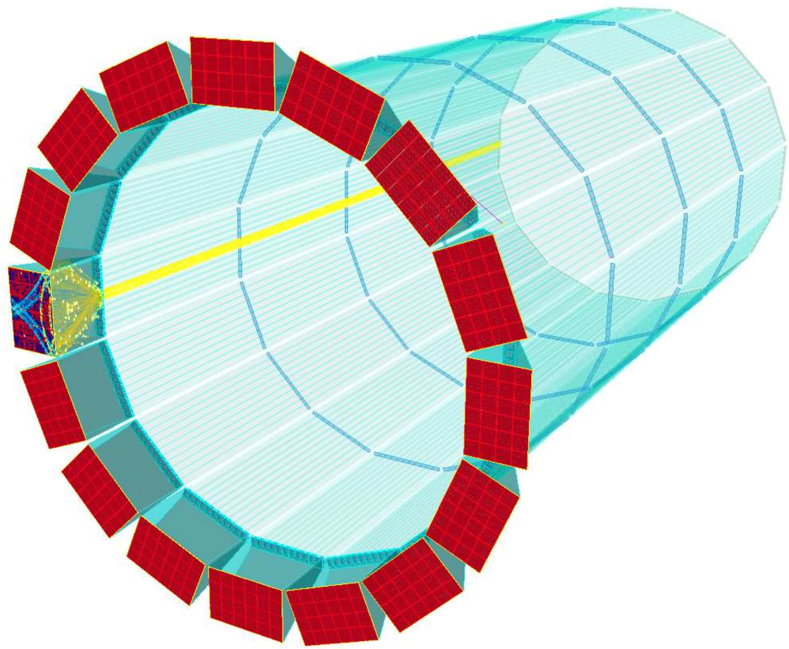
# High-Performance DIRC Detector for the future EIC Detector

**Greg Kalicy** on behalf of PID@EIC Consortium

**Outline:**

- **Electron Ion Collider**
  Three detector concepts
- **hpDIRC**
  Design and performance
- **Focusing system**
  Validated in particle beam and lab

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USC: Y. Ilieva

CUA GSI Old Dominion University Stony Brook University University of South Carolina Brookhaven National Laboratory Jefferson Lab

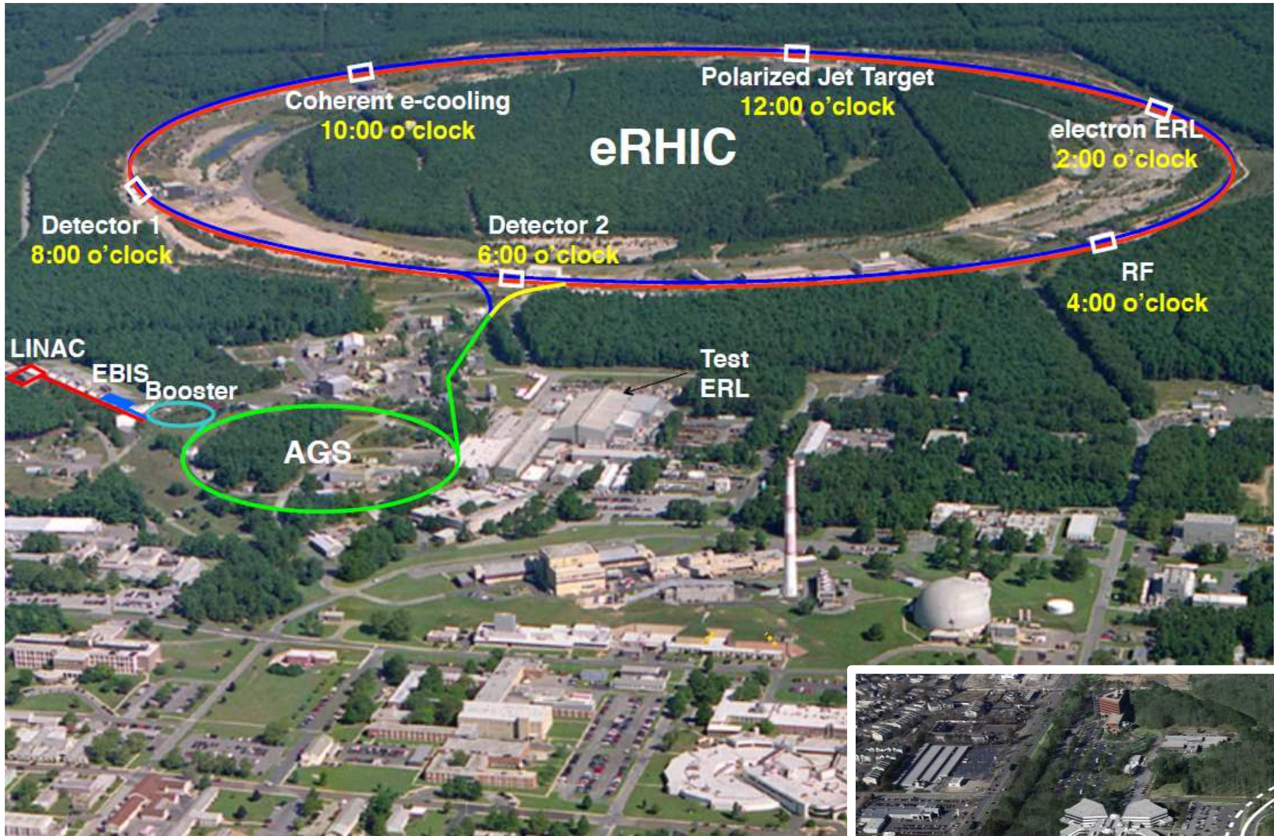
# Electron Ion Collider

## The EIC in the 2015 NSAC LRP and the recent NAS review


**NSAC:** **“We recommend a high-energy high-luminosity polarized EIC as the highest priority for new facility construction following the completion of FRIB.”**

**NAS:** **“The committee unanimously finds that the science that can be addressed by an EIC is compelling, fundamental, and timely.”**

# EIC Location



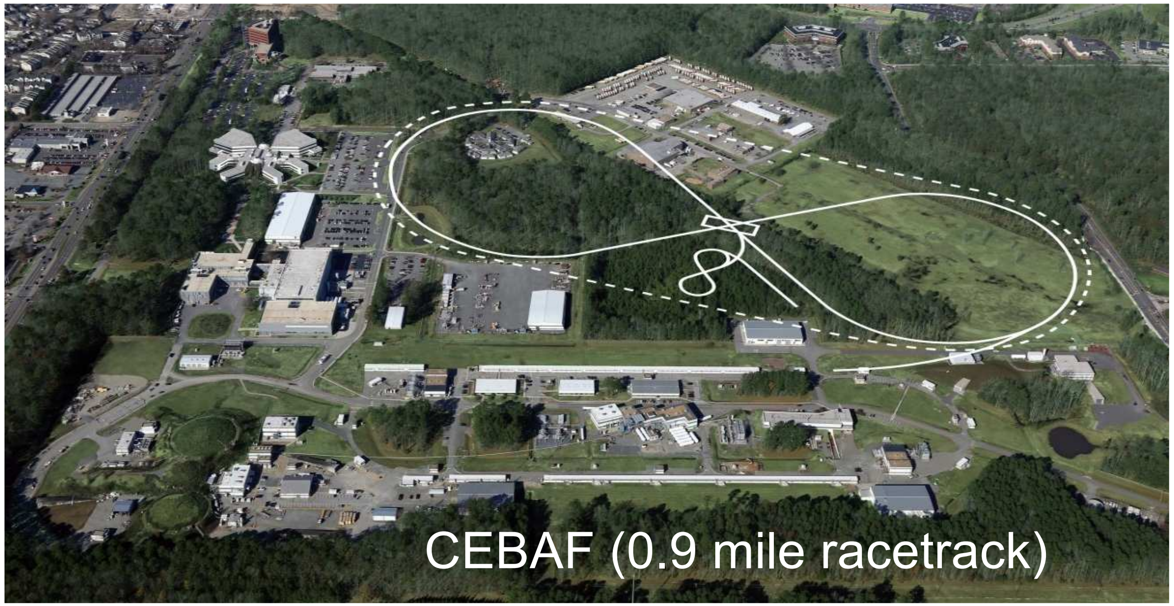

- **Two competing locations:** Jefferson Lab and Brookhaven
- **CD0 and site decision expected soon**
- Both concepts support 2 detectors

## BNL EIC at RHIC

18 GeV e (10 GeV lumi max) on 275 GeV p

## JLab EIC

12 GeV e (5 GeV lumi max) on 200 GeV p

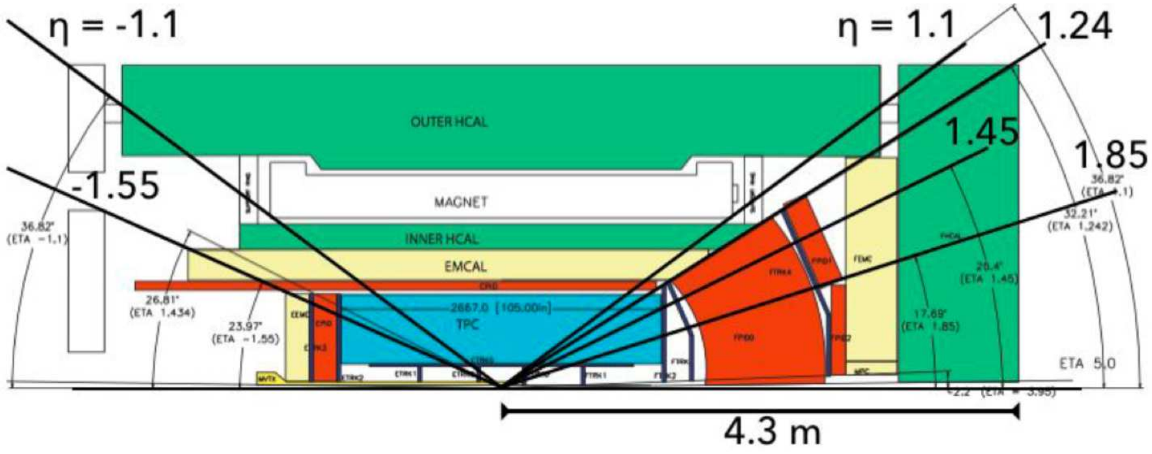


# EIC Central Detector

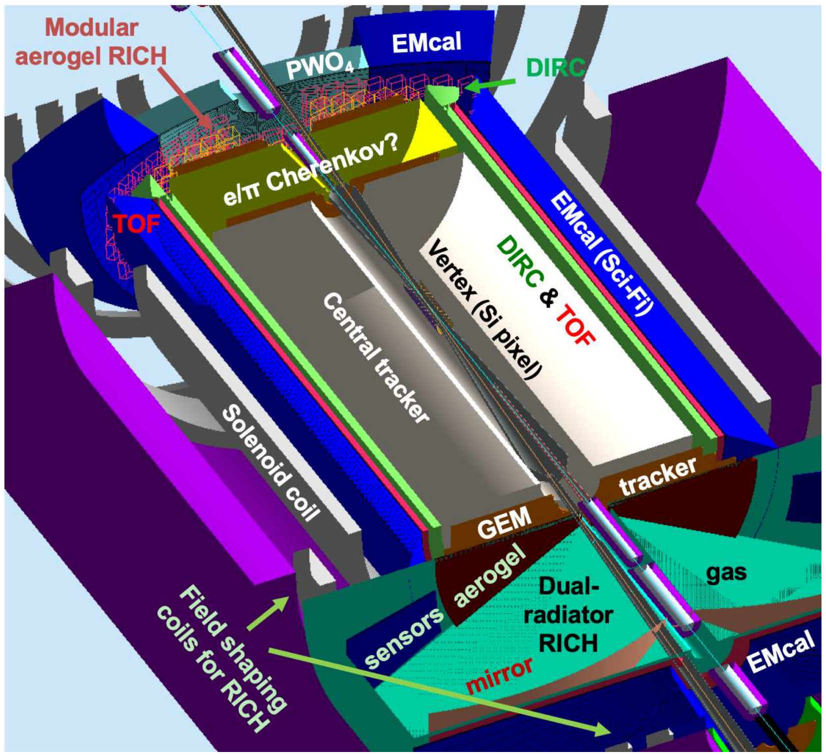
- **Two competing locations:**
  Jefferson Lab and Brookhaven

- **Three central detector concepts:**
  BeAST, ePHENIX, JLab central detector

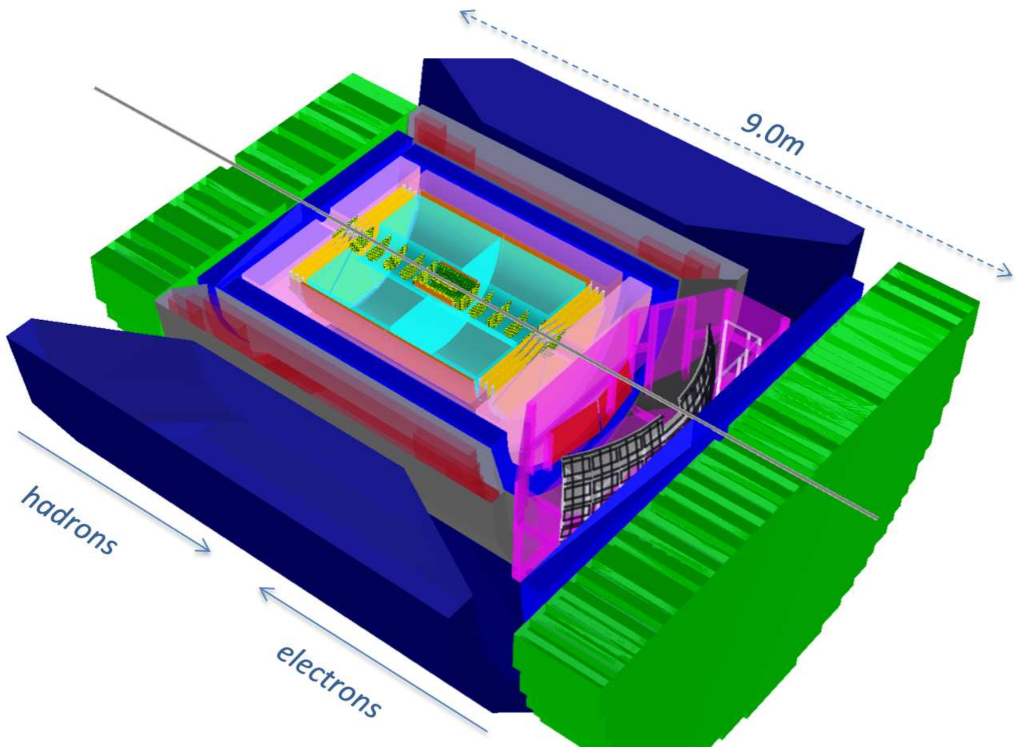
**BNL ePHENIX EIC detector**



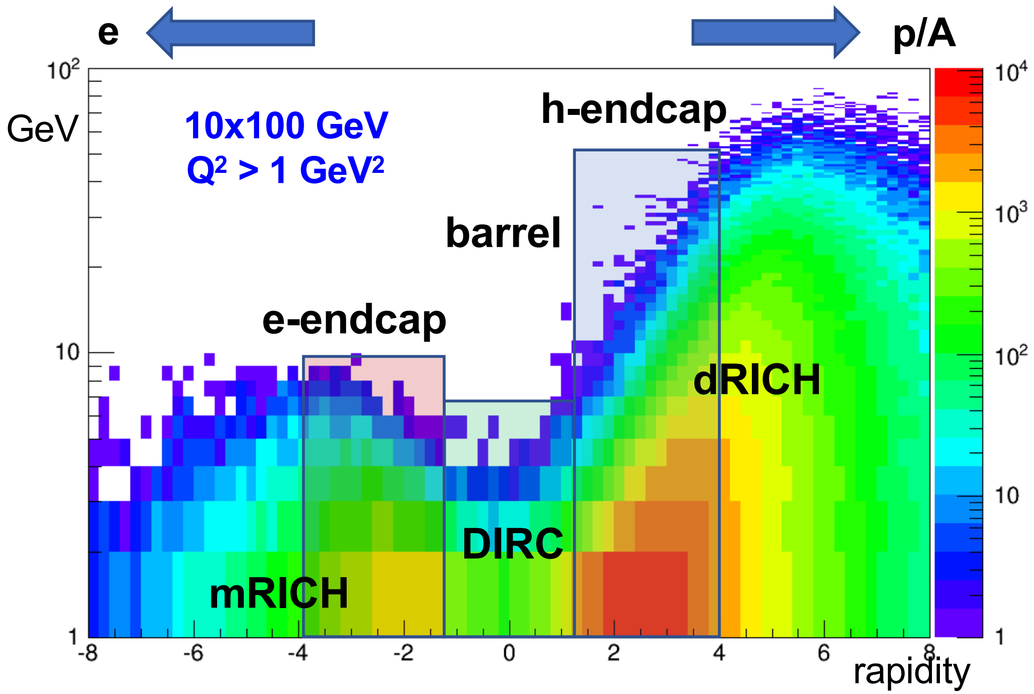

**JLab central detector**

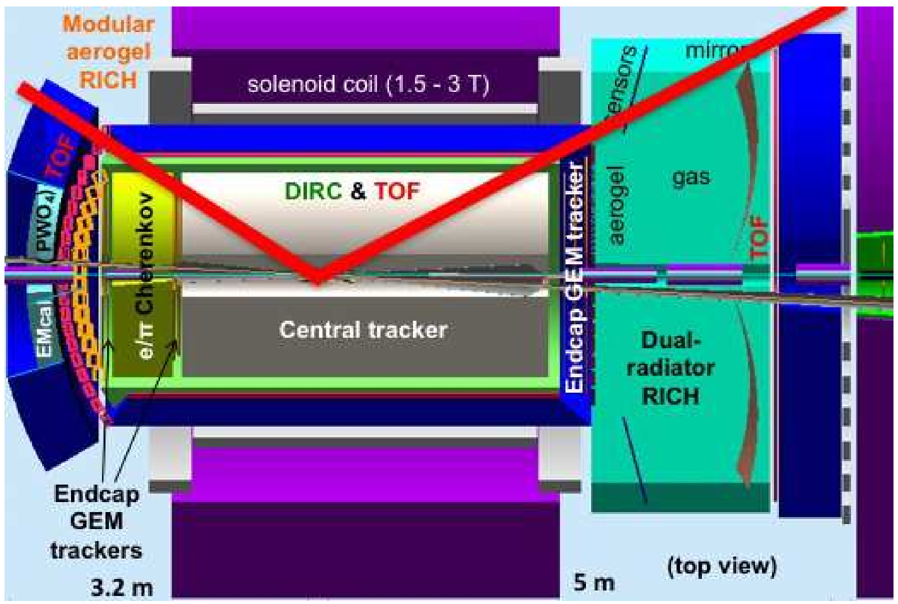



**BNL BeAST EIC detector**



# EIC PID Solutions

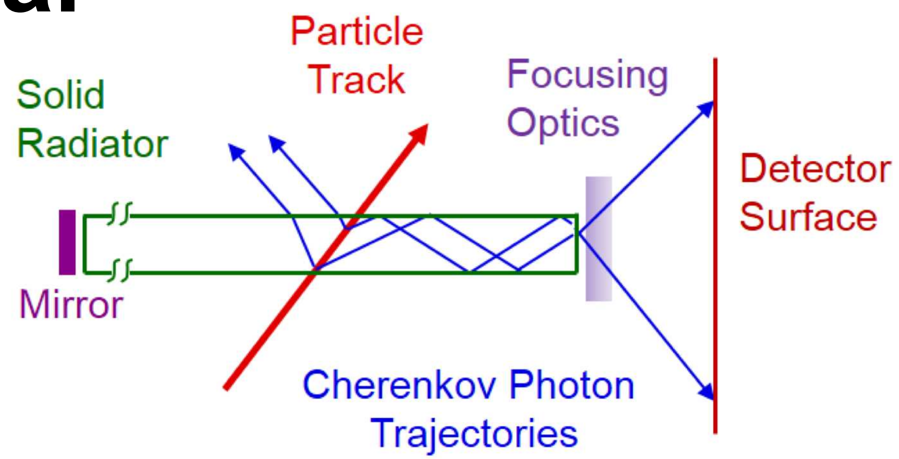


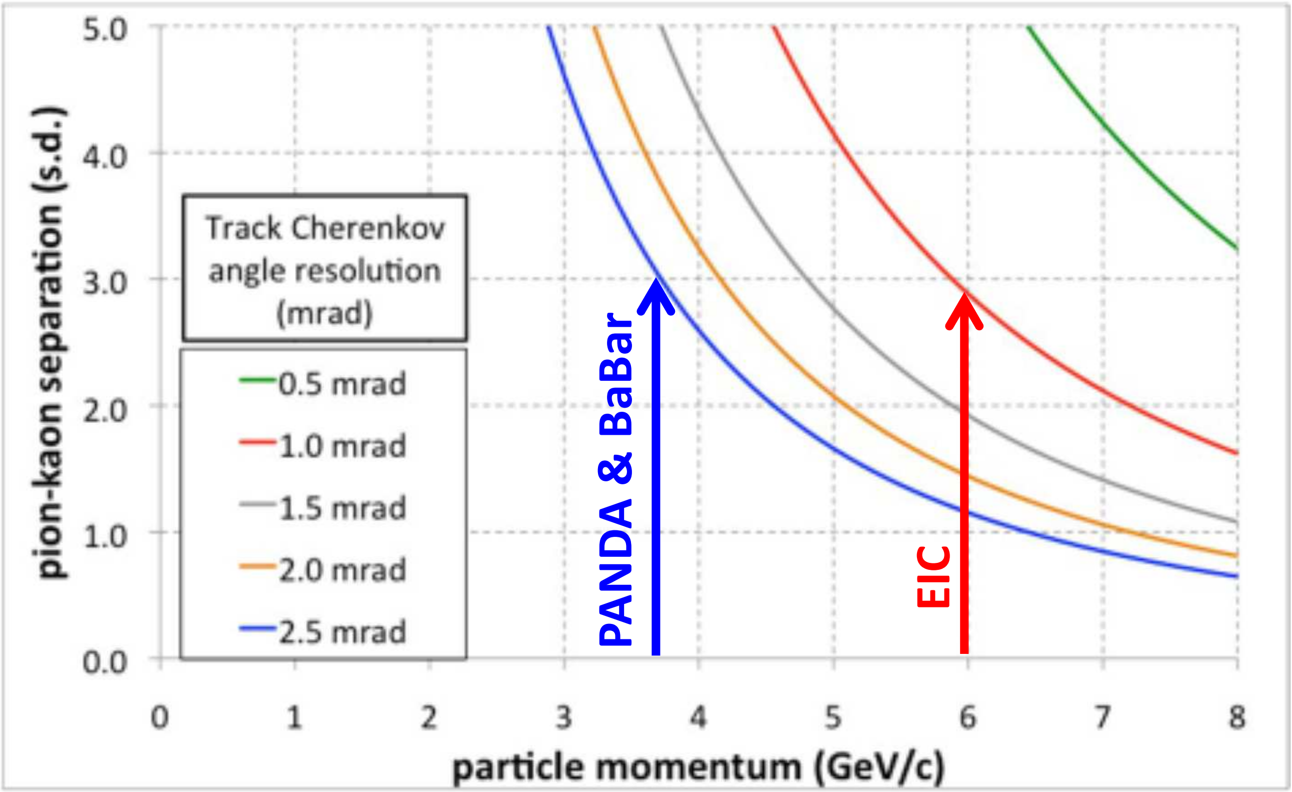

- **h-endcap**: A RICH with two radiators (gas + aerogel) is needed for
  *π/K separation up to ~50 GeV/c*
- **e-endcap**: A compact aerogel RICH which can be projective
  *π/K separation up to ~10 GeV/c*
- **barrel**: A high-performance DIRC provides a compact and cost-effective way to cover the area.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

# hpDIRC Performance Goal

$$\sigma_{\theta_c}^{track} = \sqrt{\left(\frac{\sigma_{\theta_c}^{photon}}{\sqrt{N_{pe}}}\right)^2 + (\sigma^{correlated})^2}$$



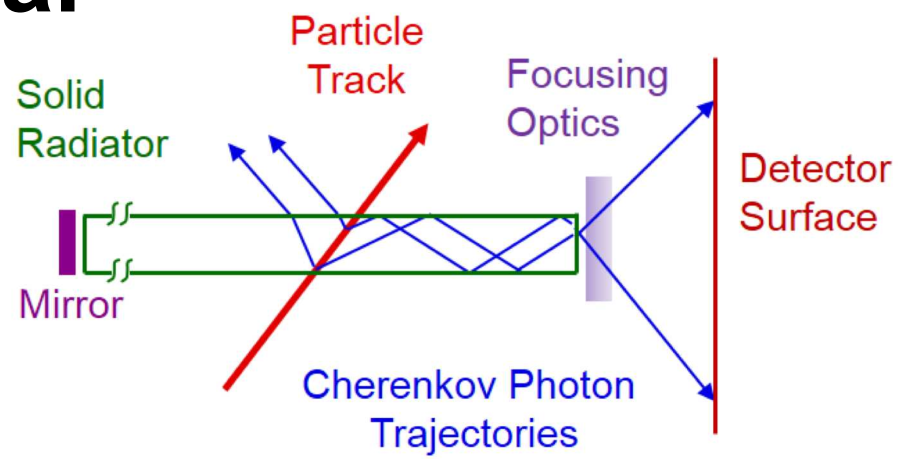

**π/K identification as a function of the $\theta_c$ resolution**



# hpDIRC Performance Goal

**Expected PID capability of hpDIRC:**

- **π/K up to 6 GeV/c**

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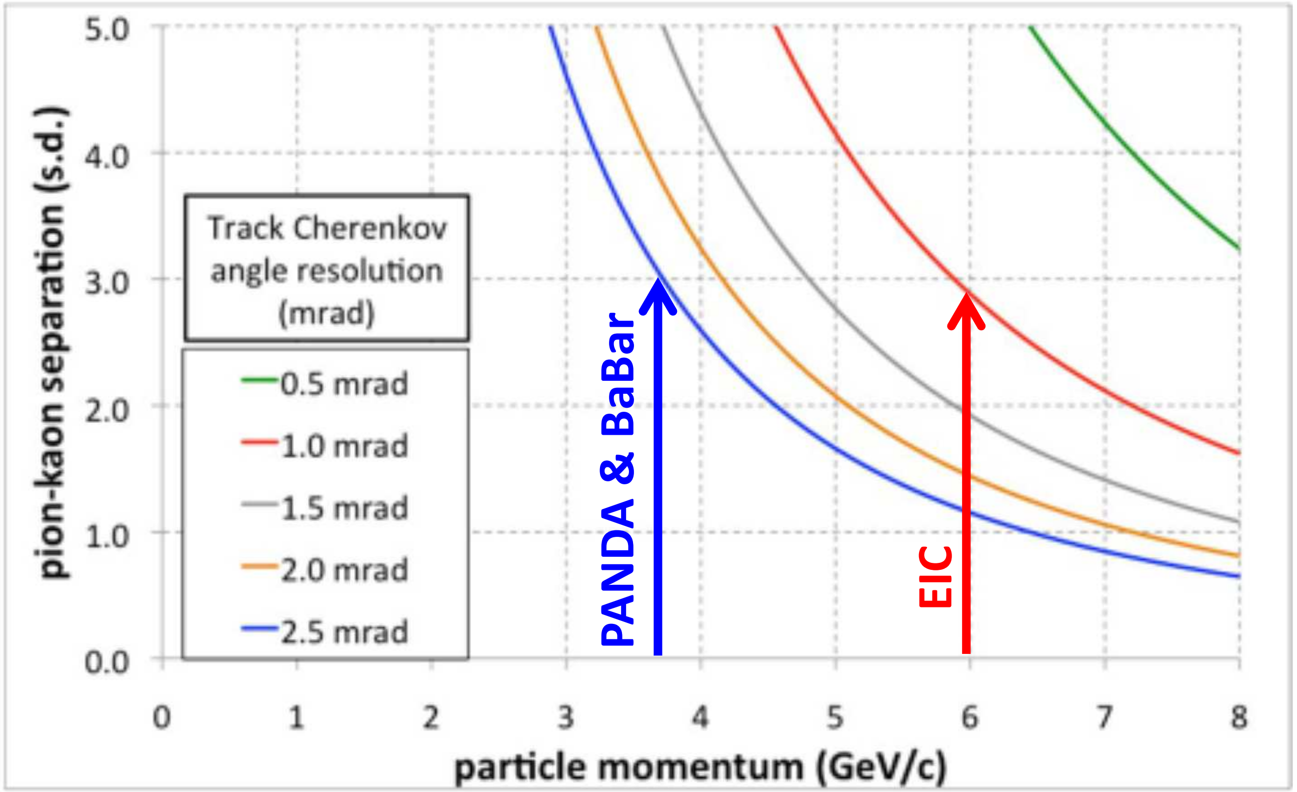
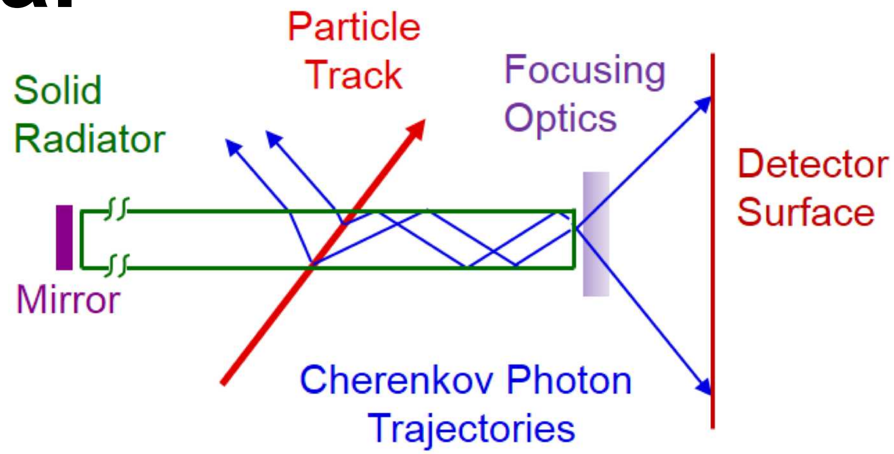


# hpDIRC Performance Goal

**Expected PID capability of hpDIRC:**

- **π/K up to 6 GeV/c**
- **e/π up to 1.8 GeV/c**
- **p/K up to 10 GeV/c**

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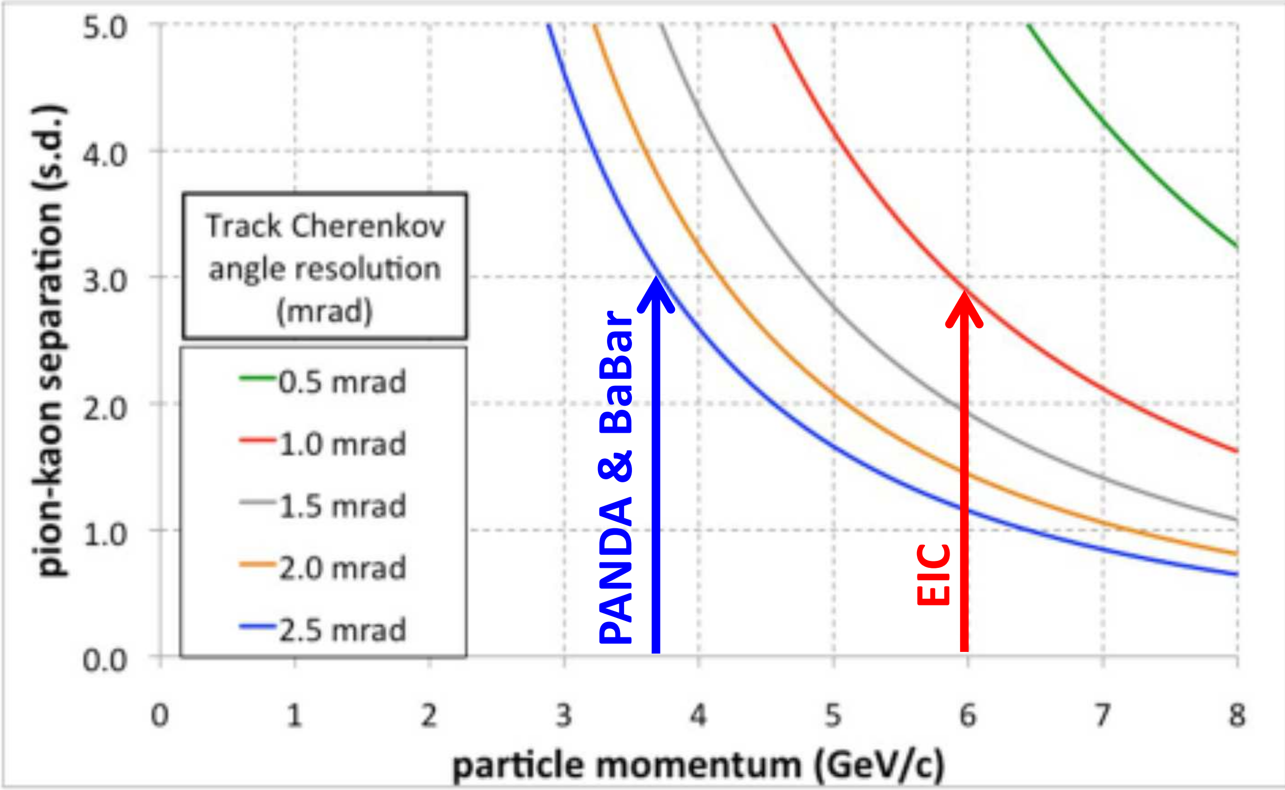
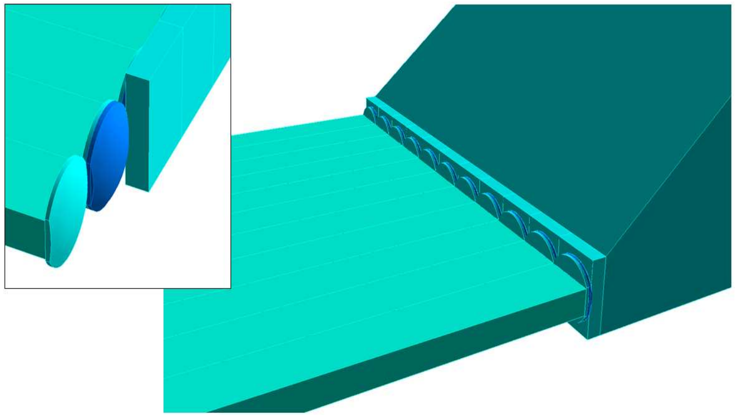
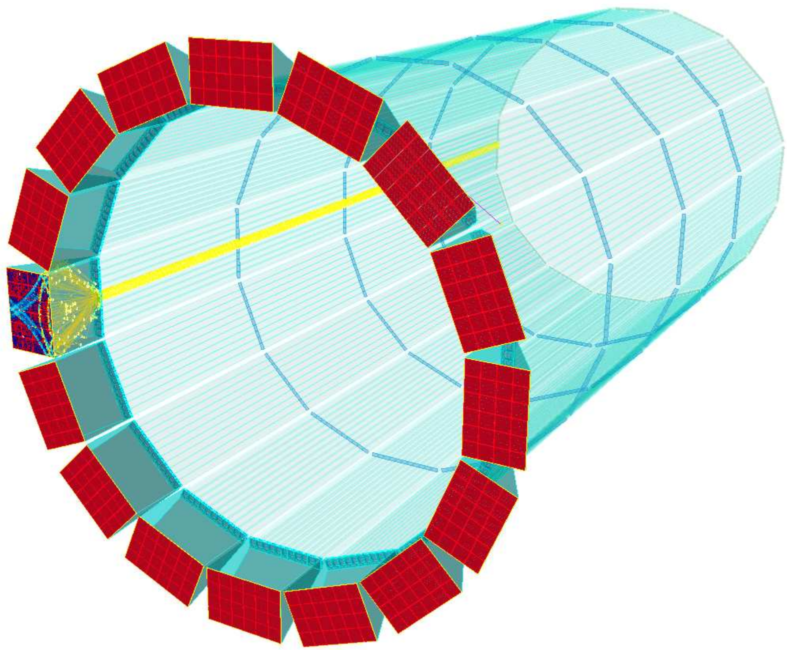


# Initial hpDIRC Design

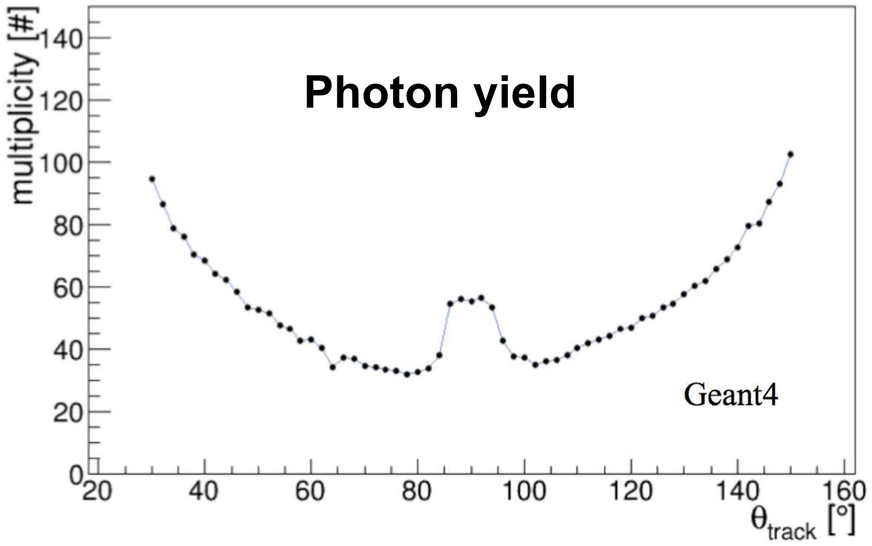
- **Concept – fast focusing DIRC**
- **Components:**
  - **Radiator bars**
    - 17 x 35 x 4200 mm
    - 11 bars per box
    - 16 bar boxes, 1m from IP
  - **Spherical 3-layer lens**
    - 14 x 35 x 50 mm
    - radiuses: 47 mm, 29 mm
  - **Compact expansion volume**
    - Prism with 38° opening angle
    - 285 x 390 x 300 mm
  - **Fast pixelated sensors**
    - 100k pixels, each 3 mm$^2$

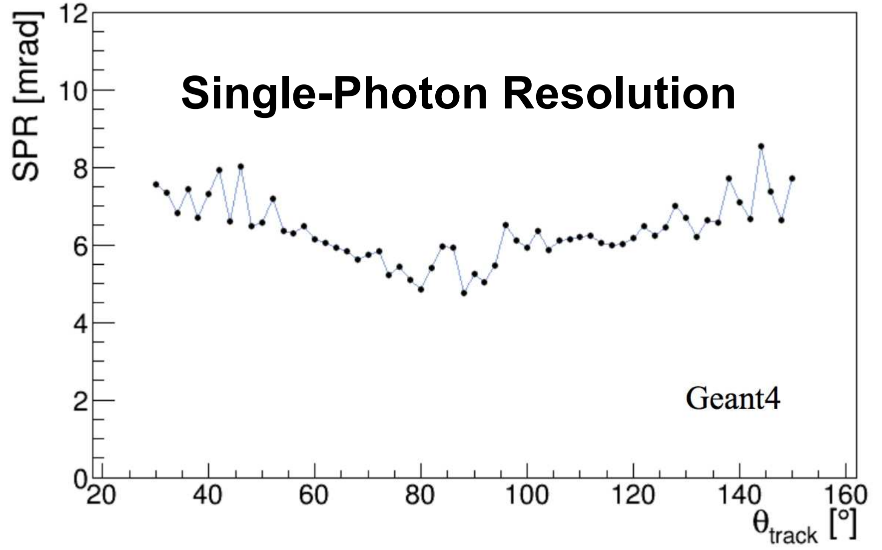
**Geant4 simulation of hpDIRC detector**

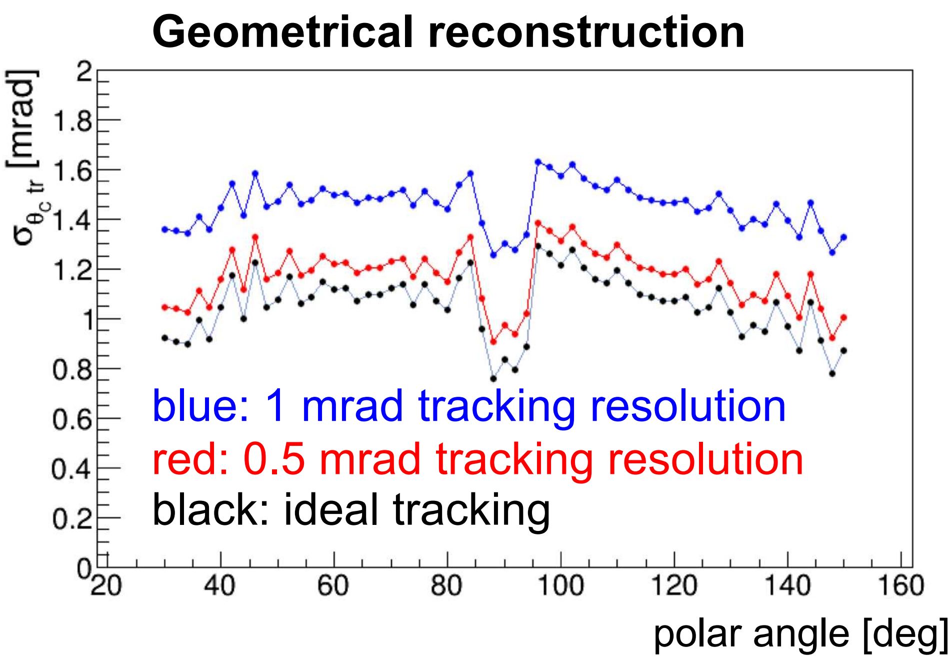




# hpDIRC Simulated Performance



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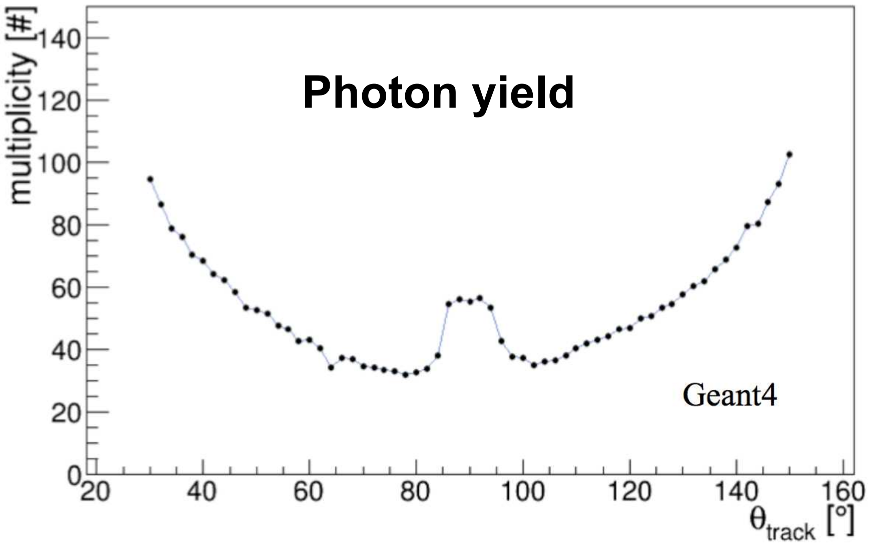
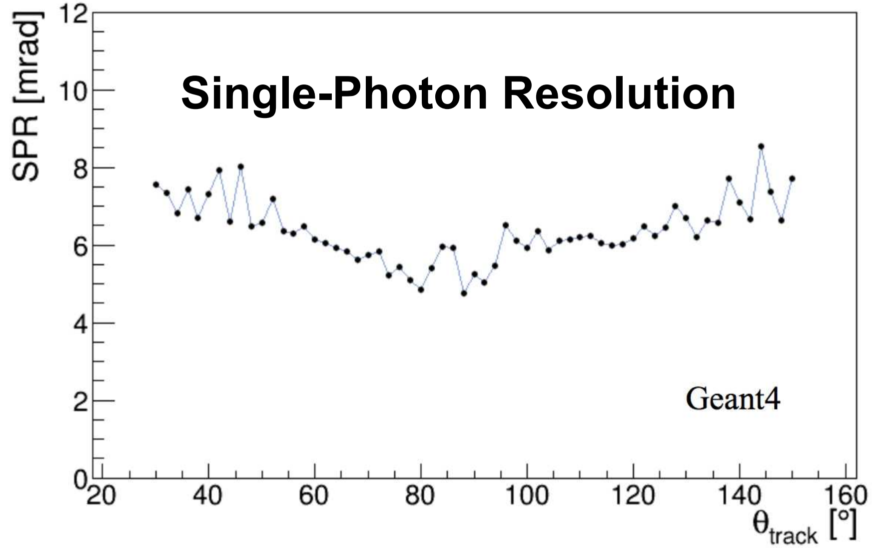
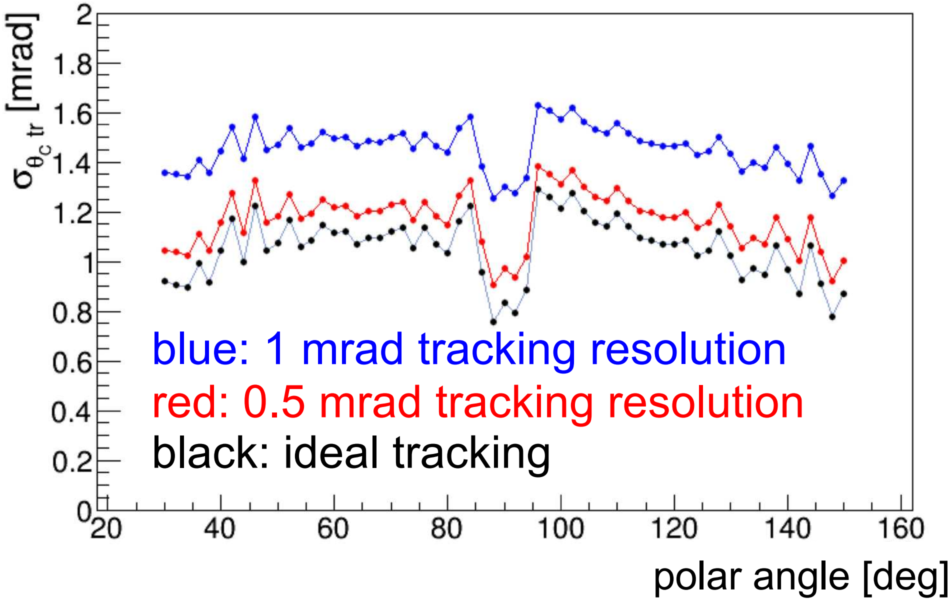
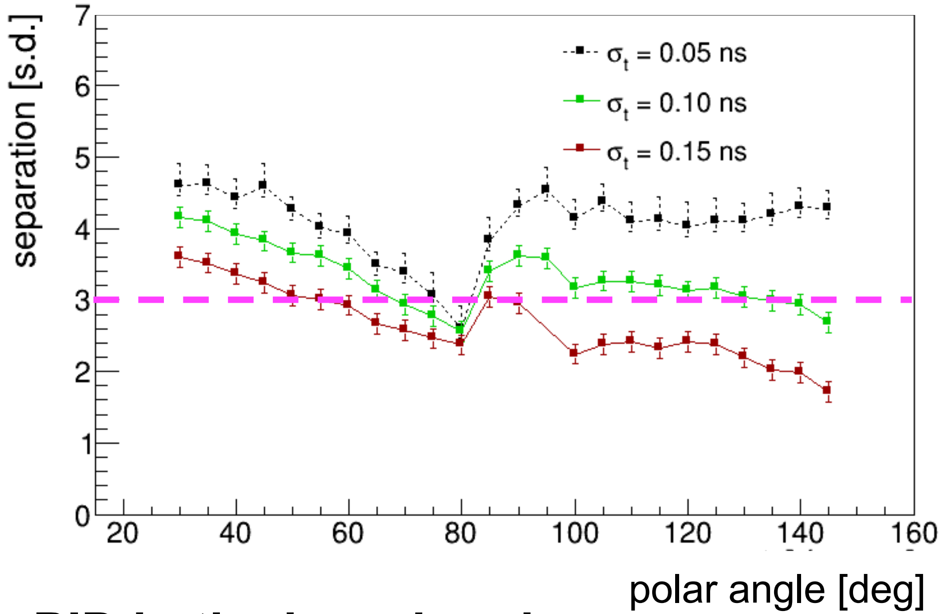



Geometrical reconstruction

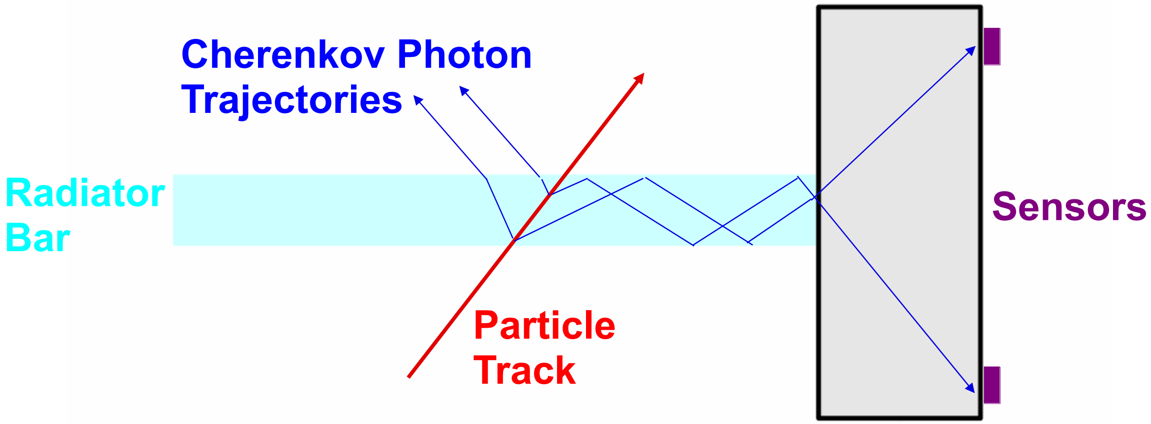



Time based reconstruction at 6 GeV/c




**design meets the requirements for PID in the barrel region**

# Critical hpDIRC Components

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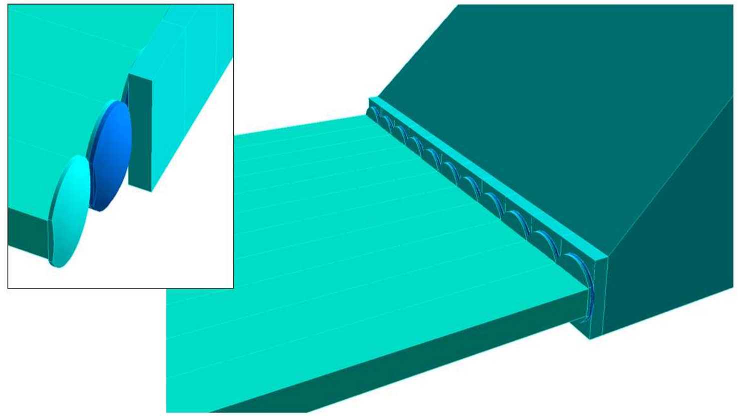
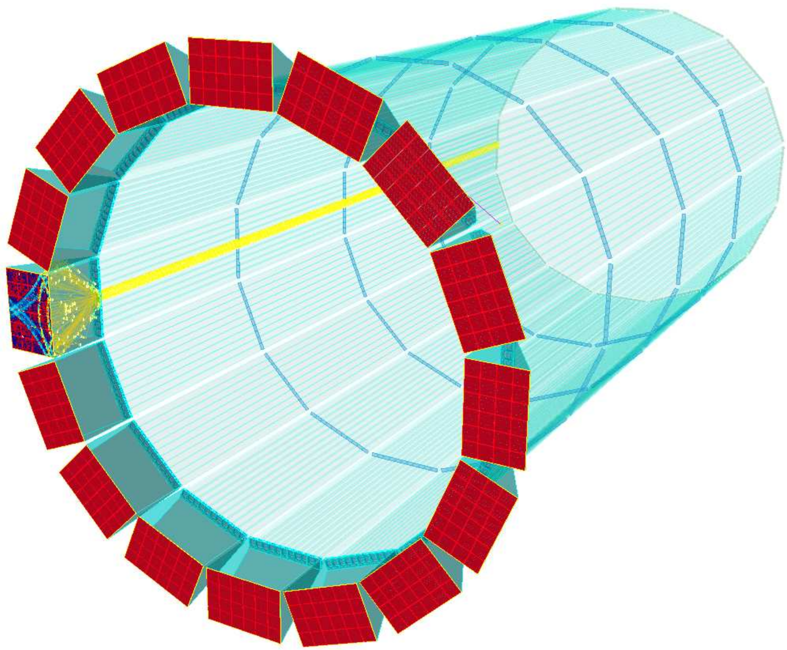


- **Radiator bars** (Major decision between radiator has to made)
- **Imaging system:**
  - **Expansion volume** (shape)
  - **Sensors** (small pixels, fast timing, operating in magnetic field)
  - **Focusing system** (new materials, custom design)



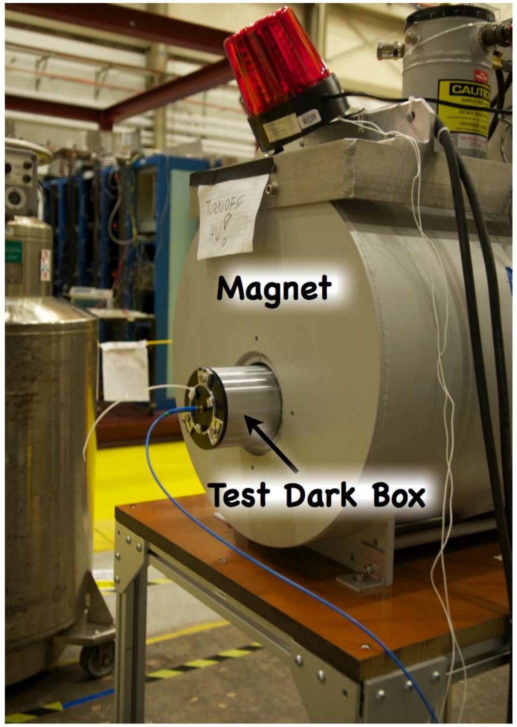
# High-B Facility

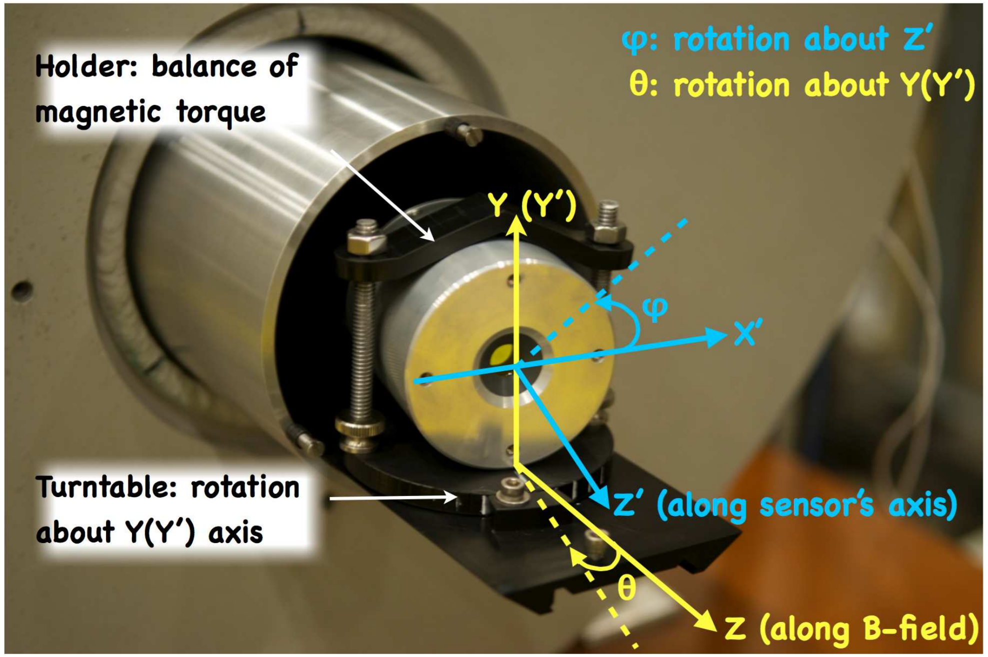
**Magnet**:

- superconducting solenoid
- max. field: 5.1 T at 82.8 A
- 12.7cm (5inch) diameter
  76.2cm (30inch) length bore:

**Test Box:**

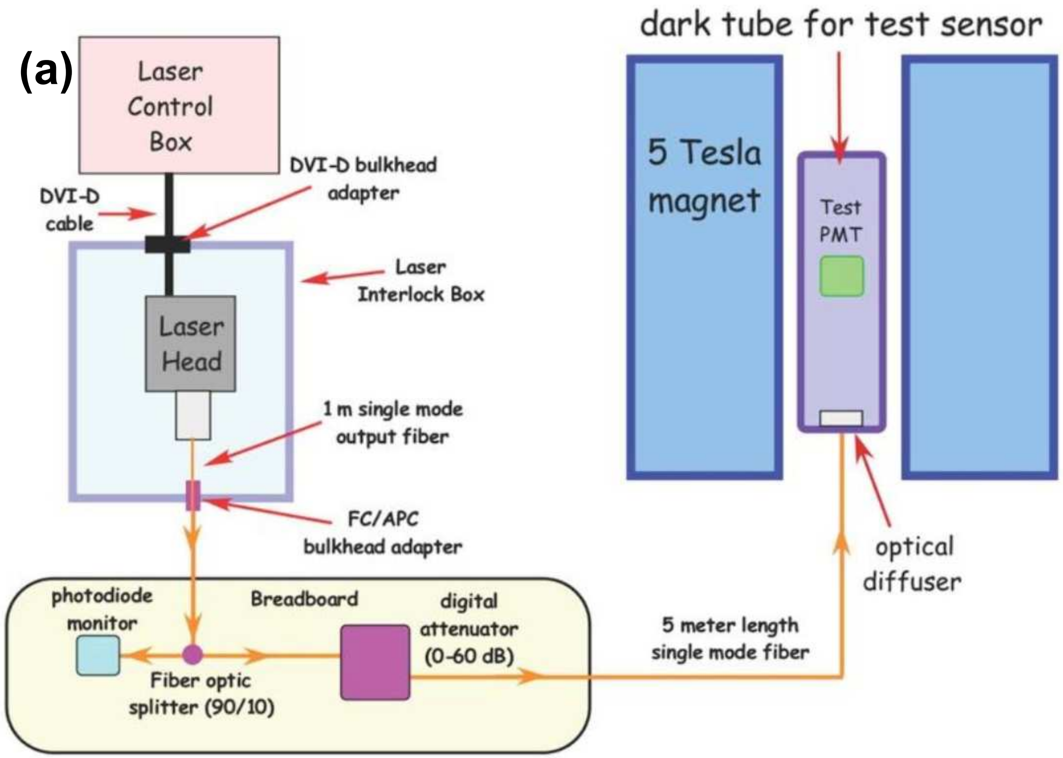
- non-magnetic, light-tight
- allows for rotation of sensors
- LED light source (470nm)

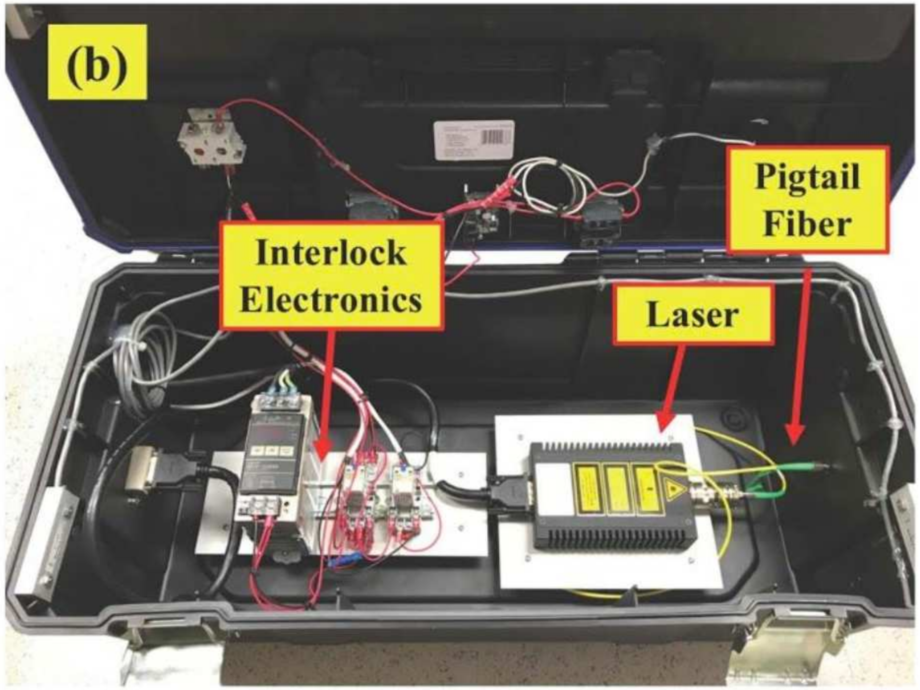


# High-B Facility

**Picosecond laser added for timing studies**

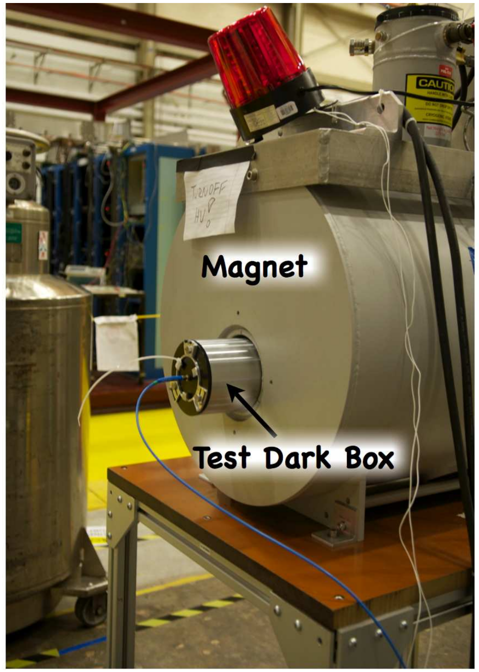


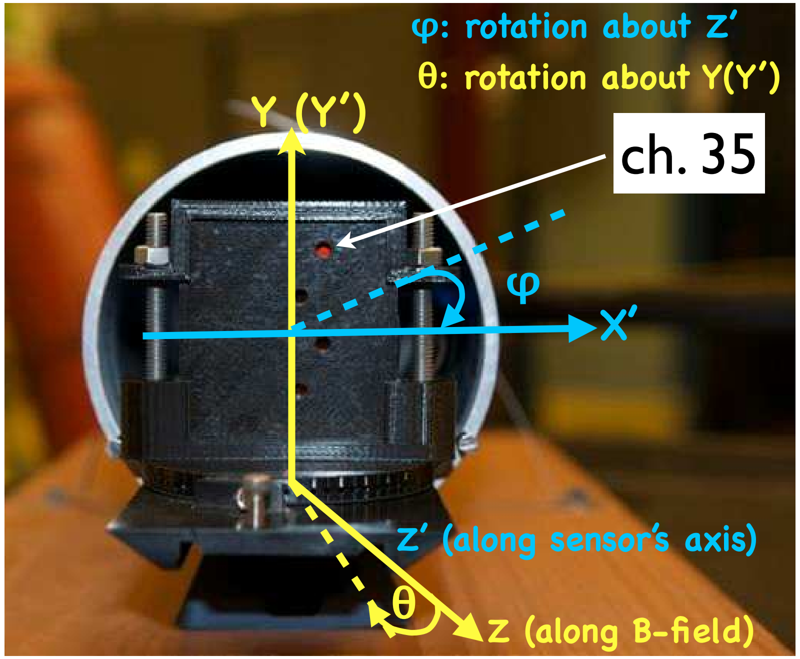



# High-B Facility

**Past year: focused on testing 10-μm Planacon XP85112 (6mm pixel size) tests**

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



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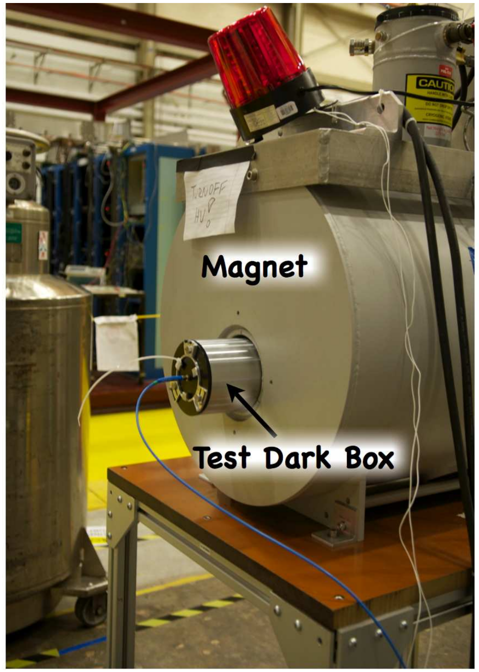
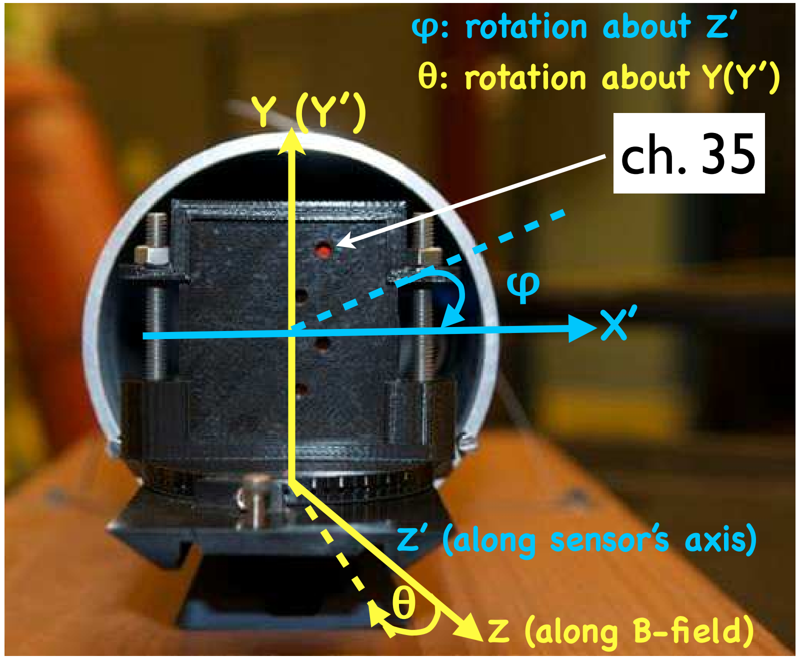
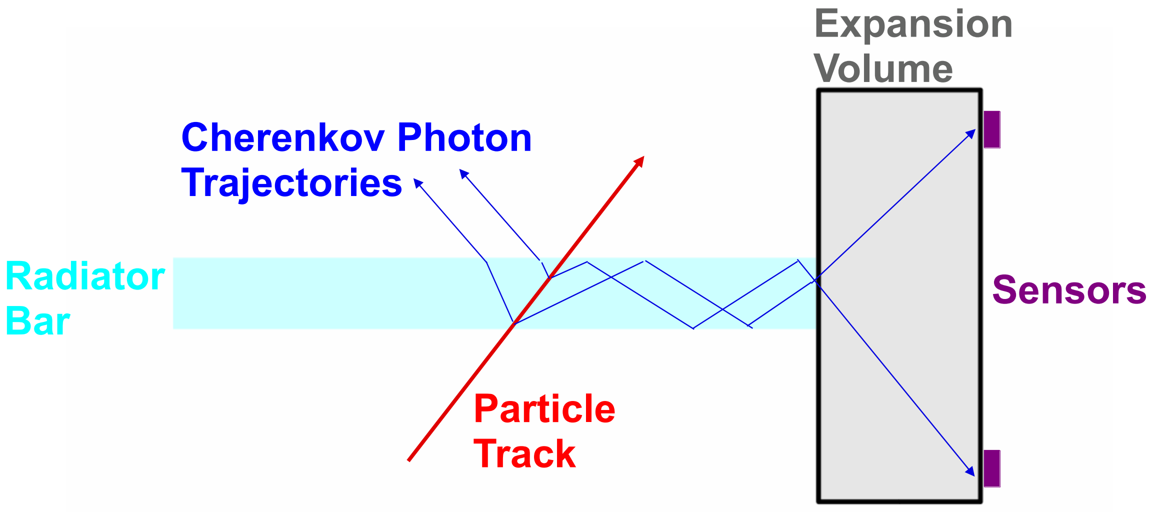



**Next: XP85122-S (10-µm Planacon with 1.6mm pixel size)**

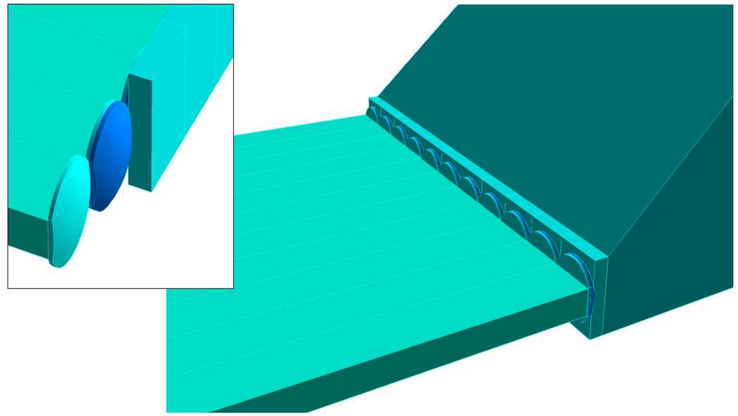
- Evaluation of gain and timing-resolution
- Comprehensive gain, timing and ion feedback studies as a function of B, HV, and sensor orientation relative to field direction
- Studies with costumed HV settings

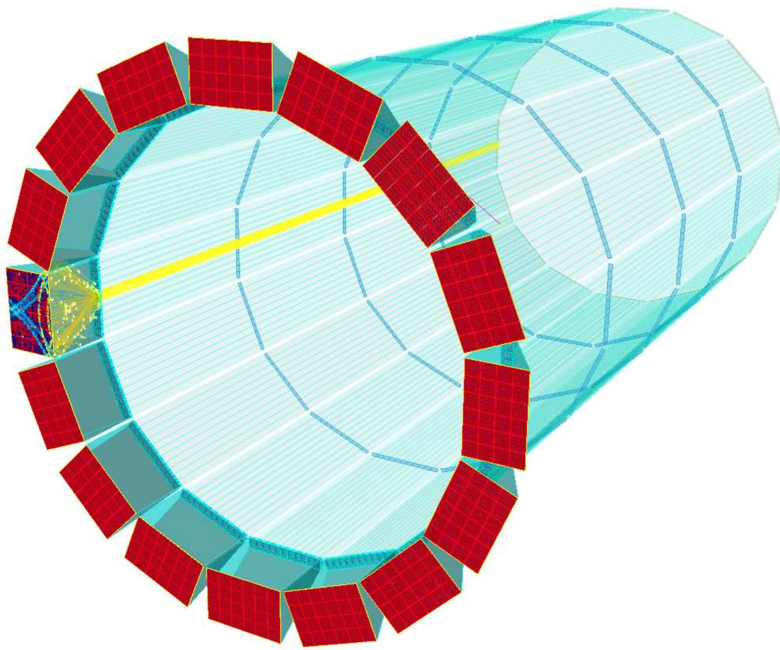


# Critical hpDIRC Components




Geant4 simulation of hpDIRC detector



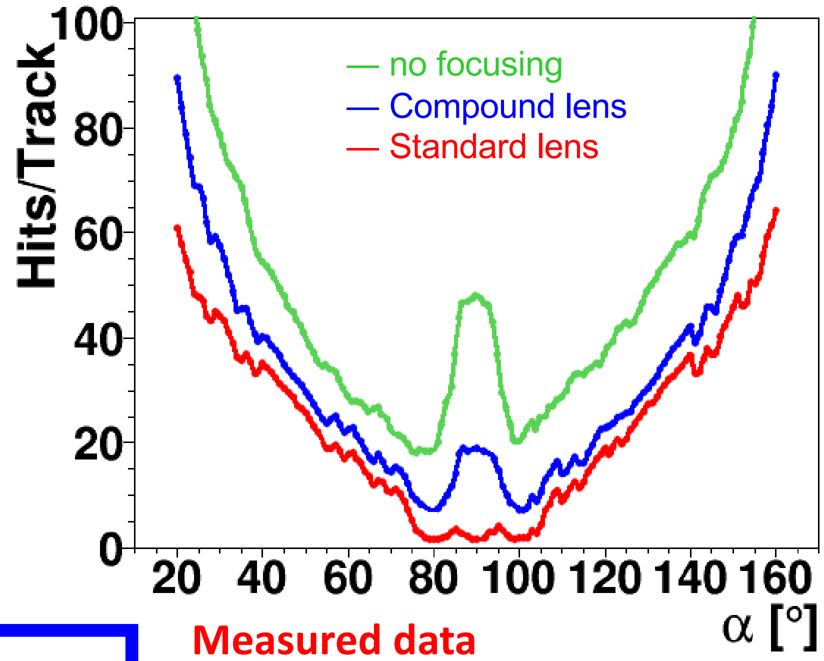


- Radiator bars (Major decision between radiator has to made)
- Imaging system:
  - Expansion volume (shape)
  - Sensors (small pixels, operating in magnetic field)
  - **Focusing system (new materials, custom design)**

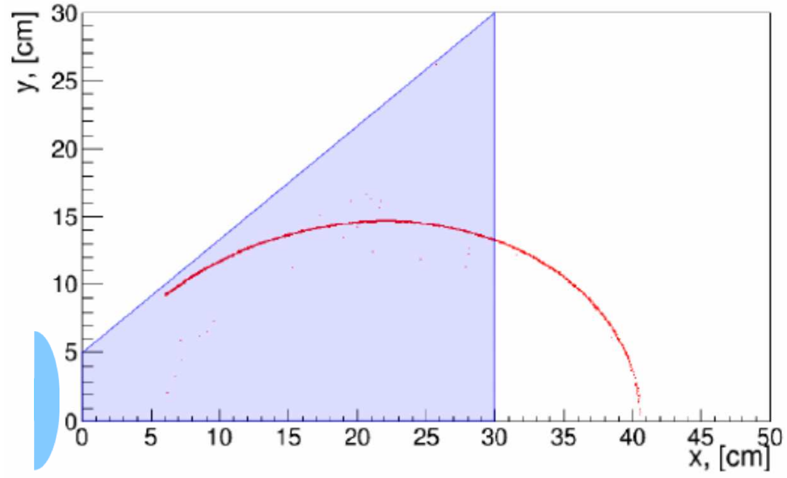
# 3-layer Lens

**Limitations of standard plano-convex focusing lenses with air gap:**

- Significant photon yield loss around 90° particle track
- Aberration for photons with steeper angles




Measured data




Simulated data

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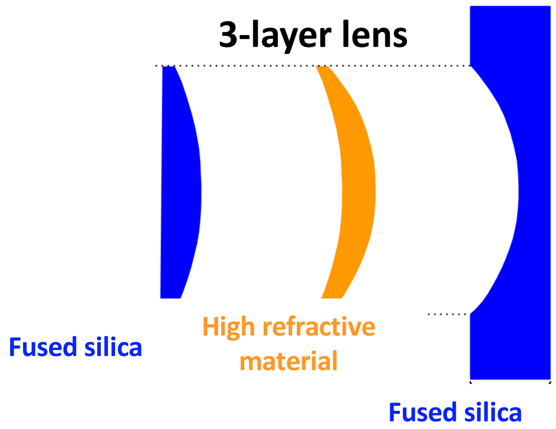
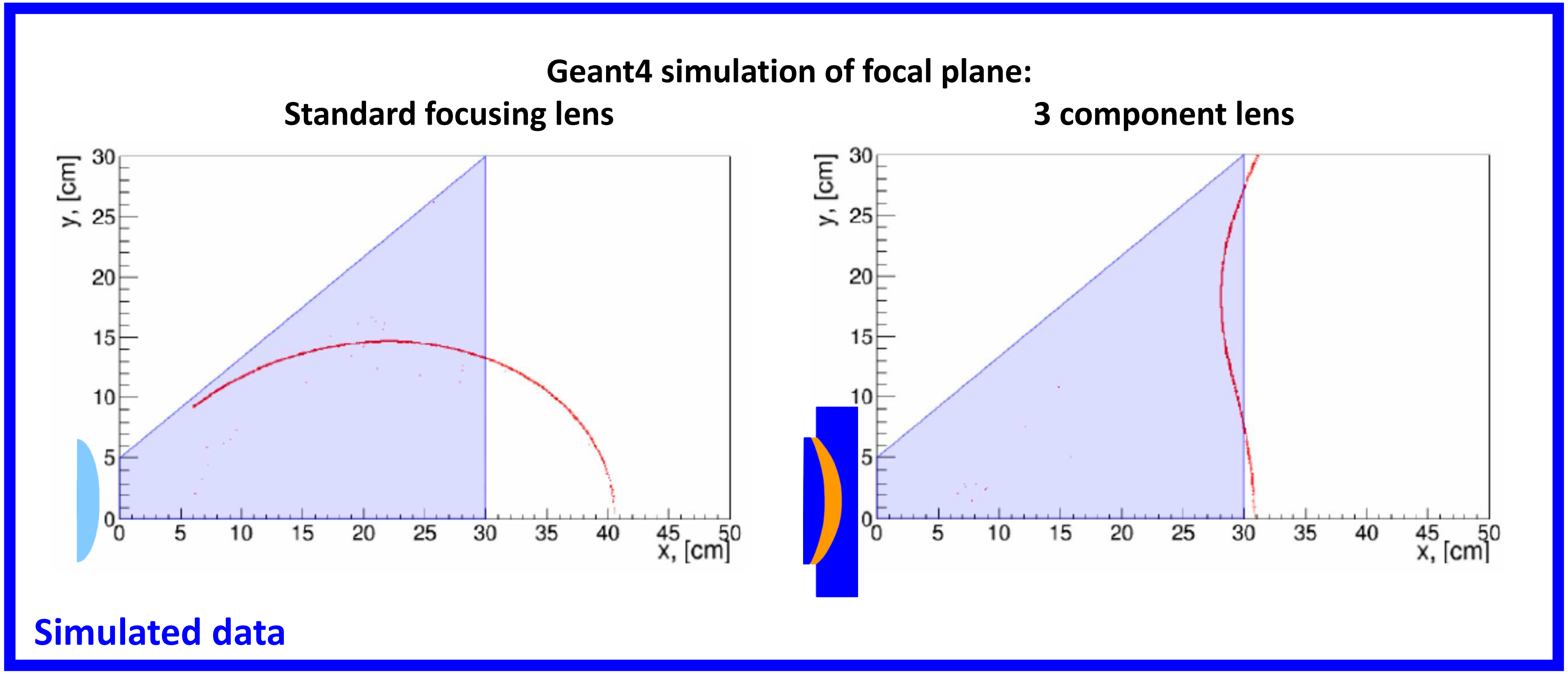


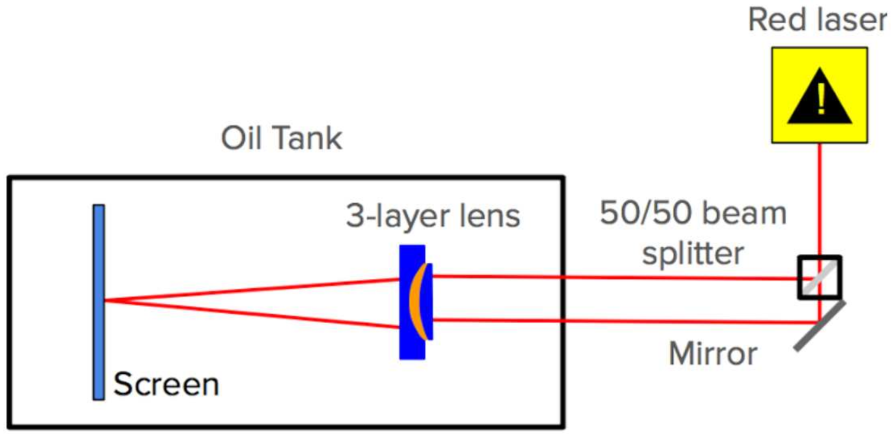



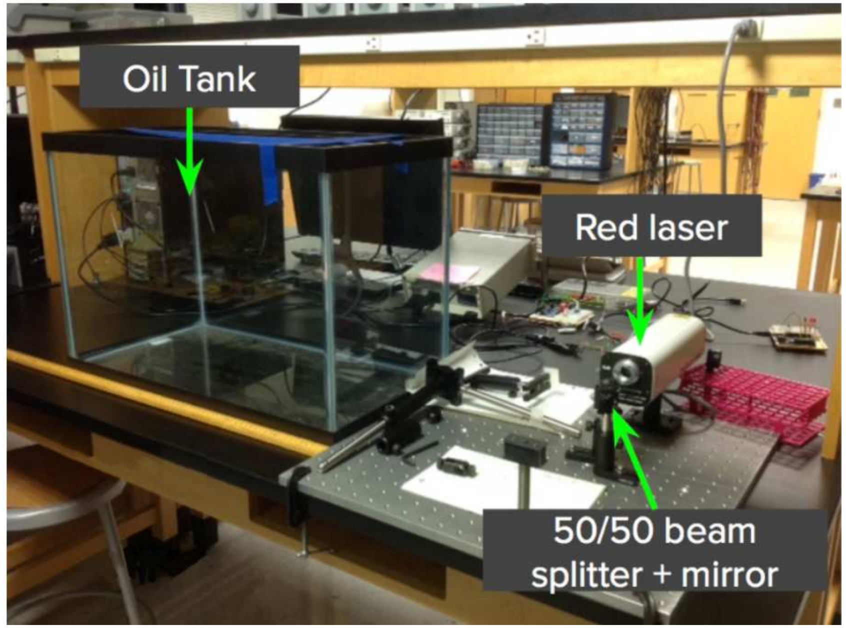
# Mapping 3-layer Lens

**Mapping focal plane of 3-layer lens:**

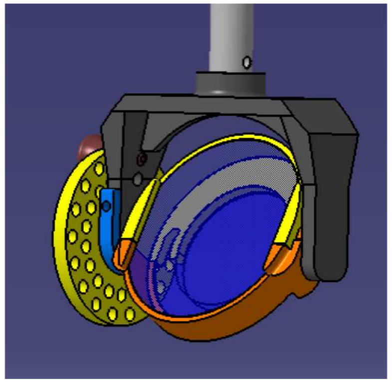
- Lens holder designed to rotate in two planes for the 3D mapping of the focal plane and shifts of lens in horizontal plane.

**Laser setup to map the focal plane**



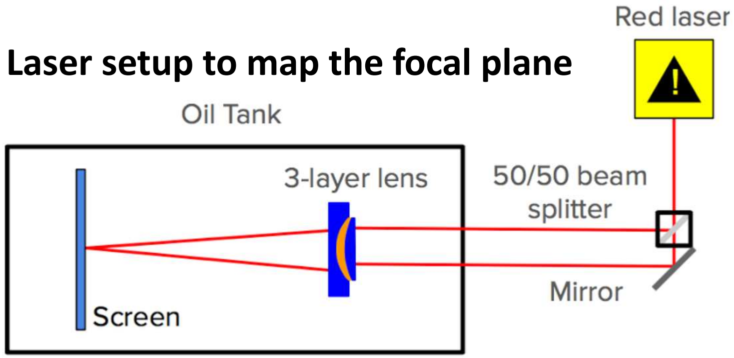

**3D lens holder**

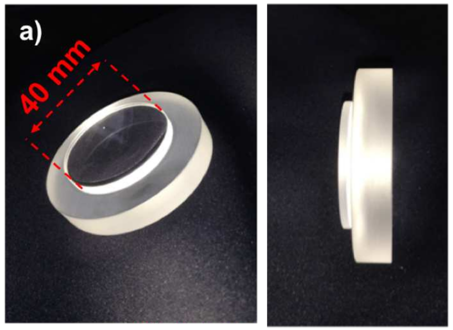


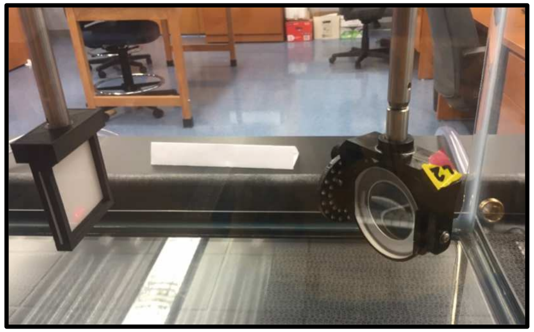
# Mapping 3-layer Lens

- Two prototype lenses characterized
- Stability and efficiency of setup has to be improved for new prototypes

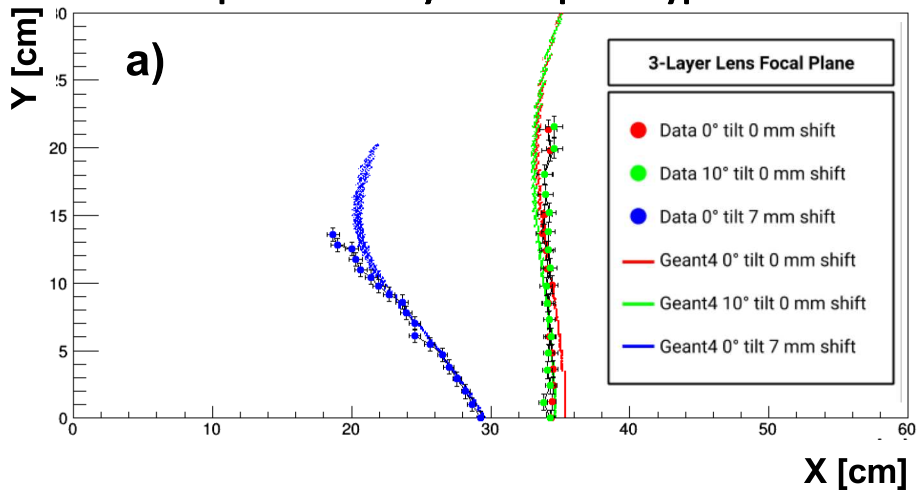
**Laser setup to map the focal plane**



**Spherical 3-layer lens prototype**



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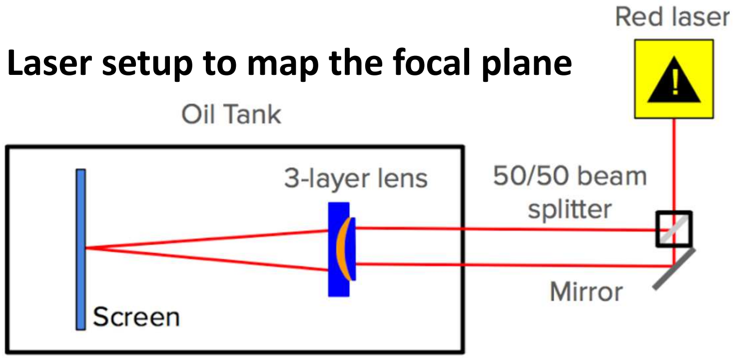
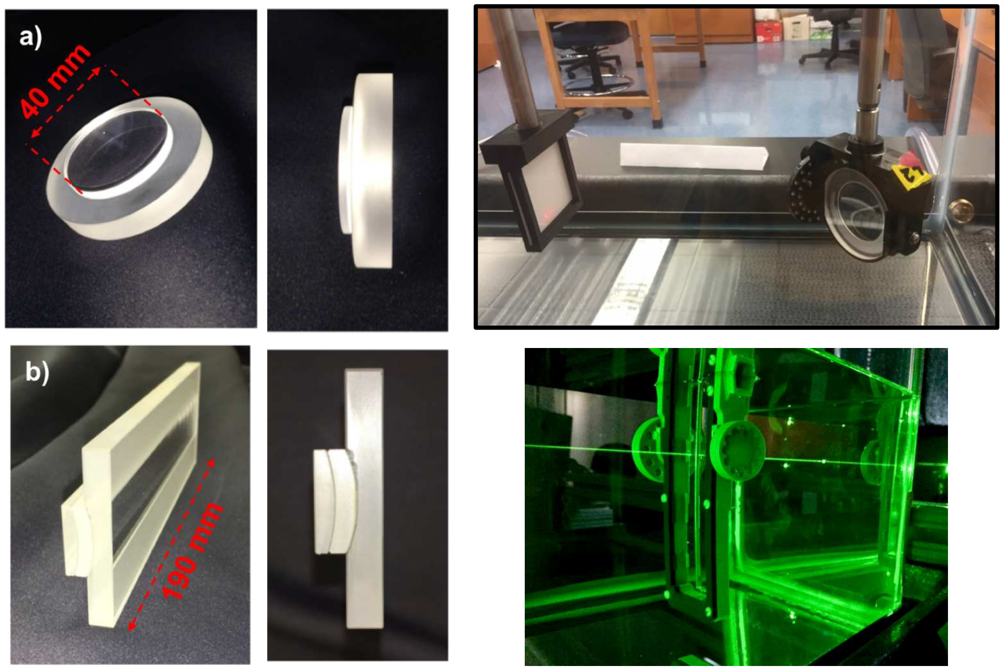
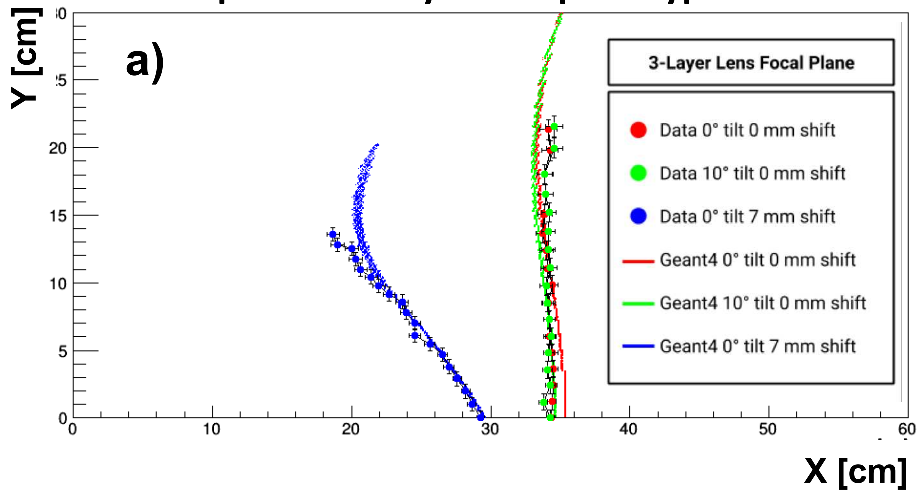
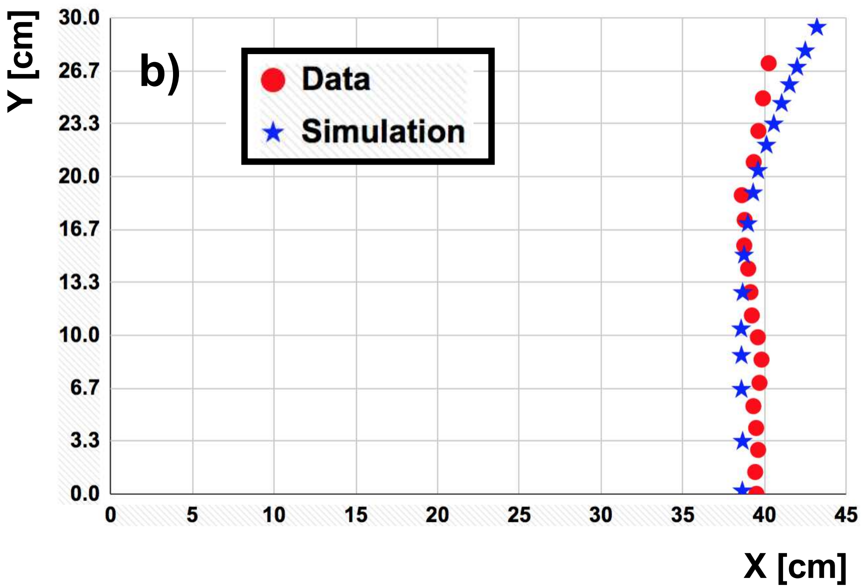



**Spherical 3-layer lens prototype**



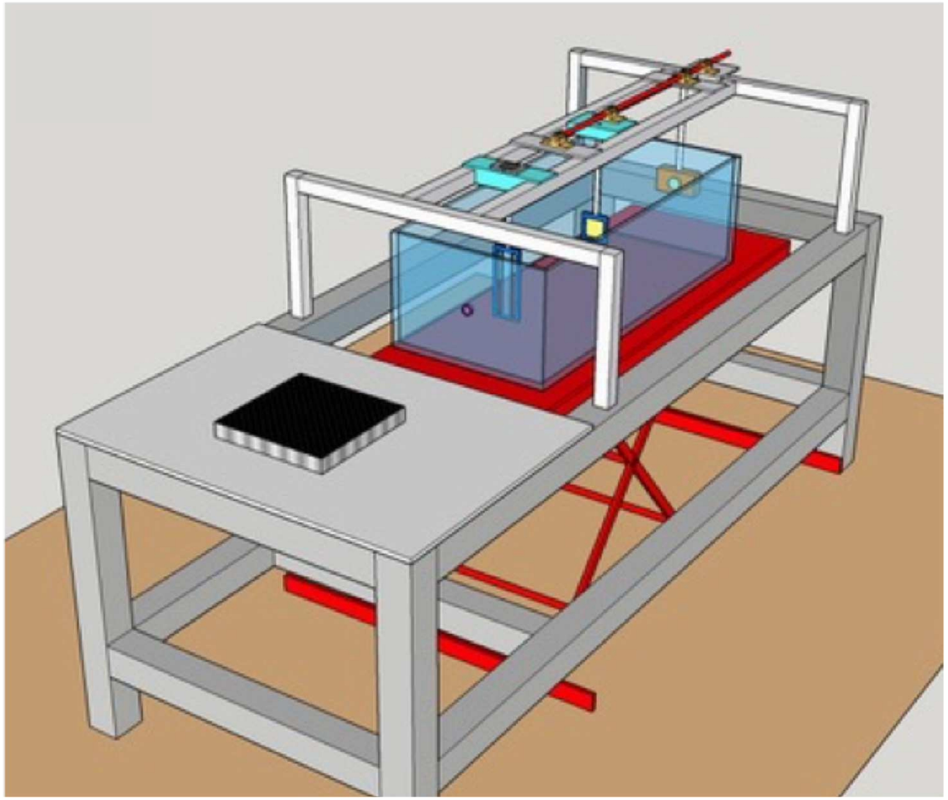

**Cylindrical 3-layer prototype**



# Mapping 3-layer Lens

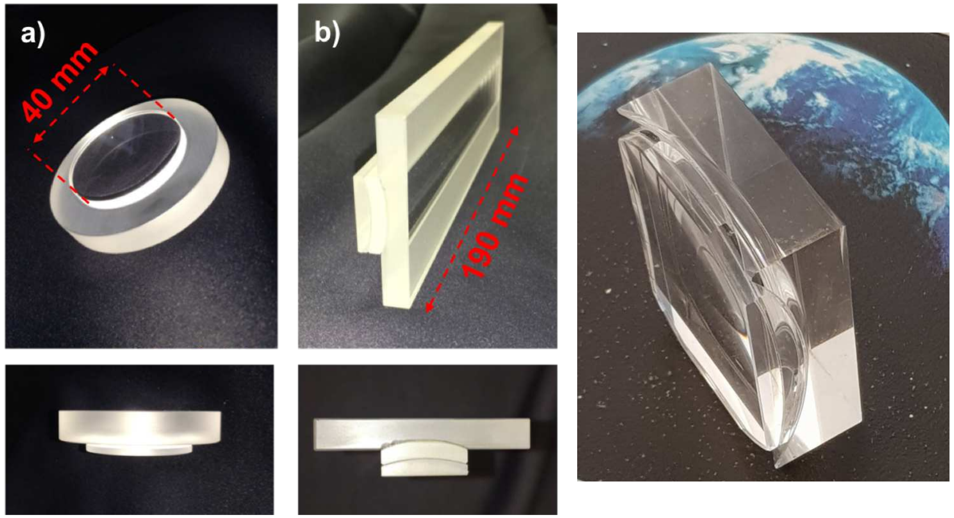
- Two radiation-hard 3-layer spherical prototype lenses currently in production, will be available fall 2019.

- Upgrade of setup will simplify the calibration and the exchange of lenses, and increase the precision and speed of the measurements!



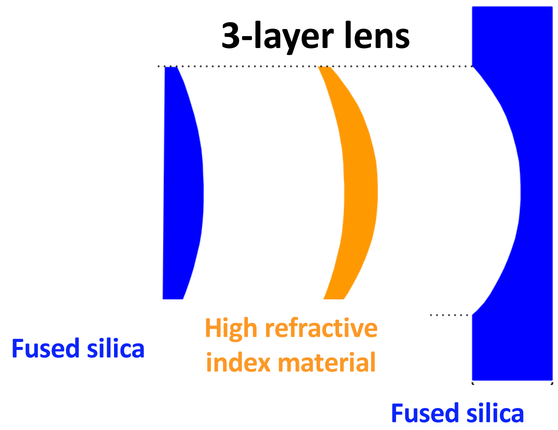
**Laser setup at ODU to map the focal plane**
**Current setup:**


**Spherical and cylindrical 3-layer lens prototypes**



# Radiation Hardness of 3-layer Lens

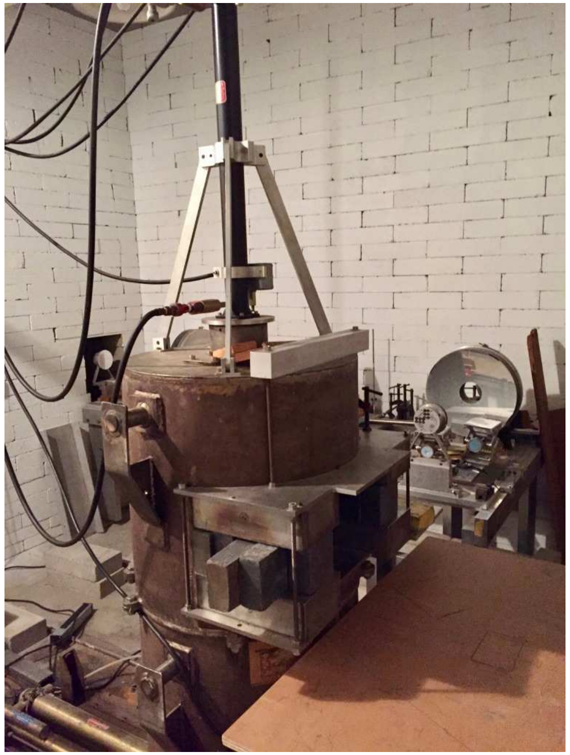
- First lens prototypes used lanthanum crown glass (NLaK33) as the middle layer.




R. Dzhygadlo, T. Hartlove, G. Kalicy, J. Kierstead

# Radiation Hardness of 3-layer Lens

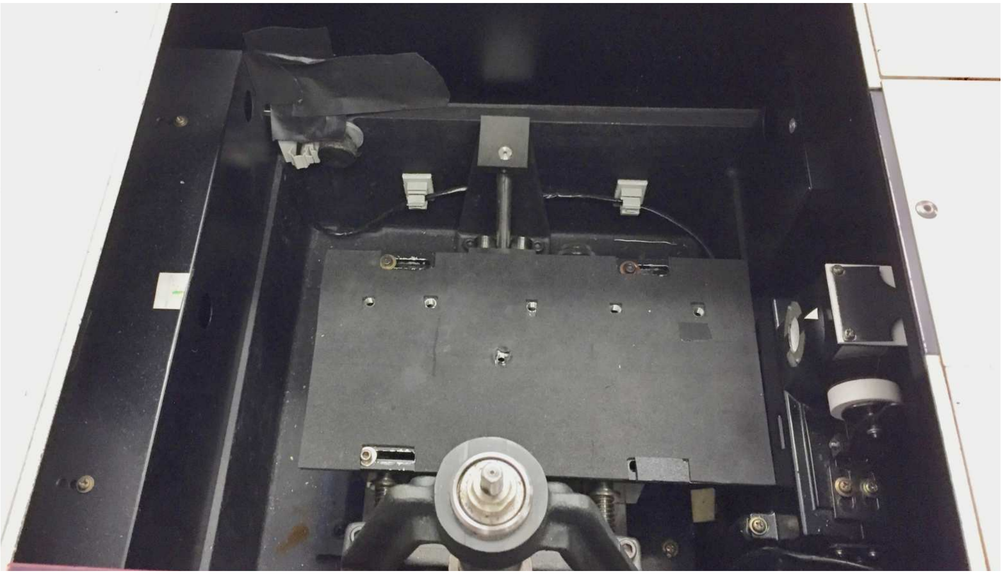
Co$^{60}$ Chamber



**$^{60}$Co irradiation setup at BNL**

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

**Monochromator**



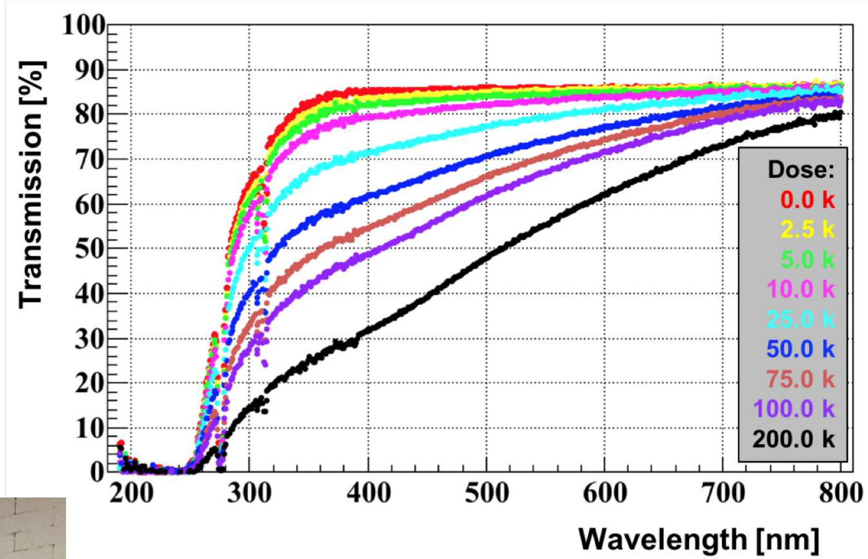
T. Hartlove, G. Kalicy, J. Kierstead

# Radiation Hardness of 3-layer Lens

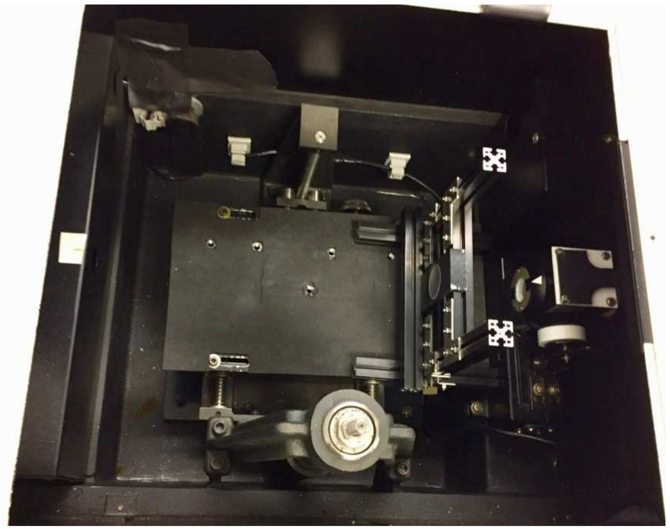
**$^{60}$Co irradiation results**

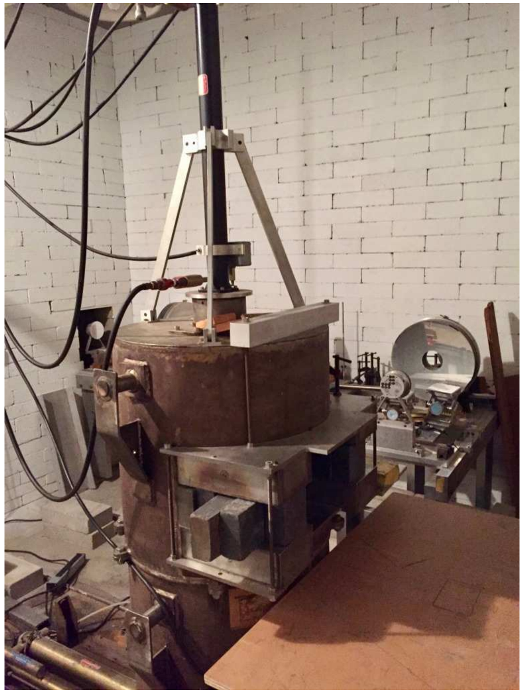
- Radiation damage quantified by measuring the transmission in the 190-800 nm range in a monochromator
- Transmission loss of both lanthanum crown glass materials (NLaK33 and S-YGH51) observed

**S-YGH51 (NLaK33 equivalent)**




**Monochromator**

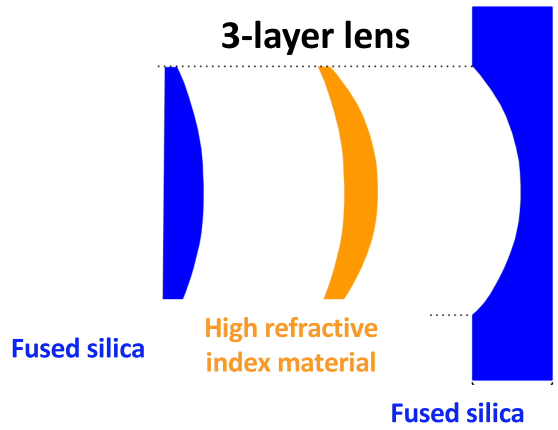




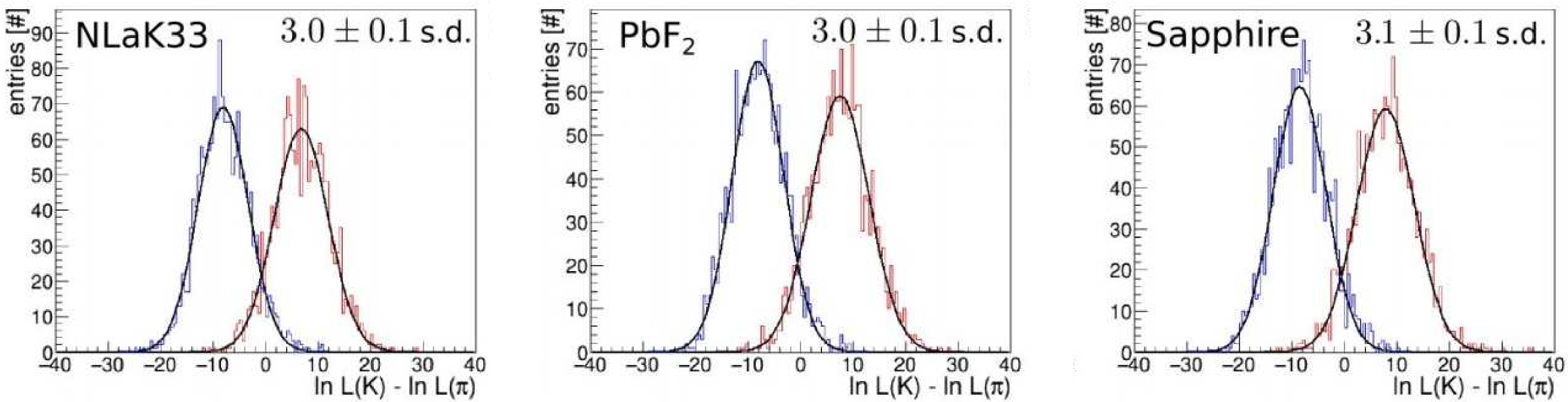
**Co$^{60}$ Chamber**

# Radiation Hardness of 3-layer Lens

- First lens prototypes used lanthanum crown glass (NLaK33/S-YGH51) as the middle layer.
- Both Sapphire and $PbF_2$ are very challenging to process.
- Two vendors are building 3-layer lens with Sapphire and $PbF_2$.



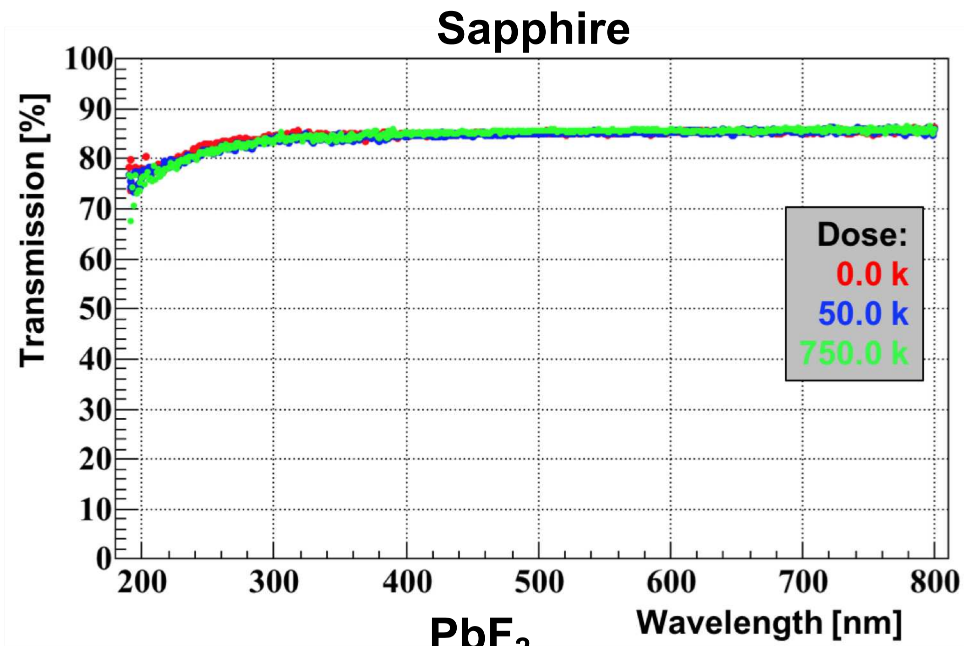

**Simulated π/K separation for charged pions and kaons with 6 GeV/c momentum and 30° polar angle, assuming a tracking resolution of 0.5 mrad.**

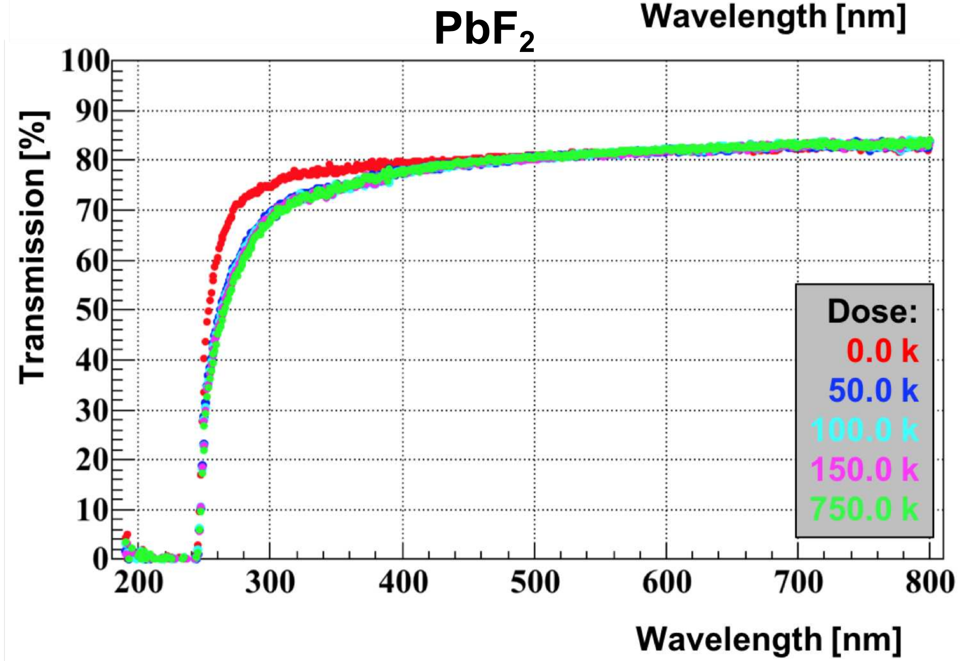



Simulated data

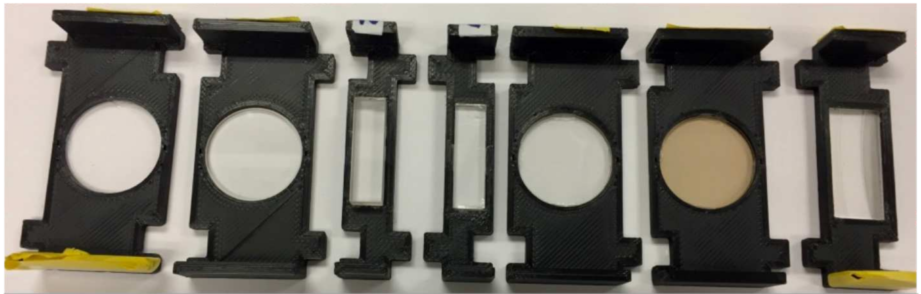
# Radiation Hardness of 3-layer Lens

- Seven materials studied
- Radiation hardness of sapphire and $PbF_2$ confirmed
- Luminescence studies started




**Tested samples**

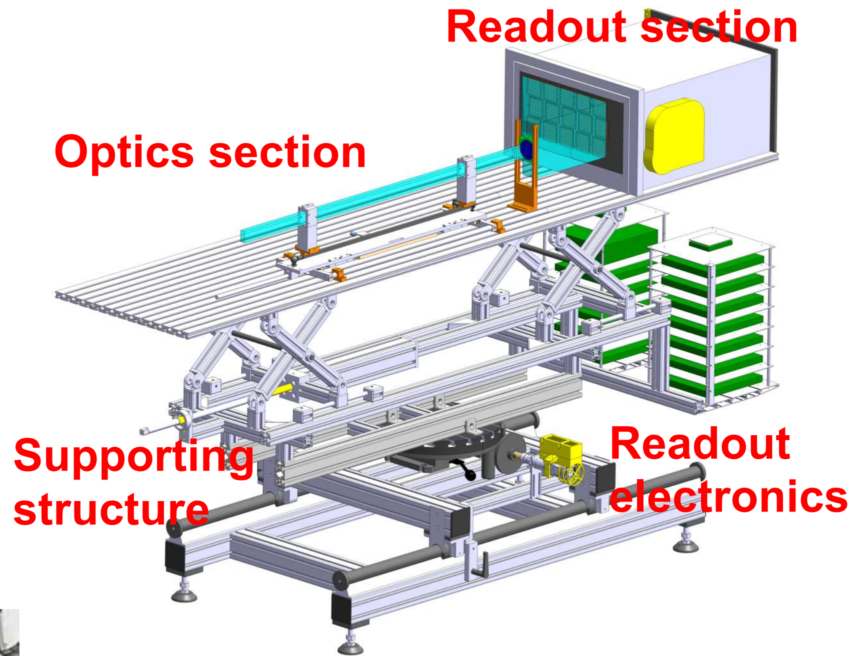


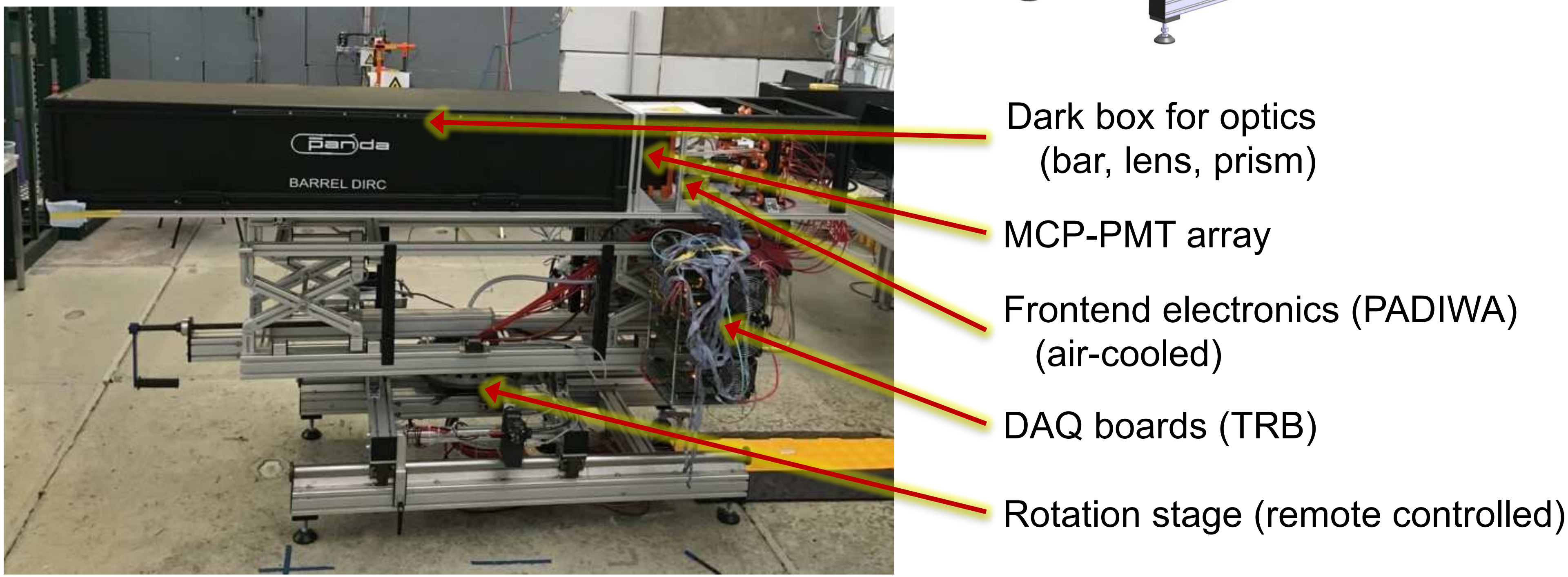
| Fused Silica | Sapphire | 8mm $PbF_2$ | 4mm $PbF_2$ | S-YGH51 | S-YGH51 | Fresnel Lens |
|---|---|---|---|---|---|---|
| 0k | 750k | 750k | 750k | 5k | 100k | 400k |

# hpDIRC Prototype

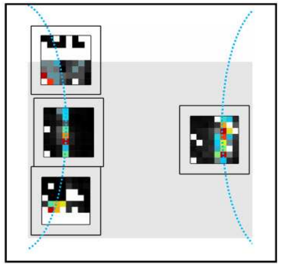
**Full system PANDA barrel DIRC prototype**

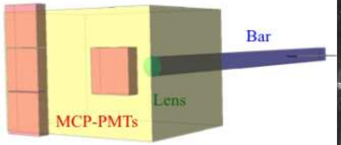
- Modular design modified and improved over 11 years
- Wide range measurements performed in GSI and CERN
- Several different focusing lenses were tested



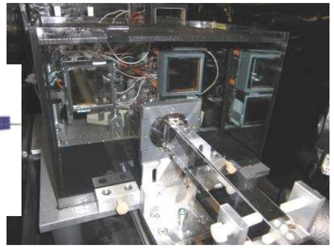



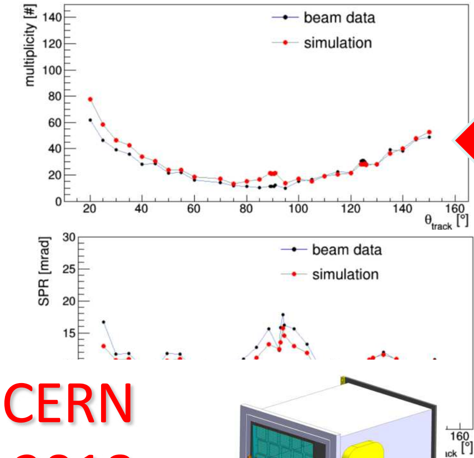
# Test Beam Program



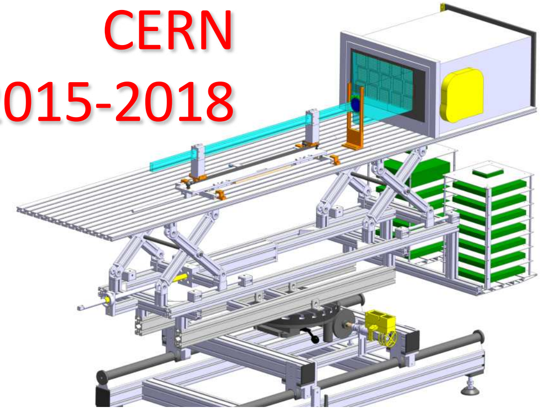



GSI
2008/2009

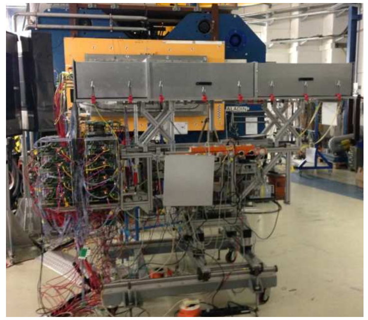


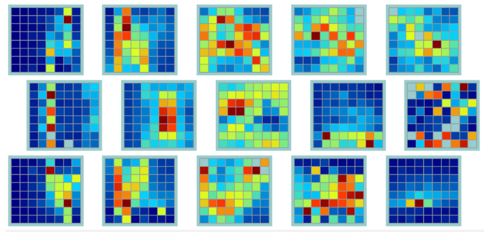


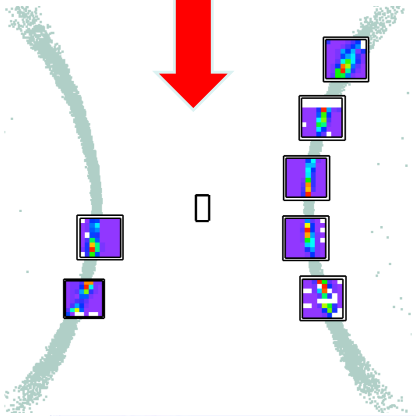

CERN
2015-2018



GSI 2014

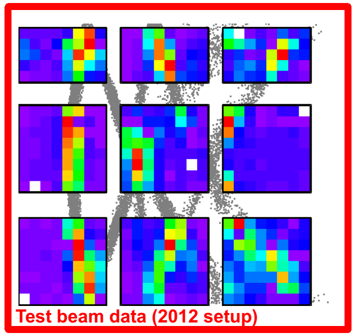


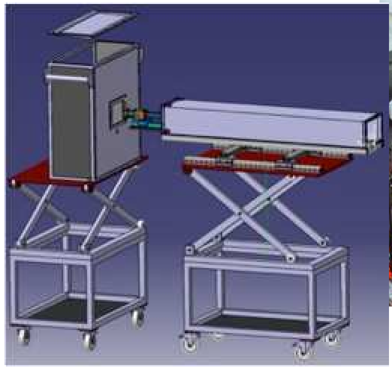


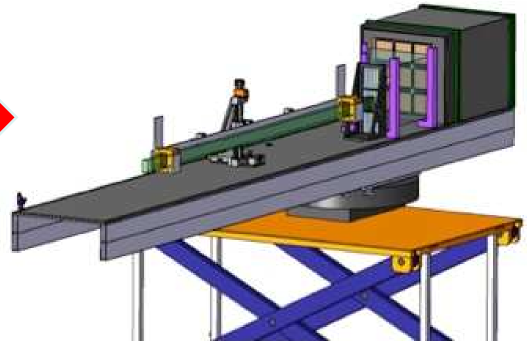


GSI, CERN
2011

CERN
2012





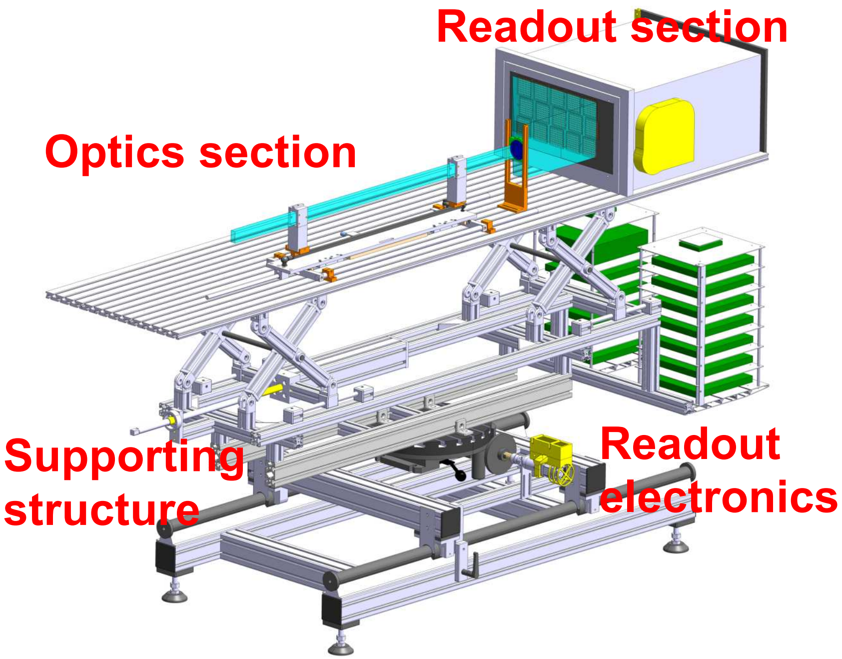
# hpDIRC Prototype

**Full system PANDA barrel DIRC prototype**

- Modular design modified and improved over 11 years
- Wide range measurements performed in GSI and CERN
- Several different focusing lenses were tested

**Ultimately hpDIRC Prototype with proper geometry is needed**

- Radiator choice (narrow bars vs  wide plates radiators)
- Fast timing, readout electronics
- Pixel size, sensor coverage



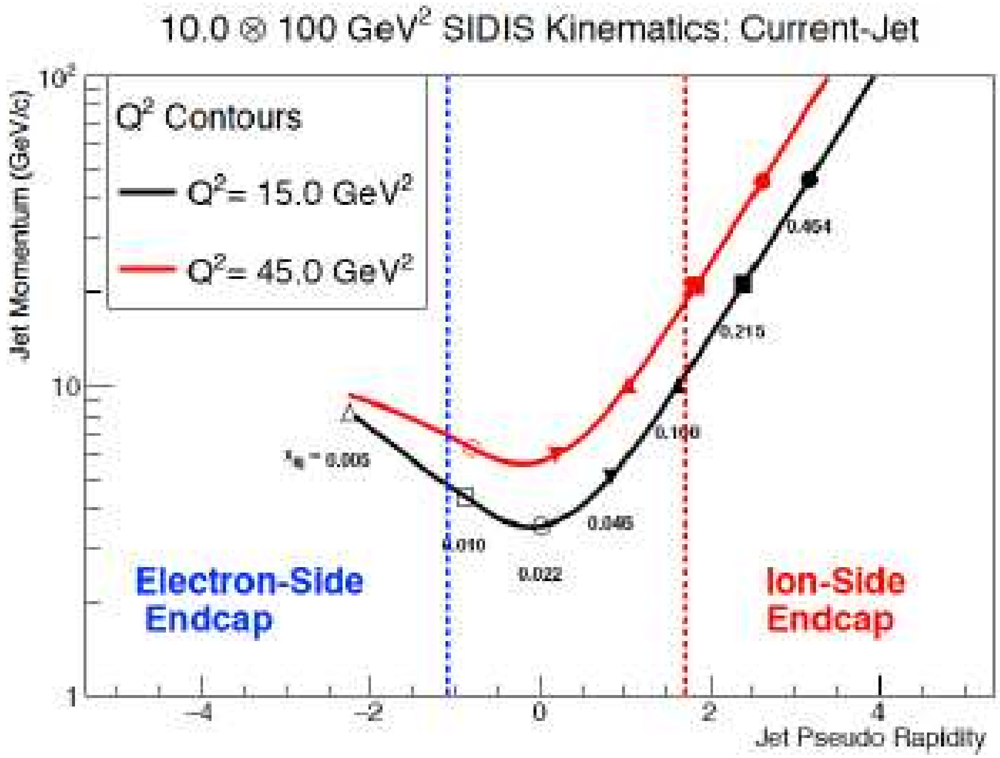
# Summary

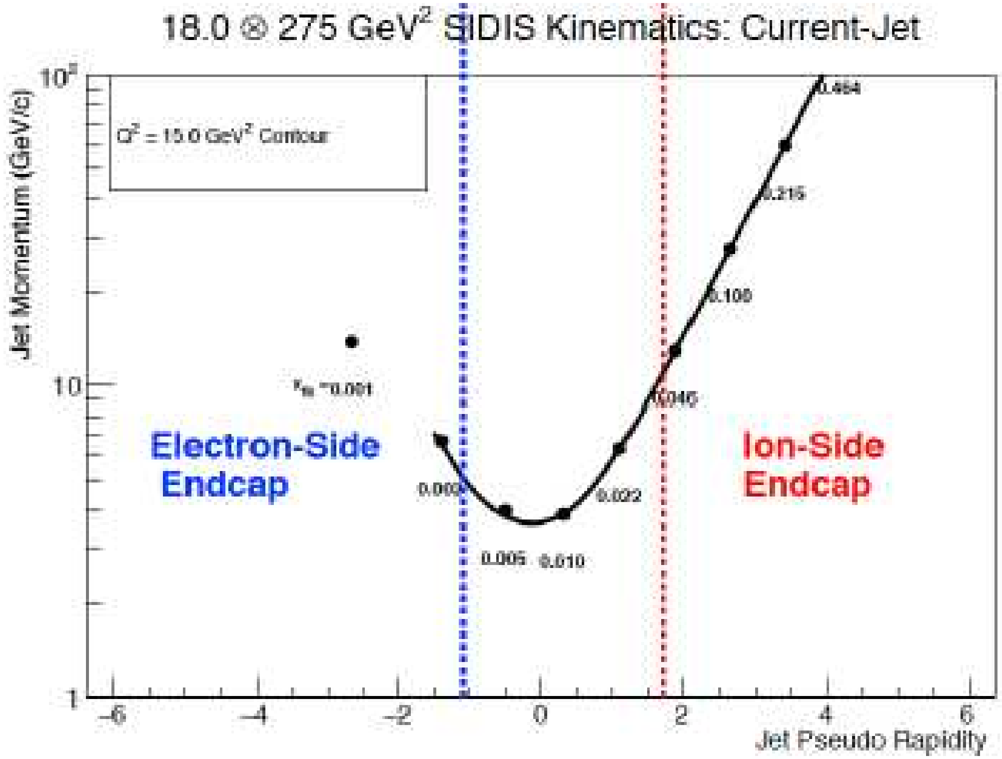
- **High-Performance DIRC is being developed to fit all three concepts for the future EIC central detector.**
- **Initial design (narrow bar) based on 3-layer lens has potential to cover beyond 10 GeV/c for p/K, 6 GeV/c for $\pi$/K, and 1.8 GeV/c for e/$\pi$, pushing performance well beyond state-of-the-art.**
- **Optical properties of first spherical and cylindrical 3-layer lens prototypes were validated in the particle beam and on the test bench.**
- **Sapphire and PbF2 materials were investigated and confirmed in radiation hardness tests as alternative high refractive index material.**
- **The new radiation hard 3-layer lens prototypes are being finished.**
- **Next step: design optimization, particle beam tests**

# Backup

# EIC PID Solutions

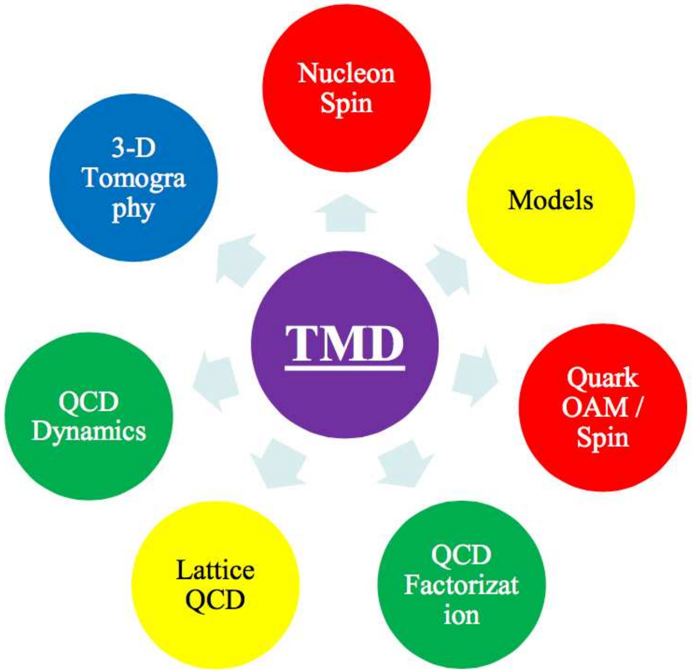
## Hadron kinematic at EIC



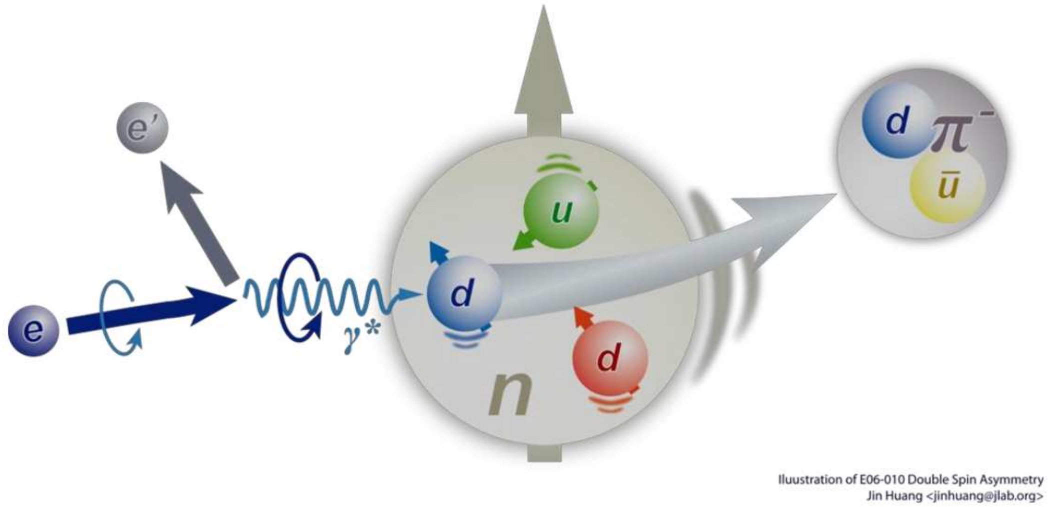




- The maximum hadron momentum in the endcaps is close to the electron and ion beam energies, respectively.
- The momentum coverage need in the central barrel depends on the desired kinematic reach, in particular in $Q^2$ – important for QCD evolution, etc.
  - Weak dependence on beam energies

# PID Semi-Inclusive DIS (SIDIS)

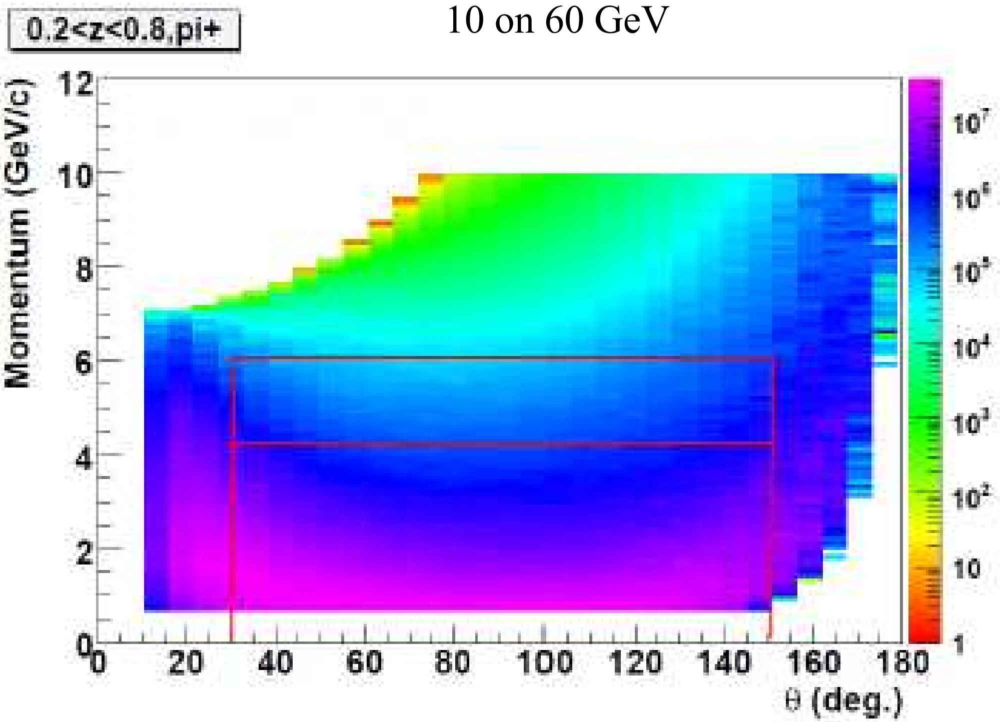



**Precision mapping of transverse momentum dependent parton distributions (TMD)**

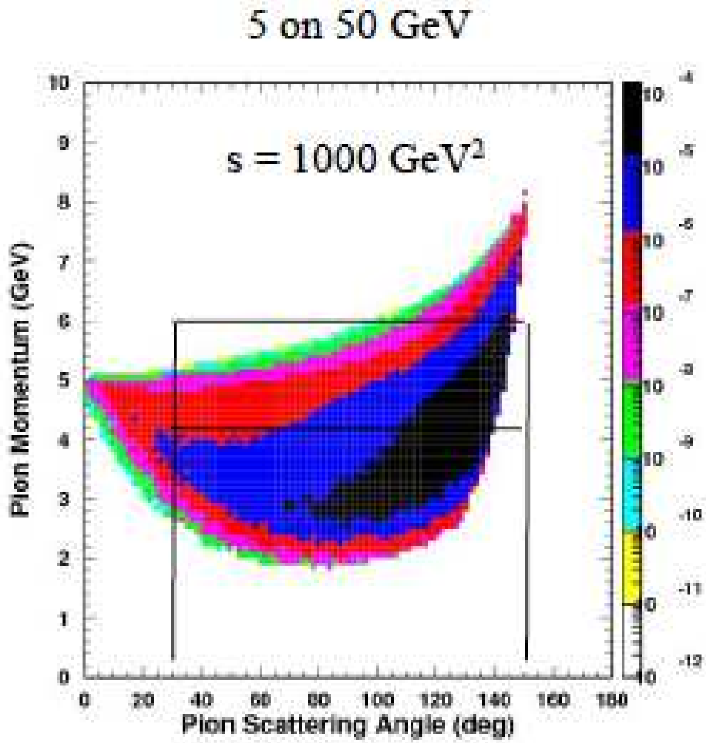



- **Highly polarized electron collide with highly polarized nuclei (proton, deuteron, 3He ,etc)**
- **Detect scattered electron and pion at full angle and full momentum range**

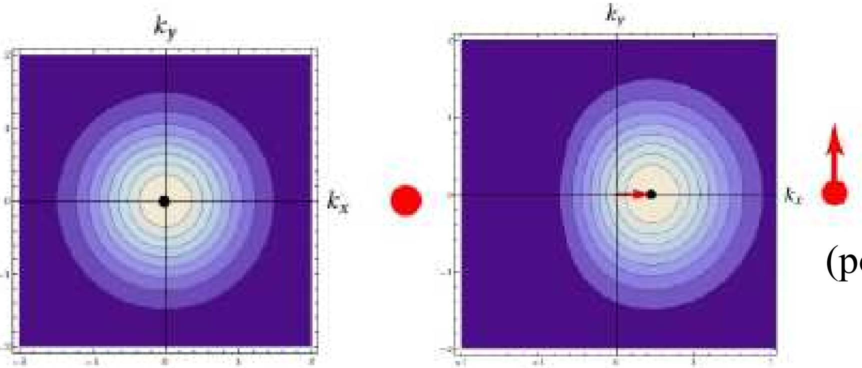
# PID 3D structure of the proton



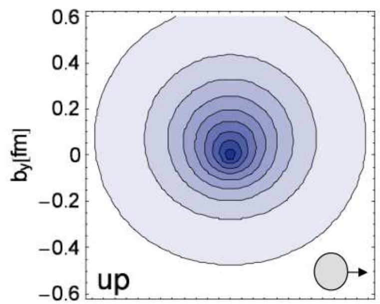

Semi-Inclusive DIS – mapping of transverse momentum distributions of (sea) quarks




Exclusive meson production – mapping of transverse spatial distribution of light and strange quarks



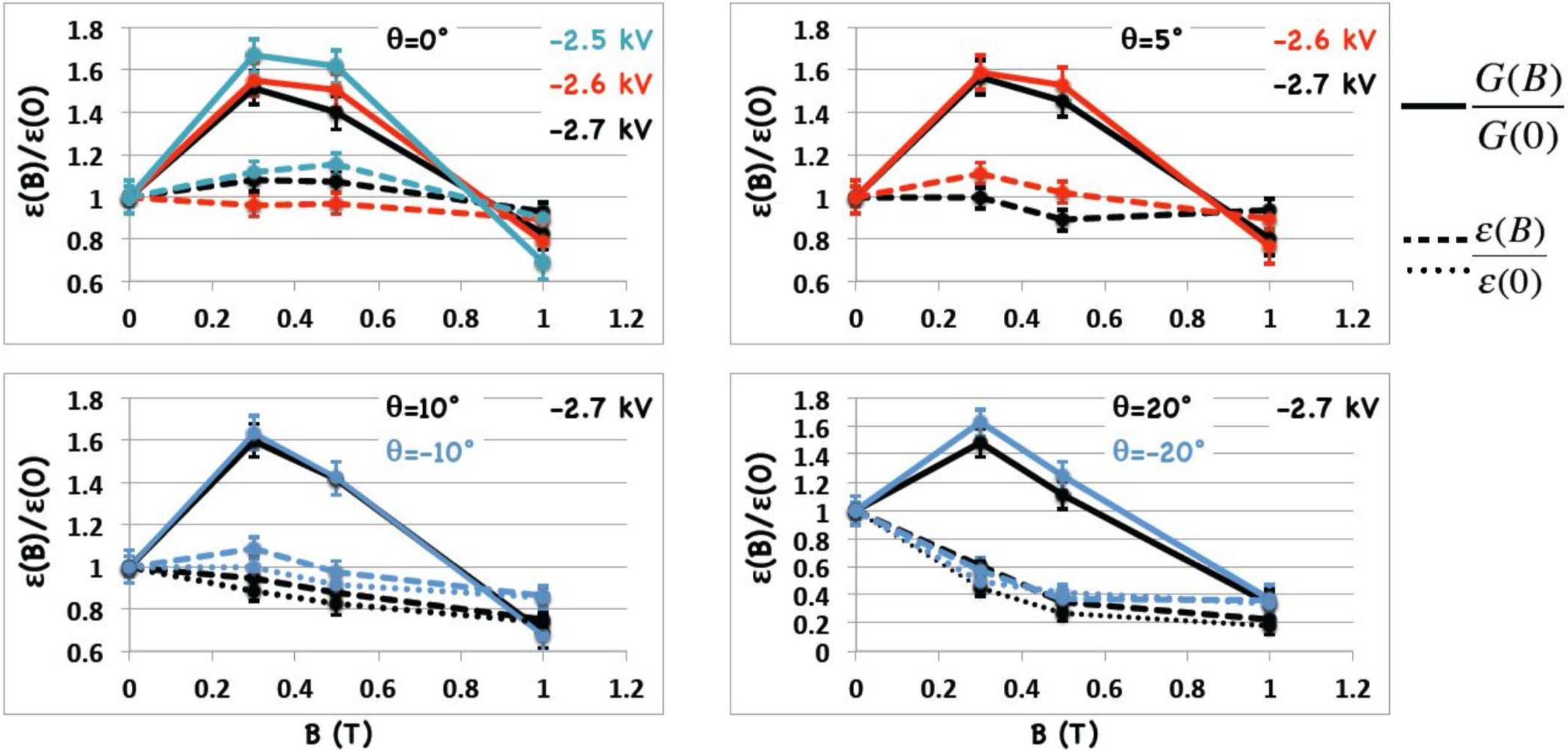

(polarized)



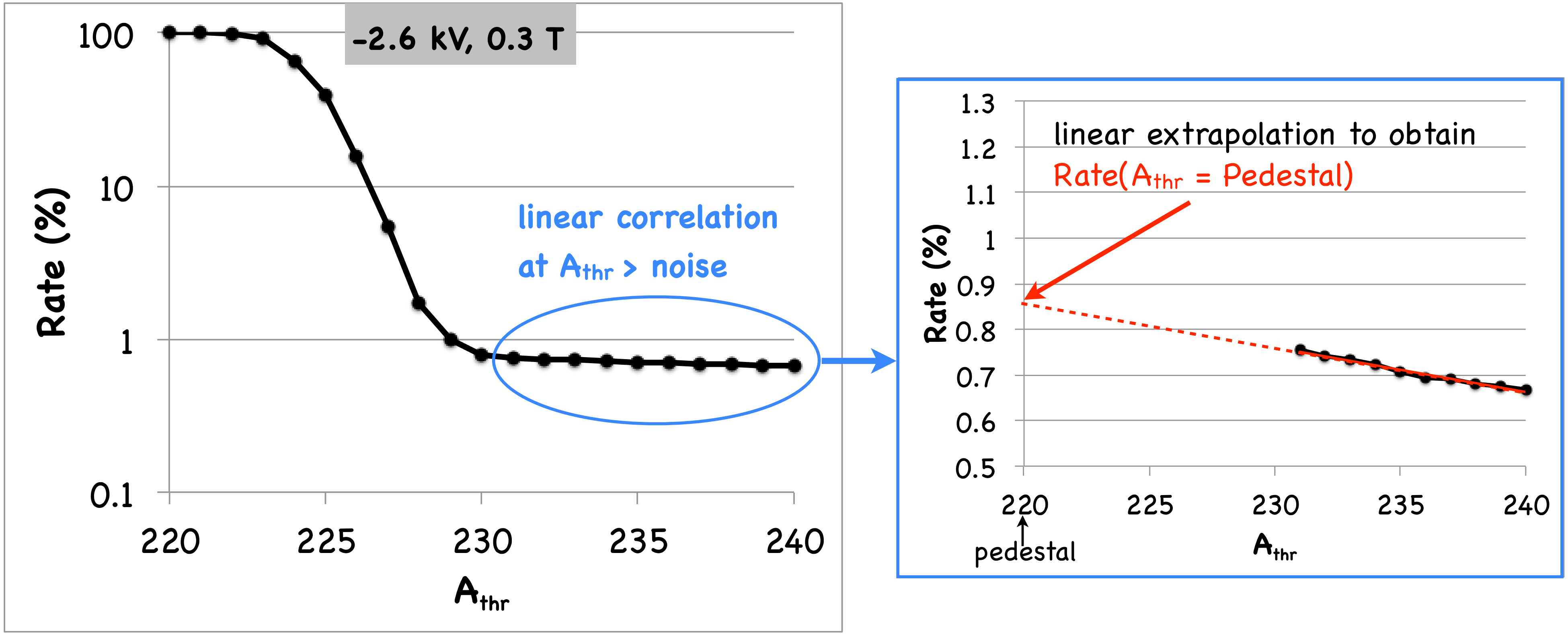

(polarized)

# Efficiency

**Relative gain (solid lines) and relative efficiency (dashed and dotted lines)**



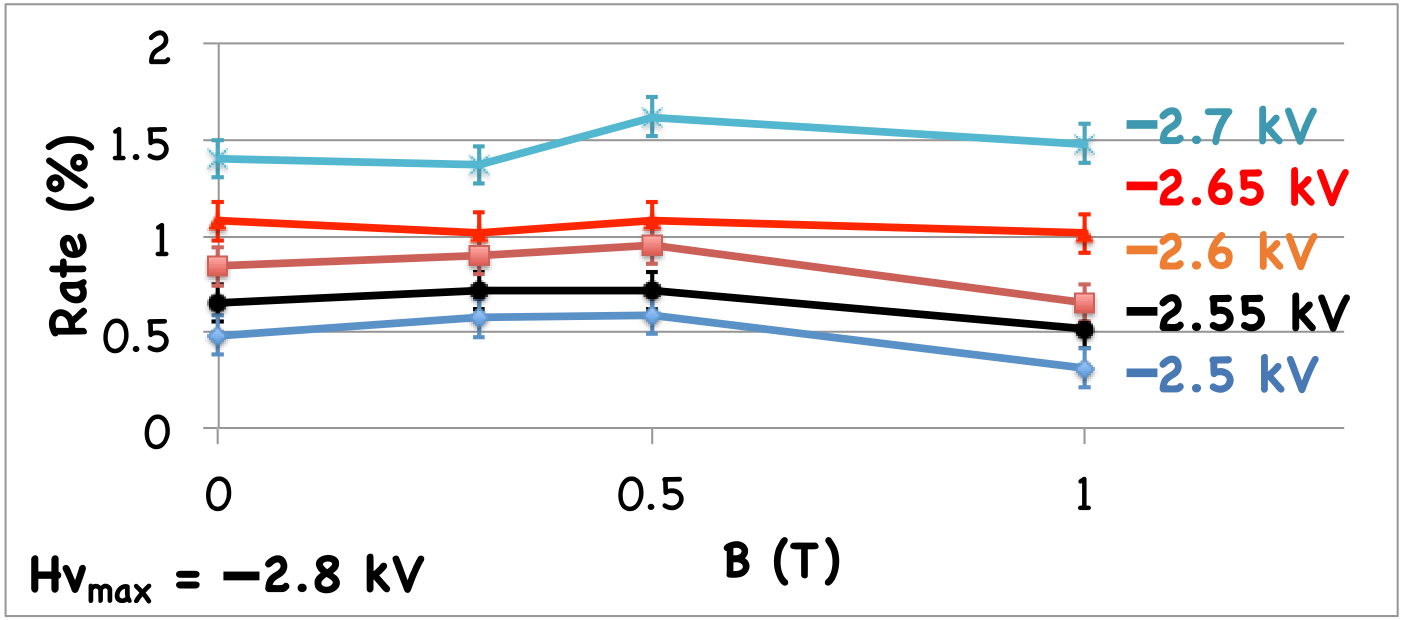
# 10-µm Planacon Ion Feedback

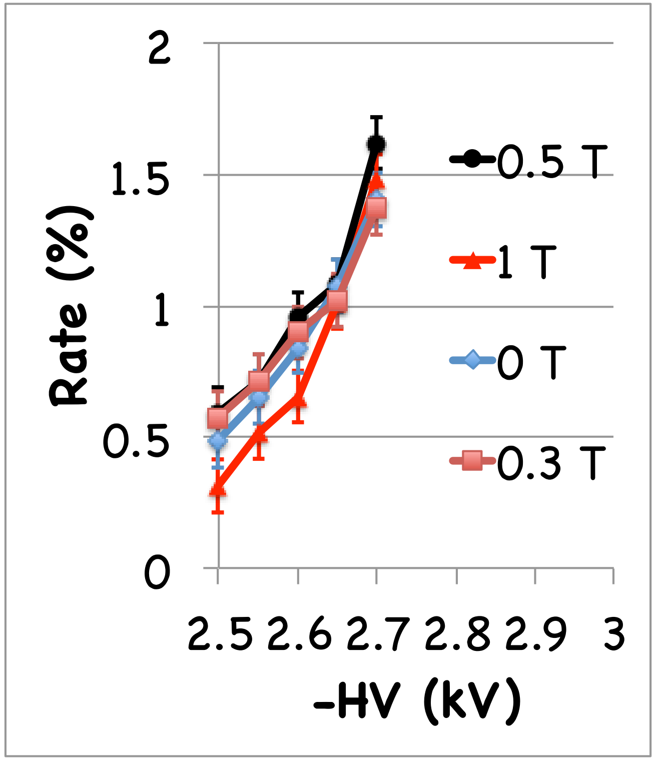



- *Rate* is evaluated over a range of $A_{thr.}$ *Rate*($A_{thr}$=Pedestal) is obtained from a linear fit to the high-$A_{thr}$ tail. This is the best estimate of the true ion rate, i.e. as would be obtained if there were no noise on the waveform, but only signal(s).

# 10-µm Planacon Ion Feedback

**Estimates of backscattering rate (normalized to number of signals)**



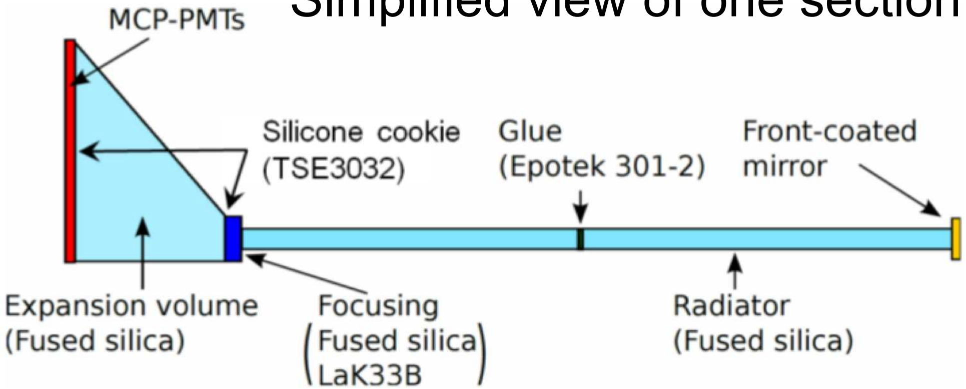




- $A_{thr}$- Theshold amplitude, above it signals are counted
- At all voltages the ion rate is below 2%.
- Results suggest that ion-feedback is primarily driven by HV.
- Ion-feedback rate dependence on B-field magnitude is relatively weak.
- Method established; ion rate can be monitored in experiments using calibration data.

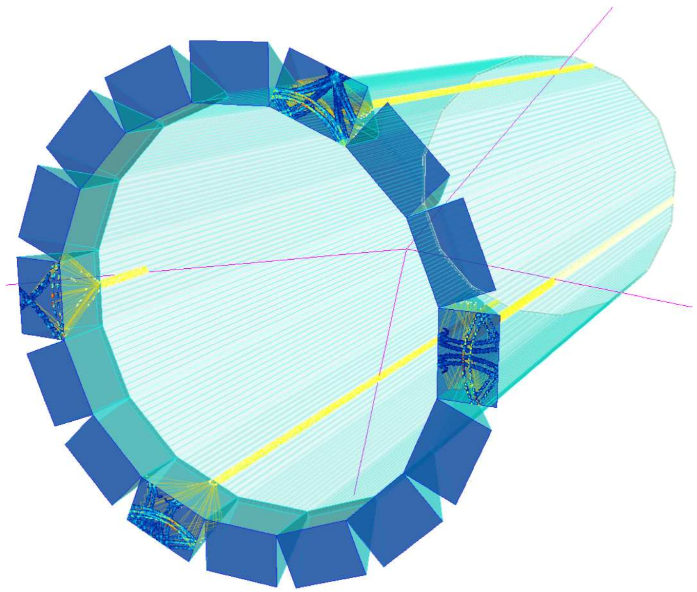
# hpDIRC Design Decisions

- 16 section design with one prism in each as expansion volume
- Prism size has to be optimized to final detector design
- Major decision between radiator has to made

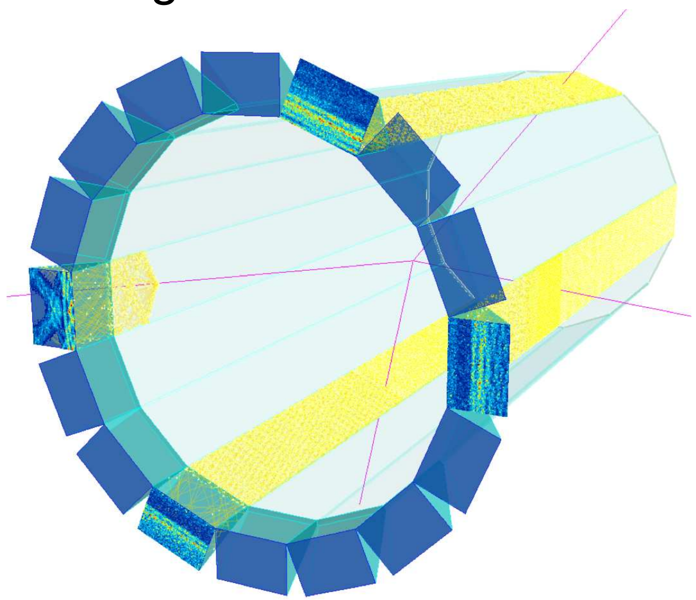
Simplified view of one section:




GEANT4 visualization of the designs:

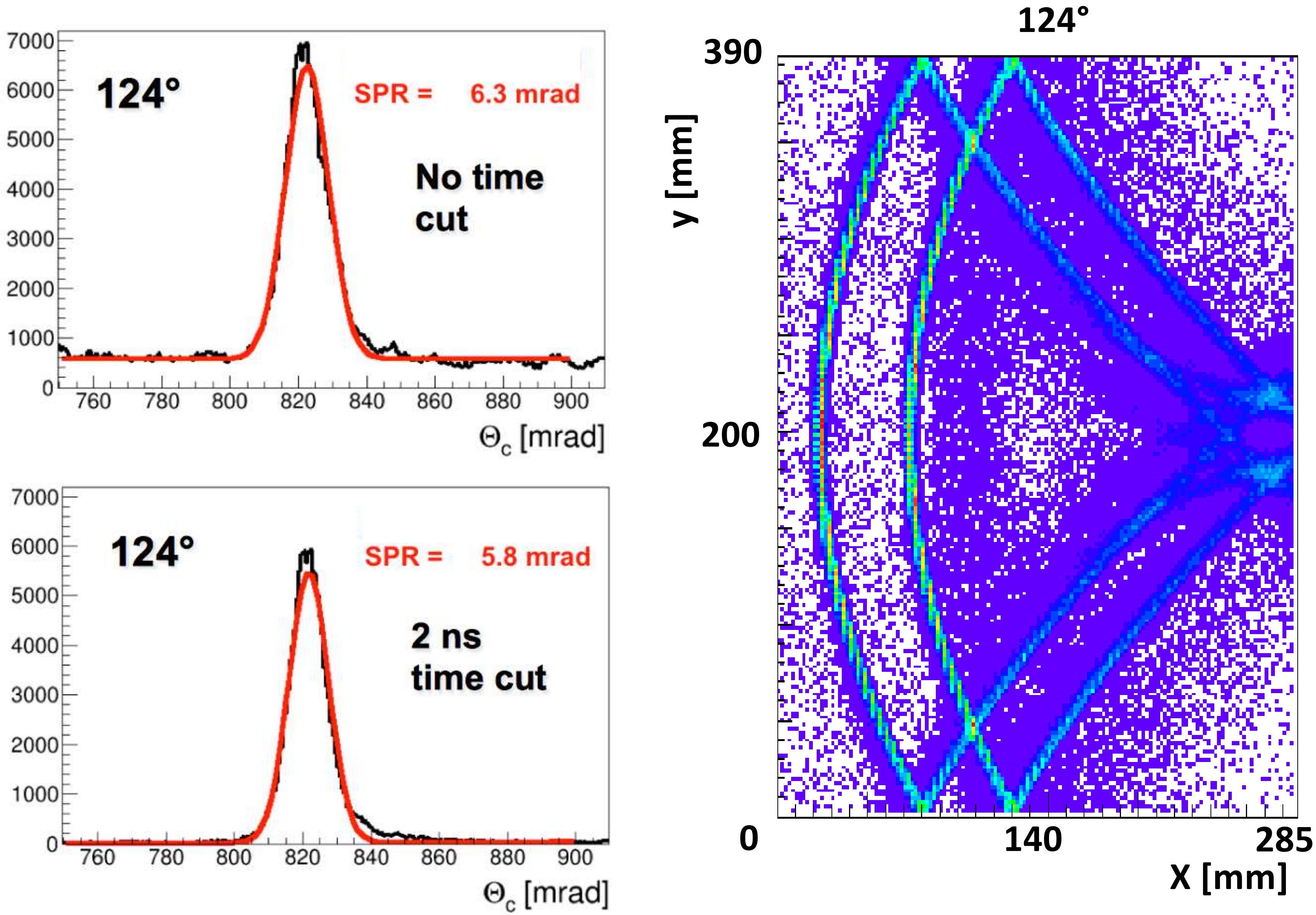


11 narrow bars in each section



1 wide bar (plate) in each section

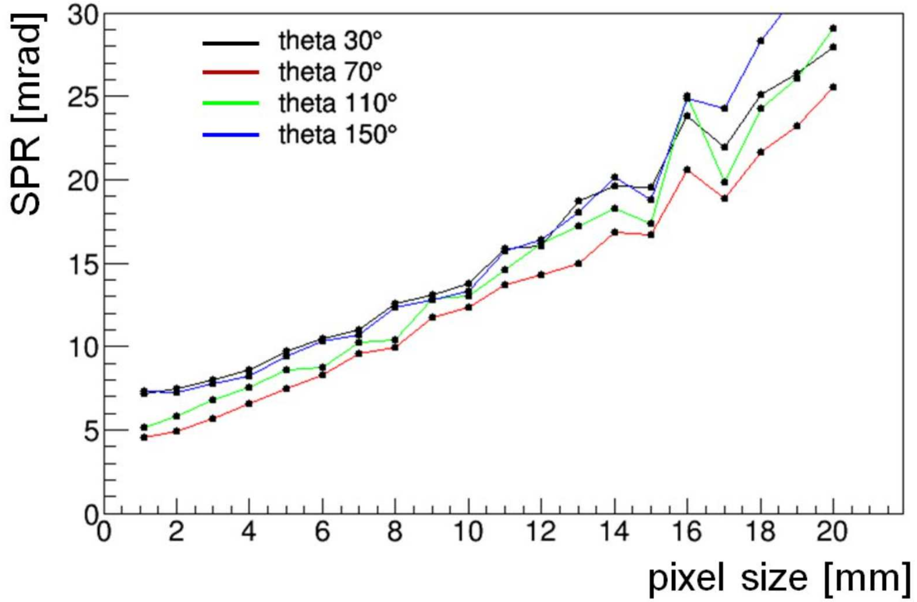
# hpDIRC Single Photon Resolution (SPR)

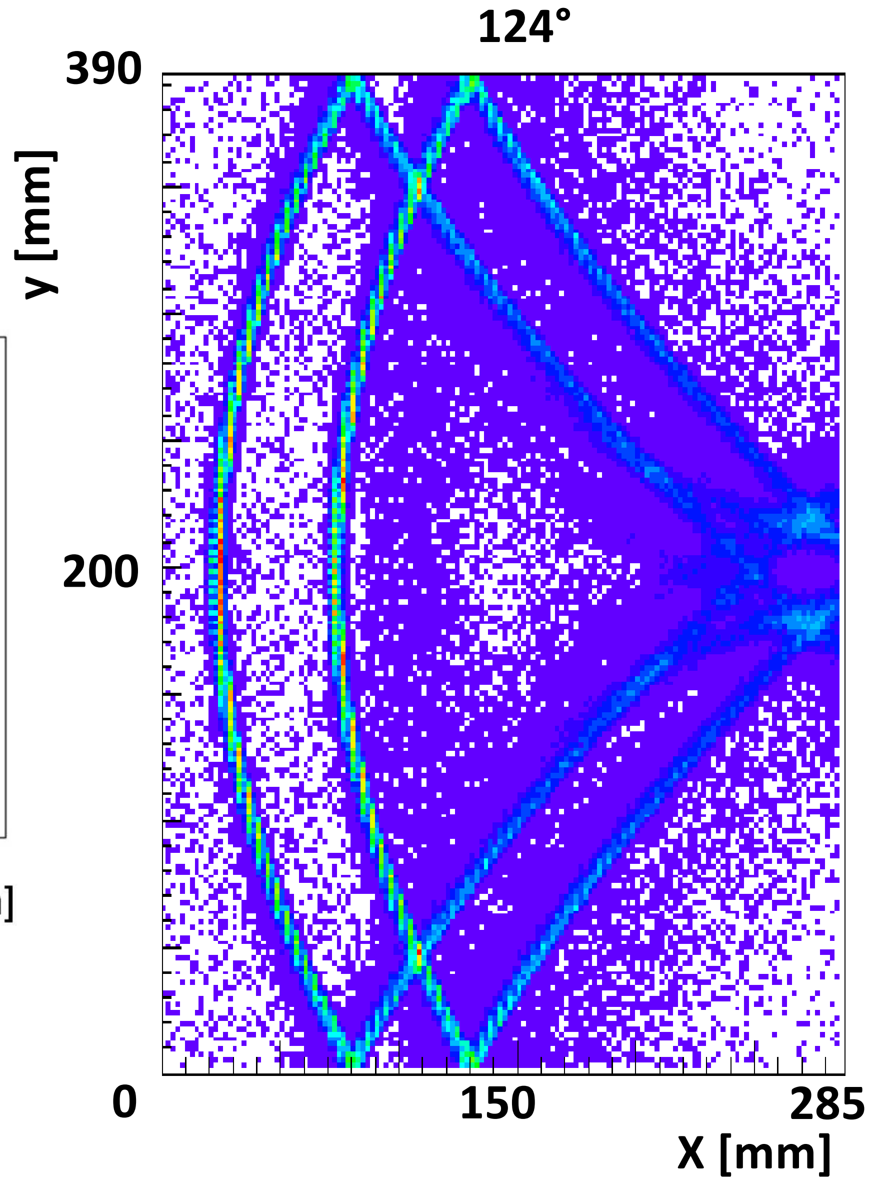



Simulated data

# hpDIRC Single Photon Resolution (SPR)

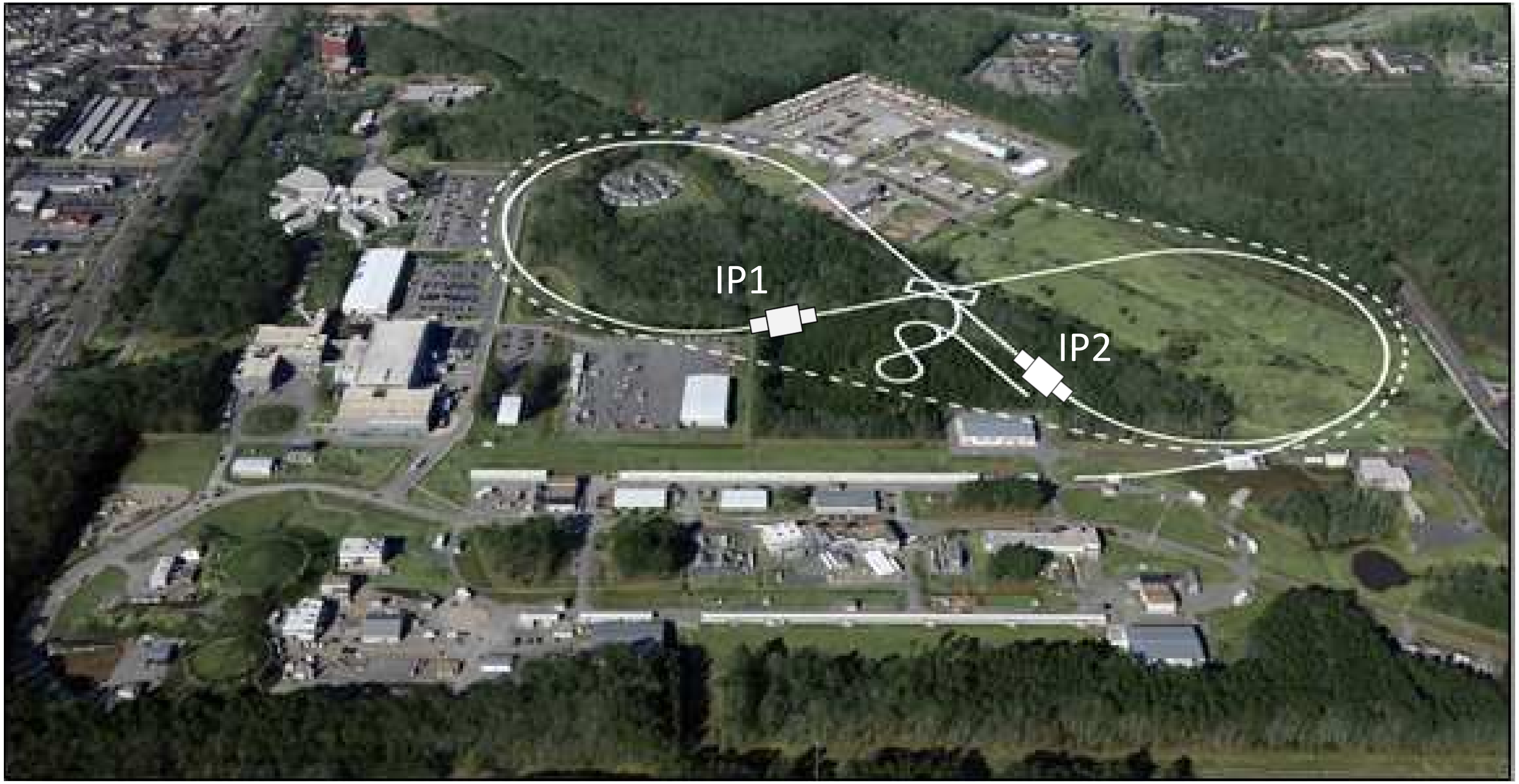
Influence of the pixel size on SPR for selected track polar angles (theta)




Simulated data

# EIC@Jlab Siteplan



# JLEIC Performance goals

## Energy

$\sqrt{s}$ from **15** to **65** GeV

Electrons **3-10** GeV, protons **20-100** GeV, ions **12-40** GeV/u

## Ion species

Polarized light ions: **p**, **d**, **$^{3}$He**, and possibly **Li**

Un-polarized light to heavy ions up to A above 200 (Au, Pb)

## Space for at least 2 detectors

Full acceptance is critical for the primary detector

High luminosity for the second detector

## Luminosity

**$10^{33}$ to $10^{34}$cm$^{-2}$s$^{-1}$ per IP** in a *broad* CM energy range

## Polarization

At IP: longitudinal for both beams, transverse for ions only

**All polarizations >70%**

## Upgrade to higher energies and luminosity possible

**20 GeV** electron, **250 GeV** proton, and **100 GeV/u** ion

**Design goals consistent with the White Paper requirements**

# High B field tests Gain measurements of photosensors

**Measurement in 2015 of Photek sensor with special voltage divider:**

- Independently change the voltages cathode-MCP, across MCPs, and MCP-anode and study gain dependence
- Confirmed that voltage across the MCPs affects the gain the most
- Data at other angles are under analysis