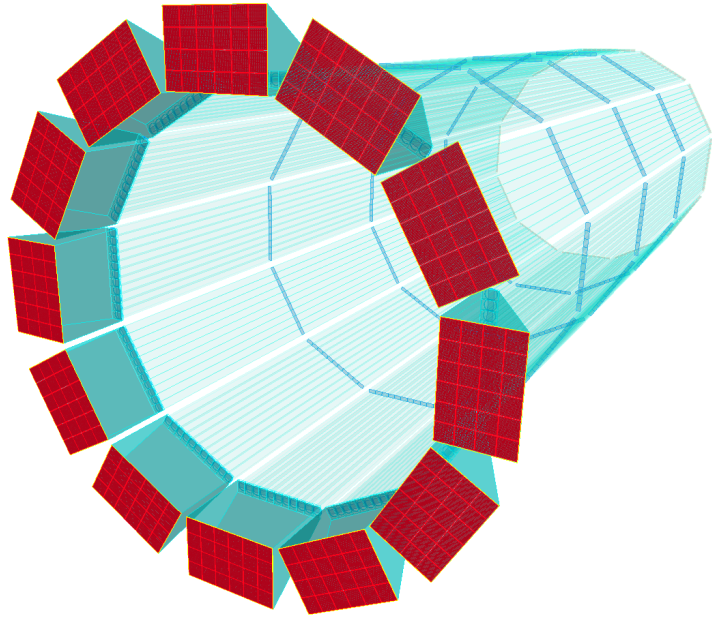
eRD103: The High-Performance DIRC

Directed R&D Program to Mitigate Key Risks for the ePIC DIRC Detector

- BaBar DIRC bars reuse
- hpDIRC Prototype in CRT
- hpDIRC from concept to ePIC barrel PID



Greg Kalicy CUA

August 28th, 2024

eRD103 hpDIRC Group

C. Ayerbe Gayoso, J. Datta, K. Dehmelt, A. Deshpande, R. Dzhygadlo, A. Garrett,
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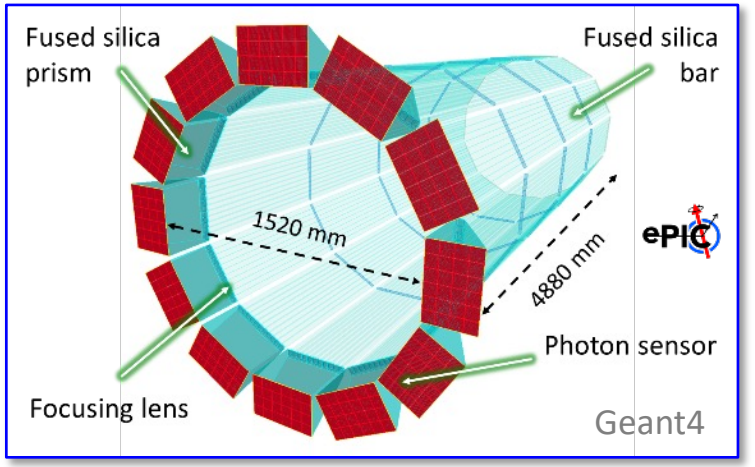
CUA FAU GSI Jefferson Lab Old Dominion University of South Carolina Stony Brook University

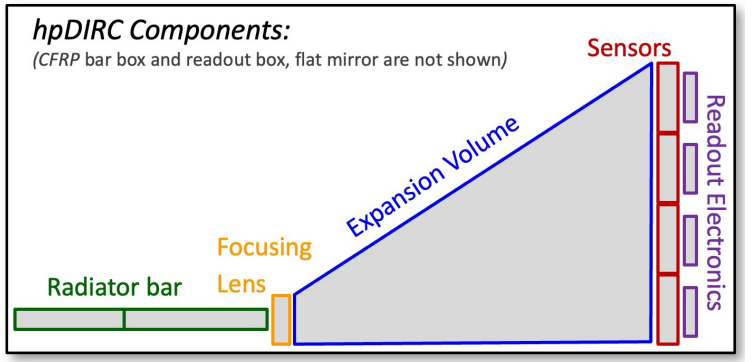
HPDIRC OVERVIEW

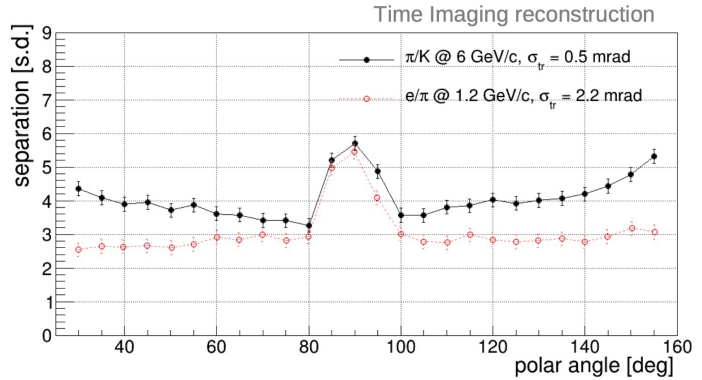
Compact fused silica prisms, narrow bars, 3-layer spherical lenses

- Barrel radius: 762 mm, 12 sectors, 10 long bars per sector
- Reuse bars from decommissioned BABAR DIRC, supplemented by new bars/plates
- Focusing optics: innovative radiation-hard 3-layer spherical lens
- Compact expansion volume: 30 cm-deep solid fused silica prism
- Readout system:
  - Small-pixel MCP-PMT sensors (~3 mm pixel pitch, e.g. Photek or Incom)
  - Fast ASIC-based readout (e.g. EICROC or FCFD)
- Full Geant4 simulation based on validated PANDA Barrel DIRC code is base for all hpDIRC simulation studies

  (joint EIC/PANDA CERN beam tests 2015-2018)
- Preparation towards TDR readiness
  - Several final decisions to be made this fall/winter







HPDIRC RECENT ACTIVITIES

hpDIRC prototype in Cosmic Ray Telescope (CRT):

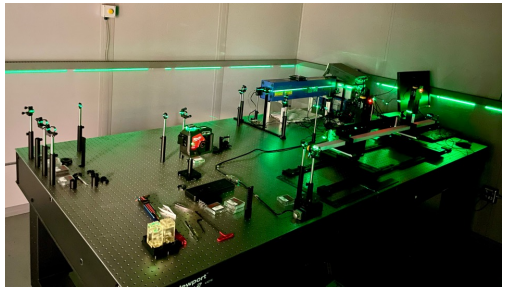
- CRT construction in final stage at SBU to become test bench for incremental upgrades of new components (bars, sensors, readout electronics, eventually full hpDIRC modules)

hpDIRC prototype at SBU

Validation of the BaBar DIRC bar reuse:

- Bar boxes transferred from SLAC to JLab in April 2024
- Preparations for disassembly and QA at JLab are in advanced stage
- Decision on reuse of bars expected by Q1-Q2/2025

QA lab at JLab

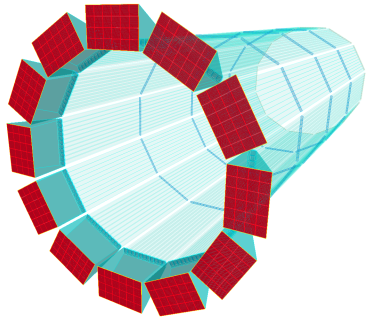


Disassembly setup at JLab

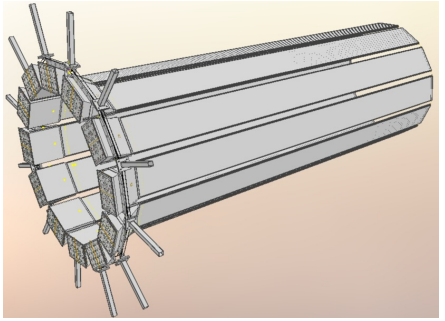
Ongoing hpDIRC studies in simulation:

- Light-guide, prism, sensor coverage design optimization

hpDIRC in Geant4



hpDIRC in CAD



Mechanical Design and Integration:

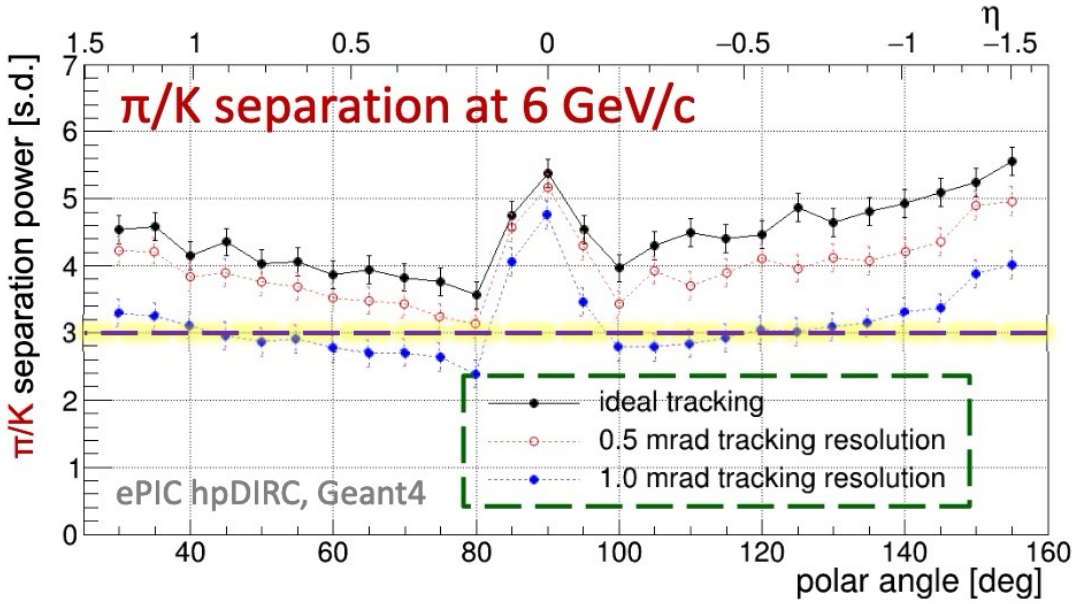
- Work with two engineers and synergies with PANDA Barrel DIRC

HIGH-PERFORMANCE DIRC PERFORMANCE

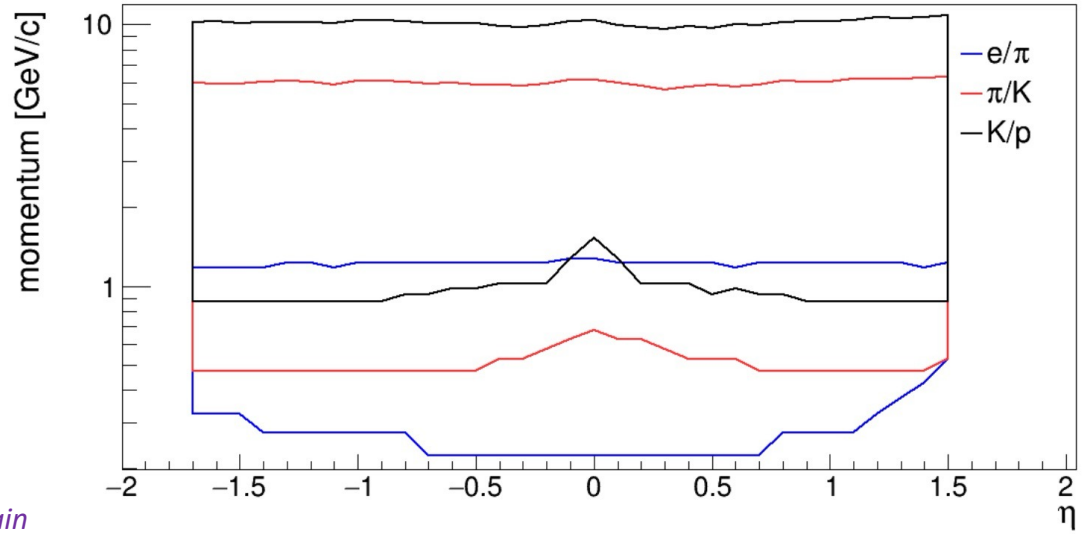
- hpDIRC performance studies:

  (Detailed Geant4 simulation fully validated with test beam data)

  - Studies with particle gun in whole required angular range
  - Impact of realistic ePIC magnetic field map
  - Studies with Pythia physics events
  - Impact of multiple tracks per event in single bar
  - Detailed PID LUT with threshold mode
  - Most studies assumed 0.5 mrad angular tracking resolution at 6 GeV/c but software ready to import and include detailed parametrization of tracking



3 sigma s.d. PID efficiency contours for hpDIRC at ePIC

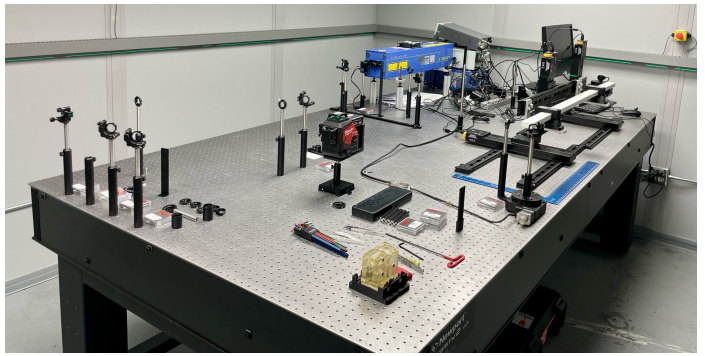


Roman Dzhygadlo, Nilanga Wickramaarachchi, Bill Llope, Md Imran Hossain

Reuse of BaBar DIRC Bars

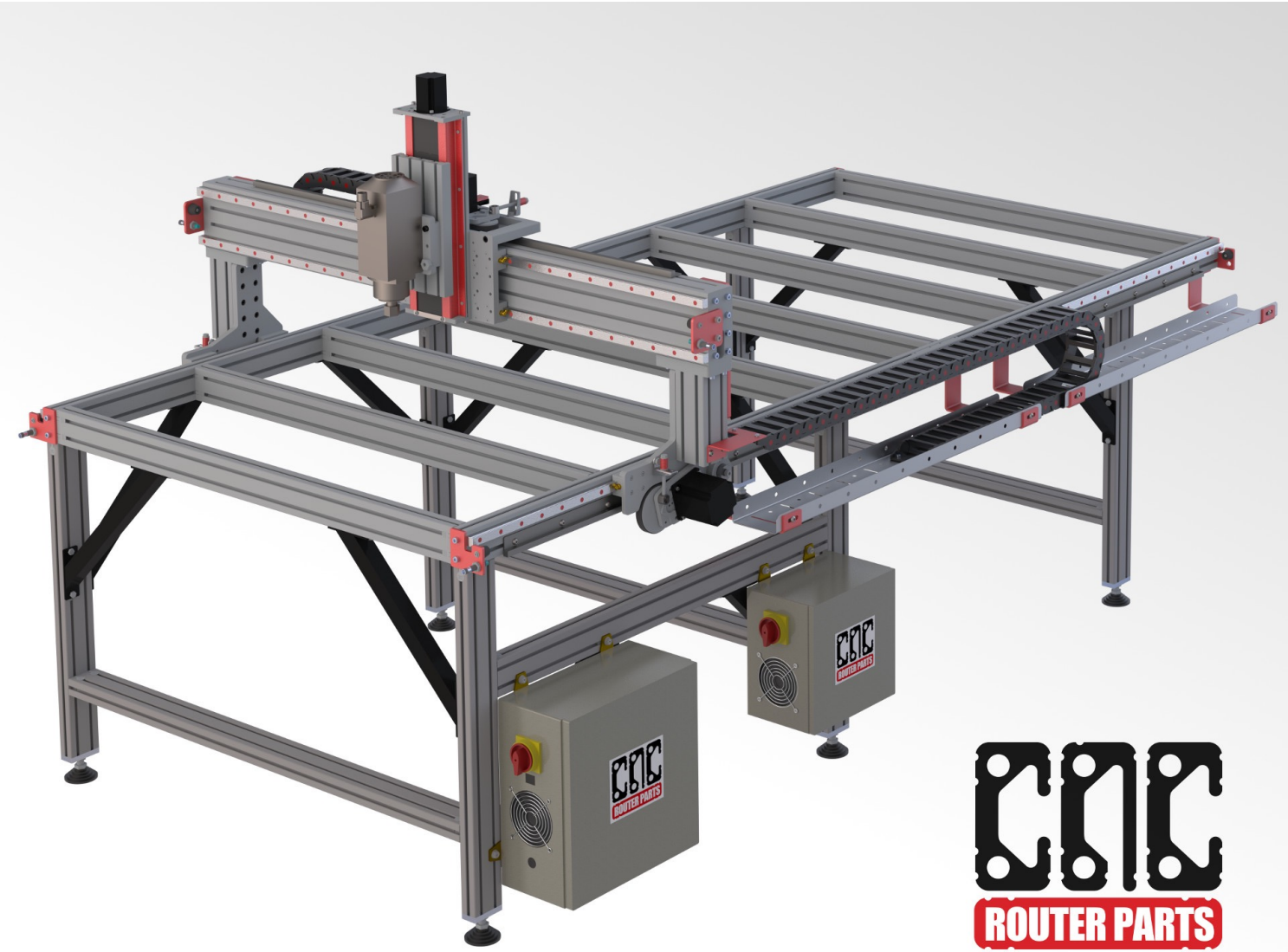
- Bar boxes will be disassembled into individual bars at JLab (starting in Winter)
  - Never done before, working on detailed plan
  - Aluminum covers will need to be ”opened”, glue joints between bars decoupled using heat gun
- Optical quality of bars after disassembly will be evaluated in QA DIRC lab, located next to disassembly tent
- QA DIRC lab close to ready for commissioning
- Reference DIRC bars (never used in BaBar) from SLAC available for commissioning and as reference
- QA Lab will consist of three parts:
  - Cleaning/inspection station
  - Darkroom with laser setup to measure quality of DIRC bars
  - Storage (long and short-term)
- Reflection coefficient measurement to evaluate surface quality

QA Laser Lab



DIRC labs under construction at JLab EEL108

Preparation for the Disassembly



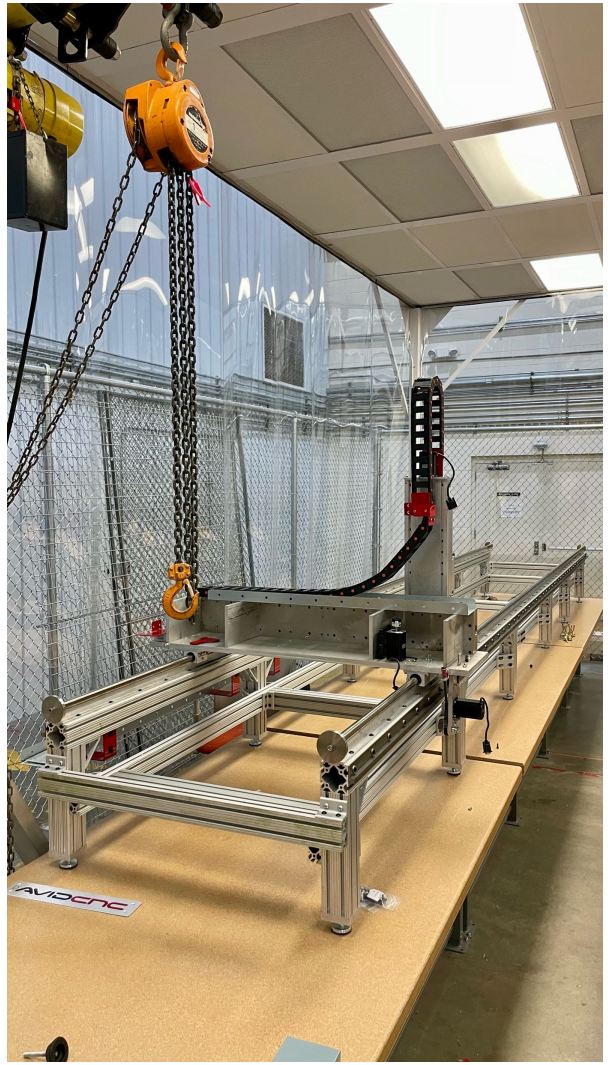
Custom-made support structure and CNC

- Y-Axis linear rails (Thompson rails)
- X-Axis actuator (Ball screw) and Al. support plate
- 80/20 support frame
- 4 hp air cooled spindle
- Multiple E-stops
- Dust collector system
- Guards
- Mach 4 software
- End stops & Proximity sensors

Andrew Lumanog, Caleb Graham, Greg Kalicy

Preparation for the Disassembly

Customized CNC setup under construction

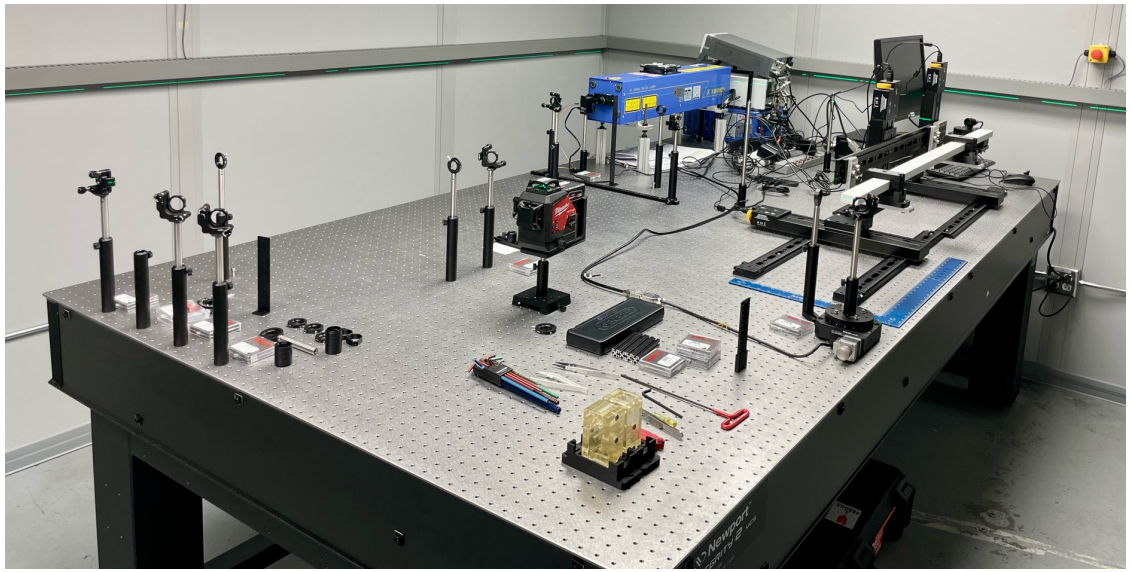


LASER QA SETUP FOR DIRC BARS

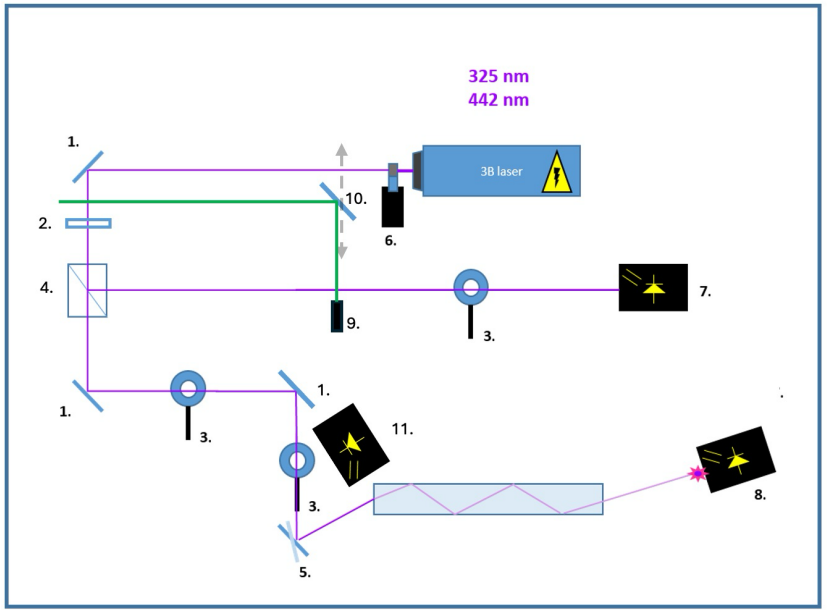
- Laser setup built in JLab based on similar setup at GSI for PANDA Barrel DIRC
- Reflection coefficient measurement will allow to evaluate surface quality of the bars with sub nm precision
- HeCd laser with two wavelengths will be used (325 nm, 442 nm)

QA laser setup during alignment

Photo of QA laser setup during installation



Schematic of the QA laser setup in JLab



1. Mirrors
2. Polarizing cube
3. Diaphragms
4. Beam splitter
5. Brewster mirror
6. Low power filter
7. Reference diode
8. Value diode
9. 532 nm laser pointer
10. Movable mirror on rail
11. Brewster Assurance Diode

Tyler Lemon, Greg Kalicy

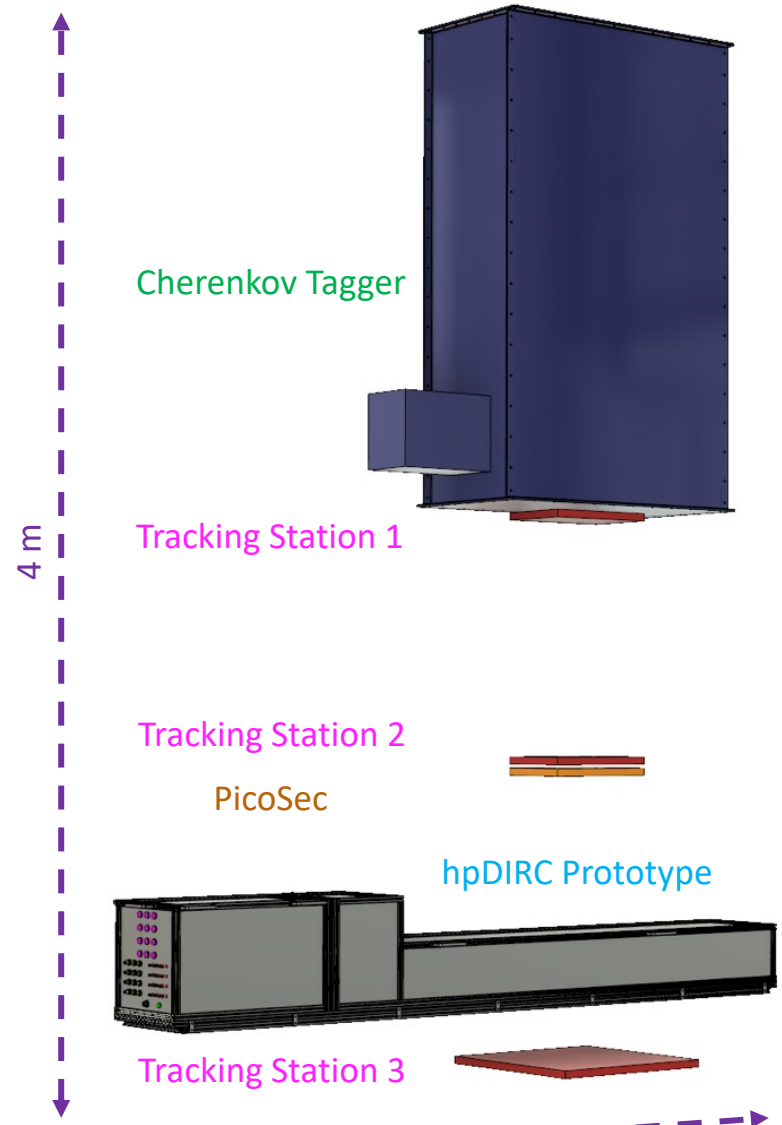
HPDIRC PROTOTYPE IN CRT

Cosmic Ray Telescope (CRT) at SBU

Facility to test incremental upgrades of prototype components, performance evaluation

- Initial PANDA Barrel DIRC-based prototype to commission setup
- Modular design will allow to add new ePIC hpDIRC components once they become available
- Cherenkov Tagger to select muons above 3.5 GeV/c
- Three tracking stations for high-precision 3D-track reconstruction
- PicoSec detector for event timing
- Geant4 simulation used to optimise setup arrangement

CRT setup CAD schematic



Nathan Shankman, Jaydeep Datta, Carlos Ayerbe-Gayoso, Alex Garrett, Charles Hyde, Roman Dzhygadlo, Greg Kalicy, Klaus Dehmelt, Joe Schwiening

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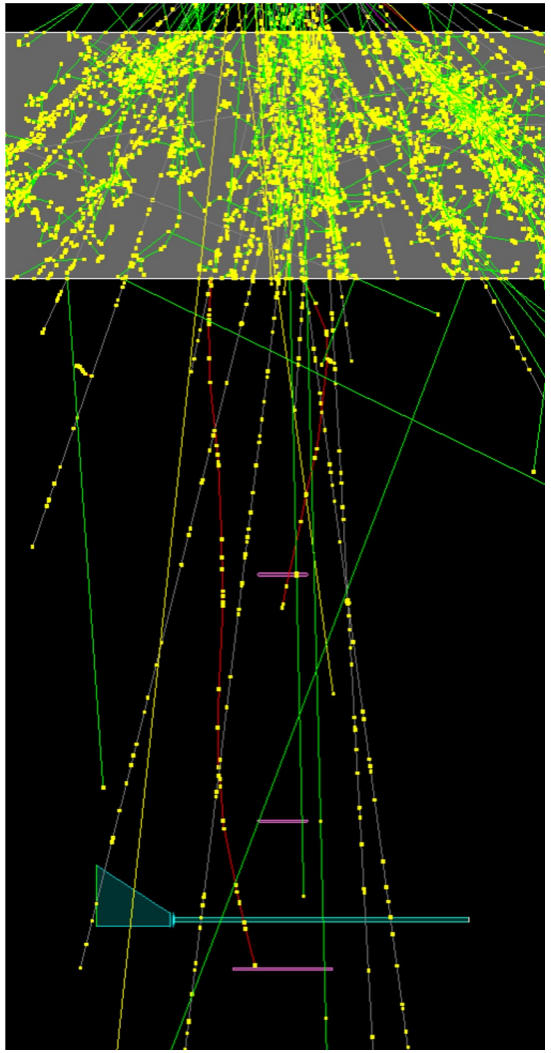
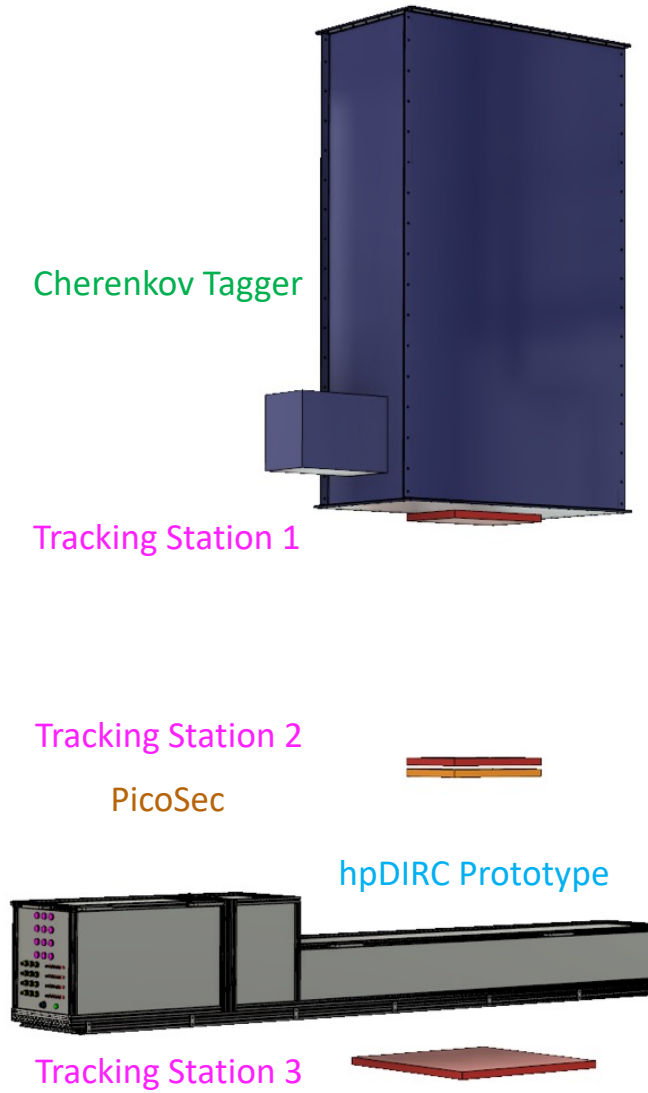
Geant4 simulation of CRT setup



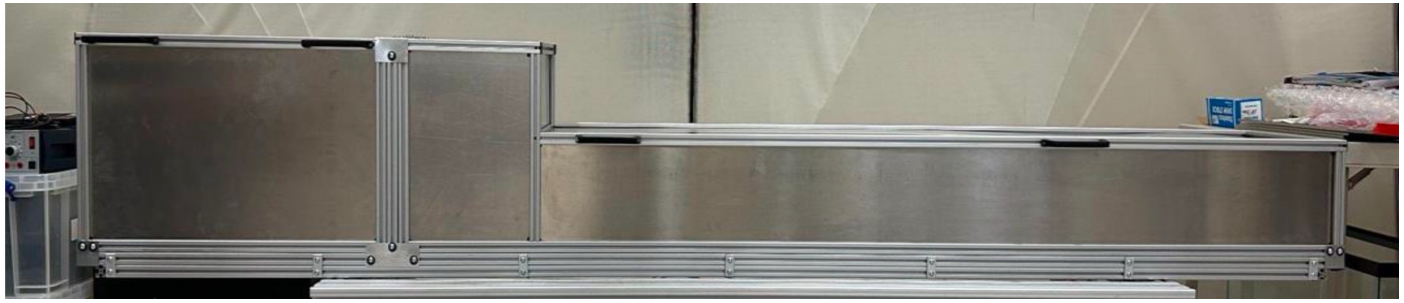
CRT setup CAD schematic

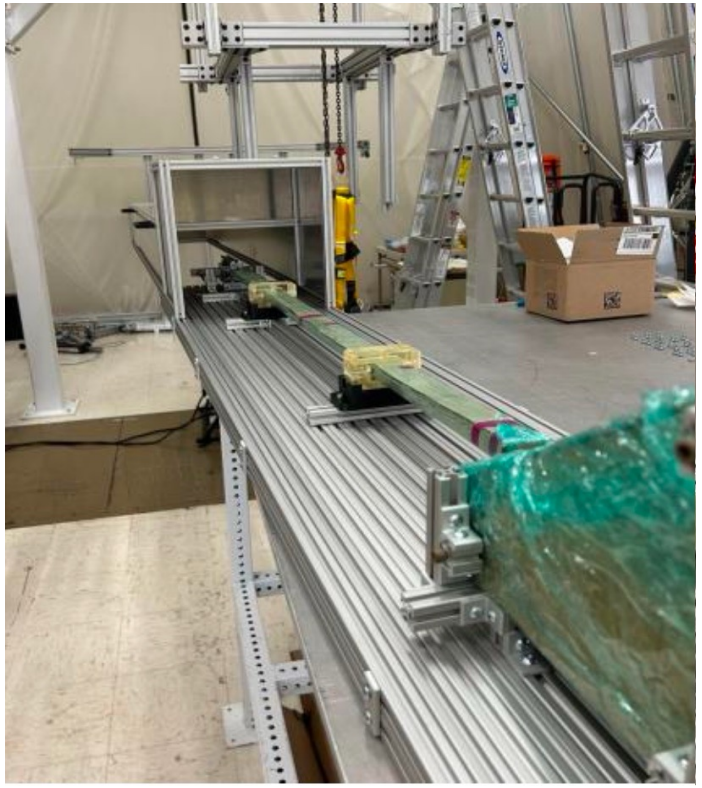


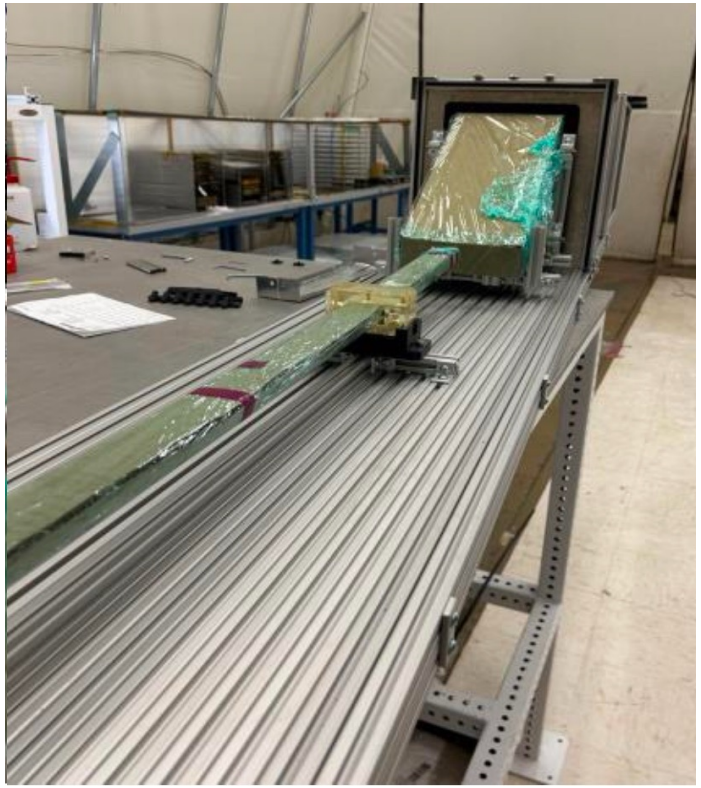
CRT DEVELOPMENT: HPDIRC PROTOTYPE

- Stewart platform adapted to control position and angle of hpDIRC prototype
- Dark box tested for light tightness
- Mock-up optics was used to test functionality of support system inside the dark box

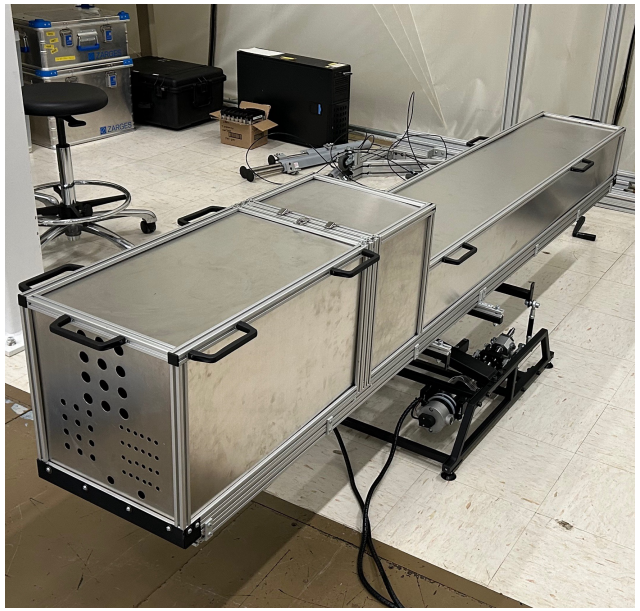
hpDIRC prototype during light-tight and inner functionality tests







hpDIRC prototype on motion control stage

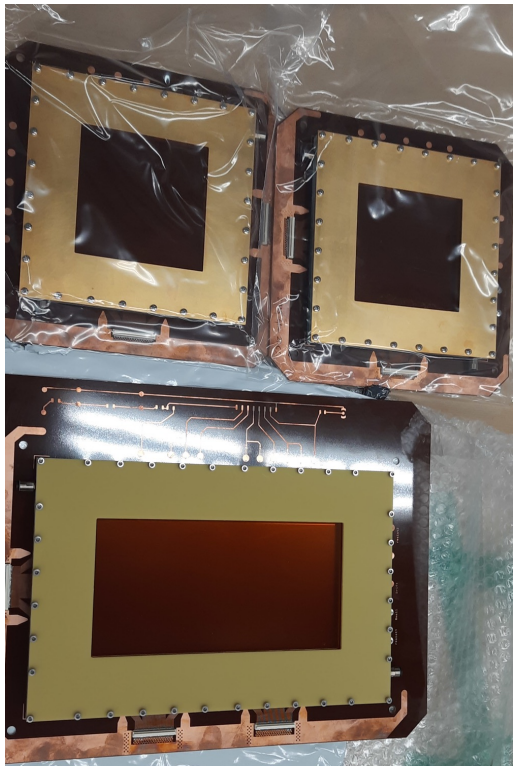


Stewart platform for 3D motion of Protype

CRT Development: Tracking and Timing

- Tracking
  - Two µRWELL stations (10 cm x 20 cm)
  - One GEM tracker (50 cm x 50 cm)
  - Each layer will measure the position of a cosmic particle with a spatial precision of about 60–70 µm
  - Tested in recent test beam in CERN
  - DAQ tests and integration with DIRC prototype DAQ are in progress
- Event Timing
  - PicoSec prototype will be loaned and operated by experts from JLab
  - Readout ordered, temporary readout arranged
  - SBU experts joined two CERN test beams to get familiar with operating procedure

Two µRWELL and GEM tracking stations



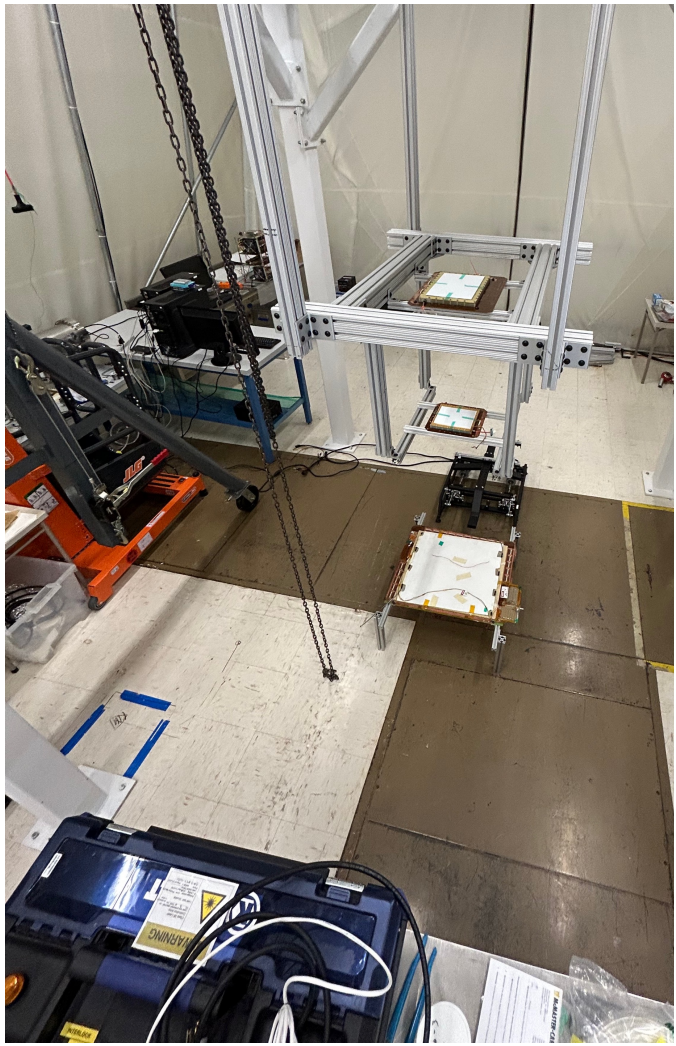
DAQ test setup at SBU

CRT Development: Support Structure and Tests

- Support structure completed and ready for installation of all CRT components
- Recently installed tracking stations for preliminary tests
- Design of support structure was optimized to allow usage of crane in the area to install Cherenkov Tagger

Full CRT setup CAD schematic

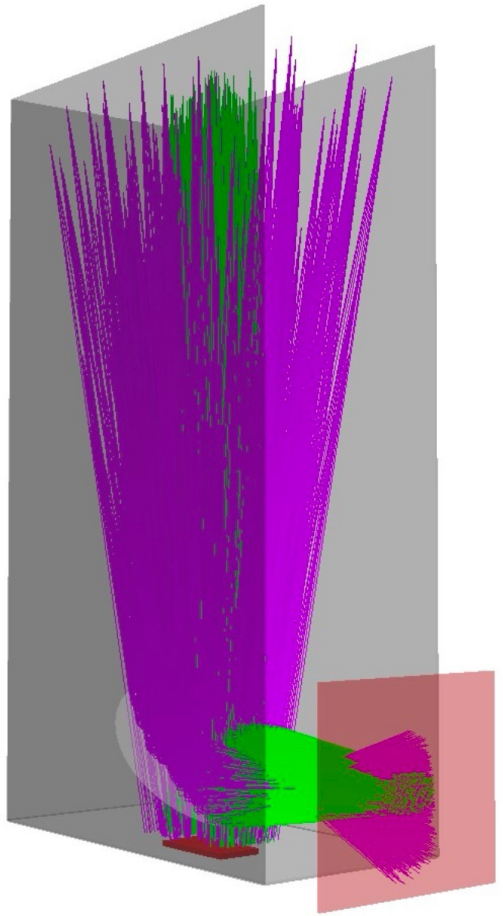
Installation and alignment of CRT tracking stations



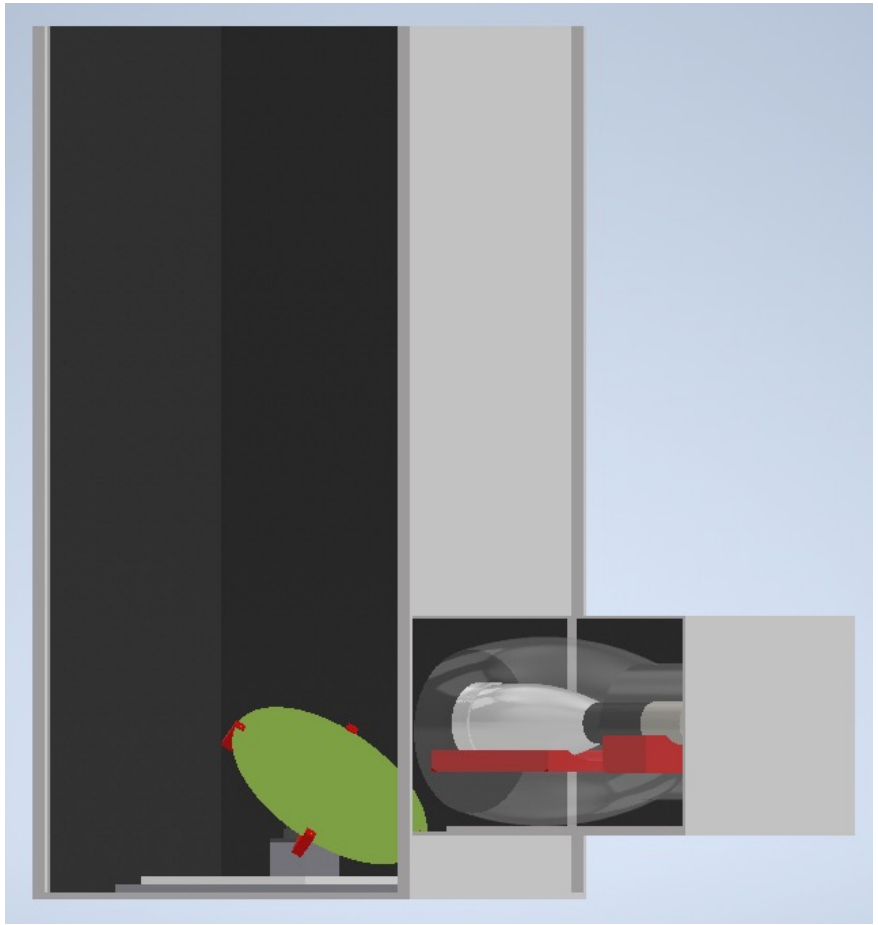
CRT Development: Cherenkov Tagger

- Cherenkov tagger, CO_2 Cherenkov threshold counter at atmospheric pressure, read out by a 3-inch PMT has been developed and constructed at ODU

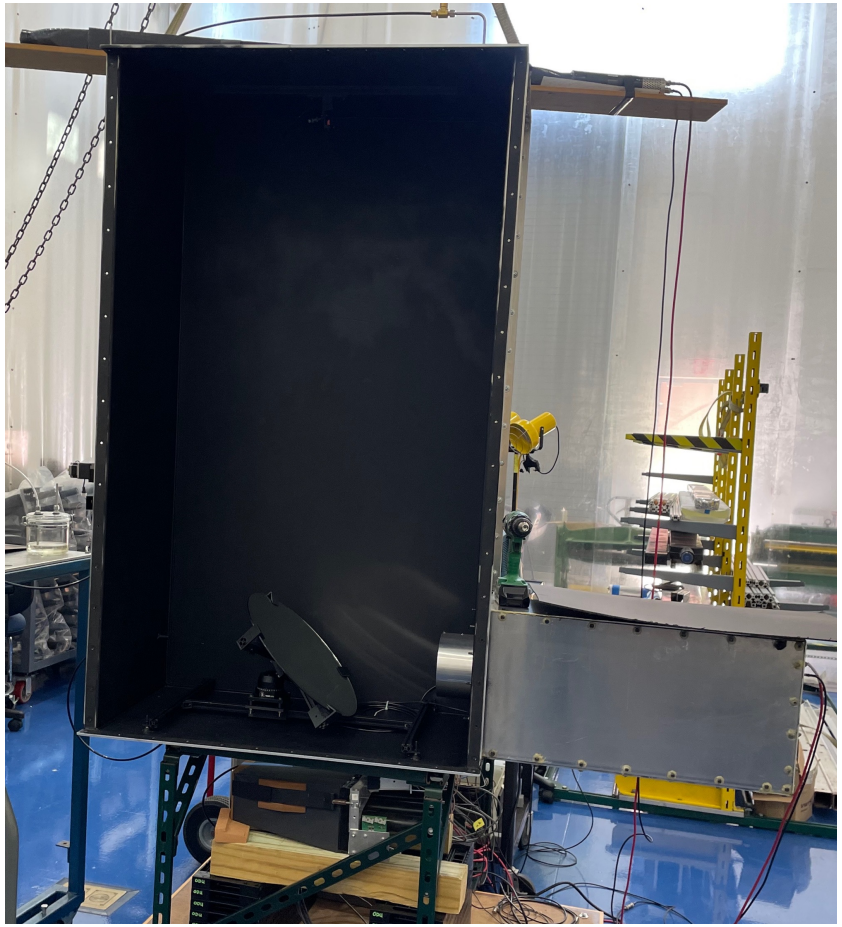
Cherenkov tagger in simulation



CAD drawing of Cherenkov tagger



Cherenkov tagger in construction at ODU

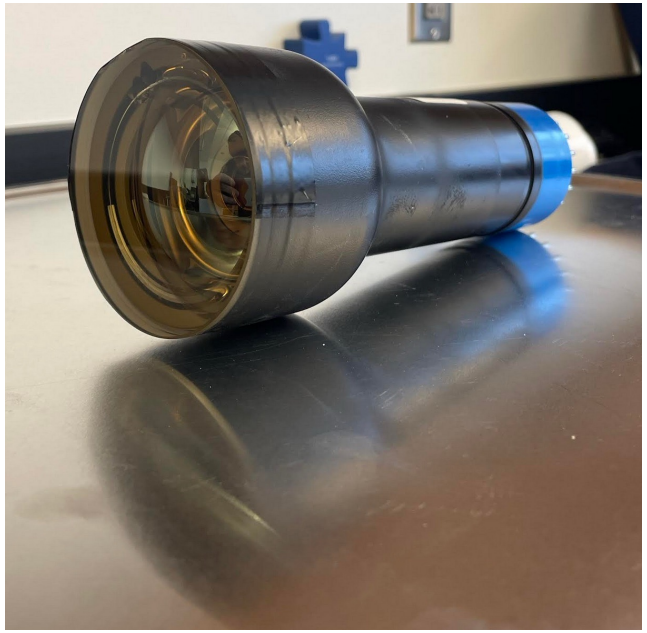


Carlos Ayerbe-Gayoso, Alex Garrett, Charles Hyde

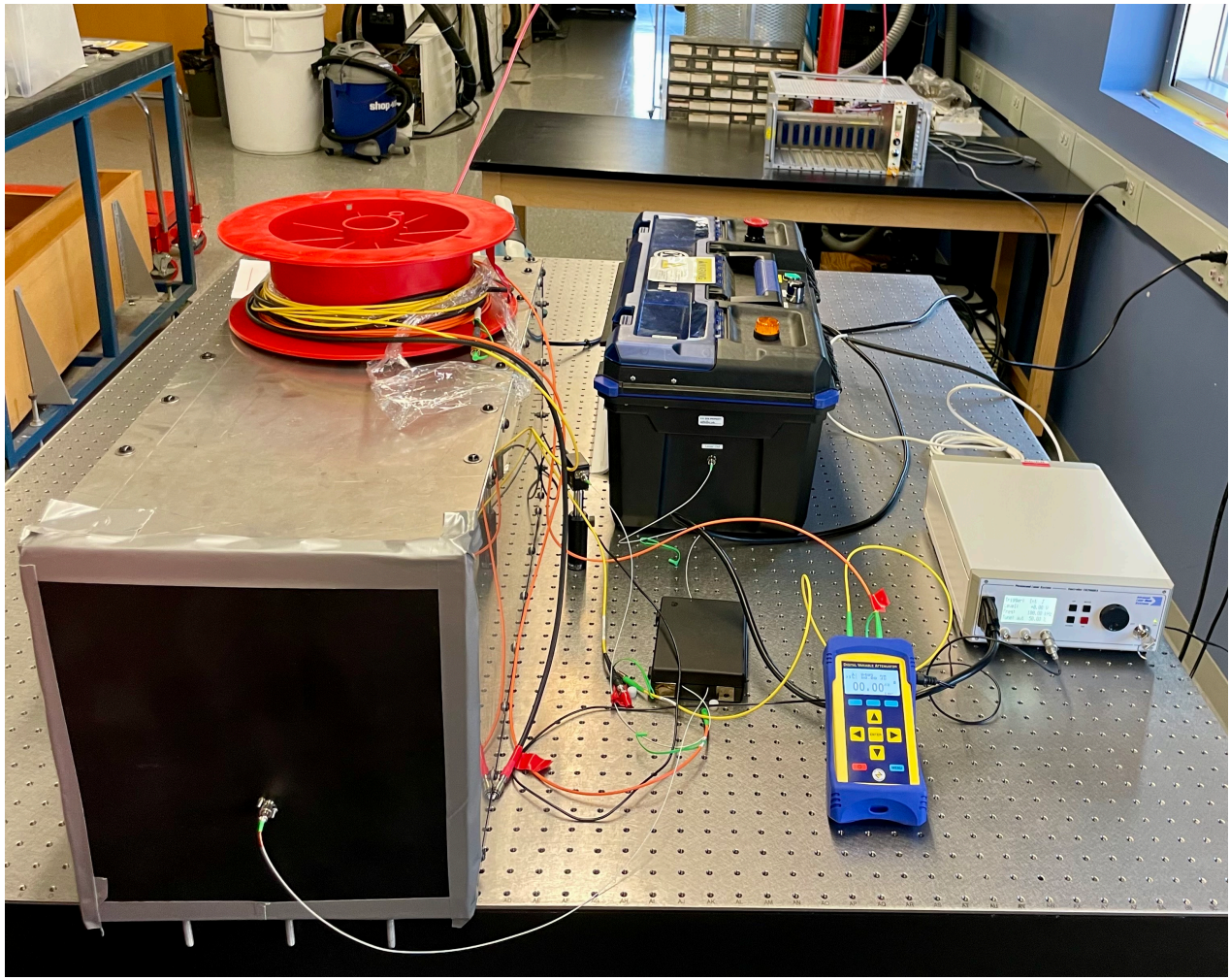
CRT Development: Cherenkov Tagger

- Replacement 3-inch phototube was tested with PiLas laser and installed in the Tagger

3-inch PMT



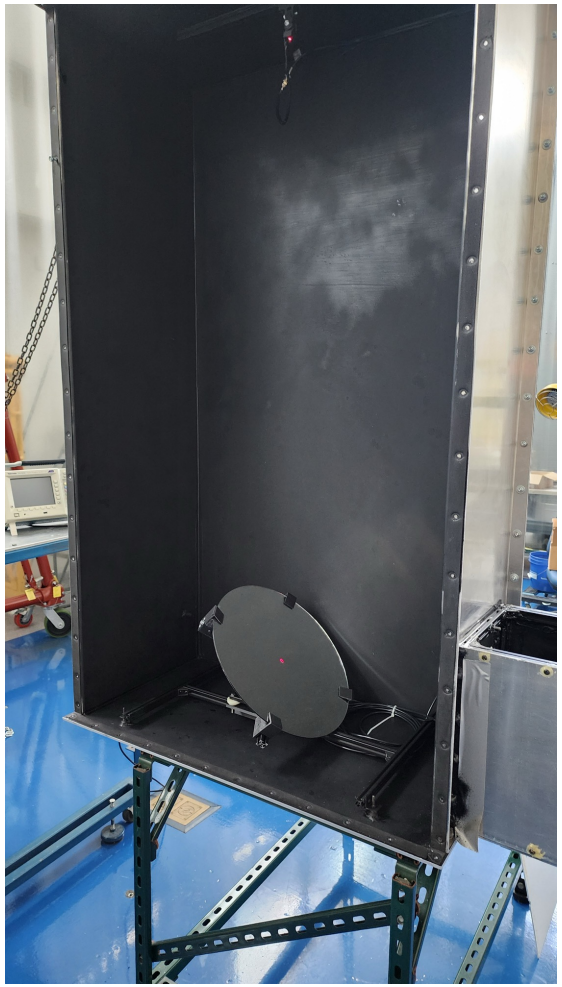
Setup to validate and characterize PMT

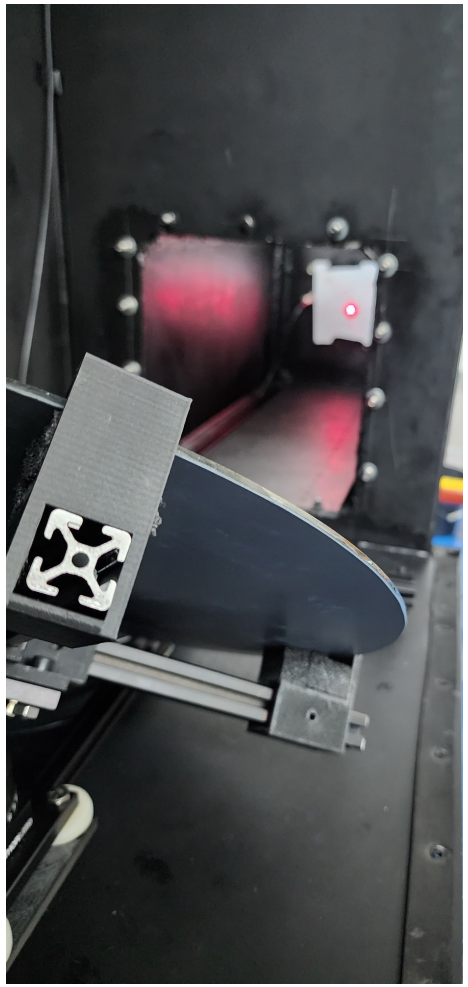


CRT Development: Cherenkov Tagger

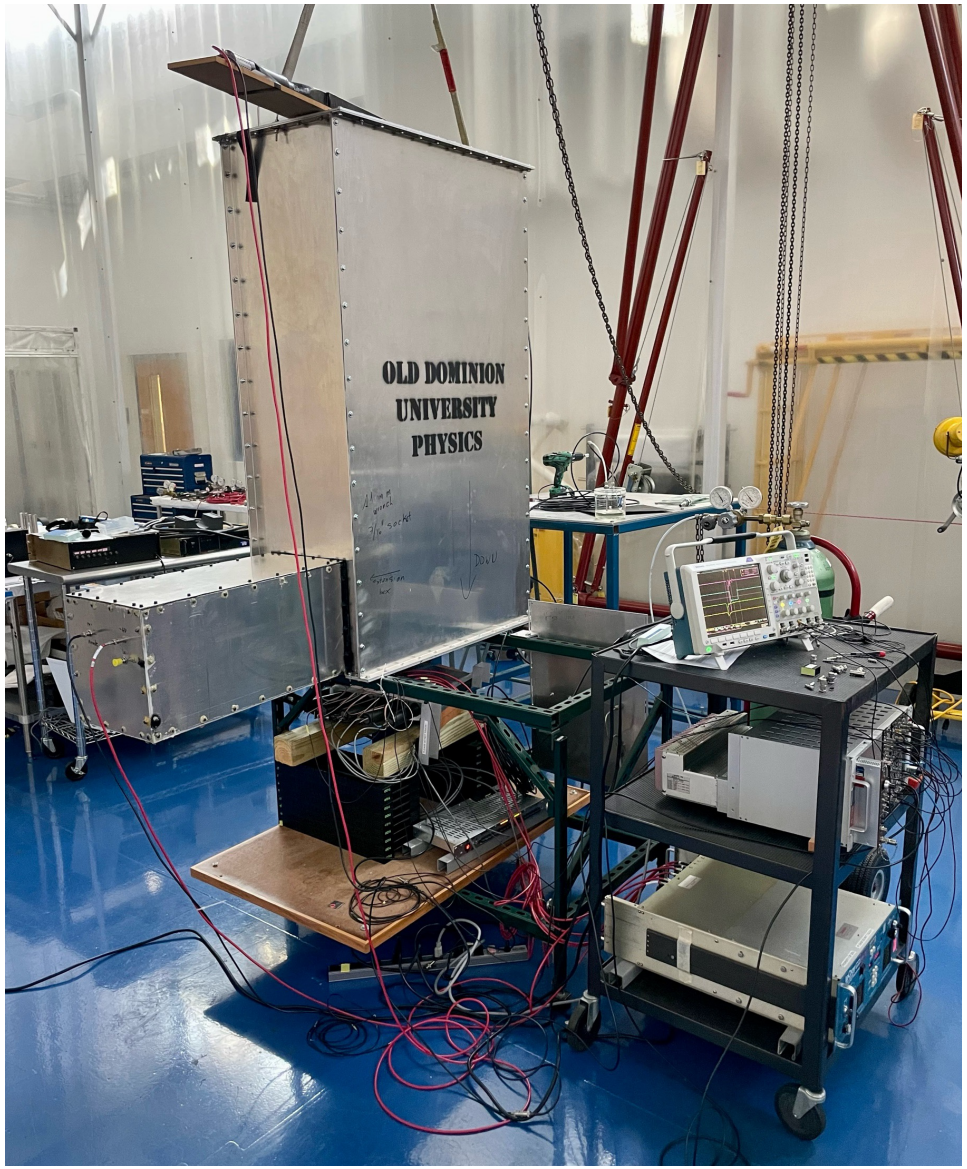
- Assembly of Tagger was finished in early August, tested through tests with set of scintillators and scope

Mirror alignment during Cherenkov Tagger construction





Validation of Cherenkov Tagger with scintillators



CRT Development: Cherenkov Tagger

- Transport to SBU this Monday, Installation and calibration in progress

Cherenkov Tagger during transport from ODU to SBU

Installation of Cherenkov Tagger in CRT at SBU

eRD103 R&D FY24 Milestones

Milestones:

- M1: Evaluated initial hpDIRC prototype with cosmic rays (CUA/GSI/SBU, Q4/2024)
  - Status: hpDIRC prototype tested for light-tightness, ready for installation
- M2: Cherenkov Tagger finished and integrated in CRT (CUA/ODU, Q3-Q4/2024)
  - Status: Tagger assembled, validated, transported to SBU, ongoing installation
- M3: Commissioning of full CRT setup completed (CUA/ODU/SBU, Q4/2024)

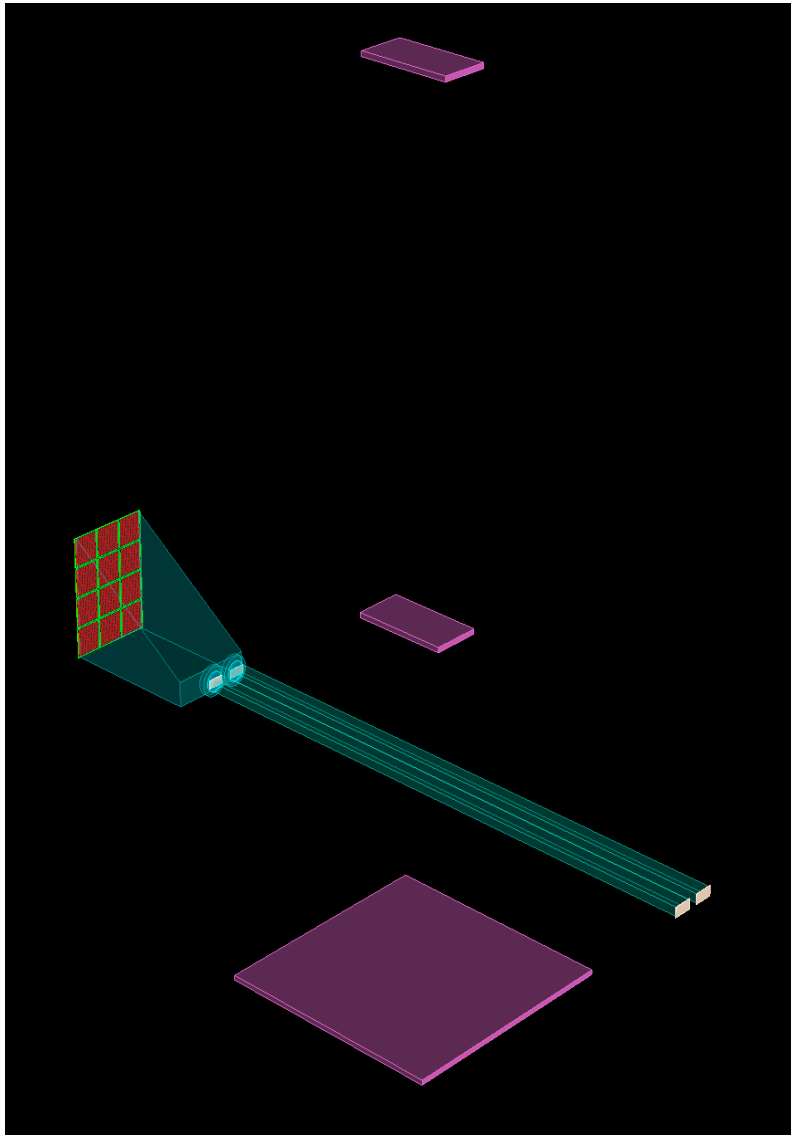
  Status:
  - CRT mechanical support structure ready
  - Integration of DAQs and commissioning of tracking on test bench in progress
  - PicoSec prototype will be transported and installed by JLab experts
- M4: Functional hpDIRC prototype with single bar (CUA/SBU, Q4 2024 – Q1 2025)
- M5: Upgraded hpDIRC setup with two bars and radiation hard 3-layer lenses (FY25)

DIRC lab and Cosmic Ray setup at SBU

HPDIRC PROTOTYPE: FUTURE PLANS

- Commissioning of full setup starting in the Fall
  - Initial prototype with bar from PANDA Barrel DIRC
  - Two radiation-hard 3-layer lenses are in hand and will be tested for the first time in prototype
- Disassembled BaBar DIRC bars will be used once available
- Prototype with two bars arranged side-by-side will enable studies of additional aspects of performance, increase statistics
- Readout box designed to allow easy addition of small-pixel sensors once they become available
- CRT will be commissioned and operated in FY25 at SBU
- Possible transport to JLab will be evaluated by the end of FY25
- Testing a vertical slide prototype once all components are available
- Ultimate CRT goal: test of fully-assembled hpDIRC modules

Simulation of hpDIRC Prototype with 2 bars in CRT



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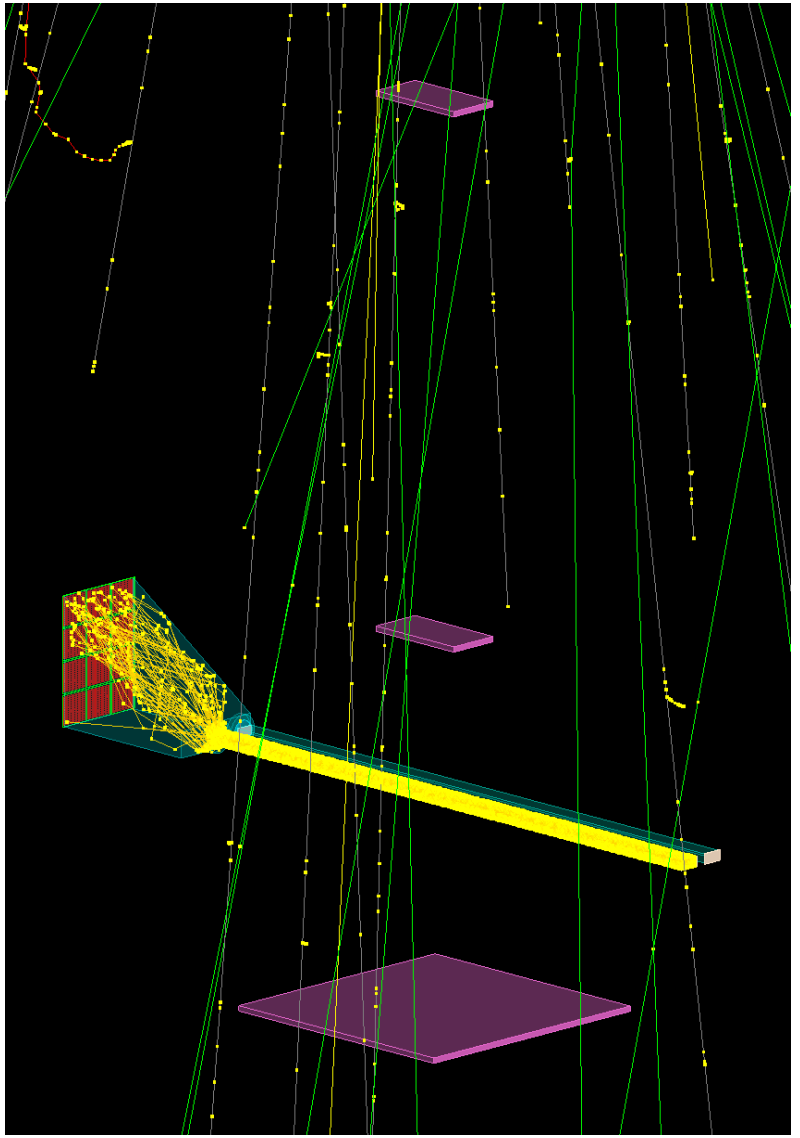
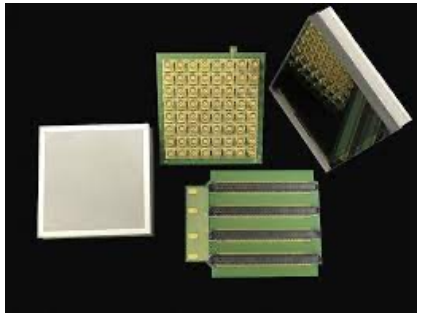


IMPACT OF OTHER ERD PROJECTS ON HPDIRC

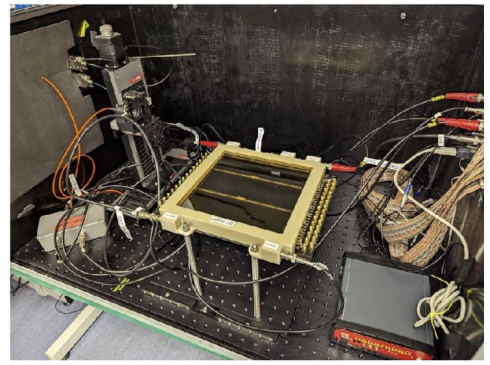
- MCP-PMT sensors: commercial Photek MAPMT253 (baseline) or Incom HRPPD (potential option)
  - Performance needs to be verified with single photons at high rates and occupancies
  - eRD110 is coordinating test bench studies of both types of sensors
    - HRPPDs will be evaluated at BNL (pfRICH)
    - Preparations for study of commercial MCP-PMT and HRPPDs in Glasgow in progress (Glasgow group, R. Montgomery et al)
- Readout electronics:
  eRD109 is coordinating development of two options, FCFD ASIC with 128 channels and the EICROC with 1024 channels

Photek MAPMT 253



INCOM Gen III HRPPD

Setup at Glasgow



HIGH-PERFORMANCE DIRC R&D

- 10+ years ago: DIRC good candidate for hadronic particle in EIC detector barrel – if π/K momentum coverage achieved by BaBar DIRC is increased by 50%
- R&D for a high-performance EIC DIRC started in 2011 (synergetic with PANDA DIRC)

(Funded by DOE/BNL/JLab as RD2011-3, eRD4, eRD14, eRD103, EICGENRandD2022_12)

Two EIC detector concepts with DIRC PID (2011)

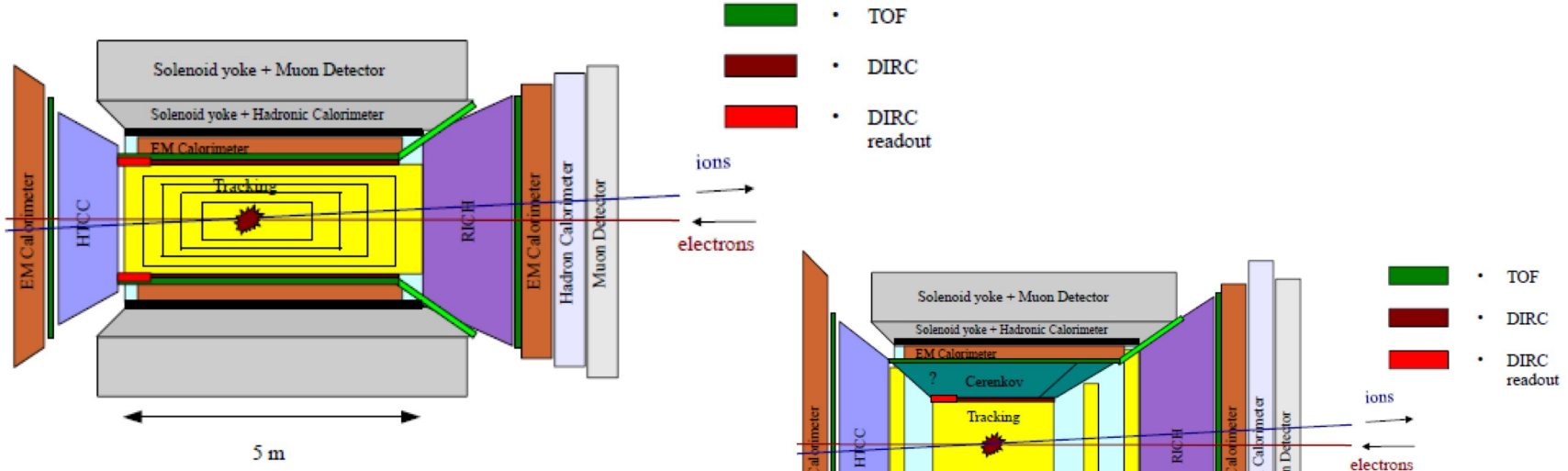


Fig. 6: EIC central detector cartoon showing a DIRC-only configuration.

Fig. 8: Detector cartoon showing the DIRC inside of the supplementary gas Cherenkov (Option 2).

First DIRC PID for EIC proposal (2011)

DIRC-based PID for the EIC Central Detector

T. Horn[1] (co-PI), C. Hyde[2] (co-PI), P. Nadel-Turonski[3,*] (co-PI), K. Peters[4], C. Schwarz[4], J. Schwiening[4] (co-PI).

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An essential requirement for the central detector of an Electron-Ion Collider (EIC) is to provide radially compact particle identification (PID) over a wide momentum range. To this end, the electromagnetic calorimeter (EC) needs to be complemented by one or more Cherenkov detectors, primarily for hadron identification. With a radial size of only a few cm, a Detector of Internally Reflected Cherenkov light (DIRC) provides a very attractive option. However, the requirements of the BaBar detector, where the first DIRC was used, differ somewhat from the needs of an EIC, in particular in terms of the momenta of the produced particles and the impact of the readout of the DIRC bars on the required detector acceptance. Currently, R&D is being undertaken for several DIRC projects around the world (PANDA, SuperB, Belle-II). A future EIC DIRC can benefit from many aspects of this R&D, but also provides its own unique set of challenges and priorities.

The proposed R&D has three major goals. The first is to demonstrate the feasibility of using a DIRC as part of a full-acceptance EIC detector. The key question in this regard is how to build a suitable readout, which is both reasonably compact, and can operate inside of the strong magnetic field (2-4 T) of the central detector solenoid. The second goal is to investigate the possibility of pushing the state-of-the-art of DIRC performance in terms of momentum coverage. This would be required if a DIRC would be the only means of π/K separation in the central detector. The third goal is to determine the optimal configuration for using a DIRC together with a supplementary gas Cherenkov detector, which would extend the e/π and the π/K coverage. The integration of the DIRC into the EIC detector, and the study of the overall detector performance are, however, important with or without the supplementary gas Cherenkov.

Early simulation studies (2013)

Figure 16: Reference expansion volume used for the drcprop simulations. The length of the box is 30 cm. The height of the box extends 15 cm above and 1 cm below the DIRC bar.

Figure 17: A prism with a flat vertical back wall is functionally similar to the box shown in Fig.16, but requires less space and material. Here. there are 1 cm steps both below and above the bar. Future optimizations will match the lens focal plane and the EV back plane to achieve the best single-photon resolution.

HIGH-PERFORMANCE DIRC R&D

- In early stage of R&D program the superb focusing was identified as crucial innovation to advance hpDIRC performance

- EIC DIRC R&D Milestones for focusing lens:
  - 2012: First multi-layer high-refractive index lens concept to avoid photon loss at air gaps
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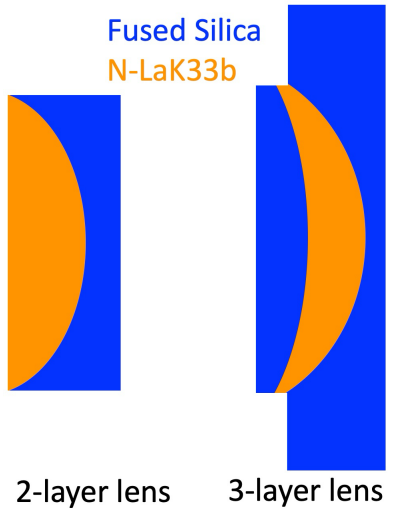
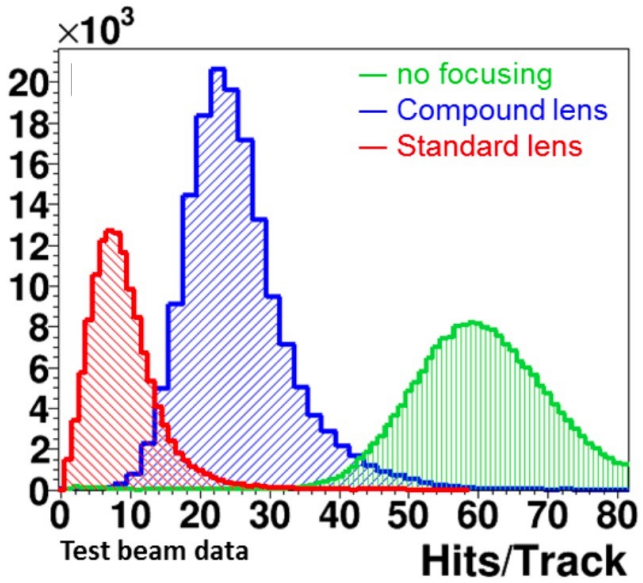
Initial compound lens concepts



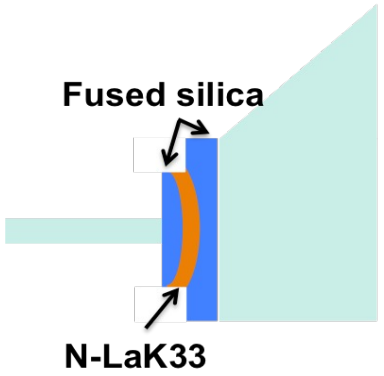
Photon yield from PANDA Barrel DIRC (2012)

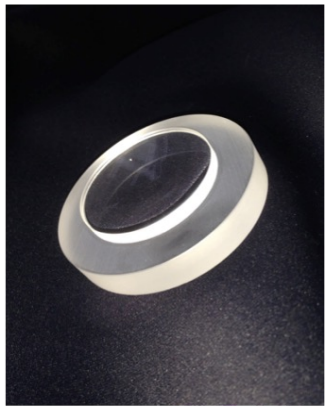


HPDIRC COMPONENTS: 3-LAYER LENS

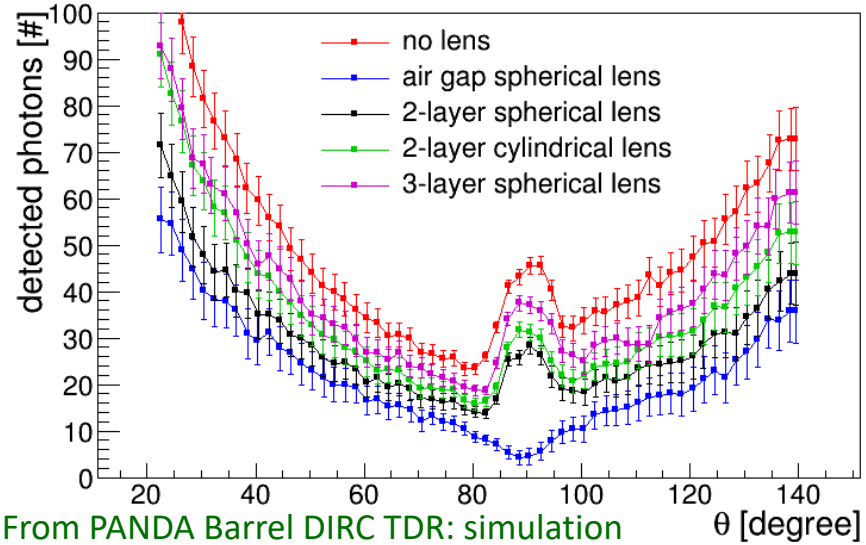
3-layer compound lens (without air gap):

layer of high-refractive index material (focusing/defocusing)
sandwiched between two layers of fused silica





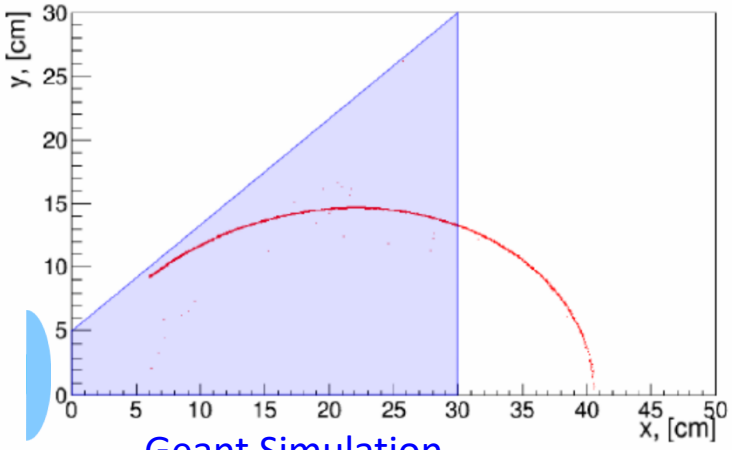
- Creates flat focal plane – matched to fused silica prism shape
- Avoids photon loss and barrel PID gap
- Successfully produced prototype lenses and validated performance in PANDA Barrel DIRC prototype with particle beams at CERN and GSI



From PANDA Barrel DIRC TDR: simulation

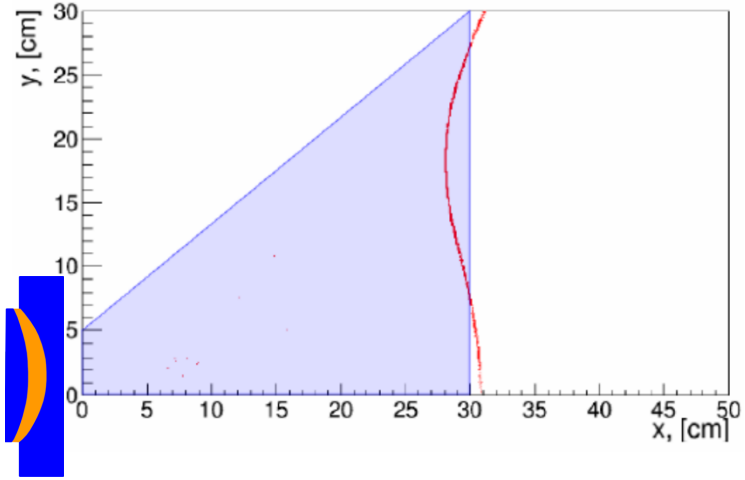
Geant4 simulation of focal plane:

air gap lens



Geant Simulation

3-layer lens



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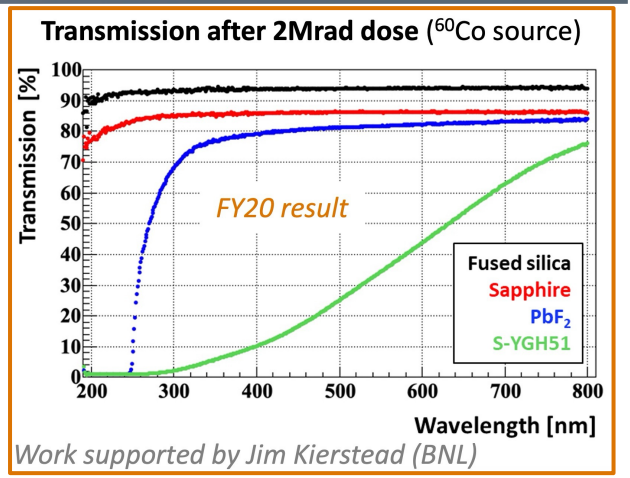
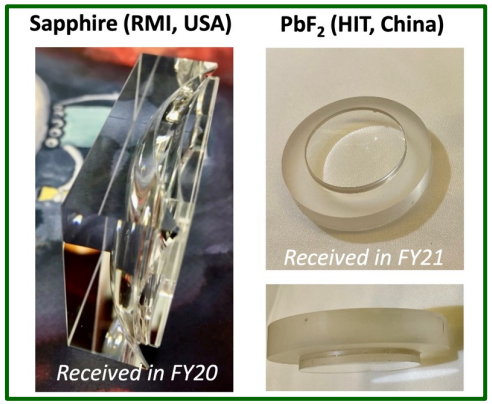


Work supported by Jim Kierstead (BNL)



Laser lab in ODU

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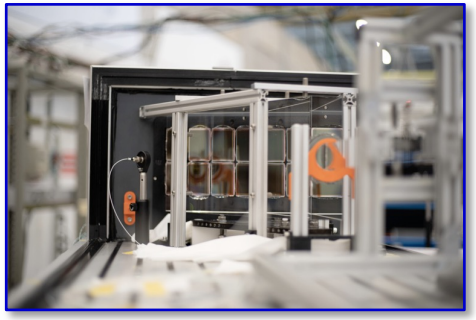
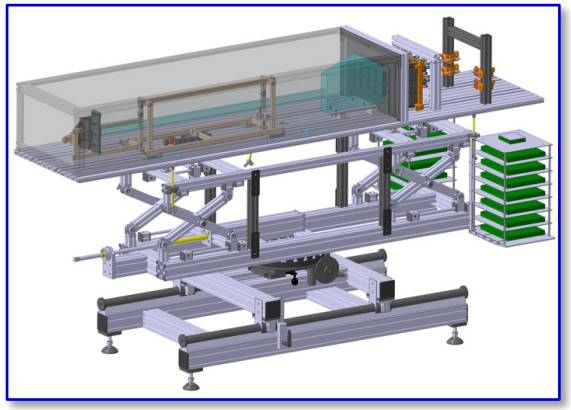
View from inside the Barrel DIRC dark box

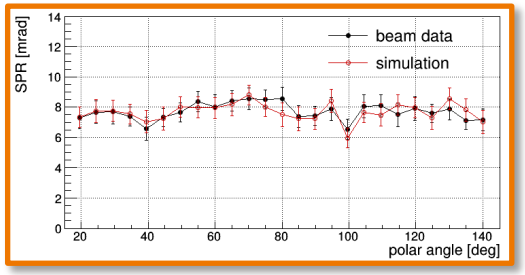


Schematic view of 2018 prototype

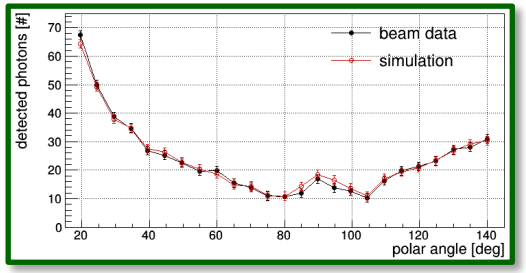


Beam data/simulation comparison for 2018 CERN beam test

Cherenkov angle resolution per photon



photon yield

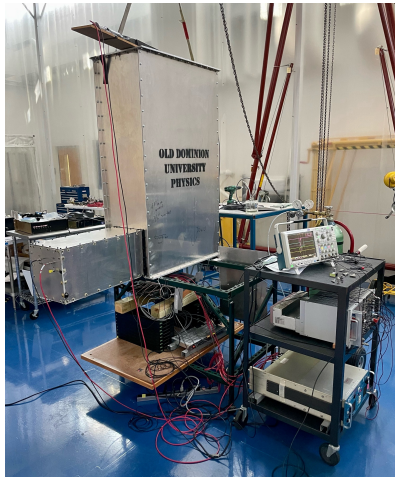


SUMMARY/OUTLOOK

- Important eRD103 progress in 2024, on track to meet declared milestones with delay
- hpDIRC Prototype at Cosmic ray telescope (CRT):
  - hpDIRC Prototype, Trackers, PicoSec, and Cherenkov tagger are completed and ready or in progress of installation. Commissioning in the Fall/Winter 2024
  - Preparing the way for future incremental upgrade of the hpDIRC prototype when bars, sensors, and readout electronics become available
  - The ultimate goal for CRT to test the full hpDIRC module is well-aligned with ePIC schedule
- Validation of BaBar bars reuse option, and completion of cost-optimized hpDIRC design aims at the winter of 2024 (new bars backup solution fits into ePIC schedule)
- hpDIRC for EIC R&D program concludes after 13 years.

  From ambitious concept, through detailed simulations and experimental tests, to becoming the barrel ePIC PID system, almost ready for construction.

Cherenkov Tagger



hpDIRC prototype