Generalized Parton Distributions in a multichannel experimental approach

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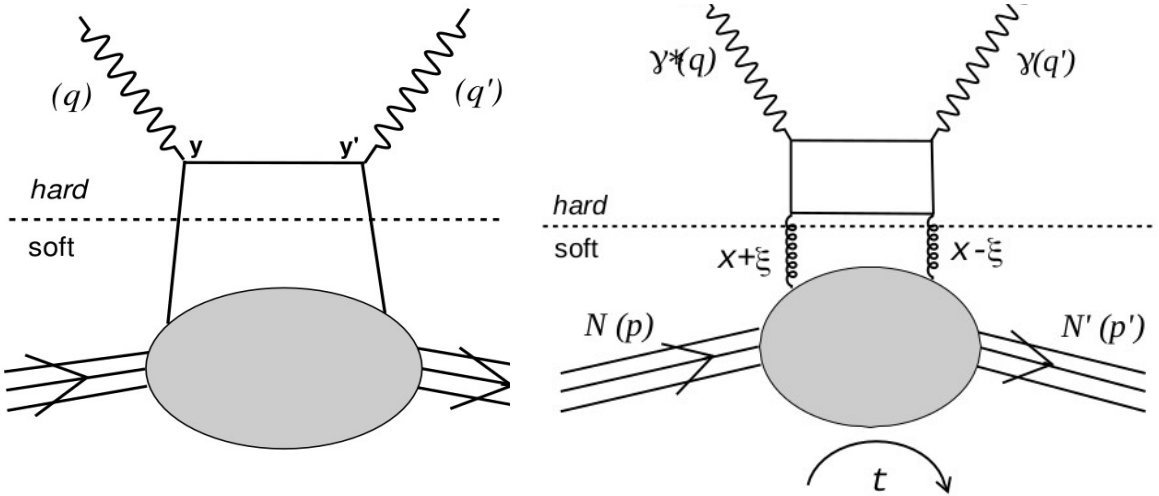
DIS conference – Michigan State University

PARTONIC STRUCTURE OF THE HADRONS

Our goals

- Multidimensional imaging of the nucleon
- Multichannel fits of GPDs
- Studies of potential channels to access GPDs beyond DVCS
- What can be done at JLab, and what are we preparing (Hall A & C)

Accessing 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)

→ Lot of measurements, but would still need (polarized) observables at some kinematics

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

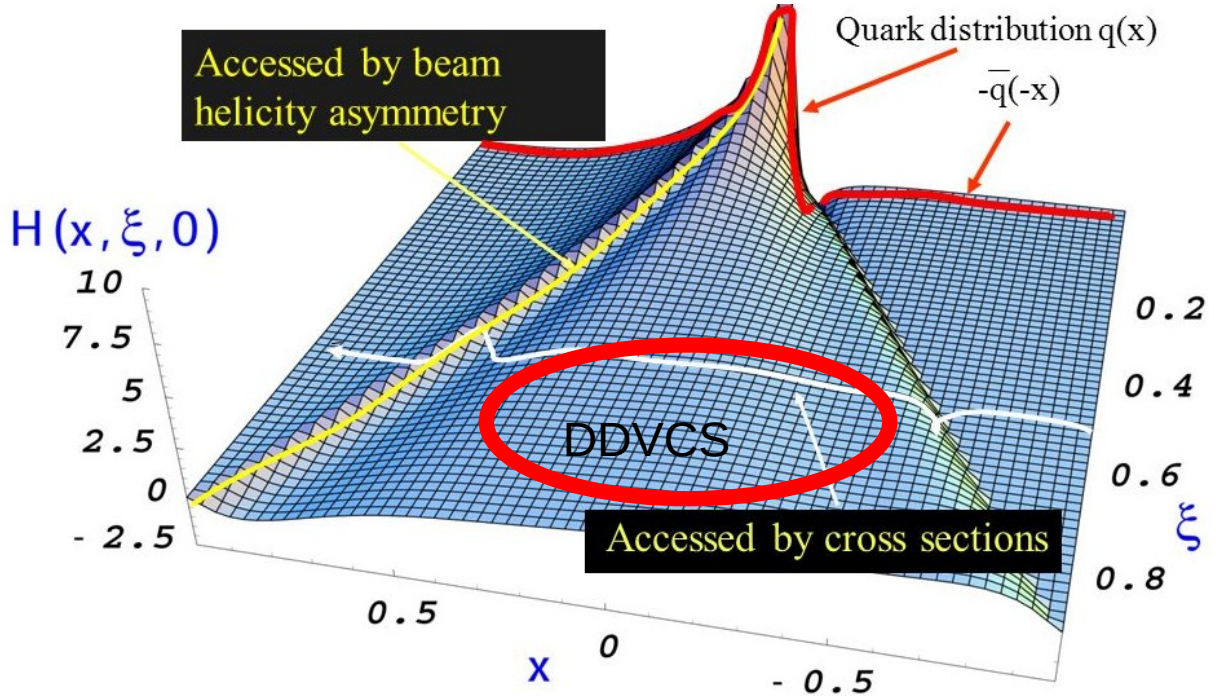
→ Need measurements

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

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

→ Theoretical studies for now (very interesting)

Accessing GPDs with Compton-like reactions



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

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

Accessing GPDs with Compton-like reactions

1. Universality of the GPDs

- DVCS versus TCS or DDVCS in different kinematic regions
- test of QCD “building blocks”, assumption that structure functions are universal
- can explained effects observed in DVCS from higher twist / NLO, thanks to different subprocesses in TCS

2. Tomographic interpretations, access to ERBL region

- DDVCS access “off diagonal”, needed to deconvolute x and xi, extrapolation to zero momentum
- DDVCS is the “golden channel”
- other channels: multi-final states, mesons

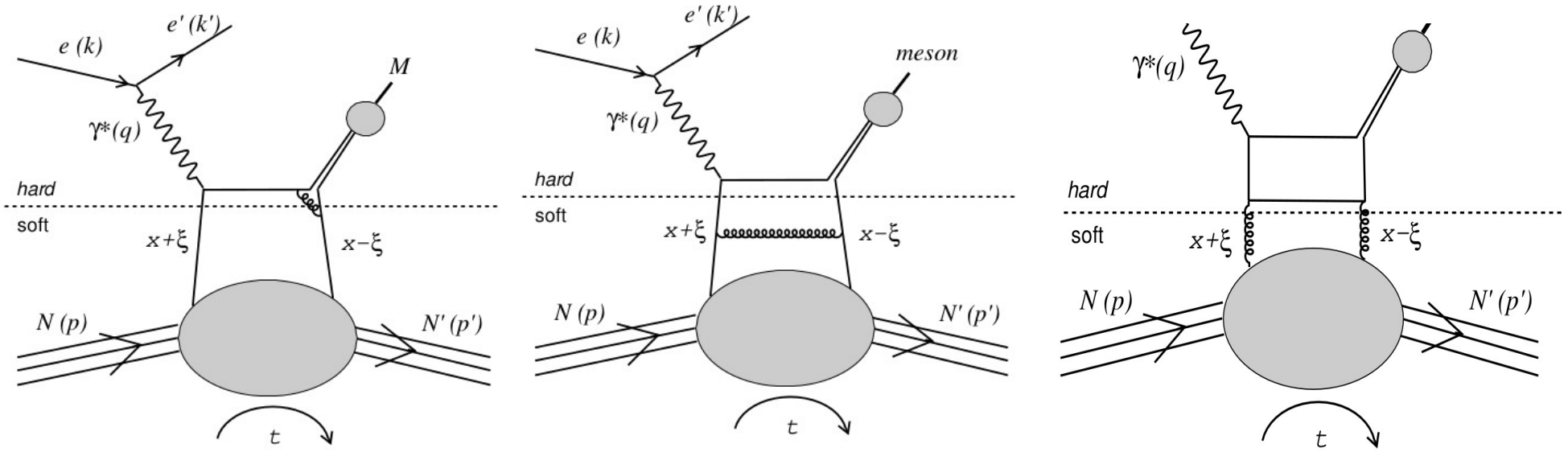
3. Spin structure

- Assuming GPD universality: complementing data sets with new observables from TCS, DDVCS, others...

Many other interpretations we are not focused on for now

Complementary: (vector) mesons

GPDs with Hard Exclusive Meson Production (few example of diagrams, we focus on VM)



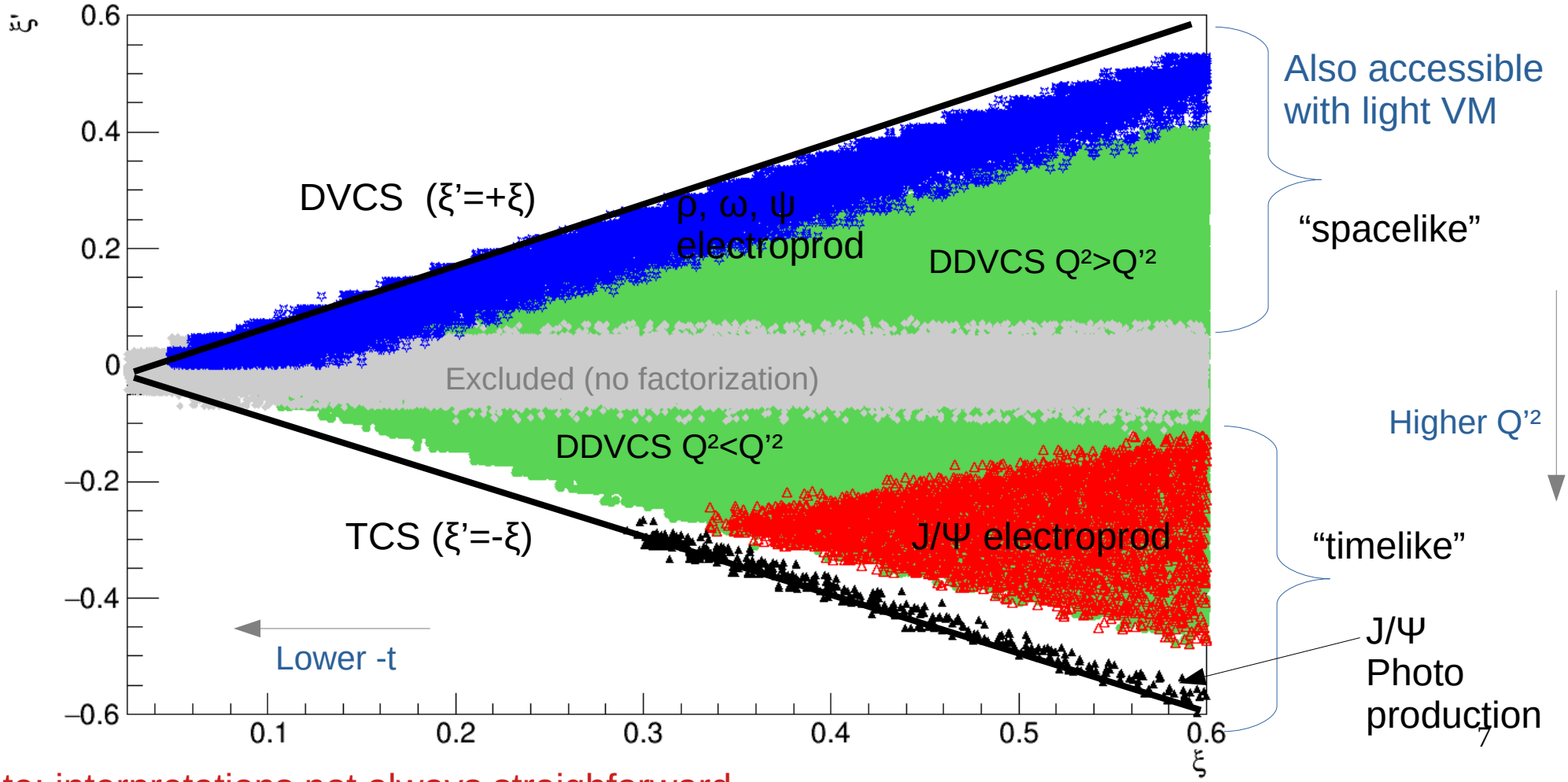
- Flavor decomposition
- Enhancement of sensitivity to certain GPDs
- Direct access to gluon GPDs with heavy mesons…

- VM: can be directly compared to Compton reactions (same spin-parity), large cross sections.

Interpretation is more difficult, but VM measurements complement our program

Using DDVCS Q'² and meson masses to go "off-diagonal" (~JLab E)

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



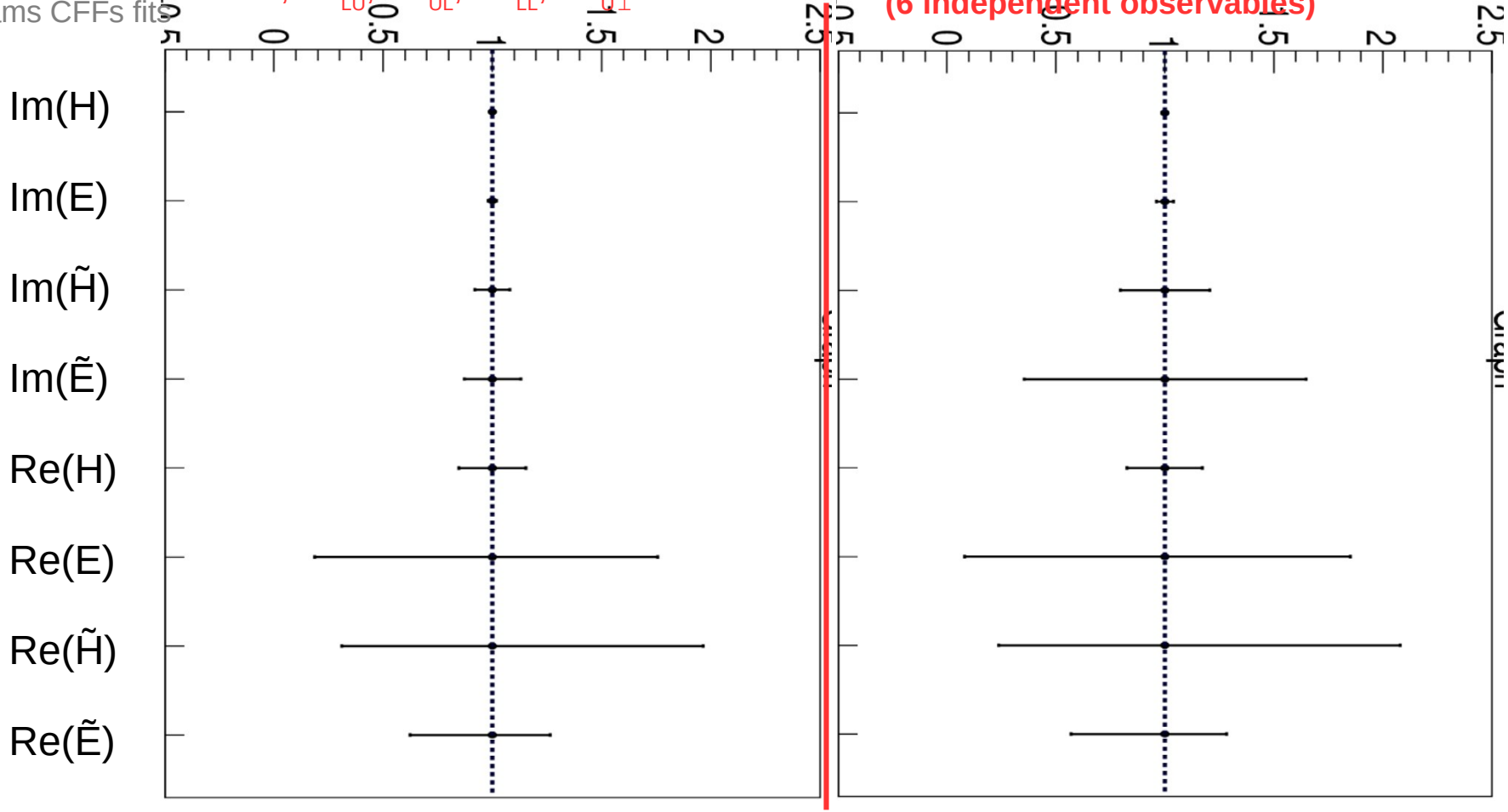
Note: interpretations not always straighforward

Example of multichannel fit including DVCS and TCS data, in potential JLab experiments

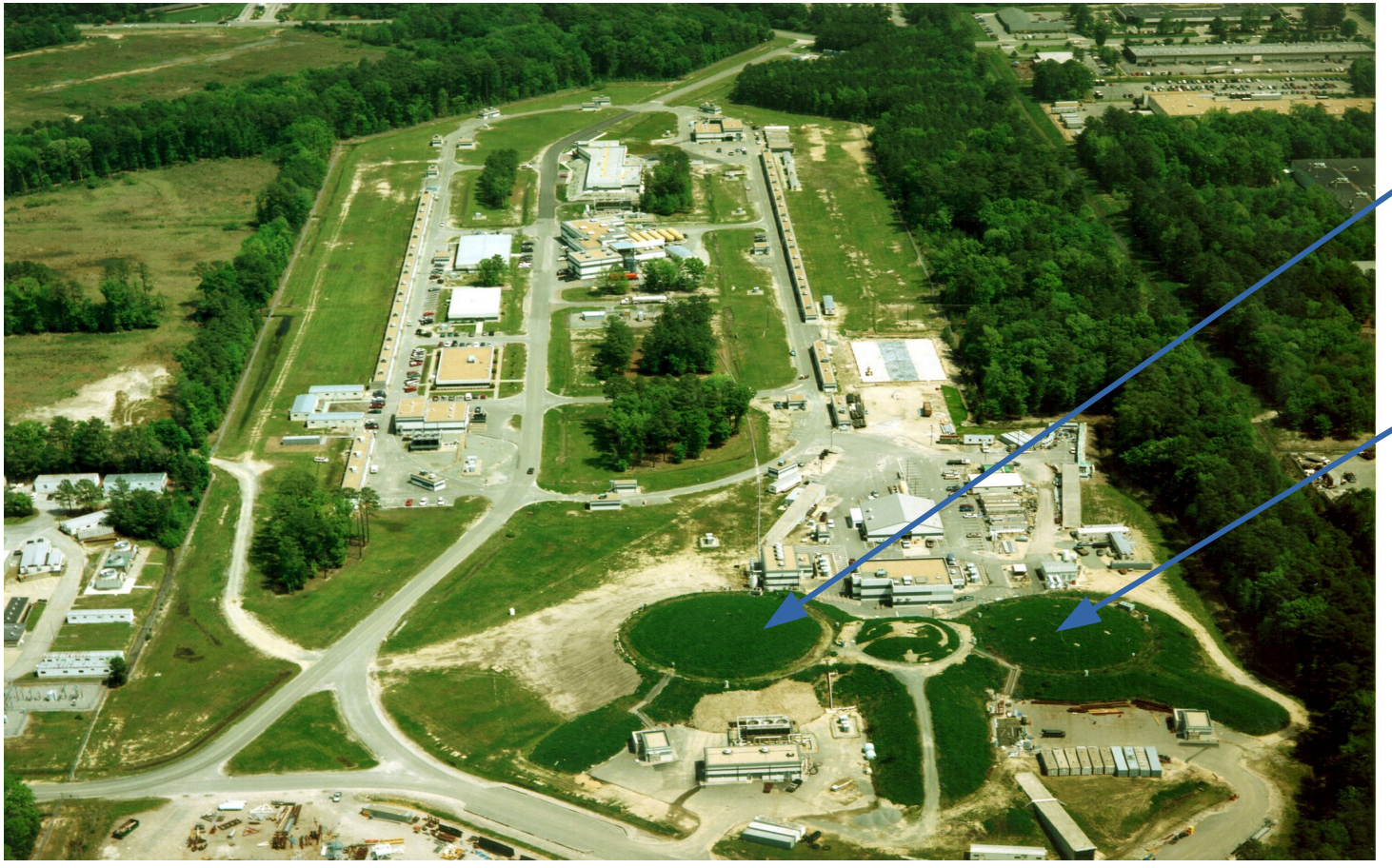
Pseudo-data with 5% error on unpolarized σ, 7% pol. σ, 16 bins φ, **8** params CFFs fits

DVCS+TCS
(6 independent observables):
$\sigma, \Delta\sigma_{LU}, \Delta\sigma_{UL}, \Delta\sigma_{LL}, \Delta\sigma_{U\perp}$

DVCS (4 obs.): $\sigma, \Delta\sigma_{LU}, \Delta\sigma_{UL}, \Delta\sigma_{LL}$
+ TCS (4 obs.): $\sigma, \Delta\sigma_{\odot U}, \Delta\sigma_{U\perp}$
(6 independent observables)



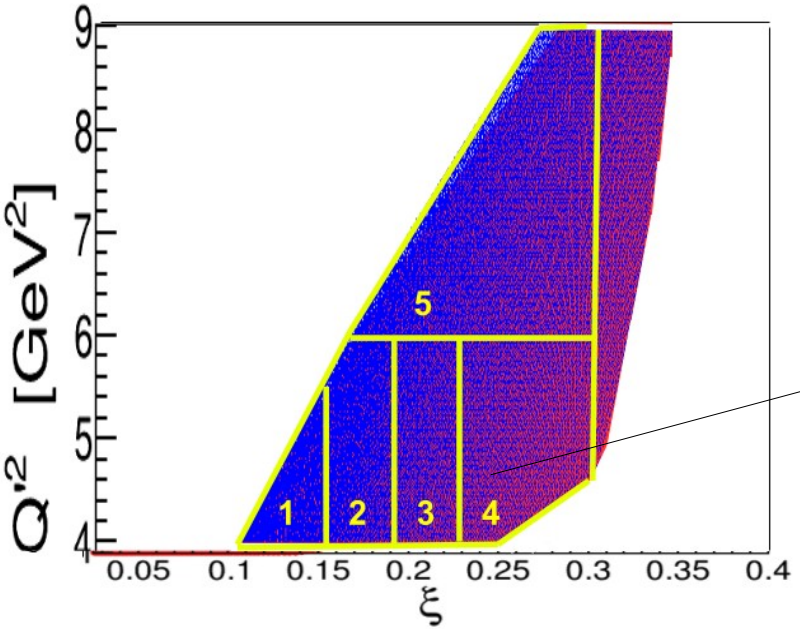
Experimental perspectives for JLab Hall A & C
And our project (for TCS and DDVCS, VM is for the future)



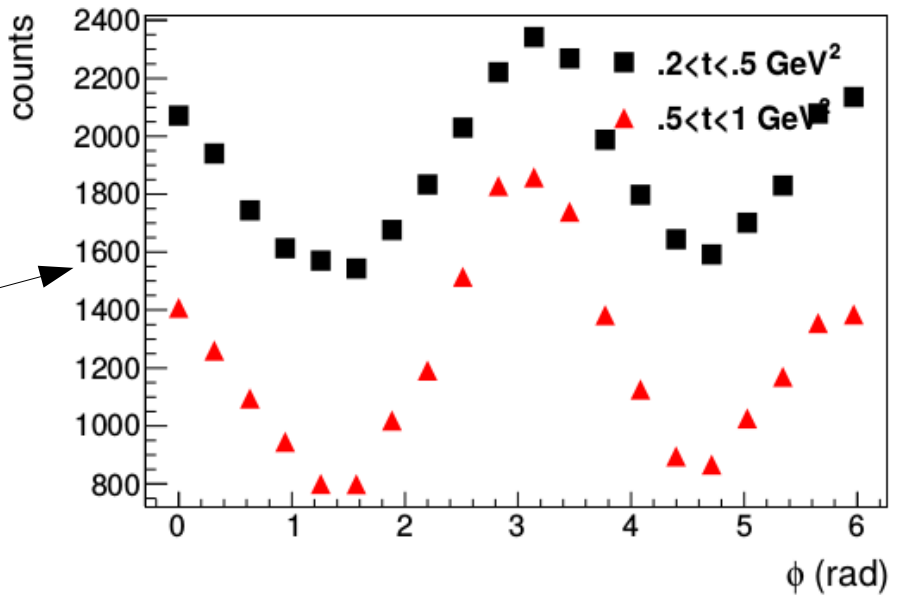
Our plans for TCS in Hall A

Hall A.

Quasi real unpolarized & beam polarized TCS with SoLID (approved, SoLID not yet approved)
- large acceptance, large statistics. Q'² dependence, bins in -t, "local fits"

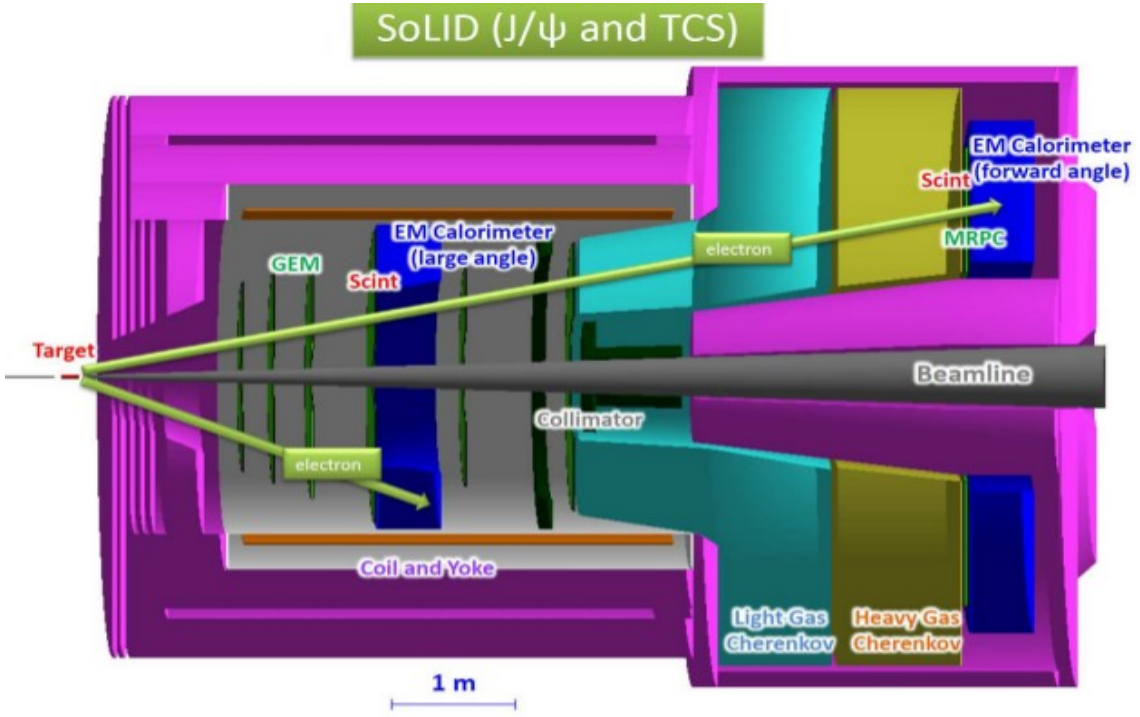


bin 3



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

Our plans for TCS in Hall A



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.
But not dedicated / "tuned" for TCS, we can get higher intensity dedicated exp in Hall C

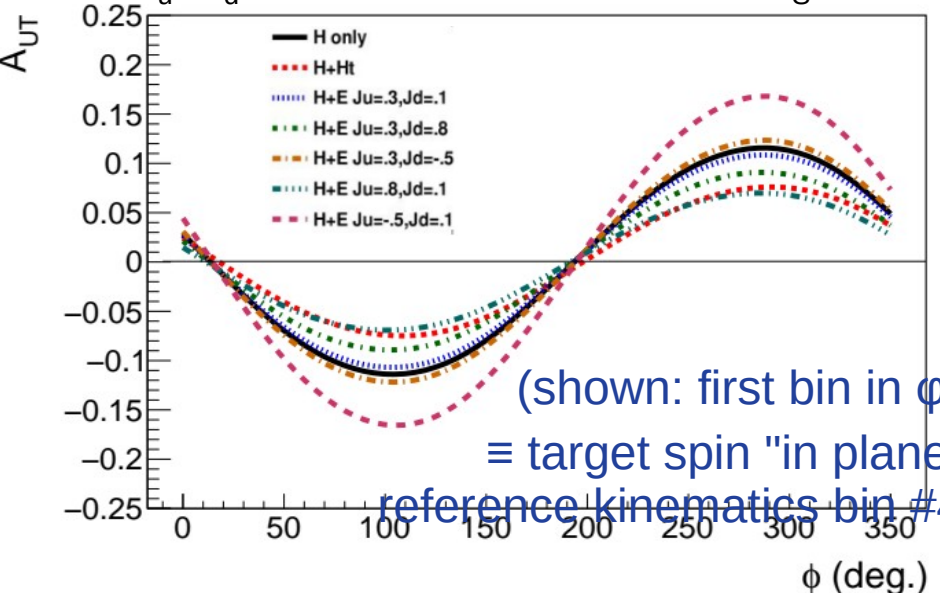
Our plans for TCS in Hall C

- We can and want to have a multi-observable program.
- Advantage: dedicated setup, high precision, real photon beam at high intensity

Proposed to previous PAC: transversely polarized (single proton spin asymmetry)
Plan to propose soon: unpolarized TCS off proton and neutron, longitudinally polarized off neutron

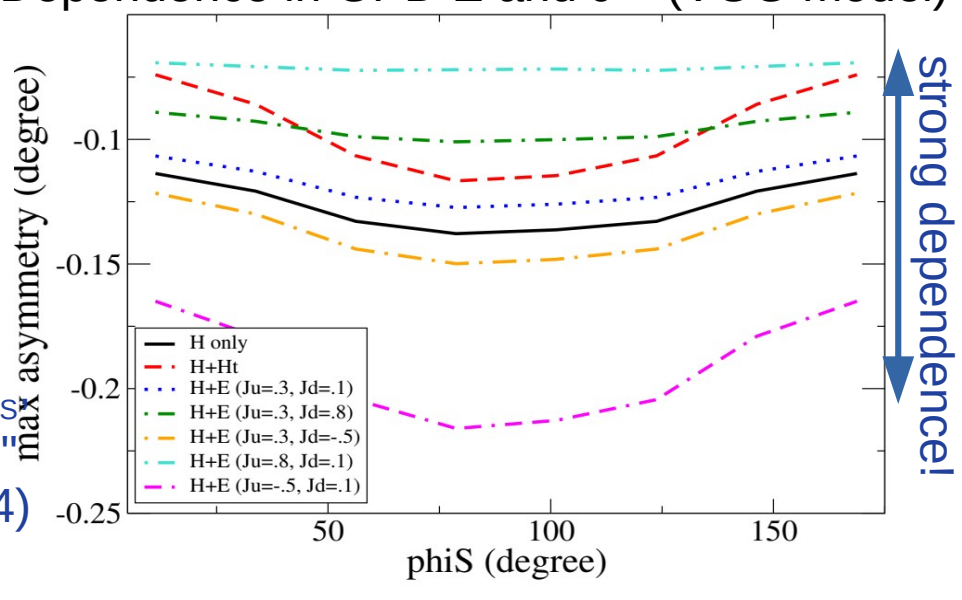
Physics case for proposed experiment: TSA dependencies, GPD E and proton spin decomposition

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

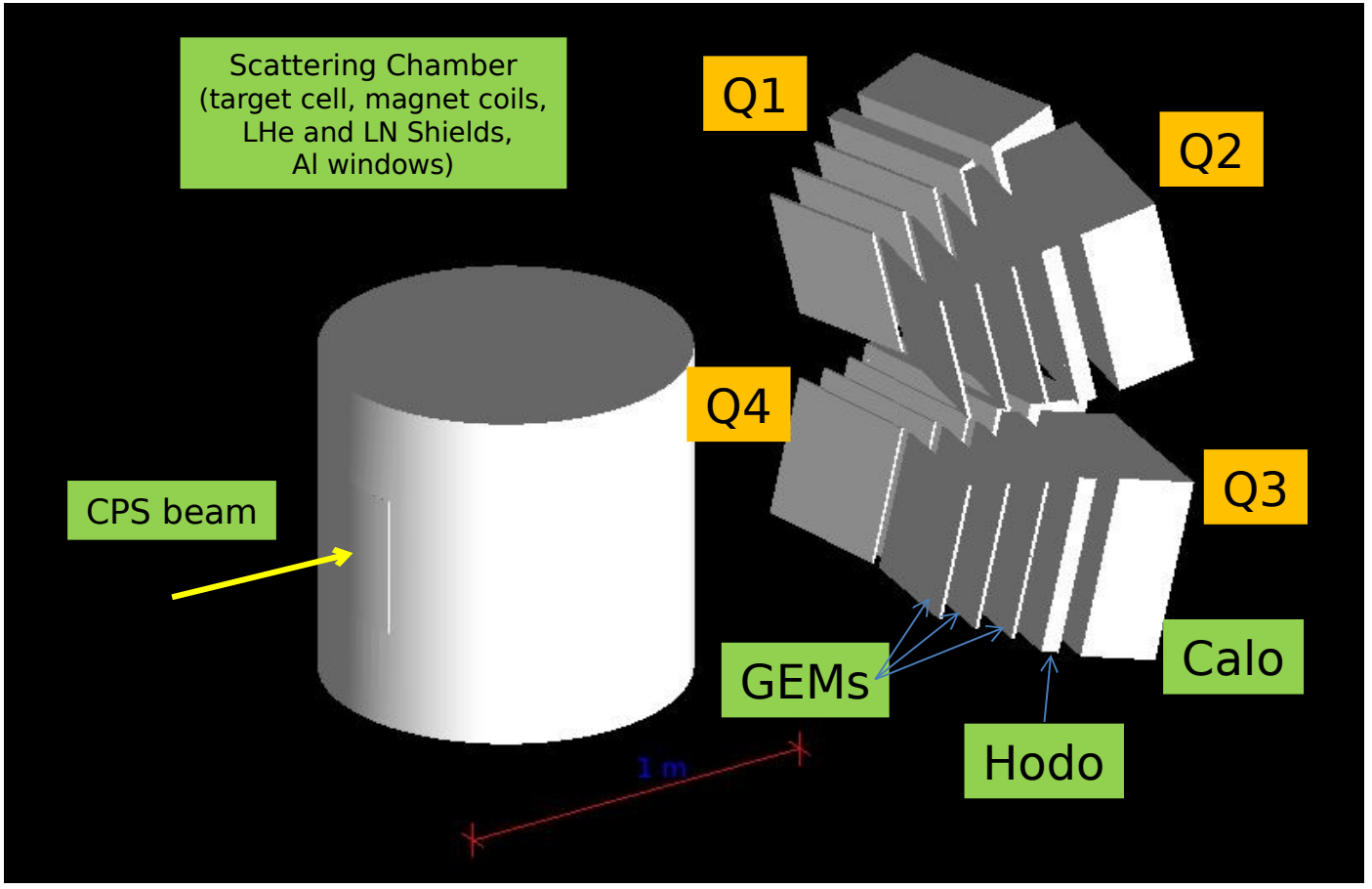


(shown: first bin in φ_S ≡ target spin "in plane" reference kinematics bin #4)

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



Experimental setup proposed for Hall C with transverse target

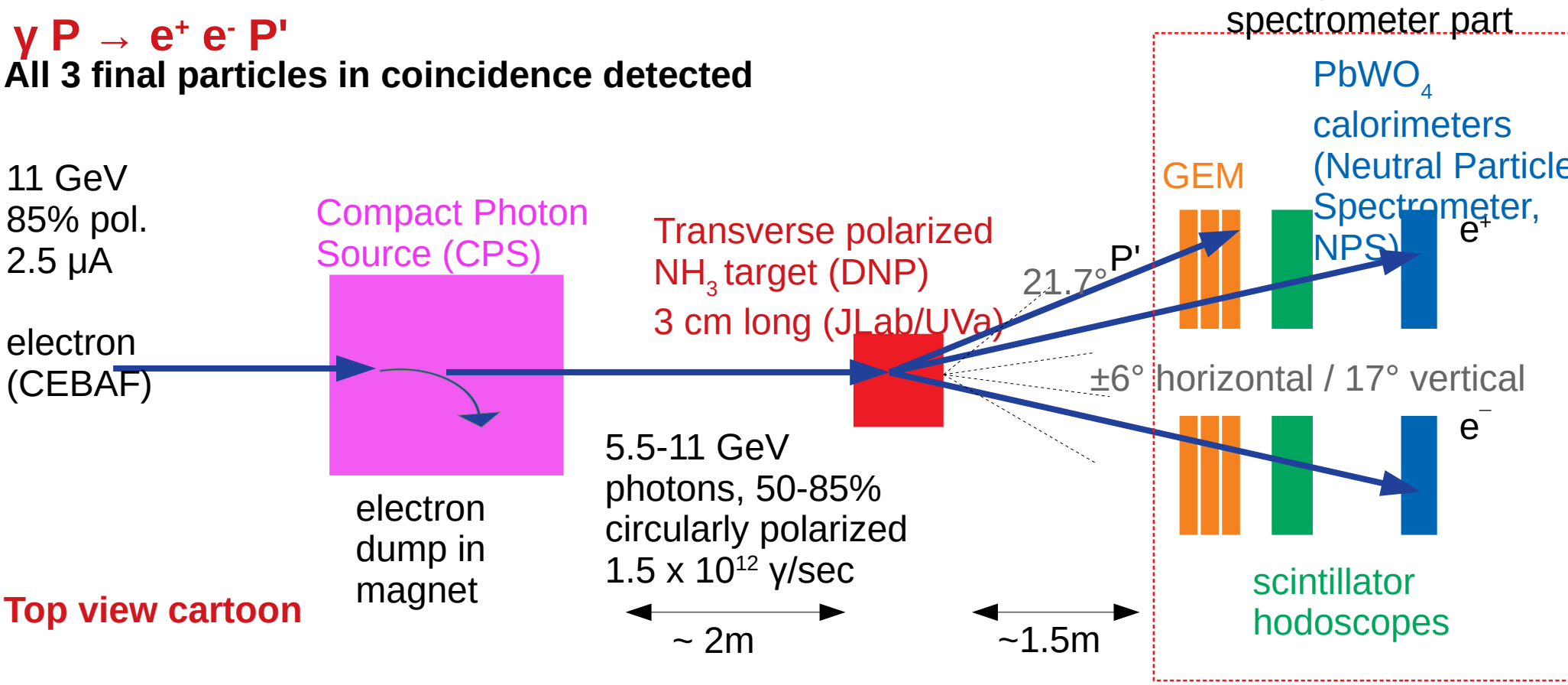


Setup to measure Timelike Compton Scattering at Jefferson Lab
(credit: V. Tadevosyan)

Experimental setup proposed for Hall C with transverse target

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

All 3 final particles in coincidence detected



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

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

Note: was deferred by PAC50, we still have a lot of work before going back to PAC

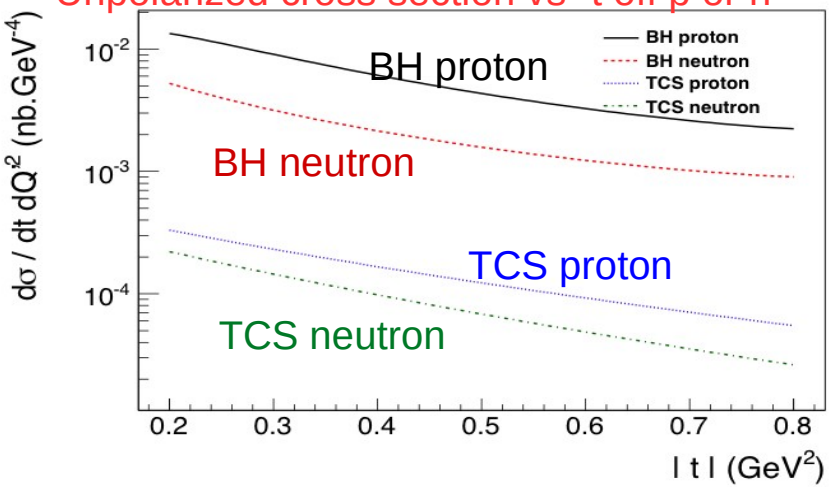
Our plans for TCS in Hall C

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

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

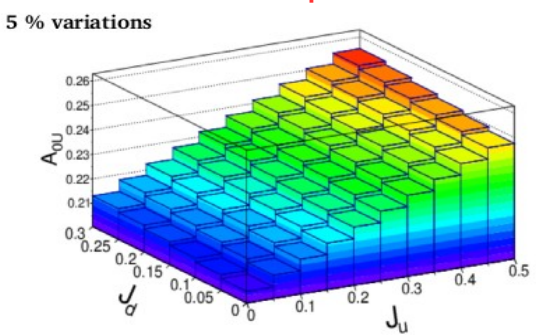
- **Neutron: flavor separation and spin**

Unpolarized cross section vs -t off p or n

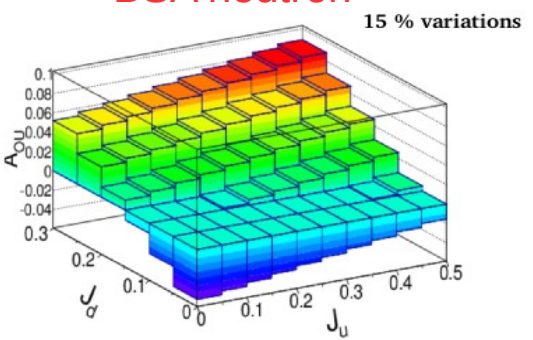


- σ off neutron not suppressed, sizeable asymmetries
- similar sensitivities to GPDs expected
- strong sensitivity to J_u, J_d

BSA proton

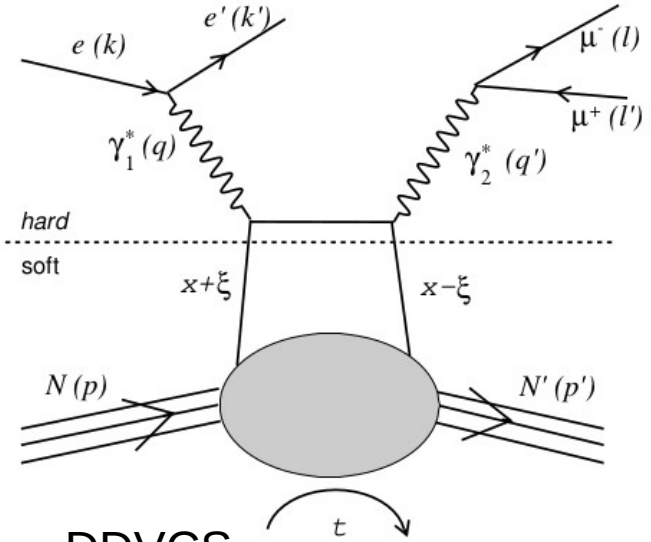


BSA neutron

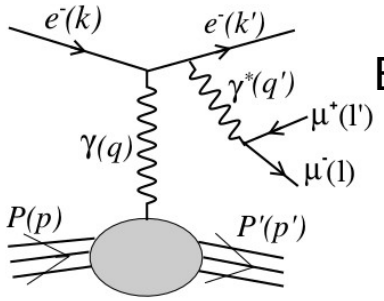


- Equivalent flavor separation for GPD E and “matching” transverse proton: longitudinal neutron (ND3 target) – will complement full program, once the first part is more advanced

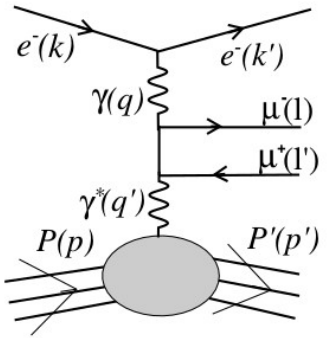
Our plans for DDVCS in Hall A & C



DDVCS



BH "I"

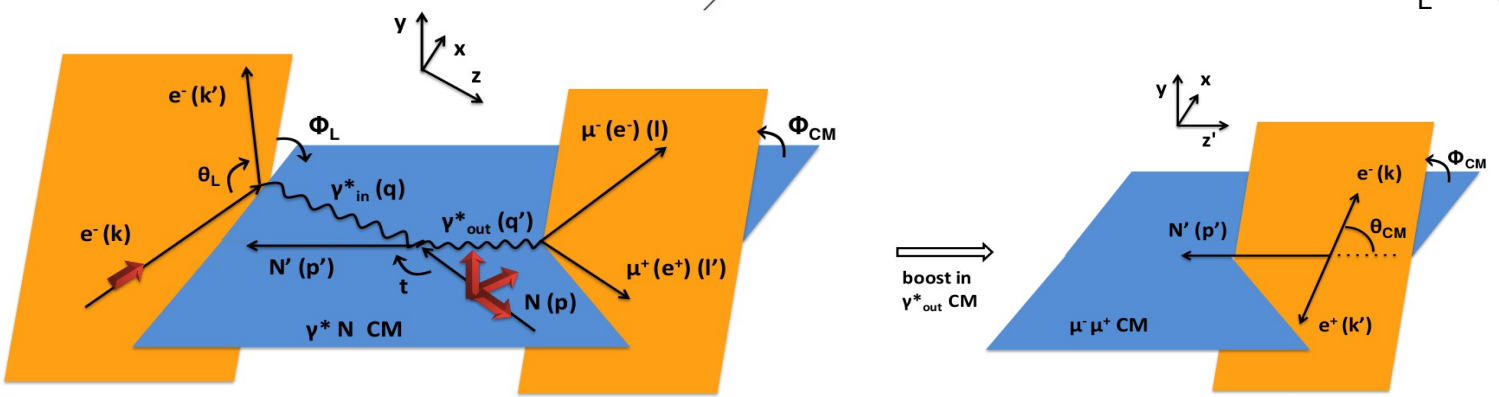


BH "II"
Angular behavior "as TCS"

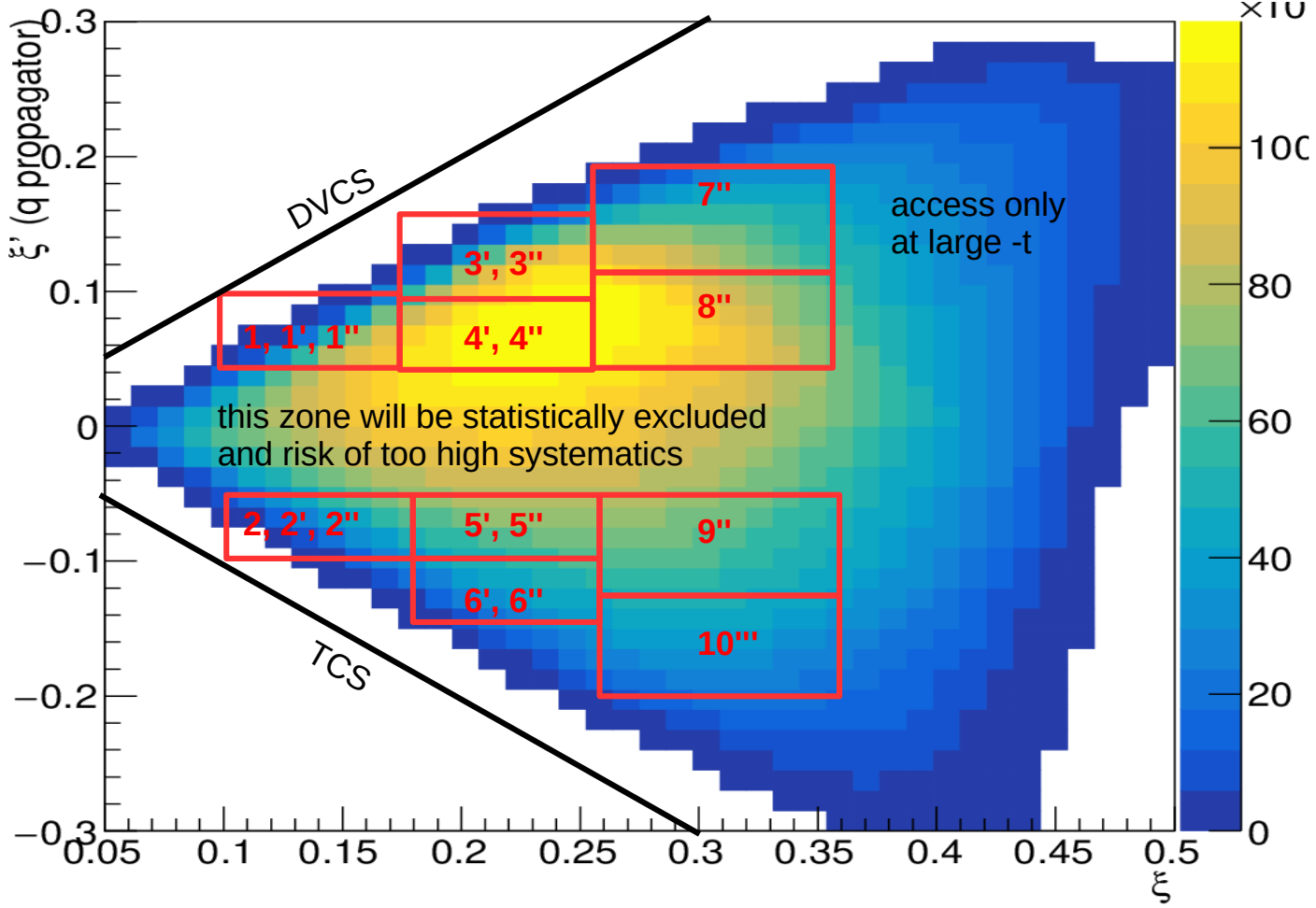
e P → e' P' μ+ μ-

Need to measure a muon pair (antisymetrization, possibility to get the kinematics of 2 forward leptons)

7-independent variables for cross section.
Choice: E_e, ξ (or x_{bj}), t, Q^2, Q'^2, Φ_L, Φ_{CM}, θ_{CM}



Binning in ξ, ξ', all t: going “off-diagonal” for tomographic views



Bin in ξ

A) .1 < ξ < .18 (all t bins)
- 1) .05 < ξ' < .1 — 1, 7, 17
- 2) -.05 > ξ' >-.1 — 2, 8, 18

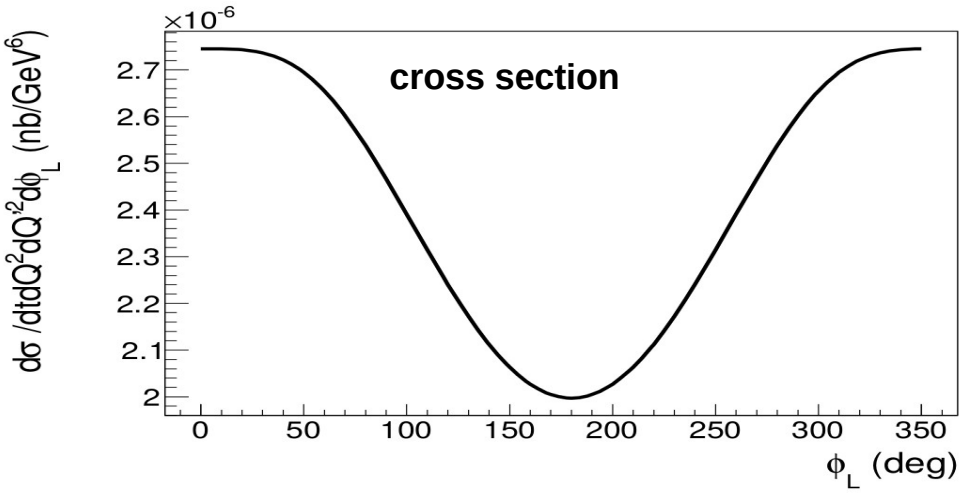
B) .18 < ξ < .26 (t bins 2 and 3)
- 3) .1 < ξ' < .15 — 3, 9
- 4) .05 < ξ' < .1 — 4, 10
- 5) -.05 > ξ' > -.1 — 5, 11
- 6) -.1 > ξ' > -.15 — 6, 12

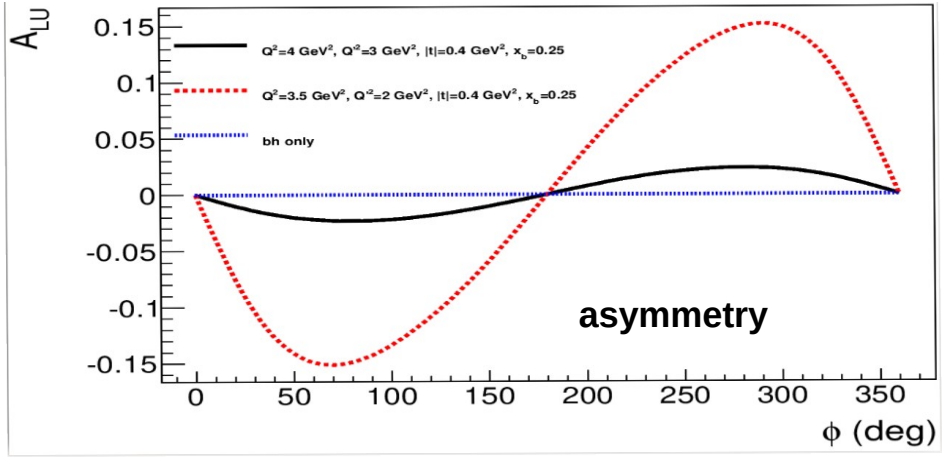
C) .26 < ξ < .36 (t bin 3)
- 7) .12 < ξ < .2 — 13
- 8) .05 < ξ < .12 — 14
- 9) -.05 > ξ > -.12 — 15
- 10) -.12 > ξ > -.2 — 16

code # large/low 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 ', '')

Our plans for DDVCS in Hall A & C

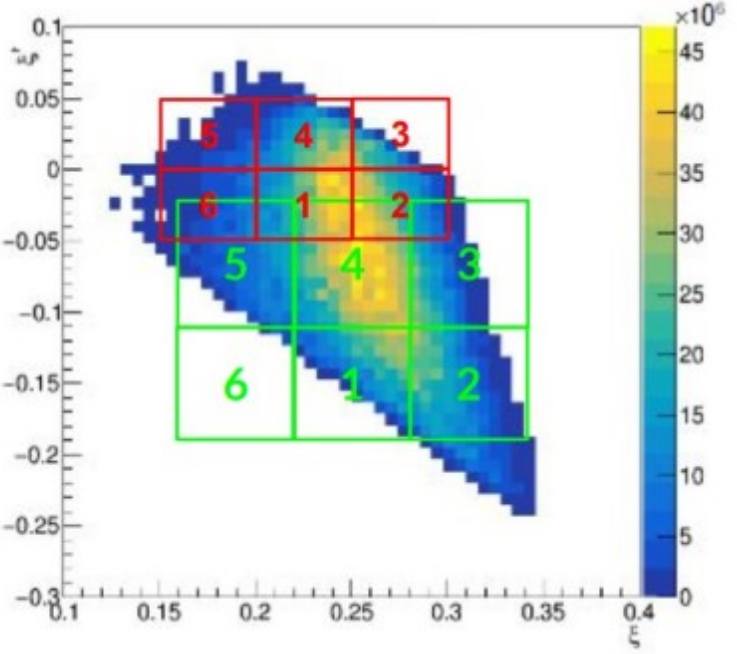




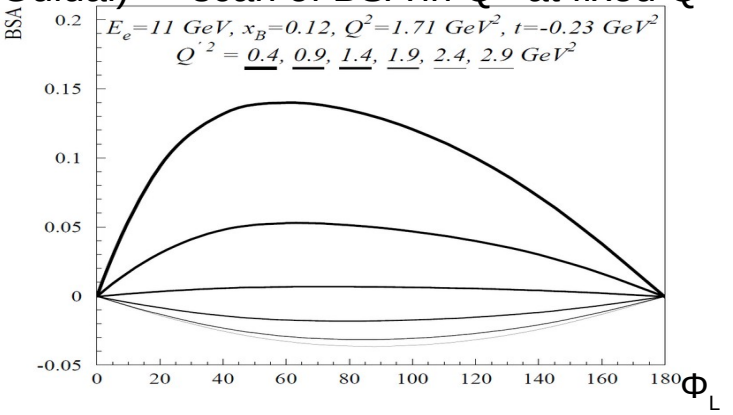
integrated over θ

(above: SoLID kinematics, from LOI 2015

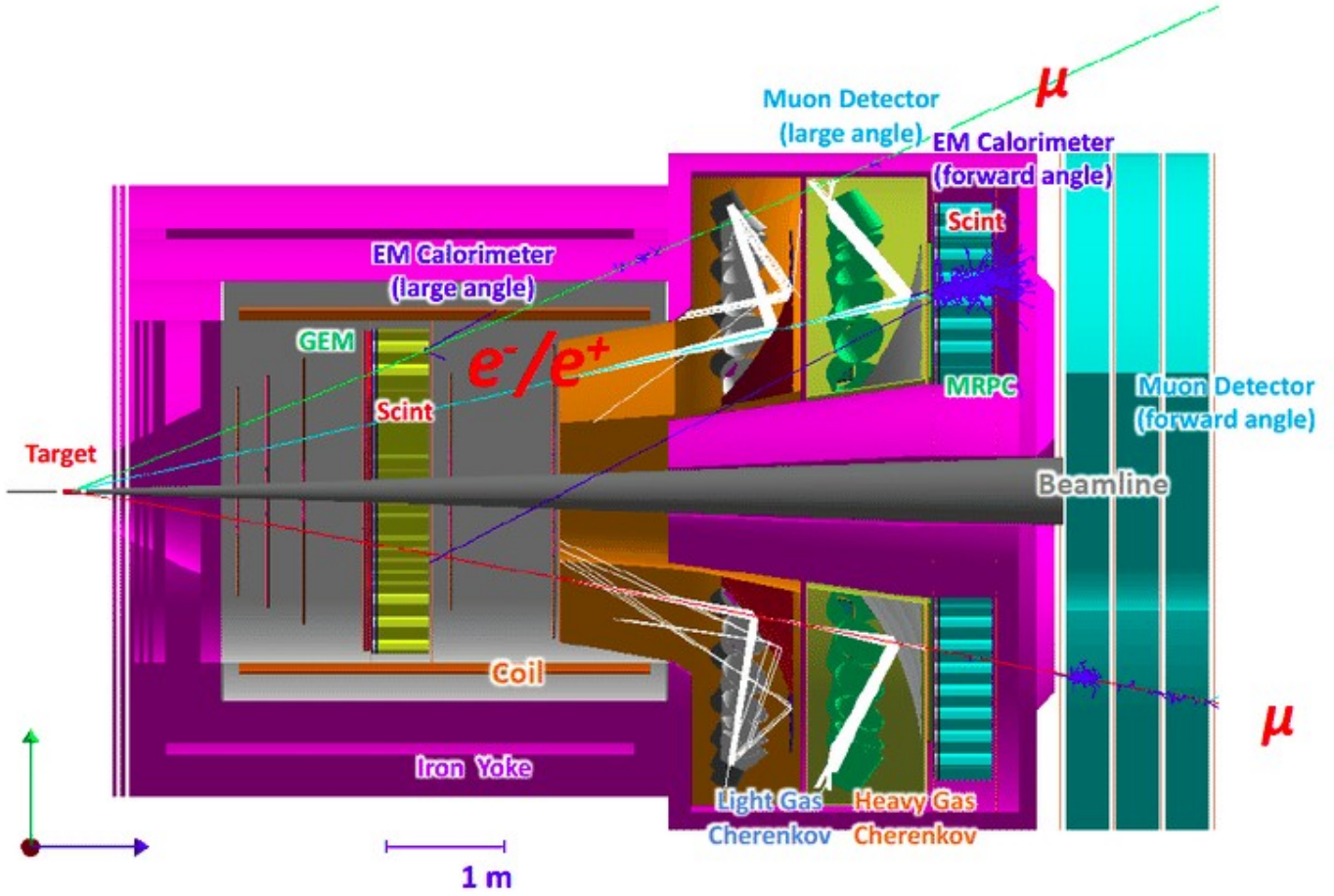
Top right: undegrad students studies of phase space)



Sign changed between “timeliek”/ “spacelike” regions (from M. Guidal) → scan of BSA in Q'² at fixed Q²



Our plans for DDVCS in Hall A



SoLID spectrometer
With additional muon
Detectors

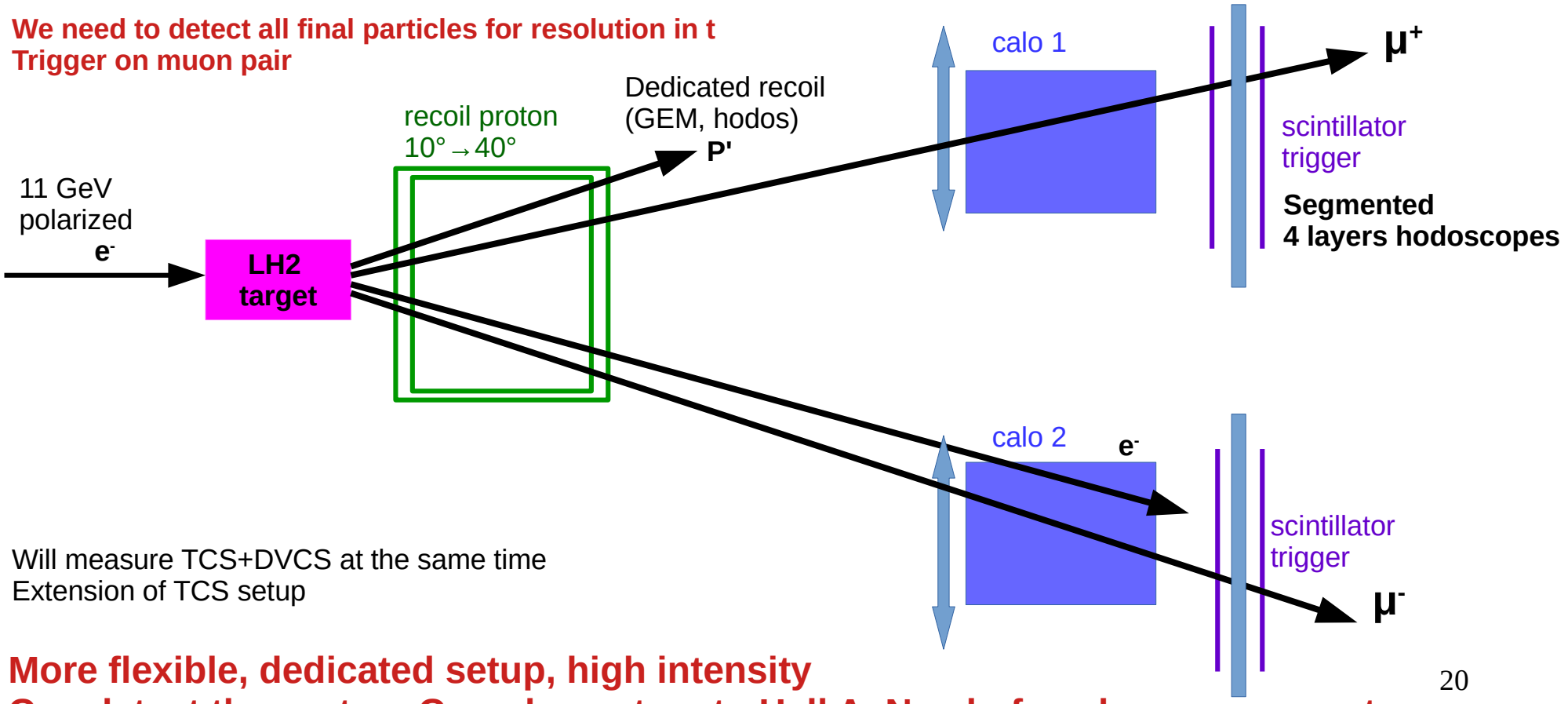
Current R&D:
Straw tubes
or scintillators,
looking at options

- Collaboration working on simulations
- Plan to submit to JLab PAC51 in 2023

Possible setups for DDVCS in Hall C

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

More flexible, dedicated setup, high intensity
Can detect the proton. Complementary to Hall A. Need of such measurements

DDVCS and extension to other measurements with muon pairs

- Developing a muon detector for Hall A (SoLID) and Hall C (dedicated setup)
- Working on a prototype “small scale” of the full detector, to be tested / currently: simulations
- Planning for short test run with “mini spectro” for TCS and DDVCS experiments,
to guide R&D and help assessing if tracking and PID will be sufficient

These projects keeping the whole group busy, lot of “subprojects” for undergrads

Mahmoud, Gyang (grads), MB Debaditya (PD), Erik, MB, Melinda, Jocelyn (undegrads)

+ many other undergrads worked on these studies since 2021

Some advertisement…

Towards improved hadron femtography with hard exclusive reactions
August 7-11th, 2023. "2nd edition", Blacksburg, VA – Virginia Tech.

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
- Lattice QCD
- Hardware for exclusive measurements

PLEASE COME ! ABSTRACTS VERY WELCOME

70+ participants in 2022, group picture:

SUMMARY

- TCS is a key channel for GPD universality studies in complement to DVCS

- DDVCS is the golden channel to access GPDs at multiple kinematics and Tomographic interpretations

Multichannel / multiobservables fits to constrain all GPDs, provide access to new information
- on the proton structure. In particular (here) spin decomposition

- Potential for new experiments at JLab Hall A & C

- Hall A SoLID: large acceptance, high intensity, can be complemented with muon detectors, opens a broad range of “GPD channels” that can be measured

- Hall C: potential for high intensity precision measurements with dedicated setups, Flexible.

- R&D for muon detectors for Hall A & C (complementary)