Background study for solar neutrino measurement in Super Kamiokande

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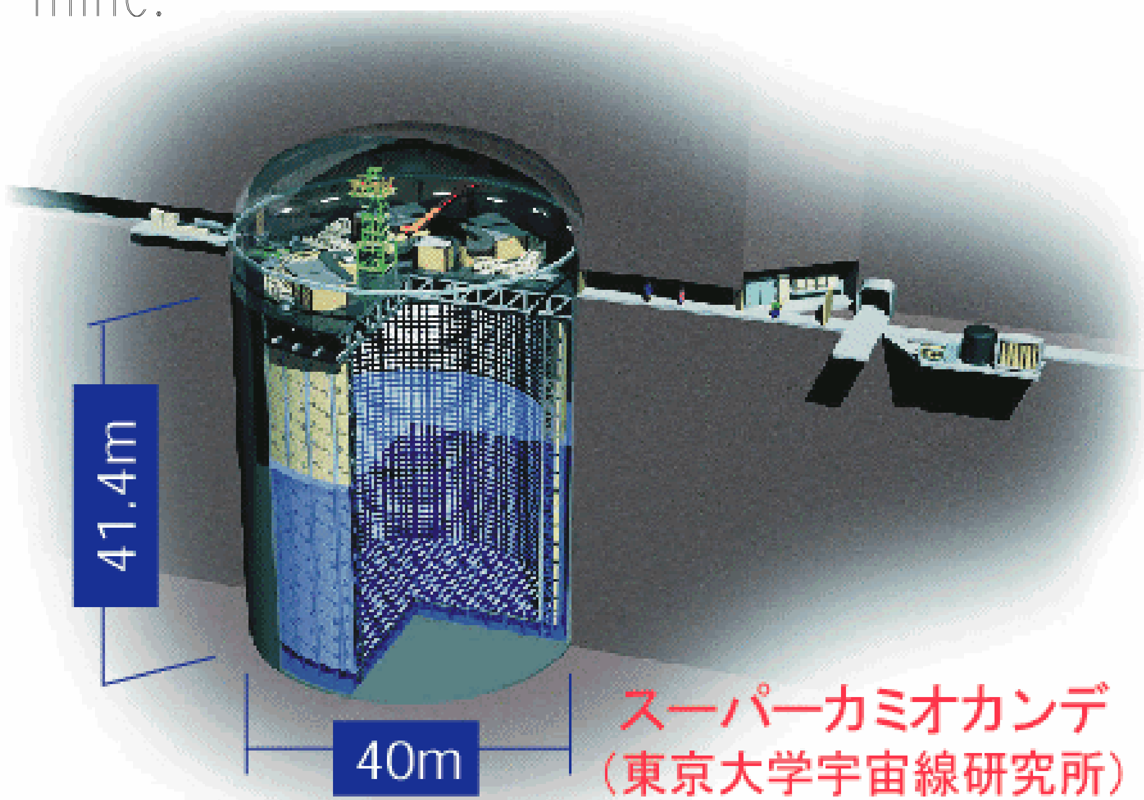
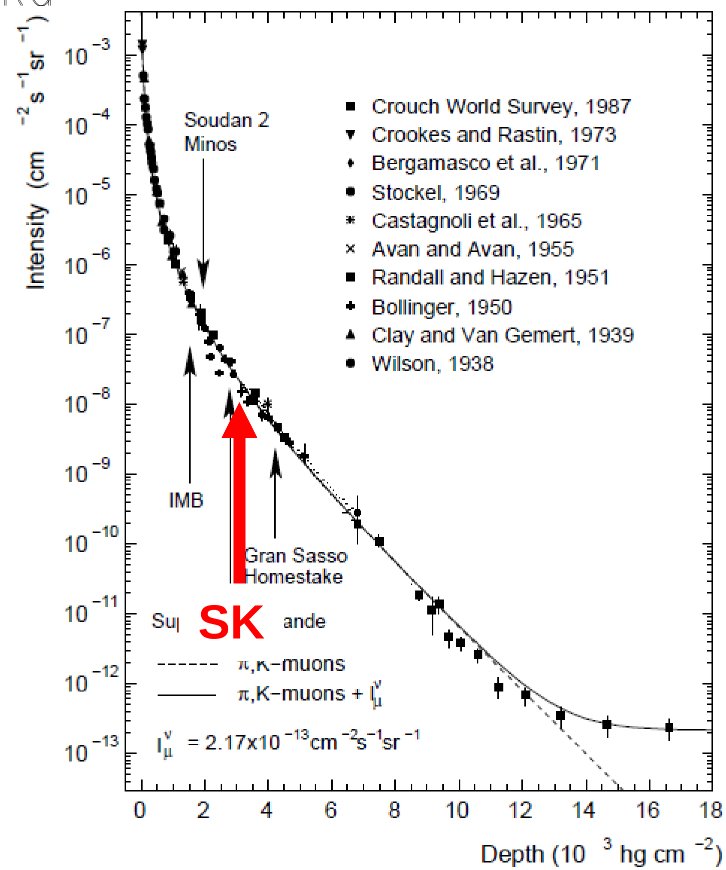
Outline

- Introduction of SK and SK-III.
- Motivation for the solar neutrino measurement.
- Origin of the background events and the efforts for reduction.
  - Water purification system.
  - Germanium Radioactivity measurements
  - Lantern-Mantle Experiments
- Summary

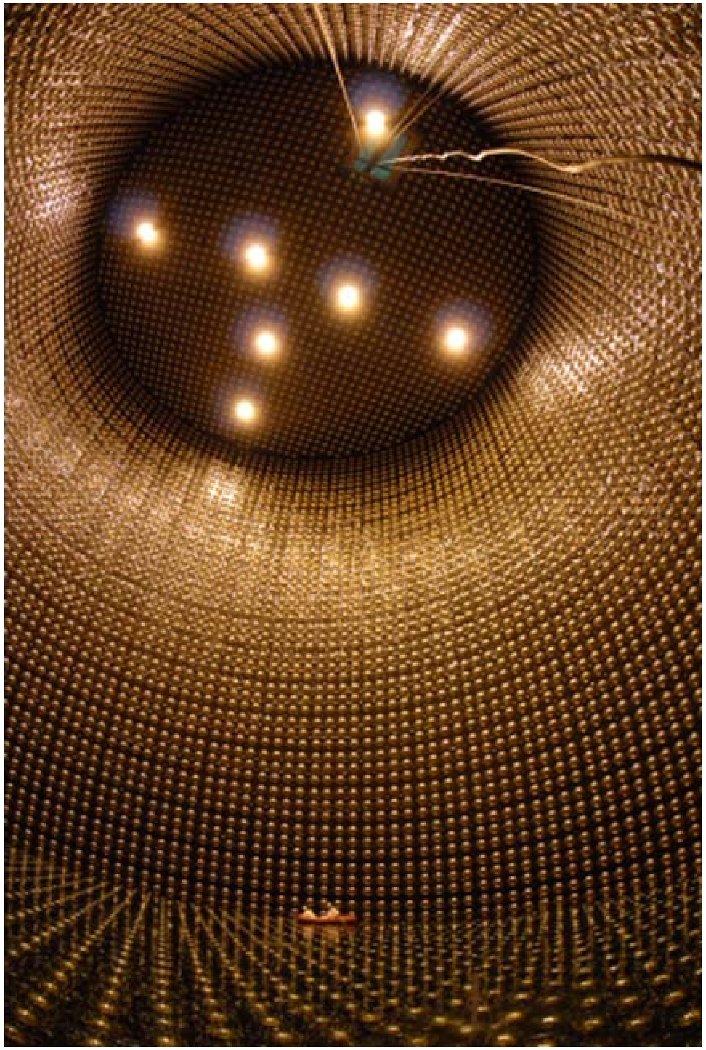
Super Kamiokande

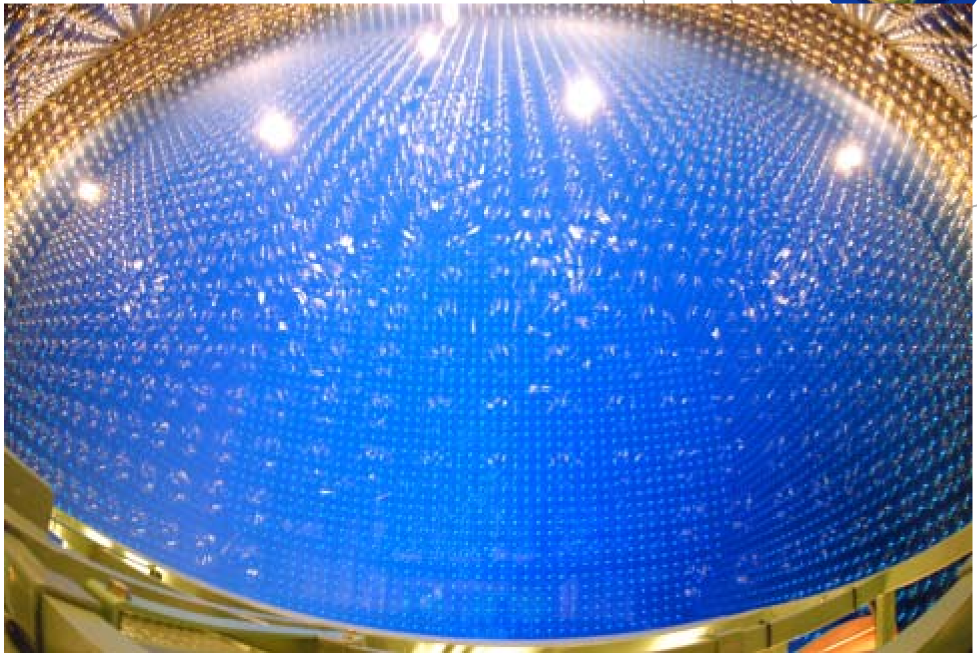
- Super-Kamiokande is a 50000 ton water Cherenkov detector with 13000 PMTs located 1000m (2700m.w.e.) underground in Kamioka mine.





SK-III reconstruction completed!

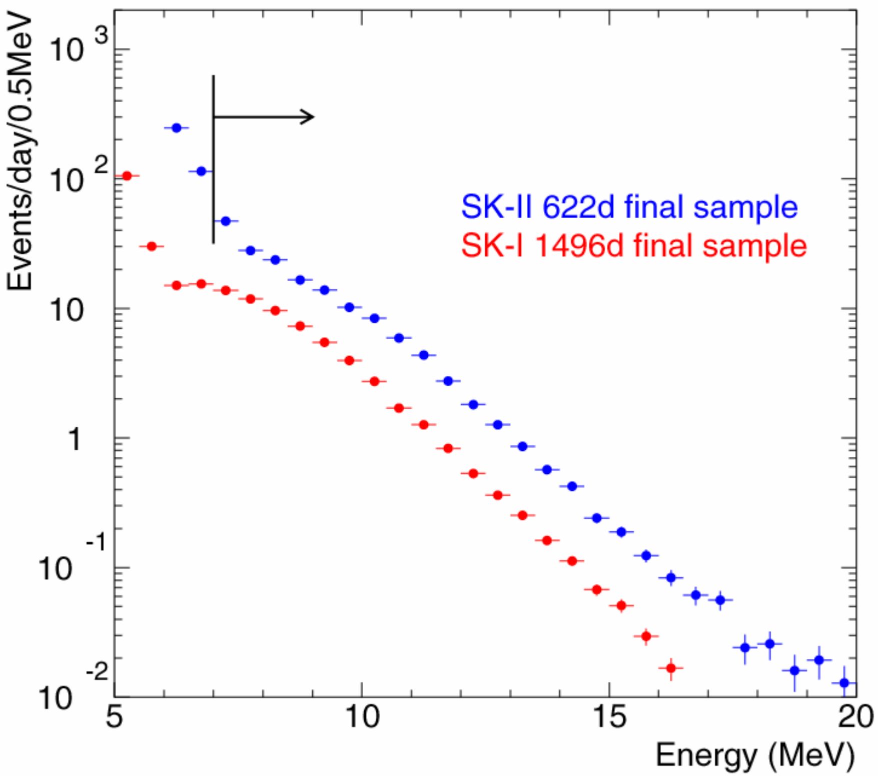




- 2001 Accident, 2002 SK-II
- 12 Apr. 2006. PMT mount finished
- 11 Jul. 2006. Tank filled
- 3 Oct. 2006 Water purification is progressing.

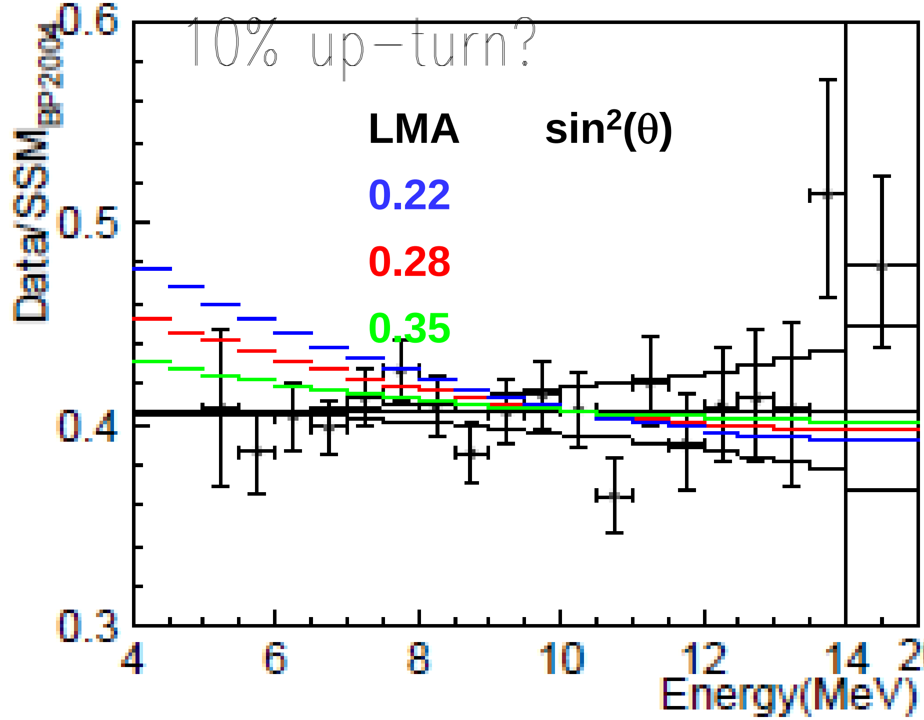
Motivation for solar neutrino

- Energy Spectrum in SK-I,II



- SK-I ^8B Solar ν Spectrum

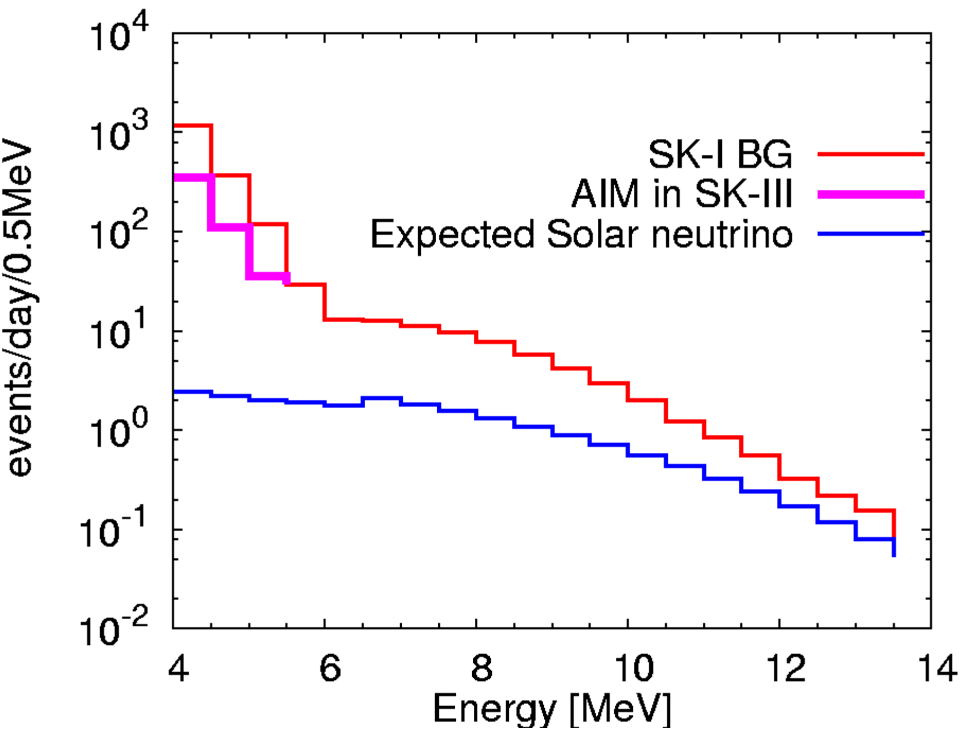
10% up-turn?

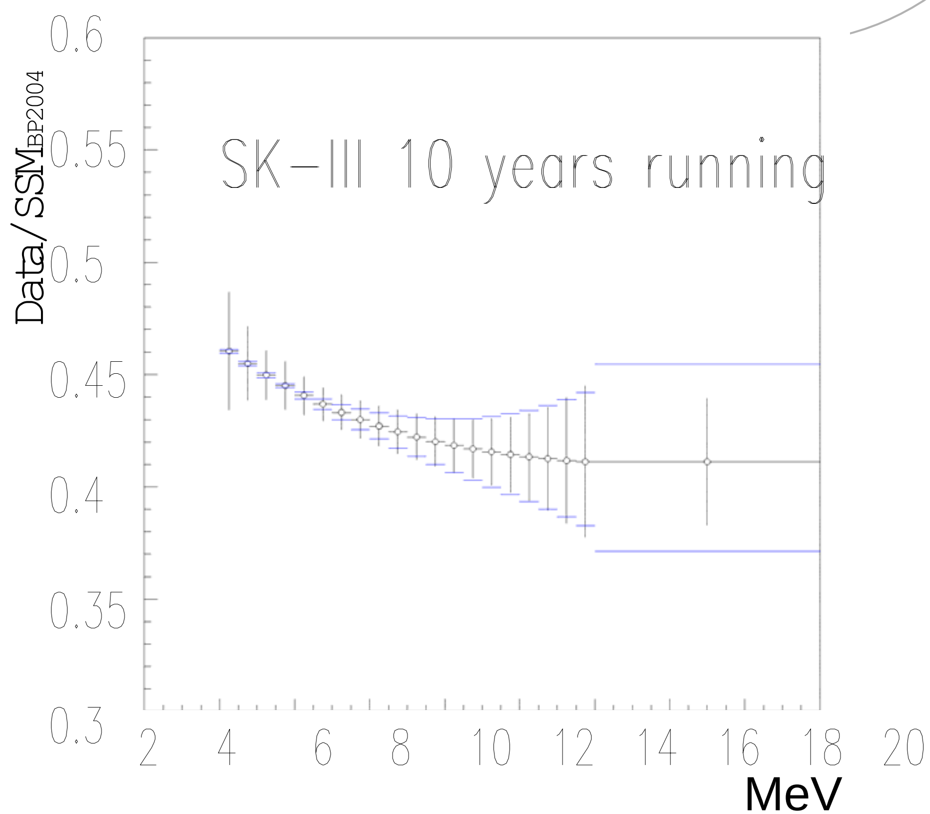


- Lower the background and lower the energy threshold with small errors in order to observe the distortion of the ^8B neutrino spectrum and measure the oscillation parameter precisely.

Goal of SK-III in solar neutrino

- 70% reduction from SK-I in 4-5MeV region.
- Energy threshold 4.5MeV → 4.0MeV





- Expected up-turn of the ^{8}B solar neutrino spectrum

Low Energy Background Sources

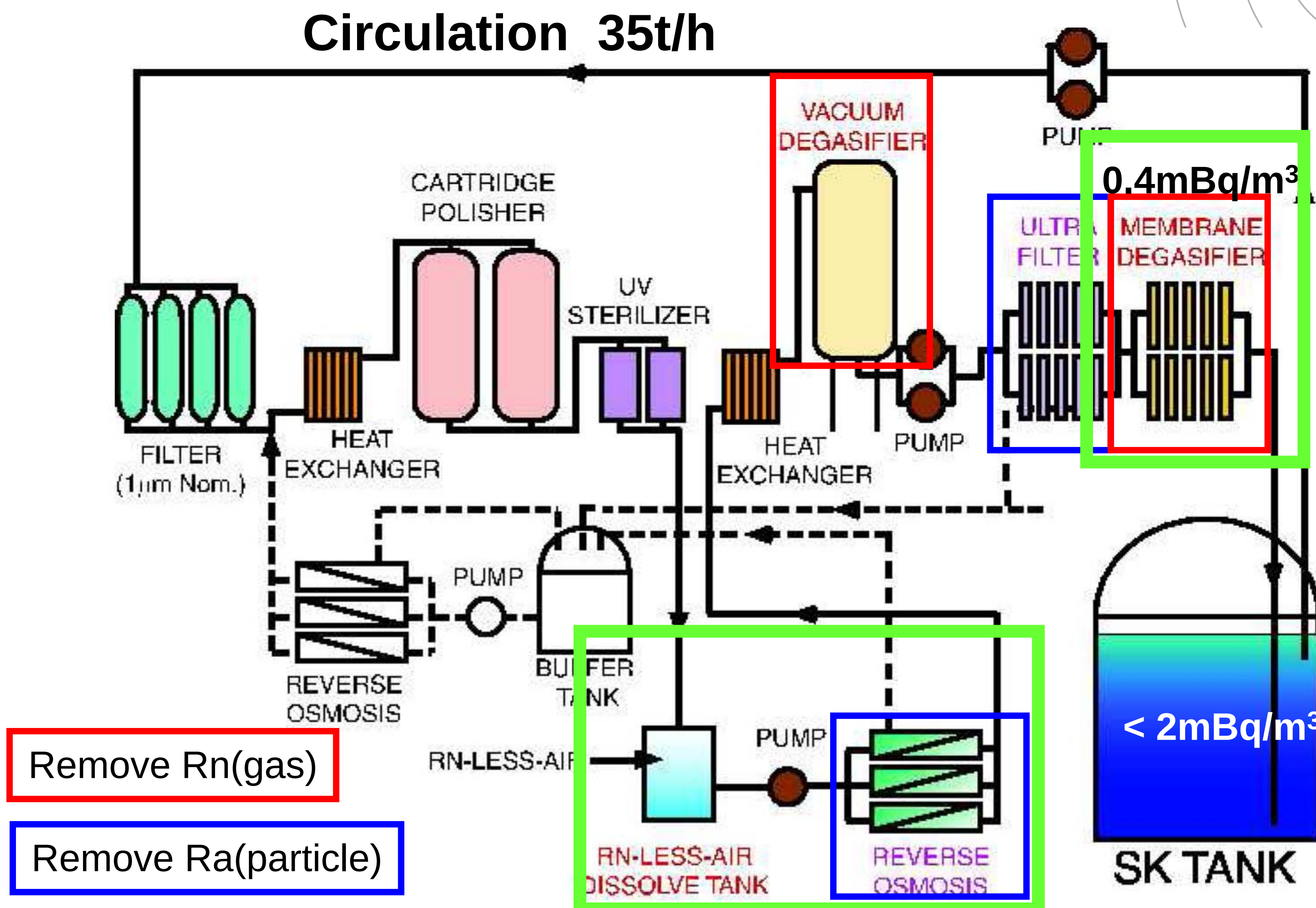
- Water supply origin $^{222}Rn(^{214}Bi,\ E_{\beta max}=3.26MeV)$
  - Residual radon dissolved in the purified water
  - Accumulated radioactive dusts/radon (emanated from SK components, Air?) in the bottom of the tank diffuses with the convection.

  Expected to be reduced!

- Internal origin
  - Radioisotopes in the SK components such as PMT, FRP case,…

  Now we are studying.

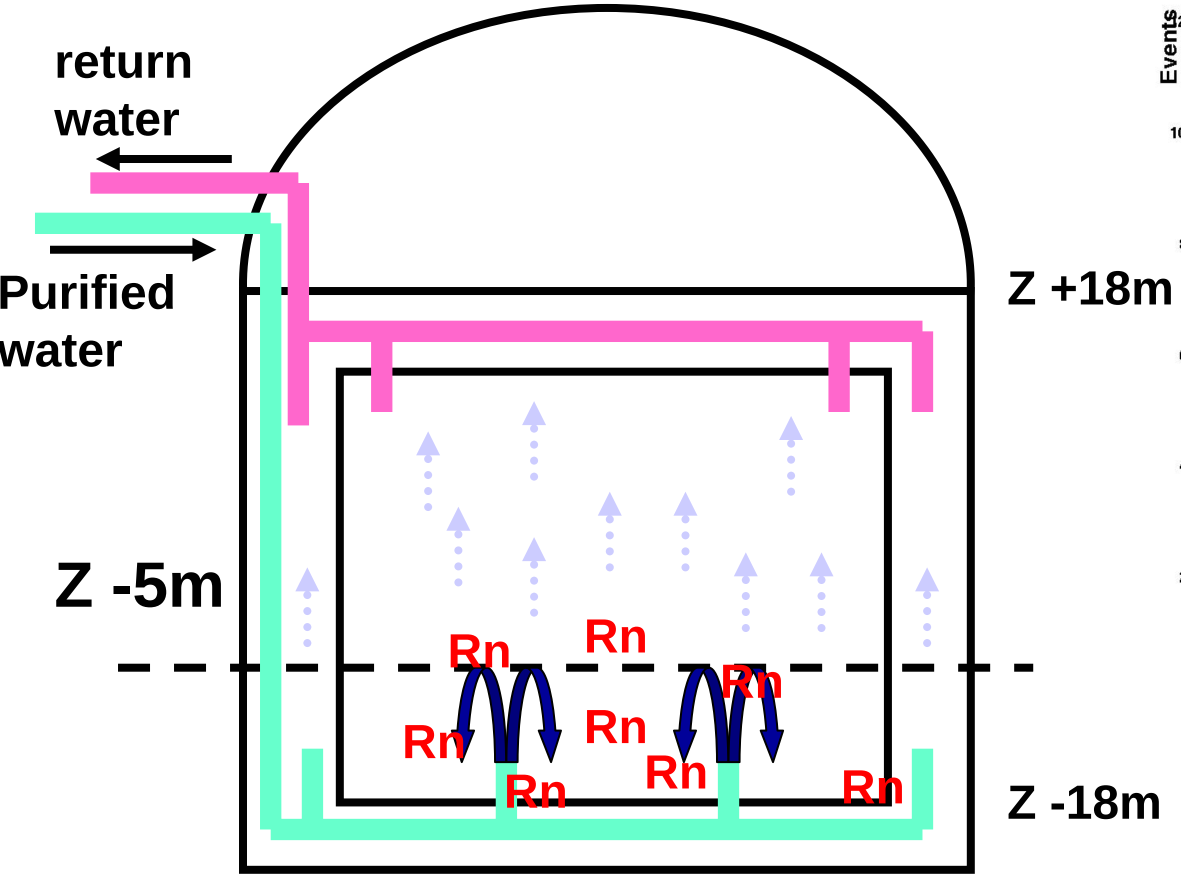
SK Water Purification System



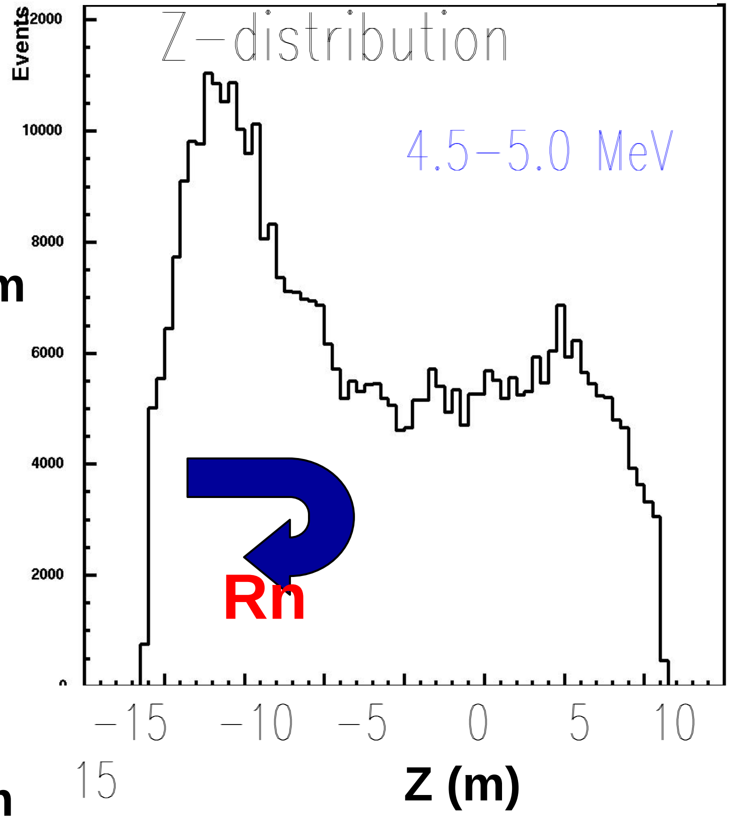
Water flow in SK-I tank (Old system)

- SK-I water supply

Rn was stired up by the convection of the water

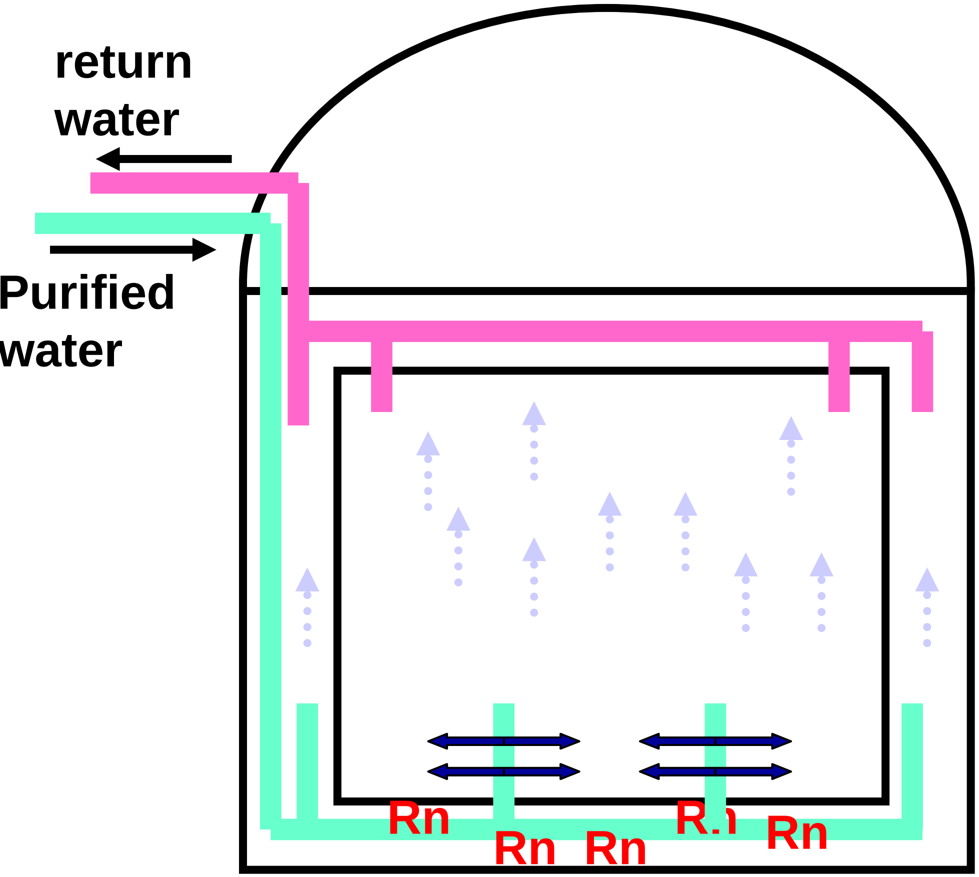


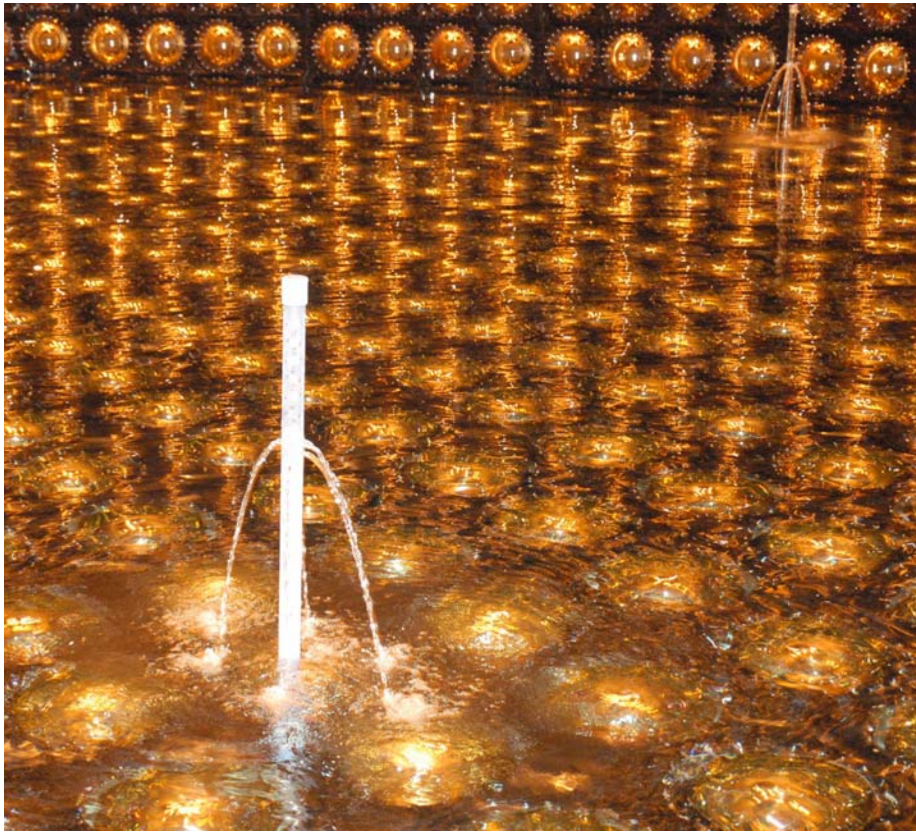
- SK-I final sample
Z-distribution



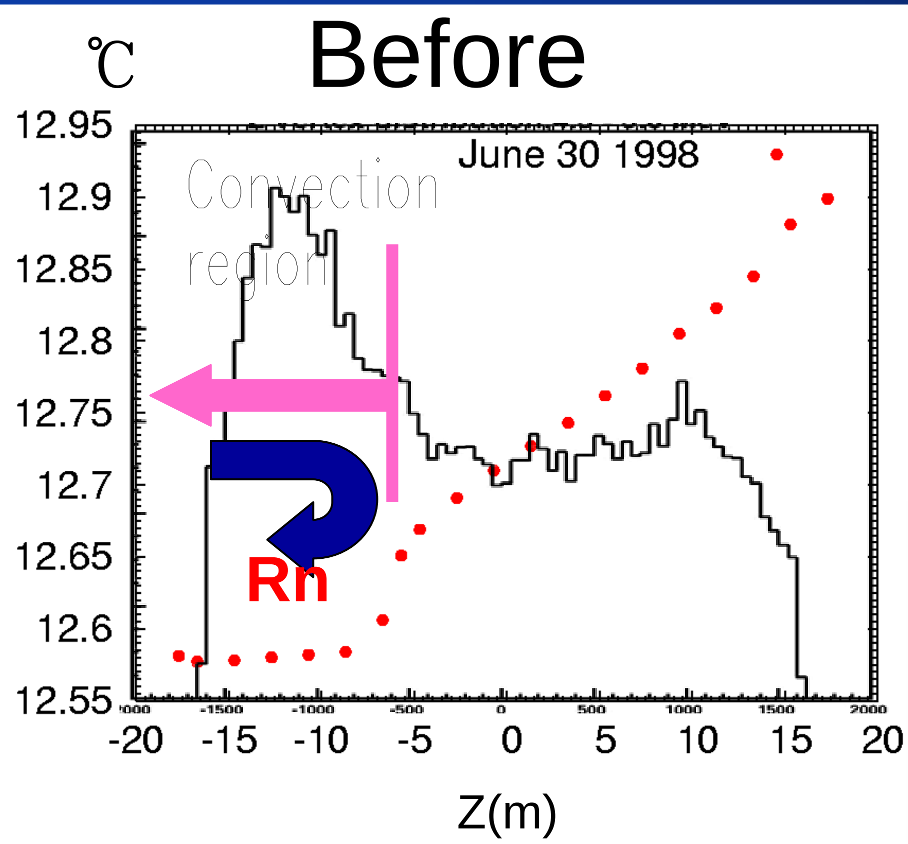
Water flow in SK-III tank (New system)

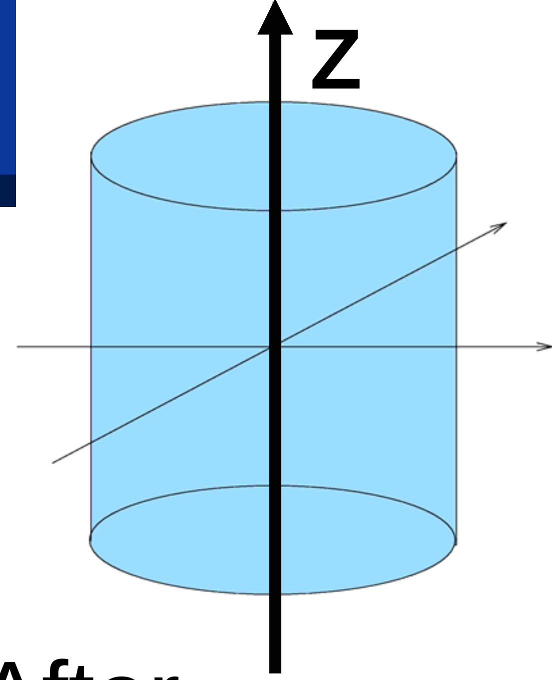
- The water inlet pipe was extended with holes to prevent the convection

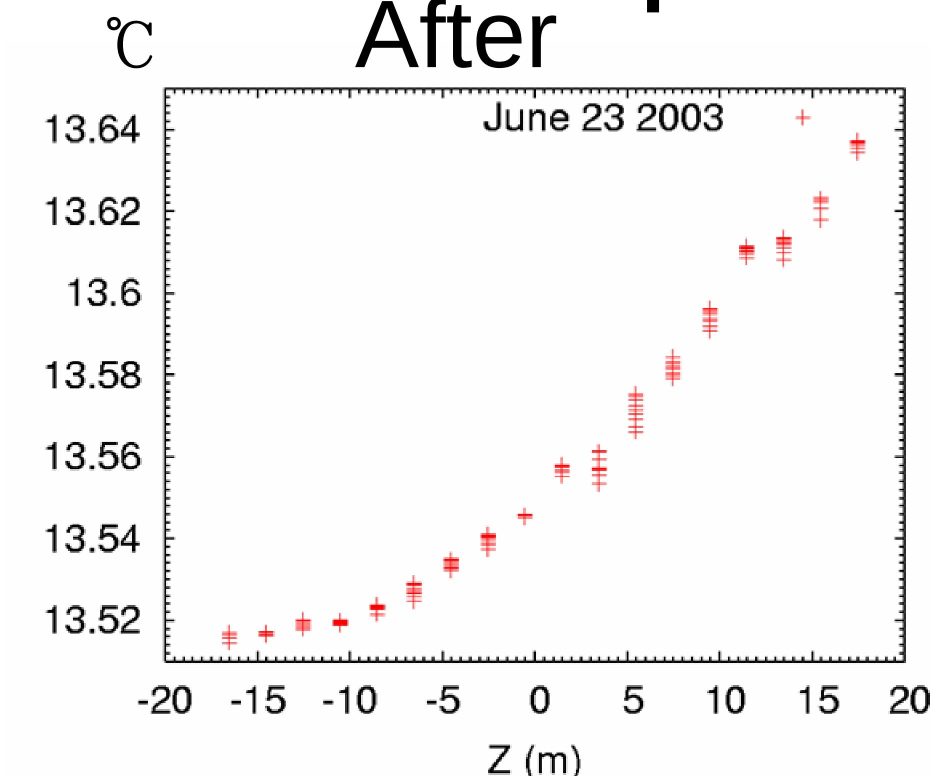




Profile of the water temperature





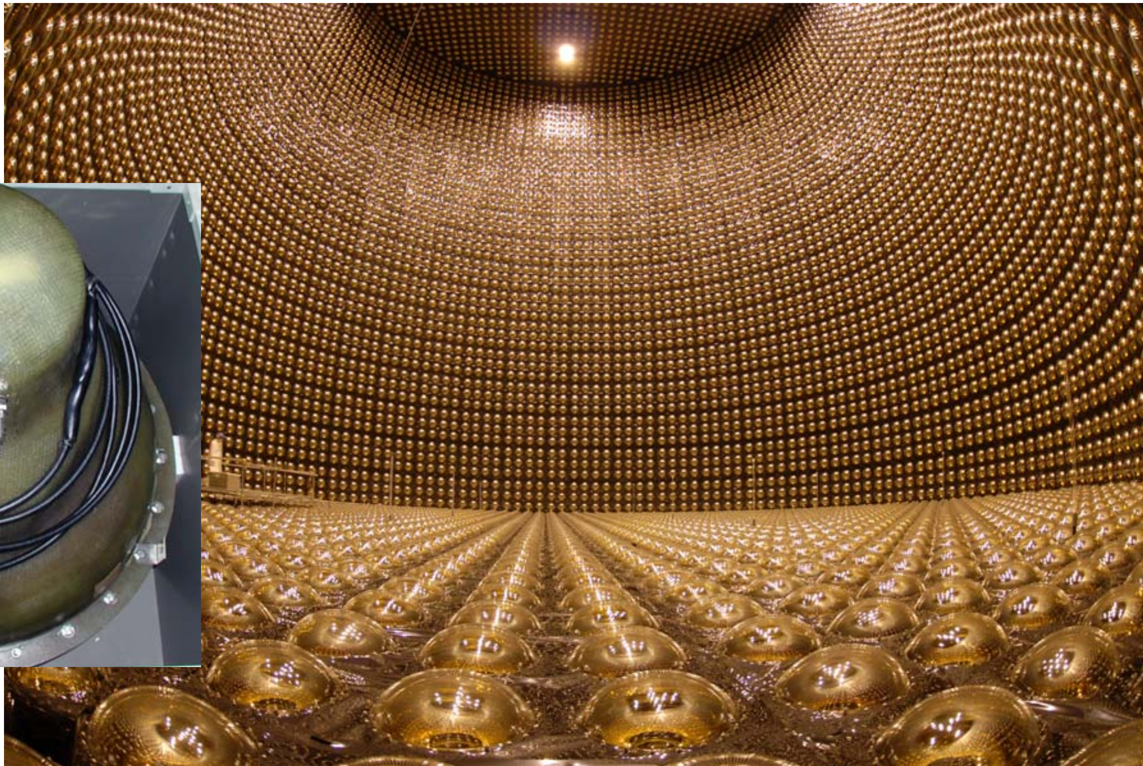


Convection was clearly suppressed!

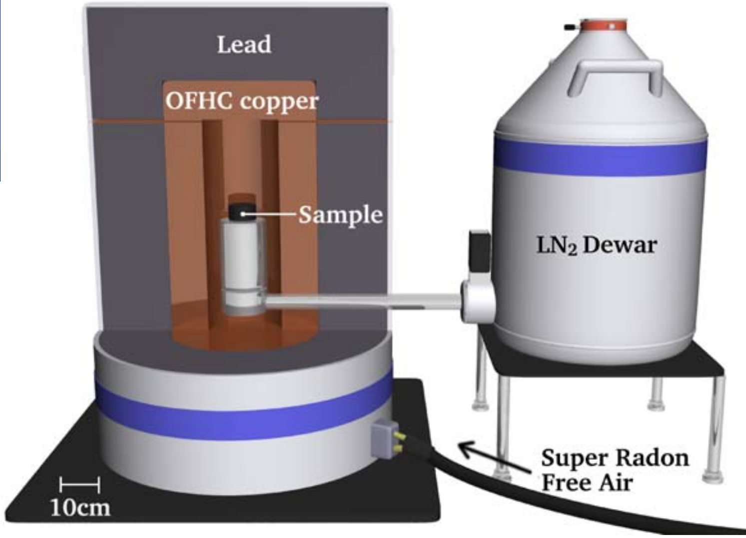
Internal Origin Background

- The effects of the radioisotopes (U/Th/K) in the SK-III detector should be understood to achieve further lowering BG.
- Especially, the newly installed FRP PMT-enclosing cases designed to prevent shockwave propagation (in case of PMT breaking) seemed to contain many radioisotopes!

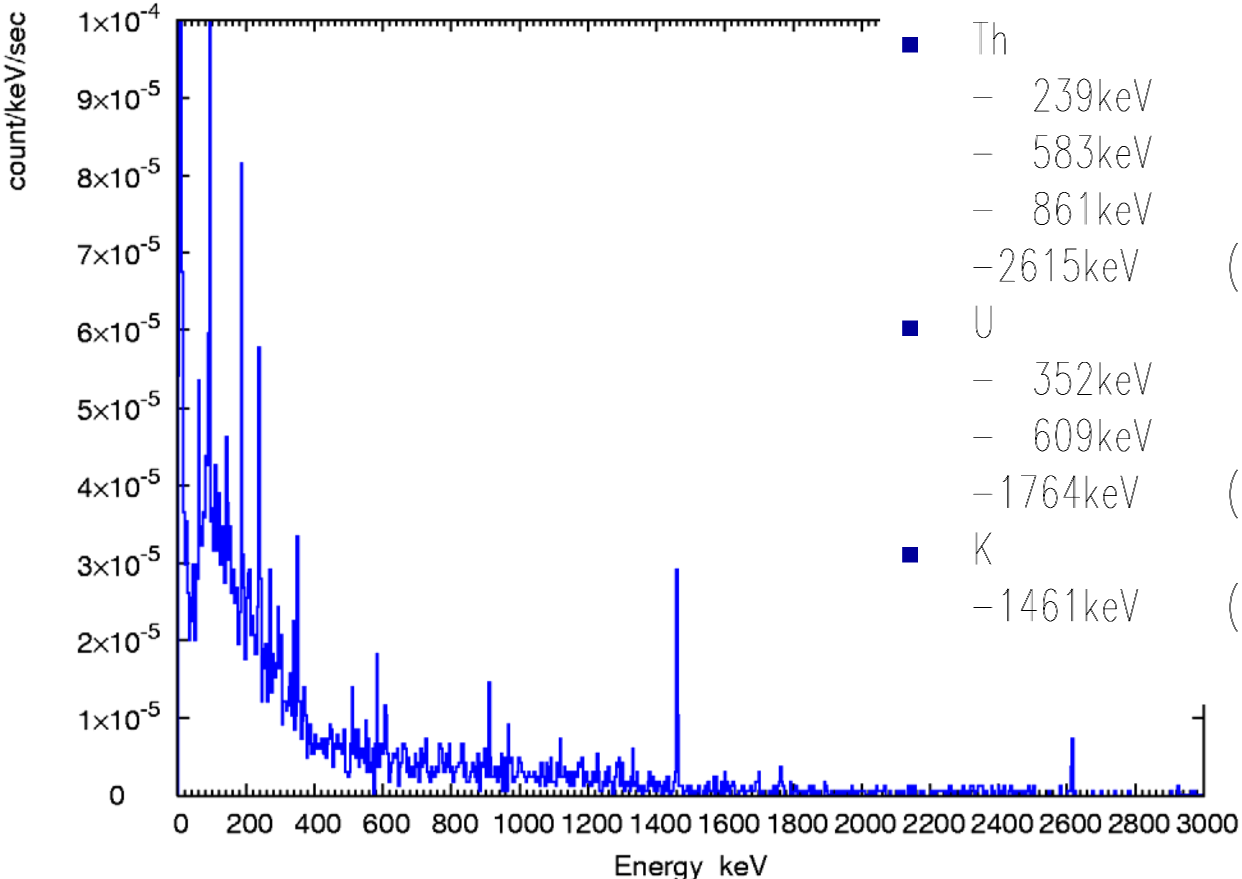




Radioactivity measurement



- We checked all the SK components with HP Ge detector in Kamioka.
- BG spectrum ($370\ cm^3$)

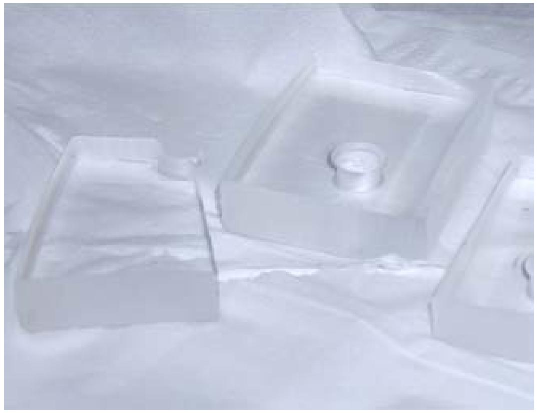


- Th
  - 239keV $(6.90\pm3.29)\times10^{-5}$ counts/sec
  - 583keV $(4.70\pm1.65)\times10^{-5}$ counts/sec
  - 861keV $(1.81\pm1.44)\times10^{-5}$ counts/sec
  - 2615keV $(4.21\pm0.99)\times10^{-5}$ counts/sec
- U
  - 352keV $(6.90\pm3.29)\times10^{-5}$ counts/sec
  - 609keV $(3.83\pm1.68)\times10^{-5}$ counts/sec
  - 1764keV $(0.96\pm1.02)\times10^{-5}$ counts/sec
- K
  - 1461keV $(11.7\pm2.01)\times10^{-5}$ counts/sec

Detector Components of the SK-III

FRP for PMT case

Acyclic cover for PMT



SUS for the Frame

Glass for PMT

PMT base with cable

Dust with wiping paper

Summary of the Activity Measurement

Normalized to 1PMT

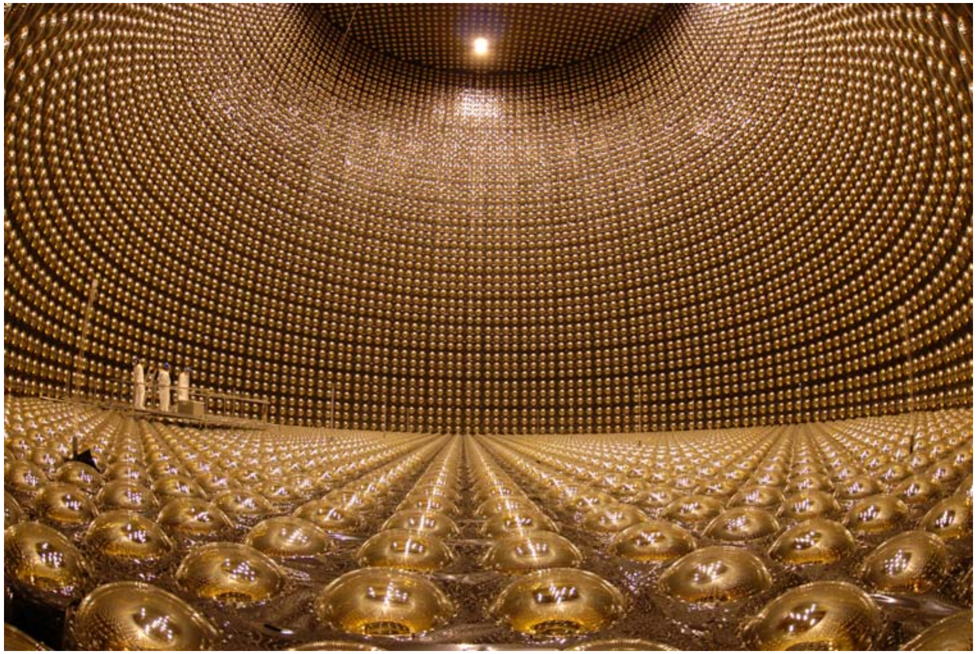
- FRP (barrel) No production year dependence!
  - Th 15Bq/kg×7.4kg/PMT= 110Bq/PMT
  - U 10Bq/kg×7.4kg/PMT= 70Bq/PMT
  - K 16Bq/kg×7.4kg/PMT= 120Bq/PMT

10000 PMTs
= 1MBq source!

- PMT glass (After furnace repair)
  - Th 1.4Bq/kg×5.2kg/PMT= 7.8Bq/PMT
  - U 5.1Bq/kg×5.2kg/PMT= 27Bq/PMT
  - K 18 Bq/kg×5.2kg/PMT= 94Bq/PMT
- PMT glass (Before furnace repair)
  - Th 1.8Bq/kg×5.2kg/PMT= 9.4Bq/PMT
  - U 8.3Bq/kg×5.2kg/PMT= 43Bq/PMT
  - K 22 Bq/kg×5.2kg/PMT= 110Bq/PMT
- PMT Base
  - Th 0.47Bq/kg×0.9kg/PMT=0.42Bq/PMT
  - U 0.70Bq/kg×0.9kg/PMT=0.63Bq/PMT
  - K 0.54Bq/kg×0.9kg/PMT=0.49Bq/PMT
- SUS
  - Th 0.01Bq/kg×31Kg/PMT = 0.3Bq/PMT
- Dust
  - Th 40Bq/kg×0.03g/PMT = 0.0012Bq/PMT
  - U 30Bq/kg×0.03g/PMT = 0.0009Bq/PMT
  - K 300Bq/kg×0.03g/PMT = 0.009 Bq/PMT

2.6MeV gamma (^{232}Th) behind PMT

- Can SK detect the 2.6MeV gammas emitted behind PMTs?
- We put source behind the PMTs!



Lantern Mantle Source

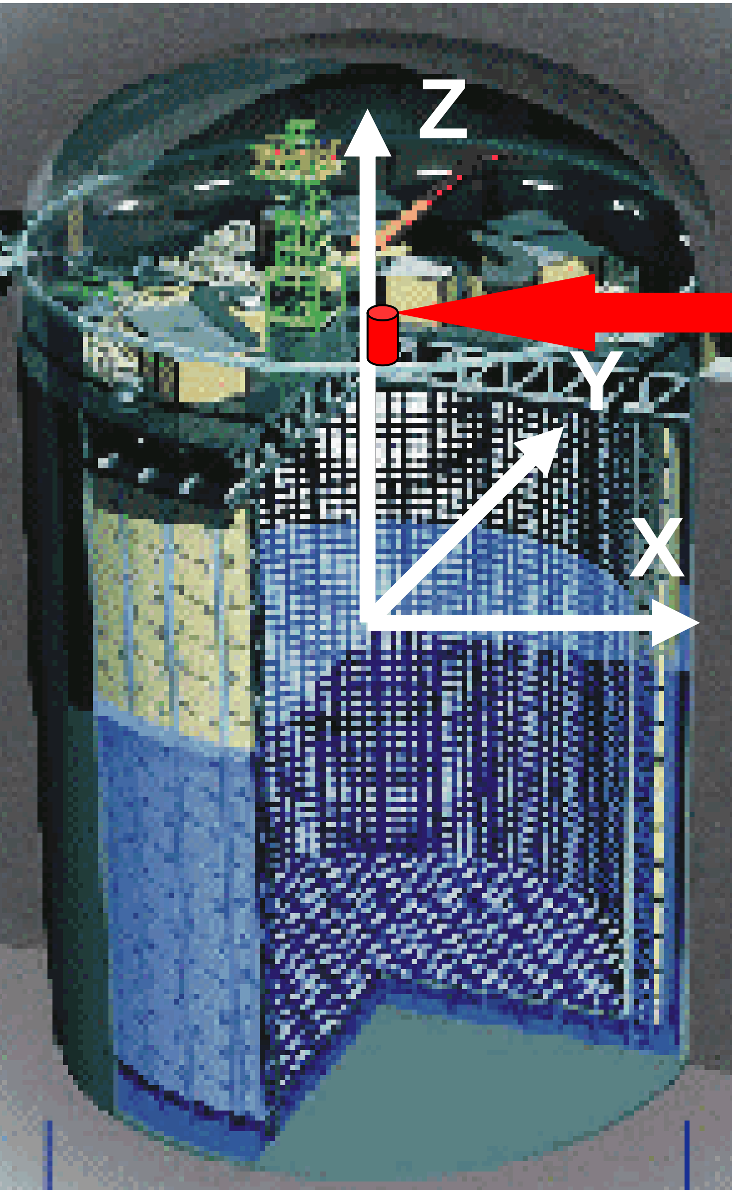
- The mantle contains ^{208}Tl for brightening the lantern lights.

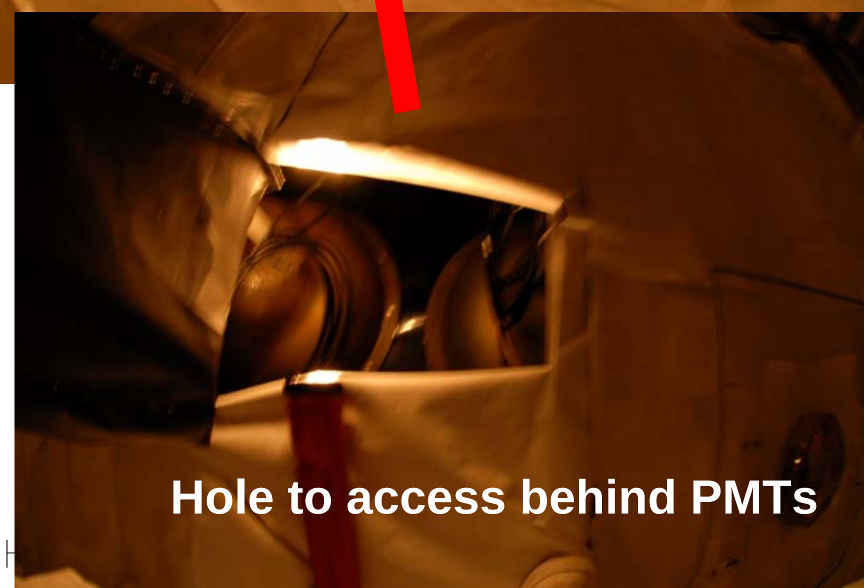
$^{208}\mathrm{Tl} \rightarrow {}^{208}\mathrm{Pb}$

2.615 MeV(99.2%)
861 keV(12.4%)
583keV(84.5%)
511keV(22.6%)

- We put 300 pieces of Lantern mantle into a SUS container.
- The source intensity is 59.5kBq (measured by Ge) and that corresponds to 500 FRP cases.

Source Position

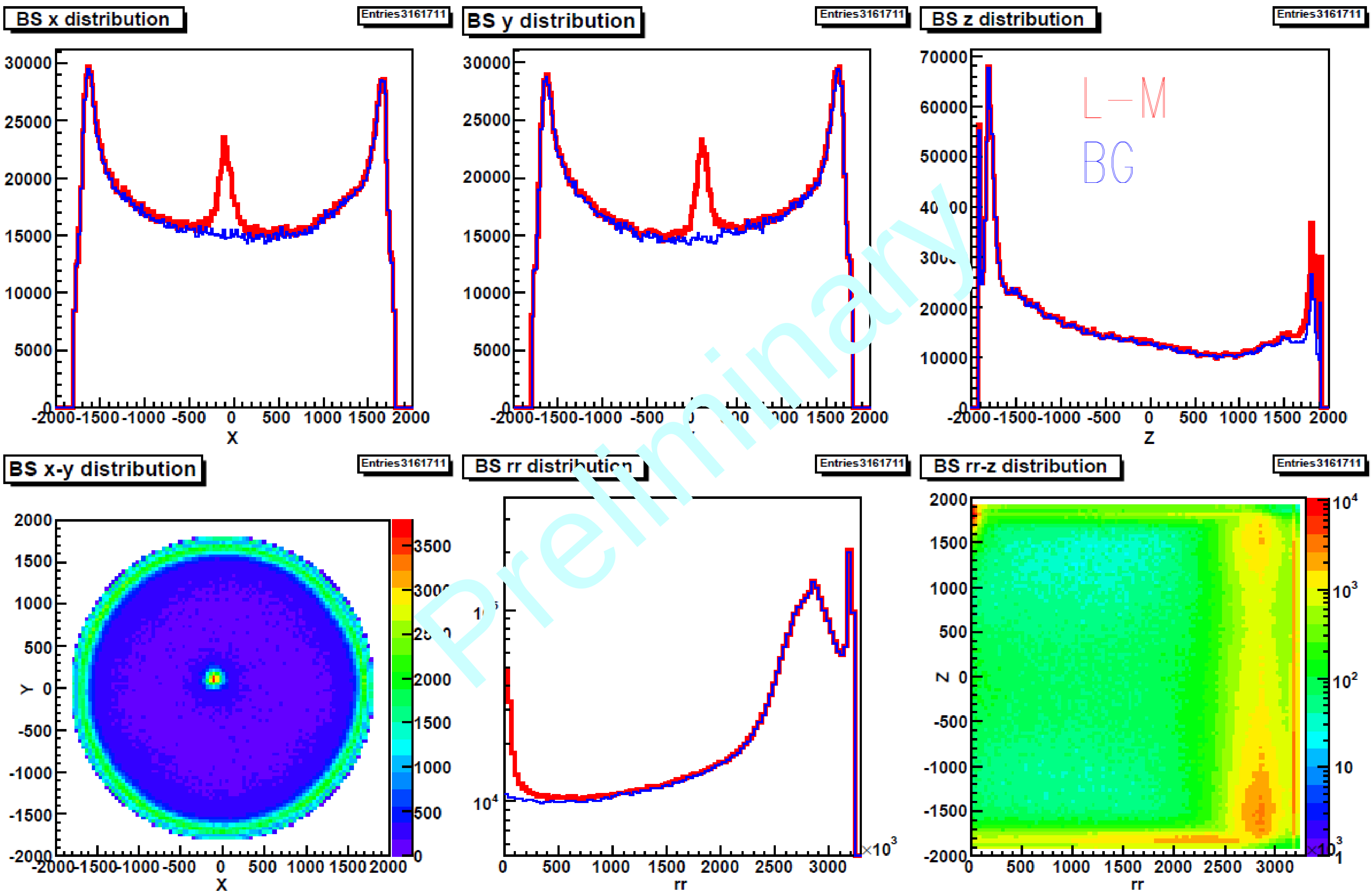




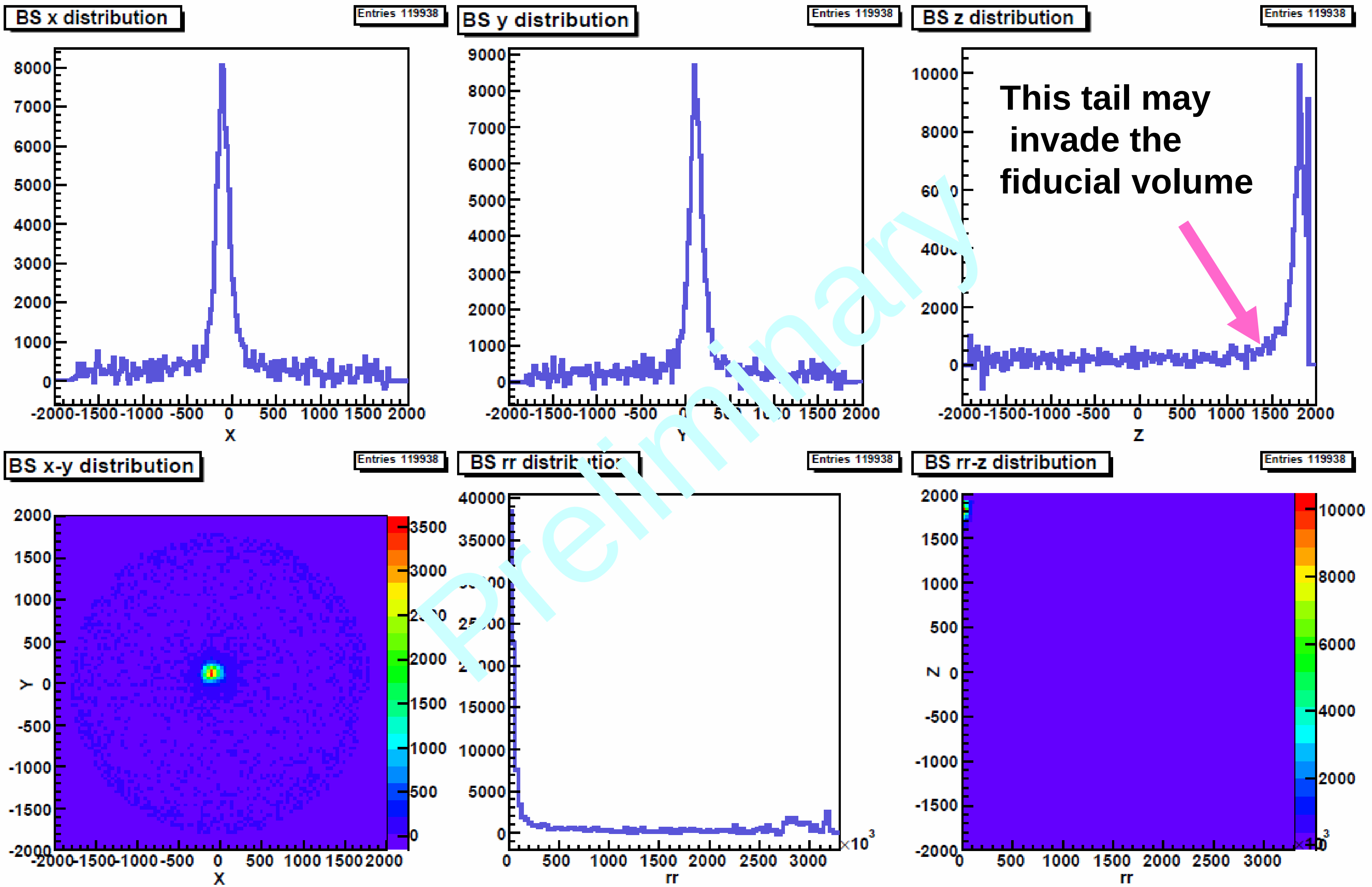
The measurement

- The measurement was conducted on 23 Aug.
- In that period, the water is in the early stage of purification and the transparency was only 75m. (In stable SK, >100m)
- Energy calibration is not completed.
- The analysis is not optimized and the following results are preliminary!

Reconstructed vertices

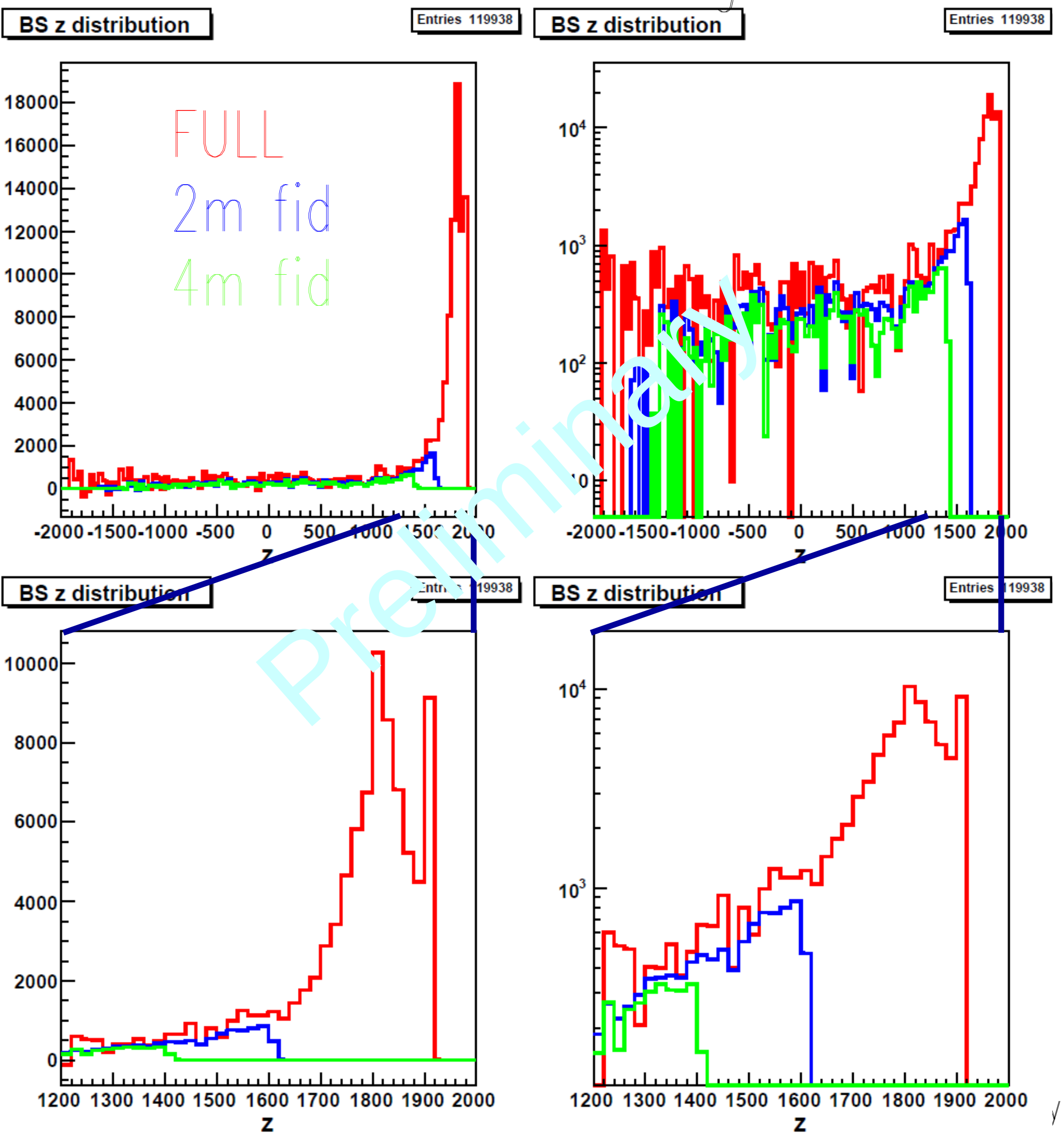


BG subtracted distribution

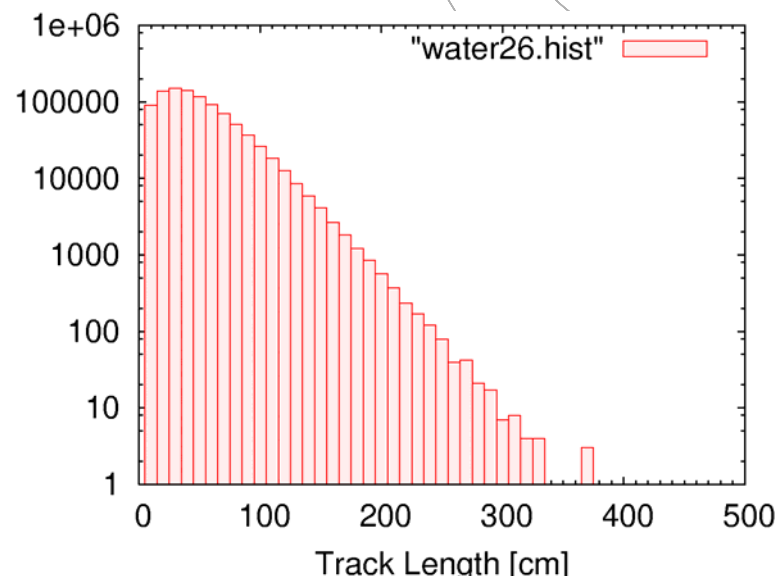


The tail (in this early analysis)

Linear scale Log scale

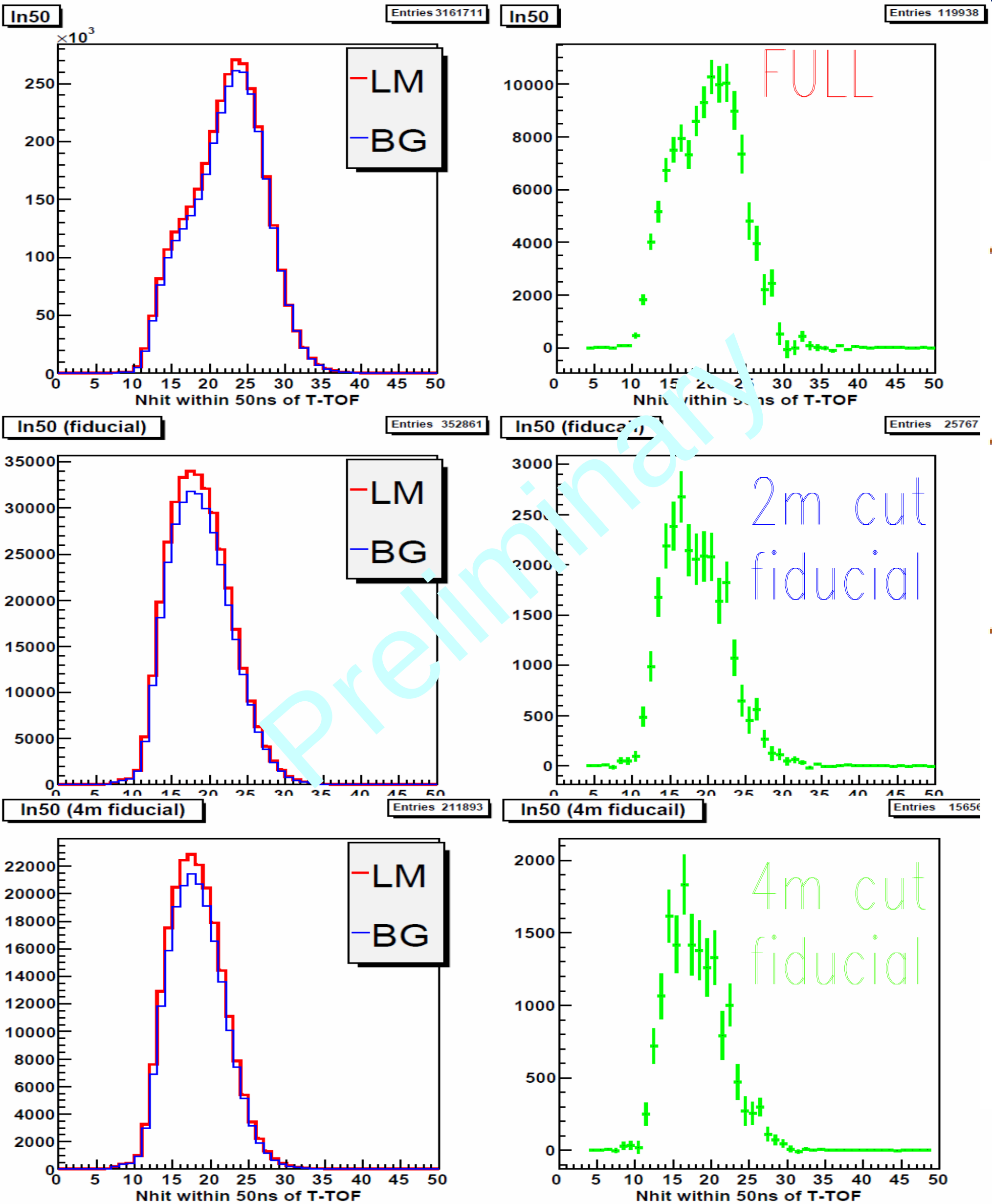


2.6MeV gamma in water

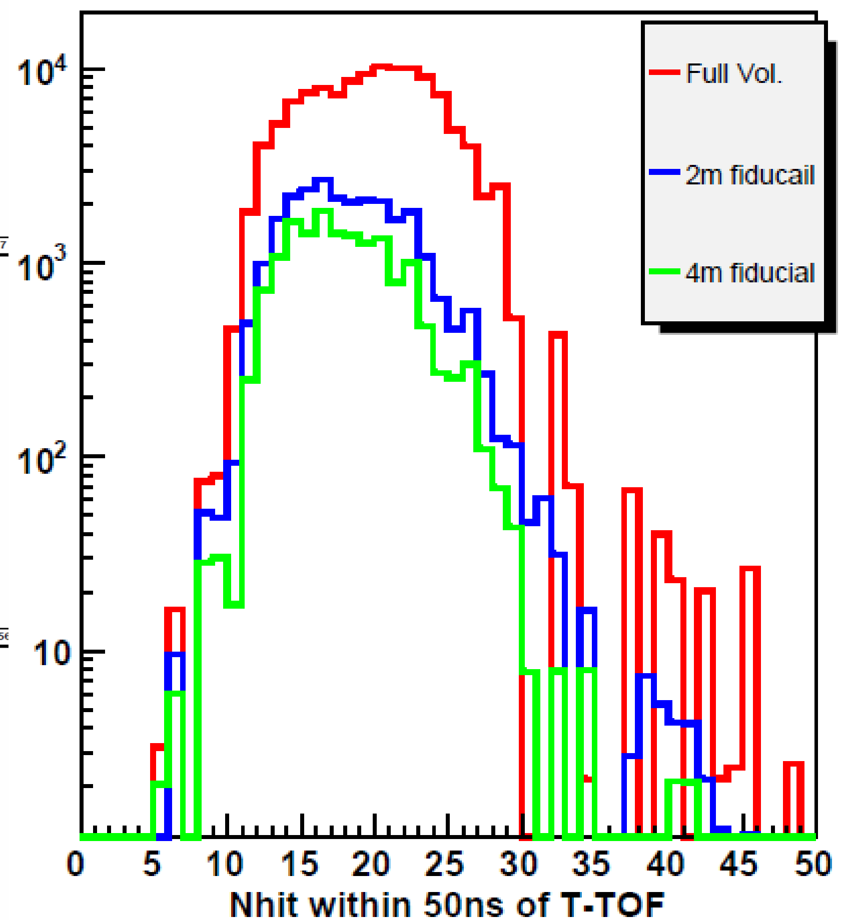


- 2m fiducial cut should be effective, but**...**
- Resolution will be better.
  - –Water purification
  - –Tuning the analysis

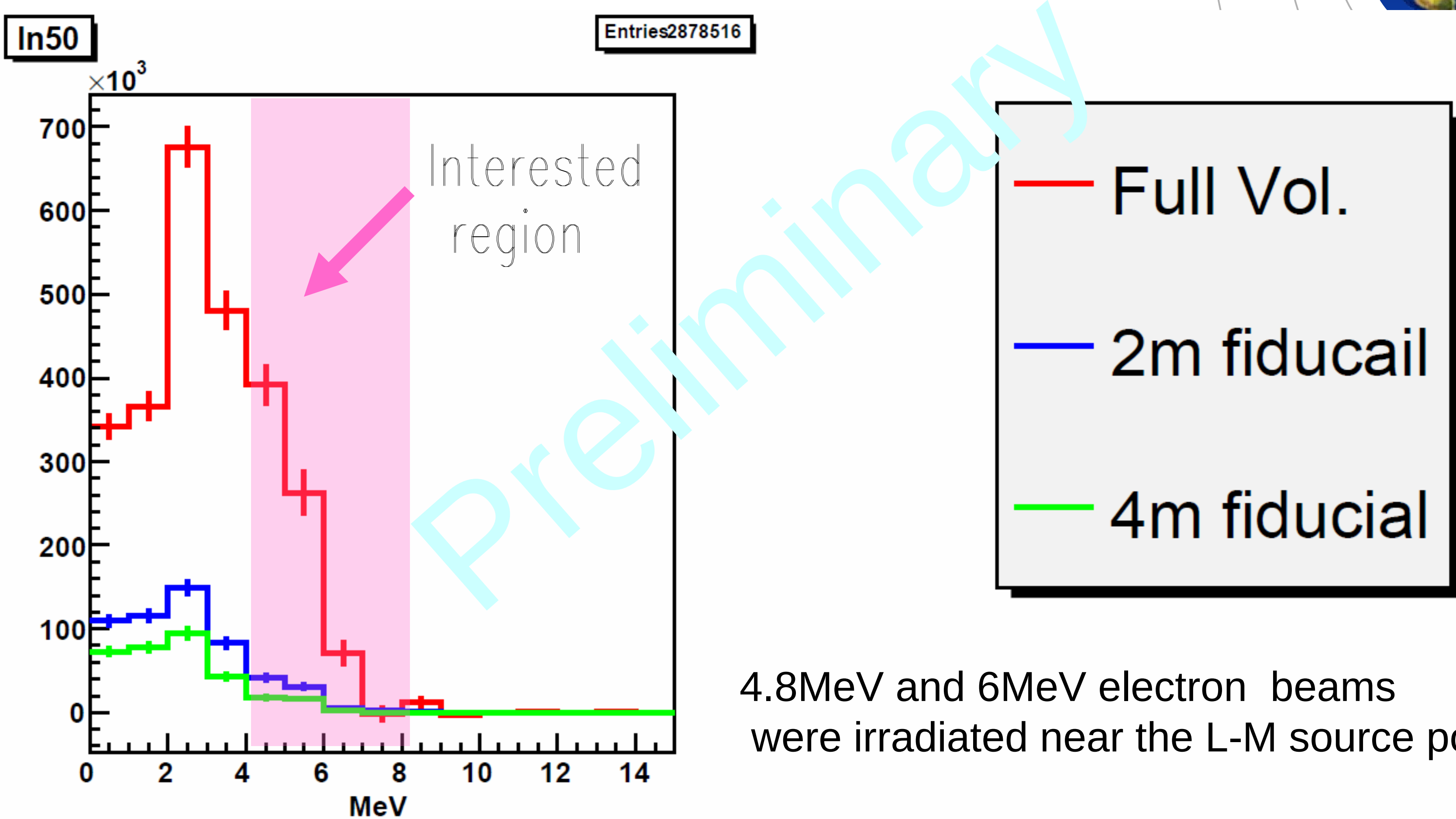
N_{hit} spectrum –Dependence of fiducial volume



BG subtracted L-M spectrum



Preliminary calibrated (by linac) spectrum



4.8MeV and 6MeV electron beams were irradiated near the L-M source positon

- Energy of surviving events seems to be mostly below 4MeV

Summary

- Backgrounds for low energy solar neutrino are being studied.
- Backgrounds originated from Rn might be reduced by upgrading water supplying system.
- We confirmed that radioisotopes (2.6MeV) are also background sources in the water Cherenkov detector by Lantern–Mantle experiment.
- 2m fiducial cut should be sufficient for reject the events emanated from the wall material, however, some events survives in fiducial volume at this stage. (Water transparency, energy resolution, position resolution will be improved!)
- We have got "controlled samples!"
- We can tune the analysis to reduce backgrounds by getting rid of Lantern–Mantle event from fiducial volume.

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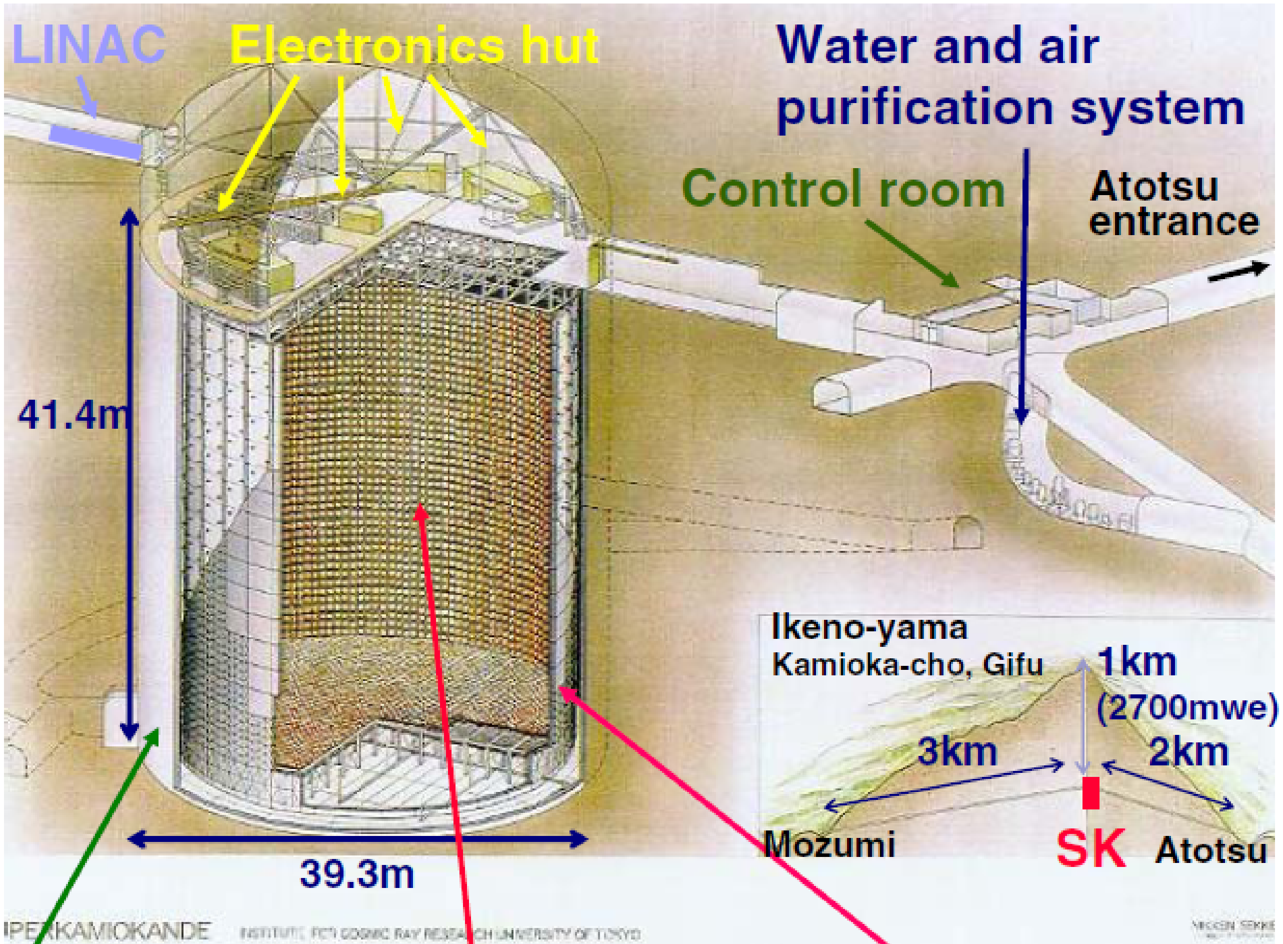
Super-Kamiokande



50000 ton stainless steel tank

Inner Detector (ID)
11129 of 20 inch PMTs
(SK-III)

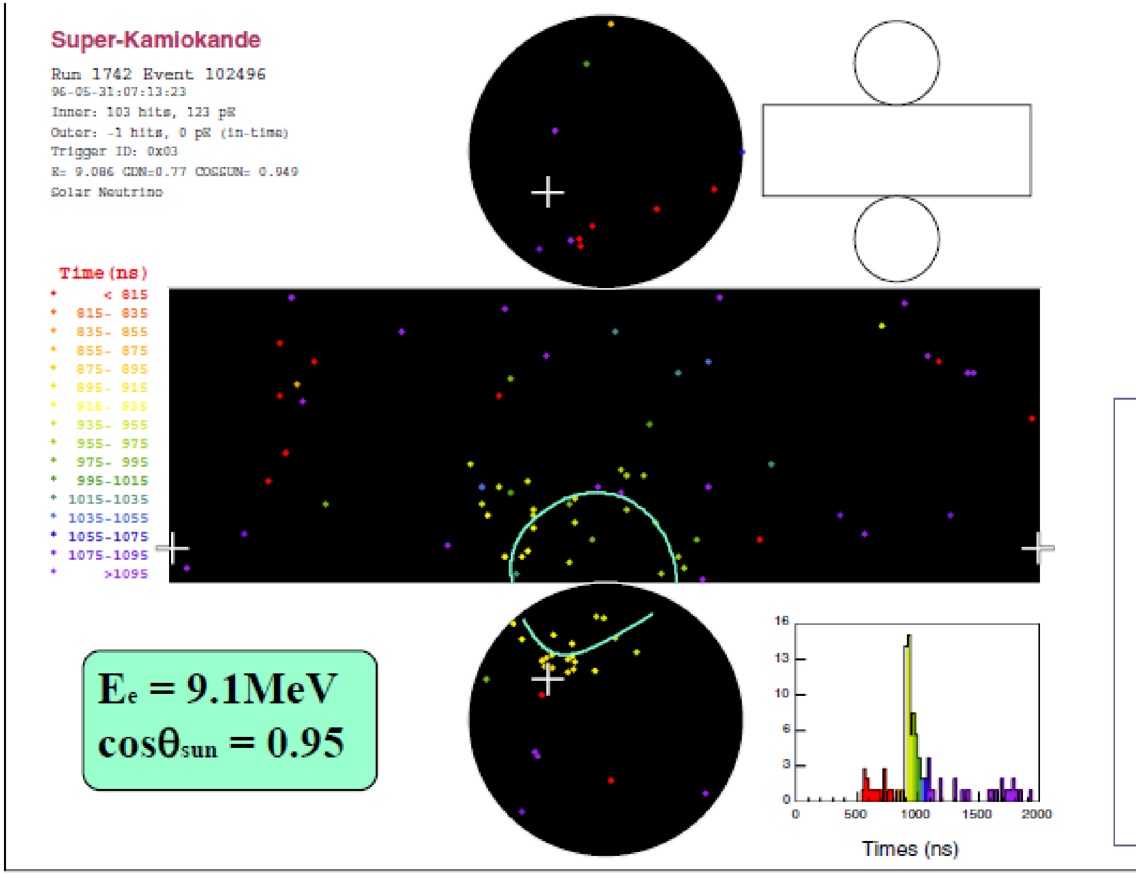
Outer Detector (OD)
1885 of 8 inch PMTs
(SK-III)

- **SK-I (1996~2001)**
- 50000ton water
- ~11200 of 20inch PMTs
- Fid. vol. 22.5kt
- Photo coverage 40%
- Stopped by the accident in Nov. 2001

- **SK-II (2002~2005)**
- ~5200 of 20inch PMTs
- Photo coverage 19%

- **SK-III (Jul. 2006~)**
- 40% coverage
- OD Segmentation

Typical low-energy event at SK



$\nu + e^- \rightarrow \nu + e^-$

(for solar neutrinos)

Sensitive to ν_e, ν_μ, ν_τ

$\sigma(\nu_{\mu(\tau)}e^-) = \sim 0.15 \times \sigma(\nu_e e^-)$

- Timing information
  ➡ vertex position
- Ring pattern
  ➡ direction
- Number of hit PMTs
  ➡ energy

Resolutions (for 10MeV electron)

Energy: 14% Vertex: 87cm Direction: 26°

FULL Volume mean, with obsolete fitter

ance

Abstract

Super-Kamiokande [SK] is a 50000 ton water Cherenkov detector located 1000 meters underground in the Kamioka mine. One of the main tasks of SK is a precise measurement of B8 solar neutrinos.

The lower energy threshold of SK-I (before the accident) had been limited to around 5.0 MeV due to residual radon dissolved in the purified water. After reduction of this Rn contamination through improvements in the SK water purification system, we eventually succeeded in observing the solar neutrino energy spectrum as low as 4.5 MeV near the end of the SK-I data-taking period.

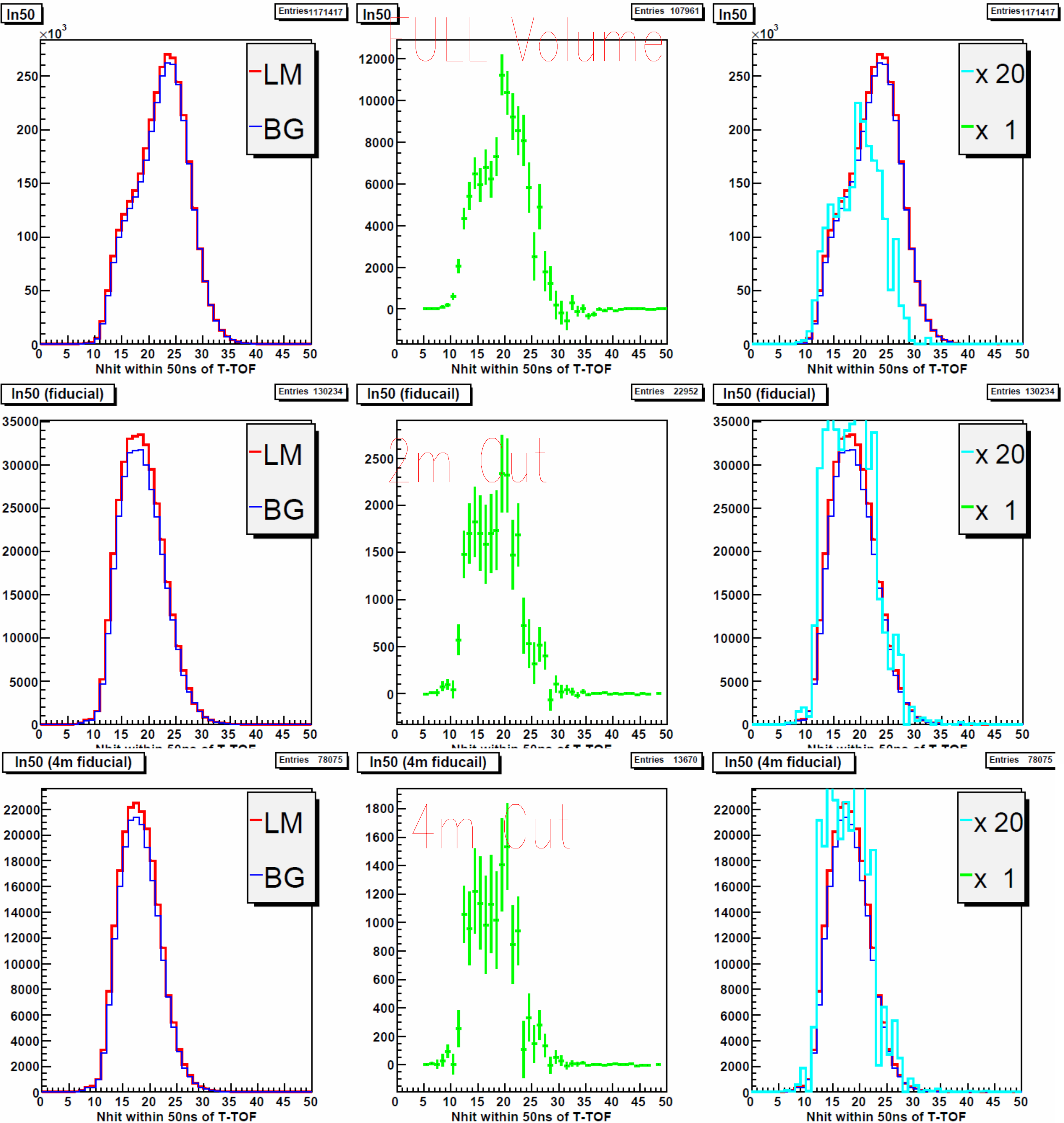
Now, we have reconstructed the SK-III detector with 11129 PMTs. In order to measure the solar neutrino oscillation parameters more precisely and to examine the distortion of the energy spectrum of the 8B solar neutrinos, lowering SK's analysis energy threshold down to about 4.0 MeV is highly desirable.

In order to achieve further lowering, we will need to understand the effects of the remaining radioisotopes in the SK-III detector. These include emanations from newly added detector components such as PMT-enclosing cases designed to prevent shock wave propagation. Therefore, we have measured the radioactivities of the SK detector components using HPGe and simulated their effects in the SK fiducial volume.

In this talk, we will present our current attempts to understand and further reduce these backgrounds and to lower the energy threshold to 4.0 MeV.

Cuts in the 2 nd Reduction Process

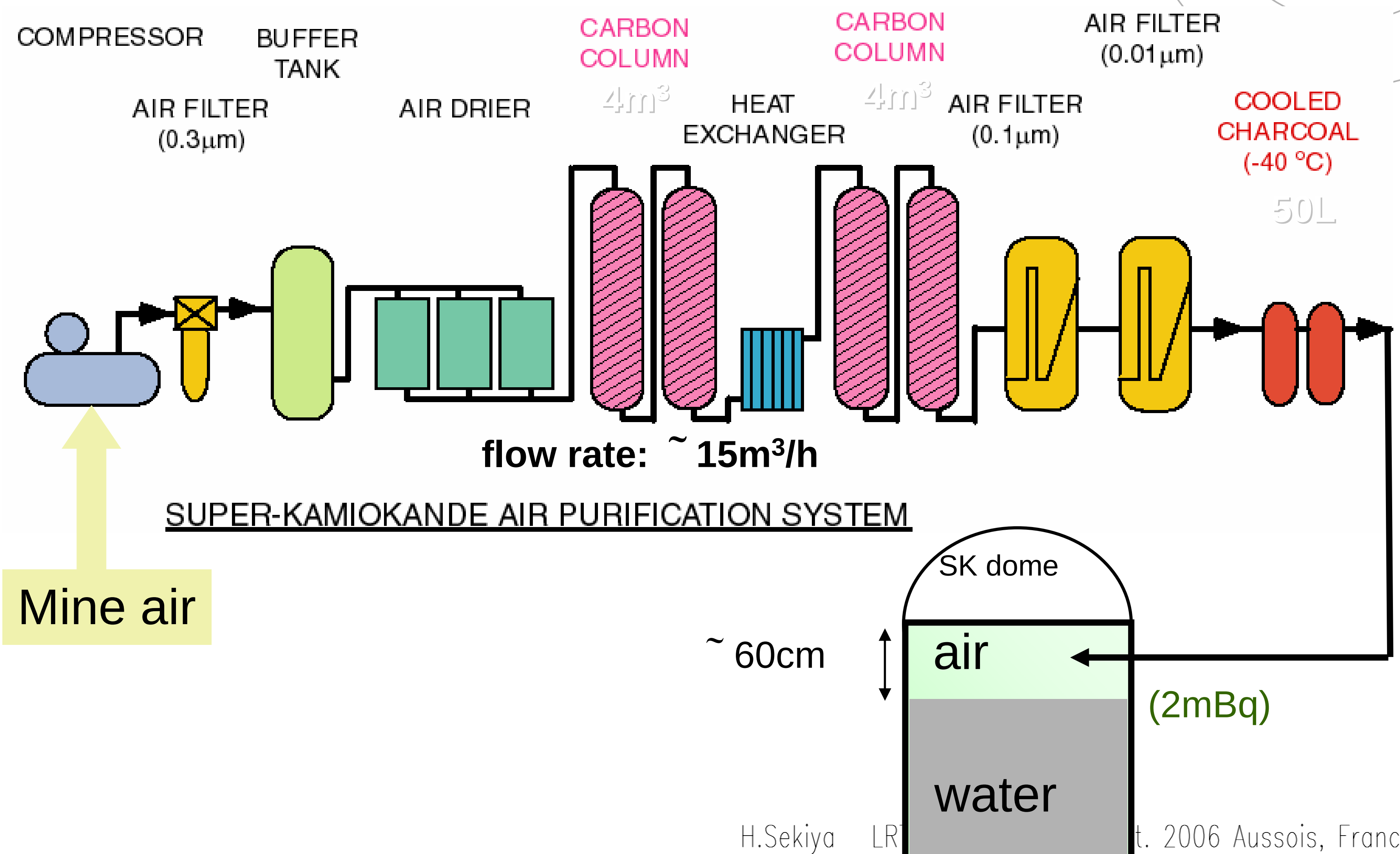
- GRINGO cut (goodness stability cut)
  - evaluation of the difference between the "goodness" of the reconstructed vertex and those at test vertices around the original one to reject noisy hit events
- Patlik cut (pattern likelihood cut)
  - Test of the pattern of the Cerenkov ring image to reject ex. Gamma-induced smeared pattern.
- Gamma cut
  - the reconstructed direction of each event is projected backwards and evaluate the distance from the reconstructed vertex to the ID wall (Energy dependent!)

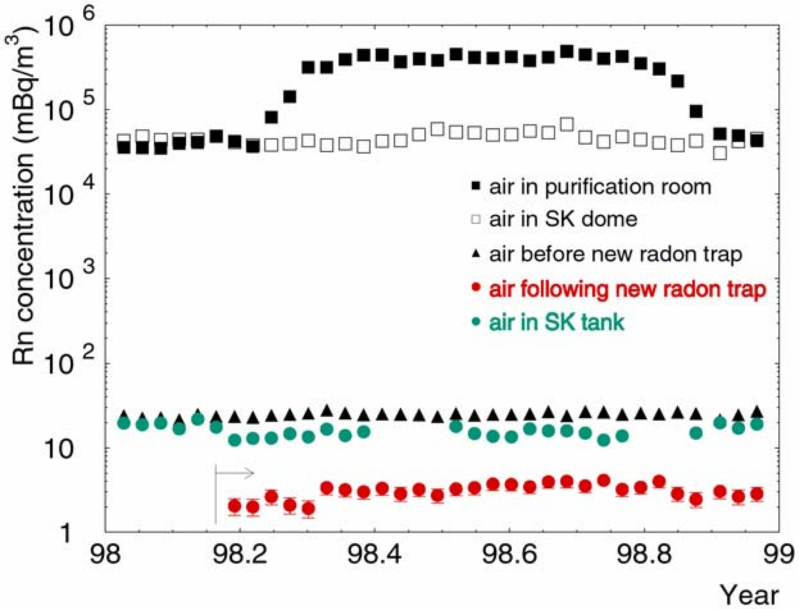


- By scaling the intensity of lantern–mantle (60kBq) to real FRP (100Bq x 11000 PMTs), the total background in 2m and 4m fiducial volume can be explained. But, there is some discrepancy for all volume.

Air purification system

• Remove radon by (cooled) activated charcoal





Radon concentration in

mine air: ~ $1000 Bq/m^3$ (summer)

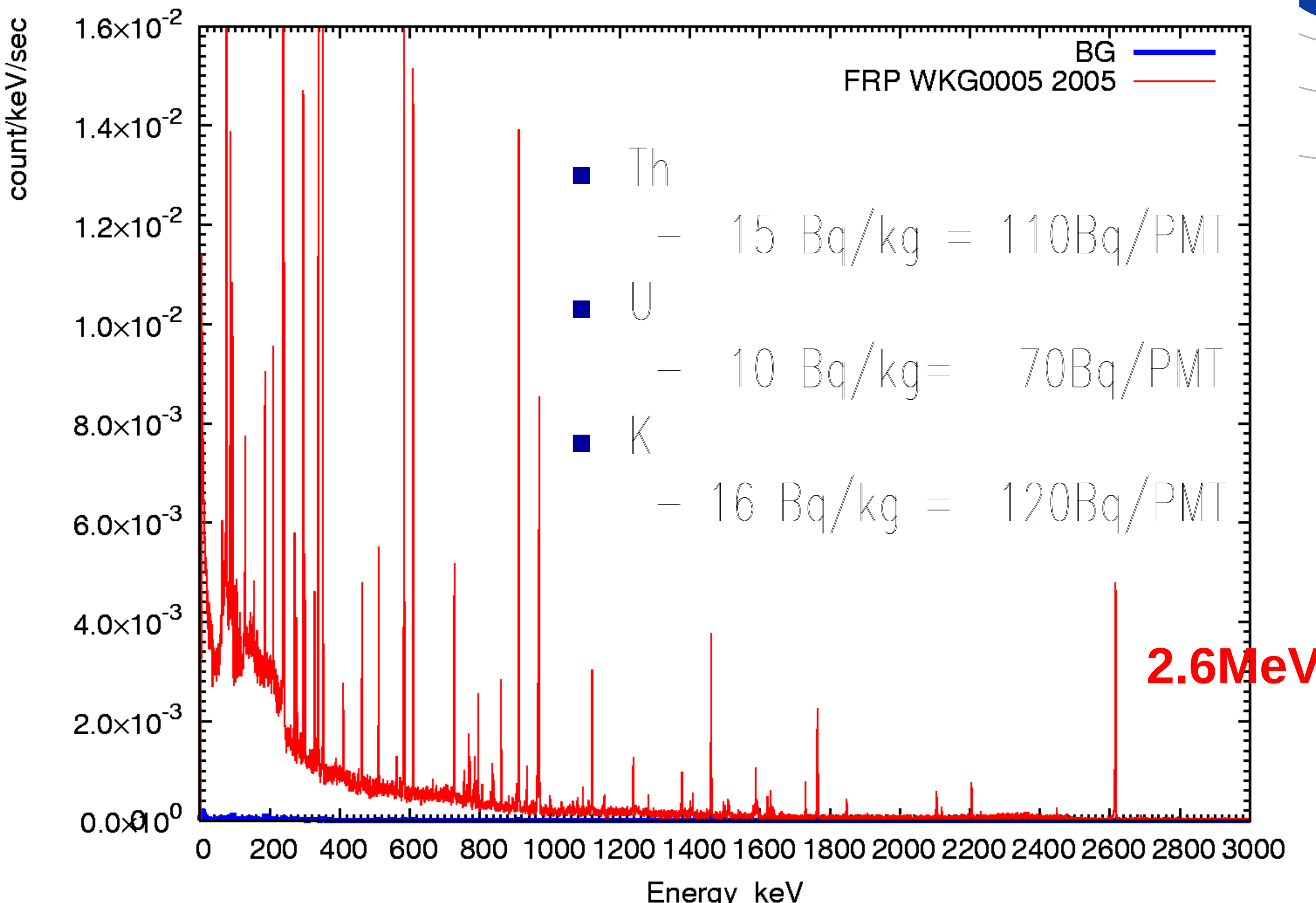
~ $40 Bq/m^3$ (winter)

purified air: **2 ~ $3 mBq/m^3$**

air in SK tank: **10 ~ $20 mBq/m^3$**

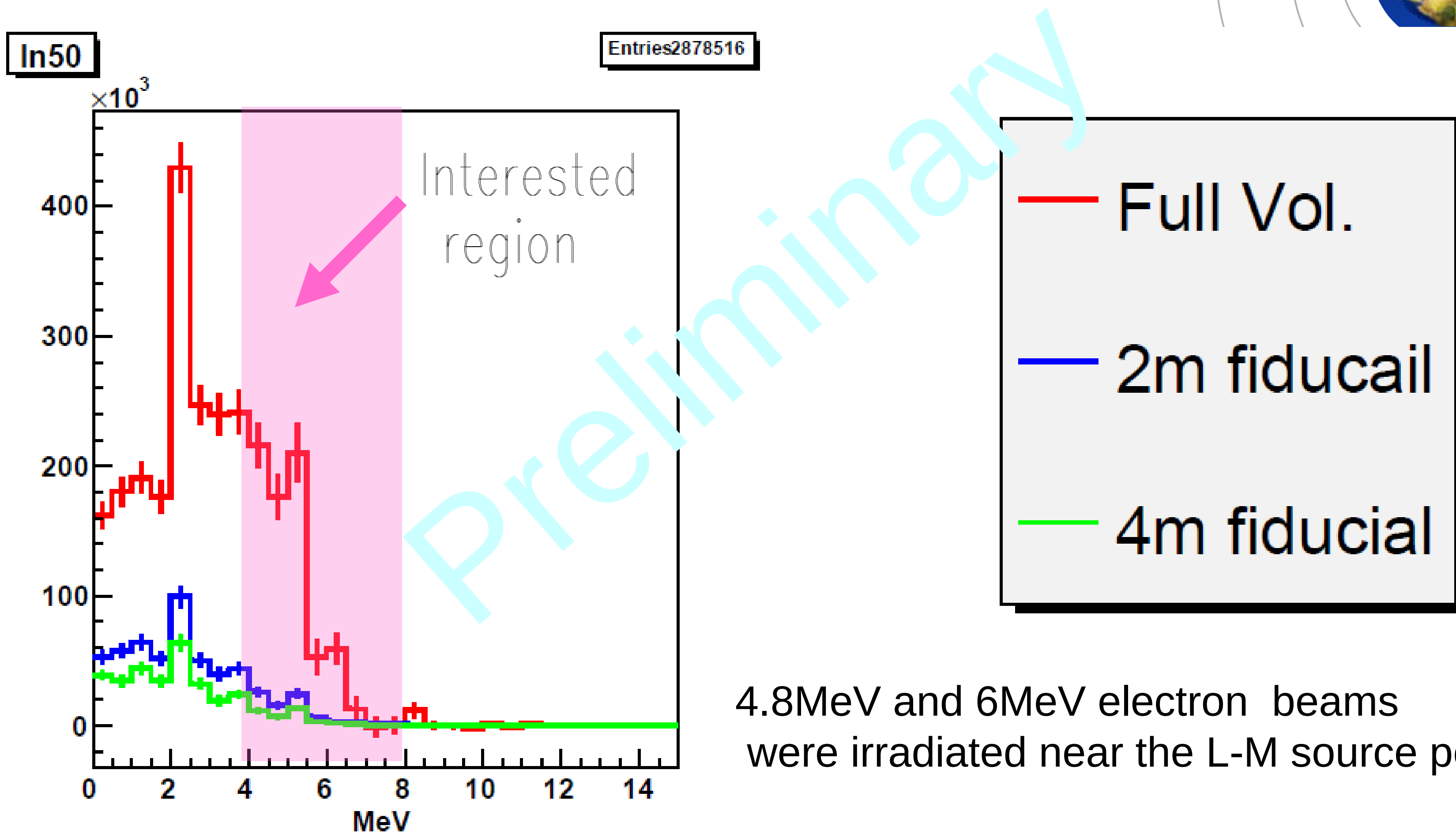
seasonal variation is caused by different wind direction in mine tunnel

Measured Spectrum of the FRP Case



- Th
  - 15 Bq/kg = 110Bq/PMT
- U
  - 10 Bq/kg= 70Bq/PMT
- K
  - 16 Bq/kg = 120Bq/PMT

Preliminary calibrated (by linac) spectrum



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BG Comparison between experiments