RICH Detector for the EIC's Forward Region Particle Identification

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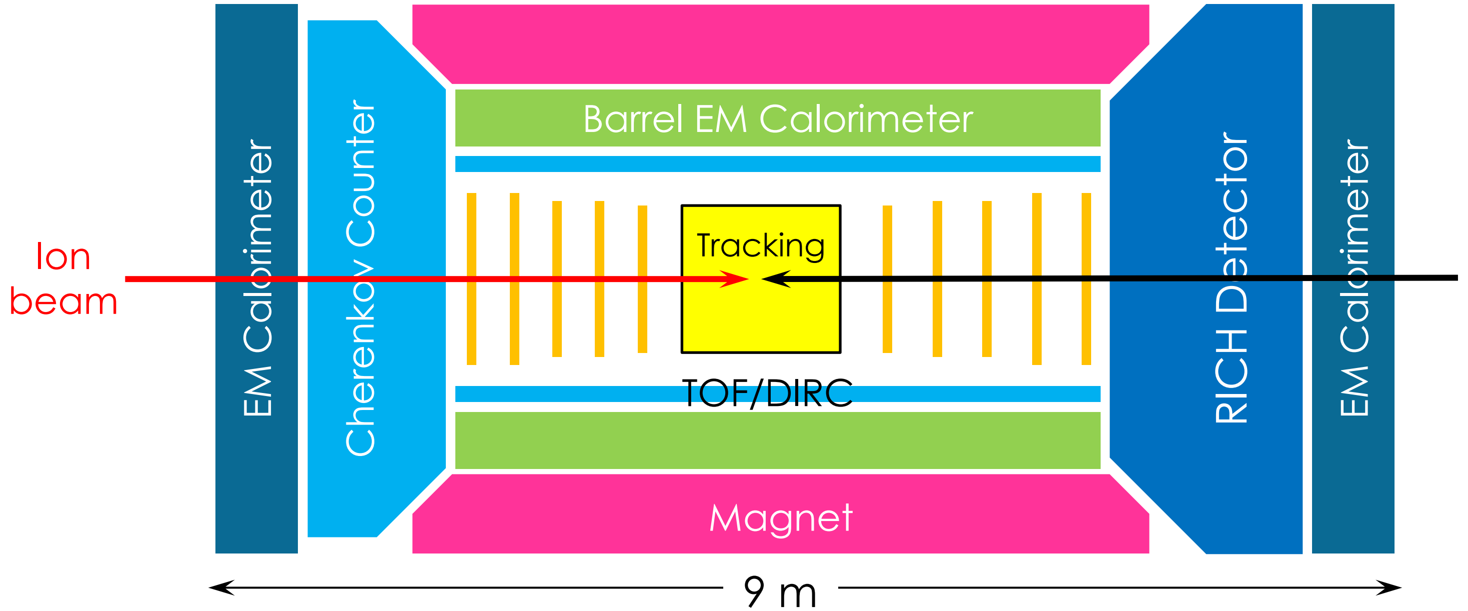
an EIC R&D Proposal – Jan 13, 2014

Overview

- Motivation
- Detector Concepts and Key Technologies
  - Dual radiator RICH
  - Modular RICH
  - Aerogel
  - MCP-based LAPPD
  - GEM-based readout
- Proposed RICH R&D Project
  - Tasks and milestones
  - Budget
- Summary

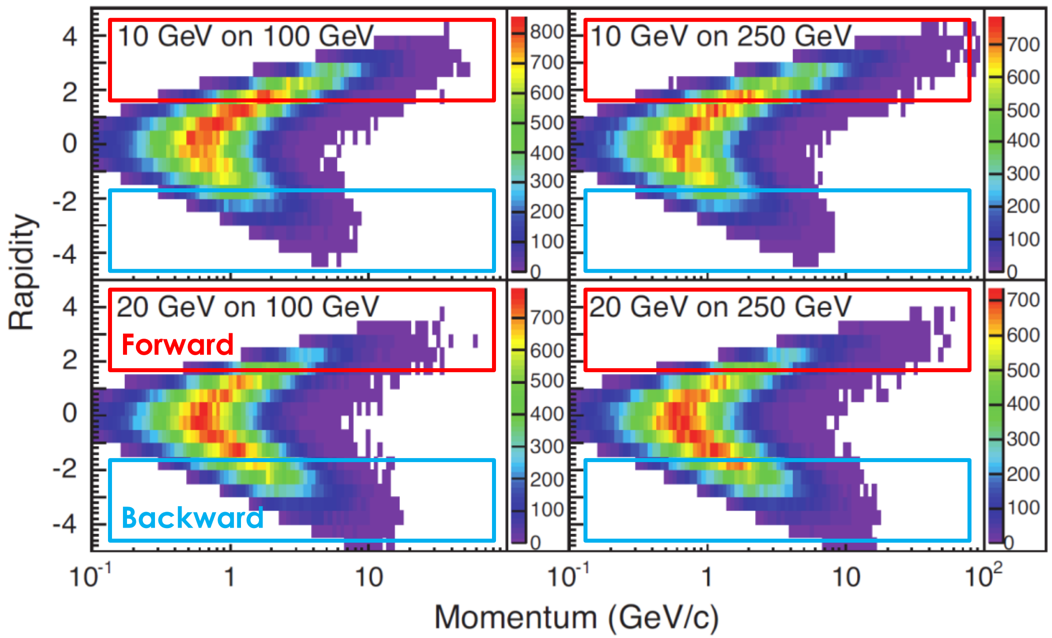
EIC PID Requirements

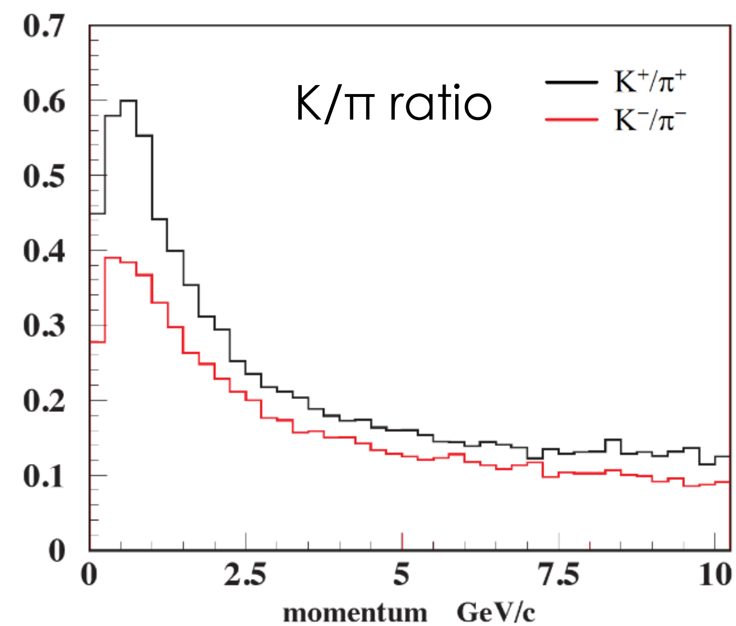
- Very rich physics program:
  - Nucleon tomography and spin structure
  - Quark hadronization
  - Spectroscopy
  - Many more …
- Dedicated EIC machine and spectrometer
  - Hermetic detector system
  - Large momentum range
  - Multi-particle detection in final states



Kaon Identification in SIDIS

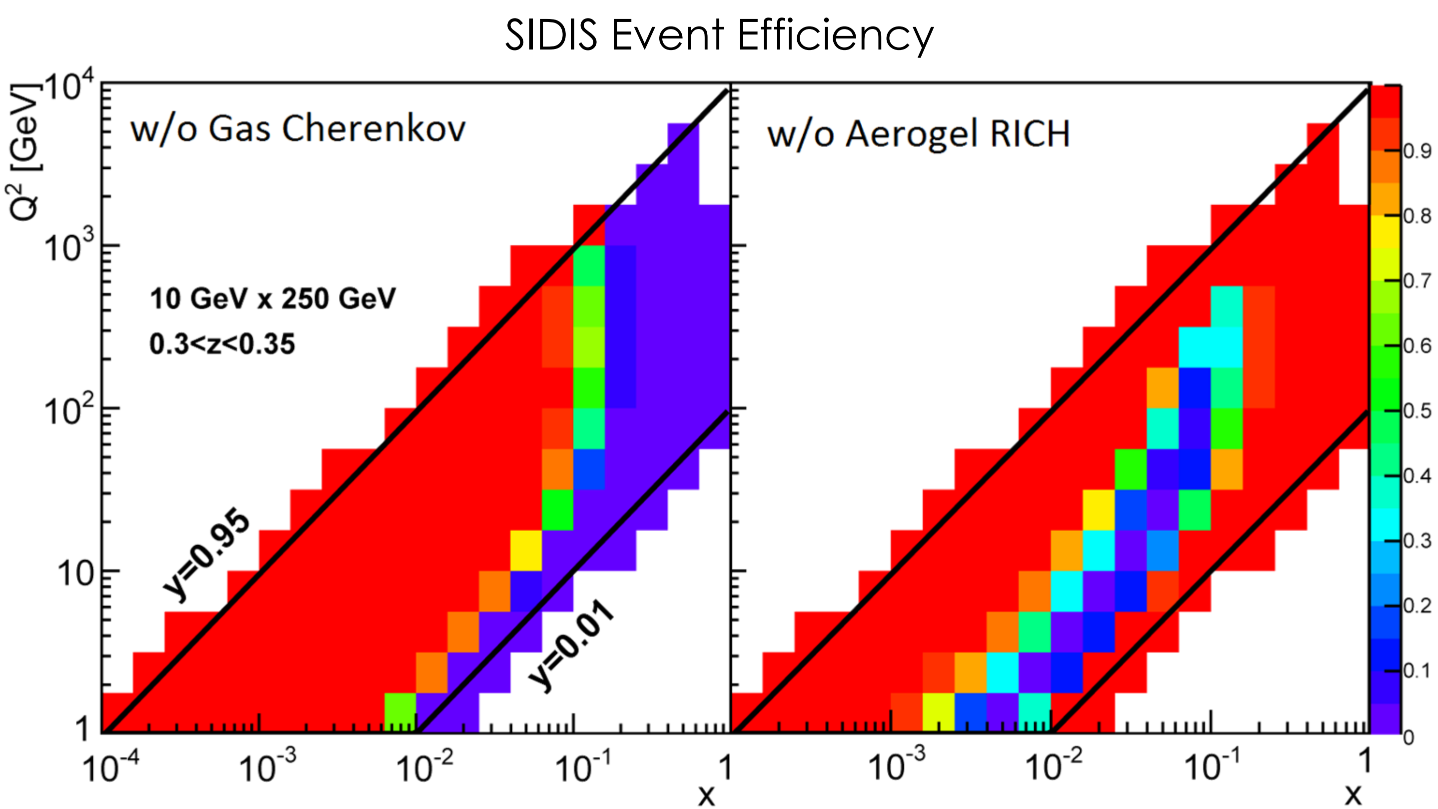
- Semi-Inclusive Deep-Inelastic Scattering (SIDIS)
  - Golden channel to study quark's orbital motion through transverse momentum-dependent parton distributions (TMDs)
  - Kaon identification crucial for sea quark contribution
- K/π identification in Forward(Backward) region:
  - 0 – 15 GeV, 4-σ separation





Solution to Forward PID

- Multiple radiators are needed to cover the broad kinematic range
  - TOF + high-n radiator (aerogel) + low-n radiator (gas)
  - Can we combine them into one detector?

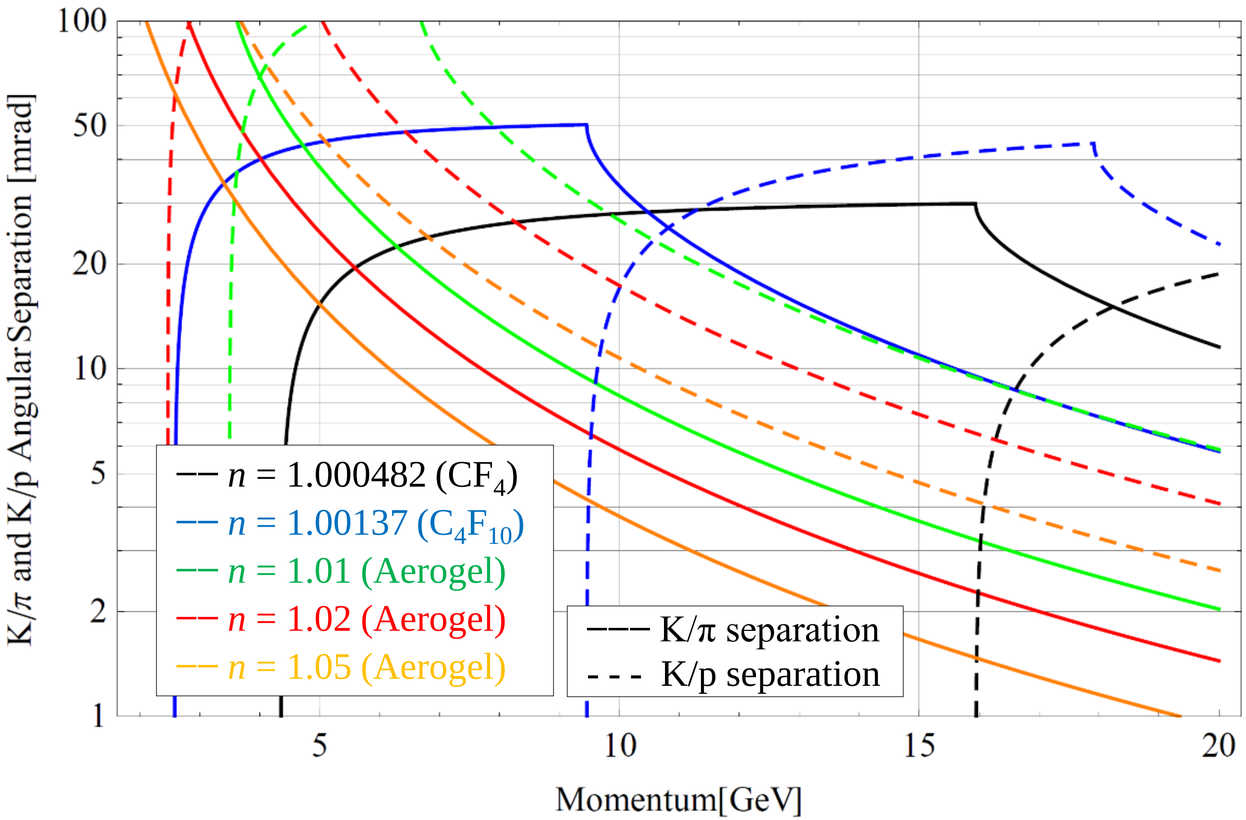


Choice of Radiators

- 5 – 10 GeV range: Aerogel RICH
  - Index ranges 1.01 ~ 1.10
  - Used as RICH in HERMES, LHCb, AMS, BELLE …

	Aerogel	C_4F_{10}	CF_4
Emission	0.4	0.8	0.2
Chromatic	2.1	0.9	0.5
HPD	0.5	0.6	0.2
Track	0.4	0.4	0.4
Total	2.6	1.5	0.7

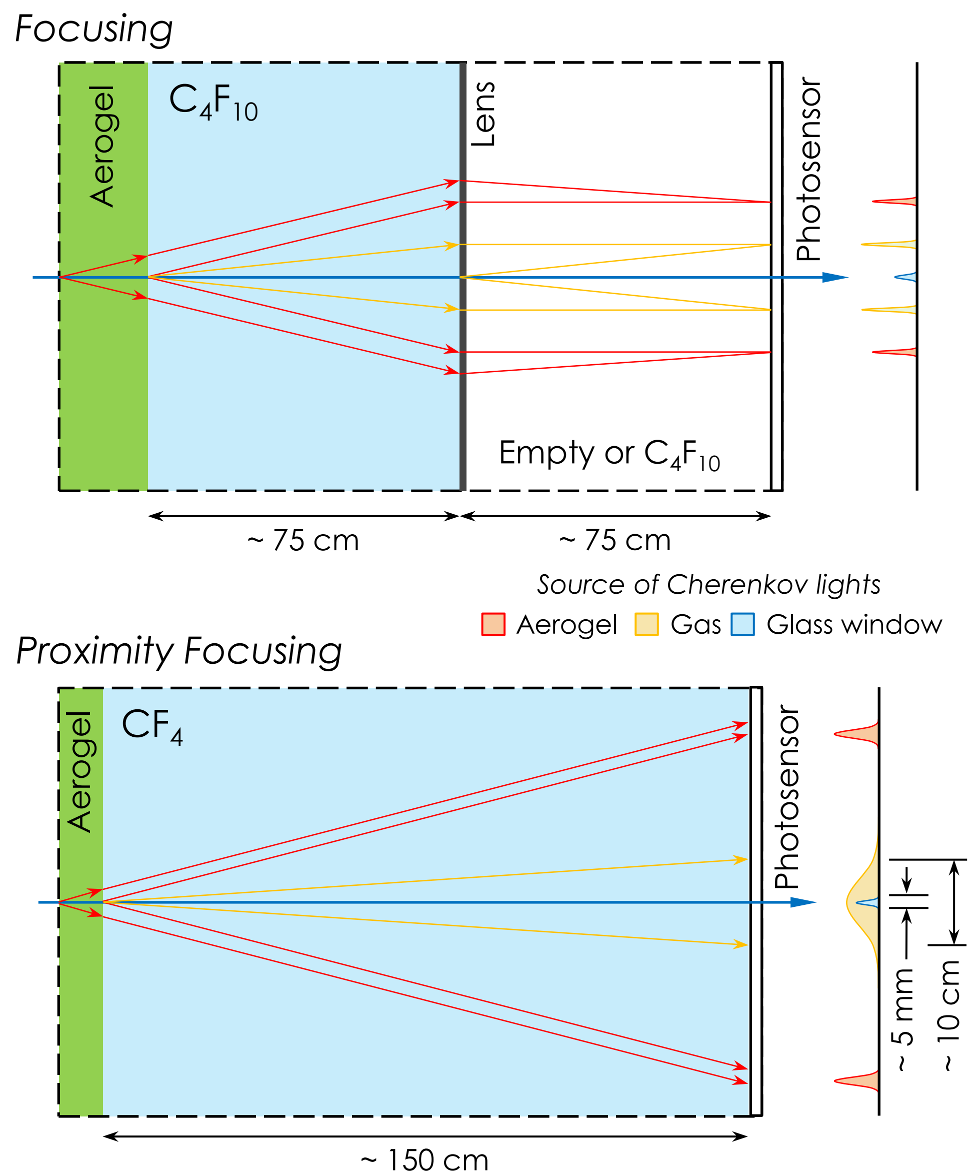
Single photon resolution (LHCb)



- 10 – 15 GeV range: heavy gas
  - C_4F_{10}/C_4F_8O RICH
    - Good light yield
    - May need recycling
  - CF_4 threshold counter
    - Need Aerogel RICH to veto protons
    - Can cover much higher range as RICH

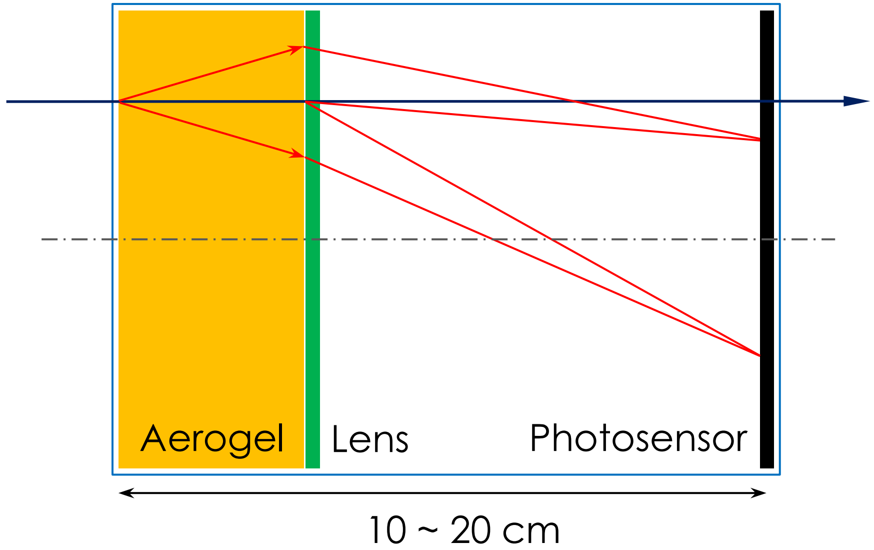
Dual Radiator Concept

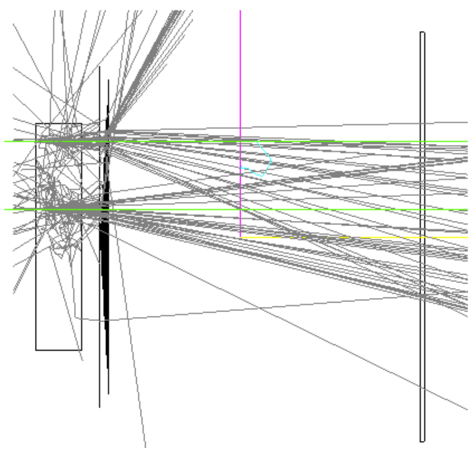
- General geometry constraint: ~150 cm length
- Focusing RICH
  - Aerogel RICH: 3 – 10 GeV
  - C_4F_{10}: 10 – 20 GeV
  - Focused by a Fresnel lens
  - Readout resolution: < 2 mm
- Proximity Focusing
  - Aerogel RICH: 3 – 10 GeV
  - CF_4 threshold counter: 8 – 17 GeV
    - Signals from readout window will be mixed with photons from CF_4
  - Readout resolution: < 4 mm

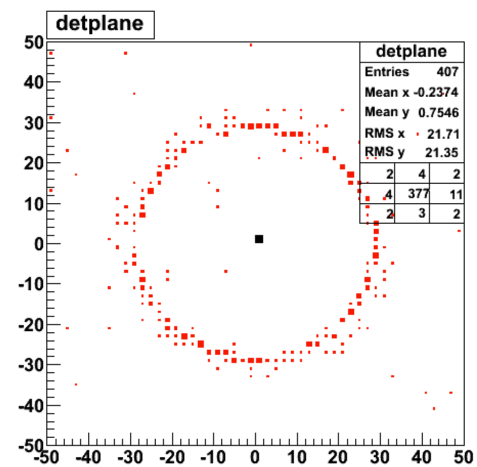


Modular Concept

- Single aerogel radiator
  - Covers 3 – 10 GeV
  - Needs to be paired with additional gas RICH detector for higher momentum range
- Modular design for maximum flexibility
  - Very compact design, size of a shoe box
  - Can be tiled to cover different geometry, used in various experiments
  - Fresnel lens for focusing
  - Concentric rings for parallel tracks
  - Readout resolution: < 0.5 mm



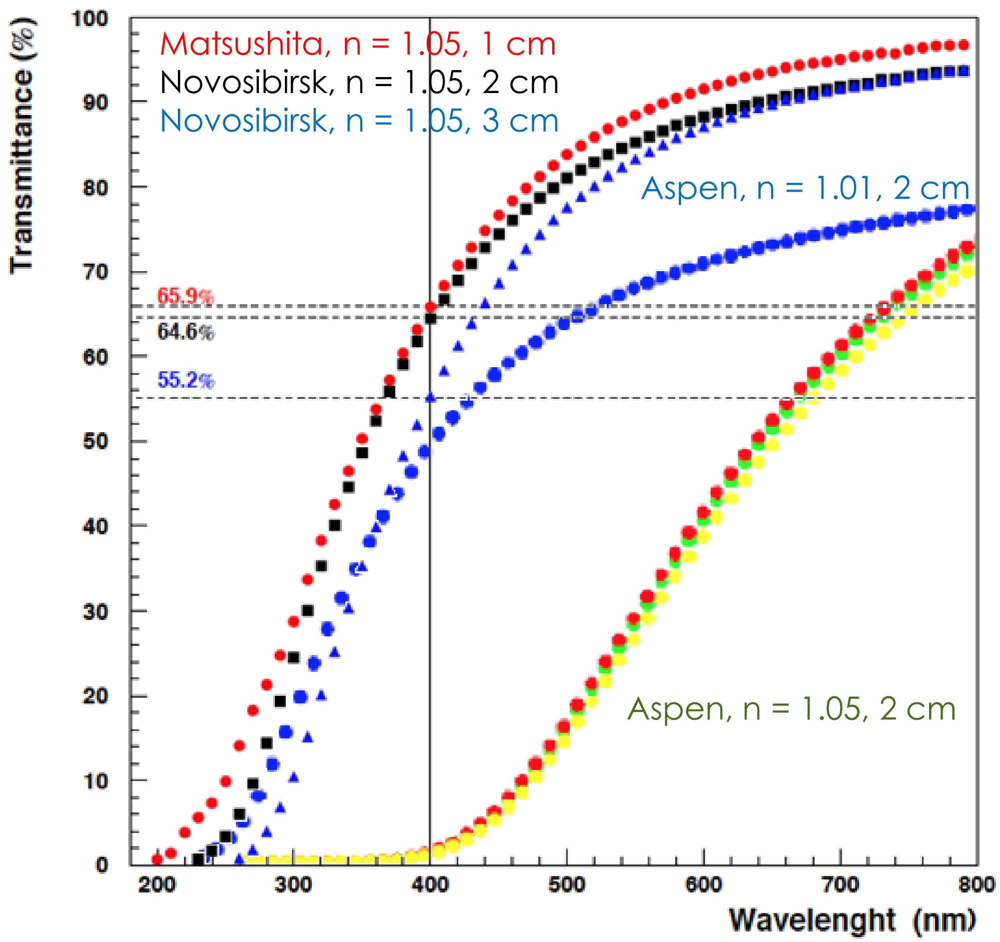




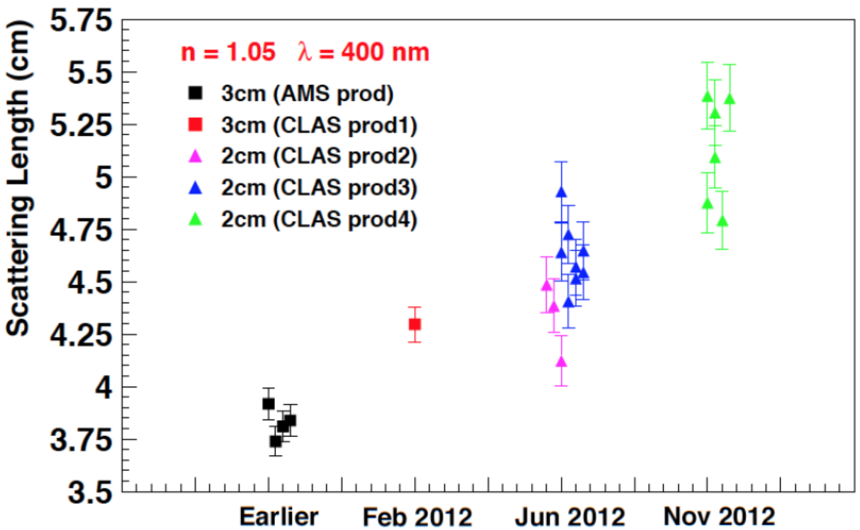
Status of Aerogel

Transmittance: $T = e^{-t(1/\Lambda_{abs}+1/\Lambda_{sc})}$

Scattering length: $\Lambda_{sc} = C \cdot \lambda^4$

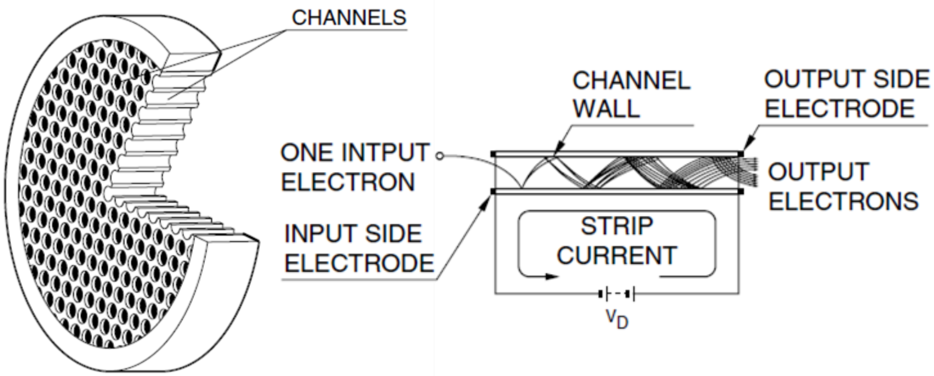


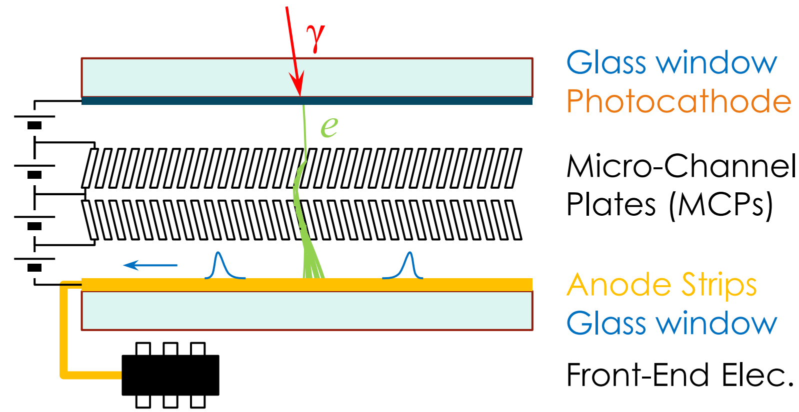
- Aerogel strongly scatters UV lights
- Slowly being improved
- Major manufactures
  - Novosibirsk, Russia
  - Matsushita-Panasonic, Japan
  - Aspen, US
- Some comparisons available (CLAS12 etc.)



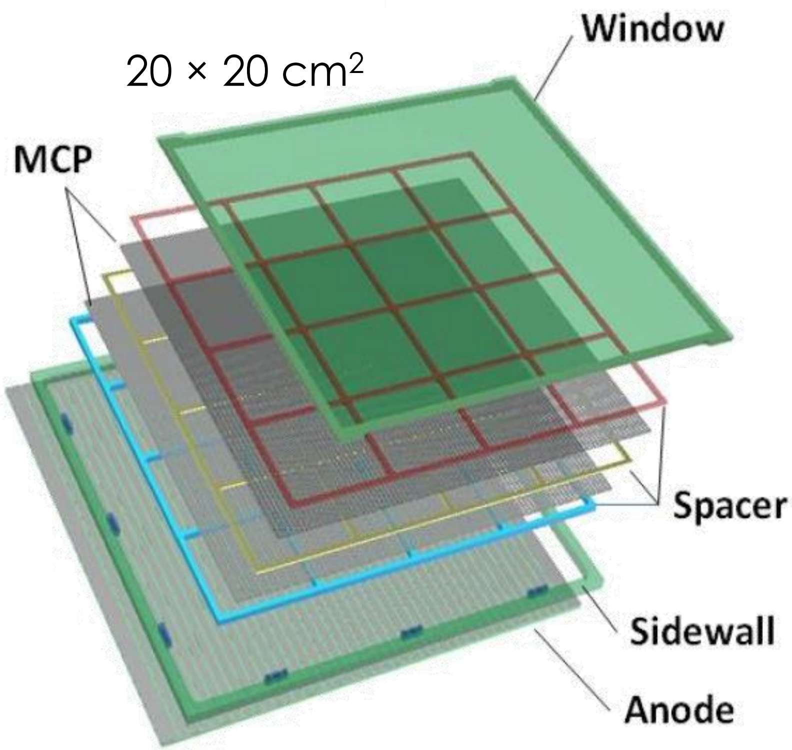
Micro-Channel Plate-based LAPPD

LAPPD: Large Area Picosecond Photo-Detector

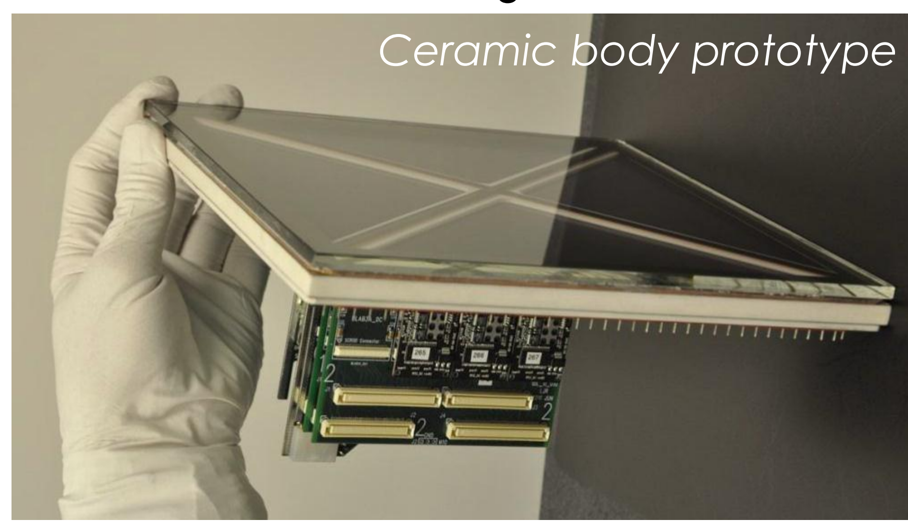




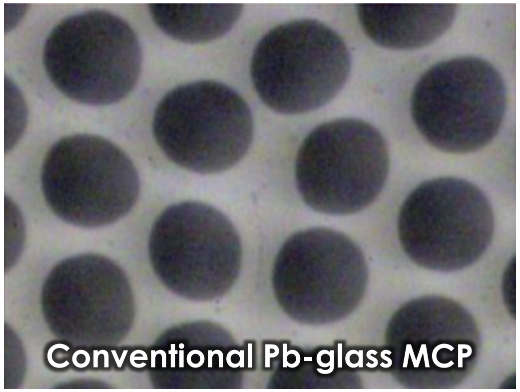
20 × 20 cm^2



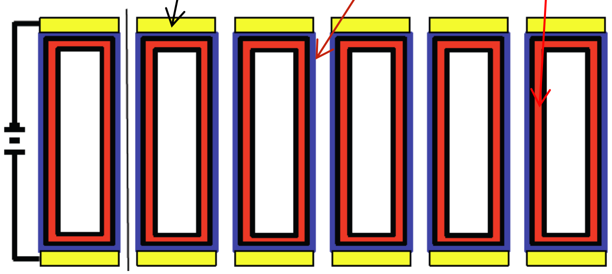
Compact size, good time resolution, expect good tolerance to magnetic field



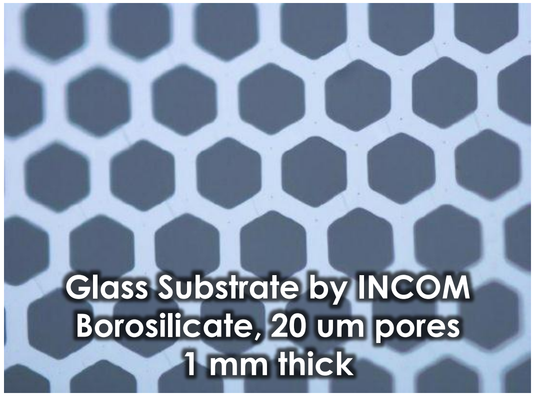
ALD Micro-Channel Plate



- Conventional Pb-glass MCP
  - Single material, three functions: pore, Pb-glass resistive layer, Pb-Oxide emissive layer
  - Higher cost
  - Space charge: rate limitation

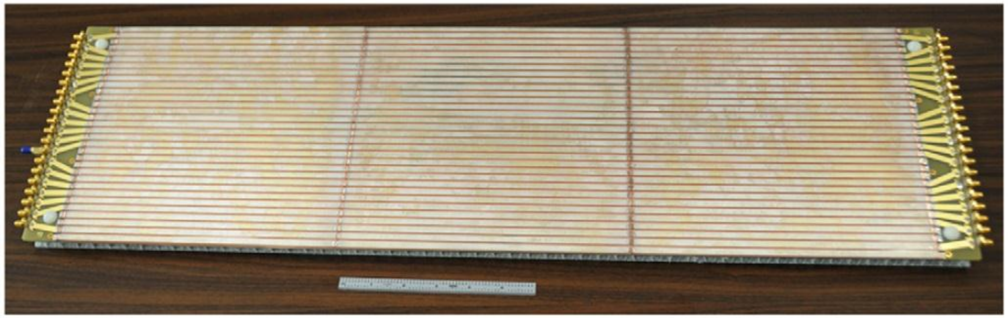


- MCP produced with Atomic Layer Deposition (ALD): Separate three functions, more freedom for optimization
  - Glass substrate with pores
  - Tuned resistive layer provides current for electric field
  - Specific emissive layer (Al_2O_3) provides secondary electron emission
- Good performance with lower cost
  - Gain > 10^7 for pair MCPs
  - Longer lifetime >> 5 C/cm^2



LAPPD Readout and Status

- Transmission line readout
  - 5 mm silver strips
  - Waveform sampled on both ends at 10 GS/s
  - Lower channel count
  - Can be chained
  - < 5 mm spatial resolution

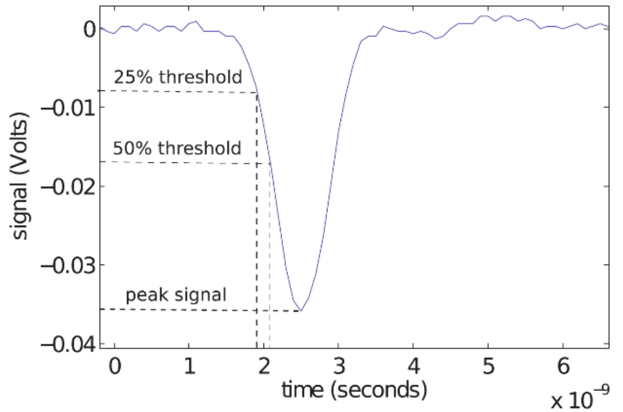


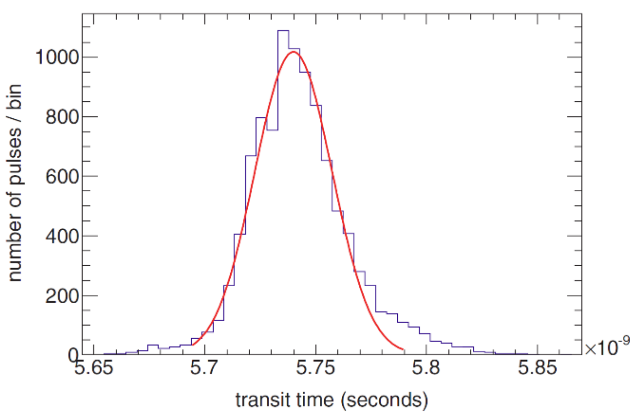
Three 20×20 cm^2 readout board chained

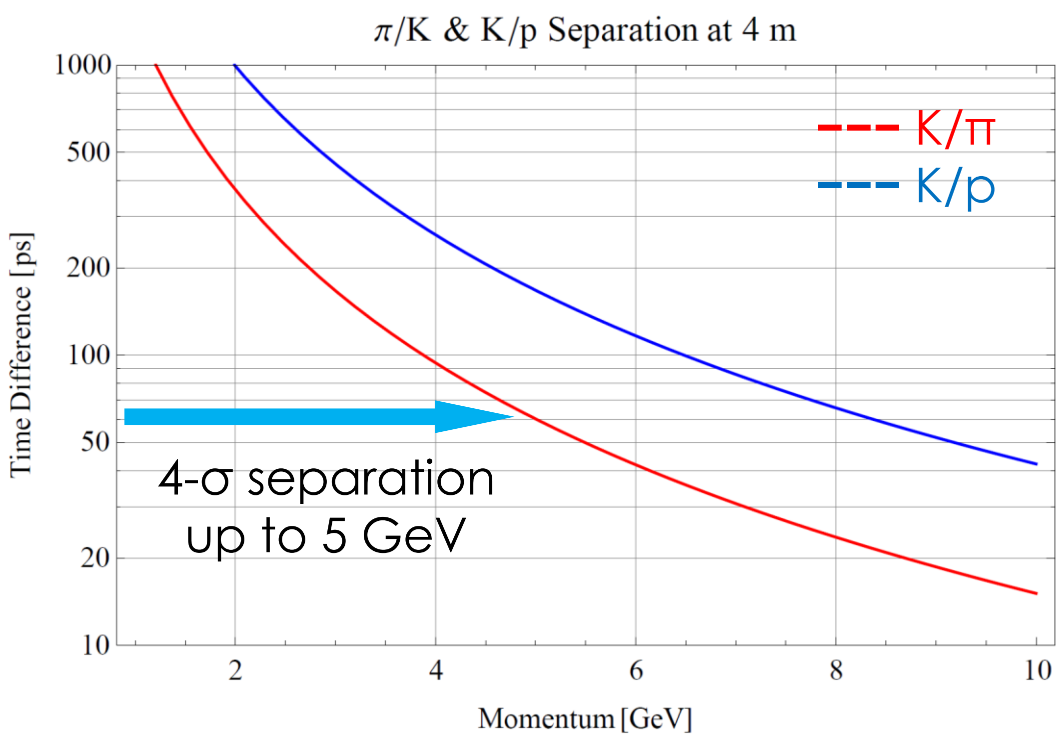
- Status of the LAPPD development
  - Funded by DOE since 2009
  - Individual components proved working
  - A working demountable prototype using Al photocathode sealed by O-ring
  - First ceramic prototype assembled with bi-alkali photocathode
  - Small glass body samples available this year

Bonus TOF feature

- Excellent time resolution of LAPPD provide additional PID power through time-of-flight
  - Use Cherenkov light generated in the entrance window
  - Single photon time resolution < 44 ps



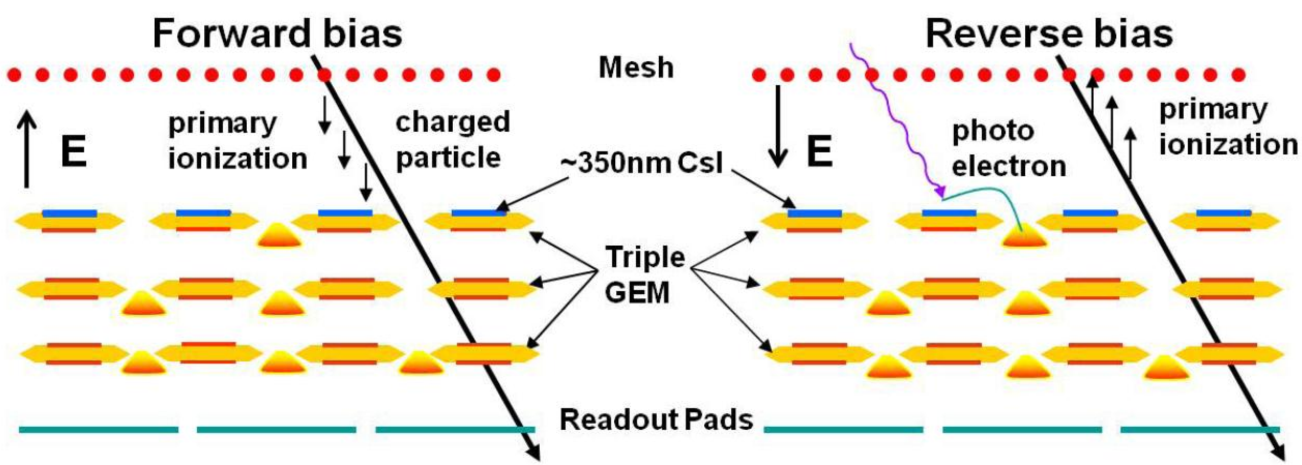


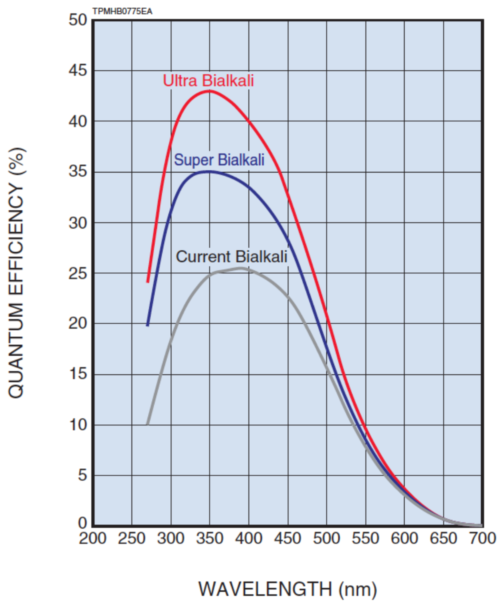


Expected TOF resolution ~ 15 ps

GEM-based Readout

- CsI-coated GEM detector successfully used in PHENIX's hadron blinded-detector (HBD)
  - CsI only sensitive to UV light, not suitable for aerogel
  - Bi-alkali coating possible (Breskin *et al.*), however very sensitive to operating gas
  - Development needed for optimal combination of bi-alkali and gas mixture





Goal of the Proposed Project

- Final goal of the three-year project
  - Determine the optimal detector technology and finish the conceptual design of the RICH detector
- Five parallel tasks
  - Detector simulation and conceptual design
  - Characterization of LAPPDs
  - Improvement of LAPPD
  - Study of GEM-based readout
  - Characterization of aerogel radiators
- Further work is anticipated given the success of the project

Detector Simulation and Design

- Goals
  - Simulation of detector performance in the EIC environment
  - Provide requirements on detector components, e.g. readout performance, aerogel quality etc.
  - Optimize optics and detector design
- Approaches
  - Extended from existing EIC simulation codes/event generators
  - Model the optical elements: aerogel, lens, readout
  - Model the strip or pixel readout and embed in the EIC environment. Determine maximum pixel/strip size, multiplicity, background rate etc.
  - Develop reconstruction software

Characterization of LAPPDs

- Goal
  - Characterize the MCP-based LAPPD with the needs of the EIC
- Properties to be tested
  - Single photon detection efficiency at different wavelengths, particularly between UV and green
  - Gain with different voltages and input pulse rates
  - Time and position resolution
  - Background noise level
  - Neutron and EM radiation hardness
  - Sensitivity to magnetic field
  - Lifetime

Improvement of LAPPD

- Goal
  - Improve and balance the performance of LAPPDs towards the needs of the EIC
- List of possible items
  - High rate capability: resistance, gain …
  - Tolerance to magnetic field: pore orientation, shielding …
  - Thinner glass window (now 2.75 mm) to reduce background hits from primary tracks
  - Optimize existing readout for high multiplicity: narrower strips, deconvolution in FPGA …
  - Alternative readout option if needed: pixel readout, induced signal readout …

Study of GEM-Based Readout

- Goals
  - Find out proper combinations of photocathode coating and gas mixture of a GEM detector to allow detection of photons with wavelength > 300 nm
  - Develop a suitable readout pattern
- Approaches
  - Existing Cs-I coated GEMs for UV photons
  - Triple-GEM detector kits from CERN
  - Small vacuum chamber for bialkali photocathode deposition
  - LED sources for quantum-efficiency measurements
  - Simulation to optimize readout resolution and channel count

Characterization of Aerogel Radiator

- Goal
  - Working closely with different vendors, Novosibirsk, Matsushita-Panasonic, Aspen etc. to choose the optimal aerogel tiles for the EIC RICH detector
- List of measurements
  - Measurement of transmittance, absorption length and scattering length for different aerogel tiles
  - Measurements of refractive index and chromatic dispersion using the prism method and a monochromator coupled to a Xe-UV lamp or monochromatic lasers.
  - Refractive index mapping with gradient method
  - High precision mapping of the tiles thickness

Responsibilities and Resources

- Jefferson Lab
  - Responsibilities
    - Testing LAPPDs
    - Assist development of LAPPDs
    - Detector simulation and design
    - Provide space and manpower testing aerogels
  - Resources
    - Expertise in photosensors, aerogel RICH detector, fast electronics, , EIC simulation
    - Existing testing facilities for photodetectors: dark boxes, picosecond pulsed laser source, electronics etc.
    - Existing EM and neutron irradiation facilities
    - Existing spare 5-Tesla magnet
    - Parasitic beam test will be available
    - Will hire a postdoctoral researcher for the project

Responsibilities and Resources

- Los Alamos National Lab
  - Responsibilities
    - Study GEM-based readout
    - Detector simulation and design
    - Assist testing aerogel samples
  - Resources
    - Expertise in CsI-coated GEM detector, aerogel Cherenkov detectors, readout electronics, EIC detector simulation
    - Existing neutron and proton irradiation facilities
    - Will hire a postdoctoral researcher for the project

Responsibilities and Resources

- Argonne National Lab
  - Responsibilities
    - Fabricate LAPPD samples
    - R&D of LAPPDs
  - Resources
    - Expertise in photocathode, micro-channel plate and fast readout electronics
    - Existing facilities for fabricating and testing LAPPDs
    - Will hire a postdoctoral researcher for the project
- INFN
  - Responsibility
    - Characterization and selection of aerogel samples
  - Resources
    - Expertise in various RICH detector including aerogel based RICH

Budget

Item	Cost		
	Year 1	Year 2	Year 3
Jefferson Lab			
M&S – LAPPD testing	$10,000	$10,000	$10,000
Equipment – LAPPD testing	$20,000	$0	$0
Labor – Postdoc (0.7 FTE)	$70,000	$70,000	$70,000
Travel	$10,000	$10,000	$10,000
Subtotal	$110,000	$90,000	$90,000
Los Alamos National Lab			
GEM detector kits (5×$3200)	$16,000	$0	$0
CERN RD51 SRS Readout System	$3,000	$0	$0
Components for deposition chamber	$30,000	$20,000	$20,000
Labor – Post doc (0.4 – 0.5 FTE)	$60,000	$80,000	$80,000
M&S and Travel	$20,000	$20,000	$20,000
Subtotal	$129,000	$120,000	$120,000
Argonne National Lab			
M&S – LAPPD fabrication	$15,000	$15,000	$15,000
Labor – LAPPD fabrication and R&D	$50,000	$50,000	$50,000
Travel	$5,000	$5,000	$5,000
Subtotal	$70,000	$70,000	$70,000
INFN			
M&S – Aerogel Testing	$10,000	$10,000	$10,000
Equipment – Aerogel Testing	$30,000	$0	$0
Travel	$10,000	$10,000	$10,000
Subtotal	$50,000	$20,000	$20,000
Grand Total	**$359,000**	**$300,000**	**$300,000**

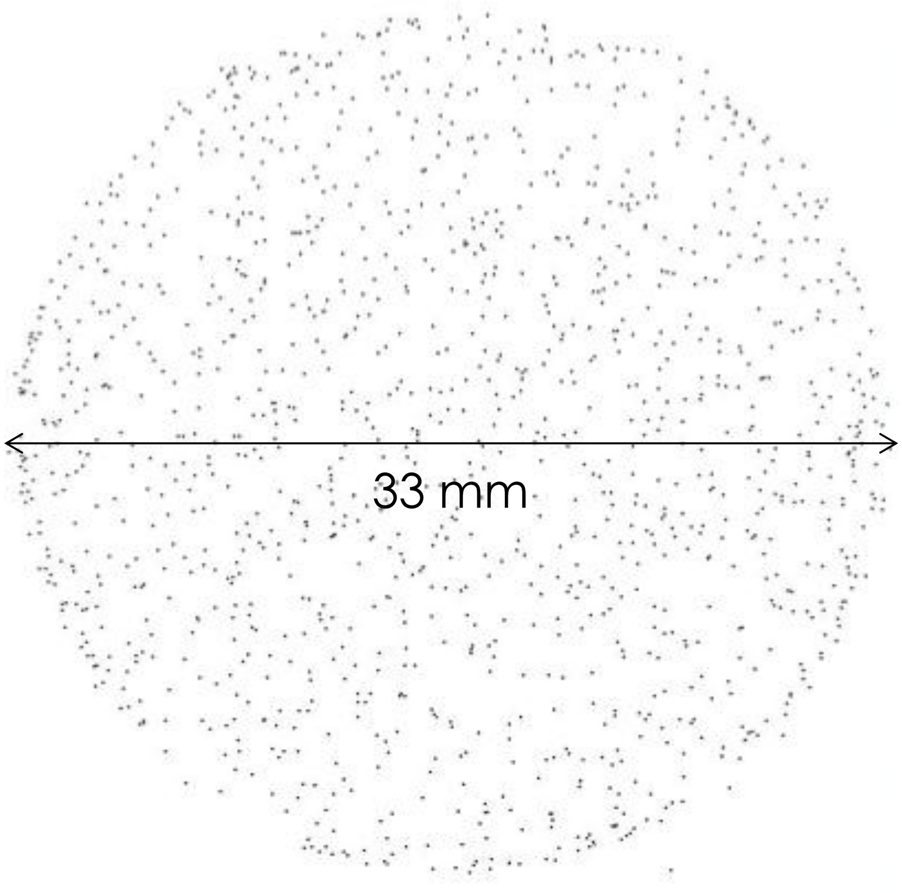
Summary

- An aerogel-based RICH detector is proposed for the EIC's forward region particle identification
- A dual-radiator option or a combination with an additional gas Cherenkov detector is necessary to cover important momentum range of SIDIS processes
- A three-year joint effort is planned to investigate different options, find optimal solution and provide a conceptual design at the end
  - Two design options will be evaluated: dual-radiator and modular
  - Two economical novel readout options will be studied: MCP-based LAPPD and GEM-based readout
- The success of the project will become the base of the second phase: development of a prototype

Backup Slides

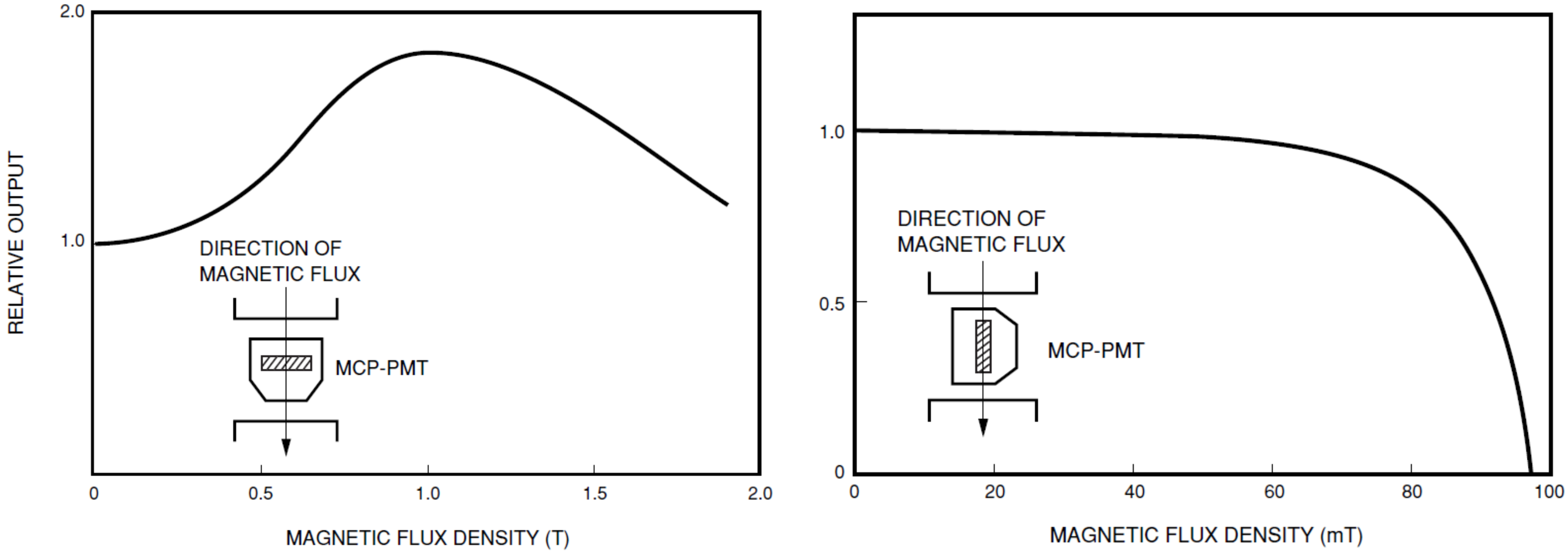
Background rate in ALD-MCP

- Background rate of a 33 mm ALD-MCP with 20 μm pores and 1.2 mm thickness measured at 7×10^6 gain
  - 33 mm diameter
  - 20 μm pores, 1.2 mm thickness
  - 0.84 counts/cm^2/s, comparable with comic ray
- More test needed for full assembly with photocathode



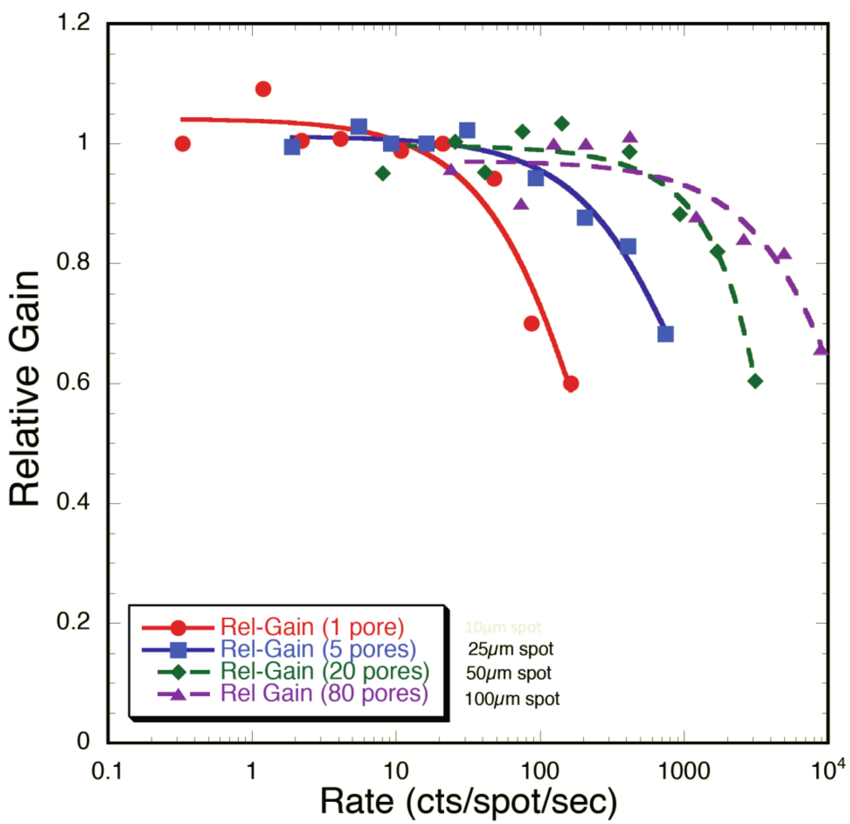
Background hits over 3000 s

Magnetic Field Tolerance of MCPs

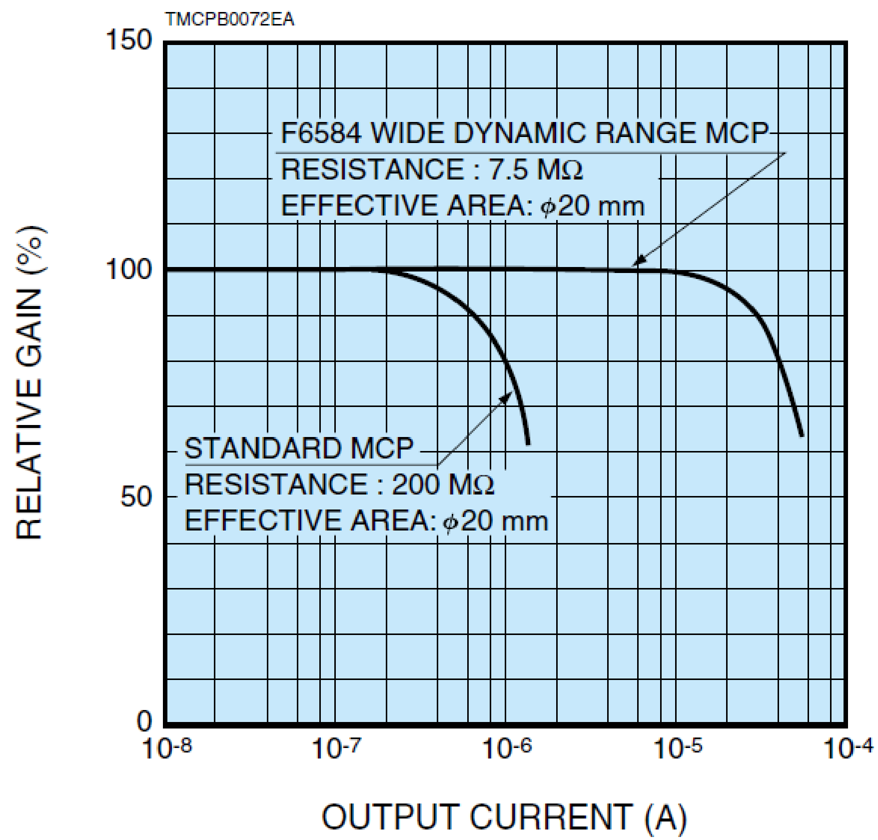


Typical field response of commercial MCPs

Gain of MCP with different rates



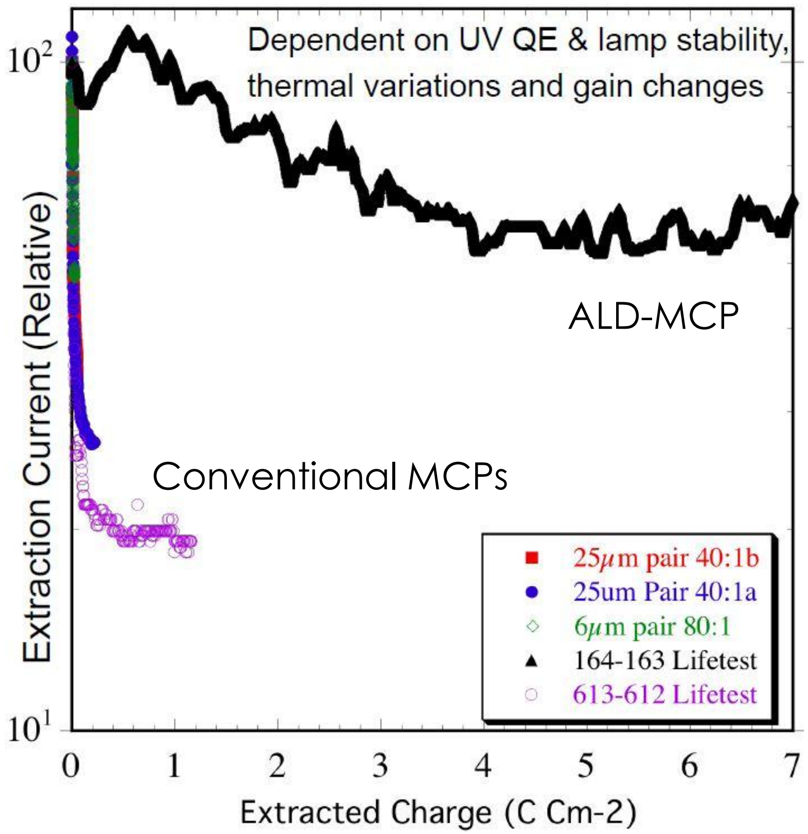
Measurement of an older 10 μm pore ALD-MCP with MgO emission layer



Performance of Hamamatsu MCP-PMTs
10^6 gain → 300 kHz/cm^2

Lifetime of ALD-MCPs

- Significant improvement with preconditioning over traditional MCPs
  - Possibility due to cleaner glass substrate with much less contamination to create ion backflow



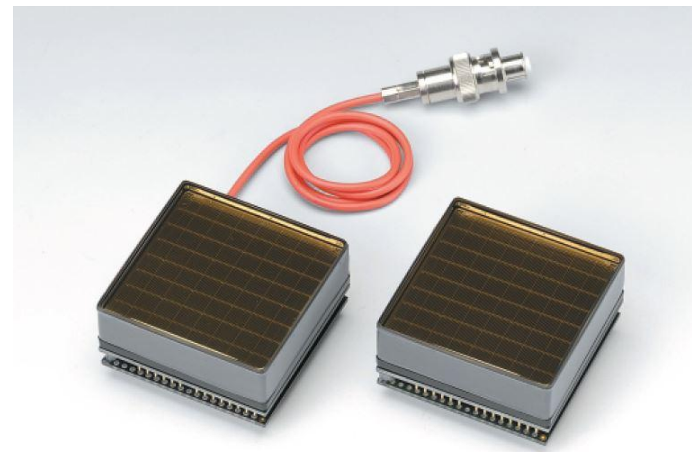
Lifetime of an older ALD-MCP pair (20 µm pore, MgO emission layer, 60:1 L/d, 8° bias) compared with conventional MCPs

Estimated Final Detector Cost

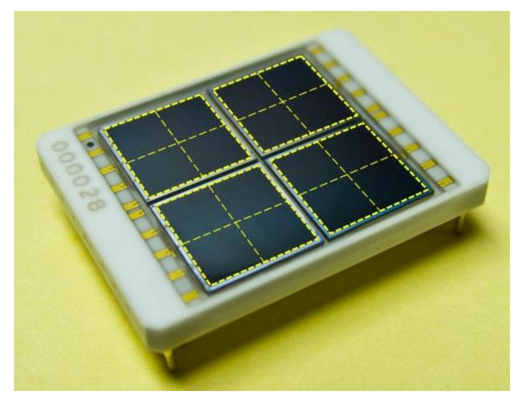
- Total Coverage ~ 10 m^2
- Dual-radiator RICH using LAPPD ~ $5M
  - Aerogel ~ $1M
  - Gas system ~ $1M
  - LAPPD readout ~ $2M (MaPMT ~ $10M)
  - Electronics ~ $2M (MaPMT ~ $3.5M)
  - MISC ~ $1M

Other Readout Options

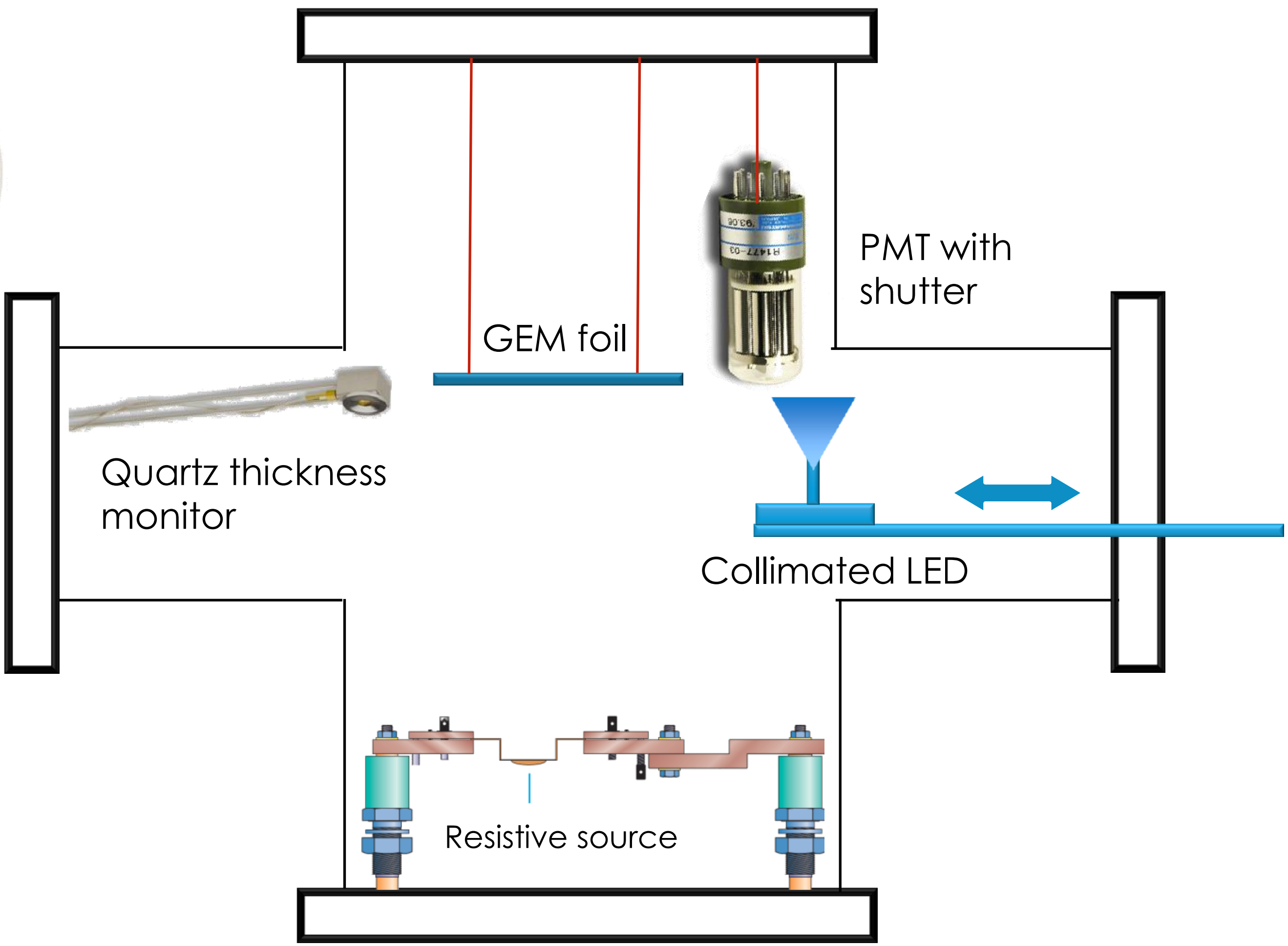
- Multi-anode MPTs
  - Well known technology, will be used in CLAS12 RICH and LHCb
  - As small as 3 mm pixel sizes
  - Sensitive to visible light
  - Low noise
  - Moderate resistance to magnetic field
  - Expensive (~\$1M for 1 m^2 sensor only)



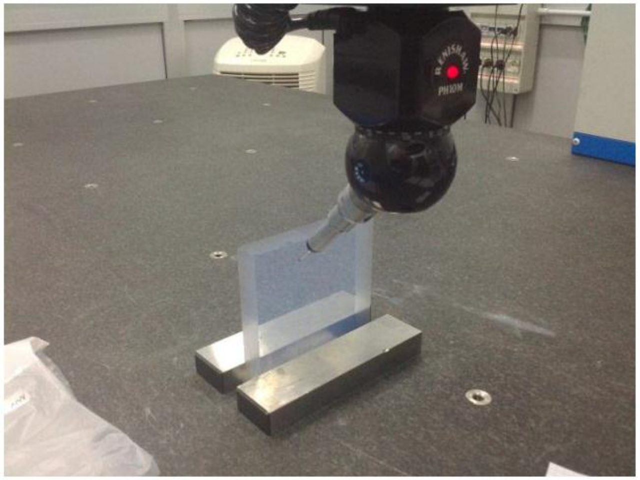
- Silicon Photo-Multipliers
  - Relative new technology
  - 3 mm pixels available
  - Sensitive to visible light
  - Resistant to strong magnetic field
  - Large dark noise, needs to be cooled
  - Low neutron radiation tolerance
  - Expensive (~\$3 M for 1 m^2 sensor only)



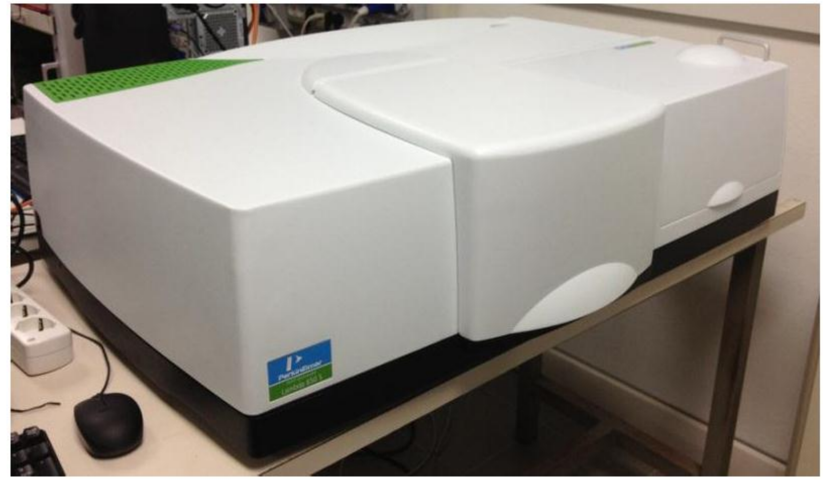
Deposition Chamber/QE measurement



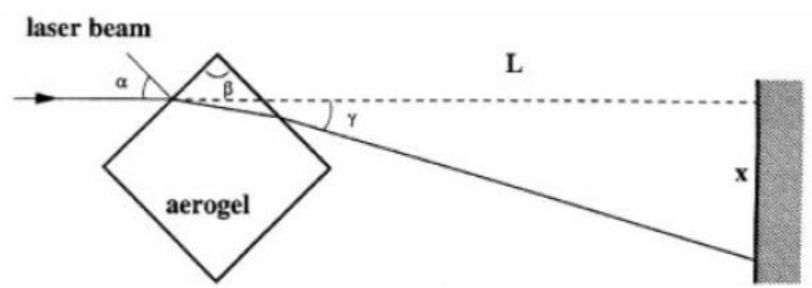
Characterizating Aerogel Tiles



Thickness mapping

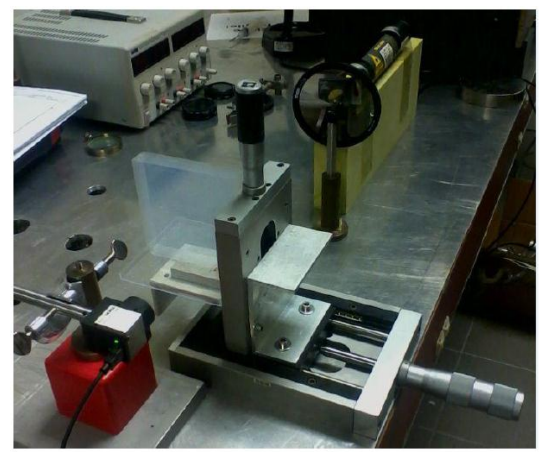


Spectrophotometer as light source



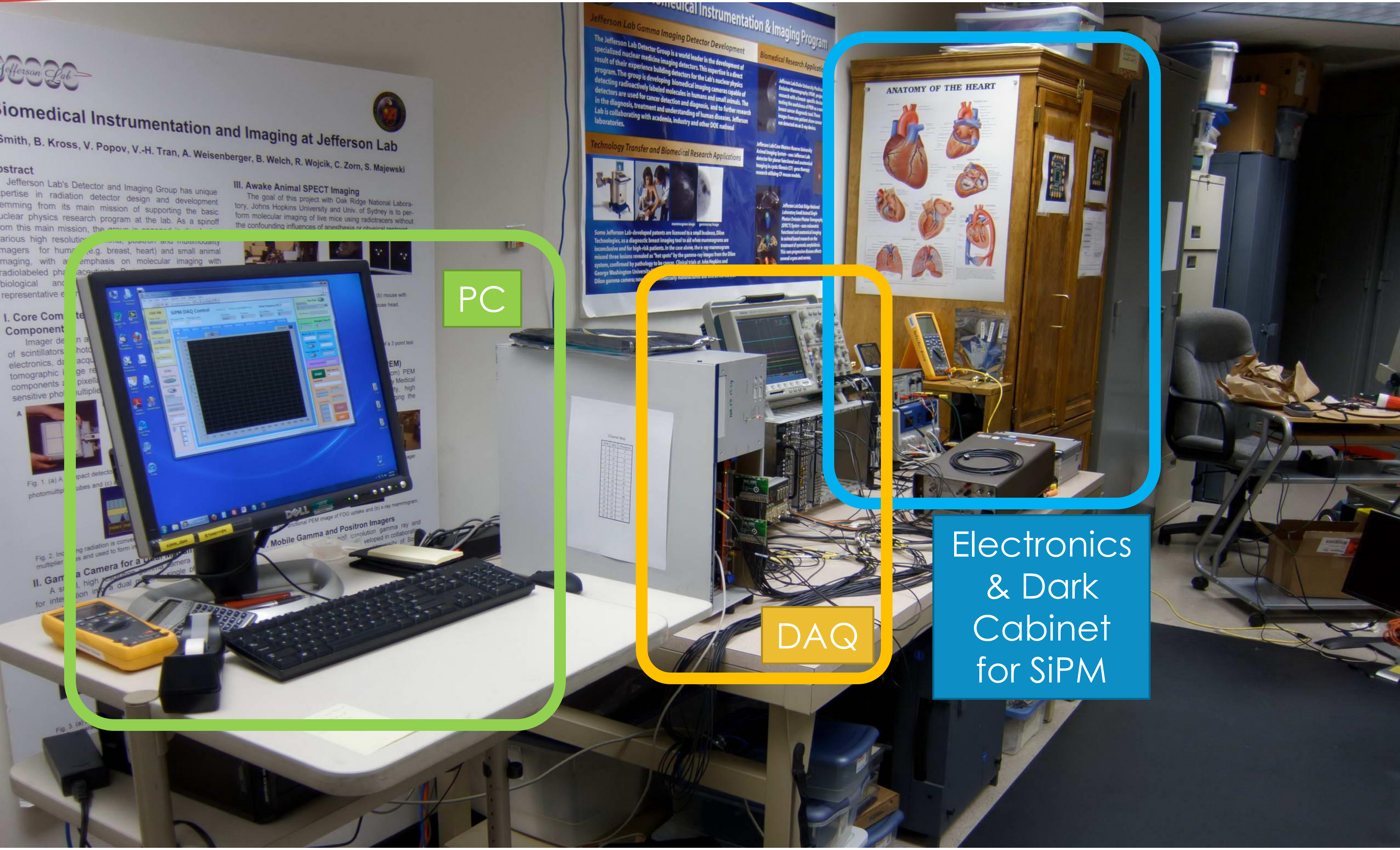
$$\delta = \alpha - \beta + \arcsin\left\{ n \cdot \sin\left[\beta - \arcsin\left(\frac{\sin\alpha}{n} \right) \right] \right\}$$

Prism method for chromatic dispersion

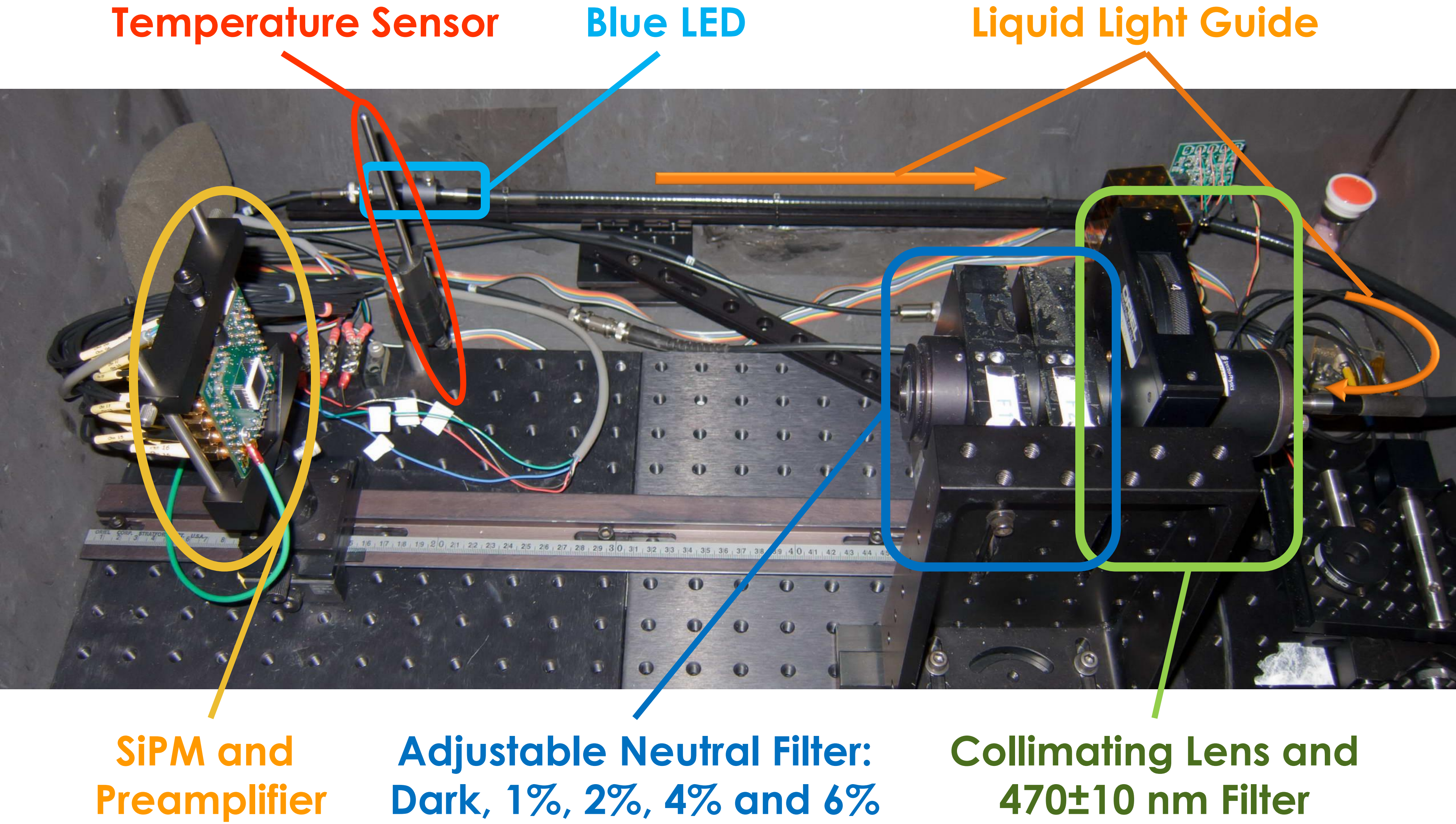


Gradient method for uniformity

SiPM Test Setup

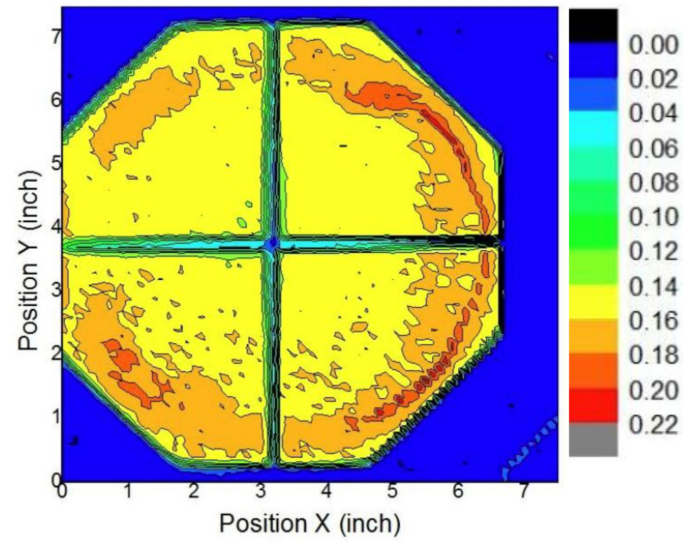


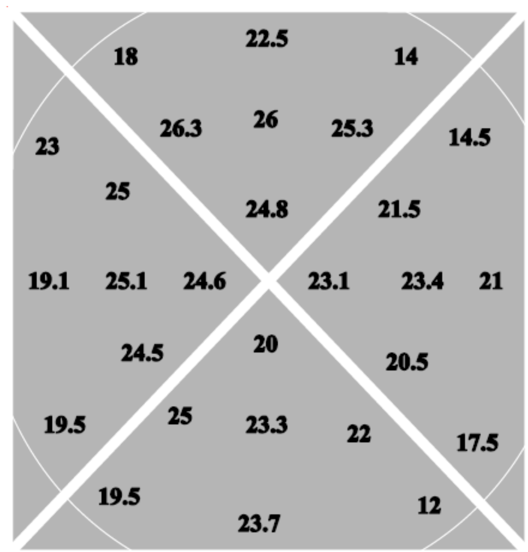
SiPM Test Setup



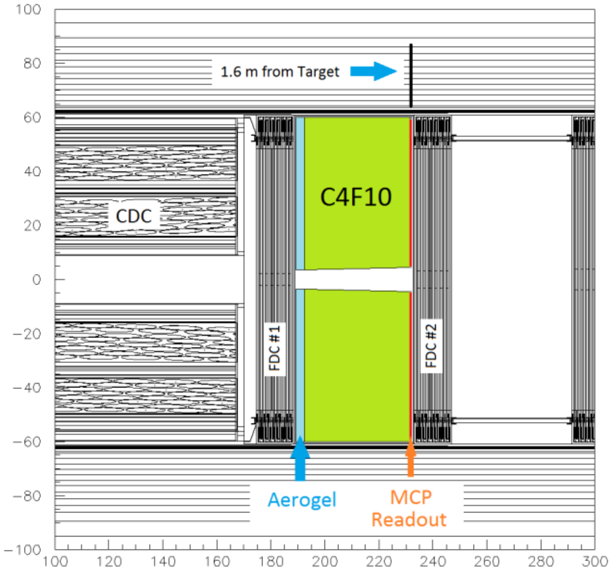
LAPPD's 8" Photocathode

- Argonne National Lab
  - Using Burle PMT processing station with home-made photocathode deposition chamber
  - 7"×7" flat K_2CsSb photocathode was produced
  - Max QE: 22% (350 nm, average: 16%)
- UC Berkeley
  - Deposited Na_2KSb photocathode on 8" windows
  - 25% QE (350nm) with good uniformity (15%) and stability

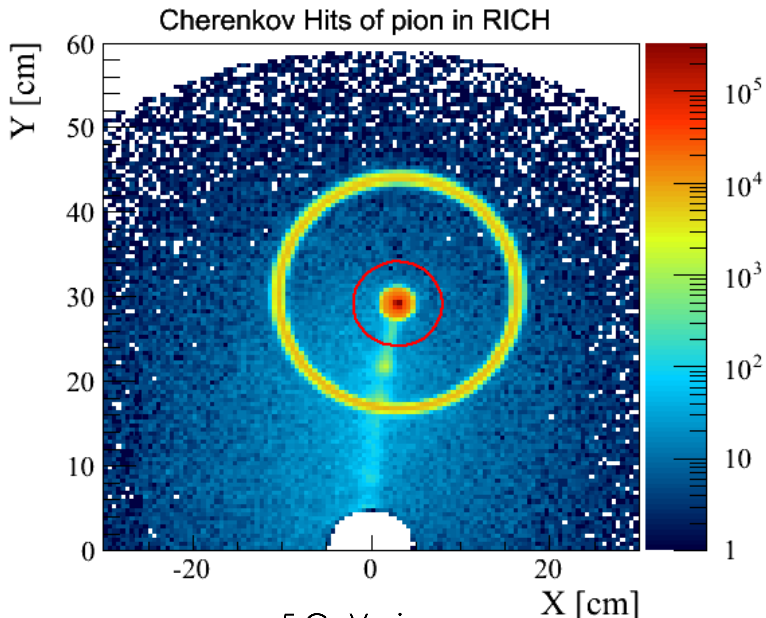




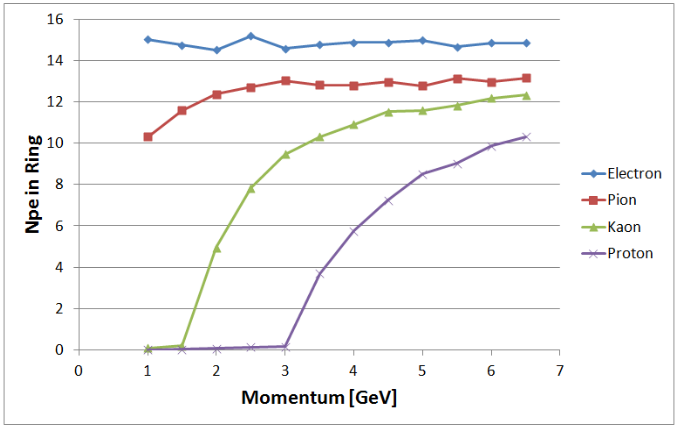
Dual-Radiator RICH Simulation



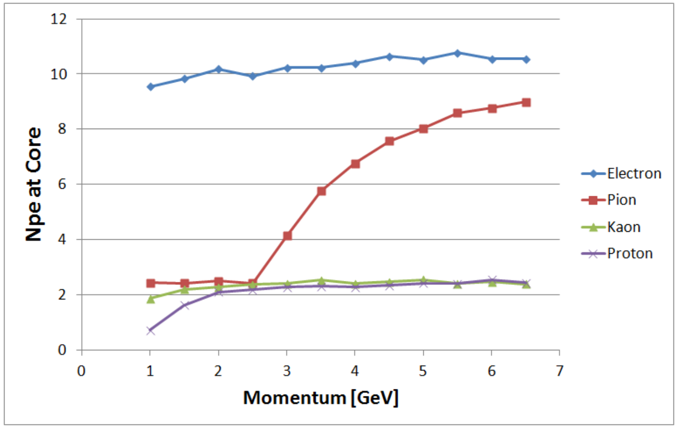
Simulation in GlueX Environment



5 GeV pions



Cherenkov hits from 3 cm aerogel



Cherenkov hits from 40 cm C_4F_{10} and 0.5 mm glass