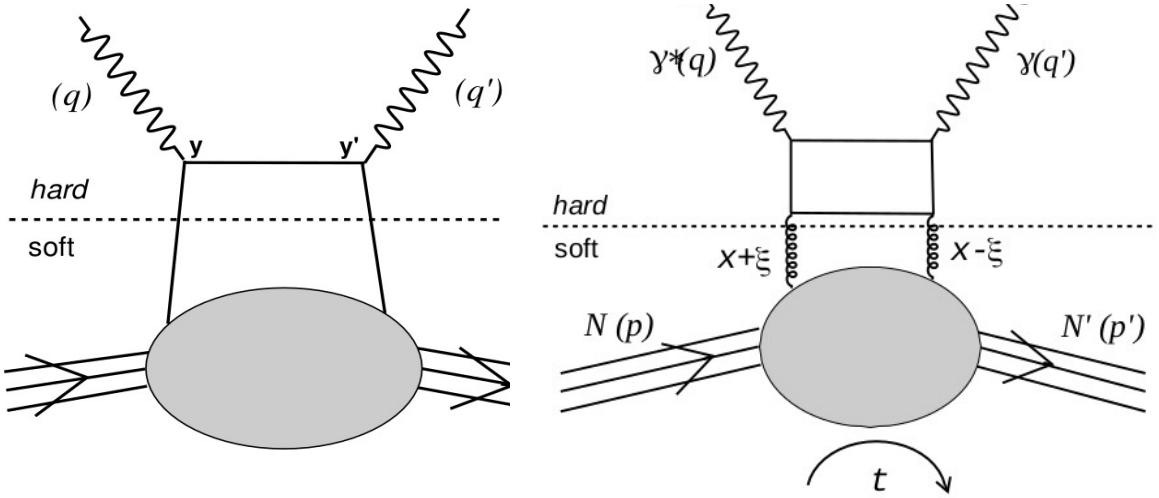
Double Deeply Virtual Compton Scattering at Jefferson Lab Hall A with SoLID

Marie Boër, SPIN 2023, DUKE
Sept. 26th, 2023

VIRGINIA TECH

PARTONIC STRUCTURE OF THE HADRONS

Hard Exclusive Compton-like reactions and Double Deeply Virtual Compton Scattering



Leading order / leading twist generic handbag diagram

γ (*) N → γ'(*) N'

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

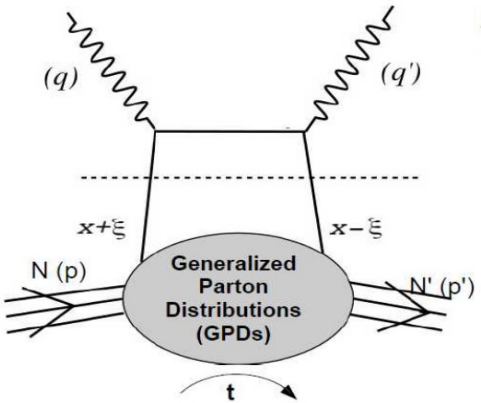
Other: multi-photons, photon+meson, ...

Parameterized by GPDs
Generalized Parton Distributions

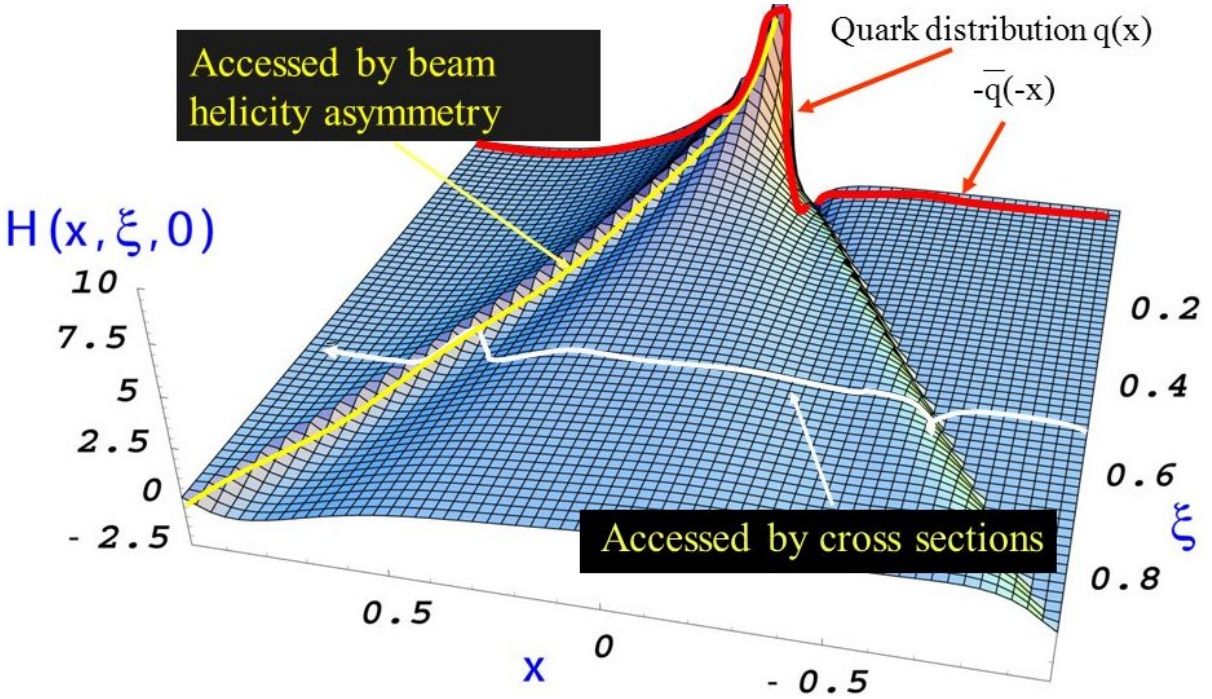
Depend on x, xi, t

GPDs at xi=0 for tomographic interpretations: need deconvolution

Generalized Parton Distributions from CFF fits (with DVCS or TCS)



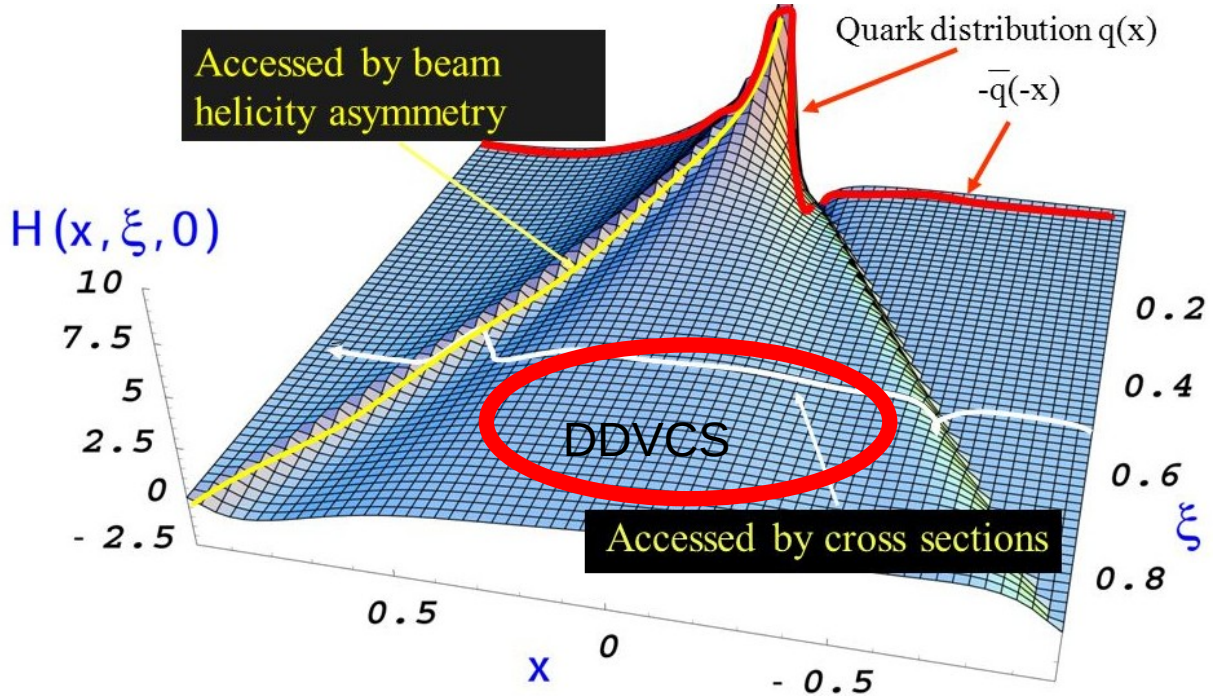
Extracted at ξ (skewness // momentum) and t (momentum transfer ²) from experimental data [can't access x]



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

Propagator: only access "diagonal" part |x|=xi

Generalized Parton Distributions from CFF fits (with DDVCS)



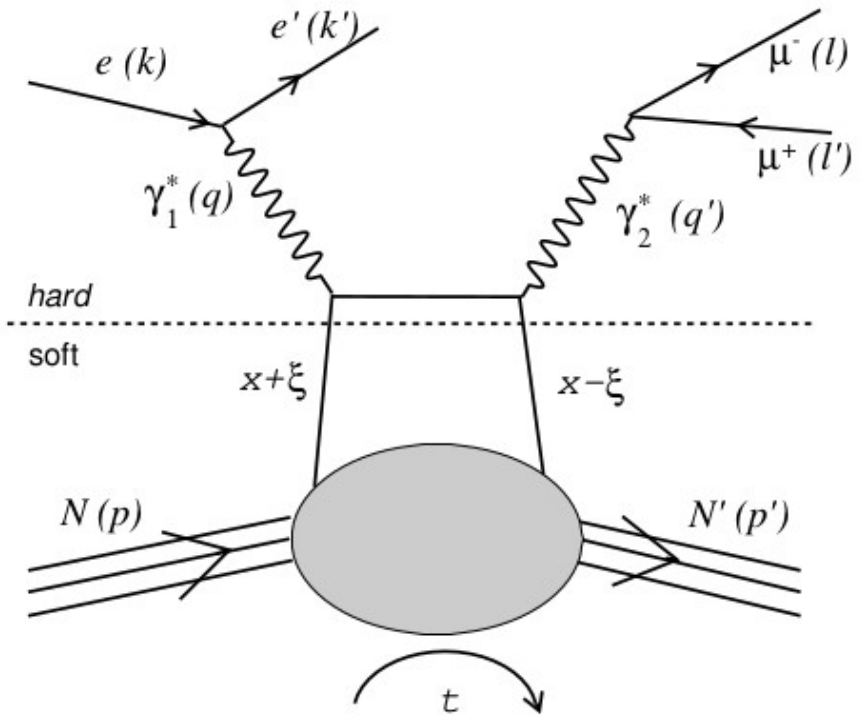
unique access to ERBL region

Deconvolution x, xi

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

Measuring DDVCS, observables and projections

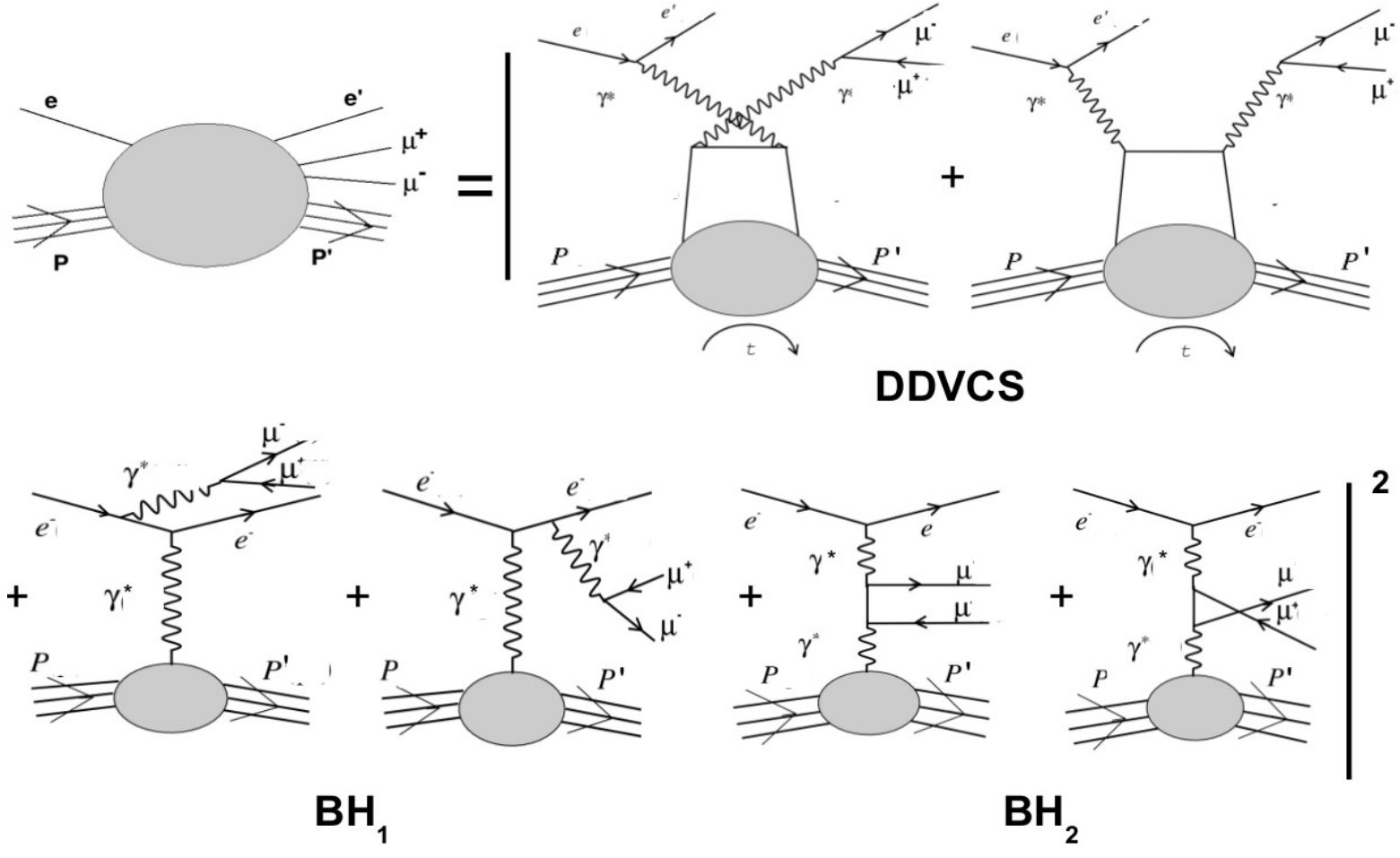


e P → e' P' μ+ μ-

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

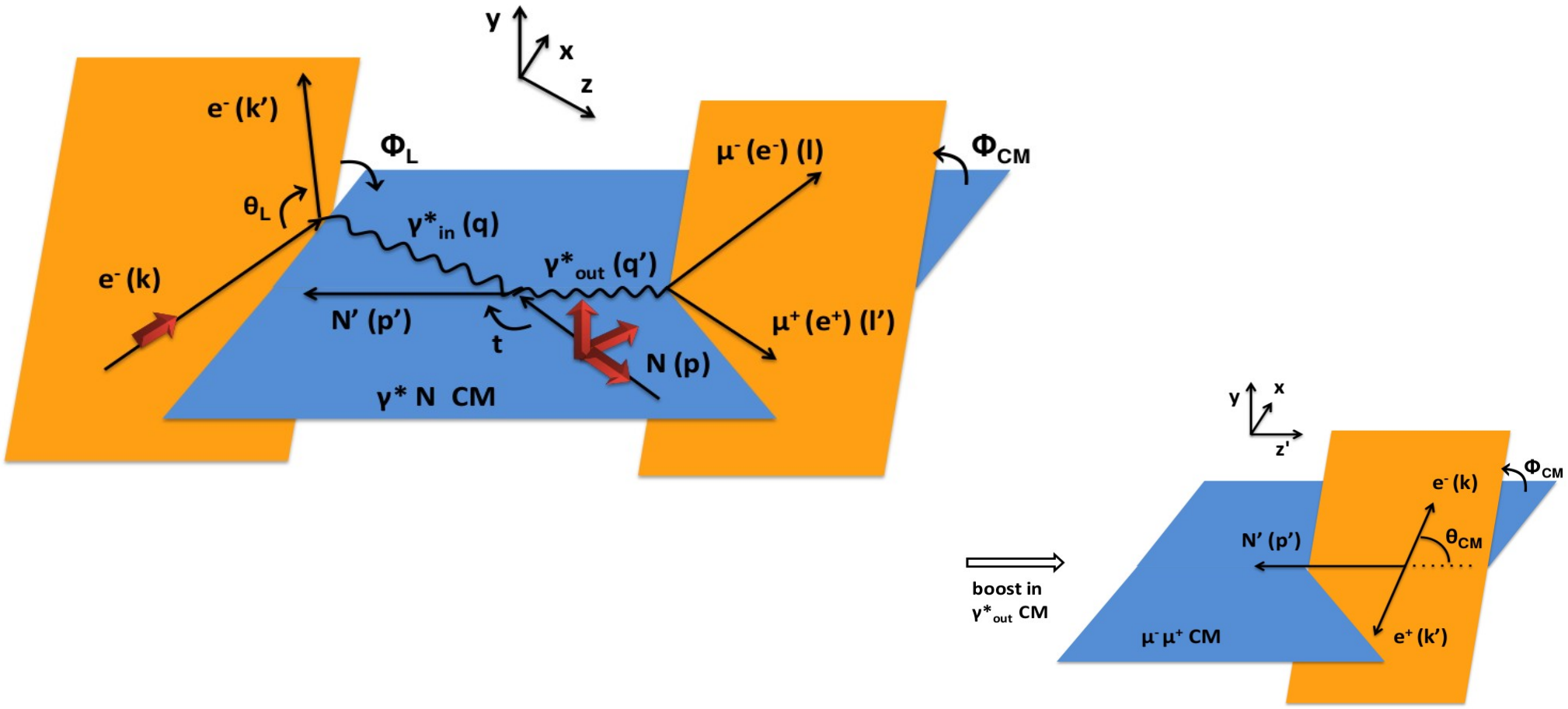
7-independent variables for cross section.
Choice: E_e, ξ (or x_{bj}), t, Q^2, Q'^2, Φ_L, Φ_{CM}, θ_{CM}

Interference with Bethe-Heitler



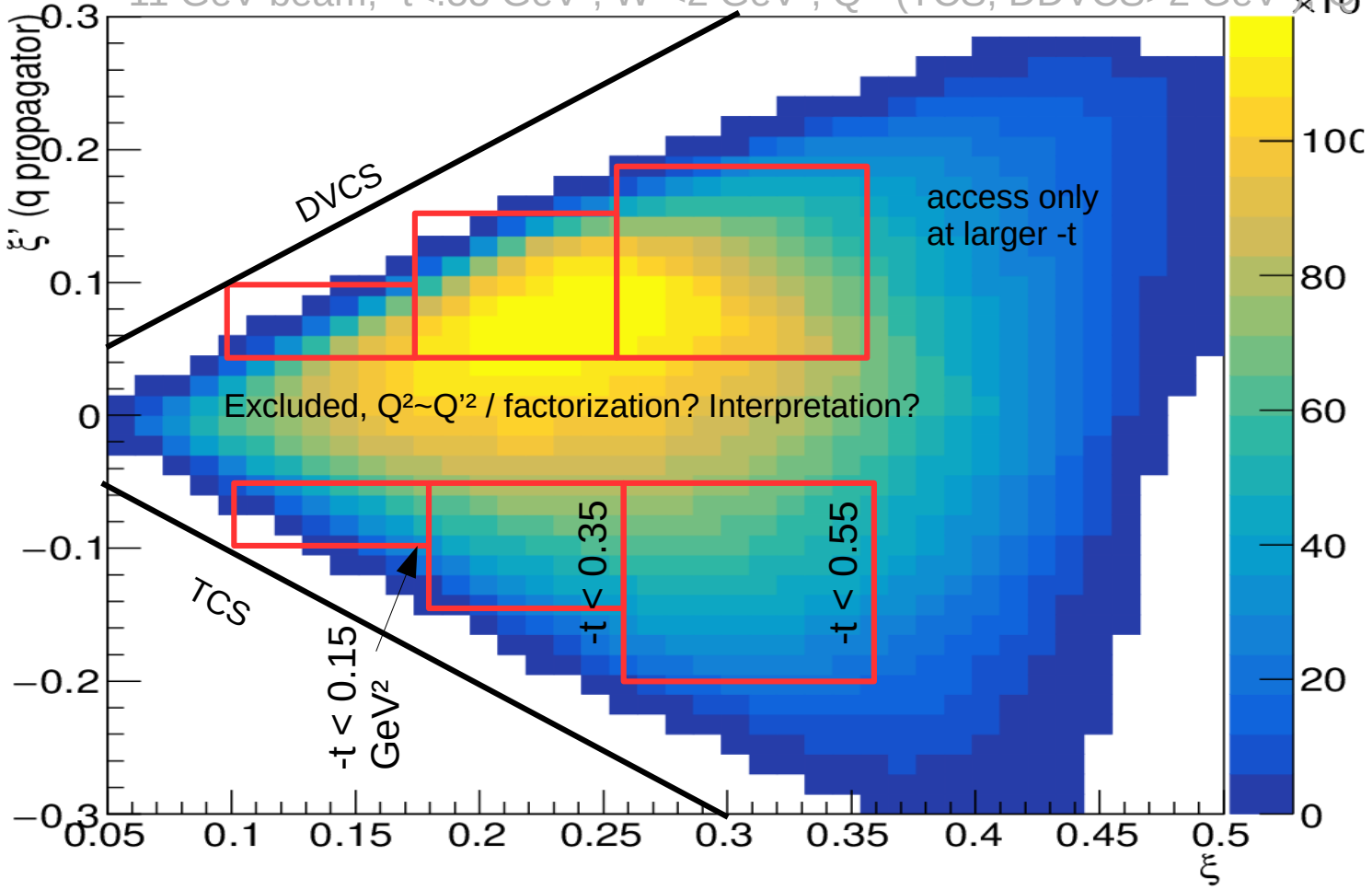
BH1: understood from DVCS+BH ; BH2: understood from TCS+BH (“peaks” in thetaCM)

Definition of the angles



Off diagonal “lever arm”: phase space for JLab, 11 GeV electron

11 GeV beam, -t<.55 GeV², W²<2 GeV², Q’² (TCS, DDVCS>2 GeV²), Q² (electroprod. > 1 GeV²)



Q’² < Q² : spacelike”

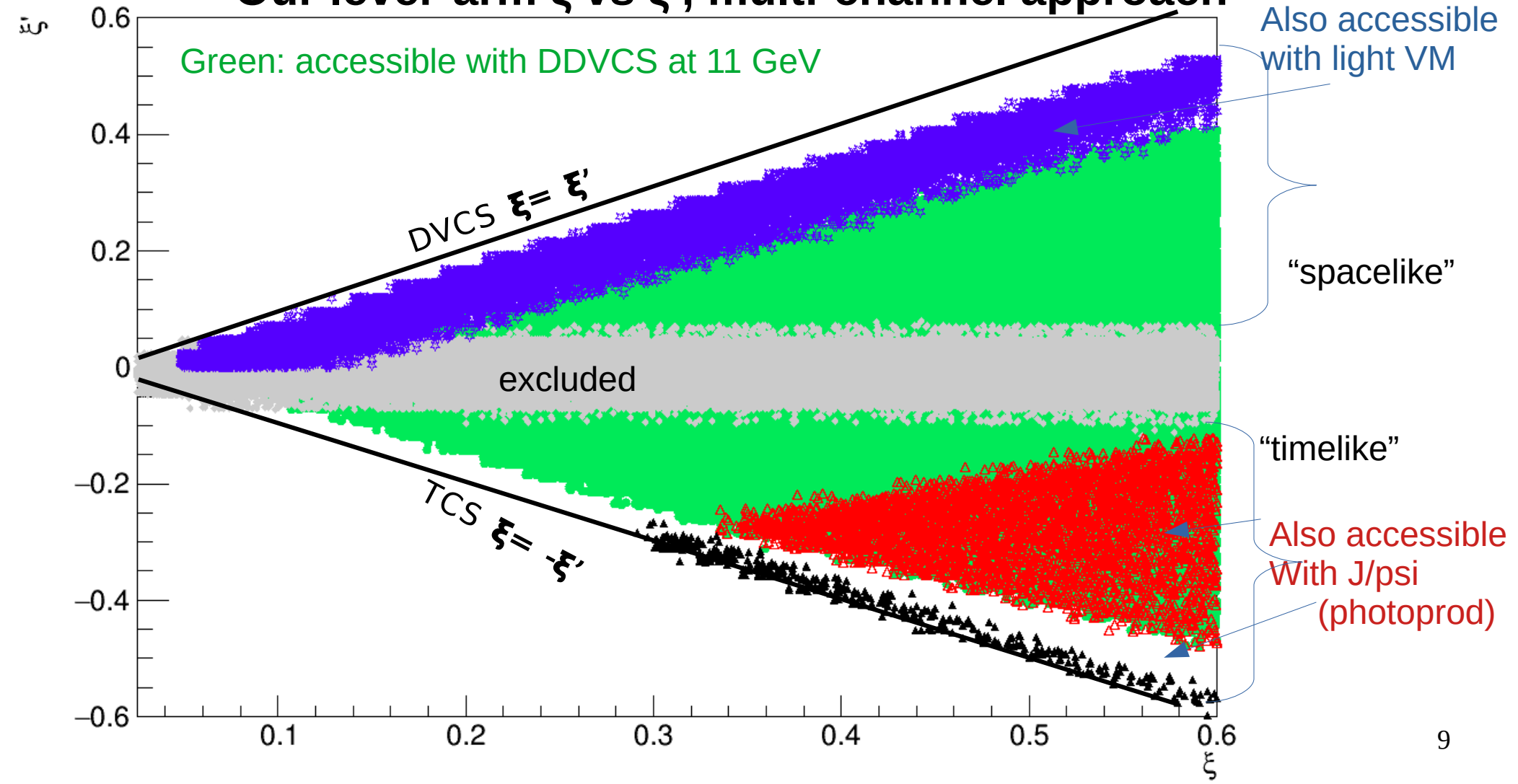
Bins in ξ, ξ’, -t

-.2 < ξ’ < .2
.05 < ξ < .36
[correlated to t bin]
0.05 < -t < .55

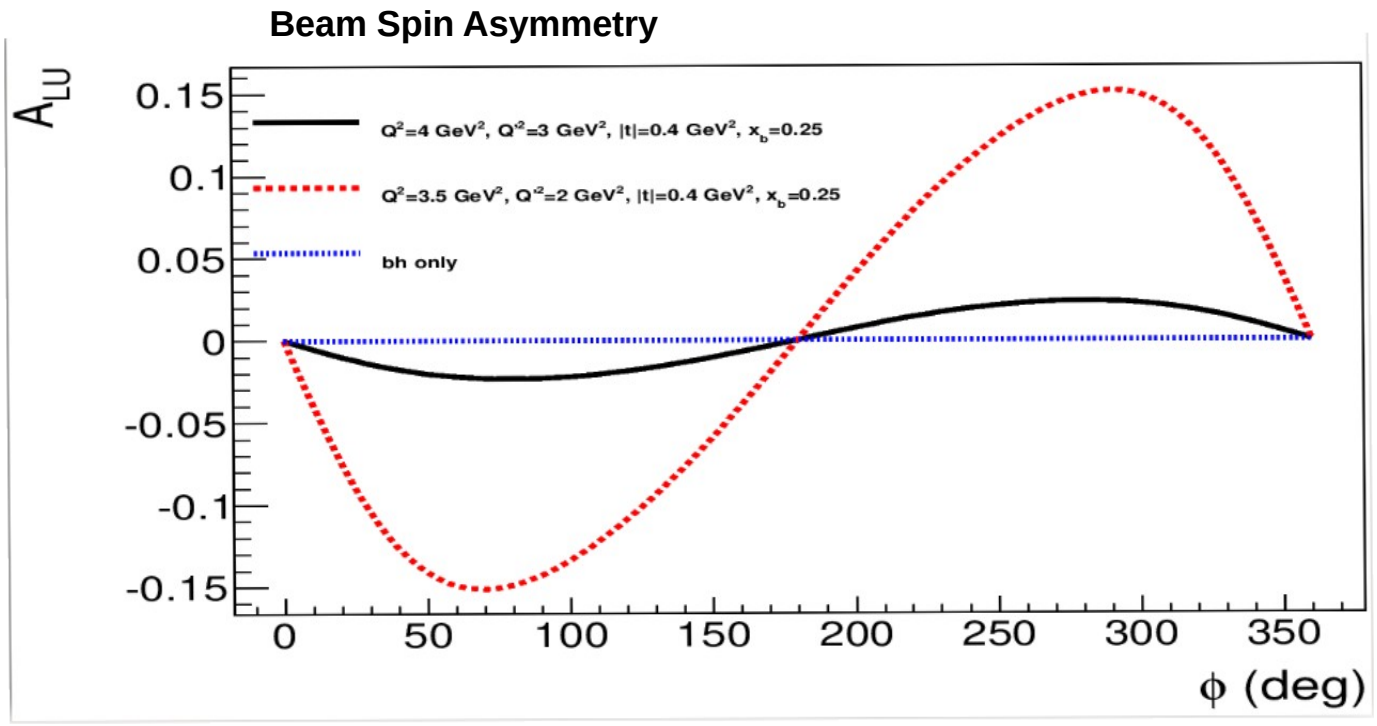
Q² < Q’² : “timelike”

Larger -t opens up more phase space

Our lever-arm ξ vs ξ', multi-channel approach



DDVCS +BH Beam Spin Asymmetry



purely coming from interference between BH(1+2)*DDVCS asymmetries are sizeable.

Change of sign to be observed in different kinematic regions

Imaginary part of amplitude

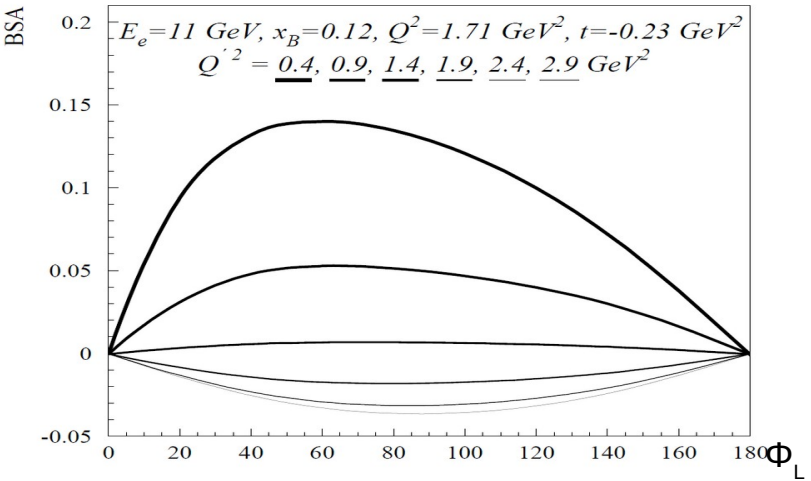
BH cancels, comes from interference. Sizeable asymmetry and counts thanks to interference

Evolution of the beam spin asymmetry

Sign change in BSA and interplay “spacelike” and “timelike” regions

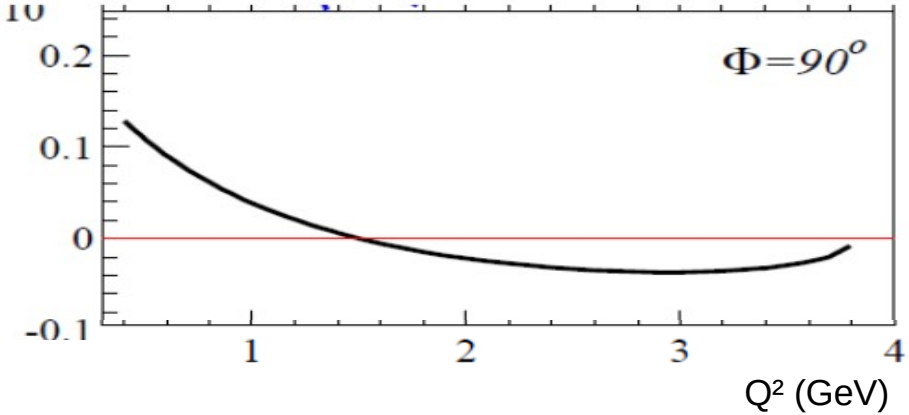
Calculations from M. Guidal (Trento, 2016)

→ scan of BSA in Q'² at fixed Q²



→ sign change in BSA vs Φ_L and vs φ_{CM} when Q'² ≈ Q²

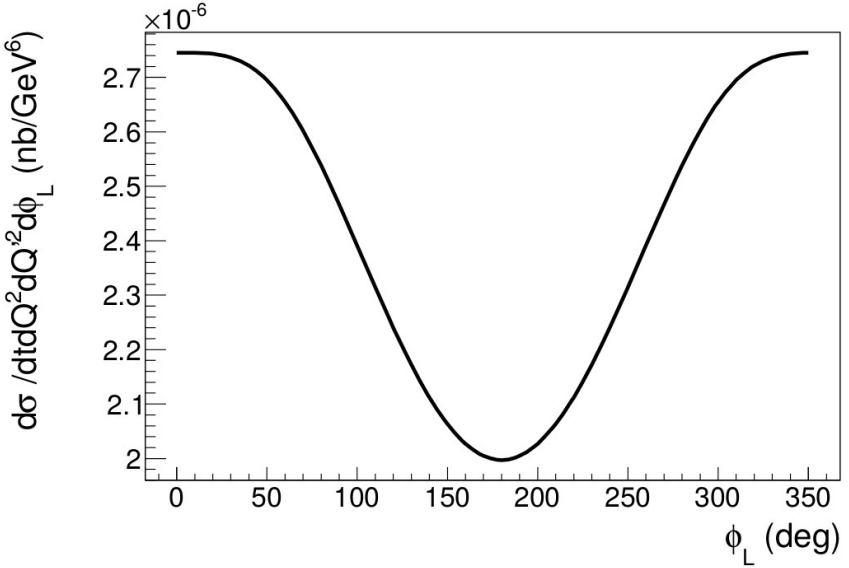
asymmetry Q² scan

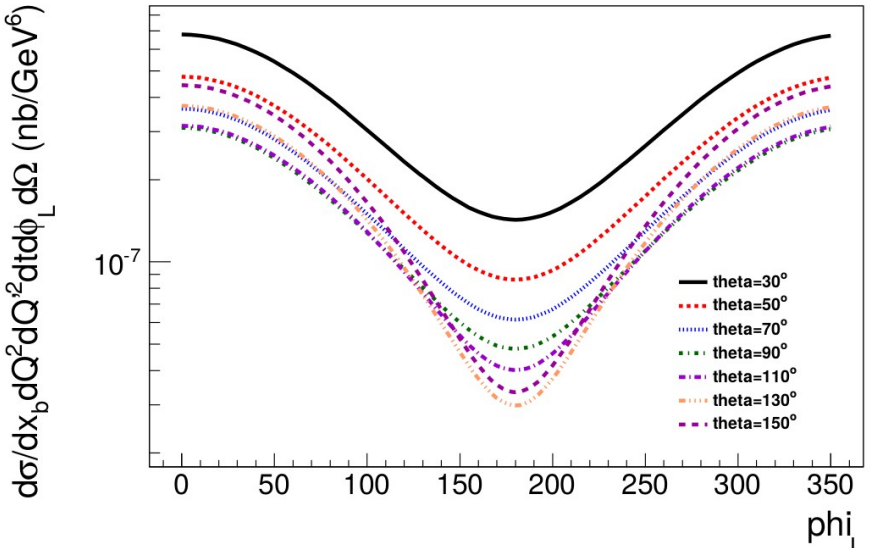


- Probing GPDs at x ≠ ξ → tomographic interpretations....
- Expectation of sign change for observables sensitive to Im (DDVCS) when moving from « spacelike » to « timelike » region

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

Cross sections versus angles

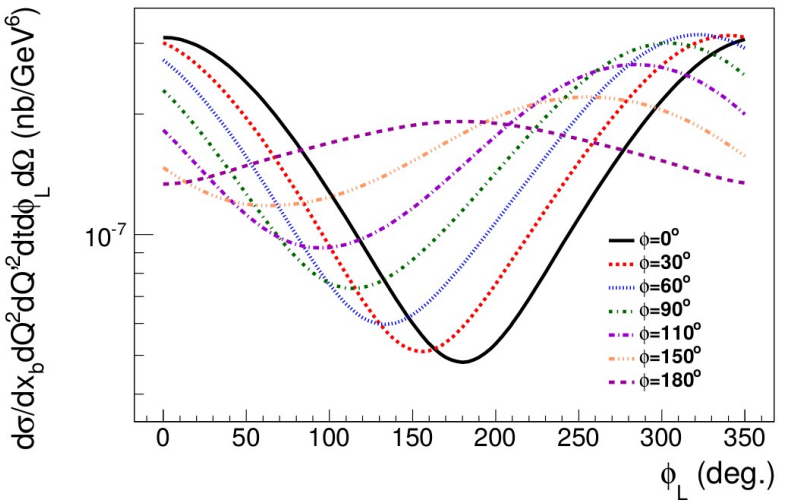




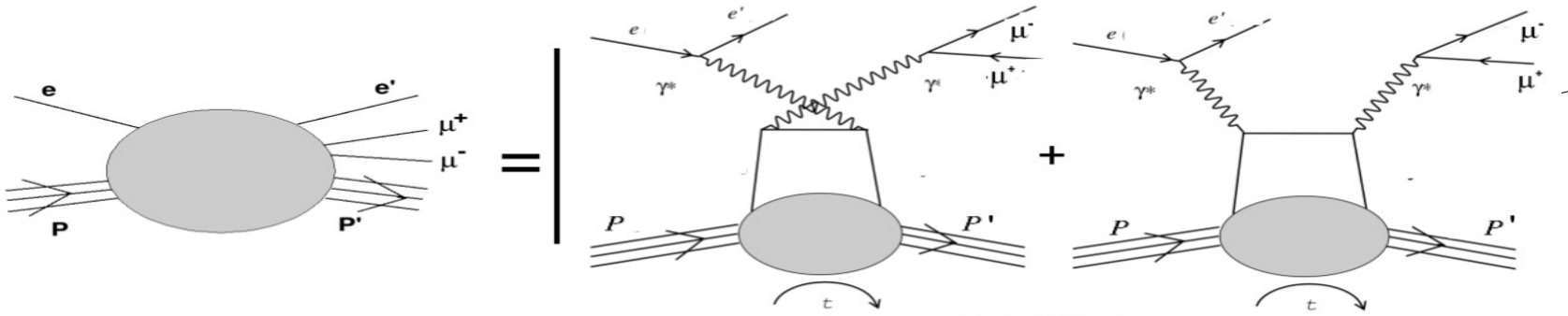
Due to strong angular dependence in 3 angles:

CFFs: 2D fits in φ_{CM}, φ_{LH}, as a function of ξ, ξ', t

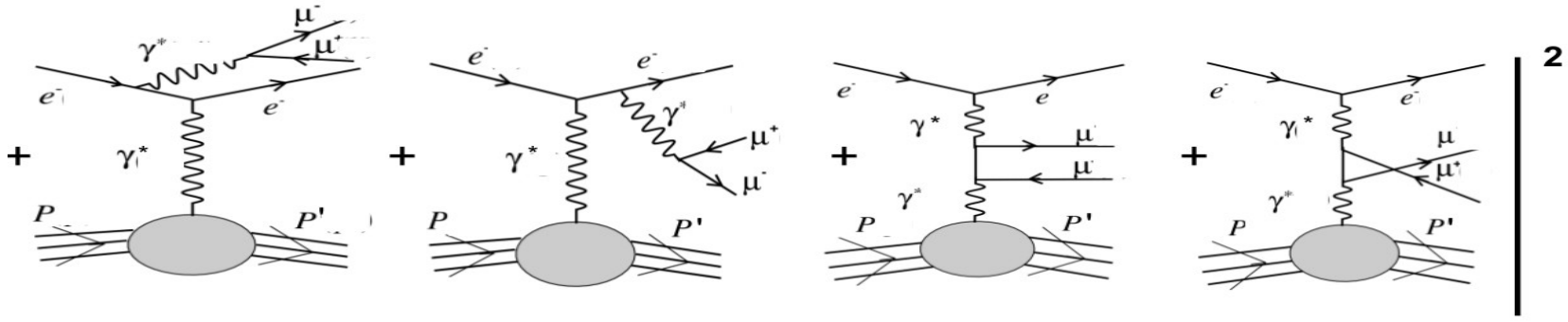
only Im($\mathcal{H}$) (ξ', ξ, t) will be possible to extract with unpolarized cross section and beam asym.



Angular behavior and “effective” observables



no favored direction for γ* emission or decay leptons



BH_1

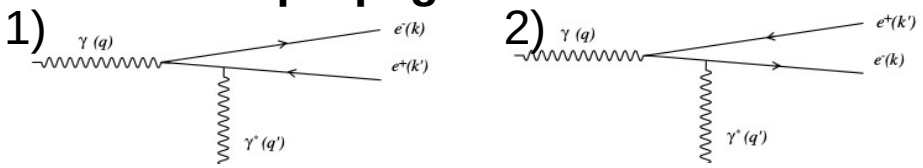
peak when γ' becomes collinear to e related to $\varphi_{LH}=0$,
and depends $\cos\theta_{\gamma\gamma}$ (kinematics)
and "γ"→e' angle

BH_2

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

Angular correlations (will be implemented as for TCS)

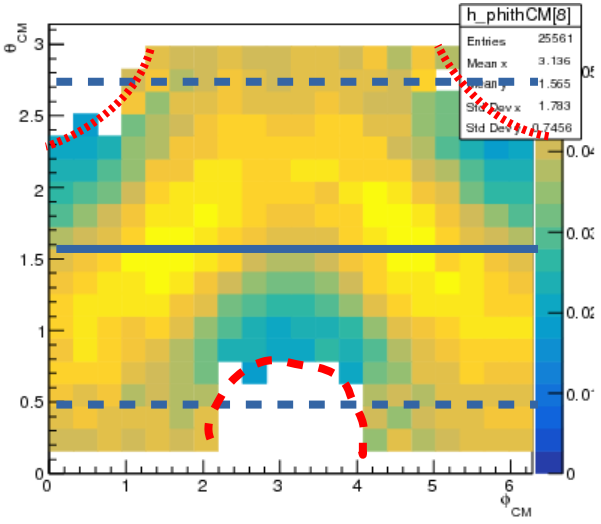
BH propagators



- BH peaks when e- or e+ collinear to incoming γ (from BH II)
- strong kinematic dependence at JLab energy
- one diagram becomes largely dominant / very asymmetric decays

- Momentum and θ_{lab} cuts help already
- Q^2, Q'^2, xb, t dependent angular cut for “effective” observables

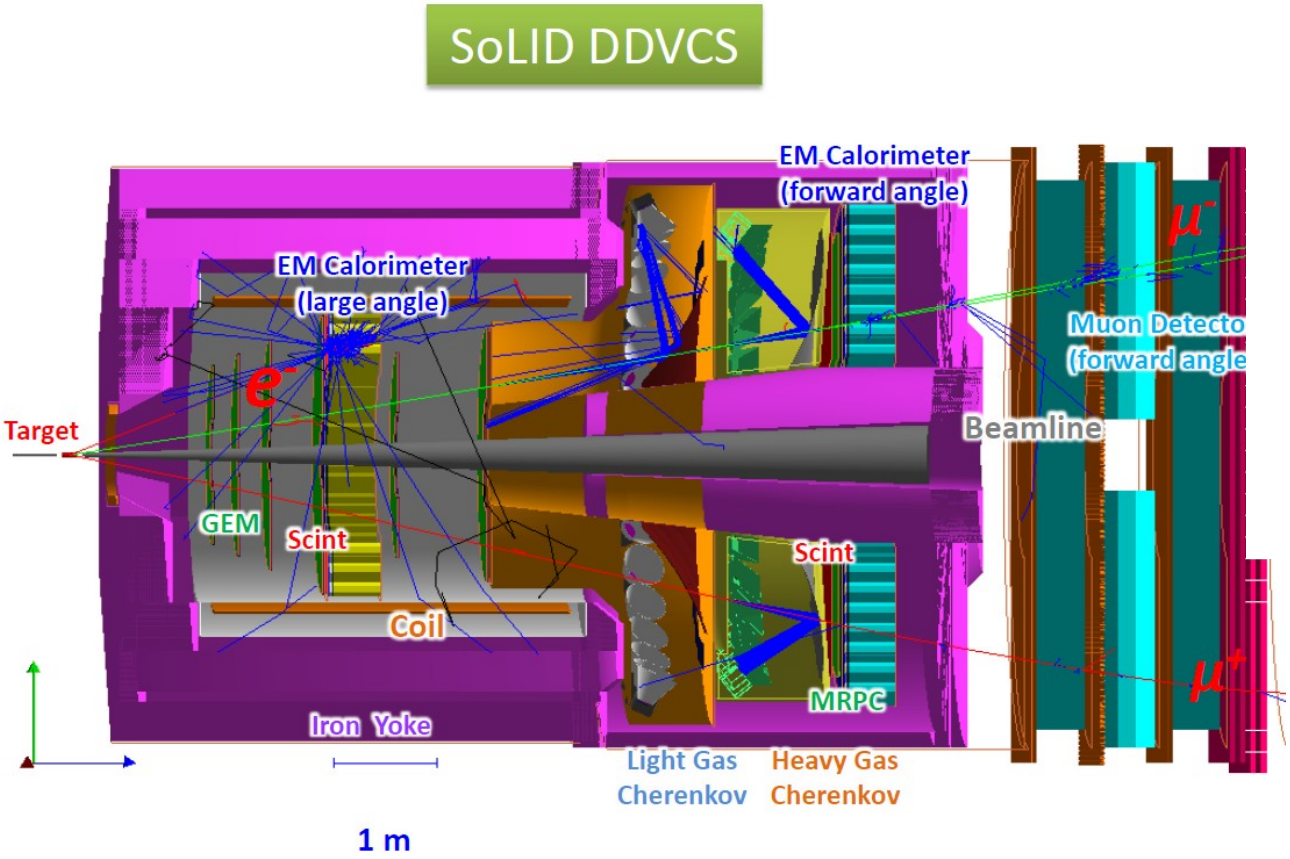
BH peaks: lepton 1 to beam direction, other almost "at rest" ⇒ momentum threshold and geometrical acceptance mostly prevent for too high rates and singularitie regions.
Angular + momentum acceptance is important

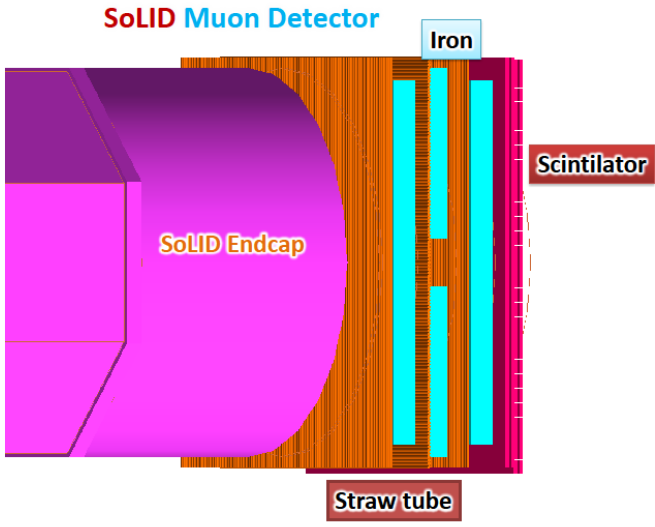


-- cut at 30°; 150°
-- acceptance cut
not included: cut of some bins next to singularities if not experimentaly "solvable" due to limited statistics (example 2 orders of magnitude increase of σ within a bin)

SoLID Setup

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



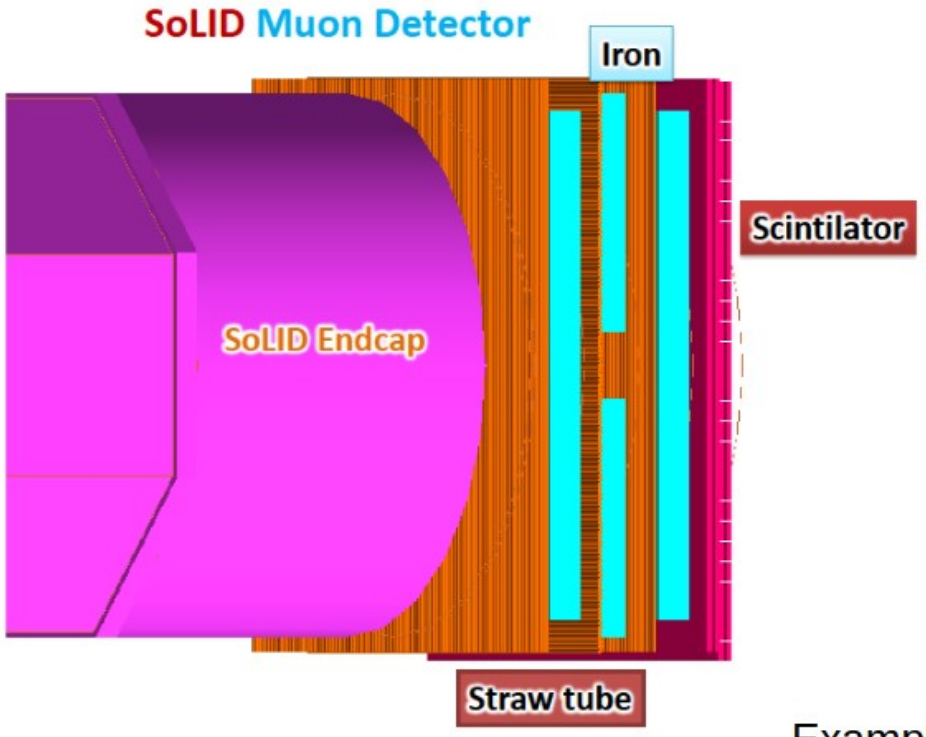


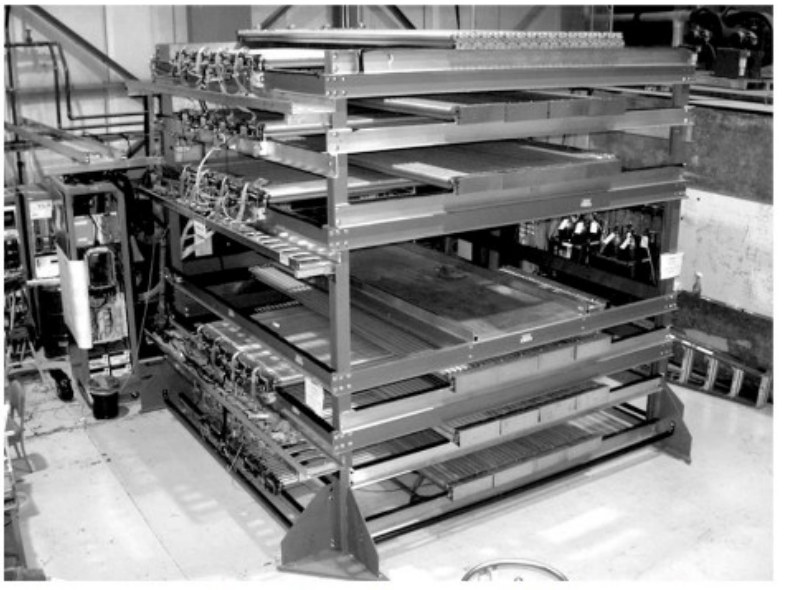
3 layers iron (shielding)
3 layers straw tubes (tracking)
2 layers scintillators (trigger)

Boër, Camsonne, Voutier, Zhao, et al. LOI submitted 2023

Forward muon detector (proposed addition)

3 layer iron to block charged pions, 3 layer straw tubes for tracking, 2 layer scintillators for trigger

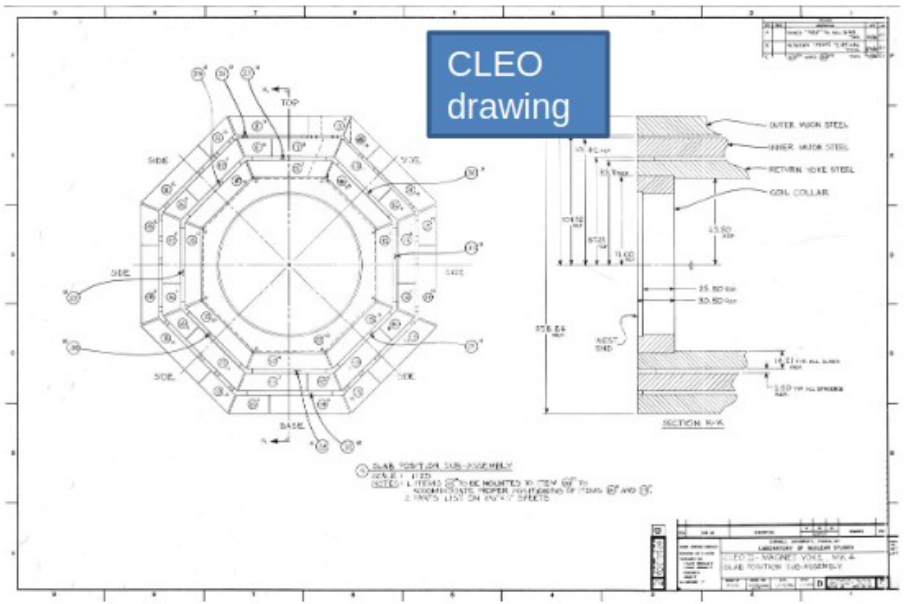


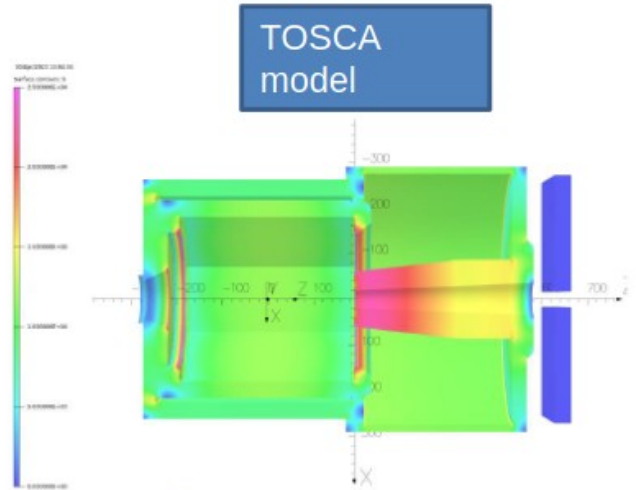


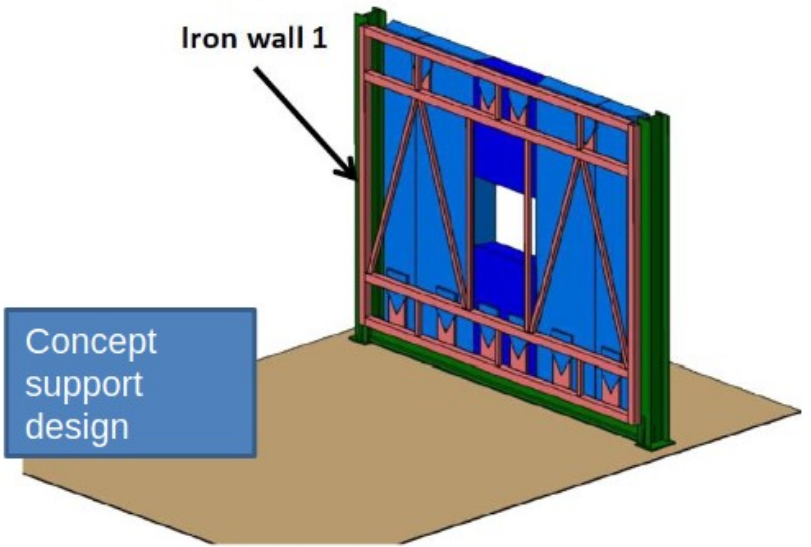
Example of straw tube chambers similar to Seaquest experiment

Iron Shielding: from CLEO

Reuse 6 of 8 CLEO octagon outer layer iron
Each one is about 36x254x533cm
No problem with space
Field (<10G),force(<1N),torque(<2Nm) are small







Software

- Projections from VGG model
- Effective observables calculated with VGG model for GPDs and DEEPGen generator
- Angular studies with DEEPGen
- Acceptance studies with Grape
- Work in progress to add EPIC, will be able to compare models

Collaborators / Hardware R&D

Main collaborators: JLab, IJCLab, Duke, Virginia Tech, Rutgers

- muon detector first tests to be done at soon, all groups work together to develop a realistic experiment,

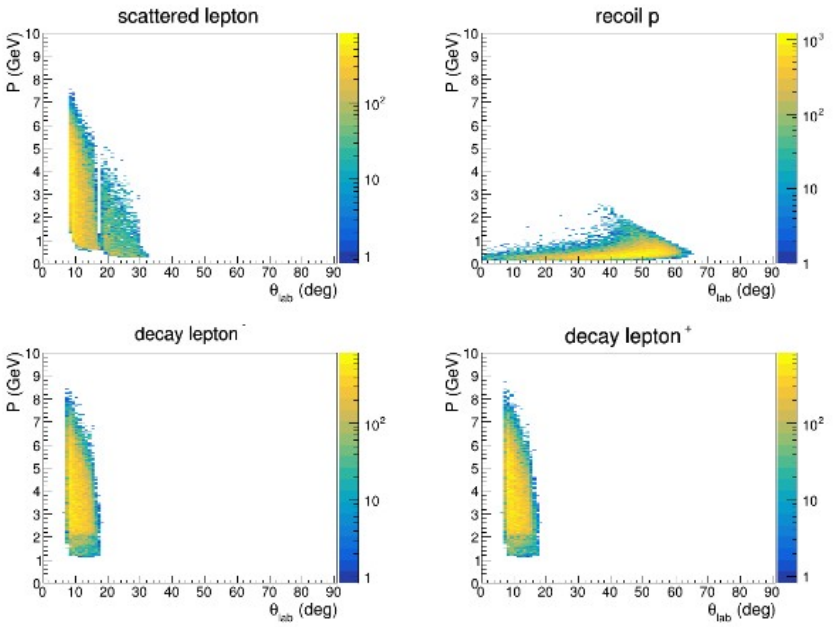
- exploring various options for muon detector

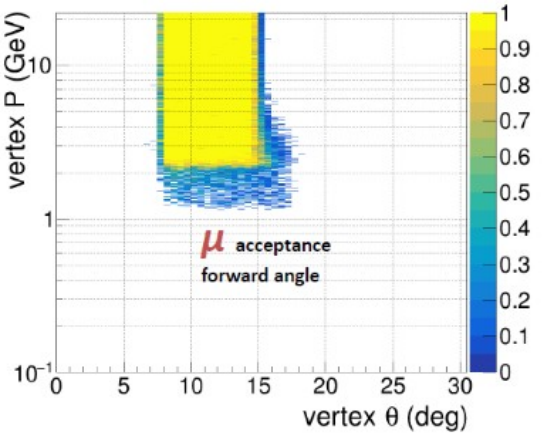
- also exploring shorter scale experiment(in Hall C, not shown in this talk)

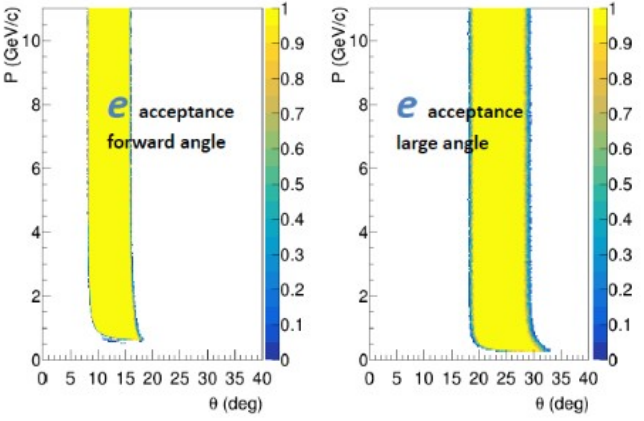
SoLID Acceptance studies

BH generator grape-dilepton

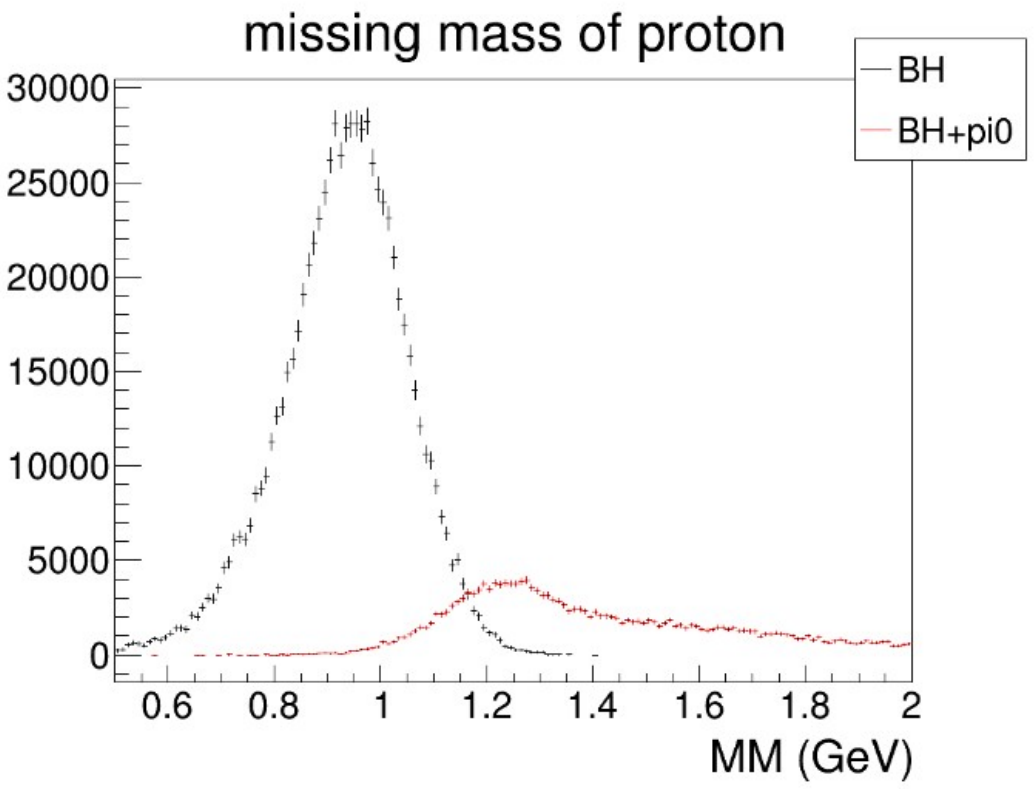
- Muon mom>2GeV is accepted
- Scattered e- and both muons are detected
- recoil proton is not required, but some can still be detected by time of flight



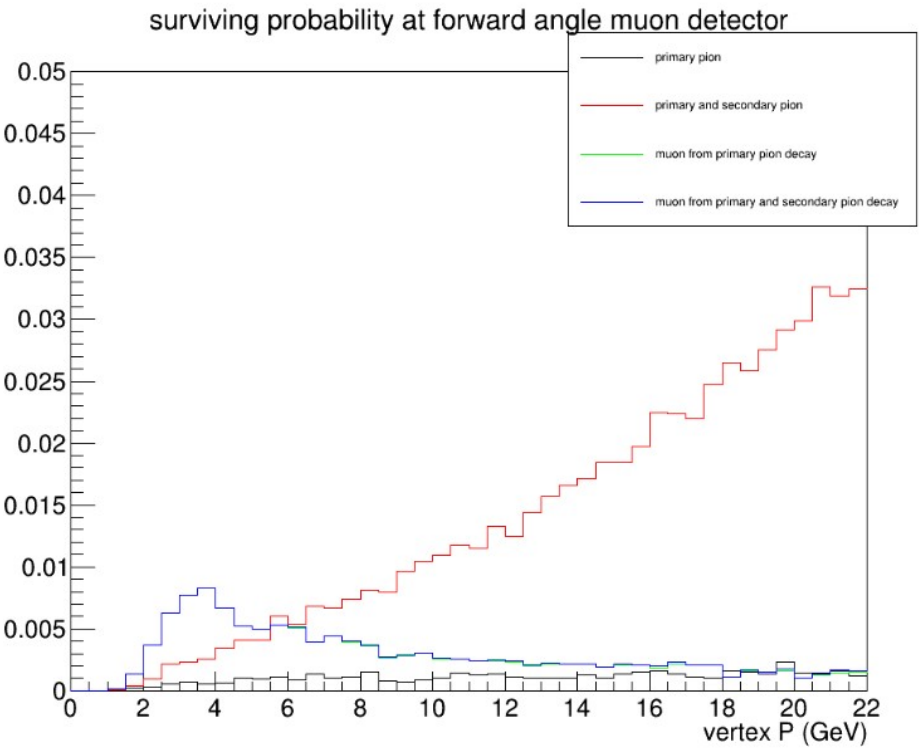




Exclusivity and background rejection



fine enough resolution to select DDVCS+BH



high rate of pion rejection after muon detector

Single pion rates at muon detector

- Start from “evgen_bggen” generator based on resonance fit and pythia
- go through full SoLID simulation for pion blocking and muon decay including both primary and secondary particles
- pi-/pi+ rate 9khz, mu-/mu+ rate 26khz, total 70khz
- Two charge particle coincidence rate 70e3*70e3*100ns<1khz

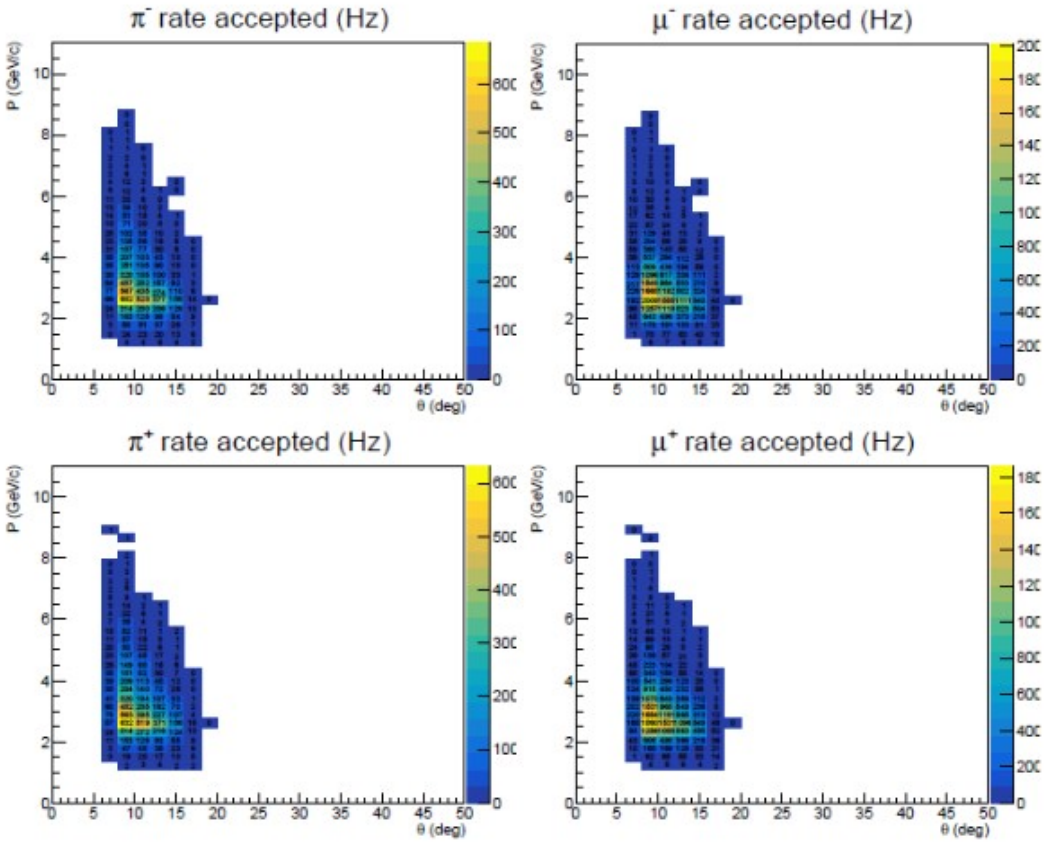
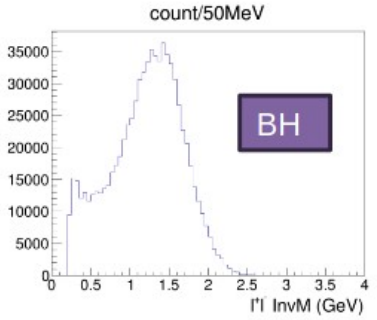


Figure 22: Single particles rate of pion and muon from pion decay at the back of forward angle muon detector. They include both pions directly from target and all secondaries and muons from their decay.

Two pion exclusive background



- Start from “twopeg” generator based on CLAS data fit and extrapolation to 11GeV beam kinematics
- go through full SoLID simulation for pion blocking and muon decay including primary particles only
- Left with counts about 10% of BH counts, mainly from both pions decay into muons.
- Tracking with vertex cut could reduce it further

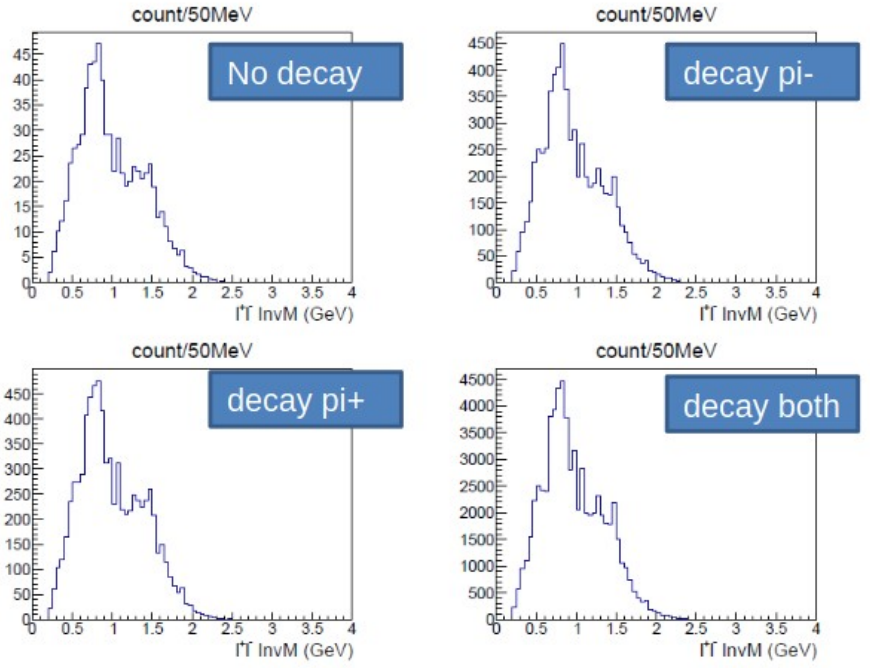


Figure 23: From left to right and top to bottom, the counts from the two pion exclusive channel contamination are shown in 4 cases, neither pion decay, negative pion decays into muon, positive pion decays into muon, and both pions decay.

SUMMARY

- Cross section and beam spin asymmetry for DDVCS+BH

- Enable extration of CFF and deconvolution x, xi for tomographic interpretations

- LOI 2023 following earlier work (first LOI) in 2015

- Theory progress in recent years (Shenying Zhao et al., 2021 / see Viktor’s talk today)

- R&D and planned tests with realistic muon detectors

- considering a short term experiment too in Hall C, complementary