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, M. Boer, W. Brooks, T. Cao, M. Chiu, E. Cisbani, M.Contalbrigo, S. Danagoulian, A. Datta, A. Deldotto, M. Demarteau, A. Denisov, J.M. Durham, A. Durum, R. Dzhygadlo, 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, 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 24-25, 2019

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)

eRD14: an integrated program for PID at an 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

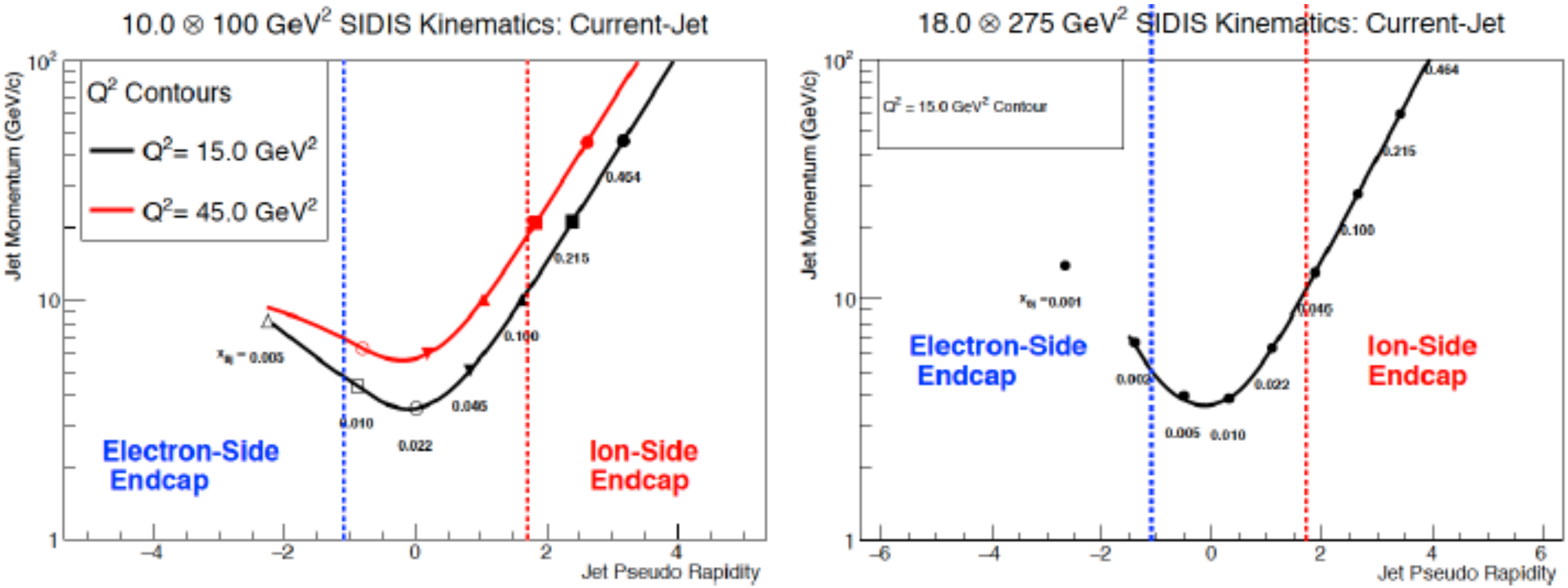
2. A cost-effective sensor and electronics solution

- 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)

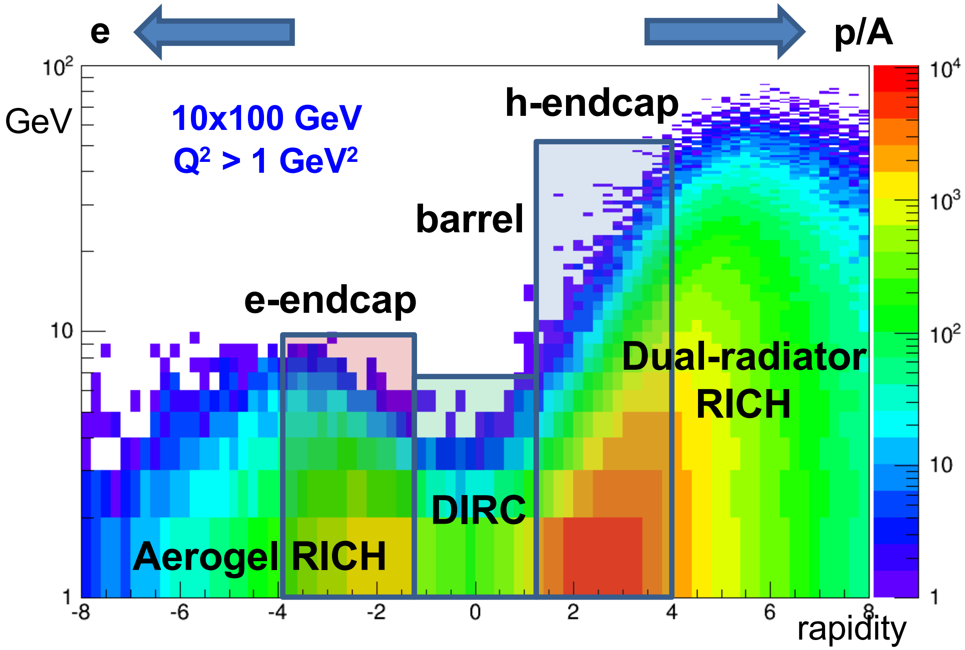
- Close collaboration within the consortium, with coordinated goals and timelines (*e.g.*, DIRC & LAPPD, mRICH & dRICH, etc).
- Strong synergies with non-EIC experiments and R&D programs (PANDA, CLAS12, GlueX, PHENIX, commercial LAPPDs) resulting in large savings.

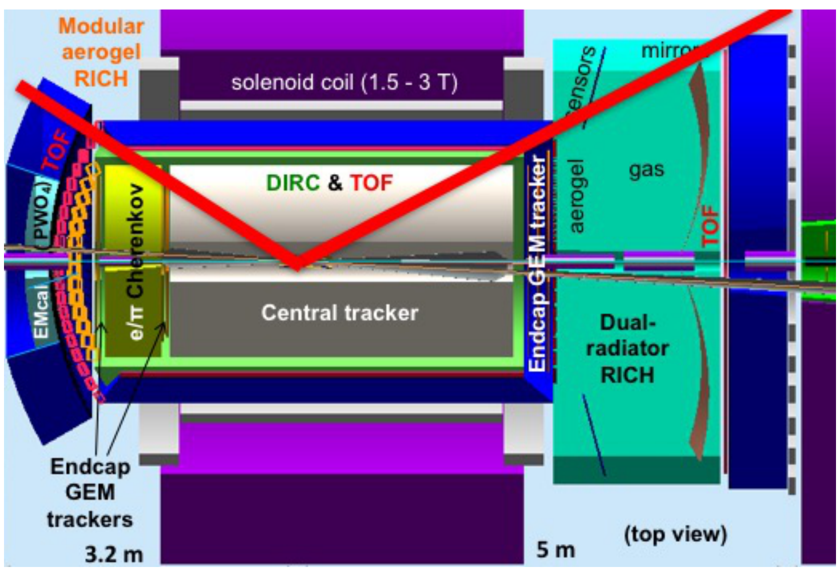
Hadron kinematics at an EIC



- 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

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

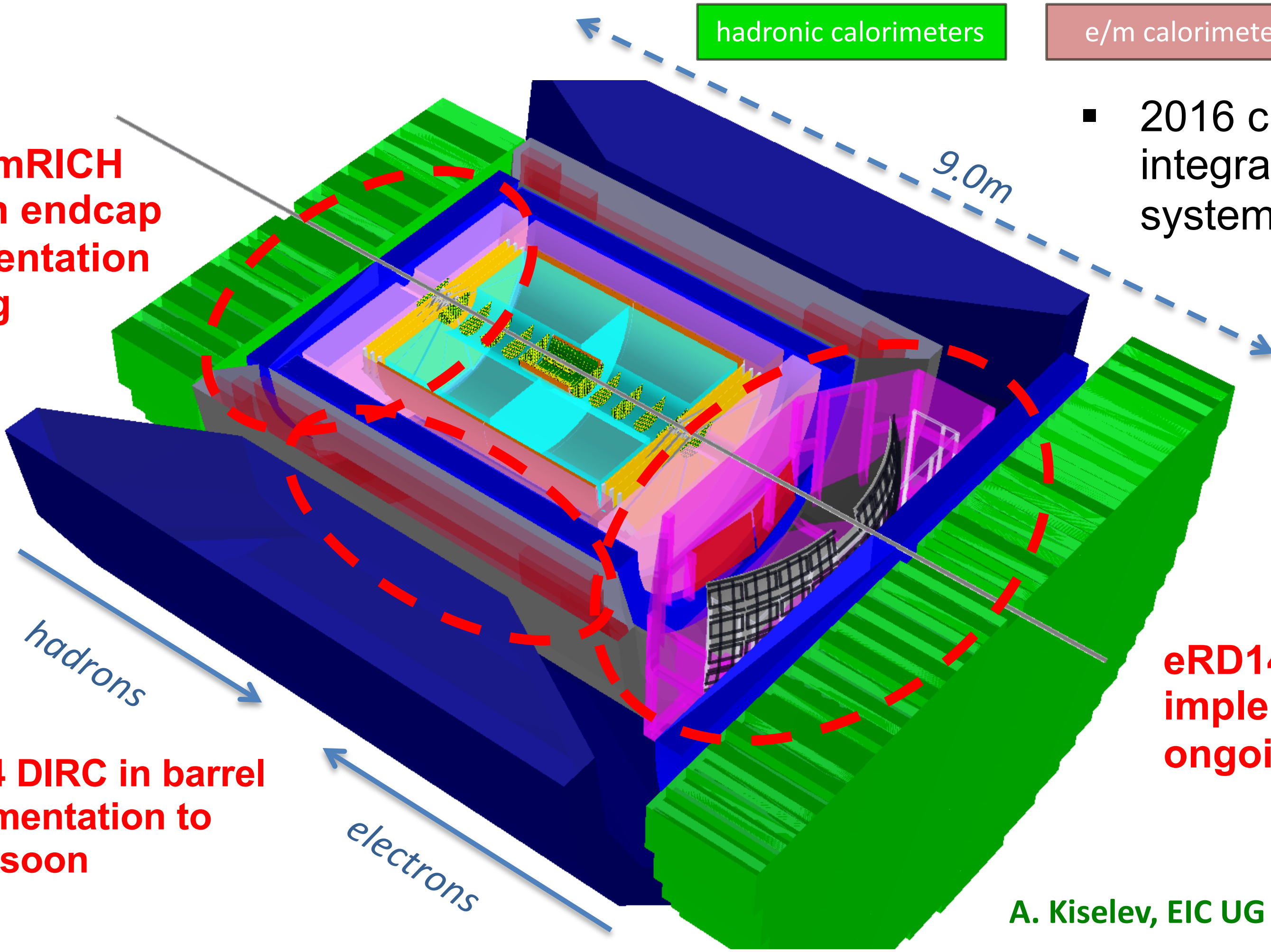
PID in the EIC concept detectors and integration of eRD14 systems

BNL BeAST EIC detector

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

- 2016 changes made integration with eRD14 systems much easier!

eRD14 mRICH electron endcap implementation ongoing



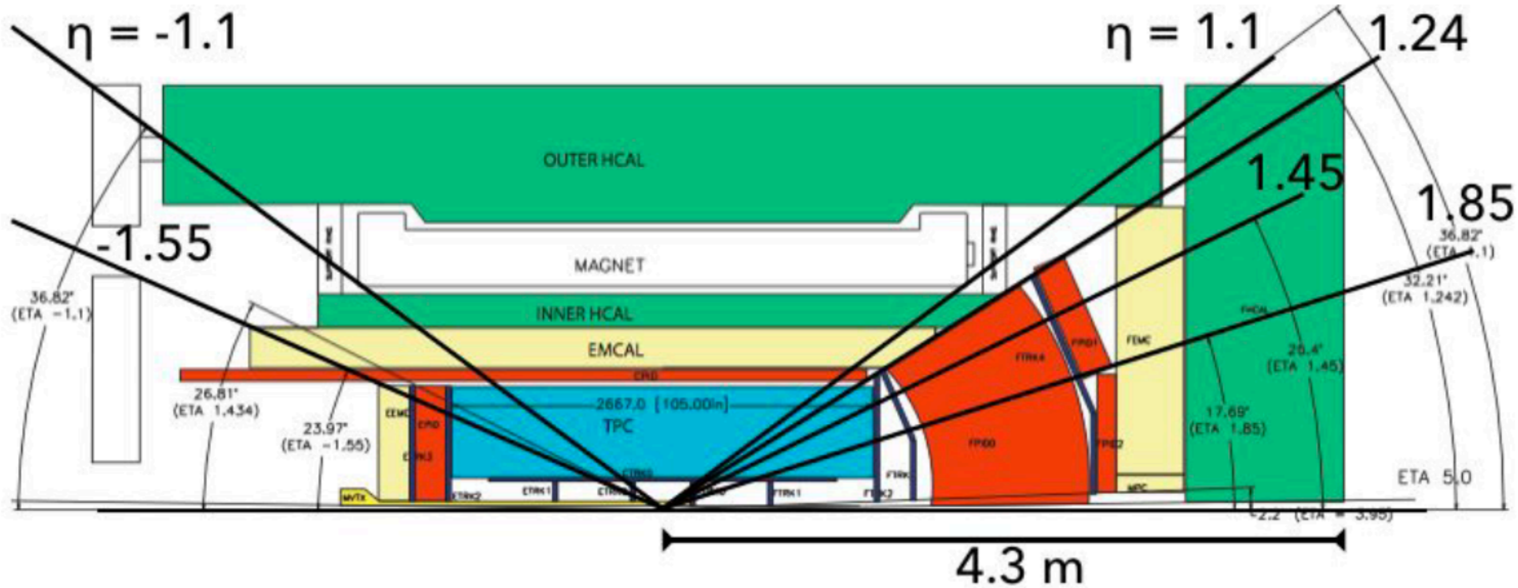
eRD14 dRICH implementation ongoing

eRD14 DIRC in barrel implementation to begin soon

A. Kiselev, EIC UG meeting, July 2016

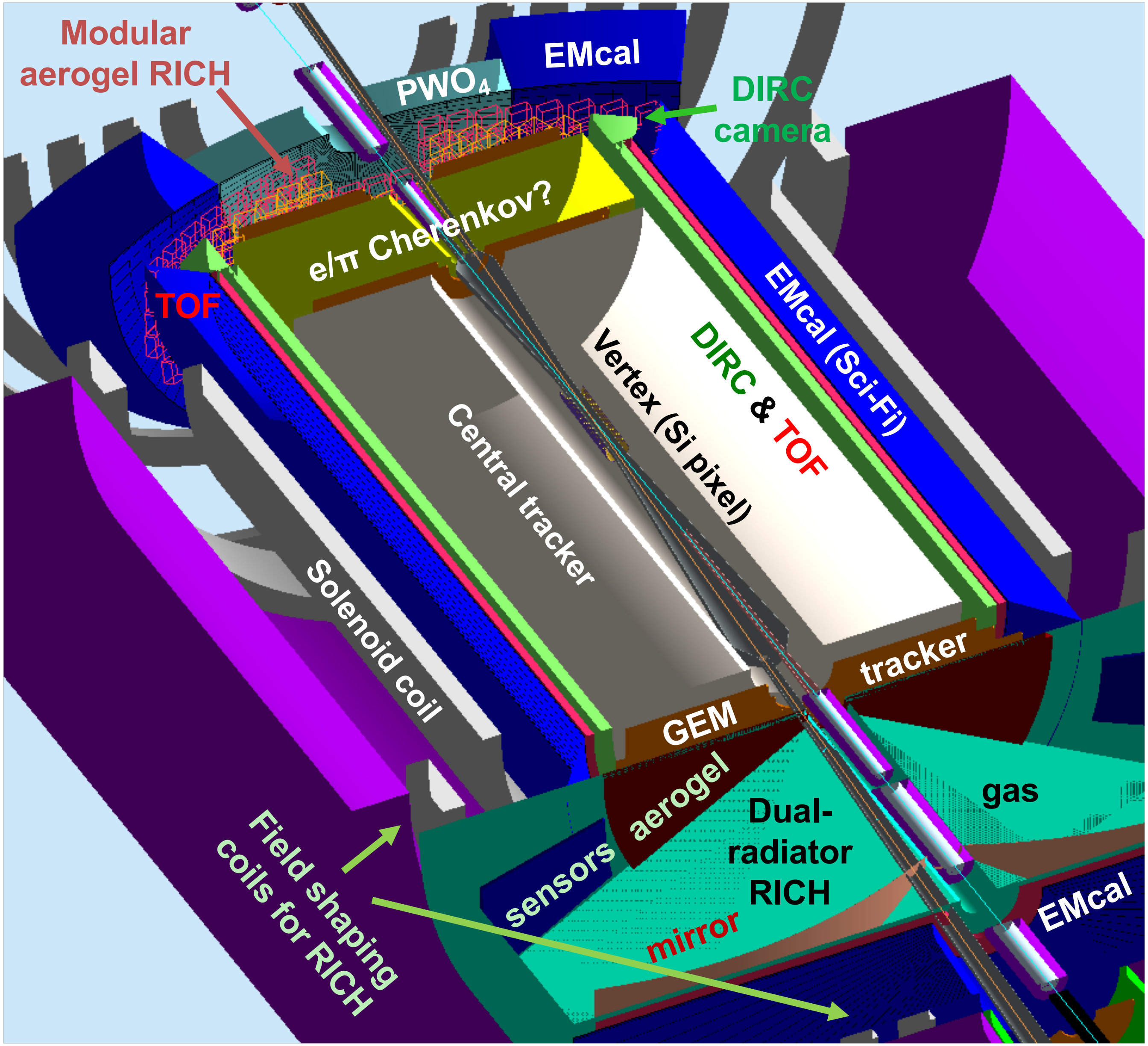
BNL ePHENIX EIC detector

- 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. The two options have been compared in a collaborative effort.

JLab EIC central detector showing PID integration



- All eRD14 systems (DIRC, mRICH, dRICH, and TOF) are part of the baseline JLab detector concept.

High-resolution TOF

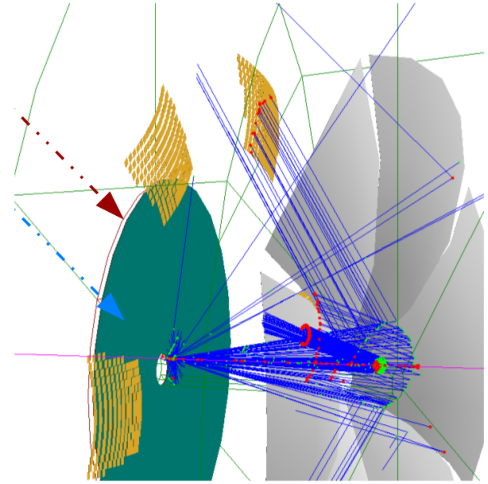
Goals:

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

Progress in 2nd half of 2018:

- The R&D goals have been achieved.
- No funding requested for FY19.

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.

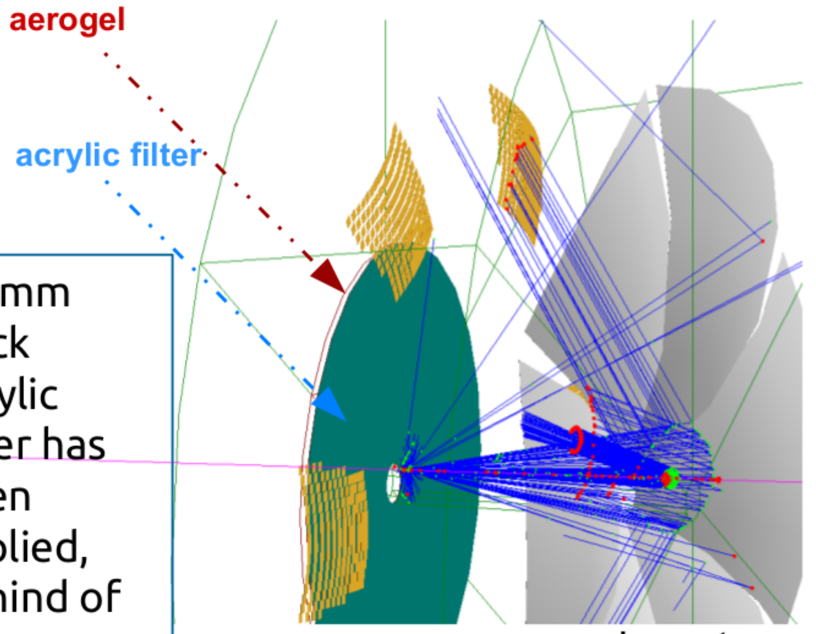
Progress in 2nd half of 2018:

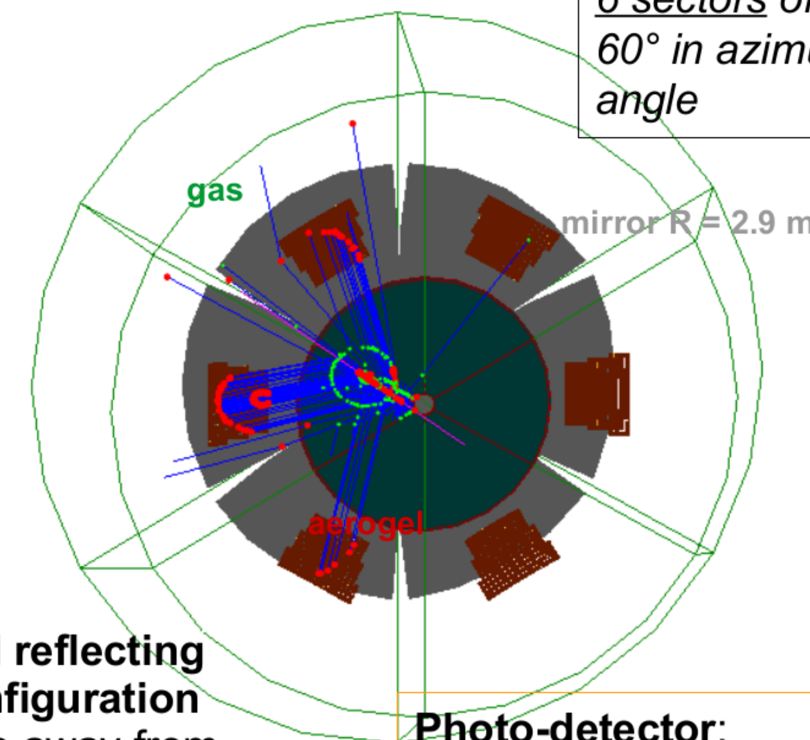
- Refinements on:
  - Global particle ID reconstruction
  - Evaluation of performance in a realistic physics case
- Moving towards a prototype implementation

Dual-radiator RICH

Aerogel & C_2F_6 gas (160 cm)

Simulation in GEMC (GEANT based framework)





Polar coverage
[5°,25°]
6 sectors of 60° in azimuthal angle

A 3mm thick acrylic filter has been applied, behind of the aerogel, to minimize Rayleigh scattering effects < 300 nm

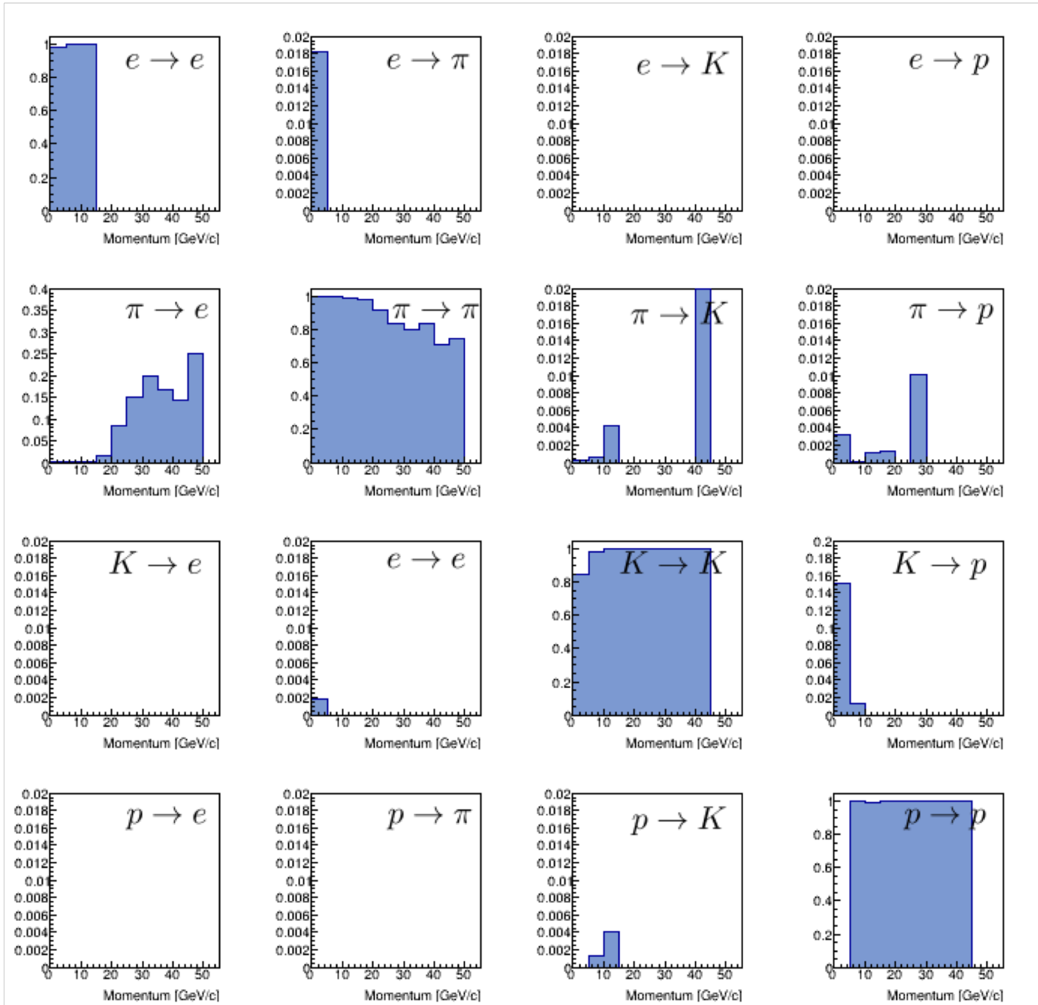
in **outward reflecting mirror configuration** (focal plane away from the beam, reduced area and background)

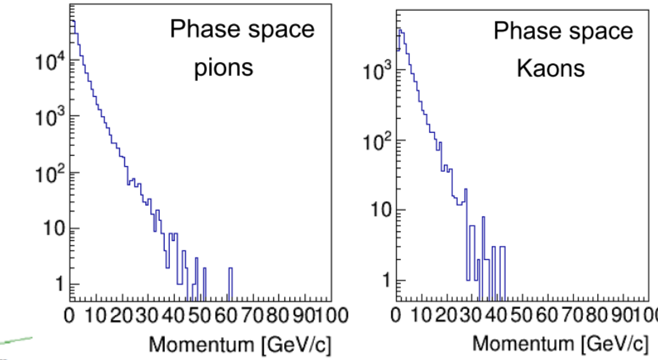
Photo-detector:
spherical shape
8500 cm² (per sector)
pixel size 3 mm,
from UV to visible light

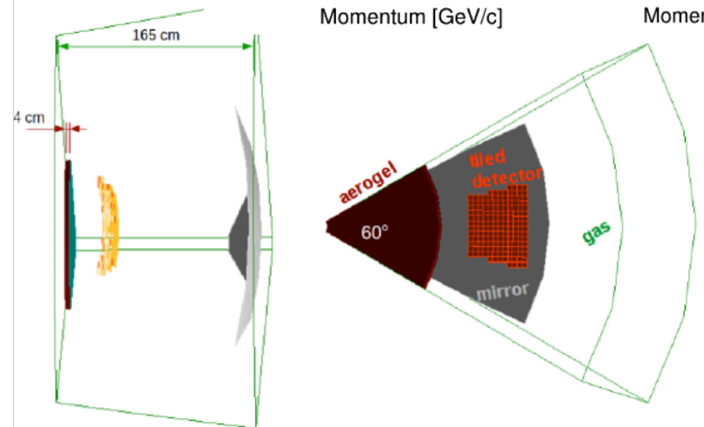
dRICH is in magnetic field (3T central field in simu)

First dual-RICH to demand excellent performance from aerogel radiator!

dRICH performance for a key process (Semi-Inclusive DIS)



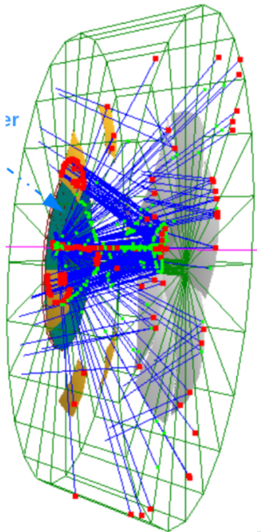




one of the six dRICH sectors

Momentum Threshold (GeV/c)		
Particle	Aerogel (1.02)	C2F6 (1.0008)
e	0.003	0.013
pi	0.694	3.49
K	2.46	12.3
p	4.67	23.5

The PID capability fulfills the design goals



Inverse Ray Tracing: global reconstruction

Nt : tracks (+ background «dummy track»)
Nh : photon hits

Nr : radiators (aerogel and gas)
Np : potential particle types (e,pi,K,p)

PID problem:
associate to each track a particle type (based on some sort of Likelihood)

Global «brute force» approach: explore all possible combinations of:
Track ∈ Particle type : Np^Nt
Photon hits ∈ (Track ⊗ Radiator + Background) : **(Nt*Nr+1)^Nh**
Each combination has an associated Likelihood; take the one that maximize it.

Our approach:
1) Determine (by IRT) the possible emission angles corresponding to each photon hit
2) Associate, in sequence, each photon hit to (tracks ⊗ radiator) driven by a Likelihood (L1) that depends on emission angle and a-priori (previous associations) probability; number of combinations drops to **(Nt*Nr+1)*Nh**
3) Once all hits are associated, estimate a global Likelihood (L2) for each (track ∈ particle) combination; choose the combination that maximize L2

Example: event with 2 tracks and 15 hits

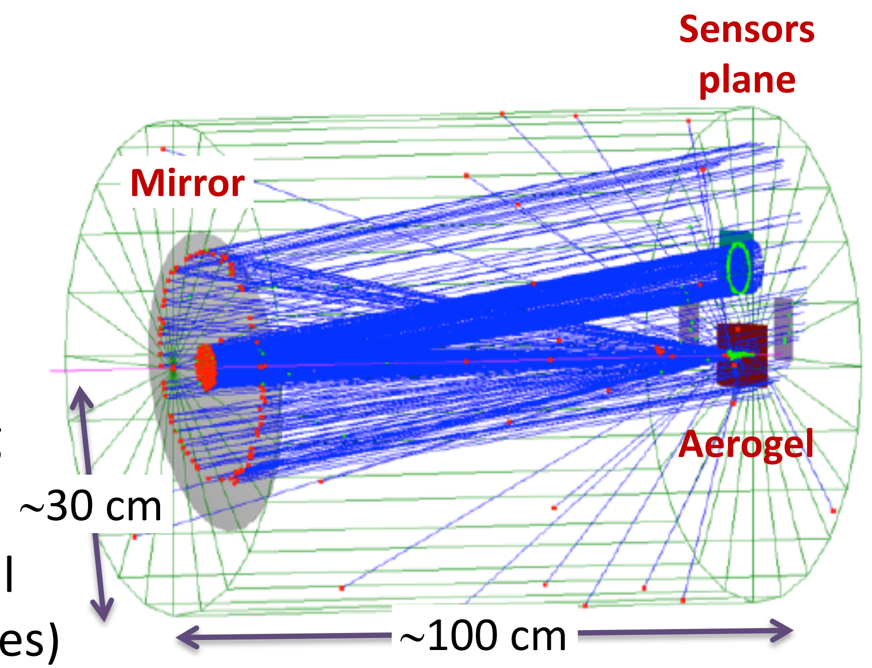
Brute Force:	up to	**~488 billion** combinations
Our approach:		**1200 combinations**

dRICH prototype

Why: **evaluate critical aspects of the proposed solutions; tune relevant parameters used in MC and consolidate the estimated performances**

The prototype must:

- mimic the performances of the proposed dRICH components, minimizing modeling and assumptions
- be cost effective (trade-off between small scale, versatility and measurable quantities)



The preliminary prototype vessel size (with spherical mirror of ~2 m radius) driven by two main considerations:

1. **reasonable (order of 10) photoelectrons from gas** per particle; depend almost linearly on the thickness (**length**) of the gas and therefore of the vessel.
2. **catch the aerogel ring (20 cm radius)** in order to estimate its angular resolution; constraints the **transverse size** of the vessel.

We also need to minimize vessel volume, sensor area, isolate aerogel from gas …

… going to start the detailed definition in coming months

FY19 outlook

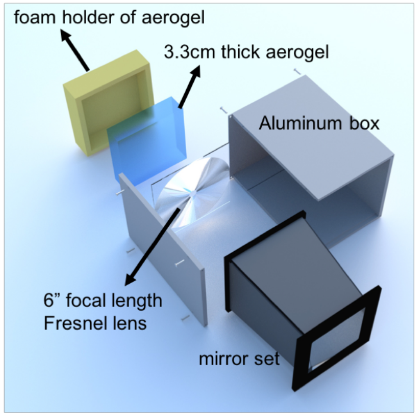
Activity	T1	T2	T3	T4	Funding (USA+ITA) kUSD (1€ ~ 1USD)		
Finalize the event based (global) IRT reconstruction (article!)					Post Doc	Mat erial	Travel
Design the small scale prototype							
Implement the prototype						4.2	
Study the interface between gas and aerogel (and long term aerogel characterization, if able to get samples!)						1.5	
(m+d)RICH - electronics: consolidate design and test SiPM sensor matrix with proper cooling and thermal stability; setting up the lab laser test bench for characterization (also for irradiation campaigns); follow SiPM ongoing development toward rad hard solutions					30*	3*	2.5*
(m+d)RICH - electronics: implement Hawaii (TARGETX/SiREAD) + JLab/CLAS12 readout on chosen front-end; integration/test of the JLab backend and SiREAD						2*	

* (m+d)RICH

Important components (electronics and sensors) of the dRICH prototype are shared with the mRICH development

CLAS12 infrastructures available in Ferrara will be used for aerogel-gas studies

Modular aerogel RICH (mRICH)



Goals:

- 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)

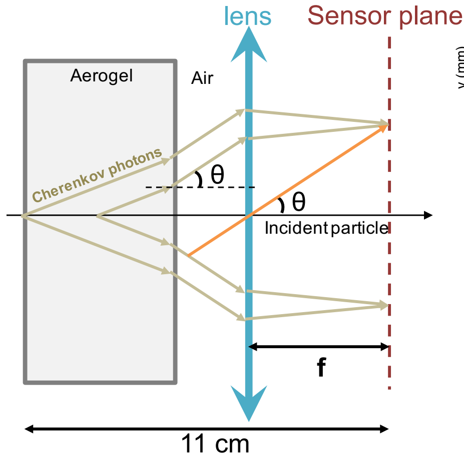
Progress in the 2nd half of 2018:

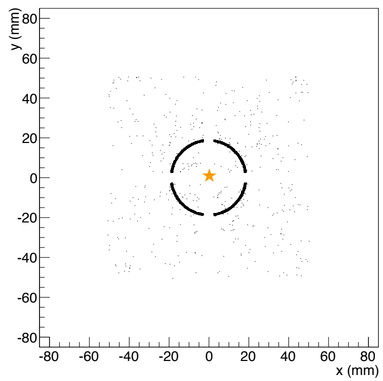
- Completed data quality assurance analysis of the mRICH 2018 test data.
- Implemented mRICH detector array in Geant4 simulation built around the sPHENIX solenoid. The results of this effort were included in an EIC detector design study which was submitted to BNL management in October 2018.
- Purchased more samples for studying Fresnel lens radiation hardness.

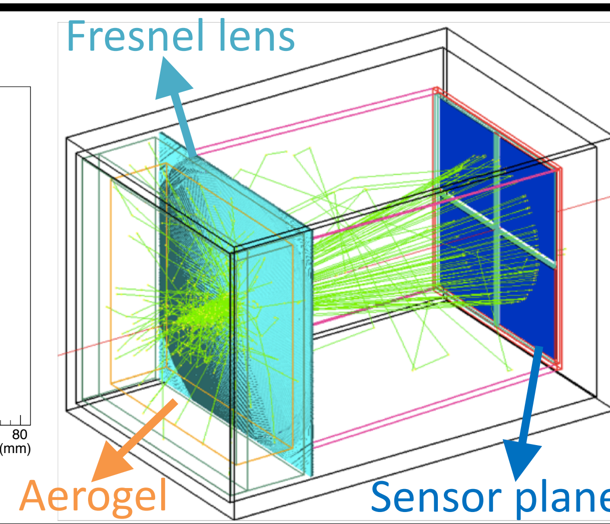
mRICH – lens-based focusing aerogel detector design

Smaller, but thinner ring improves PID performance and reduces length

Lens-Based mRICH Design

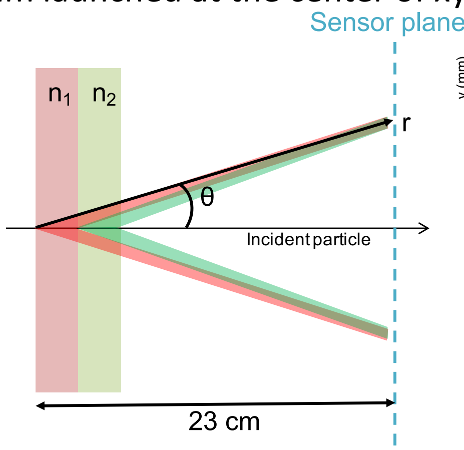


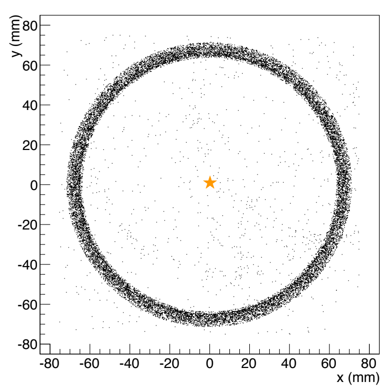




9 GeV/c pion beam launched at the center of xy plane in simulation

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



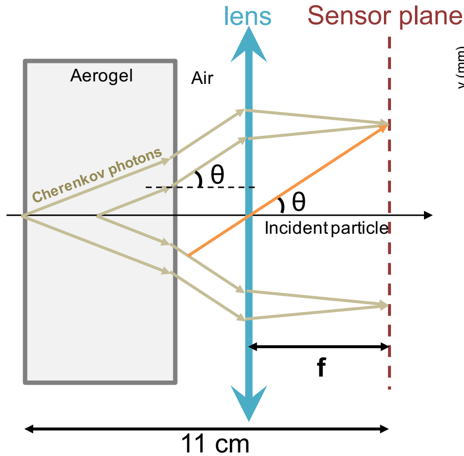


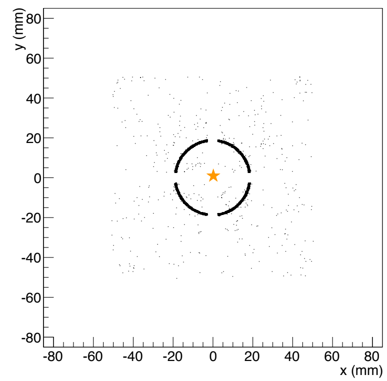
- EIC mRICH designed for K/pi ID up to 10 GeV/c
- BELLE-2 ARICH aims to separate pion and kaon up to 4 GeV/c

mRICH – lens-based focusing aerogel detector design

Smaller, but thinner ring improves PID performance and reduces length

Lens-Based mRICH Design

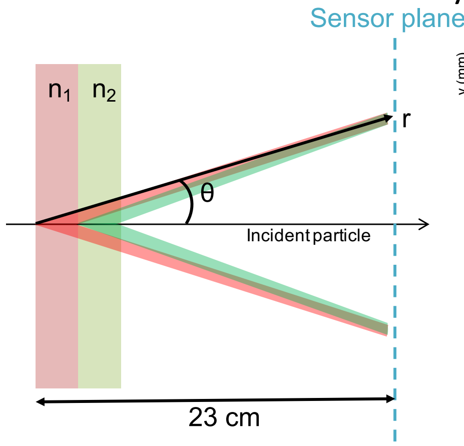


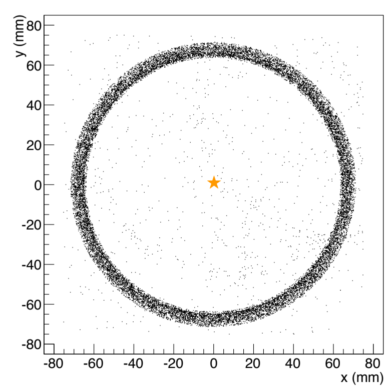


- 9 GeV/c pion beam launched at the center of xy plane in simulation
- **Smaller and thinner** ring image

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

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



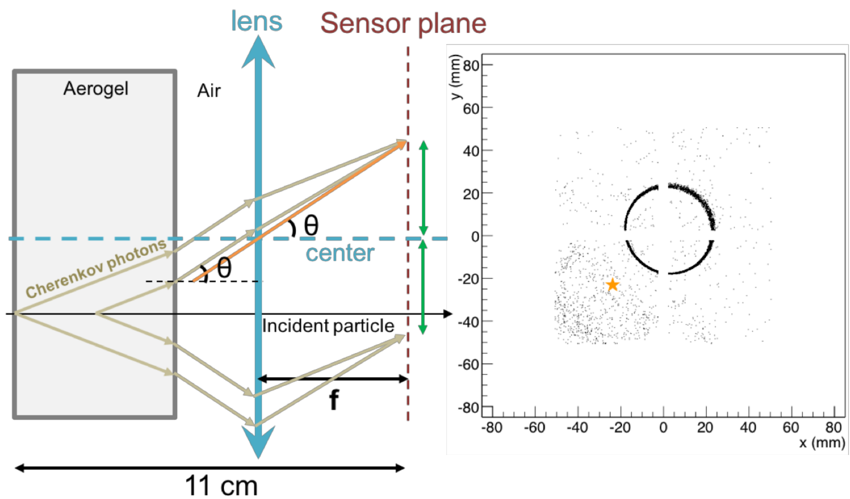


- EIC mRICH designed for K/pi ID up to 10 GeV/c
- BELLE-2 ARICH aims to separate pion and kaon up to 4 GeV/c

mRICH – lens-based focusing shifts image to center

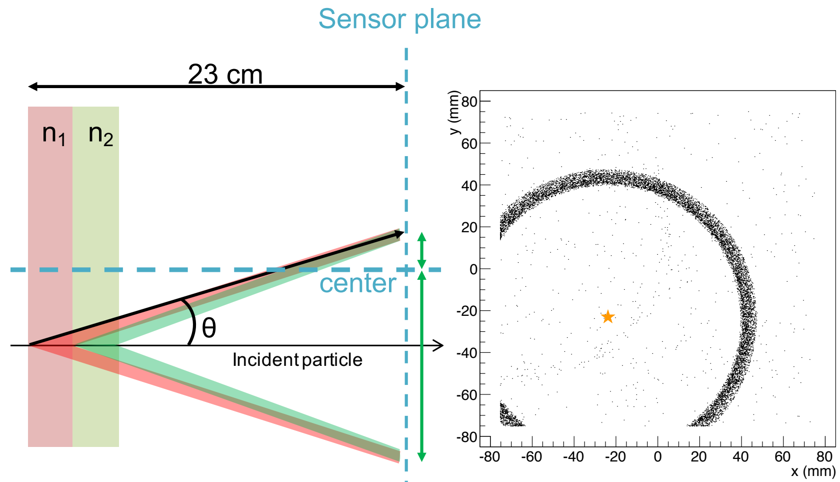
Ring centering of lens-based optics reduces sensor area (main cost driver)

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)

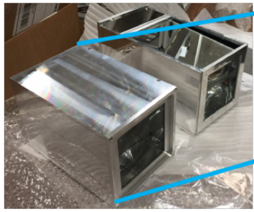


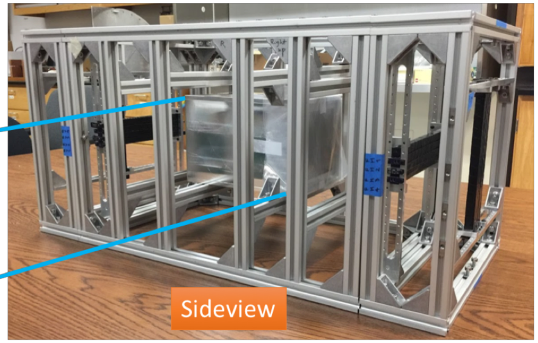
- 9 GeV/c pion beam incident at third quadrant (star) in simulation
- Ring is centered at point of incidence

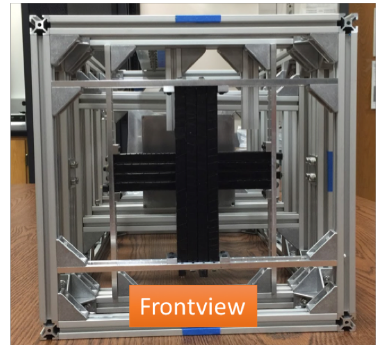
2nd mRICH Beam Test

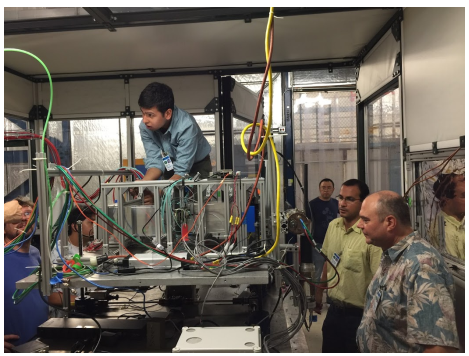
Another very successful mRICH prototype beam test at Fermilab (6/25 to 7/6/2018)

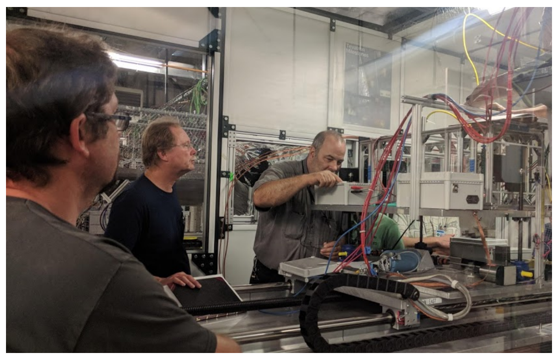
Two completed mRICH prototypes

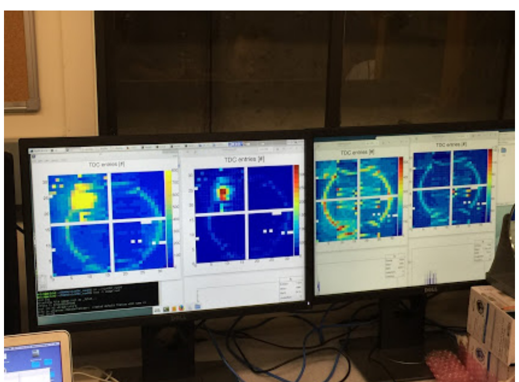


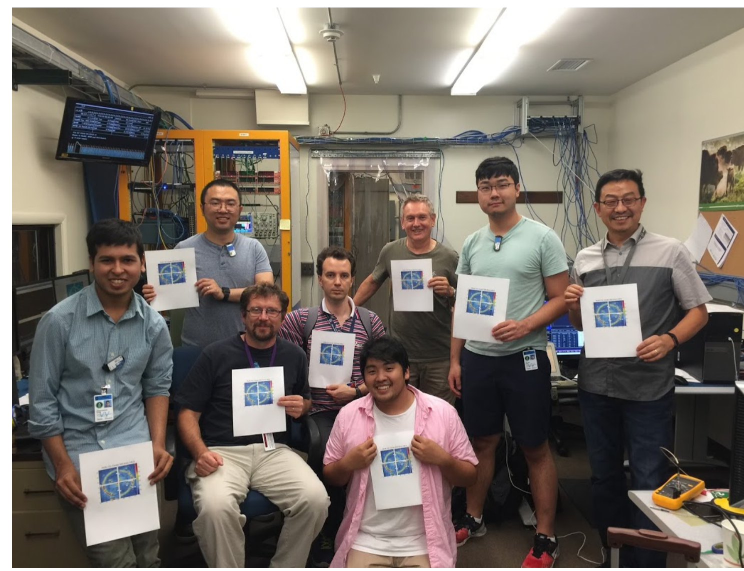








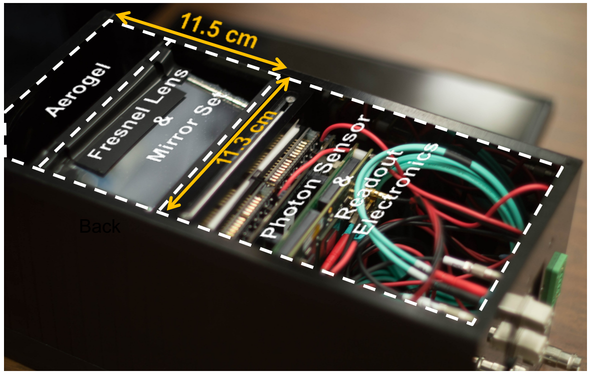




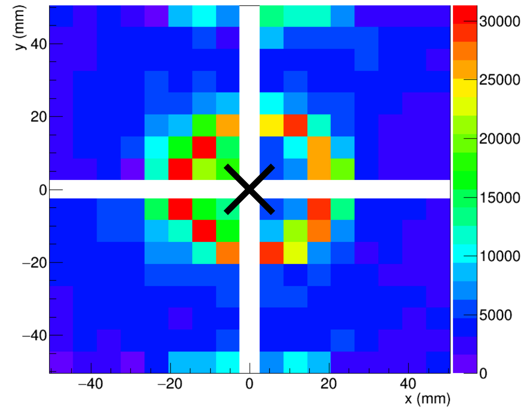
Group photo (missing two members) – the first confirmed ring image

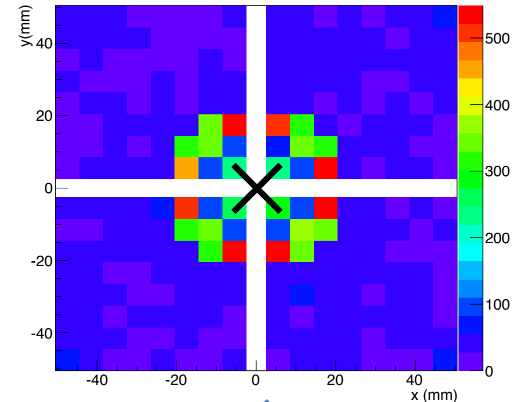
1st and 2nd Beam Test Comparison (120 GeV Proton Beam)

The 1st test beam result verified mRICH working principle and validated simulation



1st mRICH prototype was tested at Fermilab Test Beam Facility in April 2016

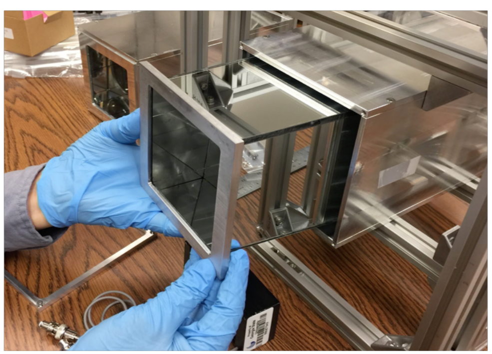




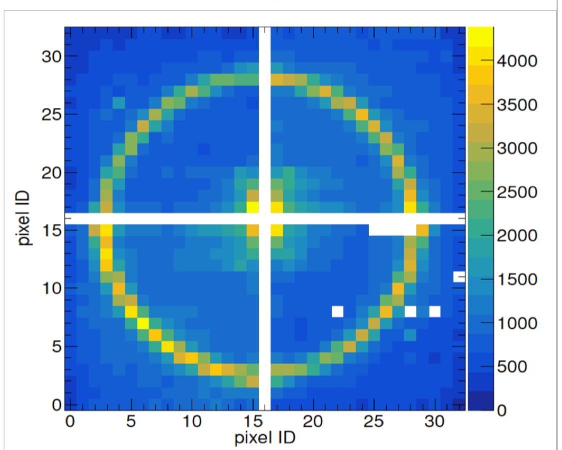
Images from 120 GeV Proton beam

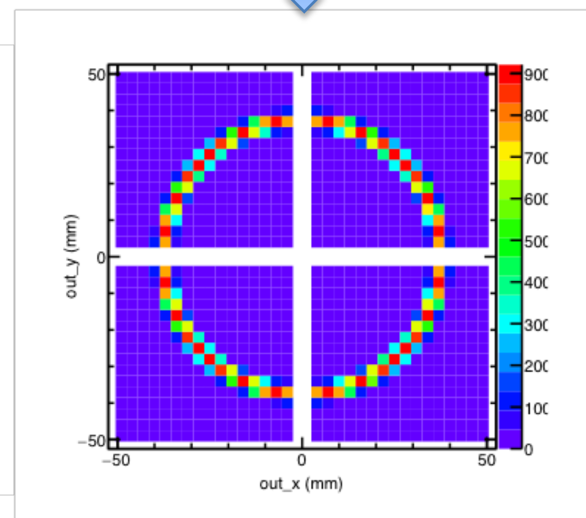
Simulated Images Using GEANT4

New features: a) separation of optical and electronic components; b) longer focal length (6”); c) 3mm x 3mm photosensors.



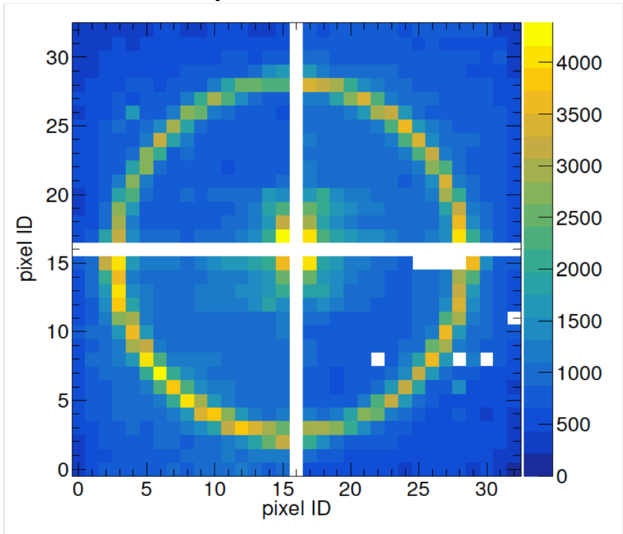
2nd mRICH prototype was tested at Fermilab Test Beam Facility in June/July 2018

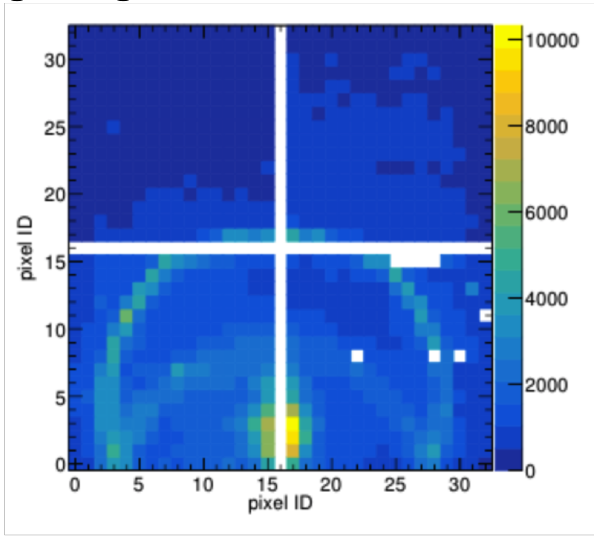


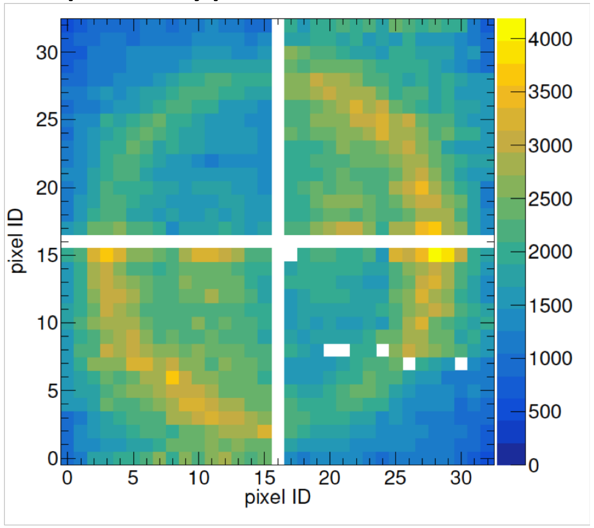


Completed Data QA Analysis for the 2nd Beam Test

Examples of cumulative ring images from the second mRICH prototype beam test







Left: ring images formed by 120-GeV primary proton beam incident on the center of mRICH. White gaps are the PMT frames.

Middle: ring images from 120-GeV primary proton beam incident at an angle of 11° toward the lower section of mRICH.

Right: images from an 8-GeV meson run. The challenge of this analysis is to determine the beam position since the beam hodoscope readout was not ready for this test.

Four Hamamatsu H13700 PMTs (3mm x 3mm pixel size; 16x16 channels) were used in these test runs. Each costs ~$5k. These sensors will NOT work in high magnetic field!!!

mRICH Ring Images from SiPM Sensors

To meet the requirement of operating photosensors in high magnetic field in EIC experiment, we successfully demonstrated ring imaging construction using mRICH in the 2nd beam test. There were only three Hamamatsu SiPM matrices available at the time of this test. Given the limited beam time, we only took data with the primary proton beam at 120 GeV with cooling temperature settings at -30°C, -20°C, -10°C, 0°C and room temperature.

SiPM matrix: 16 x 16 channels, 3mm x 3mm pixel size

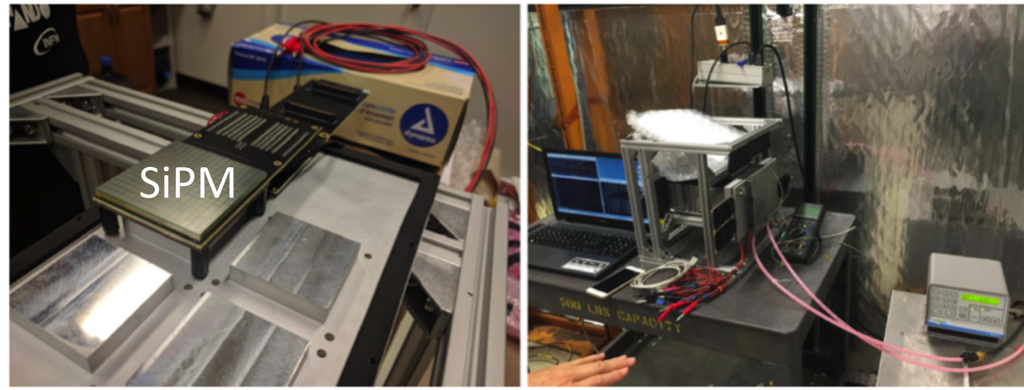


Figure 2.3.2: SiPM matrices setup (left picture) and the cooling system, liquid cooling (right picture). Only three matrices were available for this test.

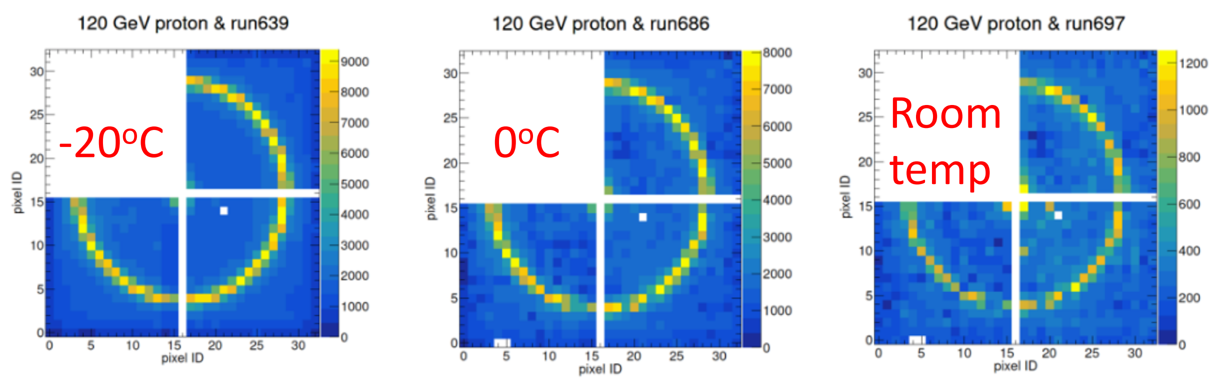
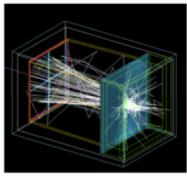
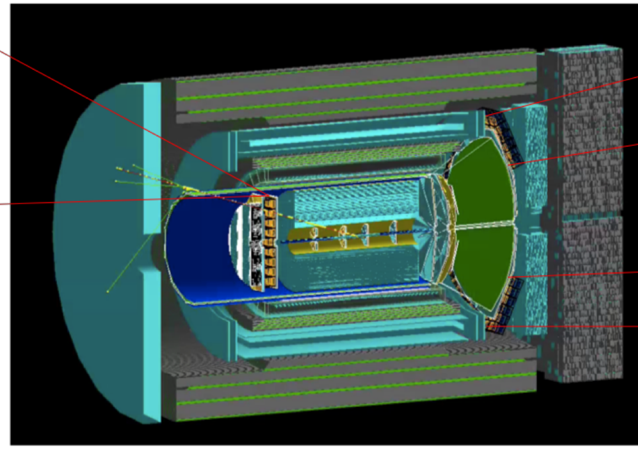


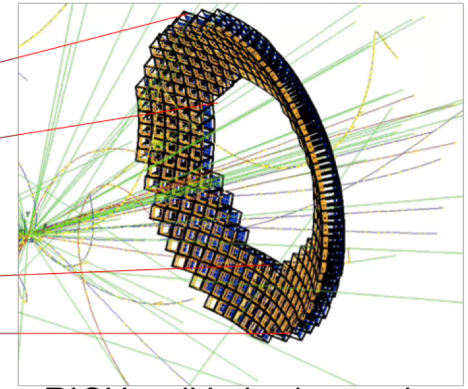
Figure 2.3.3: Examples of cumulative ring images from the second mRICH prototype beam test using three SiPM matrices. **Left:** at a cooling temperature of -20^0 C. **Middle:** at a cooling temperature of 0^0 C. **Right:** at room temperature.

See details in the progress report

mRICH in an EIC Detector Built Around the sPHENIX Solenoid





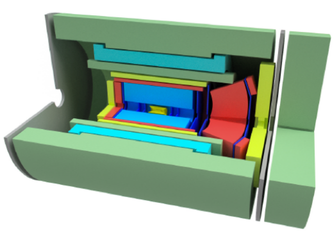


mRICH wall
e/π separation

mRICH wall in hadron-going
direction for hadron PID

An EIC Detector Built Around The sPHENIX Solenoid

A Detector Design Study



Christine Aidala, Alexander Bazilevsky, Giorgian Borca-Tasciuc, Nils Feege, Enrique Gamez, Yuji Goto, Xiaochun He, Jin Huang, Athira K V, John Lajoie, Gregory Matousek, Kara Mattioli, Pawel Nadel-Turonski, Cynthia Nunez, Joseph Osborn, Carlos Perez, Ralf Seidl, Desmond Shangase, Paul Stankus, Xu Sun, Jinlong Zhang

For the EIC Detector Study Group
and the sPHENIX Collaboration

October 2018

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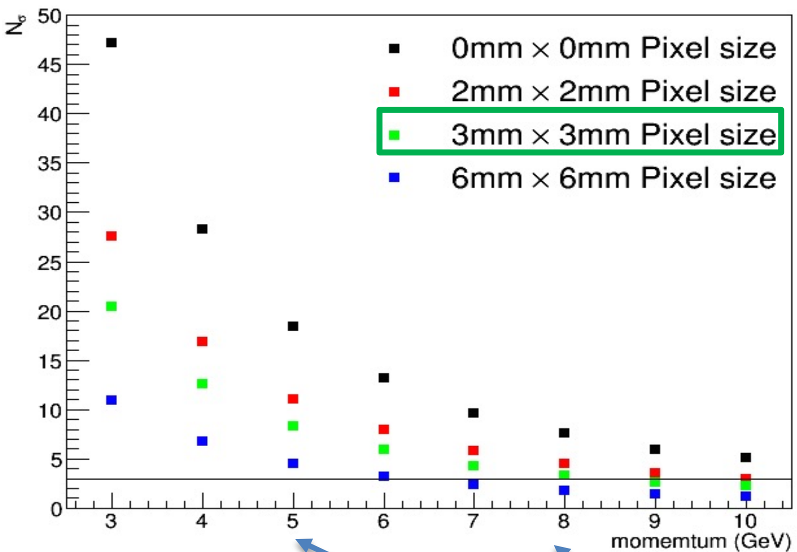
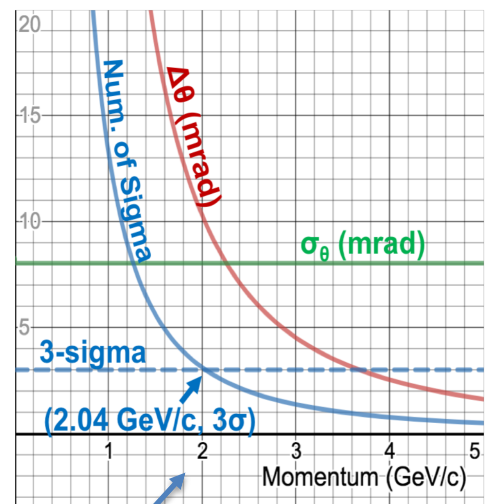
mRICH – FY19 activity (part one)

- Data analysis of the 2nd mRICH beam test and publish the new results – **verify the PID performance at 2, 5 and 8 GeV/c**



- 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

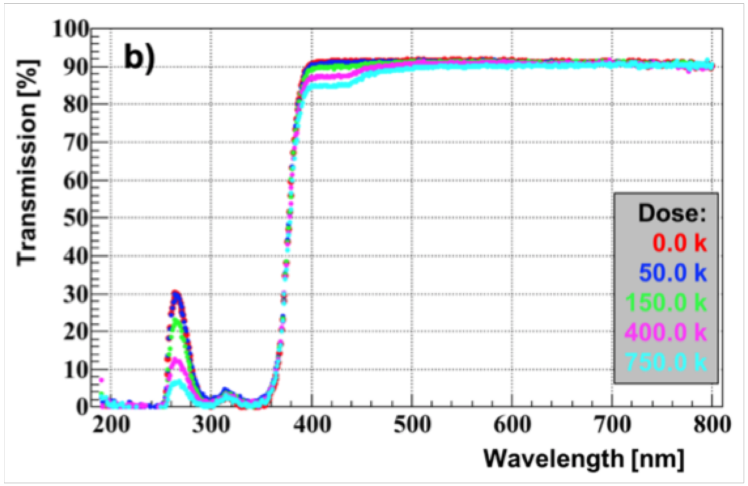


- Projected e/pi separation of mRICH 2nd prototype detector (**blue solid line**)
- 2nd prototype detector can achieve 3-sigma e/pi separation up to 2 GeV/c

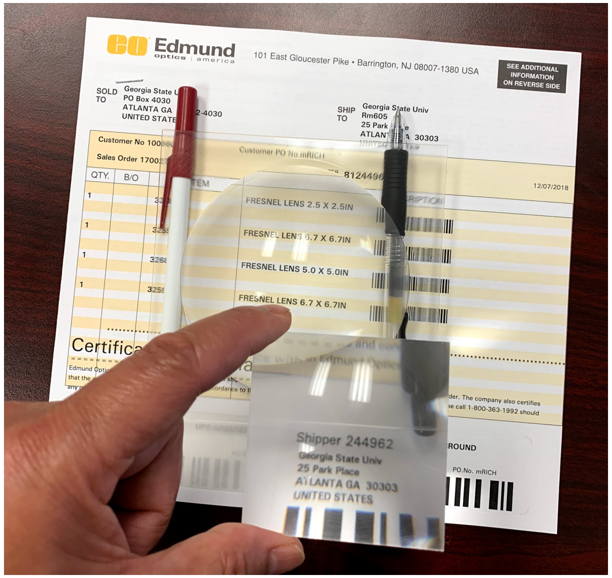
Data sets taken during the second mRICH beam test at Fermilab in June/July 2018

mRICH – FY19 activity (part two)

- Study of the radiation hardness of Fresnel lens (i.e., address the committee concern!) in spring 2019 at BNL using ^{60}Co source together with DIRC team to confirm the earlier test result shown below. Have purchased more lens samples from Edmund for this test.



Tested by Greg Kalicy. 2 mm-thick acylic mRICH lens sample. A small drop of transmission was observed below 500 nm. This material seems surprisingly radiation hard even after a dose of 750 krad.



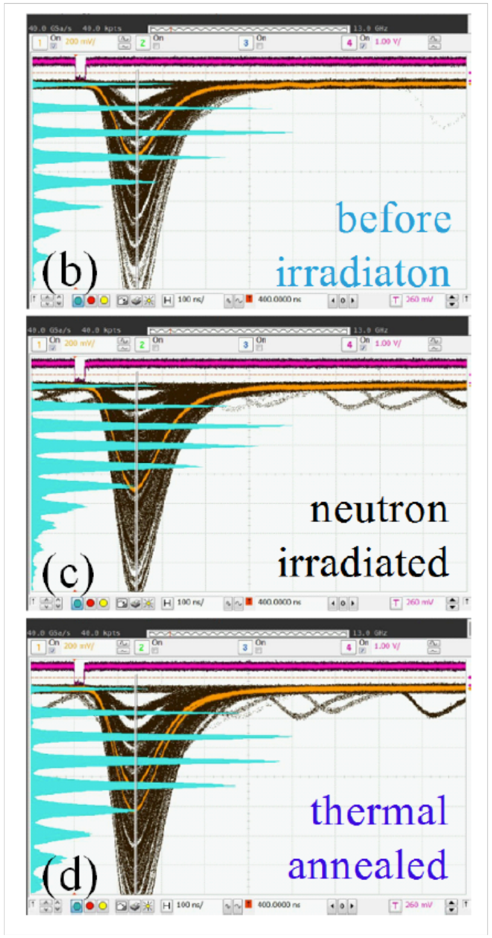
- Simulation study of mRICH performance in the Forward sPHENIX experiment at BNL (ongoing effort).
- Simulation study of mRICH performance in the electron endcap in JLEIC (ongoing effort).
- Work with dRICH group to develop a plan for a join dRICH/mRICH beam test.

Studies of SiPM radiation toleranace

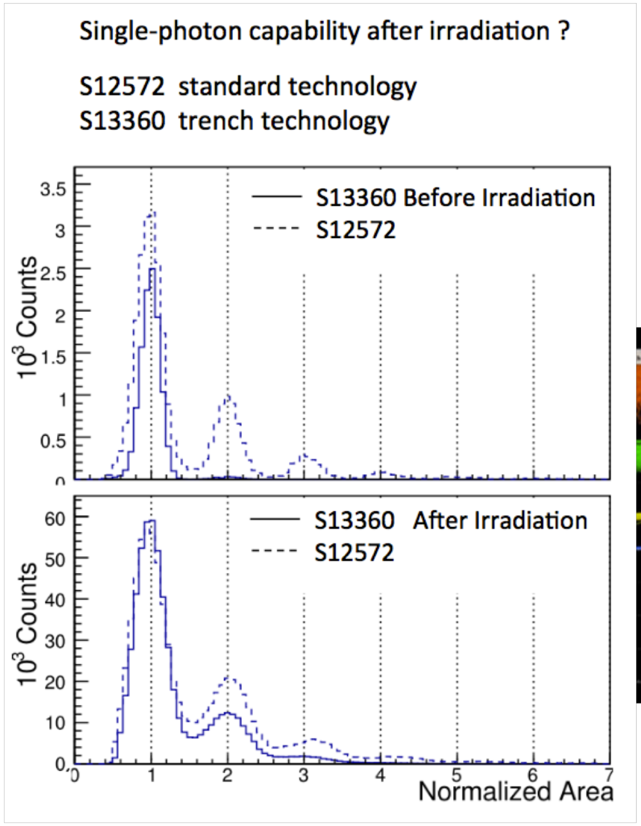
T. Tsang et al.
JINST 11 (2016) P12002

I. Balossino et al.
NIMA 876 (2017) 89

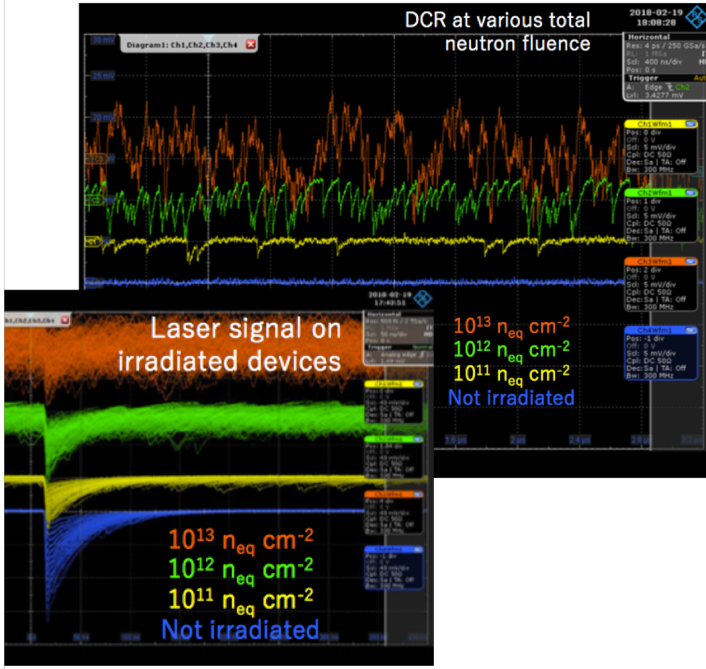
Paolo Carniti
@ RICH 2018



T= 84 K
10^9 n_{eq} cm^2
Annealing at 250 °C



T= 0 C
few 10^9 n_{eq} cm^2



SiPM: Hamamatsu S13360-1350CS (50 μm cells)

Temperature: –30 °C

Bias: V_{BR} + 1.5 V

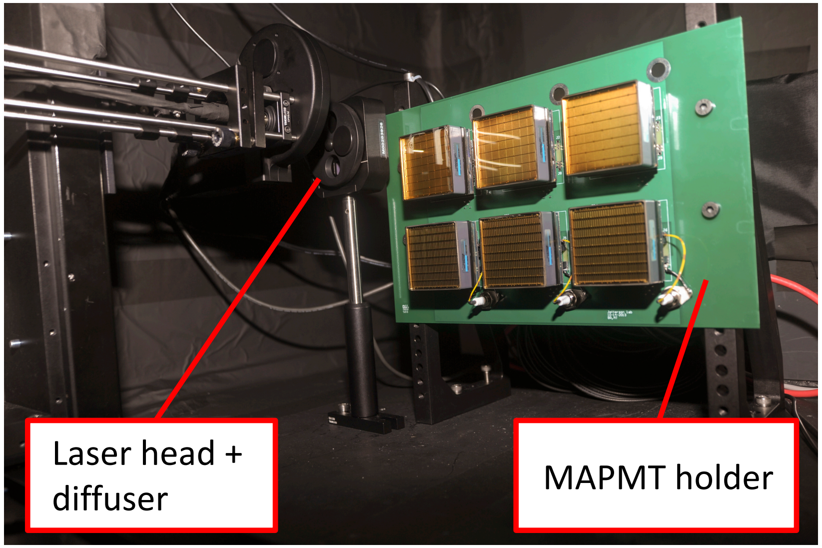
The viability of using irradiated SiPMs for single-photon detection at the EIC will be the focus of future R&D on this topic.

Pulsed laser test benches

Detailed characterization
Sensors: gain, efficiency, cross-talk, radiation tolerance
Electronics: gain, cross-talk, thresholds, time resolution

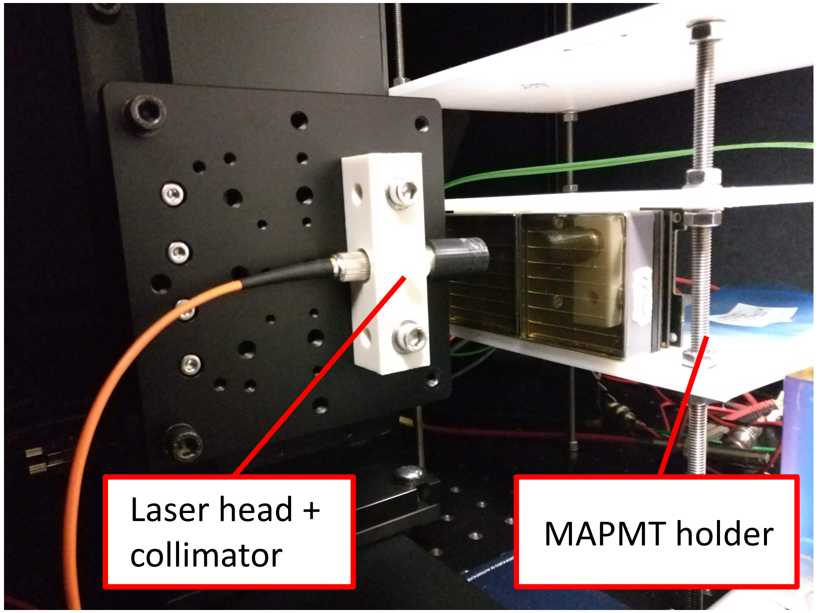
JLab

632 nm picosecond pulsed laser light
Light diffuser to illuminate the whole MaPMT surface
Standardized system with CLAS12 electronics
H8500 6x6 mm^2 pixel sensor so far

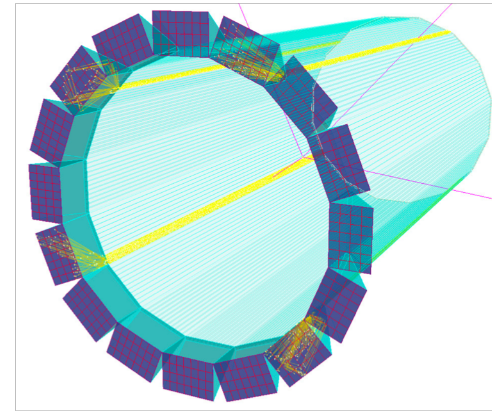


Ferrara

632 nm and 407 nm picosecond pulsed laser light
Light concentrator to scan the pensor surface
Flexible layout supporting various sensors and
Front-End electronics



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 2018:

- Successful radiation hardness study of lens materials at BNL
- Order process for two custom-made 3-layer lenses using sapphire and PbF_2 as the middle layer is close to completion
- Successful beam test of the PANDA Barrel DIRC prototype performed at CERN

DIRC – overview

Radiation hardness test in ^{60}Co source

- Detailed radiation hardness study was performed at BNL, five materials were tested up to 750 krad.
- Sapphire and PbF_2 were confirmed to be very radiation hard.

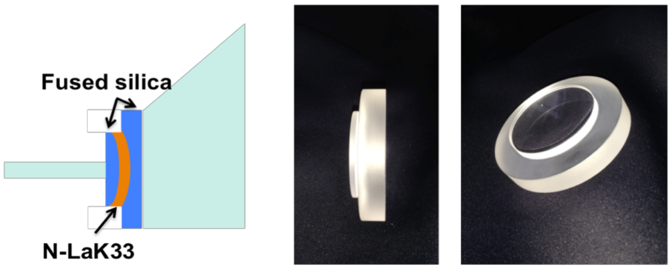
Radiation hard 3-layer lens prototypes

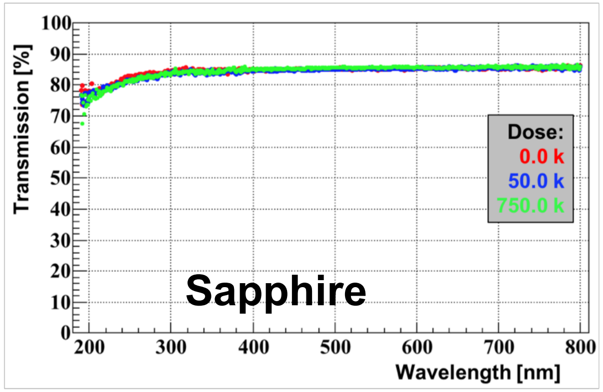
- Both sapphire and PbF_2 present new manufacturing challenges that have to be addressed by potential vendors.
- Discussions are at final stage to complete the purchase of two custom-made 3-layer spherical lenses using sapphire and PbF_2 as the middle layer.

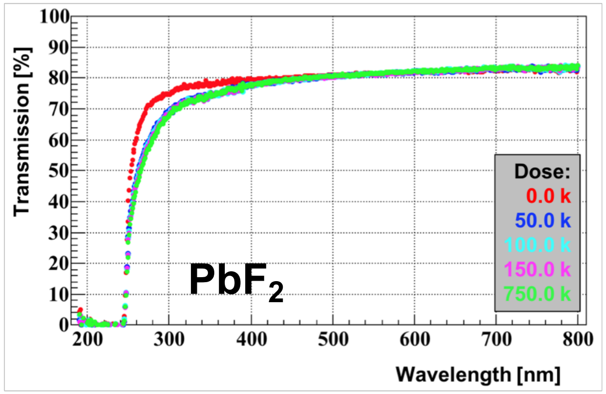
Reducing sensor coverage

- The successful beam test of the PANDA Barrel DIRC prototype identified the potential for a significant reduction in the number of sensors required to cover the detector plane.

3-layer lens







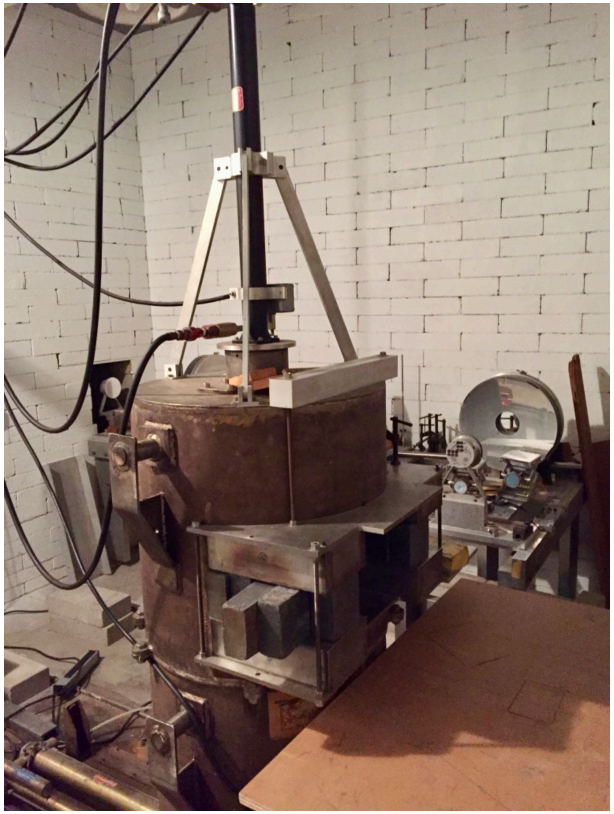
Radiation Hardness Test

^{60}Co irradiation setup at BNL

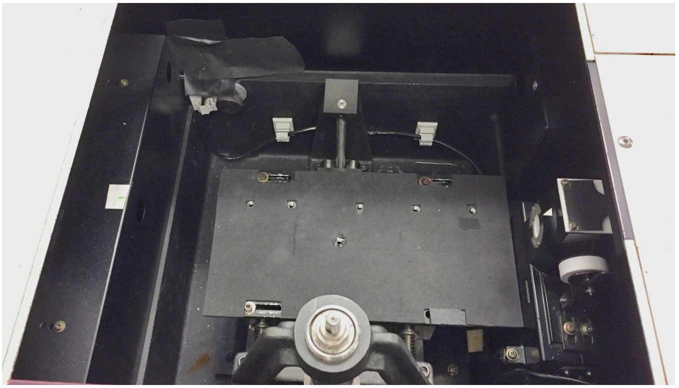
- Radiation damage quantified by measuring the transmission in the 190-800 nm range in a monochromator.
- Five materials studied.
- Sapphire and PbF_2 confirmed to be radiation hard.

Tested samples

Co^{60} Chamber



Monochromator

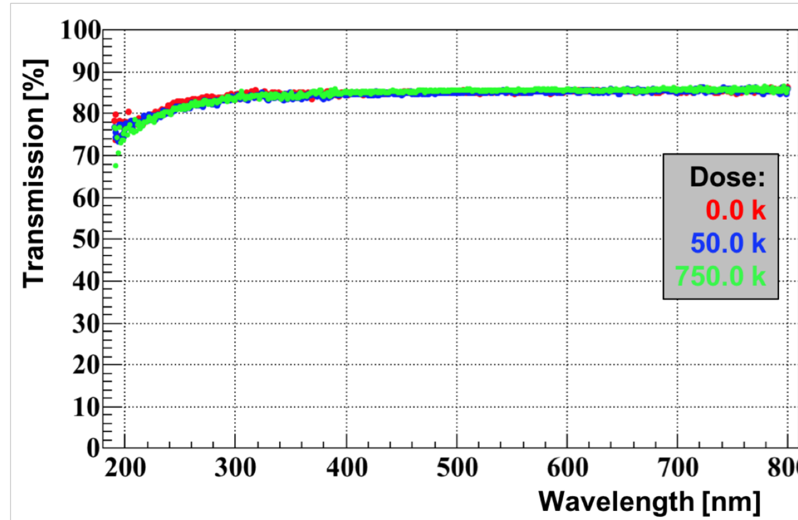


Radiation Hardness Test

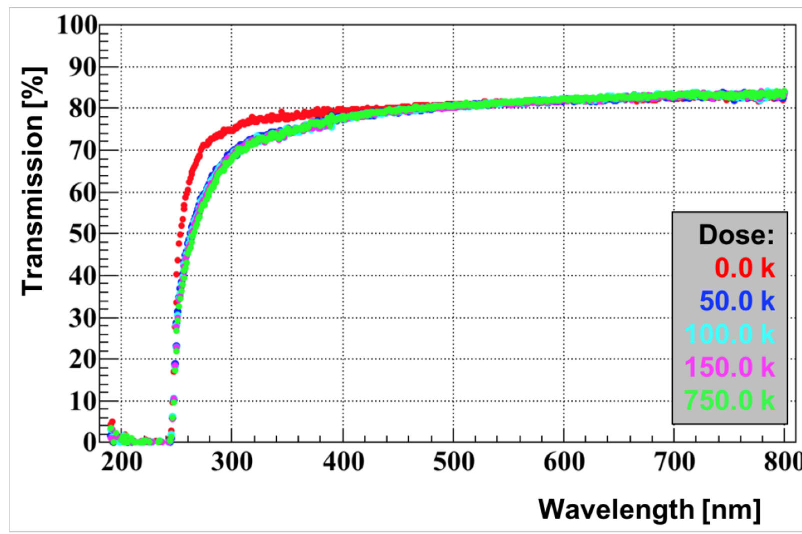
^{60}Co irradiation results

- Radiation damage quantified by measuring the transmission in the 190-800 nm range in a monochromator
- Five materials studied
- Radiation hardness of sapphire and PbF_2 confirmed

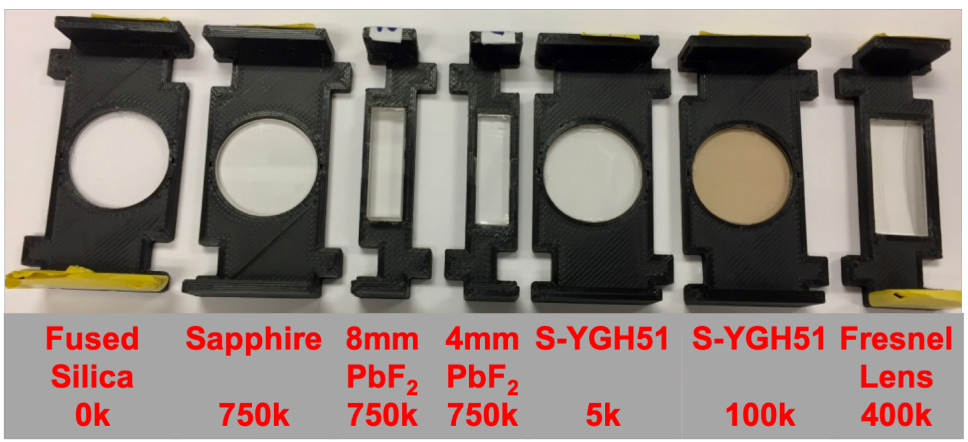
Sapphire



PbF_2



Tested samples

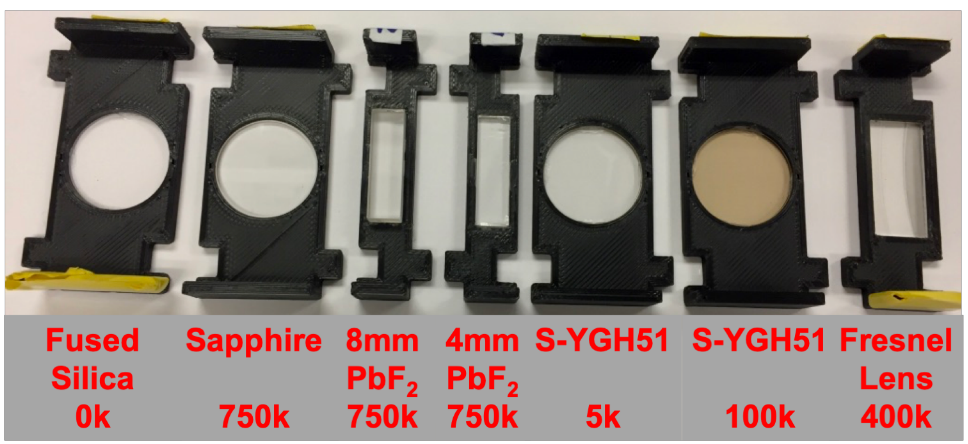


Radiation Hardness Test

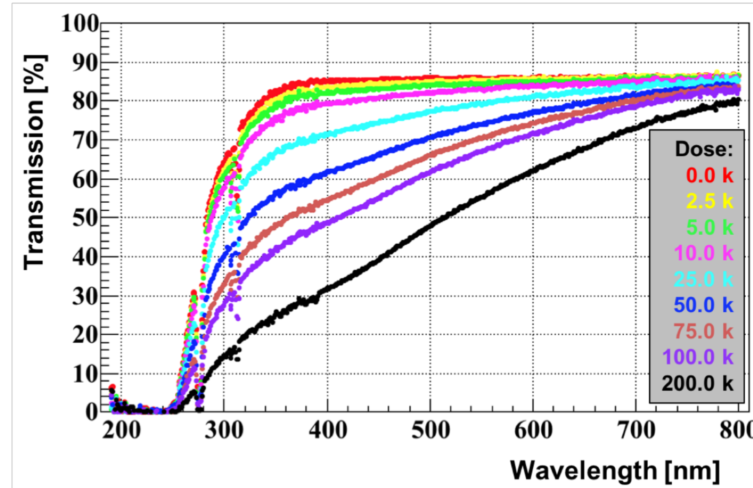
^{60}Co irradiation results

- Radiation damage quantified by measuring the transmission in the 190-800 nm range in a monochromator
- Transmission loss of alternate lanthanum crown glass material (S-YGH51) confirmed
- Acrylic glass samle for mRICH Fresnel lens quite radiation hard.

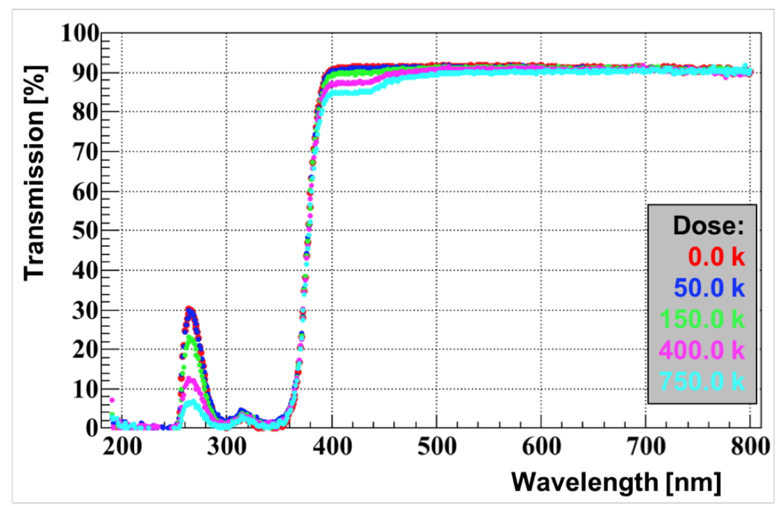
Tested samples



S-YGH51 (NLaK33 equivalent)



mRICH Fresnel lens material

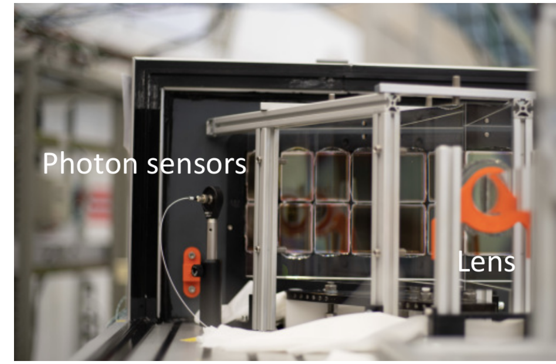


Reducing sensor coverage

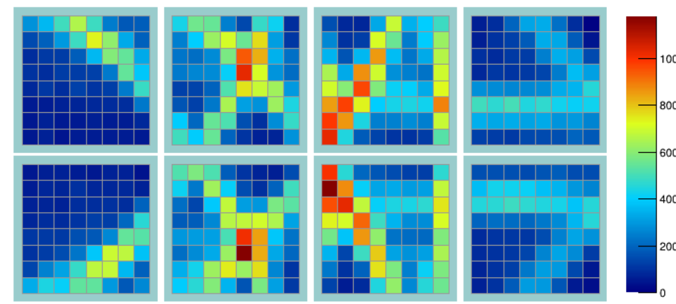
PANDA Barrel DIRC prototype at CERN PS in July/Aug 2018: reduced number of MCP-PMTs.

- Caveat: larger sensor pixels, slower electronics than EIC DIRC → PANDA goal: 3σ π/K separation @ 3.5 GeV/c
- Optics similar to EIC DIRC design: narrow bar, fused silica prism, 3-layer spherical lens
- Reduced MCP-PMT coverage by 33% compared to 2017, gaps near prism sides (data analysis ongoing)
- Measured key quantities: photon yield, Cherenkov angle resolution per photon and per particle, and π/K separation power – all in good agreement with simulation (used for EIC DIRC)
- PID performance in 2018 close to 2017 results (photon yield lower but π/K separation still > 3σ)
- Impact of reducing number of sensors promising, has to be tested in EIC simulation.

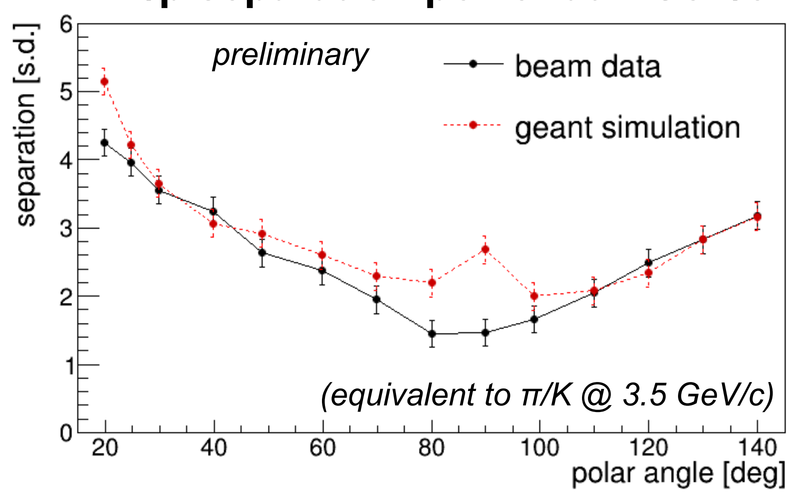
2x4 MCP-PMT arrangement



Example of hit pattern

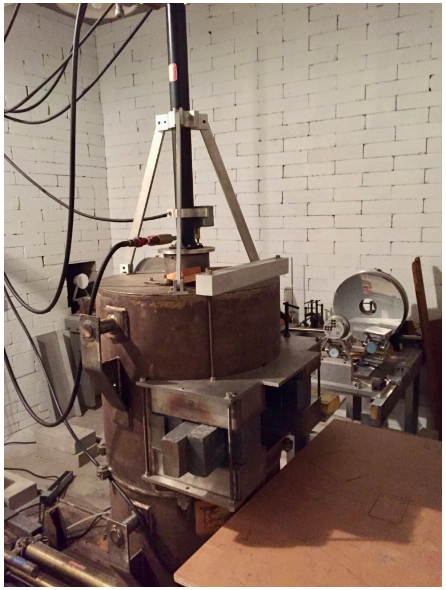


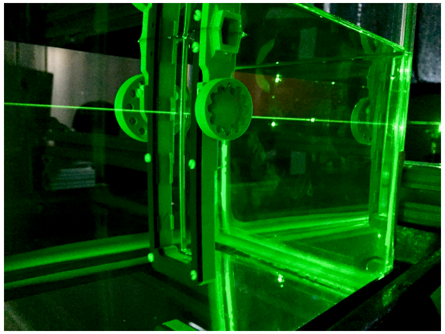
π/p separation power at 7 GeV/c

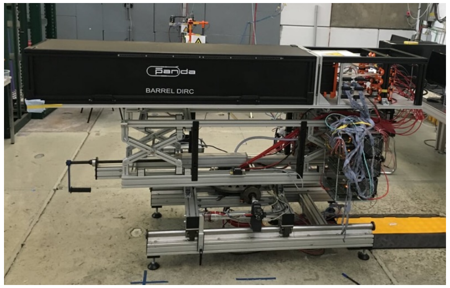


FY19 outlook

- Two more radiation hardness tests planned for winter/spring and summer 2019 with the goal to produce NIM publication draft by the end of FY19.
- Two new prototype lenses with sapphire and PbF_2 will be build and studied on 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 with the goal to produce NIM publication draft by the end of FY19.
- Simulation studies of the reduced sensor coverage and of the impact of the very good timing precision (rms of 100ps or better) of the LAPPD sensors prototypes on the PID performance will be performed.
- Administrative aspects and detailed plans of the transfer of the DIRC prototype from GSI to CUA will be finalized.







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.
- Adaptation of readout electronics (U. Hawaii and INFN-Ferrara) to detector PID prototypes.

Sensors in High-B Fields

Goals:

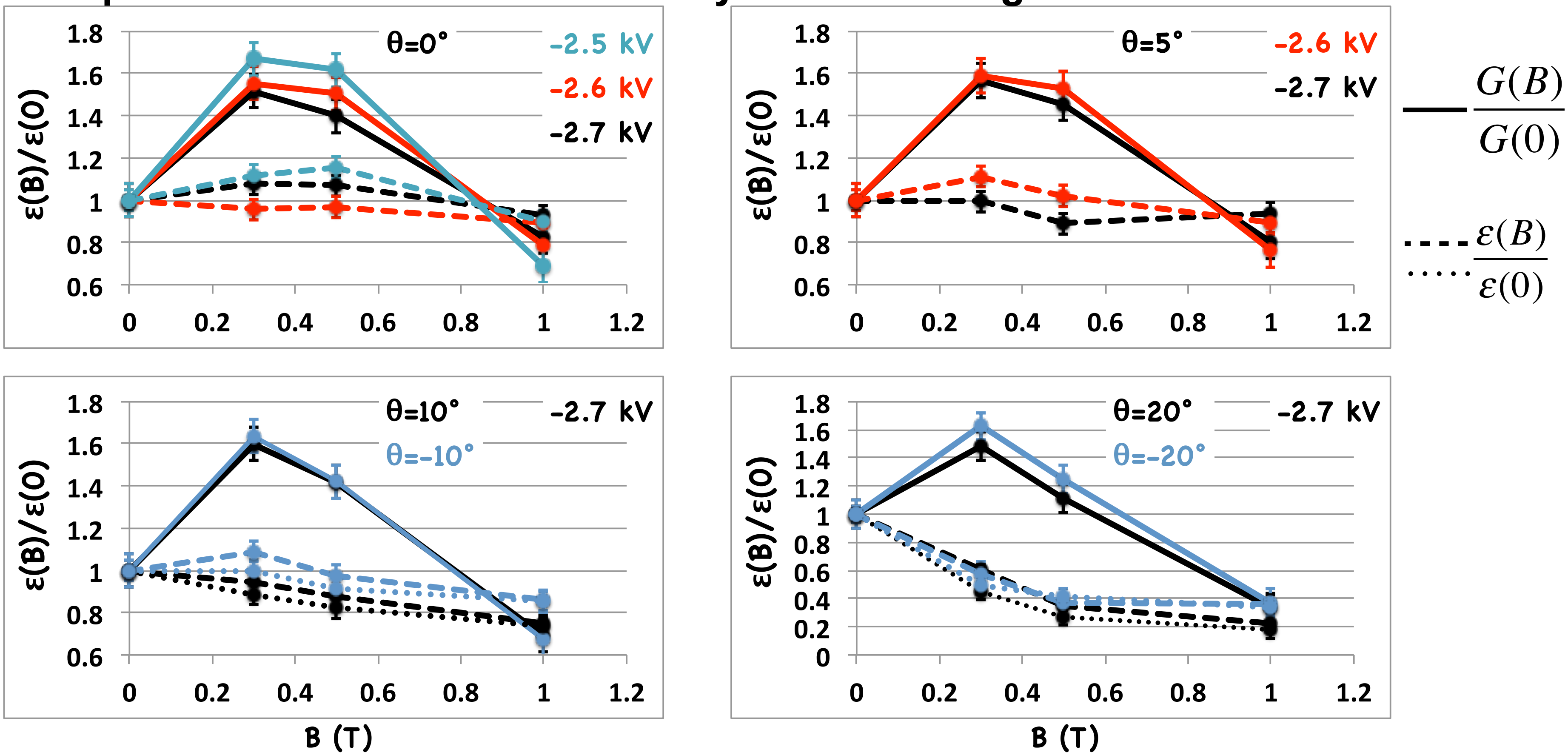
- Identify the limitations of current MCP-PMTs and provide guidance for development of new photo-sensors.
- Find the optimal location and orientation of sensors in the EIC detector.
  - Example: tilt angle with respect to the local B-field; different sensor options
- Investigate suitable parameters for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

Progress in 2nd half of 2018:

- Construction, installation, and commissioning of a timing upgrade for timing measurements (fast laser system, electronics).
- Efficiency evaluation of a 10-μm Planacon MCP-PMTs as a function of field, orientation, and $HV_{photocathode\text{-}MCP1}$.
- Ion feedback measurement as a function of HV and B-field magnitude.

Results from Summer 2018 Efficiency Studies

10-μm Planacon: Relative efficiency and Relative gain

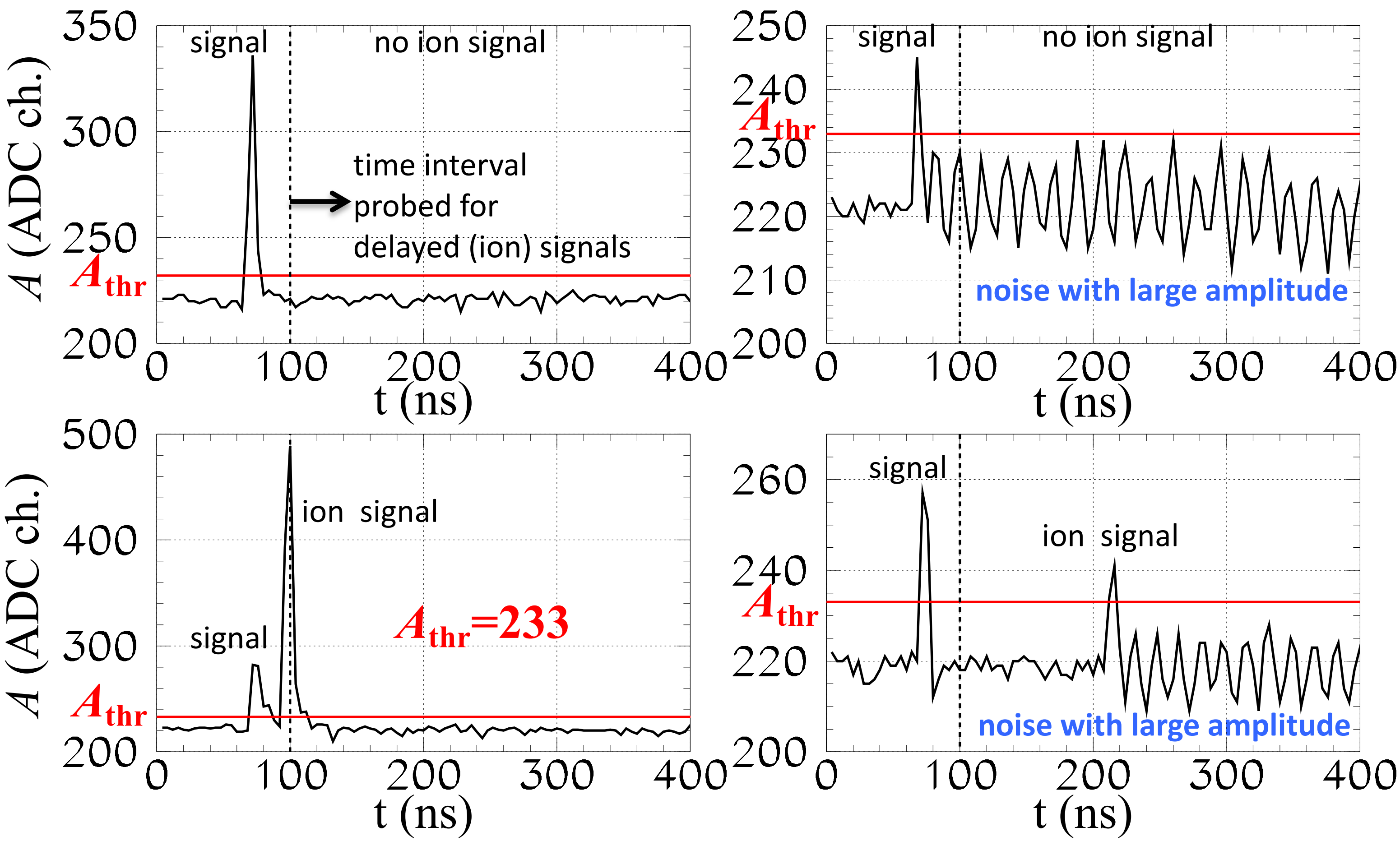


- Efficiency: $\varepsilon = N_{1phe}/N_{ped.}$
- At θ=20° between the sensor and the B-field axes, the efficiency drops continuosly as B increases even though the gain shows a maximum at 0.3 T.
- An increase of $HV_{photocathode\text{-}MCP1}$ by 200 V (close to maximum allowed) recovers only about 13% of the efficiency (θ=20°).

Results from Summer 2018 Ion-Feedback Studies

10-μm Planacon: Ion Feedback

The accuracy of the extracted ion-feedback rate strongly depends on the **noise** of the signal line. The value of the **threshold amplitude defining a signal, A_{thr},** critically affects the estimate of ion feedback rate.



$N_{signals}$:

$A_{\max} \geq A_{thr}$

$t < 24$ ns

N_{ions} :

$A_{\max} \geq A_{thr}$

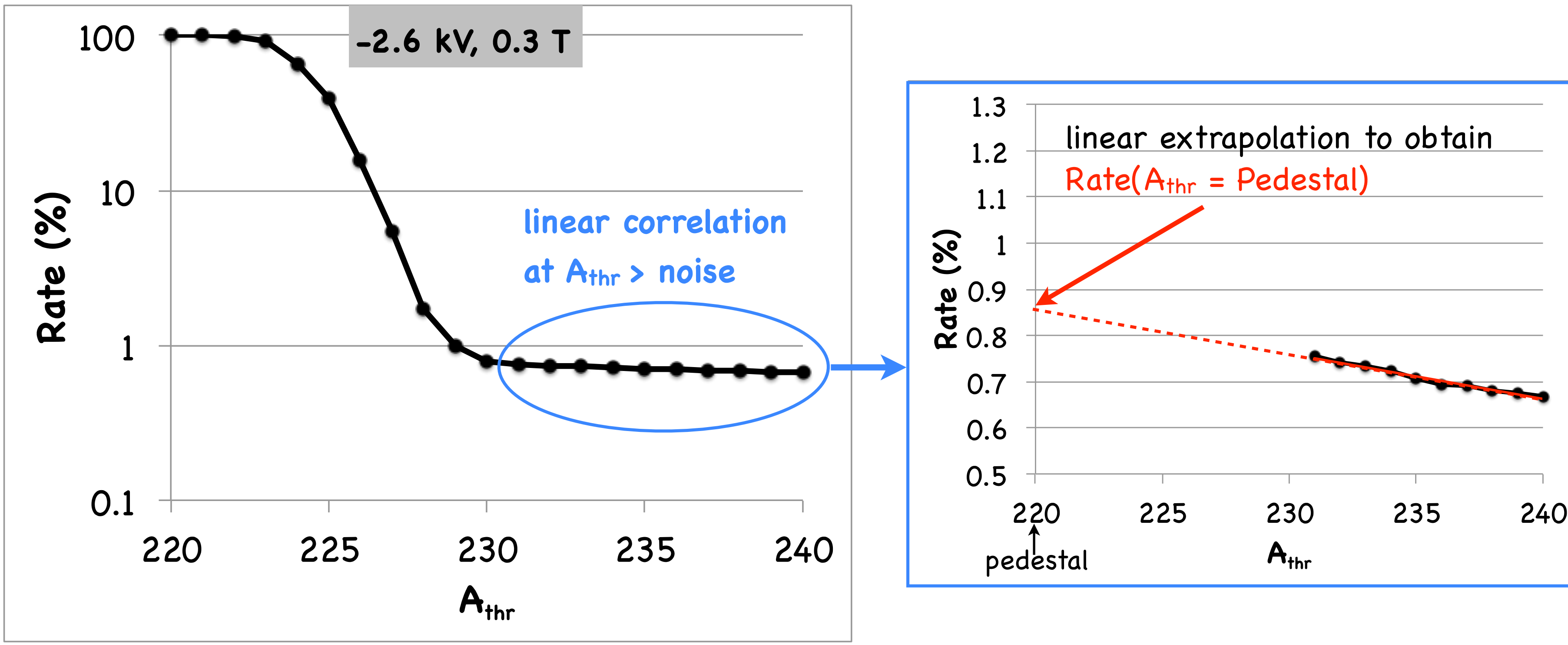
$t > 100$ ns)

$$Rate = \frac{N_{ions}}{N_{signals}}$$

Results from Summer 2018 Ion-Feedback Studies

10-µm Planacon: Ion Feedback

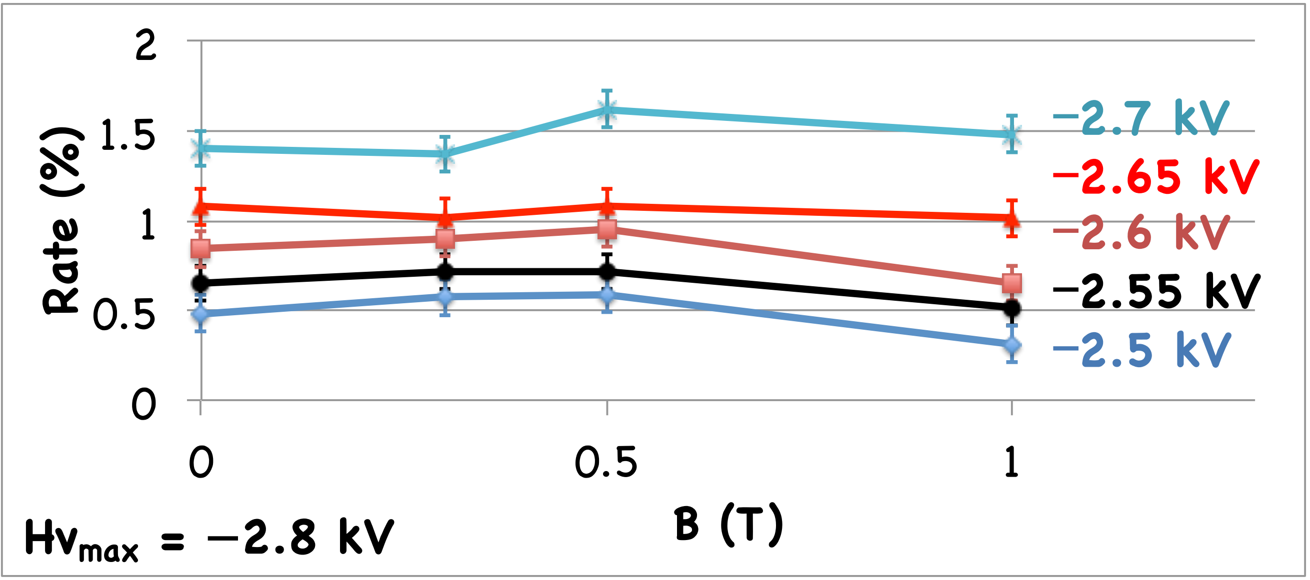
- Too low A_{thr} leads to an overestimate of the ion-feedback rate due to some noisy waveforms. $A_{thr}=233$ is the best empirically found value for Summer 2018 data.
- **Problem:** Waveforms where $A_{signal} < A_{thr}$ or/and $A_{ions} < A_{thr}$ are not taken into account.

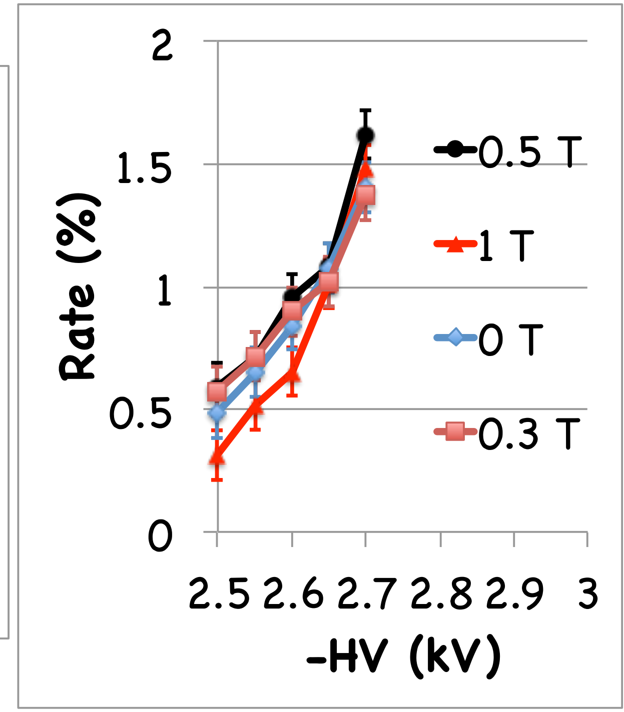


- *Rate* is evaluated over a range of A_{thr}. *Rate*(A_{thr}=Pedestal) is obtained from a linear fit to the high-A_{thr} tail. This is the best estimate of the true ion rate, i.e. as would be obtained if there were no noise on the waveform, but only signal(s).

Results from Summer 2018 Ion-Feedback Studies

10-µm Planacon: Ion Feedback





$\Delta = Rate(A_{thr}=\text{Pedestal}) - Rate(A_{thr}=233)$. $\bar{\Delta} = 0.13$. Reported above: $Rate(A_{thr}=233) + \bar{\Delta}$

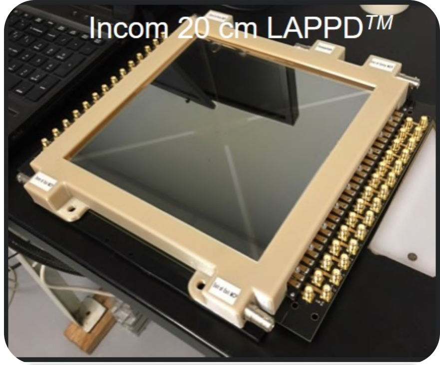
- At all voltages the ion rate is below 2%.
- Results suggest that ion-feedback is primarily driven by HV.
- Ion-feedback rate dependence on B-field magnitude is relatively weak.

Outlook

Planned FY19 activities

- Timing measurements of a 10-μm Planacon.
- Some gain and efficiency measurements to understand trends observed in 2017-2018.
- Work on a simulation for optimization of MCP–PMT design parameters as time permits.

MCP-PMT/LAPPD^{TM}



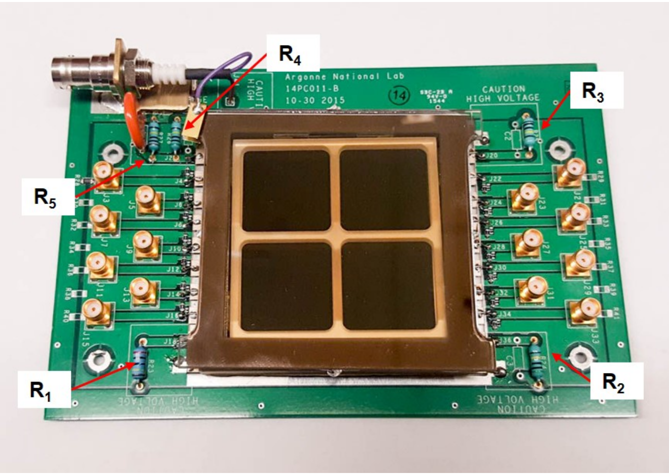
Goal:

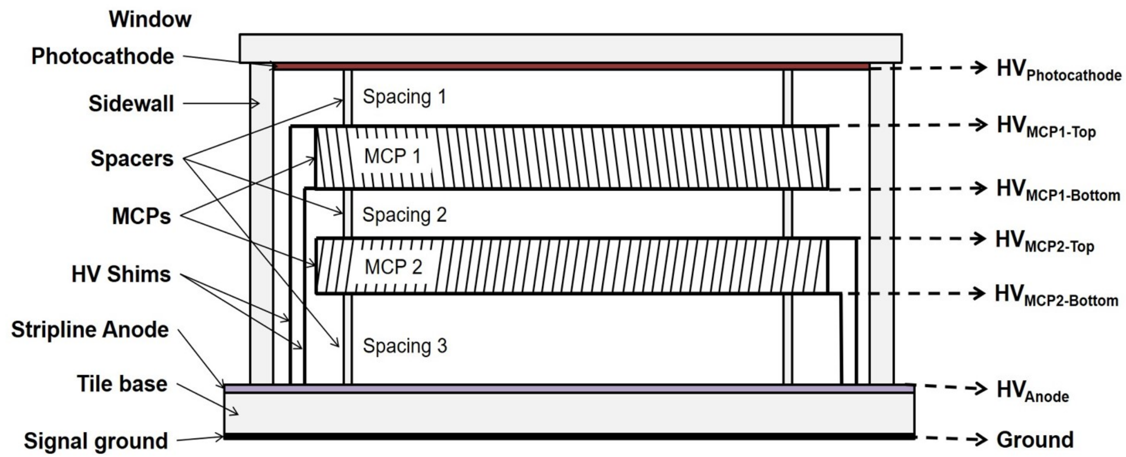
- Adapt LAPPD^{TM} to the EIC requirements:
  Highly pixelated LAPPD^{TM} working at 2~3 Tesla, to be used as photosensors for mRICH, dRICH, and DIRC detectors, as well as TOF applications.

Progress in the 2nd half of 2018:

- Produced and tested 6cm MCP-PMT with Incom 10 µm pore size MCPs, the spacing is the same as current standard design
- Ordered glass components (side wall and spacer), designed and prepared for another 10 µm MCP-PMT with reduced spacing
- Enhanced communication with Incom, Inc on LAPPD^{TM}, much stronger ties
- Initiated MCP-PMT simulation effort to guide MCP-PMT design
- Performed initial test of newly produced LAPPD^{TM} compatible in high magnetic field
- Establishing 2D single photoelectron efficiency and TTS timing scan capability

Fabrication of MCP-PMTs with 10 μm pore size MCPs





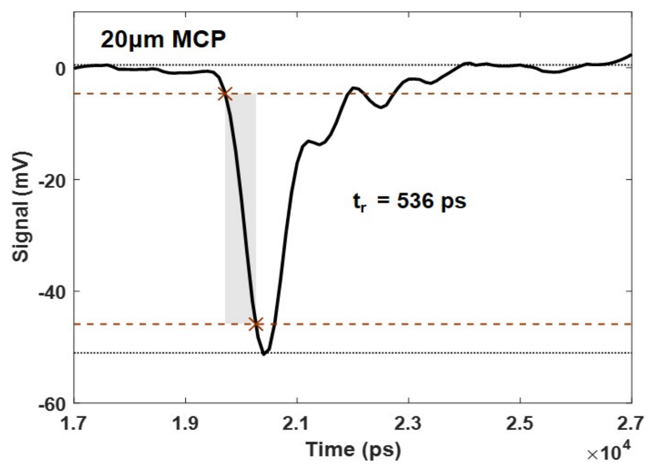
		Version 2 Standard 20 μm MCP-PMT	Version 3 10 μm MCP-PMT without reduced spacing	Version 4 10 μm MCP-PMT with reduced spacing
MCP	Pore size	20 μm	10 μm	10 μm
	Length to diameter ratio (L/d)	60:1	60:1	60:1
	Thickness	1.2 mm	0.6 mm	0.6 mm
	Open area ratio	60 %	70 %	70 %
	Bias angle	8°	13°	13°
Detector geometry	Window thickness	2.75 mm	2.75 mm	2.75 mm
	Spacing 1	3.25 mm	2.25 mm	2.25 mm
	Spacing 2	1.75 mm	2.0 mm	0.7 mm
	Spacing 3	2.0 mm	4.0 mm	1.1 mm
	Shims	0.3 mm	0.3 mm	0.3 mm
	Tile base thickness	2.75 mm	2.75 mm	2.75 mm
MCP-PMT stack	Internal stack height	**9.70 mm**	**9.75 mm**	**5.55 mm**
	Total stack height	15.20 mm	15.25 mm	11.05 mm

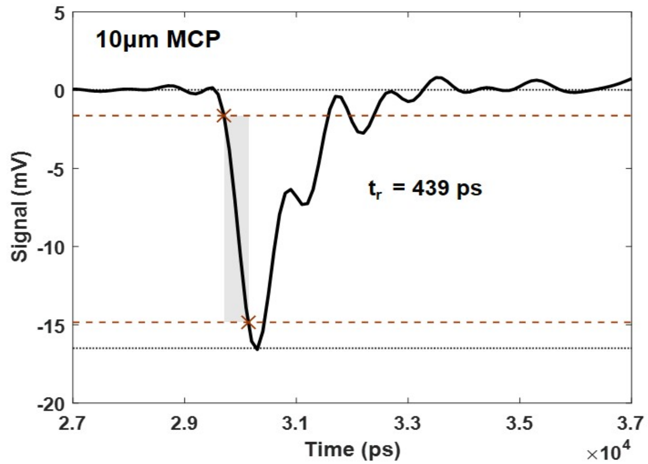
MCP-PMT performance improvement with 10 μm MCPs

- Same stack height, no spacing reduction yet

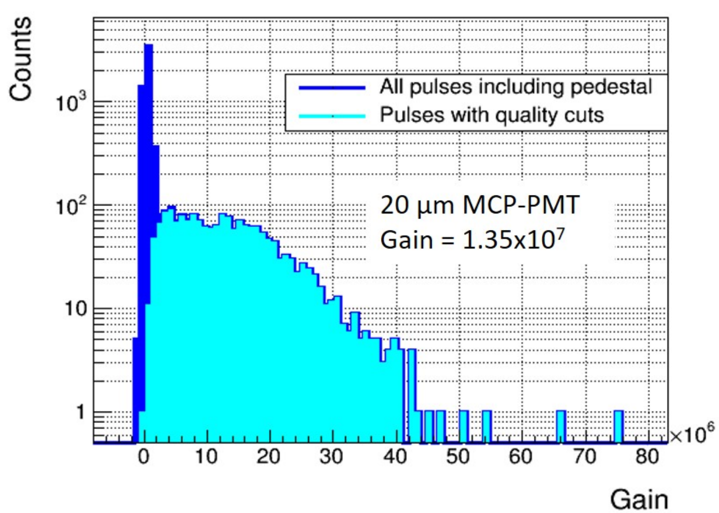
version 2: IBD design 20 μm | **version 3: IBD design 10 μm**

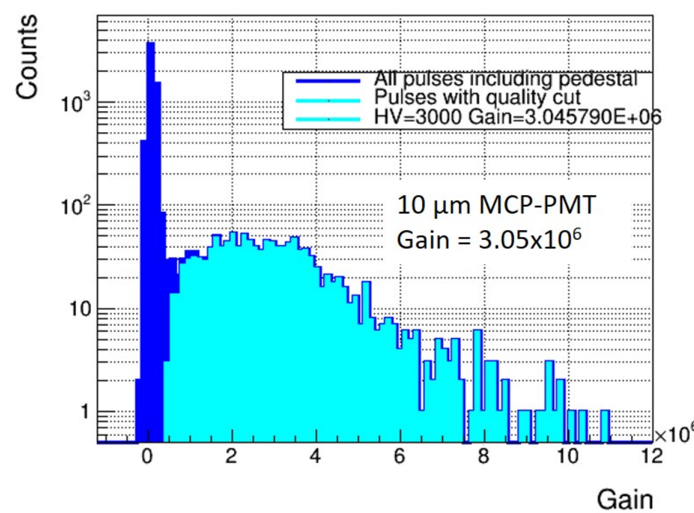
Rise time





Gain



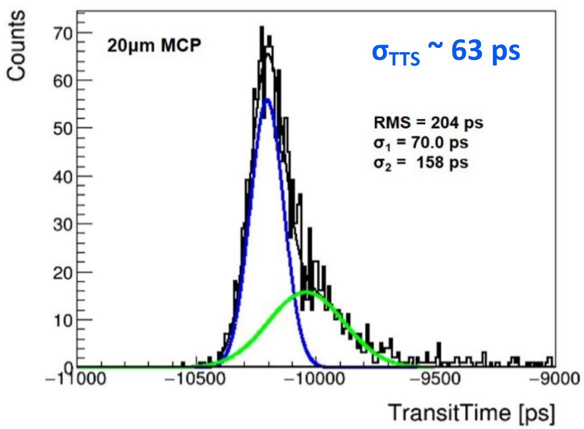


MCP-PMT performance improvement with 10 μm MCPs

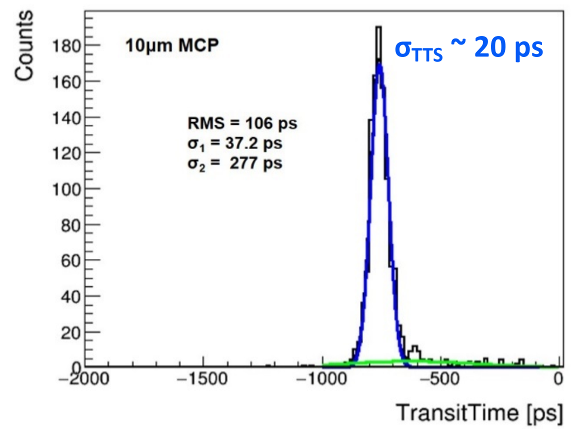
- Same stack height, no spacing reduction yet

Timing resolution (SPE)

version 2



version 3



$$\sigma_{MCP-PMT} = \sqrt{\sigma_1^2 - \sigma_{Laser}^2 - \sigma_{Ele.}^2}$$

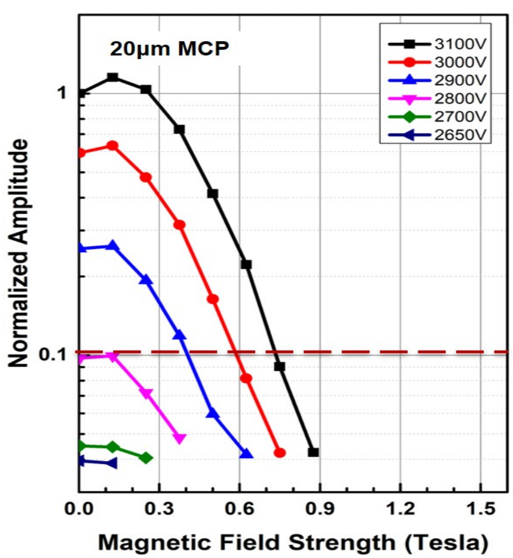
System: σ_1 = 37.2 ps

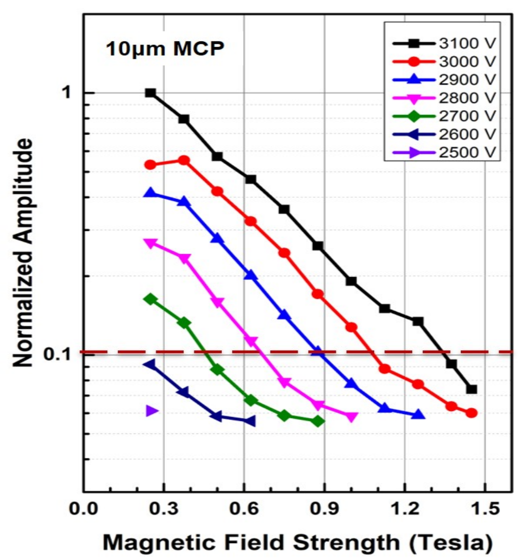
Laser jitter: σ_{Laser} = 30 ps

Electronics: $\sigma_{Ele.}$ = 7 ps

*10 μm MCP-PMT: **σ = 20 ps***

Magnetic field tolerance





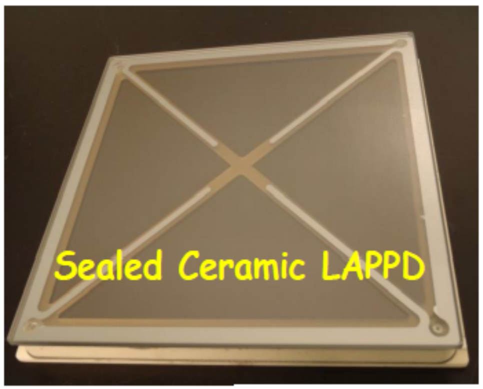
V3 achieved 100 ps rms timing, which is critical for future DIRC applications!

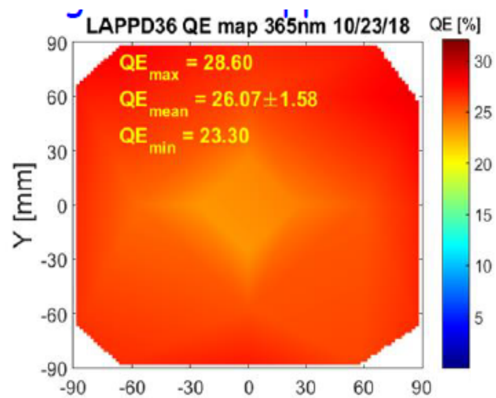
20 μm MCP-PMT	10 μm MCP-PMT
0.7 Tesla	**1.3 Tesla**

Enhanced communication with Incom on LAPPD^{TM}

The advices and recommendations from the committee and feedbacks from EIC users were well explained and emphasized during ANL-Incom bi-weekly meetings.

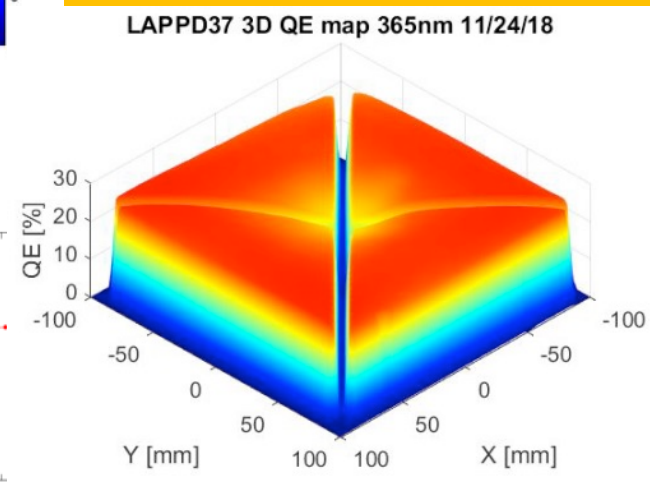
Pixel LAPPD^{TM} is available for the first time; negotiating for one to be delivered to ANL.

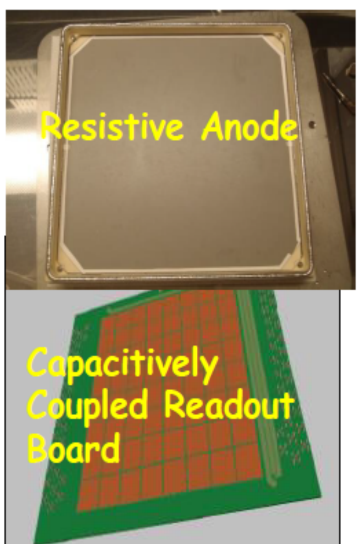


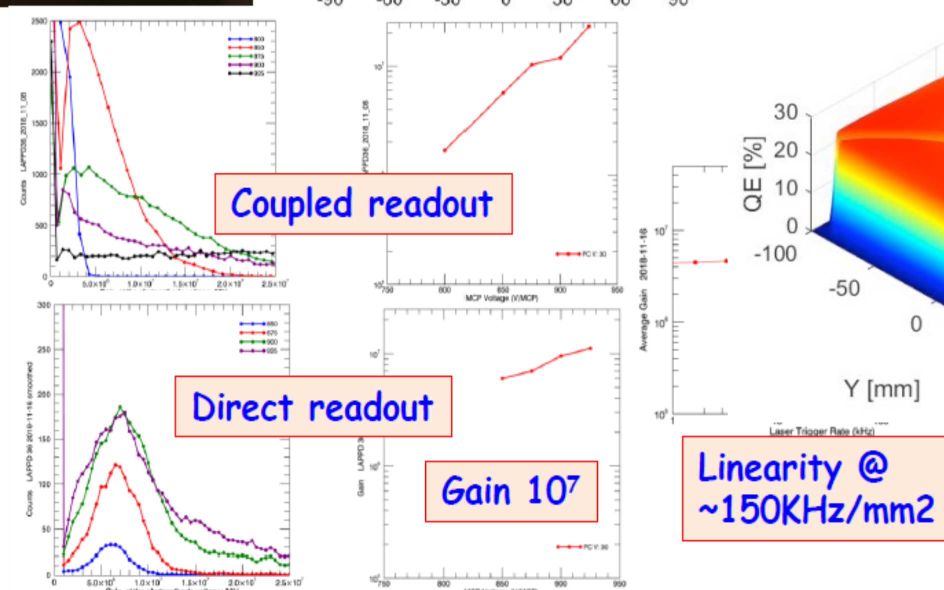


Current demonstrated pixel size: 25 mm x 25 mm

QE uniformity issue was solved here!







Incom Inc. LAPPD Performance, CPAD18, Dec 9 - 11, 2018, Providence, RI

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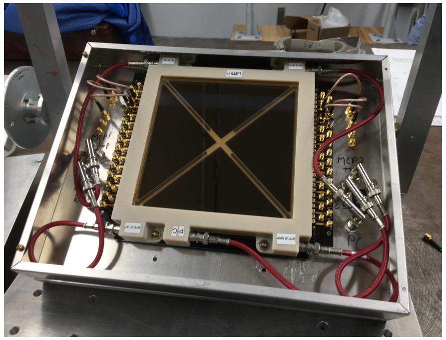
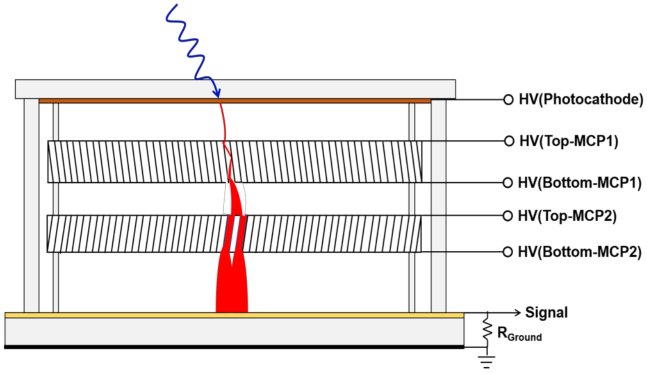
Magnetic field test on new LAPPD^{TM}

- without magnetically sensitive components

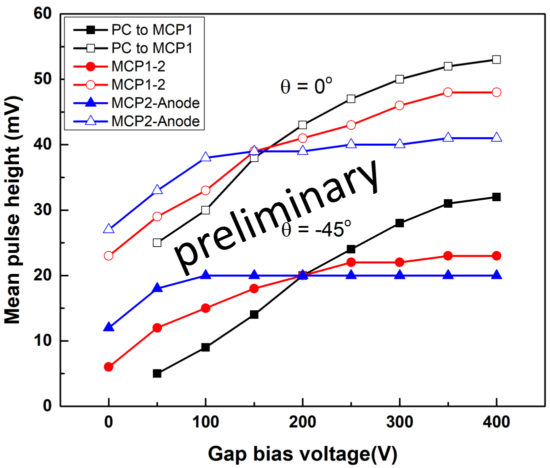
A new LAPPD^{TM} without magnetic sensitive components was delivered at ANL for a one day test.
SBIR Phase I was fulfilled, Phase II will be submit at end of Jan. 2019.

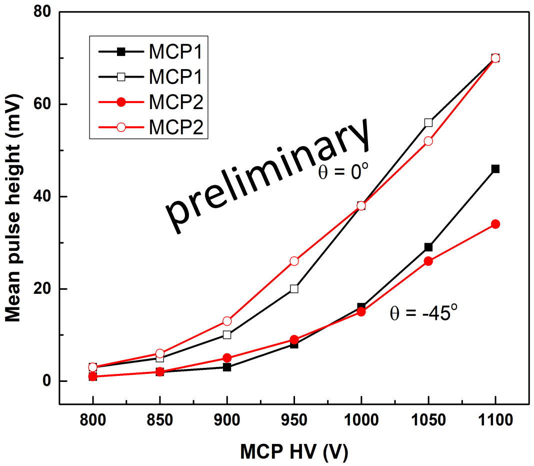


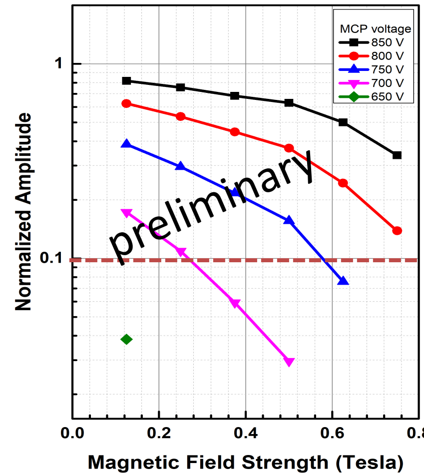


5 HV bias connection

LAPPD^{TM} shows better B field tolerance than the 6cm one with individual HV biases.







The B field tolerance can also be further enhanced by adjusting the HVs, further study planned.

FY19 plans and outlook

- ~~Achieve great improvement from 0.7 T to 1.3 Tesla, and ~ 20ps timing (SPE) (Done)~~
- ~~2nd magnetic field testing of 20 cm LAPPD (Done)~~
- ~~Laser setup and approval (Done)~~
- SBIR Phase II application (Jan. 29, 2019)
- Fabrication and testing of MCP-PMT with 10 um MCPs and reduced space
- Detailed testing and comparison of ANL version 2, 3, 4 MCP-PMTs in B field with fast laser setup
- Establish uniformity scan capability
- MCP-PMT simulation

Readout Electronics

Goals:

- Develop an suite of readout electronics for all photosensors used by the Cherenkov detector prototypes.
  - Need to read out MCP-PMTs and SiPMs with 3 mm pixels
  - The DIRC also requires good timing (< 100 ps)

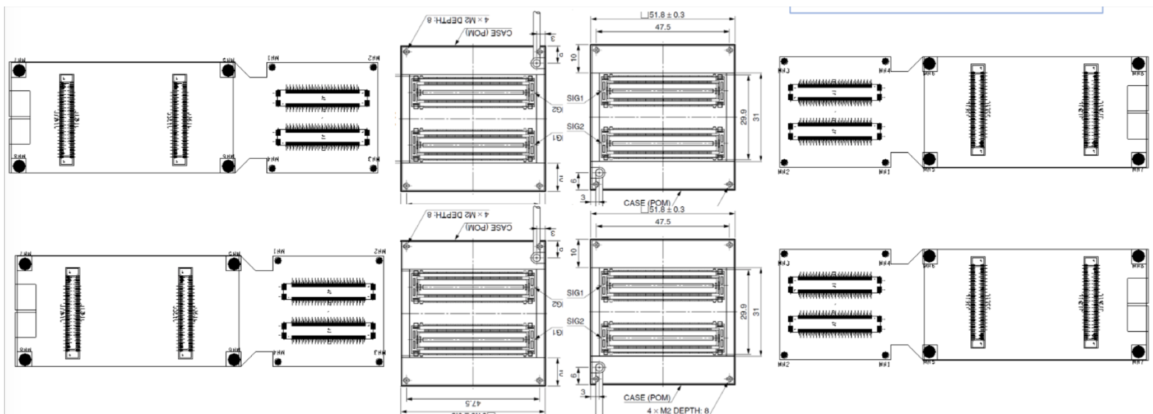
Progress in 2nd half of 2018:

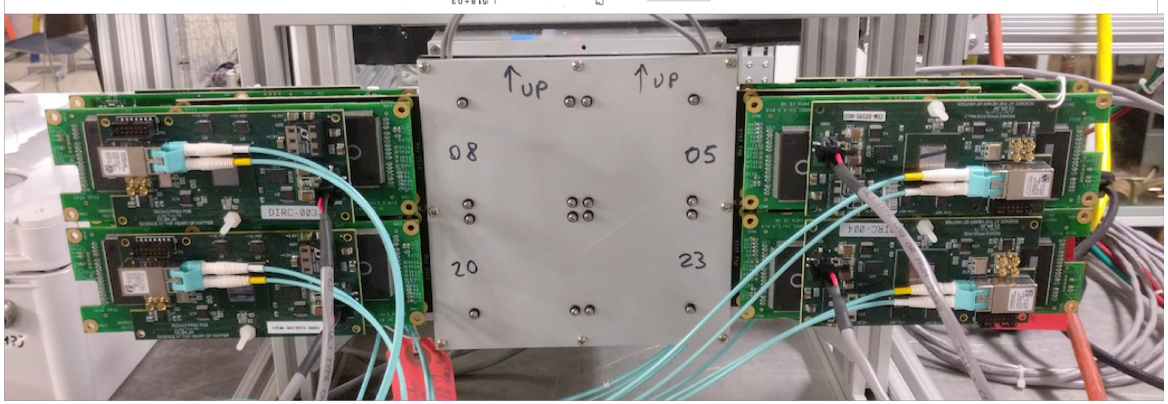
- Maroc-based CLAS12 front end was used for the first two mRICH beam tests, demonstrating 3 mm pixel compatibility, and is currently utilized for ongoing mRICH, dRICH, and SiPM R&D
  - Maroc is not an option for the DIRC due to its poor timing
- A front end based on TARGETX (used in Belle II) is being developed in Hawaii to meet the requirements of all detectors, including the DIRC.
  - TARGETX will eventually be replaced by the new SiREAD chip
- A generic DAQ system for all the consortium needs is deing developed by INFN

MaPMT (H13700) readout used in the mRICH beam test

Derived from CLAS12 RICH readout:

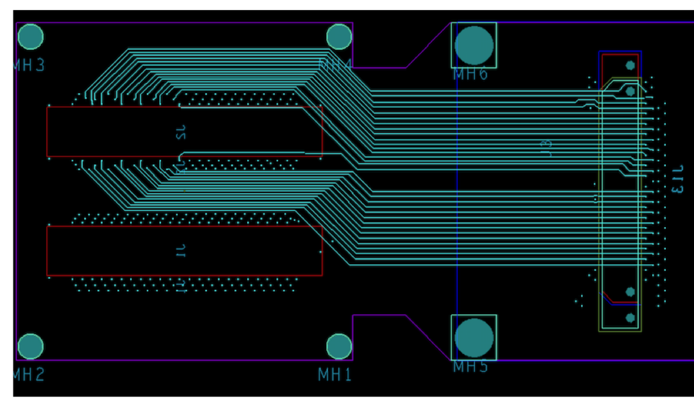
- 1024 channels
- MAROC 64 channel parallel digitalization
- FPGA generated 1 ns timestamp
- DAQ protocol based on VME/VSX SSP





Custom adapter boards

- Compact distribution
- Use of existing MAROC boards
- Light and gas tightness



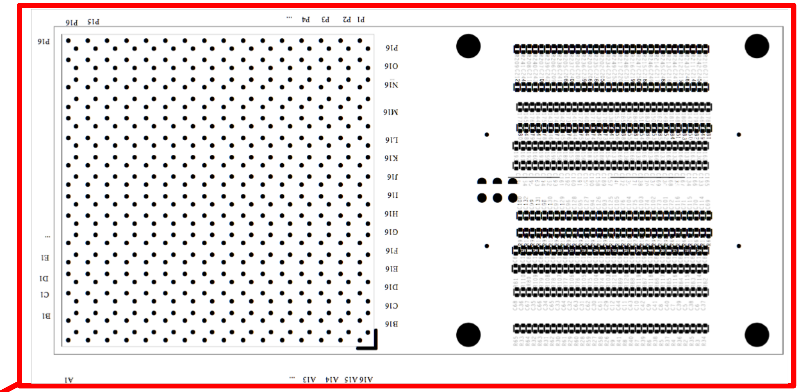
SiPM readout used in the mRICH beam test

SiPMs might offer a cheaper and more efficient solution, expecially in the longer term, potentially providing a device with low sensitivity to magnetic fields.

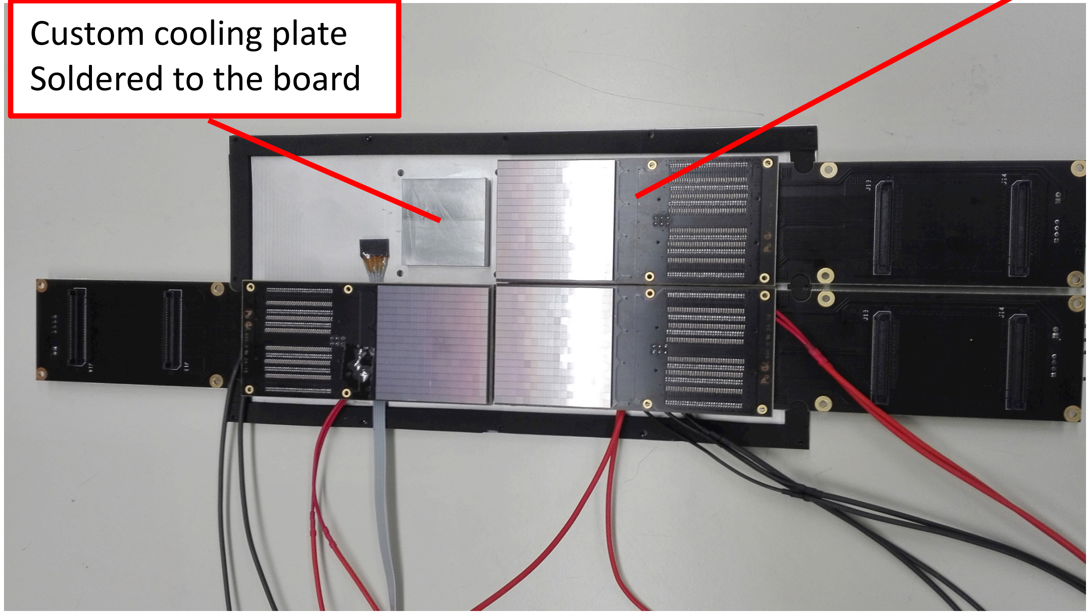
However, despite improvement in dark rate (and cost), radiation hardness remains an issue.

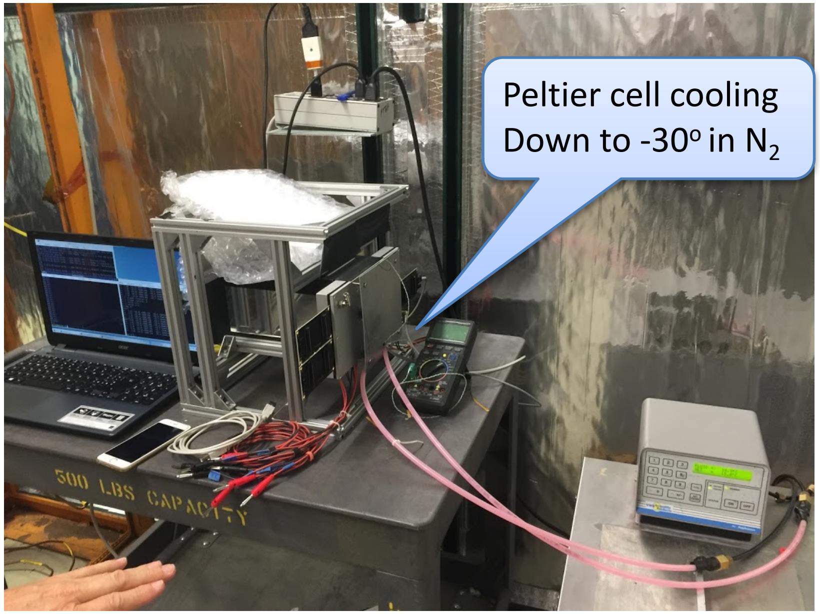
Challenge: cooling integrated into the sensitive readout

Dedicated board for readout and cooling of a surface Mounting SiPM Matrix



Custom cooling plate Soldered to the board

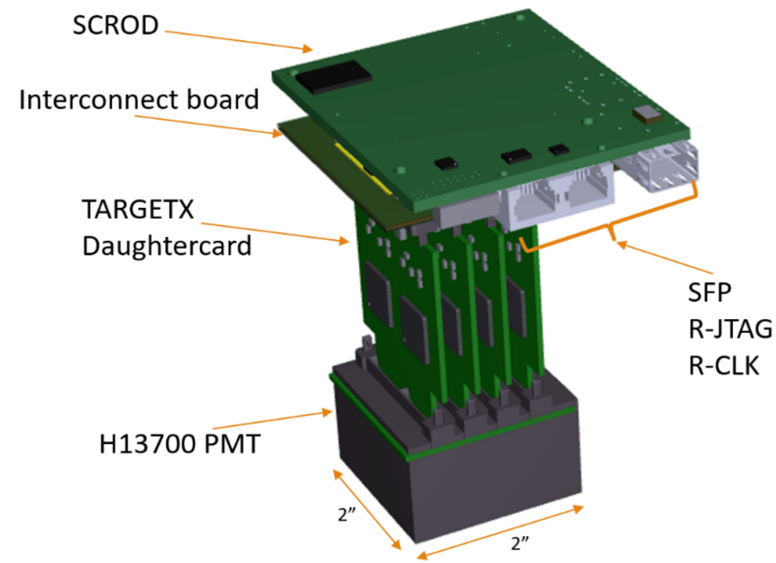


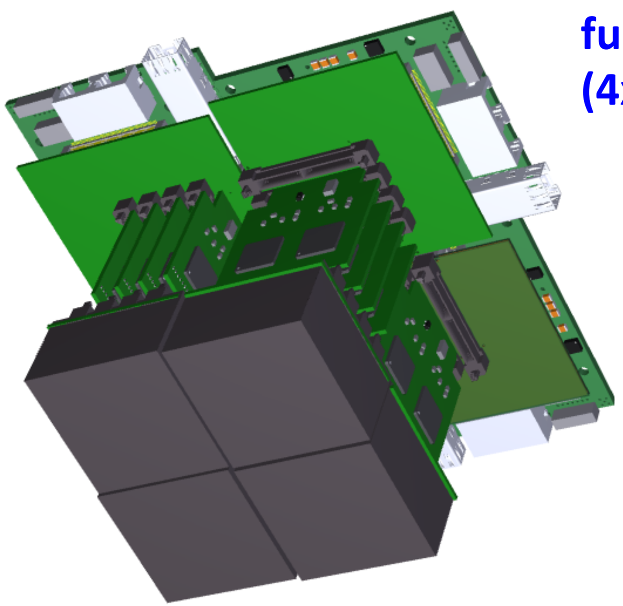


Peltier cell cooling Down to -30º in N_2

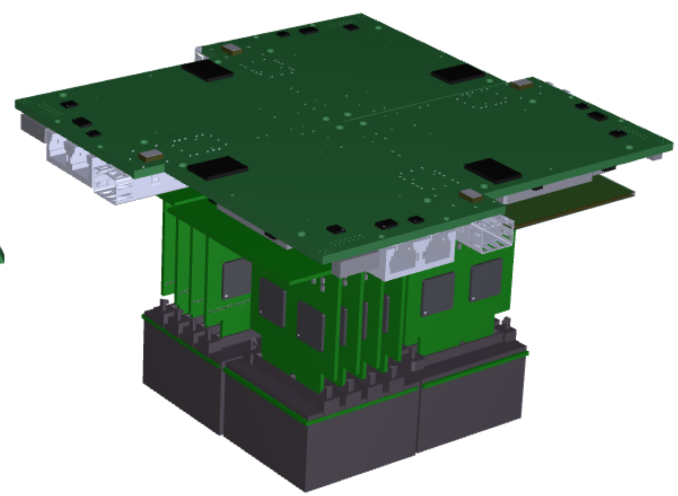
TARGETX-based electronics for mRICH, Rev 1.0 design

- Mechanical fitting and PCB routing
- 4 TARGETX chips on one daughtercard
- SCROD (s6 FPGA) boards already fabricated and tested
- Interconnect card purely passive routing
- Reuse KLM detector readout FW and SW
- Can readout all 256 PMT channels
- Compatible with mRICH layout (2x2 PMTs)

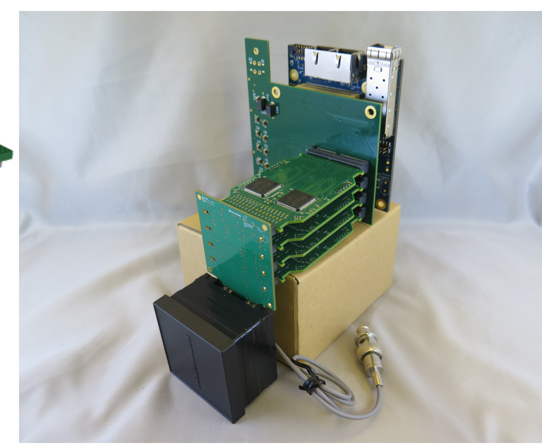




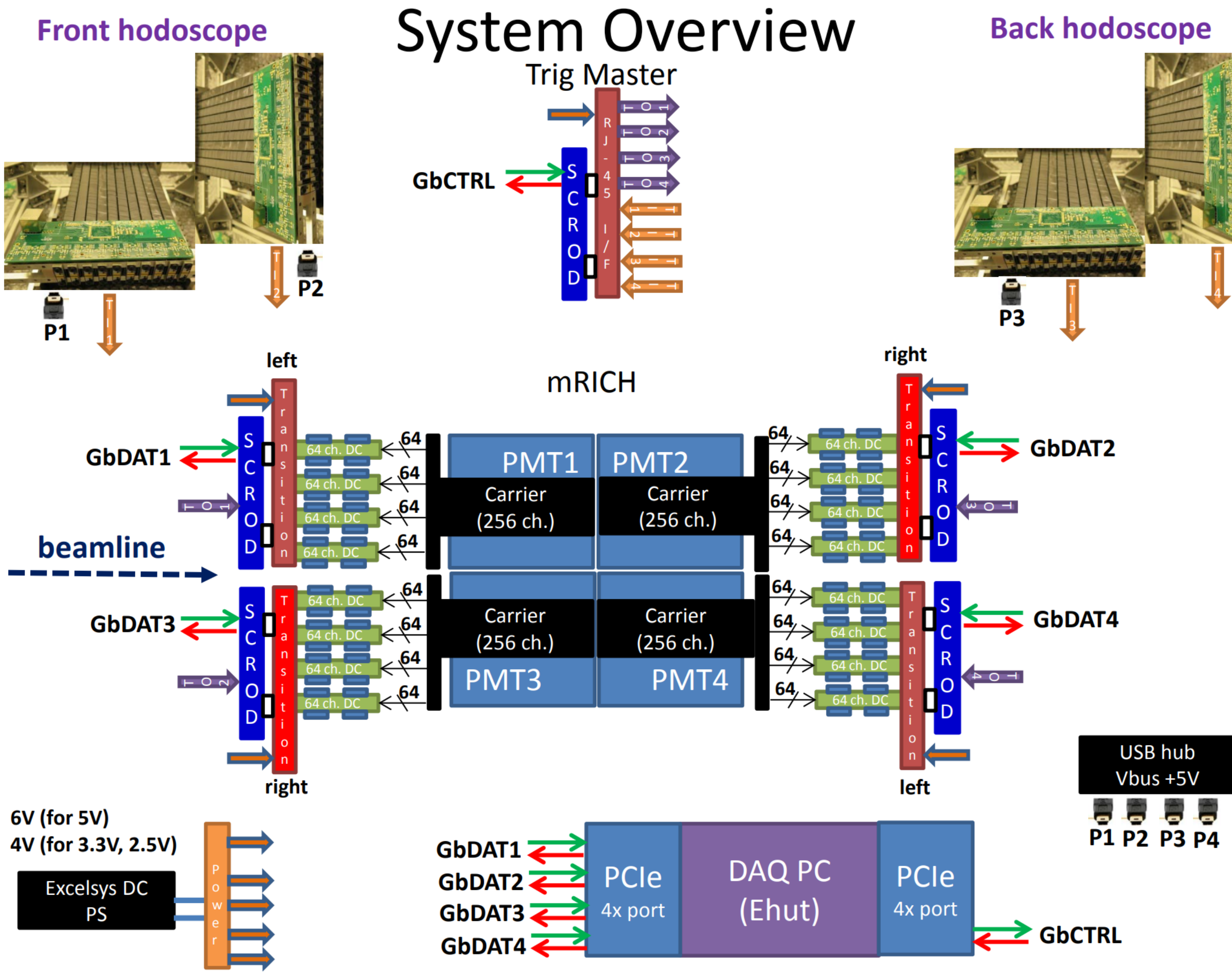
full 1024 channel (4x256) readout block



4x64 channel building block



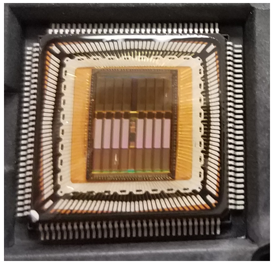
TARGETX-based beam hodoscope readout

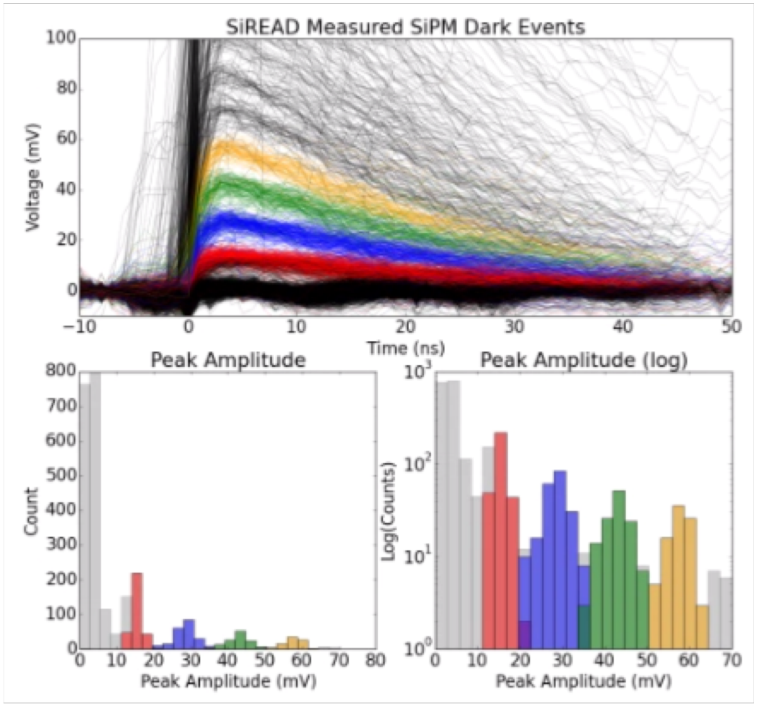


– Used in 2018 beam test at Fermilab

Transition from TARGETX to SiREAD
– a common readout for all Cherenkov detectors

- Specialized full waveform sampling SiPM/PMT readout System-on-Chip
  - initially 32 channels (prototype), but could be expanded to 64 channels
  - timing properties match for all Cherenkov detectors, including the DIRC (< 100 ps)
  - 1 GSa/s, Region of Interest (RoI) readout capable
- Initial testing of SiREAD complete
  - Results presented at IEEE NSS - Sydney
- Various small 'bugs' found in chip that require re-submission
- Next beam test in FY19:
  - Front-end electronics operation (ideally with SiREAD rev2),
  - Using SiREAD 1.0 is possible if mated with a 'co-processing' FPGA – Design is under way
  - DAQ verification,
  - different photosensors (including MCP-PMTs / LAPPDs)





eRD14 FY19 budget (including overhead)

5.9 Budget by project

	requested	approved	fraction
dRICH	52,000	31,200	60.0%
mRICH	77,300	61,840	80.0%
DIRC	112,000	61,140	54.6%
high-B	39,200	31,360	80.0%
LAPPD	95,000	76,000	80.0%
Electronics	86,000	60,200	70.0%
Total	*461,500*	*321,740*	*69.7%*

5.10 Budget by institution

	requested	approved	fraction
ANL	95,000	76,000	80.0%
CUA + GSI	112,000	61,140	54.6%
GSU	69,800	53,840	77.1%
INFN	95,500	64,400	67.4%
JLab	7,600	7,636	100.5%
U. Hawaii	50,000	35,000	70.0%
U. SC	31,600	23,724	75.1%
Total	*461,500*	*321,740*	*69.7%*

- Please note that the rollover funds from FY18 are very small. There was some confusion in this regard due to slow reporting and, in two cases, PI grants being charged by universities rather than the R&D accounts, but all these administrative issues are being addressed.

Thank you!

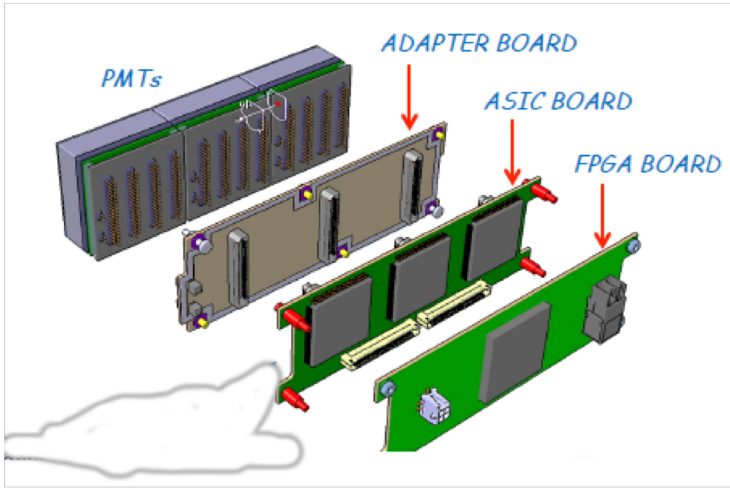
Also, please visit the eRD14 wiki

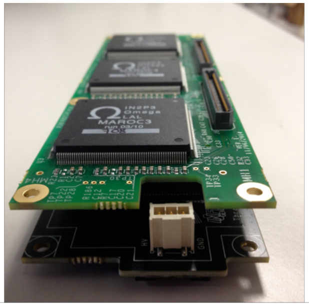
http://phynp6.phy-astr.gsu.edu/eRD14/index.php/Main_Page

Backup

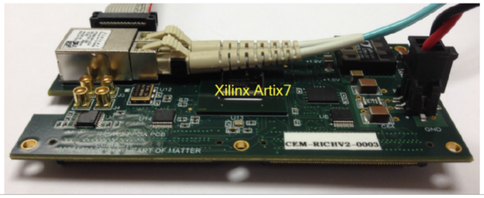
Electronics – Maroc (used for FY17-18 mRICH beam tests)

CLAS12 RICH electronics



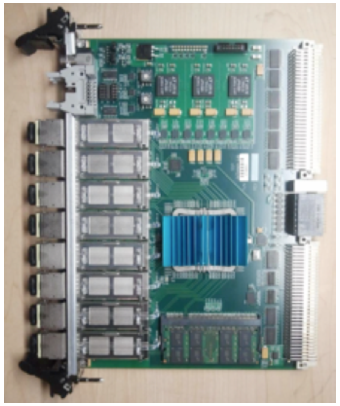


Adapter & Asics Boards



FPGA Board

SSP Fiber-Optic DAQ

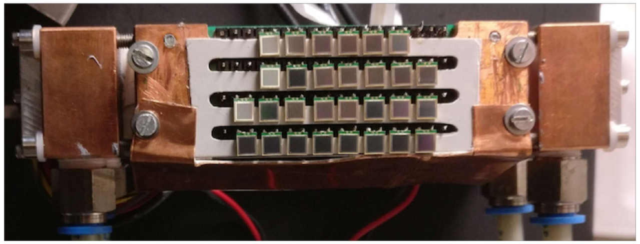


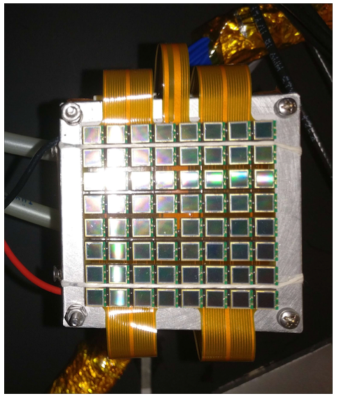
SiPMs

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

- ✗ High dark rate
- ✗ Low radiation tolerance

} Work at low temperature





Electronics – TARGETX

- 1^{st} generation 1024 channel compact readout for the mRICH prototype (and hodoscope) based on existing TARGETX chip:
  - Initial sensor: 4 x H13700 MaPMTs, each with 256 channels
  - 1 GSa/s full waveform sampling
  - 16 us trigger buffer
  - 16 channels
  - Built-in comparator generates trigger primitives
  - Low cost 250nm CMOS
  - Readout close to PMT avoids costly cabling and amplification

- Technology already used in 3 projects – developed FW/SW base:
  - Belle II KLM upgrade, ~20k SiPM channels
  - Borehole Muon Detector (BMD) prototype: ~100 SiPM channels
  - Hawaii Muon Beamline (HMB): ~60 SiPM channels
  - Cherenkov Telescope Array (CTA) ~2k SiPM or PMT /telescope

- Firmware development underway at Hawaii and Nalu Scientific