XMASS experiment

WIN05

8th June 2005

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University of Tokyo

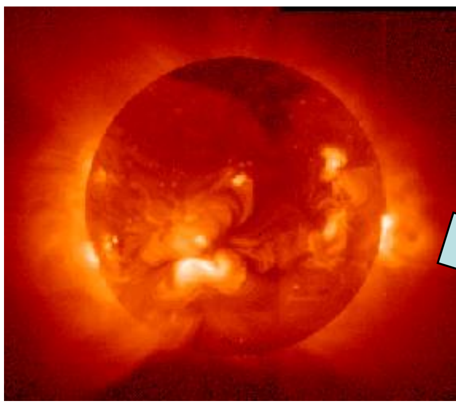
1. Introduction
2. R&D status using prototype detector
3. Summary

1. Introduction

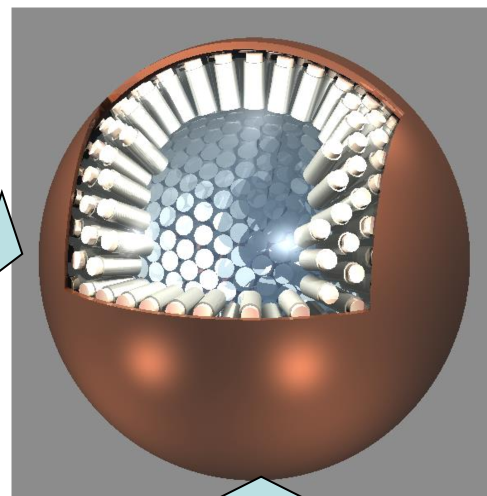
➢ What's XMASS

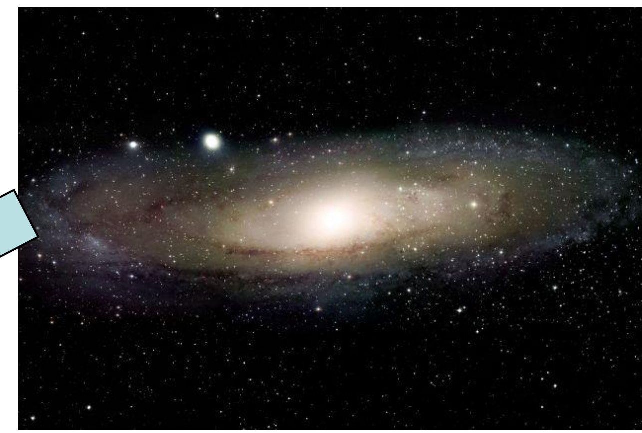
Multi purpose low-background experiment with liq. Xe

- **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**)

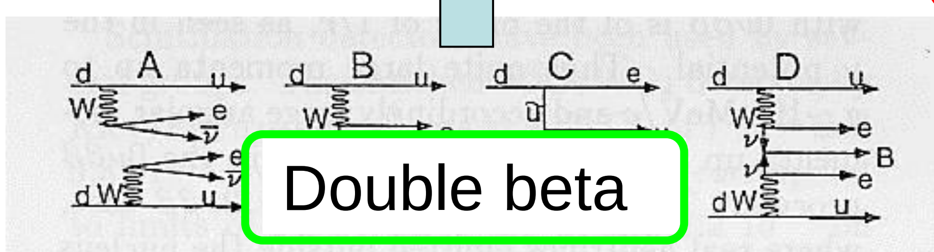


Solar neutrino





Dark matter



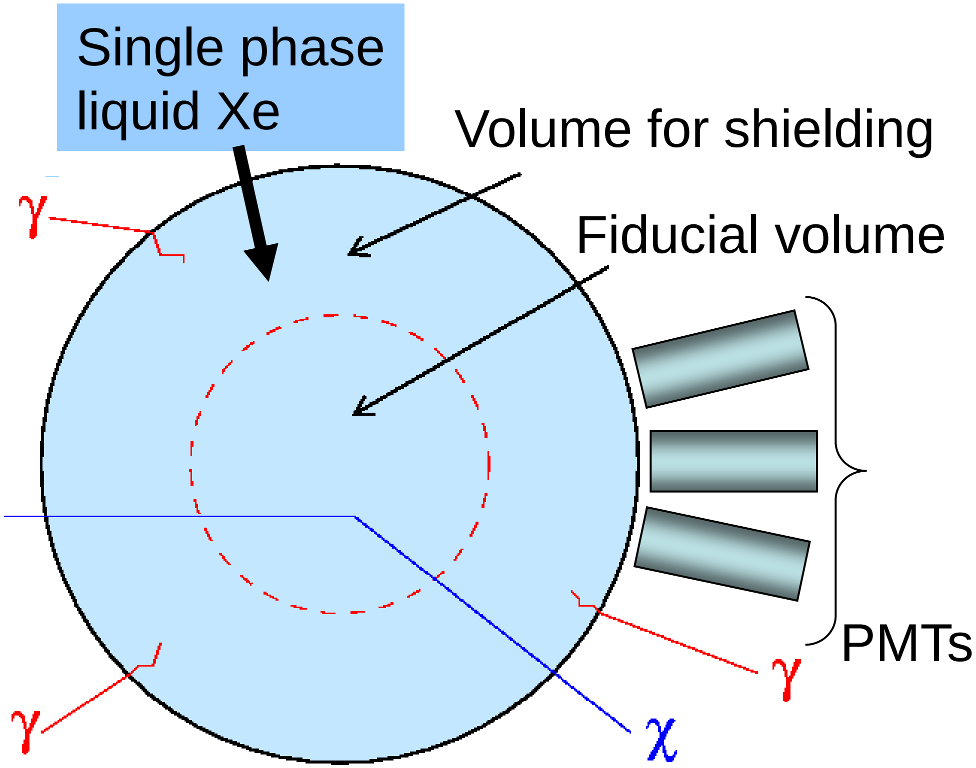
Double beta

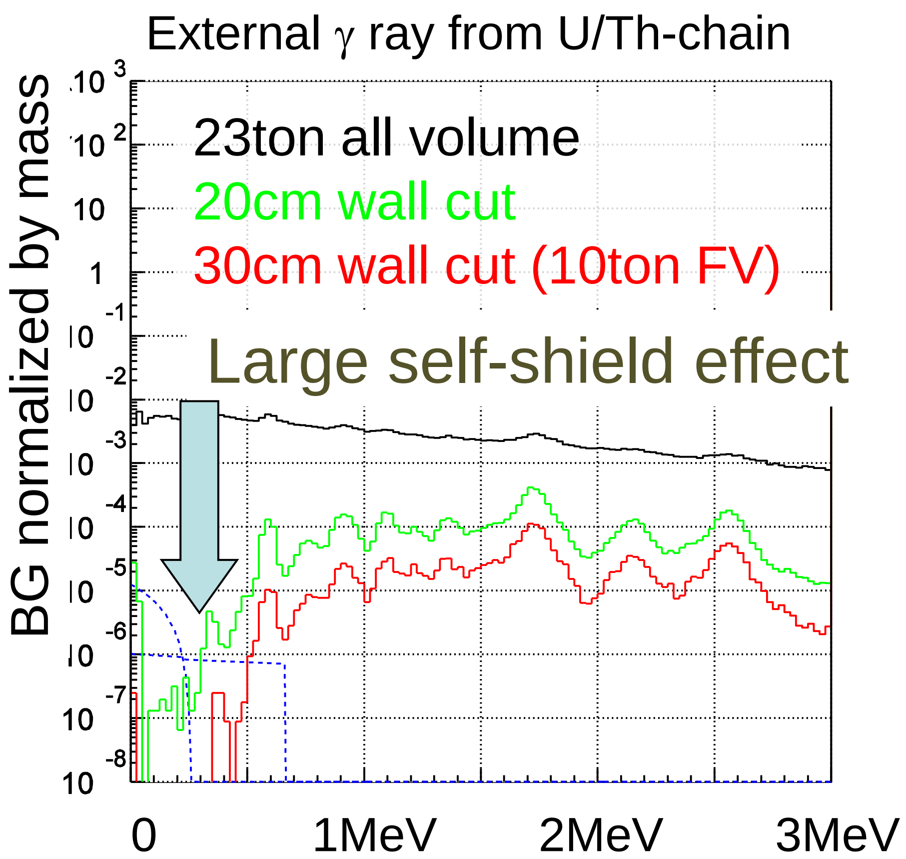
➢ Why liquid xenon

- **Large Z (=54)**
  Self-shielding effect
- **Large photon yield (~42 photons/keV ~ NaI(Tl))**
  Low threshold
- **High density (~3 g/cm^3)**
  Compact detector (10 ton: sphere with diameter of ~2m)
- **Purification** (**distillation**)

- No long life radioactive isotope
- Scintillation wavelength (175 nm, detected directly by PMT)
- Relative high temperature (~165 K)

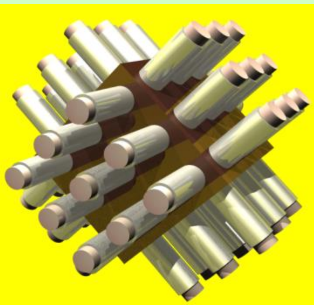
➢ Key idea:
self-shielding effect for low energy events



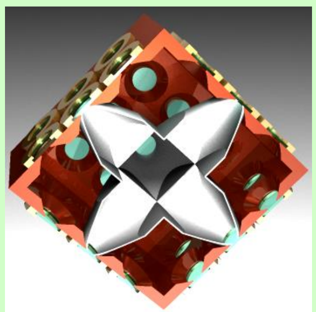


➢ Strategy of the scale-up

100kg Prototype

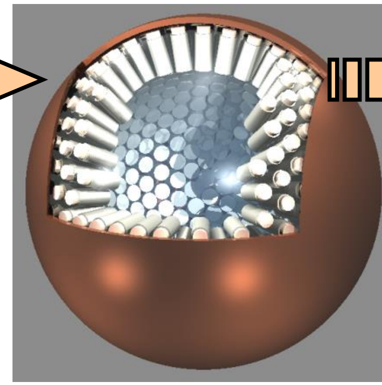


With light guide



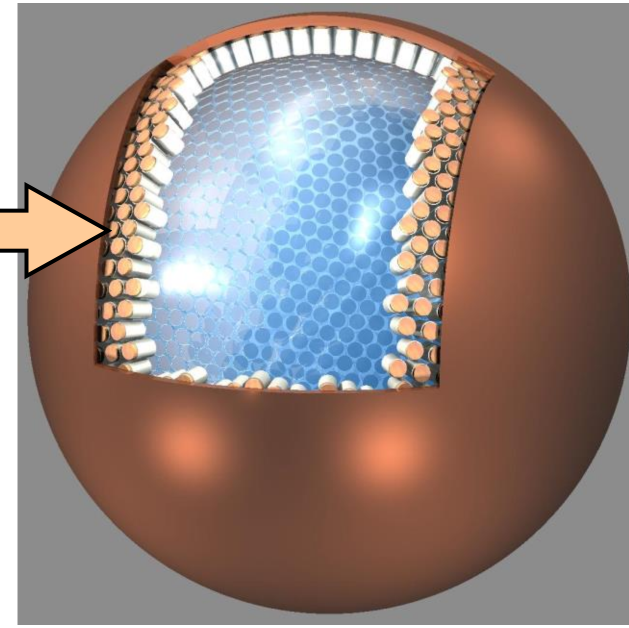
～30cm

800kg detector



～80cm

10 ton detector



～2.5m

R&D

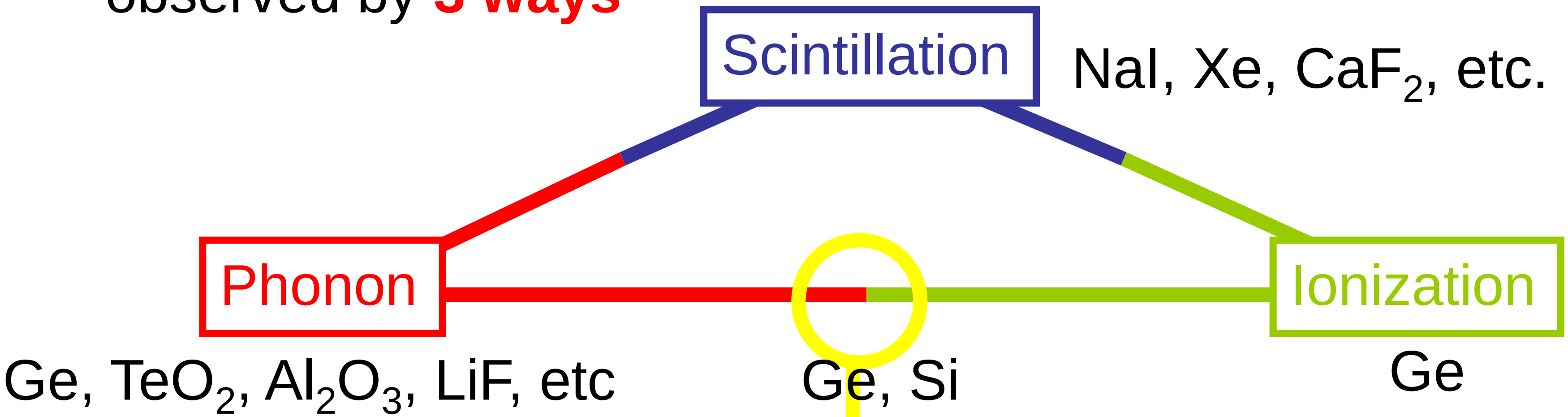
We are now here

Dark matter search

Multipurpose detector
(solar neutrino, ββ …)

Trend of Dark matter (WIMPs) direct searches

- Recoiled nuclei are mainly observed by **3 ways**



- Taking **two type of signals simultaneously** is recent trend

CDMS, EDELWEISS: phonon + ionization

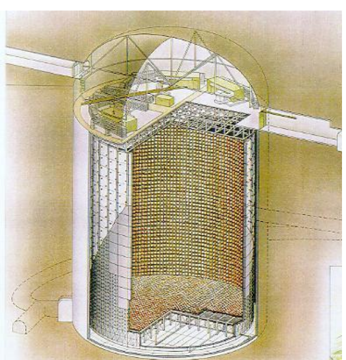
- ◆ γ ray reduction owing to powerful particle ID
- ◆ However, seems to be difficult to realize a large and uniform detector due to complicated technique

Strategy chosen by XMASS

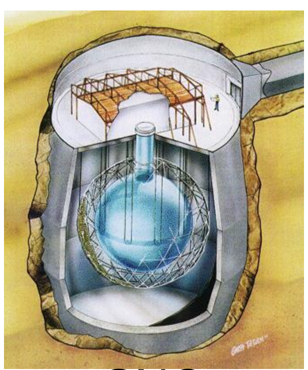
- Make **large mass** and **uniform** detector (with liq. Xe)

  ⇨ Same style as successful experiments of Super-K, SNO, KamLAND, etc.

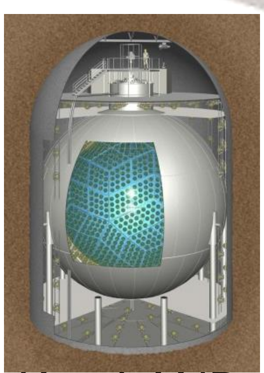
- Reduce γ ray BG by fiducial volume cut (**self shielding**)



Super-K



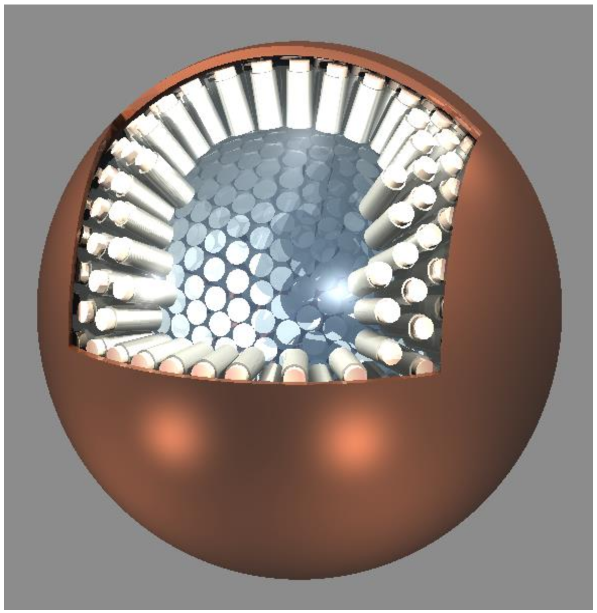
SNO



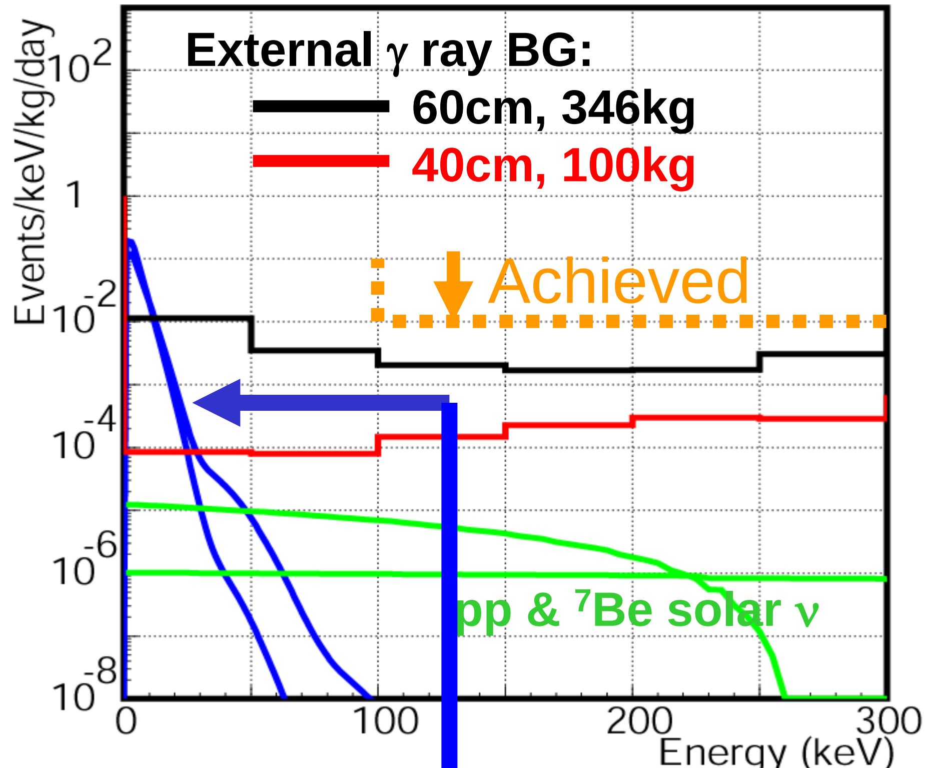
KamLAND

➢ 800 kg detector

Main purpose: **Dark Matter search**



~80cm diameter

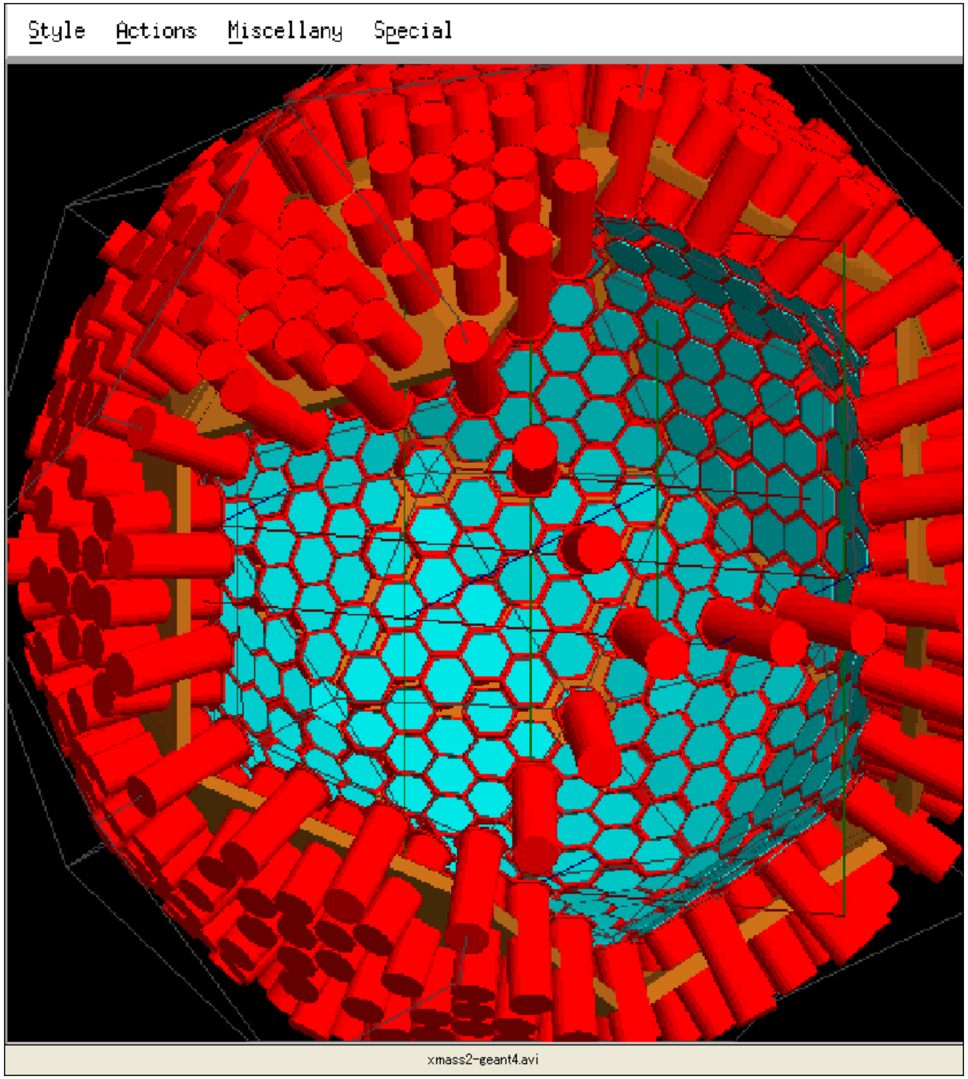


- **~800-2" PMTs** immersed into liq. Xe
- **70%** photo-coverage

⇨ **~5 keVee** threshold

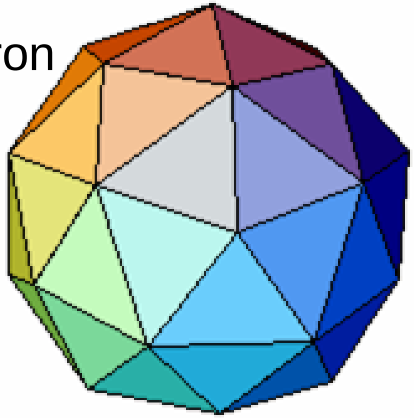
Expected dark matter signal (assuming 10^{-42} cm^2, Q.F.=0.2 50GeV / 100GeV,)

Geometry design



- A tentative design (not final one)

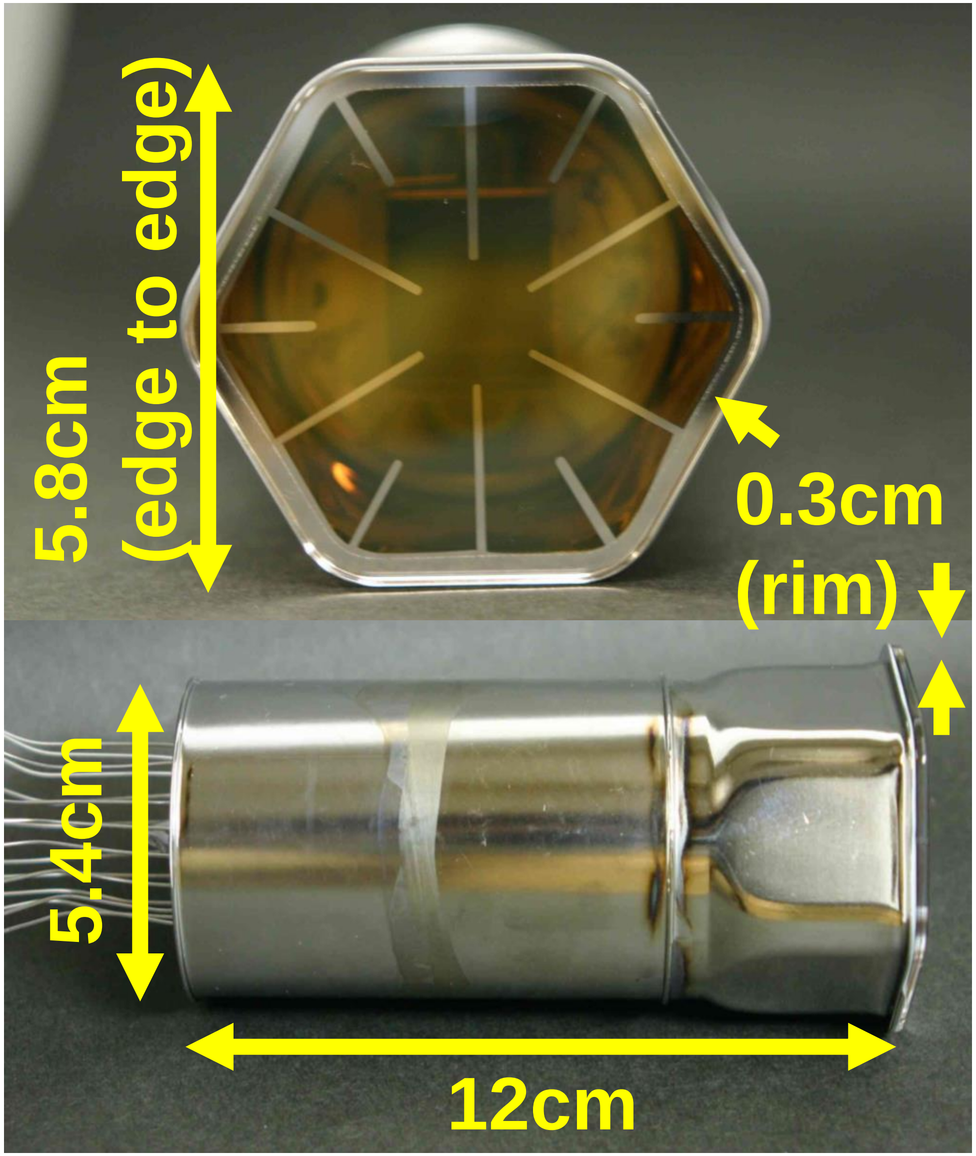
12 pentagons / pentakisdodecahedron



- Total **840** hex **PMTs** immersed into liq. Xe
- **70%** photo-coverage
- Radius to inner face **~43cm**

▲ This geometry has been coded in a Geant 4 based simulator

Hamamatsu R8778MOD(hex)



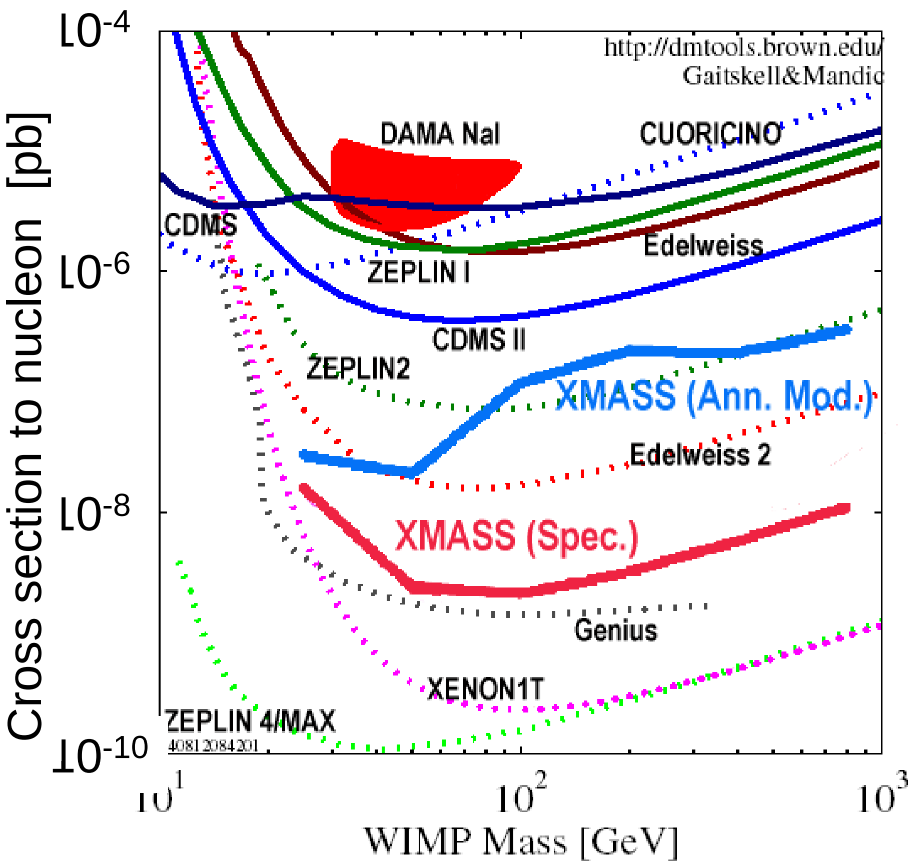
- Hexagonal quartz window
- Effective area: ϕ50mm (min)
- QE <~25 % (target)
- Aiming for 1/10 lower background than R8778

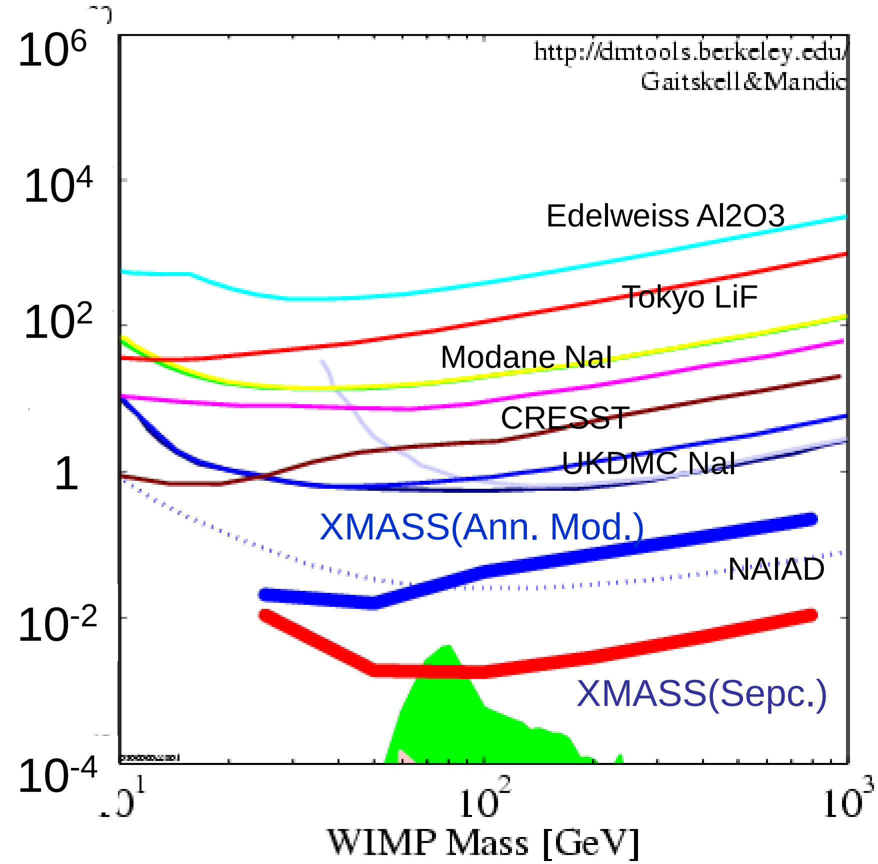
c.f. R8778	
U	$1.8\pm0.2\times10^{-2}$ Bq
Th	$6.9\pm1.3\times10^{-3}$ Bq
^{40}K	$1.4\pm0.2\times10^{-1}$ Bq

- **Prototype has been manufactured already**
- Now, being tested

Expected sensitivities

XMASS FV 0.5 ton year
E_{th} = 5 keVee~25 p.e., 3σ discovery
w/o any pulse shape info.





- Large improvements will be expected

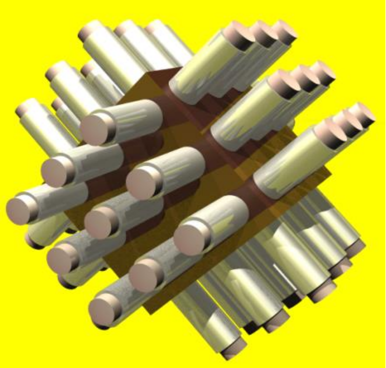
  SI ~ 10-45 cm² = 10-9 pb

  SD~ 10-39 cm² = 10-3 pb

Plots except for XMASS:
http://dmtools.berkeley.edu
Gaitskell & Mandic

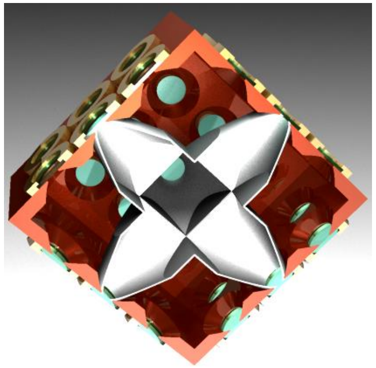
2. R&D status using prototype detector

100kg prototype



~30 cm cube
3 kg fiducial

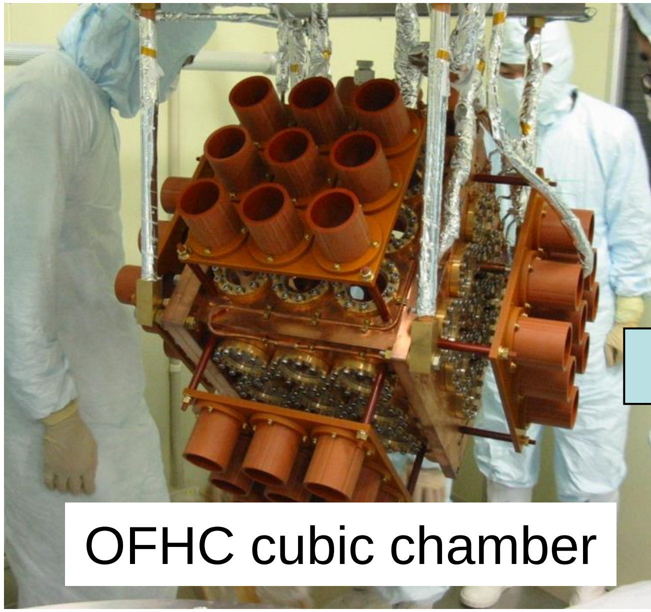
With light guide version



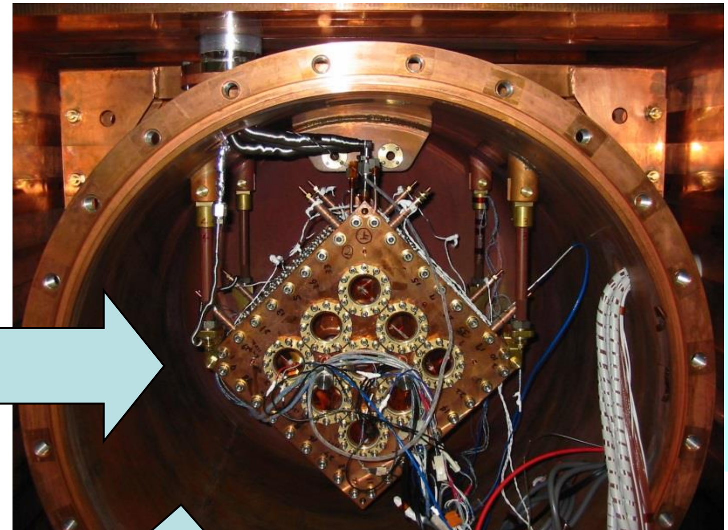
➢ Main purpose

- Confirmation of estimated 800 kg detector performance
  - **Vertex and energy reconstruction** by fitter
  - Miss fitting due to dead angle of the cubic detector ("**wall effect**", will be explained later) **can be removed** with light guide
  - **Self shielding power**
- BG study
  - Understanding of **the source of BG**
  - Measuring **photon yield and its attenuation length**

➢ 100 kg prototype detector

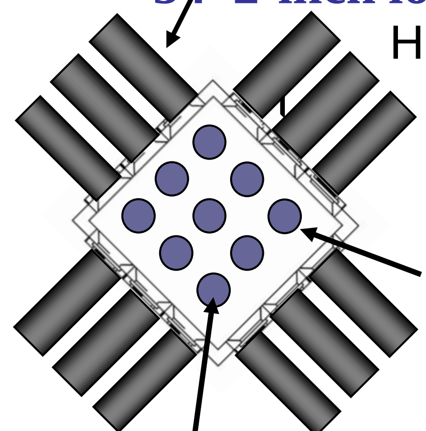


OFHC cubic chamber

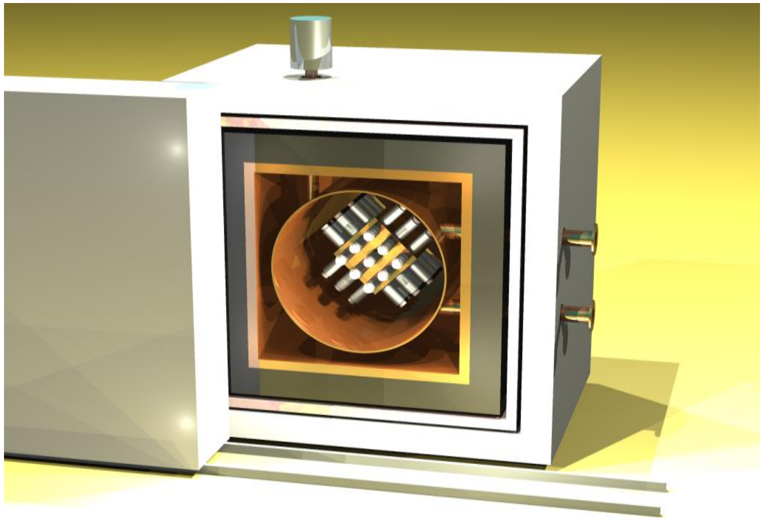


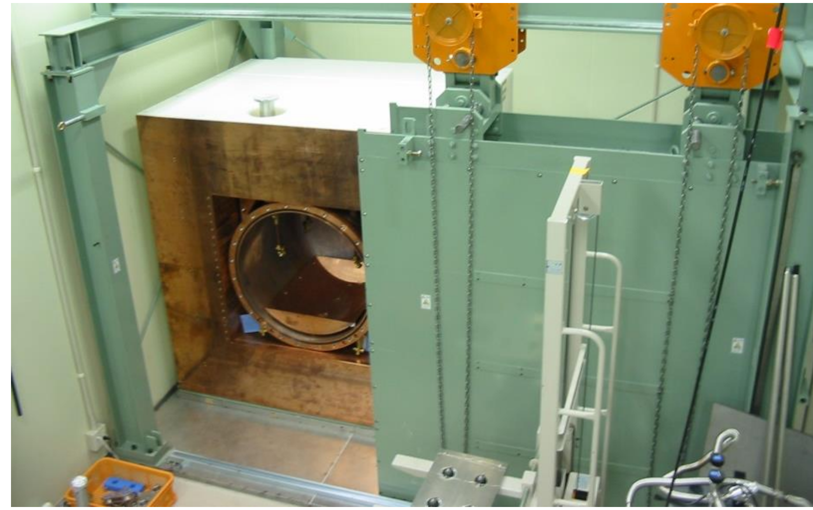
In the Kamioka Mine (near the Super-K) 2,700 m.w.e.

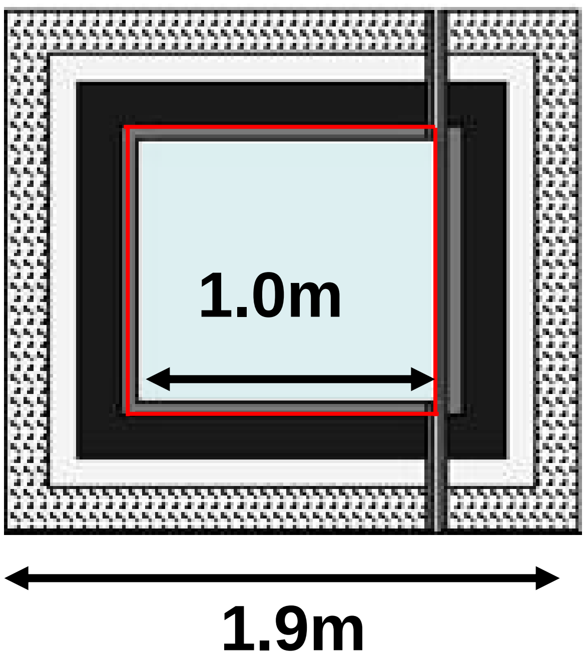
Gamma ray shield



4π shield with door







material	thickness
Polyethylene	15cm
Boron	5cm
Lead	15cm
EVOH sheets	30μm
OF Cupper	5cm

Rn free air (~3mBq/m^3)

Progress so far

- 1st run (Dec. 2003)
  - Confirmed **performances of vertex & energy reconstruction**
  - Confirmed **self shielding power** for external γ rays
  - Measured **the internal background** concentration
- 2nd run (Aug. 2004)
  - Succeeded to **reduce Kr from Xe** by distillation
  - Photo electron yield is increased
  - Measured Rn concentration inside the shield
- 3rd run (Mar. 2005) with light guide
  - Confirmed **the miss fitting (only for the prototype detector) was removed**
  - Now, BG data is under analysis

➢ Vertex and energy reconstruction

Reconstruction is performed by
PMT charge pattern (not timing)

Calculate PMT acceptances from various vertices by Monte Carlo.
Vtx.: compare acceptance map F(x,y,z,i)
Ene.: calc. from obs. p.e. & total accept.

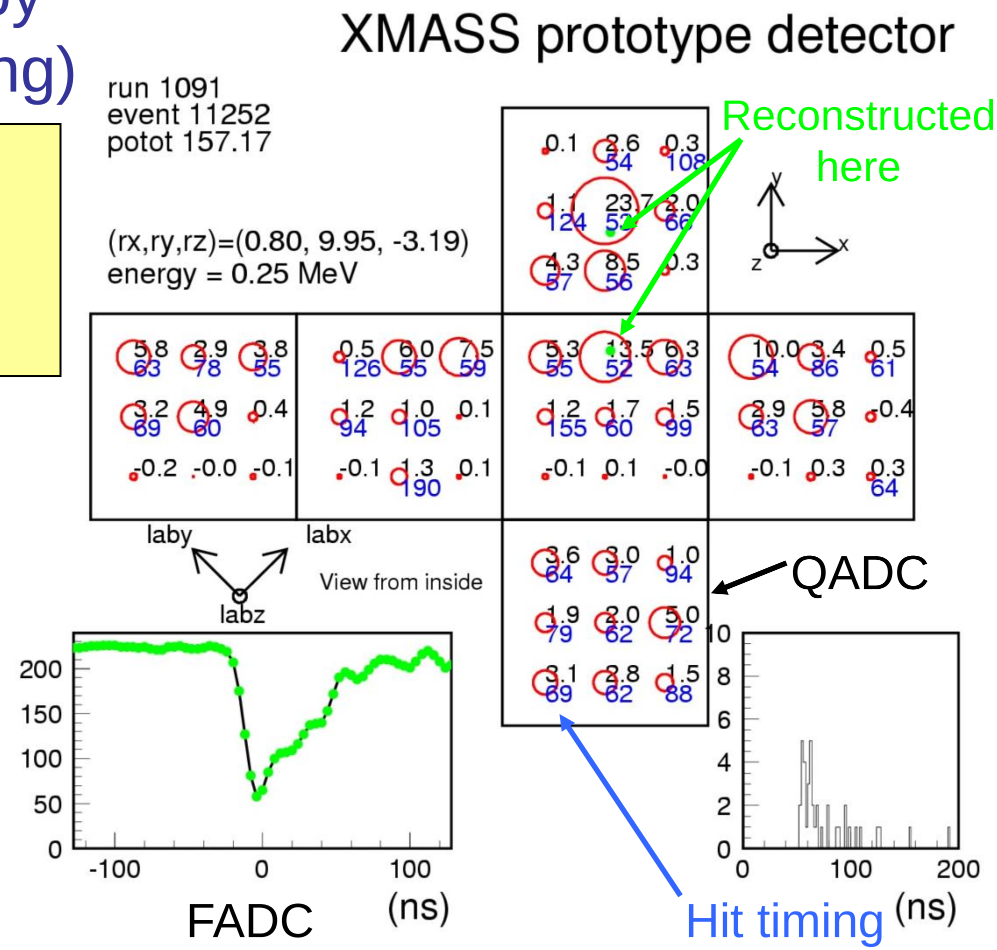
$$\mathrm{Log}(L) = \sum_{PMT} \mathrm{Log}\left(\frac{\exp(-\mu)\mu^n}{n!}\right)$$

L: likelihood

$$\mu : \frac{\mathrm{F}(x,y,z,i)}{\Sigma\, \mathrm{F}(x,y,z,i)} \text{ x total p.e.}$$

n: observed number of p.e.

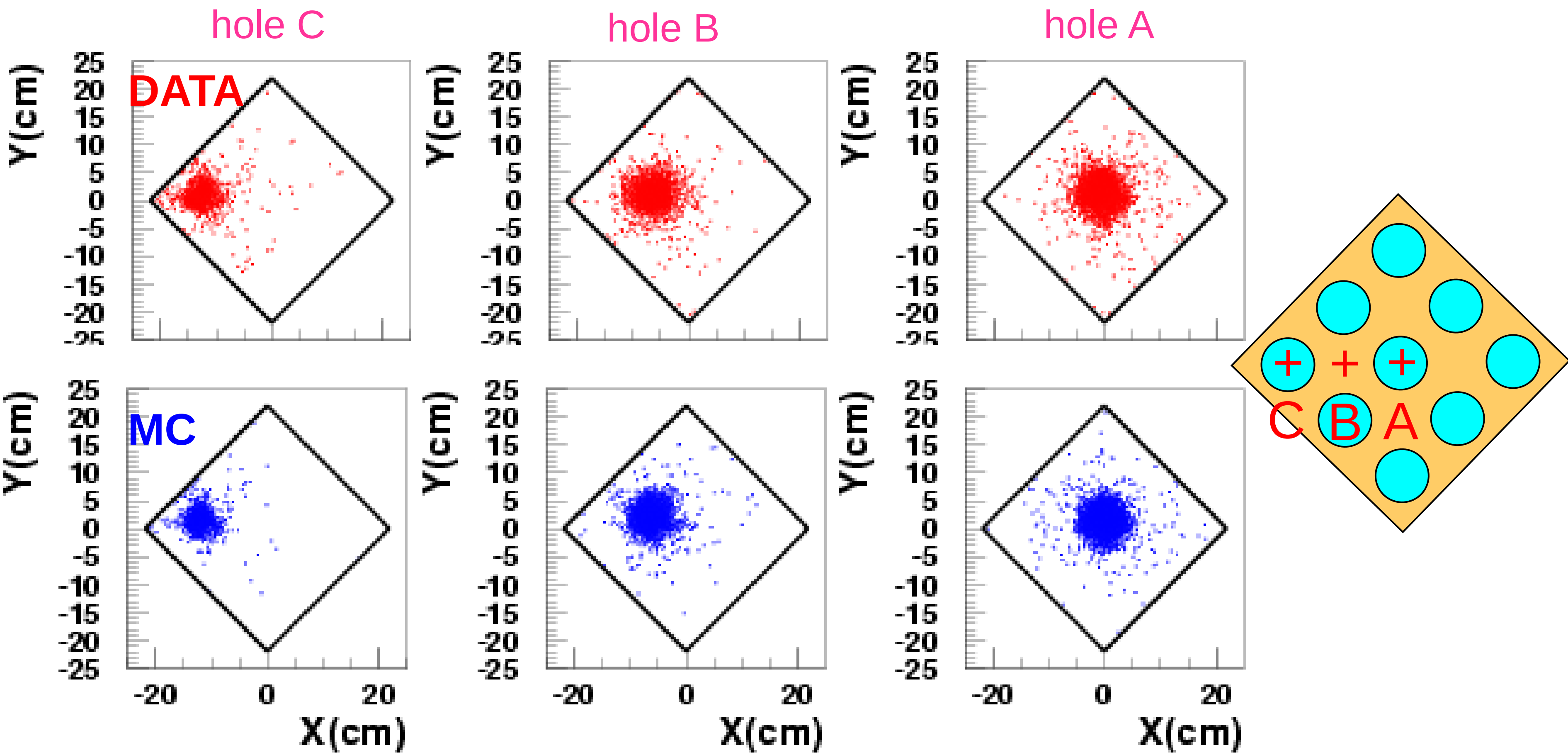
F(x,y,z,i): acceptance for i-th PMT (MC)
VUV photon characteristics:
L_{emit}=42ph/keV
τ_{abs}=100cm
τ_{scat}=30cm



=== Background event sample ===
QADC, FADC, and hit timing information are available for analysis

1. Performance of the vertex reconstruction

Collimated γ ray source run from 3 holes (^{137}Cs, 662keV)

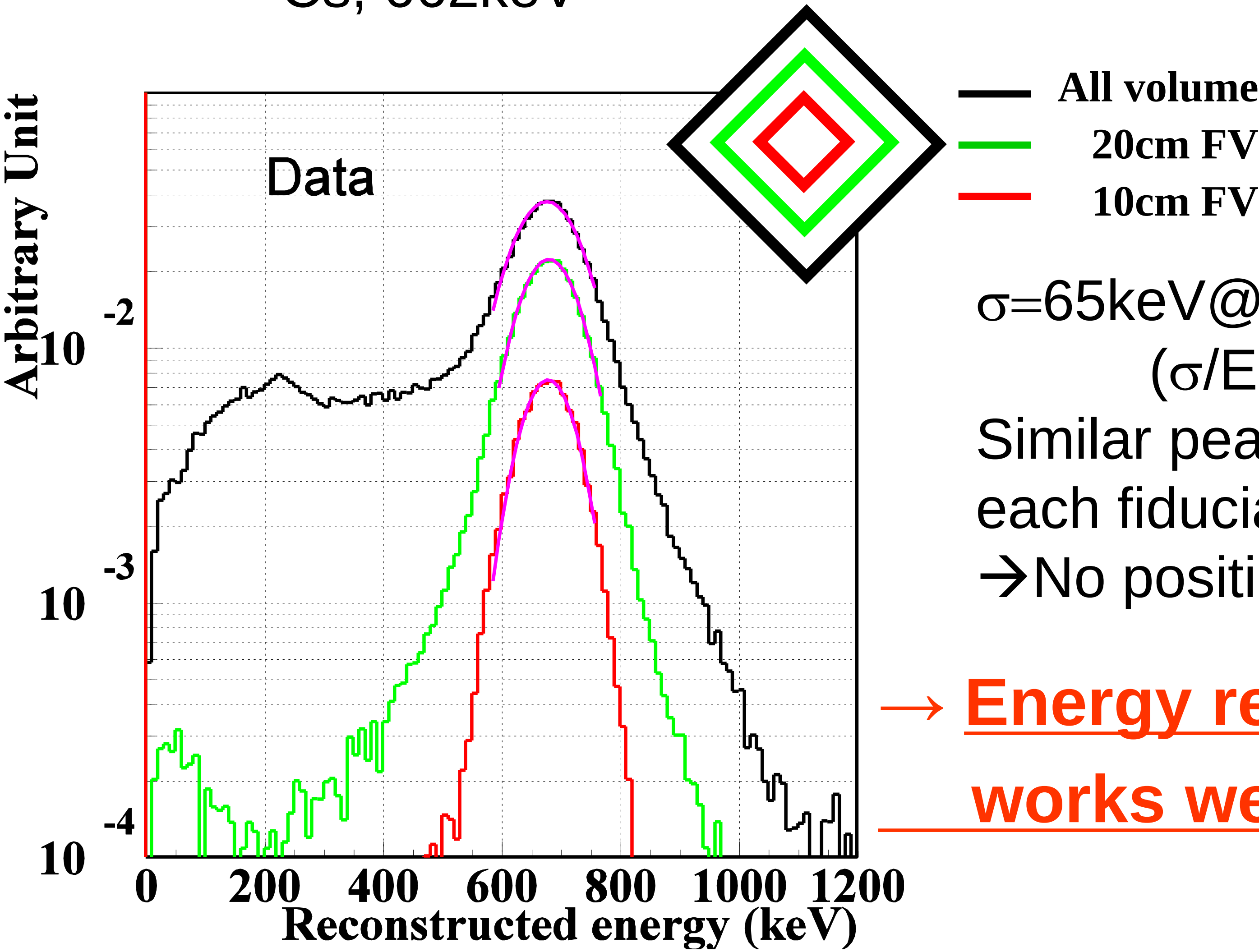


→ **Vertex reconstruction works well**

2. Performance of the energy reconstruction

Collimated γ ray source run from center hole

^{137}Cs, 662keV



σ=65keV@peak

(σ/E ~ 10%)

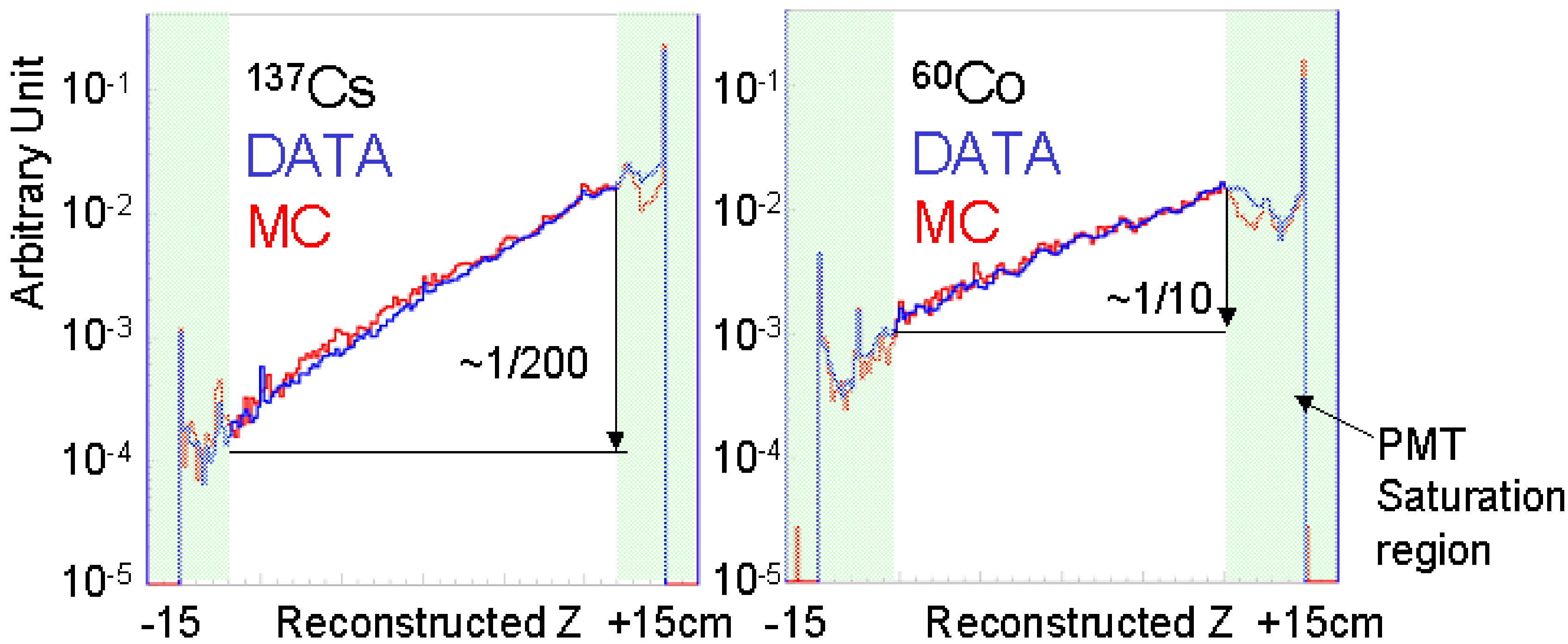
Similar peak position in each fiducial.

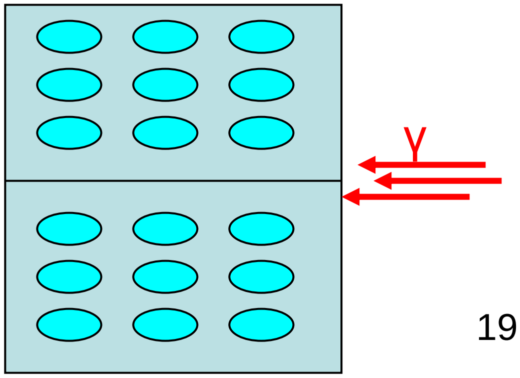
→No position bias

→ **Energy reconstruction works well**

➢ Demonstration of self shielding effect

z position distribution of the collimated γ ray source run



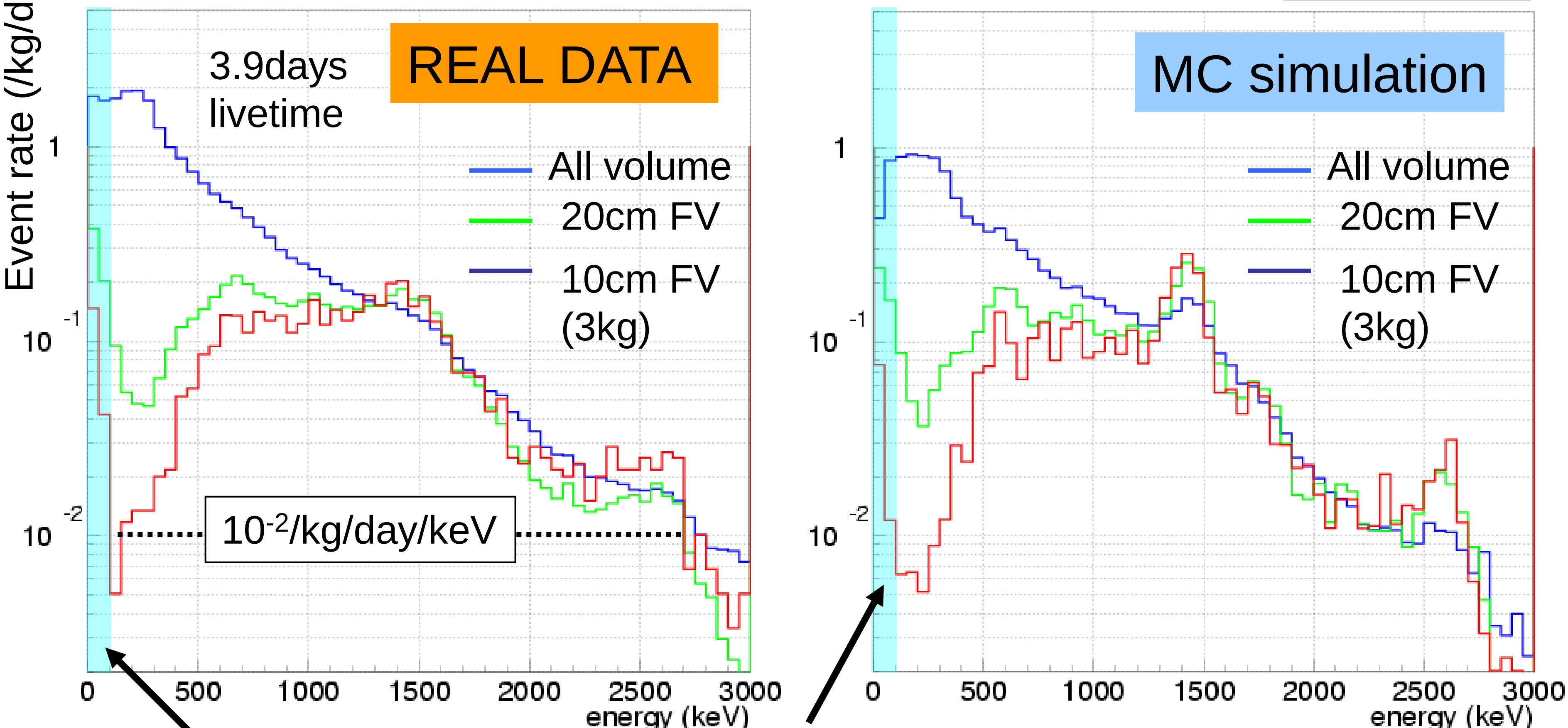


→ **<u>Data and MC agree well</u>**

Shelf shielding for real data and MC

Aug. 04 run
preliminary

~1.6Hz, 4 fold, triggered by ~0.4p.e.



Miss-reconstruction due to dead-angle region from PMTs.

- **Good agreement** (< factor 2)
- **Self shielding effect** can be seen clearly.
- **Very low background** (10^{-2} /kg/day/keV@100-300 keV)

➢ Internal backgrounds in liq. Xe were measured

Main sources in liq. Xe are **Kr**, **U-chain** and **Th-chain**

- **Kr** = **3.3±1.1 ppt** (by mass spectrometer)

  → Achieved by distillation

- **U-chain** = **$(33\pm7)\times10^{-14}$ g/g** (by prototype detector)

  Delayed coincidence search (radiation equilibrium assumed)

  $$^{214}\mathrm{Bi} \xrightarrow[\beta\ (Q=3.3\mathrm{MeV})]{} {}^{214}\mathrm{Po} \xrightarrow[\alpha\ (7.7\mathrm{MeV})]{} {}^{210}\mathrm{Pb}$$

  $\tau_{1/2}=164\mu s$

- **Th-chain** **< 23×10^{-14} g/g(90%CL)** (by prototype detector)

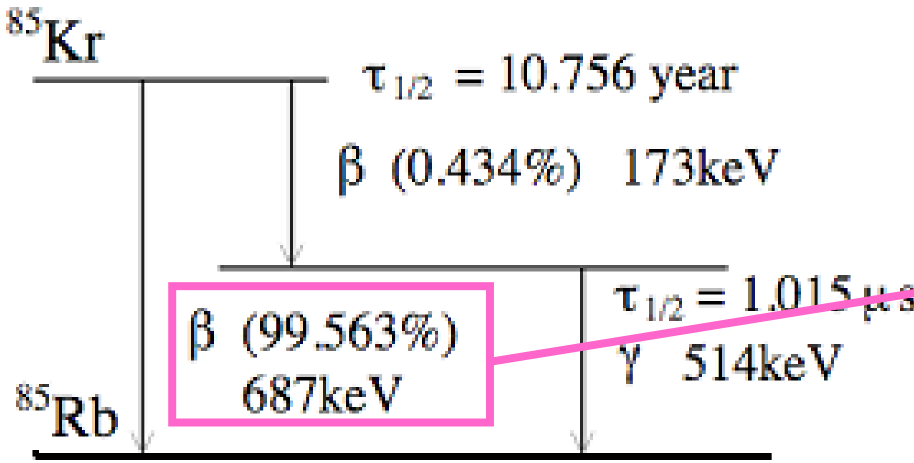
  Delayed coincidence search (radiation equilibrium assumed)

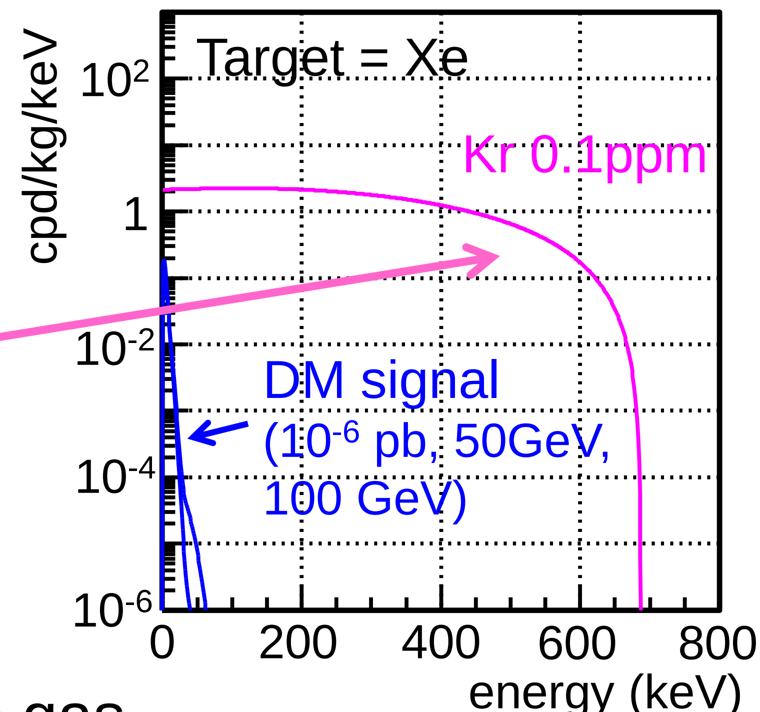
  $$^{212}\mathrm{Bi} \xrightarrow[\beta\ (Q=2.3\mathrm{MeV})]{} {}^{212}\mathrm{Po} \xrightarrow[\alpha\ (8.8\mathrm{MeV})]{} {}^{208}\mathrm{Po}$$

  $\tau_{1/2}=299\mathrm{ns}$

Kr concentration in Xe

- **^{85}Kr** makes BG in low enegy region





- Kr can easily mix with Xe
  because both Kr and Xe are rare gas

- Commercial Xe contains a few ppb Kr

Xe purification system

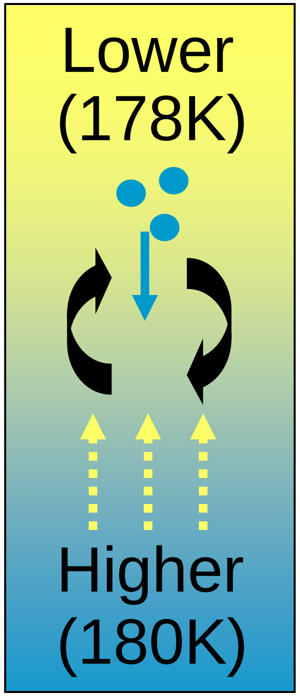
- XMASS succeeds to reduce Kr concentration in Xe from ~3[ppb] to 3.3(±1.1)[ppt] with one cycle (~1/1000)

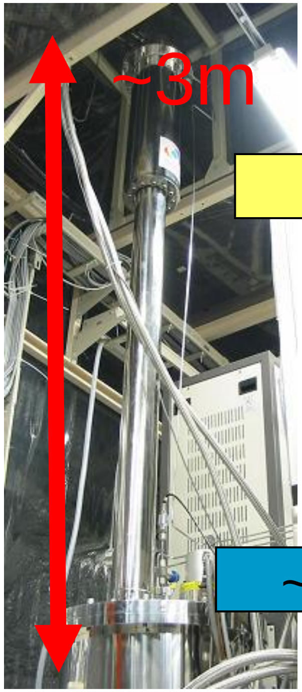
  - Processing speed : 0.6 kg / hour
  - Design factor : 1/1000 Kr / 1 pass
  - Purified Xe : Off gas = 99:1

	Boiling point (@2 atm)
Xe	178.1K
Kr	129.4K

Raw Xe:
~3 ppb Kr

Operation@2atm





~1%

Off gas Xe:
330±100 ppb Kr
(measured)

~99%

Purified Xe:
3.3±1.1 ppt Kr
(measured)
(preliminary)

Summary of BG measurement

Now (prototype detector) → **Goal** (800kg detector)

- γ ray BG ~ 10^{-2} cpd/kg/keV — 1/100 → 10^{-4} cpd/kg/keV
  → Increase volume for self shielding
  → Decrease radioactive impurities in PMTs (~1/10)

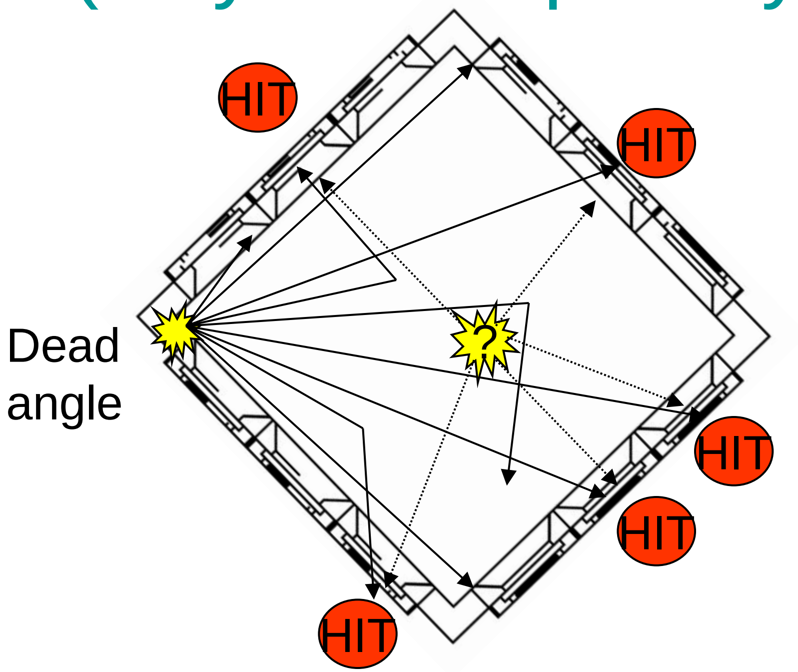
- $^{238}U = (33 \pm 7) \times 10^{-14}$ g/g — 1/33 → 1×10^{-14} g/g
  → Remove by filter

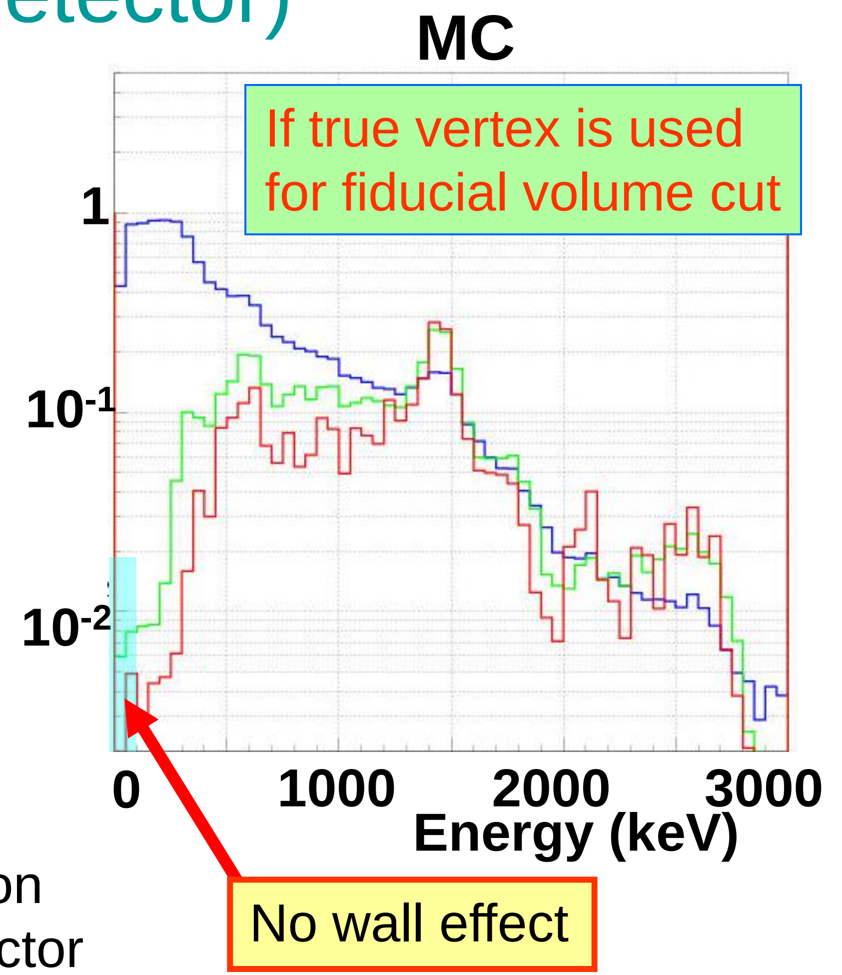
- $^{232}Th < 23 \times 10^{-14}$ g/g (90% C.L.) — 1/12 → 2×10^{-14} g/g
  → Remove by filter (Only upper limit)

- Kr = 3.3 ± 1.1 ppt — 1/3 → 1 ppt
  → Achieve by 2 purification pass

Very near to the target level!

➢ Remaining problem: wall effect (only for the prototype detector)



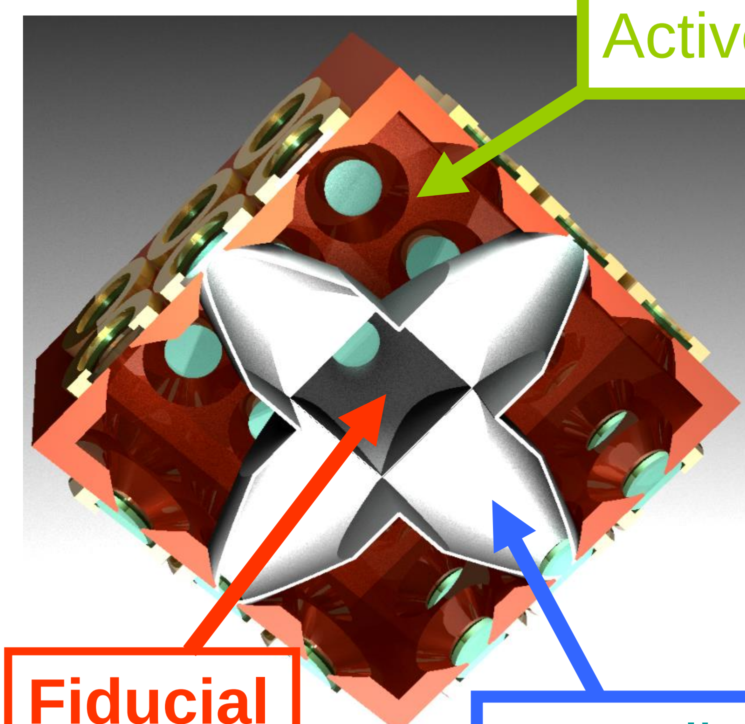


- Scintillation lights at the dead angle from PMTs give quite uniform 1 p.e. signal for PMTs, and this cause miss reconstruction as if the vertex is around the center of detector

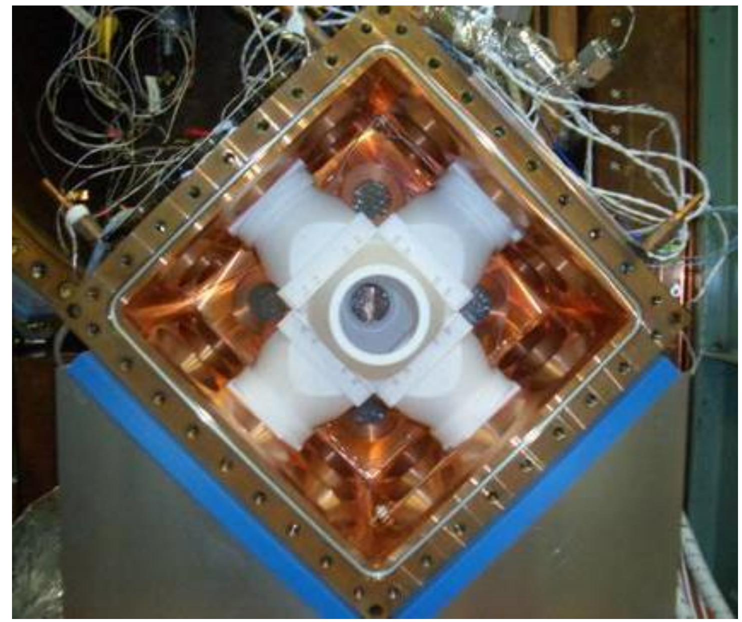
⇨ This effect does not occur with the sphere shape 800 kg detector

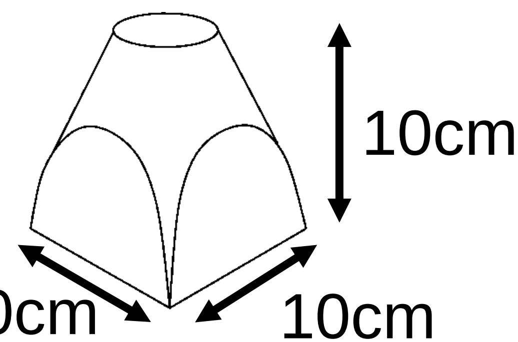
➢ Prototype detector with light guide

Purpose: **remove the wall effect and understand the source of BG in the DM region**



10X10X10cm^3
(~3 kg Xe)





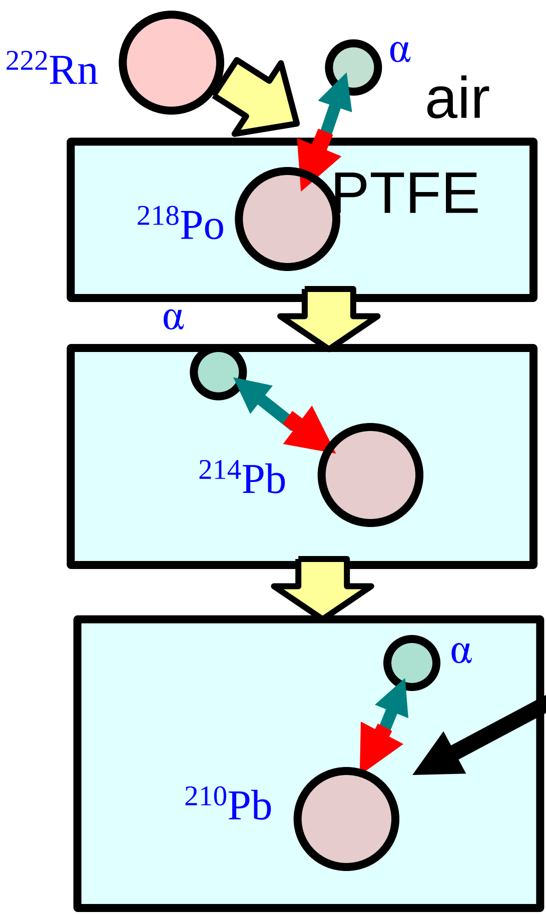
6 pieces

Light guide setup

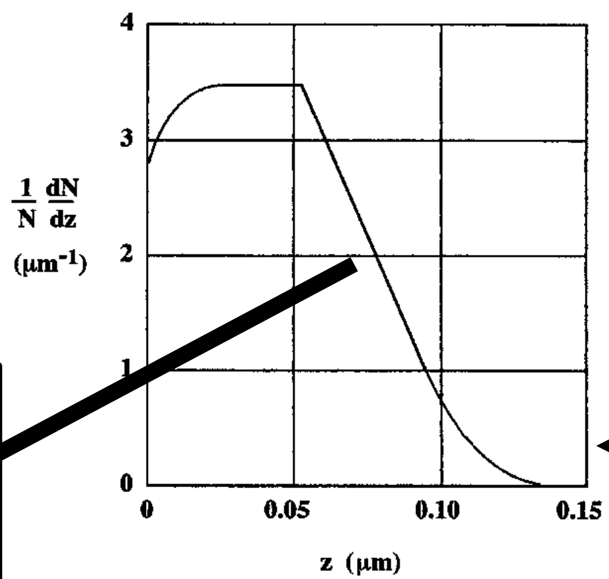
- Edging of PTFE surfaces

^{222}Rn decays (^{210}Pb β, 64 keV endpoint) implanted in PTFE surfaces might make the dominant BG

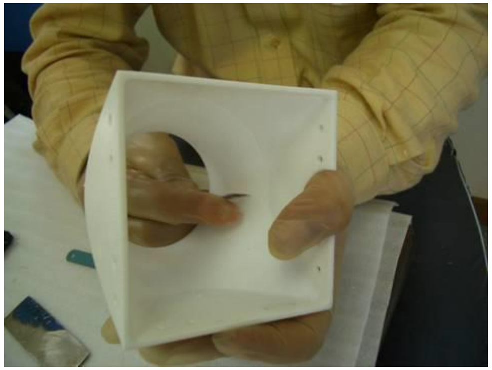
We edged the PTFE inside ~10μm



Implanted to ~0.1μm



0 0.05 0.10 0.15
Z [μm]



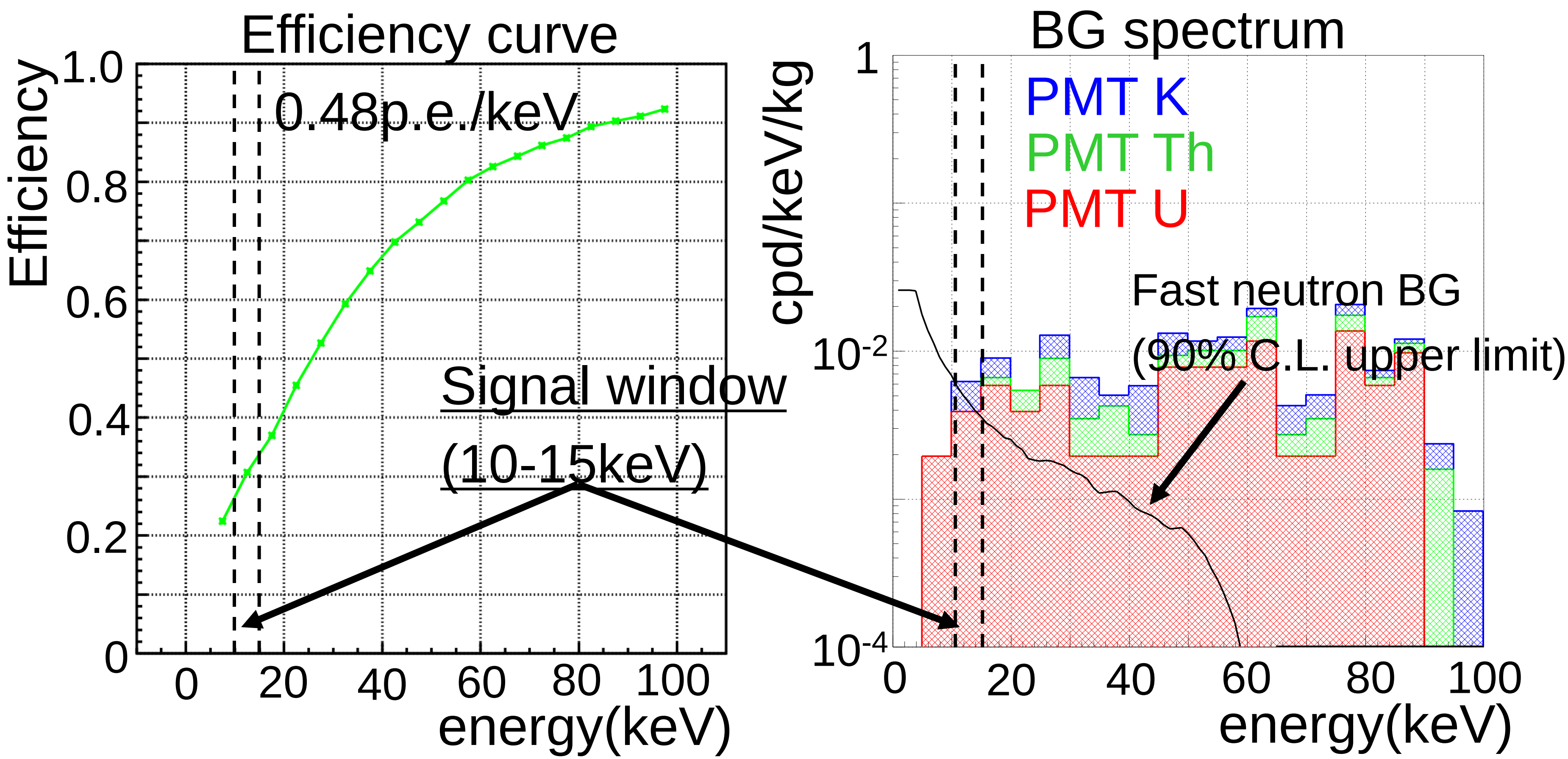
N.J.T. Smith et al., Phys. Lett. B 485 (2000) 9

Position distribution of ^{210}Pb (in NaI)

Recoil process implants **30%** of the original surface Rn decays

Expected BG spectrum

- MC simulation was done with GEANT3



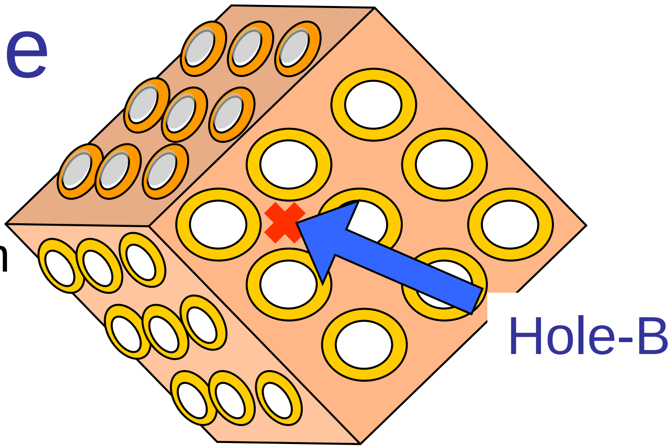
Efficiency~30% @10keV

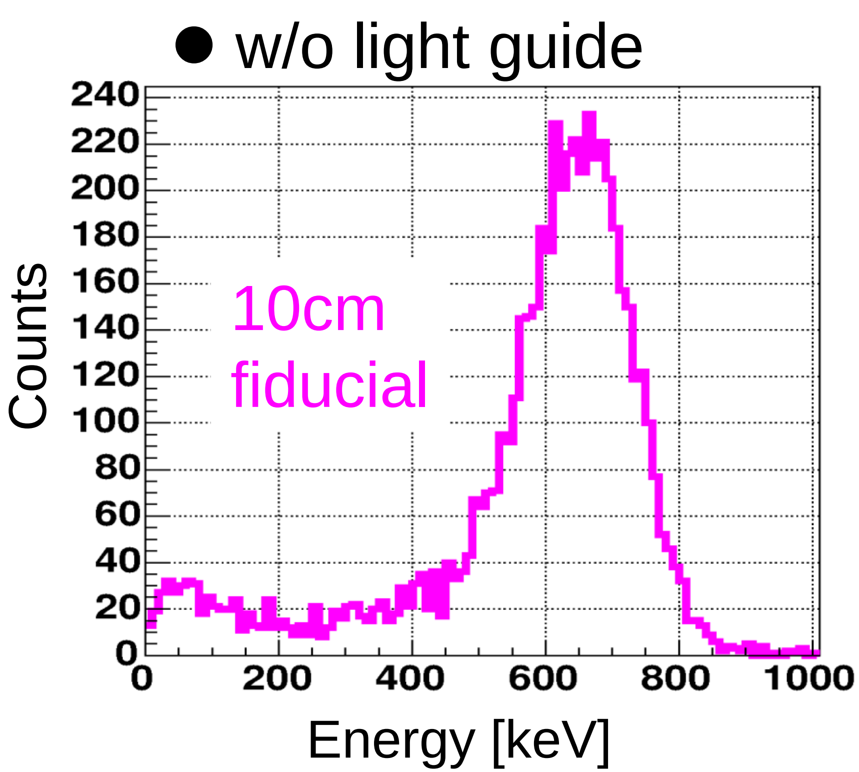
Expected BG~10^{-2}cpd/keV/kg

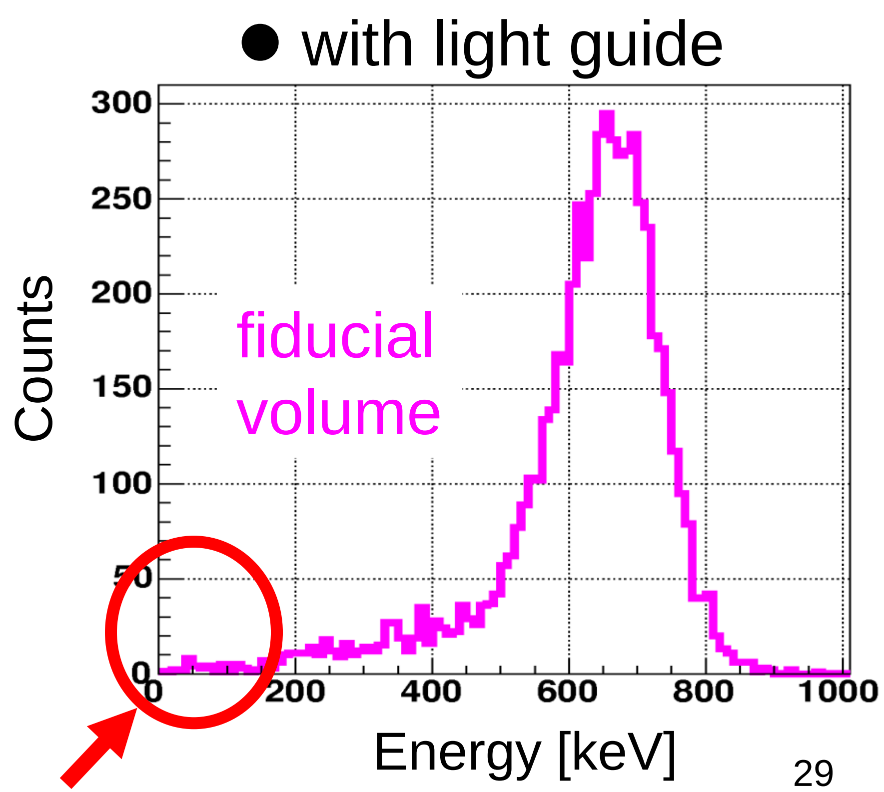
→ Very low BG ~ 10^{-2} cpd/keV/kg @ <100keV

Result 1: comparing the data taken with and without light guide

Collimated γ ray source run from hole-B (137Cs, 662keV)

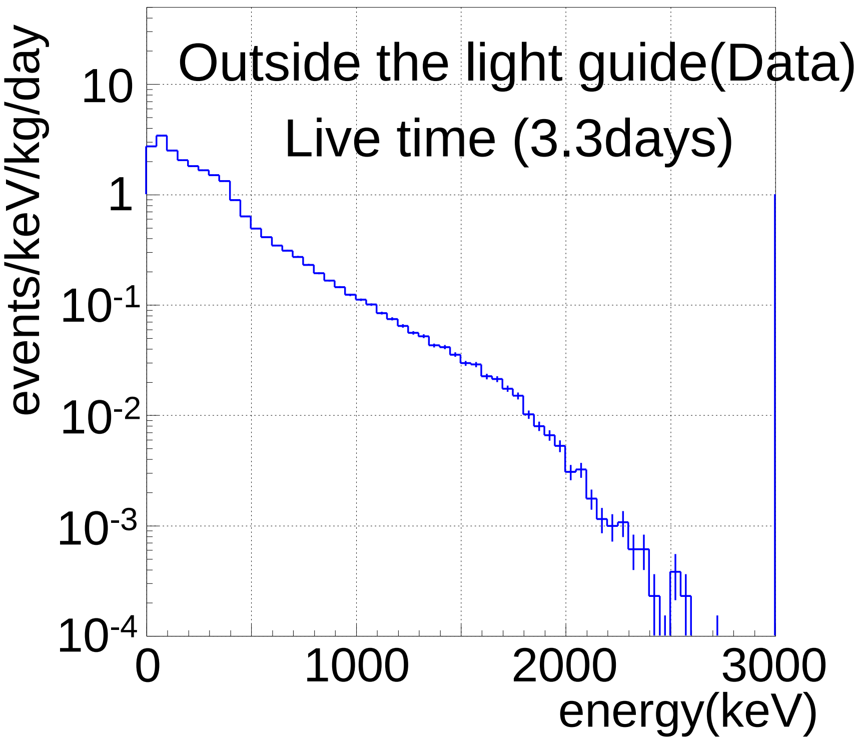


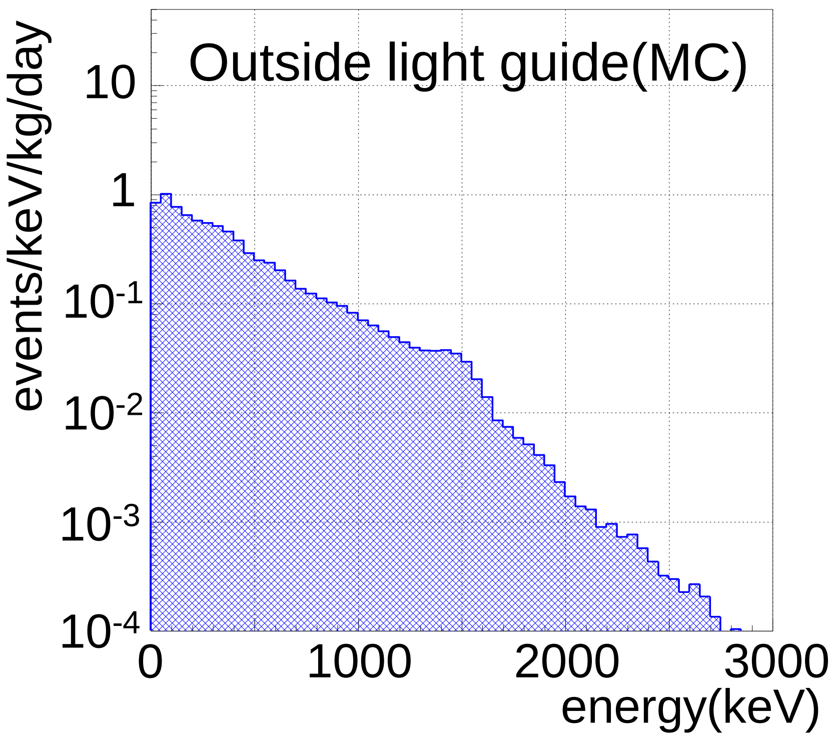




Reduce the events due to the wall effect

Result 2: Obtained energy spectrum outside the light guide





- **Good agreement** (< factor 2)
- Trigger rate is same as the measurement witout guide (Aug. 2004)

3. Summary

- XMASS experiment:
  Multi purpose low-background experiment with large mass liq. Xe

- 800 kg detector:
  Designed for dark matter shearch mainly, and **10^2 improvement of sensitivity** above existing experiments is expected

- R&D with the 100 kg prototype detector
  Most of the **performances required for 800 kg detector are confirmed**