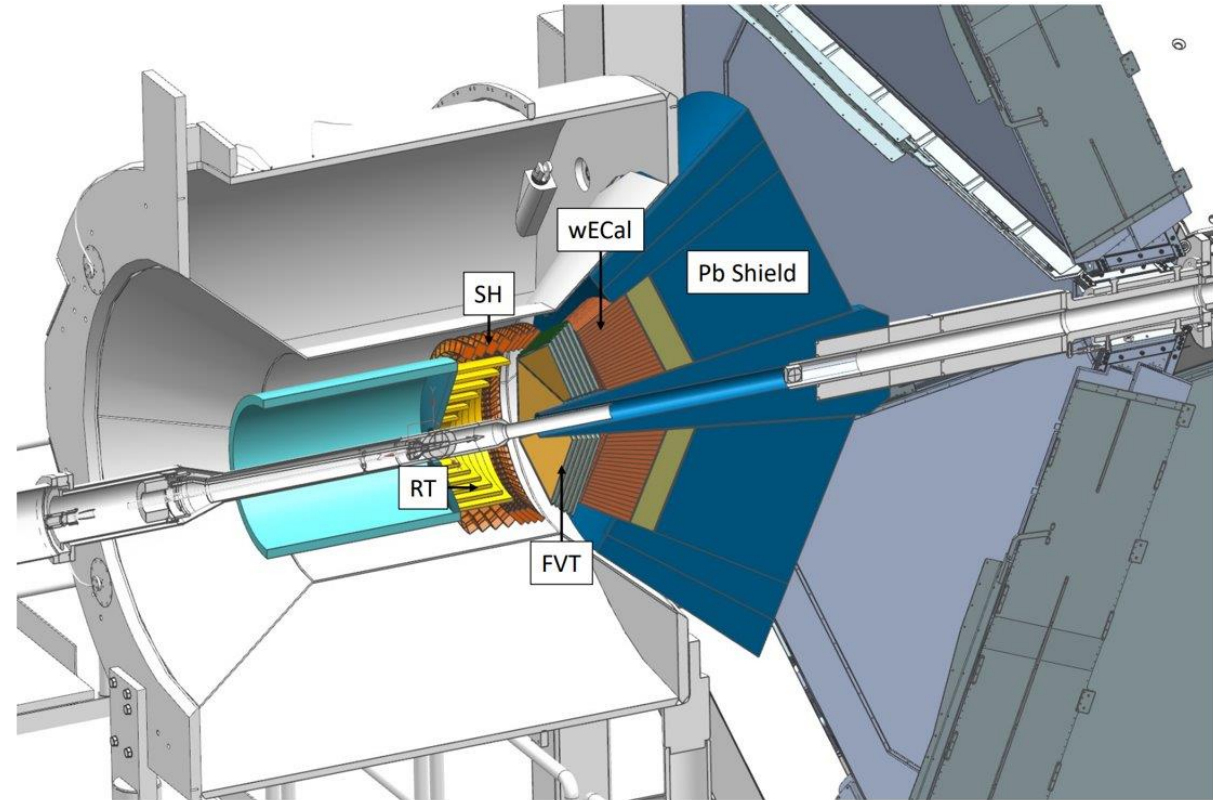


TCS and DDVCS with μ CLAS12

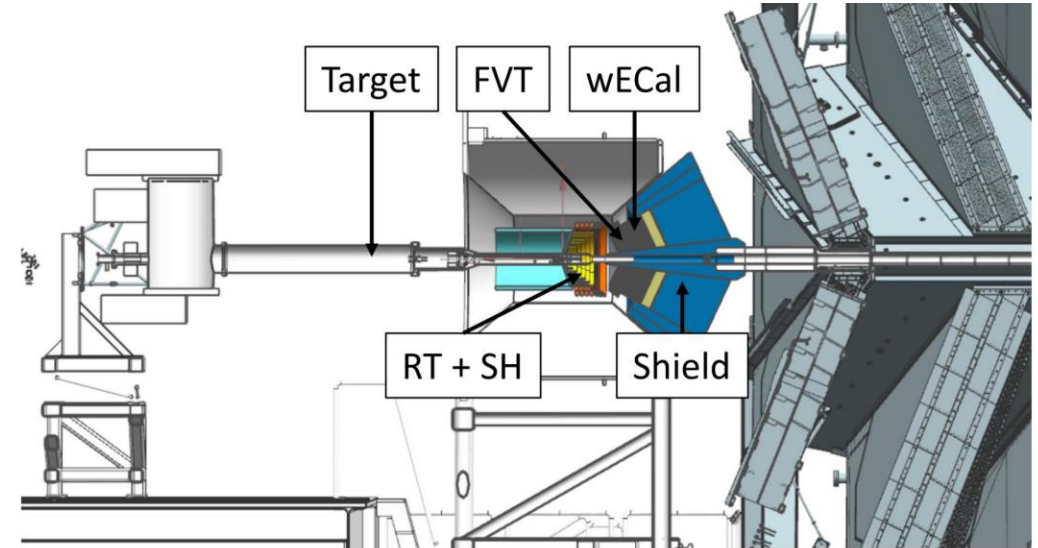
Rafayel Paremuzyan (Jefferson Lab)

Physics Program with High Luminosity Facilities, 5 - 9 October 2026, Jefferson Lab



Outline

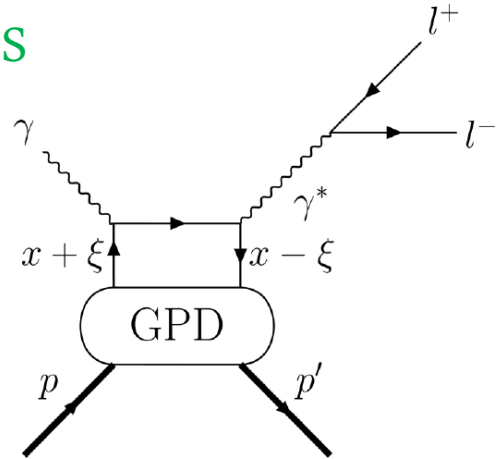
- 1 **Physics motivation** TCS, the GPD inverse problem, DDVCS
- 2 **TCS with CLAS12** analysis, first results, ongoing analyses
- 3 **μ CLAS12** detector, rates, muon ID, backgrounds
- 4 **Projections** DDVCS and TCS
- 5 **Beyond** $e^\pm$ detection at large angles: a concept
- 6 **Summary**



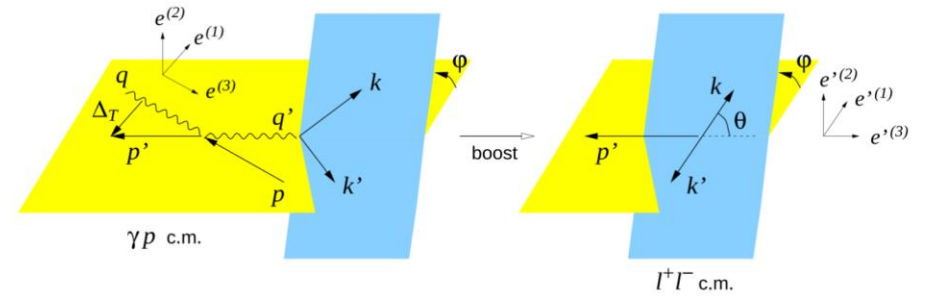
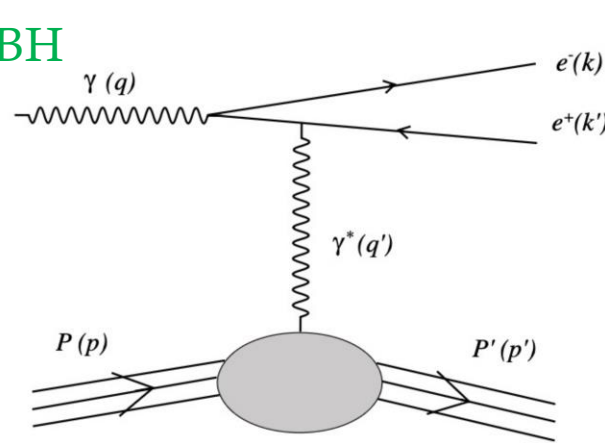
μ CLAS12: CLAS12 with a Pb shield, PbWO₄ calorimeter, vertex and recoil trackers

Timelike Compton Scattering (TCS)

TCS



BH



Decay-lepton angles θ, ϕ in the $\ell^+\ell^-$ rest frame

- $\gamma p \rightarrow \gamma^* p \rightarrow \ell^+ \ell^- p$: timelike mirror of DVCS, same CFFs
- Interferes with Bethe–Heitler (BH dominates σ)

$$\frac{d\sigma_{INT}}{dQ'^2 dt d(\cos \theta) d\varphi} = A \cos \varphi \frac{1 + \cos^2 \theta}{\sin \theta} \text{Re } \mathcal{H} + \dots$$

$$- \nu B \sin \varphi \frac{1 + \cos^2 \theta}{\sin \theta} \text{Im } \mathcal{H} + \dots$$

$$A_{FB}(\theta, \phi) = \frac{d\sigma(\theta, \phi) - d\sigma(180^\circ - \theta, 180^\circ + \phi)}{d\sigma(\theta, \phi) + d\sigma(180^\circ - \theta, 180^\circ + \phi)} \quad A_{\odot U} = \frac{d\sigma^+ - d\sigma^-}{d\sigma^+ + d\sigma^-}$$

$A_{\odot U}$: photon circular-polarization asymmetry

right- vs left-handed γ (from the polarized e^- beam); $\propto \sin \varphi \cdot \text{Im } H$

DVCS $\leftrightarrow$ TCS: universality test of GPDs

A_{FB} : forward–backward asymmetry of the decay leptons

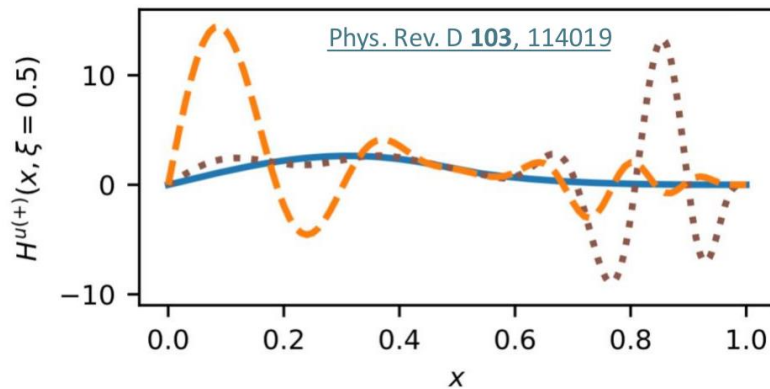
ℓ^- at (θ, φ) vs $(180^\circ - \theta, 180^\circ + \varphi)$; BH symmetric $\rightarrow \propto \cos \varphi \cdot \text{Re } H \rightarrow$ D-term

Extracting GPDs: an inverse problem

We measure Compton form factors: GPDs convoluted with a hard kernel (x integrated out)

$$\mathcal{F} = \{\mathcal{H}, \mathcal{E}, \tilde{\mathcal{H}}, \tilde{\mathcal{E}}\} \quad \text{DVCS} \quad F = \{H, E, \tilde{H}, \tilde{E}\}$$

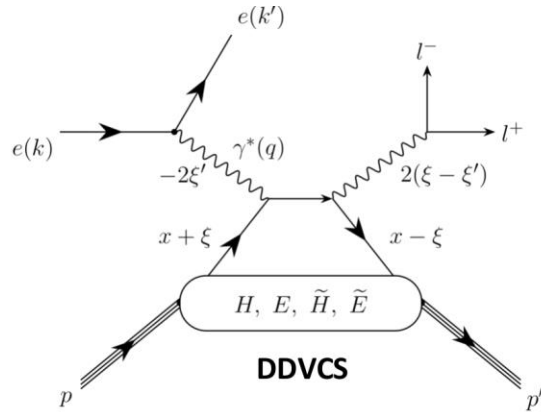
$$\mathcal{F}^\pm(\xi, t) = \int dx F(x, \xi, t) \left(\frac{1}{\xi - x - i\epsilon} \mp \frac{1}{\xi + x - i\epsilon} \right) = \mathcal{P} \int_{-1}^1 dx \left(\frac{1}{\xi - x} \mp \frac{1}{\xi + x} \right) \sum_q e_q^2 F^q(x, \xi, t) + i\pi \sum_q e_q^2 [F^q(\xi, \xi, t) \mp F^q(-\xi, \xi, t)]$$



Solid: GPD model; dashed, dotted: + two shadow GPDs $\rightarrow$ same CFFs. V. Bertone et al., PRD 103, 114019 (2021)

- $\text{Re } F$: principal-value integral over x; $\text{Im } F$: GPD only at $x = \pm\xi$
- Inverse problem: CFFs $\rightarrow$ GPDs is not unique
- **Shadow GPDs**: class of functions with null CFFs and null forward limit; can be added to any solution without changing DVCS/TCS data

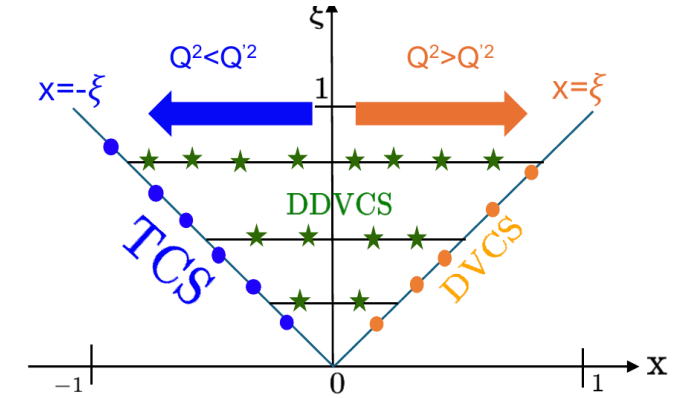
DDVCS: GPDs away from $x = \pm\xi$



$$\xi = -\xi' \frac{Q^2 + Q'^2}{Q^2 - Q'^2 + t/2}$$

$$\xi' = x_B \frac{Q^2 - Q'^2 + t/2}{(2 - x_B) Q^2 - x_B (Q'^2 - t)}$$

For DVCS/TCS $\xi \approx \mp \xi'$

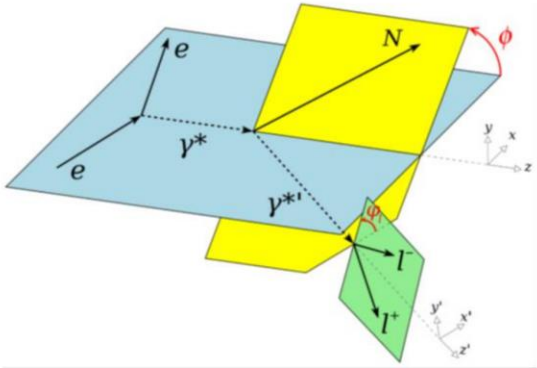


$$\mathcal{F}^\pm(\xi', \xi, t) = \mathcal{P} \int dx \left(\frac{1}{\xi' - x} \mp \frac{1}{\xi' + x} \right) \sum_q F^q(x, \xi, t) - i\pi \sum_q [F^q(\xi', \xi, t) \mp F^q(-\xi', \xi, t)]$$

- Im part $\rightarrow$ GPD at $x = \xi'$: tuning Q^2 and Q'^2 moves ξ' at fixed $\xi \rightarrow$ maps $-\xi < x < \xi$
- Sensitive to what shadow GPDs hide
- Proposed as early as 2003 [1, 2], but never measured: $\sigma \approx 10^{-3} \sigma_{\text{DVCS}}$

[1] M. Guidal, M. Vanderhaeghen, Phys. Rev. Lett. 90, 012001 (2003); [2] A.V. Belitsky, D. Müller, Phys. Rev. Lett. 90, 022001 (2003)

DDVCS: observable and challenges: A_{LU}



Observable: beam-spin asymmetry
 $A_{LU}(\varphi)$, lepton decay angles
integrated

$$\propto \text{Im}[F_1 H(\xi', \xi, t) + \dots] \sin \varphi$$

$$ep \rightarrow e' \gamma^* p \rightarrow e' p' \gamma^* \rightarrow e' \mu^+ \mu^- p'$$

$$\frac{d\sigma^5}{dQ^2 dt dx_B d\phi dQ'^2} = d^5\sigma_{BH1} + d^5\sigma_{BH2} + d^5\sigma_{VCS} + d^5\sigma_{Int_1} + \lambda(d^5\tilde{\sigma}_{VCS} + d^5\tilde{\sigma}_{Int_1})$$

$$\Delta\sigma_{LU} \propto \text{Im}[\mathbf{F_1}\mathcal{H}(\xi', \xi, t) + \xi'(F_1 + F_2)\tilde{\mathcal{H}}(\xi', \xi, t) - \frac{t}{4M^2}F_2\mathcal{E}(\xi', \xi, t)] \sin\phi$$

Observable of interest $A_{LU} = \frac{d\vec{\sigma}^5 - d\overleftarrow{\sigma}^5}{d\vec{\sigma}^5 + d\overleftarrow{\sigma}^5}$ In space like and timelike regions

Tiny cross section

$$\sigma_{\text{DDVCS}} \approx 10^{-3} \sigma_{\text{DVCS}} \rightarrow \text{need } \mathcal{L} \geq 10^{37} \text{ cm}^{-2}\text{s}^{-1}$$

● Detect $\mu^+\mu^-$, not e^+e^-

avoids identical-electron antisymmetrization;
muons survive a thick shield

Sign change of A_{LU}

spacelike ($Q^2 > Q'^2$) $\rightarrow$ timelike ($Q^2 < Q'^2$): test of factorization

DDVCS: possibility to measure $A^{\cos \phi \ell}$

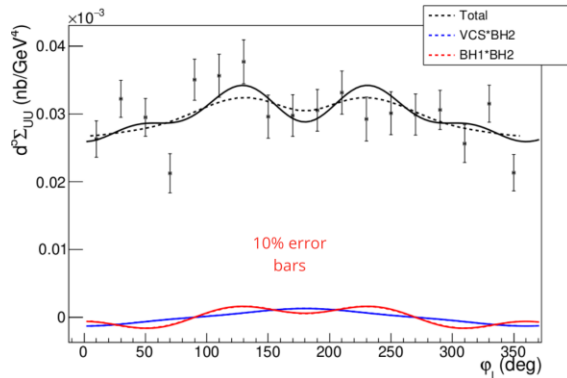
$$A^{\cos \phi \ell} = \frac{1}{\mathcal{N}} \int_{\pi/4}^{3\pi/4} d\theta_\ell \int_0^{2\pi} d\phi \int_0^{2\pi} d\varphi_\ell 2 \cos \varphi_\ell \frac{d\sigma^-}{d\Omega_\ell d\phi},$$

$$\mathcal{N} = \int_{\pi/4}^{3\pi/4} d\theta_\ell \int_0^{2\pi} d\phi \int_0^{2\pi} d\varphi_\ell \frac{d\sigma^-}{d\Omega_\ell d\phi}$$

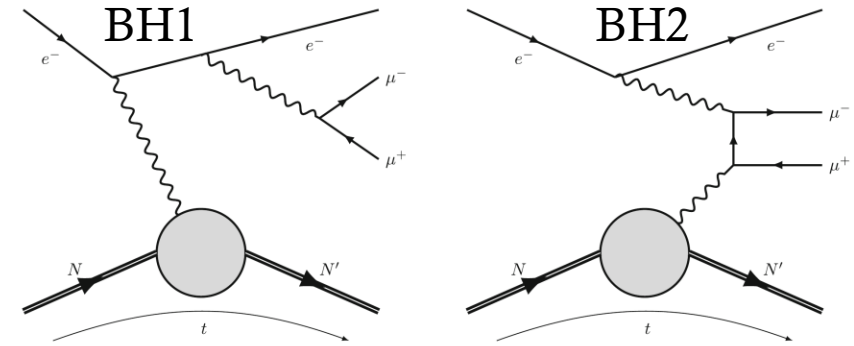
After subtracting $BH_1 \cdot BH_2$, it projects the $VCS \cdot BH_2$ term:

$$c_{10}^{VCS \cdot BH_2} \propto \text{Re} \left\{ \frac{\xi'}{\xi} F_1 \mathcal{H} - \frac{\xi'}{\xi} \frac{t}{4M^2} F_2 \mathcal{E} + \xi (F_1 + F_2) \tilde{\mathcal{H}} \right\}$$

A.V. Belitsky, D. Müller, PRD 68, 116005 (2003), Eqs. (170)–(171), in the notation of slide 5 $[(\xi, \eta, \Delta^2)_{BM} \rightarrow (\xi', \xi, t)]$; $\theta_\ell, \varphi_\ell$: decay-lepton angles in the $\mu^+ \mu^-$ rest frame



Pseudo-data, J. S. Alvarado (IJCLab): $d^5\Sigma_{UU}$ vs φ_ℓ ; total (black), $VCS \cdot BH_2$ (blue), $BH_1 \cdot BH_2$ (red); dashed: theory, solid: fits, 10% errors

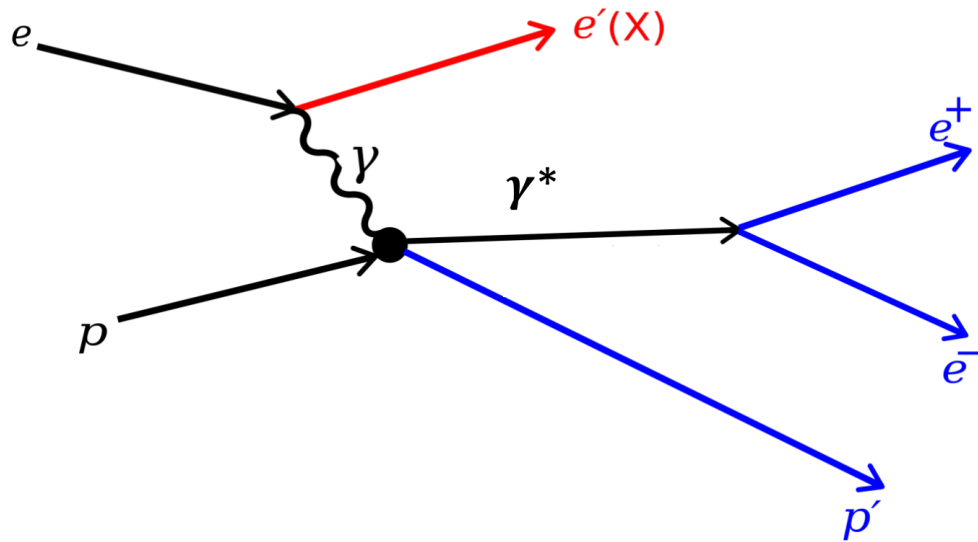


- e^- beam only: the $\cos \varphi_\ell$ moment gives access to $\text{Re } H$
- **Challenge:** the $BH_1 \cdot BH_2$ interference also modulates in φ_ℓ , with a similar size (red)
- It is calculable, but subtracting it requires **very good control of systematics due to acceptance simulations**; otherwise fake modulations will be introduced.

Challenging: not included in the proposal

We keep it in mind and will look for a way to extract it

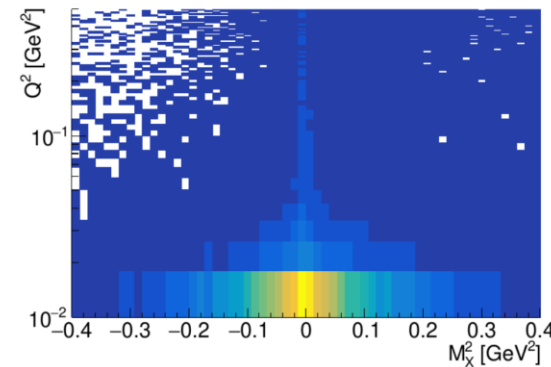
TCS analysis with CLAS12



- $ep \rightarrow e^+e^-p'(e')$: quasi-real photoproduction with the electron beam
- e^- , e^+ , p' detected in the Forward Detector; e' at small angle, undetected
- Timelike photon: $\gamma^* = e^+ + e^-$
- e^+/π^+ separation: with AI/ML using ECAL shower profiles

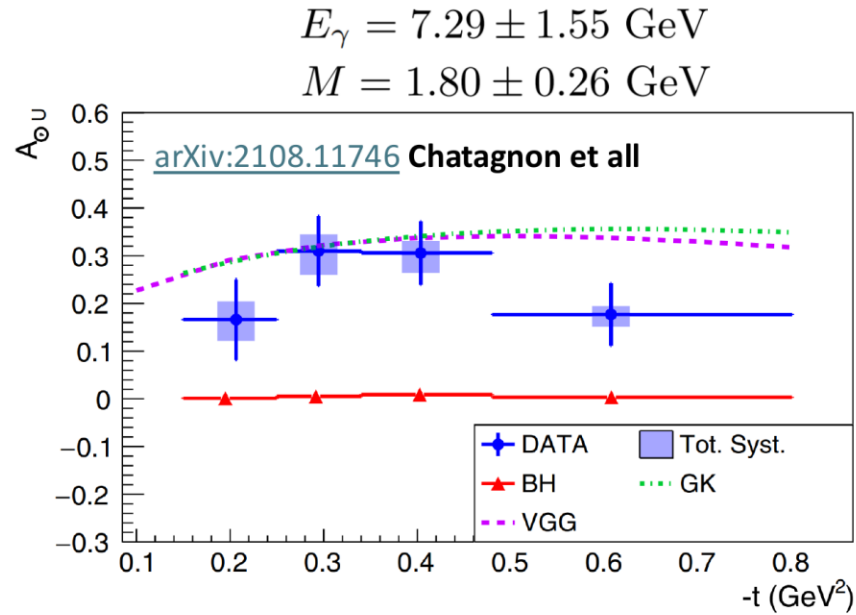
$$e'(X) = e + p - e^- - e^+ - p'$$

$$M_X^2 \approx 0, P_t/P < 0.05 \rightarrow Q^2 = 2E_b E_{e'}(1 - \cos \theta_{e'}) < 0.15 \text{ GeV}^2$$

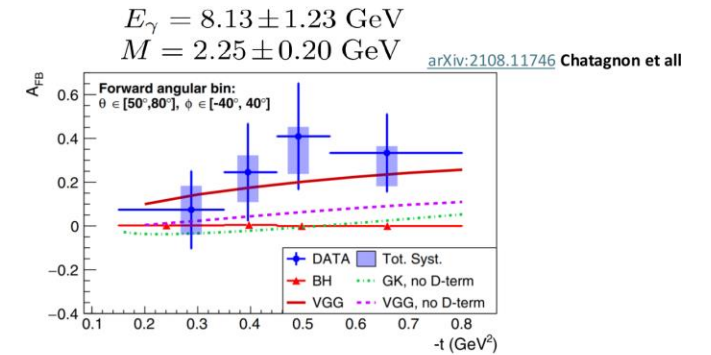
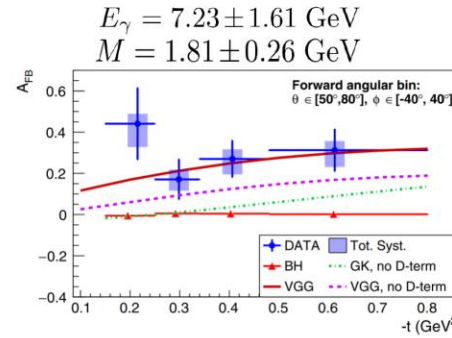


Q^2 vs M_X^2 of the missing electron: quasi-real photons at $Q^2 \approx 0$

First TCS measurement with CLAS12



Photon-polarization asymmetry A_{OU} vs $-t$



Forward-backward asymmetry A_{FB} , two mass bins

- **2921 events**, $1.5 < M_{ee} < 3 \text{ GeV}$, four $-t$ bins (RG-A, 10.6 GeV)
- $A_{OU} \neq 0$ (BH alone gives 0): TCS signal, consistent with GPD models
- A_{FB} favors VGG with D-term; errors still too large to exclude no D-term
- Statistics-limited

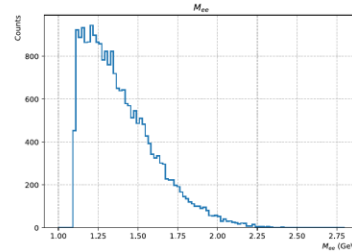
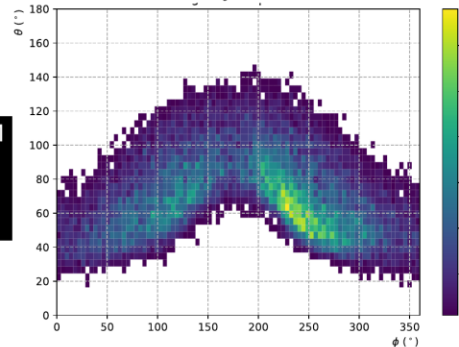
P. Chatagnon et al. (CLAS), Phys. Rev. Lett. 127, 262501 (2021)

Ongoing TCS analyses: RG-A and RG-K

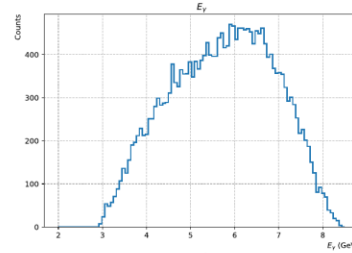
TCS studies using RGK

- Focus on RGK Sp24 8.477 GeV run period (*outbending* configuration)
 - RGK Sp24 largest existing CLAS12 dataset, 8.477 GeV data set accessing higher M_{ee}
- Current kinematic region of interest: $M_{ee} \geq 1.1 \text{ GeV}^2$, $0.15 \text{ GeV}^2 \geq -t < 0.80 \text{ GeV}^2$, $E_\gamma/E_{beam} \geq 0.35$
 - RGK Sp24 8.477 GeV TCS dataset ~23000 events before QADB, fiducial, etc. cuts
- CAA proposal written with reviews underway

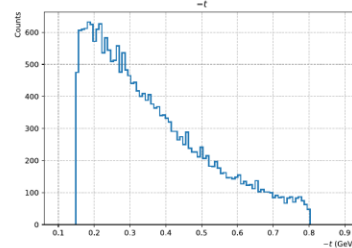
Angular Acceptance, COM θ versus COM $\phi \rightarrow$ different distribution for outbending configuration



Dilepton invariant mass, $M_{e^-e^+}$



Quasireal photon energy, E_γ



Negated Mandelstam variable $t, -t$

RG-A (K. Gopal USC)

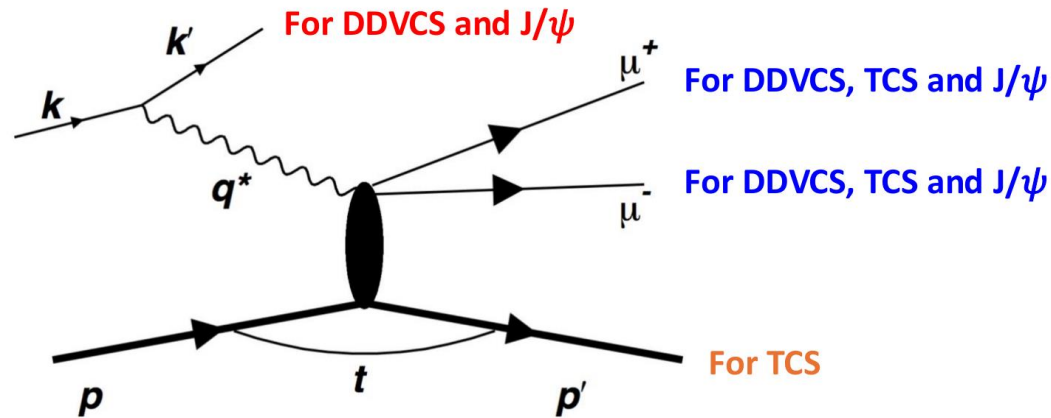
- $> 2\times$ the published data calibrated; AI-assisted tracking
- $\approx$ half of the approved RG-A beam time still to come

RG-K (M. Kerr, MIT)

- Spring 2024, 8.477 GeV, outbending: higher M_{ee} reach
- $\approx 23 \text{ k}$ candidates before QA/fiducial cuts; CAA proposal under review

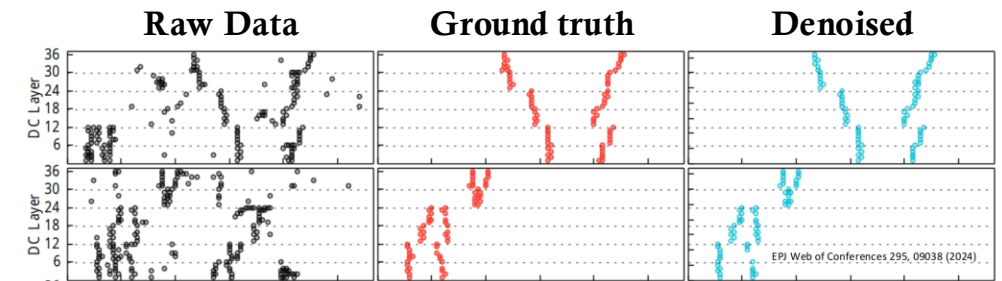
Slide courtesy of M. Kerr (MIT)

μ CLAS12: the measurement



- $ep \rightarrow e'\mu^+\mu^-p'$ at $\mathcal{L} = 10^{37} \text{ cm}^{-2}\text{s}^{-1}$ ($\times 100$ CLAS12)
- DDVCS: detect $e'\mu^+\mu^-$; p' from missing momentum
- TCS: $\mu^+\mu^-$ + recoil p' (40° – 70°); e' undetected
- J/ψ near threshold in the same data (see P. Chatagnon's talk)
- One single-MIP trigger for all channels

Why $\times 100$ is hard today

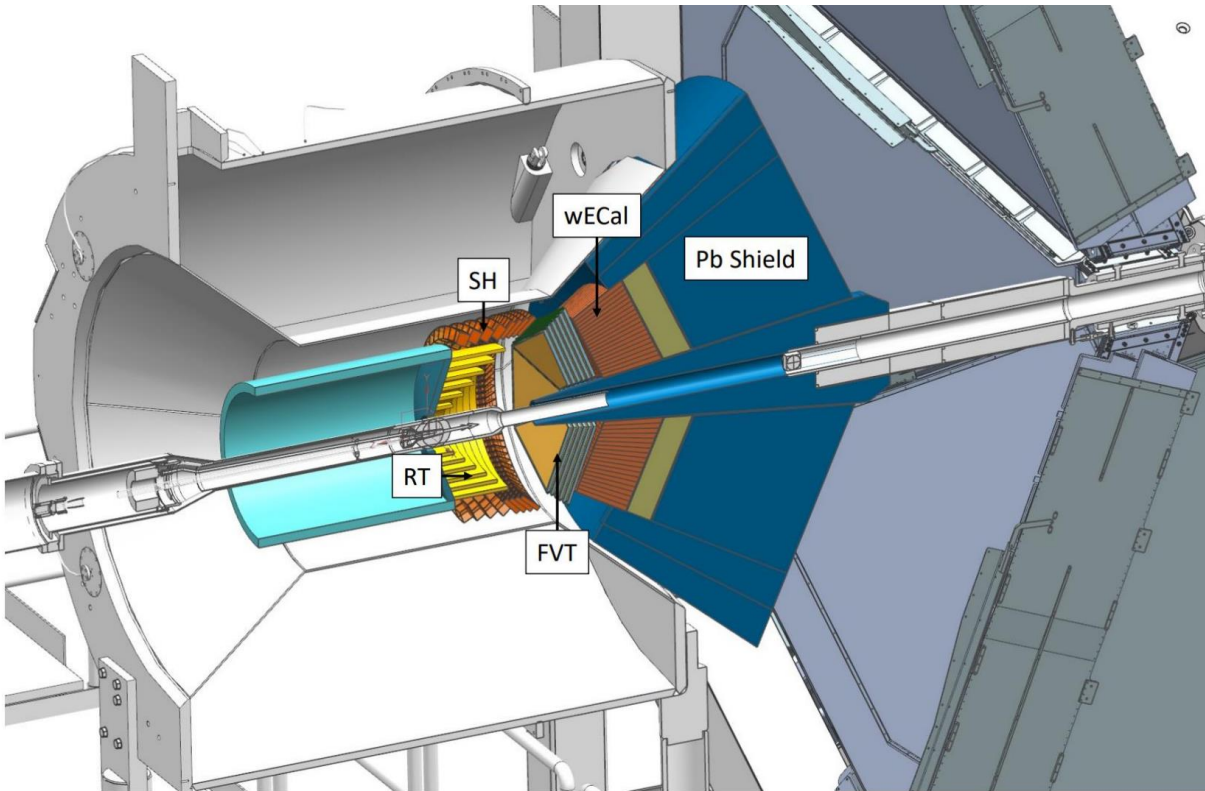


CLAS12 DC hits, two events at nominal luminosity; EPJ Web Conf. 295, 09038 (2024)

- Detectors will not survive
- Drift-chamber occupancies become intolerable ($\approx 100\%$)
- AI denoising helps, but cannot absorb $\times 100$
- Electron trigger $\rightarrow$ MHz rates

Absorb the EM background, let the muons through

μ CLAS12 detector configuration



Removed: HTCC, FT, SVT/MVT, CTOF, CND, BAND, LTCC

Kept: DC, FTOF, PCal/ECal $\rightarrow$ muon spectrometer

- 1 Möller cone**
thick lead cone (steel jacket) up to 7°
- 2 wECal**
1320 PbWO_4 crystals, 7° – 30° , APD readout
- 3 Pb shield**
60 cm, 7° – 35° , 2π : absorbs EM background
- 4 FVT**
6 triple-GEM stations at ≈ 40 cm: vertexing
- 5 Recoil detector**
6-layer μ RWELL + 540-tile hodoscope, 40° – 70°

Rates and trigger at full luminosity

DC

Max. occupancy $\approx 6 / 4 / 11 \%$
(Regions 1/2/3); CLAS12 has
run near 10%

FVT

6 GEM layers at 40 cm, VMM3
readout; $< 1 \text{ MHz/cm}^2$ max.,
 $< 500 \text{ kHz/cm}^2$ average

wECal

1320 PbWO_4 crystals, APD
readout; $< 2 \text{ MHz}$ per crystal
(HPS: $\approx 1.5 \text{ MHz}$)

Recoil tracker

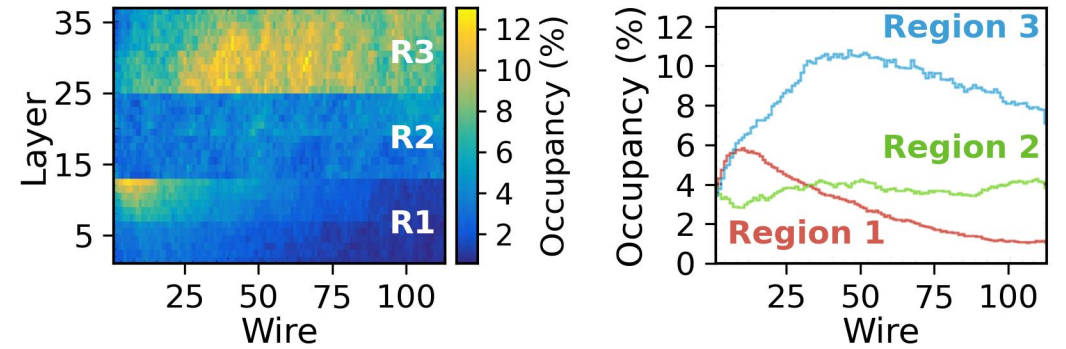
6 cylindrical μRWELL layers,
 $R = 8\text{--}23.5 \text{ cm}$, $40^\circ\text{--}70^\circ$;
 $< 250 \text{ kHz/cm}^2$

Hodoscope

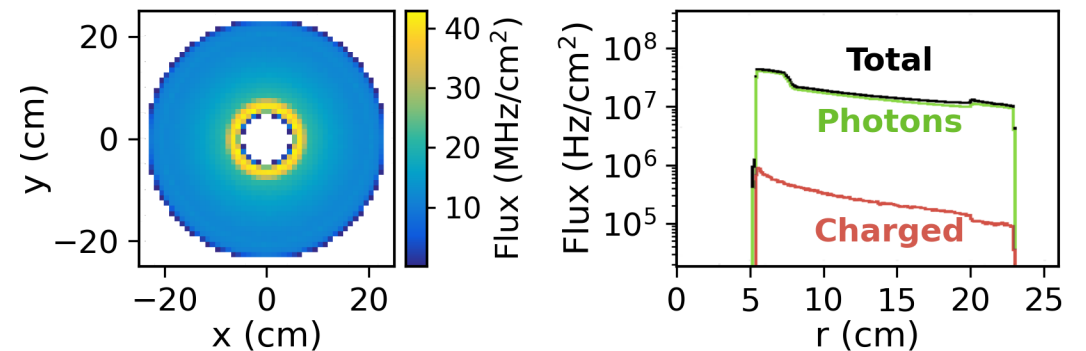
540 scintillator tiles, 2×2 and
 $4\times 4 \text{ cm}^2$; $< 200 \text{ kHz}$ per tile

Trigger

Single MIP: $\approx 21 \text{ kHz}$;
Current CLAS12 DAQ handles
30 KHz



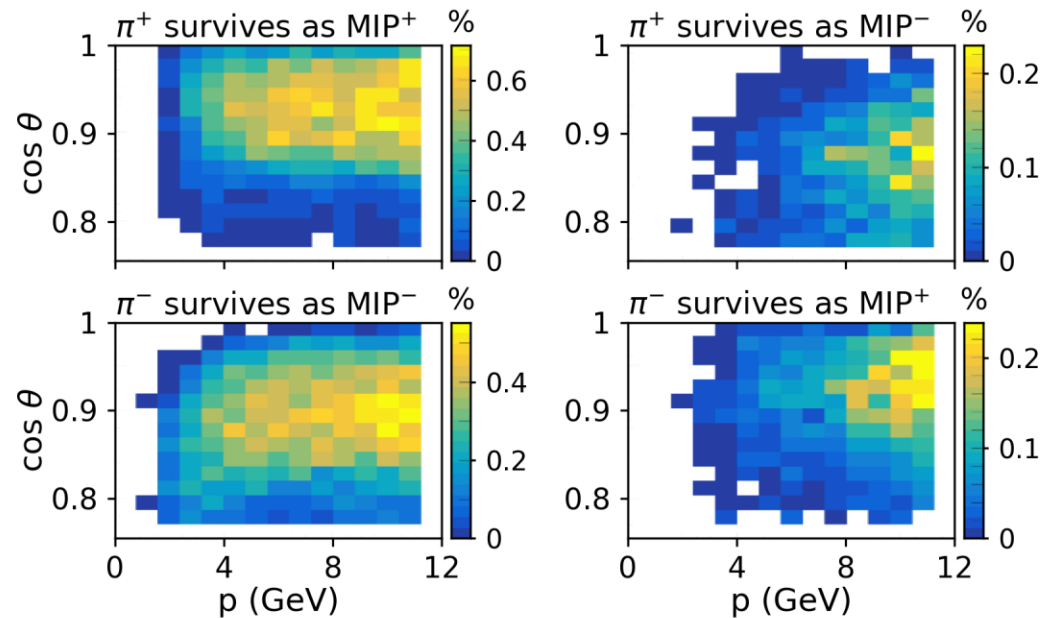
DC occupancy at $10^{37} \text{ cm}^{-2}\text{s}^{-1}$, 60 cm Pb shield



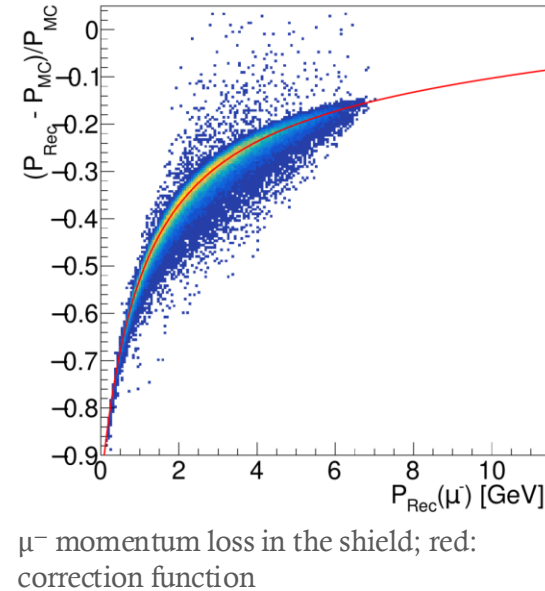
Particle flux at the FVT plane (40 cm from the target)

More details on each detector: backup slides 25–28

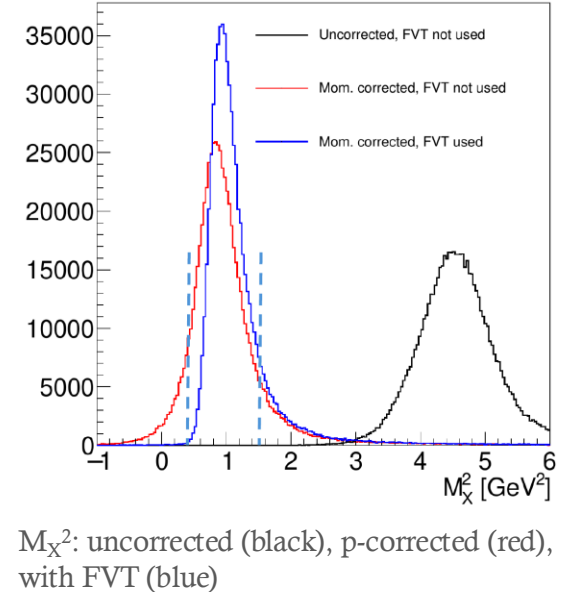
Muon identification and exclusivity



- MIP signature in PCal, EC_{in} and EC_{out} .
- $< 1\%$ of π survive as MIP ($> 99\%$ suppression)

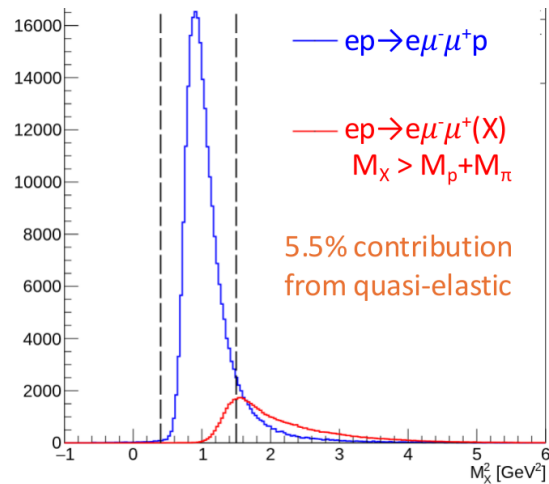


- μ lose up to ≈ 1 GeV in the shield $\rightarrow$ momentum correction



- FVT restores vertex & angles very close to true values
- Exclusivity: $0.4 < |M_X^2| < 1.5$ GeV^2

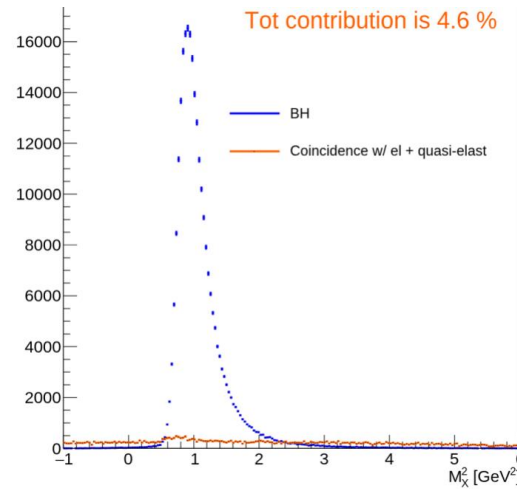
Physics backgrounds are small



M_X^2 : exclusive (blue) vs quasi-elastic (red)

5.5 %

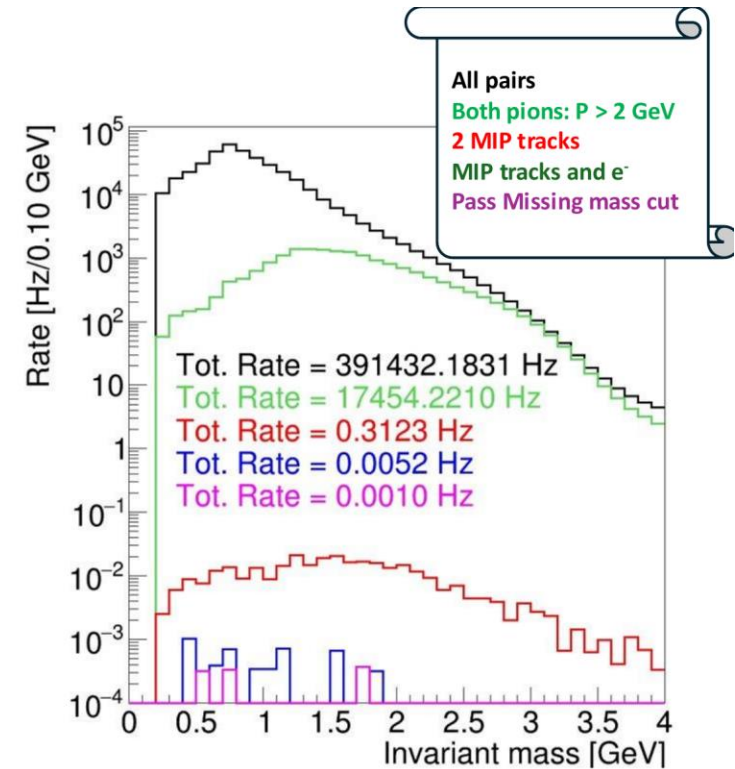
quasi-elastic $ep \rightarrow e\mu^+\mu^-X$ (GRAPE),
after exclusivity cut



M_X^2 : BH (blue) vs accidental coincidences (orange)

4.6 %

accidentals: $\mu^+\mu^-(e'X)$ from GRAPE
mixed with inclusive e' from IncEG
(inclusive generator)



$\approx 1\%$ $\pi^+\pi^-$ faking $\mu^+\mu^-$: 1.2 B CLAS12 events $\rightarrow$ 1 with $M > 1.2$ GeV

Projections: running conditions

200 days

production running

10^{37}

$\text{cm}^{-2}\text{s}^{-1}$ luminosity ($\times 100$
CLAS12)

11 GeV

e^- beam, $P_b > 85\%$

7.5 μA

on a 5 cm LH_2 target

Approved by PAC53 (C1, A rating): 200 production + 45 commissioning/calibration days

Simulation chain

GRAPE

elastic + quasi-elastic $\mu^+\mu^-$
(BH) events



μGEMC

GEANT4 model of μCLAS12



Reconstruction

CLAS12 COATJAVA +
 μ momentum correction

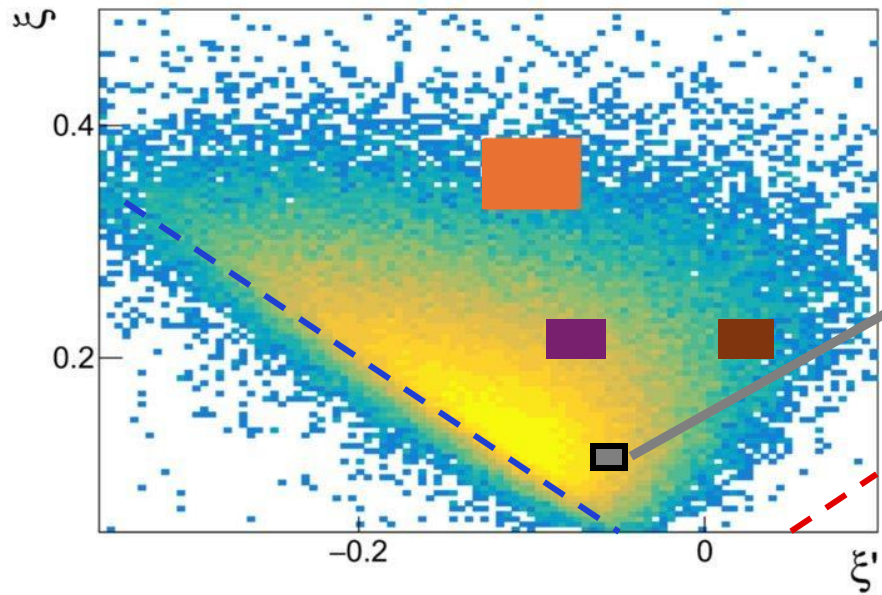


Asymmetries

From models; uncertainties
with the expected statistics
from GRAPE

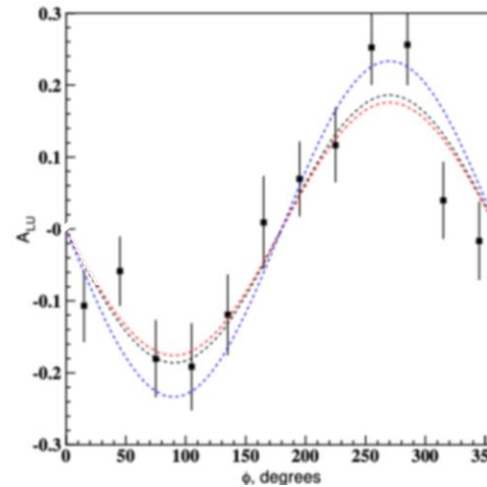
DDVCS projections: A_{LU} vs $-t$

DDVCS + BH events (> 0.5 M) in (ξ', ξ)

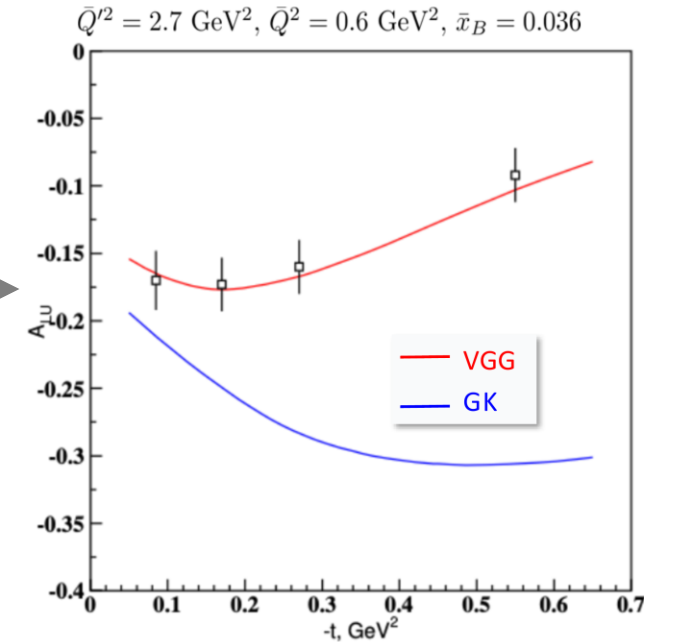


Dashed: TCS limit $\xi' = -\xi$ (blue), DVCS limit $\xi' = \xi$ (red)

Grey bin ($\xi \approx 0.1$, $\xi' \approx -0.06$): precision separates VGG and GK in the $-t$ dependence of A_{LU}



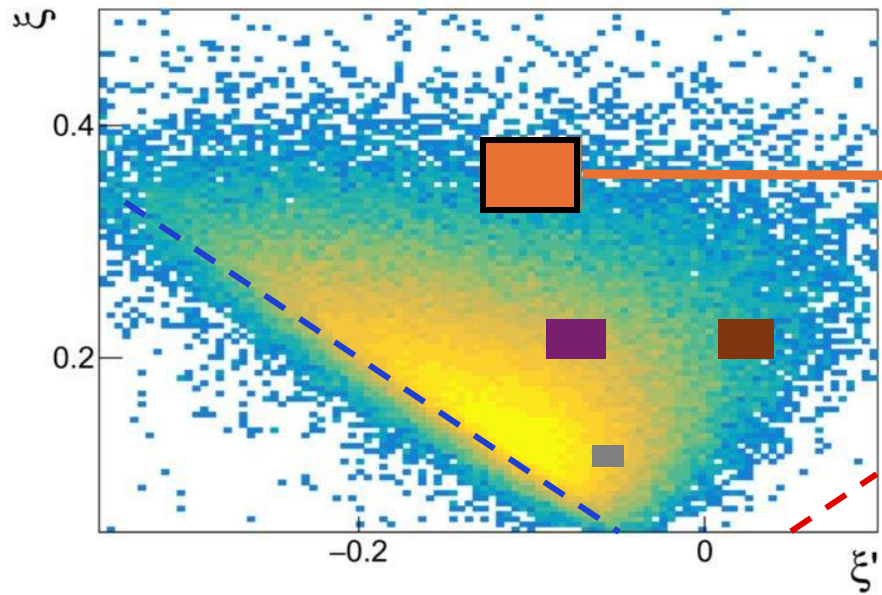
One $-t$ bin: pseudo-data, $\sin \varphi$ fit



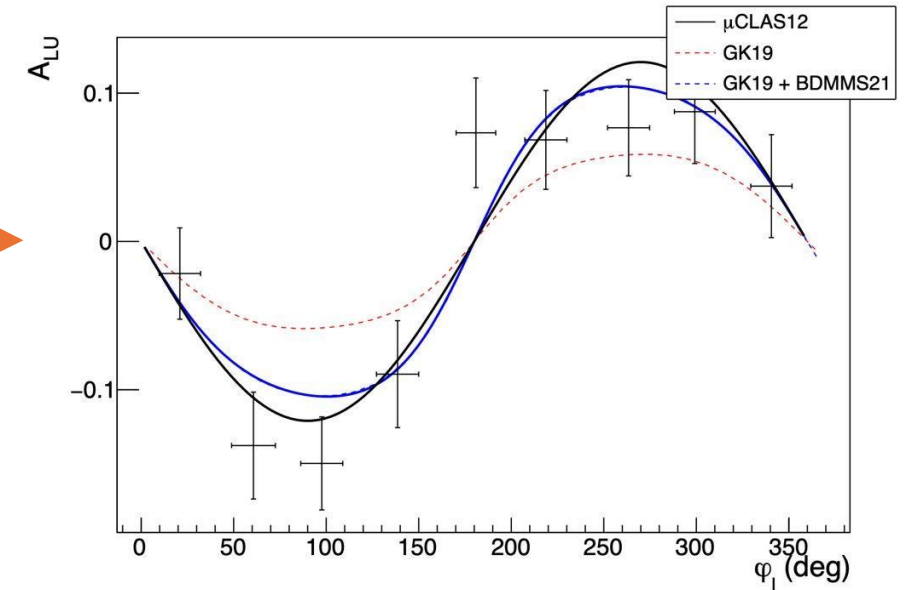
$A_{LU}^{90^\circ}$ vs $-t$, 1000 pseudo-experiments per bin

DDVCS projections: shadow GPDs

DDVCS + BH events (> 0.5 M) in (ξ', ξ)



Dashed: TCS limit $\xi' = -\xi$ (blue), DVCS limit $\xi' = \xi$ (red)

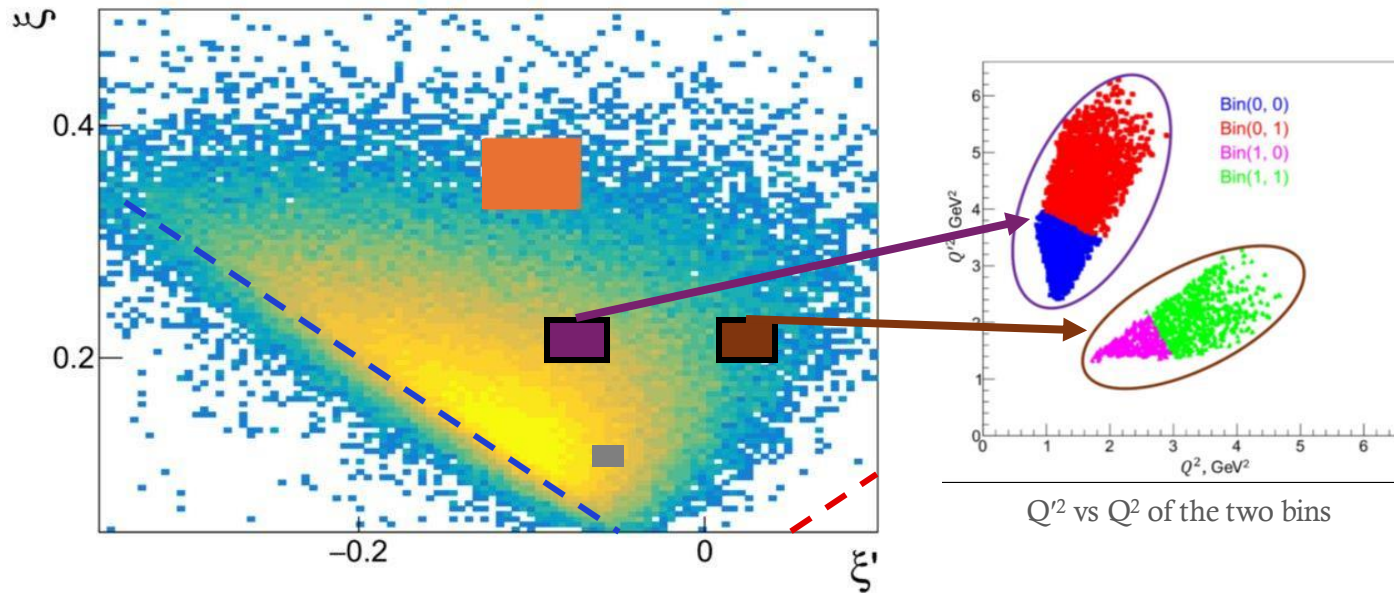


$\xi = 0.36, \xi' = -0.082, -\bar{t} = 0.82 \text{ GeV}^2$; GK19 vs GK19 + NLO shadow GPD (BDMMS21)

Orange bin: $A_{LU}^{90^\circ}$ to 13.6% (stat.) distinguishes a GPD with and without a shadow GPD

DDVCS projections: Timelike vs Spacelike

DDVCS + BH events (> 0.5 M) in (ξ', ξ)



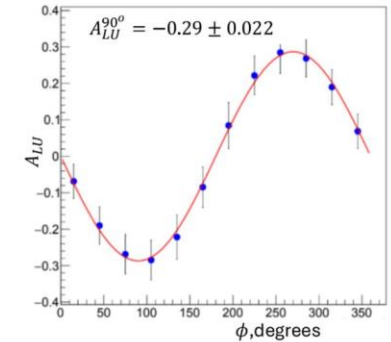
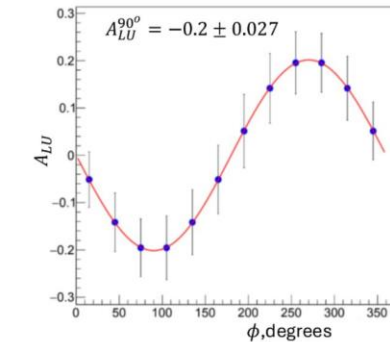
Dashed: TCS limit $\xi' = -\xi$ (blue), DVCS limit $\xi' = \xi$ (red)

A_{LU} flips sign: $\approx -0.2 \dots -0.3$ (timelike, $Q'^2 > Q^2$) $\rightarrow \approx +0.12$ (spacelike, $Q'^2 < Q^2$)

Timelike

Bin (0,0)

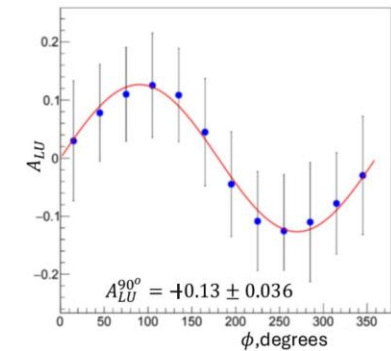
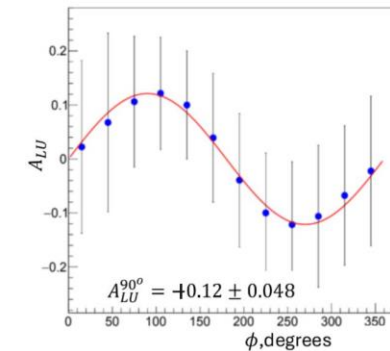
Bin (0,1)



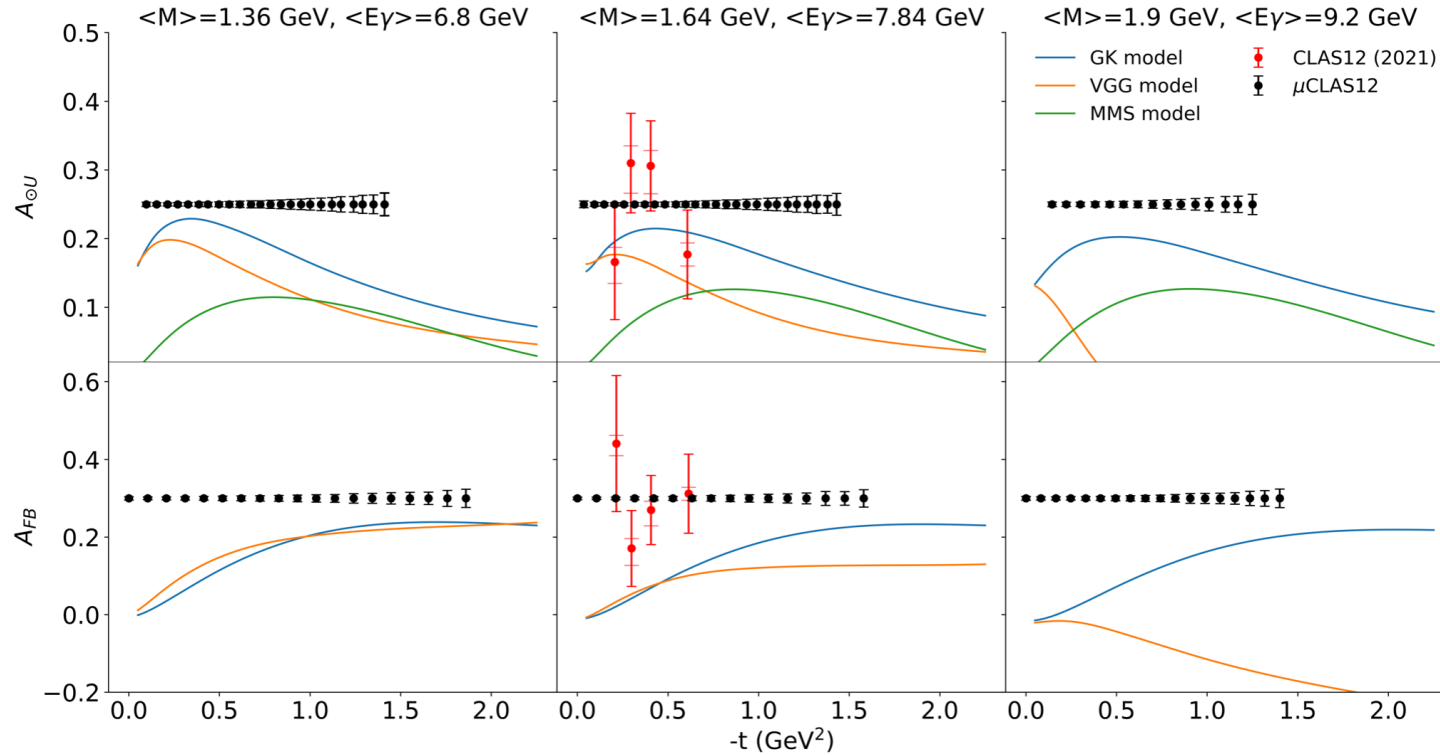
Spacelike

Bin (1,0)

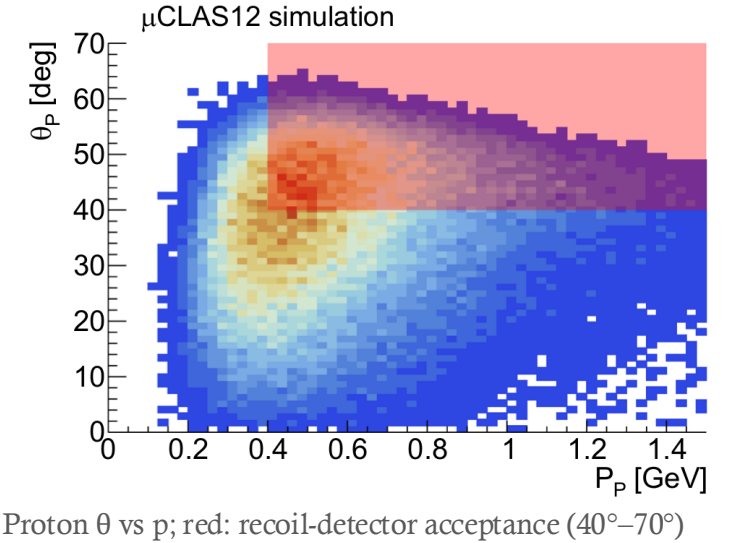
Bin (1,1)



TCS with μ CLAS12



EPJ A 62, 157 (2026), Figs. 34b and 37



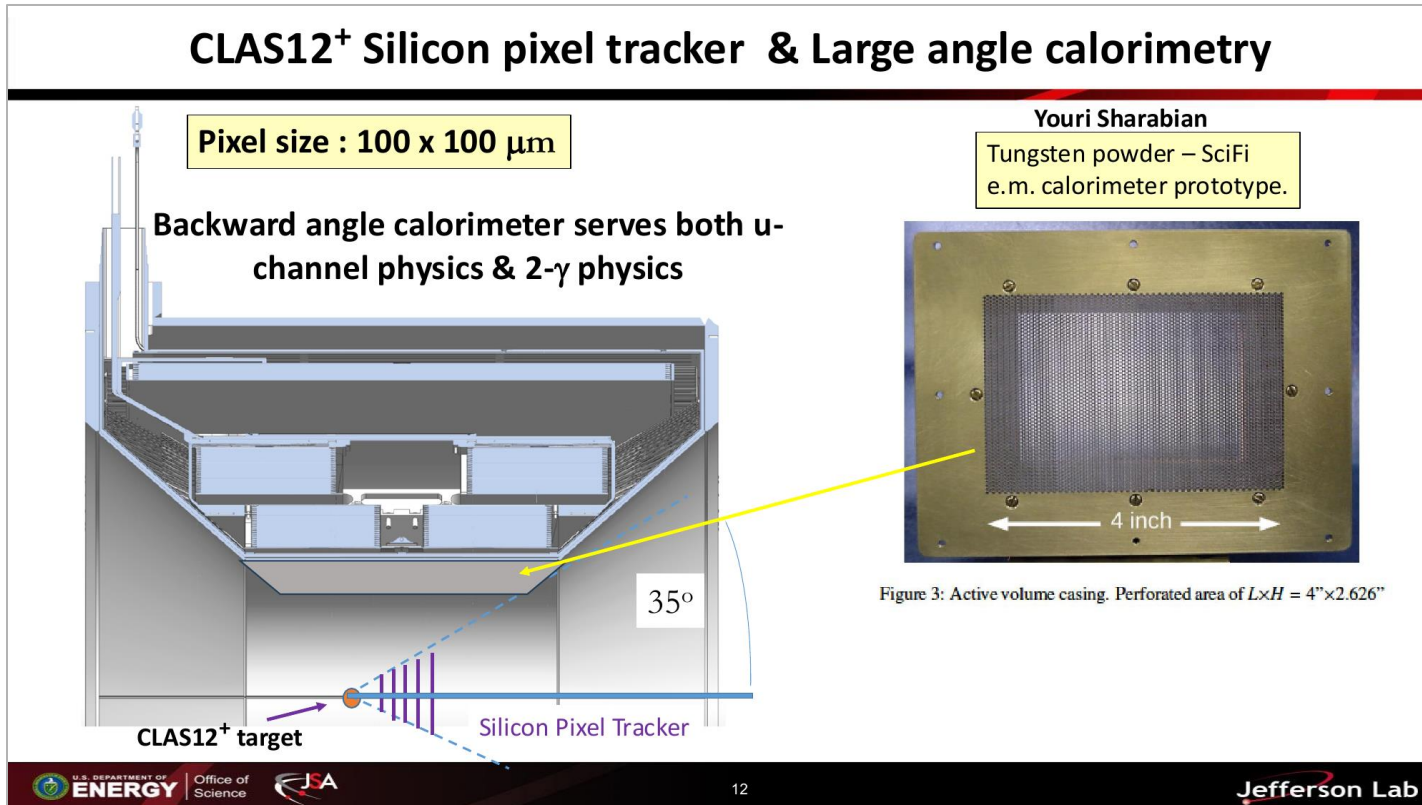
7.7 M

TCS events, $M_{\mu\mu} > 1.2$ GeV

$\times 10^3$

vs. first CLAS12 TCS result

Extending $e^\pm$ detection: a concept



- Today $e^\pm$ identified only in the Forward Detector ($\theta < 35^\circ$)
- Idea: Si pixel tracker ($100 \times 100 \mu\text{m}^2$) + large-angle EM calorimetry (W-powder/SciFi prototype, Y. Sharabian)
- Leptons at large angles $\rightarrow$ larger acceptance

Conceptual design only

No GEANT4 simulation of this configuration yet

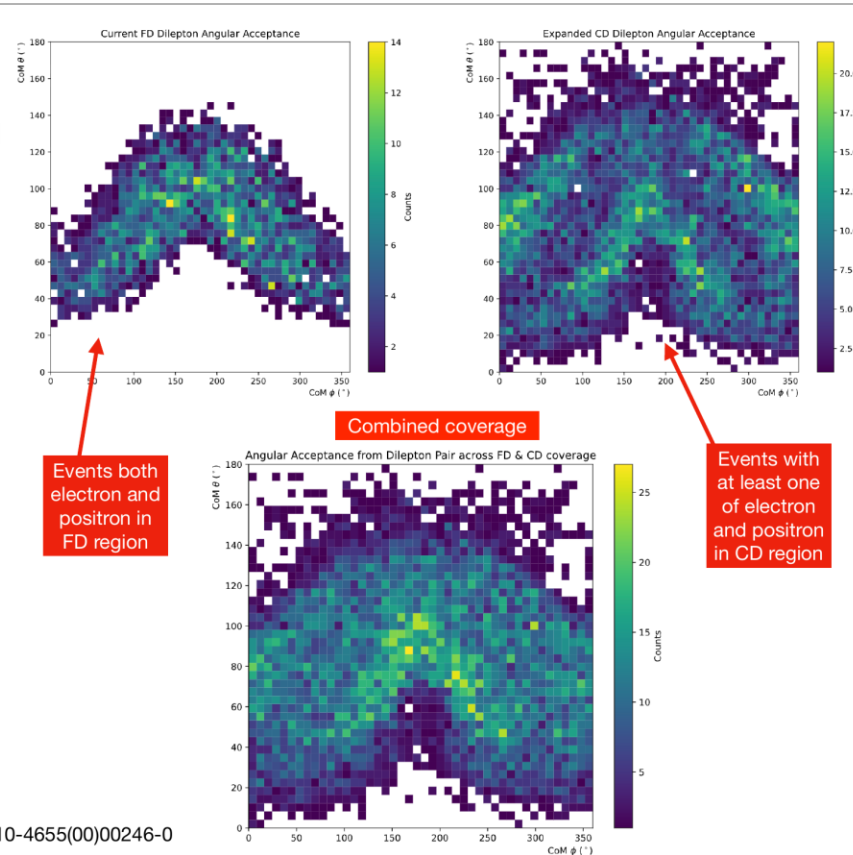
V. Burkert, Hall B round table (2026), slide 12

TCS with $e^\pm$ in the CD: first look

TCS with $e^\pm$ detection extended to CD region

- Current CLAS12 has electron/positron detection capabilities in FD region so cannot detect $e^\pm$ with polar angles $\theta > 35^\circ$, restricting dilepton studies to FD kinematics
- Possible EMCal expansion of CD as part of high luminosity upgrades
- e^-e^+ BH events simulated using GRAPE¹ event generator with 8.477 GeV electron beam to investigate gains from CD upgrades
- FD $e^\pm$ identified with reconstructed hit banks, CD $e^\pm$ identified with generated MC values
- Expanded angular acceptance particularly useful for TCS *forward backward* asymmetry studies

¹T. Abe, *Comput. Phys. Commun.* **136**, 1–2 (2001), 10.1016/S0010-4655(00)00246-0



$\approx \times 2-3$

increase of TCS statistics (FD + CD vs FD only)

- GRAPE BH e^+e^- at 8.477 GeV
- FD + CD: almost full CM (θ, ϕ) coverage, key for A_{FB}

Generator level: CD leptons at MC values, no detector simulation yet

Preliminary study, slide courtesy of M. Kerr (MIT)

Summary

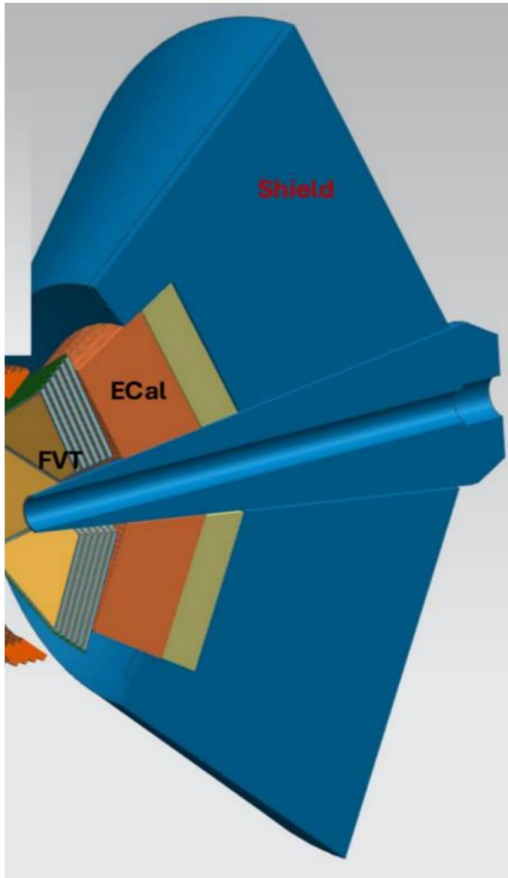
- CLAS12 published the first TCS asymmetries; Full RG-A and RG-K analyses ongoing, still statistics-limited
- μ CLAS12 at $10^{37} \text{ cm}^{-2}\text{s}^{-1}$ (PAC53, A rating): DDVCS, GPDs away from $x = \pm\xi$. First DDVCS measurements can be done with CLAS12 and SoLID (see Z. Zhao's talk)
- 7.7 M TCS events: precision $A_{\odot\text{U}}$, $A_{\text{FB}} \rightarrow \text{Re } H$, D-term
- High-statistics J/ψ near threshold in the same data (see P. Chatagnon's talk)
- Large-angle $e^\pm$ detection: a concept to boost TCS acceptance, at a very early stage

**New ideas are very
welcome!**

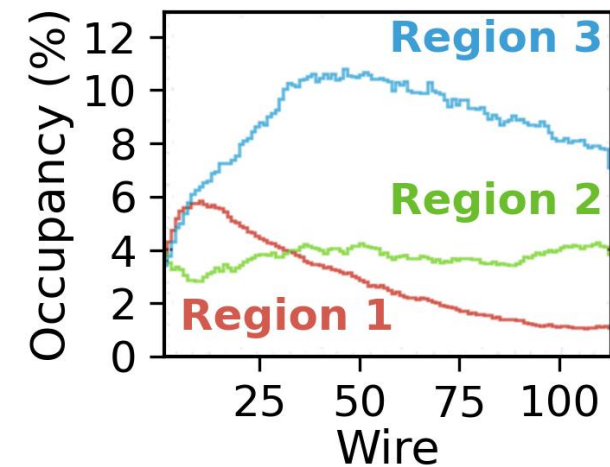
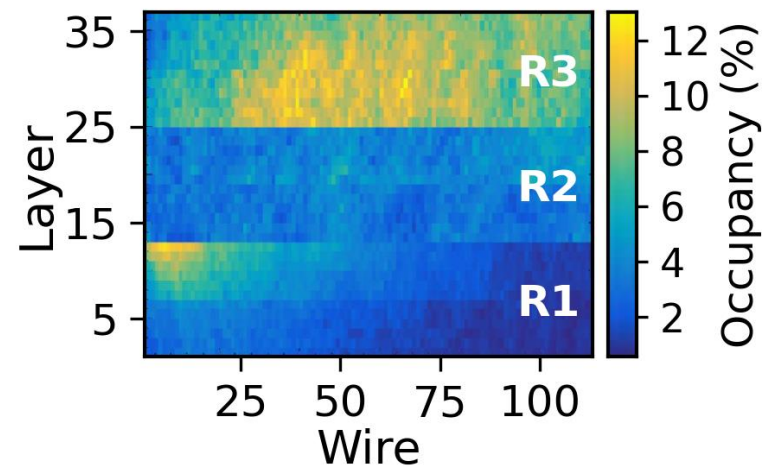
μ CLAS12 and CLAS12 upgrades are
open to new measurements

Backup

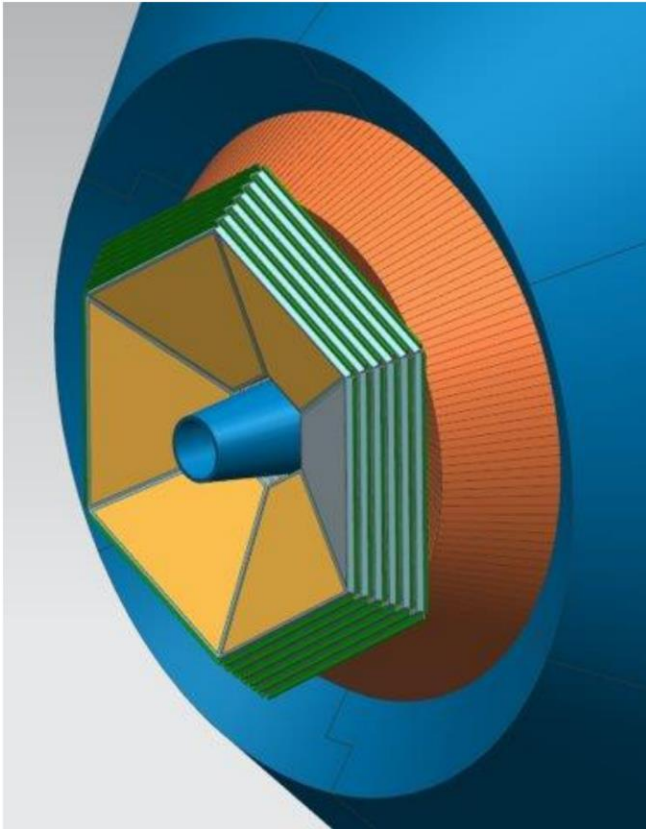
Occupancies in the drift chambers



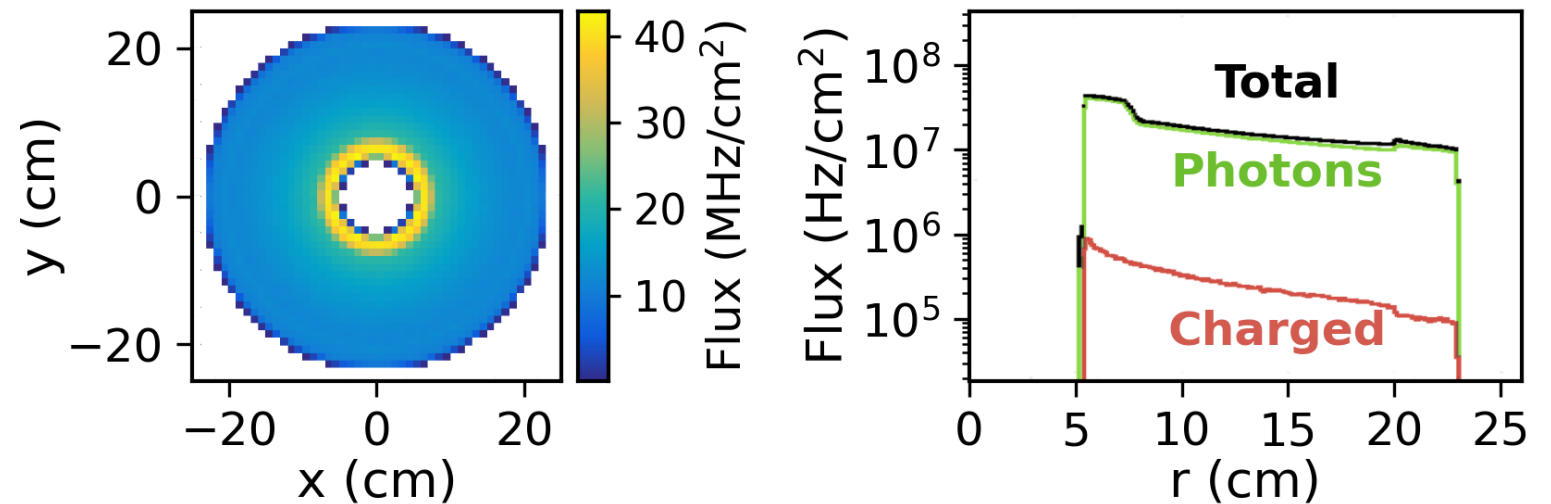
- Thick Möller cone with the lead shield and the wECal massively suppress the EM background from the target
- Occupancies $\approx 3 / 4 / 9 \%$ on average, $\approx 6 / 4 / 11 \%$ maximum (Regions 1/2/3)
- Comparable with current CLAS12 occupancies: close to 10% reached with nuclear targets
- Work continues on shielding and background mitigation for better tracking



Forward Vertex Tracker (FVT)

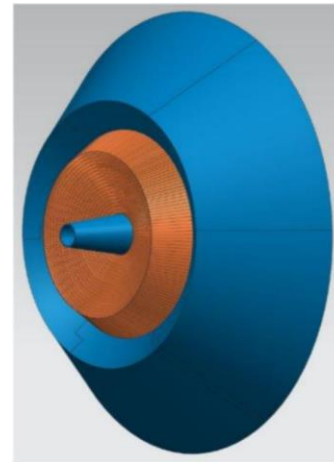


- Muons undergo **large energy loss and multiple scattering** in the shield
- With the DC alone, the vertex (position and angle) reconstruction is poor
- FVT goal: **precise reconstruction of the vertex parameters**
- 6-layer GEM assembly, 40 cm from the target; VMM3 readout
- Max. rate $< 1 \text{ MHz/cm}^2$ (very forward); average $< 500 \text{ kHz/cm}^2$ per module

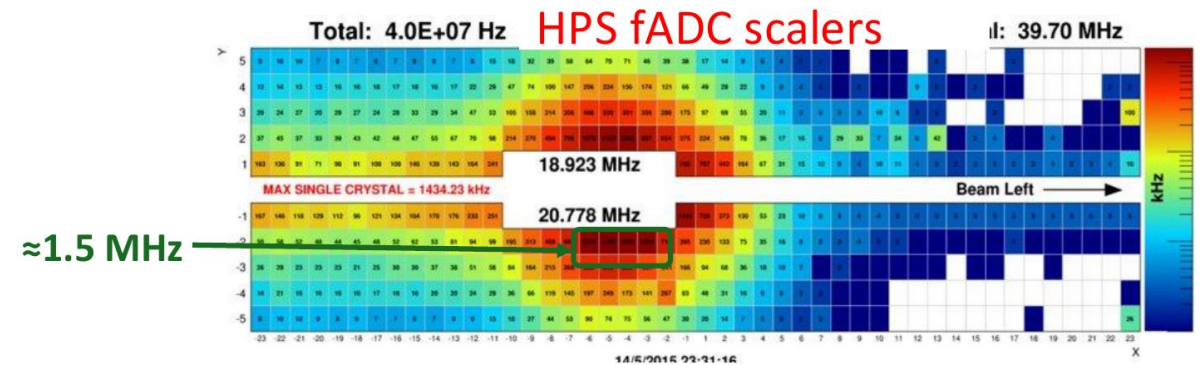
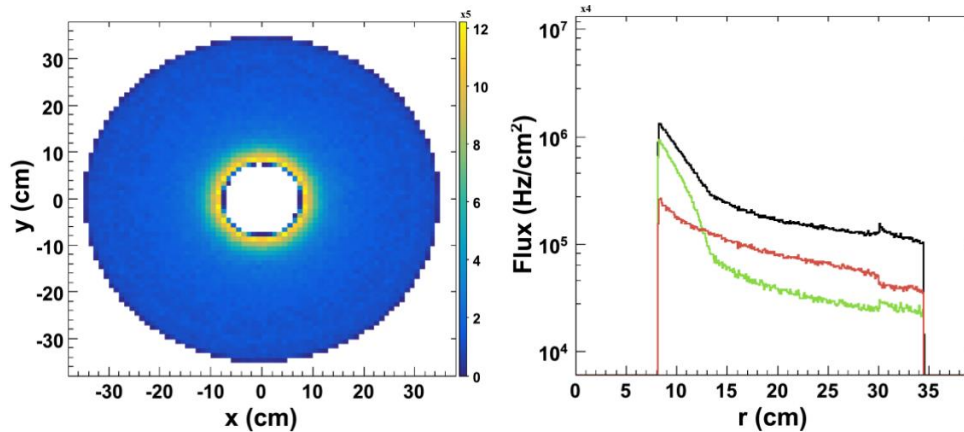
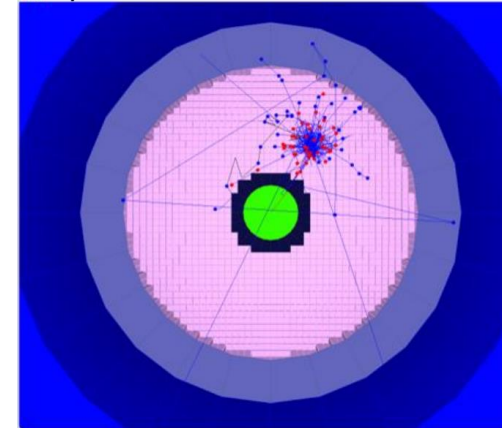


wECal: the electromagnetic calorimeter

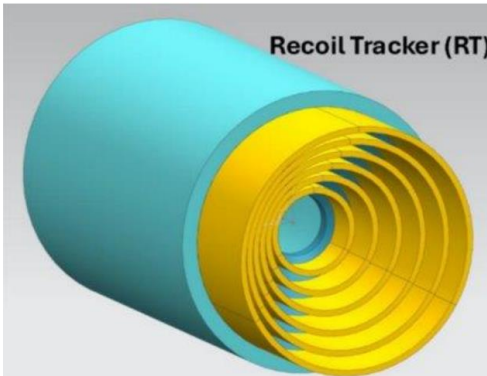
- 1320 PbWO_4 modules, 20 cm long
- $1.3 \times 1.3 \text{ cm}^2$: small angles (7° – 12°)
- $1.5 \times 1.5 \text{ cm}^2$: large angles (12° – 30°)
- APD readout
- First ring: $< 2 \text{ MHz}$ per crystal
- HPS used APD readout with comparable rates in the hottest crystals: manageable with pulse fitting



Implementation in GEANT4



Recoil detector: tracker and hodoscope



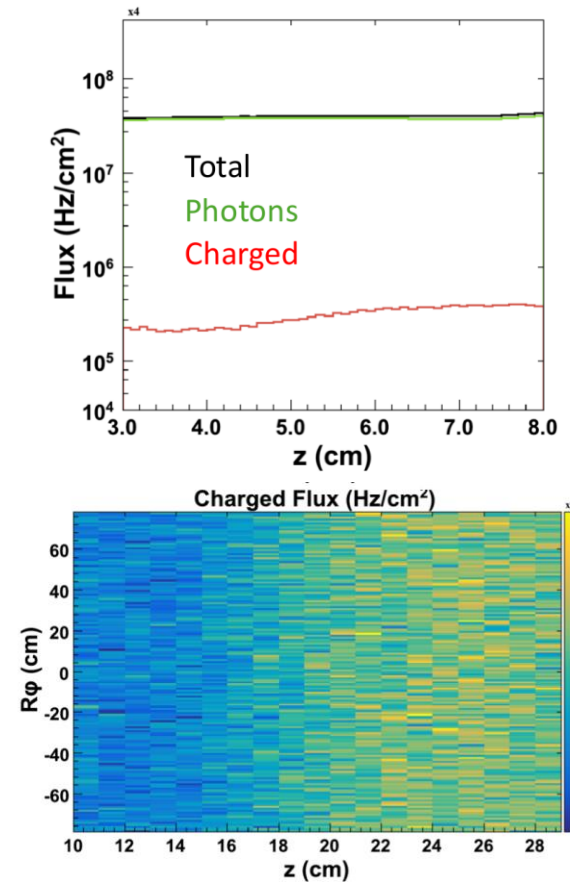
Recoil tracker (RT)

- 6 concentric cylindrical μ RWELL layers: $R = 8$ cm (1st) to 23.5 cm (6th)
- Each layer: three identical sectors
- Coverage: 40° – 70°
- Total rate < 250 kHz/cm²



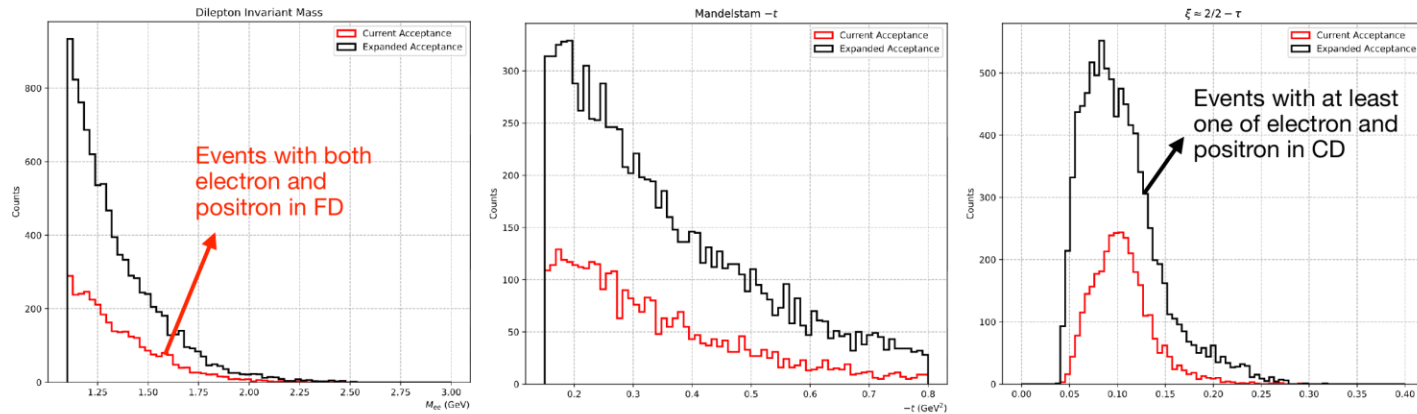
Scintillation hodoscope (SH)

- 540 truncated-pyramid tiles in rings around the beam line
- 2×2 cm² tiles (40° – 50°), 4×4 cm² tiles (50° – 70°)
- Forward charged rate < 50 kHz/cm² $\rightarrow$ **< 200 kHz per tile**



TCS with $e^\pm$ in the CD: kinematic reach

TCS with $e^\pm$ detection extended to CD region



- Expansion of $e^\pm$ detection to CD region results in significantly expanded angular acceptance, slightly expanded ξ region (access to larger ξ); similar kinematic access for M_{ee} and $-t$
- Including events in CD region also greatly increases statistical yield (note that current estimates only account for FD detector acceptance)
- Increase in statistics very beneficial to all TCS analysis, angular acceptance extension helpful particularly for forward backward asymmetry studies

- Similar M_{ee} and $-t$ reach; somewhat larger ξ
- $\approx \times 2-3$ more events across the distributions
- Current TCS projections count FD acceptance only

Preliminary study, slide courtesy of M. Kerr (MIT)

Beam time and cost estimate

Beam time request (11 GeV, 5 cm target)

Run	Current	Target	Days
Commissioning	—	LH ₂	15
Calibration	7.5 μ A	empty	10
Calibration	< 1 μ A	LH ₂	20
Production, $P_b > 85\%$	7.5 μ A	LH ₂	200
Total			245

Cost of new components (no labor)

Component	Cost
wECal: 1320 PbWO ₄ + APD + FEB	$\approx$ 4.0 M\$
FVT: 36 GEM modules	0.72 M\$
Recoil μ RWELL tracker	0.27 M\$
Tracker readout (VMM3, 63k ch.)	0.44–0.77 M\$
Scintillator hodoscope	0.07 M\$
Shield, Möller cone, carts	0.28 M\$
Total (+30% contingency advised)	$\approx$ 5.8 M\$

Systematic uncertainties

Source	DDVCS A_{LU}	TCS $A_{\odot U}$	TCS A_{FB}	J/ψ σ
Beam polarization	3 %	3 %	—	—
Background asymmetry	< 6 %	< 6 %	—	—
Radiative effects	< 5 %	< 5 %	5 %	< 5 %
Normalization / acceptance	—	—	< 10 %	< 10 %
Accumulated charge	—	—	—	1.5 %
Total	< 8.5 %	< 8.5 %	< 11.2 %	< 11.3 %

DVCS vs DDVCS cross sections

