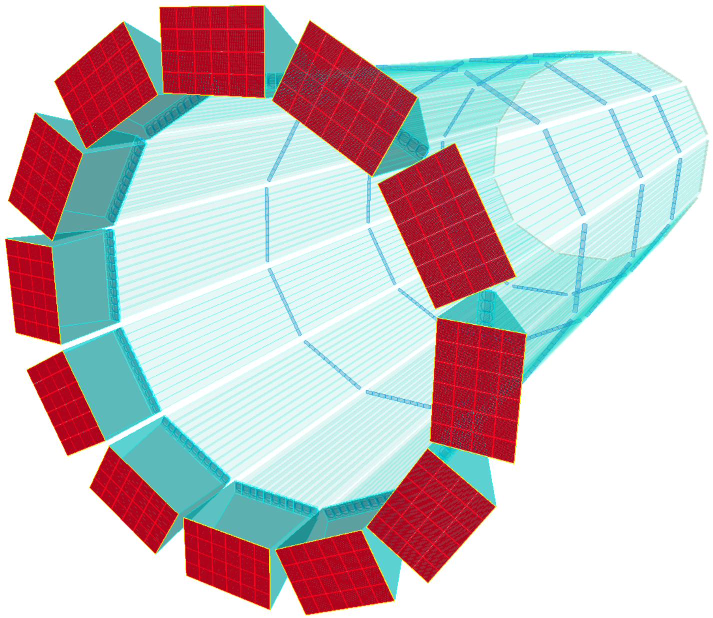
HPDIRC PREPARATIONS TOWARDS TDR



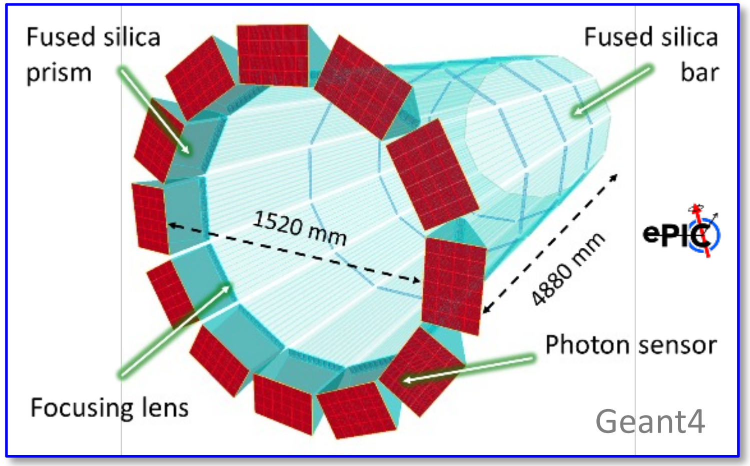
Greg Kalicy
CUA

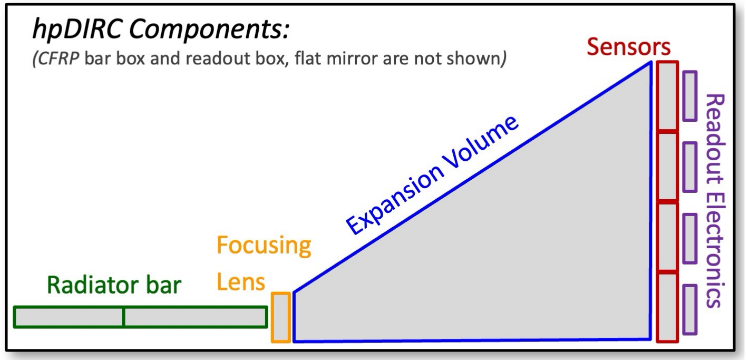
Brookhaven National Laboratory | CUA | GSI | Jefferson Lab | Old Dominion University | University of South Carolina | Stony Brook University | William & Mary | Tel Aviv University | MIT

hpDIRC Overview

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

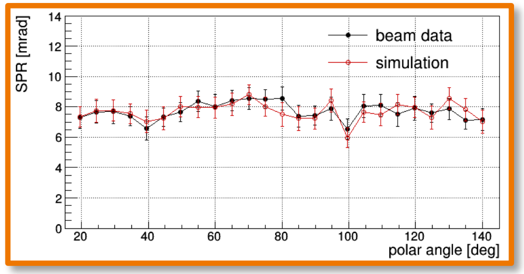
- Barrel radius: 762 mm, 12 sectors, 10 long bars per sector
- Reuse bars from decommissioned BABAR DIRC, supplemented by new bars/plates
- Focusing optics: innovative radiation-hard 3-layer spherical lens
- Compact expansion volume: 30 cm-deep solid fused silica prism
- Readout system:
  - Small-pixel 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 key decisions will be made this summer/fall



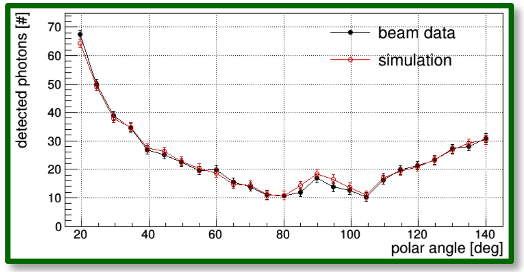


Beam data/simulation comparison for 2018 CERN beam test

Cherenkov angle resolution per photon



photon yield



hpDIRC Status

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 Q4/2024

Ongoing hpDIRC studies in simulation:

- Light-guide, prism, sensor coverage design optimization
- Updating performance plots

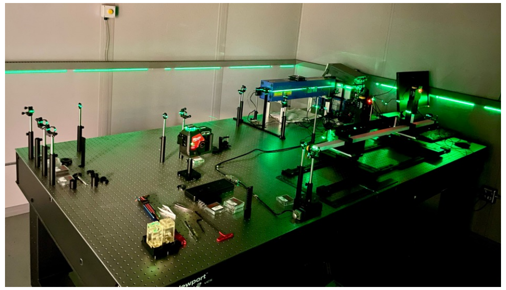
Mechanical Design and Integration (next talk):

- Progressing with work of two engineers and synergies with PANDA Barrel DIRC

hpDIRC prototype in Cosmic Ray Telescope (CRT):

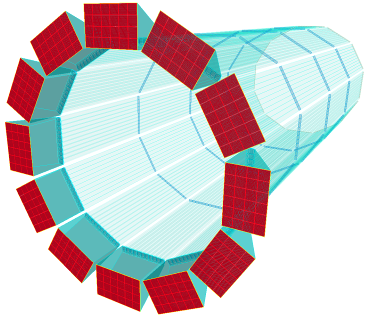
- CRT construction in final stage at SBU to become test bench for incremental upgrades of new components (bars, sensors, readout electronics, eventually full hpDIRC modules)

QA lab at JLab

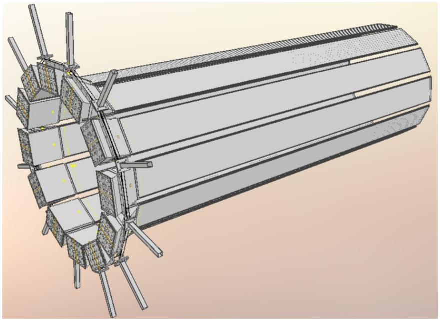


Disassembly setup at JLab

hpDIRC in Geant4



hpDIRC in CAD



hpDIRC prototype at SBU

hpDIRC TDR Preparations

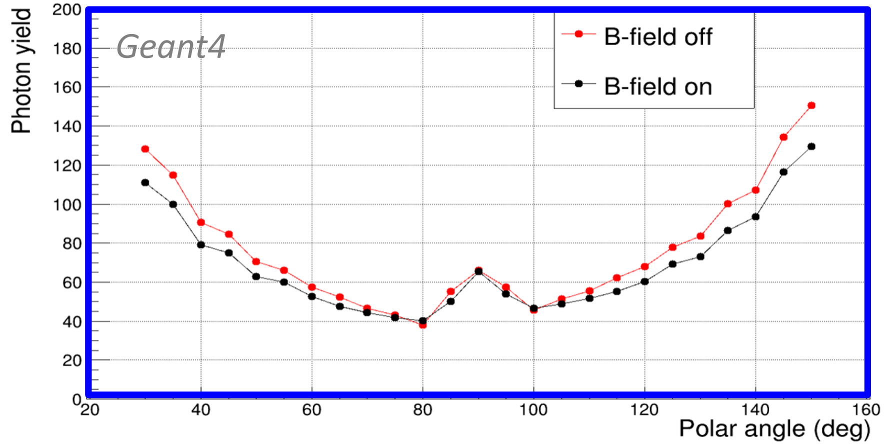
- hpDIRC TDR section outline prepared
  - Relevant needed figures identified
  - Some needed figures will be referenced (B field, radiation map, etc.), might include them in paper with zoom to hpDIRC region
  - Detailed breakdown of needed content – starting to write!
  - Remaining questions/studies identified, assigned, and ongoing
  - Performance plots will be updated for final geometry and are easy to adjust to uniformly agreed representation and style with other systems

Section	Subsecion	Content
Requirements/Motivation		
	Performance	
	Integration	
System Description		
	Concept	hpDIRC unique aspects
	Design	description of components, how the required performance (KPP) will be achieved
	Performance	description of simulation and reconstruction method, CERN validation
	Calibration	alignment - survey marks, experimental data for calibration
Implementation		
	Mechanical	Design and integration, Assembly of modules, Installation
	Services	nitrogen, cooling, voltage, controls and monitoring, laser calibration
	Other activities needed	
	QA	CRT (Full module), Readout (Sensors + Front-end Electronics), Bars/Mirrors (Laser Lab in JLab), Prisms (?), Lenses (ODU setup)
	Timeline, workforce, work packages	
	ES&H	
	Risk mitigation	Readout electronics, Sensor (Whatever is not tested)

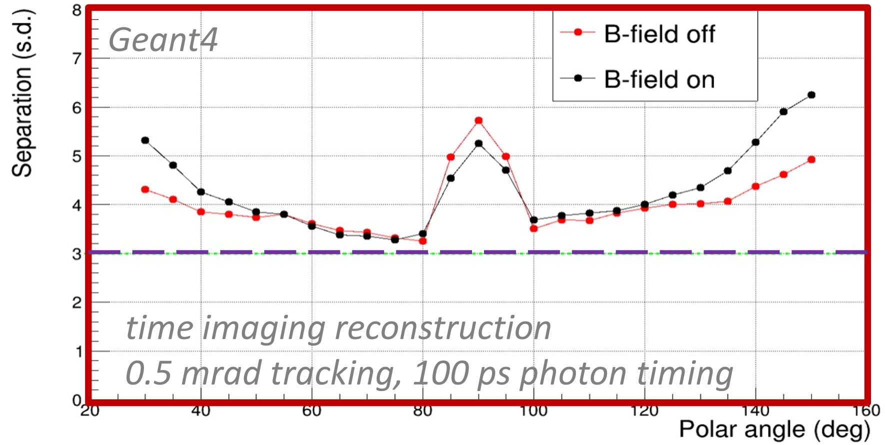
hpDIRC DSC at DIRC Annual Workshop in May 2024

- Updates to hpDIRC geometry have no significant impact on performance, small impact on acceptance
- All hpDIRC performance studies use Geant4 simulation fully validated with test beam data
  - Realistic ePIC magnetic field map was used
  - Studies with Pythia physics events were done
  - Multiple tracks per event in single bar showed very small impact on performance
  - Most studies assumed 0.5 mrad angular tracking resolution at 6 GeV/c but software ready to import and include detailed parametrization of tracking
- Detailed PID LUT with threshold mode included available for ePIC physics studies

Photon yield per particle

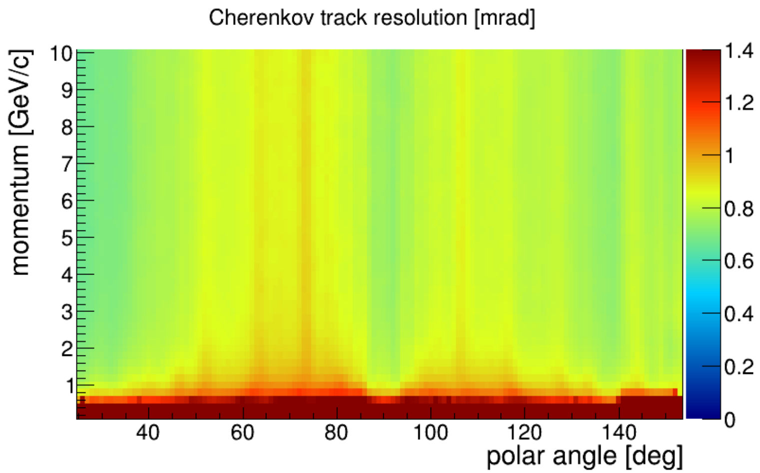


π/K separation power at 6 GeV/c



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

Based on Cherenkov track resolution map obtained by using the full standalone Geant4 simulation and reconstruction



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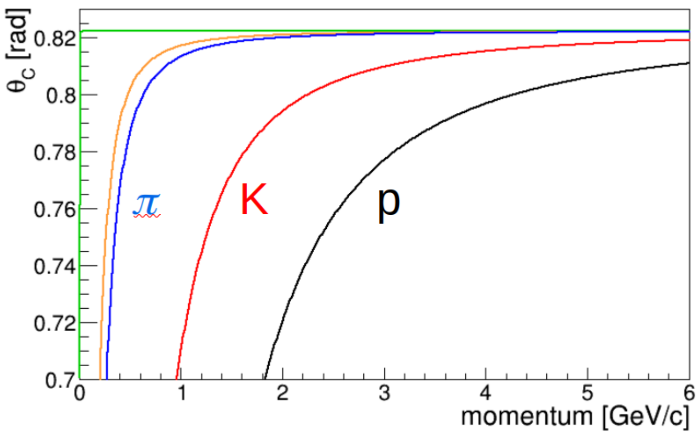
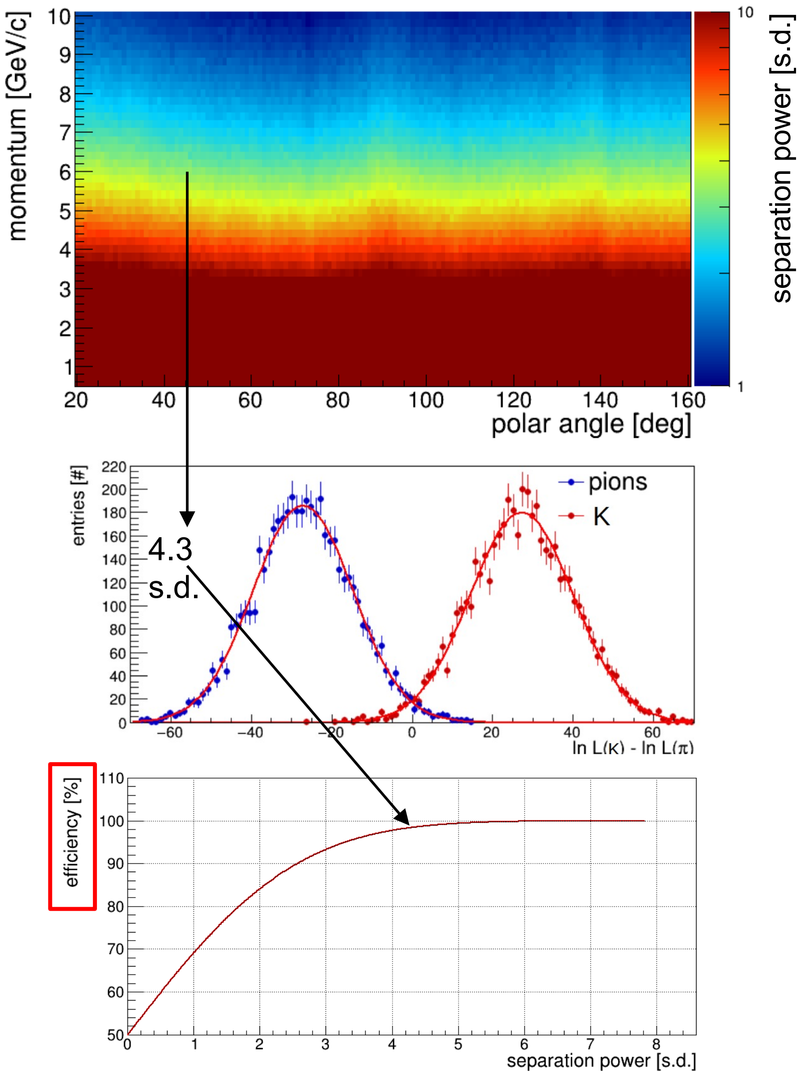
expected Cherenkov angle



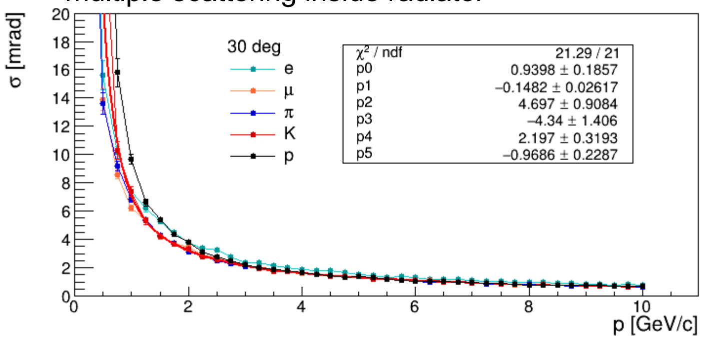
⇨

separation map, example for pion/K

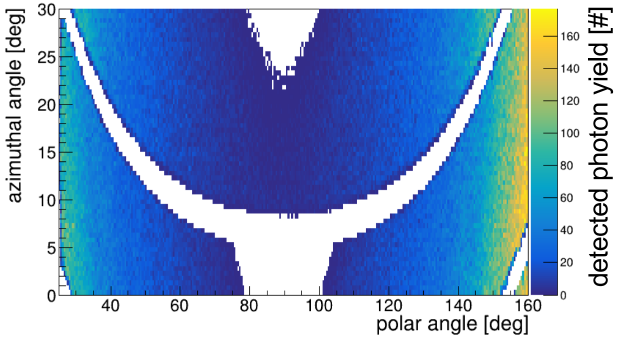


- uses 0.5 mrad tracking resolution combined with multiple scattering inside radiator
- accounts for azimuthal acceptance gaps
- includes threshold mode PID

multiple scattering inside radiator



example of phi acceptance for K^- @ 0.55 GeV/c



azimuthal acceptance gaps between bar boxes

hpDIRC LUT PID

The LUT in ASCII:

```
...
11 1 9.80 69.00 21.50 0.3932 0.3792 0.2150 0.0125
11 1 9.80 69.00 22.00 0.3894 0.3757 0.2202 0.0147
11 1 9.80 69.00 22.50 0.3945 0.3764 0.2170 0.0121
11 1 9.80 69.00 23.00 0.3933 0.3803 0.2146 0.0118
11 1 9.80 69.00 23.50 0.3929 0.3747 0.2186 0.0139
11 1 9.80 69.00 24.00 0.3919 0.3760 0.2185 0.0136
...
```

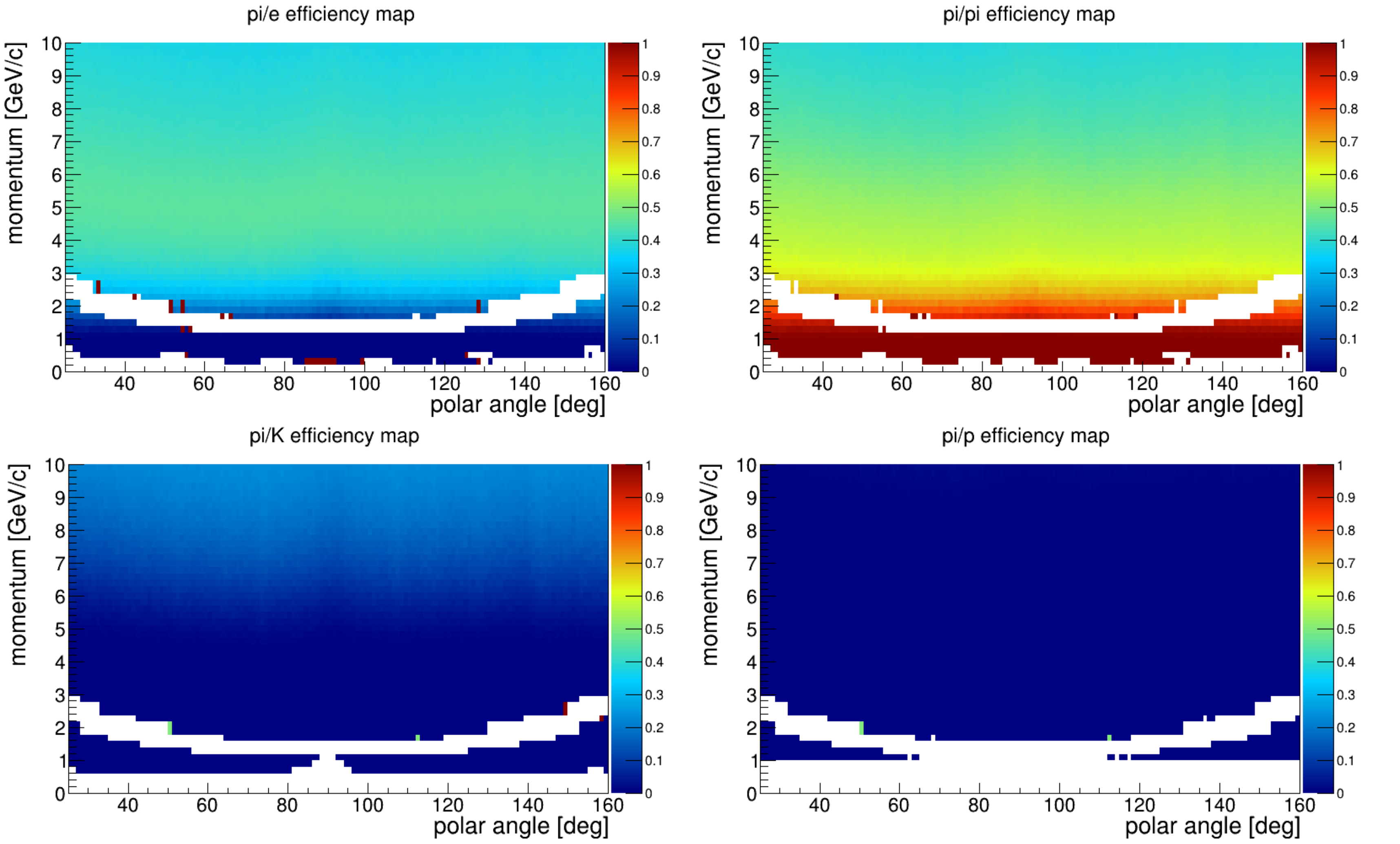
Full version is here:
https://github.com/rdom/fastpid/blob/master/hpdirc_fastpid.tar.gz

Description of PID LUT's columns:

1) PDG code of the particle (e 11, pi 211, K 321, p 2212)
2) charge (-1,1)
3) momentum, [0.2,10] with 0.2 GeV/c step, for higher momenta one should use 10 GeV/c
4) polar angle, [25,160] with 1 degree step
5) azimuthal angle [0,30] with 0.5 degree step, there is 12x azimuthal symmetry
6) probability for electron
7) probability for pion
8) probability for kaon
9) probability for proton

Probabilities are normalized to 1 (for e,pi,K,p).
If all probabilities = 0 then PID is not possible.

Example of probabilities for π^+ at 5.5° azimuthal angle:

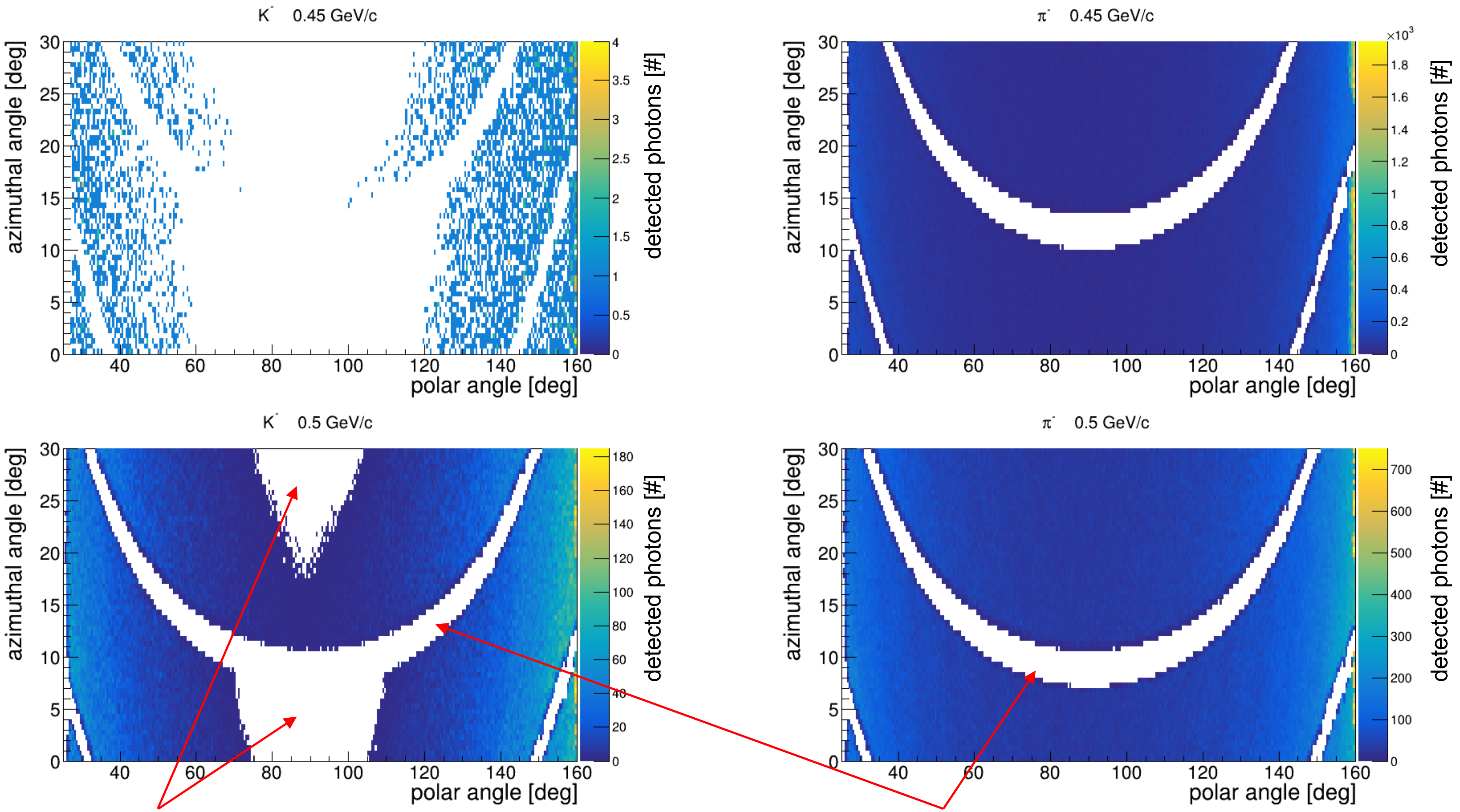


Example of threshold mode

Require more than 5 detected photons for robust PID

➡ positive ID for pions over whole phase space @ 0.45 GeV/c

➡ positive ID for pions over large part of phase space @ 0.5 GeV/c

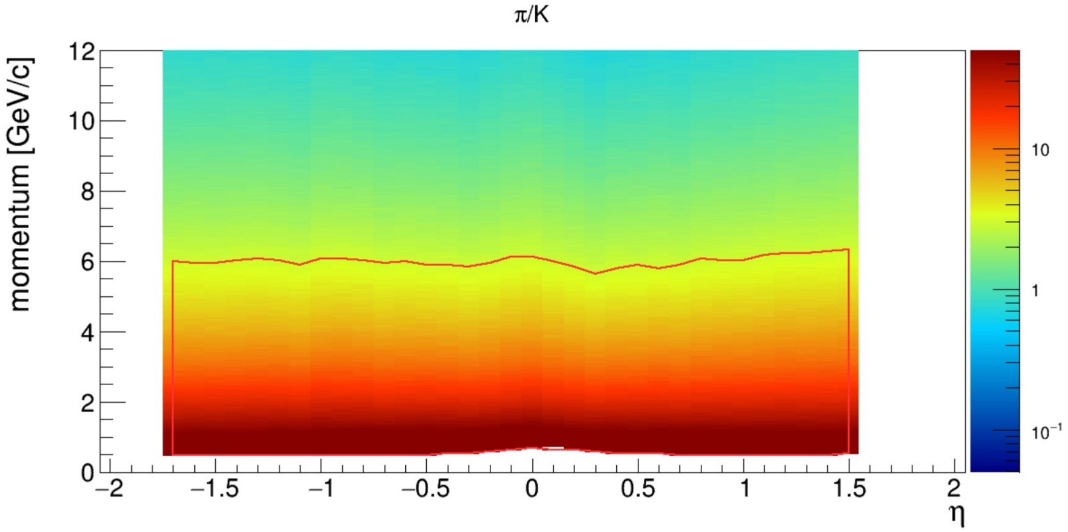


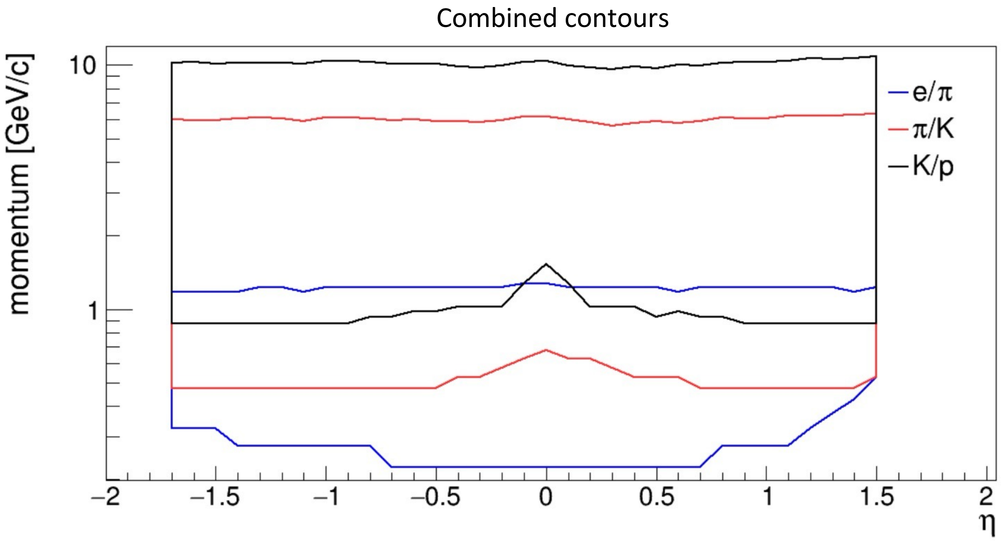
acceptance gap due to total internal reflection

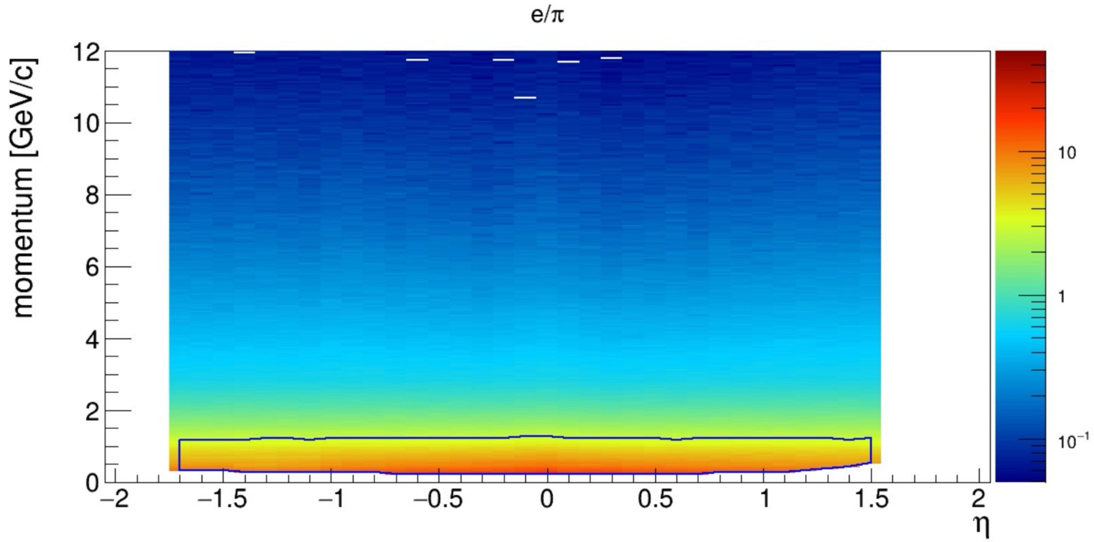
acceptance gap due to space between bar boxes

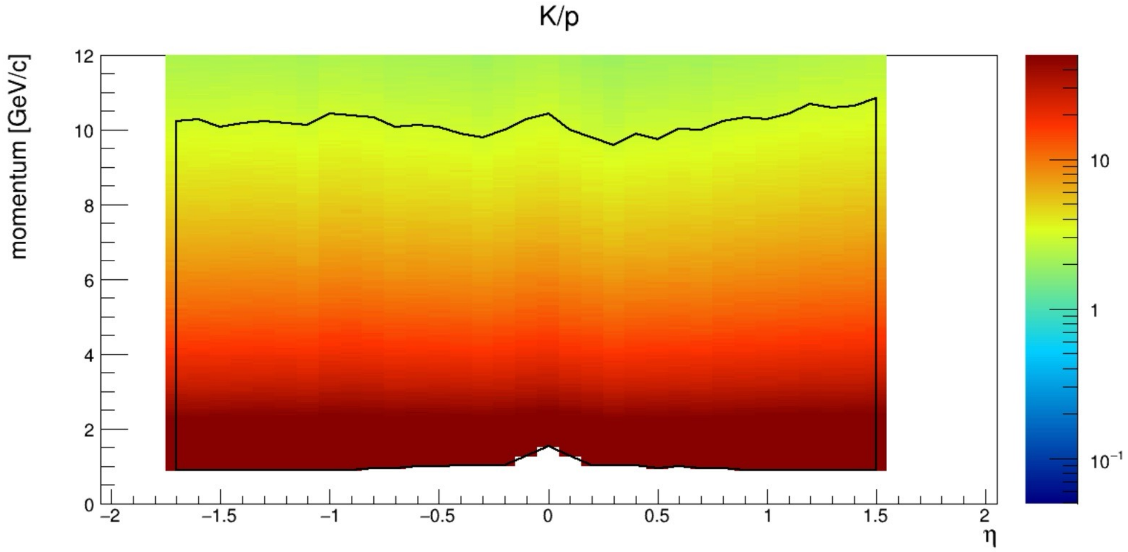
Fine binning in angle and momentum needed to deal with rapid changes in photon yield

hpDIRC PID efficiency maps with 3 sigma s.d. contour









hpDIRC “Light-guide” section

- ePIC detector barrel length requires additional “light-guide” section to connect BaBar DIRC bars to prism
- Alternative to baseline (narrow bars) is one single short wide plate

Baseline design

3 x 1225 mm (bars) + 893 mm (bars)

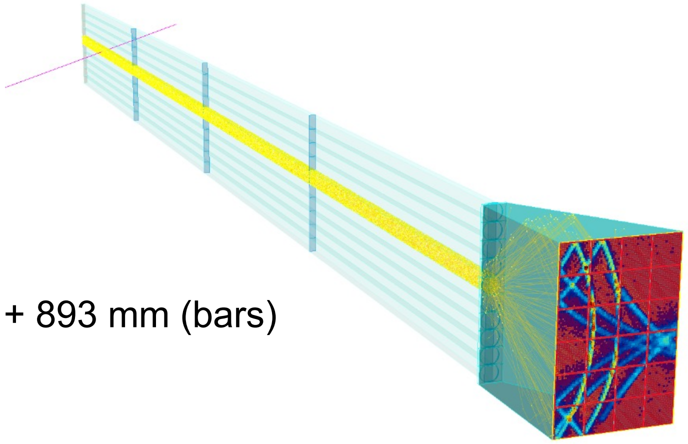
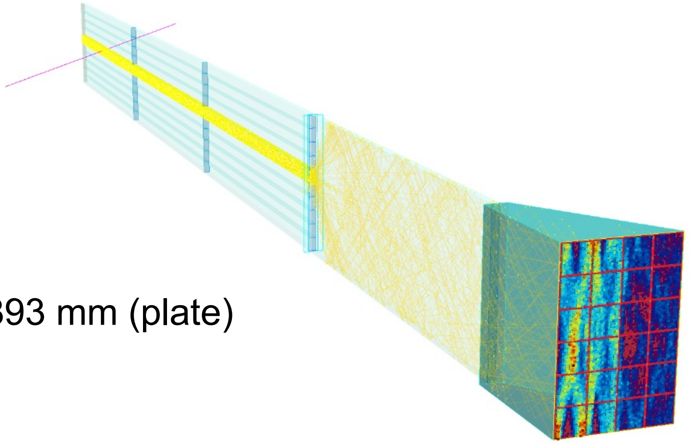
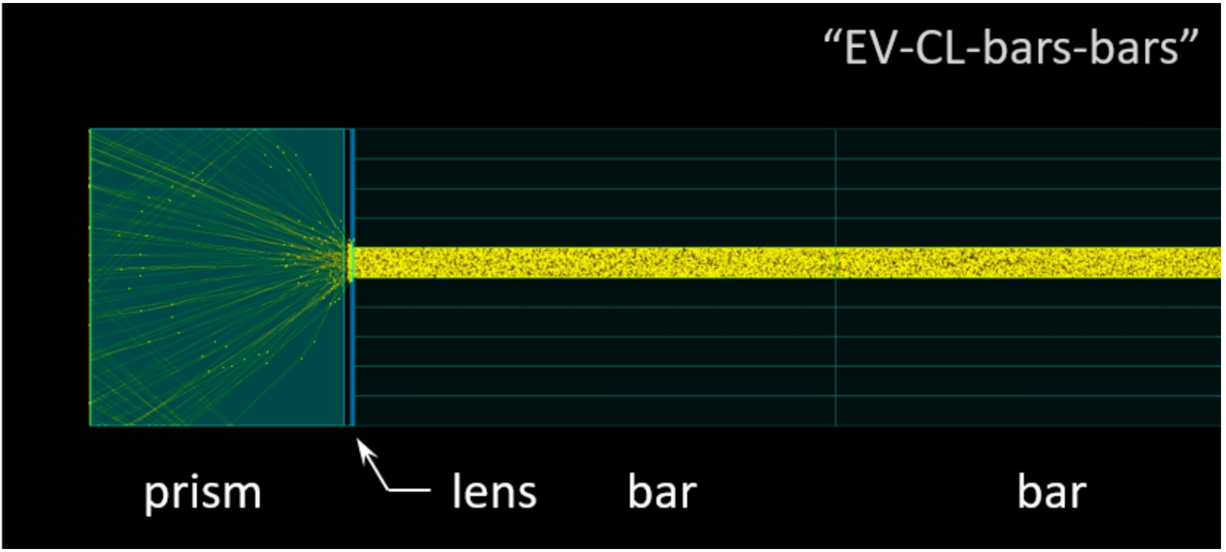


Plate as optical guide:

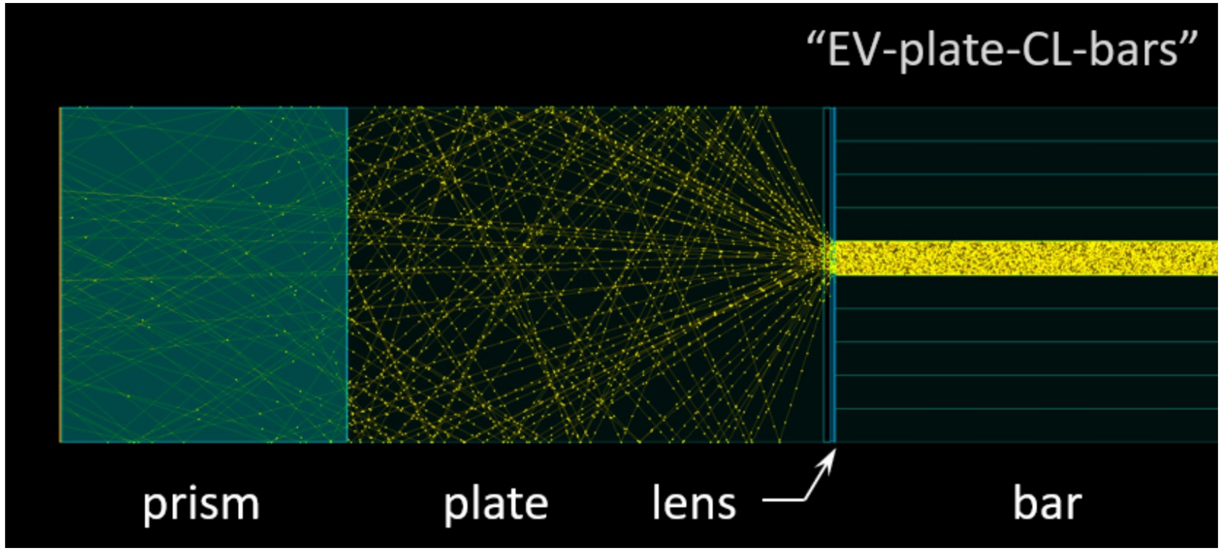
3 x 1225 mm (bars) + 893 mm (plate)



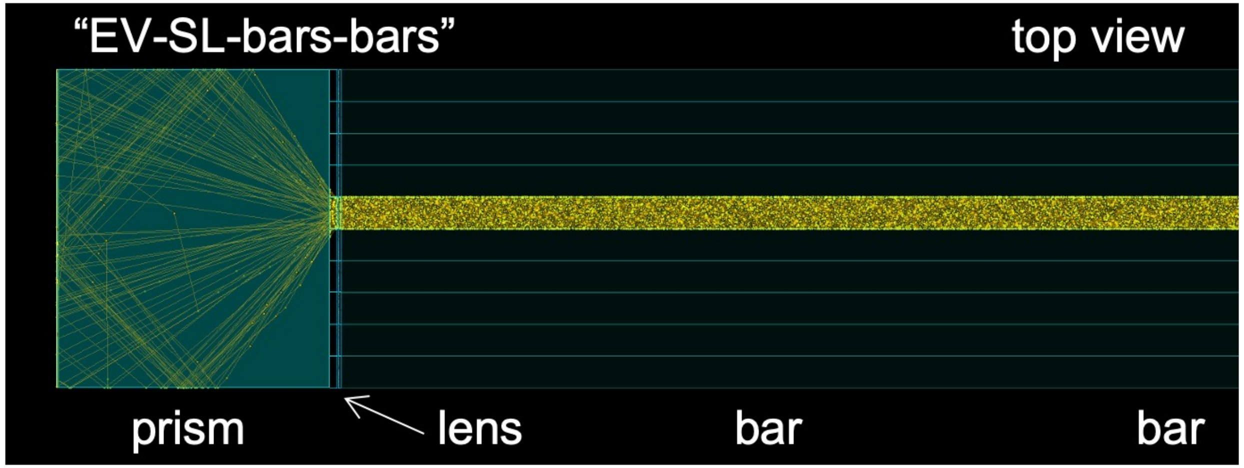
Only narrow bars in each sector

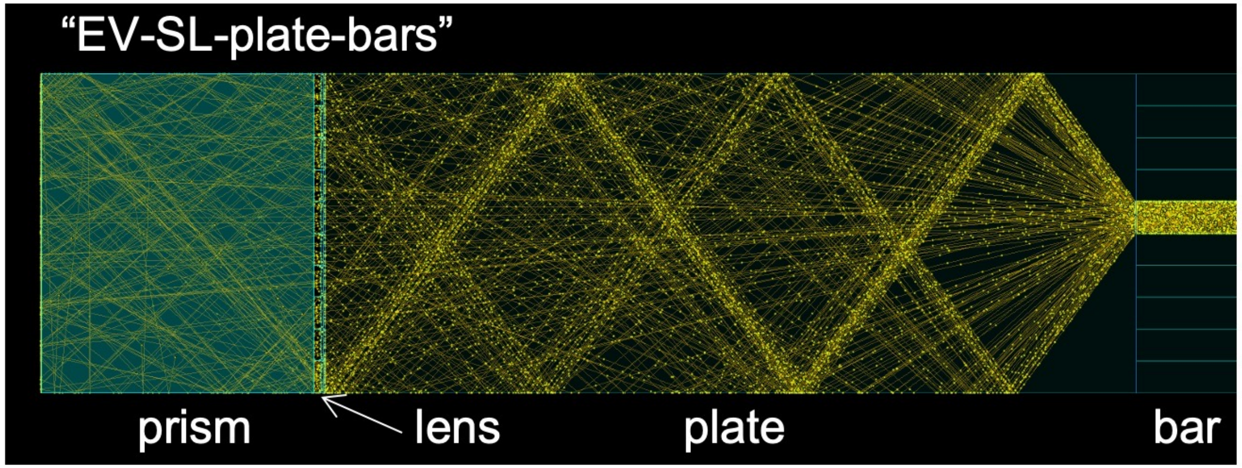


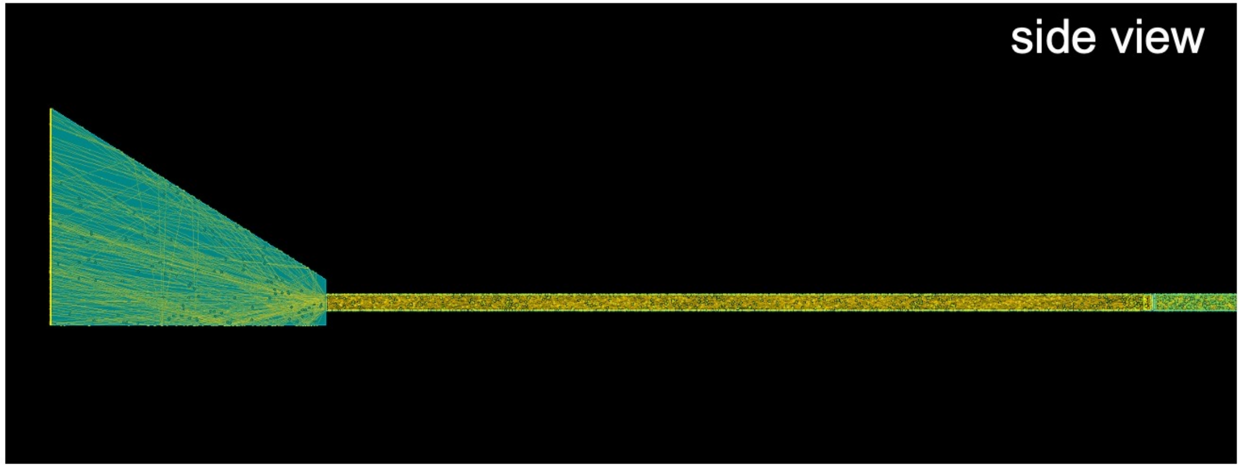
Hybrid of bars and plate in each sector

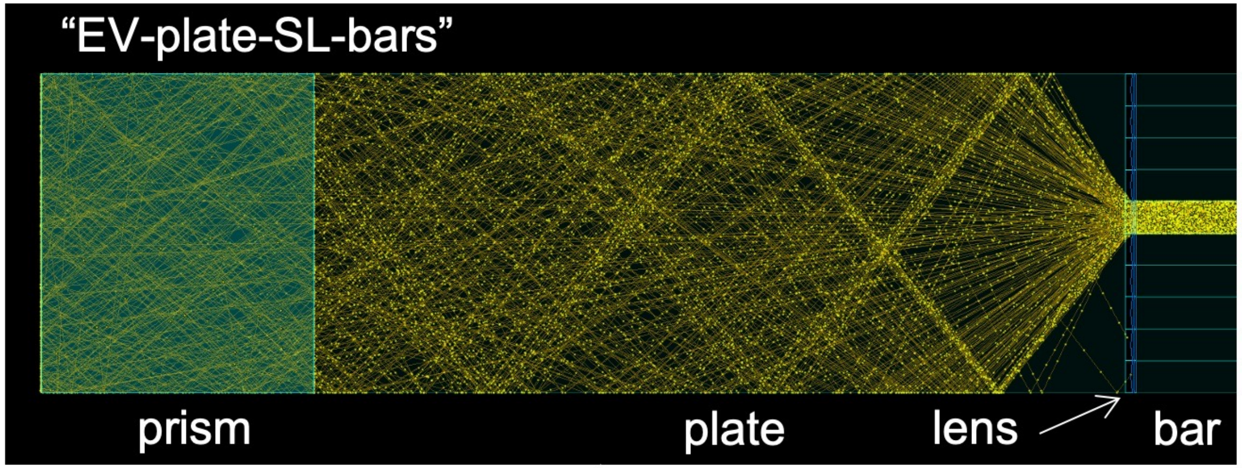


event display witch Cherenkov photons from 1 pion @ 6 GeV/c



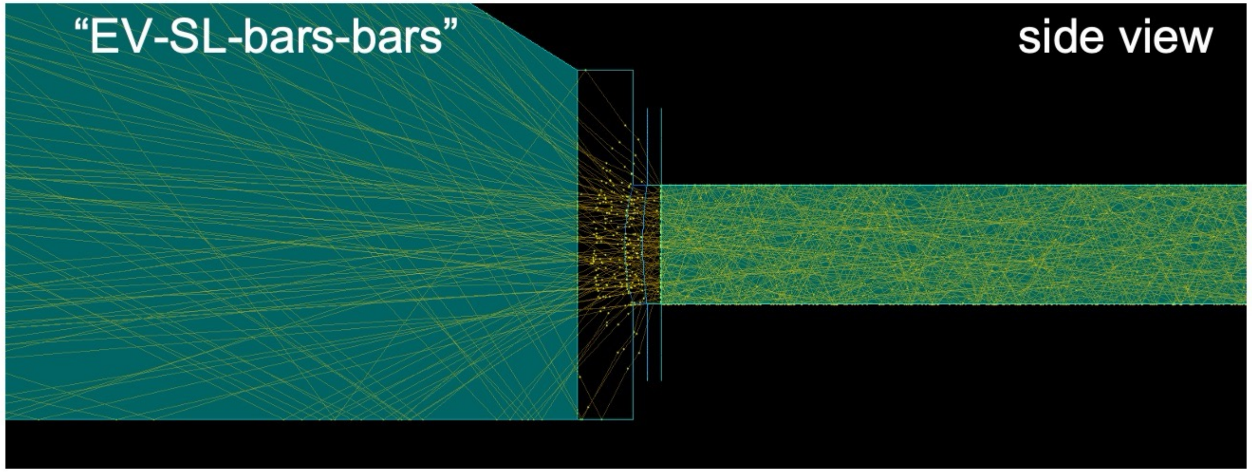


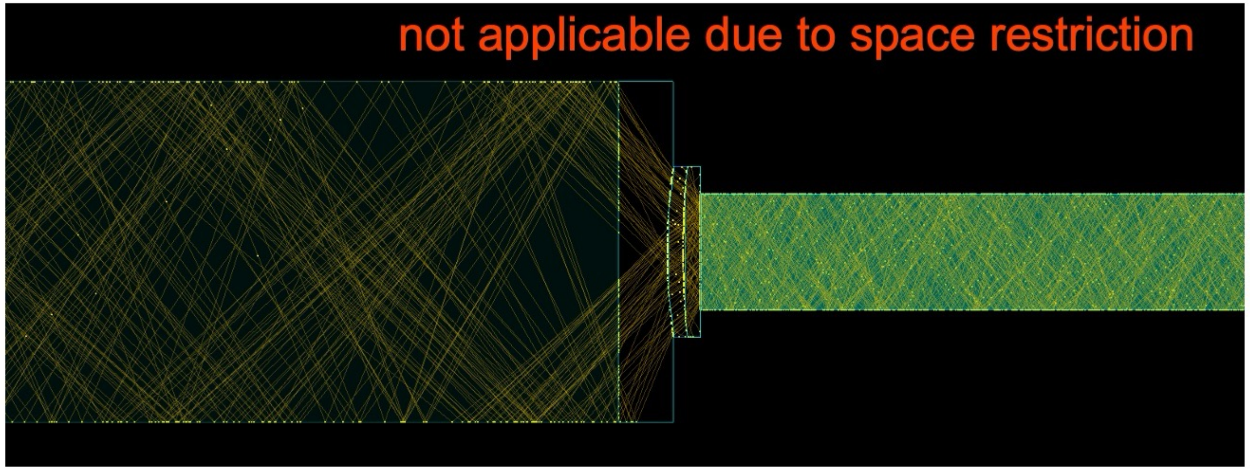


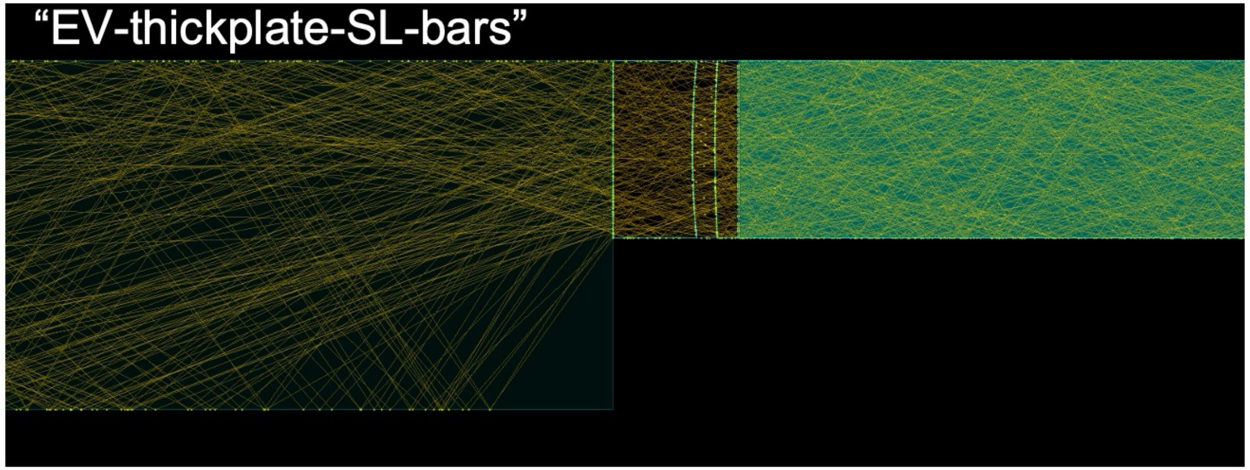


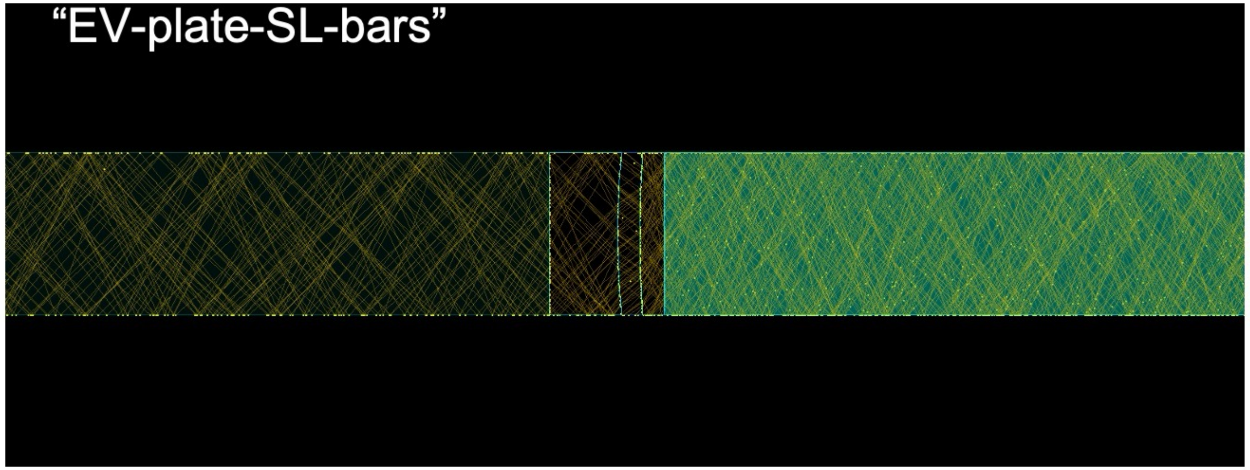
hpDIRC With Wide Plate “Light-guide” Section

event display witch Cherenkov photons from 1 pion @ 6 GeV/c

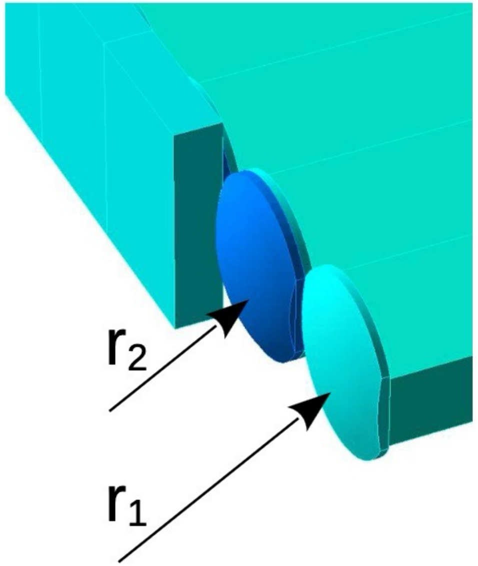




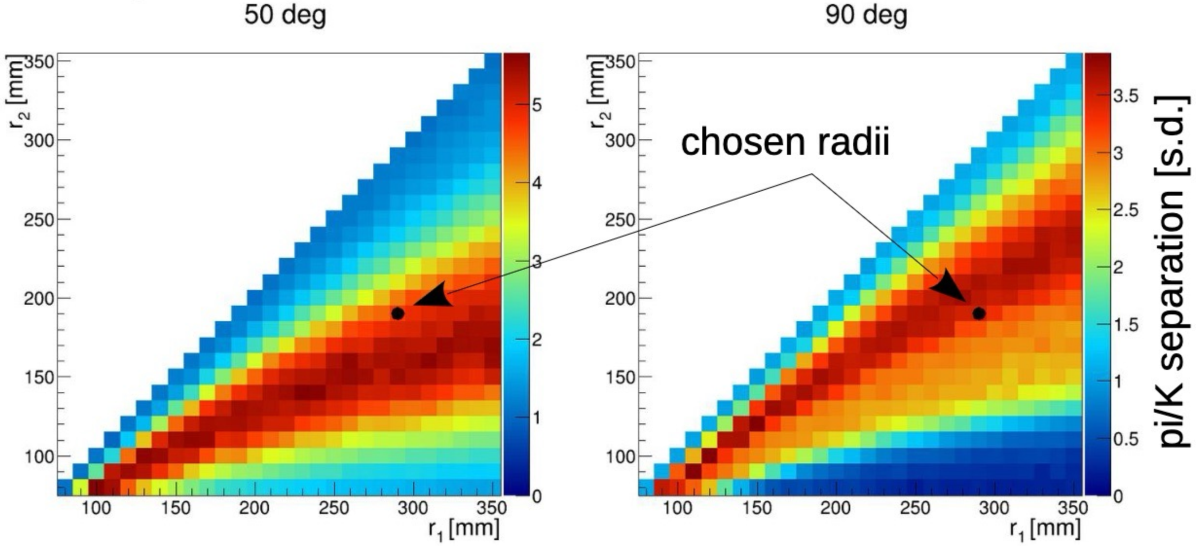




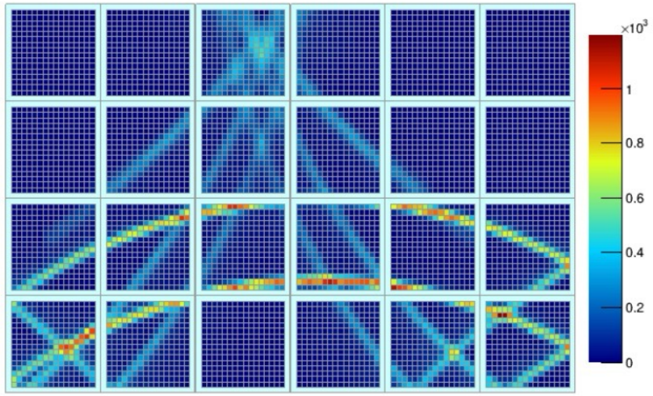
- 3-layer spherical lens
- optimized using radii scan with time imaging reconstruction
- Hit pattern is more complicated
  - kaleidoscopically effect
  - chromatic dispersion



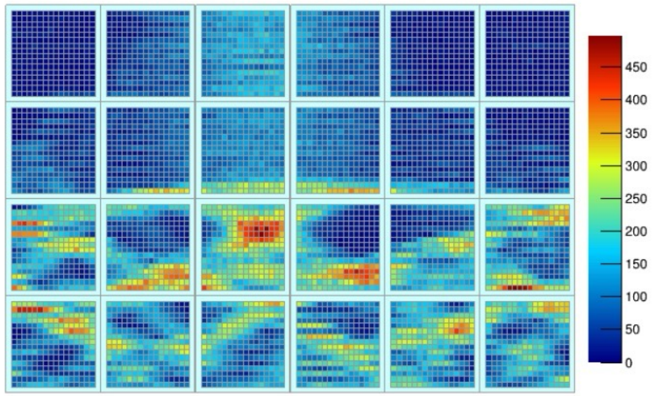
example of radii scan



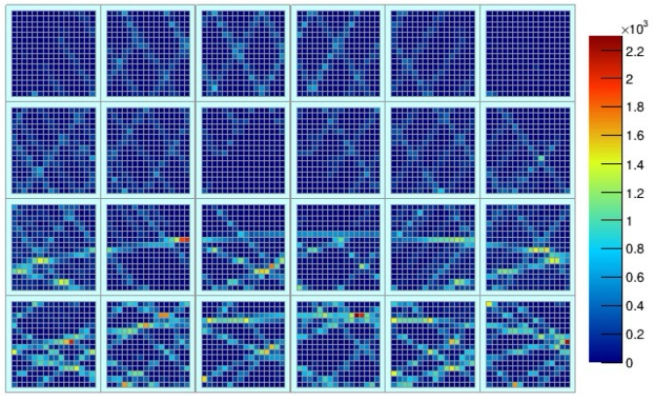
EV-SL-bars-bars



EV-plate-SL-bars



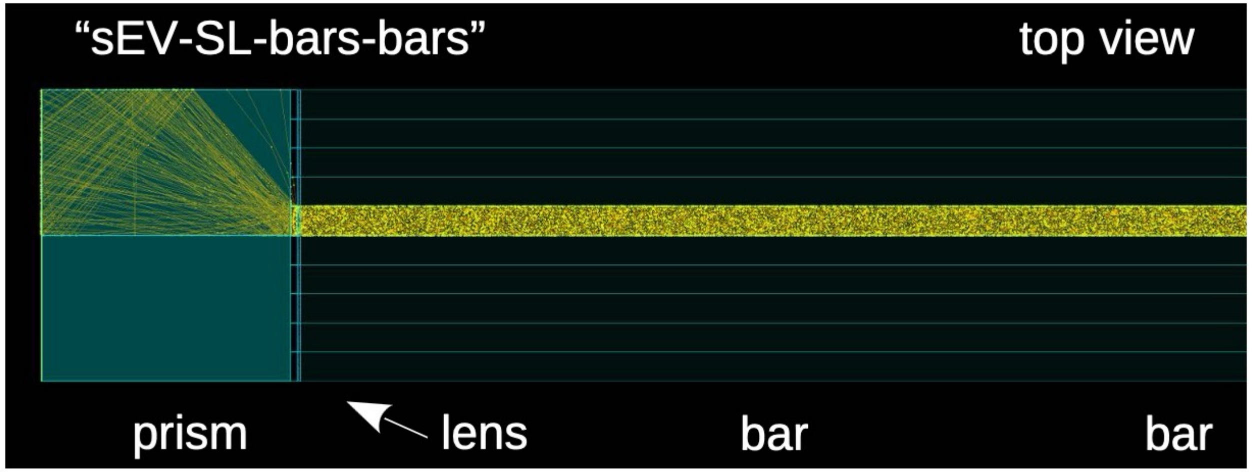
EV-plate-SL-bars with monochromatic Cherenkov light

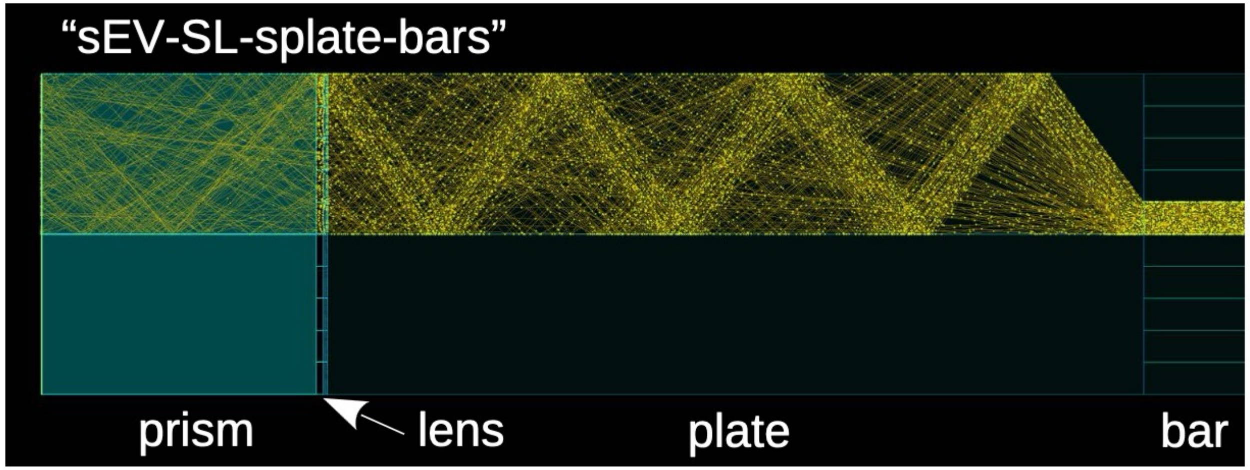


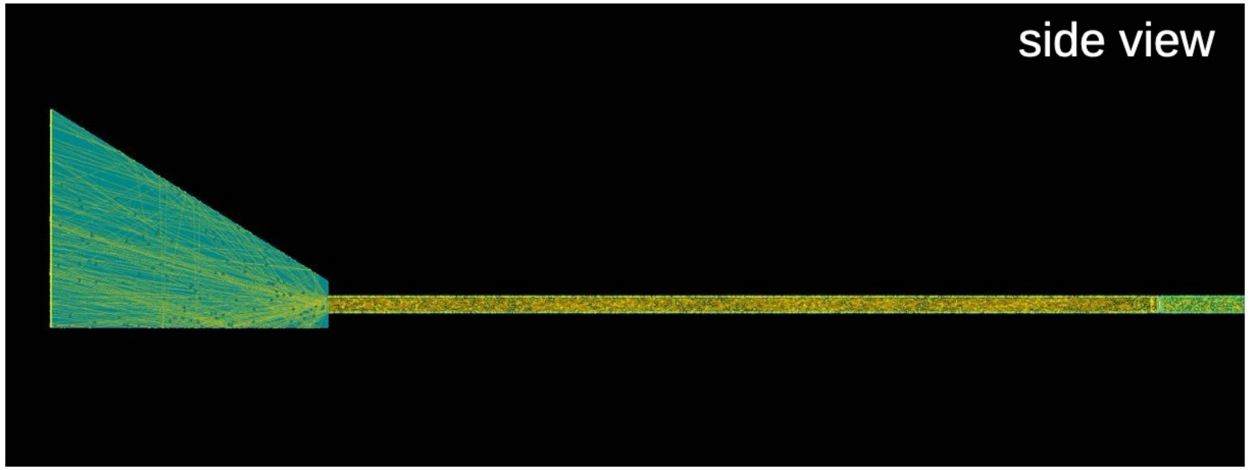
hpDIRC With Wide Plate "Light-guide" Section

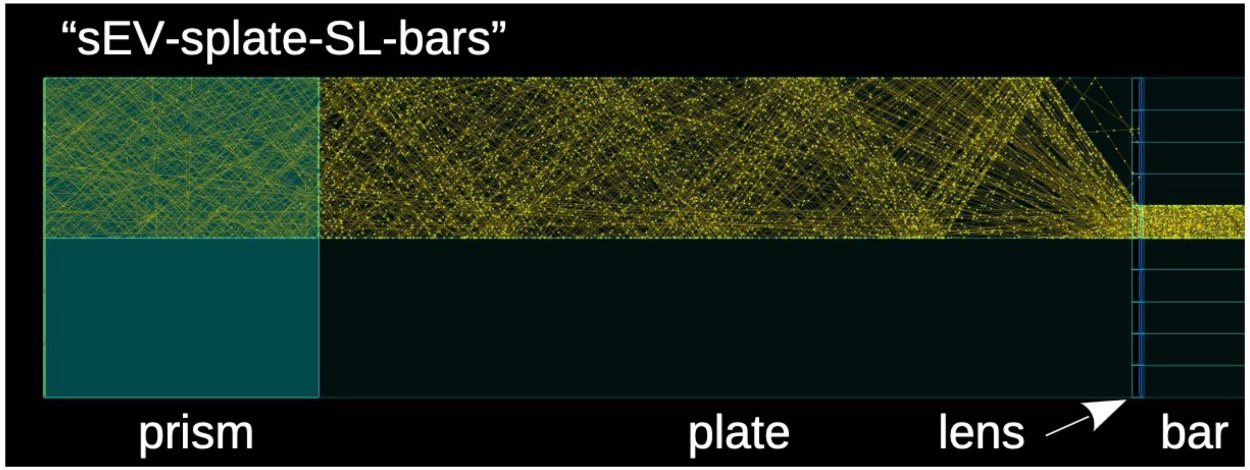
- replace single prism (35cm width) by two narrow prisms (17.5cm)
- replace single plate (35cm width) by two narrow plates (17.5cm)

event display witch Cherenkov photons from 1 pion @ 6 GeV/c









- layout optimization of PMTs (Md. Imran Hossain)
- simulation / reconstruction with high amount of dark noise from SiPM (Md. Imran Hossain)

Sim/Reco status in ePIC, EICrecon:

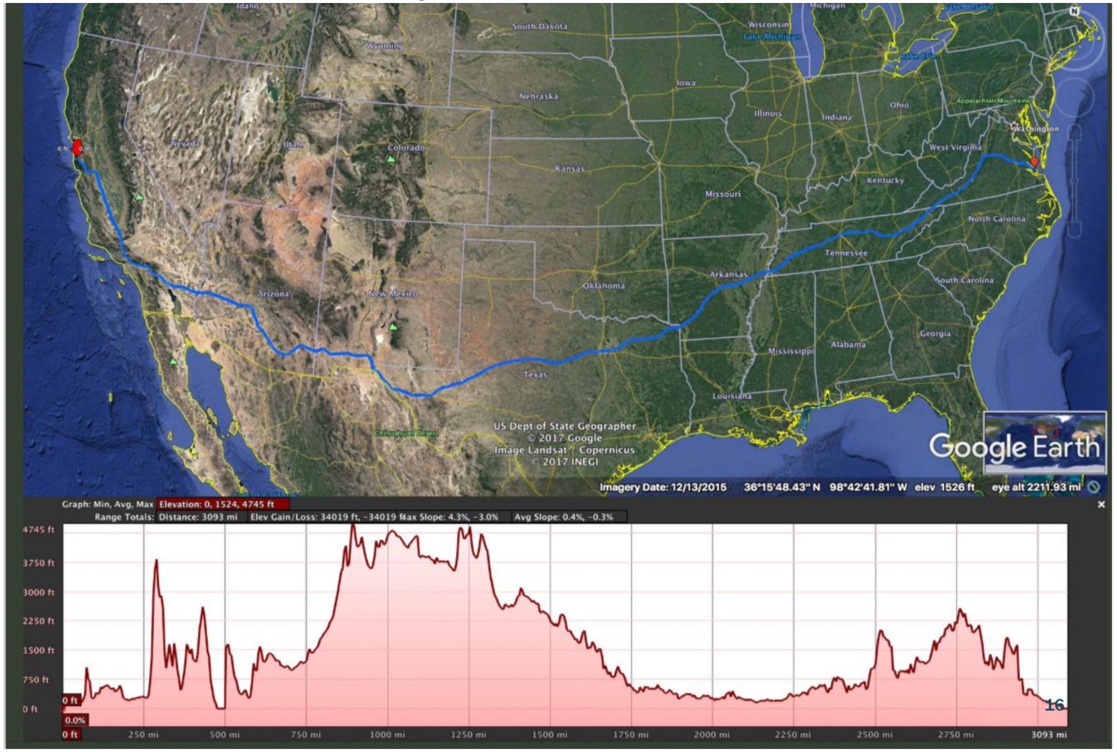
- geometry fully implemented
- quantum and collection efficiencies of PMTs are implemented (stacking action class)
- digi flow: DIRCRawHit (RawTrackerHit) → celd Id → position → PMT Id, pixel Id → dirc tree
- reco is done using dirc tree
- reco documentation is here: https://github.com/eic/snippets/tree/main/PID/hpDIRC
- realistic PID LUT is provided for a fast sim/reco

Nilanga switched to another position → we are looking for a new maintainer

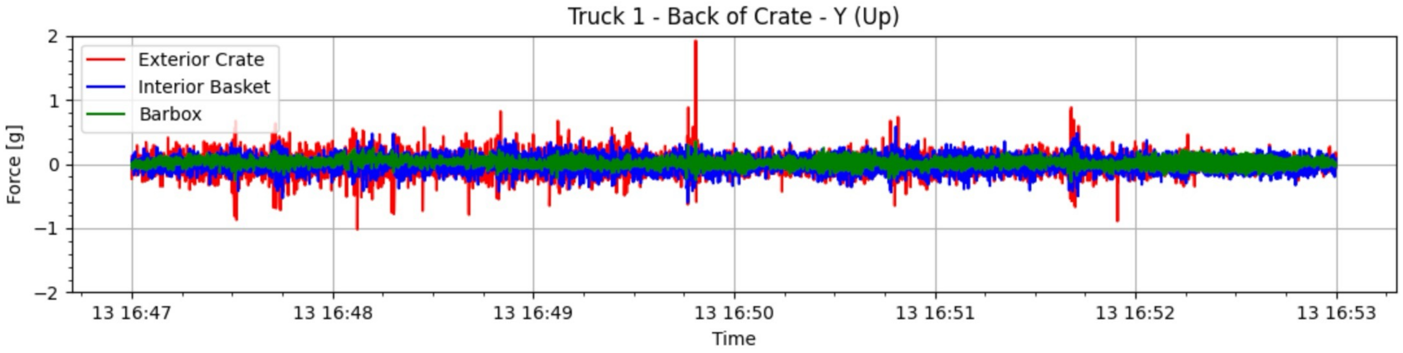
Successful transport of 8 DIRC bar boxes in April 2024

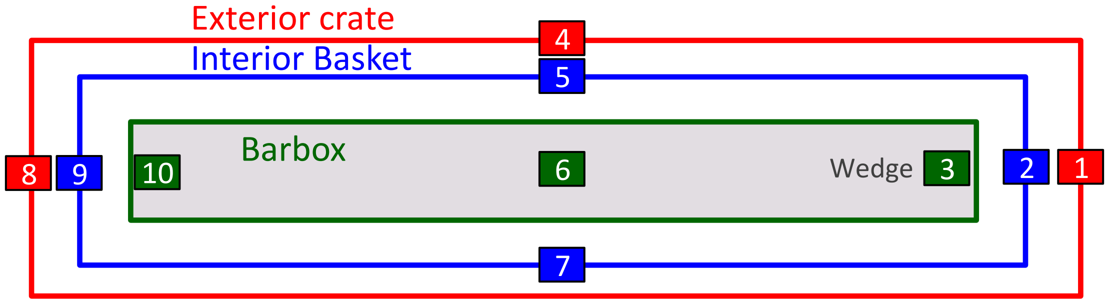
- Low attitude road from SLAC, CA to JLab, VA
- Shocks absorbing foam
- Hydraulic shocks
- Air shocks
- Shock absorbing donuts
- Air-ride, temperature control trucks
- Goal: Keep shocks on Bar box below 1g

Road from SLAC, CA to JLab, VA



Sample of vibrations during transport and location of accelerometers





Andrew Lumanog, Tyler Lemon, Random guy from Poland, Jochen Schwiening

BaBar DIRC Bar Boxes Transfer

Successful transport of 8 DIRC bar boxes in April 2024

- Low attitude road from SLAC, CA to JLab, VA
- Shocks absorbing foam
- Hydraulic shocks
- Air shocks
- Shock absorbing donuts
- Air-ride, temperature control trucks
- Goal: Keep shocks on Bar box below 1g

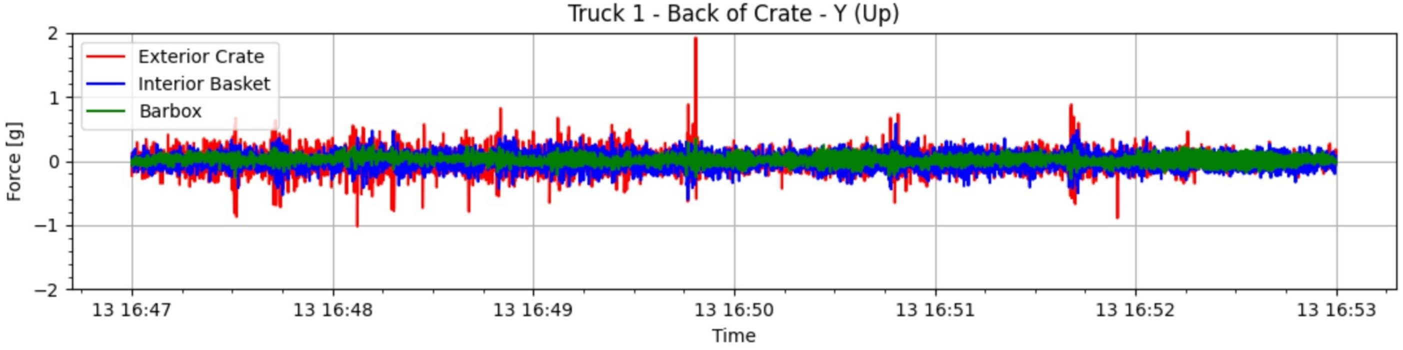
Inside of transportation crates

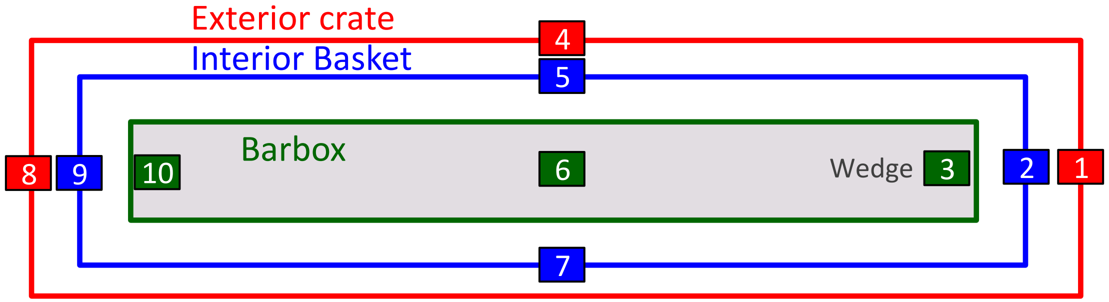
Loaded bar boxes ready for transport

8 bar boxes in two trucks

Bar boxes in Jlab ready for disassembly

Sample of vibrations during transport and location of accelerometers



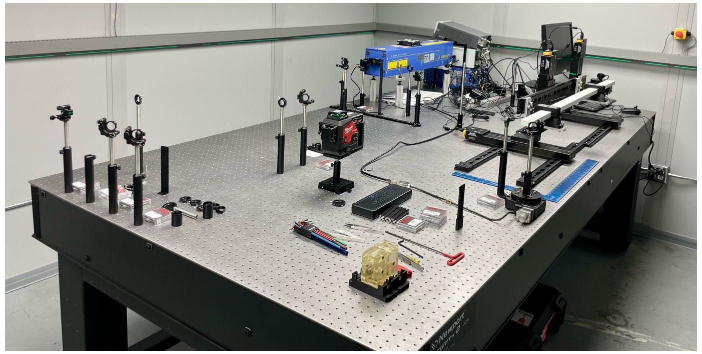


Andrew Lumanog, Tyler Lemon, Random guy from Poland, Jochen Schwiening

Can the BaBar Bars be reused for hpDIRC?

- Bar boxes will be disassembled into individual bars at JLab (starting in Fall)
  - Never done before, working on detailed plan
  - Aluminum covers will need to be ”opened”, glue joints between bars decoupled
- 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

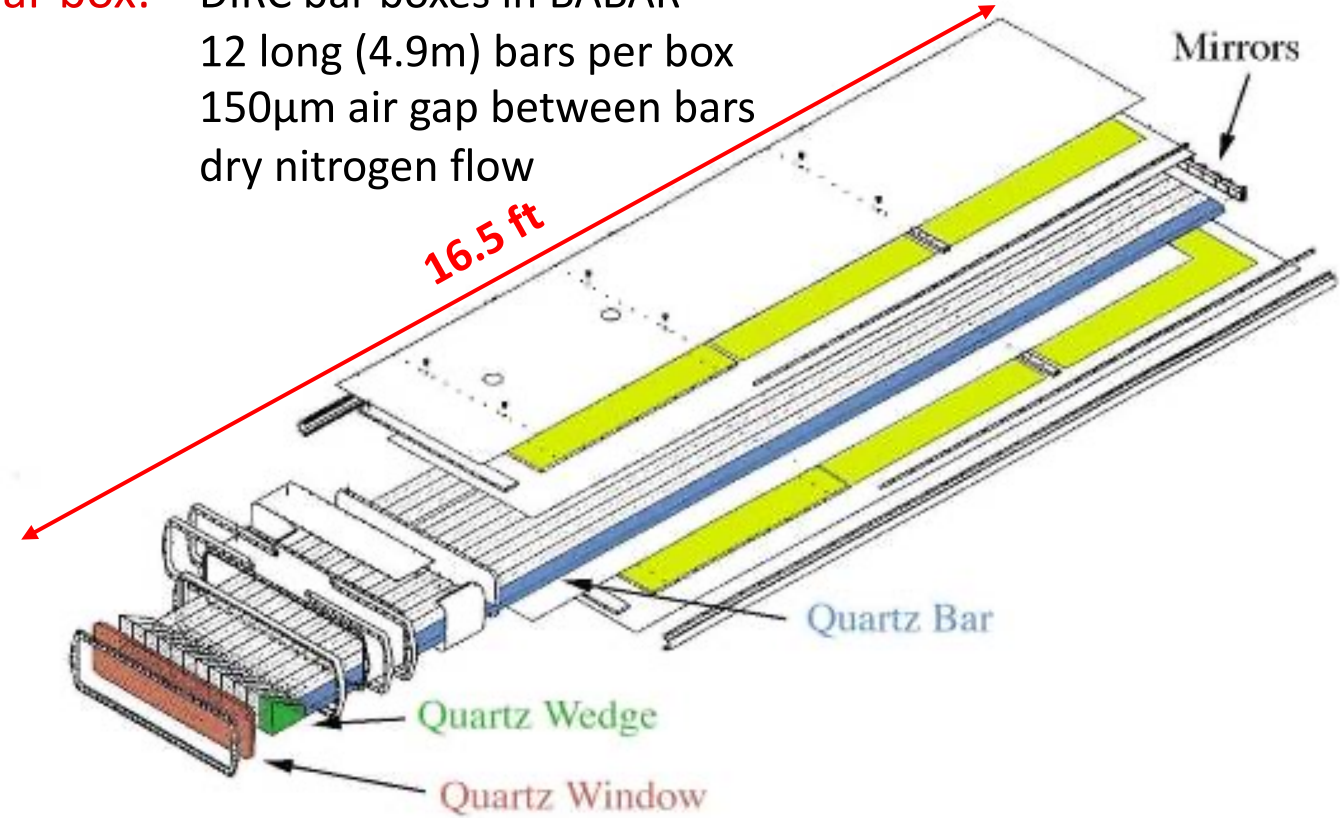
QA Laser Lab



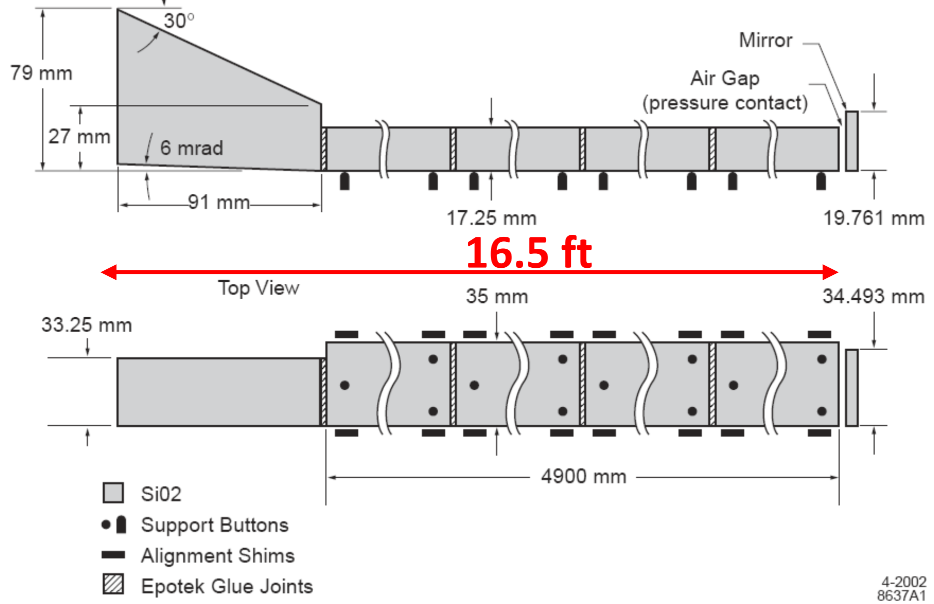
DIRC labs under construction at Jlab EEL108

BaBar DIRC Bar Boxes

Bar box: DIRC bar boxes in BABAR
12 long (4.9m) bars per box
150μm air gap between bars
dry nitrogen flow

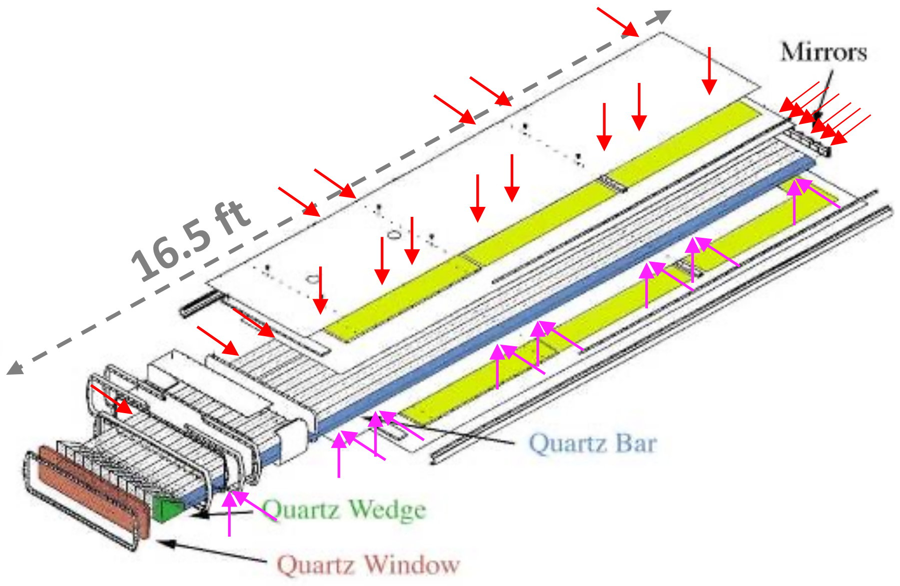


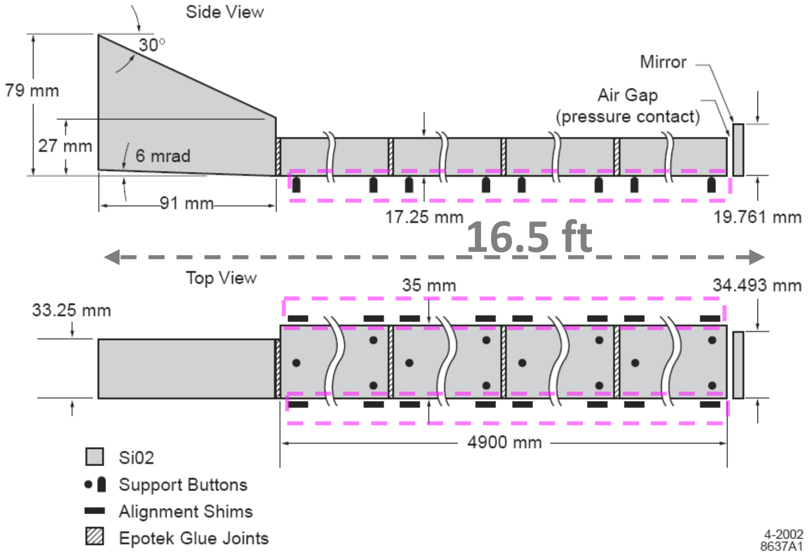
Long bar: 4 short (1.225m) bars
Mirror on forward end
Wedge on readout end



BaBar DIRC Bar Boxes

- 4 short (1.225m) bars are glued end-to-end to create long bar
- Each long bar is glued to mirror on one end and quartz wedge on the other end
- All quartz wedges in single box are glued to one quartz window
- Down to 150µm air gap between each bar **(very tight space for disassembly)**
- Each long bar supported at 8 points along the long surfaces. Two long sides are rested against fixed plastic buttons, two other long sides pressed by spring loaded screws.
- Spring loaded screws pressing mirrors against bar ends.
- All outside screws are fixed with glue (has to be softened before loosening screws)





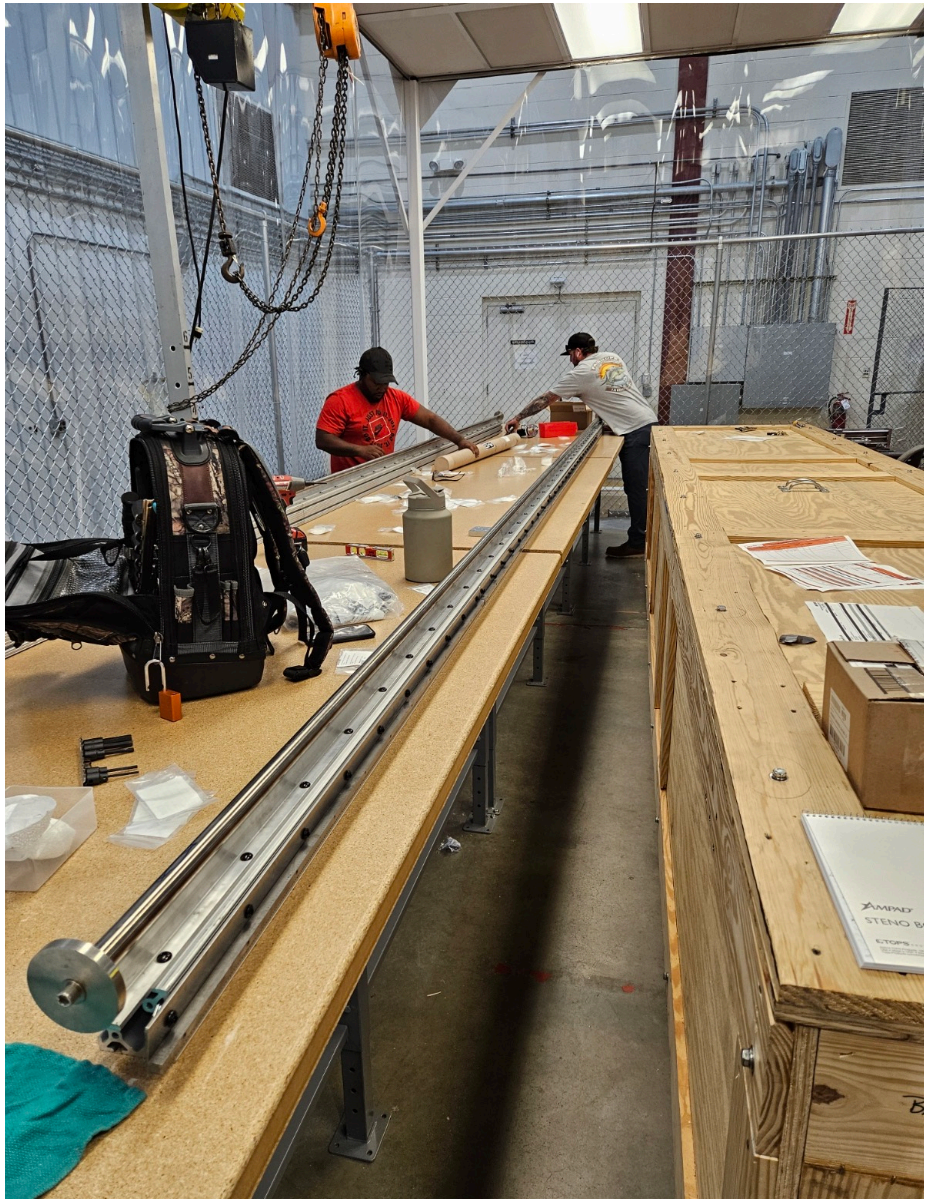
Cutting Into the Bar Box – 20-Foot CNC

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

Cutting Into the Bar Box – 20-Foot CNC

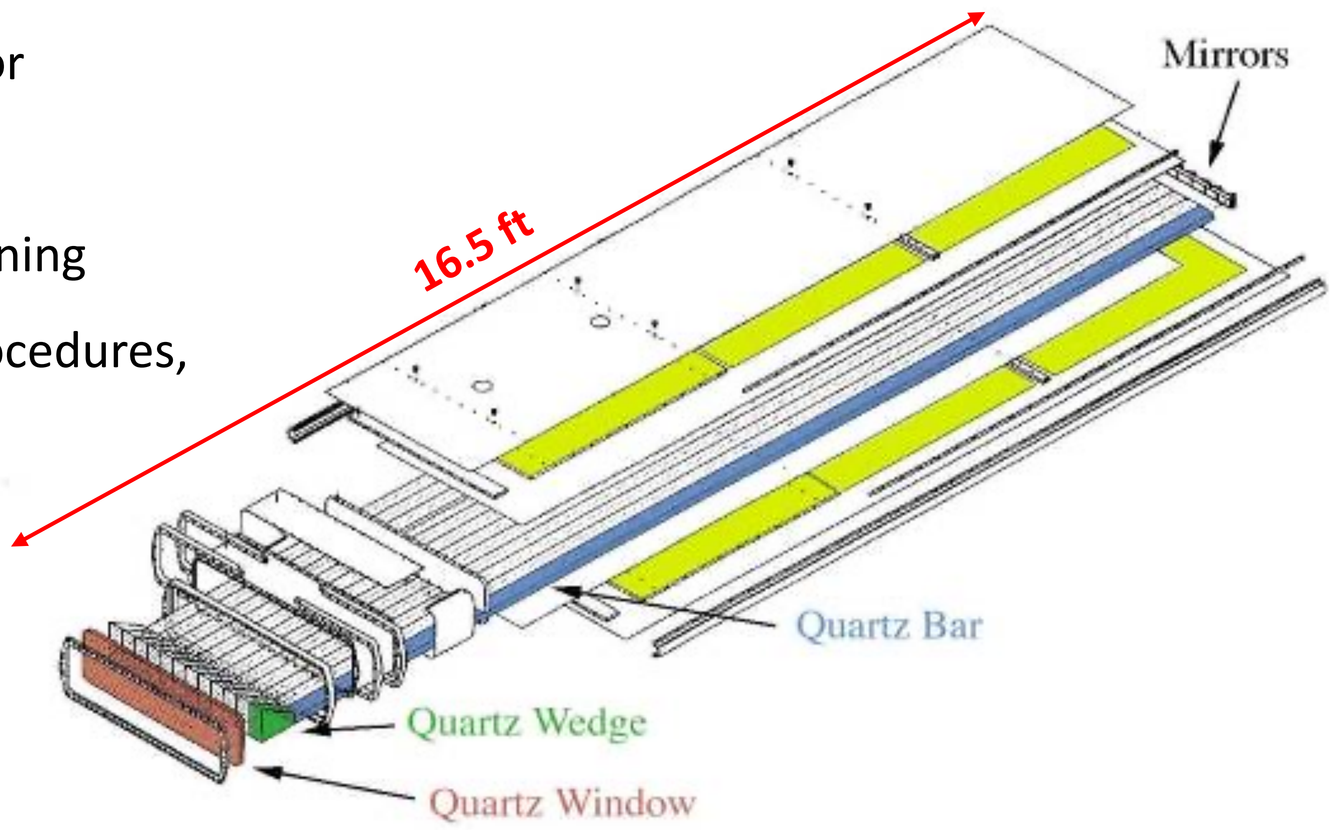
Rails for CNC under construction



Support structure to level the bar box

Tests Prior Disassembly

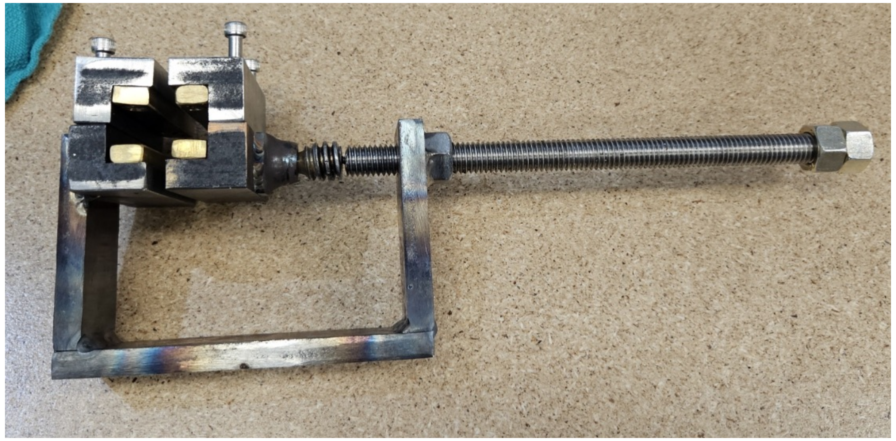
- Two different glues used for optics and aluminum
- Heat guns will be used for optics
- Soldering iron or wood burning set will be used for aluminum can and screws
- Soon will start tests to gain experience with softening glue, establish temperatures, validate heating procedures, and finalize tools design.
- Spring-loaded separation clamp will be used to gently pull bars apart once glue softens



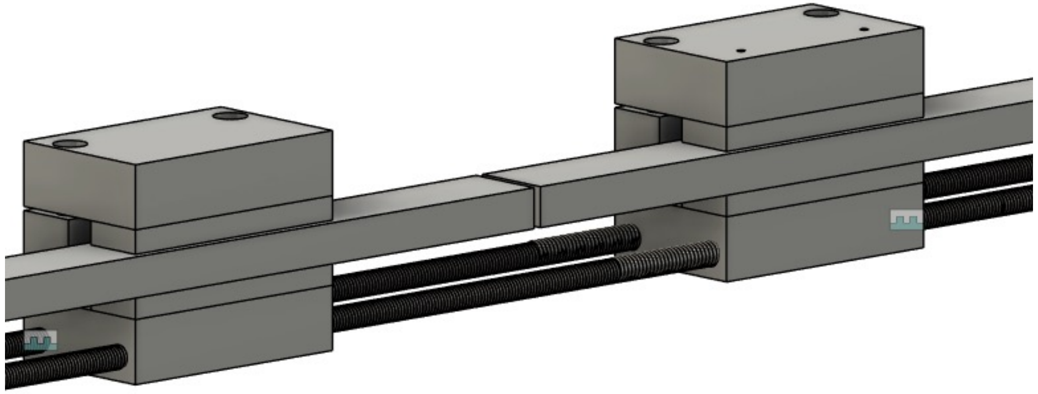
Tests Prior Disassembly

- Custom-made clamps are needed to separate bars once the glue is soft
- Prototype ready for glued sample bars to test it and establish optimal forces

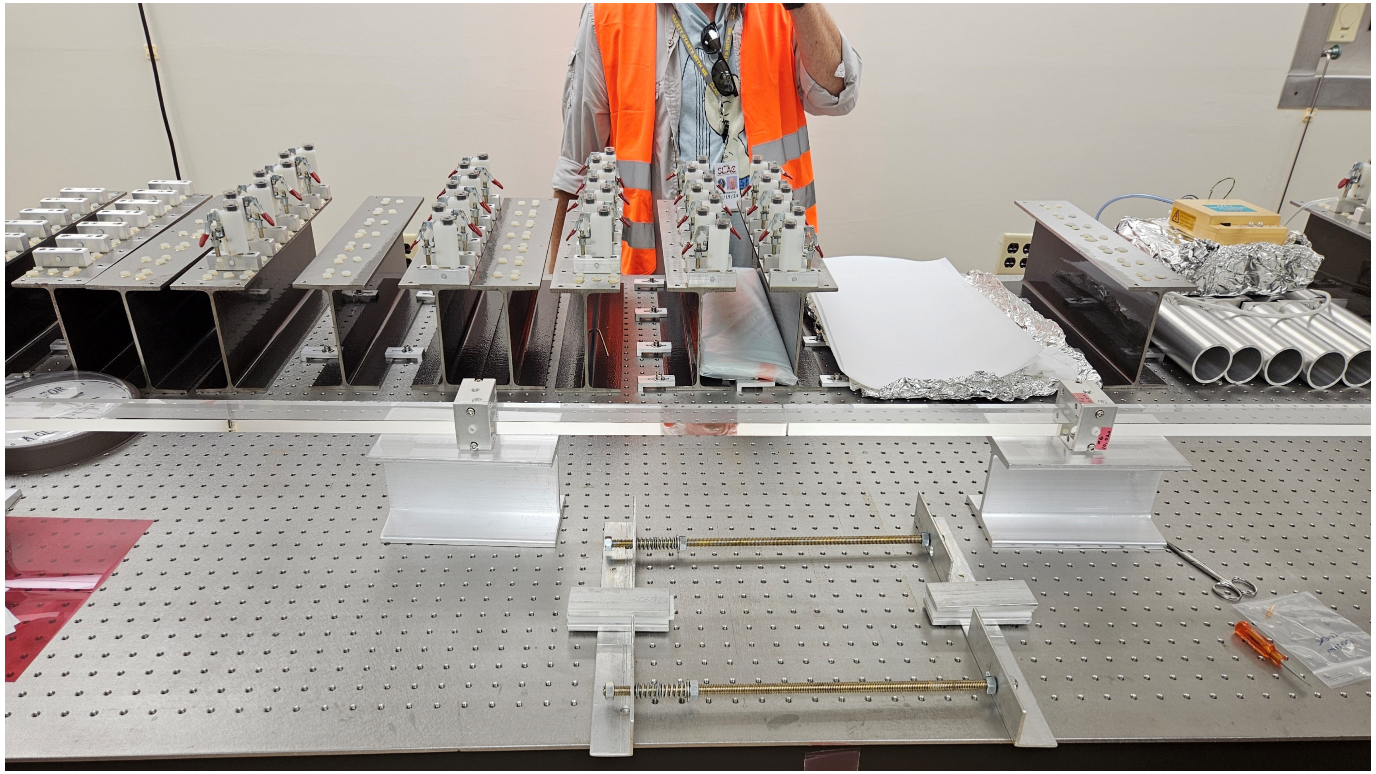
Separating-clamps for sample bars



CAD model of separation clamps



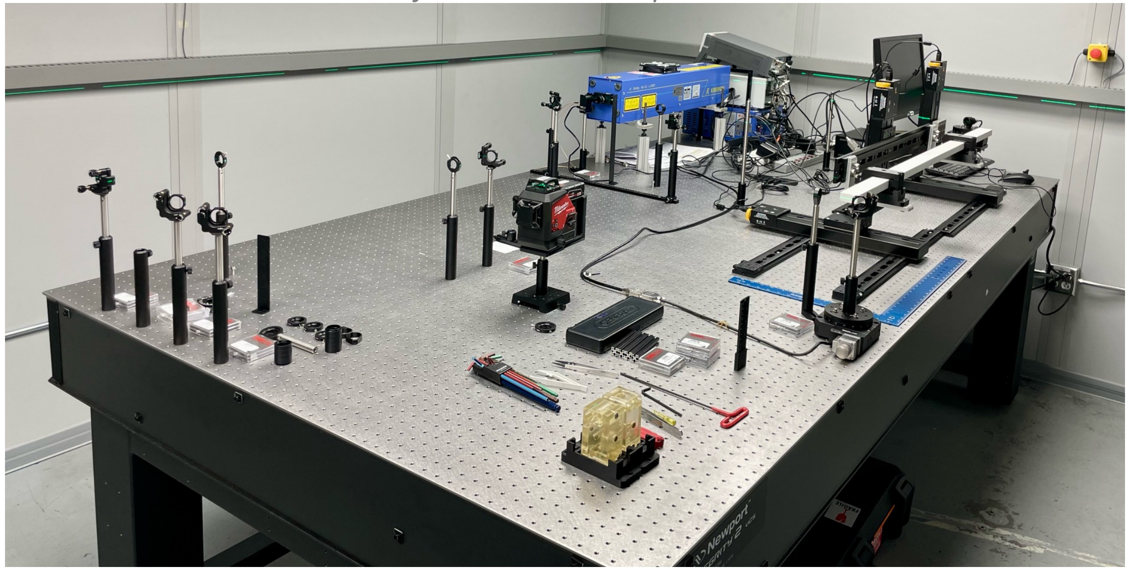
Test of bar separation at SLAC

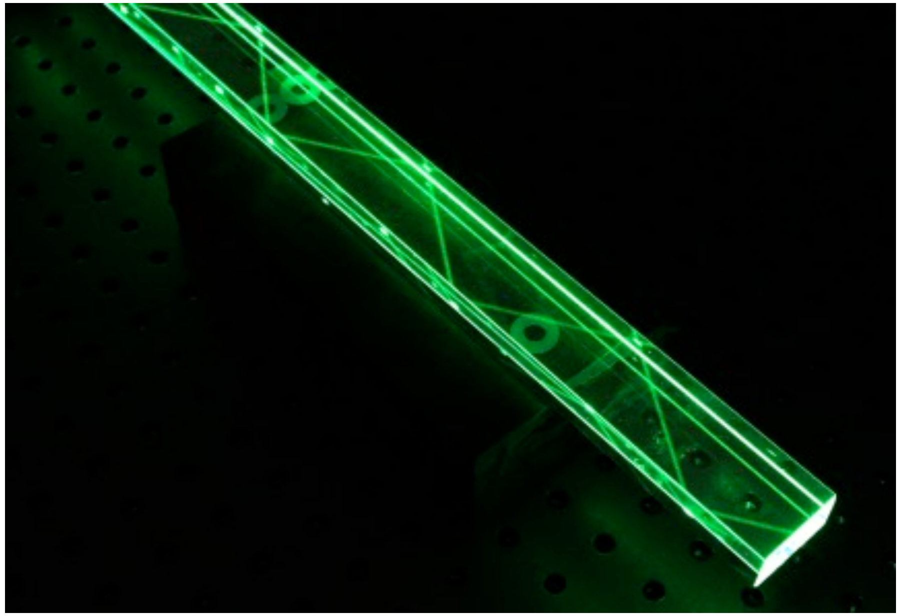


QA Laser Lab

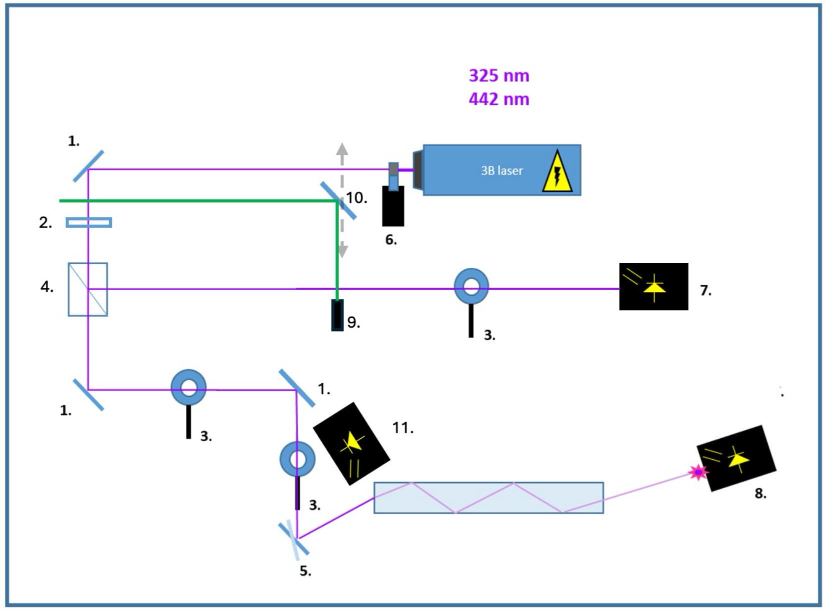
- Laser setup built in JLab based on similar setup at GSI for PANDA Barrel DIRC
- Reflection coefficient measurement will allow to evaluate quality of the bars with sub nm precision
- Two wavelengths will be used (325 nm, 442 nm)

Photo of the QA laser setup in JLab





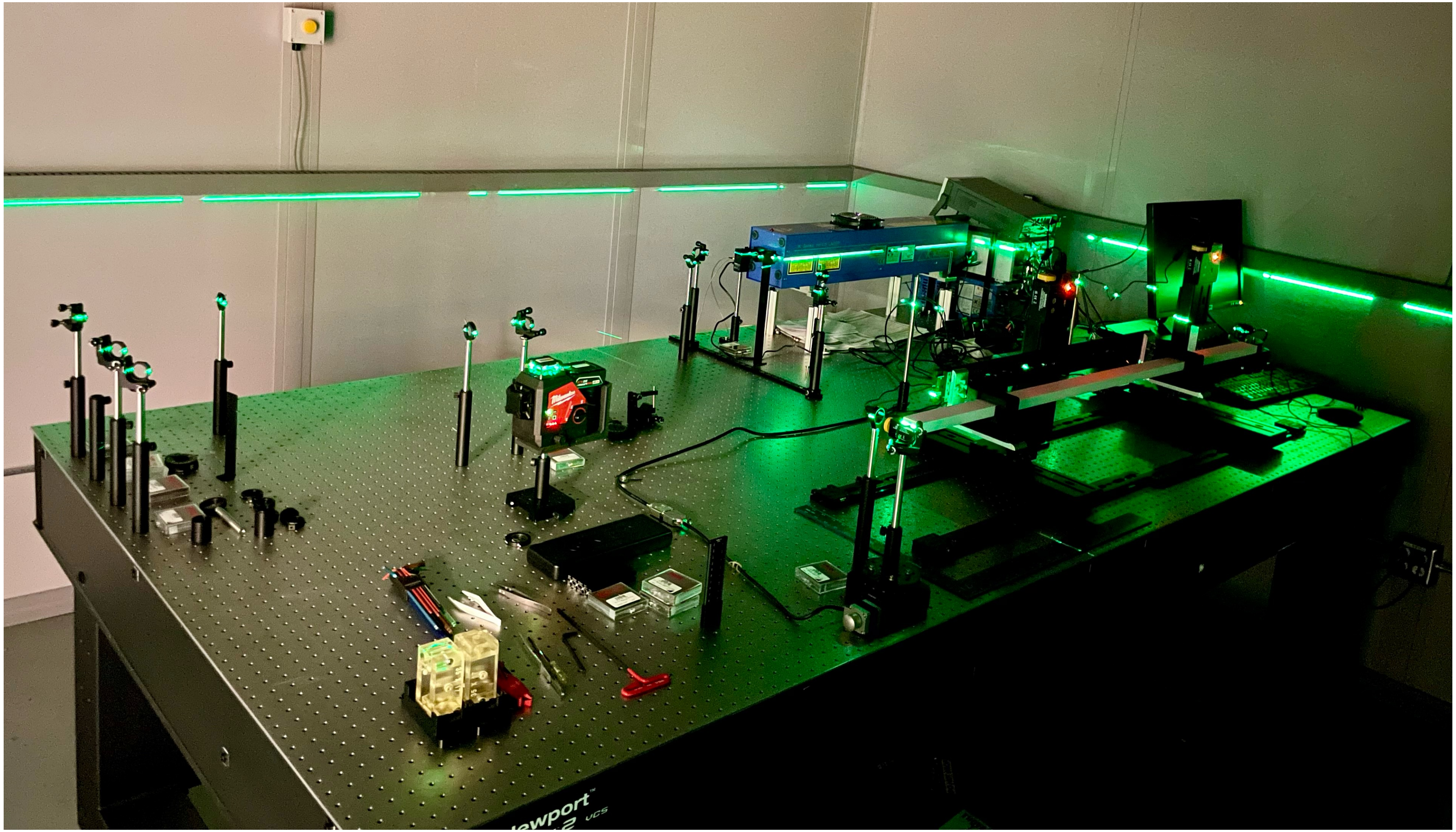
Schematic of the QA laser setup in JLab



1. Mirrors
2. Polarizing cube
3. Diaphragms
4. Beam splitter
5. Brewster mirror
6. Low power filter
7. Reference diode (x2)
8. Value diode
9. 532 nm laser pointer
10. Movable mirror on rail
11. Brewster Assurance Diode

QA Laser Lab

QA laser setup in JLab during alignment

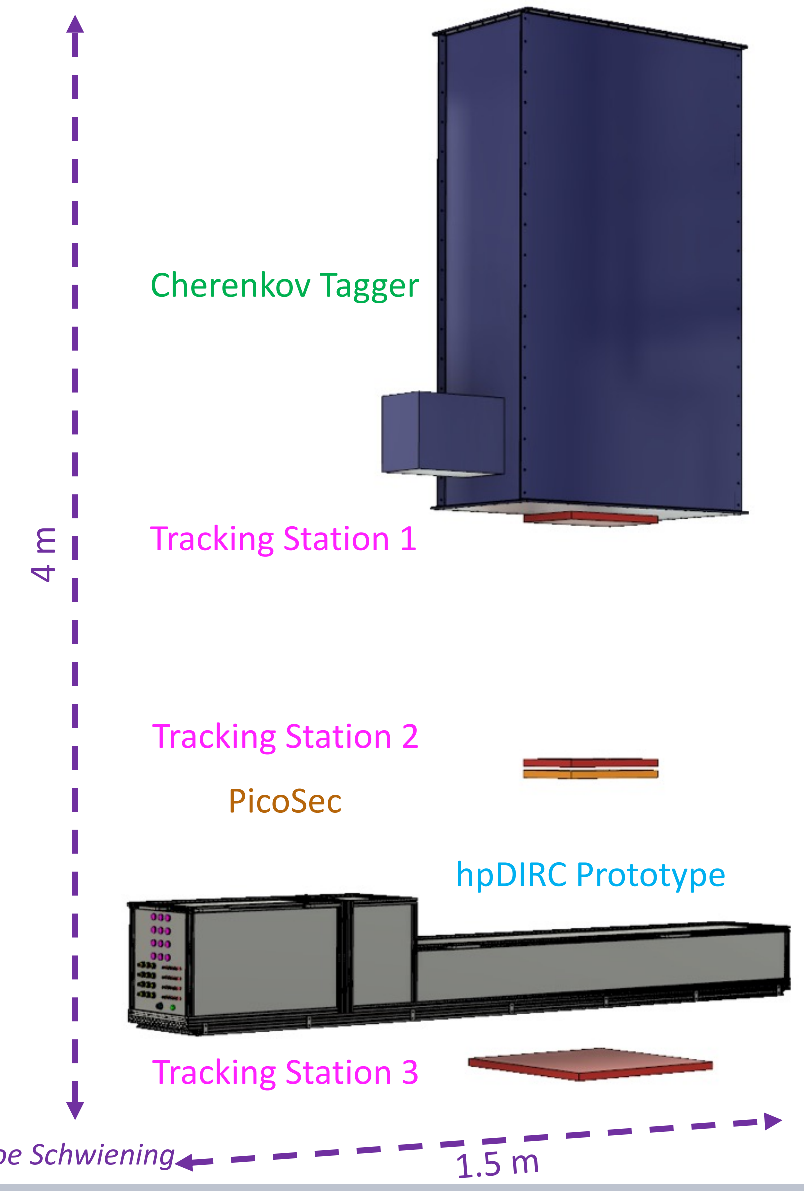


Cosmic Ray Telescope (CRT) at SBU

Facility to test incremental upgrades of prototype components, performance evaluation, and QA of the assembled bar boxes

- 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 (location optimized with simulations)
- 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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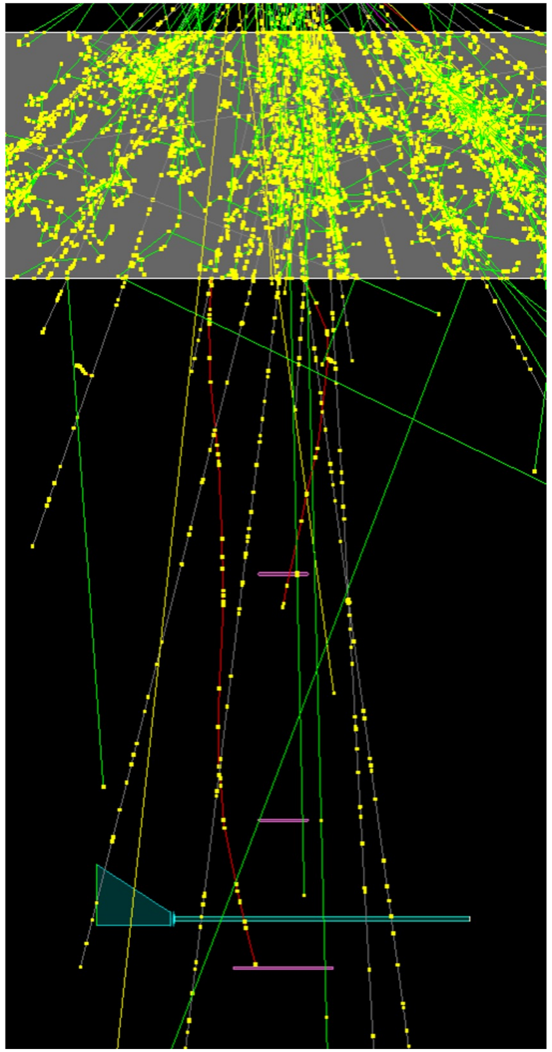
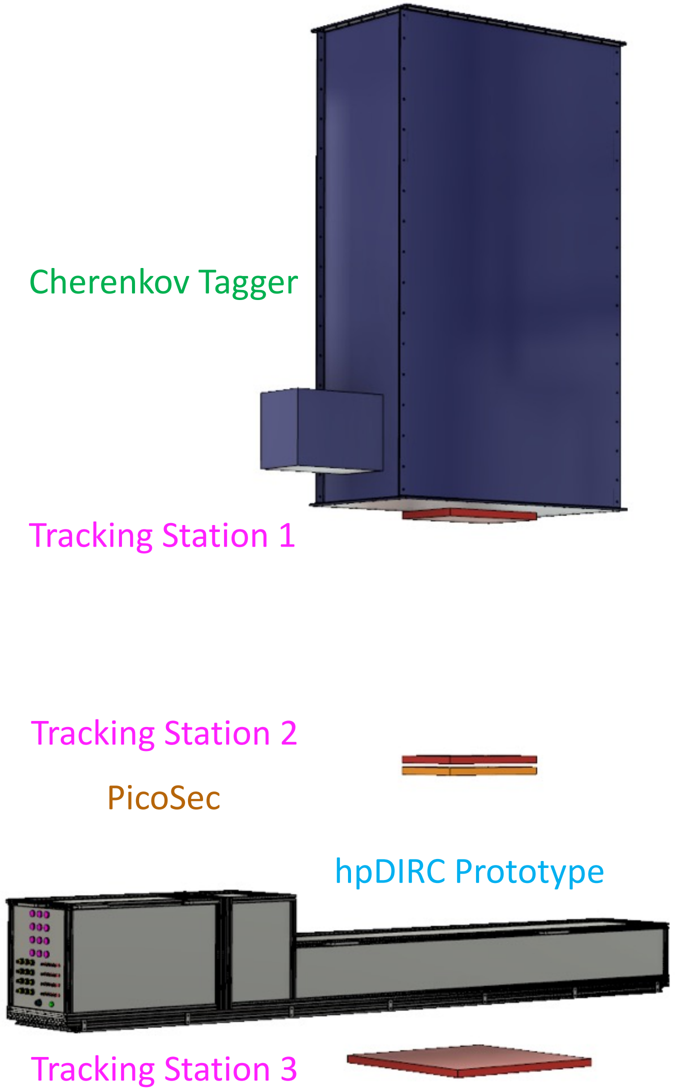
Geant4 simulation of CRT setup



CRT setup CAD schematic



hpDIRC Prototype

- Support structure completed and ready for installation of all CRT components
- Design optimized to allow usage of crane in the area to install Cherenkov Tagger
- Stewart platform adapted to control position of hpDIRC prototype

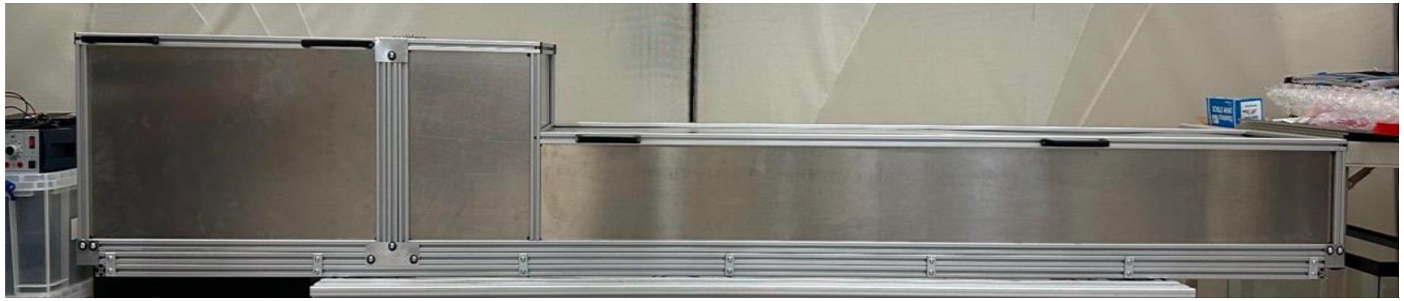
Stewart platform for 3D motion of Protype

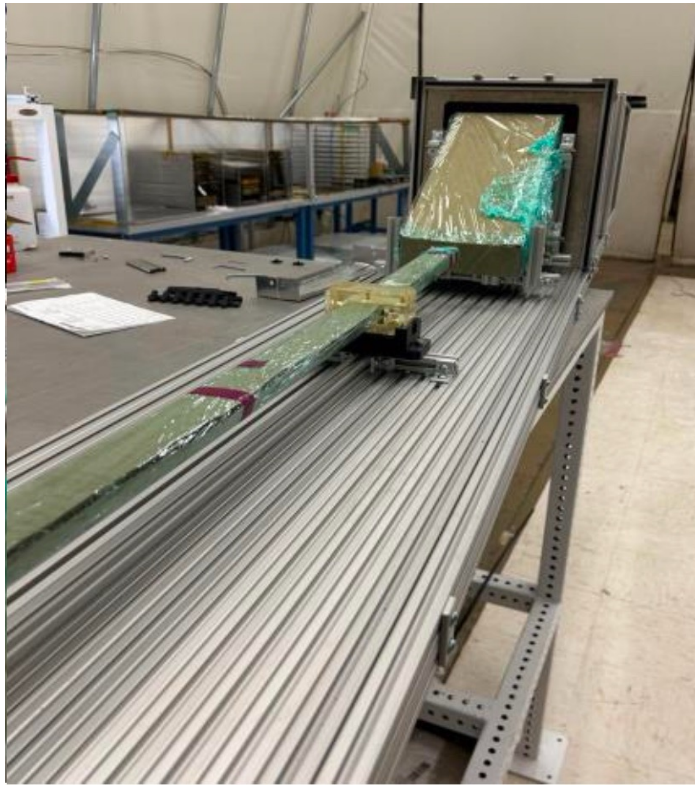
Full CRT setup CAD schematic

hpDIRC Prototype with CRT support structure at SBU

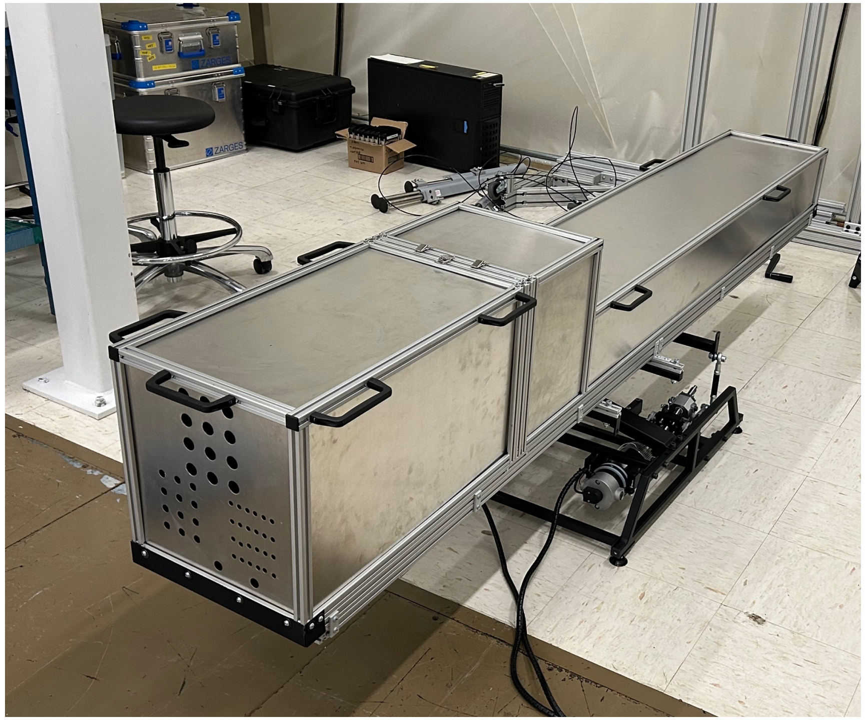
hpDIRC Prototype

hpDIRC prototype during light-tight and inner functionality tests





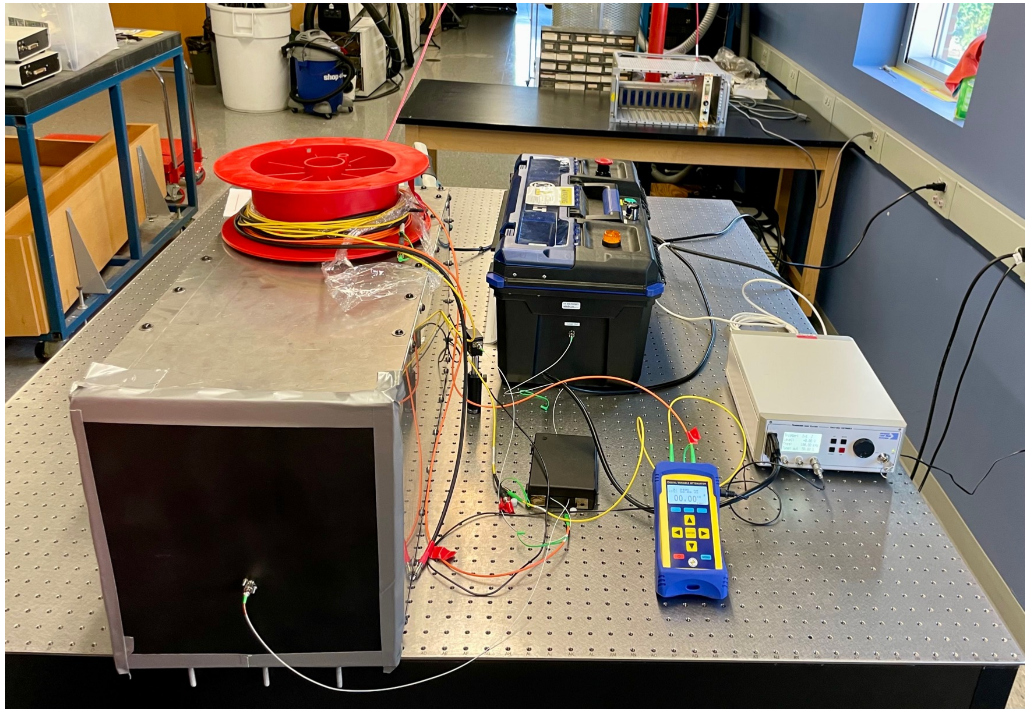
hpDIRC prototype on motion control stage



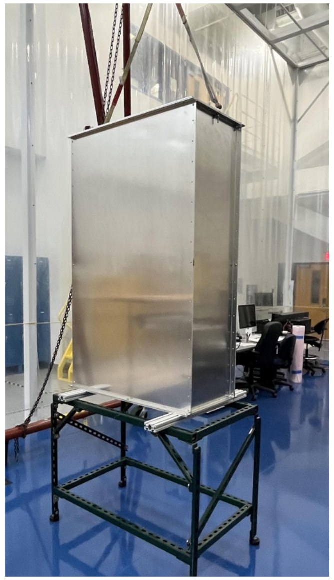
Cherenkov Tagger for CRT

- Cherenkov tagger is being developed and constructed at ODU (C. Hyde, C. Ayerbe Gayoso, A. Garrett)
- Readout section and mirror are being finished and installed
- 3-inch phototube is being tested
- Tagger will be transported to SBU in August 2024

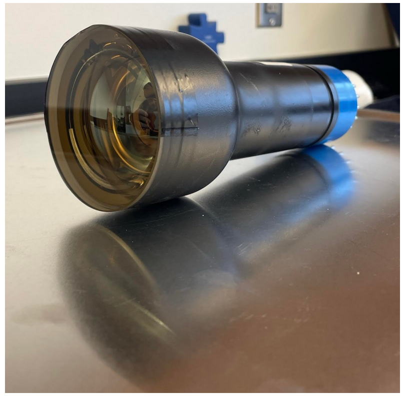
Setup to validate and characterize PMT



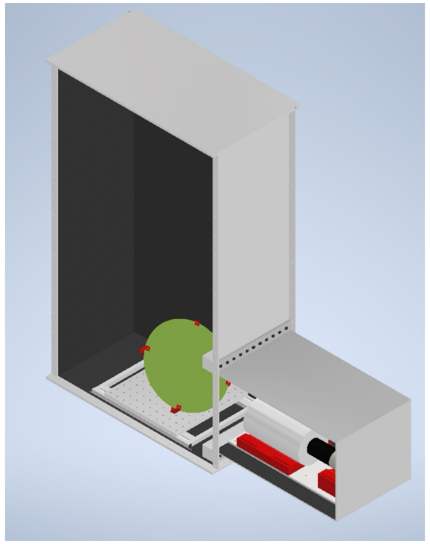
Cherenkov tagger at ODU



3-inch PMT



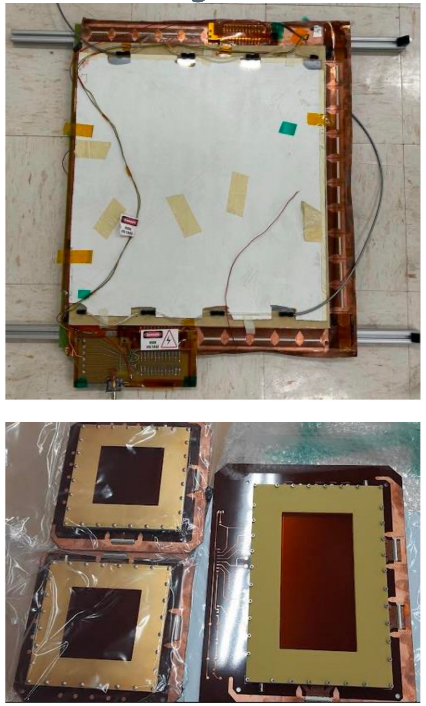
CAD of Cherenkov tagger



CRT Tracking and Timing

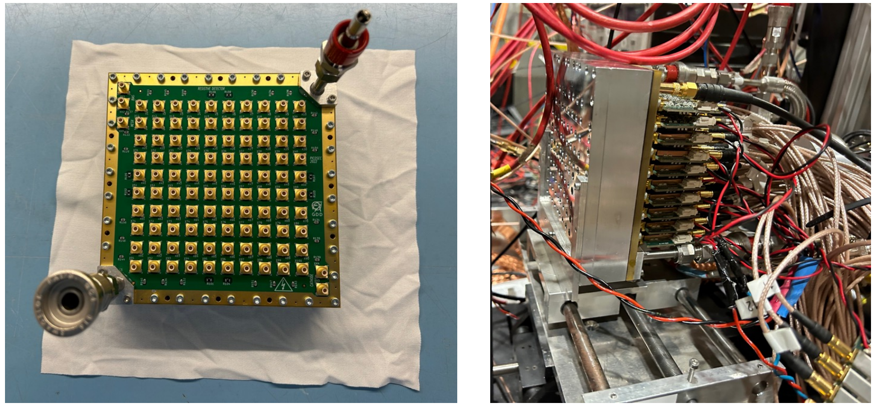
- Tracking
  - Two µRWELL stations (10 cm x 20 cm)
  - One GEM tracker (50 cm x 50 cm)
  - Each layer will measure the position of a cosmic particle with a spatial precision of about 60–70 µm
  - Tested in recent test beam in CERN
  - DAQ tests and integration with DIRC prototype DAQ are in progress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

Tracking stations



DAQ test setup at SBU

PicoSec Prototype



Summary

- Bar boxes were transported from SLAC, CA to JLab, VA
- Disassembly and test of decoupled bars is expected to start in September
- CRT assembly is underway with the commissioning to start in Aug/Sep
- On track to validate feasibility of reusing BaBar DIRC bars
- Simulation studies are underway to optimize:
  - Number of sensors and the layout on the focal plane
  - Width and thickness of the bars, if the BaBar DIRC bars cannot be reused
  - Complete the study of the hybrid optics.
- Mechanical design and integration are progressing with no showstoppers