Optical photon tracking in XMASS

Geant4 Collaboration Meeting 2011, SLAC

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Contents

- XMASS experiment
- geant4 in XMASS
  - Geometry.
  - Reflection at photo cathode.
  - Performance
  - Problems
- Summary

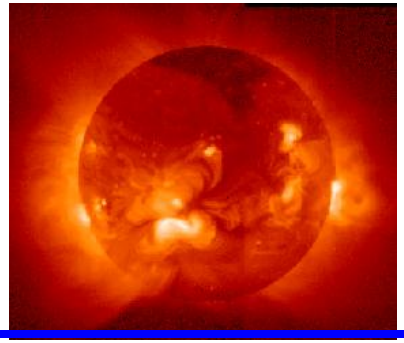
1. XMASS experiment

➢ What's XMASS

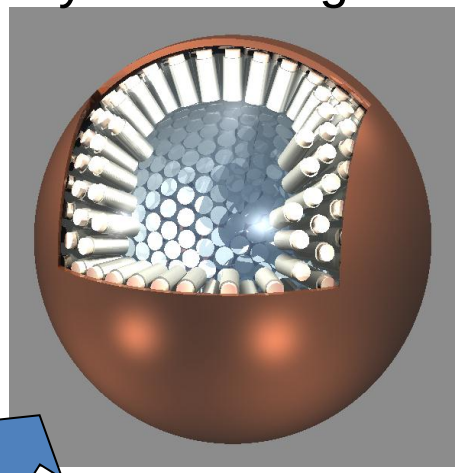
Multi purpose low-background experiment with liq. Xe

Y. Suzuki et al., hep-ph/0008296

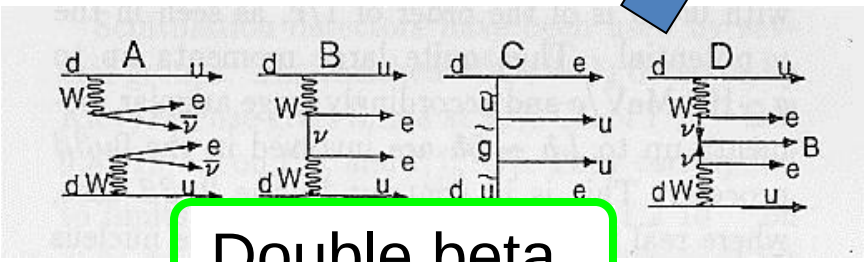
- **X**enon **MASS**ive detector for solar neutrino (**pp/^{7}Be**)
- **X**enon neutrino **MASS** detector (**ββ decay**)
- **X**enon detector for Weakly Interacting **MASS**ive Particles (**DM search**)



Solar neutrino



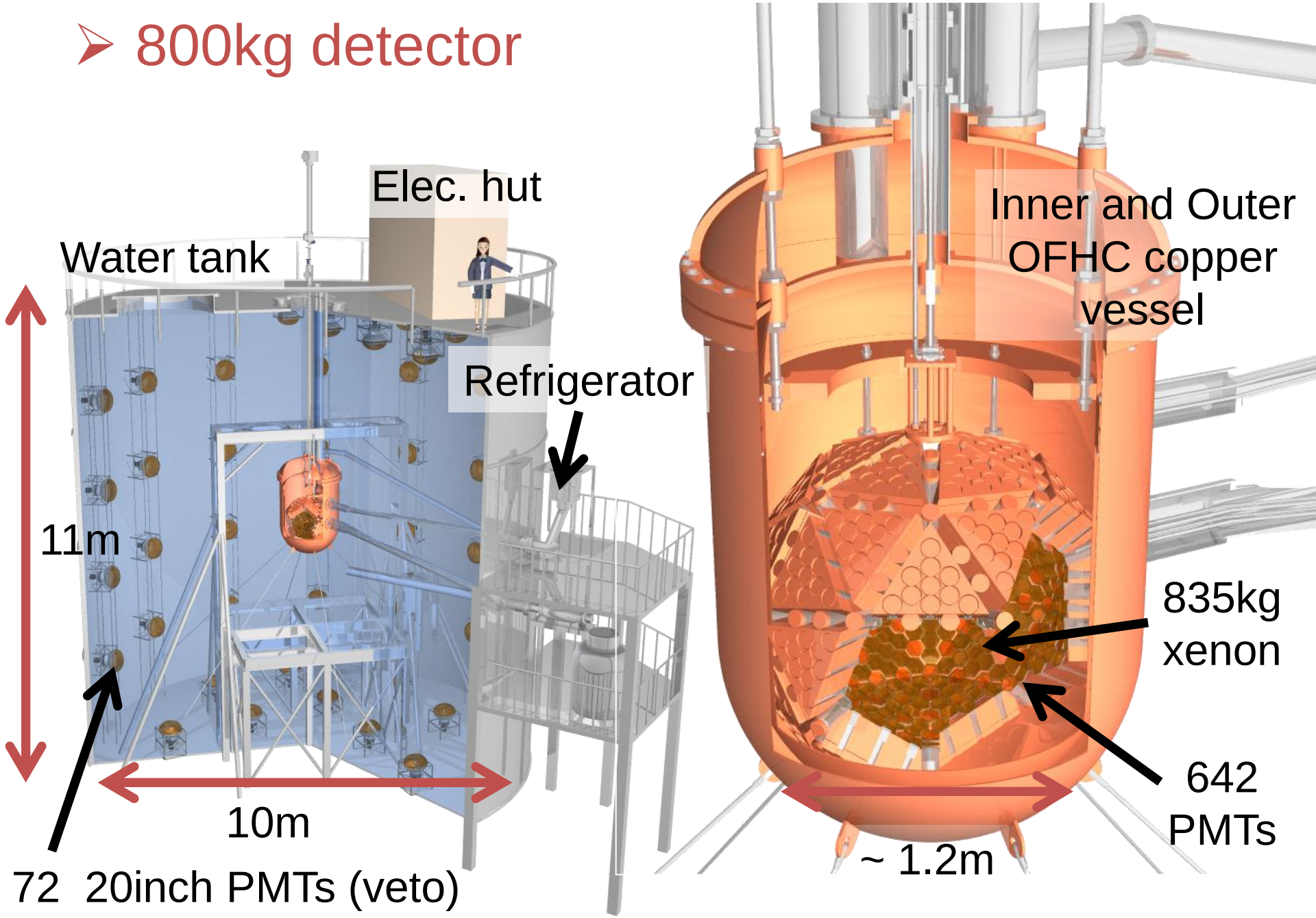
Dark matter



Double beta

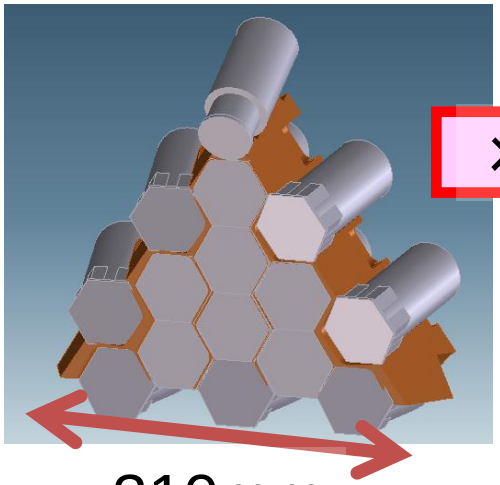
As a 1st phase, an 800kg detector for dark matter search is under comissioning.

➢ 800kg detector

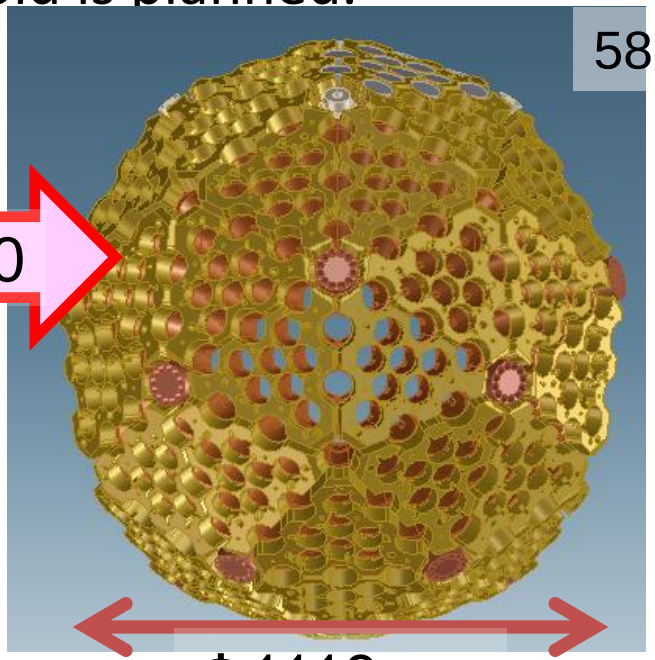


Structure of the PMT holder

- Made by OFHC copper.
- 835kg of liquid xenon, 100kg in the fiducial volume
- 642 PMTs (630 hex +12 round)
- Photo cathode coverage: 62.4%
- Q.E. : 28-39%
- 3D event reconstruction
- 5keVee threshold is planned.



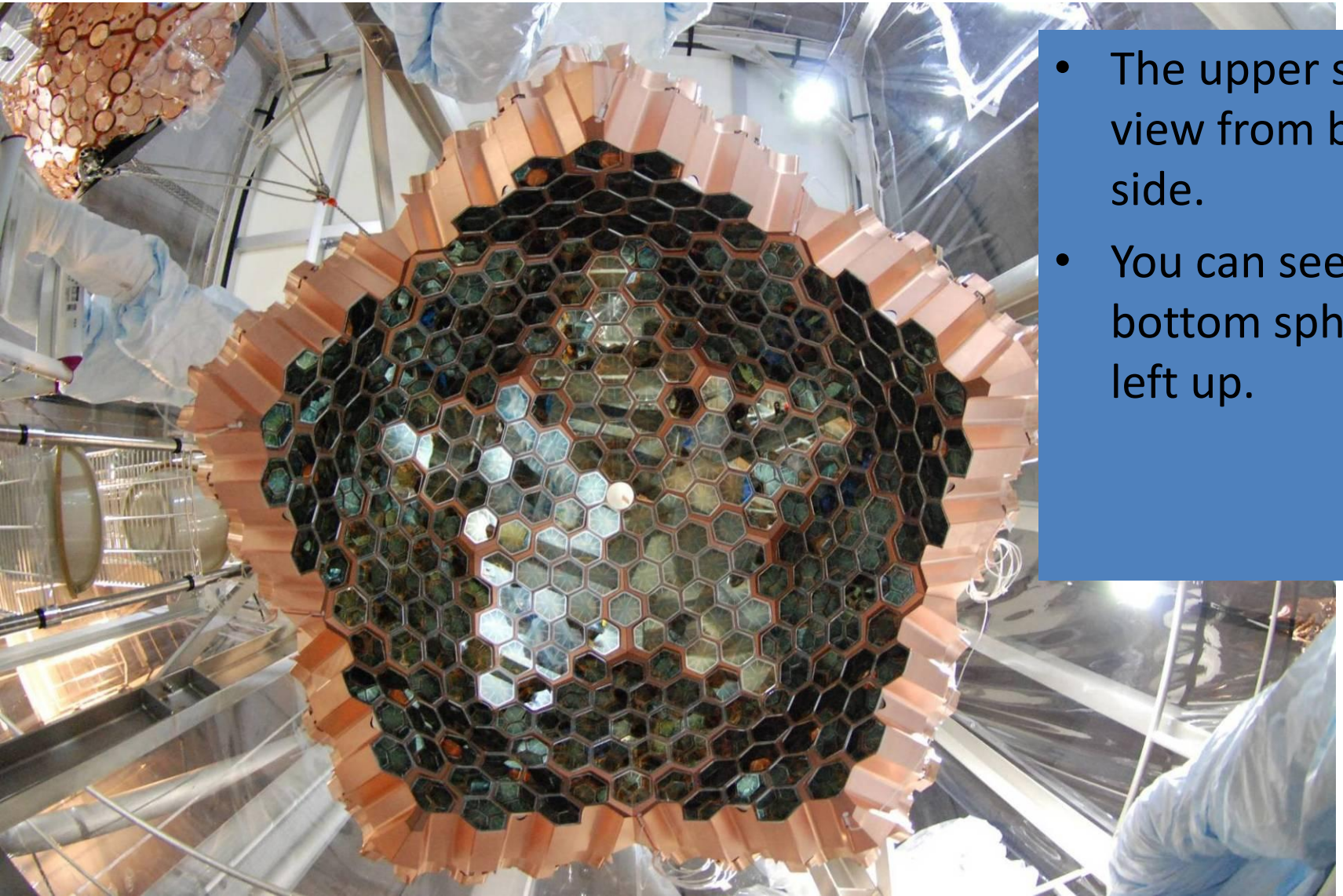
×60



Hex: R10789-11

Round: R10789-11MOD

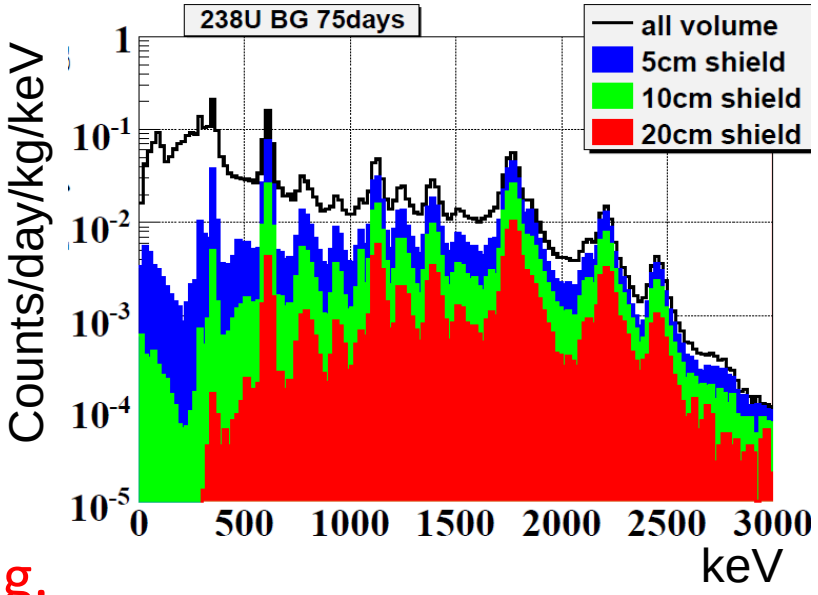
The PMT holder



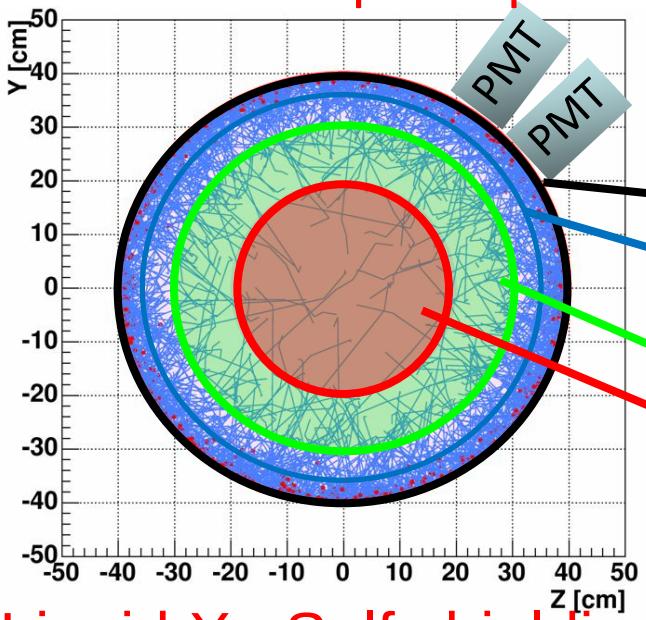
- The upper sphere, view from bottom side.
- You can see the bottom sphere left up.

➢ geant4 in XMASS

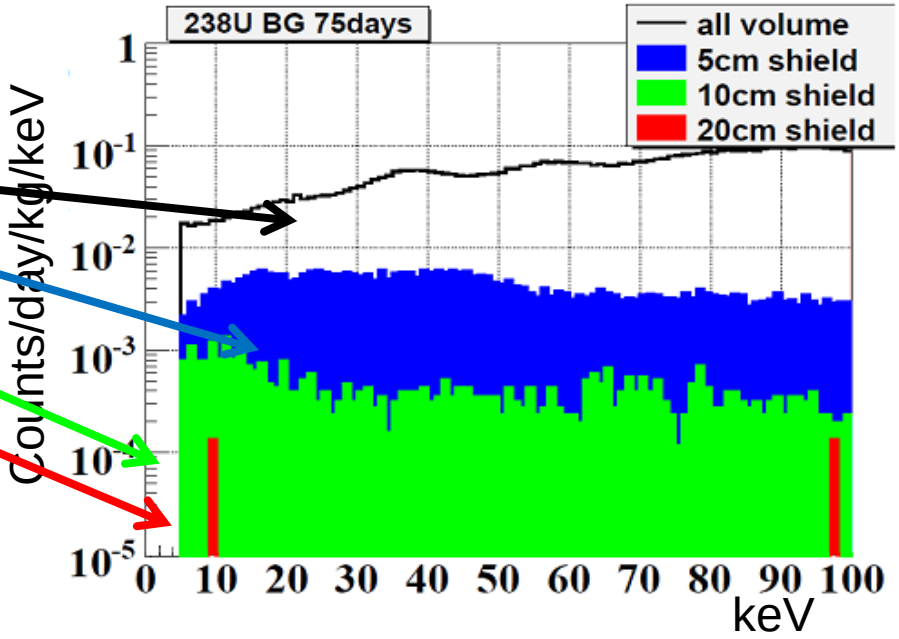
- BG estimation
- Calibration run to check detector performance.
  - Introduce RI source such as 57Co, 241Am inside detector.



- Decay of many kind radio isotope.
- Interaction inside xenon.
- Large number of optical photon tracking.

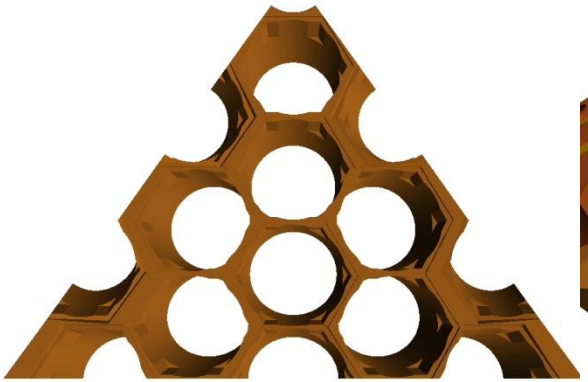


γ tracking

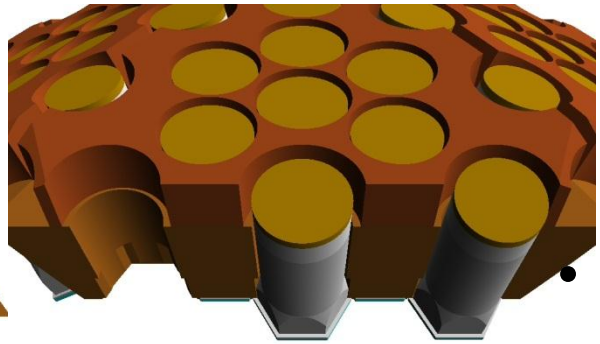


Liquid Xe Self shielding

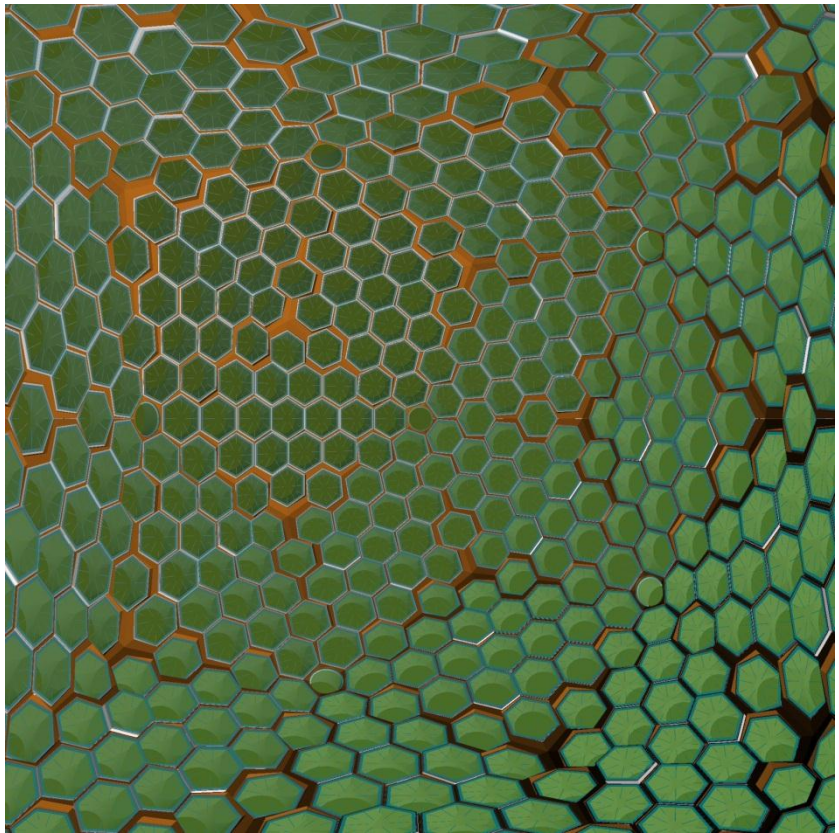
MC Geometry

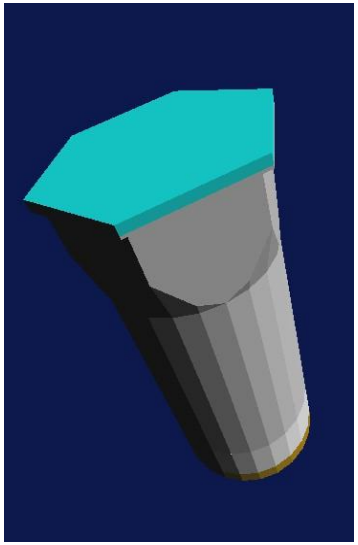


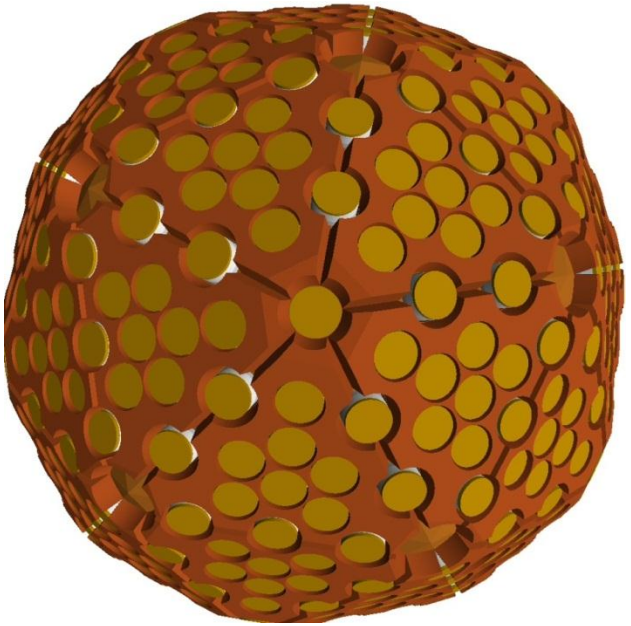
1st layer triangle from inside



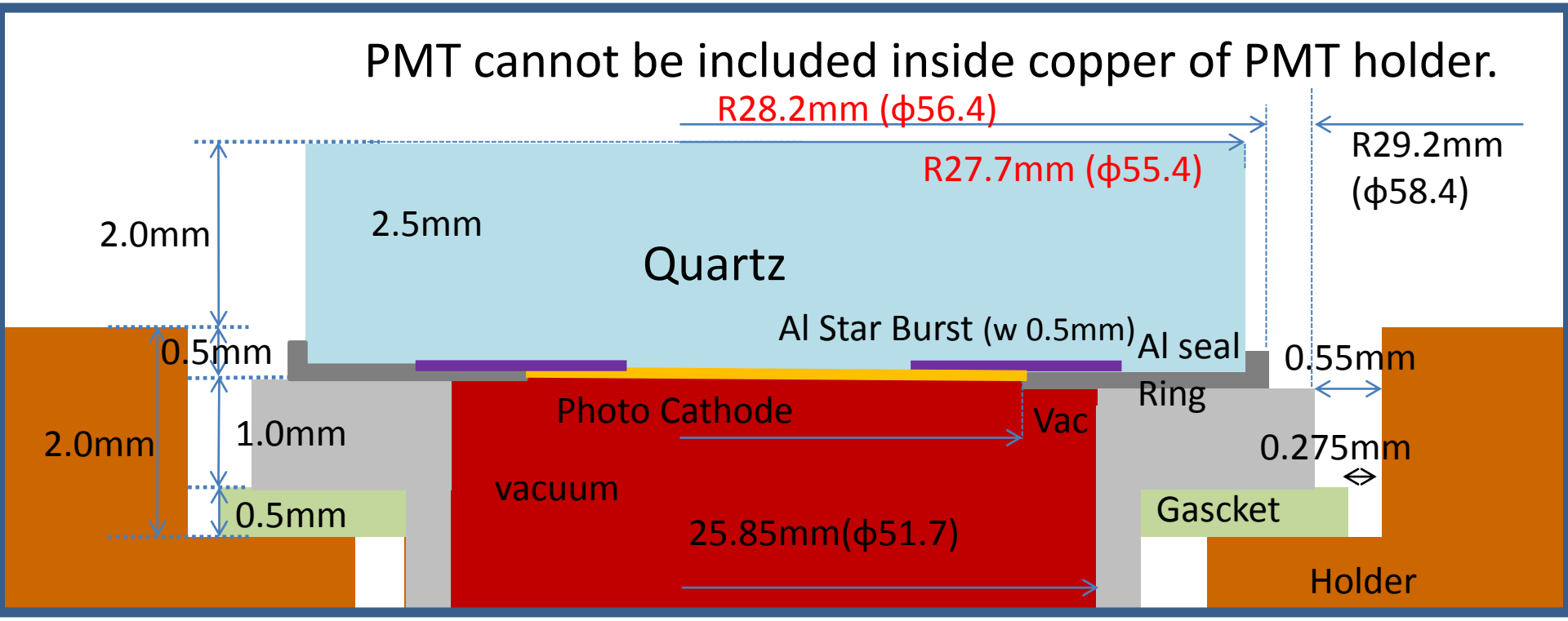
- For photon tracking, we need to realize precise geometry, all gaps, bumps are important. We care rare events.
- Very complicated, made by large number of Boolean solids, G4UnionSolid, G4SubtractionSolid…..







Geometry (PMT & Holder)



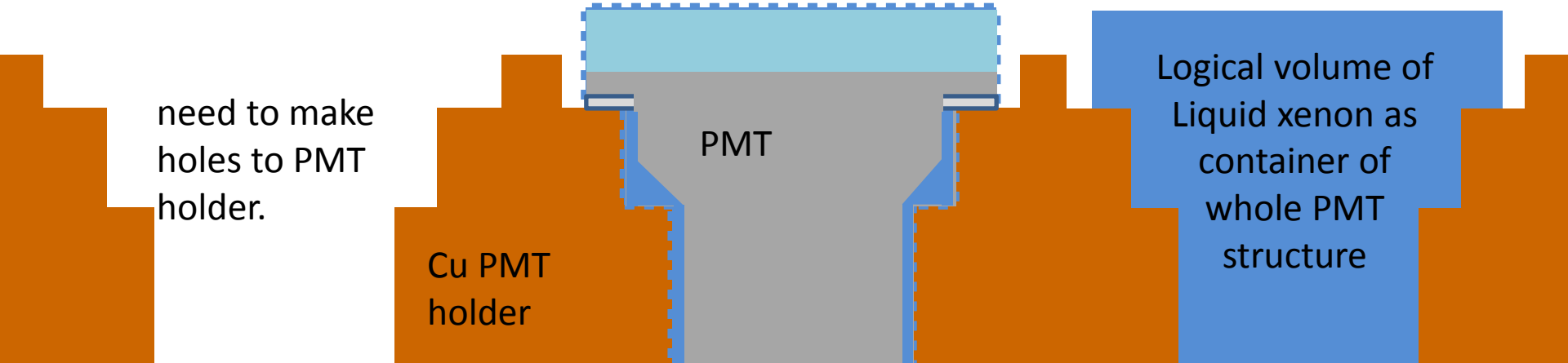
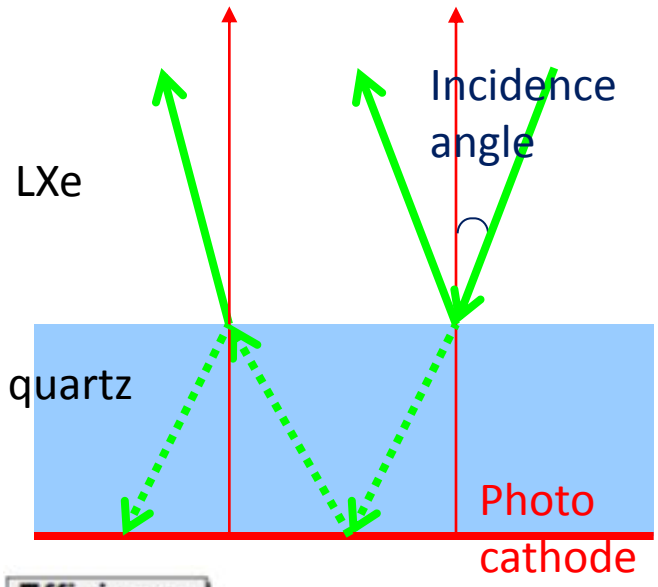
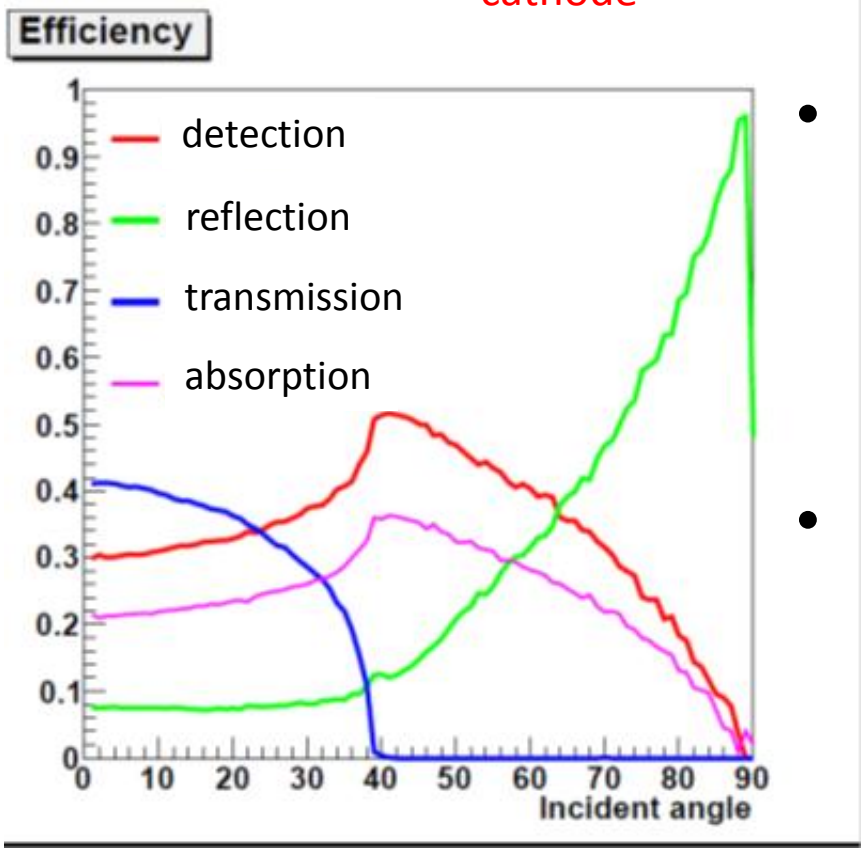


Photo cathode, Reflectivity and absorbance angle dependency.





- Add a function to calculate angle dependent reflection, detection, transmission and absorption probability to OpBoundaryProcess.
- These are calculated by using measured quartz's complex refractive index and the equation for thin film reflection at 175nm wave length.
- No wavelength dependency is considered in current version. This will be implemented in near future.

MC Performance

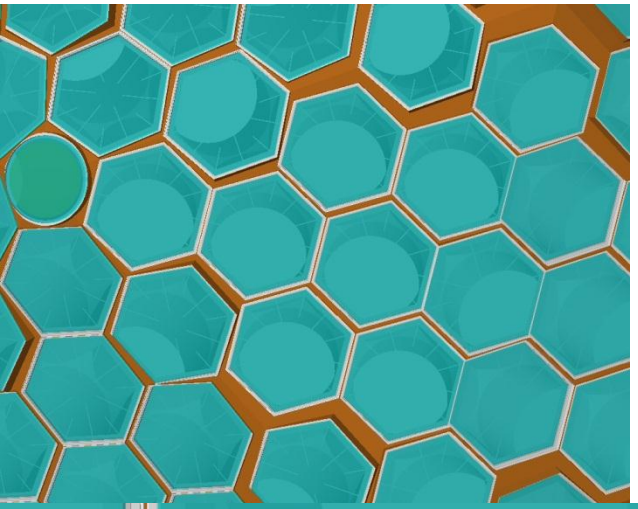
- Number of photon in one events
  - For calibration run
    - Mainly a few tens of keV to ~a few hundreds of keV.
    - 3000~6,000photon/events are tracked.
    - One real calibration run has ~20,000 events in ~5 minutes.
    - ~120,000,000 photons for each ~5minutes run.
  - For BG simulation, in the case of 238U
    - Energy region a few keV< E <~8MeV, alpha, gamma, electron.
    - Average number is ~30,000photon/event.
    - ~4,000,000 decay of whole chain for 100 days data.
    - Average event number which observed inside detector is ~0.5 event/decay.
    - 60,000,000,000 photons are tracked for 100 days data.

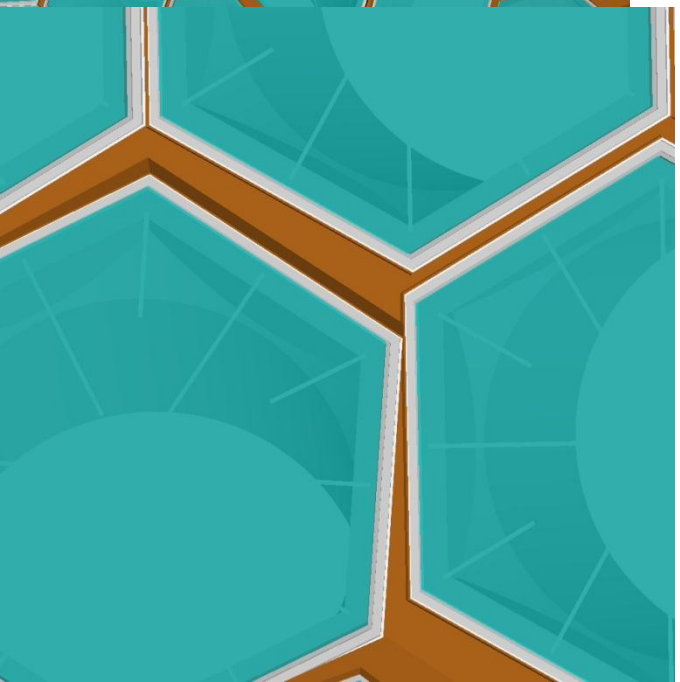
Performance

- Calibration
  - 100,000 sec/core, ~1.2 days/core.
- BG simulation, 100 days 238U
  - 50,000,000 sec/core, 579 days/core, ~6 days with 100 cores.
  - We also need Th, K, Co.

- Available cpu.
  - Xeon E5540(2.53GHz 8GB) x 30 (2 cpus x 4 cores) 240 cores
  - Data size, Background ~100days 2~3TB

Problems





- Need to simulate precise geometry.
  - To track optical photon precisely around wall, need to realize every bumps and gaps which exist in real detector.
  - Geometry becomes very complex. Many Boolean solids.
  - PMT cannot be included inside PMT holder copper volume.
    - We need to make holes in which PMTs are installed.
    - Number of Boolean solid becomes almost twice….
    - Maintenance of geometry is not so easy.

Problems

- Tracking optical photon need very long time.
  - Many Boolean solids.
  - So many optical photon, of cource.
  - We track all photon generated in xenon, no reduction by PMT QE.
    - Reflection at photo cathode has large effect.
    - Need to track photons which is not absorbed at photo cathode.
- 100 days 238U need ~600 days/core (~6 days with 100 core.).

Problems

- Visualization tool to check detail of geometry, it needs much time.
  - Most geant4 visualization tool can not reproduce detector geometry.
  - Program always failed to reproduce complicated geometry which uses many Boolean solids (G4UnionSolid, G4SutractionSolid, G4IntersectionSolid).
  - Raytracer/RaytracerX can reproduce, but it is not so easy to check geometry from many angle of view.

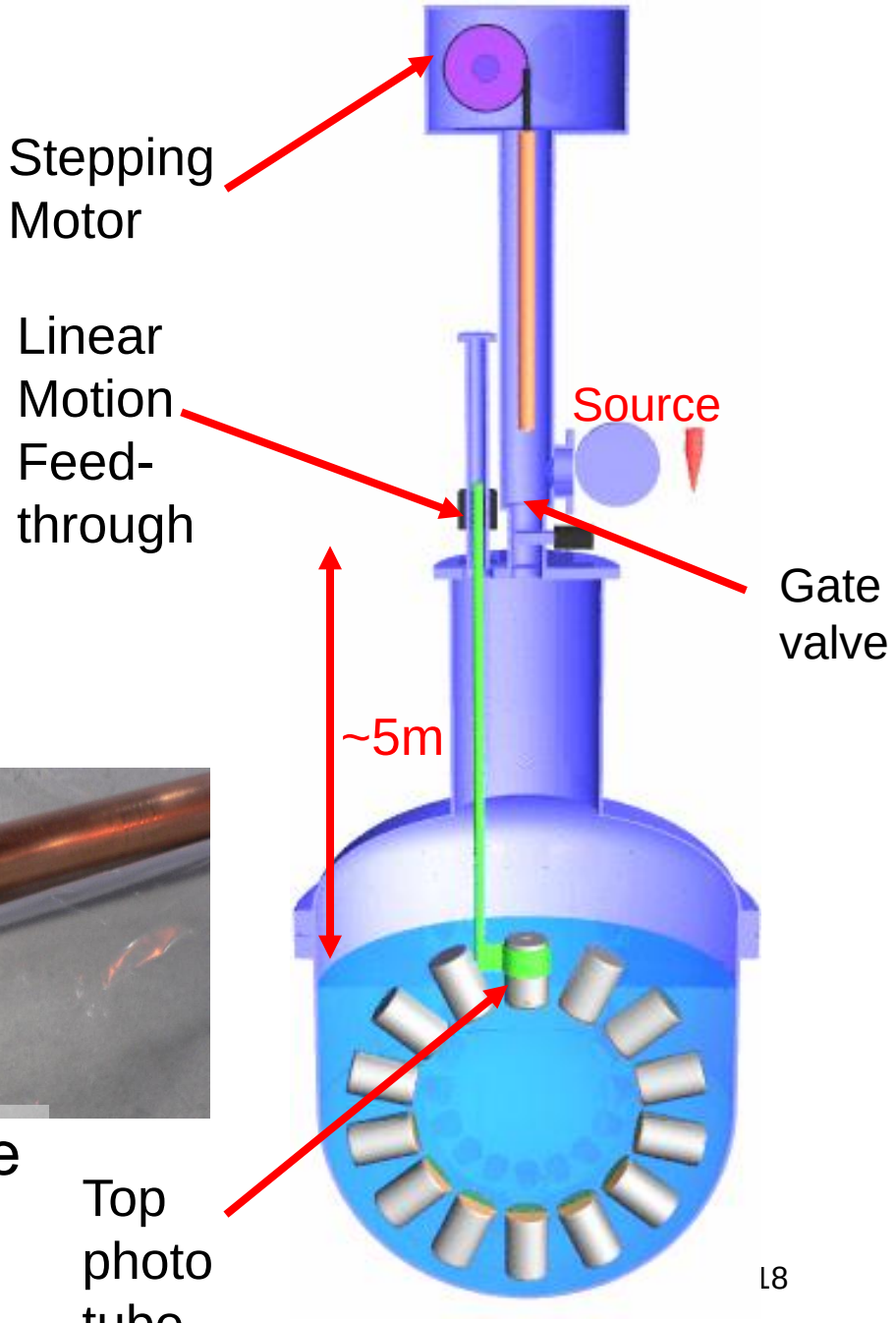
Summary

- XMASS
  - Dark matter search using liquid xenon.
- XMASS MC
  - Basic property
    - Radio active decay.
    - Interaction inside xenon, by a few keV ~ a few MeV particles.
    - Large number of optical photon.
  - Very complicated geometry.
    - We need to track optical photon precisely.
    - Rare event can not be ignored.
    - Use large number of Boolean solids.
  - Problems
    - Geometry is too complicated to maintain.
    - Need time for tracking.
    - Visualization program to check geometry.

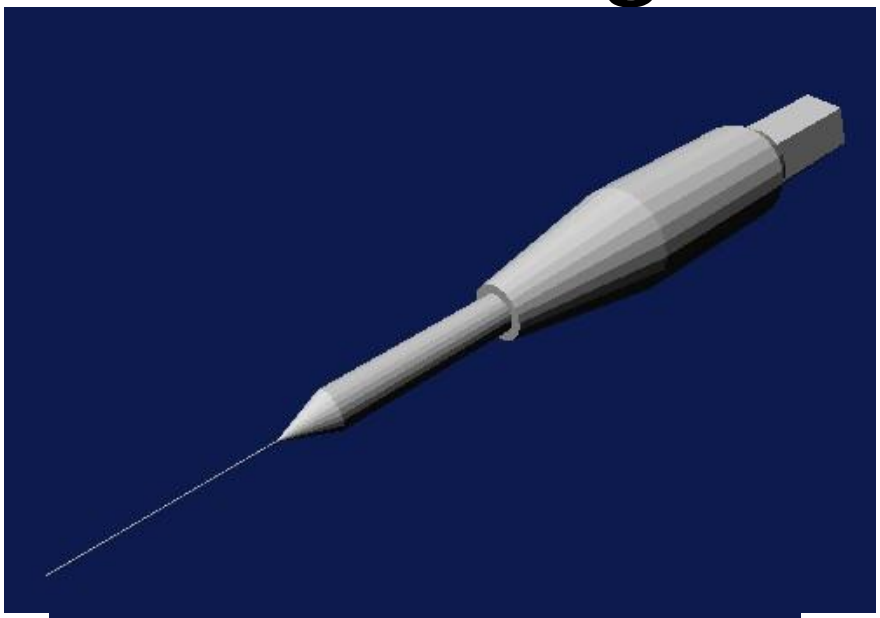
Calibration

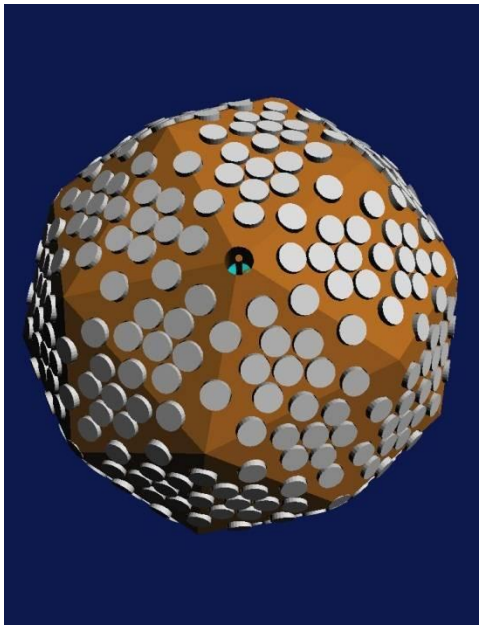
- Features
  - <1mm precision for position setting
  - Reducing effect to generated photon use very thin structure of source holder.
- Sources
  - ^{57}Co, ^{241}Am, ^{109}Cd, ^{55}Fe, ^{137}Cs, …

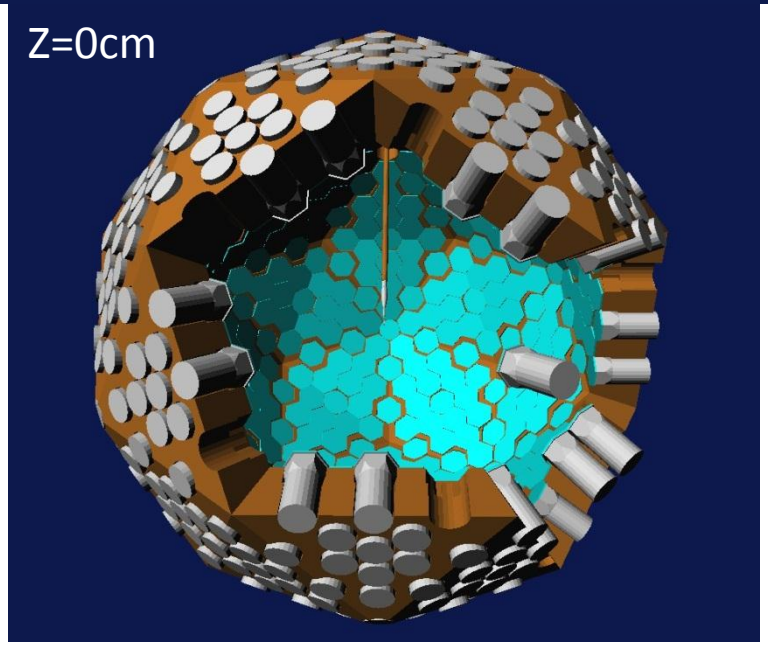
Source rod with a dummy source

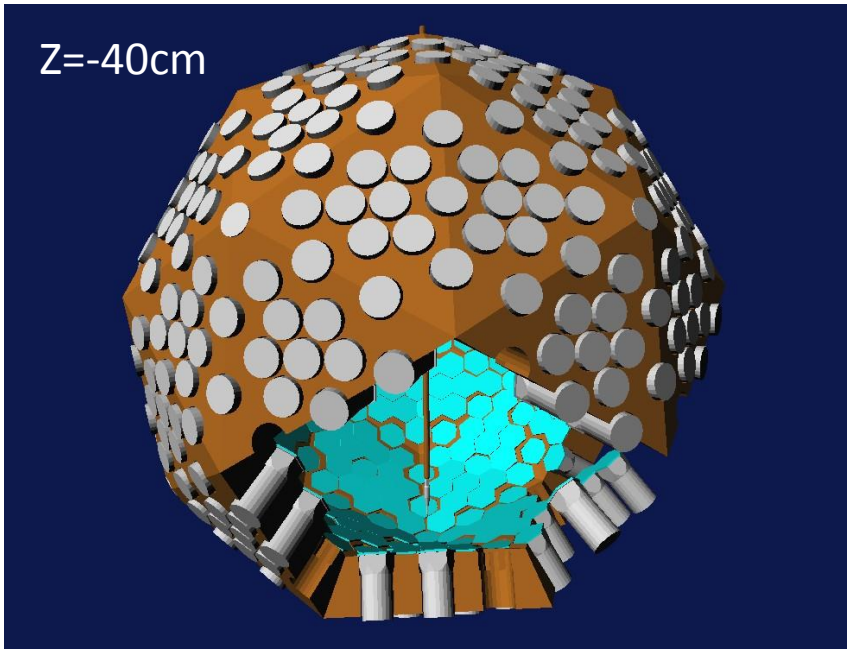


MC setting

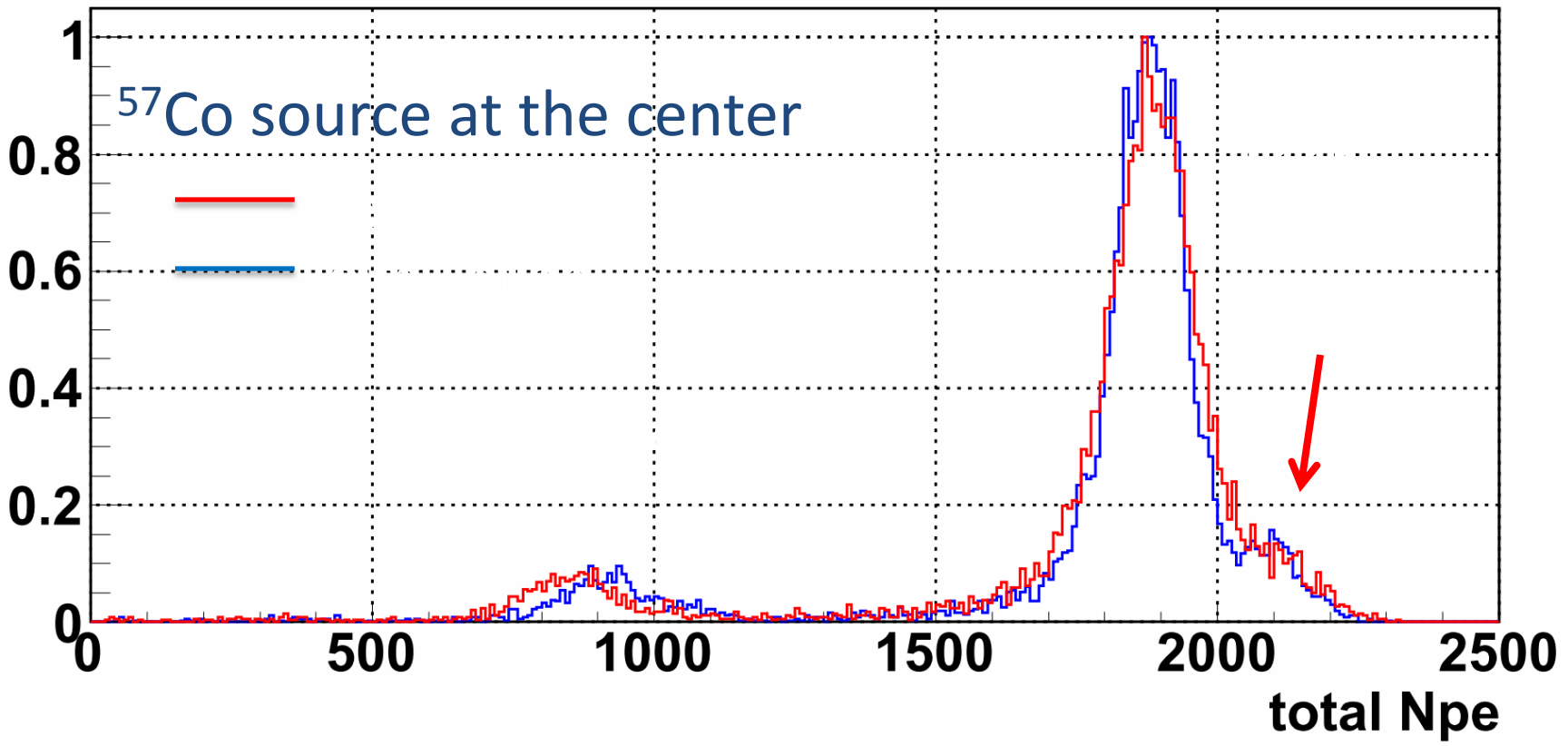








PE distribution

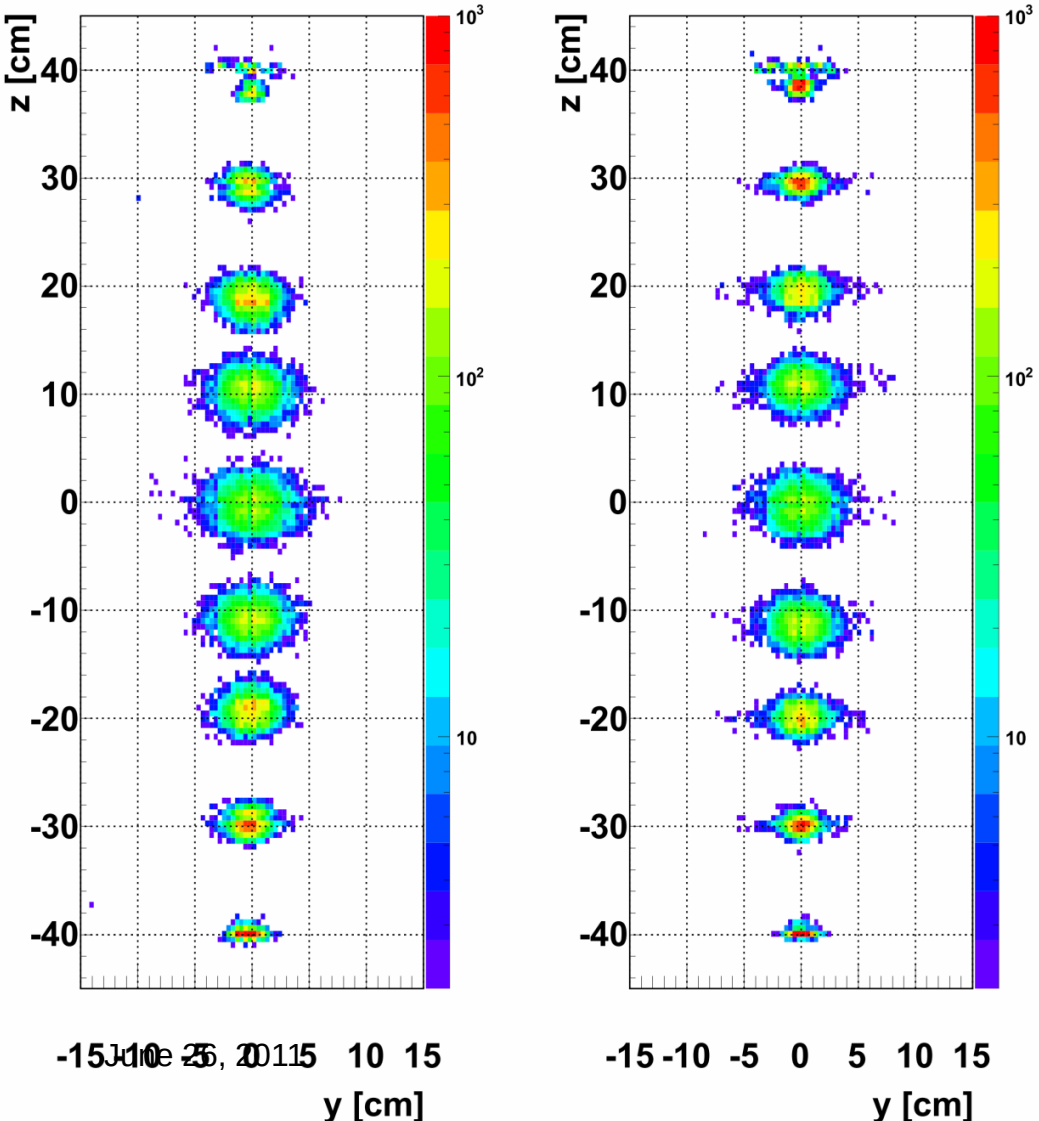


- High p.e. yield, 16.0p.e./keV, was obtained.
- The photo electron yield distribution was reproduced by a simulation well.

Vertex reconstruction

Real Data

Simulation



r is well reconstructed.

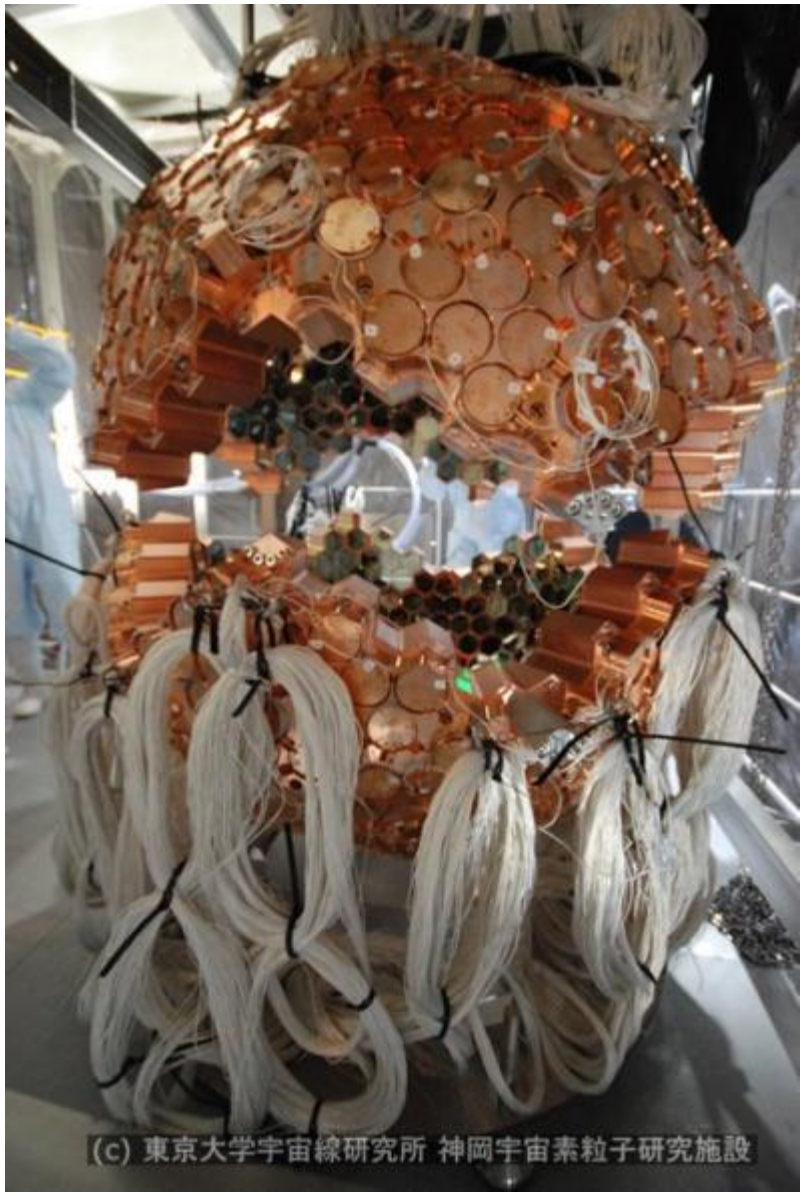
Δr is as expected by MC

1.4cm RMS @z=0cm

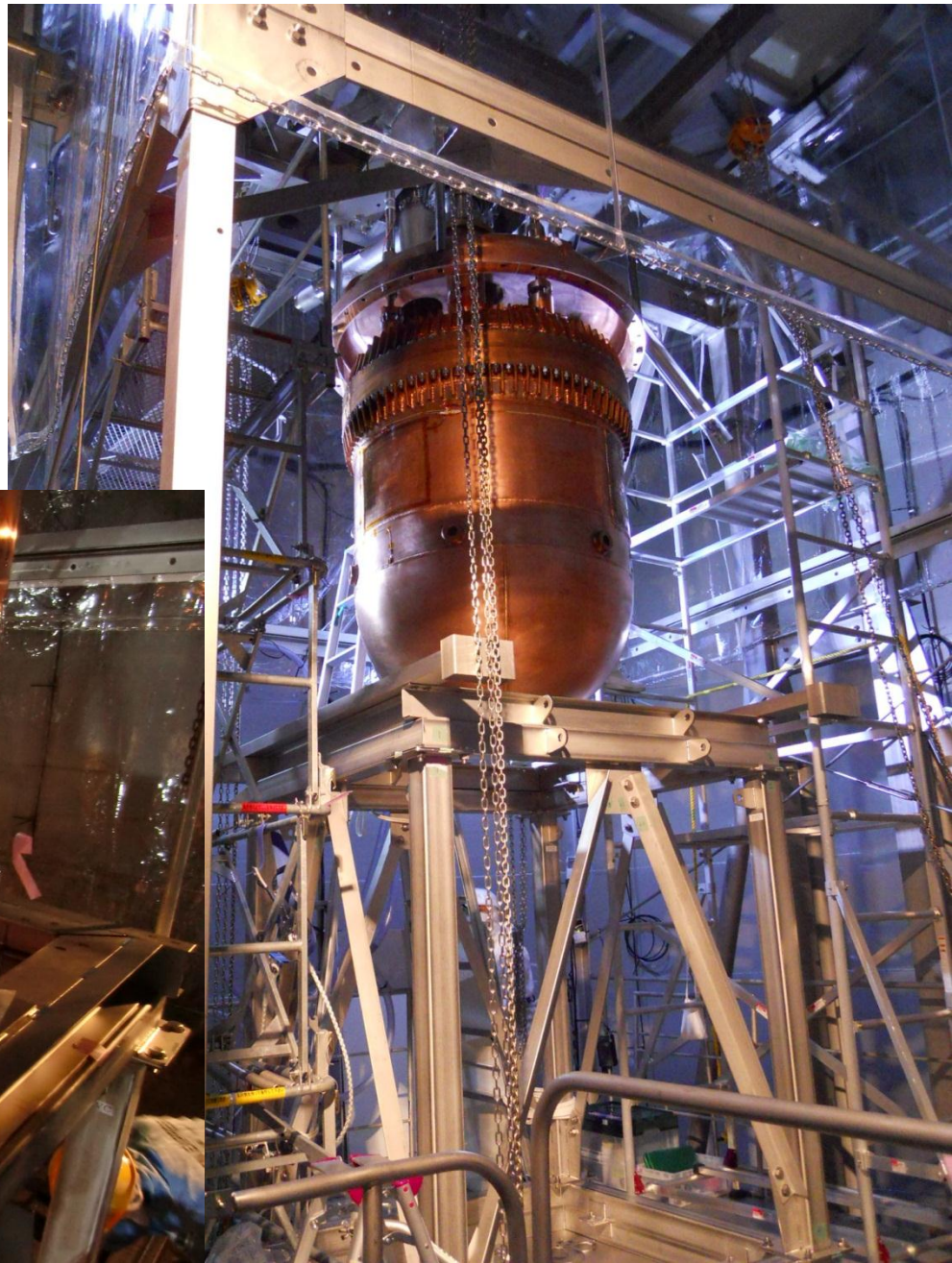
1.0cm RMS @+-20cm

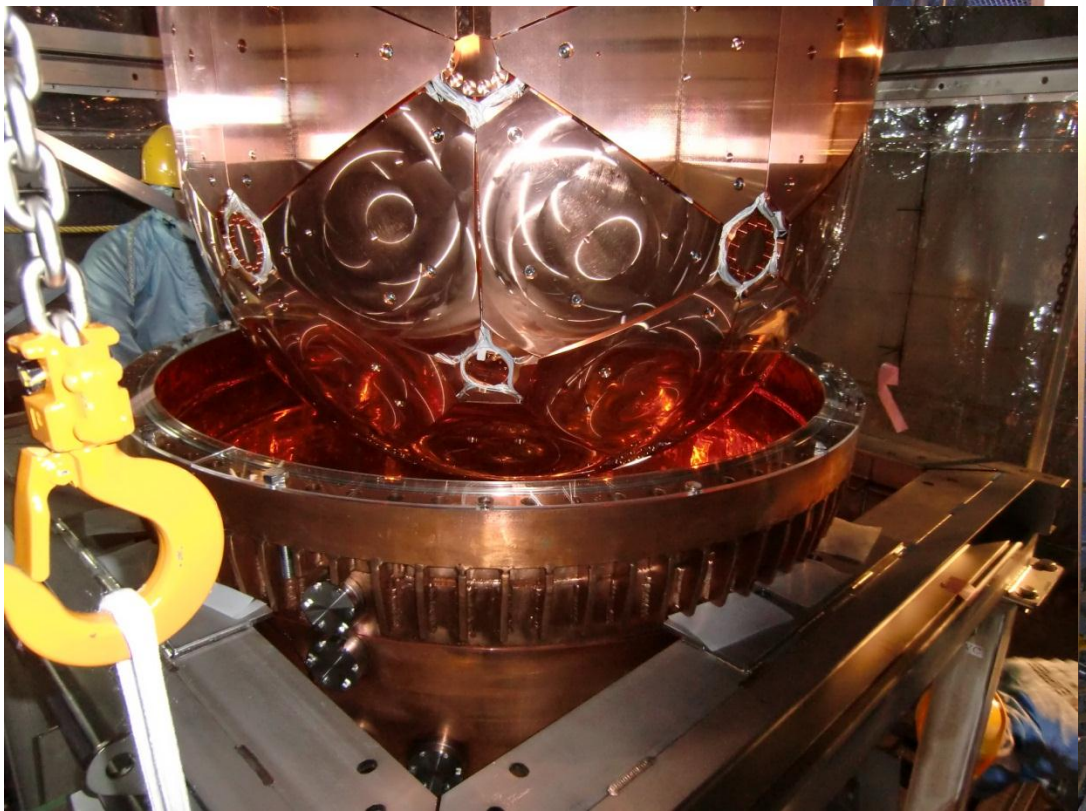
For 122keV γ rays

The PMT holder: Connection of two halves

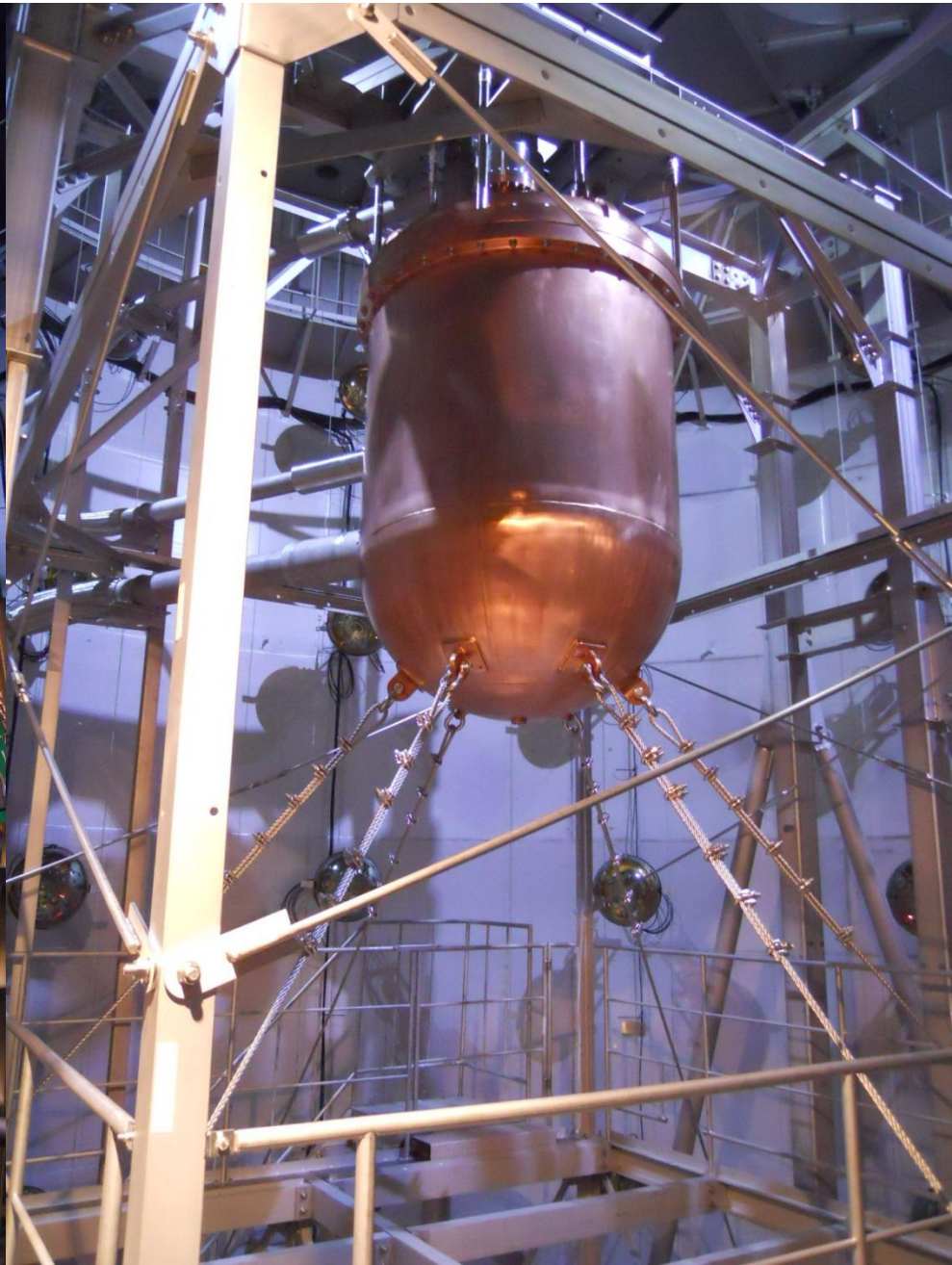


Inner vessel chamber





Outer vessel chamber

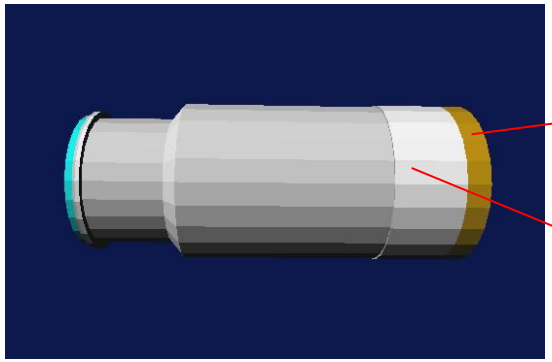


Geometry (PMT)

Round PMT

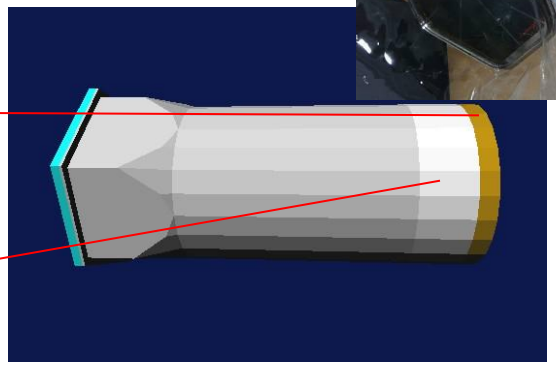
Size is actual one
Tube PMT is new

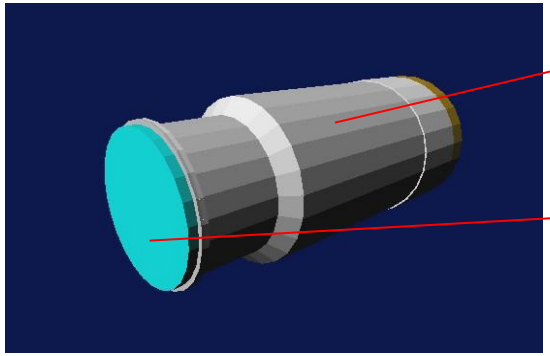
Hex PMT



Cu cover
(brown)

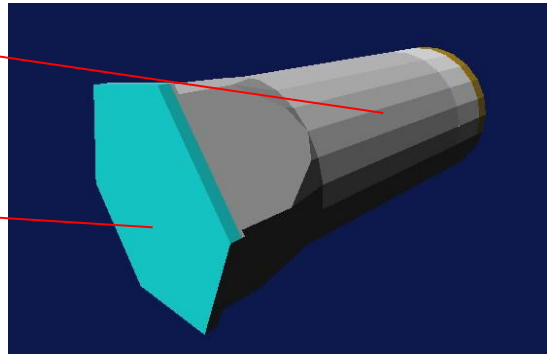
PTFE base
(white)

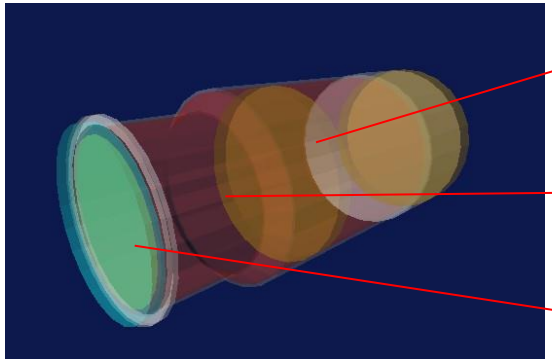




PMT body
(gray)

Window
(light blue)





Circuit board
(orange)

Vacuum
(red)

Photo cathode
(light green)