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, CUA, July 26-27, 2018

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

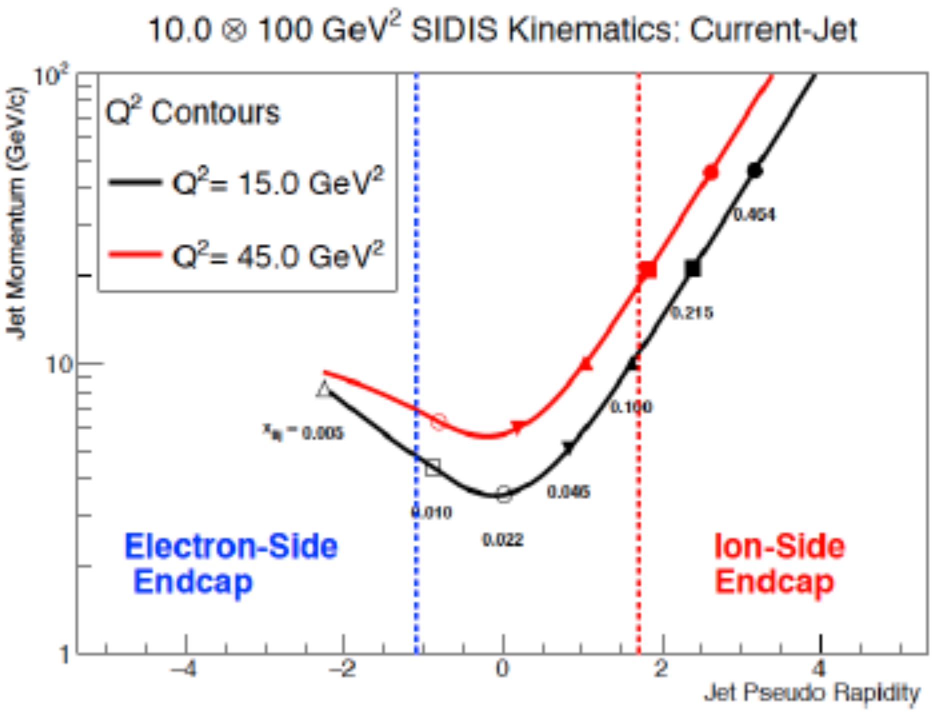
2. A cost-effective sensor and electronics solution

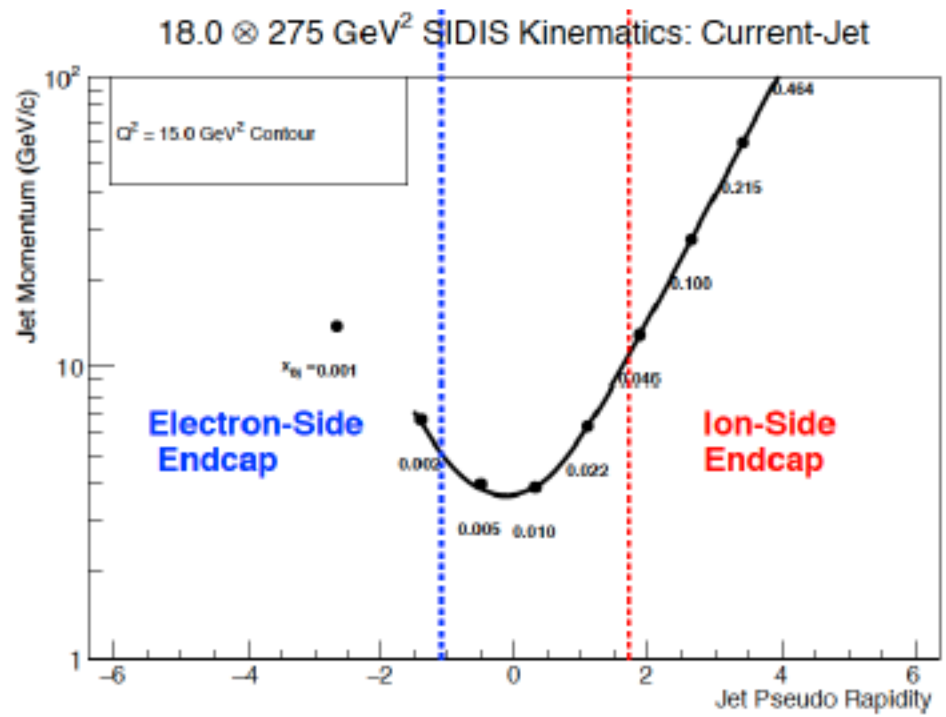
- Requirements and development of photosensors
- Development of readout electronics needed for prototyping

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

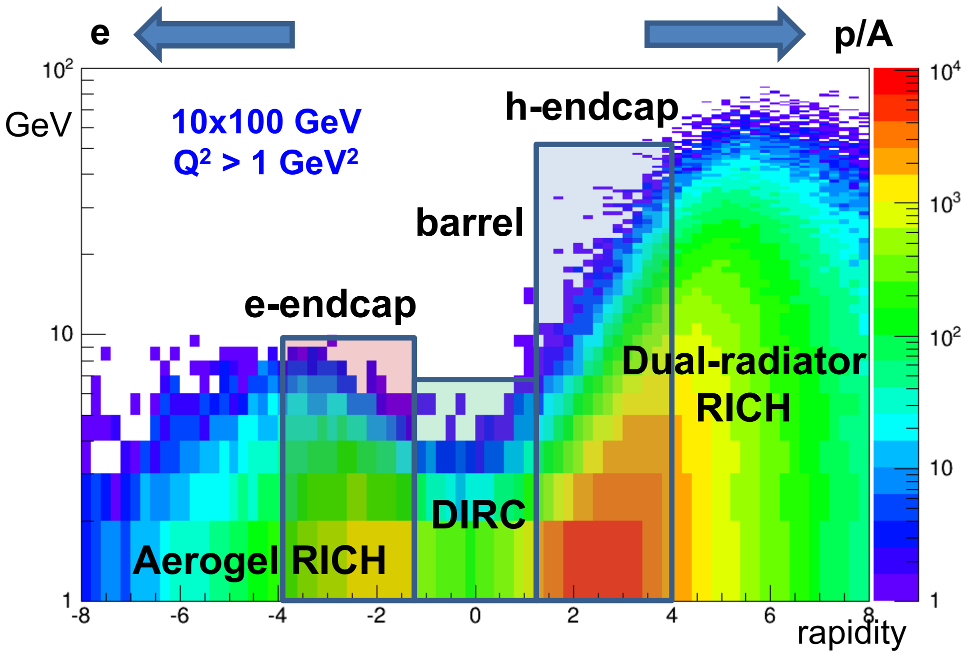


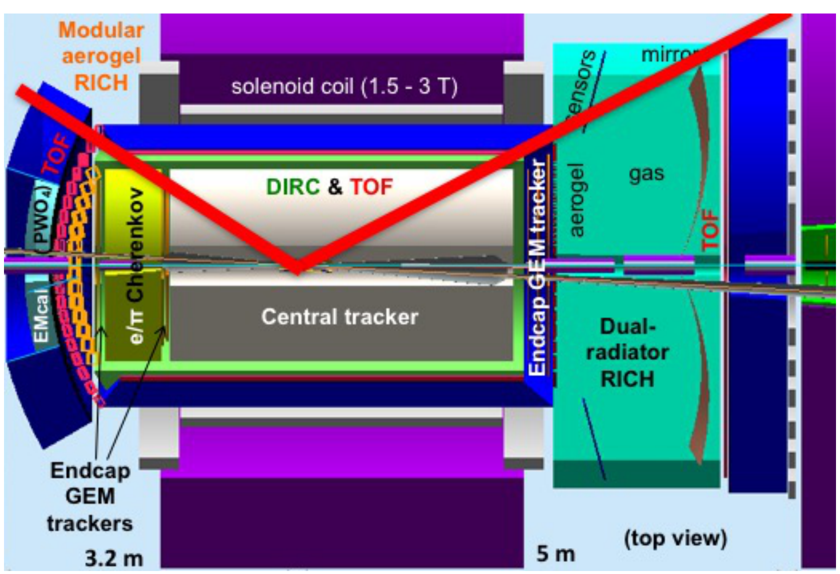


- The maximum hadron momentum in the endcaps is close to the electron and ion beam energies, respectively.

- 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





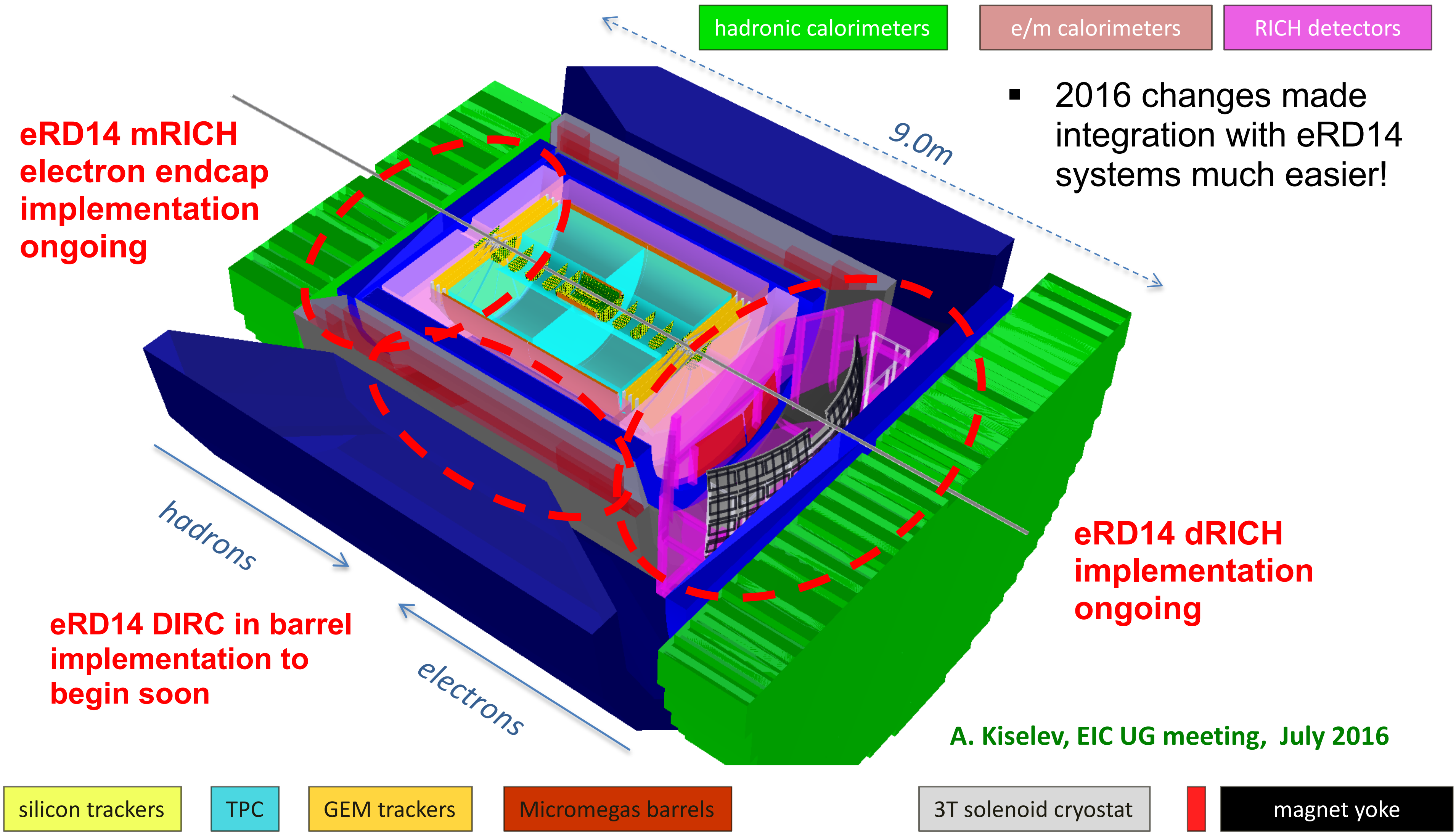
- **h-endcap**: A RICH with two radiators (gas + aerogel) is needed for
  π/K separation up to ~50 GeV/c
- **e-endcap**: A compact aerogel RICH which can be projective
  π/K separation up to ~10 GeV/c
- **barrel**: A high-performance DIRC provides a compact and cost-effective way to cover the area.
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

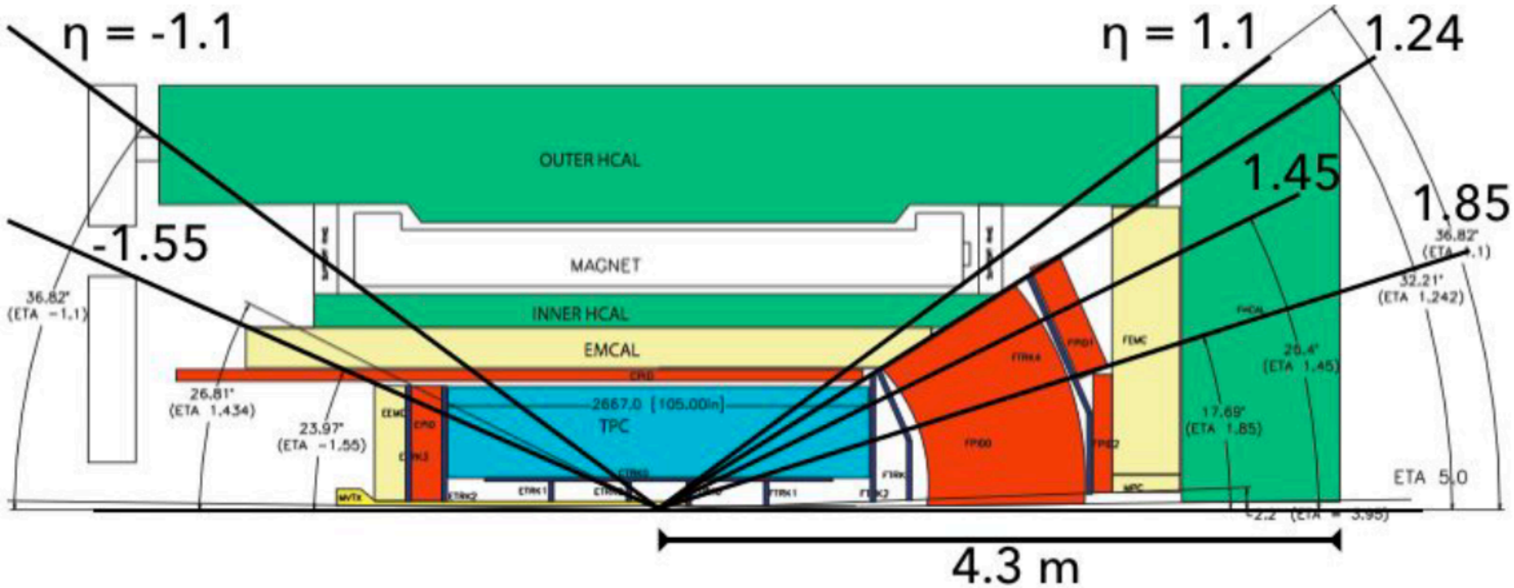
BNL BeAST EIC detector

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

- 2016 changes made integration with eRD14 systems much easier!

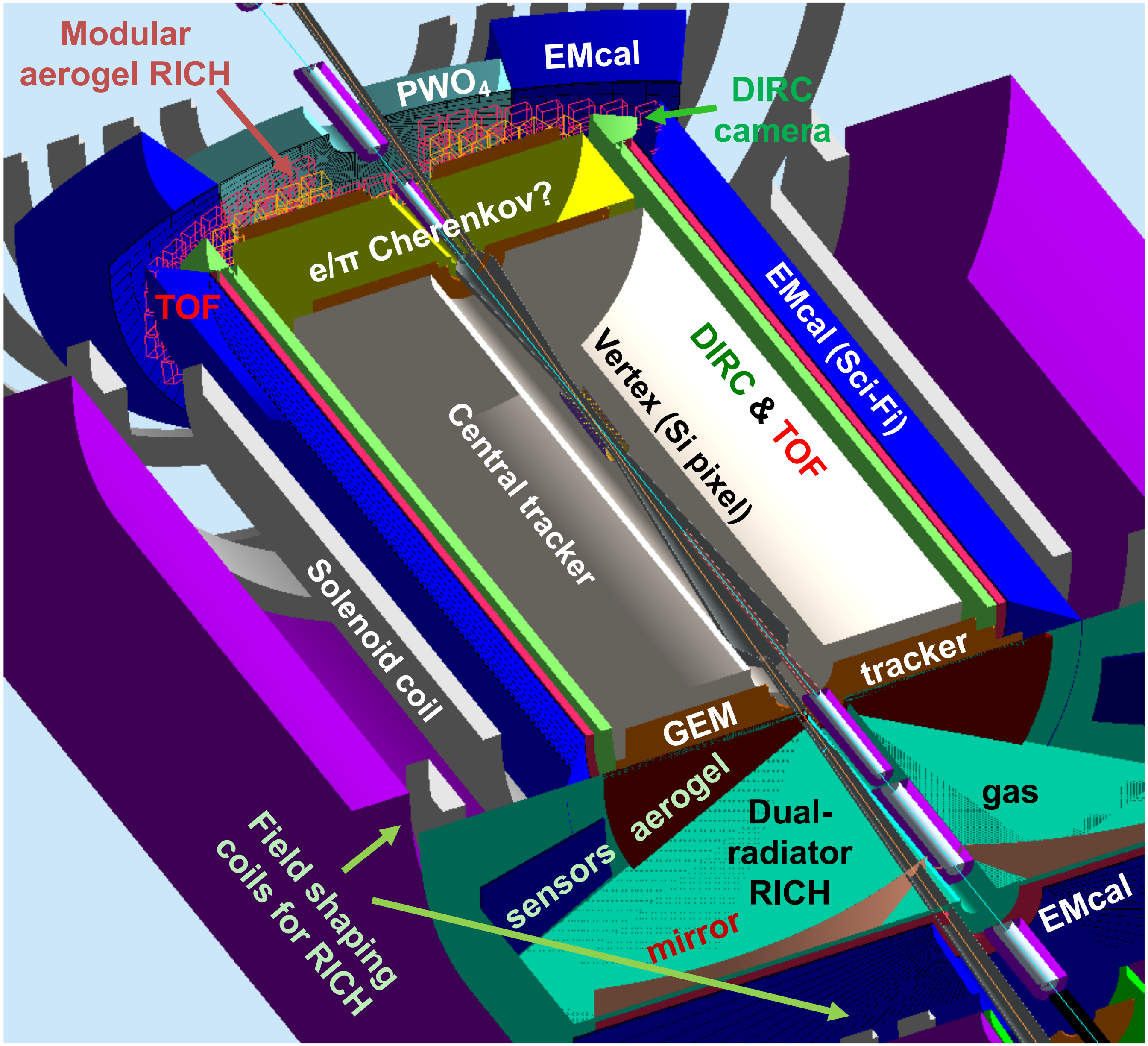


BNL ePHENIX EIC detector



- 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

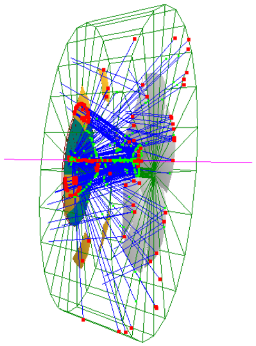
Goal:

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

FY 19:

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

Dual-radiator RICH (dRICH)



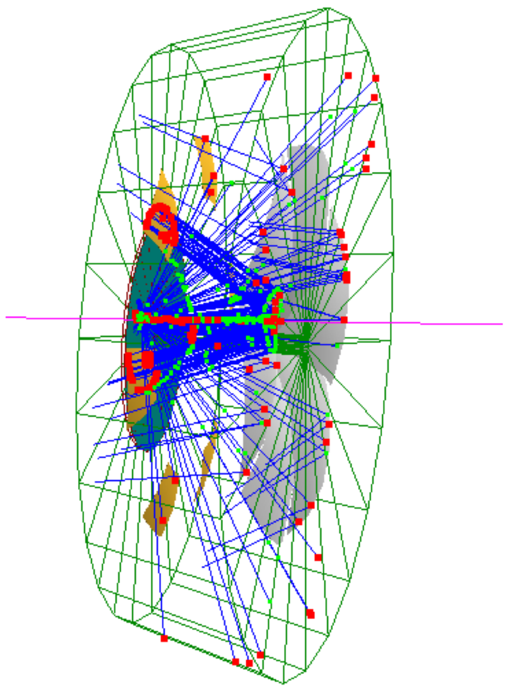
R&D Goals:

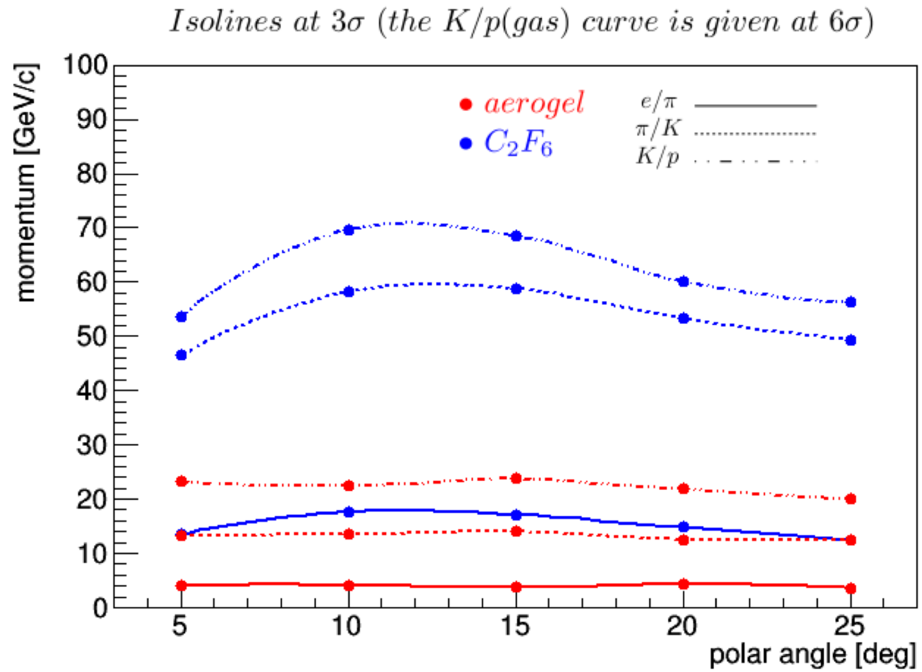
- Continuous coverage up to ~50 GeV for π/K and ~15 GeV for e/π
- First such device developed for the endcap of a solenoidal detector

FY 19:

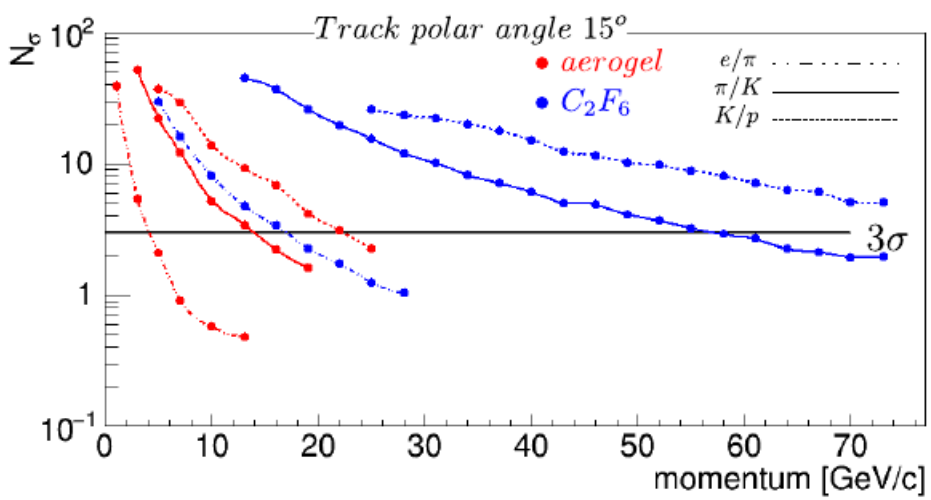
- Publish the new, extended IRT reconstruction algorithm
- Build small prototype (with INFN support)
- Investigate the gas-aerogel interface and the radiator properties
- Test and evaluate SiPM readout (synergies with mRICH)

dRICH - JLab geometry





Geant4 simulation includes magnetic field

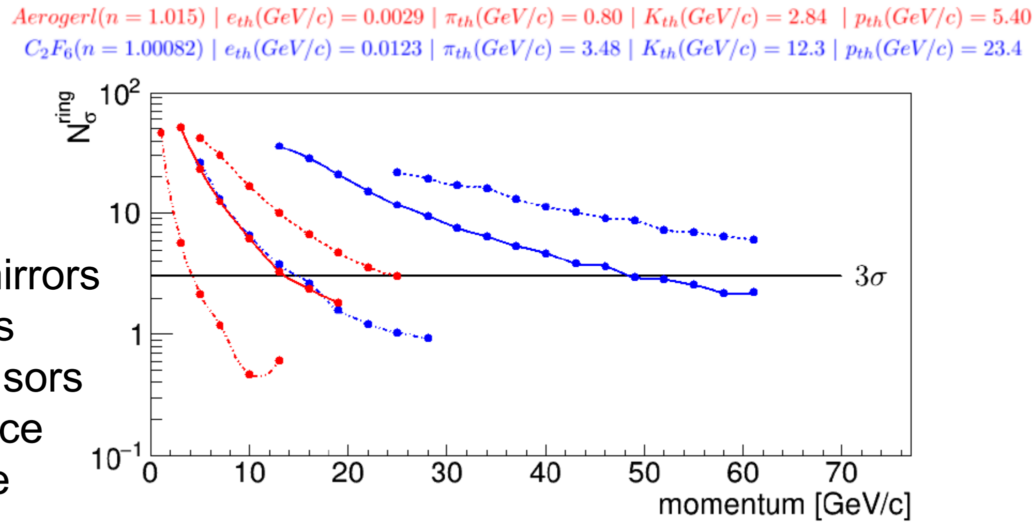


- Aerogel (n=1.02) & C_2F_6 gas
  - Continuous coverage
- Outward reflecting mirrors
  - Sensors away from the beam
  - No scattering in aerogel
- Sector-based 3D focusing
  - Reduced photosensor area
  - LAPPDs or SiPMs

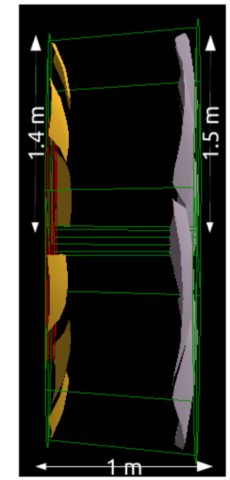
dRICH and eRD6 gas RICH – BNL geometry

dRICH
GEMC simulation:

- aerogel + C_2F_6
- outward reflecting mirrors
- six azimuthal sectors
- SiPM or LAPPD sensors
- Excellent performance despite reduced size



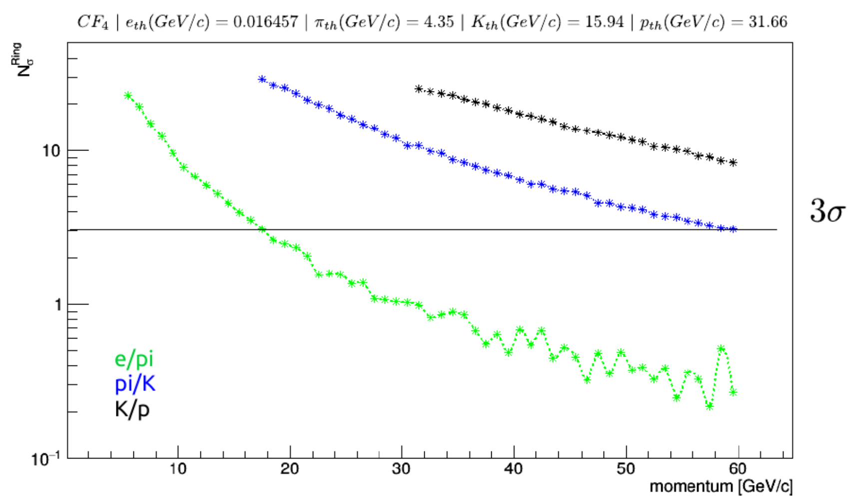
dRICH (ePHENIX)



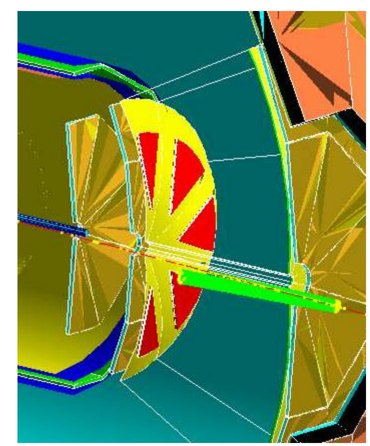
Spherical detector plane

eRD6 RICH
Fun4All simulation:

- CF_4 gas only
- inward reflecting mirrors
- eight azimuthal sectors
- GEM photosensors (sensitive in the UV)

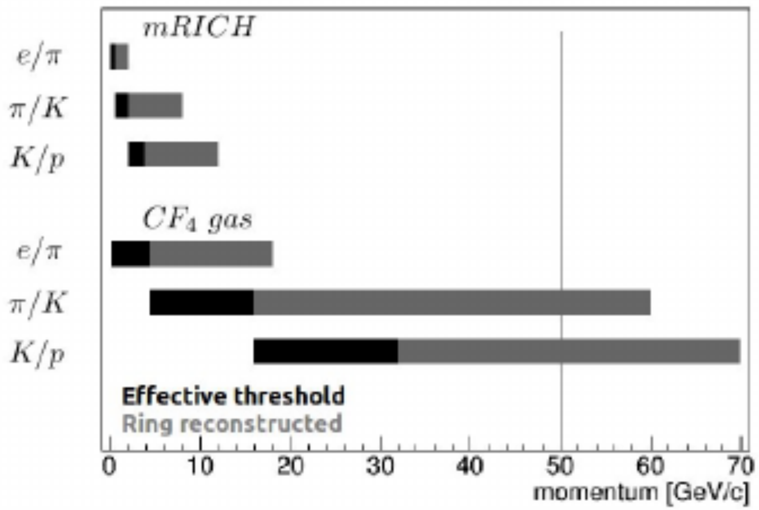


CF$_4$ gas RICH (ePHENIX)

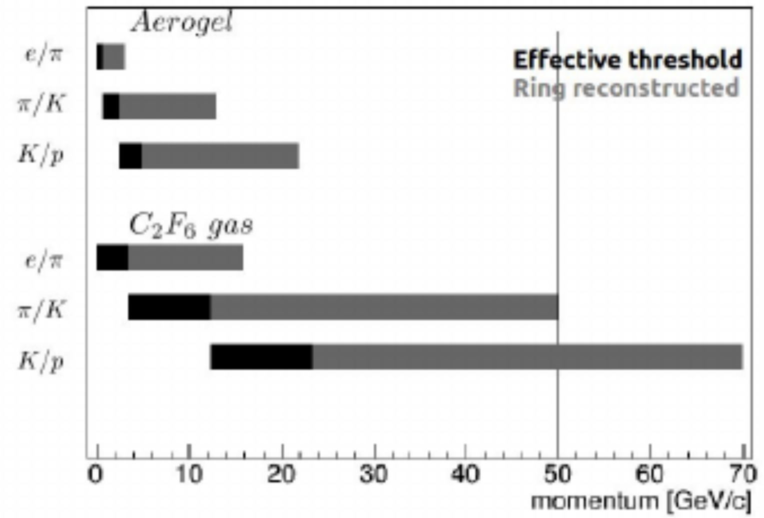


dRICH and eRD6 gas RICH comparison

mRICH + CF_4 gas RICH



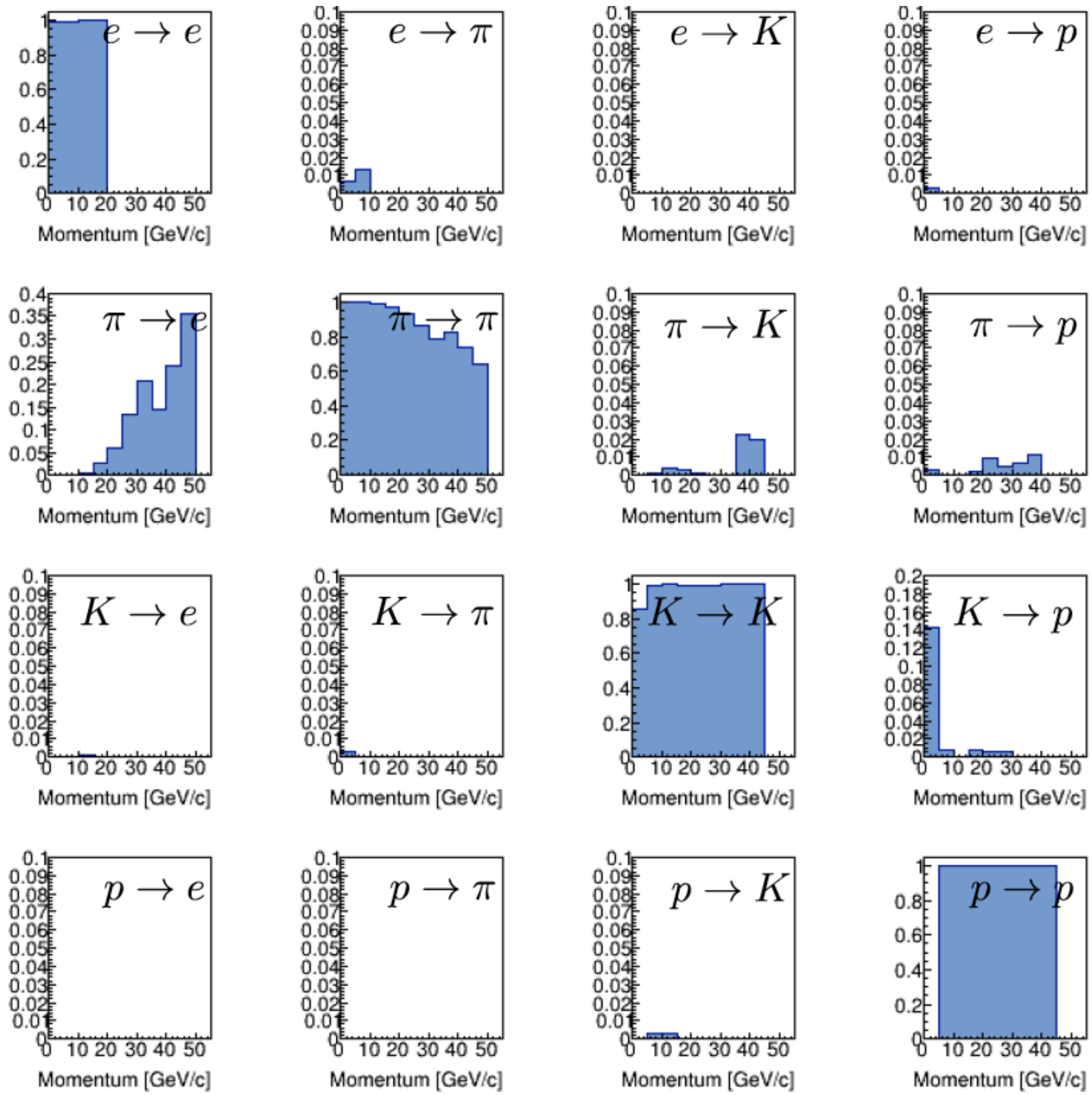
dRICH (aerogel + C_2F_6 gas)

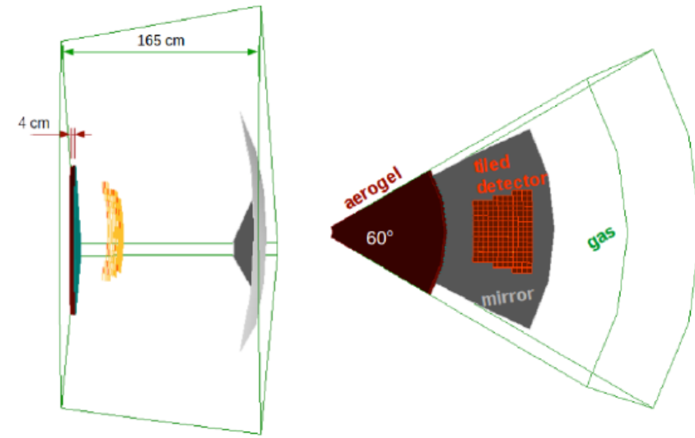


- UV GEMs: chromatic dispersion in CF_4 gas dominates the resolution.
- mRICH + CF_4 gas do not provide continuous coverage in RICH mode for pi/K and not at all for K/p.
- Joint eRD14/eRD6 simulation and reconstruction effort.

- Outward-reflecting spherical mirror: errors important at small angles with flat sensor plane. Can be optimized.
- The dRICH provides continuous momentum coverage in RICH mode.
- Prototype needed to study interface between gas and aerogel

dRICH PID capability in a real physics context (SIDIS)





	Nominal Momentum Threshold	
Particle	Aerogel (n=1.02)	Gas (C_2F_6, n=1.0008)
	(GeV/c)	(GeV/c)
e	0.003	0.013
π	0.694	3.49
K	2.46	12.3
p	4.67	23.5

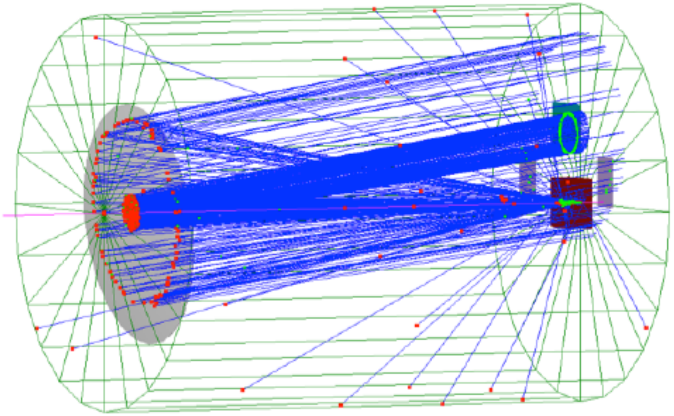
A dedicated event-based extension of the HERMES Indirect Ray Tracing has been developed and applied (useful for multiplicity >1)

The PID performance evaluated by applying the new algorithm to Pythia-generated data..

dRICH

FY18 progress

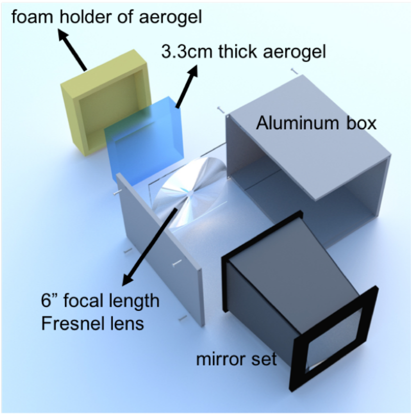
- Baseline definition of the dRICH completed
- PID performances evaluated for a channel of interest for EIC
- Shorter version of the dRICH implemented in GEMC (useful for BeAST / ePHENIX)
- The dRICH analysis framework was adapted to investigate the gas eRD6 (ePHENIX) gas RICH
- An event-based IRT approach was developed



FY19 proposed activities

- Development of a small scale, flexible, prototyp
- Study of the interface between gas and aerogel
- Consolidate design and test a SiPM detector matrix with proper cooling and thermal stability that needs to be designed and properly evaluated (this part of the activity is shared and in synergy with the activity on electronics)

Modular aerogel RICH (mRICH)



Goal:

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

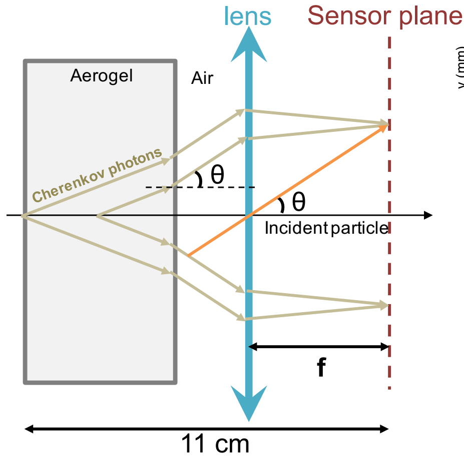
FY 19:

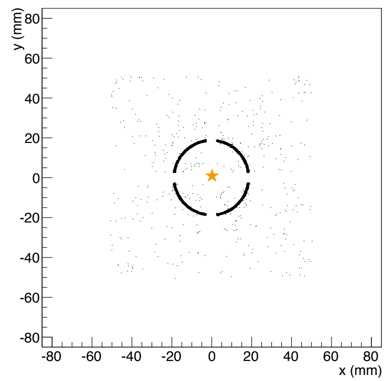
- Analyze and publish the mRICH test beam data taken in June/July 2018.
- Use the mRICH to develop an integrated readout sensor electronics solution for all Cherenkov systems (mRICH, dRICH, DIRC).
- Plan for a for a 3rd (final?) mRICH test beam in FY20.
- Search for best, radiation hard materials for Fresnel lens.
- Optical characterization of Fresnel lens and aerogel.

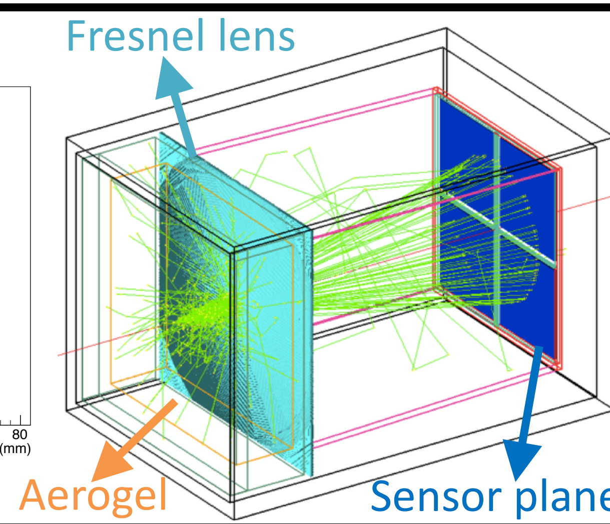
mRICH – lens-based focusing aerogel detector design

Smaller, but thinner ring improves PID performance and reduces length

Lens-Based mRICH Design

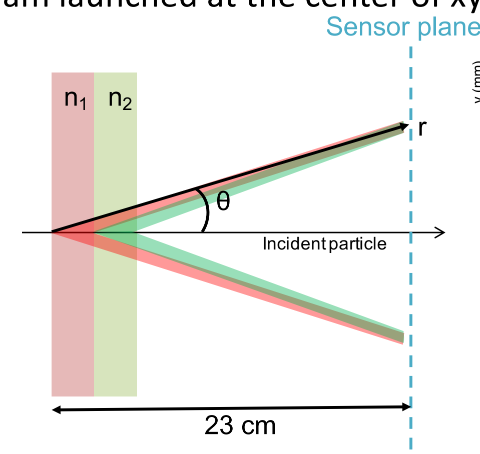


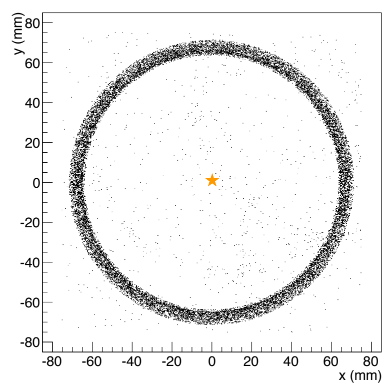




9 GeV/c pion beam launched at the center of xy plane in simulation

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



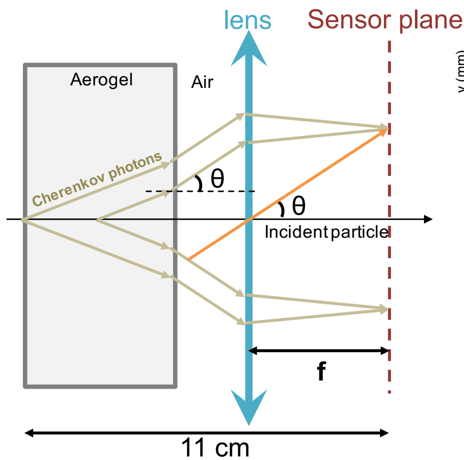


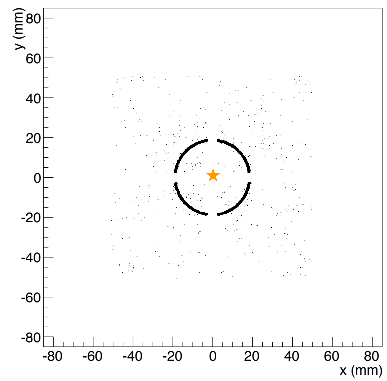
- EIC mRICH designed for K/pi ID up to 10 GeV/c
- BELLE-2 ARICH aims to separate pion and kaon up to 4 GeV/c

mRICH – lens-based focusing aerogel detector design

Smaller, but thinner ring improves PID performance and reduces length

Lens-Based mRICH Design

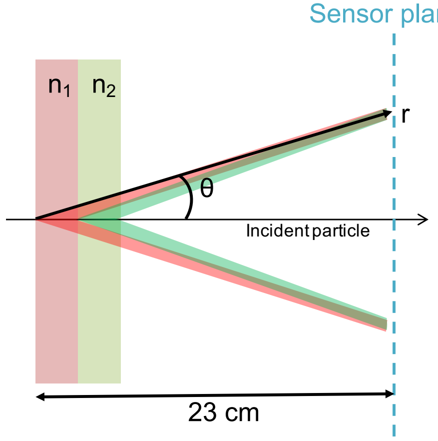


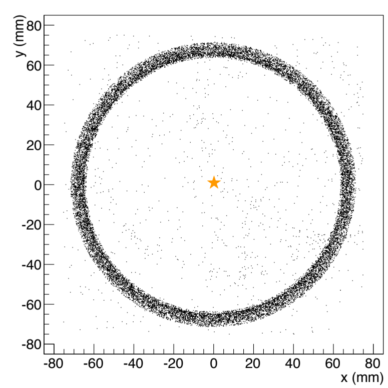


- 9 GeV/c pion beam launched at the center of xy plane in simulation
- **Smaller and thinner** ring image

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

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



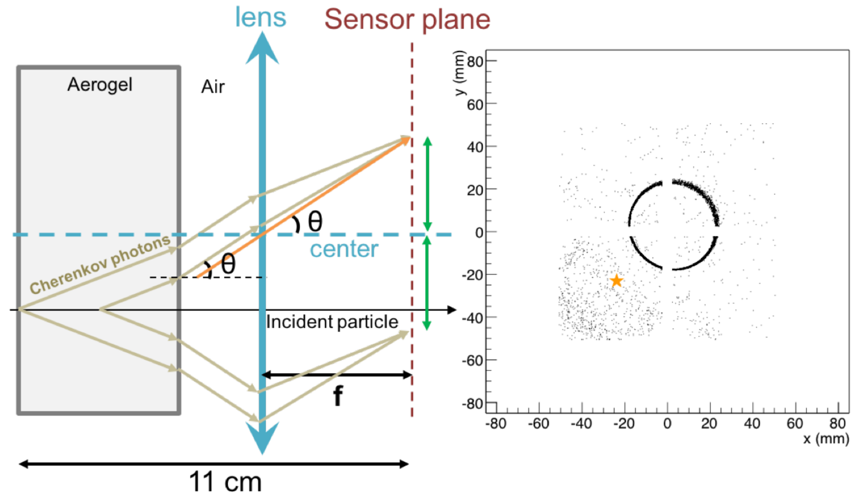


- EIC mRICH designed for K/pi ID up to 10 GeV/c
- BELLE-2 ARICH aims to separate pion and kaon up to 4 GeV/c

mRICH – lens-based focusing shifts image to center

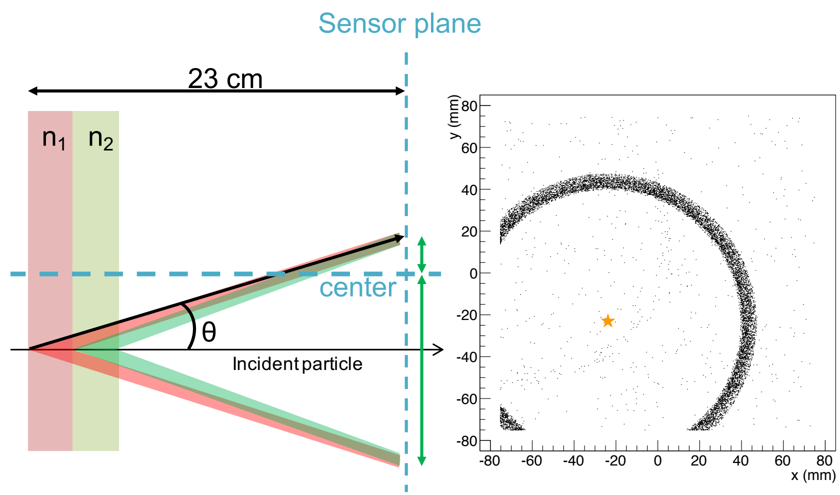
Ring centering of lens-based optics reduces sensor area (main cost driver)

Lens-Based mRICH Design



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

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

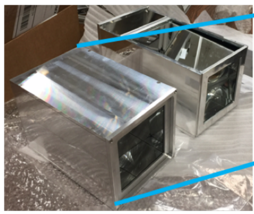


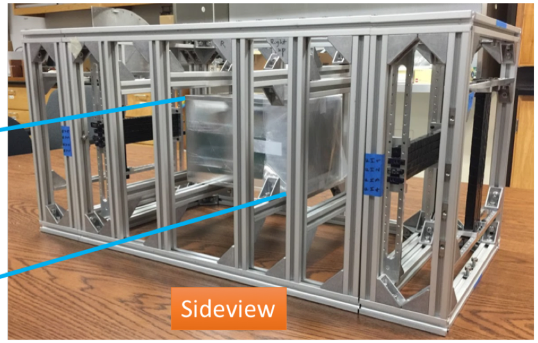
- 9 GeV/c pion beam incident at third quadrant (star) in simulation
- Ring is centered at point of incidence

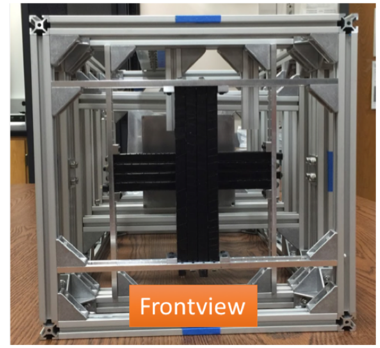
mRICH – FY18 progress (part one)

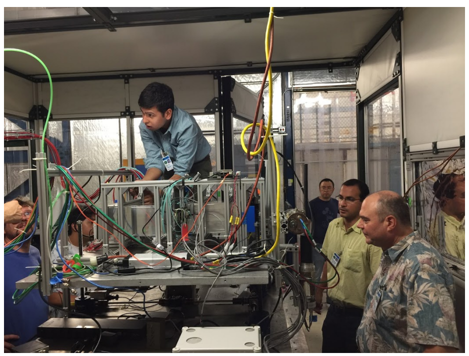
Another very successful mRICH prototype beam test at Fermilab (6/25 to 7/6/2018)

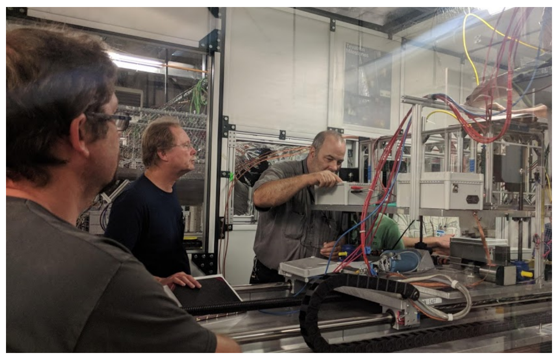
Two completed mRICH prototypes

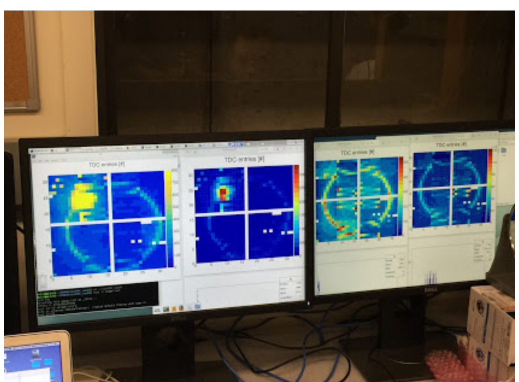


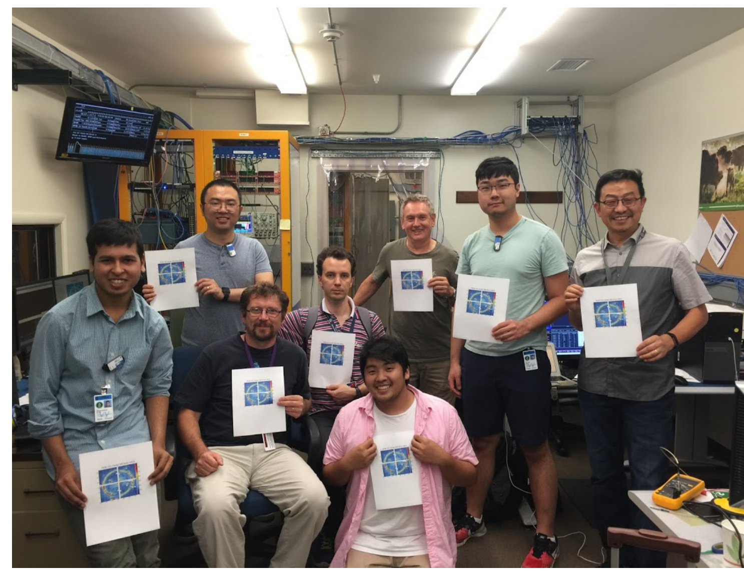








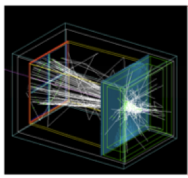




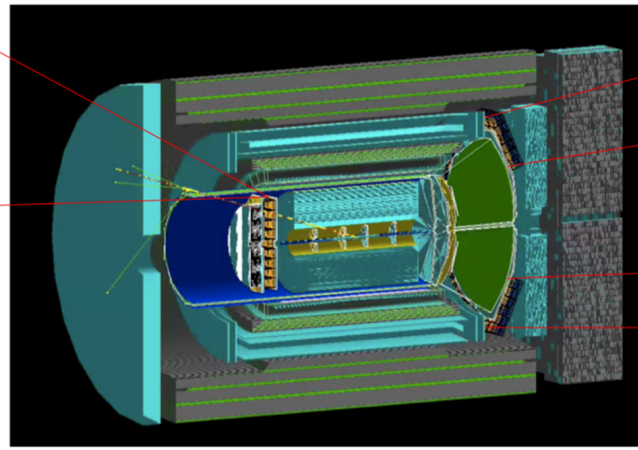
Group photo (missing two members) – the first confirmed ring image

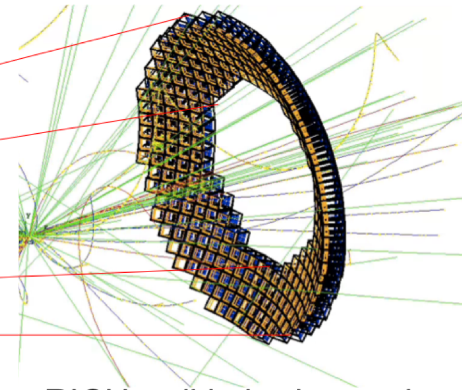
mRICH – FY18 progress (part two)

mRICH array implementation in Forward sPHENIX and JLab EIC detector concept in Geant4 simulation studies. Developed mRICH-based PID algorithms using a loglikelihood method.

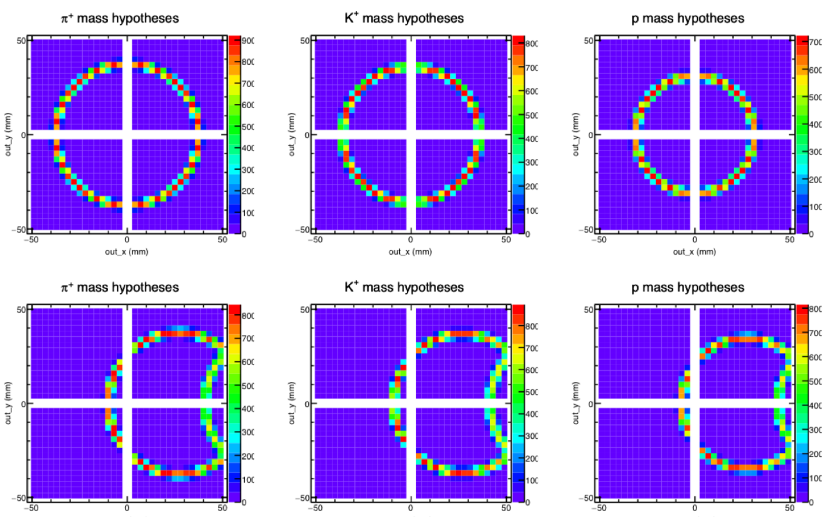


mRICH wall
e/π separation





mRICH wall in hadron-going direction for hadron PID



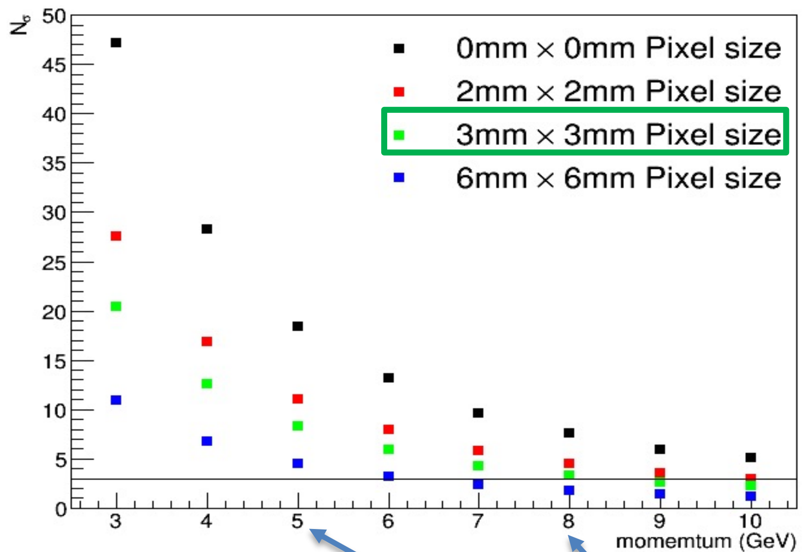
Examples of ring image patterns generated from Geant4 simulation for 5 GeV/c pi, K and proton, which are used in the loglikelihood PID method.

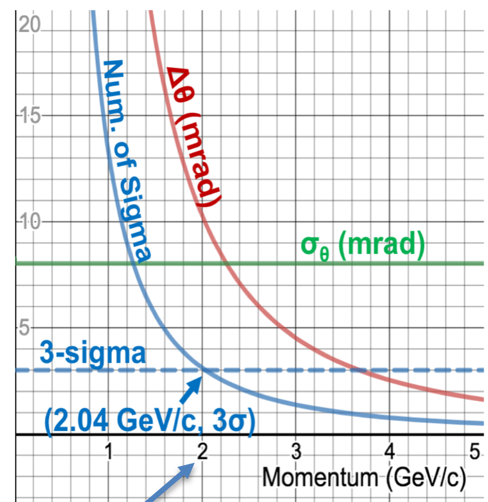
Upper row: incident at center at 0^0 angle

Lower row: incident at center at 10^0 angle

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**





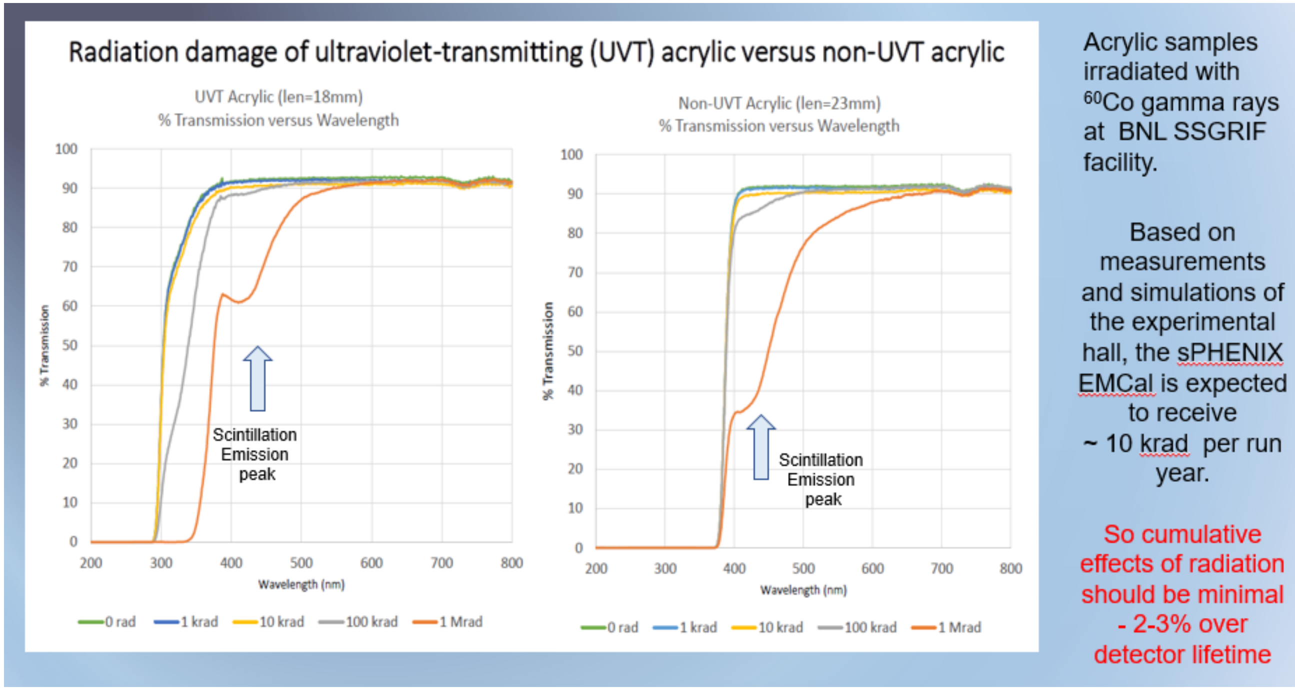
- Projected K/pi separation of mRICH 2nd prototype detector (**Green dots**)
- 2nd prototype detector can achieve 3-sigma K/pi separation up to 8 GeV/c

- 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 2018

mRICH – FY19 activity (part two)

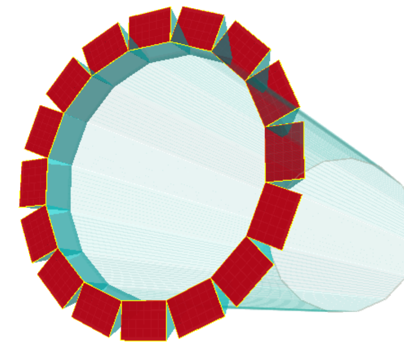
- Study of the radiation hardness of Fresnel lens (i.e., address the committee concern!)



Presented by Sean Stoll at IEEE NSS 2017

- 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.

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

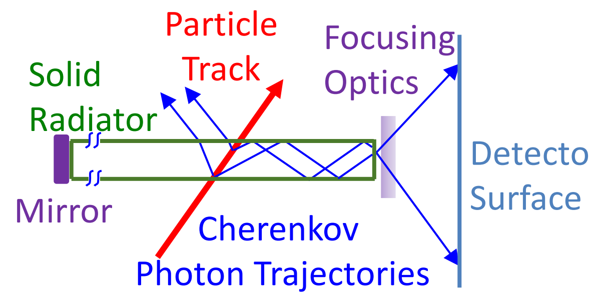
FY 19:

- Detailed radiation hardness studies of lens materials with a ^{60}Co source.
- Design and fabrication of a 3-layer lenses with improved radiation hardness using PbF_2 and sapphire.
- Implementation of the High-Performance DIRC into the JLab-EIC, BeAST, and EIC-sPHENIX detector simulation frameworks.
- Initial preparation for transfer of PANDA DIRC prototype to the US.

DIRC – overview

High Performance DIRC simulations

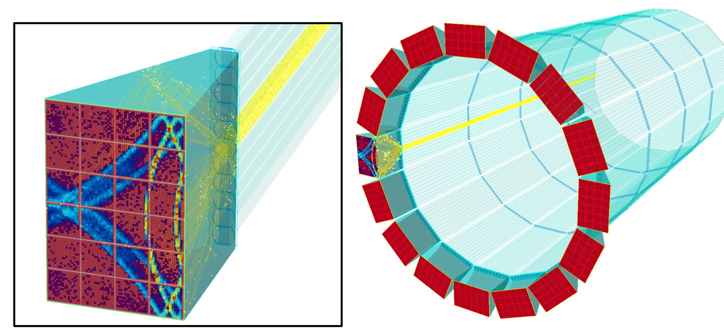
- More detailed simulations of DIRC@EIC design with 3-layer lens still show a 3σ separation p/K@10GeV/c, π/K@6GeV/c, and e/π@1.8GeV/c.

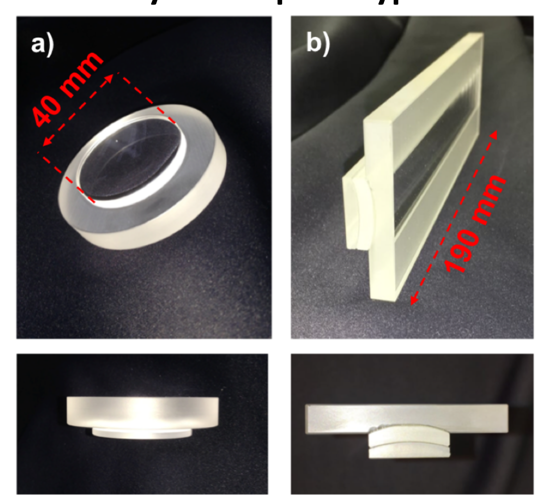


High performance DIRC in Geant 4

Experimental tests of 3-layer lens prototypes:

- Finished 3D mapping of focal plane.
- Performance in prototype placed in particle beam.
(synergy with PANDA Barrel DIRC group)
- Paper on prototype program and test bench tests of the 3-layer lens properties in preparation.



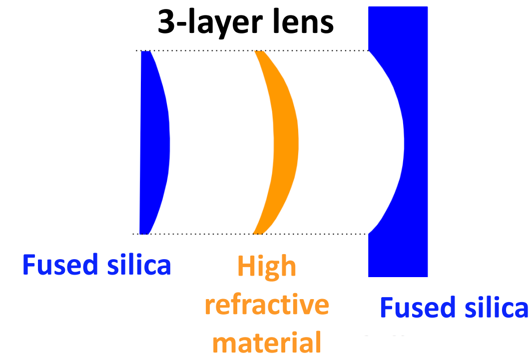

Spherical and cylindrical 3-layer lens prototypes

Alternative materials for 3-layer

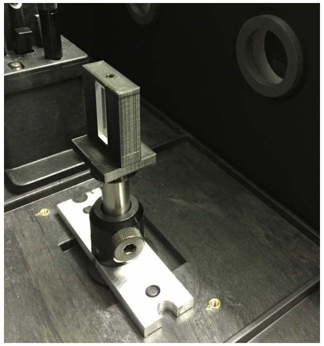
- Sapphire and PbF_2 are very attractive candidates to replace NLaK33 glass as material for middle layer.
- Two vendors are willing to build prototypes using new materials.
- Preliminary simulation studies as well as first radiation hardness measurements are very encouraging.
- Detailed radiation hardness tests and simulations are in progress.

DIRC – radiation hardness of 3-layer lens

- Detailed studies of 8mm NLak33 glass at CUA using X-Ray source finalized.
- First simulation studies and measurements of Sapphire and PbF_2 with Co^{60} are very encouraging.
- Detailed studies of several materials with Co^{60}, and neutron sources planned.

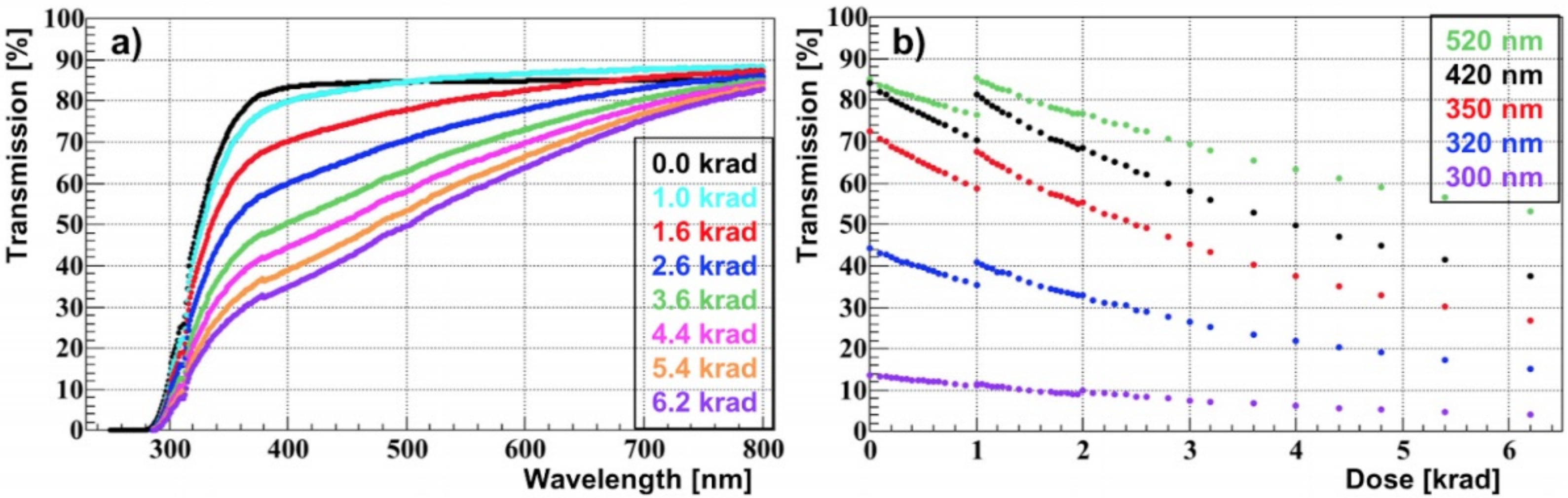


CUA setup



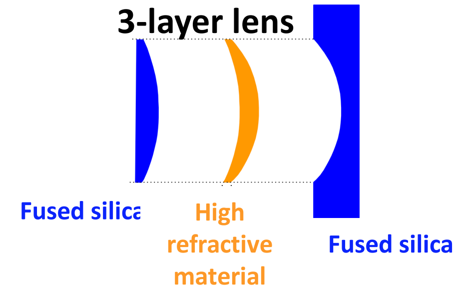
BNL Co^{60} setup

Measured transmission (not Fresnel corrected) through the 8mm thick NLaK33 glass sample

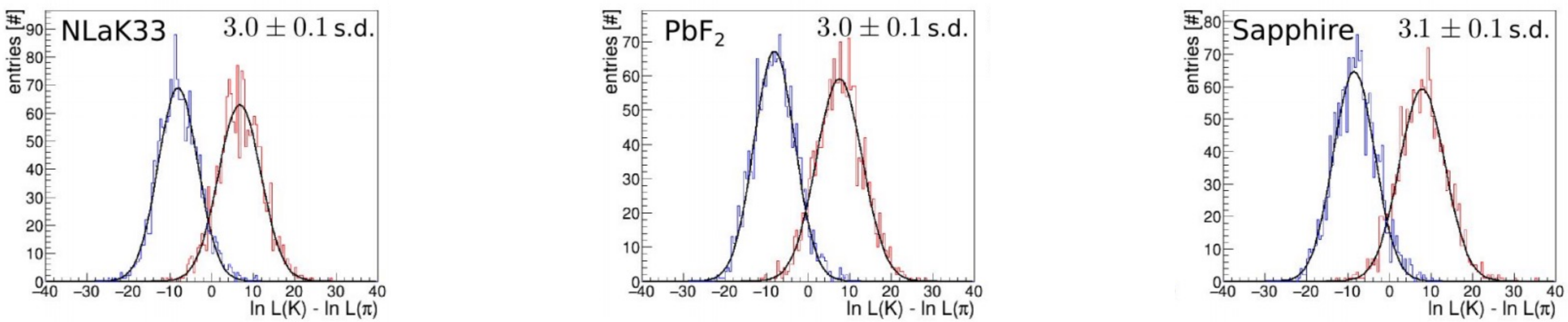


DIRC – radiation hardness of 3-layer lens

- Both Sapphire and PbF_2 are challenging to process.
- Two vendors are willing to build 3-layer lens with Sapphire and PbF_2.

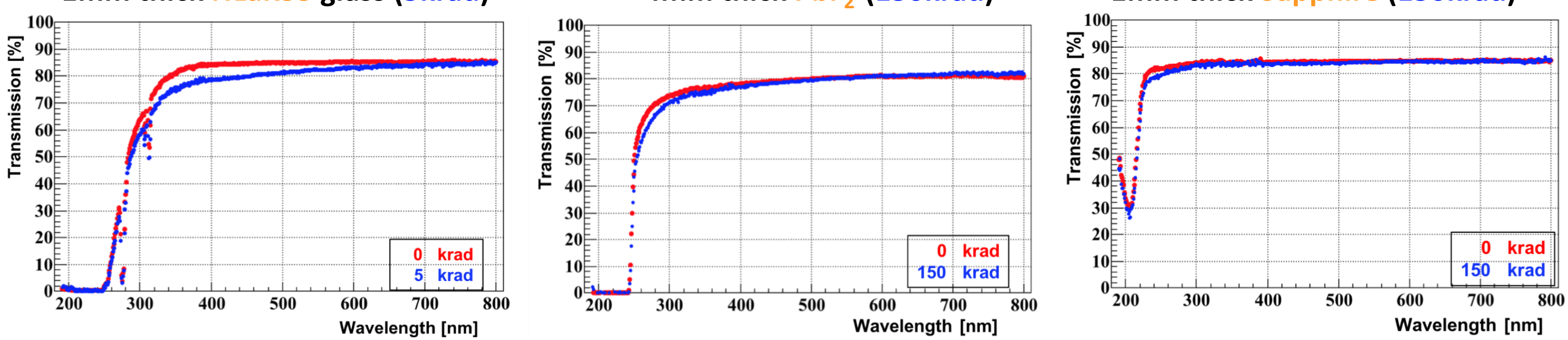


Simulated π/K separation for charged pions and kaons with 6 GeV/c momentum and 30° polar angle, assuming a tracking resolution of 0.5 mrad.



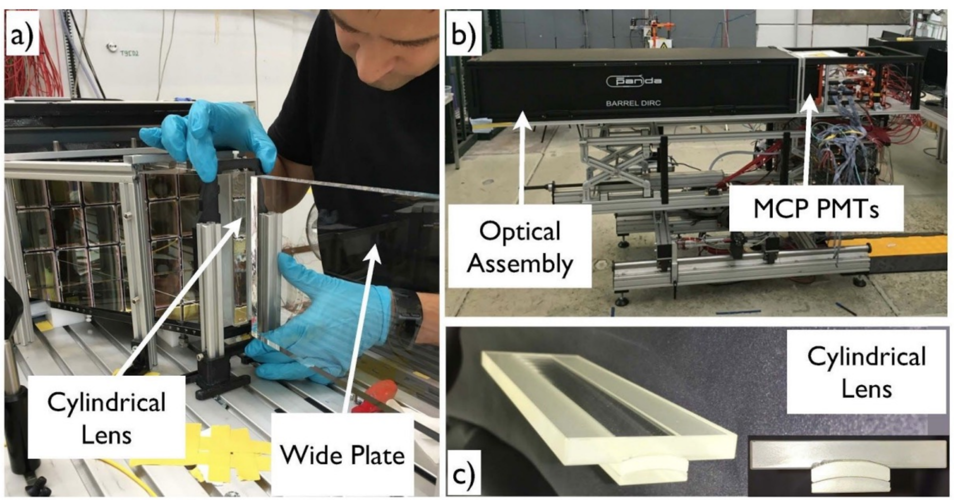
Measured transmission (not Fresnel corrected) through samples of alternative materials before and after irradiation with Co^{60} source at BNL.

1mm thick NLaK33 glass (5krad) **4mm thick PbF_2 (150krad)** **1mm thick Sapphire (150krad)**



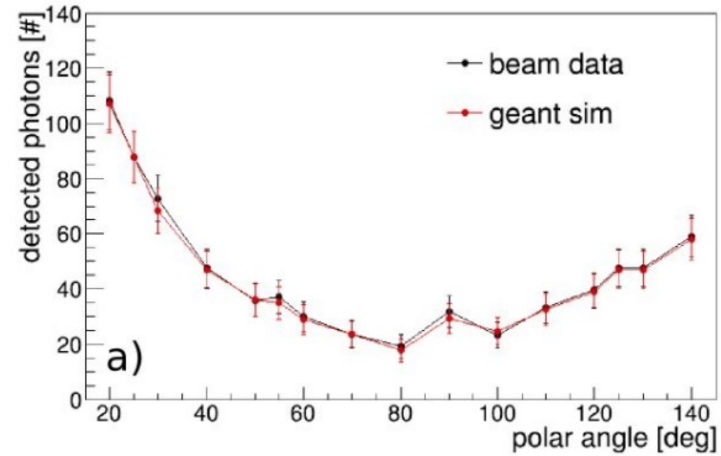
DIRC – validation in test beams at CERN

- Larger pixels, slower electronics than EIC DIRC:
  → prototype goal: 3σ π/K separation @ 3.5GeV/c
- CERN 2017 focused on validation of the PID performance of:
  - narrow bar+3-layer cylindrical lens
  - wide radiator plate with 3-layer cylindrical lens.
- 2018 test beam in August will focus more on narrow bar geometry.
- Preparation for future DIRC@EIC prototype

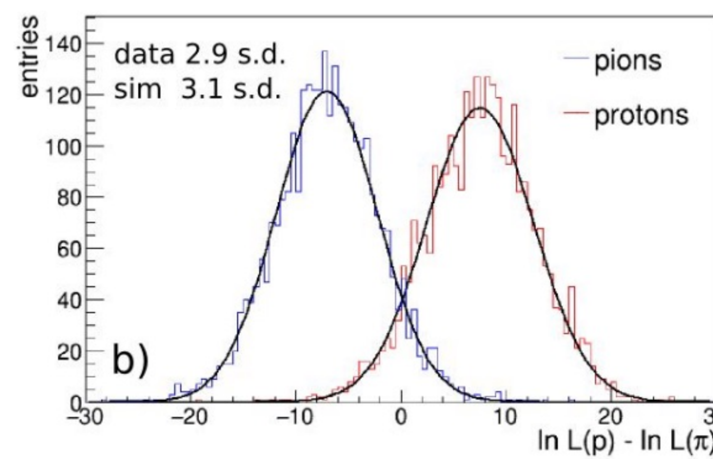


Wide plate geometry with 3-layer cylindrical lens:

Photon yield for 7 GeV/c tagged protons



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

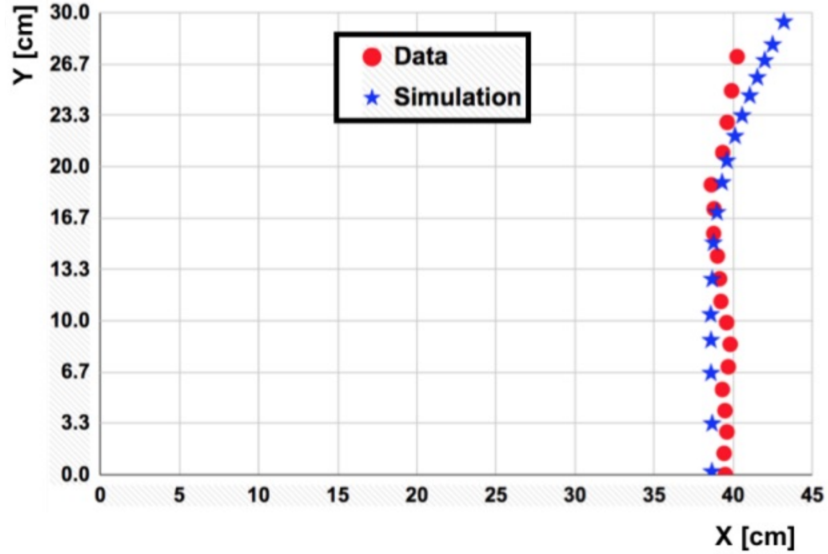


DIRC – validation of 3-layer lens optics

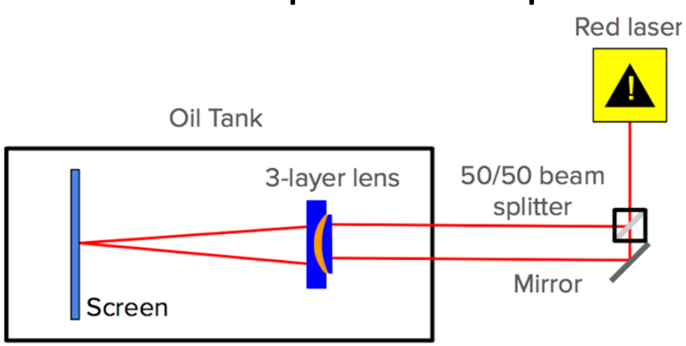
Mapping focal plane of cylindrical 3-layer lens:

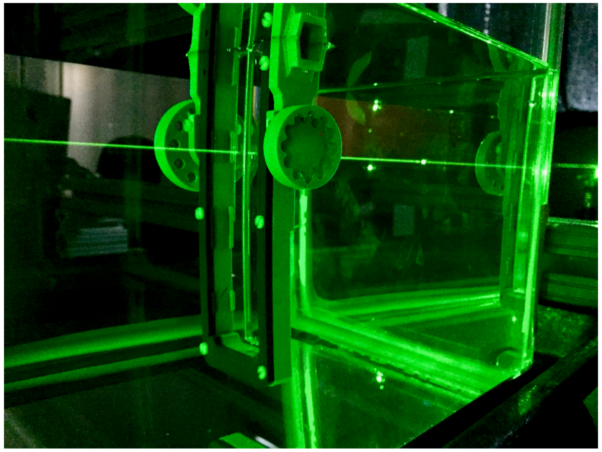
- Results of measurements confirm desired flat focal plane for centered laser beams on the lens
- Measurements with off-center laser beams planed for next year.
- Combined results for both lens prototypes planned to be published in FY19.

Measured and simulated focal plane of cylindrical 3-layer lens



Laser setup at ODU to map the focal plane





Photosensors and Electronics

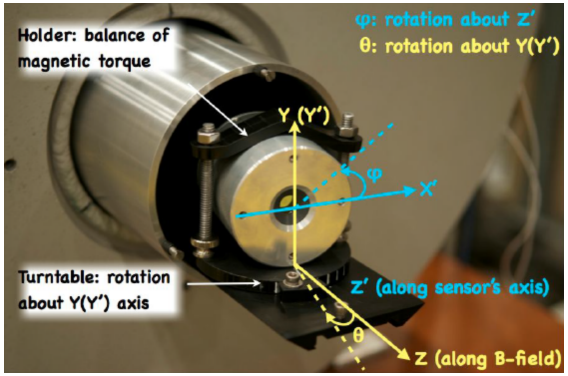
Goals:

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

FY19:

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

Sensors in High-B Fields



Goals:

- To evaluate commercial photosensors for EIC PID detectors in order to improve current PMTs design and operational parameters for High-B operations.

FY19:

- Detailed time-resolution studies of 10-mum Planacon as a function of B, HV, and sensor orientation relative to the B-field direction
- Gain and timing measurements of a Photek 10 mum sensor (if available).

Sensors in High-B Fields

FY18 funded activities

- Construction of a fast laser system for timing-resolution measurements: completed.
- Commissioning of the fast laser system: completed
- Planacon B-field gain measurements at varying HV across the three stages: in progress
- Planacon B-field studies of ion feedback: data taking completed, analysis in progress
- First timing-resolution measurements: in progress

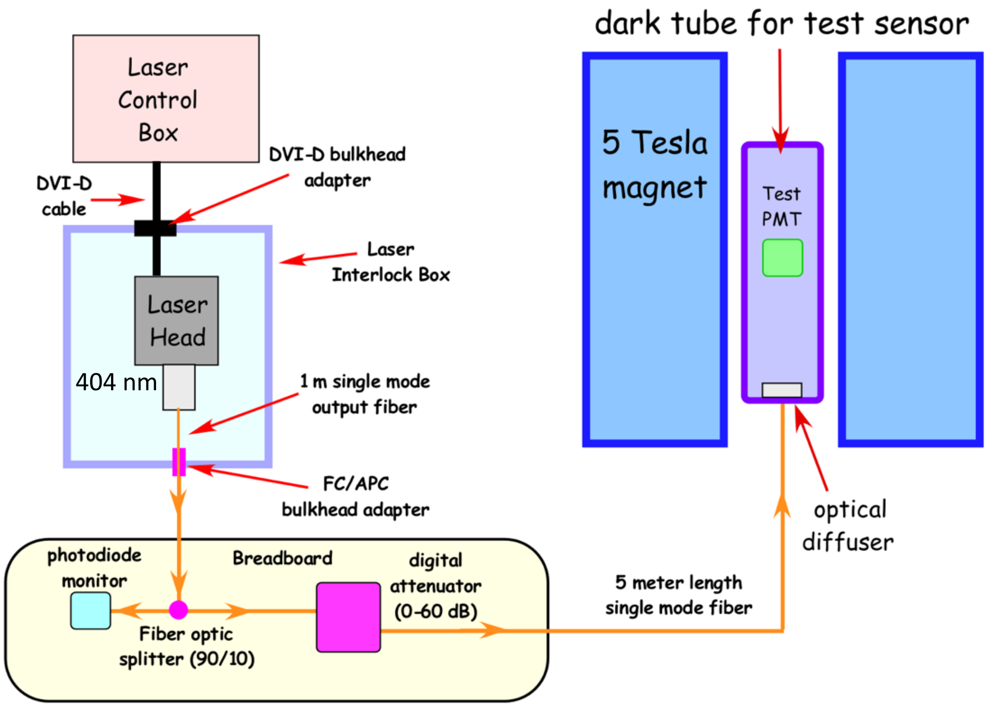
FY19 proposed activities

- Detailed time-resolution studies of 10-mum Planacon as a function of B, HV, and sensor orientation relative to field direction
- Gain and timing measurements of a Photek 10 mum sensor (if available).

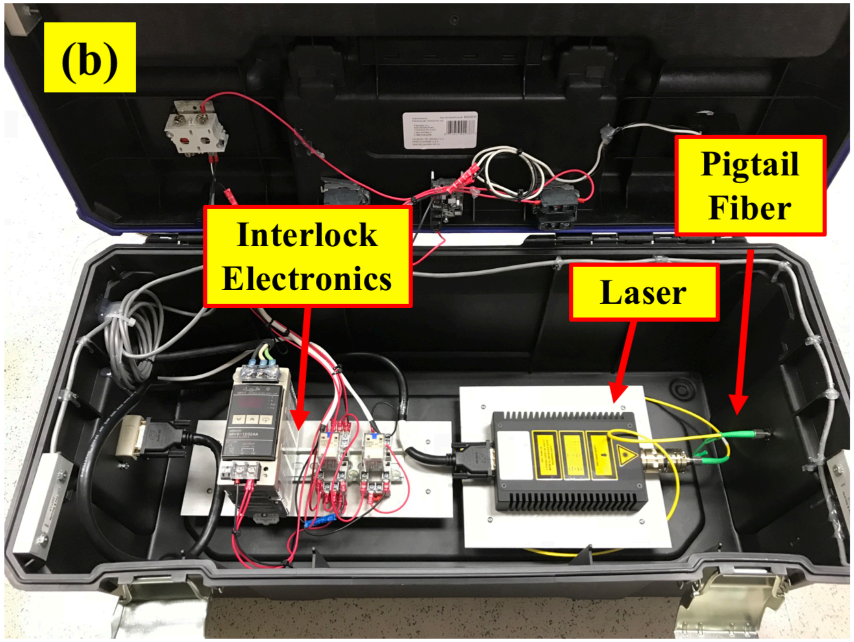
Sensors in High-B Fields FY18 Progress

Fast Laser System for Time-Resolution Measurements

Schematic Diagram of Light Distribution and Components



Photograph of Interlock Safety Box with Laser

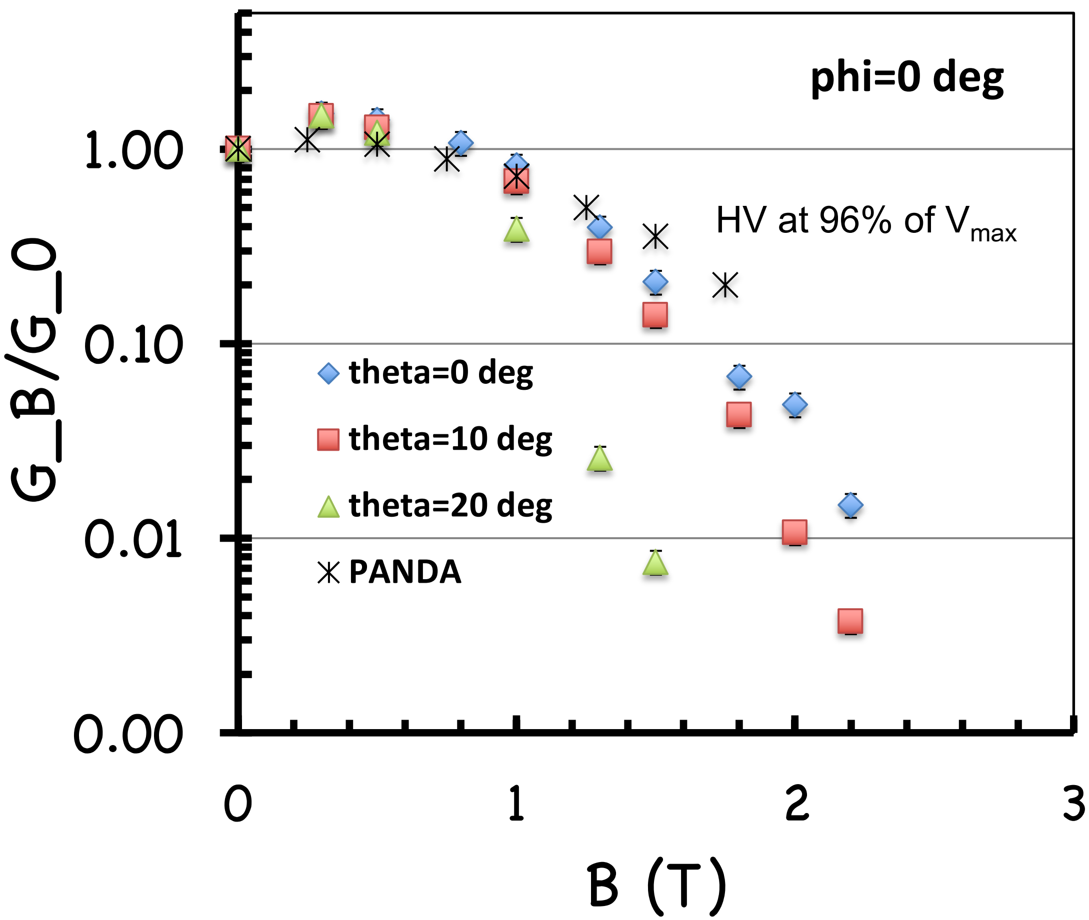


90% of light to monitoring LED

10% of light further attenuated to achieve single photon mode

Sensors in High-B Fields FY18 Progress

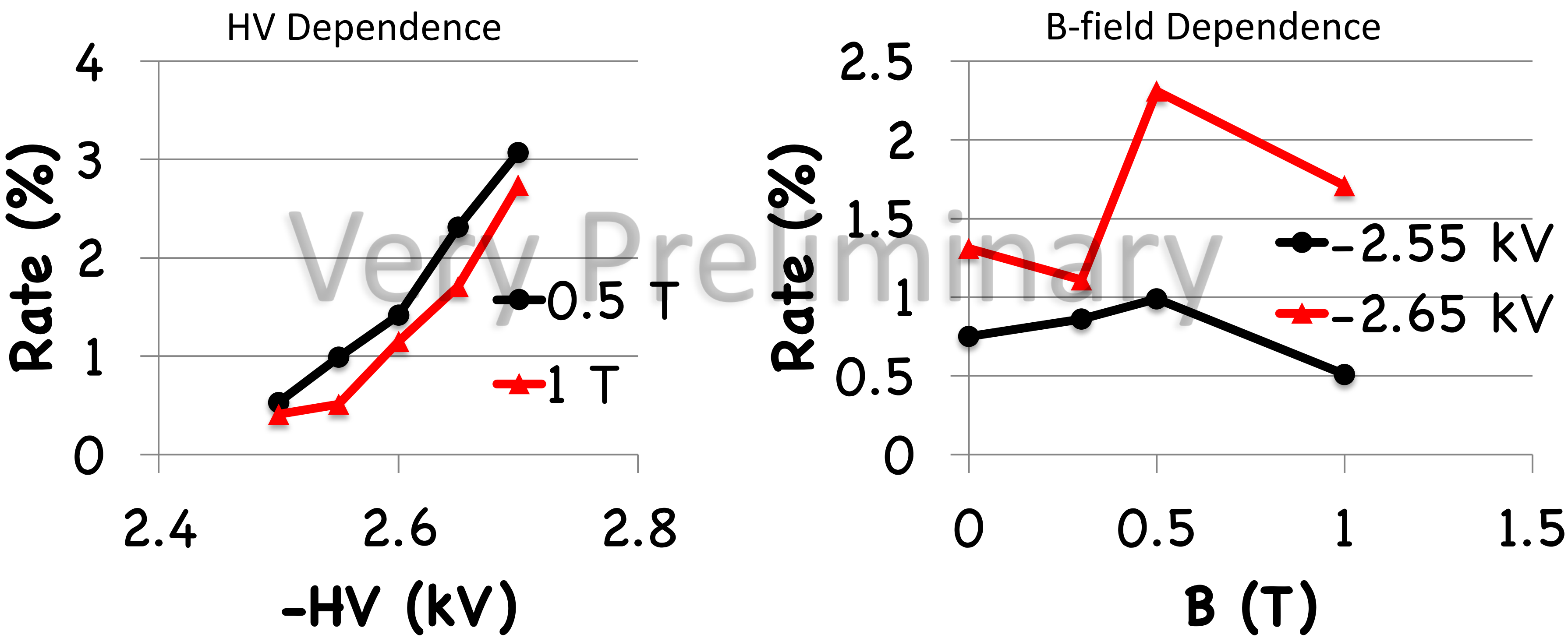
10-μm Planacon: Gain (Summer 2017 Run)



- HV = -2.7 kV (96% of V_{max})
- Standard HV distribution
- Maximum gain at ~ 0.3 T
- Gain decreases fast above 1 T
- The rate of decrease depends on the orientation and is larger at larger polar angles.
- The φ dependence of the gain is much weaker than the theta dependence.

Sensors in High-B Fields FY18 Progress

10-µm Planacon: Ion Feedback



Very first look at data:

- Strong correlation with HV at all magnetic fields
- Shape of dependence on B at fixed HV seems to depend on the HV. Larger variations with B at larger HV.
- More precise analysis to improve accuracy of estimates.

LAPPD^{TM} / MCP-PMT

Goal:

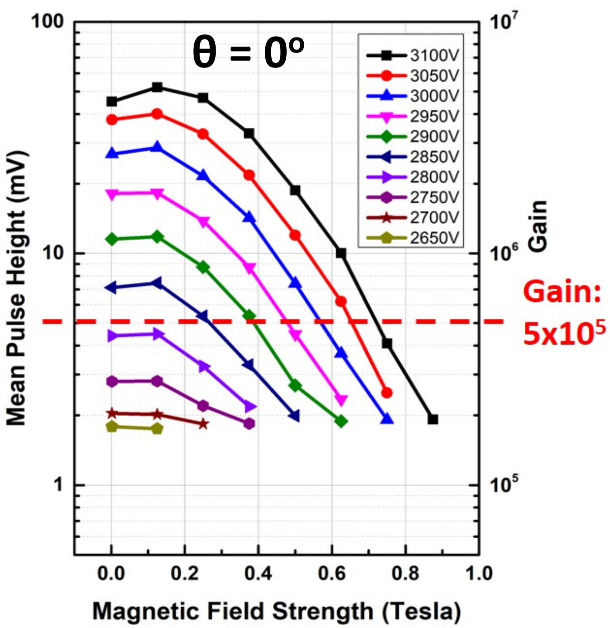
- Adapt LAPPD^{TM} to EIC requirements (magnetic fields, pixelated readout)

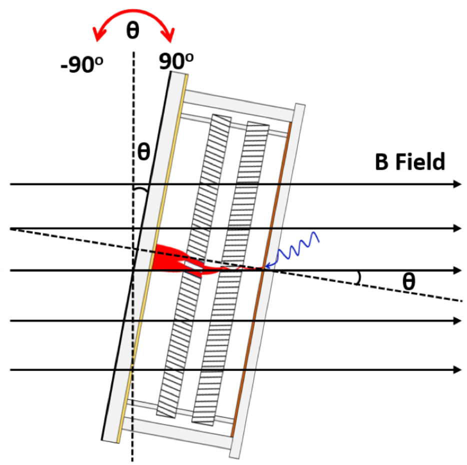
FY 19:

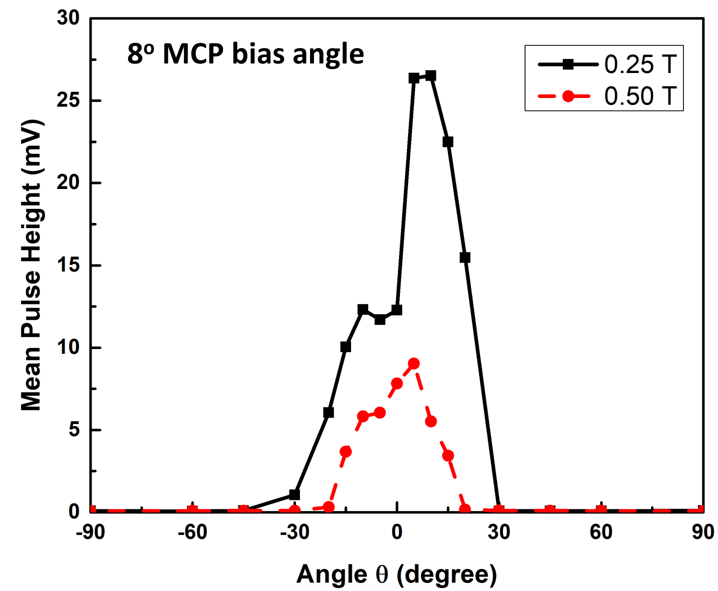
- MCP-PMT after pulse study to better understand the ion feedback for LAPPD
- Improvement of RMS timing by modifying the bias voltages
- Produce a detector with 5μm pore size MCP and minimum spacing to further improve magnetic-field performance and fast timing (possibly <10 ps)
- Test of MCP-PMT/LAPPD with different configurations (smaller pore size and reduced spacing) in lab and in a magnetic fields
- Demonstration of capacitive-coupling pixelated readout through ALD coated glass

LAPPDs – Characteristics (6 cm ones) in magnetic fields

Independently biased design

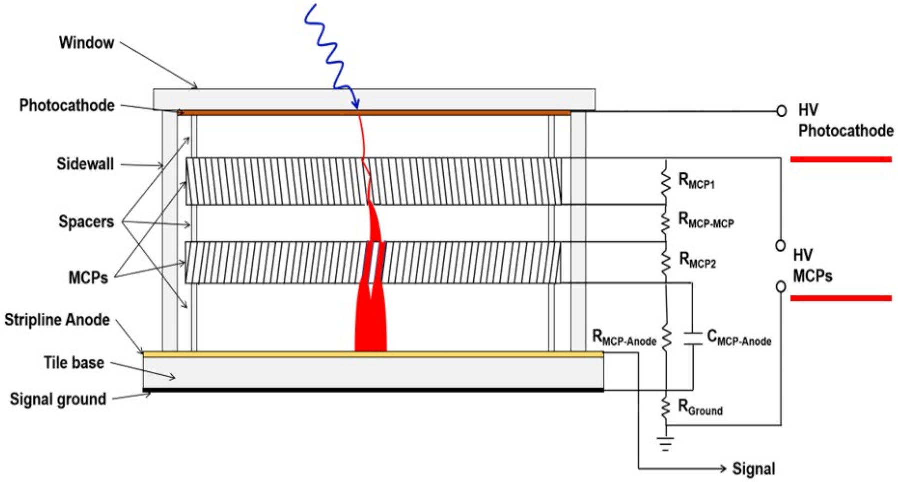


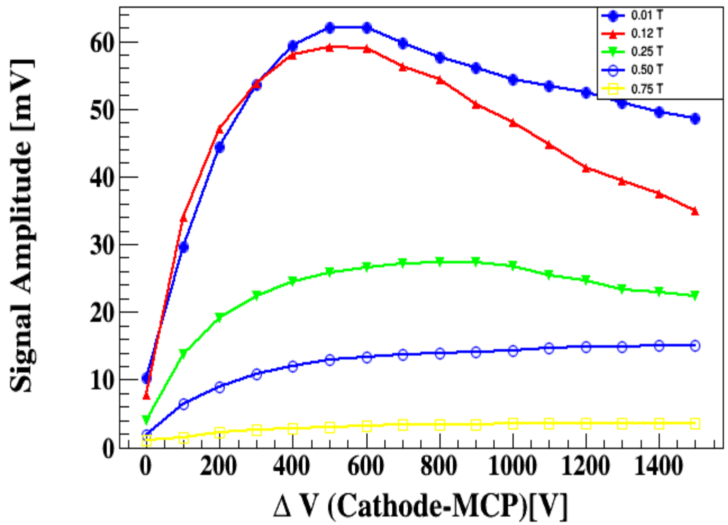




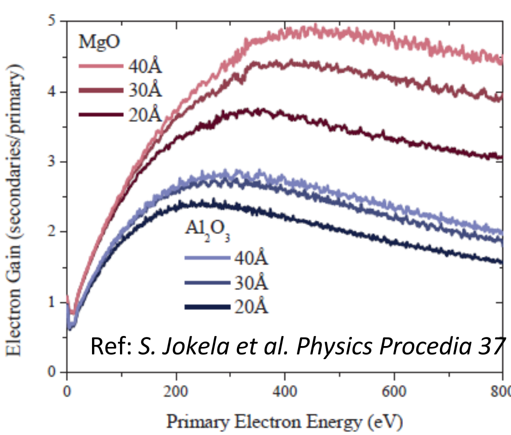
- MCP-PMT characteristics in dependence of: Magnetic field strength, HV, tilt angle, and gap voltages were all tested in magnetic fields
- Baseline tests show for a device with Gain > 5×10^5 , Magnetic Field tolerance is 0.7 T
- The MCP-PMT performance in magnetic field is clearly angle related, due to the 8° MCP bias angle, the highest gain is obtained around 8°.
- Notice the two peaks around ±8°, indicating the effect from upper and lower MCP bias angles are different. Simulation is undergoing with collaborators to explain the different effect.

LAPPDs – Characteristics (6 cm ones) in magnetic fields





- HV(MCPs) was fixed, varies the HV of first gap ΔHV(photocathode–top MCP) by adjusting HV (Cathode).
- Gain increases as ΔHV increases to a maximum then decreases, this can be explained by the MCP gain dependence of primary electron energy.

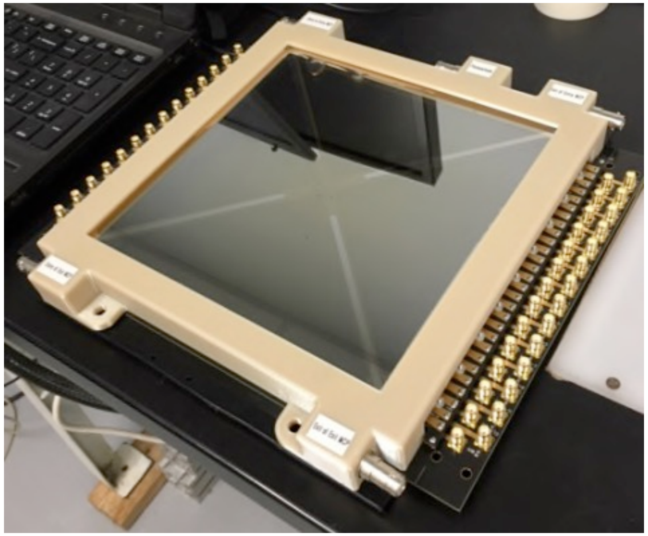


Ref: *S. Jokela et al. Physics Procedia 37 (2012) 740*

MCP-PMTs design/operation in magnetic fields resulted in a **SBIR phase 1 award** (Incomand ANL, $150k for 9 months) to develop magnetic field tolerant LAPPD^{TM} (> 1.5 Tesla)

LAPPDs – Characteristics (20 cm) in magnetic fields

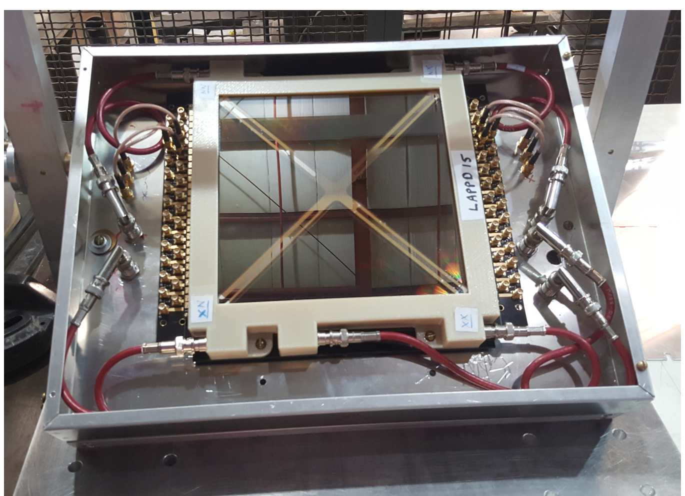
Commercial LAPPD^{TM} delivered and installed at ANL B field facility

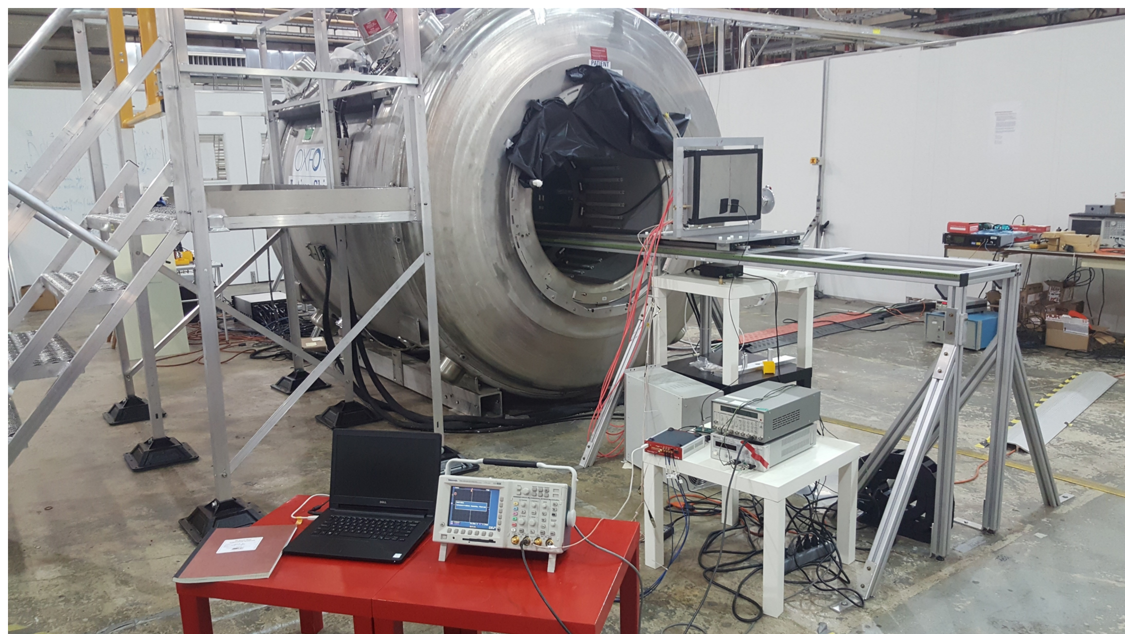


Feature	Parameter
Photodetector Material	Borosilicate Glass
Window Material	Fused Silica Glass
Photocathode Material	Multi-Alkali (K_2NaSb)
Spectral Response (nm)	160-850
Wavelength – Maximum Sensitivity (nm)	≤ 365 nm
Photodetector Active Area Dimensions	195mm X 195mm
• Minimum Effective Area	34,989 mm^2
• Active fraction with Edge Frame X-Spacers	92%
Anode Data Strip Configuration	28 silver strips, Width = 5.2 mm, gap 1.7 mm, nominal 50 Ω Impedance
Voltage Distribution	5 taps for independent control of voltage to the photocathode and entry and exit of MCP

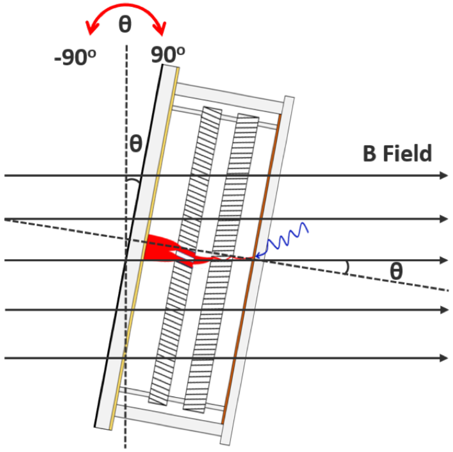
Pore size: 20 µm

Activation area: 195 mm x 195 mm

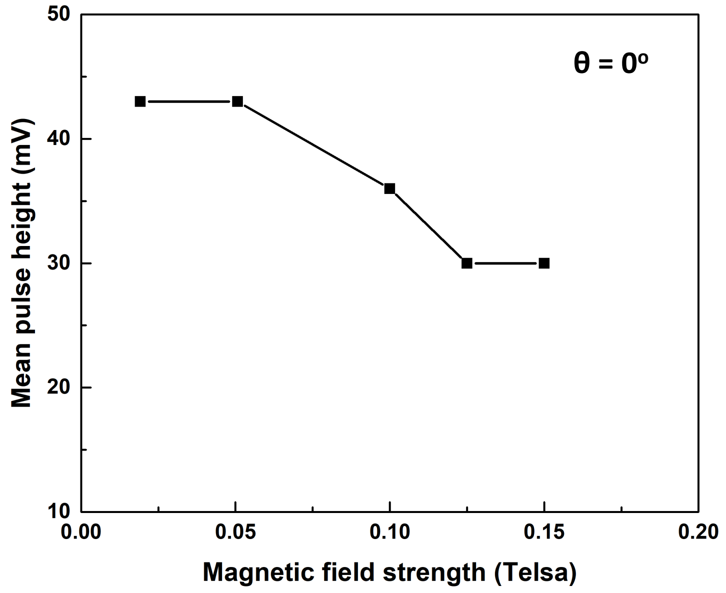


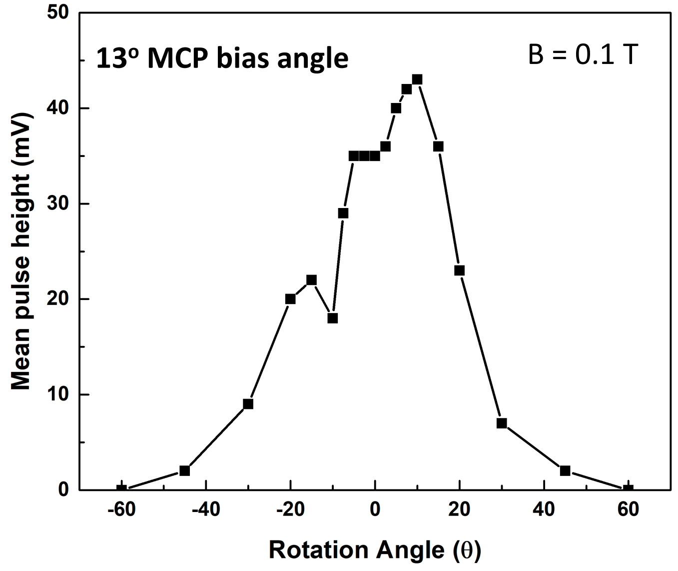


LAPPDs – Characteristics (20 cm) in magnetic fields



Due to the magnetic sensitive components (Kovar is used as shims in the current LAPPD™), we can not go to high magnet field test, a new LAPPD™ with non-magnet components is scheduled to be fabricated and tested in Sep. 2018. The results here demonstrate the capability of the facility for 20 cm LAPPD™.

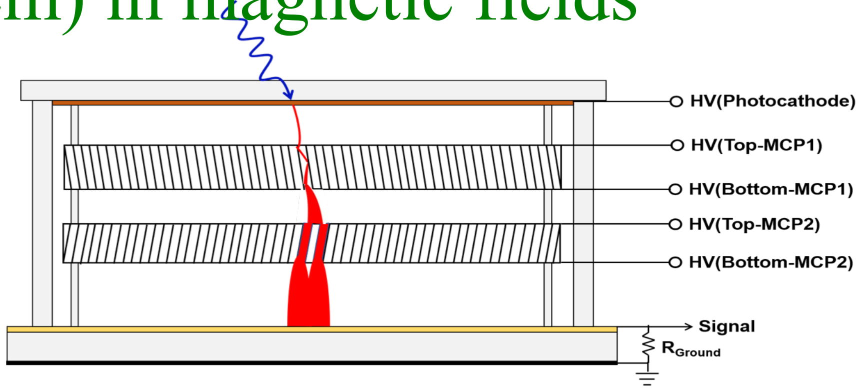


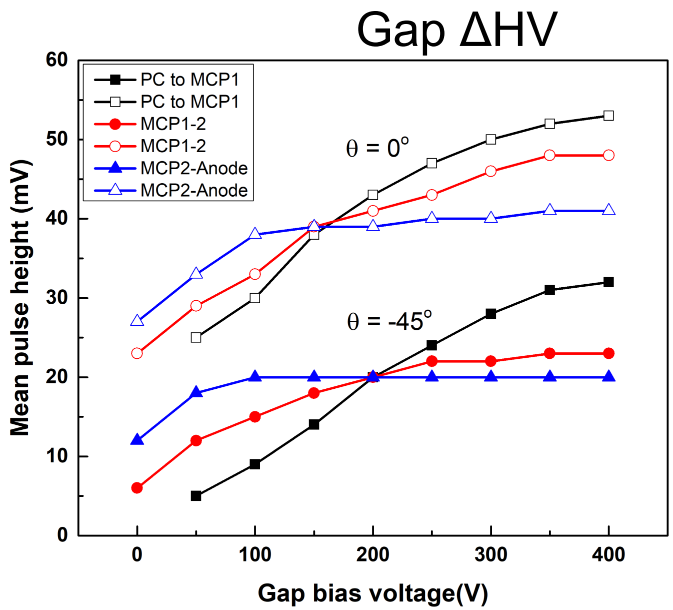


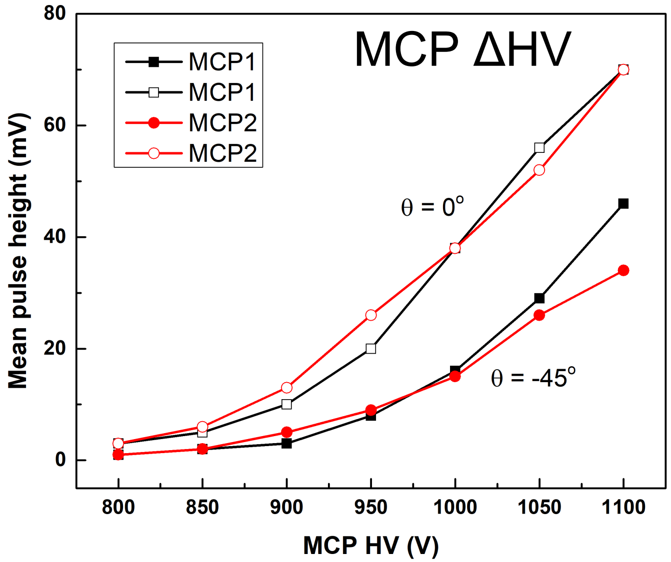
- Similar behavior as 6 cm MCP-PMT: gain decrease as the magnetic field increases
- Two local gain maximum corresponding to the 13° bias angle of MCPs used in LAPPD™

LAPPDs – Characteristics (20 cm) in magnetic fields

Gap and MCP ΔHV dependence



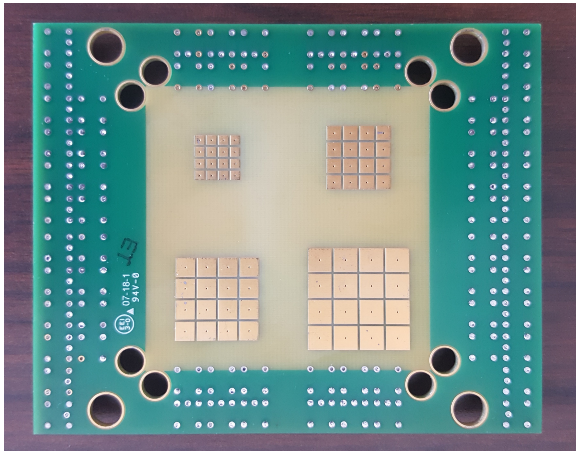




- HV applied to all three gaps affects the gain of the LAPPD
- HV between the photocathode and MCP1 gap has the greatest slope, indicating the strongest effect
- LAPPD gain becomes a constant with the MCP2-Anode bias HV above a threshold
- HV applied to MCPs seems to have NO preference, equally affects the LAPPD gain

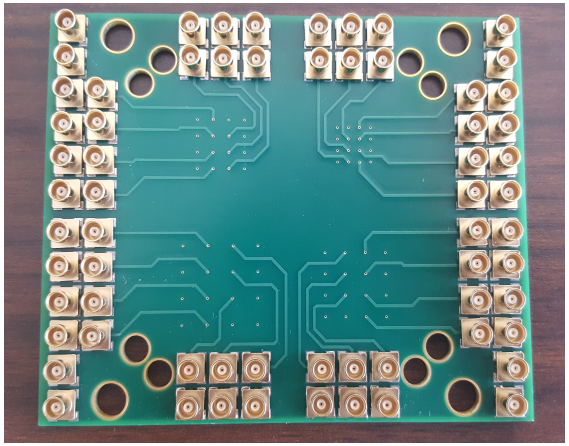
LAPPDs – Pixelated readout

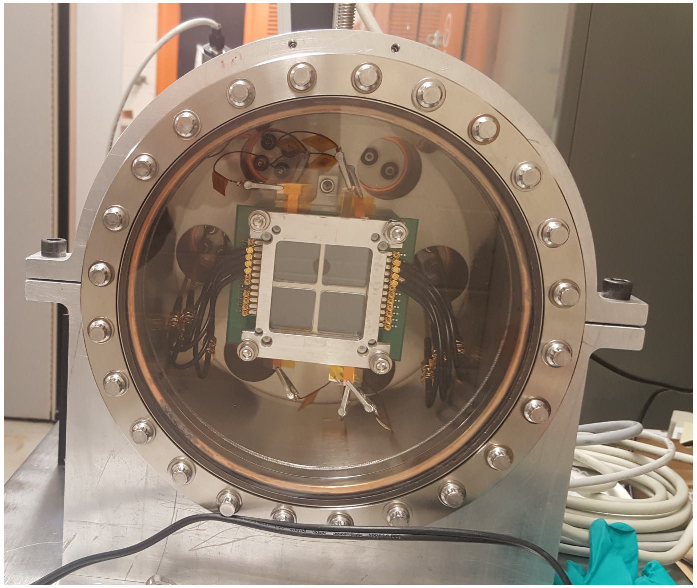
Demountable chamber installed on the stage of Fermilab Test Beam Facility MT6.2C

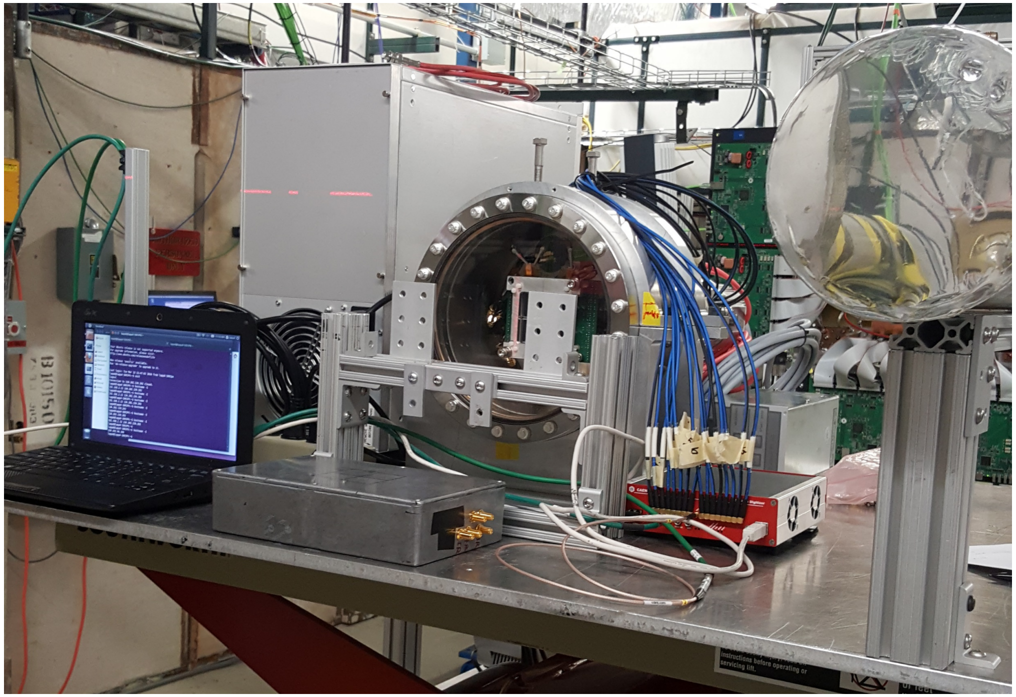


Pad sizes:
2mm x 2mm
3mm x 3mm
4mm x 4mm
5mm x 5mm

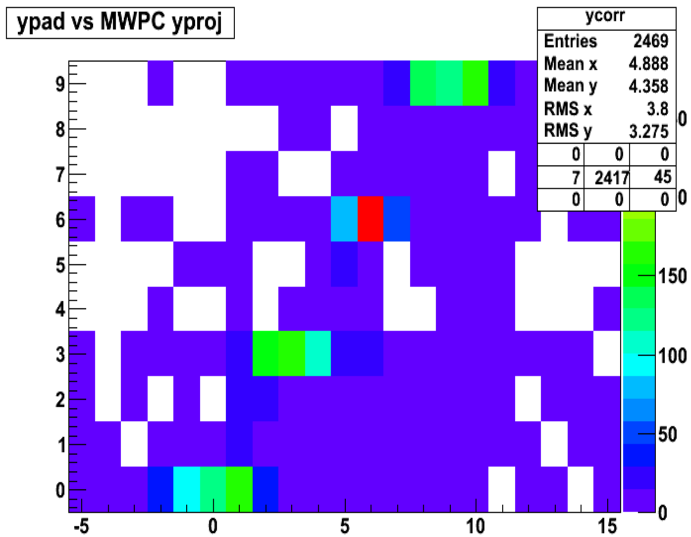
Spacing between pads:
0.5 mm

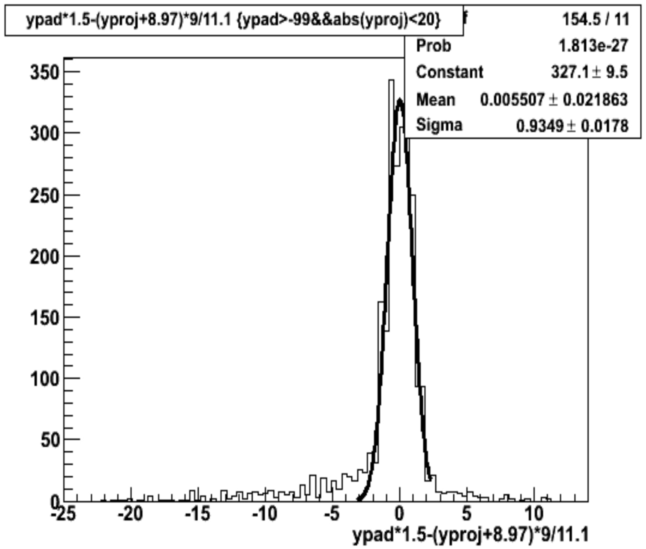






LAPPDs – Pixelated readout





Example correlation between the y-axis of a 3 mm x 3 mm pad and the MWPC projection

Pixel size	**2 mm x 2 mm**	**3 mm x 3 mm**	**4 mm x 4 mm**
σ (x)	-	1.01 mm	1.11 mm
σ (y)	0.73 mm	0.93 mm	1.43 mm
σ (expected)	0.6 mm	0.9 mm	1.2 mm

- Expected position resolution σ (expected) = pixel size/√12
- Beamline experiment preliminary results show that experimental position resolutions are close to the expected position resolutions

LAPPDs – Conclusion

- LAPPD/MCP-PMTs were characterized in details in magnetic fields
- Further development of magnetic field tolerant LAPPD progresses well
- Pixelated readout development for LAPPD was started, will be the next focus
- LAPPD R&D, DIRC R&D, electronics R&D are well aligned with each other for demonstration of DIRC prototype with LAPPD^{TM} sensors and fast readout electronics

Readout Electronics

Goal:

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

FY 19:

- Moving from the TARGETX (Belle-II) to the new SiREAD chip
- New back end (DAQ) for the TARGETX/SiREAD-based frond-ends
- Adaptation of the readout for SiPM arrays

Electronics – overview

Requirements

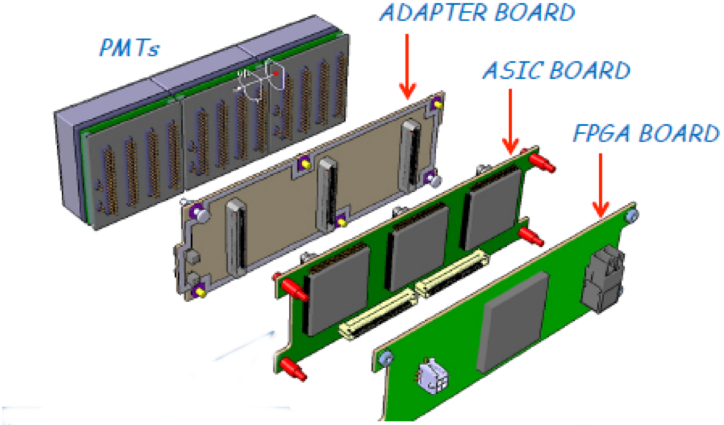
- Need to read out several photosensors (MaPMTs, MCP-PMTs, and SiPMs) with similar sensor and pixel size (16x16 array of 3 mm pixels)
  - DIRC also requires good timing (<100 ps)
- Goal is to have common front end electronics with good timing that can be used for all sensors and detectors (mRICH, dRICH, DIRC)

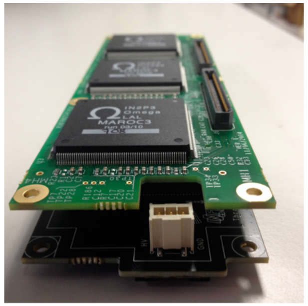
Implementation

- The Maroc-based CLAS12 front end has been used for the first two mRICH beam tests and will remain available in the future
  - Maroc is not a long-term solution due to its poor timing
- A new front end based on TARGETX (used in Belle II) has been developed by U. Hawaii and has already been used for the beam hodoscope
  - Excellent timing, can be a fallback solution also for the DIRC
- Ultimately, a front end based on the new SiREAD chip from Hawaii will be used for all EIC PID detectors and sensors.

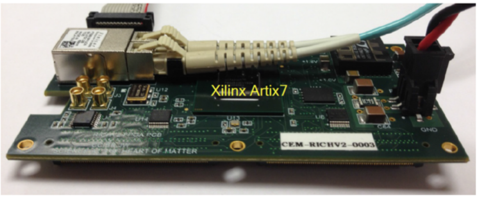
Electronics – Maroc (used for FY17-18 mRICH beam tests)

CLAS12 RICH electronics



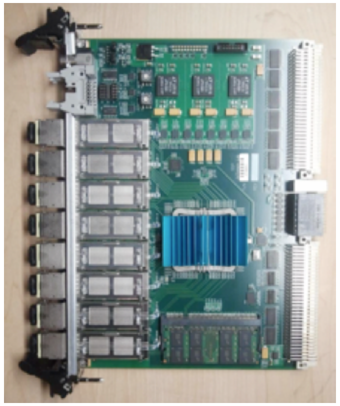


Adapter & Asics Boards



FPGA Board

SSP Fiber-Optic DAQ

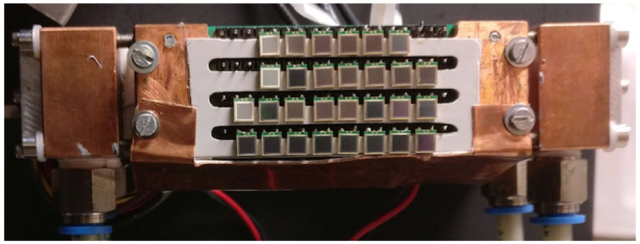


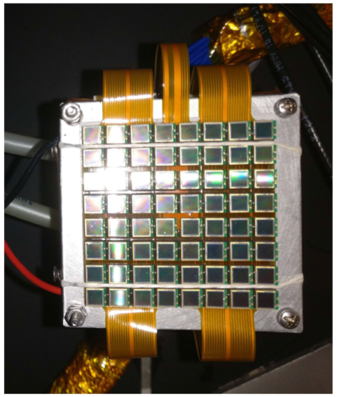
SiPMs

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

- ✗ High dark rate
- ✗ Low radiation tolerance

} Work at low temperature





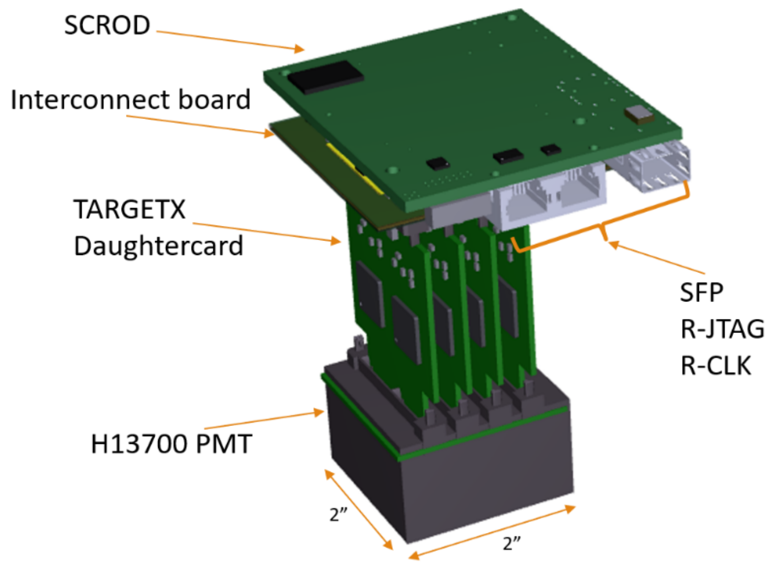
Electronics – TARGETX for mRICH

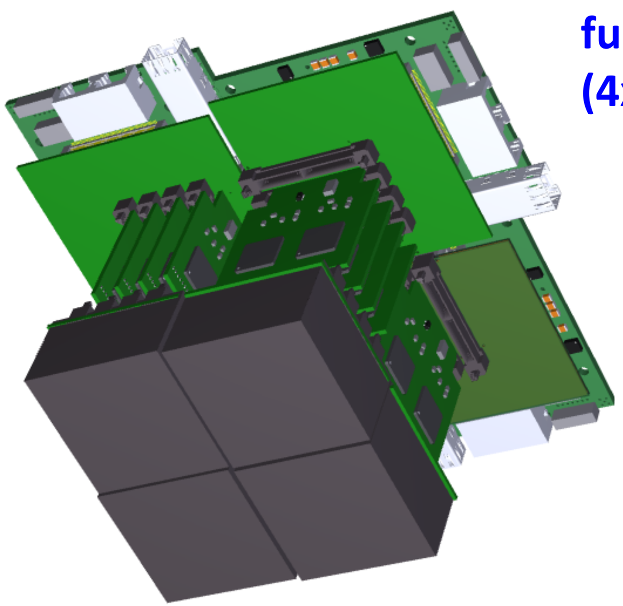
- 1st generation 1024 channel compact readout for the mRICH prototype (and hodoscope) based on existing TARGETX chip:
  - Initial sensor: 4 x H13700 MaPMTs, each with 256 channels
  - 1 GSa/s full waveform sampling
  - 16 us trigger buffer
  - 16 channels
  - Built-in comparator generates trigger primitives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

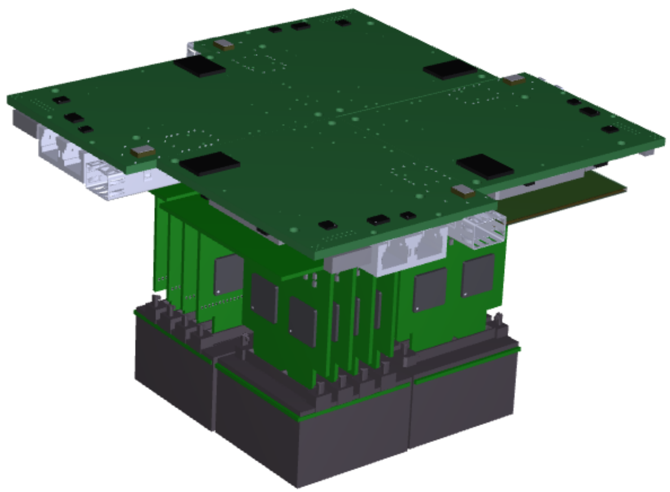
- Technology already used in 3 projects – developed FW/SW base:
  - Belle II KLM upgrade, ~20k SiPM channels
  - Borehole Muon Detector (BMD) prototype: ~100 SiPM channels
  - Hawaii Muon Beamline (HMB): ~60 SiPM channels
  - Cherenkov Telescope Array (CTA) ~2k SiPM or PMT /telescope

Electronics – TARGETX 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)

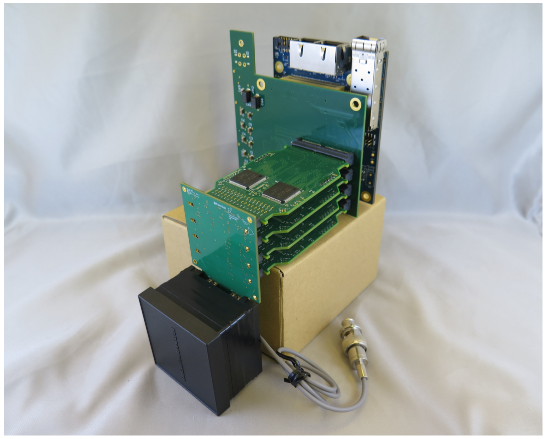




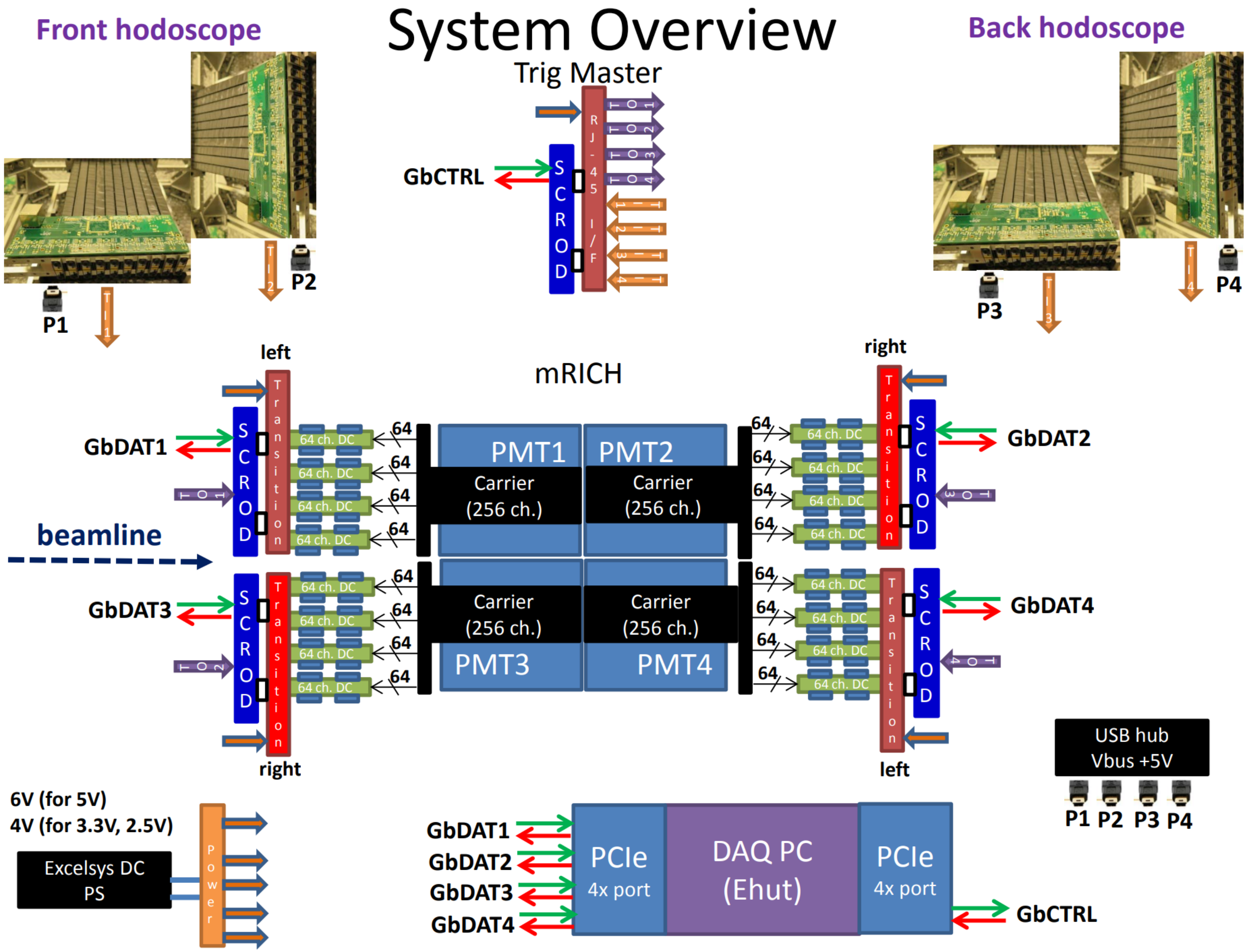


full 1024 channel (4x256) readout block

4x64 channel building block



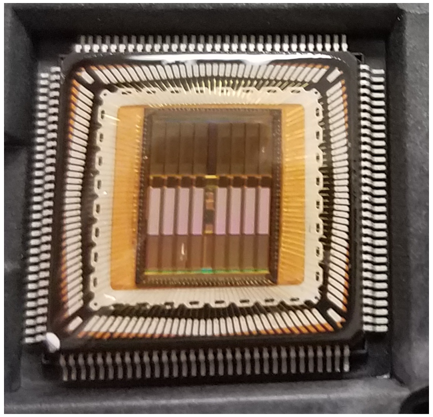
Electronics – TARGETX beam hodoscope readout



– 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)
- Initial testing of SiREAD complete
  - results to be presented at NSS/Sydney
- Various small ‘bugs’ found in chip that require re-submission
- Next beam test in FY20:
  - front-end electronics operation (ideally with SiREAD rev2),
  - DAQ verification,
  - different photosensors (including MCP-PMTs / LAPPDs)



eRD14 FY19 budget (including overhead)

5.8 Budget by project

	100%	80%	60%
dRICH	$52k	$35k	$17k
mRICH	$77.3k	$62.8k	$48.5k
DIRC	$112k	$92k	$62k
high-B	$39.2k	$25k	$25k
LAPPD	$95k	$75k	$60k
Electronics	$86k	$57k	$43k
Total	**$461.5k**	**$346.8k**	**$255.5k**

5.9 Budget by institution

	100%	80%	60%
ANL	$95k	$75k	$60k
INFN	$95.5k	$69.5k	$42.5k
CUA (and GSI)	$112k	$92k	$62k
GSU	$69.8k	$55.3k	$41k
U. Hawaii	$50k	$30k	$25k
JLab	$7.6k	$7.6k	$7.6k
USC	$31.6k	$17.4k	$17.4k
Total	**$461.5k**	**$346.8k**	**$255.5k**

Recent publications

2018 -- Publications

1. X. He, for the EIC PID Consortium (eRD14 Collaboration), *Ring Imaging Cherenkov Detector Technologies for Particle Identification in the Electron-Ion Collider Experiments*, 21st Particle and Nuclei International Conference (PANIC 2017), International Journal of Modern Physics: Conference Series, Vol. 46 (2018) 1960080. DOI: 10.1142/S2010194518600807.
2. J. Xie *et al.*, *Rate capability and magnetic field tolerance measurements of fast timing microchannel plate photodetectors*, NIMA (2018). DOI: 10.1016/j.nima.2017.10.059.
3. G. Kalicy *et al*., *High-performance DIRC detector for the future Electron Ion Collider experiment,* Proceedings of DIRC2017, JINST **13,** C04018 (2018).
   https://doi.org/10.1088/1748-0221/13/04/C04018
4. Y. Ilieva *et al*., *Particle Identification for a future EIC detector,* Proceedings of DIRC2017, JINST **13,** C03018 (2018).
   https://doi.org/10.1088/1748-0221/13/03/C03018

2018 -- Presentations

1. X. Sun, for the EIC PID Consortium (eRD14 Collaboration), *Ring Imaging Cherenkov Detector for Particle Identification in the Electron-Ion Collider (EIC) Experiments*, RHIC/AGS Users Meeting, June 12 – 15, 2018.

2017 -- Publications

1. A. Deldotto, C.-P. Wong *et al*. (EIC PID Consortium), *Design and R&D of RICH detectors for EIC experiments*, NIM A https://doi.org/10.1016/j.nima.2017.03.032
2. J. Wang *et al.*, *Design improvement and bias voltage optimization of glass-body microchannel plate picosecond photodetector*, Nuclear Science IEEE Transactions (in print) 2017.
3. C.P. Wong *et al.*, *Modular focusing ring imaging Cherenkov detector for Electron-Ion Collider experiments*, NIM A 871, 13 (2017).

2017 -- Presentations

1. R. Dzhygadlo for the EIC DIRC Collaboration, *DIRC-based PID for the EIC Central Detector*, oral presentation at the DPG spring meeting, Muenster, March 27 – 31, 2017.
2. X. He for the EIC PID Consortium, *Ring Imaging Cherenkov Detector Technologies for Particle Identification in the Electron-Ion Collider Experiments*, PANIC2017, in Beijing, September 1 – 5, 2017.
3. Y. Ilieva for the EIC PID Consortium, *Particle Identification for a Future EIC Detector*, 2017 International Workshop on Fast Cherenkov Detectors - Photon detection, DIRC design and DAQ, August 7 – 9, 2017, Giessen, Germany.
4. G. Kalicy for the EIC PID Consortium, *The High-Performance DIRC for a Future EIC Detector*, 2017 International Workshop on Fast Cherenkov Detectors - Photon detection, DIRC design and DAQ, August 7 – 9, 2017, Giessen, Germany.
5. J. Xie, *Development of fast-timing microchannel plate photomultiplier*, Fall Meeting of the Division of Nuclear Physics of the American Physical Society (DNP 2017), Pittsburgh, PA, Oct. 2017 (Invited talk

2016 -- Publications

1. Y. Ilieva *et al.*, *MCP-PMT Studies at the High-B Test Facility at Jefferson Lab*, JINST **11**, 2016; http://dx.doi.org/10.1088/1748-0221/11/03/C03061. Proceedings of the International Workshop on Fast Cherenkov Detectors - Photon detection, DIRC design and DAQ, November 11–13, 2015, Giessen, Germany.
2. G. Kalicy *et al.*, High-performance *DIRC detector for Electron Ion Collider*, submitted to JINST, 2016; Proceedings of the International Workshop on Fast Cherenkov Detectors - Photon detection, DIRC design and DAQ, November 11–13, 2015, Giessen, Germany.
3. J. Xie *et al.*, *Development of a low-cost fast-timing microchannel plate photodetector*, Nucl. Instrum. Meth. A 824 (2016) 159-161.
4. 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.

2016 -- Presentations

1. H. Hamilton, *Testing of Advanced Particle Detectors for the Next Generation Particle Collider*, oral presentation at the Abilene Christian University Undergraduate Research Festival, 5 April 2016, Abilene, TX.
2. C. Towell, *Development of an Electron Ion Collider Detector Test Stand*, oral presentation at the Abilene Christian University Undergraduate Research Festival, 5 April 2016, Abilene, TX.
3. A. Deldotto for the EIC PID consortium, *Design and R&D of RICH detectors for EIC experiments*, poster presented at RICH 2016, 9th International Workshop on Ring Imaging Cherenkov Detectors, Slovenia on September 5-9, 2016.

2016 – Presentations continued

1. Z.W. Zhao for the EIC PID consortium, EIC RICH R&D, presentation at EIC User Group Meeting, January 2016.
2. L. Allison for the EIC DIRC Collaboration, *Particle ID with DIRC Detectors*, invited talk at ODU Nuclear Group Seminar, March 17, 2016.
3. G. Kalicy for the EIC DIRC Collaboration, *DIRCs*, invited talk at ODU Nuclear Group Seminar, December 4, 2016.
4. G. Kalicy for the EIC DIRC Collaboration, *DIRC@EIC*, presentation at EIC User Group Meeting, January 2016.
5. G. Kalicy: PID systems for the JLab EIC full-acceptance detector, ICHEP2016 38th International Conference on High Energy Physics, August 3–10, 2016, Chicago, IL.
6. J. Xie *et al.*, *Planar microchannel plate photomultiplier with VUV-UV-Vis full range response for fast timing and imaging applications*, accepted for RICH 2016, 9th International Workshop on Ring Imaging Cherenkov Detectors, Slovenia on September 5-9, 2016.
7. C.P. Wong, *Performance Study of a Prototype Modular RICH Detector for EIC Experiments*, oral presentation at 2016 Fall Meeting of the APS Division of Nuclear Physics, October 13–16,2016, Vancouver, Canada.

2015 -- Publications

1. 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) 84–93. .2014.HAW.GB.147.

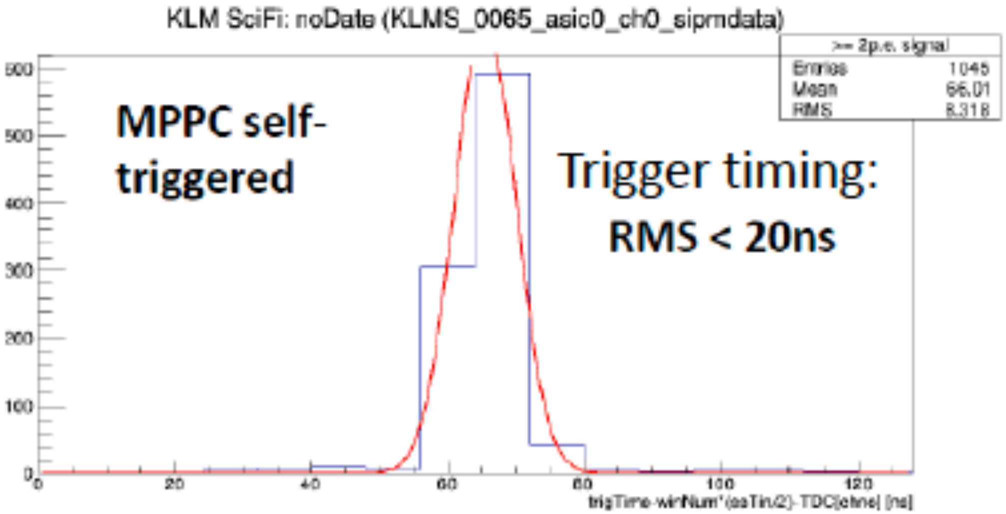
Thank you!

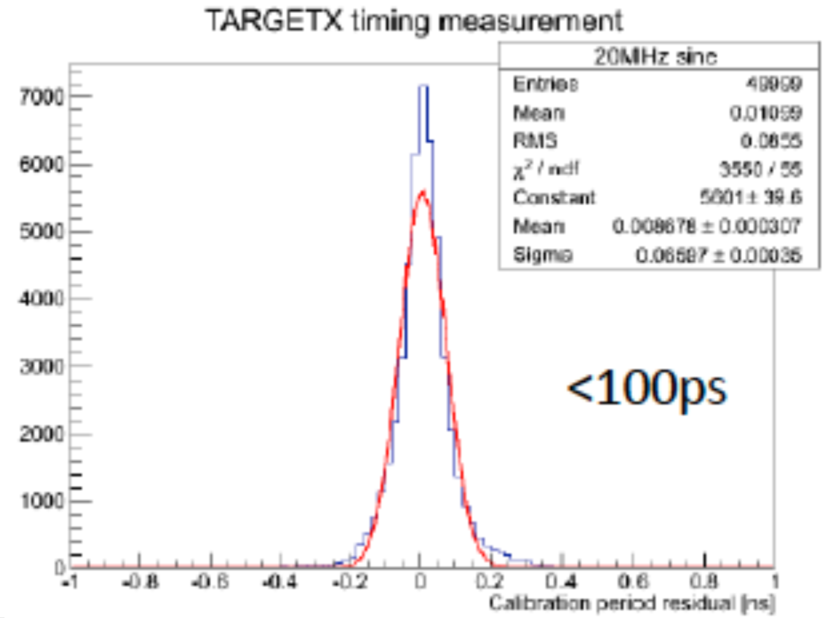
Also, please visit the eRD14 wiki

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

Backup

Electronics – TARGETX front end layout and timing





Sine scan data (zero crossing)