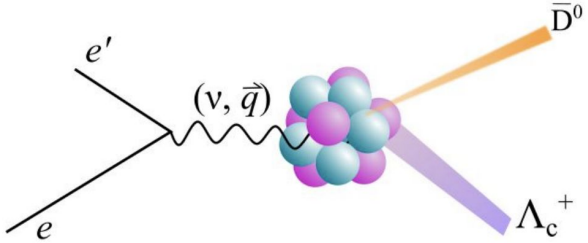
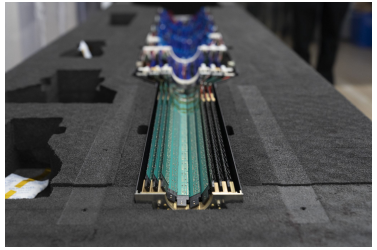
Open Charm at JLab with the sPHENIX MAPS tracker:

a CLAS Collaboration Proposal
to be sent to PAC 54



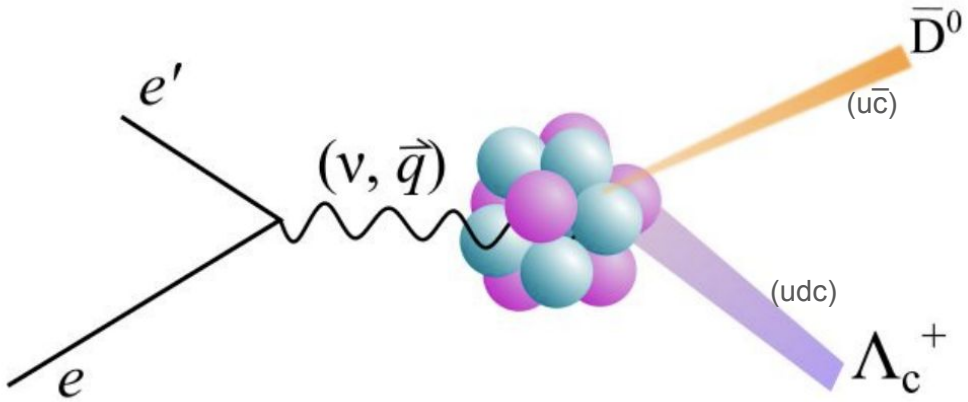
Dr. Sebouh Paul
Florida International University
on behalf of the Open Charm group
3/13/2026



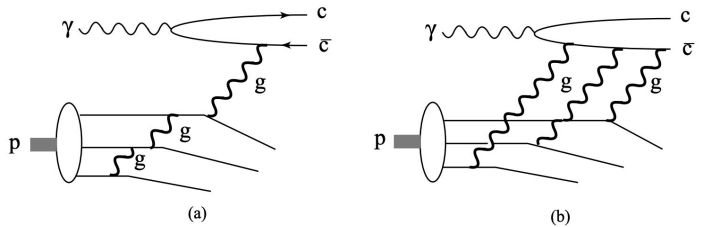
Introduction

- 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 $\bar{D}^0\Lambda_c^+$.
- Could take place in free or bound proton

Open charm



Closed charm*

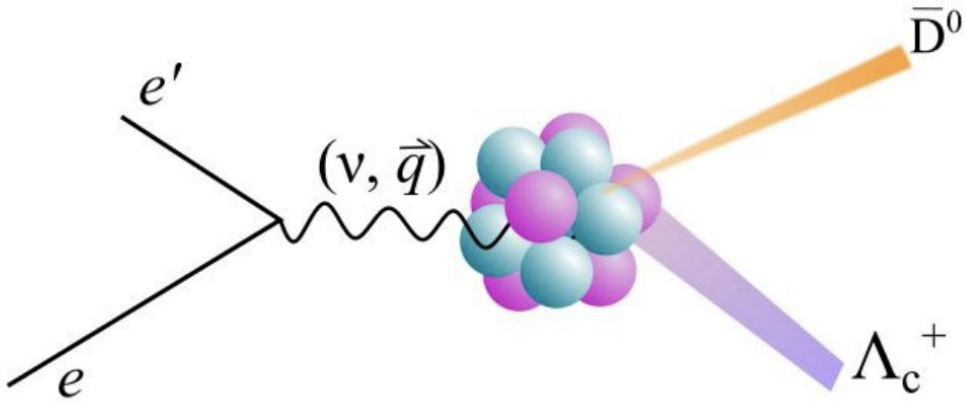


*Phys.Lett.B498:23-28,2001

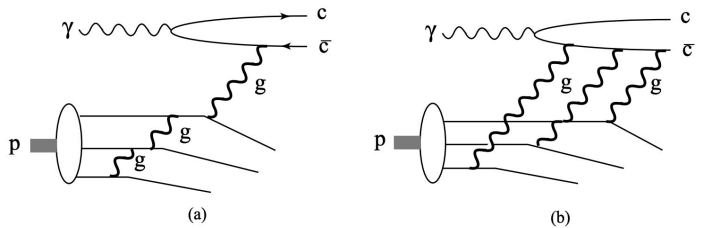
Motivation

- Measuring open-charm production in ep scattering near-threshold can reveal information about J/ψ (closed-charm) production
- This open-charm production mechanism can also be used to probe the diquark part of the proton wavefunction

Open charm



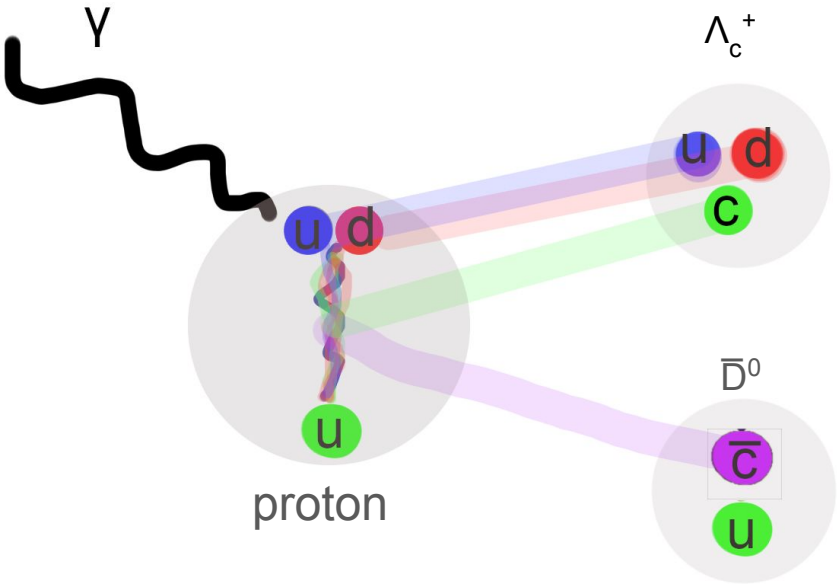
Closed charm*



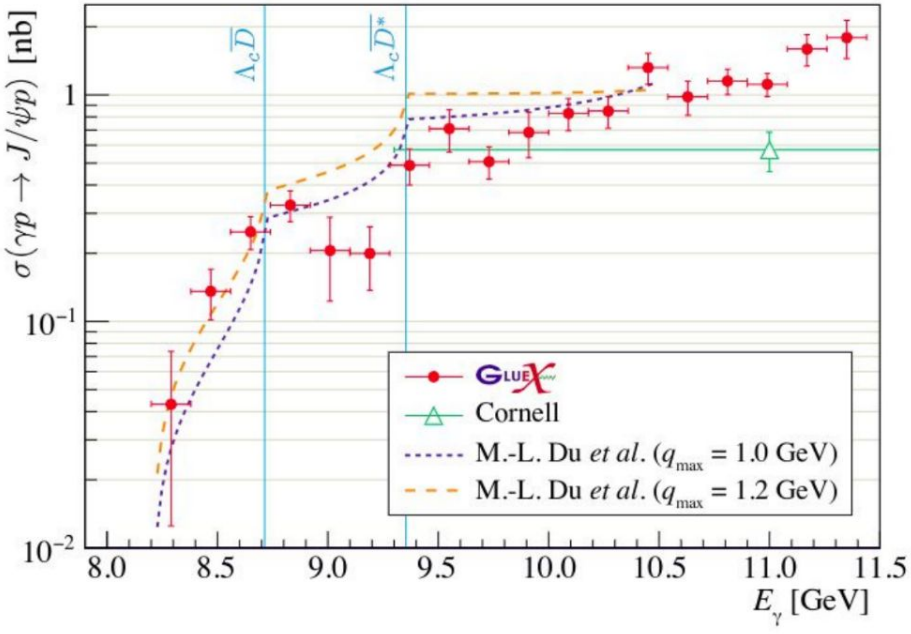
*Phys.Lett.B498:23-28,2001

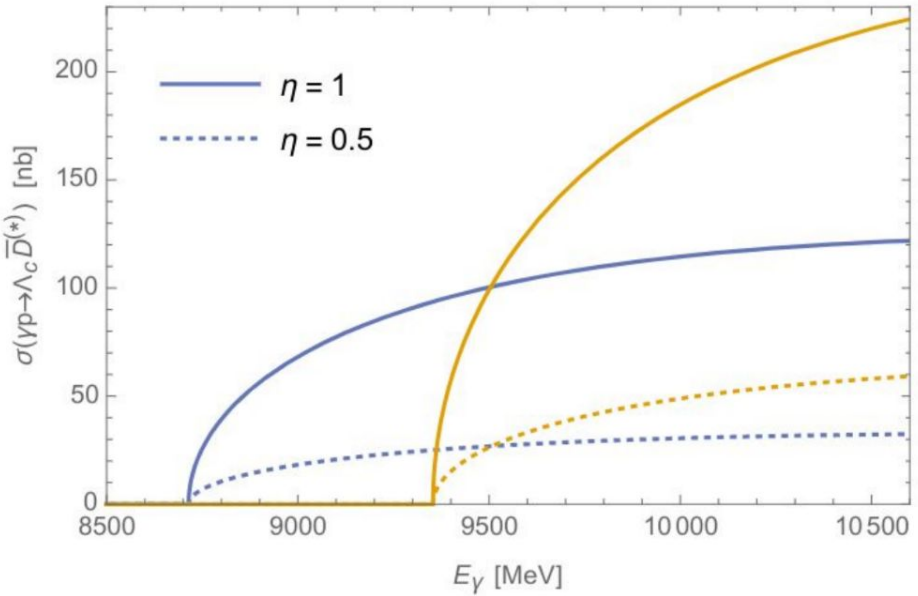
Enhanced cross-section due to di-quarks

- The presence of diquark+quark in a proton's wavefunction may enhance the cross-section of open charm production due to events where the γ strikes a diquark
- String breaking produces the $c\bar{c}$ pair.
- This ends up being a simpler process (fewer string breakings) than if a solitary quark (non-diquark state) is struck.



How is open-charm related to closed-charm (J/ψ)?





https://doi.org/10.1103/PhysRevC.108.025201

https://doi.org/10.1140/epjc/s10052-020-08620-5

Why the cusps?

It was predicted* that rescattering of open charm particles could enhance J/ψ production near thresholds

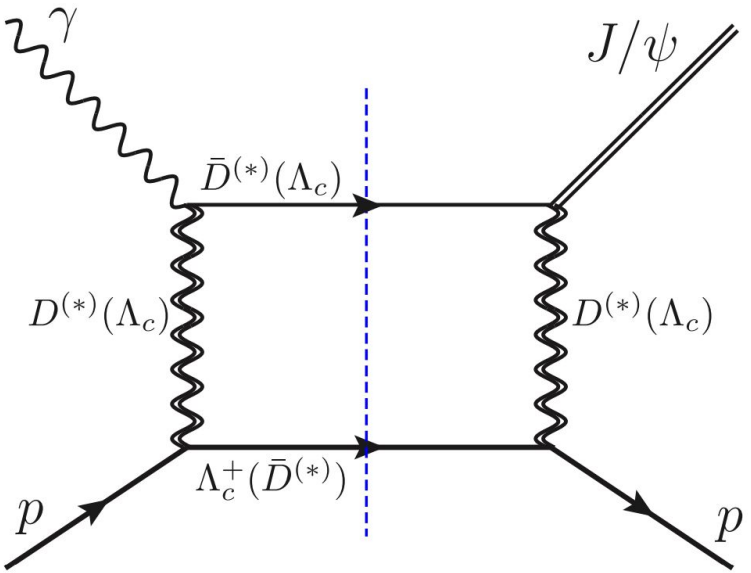
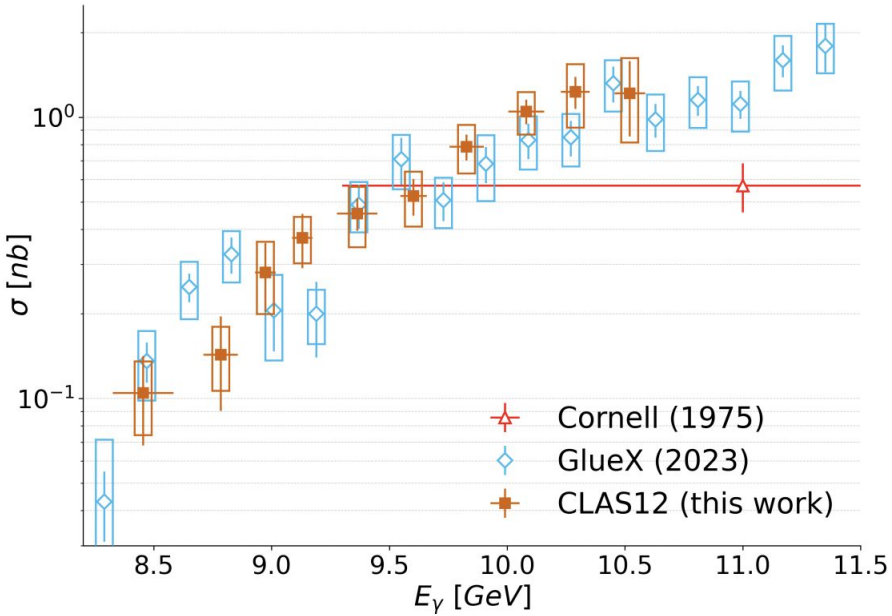
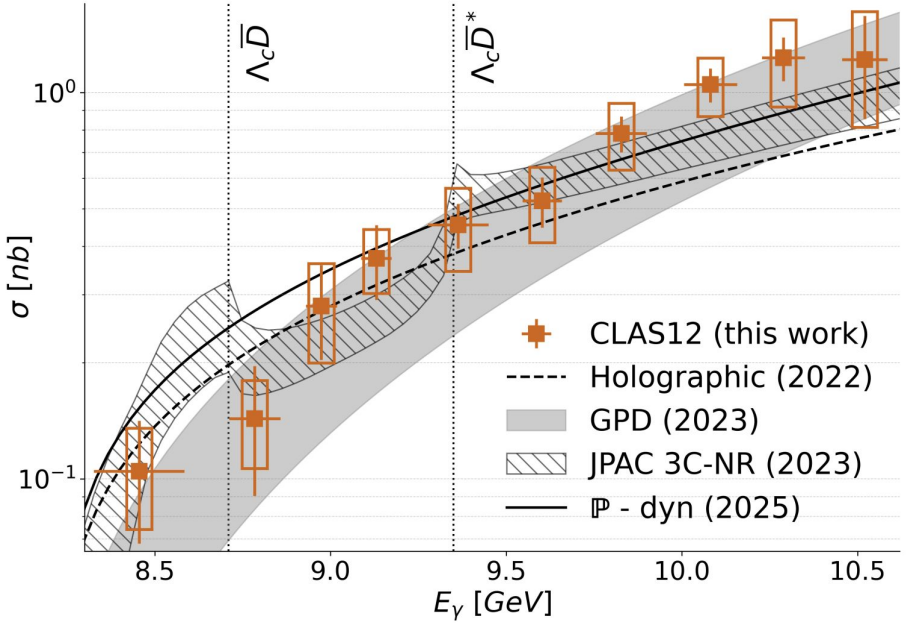


Fig. 3 Feynman diagram for the proposed CC mechanism. The dashed blue line pinpoints the open-charm intermediate state

*https://doi.org/10.1140/epjc/s10052-020-08620-5

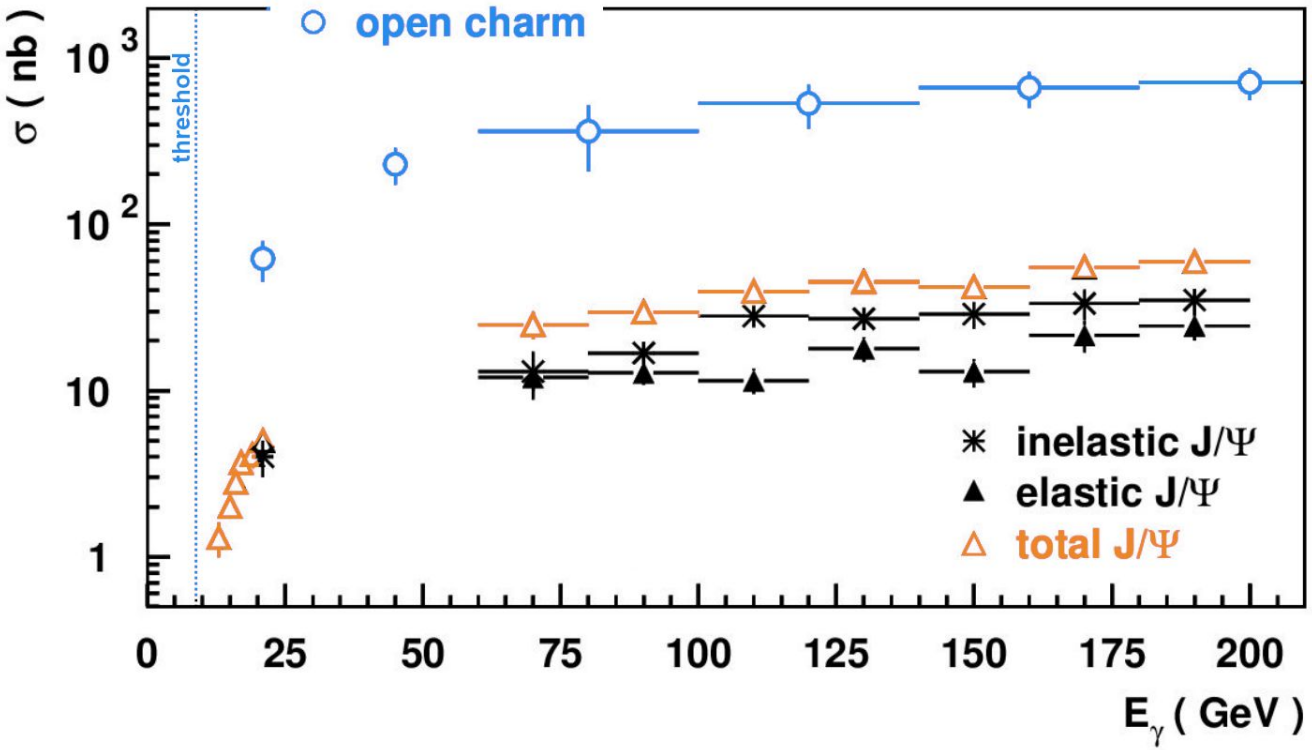
Recent CLAS12 J/ψ results: no cusps?!





P. Chatagnon et al (CLAS Collab) https://arxiv.org/pdf/2602.22128

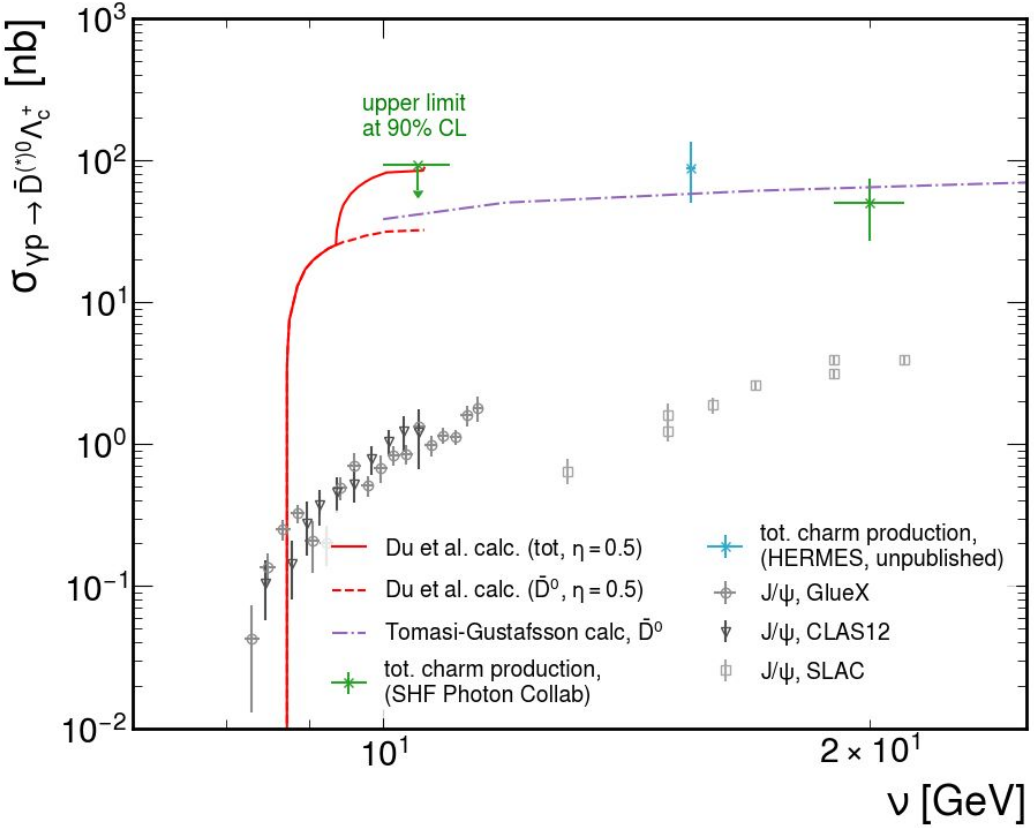
Open charm is expected to have larger cross section than J/ψ, based on measurements well above threshold



Adapted from https://inspirehep.net/literature/553290

Existing measurements and predictions

- A measurement by SLAC set *upper limit only* on cross section near threshold*
- Closest *non-zero* measurements to threshold are at about 1.8 and 2.4 times the threshold**
- Two independent predictions of σ=O(10-100) nb near threshold***
- For comparison, J/ψ has been measured near threshold by GlueX and CLAS12 at JLab.

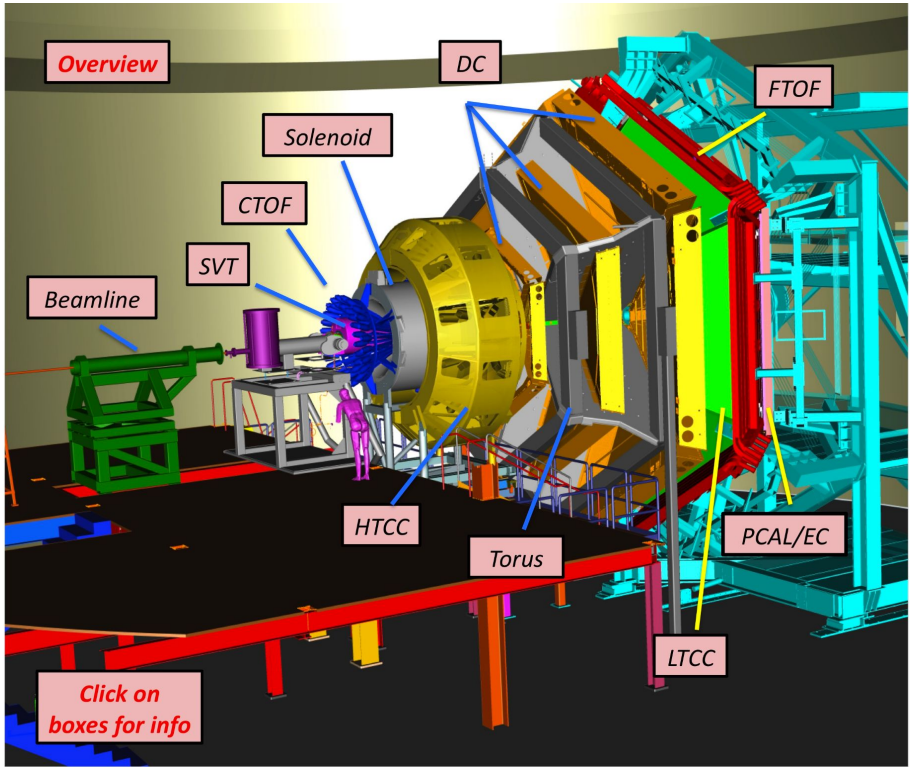


* http://doi.org/10.1103/PhysRevD.30.694
** doi.org/10.1103/PhysRevD.30.1 , https://inspirehep.net/literature/553290

*** https://inspirehep.net/literature/665047, https://doi.org/10.1140/epjc/s10052-020-08620-5

Proposed measurement with CLAS12 detector

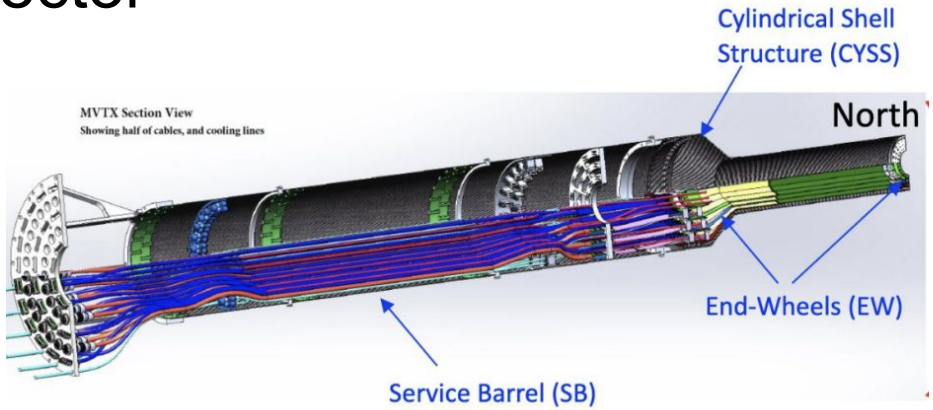
- Forward tagger can measure electrons as low as 0.5 GeV:
  - Energy transfer in quasi-real photoproduction up to 10.1 GeV, while threshold for $\gamma p \rightarrow \bar{D}^0 \Lambda_c^+$ is ν=8.7 GeV
- Our detection strategy:
  - $\bar{D}^0 \rightarrow K^+\pi^-$ decay channel
  - Hadron pair with vertex displaced from a thin target foil, with pair mass consistent with $\bar{D}^0$
- 10.6 GeV e- beam, 45 nA (C+W)
- Letter of intent* was presented at PAC 2024, which is now being turned into a proposal for PAC 2026

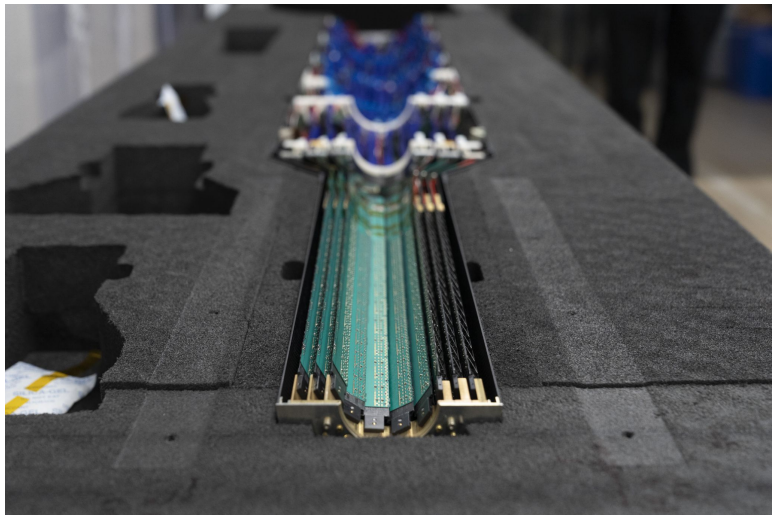


*https://arxiv.org/abs/2405.04511

The MAPS Vertex (MVTX) Detector

- In the proposal, we plan to borrow the MVTX detector from the recently completed sPHENIX experiment
  - Pixel detector with pitch 27 μm
  - Hit position resolution ~5 μm.
    - Due to crossing angle between tracks, the vertex resolution is estimated to be around 26 μm
  - Boosted lifetimes of charmed hadrons are O(100 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
- Target assembly would be multifoil (C+W with equal total areal density)
- Polar angle overlap between MVTX and CLAS12 drift chambers would be 8.9 to 40 degrees.

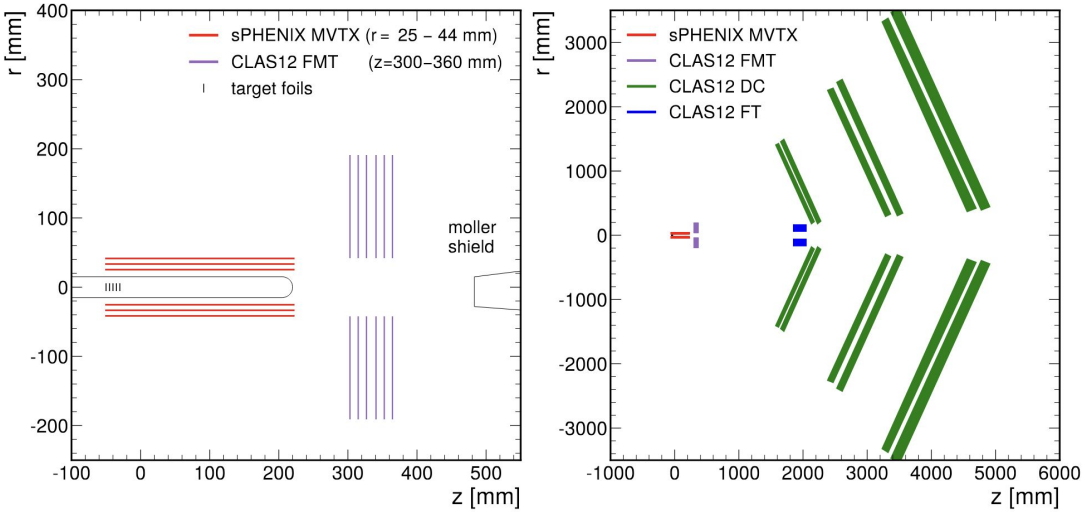


Figure 4: Placement of the MVTX inside of CLAS12. Left: zoomed-in view, right: zoomed-out view, showing the other detectors used in the proposed experiment.

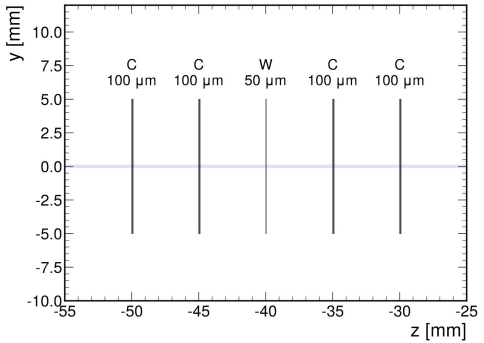


Figure 5: Target assembly.

Luminosity, beam current and runtime

- 200 days of runtime, corresponding to 100 PAC days.
- 45 nA
- 3.2×10^{34} $cm^{-2}s^{-1}$
- 1.4×10^{8} nb^{-1} for each target type

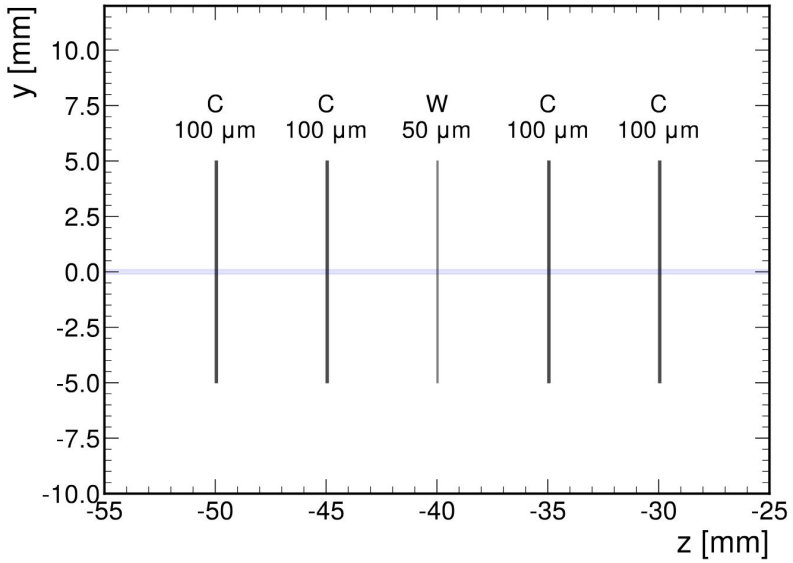


Figure 5: Target assembly.

Why two target types? Nuclear shadowing

- Decreased gluon density in nuclei → lower cross section for $c\bar{c}$ production
- Using a light nucleus (C) and a heavier one (W) allows measurements sensitive to the nuclear shadowing effects
  - ~15% for C
  - ~58% for W
- Can extrapolate our measurement to the free-proton case by correcting for nuclear shadowing

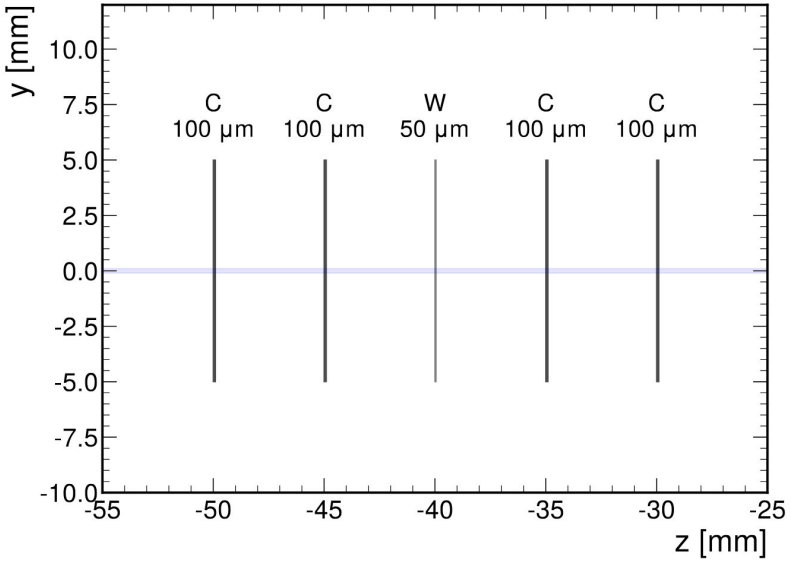
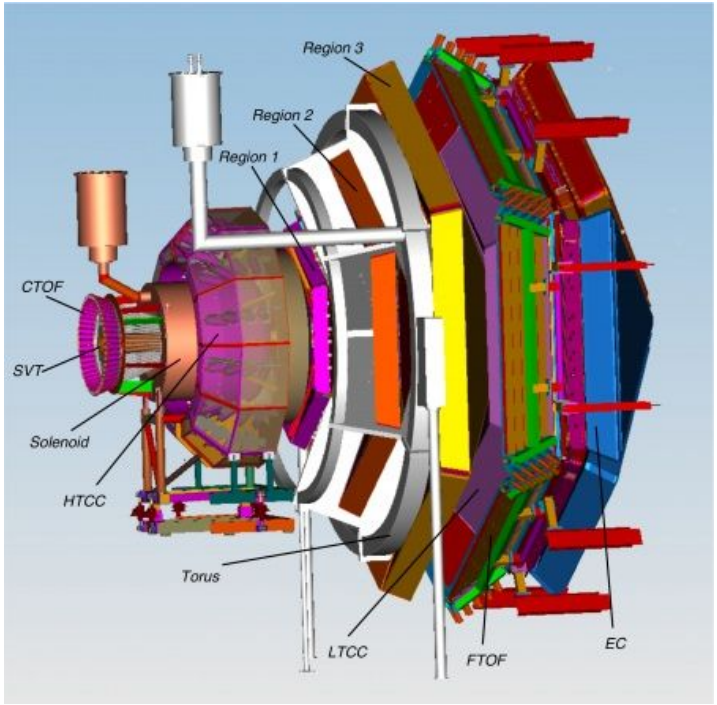


Figure 5: Target assembly.

Monte-carlo simulations

- Phase-space simulations at generator level
- CLAS12 efficiency and acceptance from GEMC
- add θ cutoff for MVTX acceptance
- Fast MC/postprocessing to determine efficiency of cuts in MVTX



CLAS12 acceptance and mass resolution from GEMC

- Combined efficiency and acceptance for K^+ and π^- is around 14% for events in the θ range of interest.
  - Calculated as the number of events under the mass peak divided by the number of generated events
- σ=12.4 MeV
  - Width of mass peak

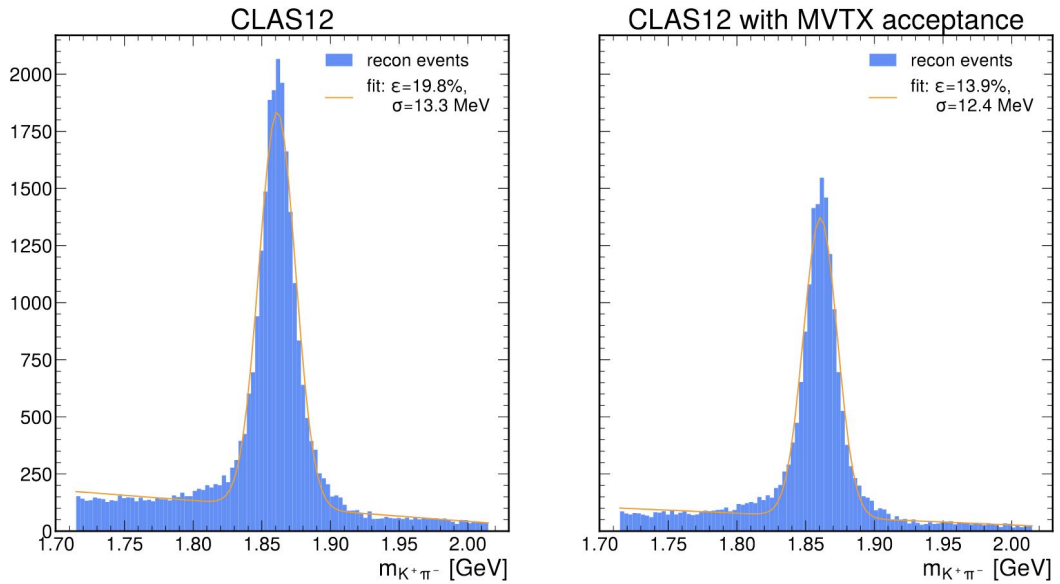
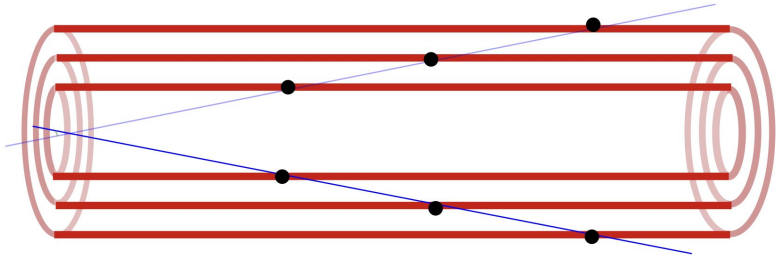


Figure 7: Invariant mass distribution for $K^+\pi^-$ candidates in the MC simulations before (left) and after (right) applying fiducial cuts to select events in the MVTX acceptance.

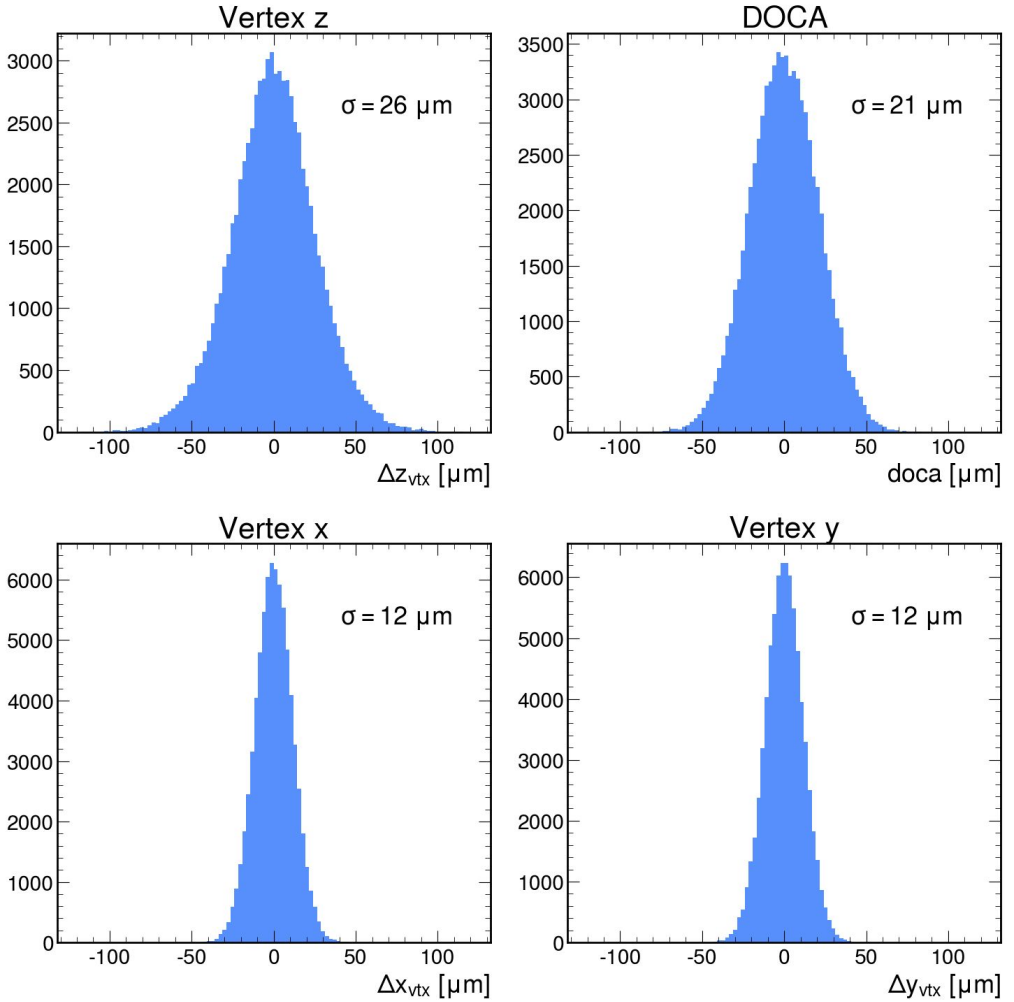
Fast MC for estimating MVTX performance

- Approximate trajectories in MVTX as straight lines, and MVTX as cylinder
- Smear all hit positions by 5 μm in each direction
- Linearly fit tracks
- Determine doca and vertex position from these linear fits.



Vertex resolution

- Resolution on the z position of the vertex is 26 μm
- 4σ cut at ~100 μm
- Cuts on doca and x_{vtx} and y_{vtx} can also filter out part of the background



Estimation of signal rates

Quantity	C	W	notes
free-proton cross-section [nb]	0.0082		$\sigma_{\gamma p}$ calculated from Ref. [25], $\eta = 0.5$, converted to σ_{ep} (Eq. 6)
Z/N	0.5	0.40	
Nuclear shadowing factor	0.85	0.42	Estimated from [37]
Tot. luminosity [nb^{-1}]	1.4×10^8	1.4×10^8	200 days, 50% PAC efficiency, 3.2×10^{34} $\text{cm}^{-2}\text{s}^{-1}$, achieved with 4-foil, 100 μm C target and 1 foil 50 μm W target at 45 nA; evaluated per nucleon
Branching ratio	3.945%		PDG 2025 [34]
CLAS12 acceptance/efficiency	18%		GEMC simulation
MVTX acceptance	70%		fraction of events in simulations in MVTX geometric acceptance
MVTX efficiency	89%		98% hit efficiency for 3 hits per particle.
v_z cut	57%	63%	assuming 100 (50) μm C (W) foils, cut at 100 μm
Tot. expected signal events	1300	600	

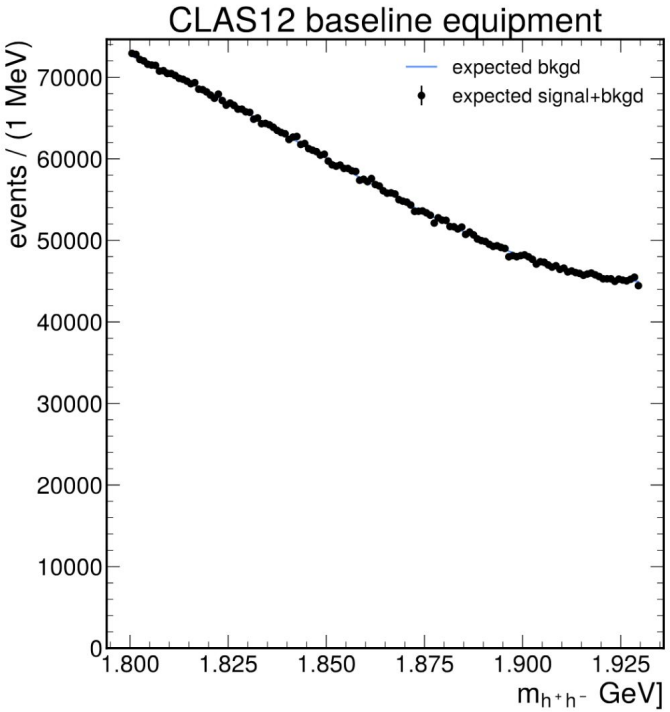
Table 1: Factors and assumptions that go into the calculations for the total expected yields (bottom row).

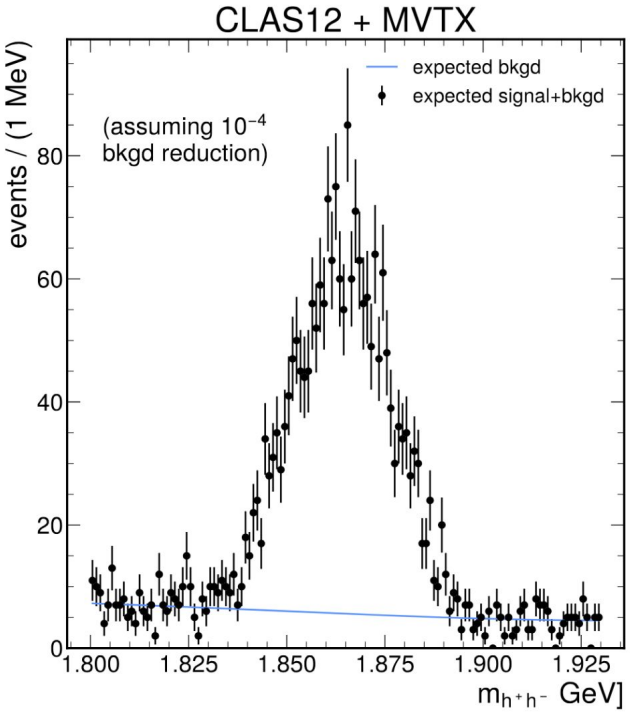
Comparison of background before/after MVTX

Pair background estimated from 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.



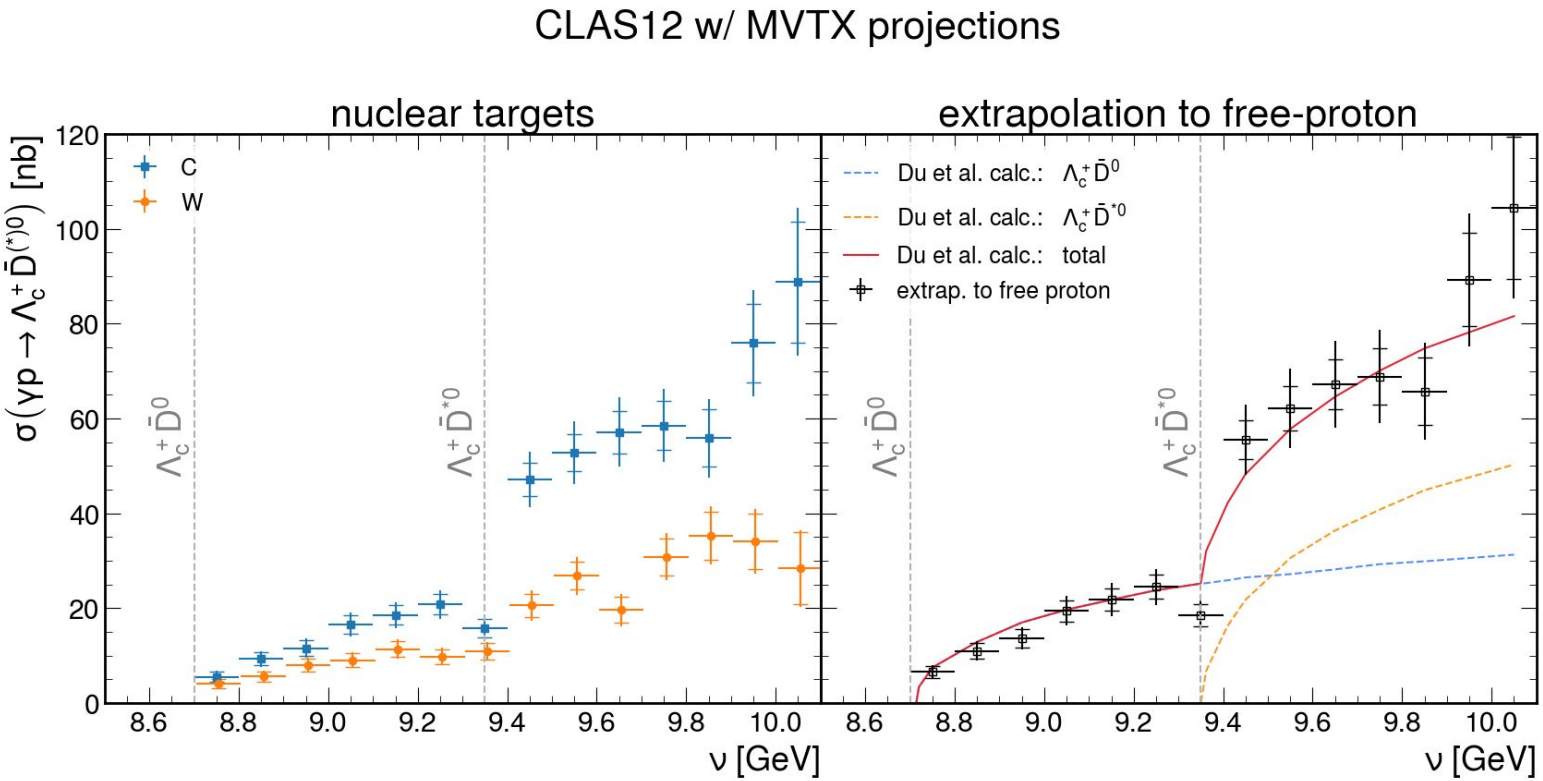


Systematic uncertainty

- Previous di-pion measurement* in CLAS12 had syst. uncertainties of 7.4%
- We make conservative assumptions about the amount of additional systematic uncertainty from signal extraction, and add these in quadrature
  - Mass-distribution fitting: 5%
  - Correction for vertex cut efficiency: 5%
- → Total systematic uncertainty estimate for measurements on C and W: 10%
- When extrapolating to the free-proton case, add additional 5% uncertainty

https://doi.org/10.1103/PhysRevC.109.065205

Projections



Expected Publications

- PRL+: “First Measurement of Open-Charm Production Near Threshold”
  - Just the cross-section data for the C and W targets

Follow-up papers:

- “Nuclear shadowing effects in open-charm production near threshold”
  - Comparison between C and W results; fitting to theoretical models
- “Open-charm production near threshold in γp scattering”
  - Extrapolation to the free-proton case

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.
- Beyond Standard Model tests:
  - High resolution on vertex position could be used for selecting dark photon candidates, if their lifetime is $c\tau \geq O(100\ \mu m)$
  - Could rule out some of the M vs ε^2 space without requiring a dedicated detector system or runtime.
- 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.
- Open to more suggestions from the Collaboration!

Conclusions

- Only an upper limit has been measured for open-charm production near threshold, unlike closed-charm (J/ψ) production
    - Open charm may reveal insights regarding J/ψ production processes.
- Open-charm near-threshold cross sections may be enhanced by diquark configurations in proton, and therefore serve as a useful probe for diquark.
- CLAS12+MVTX setup appears to be well suited for measuring open-charm production
- PAC proposal will be submitted this May
    - Looking for more authors to join our effort, and/or write other LoIs for other measurements in this run group.
- Further work:
    - Incorporate MVTX into GEMC, and confirm our estimates for its efficiency and vertex resolution

…

Thanks for feedback and support!

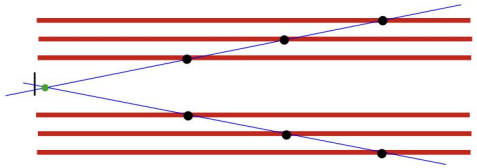
Ming Liu, Bryan McKinnon, Raphaël Dupre, Pierre Chatagnon, Miriam Diamond, Holly Szumila-Vance, Christopher Guthrie, Miguel Arratia, Yuri Gotra, Hayk Hakobyan, Bob Miller, Maurizio Ungaro

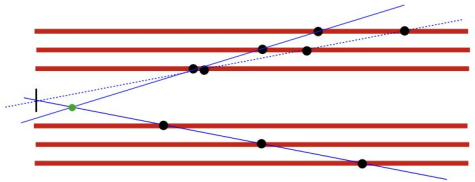
Backup slides

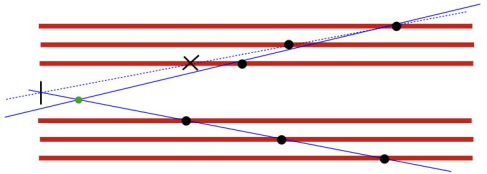
What percent of background events can we expect will pass the vertex cuts?

- Case 1: Both tracks are correctly matched between MVTX and DCs
    - 0.003% (probability of a gaussian distributed variable being 4σ from the mean)
- Case 2:One track is mismatched between the MVTX and DCs
    - 0.001% (estimated using fast MC)
- Case 3: One track contains a hit that does not belong to it, and the hit that should be in the track is missing
    - 0.004% (estimated using fast MC)

Bottom line: we estimate that less than 0.01% of non-open-charm events will pass the event-selection cuts.







Vertex cut efficiency

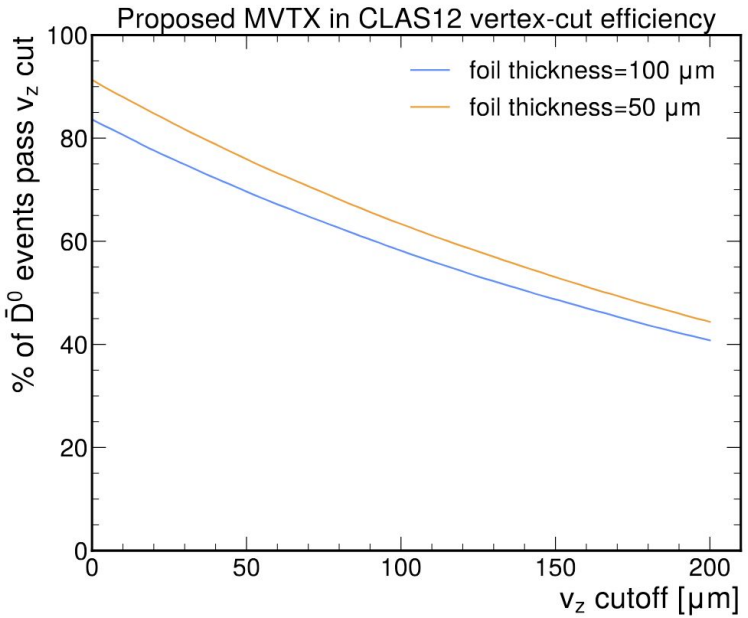


Figure 9: Efficiency for a displaced vertex cut for a $\bar{D}_0$ candidate produced with scattering off a 100 or 50 μm target, as a function of the vertex cutoff used for event selection.