XMASS experiment for double beta decay

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for XMASS collaboration

June 11 @DBD07 in Osaka

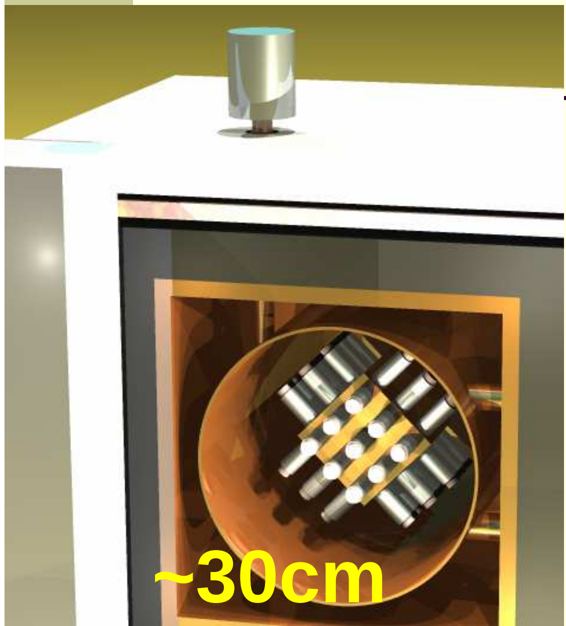
1,Strategy of XMASS project

2,Design of detector for double beta decay

3,R&D status for double beta decay

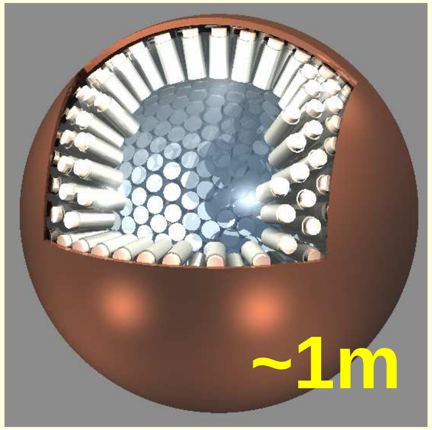
4,800kg detector for Dark Matter search

Strategy of the XMASS project



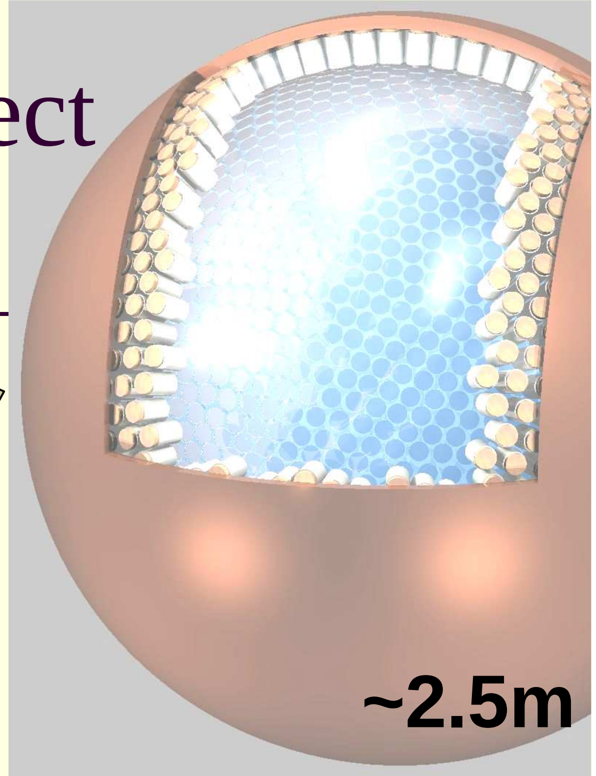
Prototype detector
(FV 3kg)

Confirmation of feasibilities of the ~1ton detector



~1 ton detector
(FV 100kg)

Dark matter search
Low BG at ~ keV



~20 ton detector
(FV 10ton)

Solar neutrinos
Dark matter search

Double beta decay option
Low BG at ~ MeV

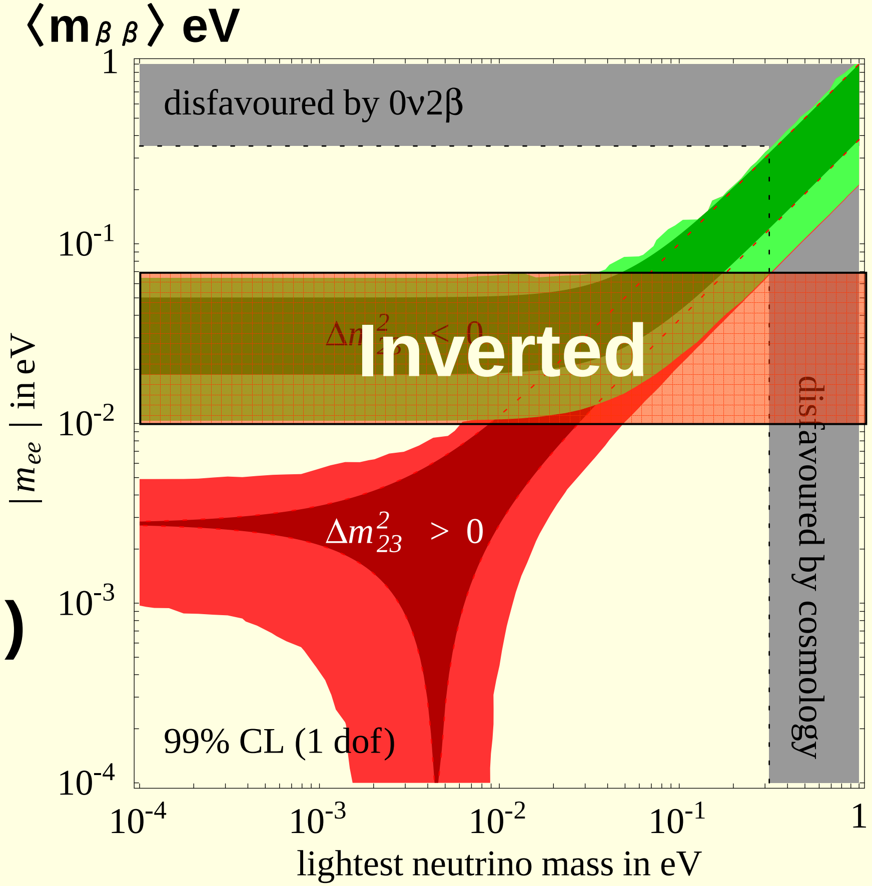
Current target sensitivity of 0νββ
Inverted hierarchy

^{136}Xe (N.A. 8.9%) is one of double beta nucleus.

The results of neutrino oscillation experiments suggest that the effective mass of neutrino is above 10meV if hierarchy is inverted.

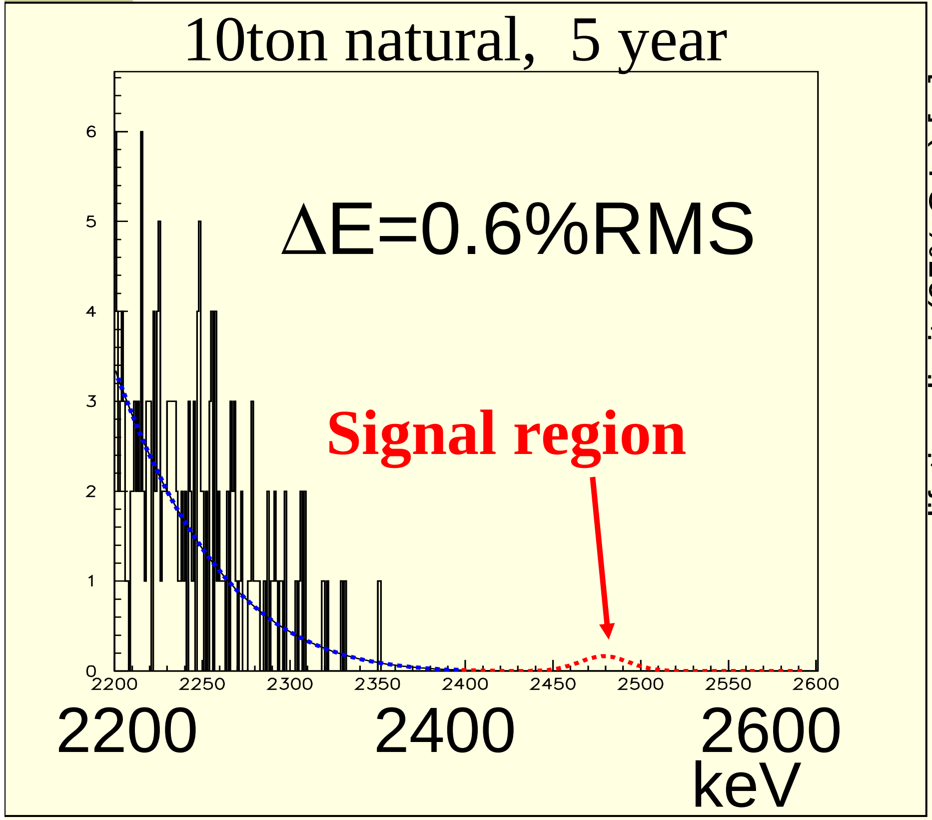
Predicted half life with this effective mass ~ 10^{27}-10^{28}year

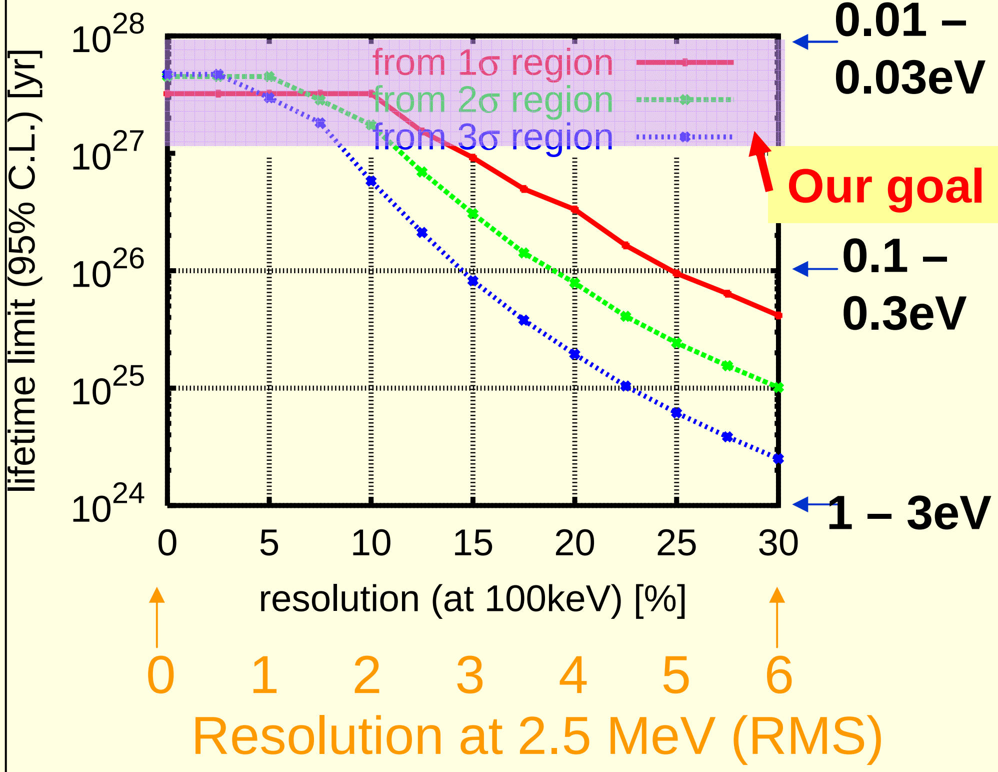
More than
10ton (^{136}Xe natural)
or
1ton (enriched)



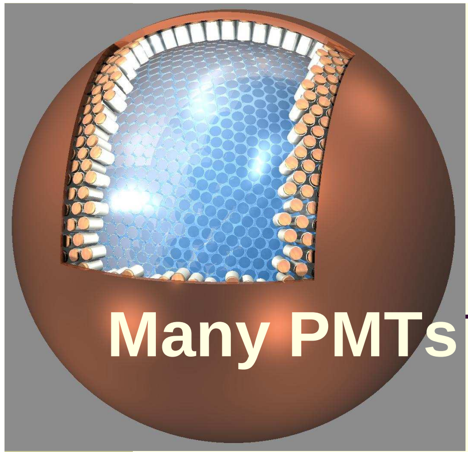
Large scintillation yield reduces 2νββ background

– Ultimate energy resolution is 0.6% @Q=2.5MeV since we have large scintillation yield (~42000photons/MeV).

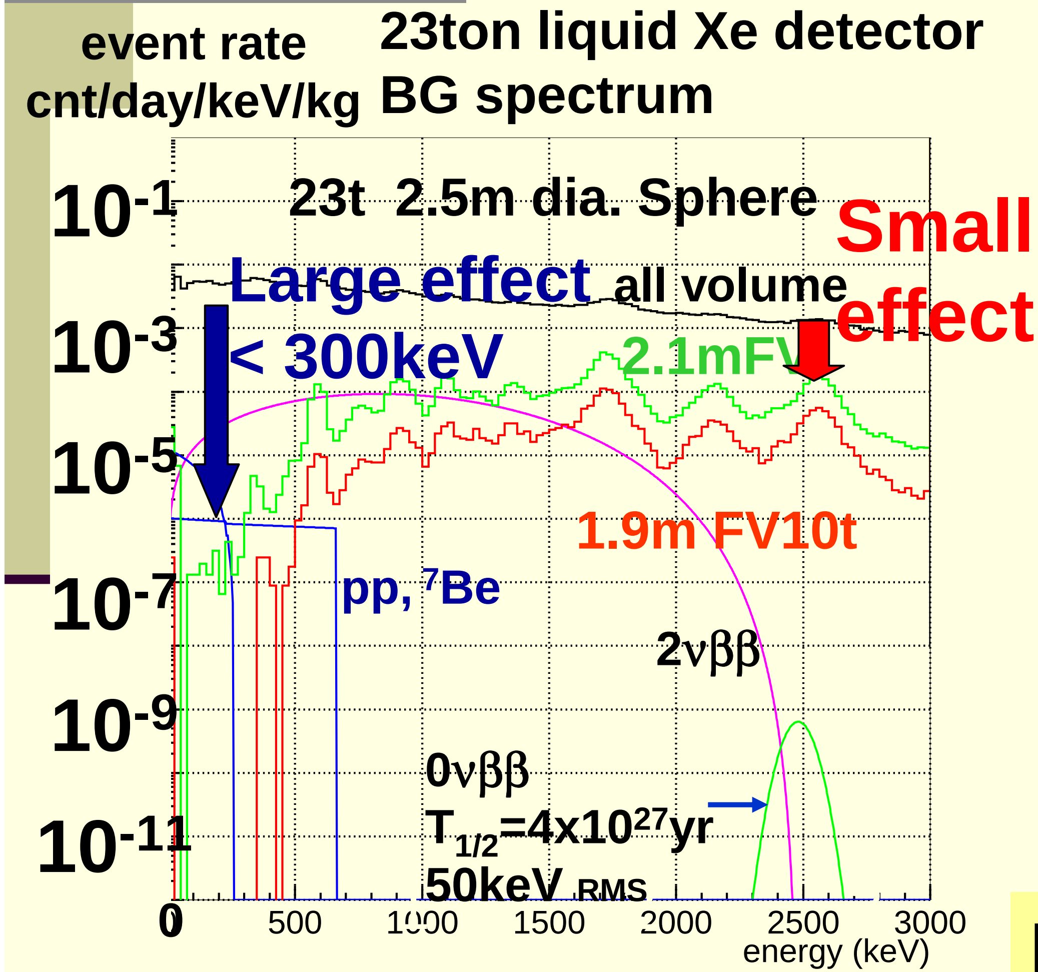




E resolution < 2% is needed for reducing 2νββ BG .



Self shielding effect of liq. Xe



Low energy: attenuation for gamma rays are very large
➔ realize low background

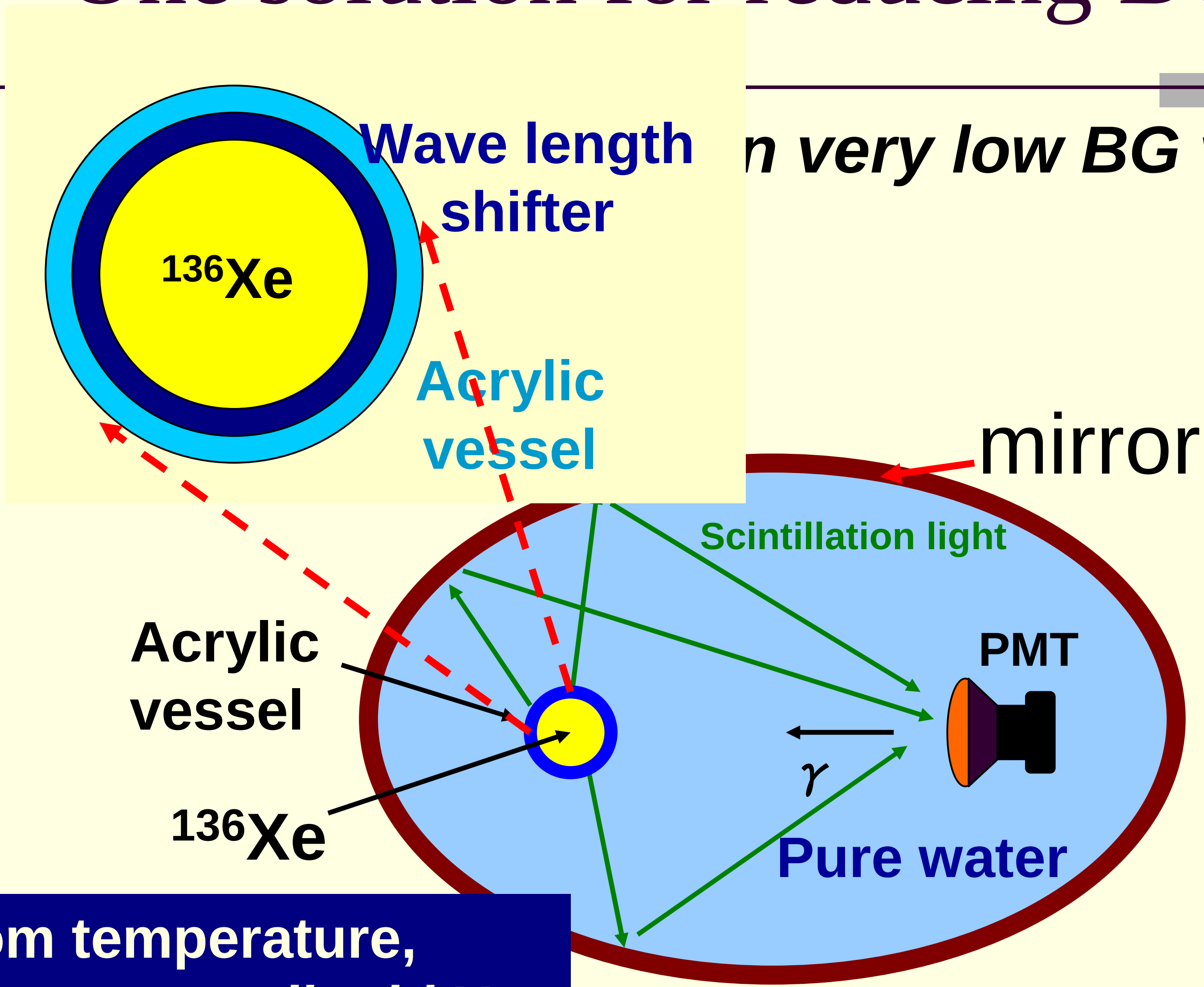
High energy: gamma rays penetrate liquid xenon easily
➔ not enough for 0νββ exp.

γ rays from PMTs, rocks, etc. need to be shielded by other material

Need a different design

One solution for reducing BG

n very low BG vessel



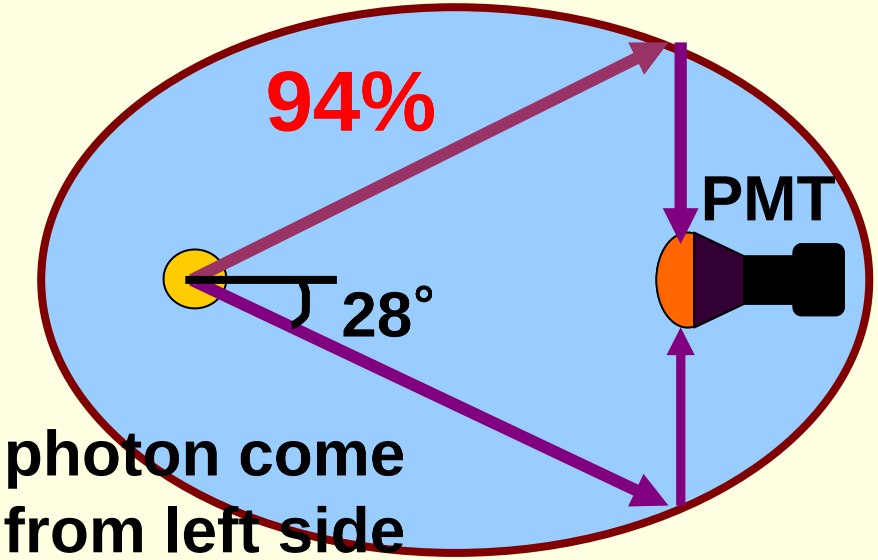
Room temperature, high pressure liquid Xe.

Optics of the elliptic water tank

- **ELliptic water Tank (ELT) detector has an interesting optical property.**
- **More than 90% of emitted photons can be collected to a single PMT.**

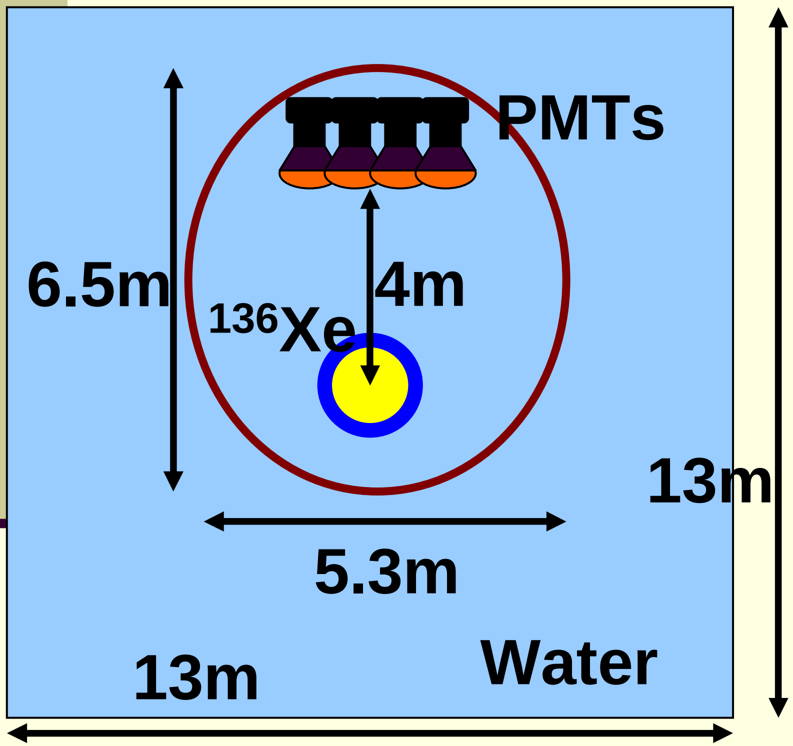
1-(1-cos(28 deg.))/2 ~ 0.94

Low BG, efficient light collection, and low cost detector !!!



Detector design and things to be solved

- Detector design to reach inverted hierarchy

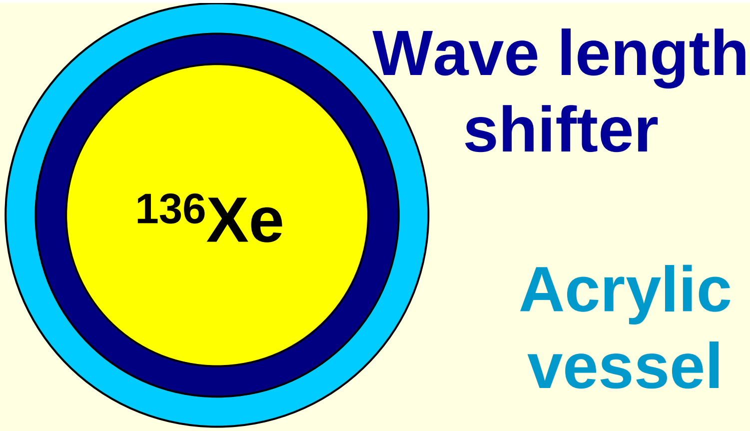


Water shield and ELT reduce gamma rays from rocks and PMTs.

- Background from vessel and WLS
- Internal background
- Attenuation of scintillation lights inside liquid xenon
- Dissolving contamination from vessel
- …

We studied this method as one of our future plans.

R&D to achieve good energy resolution



1. Measure photon yield of liquid Xe at room temperature.

   Small cell for liquid xenon at room temperature

2. Develop high efficiency wavelength shifter

   TPB doped polystyrene

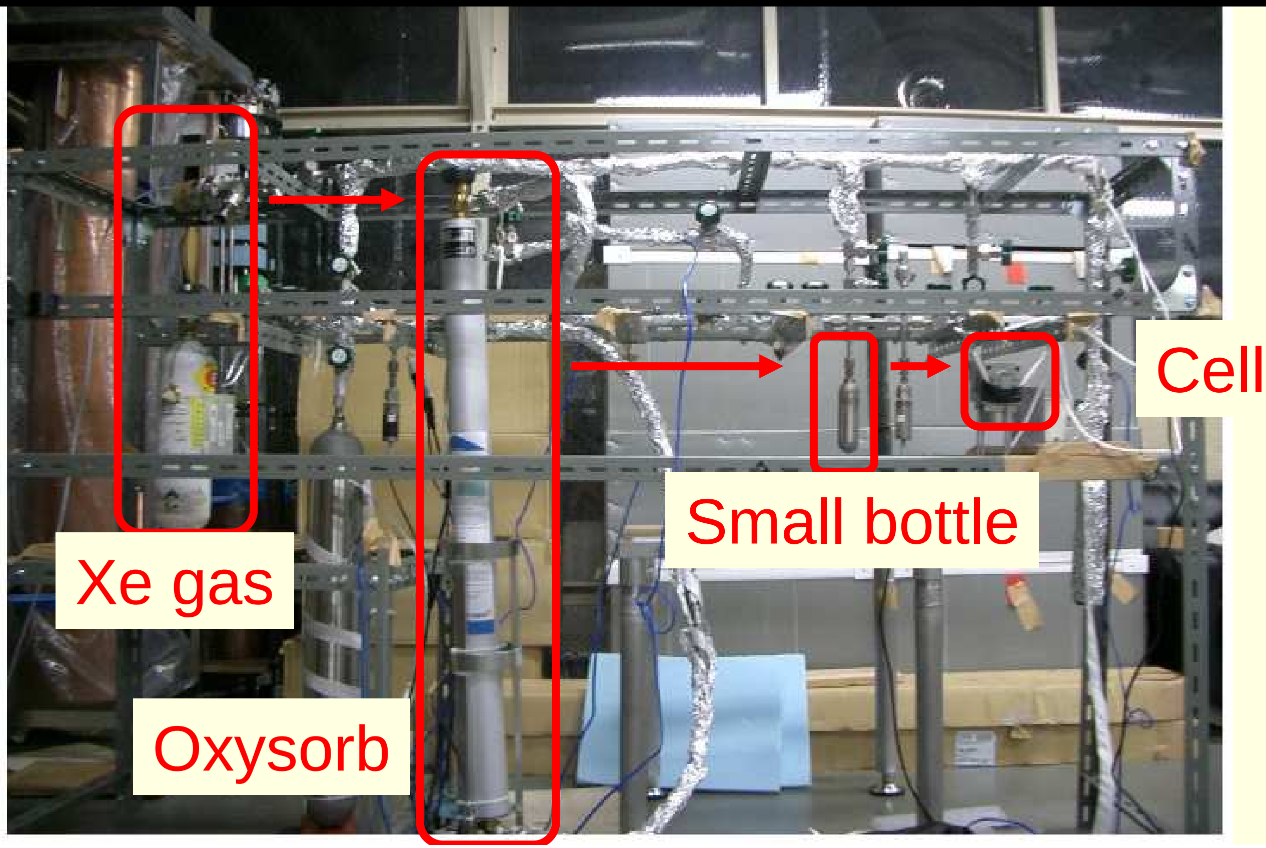
3. Study ELT for collecting photon efficiently

   MC simulation and prototype

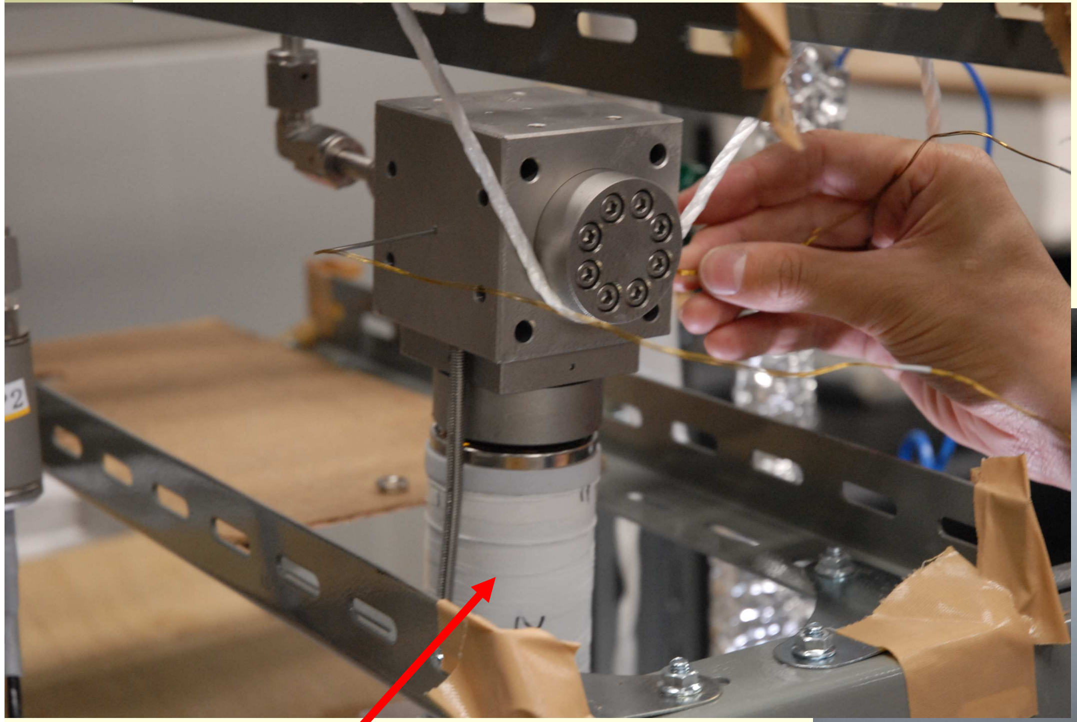
1. Measurement of light yield at room temperature.

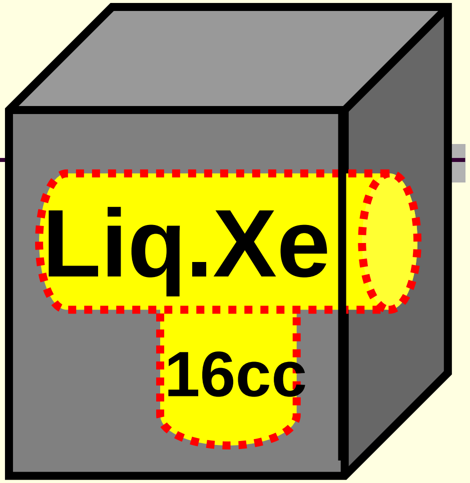
We produced liquid Xe at 1degree, 5.5MPa

Piping for producing high pressure liquid Xe

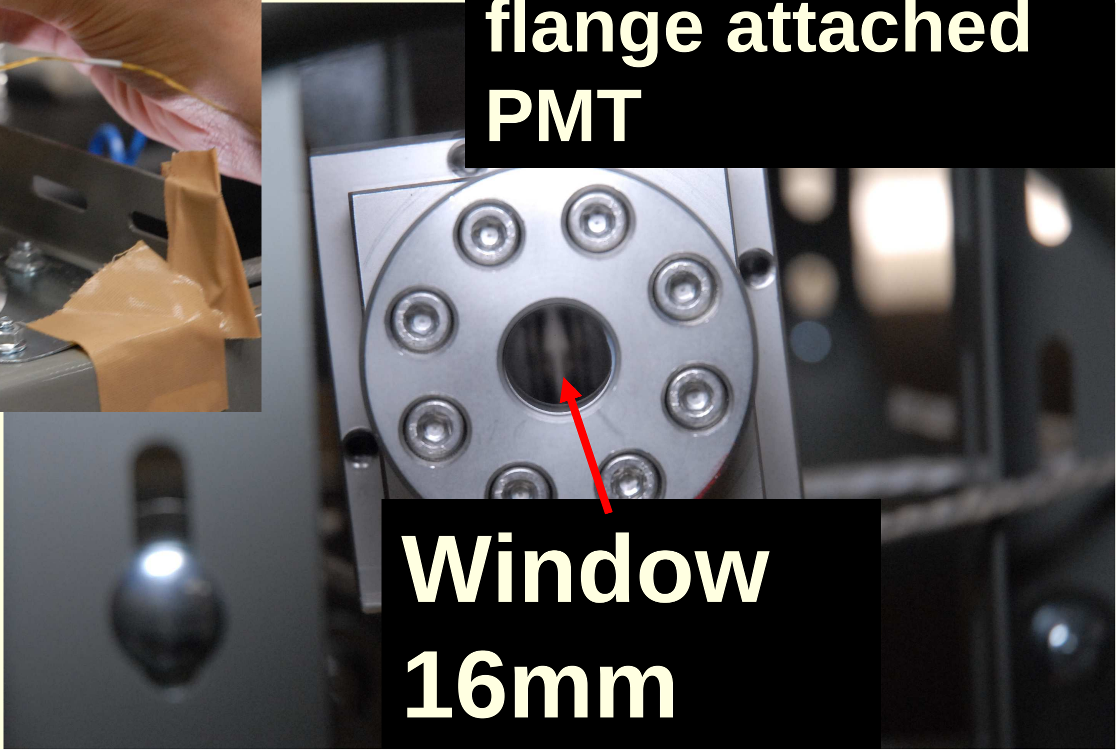


Cell





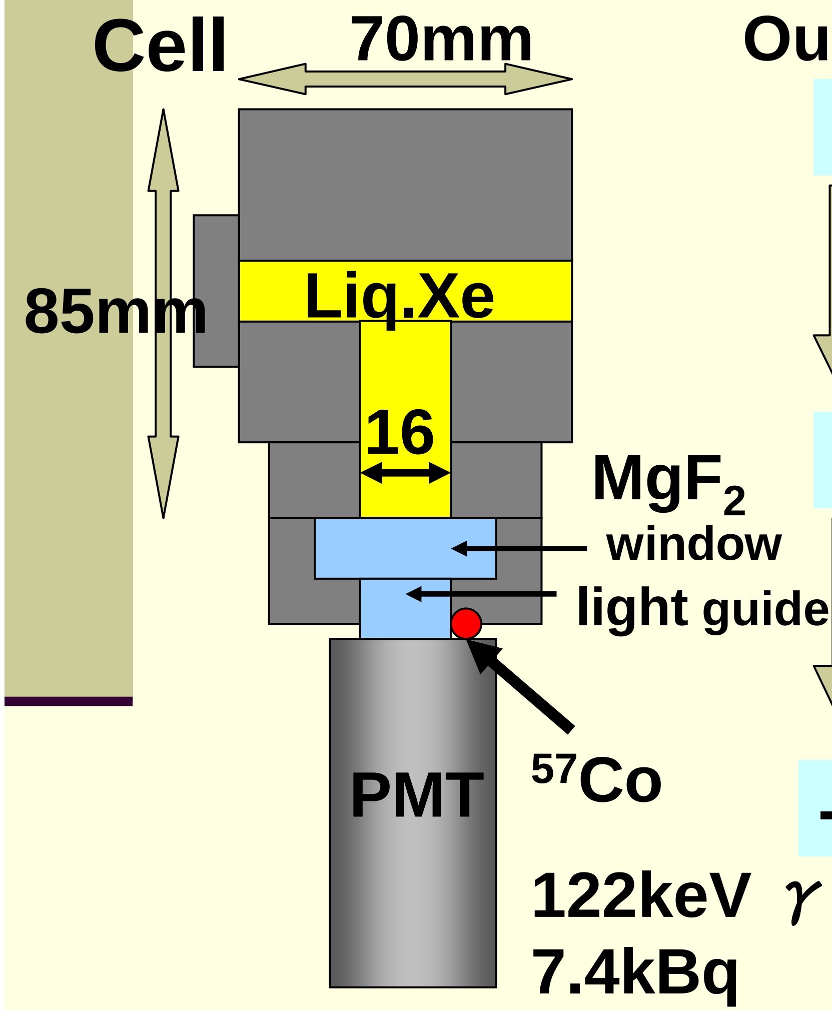
flange attached PMT



Attached PMT

Window 16mm

Measurement of light yield at room temperature.



Outline

1degree,5.5MPa

Cool down liquid Xe temperature, measured temperature dependence

-100degree,4.5MPa

Reduce liquid Xe pressure, measured pressure dependence

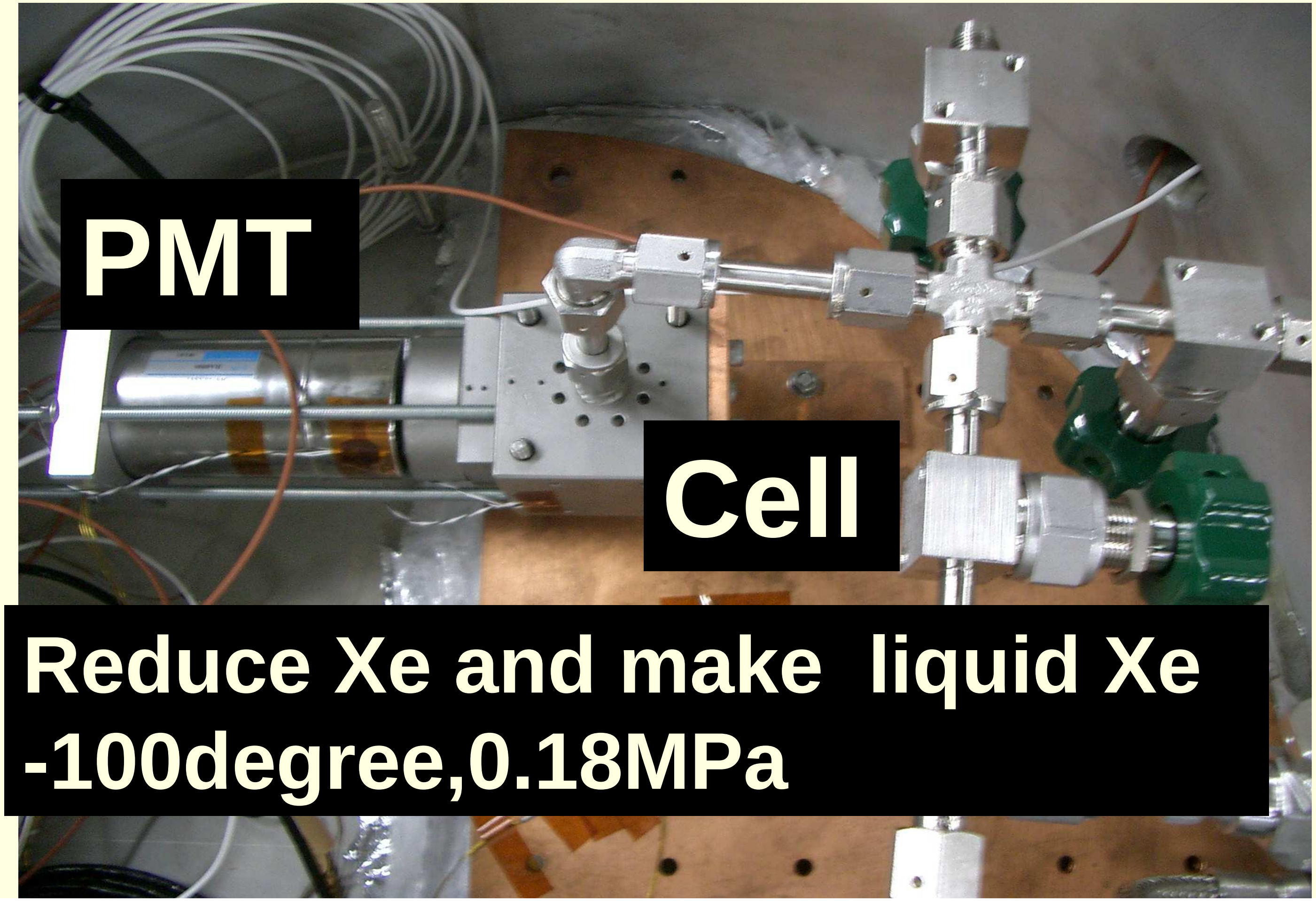
Compared

-100degree,0.18MPa

Well known scintillation yield

Measurement of light yield at room temperature and high pressure .

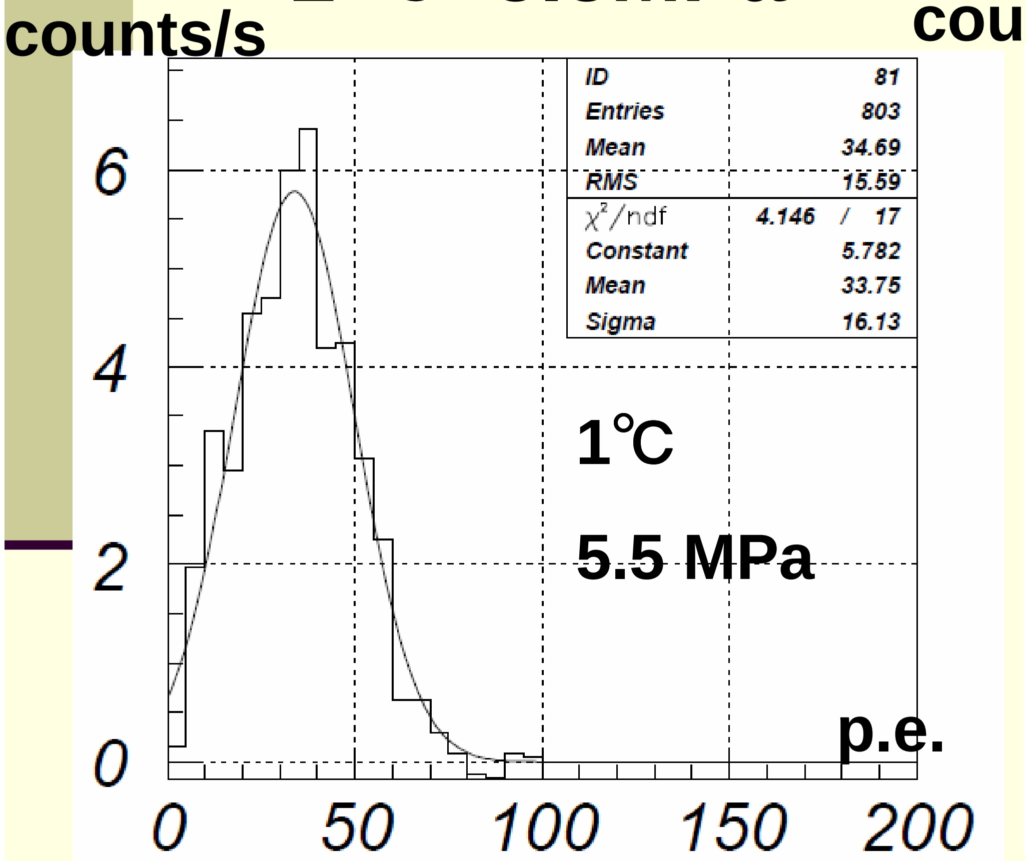
We measured and compared light yield of liquid Xe at 1degree and at -100degree.



Temperature dependence

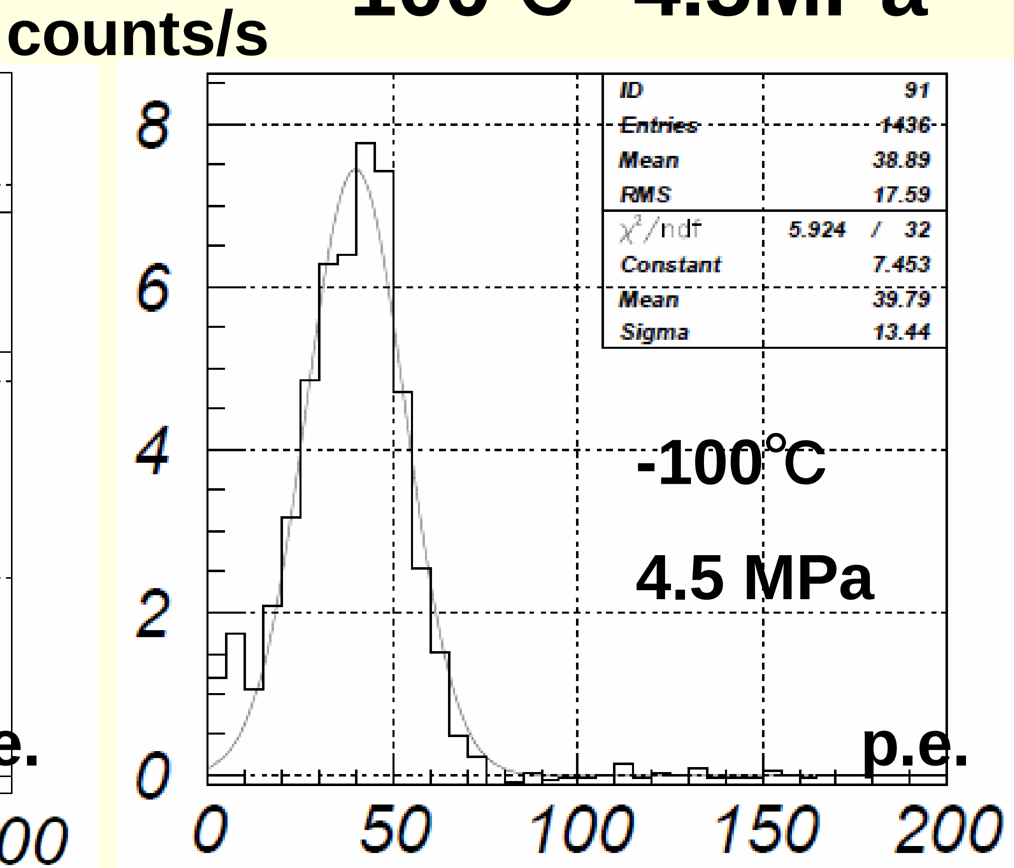
^{57}Co 122keV γ

1 ℃ 5.5MPa



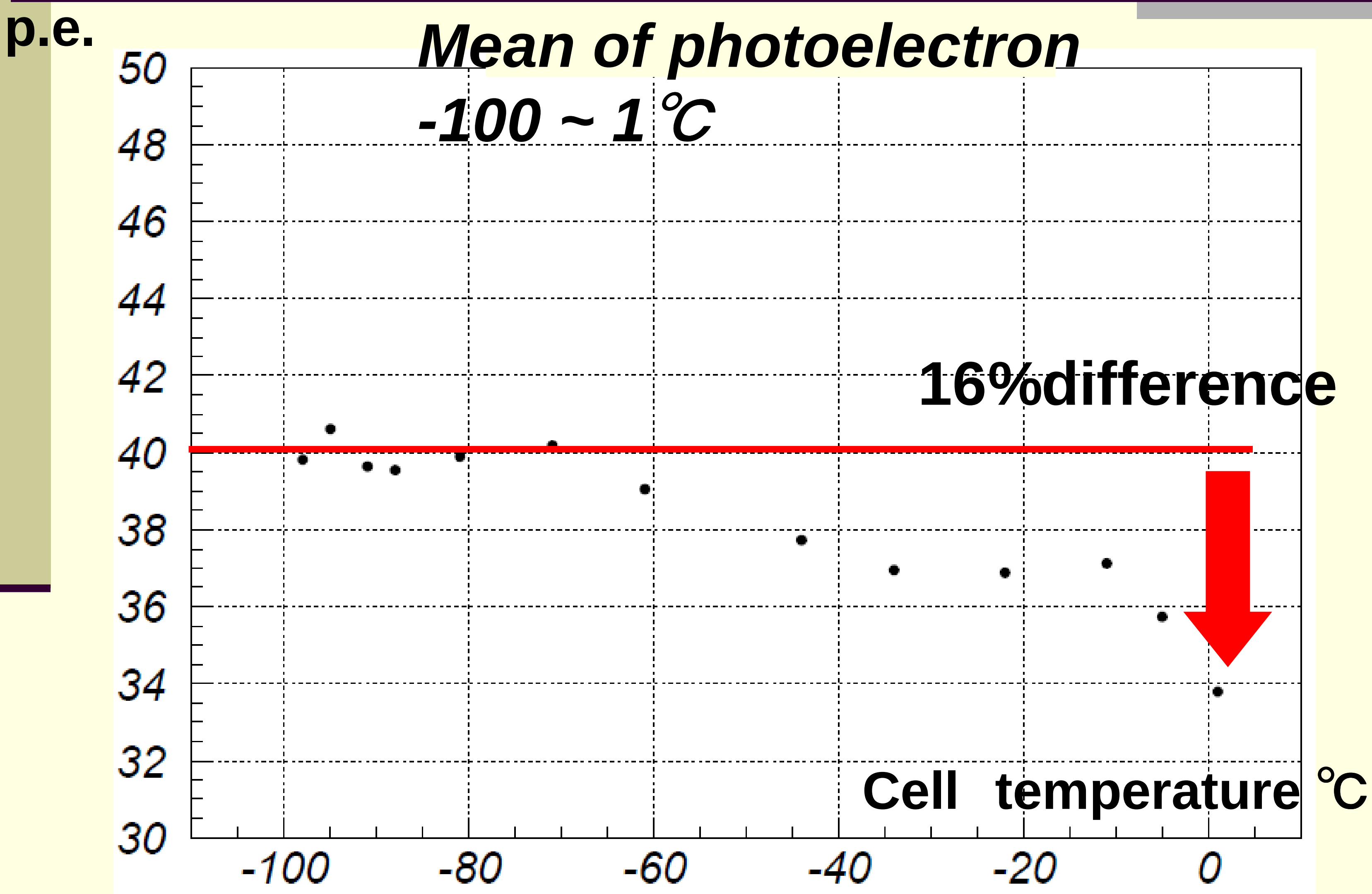
33.8±0.6p.e.

-100℃ 4.5MPa

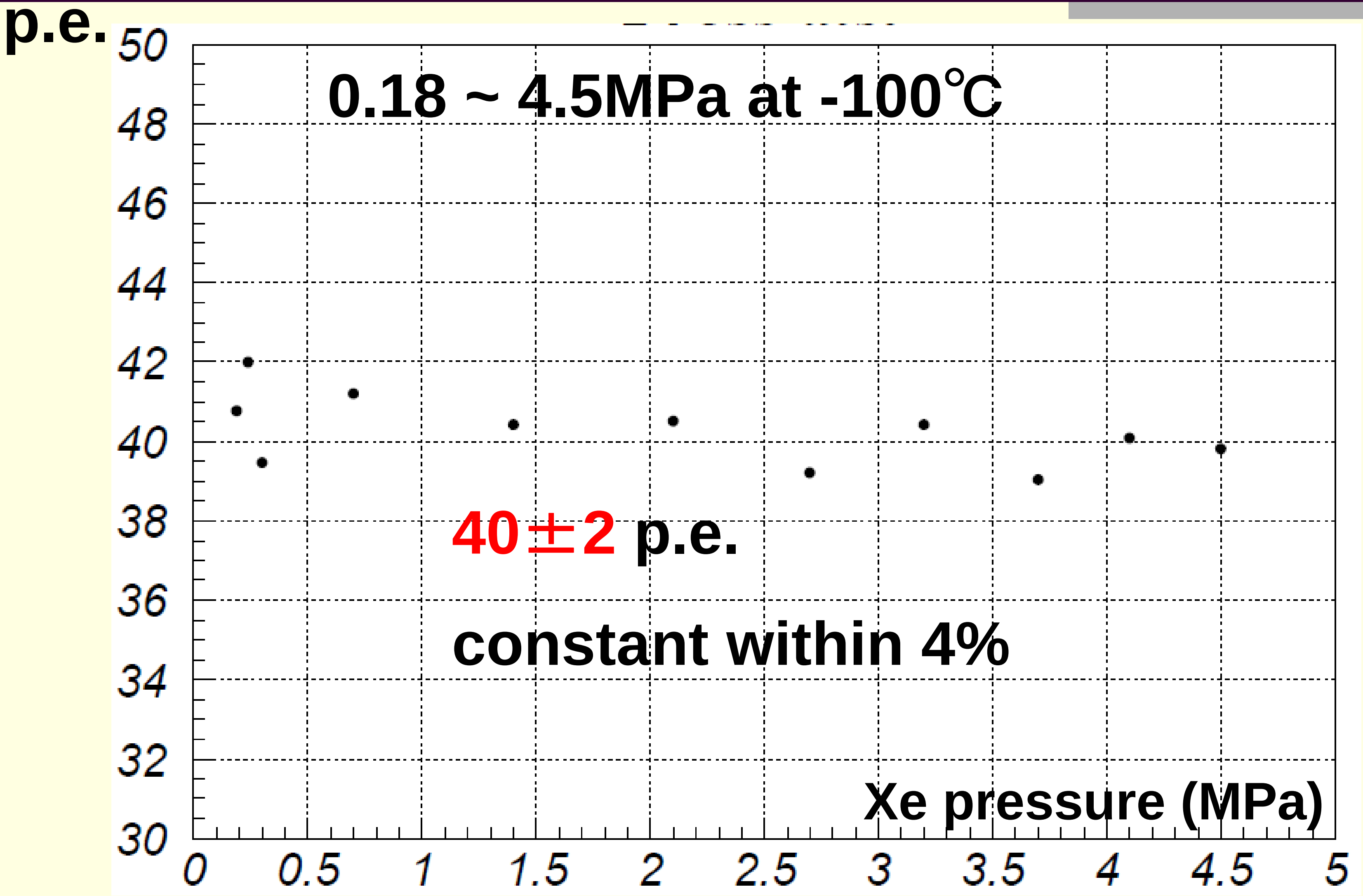


39.8±0.6p.e.

Temperature dependence (@~ 5MPa)



Pressure dependence (@-100℃)



Results for scintillation yield

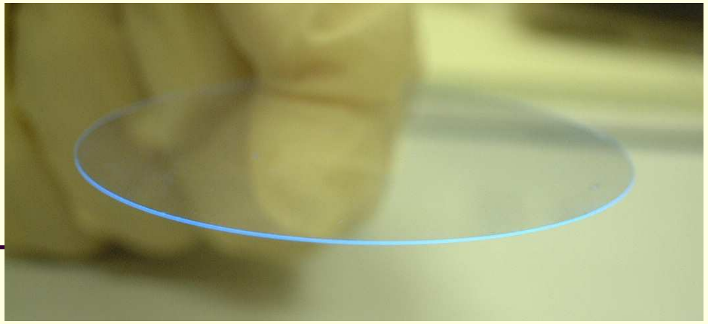
- Large light yield even at room temperature.
- pressure dependence

$$\frac{\textbf{0.18MPa.}}{\textbf{4.5MPa}} = \mathbf{0.98 \pm 0.02 \pm 0.04}$$

- temperature dependece

$$\frac{\textbf{Room temp.}}{\textbf{-100degree}} = \mathbf{0.84 \pm 0.02 \pm 0.06}$$

2. Wavelength shifter



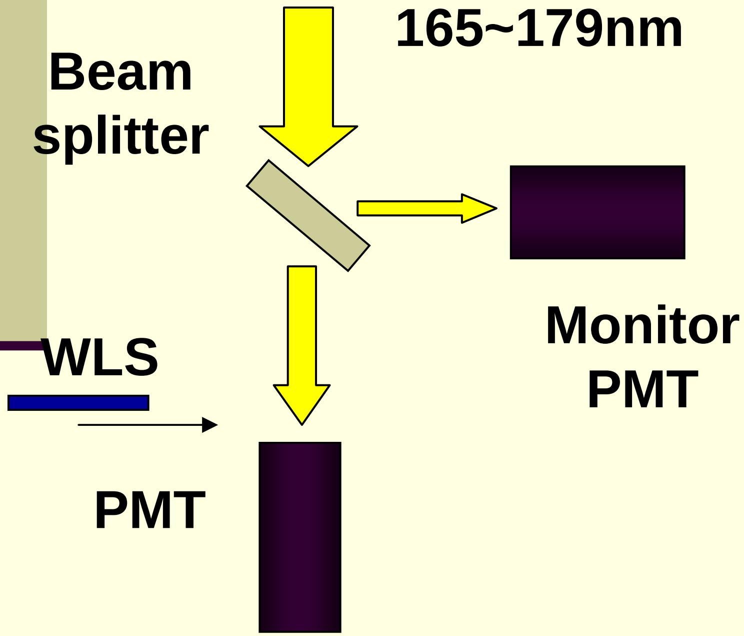
0.5% TPB doped PS, 100μm

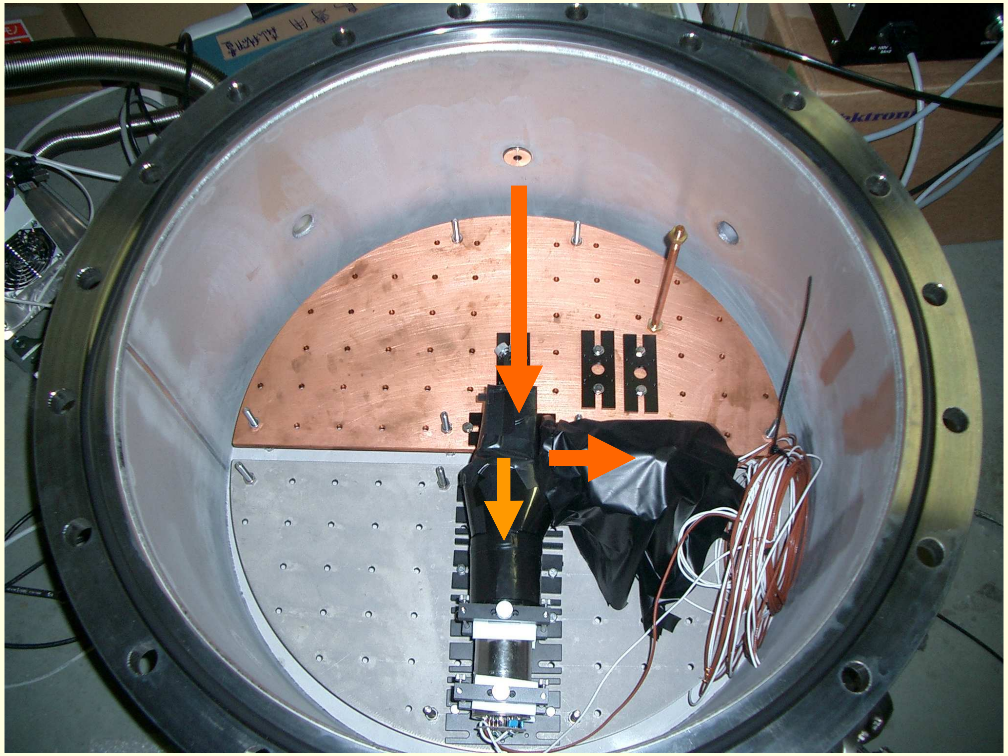
We have developed TPB doped polystyrene (PS) as WLS. High wavelength shift efficiency was measured by D.N.Mckinsey et.al. only for 75nm and 48nm (NIMB 132 (1997) 351-358)

We developed TPB doped in PS 0.5~4% and measured conversion efficiency for 175nm.

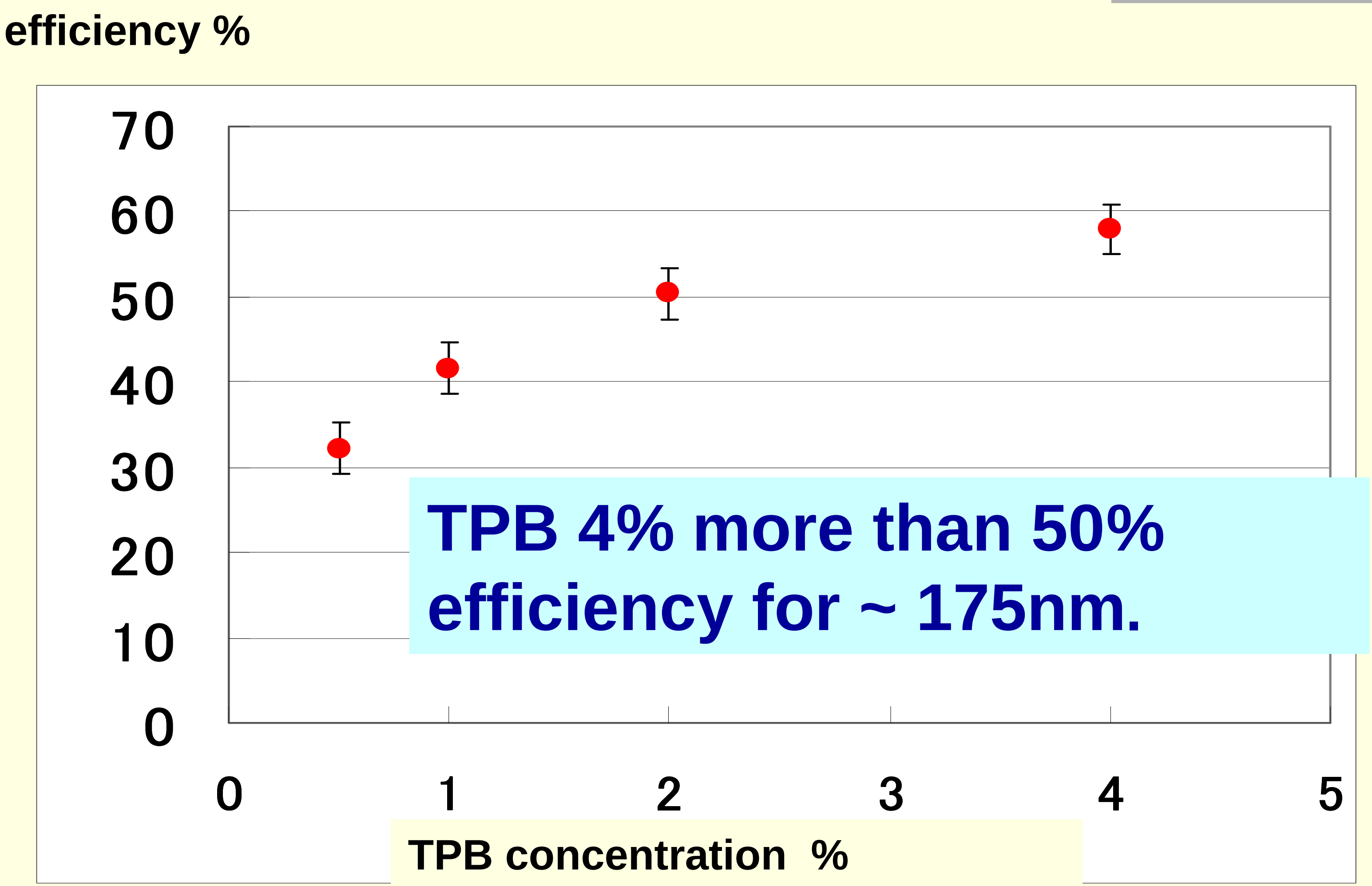
Wavelength shifter

Xe Excimer lamp
165~179nm

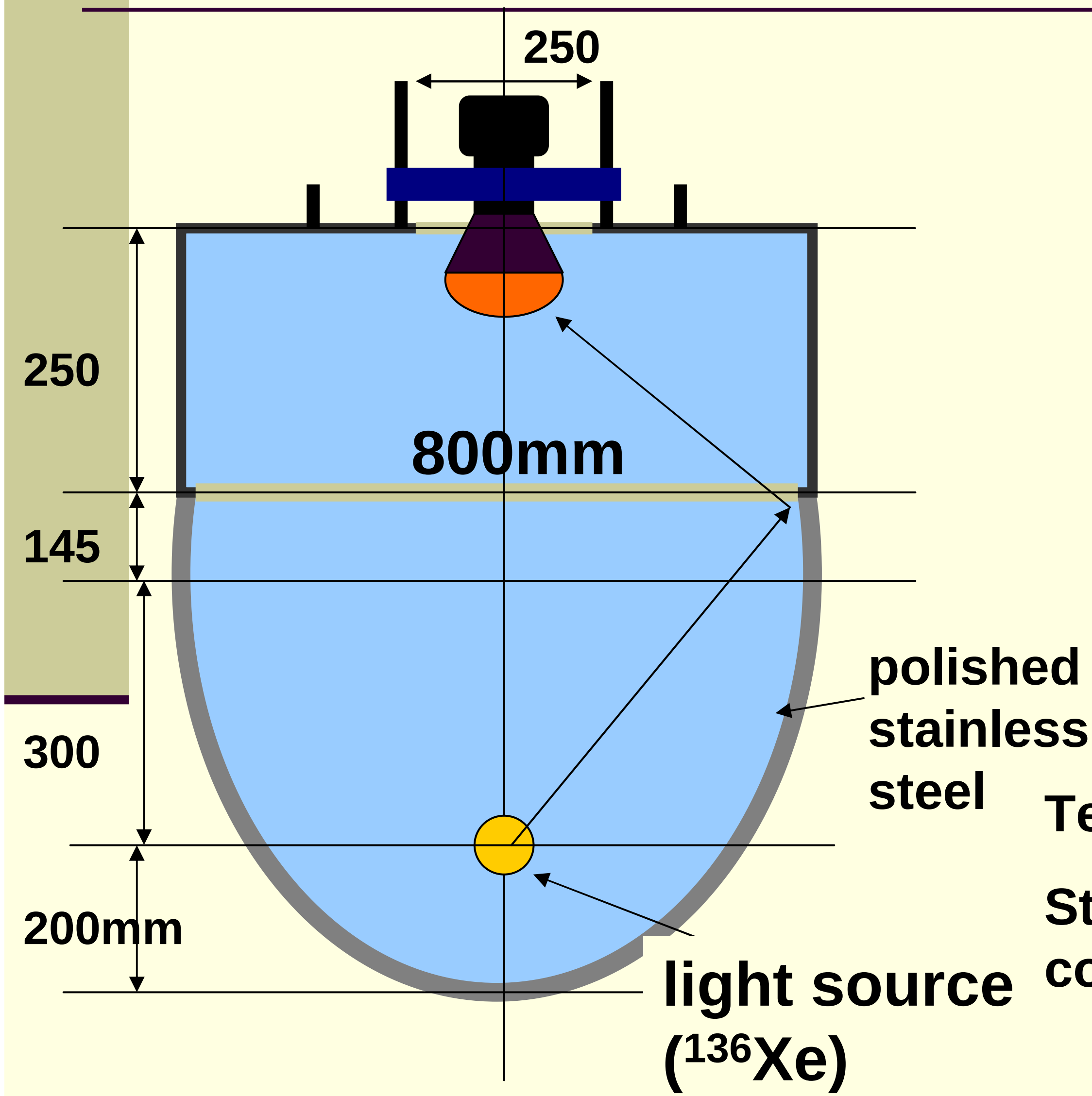




Result of conversion efficiency



3. Prototype ELT

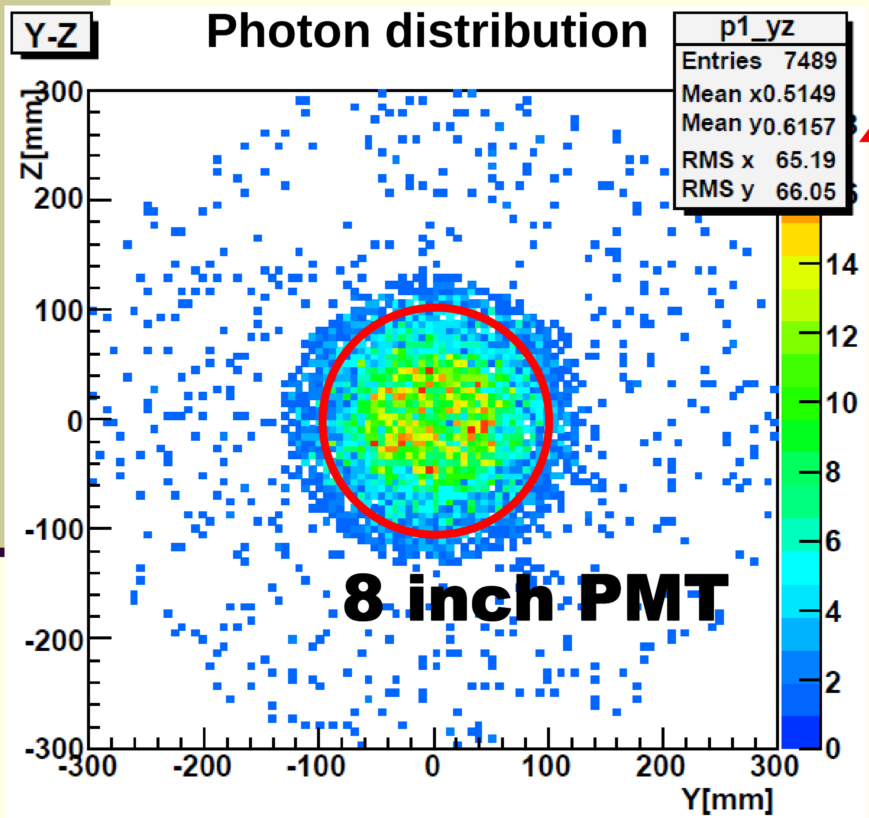


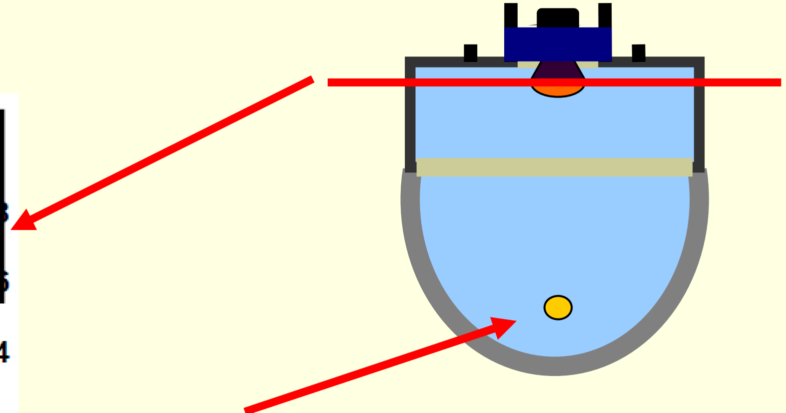
Test photon collection efficiency.

Start to measure photon collection efficiency.

Simulation of prototype ELT

– **Arrival position of photons on this plane**





Generate photon at the light source (on ϕ54mm sphere).

Water and LXe absorption and scattering. Reflection 80%

Photon collection efficiency 53% with a 8inch PMT is expected .

Current summary of R&D

- The photon yield of liquid Xe at room temperature is large.
- We developed TPB wave length shifter with an efficiency of 50%.
- Prototype ELT is being constructed.

Assuming ~ 50% of ELT photon collection efficiency

Expected number of photoelectron at $0\nu\beta\beta$

35photon/keV ×2.5MeV×0.5(wavelength shifter eff.)×0.5(ELT photo collection eff.)×0.25(PMT Q.E.) = ***5400photoelectron***

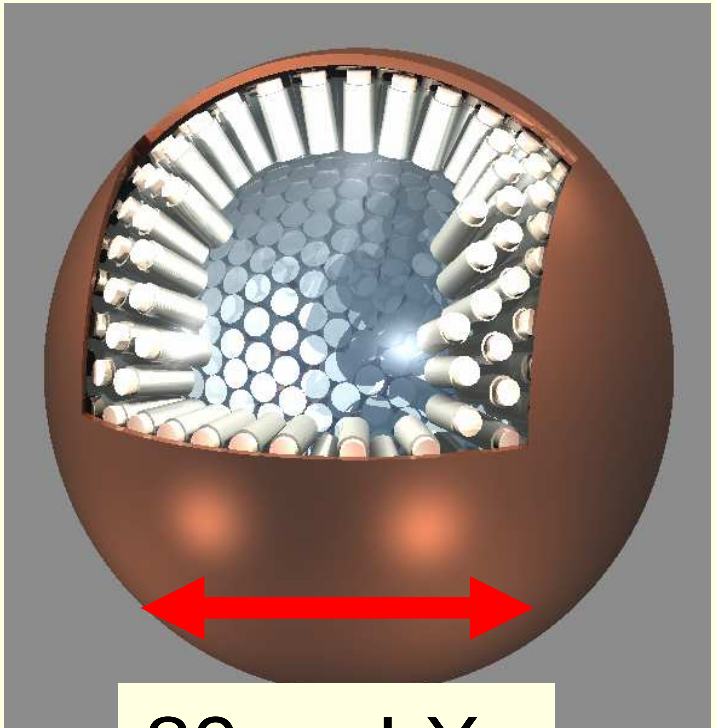
Energy resolution due to photon statistics is 1.4%.

Meet our requirement.

800kg detector for Dark Matter search

- Budget funded this year.
- We are starting detail design of the detector.
  - Detector structure
  - Purification system
  - Cooling system
  - Electronics and etc…..
- Excavation for the detector site at Kamioka mine will start soon.
- Plan to finish the construction in two years and start measurement from 2009.

Structure of 800kg detector



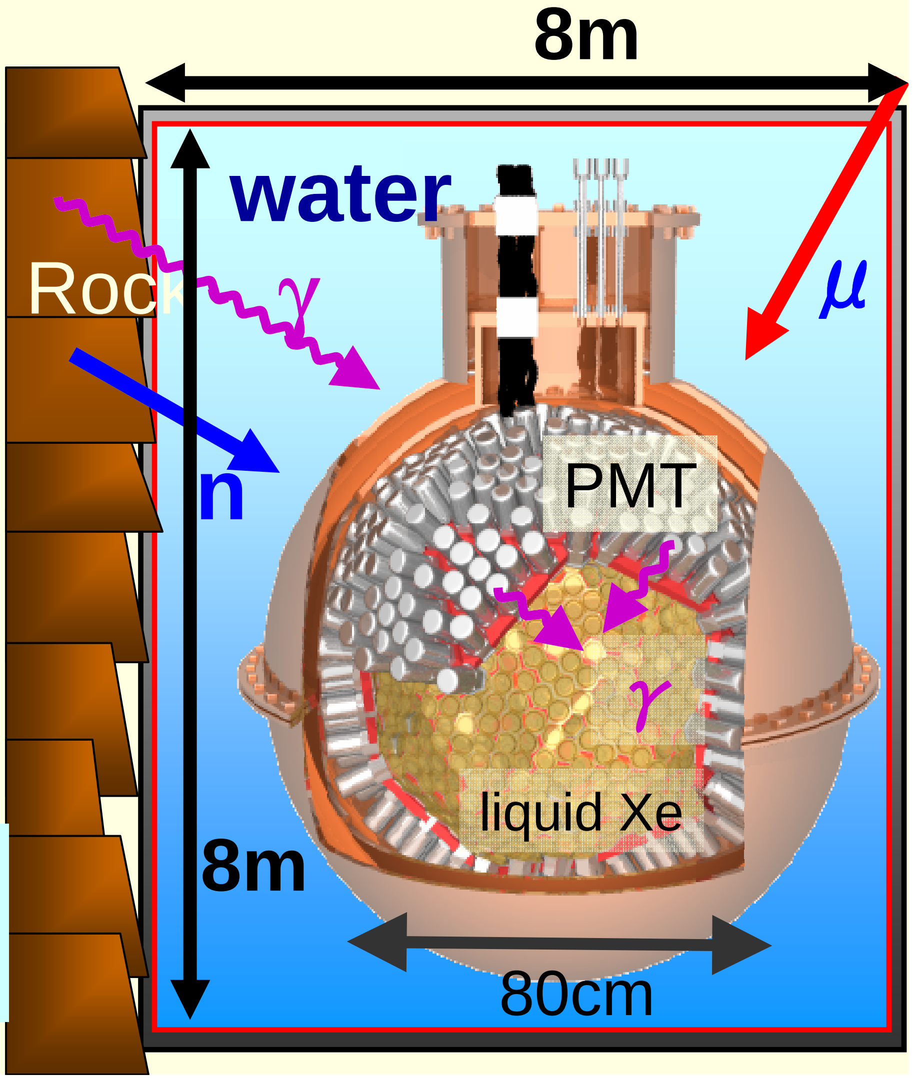
80cm LXe
(40cm FV)

- liquid Xe 800kg (FV 100kg)
- Total 812 PMTs
- Photo coverage 67%
- Diameter of LXe: 80cm
- Diameter of FV: 40cm
- PMTs immersed in LXe

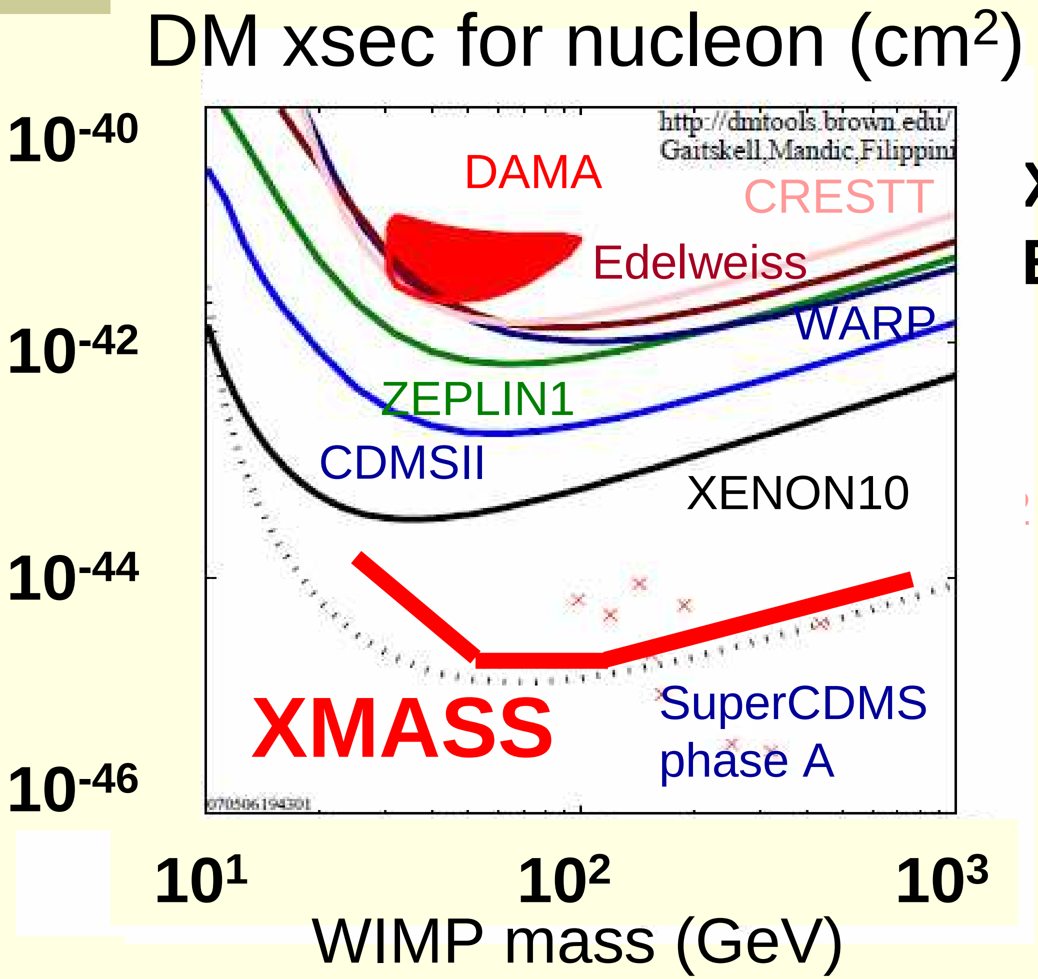
BG estimation

- PMT gamma background
  - Reduced by self shielding
- External gamma
  - Reduced by water shield
- Neutron
  - Reduced by water shield
- Internal gamma/beta
  - Reduced by distillation

Detail simulation predicts
<10^{-4} counts/day/kg/keV



Sensitivity of 800kg detector



XMASS exposure 0.5 ton yr
Eth = 5 keVee, 3σ discovery

~ factor 100 improvements expected

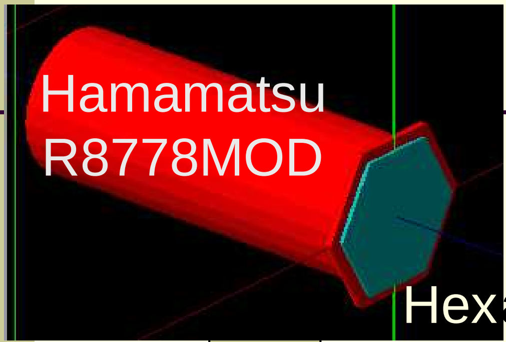
$\sim 10^{-45}$ cm^2

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

Summary

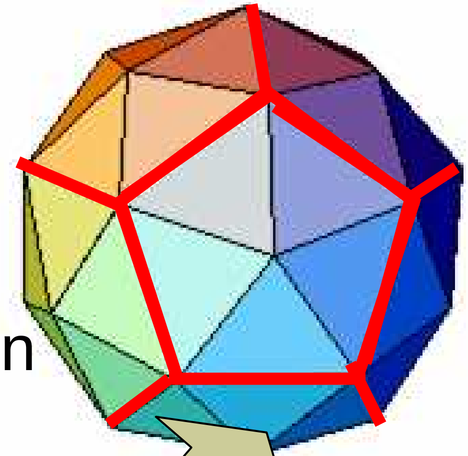
- R&D for double beta decay has been performed.
- Observed Light yield (35photon/keV) of liquid Xe at room temperature. We developed TPB wavelength shifter (50% conversion efficiency) and made prototype ELT.
- We are going to start construction of 800kg detector for dark matter search which has sensitivity of 10^{-45} cm^2 .

Structure of 800kg detector

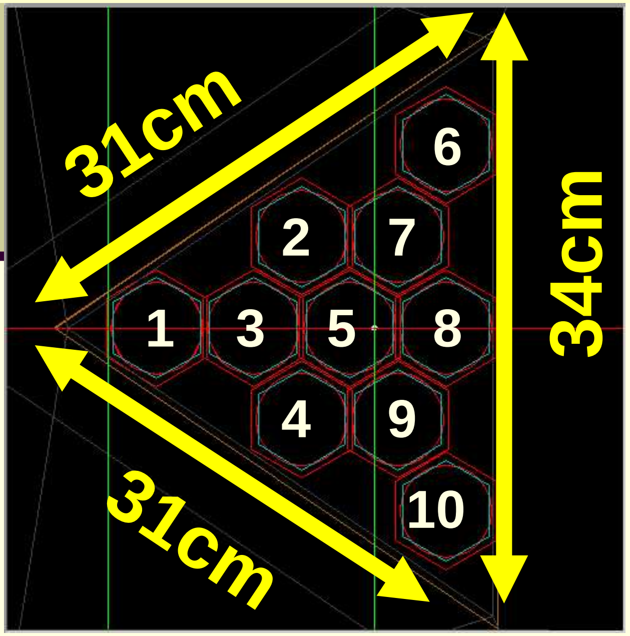


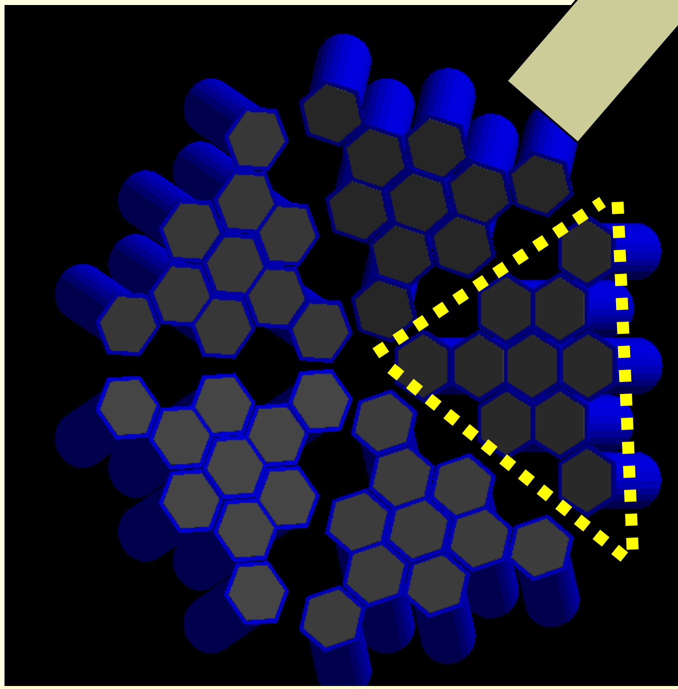
Hexagonal
quarts window

12 pyramids /
pentakisdodecahedron



10 PMTs per 1 triangle





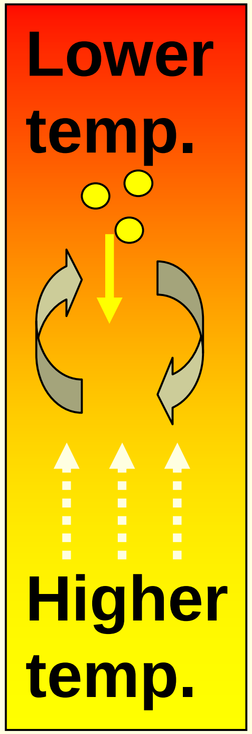
5 triangles make pentagonal pyramid

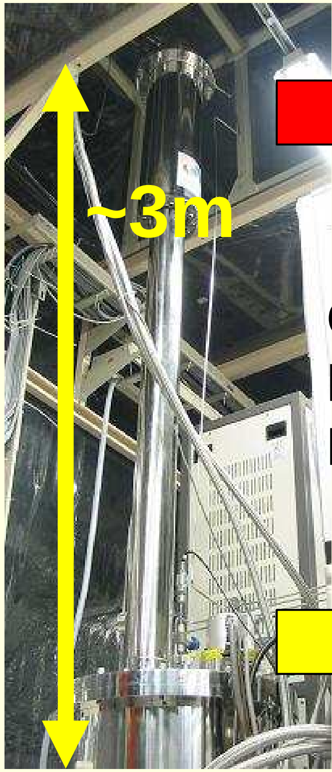
Distillation to reduce Kr (1/1000 by 1 pass)

- 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



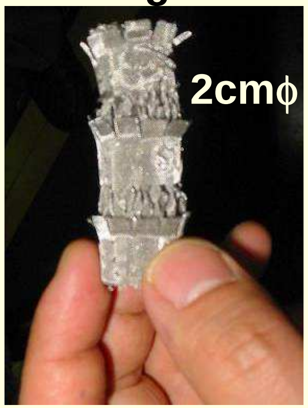


~1%

Off gas Xe:
330±100 ppb Kr
(measured)

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

13 stage of



~99%

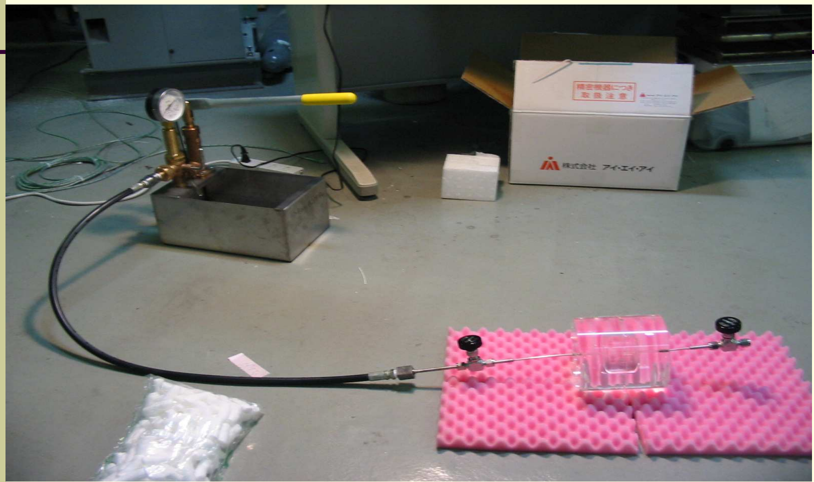
Purified Xe:
< 5 ppt Kr
(measured after Kr-enrichment)

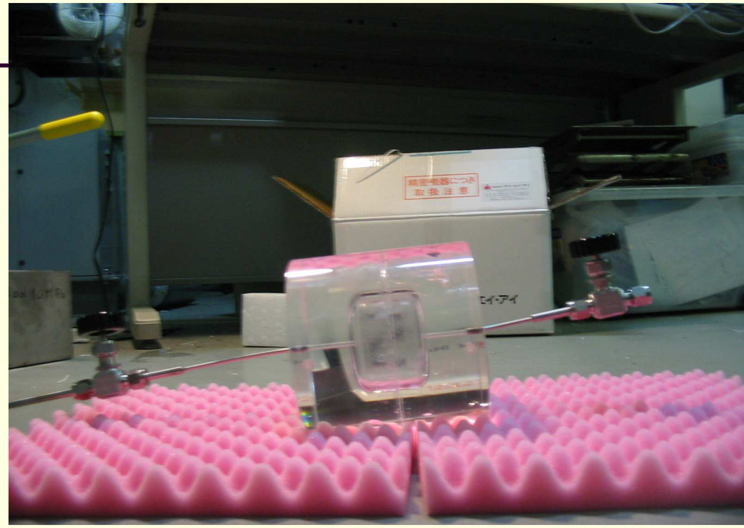
Summary of BG measurement

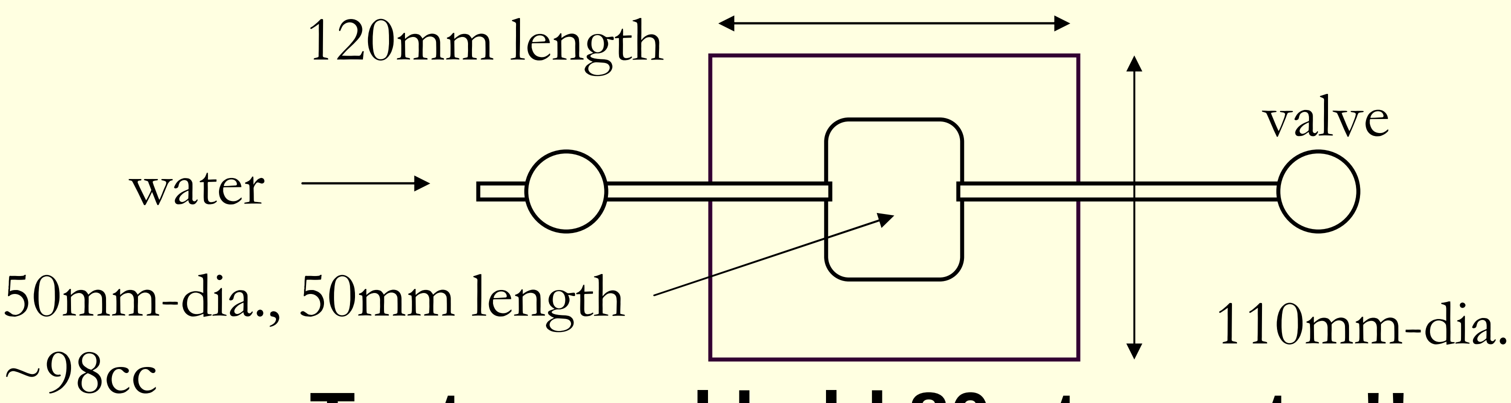
Now (prototype detector)		Goal (800kg detector)
γ ray BG ~ 10^{-2} cpd/kg/keV → Increase volume for self shielding → Decrease radioactive impurities in PMTs (~1/10)	1/100 →	10^{-4} cpd/kg/keV
^{238}U = $(33\pm7)\times10^{-14}$ g/g → Remove by filter	1/33 →	1×10^{-14} g/g
^{232}Th < 23×10^{-14} g/g (90% C.L.) → Remove by filter (Only upper limit)	1/12 →	2×10^{-14} g/g
Kr = 3.3±1.1 ppt → Achieve by 2 purification pass	1/3 →	1 ppt

Very near to the target level!

Acrylic vessel as high pressure vessel

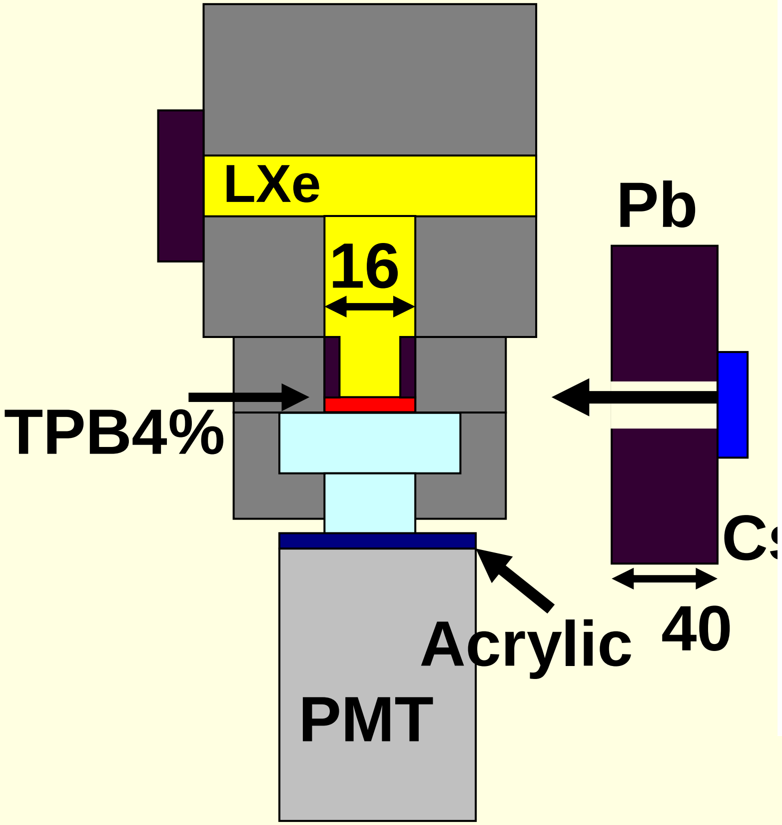


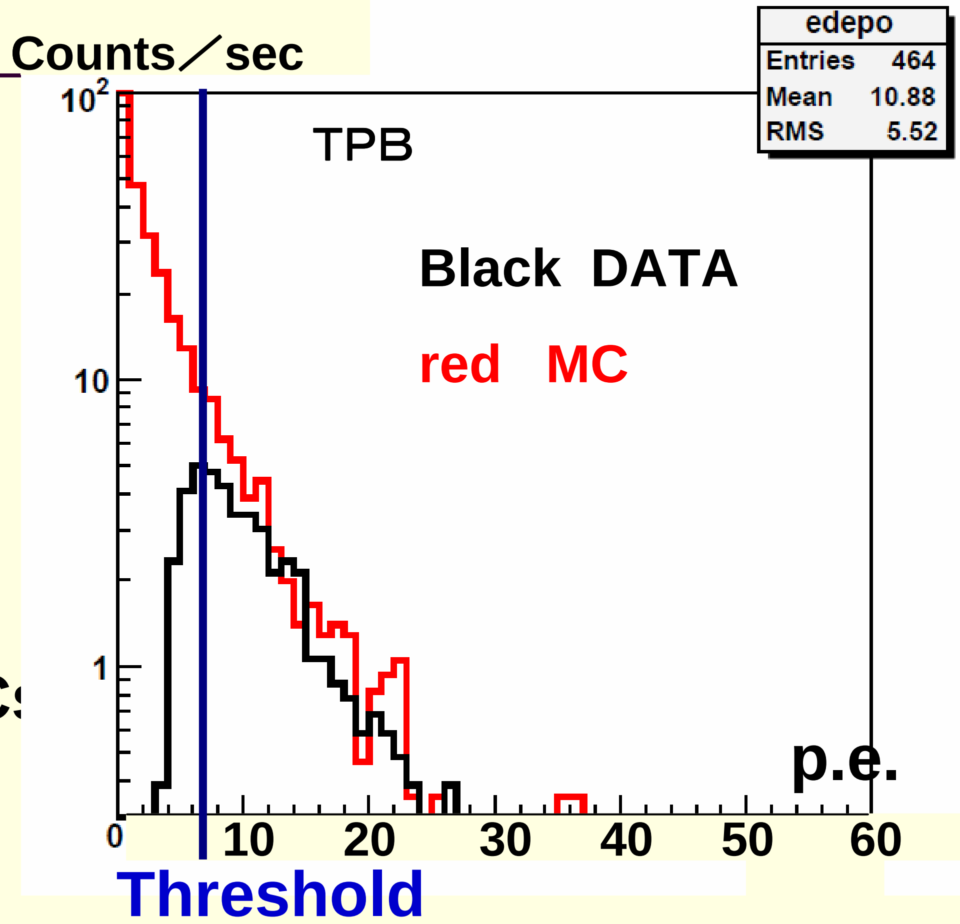




Test vessel held 80 atm water!!

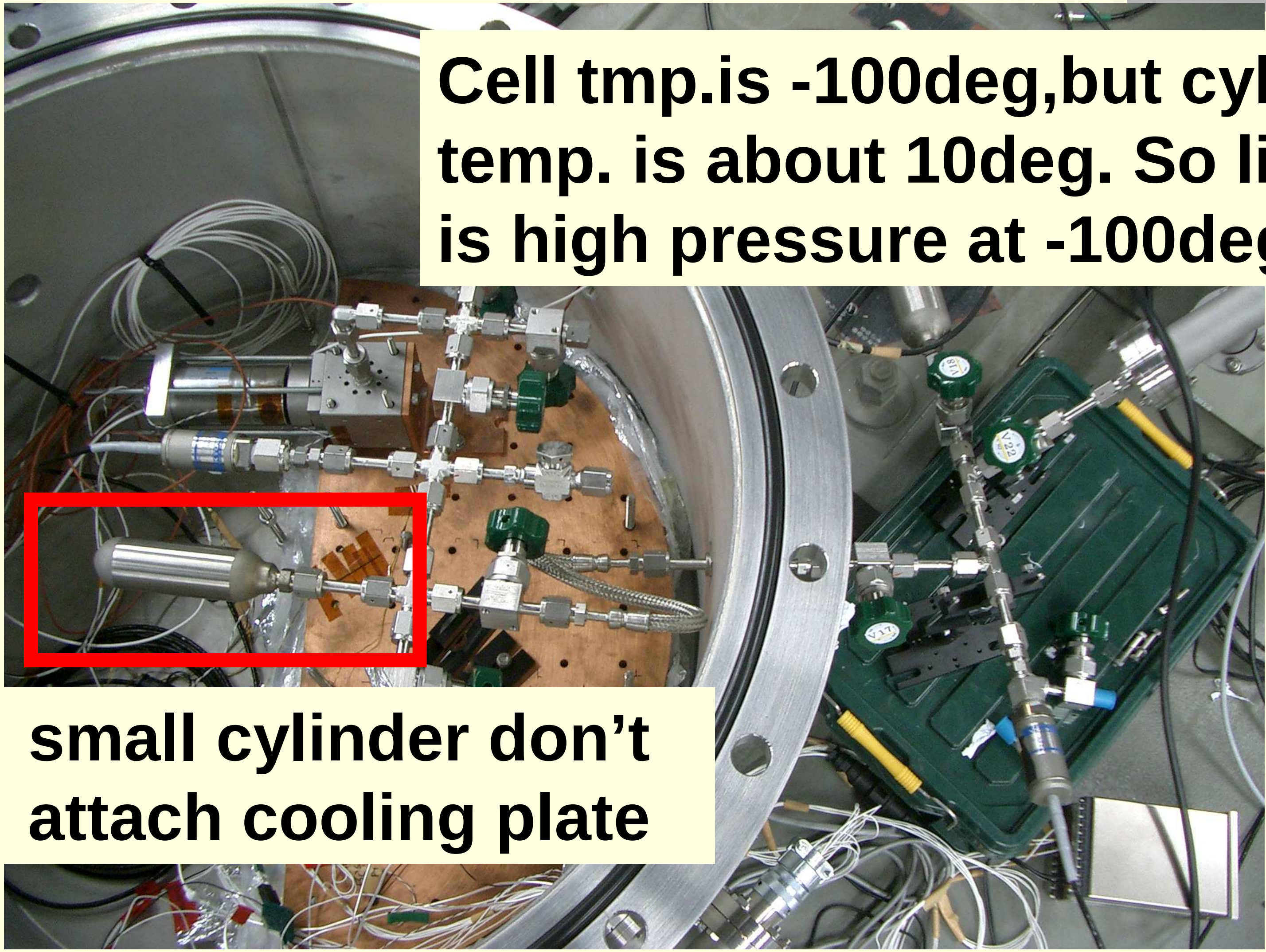
Need to test using high pressure liquid Xe (dissolution material)





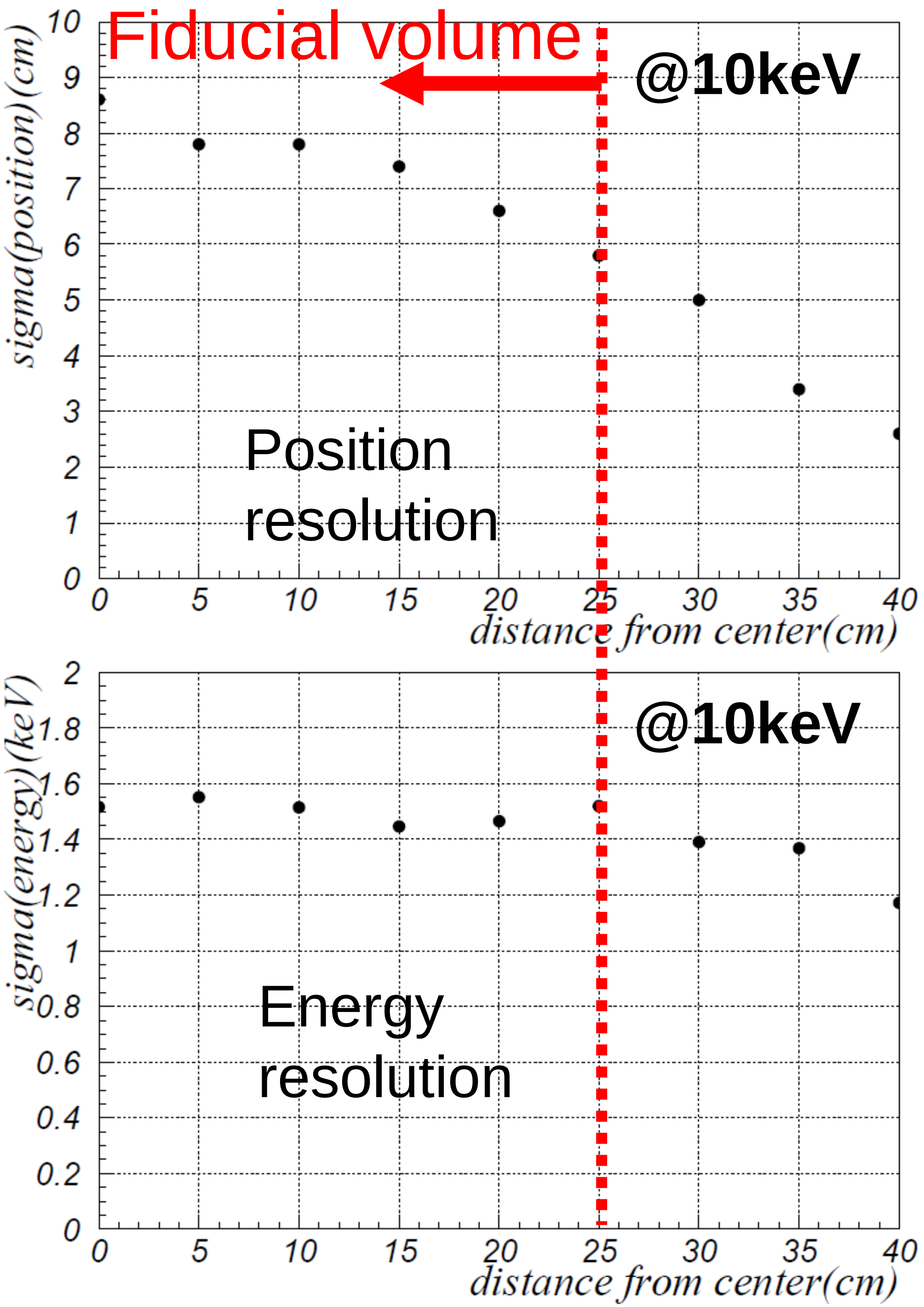
Conversion efficiency 20%

low temp. high pressure



➢PMT BG

- Reconstruction of event
  - Key part for self shielding
  - Basic part is same as the one confirmed in 100kg detector.
  - Method
    - Make grid point at every certain lengths.
    - Make the p.e. map for all PMTs at the grid points.
    - Use the event data and this map, calculate the event's likelihood.
    - Answer is the point which gives the maximum likelihood.



Kamioka underground laboratory

☆ Depth = 1000 m (2700 m.w.e.)

☆ γ ray flux = 0.71 cm^{-2} s^{-1}

☆ μ flux ~ 10^{-7} cm^{-2} s^{-1} *1

→ 10^{-5} reduction of the ground flux

☆ neutron flux

$\phi_{thermal}$ = 8.3×10^{-6} cm^{-2} s^{-1} (E < 0.5 eV)

$\phi_{non\ thermal}$ = 1.2×10^{-6} cm^{-2} s^{-1} (E > 0.5 eV)

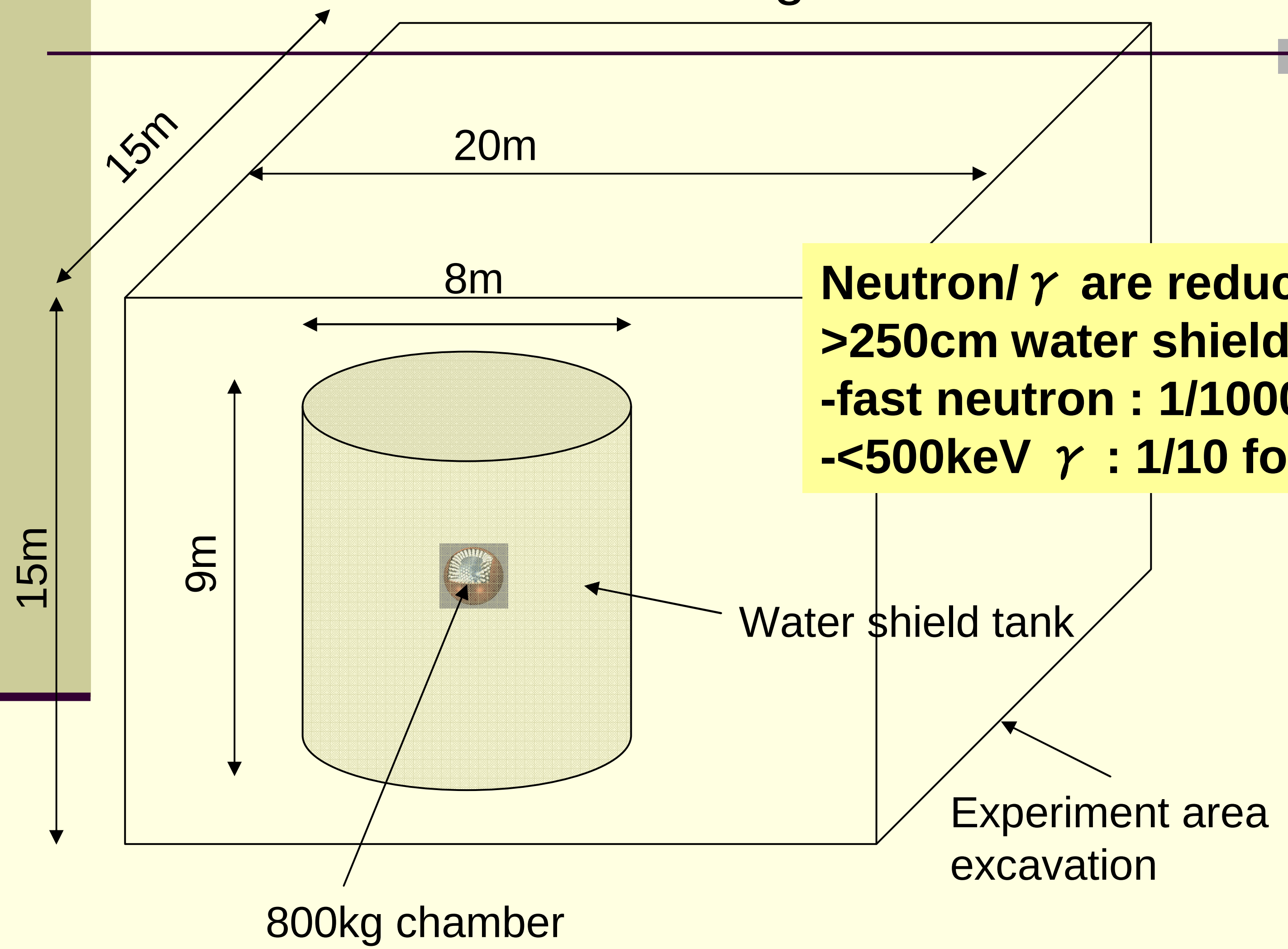
→ ~10^{-3} reduction of the ground flux

→ Good place for dark matter search (and ν observation)

1 SuperKamiokade Collaboration

New excavation will be made in kamioka mine.

※Tentative design



Neutron/γ are reduced
>250cm water shield
-fast neutron : 1/10000 for 2m shield
-<500keV γ : 1/10 for 50cm shield

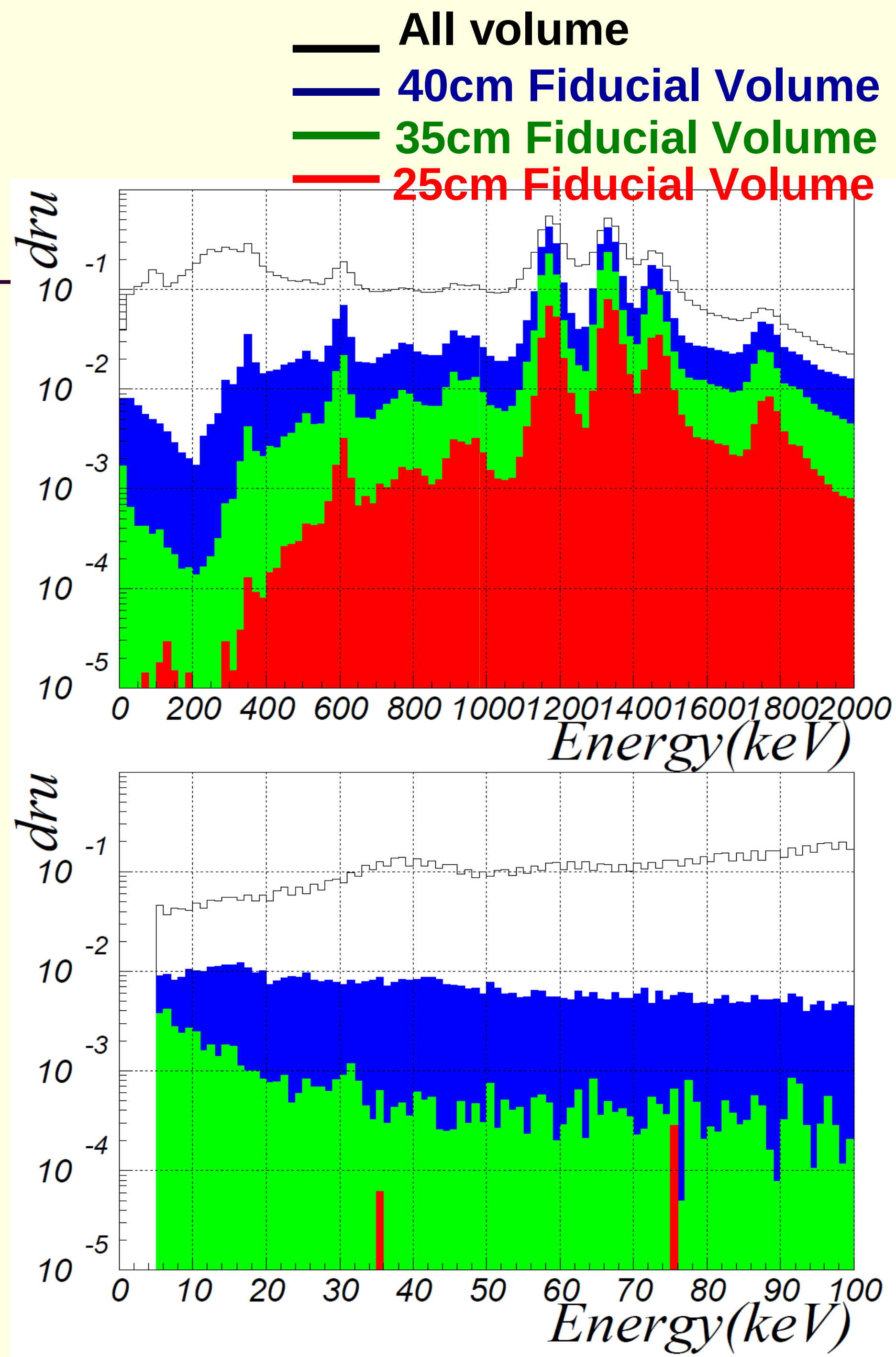
Other similar scale experiment such as DBD will be housed.

Estimation of gamma background from PMT

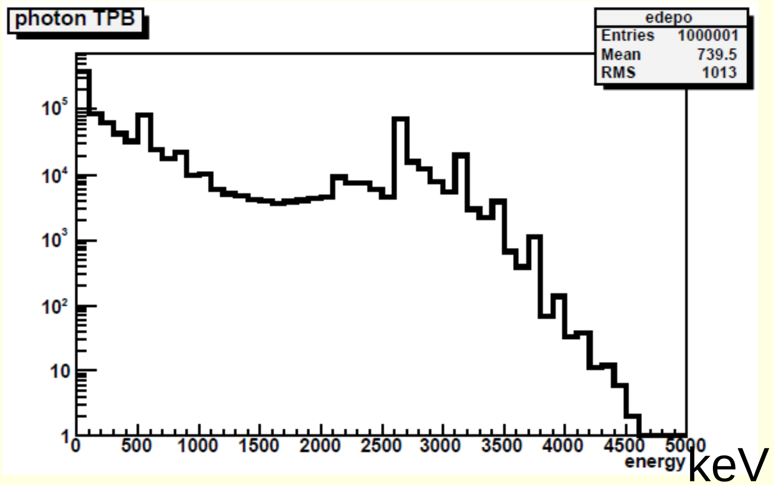
- One of the main BG source
- Reconstruction of event position is crucial.
- Activity of PMT
  - PMT used in 100kg detector
    - **^{238}U chain 1.8x10^{-2} Bq/PMT**
    - **^{232}Th chain 6.9x10^{-3} Bq/PMT**
    - **^{60}Co 5.5x10^{-3} Bq/PMT**
    - **^{40}K 1.4x10^{-1} Bq/PMT**
  - PMT to be used in 800kg detector
    - **^{238}U chain 1.8x10^{-3} Bq/PMT**
    - **^{232}Th chain 6.9x10^{-4} Bq/PMT**
    - **^{60}Co 5.5x10^{-3} Bq/PMT**
    - **^{40}K 1.4x10^{-2} Bq/PMT**

Estimated PMT BG

- Activity of PMT
  - ^{238}U chain   1.8x10^{-3} Bq/PMT
  - ^{232}Th chain 6.9x10^{-4} Bq/PMT
  - ^{60}Co   5.5x10^{-3} Bq/PMT
  - ^{40}K   1.4x10^{-2} Bq/PMT
- Below 300 keV number of events in the 25cm fiducial volume(100kg) decreases rapidly
- Below 100 keV,
  BG becomes
  <10^{-5} counts/day/kg/keV.

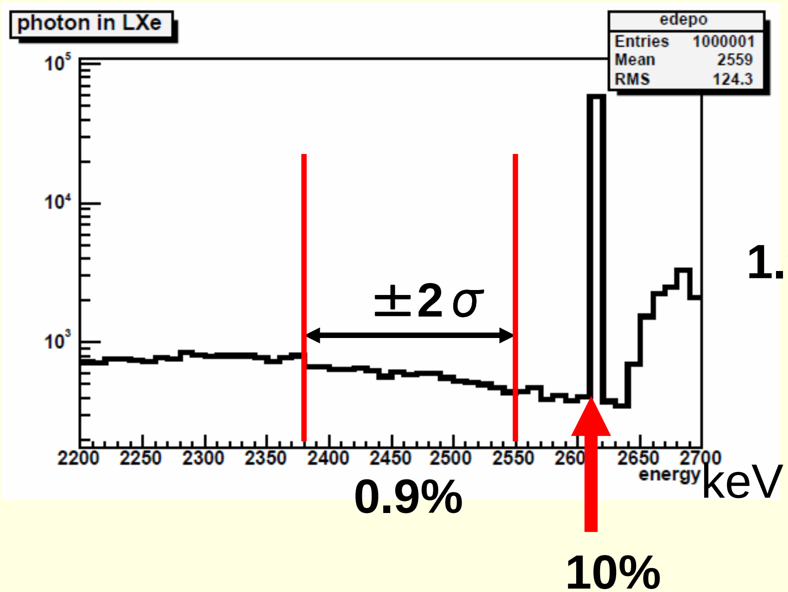


^{208}Tl ~ Vessel BG estimation



Inner 86cm outer 106cm
Sphere acrylic vessel

$10\% \times 0.05 = 0.5\ \%$



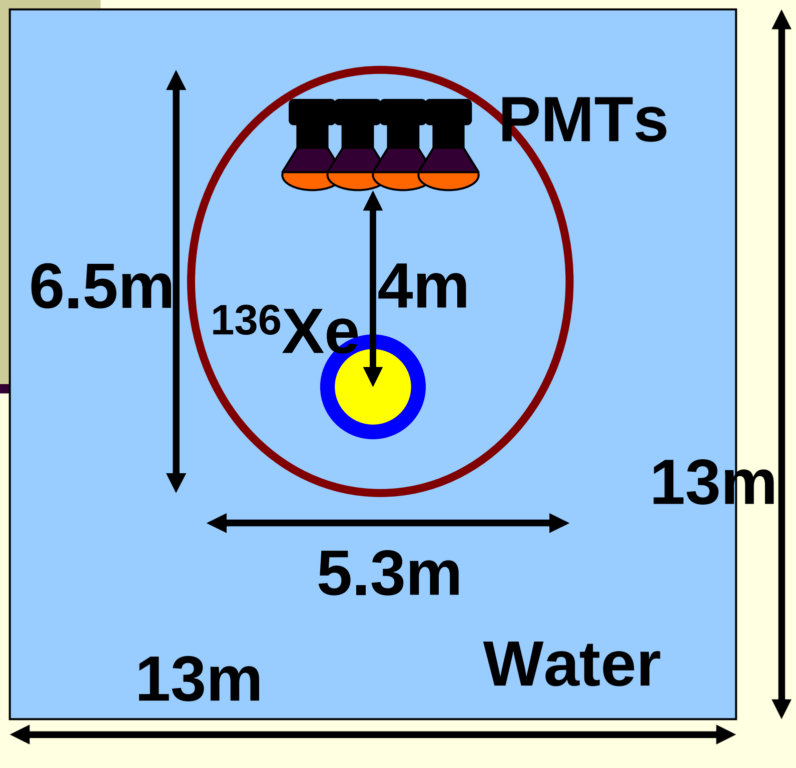
$0.9 + 0.5 = 1.4\ \%$

$\mathbf{1.9 \times 10^{17}}$ **decay/5yr** $\mathbf{\times 1.4\%} = \mathbf{2.7 \times 10^{15}}$ event

Th	$\mathbf{3.7 \times 10^{-16}}$ **g/g**

Design and requirements for ~20meV

- Detector design to achieve ~20meV sensitivity



- **1ton enriched ^{136}Xe: ϕ 90cm acrylic vessel**
- **Outer cylindrical water tank: ϕ13m, height 13m.**
- **Distance btw ^{136}Xe and PMTs: 4m.**
- **Vessel: U,Th 10^{-16}g/g.**