DDVCS with SoLID

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Jefferson Laboratory Hall A

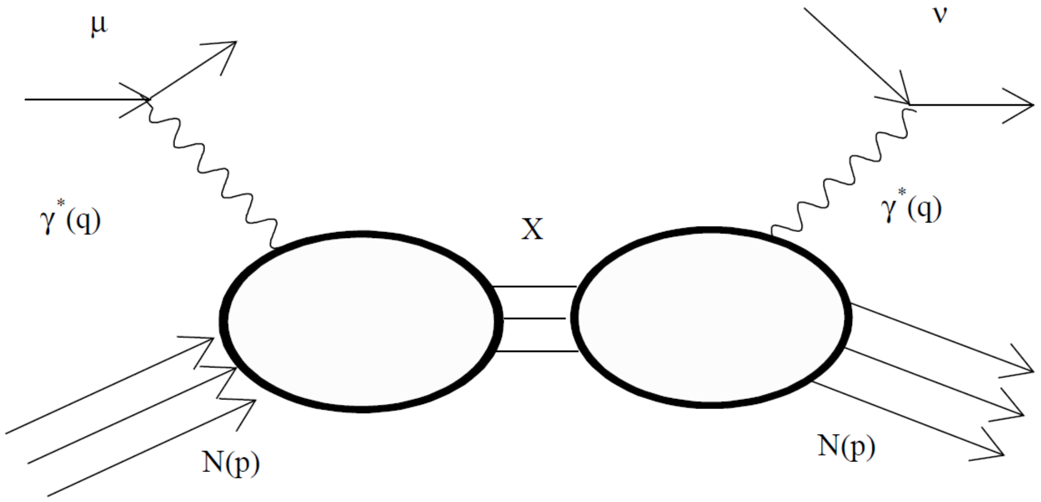
SoLID collaboration meeting

May 8th 2023

Outline

- Introduction Generalized Partons Distributions
- Double Deeply Virtual Compton Scattering
- Hall A DVCS results
- SoLID overview
- SoLID J/Psi setup
- SoLID DDVCS muon detector
- Backgrounds in Muon Detector
    - Single pion and di-pion background
    - Inelastic cut
- Expected results
- Conclusion

Optical theorem and parton distributions for Deeply Inelastic Scattering



$$W_{\mu\nu} = \frac{1}{4\pi}\sum_X < N(p)|j_v(0)|X >< X|j_\mu(0)|N(p) > (2\pi)^4\delta^{(4)}(p+q-p_x)$$
$$= \frac{1}{2\pi M}\Im[T_{\mu\nu}]$$

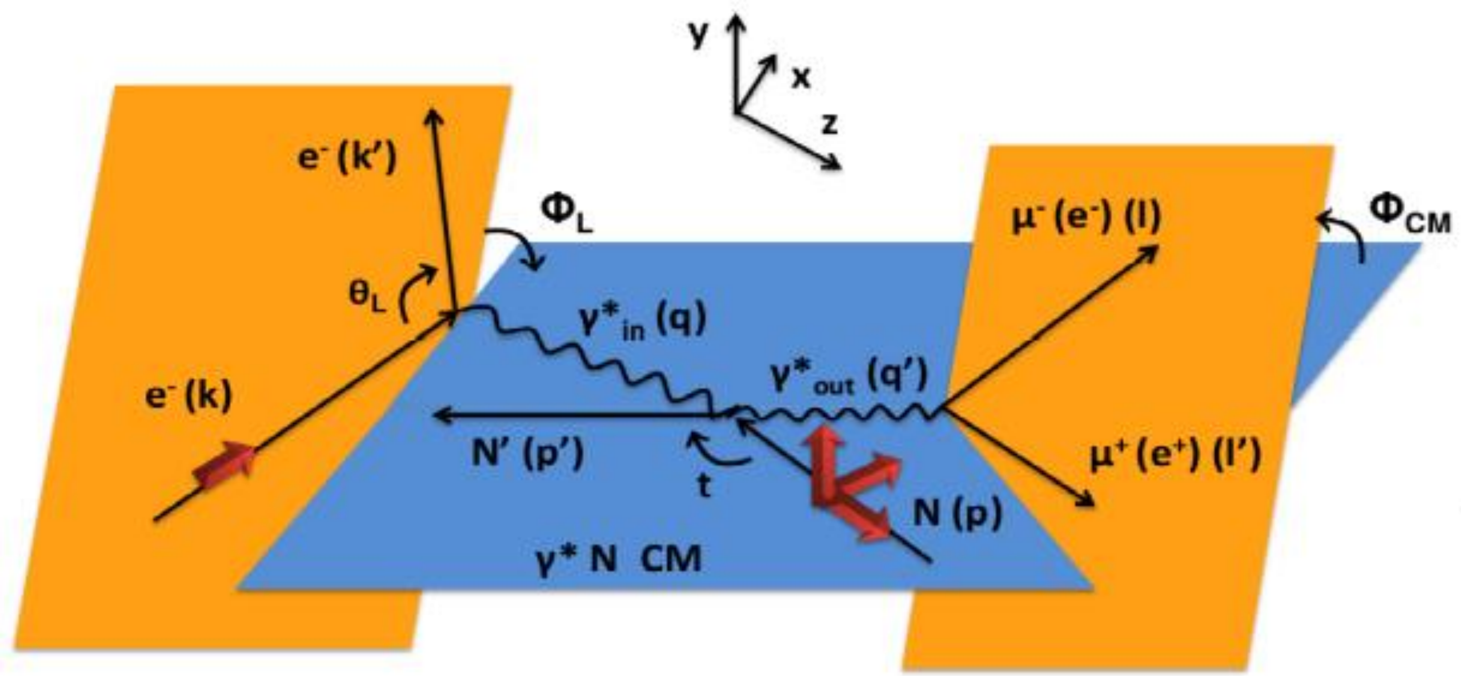
$$T_{\mu\nu} = i\int d^4 z e^{i(q\cdot z)} \langle N(p,s)|\, T\left\{J^\mu(-z/2), J^\nu(z/2)\right\} |N(p,s)\rangle$$

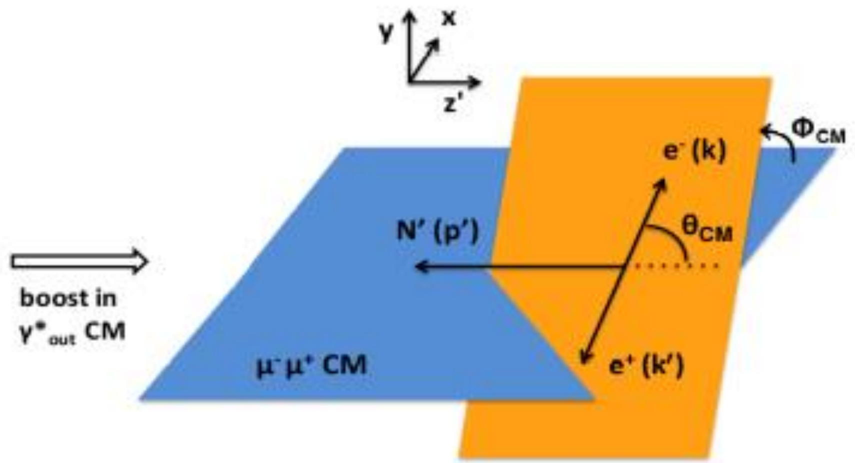
Description in terms of virtual photon absorbed and reemitted

Modern hadronic structure

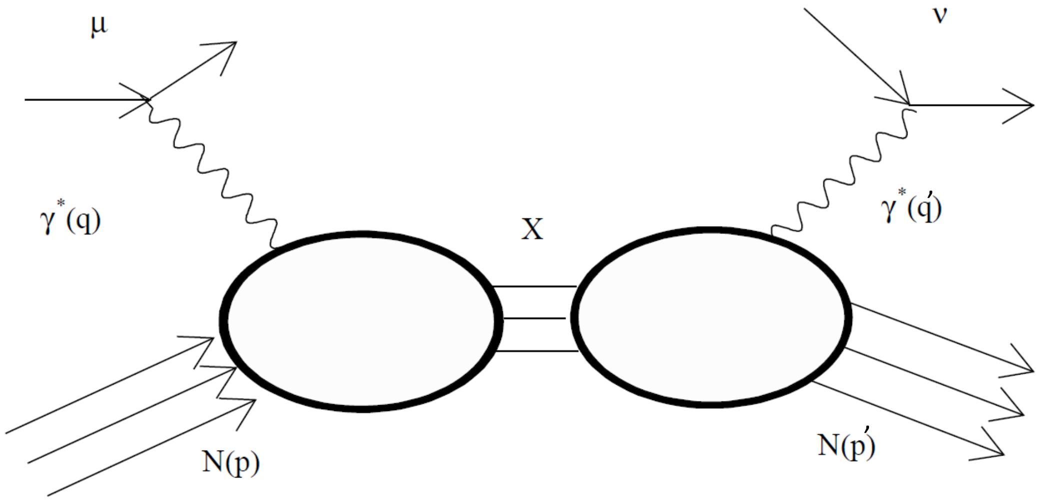
- Elastic form factors : spatial charge distribution of nucleon
- Hadronic structure through Deep Inelastic Scattering (1950s) : gives density of longitudinal momentum quarks and gluons inside a nucleon but no spatial information
- Spin crisis : spin of nucleon not simply spin of valence quarks
- Nucleon is a dynamic system, raises many questions
  - Mass repartition
  - Motion of quarks and gluons inside nucleons : quark orbital momentum

Definition of the angles





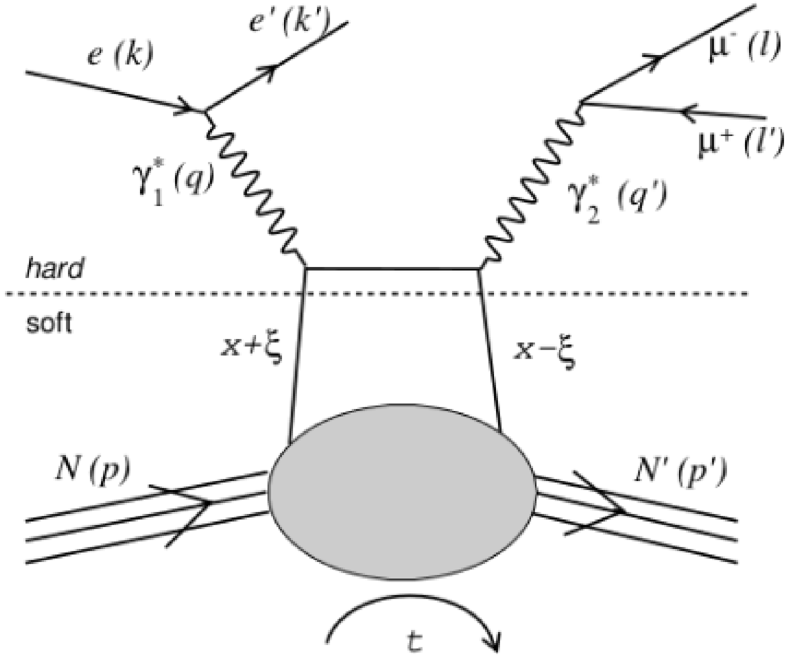
Generalized Parton Distribution



$$W_{\mu\nu} = \frac{1}{4\pi}\sum_X < N(p)|j_v(0)|X >< X|j_\mu(0)|N(p') > (2\pi)^4\delta^{(4)}(p+q-p_x)$$
$$= \frac{1}{2\pi M}\Im[T_{\mu\nu}]$$

$$T_{\mu\nu} = i\int d^4z e^{i(q\cdot z)} \langle N(p,s)| T\{J^\mu(-z/2), J^\nu(z/2)\}|N(p',s')\rangle$$

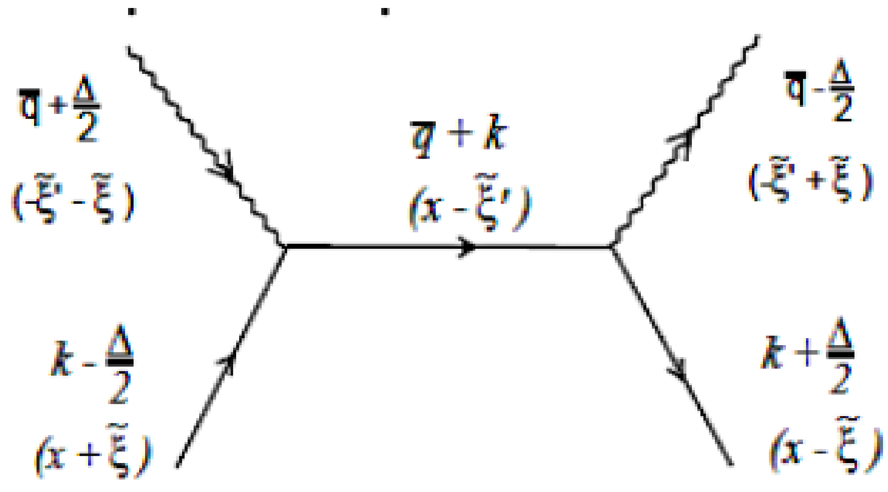
Double Deeply Virtual Compton Scattering kinematical variables



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_{LL}, Φ_{CM}, θ_{CM}



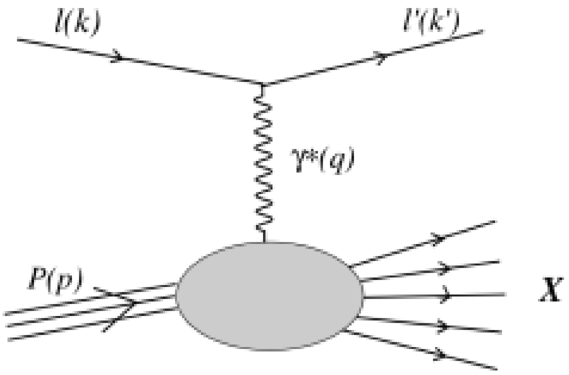
$$P = \frac{1}{2}(p + p'),$$
$$\Delta = (p' - p) = (q' - q)$$
$$\bar{q} = \frac{1}{2}(q + q')$$

$$P^\mu = \tilde{p}^\mu + \frac{\bar{m}^2}{2} n^\mu$$
$$\Delta^\mu = -2\tilde{\xi}\tilde{p}^\mu + \tilde{\xi}\bar{m}^2 n^\mu + \Delta_\perp^\mu$$
$$\bar{q}^\mu = -\tilde{\xi}'\,\tilde{p}^\mu - \frac{\bar{q}^2}{2\tilde{\xi}'} n^\mu$$

GPDs are function of a new variable skewness which is ration “transverse momentum over longitudinal “

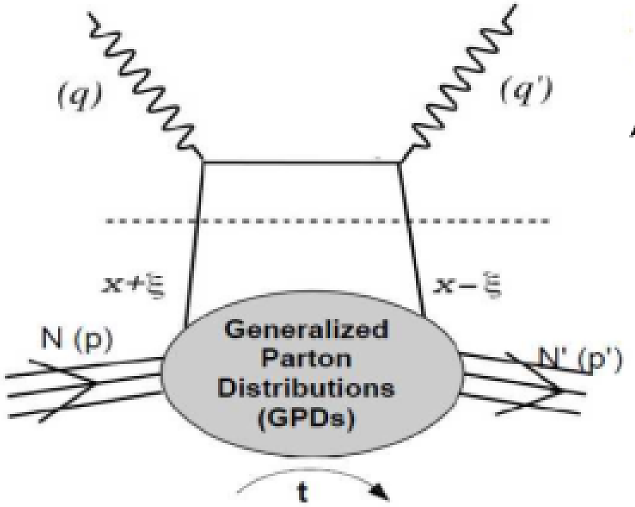
$$\xi = \frac{\Delta.\bar{q}}{P.\bar{q}}$$

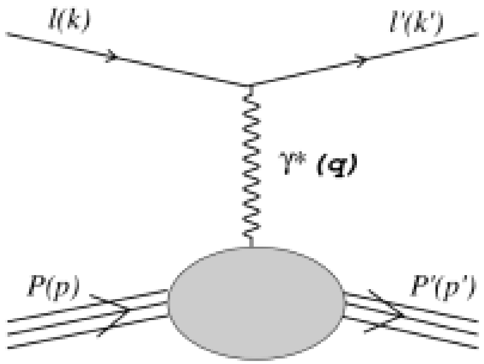
From “1D” to “3D” nucleon imaging



Deep Inelastic Scattering:
Access **“x”, longitudinal momentum of the partons**
[probabilistic interpretation]

Hard Exclusive Scattering:
Both **“x” and “impact parameter”**
We know all the final state





Elastic scattering:
Gives us the **transverse position of quarks**
From FT of squared momentum transfer “t”

Properties of GPDs

- Forward limit ($\xi = 0$)

$$H^q(x, \xi = 0, t = 0) \;=\; q(x)\,,$$
$$\widetilde{H}^q(x, \xi = 0, t = 0) \;=\; \Delta q(x)\,,$$

- Integration gives back form factors

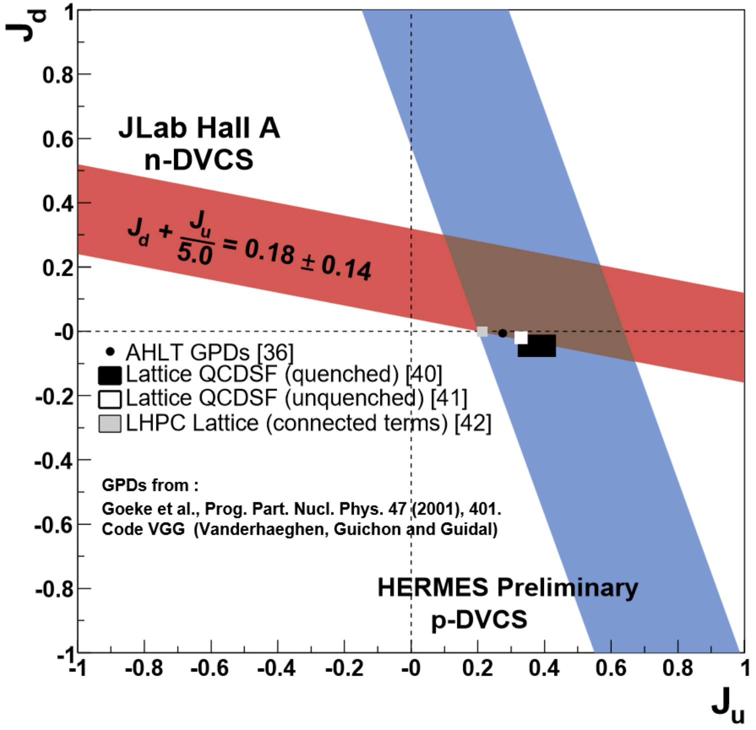
$$\int_{-1}^{+1} dx H^q(x, \xi, t) \;=\; F_1^q(t)\,, \quad \int_{-1}^{+1} dx E^q(x, \xi, t) = F_2^q(t)\,,$$
$$\int_{-1}^{+1} dx \widetilde{H}^q(x, \xi, t) \;=\; G_A^q(t)\,, \quad \int_{-1}^{+1} dx \widetilde{E}^q(x, \xi, t) = G_P^q(t)\,,$$

Informations from GPDs

- Orbital momentum of quarks Ji's sum rule

$$J^q = \frac{1}{2}\left[A^q(0) + B^q(0)\right] = \frac{1}{2}\Delta\Sigma^q + L^q$$

$$\int_{-1}^{1} x dx \left[H^q(x,\xi,t) + E^q(x,\xi,t)\right] = A_q(t) + B_q(t)$$

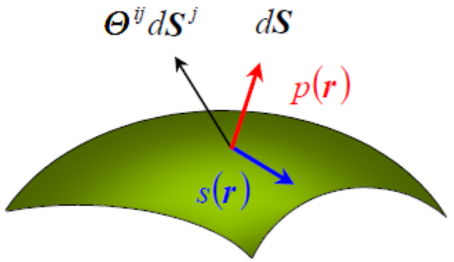


- Access to nucleon pressure

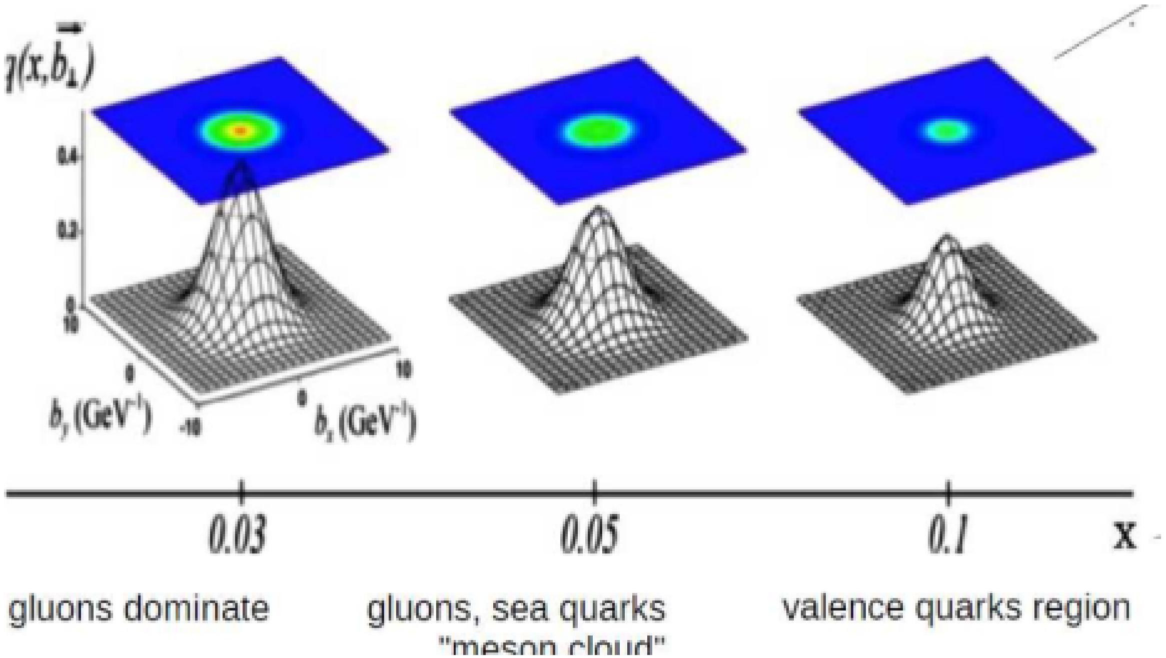
e-Print: 2104.02031 [nucl-ex] Girod, Burkert, Elouadrhiri

[hep-ph/0504030v3] Unraveling hadron structure with generalized parton distributions (arxiv.org) p64

$$\langle p_2|\Theta^{a,\mu\nu}|p_1\rangle = \frac{1}{2}\left(H^a(\Delta^2)p^{\{\mu}h^{\nu\}} + E^a(\Delta^2)p^{\{\mu}e^{\nu\}} + D^a(\Delta^2)\frac{\Delta^\mu\Delta^\nu - g^{\mu\nu}\Delta^2}{2M_N}b\right) \pm \widetilde{D}(\Delta^2)M_N g^{\mu\nu}b\,,$$



Tomographic interpretation of the Generalized Parton Distributions



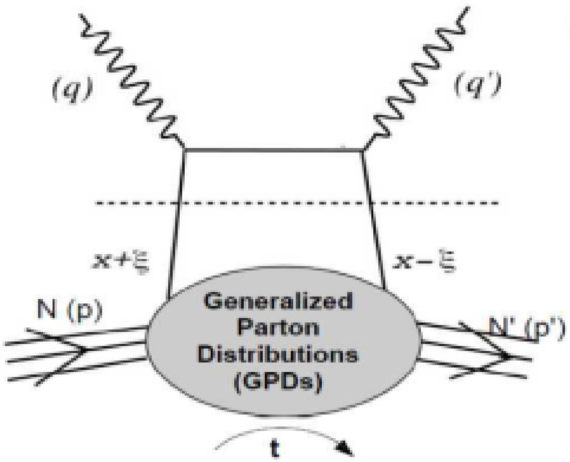
Momentum dependent Impact parameter distributions

GPDs depend on x (quark's momentum fraction), xi (skewness), t (Mandelstam) [+ evolution]

Momentum dependent Impact Parameter Distributions aka "tomographic views"
- Obtained from Fourier Transform of **GPDs at xi=0: need deconvolution of x and xi**

Not possible with other reactions such as DVCS… (why: next slides)

From Hard Exclusive Reactions to Generalized Parton Distributions



GPD: matrix element that connect N and N' and contain quark/gluons interactions

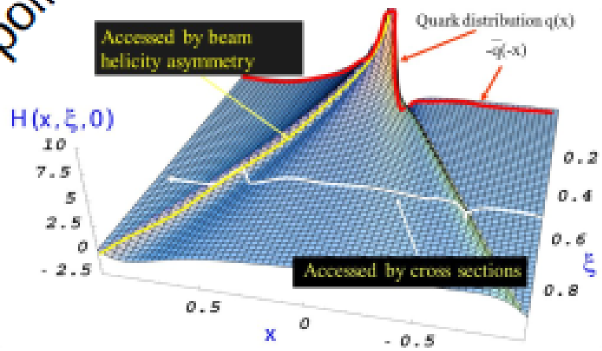
- Unpolarized GPDs: partonic distributions
- Polarized GPDs: related to spin partition
- Chiral-odd GPDs: spin flip; related to parton's mass
- Higher order / twist: extra gluons exchanges

1. Extracted at xi (// momentum) and t (momentum transfer [2]) from experimental data

"Compton Form Factors": Complex functions of amplitudes

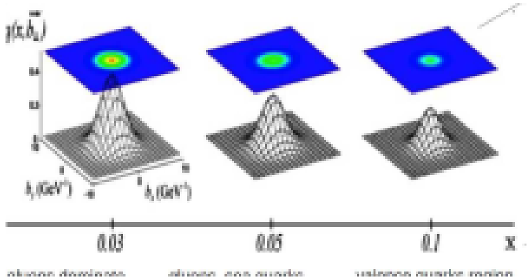
2. Extrapolation to physics points

GPD

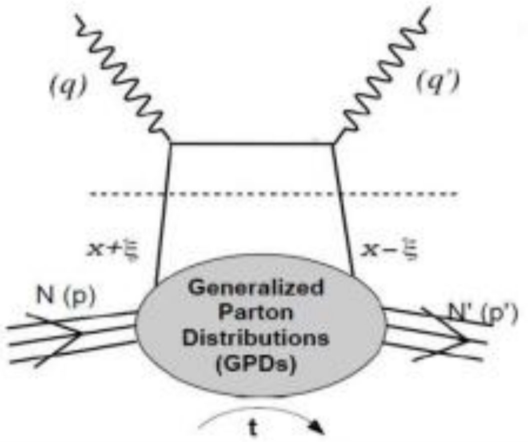


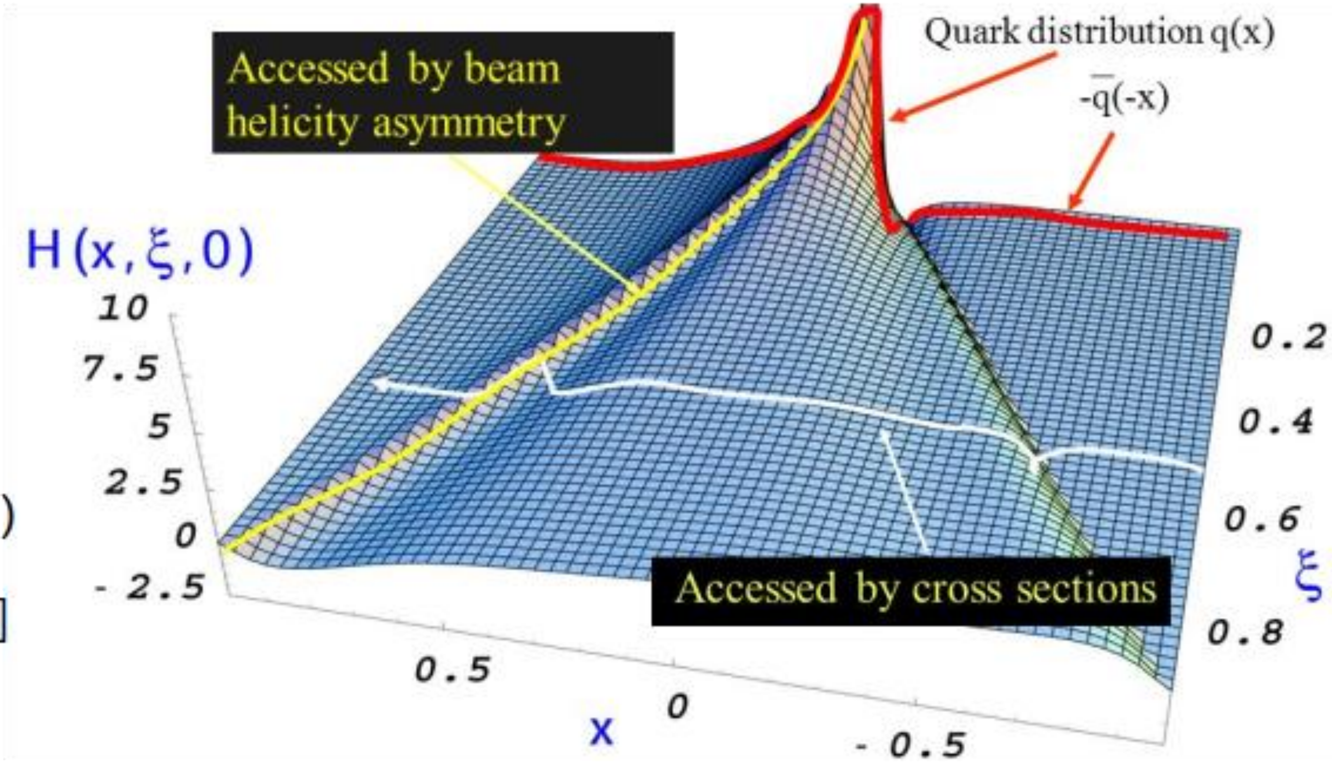
3. Fourier transform

Momentum dependent Impact parameter functions



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



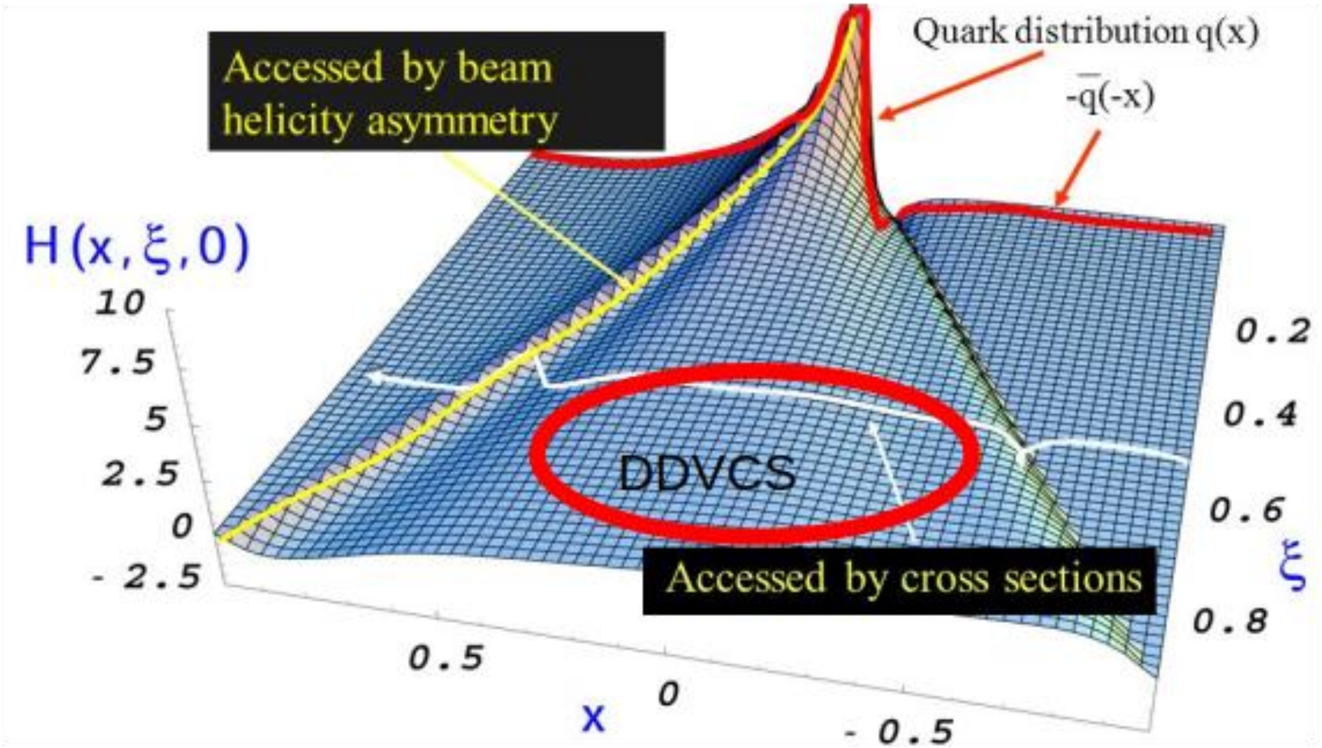


Extracted at ξ (skewness // momentum)
and t (momentum transfer ²)
from experimental data [can't access x]

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

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

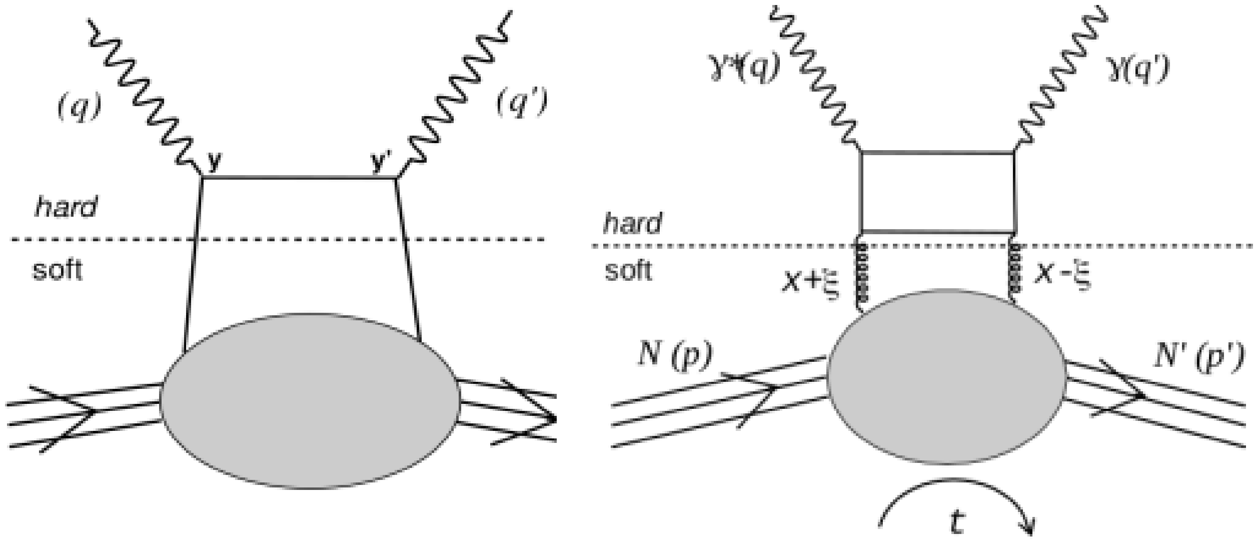
Generalized Parton Distributions from CFF fits (with DDVCS)



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

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



Leading order / leading twist generic handbag diagram

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

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

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

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

Guidal and Vanderhaegen : Double deeply virtual Compton scattering off the nucleon (arXiv:hep-ph/0208275v1 30 Aug 2002)

Phenomenology of double deeply virtual Compton scattering in the era of new experiments

Belitsky Radyushkin : Unraveling hadron structure with generalized parton distributions (arXiv:hep-ph/0504030v3 27 Jun 2005)

Phenomenology of double deeply virtual Compton scattering in the era of new experiments

K. Deja(NCBJ, Warsaw), V. Martinez-Fernandez(NCBJ, Warsaw), B. Pire(Ecole Polytechnique, CPHT), P. Sznajder(NCBJ, Warsaw), J. Wagner(NCBJ, Warsaw)

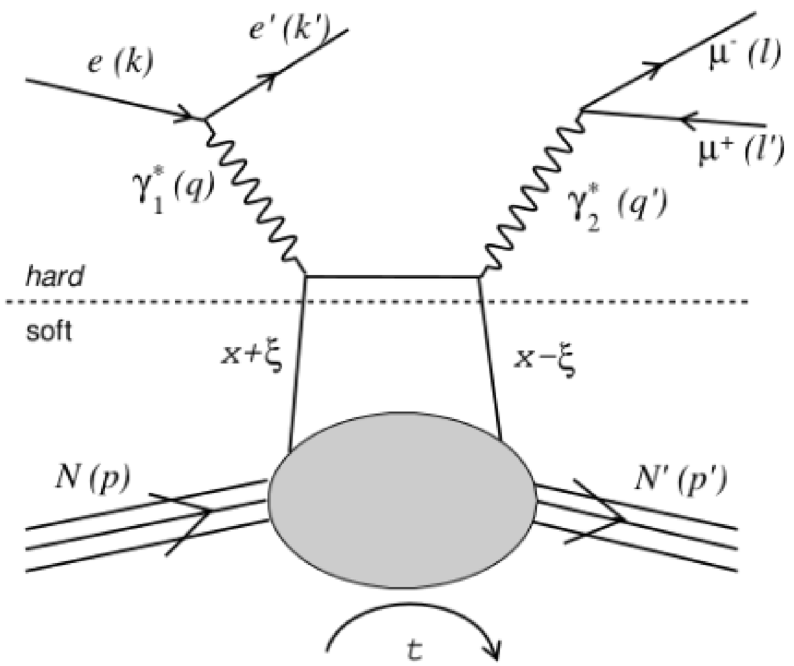
(Mar 23, 2023 e-Print: 2303.13668 [hep-ph])

Prospects for GPDs extraction with Double DVCS

K. Deja(NCBJ, Warsaw), V. Martinez-Fernandez(NCBJ, Warsaw), B. Pire(Ecole Polytechnique, CPHT), P. Sznajder(NCBJ, Warsaw), J. Wagner(NCBJ, Warsaw)

(Apr 7, 2023 e-Print: 2304.03704 [hep-ph])

What do we want to measure?



e P → e' P' μ+ μ-

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

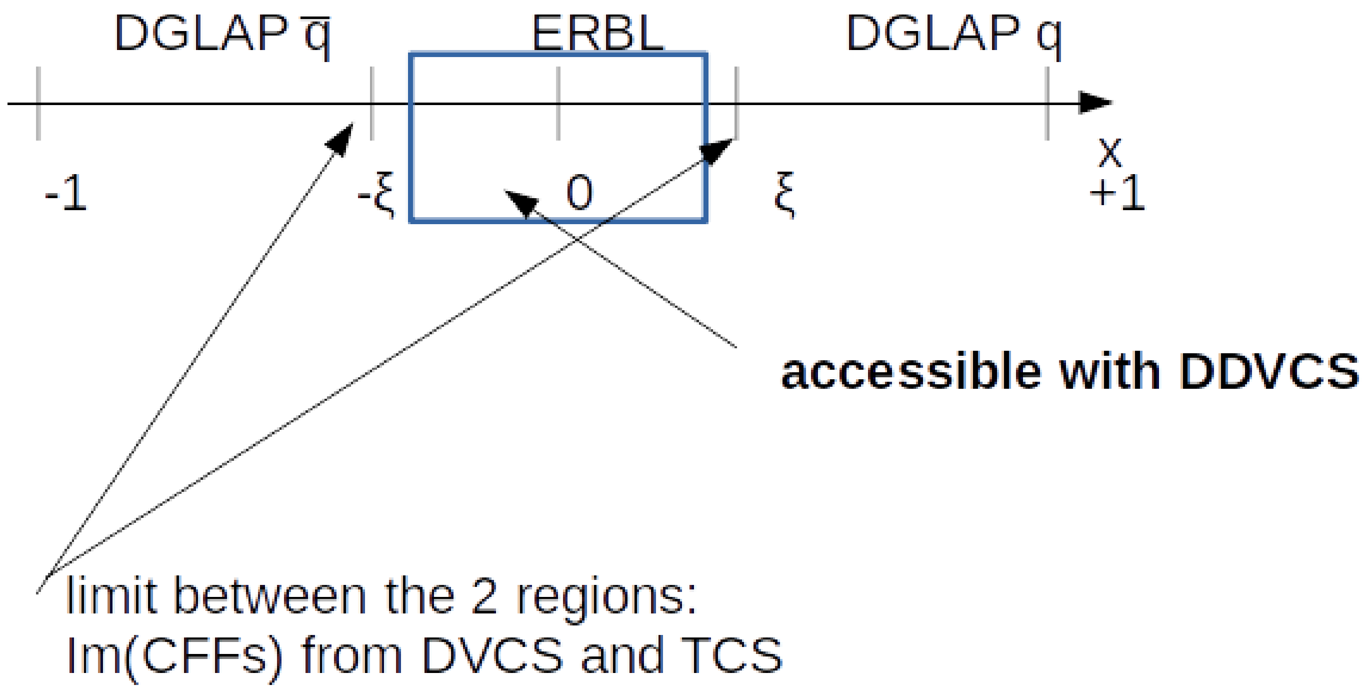
7-independent variables for cross section.
Choice: E_e, ξ (or x_{bj}), t, Q^2, Q'^2, Φ_L, Φ_{CM}, θ_{CM}

$$\begin{Bmatrix} A_{\rm LU}^{\sin\phi} \\ A_{\rm LU}^{\sin\varphi_\mu} \end{Bmatrix} = \frac{1}{\mathcal{N}} \int_{\pi/4}^{3\pi/4} d\theta_\mu \int_0^{2\pi} d\varphi_\mu \int_0^{2\pi} d\phi \begin{Bmatrix} 2\sin\phi \\ 2\sin\varphi_\mu \end{Bmatrix} \frac{d^7\overrightarrow{\sigma} - d^7\overleftarrow{\sigma}}{dx_B\, dy\, dt\, d\phi\, dQ'^2\, d\Omega_\mu} \propto \Im\mathrm{m}\left\{ F_1\mathcal{H} - \frac{t}{4M_N^2} F_2\mathcal{E} + \xi(F_1+F_2)\widetilde{\mathcal{H}} \right\},$$

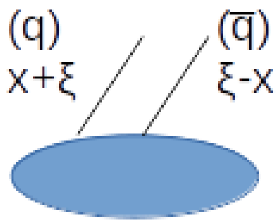
Partonic interpretation, GPDs in ERBL region

What do we learn?

from M. Diehl's representations:



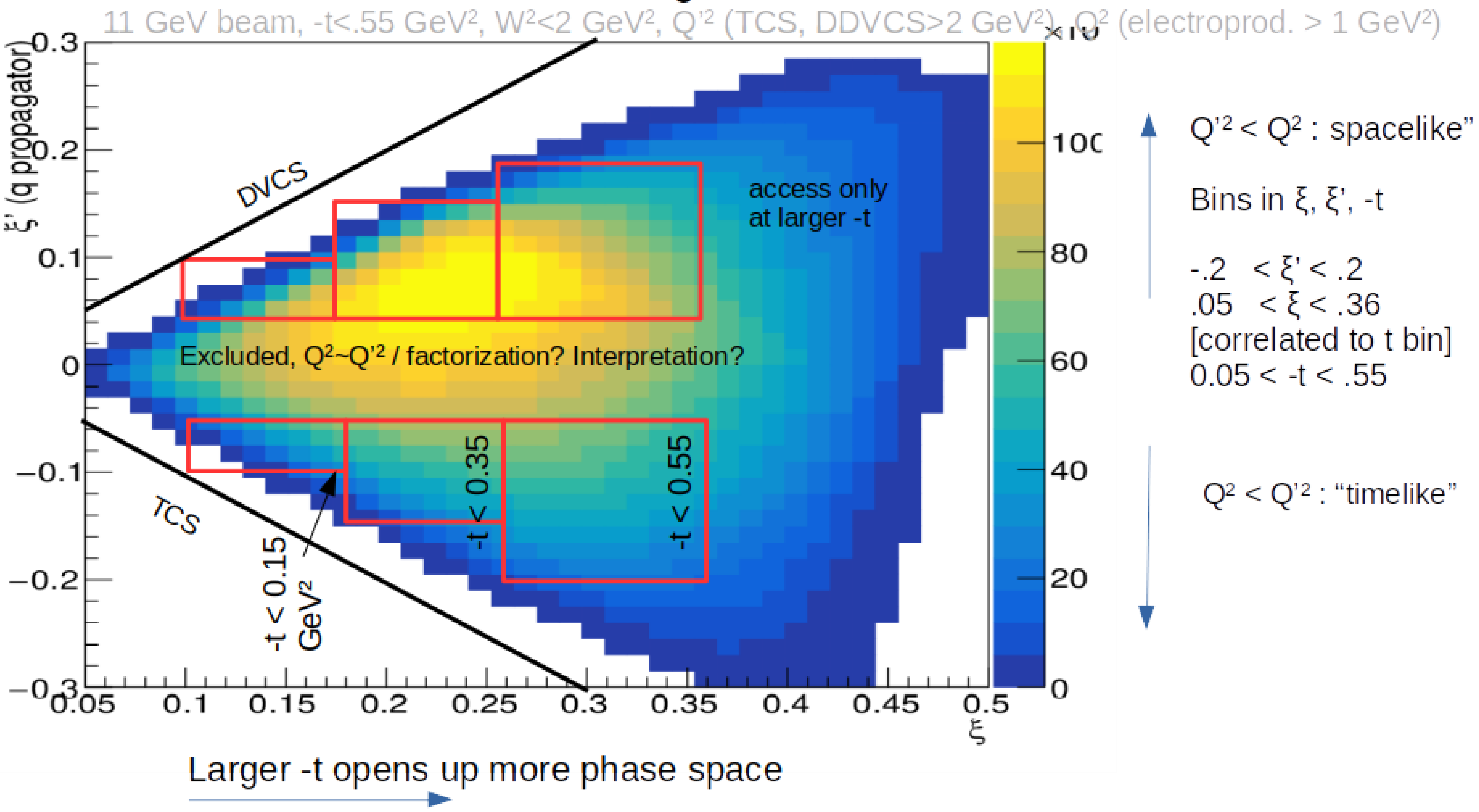
partonic interpretation from M. Diehl in ERBL region



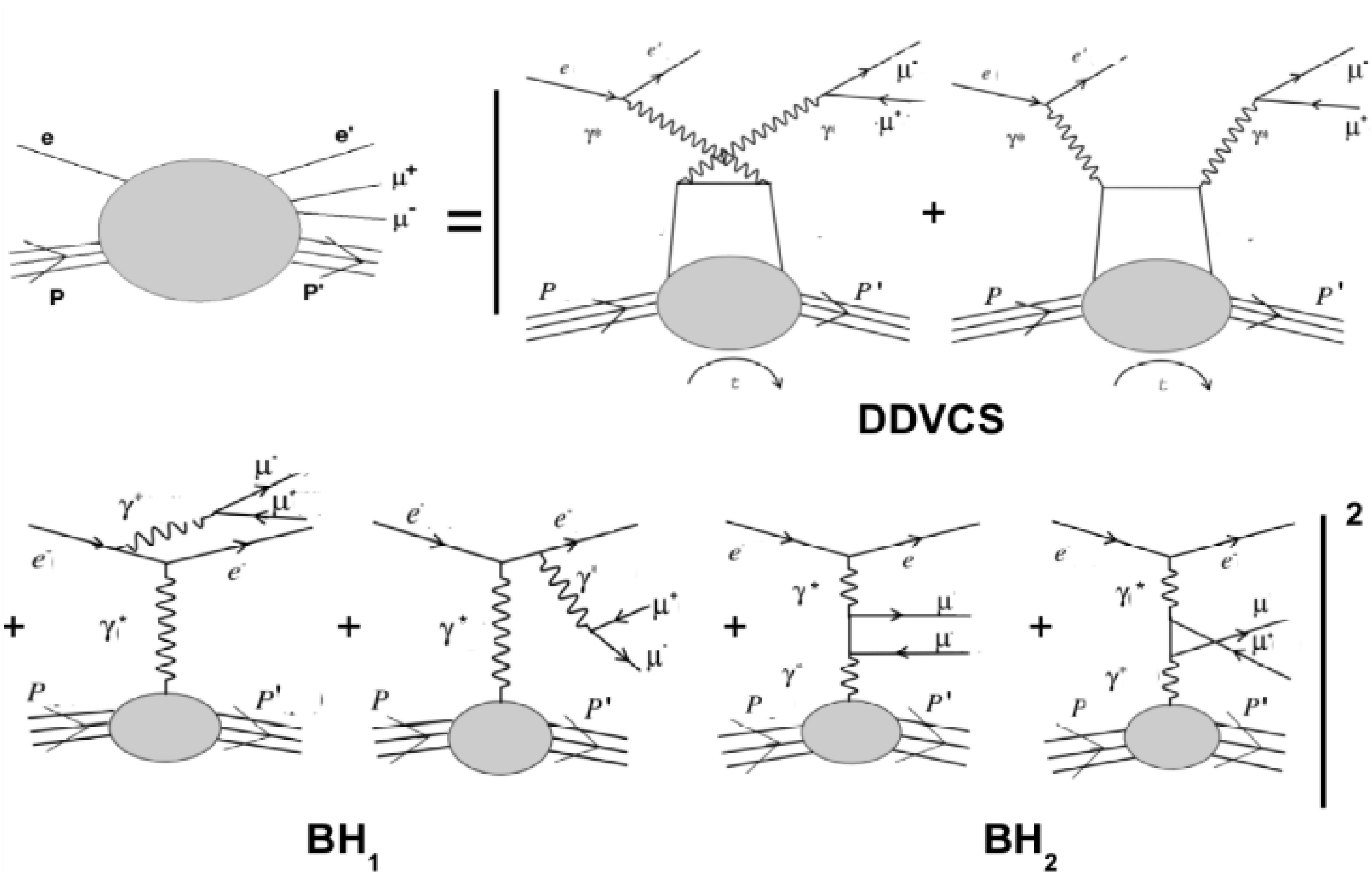
Probing quark-antiquark pairs in the nucleon

We don't know GPDs in that region, it is essential for the deconvolution and tomographic interpretations

Off diagonal access



Interference with Bethe-Heitler



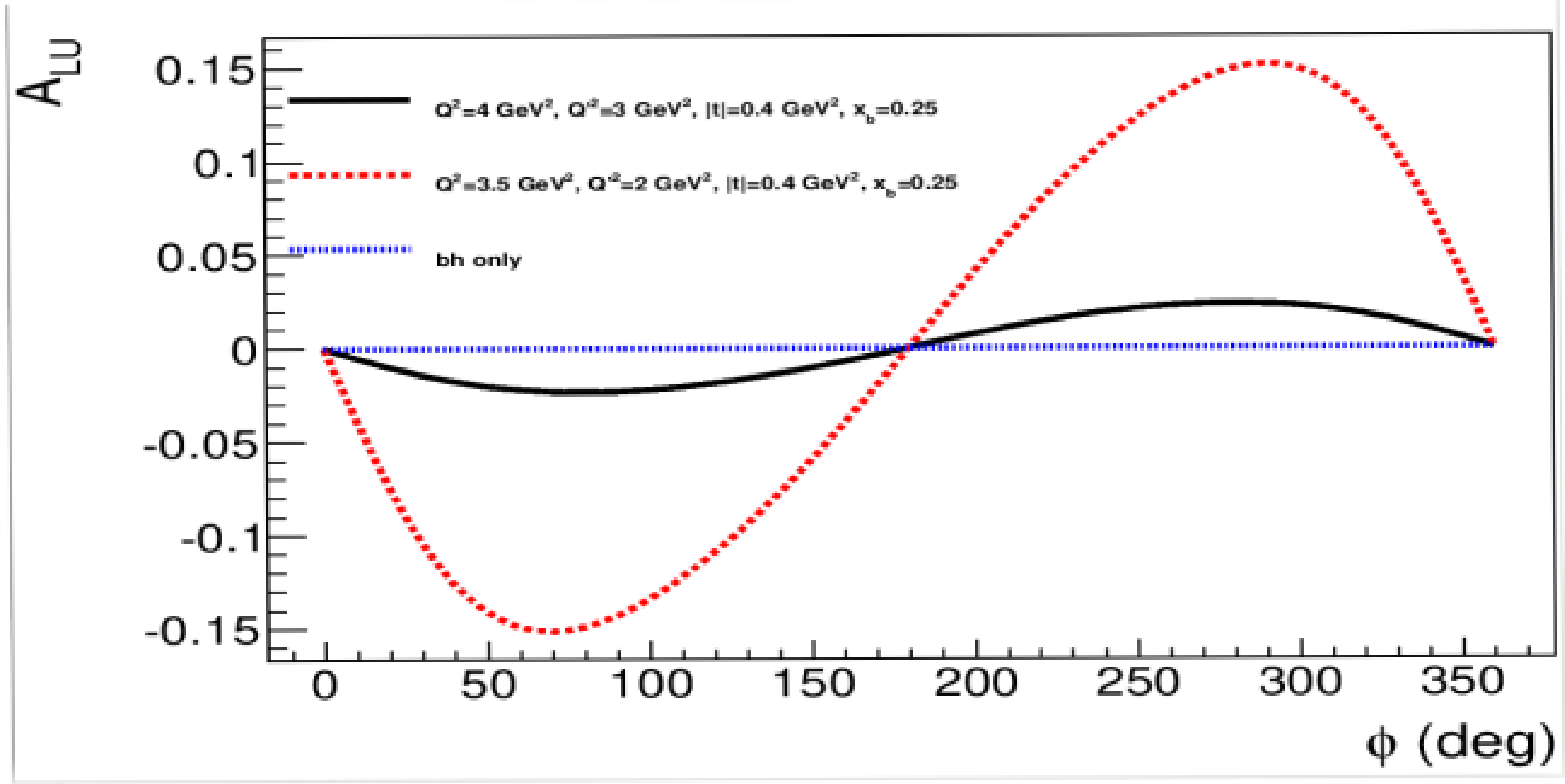
$d^5\vec{\sigma} - d^5\overleftarrow{\sigma} = Im(T^{BH}.T^{DDVCS})$

$d^5\vec{\sigma} + d^5\overleftarrow{\sigma} = |BH|^2 + Re(T^{BH}.T^{DDVCS}) + |DDVCS|^2$

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

Observables for DDVCS measurements at JLab

Beam Spin Asymmetry



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

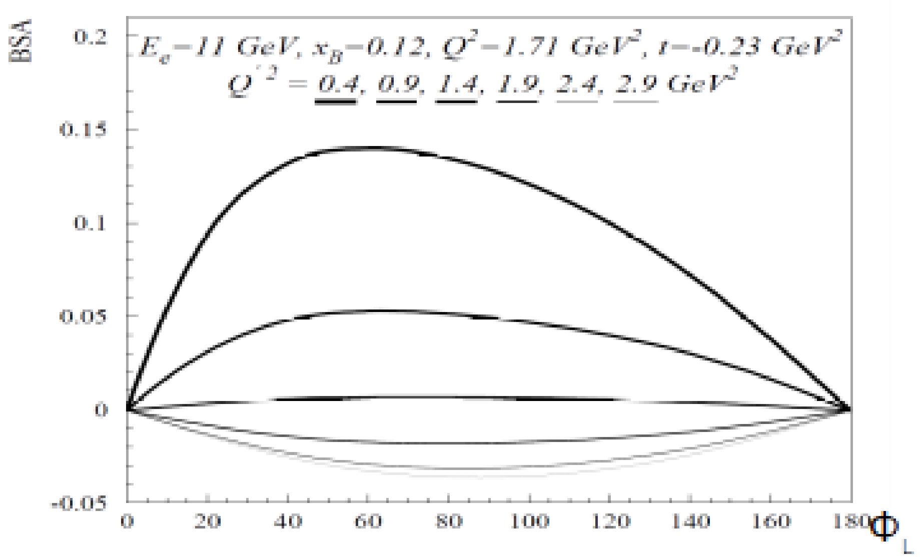
Change of sign to be observed in different kinematic regions

Observables for DDVCS measurements at JLab

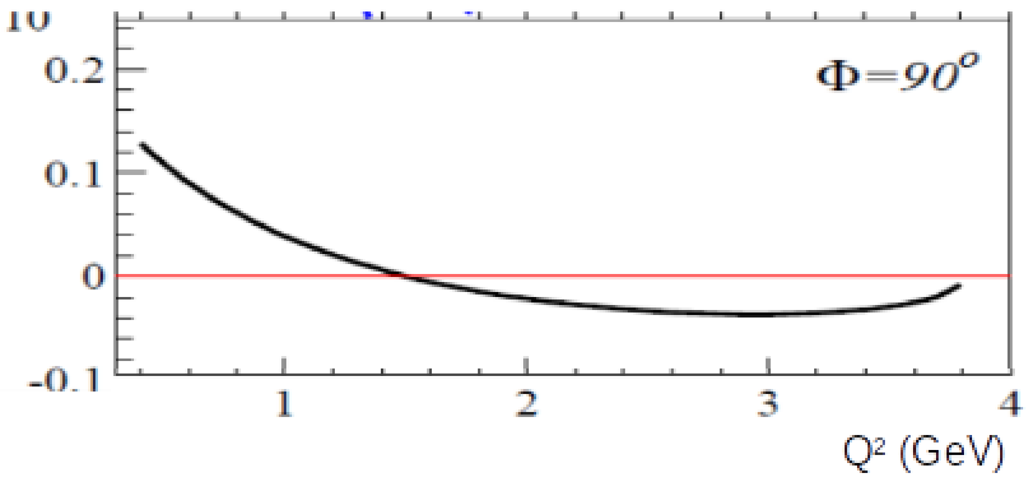
Sign change in BSA and interplay "spacelike" "timelike" regions

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



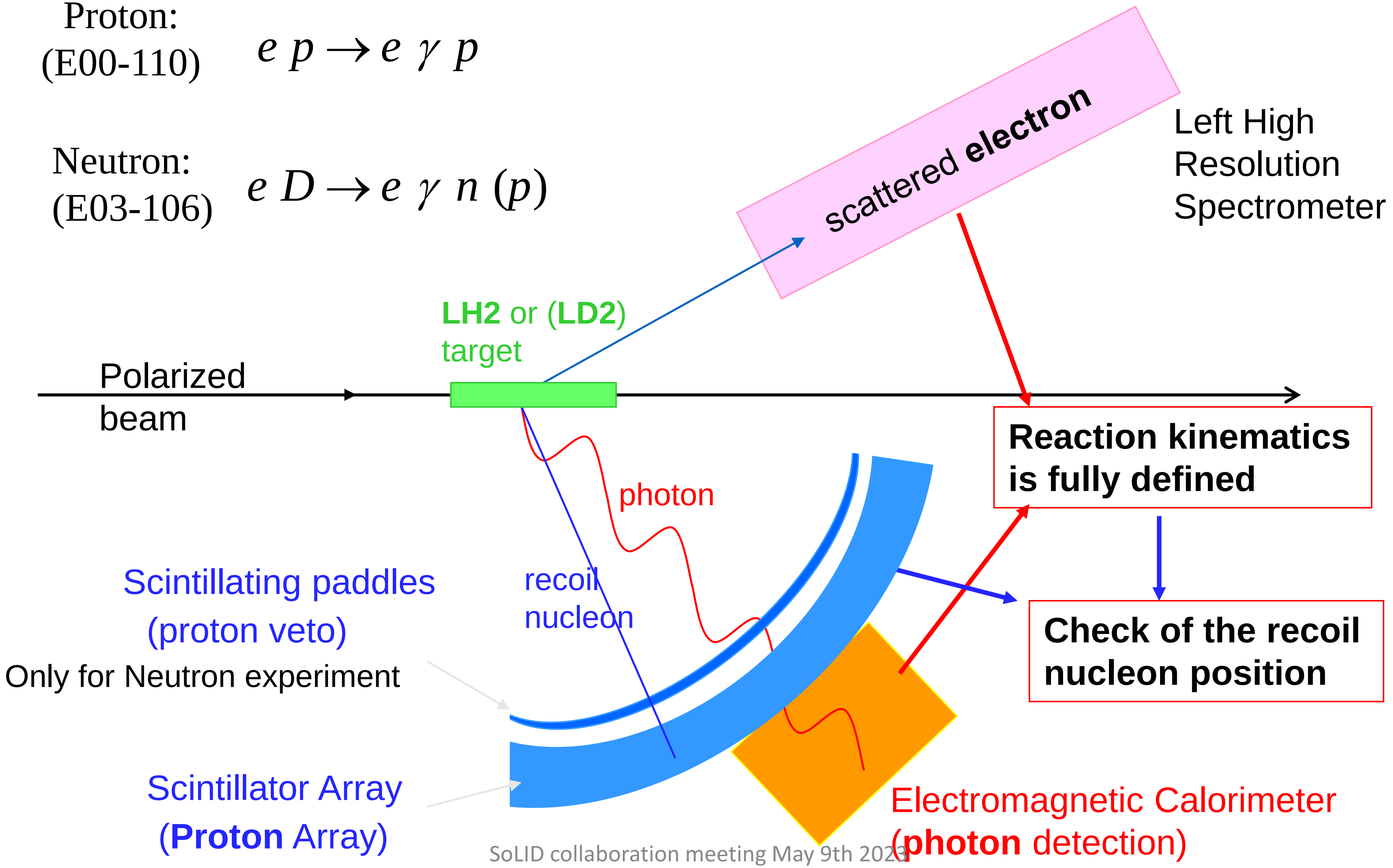
- Probing GPDs at x ≠ ξ → tomographic interpretations....
- Expectation of sign change for observables sensitive to Im (DDVCS) when moving from « spacelike » to « timelike » region

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

DVCS in Hall A on neutron and proton

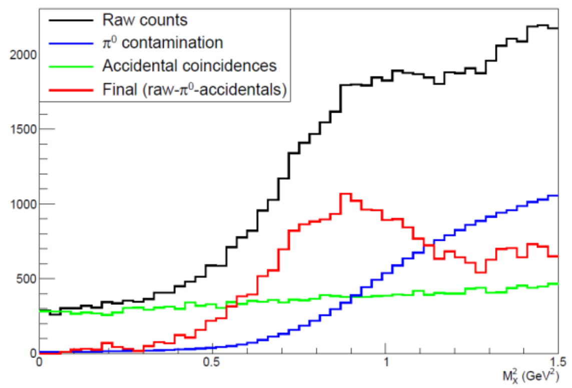
Proton:
(E00-110) $e\,p \rightarrow e\,\gamma\,p$

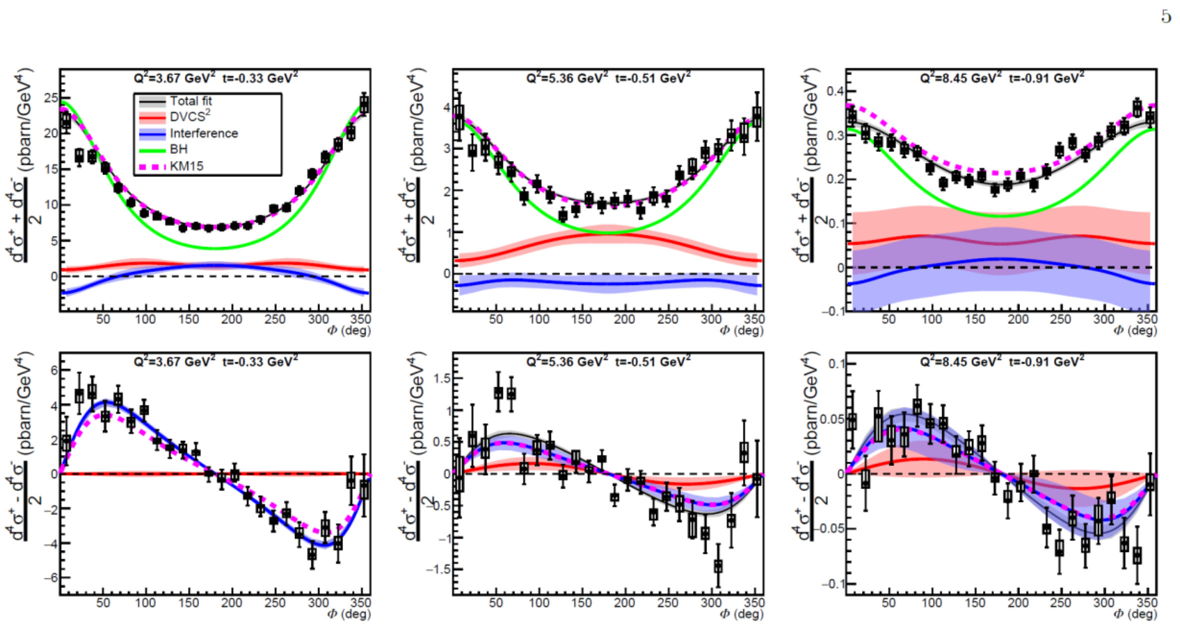
Neutron:
(E03-106) $e\,D \rightarrow e\,\gamma\,n\,(p)$



12 GeV DVCS on proton

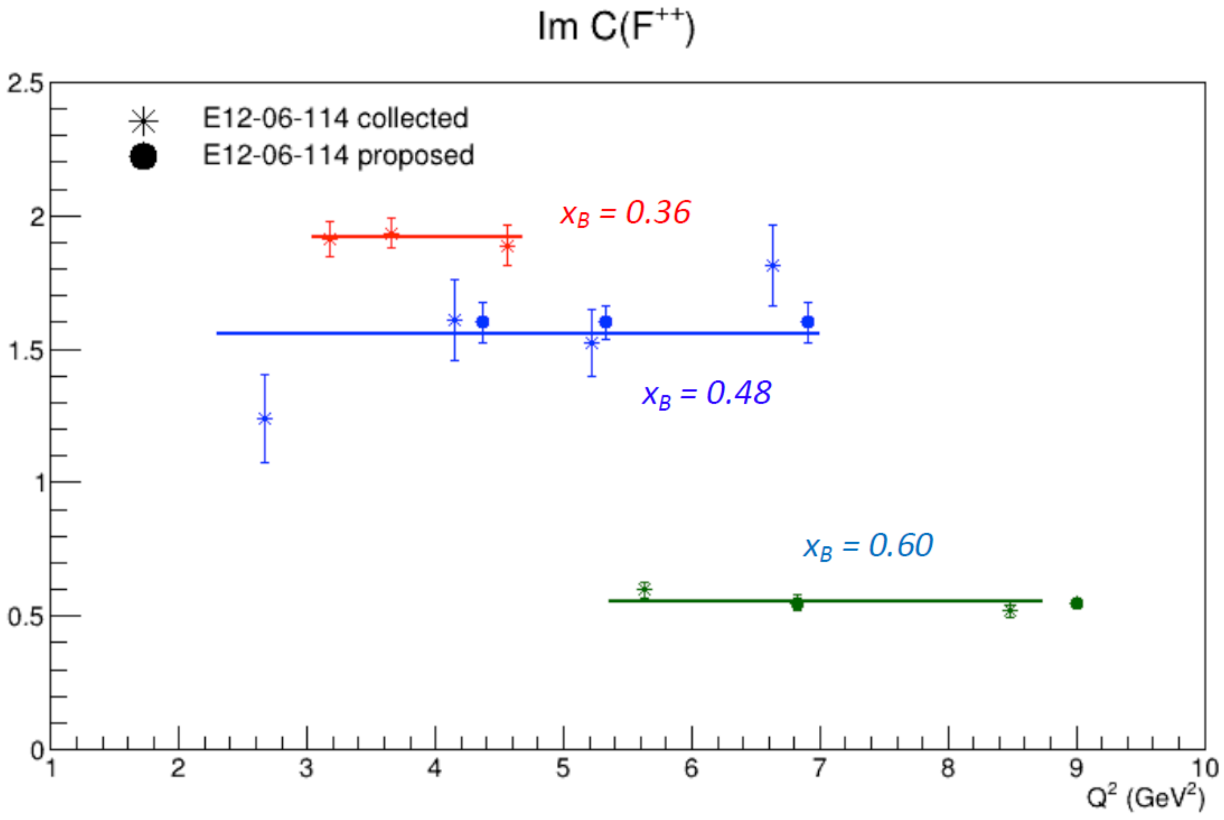
- [Jefferson Lab Hall A Collaboration•F. Georges(IJCLab, Orsay) et al. (Jan 10, 2022)]
- [e-Print: 2201.03714 [hep-ph]Deeply virtual Compton scattering cross section at high Bjorken x B*xB*]



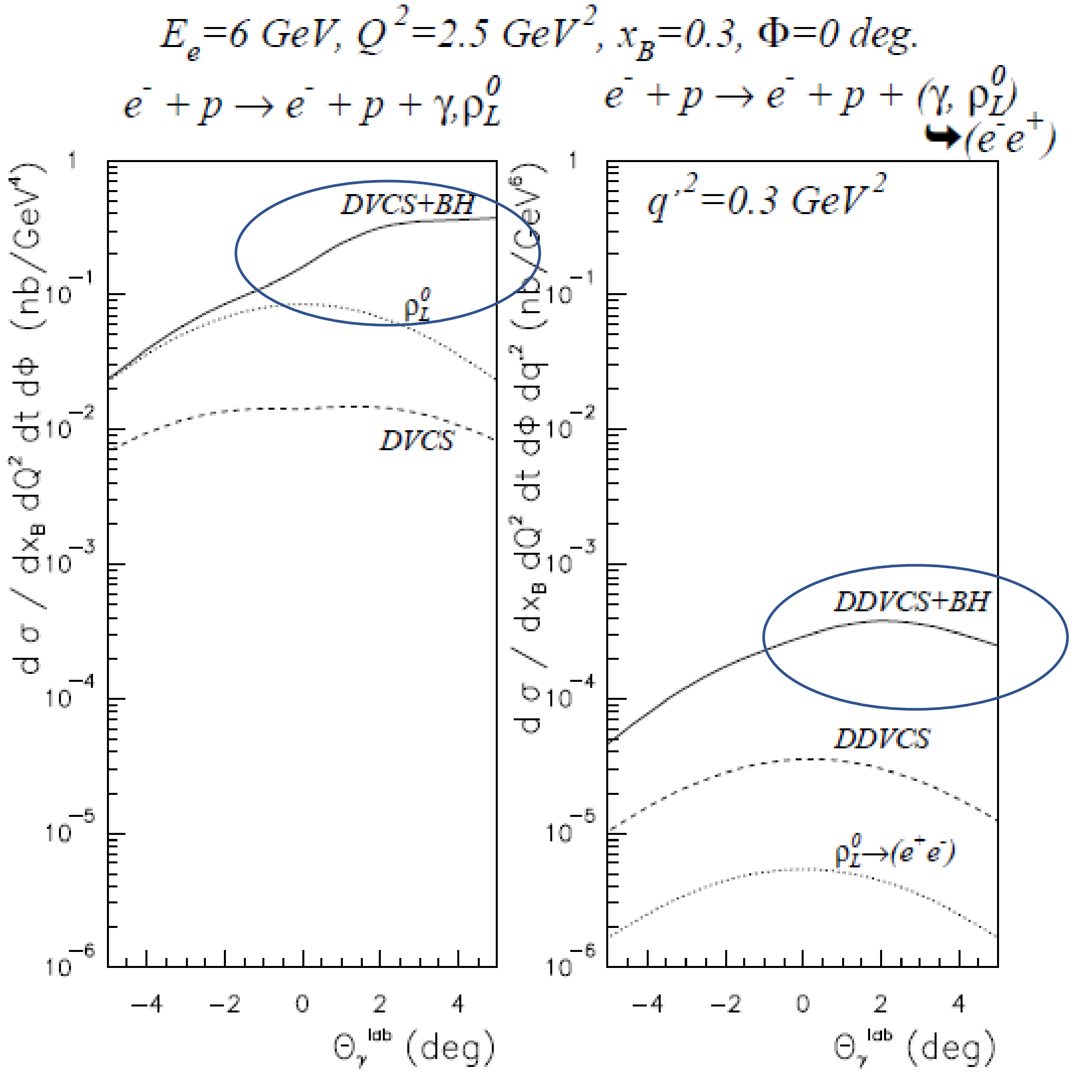


Hall A at 12 GeV: The DVCS experiment, E12-06-114

- Im[DVCS*BH]
  - "sinϕ"
- x = 0.48
  - Full statistics at full acceptance
- x=0.60
  - High statistics run at two additional Q^2 values



DDVCS cross section

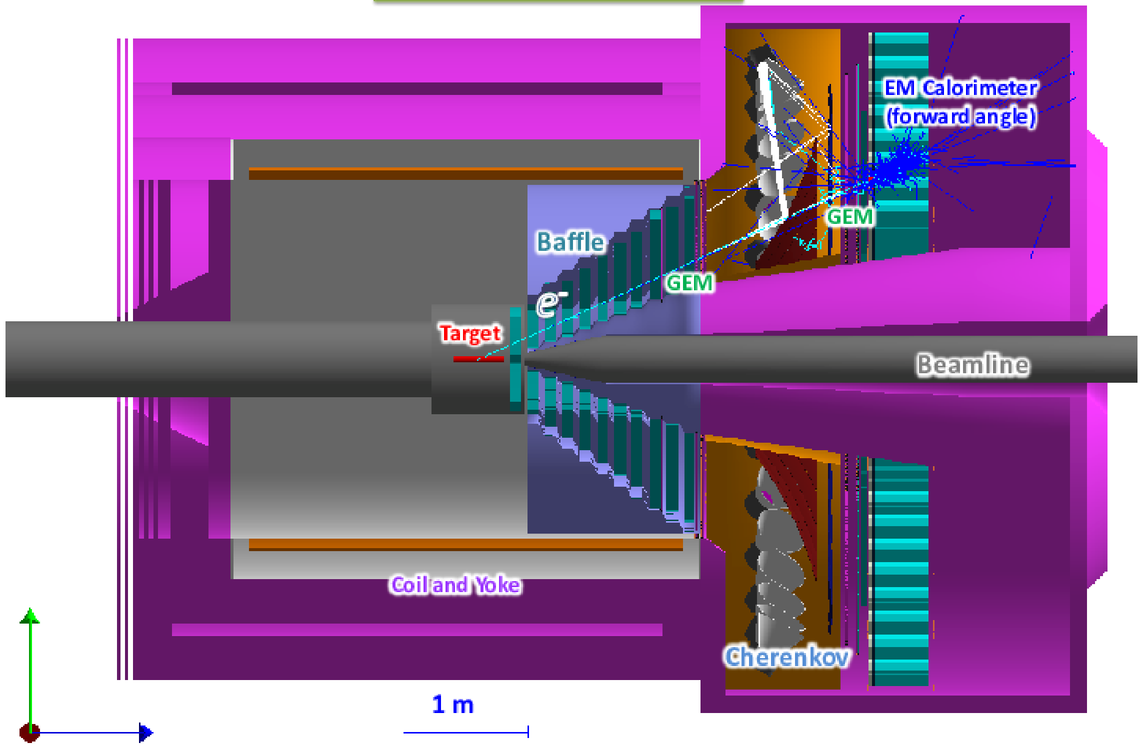


- VGG model
- Order of ~0.1 pb = 10^{-36}cm^2
- About 100 to 1000 smaller than DVCS
- Virtual Beth and Heitler
- Interference term enhanced by BH
- Contributions from mesons small when far from meson mass

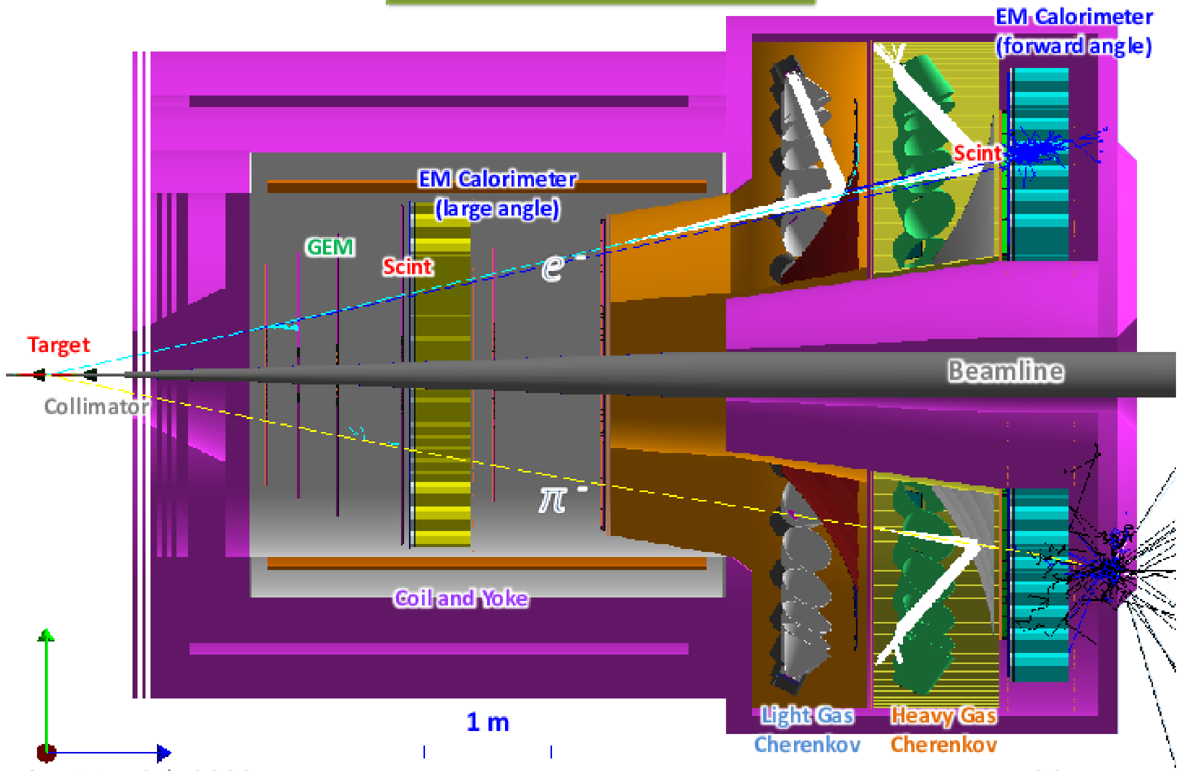
SoLID program

- SoLID detector : CLEO magnet + GEM trackers + Cerenkov + ECal
- 2 detector setup : PVDIS 60 uA, SIDIS 15 uA He3, J/Psi 3uA 15 cm LH2 target

SoLID (PVDIS)

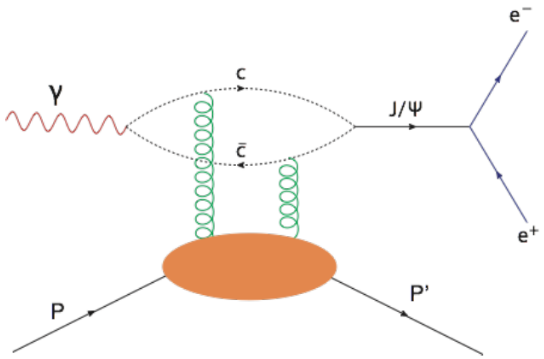


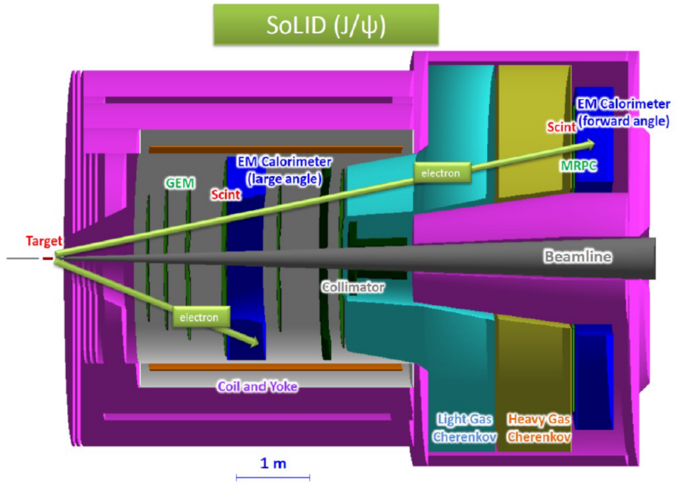
SoLID (SIDIS and J/ψ)

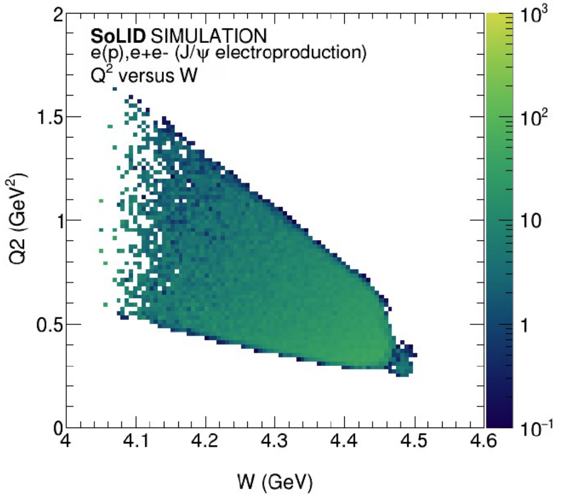


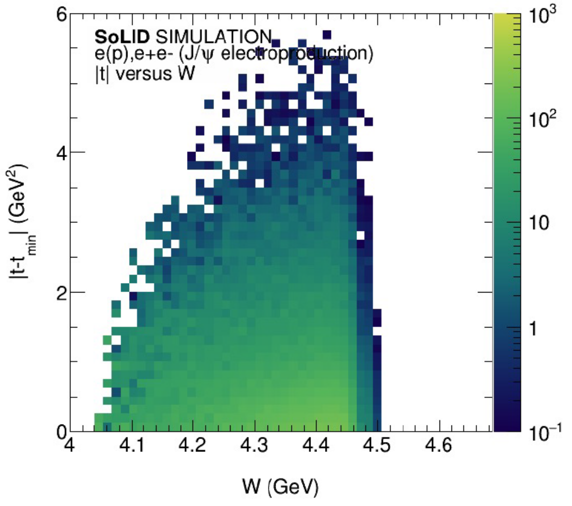
SoLID Experiment Overview

- 50 days of 3 μA beam on a 15 cm long LH_2 target at $1\times10^{37}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
  - 10 more days include calibration/background run
- SoLID configuration overall compatible with SIDIS
  - **Electroproduction trigger**: 3-fold coincidence of e, e^-e^+
  - **Photoproduction trigger:** 3-fold coincidence of p, e^-e^+
  - **Additional trigger:** 4-fold coincidence of ep, e^-e^+
  - And (inclusive) 2-fold coincidence e^+e^-





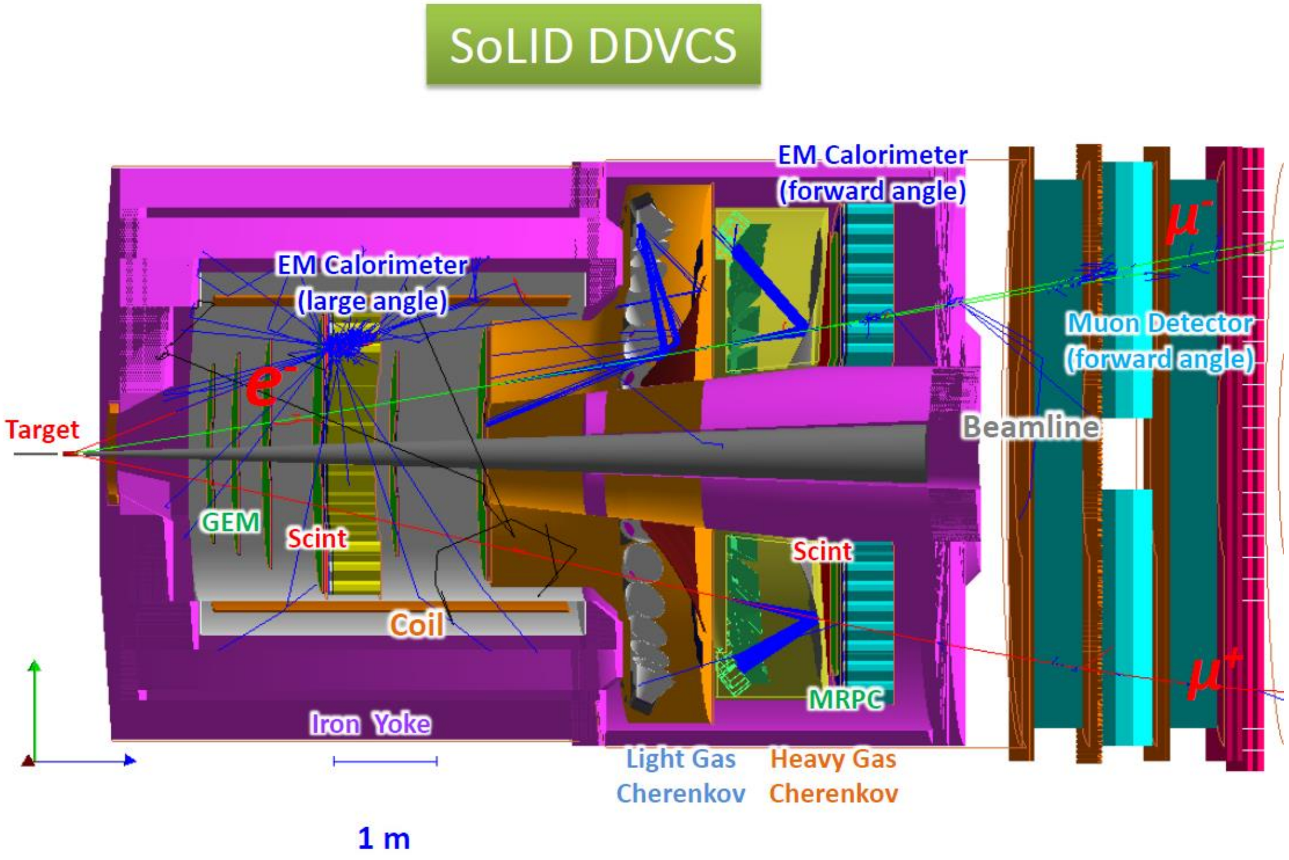




$$e^- + p \longrightarrow e^- + p + J/\psi\,(e^+ + e^-)$$

SoLID DDVCS Setup

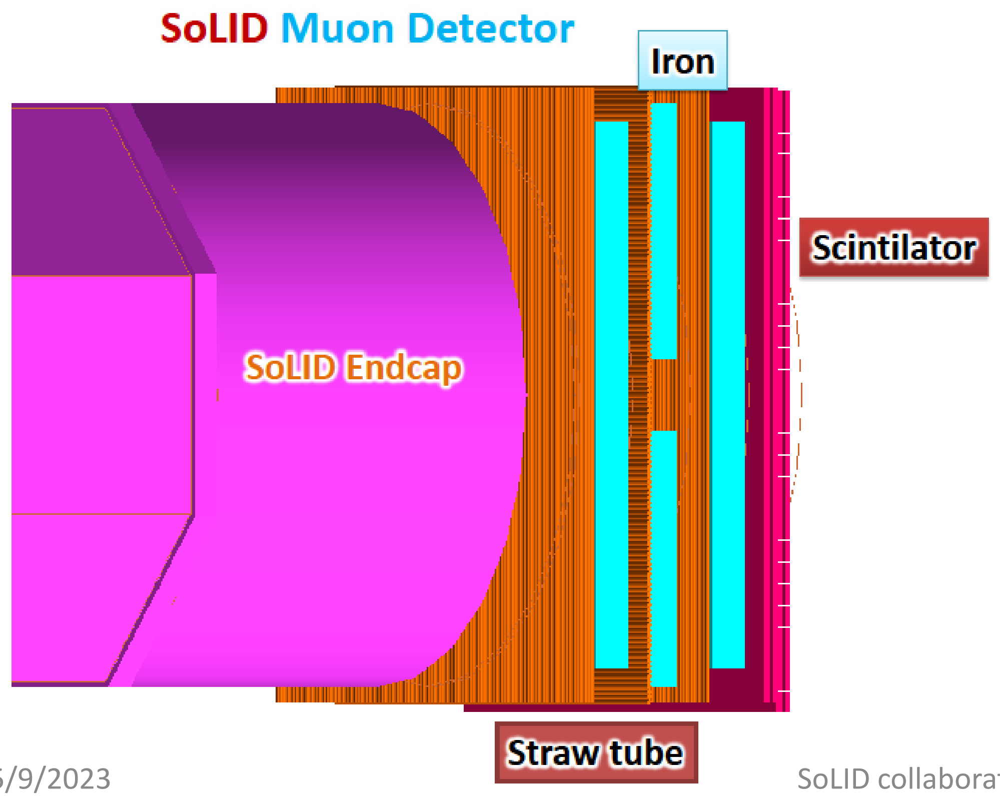
- Based on SoLID JPsi setup with forward muon detector added



- Muon detector outside from SoLID so lower background than e^+e^-
- Muons detection remove ambiguity with scattered electron compared to e^+e^- channel
- Main background behind calorimeter are pions
- Pions can be ranged out with iron plates while muon go through all layers

forward angle muon detector

- 3 layers iron to block pion, 3 layers straw tube for tracking, 2 layer2 scintillator for trigger

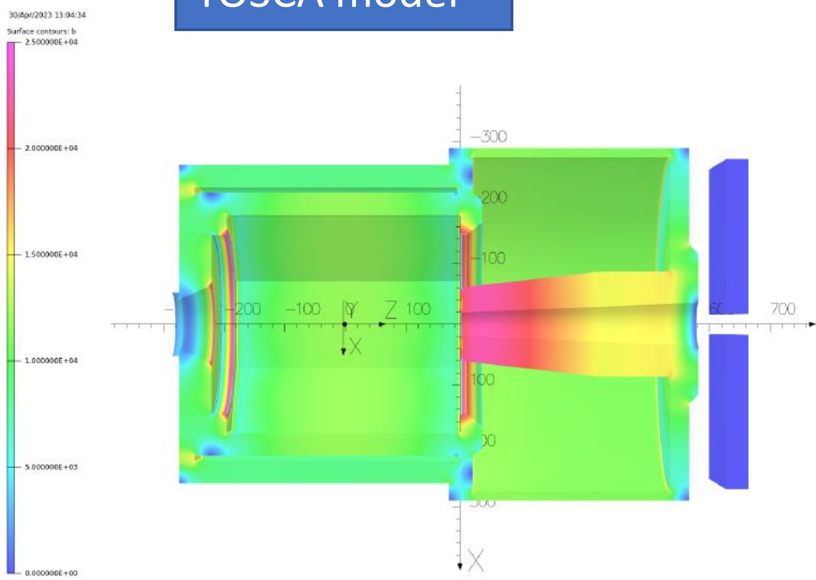


Example of straw tube chambers similar to Seaquest experiment

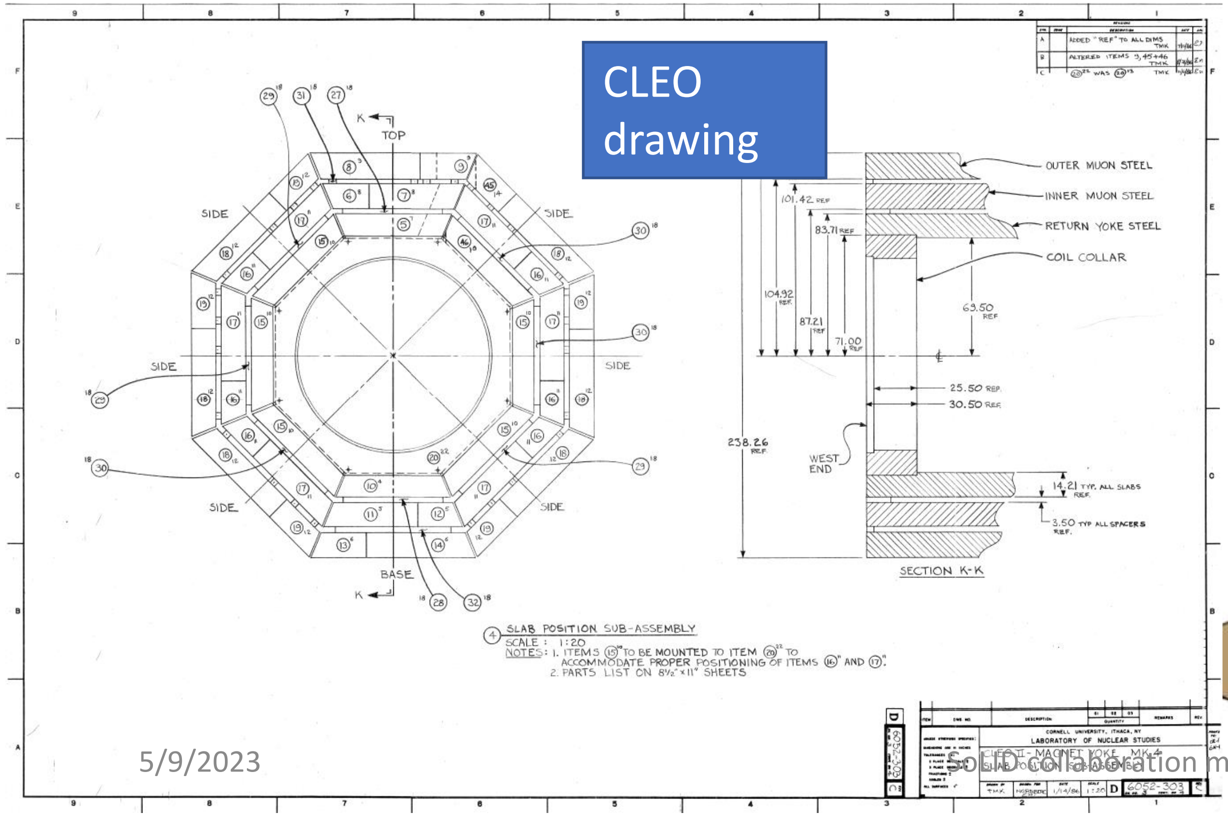
Iron forward angle muon detector

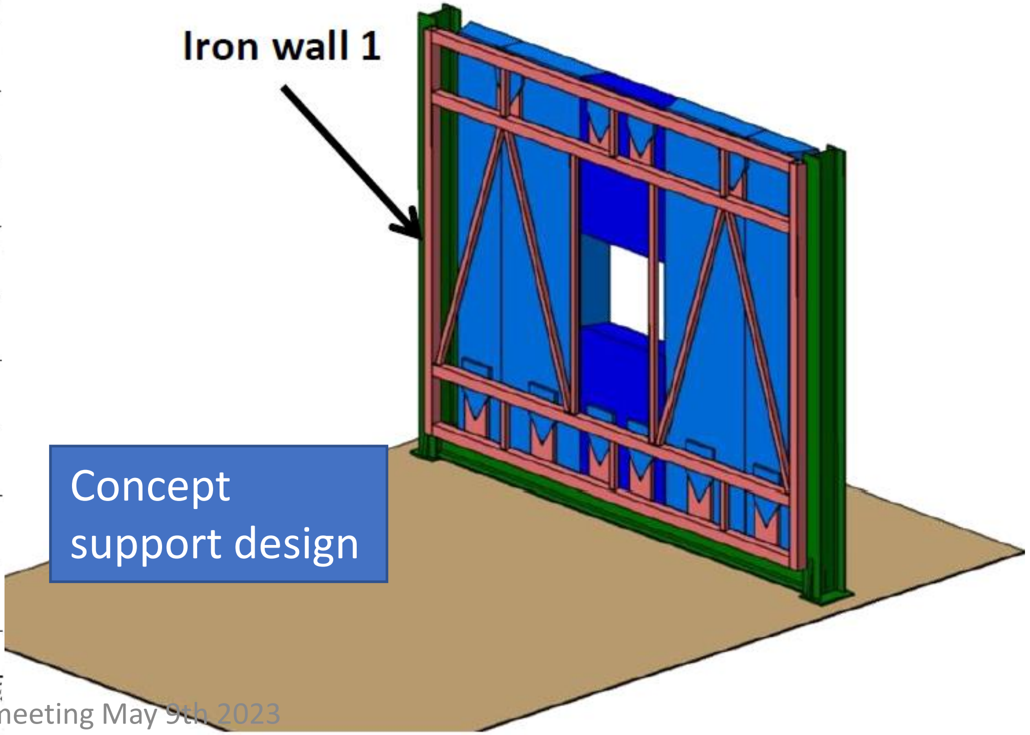
- Reuse 6 of 8 CLEO octagon outer layer iron
- Each one is about 36x254x533cm
- No problem with space
- Field (<10G),force(<1N),torque(<2Nm) are small

TOSCA model



CLEO drawing

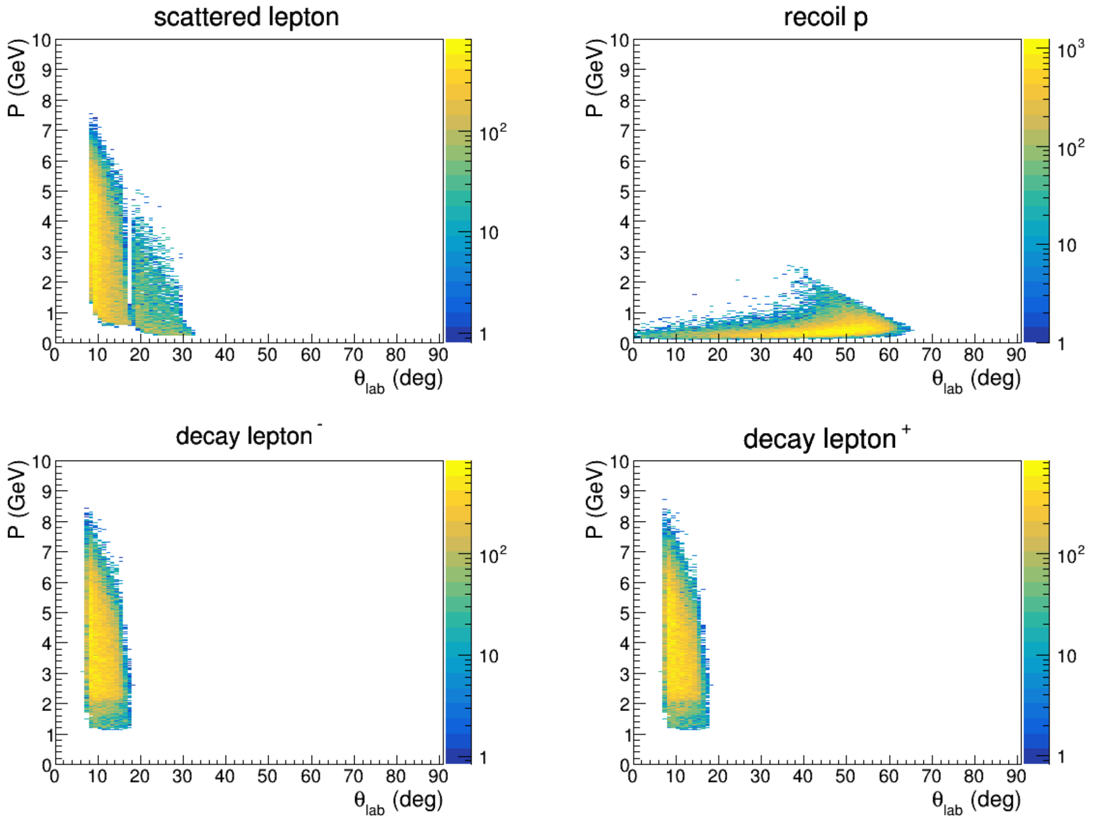


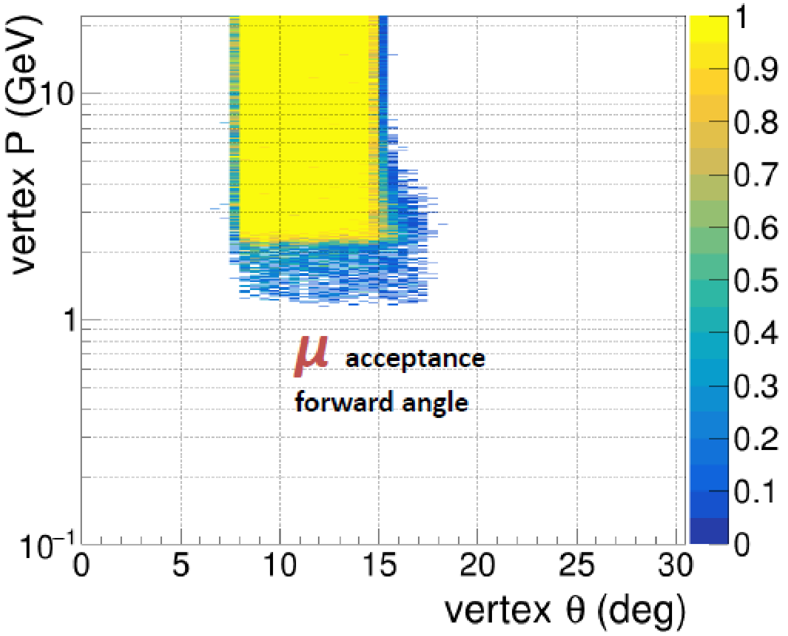


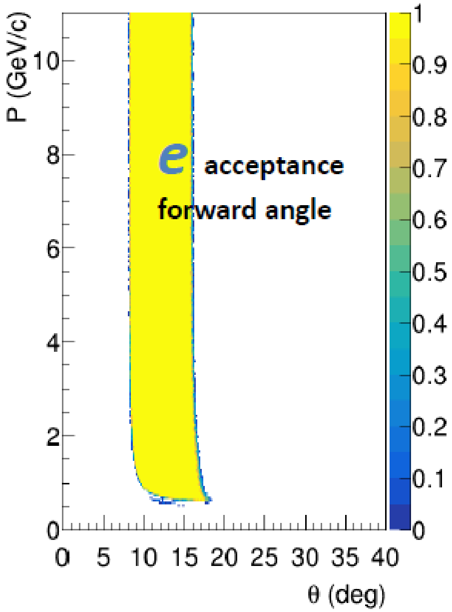
Concept support design

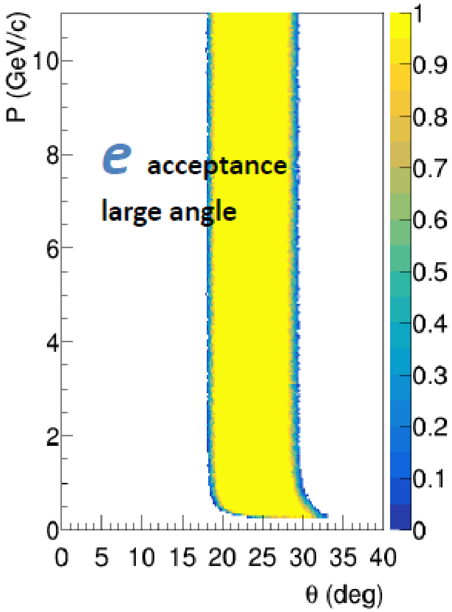
Acceptance

- Muon mom<2GeV is blocked
- recoil proton is not required, but some can still be detected



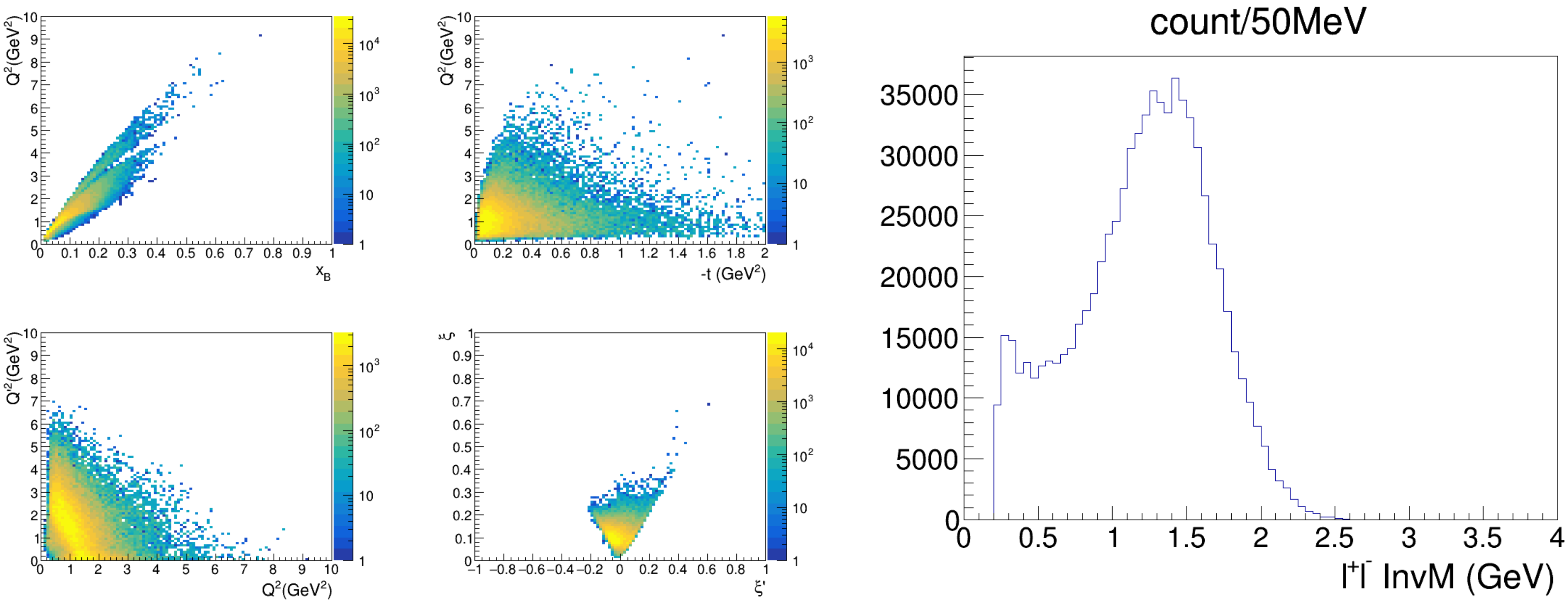






BH kinematics and counts (800k events)

- 30k events for 2GeV< InvM, 600k events for 1GeV<InvM
- Enough for ~500bins in 5D with 1000 events per bin



Single pion background 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
- Main source of rate in the muon detector
- Straw chambers and scintillators were operated up to 1 MHz for Seaquest

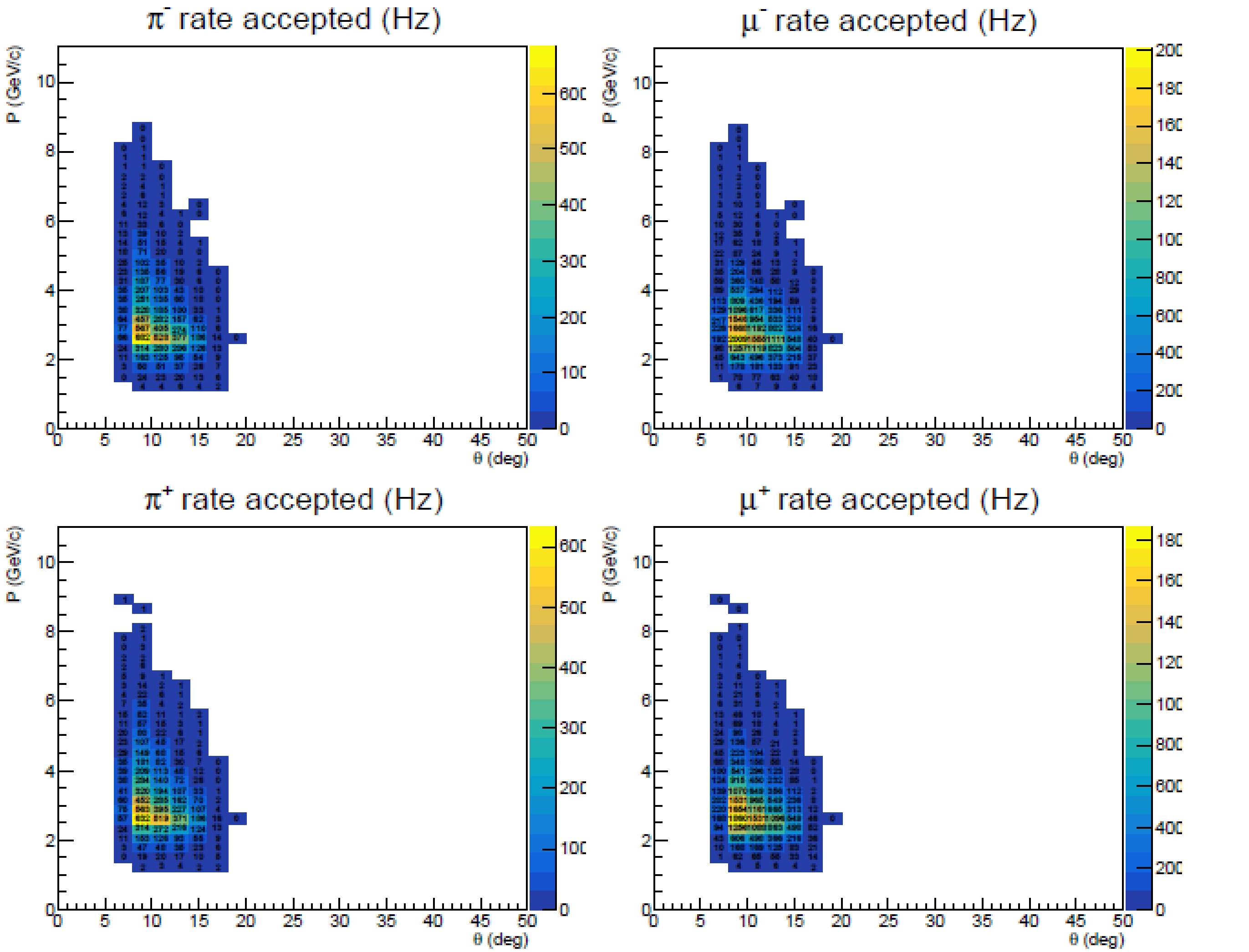
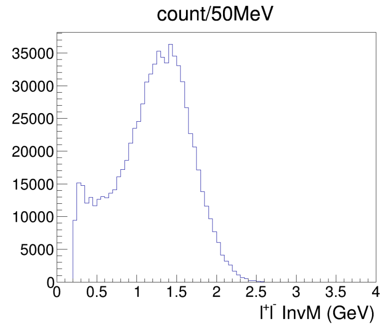


Figure 22: Single particles rate of pion and muon from pion decay at the back of forward angle muon detector. They include both pions directly from target and all secondaries and muons from their decay.

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
- 10% of BH counts, mainly from both decay into muons.
- Tracking with vertex cut could reduce it further

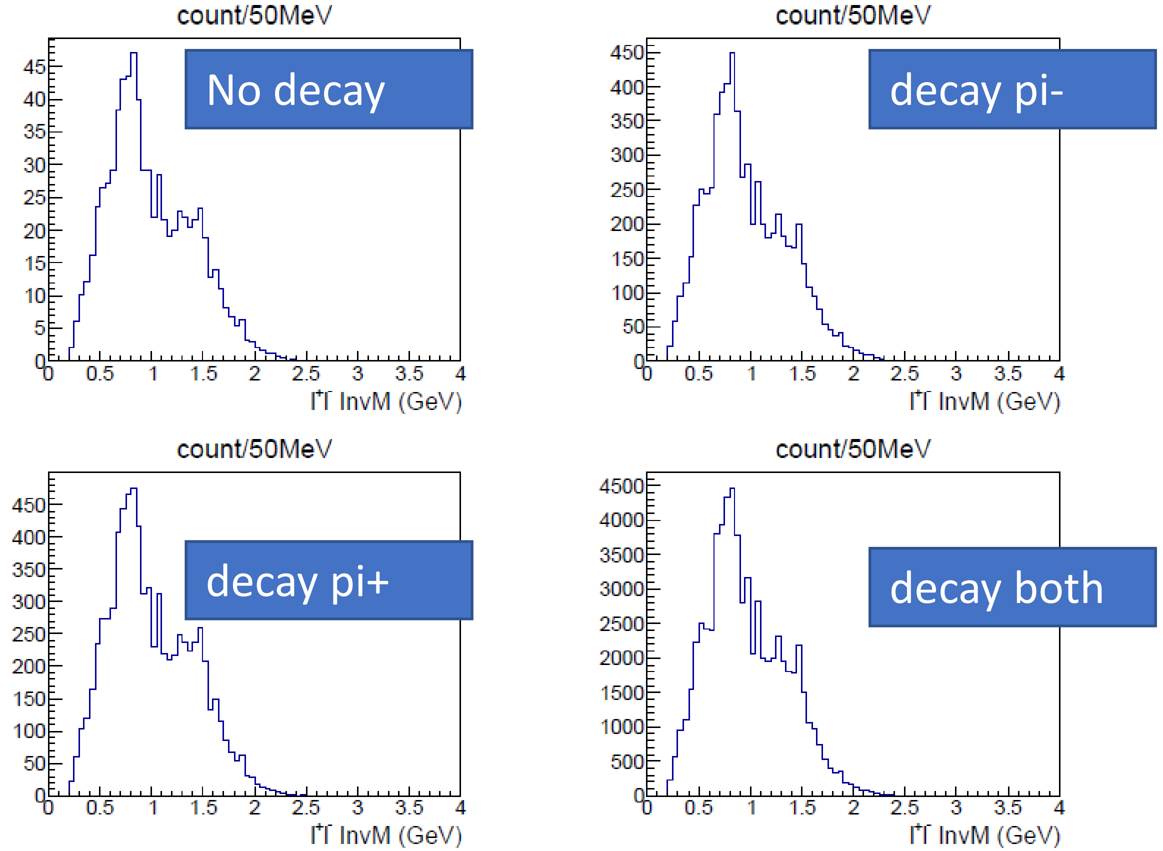
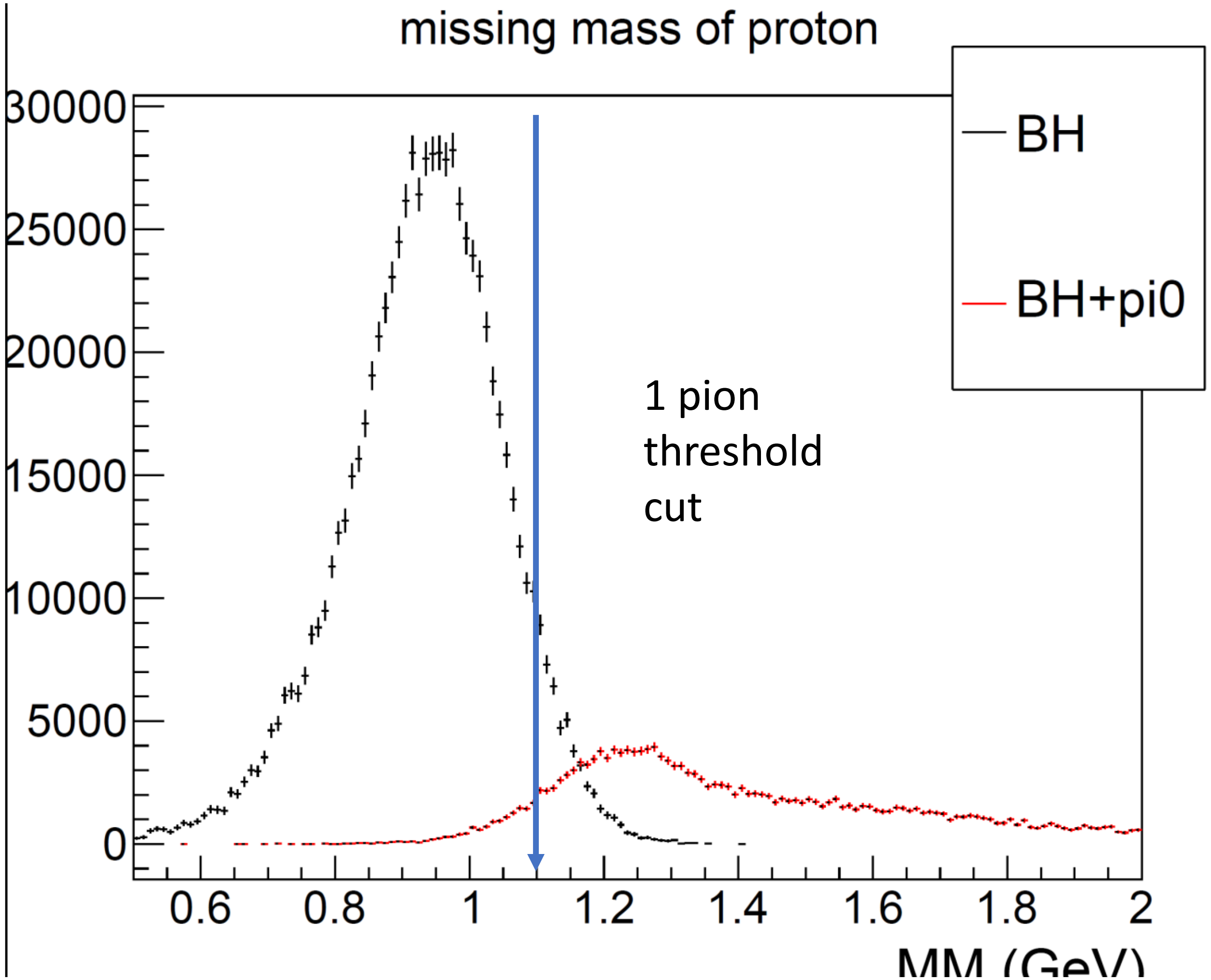


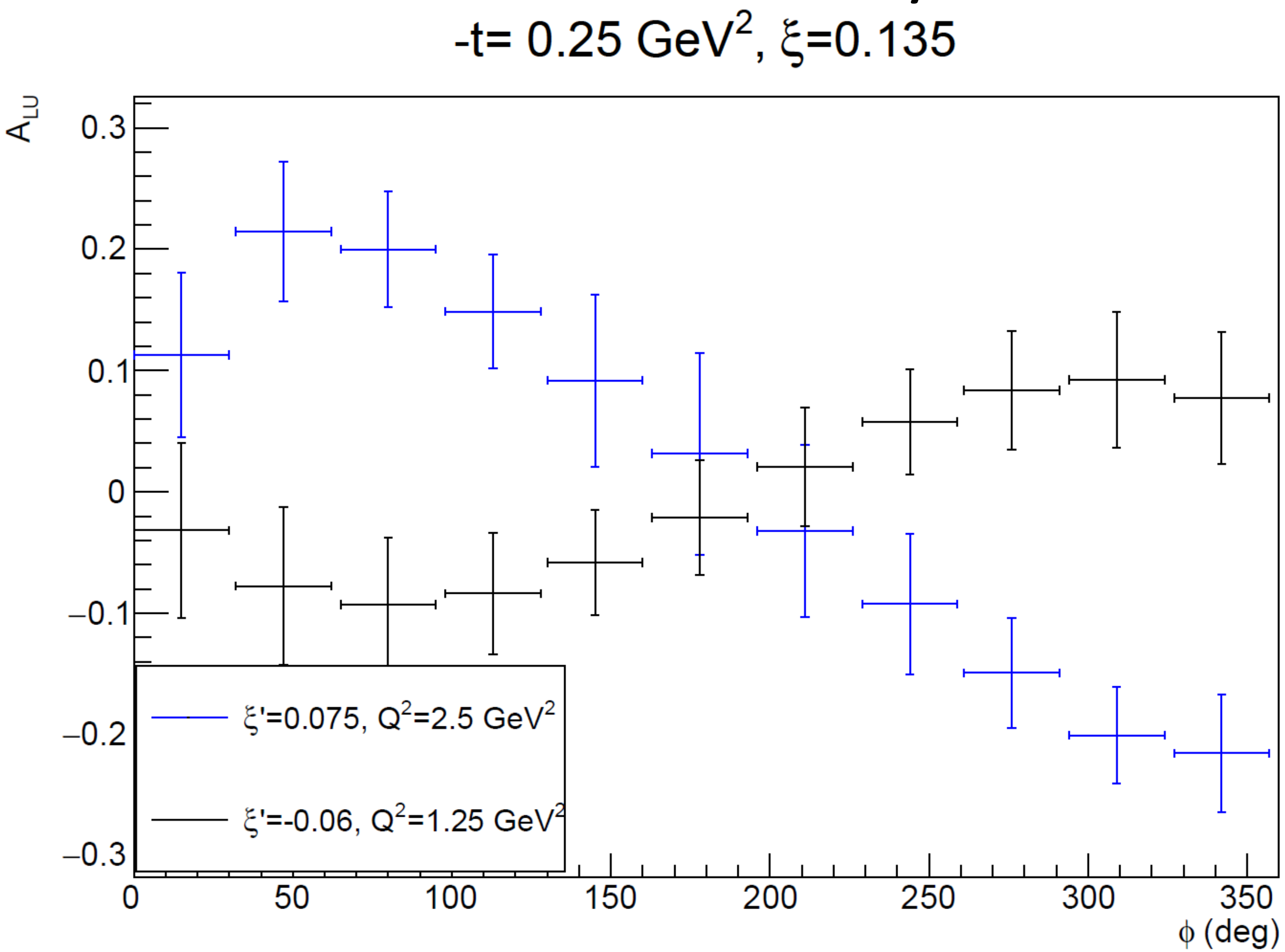
Figure 23: From left to right and top to bottom, the counts from the two pion exclusive channel contamination are shown in 4 cases, neither pion decay, negative pion decays into muon, positive pion decays into muon, and both pions decay.

Missing Mass $e\mu^+\mu^-X$



- Used proton resolution for J/Psi
- BH and inelastic from Grape normalized to J/Psi luminosity
- Missing mass resolution very good to separate exclusive events

Example one bin asymmetry with J/Psi luminosity



Budget estimate

Tubes	263		
Channels	526		5cmx5.33m
	Unit price	number	
Cable	150	1052	157800
VETROC	4000	3	12000
Amplifier Discriminator	1000	9	9000
VTP	10000	1	10000
VXS	18000	1	18000
CPU	6000	1	6000
TI	3000	1	3000
SD	3000	1	3000
Straw	17000	70	1190000
Support structure	300000	1	300000
HV Boards	7000	22	154000
HV crate	12000	4	48000
Channels	46/(5.33*0.1)*2*2	376	
Cable	300	376	112800
FADC	5000	24	120000
VTP	100000	2	200000
VXS	18000	2	36000
CPU	6000	2	12000
TI	3000	2	6000
SD	3000	2	6000
Scintillator	30000	46	1380000
Support structure	300000	1	300000
PMT	600	376	225600
HV Boards	7000	16	112000
HV crate	12000	3	36000
		Total	4457200

- Muon detector
  - Each plane is about 23 m2
  - Reuse existing 6 iron plates
  - 3 planes of straw chambers readout each end : 69 m2 = 350 x 5 cm x 5.3 m = 1.9 M$
  - 2 planes of scintillators readout each end : 56 m2 = 2.55 M$
  - Total ~ 4.5 M$

Detector responsibilities

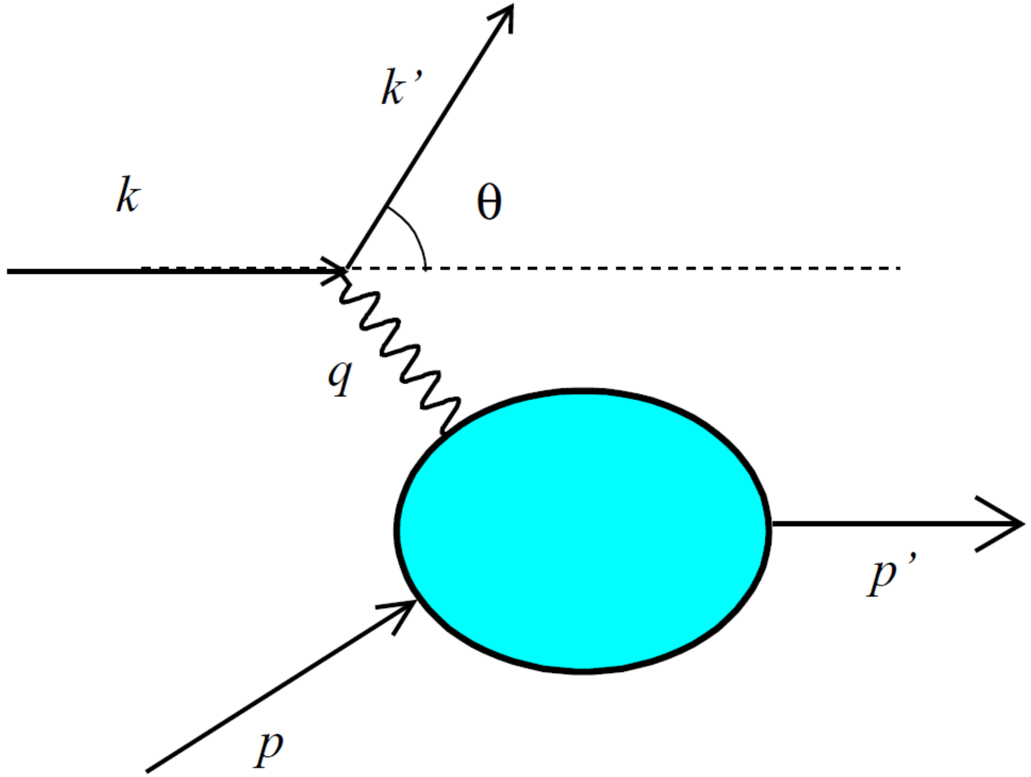
- Muon detector
  - Virginia Tech : trigger scintillator planes and electronics
  - Rutgers University : straw tube chamber planes
- Mechanical design:
  - iJCLab Orsay
  - Jlab
- Integration SoLID DAQ
  - Jlab
- Software analysis and simulation
  - Duke
  - JLab

Conclusion

- This experiment will add a muon detector behing SoLID EC calorimeter
- Muons detector for muon ID
  - 3 planes of iron reusing CLEO 3rd layer iron
  - 3 planes of straw chamber similar to MUSE or SEAQUEST
  - 2 scintillator planes for muon trigger
  - Expected dimuon rate about 1 KHz
  - Measure exclusive DDVCS by detecting scattered electron and dimuon pair
  - Rough budget estimate
- Unique opportunity to measure DDVCS in dimuons channel without additionnal beam request to complement the DDVCS
- Q^2 and Q'^2 range allows to check the scaling range for DDVCS
- First measurement of H Compton Form Factor for x different of xi
- Crucial measurement for future program with dedicated detector and with future positron beam and 22 GeV upgrade

Back-up

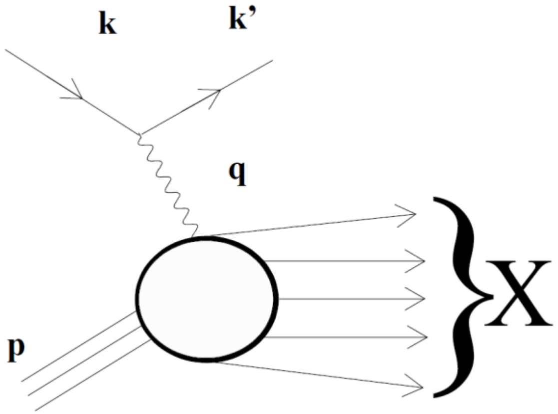
Electron scattering



$$q = k - k'$$
$$Q^2 = -q^2 = -(k-k')^2 = 4EE' \sin^2(\frac{\theta}{2})$$

Photon virtuality allows to select the scale of the interaction

Deeply Inelastic Scattering



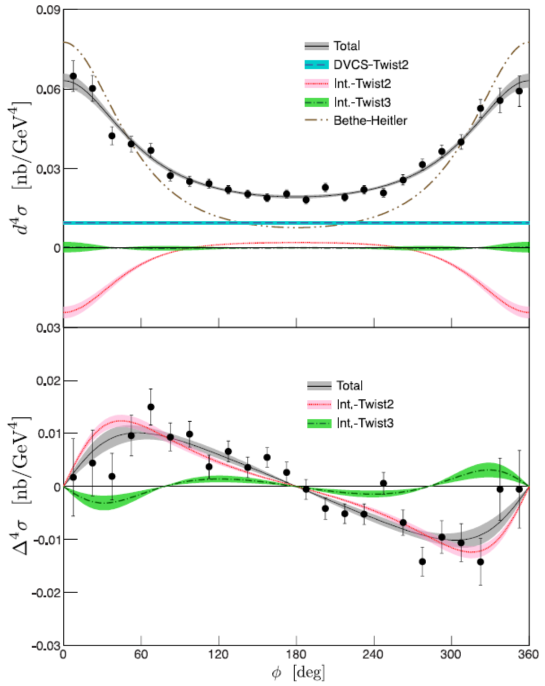
$$W_{\mu\nu} = W_1(Q^2,\nu)(-g_{\mu\nu} + \frac{q_\mu q\nu}{q^2}) + \frac{W_2}{M^2}(Q^2,\nu)(p_\mu - \frac{p.q}{q^2}q_\mu)(p_\nu - \frac{p.q}{q^2}q_\nu)$$
$$+G_1(Q^2,\nu)Mi\epsilon_{\mu\nu\lambda\sigma}q^\lambda s_h^\sigma + \frac{G_2(Q^2,\nu)}{M}i\epsilon_{\mu\nu\lambda\sigma}q^\lambda(p.qs_h^\sigma - s_h^\sigma.qp^\sigma)$$

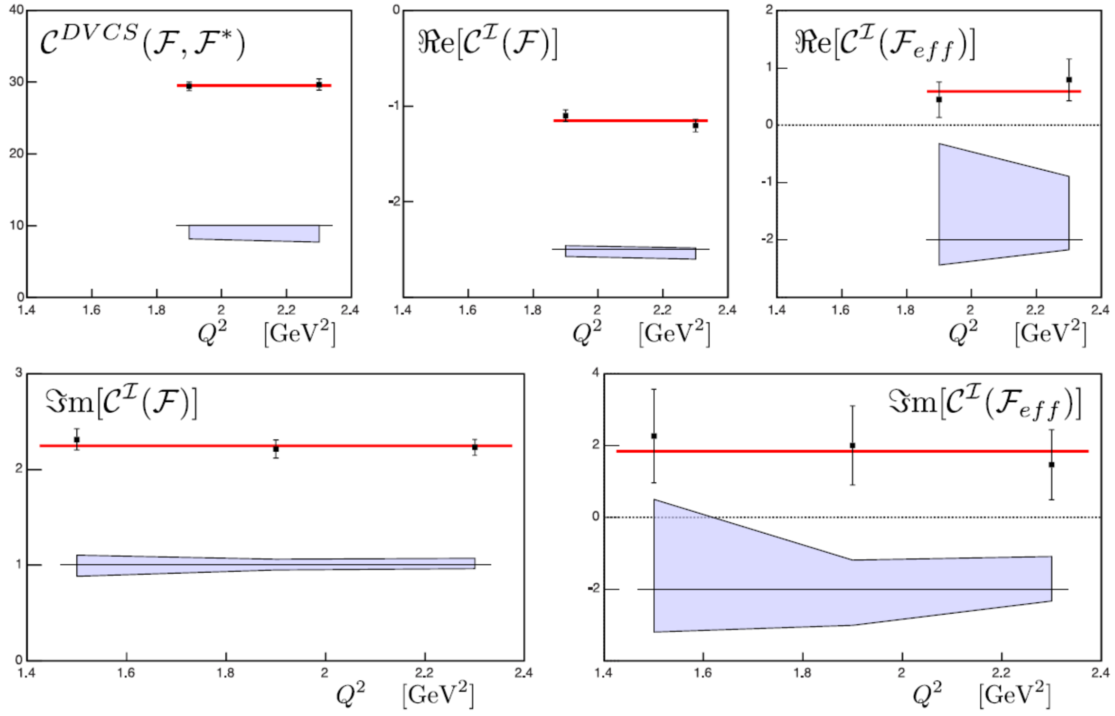
$$MW_1 = F_1(Q^2,\nu)$$
$$\nu W_2 = F_2(Q^2,\nu)$$
$$\frac{\nu}{(p\cdot q)}G_1(Q^2,\nu) = g1(Q^2,\nu)$$

$$F_1(Q^2,\nu) = \sum_{i=1}^{3} e_i q_i = \sum_{i=1}^{3} e_i(q_i^\uparrow + q_i^\downarrow)$$
$$g_1(Q^2,\nu) = \sum_{i=1}^{3} e_i \Delta q_i = \sum_{i=1}^{3} e_i(q_i^\uparrow - q_i^\downarrow)$$

6 GeV E00-110 result

- E00-110 experiment at Jefferson Lab Hall A: Deeply virtual Compton scattering off the proton at 6 GeV
- Jefferson Lab Hall A Collaboration•M. Defurne(DAPNIA, Saclay) et al. (Apr 21, 2015)
- Published in: Phys.Rev.C 92 (2015) 5, 055202 • e-Print: 1504.05453 [nucl-ex]



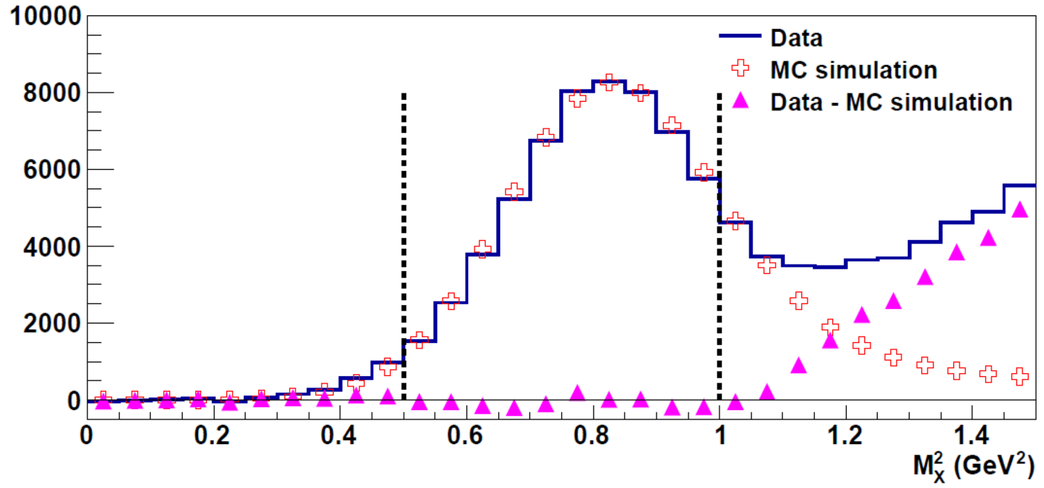


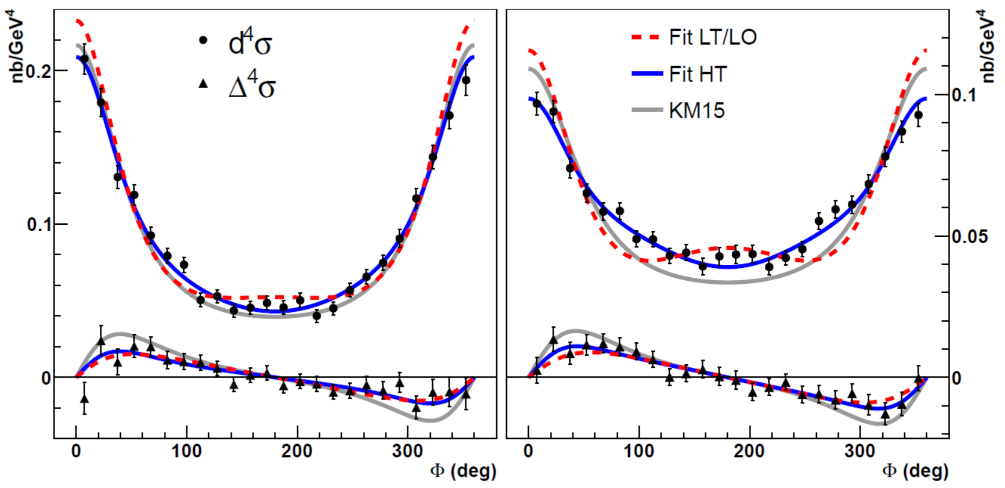
6 GeV E07-007 proton result

- A glimpse of gluons through deeply virtual compton scattering on the proton

M. Defurne(IRFU, Saclay), A. Martí Jiménez-Argüello(Orsay, IPN and Valencia U.), Z. Ahmed(Syracuse U.), H. Albataineh(Texas A-M U.-Kingsville), K. Allada(MIT) et al. (Mar 28, 2017)

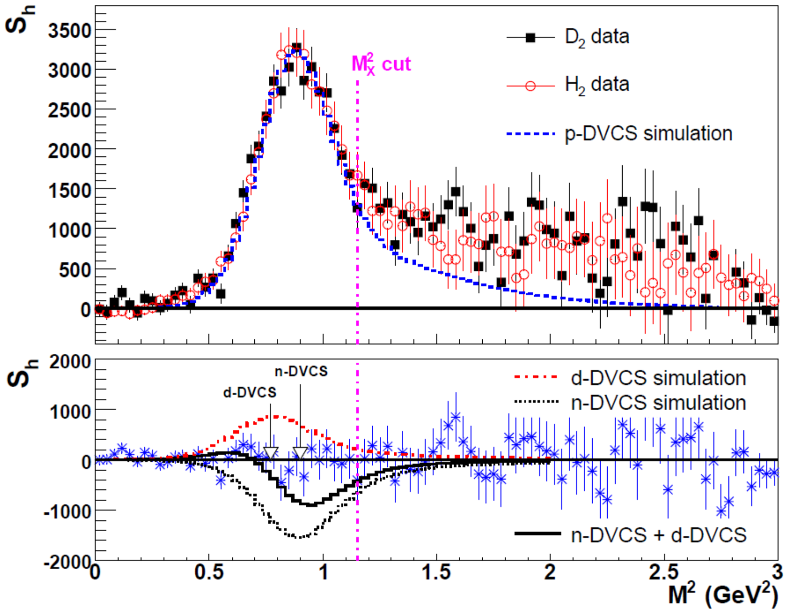
Published in: Nature Commun. 8 (2017) 1, 1408 • e-Print: 1703.09442 [hep-ex]

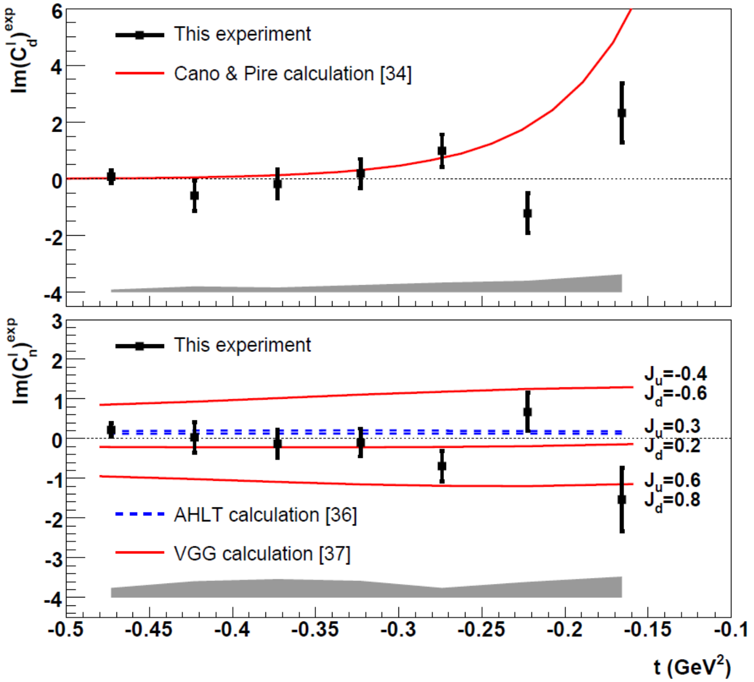




6 GeV E03-106 neutron result

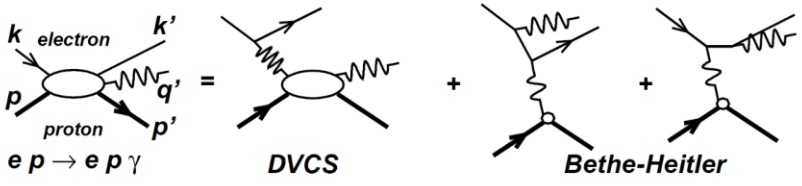
- Deeply virtual compton scattering off the neutron
- Jefferson Lab Hall A Collaboration•M. Mazouz(LPSC, Grenoble) et al. (Sep, 2007)
- Published in: Phys.Rev.Lett. 99 (2007) 242501 • e-Print: 0709.0450 [nucl-ex]





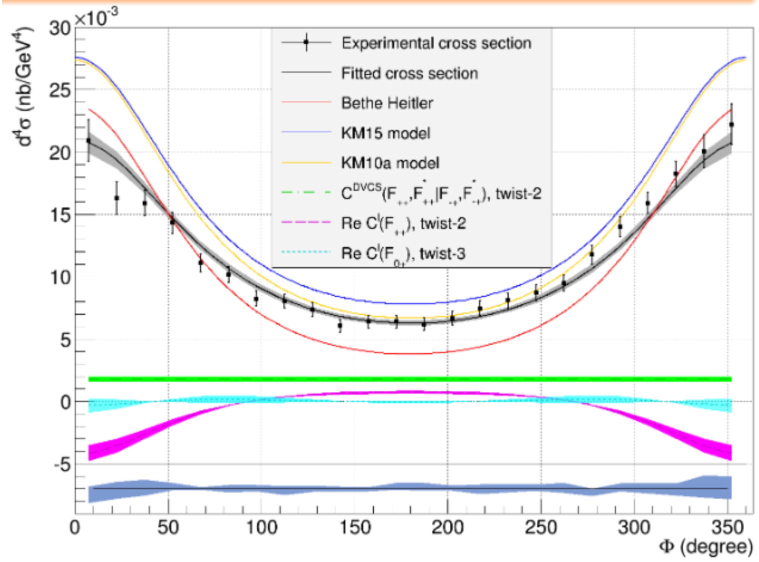
Hall A at 12 GeV: The DVCS experiment, E12-06-114

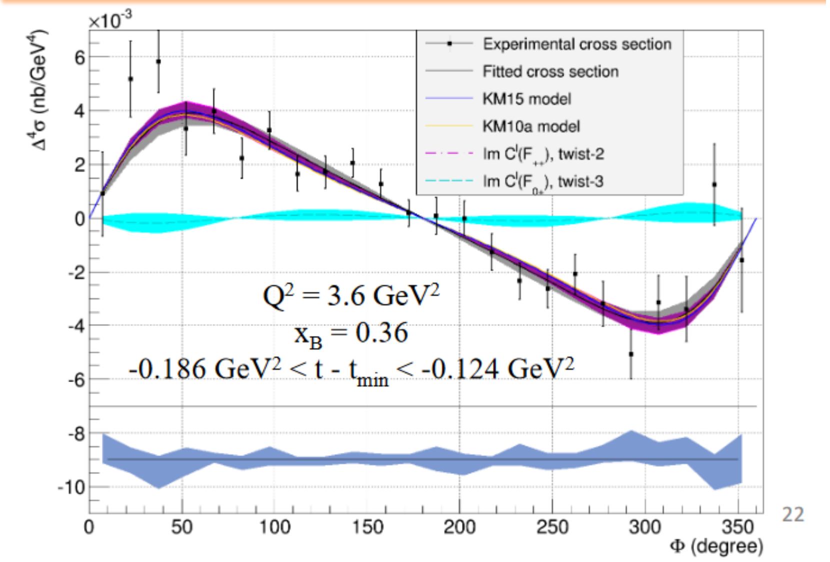
- ❑ Ran in the Fall of 2014,2016 with the goals of:
  - → testing scaling: wide Q2 scans at fixed Bjorken x
  - → separating of Re and Im parts of DVCS cross section amplitude



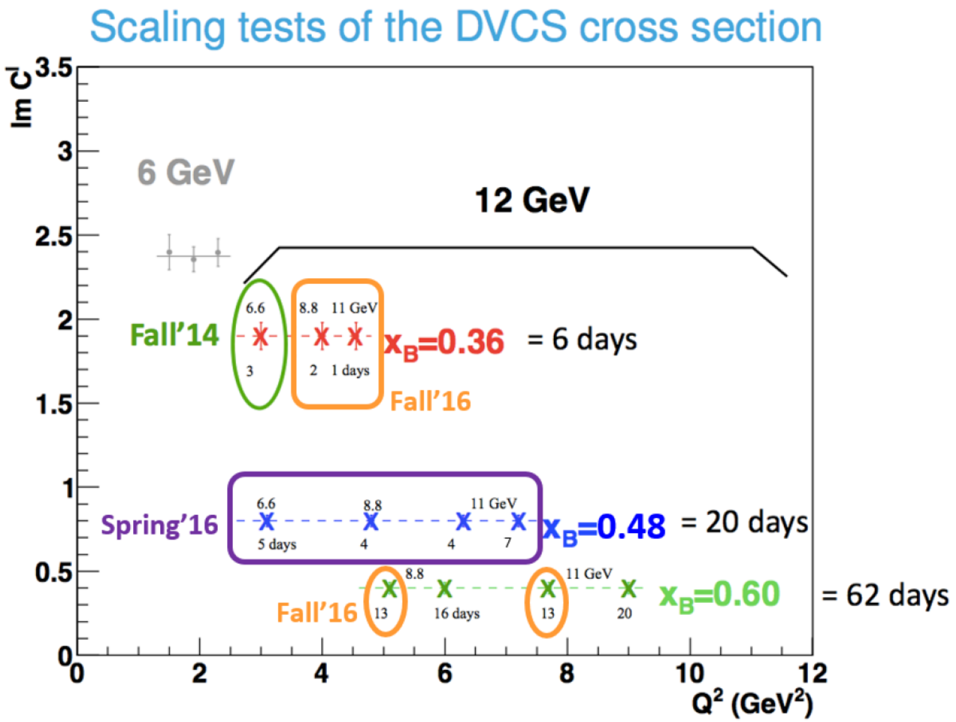
At leading twist:

$$d^5\overrightarrow{\sigma} - d^5\overleftarrow{\sigma} = \Im m\,(T^{BH}\cdot T^{DVCS})$$
$$d^5\overrightarrow{\sigma} + d^5\overleftarrow{\sigma} = |BH|^2 + \Re e\,(T^{BH}\cdot T^{DVCS}) + |DVCS|^2$$





DVCS Cumulated Statistics - Summary

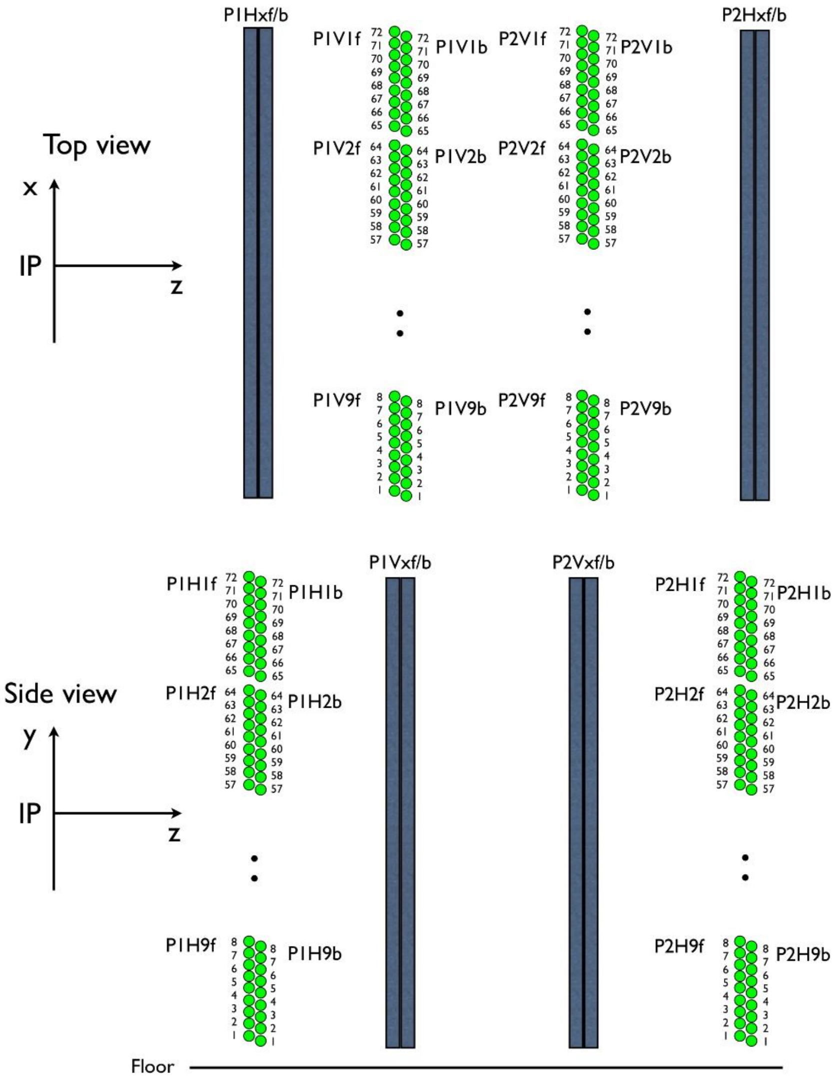


kinematic	% of target charge	PAC days
kin36_1	100.0	3
kin36_2	100.0	2
kin36_3	100.0	1
kin48_1	100.0	5
kin48_2	56.6	4
kin48_3	76.4	4
kin48_4	53.0	7
kin60_1	100.0	13
kin60_2	0.0	16
kin60_3	100.0	13
kin60_4	0.0	20

Could not go back and complete kin48_[234] because of beam energy change over the summer.

~50% of PAC allocation completed between 2014 and 2016

29


Top view
x
IP
z
P1Hxf/b
P2Hxf/b
P1V1f
P1V1b
P2V1f
P2V1b
P1V2f
P1V2b
P2V2f
P2V2b
P1V9f
P1V9b
P2V9f
P2V9b
Side view
y
IP
z
P1Vxf/b
P2Vxf/b
P1H1f
P1H1b
P2H1f
P2H1b
P1H2f
P1H2b
P2H2f
P2H2b
P1H9f
P1H9b
P2H9f
P2H9b
Floor

Surviving rate of pion and muon from pion decay at back of forward muon detector