PIONEER Calo Review

PART I: LXe

INTRODUCTION

Density	2.95 g.cm-3
Radiation length	2.87 cm
Moliere radius	5.224 cm
Light yield	>46000 photons / MeV

All work shown here is **work in progress (WiP)**
Geometry/photosensor coverages changes as we understand behaviours. What was shown at last collaboration has **greatly evolved**

KEY POINTS (to come back to for discussion) :

- homogeneous coverage on all surfaces is key but inhomogeneous coverage can be corrected for (surface scaling)
instrumentation of inner surface is mandatory

-~**1% energy resolution** from simulation looks achievable (even down to 30% cov.) : need prototype data to confirm

- Windows (500um Al + 200um Ti alloy) and SiPM with CoF (400um equivalent of Ti alloy) will degrade the energy by <15%
(effect of inhomogeneities to be studied)

- for our geometry **absorption length** is a relevant factor

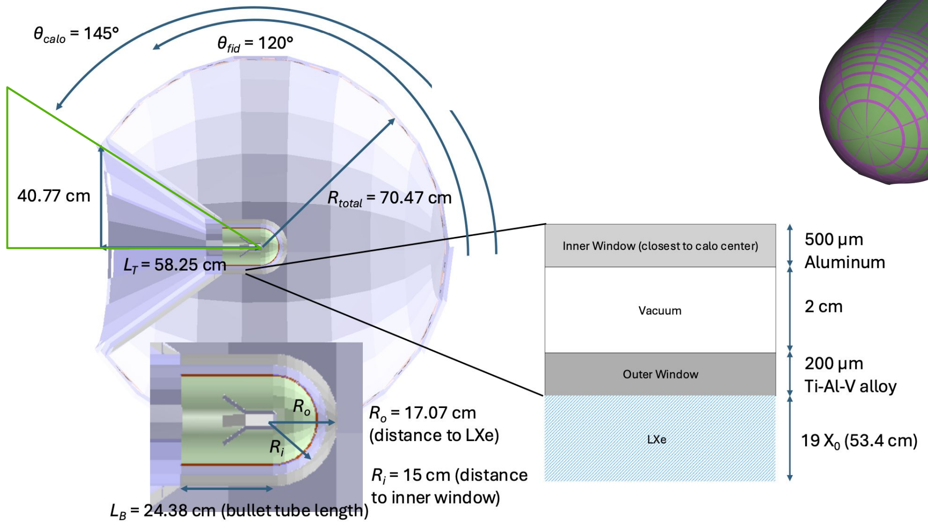
- limit to coverage lies on inner surface (much less than 30% might become problematic). 30% cov leads to ~**650** 12x12 sensors

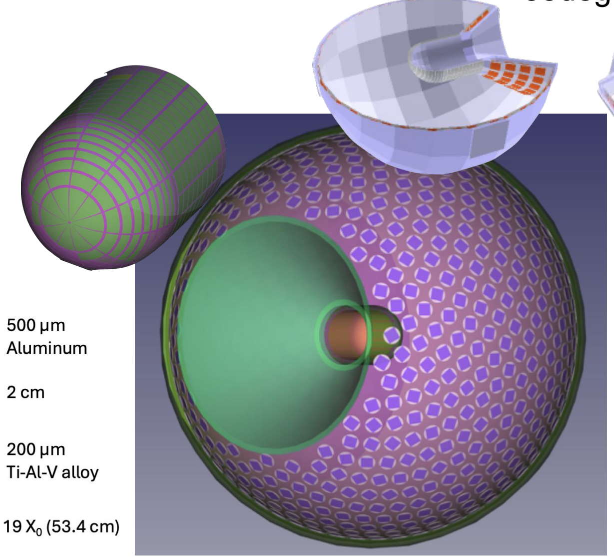
- **very good position resolution** provided by inner sensors & outer sensors: MEG achieved 2.5x2.5**mm**.
(WiP for pioneer geometry: potentially better since start of the interaction is on the surface)

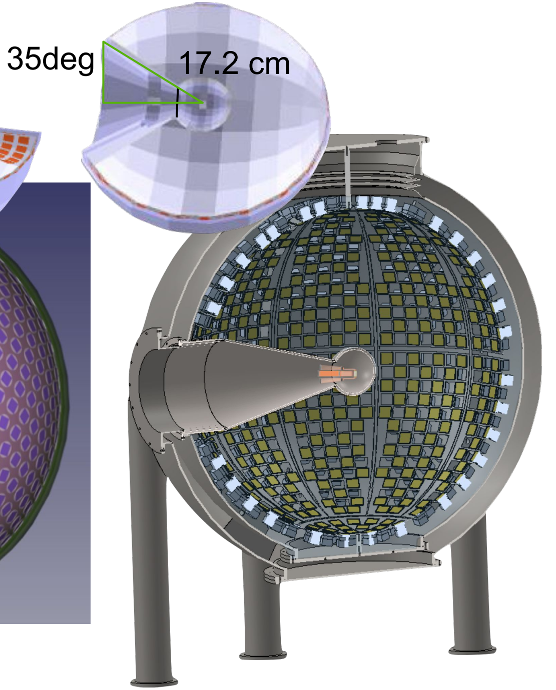
- **cone PMTs** provide a very good handle on events entering the calo upstream of the target

- **full waveform reconstruction** is WiP - Ayaka has done a lot. ready soon to do realistic pileup reconstruction and suppression

INTRODUCTION







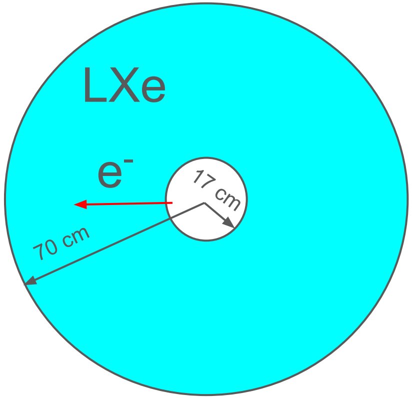
bullet geometry used currently for **optical** simulations
NOT a good geometry for beam considerations
NOT a good geometry for energy resolution/tail
Next week: switching to keyhole geometry

Current coverage for **optical** simulations
900 2'' PMTs on the outer surface (=37% cov)
100 2'' PMTs on the cone (=29% cov)
300 "fake" SiPMs (=90% cov)

KEYHOLE geometry
Used for E deposit simulations

Will be the DEFAULT geometry
For all simulations very soon
(including realistic SiPM on
the inner surface)

ENERGY RESOLUTION: Simple LXe Sphere



P (MeV)	Scint Res*	Detect Res **	Scint pe/MeV	Detect pe/MeV
20	0.003	0.026	4611	3103
30	0.003	0.023	4611	3018
50	0.002	0.021	4609	2928
70	0.002	0.019	4607	2880

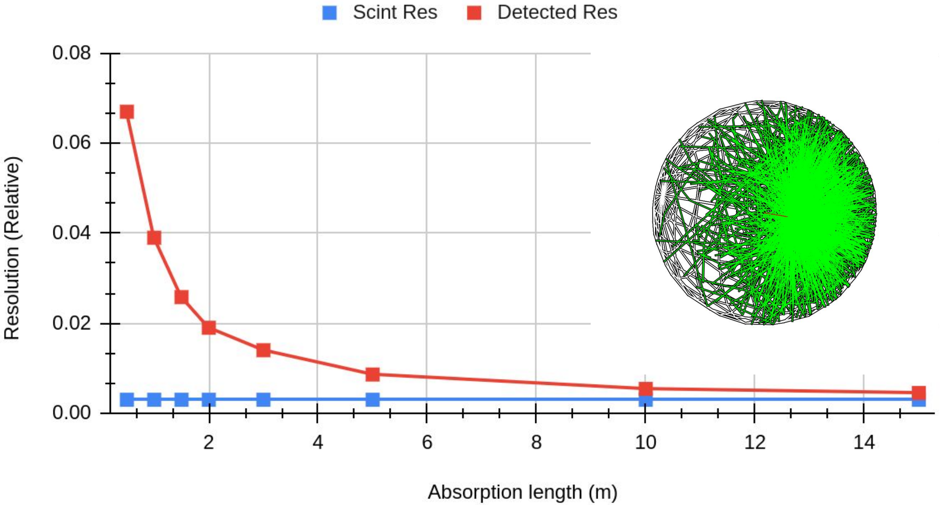
* Resolution achieved by counting every scintillating photon produced

** Fits are done with the Crystal Ball function | Resolution is Sigma/Mean

G4 Setup:

Absorption length = 150cm
Light yield = 46300 p.e./ MeV
Photodetection efficiency = 0.1
Inner/Outer surface fully detecting (1.0)
Beam of e- from the center along z-axis

Resolution vs Absoprtion length @ 20 MeV



Absorption length (m)	Scint Res	Detected Res	Detect pe/MeV
0.5	0.003	0.067	1936
1.0	0.003	0.039	2674
1.5	0.003	0.026	3103
2.0	0.003	0.019	3381
3.0	0.003	0.014	3711
5.0	0.003	0.009	4027
10.0	0.003	0.005	4298
15.0	0.003	0.005	4398

ENERGY RESOLUTION: Photo Sensor Coverage

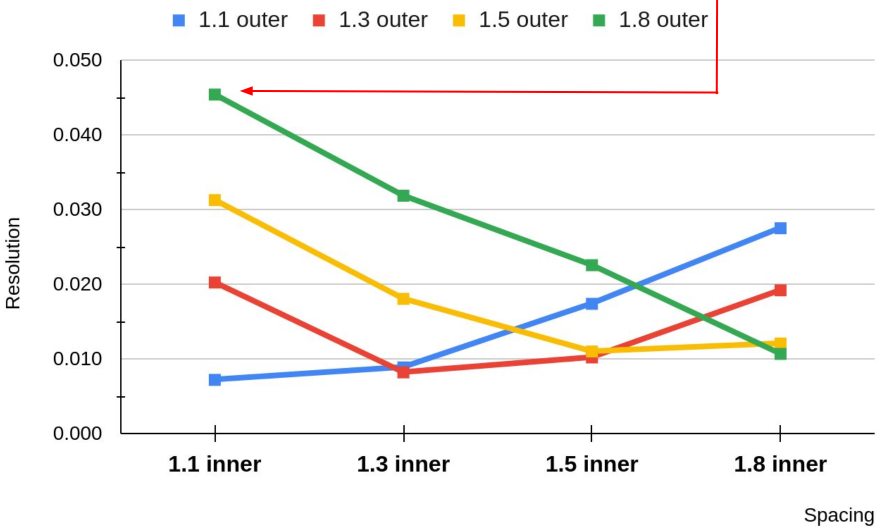
P_e=50 MeV/c
Absorption = 5m

Photo-sensor coverage study
Count photons only in predefined regions, based on characteristic photodetector size and spacing in-between (gap factor)

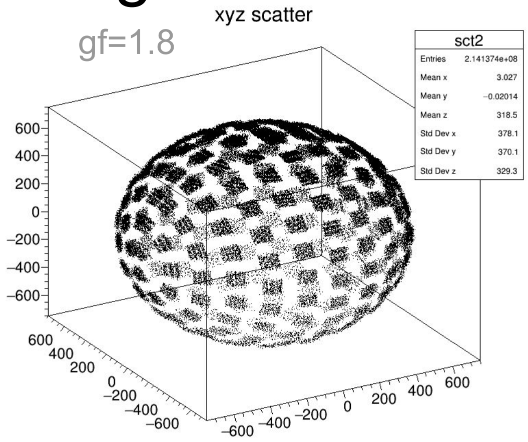
Why would the resolution decrease with better coverage on the inner surface?

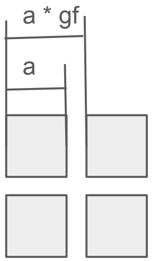
Resolution for various photo coverage

Spacing (gf)	1.1 outer	1.3 outer	1.5 outer	1.8 outer
1.1 inner	0.007	0.020	0.031	0.045
1.3 inner	0.009	0.008	0.018	0.032
1.5 inner	0.017	0.010	0.011	0.023
1.8 inner	0.028	0.019	0.012	0.011



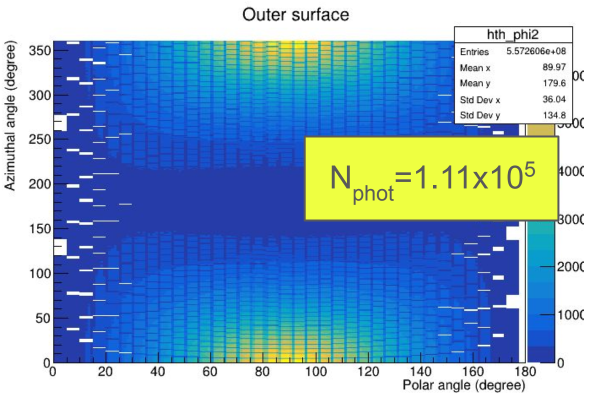
gf=1.8



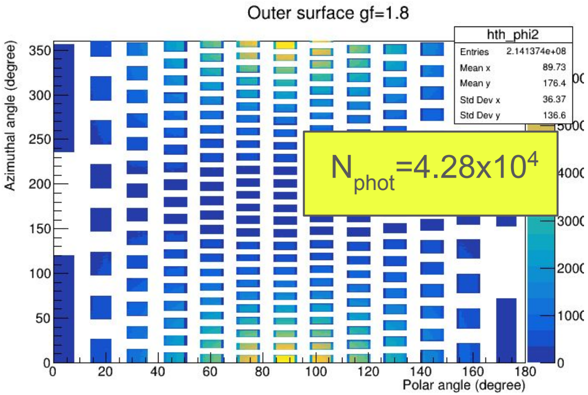


Inner SiPM size (a) **12 mm**
Outer PMT size (a) **51 mm**

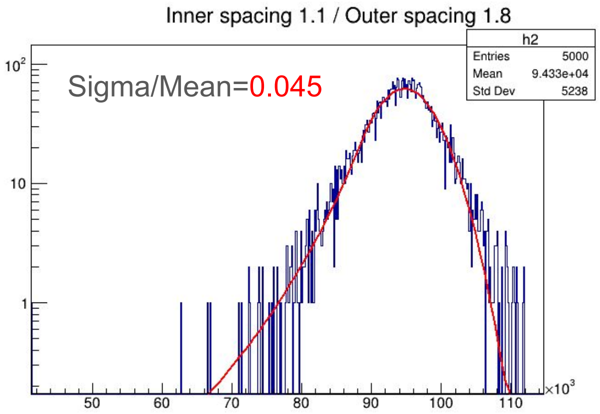
ENERGY RESOLUTION: Surface scaling



Outer surface PMTs spaced out to gf=1.8

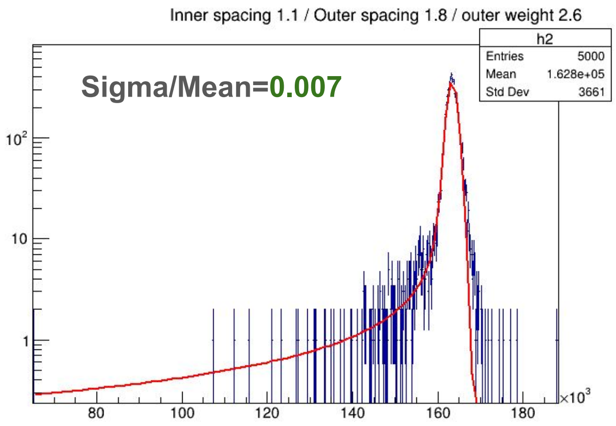


Ratio of photons for outer surface ~ **2.6** —> Scale outer surface photons



Outer surface weighted by 2.6

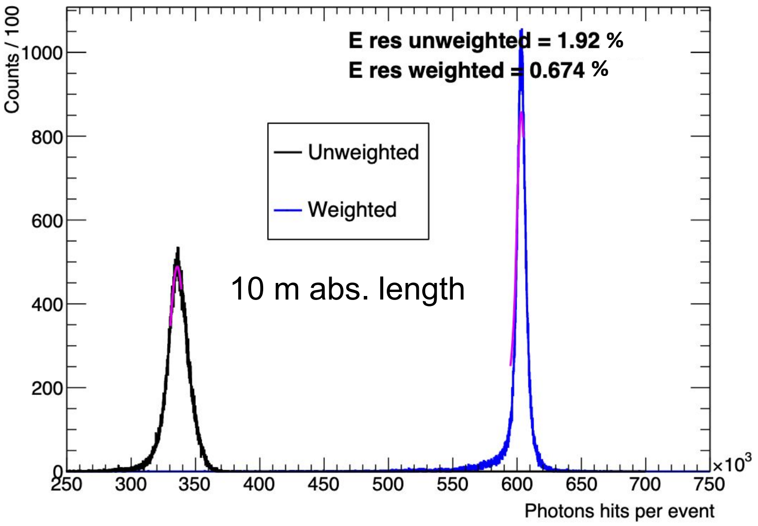
P_e=50 MeV/c



Energy Resolution: Corrections by Region

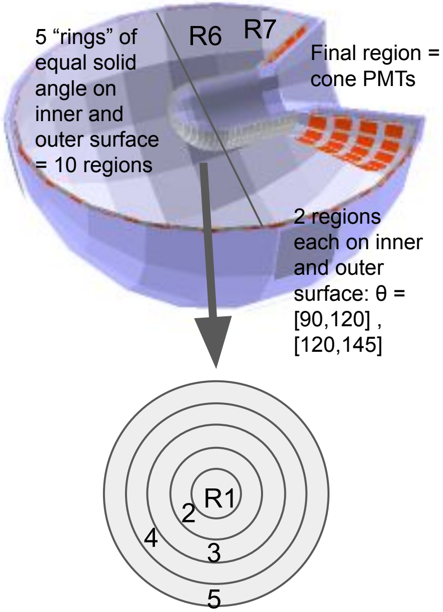
Apply MEG Face Factor correction strategy to PIONEER LXe calo - proof of concept:

- Simulate 70 MeV forward positrons (θ,ϕ) = (0,0)
- Divide calo into 15 geometric regions (final number of regions will be optimized)
- Define a coefficient for each region, such that when each coefficient is 1, summing each region = total photon hits
- Use TMinuit to solve for the coefficients that minimize the (std. dev. / mean) of the total photon hit sum

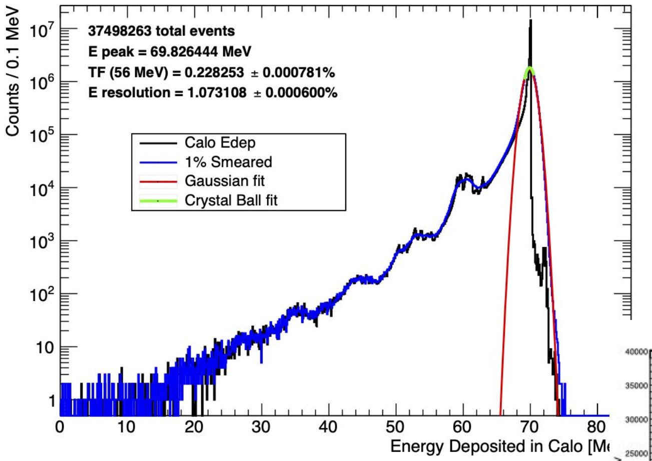


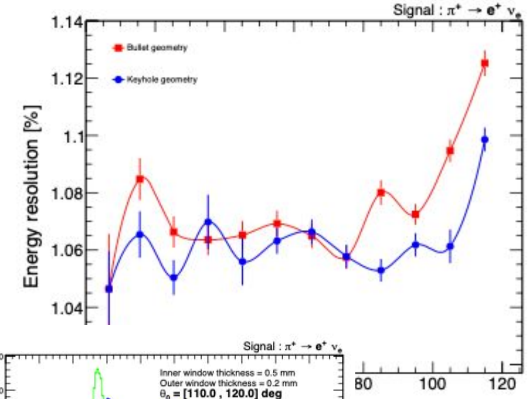
- After weighting, scale to original number of photon hits (scaling not shown here)
- Corrects energy resolution to <1%!
- Correction accounts for shower variations, detection “blind spots”

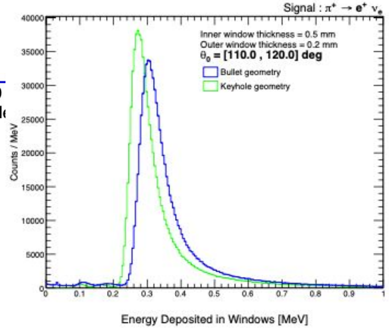
Regions:

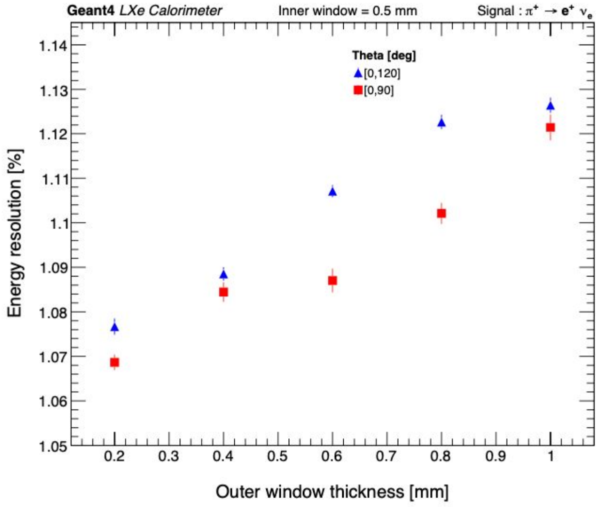


Energy resolution without optics

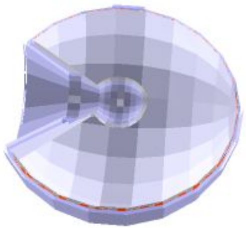








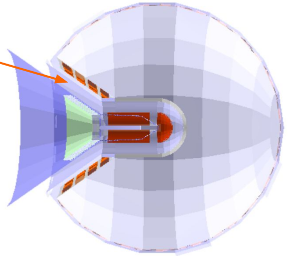
E resolution and tail fraction measured in the calo-only keyhole geometry



Energy resolution studied as a function of LXe window thickness

- Blue triangle shows full fiducial volume
- Changes to inner window thickness (Aluminum) have minimal effect on energy resolution
- Change to outer window thickness (Ti-Al-V alloy) have larger but manageable effect

PRELIMINARY CONE VETO STUDY



Can the PMTs on the cone be used to identify pile-up events?

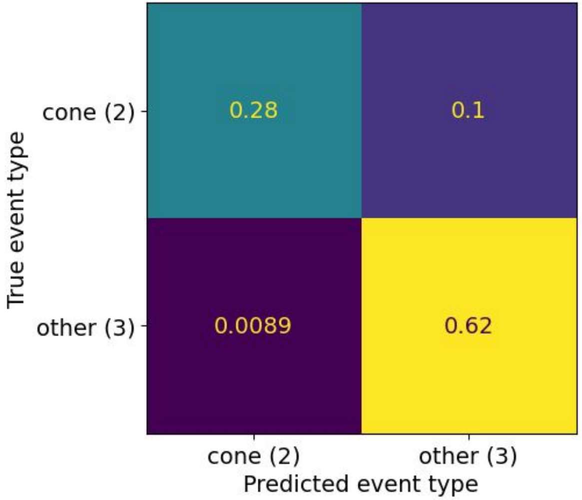
Initial study:

- Use (over) simplified cuts to separate out events
- Look at ratio of optical photon hits on cone PMTs vs all hits (= R) for each type of event
- Use this ratio instead to make the event cuts and see how well it can identify cone events

	% of events	R = cone hits/total hits
1 - ATAR hit	47.0	0.076 +/- 0.068
2 - Cone event Decay z < 0 mm θ first conversion > 120°	17.9	0.27 +/- 0.14
3 - no ATAR hit, not cone	29.2	0.041 +/- 0.031
Remaining	5.9	Most have no Edep

1e4 pure pion beam events (gaussian:swaist_sprime with xwaistsigma 9.3 mm, ywaistsigma: 6.0 mm)

Confusion matrix of how well the simple ratio cut (R > 0.12) identifies cone events

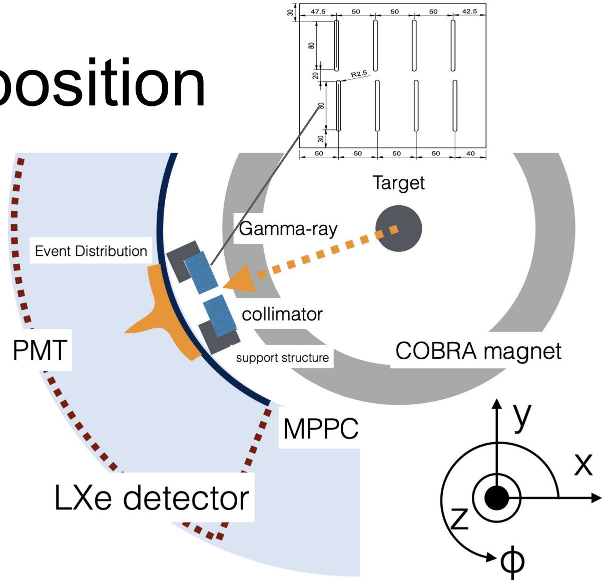


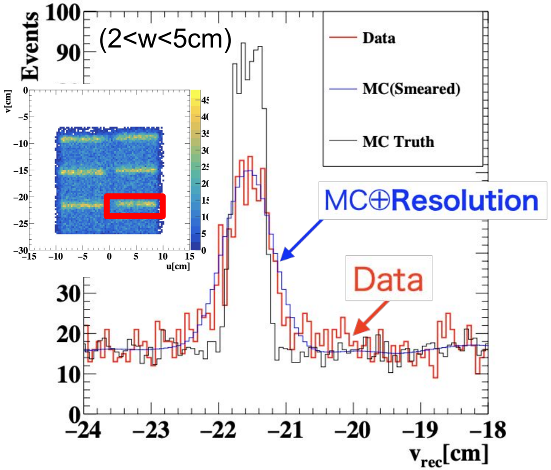
Identifies 90% of no ATAR hit events correctly.

Is it possible to use a similar technique to identify forward events that miss the ATAR?

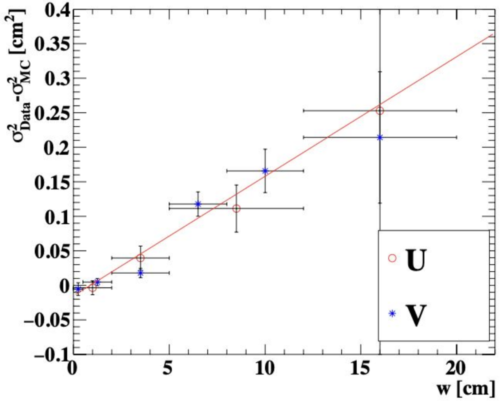
MEG II LXe detector PERFORMANCE : position

- 17.6 MeV gamma-ray with collimator run to evaluate position resolution
- Data is fitted by MC spectrum smeared by resolution to obtain detector resolution
- Then, position resolution difference between data and MC is evaluated as a function of conversion depth
- Position resolution for signal events is estimated by MC
  - with the understanding of MC v.s. data above
- Position resolution at 52.8 MeV : **σ_u : 2.5 mm, σ_v : 2.5 mm, σ_w : 5.0 mm**

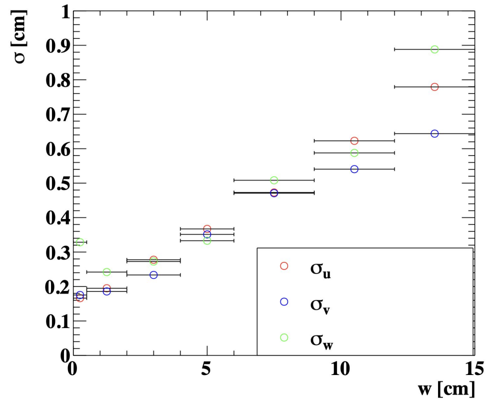




Depth dependent difference : Data vs MC



Position resolution for signal as a function of depth

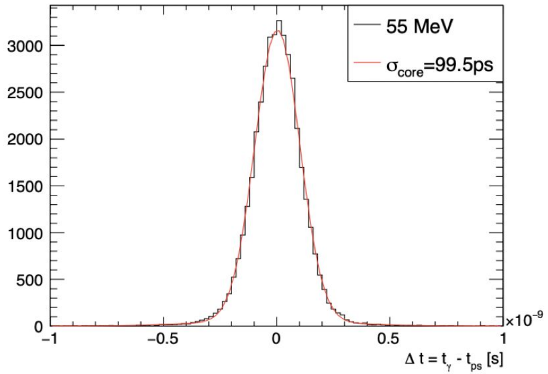


MEG II LXe detector PERFORMANCE : timing

- Timing resolution in LXe is evaluated with 55 MeV gamma-ray (π→γγ)
  - Back-to-back simultaneous gamma-rays
    - One gamma-ray incidents to the LXe detector
    - The other is detected by plastic scintillator
- Resolution : $\Delta t = t_\gamma - t_{ps} - t_{TOF}$ is calculated as follow

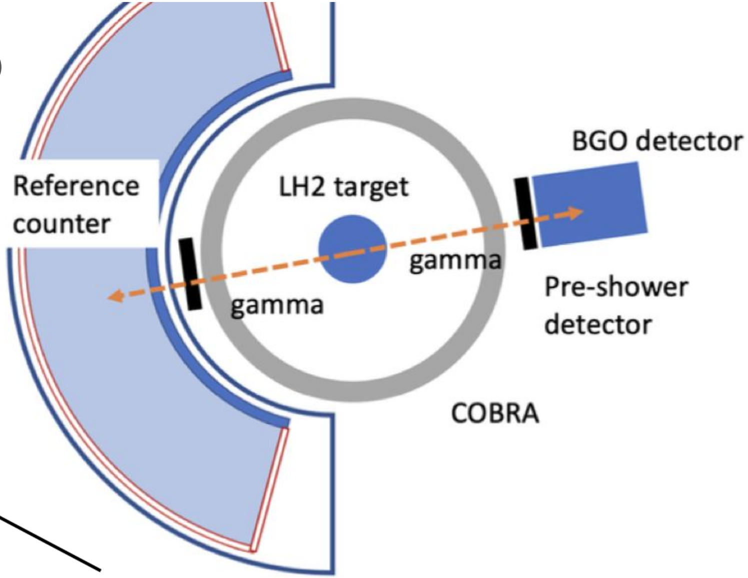
$$\sigma_{\Delta t} = \sigma_{t_\gamma} \oplus \sigma_{\mathrm{ps}} \oplus \sigma_{\mathrm{TOF}}$$

measured by (π→γγ)



28.2(2) ps
- measured in advance

Contribution	Spread [ps]
$\sigma_{\Delta t}$ (core)	99.5±0.5
σ_{ps}	28±0.2
σ_{vertex}	70 ± 6
σ_{t_γ} (core)	65 ± 6

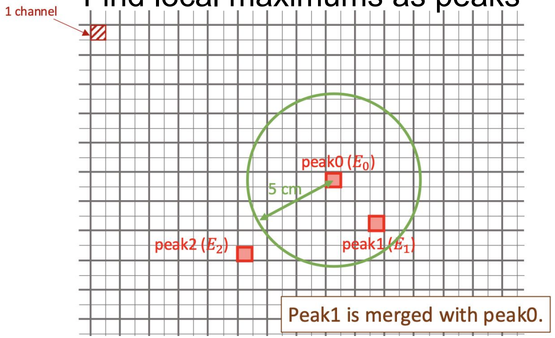


Caused by a spread of vertex (beam spread)
-> vertex spread was measured using another plastic scintillator (reference counter)

MEG II LXe detector : Pileup treatment

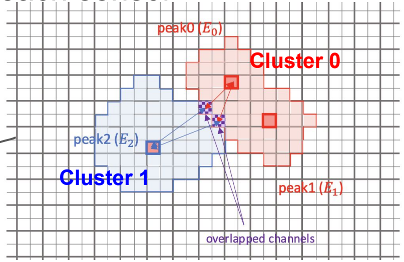
- Pileup identification and unfolding
  - Single gamma events and successfully unfolded events are used
  - Coincident events and events failed to fit are rejected

Find local maximums as peaks



Threshold for merge : 5cm for SiPM

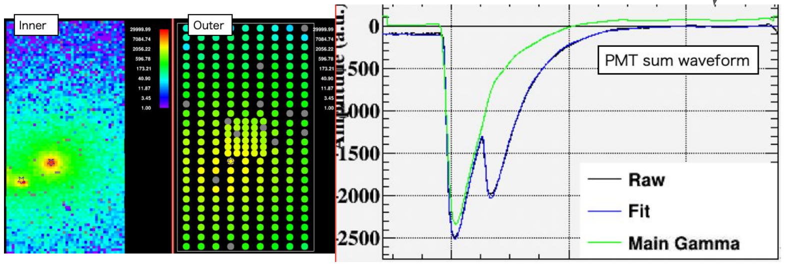
Clustering based on the hit of each sensor



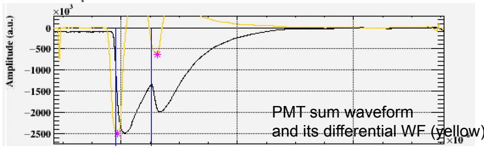
Overlapped region (SiPMs) belongs to the closer cluster (this case, cluster 0)

Input for template fitting of sum waveform
- **# of clusters**, timing as a initial values of fitting

Unfold sum waveform by template fitting



Differential WF is also used for fit initials
# of clusters, timing



Waveform analysis and #photon reconstruction (each sensors)

↓

Clustering based on distribution of sensor #ph

↓

Event position & timing reconstruction

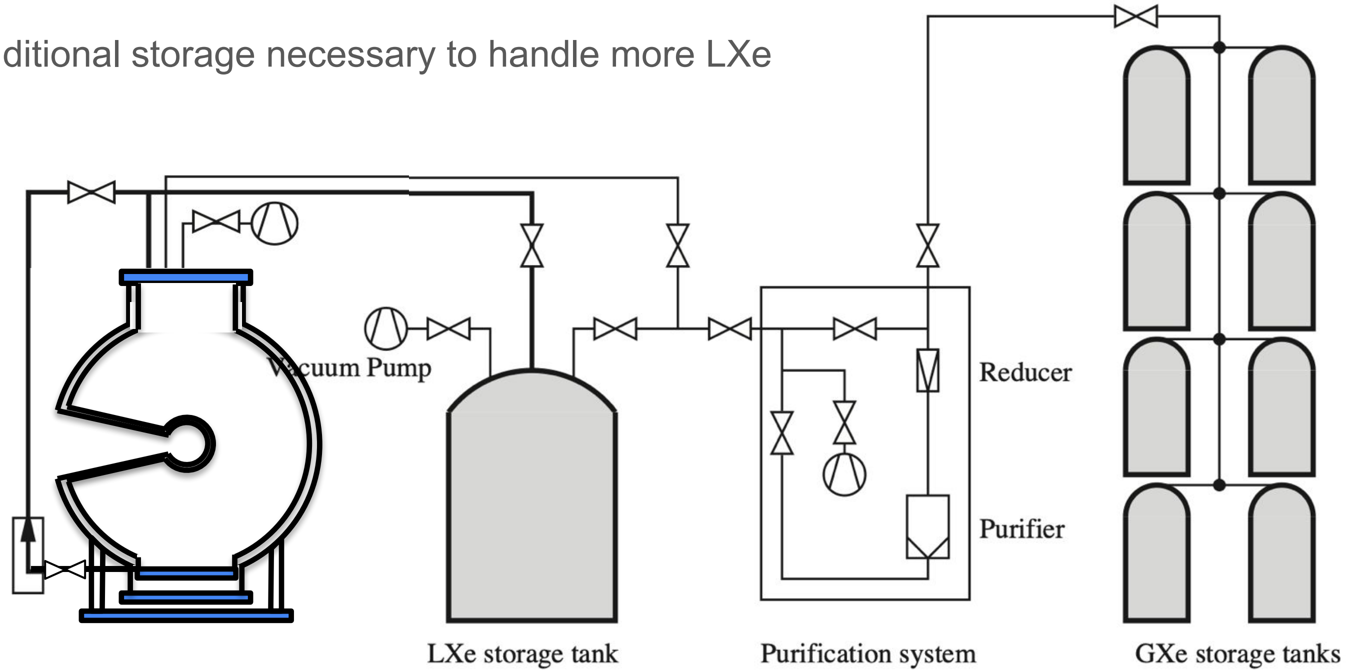
Used to determine "main gamma"

↓

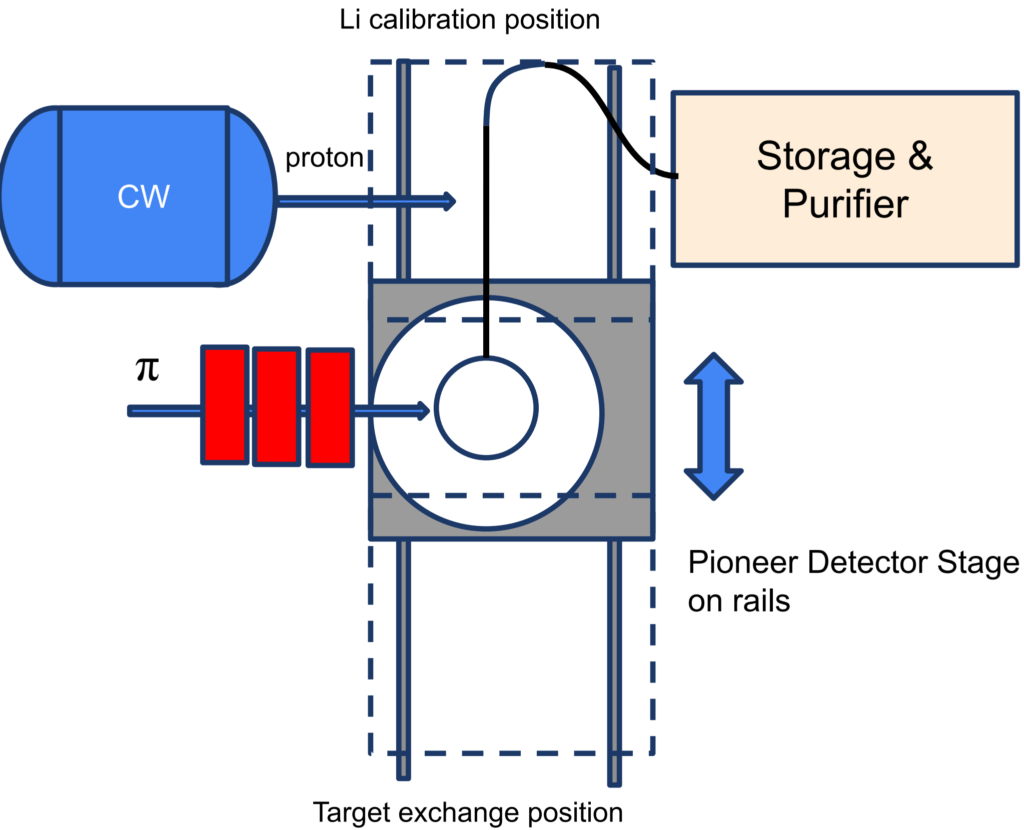
Pileup unfolding

Cryogenic facility

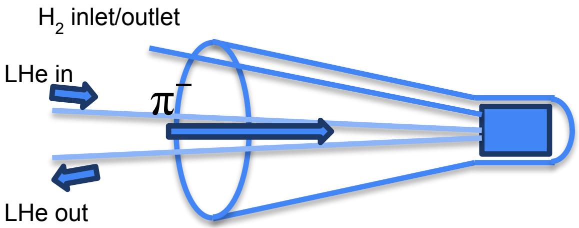
- Reuse (most of) MEG equipment
  - Additional storage necessary to handle more LXe



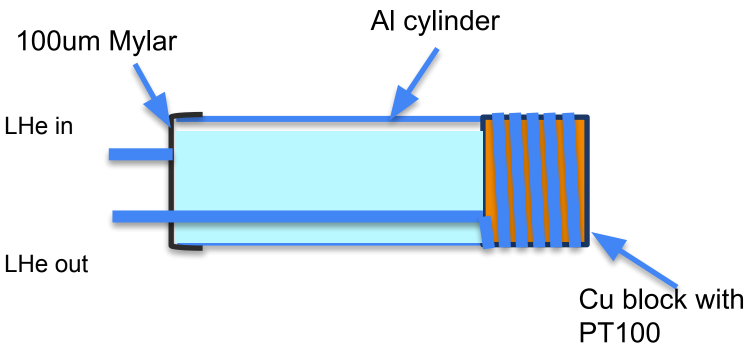
Calibration setup concept



Concept of LH_2 target for π^0 calibration

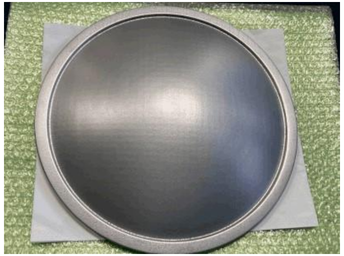


- Conical vacuum chamber to be fixed to the detector with the flange



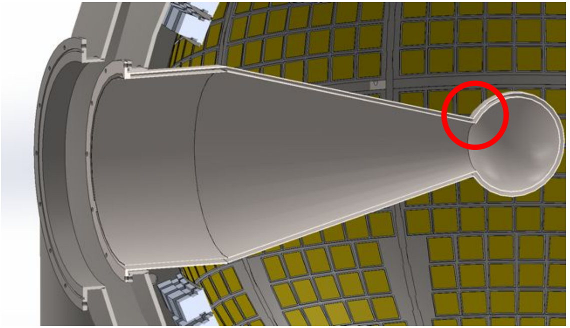
PRACTICAL ASPECTS

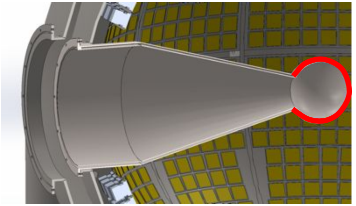
- Recent KEK R&D for beam vacuum window -Ti-6AL-4V 3d-printed window
  - 6wt% Al (X0=8.9cm) and 4wt% Vanadium (X0=2.6 cm) is added to Ti (X0=3.6cm) - 4.43 g/cm3
  - 0.2mm, grinded down from ~0.5mm, OK for 3 bar.
  - Technically not feasible to grind down more.
- Water pressured test done at KEK with a DN200 0.5mm windows - resisted up to 4MPa
- Al 3d-printed window is also possible, grinned down to 0.2mm
  - Rupture disk Al 0.15mm is strong enough for 3 bar pressure difference!
    Need R&D to fix the window on the cover
    Indium sealing should work
- Design work in progress



0.5mm 64Ti window

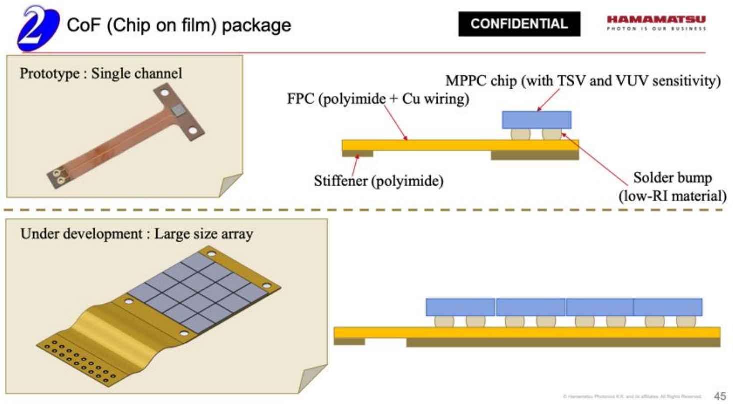
0.15mm Al Rapture disk



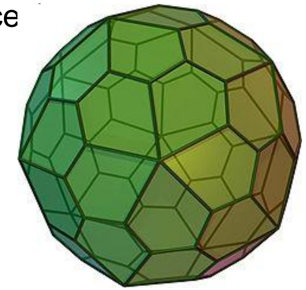


Concept for SiPM on inner windows

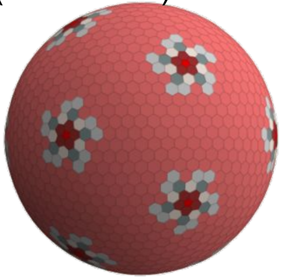
- Material thickness
    - MPPC chip: Si ^{t}200µm
    - Solder bump: Sn with a few % of Ag/Cu
    - 21 × bump (Φ200µm ^{t}150µm) → ^{t}2.7µm on average
        - Stiffer: polyimide 270µm → thinner
        - FPC: polyimide+Cu ~200µm → thinner
- SiPM mounting and cabling

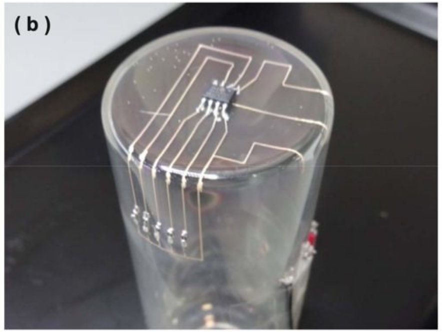


pentagonal hexecontahedron (60 face



Goldberg polyhedron (1472 faces)





Low temperature behavior
Band width

https://www.jstage.jst.go.jp/article/jiep/23/6/23_459/_pdf

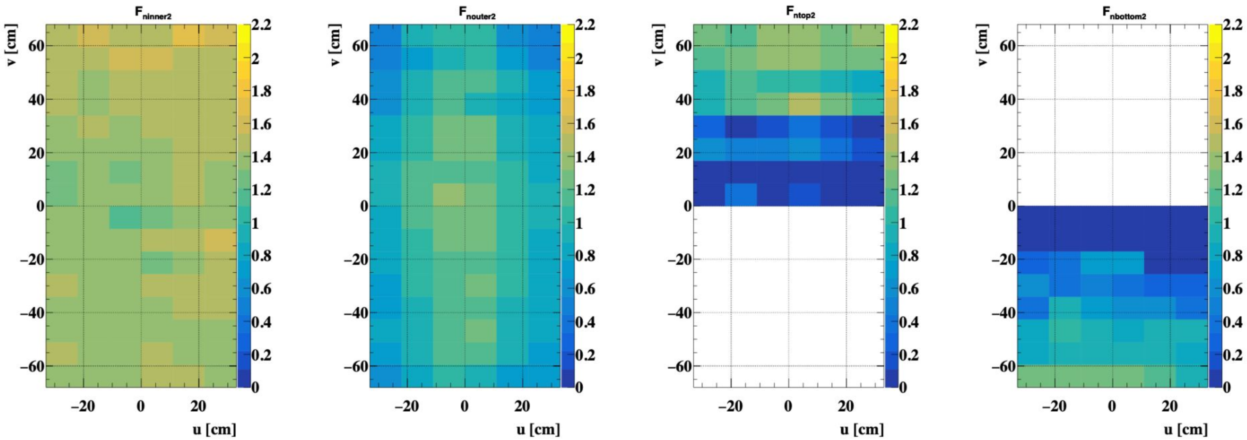
COST Doug

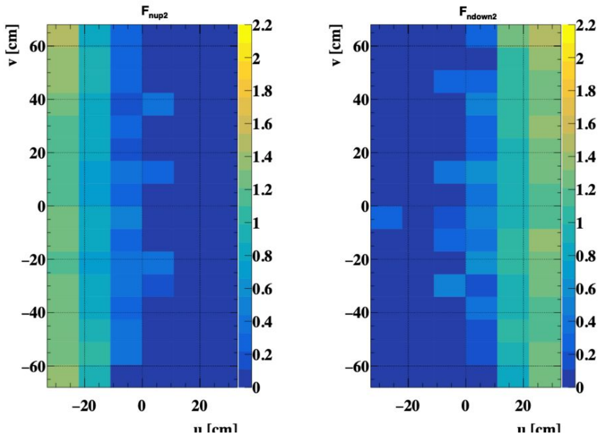
LXe Calo Budget				
	Cost C$	In-Kind/ Match	Cash C$ (CFI)	In-kind Cash (Japan)
Personnel	2092500		2095000	
Prototype Detector	1018992	250000	768992	0
Calorimeter	2320804	901308	1419496	174558
Photosensors and Instrumentation	6366540	3213590	3152950	0
Calibration System	225001	184460	0	2027
Travel	187500		187500	
Xenon	10044000	10044000		3766500
Calo Total (CFI)	**22255337**	**14593358**	**7623938**	**3943085**

Funding potential: 4200000
Xmass Xe: 2000000

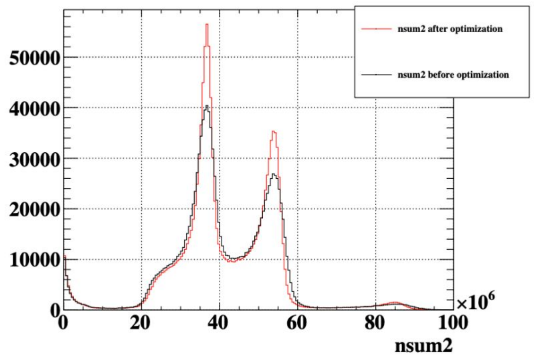
BACKUP SLIDES - ALL

MEG Face Factor Weighting





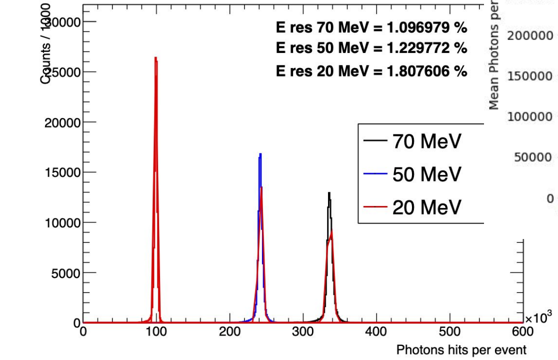
- Peak of 55/83 MeV become sharper with optimized FF
- -> ready for reconstruct weighted #photon (nsum2)

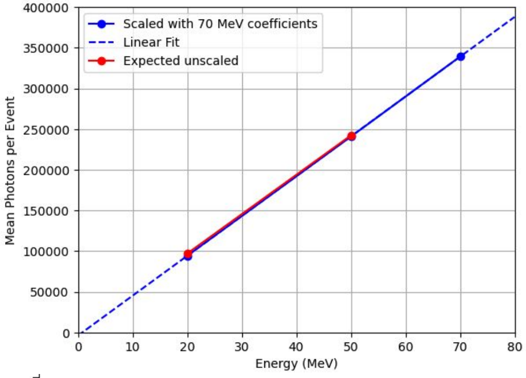


MEG applies a "face factor" (FF) correction to each of the 6 faces of their LXe calorimeter:

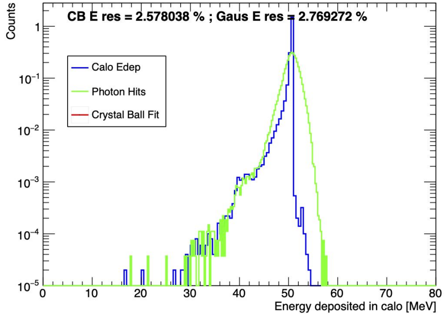
- coefficients are found to minimize the StdDev of the summed photon hits per event
- Detector is divided into 96 (u,v) regions, each with their own FF

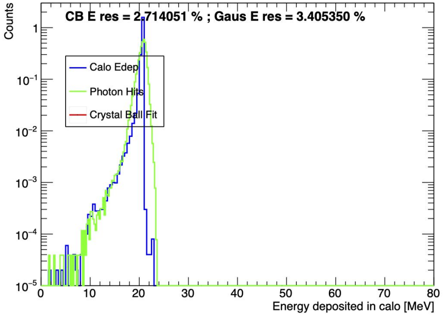
BACKUP - Coefficient Minimization Robustness





Original 50 and 20 MeV Edep and photon hits

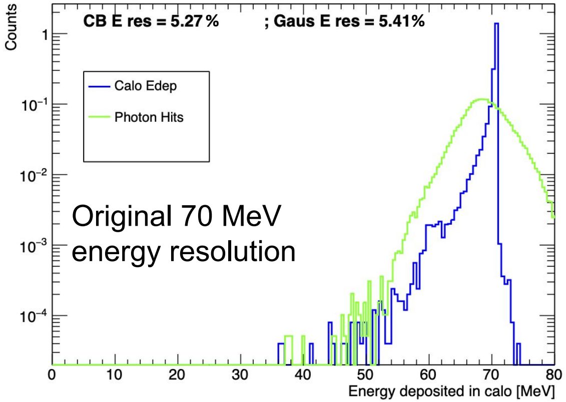


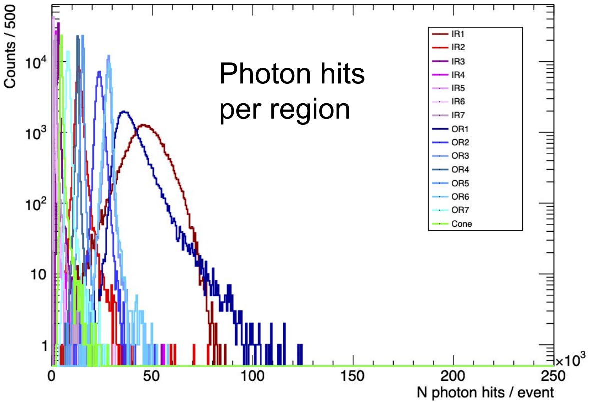


Verification of minimization process:

- Determine coefficients using 70 MeV sample, apply them to 50 and 20 MeV samples
  - In each case, energy resolution reduced from ~2.6% (plot on left)
  - Difference in peaks = ratio of energy; not affected by weighting
- Other tests:
  - Reweight weighted sample to find “new” coefficients: minimizer always finds all coefficients = 1
  - Determine coefficients using sample subset, apply this weighting to different sample subset: same final minimum energy resolution found

BACKUP - Minimization Coefficients





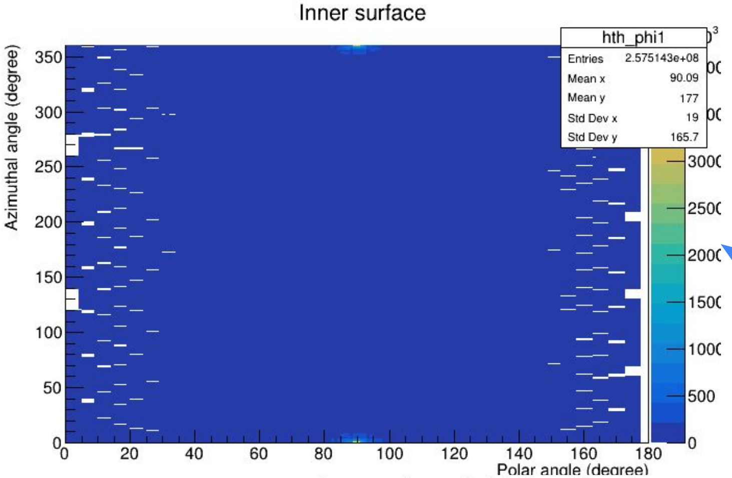
Sample 70 MeV coefficients:

Inner Region 1: 0.47
Inner Region 2: 1.40
Inner Region 3: 0.021
Inner Region 4: 0.41
Inner Region 5: 0.92
Inner Region 6: 0.58
Inner Region 7: 0.48
Outer Region 1: 0.88
Outer Region 2: 1.91
Outer Region 3: 2.45
Outer Region 4: 2.17
Outer Region 5: 1.59
Outer Region 6: 2.97
Outer Region 7: 2.07
Cone: 0.0047

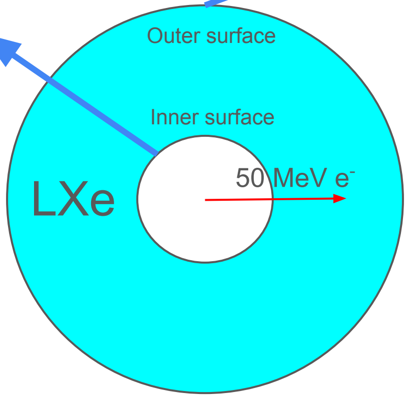
Minimization parameters: coefficients must be between (0,5), all initial values = 1

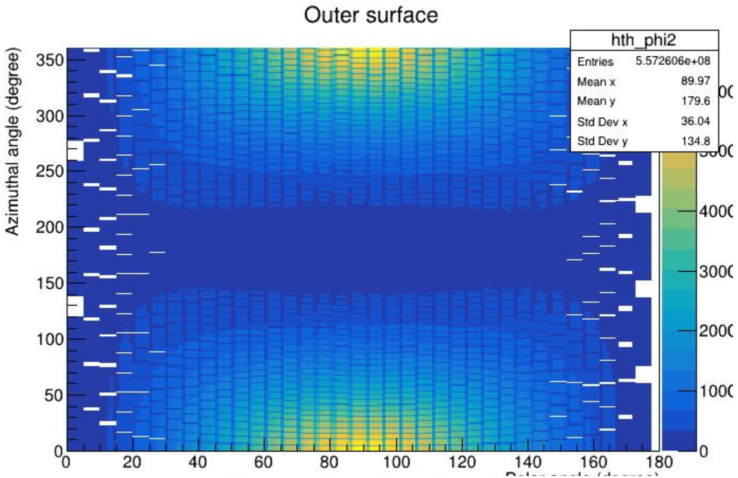
- Lots of room for optimization! MEG uses more specific initial and minimum values

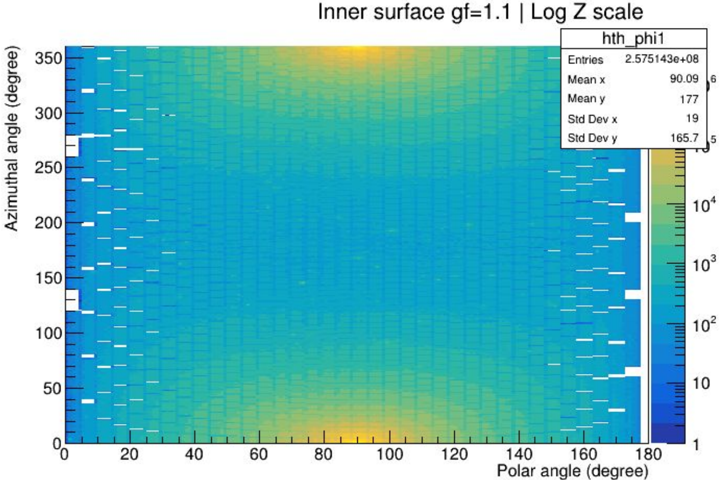
ENERGY RESOLUTION : “Heat maps”



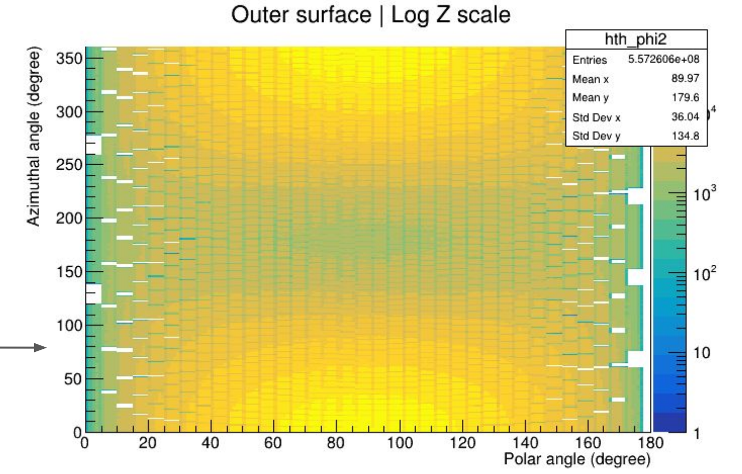
Gap factor = 1.1
P_e = 50 MeV/c
PMT = 51mm
SiPM = 12mm



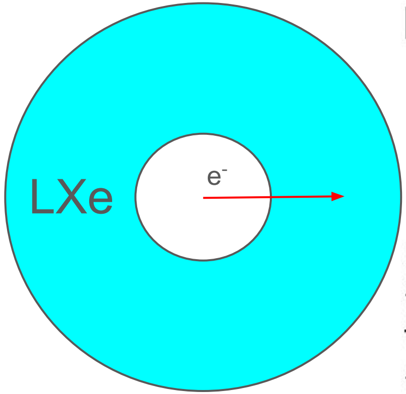


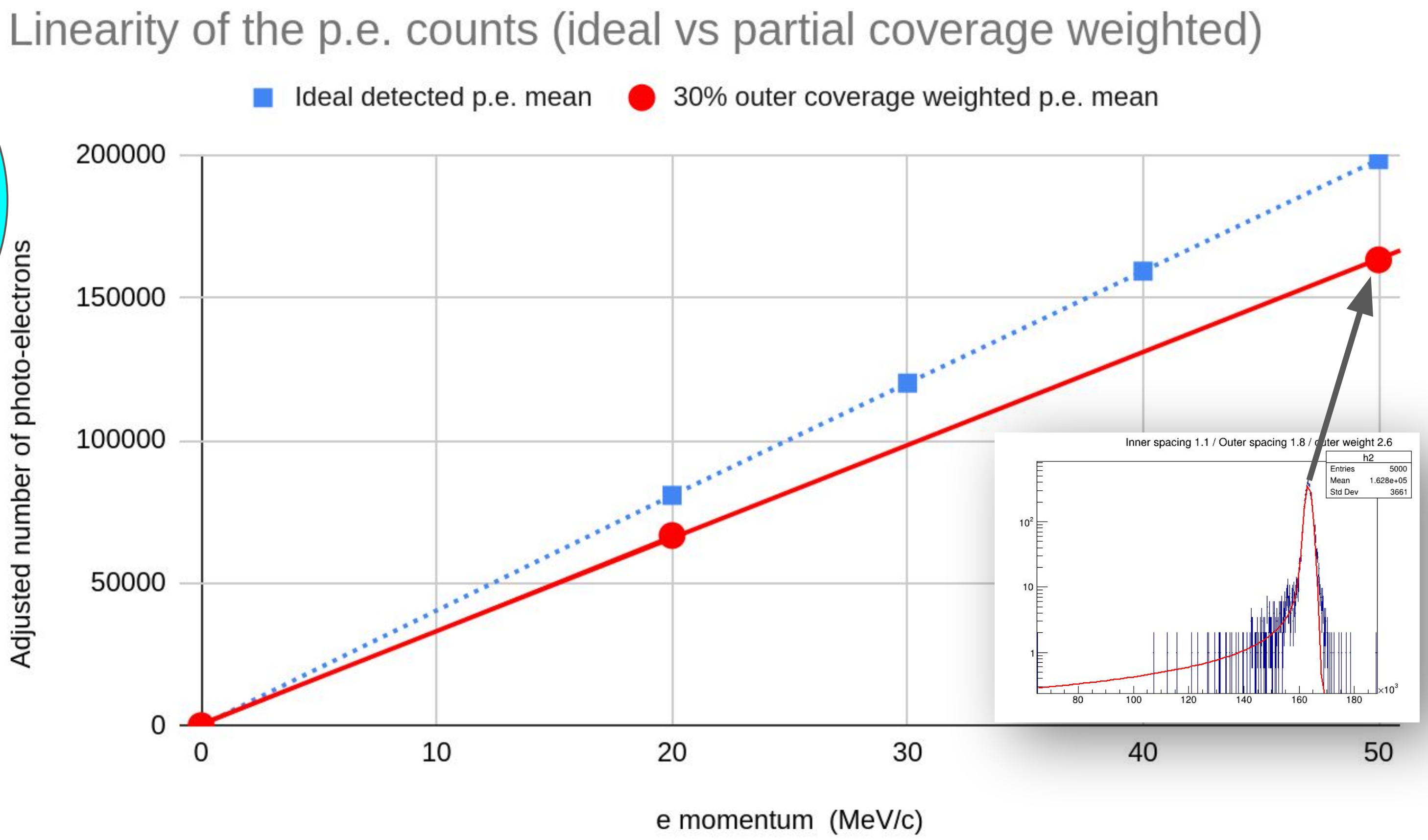


← Log Z scale →

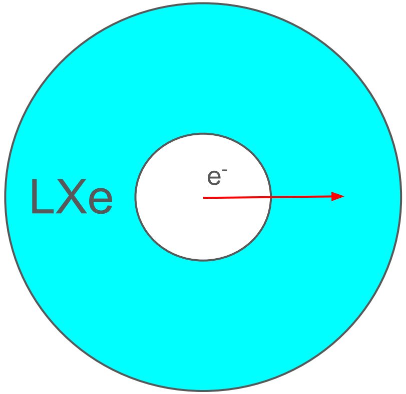


ENERGY RESOLUTION : Weighting and linearity





ENERGY RESOLUTION : Number of sensors estimate



Simple estimate for spherical geometry

- For inner surface max # channels is ~**2521** for 12mm size of sipm
- For outer surface max # channels is ~**2367** for 51mm size of PMT

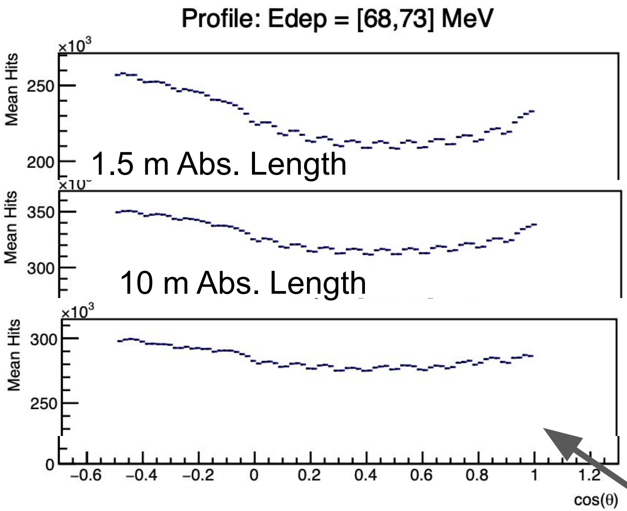
* Estimate based on surface ratio = $4\pi R^2/a^2$

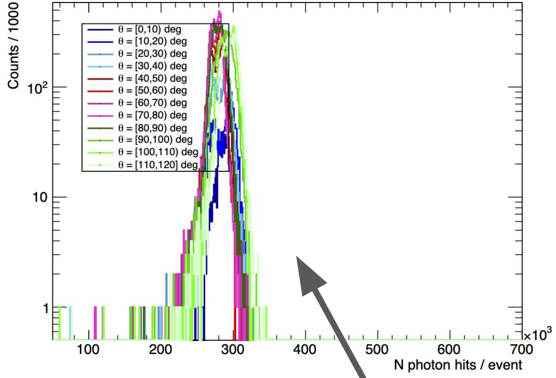
# PMT 51mm (Outer)	# SiPM 12mm (Inner)	coverage (%)	gap factor
1956	2084	83	1.1
1644	1751	69	1.2
1401	1492	59	1.3
1208	1287	51	1.4
1052	1121	44	1.5
925	985	39	1.6
819	873	35	1.7
731	778	31	1.8

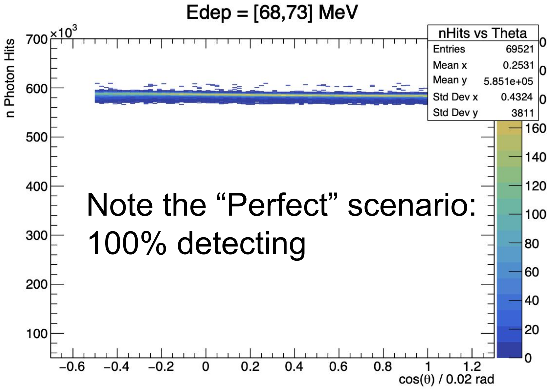
Theta Corrections

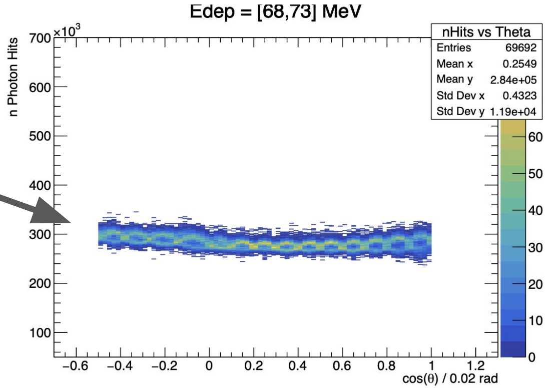
Detector angular dependence improvements:

- increased absorption length (so fewer photons lost)
- reduced number of inner surface photosensors such that % coverage is closer to outer surface – will continue to improve with further optimization





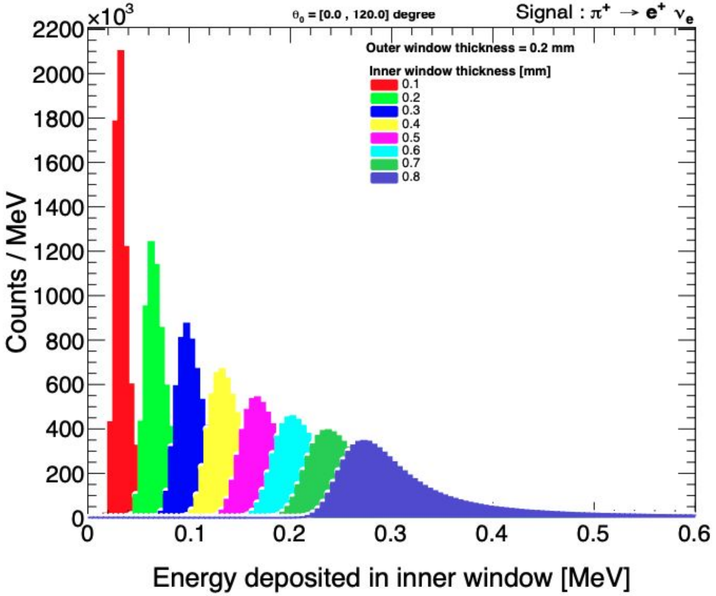


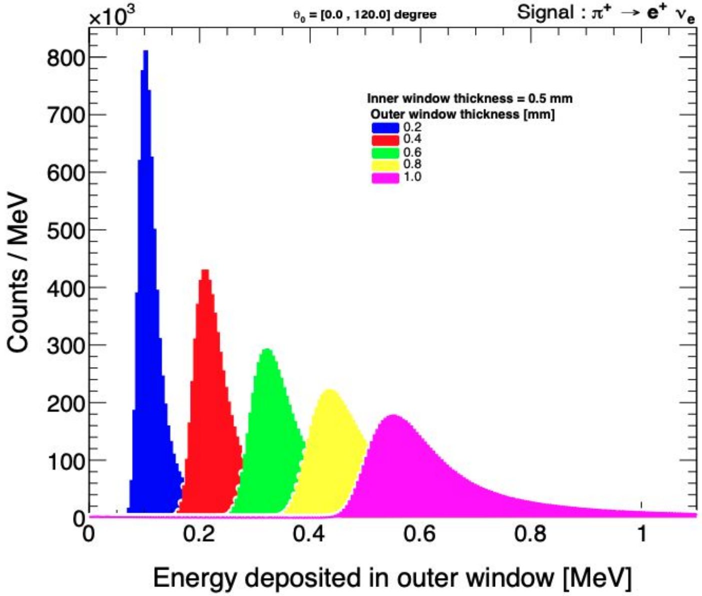


10 m Abs. Length, inner surface coverage reduced to 60% from 90% (outer surface PMT coverage is 37%)

Early results at 1.5 m absorption length required significant angle correction - this is greatly improved with larger abs. len., as well as comparable inner and outer sensor coverage. Will be further improved with scaling

Energy deposited in LXe windows





Energy deposited in windows studied for various window thicknesses.
Nominal: Inner = 0.5 mm, Outer = 0.2 mm

- Total Edep in windows ≤ 0.5 MeV for all likely configurations

CALO DIMENSIONS

LXe dimensions for beam considerations

- 17 cm to inner surface of the LXe volume
- 54.5 cm LXe (19X0)
- 3 cm for PMT and cabling
- 2 cm of vacuum
- 1 cm global StStell shell structure

==============

= 77.5 cm

Details of calo veto abilities initial study

Running full PIONEER simulation with optics on (with bullet calo geometry).

Simple cuts to separate out events:

1) With ATAR hit:
    - Any ATAR hit, calo energy deposit

Without atar hit: No ATAR hit, calo energy deposit

2) Travel through the wall of the cone into the calo
    - A decay with z < 0
    - Theta of first conversion is > 120 deg
3) Other no ATAR hit
    - Theta of first conversion is <= 120 deg

Using then a threshold of R=0.12, I can try to separate events with no ATAR hit into cone or other, and see how well a job this ratio does at separating events → a more sophisticated version of this could be used to identity pile-up events that lack ATAR information.

xz projected position of pure pion beam