eRD14 – EIC PID consortium

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

M. Alfred, L. Allison, M. Awadi, B. Azmoun, F. Barbosa, M. Boer, 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, D. Fields, Y. Furletova, C. Gleason, M. Grosse-Perdekamp, J. Harris, X. He, H. van Hecke, T. Horn, J. Huang, C. Hyde, Y. Ilieva, G. Kalicy, A. Kebede, B. Kim, E. Kistenev, Y. Kulinich, M. Liu, R. Majka, J. McKisson, R. Mendez, P. Nadel-Turonski, K. Park, K. Peters, T. Rao, R. Pisani, P. Rossi, M. Sarsour, C. Schwarz, J. Schwiening, C.L. da Silva, N. Smirnov, J. Stevens, A. Sukhanov, S. Syed, J. Toh, R. Towell, T. Tsang, G. Varner, R. Wagner, C. Woody, C.P. Wong, W. Xi, J. Xie, Z.W. Zhao, B. Zihlmann, C. Zorn.

Contacts:
P. Nadel-Turonski <turonski@jlab.org>,
Y. Ilieva <jordanka@physics.sc.edu>

Generic Detector R&D for an Electron Ion Collider

Advisory Committee Meeting, JLab, July 13-14, 2017

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)

PID – an essential part of the EIC physics program

- The physics program for a generic EIC is outlined in the 2015 NSAC LRP, the 2012 White Paper, the 2010 INT report, etc.
- Excellent PID is crucial for achieving these physics goals!

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 is on hadron ID with a supplementary electron ID capability

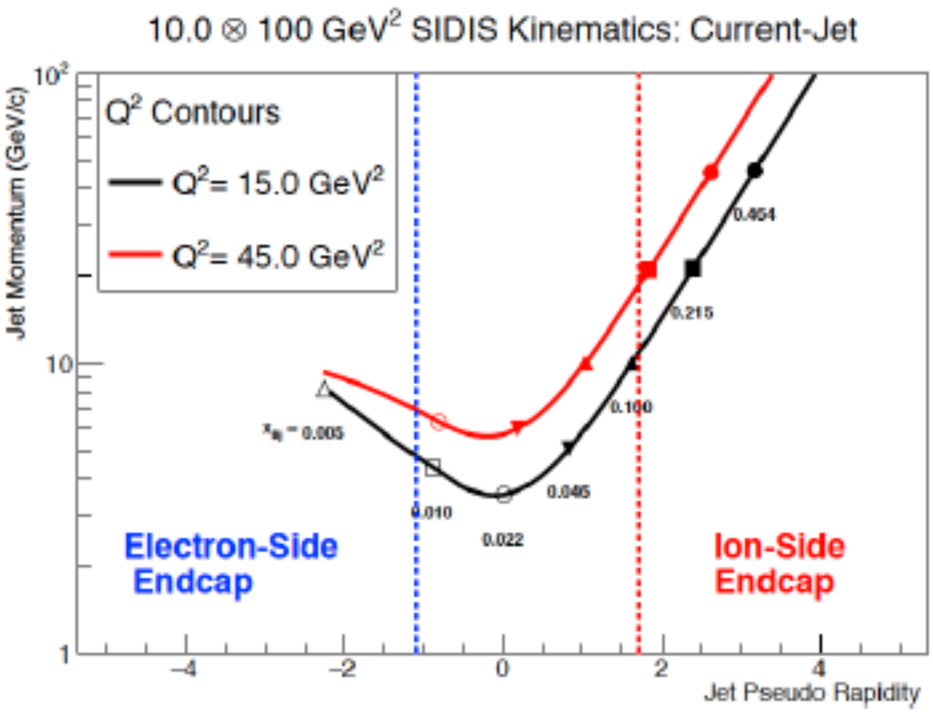
2. A cost-effective sensor and electronics solution

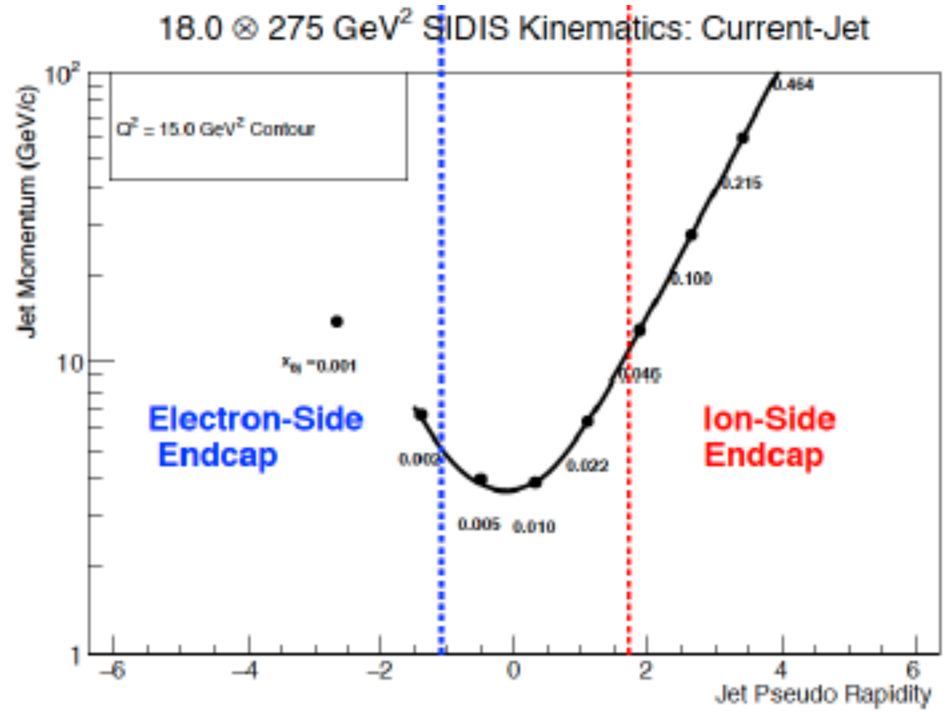
- Requirements and development of photosensors
- Development of readout electronics needed for prototyping

3. Maximized synergies and minimized cost of R&D

- Active collaboration within the consortium, sharing experience in weekly meetings, and drawing up common consortium goals and priorities.
- Strong synergies with non-EIC experiments and R&D programs (PANDA, CLAS12, GlueX, PHENIX, LAPPDs) resulting in large savings on hardware.

Hadron kinematics at an EIC

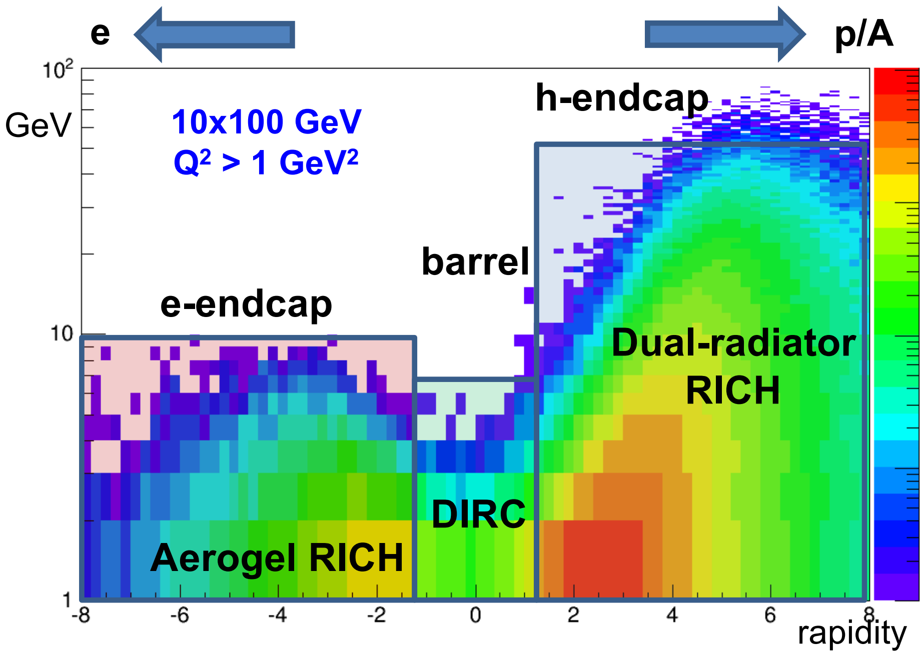


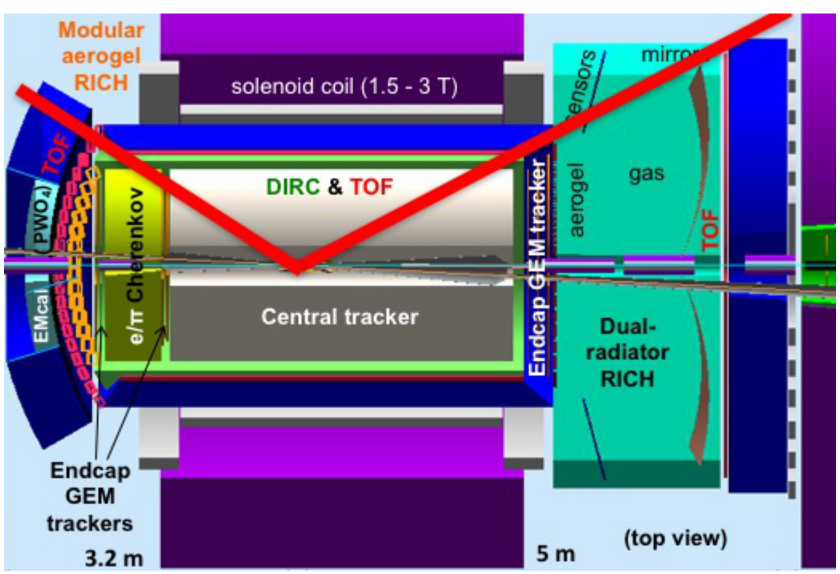


- The maximum hadron momentum in the endcaps is close to the electron and ion beam energies, respectively.

- 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 - implementation





- **h-endcap**: A RICH with two radiators (gas + aerogel) is needed for
  pi/K/p separation up to ~50 GeV/c
- **e-endcap**: A compact aerogel RICH which can be projective
  pi/K/p separation up to ~10 GeV/c
- **barrel**: A high-performance DIRC provides a compact and cost-effective way to cover the area.
  pi/K/p separation up to ~6-7 GeV/c
- **TOF (and/or dE/dx in 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

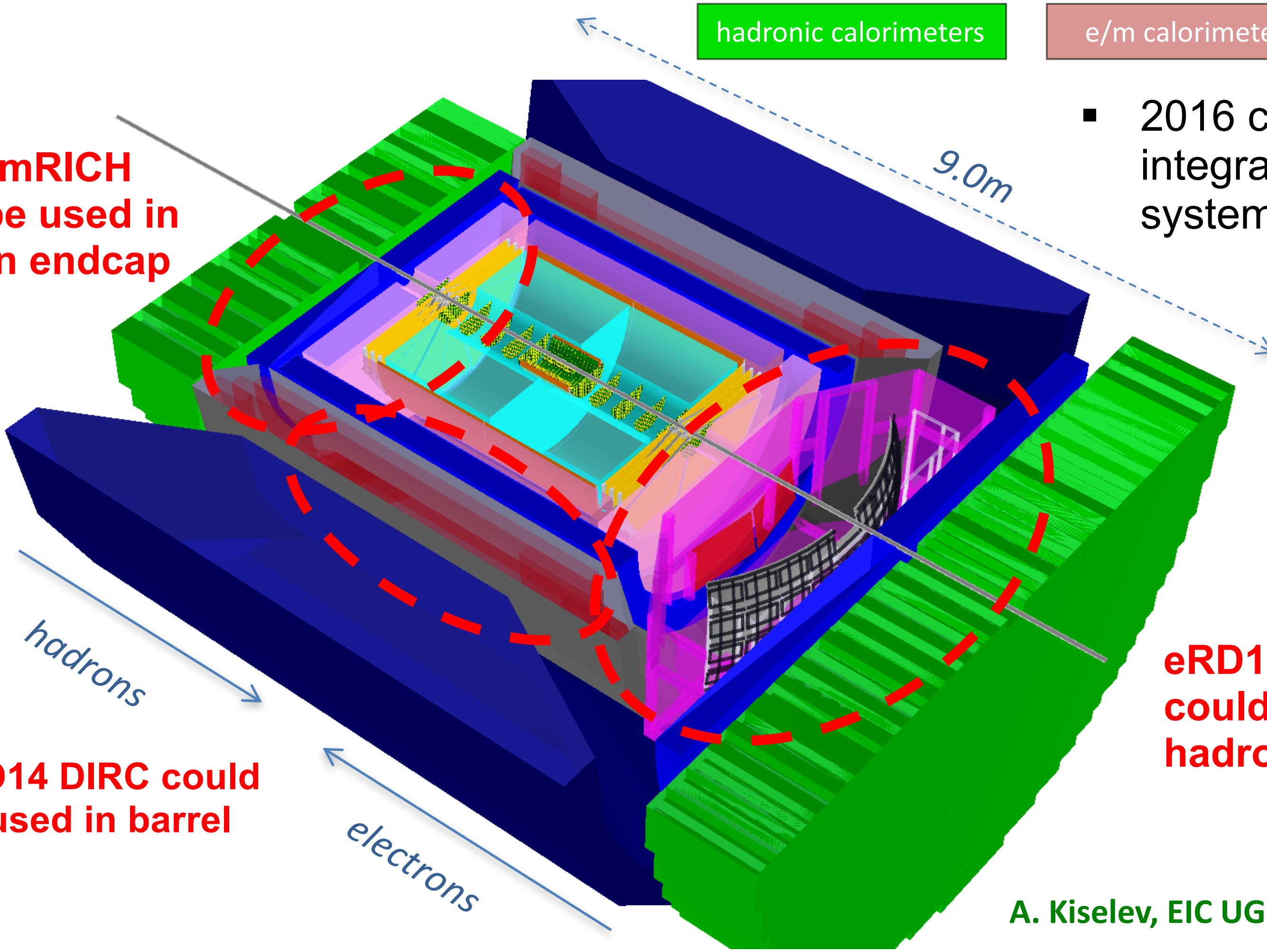
BNL BeAST EIC central detector

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

hadronic calorimeters | e/m calorimeters | RICH detectors

- 2016 changes made integration with eRD14 systems much easier!

eRD14 mRICH could be used in electron endcap



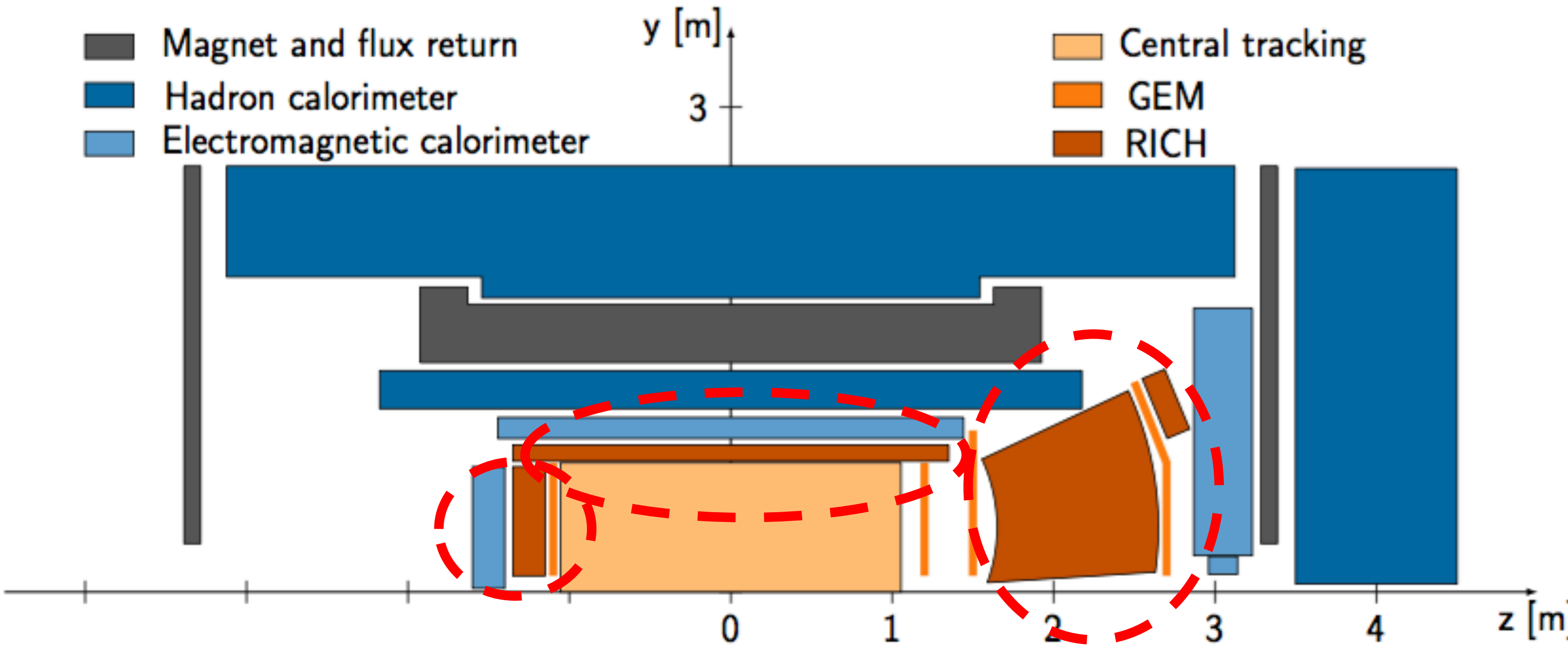
eRD14 dRICH could be used in hadron endcap

eRD14 DIRC could be used in barrel

A. Kiselev, EIC UG meeting, July 2016

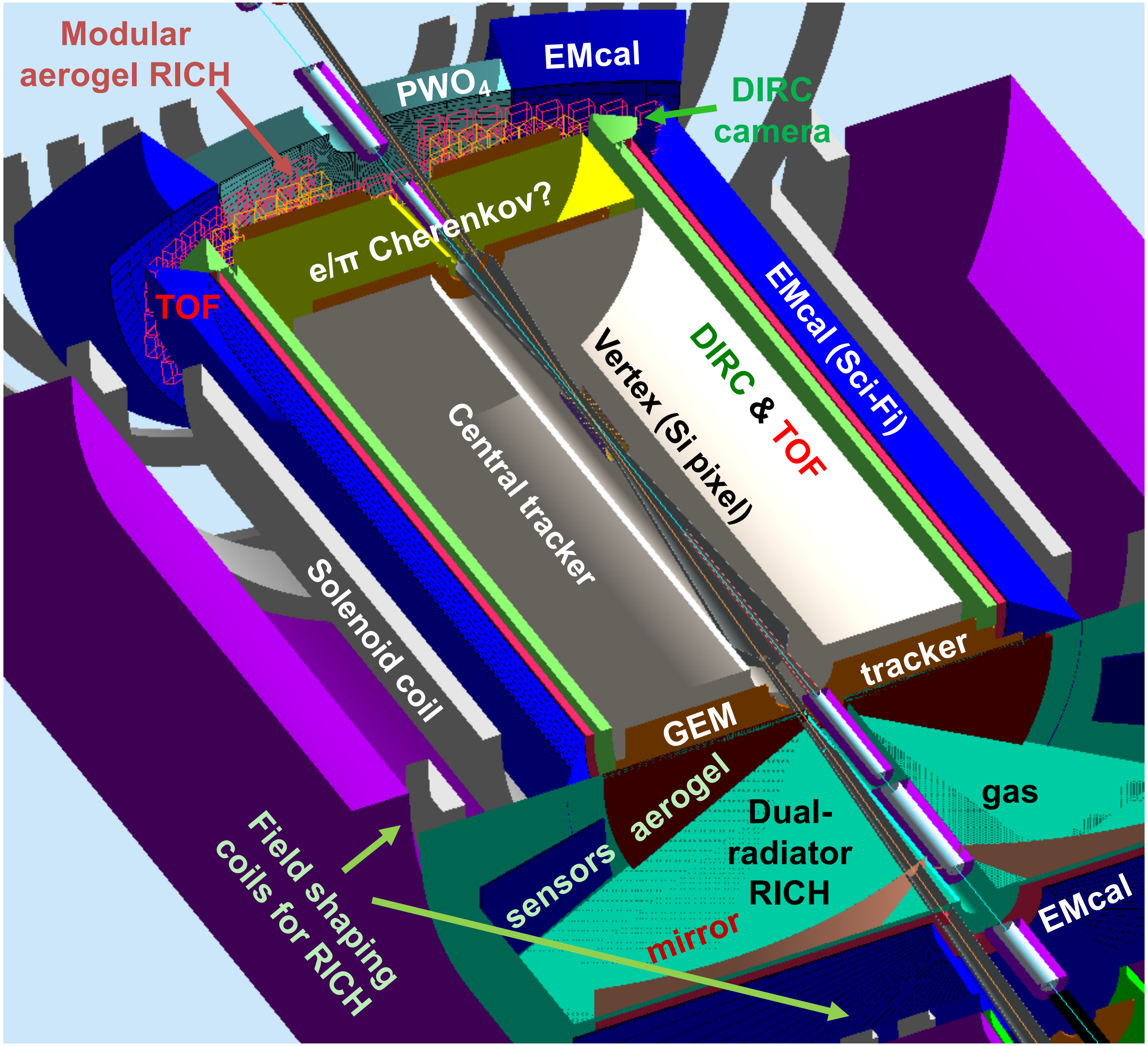
silicon trackers | TPC | GEM trackers | Micromegas barrels | 3T solenoid cryostat | magnet yoke

BNL ePHENIX EIC central detector



- The DIRC, mRICH, and TOF systems already considered in current concept.
- In addition, either the eRD14 dRICH or the eRD6 gas RICH could be used. The two options will be 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.

Dual-radiator RICH (dRICH)

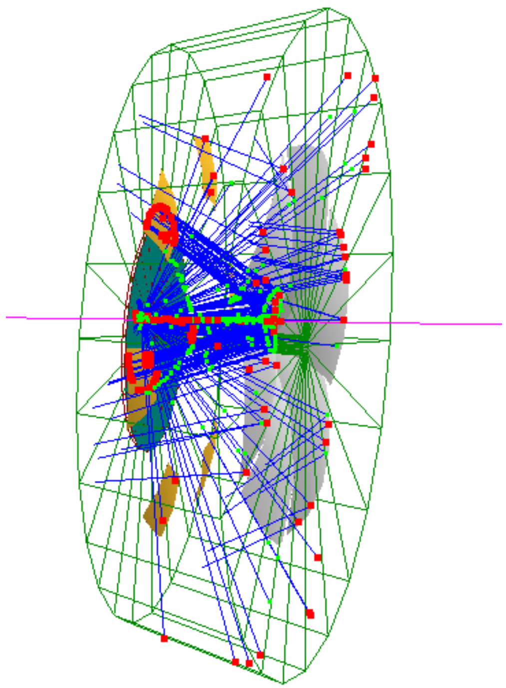
Goal:

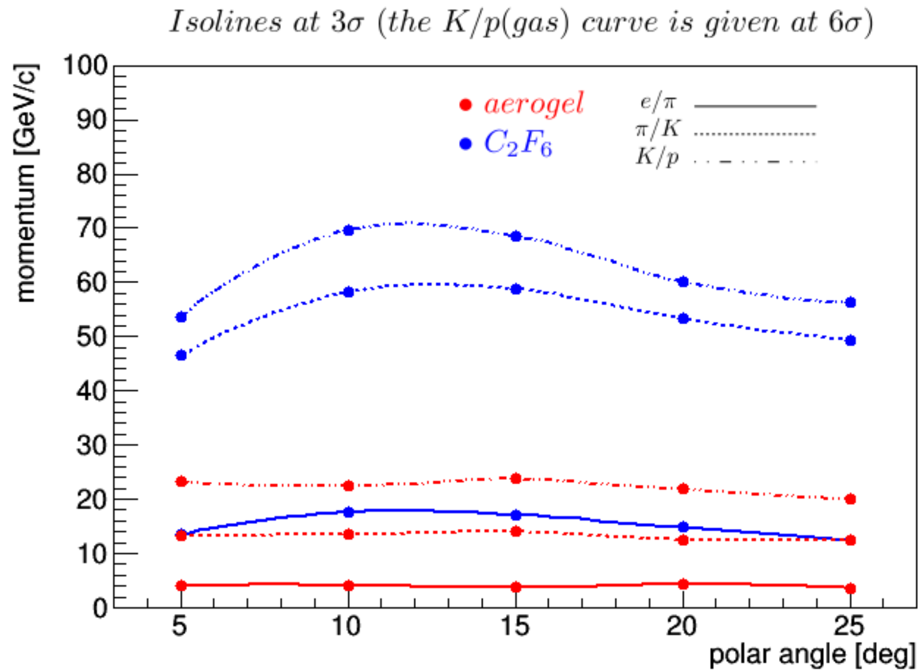
- Continuous coverage for >50 GeV/c for pi/K and >10 GeV for e/pi
- First such device developed for endcap of solenoidal detector

FY 18:

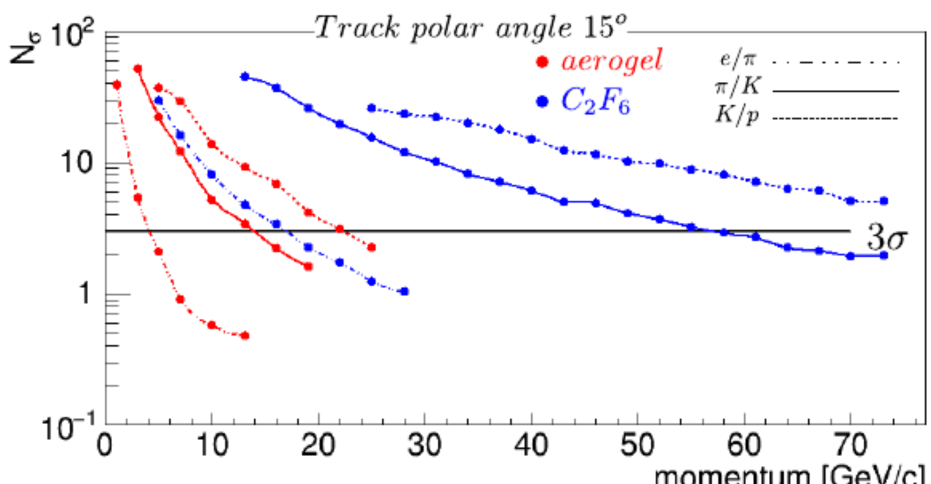
- Adaptation of dRICH geometry and comparison with eRD6 gas RICH
- Work on sensors (synergies with mRICH) and prototype (with INFN)

dRICH - overview



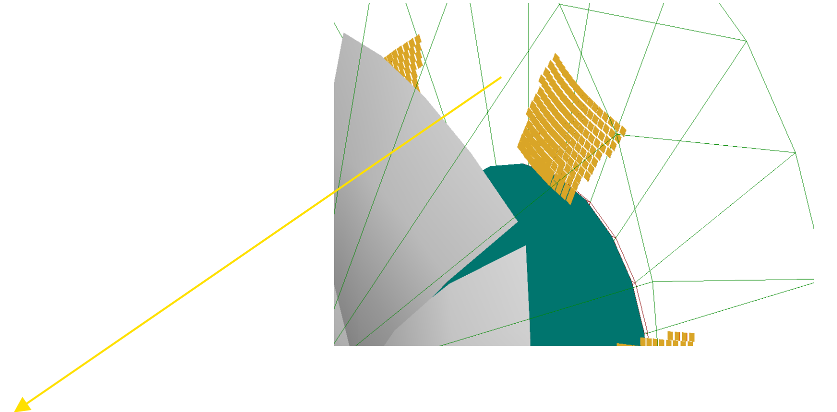


Geant4 simulation includes magnetic field



- Aerogel (n=1.02) & C_2F_6 gas
  - Continuous coverage
- Outward reflecting mirrors
  - Sensors away from the beam
  - No scattering in aerogel
- Sector-based 3D focusing
  - Reduced photosensor area

dRICH – activities



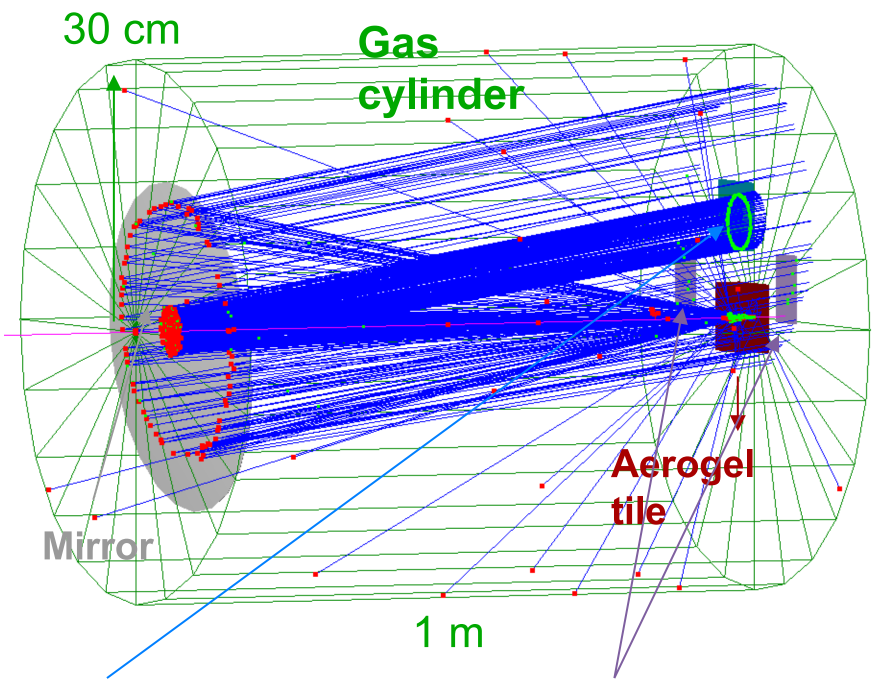
FY 17 progress

- Completed baseline design
  - Geometry and field of JLab detector
- Studied photosensor integration
  - Evaluated different sensor options
  - Focal plane layout allows optimization of emission error and could improve QE
- Designed protype
- First publication (NIM A)

Proposed FY 18 activities

- Adapt dRICH geometry to match BNL detectors (ePHENIX, BeAST)
  - Evaluate performance with the corresponding magnetic field maps
  - Apply dRICH reconstruction to eRD6 gas RICH and compare performance
- Study dRICH performance for a physics channel of interest to the EIC in presence of backgrounds
- Evaluate photosensor options in test beam (synergy with mRICH)
- Work on the dRICH prototype
  - Activities can range from testing of key concepts to a full realization

dRICH – prototype



4 PMTs 5x5 cm^2 each one, the **same 4 PMTs**
In different arrangement used for aerogel's photons

1 p.e. error (mrad)	Aerogel	gas C_2F_6
Chromatic	3.7	0.85
Emission	0.2	0.85
Pixel (3 mm)	0.9	1

- *Simulation of the dRICH prototype in a minimal configuration*
- ***Minimal equipment***:
- - 4 PMTs (SiPM) , shared with mRICH prototype activity (SiPM provided by INFN-Ferrara); used for the gas (whole ring covered) and for the aerogel in a different configuration (part of the ring)
- - aerogel block
- - a small miror with R = 2 m
- We will exploit all the possible synergies with mRICH and other outside activities (*e.g.*, CLAS12)

Modular aerogel RICH (mRICH)

Goal:

- Compact device with coverage up to 10 GeV/c for pi/K
- First aerogel RICH with lens-based focusing (for performance and cost)

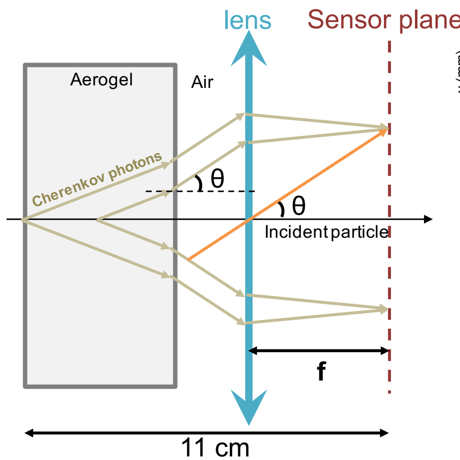
FY 18:

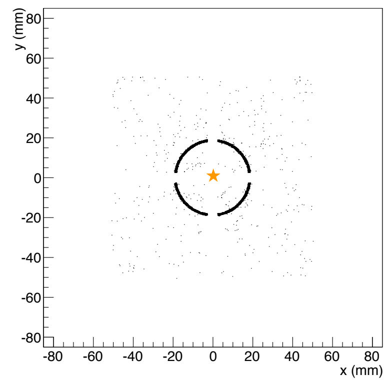
- Prepare and carry out 2nd test beam at Fermilab in the spring of 2018
- Implement the mRICH in full EIC detector simulations
- Use the mRICH to develop an integrated readout electronics solution

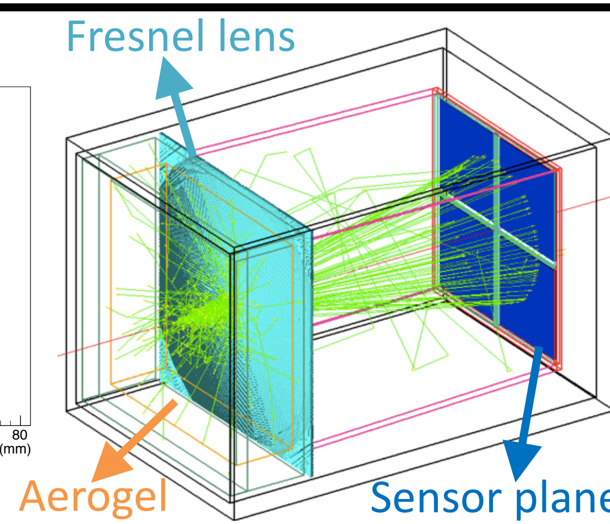
mRICH – lens-based focusing aerogel detector design

Smaller, but thinner ring improves PID performance and reduces length

Lens-Based mRICH Design

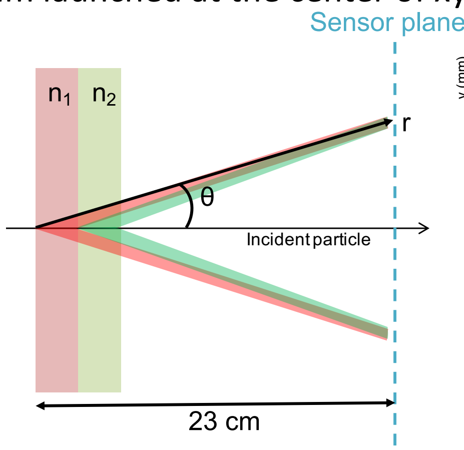


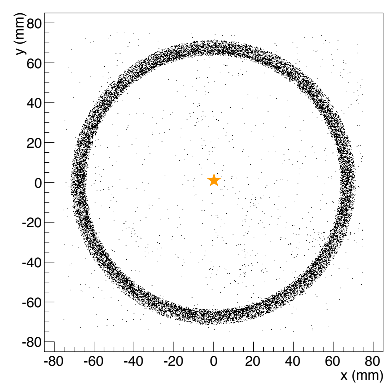




9 GeV/c pion beam launched at the center of xy plane in simulation

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



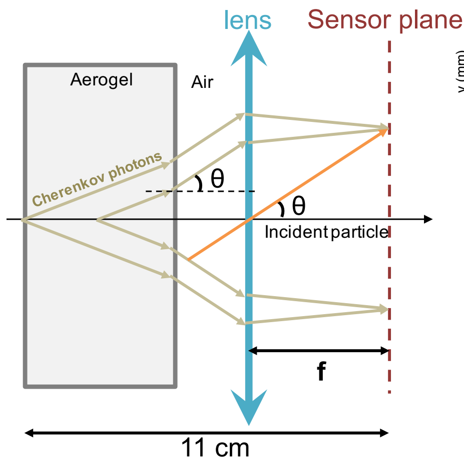


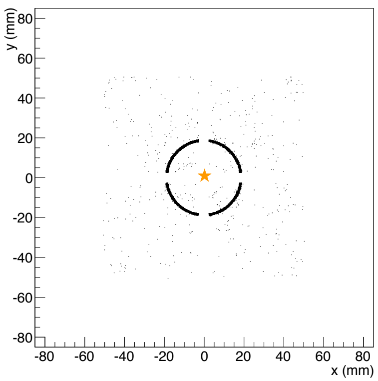
- EIC mRICH designed for K/pi ID up to 10 GeV/c
- BELLE-2 ARICH aims to separate pion and kaon up to 4 GeV/c

mRICH – lens-based focusing aerogel detector design

Smaller, but thinner ring improves PID performance and reduces length

Lens-Based mRICH Design

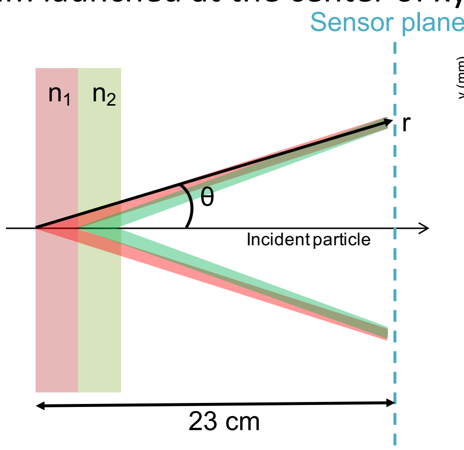


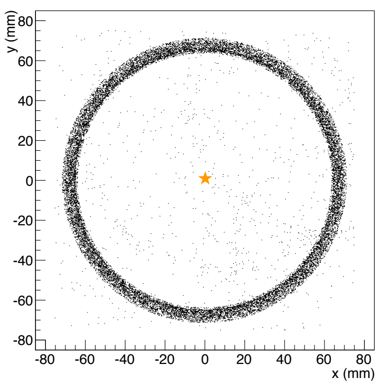


- 9GeV/c pion beam launched at the center of xy plane in simulation
- **Smaller and thinner** ring image

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

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



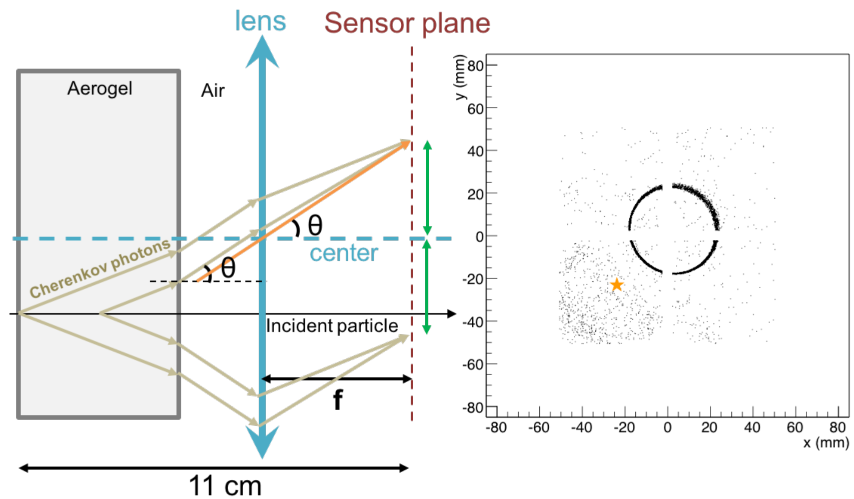


- EIC mRICH designed for K/pi ID up to 10 GeV/c
- BELLE-2 ARICH aims to separate pion and kaon up to 4 GeV/c

mRICH – lens-based focusing shifts image to center

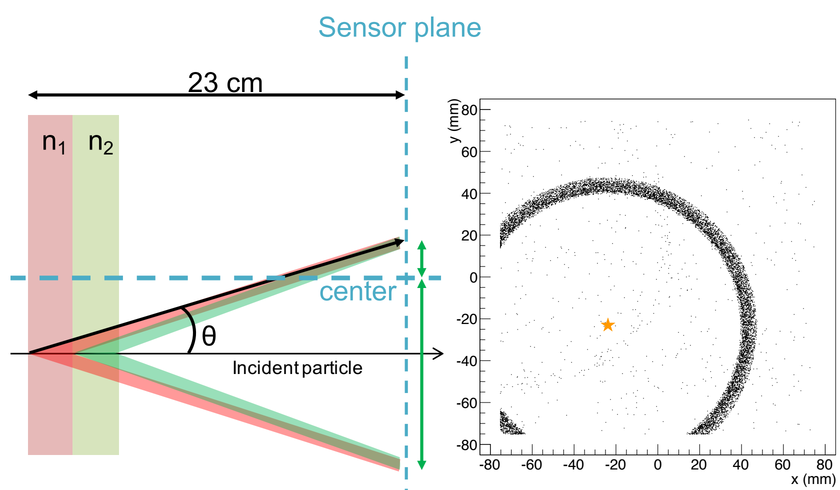
Ring centering of lens-based optics reduces sensor area (main cost driver)

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)

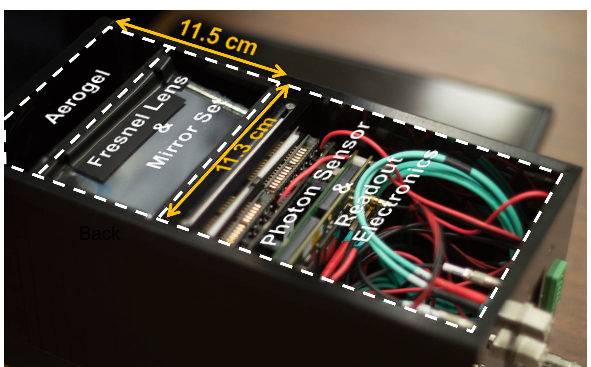


- 9 GeV/c pion beam incident at third quadrant (star) in simulation
- Ring is centered at point of incidence

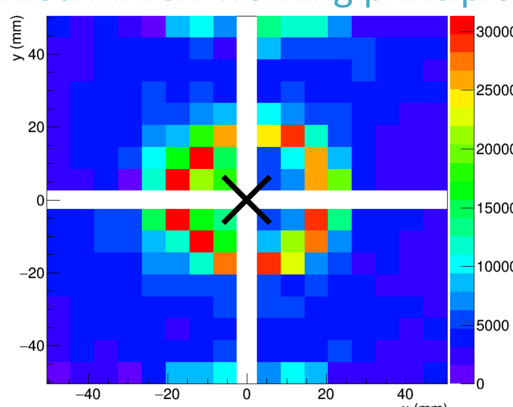
mRICH – FY17 progress

Achievement	Status and Related Proposed Activities
The 1st beam test results (see the January 2017 report for details) accepted for publisation in NIM A	**Done**
The 2nd prototype components have been constructed at GSU with the following improvements: • Longer lens focal length (6”) • Smaller sensor pixel size (3mm x 3mm) • Separation of the optical components from the readout electronics	Continue in FY 2018 2nd Beam test in Spring 2018 • k/pi separation power • e/pi separation power (<2 GeV/c)
Initial implementation of the mRICH detector system in both the sPHENIX/ePHENIX and JLEIC simulations	Continue in FY 2018 simulation with event generator

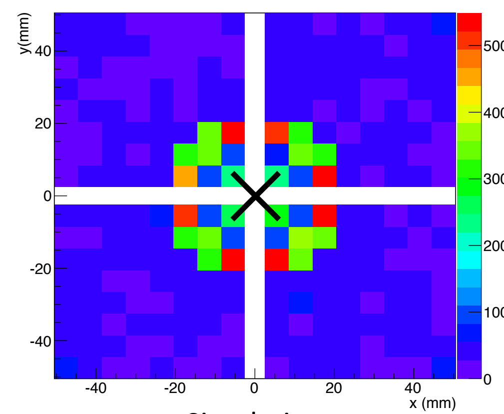
The 1st test beam result verified mRICH working principle and validated simulation



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



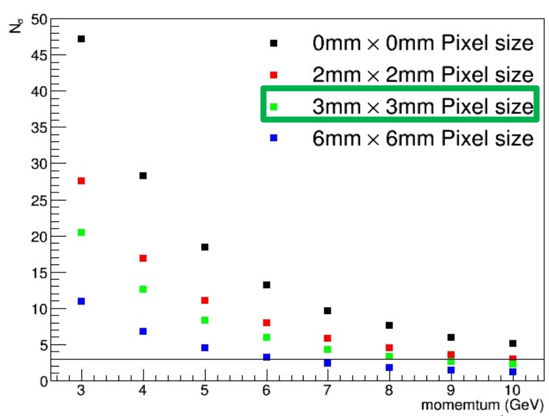
Test beam



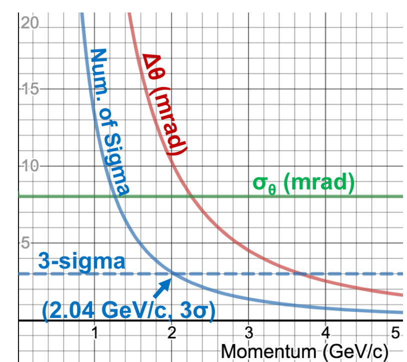
Simulation

mRICH – progress and proposed FY18 activities

Achievement	Status and Related Proposed Activities
The 1st beam test results (see the January 2017 report for details) will be published in NIM A	Done
The 2nd prototype components have been constructed at GSU with the following improvements: • **Longer lens focal length (6")** • **Smaller sensor pixel size (3mm x 3mm)** • **Separation of the optical components from the readout electronics**	**Continue in FY 2018** **2nd Beam test in Spring 2018** • **k/pi separation power** • **e/pi separation power (<2 GeV/c)**
Initial implementation of the mRICH detector system in both the sPHENIX/ePHENIX and JLEIC simulations	Continue in FY 2018 simulation with event generator



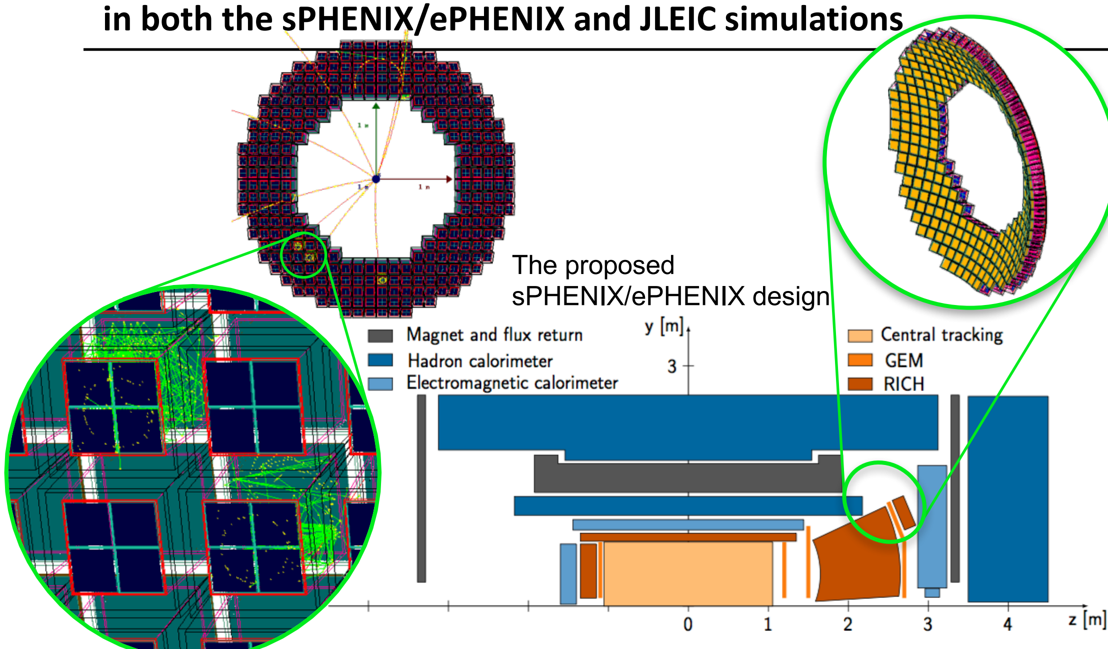
- Projected K/pi separation of mRICH 2nd prototype detector (Green dots)
- 2nd prototype detector can achieve 3-sigma K/pi separation up to 8 GeV/c

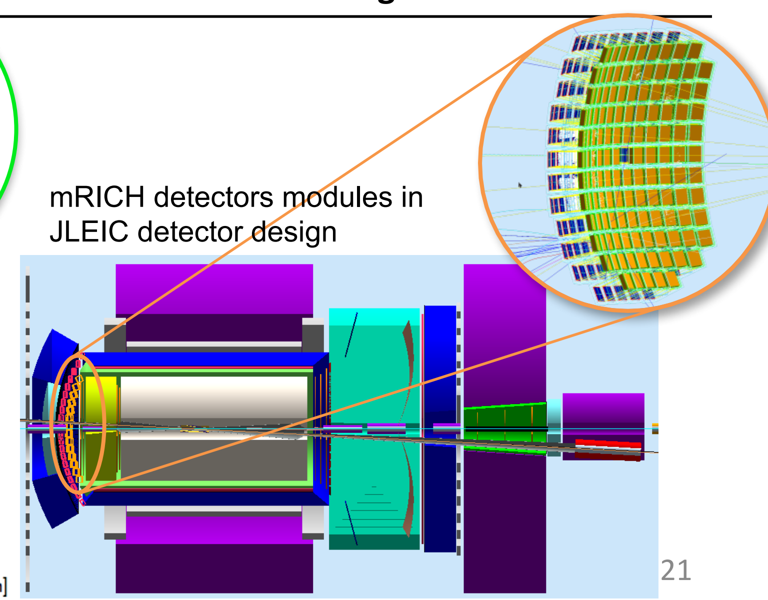


- Projected e/pi separation of mRICH 2nd prototype detector (blue solid line)
- 2nd prototype detector can achieve 3-sigma e/pi separation up to 2 GeV/c

mRICH – progress and proposed FY18 activities

Achievement	Status and Related Proposed Activities
The 1st beam test results (see the January 2017 report for details) will be published in NIM A	Done
The 2nd prototype components have been constructed at GSU with the following improvements: • Longer lens focal length (6") • Smaller sensor pixel size (3mm x 3mm) • Separation of the optical components from the readout electronics	Continue in FY 2018 2nd Beam test in Spring 2018 • k/pi separation power • e/pi separation power (<2 GeV/c)
Initial implementation of the mRICH detector system in both the sPHENIX/ePHENIX and JLEIC simulations	**Continue in FY 2018** **simulation with event generator**





High-performance DIRC

Goal:

- Very compact device with coverage beyond 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

FY 18:

- Implementation of the high performance DIRC in a full EIC detector simulation
- Analysis of 2017 test beam at CERN using wide plates and cylindrical lens
- Evaluation of radiation hardness of NLak33 and replacement materials

DIRC – overview

High-Performance DIRC simulations

- Time-based reconstruction in combination with spatial imaging can significantly improve performance and/or allow cost-optimized wide plate geometry.
- Better timing (~50 ps) and short bars would further improve the electron ID capabilities.
- In FY18 the DIRC will be implemented in a full EIC detector simulation (ePHENIX)

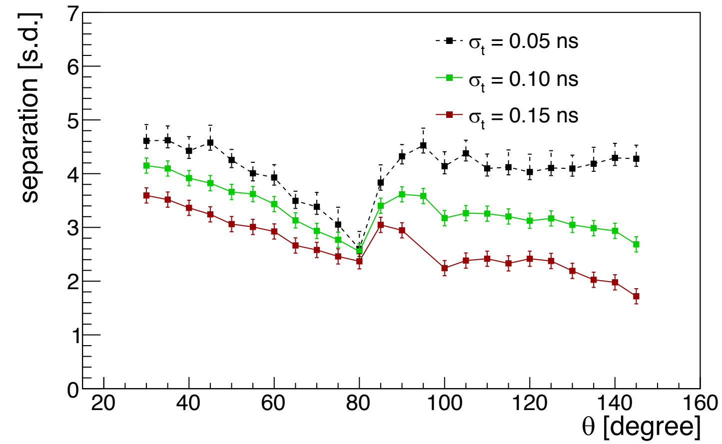
Experimental validation of simulations

- In FY17, the validation of simulations using the 3-layer spherical lens was concluded.
- A paper on prototype program and test bench tests of the 3-layer lens properties in preparation

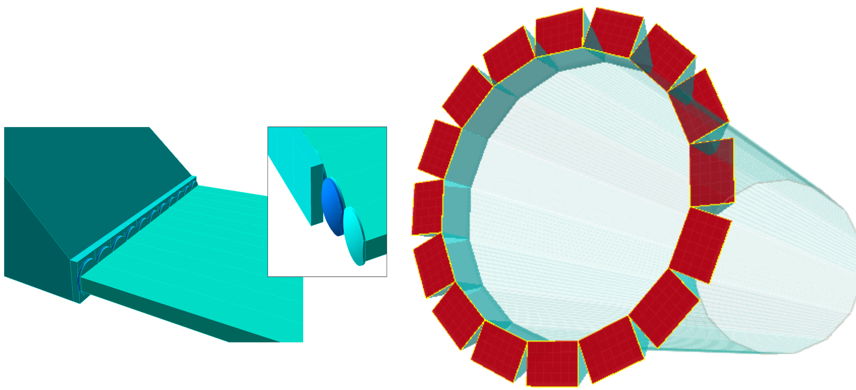
Wide plate geometry with cylindrical lens

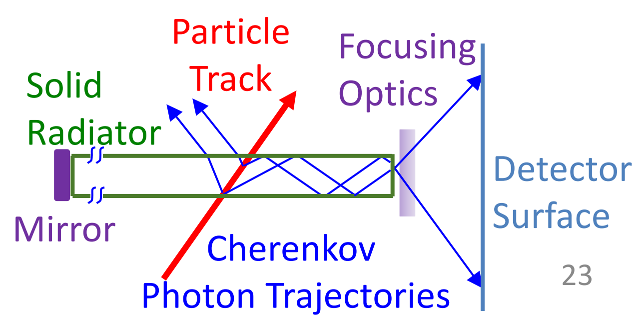
- New lens procured for the August 2017 test beam, which will be analyzed in FY18

Time-based reconstruction



High performance DIRC in Geant 4



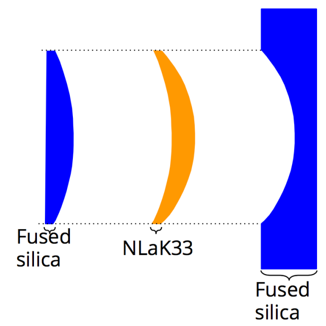


DIRC – radiation hardness of 3-layer lens

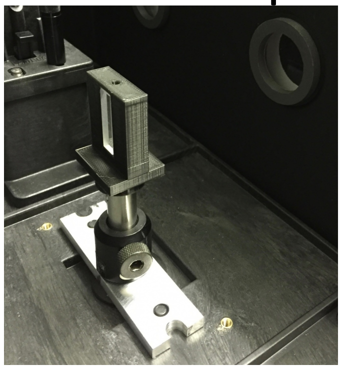
Radiation hardness tests of NLaK33 material at CUA

- First results using X-Ray source show the transmission at 420 nm drops by 1.3% per 100 rad.
- Further studies of NLaK33 planned using Co^{60}, and neutron sources.
- Radiation-hard alternatives to NLaK33 will be validated in FY18.
  - Promising candidate found

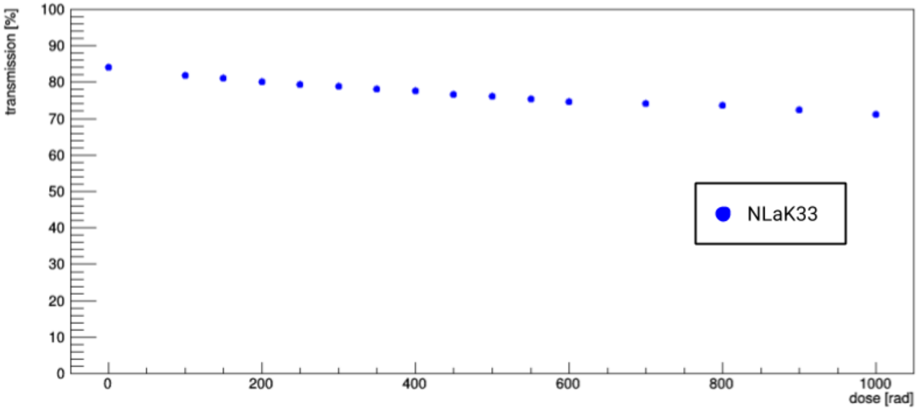
Spherical 3-layer lens



NLaK33 sample in CUA setup



Measured transmission (not Fresnel corrected) through the NLaK33 irradiation dose for 420 nm.

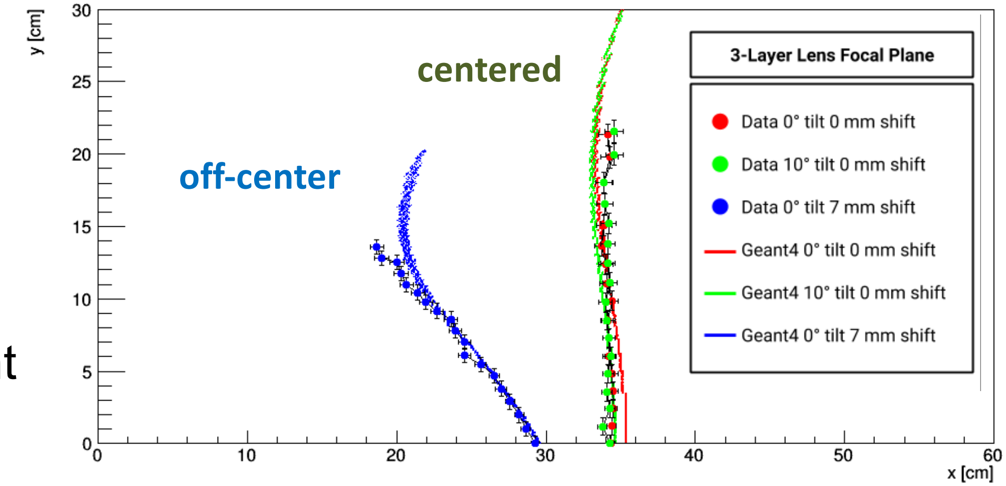


DIRC – validation of 3-layer lens optics

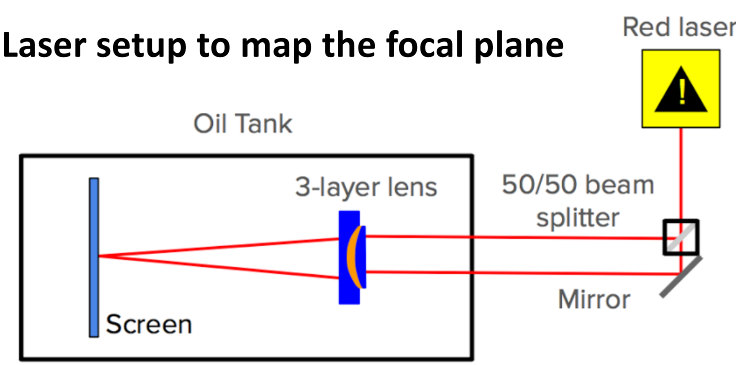
Mapping the focal plane at ODU

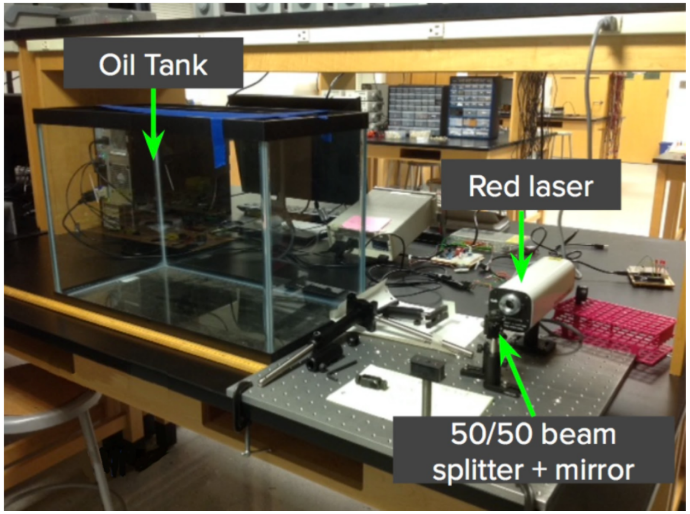
- 3D mapping of the focal plane and lens shifts in the horizontal plane.
- Results of measurements confirm flat focal plane for centered laser beams
- Off-center laser beams in agreement with simulation
- The new cylindrical 3-layer lens will be tested in FY18.

Measured and simulated focal plane 3-layer lens



Laser setup to map the focal plane





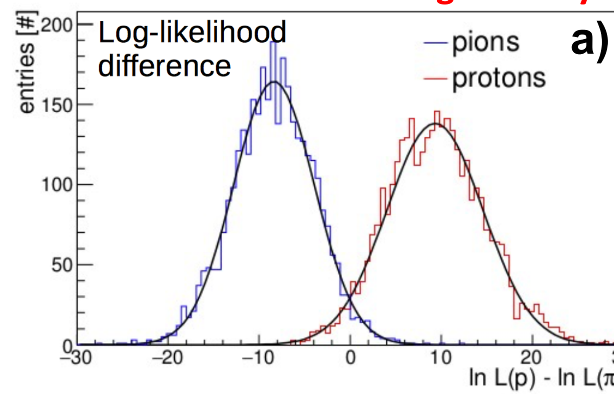
DIRC – validation in test beams at CERN

Test beams at the CERN PS using the PANDA Barrel DIRC prototype

- Larger pixels, slower electronics than EIC DIRC
  - prototype goal: 3σ π/K separation @ 3.5GeV/c
- CERN 2015 and 2016 data analysis finalized in FY17
  - Validated Geant4 simulation used for the EIC
  - Ph.D. thesis of L. Allison (ODU)
- With time-based reconstruction, a 3.6σ π/K separation at 3.5 GeV/c was achieved.
- Test beam in August 2017 will focus on wide plate geometry with the new cylindrical 3-layer lens.
  - Data analysis will be done in FY18
- Preparation for a future prototype program in the US directly validating the EIC DIRC performance

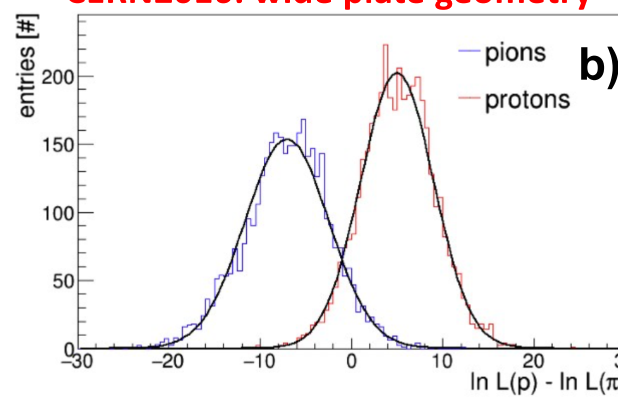
π/p separation power at a momentum of 7 GeV/*c* and a polar angle of 25°

CERN2015 narrow bar geometry



~3.6 s.d. π/K @ 3.5 GeV/c

CERN2016: wide plate geometry



~3.2 s.d. π/K @ 3.5 GeV/c

High-resolution TOF

Goal:

- Explore possibility of achieving very high timing resolution (~10 ps)

FY 18:

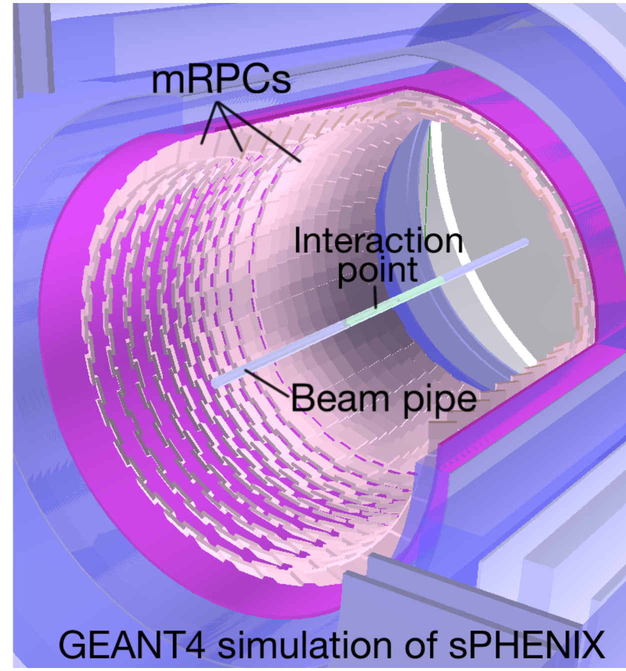
- Use new, thin glass plates to build an mRPC with 48 gaps
- Develop new amplifiers and electronics
- Measure time resolution of ANL MCP-PMT

TOF – overview

High Resolution TOF R&D w/ Goal of 5-10 ps

Currently at 20 ps, and only 2nd group in world to achieve this

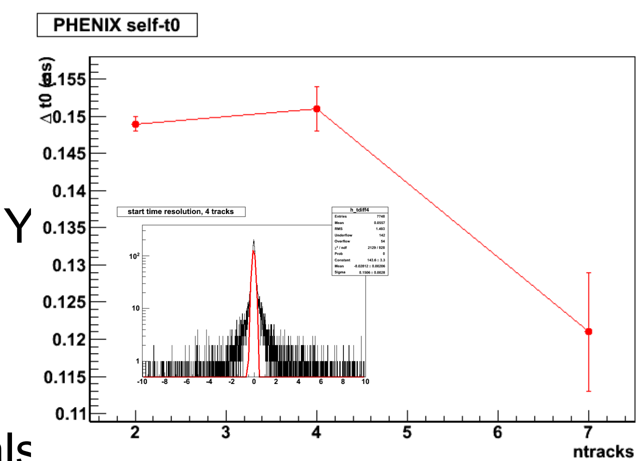
- Capability (3σ separation. assuming 10 ps):
  - Barrel@1m: π/K@3.5, K/p@6 GeV/c
  - Forward@3m: π/K@6.5, K/p@11 GeV/c
- Compact (~10 cm radial space required)
  - *verified in GEANT4 detector simulation*
- Very cost effective



GEANT4 simulation of sPHENIX

Accomplishments in FY17

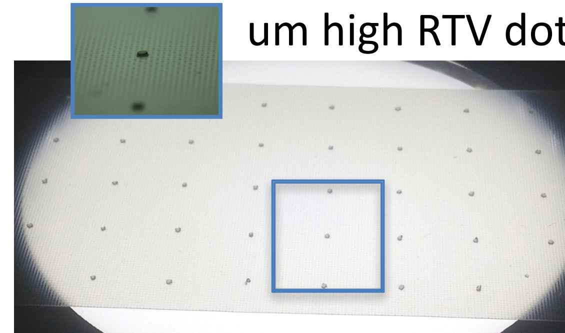
- Studies of self-determined start time in
  - PYTHIA e+p toy Monte Carlo
  - PHENIX real data using the TOF.E (consistent with TOF.E resolution of 150 ps)
  - Full GEANT4 sPHENIX simulation (study in progress)
- Addition of IHEP (Dr. Alexei Denisov *et al*.) and CCNY (Prof. Bruce Kim) - crucial detector and EE experts
- Systematic study done of signal bottlenecks
- Investigation of methods for stacking flexible materials



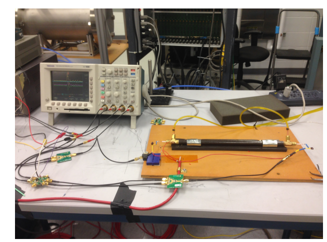
TOF – FY17 activities

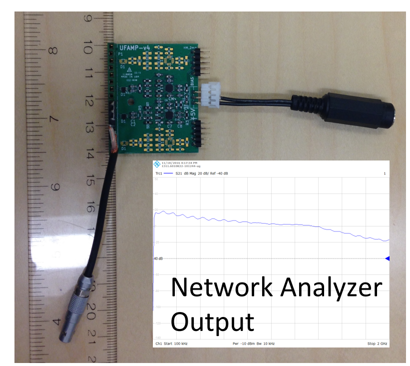
- Investigated techniques for creating parallel gas gaps for flexible materials, which would allow novel dielectrics for mRPCs such as G10 or nylon, which can be made very thin
- Fortunately, industry has provided an alternative sol'n: ultra-thin (100 um) glass for smartphone screen protectors. While semi-flexible, should be easily possible to make parallel gas gaps
- Building straw tube trackers to study positional dependence of resolution using cosmic rays
- Systematic study of issues and bottlenecks along the signal path using multiple techniques
    - Custom preamp limited to 300 MHz due to parasitic capacitances in board design
    - Cathode pickup strips transmission bandwidth also determined to be ~300 MHz!
    - Reflections from impedance mismatch studied and believed to be understood

screen-printed 160 um high RTV dots

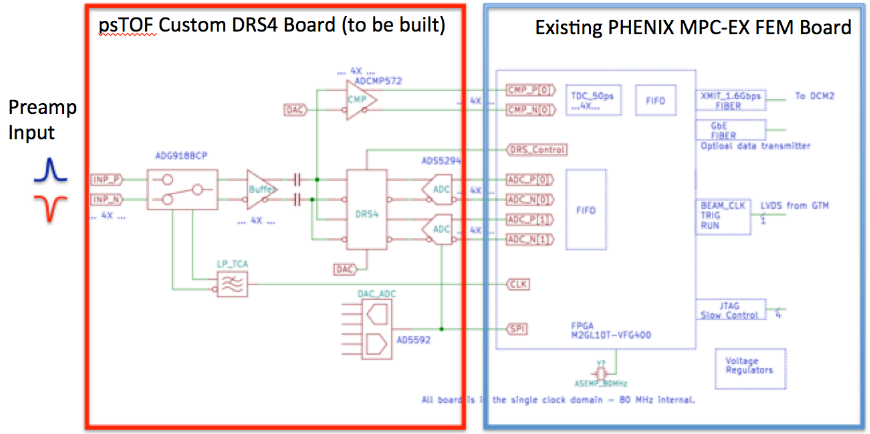


x10 lower cost for 100 um glass!





TOF – proposed FY18 activities



1. Rev2 of UFAMP (~0.8 GHz bandwidth and x10 gain) will be built and tested by CCNY/BNL
2. Ultra-thin glass (0.1 mm) mRPC with ~48 gas gaps (most ever), correcting impedance matches and bandwidth limits in Cu strip transmission bandwidth.
   - Test in cosmic rays using straw trackers, then in test beam at FNAL.
3. DRS4 prototype analog DRS4 board (1st prototype) will be built and tested.
   - Layout current being done by A. Denisov (IHEP), and FPGA control will be done by A. Sukhanov (BNL). Expect will need at least 3 iterations to perfect this board.
4. The QE and the TTS of single photoelectrons of the ANL UV sensitive MCP-PMT will be measured as a function of wavelength down to the cutoff of fused silica at ~170 nm

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.
- New FY18 effort on readout electronics (U. Hawaii and INFN-Ferrara)

Sensors in High-B Fields

Goals

- Identify the limitations of current MCP-PMTs and provide guidance for development of new photosensors
- 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

FY17 progress

- Measurement of gain performance of MCP-PMTs from Hamamatsu (10-μm) and Photonis (25-μm) as a function of field and orientation photosensors

Planned FY18 activities

- Gain measurements of other 10-μm MCP-PMTs in high-B fields
  - Extend gain optimization studies using new universal voltage divider
- Upgrade of JLab facility with a laser ($20k from ODU) for timing studies
- Development of a simulation for optimization of MCP–PMT design parameters
- Explore synergies with ANL high-B facility

LAPPDs

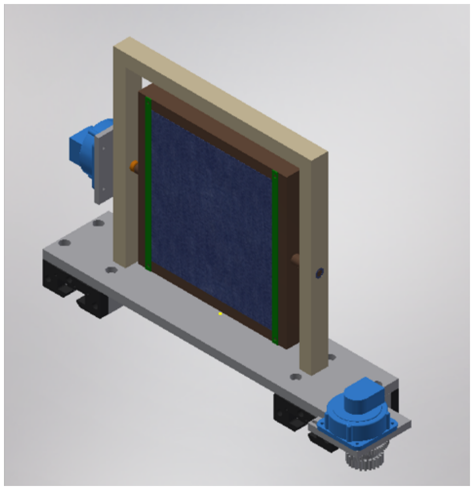
Goal:

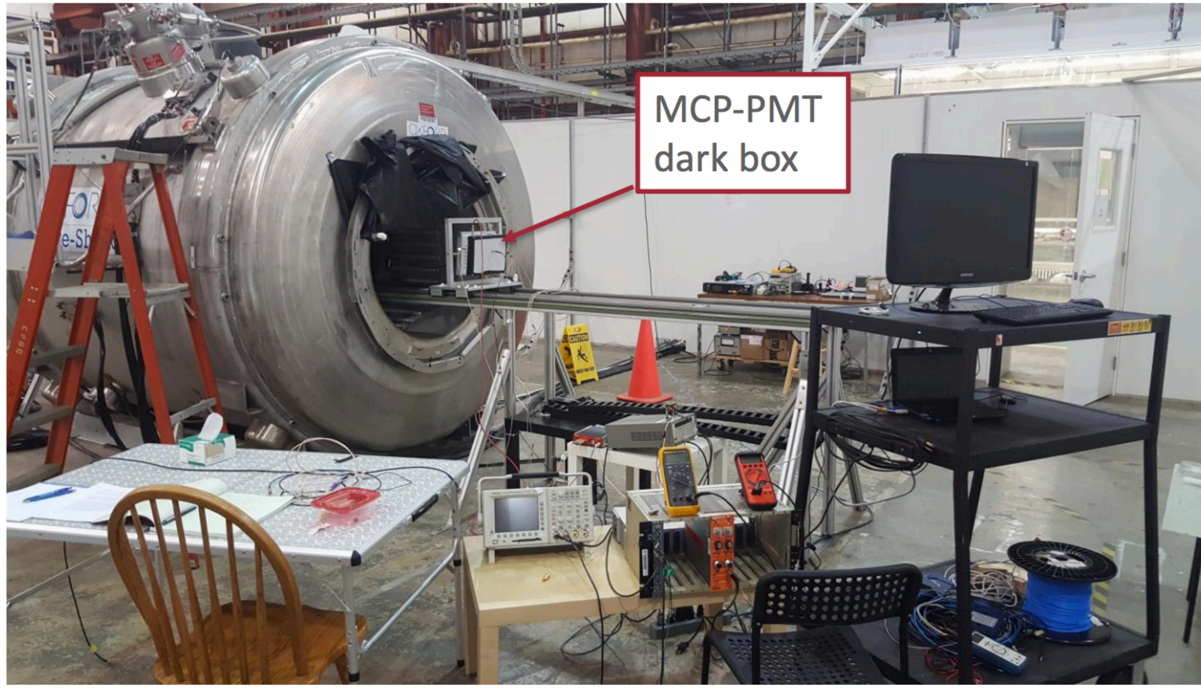
- Adapt LAPPDs to EIC requirements (pixelated readout, magnetic fields)

FY 18:

- Produce pixelated readout board with 2.5 x 2.5 mm^2 pad size
- Test the MCP-PMT with capacitive-coupling pixelated readout
- Produce and test an MCP-PMT with 10-μm pore size MCP and reduced spacing to improve high-B performance and timing (<10 ps?)
- Evaluate the 20 x 20 cm^2 LAPPD for EIC applications (in modified ANL characterization facility)

LAPPDs – high-B test facility at ANL



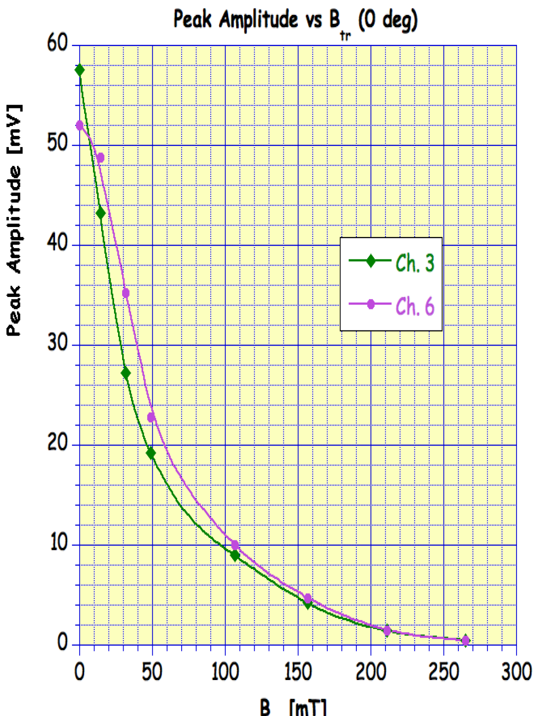


(left) Test stand with the capability of testing MCP-PMTs up to 20 x 20 cm^2
(right) Picture of MCP-PMT magnetic field test setup at ANL in building 366.

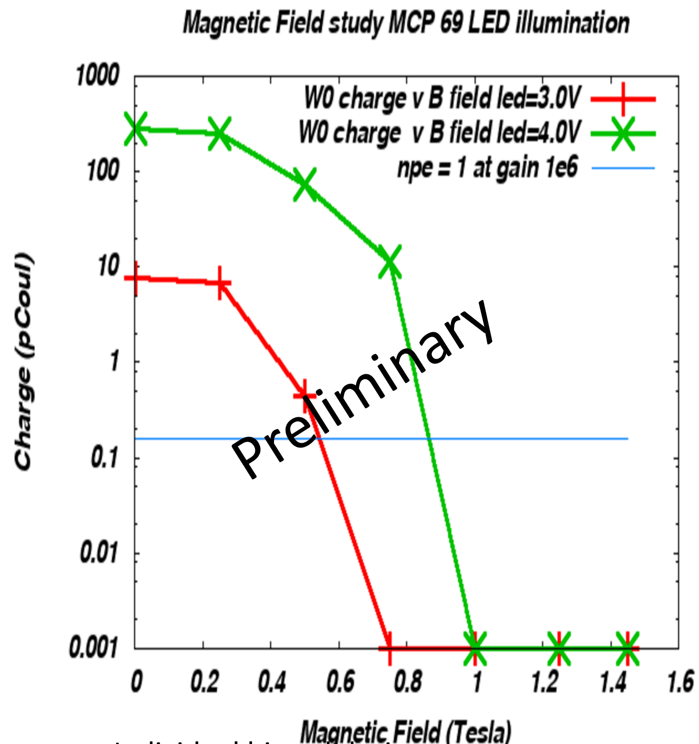
- A transporter with the capability of testing MCP-PMTs up to 20 cm x 20 cm
- All components are made of non-magnetic materials
- Electrically controlled router
- MCP-PMT center is well aligned with the center of the magnetic facility

First test experiment was done June 12-27: High voltage, magnetic field strength and angle dependences were all tested.

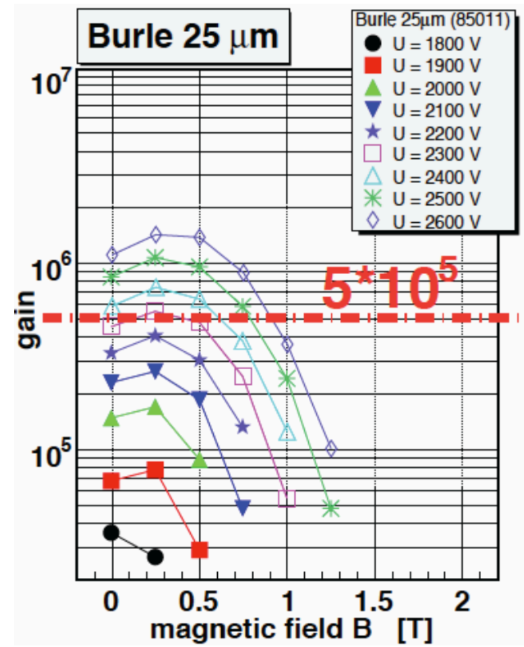
LAPPDs – high-B performance of 6x6 cm² MCP-PMT



Internal resistor chain design
Gain drops quickly 0< B < 0.15 T



Individual biased design
B field tolerance 0< B < 0.8 T



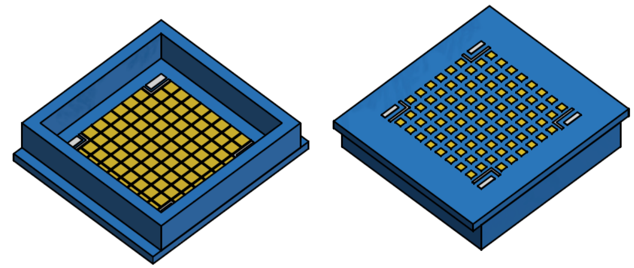
Burl 25um pore size MCP-PMT
B field tolerance 0< B < 1.0 T

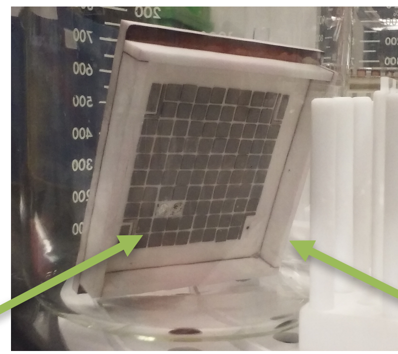
- Improvement from internal resistor chain design to individualyl biased design.
- Optimization of bias voltages for both MCPs is important, as found in high-B studies at JLab (consortium synergy).
- Comparable performance of LAPPD (unoptimized) to Burle tube in B field
- Performance dependence on high voltage and angle are currently under analysis

LAPPDs – pixelated readout

Baseline design is based on strip line readout, but EIC Cherenkov detectors (such as the DIRC) will see high rates and require pixelated pad readout

A new Cu pad and ceramic housing and thru-ceramic vias was designed w/ Innosys





Unfortunately, the pixelated design with VIAs failed due to technical difficulties

Current effort and FY 18 plan on pixelated readout:

Innoysys Inc. is making a second attempt to provide a new pad tile.

Meanwhile, we shifted our effort to pixelated readout detector through capacitive coupling design:

- The lower glass is coated with resistive ALD layer, 10kΩ
- Pad sizes are directly designed on the electronic board
- *Needs validation for Cherenkov applications*

Readout Electronics

New effort led by U. Hawaii (front end) and INFN-Ferrara (back end and integration)

Goal:

- Develop an integrated suite of readout electronics for the different photosensors used for the Cherenkov detector prototypes.

FY 18:

- Adaptation of CLAS12 electronics for 256 channel sensors and SiPMs
- Development of new front end based on TARGETX chip (Belle II)
- Integration of both front ends with a new back end based on CLAS12

Electronics – overview

Requirements

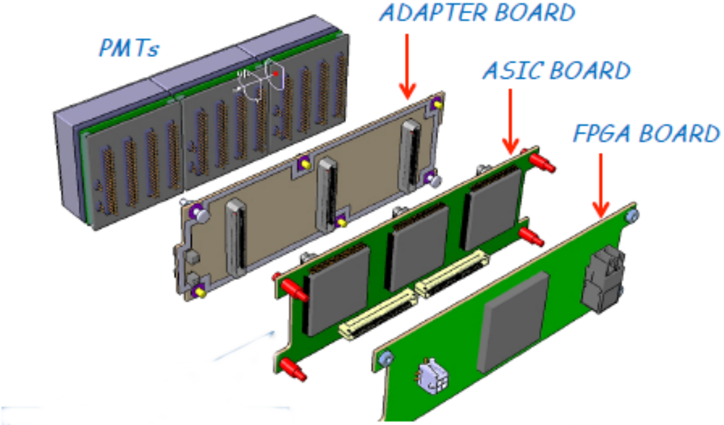
- Need to read out a range of different photosensors (MaPMTs, MCP-PMTs, and SiPMs) with similar size and pixelization (16x16 array of 3 mm pixels)
  - DIRC also requires good timing (<100 ps)
- The ultimate goal is to have common front end electronics with good timing that can be used for all sensors and a back end using a CODA-based DAQ
- To reduce cost and risk, a staged approach is adopted for the front end.
  - The back end / DAQ will be compatible with all front end stages

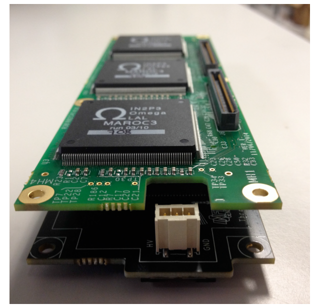
Implementation

- The existing Maroc-based CLAS12 front end was designed for MaPMTs with larger pixels, but will adapted by INFN for SiPMs with smaller pixels
  - For SiPMs; also a MaPMT fallback solution for the upcoming mRICH test beam
- A new front end based on TARGETX, which is used in Belle II, will be developed by U. Hawaii for initial use in the mRICH test beam
  - Initial focus on MaPMTs; can support SiPMs and MCP-PMTs (< 100 ps timing)
- Ultimately, a front end based on the new SiREAD chip from Hawaii will be used for all EIC PID needs.
  - SiREAD development currently has SBIR I funding

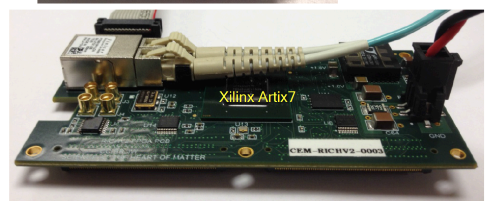
Electronics – Maroc

CLAS12 RICH electronics





Adapter & Asics Boards



FPGA Board

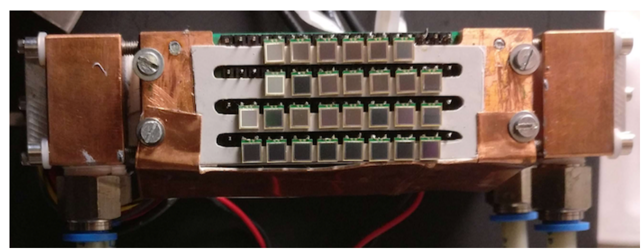
SSP Fiber-Optic DAQ

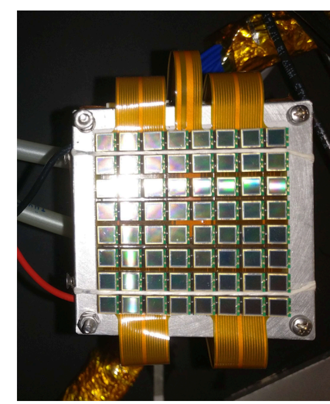
SiPMs

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

- ✗ High dark rate
- ✗ Low radiation tolerance

} Work at low temperature





Electronics – new front end development in FY18

- Task:
  - mRICH basic block
  - H13700 MCP-PMT with 256 channels
  - Compact form-factor: must be able to abut and tile
  - Readout close to PMT -> avoid cables and amplification

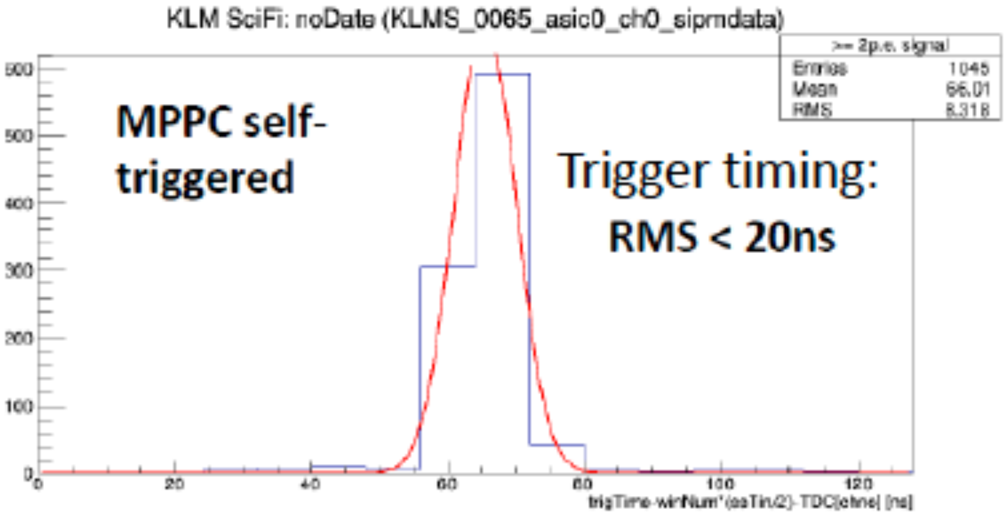
1st gen mRICH prototype based on existing TARGETX chip:

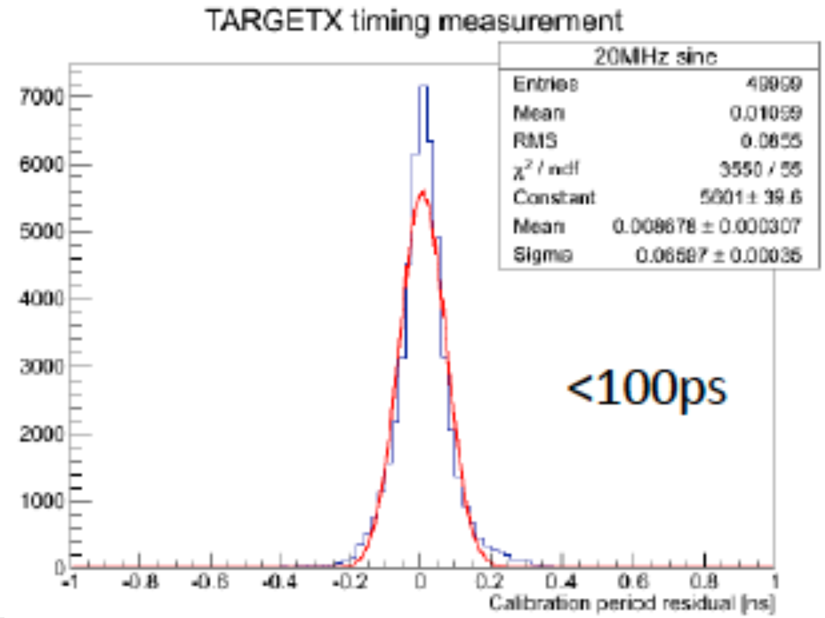
- 1GSa/s full waveform sampling
- 16 us trigger buffer
- 16 channels
- Built-in comparator generates trigger primitives
- Low cost 250nm CMOS

Used in 3 projects:

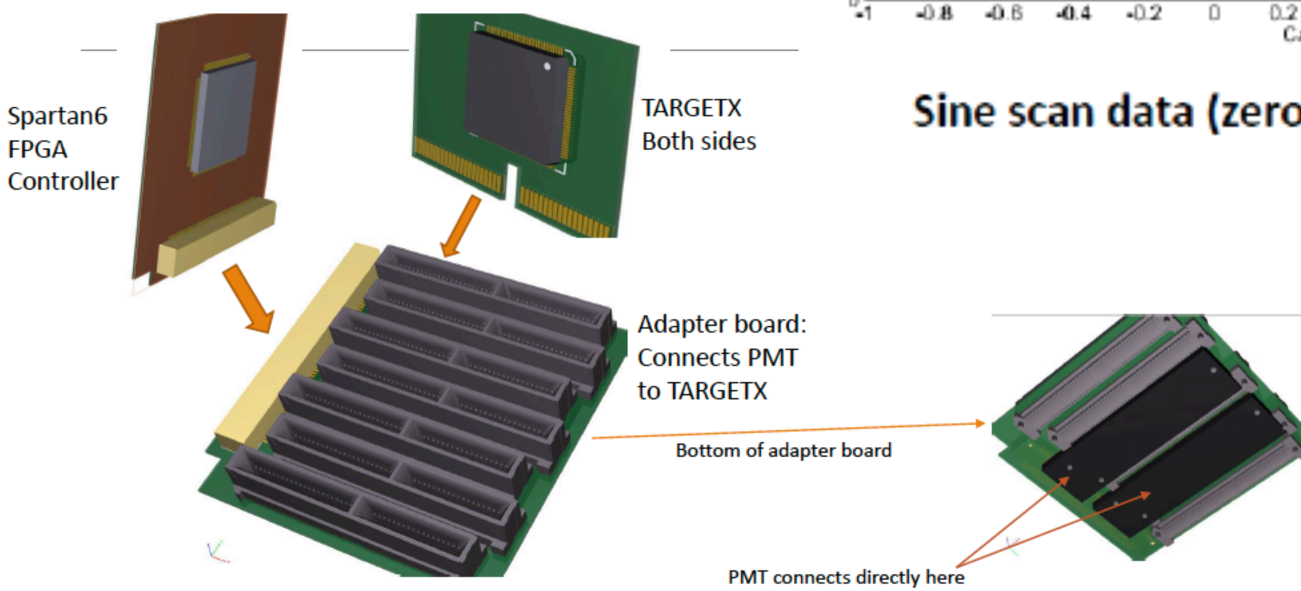
- Belle II KLM upgrade ~20k SiPM channels (Performance in next slides)
- Borehole Muon Detector (BMD) prototype: ~100 SiPM channels
- Hawaii Muon Beamline (HMB): ~60 SiPM channels

Electronics – TARGETX front end layout and timing





Sine scan data (zero crossing)



eRD14 FY18 budget (including overhead)

5.9 Budget by project

	100%	80%	60%
dRICH	$36.5k	$36.5k	$31.5k
mRICH	$99.8k	$81.8k	$64.8k
DIRC	$94k	$75k	$67k
TOF	$43k	$26.5k	$11.5k
high-B	$27.7k	$27.7k	$22.5k
LAPPD	$75k	$50k	$40k
Electronics	$44k	$38k	$29k
Total	***$420k***	***$335.5k***	**$266.3k**

5.10 Budget by institution

	100%	80%	60%
ANL	$75k	$50k	$40k
BNL	$38k	$21.5k	$6.5k
CCNY	$5K	$5K	$5K
CUA (and GSI)	$94k	$75k	$67k
GSU	$66.3k	$53.3k	$42.3k
U. Hawaii	$30k	$30k	$25k
INFN	$52.5k	$41.5k	$26.5k
JLab	$10.5k	$10.5k	$10.5k
USC (and INFN)	$48.7k	$48.7k	$43.5k
Total	***$420k***	***$335.5k***	**$266.3k**

Recent publications

C.P. Wong *et al.*, Modular Focusing Ring-Imaging Cherenkov Detector for Electron-Ion Collider Experiments, accepted for publication in Nucl. Instrum. Meth. A.

A. Deldotto et al.: Design and R&D of RICH detectors for EIC experiments, poster at RICH2016 (9th International Workshop on Ring Imaging Cherenkov Detectors), September 5-9, 2016, Bled, Slovenia, in press, published in Nucl. Instrum. Meth. A.

L. Allison: High-performance DIRC detector for use in an Electron-Ion Collider, Proceedings for ICHEP2016 (38th International Conference on High Energy Physics), August 3-10, 2016, Chicago, IL, submitted to Proceedings of Science.

G. Kalicy: PID systems for the JLab EIC full-acceptance detector, Proceedings for ICHEP2016 (38th International Conference on High Energy Physics), August 3-10, 2016, Chicago, IL, submitted to Proceedings of Science.

G. Kalicy et al.: DIRC detector for the future Electron Ion Collider experiment; Proceedings of the DIRC2015 Workshop, 11-13 November, Giessen, Germany, Journal of Instrumentation, 11, C02019 (2016).

Y. Ilieva et al.: MCP-PMT studies at the High-B test facility at Jefferson Lab; Proceedings of the DIRC2015 Workshop, 11-13 November, Giessen, Germany; Journal of Instrumentation, 11, C02019 (2016).

R. Dharmapalan et al: MCP-based photodetectors for cryogenic applications, Journal of Instrumentation, 11, C02019 (2016).

J. Xie et al.: Development of a low-cost fast-timing microchannel plate photodetector; Nucl. Instrum. Meth. A 824 (2016) 159-161.

J. Wang et al.: Development and testing of cost effective, 6cm×6cm MCP-based Photodetectors for fast timing applications; Nucl. Instrum. Meth. A 804 (2015) 84.

J. Xie et al. (LAPPD collaboration): Design and fabrication of prototype 6×6 cm2 microchannel plate photodetector with bialkali photocathode for fast timing applications, Nucl. Instrum. Meth. A 784 (2015) 242.

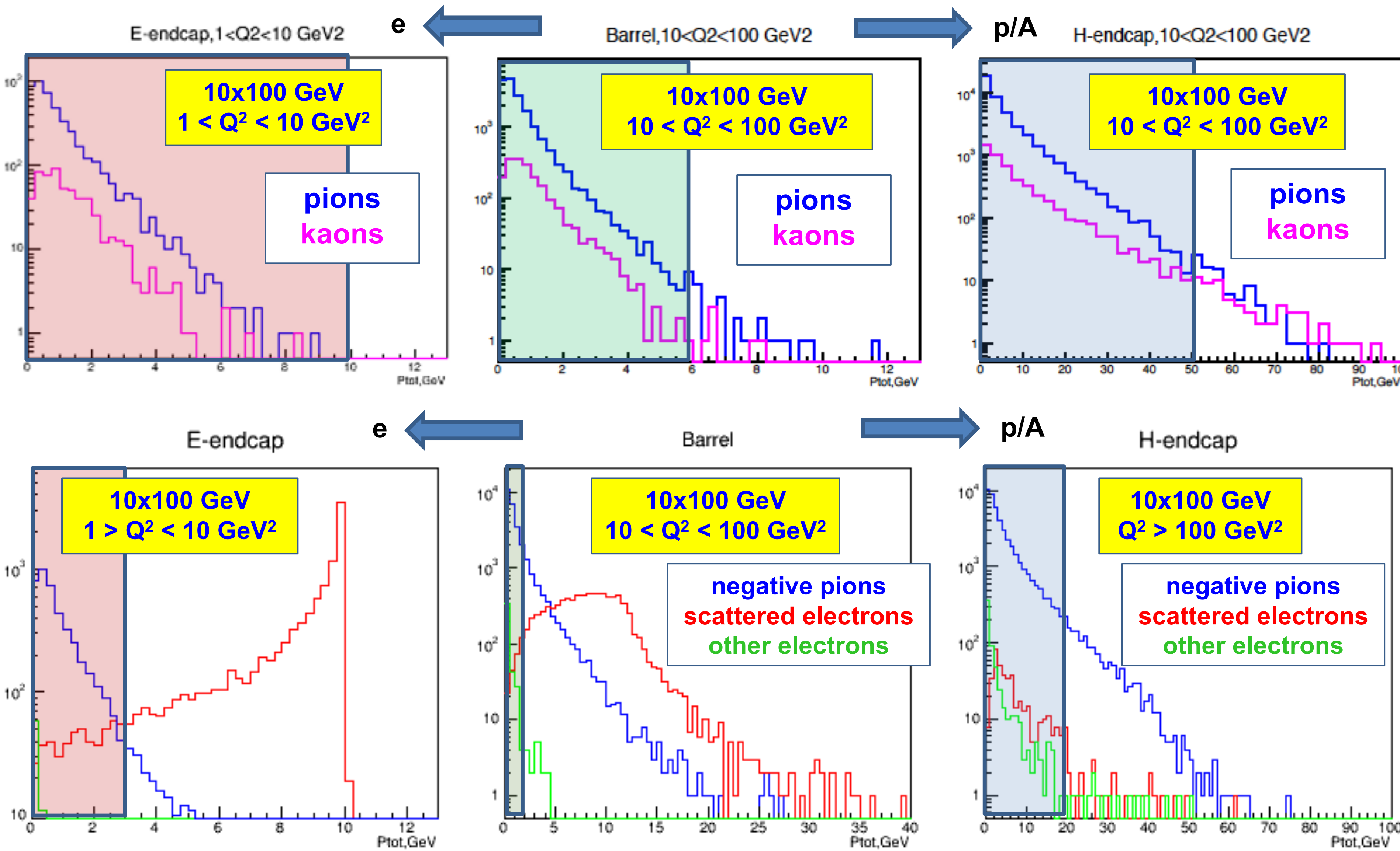
Thank you!

Also, please visit the eRD14 wiki

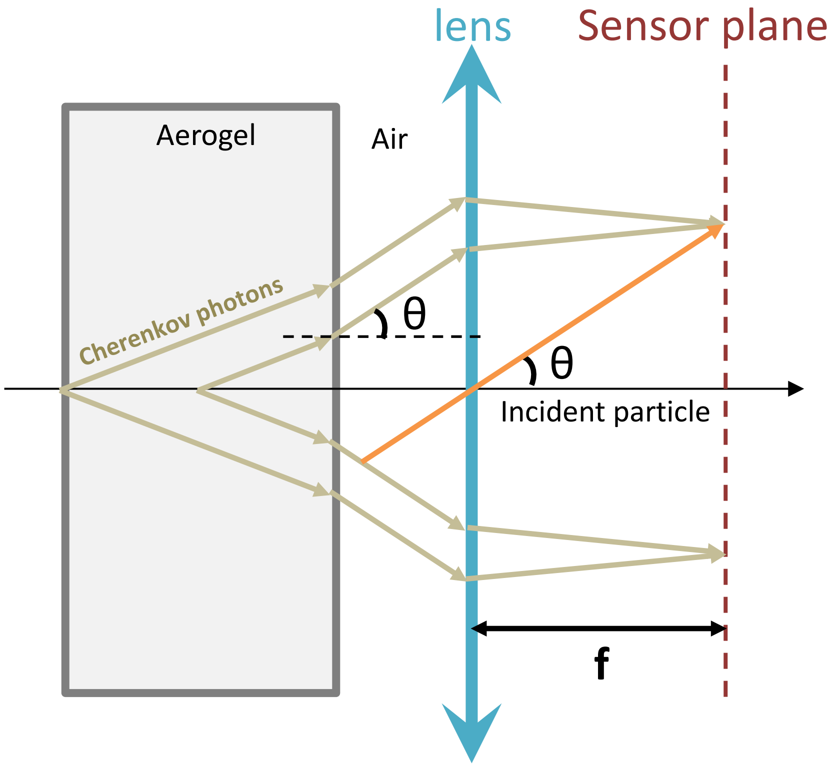
http://phynp6.phy-astr.gsu.edu/eRD14/index.php/Main_Page

Backup

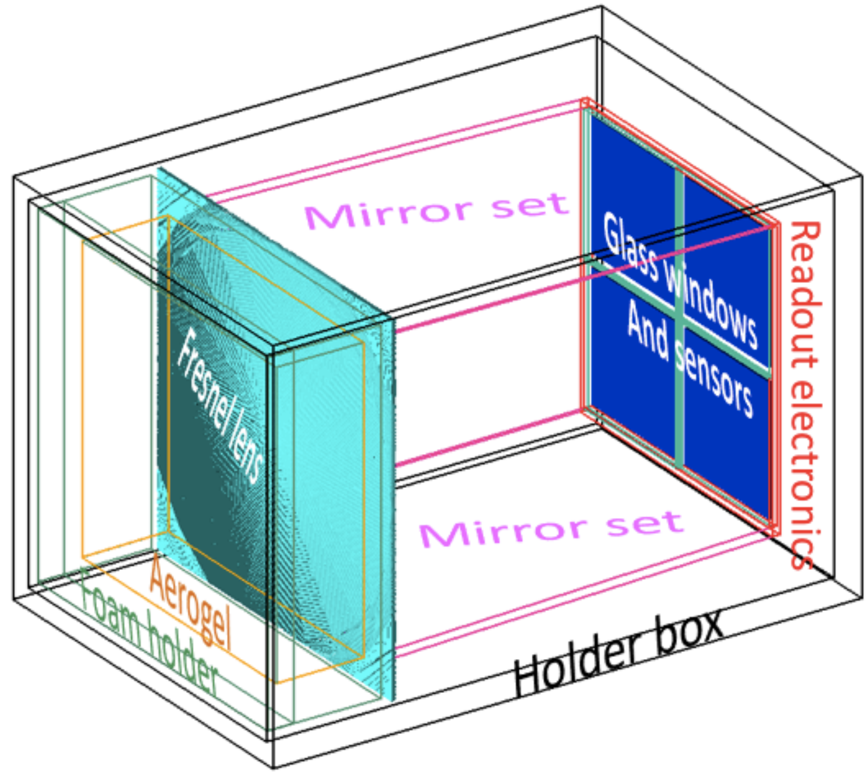
Particle distributions



Design of Modular RICH Prototype

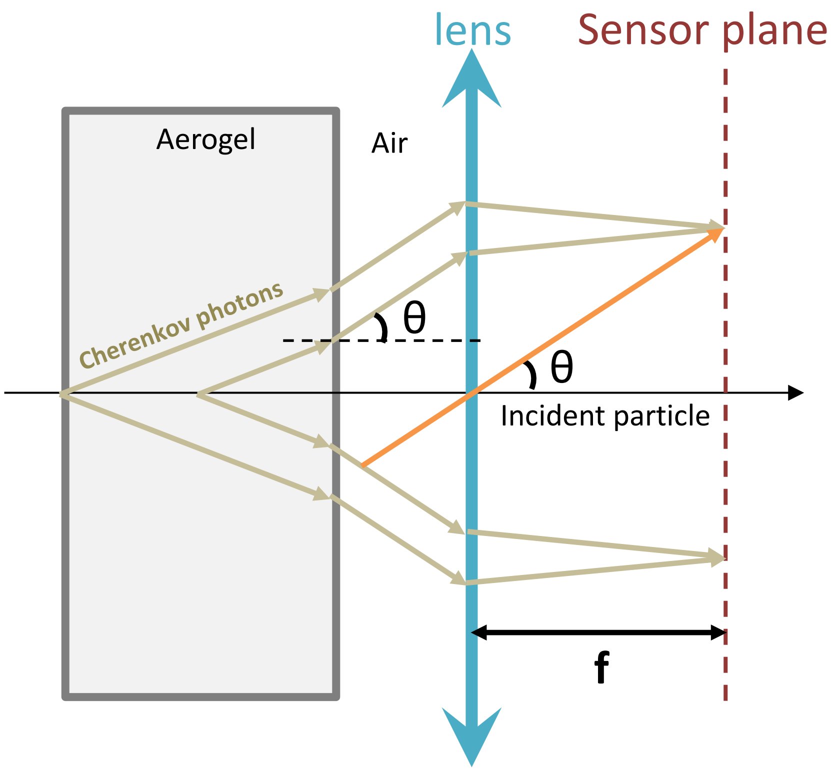


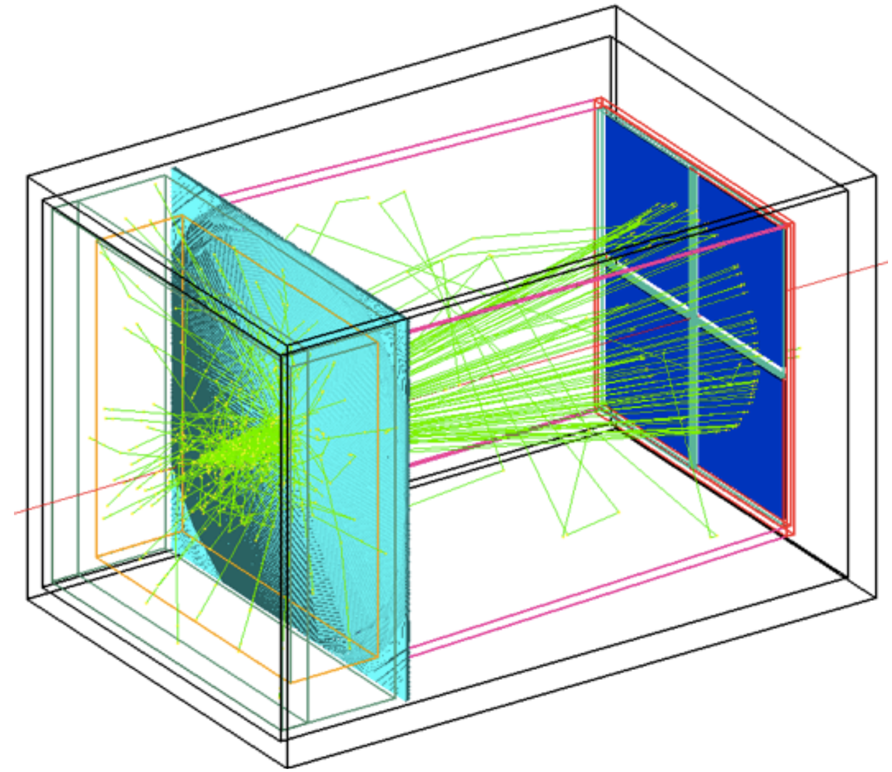
Since parallel rays are focused at the same point, emission point uncertainty which is raised by thickness of aerogel is minimized



Detector layout shown in Geant4 simulation

Design of Modular RICH Prototype





Since parallel rays are focused at the same point, emission point uncertainty which is raised by thickness of aerogel is minimized

Simulation of single 9 GeV pion. The incident pion emitted Cherenkov photons inside the aerogel. These Cherenkov photons were then focused on the sensor plane

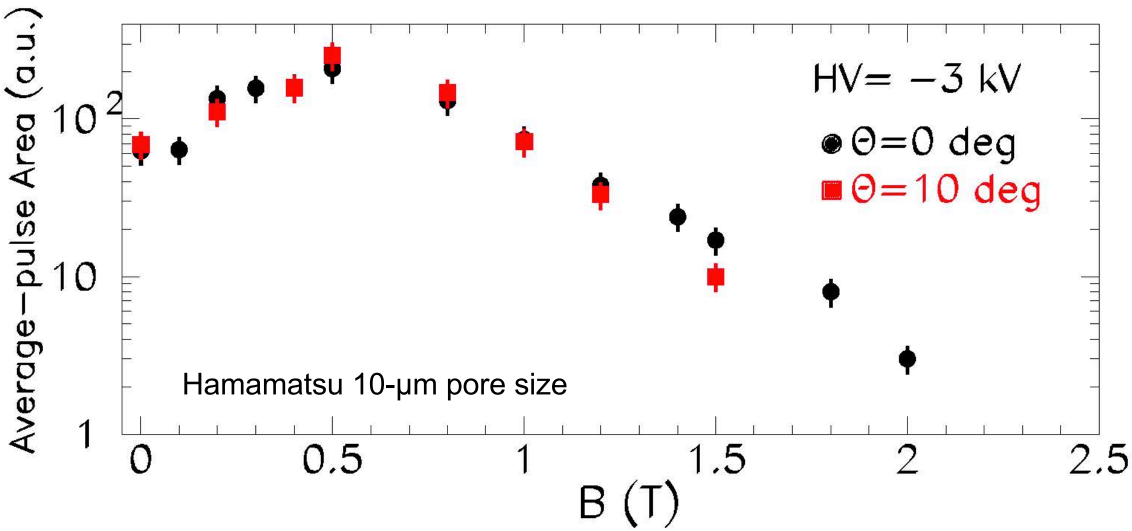
Naïve Expected Performance of mRPC Prototypes

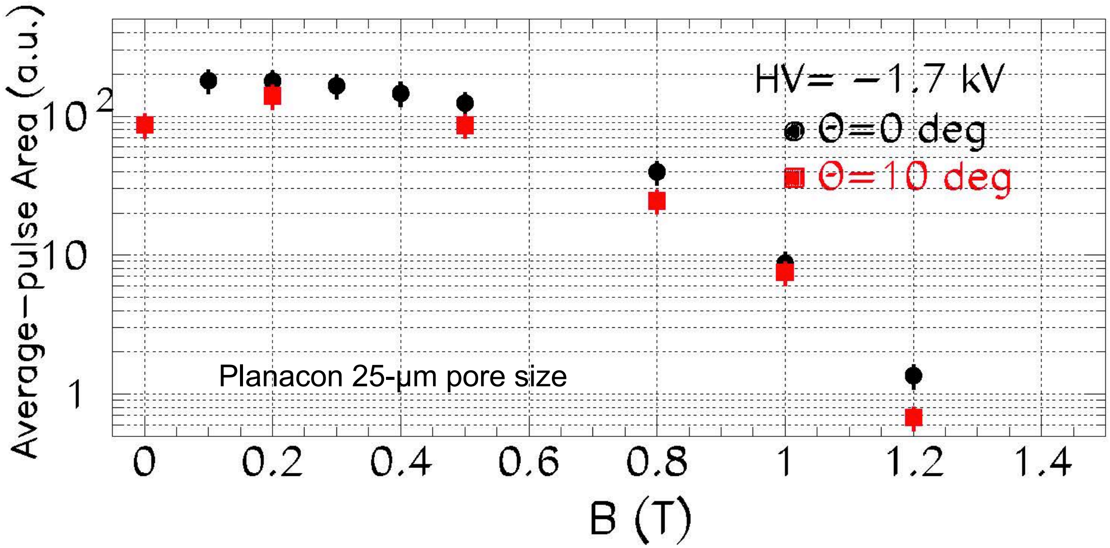
- *Narrower gap width -> fast charge dominant in the induced signal -> Better timing resolution*
- *Efficiency is recovered by adding more gas gaps*

	mRPC (C. Williams et al.)	eRD14 mRPCv1 (UIUC & BNL)	eRD14 mRPCv2
Gas Gap Width	160um (fishing line)	105um (diameter of fishing line)	160 um
# of Gas Gaps	4 stack x 6 gas gaps = 24	4 stack x 9 gas gaps = 36	4 stack x 12 gas gaps = 48
# of thin glass layers	4 stacks x 5 layers = 20 (250um thick glass)	4 stack x 8 layers = 32 (210um thick glass)	4 stack x 11 layers = 44 (100um thick glass)
Total Gas (mm)	3.84	3.78	7.92
Stack Width (mm)	3.01	3.11	3.28
Preamplifier	Differential type, NINO chip (3GHz bandwidth)	LMH6554 2.8-GHz + Evaluation Board	LMH6554 2.8-GHz + Evaluation Board
TDC and DAQ	Oscilloscope (Sampling speed of 10Gs)	DRS4-V5(5Gs) + PC	DRS4-V5(5Gs) + PC
Time resolution	20 ps	18-25 ps	???

- Risetime is a primary determinant of timing resolution: $\sigma_t \propto \frac{\sigma_V}{dV/dt}$
- Since the active volume of gas in our proposed mRPC is double previous prototypes, while keeping the same cathode geometry, the risetime can naively be doubled while noise should stay the same (up to bandwidth limitations). Thus, we naively expect up to a factor of two improvement in the timing resolution of our proposed device.

Sensors in High-B Fields – FY17 analysis results

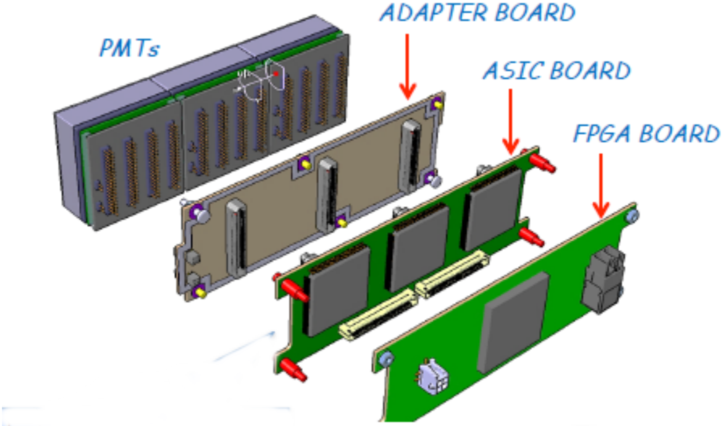


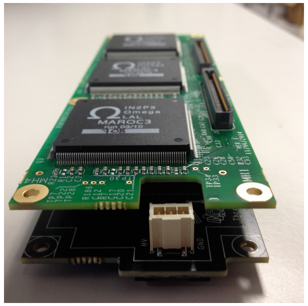


- Measurements performed at 96% of maximum allowed high voltage.
- 10-μm sensor
  - Can be operated up to about 2 T at standard orientation.
  - Can be operated up to about 1.5 T at larger angles.
- 25-μm sensor
  - At both orientations sensor can be operated up to about 1.2 T
  - Main objective of measurements is to negotiate 10-μm sensor on loan from Photonis.

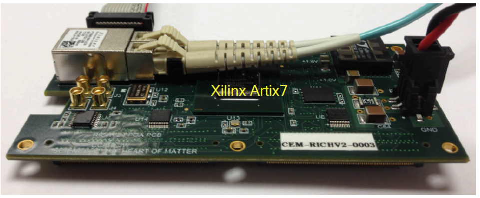
CLAS12 RICH Readout Electronics

Compact (matches sensor area)
Modular Front-End (Mechanical adapter, ASIC, FPGA)
Scalable fiber optic DAQ (TCP/IP or SSP)
Tessellated (common HV, LV and optical fiber)



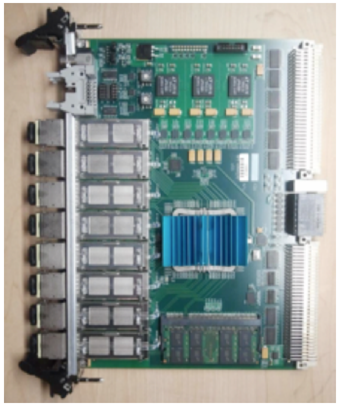


Adapter & Asics Boards



FPGA Board

SSP Fiber-Optic DAQ



Analog: Charge (1 fC)
Digital: Time (1 ns)

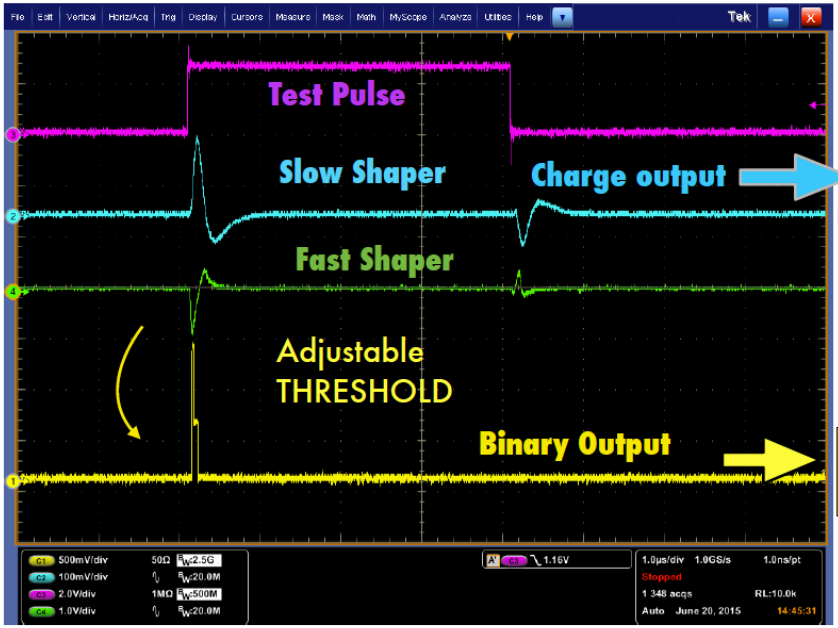
Trigger latency (8 μs)

Optical ethernet (2.5 Gbps)

Trigger: external, internal, self

On-board pulser

example of MAROC signal processing



Single channel response, 1 microsecond/div

ADC (MAROC) calibration only
more on backup slide

SCALER/TDC (FPGA)

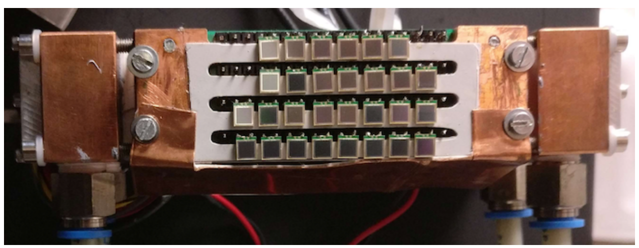
TDC used for physics runs!

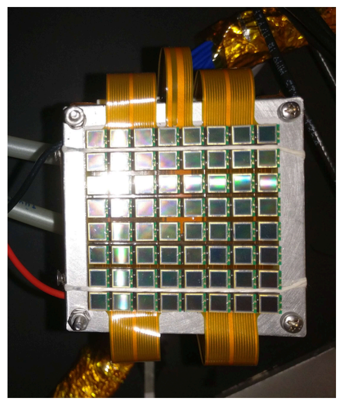
SiPMs

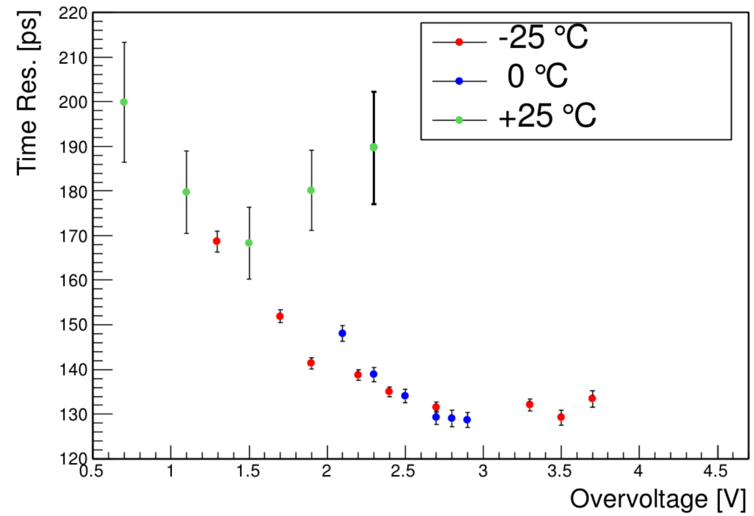
- ✓ Mass production technology
- ✓ Photon counting
- ✓ Excellent time resolution
- ✓ Compatible with magnetic field

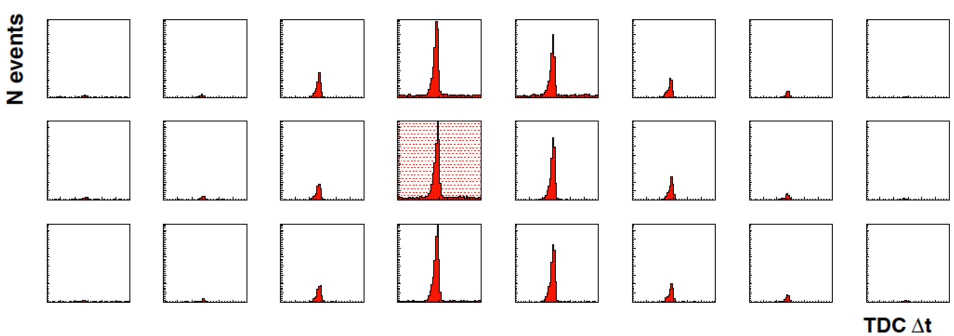
- ✗ High dark rate
- ✗ Low radiation tolerance

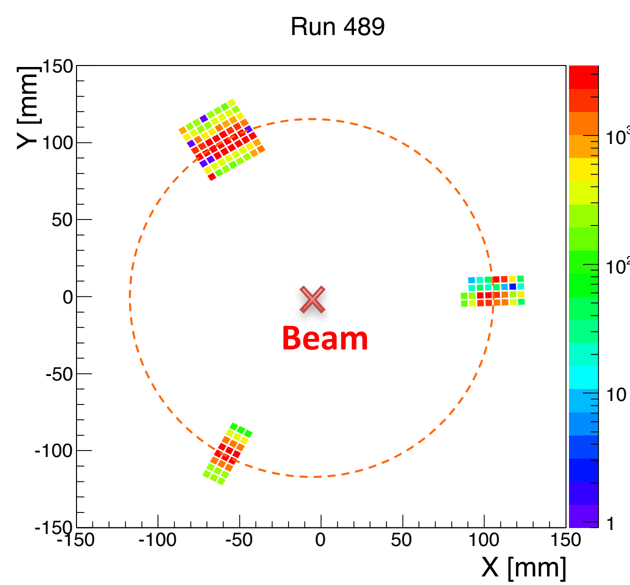
} Work at low temperature



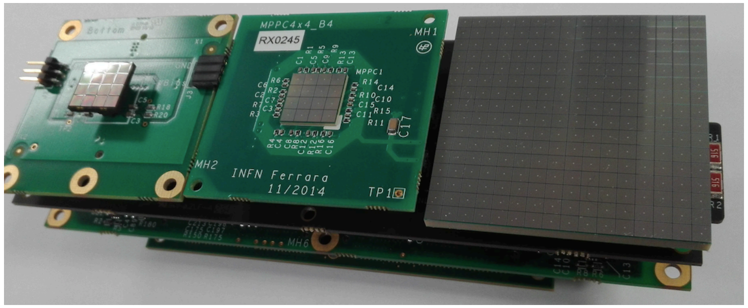




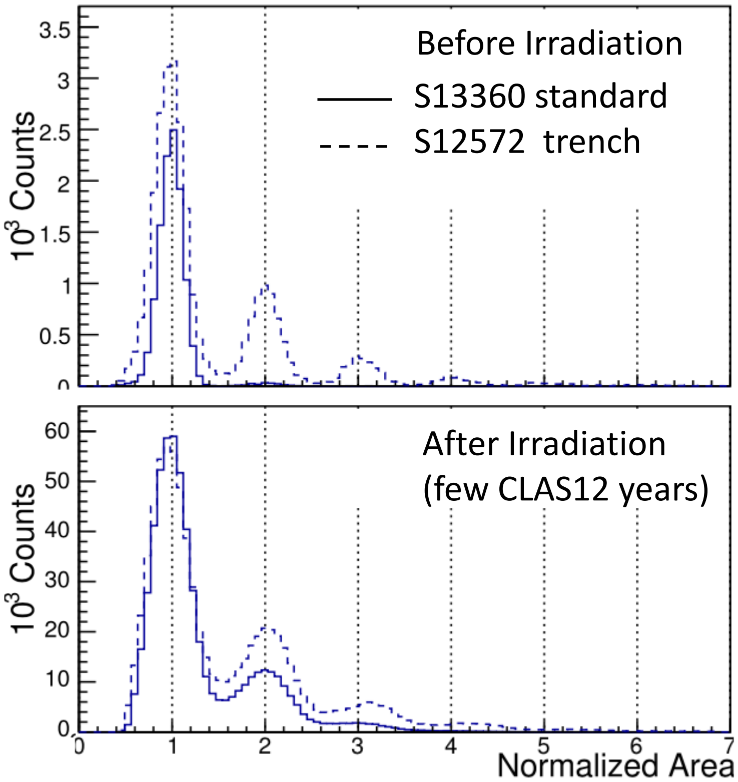




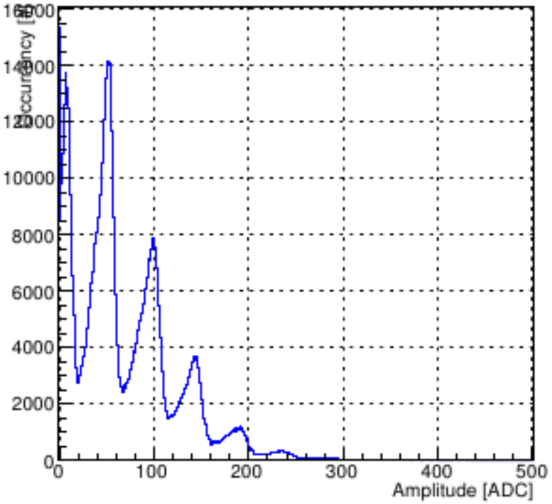
Photon Sensor: SiPM



Single-photon capability after irradiation



Photon counting with ADC charge measurement



Single photon discrimination with TDC time measurement