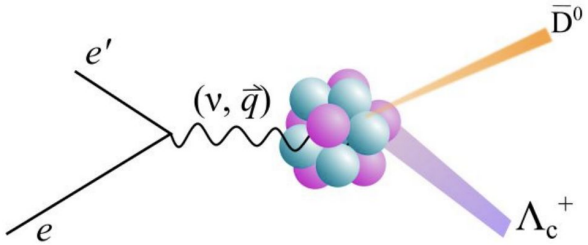
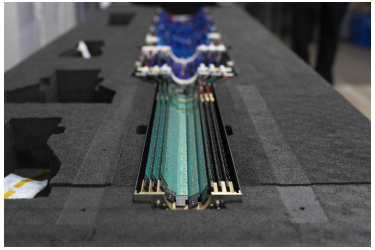
Update on Open Charm Proposal

PR12-26-004



Dr. Sebouh Paul
Old Dominion University
11/19/2026

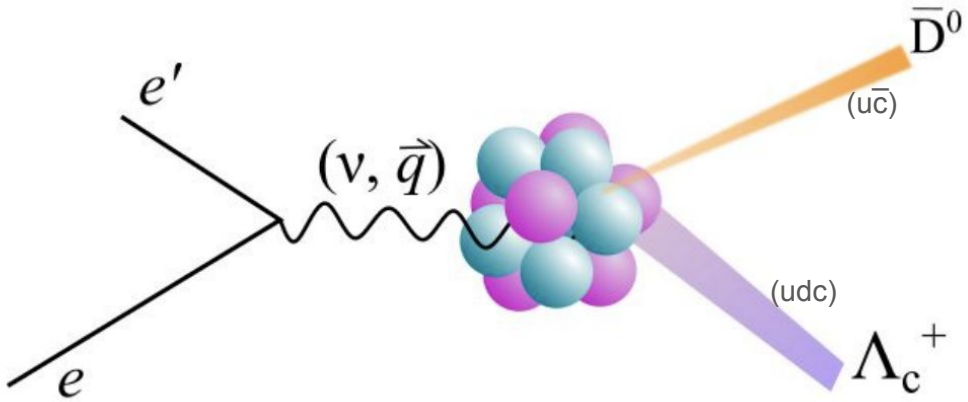
On behalf of the spokespersons
Meng-Lin Du (UESTC), Raphaël Dupre (SACLAY), Yuri Gotra (JLab),
Ming Liu (LANL), Bryan McKinnon (U. Glasgow), Igor Strakovsky (GWU)



Summary of PR12-26-004

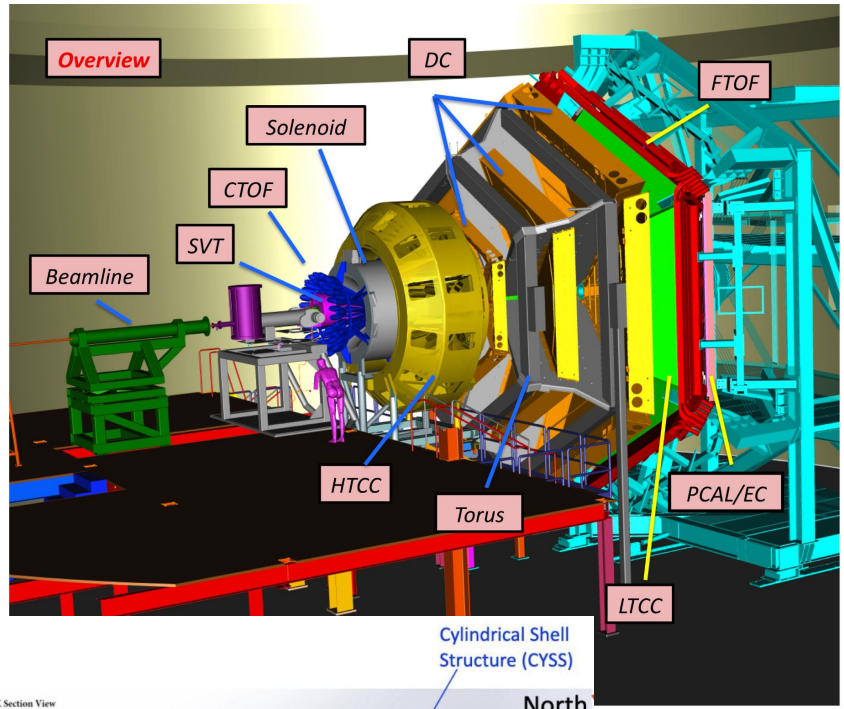
- Open-charm production is when c and $\bar{c}$ are produced and end up in different hadrons in the final state.
- The lightest open-charm final state available is $\bar{D}^0\Lambda_c^+$
  - v=8.7 GeV
- Could take place in free or bound proton
- No measurements of open-charm production (or heavy flavor in general) exist near threshold
- **Goal: Make first open-charm production measurement near threshold.**

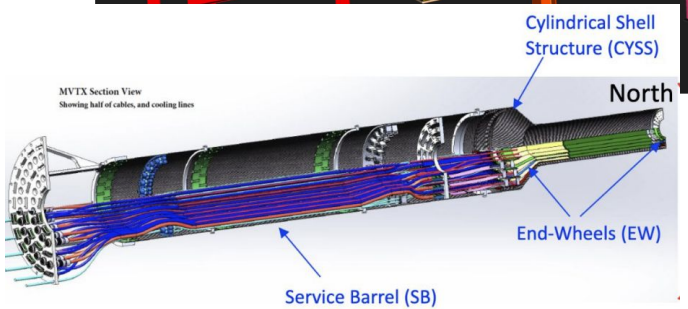
Open charm



Proposed measurement with CLAS12 detector + MVTX

- Our detection strategy:
  - $\bar{D}^0 \rightarrow K^+\pi^-$ decay channel
  - Hadron pair with vertex displaced from a thin target foil, with pair mass consistent with $\bar{D}^0$
    - Borrow MVTX from sPHENIX to get the necessary displaced vertex resolution
  - Inclusive ep → e' $\bar{D}^0$ X measurement, with e' in FT
  - No missing-mass cut





Feedback from the PAC (July 2026). Status: deferred.

The proposal is very appealing; however, several aspects require further attention:

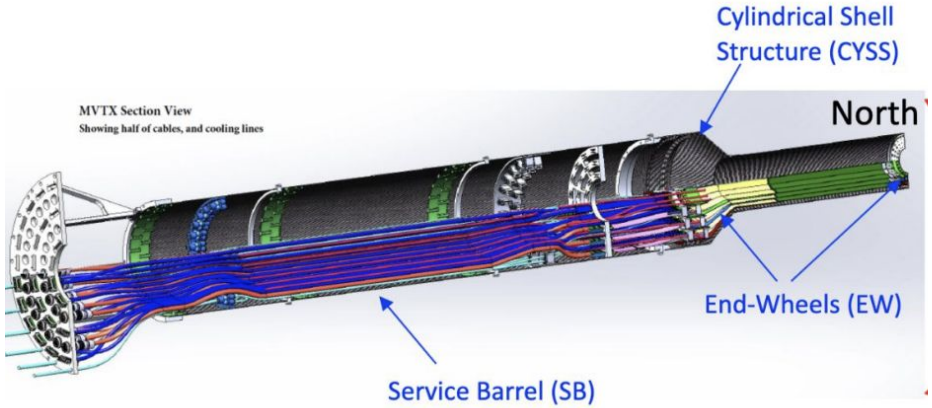
1. The cross section is measured on bound protons in C and W target but extrapolation to the free-proton target requires a more careful analysis of nuclear matter effects which will impact the theoretical interpretation of the measurement. These effects are only marginally described in the proposal. A clearer plan for handling these corrections and the associated systematics is needed.
2. The conceptual design of the target chamber should be in compliance with the JLab target group.
3. The simulation used for the study does not include yet a fully CAD-based model of the MVTX with its support structure in the simulation framework. This should be included in a future proposal to refine the vertex resolution and background studies. For the latter, the 5 us readout window of the MVTX should be precisely included in the simulation
4. The proponents should demonstrate that the streaming readout and offline trigger of the MVTX, combined with CLAS12 detectors, is feasible.

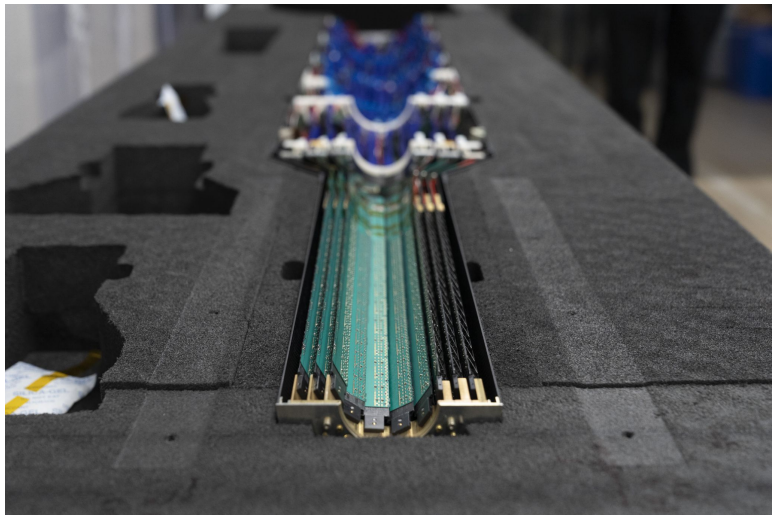
Updates since PR12-26-004 (PAC 54, July 2026)

- Increased total luminosity from 3×10^{34} to 1.0×10^{35} $cm^{-2}s^{-1}$ (as justified by new studies)
  - Corresponds to 140 nA, which is a total of 4.2×10^{8} nb^{-1} for each target type
- Developed algorithm for background reduction in streaming mode
- Reproduced the vertex resolution and background studies using full MVTX geometry
- Added more details on a free-proton cross-section extraction method
- On-going: updates to the target-chamber design

DAQ feasibility

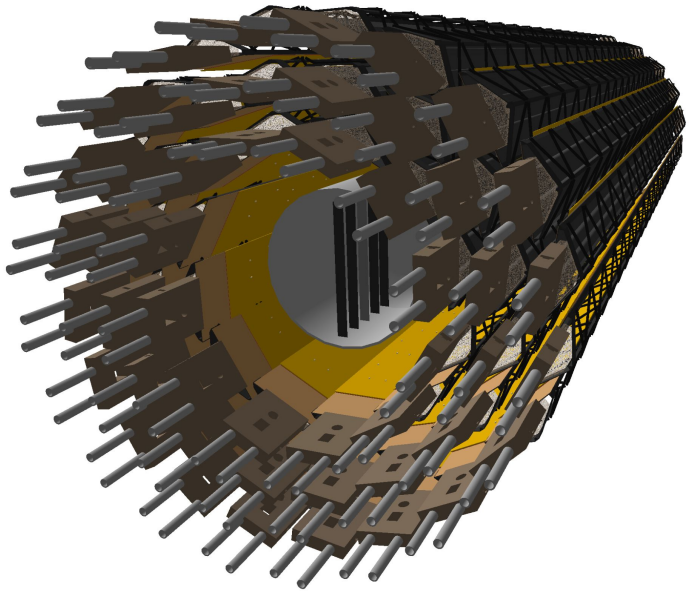
- Streaming mode, with a software trigger emulator
  - Hit multiplicity in DC and FTOF (2 non-consecutive sectors), FT-CAL, FT-TRK, FT-HODO
- Estimated trigger rate: 6.7 kHz
  - Determined by running algorithm on existing RGA data and scaling for the luminosity
- Estimated avg. event size: 18 kB
  - Includes baseline CLAS12 + MVTX
- **Total data rate: ~120 MB/s**
  - Much less than the ~1 GB/s bottleneck from the tape system





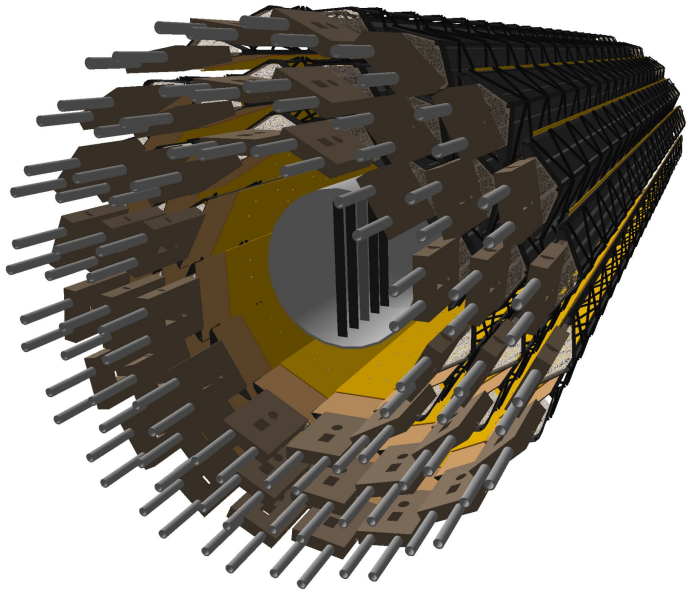
Monte-Carlo simulations

- Phase-space simulations at generator level
- Detector simulations with GEMC, with MVTX added to the CLAS12 baseline geometry
  - **Updated the MVTX geometry in GEMC to match the one used by sPHENIX collaboration**
  - Also includes service barrel, target chamber and foils
  - Currently working on creating a hitprocess routine.
    - For now, using flux hitprocess and adding resolution effects in post.



Results of updated MC simulations

- Vertex position resolution: 77 μm
- Mass resolution 6.3 MeV
  - Improved from 9.2 MeV, due to using MVTX for θ_{open} instead of using tracks from DC
- Efficiency: 12.7 %
- Estimated background reduction factor: $>10^4$



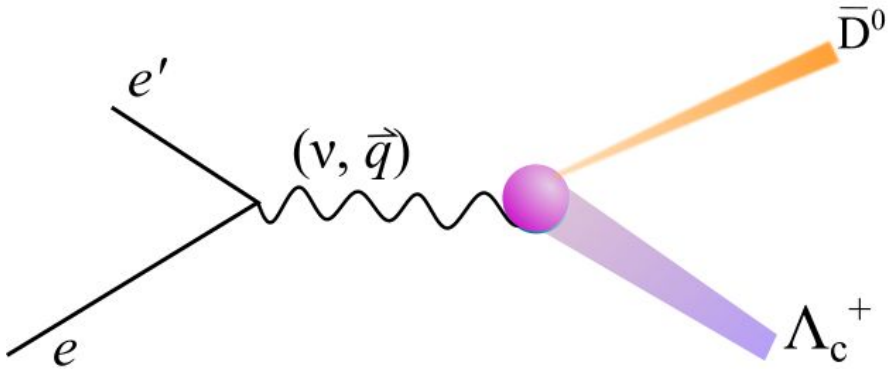
Estimation of signal event counts

Quantity	C	W	notes
free-proton cross-section [nb]	0.0082		$\sigma_{\gamma p}$ calculated from Ref. [21], $\eta = 0.5$, converted to σ_{ep} Eq. (9)
Z/N	0.50	0.40	
Nuclear effects	0.85	0.55	Estimated from CLAS [57] and HERMES [56] hadron multiplicity ratios
Tot. luminosity [nb^{-1}]	4.2×10^8	4.3×10^8	200 days, 50% PAC efficiency, 1.0×10^{35} cm^{-2}s^{-1}, achieved with 4-foil, 100 μm C target and 1 foil 50 μm W target at 140 nA; evaluated per nucleon
Branching ratio	3.945%		PDG 2025 [66]
Detector acceptance/efficiency	12.7%		GEMC simulation
v_z cut	28%	30%	assuming 100 (50) μm C (W) foils, cut at 312 μm
Tot. expected signal events	2000	1200	

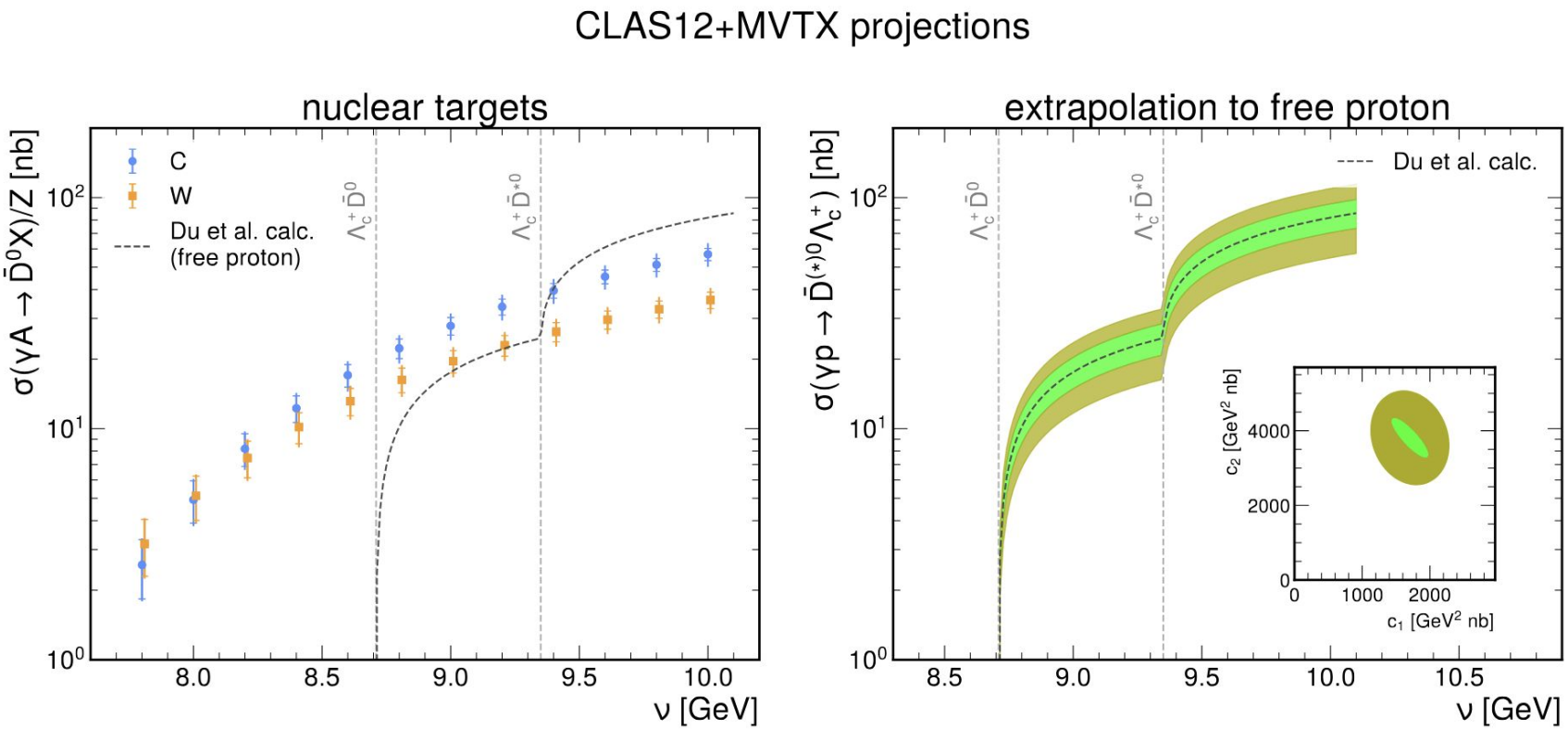
*Updated based on PAC feedback

Extrapolation to free proton target

- Updated to include a procedure to extrapolate from eA cross sections to free-proton cross sections and to determine systematic uncertainties.
- Simultaneously fit the results for W and C to a model
  - Includes Fermi-motion smearing and attenuation effects
  - Assumes that the shape of the v dependence of the free-proton cross section is primarily driven by available phase space
  - Free parameters are coefficients for the $\overline{D}^0$ and $\overline{D}^{0*}$, and the attenuation factor.



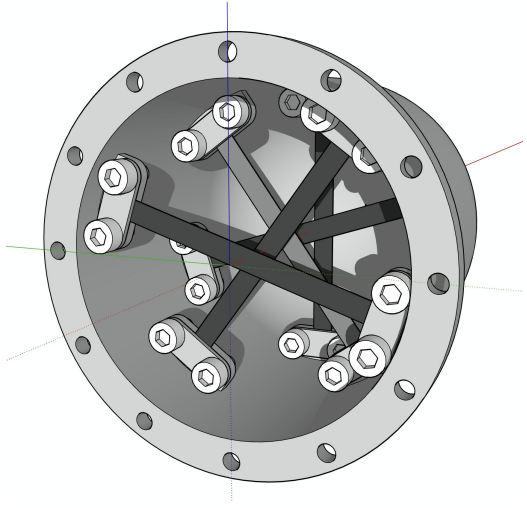
Projections

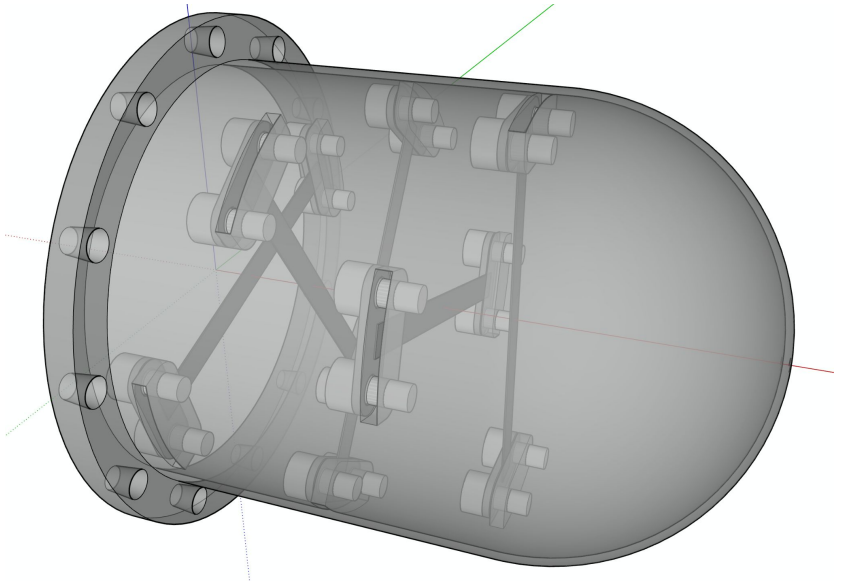


*Updated based on PAC feedback

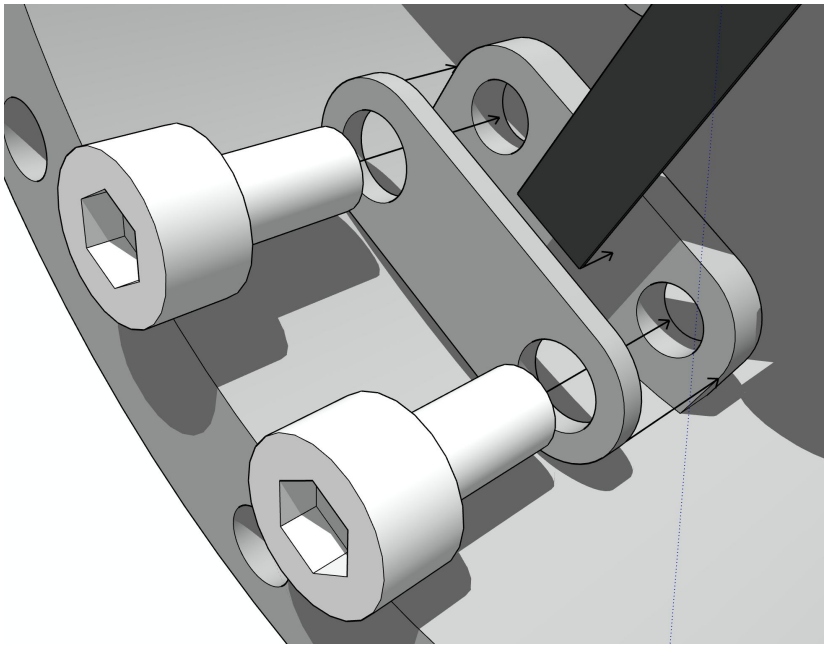
Updating the target chamber geometry

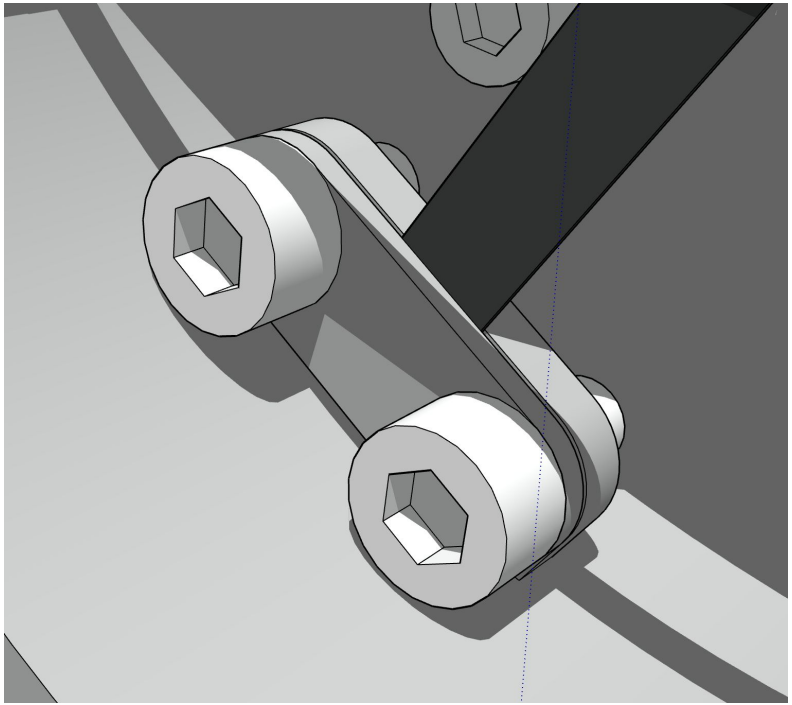
- Currently working on a more realistic design to be sent to the target group for approval
- Once this is approved, we'll rerun the simulations with the new target chamber geometry





Chamber geometry (continued)





Progress on addressing the PAC's feedback

- The cross section is measured on bound protons in C and W target but **extrapolation to the free-proton target** requires a more careful analysis of nuclear matter effects which will impact the theoretical interpretation of the measurement. These effects are only marginally described in the proposal. A clearer plan for handling these corrections and the associated systematics is needed.
    - Updated the free-proton cross-section extraction procedure to make this clearer, and added description of how to do systematic studies
- The conceptual design of the **target chamber** should be in compliance with the JLab target group.
    - Currently documenting the new design
    - TODO: send this to the the target group for approval
- The simulation used for the study does not include yet **a fully CAD-based model of the MVTX** with its support structure in the simulation framework. This should be included in a future proposal to refine the vertex resolution and background studies. For the latter, the 5 us readout window of the MVTX should be precisely included in the simulation
    - Updated the GEMC simulations to use sPHENIX's model of the MVTX, instead of a simplified version thereof.
    - Repeated existing background and vertex resolution studies; performance is as good if not better than in proposal
    - TODO Repeat studies with new scattering chamber geometry
- The proponents should demonstrate that the s**treaming readout and offline trigger** of the MVTX, combined with CLAS12 detectors, is **feasible**.
    - Demonstrated that the estimated data rate from the CLAS12+MVTX setup, with a reasonable software trigger program, (~120 MB/s) is well below the bottleneck from the tape system (~1 GB/s).

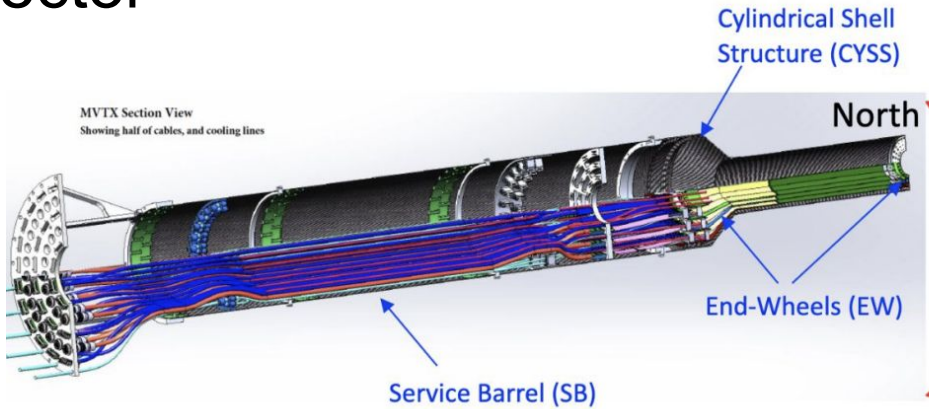
Conclusions

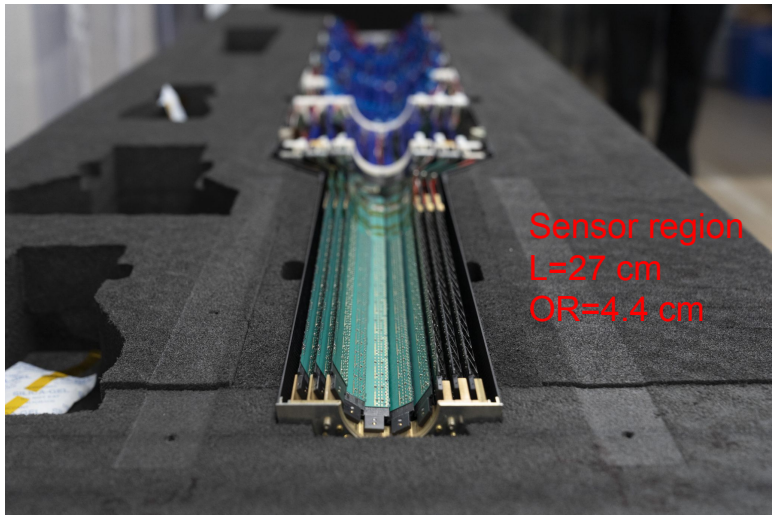
- Proposal was made at PAC 54 to measure open-charm production in CLAS12 with the MVTX detector from sPHENIX.
  - Deferred, requiring a resubmission at next PAC meeting (July 2027)
- TODO:
  - Get approval from target group on the target-chamber design
  - Repeat simulation studies using the new target chamber in GEMC
  - Finish integrating MVTX into CLAS12 software (GEMC's clas12Tags and coatjava)

Backup slides

The MAPS Vertex (MVTX) Detector

- In the proposal, we plan to borrow the MVTX detector from the recently completed sPHENIX experiment
  - 3 layers, 27 μm pixels
  - Hit position resolution ~5 μm.
    - Due to crossing angle between tracks, and multiple scattering in detector support materials, the vertex resolution is estimated to be around ~78 μm
  - Boosted lifetimes of $\bar{D}^0$ are ~200-400 μm
  - Requiring hadron pair to have vertices >4σ downstream of target should reduce background by at least 4 orders of magnitude





Integrating the MVTX into CLAS12

- The MVTX detector will replace the CVT during this experiment
  - MVTX + service barrel to be cantillevered from upstream end
  - Service barrel radius ≈ 11 cm fits inside solenoid warm bore (radius = 39 cm)
- Target assembly would be multifoil (C+W with equal total areal density)
  - Also cantilevered from upstream
- Polar angle overlap between MVTX and CLAS12 drift chambers would be ~8.7 to 40 degrees.

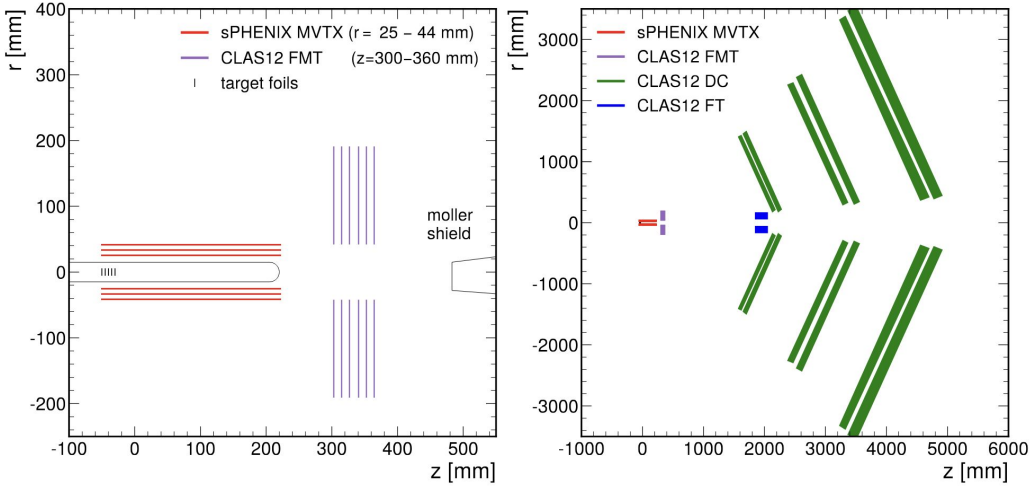
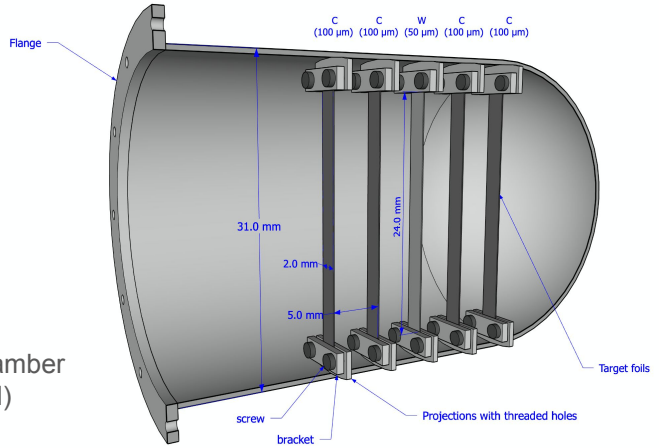


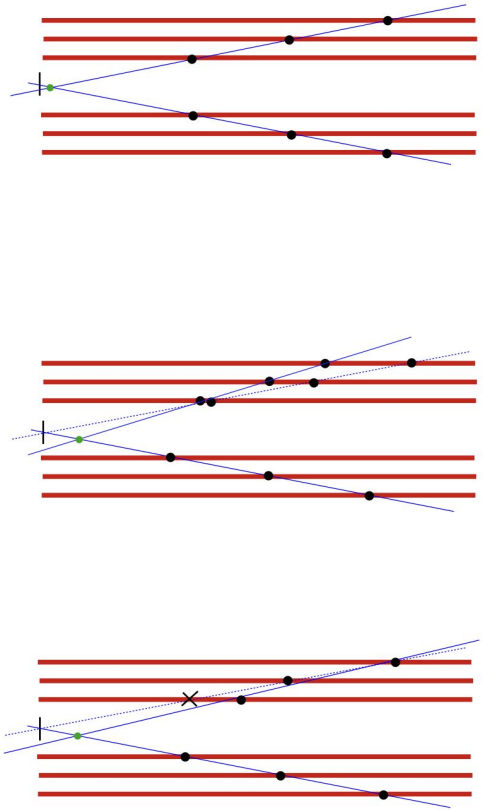
Figure 4: Placement of the MVTX inside of CLAS12. Left: zoomed-in view, right: zoomed-out view, showing the other detectors used in the proposed experiment.



Preliminary target chamber design (from proposal)

What percent of background events can we expect will pass the vertex cuts?

- Case 1: Both tracks are correctly matched between MVTX and DCs: 0.003%
- Case 2: One track is mismatched between the MVTX and DCs*: 0.001%
- Case 3: One track contains a hit that does not belong to it, and the hit that should be in the track is missing: 0.000024%

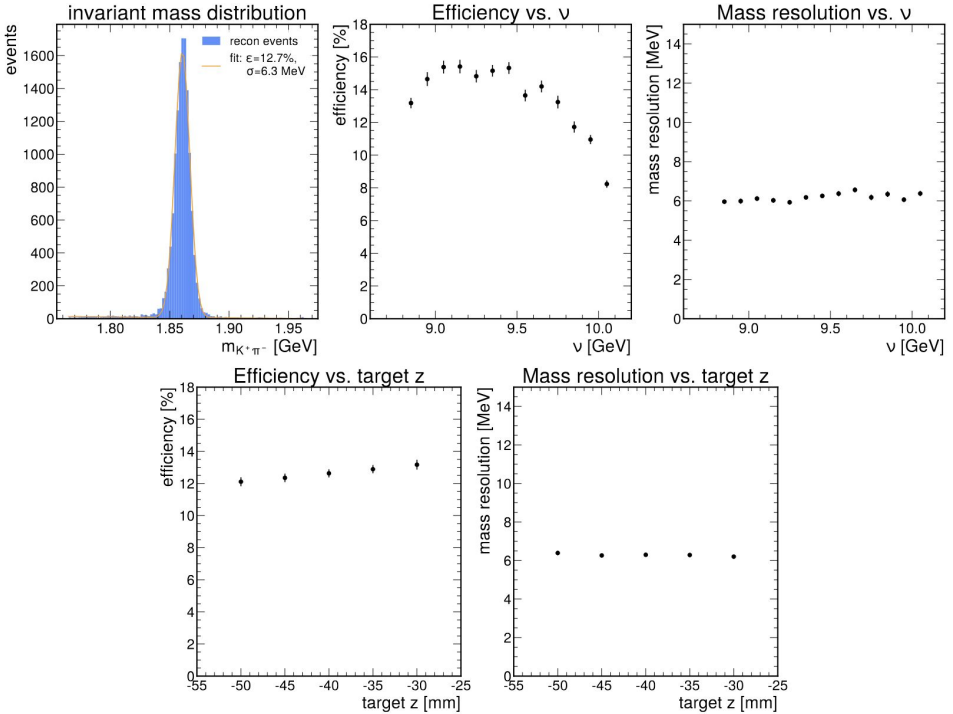


Background reduction > 10^4.

*Estimate updated using GEMC, based on PAC feedback

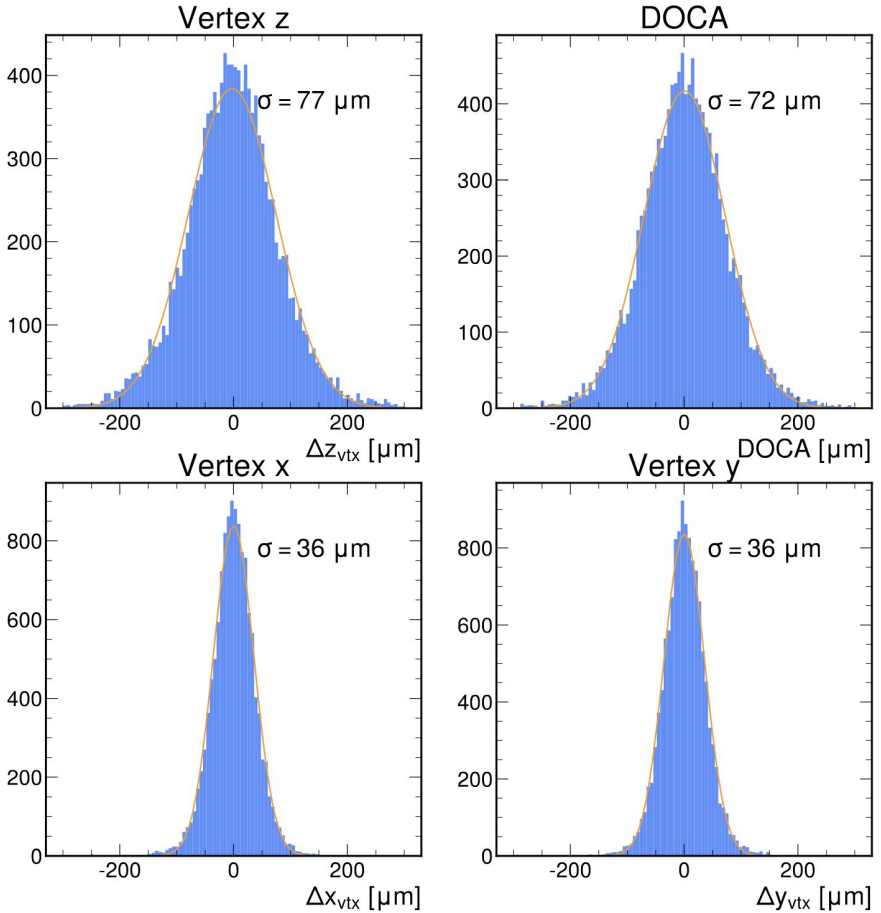
CLAS12 acceptance and mass resolution from GEMC

- Combined efficiency and acceptance for e- K^+ π^- is around 12.7%
- Mass resolution ~ **6.3 MeV (using MVTX for θ_{open} and DC for p)**



Vertex resolution

- Resolution on the z position of the vertex is 77 μm
  - Large contribution due to multiple scattering inside the support material of the MVTX*
- 4σ cut at ~308 μm
  - About 30% of simulated $\overline{D}^0$s survive this cut
- Cuts on DOCA and x_{vtx} and y_{vtx} can also filter out part of the background



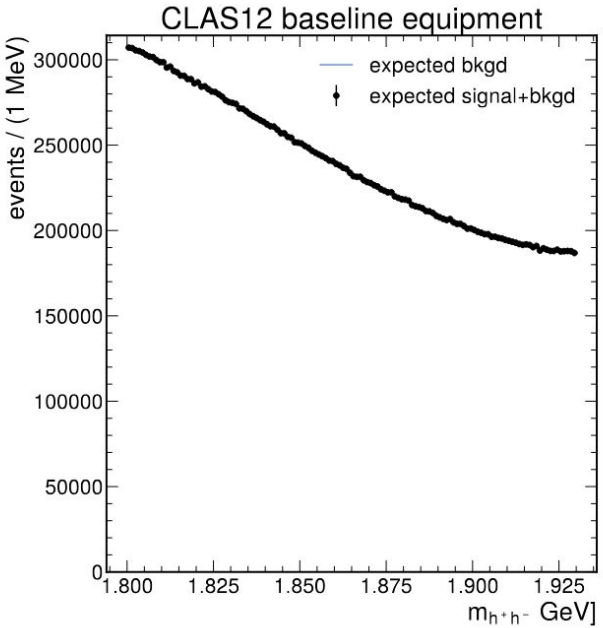
*Updated based on PAC feedback

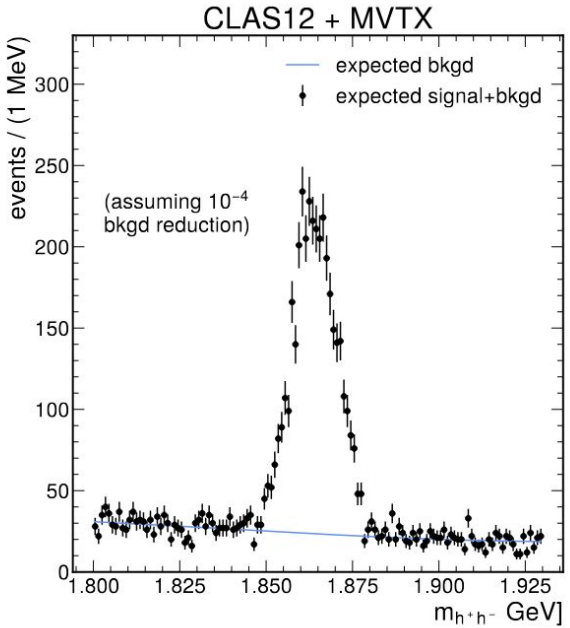
Comparison of background before/after MVTX

Pair background estimated from existing CLAS12 data (RGA):

- Counted events with e^- in FT, h^+h^- in DC, scaled by luminosity
  - Dwarfs the expected signal by about 3 orders of magnitude

MVTX is *required* for reducing this background to a manageable amount.

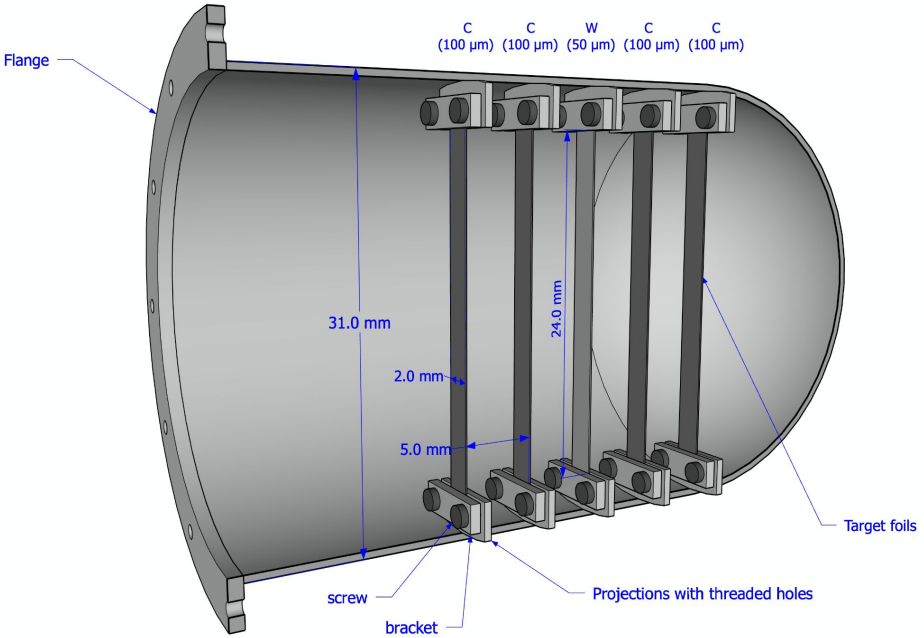




*Updated based on PAC feedback

Runtime and luminosity

- 100 PAC days.
  - 10 for commissioning, 90 for production
  - Justification: large uncertainty on the cross section, so this includes a safety factor in case the cross section is lower than we expect.
- **140 nA**
- **4.2×10^8 nb^{-1}** for each target type

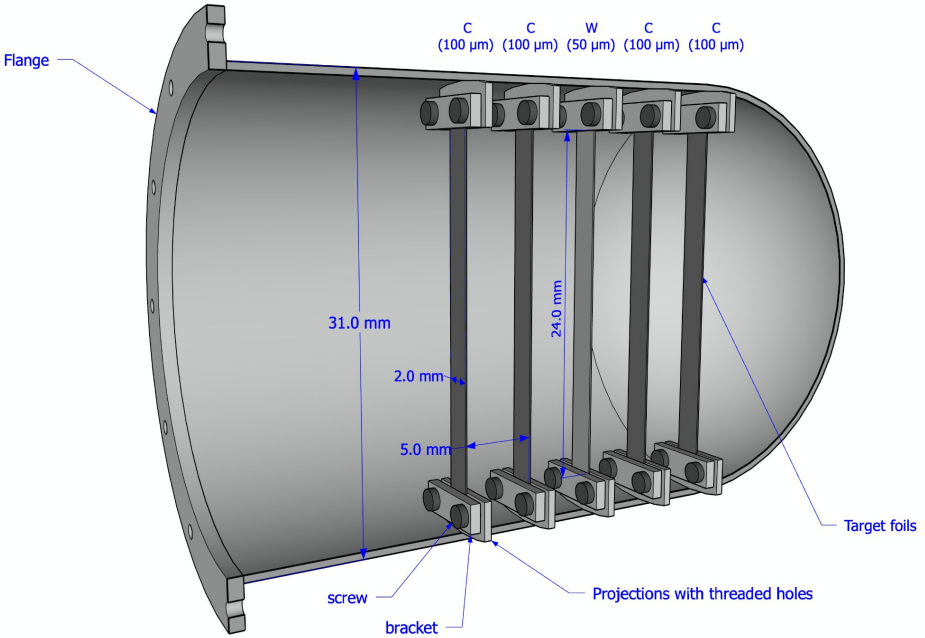


Preliminary target design, to be refined by the target group

Why two target types?

- Better grasp on the nuclear effects, such as absorption of $\overline{D}^0$ in the nucleus
- Allows an estimation of the cross section for the free-proton case, extrapolating from the two nuclear targets
  - Two steps: Unfold Fermi-motion smearing effects, then extrapolate for absorption effects

$$R_h \approx \exp\left(-cA^{1/3}\right) \implies \sigma_p = \sigma_C^{\text{corr}} \exp\left(\frac{A_H^{1/3} - A_C^{1/3}}{A_W^{1/3} - A_C^{1/3}} \times \log \frac{\sigma_W^{\text{corr}}}{\sigma_C^{\text{corr}}}\right)$$



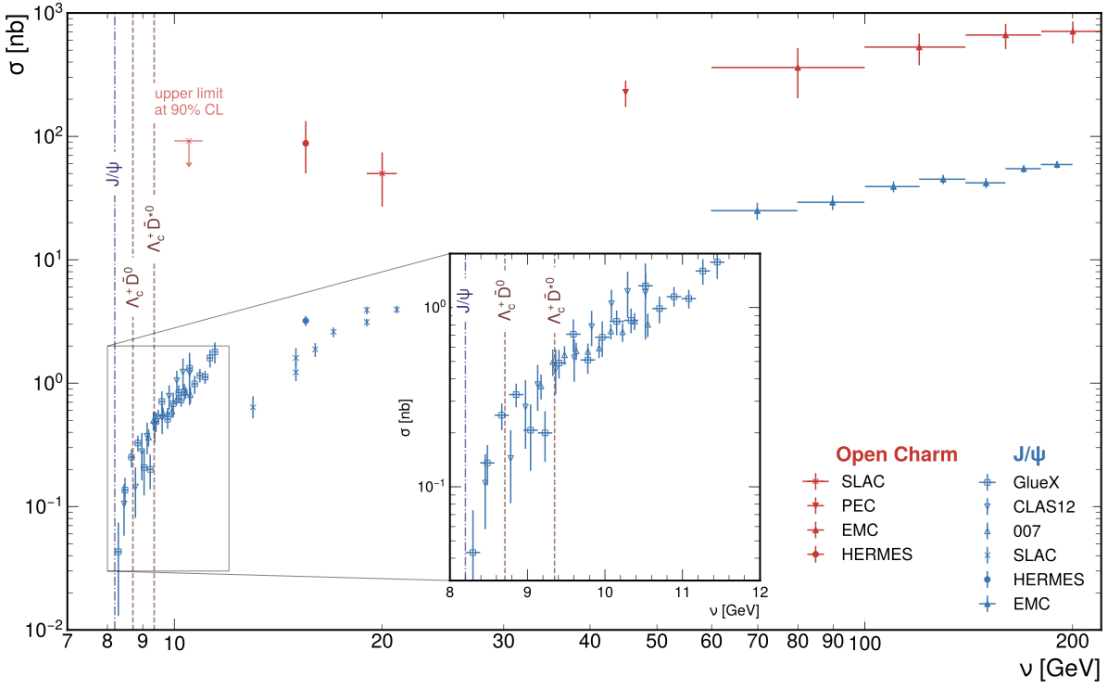
Preliminary target design, to be refined by the target group

Conclusions

- Only an upper limit has been measured for open-charm production near threshold, unlike hidden-charm (J/ψ) production
  - Open charm may reveal insights regarding J/ψ production processes, and would create a more complete charm-production program at Jefferson Lab
- Proposed experiment will make the first-ever open-charm measurement near threshold
  - CLAS12+MVTX setup is well suited for making this measurement, and Jefferson Lab is uniquely equipped for facilitating it.
  - Existing run groups lack the ability to sufficiently filter the large amount of hadronic background.
- The results of the proposed measurement will be useful in a variety of other topics, including diquark phenomena, hadron-absorption in nuclei, and scattering-length meta-analyses

Existing open and hidden-charm measurements

- A measurement by SLAC set *upper limit only* on cross section near threshold*
- Closest *non-zero* measurements are at about twice the threshold energy**
- For comparison, J/ψ has been measured near threshold at JLab by GlueX, 007, and CLAS12.
    - Open charm cross section expected to be one to two orders of magnitude higher than J/ψ near threshold
- Difficulty in measuring open-charm comes from large hadronic background, rather than limited cross section.

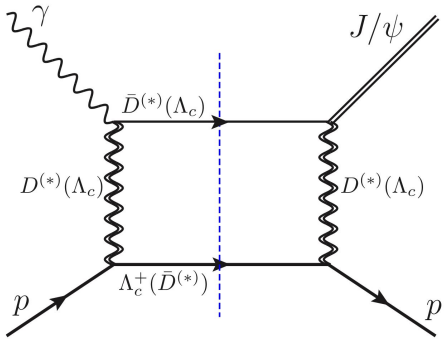


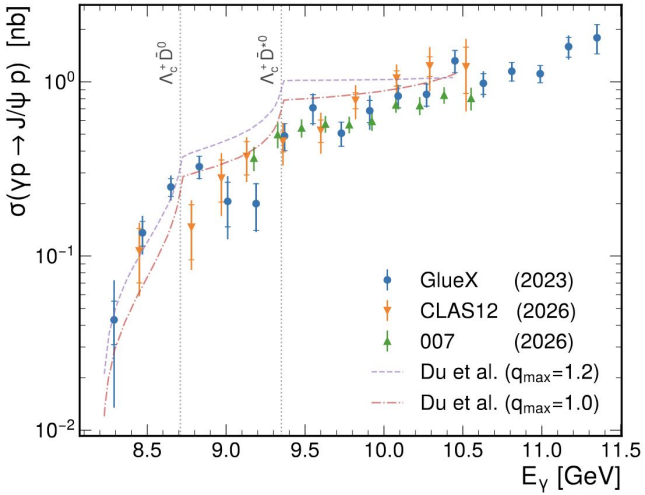
* http://doi.org/10.1103/PhysRevD.30.694

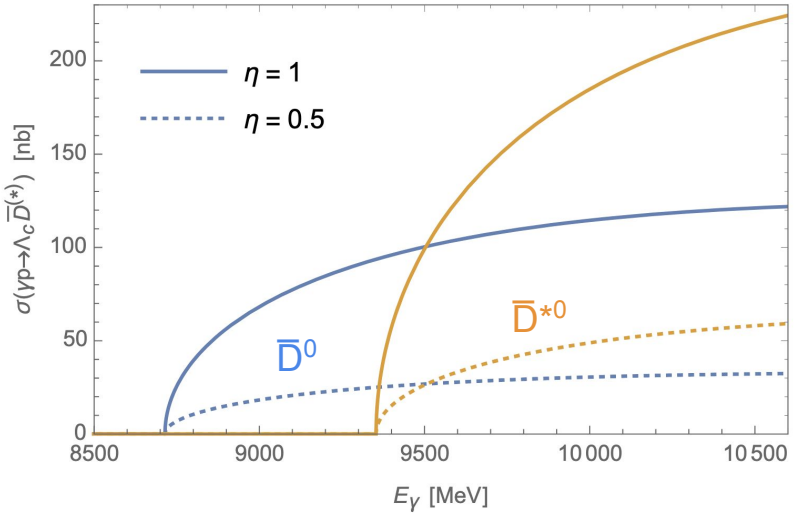
** doi.org/10.1103/PhysRevD.30.1 , https://inspirehep.net/literature/553290

What cross section do we expect?

- M.-L. Du *et al** made predictions both open and hidden charm production near threshold
  - Recent J/ψ results show fair agreement with model.
- For open-charm, we use their lower estimate for our statistical projections
  - Agrees with independent predictions from Tomasi-Gustafsson**



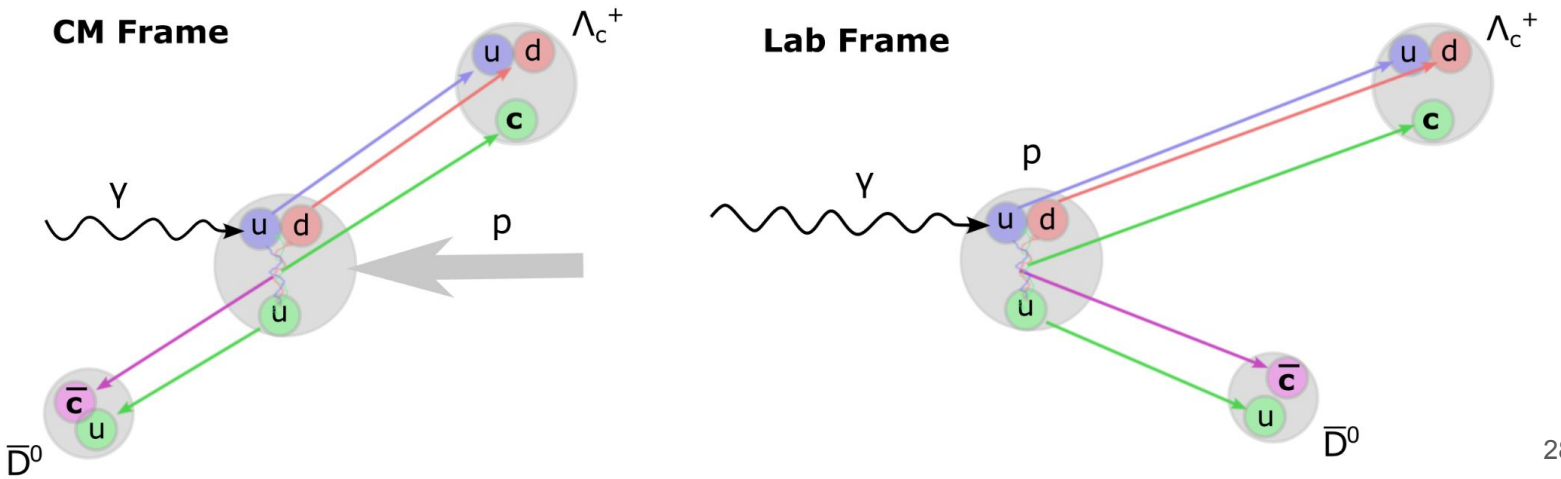




*https://doi.org/10.1140/epjc/s10052-020-08620-5
**https://arxiv.org/abs/hep-ph/0411295

Enhanced cross-section due to di-quarks

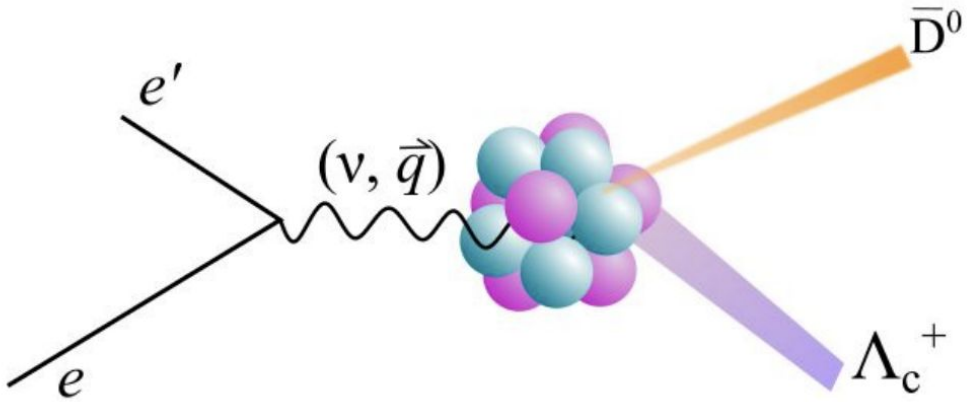
- The presence of diquark+quark in a proton's wavefunction may affect the open-charm production if the diquark is struck, producing the Λ_c^+
- String breaking produces the $c\bar{c}$ pair.
- If this mechanism contributes, it will enhance events where the $\bar{D}^0$ is at backwards angles in the γp center-of-mass frame



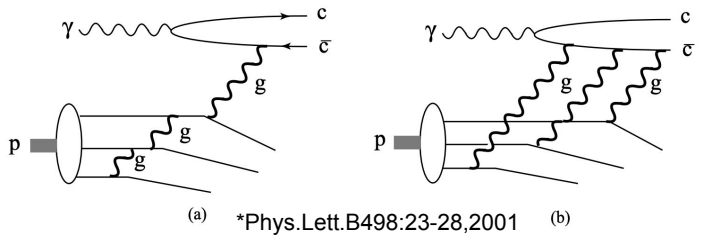
Motivation

- Open charm is related to hidden-charm (J/ψ) production,
  - The measurement of the former would complement the measurements of the latter
- This open-charm production mechanism can also be used to probe the diquark part of the proton wavefunction

Open charm



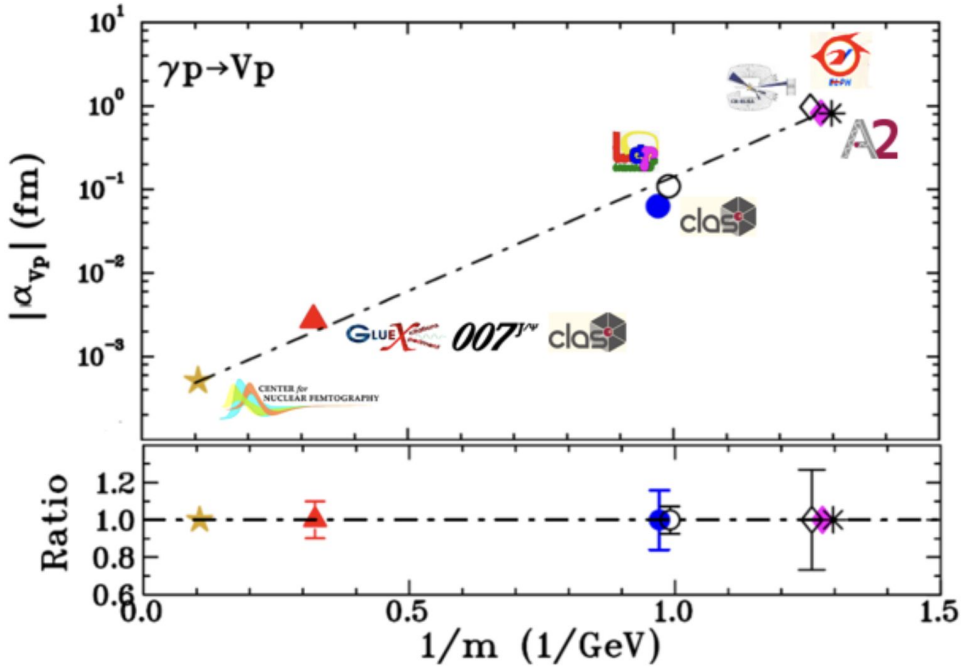
Hidden charm*



*Phys.Lett.B498:23-28,2001

Relation to scattering length analysis

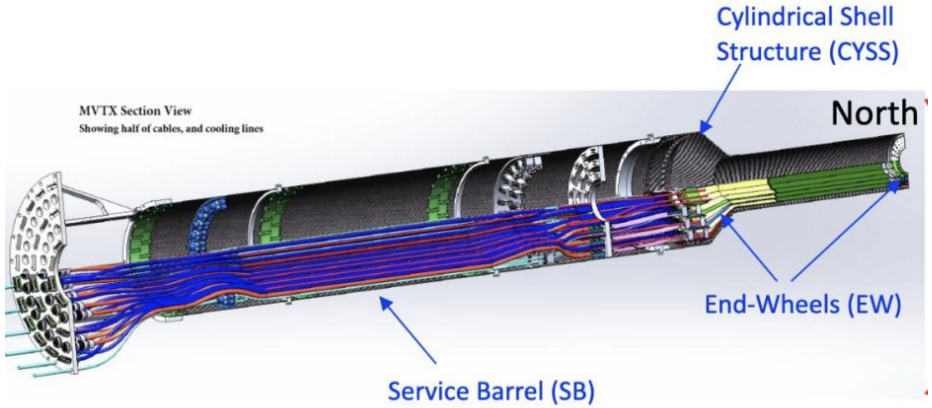
- Scattering lengths for vector-meson on proton scattering determined from γp→Vp scattering show a linear trend for $1/m_V$ versus log $|\alpha_{Vp}|$.
  - Will this trend persist for other meson-baryon combinations such as $\bar{D}^0\Lambda_c^+$ or $\bar{D}^{*0}\Lambda_c^+$?

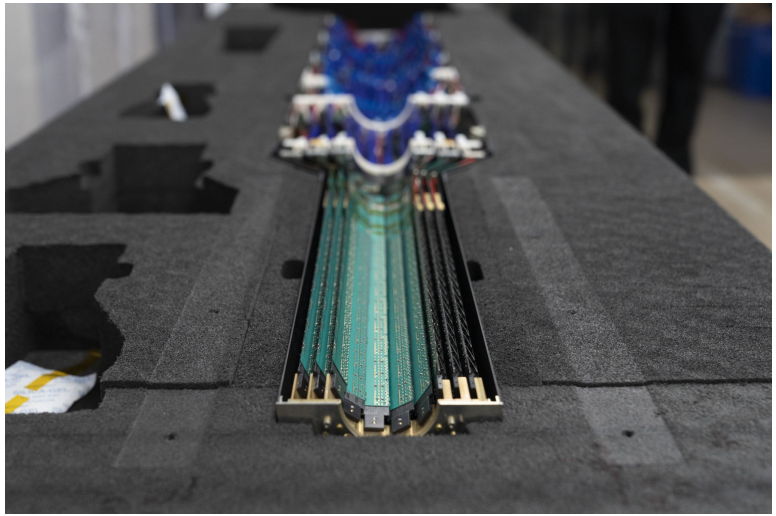


https://arxiv.org/abs/2603.09622

Equipment loan

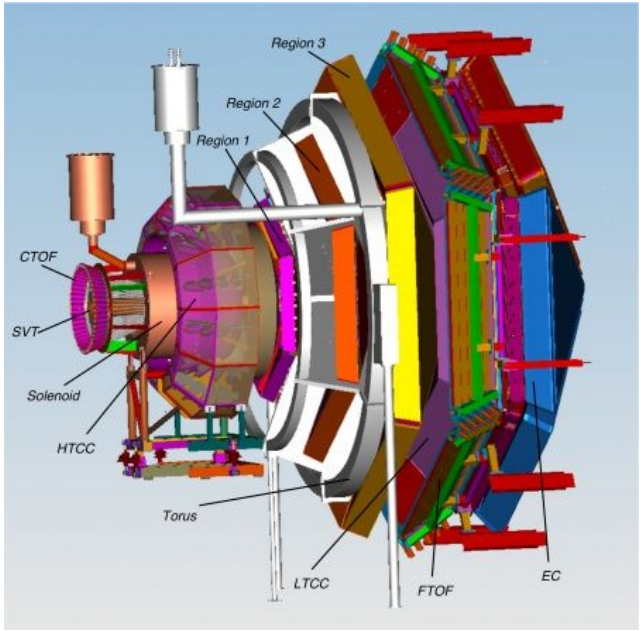
- MVTX currently being transferred ownership from BNL to LANL, where it was initially developed
- Loan from LANL would include
  - The MVTX detector in its support/service barrel
  - Cables for power and readout
  - Power units
  - Front-end readout
  - Chiller system
  - Spare cables/power units and front-end readouts
- However, JLab will need to purchase FELIX boards for backend readout, and use its own servers for online data-processing
  - *BNL will be retaining its FELIX boards for EIC

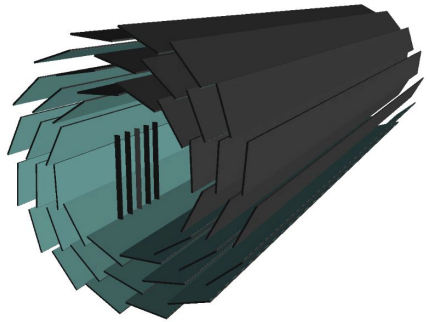




Recon of Monte-Carlo simulations

- Particle four momenta determined using the CLAS12 baseline reconstruction software (coatjava)
- Vertex position determined by fitting the MTX hits for each track to a helix with the ROC determined from the pT in the baseline detectors…
- … then finding the point of closest approach between the two helices



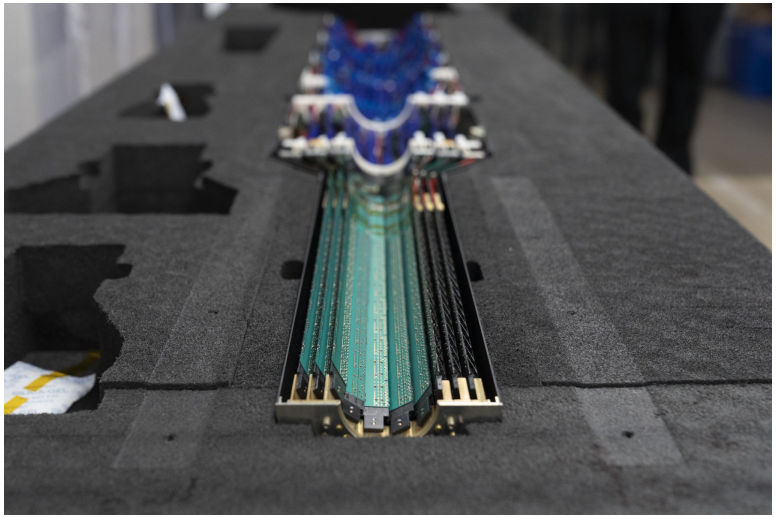


Additional possible measurements (Run Group)

- J/ψ on nuclear targets
  - Triggering with scattered electron in FT and/or with lepton pair in FD.
  - MVTX may improve pair mass resolution, which could reduce systematic uncertainty from fitting invariant mass distribution.
- Inclusive Λ_c^+ measurement
  - Corroboration for the inclusive $\bar{D}^0$ measurement, since Λ_c^+ and $\bar{D}^0$ would be formed together in these reactions
  - Inclusive cross sections for Λ_c^+ and $\bar{D}^0$ may differ from one another due to different FSI.

Alignment procedure

- Installation: 500 μm
- Optical survey: O(100 μm)
- Cosmic run: O(50 μm) using Millepede
- During the run period using Millepede
  - External alignment relative to CLAS12
  - Internal alignment (5 μm level)



Hit distribution in a single event

