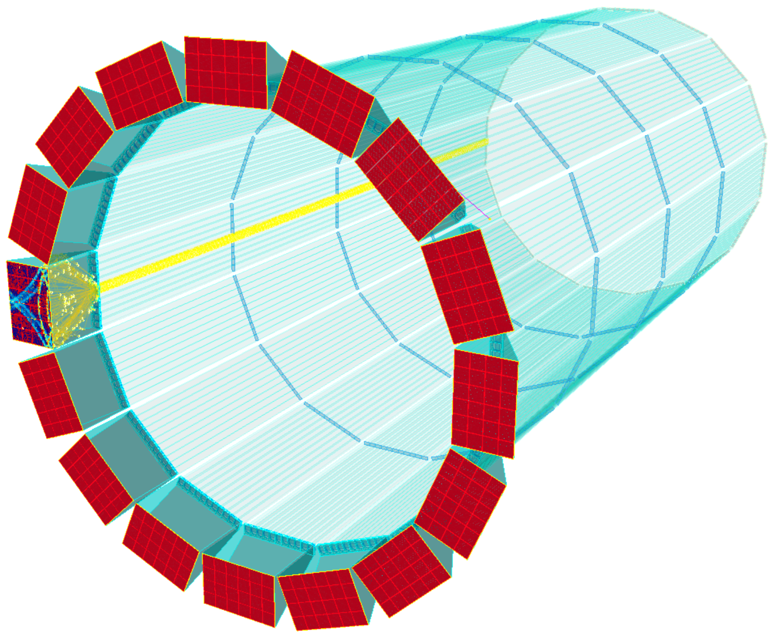
High-Performance DIRC for EIC

Greg Kalicy

Outline:

- **Design and Simulation studies**
- **Developing and evaluating 3-layer lens**
- **hpDIRC prototype program**

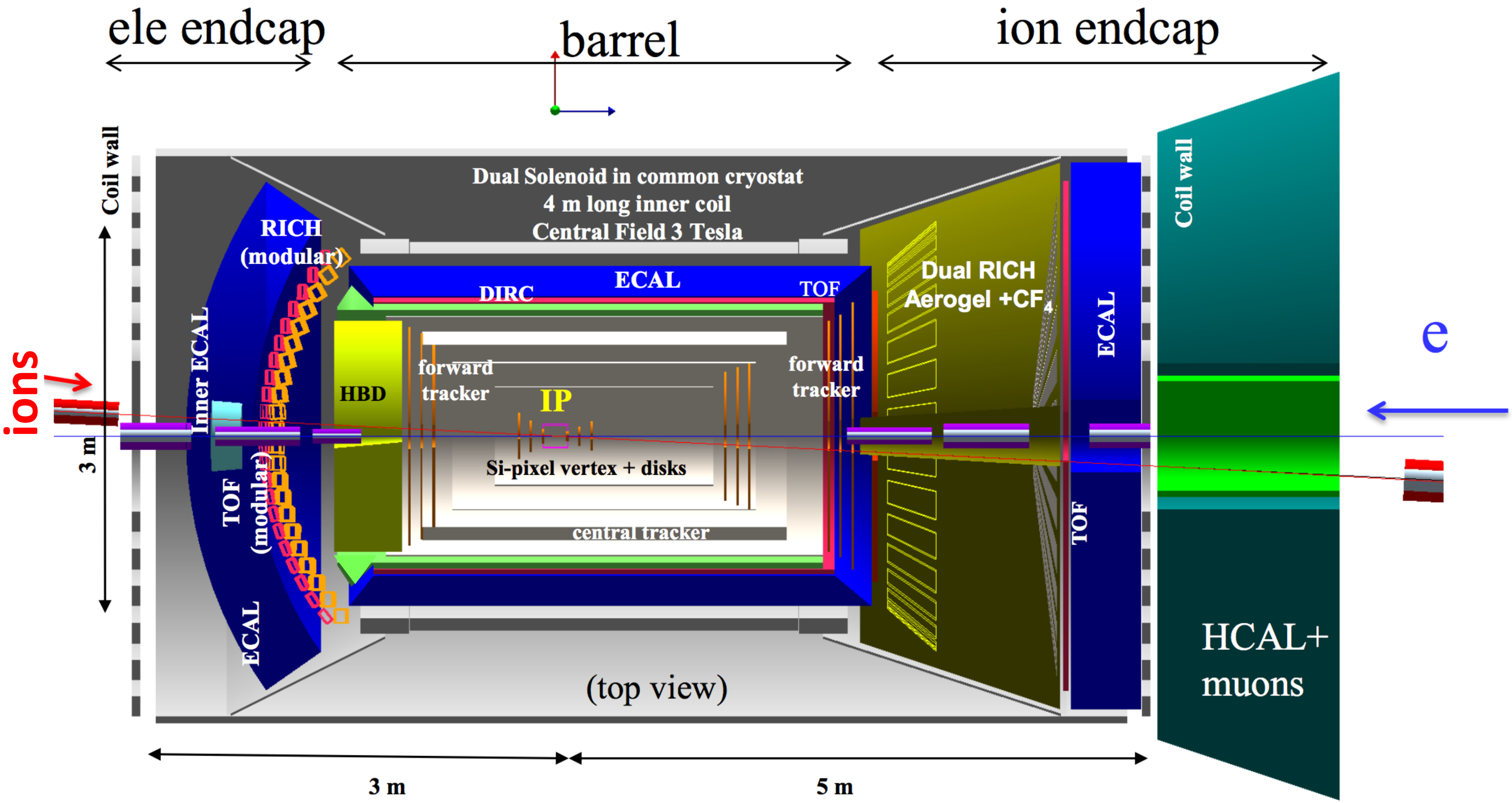


CUA

July 10th, 2019

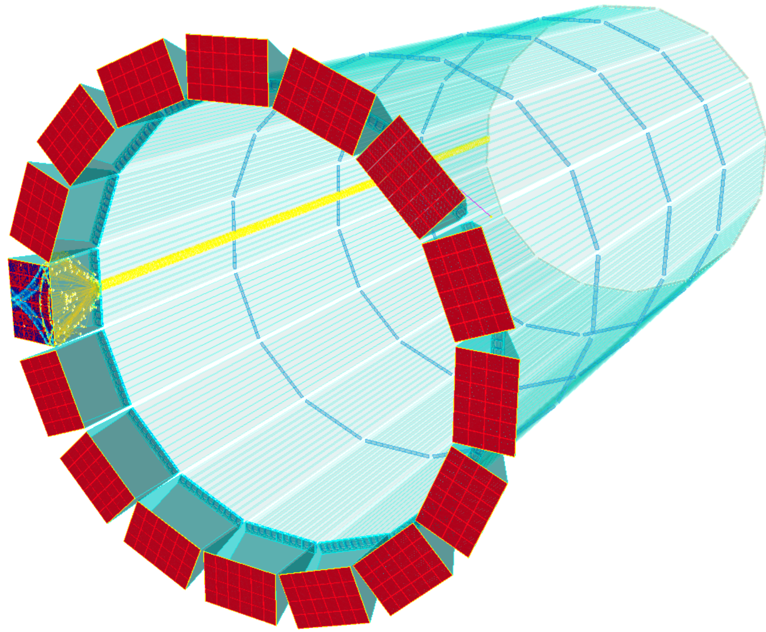
Jefferson Lab

hpDIRC


ele endcap
barrel
ion endcap
Coil wall
Dual Solenoid in common cryostat
4 m long inner coil
Central Field 3 Tesla
RICH
(modular)
ECAL
DIRC
TOF
Dual RICH
Aerogel +CF4
ECAL
Coil wall
e
ions
Inner ECAL
HBD
forward
tracker
IP
forward
tracker
Si-pixel vertex + disks
central tracker
TOF
(modular)
ECAL
TOF
HCAL+
muons
(top view)
3 m
3 m
5 m

hpDIRC

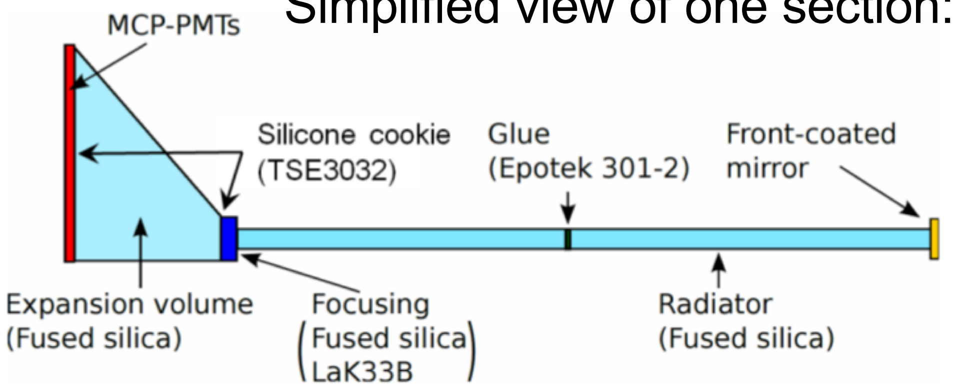
Geant4 simulation of High-Performance DIRC detector



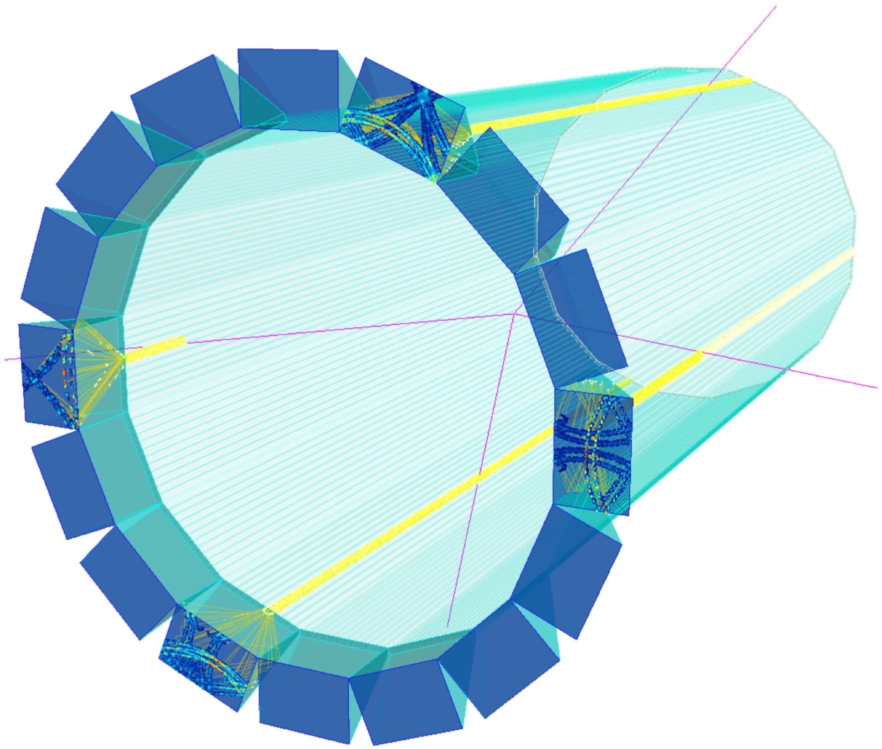
hpDIRC Design

16 section design with one prism in each as expansion volume

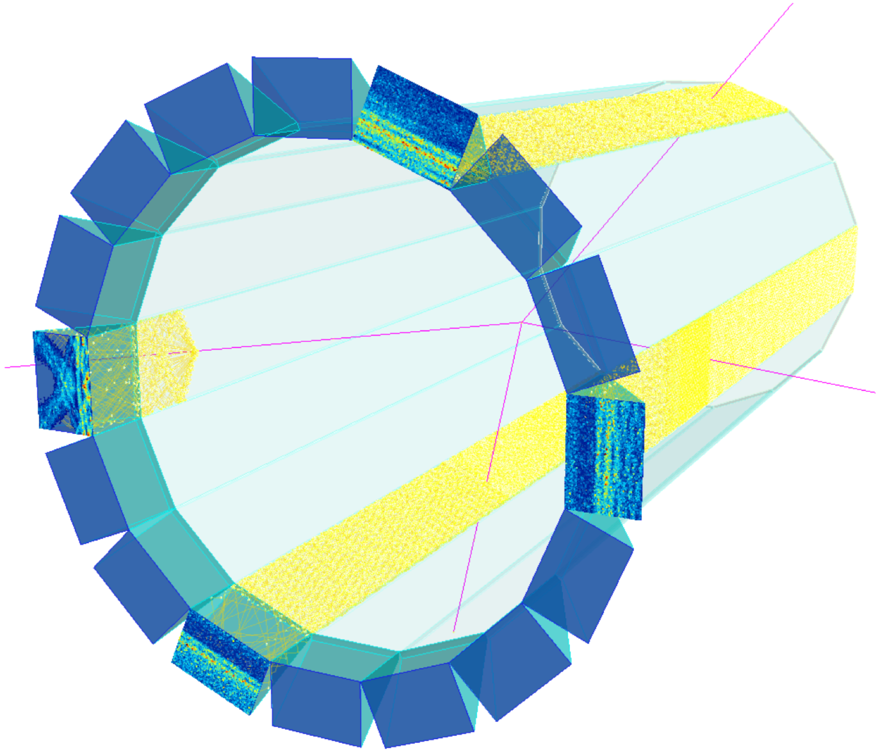
Simplified view of one section:



GEANT4 visualization of the designs:



11 narrow bars in each section

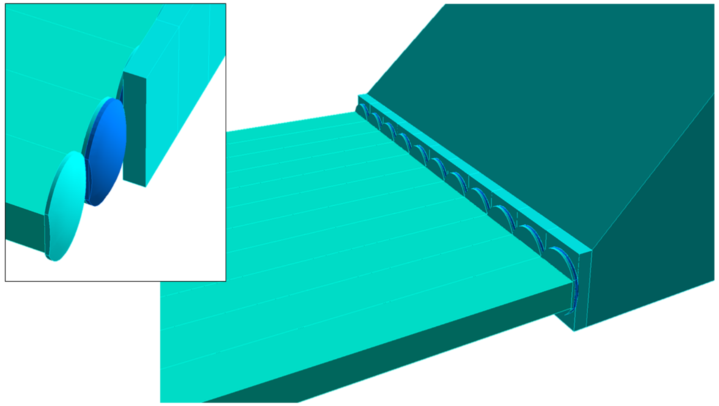


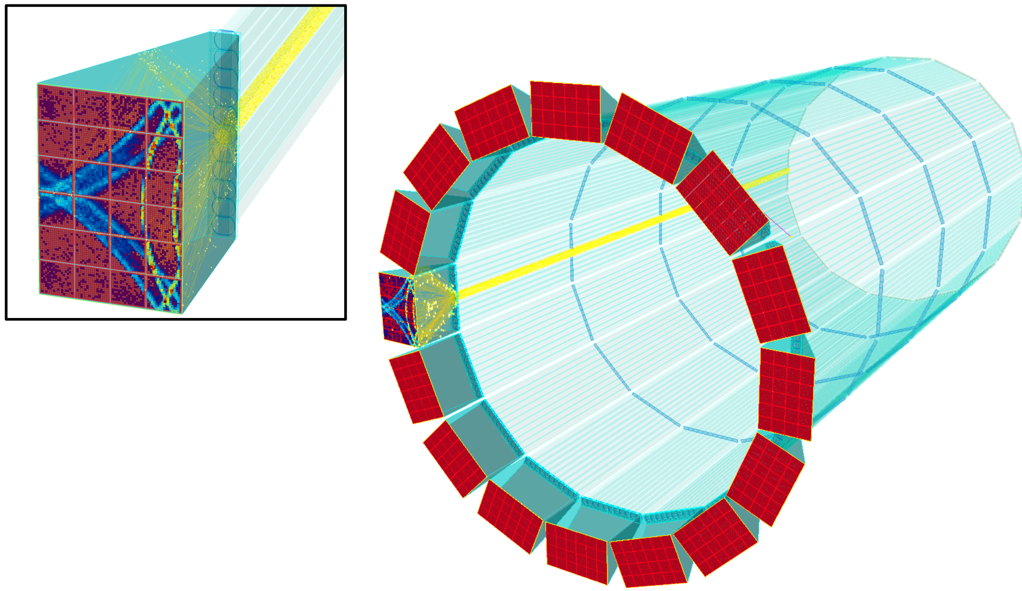
1 wide bar (plate) in each section

hpDIRC Narrow bar design

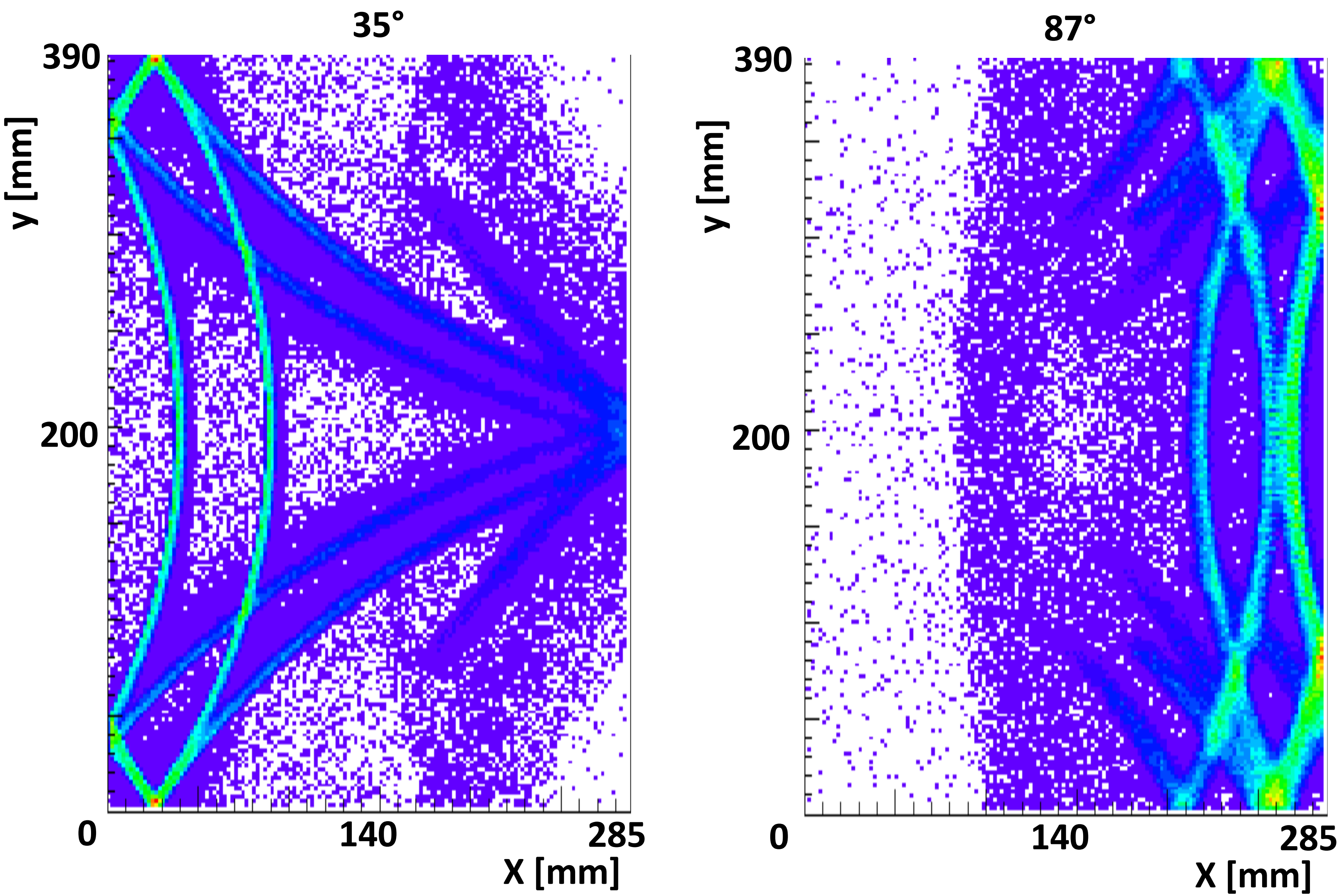
- **Radiator bars**
  - 17 x 35 x 4200 mm
  - 11 bars per box
  - 16 bar boxes, 1m from IP
- **3 component lens**
  - 14 x 35 x 50 mm
  - radiuses: 47 mm, 29 mm
- **Expansion volume**
  - Prism with 38° opening angle
  - 285 x 390 x 300 mm
- **Sensors**
  - Pixelated (3 mm^2)

Geant4 simulation of High-Performance DIRC detector



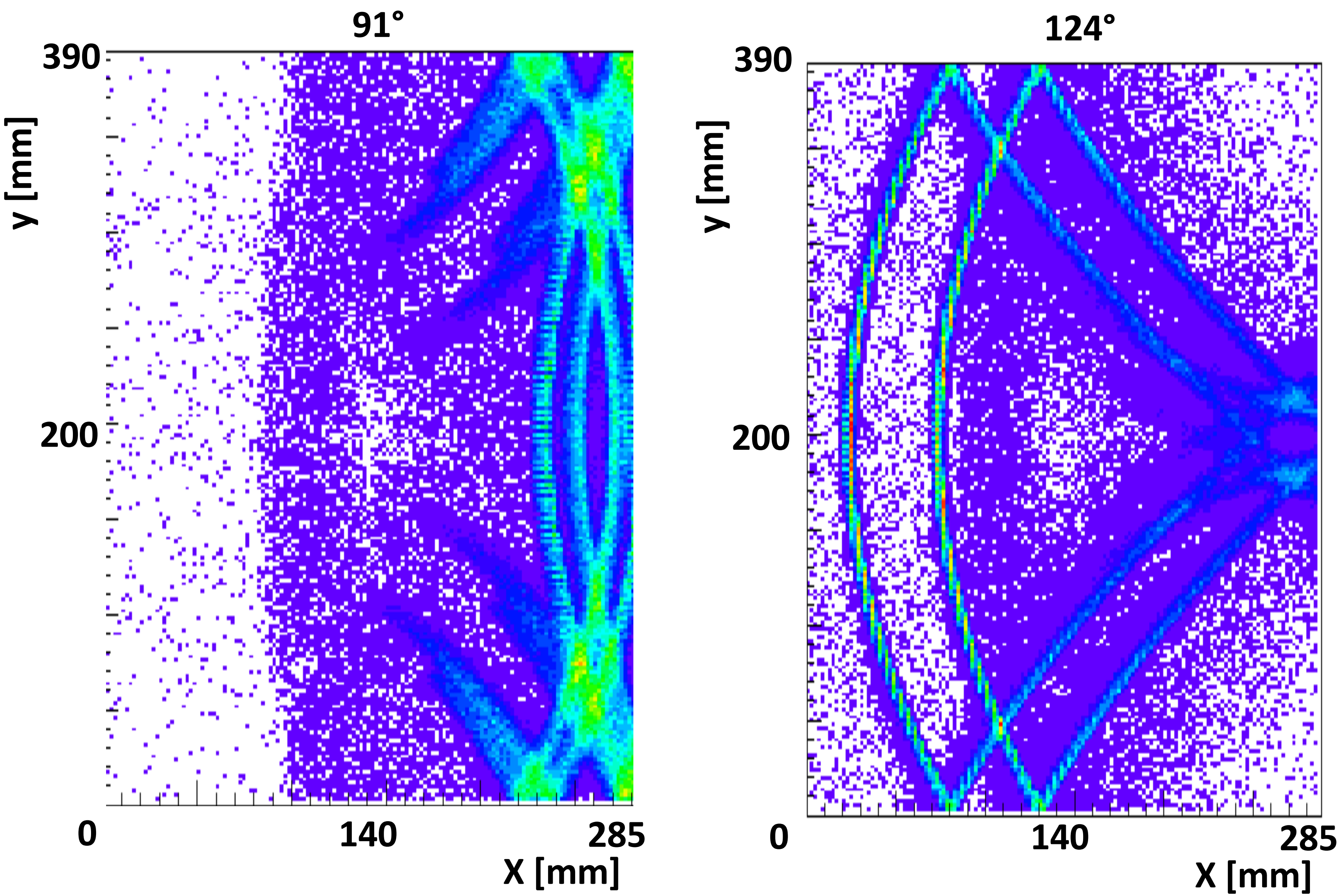


hpDIRC Hit Patterns



Simulated data

hpDIRC Hit Patterns

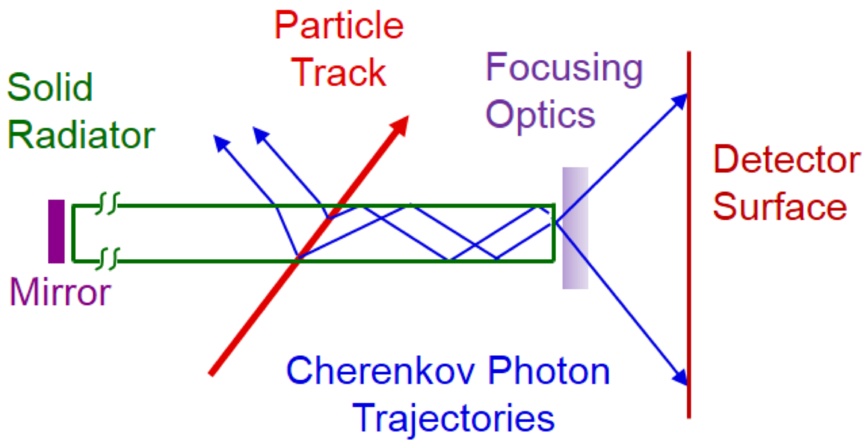


Simulated data

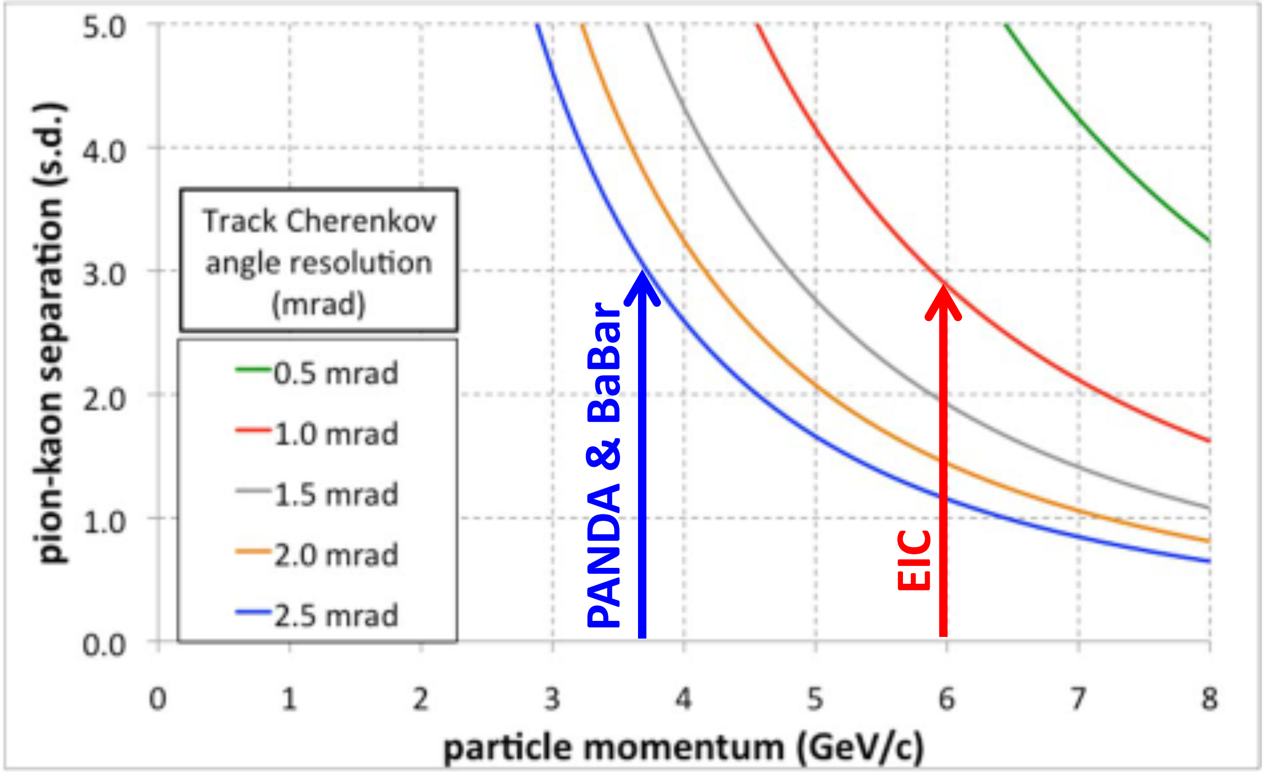
hpDIRC Performance goal

DIRC@EIC PID capability using geometrical reconstruction:

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



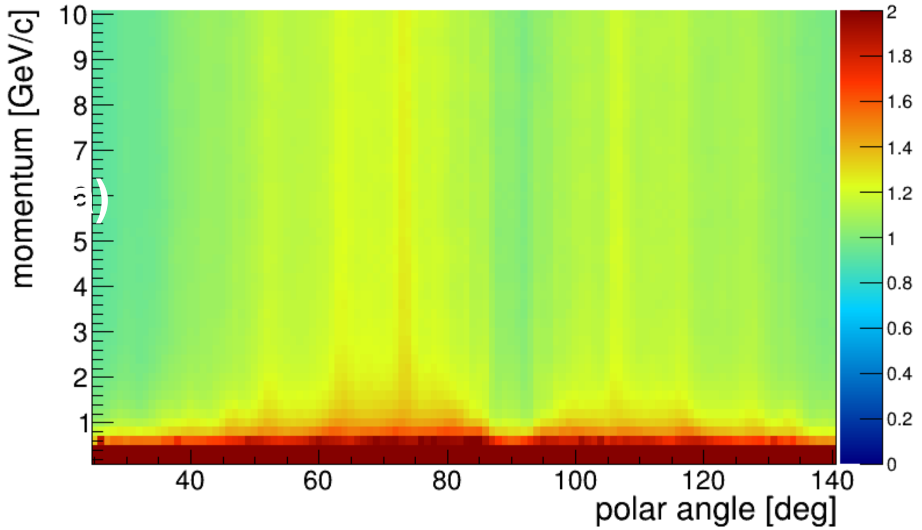
π/K identification as a function of the θ_c resolution



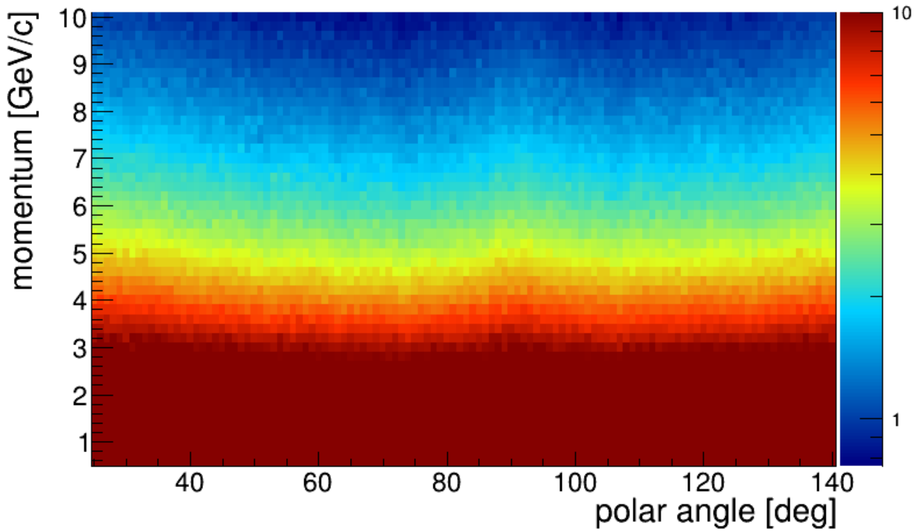
hpDIRC Parametrisation for fast simulation

- A special C++ class was designed and released to the EIC software community
- Geant4 simulation of the current hpDIRC baseline design used to calculate the Cherenkov track resolution (CTR)
- The fast simulation returns the deviation of the smeared Cherenkov angle from the expected values in units of CTR
- The derived *π/K* separation power in standard deviations is a result of the fast reconstruction

Geant4 simulated Cherenkov track resolution



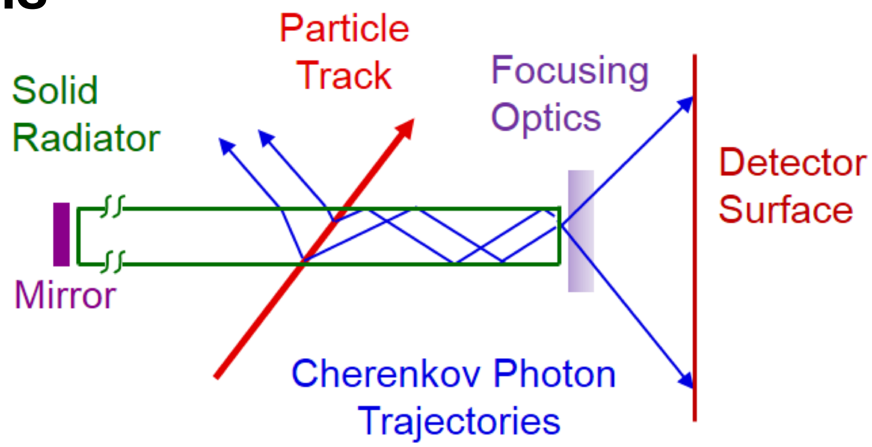
Derived *π/K* separation power (tracking resolution of 0.5 mrad)



hpDIRC Prototype 3-component lens

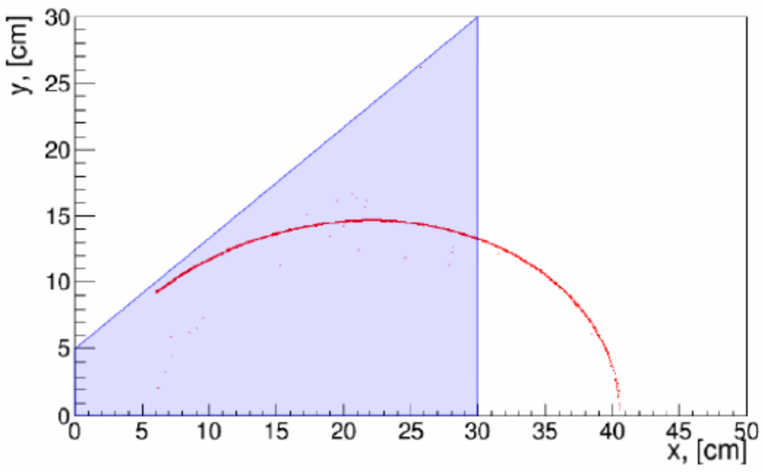
Limitations of standard focusing lenses:

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



Geant4 simulation of focal plane:

2 component lens



Simulated data

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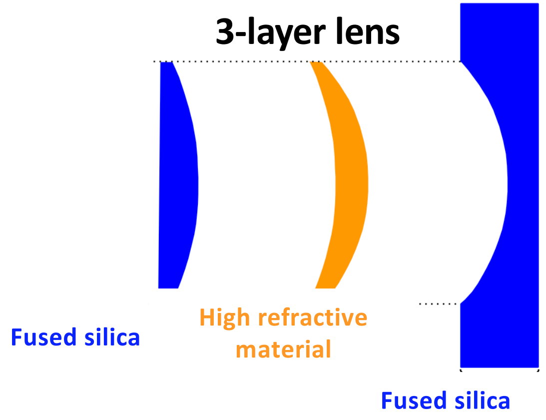
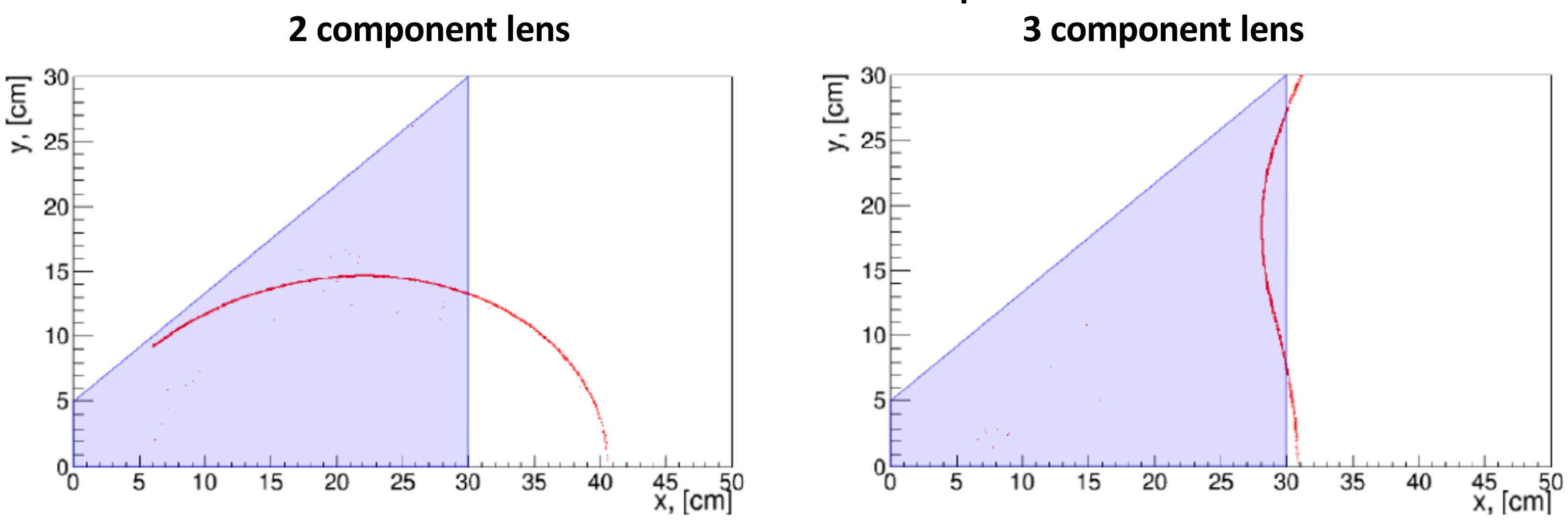


Geant4 simulation of focal plane:



Simulated data

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hpDIRC Prototype 3-component lens

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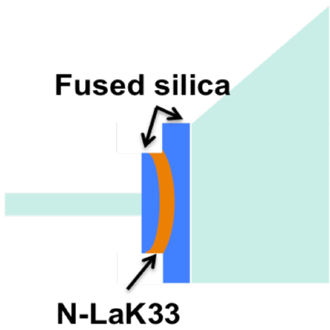
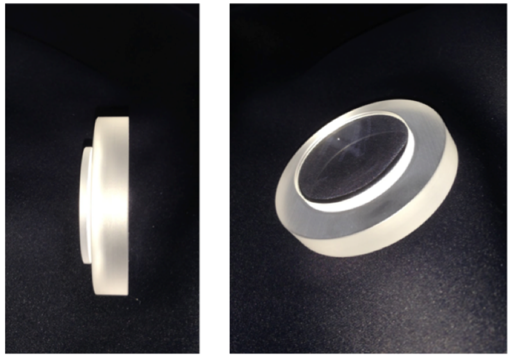
Spherical 3-layer lens prototype





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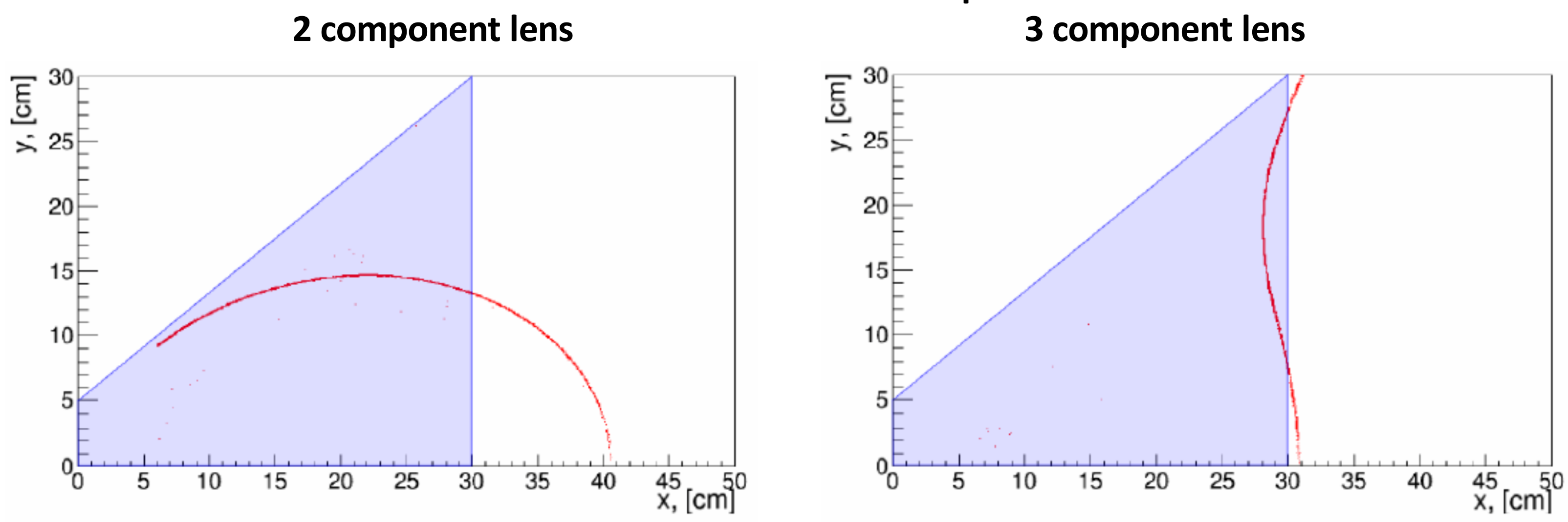

Simulated data

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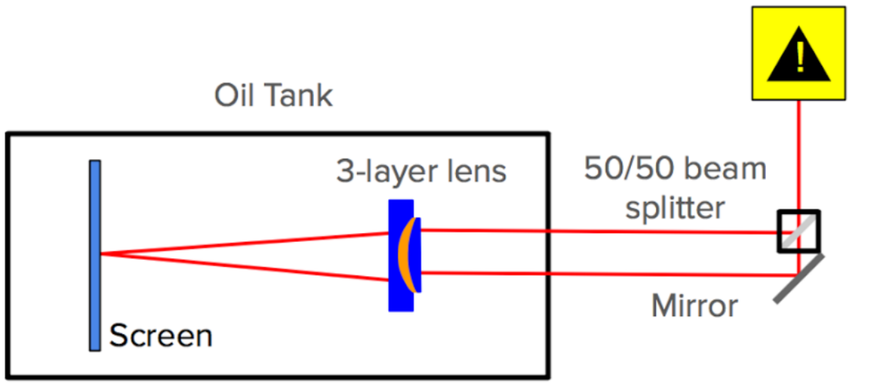
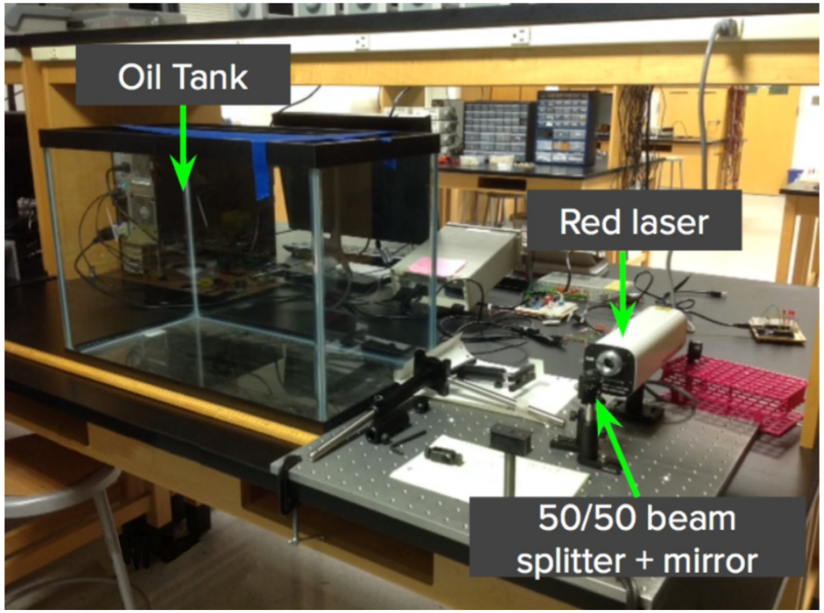
Mapping 3-layer Lens

Mapping focal plane of 3-layer lens:

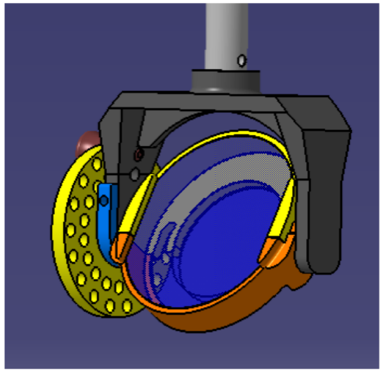
- Lens holder designed to rotate in two planes for the 3D mapping of the focal plane and shifts of lens in horizontal plane.

Laser setup to map the focal plane





3D lens holder



L. Allison, R. Dzhygadlo, T. Hartlove, G. Kalicy, C. Schwarz

Mapping 3-layer Lens

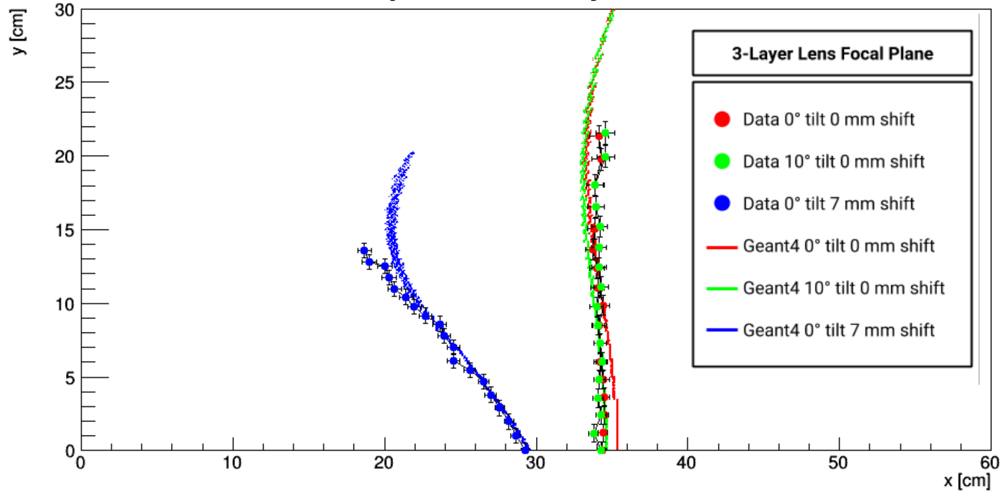
Mapping focal plane of 3-layer lens:

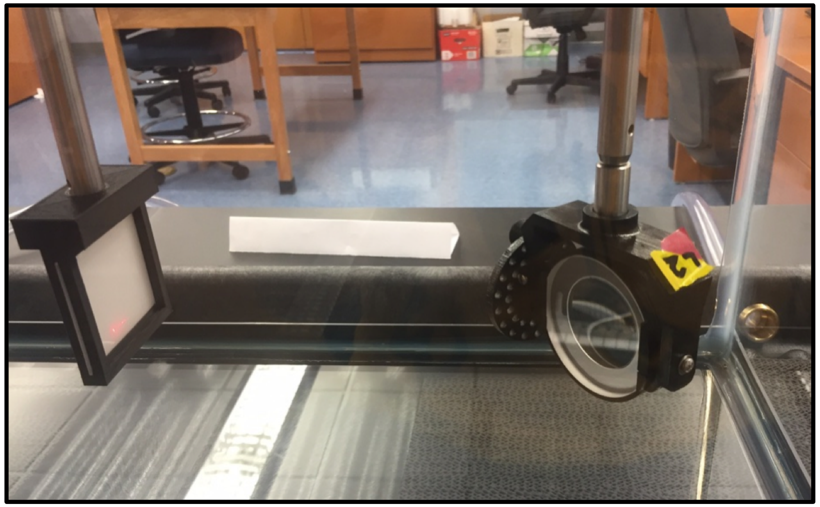
- Lens holder designed to rotate in two planes for the 3D mapping of the focal plane and shifts of lens in horizontal plane.

Spherical 3-layer lens:

- Results of measurements confirm desired flat focal plane for centered laser beams on the lens
- Off-center laser beams in agreement with simulation

Measured and simulated focal plane of spherical 3-layer lens





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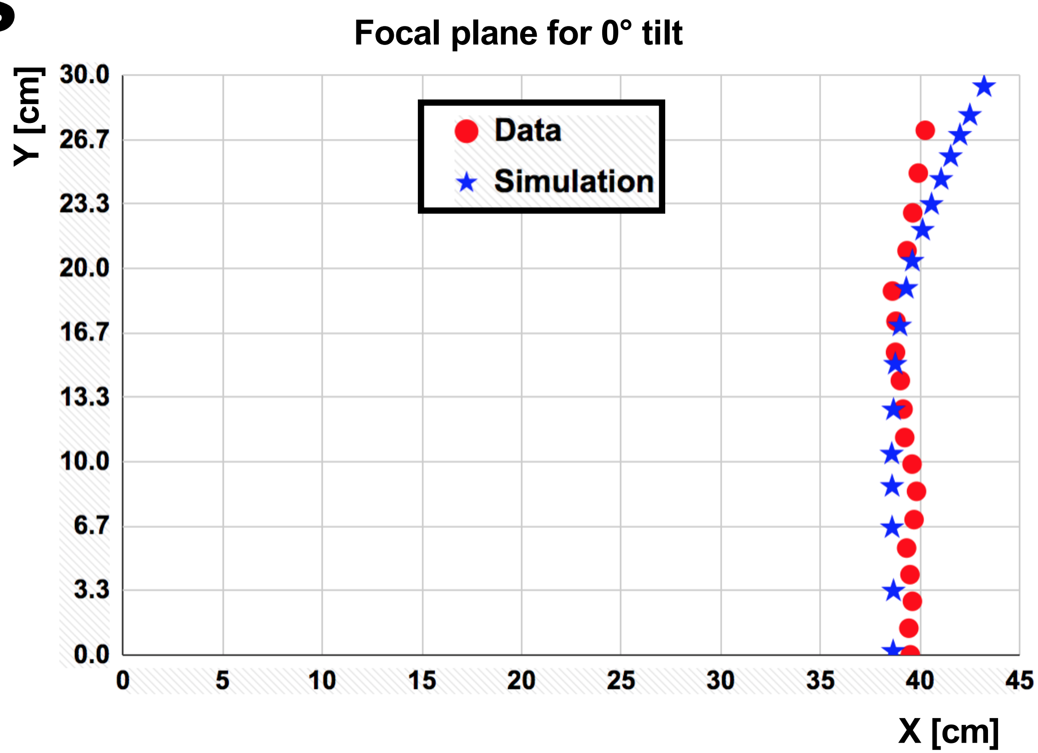
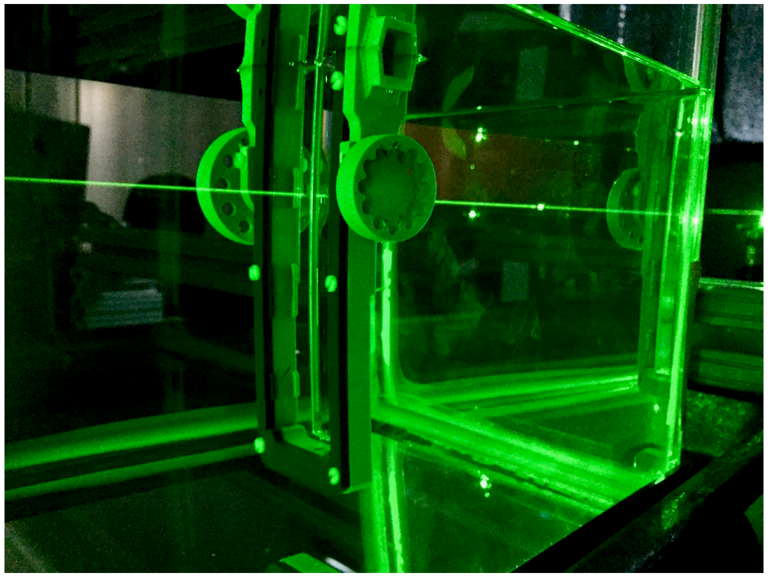
Mapping 3-layer Lens

Cylindrical 3-layer lens

- Very good agreement of measured data with simulation





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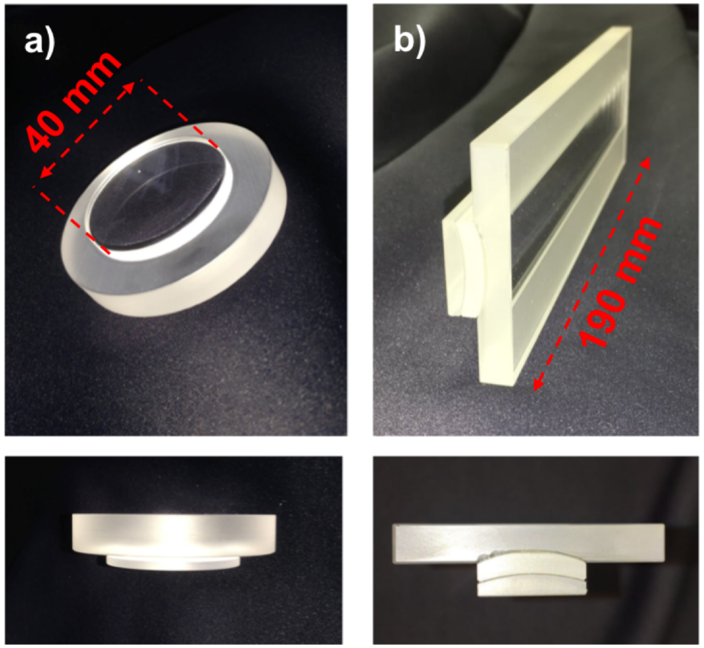

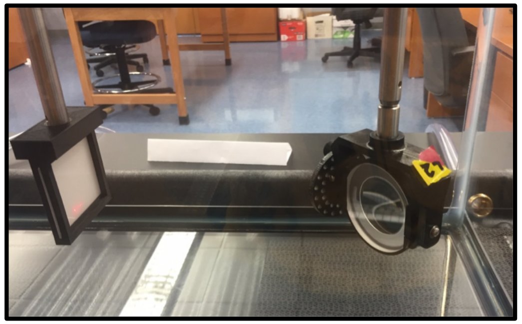

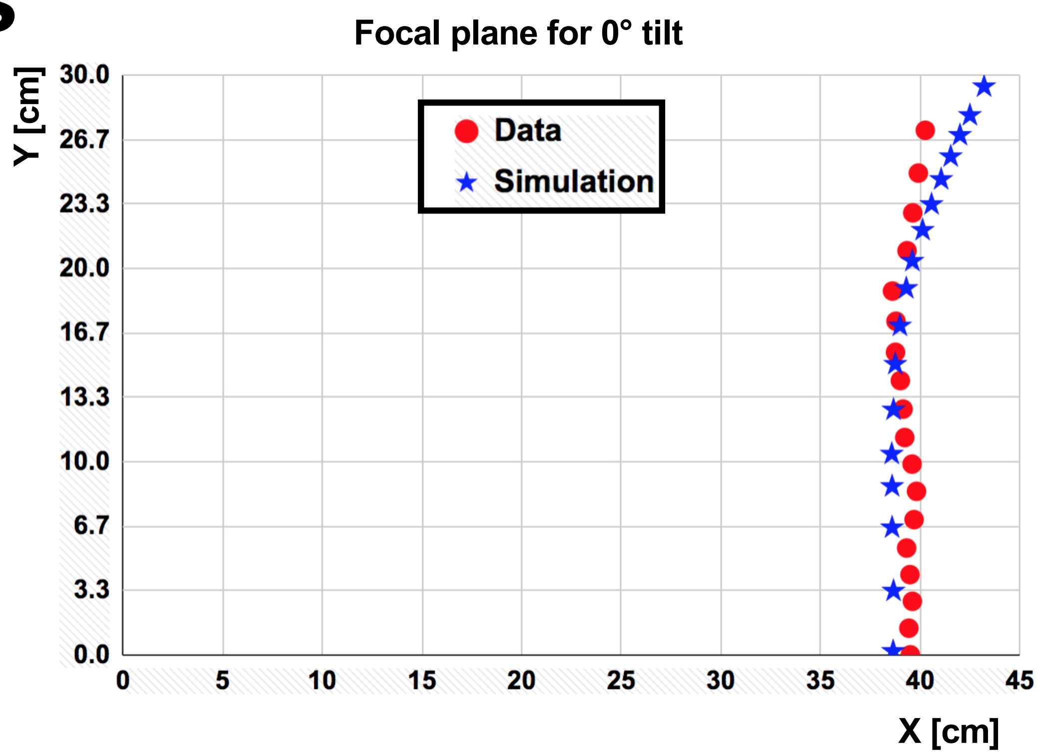

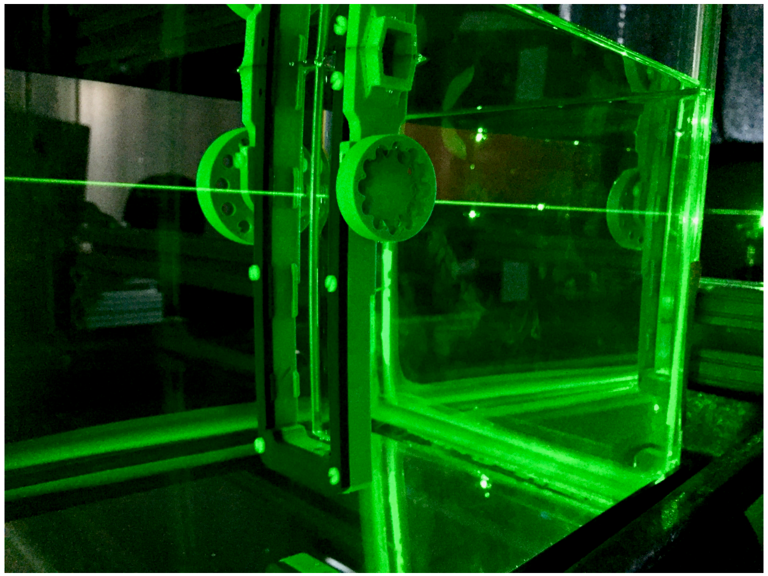

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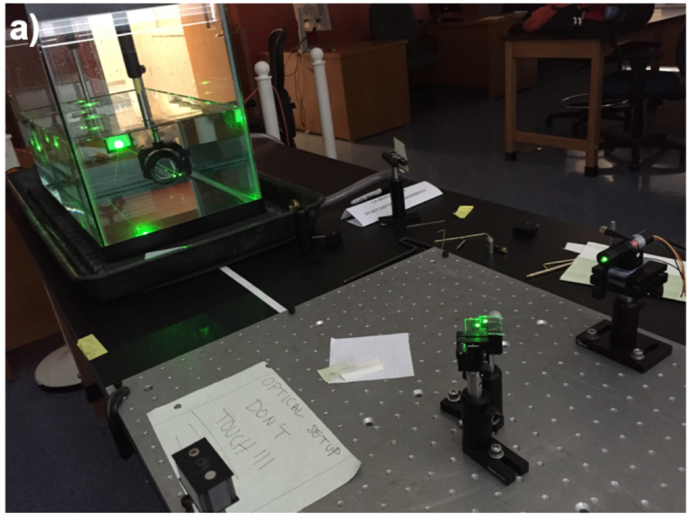
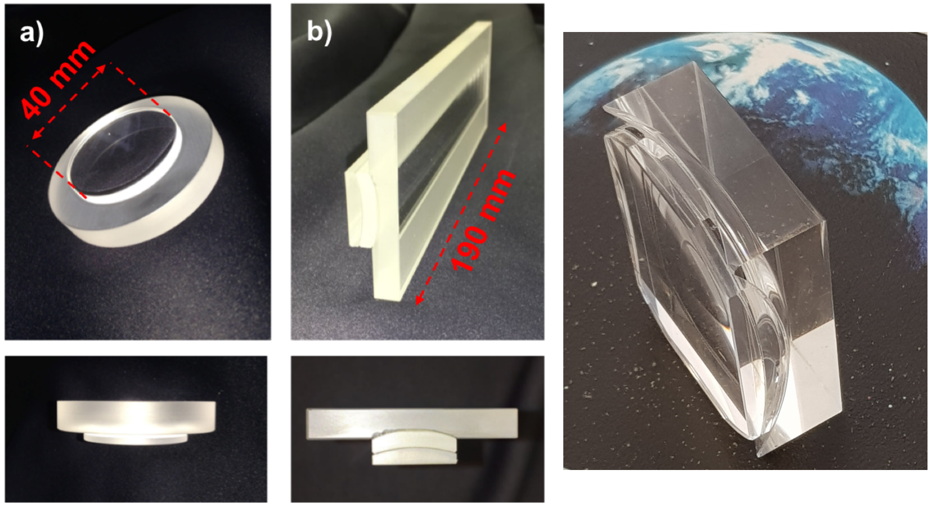
Mapping 3-layer Lens

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

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



Spherical and cylindrical 3-layer lens prototypes



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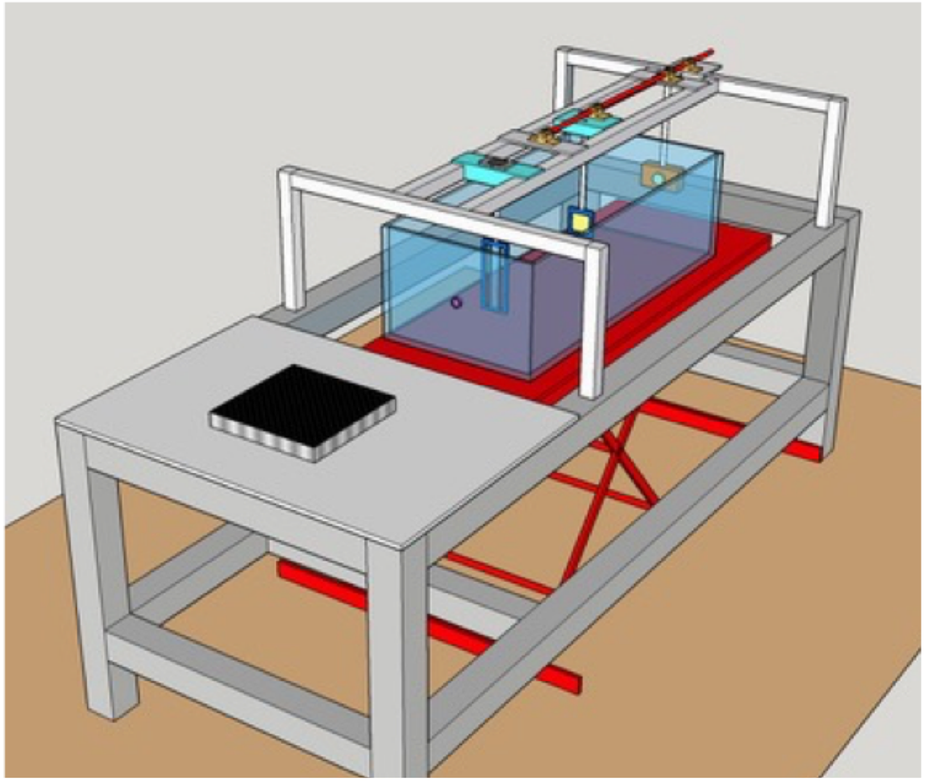
Mapping 3-layer Lens

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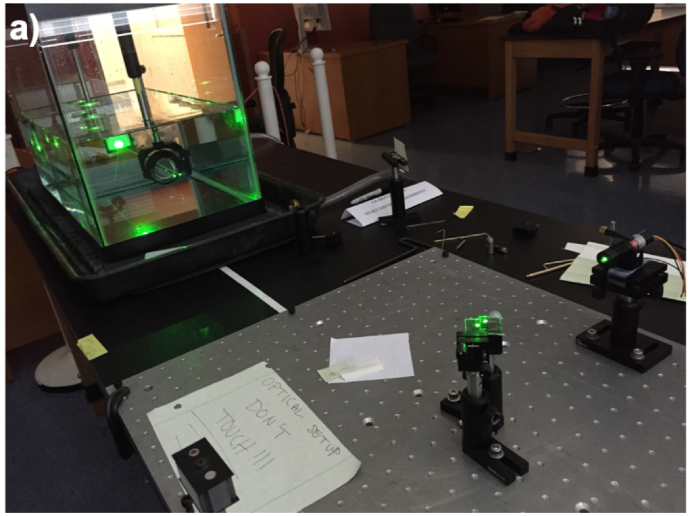

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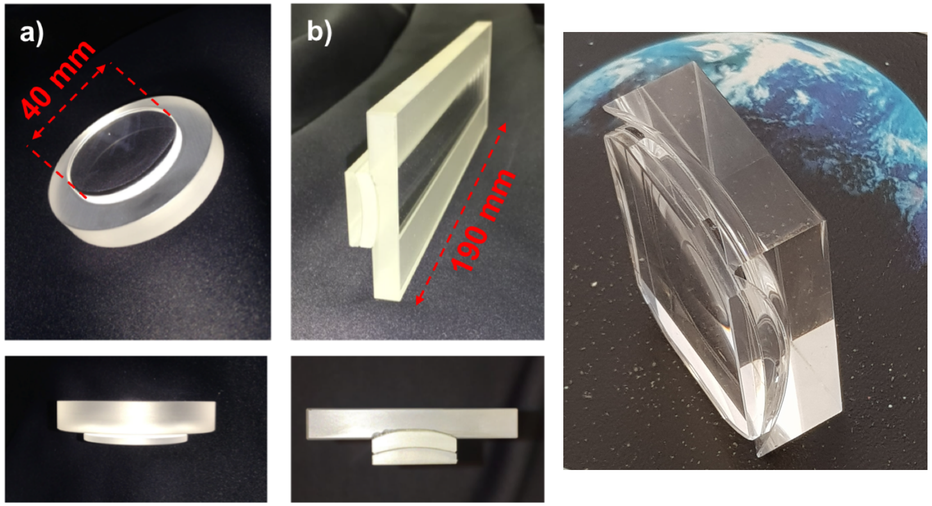

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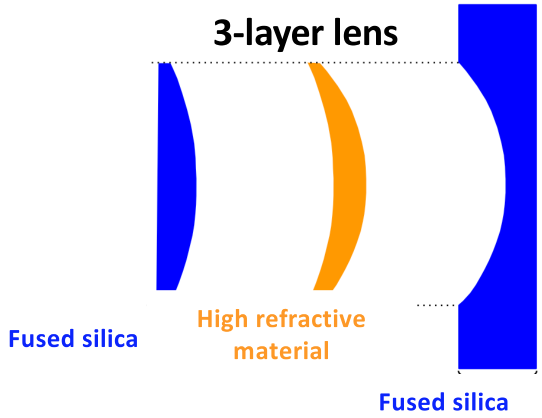
Radiation Hardness of 3-layer Lens

- So far we used lanthanum crown glass as the middle layer



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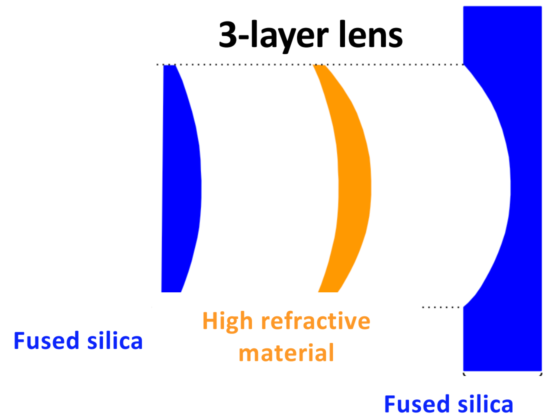
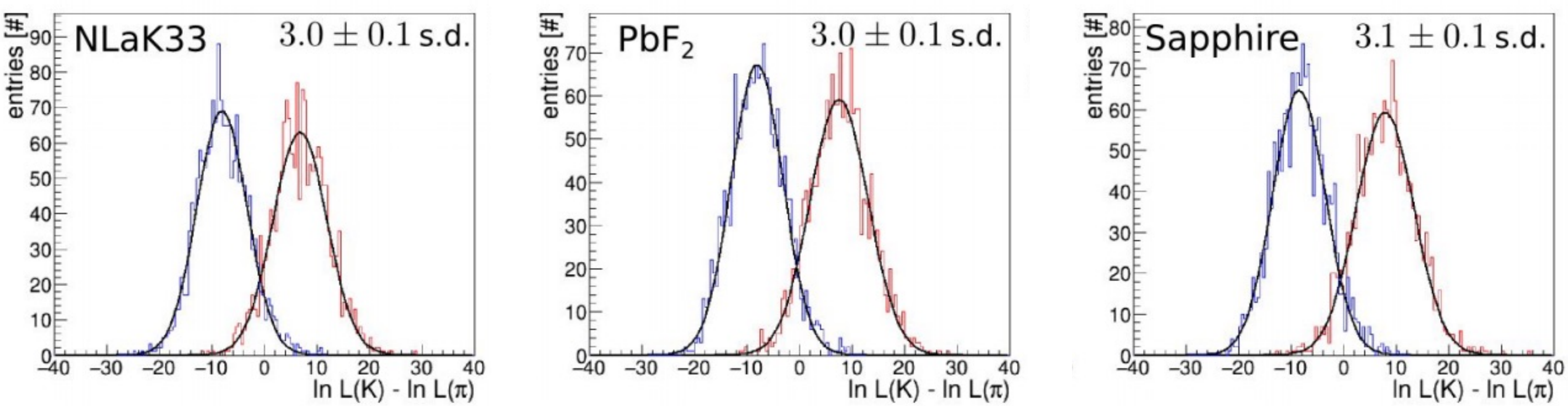
Radiation Hardness of 3-layer Lens

- So far we used lanthanum crown glass as the middle layer
- Both Sapphire and PbF_2 are very 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.



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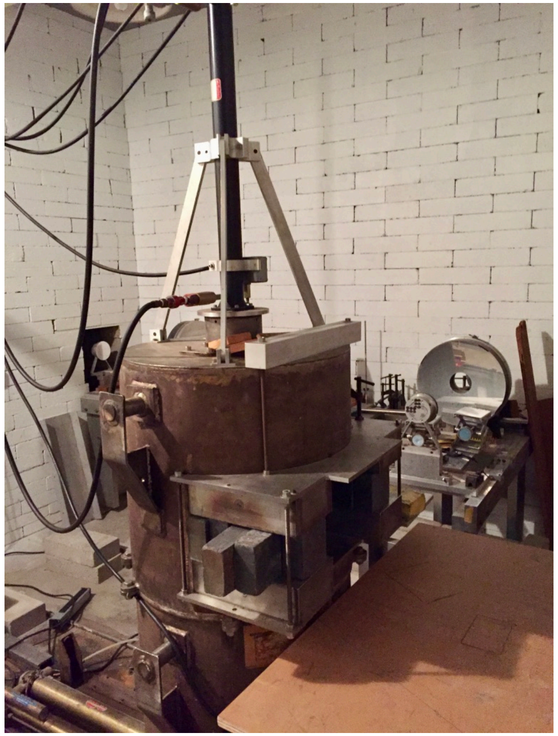
Radiation Hardness of 3-layer Lens

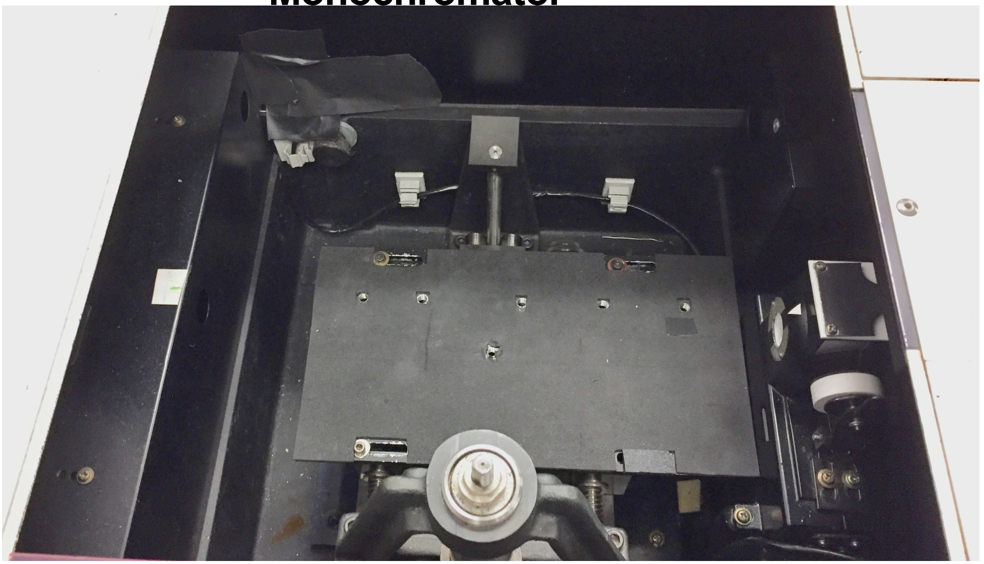
Co^{60} Chamber



^{60}Co irradiation setup at BNL

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

Monochromator



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Radiation Hardness of 3-layer Lens

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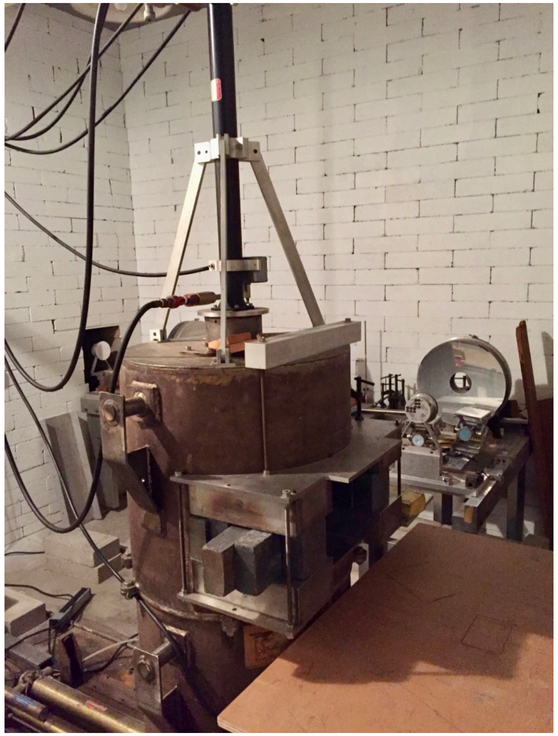

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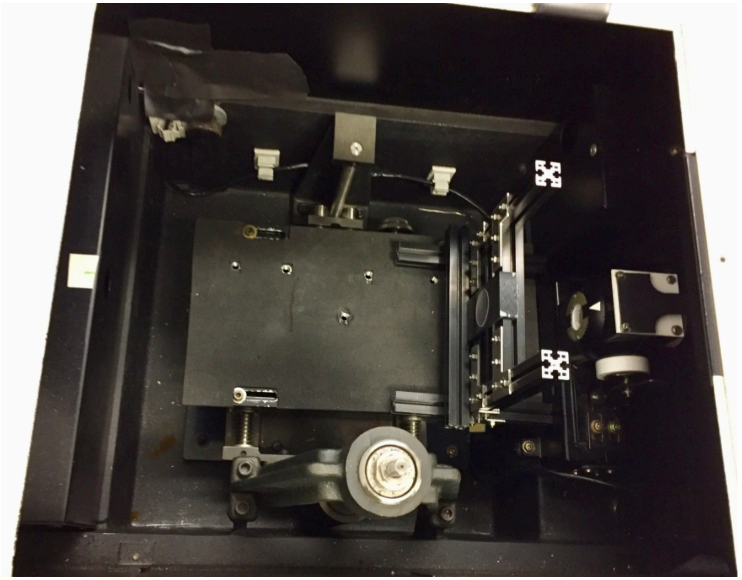

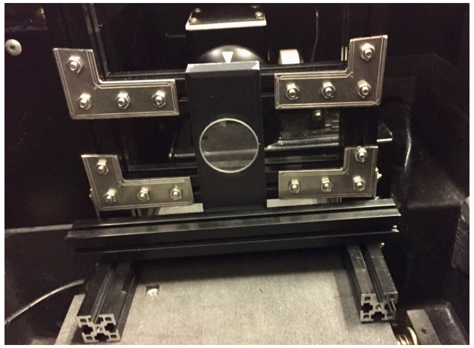

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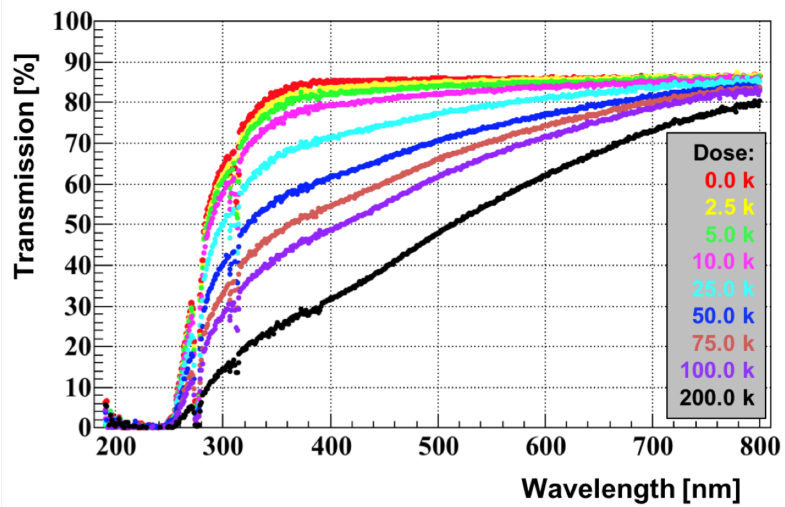
Radiation Hardness of 3-layer Lens

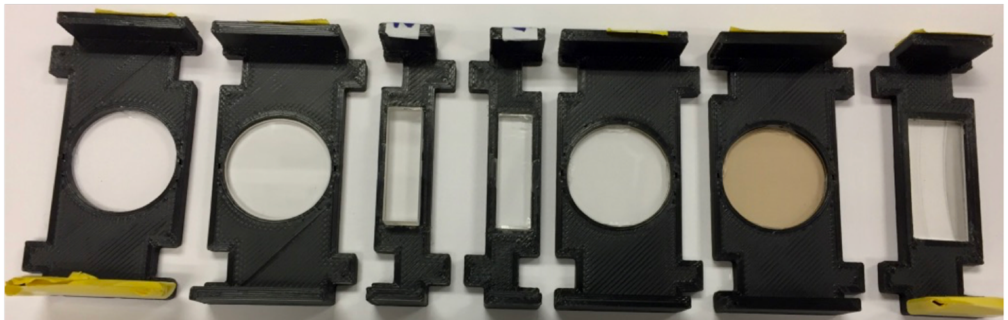
^{60}Co irradiation results

- Radiation damage quantified by measuring the transmission in the 190-800 nm range in a monochromator
- Transmission loss of alternate lanthanum crown glass material (S-YGH51) confirmed

S-YGH51 (NLaK33 equivalent)



Tested samples



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

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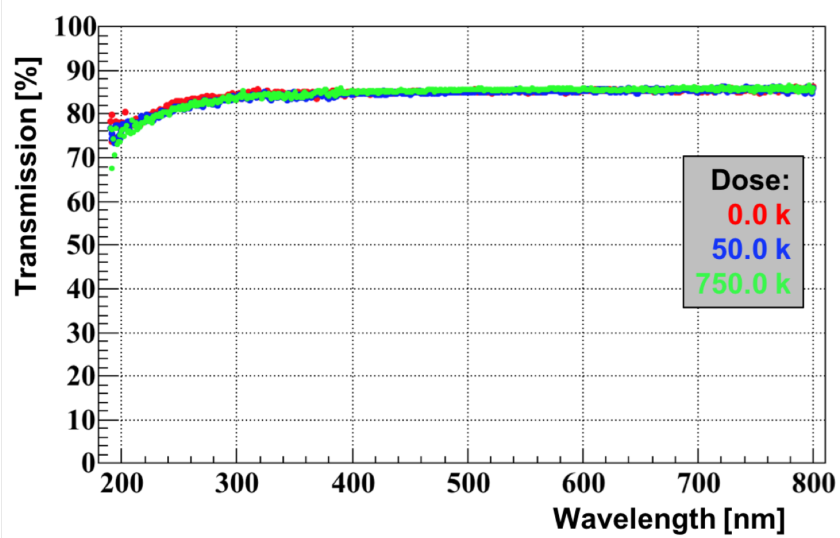
Radiation Hardness of 3-layer Lens

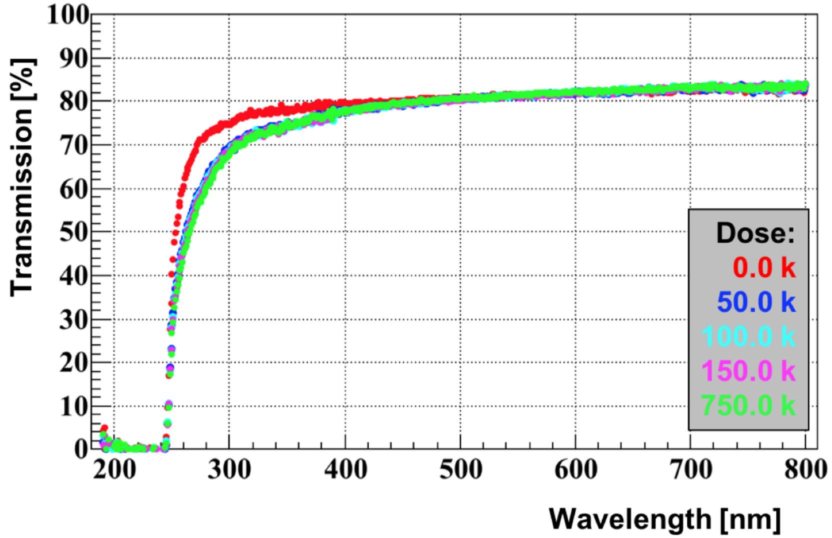
^{60}Co irradiation results

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

Sapphire



PbF_2



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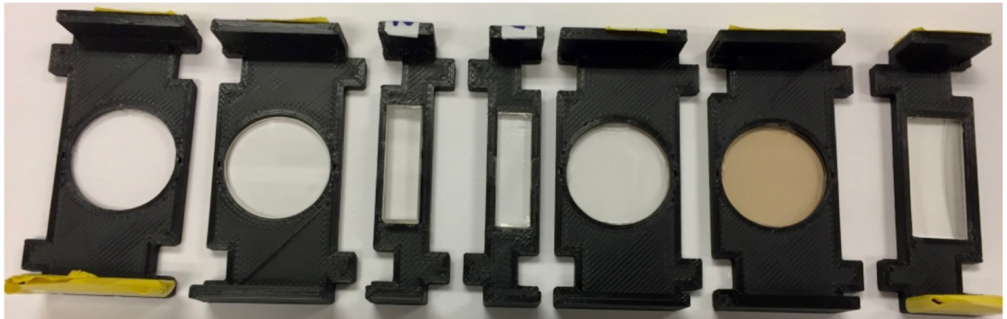

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Radiation Hardness of 3-layer Lens

^{60}Co irradiation next steps

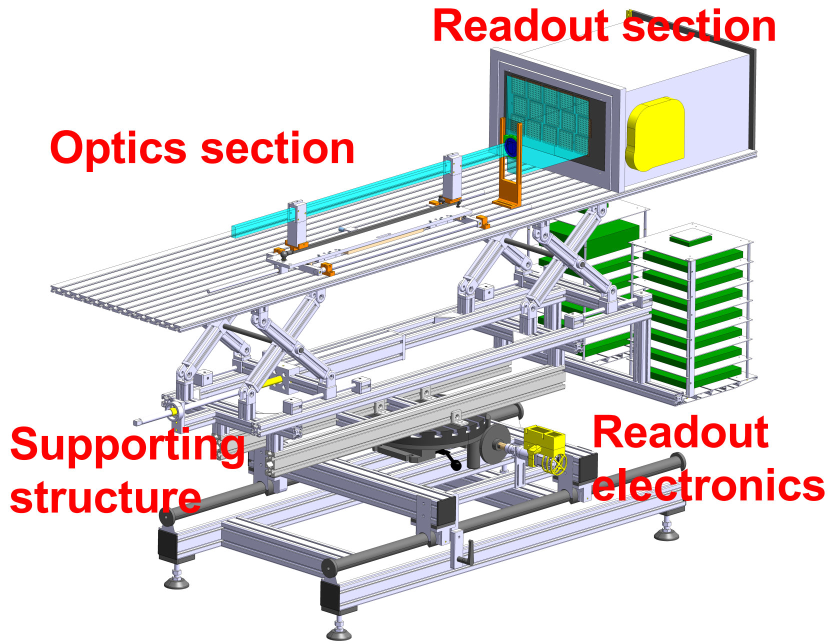
- Evaluating different materials
- Luminescence
- Radiation hardness to neutrons

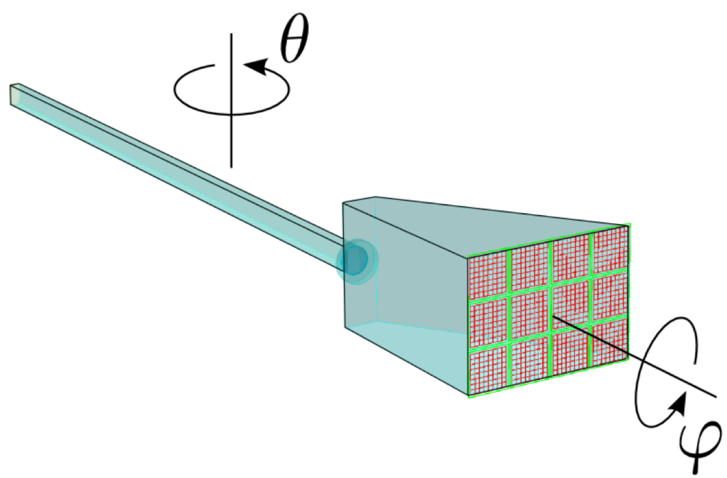


hpDIRC Prototype

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





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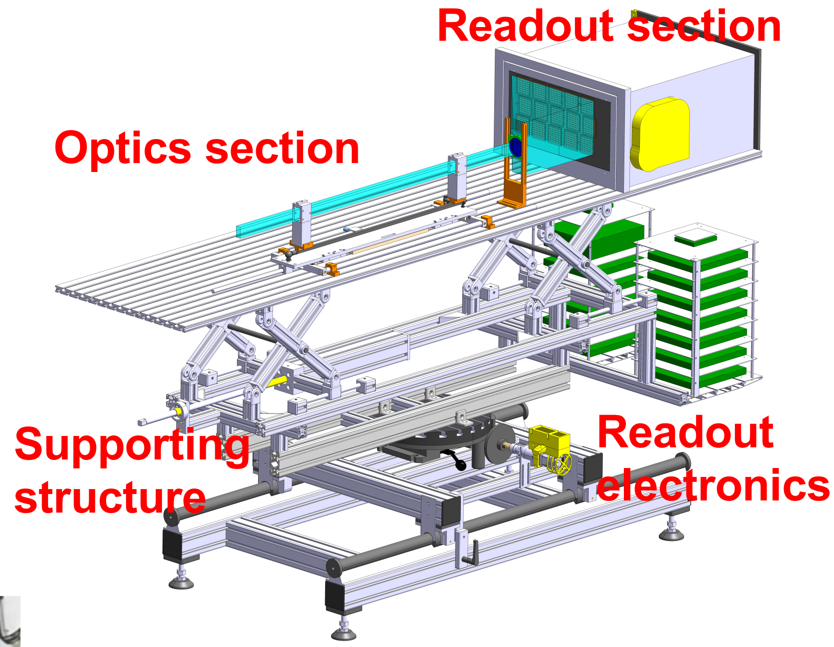
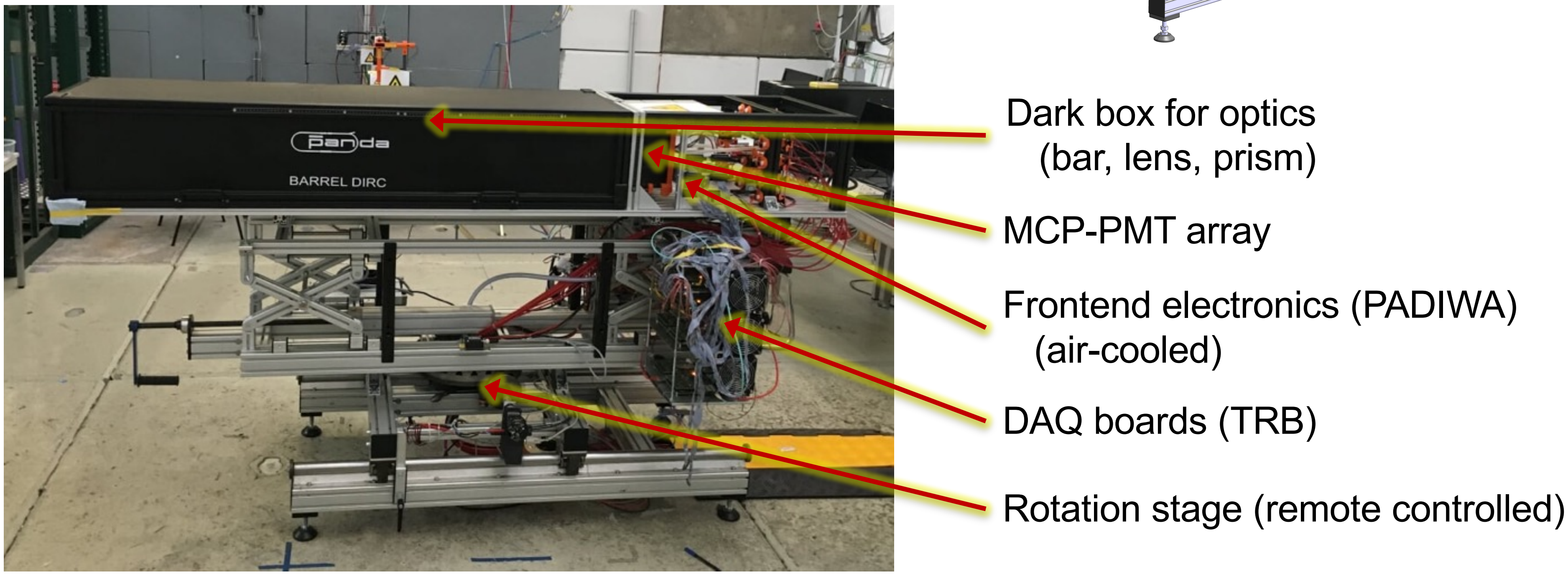
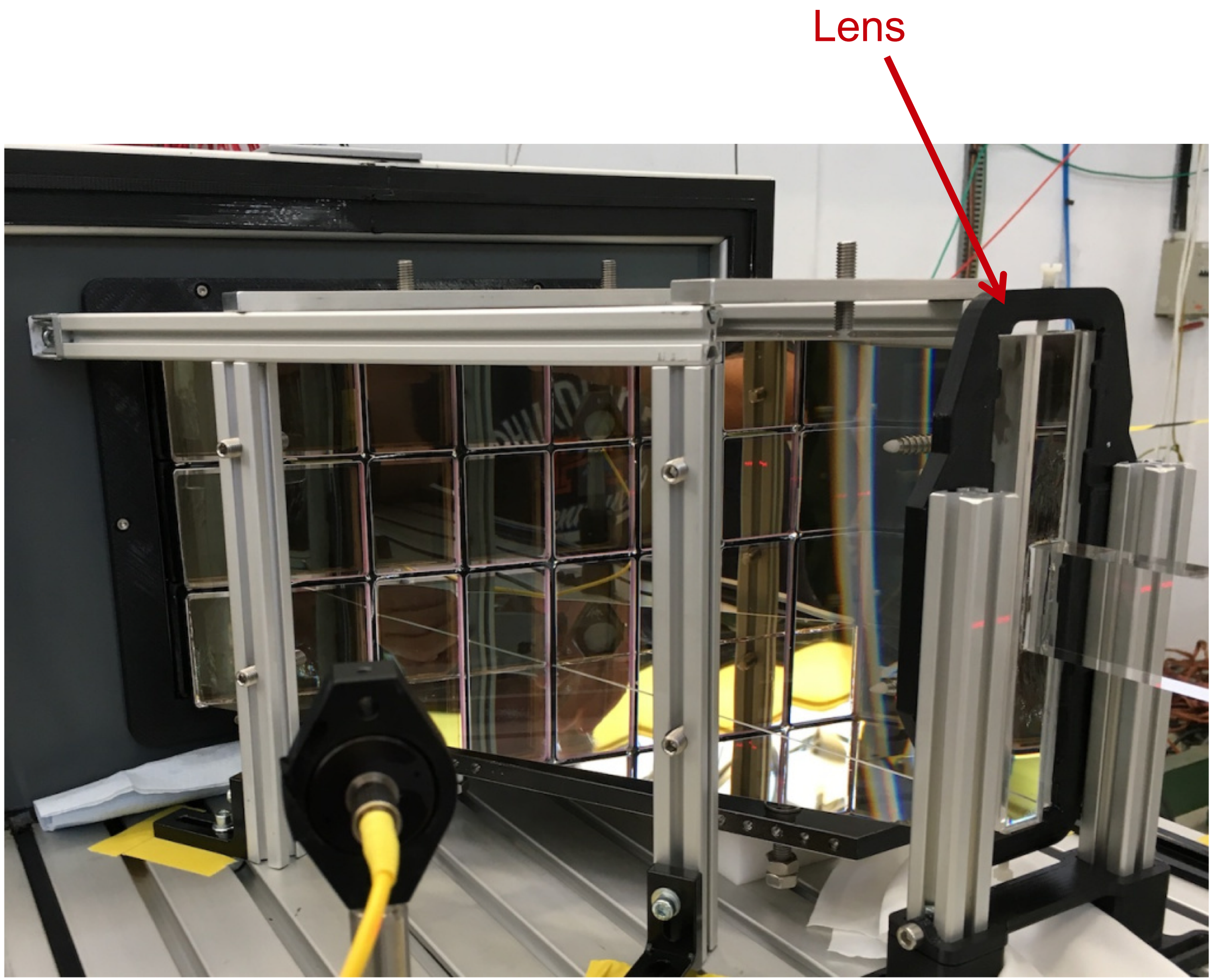
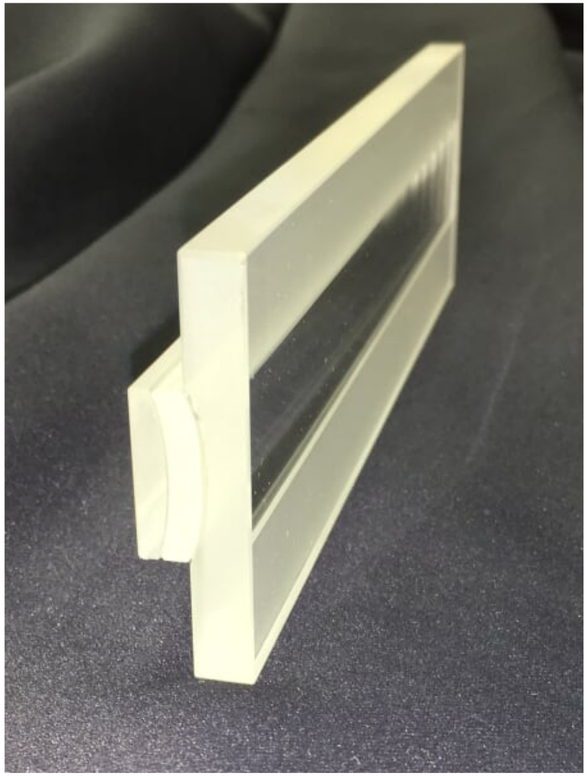
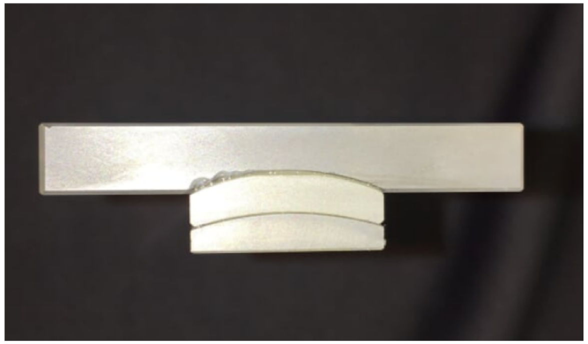




3-layer Lens CERN Beam Test 2017



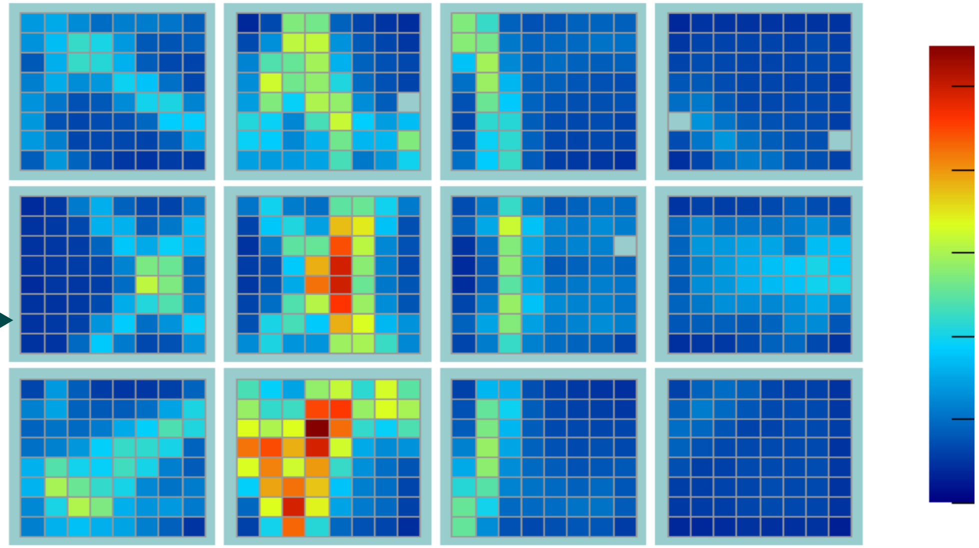


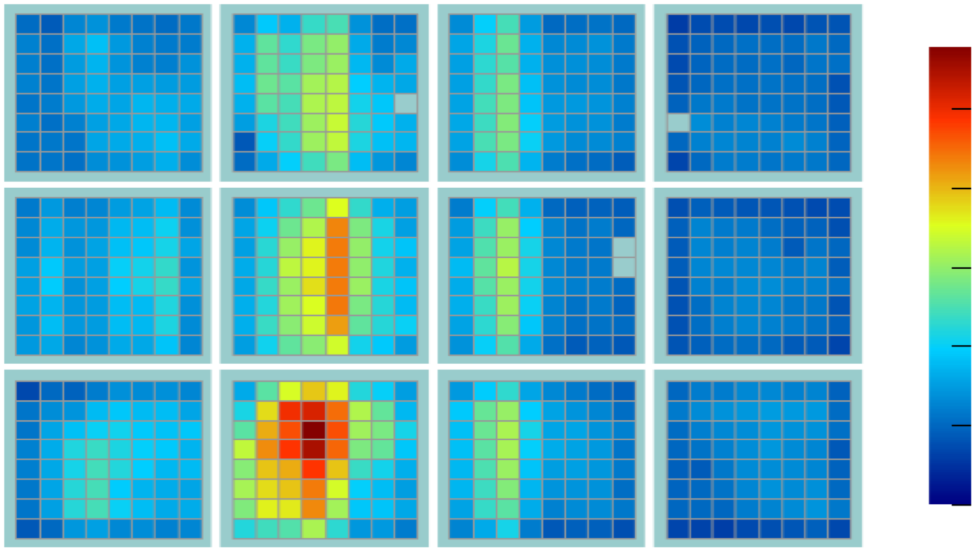


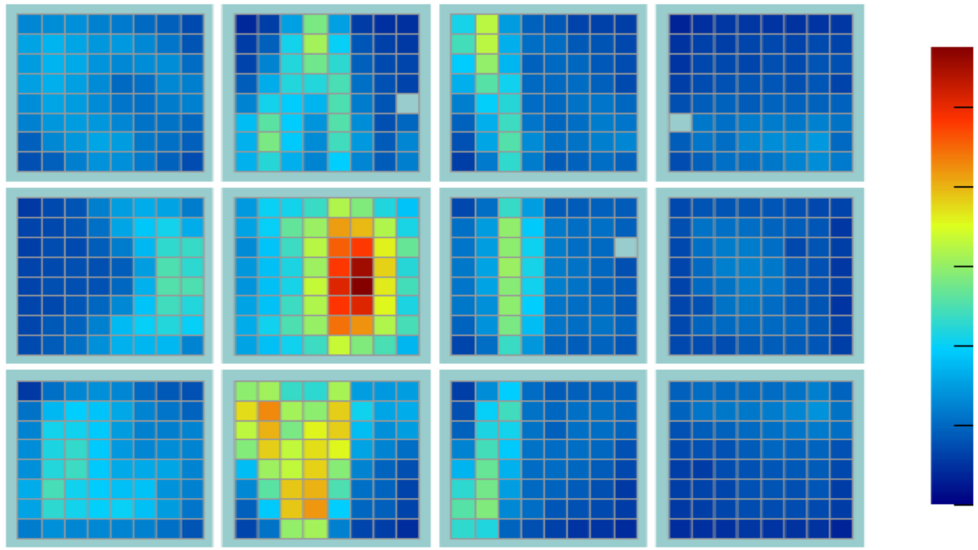
3-layer Lens CERN Beam Test 2017

25 degree polar angle
beam data with pion tag @ 7 GeV/c

bar + 3 layer spherical lens
bar + 3 layer cylindrical lens
plate + 3LC lens

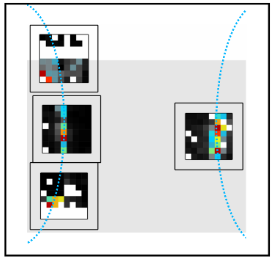


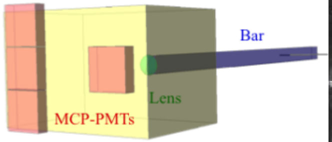




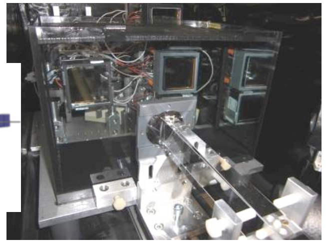
Roman Dzhygadlo

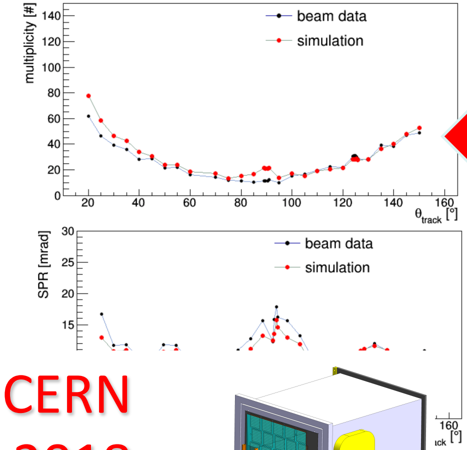
Test Beam Program



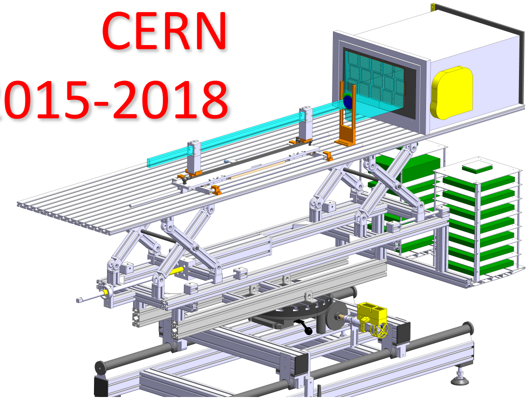


GSI
2008/2009

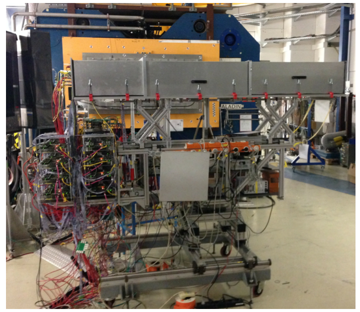


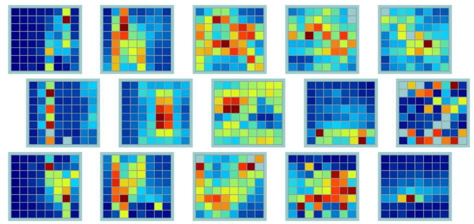


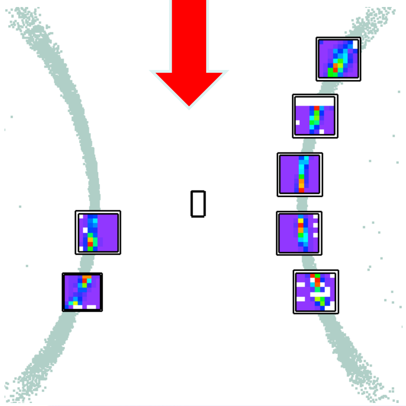
CERN
2015-2018



GSI 2014

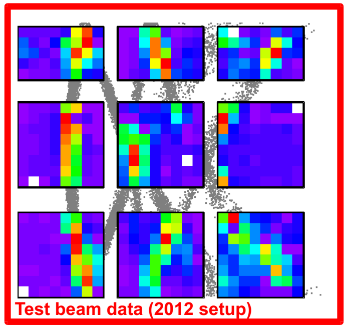


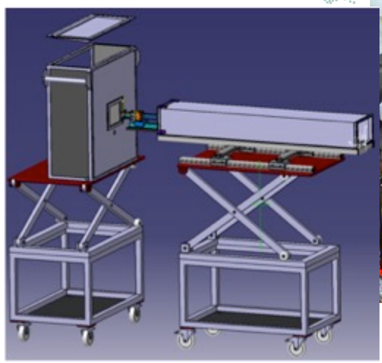


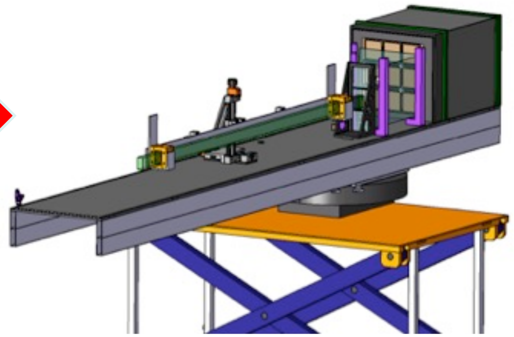


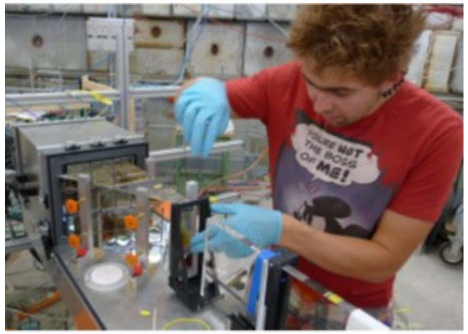
GSI, CERN
2011

CERN
2012







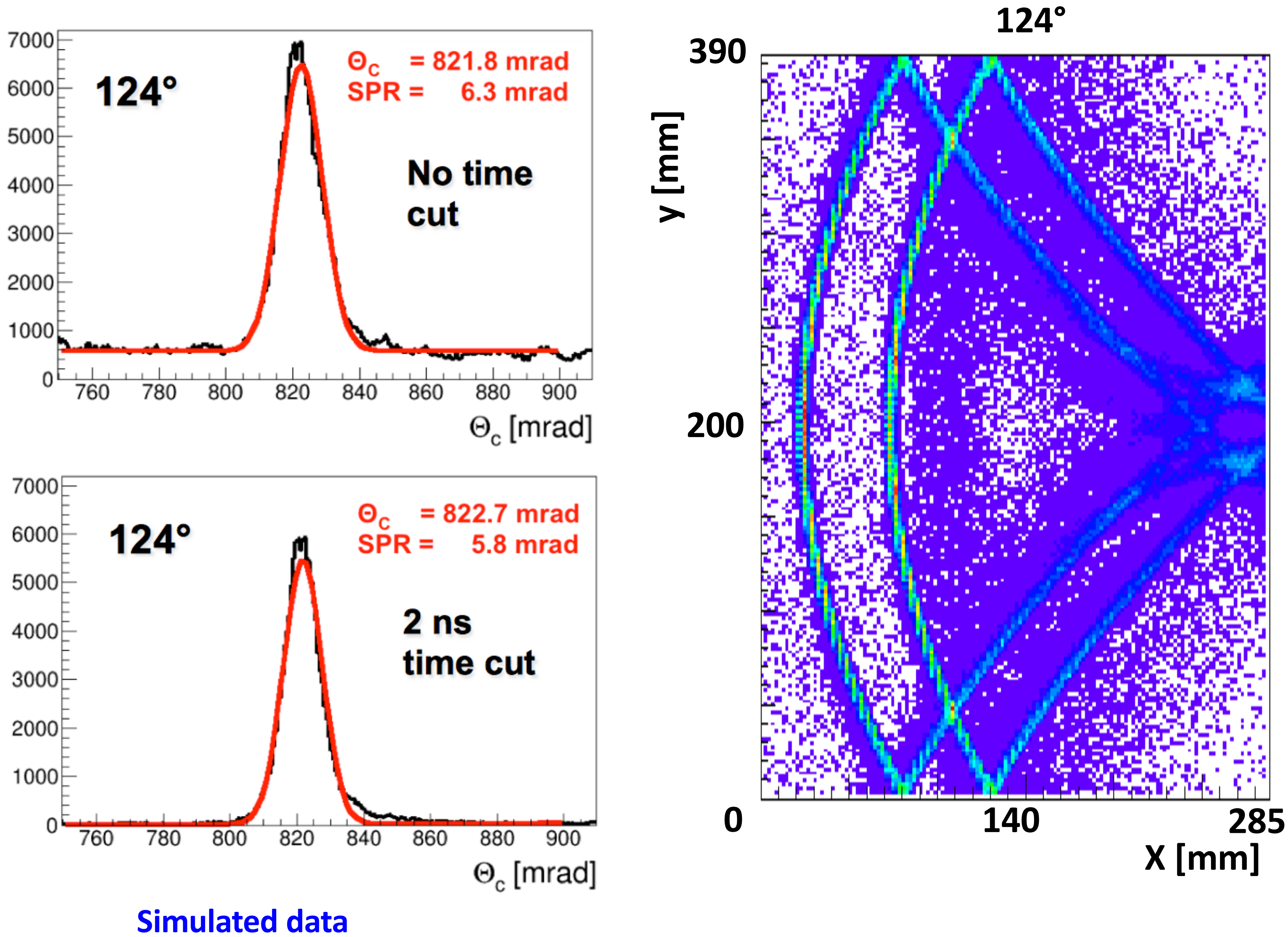


hpDIRC Activities

- **Software:**
  - Studies of design using stand alone Geant4 package.
  - Implementing hpDIRC into the full detector simulation.
  - Developing hpDIRC Prototype software.
- **Hardware:**
  - Validating radiation hard 3-layer lens prototypes.
  - Finalizing detailed radiation hardness tests of candidates for middle layer of the lens.
  - Transferring PANDA DIRC prototype to US as a base for hpDIRC prototype.

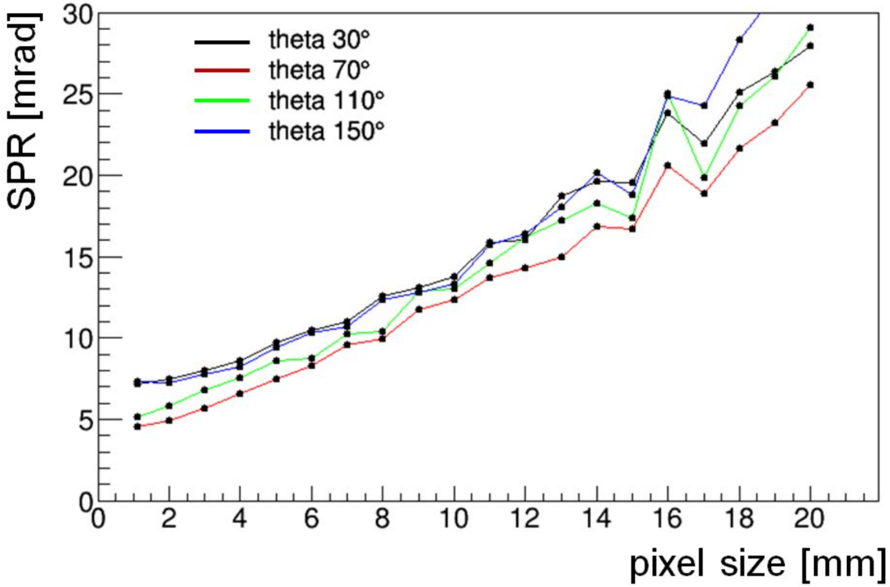
Backup

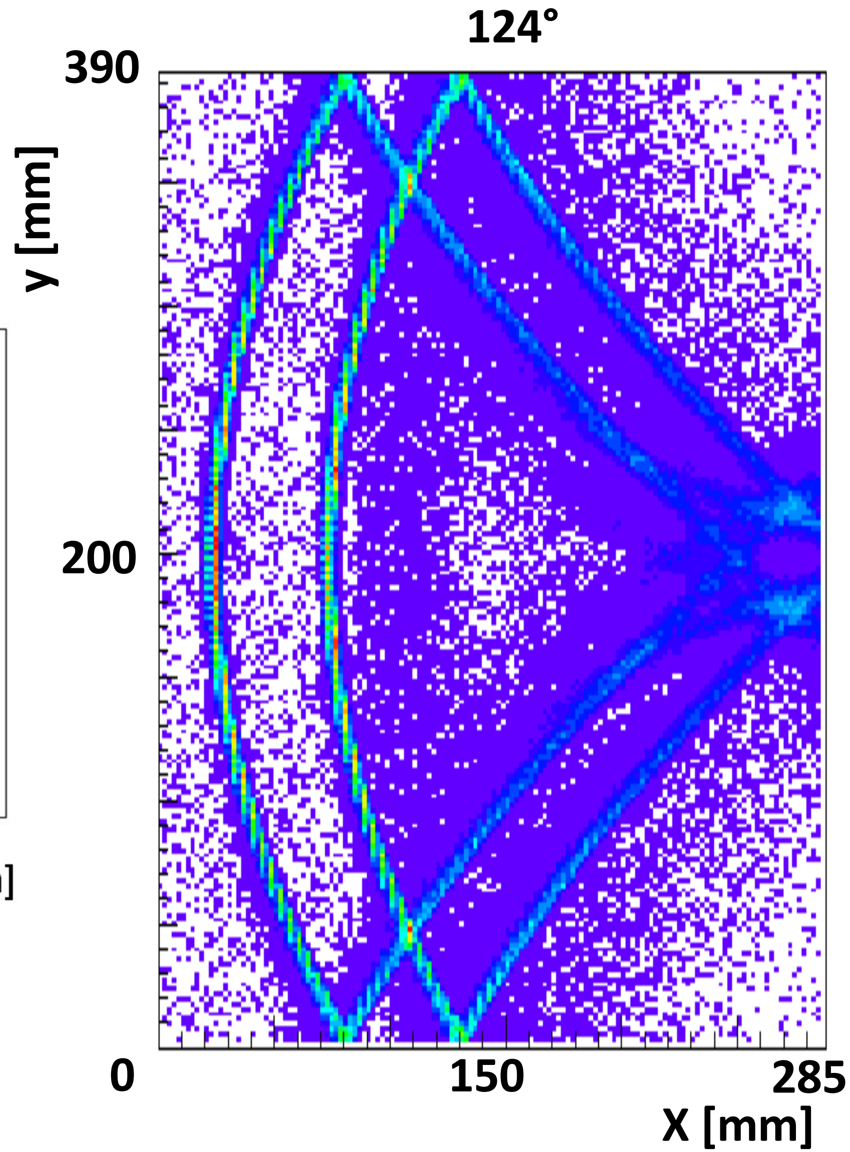
hpDIRC Single Photon Resolution (SPR)



hpDIRC DIRC Single Photon Resolution (SPR)

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

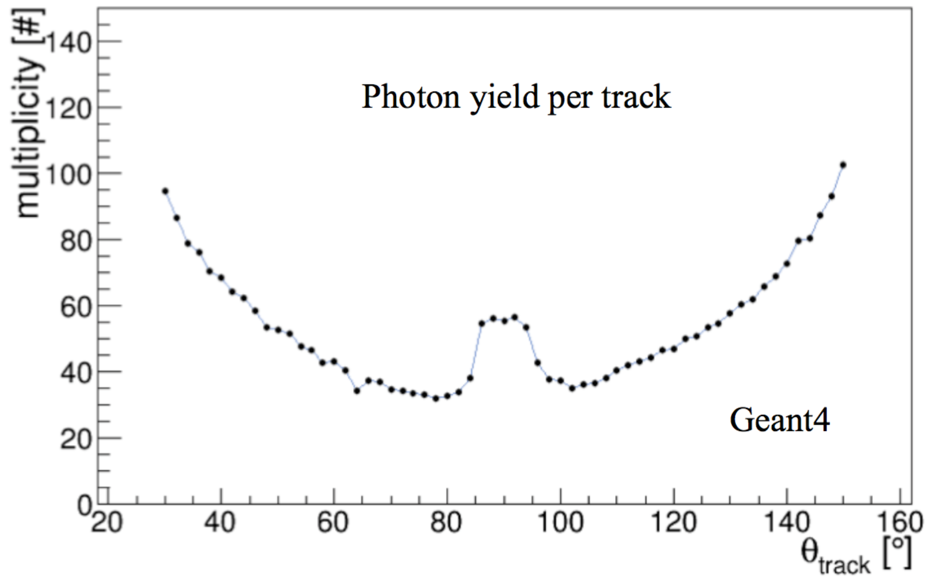


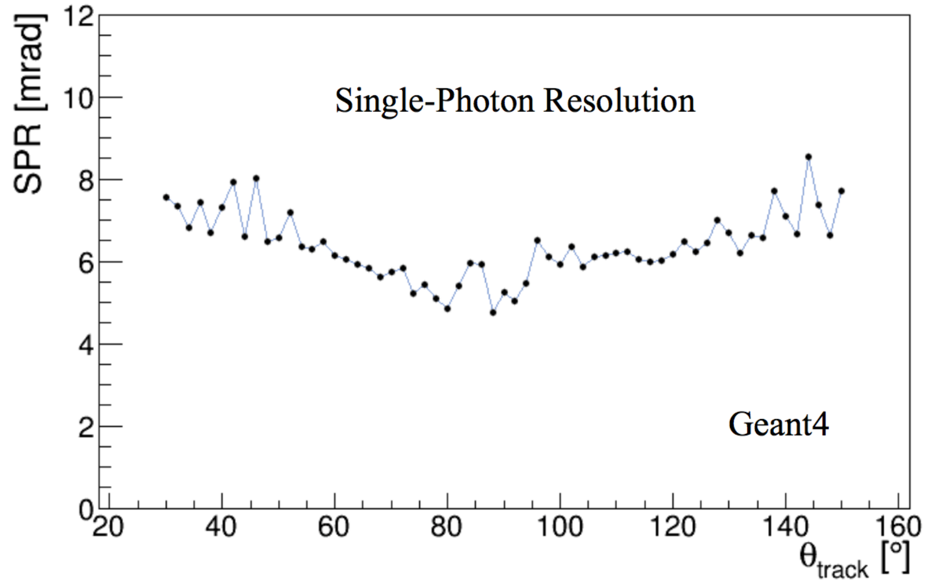


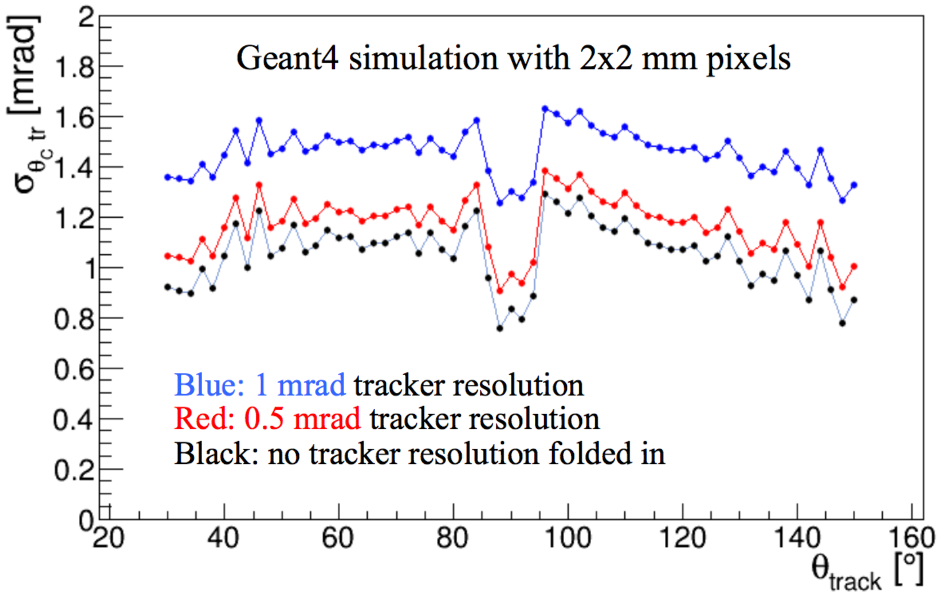
Simulated data

High-performance DIRC Track Resolution

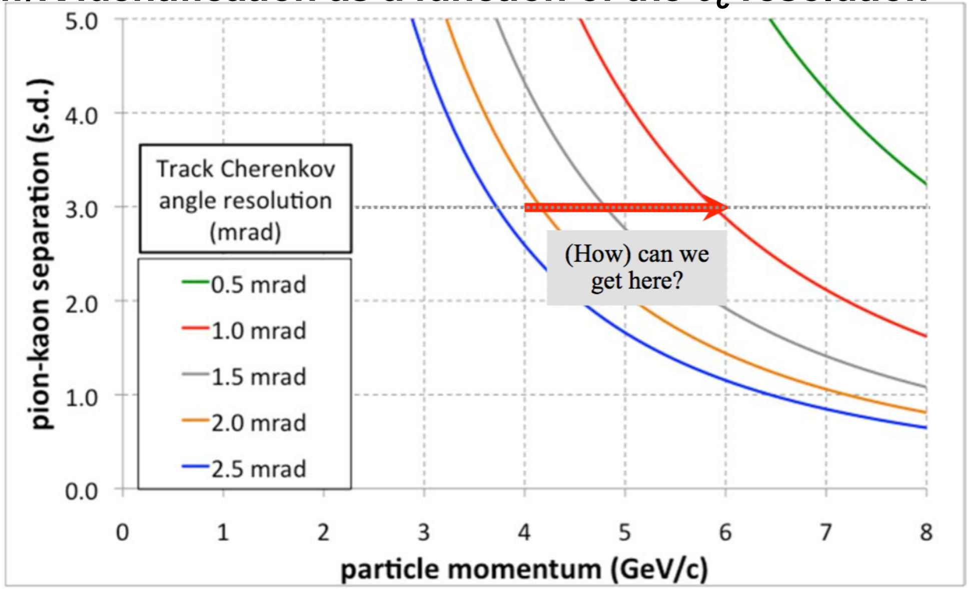
Simulated data





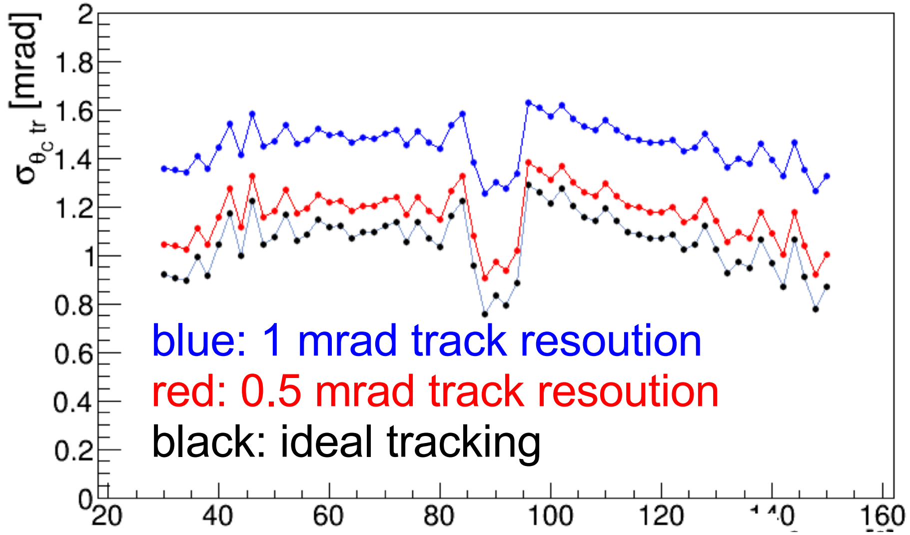


π/K identification as a function of the θ_c resolution

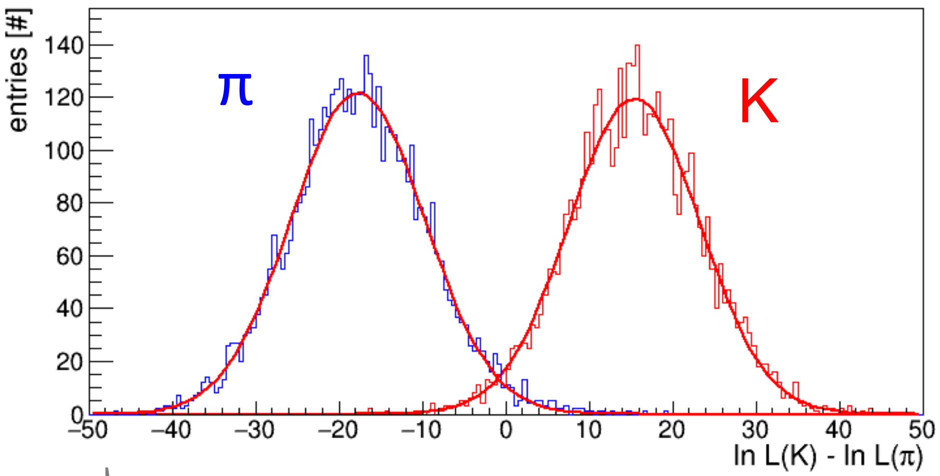


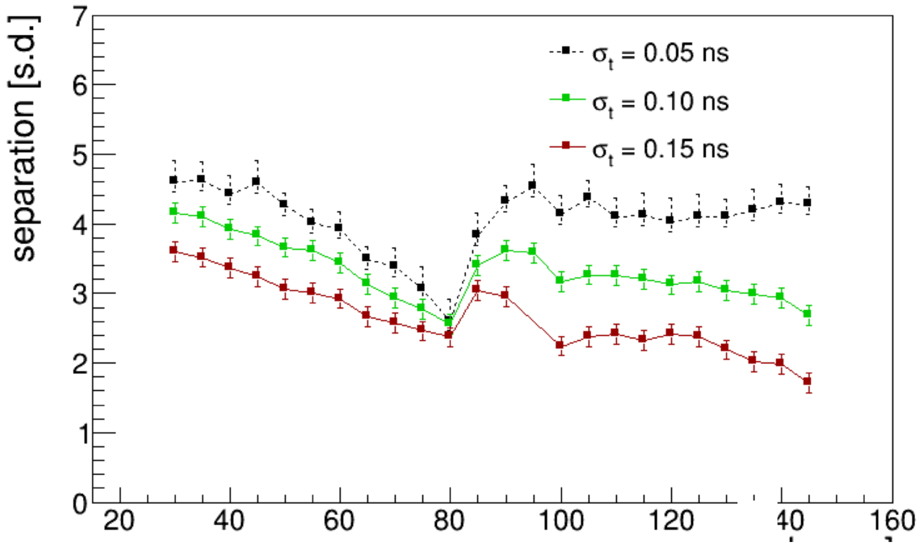
High-performance DIRC Performance

Configuration:
17x32x4200 mm³ bars
3-layer spherical lens
3x3 mm² pixels
100 ps time resolution



~4.2 s.d. separation at 6 GeV/c,
30° polar angle





design meets the requirements for PID in the barrel region