Light Guide Tests at KNU

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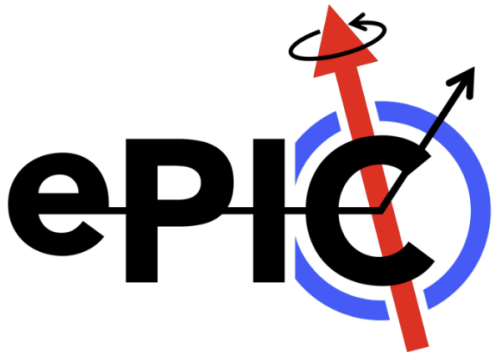
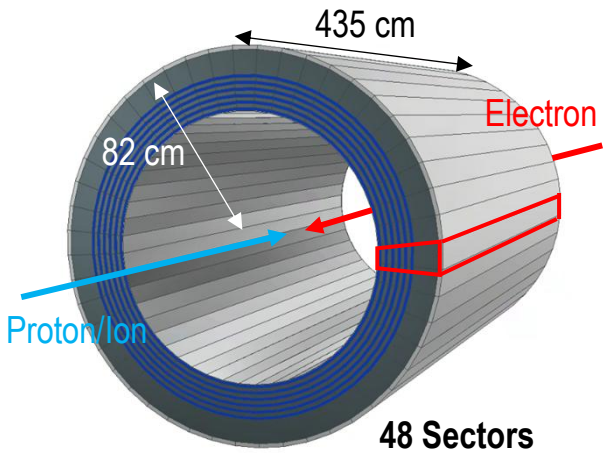
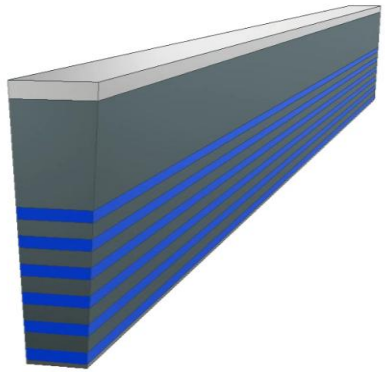


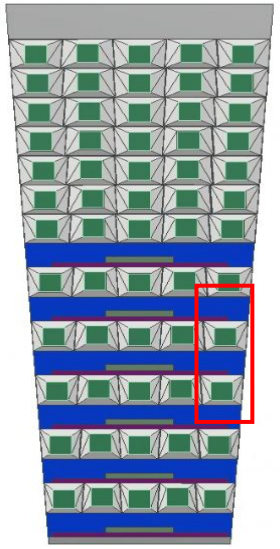
Introduction



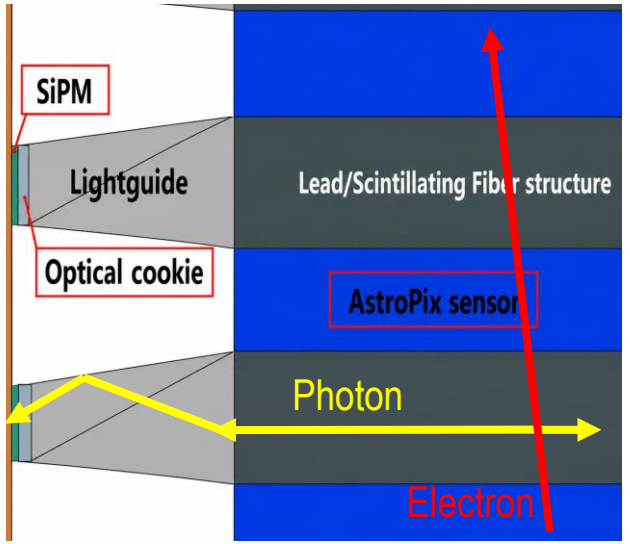
48 Sectors



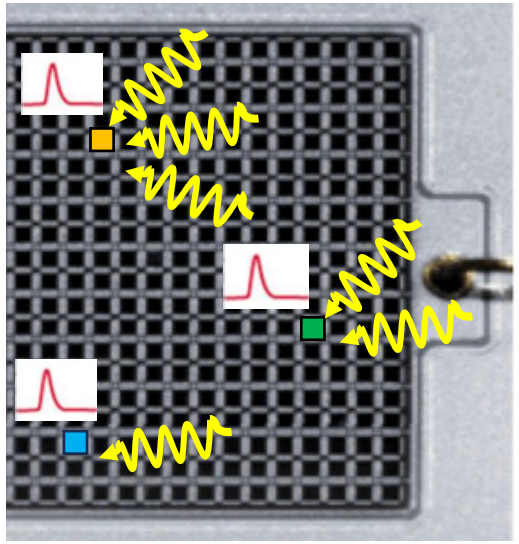
1 Sectors



Front view



Side view



Multi photon hit in same pixel
→ single photoelectron

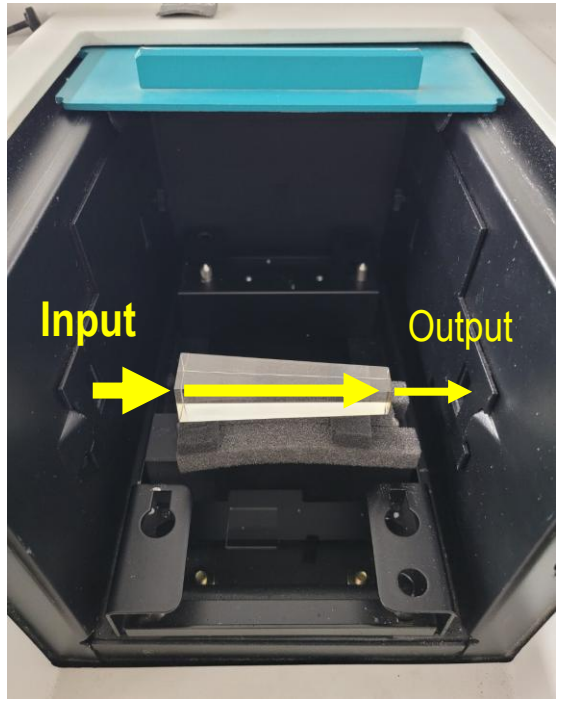
Barrel Imaging Calorimeter (BIC) in Electron Ion Collider (EIC)

- Light Guide : guide photons from calorimeter to SiPM (Silicon Photomultiplier)
- Limited space inside the detector → Light Guide length optimization
- **Issue**
  - **1. Efficiency**
  - **2. Linearity**

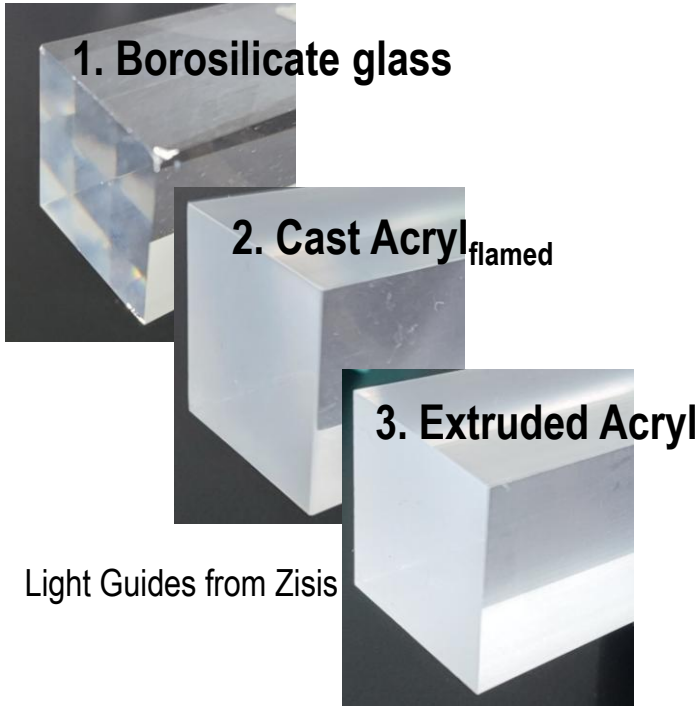
optimization →

1. Material
2. Length
3. Shape
4. Optical cookie

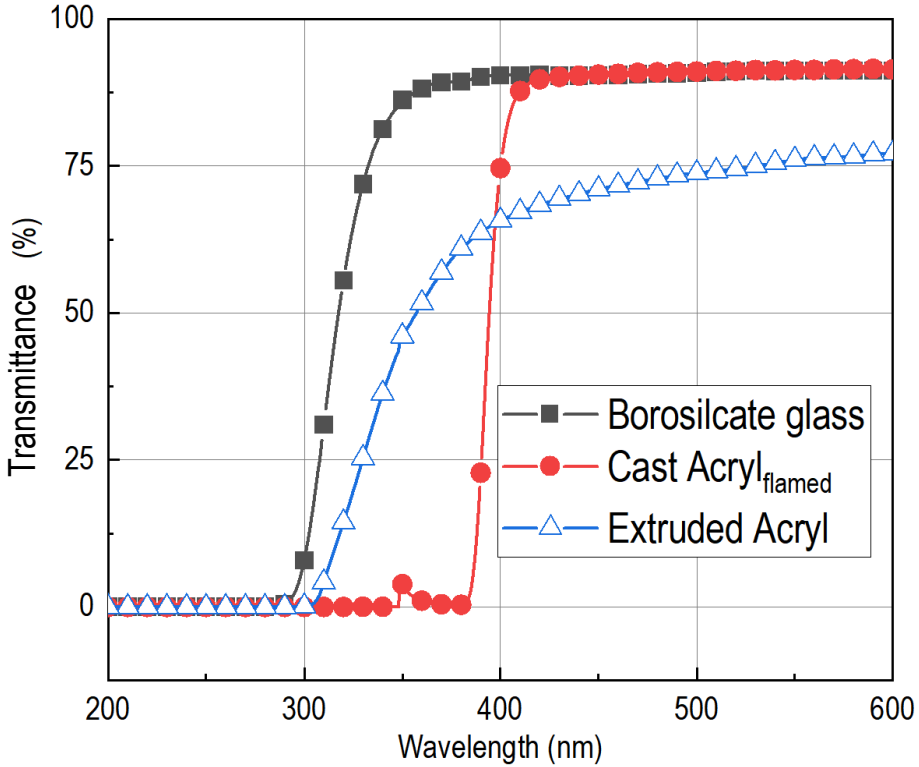
Material : Transmittance measurement (UV/Vis)



Transmittance measurement (KNU)
UV/Vis spectrophotometer (Cary 100)
Output / Input



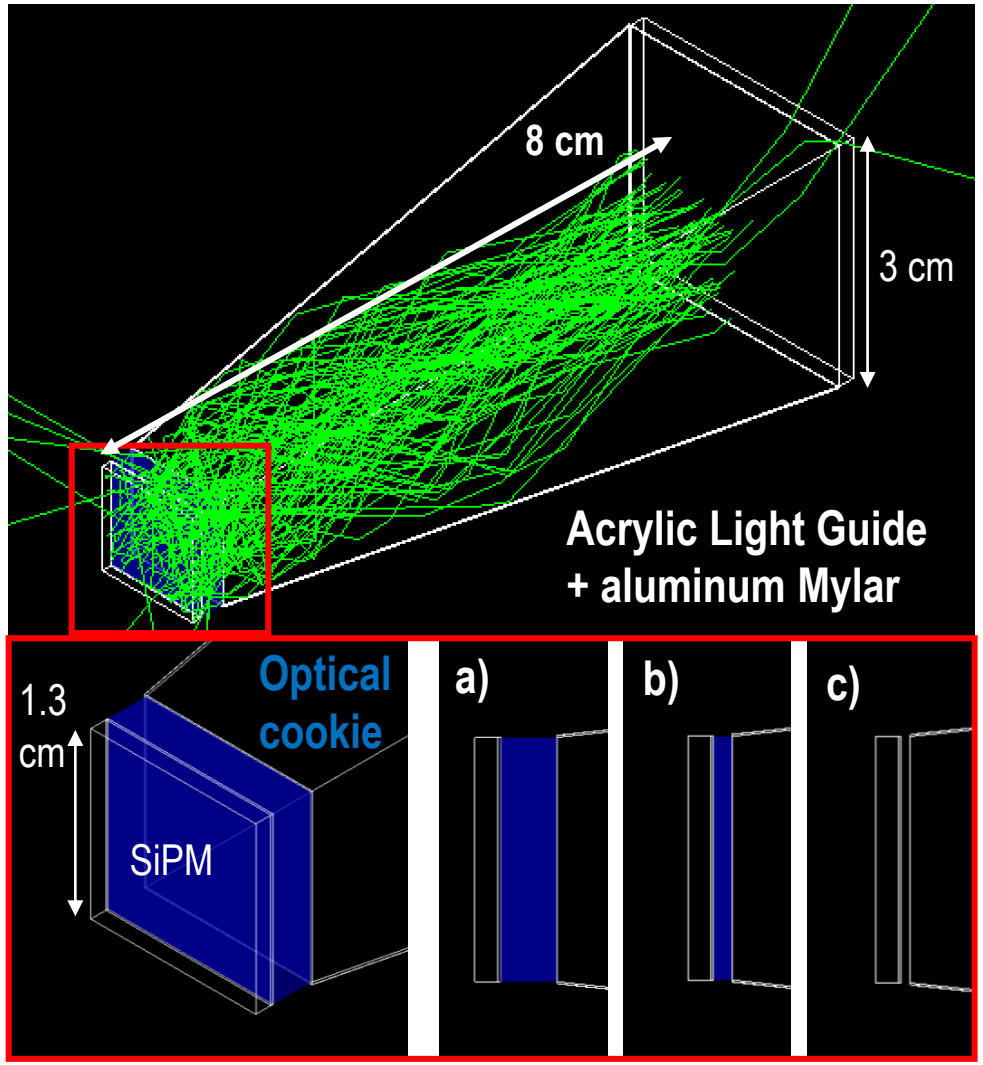
Light Guide materials
1. Borosilicate glass (BrainShift)
2. Cast Acryl$_{flamed}$ (Ross Machine)
3. Extruded Acryl (Ross Machine)



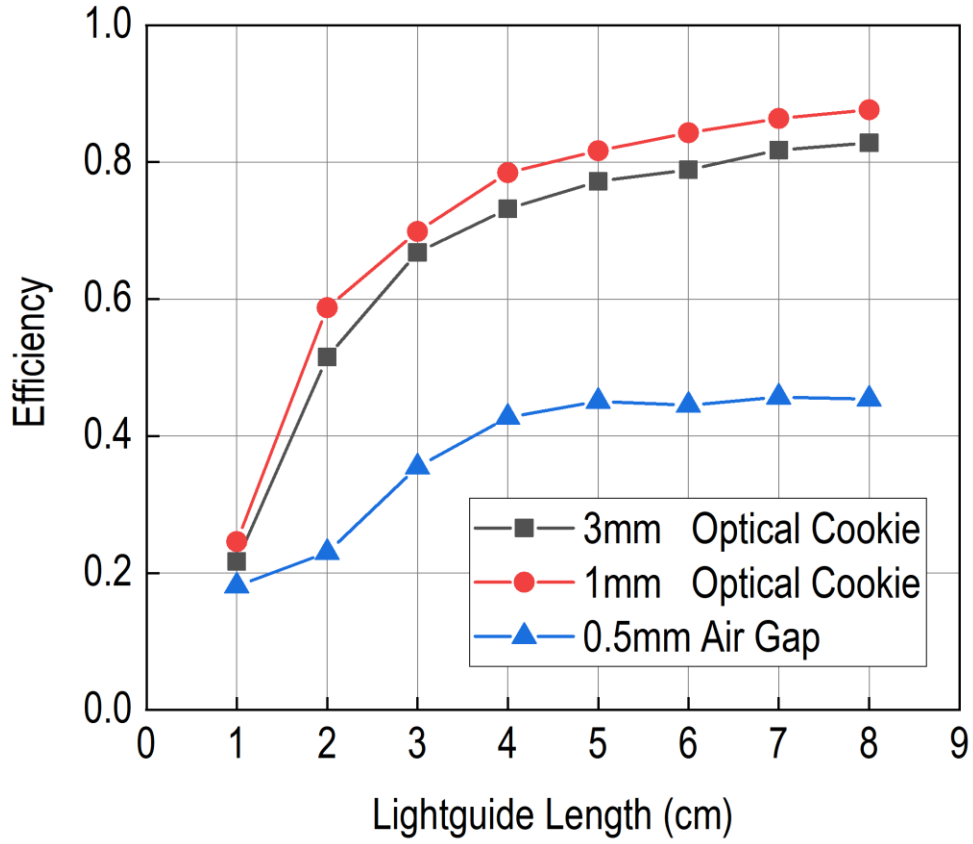
Borosilicate glass : heavy and expensive
Scintillating fiber emission spectrum : 400 – 600 nm

→ **Cast acryl$_{flamed}$**

Efficiency : Transmission efficiency with Light Guide Length (Geant4)



1. Different Light Guide (LG) length
2. (a) 3 mm and (b) 1 mm Optical cookie, (c) 0.5 mm air gap

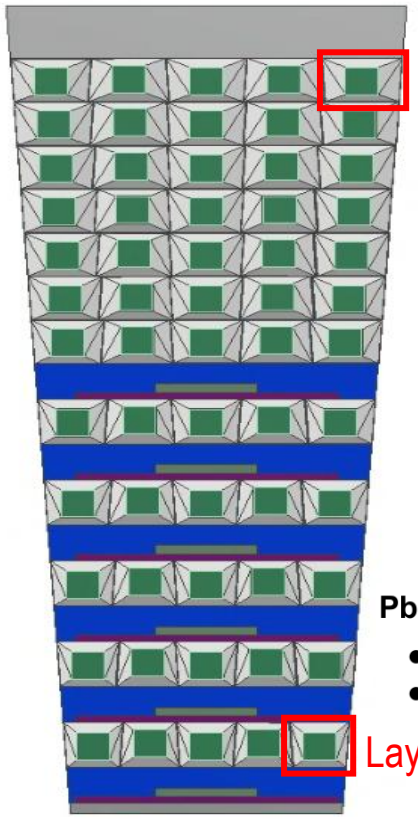


Efficiency = Collected photon / Thrown photon

Sublinear efficiency near ~ 5 cm

Optical cookie needed

Light Guide shape



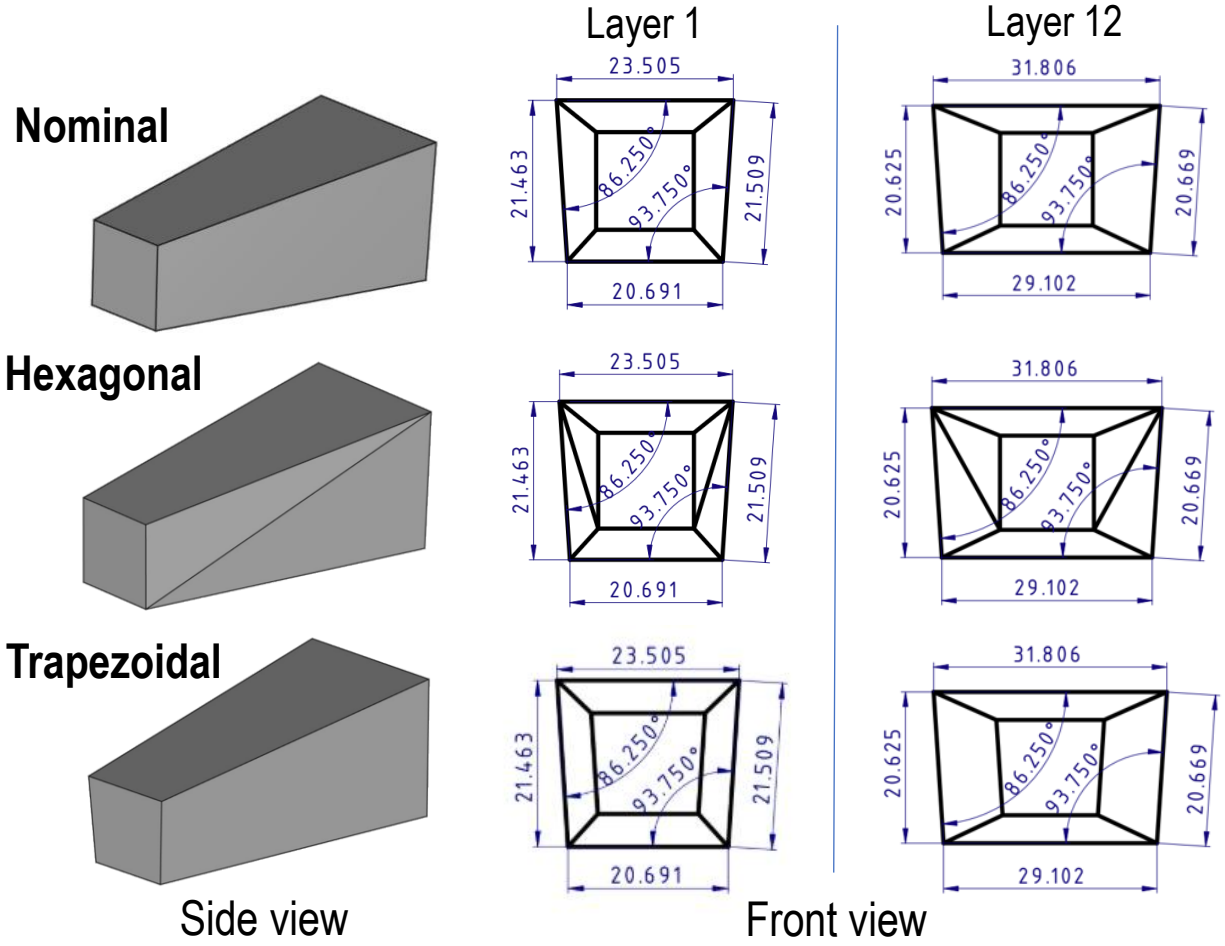
Pb/SciFi Layer (1.4X0)

- 5 readout cells per layers
- 1 light-guide per cell

Constraint

Photon entrance area

Photon exiting area



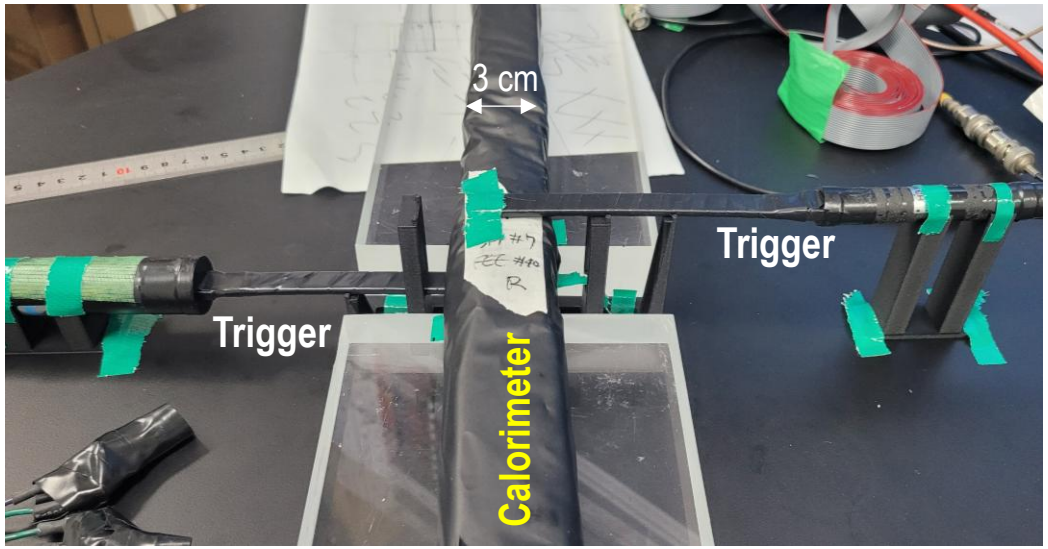
Shape

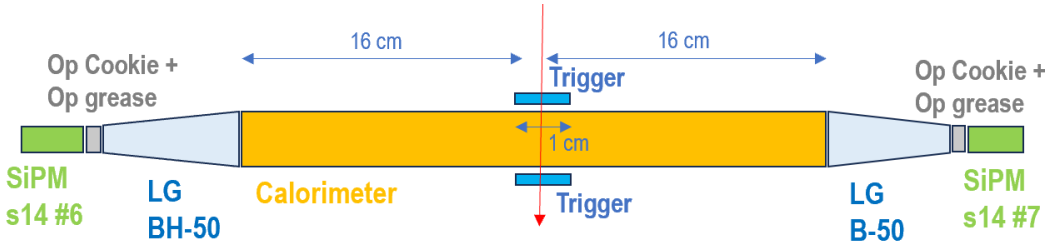
Nominal

Hexagonal

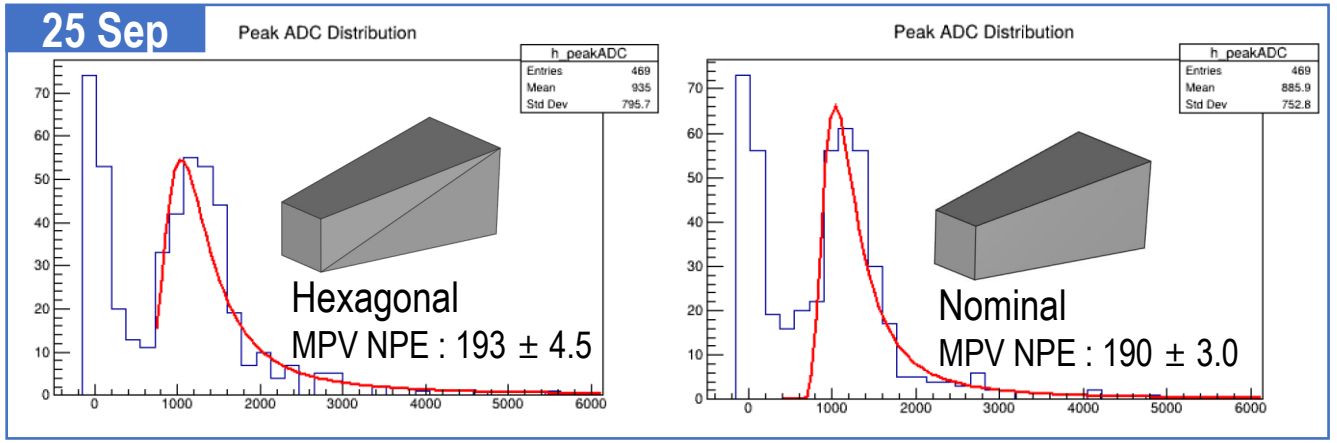
Trapezoidal

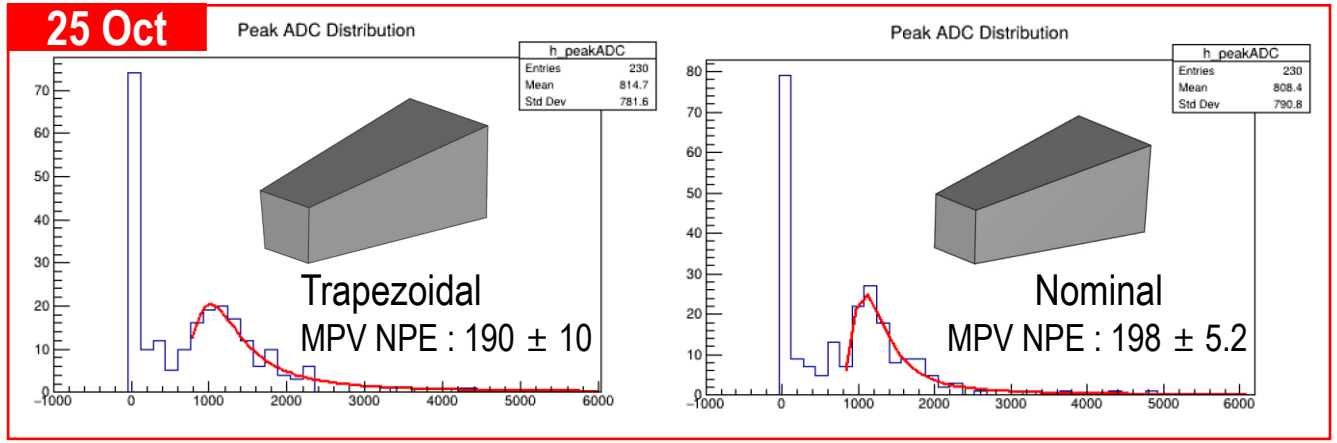
Efficiency : Cosmic ray test





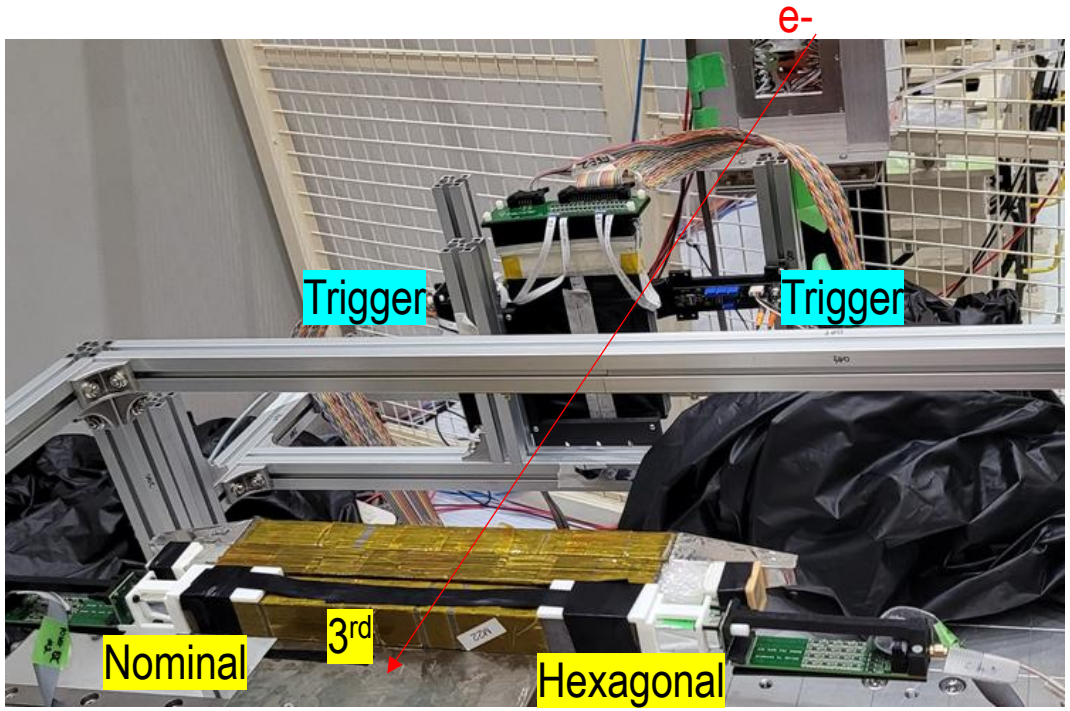
Cosmic ray setup (KNU)
Pb/SciFi calorimeter
2 triggers (scintillator + PMT)
Different Light Guides (from Zisis) at each end

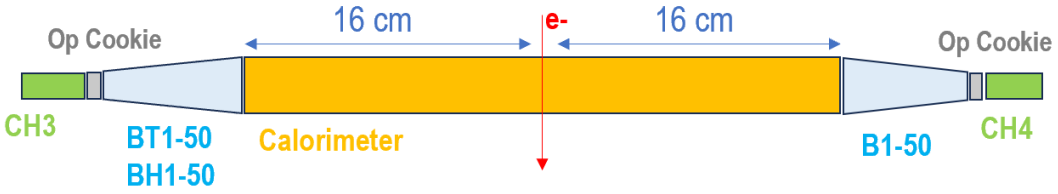




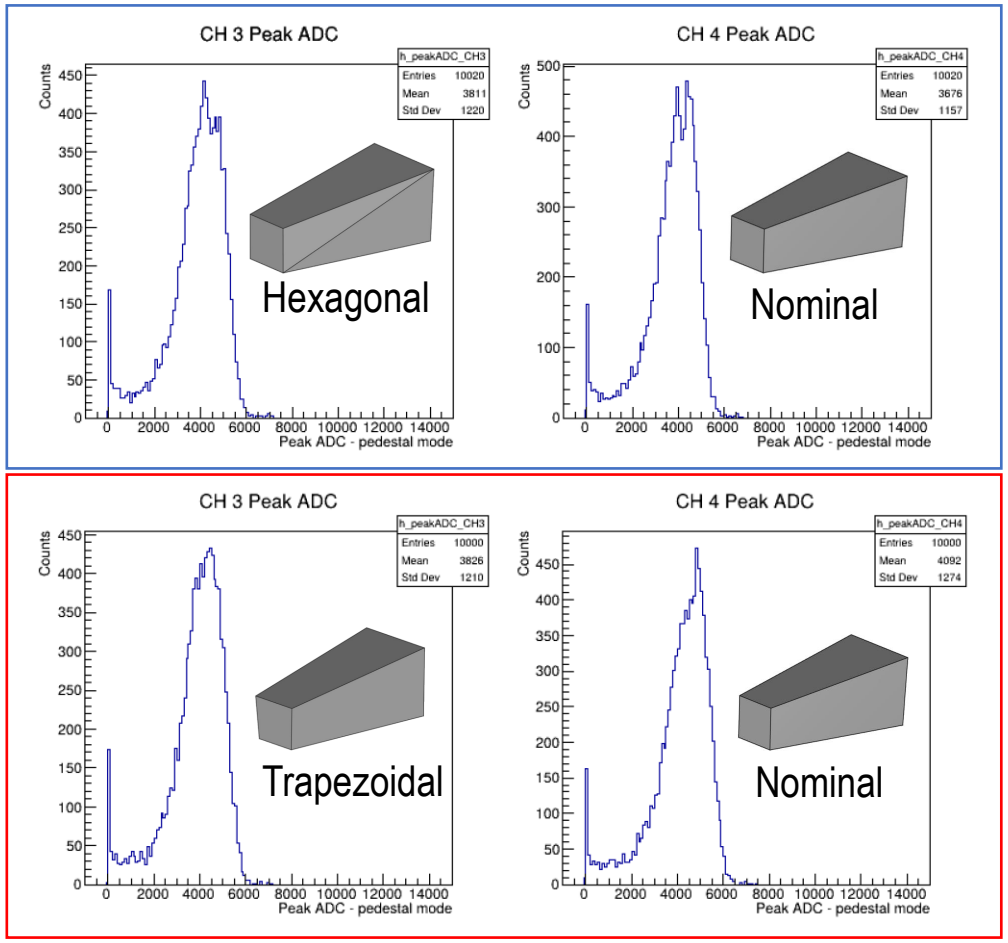
Light yield
Almost no difference in efficiency
Trapezoidal : Nominal : Hexagonal = **0.96 : 1 : 1.02**

Efficiency : Electron beam test





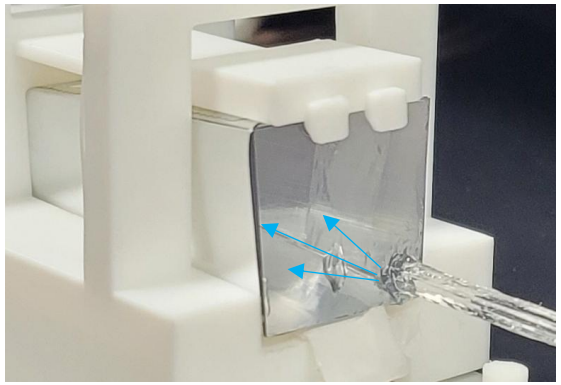
Beam :
5 GeV/c

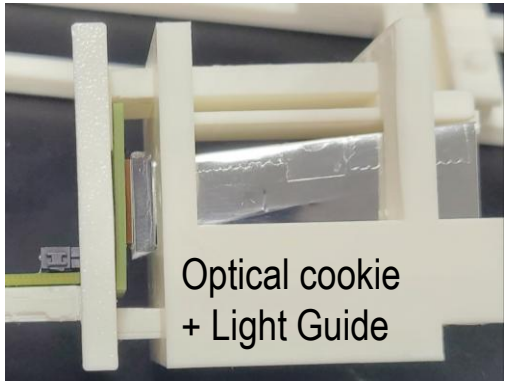


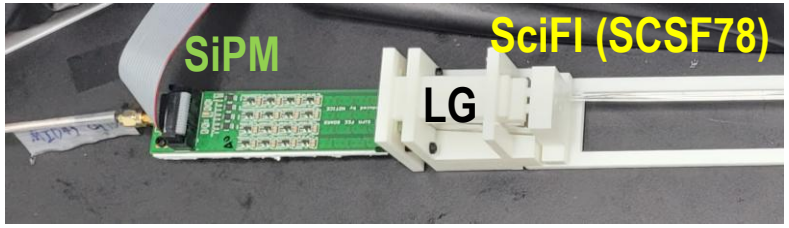
Electron beam at KEK (2026 May)
Beam momentum : 1, 2, 3, 5 GeV/c
Different Light Guides (from Zisis) at each end

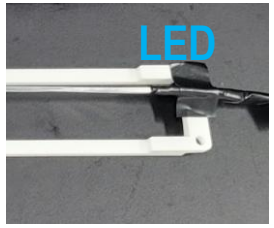
Light yield
Ratio of mean ADC of Light Guides at 5GeV/c electron beam
Trapezoidal : Nominal : Hexagonal = **0.94 : 1 : 1.02**

Light mixing : Fiber + LED





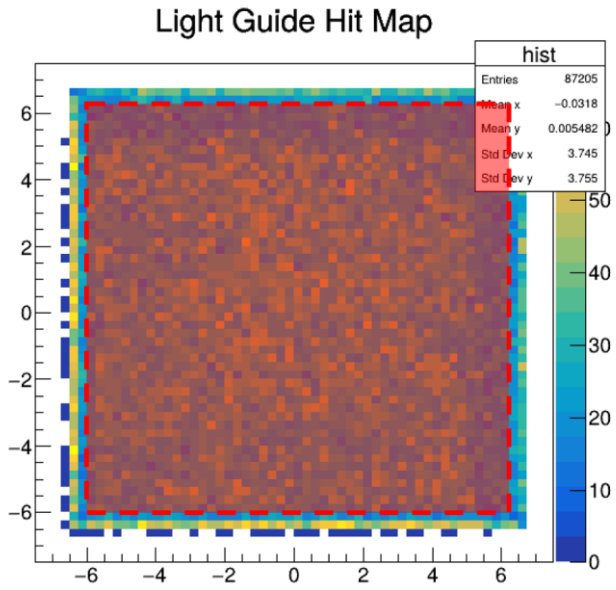




Light mixing (KNU)

1. 7 Fiber at right obtuse corner
2. **Light yield per SiPM ch. (spe calibrated)**

Fiber bundle (7 fibers)
polished with 2000 grit sandpaper



Region of interest
Simulation result

$$\mathrm{NAAD} = 1 - \frac{1}{N\bar{Y}} \sum_{i=1}^{N} |Y_i - \bar{Y}|$$

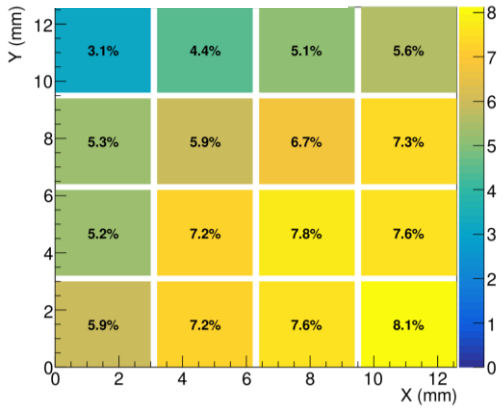
Normalized Absolute Average Deviation (NAAD)
N : number of pixels in the region of interest
$\mathbf{Y_i}$: bin in the region of interest
Y : average bin value of the region of interest.

1 : perfect uniformity
-1 : worst uniformity

Light mixing : Fiber + LED

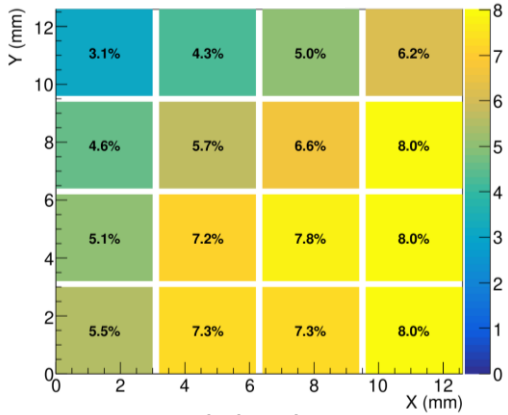
3 mm Optical cookie

Nominal



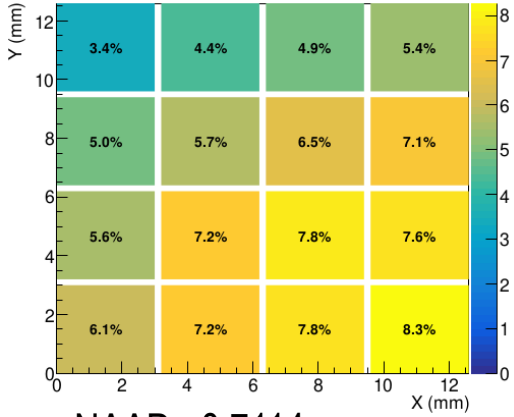
NAAD : 0.7072

Hexagonal



NAAD : 0.6773

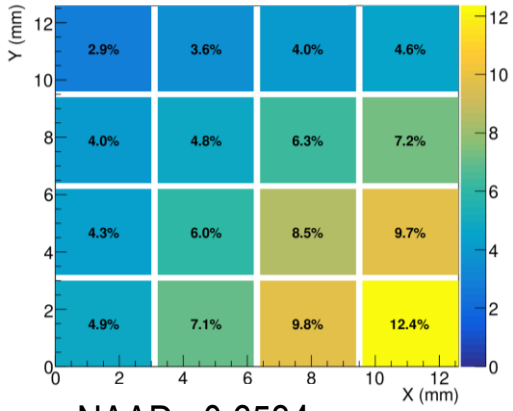
Trapezoidal



NAAD : 0.7114

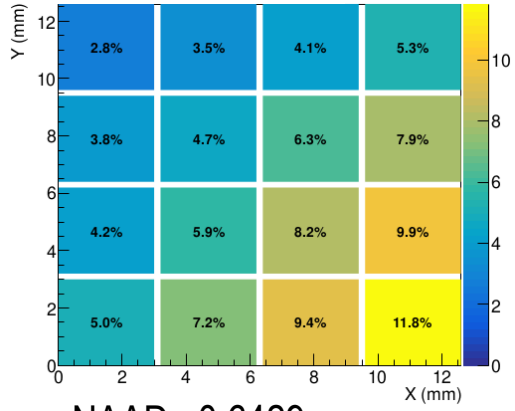
1 mm Optical cookie

Nominal



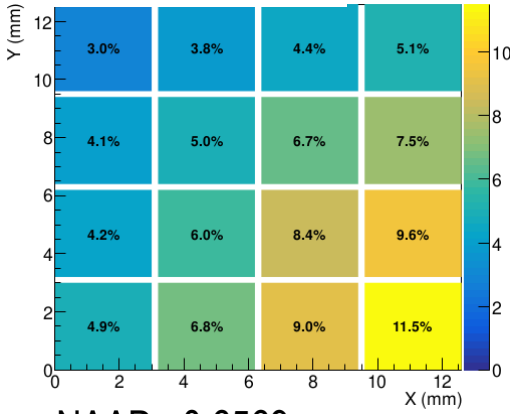
NAAD : 0.6534

Hexagonal



NAAD : 0.6429

Trapezoidal

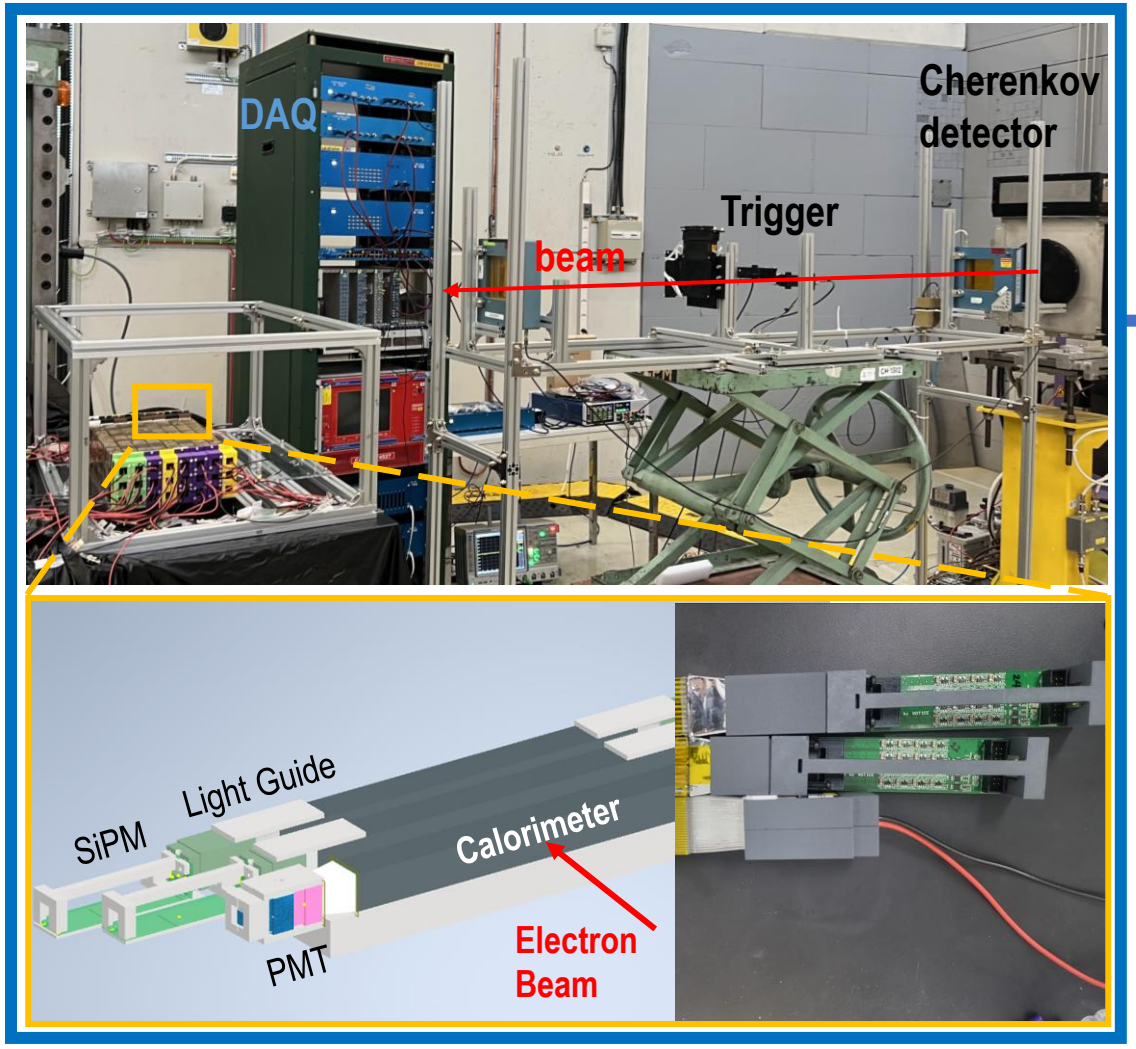


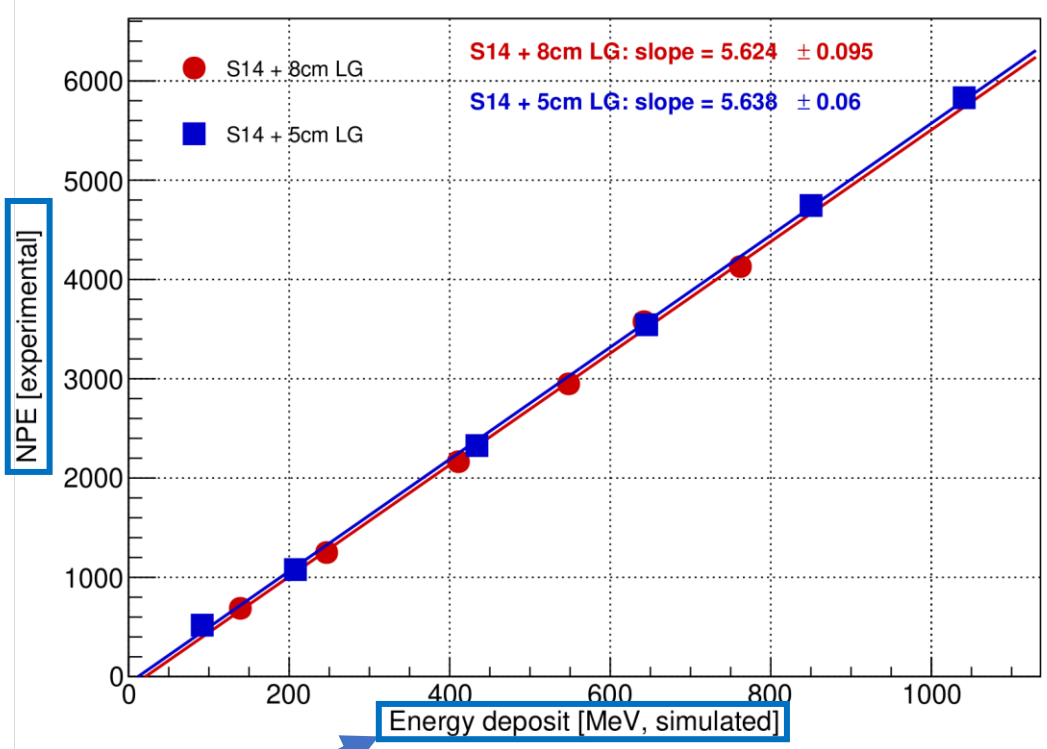
NAAD : 0.6569

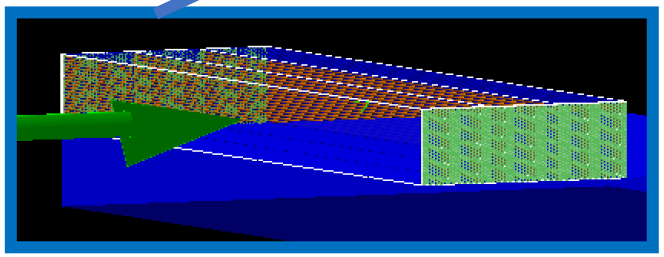
NAAD with 16 channels
1 mm cookie : bad light mixing
→ **3 mm optical cookie**

Linearity : electron beam

2025 CERN PS T-10 beam line







Geant4 simulation
Energy deposition per calorimeter
Energy : 0.5 ~ 5 GeV

3 Calorimeter modules with different readouts
S14 + 3 cm x 3 cm x **5 cm, 8 cm Light Guide (G Tech)**
PMT + bundling (reference)

Great linearity checked with electron beam
(3 cm x 3 cm Light Guides)

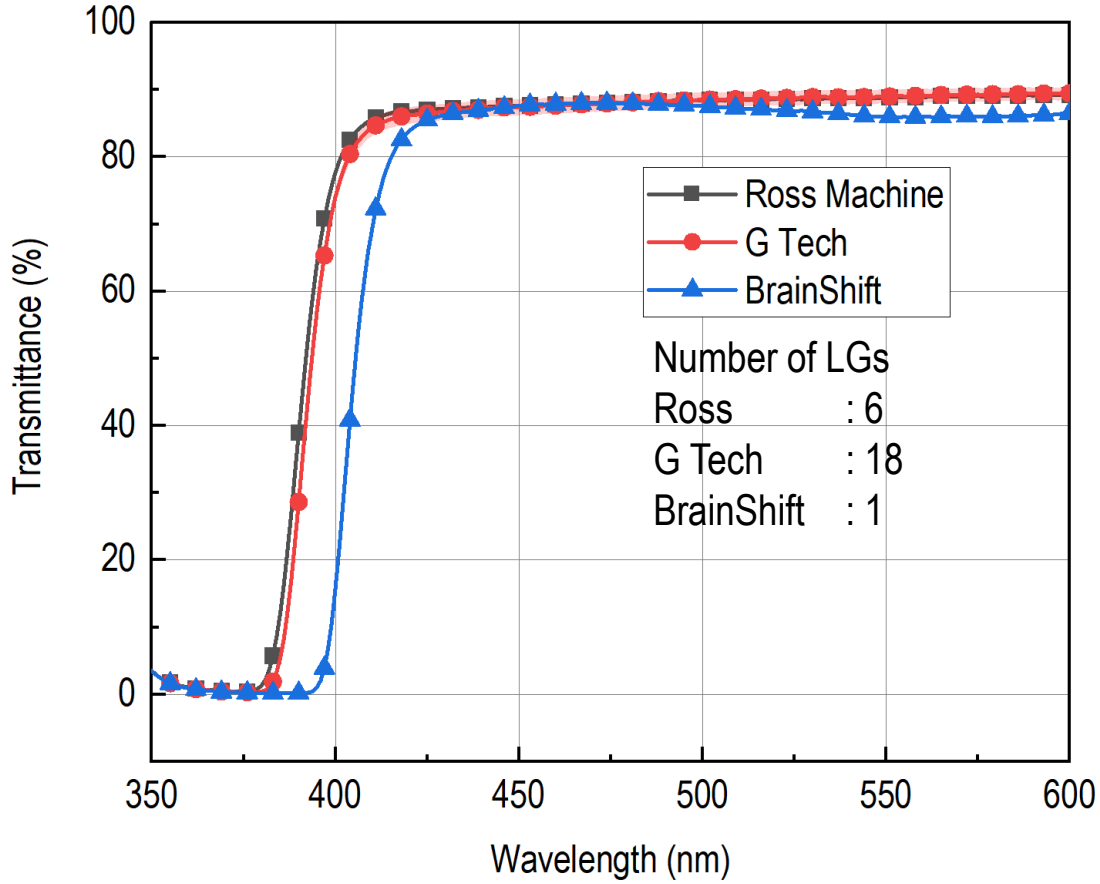
Light Guides in KNU

LGs in KNU

	Ross Machine (Zisis)	G Tech	Brain Shift (Zisis)
Layer	1, 12	1, 4 - 12	X
Shape	Nom, Hex, Trz	Hex, Trz (layer 1, 2) Hex (layer 4 -12)	X
Total	6	90	1

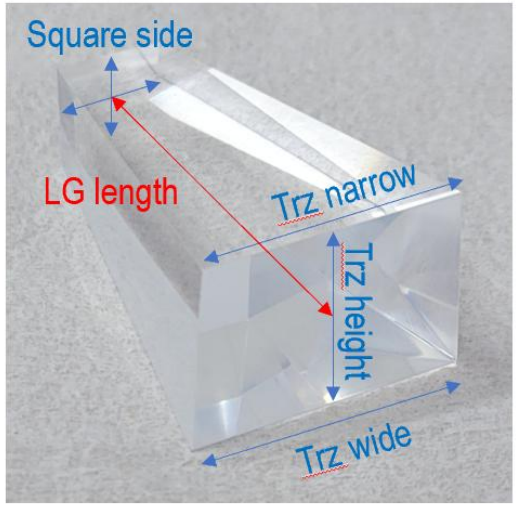
Cast acrylic LGs
Capable of making 2 SFIL (layer 4, 5) & 1 Bulk (layer 5 - 12)

Transmittance

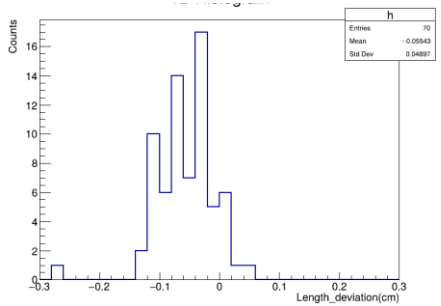


Light Guides from G Tech

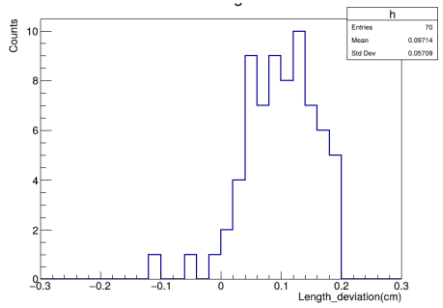
Dimension



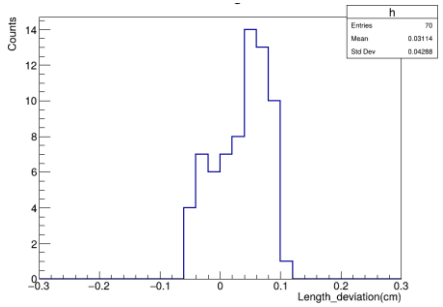
Layer 6~12 (G Tech) measurement



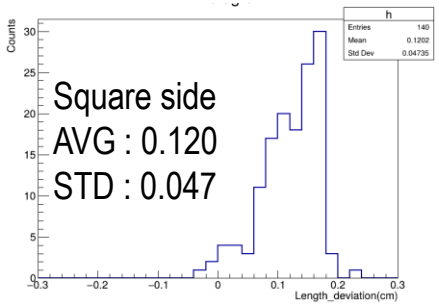
Trapezoid Wide side
AVG : -0.055
STD : 0.049



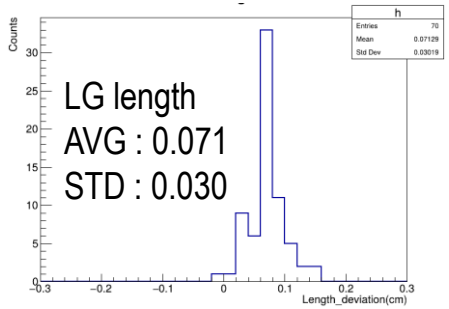
Trapezoid Narrow side
AVG : 0.097
STD : 0.057



Trapezoid height
AVG : 0.031
STD : 0.043



Square side
AVG : 0.120
STD : 0.047



LG length
AVG : 0.071
STD : 0.030

G tech requirements :
Length : ± 0.1 mm
Side : ± 0.3 mm

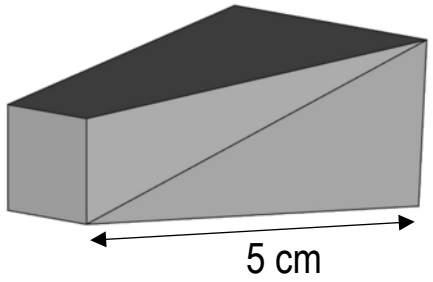
Length (red)
Side (blue) :
Square side
Trz wide, narrow, height

	Ross Machine	G Tech
LG #	6	90
Length	0.08 ± 0.05 cm	0.07 ± 0.03 cm
Side	0.09 ± 0.14 cm	0.06 ± 0.08 cm

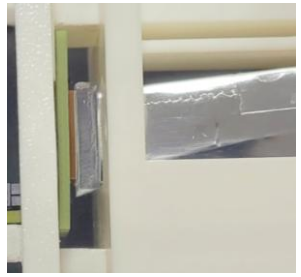
Summary : Light Guide optimization

- Light Guide parameter
  - **1. Material : Cast Acrylic$_{flamed}$**
  - **2. Length : 5cm**
  - **3. Shape : Hexagonal (tentative)**
  - **4. Optical cookie : 3 mm thick**

Cast acyrlic$_{flamed}$

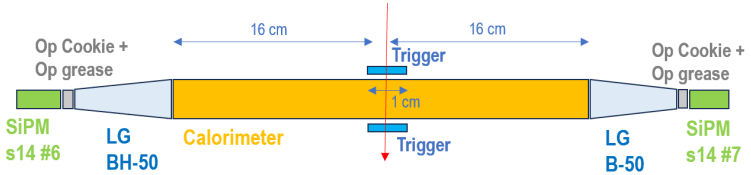


5 cm, Hexagonal



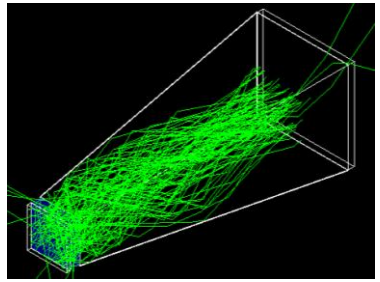
3 mm Optical cookie

- Efficiency
  - Geant4 optical simulation
  - Cosmic ray test
  - Electron beam test
- Light mixing
  - Scintillating fiber + LED
  - Geant4 optical simulation
- Linearity
  - Electron beam test

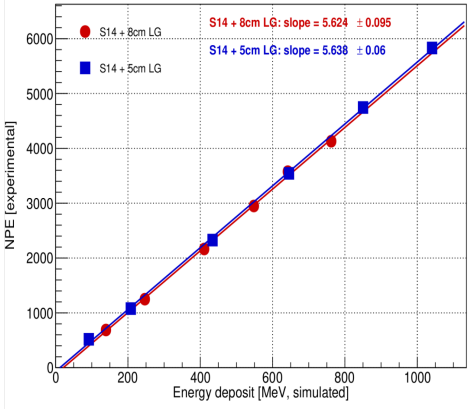


Cosmic ray test

SciFi + LED



Optical simulation

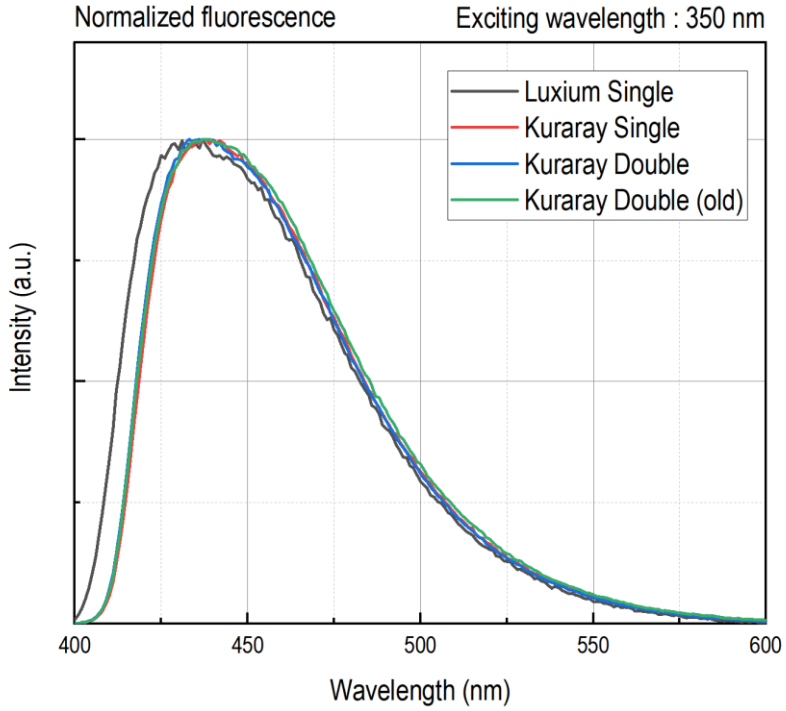


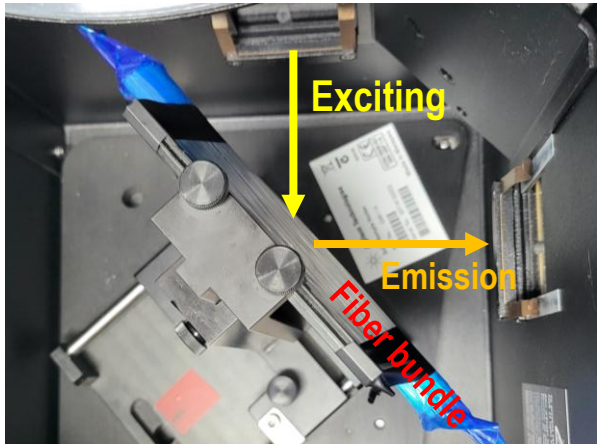
Electron beam test

Backup

Emission spectra

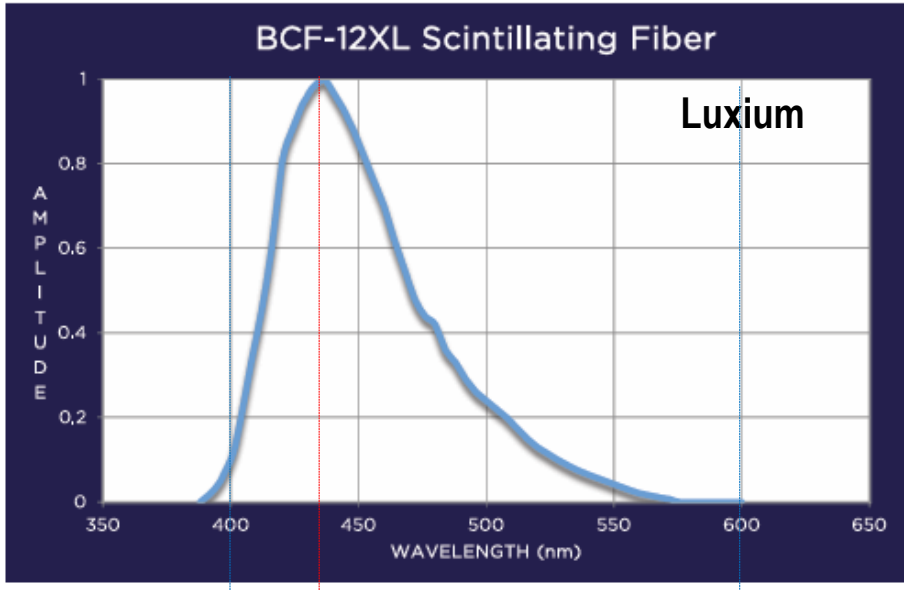
Measurement



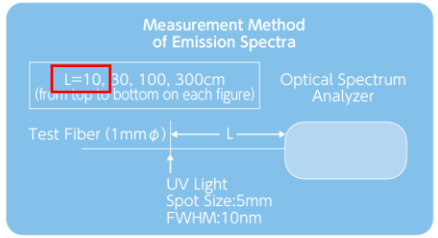


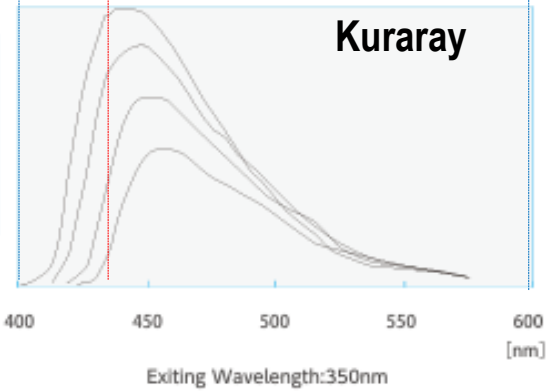
SciFi Fluorescence measurement with
Varian Cary Eclipse Fluorescence Spectrometer

Data sheet



SCSF-78

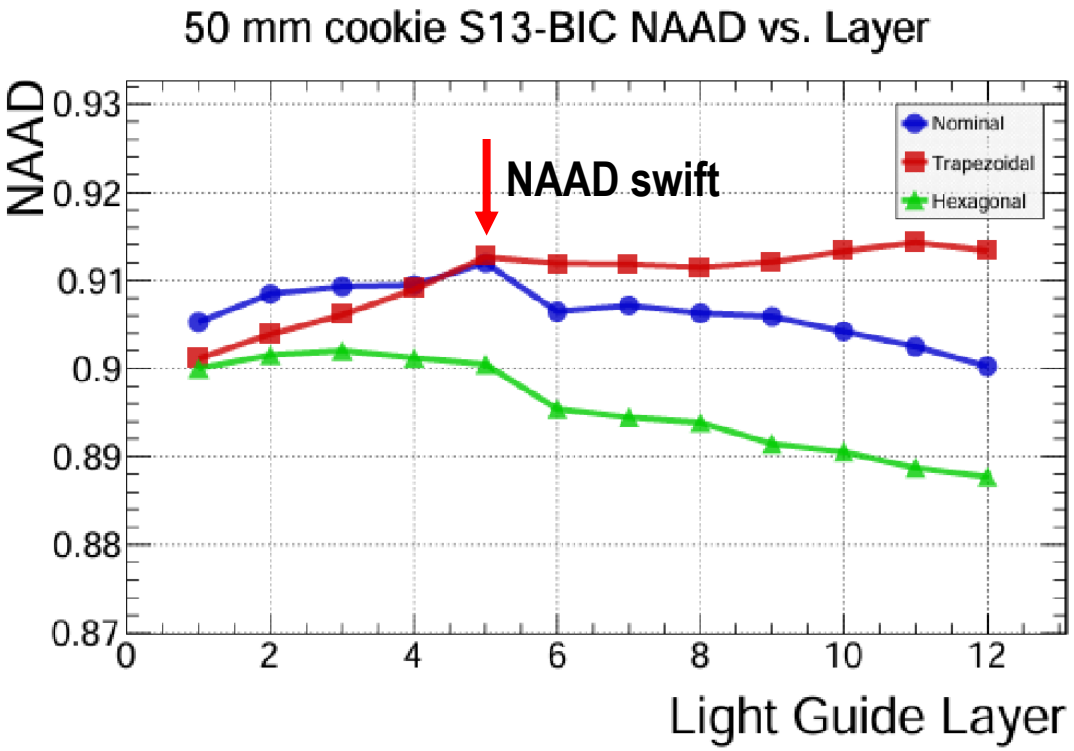




Peak wavelength
Luxium > Kuraray

Good agreement with data sheet

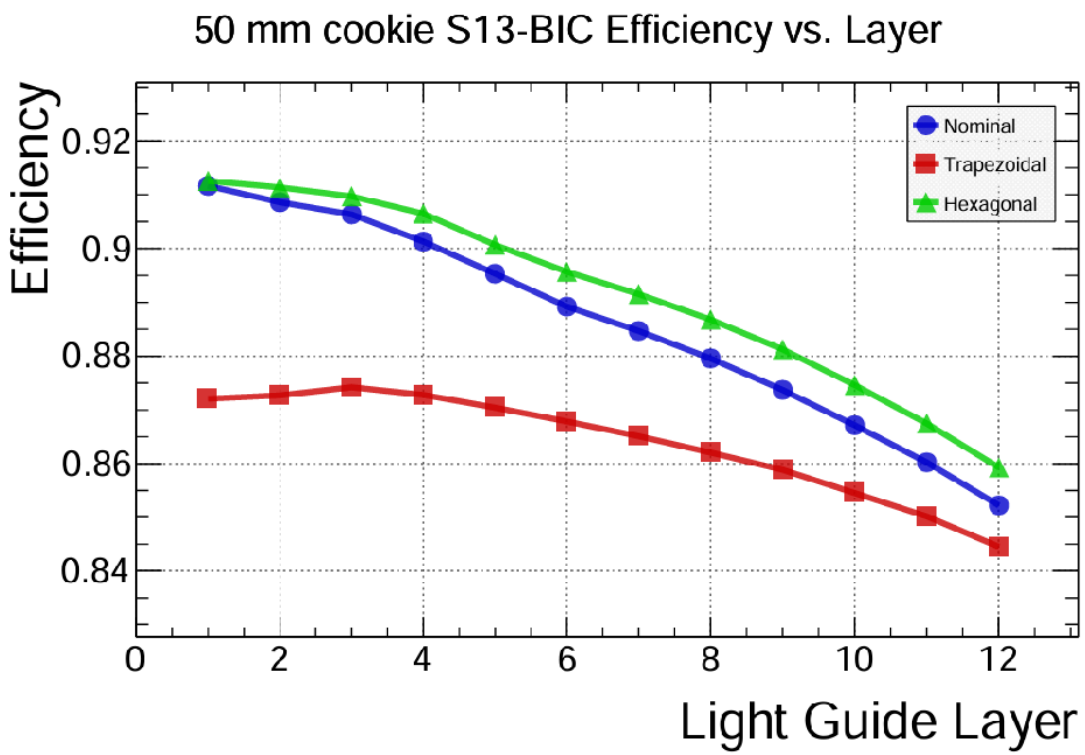
Light guide simulation (by Tegan)



NAAD vs layer number for 50 mm BIC Light Guides of Various shapes with a 1 mm optical cookie

Nominal ~ Trape > Hex

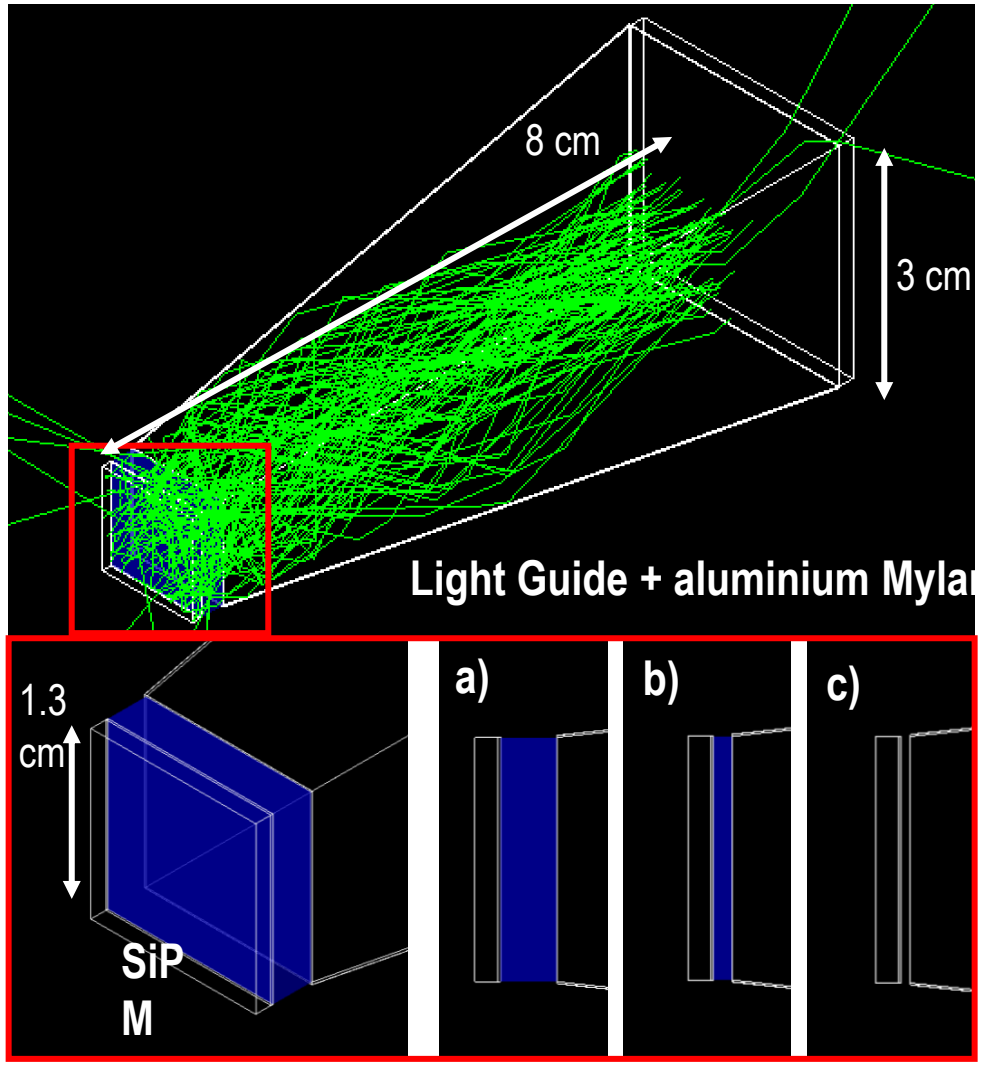
Photon emission all area

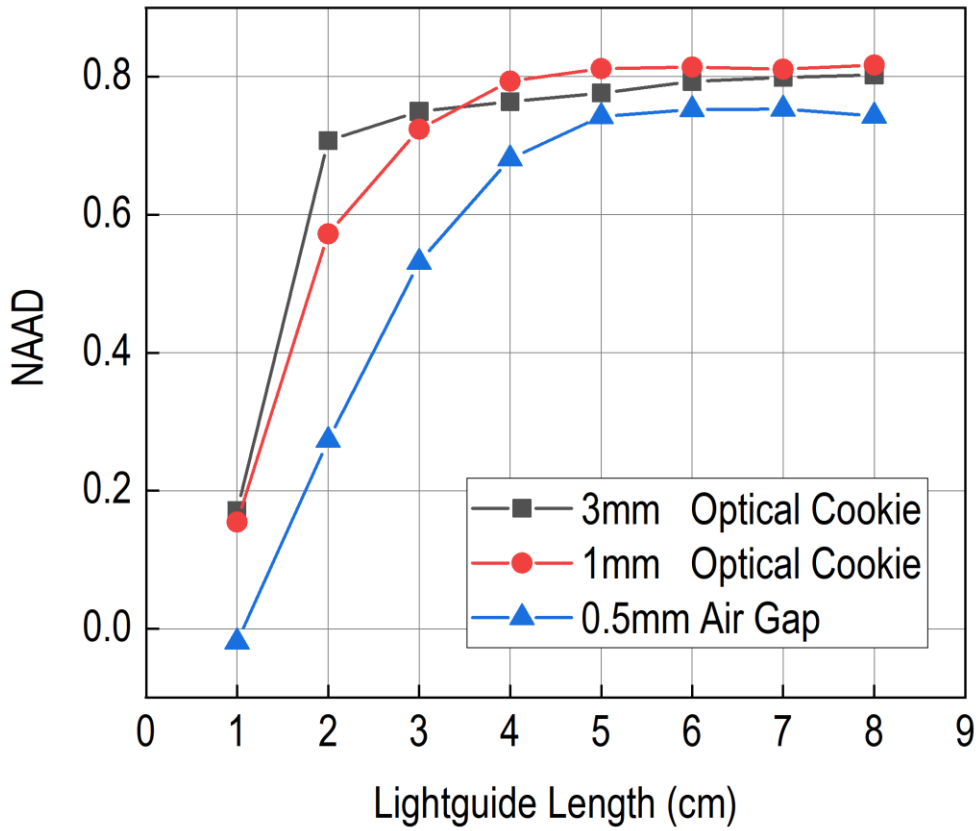


Efficiency vs layer number for 50 mm BIC Light Guides of Various shapes with a 1 mm optical cookie

Hex > Nominal > Trape

NAAD with Light Guide Length (Geant4)





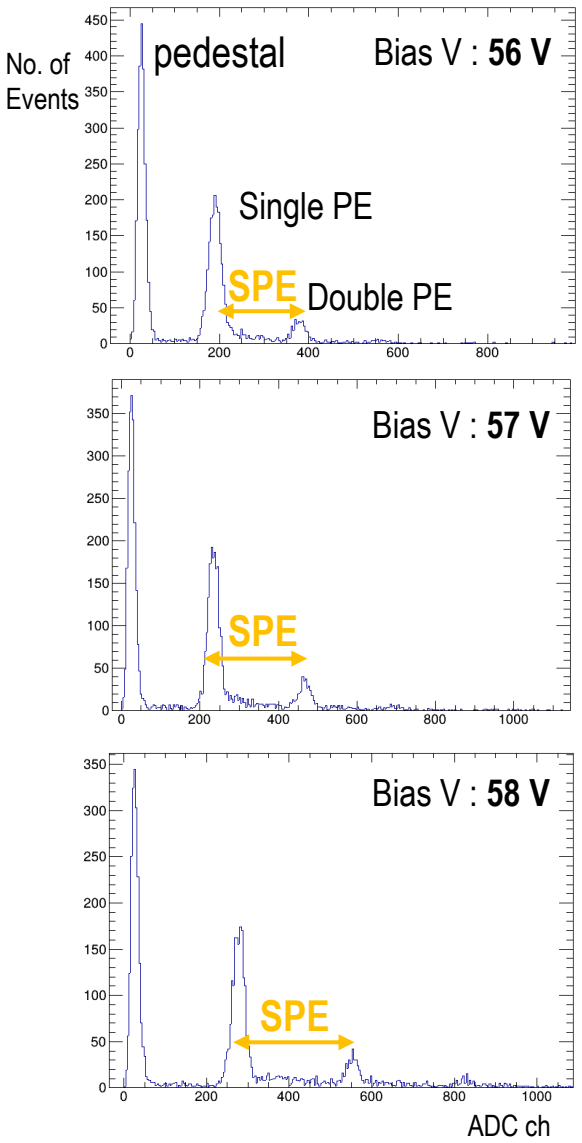
NAAD
1 mm > 3 mm when 4 – 8 cm

1. Different Light Guide (LG) length
2. (a) 3 mm and (b) 1 mm Optical cookie, (c) 0.5 mm air gap

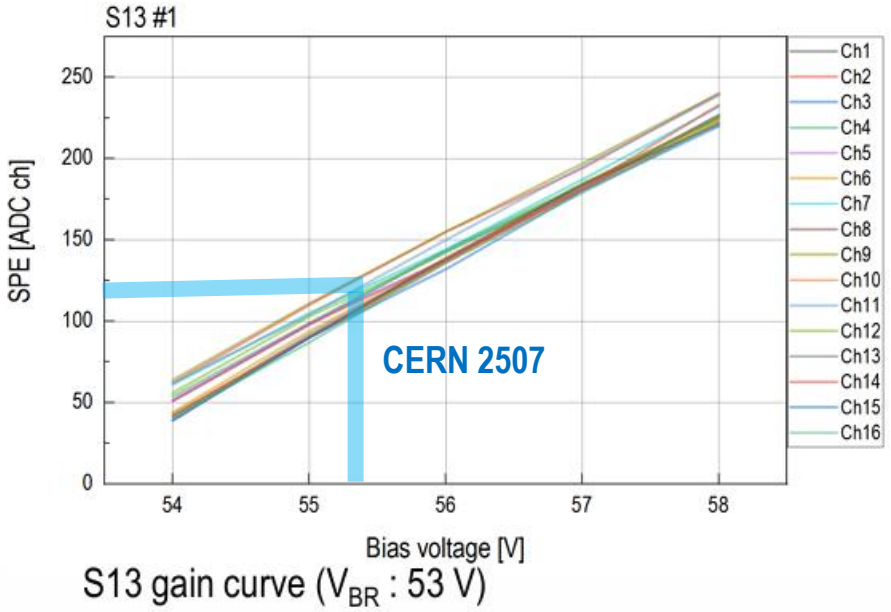
SPE ADC

SiPM SPE

Peak ADC Distribution



Increasing SPE (x21) with increasing bias voltage (S13)

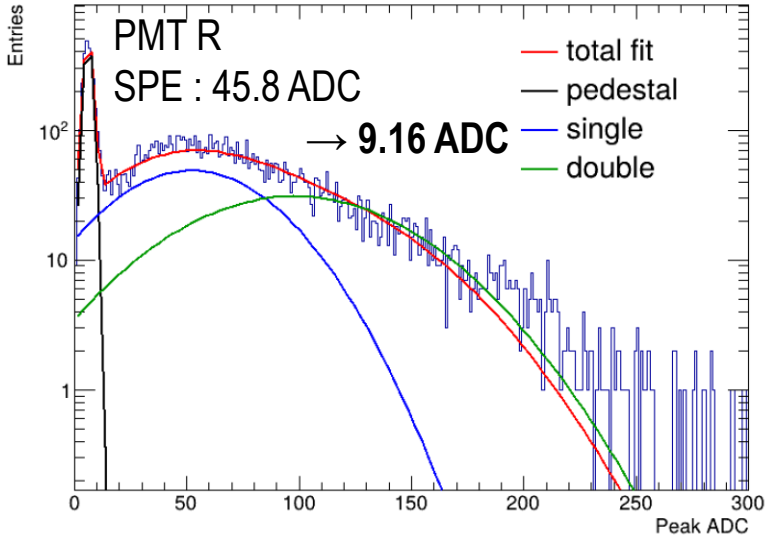


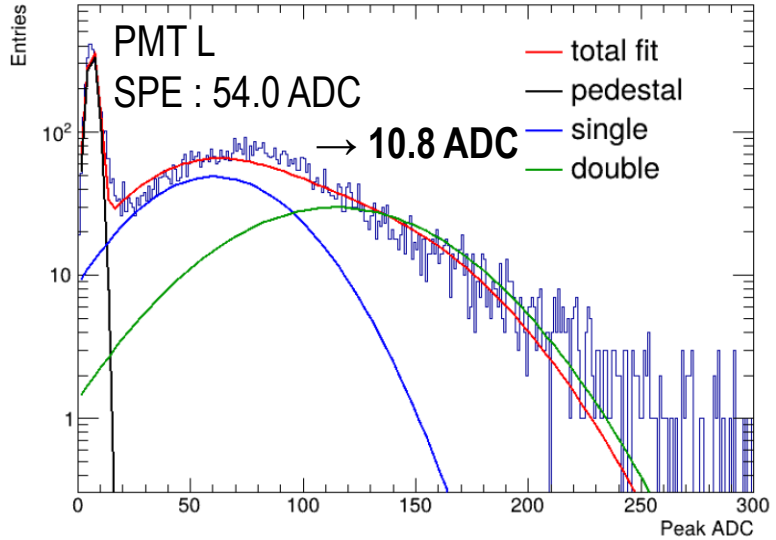
S13 gain curve (V_{BR} : 53 V)

Spe for all 16 channels of S13 and S14 Setted to **5.4 ADC**

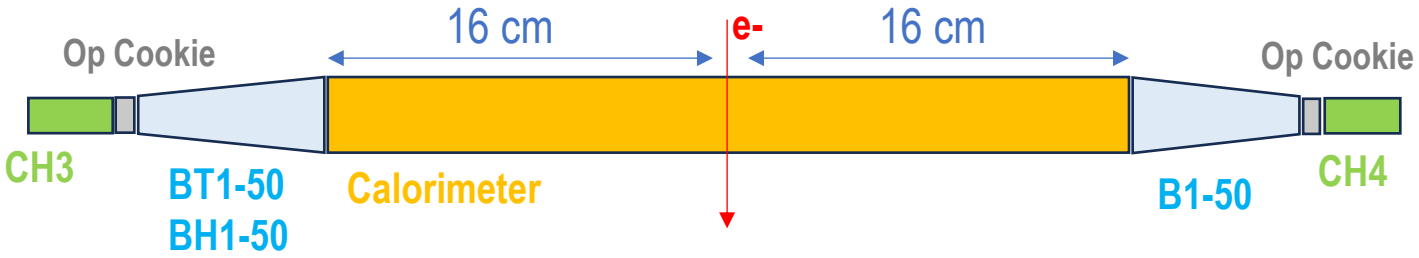
SPE measurement with LED

PMT SPE at 950 V (x5)





Efficiency : Electron beam test



Pb	Fiber	Air
Pb	Fiber	Air
43	38	19