XMASS experiment

特定宇宙ニュートリノ研究会第9回
8th May 2002 @ 東京都立大学

S. Moriyama (ICRR)
For XMASS collaboration

●XMASS

◎ Xenon MASSive detector for Solar neutrino (pp/^{7}Be)
◎ Xenon detector for Weakly Interacting MASSive Particles (Dark Matter search)
◎ Xenon neutrino MASS detector (double beta decay)

1. Introduction
2. Sensitivity for double beta decay detection
3. Other techniques and sensitivity
4. Summary

XMASS collaboration

- ICRR, Kamioka observatory

Y. Suzuki, M. Nakahata, Y. Itow, M. Shiozawa, Y. Takeuchi, S. Moriyama, T. Namba, M. Miura, Y. Koshio, Y. Fukuda, S. Fukuda,

- ICRR, RCNN

T. Kajita, K. Kaneyuki, A. Okada, M. Ishitsuka

- Saga Univ.

T. Tsukamoto, H. Ohsumi, Y. Iimori,

- Niigata Univ.

K. Miyano, K. Ito

- Tokai Univ.

K. Nishijima, T. Hashimoto

- Gifu Univ.

S. Tasaka,

- Waseda Univ.

M. Yamashita, S. Suzuki, K. Kawasaki, J. Kikuchi, T. Doke,

- TIT

Y. Watanabe, K. Ishino,

- Seoul National Univ.

Soo-Bong Kim, In-Seok Kang,

- INR-Kiev

Y. Zdesenko, O. Ponkratenko,

- UCI

H. Sobel, M. Smy, M. Vagins

- YNU

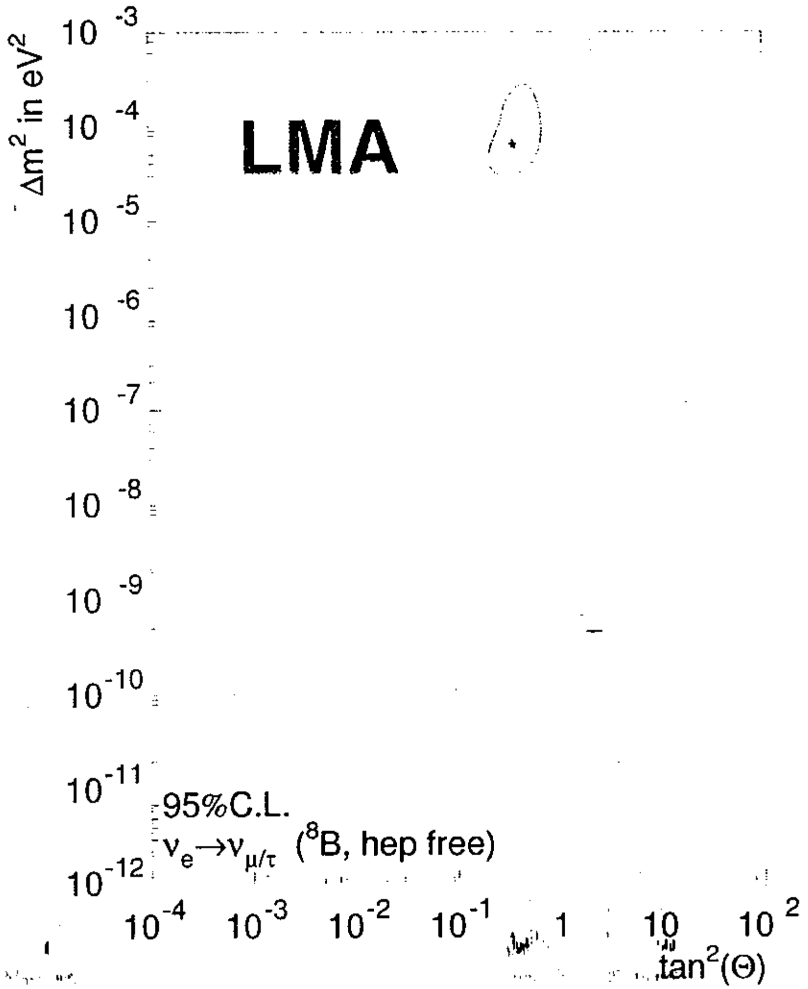
S. Nakamura

1. Introduction

- Goal: low energy solar neutrino detection; pp and ^{7}Be

Low energy solar neutrinos <u>Plenty information for osc. parameters</u>

Electron scattering: $\nu + e \longrightarrow \nu + e$ <u>No need to calibrate σ</u>



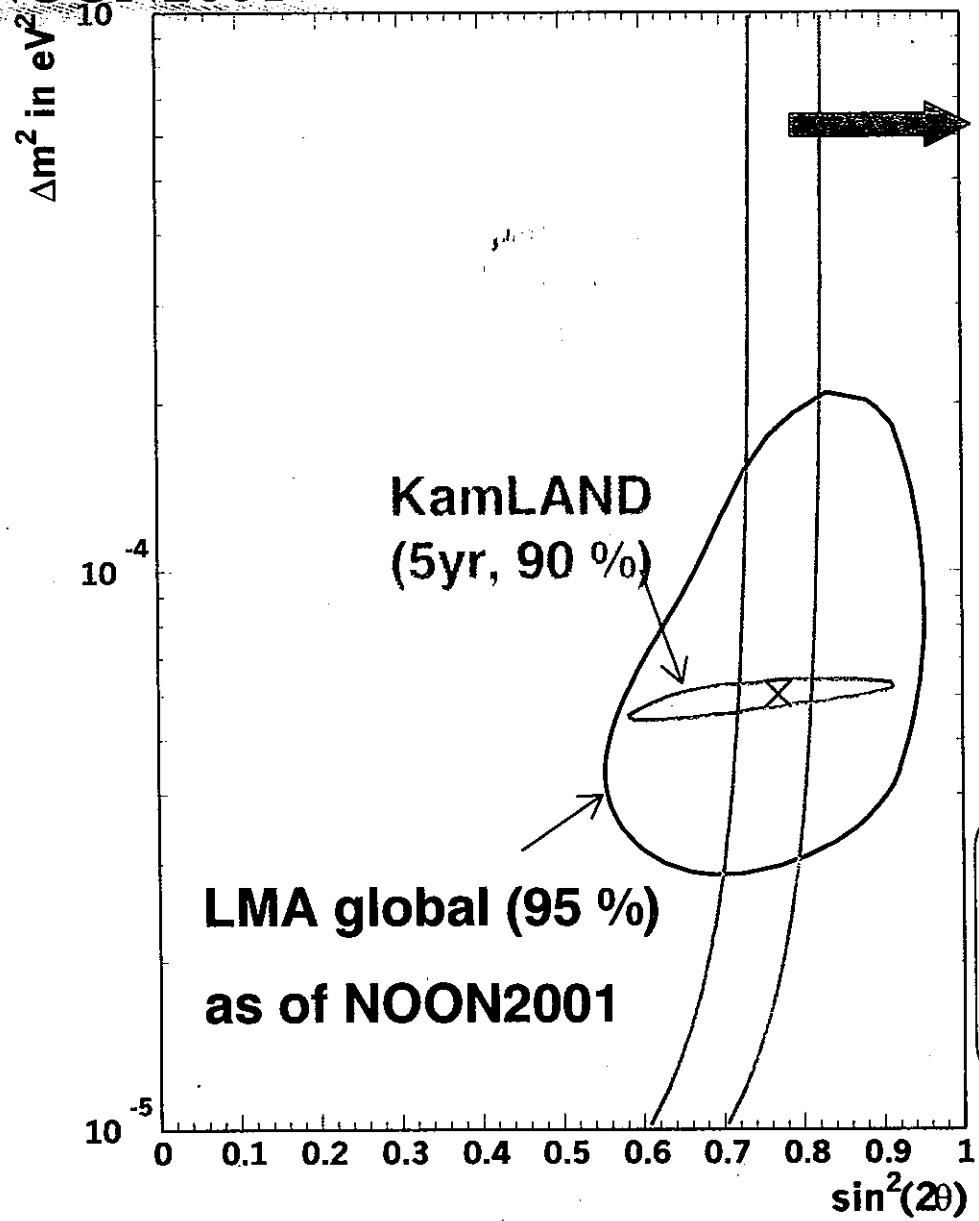
Oscillation parameters
from global analysis

- **Rates: Homestake (Cl), GALLEX (Ga), SAGE (Cl), SK (H2O), SNO (D2O)**
- **Zenith spectra; energy spectra of electrons at 7 zenith angle bins (day + 6 nights) from Super-K**

Even post SNO:
Need to pindown
the oscillation parameters
see Nakahata, NOON2001

M. Nakahata, NOON2001

Sensitivity for two neutrino oscillations



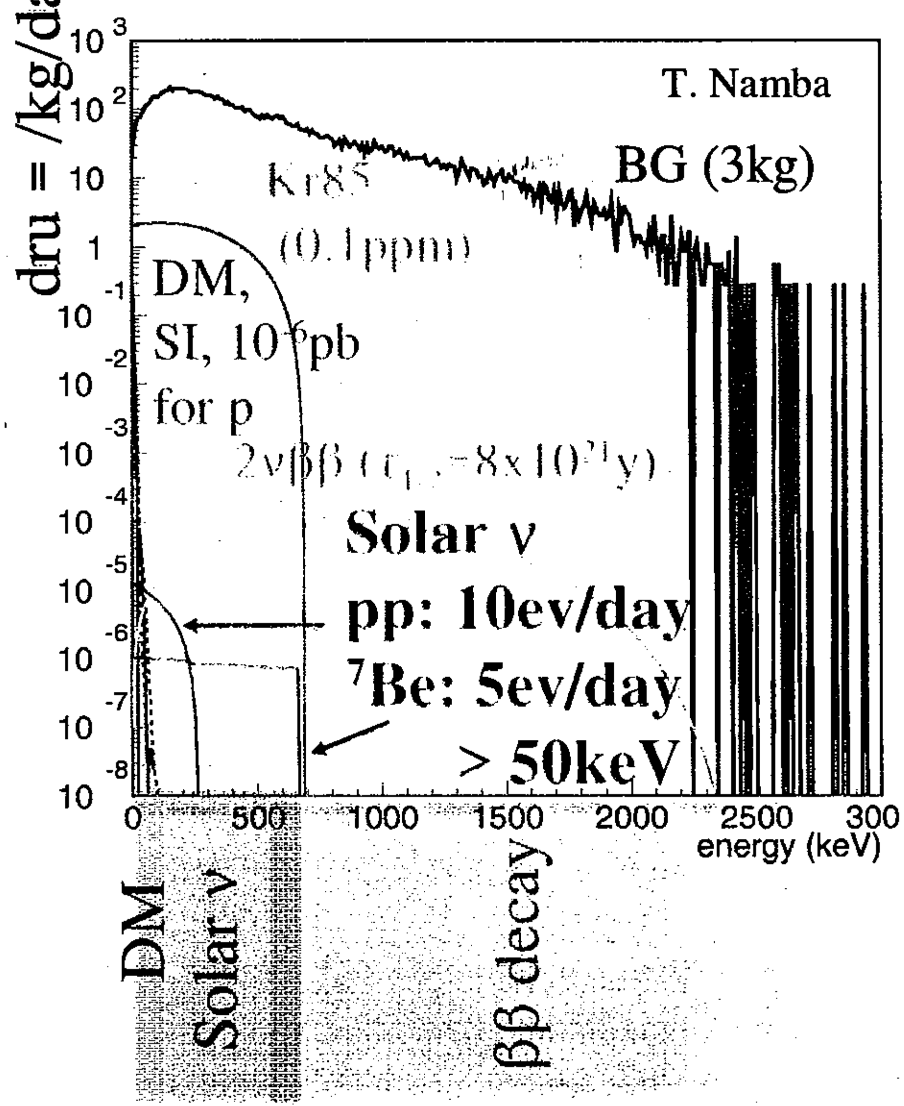
- pp neutrino flux measurement (90 % C.L.) by :
  - 10 ton detector
  - νe scattering experiment
  - 5 years data
  - Statistical error + SSM flux error
- Accuracy of mixing angle : $\sin^2 2\theta = 0.77 \pm 0.03$ (stat.+SSM)

Precise determination of oscillation parameters by KamLAND and pp experiments.

KamLAND contour from K.Inoue

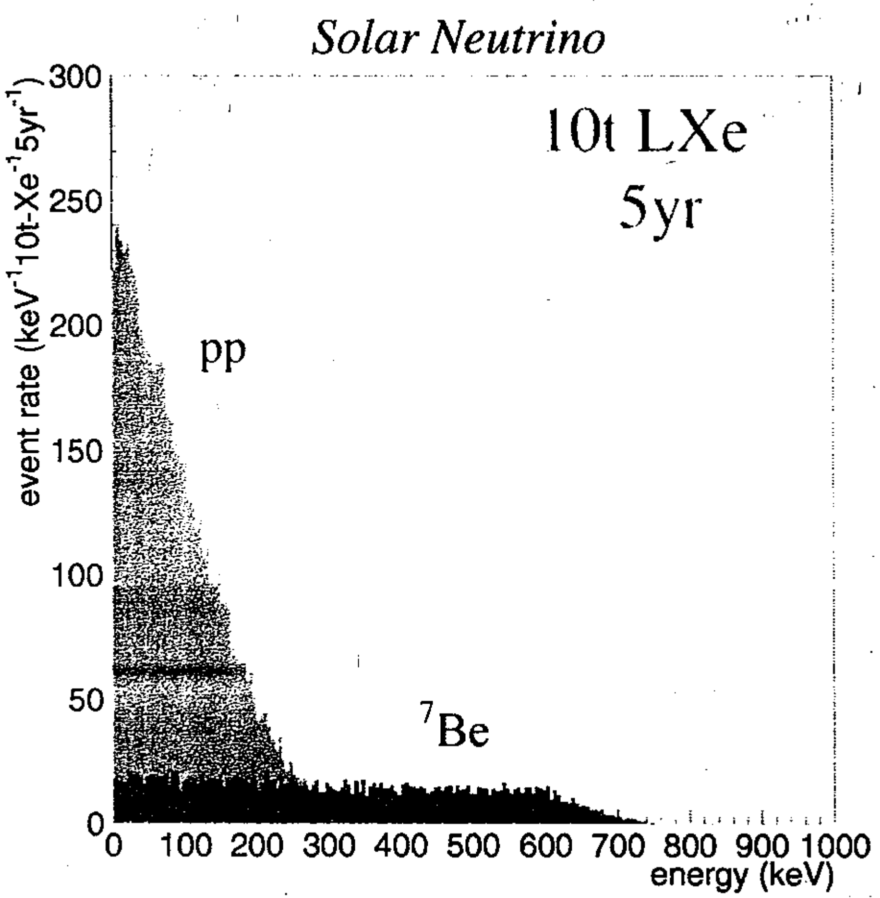
Challenge

Extreme Low Background, but **QUITE HIGH STATISTICS!!**



Different energy window

Even in SK, ~ 13 events/day



Key idea to use LXe:

large Z → Self shielding

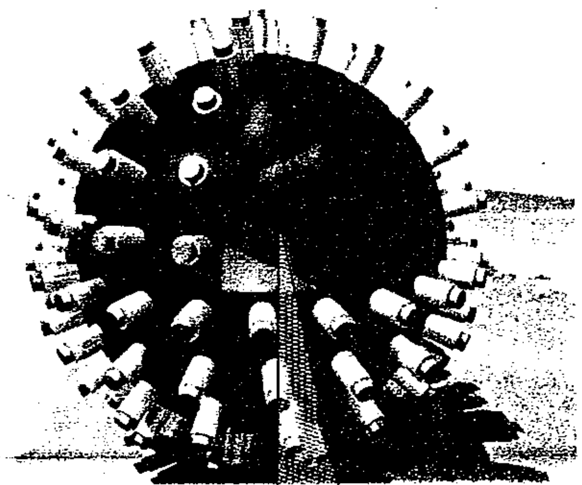
Key idea

γ (U/Th/K/Co/Cs/…)

Self shield

μ

No long life RI



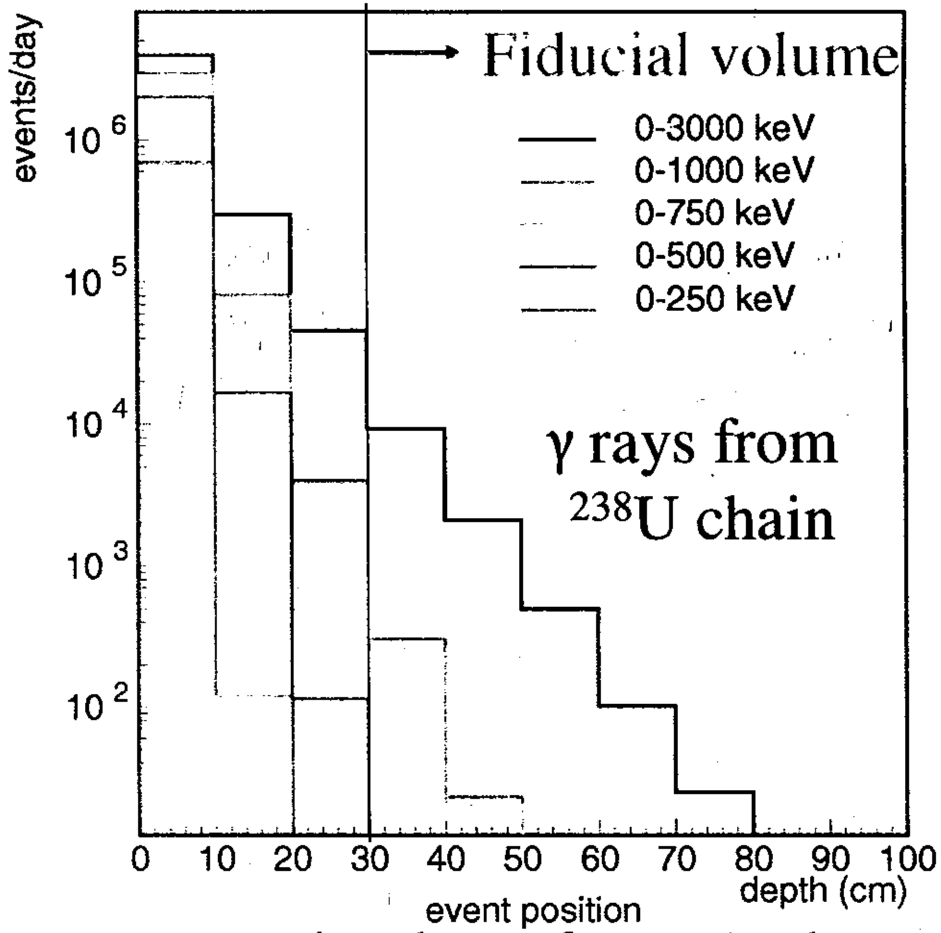
H_2O shield

neutron

Distillation etc.

α,β,γ rays from ^{85}Kr, ^{42}Ar, U/Th

- Self shielding (ext. γ bg)



Several orders of magnitude reduction can be expected for energy less than 500keV

HPGe/ICPmass/NAA(not yet) + detailed MC study

Why liquid xenon detector?

1. Scintillation/Ionazation detector:
   scintillation yield: 42,000 photons/MeV ~ NaI(Tl)
2. Wavelength: 175 nm
   ➔ direct PMT readout w/o wavelength shifter
3. Self shielding: (ρ=3.06g/cm^3, Z=54)
   ➔ X_0=2.7cm (Xe 30cm~ 4m water)
4. Compact: r=0.92m for 10ton, r=1.22m for 23ton
5. Cooling temperature: ~ 165K
   ←➔ He 4K, Ne 27K
6. Scale up
7. Isotope separation

Isotope separation & Xe complex

One of the best isotope separation for
'Solar neutrino, dark matter, $0\nu\beta\beta$ search'

Y. Suzuki

^{124}Xe	^{126}Xe	^{128}Xe	^{129}Xe	^{130}Xe	^{131}Xe	^{132}Xe	^{134}Xe	^{136}Xe
(0.10%)	(0.09%)	(1.92%)	(26.4%)	(4.07%)	(21.2%)	(26.9%)	(10.4%)	(8.87%)

Mostly Odd | Mostly Even

$\beta\beta$–nulceus

Separate here

Odd enriched

Even enriched:containing ^{136}Xe

Solar neutrino

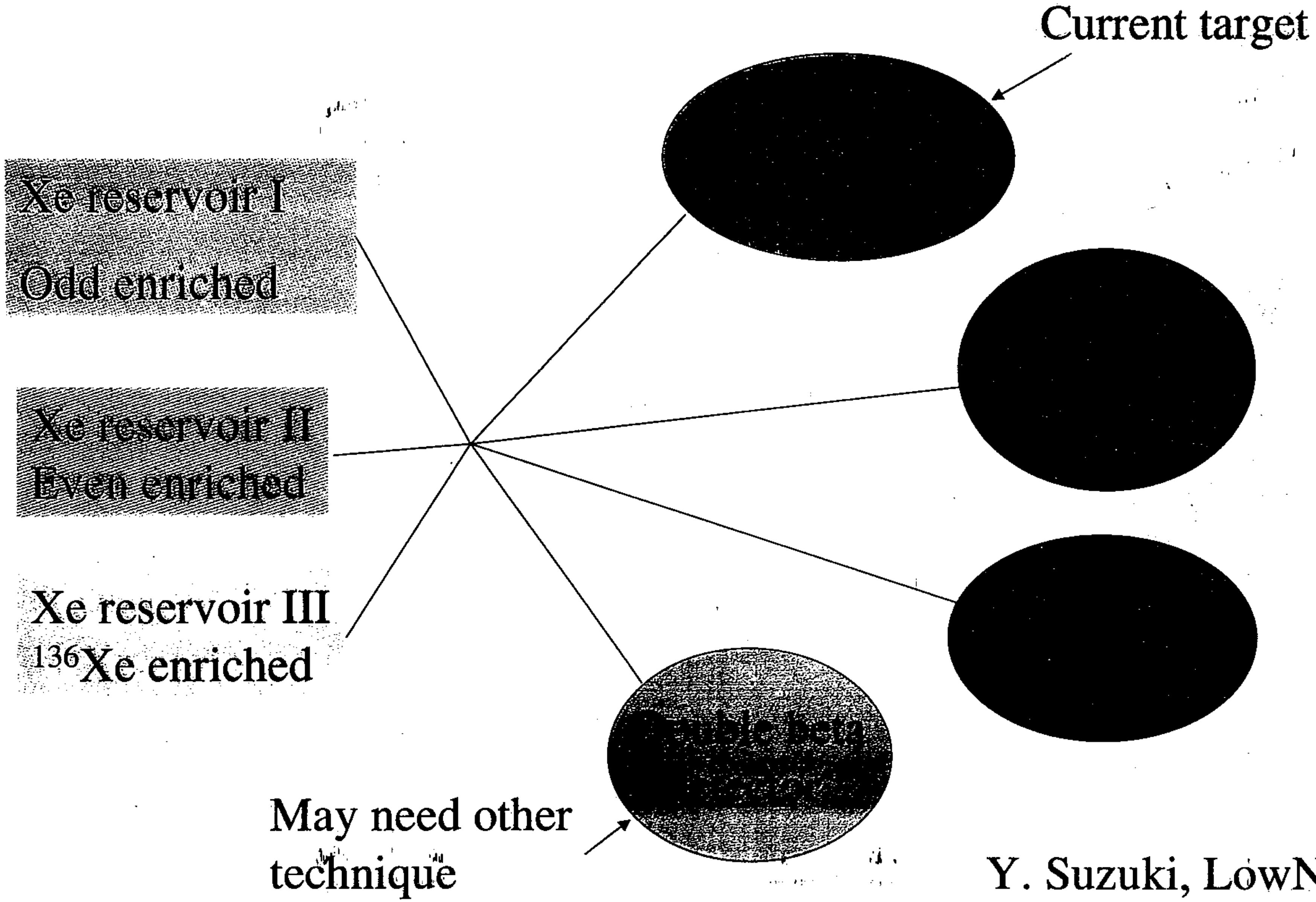
$2\nu\beta\beta/0\nu\beta\beta$

Dark matter
Spin dependent

Dark matter
Spin independent

Xe complex

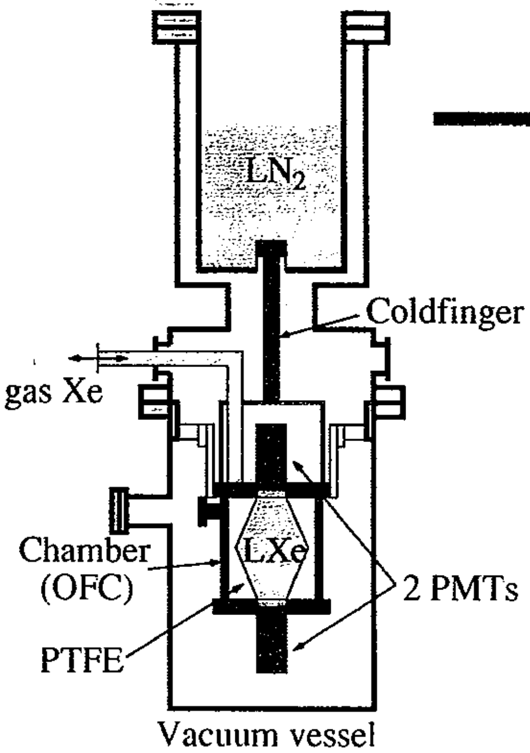
- Xe: very easy to transfer Xe from one detector to the other.

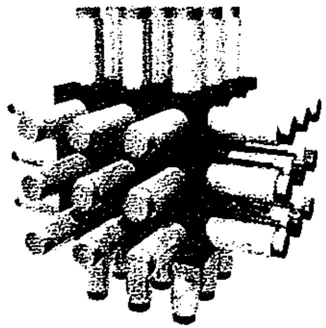


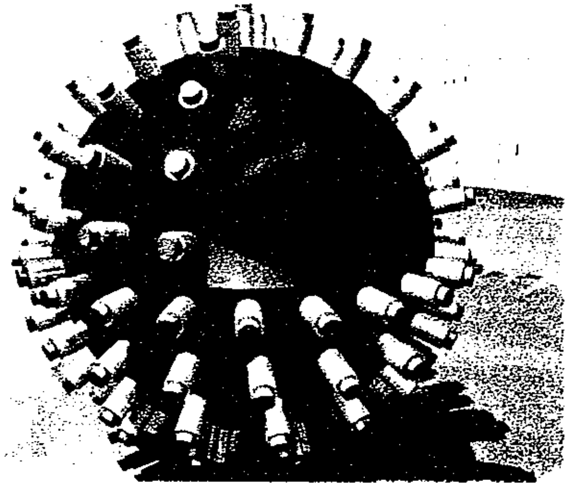
Y. Suzuki, LowNu

Strategy

- 3kg detector (finished)
- 100kg detector (now designing)
- 10t scale detector







Fundamental study of LXe

PMT improvement (QE, radioactivity)

Low background setup

Vertex, energy reconstruction

[illegible]

[illegible]

e/gamma separation

attenuation length (special setup)

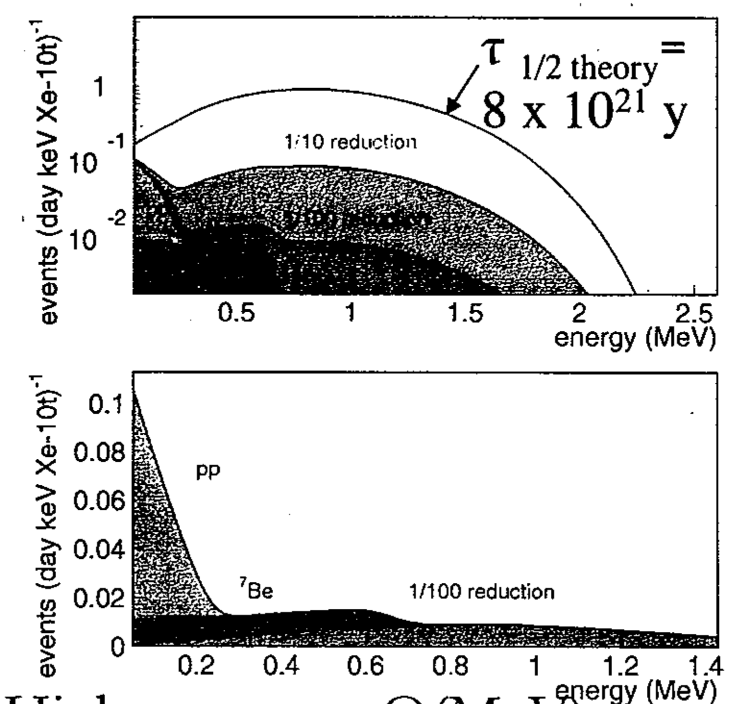
Achievement of super low bg in FV!

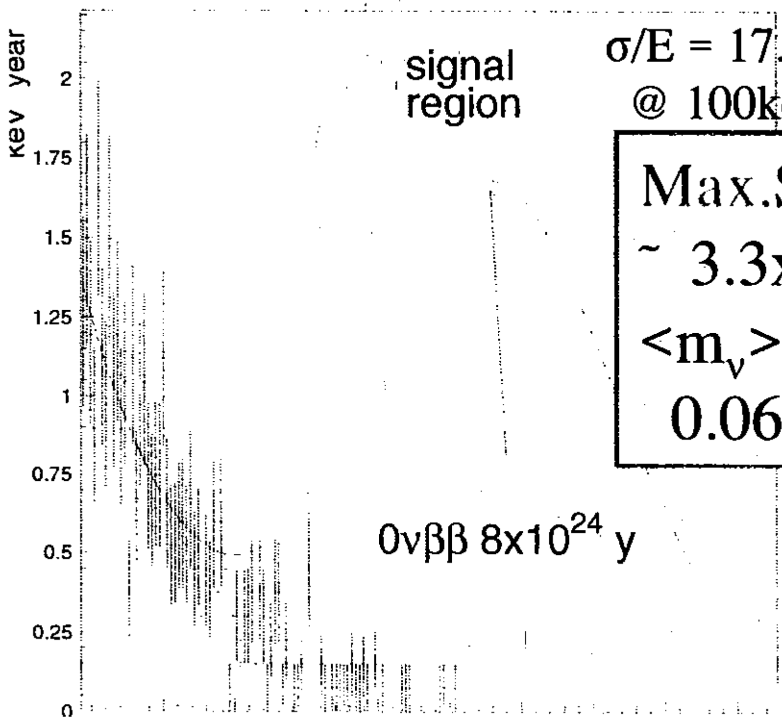
Drawings: T. Namba

2. Sensitivity for double beta decay detection

Since the solar neutrino signal is extremely small,
interesting and important physics can be accessed…

- $2\nu\beta\beta$ ($0\nu\beta\beta$) decay of ^{136}Xe





Max.Sensitivity
~ 3.3×10^{26}yr
$\langle m_\nu \rangle <$
0.06-0.09eV

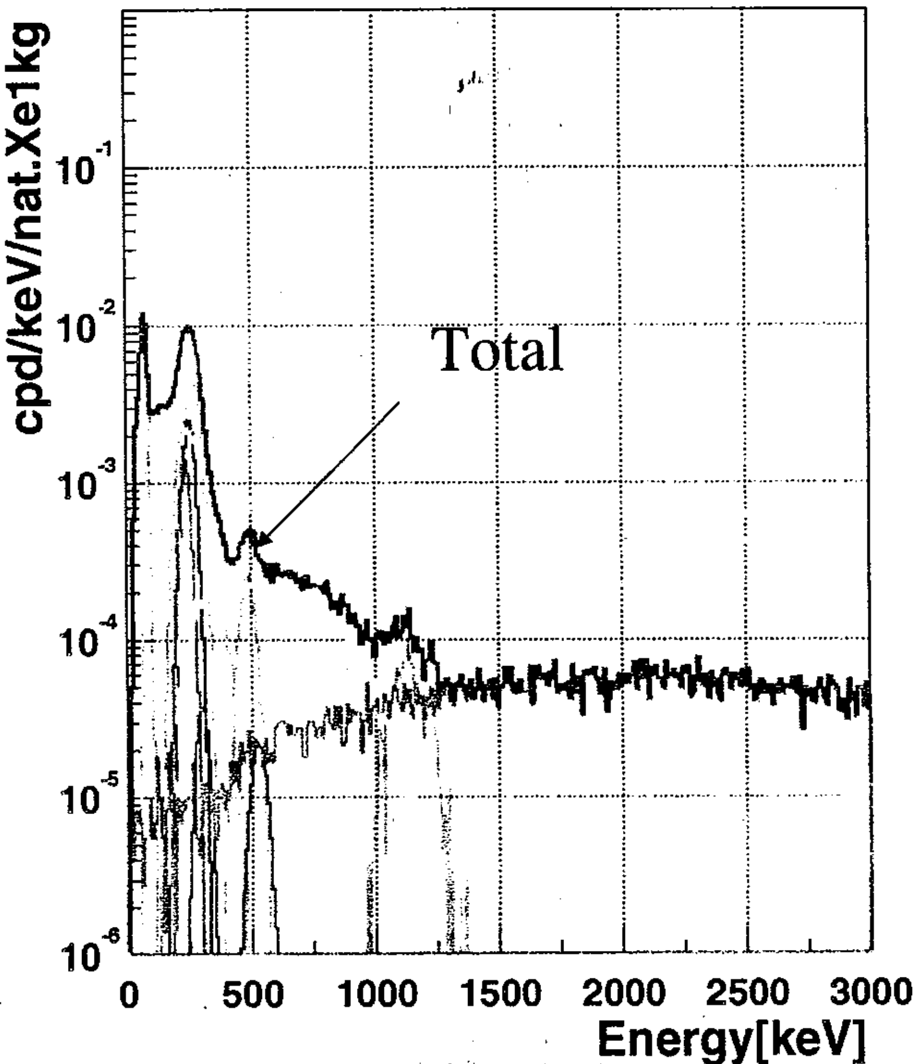
50t yr,
No BG
except for
$2\nu\beta\beta$

High energy ~ O(MeV) 2.2MeV 2.5MeV

$0\nu\beta\beta$: need high energy resolution to avoid $2\nu\beta\beta$ bg

Main candidate of background for solar neutrino detection.

Neutron background; activated by thermal neutrons



- No neutron sheild
- Kamioka mine

1.5×10^{-3} n/cm^2

Need 4 orders of magnitude reduction

(5cm boric acid gives 3 orders of magnitude reduction)

Xe nuclide as 0νββ decay candidate

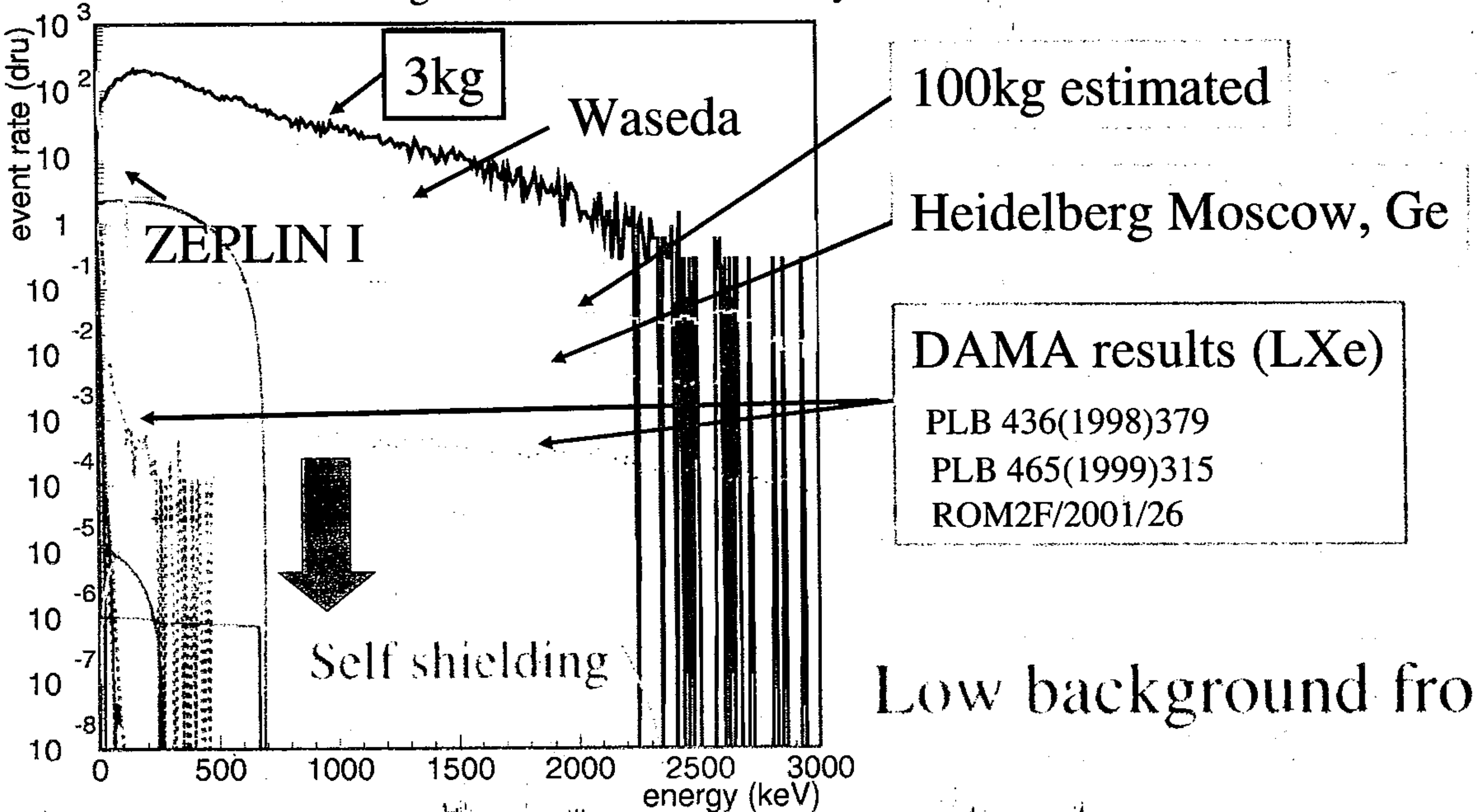
ββ candidate	Q (MeV)	Abund. (%)	$1/G^{2\nu\beta\beta}$	$T^{2\nu\beta\beta}_{1/2}$ Experimental (yr)	$1/G^{0\nu\beta\beta}$	$T^{0\nu\beta\beta}_{1/2}$ Experimental (yr)	$<m_\nu>$ (eV)
$^{136}Xe \rightarrow {}^{136}Ba$	2.479	8.9	$2.07x10^{17}$	$>1.1x10^{22}$ (DAMA)	$5.52x10^{24}$	$>7.0x10^{23}$ (DAMA)	<1.5-2.2
$^{76}Ge \rightarrow {}^{76}Se$	2.040	7.8	$7.66x10^{18}$	$1.77x10^{21}$ (Heidelberg-Moscow)	$4.09x10^{25}$	$\sim 1.5x10^{25}$ (Heidelberg-Moscow)	0.11-0.56

DAMA: ROM2F/2001/26
HM: hepph/0201231

$$< m_\nu >^2 = \left(T_{1/2}^{0\nu\beta\beta} G^{0\nu\beta\beta}(E_0, Z) \left| M_{GT}^{0\nu\beta\beta} - \frac{g_V^2}{g_A^2} M_F^{0\nu\beta\beta} \right|^2 \right)^{-1}$$

Background

- Gamma rays from ^{238}U, ^{232}Th, ^{40}K in 54 PMTs and structure
  ^{238}U: 2.4Bq, ^{232}Th: 1.4Bq, ^{40}K: 0.86Bq, determined by the HPGe.
  PMTs have been improved
  ^{238}U: $1.8 \pm 0.2\ 10^{-2}$Bq, ^{232}Th: $6.9 \pm 1.3\ 10^{-2}$Bq, ^{40}K: $1.4 \pm 0.2\ 10^{-2}$Bq
- Events were reconstructed by a simple reconstruction tool.
- Neutron background should be seriously studied.



Low background frontier

Realistic sensitivity for double beta decay with 10t class detector; $2\nu\beta\beta$

- Self shielding is not so effective for high energy γ rays (~ MeV).
- PMT contains large U/Th contamination even if clean material is used.
- Order estimation of the sensitivity for $2\nu\beta\beta$
- Assume: natural 10t LXe

  30cm wall cut (2.2t FV)

  PMTs with further 1/10 reduction of U/Th contamination

  Energy window = 50~ 400keV
- Rough estimation of sensitivity ~ similar rate as solar neutrinos

  ➔ $T_{1/2}$ ~ 10^{24} y

$0\nu\beta\beta$

- Background around 2.5MeV determines the sensitivity.
- Rough estimate

BG level @ endpoint ~ 1×10^{-4} /kg/day/keV
Resolution @ endpoint ~ $\sigma=100\text{keV}_{rms}$
Signal region ~ $\pm2\sigma$, $S/\sqrt{B}$~ 1, ^{136}Xe 8.9%, 1yr
Additional γ/e separation ~ 1/10 BG reduction

↓

$T_{1/2}^{0\nu\beta\beta} = 1.1\times10^{25}$yr

↓

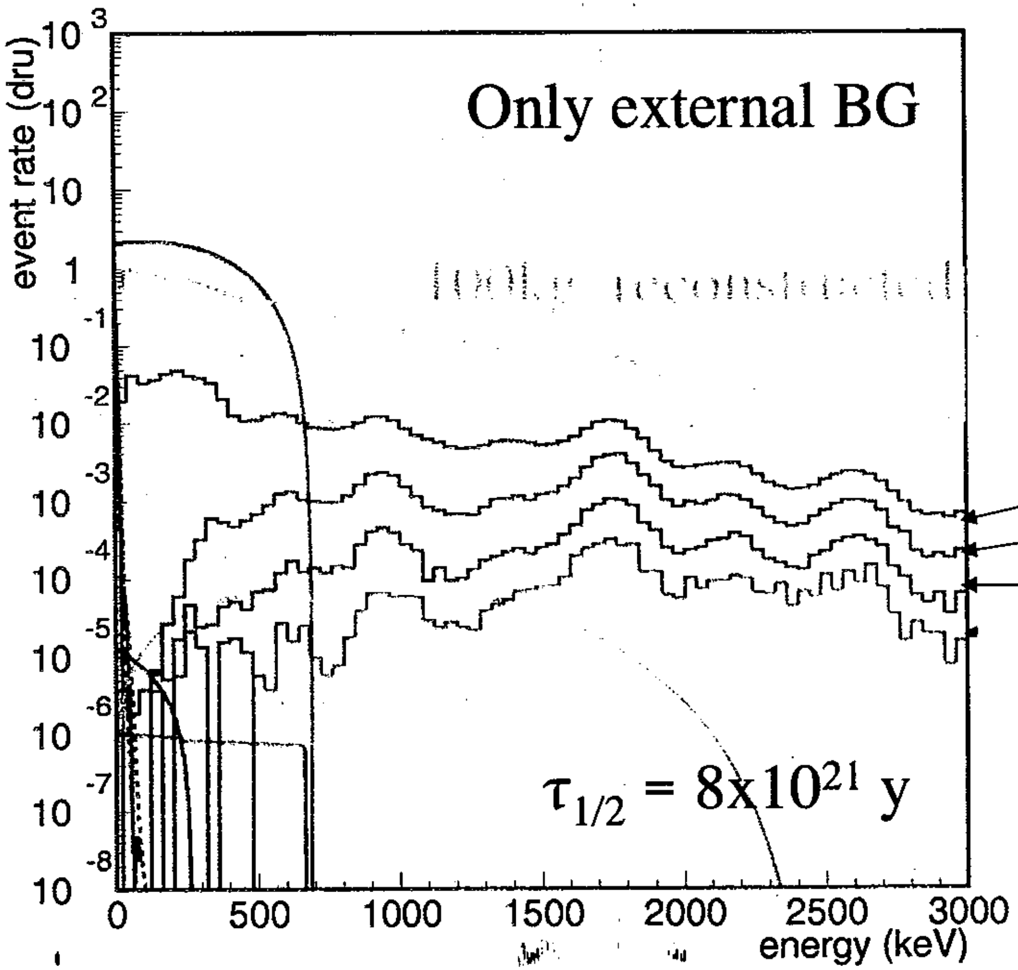
$<m_\nu>$ ~ 0.4-0.6 eV

Need to tune the detector for the double beta decay detection

282

10t class detector

- Cubic shape, $(150\text{cm})^3$ volume (total 10t, FV 2.2t),
- 1350 PMT (3'', 10cm spacing)
- Self shielding + further 1/10 reduction of PMTs BG



- Not reconstructed spectrum. σ_E = 17.5% @ 100keV vertex is the barycenter of energy deposition.

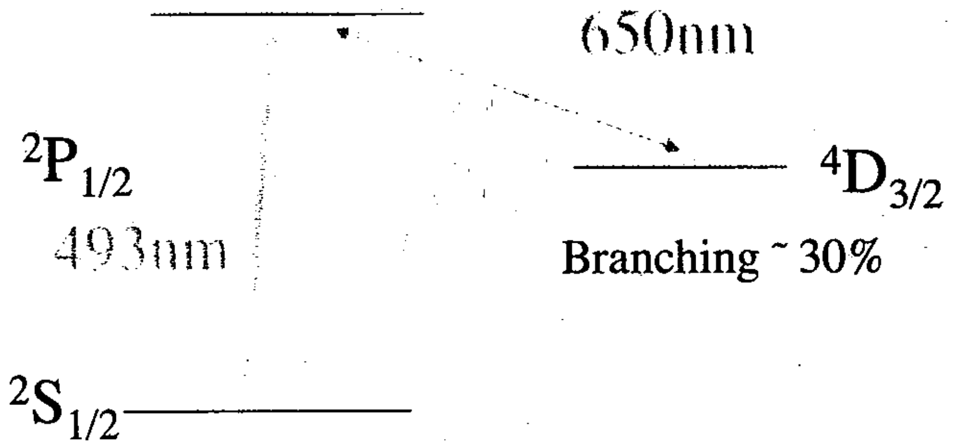
Total volume
10cm wall cut
20cm wall cut
30cm wall cut (FV 2.2t)

0-500keV region will be clean
→ pp/^{7}Be observation!!

EXO (Enriched Xenon Observatory) method

- Utilize atom physics; identify ^{136}Ba (decay products) by laser excitation.

493nm
Fluorescence light



Atomic level scheme for Ba^+ ion

$^{136}Ba^+$ ion

Observe fluorescence light by PMTs

Single ion can emit 6×10^7 photons/sec.
Even by the eye, one can identify the ion.

493nm laser (+ 650nm)

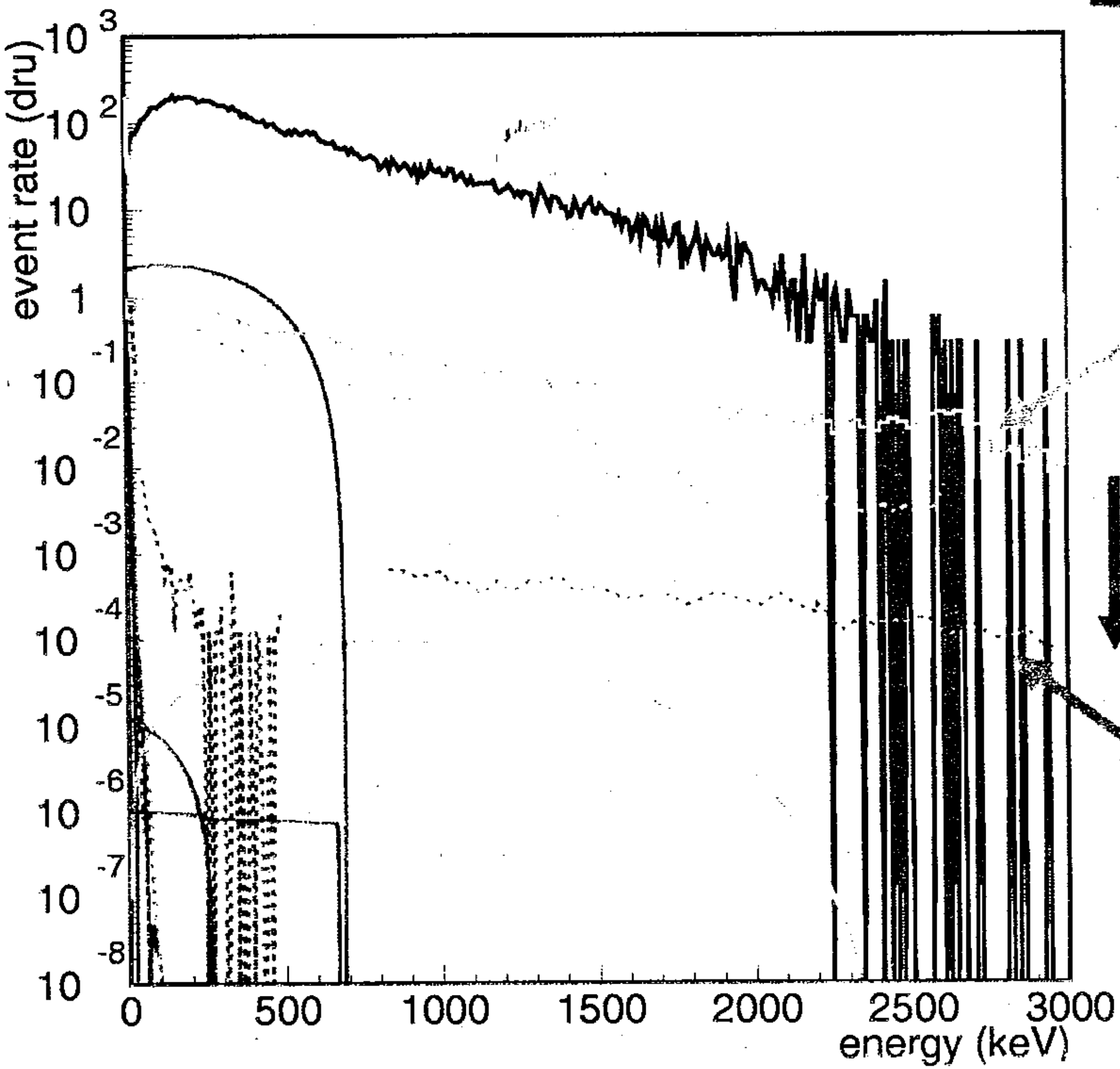
Sensitivity of this method

- Background ~ free, but to distinguish between $2\nu\beta\beta$ and $0\nu\beta\beta$, good energy resolution is needed
- Experimental challenge
- Can reach maximum sensitivity!!

DAMA technology

- low background with PMTs

We can improve PMTs!



100kg estimated

PMTs with 2.5 orders of magnitude lower activity

DAMA group

Summary

- Low energy solar neutrino → small errors for $\sin^2 2\theta$
- 10t scale LXe detector can observe solar neutrino signals
- $2\nu\beta\beta$ mode can be accessible with
  10t detector + further 1/10 reduction of PMT background
- $0\nu\beta\beta$ mode may require different approach
  Simple 10t scale LXe detector → $\langle m_\nu \rangle \sim$ 0.4 - 0.6eV
- Dark matter search
  10 t detector with E_{th}=5keV; SI $\sigma \sim 10^{-9}$ pb; SD, $\sigma \sim 10^{-4}$pb
- 100kg detector is under constructing