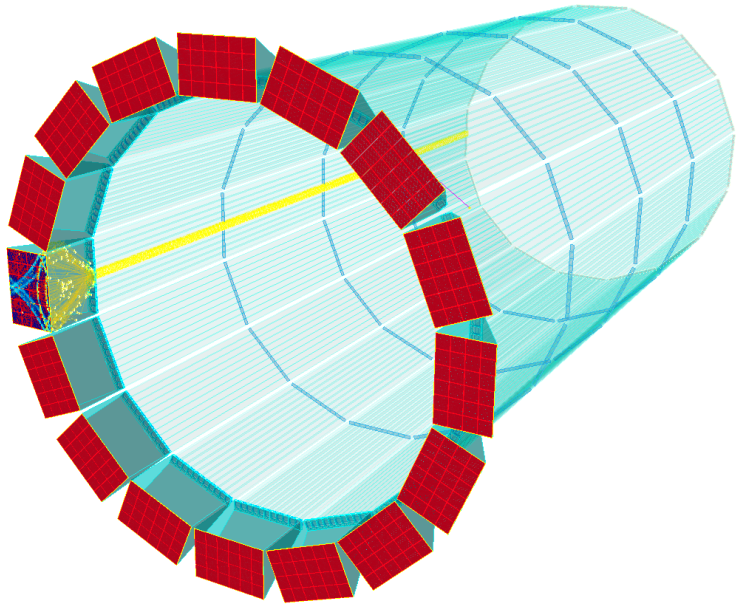
The High-Performance DIRC

Greg Kalicy — CUA

Jochen Schwiening — GSI



- **Concept and Design**
- **Key R&D projects:**
  Test bench tests, and Prototype
- **Remaning questions**
- **Cosmic Ray Telescope**

eRD103 hpDIRC Group

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C. Schwarz, J. Schwiening, G. Varner, N. Wickramaarachchi, C. Zorn

CUA · FAU Friedrich-Alexander Universität Erlangen-Nürnberg · GSI · University of Hawaii · Jefferson Lab · Old Dominion University · University of South Carolina · Stony Brook University

HPDIRC CONCEPT

Concept:

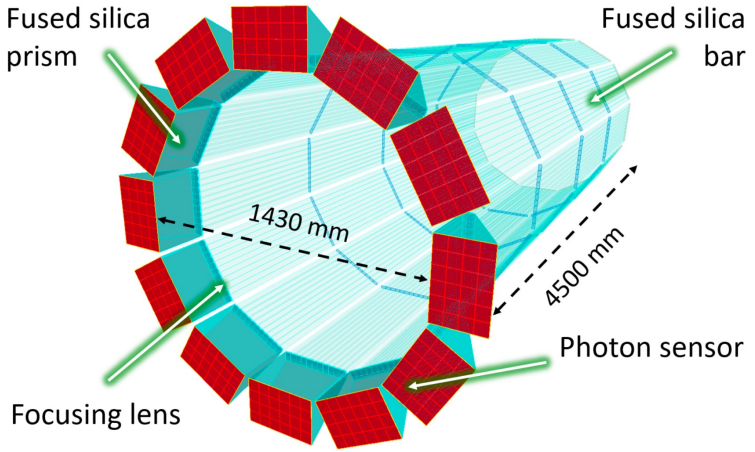
- Fast focusing DIRC, utilizing high-resolution 3D (x,y,t) reconstruction
- Innovative 3-layer spherical lenses, compact fused silica expansion volumes
- Fast photon detection using small-pixel MCP-PMTs *(eRD14)* and high-density readout electronics *(eRD14)*

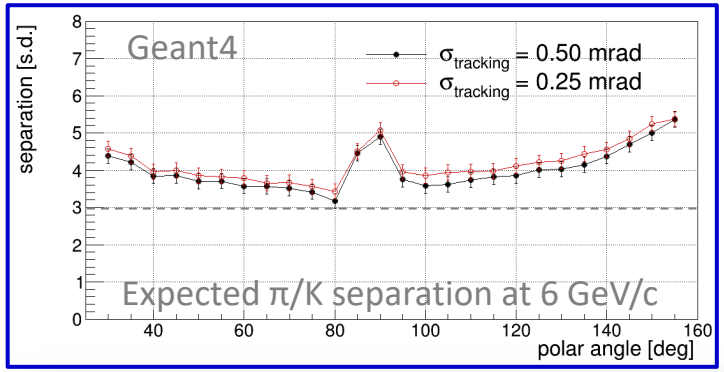
Excellent performance over wide angular range:

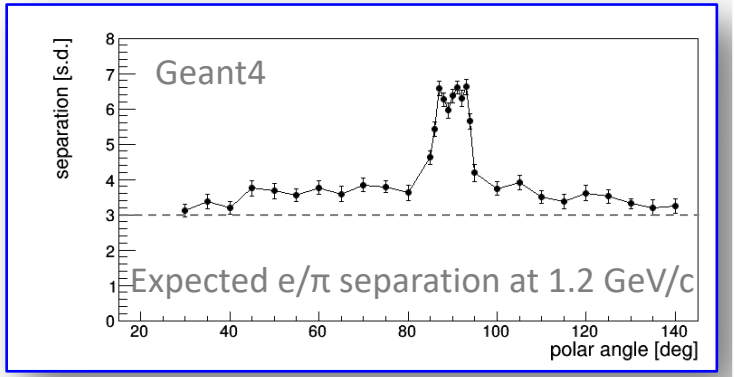
- ≥ 3 s.d. π/K up to 6 GeV/c, ≥ 3 s.d. e/π up to ~1.2 GeV/c
- Low momentum π/K identification in "veto mode" down to 0.2-0.3 GeV/c

Key Features:

- **Radially compact** (~6 cm; impact on cost of post-DIRC systems)
- **Flexible design** (to deal with sensor in B-field and detector integration)
- **Low demand on detector infrastructure** (no cryogenic cooling, no flammable gases)
- **R&D at advanced stage** (PID performance estimate based on test beam results, excellent agreement between detailed simulation and prototype data, fast simulation available)







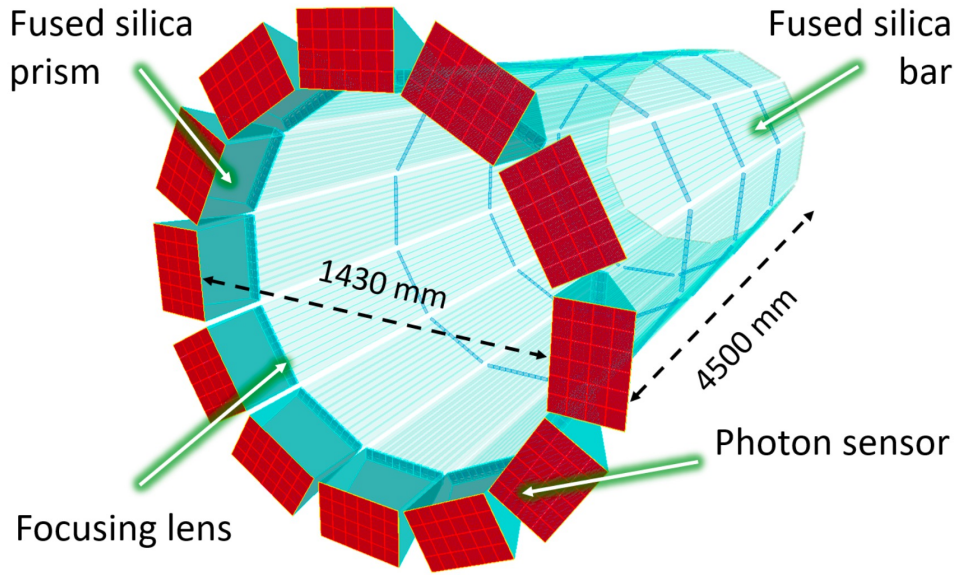
EIC HPDIRC

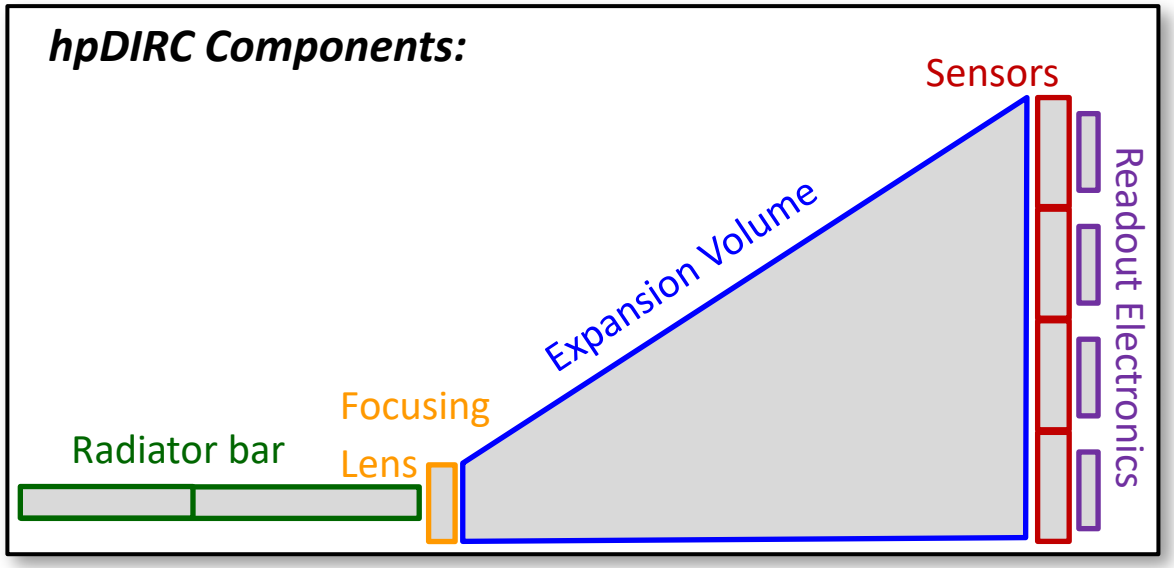
- **Barrel hpDIRC with 72cm radius**
- **Radiator bars:**
  - **420cm bar length** (works with both reused BaBar DIRC bars or new bars)
  - **12 bar boxes**, 10 long bars side-by-side in a bar box, 3 BaBar DIRC bars plus one half BaBar DIRC bar glued to form one long bar (or 3 BaBar DIRC bars plus one new short plate)
- **Focusing optics:**

  Radiation-hard 3-layer spherical lens
- **Expansion volume:**

  Solid fused silica prism: 24 x 36 x 30 cm^3 (H x W x L)
- **Readout:**

  PHOTONIS MCP-PMT Sensors + NALU's ASIC based Readout Electronics





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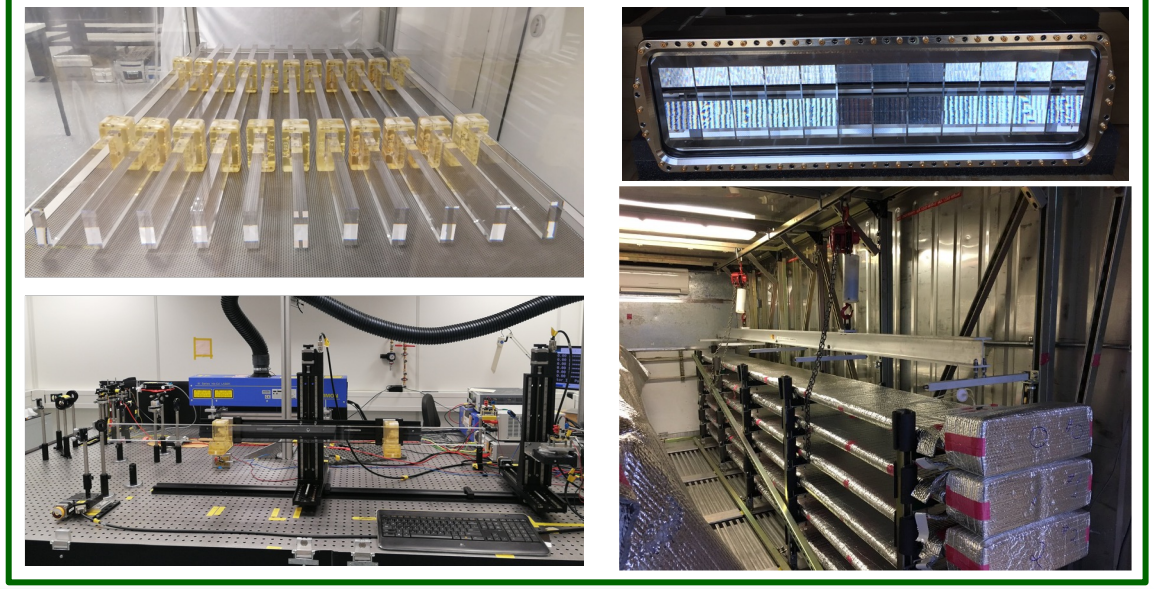
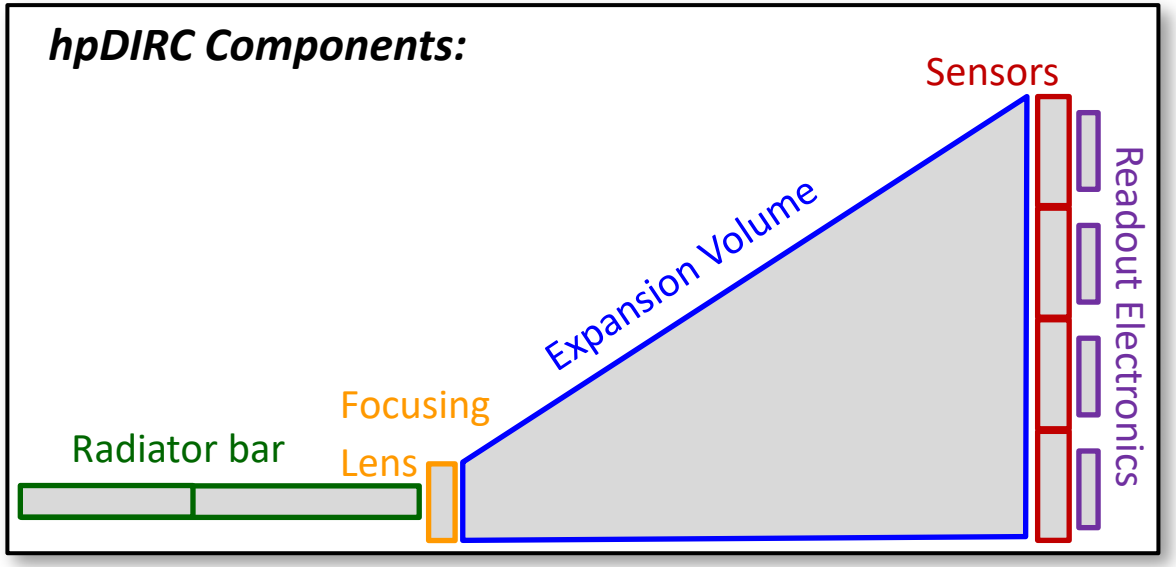
BaBar Bars dissasambly soon to start, new QA lab in JLab



hpDIRC Components:



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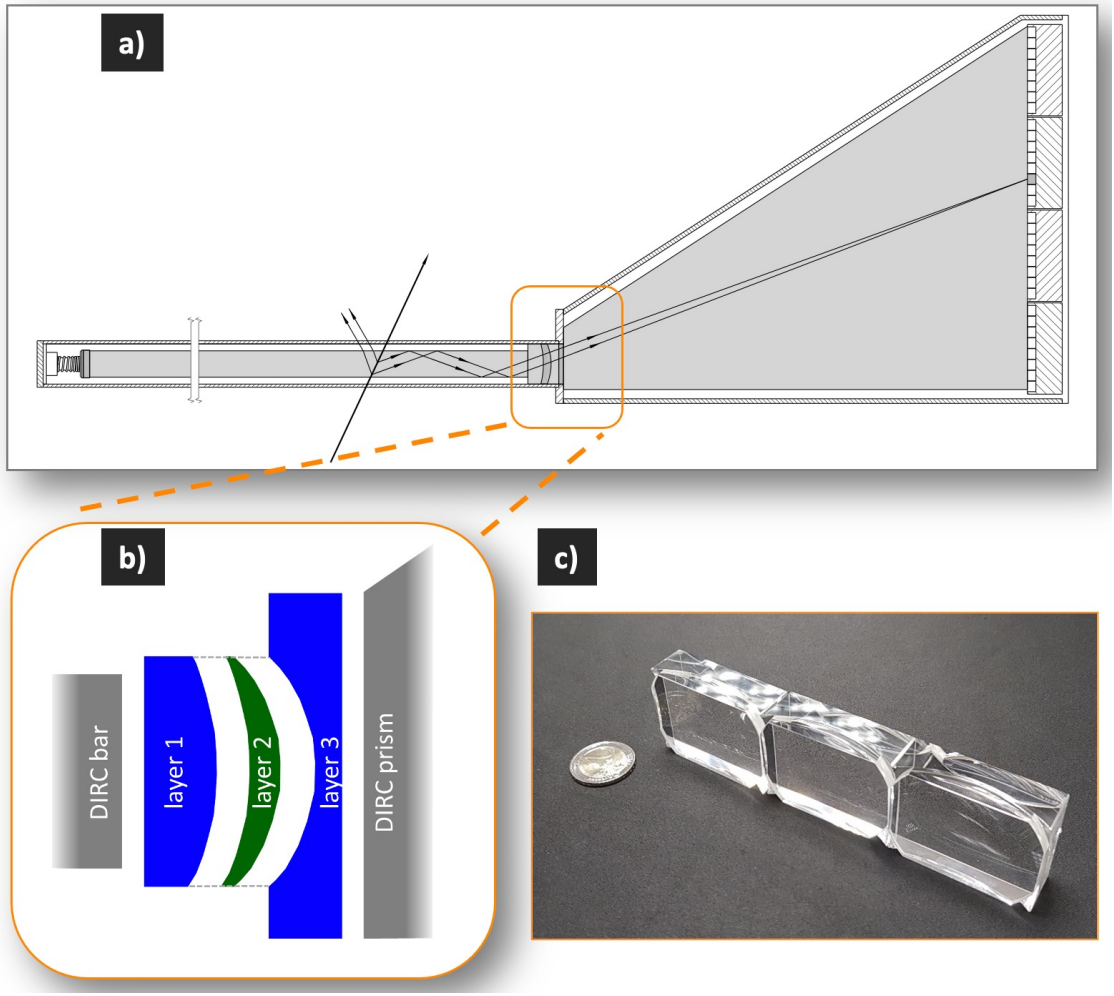
3-layer lens:
Solves chalenges of photon loss and optical abberations!
Radiation hard prototypes are produced, in progress of characterization!



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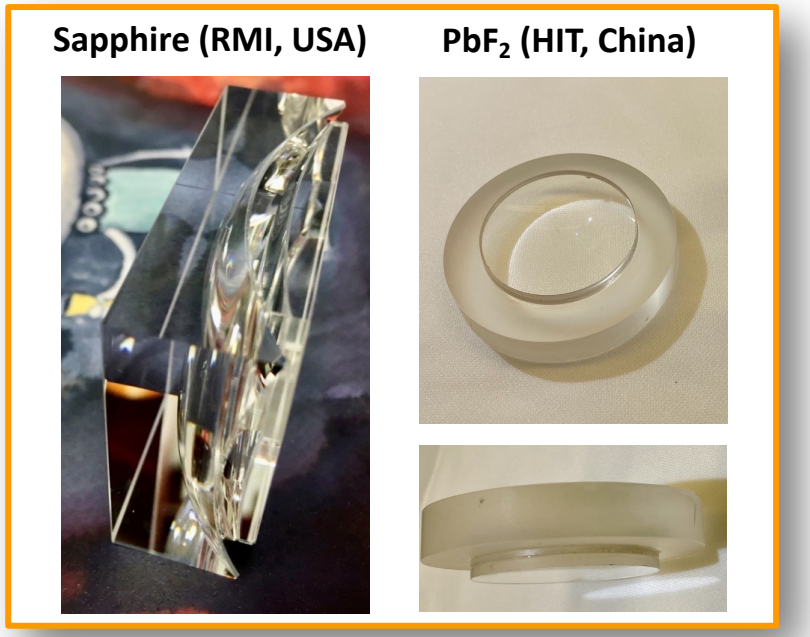

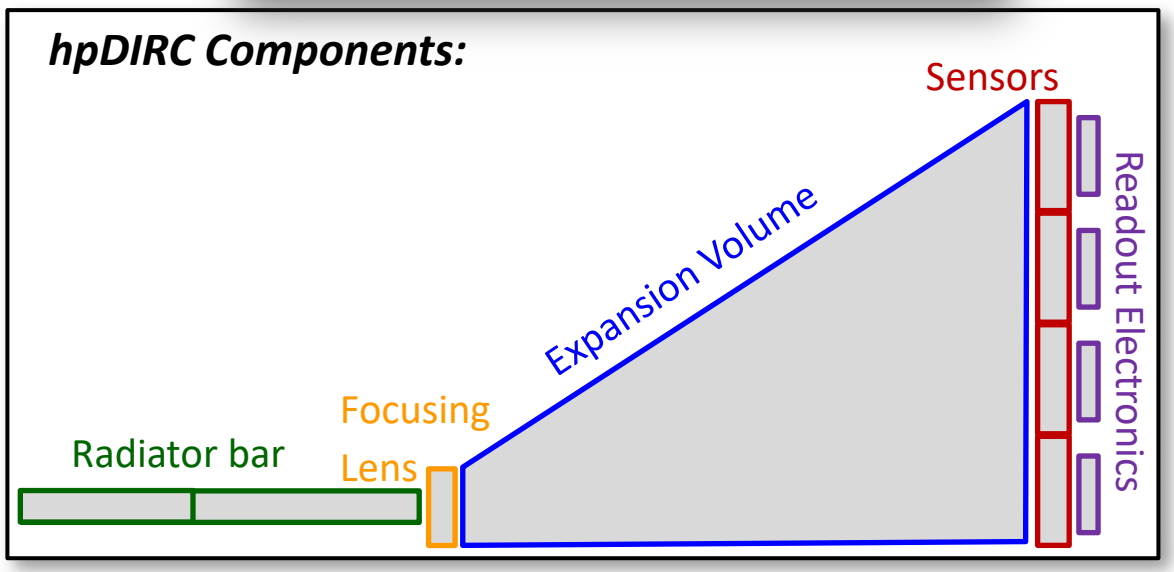

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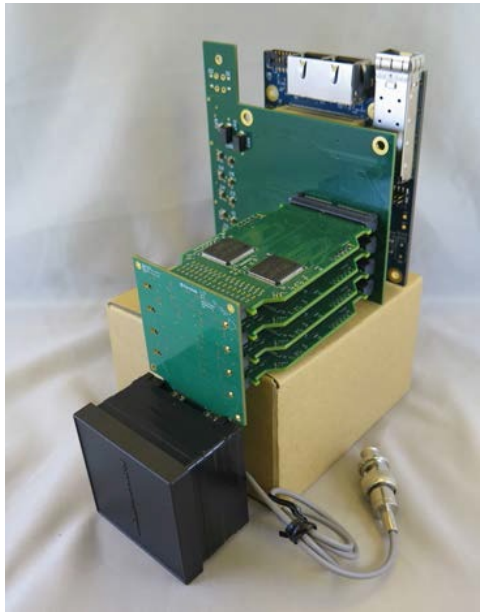

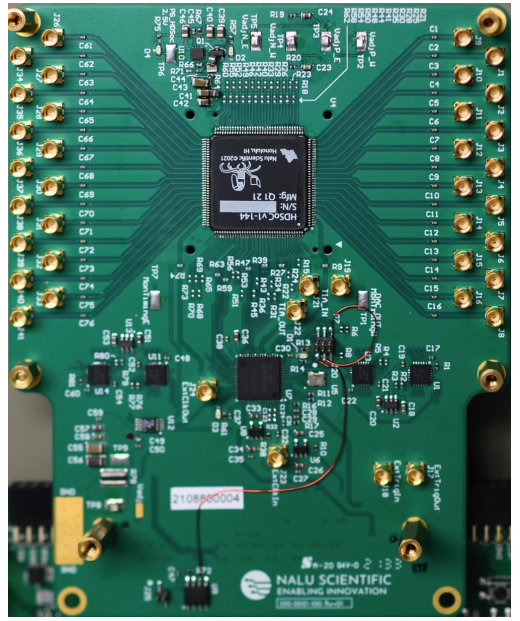

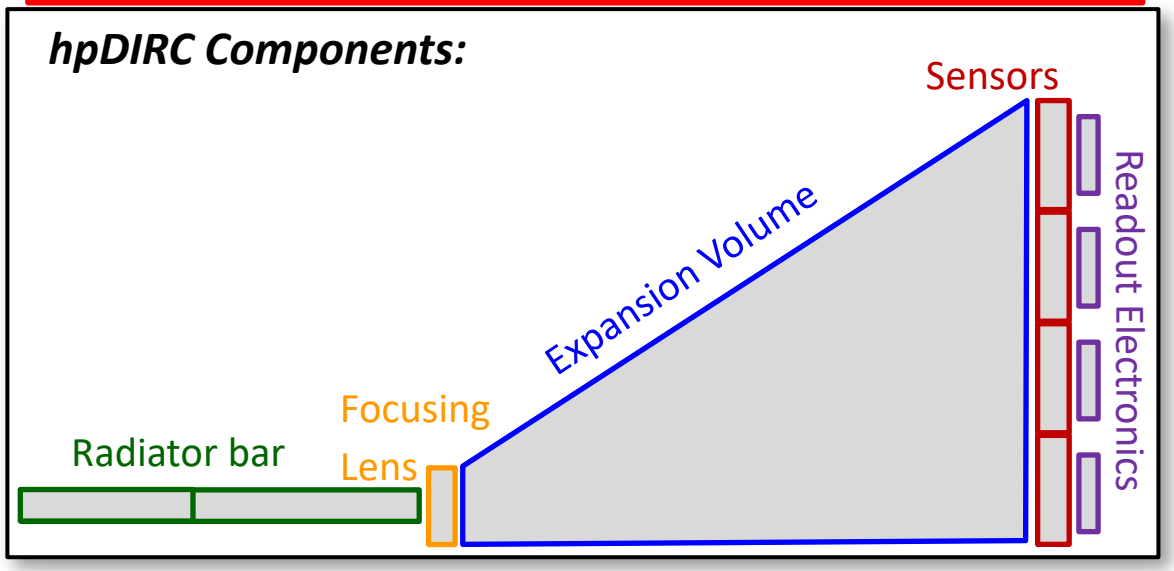

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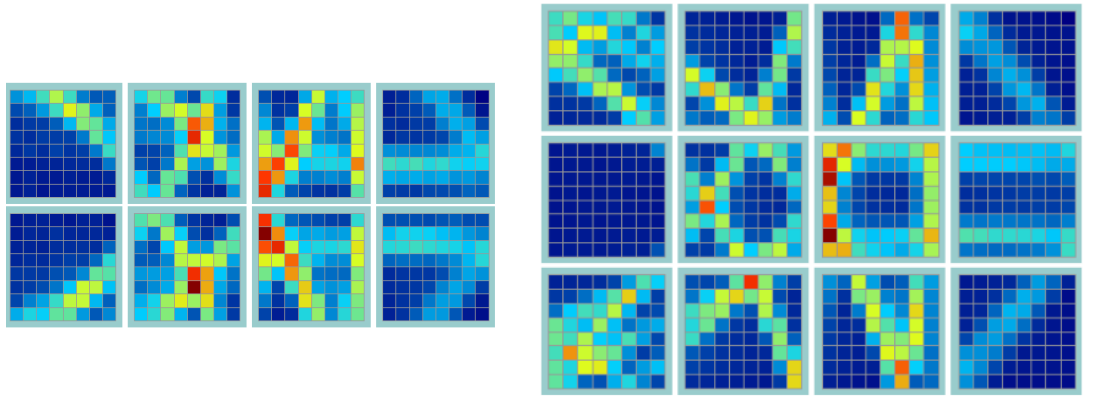
Photosensor coverege vs PID performance



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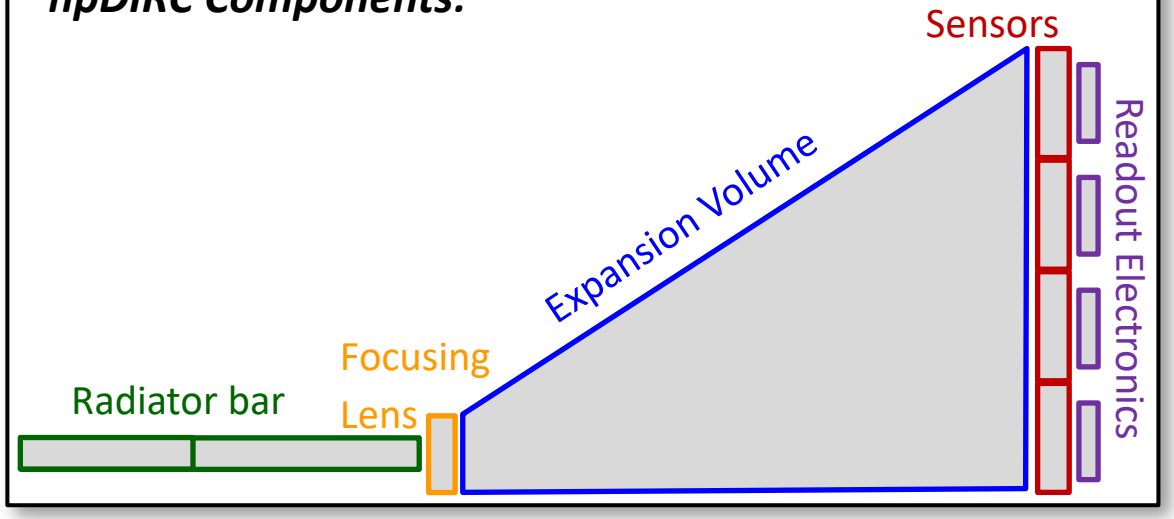
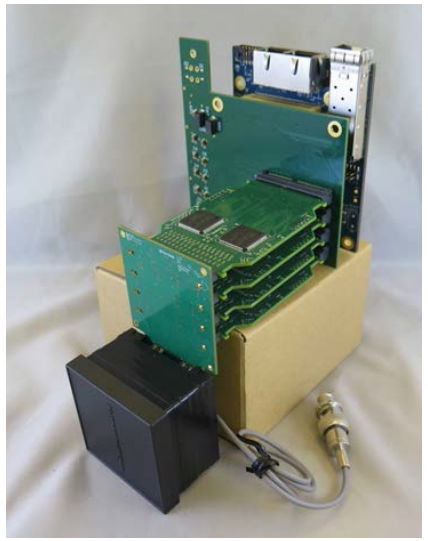
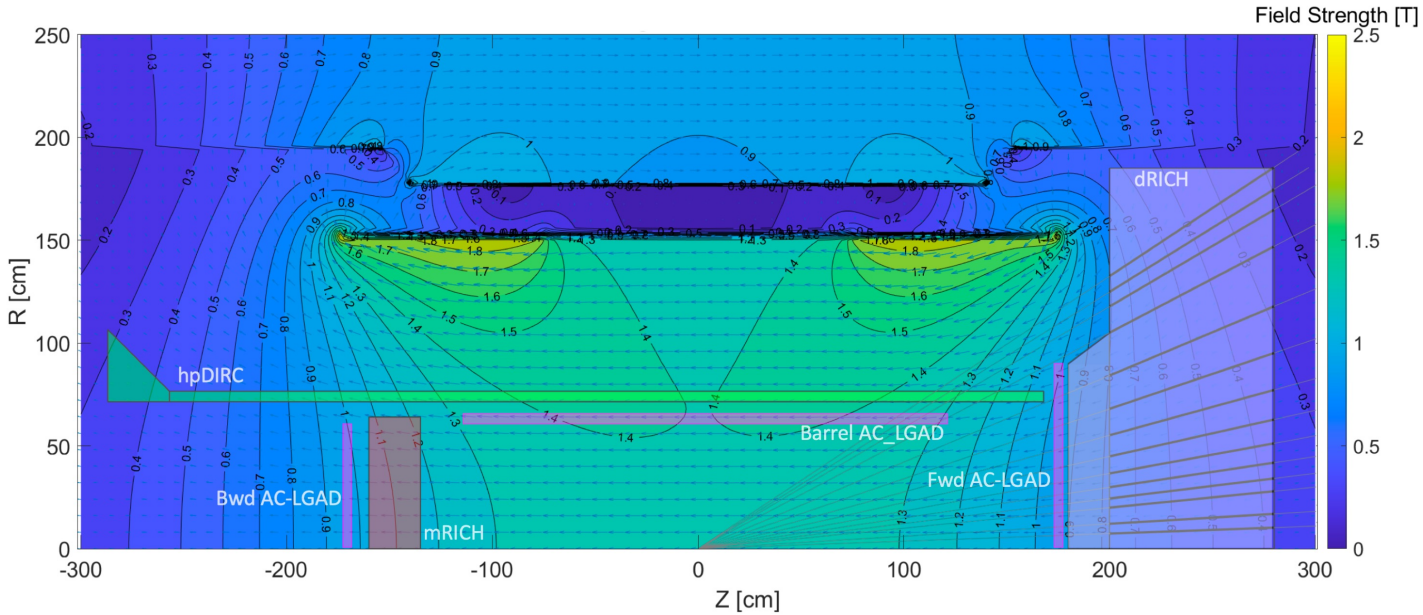


EIC HPDIRC

- **Photon sensor performance in magnetic field**
  - Different maturity of sensor development:
    - **Established**: PHOTONIS XP85122-S
    - **Freshly Developed**: Photek MAPMT 253
    - **Under development**: INCOM Gen III HRPPD
  - Small-pore MCP-PMTs shown to be OK for fields up to 2 Tesla (see result from A. Lehmann et al. for 6µm-pore 2'' Photek AuraTek MCP-PMT)
  - SiPMs as alternative (dark noise, radiation damage, cooling, annealing, integration issues)
- **Development of readout electronics and integration not trivial and require support soon!**



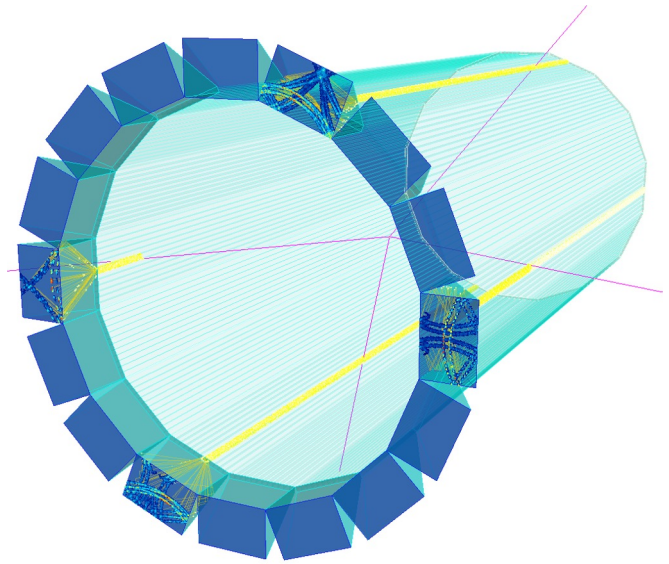


HPDIRC PROTOTYPE: HYBRID RADIATOR DESIGN

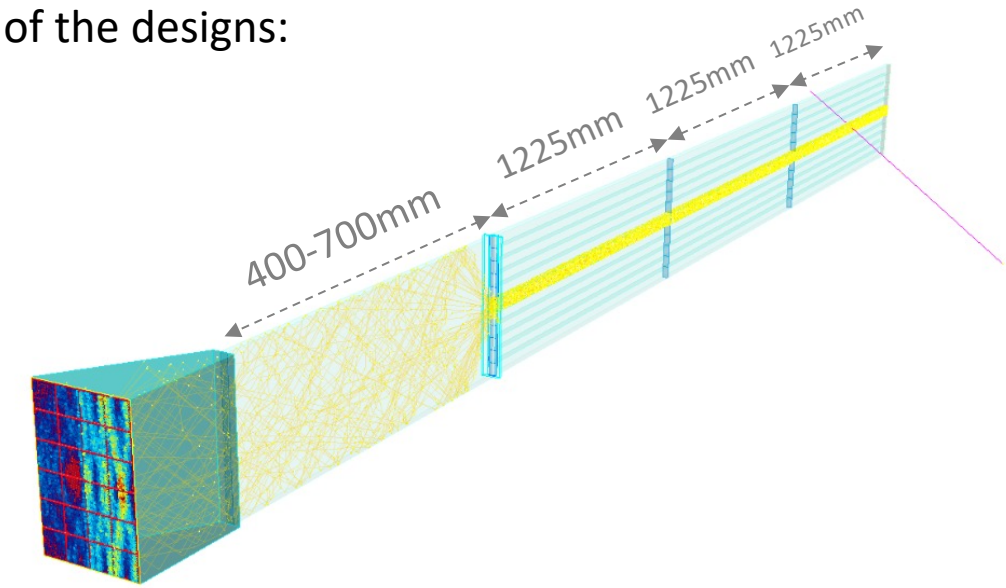
Opportunity: Cost saving and performance improvement

- EIC detector barrel length requires additional fused silica bars or plate to connect BaBar DIRC bars to prism
- Narrow bars could be obtained by cutting and repolishing BaBar DIRC bars or by ordering new bars from industry
- Alternative: **use single short wide plate as transition light guide between BaBar DIRC bars and prism**
- Would significantly reduce cost compared to new narrow bars and potentially improve hpDIRC performance
- Hybrid designs can be tested in prototype with no investment in new optics (using PANDA DIRC bar, plate and prism)

GEANT4 visualization of the designs:



Narrow bars in each sector



Hybrid of bars and plate in each sector

HPDIRC R&D PLAN

FY 22

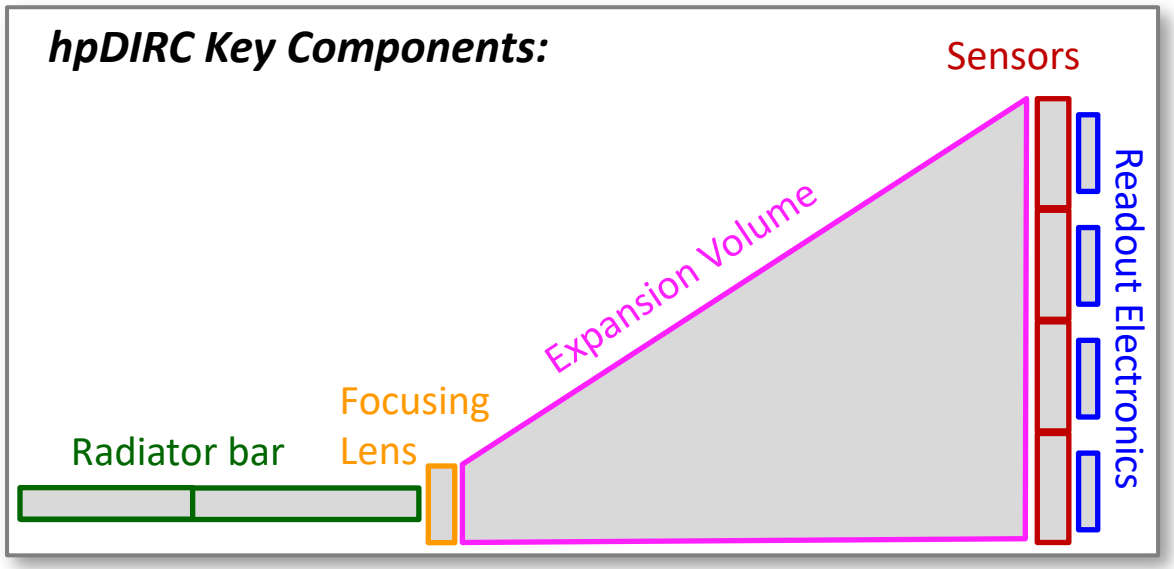
- Validation of BaBar DIRC radiator bar reuse option
- **Assembly and integration of initial prototype into CRT with tracking and timing detectors**
- Development of DAQ and 3D tracking code
- Cost/performance optimization of design in simulation

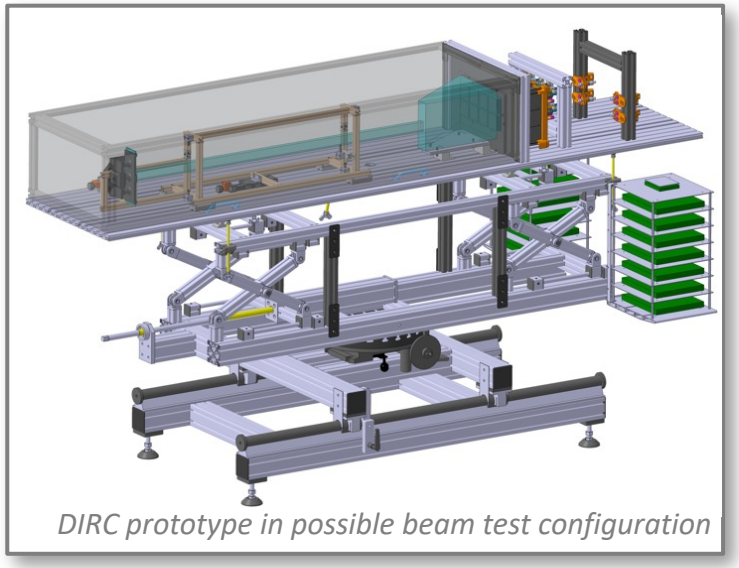
FY 23

- Incremental upgrade of hpDIRC prototype
- Development and adaptation of readout electronics (eRD109)
- Evaluation of sensors and readout electronics in hpDIRC prototype
- Evaluation of initial prototype, tracking/timing/DAQ (particle beam)

FY 24

- Evaluation of the optimized sensor arrangement and radiator/focusing options (bar/plate hybrid design with matching focusing lens) with final prototype in particle beam
- Conclusion of prototype program with final cost/performance-optimized design





DIRC prototype in possible beam test configuration

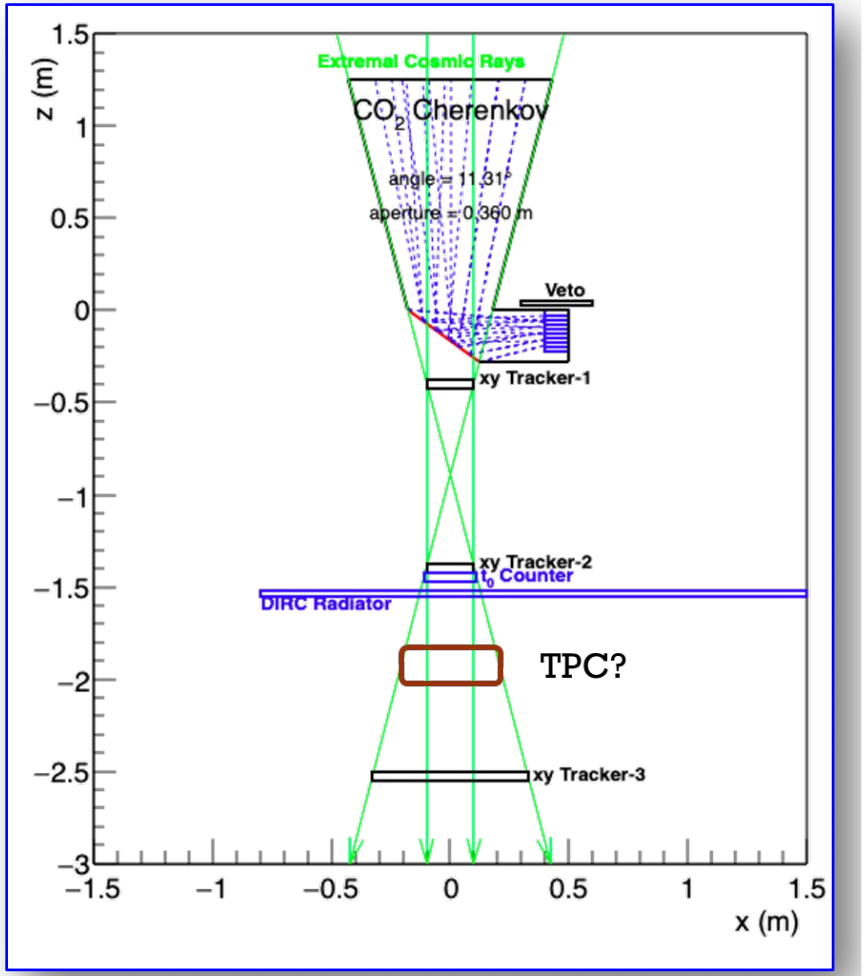
HPDIRC PROTOTYPE: DEVELOPMENT AND VALIDATION

Opportunity: Preparation of Tests of DIRC Prototype with Cosmic Rays

- Crowded beam test schedules – validate hpDIRC with cosmic muons
- Work on mechanical and readout aspects of hpDIRC prototype
- Collaboration of CUA – GSI – ODU – SBU to develop cosmic ray telescope (CRT) design and measurement plan

Current design:

- Momentum selection: new CO_2 Cherenkov threshold tagger (> ~3.5 GeV/c)
- 3D tracking: two GEM tracker stations (from sPHENIX) above and below DIRC bar, potentially combined with TPC prototype
- Shower rejection: scintillator plates as veto counters
- T_0 start counter: MCP-PMT/LAPPD or PICOSEC-Micromegas counter
- Mechanical design progressing, prototype polar angle rotation foreseen
- Geant simulation package in preparation



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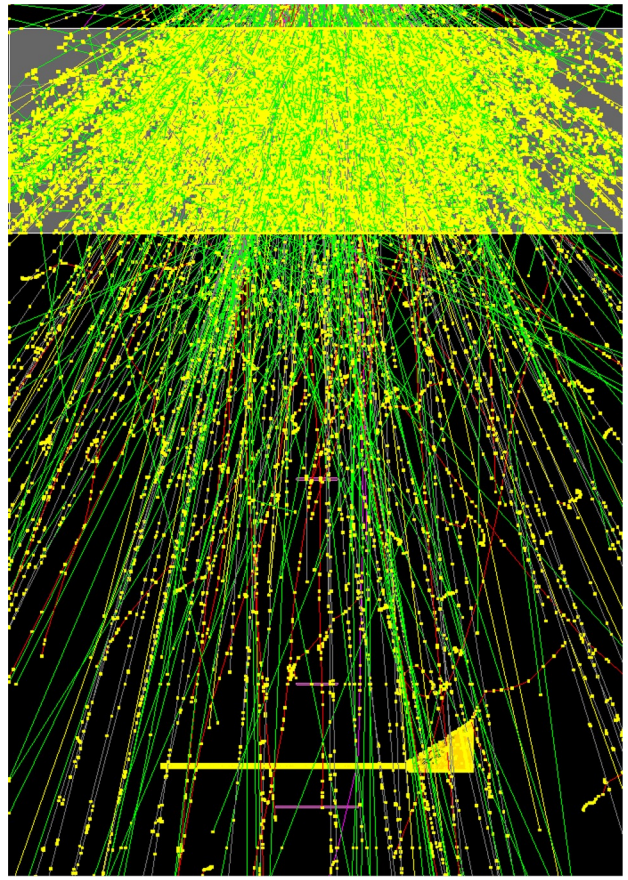
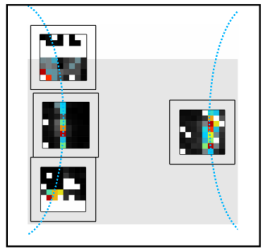
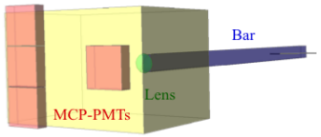
Geant: ~10 seconds of real time

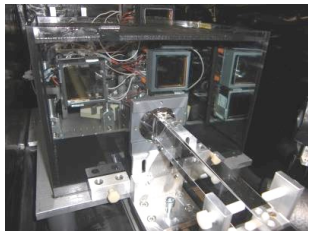


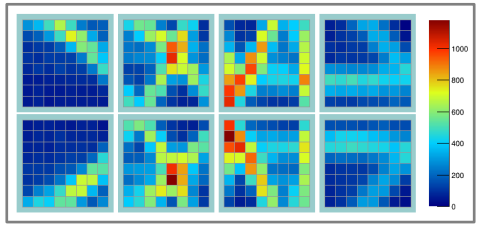
HPDIRC PROTOTYPE PROGRAM



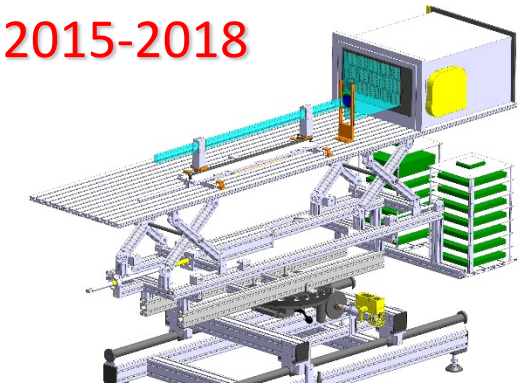


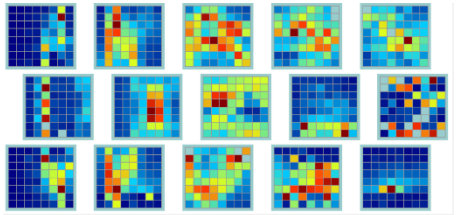
GSI
2008/2009



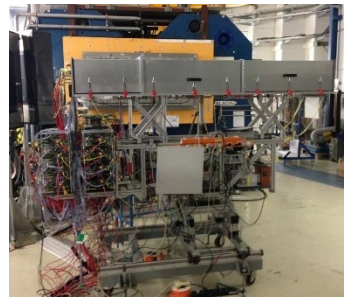


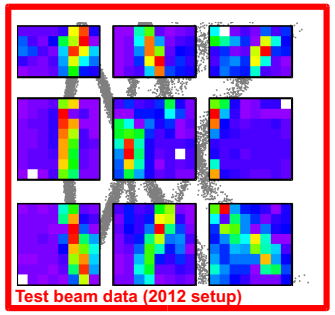
CERN
2015-2018



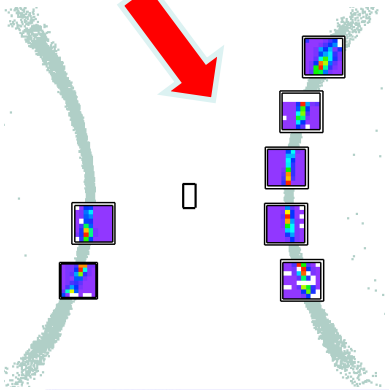


GSI 2014

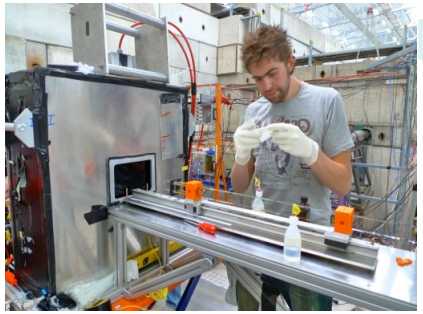


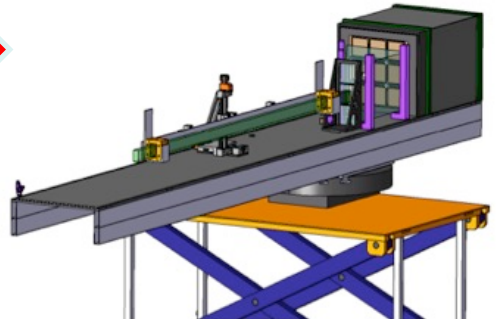


CERN
2012



GSI, CERN
2011

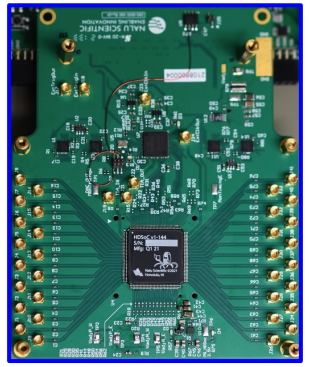


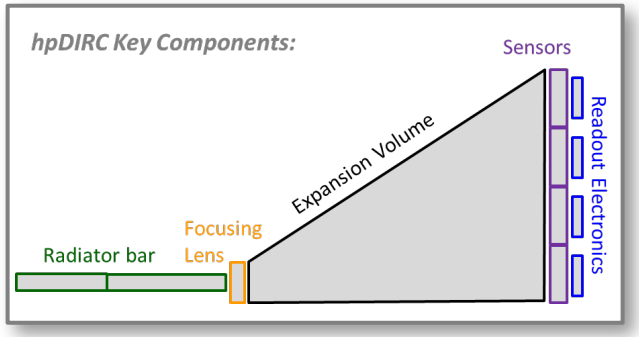


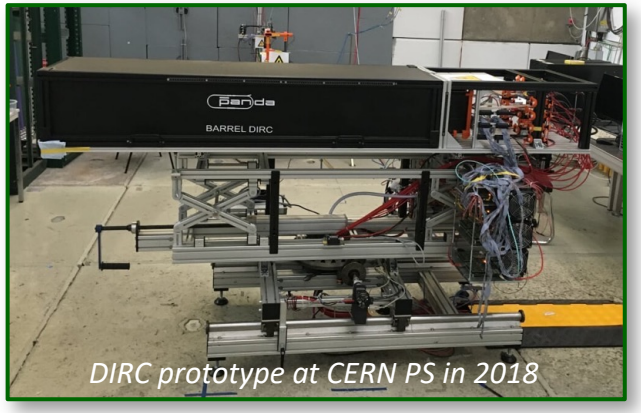
HPDIRC: REMAINING R&D

- **Main objective:** To validate the PID performance of a cost-optimized hpDIRC design for the EIC detector with a vertical-slice prototype in a particle beam by FY24
- Currently evaluating components and prototypes in DIRC labs (ODU, Jlab, GSI)
- Cosmic ray telescope (SBU) will be used for incremental hpDIRC prototype assembly, readout integration and preparation for particle beam test in Fermilab
- Some components transferred from PANDA Barrel DIRC can be used to save cost and time

Prototype readout stack at UH/Nalu



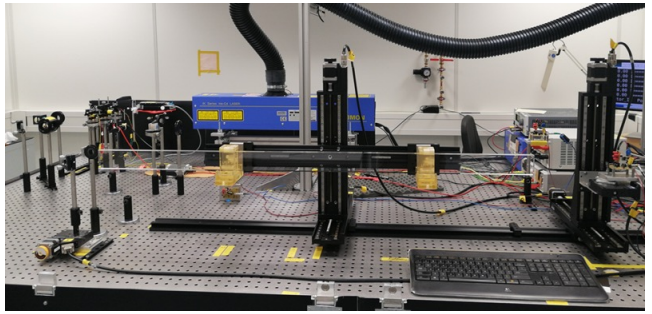


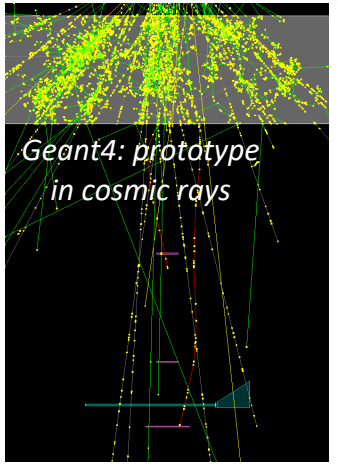


DIRC prototype at CERN PS in 2018

DIRC lab @ ODU

DIRC lab @ GSI

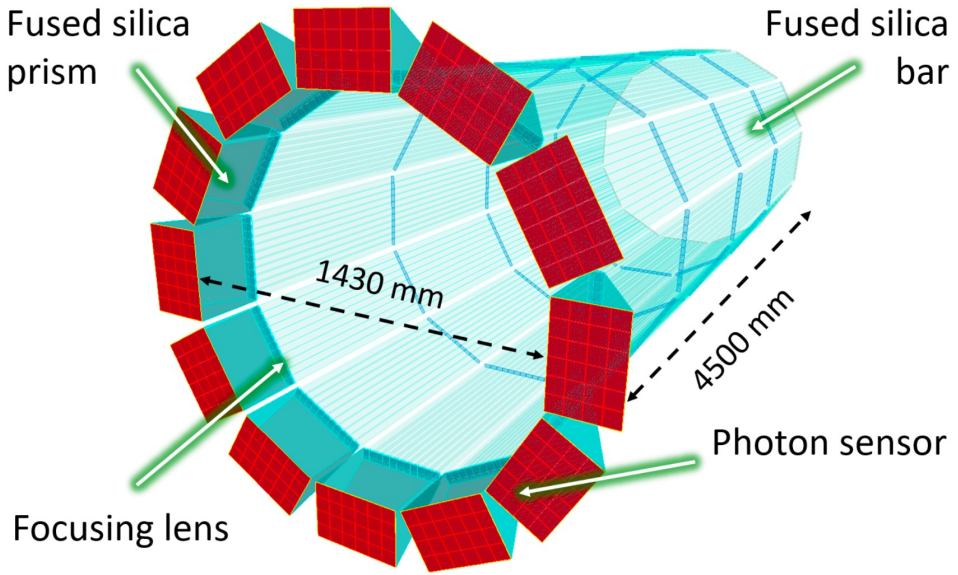


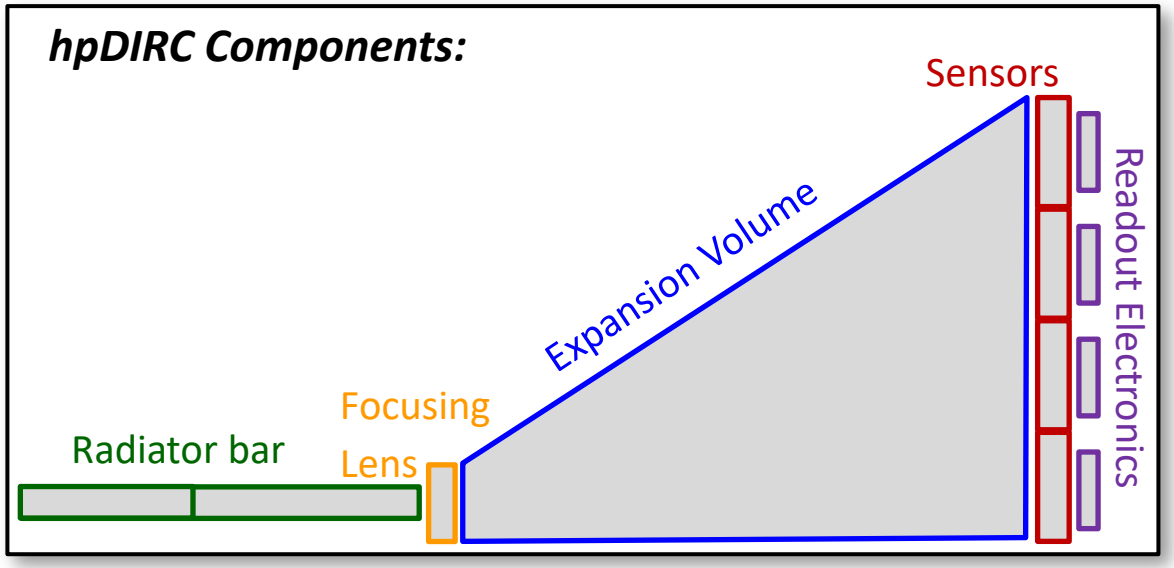


Geant4: prototype in cosmic rays

SUMMARY

- Barrel hpDIRC almost identical designs in all three proposals with the same components and no unique R&D plans
- The proof of principle, validation of stand alone simulation software, and initial component tests were done in particle beam tests with PANDA DIRC group
- The lens radiation hardness issue solved, prototypes build and tested
- The magnetic field strength for the BaBar magnet is suitable for the use of MCP-PMTs
- **Remaining R&D focused on reuse of BaBar radiator bars (JLab) and prototype program in CRT and particle beam**
- **Number of opportunities for cost/performance optimization and risk mitigation but no real showstopper challenges foreseen!**





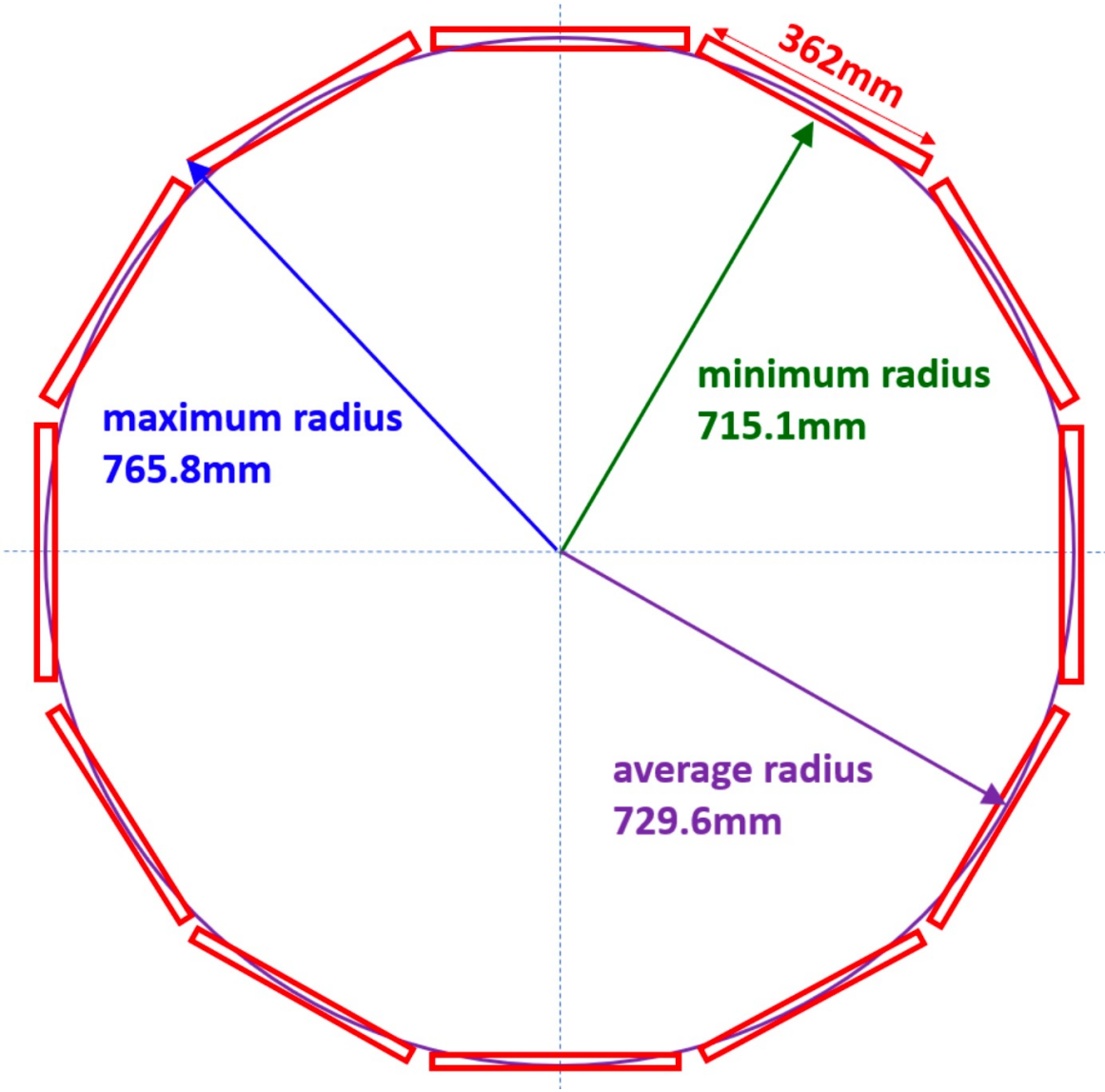
EIC HPDIRC

- **Barrel hpDIRC with 72cm radius**
- **Radiator bars:**
  - **420cm bar length** (works with both reused BaBar DIRC bars or new bars)
  - **12 bar boxes**, 10 long bars side-by-side in a bar box, 3 BaBar DIRC bars plus one half BaBar DIRC bar glued to form one long bar (or 3 BaBar DIRC bars plus one new short plate)
- **Focusing optics:**

  Radiation-hard 3-layer spherical lens
- **Expansion volume:**

  Solid fused silica prism: 24 x 36 x 30 cm^3 (H x W x L)
- **Readout:**

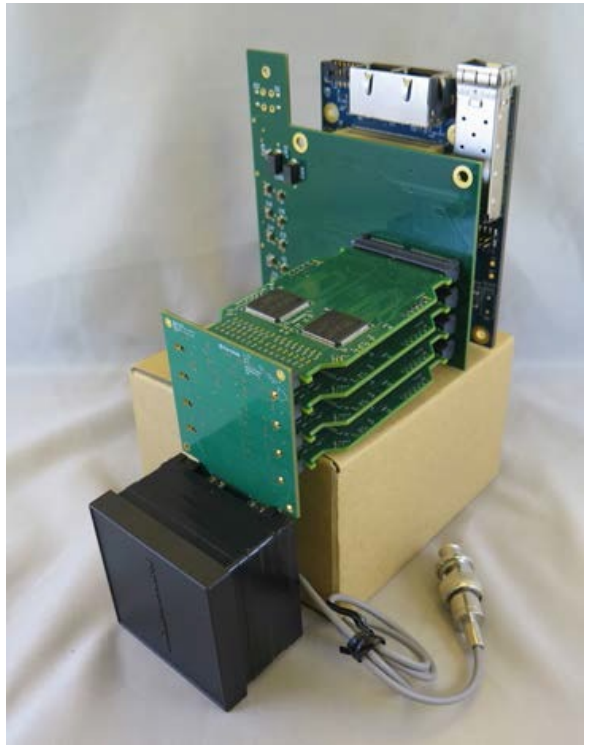
  PHOTONIS MCP-PMT Sensors + NALU's ASIC based Readout Electronics



READOUT ELECTRONICS

hpDIRC unique readout requirements:

- All three leading sensor candidates (MCP-PMT, MAPMT, SiPM) share:
  - Large number of small pixels
  - Fast single photon timing
  - Relatively high photon rates and sensor occupancies
- Readout electronics must maintain 60-100ps timing resolution, matching sensors
- Performance requirements for e.g. triggerless streaming, data reduction, bandwidth, latency and throughput must be achieved while simultaneously meeting technical requirements for other critical factors such as e.g. power consumption, integration issues at the detector front end along with robust electromechanical sensor interfaces and biasing
- There is **NOTHING** on the market that meets all requirements and scales well
- Test all sensors with minimal effort on electronics and a common readout solution



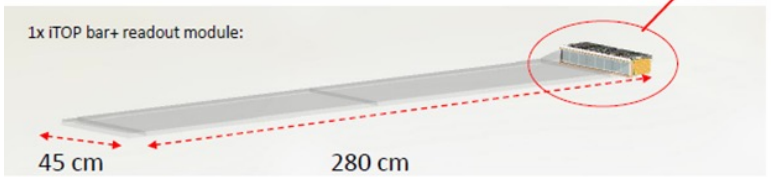
READOUT ELECTRONICS

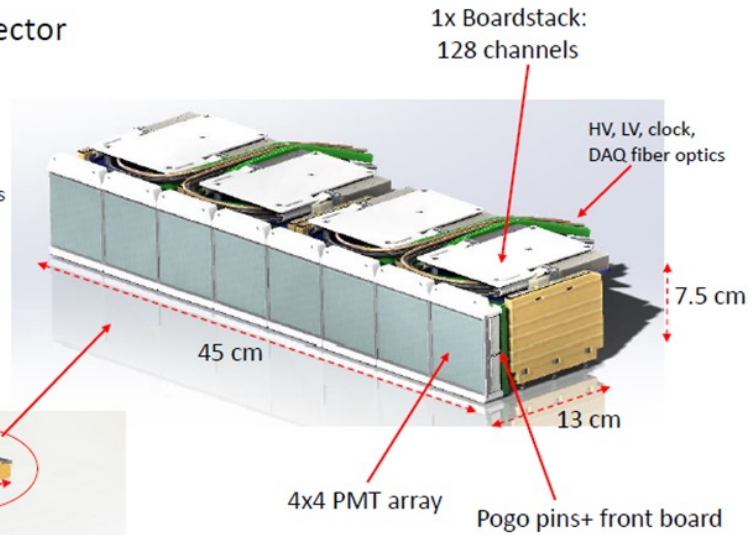
The close collaboration between Nalu and UH was established several years ago in the design, fabrication and deployment of the Belle II DIRC TOP detector (below left), which shares many similarities to the hpDIRC.

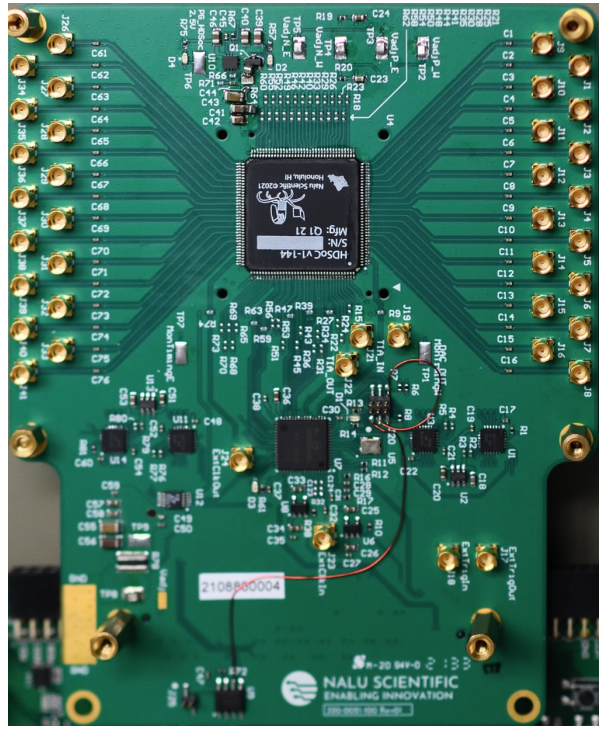
The TOP project was awarded the DOE's Project Management Achievement Award in 2017, and was completed two months ahead of schedule and under budget while meeting or exceeding all objective Key Performance Parameters.

Nalu's HDSoC ASIC (32-chnl test board below right), currently under development with a DOE Phase II SBIR, is well matched to EIC-PID's performance and technical requirements and the plan is to continue to evolve the platform to systematically address the challenges inherent in ultimately bringing the full EIC detector(s) online and ready for physics data-taking.

- 8192 channels of readout for iTOP subdetector
- 16 quartz bars, 1x module/bar
  - 1x readout module:
    - Photons in, DAQ data out
    - PMTs, interconnectes, amps, ASICs, FPGAs, heatsinks
    - 45 cm x 7.5 cm x 13 cm
    - 512 channels
    - Dense and compact- operates inside magnet
- All modules installed in detector







READOUT ELECTRONICS IDEAL PLAN

FY'22- Develop and de-risk electronics

- Use 32ch HDSoC eval card as a building block to readout a subset of channels of various sensors (Photonis, HRPPD, Photek…)
- Nalu will provide 32 ch HDSoC eval board+engineering knowhow and FW/SW customization
- UH will provide post-doc and lab for testing and data analysis - prepare for cosmic telescope testing (for 32 or 64ch)
- Nalu will develop and fab the 64 channel HDSoC using Phase II SBIR funds
- Preliminary design for a modular integrated readout solution.

FY'23 - Prepare for summer '23 beam tests

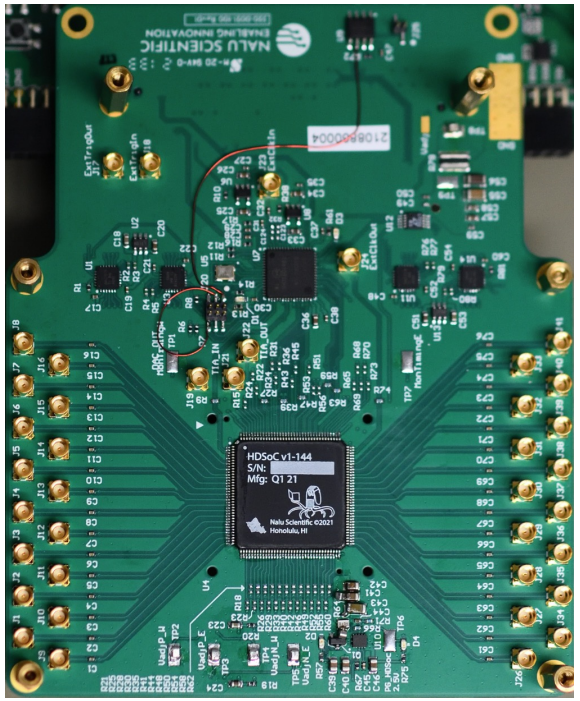
- Design and fab sensor specific 4-6k channel electro-mechanically integrated readout based on 64ch HDSoC (with design reuse in mind) and prepare for beam tests - contingent on proper budget allocation and prompt start on day one of FY23.
- Perform beam tests, analyze data and present results
- Perform a study on ASIC customization for various subdetectors (SBIR funds slightly more generic R&D than detector specific work).

FY'24-25- ASIC and electronic customization

- Customize HDSoC for speed (60ps resolution), data rates, processing capacity of each detector.
- Fab, package, test and qualify - rather low risk given underlying ASIC is mature
- Design high channel count subdetectors using customized ASICs.

FY'26-27 - Mass production

- Design for cost, dedicated ASIC fab and packaging.
- Board level designs tweaked for cost and sent to contract fab/assy houses
- Calibration, qualification, installation.



Readout electronics schedule matches hpDIRC timeline