
Need of experimental data!

calculations based on Boër, Guidal, Vanderhaeghen
GPDs from Vanderhaeghen, Guidal, Guichon (VGG)

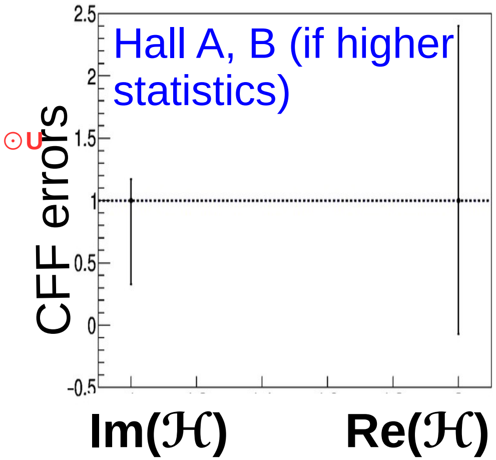
Compton Form Factors from DVCS and TCS

[fit of simulations with same errors]

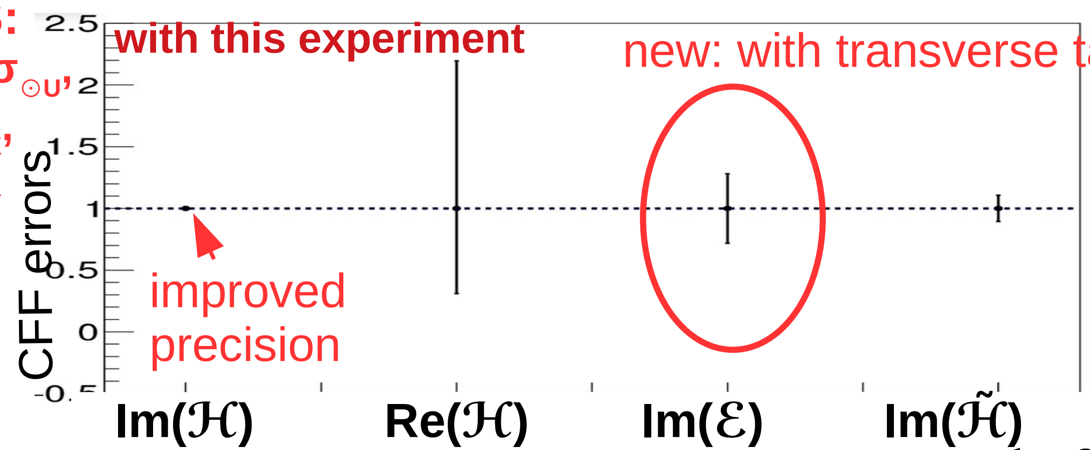
DVCS:
σ, $\Delta\sigma_{LU}$



TCS:
σ, $\Delta\sigma_{\odot U}$



TCS:
σ, $\Delta\sigma_{\odot U}$, $\Delta\sigma_{UX}$, $\Delta\sigma_{UY}$



← extracted CFFs (generated at value=1)

- **CFFs from TCS can be extracted at same level than DVCS**
- **Im($\mathcal{E}$) extracted thanks to transverse target**
- **Precision on H greatly improved with new constraints**

Main goal: **GPD E (proton) → unique, not measured in other exp.**

Secondary goal: **complement universality studies**

→ universality or breaking? Higher twist/NLO effects?

- Studied with Q^2 evolution in other experiments

- Comparison of fit results DVCS only, TCS, TCS+DVCS

→ **interpretation depends on size of observed effects**

Caveat: for comparison purpose and sensitivity studies; assuming same uncertainties for all cases (based on Boër, Guidal...)

Accessing Im(E) and proton versus neutron in DVCS and TCS

ξ=.2, -t=.15 GeV²

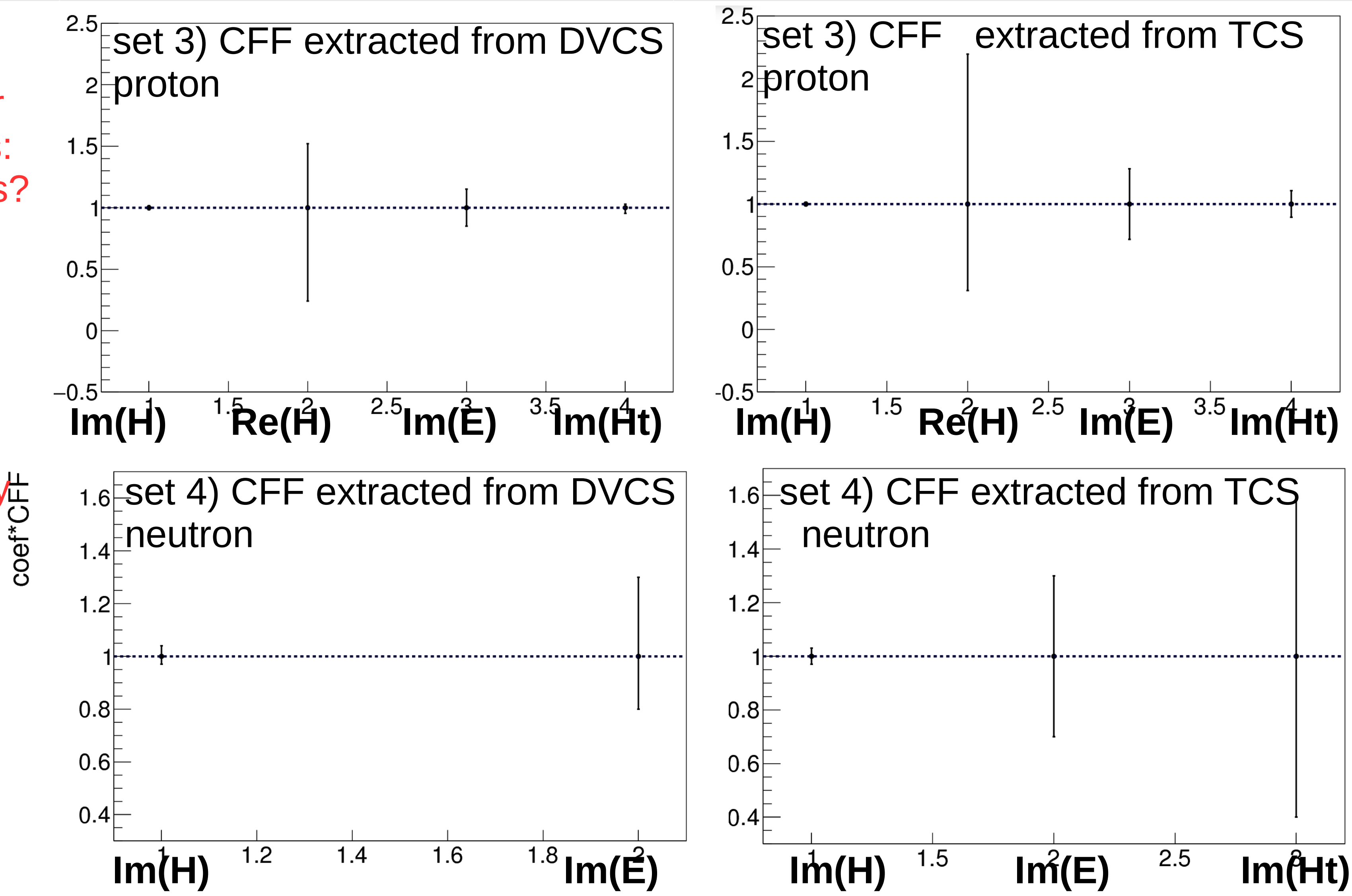
set of obs.	DVCS (Q^2=2.5 GeV², E=11 GeV)	TCS (Q'^2=4.5 GeV², θ=90°)
3) proton σ, $\Delta\sigma_{LU}$, $\Delta\sigma_{UX}$, $\Delta\sigma_{UY}$	Im(H), Re(H), Im(E), Im(Ht) extracted	Im(H), Re(H), Im(E) and Im(Ht) extracted
4) neutron σ, $\Delta\sigma_{LU}$, $\Delta\sigma_{UL}$, $\Delta\sigma_{LL}$	Im(H) and Im(E) extracted	Im(H), Im(E) and Im(Ht) extracted

GPD E & angular momenta studies: what observables?

for flavor separation from both DVCS & TCS

→ complementary measurements

→ universality studies



Simulations and studies of TCS and DDVCS

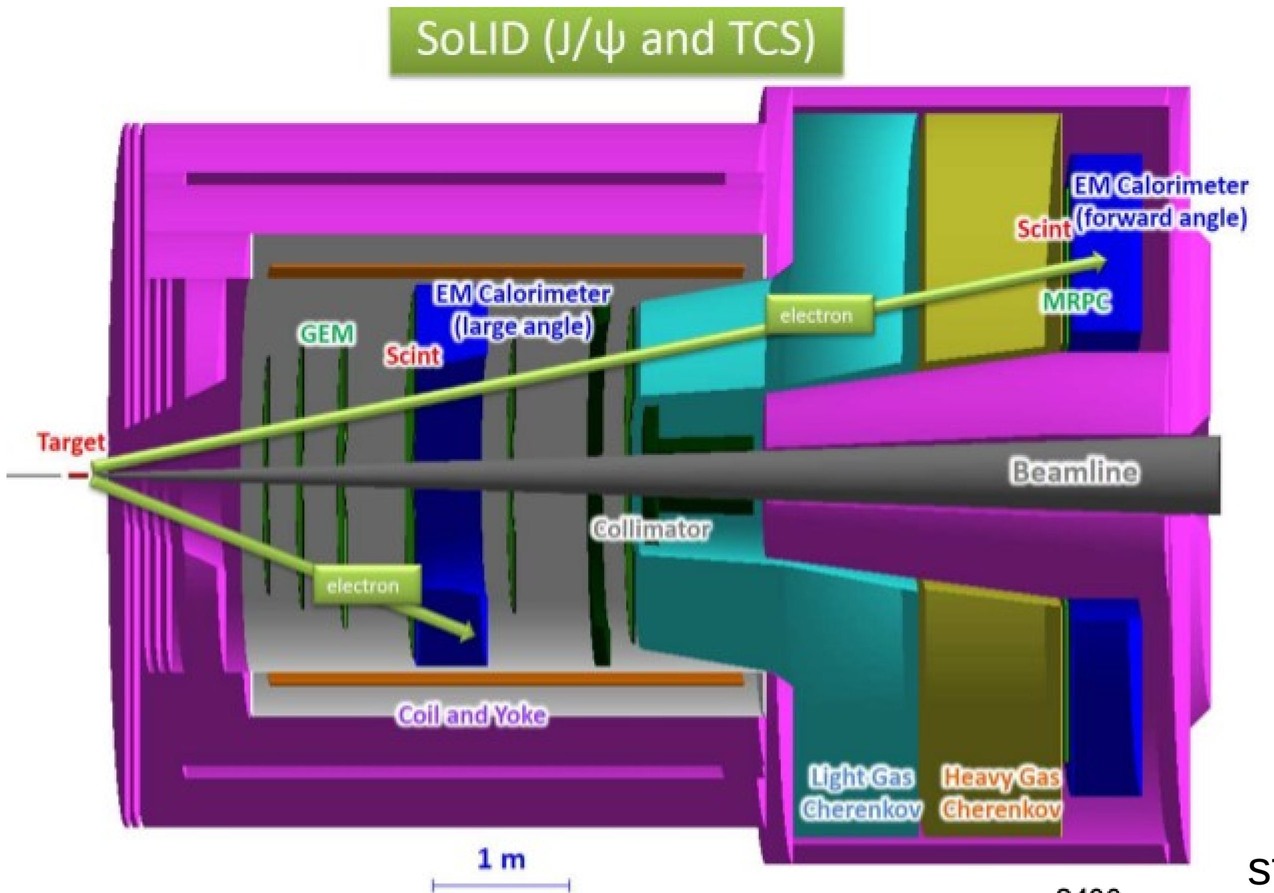
Impact studies for new experiments at JLab

1) Understanding angular correlations
2) Kinematics for JLab 11 GeV
3) Observables, what can be measured
4) **Future and potential experiments**

Experimental program, JLab

TCS with SoLID: complementary to CLAS 12 with high luminosity

E12-12-006A PAC43

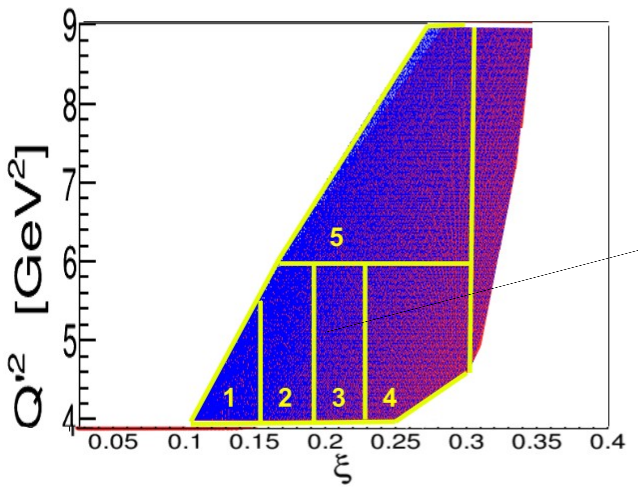


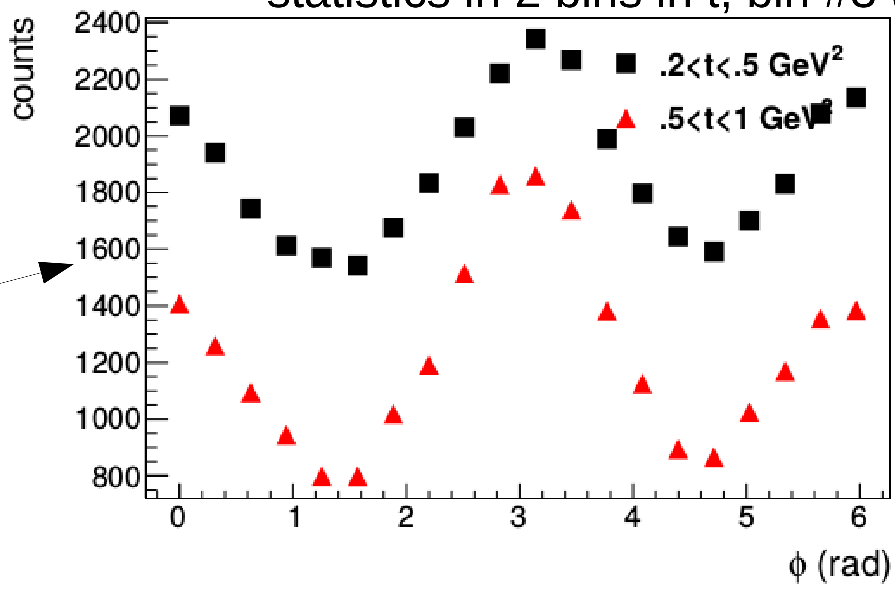
SoLID setup for J/ψ approved exp.

- no beam time request for TCS
- 50 days approved up to 10^37 cm-²

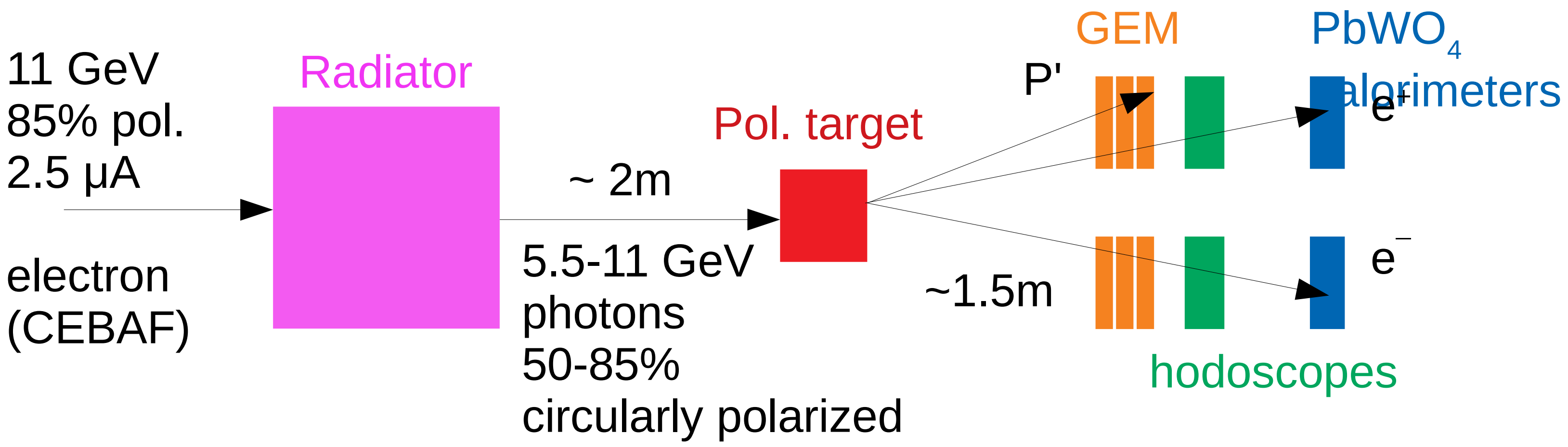
Similar as CLAS12, with larger statistic, narrower acceptance
→ binning in Q'²: evolution...
→ studies of GPD universality by comparing H extracted from TCS and DVCS

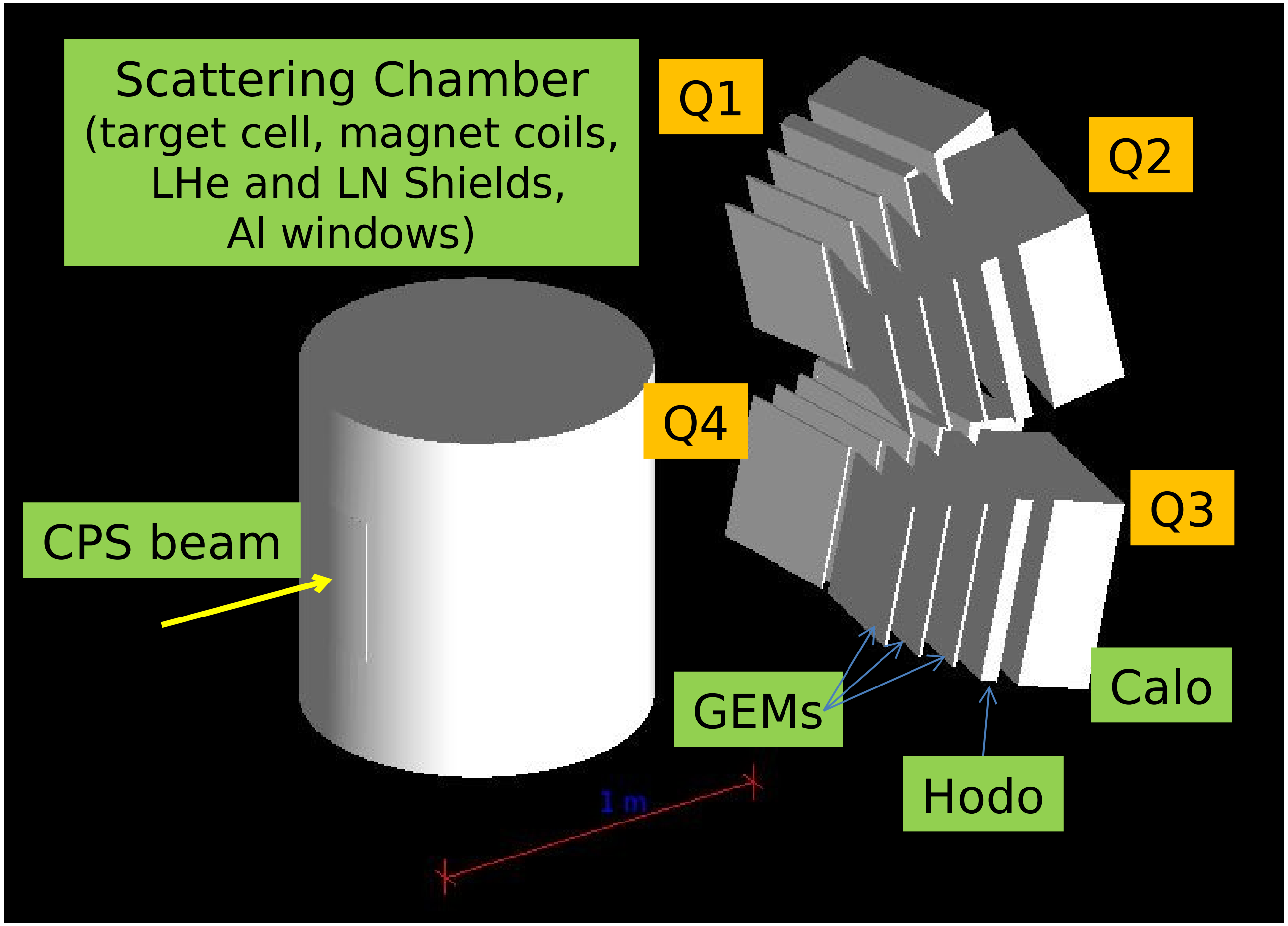
statistics in 2 bins in t, bin #3 (Q'², ξ)





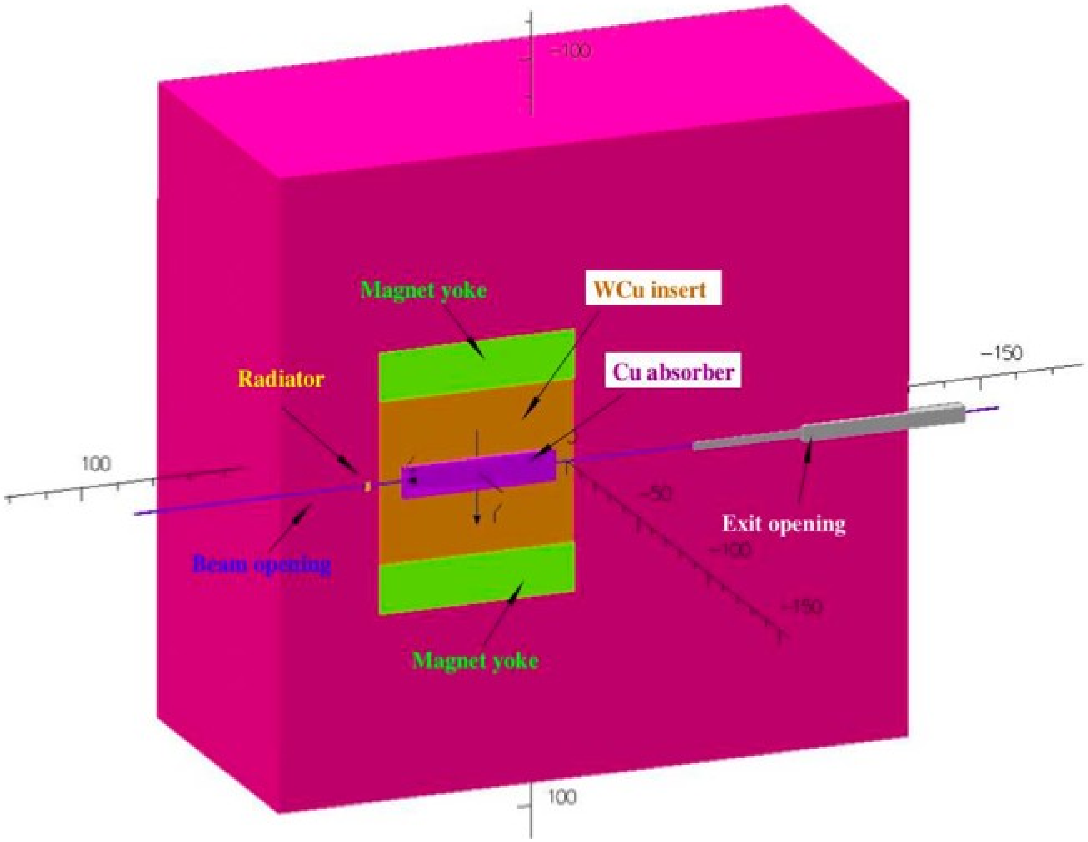
Experimental setup polarized TCS Hall C





- Radiator: Compact Photon Source
- Target: ⊥ polarization, NH_3
- GEMs, scintillator hodoscopes
- Calorimeters: $PbWO_4$

Radiator: Compact Photon Source



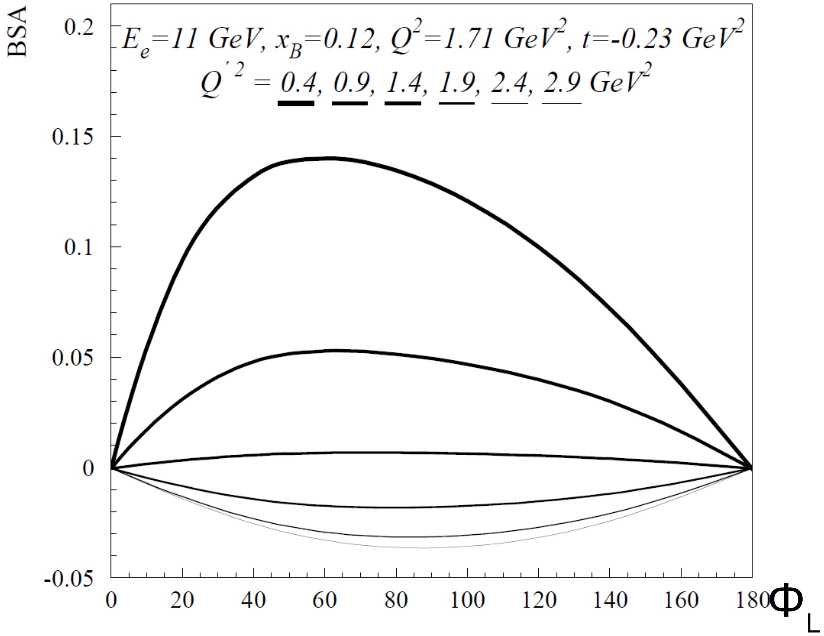
- 10% Cu radiator
- used for beam dump with 3.2 T warm magnet
- W/Cu shielding: minimal radiation, negligible interference with target field
- 1.5e12 γ/s at 2.5 μA, 5.5 to 11 GeV (5.8e5 pb^{-1} integrated luminosity)
- ~1 mm spot size at 2m

Nucleon tomography and sign change in DDVCS beam spin asymmetry

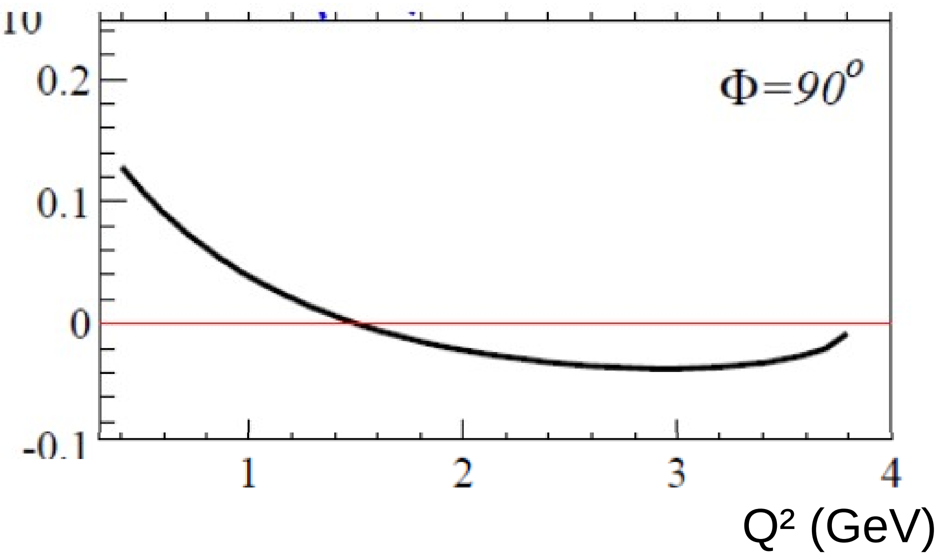
Calculations from M. Guidal

→ scan of BSA in Q'^2 at fixed Q^2

→ sign change in BSA vs Φ_L and vs φ_{CM} when $Q'^2 \approx Q^2$



asymmetry Q^2 scan



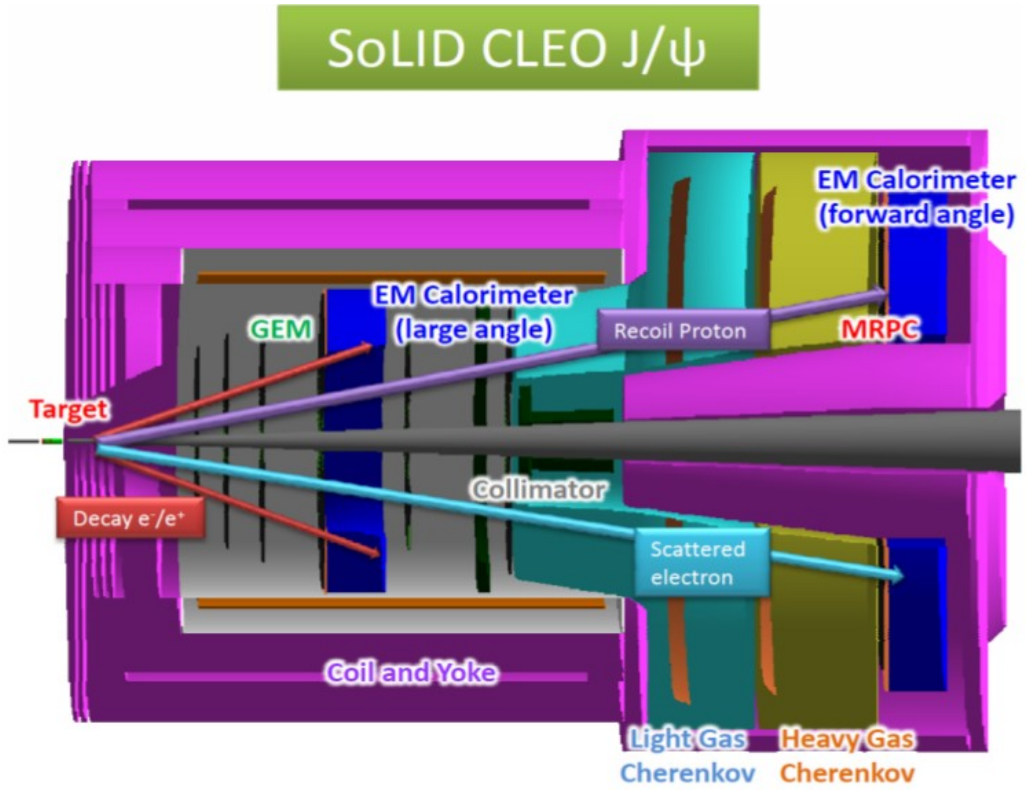
- **Probing GPDs at x ≠ ξ → tomographic interpretations....**
- **Expectation of sign change for observables sensitive to Im (DDVCS) when moving from « spacelike » to « timelike » region**

→ this reaction is unique for probing effects between these 2 regions.

- Cross section + beam spin asymmetry projects in development for JLab Hall A and B, for exploratory measurements with aim of future dedicated experiment at very high luminosity

SoLID: LOI12-15-005 (2015)
CLAS12 note: (2015), LOI12-16-004 (2016)

DDVCS with SoLID: experimental setup

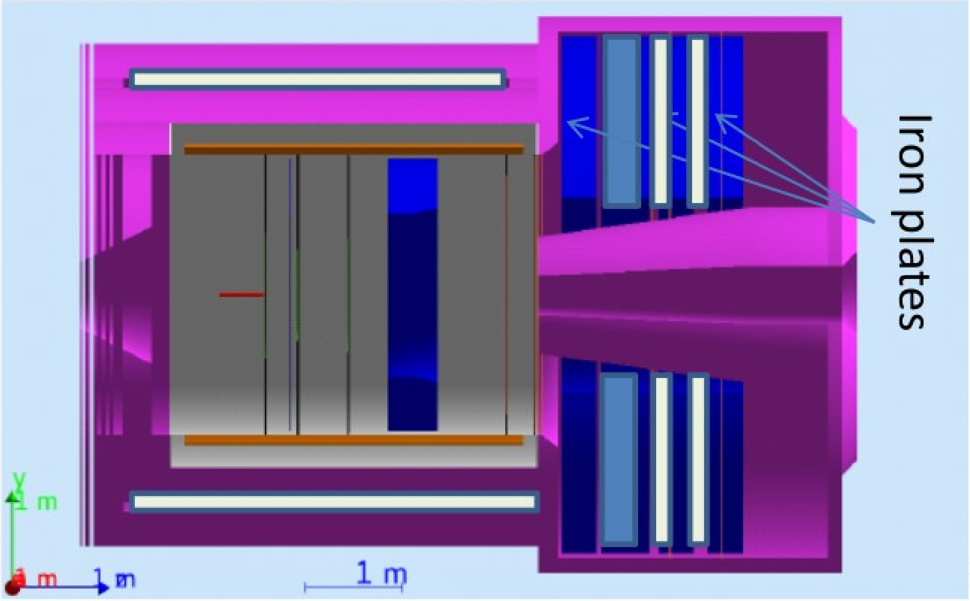


- J/Ψ setup: electrons, (proton)
- CLEO muon chambers: muon pair

50 days at 10^37 cm-²
reasonnable rates: measurement feasible

To do:
- GPD extraction from simulations / impact
- optimal setup
- updated rates

Dedicated setup



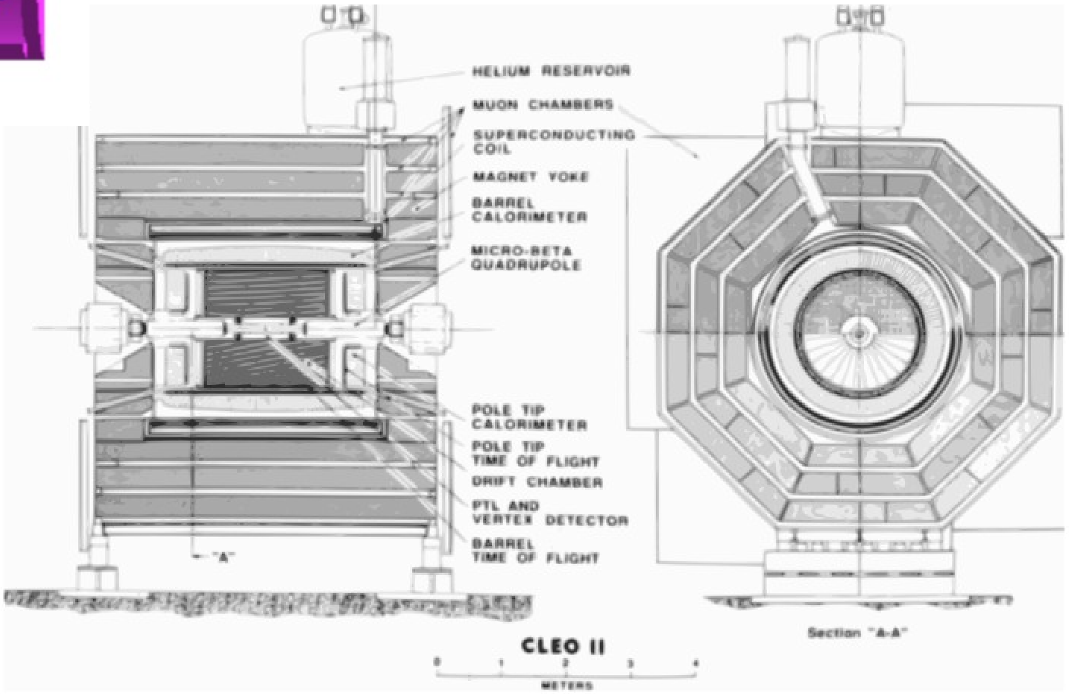


Figure 10: CLEO II setup with muon chambers installed inside the iron yoke.

DDVCS with CLAS12 in Hall-B

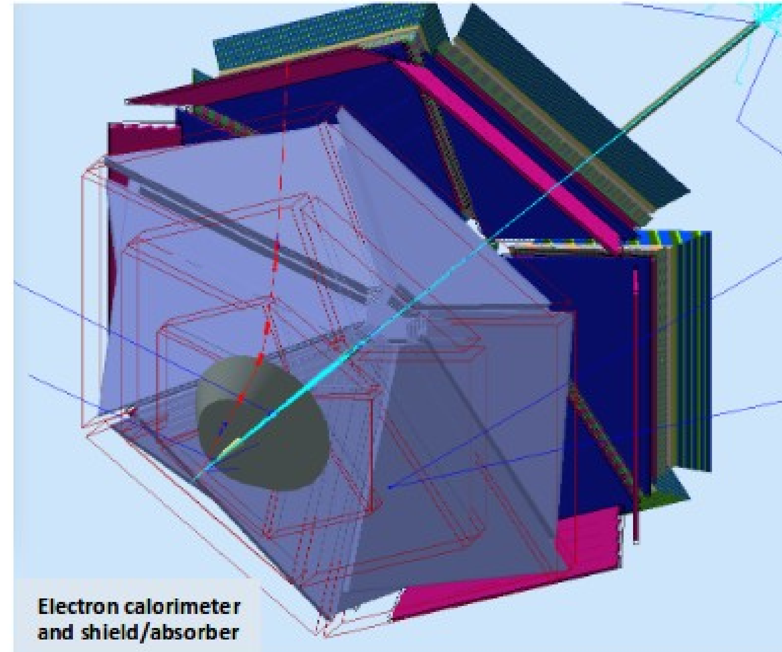
Two main challenges in DDVCS measurements:

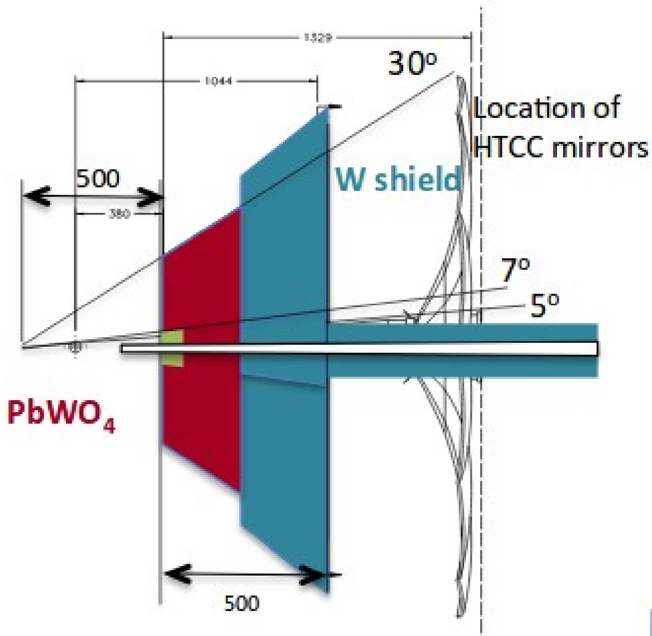
- cross section is two to three orders of magnitude smaller than the DVCS cross section
- decay leptons of the outgoing virtual photon must be distinguishable from the incoming-scattered lepton

Both challenges can be solved with by studying di-muon electroproduciton, $ep \rightarrow e'p'\mu^+\mu^-$

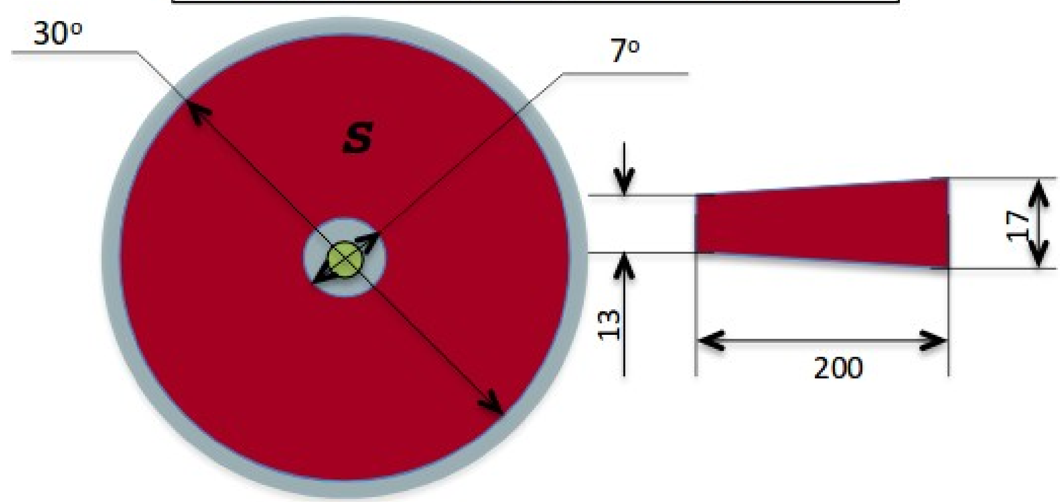
CLAS12 FD will be blocked with heavy shielding/absorber from electromagnetic and hadronic backgrounds to be able to run at luminosities ~10^{37} cm^{-2} s^{-1}, and will be used as muon detector

Scattered electrons will be detected in a compact $PbWO_4$ calorimeter that is part of the shielding



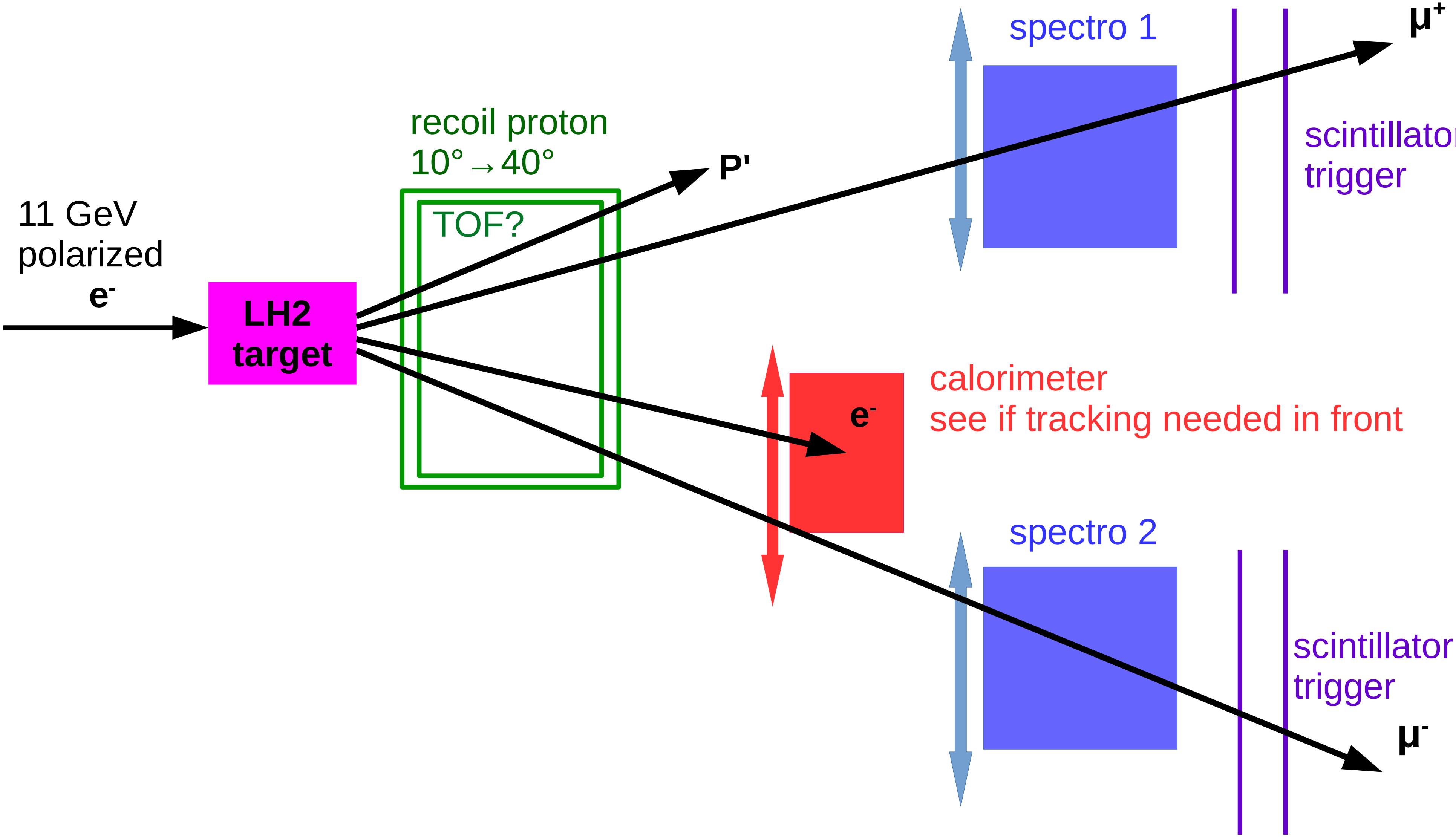


$$S = \pi l^2[(tg^2(30^o) - tg^2(7^o)] = 3600\,cm^2;\ l = 60\,cm$$



$PbWO_4$ modules with APD readout - ~ 1500 modules

In progress: DDVCS setup for measurements in Hall C
*** note: several possibilities under exploration, here is one**



SUMMARY

- Other "Deep Compton" processes complementary to DVCS for GPD studies
- Lack of experimental measurements, very few theoretical and phenomenology work

***** please work on it!**

- New opportunities at JLab with intensity raise and potential higher energy beam
- Program for JLab at 11 GeV (all Halls) under development. Lots of people interested, but lack of manpower
- Several designs studied, projects to add muon detectors in Hall C (or A). Several groups looking at different approaches

Note: we will have a dedicated session+round table for non-DVCS Compton processes for GPDs at our workshop in Blacksburg (VT). July 18-22: https://indico.phys.vt.edu/event/51/