Multichannel approach for new GPD sensitive experimental measurements

Marie Boër et al., Virginia Tech

Presented work also includes: Debaditya Biswas, Brannon Semp, Tyler Schroeder, Erik Wrightson, Camille Zindy (VT); Vardan Tadevosyan (ASNL), Alexandre Camsonne (JLab), Zhiwen Zhao (Duke); And other Hall A and Hall C collaborators

QNP conference, Hadron Structure session – Sept. 7th, 2022

Motivations

* also see Kresimir's talk

Among other interpretations: tomographic views
- need to extrapolate GPDs to zero skewness
- need to constrain all GPDs and reduce correlation uncertainties
*** focusing on quarks and "JLab" energies here**

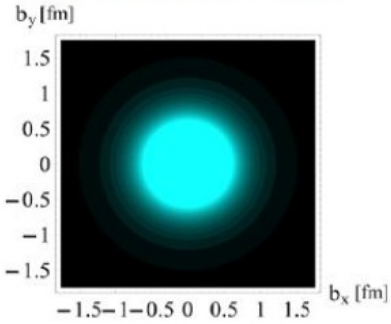
3D mapping of the nucleon ⇒ tomography

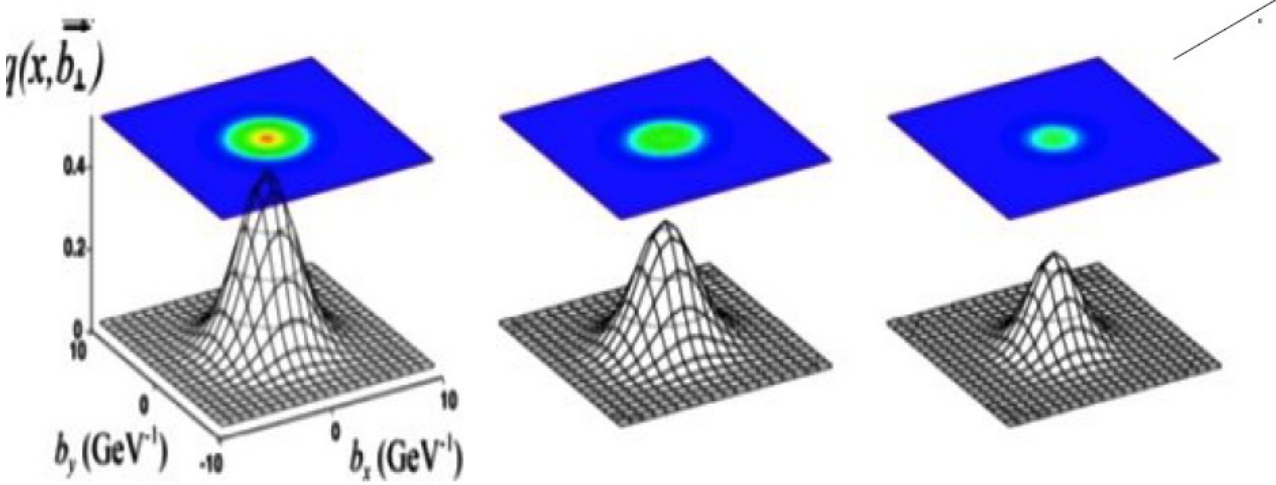
Transverse parton distributions for different region in x
→ probabilistic interpretation ≡ gluons, valence quark regions

"momentum dissected Form Factors"

integral over x

transverse charges from Elastic Scat.





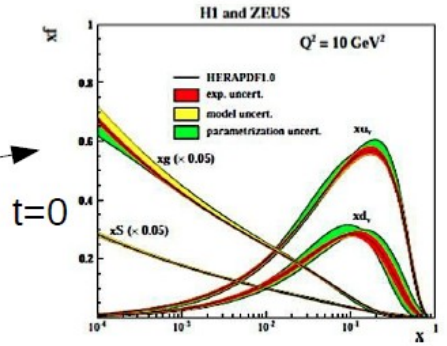
gluons dominate

gluons, sea quarks "meson cloud"

valence quarks region

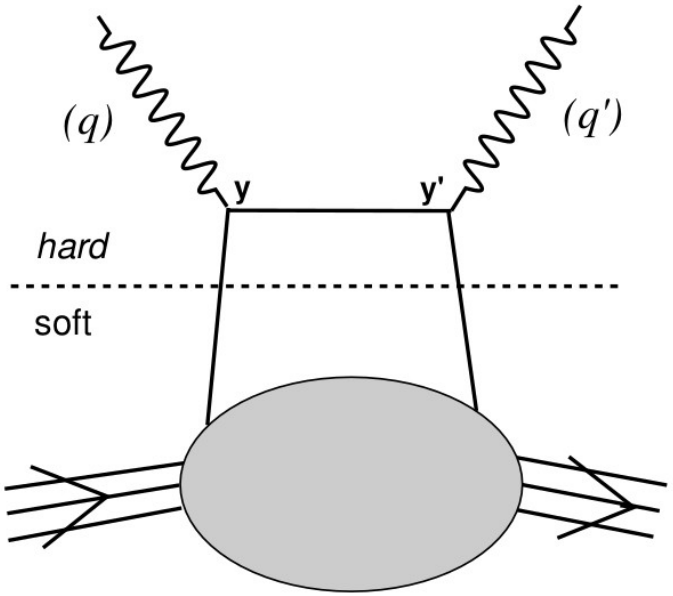
parton densities from Deep Inelastic Scat.

t=0



Motivations

GPDs with Compton-like reactions



Leading order / leading twist generic handbag diagram
For “lower” energy experiments (JLab…)

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

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

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

Quark GPDs; as function of x (// momentum fraction), xi (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, since only one non-perturbative part
Most measurements = DVCS; GPD models constrained by DVCS mainly
(see Pierre’s and Kresimir’s talks this session for TCS and complementarity in GPD modeling)

Complementarity
Compton-like processes

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

(similar for TCS)

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

With $\xi' = \frac{x_B}{2 - x_B}$ and $\xi = \xi' . \frac{Q^2 + Q'^2}{Q^2}$ (our notations, VGG models for JLab projections)

TCS and DVCS access Im(CFFs) at x = 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

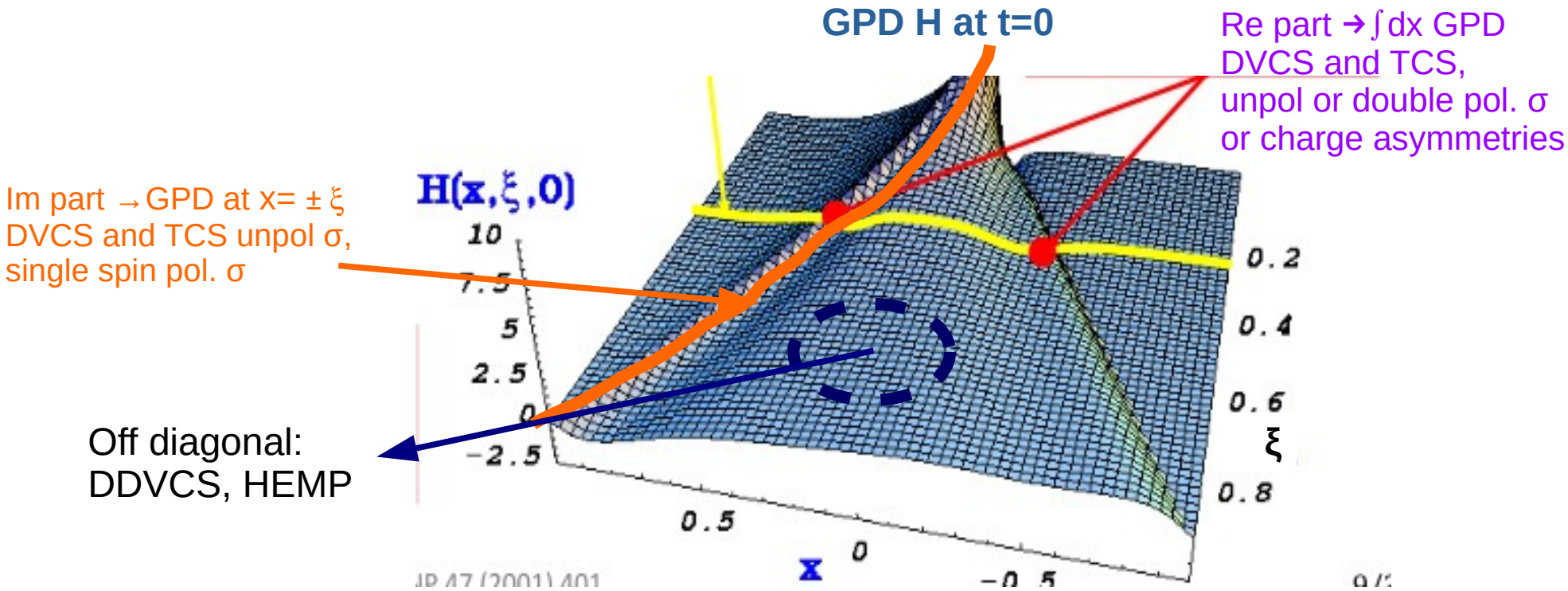
DDVCS gives a lever arm for going “off diagonal”, needed to **extrapolate to zero skewness**
- tomographic interpretations
- can move from “timelike” to “spacelike” region
- complementary observables for GPD data sets

Multichannel fit approach

“diagonals” with DVCS and TCS, “off diagonal” ERBL region with DDVCS

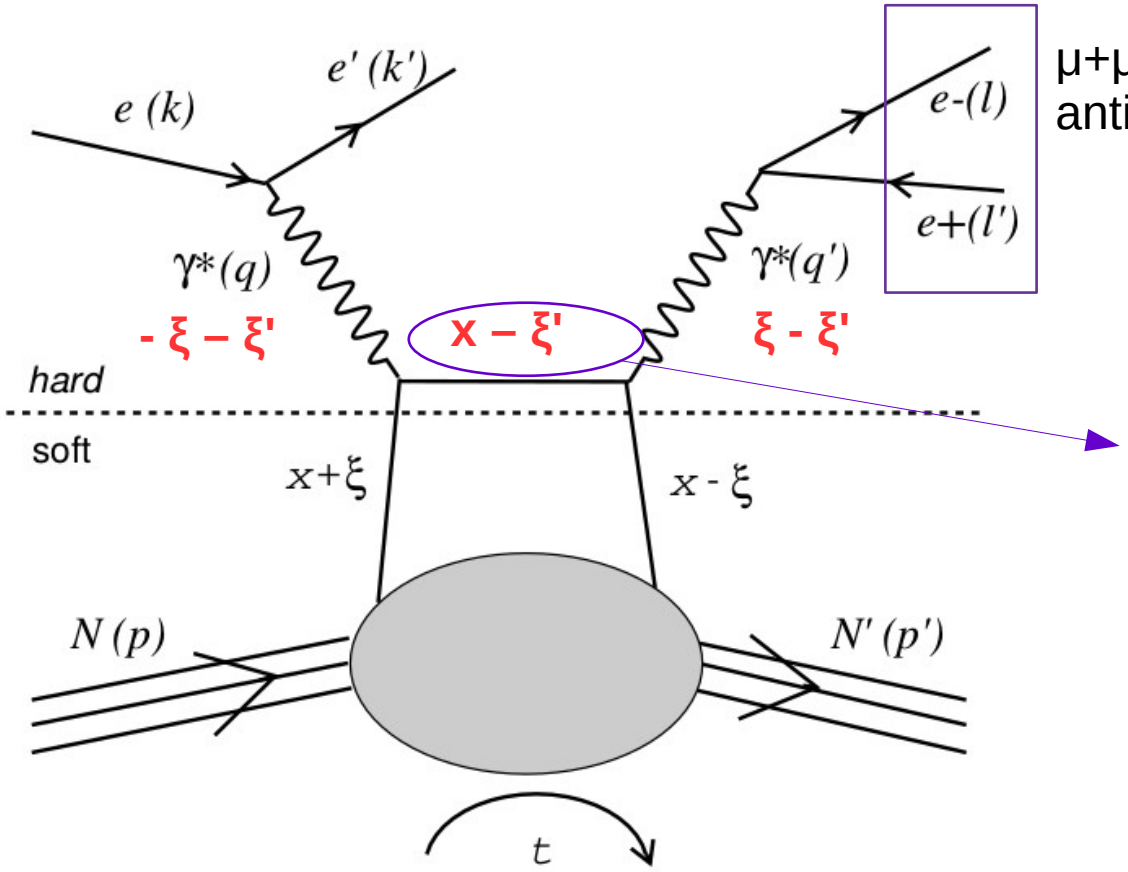
Slightly off diagonal with light mesons (meson mass gives lever arm)

However, unclear for gluon GPDs in this approach (gluon loop)



GPD in VGG model,
from Guichon, Vanderhaeghen, Guidal
Image: M. Guidal

Accessing GPDs with Double Deeply Virtual Compton Scattering



μ+μ- → avoid antisymmetrisation

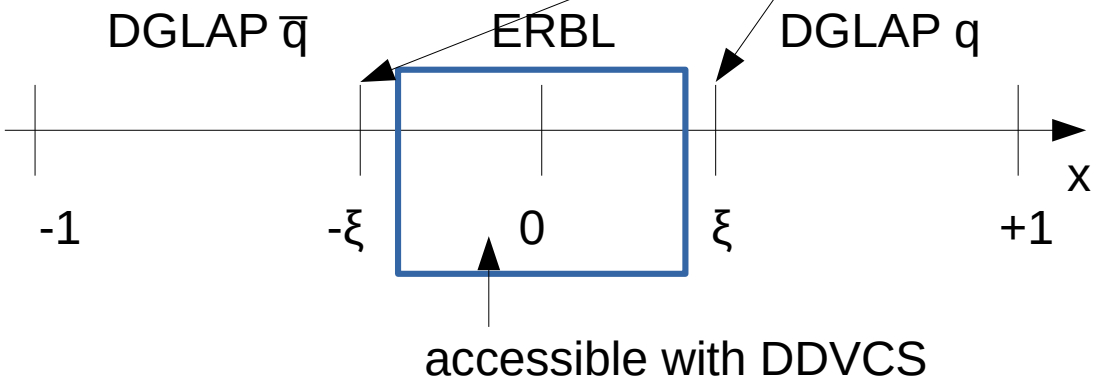
- ξ = + component of P=(p+p') in light cone frame. GPDs depend on it. "skewness"
- ξ' = + component of $\bar{q}$=(q+q')/2 in light cone frame. quark propagator can be related to x_{bj}

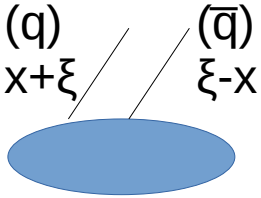
Special cases (at asymp. limit):
DVCS: ξ'=ξ; TCS: ξ'=-ξ

What do we learn?

M. Diehl's representations:

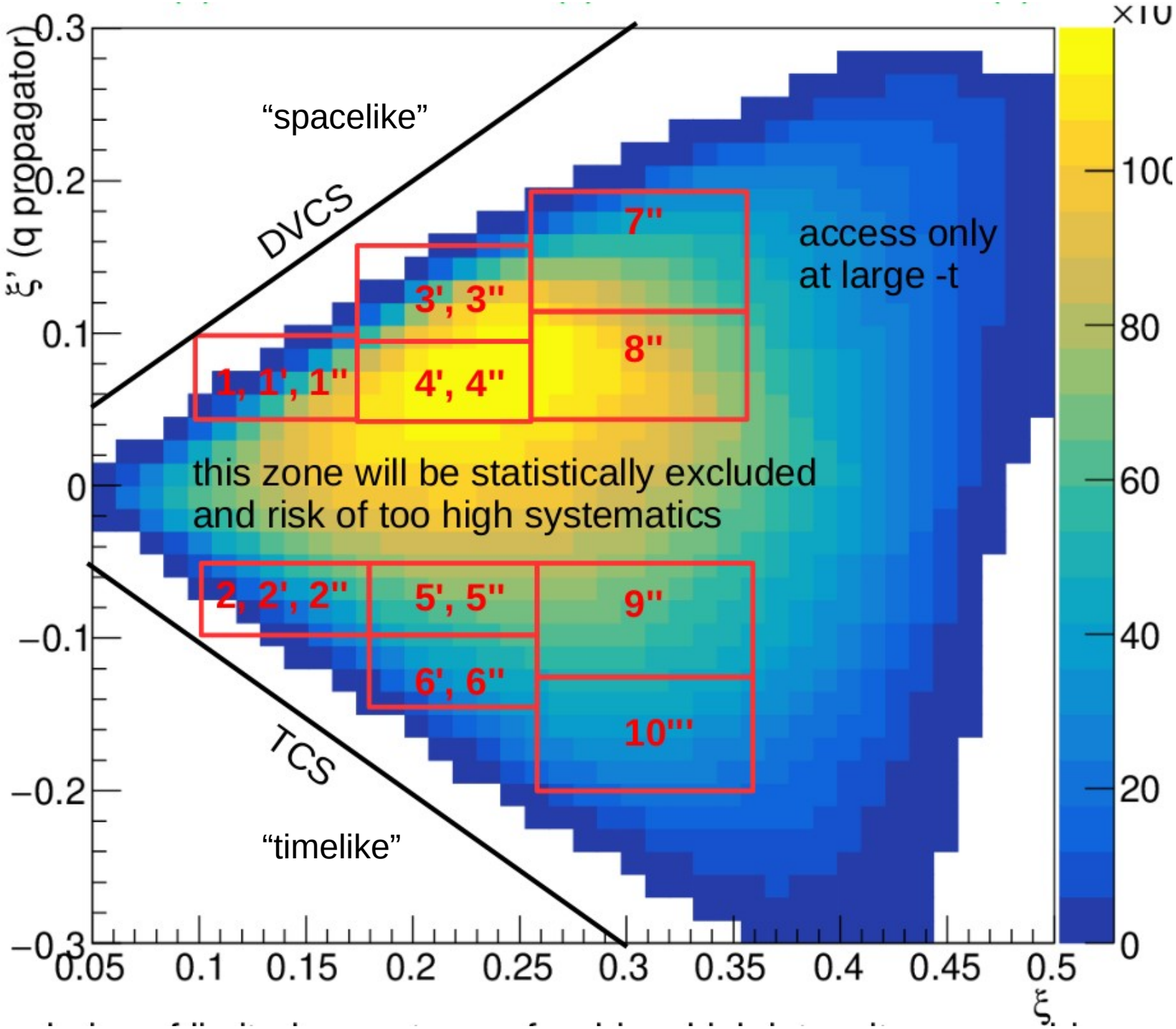
limit between the 2 regions:
Im(CFFs) from DVCS and TCS





partonic interpretation from M. Diehl in ERBL region

Full phase space to go “off diagonal” with DDVCS using a 11 GeV beam



What can we do with meson?

- Several measurements at JLab, mainly Hall B.
Rho is the “easiest” to measure given larger cross section and pion decay channel
*see presentations related to Hall B.

For JLab Hall A & C, high precision measurements with lower acceptance

- measurements of pseudo-scalars (pion…) together with DVCS
- Other mesons can be measured up to J/psi mass with 11 GeV beam

* Light vector meson:

- no officially existing program yet for Hall C
- projection made by SoLID collaboration (Hall A)
=> can existing data be used?
=> developing dedicated experiments for rho and omega

No results yet for Hall C,
Projections in progress
Working on developing such a program
(Deb. Biswas et al)

* Quarkonia

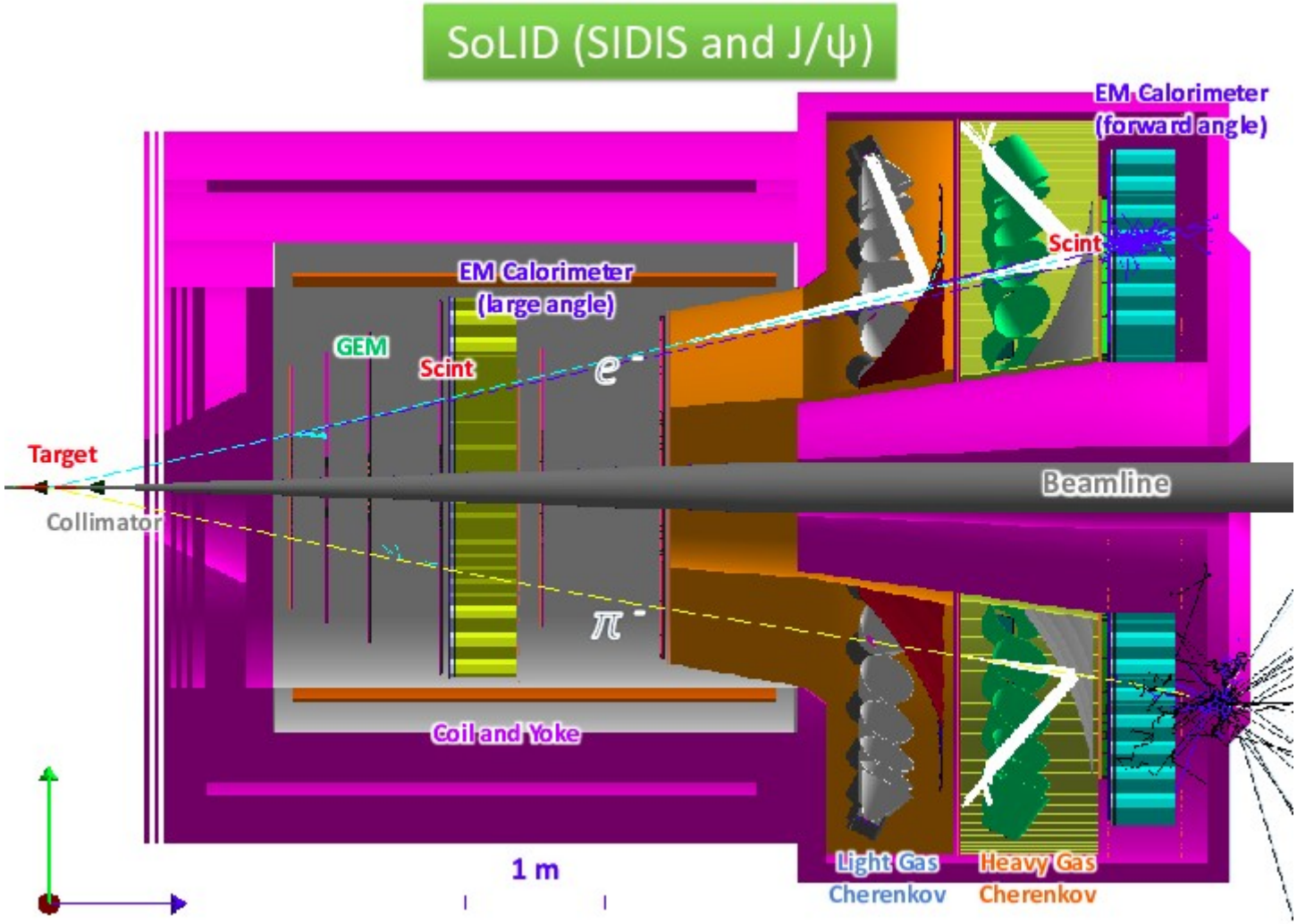
- J/psi measured in Hall C (unpolarized) and approved with SoLID
  (see J/psi-007 and SoLID collaborations results/projections)

- can we have a GPD interpretation near threshold?

Exploring what can be done
further: polarized targets…
(Erik Wrightson et al)

VT group & collaborators
Other groups have independent approaches also interesting in a GPD perspective

Experimental programs with SoLID for GPDs



TCS: approved experiment, together with J/psi (ranked A by PAC50)

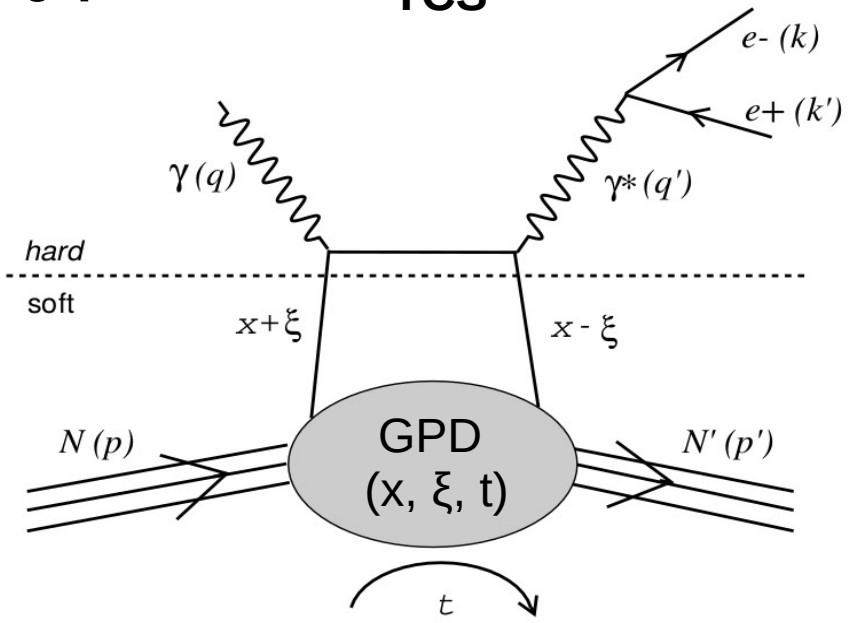
DDVCS: LOI in 2015, collaboration has updated projections but no full proposal yet

Mesons: some approved measurements, other projections in progress

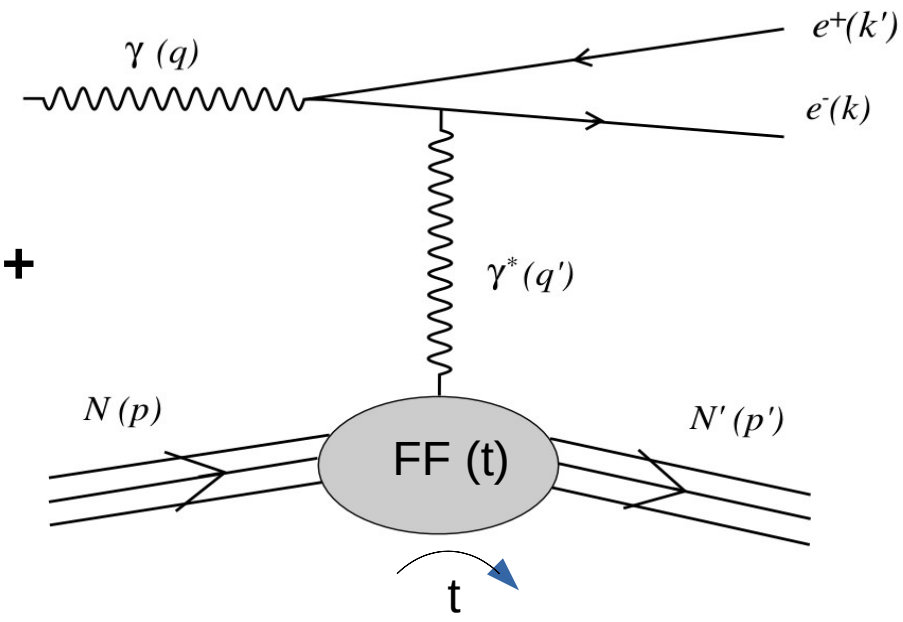
TCS with SoLID high precision measurement for GPDs universality

γ P → e⁺e⁻ P' =

TCS

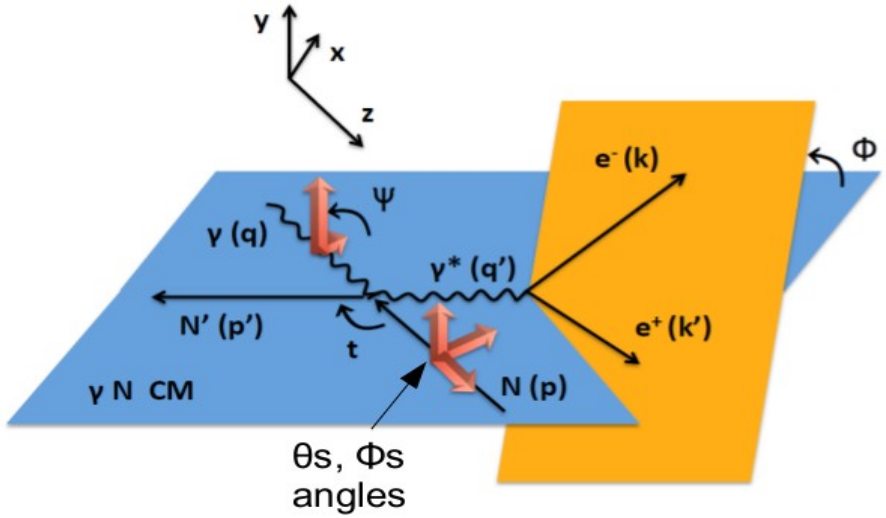


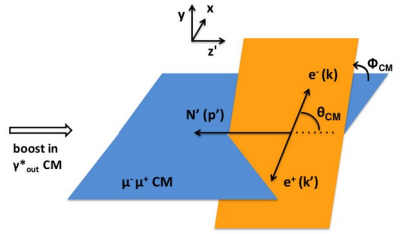
Bethe-Heitler



SoLID: using quasi-real photon from
5 to 11 GeV,
circularly polarized

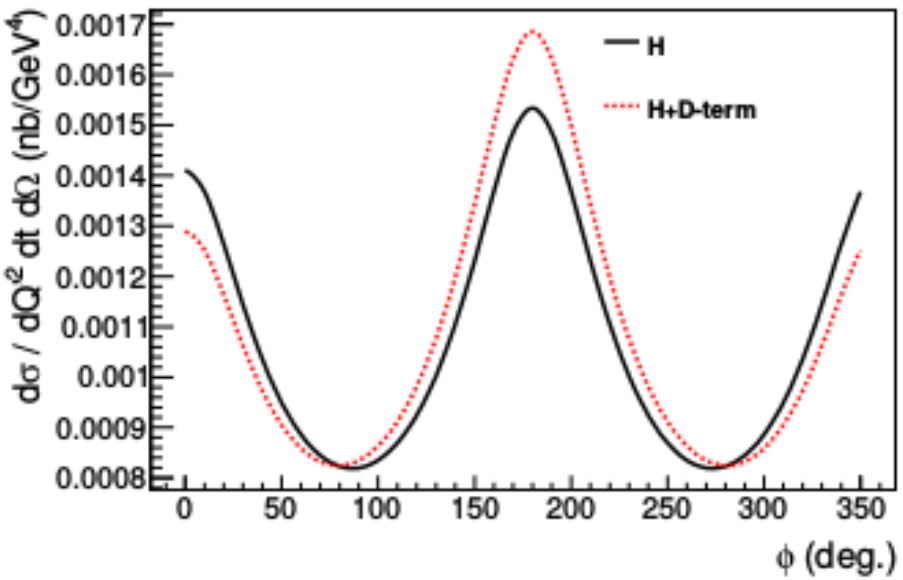
5 independent variables if
unpolarized
+1 with transverse target (phi_S)



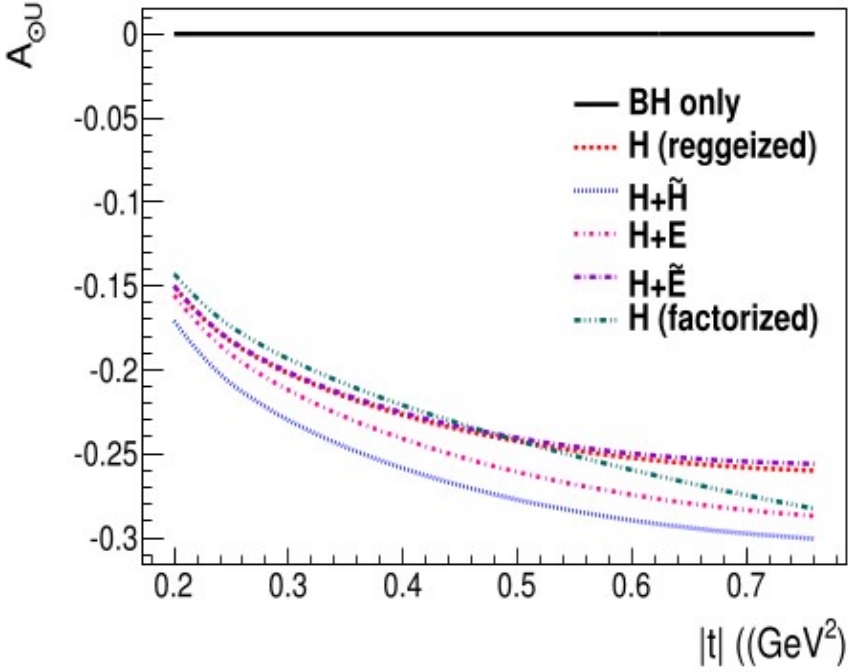


TCS with SoLID high precision measurement for GPDs universality

unpolarized x-sec vs φ, sensitivity to D-term (GPD H = VGG)



parametrization and t- dependence of beam spin asymmetry



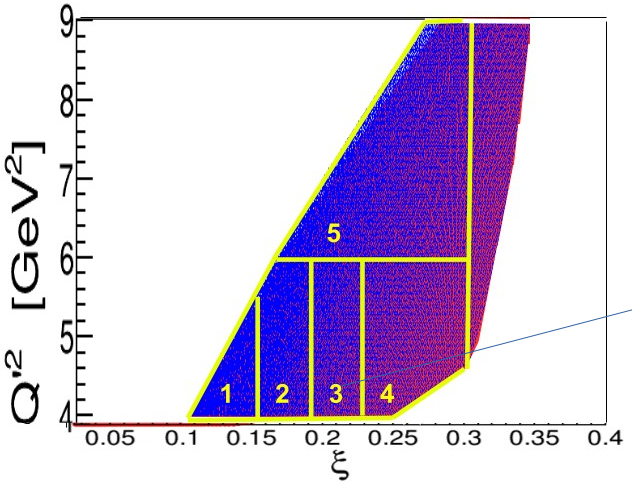
- Unpolarized cross section
- Beam polarized cross section differences

Large acceptance and high intensity measurement will enable access to cross sections

- extracting GPD H with enough precision level for GPD universality studies
- complement other TCS programs (need unpolarized cross section as “basis”)
- complement DVCS measurement in multi-channel fit approach

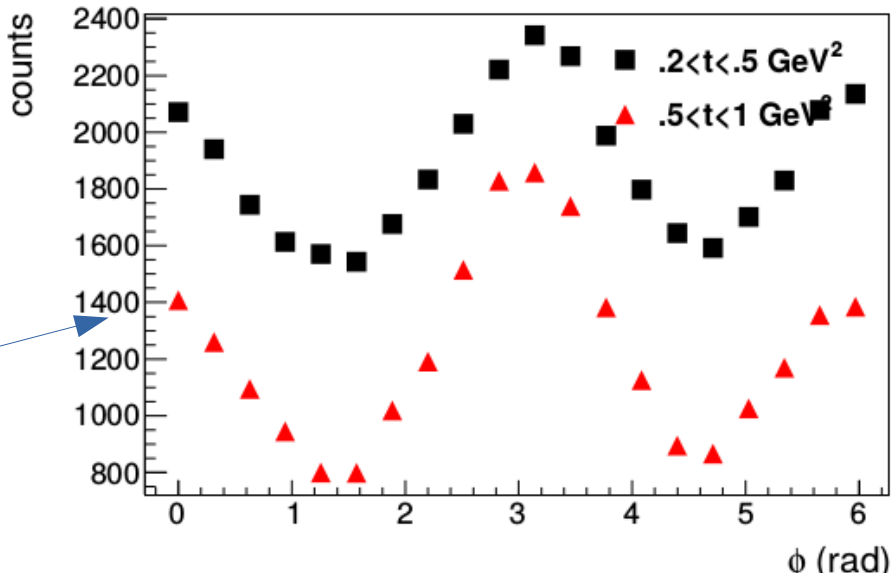
TCS with SoLID high precision measurement for GPDs universality

- Unpolarized cross section
- Beam spin asymmetry

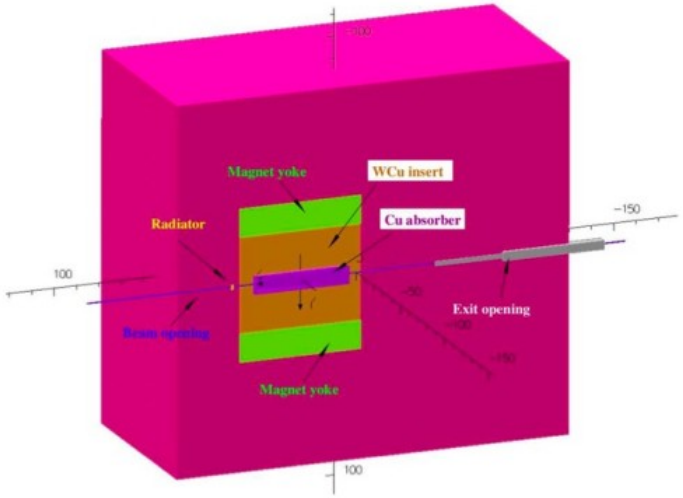


bin 3

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



Projections with quasi-real photon beam. Possibility for dedicated experiment with real photon, using CPS and slightly modified design

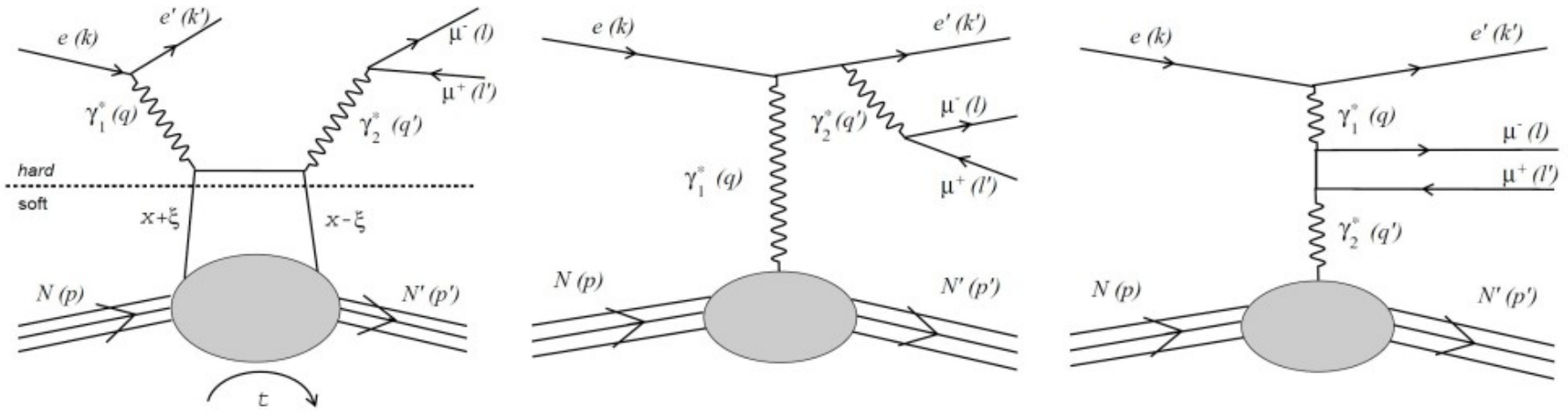


Compact Photon Source under development in Hall C at JLab:

- Combines polarized photon source, collimator and beam dump;
- High intensity directed brem. photon beam (**1.5x10¹² γ/s in [5.5 GeV, 11 GeV]** range from **2.5 μA primary e-** beam on **10% X_0 Cu radiator** , **~1 mm spot size** at 2 m from radiator);

DDVCS with SoLID

Unpolarized DDVCS. Below: Feynman diagram at leading twist/order for DDVCS & interfering BH

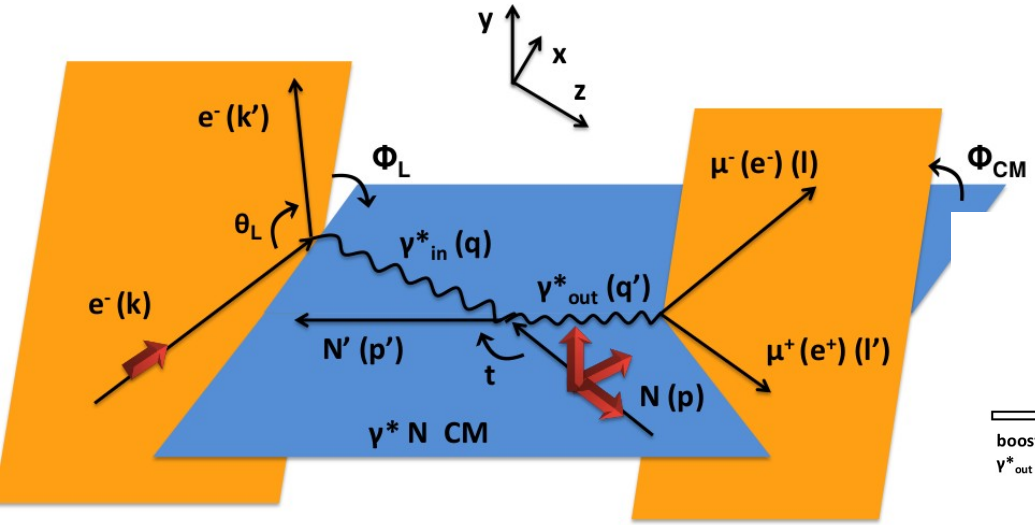


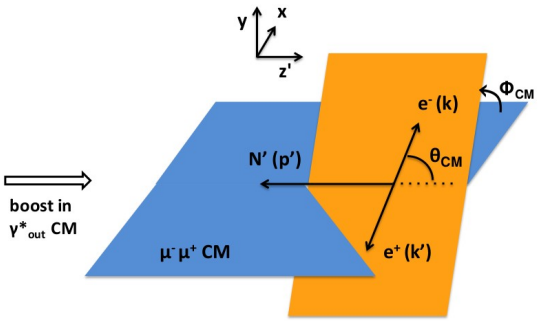
DDVCS
Access GPDs
Q'² != Q² & greater than 1 GeV²
Depends on x, xi, t + evolution

BH "type I"
(behavior similar to DVCS one)

depends on Form Factors (t), calculable

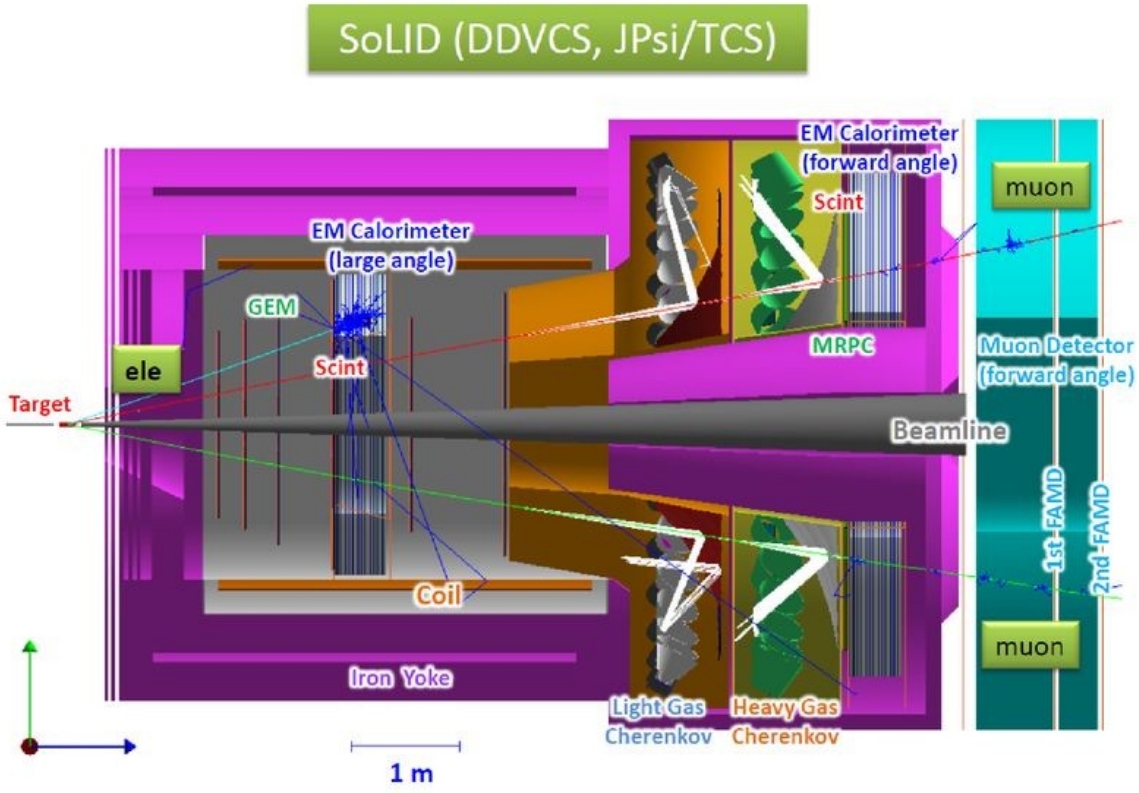
BH "type II"
(behavior similar to TCS one)





With 11 GeV polarized electron beam
7 independent variables for
unpolarized DDVCS

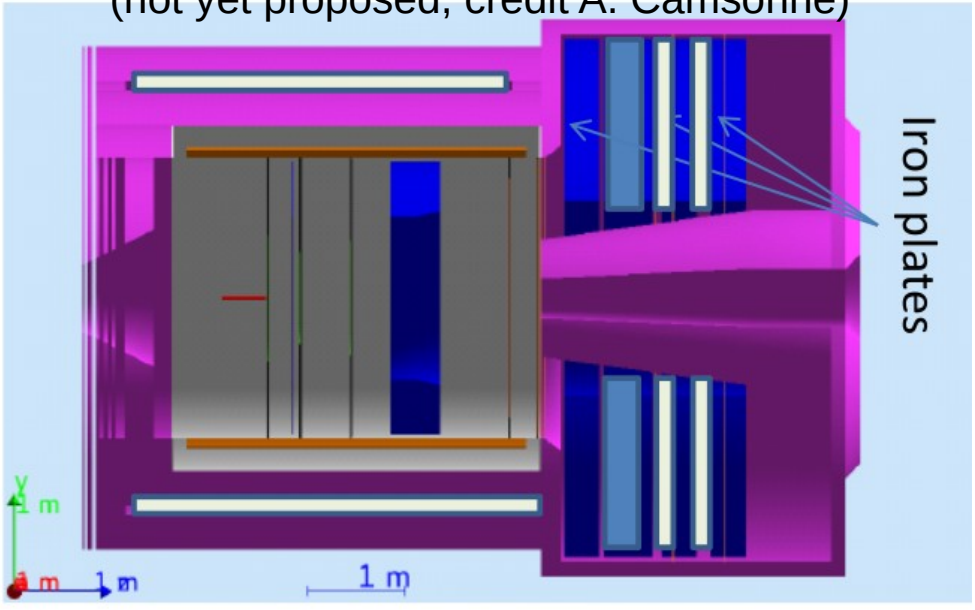
DDVCS with SoLID: proposed experimental setup



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

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

Dedicated setup
(not yet proposed, credit A. Camsonne)



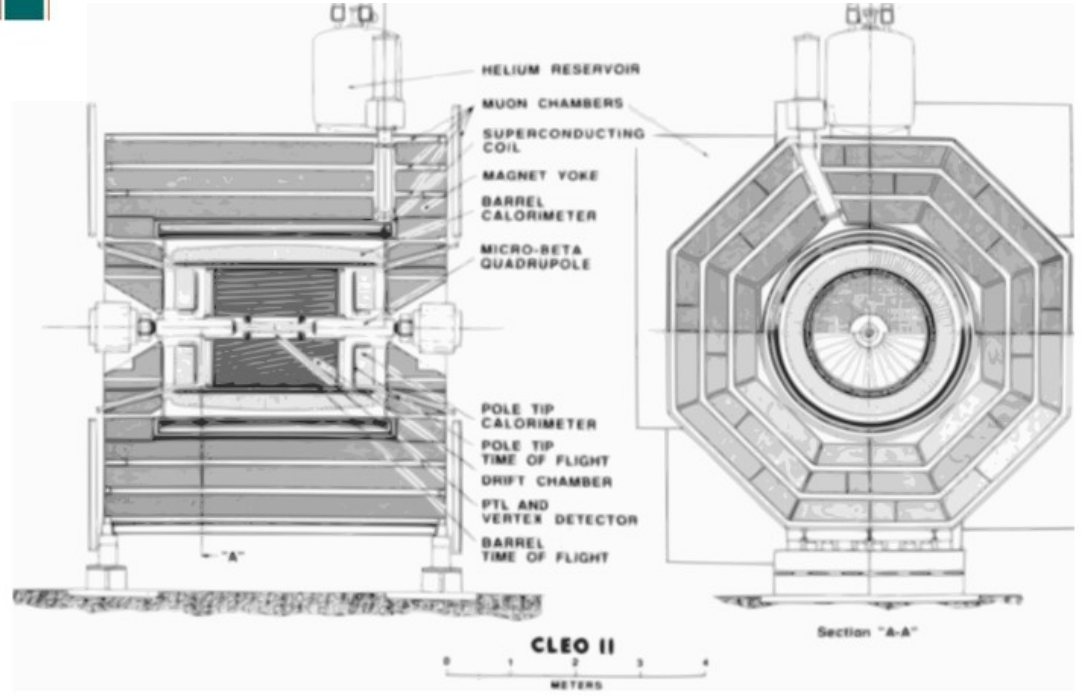


Figure 10: CLEO II setup with muon chambers installed inside the iron yoke.

Perspectives for high precision measurements with dedicated high intensity experiments at JLab Hall C

TCS: off proton and neutron, polarized and unpolarized

Opens to multi-observables to constrain all leading order, leading twist CFFs
+ flavor separation with neutron

DDVCS: dedicated setup will enable high intensity measurement

- statistics is the limiting factor with DDVCS, besides technical difficulties
- need a muon detector

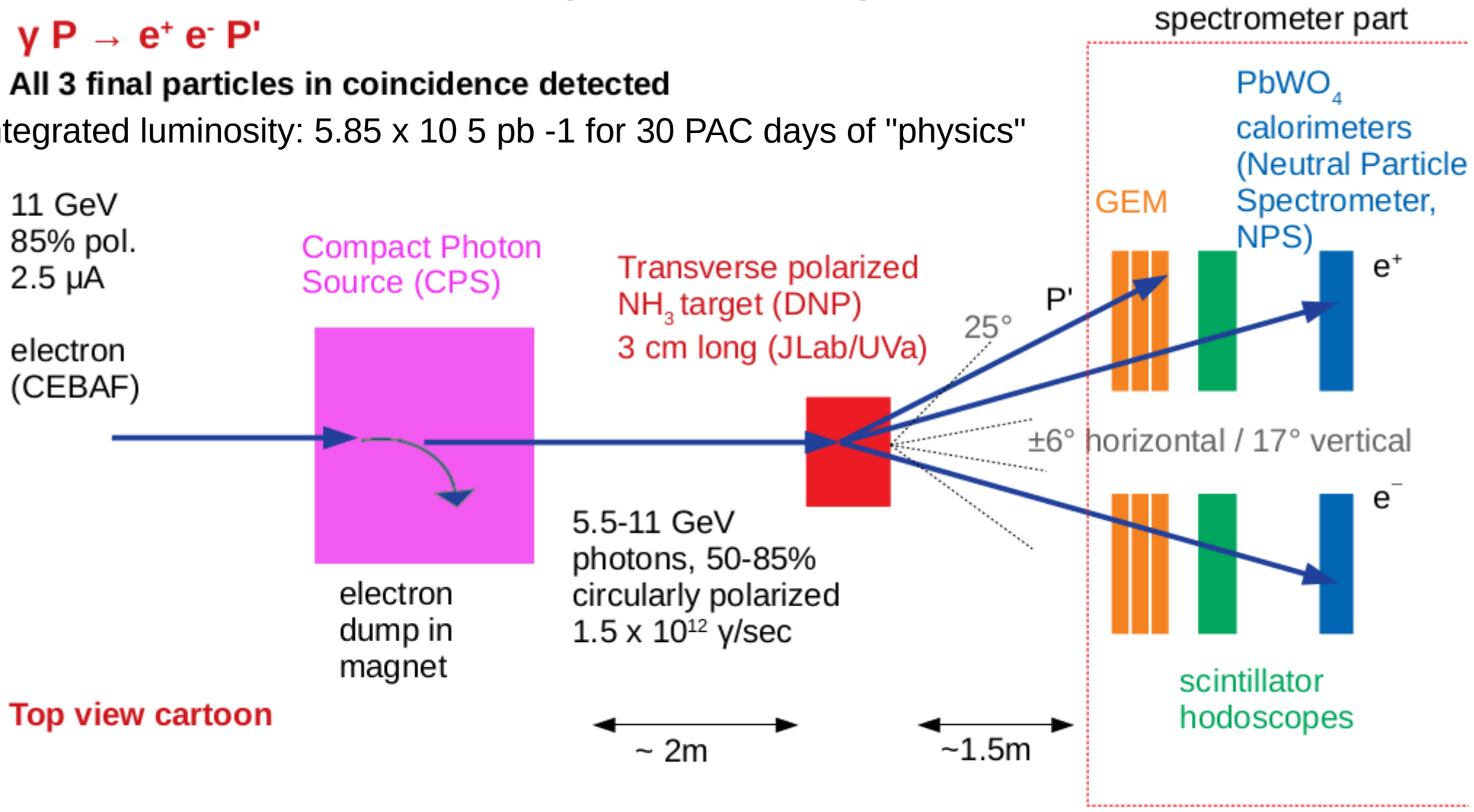
Proposed Timelike Compton Scattering in Hall C

Experimental setup

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

All 3 final particles in coincidence detected

Integrated luminosity: 5.85 x 10 5 pb -1 for 30 PAC days of "physics"



Top view cartoon

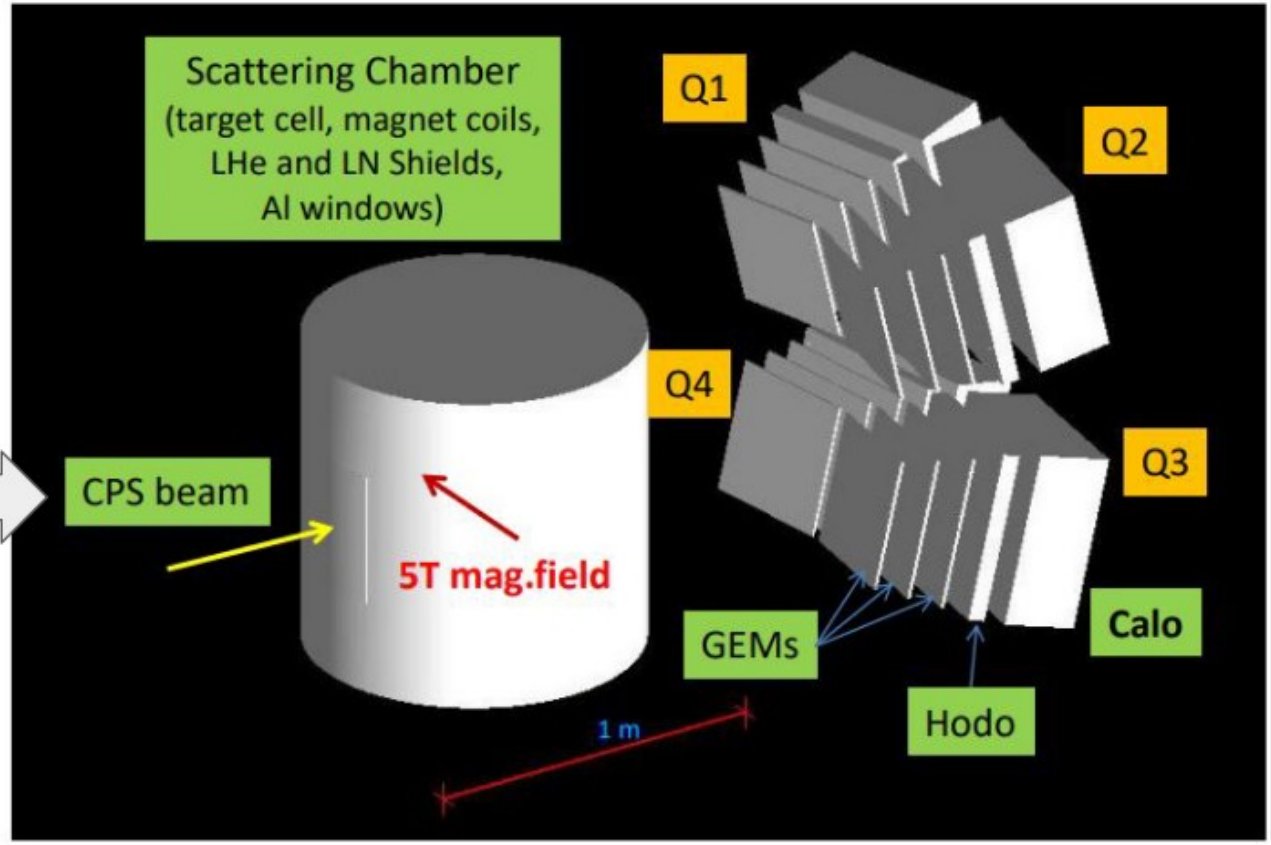
Trigger: GEMs, hodoscopes, calorimeters (all 3 particles)

PAC50 (deferred) encourages the efforts and loves the physics, but several technical aspects need more efforts/people in particular to handle high rates. The collaboration is actively working on returning

Proposed Timelike Compton Scattering in Hall C

Compact Photon Source and Neutral Particle Spectrometer collabs, JLab Hall C

$\gamma + p \rightarrow \gamma^* (e^+ + e^-) + p'$



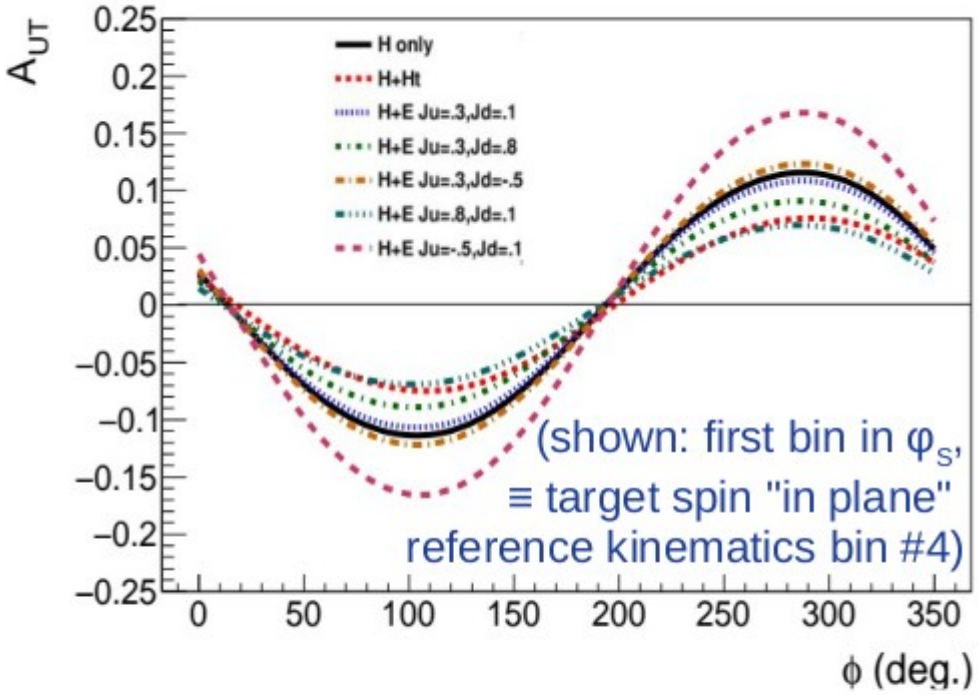
- Detect e^+, e^-, recoil p in coincidence
- CPS bremsstrahlung photon beam
- UVA/Jlab NH_3 target, transversely polarized
- Detectors arranged in 4 quarters, oriented to target
- Triple-GEMs for e^+, e^-, p tracking
- Hodoscopes for recoil proton detection/PID
- $PbWO_4$ calorimeters for e^+, e^-, p detection/PID

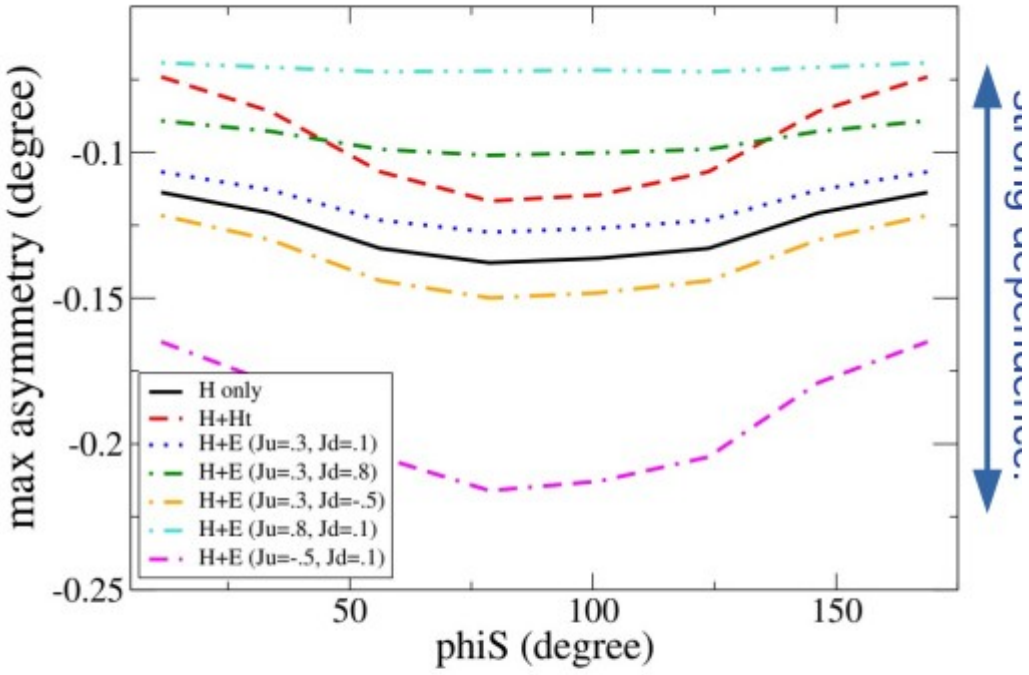
Slide Credit: V. Tadevosyan

Proposed Timelike Compton Scattering in Hall C

To be measured: single and double spin asymmetries with transversely polarized target

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





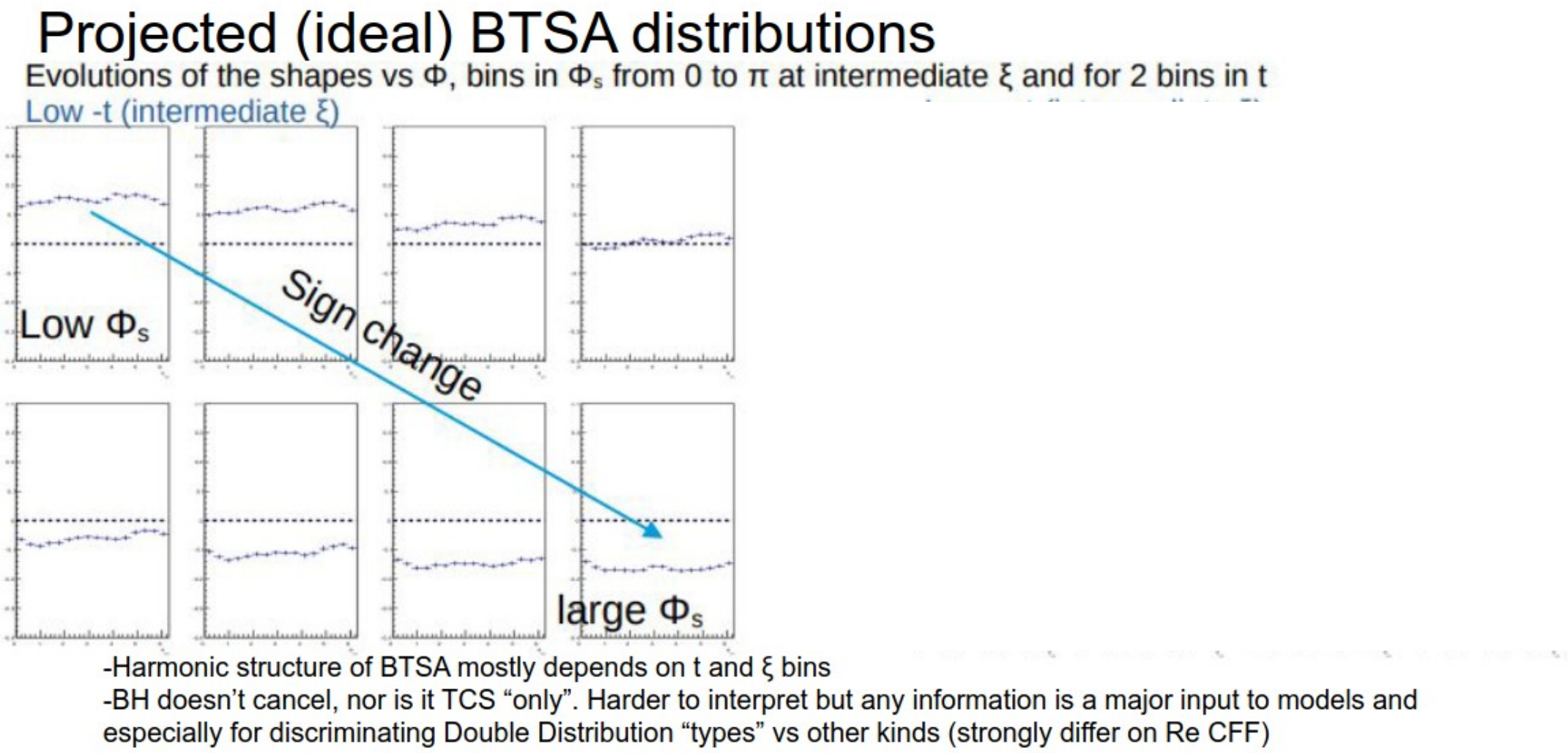
TSA with various quark angular momenta scenarios
(choice of same parameters as Jlab DVCS experiments)

- strong model dependence
- large sensitivity to angular momenta

Sinus momenta versus spin angle
=> discriminates model
=> huge dependence in J(quarks)

BH cancels: asym from Compton contribution

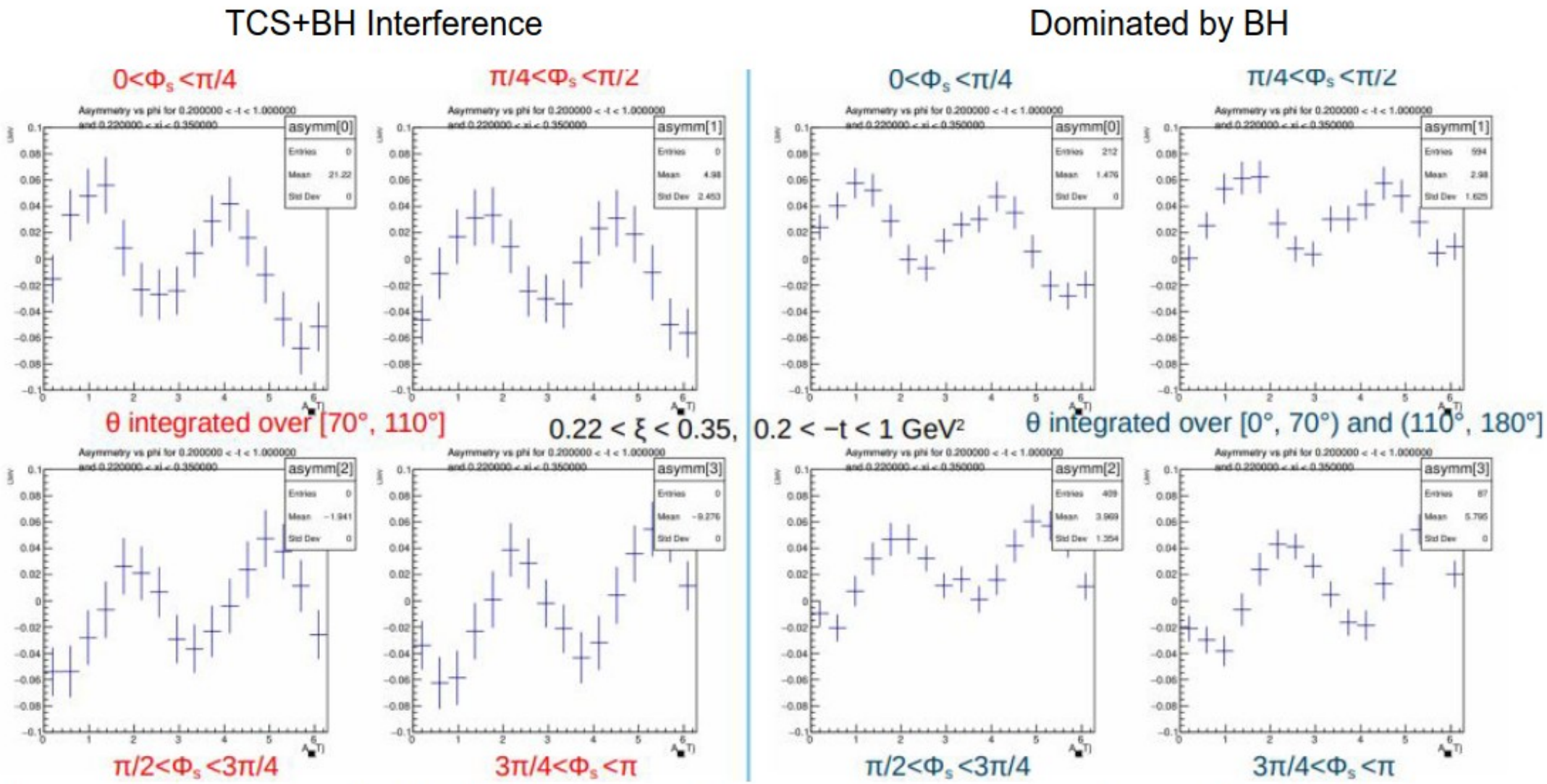
Double spin asymmetries, 1 bins as example (from B. Semp)



Unique access to real part. GPDs H and E, best way to access them

Doing TCS is technically more difficult than DVCS, but real photon beam off polarized target enables use of DNP transverse target without much depolarization effects

Double spin asymmetries, 1 bins as example (from B. Semp)

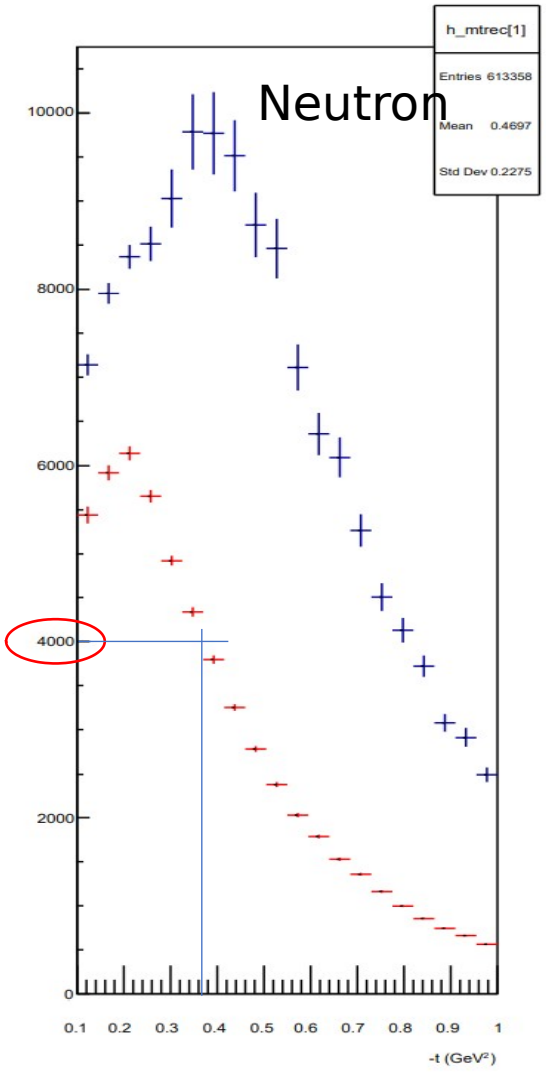


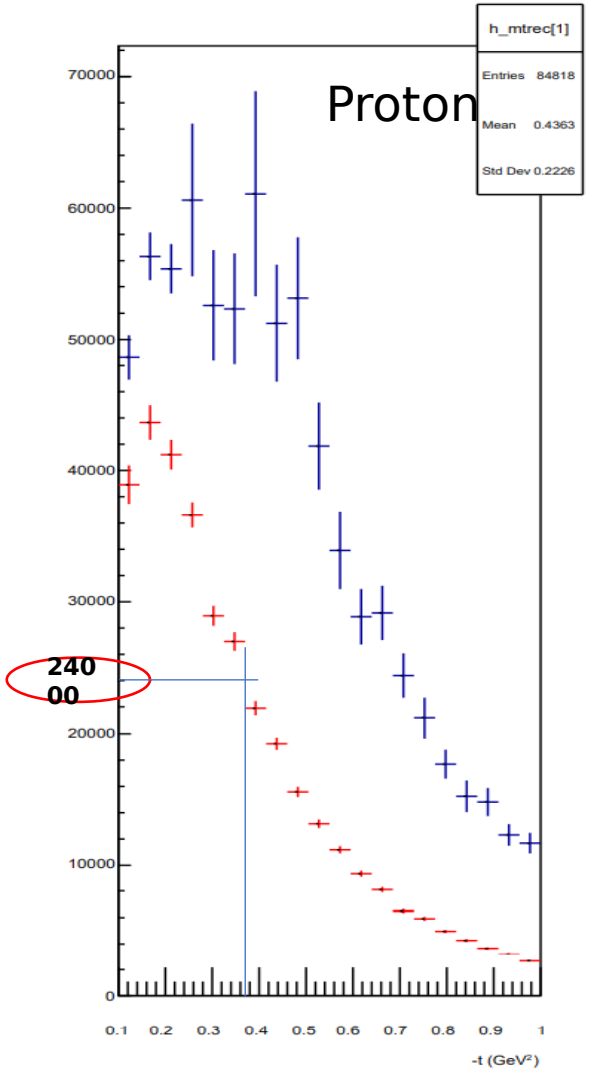
Asymmetries integrated inside [70°, 110°] show more extreme negative values compared to outside, which is only BH

Observable: BTSA, reduced from BH. Will fit the “full” BTSA in dynamic theta integration range
As a function of phi and phi_S

Other (yet to be proposed to PAC) upcoming TCS in Hall C
For universality studies and multi-channel DVCS+TCS fit approach

From C. Zindy



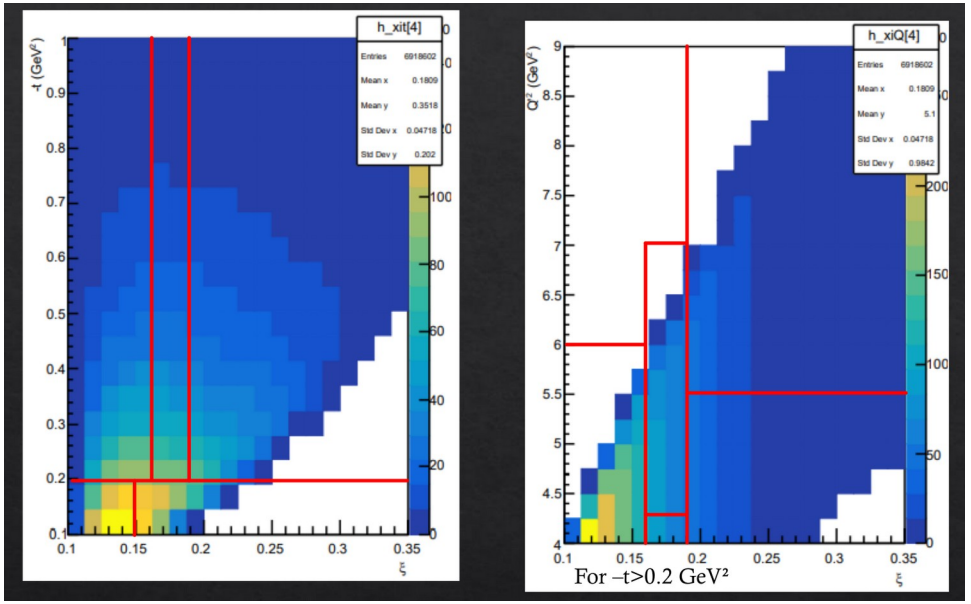


-t dependent cross sections, projection
For 30 days in hall C with similar setup as for polarized TCS,
LH2 and LD2 targets

- Both found to be measurable
- background easier than polarized (less “high rate” in transverse region)
- CFFs can be extracted

x6 statistics between proton and neutron

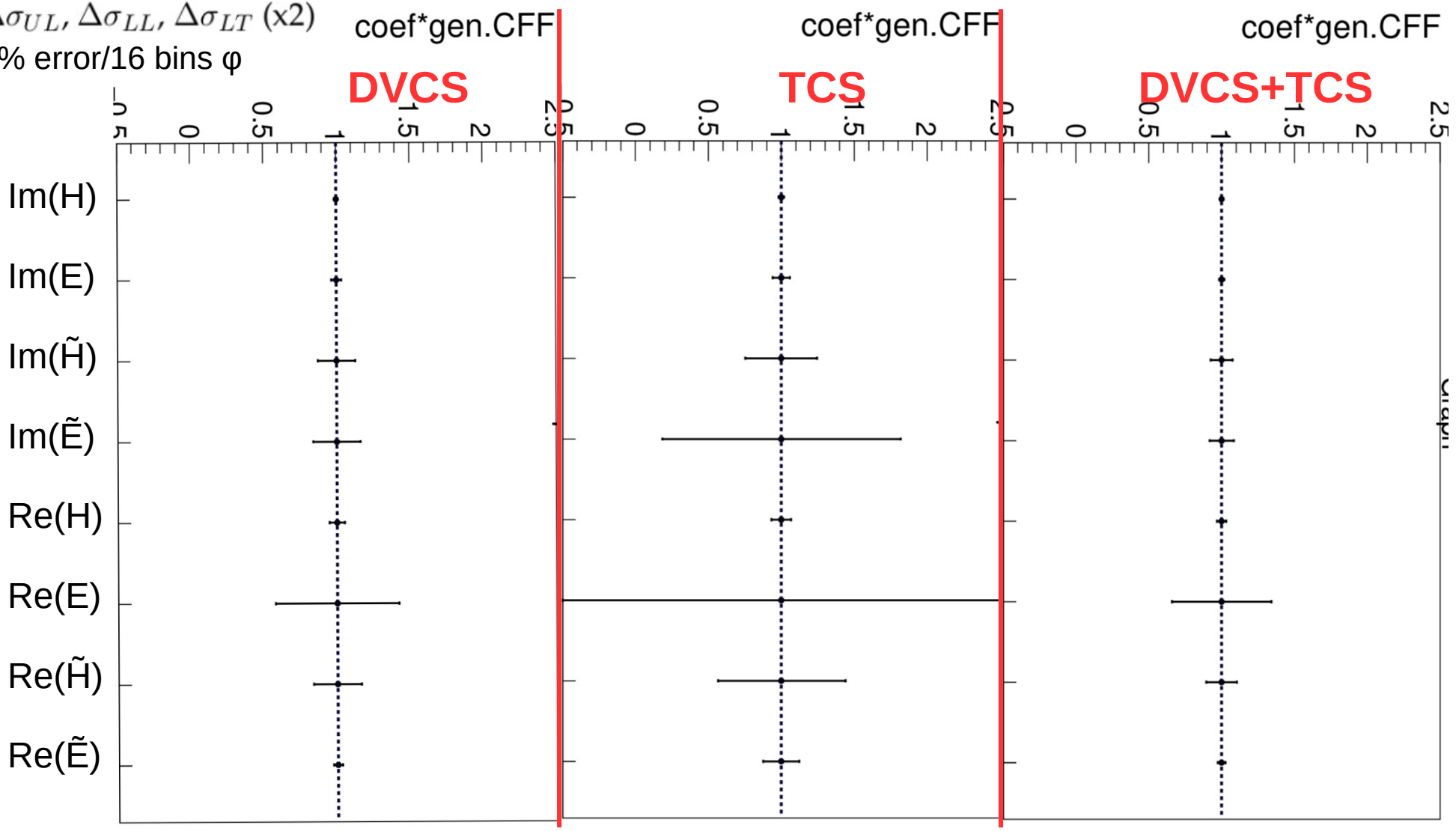
Binning in these studies, 5-11 GeV photon:



Status: updating projections with setup and background,
To be proposed in 2023.
Unpolarized+beam p & n. Next: longitudinal target

Global fits of Compton Form Factors with TCS

5) σ, $\Delta\sigma_{LU}$, $\Delta\sigma_{UT}$ (x2)
$\Delta\sigma_{UL}$, $\Delta\sigma_{LL}$, $\Delta\sigma_{LT}$ (x2)
7% error/16 bins φ



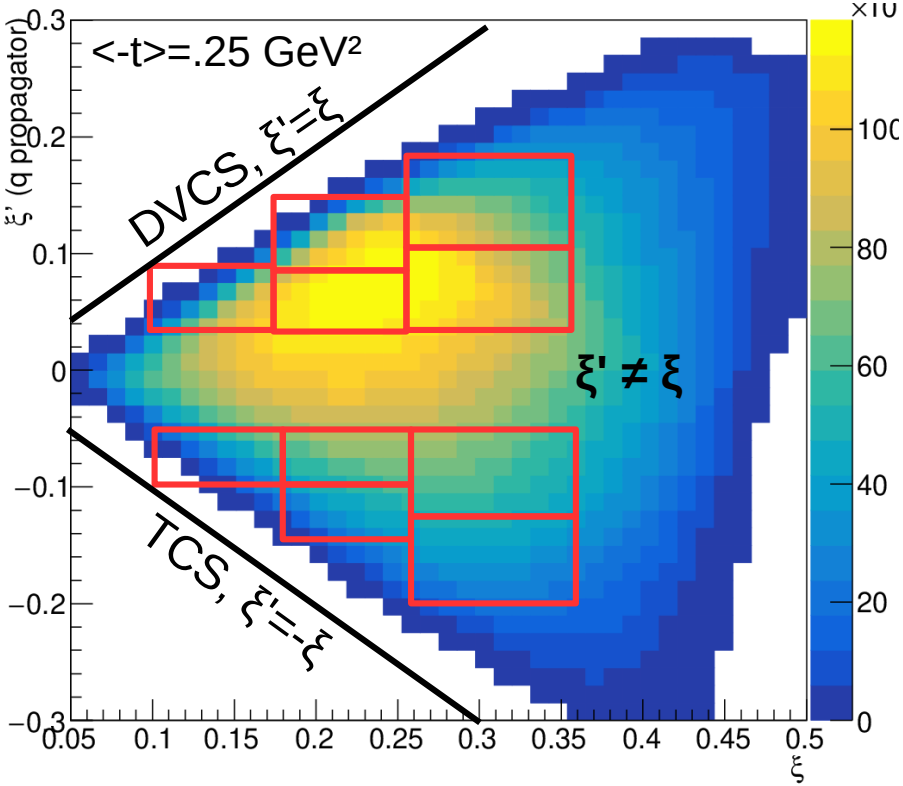
8 independent variables for each process: all unpolarized and polarized cross section differences
-t=.2 GeV², ξ=.15, Q²=2 GeV² or Q'²=4.5 GeV², E=11 GeV for DVCS, θ=90° for TCS
at asymptotic limit

This figure: assumes Hall A + Hall C + complementary measurements.
SoLID only: universality studies for GPD H, with Hall C: GPD E

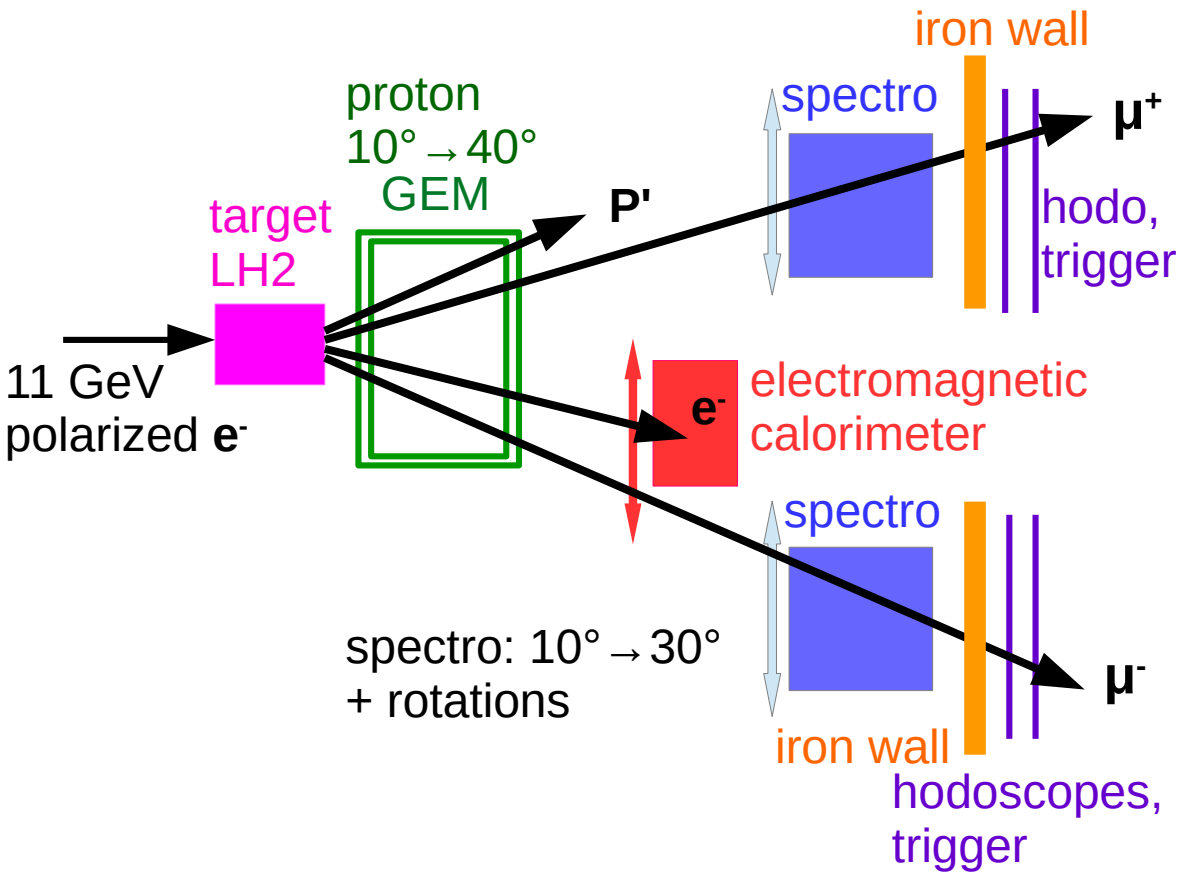
Prospects for DDVCS at JLab Hall C: e P → e' μ⁺μ⁻ P

- mesurements: σ(unpol.) + asymmetry(beam)
- GPDs can be extracted from 2D fits: φ_{pair} vs φ_L at fix E, xbj, t, (Q^2, Q'^2 if no evolution)

"off diagonal" GPD access: ξ' (±x) vs ξ,



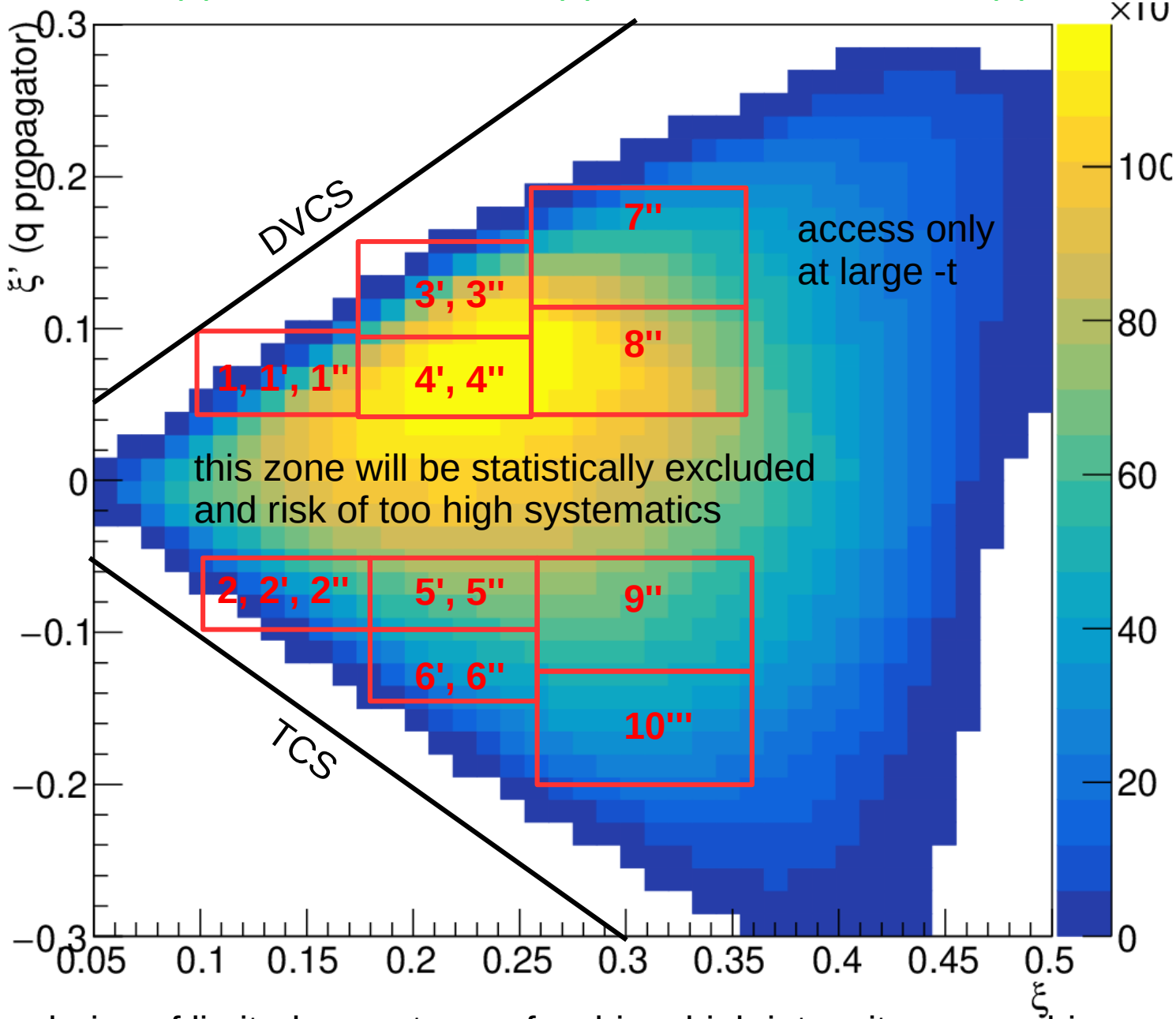
one idea for a setup in Hall C :
80 days at 75 μA, LH2 target. L=5.10³⁸ cm⁻²s⁻¹



Other setups “investigated”
- DVCS-like setup with proton detector + HMS + muon segmented hodoscopes
- similar with Hall A SBS spectrometer, for experiment in Hall C

Binning in ξ, ξ', all t

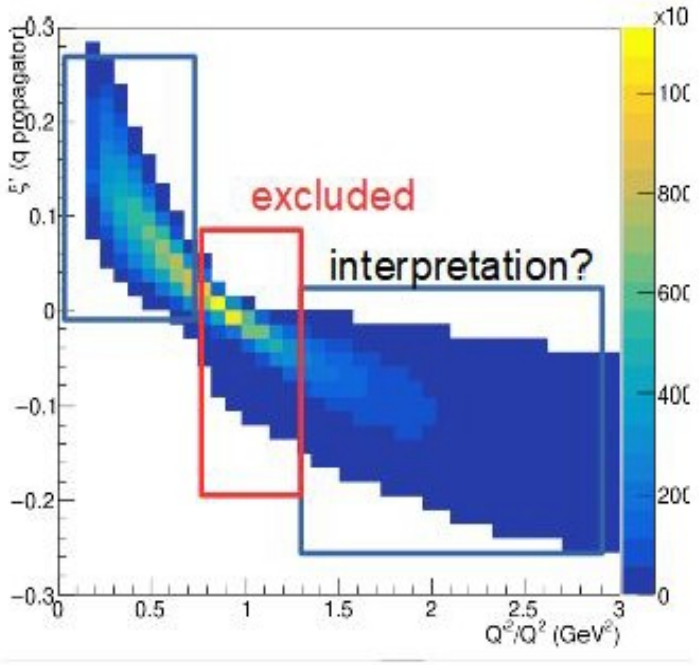
Bins in t: (1) 0 < -t < 0.15 GeV², (2) 0.15 < -t < 0.35 GeV², (3) 0.35 < -t < 0.55 GeV² (indicated ', '')

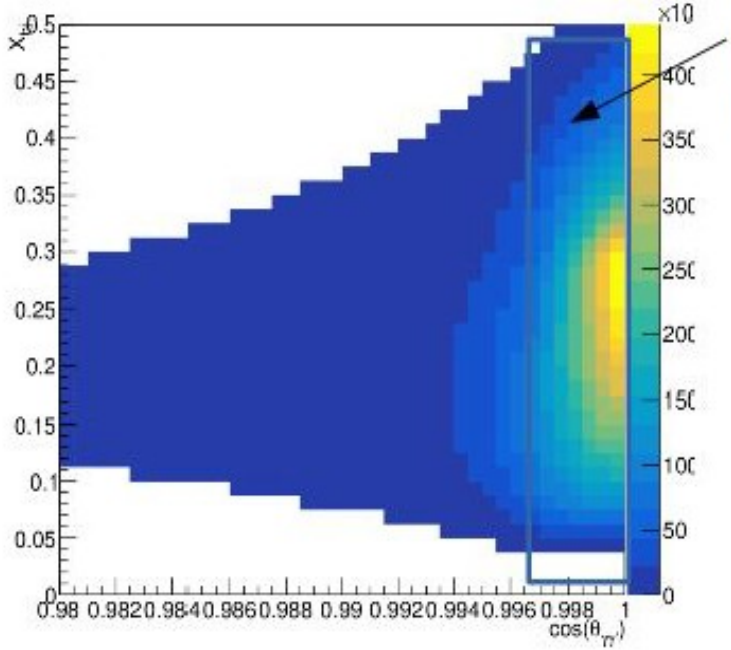


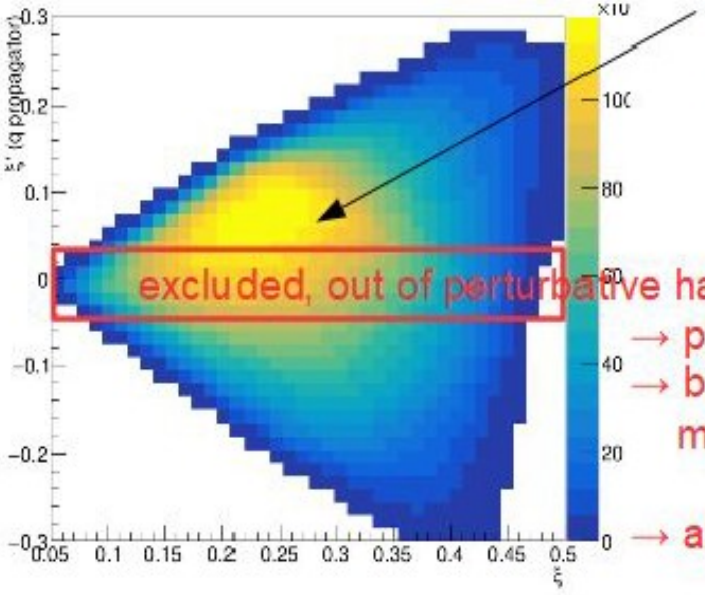
Bin in ξ	code # large/low t
A) .1 < ξ < .18 (all t bins)	
1) .05 < ξ' < .1	1, 7, 17
2) -.05 > ξ' >-.1	2, 8, 18
B) .18 < ξ < .26 (t bins 2 and 3)	
3) .1 < ξ' < .15	3, 9
4) .05 < ξ' < .1	4, 10
5) -.05 > ξ' > -.1	5, 11
6) -.1 > ξ' > -.15	6, 12
C) .26 < ξ < .36 (t bin 3)	
7) .12 < ξ < .2	13
8) .05 < ξ <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

- 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

Kinematic region we access with Hall C and setups we are looking for







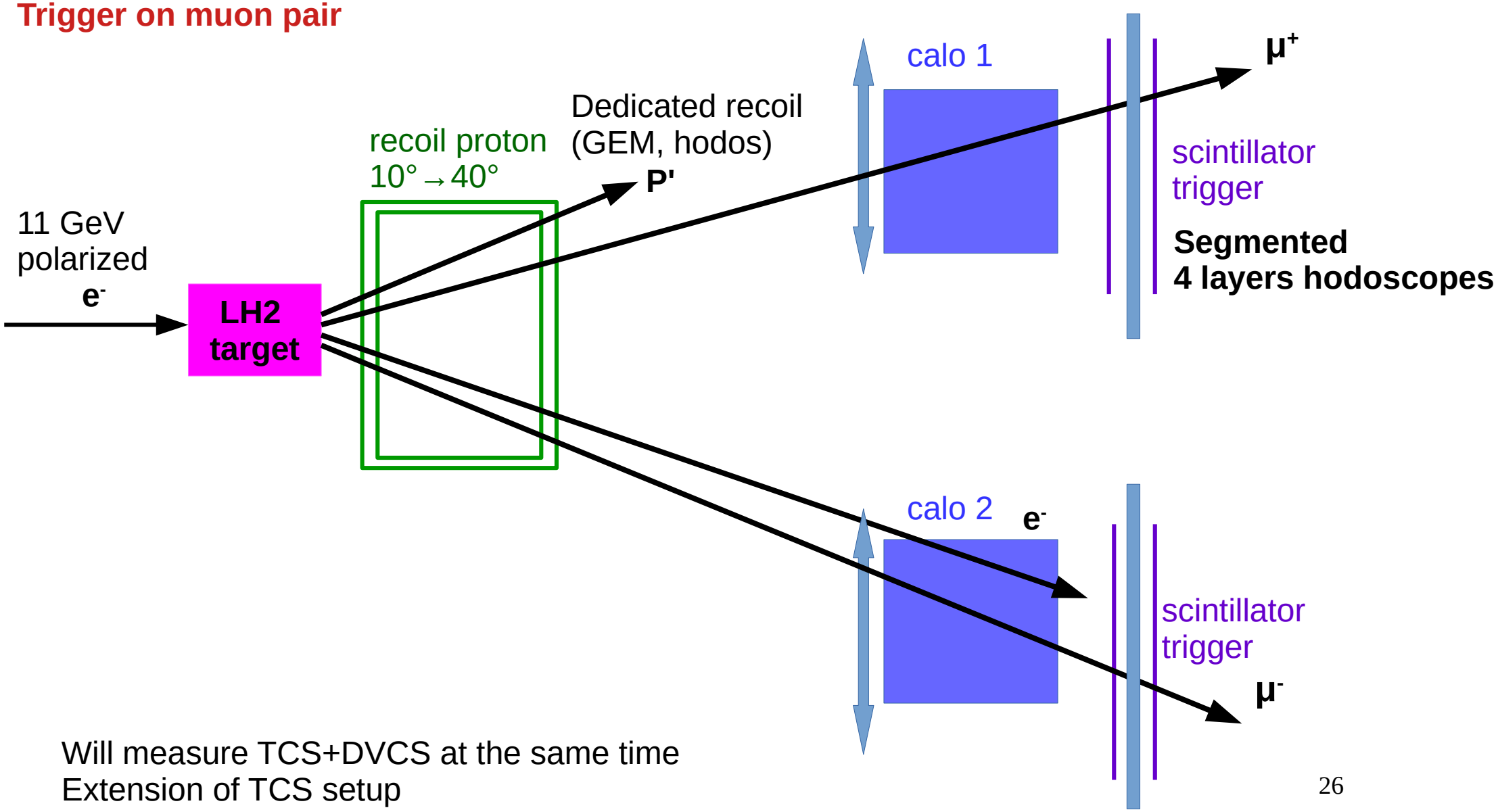
where do we want to have measurement?
this show how much "out of diagonal" we can go

→ 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 !!!

ideal detector position for different bins, assuming previous distributions "at vertex" are similar to the one with magnetic field
symmetric configuration for μ+ and μ- ⇒ better for interpretation and treatment of BH2

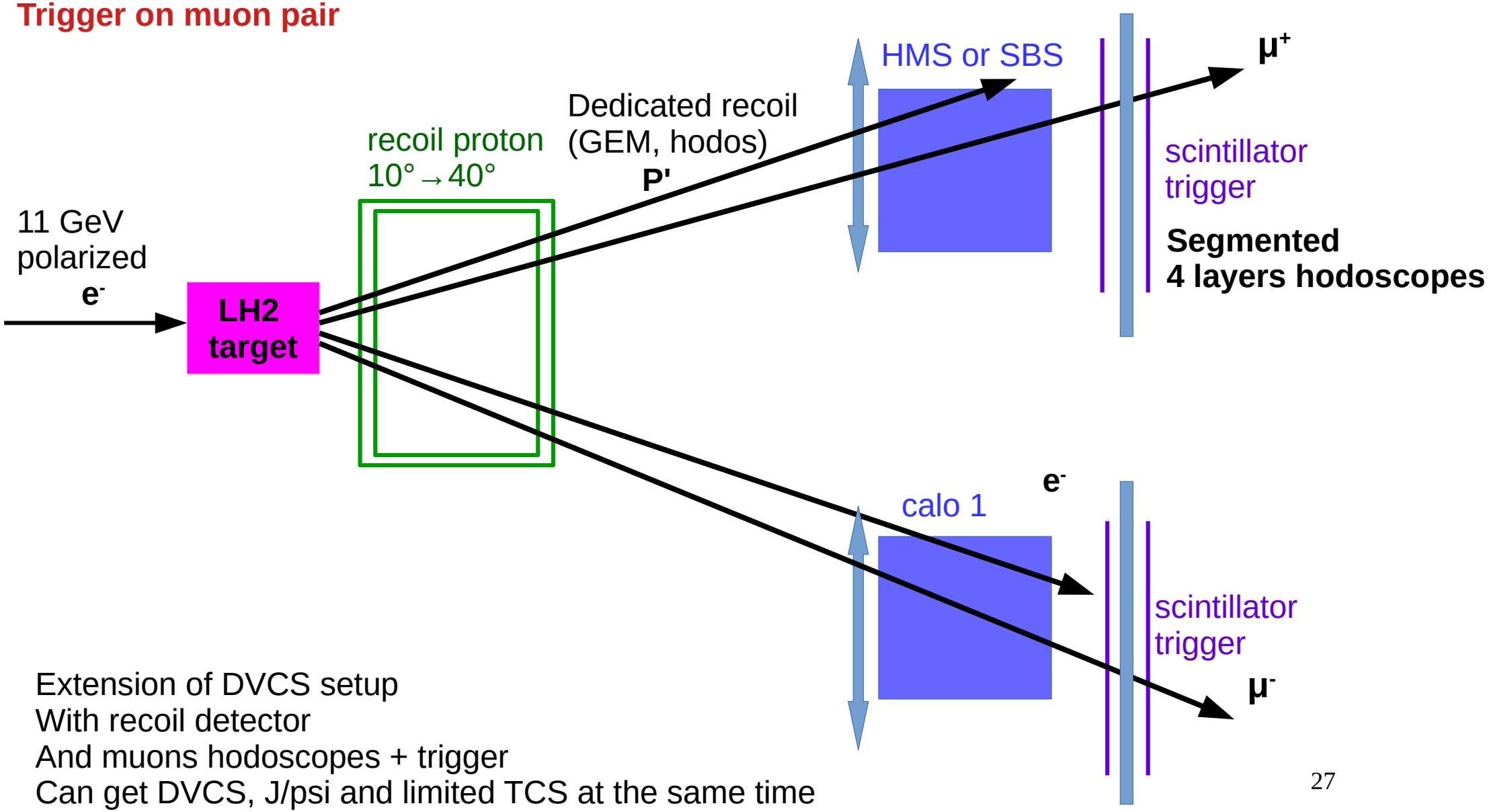
We need to detect all final particles for resolution in t
Trigger on muon pair



Will measure TCS+DVCS at the same time
Extension of TCS setup

ideal detector position for different bins, assuming previous distributions "at vertex" are similar to the one with magnetic field
symmetric configuration for μ+ and μ- ⇒ better for interpretation and treatment of BH2

We need to detect all final particles for resolution in t
Trigger on muon pair



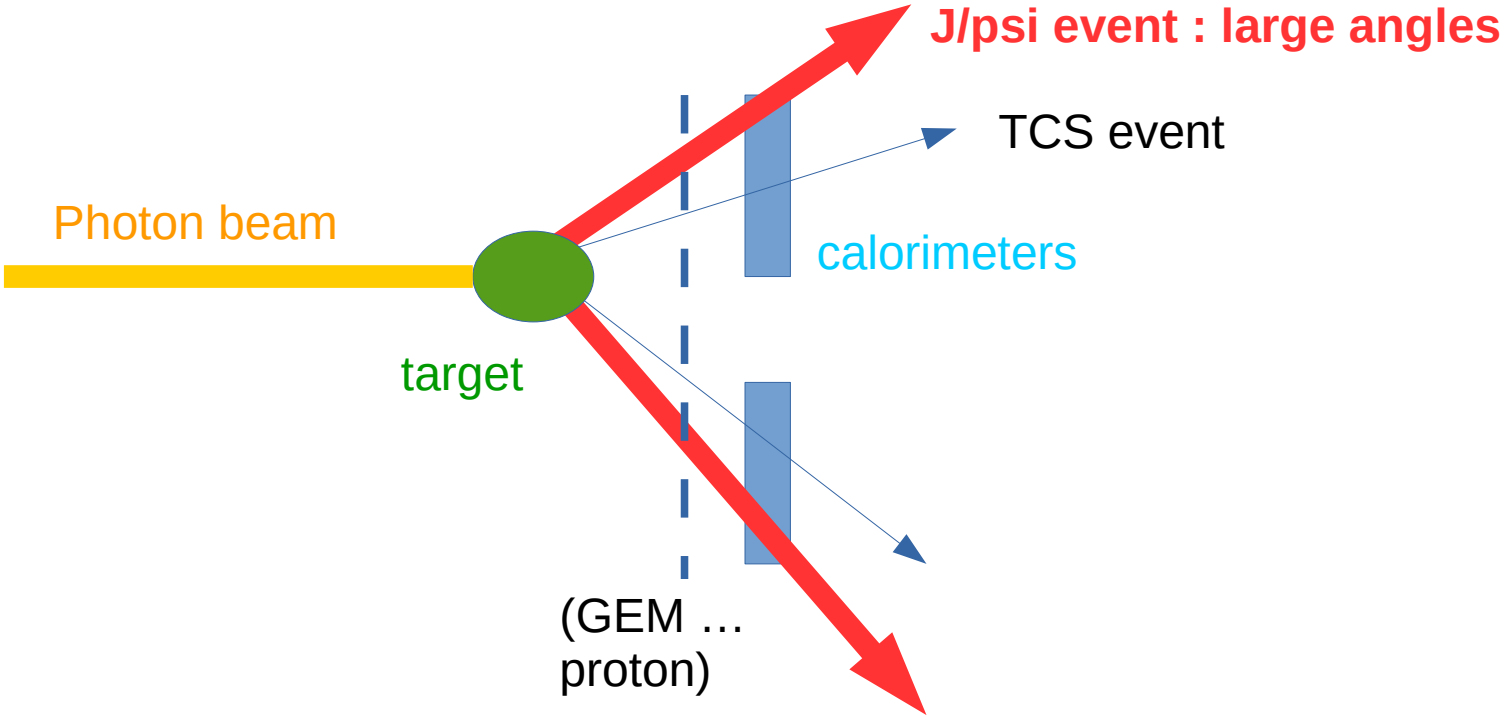
Extension of DVCS setup
With recoil detector
And muons hodoscopes + trigger
Can get DVCS, J/psi and limited TCS at the same time

Our plans for transversely and longitudinally polarized J/psi in Hall C

- similar as TCS setup
- larger calorimeter angles

Goal: J/psi production mechanism with 2 gluons exchange or dominated by higher twist
- bringing constrain to models
- when can we start to have a GPD interpretation?

(E. Wrightson et al)



SUMMARY

Accessing GPDs from multiple reactions

- GPD models with multichannel fits
- universality
- extrapolation to zero skewness

Existing programs at JLab (not in this talk)

SoLID large acceptance spectrometer

- several approved experiments: TCS…

Hall C dedicated experiments

- several DVCS measurements approved
- TCS program partially submitted, still some work and other observables to submit
- light VM program in progress
- going further with polarized J/psi?

THANK YOU