XMASS experiment and its double beta decay option

18th Sep. 2005,
HAW05 workshop,
Double beta-decay and neutrino masses
S. Moriyama, ICRR

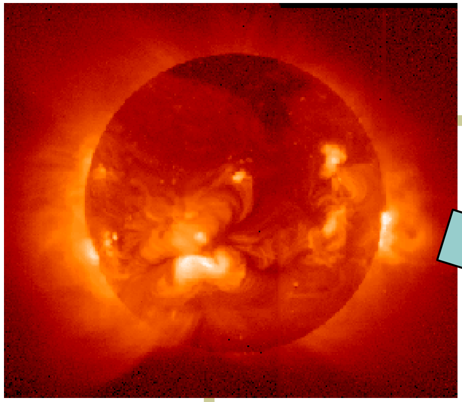
- XMASS experiment for dark matter search and low energy solar neutrino detection
- Double beta decay option

1. Introduction

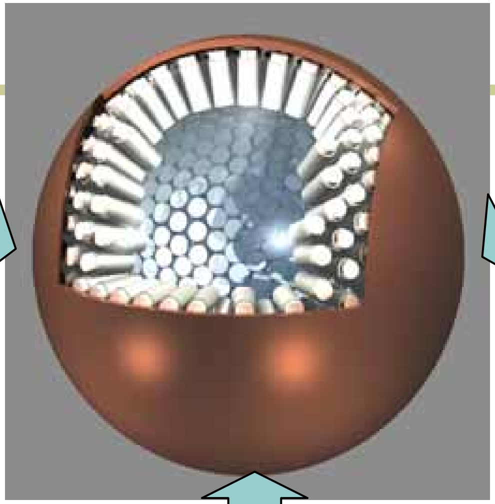
➢ What's XMASS

Multi purpose low-background experiment with liq. Xe

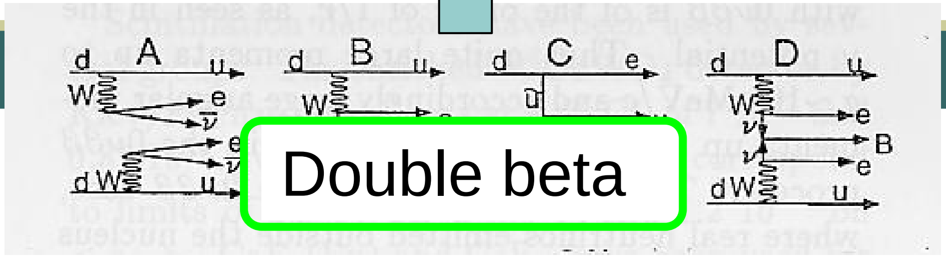
- **X**enon **MASS**ive detector for solar neutrino (**pp/^{7}Be**)
- **X**enon detector for Weakly Interacting **MASS**ive Particles (**DM search**)
- **X**enon neutrino **MASS** detector (**ββ decay**)



Solar neutrino



Dark matter



Double beta

Why Liquid Xenon?

General properties:

Large scintillation yield (~42000photons/MeV ~NaI(Tl))

Scintillation wavelength (175nm, direct read out by PMTs)

Higher operation temperature (~165K, LNe~27K, LHe~4K)

Compact (ρ=2.9g, 10t detector ~ 1.5m cubic)

Not so expensive

Well-known EW cross sections for neutrinos

External gamma ray background:

Self shielding (large Z=54)

Internal background:

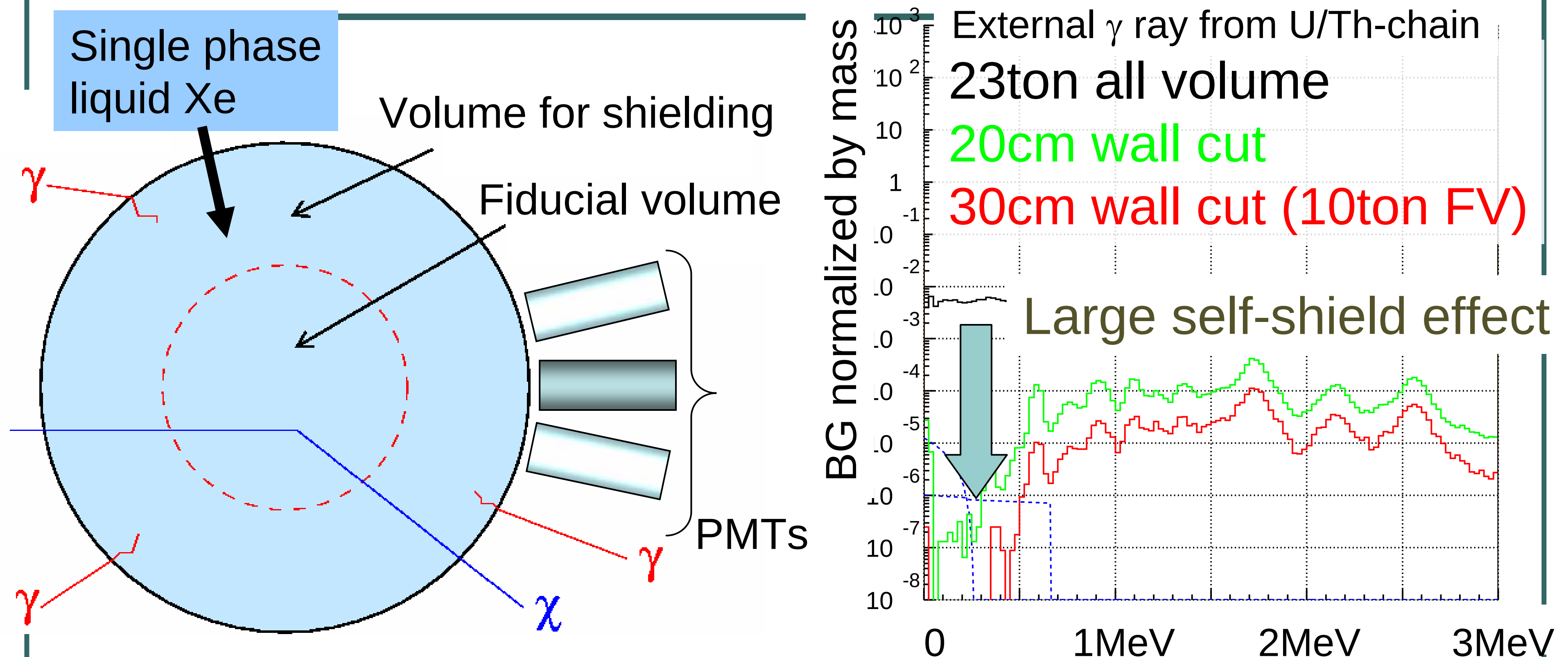
Purification (distillation, etc) **Circulation**

No long-life radio isotopes

Isotope separation is relatively easy

No ^{14}C contamination (can measure low energy)

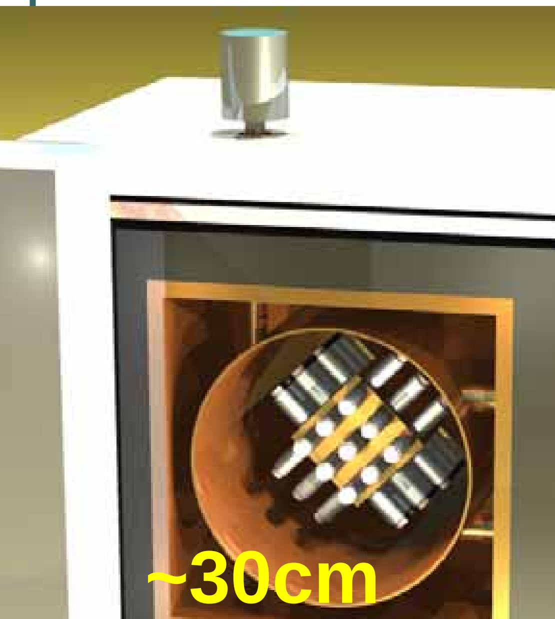
Key idea: self shielding effect for low energy signals



- Large Z makes detectors very compact
- Large photon yield (42 photon/keV ~ NaI(Tl))

Liquid Xe is the most promising material.

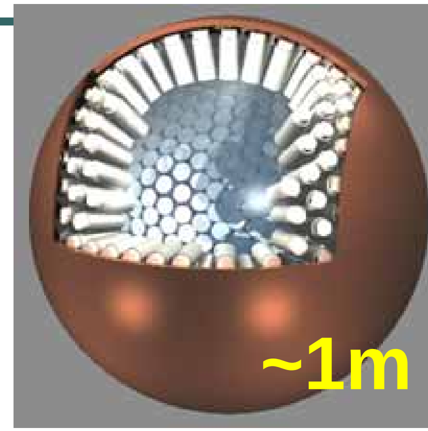
Strategy of the XMASS project



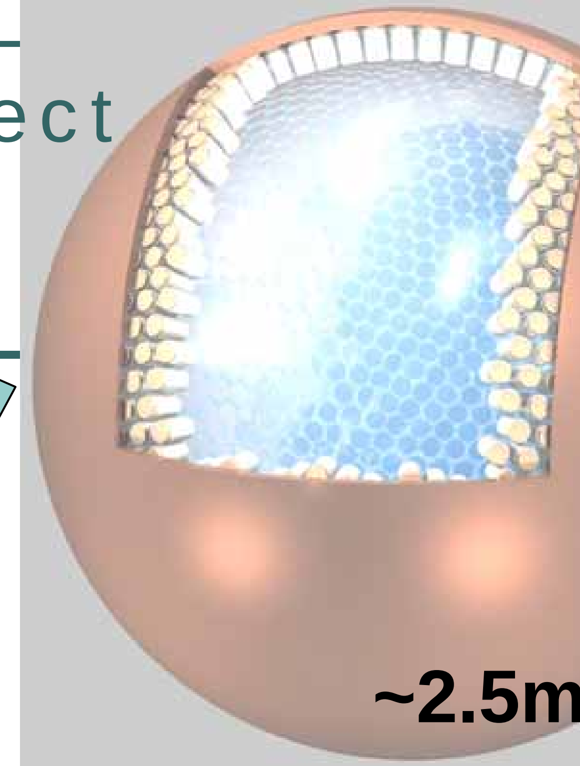
Prototype detector
(FV 3kg) R&D

Confirmation of feasibilities of the ~1ton detector

Good results



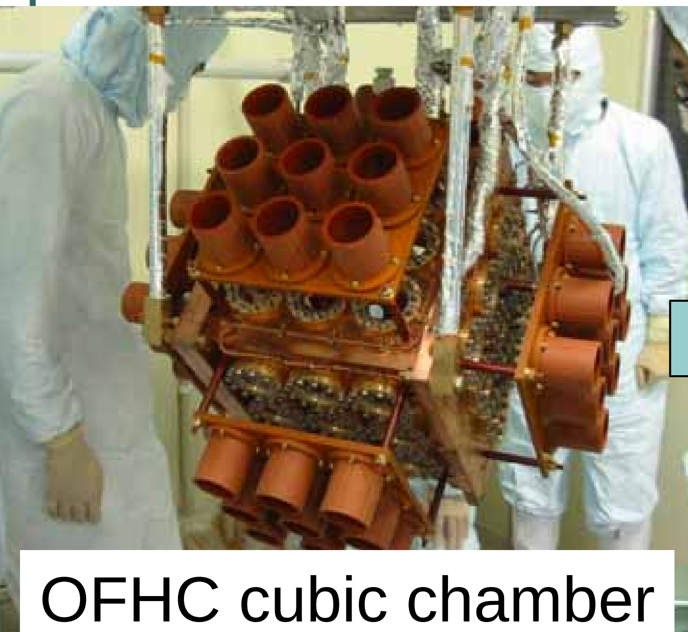
~1 ton detector
(FV 100kg)
Dark matter search



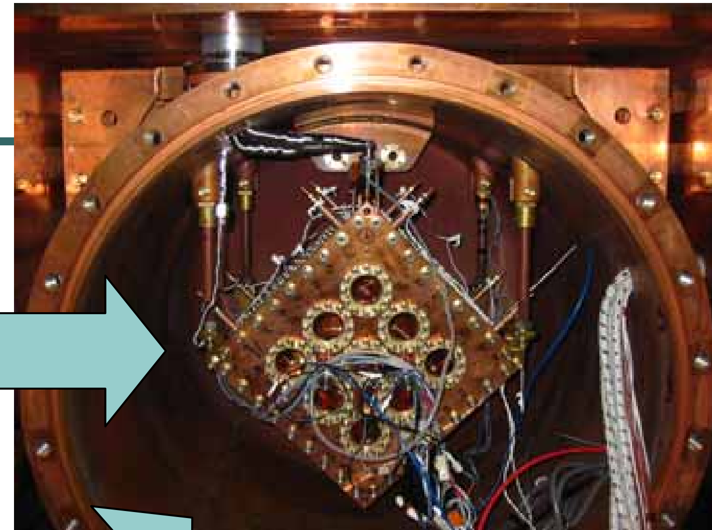
~20 ton detector
(FV 10ton)
Solar neutrinos
Dark matter search

Double beta decay option?

3kg FV prototype detector



OFHC cubic chamber

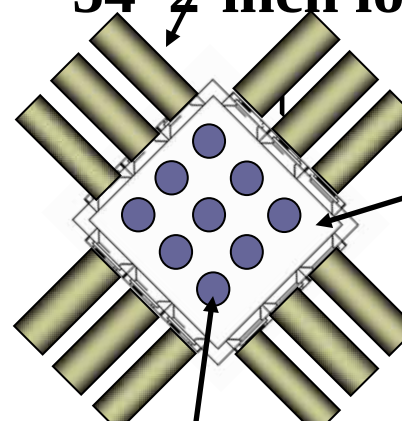


In the Kamioka Mine (near the Super-K)

Gamma ray shield

54 2-inch low BG PMTs

Hamamatsu R8778



Liq. Xe
$(31cm)^3$

16% photo-coverage

MgF_2 window

- Demonstration of reconstruction, self shielding effect, and low background properties.

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.

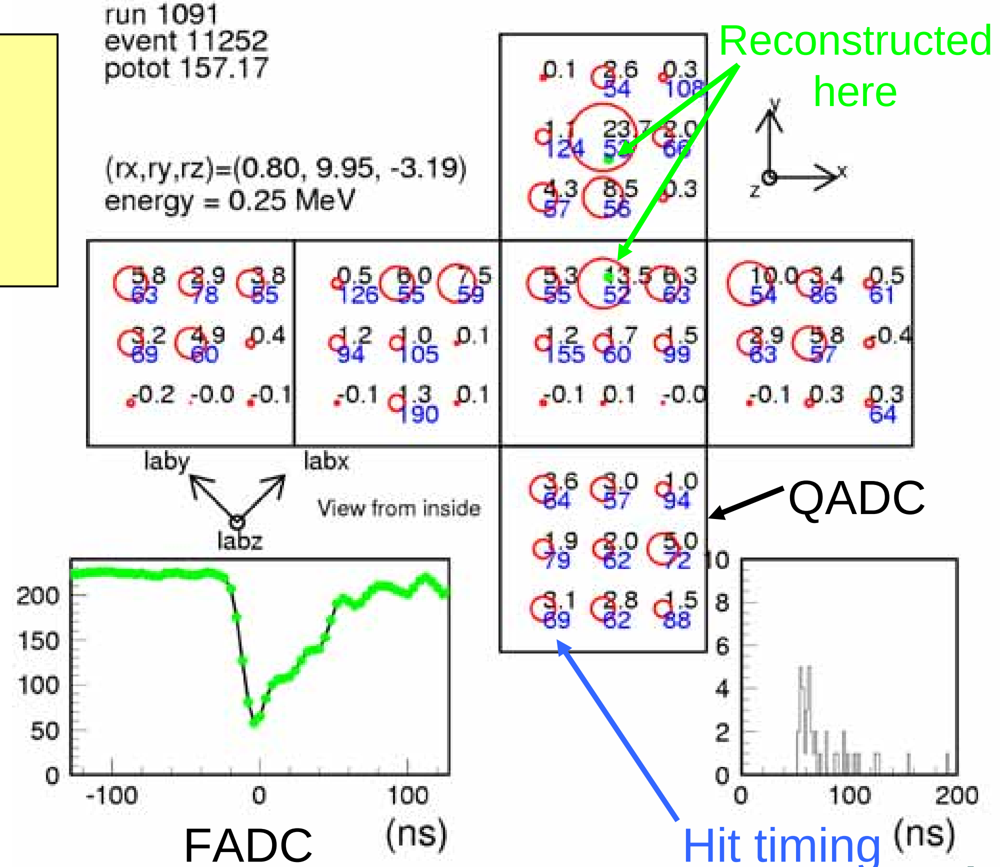
$$\mathrm{Log}(L) = \sum_{PMT} \mathrm{Log}\left(\frac{\exp(-\mu)\mu^n}{n!}\right)$$

L: likelihood

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

n: observed number of p.e.

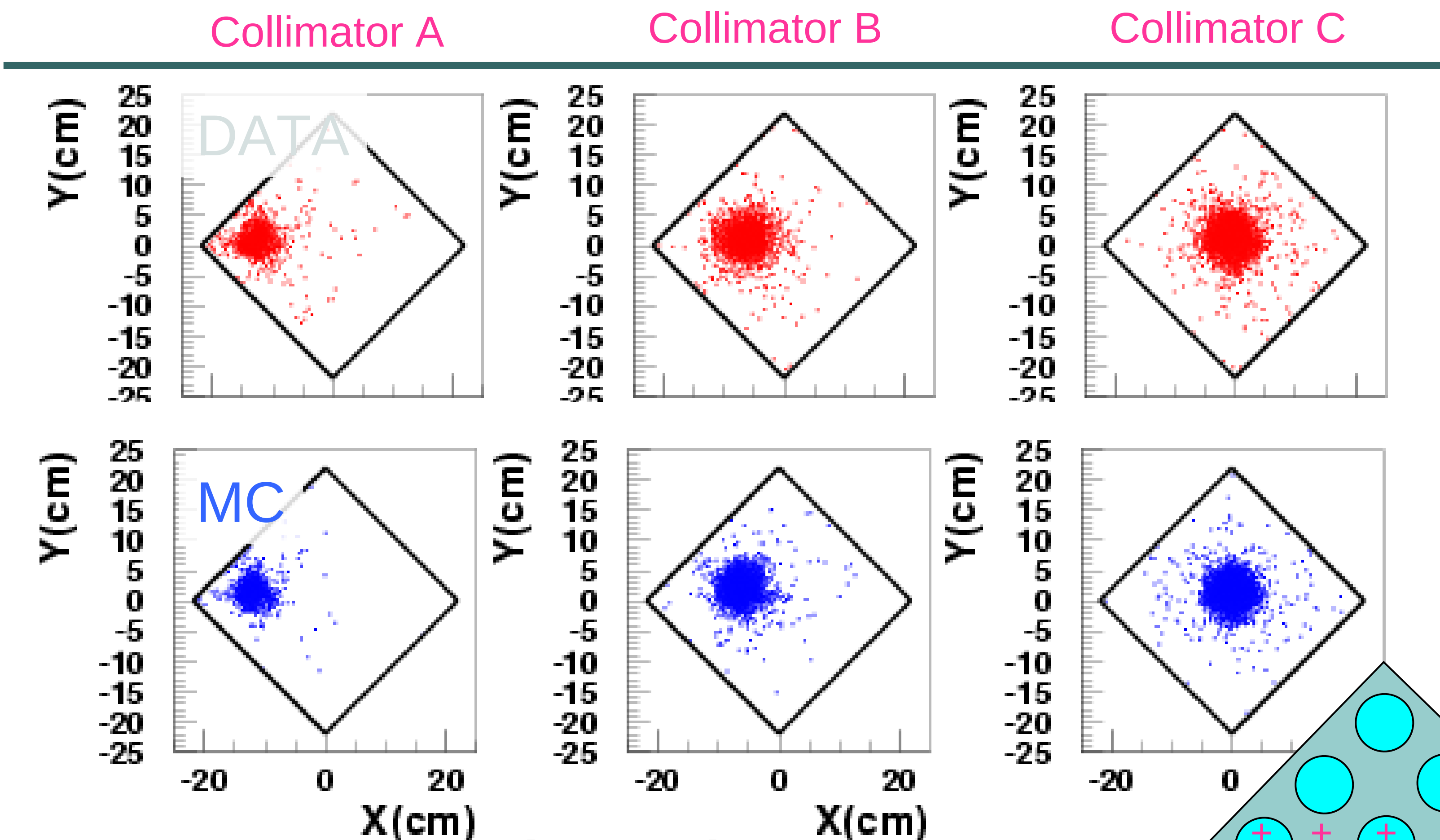
XMASS prototype detector

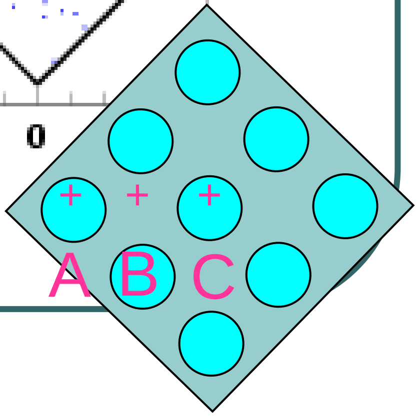


F(x,y,z,i): acceptance for i-th PMT (MC)
VUV photon characteristics:
L_{emit}=42ph/keV
τ_{abs}=100cm
τ_{scat}=30cm

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

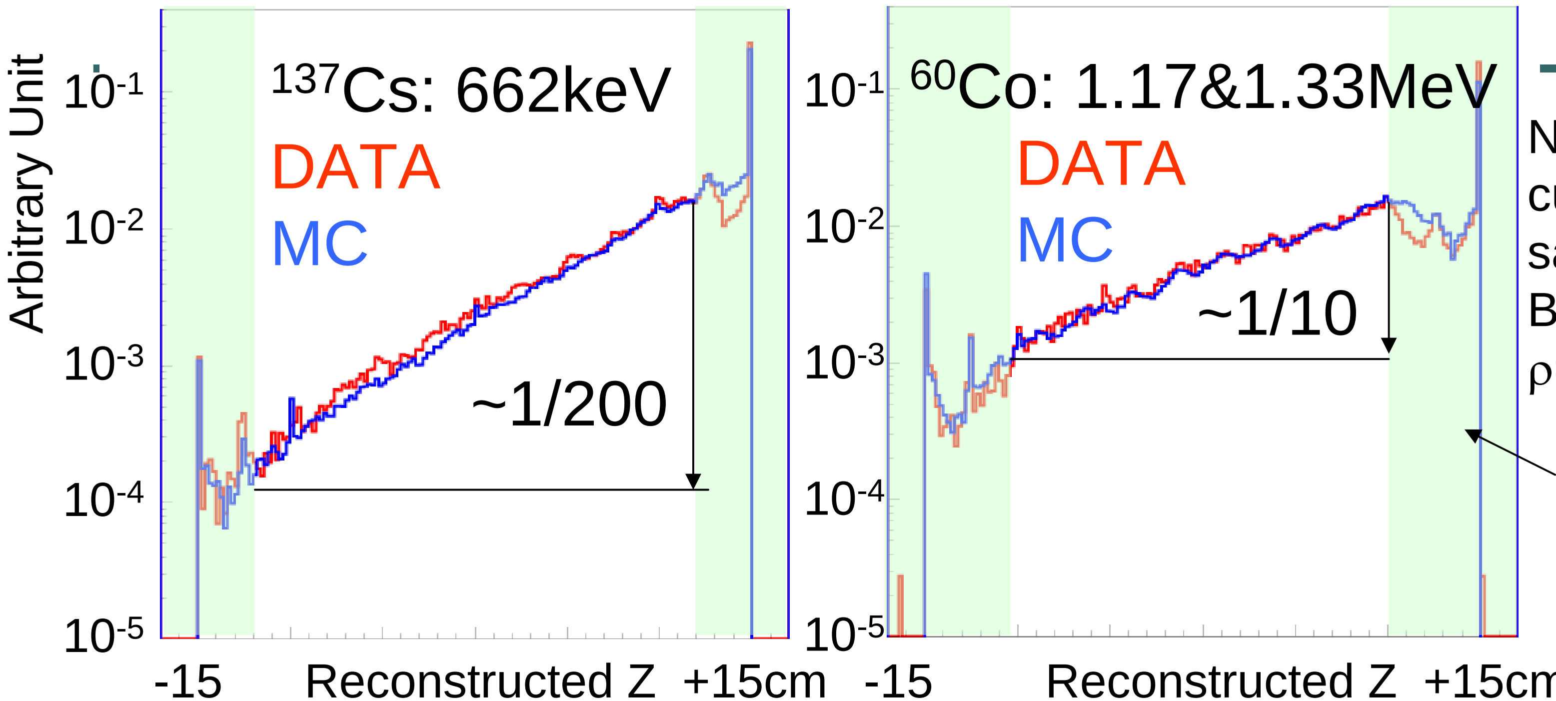
Source run
(γ ray injection from collimators) I





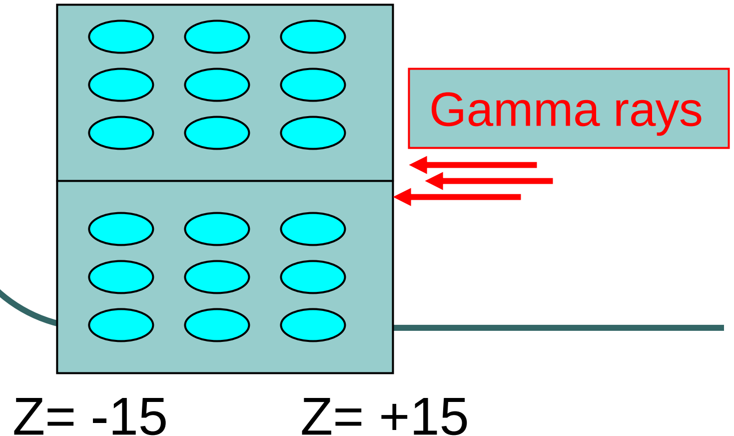
- Well reproduced.

Source run
(γ ray injection from collimators) II



No energy cut, only saturation cut. BG subtracted ρ=2.884g/cc

PMT Saturation region

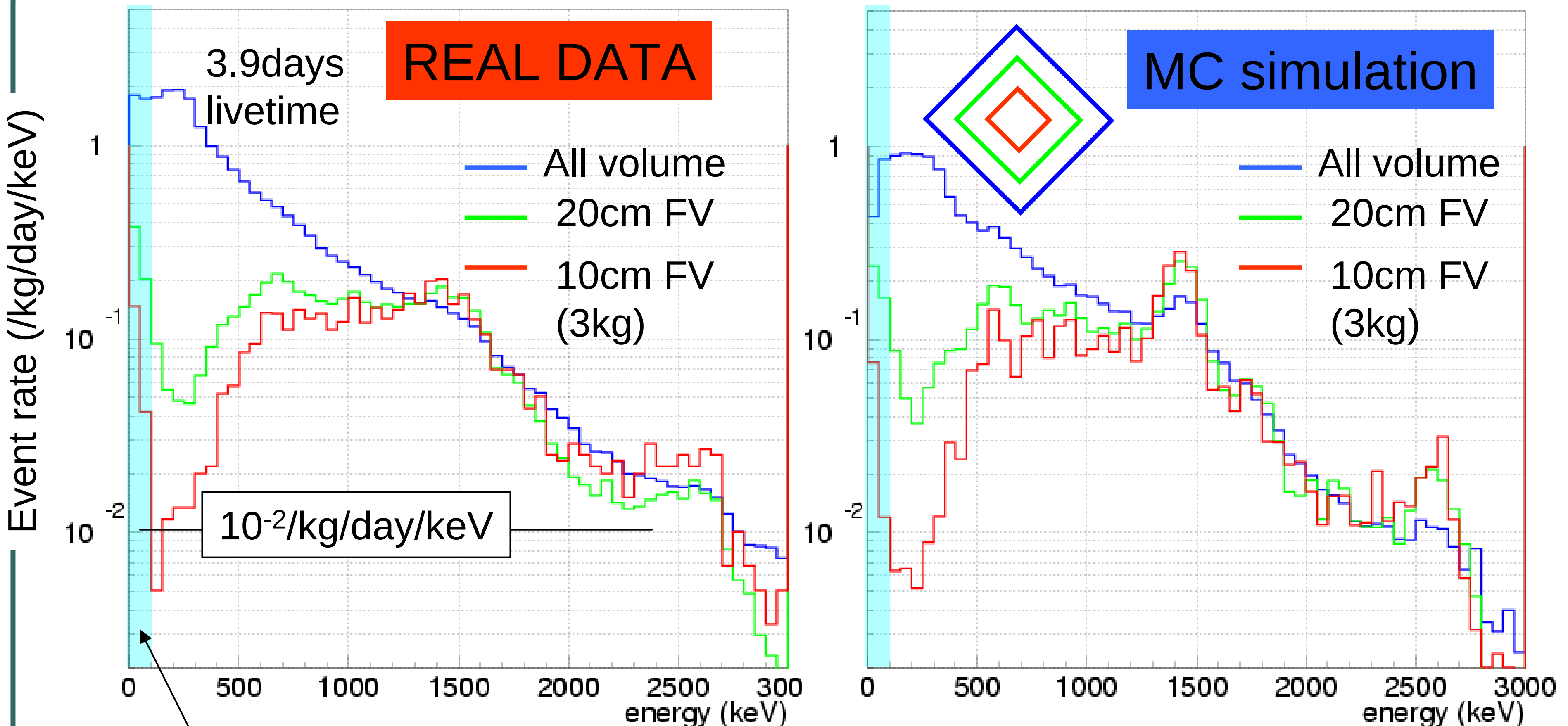


- Good agreements.
- Self shield works as expected.
- Photo electron yield ~ 0.8p.e./keV for all volume

Background data

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

Aug. 04 run



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

- MC uses U/Th/K activity from PMTs, etc (meas. by HPGe).
- Good agreement (< factor 2)
- Self shield effect can be clearly seen.
- Very low background (10^{-2} /kg/day/keV@100-300 keV)

Internal background activities

Goal to look for DM by 1ton detector

- Current results
  - ^{238}U(Bi/Po): = $(33+-7)\times10^{-14}$ g/g ← 1×10^{-14} g/g x33

    Factor ~30, but may decay out further
  - ^{232}Th(Bi/Po): < 63×10^{-14} g/g ← 2×10^{-14} g/g x32

    Factor <~30 (under further study)
  - Kr: < 5ppt ← 1 ppt x5

    Achieved by distillation

Very near to the target level of U, Th Radon and Kr contamination.

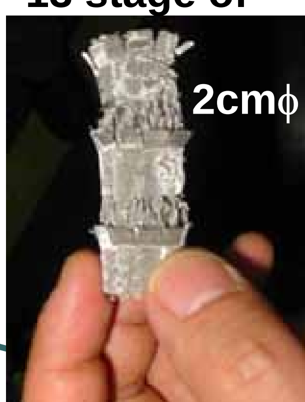
Distillation to reduce Kr (1/1000 by 1 pass)

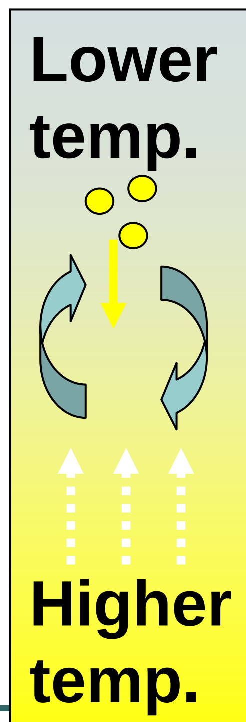
- Very effective to reduce internal impurities (^{85}Kr, etc.)
- We have processed our Xe before the measurement.

	Boiling point (@1 atm)
Xe	165K
Kr	120K

Original Xe:
~3 ppb Kr

13 stage of





~1%

Off gas Xe:
330±100 ppb Kr
(measured)

Operation: 2 atm
Processing speed: 0.6 kg / hour
Design factor: 1/1000 Kr / 1 pass

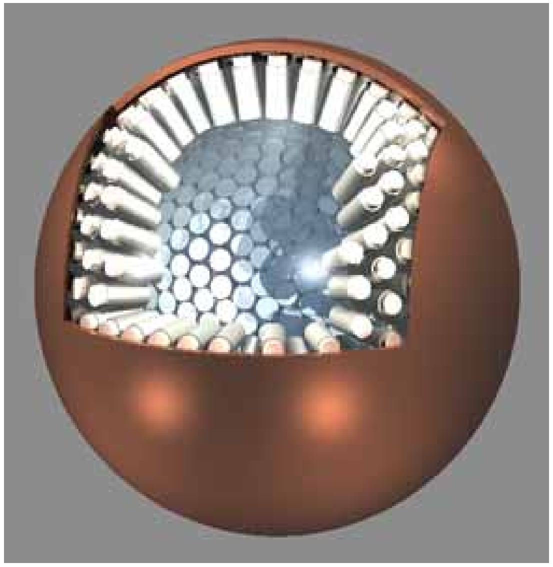
~99%

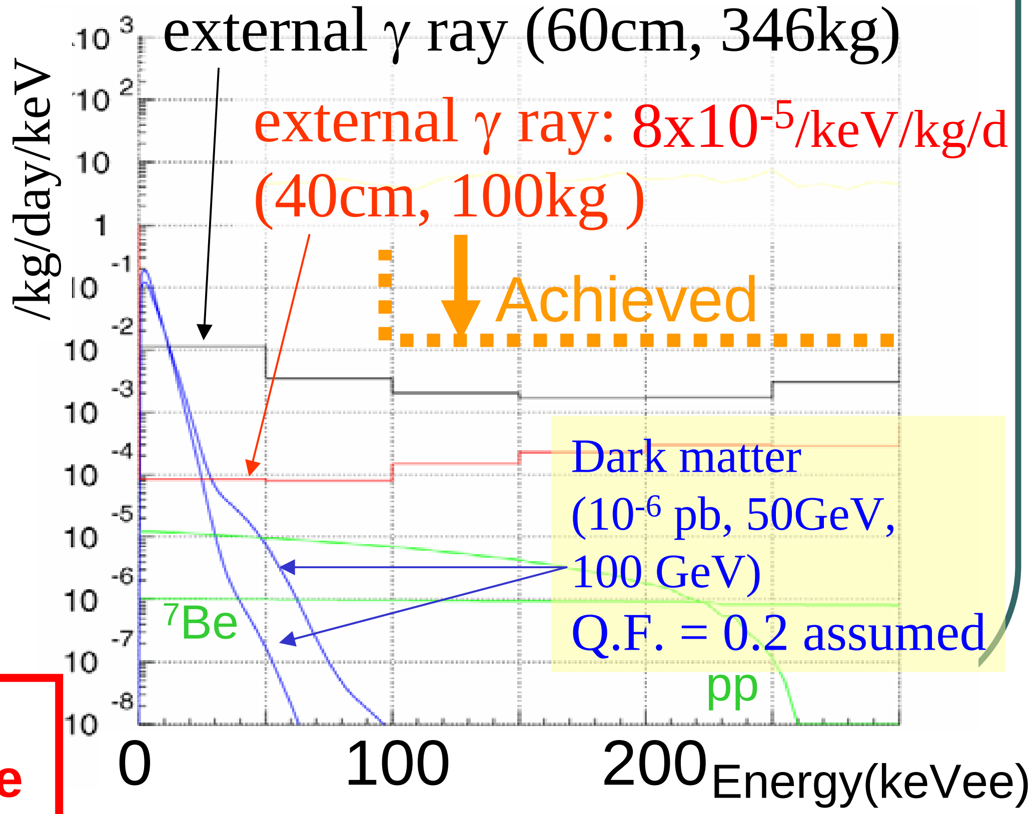
Purified Xe:
< 5 ppt Kr
(measured after Kr-enrichment)

1 ton (100kg FV) detector for DM Search

- Solve the miss reconst. prob. ➔ immerse PMTs into LXe
- Ext. γ BG: from PMT's ➔ Self-shield effect demonstrated
- Int. BG: Kr (distillation), Radon ➔ Almost achieved

"Full" photo-sensitive, "Spherical" geometry detector

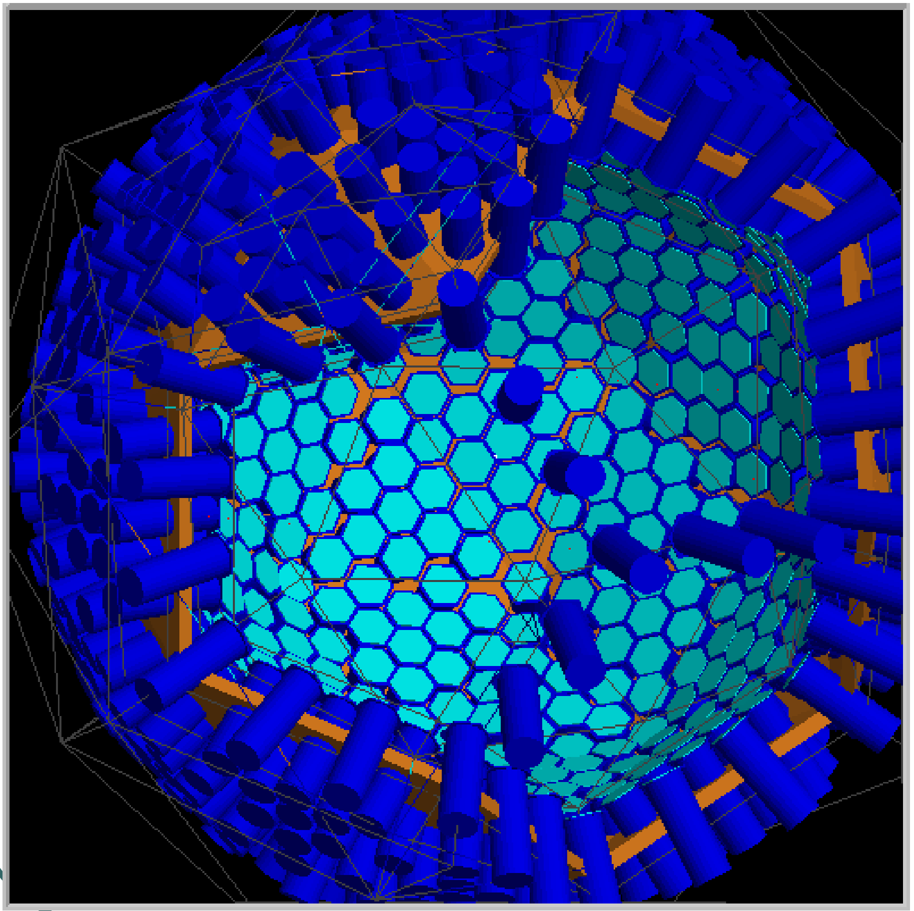




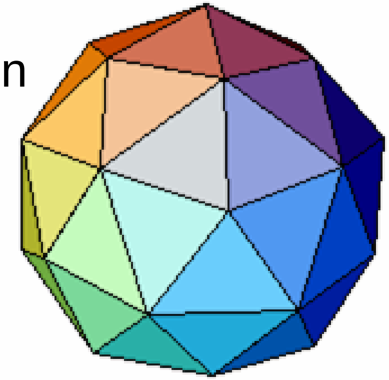
~800-2" PMTs (1/10 Low BG)
70% photo-coverage ~5p.e./keVee

More detailed geometrical design

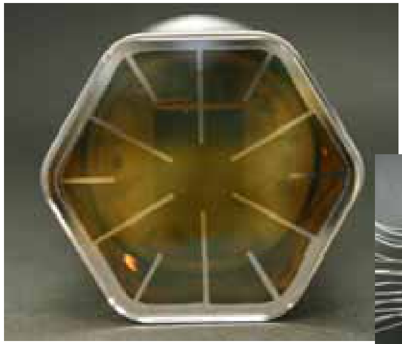
- A tentative design (not final one)



12 pentagons / pentakisdodecahedron



Hexagonal PMT ~50mm diameter



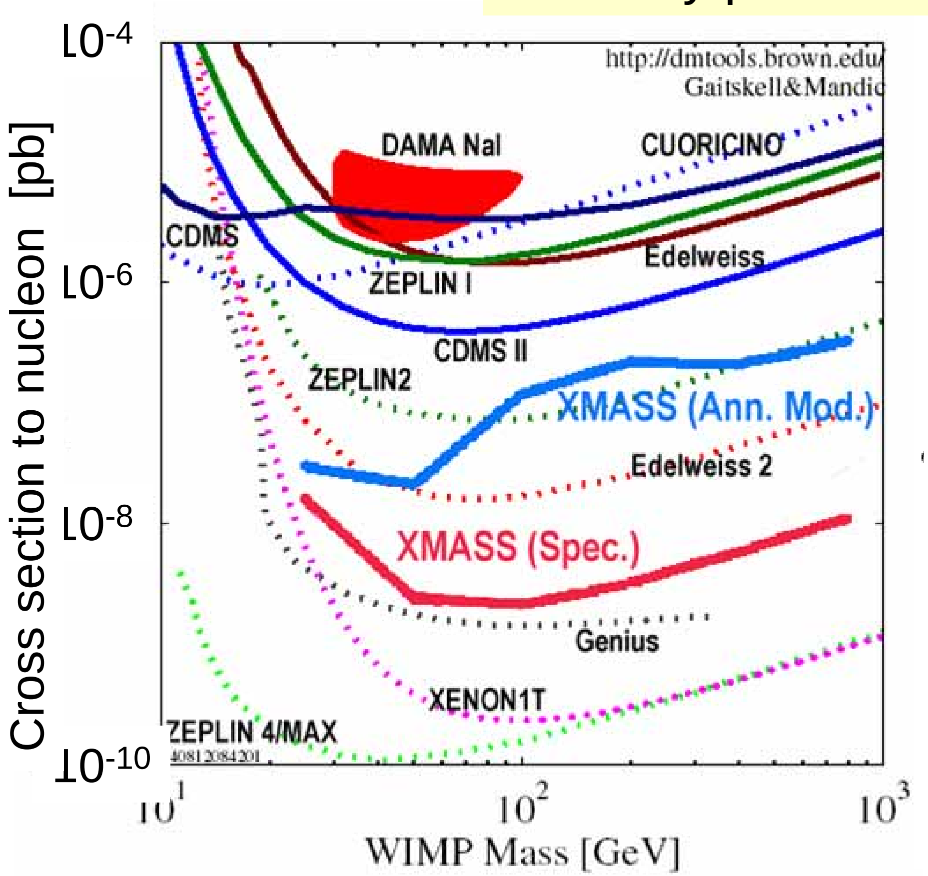
Aiming for 1/10 lower BG than R8778

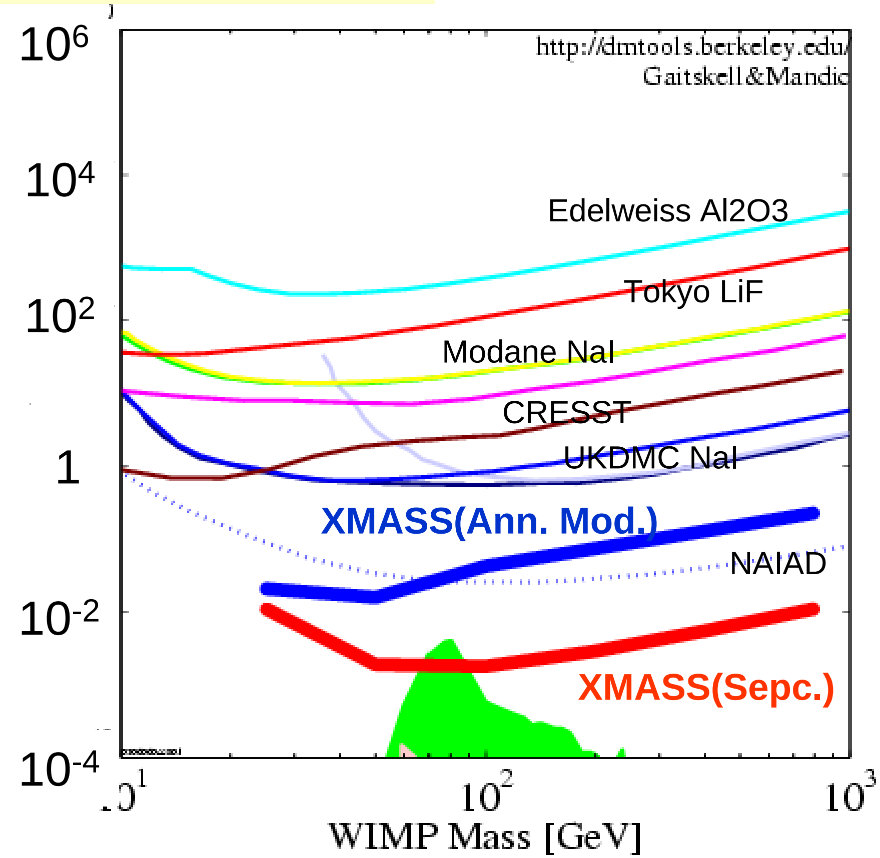
R8778: U 1.8±0.2x10^{-2} Bq
Th 6.9±1.3x10^{-3} Bq
^{40}K 1.4±0.2x10^{-1} Bq

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

Expected sensitivity

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





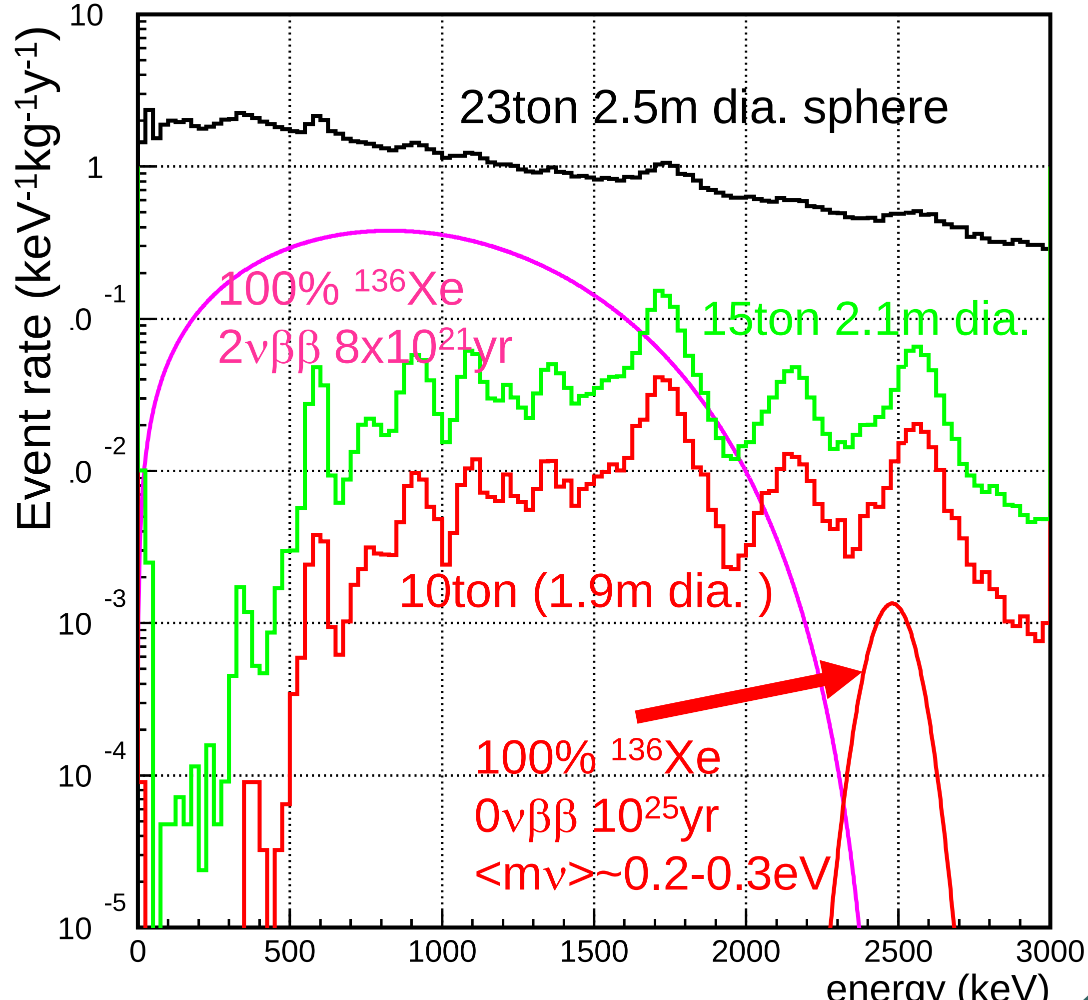
- Large improvements expected.

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

Double beta decay option

BG for double beta decay signals with conventional XMASS detector

- $2\nu\beta\beta$ not yet observed.
  NA 8.9%
- Q=2.467MeV, just below ^{208}Tl 2.615MeV γ rays
- Self shielding of liquid xenon is not very effective for high energy γ rays.
- <u>γ rays from rock & PMTs need to be shielded.</u>



One of possible solutions

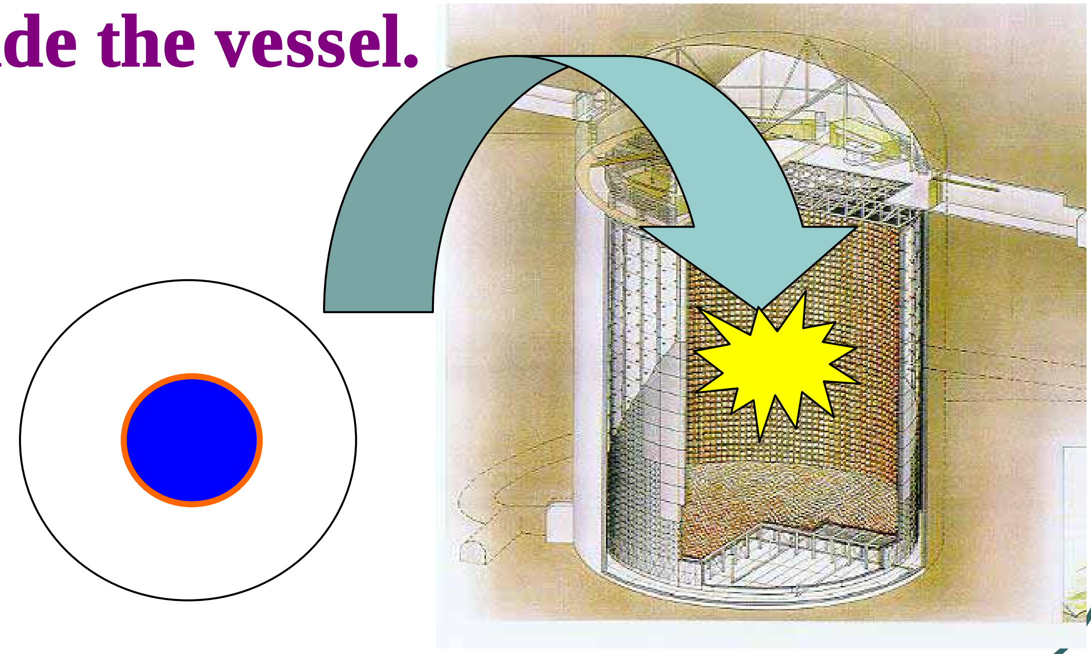
Put room temperature LXe into a thick, acrylic pressure vessel (~50atm).

Symbolically…

Wavelength shifter inside the vessel.

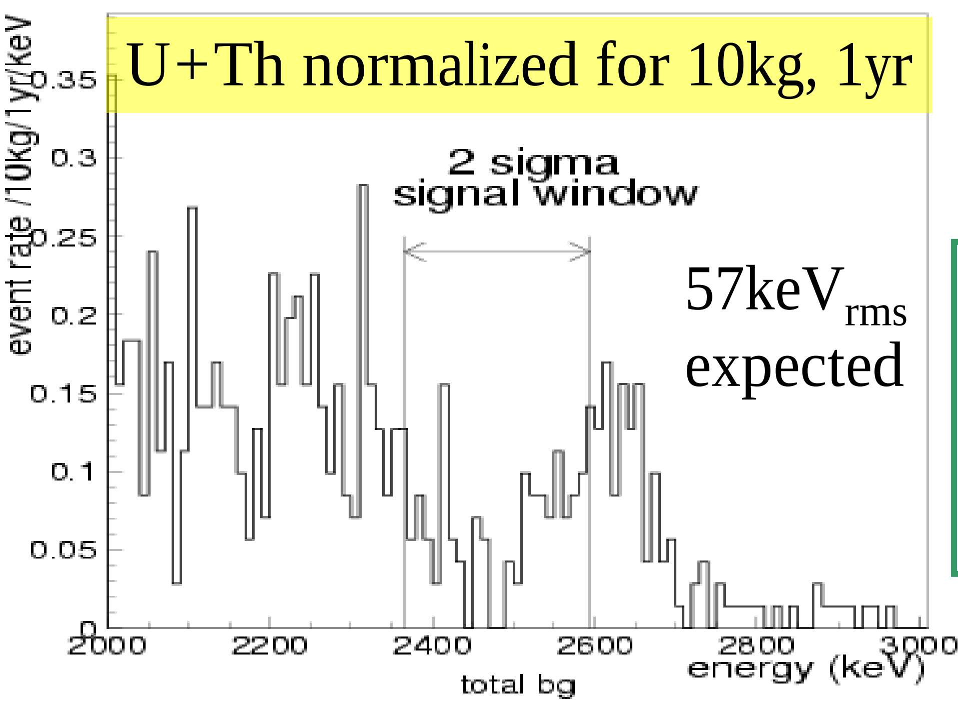
We already have 10kg enriched ^{136}Xe.

Merit: Xe can be purified even after experiment starts!



Expected sensitivity

- Assume acrylic material U,Th~10^{-12}g/g, no other bg.
- Cylindrical geom. (4cm dia. LXe, 10cm dia. Vessel)
- 10kg ^{136}Xe
- 42000photon/MeV but 50% scintillation yield, 90% eff. shifter, 80% water transp., 20% PMT coverage, 25% QE
  → **57keVrms @ $Q_{\beta\beta}$=2.48MeV**



1yr, 10kg measurement
1.5 x 10^{25} yr ⇔ <m_ν>=0.2~0.3eV
c.f. DAMA > 7 x 10^{23} yr (90%)

If U/Th ~ 10^{-16} g/g + larger mass
→ <m_ν>~0.02-0.03eV
2νββ **will not be BG**
thanks to high resolution!!

R&D items

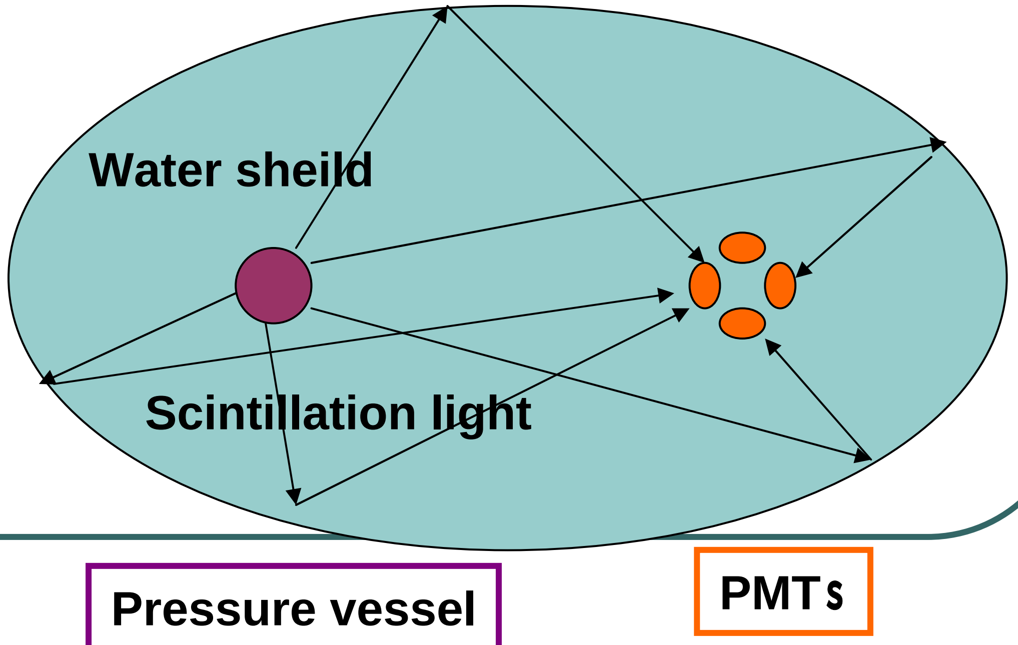
- ✓ Pressure test
- ✓ Wavelength shifter
- Scintillation yield
- Possible creep effect on acrylic material
- Degas from acrylic surface
- BG consideration (time anal., plastic scinti. vessel)
- Detector design

c.f. wavelength shifter:

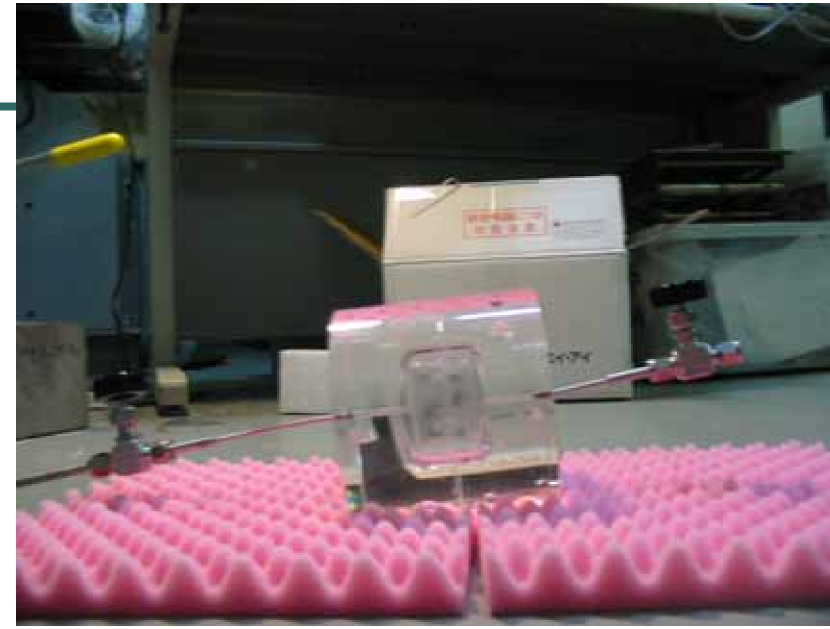
M.A.Iqbal et al., NIMA 243(1986)459
L. Periale et al., NIMA 478(2002)377
D. N. McKinsey et al., NIMB 132 (1997) 351

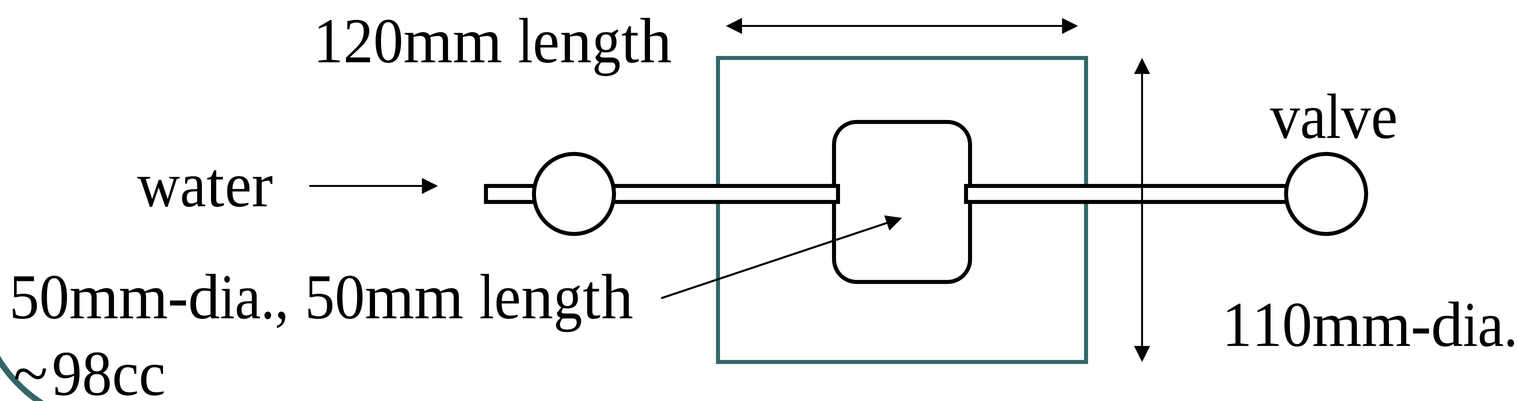
Double focus detector
- Cheap
- Easy
- Safe

Useful for any scintillators



Pressure test vessel



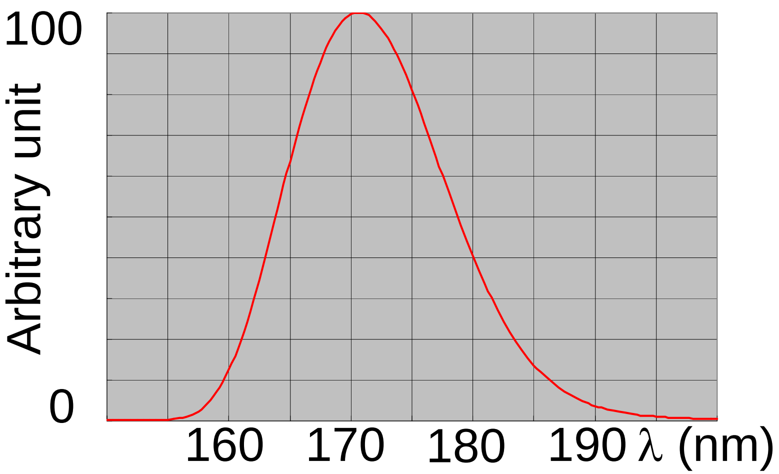


Test vessel held 80 atm water!!

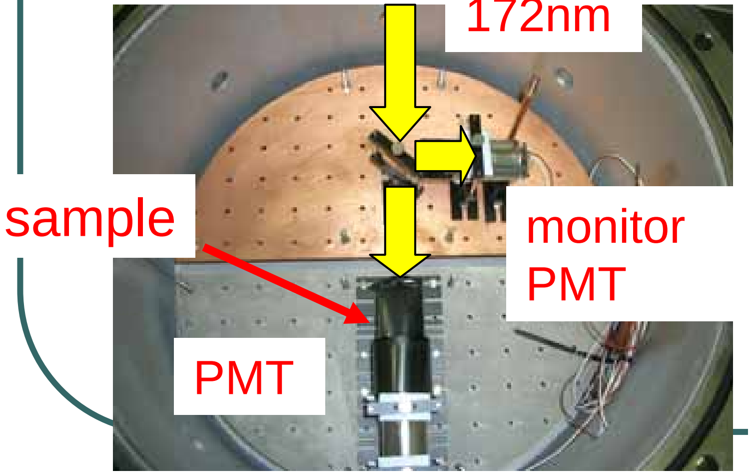
R&D study for wavelength shifter

- DC light source: excimer xenon lamp

Wavelength ~ LXe scintillation light



- Vacuum vessel, signal PMT and monitor PMT



- Vacuum vessel ~80cm diameter
- Signal and monitor PMTs
  R8778 for XMASS
- Sample fixed in 50mm dia. holder
- Beam splitter: MgF_2 tilted by 45 deg.

TPB in PS

- Famous WLS for VUV lights

TPB: Tetraphenyl butadiene 🡐 This measurement –

TPH: p-terphenyl

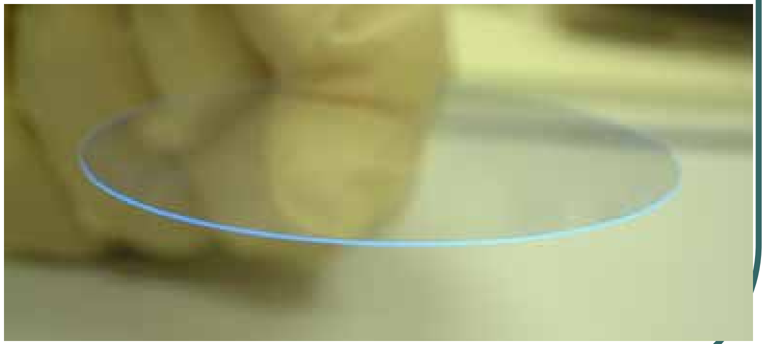
DPS: Dephenyl stilbene

Sodium salicylate

- Doped in a polystyrene films

0.5, 1.0, 2.0, 4.0, 8.0, 16.0% (in weight)

Ref. systematic study on doped films for 58nm and 74nm, D. N. McKinsey *et al.*, NIMB, 132 (1997) 351-358



0.5% TPB doped PS, 100μm

TPB 0.5% doped PS

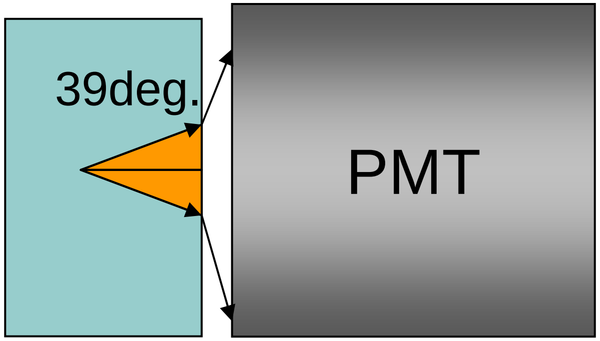
- Two measurements for systematic study

(1) Gap between PS and PMT: PS n=1.59

➔ Due to total reflection <39deg. light go into PMT

➔ Solid angle 11%

Correction applied



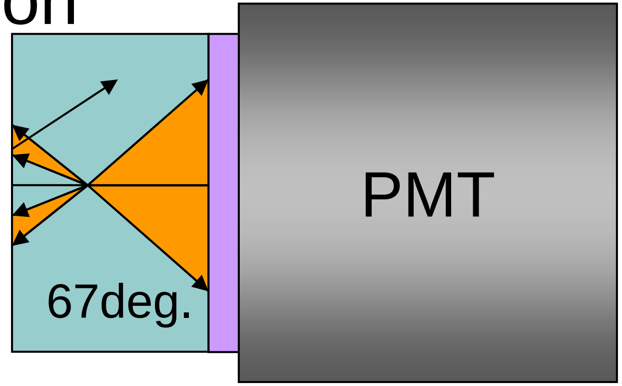
Quartz
n=1.5-1.6

(2) Optical grease btw PS and PMT: grease n=1.47

➔ Light to orange region go into PMT (67deg., 39deg.)

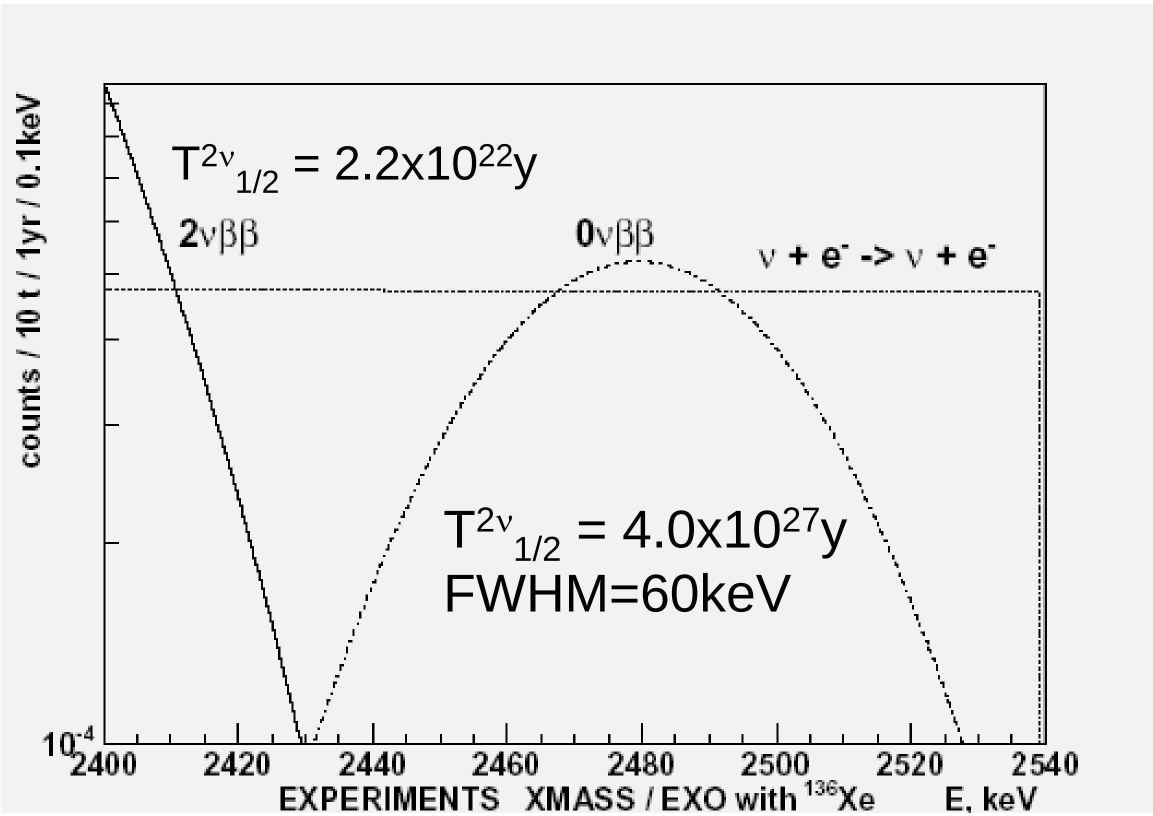
➔ Solid angle 50%

Correction applied



- Efficiency 37+/-6% is obtained for 0.5% TPB PS.
- However, 2% TPB PS does not give consistent results. Further careful study needed.

Background due to ^{8}B solar neutrinos



^{8}B solar neutrinos will be background for ^{136}Xe double beta decay search.
4.0x10^{27}y ⇔ 23meV

Need Ba daughter tag, two track ID, or ??

Ge is safe because of its high energy res.

^{8}B solar neutrinos for double beta decay search
A. A. Klimenko, hep-ph/0407156,

Summary

- XMASS experiment: dark matter, low energy solar neutrino, and double beta decay observation.
- With 3kg FV R&D detector, we have demonstrated event reconstruction, self shielding, and low radioactive contamination in xenon.

  (1)^{238}U(Bi/Po) = (33+-7)x10^{-14} g/g

  (2) ^{232}Th(Bi/Po) < 63x10^{-14} g/g

  (3) Kr < 5ppt.

  (4) Background @ 200keV ~10^{-2}/kg/keV/day
- 100kg FV XMASS detector is expected to give ~100 improvement for current dark matter search.
- For double beta decay option, another design is discussed.
- Wavelength shifter (0.5% TPB in PS) gives 37+/-6% conversion efficiency for 172nm light.
- Further R&D is ongoing for double beta decay option.