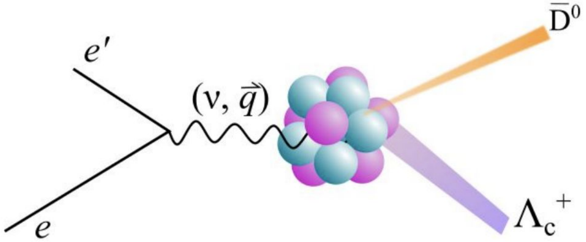
Open Charm at JLab with the sPHENIX MAPS tracker:

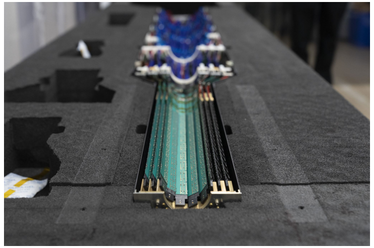


PR12-26-004-PAC 54

Dr. Sebouh Paul
Florida International University

7/6/2026

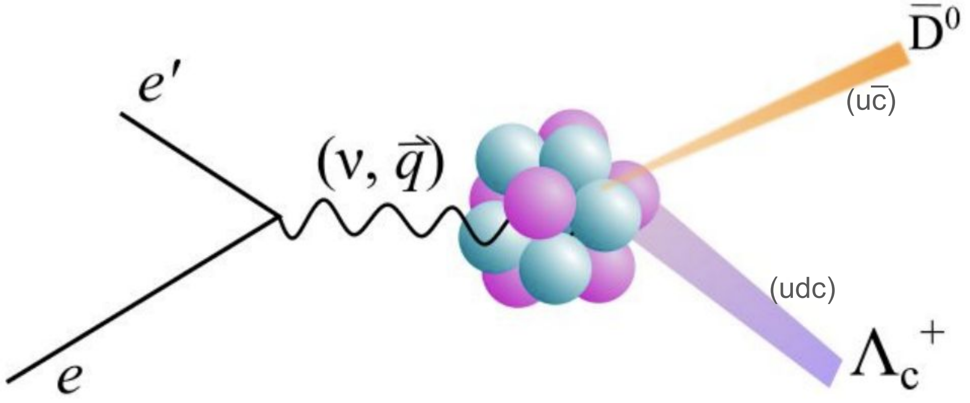
On behalf of the spokespersons
Meng-Lin Du (UESTC), Raphaël Dupre (SACLAY), Yuri Gotra (JLab), Ming Liu (LANL), Bryan McKinnon (U. Glasgow), Igor Strakovsky (GWU)



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 $\bar{D}^0\Lambda_c^+$
  - ν=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.**

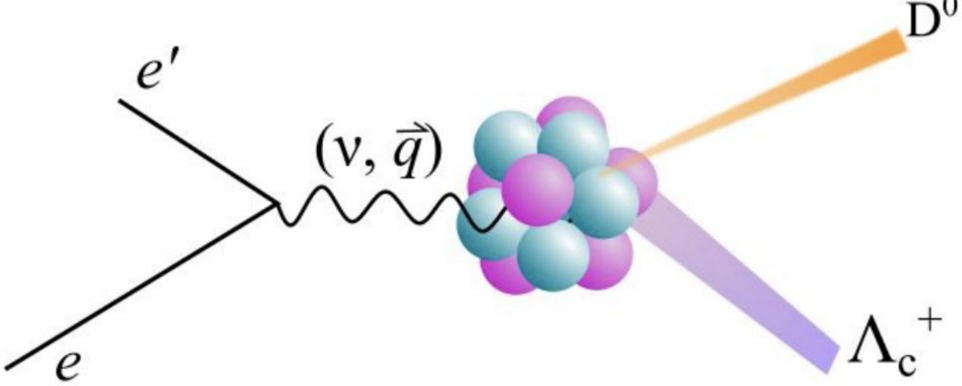
Open charm



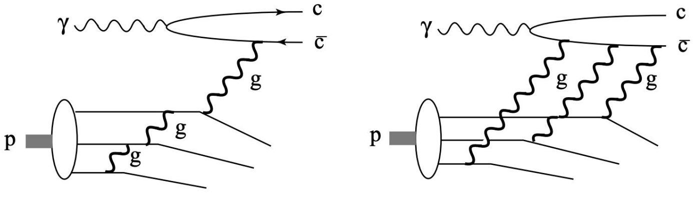
Motivation

- 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



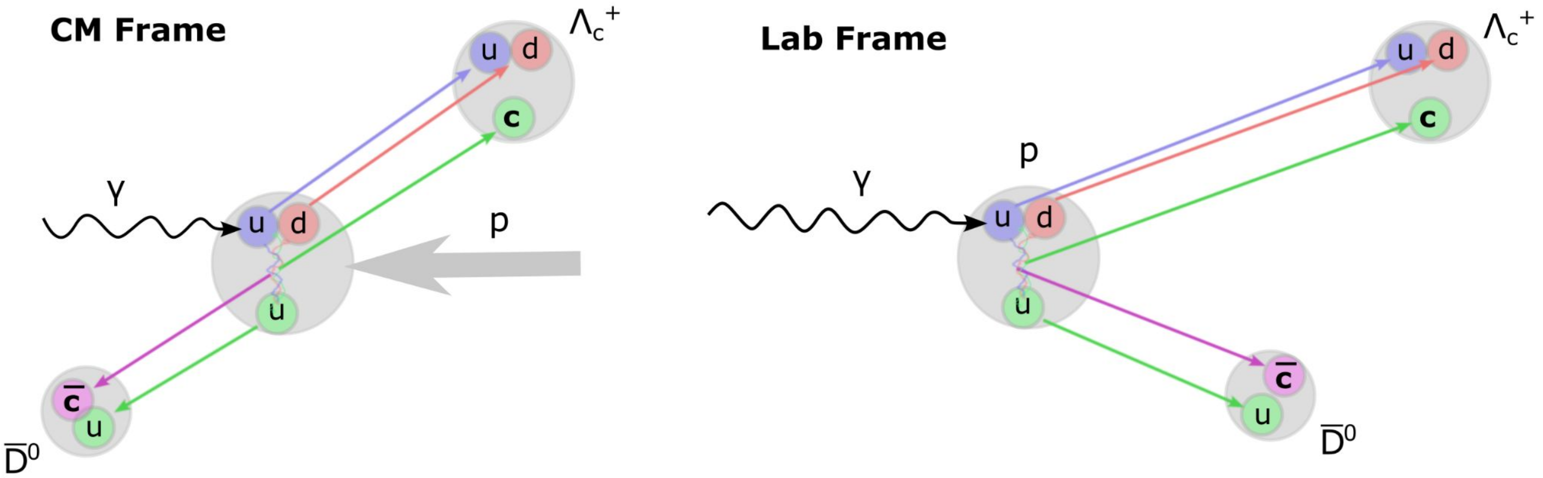
Hidden charm*



(a) *Phys.Lett.B498:23-28,2001 (b)

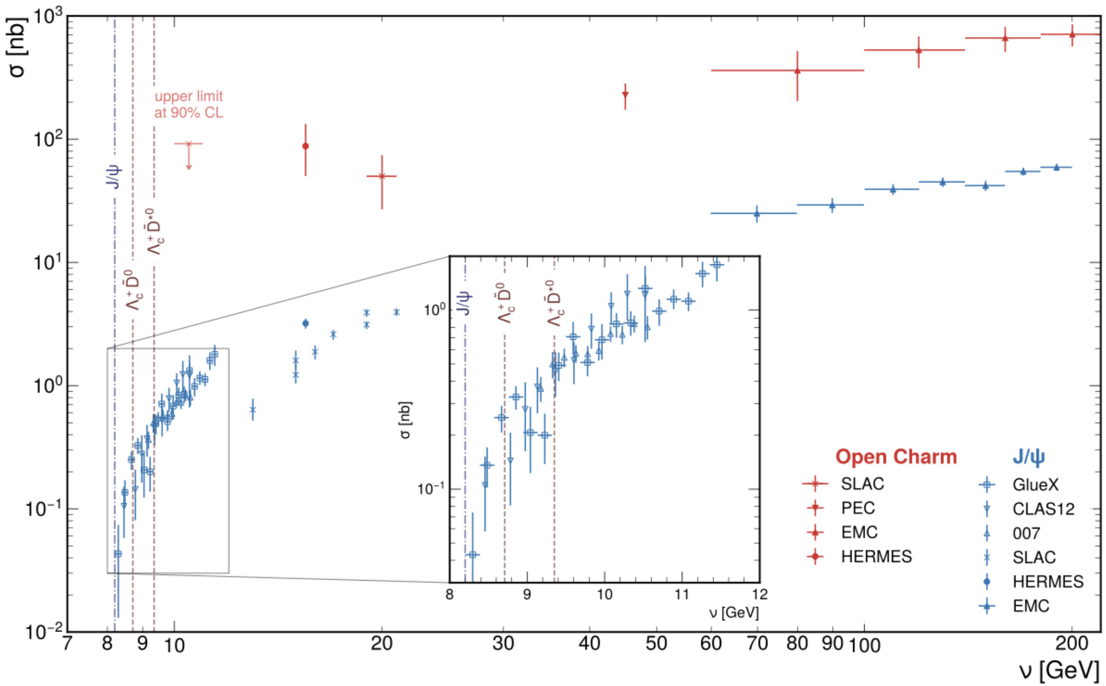
Enhanced cross-section due to di-quarks

- 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



Existing open and hidden-charm measurements

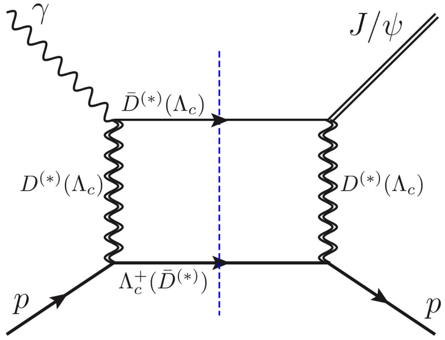
- A measurement by SLAC set *upper limit only* on cross section near threshold*
- Closest *non-zero* measurements are at about twice the threshold energy**
- For comparison, J/ψ has been measured near threshold at JLab by GlueX, 007, and CLAS12.
  - Open charm cross section expected to be one to two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

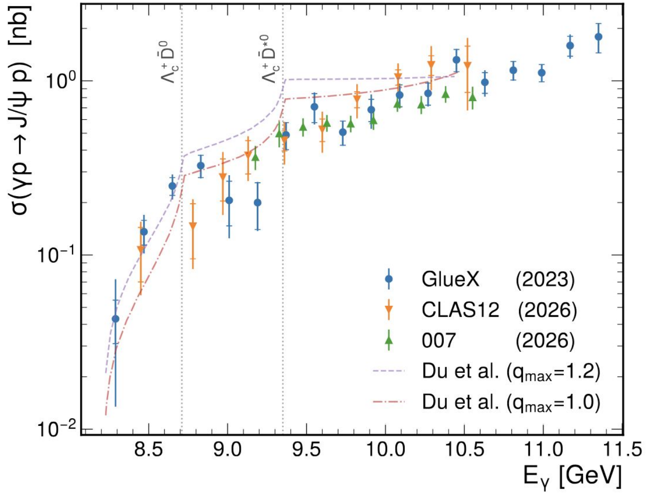


* http://doi.org/10.1103/PhysRevD.30.694

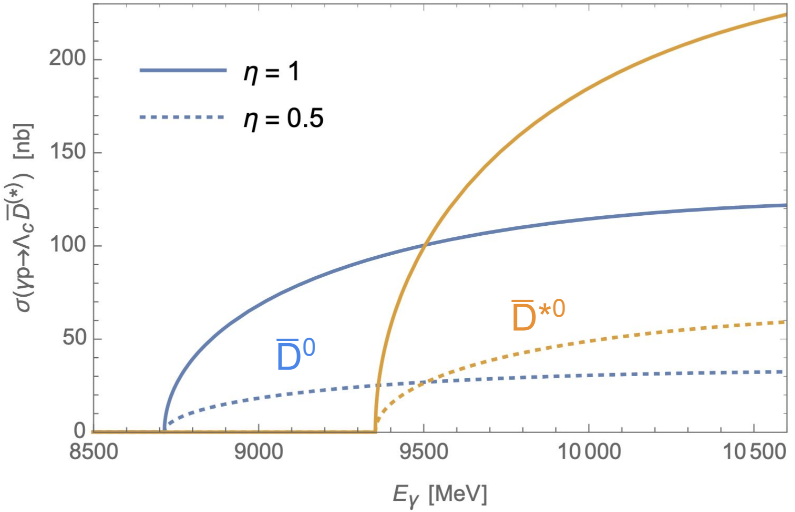
** doi.org/10.1103/PhysRevD.30.1 , https://inspirehep.net/literature/553290

What cross section do we expect?





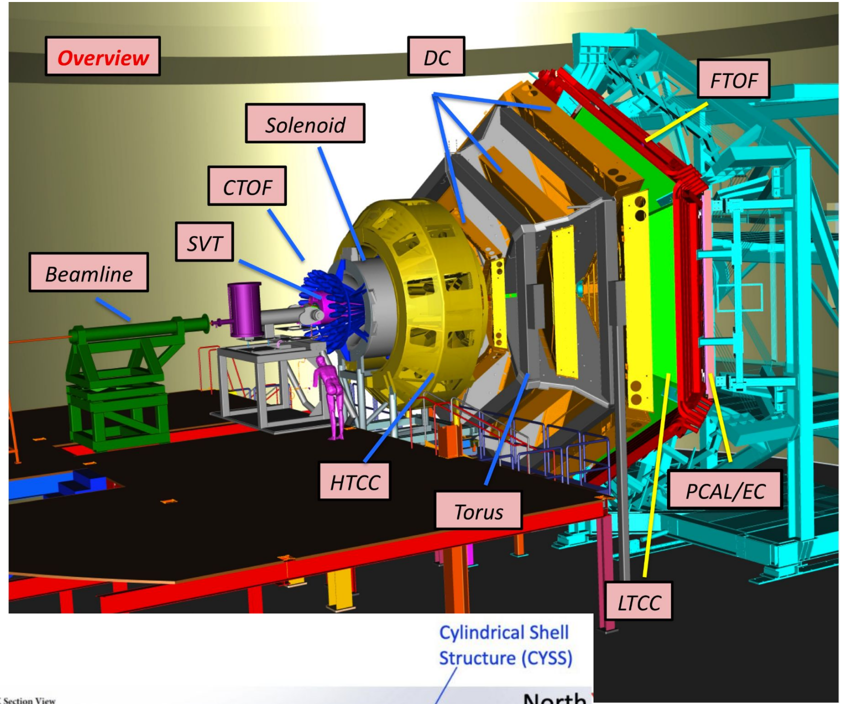
- M.-L. Du *et al** made predictions both open and hidden charm production near threshold
  - Recent J/ψ results show fair agreement with model.
- For open-charm, we use their lower estimate for our statistical projections
  - Agrees with independent predictions from Tomasi-Gustafsson**

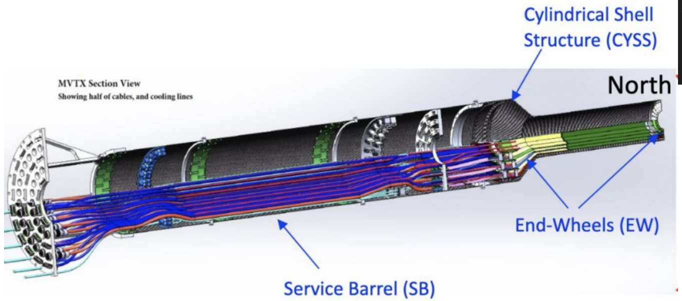


*https://doi.org/10.1140/epjc/s10052-020-08620-5
**https://arxiv.org/abs/hep-ph/0411295

Proposed measurement with CLAS12 detector + MVTX

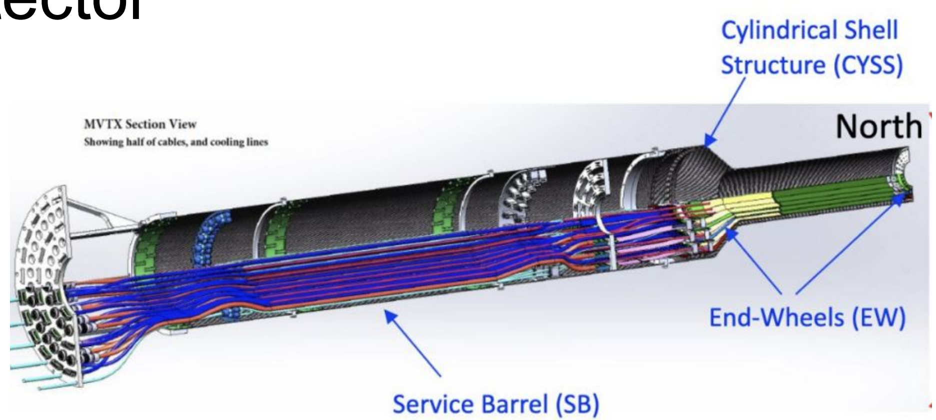
- Our detection strategy:
  - $\bar{D}^0 \rightarrow K^+\pi^-$ decay channel
  - Hadron pair with vertex displaced from a thin target foil, with pair mass consistent with $\bar{D}^0$
  - Inclusive $\gamma^*p \rightarrow \bar{D}^0 X$ measurement
  - No missing-mass cut
- 10.6 GeV e- beam, 45 nA (C+W)
- 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
- DAQ in streaming mode:
  - Data-reduction based on a triple coincidence between FT and two non-adjacent FD sectors
  - Estimated filtered data rate <1 kHz
  - Triggered DAQ with increased MVTX latency mode also an option



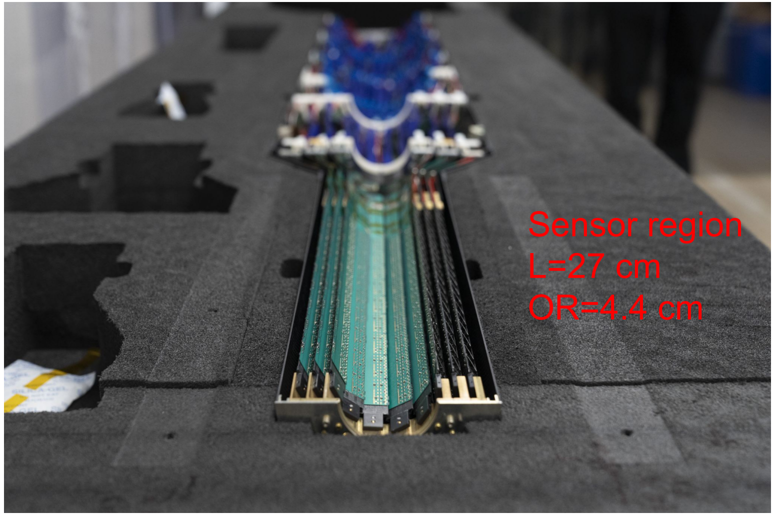


The MAPS Vertex (MVTX) Detector

- 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 $\overline{D}^0$ are ~200-400 μm
    - Requiring hadron pair to have vertices >4σ downstream of target should reduce background by at least 4 orders of magnitude



(L~120 cm, R~11 cm)



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.

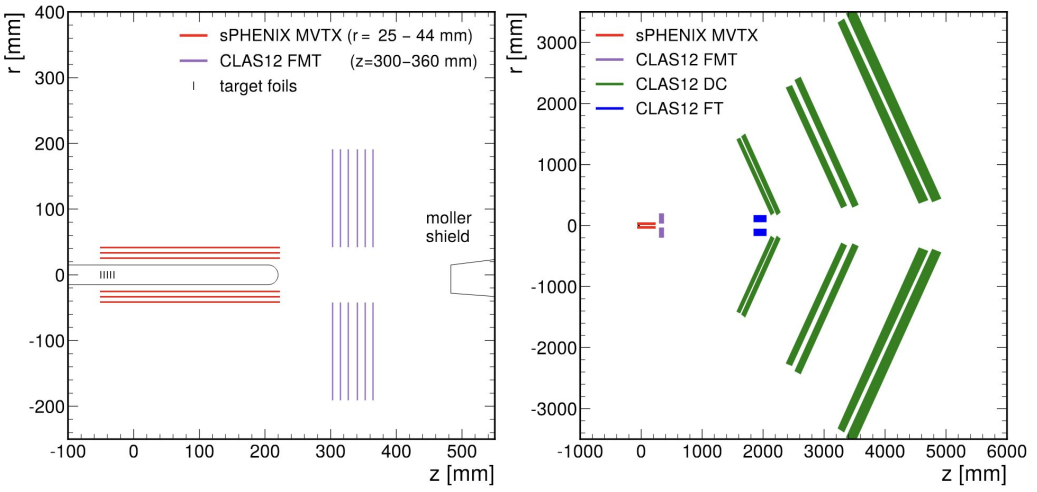
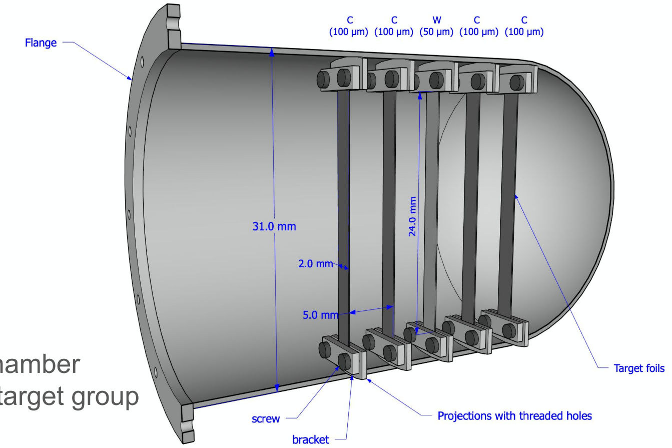


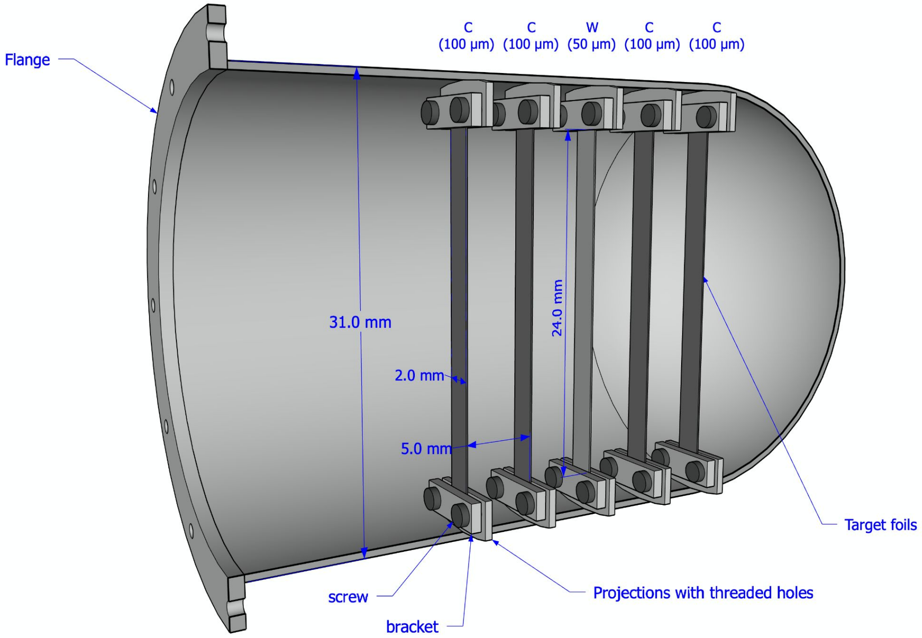
Figure 4: Placement of the MVTX inside of CLAS12. Left: zoomed-in view, right: zoomed-out view, showing the other detectors used in the proposed experiment.



Preliminary target chamber design reviewed by target group

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.
- 45 nA
- 1.4×10^8 nb^{-1} for each target type



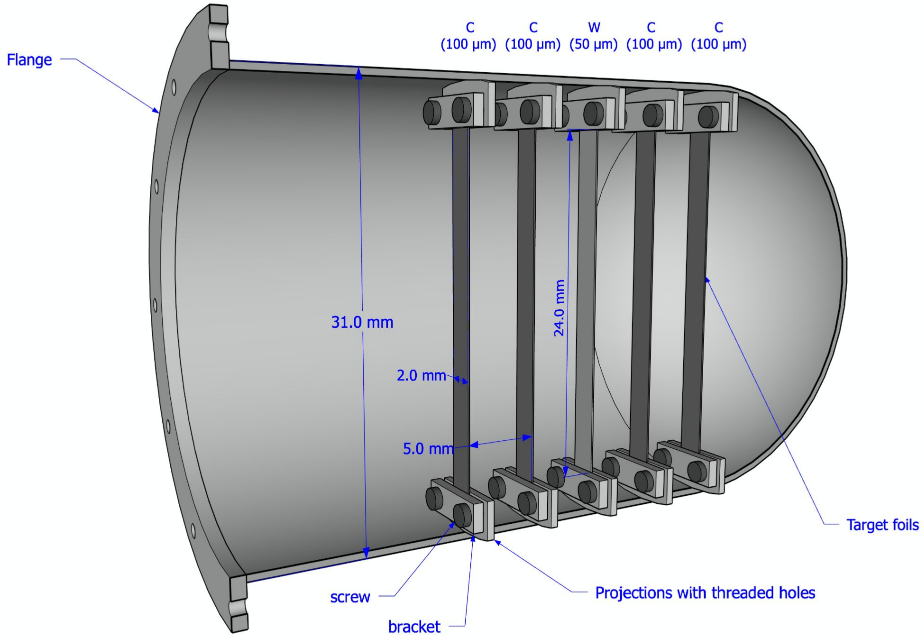
Preliminary target design, to be refined by the target group

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

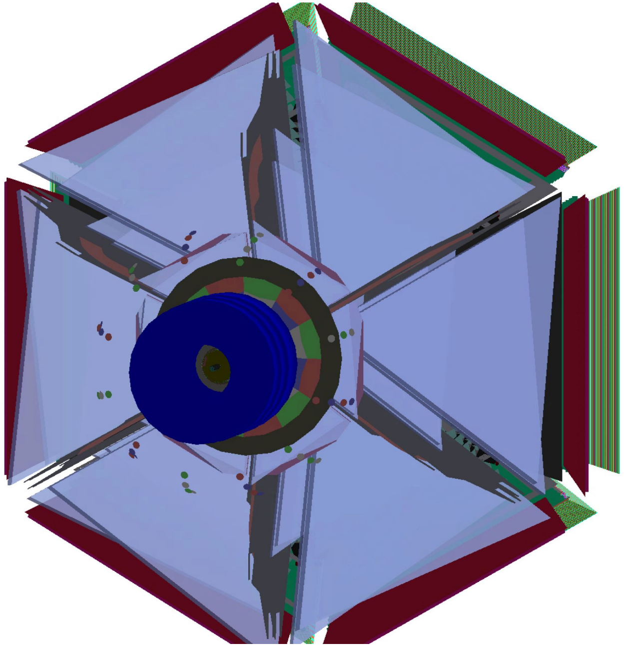
$$R_h \approx \exp\left(-cA^{1/3}\right) \implies \sigma_p = \sigma_C^{\text{corr}} \exp\left(\frac{A_H^{1/3} - A_C^{1/3}}{A_W^{1/3} - A_C^{1/3}} \times \log\frac{\sigma_W^{\text{corr}}}{\sigma_C^{\text{corr}}}\right)$$

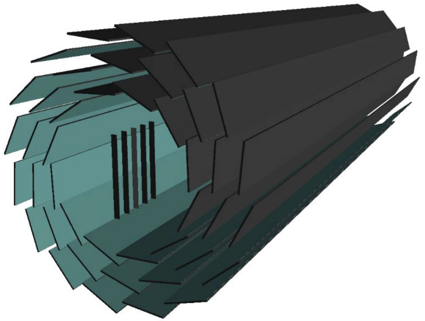


Preliminary target design, to be refined by the target group

Monte-Carlo simulations

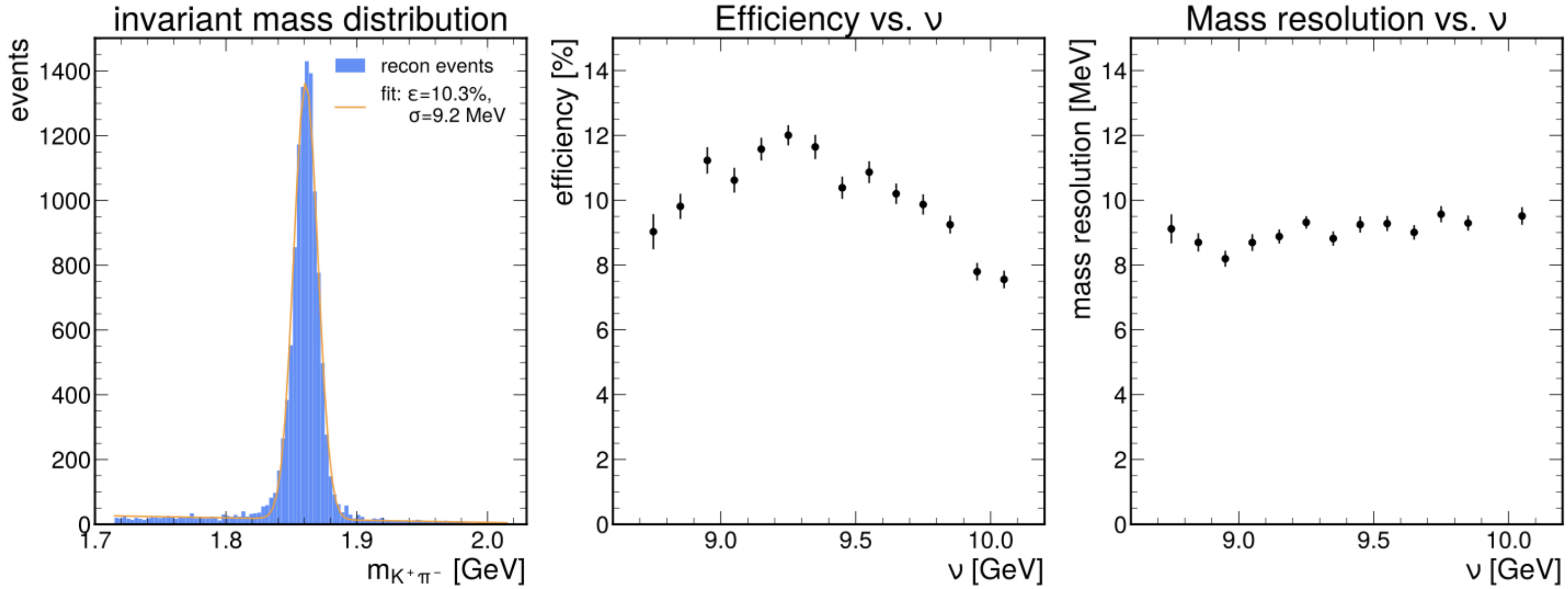
- Phase-space simulations at generator level
- Detector simulations with GEMC, with MVTX added to the CLAS12 baseline geometry
  - Geant4-based Monte-Carlo
  - Includes realistic multiple scattering of the hadrons in the target foils, MVTX, and CLAS12 baseline detector, realistic field maps, and readout emulation for CLAS12 baseline detector
  - Resolution effects for MVTX added in post.





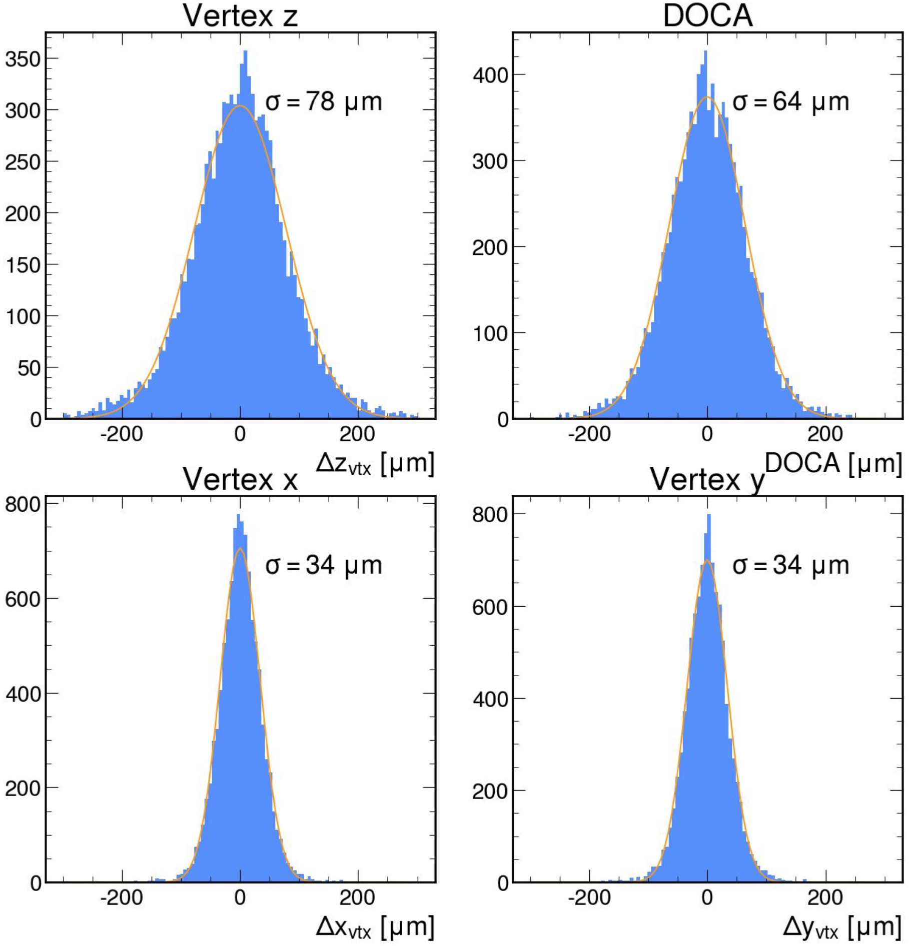
CLAS12 acceptance and mass resolution from GEMC

- Combined efficiency and acceptance for e- K^+ π^- is around 10.3%
- Mass resolution ~ 9.2 MeV



Vertex resolution

- Resolution on the z position of the vertex is 78 μm
  - Large contribution due to multiple scattering inside the support material of the MVTX*
- 4σ cut at ~312 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

Estimation of signal rates

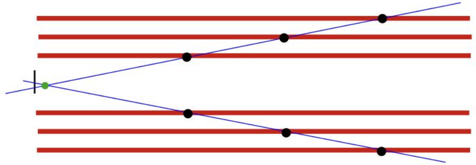
Quantity	C	W	notes
free-proton cross-section [nb]	0.0082		$\sigma_{\gamma p}$ calculated from Ref. [20], $\eta = 0.5$, converted to σ_{ep} Eq. (9)
Z/N	0.50	0.40	
Nuclear effects	0.85	0.55	Estimated from CLAS [57] and HERMES [56] hadron mulitplicity ratios
Tot. luminosity [nb^{-1}]	1.4×10^8	1.4×10^8	200 days, 50% PAC efficiency, 3.2×10^{34} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$, 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 [64]
Detector acceptance/efficiency	10.3%		GEMC simulation
v_z cut	28%	30%	assuming 100 (50) μm C (W) foils, cut at 312 μm
Tot. expected signal events	530	310	

Table 3: Factors and assumptions that go into the calculations for the total expected yields (bottom row).

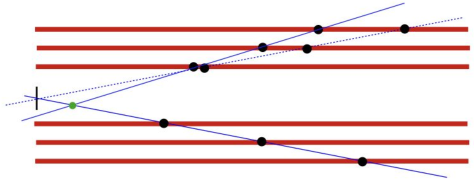
*Updated based on PAC feedback

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

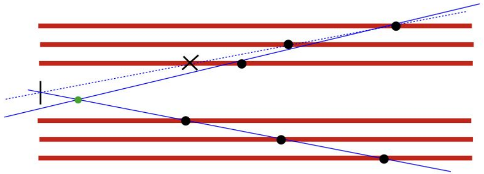
- Case 1: Both tracks are correctly matched between MVTX and DCs: 0.003%



- Case 2: One track is mismatched between the MVTX and DCs*: 0.005%



- Case 3: One track contains a hit that does not belong to it, and the hit that should be in the track is missing: 0.0004%



Background reduction > 10^4.

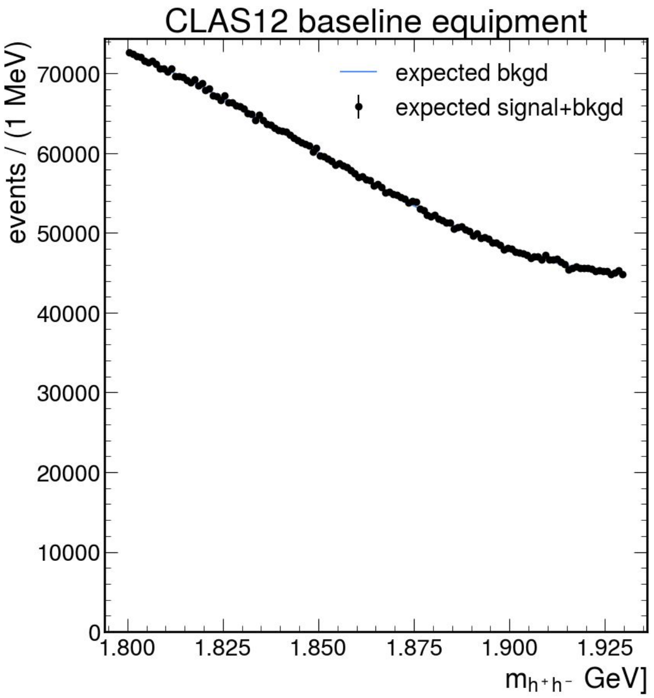
*Estimate updated using GEMC, based on PAC feedback

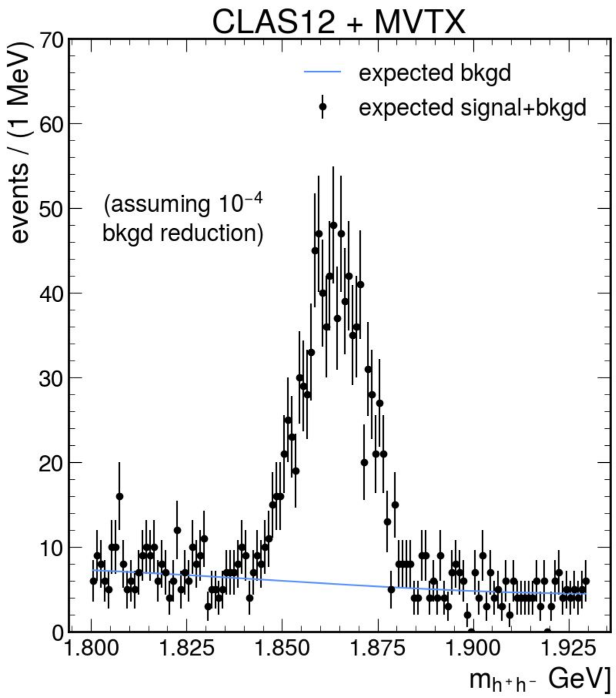
Comparison of background before/after MVTX

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

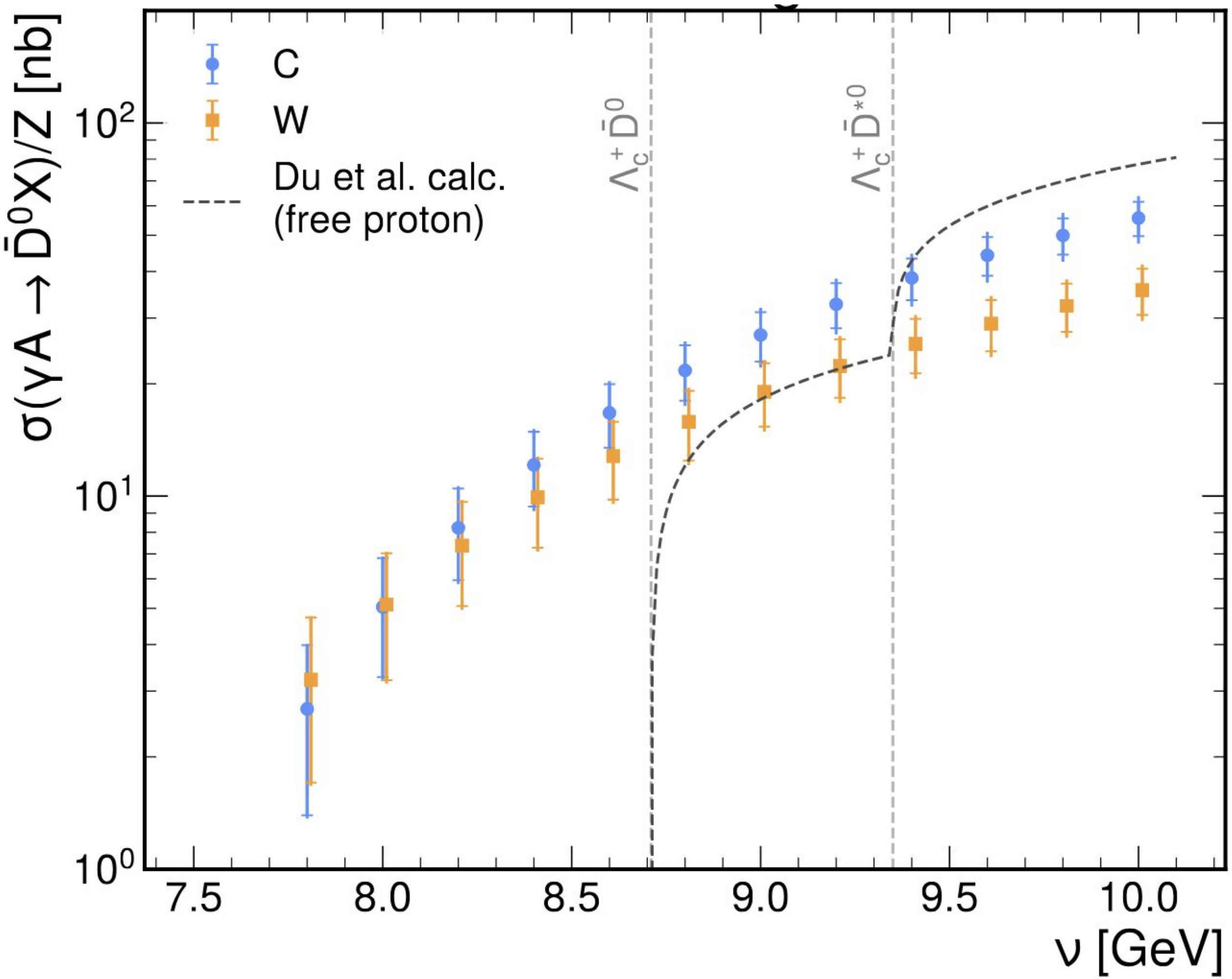
MVTX is *required* for reducing this background to a manageable amount.





*Updated based on PAC feedback

Projections



*Updated based on PAC feedback

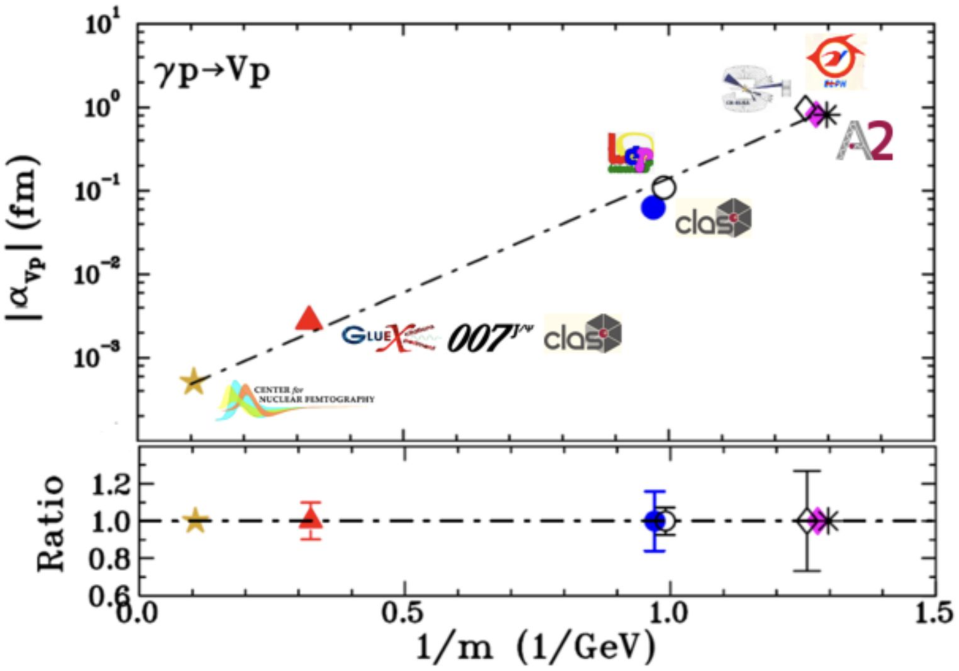
Conclusions

- 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

Backup slides

Relation to scattering length analysis

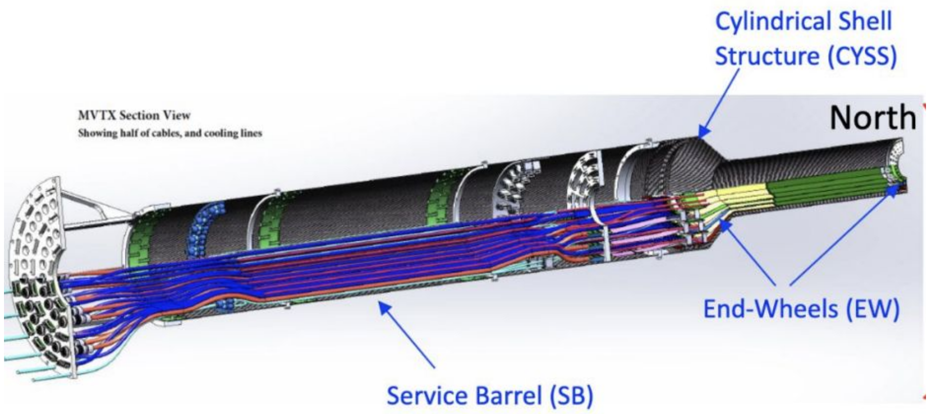
- Scattering lengths for vector-meson on proton scattering determined from $\gamma p \to Vp$ scattering show a linear trend for $1/m_V$ versus $\log|\alpha_{Vp}|$.
    - Will this trend persist for other meson-baryon combinations such as $\bar{D}^0\Lambda_c^+$ or $\bar{D}^{*0}\Lambda_c^+$?

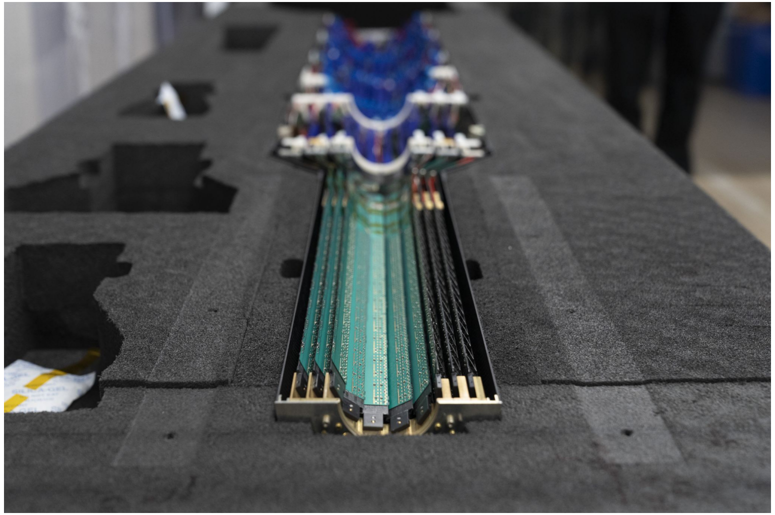


https://arxiv.org/abs/2603.09622

Equipment loan

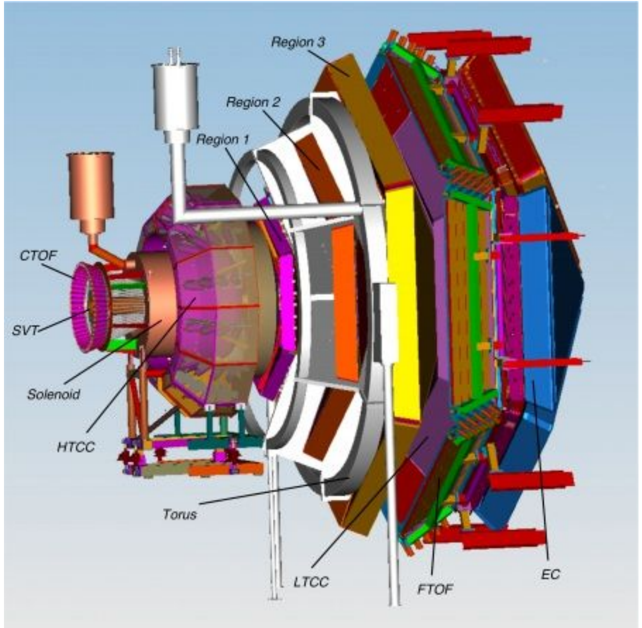
- MVTX currently being transferred ownership from BNL to LANL, where it was initially developed
- Loan from LANL would include
  - The MVTX detector in its support/service barrel
  - Cables for power and readout
  - Power units
  - Front-end readout
  - Chiller system
  - Spare cables/power units and 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

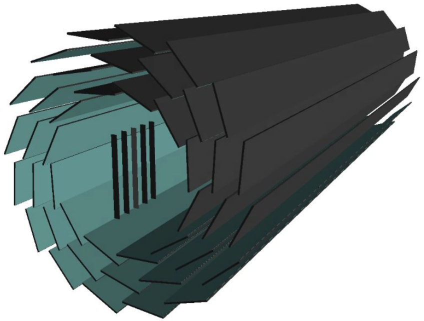




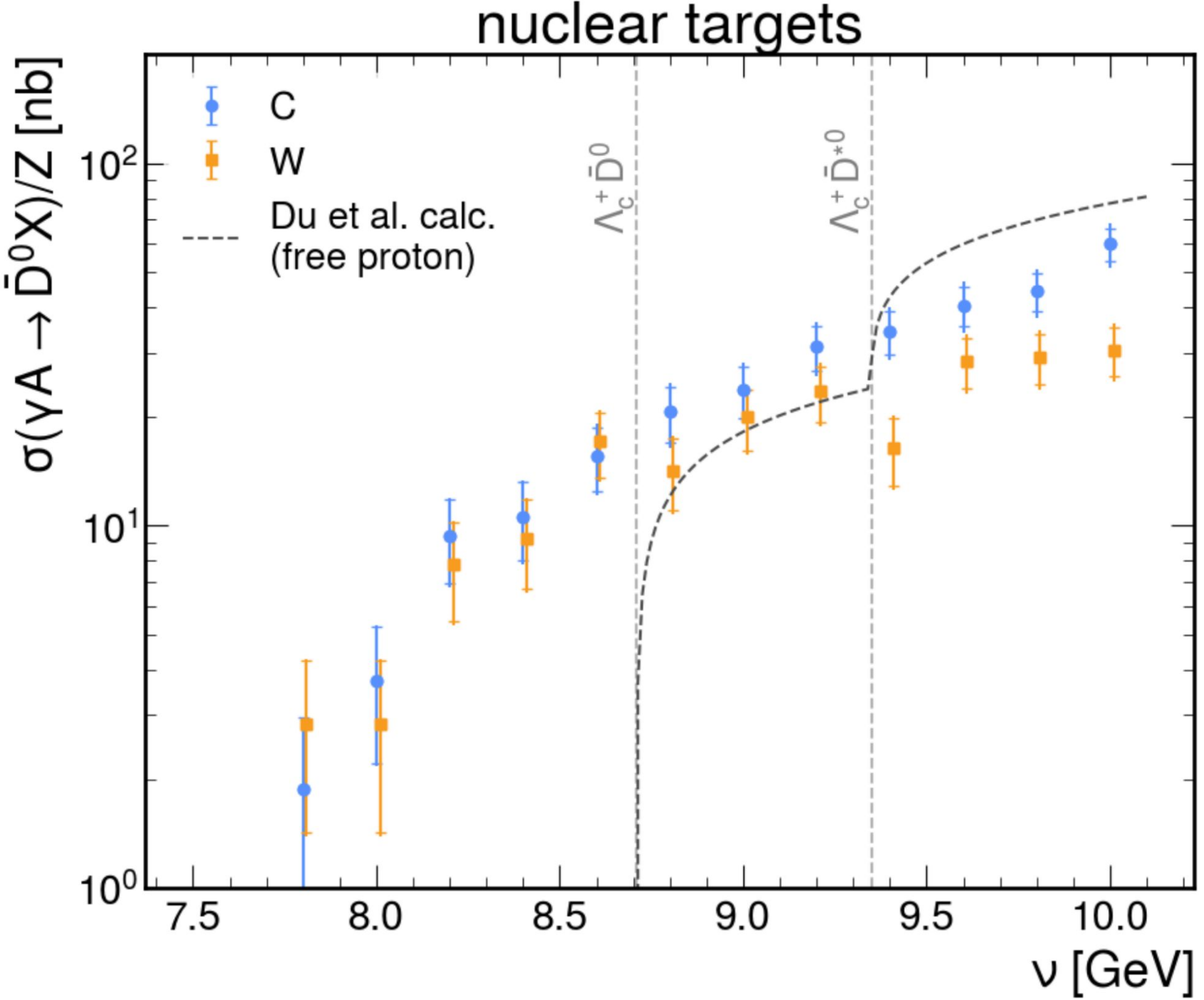
Recon of Monte-Carlo simulations

- 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

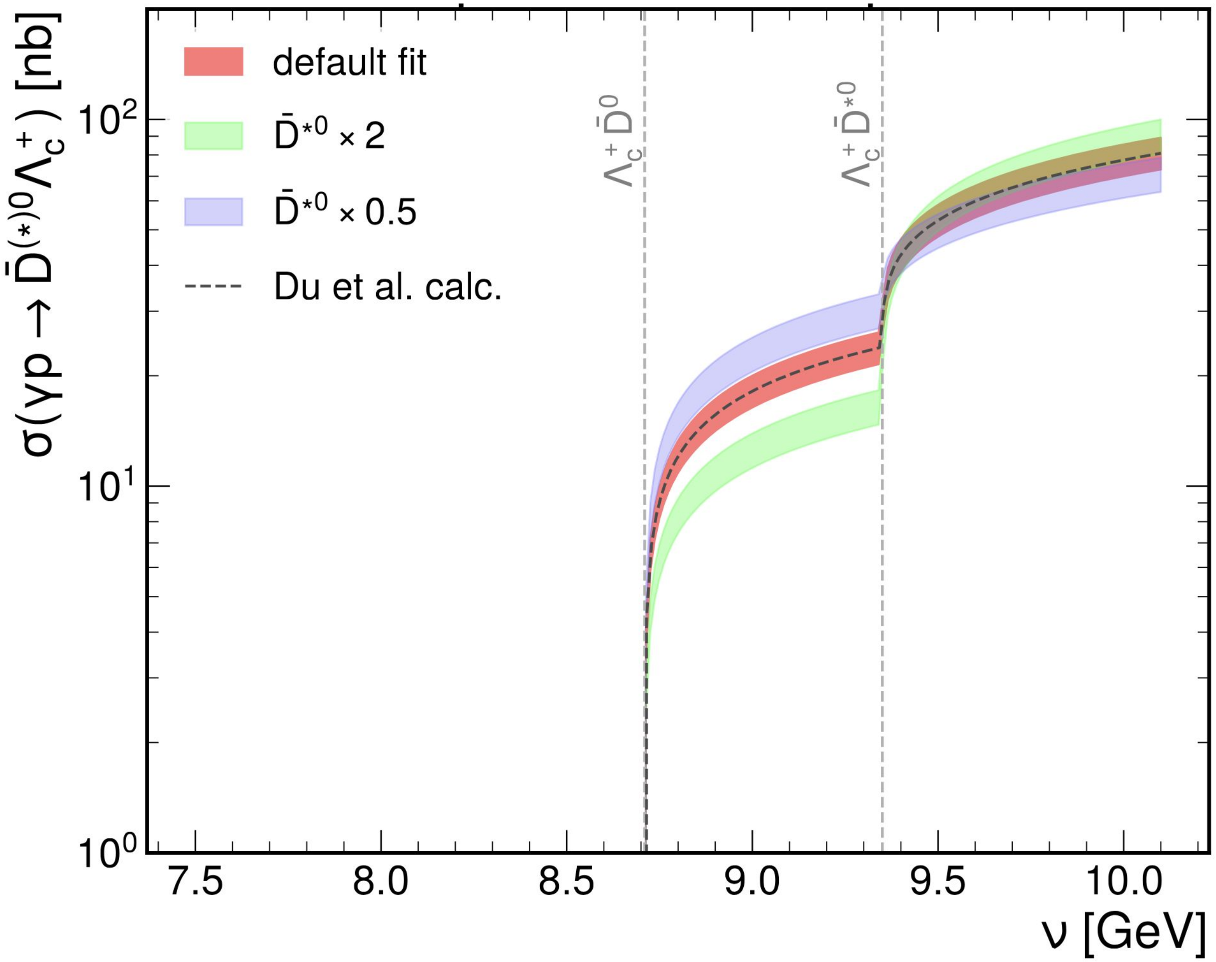




Projections (raffled)

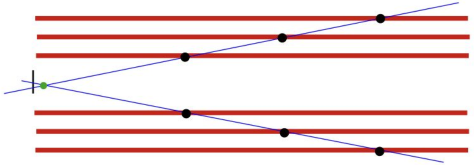


Projections
for extrapolation
to free proton

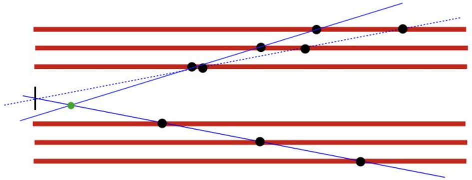


What percent of background events can we expect will pass the vertex cuts? details

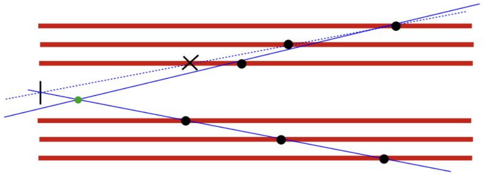
- Case 1: Both tracks are correctly matched between MVTX and DCs
  - 0.003% (probability of a gaussian distributed variable being 4σ from the mean)



- Case 2: One track is mismatched between the MVTX and DCs
  - 0.005% (estimated by combining tracks from different events with one another, and checking if the pair pass the vertex cuts).



- Case 3: One track contains a hit that does not belong to it, and the hit that should be in the track is missing
  - 0.0004% (estimated based on the expected density of hits in the innermost layer, expected resolution of extrapolation, and probability of missing the correct hit).



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

*Updated based on PAC feedback

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:

- “Excited-state production in open-charm production near threshold”
    - Determining the fraction of the events from the first paper in which the $\overline{D}^0$ comes from the $\overline{D}^{*0}$ decay by finding the π^0 or γ produced in the decay of the excited state.
- “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.
- Inclusive Λ_c^+ measurement
    - Corroboration for the inclusive $\overline{D}^0$ measurement, since Λ_c^+ and $\overline{D}^0$ would be formed together in these reactions
    - Inclusive cross sections for Λ_c^+ and $\overline{D}^0$ may differ from one another due to different FSI.

Systematic uncertainty

- Previous di-pion measurement* in CLAS12 had syst. uncertainties of 7.4%
  - 5% from normalization
  - 5% from inclusive radiative corrections
- 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, additional uncertainties come from correcting for the Fermi motion (model-dependent) and absorption effects

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

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)