CLAS12 @ High luminosity:

A new facility for precision hadron physics

Mariangela Bondì
INFN - Sezione di Catania

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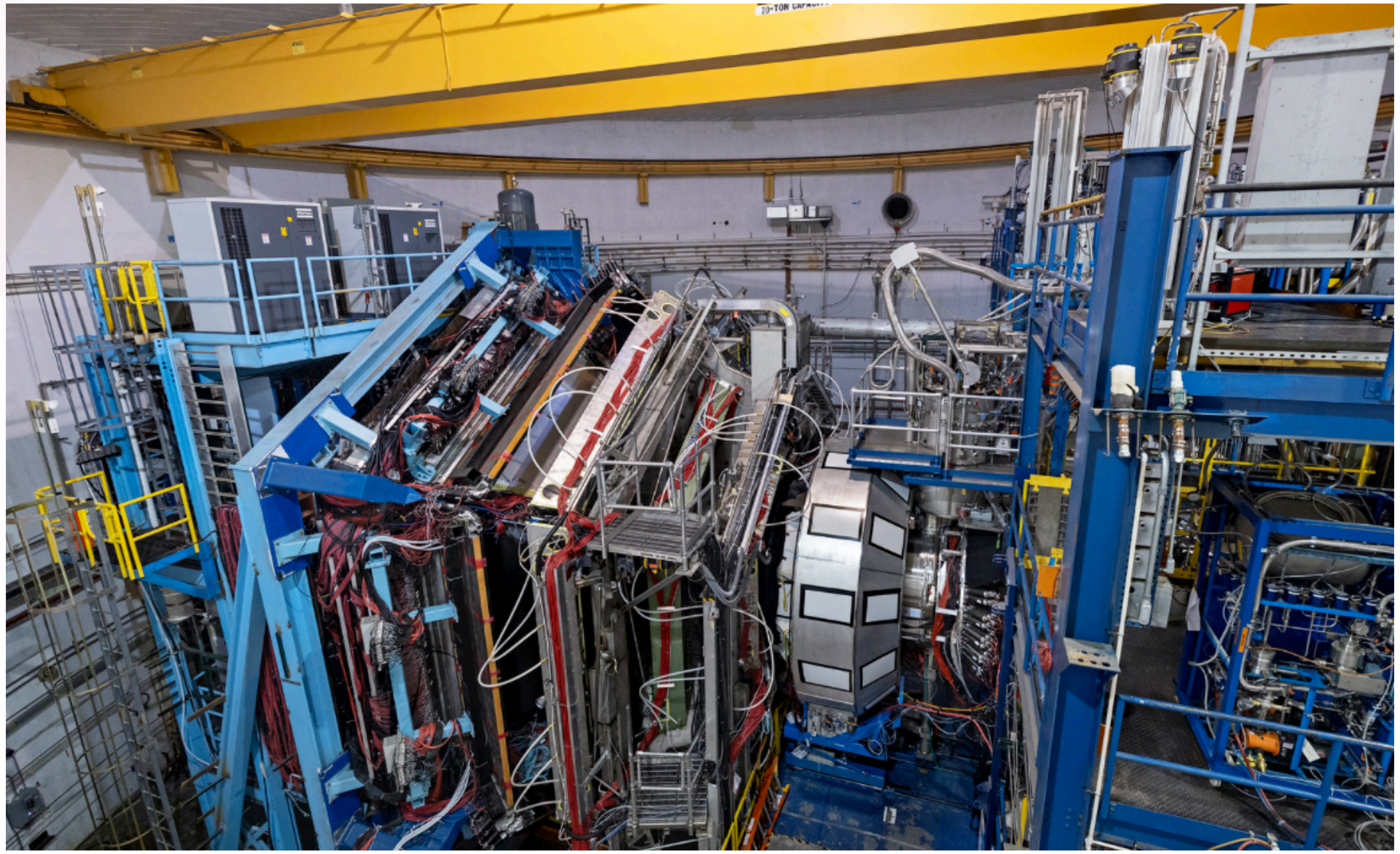
CLAS12 in HALL B: the facility today

CENTRAL
- Beamline
- Target
- Central Vertex Tracker
- Central Time of Flight
- Central Neutron Detector
- Back-Angle Neutron Detector

FORWARD
- High Threshold Cherenkov
- Forward Tagger
- Drift Chambers
- Low Threshold Cherenkov
- Ring Imaging Cherenkov
- Forward Time of Flight
- EM Calorimeter



Design Luminosity:
- **10^{35} cm^{-2}s^{-1}**

Physics targets:
- LH_2, LD_2, LHe, LAr
- D, ^4He
- ^{12}C to ^{208}Pb
- Polarized NH_3, ND_3, ^6LiH, ^7LiD, ^3He-gas

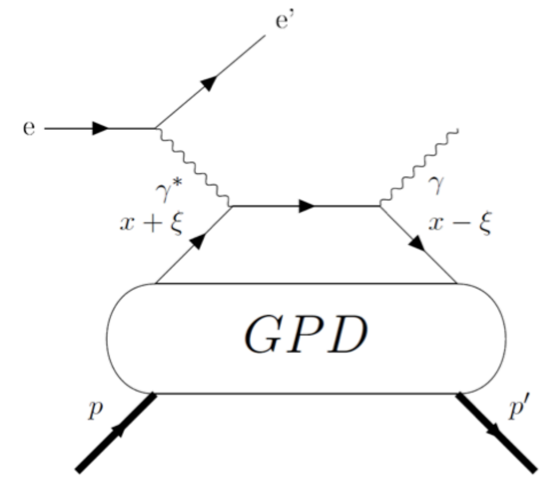
	Forward	Central
Angular coverage	$5^o – 40^o$	$35^o – 135^o$
Momentum resolution	dp/p < 1%	dp/p < 5%
θ resolution	1 mrad	5 – 10 mrad
ϕ resolution	1 mrad/sinθ	5 mrad/sinθ

Scientific program: **3D imaging of quarks in nucleons**, spectroscopy, etc…

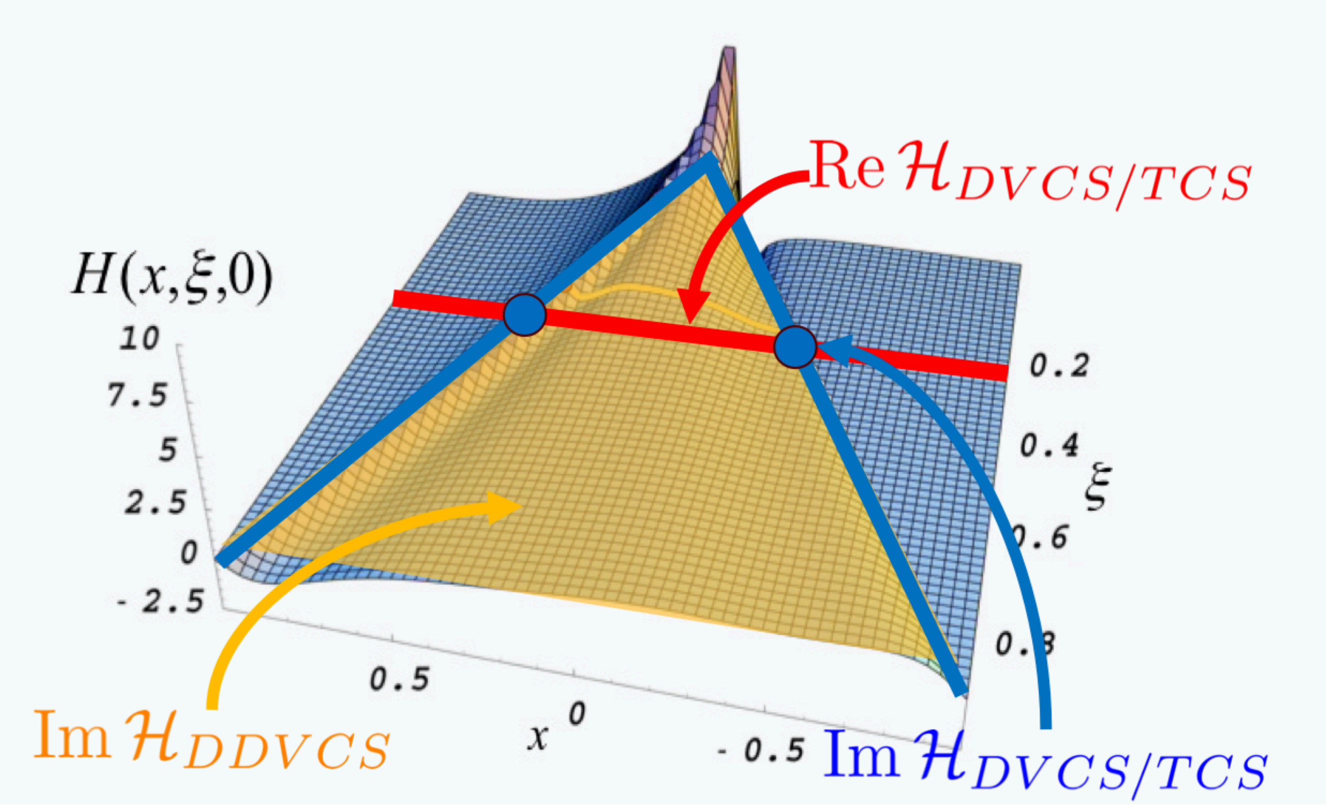
Why DVCS and TCS are not enough

- A large body of DVCS data since the early 2000s — JLab, HERA, COMPASS — plus the first TCS asymmetries, measured by CLAS12. All of it is analyzed in terms of Compton Form Factors

$$ep \to e'\gamma^* p \to e'p'\gamma$$



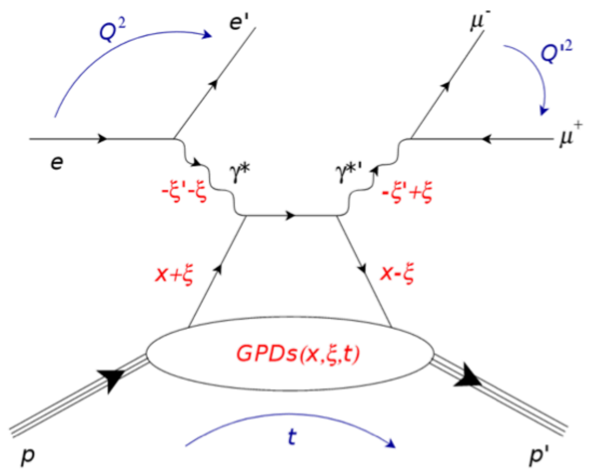
$$\mathcal{H}_{\mathrm{DVCS}}(\xi,t) = \int_{-1}^{1} dx H(x,\xi,t)\left(\frac{1}{\xi - x - i\epsilon} - \frac{1}{\xi + x - i\epsilon}\right)$$



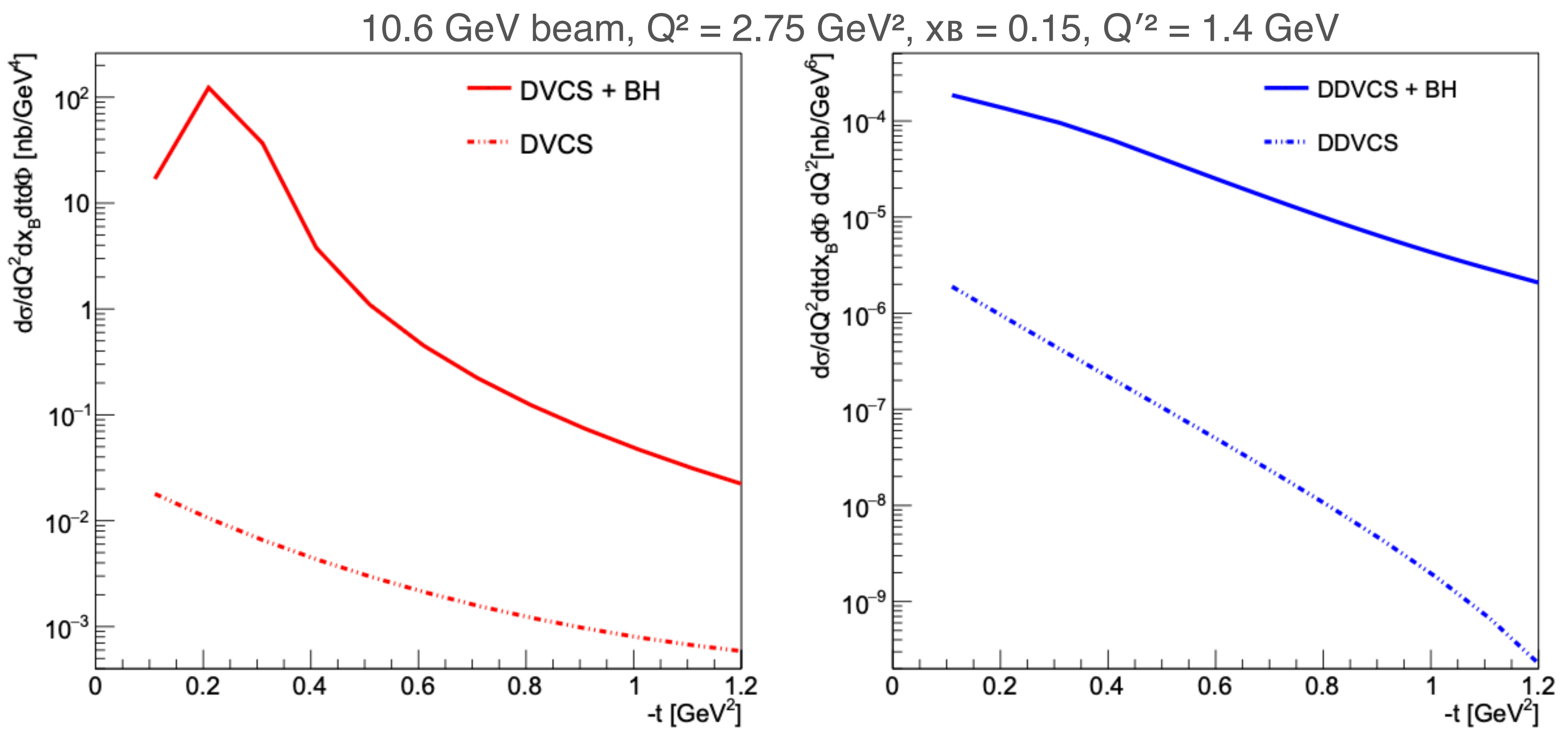
- CFFs are convolutions of GPDs over x: the imaginary part is fixed at x = ±ξ
- Only 2 of the 3 GPD variables are accessible → the inversion has no unique solution
- Different GPD models reproduce the same data, and present uncertainties do not favor any of them
- Shadow GPDs have vanishing CFFs and a vanishing forward limit: invisible to the data, yet part of the solution

DDVCS: the missing lever arm

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



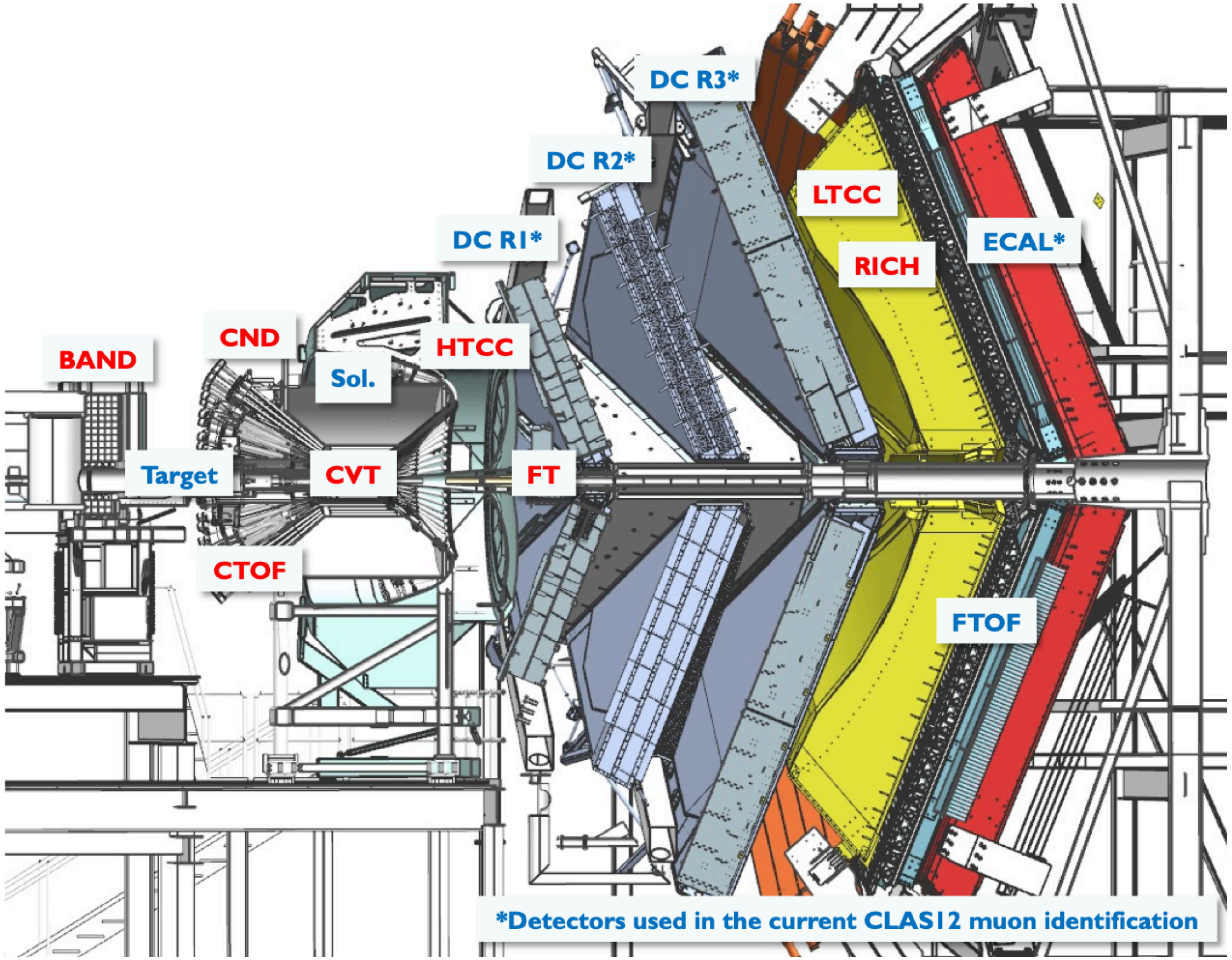
$$\mathcal{H}_{\mathrm{DDVCS}}(\xi',\xi,t) = \int_{-1}^{1} dx H(x,\xi,t) \left(\frac{1}{\xi'-x-i\epsilon} - \frac{1}{\xi'+x-i\epsilon}\right)$$



- ep → e′ μ⁺ μ⁻ p′: Q^2 and Q'^2 vary independently, so the amplitude probes $x = \xi'$, decoupled from ξ → GPDs off the diagonal, in $-\xi < x < \xi$
- A_LU can be measured in both the spacelike ($Q^2 > Q'^2$) and timelike ($Q^2 < Q'^2$) regions: a **sign change** is expected in the transition.
- Ambiguities and anti-symmetrization issues with the decay leptons of the outgoing virtual photon and the incoming-scattered lepton: **muon detection is essential**
- σ(DDVCS) is 3–4 orders of magnitude below σ(DVCS)
- It takes $L \geq 10^{37}$ cm^{-2}s^{-1} with large acceptance and clean muon detection

The μCLAS12 setup

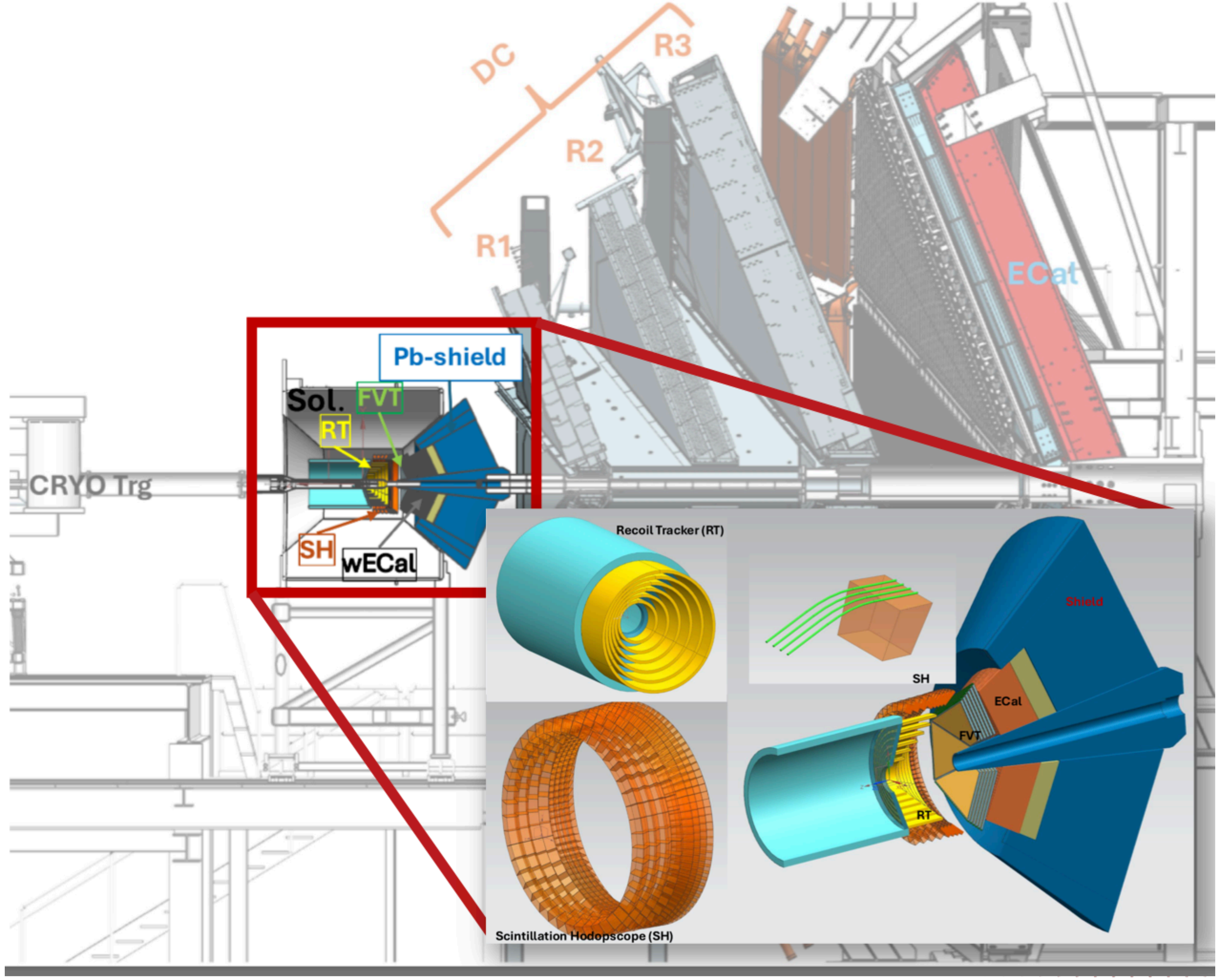
- The μCLAS12 setup will mostly use existing CLAS12 detectors.
- The CLAS12 FD detector will be effectively used as a muon detector
- The CTOF, CND, CVT, HTCC, FT, LTCC, RICH and BAND will be removed
- Increase luminosity by a factor 100: 10^{37} cm^{-2}s^{-1}



Eur. Phys. J. A (2026) 62:157 https://doi.org/10.1140/epja/s10050-026-01909-1

The μCLAS12 setup: new detectors

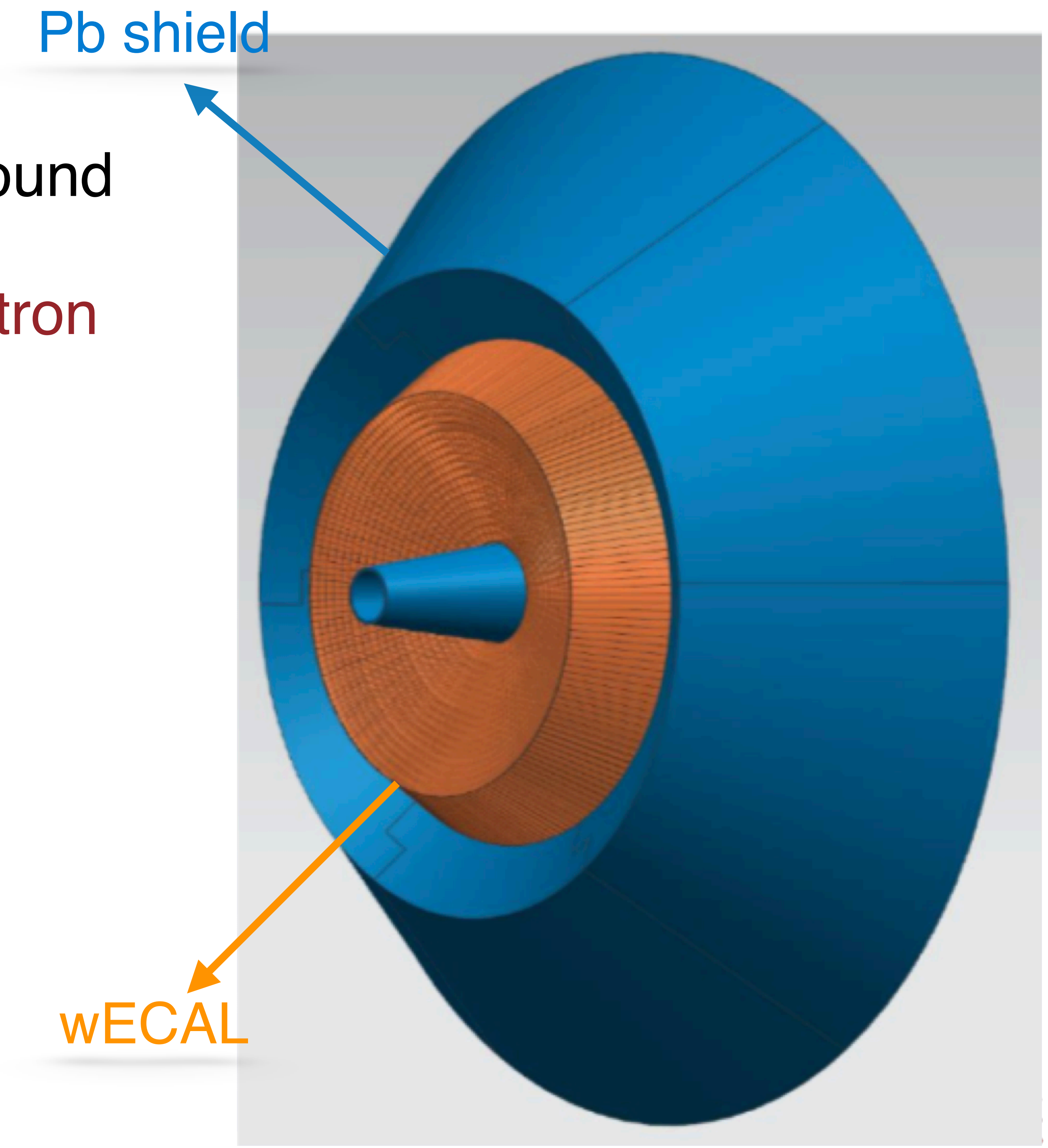
- A lead shield to reduce pion background in the FD.
- A PbWO4 calorimeter will identify scattered electron
- A MPGD Forward Vertex tracker will be used for vertexing.
- A MPGD recoil tracker surrounds the target to detect recoil proton



The µCLAS12 setup: wECAL calorimeter + Pb shield

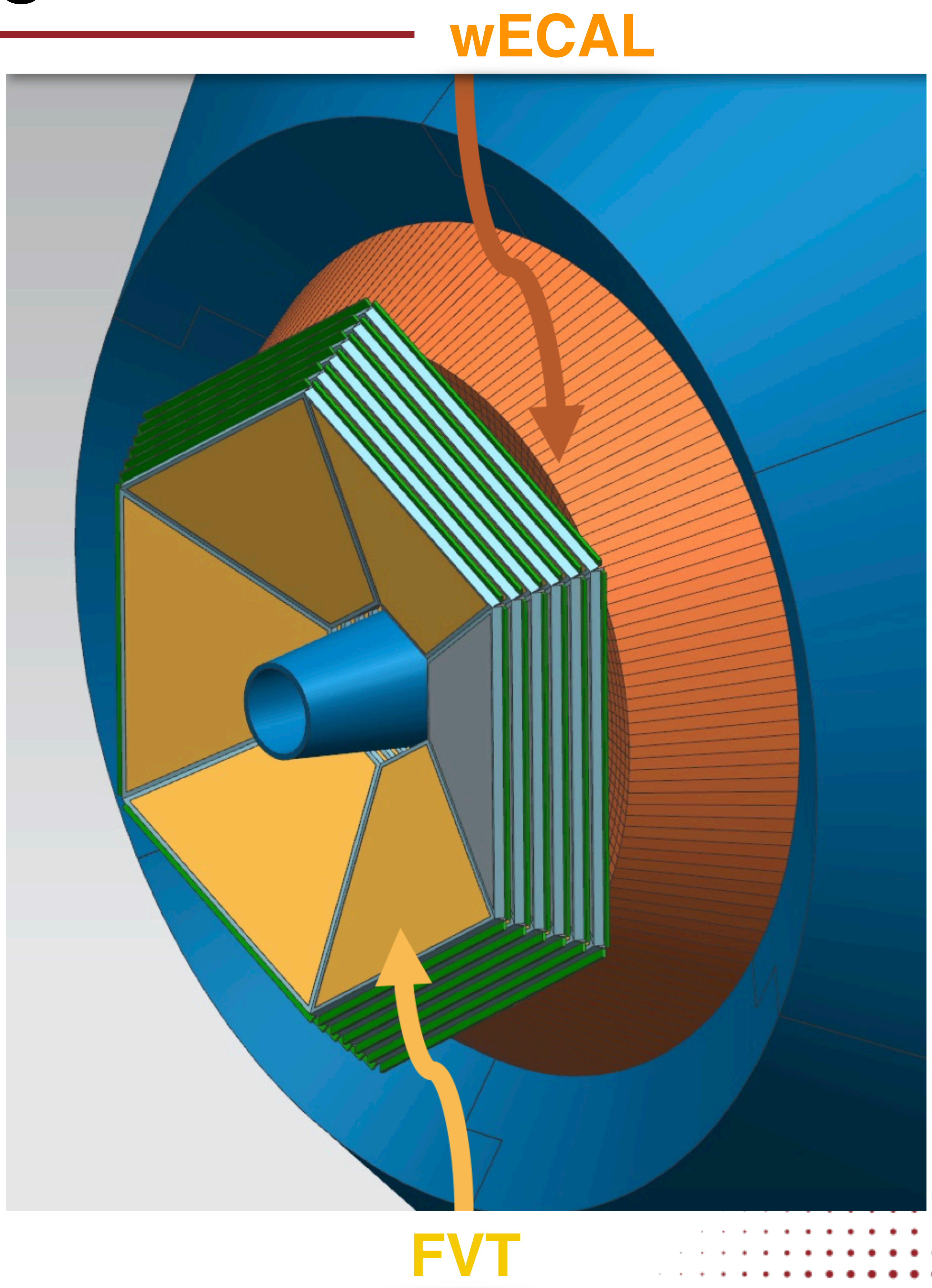
- A 60cm-thick lead shield to reduce pion background in the FD
- A PbWO4 calorimeter will identify scattered electron

- **Geometry**:
  - ~1320 PbWO4 crystals, 20 cm length
- **Angular coverage**:
  - Pb shield + calorimeter: **7° – 35°**, full azimuth
  - PbWO4 ring: **7° – 30°**
- **Rate capability:**
  - Expected rate: ~ 2MHz at the first ring



The µCLAS12 setup: Forward Vertex Tracking

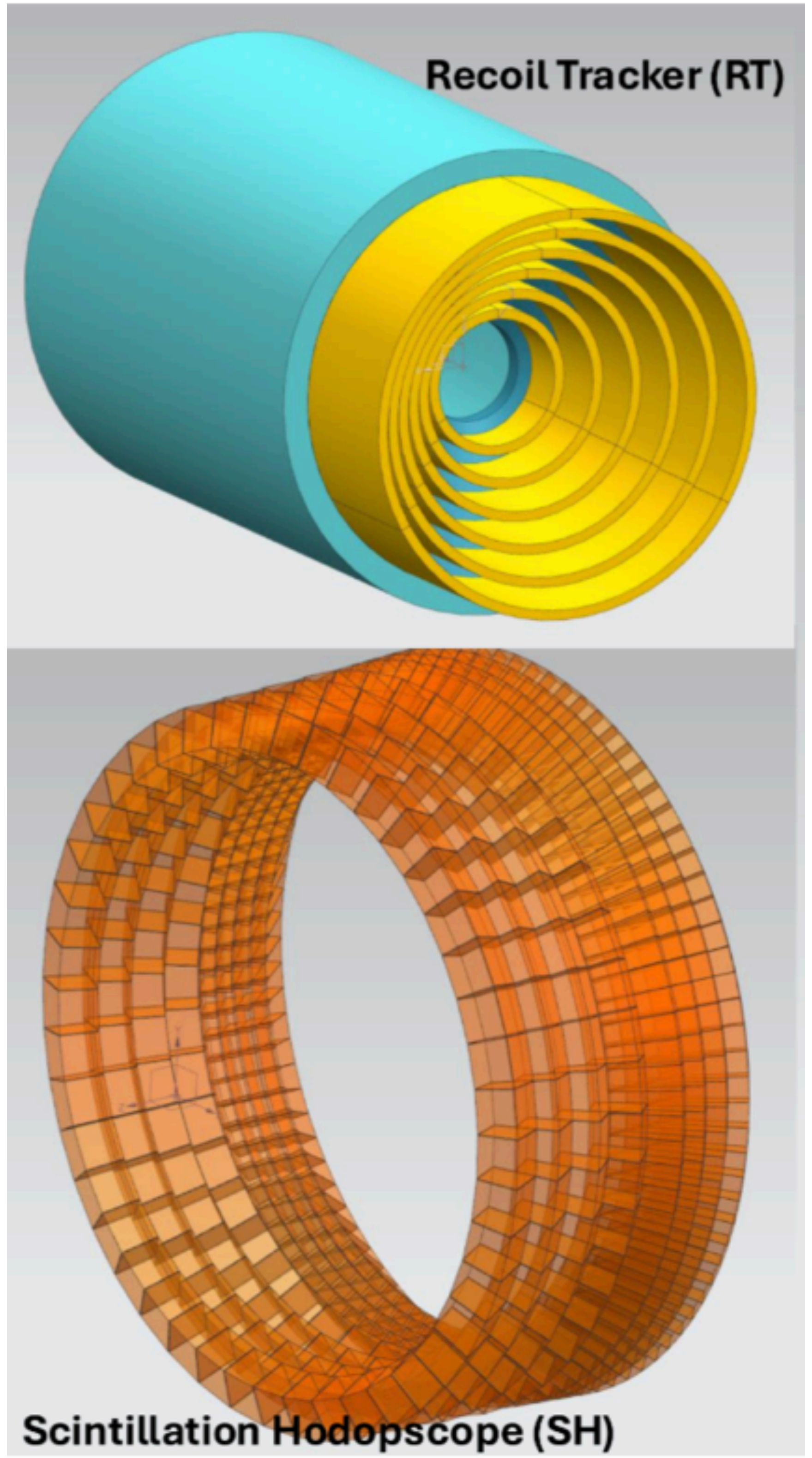
- A MPGD Forward Vertex tracker will be used for vertexing.
- **Geometry**:
  - 6-station 3GEM tracker
  - Each station:
    - 6 trapezoidal modules
    - Angular coverage: **7° – 30°, full azimuth**
    - First station located at 40 cm from target
  - 2D COMPASS-style stereo strip readout (U–V): parallel to the trapezoid sides
    - Readout: VMM3/SALSA chip (ok for SRO DAQ)
  - ~ Total FVT channels: 43,200 strips



- **Rate capability:**
  - Maximum rate is 1MHz/cm2 at the very forward region

The µCLAS12 setup: Recoil Tracker

- A MPGD recoil tracker surrounds the target to detect recoil proton
- Recoil tracker:
  - 6 cylindrical layers
  - Polar angle coverage: 40° - 70°
  - First layer at 8 cm from the target
  - 2D Z-C strip readout (N of channels < 22k)
  - Baseline technology: µRWELL (maybe Micromegas)
- Scintillation Hodoscope:
  - 540 scintillator modules arranged in concentric rings
  - Light collection via WLS fibers -> SiPMs or MAPMTs
  - Provides: ToF and Energy Loss
- **Rate capability:**
  - Expected rate for recoil tracker: < 250 kHz/cm^2
  - Expected rate for Hodoscope: ~100 kHz/cm2

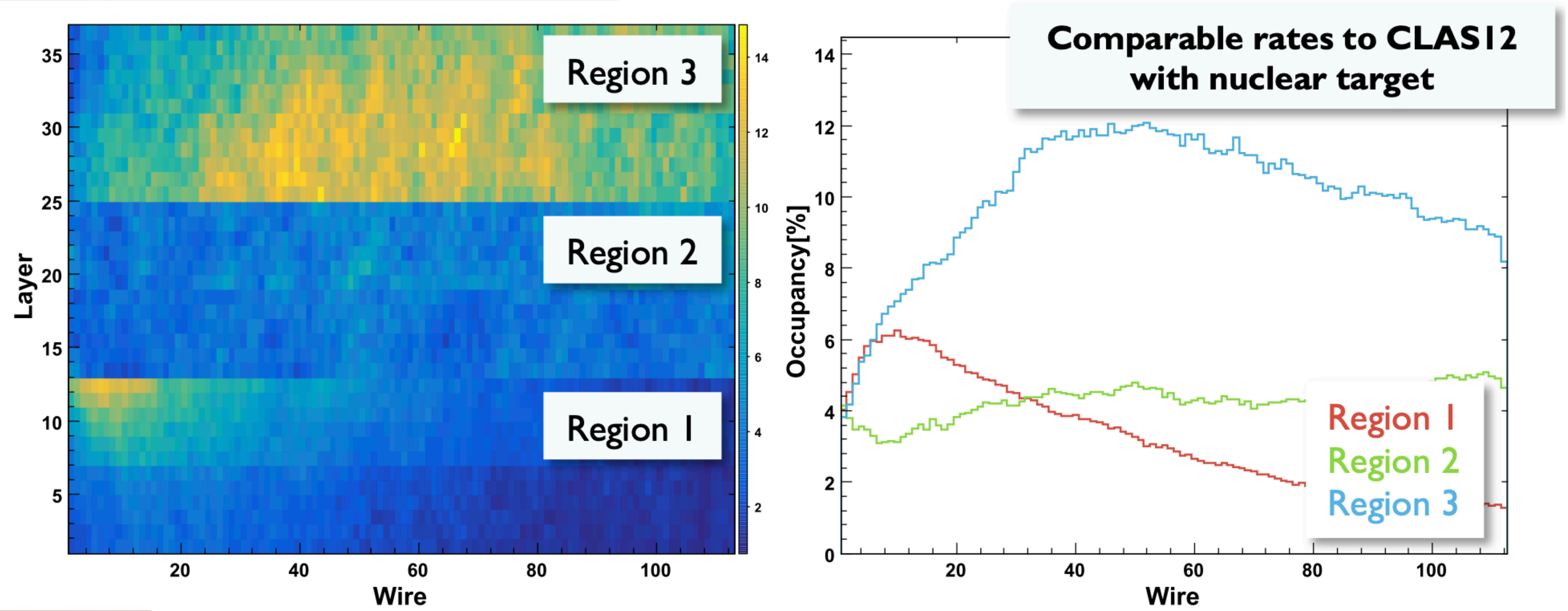


Trigger rate and Background

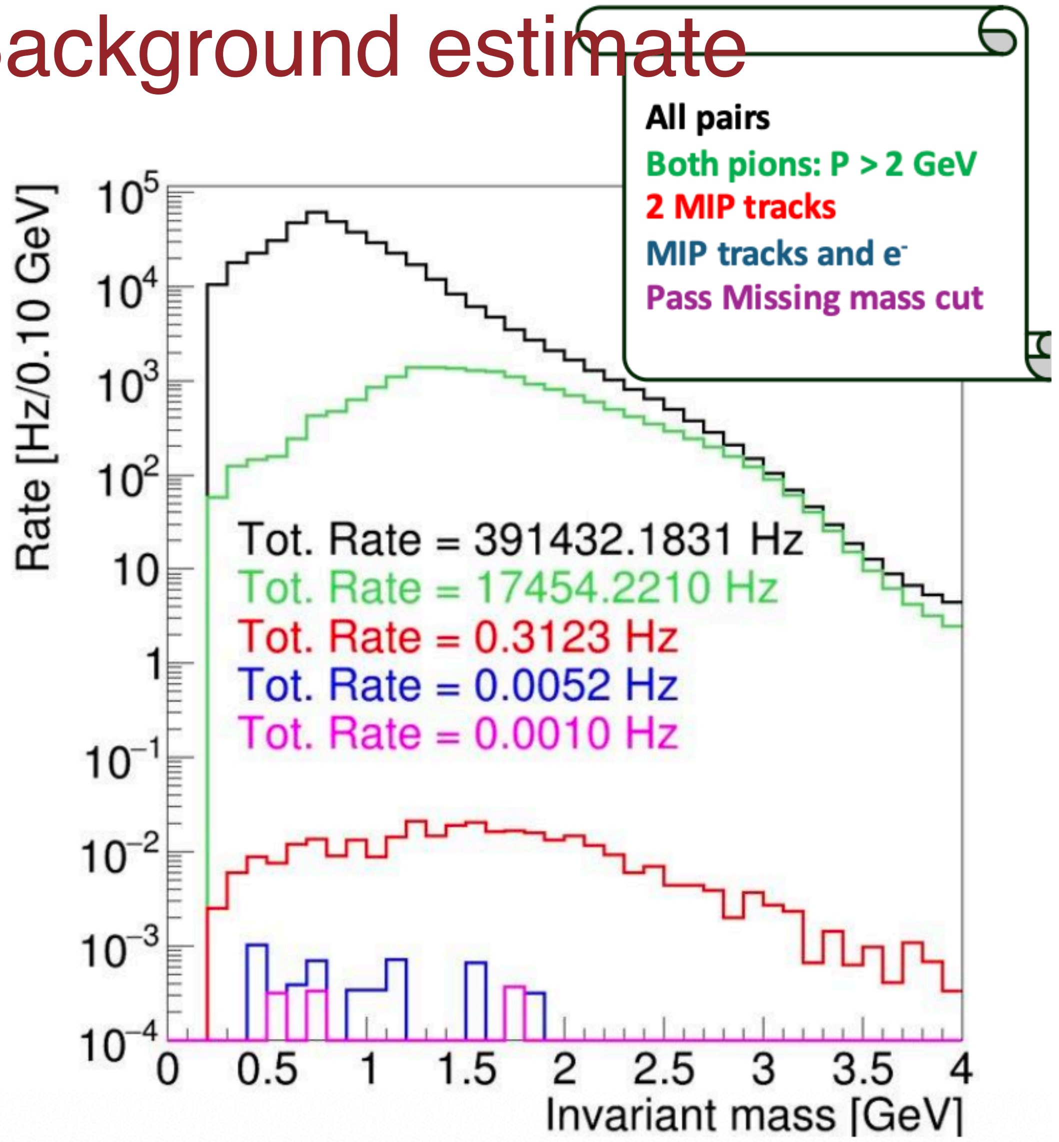
Trigger rate

- **Single MIP Trigger rate: 21kHz**
- Maximum CLAS12DAQ rate: 30kHz with 90% live time
- All proposed physics channels included in the trigger and measured at the same time

DC Chambers Occupancies



Background estimate



- Pions background: 1% contamination to the $e\mu_+\mu_-$ final state in the $M_{\mu+\mu-}$> 1.2 GeV region
- Quasi-elastic muon pair production: ep->eμμ(X): ~5.5%
- Accidentals with inclusive electron: ~4.6%

One data set, four measurements

Double Deeply Virtual Compton Scattering

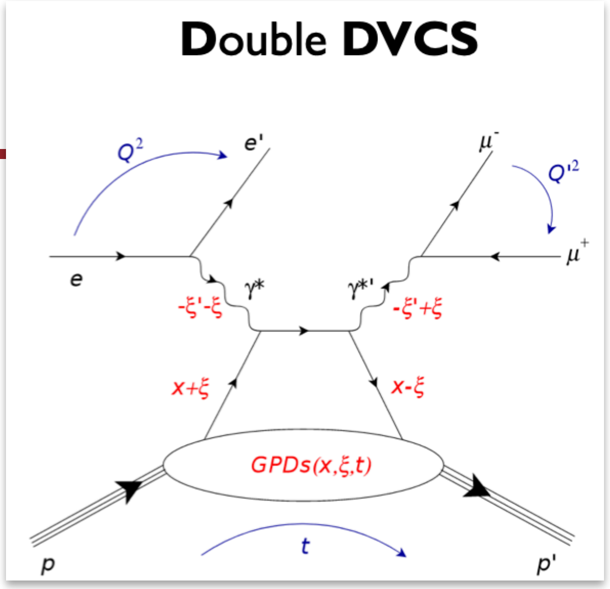
- Mapping of GPDs in (x, ξ, t)
- Ambiguities and anti-symmetrization issues with the decay leptons of the outgoing virtual photon and the incoming-scattered lepton: Muon detection is essential
- Small cross section → high-luminosity experiment

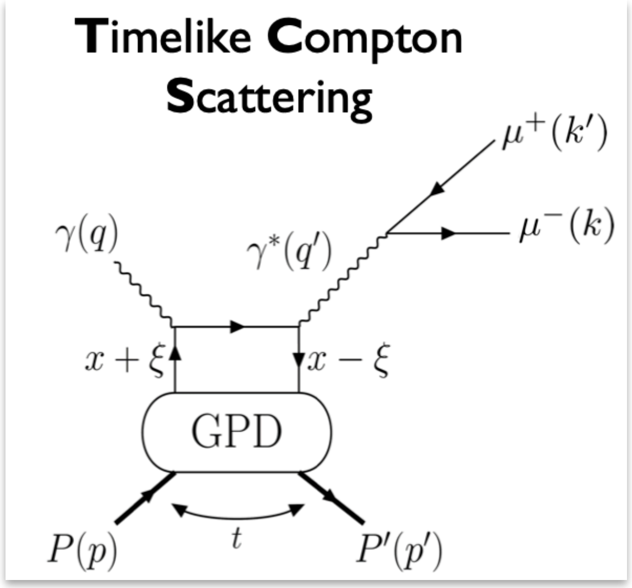
Timelike Compton Scattering

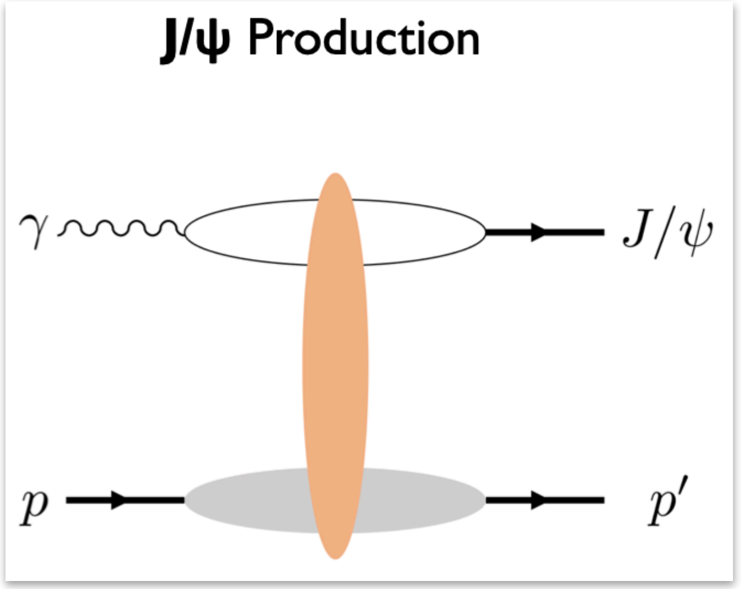
- Access to real and imaginary parts of CFFs
- $\mu^+\mu^-$ final state measurement
- Recoil proton detection ensures exclusivity

Near-threshold J/Ψ production

- Probe of gluonic dynamics in the nucleon
- High-statistics measurement
- Improved precision with respect to GlueX and Hall-C
- Sensitivity to the **hidden-charm pentaquark** region observed by LHCb

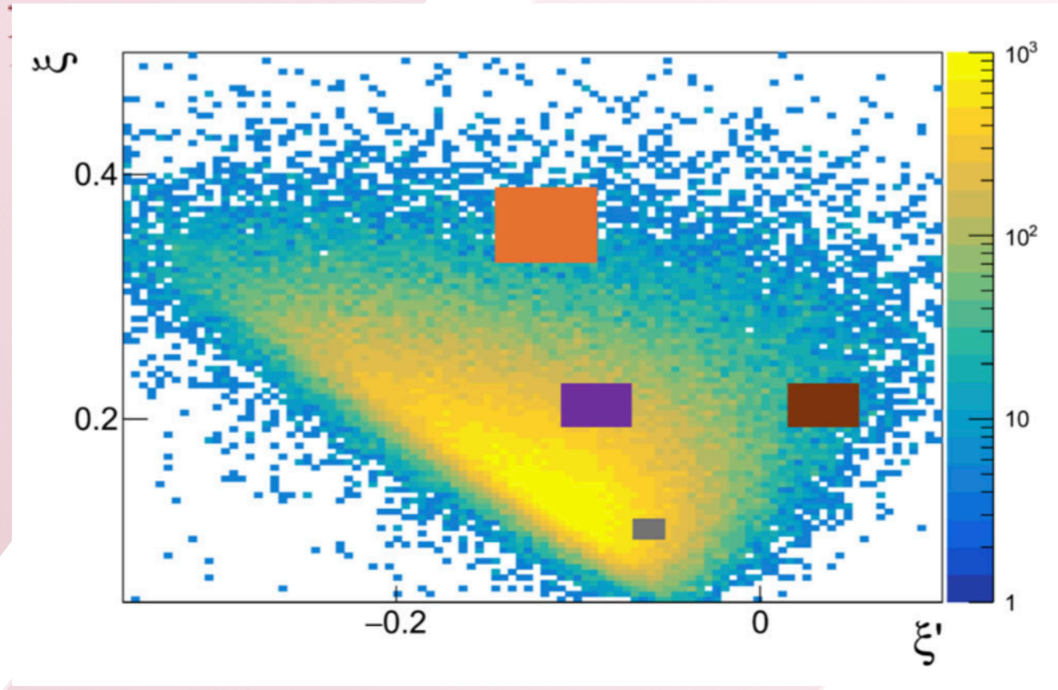




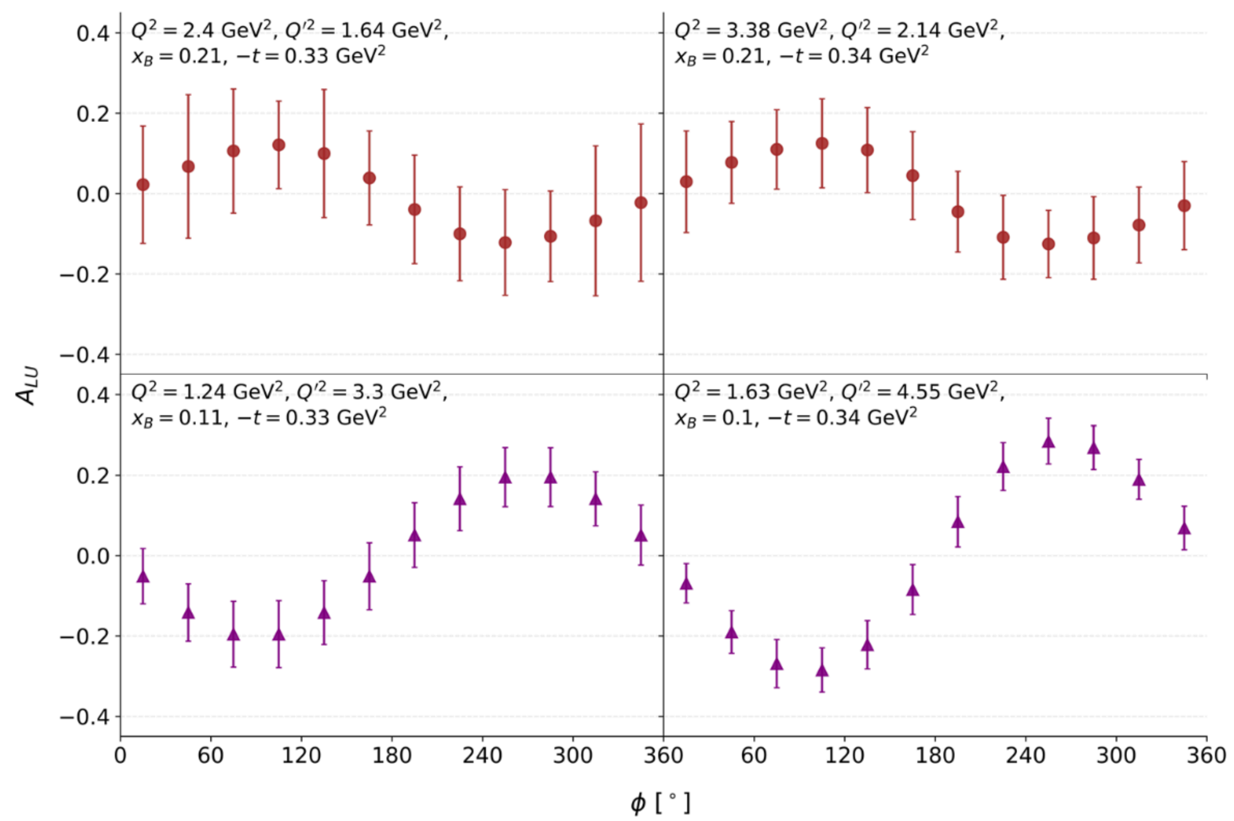


7.4 uA 11GeV e- beam on 5cm LH2 target

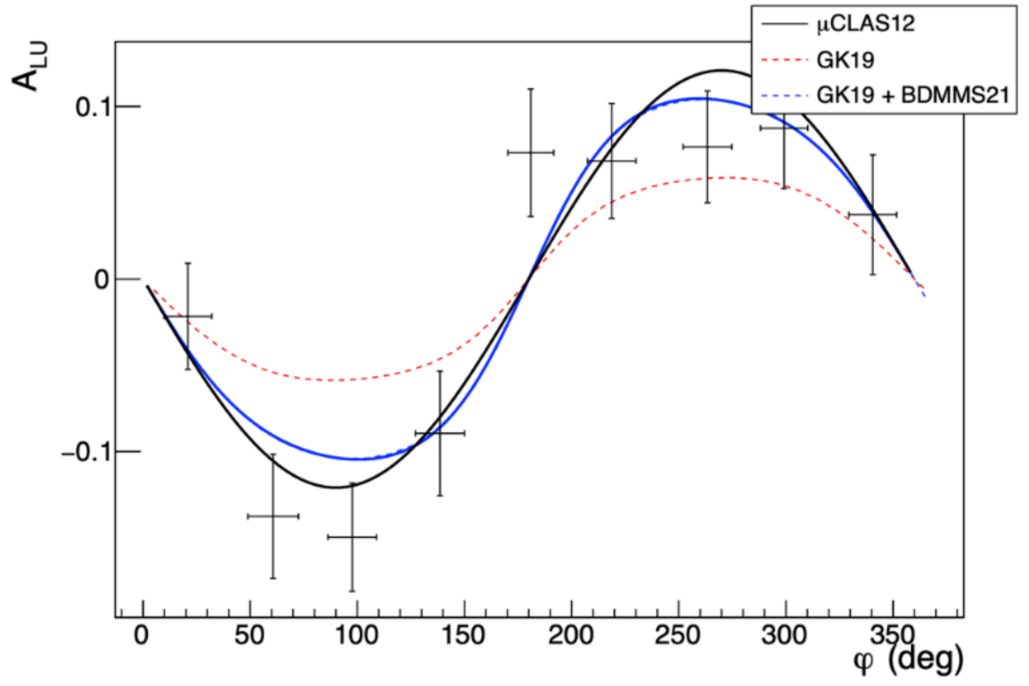
Expected results: DDVCS



ξ vs ξ′ coverage; boxes = illustrative bins



A_LU vs ϕ: spacelike (top) and timelike (bottom)



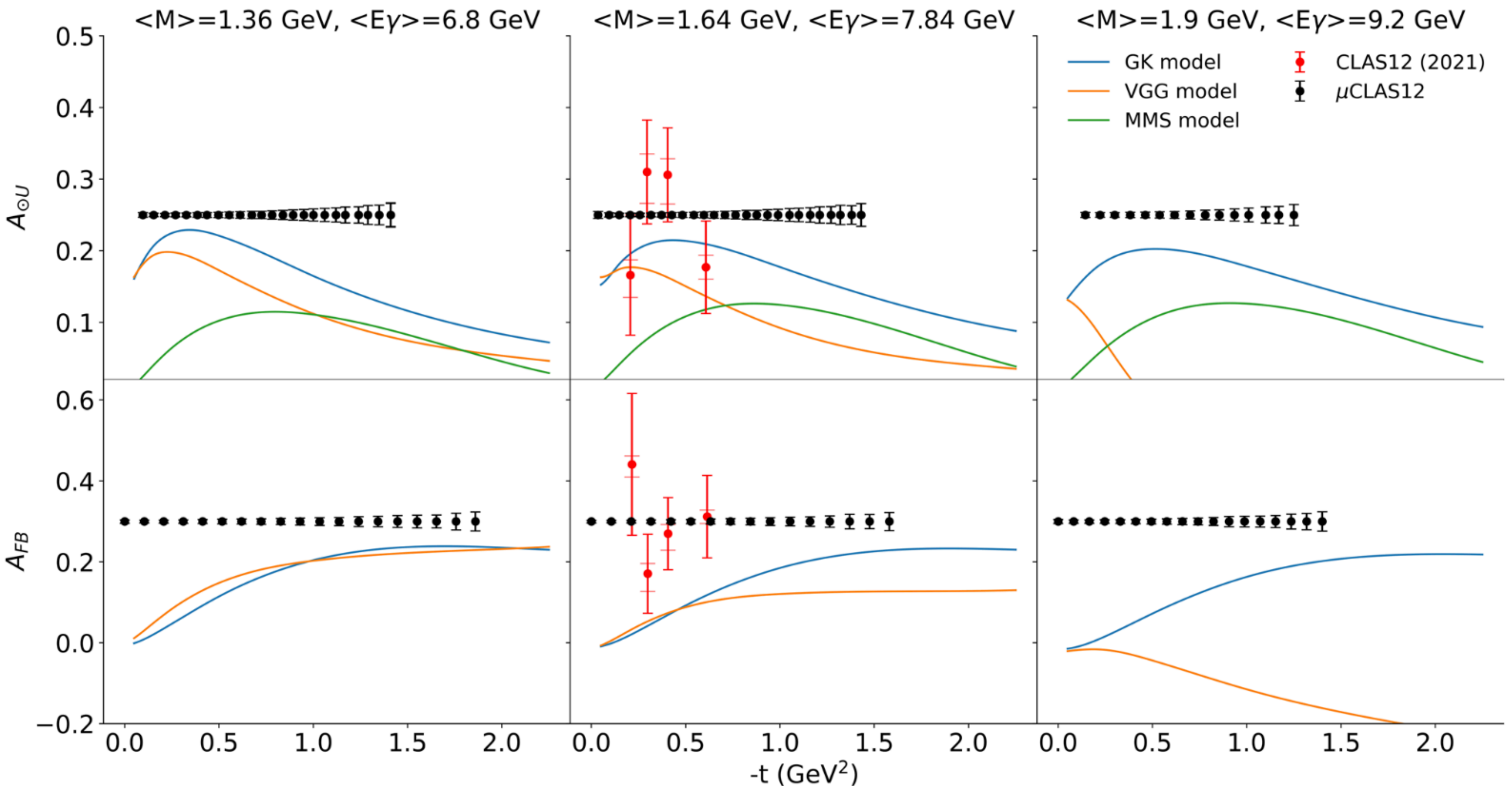
GK19 vs GK19 + shadow GPD

- More than 5 × 10^5 DDVCS events (Mµµ > 1.2 GeV) in 200 days – beam-spin asymmetries in both the spacelike and the timelike region
- The predicted sign change of the asymmetry is clearly resolved; its sinϕ moment is extracted with ~13.6% accuracy in a representative (ξ, ξ′) bin
- Sensitivity to shadow GPDs: GK19 and GK19 + SGPD are separated by the projected data; a direct handle on the deconvolution ambiguity

Expected results: TCS

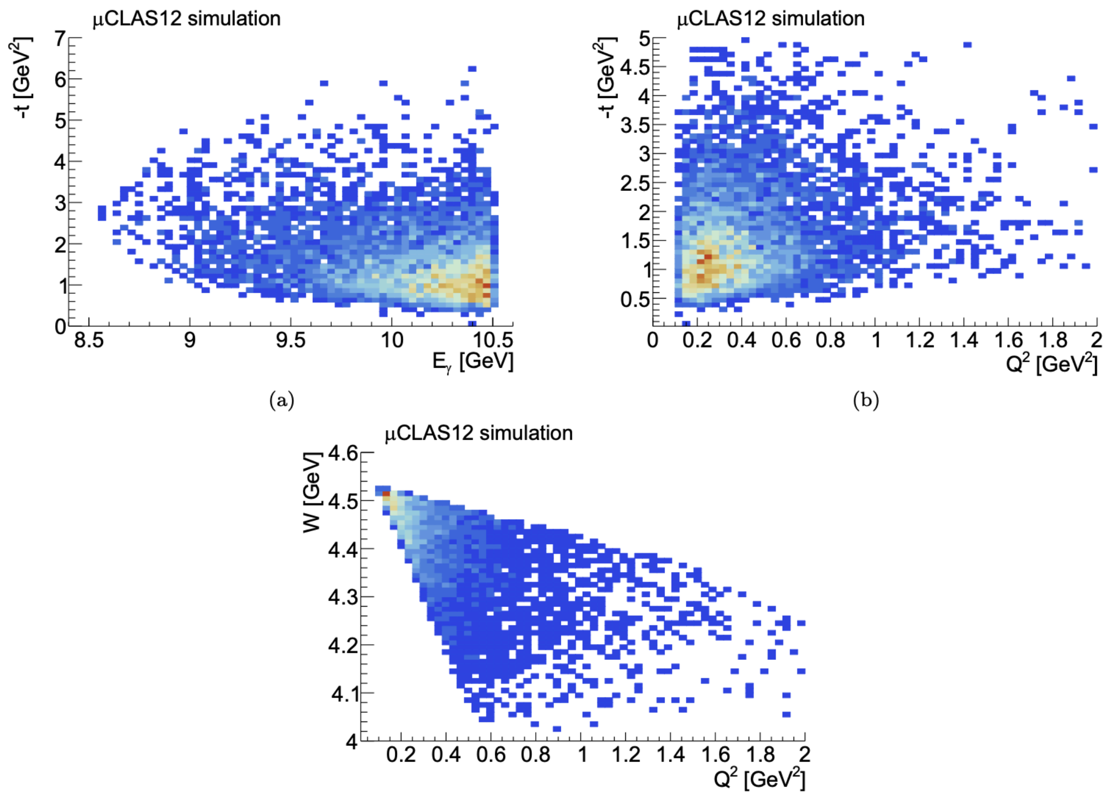
- Quasi-real photoproduction regime, proton tagged in the recoil tracker, muon pair in the FD
- 7.7×10^6 events in 200 days – three orders of magnitude above the first CLAS12 TCS measurement
- Mμμ up to 2.3 GeV with wide t coverage, especially below 0.4 GeV² where the GPD extraction is most sensitive
- The forward–backward asymmetry gives direct access to the real part of the CFF → $\mathcal{H}$ the D-term and the mechanical properties of the proton
- Same angular bins as the published analysis: a direct cross-check and a much wider t range

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

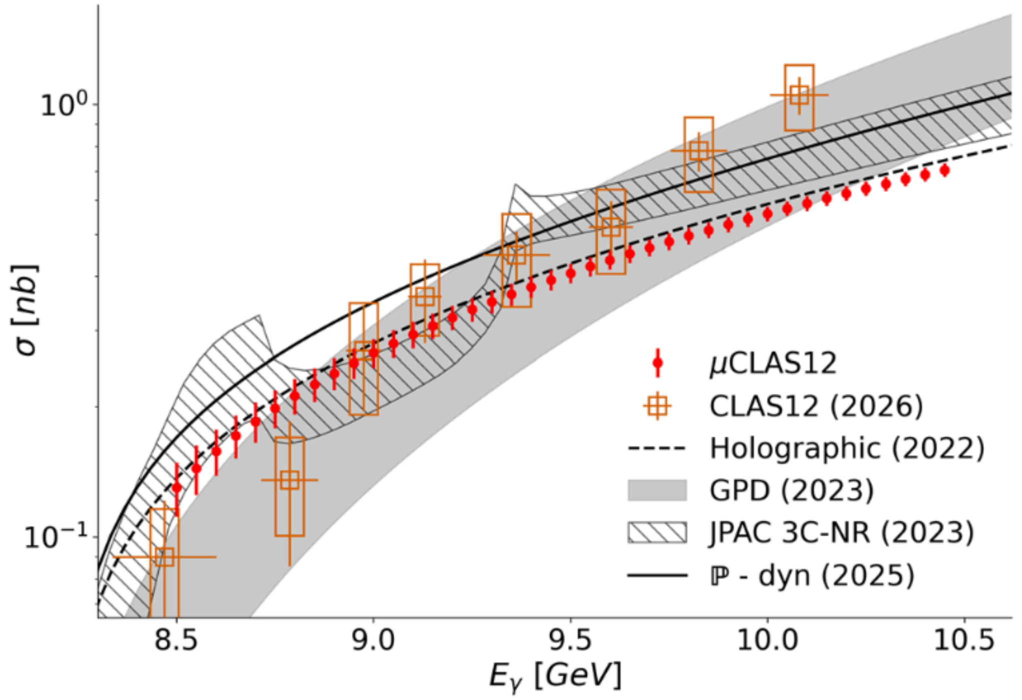


Projected photon-polarisation asymmetry A_OU (top) and forward–backward asymmetry A_FB (bottom) vs –t in three Mμμ bins; red points = published CLAS12

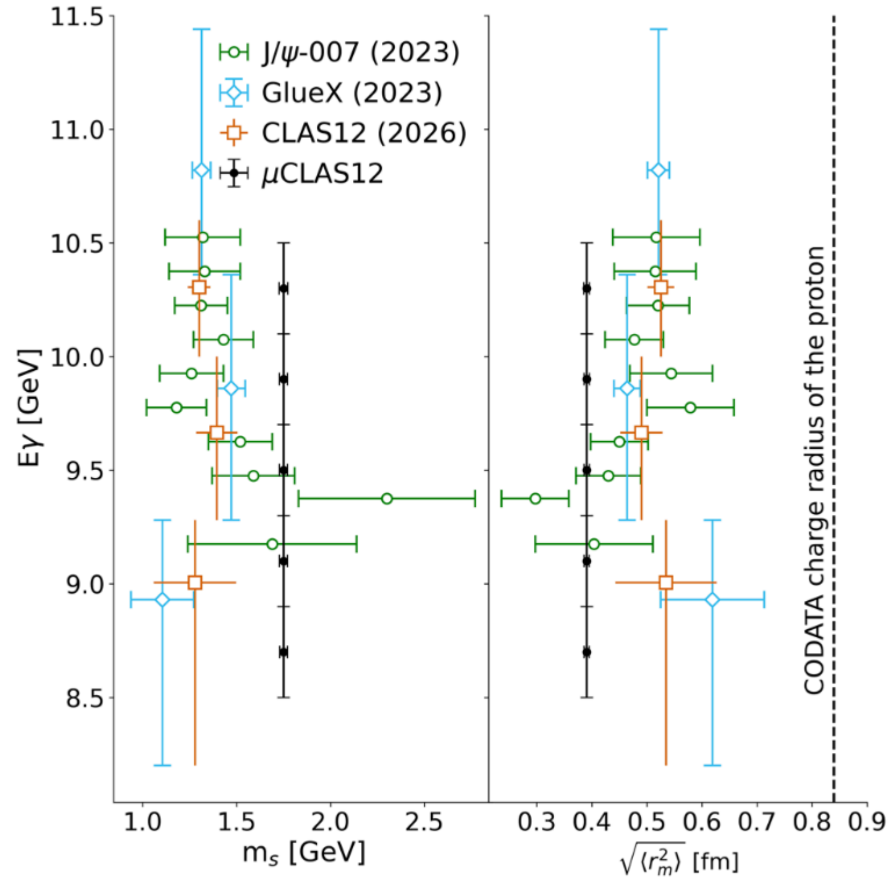
Expected results: near-threshold J/ψ and gluon GFFs



Kinematic reach in Eγ, Q² and W



σ(Eγ): μCLAS12 projections vs models

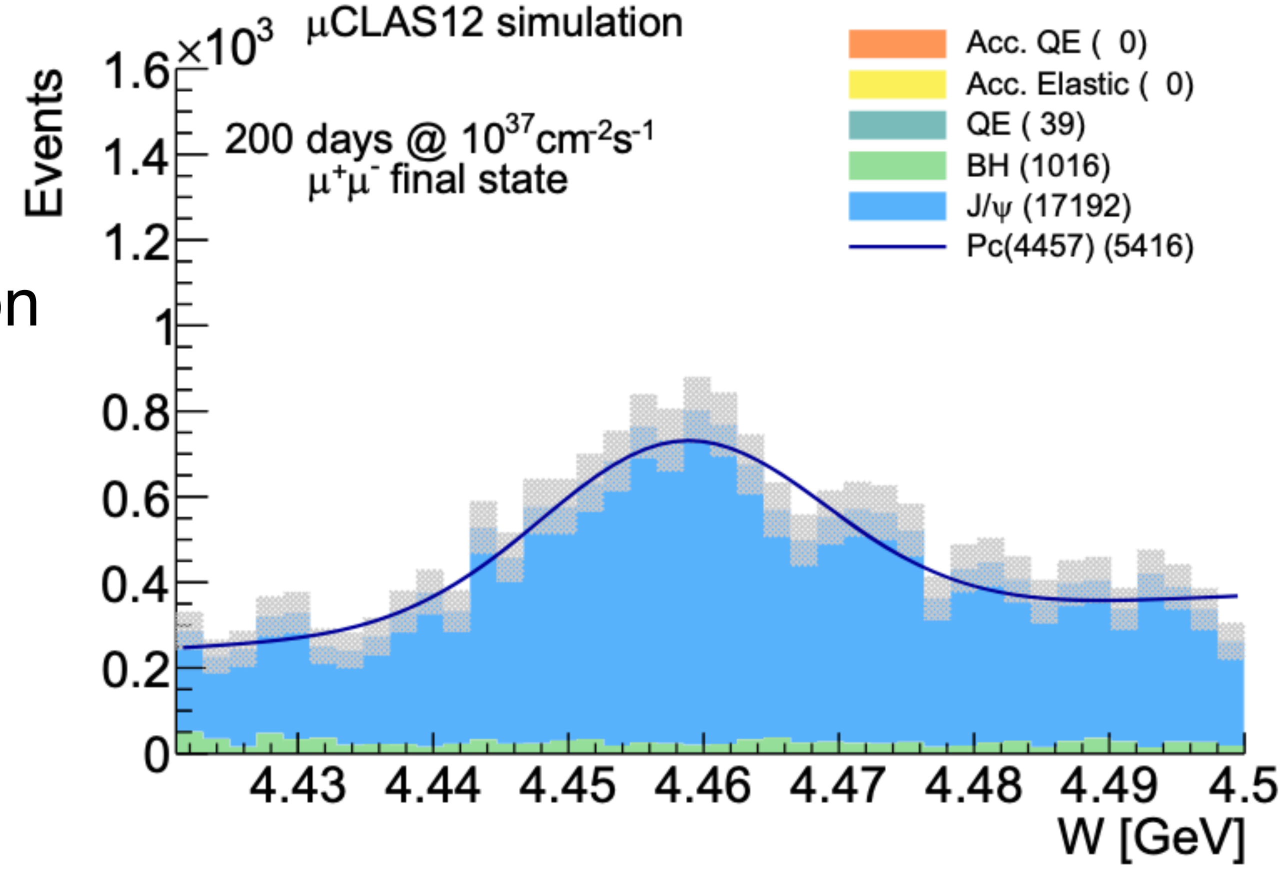


Dipole mass m_S and gluon mass radius

- 3×10^4 J/ψ → μ+ μ- expected (≥ 2.7×10^4 with 90% muon-ID efficiency): ~40× the CLAS12 sample and ~3× the GlueX-III projection
- Coverage: Eγ up to 10.5 GeV, photon virtuality up to ~1 GeV², –t from 0.5 to 4 GeV² – including the open-charm region 8.7–9.4 GeV
- The t-dependence of the cross section constrains the gluon gravitational form factors, the gluon mass and scalar radii of the proton, and the gluon pressure profile

Expected results: hidden-charm pentaquark search

- LHCb observed three hidden-charm pentaquarks in J/ψ p: Pc(4312), Pc(4440), Pc(4457)
- In photoproduction they would appear as s-channel resonances around Eγ~10 GeV – not observed so far
- μCLAS12 reaches W up to 4.5 GeV with the statistics and the electron resolution needed to resolve the peak
  - ≈ 4500 Pc(4457) produced with a 2% branching ratio (GlueX limit)
  - ≈ 1000 detected using the J/ψ-007 cross-section estimate (CLAS12 unpublished data)
- Large statistics is imperative: the states are narrow and sit on a large J/ψ continuum
- Either a direct measurement of the pentaquark photoproduction cross section, or the most stringent upper limit to date



W spectrum in the Pc(4457) region, 200 days @ 10^{37}, 2% branching ratio

Conclusions

- µCLAS12 shields the Forward Detector and turns it into a muon spectrometer: 10^{37} cm^{-2} s^{-1} , two orders of magnitude above design, fully simulated and validated against CLAS12 data

- One 200-day run delivers four measurements from the same muon pairs:
  - **the first-ever DDVCS** – GPDs off the diagonal, and a direct handle on the shadow-GPD ambiguity
  - **TCS asymmetries** with 10^6–10^7 events – the real part of , the D-term, the mechanical properties of the proton
  - **Near-threshold J/ψ** with ~40× the present statistics – the gluon gravitational form factors and the gluon radii
  - A decisive search for the **hidden-charm pentaquarks** in photoproduction – measurement or the most stringent limit to date

- Workshop on the Physics Program with High Luminosity Facilities Jefferson Lab, CEBAF Center • 5–9 October 2026 — you are all very welcome https://indico.jlab.org/event/1089/