eRD14 – EIC PID consortium

- An integrated program for particle identification (PID) for a future Electron-Ion Collider (EIC) detector.

M. Alfred, B. Azmoun, F. Barbosa, L. Barion,, W. Brooks, T. Cao, M. Chiu, E. Cisbani, M. Contalbrigo, S. Danagoulian, A. Datta, A. Del Dotto, M. Demarteau, A. Denisov, J.M. Durham, A. Durum, R. Dzhygadlo, C. Fanelli, D. Fields, Y. Furletova, C. Gleason, M. Grosse-Perdekamp, J. Harris, M. Hattawy, X. He, H. van Hecke, T. Horn, J. Huang, C. Hyde, Y. Ilieva, G. Kalicy, A. Kebede, B. Kim, E. Kistenev, A. Lehmann, M. Liu, R. Majka, J. McKisson, R. Mendez, I. Mostafanezhad, P. Nadel-Turonski, K. Peters, R. Pisani, W. Roh, P. Rossi, M. Sarsour, C. Schwarz, J. Schwiening, C.L. da Silva, N. Smirnov, J. Stevens, A. Sukhanov, X. Sun, S. Syed, R. Towell, G. Varner, R. Wagner, C. Woody, C.-P. Wong, W. Xi, J. Xie, Z.W. Zhao, B. Zihlmann, C. Zorn.

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Generic Detector R&D for an Electron Ion Collider
Advisory Committee Meeting, BNL, January 30-31, 2020

Participating institutions

- Abilene Christian University (ACU)
- Argonne National Lab (ANL)
- Brookhaven National Lab (BNL)
- Catholic University of America (CUA)
- City College of New York CCNY)
- College of William & Mary (W&M)
- Duke University (Duke)
- Georgia State University (GSU)
- GSI Helmholtzzentrum für Schwerionenforschung, Germany (GSI)
- Howard University (HU)
- Institute for High Energy Physics, Protvino, Russia
- Istituto Nazionale di Fisica Nucleare, Sezione di Ferrara, Italy (INFN-Ferrara)
- Istituto Nazionale di Fisica Nucleare, Sezione di Roma, Italy (INFN-Rome)
- Istituto Superiore di Sanità, Italy (ISS)
- Jefferson Lab (JLab)
- Los Alamos National Lab (LANL)
- North Carolina A&T State University (NCAT)
- Old Dominion University (ODU)
- Stony Brook University (SBU)
- Universidad Técnica Federico Santa María, Chile (UTFSM)
- University of Hawaii (UH)
- University of Illinois Urbana-Champaign (UIUC)
- University of New Mexico (UNM)
- University of South Carolina (USC)
- Yale University (Yale)

In-depth review

https://indico.bnl.gov/event/6819/

Report of the in-depth Review of the eRD14 Collaboration: "Integrated Particle Identification for a Future EIC"

EIC Detector Advisory Committee

November 25, 2019

M. Demarteau (ORNL), C. Haber (LBNL), P. Krizan (Ljubljana University/J. Stefan Institute), B. Ratcliff (SLAC), I. Shipsey (Oxford University), R. Van Berg (U. Pennsylvania), J. Va'vra (SLAC) and G. Young (BNL)

- We would like to thank the committee for the detailed report!

eRD14: an integrated program for PID at the EIC

1. A suite of detector systems covering the full angular- and momentum range required for an EIC detector

- Different technologies in different parts of the detector
- Focus on hadron ID with an electron ID capability

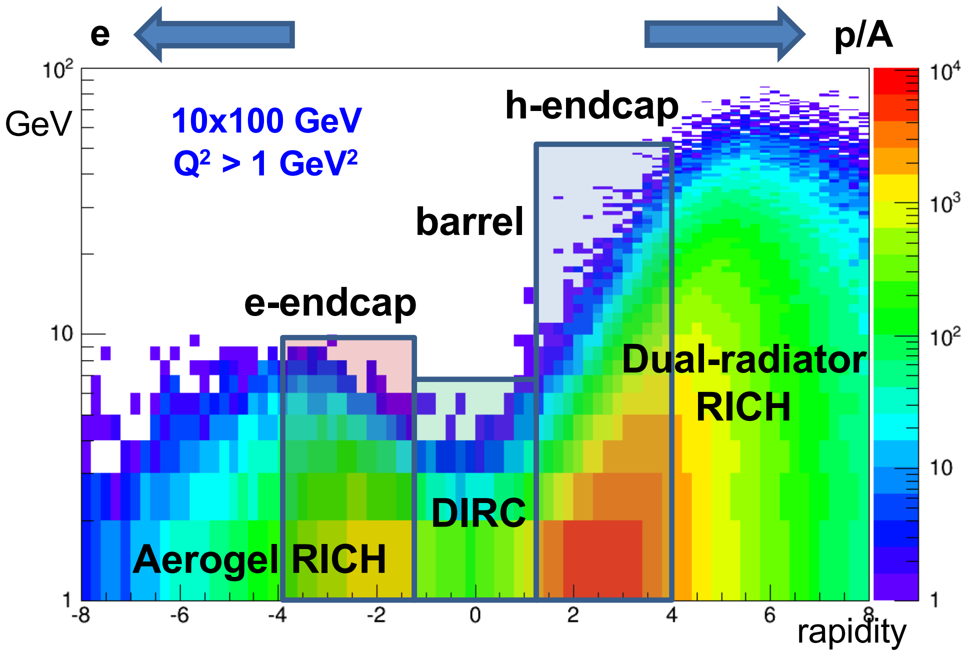
2. A cost-effective sensor and electronics solution

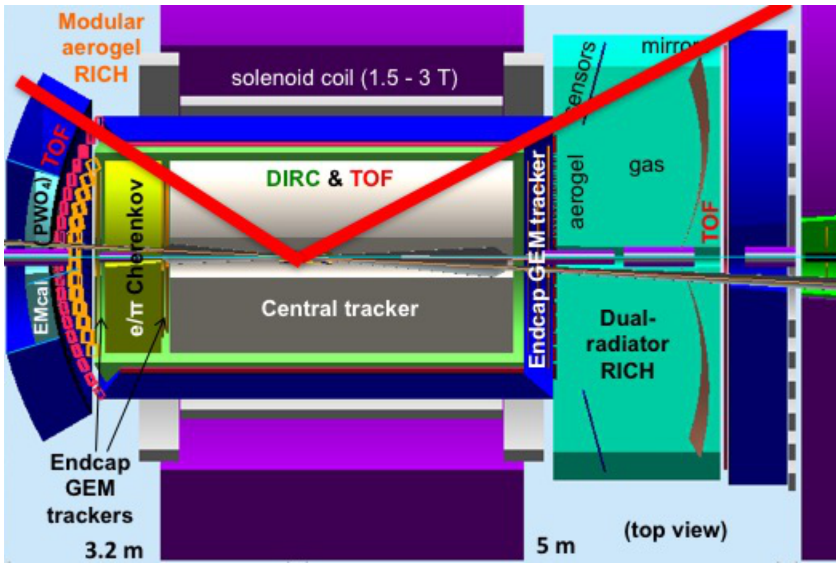
- Development and testing of photosensors (to satisfy EIC requirements)
- Development of readout electronics needed for prototyping

3. Consortium synergies (including reduction of overall R&D costs)

- Close collaboration within the consortium, with coordinated goals and timelines (*e.g.*, DIRC & LAPPD, mRICH & dRICH, etc).
- Strong synergies with non-EIC experiments and R&D programs (PANDA, CLAS12, GlueX, PHENIX, commercial LAPPDs) resulting in large savings.

A PID solution for the EIC



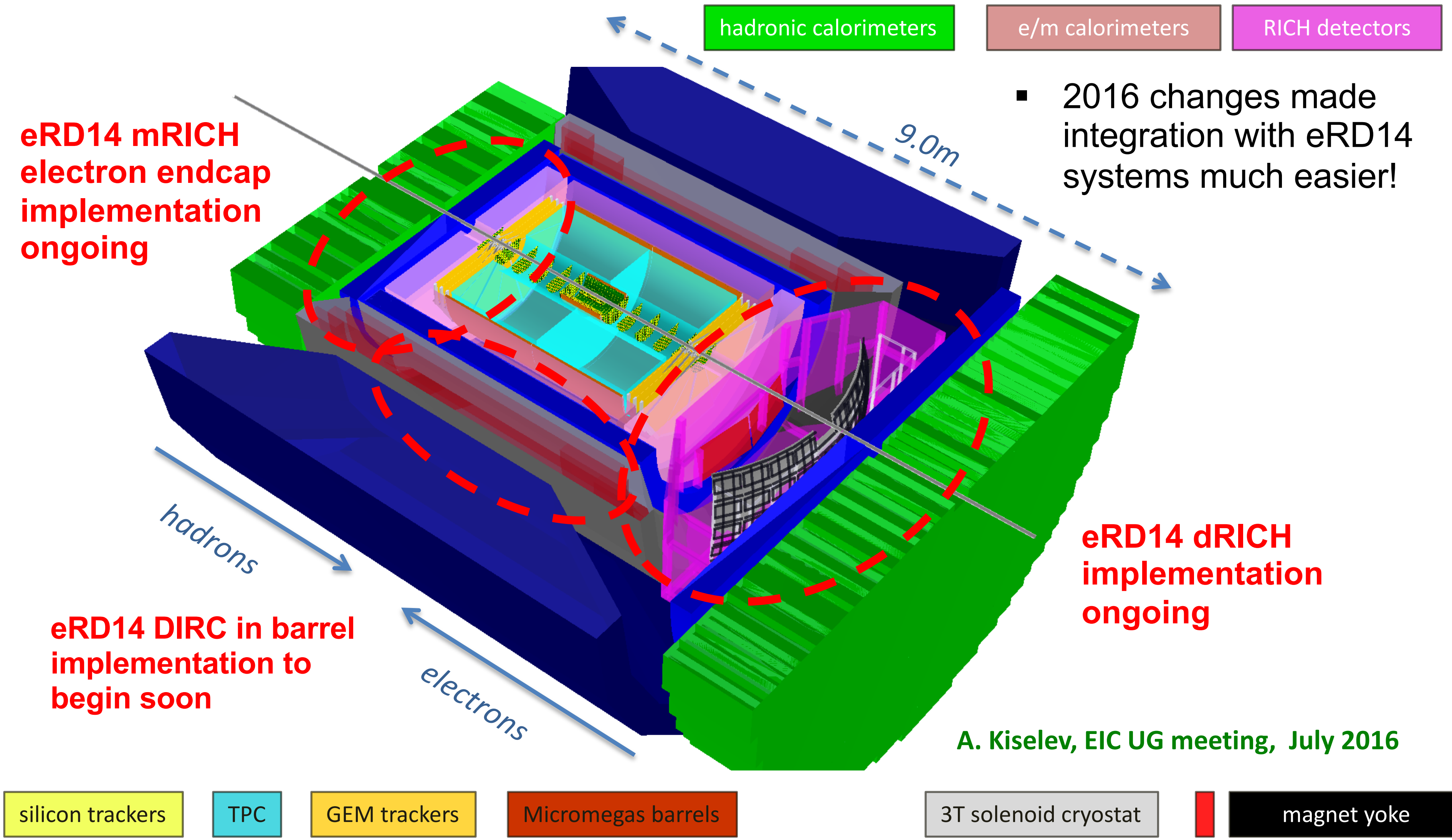


- **h-endcap**: A RICH with two radiators (gas + aerogel) is needed for
  π/K separation up to ~50 GeV/c
- **e-endcap**: A compact aerogel RICH which can be projective
  π/K separation up to ~10 GeV/c
- **barrel**: A high-performance DIRC provides a compact and cost-effective way to cover the area.
  π/K separation up to ~6-7 GeV/c
- **TOF and/or dE/dx in a TPC**: can cover lower momenta.
- **Photosensors and electronics**: need to match the requirements of the new generation devices being developed – both for the final system and during the R&D phase

PID in the EIC concept detectors and integration of eRD14 systems

BeAST detector

-3.5 < η < 3.5: Tracking & e/m Calorimetry (hermetic coverage)



eRD14 mRICH electron endcap implementation ongoing

eRD14 DIRC in barrel implementation to begin soon

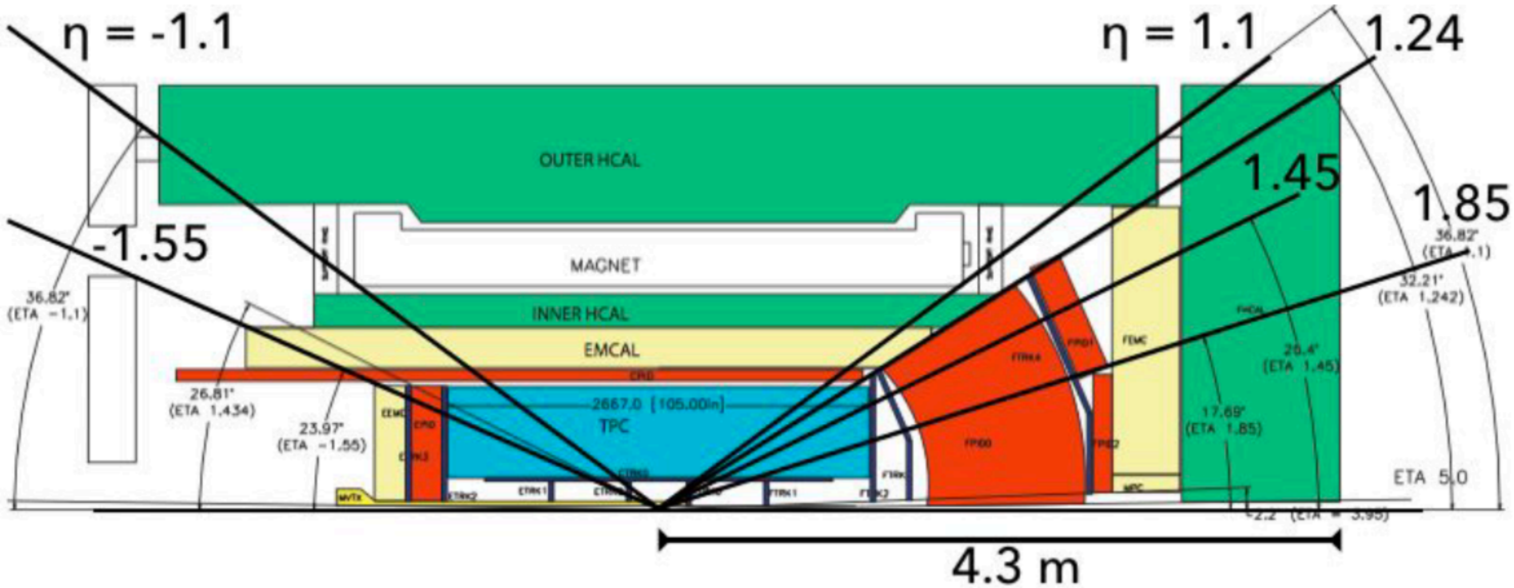
- 2016 changes made integration with eRD14 systems much easier!

eRD14 dRICH implementation ongoing

A. Kiselev, EIC UG meeting, July 2016

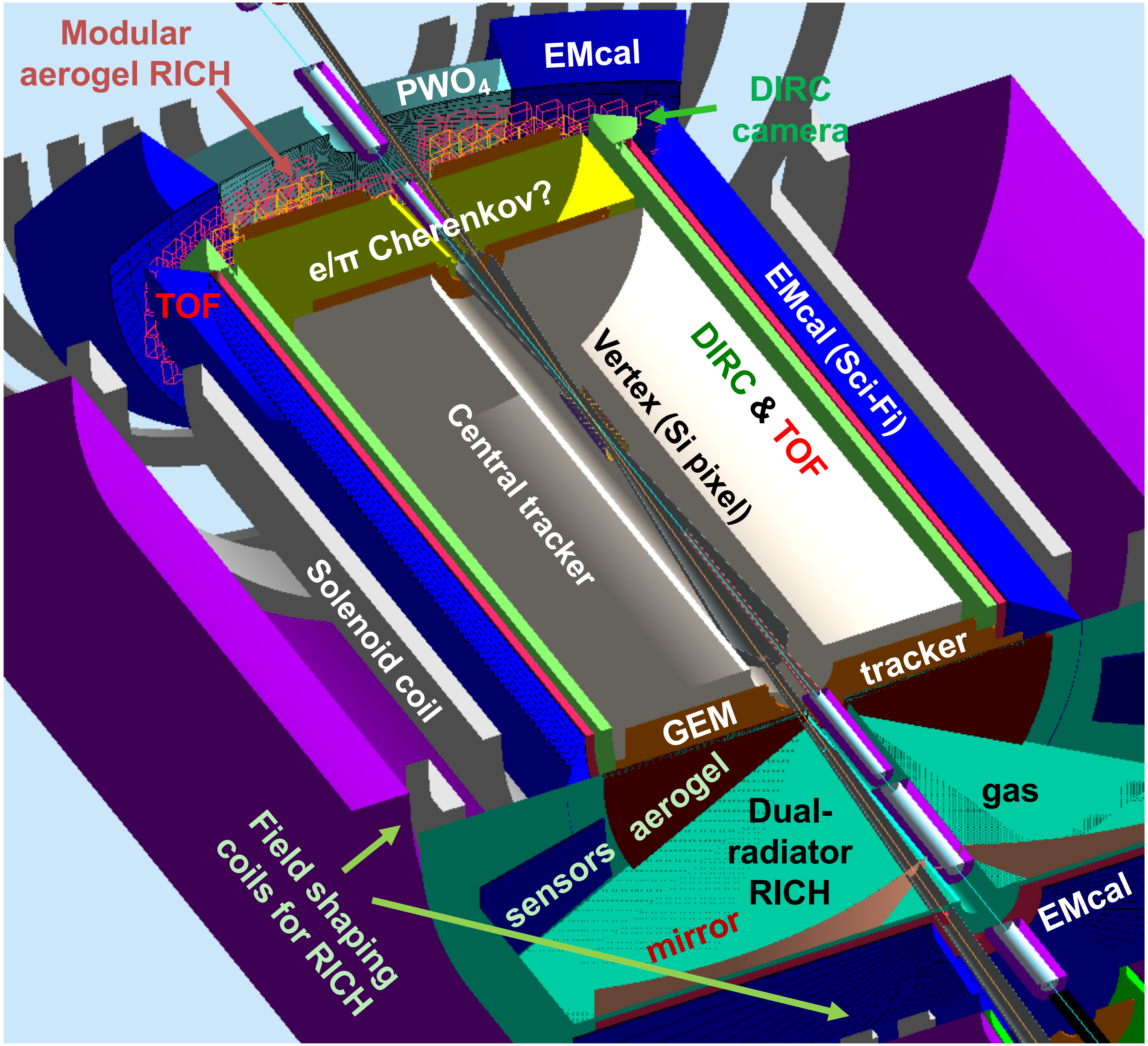
Day-one detector based on sPHENIX

- 2016 layout shown



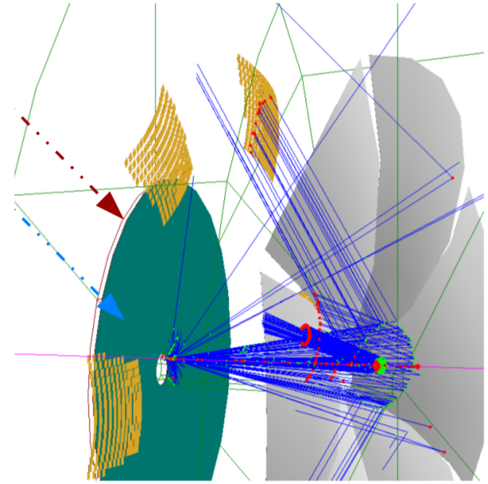
- The DIRC, mRICH, and TOF systems already part of the current concept. An implementation in Geant4 (Fun4All) is ongoing.
- In addition, either the eRD14 dRICH and eRD6 gas RICH could be used.

EIC detector concept developed at JLab



- All eRD14 systems (DIRC, mRICH, dRICH, and TOF) were part of the baseline JLab detector concept.
- The figure clearly shows the very compact DIRC expansion volume optics and readout.

Dual-radiator RICH (dRICH)



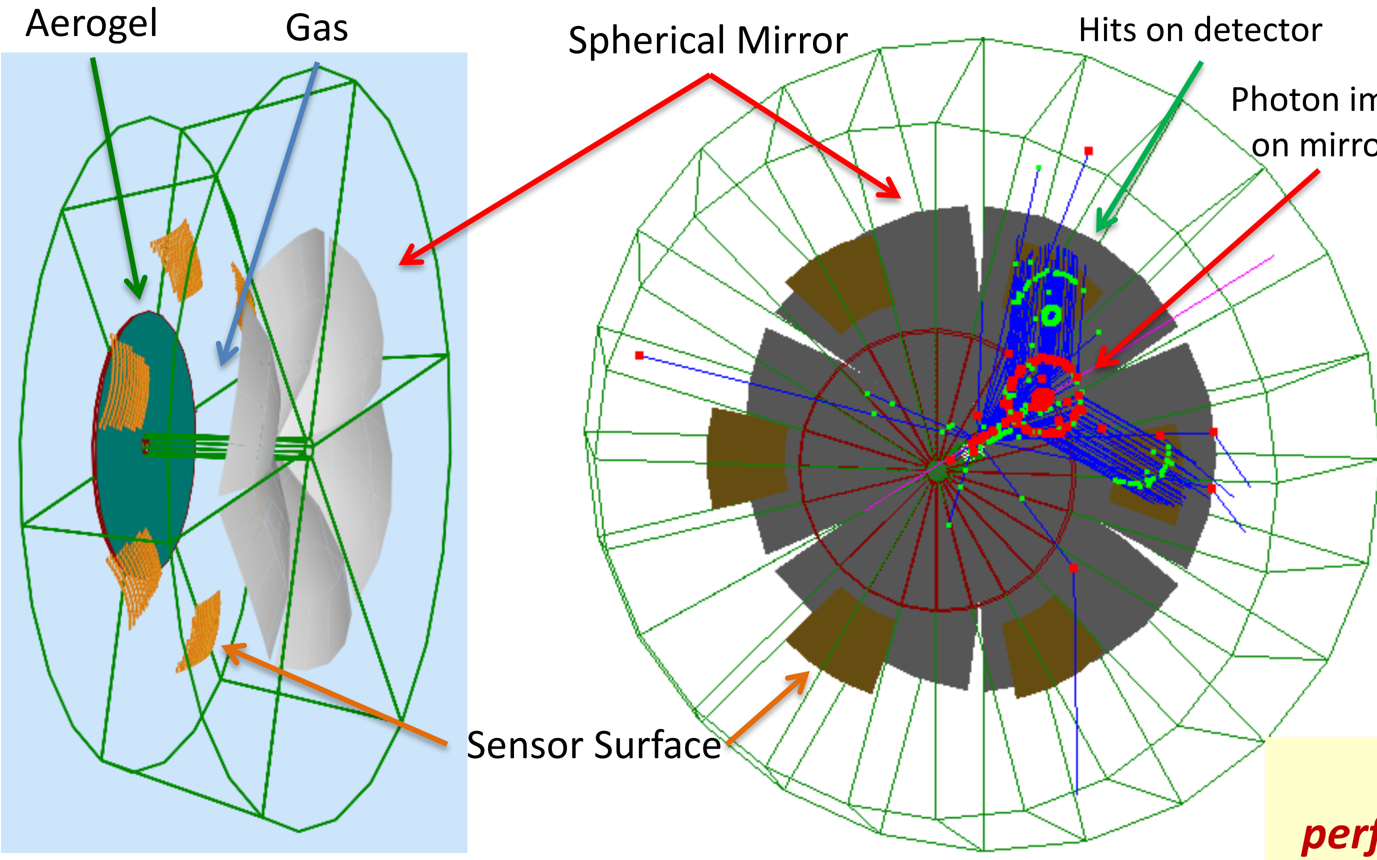
Goal:

Provide hadron identification (π/K/p) from 3 to 50 GeV/c (3 sigma) and electron identification (e/π) up to 15 GeV/c, in the forward ion-side endcap of the EIC detector, covering polar angles up to ~25 deg in the current implementation.

Progress in 2nd half of 2019:

- Prototyping
  - Consolidated prototype design
  - Started procurement of prototype components
- Finalized Bayesian Optimization Method for detector design, tested on dRICH
- Detailed analysis of the event-based reconstruction algorithm performance

dRICH in the EIC – baseline model



Available:
- detailed simulation model including photon scattering in aerogel and 3 T central magnetic field
- event-based reconstruction

Demand excellent performance from aerogel!

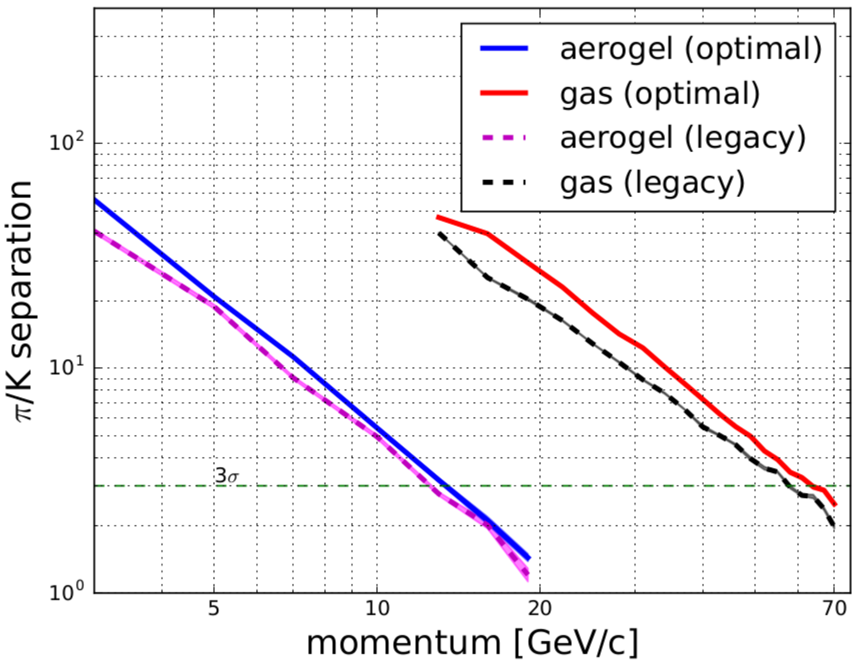
- Radiators: Aerogel (4 cm, $n_{(400nm)}$~1.02) + 3 mm acrylic filter, Gas (1.6 m, n_{C2F6}~1.0008)
- 6 Identical Open Sectors (Petals):
  - Large Focusing Mirror with R ~2.9 m
  - Optical sensor elements: ~4500 cm^2/sector, 3 mm pixel size, UV sensitive, out of charged particles acceptance

Advantages:
- **Full, continuous momentum coverage**
- Relatively simple geometry/optics
- Expected to be Cost Effective (with respect to 2 x detectors solution)

dRICH performance optimization

- Combine detailed MonteCarlo simulations with **Bayesian Approach** to efficienty maximize a proper Figure of Merit (π-K Cherenkov angles separation in critical phase spaces regions, e.g. aerogel-gas transitions, high momentum limit …)
- Current implementation uses 8 independent parameters (can be easily extended) →

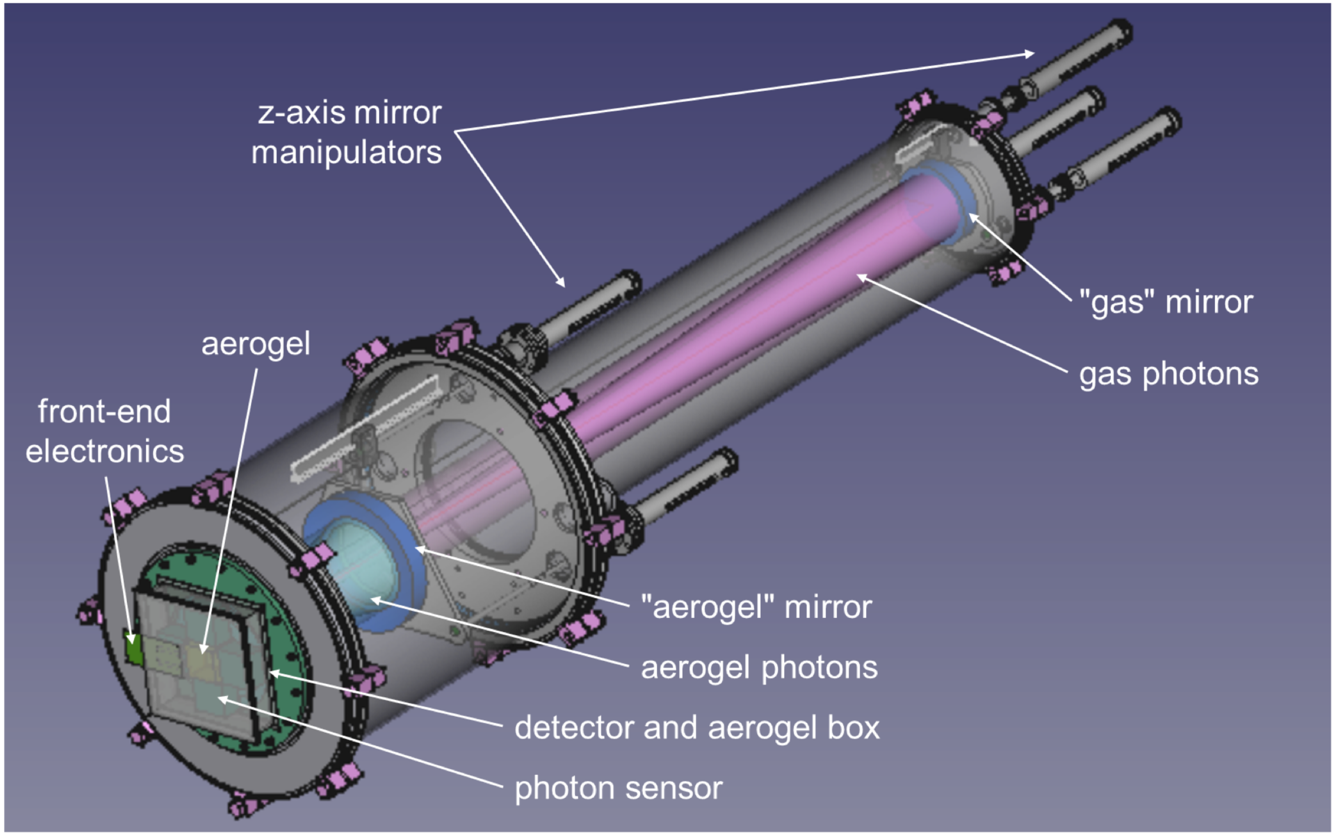
parameter	**description**	**range** [units]
R	mirror radius	[290.0,300.0] [cm]
pos r	radial position of mirror center	[125.,140.] [cm]
pos l	longitudinal position of mirror center	[-305.,-295.] [cm]
tiles y	shift along y of tiles center	[-5,5] [cm]
tiles z	shift along z of tiles center	[-105,-95] [cm]
tiles x	shift along x of tiles center	[-5,5] [cm]
$n_{aer.}$	refraction index of aerogel	[1.015,1.03]
$t_{aer.}$	aerogel thickness	[3.0,6.0] cm



arXiv:1911.05797 submitted to JINST

- The method provides optimized performances and hints on relevance of different detector features
- **It can be applied to any detector development (or combination of detectors) for which a detailed Monte Carlo exists**

dRICH prototype (a new detector …)



- Standard Vacuum Technologies to optimize gas handling
- Two tuneable mirrors system for using the same (limited) photodetector surface for both aerogel and gas photons
- Detector and aerogel box isolated from the gas tank

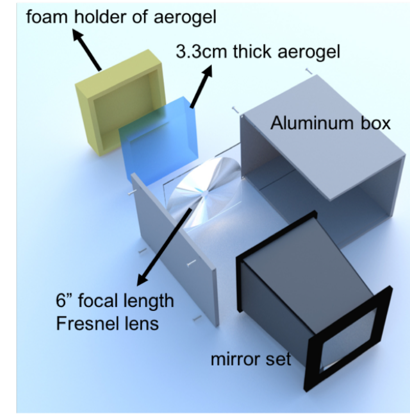
dRICH FY20 outlook

Activity	T1	T2	T3	T4	Funding (USA+ITA) kUSD (1€ ~ 1USD)		
					Post Doc	Material	Travel
Prototype Component procurement	■	■					
Prototype construction		■	■				
Prototype simulation analysis	■	■	■				
Prototype lab test			■	■			
Aerogel-gas long term test	■	■	■	■			
Sensor characterization (mRICH + dRICH)	■	■	■	■			
Electronics test and integration (mRICH + dRICH)	■	■	■	■			

* (m+d)RICH

Important components (electronics and sensors) of the dRICH prototype are shared with the mRICH development
CLAS12 infrastructures available in Ferrara is used for aerogel-gas studies and photon sensors characterization

Modular Aerogel RICH (mRICH)



- ✓ Compact
- ✓ Modular
- ✓ Projective

Goal:

- Compact PID device with momentum coverage up to 10 GeV/c for π/K and e/π up to 2 GeV/c.
- First aerogel RICH with lens-based focusing (for performance and cost).

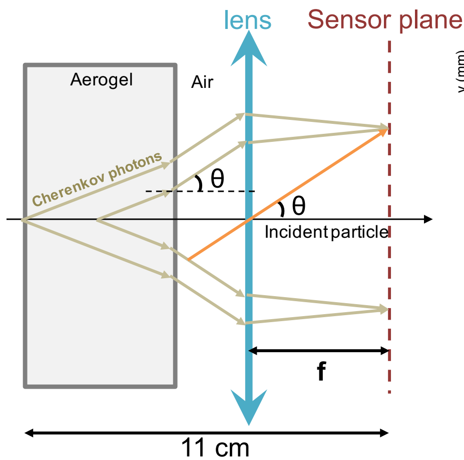
Progress in 2nd half of 2019

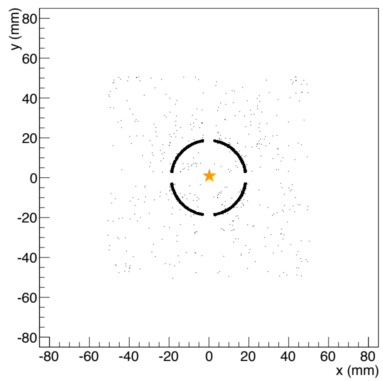
- Obtained the preliminary results from the calibration data set of the second mRICH beam test (in 2018).
- Simulation study of mRICH performance in the Forward sPHENIX experiments at BNL (ongoing effort).
- Built three more identical mRICH prototypes at GSU for supporting a beam test at JLab with secondary electron beam, optical alignment and mRICH array integration.

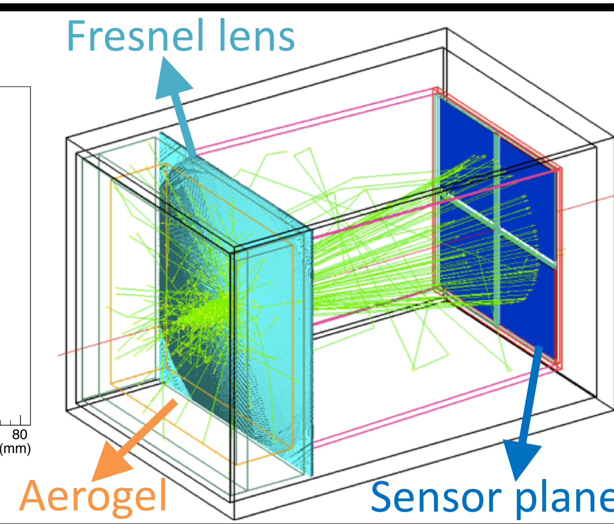
mRICH – lens-based focusing aerogel detector design

Smaller, but thinner ring improves PID performance and reduces length

Lens-Based mRICH Design

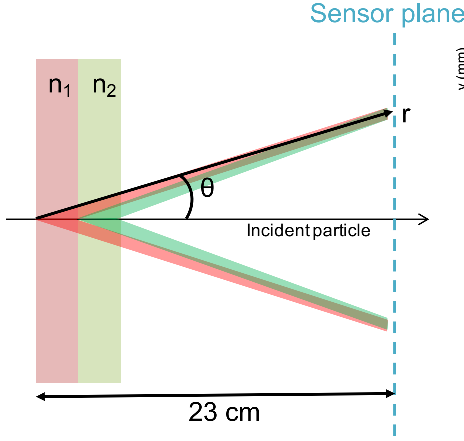


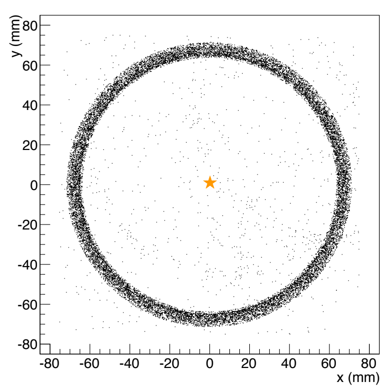




9 GeV/c pion beam launched at the center of xy plane in simulation

Two-Layer Proximity Focusing Design (BELLE-2 ARICH)



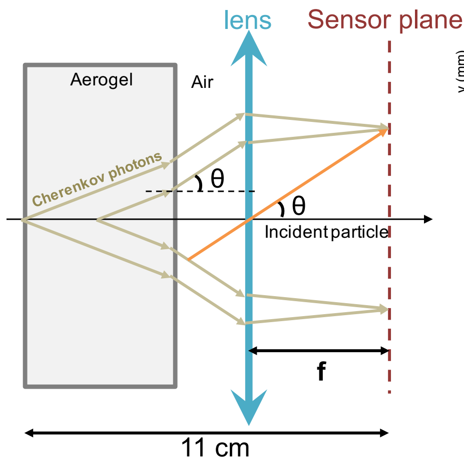


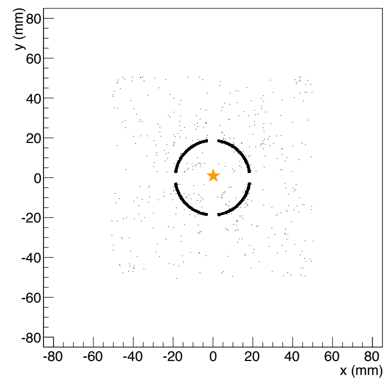
- EIC mRICH designed for K/pi ID up to 10 GeV/c
- BELLE-2 ARICH aims to separate pion and kaon up to 4 GeV/c

mRICH – lens-based focusing aerogel detector design

Smaller, but thinner ring improves PID performance and reduces length

Lens-Based mRICH Design

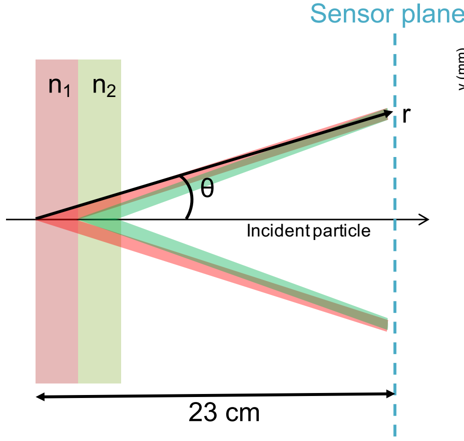


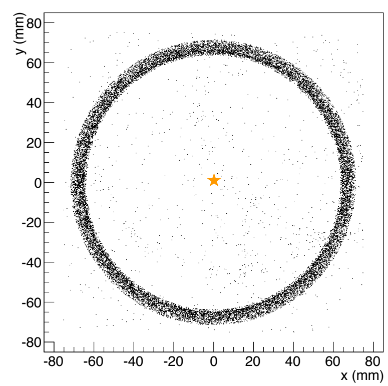


- 9 GeV/c pion beam launched at the center of xy plane in simulation
- **Smaller and thinner** ring image

9 GeV/c pion beam launched at the center of xy plane in simulation

Two-Layer Proximity Focusing Design (BELLE-2 ARICH)



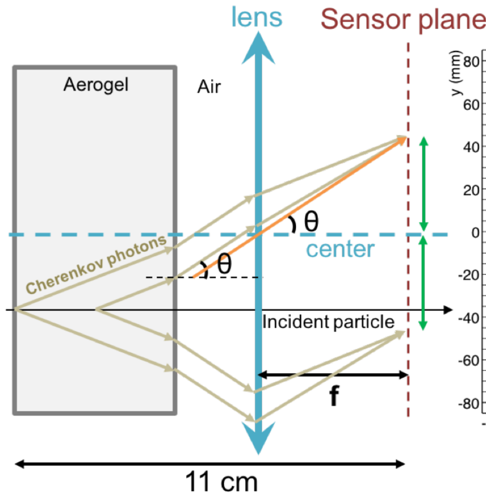


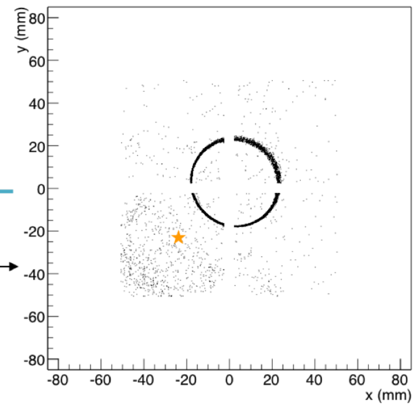
- EIC mRICH designed for K/pi ID up to 10 GeV/c
- BELLE-2 ARICH aims to separate pion and kaon up to 4 GeV/c

mRICH – lens-based focusing shifts image to center

Ring centering of lens-based optics reduces sensor area (main cost driver)

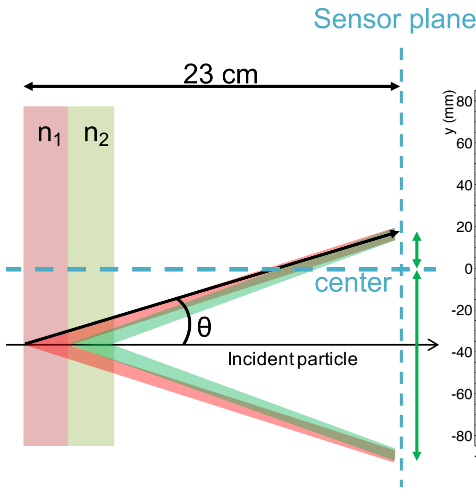
Lens-Based mRICH Design

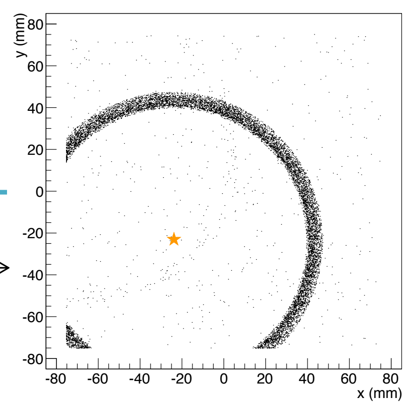




- 9 GeV/c pion beam incident at third quadrant (star) in simulation
- Ring image is center on the middle of the sensor plane

Two-Layer Proximity Focusing Design (BELLE-2 ARICH)

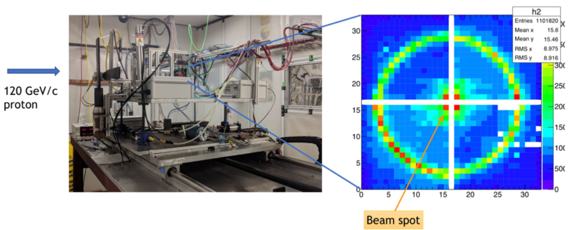




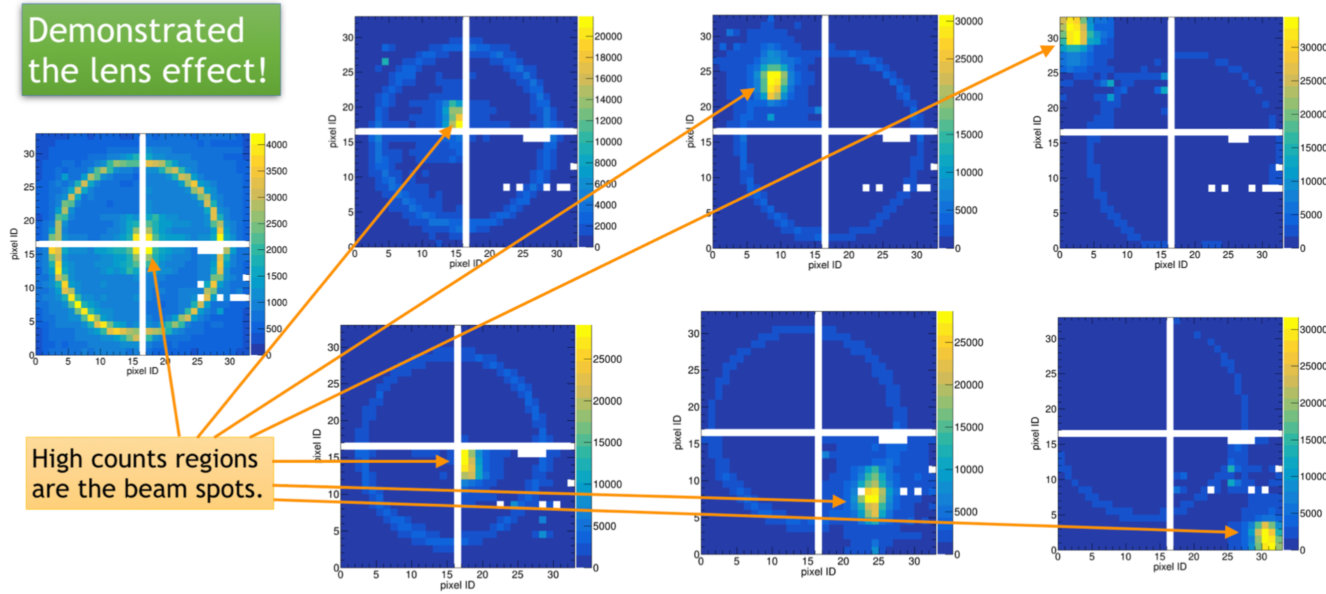
- 9 GeV/c pion beam incident at third quadrant (star) in simulation
- Ring is centered at point of incidence

mRICH 2nd beam test data analysis continued

Fermilab Beam Test Facility, from July 25 to August 6, 2019

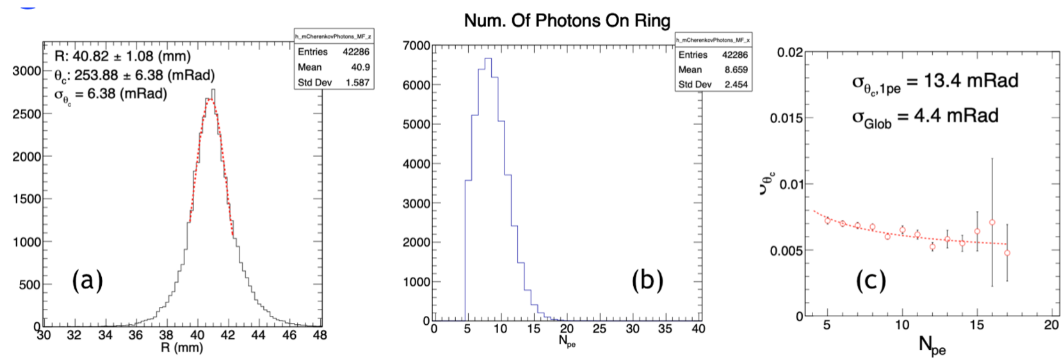


Focused on the calibration data set from 120 GeV proton incident at the central region of mRICH

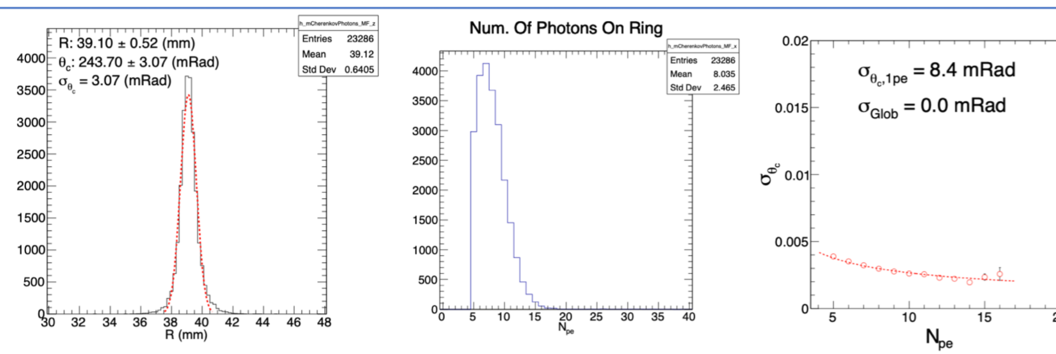


Data

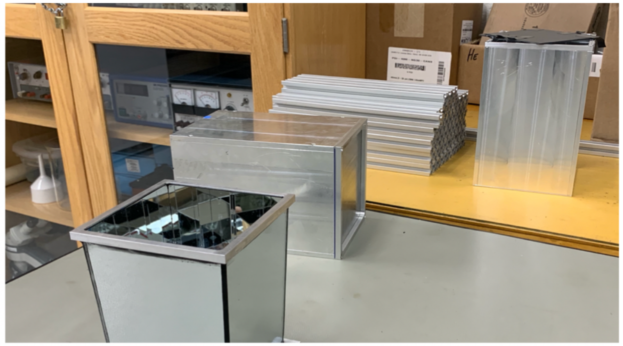
No precision tracking was available. Beam size is ~6mm in radius.



Simulation

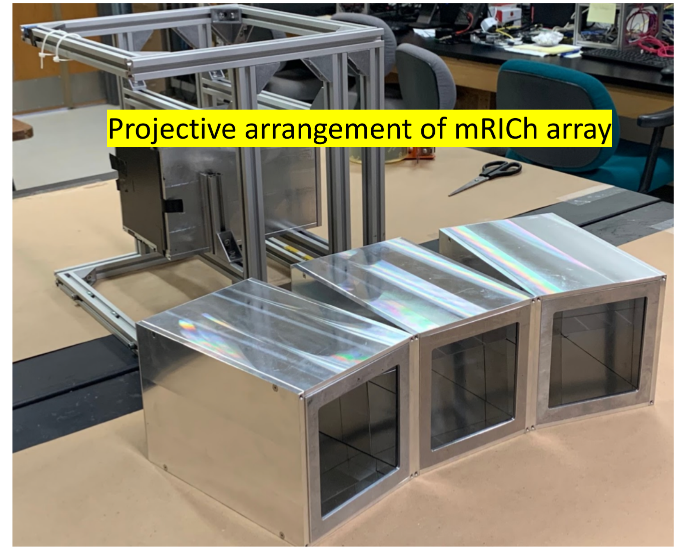


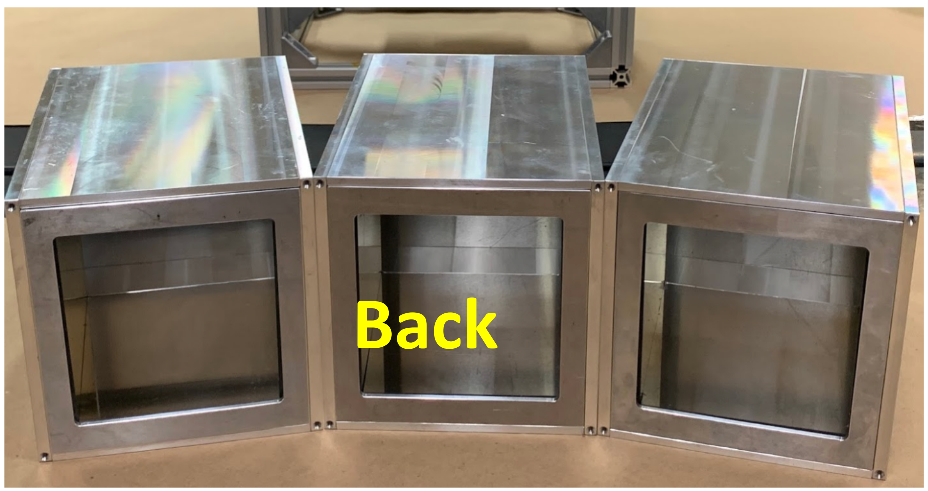
Preparation for a beam test in Hall D at JLab

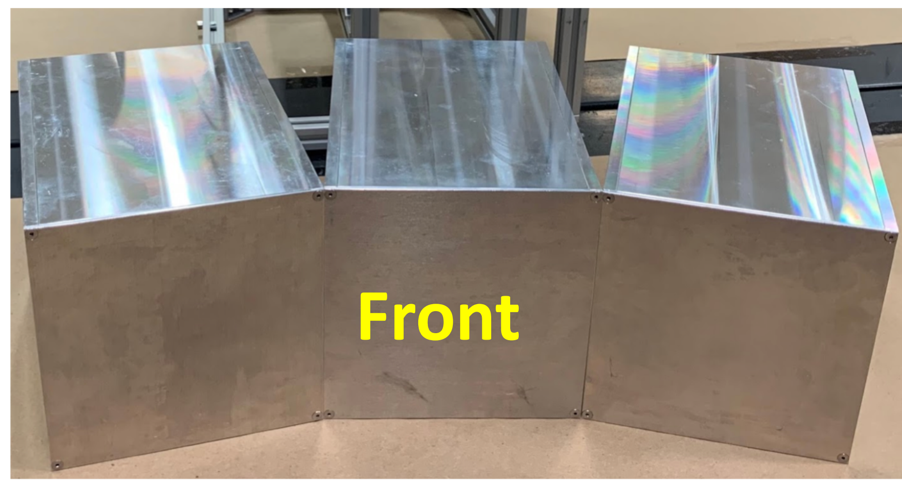


MRICH TEST PLANNING AT JLAB

CONSTRUCT 3 MORE mRICH OPTICAL UNITS AT GSU TO BE IDENTICAL TO THE ONE USED IN THE 2ND BEAM TEST







Taking the advantage of having a tracking system available for studying quantitatively the mRICH sensitivity on alignment and focalization, and the evaluation of material budget.

mRICH FY20 outlook

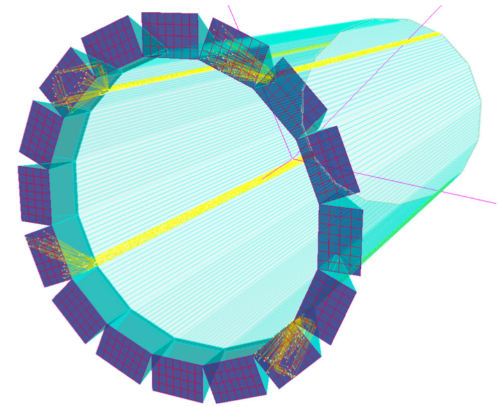
Continue the mRICH data analysis and fine tune simulation (based the 2nd mRICH beam test data):

- Quantitatively assess the effects of optical alignment on mRICH performance, which include focal plane location, sensor plane orientation, etc.
- Quantify the temperature-dependent noise levels in the data set taken with three SiPM matrices.

The third mRICH beam test at JLab

- Set up an optical characterization system at GSU for measuring the optical properties of Aerogel, lens and mirrors.
- This test is planned in Hall D at Jlab using secondary electron beam (momentum range from 1 to 6 GeV/c).

High-performance DIRC



Goals:

- Very compact device with coverage up to 10 GeV/c for p/K, 6 GeV/c for π/K, and 1.8 GeV/c for e/π, pushing performance well beyond state-of-the-art
- First DIRC aiming to utilize high-resolution 3D (x,y,t) reconstruction (performance and cost)

Progress in 2nd half of 2019:

- Successful radiation hardness study of lens materials at BNL
- Radiation hard custom-made 3-layer lens using sapphire received, lens with PbF_2 as the middle layer is close to completion
- New laser setup to measure lens properties
- Prototype transfer

DIRC – overview

Radiation hardness test in ^{60}Co source

- Detailed radiation hardness study was performed at BNL, four materials were tested up to 2 Mrad.
- Initial photo-annealing and luminescence tests were performed.

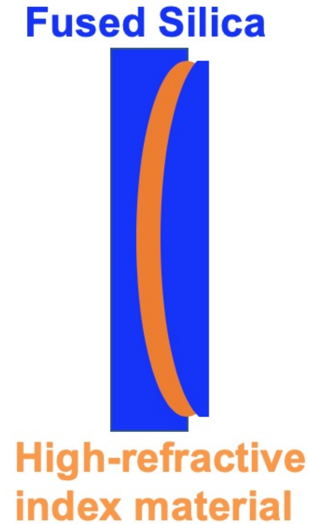
Radiation hard 3-layer lens prototypes

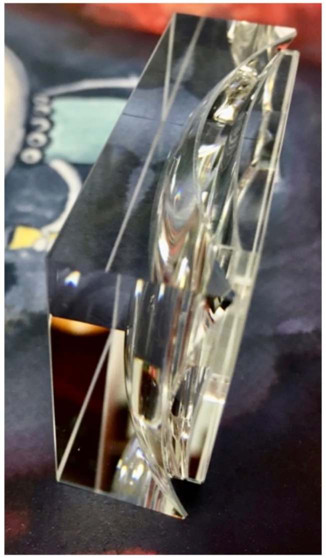
- The custom-made 3-layer spherical lens using sapphire as the middle layer was fabricated and received. Second prototype with PbF_2 instead of sapphire is being manufactured.
- New laser setup to evaluate focusing properties of new lenses is in construction.

Prototype Transfer

- Administrative process required for a loan agreement between GSI, CUA, and SBU is being finalized.
- Negotiations with three potential shipping companies are ongoing

3-layer lens





Laser Setup

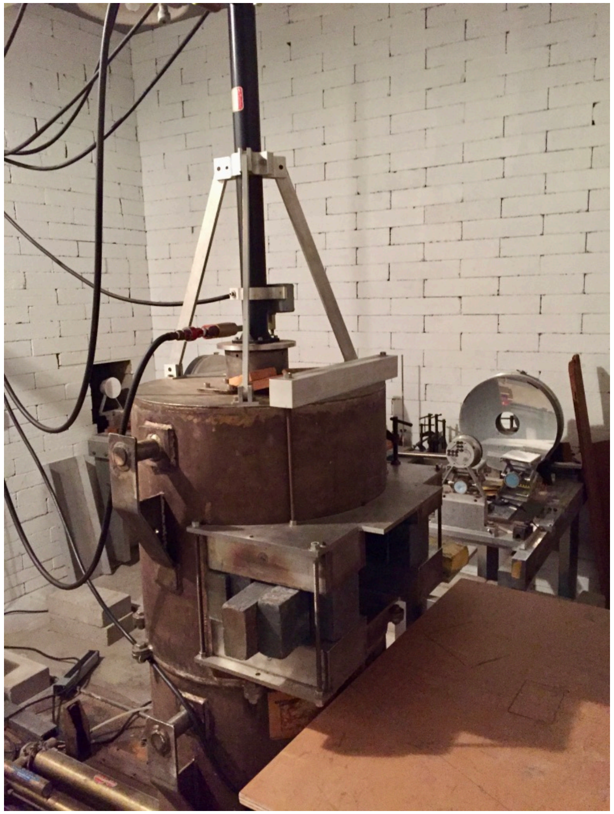
Radiation Hardness Test

^{60}Co irradiation setup at BNL

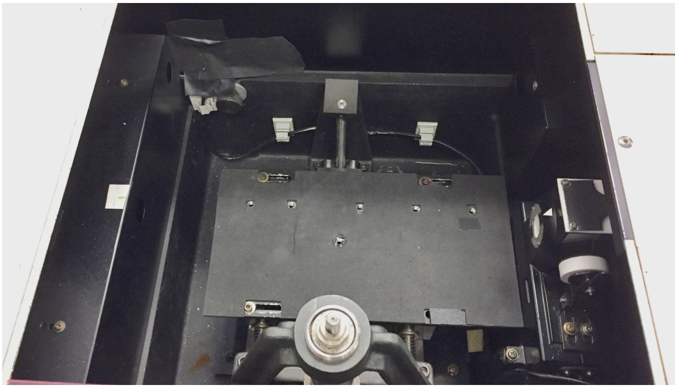
- Radiation damage quantified by measuring the transmission in the 190-800 nm range in a monochromator.
- Four materials studied up to 2 Mrad.

Tested samples

Co^{60} Chamber



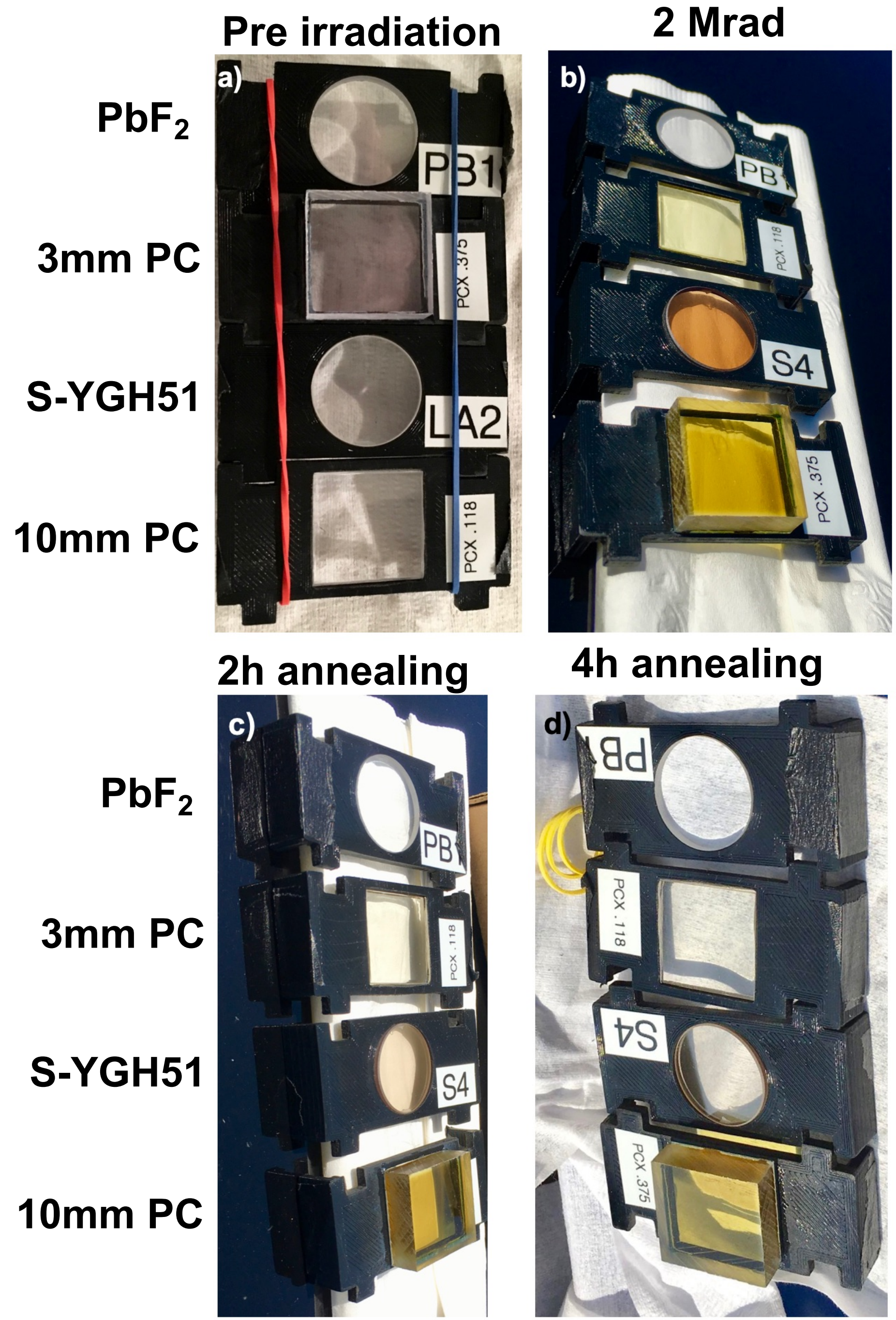
Monochromator



Radiation Hardness Test

^{60}Co irradiation setup at BNL

- Radiation damage quantified by measuring the transmission in the 190-800 nm range in a monochromator.
- Four materials studied up to 2 Mrad:
  - sapphire
  - lead fluoride (PbF_2)
  - lanthanum crown glass (S-YGH51)
  - polycarbonate (PC)
- Sapphire confirmed to be extremely radiation hard. PbF_2 showed very small deterioration.
- Initial photo-annealing and luminescence tests were performed.



Radiation Hardness Test

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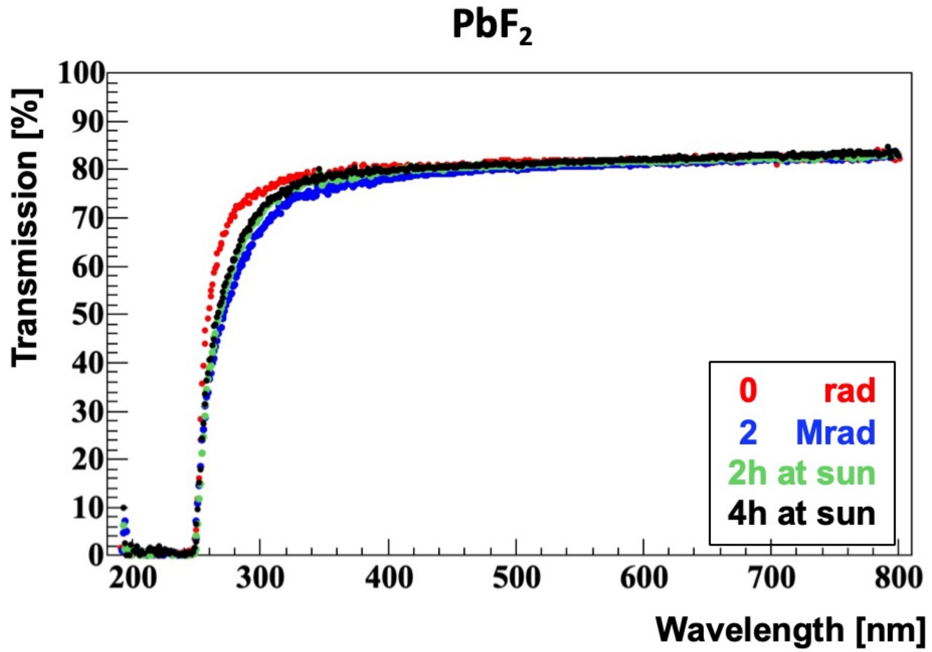
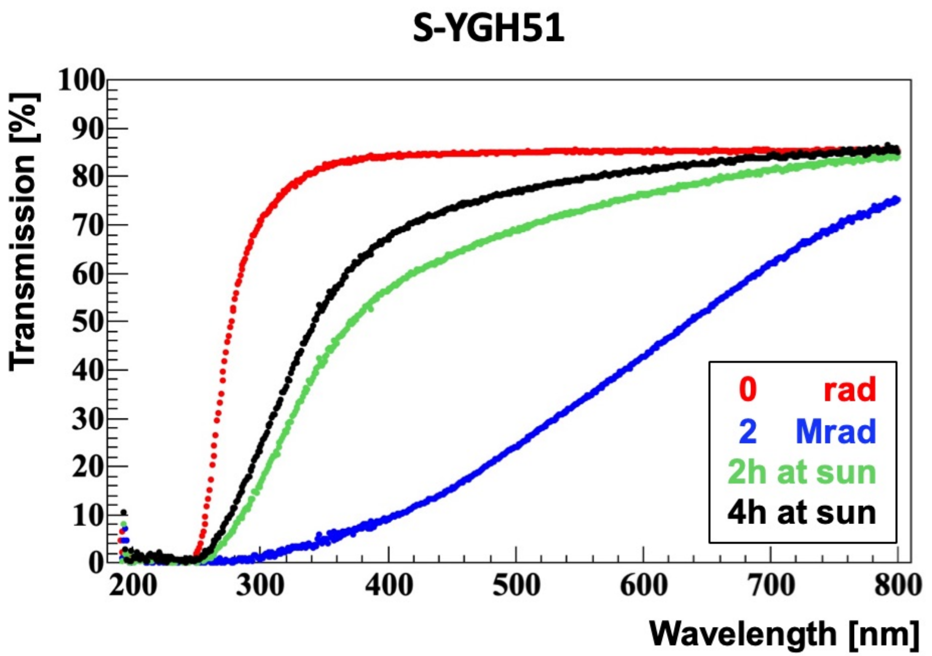




Radiation Hardness Test

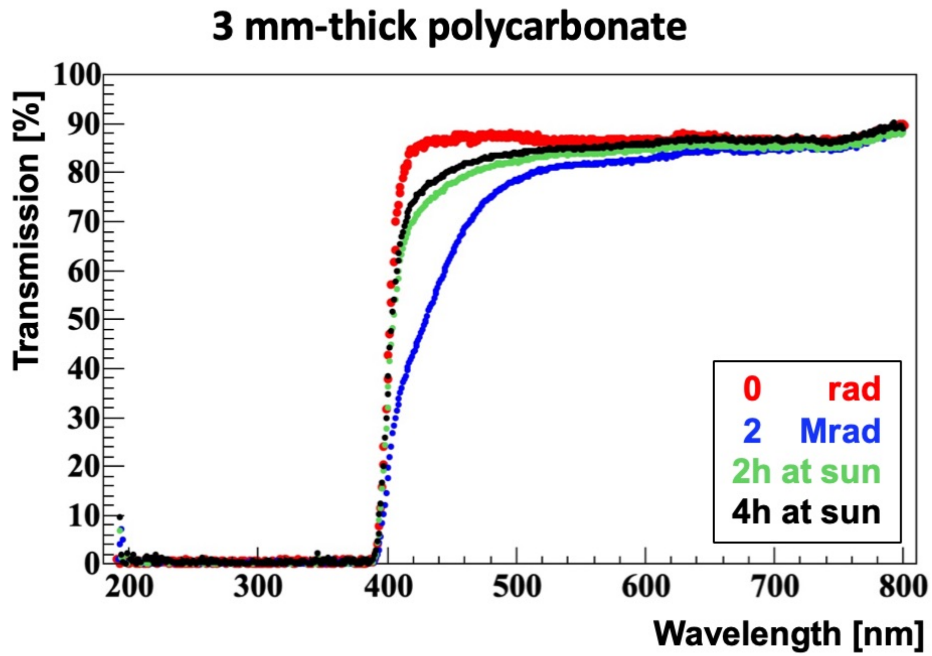
^{60}Co irradiation setup at BNL

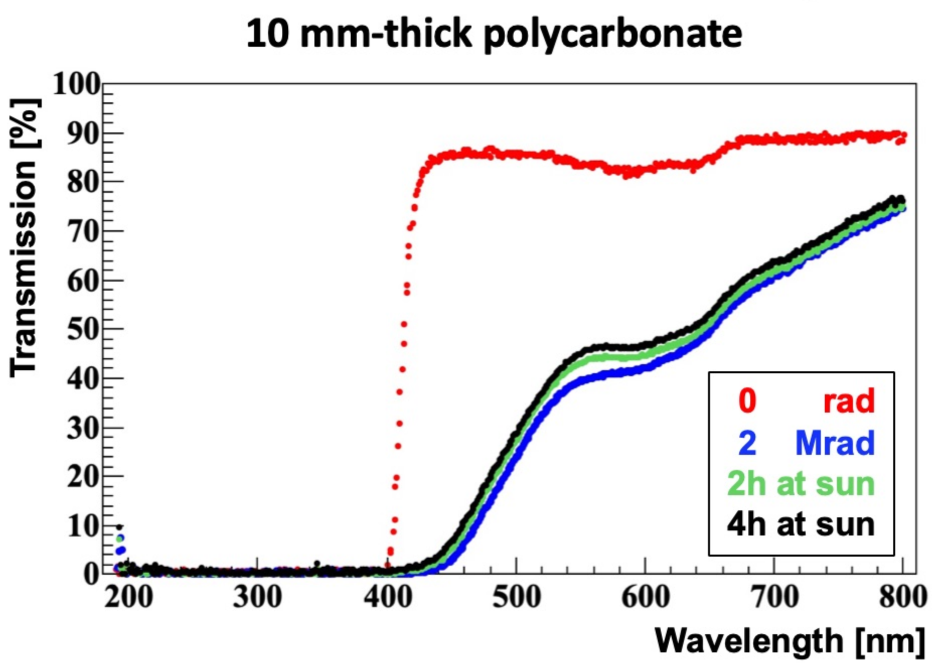
- Radiation damage quantified by measuring the transmission in the 190-800 nm range in a monochromator.

- Four materials studied up to 2 Mrad:
  - sapphire
  - lead fluoride (PbF_2)
  - lanthanum crown glass (S-YGH51)
  - polycarbonate (PC)

- Sapphire confirmed to be extremely radiation hard. PbF_2 showed very small deterioration.

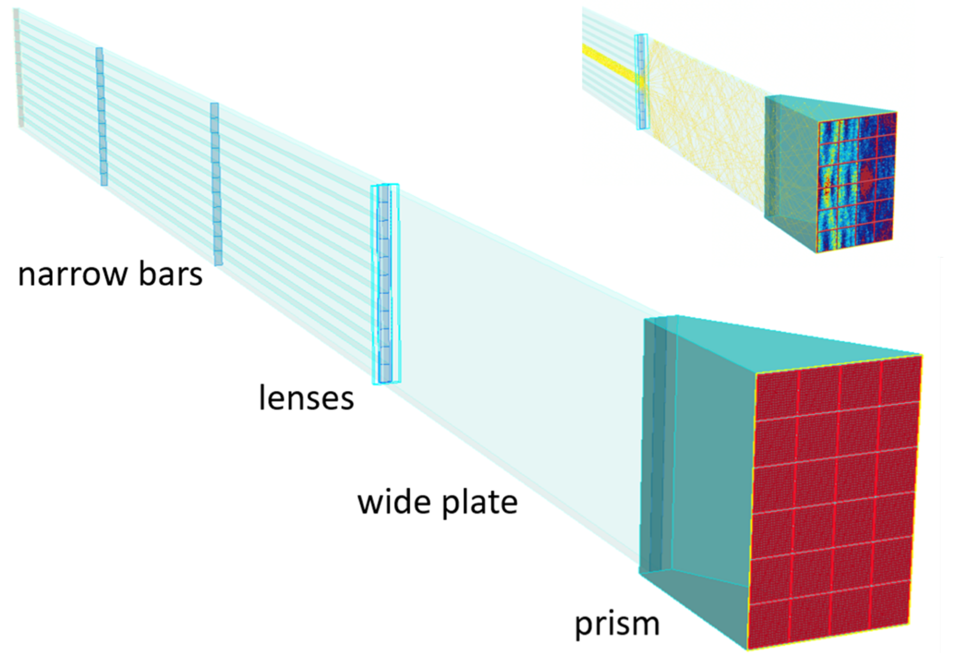
- Initial photo-annealing and luminescence tests were performed.





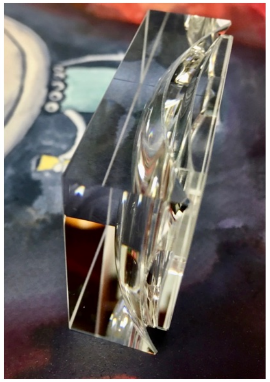
Simulation

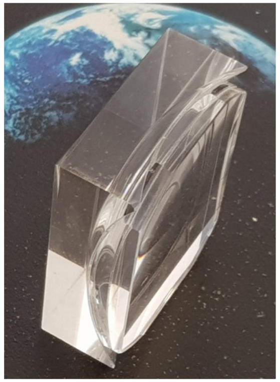
- Design optimization and prototype simulation: primary responsibility of future hpDIRC PostDoc at CUA
- PostDoc search making progress after initial candidate decided to pursue faculty position, job ad in circulation
- Fall 2019: Prepared simulation framework for PostDoc
  - used hybrid design option (bars plus plates, cylindrical lens or spherical lenses)
  - successfully validated standalone Geant environment
  - performance evaluation to follow



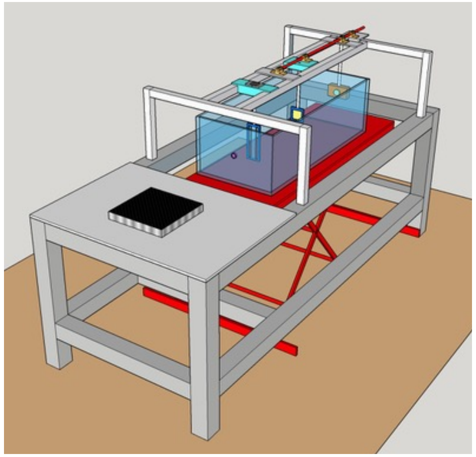
Geant simulation of hybrid design option, inspired by SLAC "ultimate DIRC" concept

hpDIRC FY20 outlook

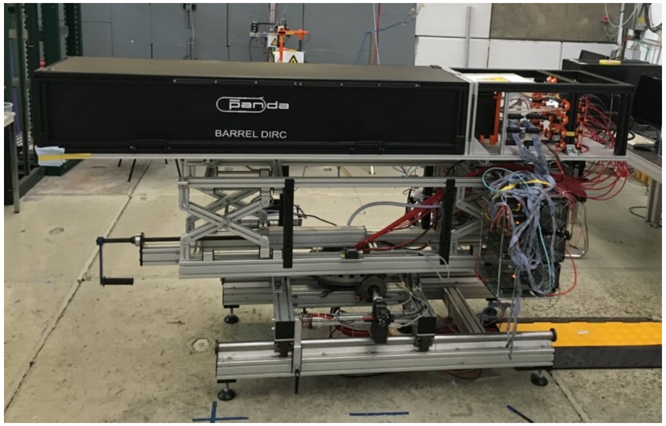




- Photo-annealing and luminescence tests planned for summer 2020 → NIM publication in FY21.



- New prototype lenses (including ones with sapphire and PbF_2) will be studied on new test bench to qualify their imaging properties.
- The laser setup for the 3D mapping of the focal plane will be upgraded to improve measurement precision → NIM publication in FY21.



- Resume design optimization and prepare prototype simulation as soon as new PostDoc is hired.
- The transfer of the DIRC prototype from GSI is planned for late spring 2020.

Photosensors and Electronics

Goals:

- To evaluate commercial photosensors for EIC PID detectors and to develop alternative, cost-effective photosensors (LAPPDs).
- To develop readout electronics for PID detector prototypes.

Activities:

- Evaluation of photosensors in high-B fields at JLab.
- Adaptation of LAPPDs to EIC requirements at ANL.
- Development of readout electronics (U. Hawaii and INFN-Ferrara) for detector PID prototypes.

Sensors in High-B Fields

Goals:

- Identify the limitations of current MCP-PMTs and provide guidance for development of new photo-sensors.
- Find the optimal location and orientation of sensors in the EIC detector.
  - Example: tilt angle with respect to the local B-field; different sensor options
- Investigate suitable parameters for operations in high magnetic fields.

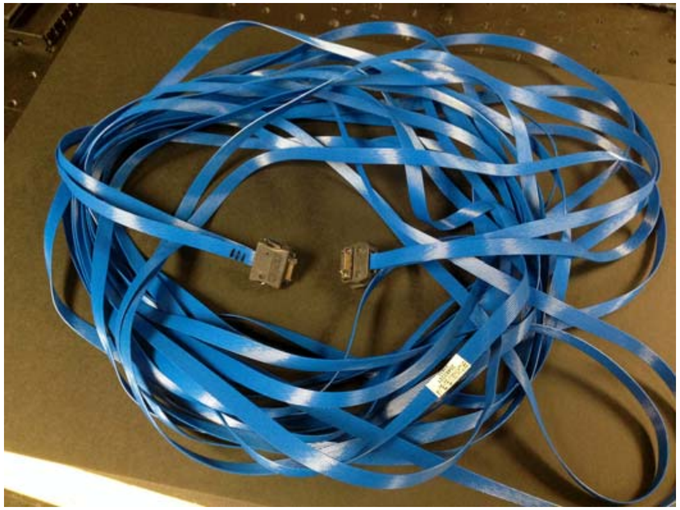
Progress in 2nd half of 2019:

- Study of different readout solutions on the gain assessment of a 10-μm Planacon MCP-PMTs in a B-field
  - New: for fast timing (no internal pre-amplifier, 5m RG188 coax cables
  - Old: ×20, 250-MHz internal preamp, 7.62m micro-coax ribbon cable
- Purchase of a 25-ps timing resolution (LSB) CAEN TDC V1290N for timing measurements.

eRD14: 2017 Planacon XP85112

Micro-coax ribbon cable used in readout for gain evaluation

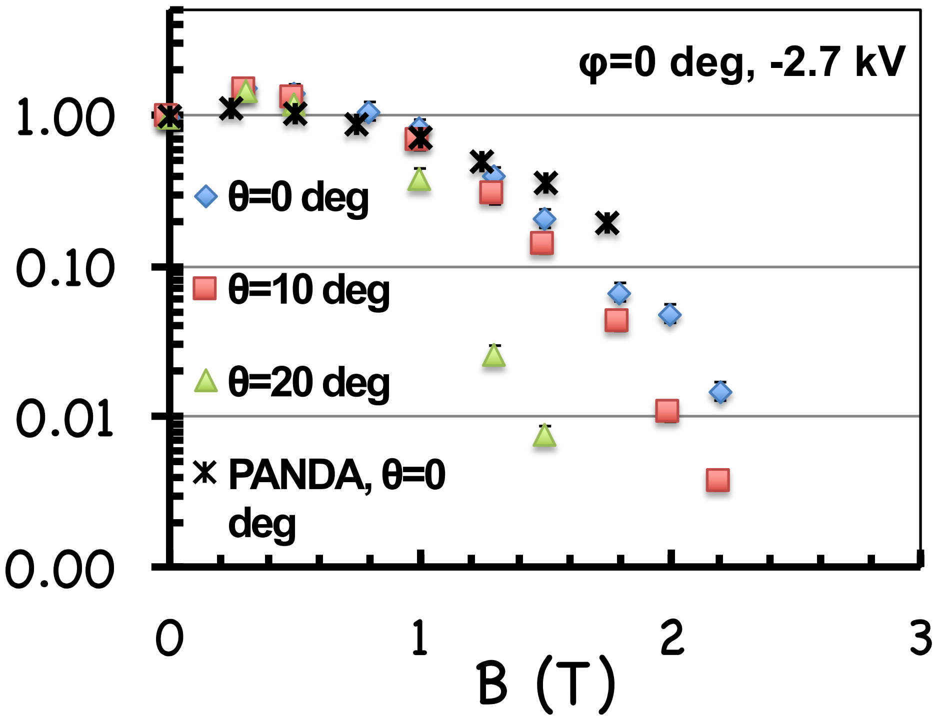
25 ft micro coax ribbon



Pulse Height Loss	−40%
Rise Time Increase	+70%
Fall Time Increase	+25%
Pulse Width Increase	+40%

To first order, the total pulse area is preserved.

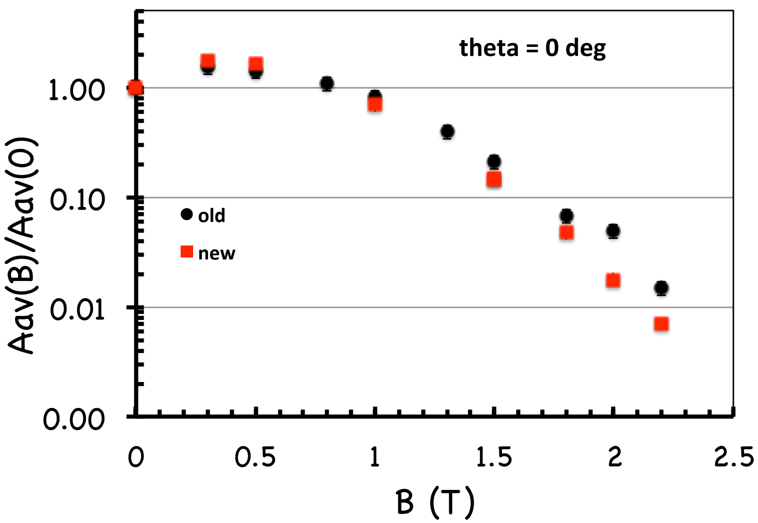
eRD14 (2017) vs PANDA (2016)

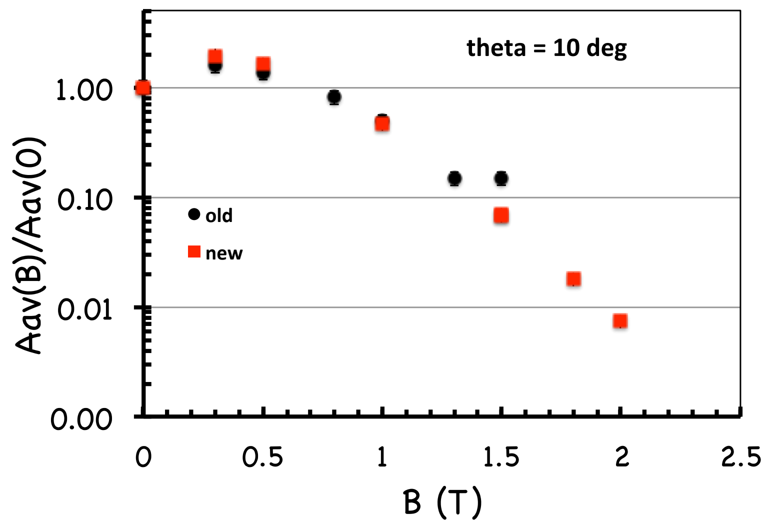


- PANDA data from RICH (2016) talk.
- PANDA data on XP85112 (prototype).
- PANDA and eRD14 consistent up to 1.3 T. Above 1.3 T PANDA data have a slower decrease than our data.

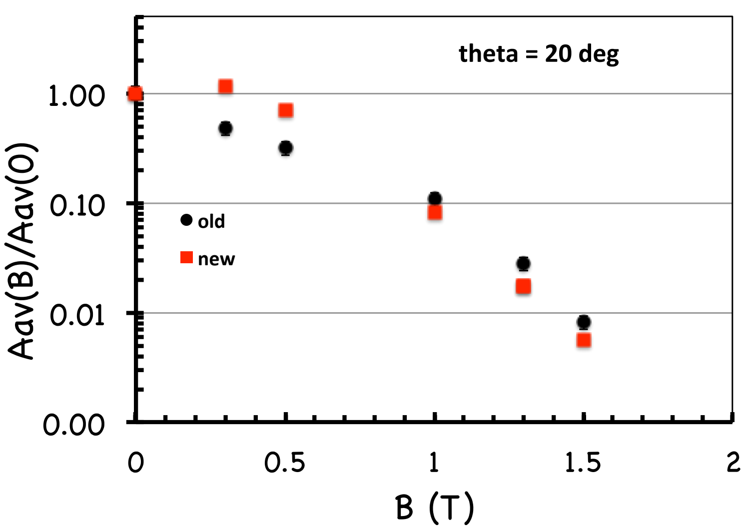
Results from Summer 2019

Assessment of the effect of different readout on gain characterization





HV = -2.65 kV



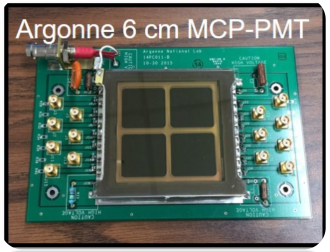
- Below 1 T, the new readout yields overall higher relative gain.
- Above 1 T, the new readout yields overall smaller relative gain.
- Possible explanations: limited bandwidth of the preamp in old readout; smaller amplitudes at high fields in new readout -> different errors.
- The PANDA trend is not reproduced -> possible differences between prototype and commercial version of the PMT.

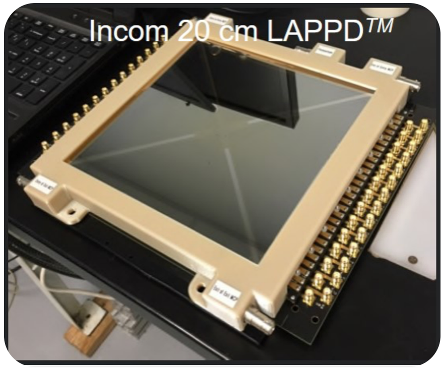
High-B FY20 outlook

Planned FY20 activities

- Purchase of a small-pixel-size (1.6 mm) 10-μm Planacon (ALD coated). This pixel size is important for detector prototypes, and specifically critical for DIRC.
    - Availability of R&D funds is **critical** for the realization of this measurement. **We need the funds in January 2020**.
- Timing and gain scan of the ALD coated 10-μm Planacon.
- If available, timing and gain scan of a 10-μm multi-anode Photek MCP-PMT (on loan).

MCP-PMT/LAPPD^{TM}





Goal:

- Adapt LAPPD^{TM} to the EIC requirements:
  Highly pixelated LAPPD^{TM} working in ~2 Tesla, applicable as photosensors for mRICH, dRICH, and DIRC detectors, as well as for TOF applications.

Progress in the 2nd half of 2019:

- Further bench test of Argonne MCP-PMTs with 10 μm pore size MCPs
- Simulation on understanding ALD effect on magnetic field tolerance
- Prepare Argonne MCP-PMT fabrication with integrated R&D results

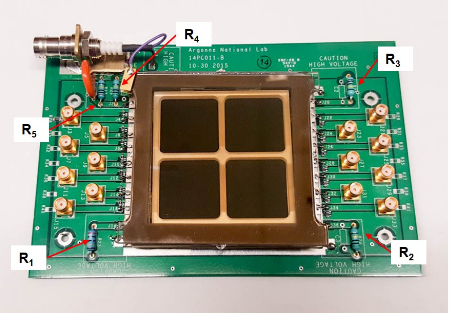
- Design and fabricate multi-pixel PCB board for ceramic Gen II LAPPD small pixel size performance validation
- Strong communication with Incom to develop pixelized LAPPD with high magnetic field tolerance and fast RMS timing
- Collaboration with Incom to secure SBIR funding to develop the pixel LAPPD with integrated Argonne MCP-PMT performance

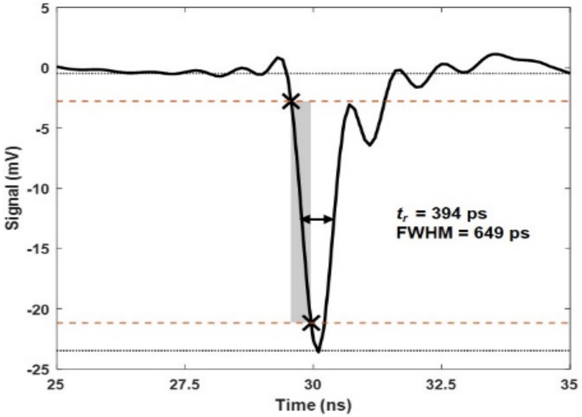
Further bench test of Argonne 10 μm ALD-MCP-PMTs

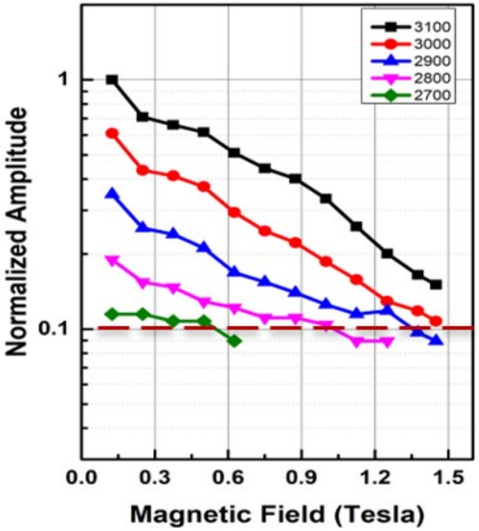
ANL Version 4 10 μm MCP-PMT with reduced spacing

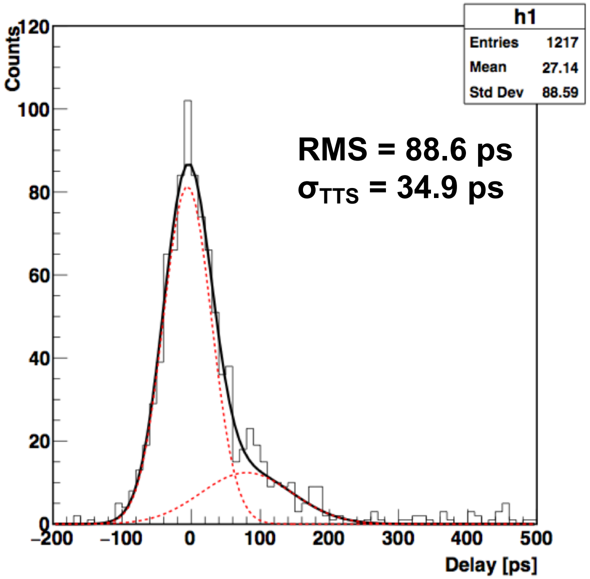
MCP	Pore size	10 μm
	Length to diameter ratio (L/d)	60:1
	Thickness	0.6 mm
	Open area ratio	70 %
	Bias angle	13°
Detector geometry	Window thickness	2.75 mm
	Spacing 1	2.25 mm
	Spacing 2	0.7 mm
	Spacing 3	1.1 mm
	Shims	0.3 mm
	Tile base thickness	2.75 mm
MCP-PMT stack	Internal stack height	**5.55 mm**
	Total stack height	11.05 mm

Gain Characteristic	Gain	2.0×10^7
Time Characteristic	Rise time	**394 ps**
	TTS RMS time resolution	88.6 ps
	TTS resolution	35 ps
Magnetic Field	Magnetic field tolerance	**Over 1.5 T**





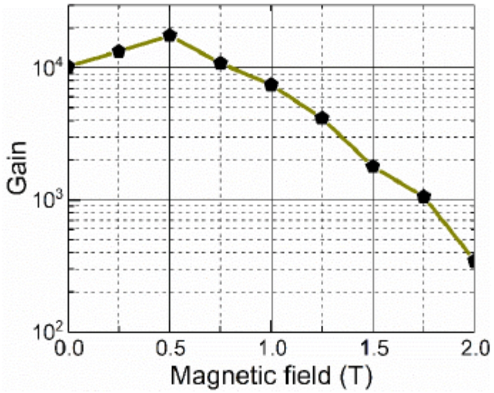


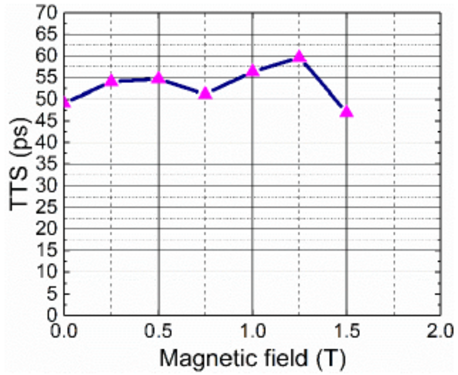


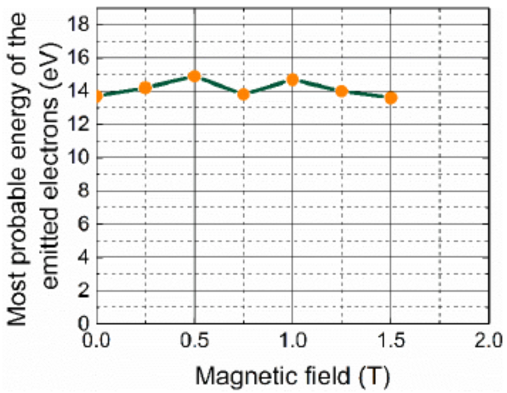
Simulation of MCP performance in magnetic field

Credit to Ping Chen (XIOPM, China)

1. Magnetic field effect on regular MCP: Gain (left), TTS (middle) and the energy of the emitted secondary electrons (right)

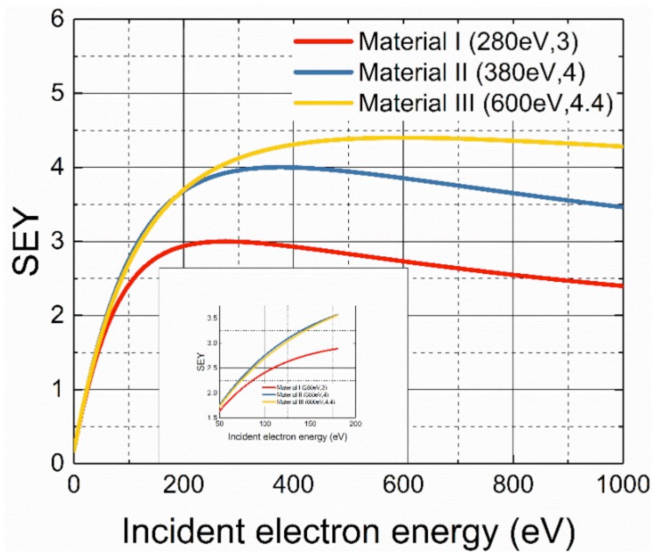


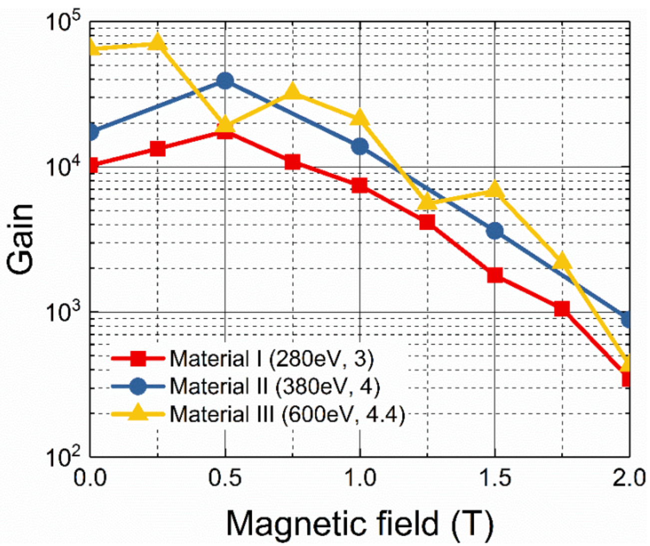




2. Magnetic field effect on ALD-MCP: MCPs with different SEY properties (left), ALD-MCP with high SEY shows direct gain decrease (orange color), lower SEY MCPs show gain increase at 0.5T (right)

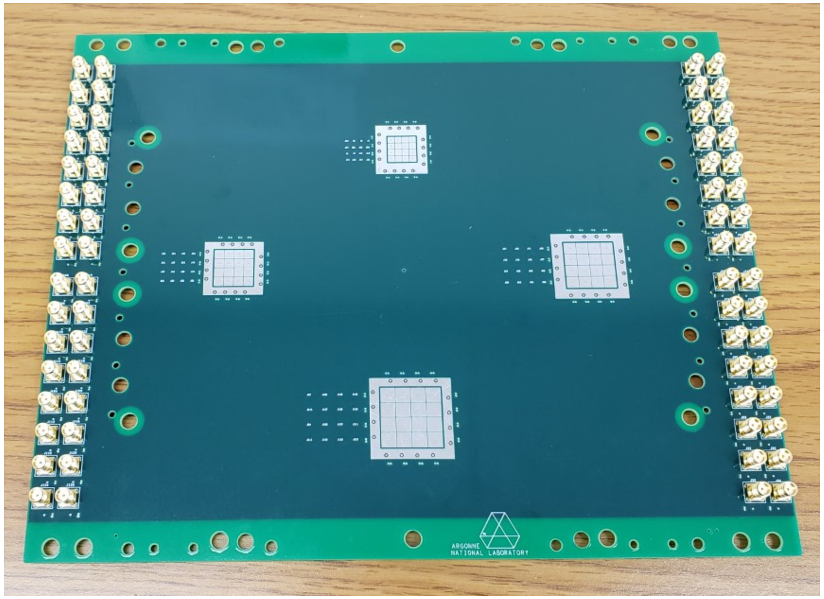
SEY:
Secondary
electron
Emission Yield





Multipixel board with different pixel size for Gen II LAPPD evaluation

4x4 pixel array at ANL with
3mm, 4mm, 5mm and 6mm pixels



An easy quick bench board to evaluate Gen II LAPPD with ceramic capacitive coupling performance at small pixel sizes: charge sharing, cross talk etc.

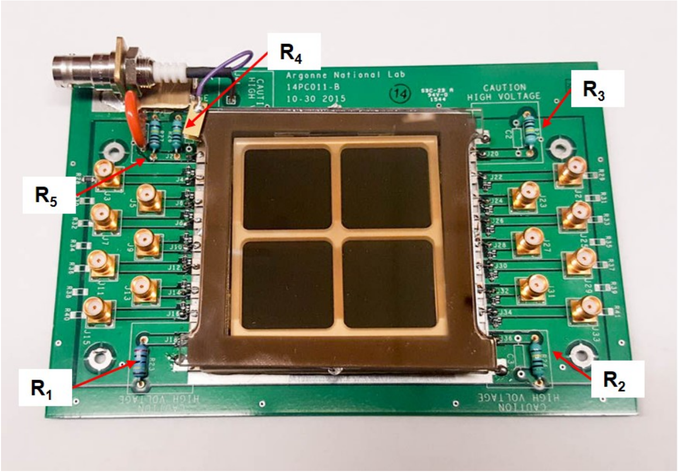
Also will be used to test Argonne MCP-PMT with glass capacitive coupling for small pixels at bench for comparison.

Gen II LAPPD with ceramic
capacitive coupling anode

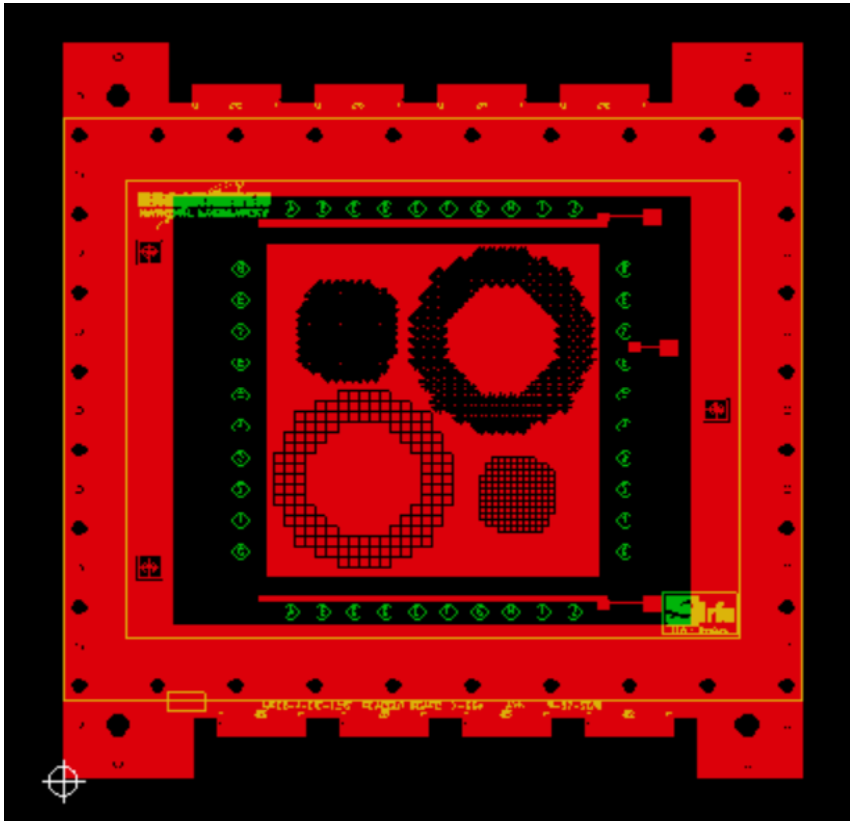
Board was just delivered. Coordinating with Incom on where and how to perform this test.

Preparing FTBF MCP-PMT/LAPPD test in April 2020

Fabricating Argonne designed MCP-PMT with glass tile and fused silica window
Bench test for position resolution with capacitively coupled glass anode
FTBF beam test for position resolution in beam
With a radiator in front, to see if Argonne MCP-PMT can achieve the imaging capability



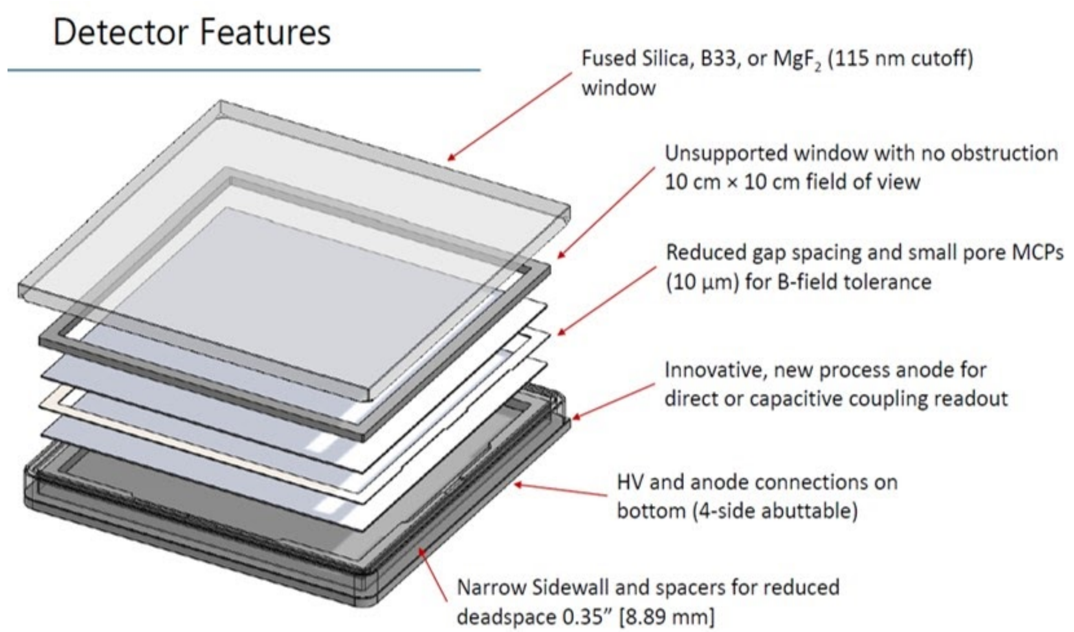
LAPPD with glass anodes are also under discussion to be delivered for April FTBF test.

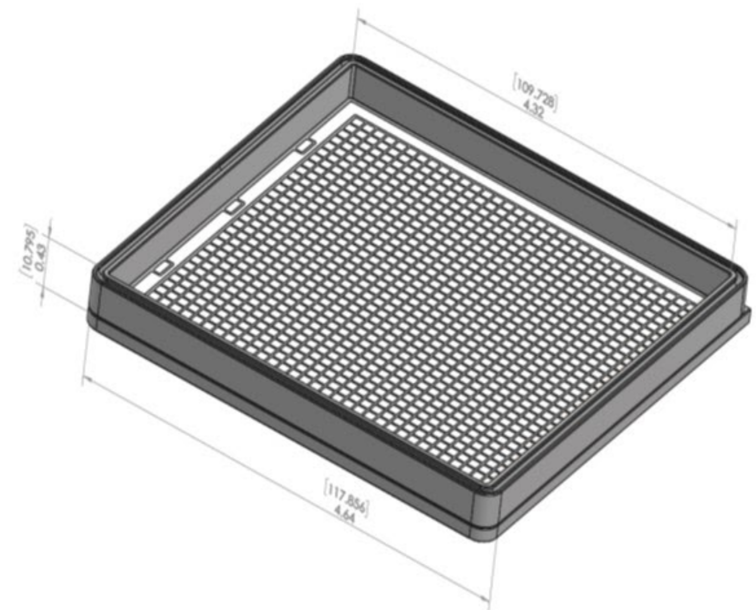


Board designed at BNL for ring imaging (BNL-LDRD: Alexander Kiselev)

New High Rate Picosecond Photodetector (HRPPD)

SBIR phase I “Large Area Multi-Anode MCP-PMT for High Rate Applications” was just awarded, aiming to solve the required pixel LAPPD with integrated magnetic field tolerance and fast RMS timing resolution.



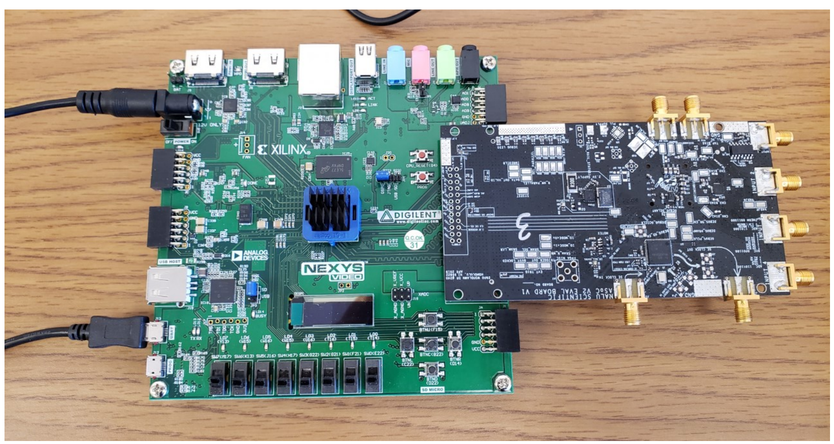


Argonne R&D study on 10 μm ALD-MCP-PMTs were integrated in the HRPPD design together with required via readout using low temperature co-fire ceramic anode for hpDIRC purpose.

LAPPDs FY20 plans and outlook

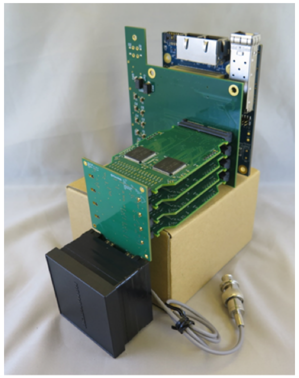
- Fabricate Argonne full glass/fused silica MCP-PMT with integrated R&D results
- Complete Fermilab April FTBF beam test
- Complete ceramic Gen II LAPPD small pixel performance evaluation
- Compare ceramic and glass anode performance

- Support Incom HRPPD SBIR work to push the delivery of HRPPD to EIC-PID for evaluation and possible beamline test at end.
- Familiar with ASoC chip and software through synergetic effort at Argonne for SoLID Cherenkov counter, explore HDSoC integration with MCP-PMT/LAPPD for EIC-PID.



Artix-7 FPGA with Nalu ASoC evaluation board on loan at ANL for MCP-PMT/LAPPD test for SoLID to gain experience.

Front-end Electronics for EIC-PID



Goal:

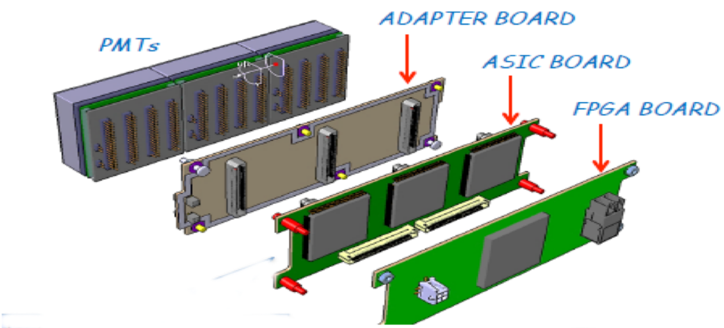
- Readout several photosensors (MaPMTs, MCP-PMTs, and SiPMs) with similar sensor and pixel size (16x16 array of 3 mm pixels) with <100 ps
- Have a common front end electronics with good timing that can be used for all sensors and detectors (mRICH, dRICH, DIRC)

Progress in the 2nd half of 2019:

- MAROC electronics tested with SiPMs and MA-PMTs
- 32 ch SiREAD break out board designed and fabricated for testing

Electronics – Maroc
(used for previous mRICH beam tests)

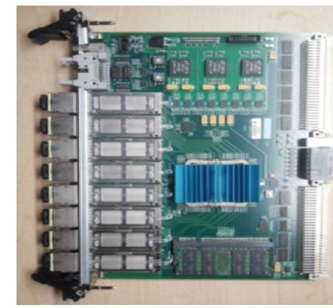
CLAS12 RICH electronics



Adapter & Asics Boards

FPGA Board

SSP Fiber-Optic DAQ

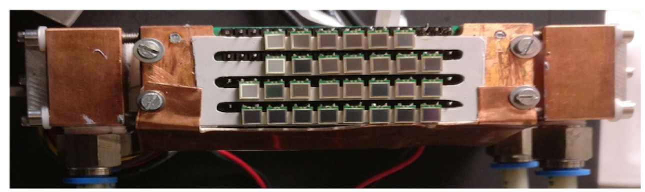


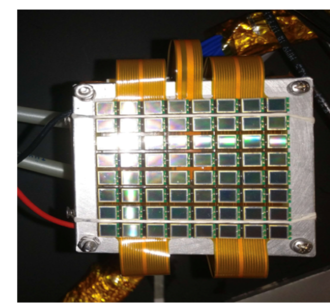
SiPMs

- ✓ Mass production technology
- ✓ Photon counting
- ✓ Excellent time resolution
- ✓ Compatible with magnetic field

- ✗ High dark rate
- ✗ Low radiation tolerance

} Work at low temperature

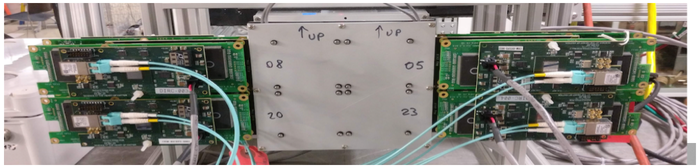


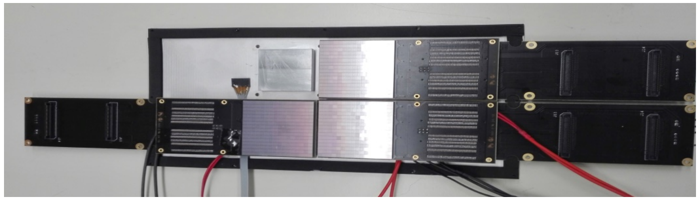


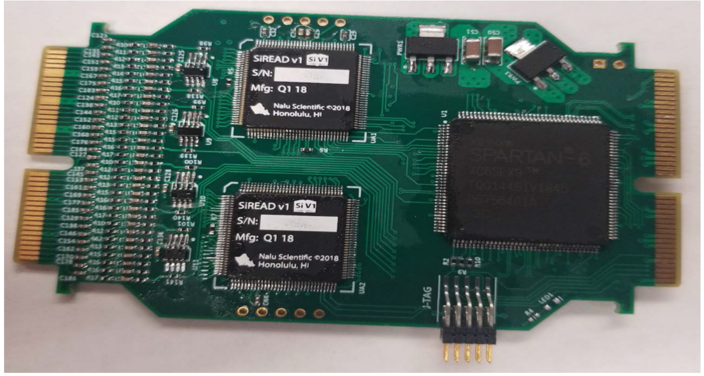
Readout Electronics Development

Goal:

- Develop an integrated suite of readout electronics for the different photosensors used for all the Cherenkov detectors and prototypes.
- Provide a reference readout system for prototypes performance assessment
- Developed a generic DAQ system compatible with the Consortium needs
- Test applications with various sensors (including SiPMs)



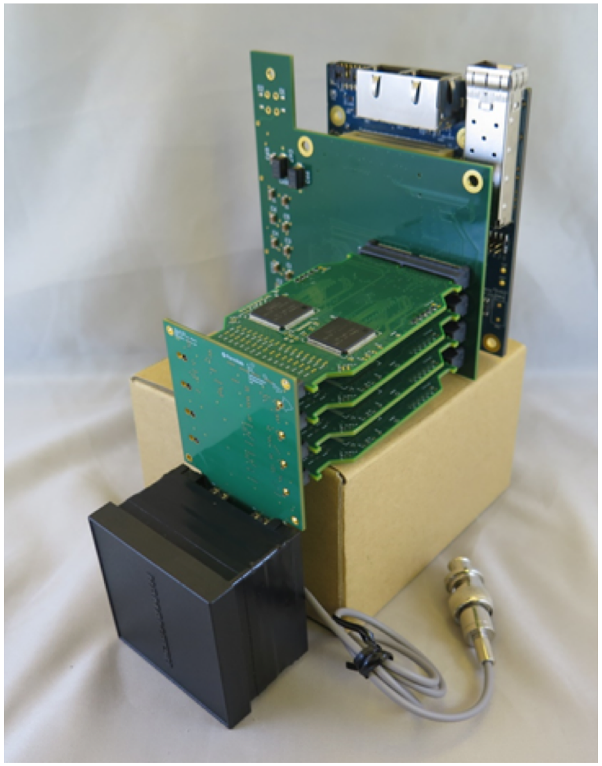




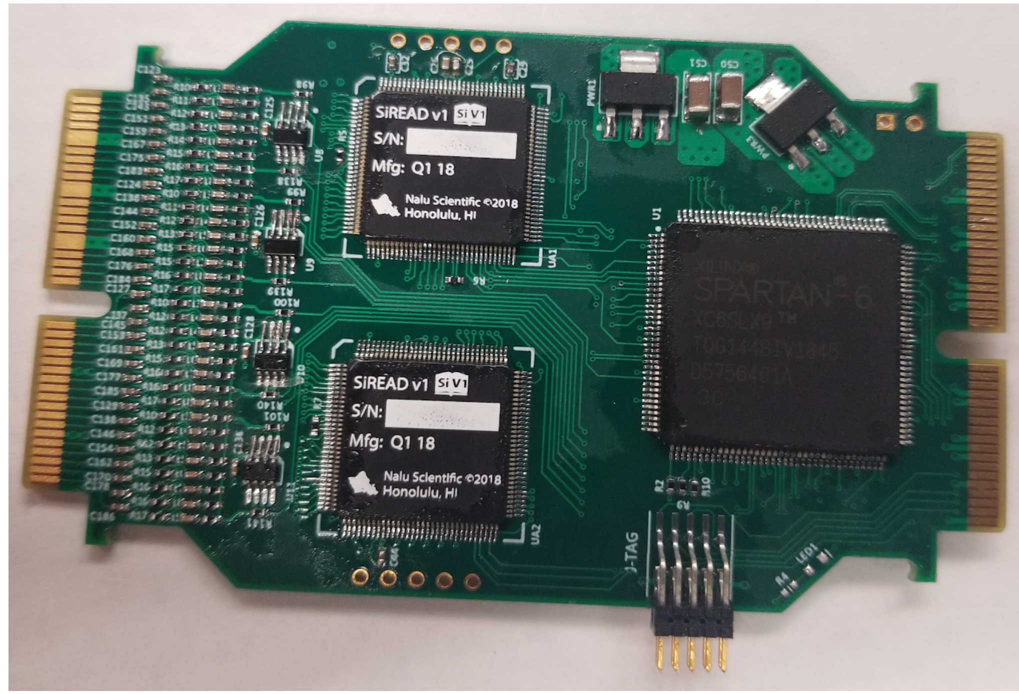
FY 20 Activities:

- Moving from the TARGETX (Belle-II) to the new SiREAD chip
- Development of pulsed laser test benches for detailed characterization

Ma-PMT readout

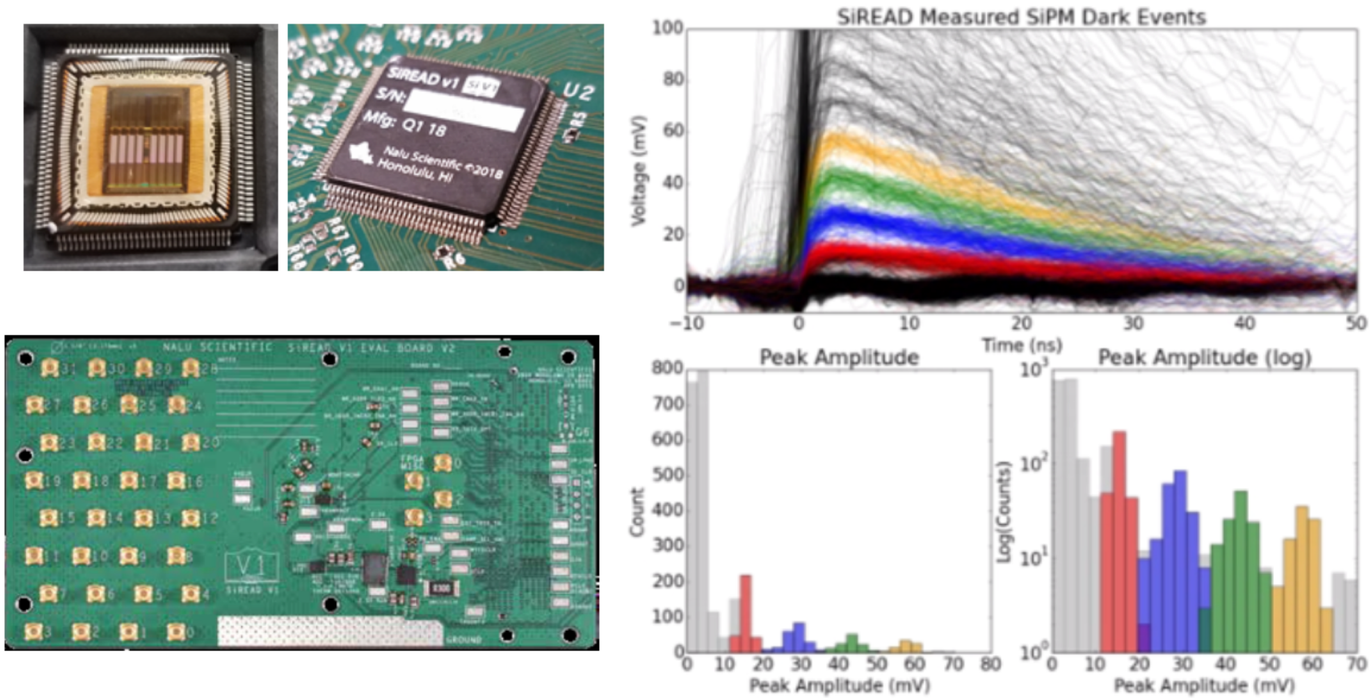


Photograph of the first generation of 256-anode 2" PMT readout for use with mRICH prototype in the Fermilab beam test facility.



Photograph of the 64 channel SiREAD based (2x SiREAD rev.1) readout card as a building block for the 256 MA-PMT readout.

SiREAD performance

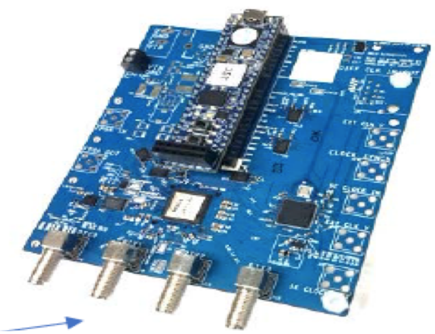


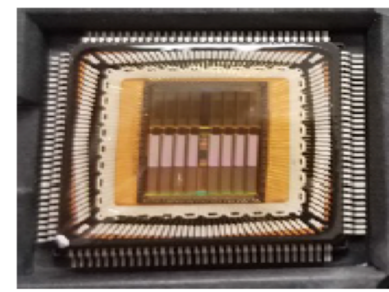
- Micrograph of the fabricated prototype SiREAD (**top left**). Prototype SiREAD on the evaluation PCB (**top middle**). Superimposed dark count waveforms recorded from a SiPM using the SiREAD operating at 1 Gsa/s (**right**). High channel count evaluation PCB for SiREAD with 32 dedicated MMCX connectors (**bottom left)**.

Nalu Scientific
System-on-Chip Digitizer Portfolio

Nalu Scientific
Data Acquisition Systems

Project	Sampling Frequency (GHz)	Input BW (GHz)	Buffer Length (Samples)	Number of Channels	Timing Resolution (ps)	Available Date
ASoC	3-5	0.8	32k	8	35	Rev 2 avail
HDSoC	1-3	0.6	4k	64	80-120	Rev 1 avail
AARDVARC	6-10	2.5	32k	4-8	4-8	Rev 2 avail
AODS	1-2	1	8k	1-4	100-200	May 2020





- **ASoC**: Analog to digital converter System-on-Chip
- **HDSoC**: High Density specialized readout chip with bias and control (SiREAD revival)
  - Phase I DOE SBIR recently funded
- **AARDVARC**: Variable rate readout chip for fast timing and low deadtime
- **AODS:** Low density digitizer with High Dynamic Range (HDR) option

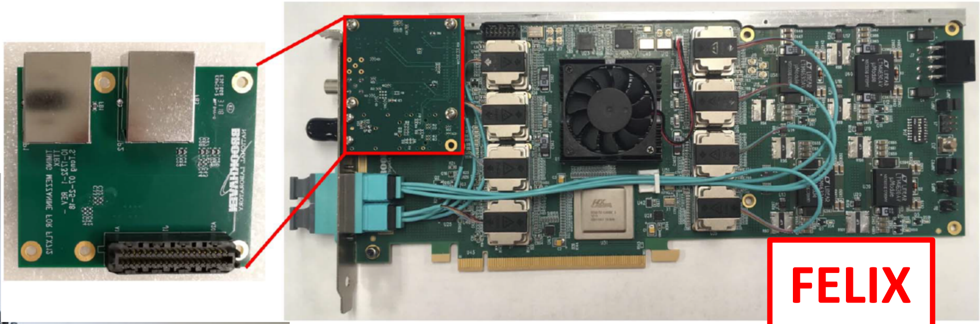
Nalu Scientific has received substantial DOE SBIR funding for SoC development from DOE NP program. All chips, are designed with commercial grade tools and licenses and can be commercially available.

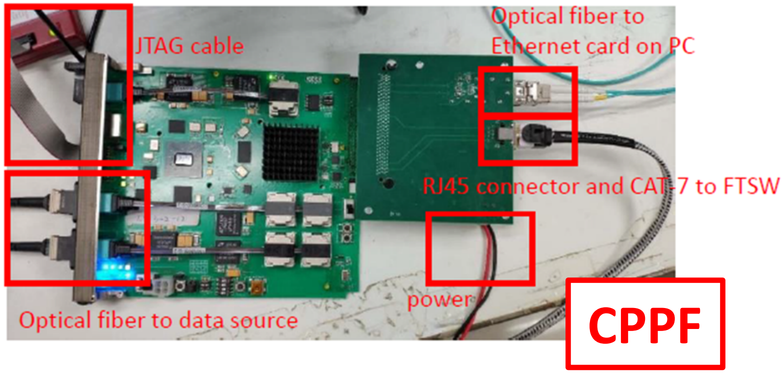
HW/FW Development

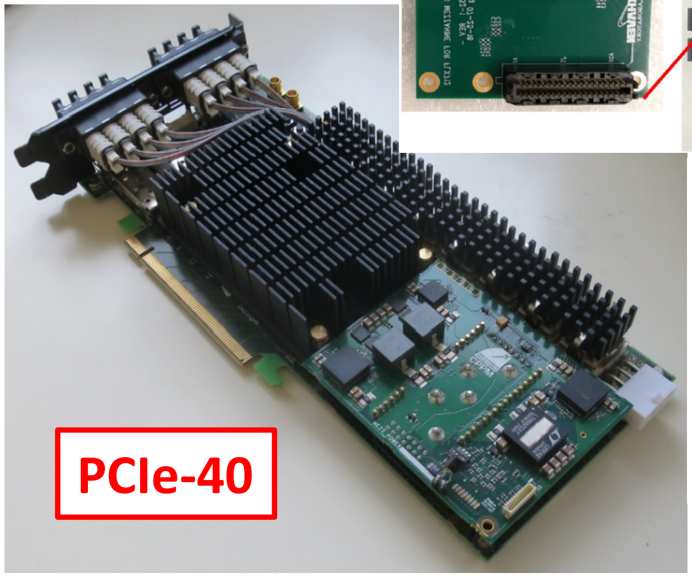
- **Need for robust firmware development (lesson from Belle II)**
- **Nalu Scientific team provides in-house FW development, with institutional memory**
- **UH provides comprehensive bench, environment and picosecond laser/photosensor testing**
- **UH has hired new post doc, started mid January 2020**
- **Immediate push is to get SiREAD version of 256 anode PMT readout working; evaluate performance; design more compact version with HDSoC**

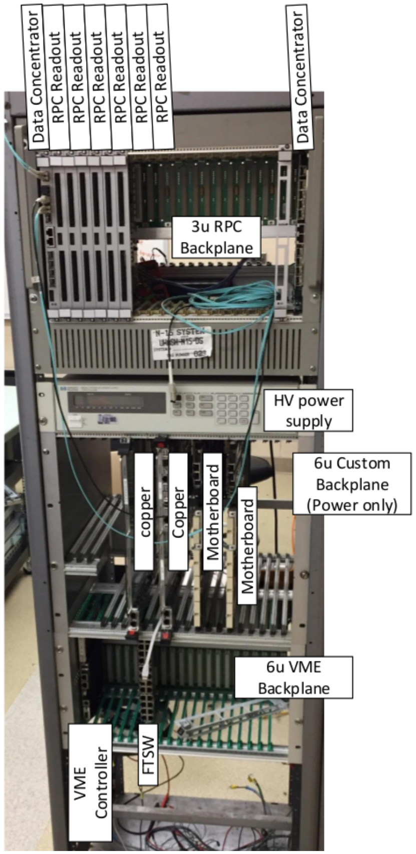
Backend Control / Readout

- **Current: JLab and Belle2link readout as baseline**
- **Experience with Belle II DAQ upgrade**









Electronics FY20 plans and outlook

- **Complete MAROC based readout**
- **Complete SiREAD-based MA-PMT readout**
  - **Develop FW and perform benchtests**
  - **Test already built hardware at IDL laser setup**
- **Identify HDSoC specifications for EIC related readout development**
- **FY2021: MCP-PMT readout for DIRC prototype (beamtest)**
- **FY2022: Integrated-cooling Si-PM readout**
- **FY2023: Triggerless DAQ readout demonstrator (FELIX-based)**
- **One full-time Postdoc**
- **Yearly contract with Nalu Scientific for engineering support**

eRD14 FY20 budget (including overhead)

5.9 Budget by project

	requested	approved	fraction
dRICH	52,000	36,400	70.0%
mRICH	78,300	54,810	70.0%
hpDIRC	134,000	134,000	100.0%
high-B	39,300	19,650	50.0%
LAPPD	120,000	84,000	70.0%
Electronics	92,000	64,400	70.0%
Total	*515,600*	*393,260*	*76.3%*

5.10 Budget by institution

	requested	approved	fraction
ANL	120,000	84,000	70.0%
CUA + GSI	134,000	127,500	95.1%
GSU	68,300	46,810	68.5%
INFN	94,000	67,400	71.7%
JLab	9,700	3,237	33.4%
U. Hawaii	60,000	41,400	69.0%
U. SC	29,600	22,913	77.4%
Total	*515,600*	*393,260*	*76.3%*

- Please note that the rollover funds from FY19 are very small.

TDR Readiness

How much time is needed to complete ongoing projects?
4 years (FY20 – FY23), if funding is increased in the next R&D phase

What achievements are required for TDR readiness in 2023

1) A cost-optimized baseline design for each subsystem (for the first EIC detector at the selected site).
2) Completed performance validation in test beams with prototypes for all subsystems.
3) Completed validation of readout electronics compatible with EIC requirements.
4) Investigation of broader integration issues – both mechanical and readout-related

What are the bottlenecks?

The main bottleneck is performance validation. Development of a baseline design and electronics can be speeded up by "throwing money (postdocs) at the problem," but test beams have a natural cycle, where lessons learned need to be incorporated in-between tests. Thus,

full support for prototyping for all systems is critical.

Thank you!

	FY20	FY21	FY22	FY23
dRICH	Prototype Design and Simulation • Basic Mechanics • Components selection and tests	- Basic Prototype Ready (basic tracking, commercial mirrors, 1 radiator choice) - Component selection and tests - Test-beam 1: MA-PMTs (SiPMs); Proton pencil beam; Critical aspects	-Refined Prototype Ready (custom mirrors, various radiators, refined tracking, gas system) -Component selection and tests -Test-beam 2: MCP-PMTs, SiPMs, Hadron beam -Performance optimization	TDR
mRICH	-Data Analysis of 2 beam test -Preparation for 3rd beam test	- Beam test for verification of mRICH performance parameters (characterized aerogel, lens, and mirrors; tracking subsystem; readout; photosensors – SiPM, MCP PMT)		-System Integration studies -mRICH array simulation studies in EIC experiments PID algorithm development
DIRC	-Simulation (prototype, beamline) -Reconstruction (time-imaging optimization, prototype analysis code) -Prototype transfer GSI-US -Initial prototype commissioning in lab (SB) -Lens evaluation	-Simulation (prototype, beamline; explore hpDIRC design options; cost/performance optimization; integrated PID performance study) -Reconstruction (time-imaging optimization, prototype analysis code) -Prototype upgrade and commissioning -Beam test (FNAL); analysis -Lens evaluation	-Simulation (explore hpDIRC design options; cost/performance optimization; integrated PID performance study) -Reconstruction (prototype analysis code) -Beam test (FNAL); analysis	-Simulation (integrated PID performance study) -Beam test analysis
Sensors	-6-cm LAPPD; ALD-coating studies -GenII LAPPD min. pixel size validation -LAPPD full test -Planacon characterization	-ALD coating studies -GENIII LAPPD pixel performance validation -LAPPD full test -LAPPD electronics integration -LAPPD beam test -Planacon, Photek characterization	-LAPPD full test -LAPPD beam test -Photek characterization -Characterization (gain, timing, uniformity) of MCP PMTs for DIRC prototype	-LAPPD full test -LAPPD beam test -Commercially available MCP PMTs characterizations as needed
Electronics	-Complete SiRead MaPMT readout	-Readouts for different prototypes	-Readouts for different prototypes	-DAQ readout demonstrator

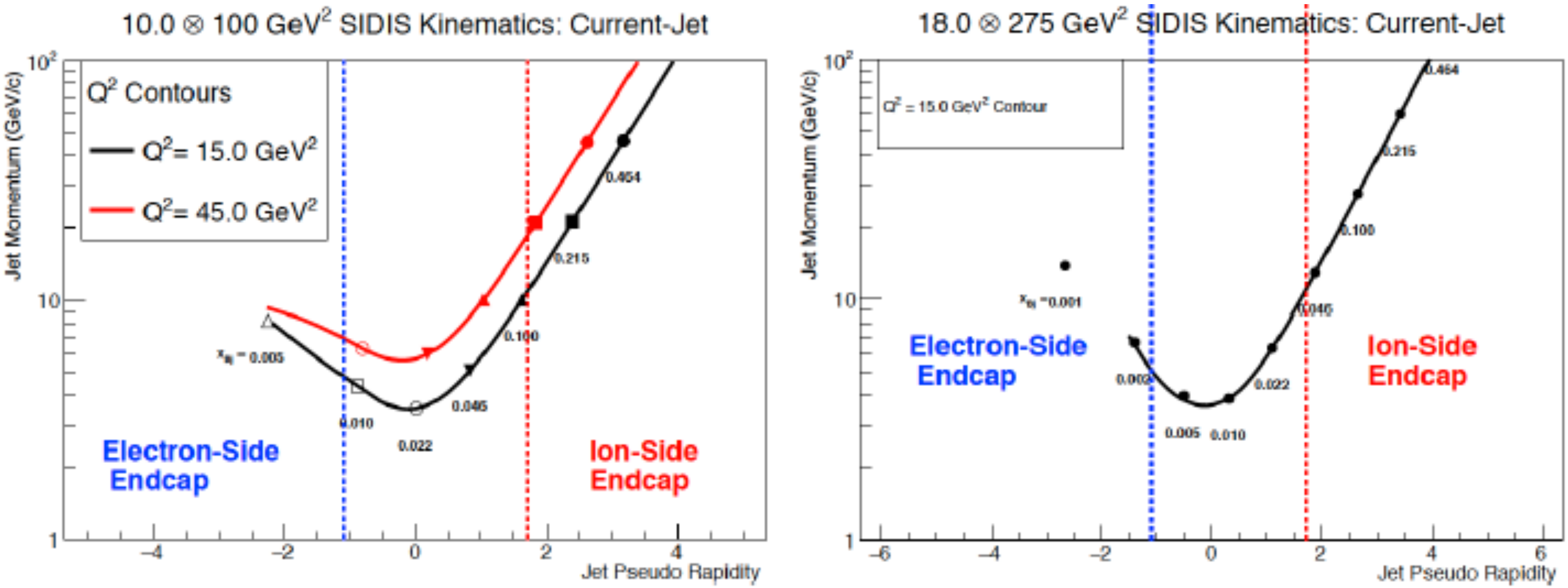
Four-year (FY20-23) funding profile

		FY20	FY21	FY22	FY23	total
DIRC	personnel	60	190	190	130	570
	materials	89	255	55	50	449
	total	149	445	245	180	1019
dRICH	personnel	50	68	58	30	206
	materials	15	89	96	26	226
	total	65	157	154	56	432
mRICH	personnel	80	104	104	80	368
	materials		62	62		124
	total	80	166	166	80	492
high-B	personnel	11	11	11	11	44
	materials	28	21	21	21	91
	total	39	32	32	32	135
LAPPD	personnel	115	105	40	40	300
	materials					0
	total	115	105	40	40	300
Electronics	personnel	25	65	122	69	281
front end	materials	10	85	215	75	385
	total	35	150	337	144	666
Electronics	personnel	24	60	60	34	178
back end	materials	10	50	30	20	110
	total	34	110	90	54	288

Summary table of the budgets for FY20-23 (in k$). Materials include everything except personnel (also travel).

The budget only includes the US contribution. The DIRC and dRICH in particular will also receive substantial support from GSI and INFN, respectively.

Hadron kinematics at an EIC

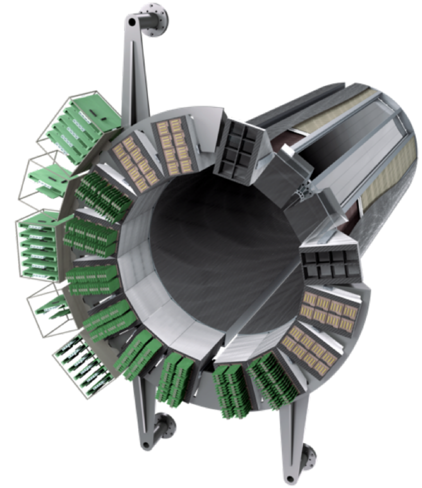


- The maximum hadron momentum in the endcaps is close to the electron and ion beam energies, respectively.

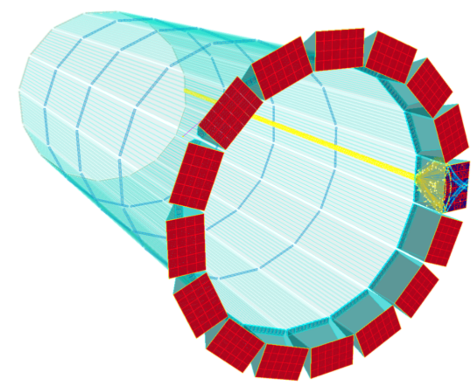
- The momentum coverage need in the central barrel depends on the desired kinematic reach, in particular in Q^2 – important for QCD evolution, etc.
  - Weak dependence on beam energies

hpDIRC Topics from September 2019 Review Report

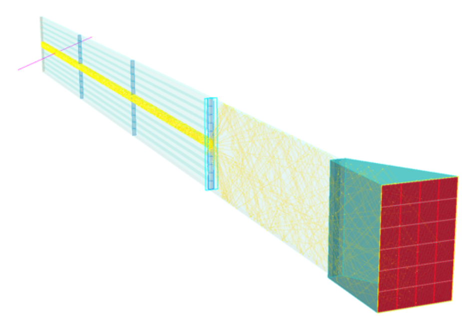
- Committee commented on design strategy, PANDA vs. hpDIRC vs. “ultimate DIRC”
- PANDA Barrel DIRC design goal
  3σ π/K separation up to 3.5 GeV/c
- hpDIRC design goal:
  3σ π/K separation up to 6 GeV/c
- “ultimate DIRC” is one of several possible hpDIRC design options to reach the 6 GeV/c goal, “PANDA-like” is another option, curved or titled sensor plane (B-field) another option.
- Main improvements from PANDA to hpDIRC: smaller pixels, faster timing, rad-hard optics, improved reconstruction, better tracking resolution
- We plan to investigate several hpDIRC options in simulation, including “ultimate DIRC”, before proposing final design for TDR



PANDA Barrel DIRC



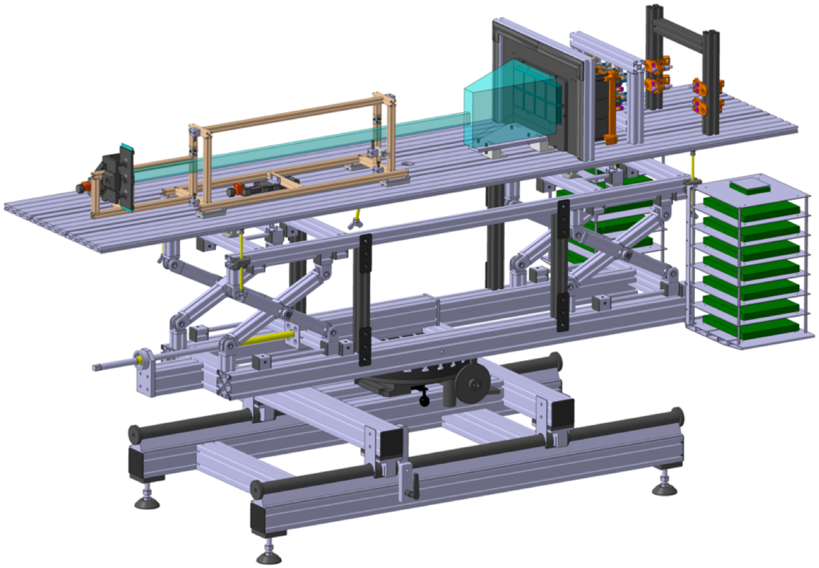
hpDIRC: “PANDA-like” design



hpDIRC: “ultimate” design

hpDIRC Topics from September 2019 Review Report

- Committee requested more detail on planned Fermilab beam tests in 2020/21, improvements compared to PANDA DIRC beam tests at CERN
- PANDA Barrel DIRC prototype will be set up in DIRC lab at Stony Brook in summer 2020
- Initial validation using laser pulser and PANDA DAQ with 6.5mm pixel MCP-PMTs
- 2021 beam test: reproduce PANDA results, understand beam properties and beam line instrumentation
- Between 2021 and 2022 beam test:
  study small-pixel MCP-PMT and fast timing DAQ with laser pulser in DIRC lab at SBU
- 2022 beam test: validate hpDIRC TDR performance using small pixels, fast timing DAQ; possible test of hybrid bar/plate ("ultimate") geometry

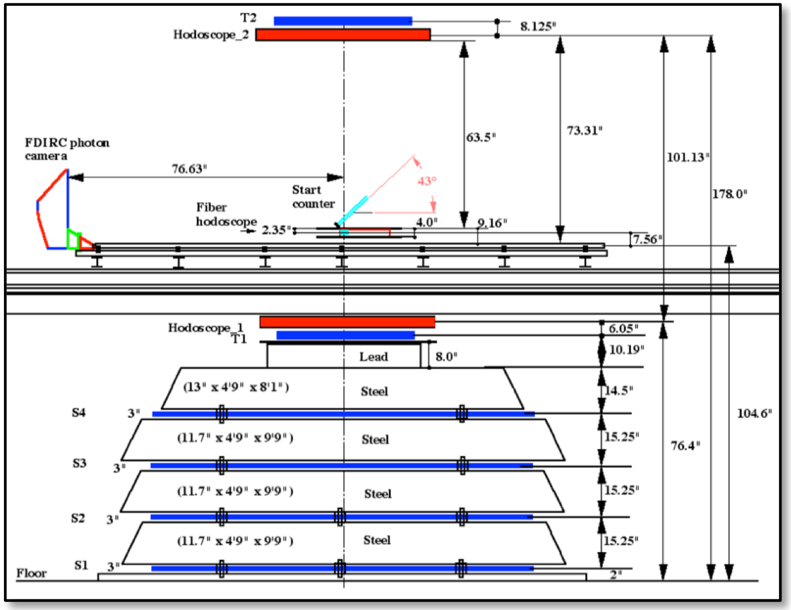


PANDA Barrel DIRC prototype, foundation for hpDIRC prototype

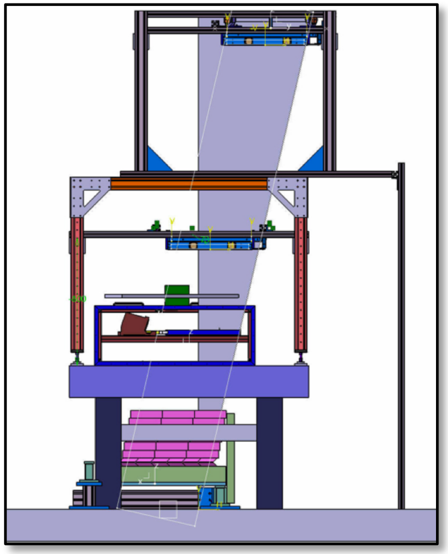
hpDIRC Topics from September 2019 Review Report

- Committee encouraged investing in a good cosmic ray telescope and testing various eRD14 prototypes in it.
- Cosmic Ray Telescope (CTR) has many attractive features for hpDIRC R&D
  - Facility always available for prototype tests without having to rely on beam test availability
  - SLAC CRT, with 3D tracking and fast timing, successfully validated fDIRC design, was complementary to SLAC beam tests
- Construction and operation of a CRT is challenging (see Belle II CRT) and needs significant up-front investment
- Consortium is interested, has been investigating CRT option at ODU/JLab (LDRD proposal)
- However, timescale for TDRs makes validation of eRD14 prototypes in a new CRT very challenging, maybe impossible (more detail on CRT plan to follow)

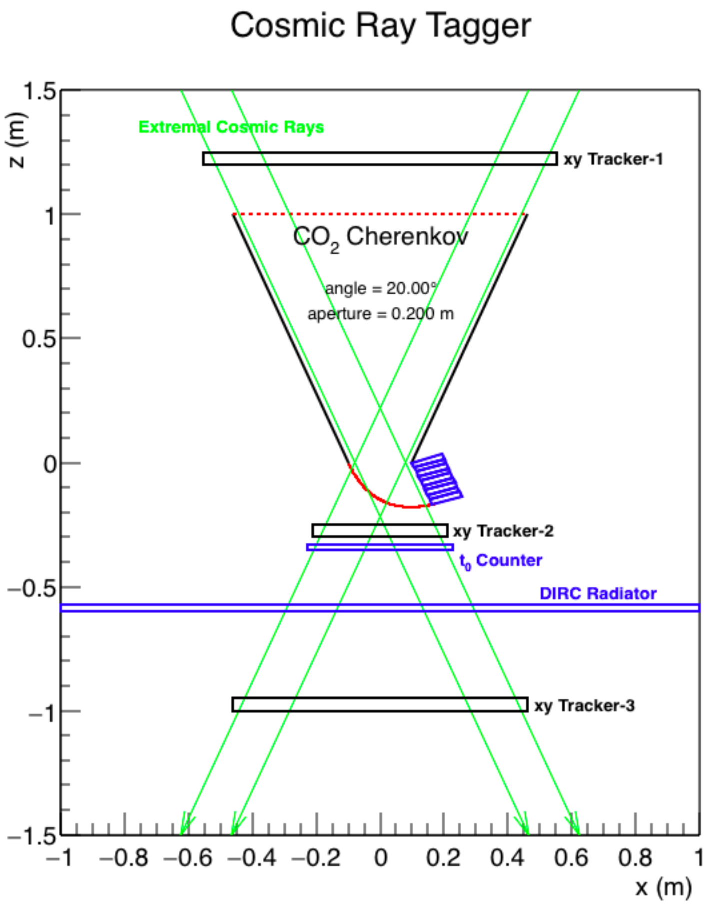
SLAC CRT for SuperB fDIRC

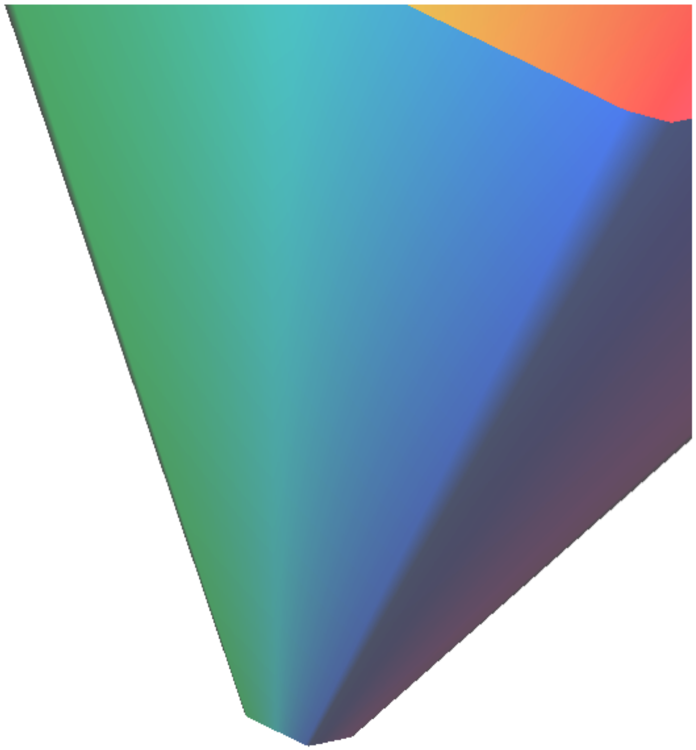


Giessen Cosmic Station for PANDA Disc DIRC

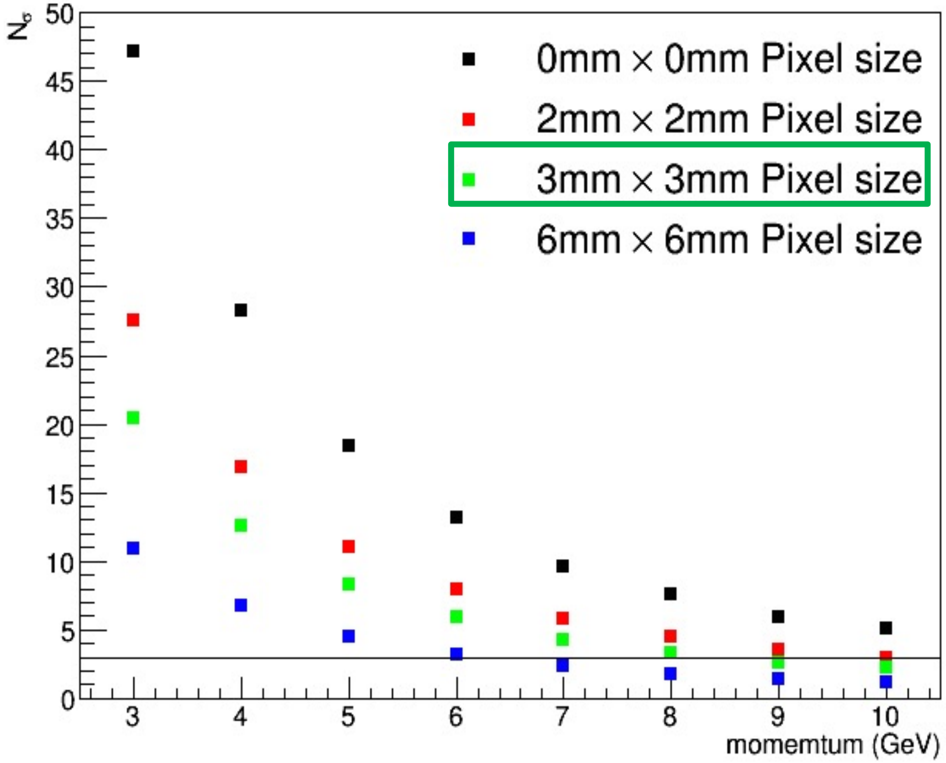


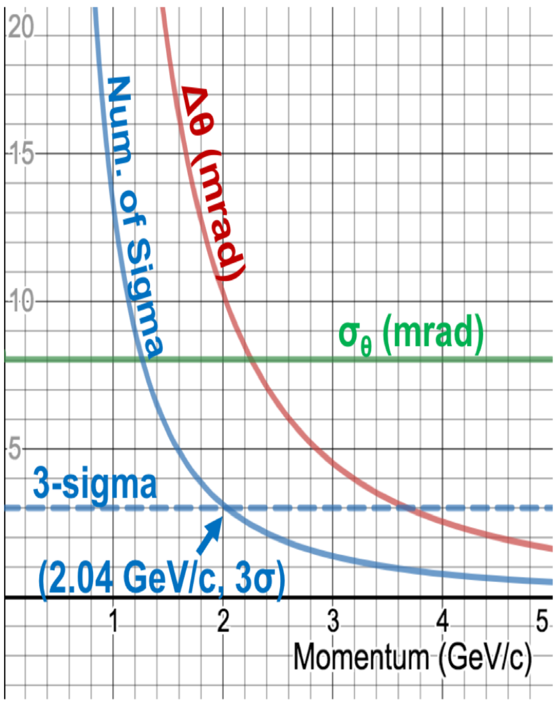
ODU CRT idea


Cosmic Ray Tagger
Extremal Cosmic Rays
xy Tracker-1
CO_2 Cherenkov
angle = 20.00°
aperture = 0.200 m
xy Tracker-2
t_0 Counter
DIRC Radiator
xy Tracker-3
z (m)
x (m)
1.5
1
0.5
0
−0.5
−1
−1.5
−1
−0.8
−0.6
−0.4
−0.2
0
0.2
0.4
0.6
0.8
1



Projected mRICH Performance





- Projected K/pi separation of mRICH 2nd prototype detector (**Green dots**)
- 2nd prototype detector can achieve 3-sigma K/pi separation up to 8 GeV/c

- Projected e/pi separation of mRICH 2nd prototype detector (**blue solid line**)
- 2nd prototype detector can achieve 3-sigma e/pi separation up to 2 GeV/c

High-resolution TOF

Goals:

- Explore the possibility of achieving very high timing resolution (~10 ps)
- Demonstrate 20 ps mRPC resolution in the lab.

Progress in 2nd half of 2019:

- The R&D goals have been achieved.
- No funding requested for FY20.