Light Guide Design for Wide Field Imaging Cherenkov Telescope

Wang.Chong

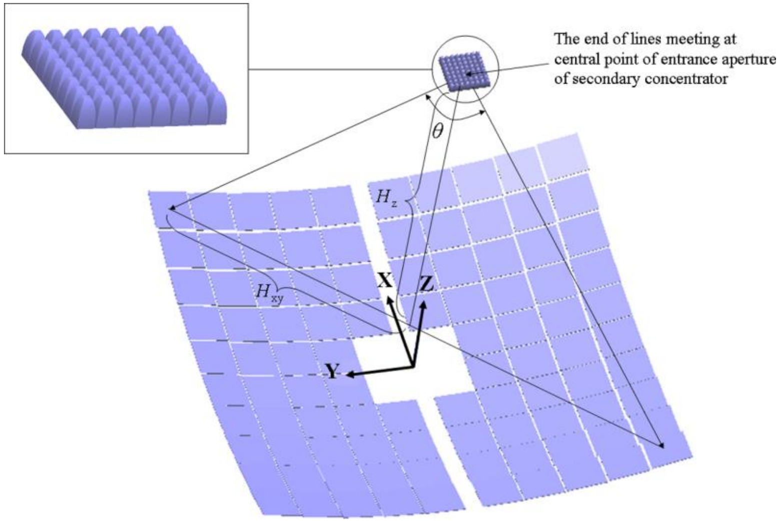
2017.1

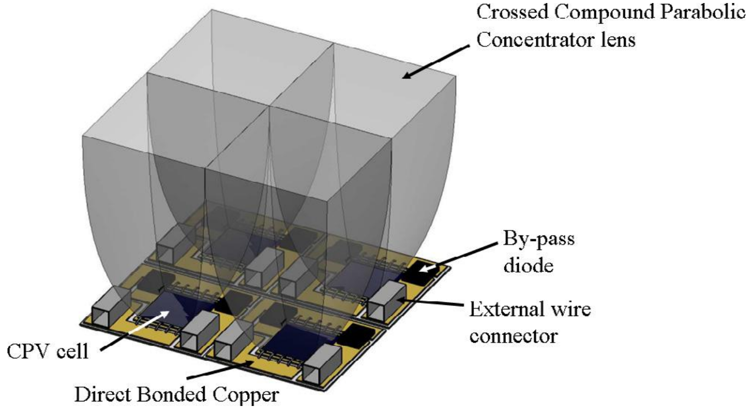
Outline

- *Background*
- *Motivation*
- *Light guide design for wide field Cherenkov telescope*
- *Performances*
- *Further works*

Background

- *The compound parabolic concentrator (CPC) is one of non-imaging devices which has been explored for various applications since 1960s.*



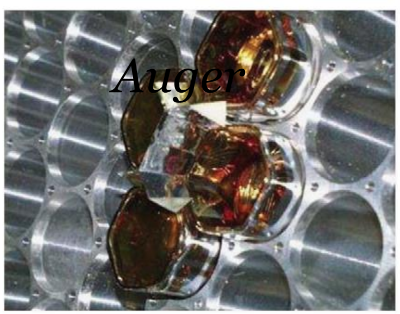


Background

- *Nonimaging light collectors are used in VHE gamma-ray astronomy to concentrate light on the photocathodes of the photomultiplier tubes and to reduce the background light from the night sky.*

Light concentrator for Auger

a



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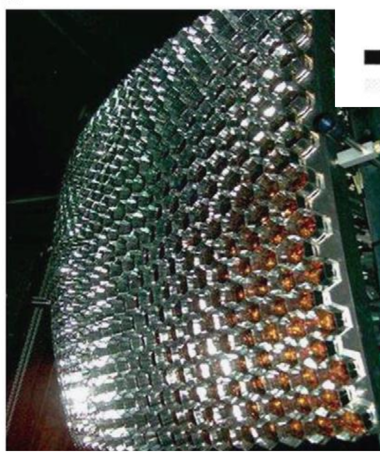
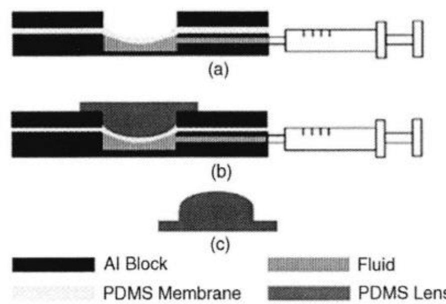
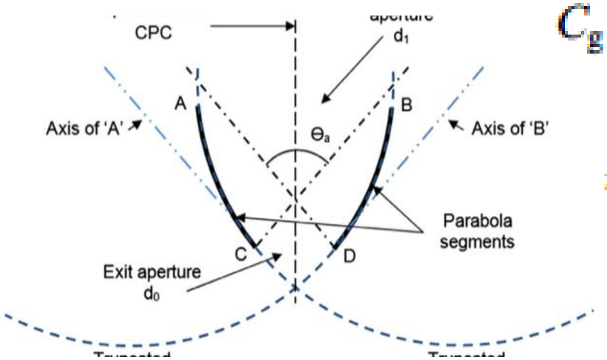




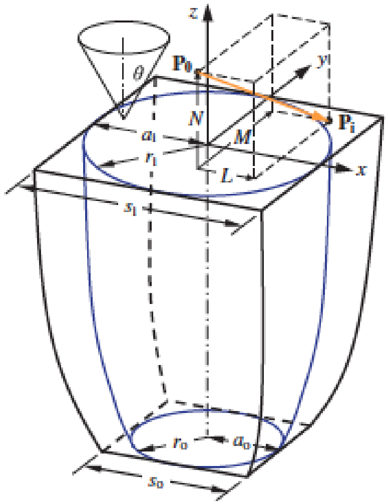
for CTA SST

- *Principle*



$$C_g = \frac{A_i}{A_o} = \frac{n r_i^2 \tan(\pi/n)}{n r_o^2 \tan(\pi/n)} = \frac{1}{\sin^2 \theta_i}$$

$$\eta_{opt} = Q_o / Q_i$$



- *optimizing criterion*

•*Dead area*

•*Photon collection efficiency*

•*Background suppression*

•*Cross talk*

•*Price*

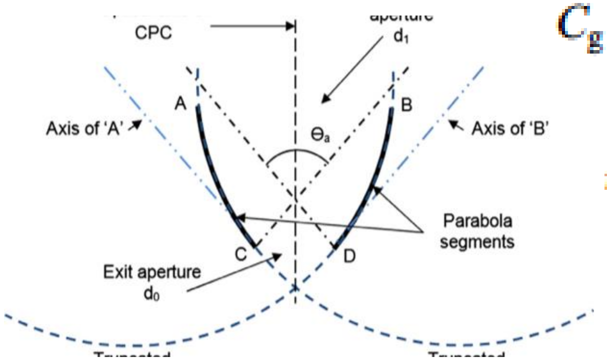
•*Homogenous of photon distribution density*

•*Cherenkov image reconstruction*

Motivation

- *Reflective light concentrators are frequently used at the focal plane of gamma-ray telescopes in order to reduce the size of the dead area caused by the geometries of the photodetectors, as well as to reduce the amount of stray light entering at large field angles.*
- *FACT, CTA-SST, AUGER*
- *LHAASO WFCTA*

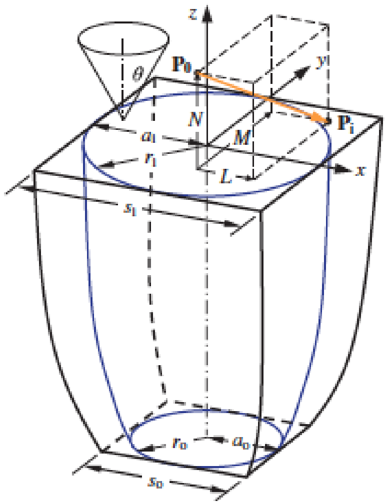
- *Principle*



$$C_g = \frac{A_i}{A_o} = \frac{n r_i^2 \tan(\pi/n)}{n r_o^2 \tan(\pi/n)} = \frac{1}{\sin^2 \theta_i}$$

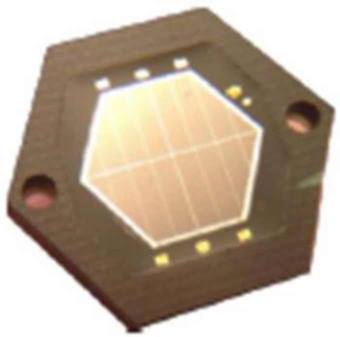
$$\eta_{opt} = Q_o / Q_i$$

- *Skew ray tracing*

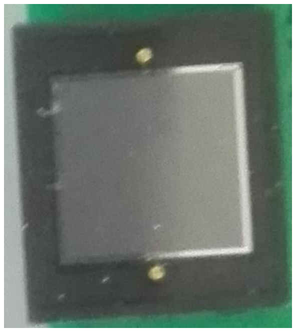


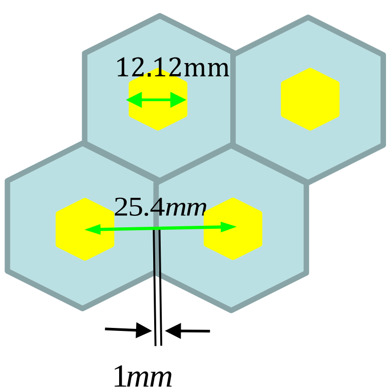
Requirements for LHAASO WFCT

- *Geiger-mode SiPM*
- *The price per unit sensitive area of SiPM is still higher than for more conventional photosensors, such as photomultiplier tubes. Therefore, a higher area concentration ratio is desired than in previous experiments.*

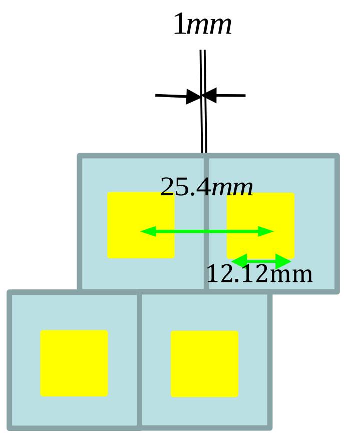


S13360-6025C





Hexagonal Light Cones



Square Light Cones

- *Dead area*
- *Photon collection efficiency*
- *Background suppression*
- *Cross talk*
- *Prize*
- *Homogenous of photon distribution density*
- *Cherenkov image reconstruction*

- *Optics of LHAASO WFCT*

•*transmittance*：>90% @ 300 nm – 650 nm

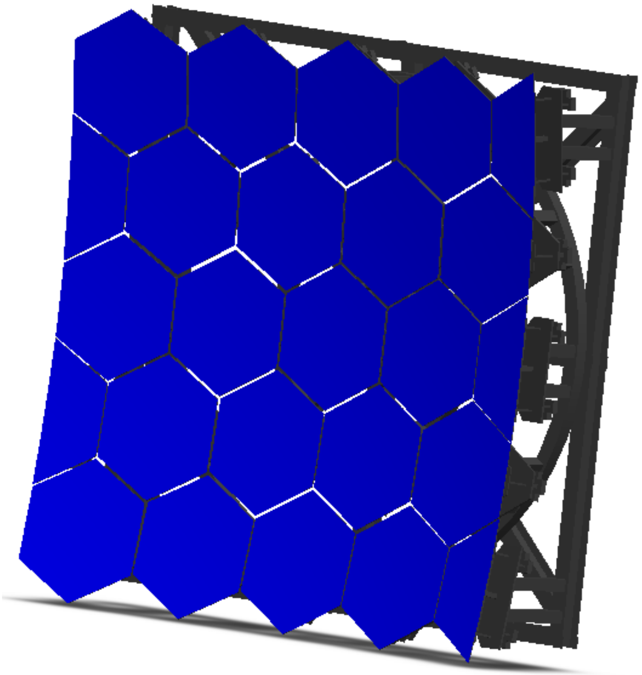
•*reflectance*：>83% @ 300 nm – 650 nm

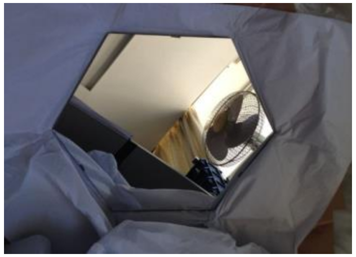
• *spot size*： >65% photons @ Φ25.4mm

•*difference*：<±10%;

•*angular resolution* ：0.5°

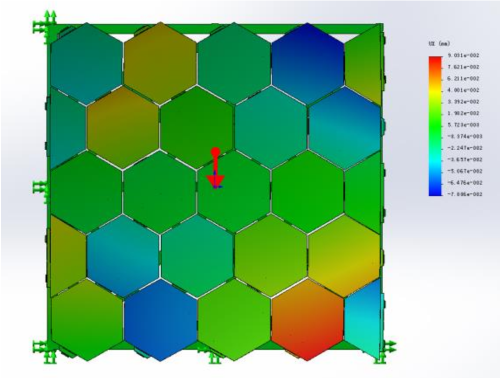
• *FOV*：16°×14°



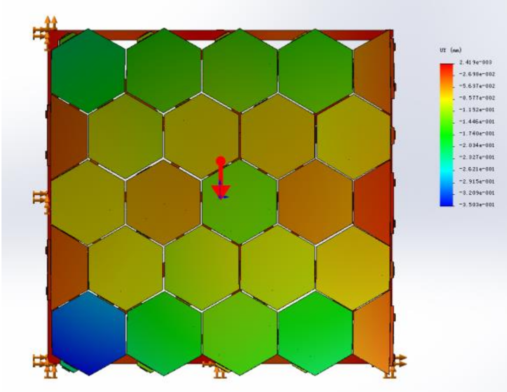


- *Mechanical deformation*

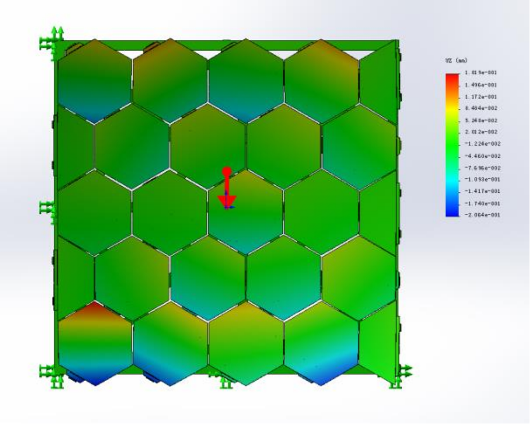
0° Pitch Observation



x

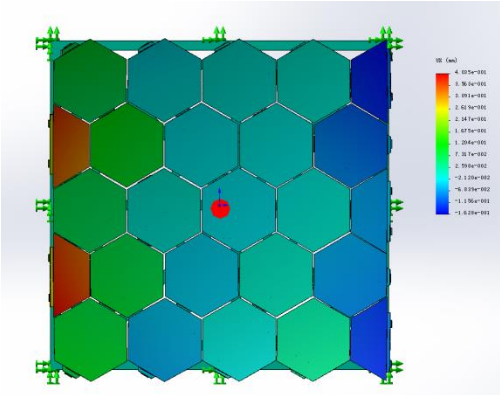


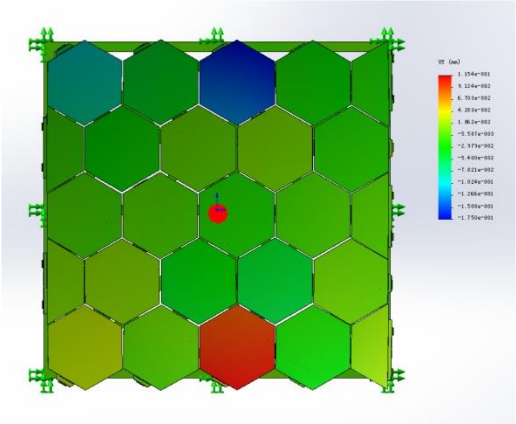
y

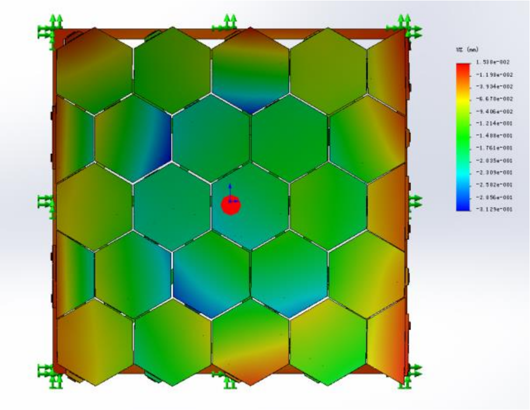


z

90° Pitch Observation



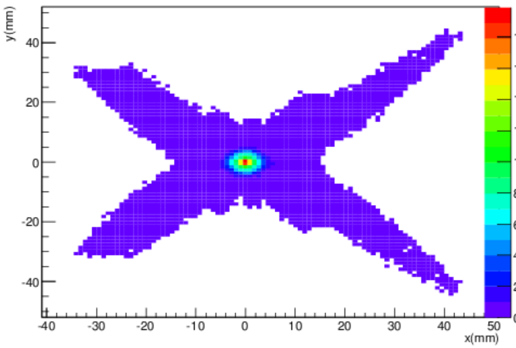




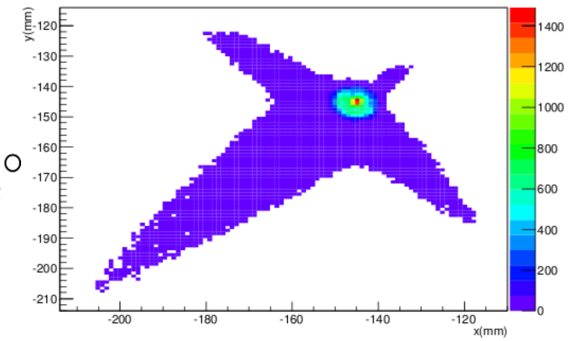
- *Spots simulations*

$\Delta\theta = 0$
$\mathrm{Z} = 2870\mathrm{mm}$
$\eta = 0.79 \sim 0.82$

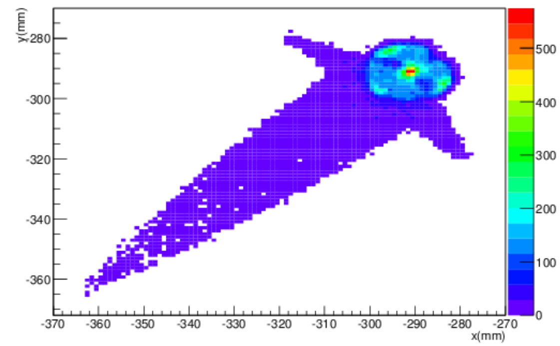
0°



4°

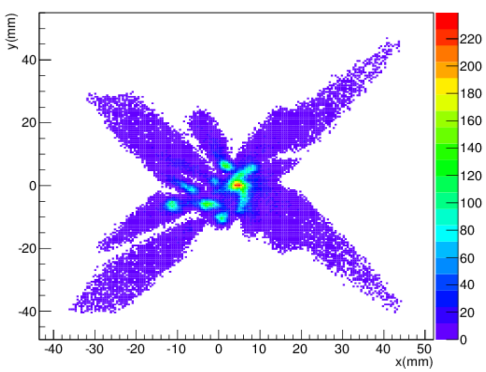


8°

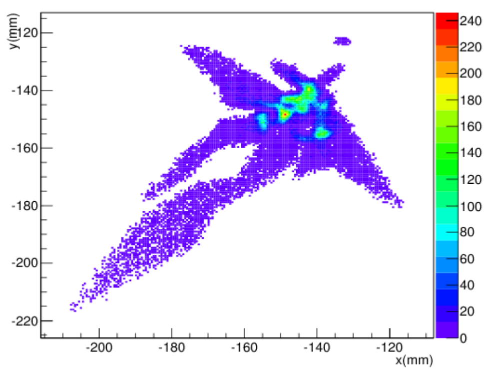


$\alpha, \beta \sim \mathrm{N}\left(0, 0.05^{\circ}\right)$
$\mathrm{Z} = 2870$
$\eta = 0.67 \sim 0.78$

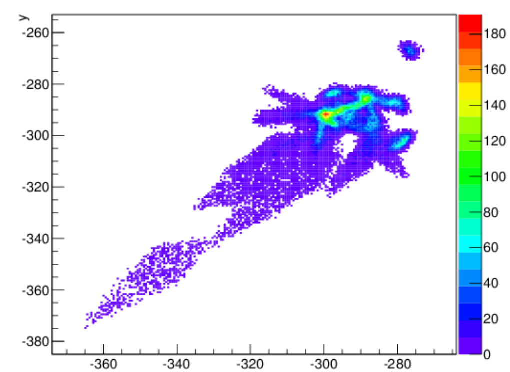
0°



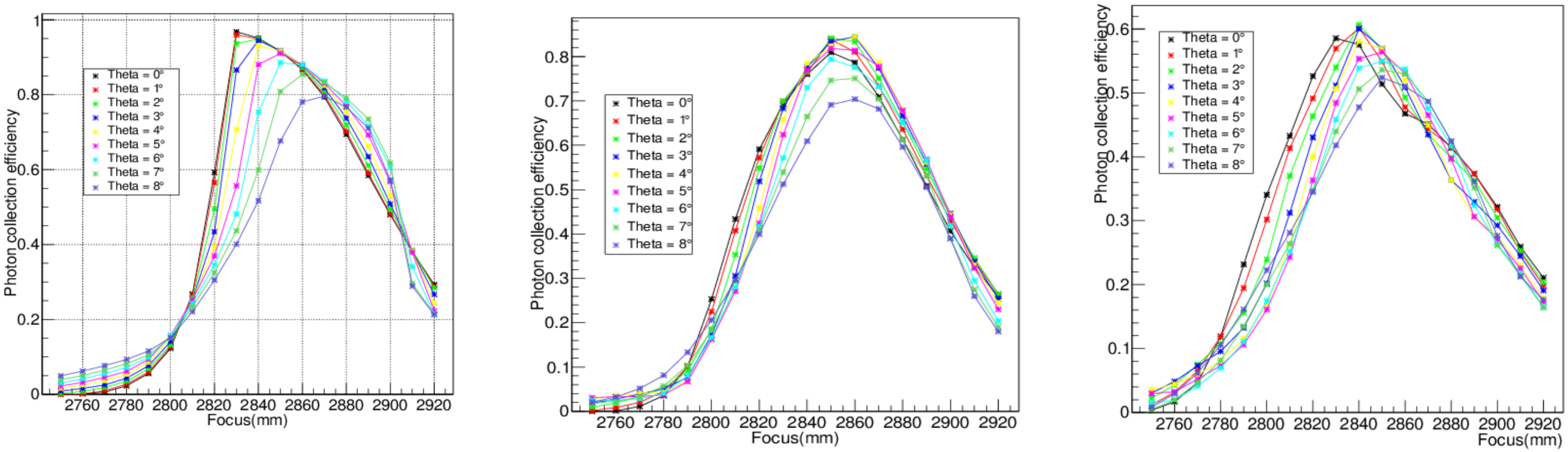
4°



8°



Spots Optimization

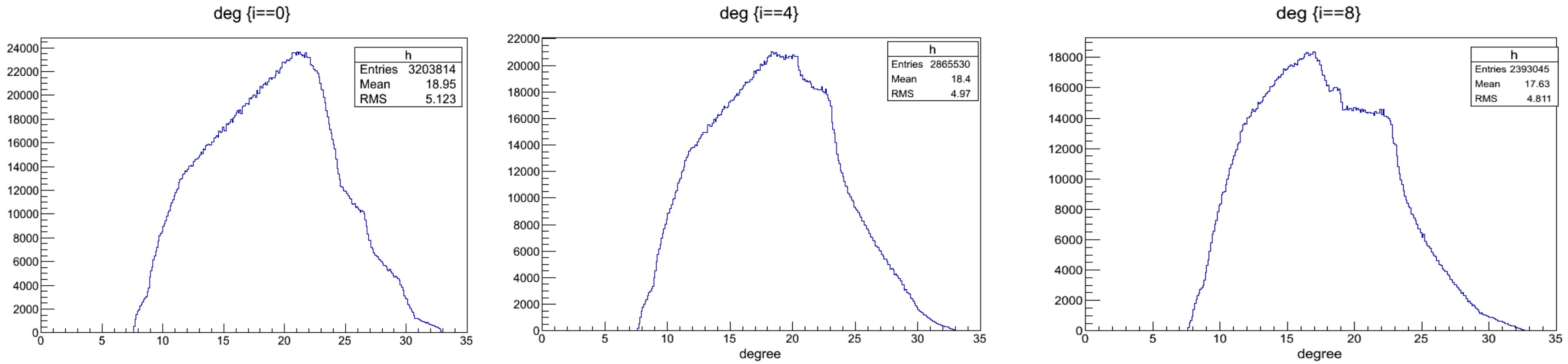


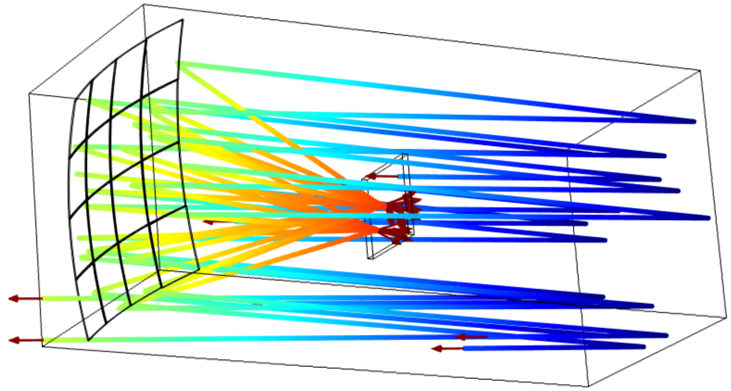
$\Delta\theta = 0$
$Z = 2870$
$\eta = 0.79 \sim 0.82$

$\Delta\theta \sim N(0, 0.05°)$
$Z = 2870$
$\eta = 0.67 \sim 0.78$

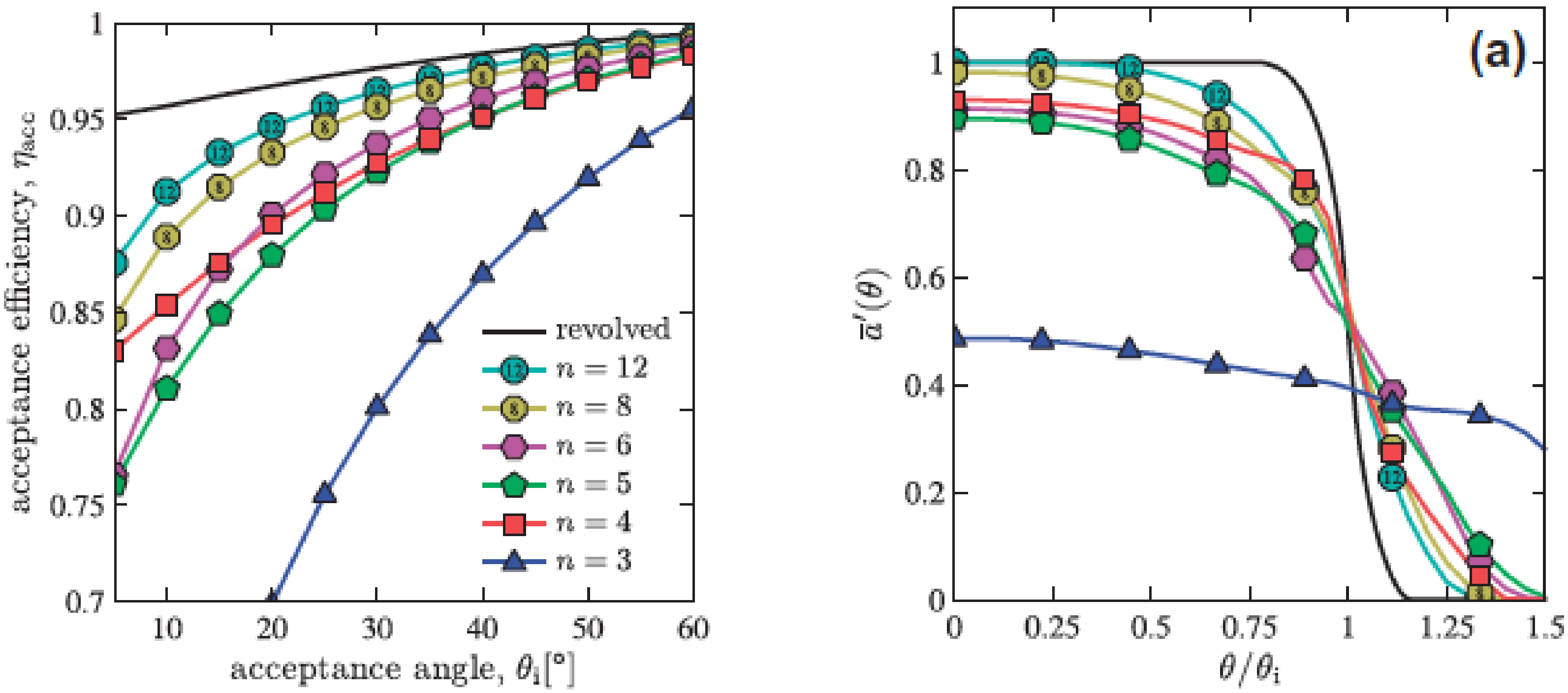
$\Delta\theta \sim N(0, 0.1°)$
$Z = 2870$
$\eta = 0.52 \sim 0.57$

- *Distribution of photon incident angles for light guide*



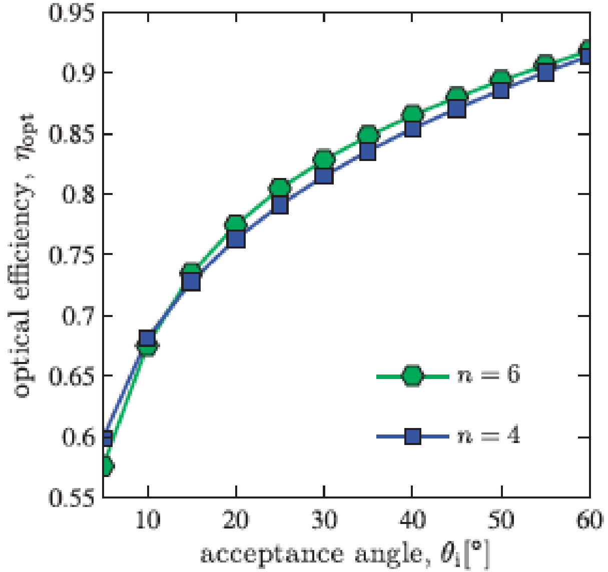


Light guide design

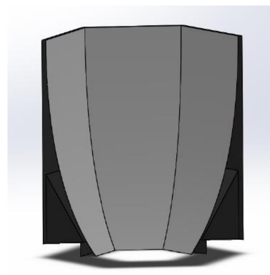


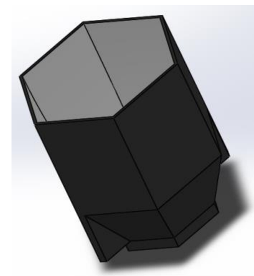
Light guide design

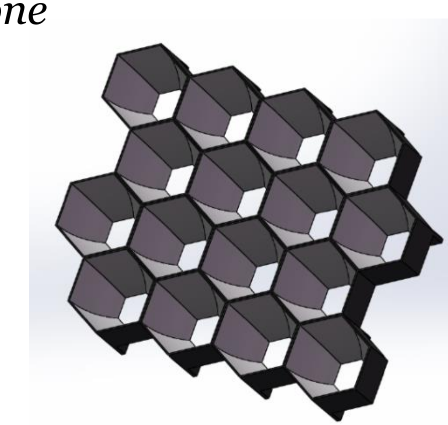
2D Compound Parabolic Concentator



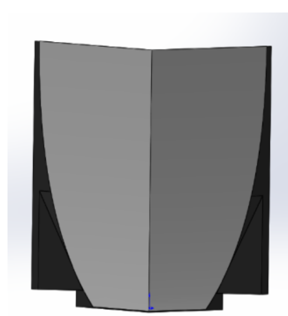
Hexagonal Light Cone

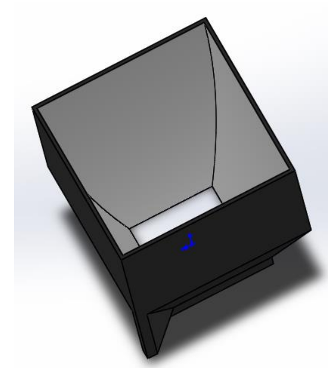


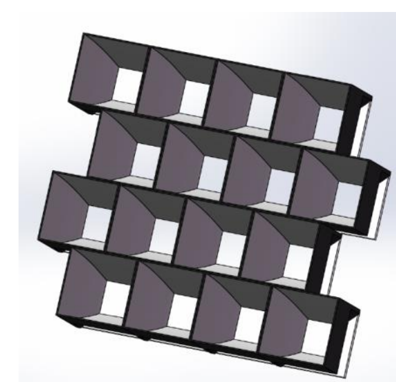


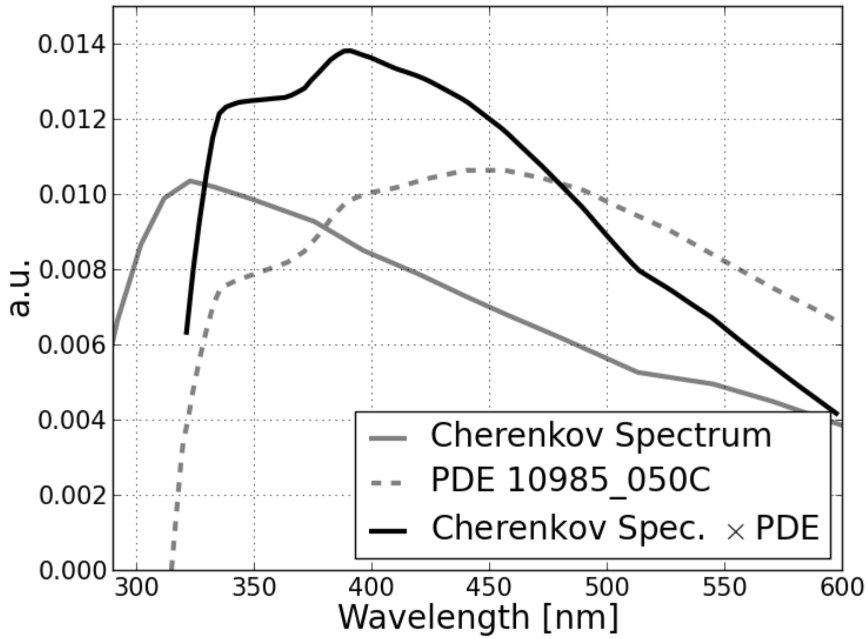


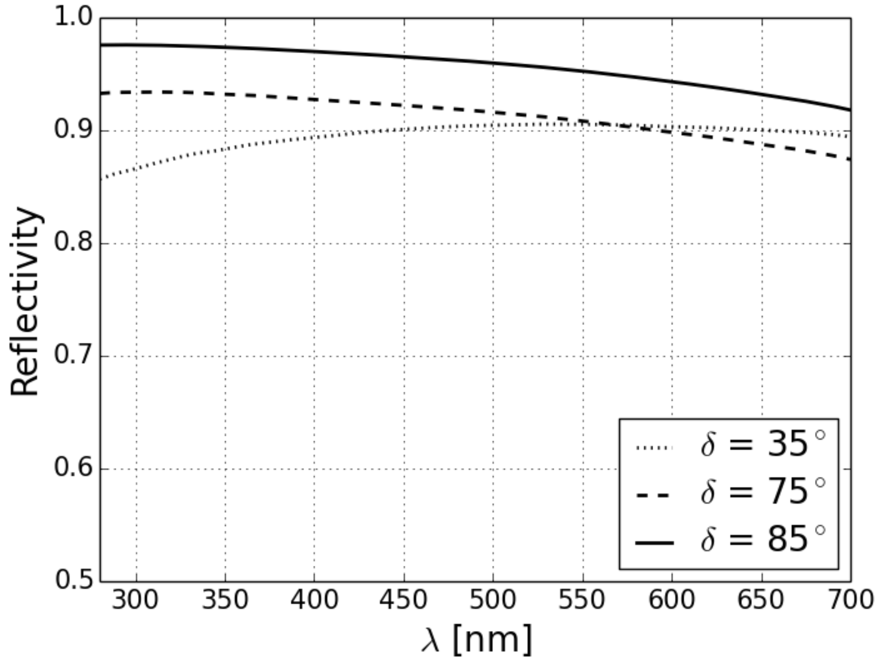
Square Light Cone









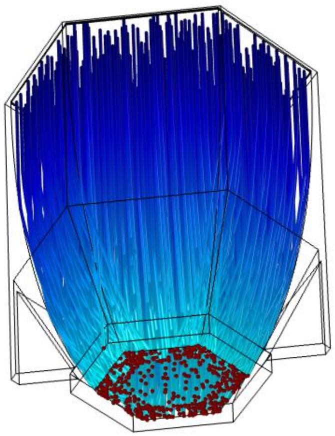


Aluminum with superimposed dichroic layers(R-enhanced coating or Al+R)

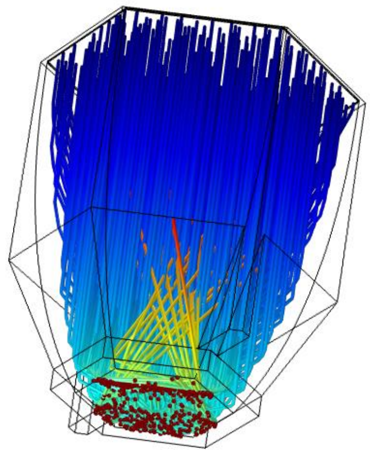
J. A. Aguilar et.al. Astroparticle Physics Volume 60, January 2015, Pages 32–40

Performances

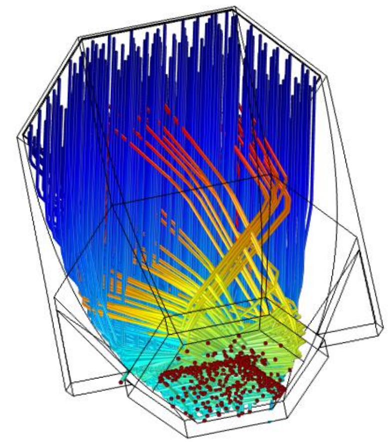
1. Parallel Incidence (Non-Sequential Ray Tracing)



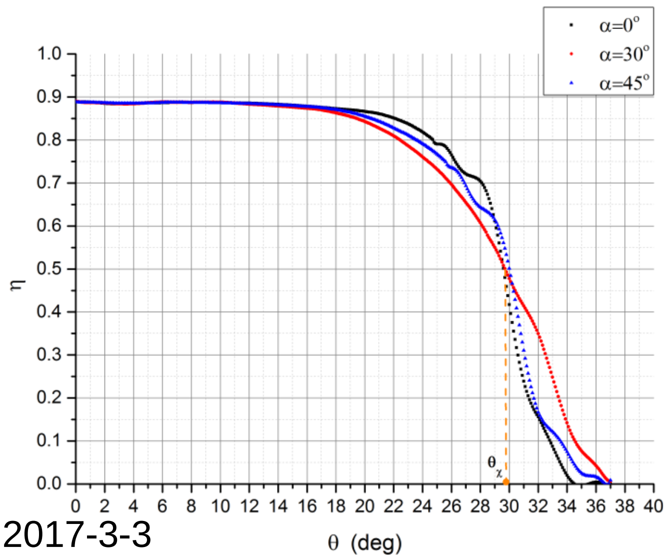
$\theta_{in} = 0^\circ, \alpha = 0^\circ$

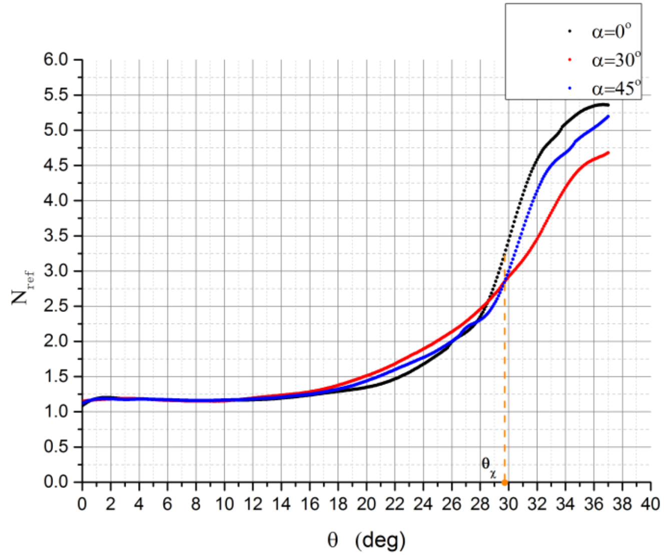


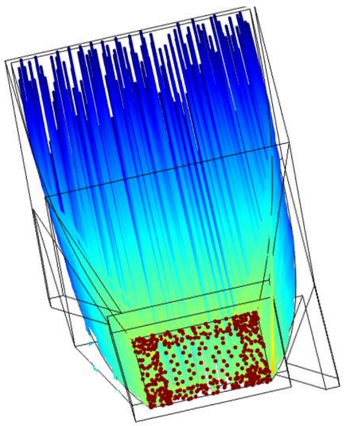
$\theta_{in} = 29.7^\circ, \alpha = 0^\circ$

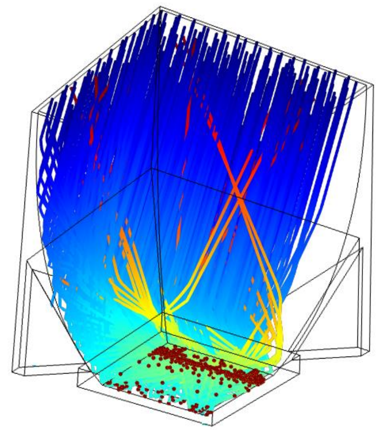


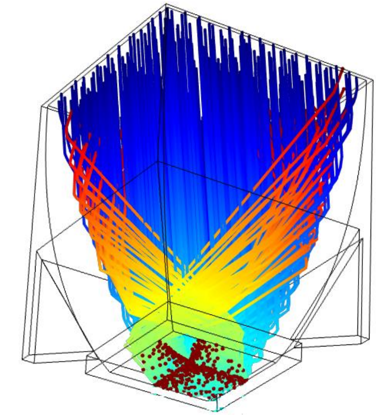
$\theta_{in} = 29.7^\circ, \alpha = 30^\circ$

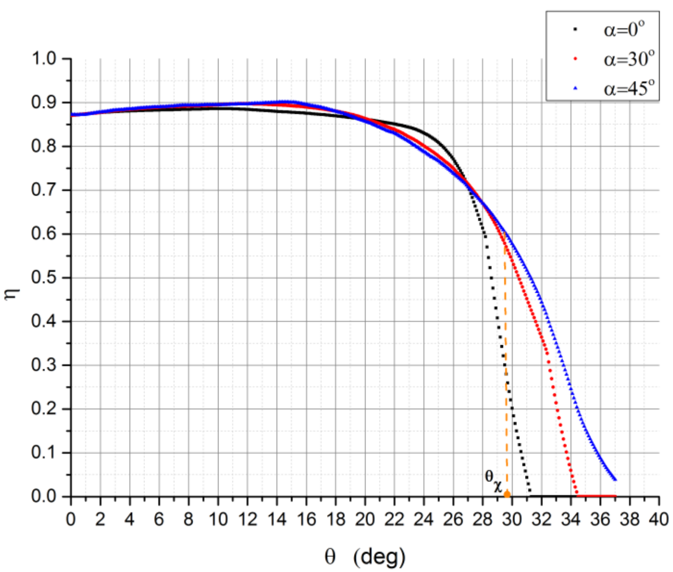


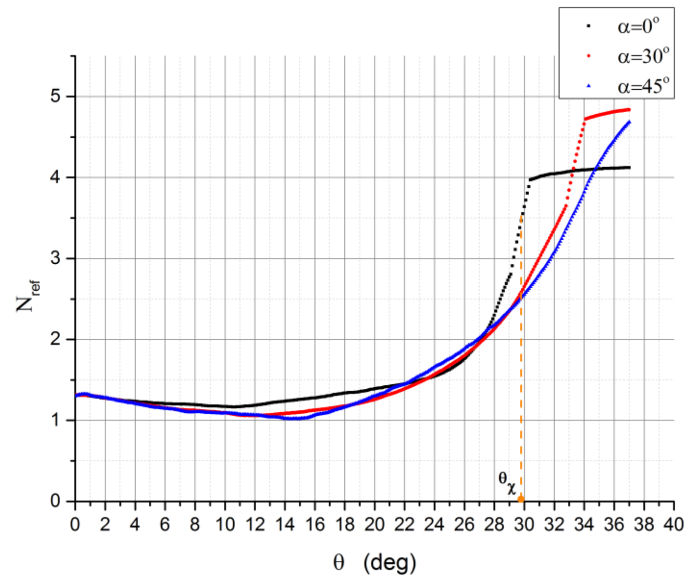




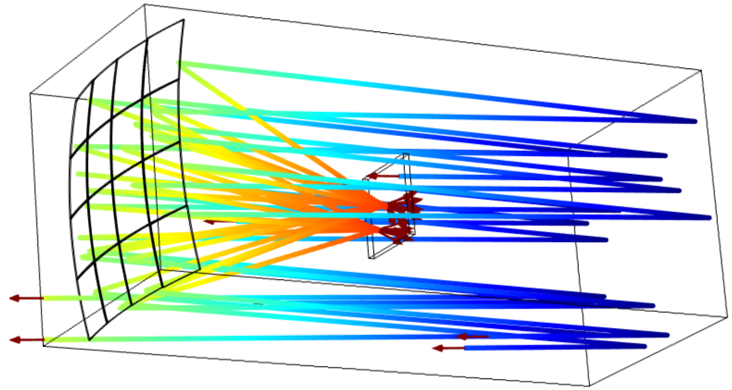





α=0°
α=30°
α=45°
η
θ (deg)
θχ
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40


α=0°
α=30°
α=45°
N_ref
θ (deg)
θχ
5
4
3
2
1
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40

2. Light Spot Scan



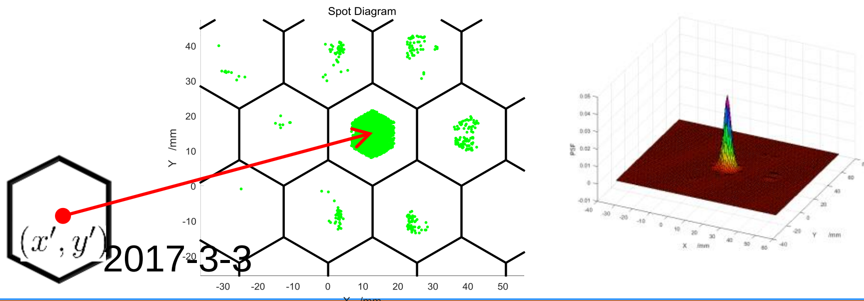
Modulation of Cherenkov image by Optical system:

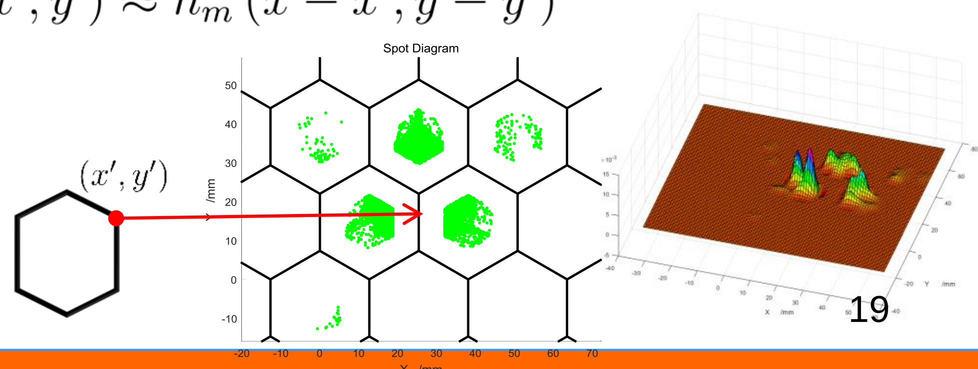
$$g\left(x,y\right)=\left\{\int_{\Omega} f\left(x',y'\right)\cdot h\left(x,y;x',y'\right)dx'dy'\right\}\cdot\sum_{i=1}^{1024}\mathscr{H}\left(x,y;x_i,y_i\right)\cdot p\left(x,y;x_i,y_i\right)+n\left(x,y\right)$$

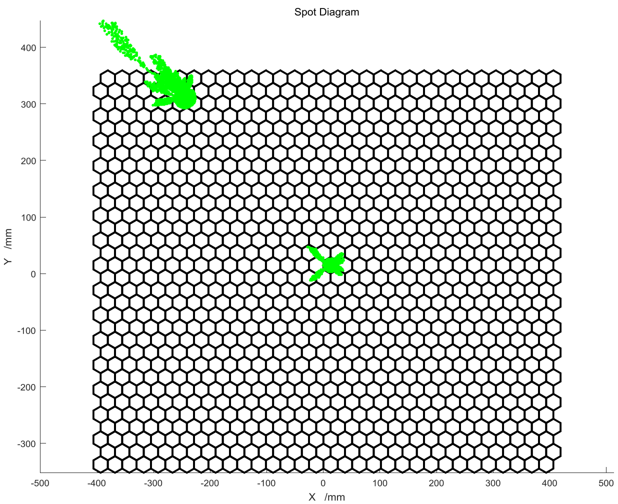
Spatial Variant PSF for whole image plane

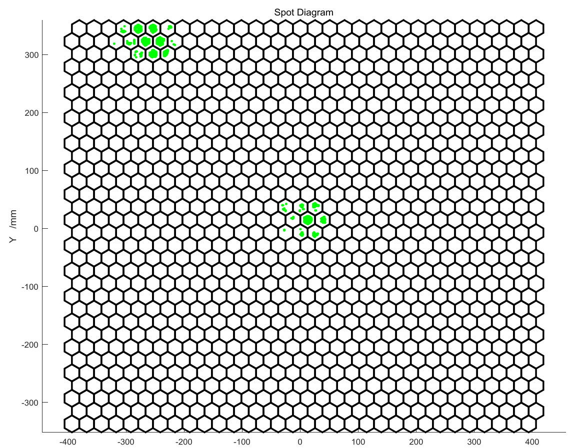
In each bin PSF $h\left(x,y;x',y'\right)\approx h_m\left(x-x',y-y'\right)$

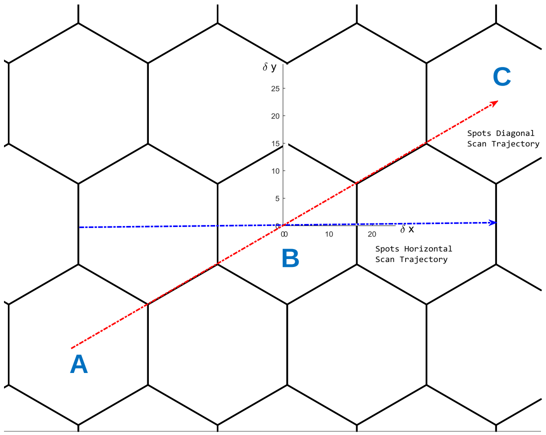
Combing with Light Concentrator $h\left(x,y;x',y'\right)\approx h_m\left(x-x',y-y'\right)$

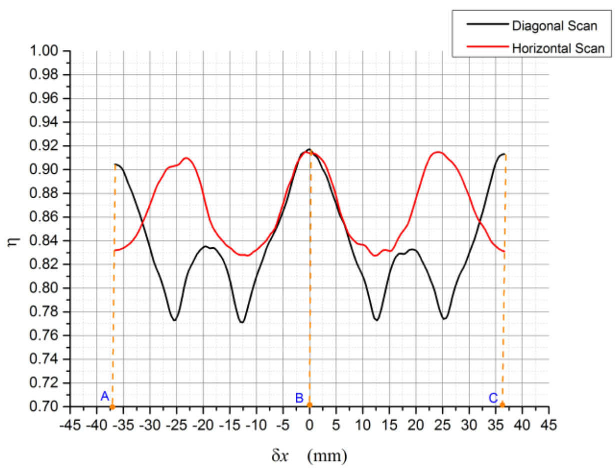


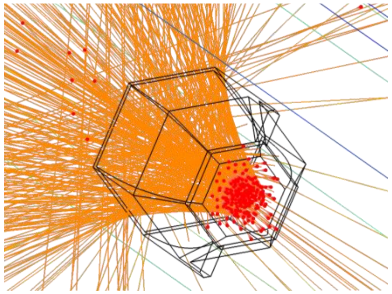


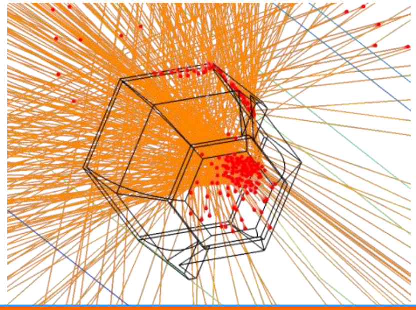

Spot Diagram
Y /mm
X /mm

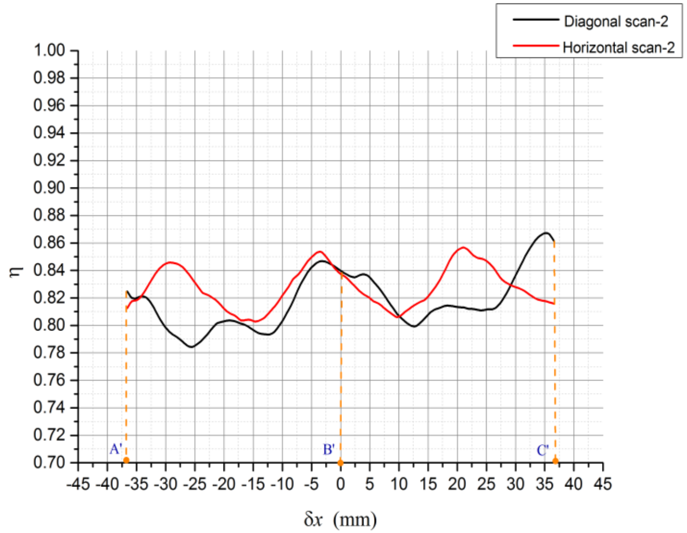

Spot Diagram
Y /mm

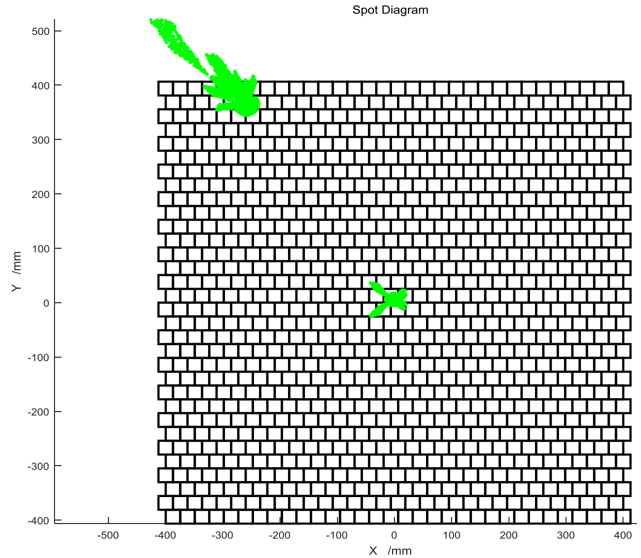

C
Spots Diagonal
Scan Trajectory
B
Spots Horizontal
Scan Trajectory
A

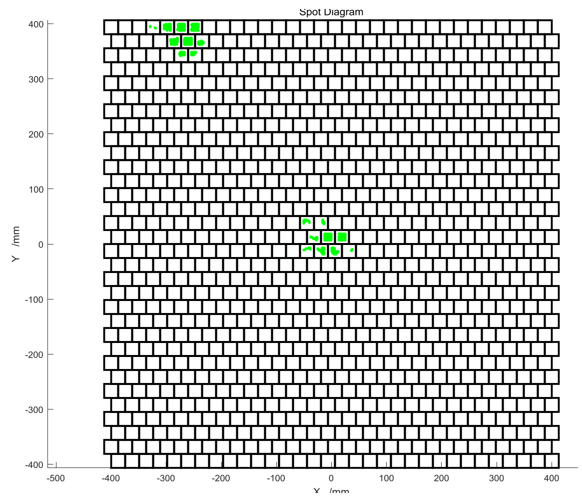

Diagonal Scan
Horizontal Scan
η
A
B
C
δx (mm)

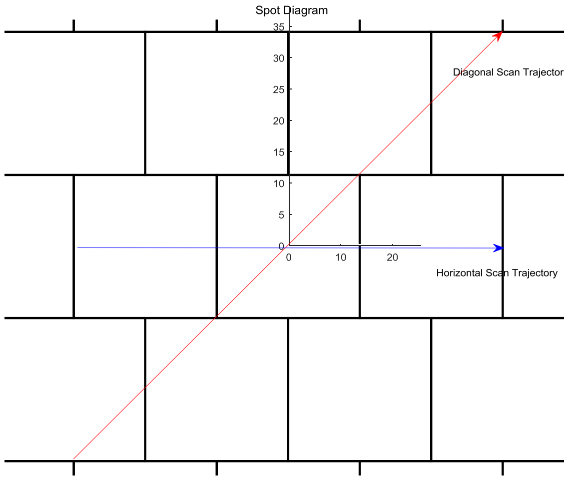


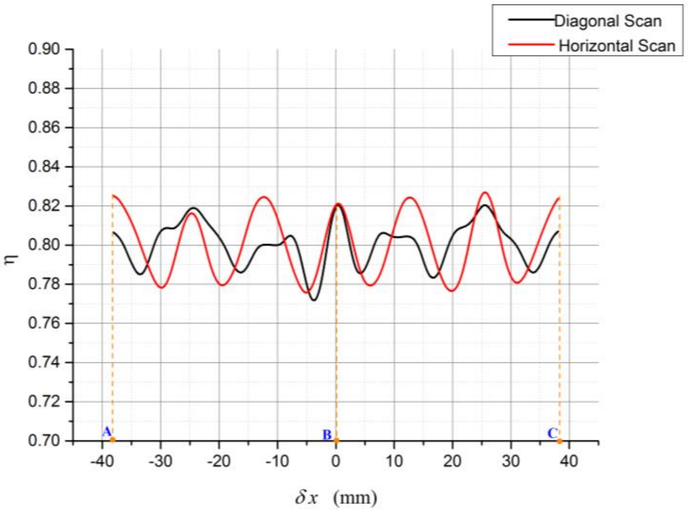


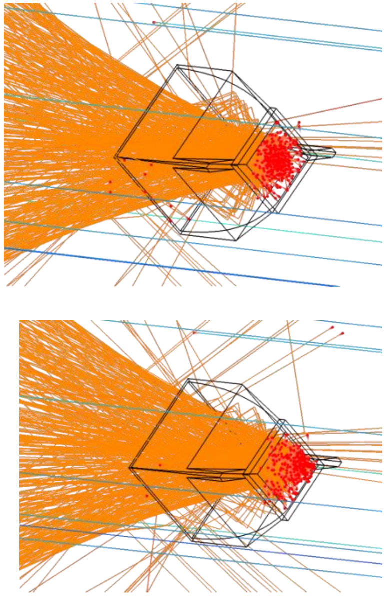

Diagonal scan-2
Horizontal scan-2
η
A'
B'
C'
δx (mm)

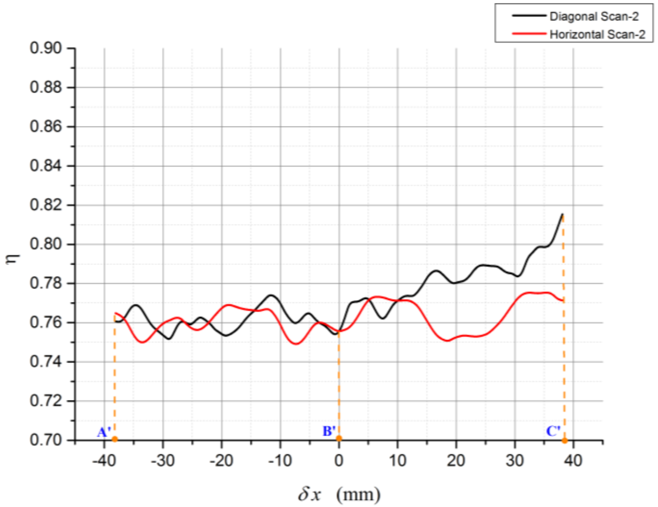

Spot Diagram
Y /mm
X /mm
500
400
300
200
100
0
-100
-200
-300
-400
-500
400


Spot Diagram
Y /mm
400
300
200
100
0
-100
-200
-300
-400
-500
400

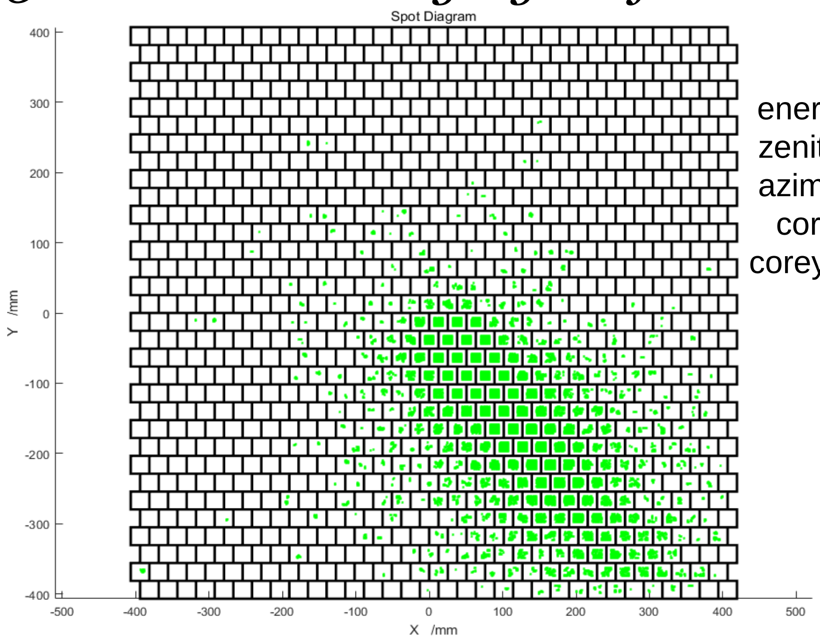

Spot Diagram
Diagonal Scan Trajector
Horizontal Scan Trajectory
35
30
25
20
15
10
5
0
10
20


Diagonal Scan
Horizontal Scan
η
δx (mm)
0.90
0.88
0.86
0.84
0.82
0.80
0.78
0.76
0.74
0.72
0.70
-40
-30
-20
-10
0
10
20
30
40
A
B
C

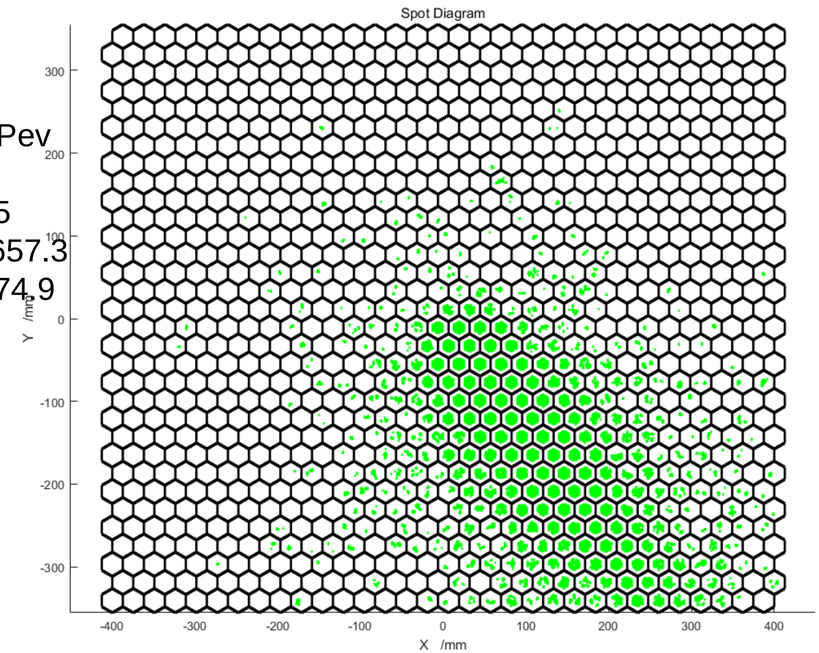


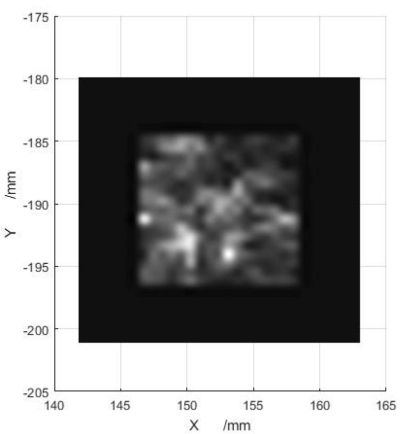

Diagonal Scan-2
Horizontal Scan-2
η
δx (mm)
0.90
0.88
0.86
0.84
0.82
0.80
0.78
0.76
0.74
0.72
0.70
-40
-30
-20
-10
0
10
20
30
40
A'
B'
C'

3. Cherenkov Imaging Performances

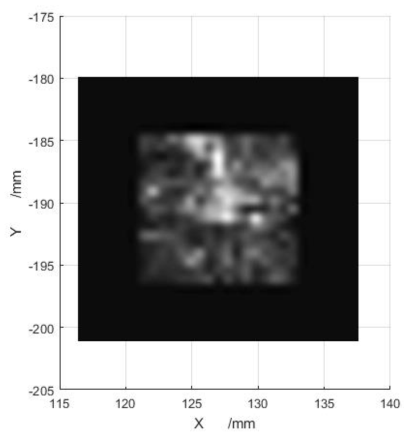


energy = 7.12Pev
zenith = 0.8
azimuth = 2.55
corex = -39657.3
corey = 11474.9

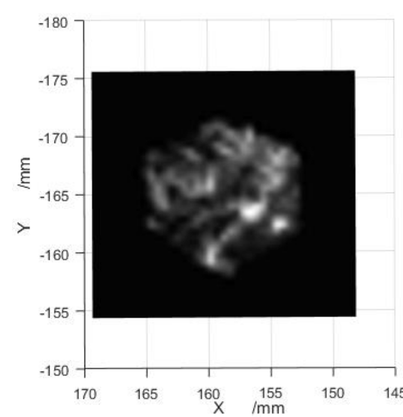




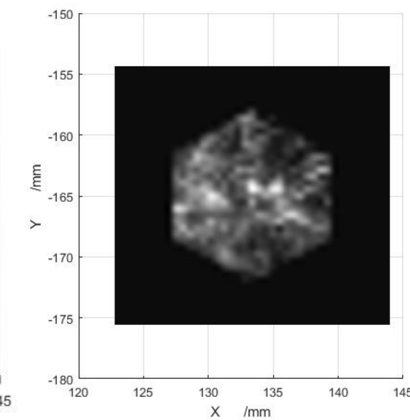
No.746 SiPM



No.747 SiPM

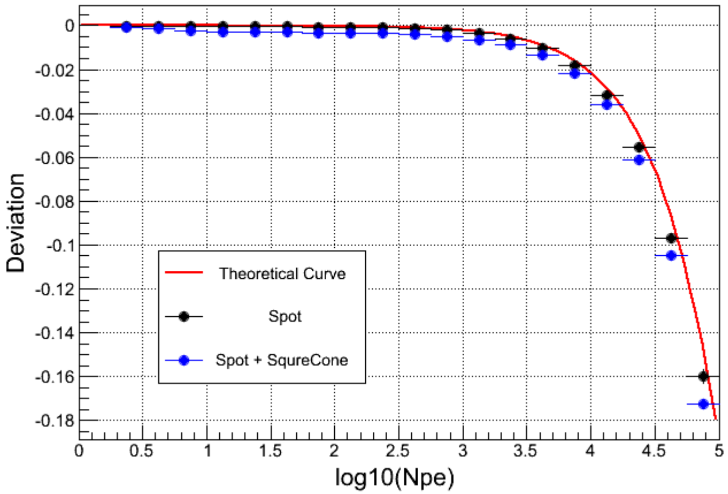


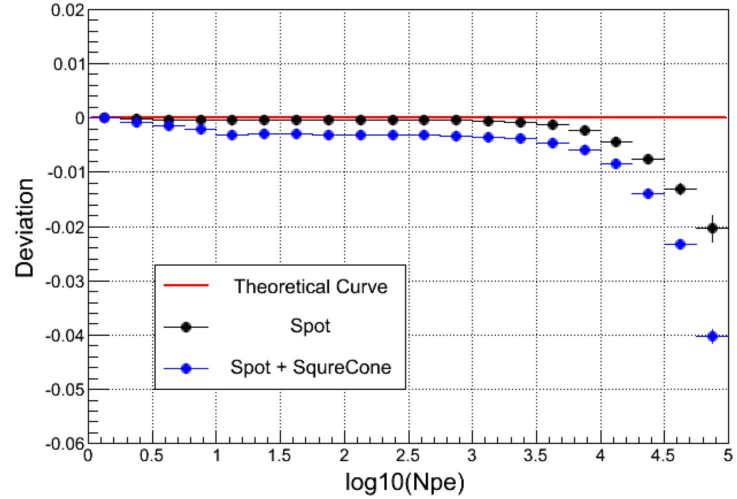
No.746 SiPM



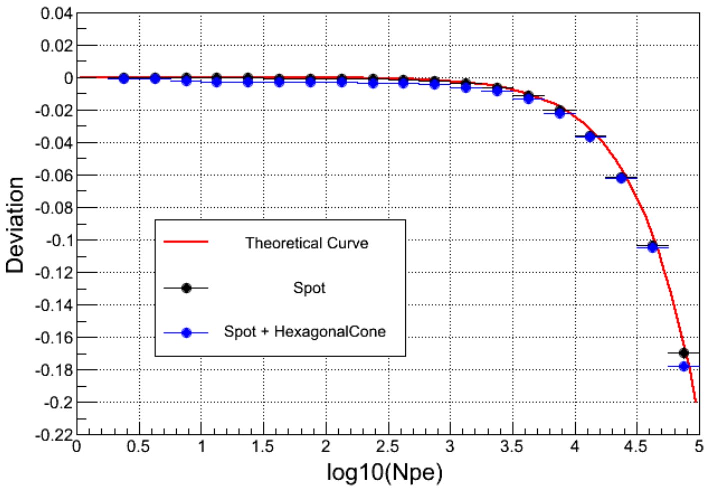
No.747 SiPM

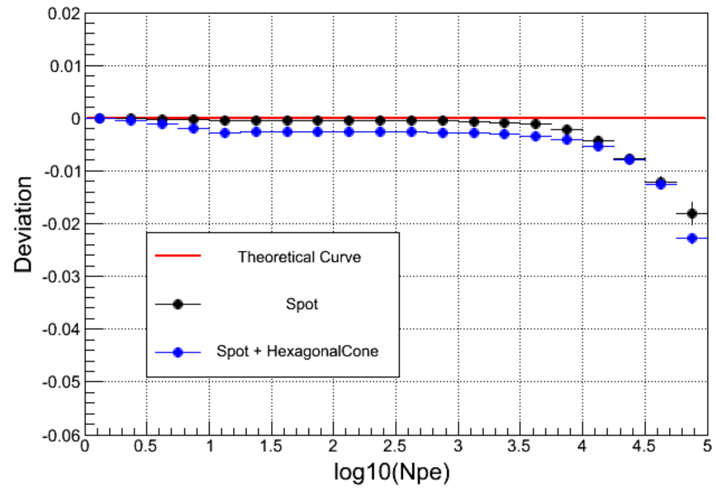
Square SiPM array



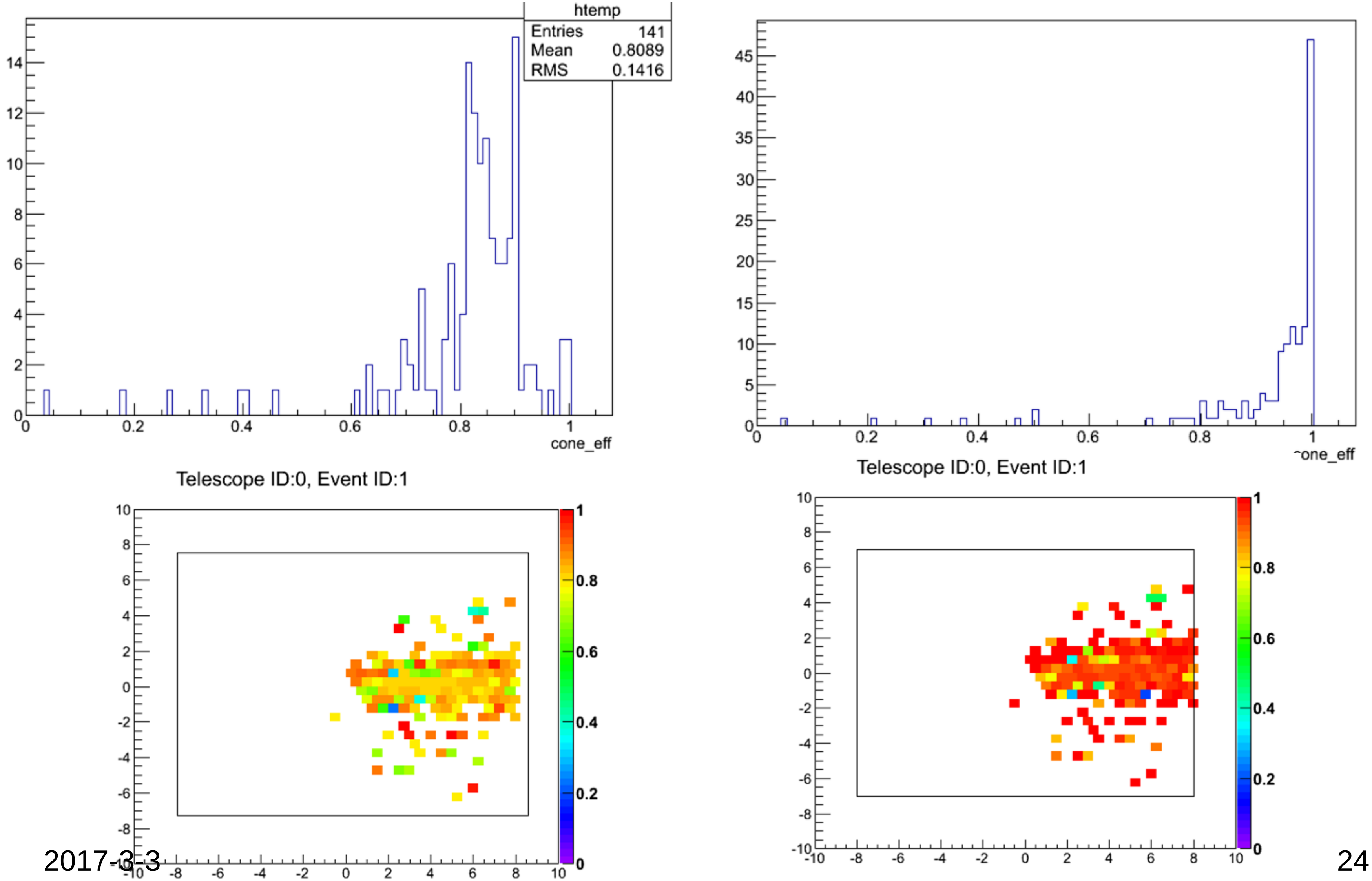


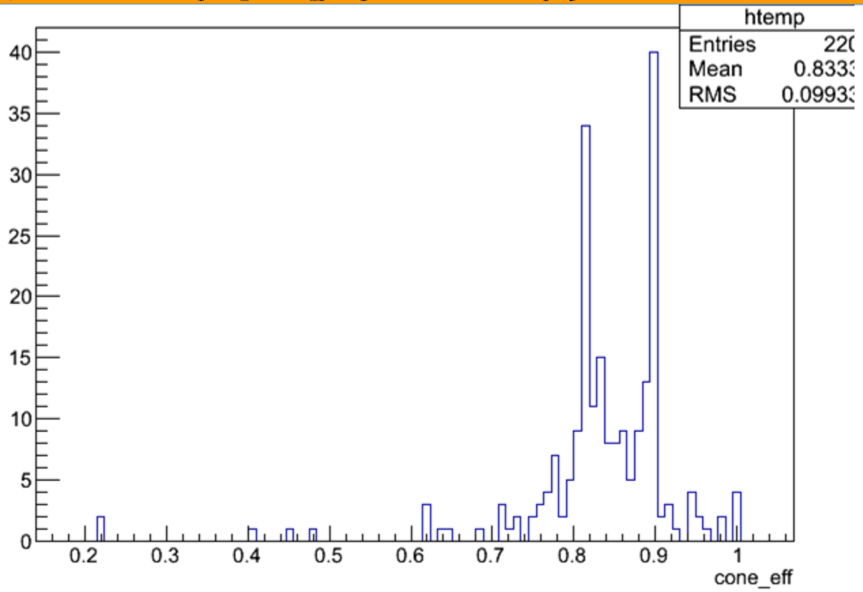
Hexagonal SiPM array

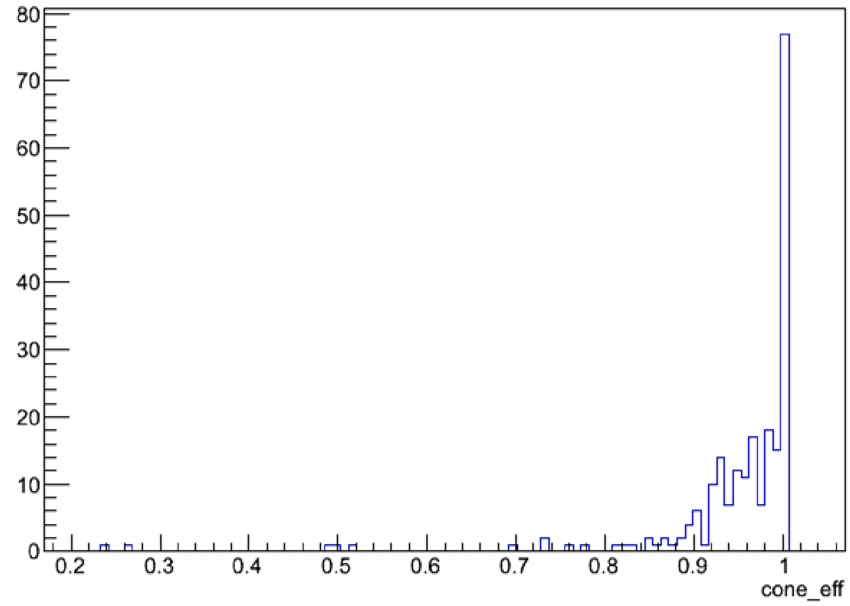


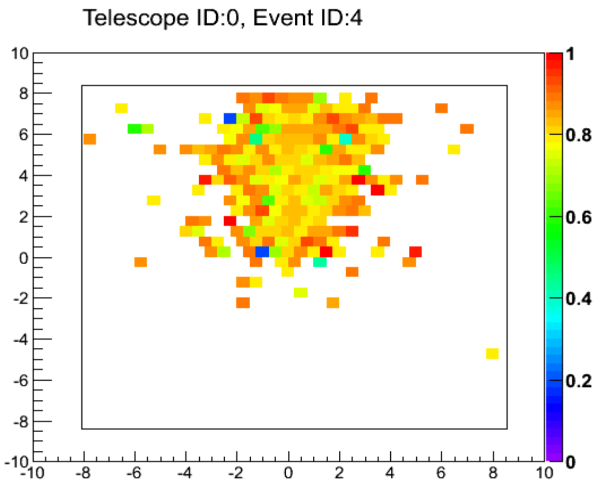


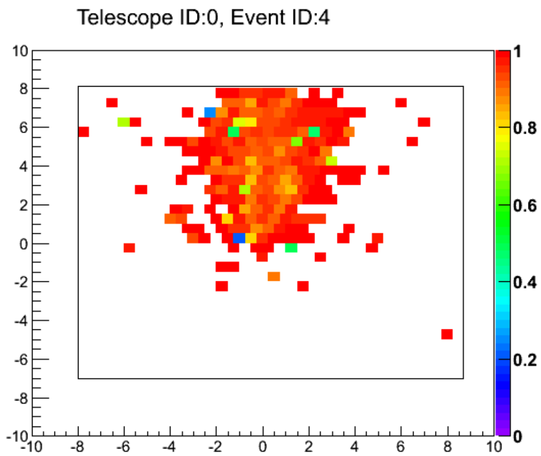
3. Efficiency uniformity for the whole detector arrays

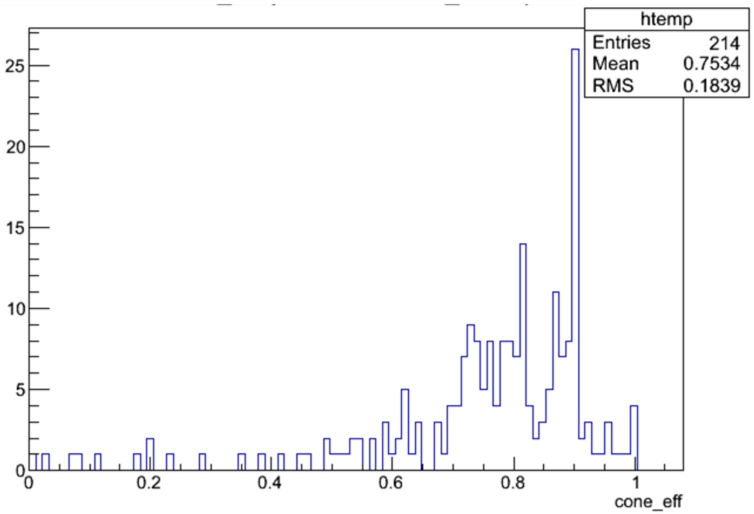


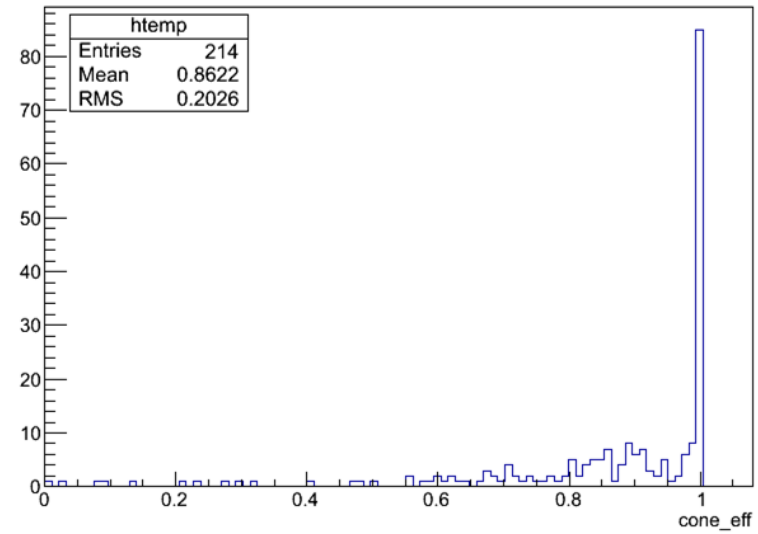

htemp
Entries 220
Mean 0.8333
RMS 0.09933
0
5
10
15
20
25
30
35
40
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
cone_eff

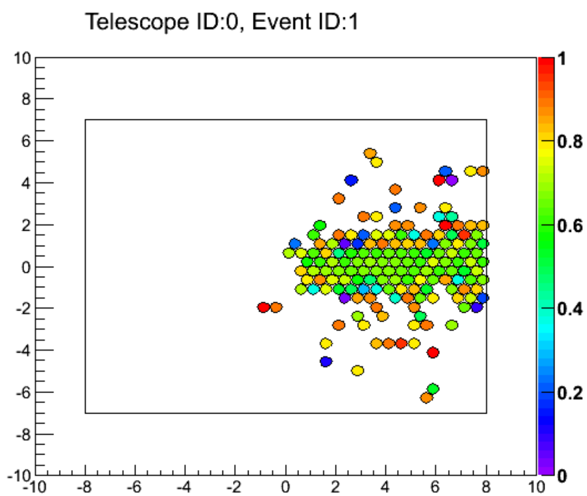

0
10
20
30
40
50
60
70
80
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
cone_eff

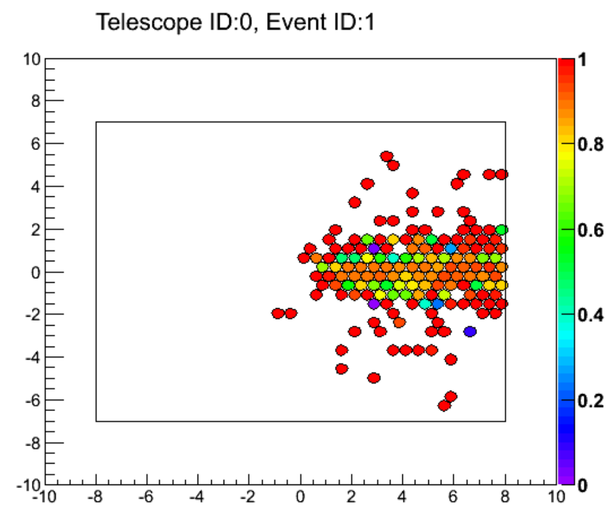

Telescope ID:0, Event ID:4

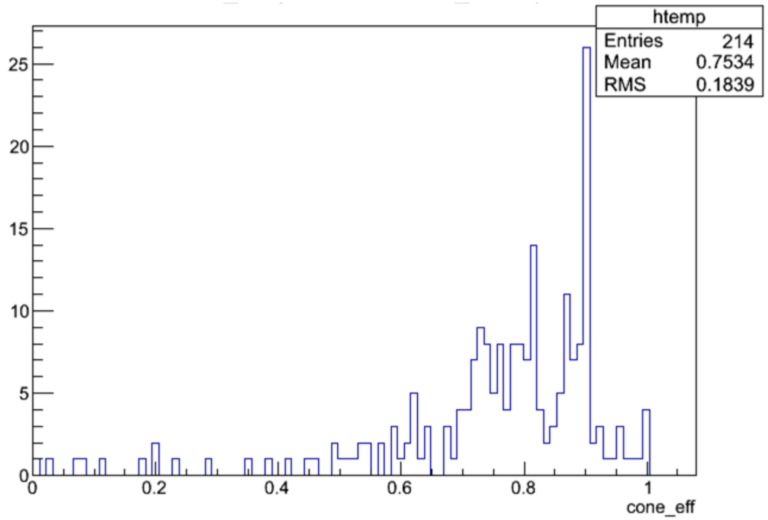

Telescope ID:0, Event ID:4

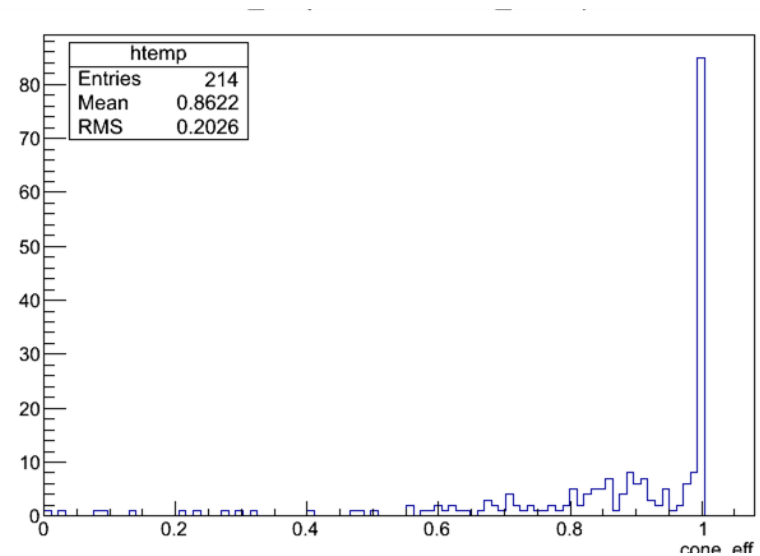

htemp
Entries 214
Mean 0.7534
RMS 0.1839
cone_eff

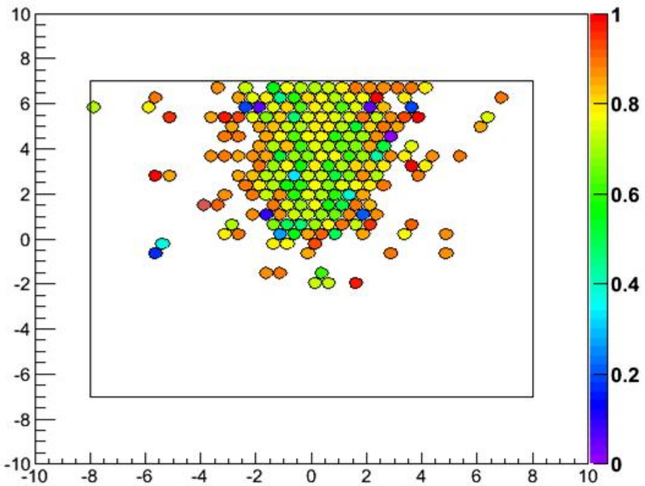

htemp
Entries 214
Mean 0.8622
RMS 0.2026
cone_eff

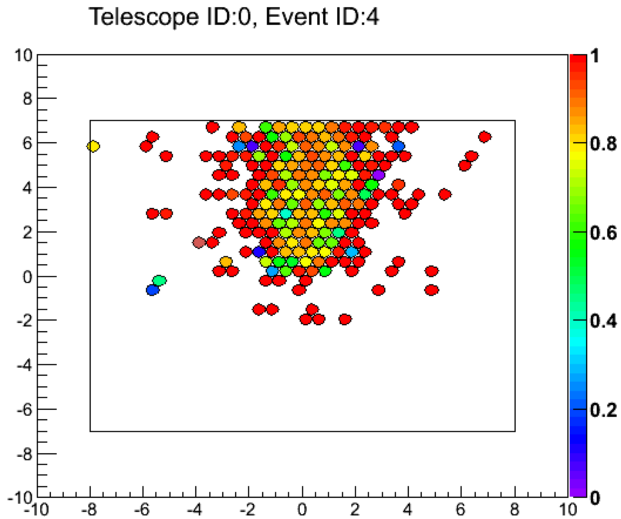

Telescope ID:0, Event ID:1


Telescope ID:0, Event ID:1


htemp
Entries 214
Mean 0.7534
RMS 0.1839
cone_eff

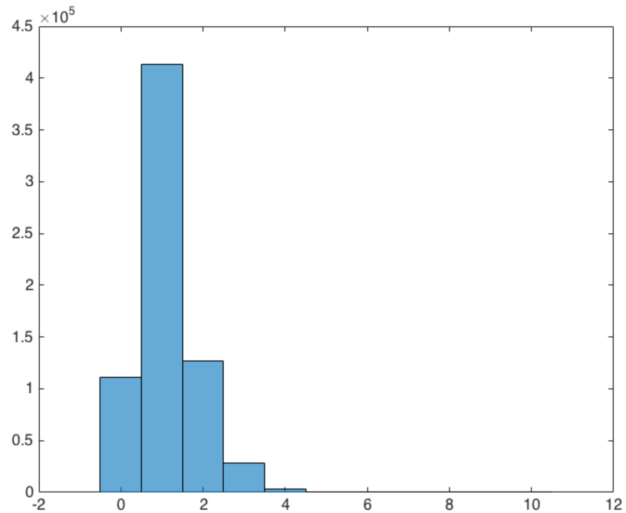

htemp
Entries 214
Mean 0.8622
RMS 0.2026
cone_eff

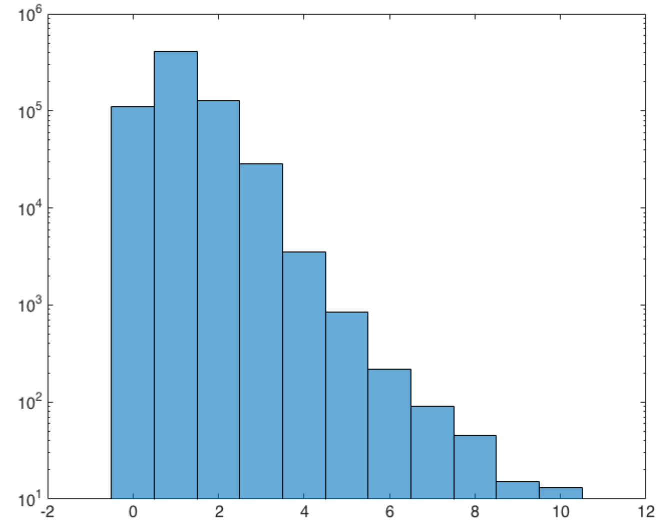



Telescope ID:0, Event ID:4

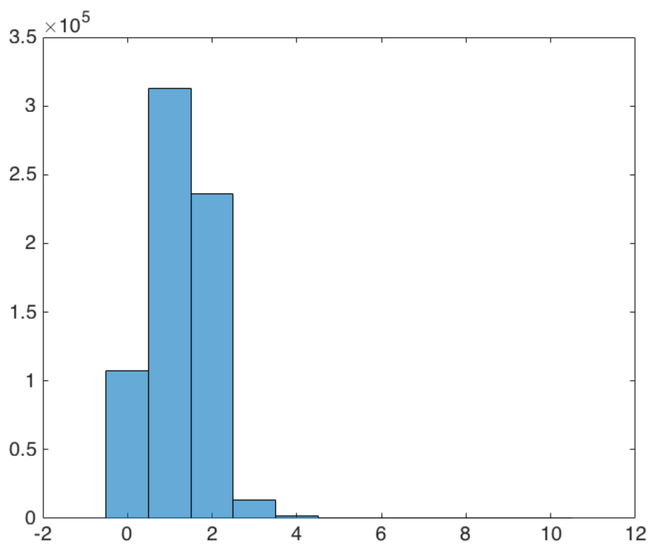
Reflecting rounds comparison

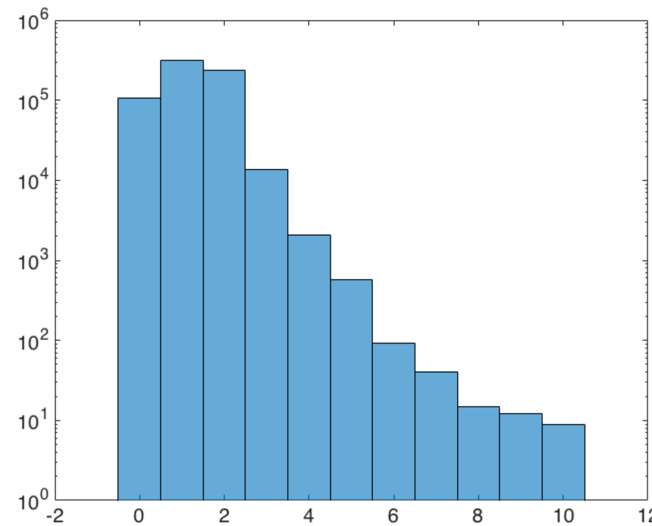
hexagonal





square





Summary

1. *The mean efficiency of the cones is superior to 0.85 and without significant dependence upon the focal plane position, which implies the characteristics of spatial invariant and will be favorable in subsequent data analysis.*
2. *Comparing to the ideal case that reflectance equals to 1.0, the actual efficiency becomes lower, and spreads more disperse because some incident photons may undergo multiple reflections in 3D light cones.*
3. *Most of the SiPM detectors get uniform mean efficiencies from their associated light cones. However, the fluctuation inter pixels would degraded the accuracy of images calibration.*

Thank you