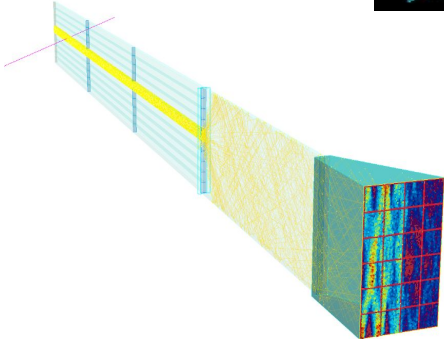
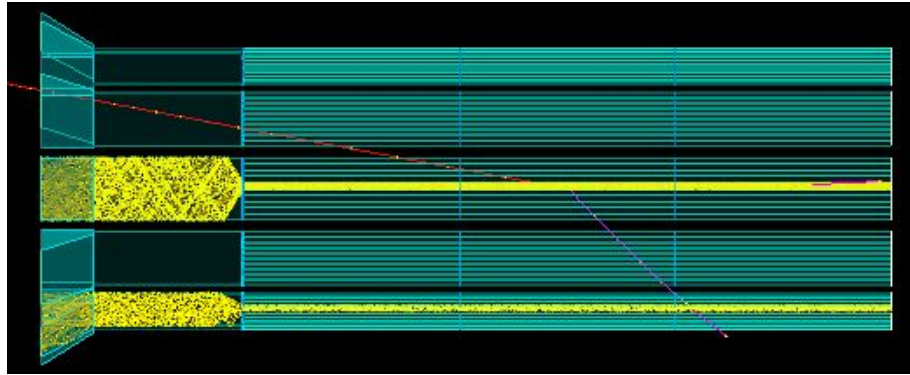
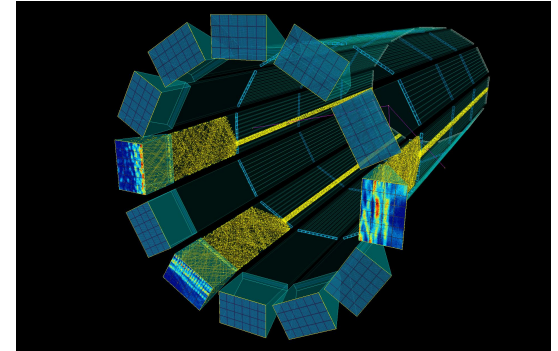


# xpDIRC Study

Md. Imran Hossain  
Graduate student, CUA

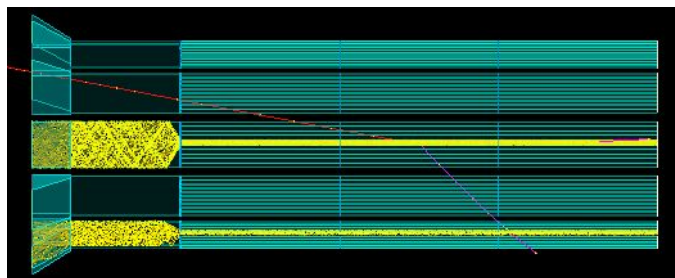
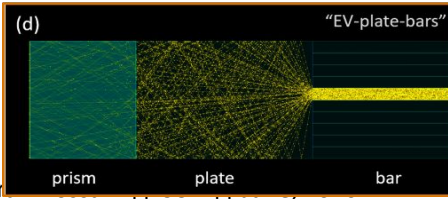
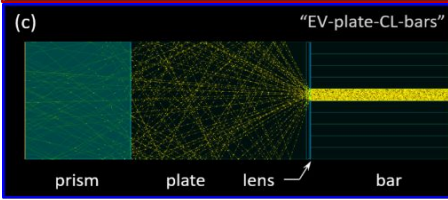
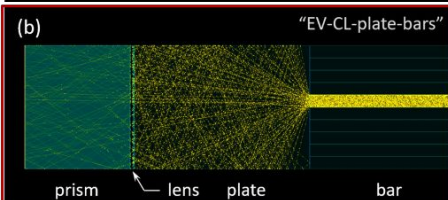
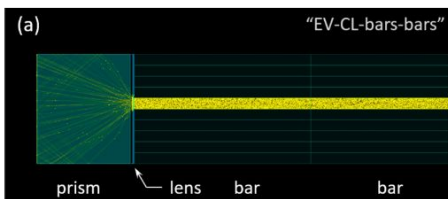


Annual DIRC Meeting, June 2026

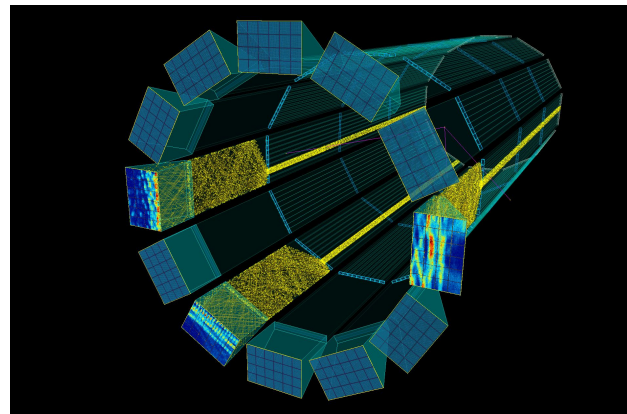


# xpDIRC Development

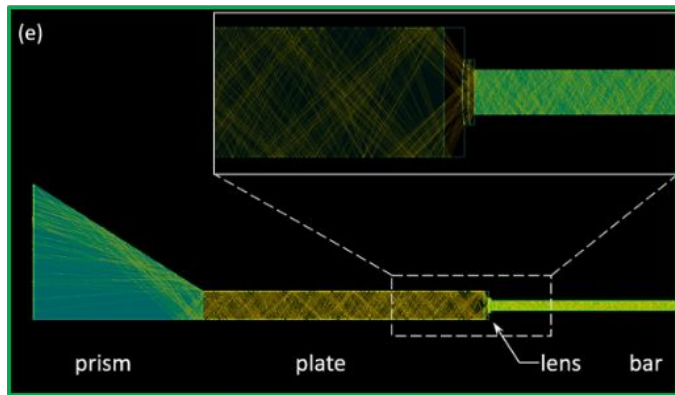
- Novel hybrid optical geometry design
- Combines narrow fused-silica radiator bars with enhanced focusing optics
- Utilizes a wide plate as a light-guide
- Incorporates a compact prism-shaped expansion volume



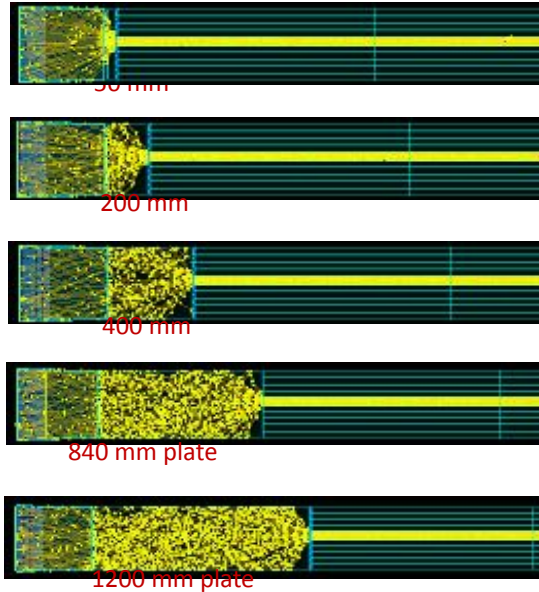
Side view of barrel xpDIRC



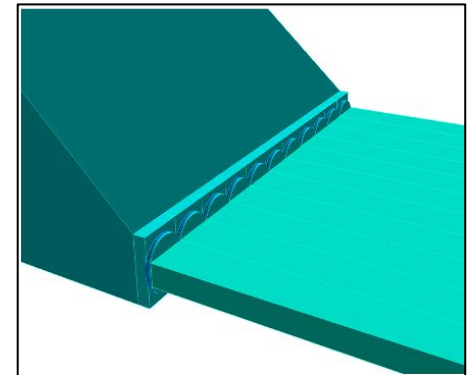
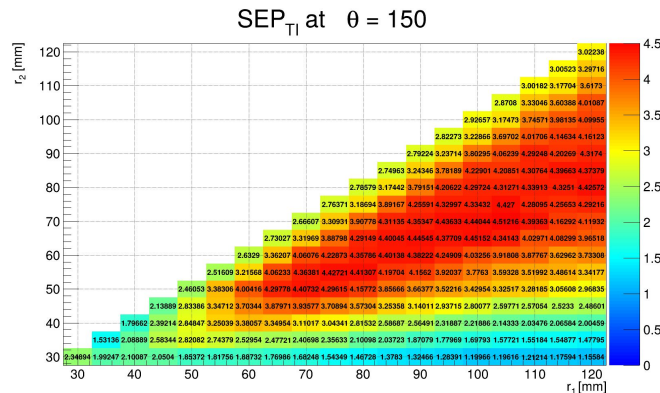
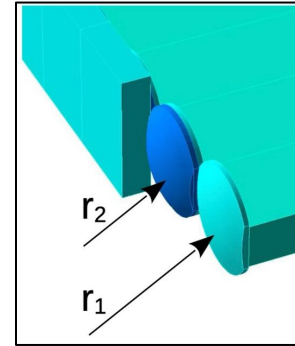
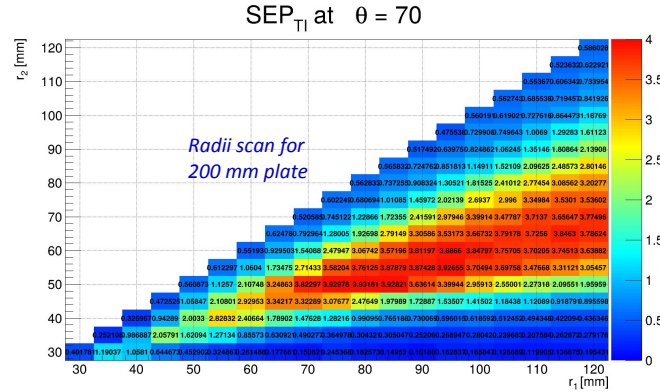
Narrow bars with wide plate hybrid design



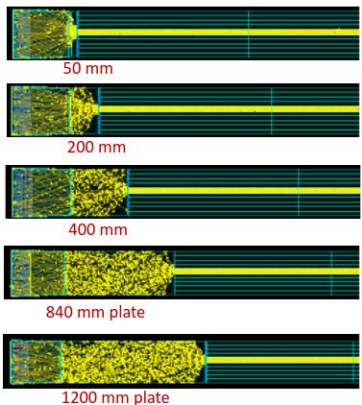
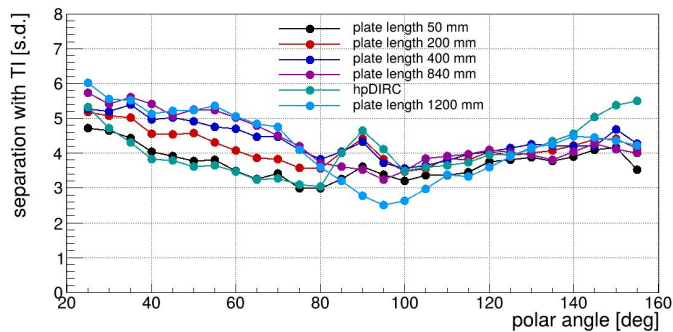
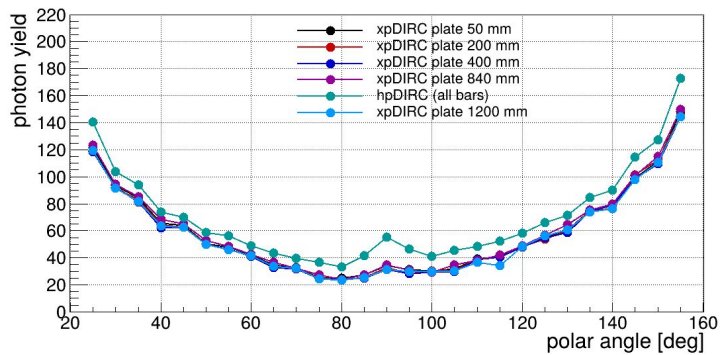
# xpDIRC Pre Expansion volume Plate length study



- Optimized the focusing optics for each plate-length configuration.
- Performed full reconstruction for all configurations.
- Compared the hybrid xpDIRC performance with the baseline hpDIRC design.



# Performance plots for different plate lengths



50 mm plate:  $(r_1, r_2) = (105, 55)$   
 200 mm plate:  $(r_1, r_2) = (70, 50)$   
 400 mm plate:  $(r_1, r_2) = (65, 50)$   
 840 mm plate:  $(r_1, r_2) = (65, 55)$   
 hpDIRC :  $(r_1, r_2) = (62, 36)$   
 1200 mm plate:  $(r_1, r_2) = (75, 65)$

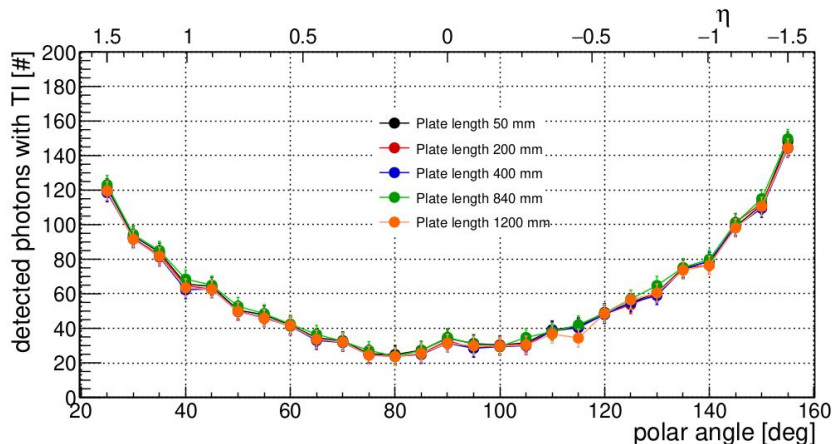
3 mm pixels HIQ400, CE=95%

- pions and kaons @ 6 GeV/c;  
phi = non zero ( field on );
- 100 ps time precision
- 45k tracks for pdf generation  
(per each particle species)  
(generated with  
corresponding track  
resolution); 5k for  
determining separation

xpDIRC: (Configuration of 3 layer  
spherical lens between bars and  
plate (EV-plate-SL-bars).)

Sensor: Mcp\_pmt

# xpDIRC Pre Expansion volume Plate length study



50 mm plate:  $(r_1, r_2) = (105, 55)$

200 mm plate:  $(r_1, r_2) = (70, 50)$

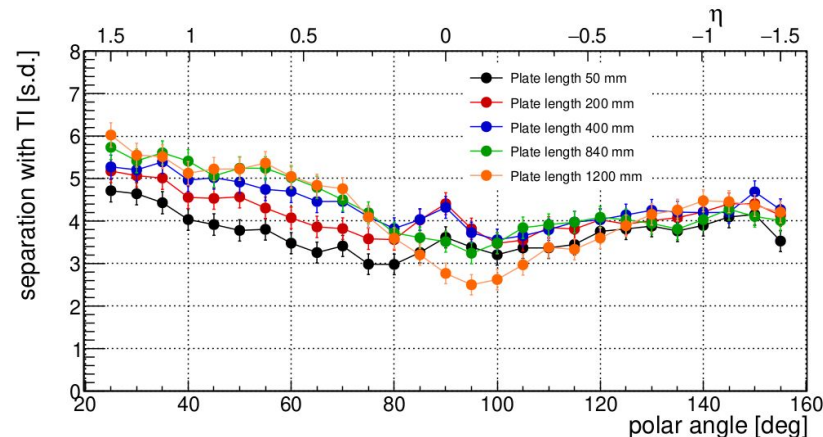
400 mm plate:  $(r_1, r_2) = (65, 50)$

840 mm plate:  $(r_1, r_2) = (65, 55)$

1200 mm plate:  $(r_1, r_2) = (75, 65)$

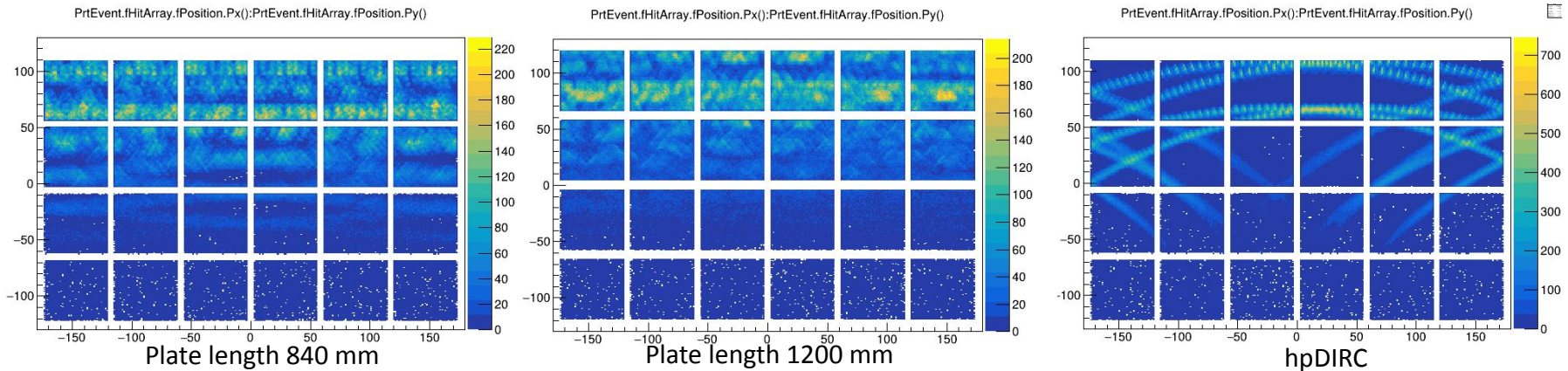
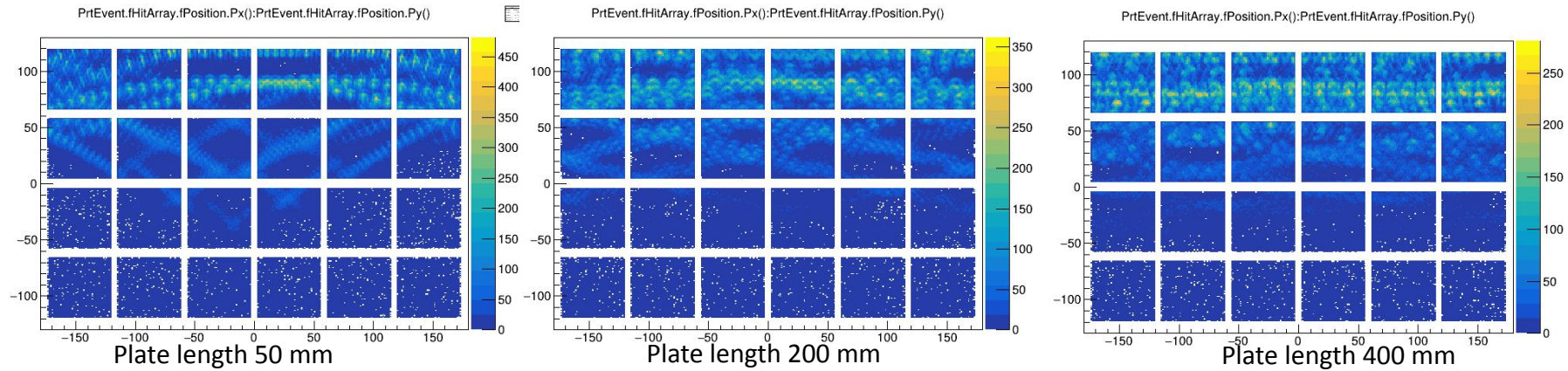
- PID performance is influenced by the plate length.
- An increase in plate length results in improved PID performance.

## $\pi/K$ separation power at 6 GeV/c



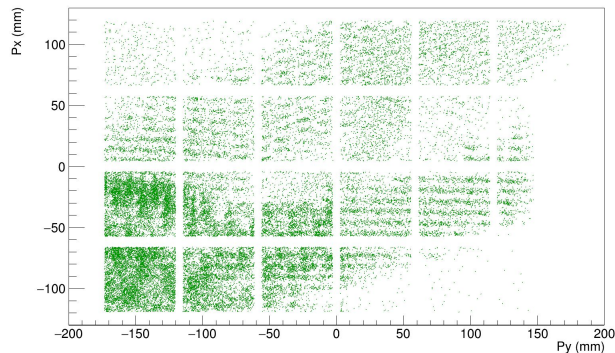
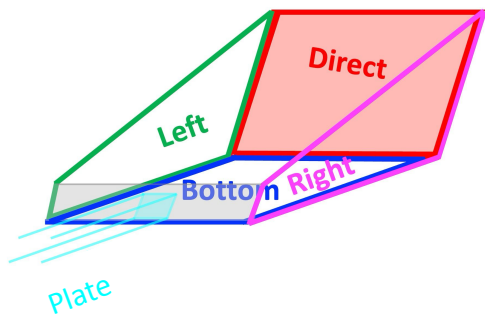
xpDIRC: (Configuration of 3 layer spherical lens between bars and plate (EV-plate-SL-bars).)

Sensor: Mcp\_pmt

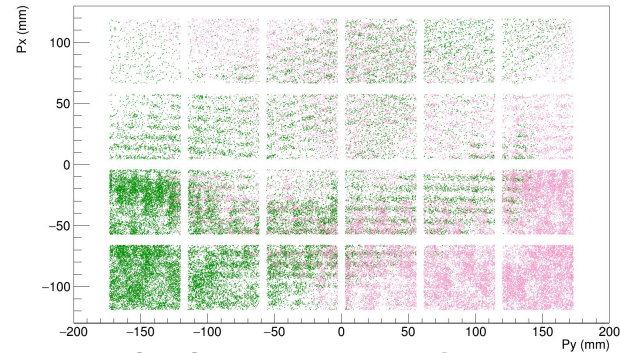


Polar angle = 90 deg.

# xpDIRC Hit Pattern Breakdown using last reflection inside Prism (30° polar angle)

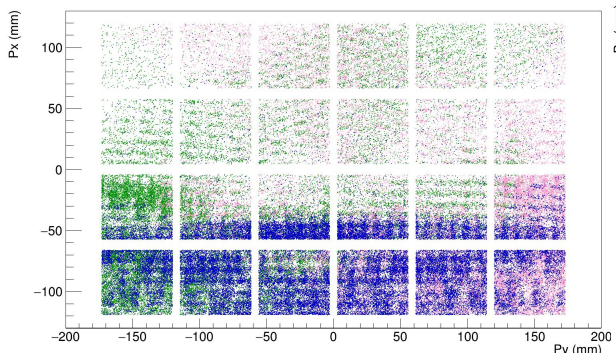


Left reflection

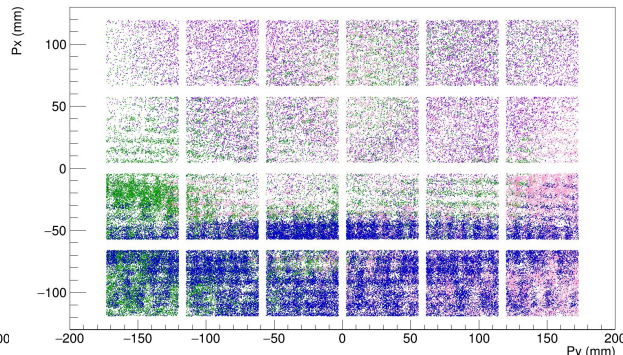


Left reflection + Right reflection

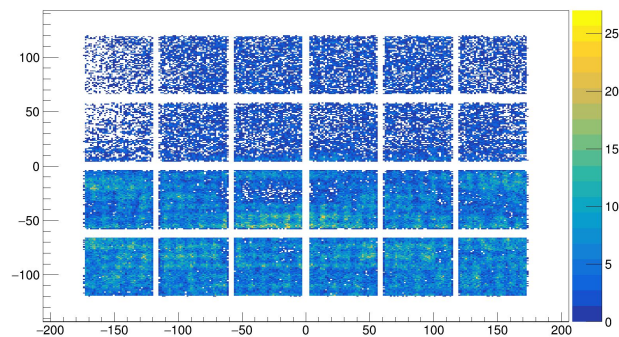
`PrtEvent.fHitArray.fPosition.Px():PrtEvent.fHitArray.fPosition.Py()`



Left + Right + bottom



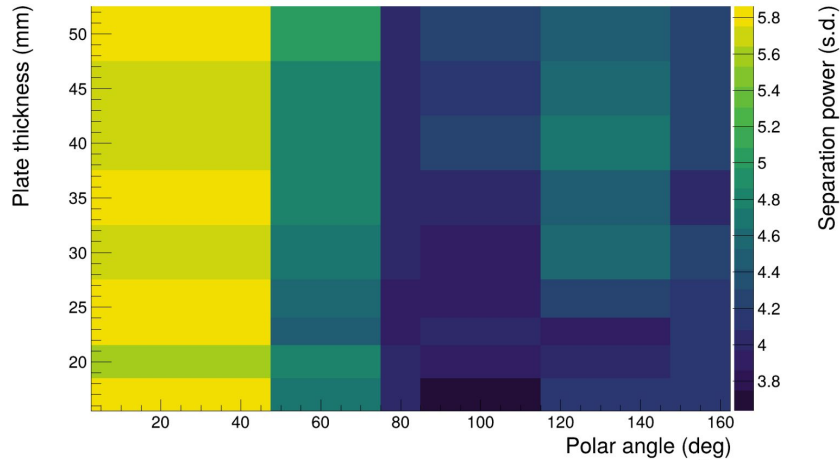
Left + Right + bottom + top



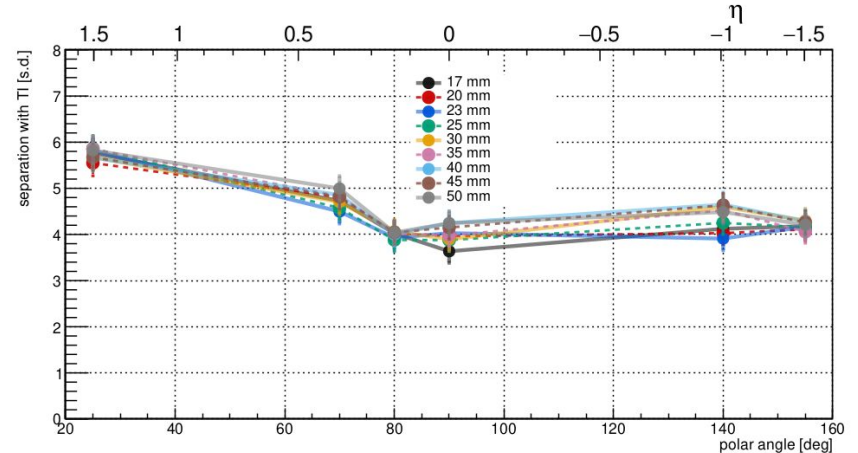
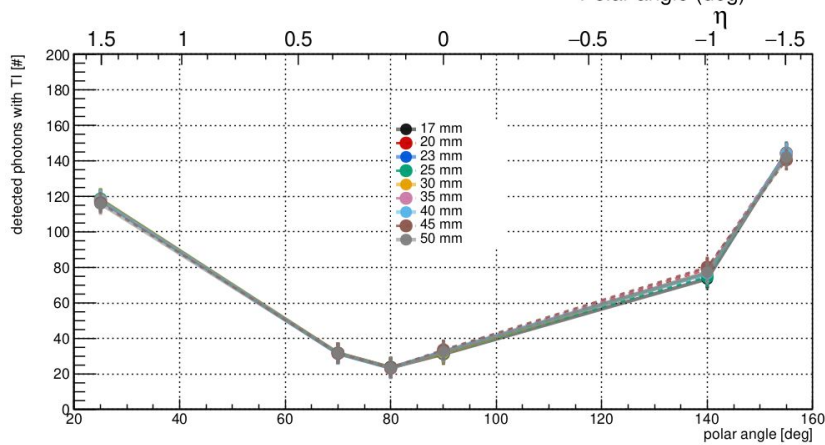
True hit positions

# Plate Thickness Study

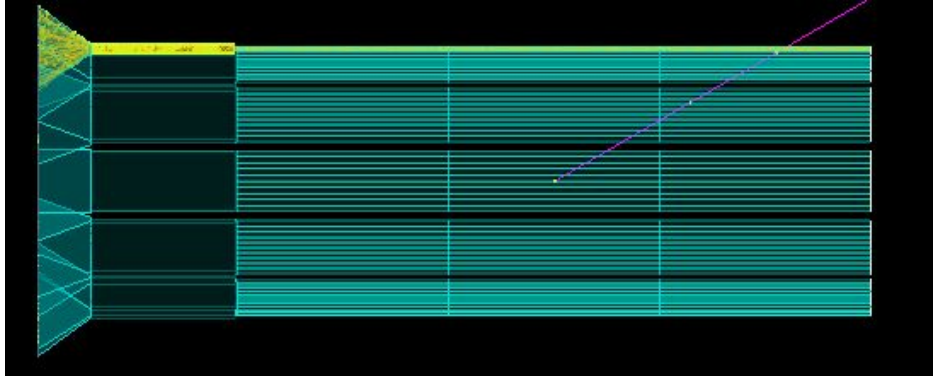
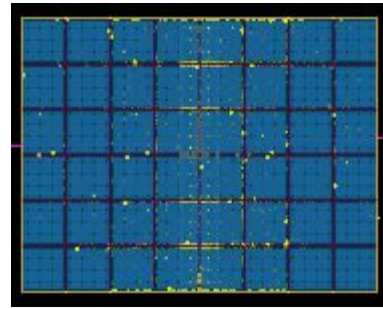
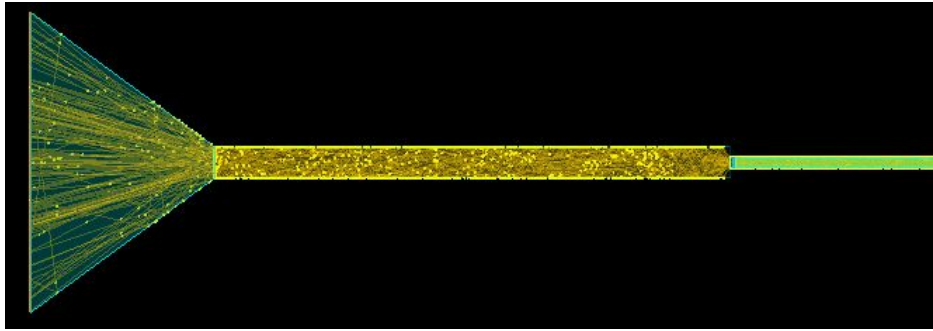
# Performance plots



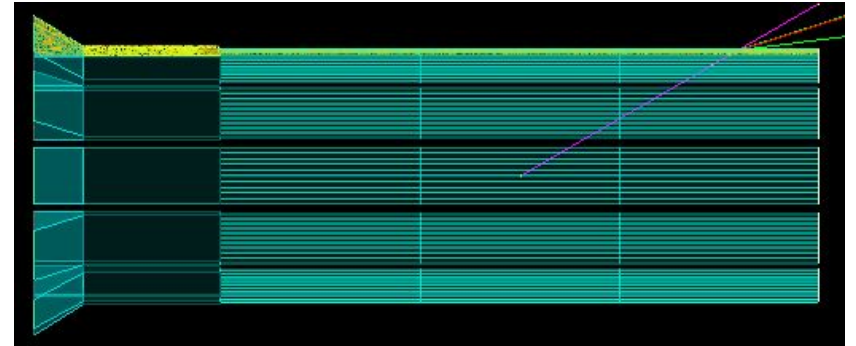
- No significant variation in photon yield was observed for thicknesses ranging from 17 mm to 50 mm.
- Among the configurations studied, the 50 mm thickness exhibits the highest separation power.



# Prism design study

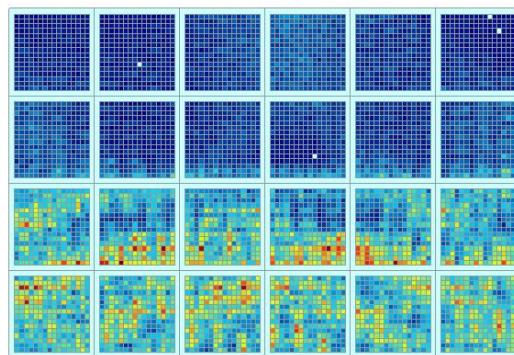
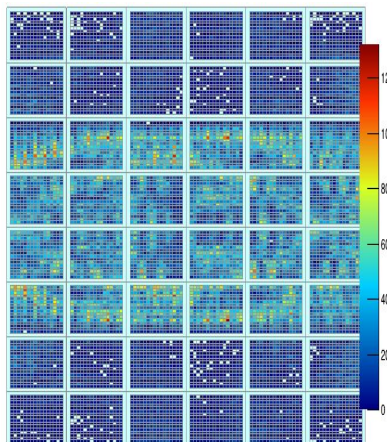
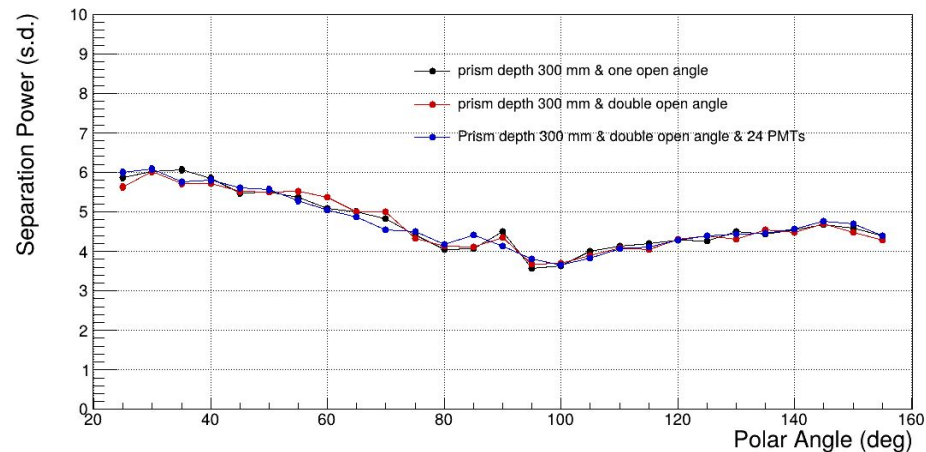
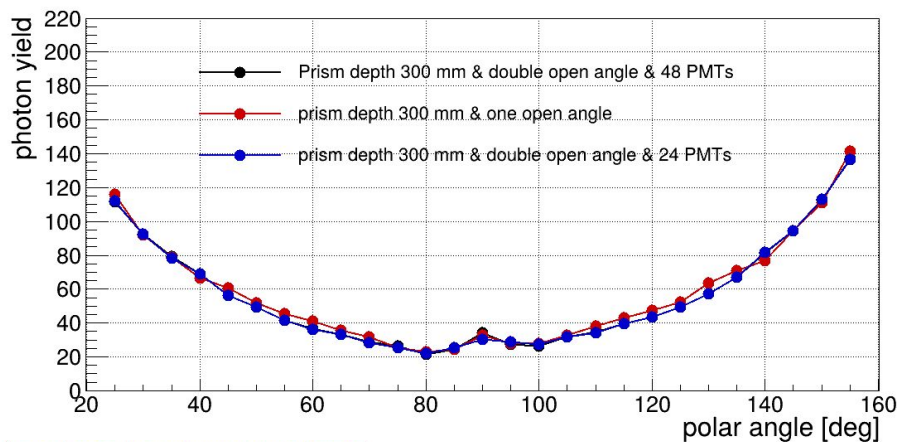


48/24 PMTs + double/One Open angle + Plate + SL + bars

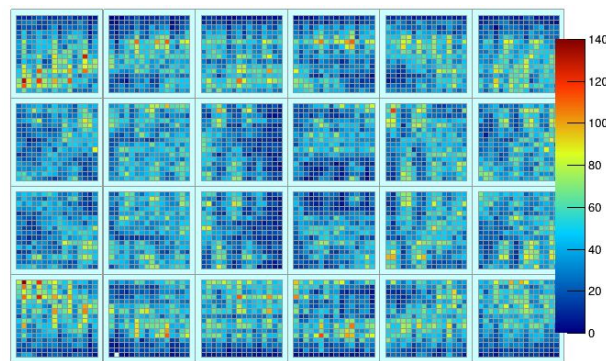


# Performance plots for different Prism design

Pion-Kaon Separation Power at 6 GeV - Time Imaging Reconstruction



One open ang + 24 pmts

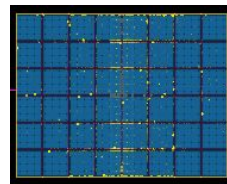
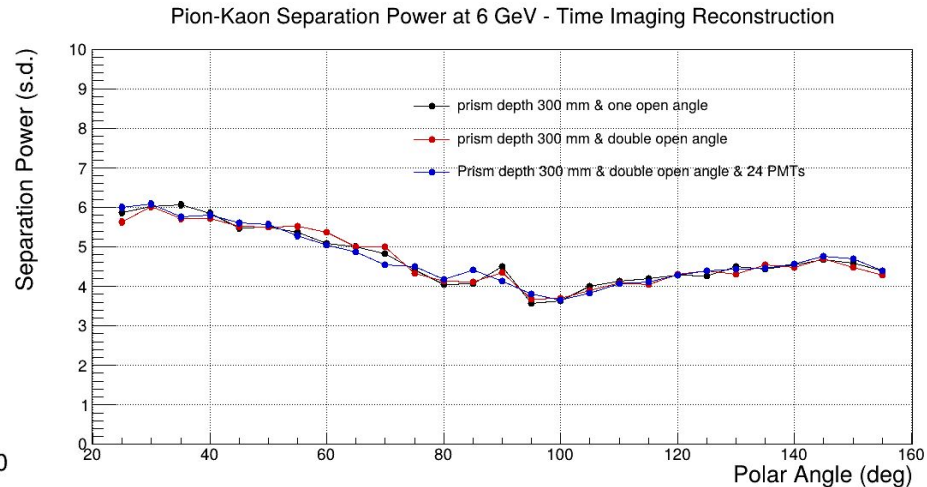
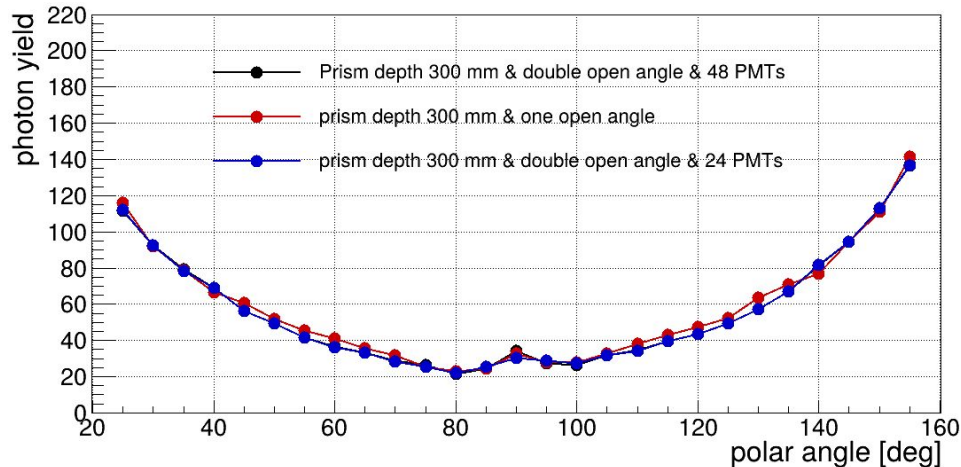


double open ang + 24 pmts

Double open ang + 48 pmts

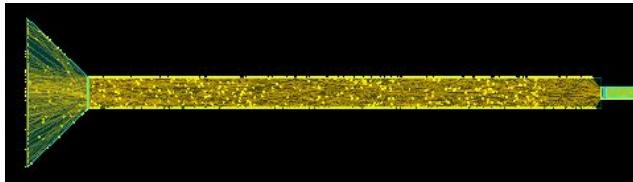
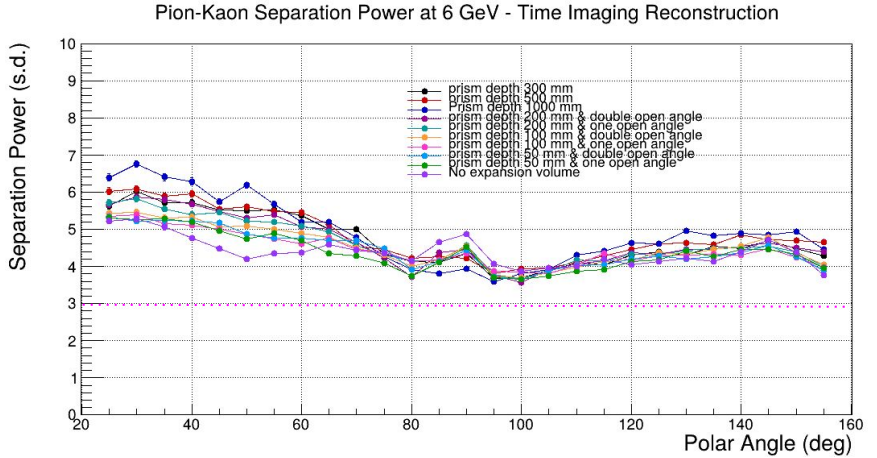
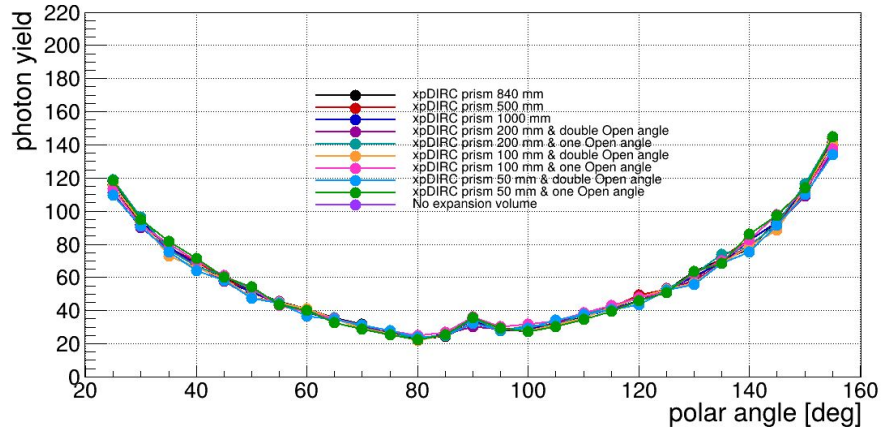
Imran Hossain || CUA || June, 2026

# Performance plots for different Prism design

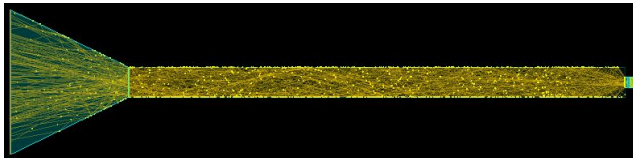


- As observed for the hpDIRC, different prism designs have only a minor impact on PID performance in the xpDIRC.

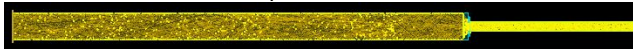
# Performance plots for different Prism design and shorter prism depth



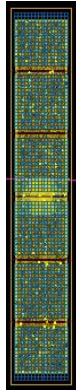
Prism depth 50 mm



Prism depth 100 mm



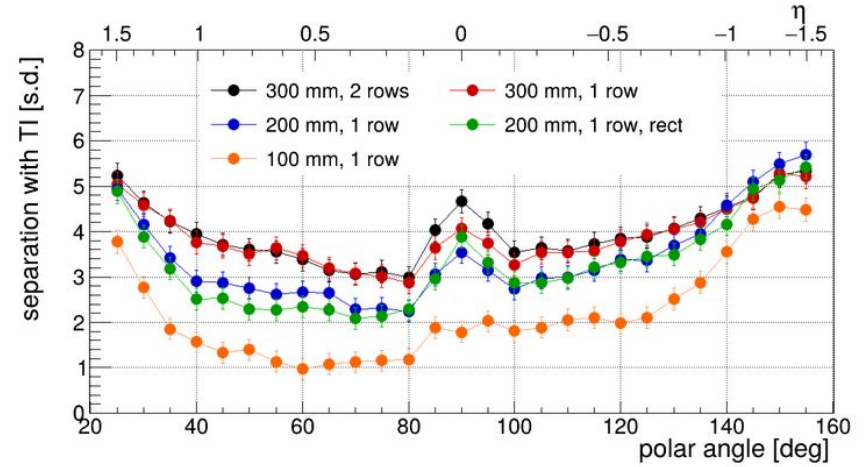
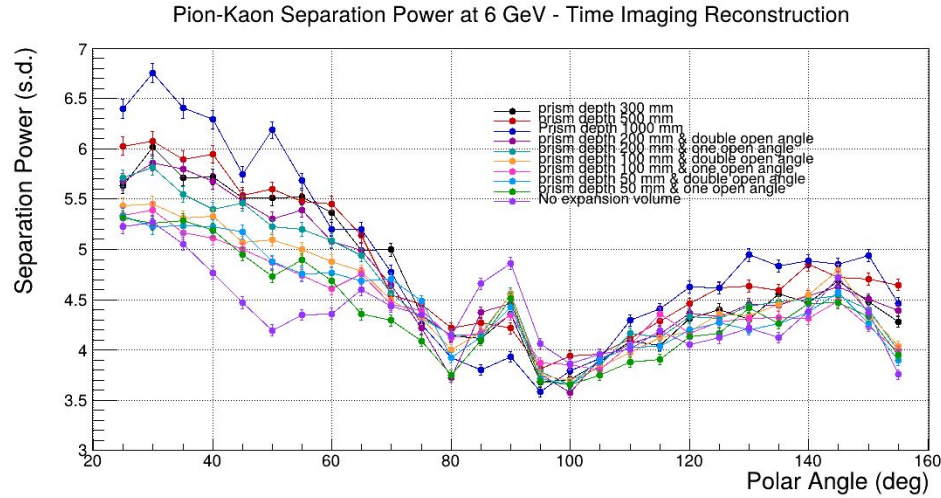
No expansion volume



No expansion volume  
Front view of sensors

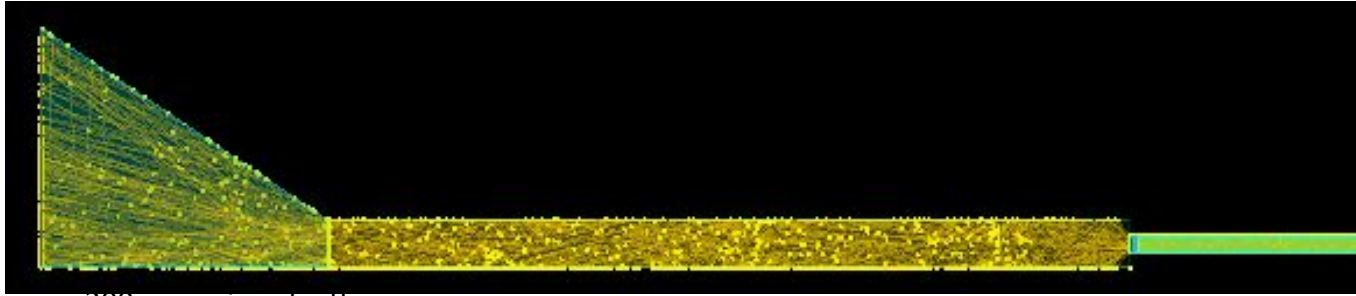
- Prism depth = 500 mm,  $r_1 = 70$  mm,  $r_2 = 60$  mm
  - Prism depth = 300 mm,  $r_1 = 65$  mm,  $r_2 = 55$  mm
  - Prism depth = 1000 mm,  $r_1 = 80$  mm,  $r_2 = 70$  mm
  - Prism depth = 200 mm,  $r_1 = 75$  mm,  $r_2 = 62$  mm
  - Prism depth = 100 mm,  $r_1 = 80$  mm,  $r_2 = 65$  mm
  - Prism depth = 50 mm,  $r_1 = 73$  mm,  $r_2 = 59$  mm
  - No expansion volume,  $r_1 = 79$  mm,  $r_2 = 62$  mm
- Design: EV+Plate+SL+bar
- Plate thickness 50 mm

# Performance plots for different Prism design and shorter prism depth



- The impact of a reduced prism depth is more pronounced in the hpDIRC than in the xpDIRC.

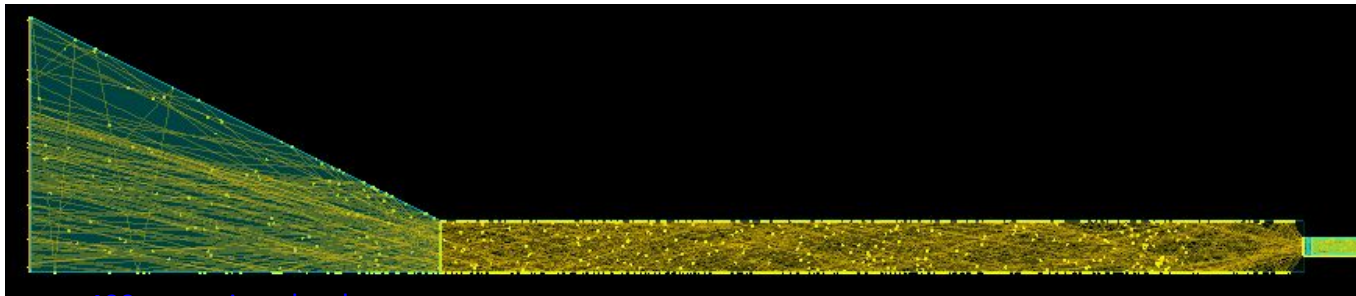
# Prism depth study



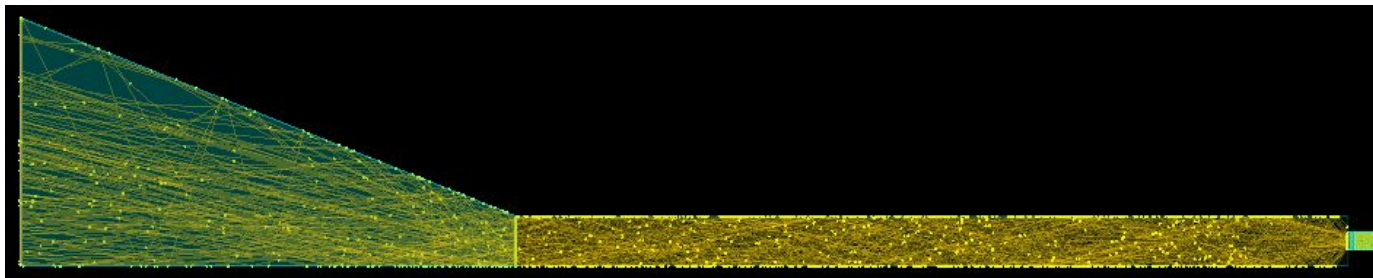
300 mm prism depth

Plate length = 840 mm  
Plate thickness = 50 mm  
Design: EV+Plate+SL+bar  
Magnetic field on  
Pdf = 45k

Radii scan in 5 mm  
interval

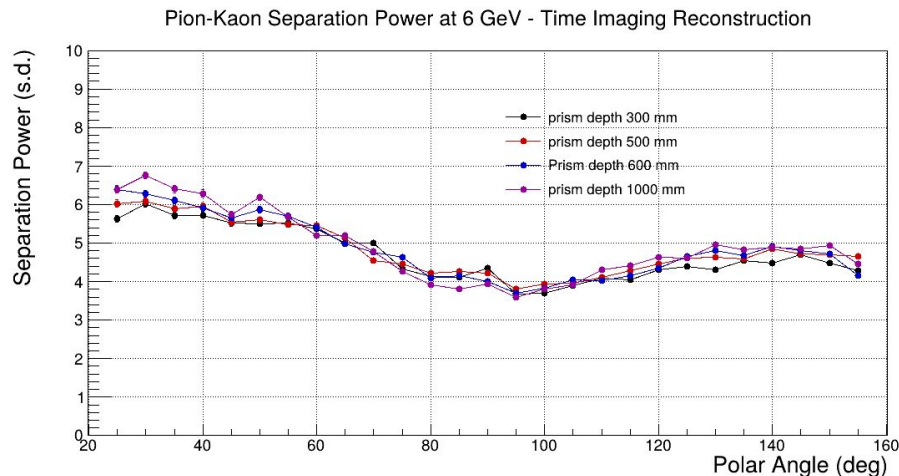
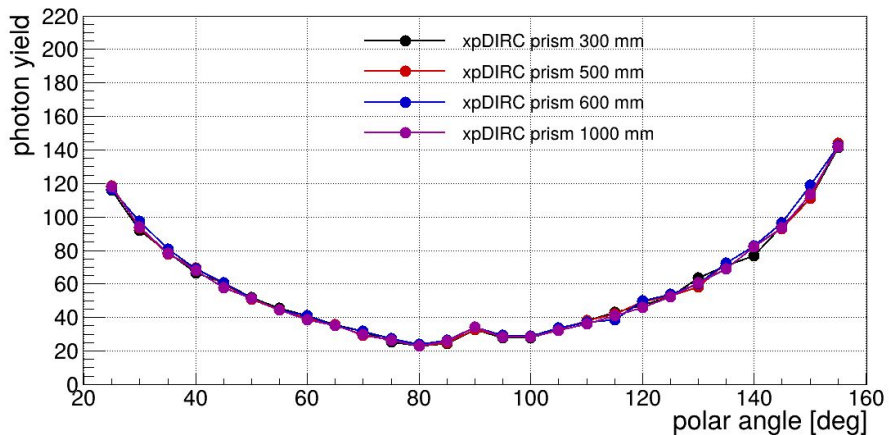


400 mm prism depth



500 mm prism depth

# Performance plots for Different Prism Depths (xpDIRC, 24 PMTs)



Prism depth = 500 mm,  $r_1 = 70$  mm,  $r_2 = 60$  mm

Prism depth = 300 mm,  $r_1 = 65$  mm,  $r_2 = 55$  mm

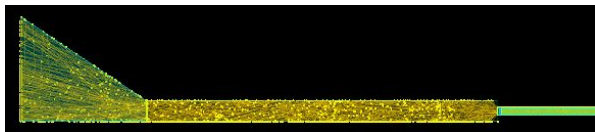
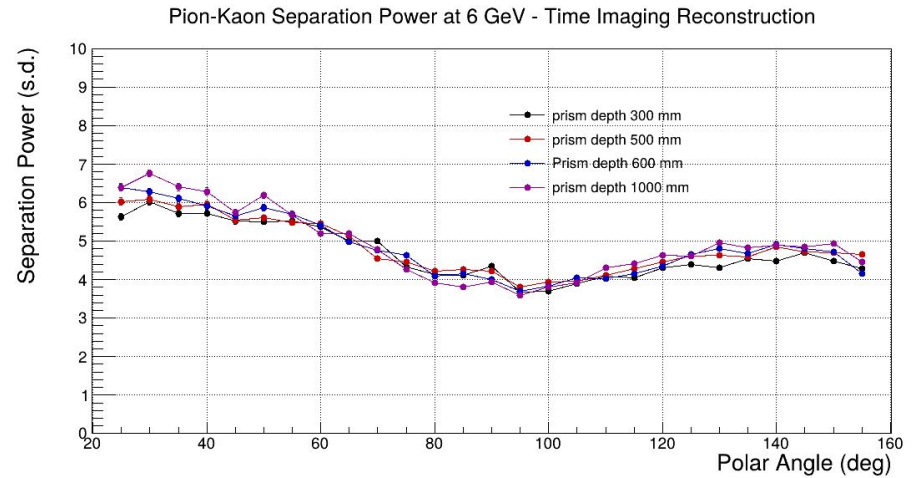
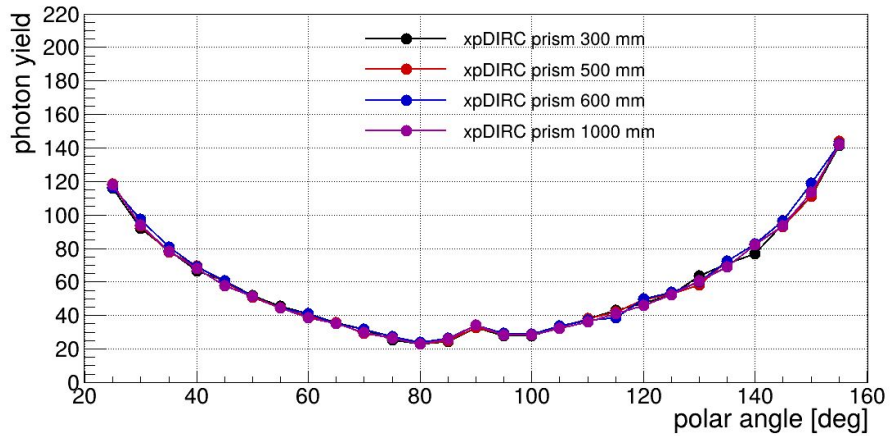
Prism depth = 600 mm,  $r_1 = 90$  mm,  $r_2 = 75$  mm

Prism depth = 1000 mm,  $r_1 = 80$  mm,  $r_2 = 70$  mm

Design: EV+Plate+SL+bar

Plate thickness 50 mm

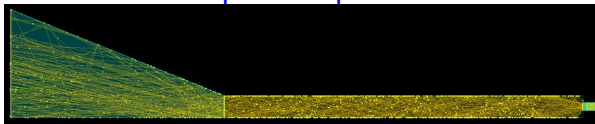
# Performance for Different Prism Depths (xpDIRC, 24 PMTs)



300 mm prism depth



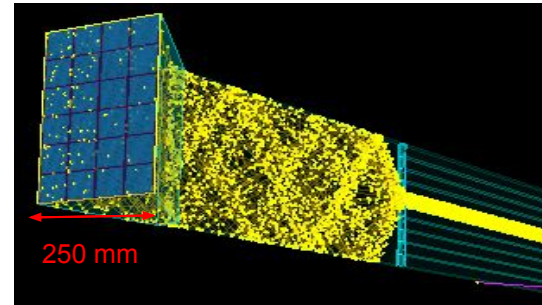
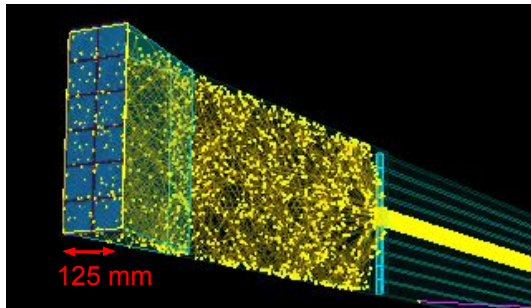
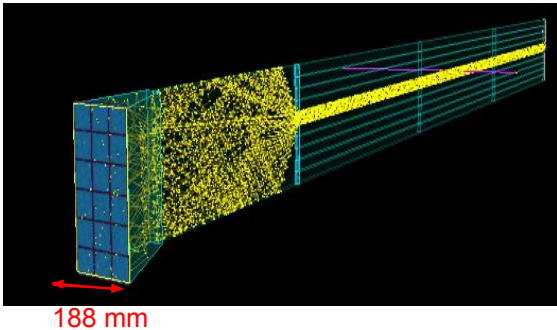
400 mm prism depth



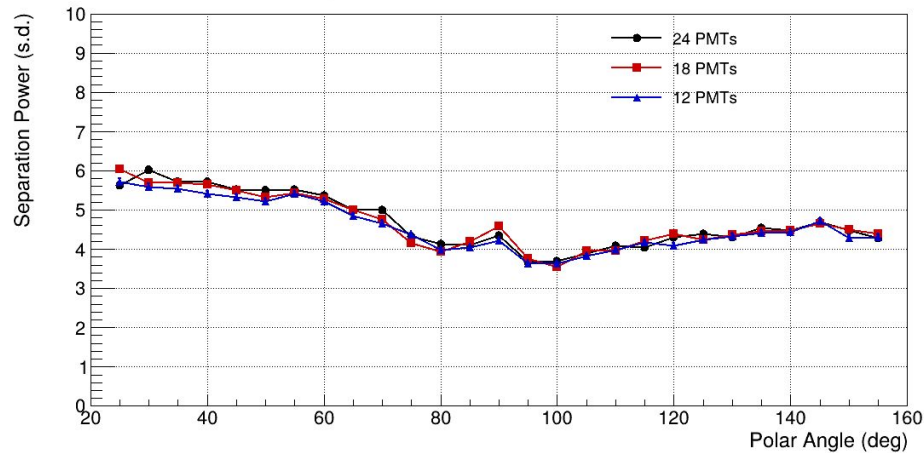
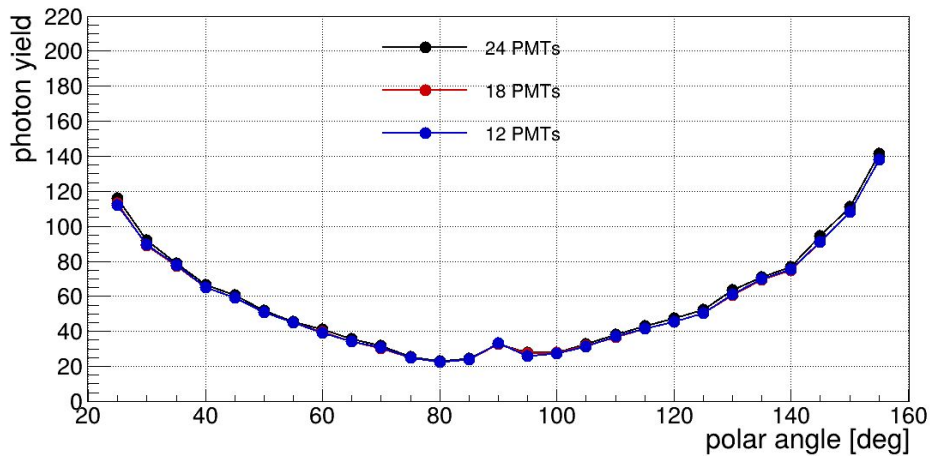
500 mm prism depth

- Increasing the prism depth has only a limited impact on the xpDIRC, as the plate already serves as a pre-expansion volume.

# Prism Height Study

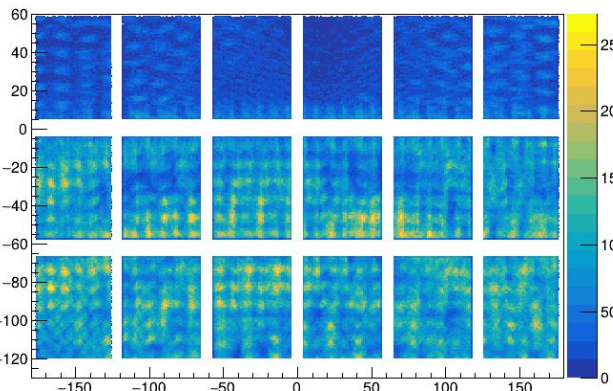


Pion/Kaon Separation Power at 6 GeV (TI Reconstruction)



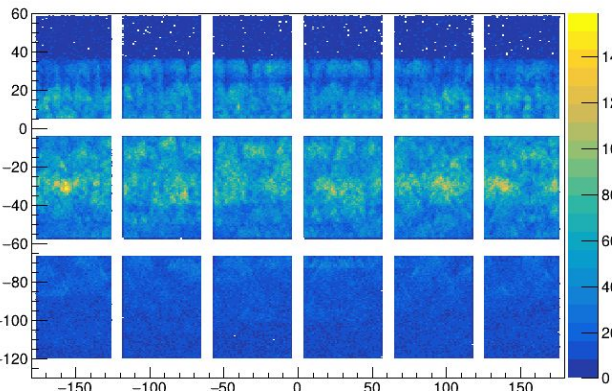
- Results show only a **small impact on performance**.
- A shorter prism could reduce the required sensor area.

PrtEvent.fHitArray.fPosition.Px():PrtEvent.fHitArray.fPosition.Py()



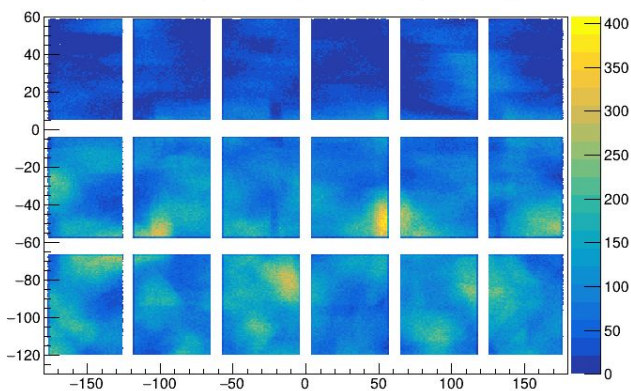
30 deg.

PrtEvent.fHitArray.fPosition.Px():PrtEvent.fHitArray.fPosition.Py()



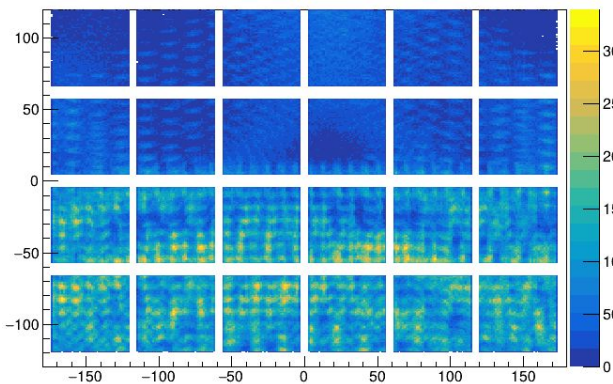
90 deg.

PrtEvent.fHitArray.fPosition.Px():PrtEvent.fHitArray.fPosition.Py()

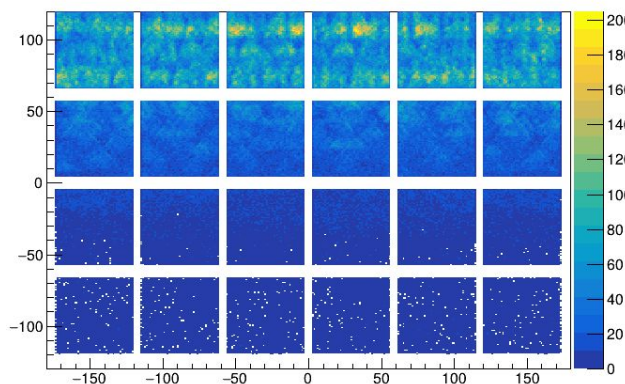


150 deg.

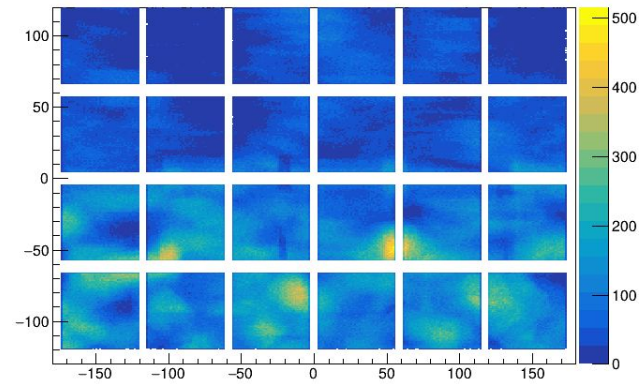
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PrtEvent.fHitArray.fPosition.Px():PrtEvent.fHitArray.fPosition.Py()

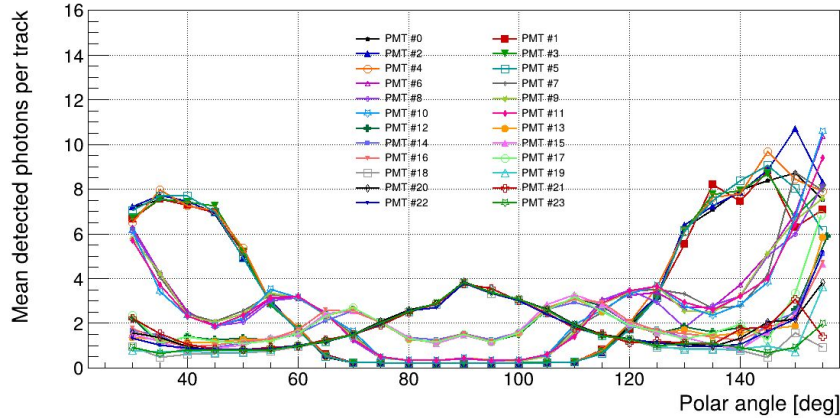


PrtEvent.fHitArray.fPosition.Px():PrtEvent.fHitArray.fPosition.Py()

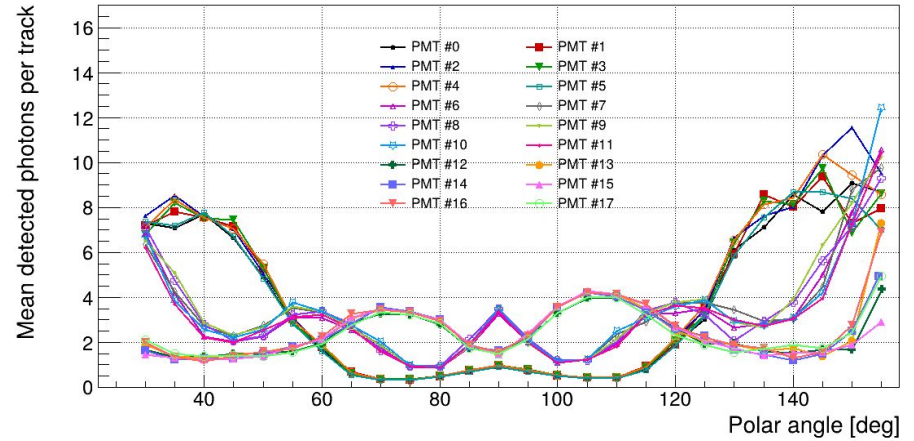


# PMT Occupancy

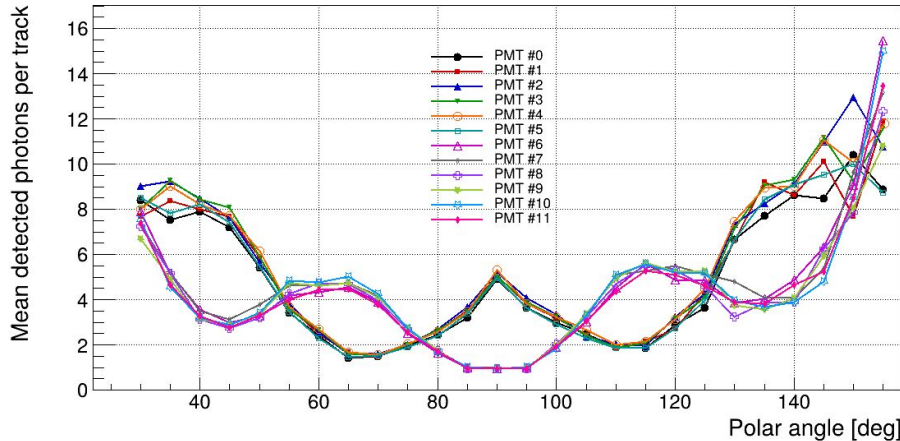
24 PMTs: detected photons per track vs polar angle



18 PMTs: detected photons per track vs polar angle



12 PMTs: detected photons per track vs polar angle

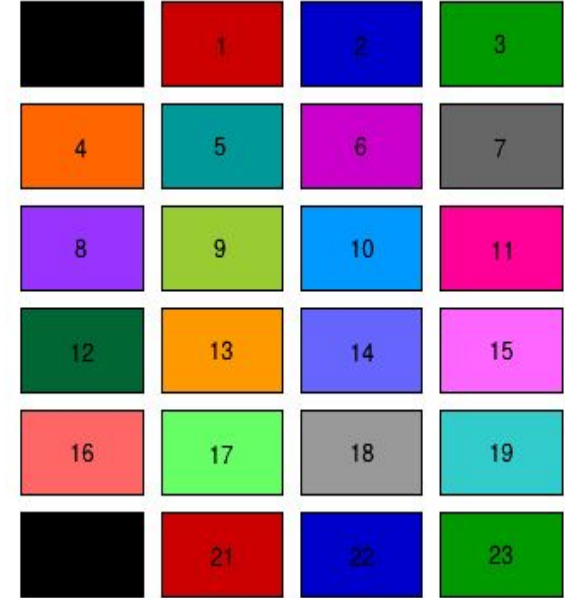
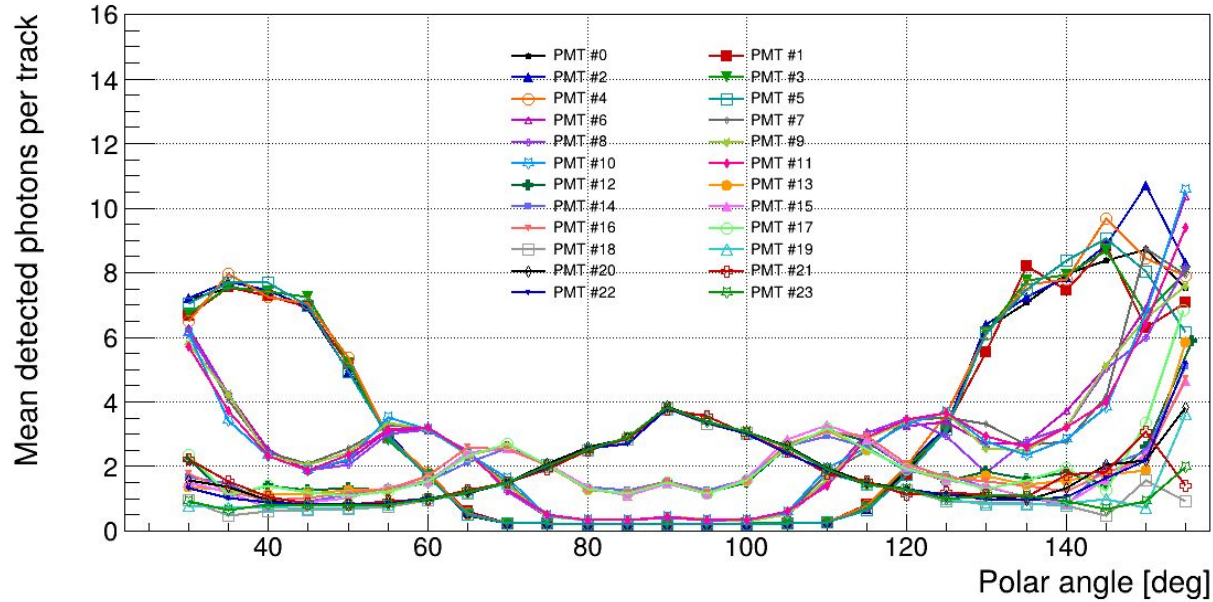


Events = 50k  
 xpDIRC Geometry (EV + Plate+SL+bars)  
 Sensor: Mcp\_Pmt  
 Phi angle is not zero  
 Magnetic field on  
 Track hitting in the middle bar

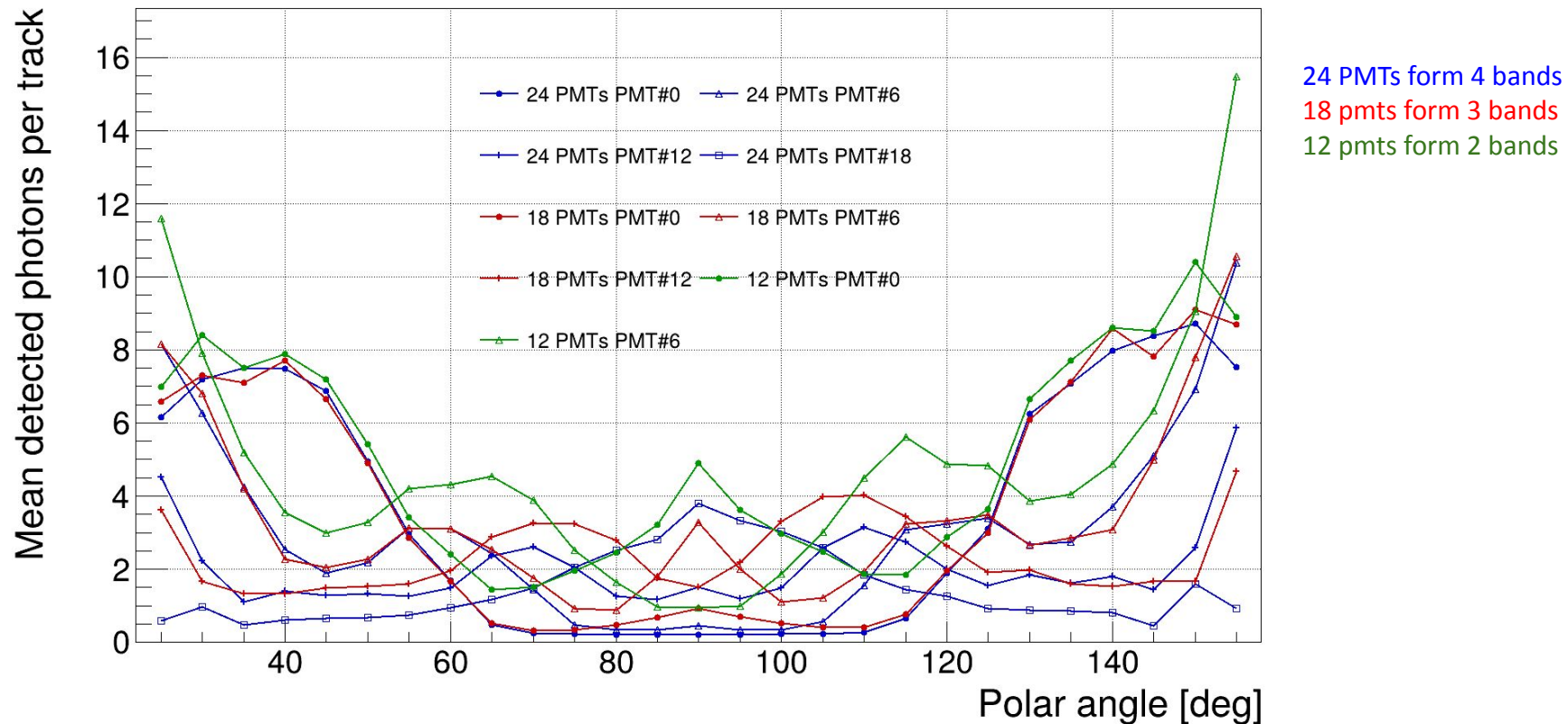
Mean detected photons per track per pmt (xpDIRC)

# Mean detected photons per track per pmt (xpDIRC)

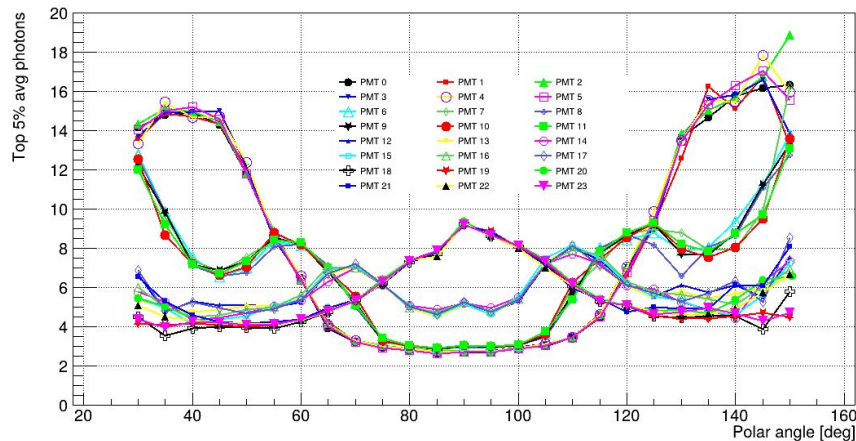
24 PMTs: detected photons per track vs polar angle



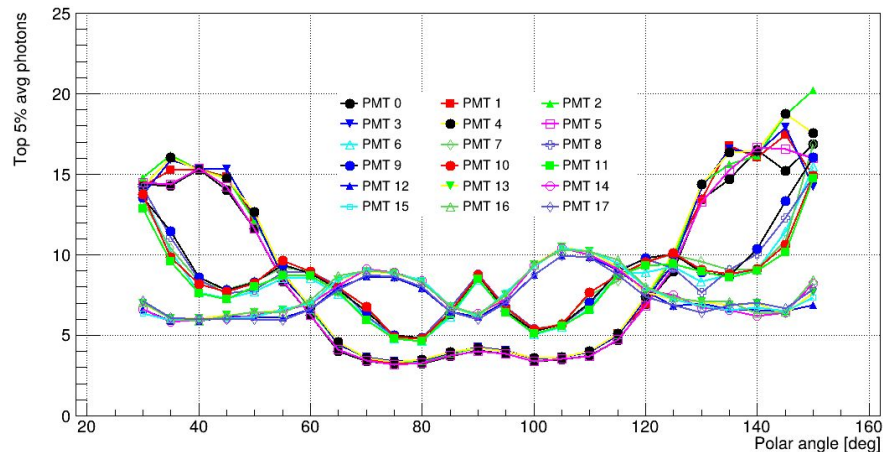
# Selected PMTs: Mean detected photons per track vs polar angle



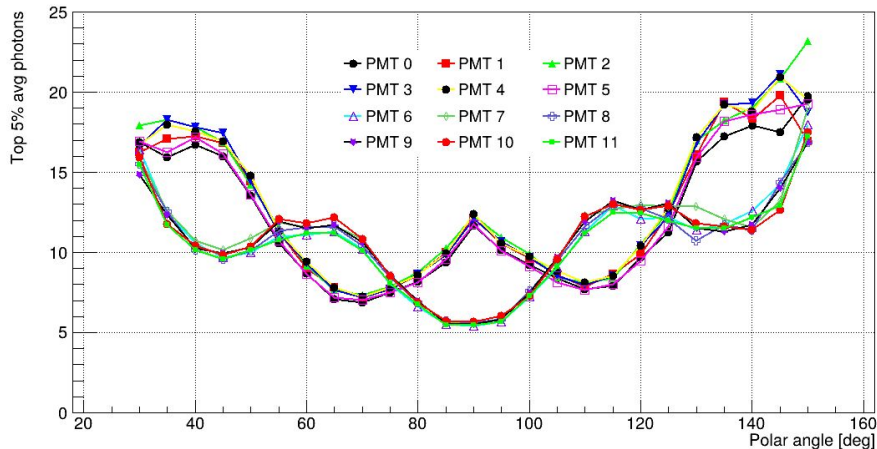
24 PMTs: Top 5% average photons per PMT



18 PMTs: Top 5% average photons per PMT



12 PMTs: Top 5% average photons per PMT



Events = 50k  
 xpDIRC Geometry (EV + Plate+SL+bars)  
 Sensor: Mcp\_Pmt  
 Phi angle is not zero  
 Magnetic field on  
 Track hitting in the middle bar

Maximum detected photons  
 per track per pmt (xpDIRC)

# Sensor Coverage study

# 6 x 4 arrangement of Mcp\_Pmt

## 6x4 Sensor arrangement

- ❖ Total area =  $6 \times 4 \times 61.5 \times 60$  mm<sup>2</sup>  
= 88,560 mm<sup>2</sup>
- ❖ Active area =  $6 \times 4 \times 53 \times 53$  mm<sup>2</sup>  
= 67416 mm<sup>2</sup>

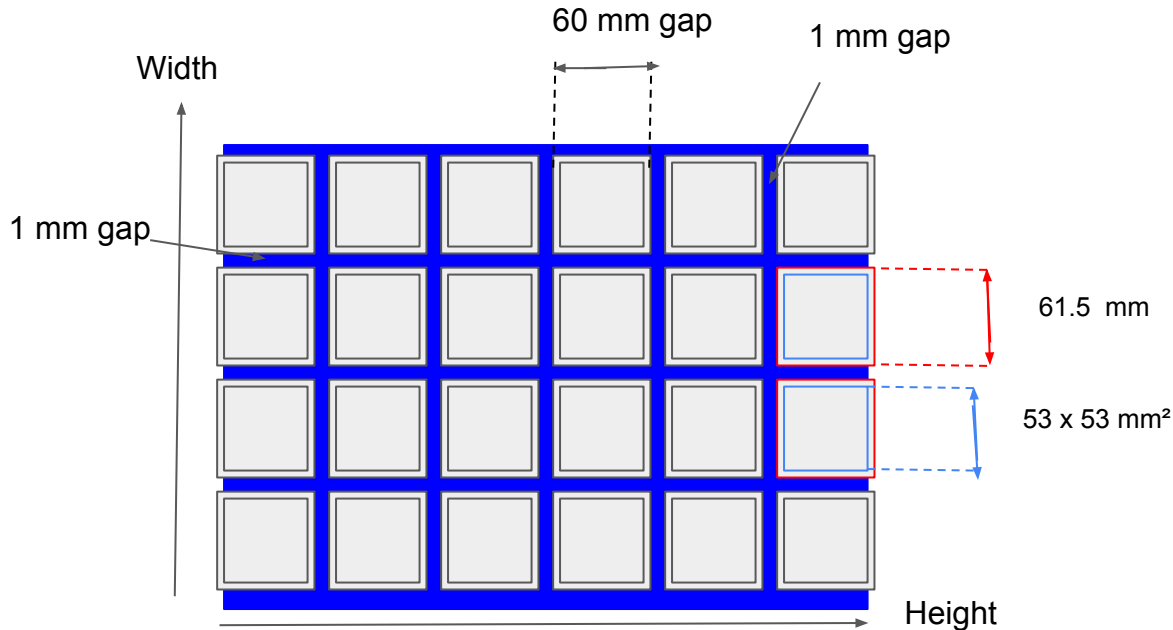
Prism Opening angle = 33.8 deg  
Prism width = 250.83 mm  
Prism height = 351.35 mm

For 6 x 4 pmts:

Width = 249 mm (inside the plane)

Height = 365 mm

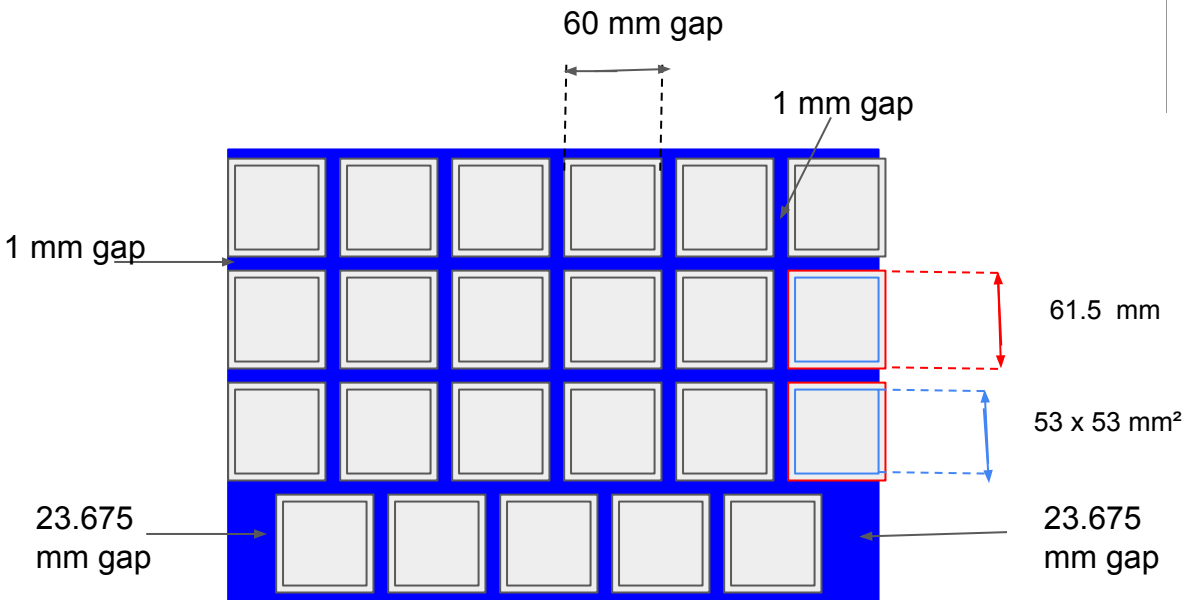
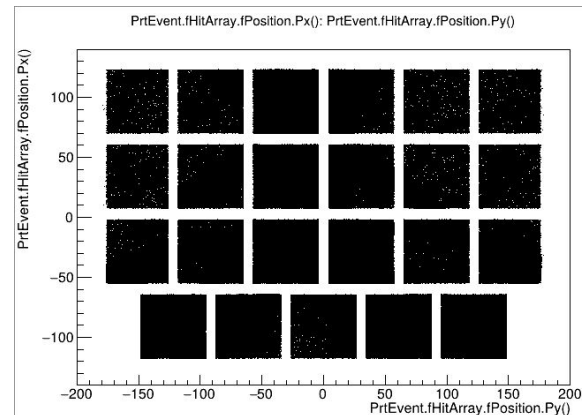
Stick out = 6.825 mm (along height)



# 1 pmt removed from one column

## 6x3 + (5 x 1) Sensor arrangement

- ❖ Total area =  $6 \times 3 \times 61.5 \times 60 + (5 \times 1 \times 61.5 \times 60)$  mm<sup>2</sup>  
= 84870 mm<sup>2</sup>
- ❖ Active area =  $(6 \times 3 \times 53 \times 53) + (5 \times 53 \times 53)$  mm<sup>2</sup>  
= 64607 mm<sup>2</sup>



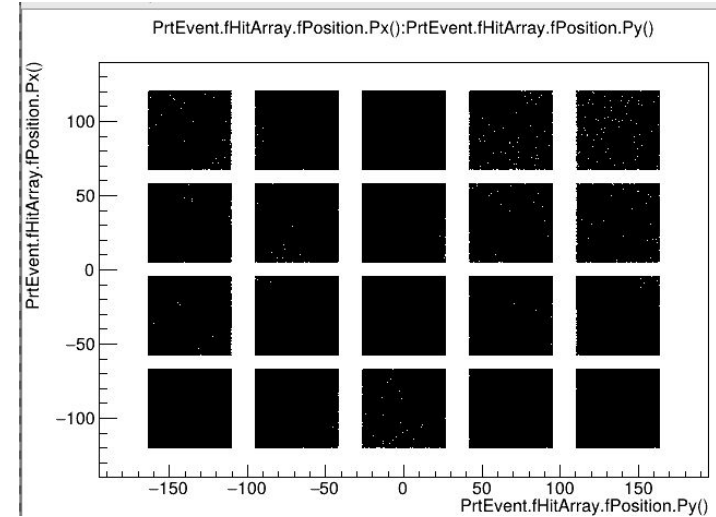
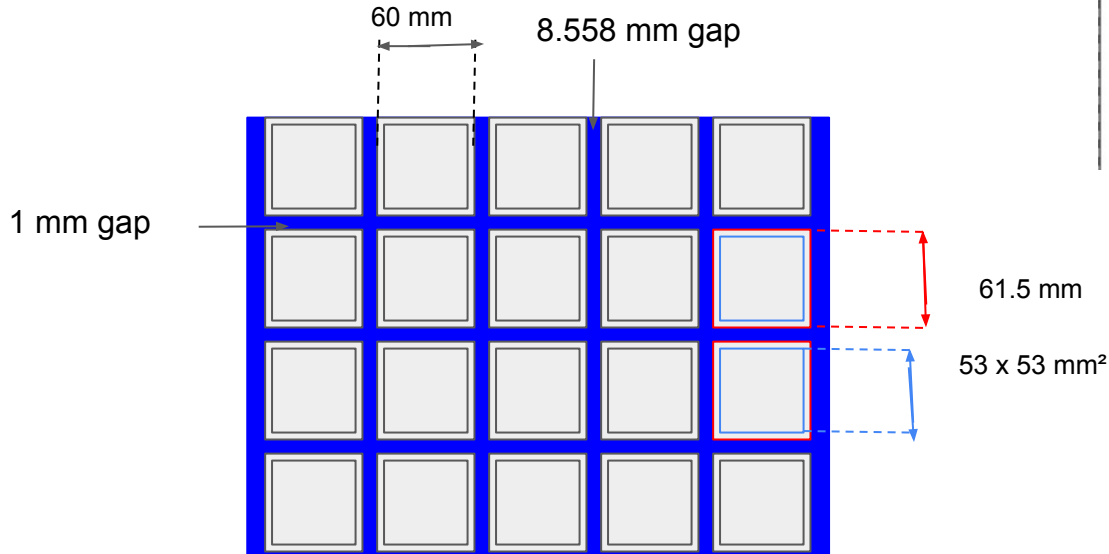
# 5 x 4 Symmetrical Spread Layout of Mcp\_Pmt

## 5x4 Sensor arrangement

- ❖ Total area =  $5 \times 4 \times 61.5 \times 60 \text{ mm}^2$   
=  $73,800 \text{ mm}^2$
- ❖ Active area =  $5 \times 4 \times 53 \times 53 \text{ mm}^2$   
=  $56,180 \text{ mm}^2$

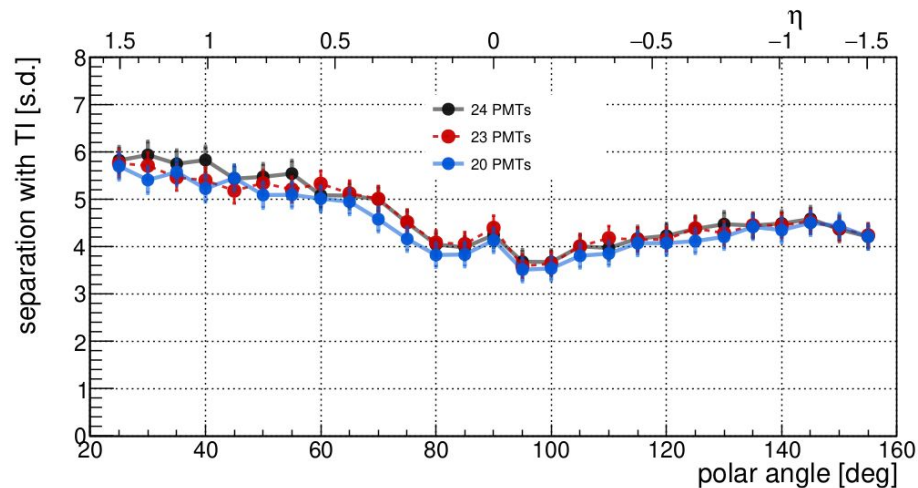
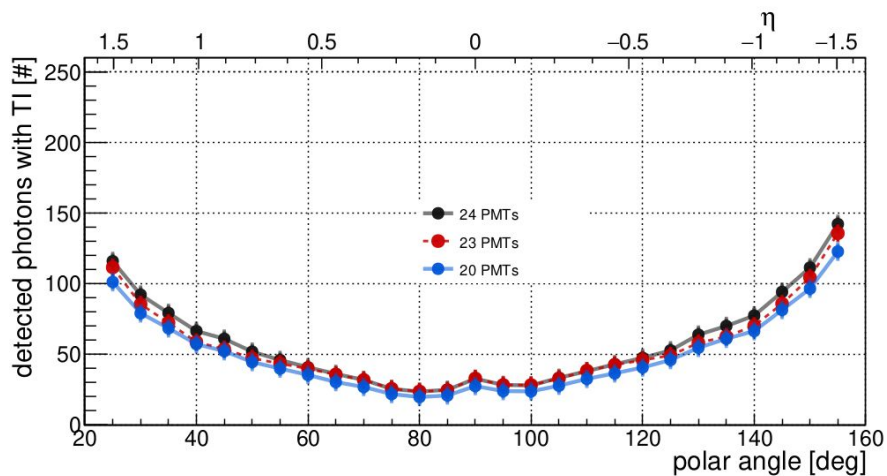
**Mcp\_pmt =  $61.5 \times 60 \text{ mm}^2$**

gap x = 1 , gap y = 8.55833



# Impact of Sensor Coverage on Performance

- Systematically **reduced the number of sensors** to study the impact on performance.
- Impact on PID performance in agreement with expectations.

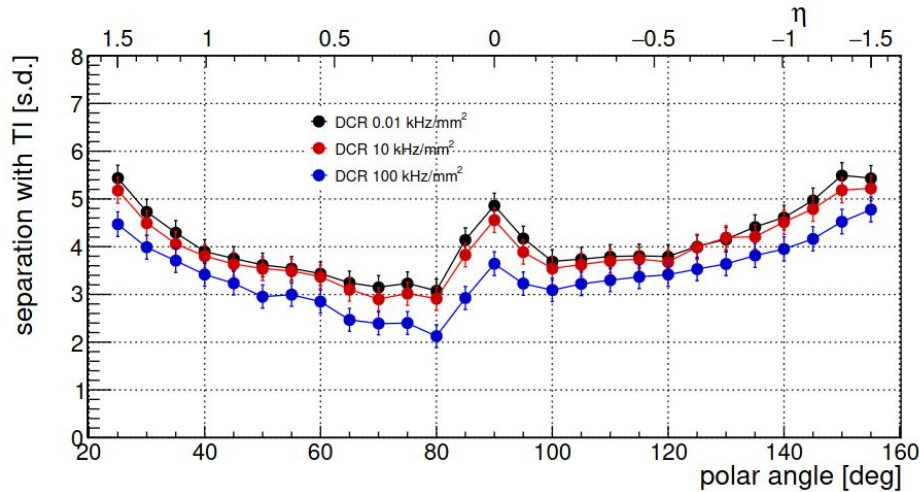


# xpDIRC Performance under Varying Dark Count Rates

# xpDIRC Performance: SiPM Dark Count Rates

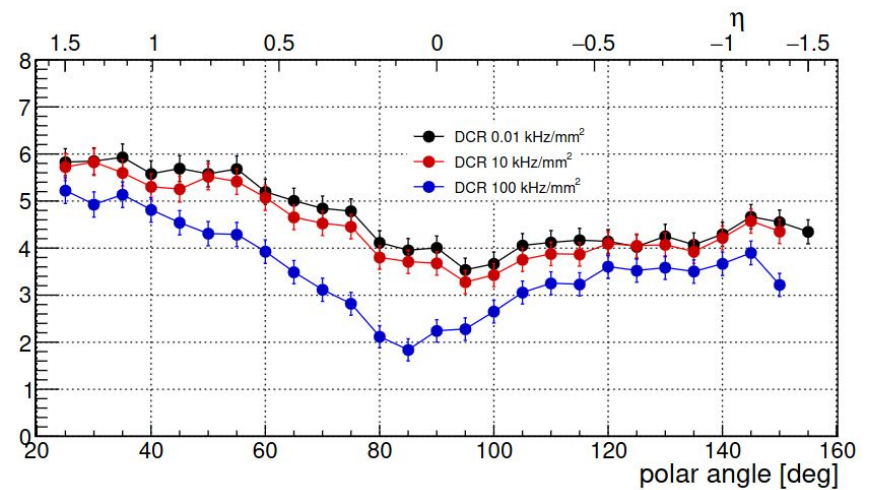
- Dark Count Rate (DCR) expected to have significant impact on detector performance.
- Performance degradation due to DCR not dramatic! (but more pronounced in the plate-based xpDIRC geometry compared to the bar-based hpDIRC)

$\pi/K$  separation power at 6 GeV/c



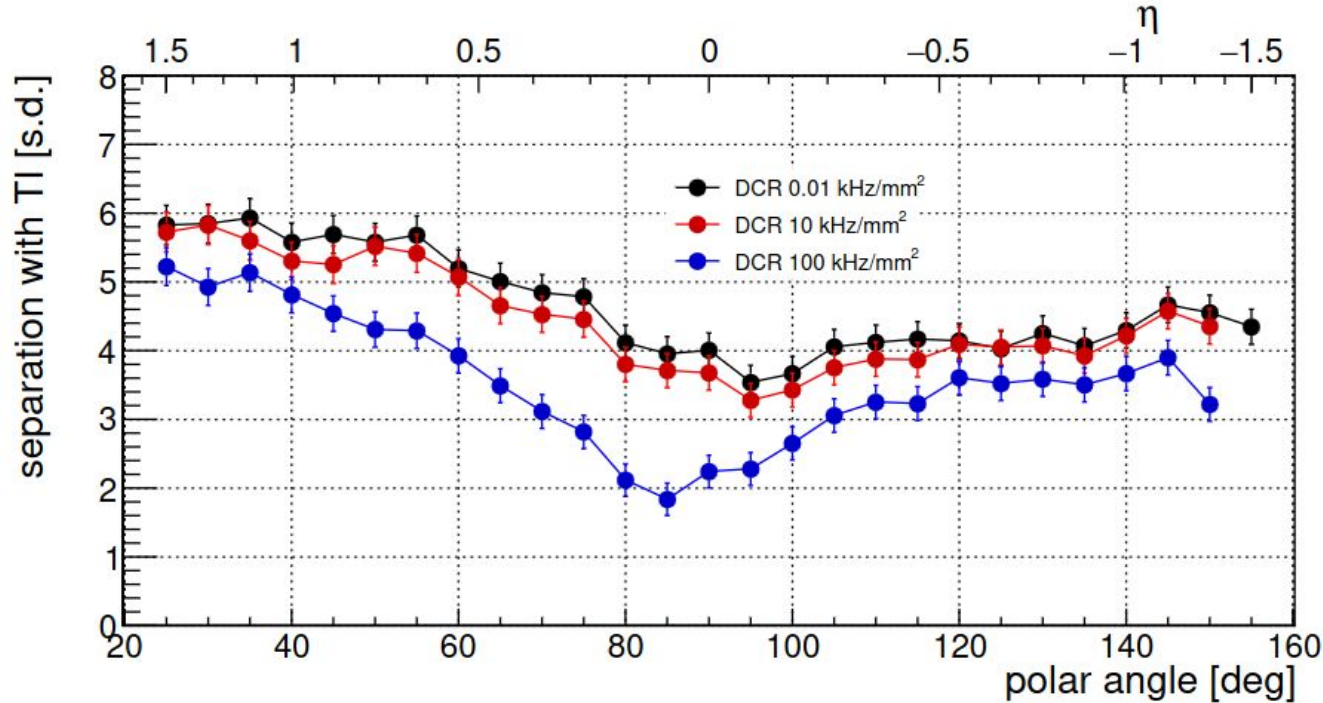
hpDIRC

$\pi/K$  separation power at 6 GeV/c



xpDIRC

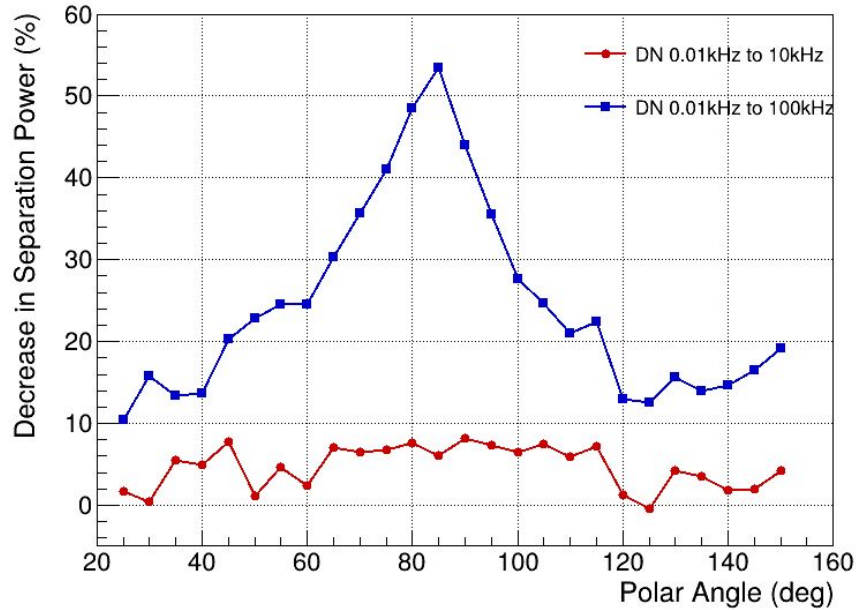
# xpDIRC Performance under Varying Dark Count Rates



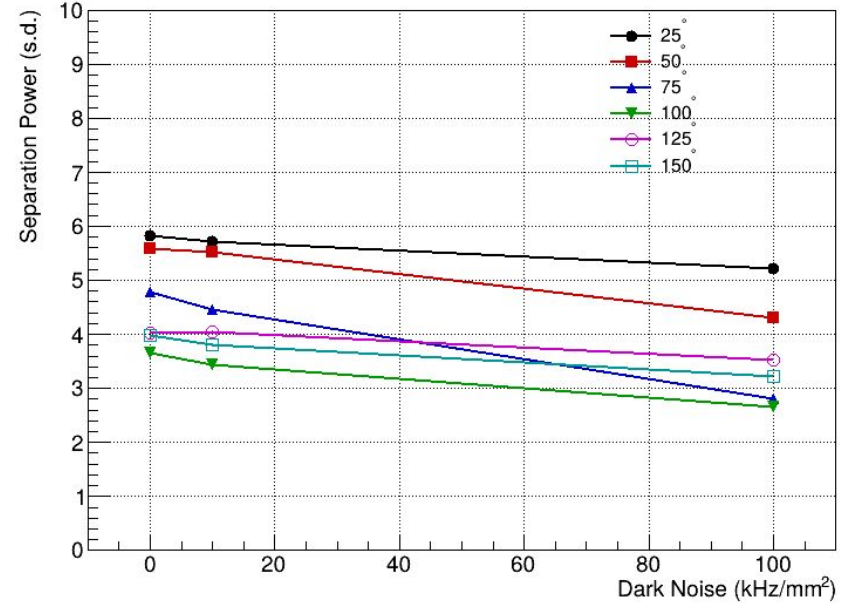
xpDIRC:  
Design: spherical lens in between bars and plate  
Lens,  $r_1 = 65$ ,  $r_2 = 55$   
Events = 50000  
Pdf = 45k  
Sensor: HRPPD  
Time res = 100 ps  
Trackingres = 0.5 mrad  
Magnetic field = 1.7 T

# Separation power as a function of dark count rate

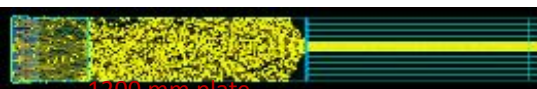
Percentage Decrease in Separation Power (xpDIRC)



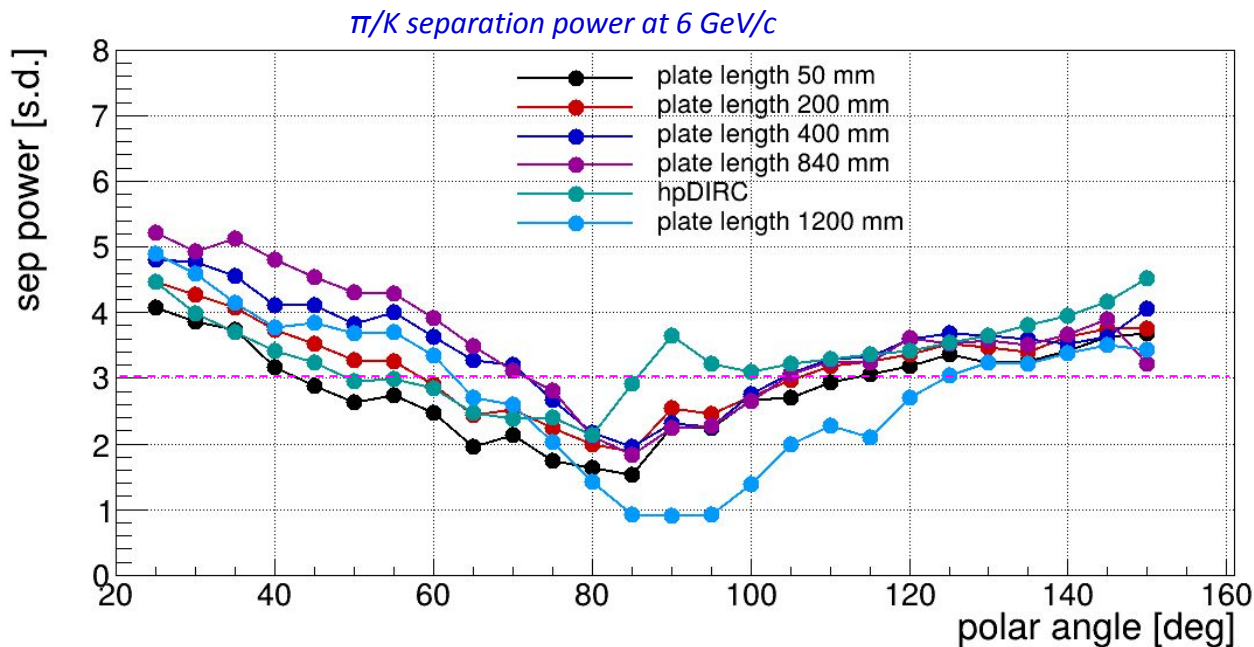
Separation Power vs Dark Noise (xpDIRC)



# DCR impact on xpDIRC performance for different plate length



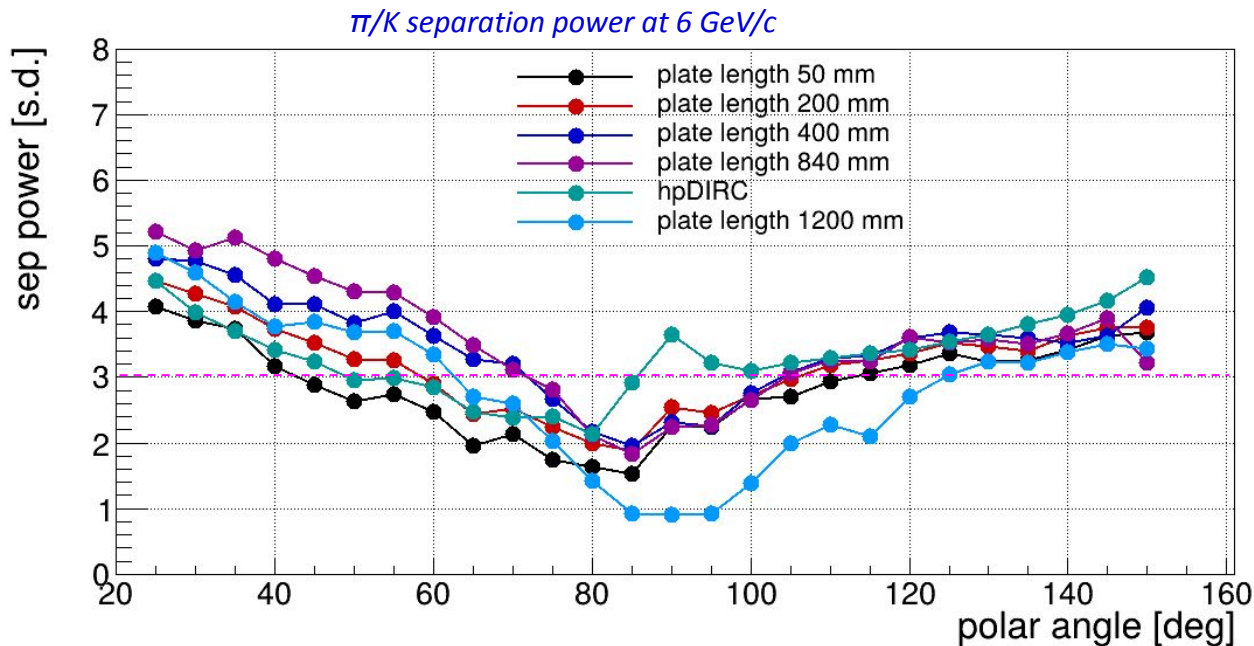
- Optimized the focusing optics for each plate-length configuration.
- Performed full reconstruction for all configurations.
- Compared the hybrid xpDIRC performance with the baseline hpDIRC design.

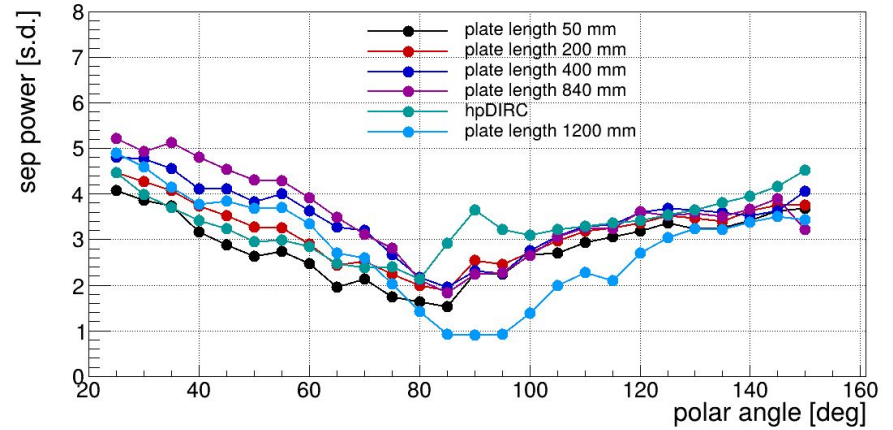
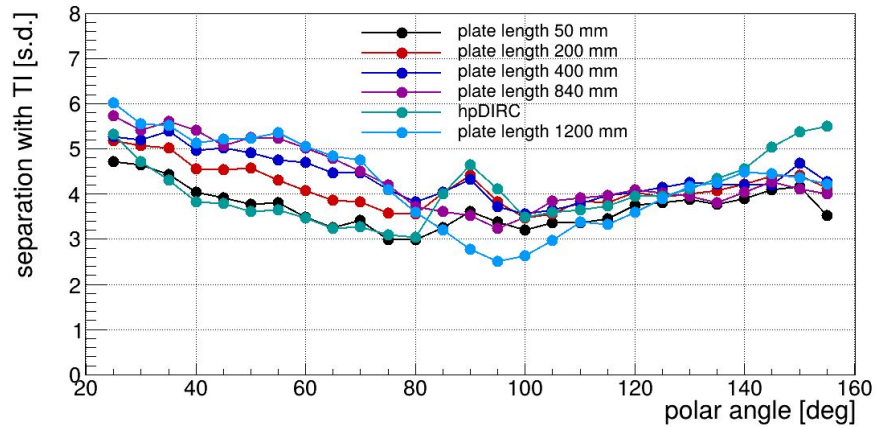


# DCR impact on xpDIRC performance for different plate length



- Optimized the focusing optics for each plate-length configuration.
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- Compared the hybrid xpDIRC performance with the baseline hpDIRC design.

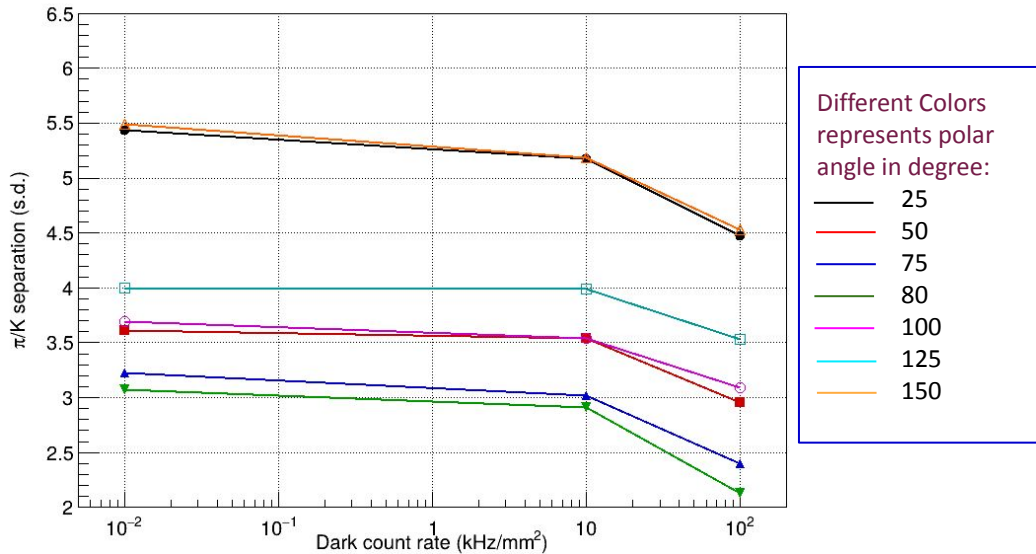




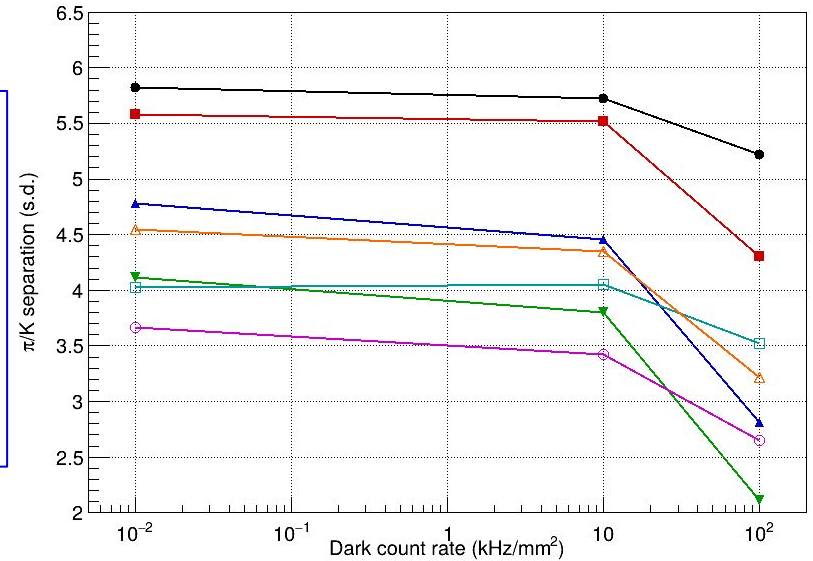
# xpDIRC Performance: SiPM Dark Count Rates

- Dark Count Rate (DCR) expected to have significant impact on detector performance.
- Performance degradation due to DCR not dramatic! (but more pronounced in the plate-based xpDIRC geometry compared to the bar-based hpDIRC)

hpDIRC: Separation Power vs Dark Count Rate

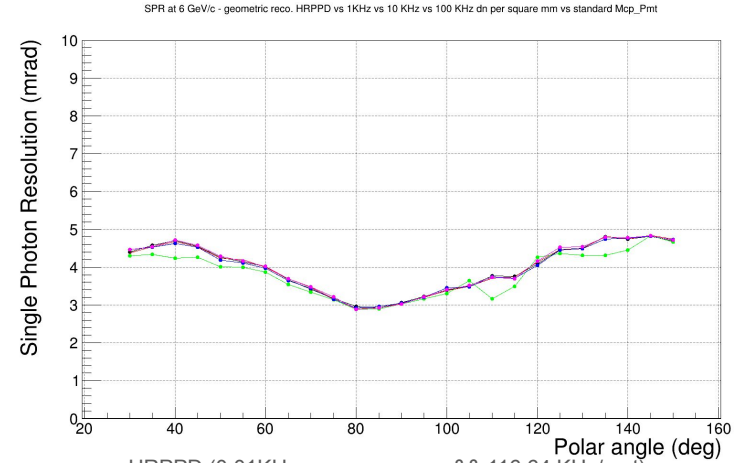
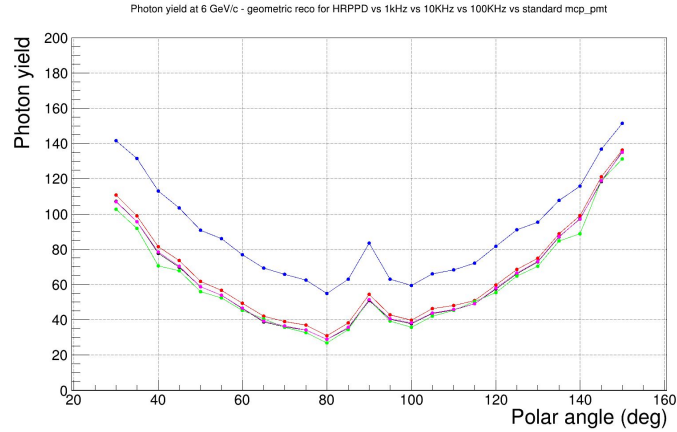


xpDIRC: Separation Power vs Dark Count Rate



# Backup

# Studying Photon Yield - changing time cut



HRPPD (0.01KHz per square mm && 116.64 KHz/pmt)

1KHz DN per square mm, **11664** KHz/Pmt

10KHz DN per square mm, **116640** KHz/Pmt

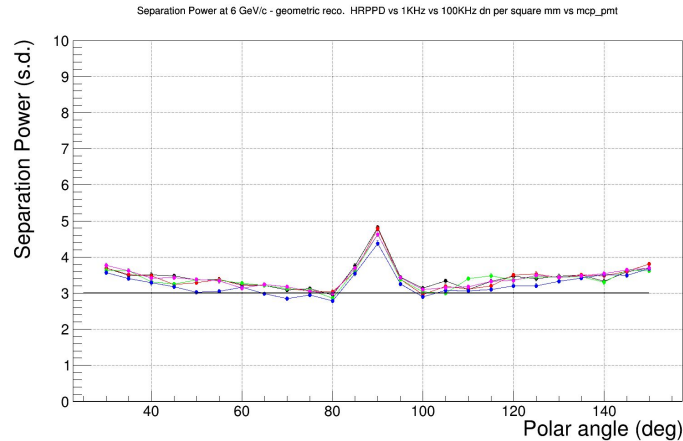
100KHz DN per square mm, **1166400** KHz/Pmt

Standard mcp\_pmt (0.01KHz per square mm && 28.09 KHz/pmt)

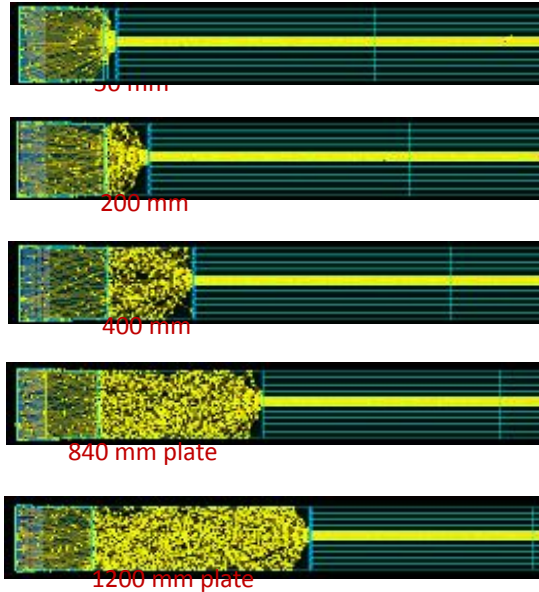
For Mcp\_pmt, pixel size (16 x 16) = 3.3125 x 3.3125 mm<sup>2</sup>, active area =53  
 For HRPPD, pixel size (32 x 32) = 3.375 x 3.375 mm<sup>2</sup>, active area = 108

timecut 0.5 ns

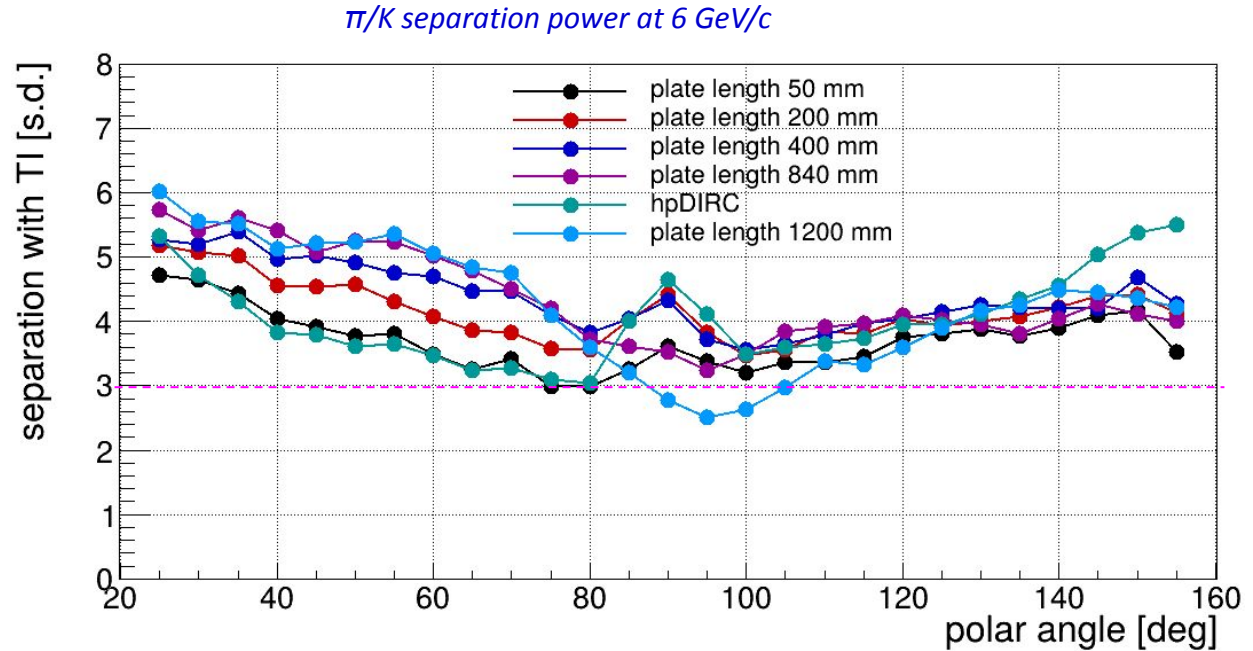
Date: August 22, 2024



# xpDIRC Pre Expansion volume Plate length study

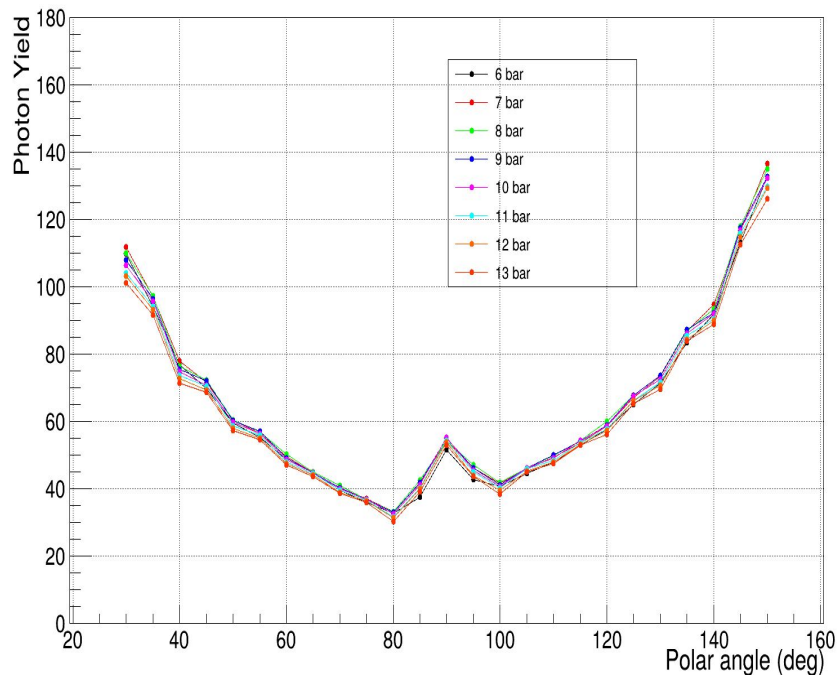


- Optimized the focusing optics for each plate-length configuration.
- Performed full reconstruction for all configurations.
- Compared the hybrid xpDIRC performance with the baseline hpDIRC design.

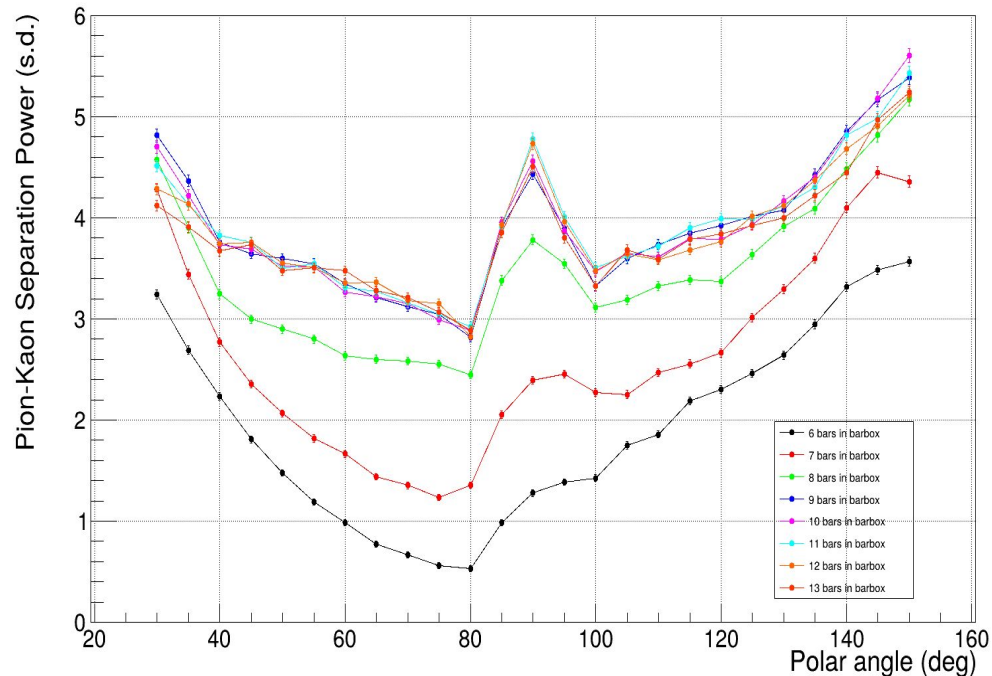


# Performance Plots for B-field in widening bar

## Photon Yield at 6 GeV with B-field (TI) in widening bar



## Pion/Kaon Separation Power at 6 GeV with B-field (TI)



# hpDIRC Hit Pattern Breakdown using last reflection inside Prism (30° polar angle)

