Low energy solar neutrino detection by using liquid Xenon

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for the XMASS Collaboration

Solar ν : **X**enon **MAS**sive detector for **S**olar neutrinos
Dark M: **X**enon detector for weakly interacting **MASS**ive Particles
ββ : **X**enon neutrino **MASS** detector

Kamioka Observatory. ICRR, U. of Tokyo
Neutrino Center, ICRR, U. of Tokyo
Niigata University
Saga University
Tokai University
Waseda University

Why Xenon ?

Future of non-accelerator experiments

(1) Atmospheric ν --- established

→ accelerator based long baseline experiments
JHF, ν-factory,…
θ_{13}, matter effect, CP violation etc.

(2) Solar ν --- ???

→ Need smoking gun evidence?
SK (^{8}B: effect is small), NC (SNO)
KamLAND (LMA)

→ **^{7}Be & pp**

(3) Absolute mass

(4) **0νββ**

(5) **Dark matter**

(6) **Proton decay**

(7) …..

Liq. Xenon Detector

Multi-Megaton
Water Cherenkov Detector
(longer time schedule)

Xenon experiments have multiple-physics subjects

→ **Good for an observatory like Kamioka**

Comparison among noble gas detectors

	Helium	Neon	Xenon
Boiling temperature	4.2^{o}K	27^{o}K	165^{o}K
Atomic number (Z)	2	10	54
density (g/cm^3)	0.125	1.20	3.06
Radiation length (cm)	756	24	2.7
scintillation w.l. (nm)	73	80	175
numbers of photon	15,000	15,000?	42,000

Kr and Ar can be excluded as a solar neutrino detector due to ^{42}Ar and ^{85}Kr contamination

Advantage

1. Scintillation and ionization
2. PMTs (w/o wave length shifter)
3. Self shields
4. Compact
5. Higher operating temperature (165^{o}K)
   can use liq.-N_2 to liquefy Xe
   can use acrylic material
6. DM search and double beta decay as well

7. Easy to upgrade and scale up
8. Purification during the experiment

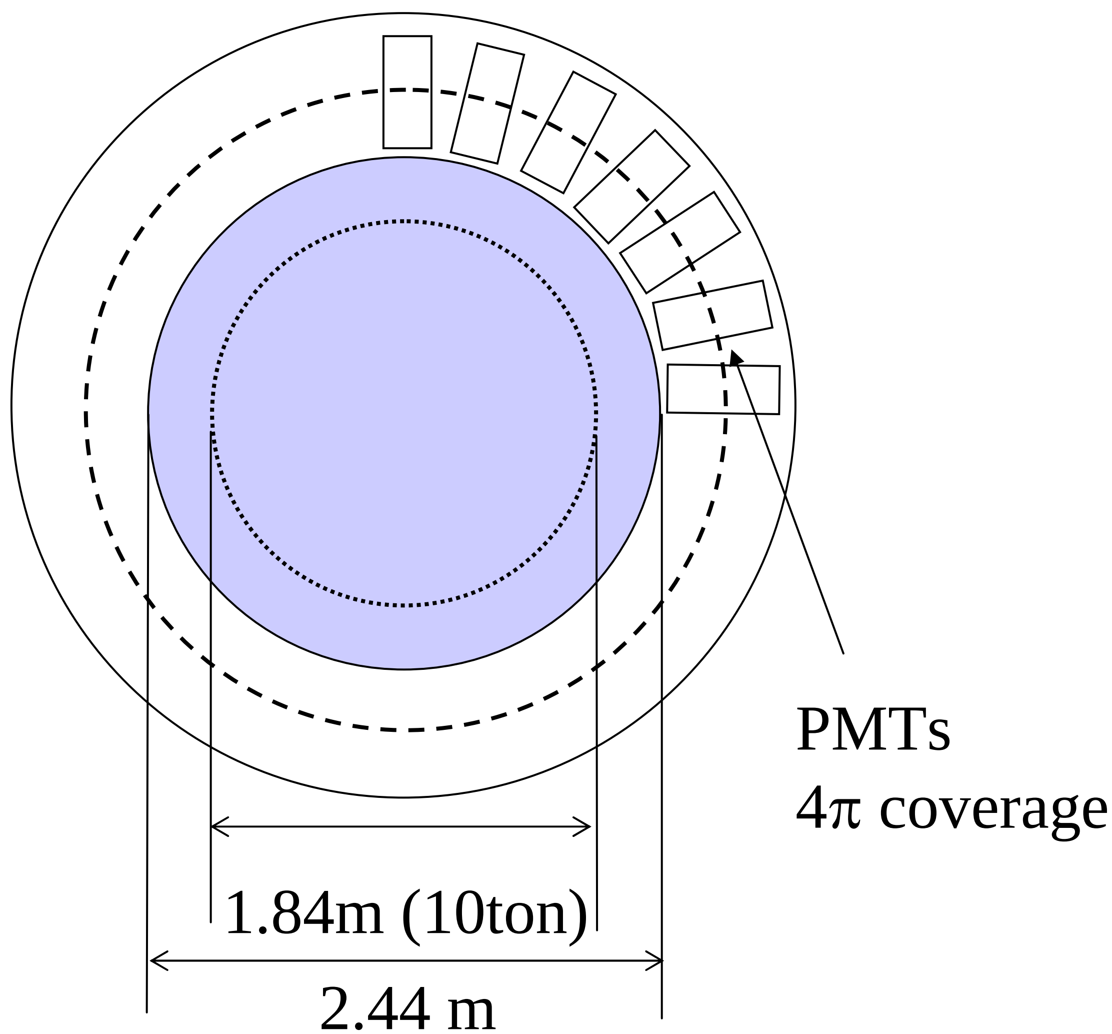
Disadvantage

1. ^{85}Kr (10.7y, 687keV(β, βγ(0.4%)))contamination
   10 Hz for 1 liter w/10ppm
2. Expensive (May not?)
   $1M for 1 ton liq. Xe
3. Isotope separation
   longer time to produce
   higher cost
   advantage for physics point of view

Other characteristics

1. Absorption > 1m(?), scattering > 30cm

Detector



10 ton (fid.) detector

10 ton + 13 ton = 23 ton (30 cm self-shields)

1.84 m (2.44 m)

1640 3” PMTs for 40% coverage

5 ton (fid.) detector

5 ton + 5 ton = 10 ton (20 cm self-shields)

1.46 m (1.84 m)

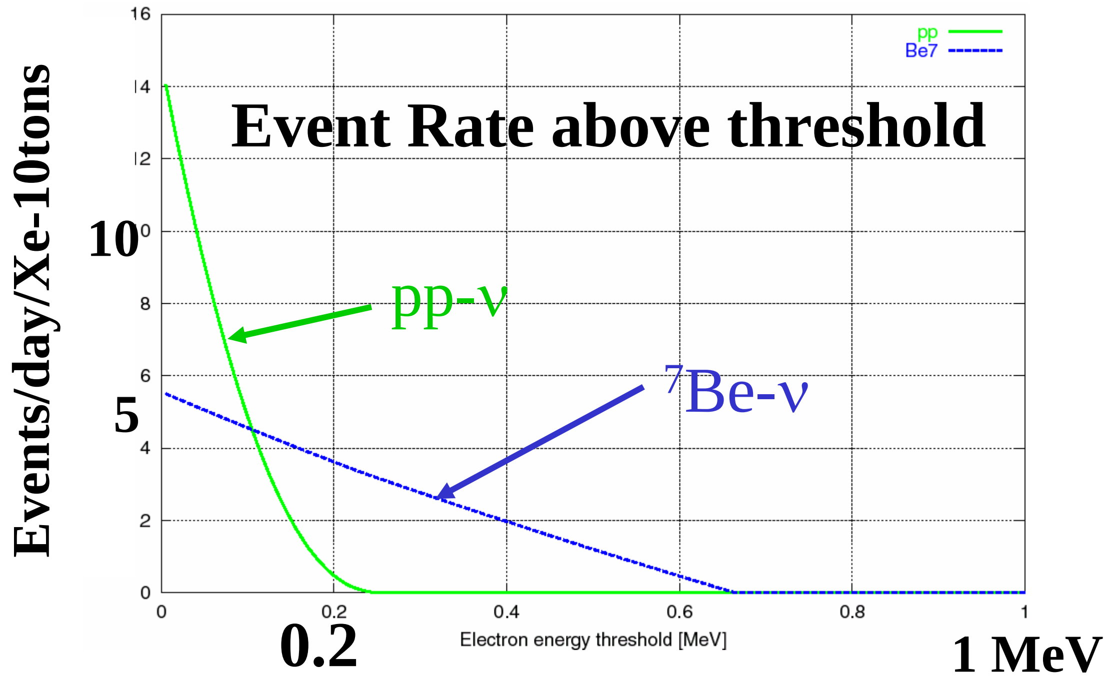
930 3” PMTs for 40% coverage

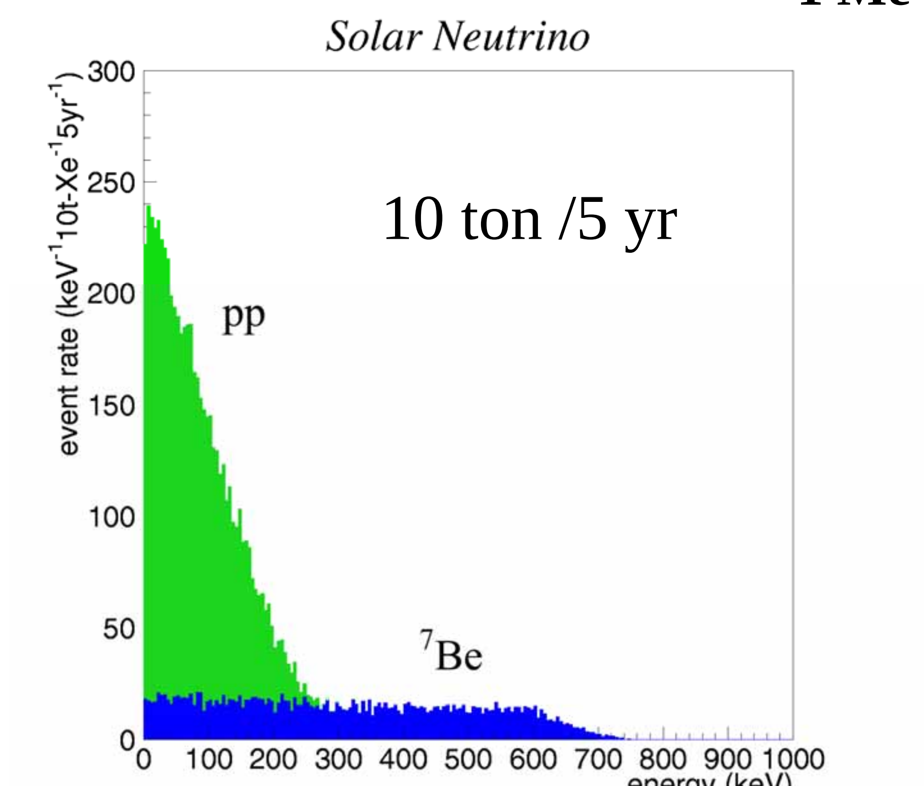
Solar Neutrino Measurements w/ 10 ton mass

Signal (high rate) $\nu_e + e \rightarrow \nu_e + e$ scattering

10 pp and 5 ^{7}Be events/day/10ton (> 50 keV)

$\leftrightarrow$ SK : 13 events/ day





Essence of the experiment

1. **Isotope Separation**
2. **Ultra low backgrounds**

Why do we need isotope separation?

Most serious Backgrounds for the solar neutrino measurements

2ν $\beta\beta$ **decay from ^{136}Xe**

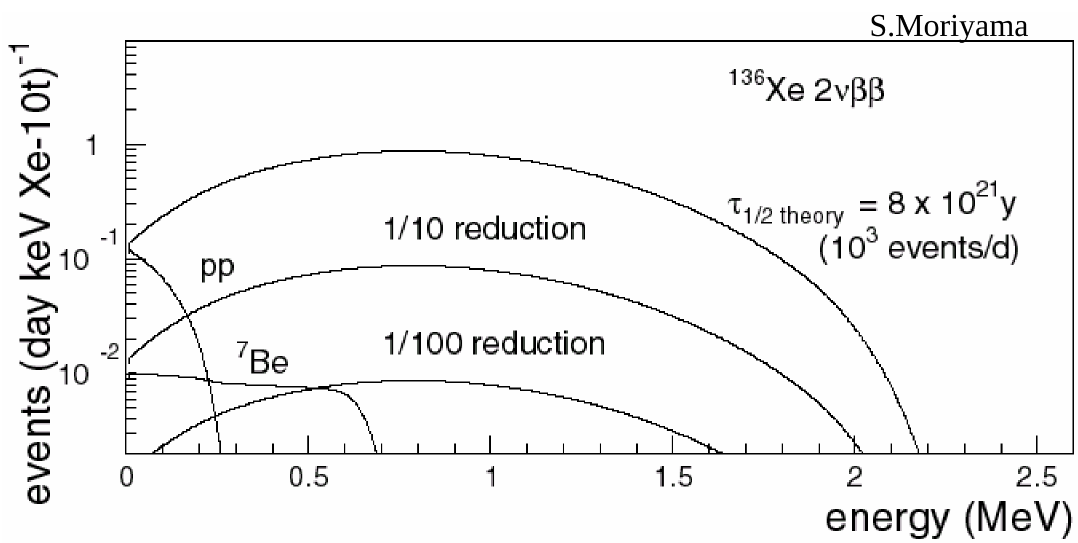
^{136}Xe 2ν ββ decay BACKGROUND

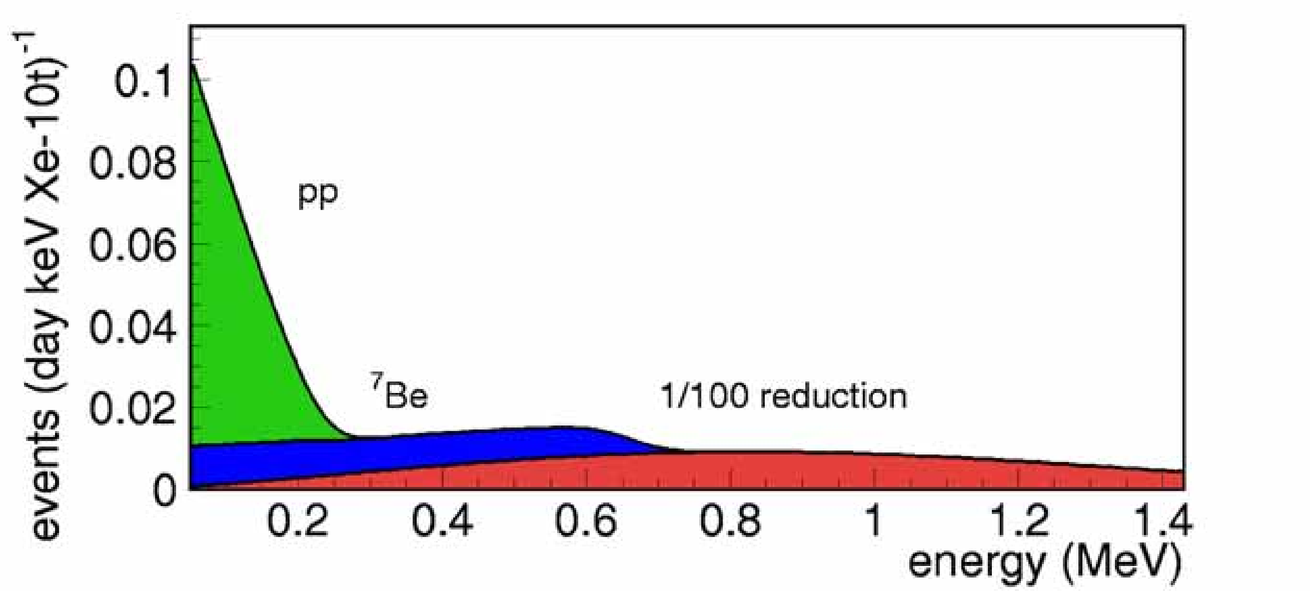
Q=2.476±8 MeV

~1000 events /day for $8x10^{21}$yr.

(exp. > $0.5x10^{21}$yr)

Rate of ^{136}Xe 2ν ββ decay



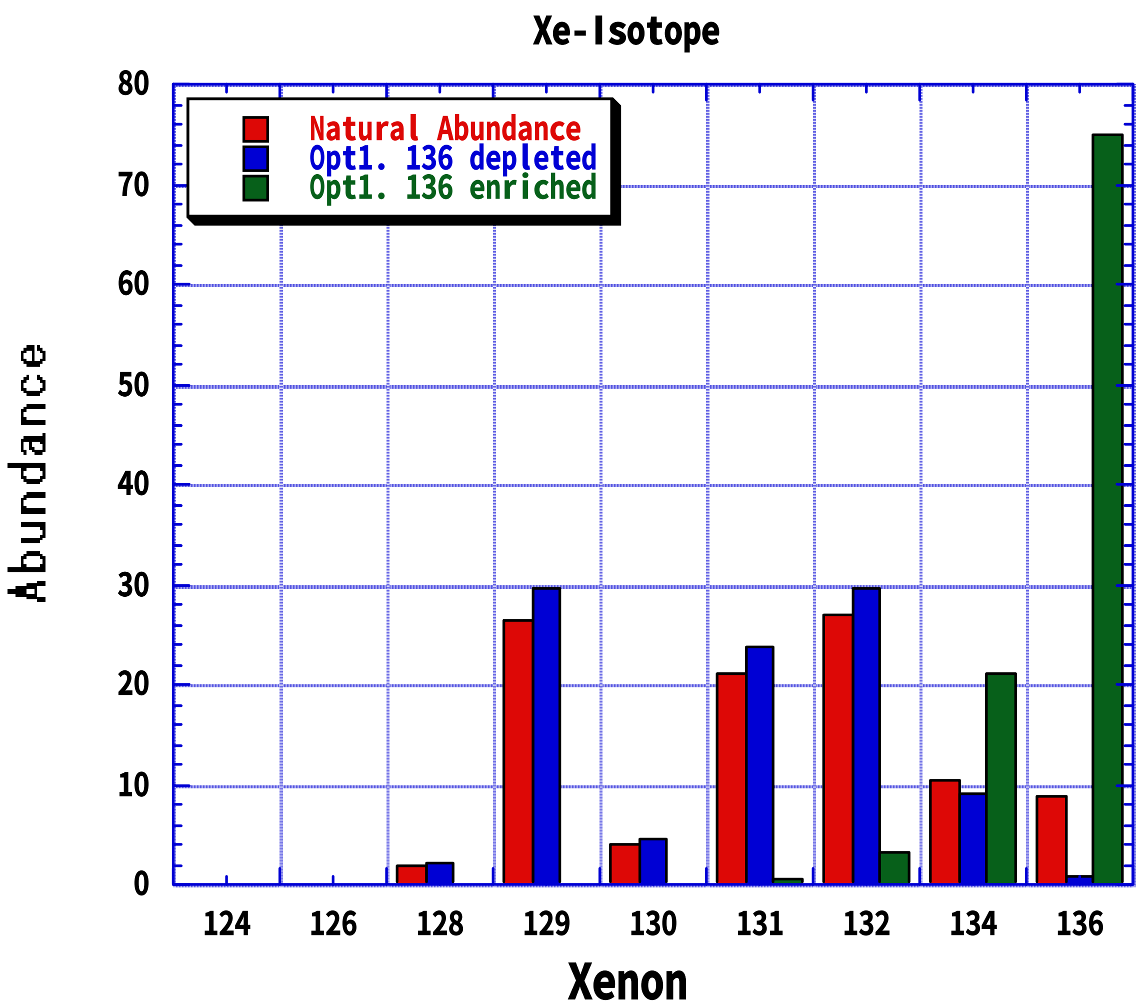


If $\tau_{1/2}$ < (10~100) x ($8x10^{21}$y)

➔ Isotope Separation

Need 2νββ life time measurement

Xe-Isotope separation (^{136}Xe enrichment)



Isotope separation is also useful for the dark matter search

Definitive Evidence

1) Seasonal variation
2) Difference in interaction rate for Odd vs Even nuclei

^{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%)

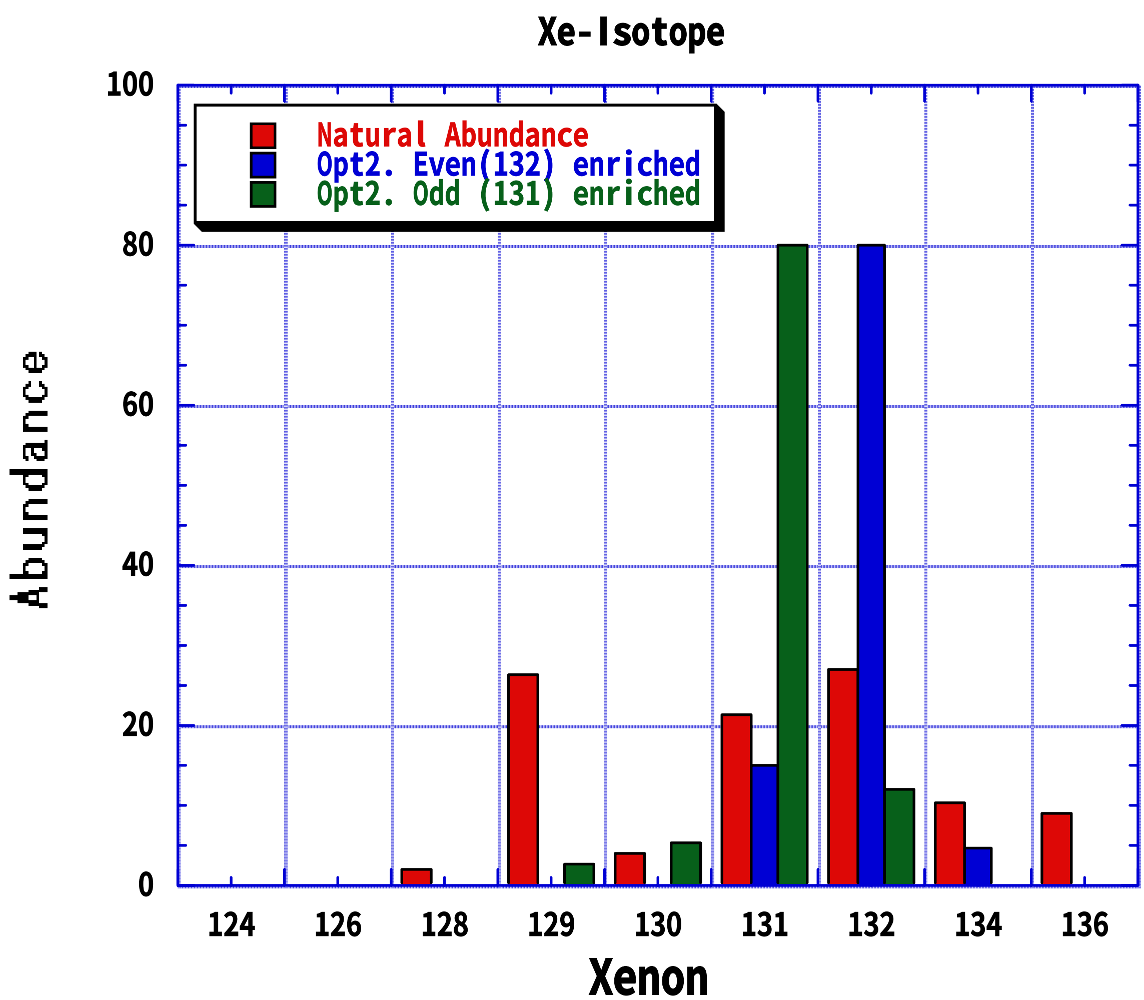
Mostly Odd | Mostly Even

Separate here

Spin independent
Spin dependent

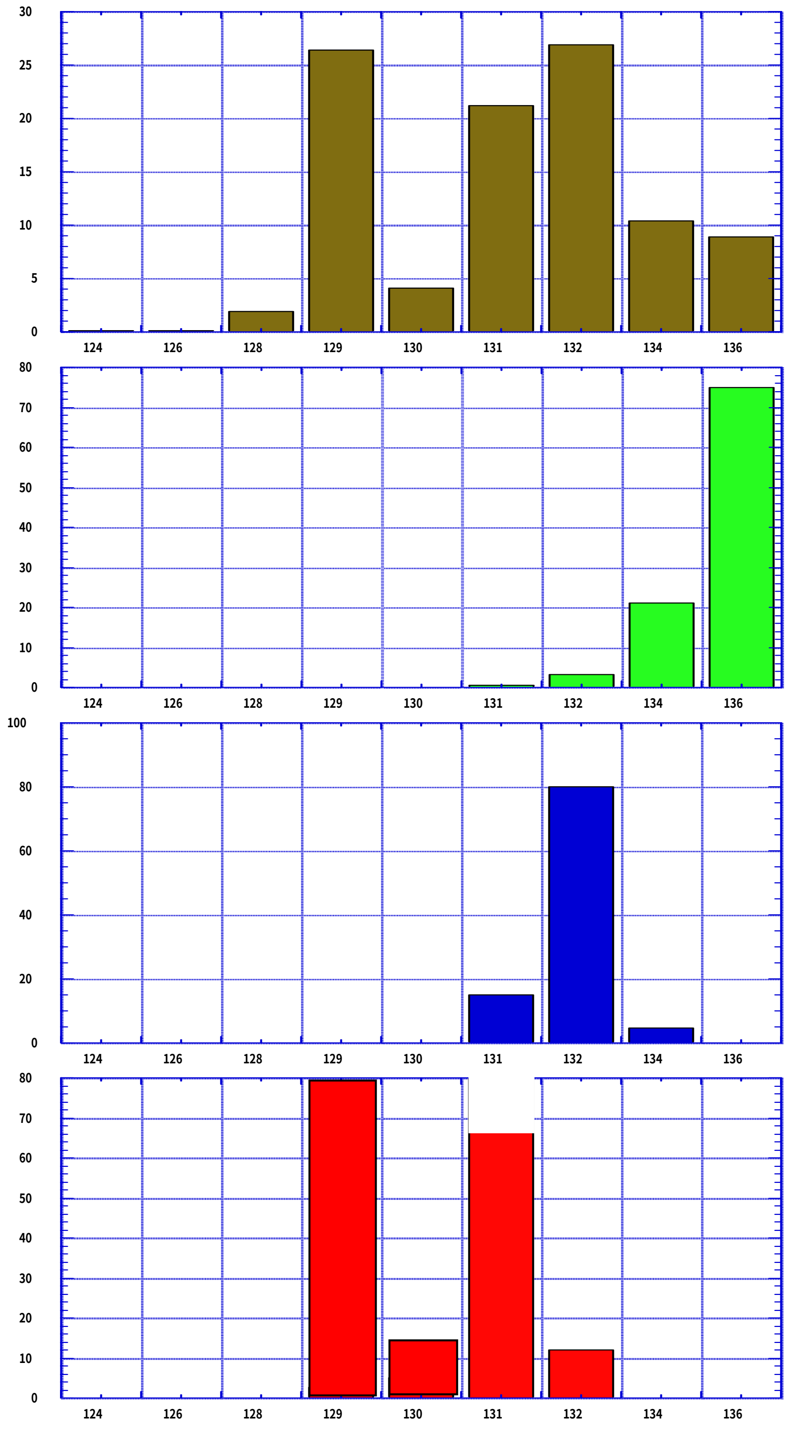
Spin independent

Xe-Isotope separation (Odd/Even enrichment)



What is the 'Best Isotope Separation' for solar, dark matter and double beta decay

^{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%)



Natural

^{136}Xe enriched

Even enriched

Odd enriched

Will be discussed by
A.N.Choubine

Challenge---Ultra Low Backgrounds

Internal Backgrounds

Cosmogenics

Xe: no long-life isotopes

longest: $\tau_{1/2}(^{127}Xe)$=36.4 days

^{85}Kr ($\tau_{1/2}$=10.7y): ^{85}Kr/Kr~2x10^{-11}

1Bq/m^3 in air

10Hz ^{85}Kr decays in 1 l liq-Xe

(if 10 ppm contamination)

need < 4x10^{-15}g/g for Kr/Xe(for < 1BG/day)

^{42}Ar ($\tau_{1/2}$=33y): ^{42}Ar/Ar=7x10^{-15}

1Bq/m^3 in air

need < 2x10^{-11}g/g for Ar/Xe

U/Th

should be < 10^{-16}g/g (for < 1BG/day)

Spallation (250μ/day at Kamioka site)

assuming 10 mb on each Xe isotope

→ 2 events /day x ??

External Backgrounds

+30 cm (or +20cm) self-shields

→ 4m water eq.

U/Th in materials : < $10^{-11\sim-10}$g/g??

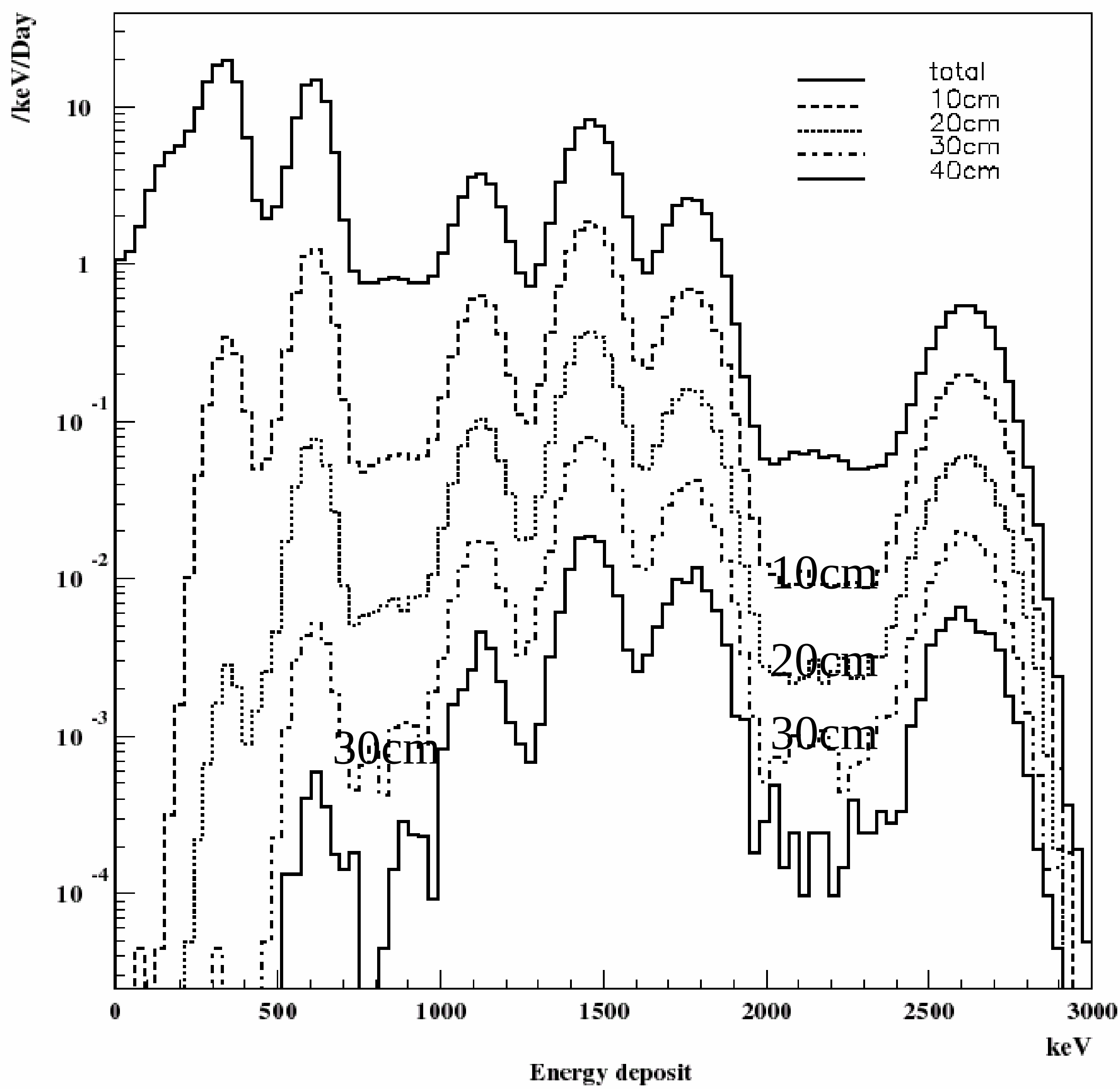
Measured contamination of U/Th and K by Ge-detector

	K		U		Th	
	ppm	Bq	ppb	Bq	ppb	Bq
Breeder (C6380) for EMI9424B **(27g)**	209	0.18	311	0.10	625	0.069
PMT Glass (NEMO) not our measurement		0.34		0.08		0.005
MgF_2 5mm 65ϕ **(53g)**	1.2	1.9 $\times 10^{-3}$	18.2	12.0 $\times 10^{-3}$	37	7.9 $\times 10^{-3}$
PMT Glass (R329) not low BG glass	3% →1		1980		601	
Pb Block (Peru) (meas. by Miuchi)	1		0.6		1.5	

→ Use those numbers for the simulation

The effect of the self-shields

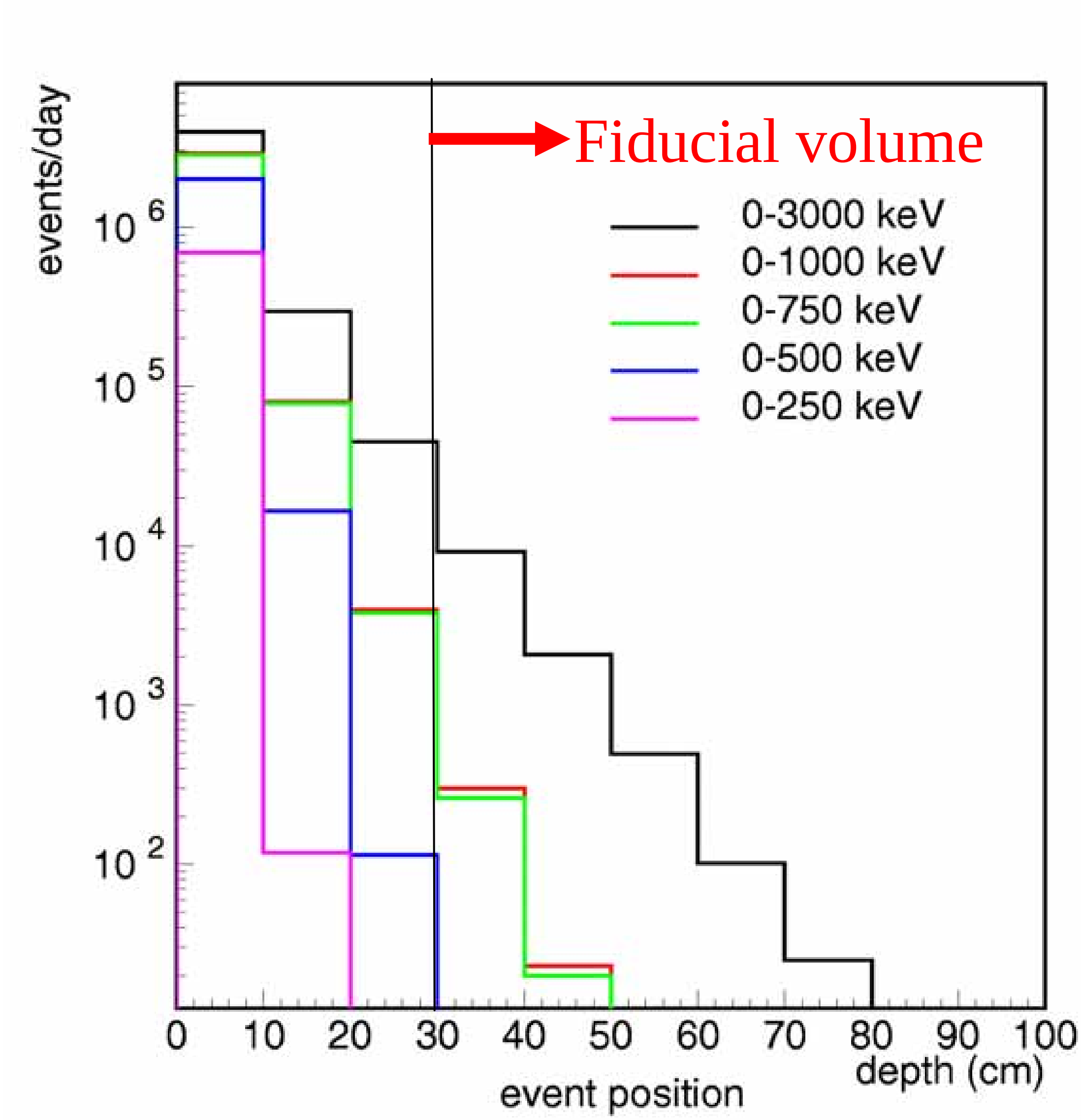
2m x 2m x 2m detector (24 tons of liq-Xe)
$(1.4\ m)^3$ fiducial volume
30 cm self shields



major γ-modes are included → to include all

γ-ray backgrounds from outside

2m x 2m x 2m detector (24 tons of liq-Xe)
(1.4 m)^3 fiducial volume
30 cm self shields



BG is small in the energy region less than 500 keV

Technology

If ultra-low background has been achieved

May be ok by scintillation only

vertex resolution →
e/γ separation →
energy resolution →
ion sweeper (U/Th decay $ spallation)

Probably need hybrid with other technique like two phase detector

supplemental information for PID
(e/γ)/N separation
precise vertex determination

→ see S.Suzuki's talk.

Ionization: Proportional chamber,
TPC (gas & liquid)

Vertex reconstruction and resolution

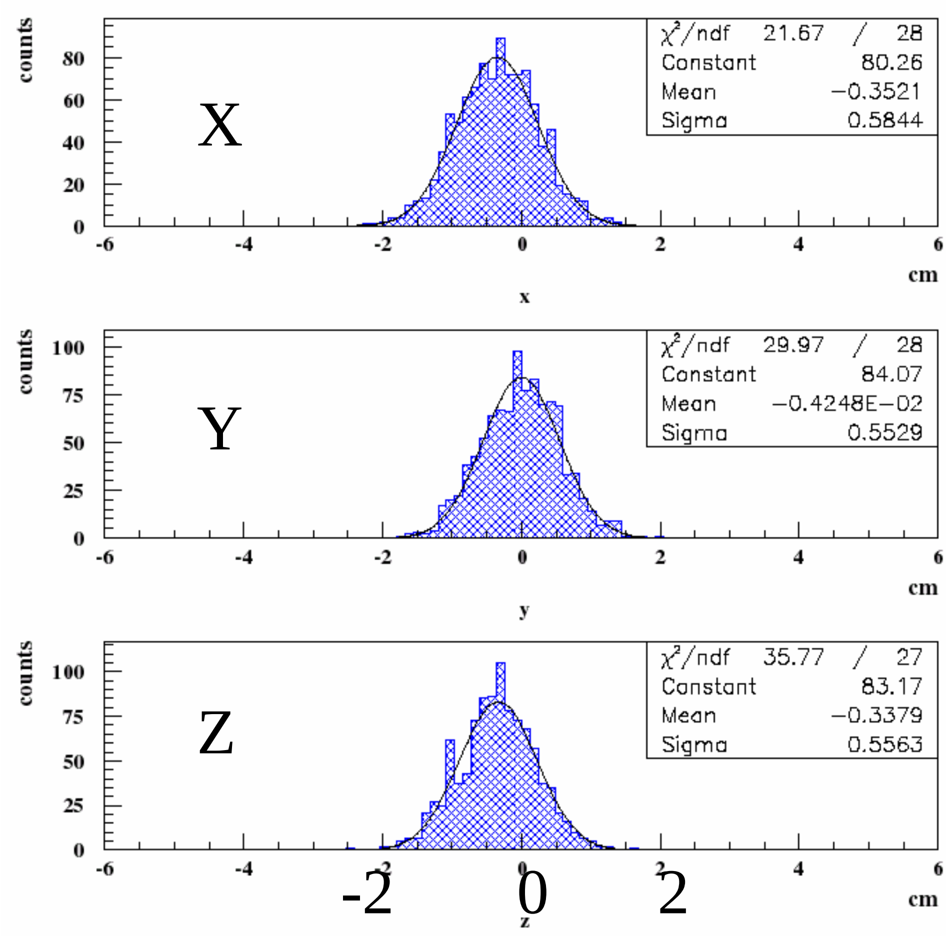
1) Define effective acceptance $A_i^{eff}(d, \cos\theta)$ for each PMT at a distance, d, from 'vertex' for the absorption length (1m) and the scattering length (30cm).

2) Define expected number of photons at each detector point:

$$\mu = n_i^{exp}(d, \cos\theta) = (\Sigma n_j^{obs})\, A_i^{eff}(d, \cos\theta) / (\Sigma A_k^{eff}(d, \cos\theta))$$

$$[d = d(x,y,z),\ \cos\theta = \cos\theta(x,y,z)]$$

3) maximize $L(x,y,z) = \Sigma e^{-\mu} \mu^{n_j^{obs}} / n_j^{obs}!$



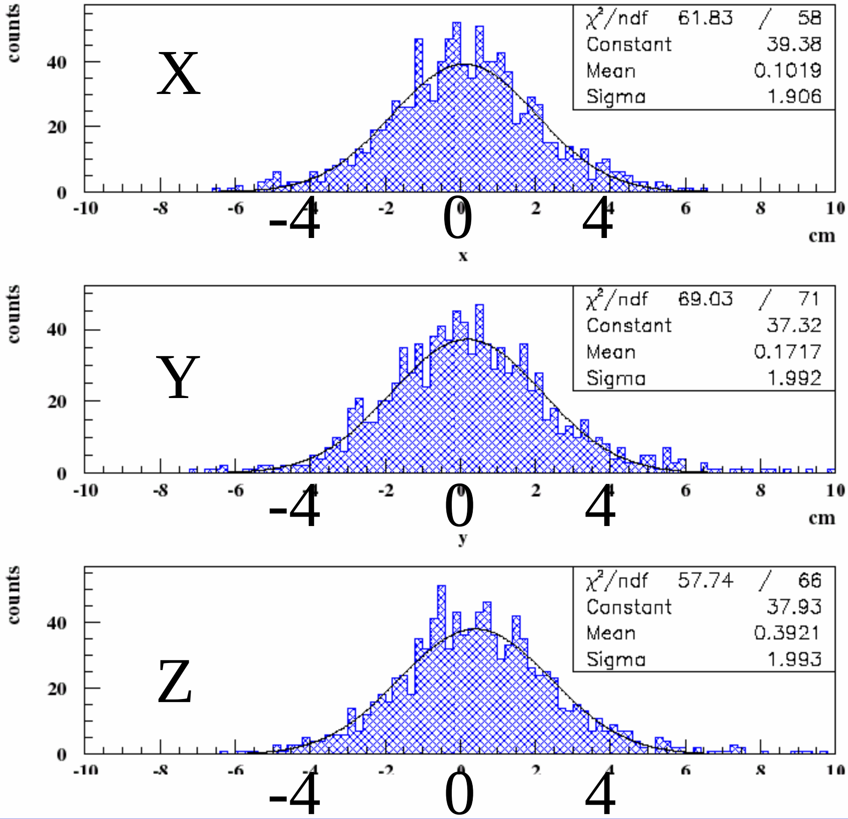
@(30,70,50)

Δx = -0.4cm
σ = 0.6cm

Δy = 0 cm
σ = 0.6cm

Δz = -0.3cm
σ = 0.6cm

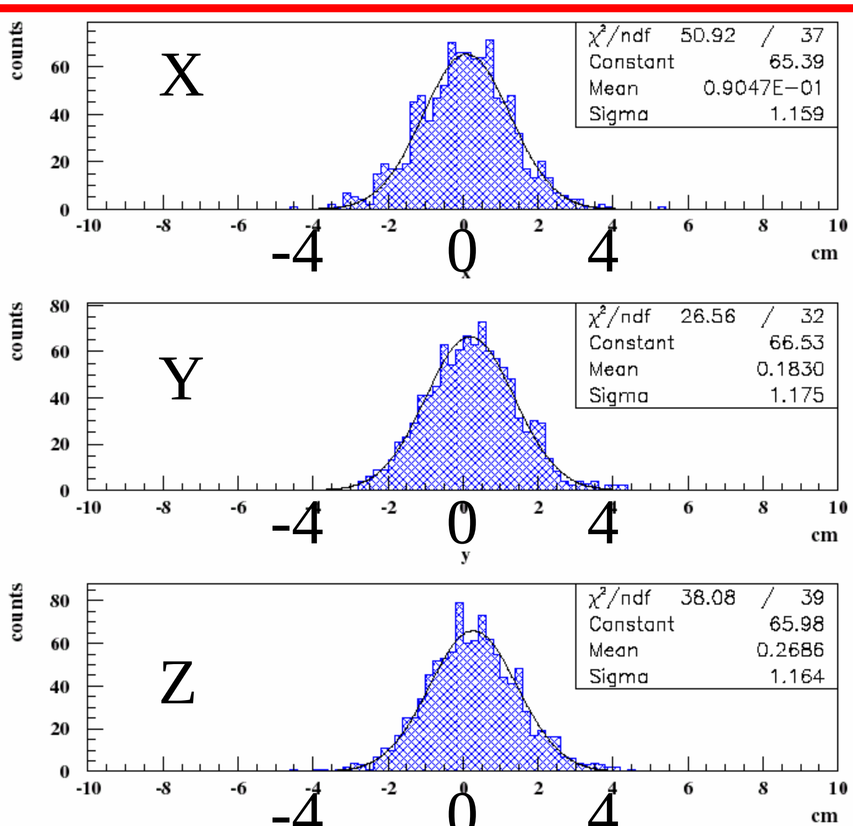
All fiducial volume



$\Delta x = 0.1cm$
$\sigma = 1.9cm$

$\Delta y = 0.2cm$
$\sigma = 2.0cm$

$\Delta z = 0.4cm$
$\sigma = 2.0cm$



$\Delta x = 0 cm$
$\sigma = 1.2cm$

$\Delta y = 0.2cm$
$\sigma = 1.2cm$

$\Delta z = 0.3cm$
$\sigma = 1.1cm$

e/γ sepatration

Electron: single points

good χ^2 for the vertex reconstruction

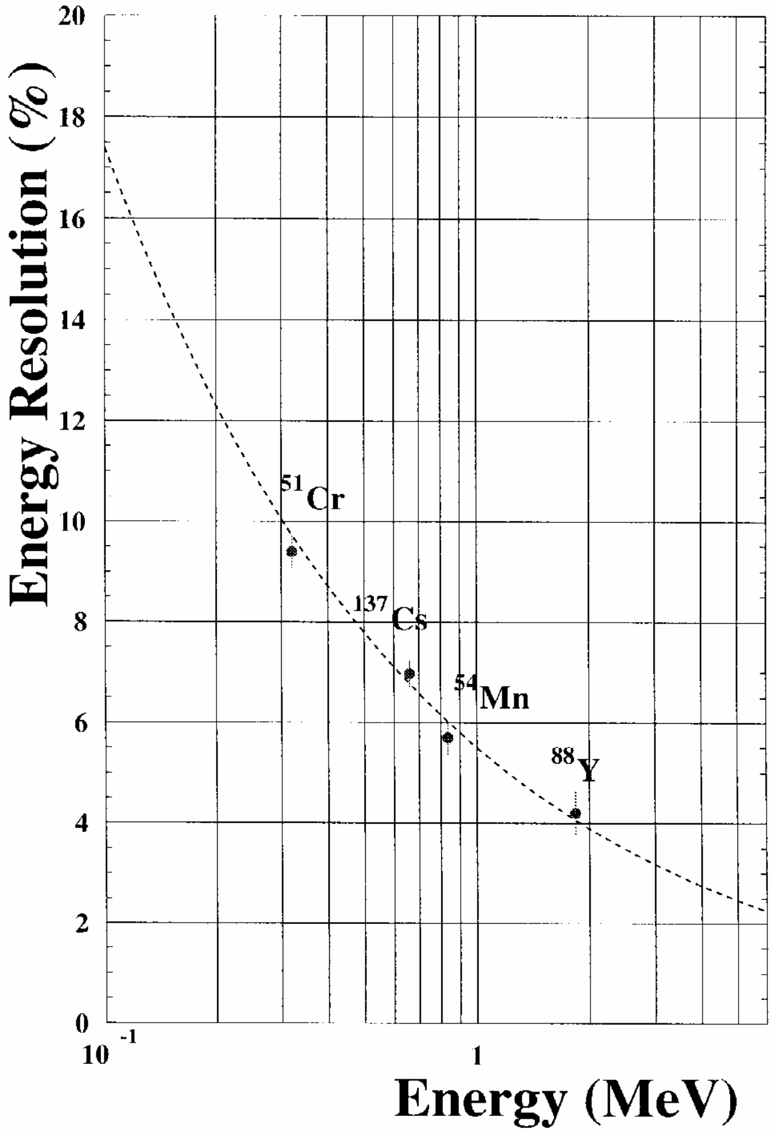
γ : multi-vertex/interaction points

bad χ^2 for the vertex reconstruction

To be studied

Energy Resolution

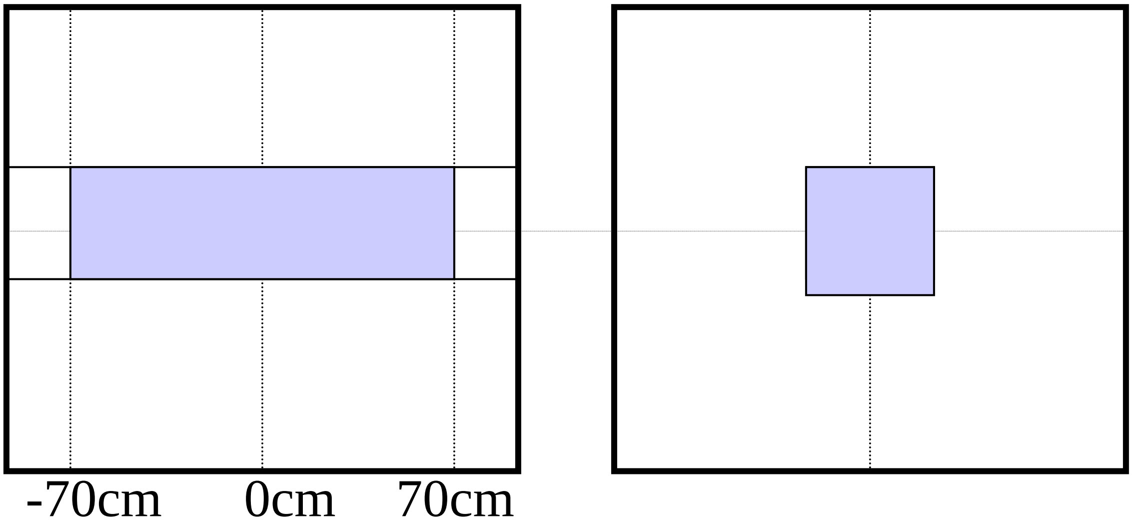
μ→eγ exp. proposal



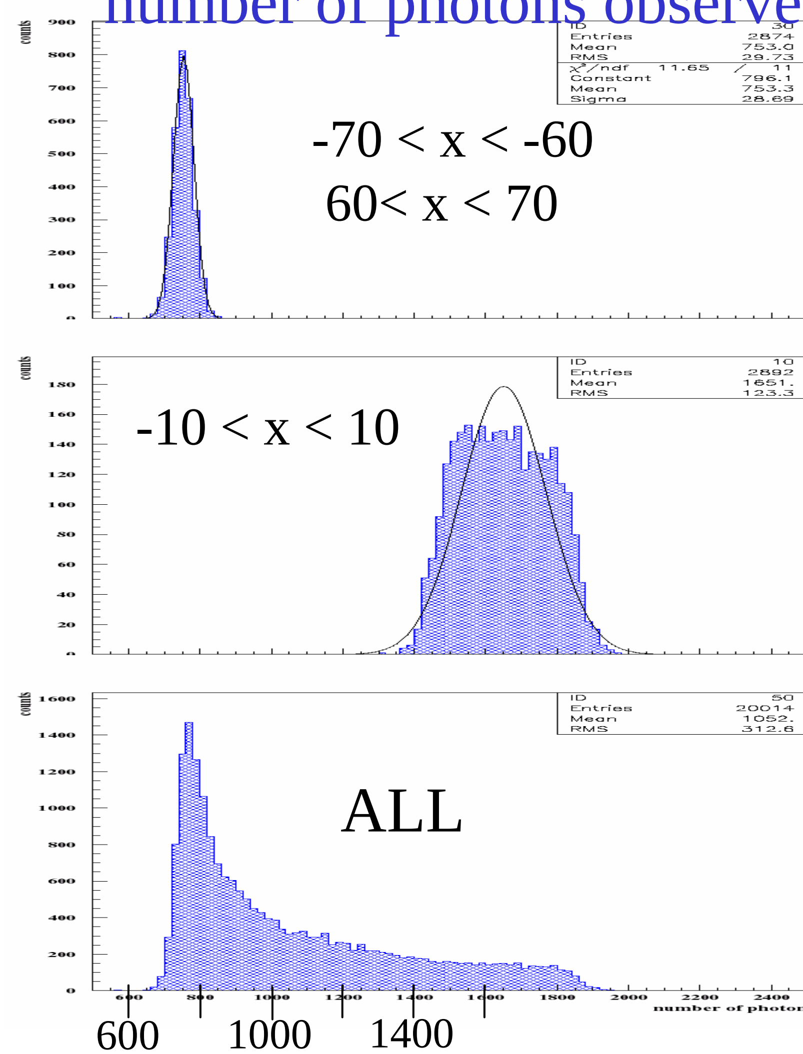
17% @ 100 keV

Energy resolution for the large chamber

select 20cmx20cmx1.4m region



number of photons observed (no correction)



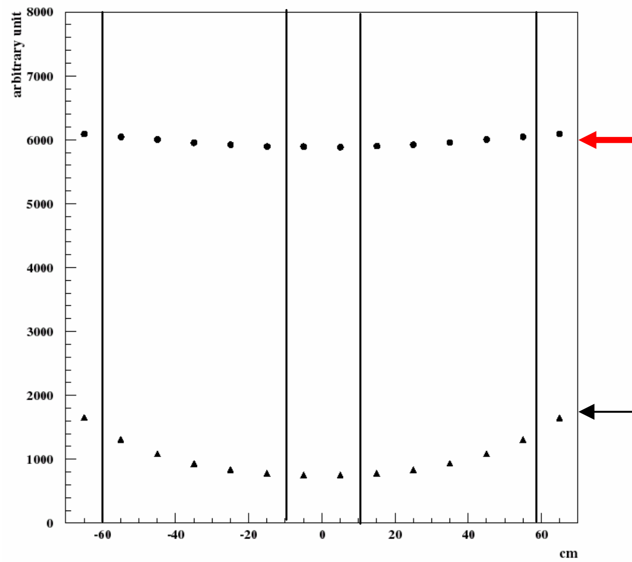
N = 735

σ/N = 4.0%

N = 1651

σ/N = 7.5%

Corrected energy

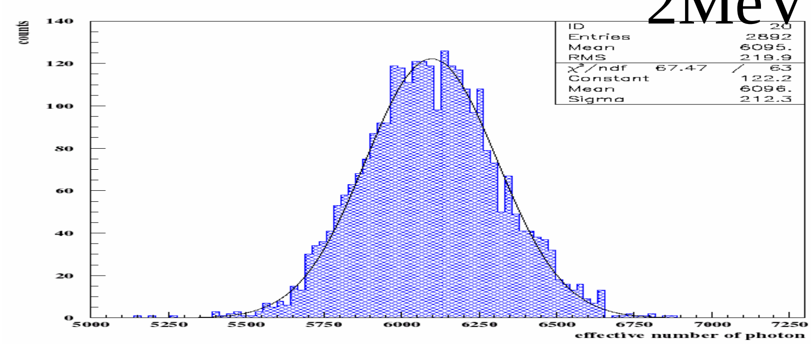


$$\frac{\Sigma n_j^{obs}}{\Sigma A_k^{eff}(d, \cos\theta)}$$

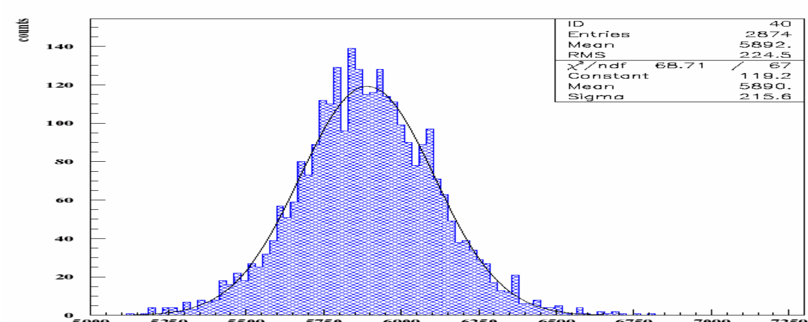
corrected for the effective acceptance

w/o correction

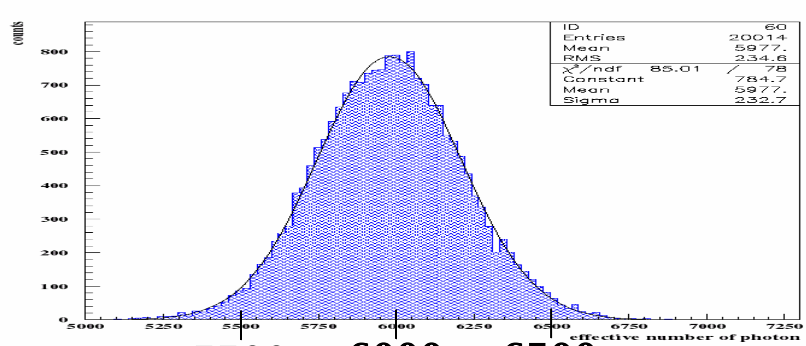
2MeV



Edge
"N" = 6096
σ/"N" = 3.5%



Center
"N" = 5890
σ/"N" = 3.6%



5500 6000 6500

All volume
"N" = 5977
σ/"N" = 3.9%

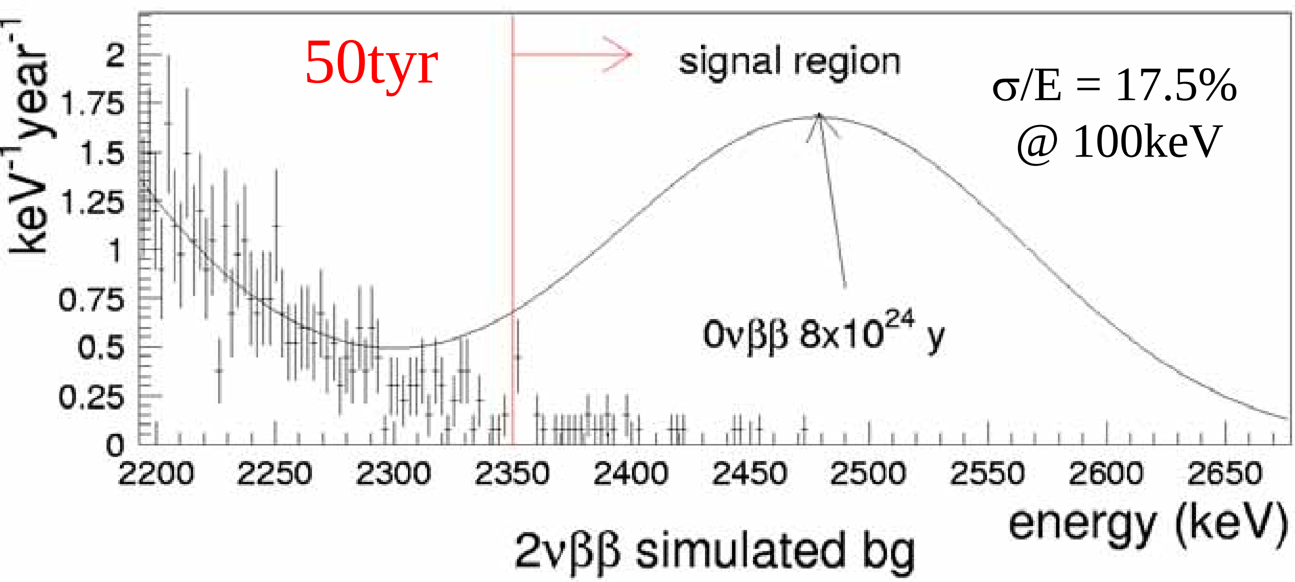
Sensitivity to Dark Matter and Double Beta Decay Search

Sensitivity of 0νββ decay

Natural Xenon 10ton

^{136}Xe 887kg

Assumption: BG only from 2νββ

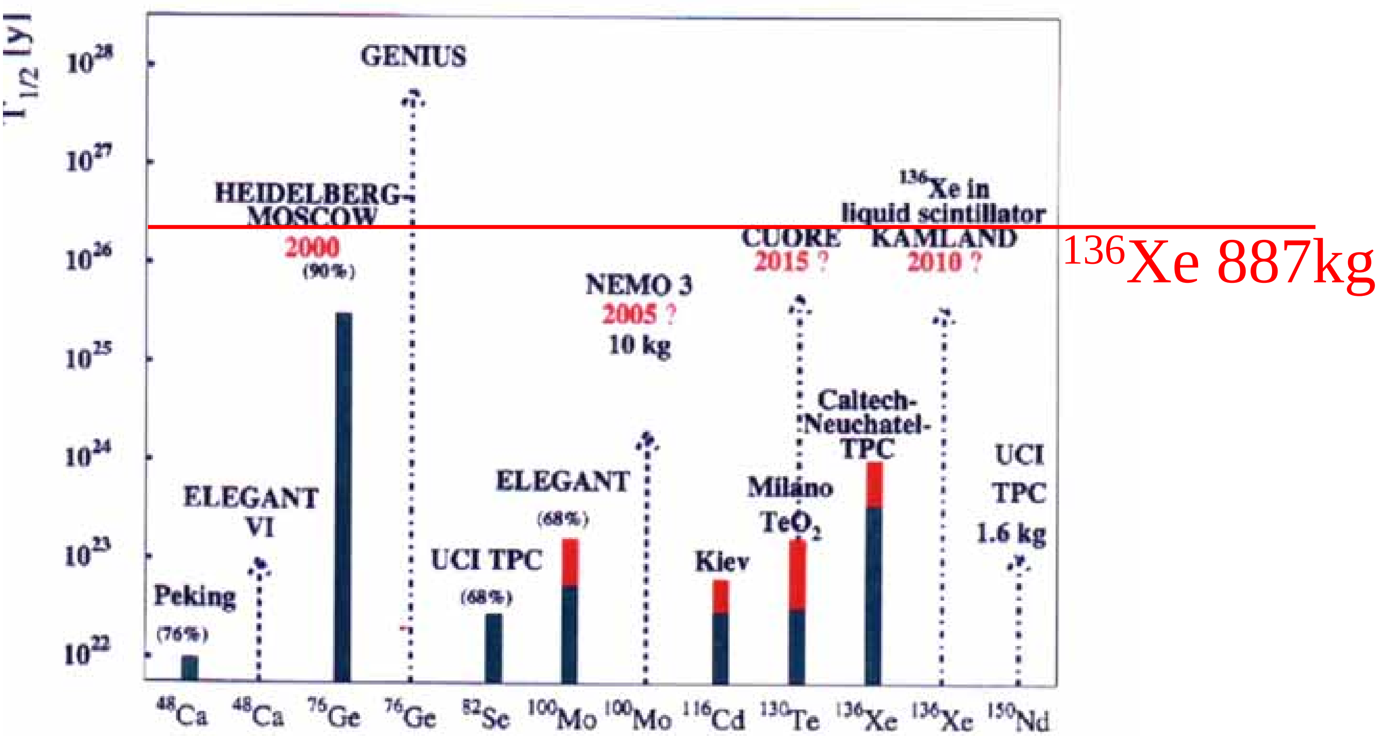


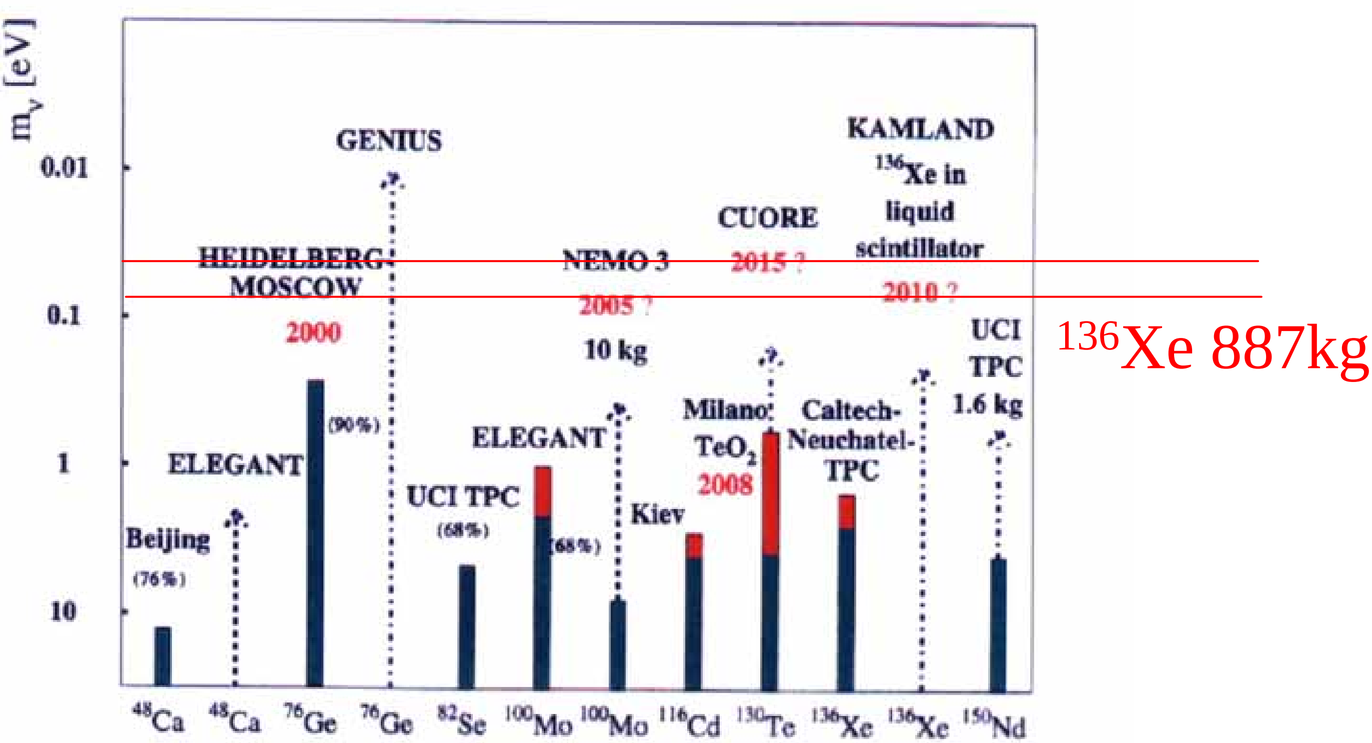
Sensitivity ~3.3x10^{26} yr (5yr)

→ $\langle m_\nu \rangle$ < 0.06-0.09 eV

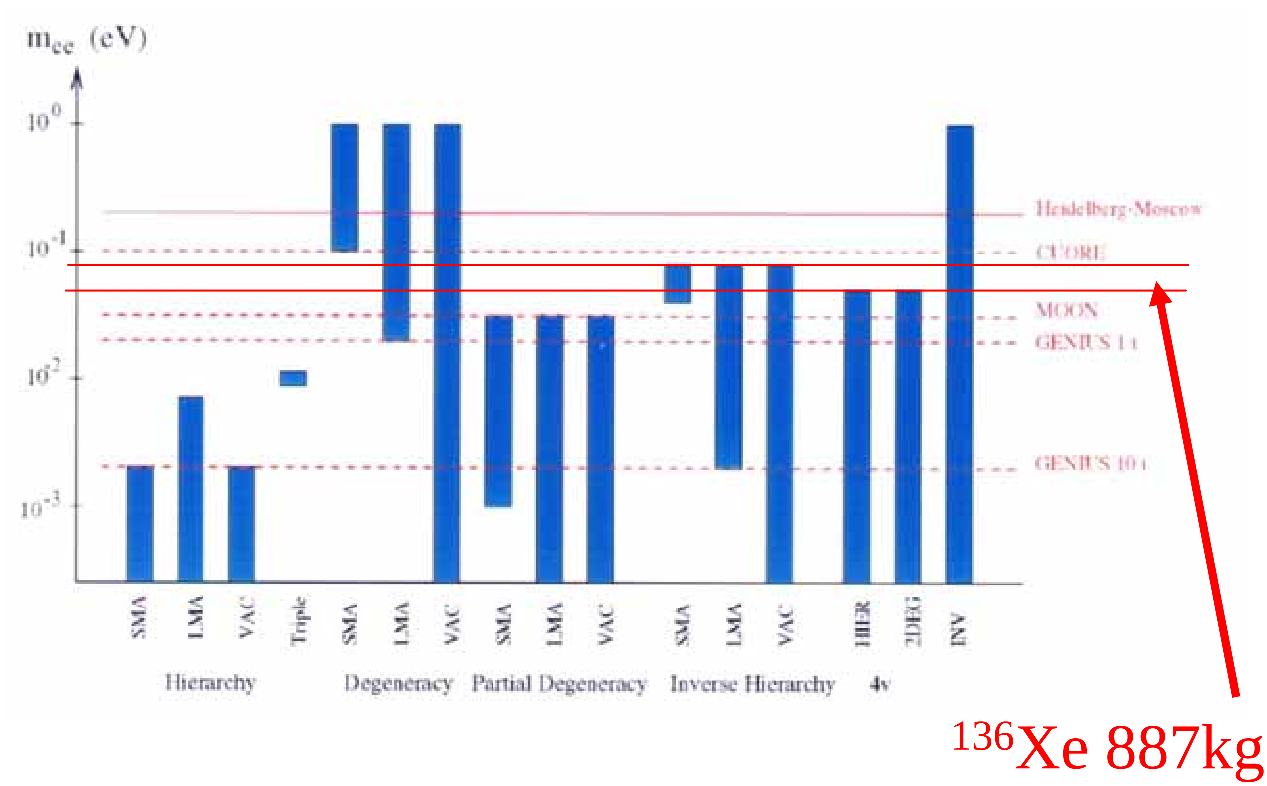
Status of the double beta decay experiments

Present limits of $0\nu\beta\beta$-experiments (H.V.Klapdor)

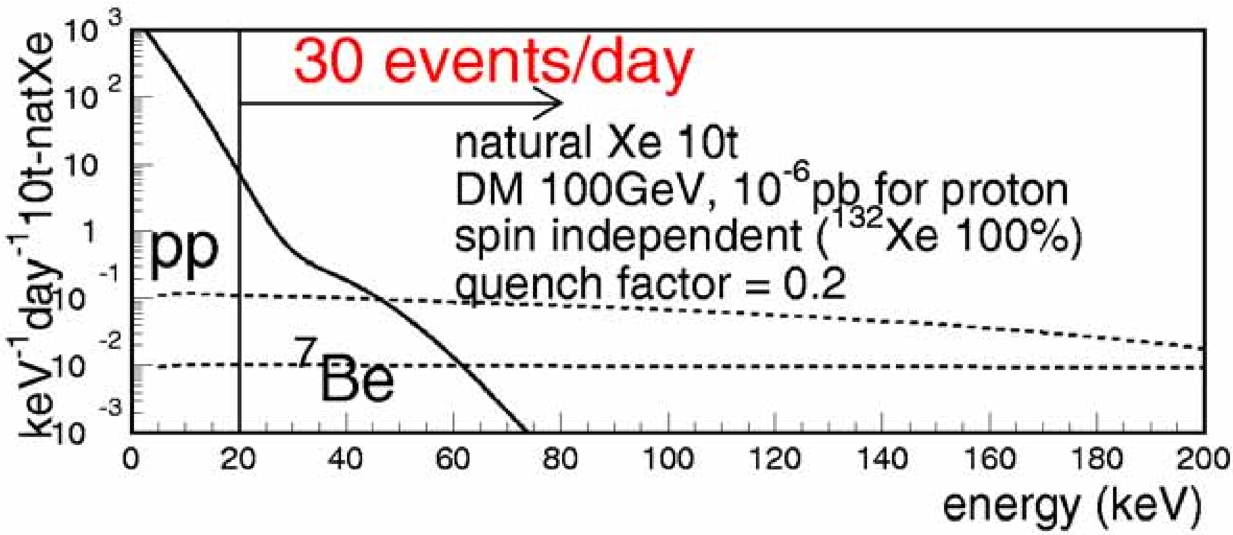


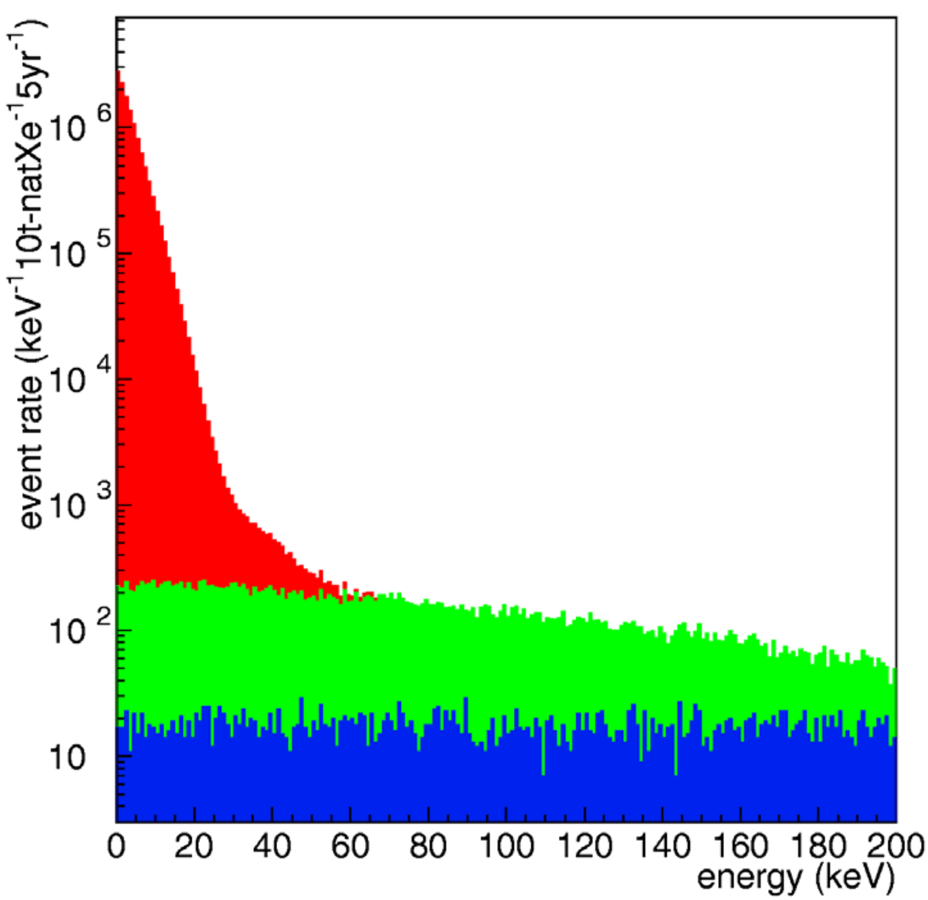


Double beta decay and solar neutrino solutions

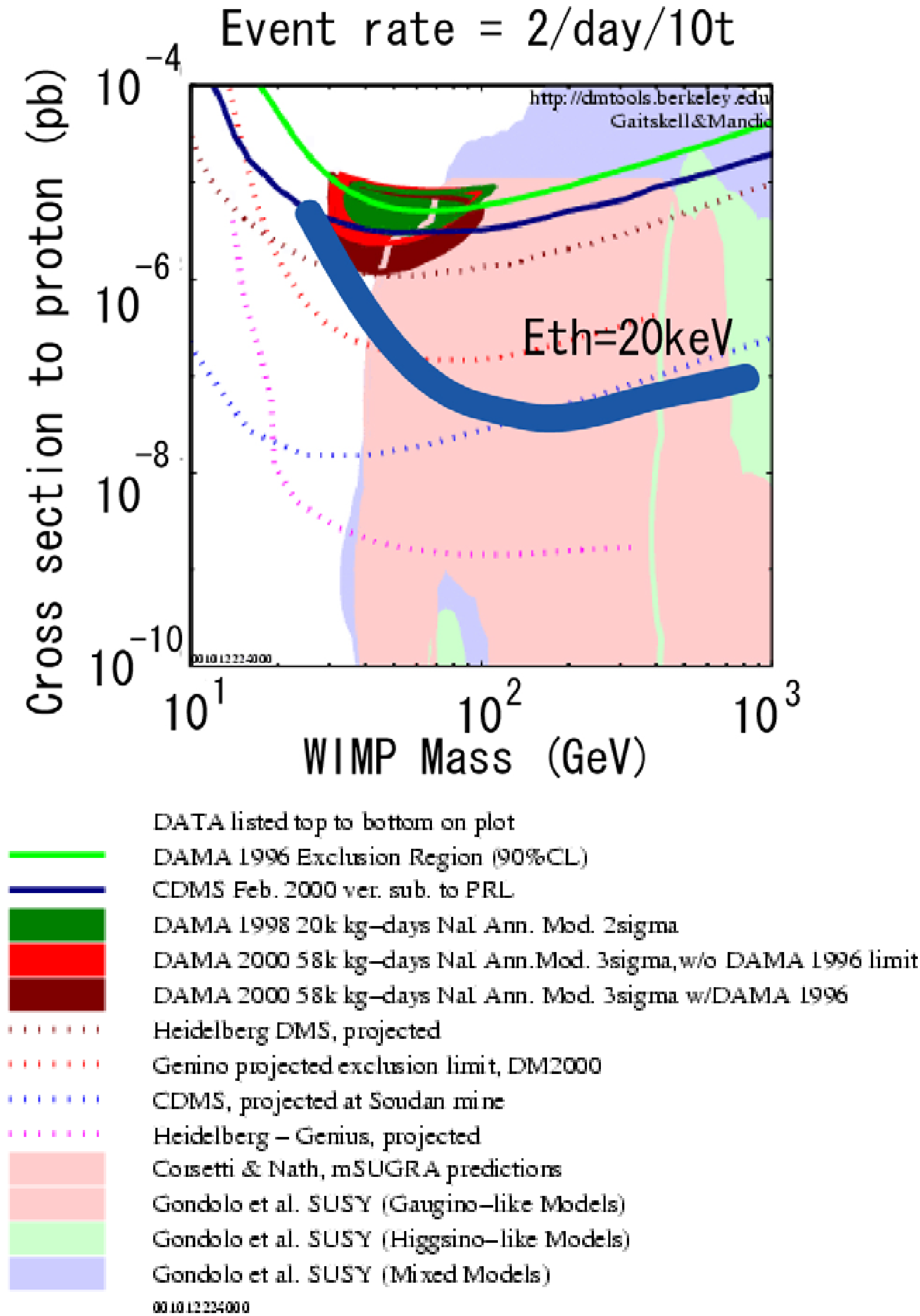


Sensitivity to Dark matter search

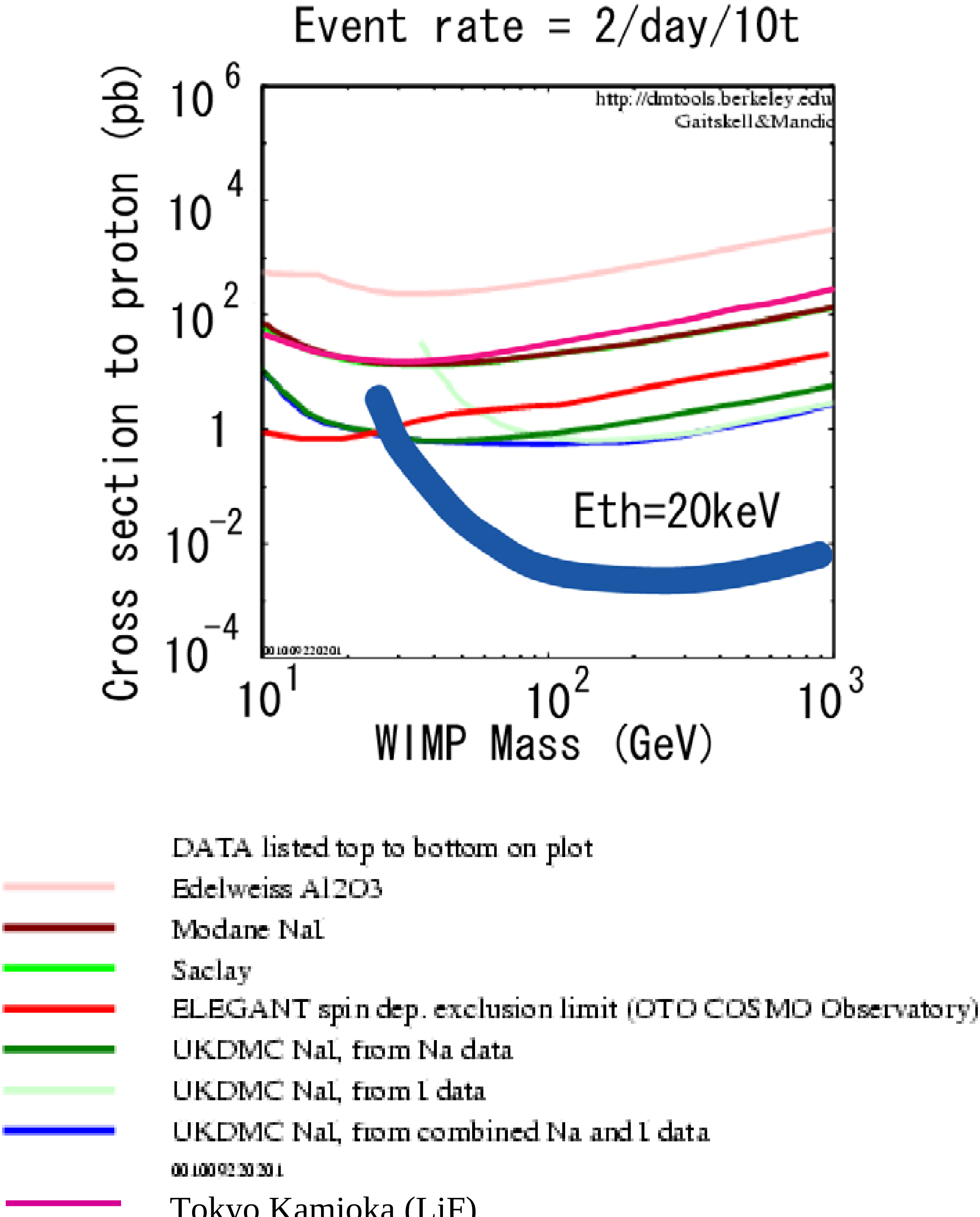




Spin independent case

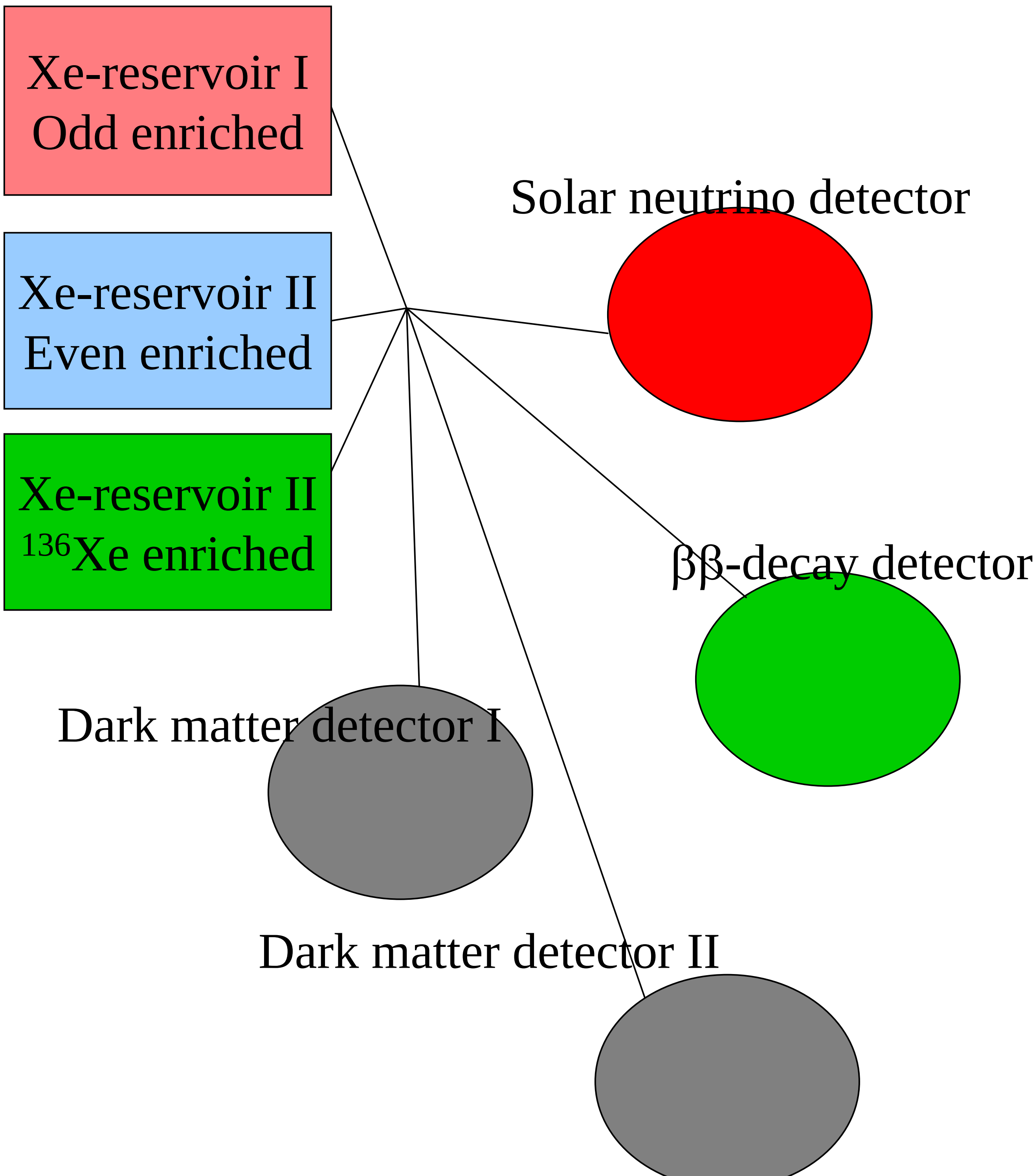


Spin dependent case



Xe-complex

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



Schedule

2000.12. Clean room in Kamioka Observatory
3kg (1liter) test chamber
3kg (1litter) chamber (Waseda Group)
→ DM search (Next speaker)
6kg (2 litter) of Kr-free (< 1ppb)Xenon
→ Order has been placed
Enriched Xenon for test (for U/Th ^{85}Kr)
→ thinking to place
order of 6 kg ?
Cryogenic system for 100 kg (33litter)
→ has been ordered

2001 1) 100kg (33 liter) of Kr-free Xe
2) or 100kg of Odd-enriched and
10kg of ^{136}Xe enriched Xe
(2νββ rate and DM search)

2003 < 5 +5 ton Odd enriched??
(for DM and solar ν)
1 ton ^{136}Xe ??
?????

Clean Room

2000.11.27

To be completed in the middle of December