

Neutrino-mass studies in Asia

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Experiments in Asia

- Japan
 - CANDLES: ^{48}Ca CaF_2 @Osaka-Kamioka
 - KamLAND-Zen ^{136}Xe @Tohoku-Kamioka
 - DCBA ^{150}Nd @KEK
 - XMASS ^{136}Xe @Kamioka
- Korea
 - AMoRE $^{100}\text{Mo}(\text{Ca}^{100}\text{MoO}_4)$; Kim's talk
- China
 - PandaX ^{136}Xe @Jinping; Chen's talk

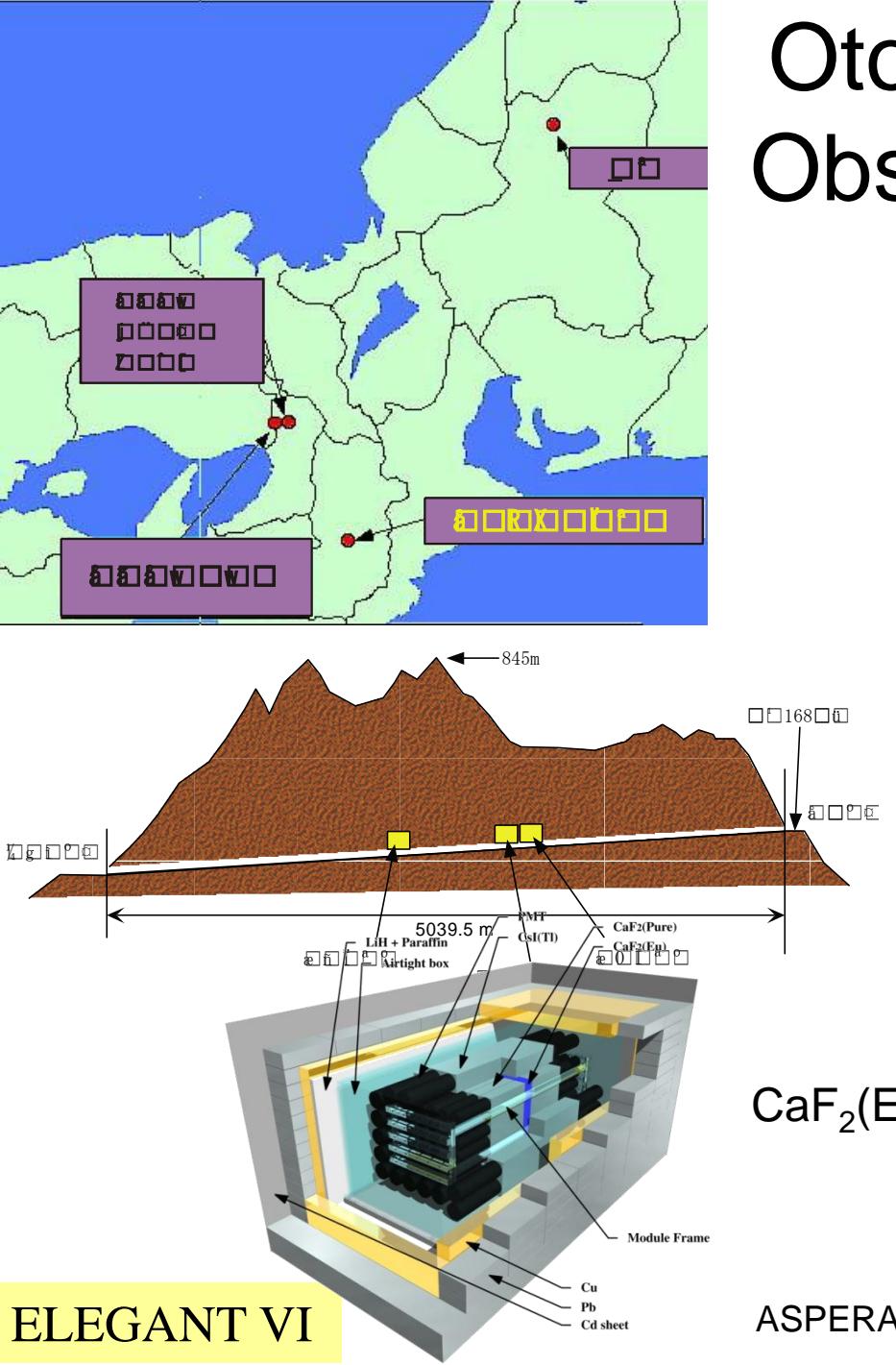
CANDLES

^{48}Ca

CaF_2 crystal

Why ^{48}Ca

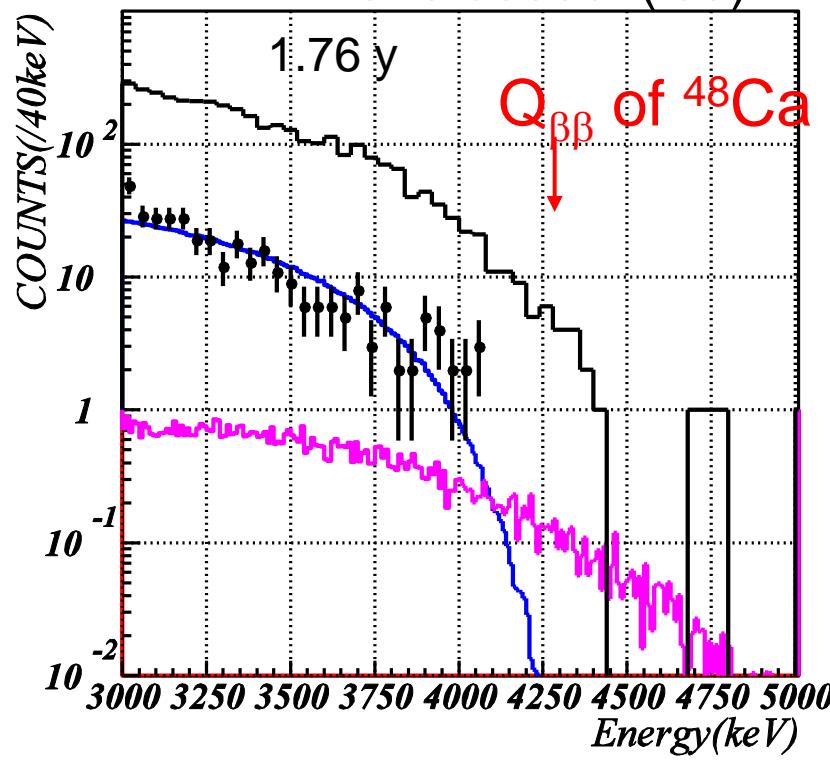
- Highest Q value (4.27 MeV, ^{150}Nd : 3.3 MeV)
 - Large PV, Little BG (γ : 2.6 MeV, β : 3.3 MeV)
- Small natural abundance: 0.187%
 - Isotope separation → expensive (no Gas)
- Next generation
 - $m_\nu \sim T^{-1/2} \sim (\text{Det. Mass})^{-2}$ (no BG)
 - $\sim (\text{Det. Mass})^{-4}$ (BG limited)
$$\left(\frac{\Delta EB}{Mt} \right)^{1/4}$$
 - ^{48}Ca (no BG so far)
- Nuclear matrix element $\Rightarrow \langle m_\nu \rangle$
- If we want to sense normal hierarchy region, only $^{48}\text{Ca} + \text{enrichment}$ have a chance.



Oto Cosmo Observatory

A tunnel constructed for a railroad but never used. It is 60km south from Osaka

PRC78 058501('08)



$$T_{1/2}^{0\nu\beta\beta} > 5.8 \times 10^{22} \text{ year (90 \% C.L.)}$$

$$\langle m_\nu \rangle < 3.5 \sim 22 \text{ eV (90 \% C.L.)}$$

Not limited by backgrounds

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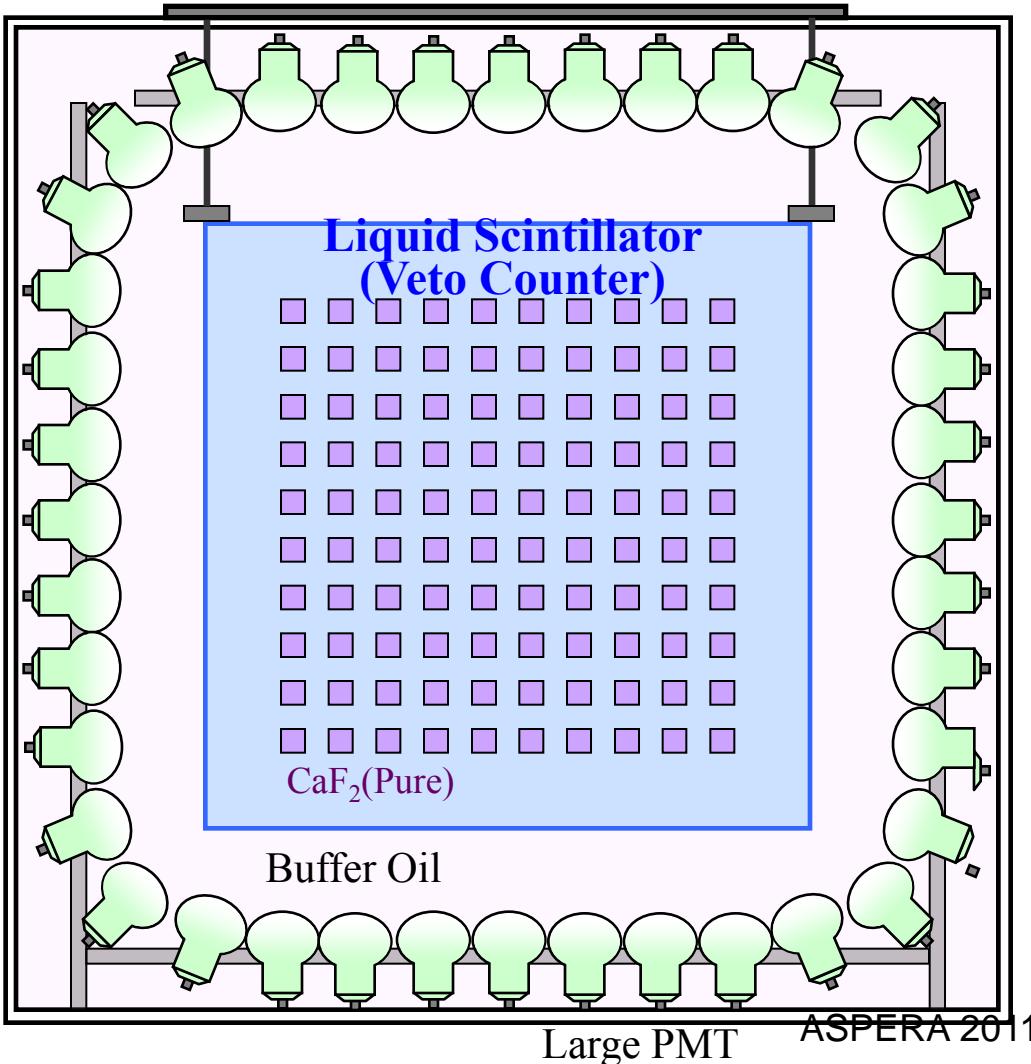
But only 6.4g of ${}^{48}\text{Ca}$

How to sense $m_\nu = 1 \sim 10^{-2} \text{eV}$

- Big detector
 - Huge amount of materials
- Low radioactive background
 - Active shield
 - Passive shield
 - Low background material
 - BG rejection by signal processing
- High resolution
 - Backgrounds from $2\nu\beta\beta$ decay
- **CANDLES** is our solution

CANDLES

Calcium fluoride for studies of Neutrino and Dark matrters
by Low Energy Spectrometer



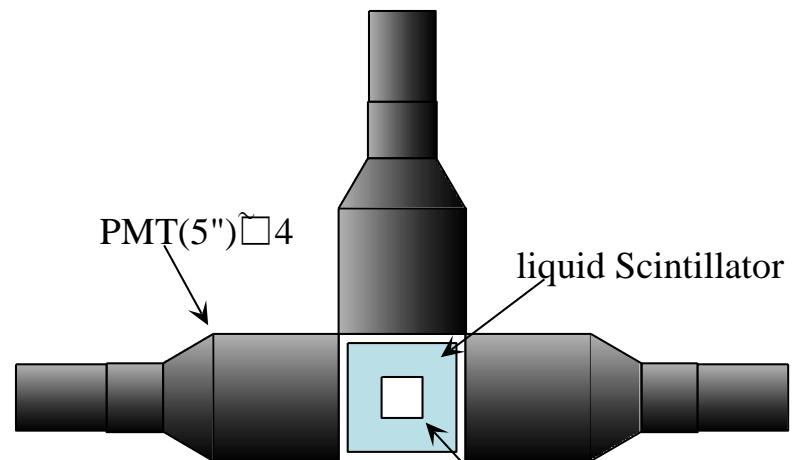
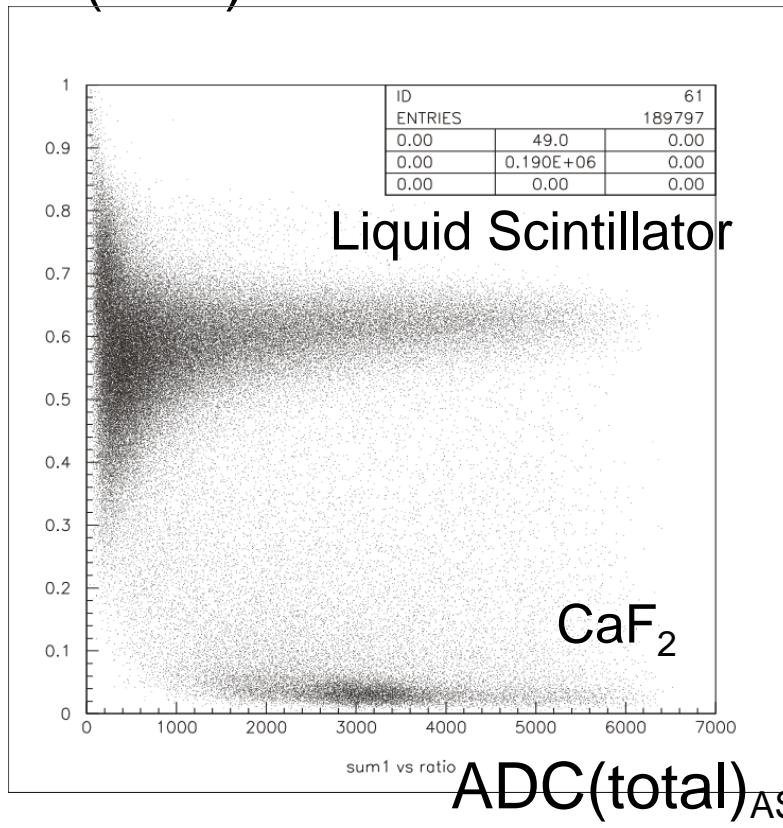
- ❖ **$\text{CaF}_2(\text{Pure})$**
200kg, 300kg, 2t, ..
enrichment
 ${}^{48}\text{Ca}$ ($Q_{\beta\beta} = 4.27\text{MeV}$)
- ❖ **Liquid Scintillator**
Wave Length Shifter
 4π Active Shield
Passive shield
- ❖ **Photomultiplier**
energy resolution

CANDLES I

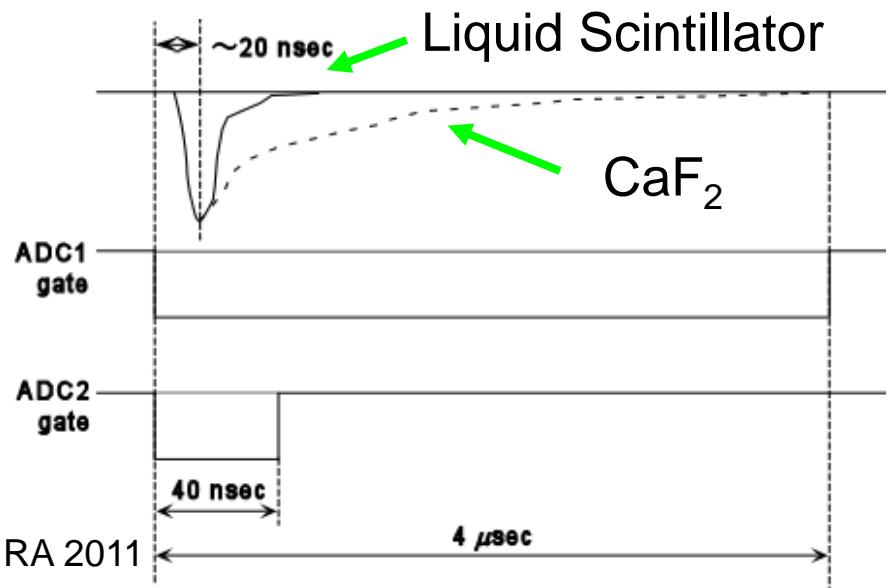
Background rejection

POP(Proof of Principle)

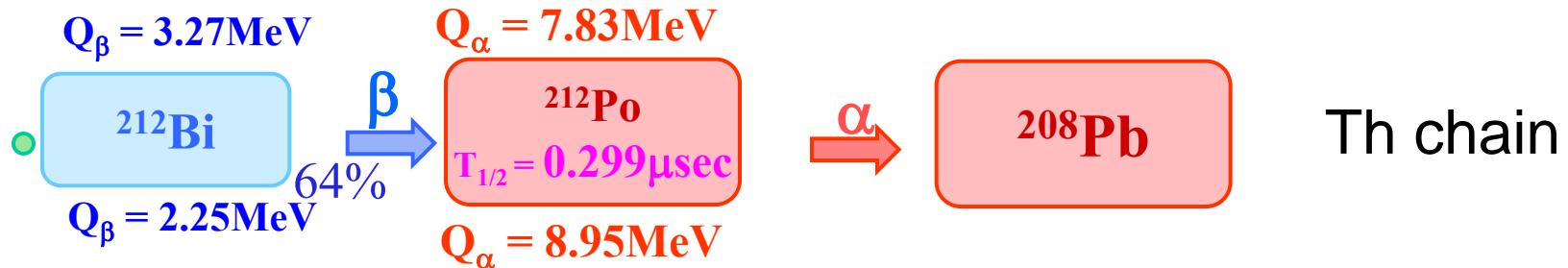
ADC(fast)
ADC(total)



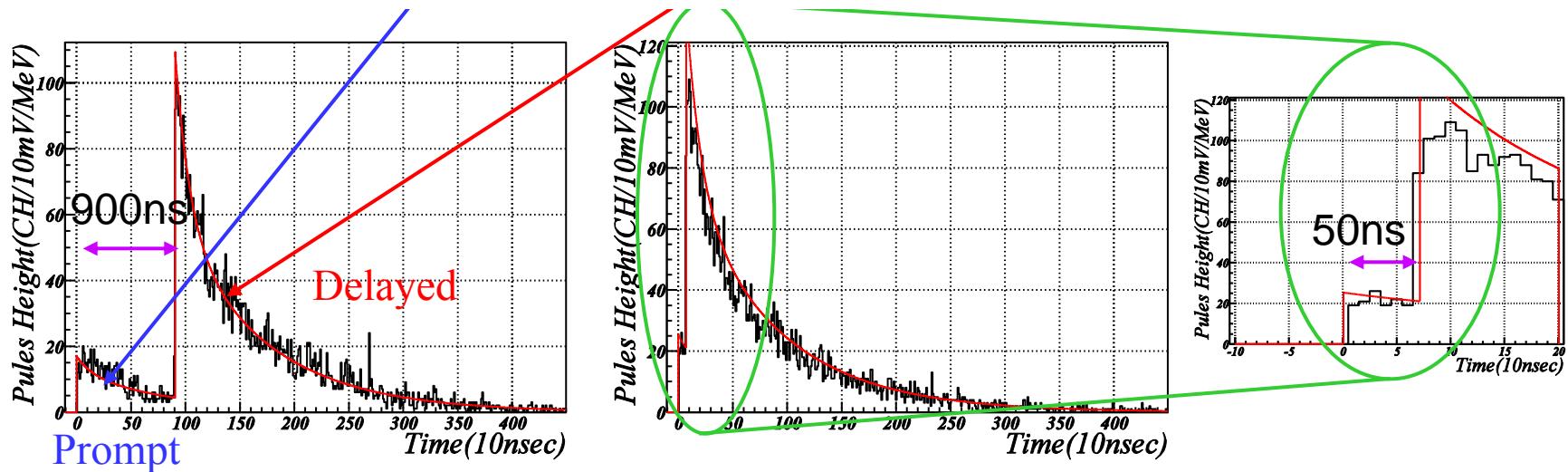
liq. scint. : mineral oil
+ DPO (3 g/l)
+ Bis-MSB (0.3 g/l)



Rejection of Double Pulse



Typical Pulse Shape(100MHz FADC)



Reduction

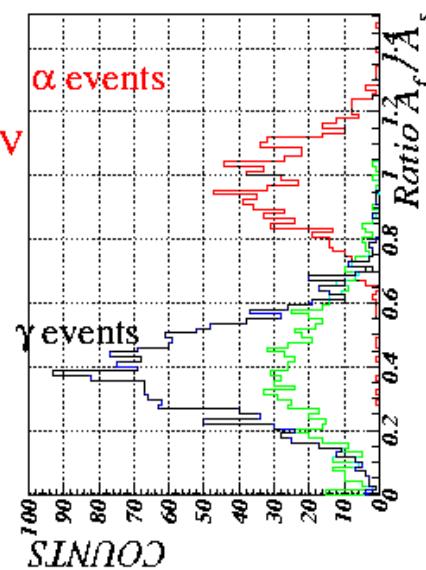
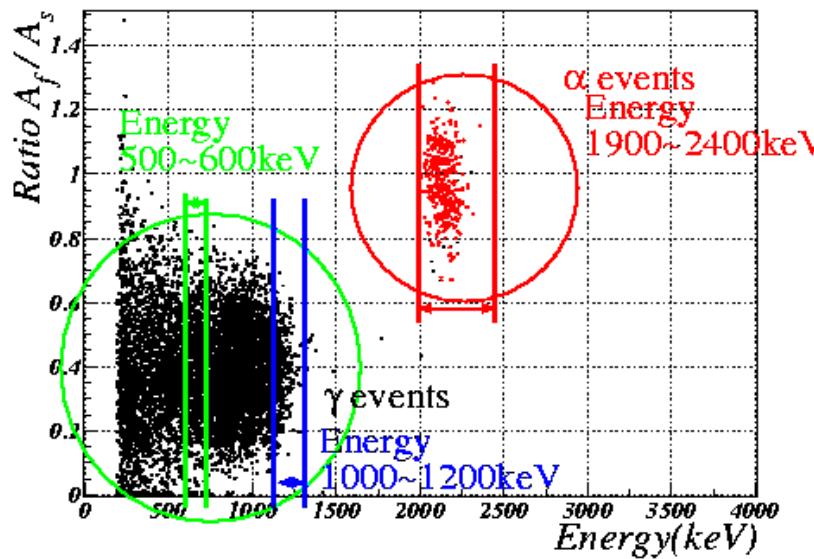
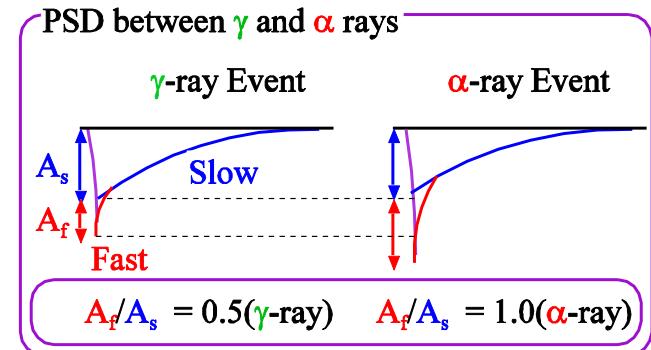
100MHz FADC $\Delta T > 30\text{ns}(3\text{ch})$; $\sim 3\%$

500MHz FADC $\Delta T > 5\text{ns}$; $\sim 1\%$

Pulse Shape Discrimination

Difference in decay time
between α and γ rays

- PSD (Event by Event)
 - FADC (100MHz)
 - A_{fast}/A_{slow} (Fast and slow component)

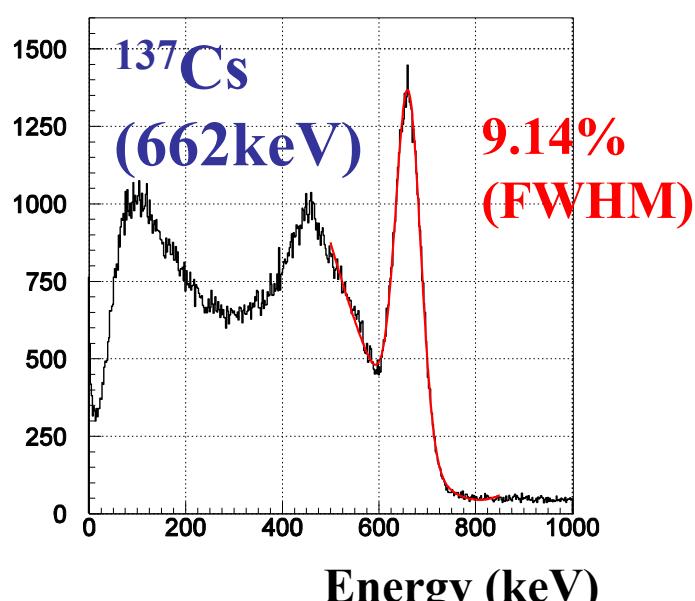
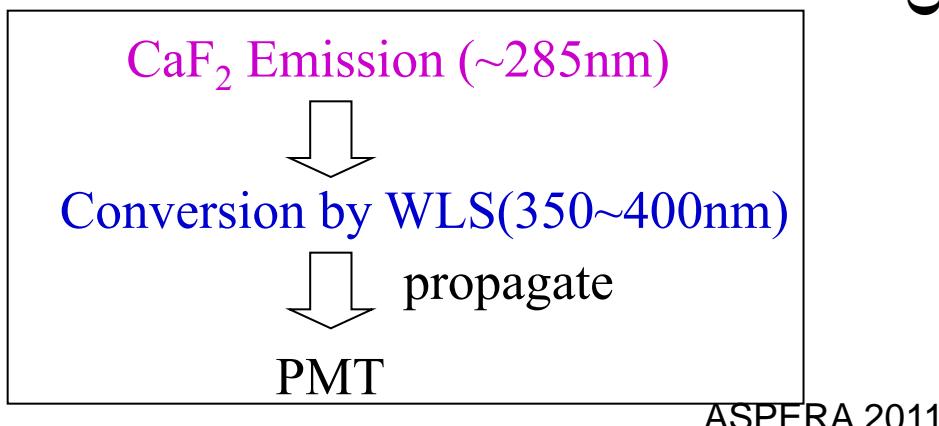
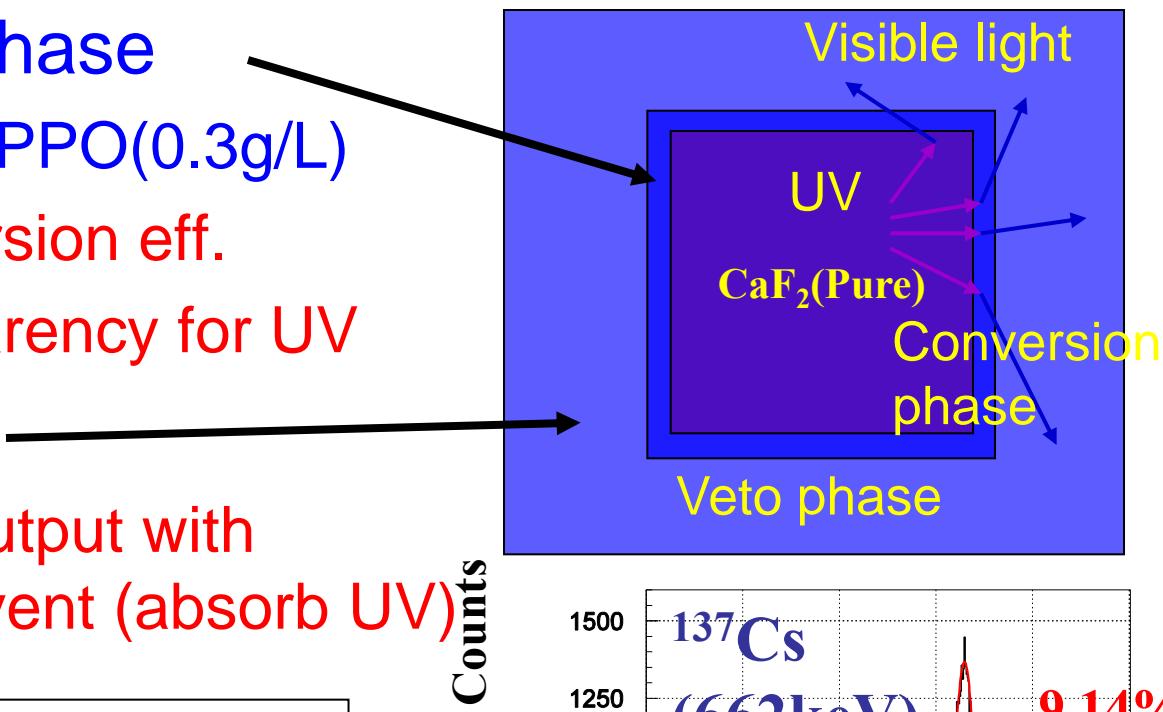


Discrimination between α and $\gamma(\beta)$ Events
Background Reduction $\sim 0.3\%$
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Two Phase System

High resolution
High veto efficiency

- Conversion Phase
 - M.O(100%)+PPO(0.3g/L)
 - Large conversion eff.
 - good transparency for UV
- Veto Phase



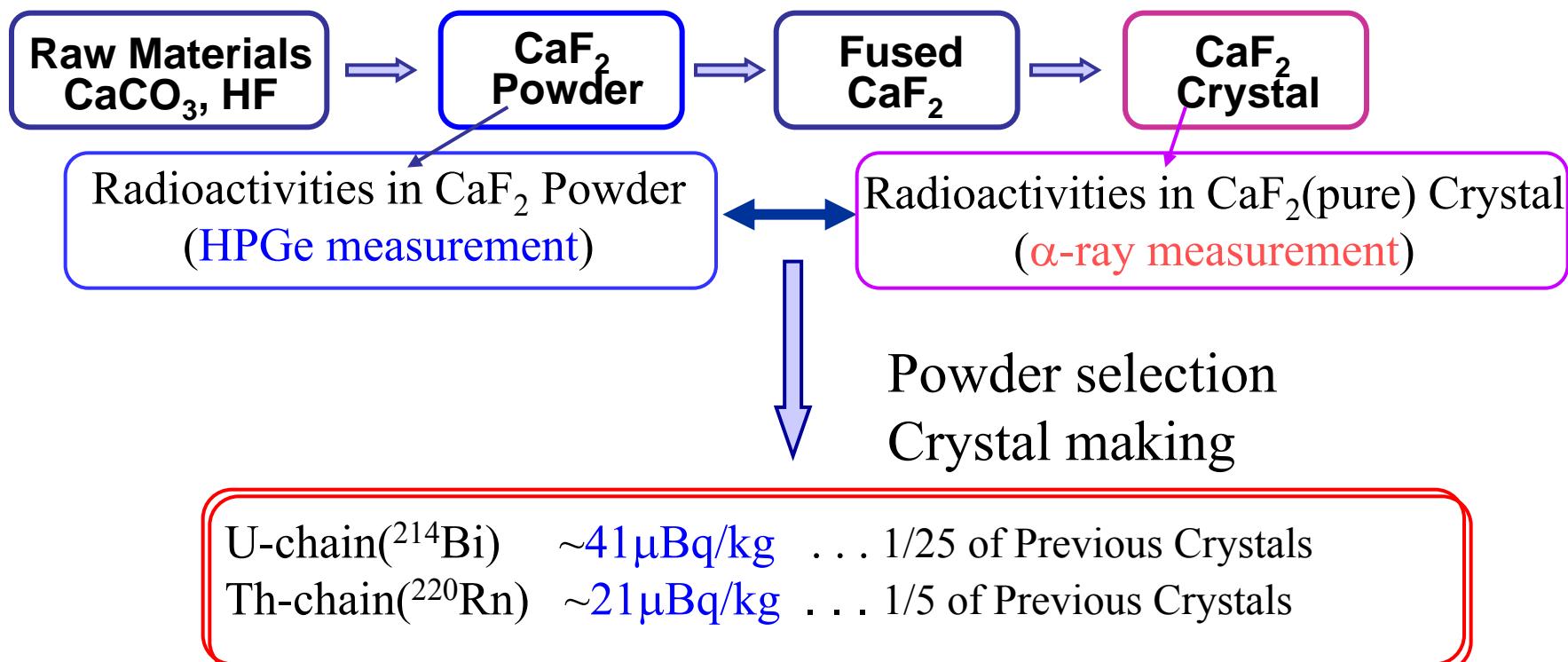
Development of Low Background CaF₂ Crystals

CaF₂(Eu) in ELEGANT VI

U-chain(214Bi) : 1100 μ Bq/kg

Th-chain(220Rn) : 98 μ Bq/kg

Where is the crystals contaminated?



CANDLES III(UG)



❖ Kamioka Experimental hall D

❖ CANDLES III(UG)

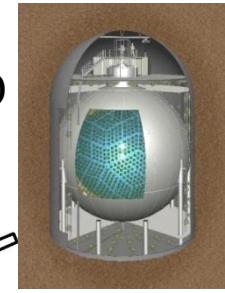
❖ 3m $\phi \times 4\text{m h}$



CANDLES III(UG)

Kamioka

KamLAND



KamLAND-ZEN

Super Kamiokande



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CANDLES

CANDLES III(UG)

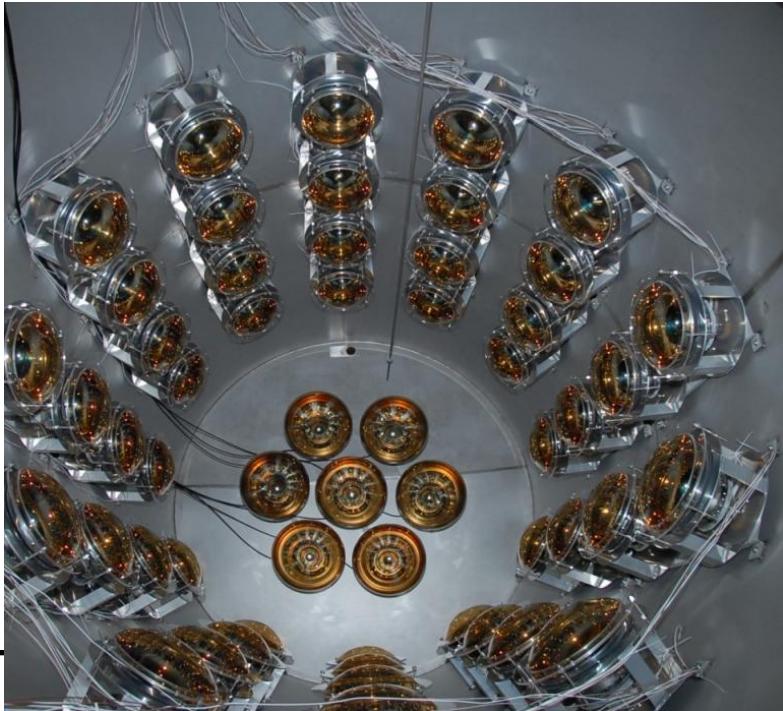


CANDLES III(UG)

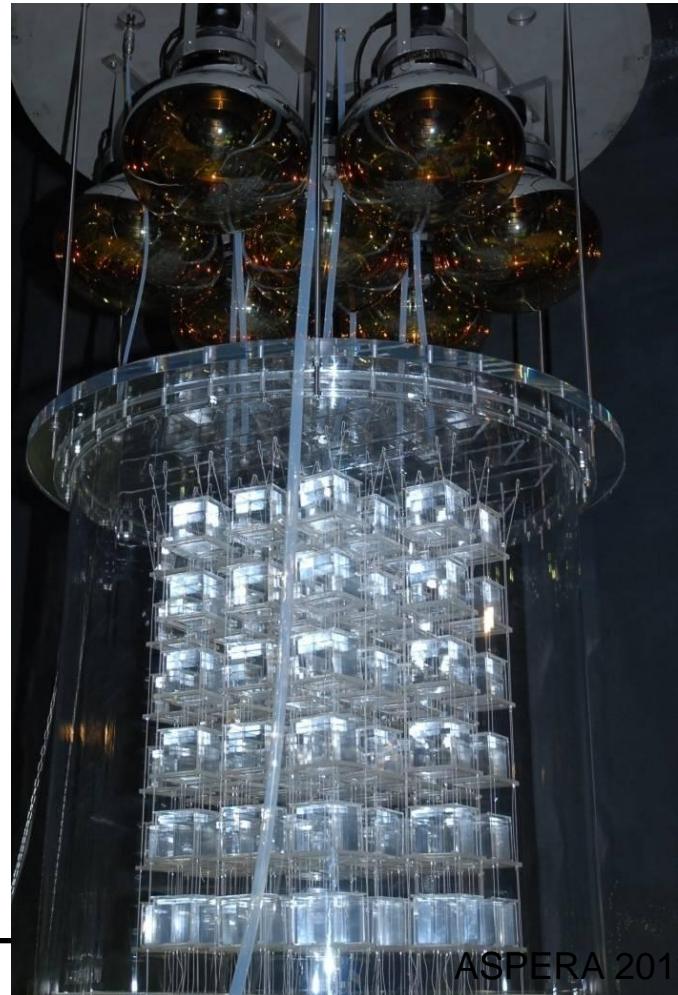
62 PMT's

96 CaF_2 (305 kg) crystals:

Completed

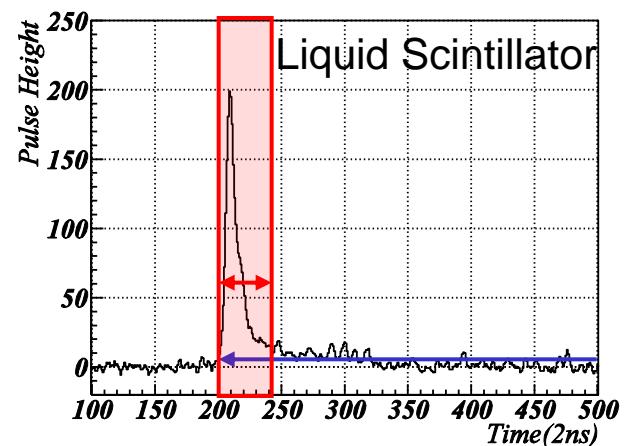
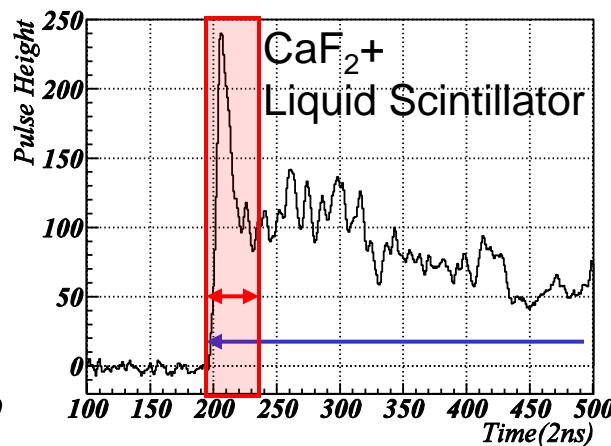
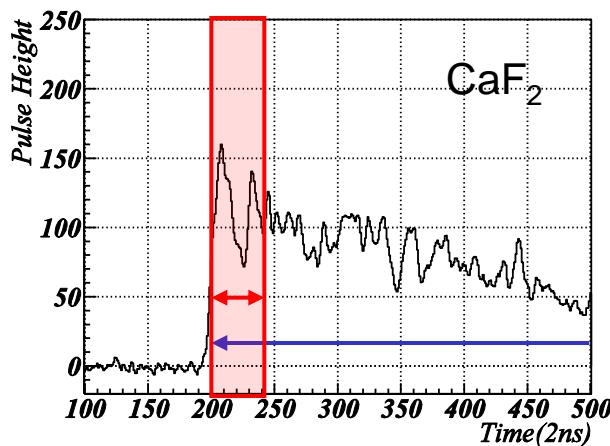


(CaF_2 crystals)



Rejection of LS Events

- Rejection by using Pulse shape information
 - Typical Pulse Shapes



$$\text{Charge Ratio} = \frac{\text{charge in partial gate}}{\text{charge in full gate}}$$

Characteristic of CANDLES

- BG rate (events/weight)
 - So far the best
 - 2~3 orders
- Scale up:
 - CANDESL IV, V
- Enrichment
 - increase $\beta\beta$ nuclei
 - BG reduction

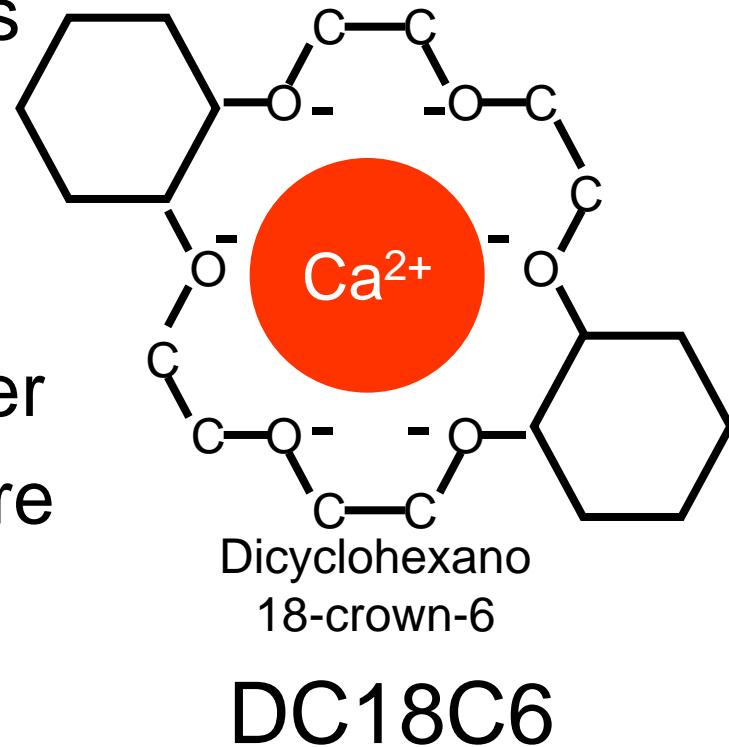
Target	Project	Abund. (%)	Background rate (counts/kg/year)
^{48}Ca	ELEGANT VI	0.187	0 (measured) 0.075 (expected)
	CANDLES III	0.187	5×10^{-4}
	CANDLES IV	0.187	5×10^{-5}
^{76}Ge	HDM	~86	0.61
	CUORICINO	33.9	2.4
^{130}Te		33.9	0.8 (CUORE-0) $10^{-2} \sim 10^{-3}$ (Goal)
^{136}Xe	EXO-200	~80	0.1

}

0.2% -> 100%
500 times improvement

Enrichment of ^{48}Ca by Crown Ether

- Crown ether
 - Cyclic chemical compounds that consist of a ring containing several ether groups.
 - Absorbs Ca ion at the center
 - absorbs lighter Ca ions more
 - Separation coefficient
 - $\varepsilon \sim (3.5\text{--}6) \times 10^{-3}$ for 18C6



Experiment by CE resin

- **Chromatographic method (migration)**

2. Ca solution

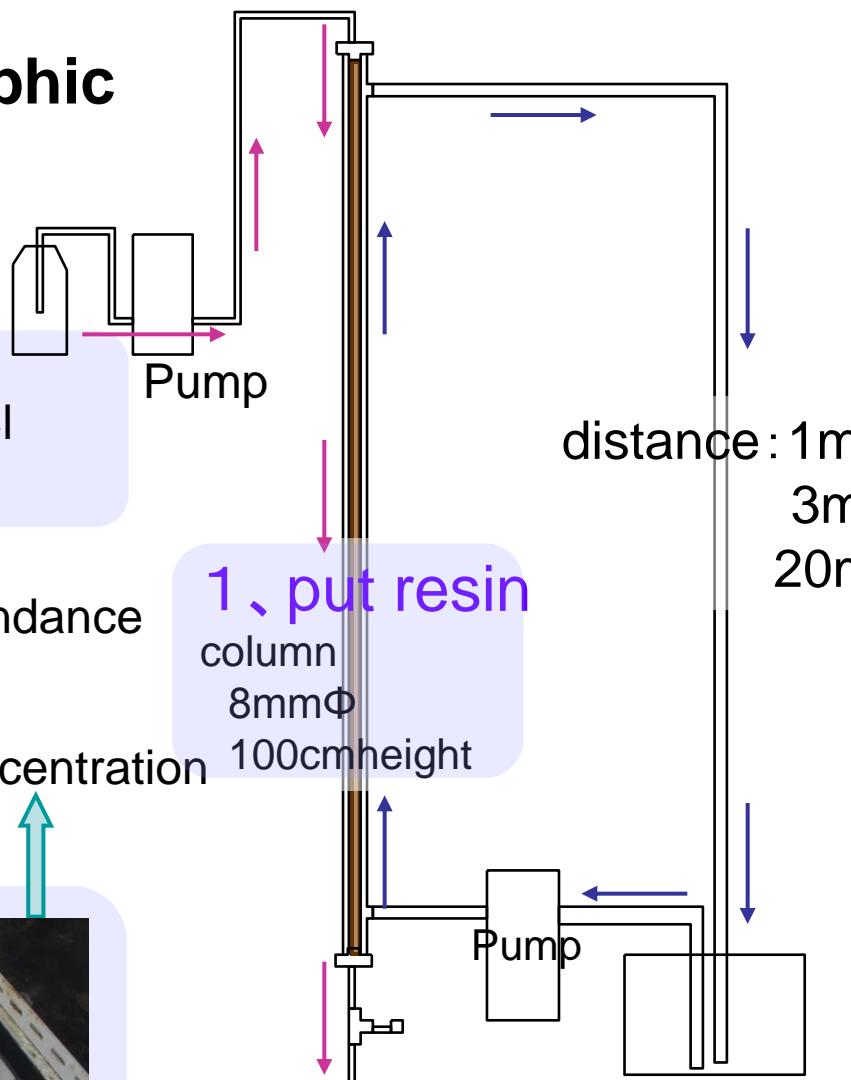
0.09M $\text{CaCl}_2 + 9\text{M HCl}$
0.34ml/min

5. measure abundance

4. measure concentration



3. Fraction collector
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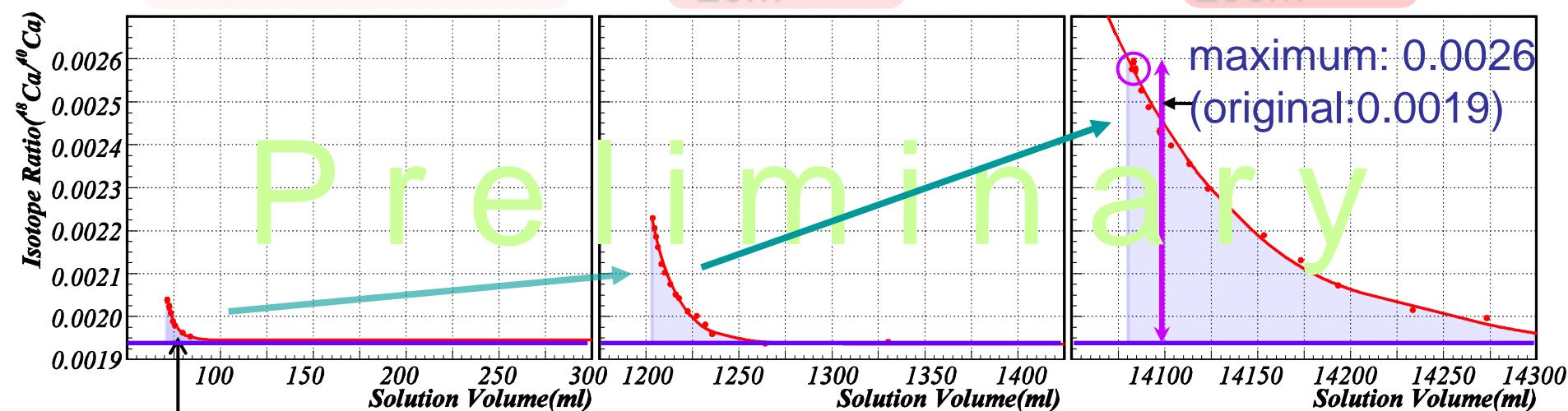


Enrichment for long migration

~7 hours
1m

~70 hours
20m

~250 hours
200m



Enrichment due to crown ether

- long migration length
 - higher enrichment and larger amount
- ~7hours(1m) → ~250 hours (200m)
amount: × 17, enrichment: × 8

CANLDES

- CANDLES IV
 - 2t: 2.5 kg ^{48}Ca
- Enrichment (CE resin) Current parameter
 - 2% 100kg(CaF_2)/year $\Rightarrow 1.3(^{48}\text{Ca})\text{kg /year}$
 - Further study of parameters
 - Enrichment of 5% or more
 - Other methods (Laser, electro-migration)
- $\langle m_\nu \rangle \sim 90\text{meV}, 50\text{ meV},$
- 10 meV CaF_2 (energy resolution: bolometer)

AMoRE

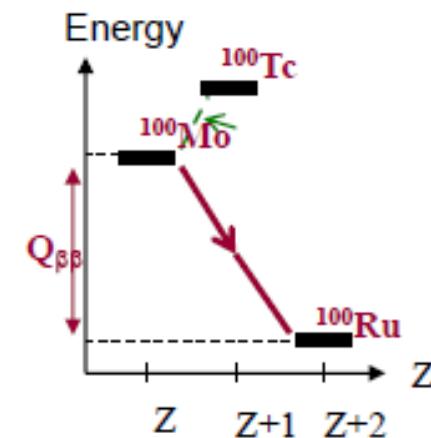
^{100}Mo

$^{40}\text{Ca}^{100}\text{MoO}_4$ crystal

CaMoO_4 for $0\nu\beta\beta$

CaMoO_4

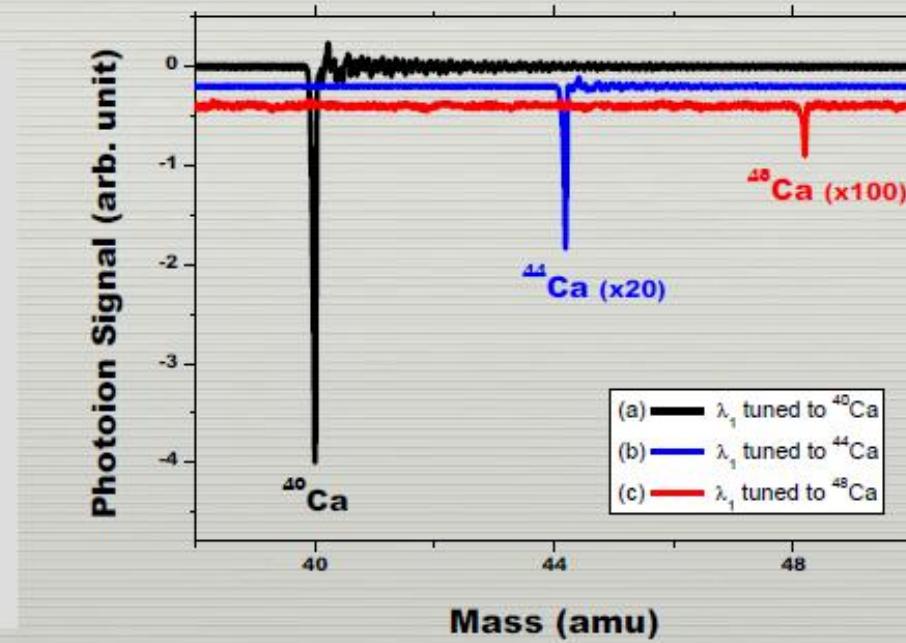
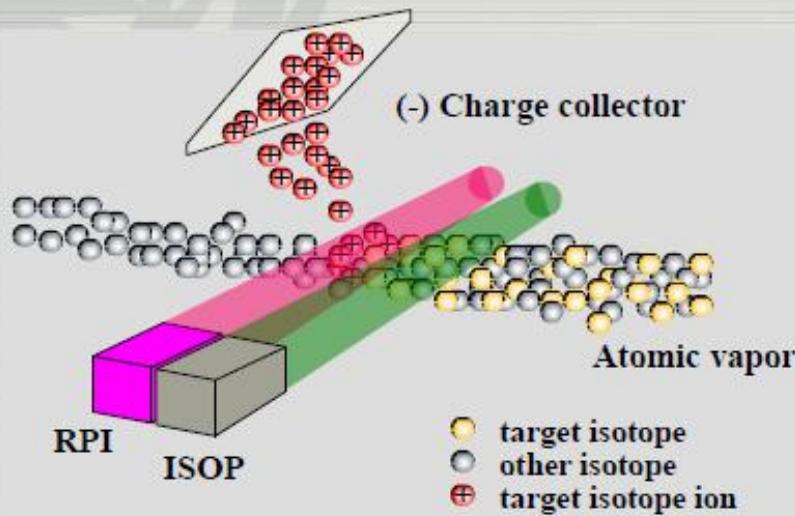
- DBD for Mo-100 (3034 keV), Ca-48(4272 keV)
high energy → less background
- Mo-100 enrichment >90% not so difficult
- for Mo-100 search, Ca-48 needs to be depleted
- Scintillator
 - At room temp; 10-20% of CsI(Tl) at 20°
 - Decay time ; 16 μ sec
 - LY increases at lower temp. (almost the same as CsI(Tl))
 - Wavelength; 450-650ns-> RbCs PMT or APD
 - Pulse Shape Discrimination
- Can be used as cryogenic detector
 - Debye temperature: 438 K (Ge : 360 K, Si: 625 K)
 - Combining with Scintillation detection : NR, alpha/gamma separation
 - Good dark matter detector as well



^{48}Ca Enrichment/Depletion at

KAERI (Korea Atomic Energy Research Institute)

- ◆ ALSIS (Advanced Laser Stable Isotope Separation)
 - Features : Isotope-Selective Optical Pumping (ISOP)
followed by Non-selective Resonant Photoionization (RPI)
 - ISOP gives good isotope-selectivity and non-selective RPI high yield.



$^{40}\text{Ca}^{100}\text{MoO}_4$

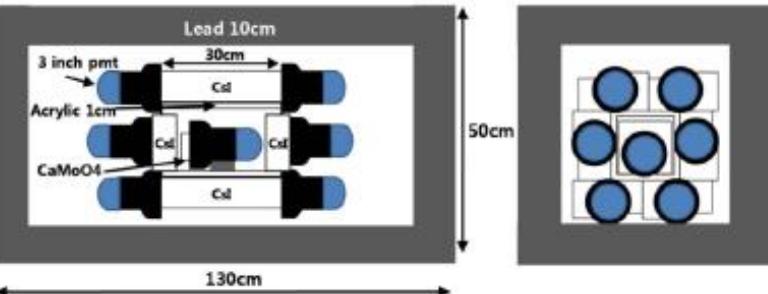
First $^{40}\text{Ca}^{100}\text{MoO}_4$ crystal
after big bang



CMO «Z0Y-25»
 CaMoO_4 изотопнообогащенный

3 crystals with enriched
material $\sim 845\text{g}$

Being tested at Y2L

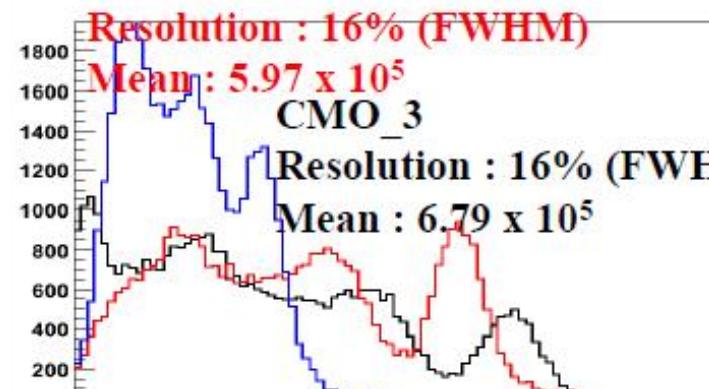


Cs-137 source

SB28

Resolution : 30% (FWHM)

Mean : 2.88×10^5



Experimental setup at KRISS with MMC to measure temperature changes

~ 500 μm thick brass

alphas and gammas

Collimator

crystal size

~ 1 cm \times 0.7 cm \times 0.6 cm

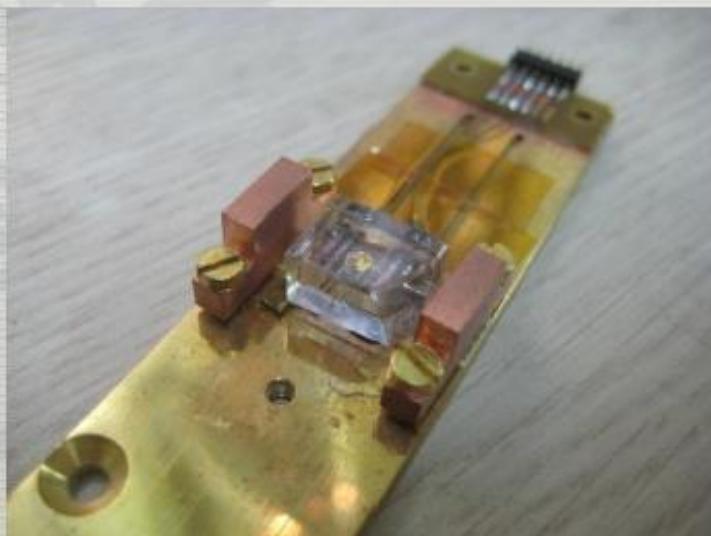
CaMoO₄

Au:Er

SQUID chip

field coil

base temperature : 13 ~ 100 mK

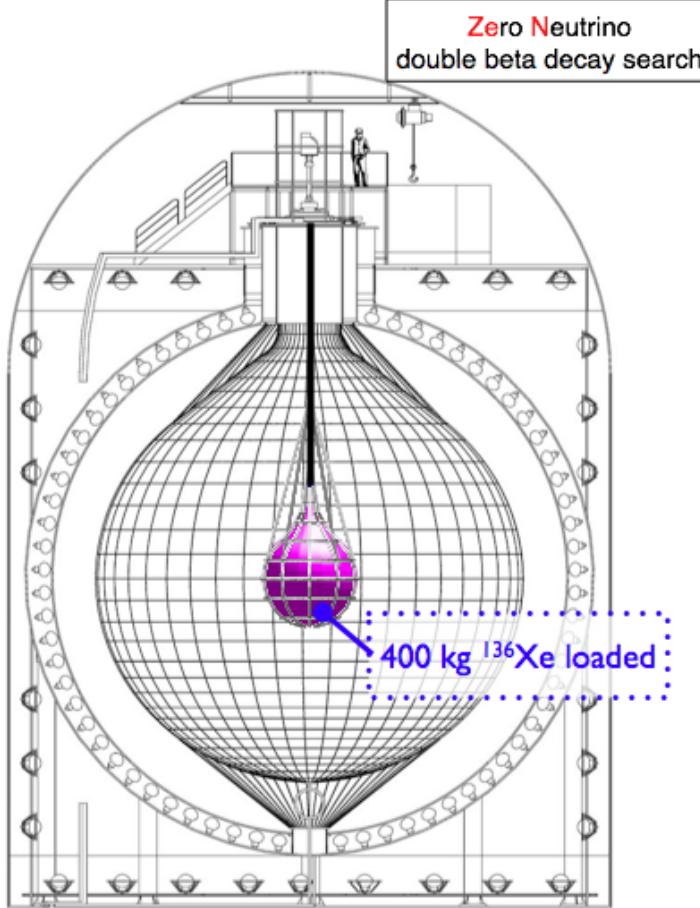


KamLAND-Zen

^{136}Xe

Xe in Liquid scintillator

KamLAND-Zen

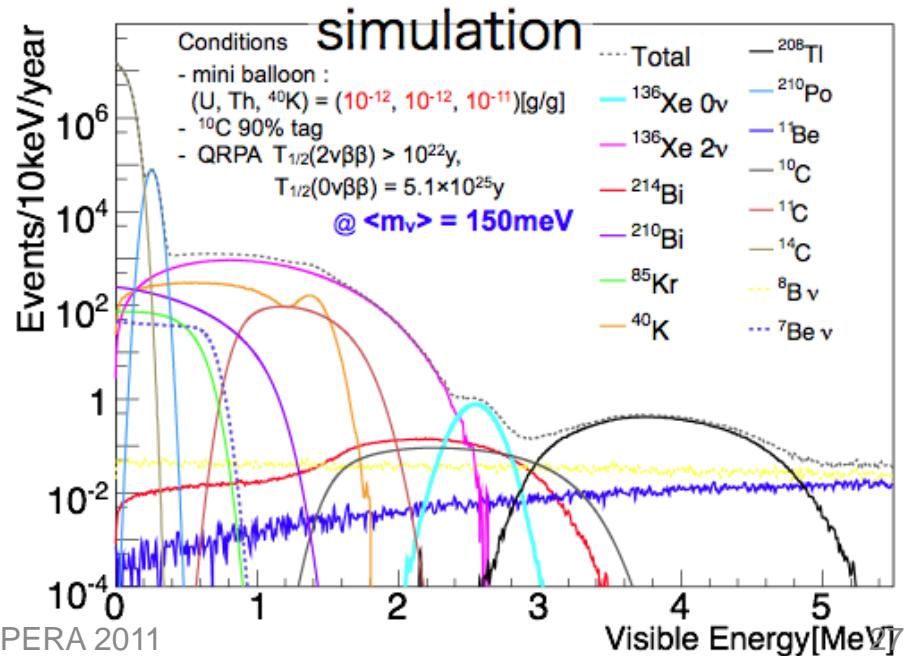


Merit of using Xe

- isotopic enrichment, purification established
- soluble to LS more than 3 wt%, easily extracted
- slow $2\nu 2\beta$ ($T_{1/2} > 10^{22}$ years) requires modest energy resolution

Merit of using KamLAND

- ultra low radioactivity environment based on ultra pure LS and 9m radius active shield
U: $< 3.5 \times 10^{-18}$ g/g, Th: $< 5.2 \times 10^{-17}$ g/g
- no modification to the detector is necessary
- high sensitivity with low cost (1st phase budget secured, 348 kg in hand, 72kg to be delivered in July)
 ~ 60 meV in 2 years
- reactor and geo- antineutrino observations continue
- high scalability (2nd phase)
1000 kg ^{136}Xe , improvement of energy resolution with light concentrators and brighter LS, maybe higher concentration with pressurized Xenon
 ~ 20 meV in 5 years



Preparation Status

- Xenon loaded LS with the same density, luminosity, transparency

done

KamLAND LS	
dodecane	80%
pseudo-cumene	20%
PPO	1.36 g/liter

Xenon loaded LS	
decane	82%
pseudo-cumene	18%
PPO	2.7 g/liter
Xenon	3 wt%

- 3.16 m ϕ Mini-balloon (target: thin, $25\mu\text{m}$ and low radioactivity, $10^{-12} \text{ g/g U/Th}$)



Mini-balloon fabrication with
 $25\mu\text{m}$ Nylon film



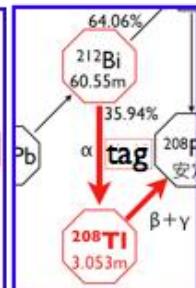
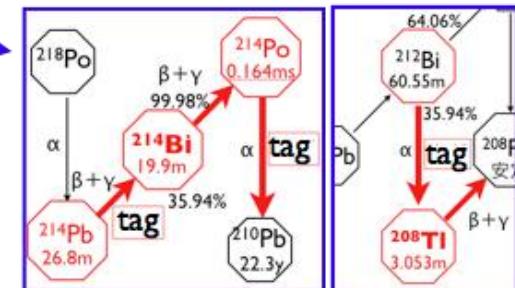
Rehearsal of the deployment
and inflation

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make these possible



Mini-balloon
suspension
structure



Mini-balloon fabrication in Class 1₂₈ super
clean room to be completed in early July

- Xenon handling system (mixing, extraction) etc



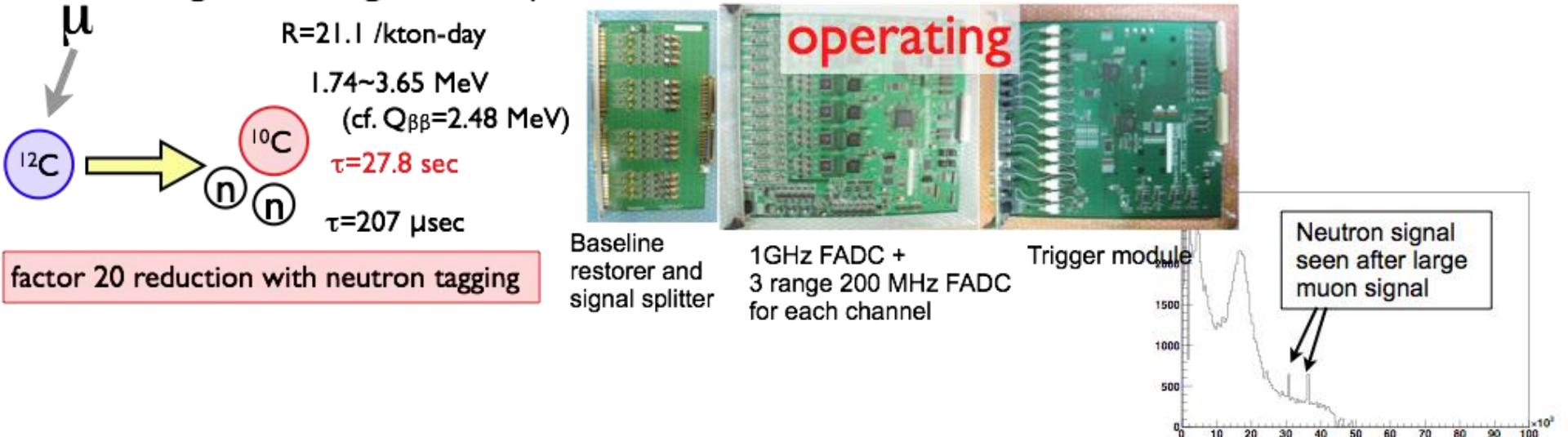
Xe mixing line



Xe extraction and storage line

installed, starting up

- Cosmogenic background rejection with dead-time free electronics

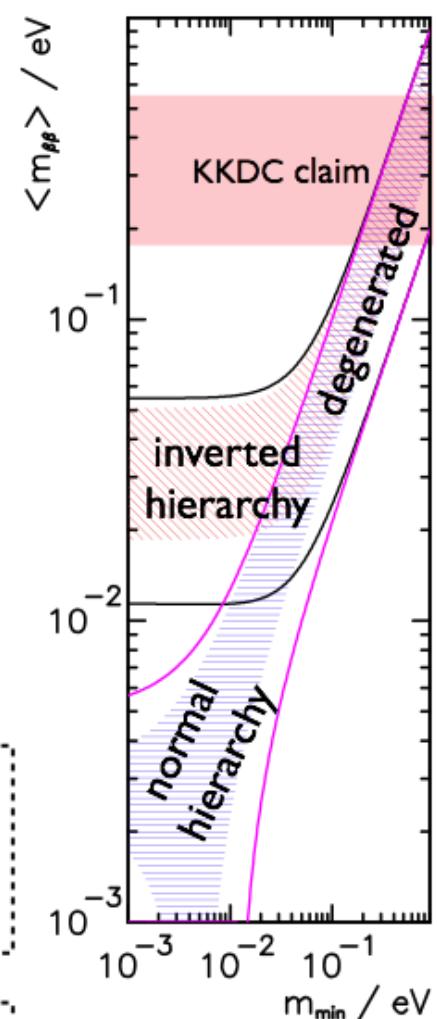
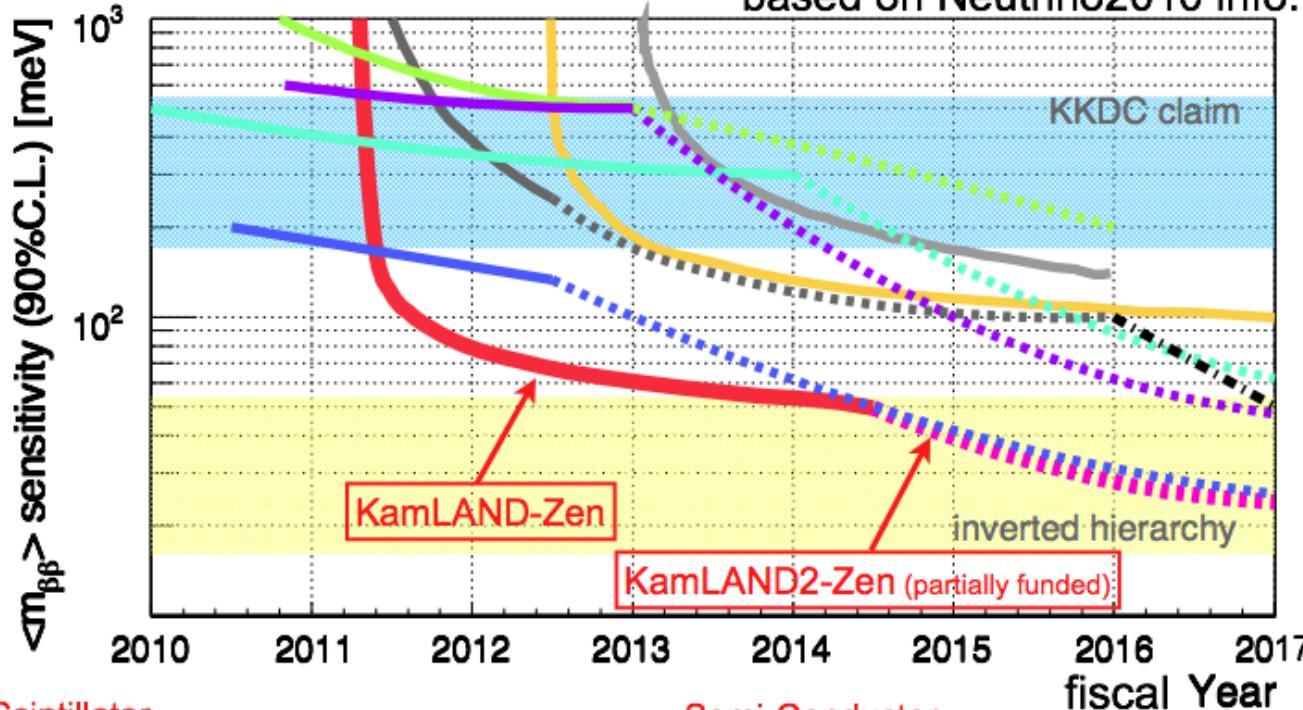


KamLAND-Zen planned to start in August

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Expected sensitivity of KamLAND-Zen

based on Neutrino2010 info.



Scintillator

- KamLAND (^{136}Xe , 400kg)
- KamLAND (^{136}Xe , 1000kg) light concentrator
brighter LS
(pressurized Xenon)
- SNO+ (^{150}Nd), 56kg
- CANDLES III (^{48}Ca 300g)
- CANDLES IV (^{48}Ca 3kg)

Tracking

- NEMO-3 (^{100}Mo 7kg)
- SuperNEMO (^{150}Nd or ^{82}Se 100-200)

Semi-Conductor

- MAJORANA (^{76}Ge), 30-60kg
- GERDA phaseI (^{76}Ge : 17.66kg)
- GERDA phaseII (^{76}Ge : 37.5kg)
- GERDA phaseIII + MAJORANA (^{76}Ge : ~80kg)

Bolometer

- CUORE-0 (^{130}Te ~10kg)
- CUORE (^{130}Te 204kg)

Liquid TPC

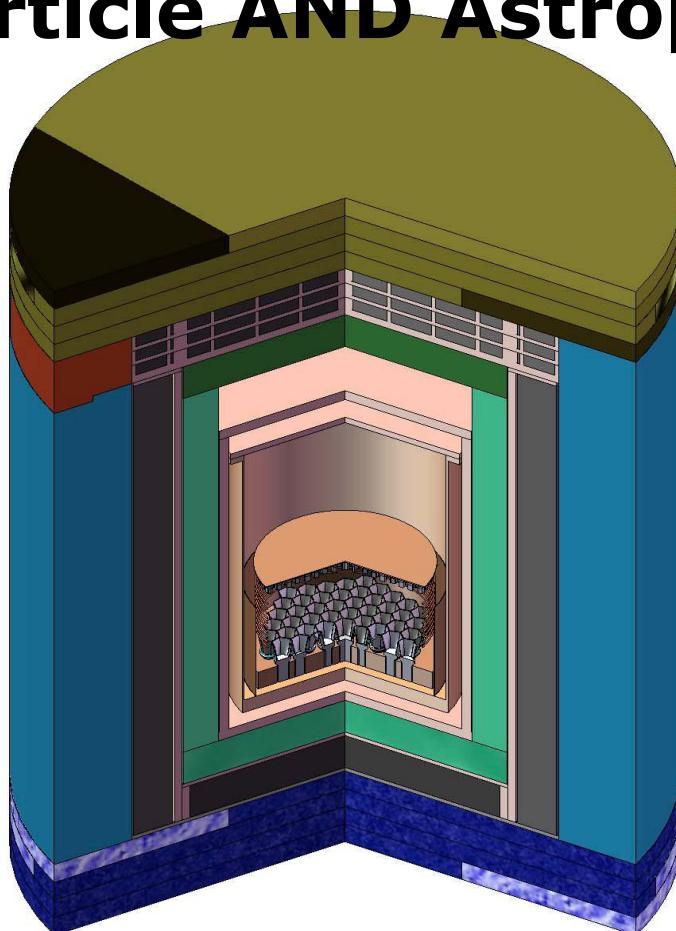
- EXO-200 (^{136}Xe 200kg)
- ASPERA 2011
- EXO (^{136}Xe 1t)

PANDA-X

^{136}Xe

Liquid Xe

Proposal for neutrinoless double beta decay search in Xe136 with PANDA-X (Particle AND Astroparticle Xenon TPC)



Xiang Liu
Institute of Nuclear, Particle,
Astronomy and Cosmology
Physics Department
Shanghai Jiaotong University

Nov. 10th, 2010

PandaX sensitivity projection

25kg fiducial volume, assume 2 years operation,

<1400 2v $\beta\beta$ events ($T_{1/2} > 10E-22$ year)

~55k bg. events

in $\pm 2\sigma$ window:

< 12 0v $\beta\beta$ events ($T_{1/2} > 1.2 \times 10E-24$ year)

< 0.001 2v $\beta\beta$ event

~ 20 bg. events, mostly from PMT and bases

Xenon100 MC:

10E-5 events/keV kg day

75% from PMT+base

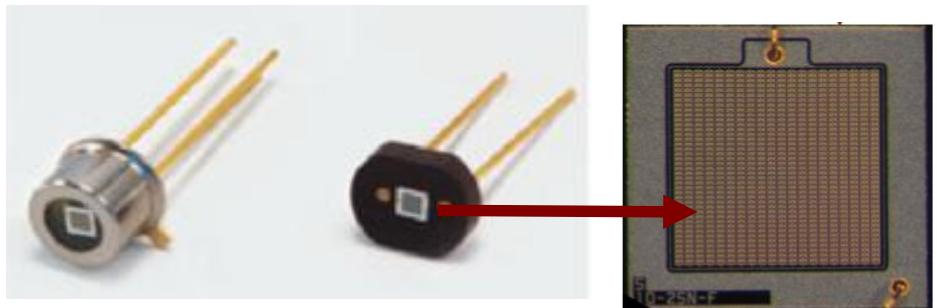
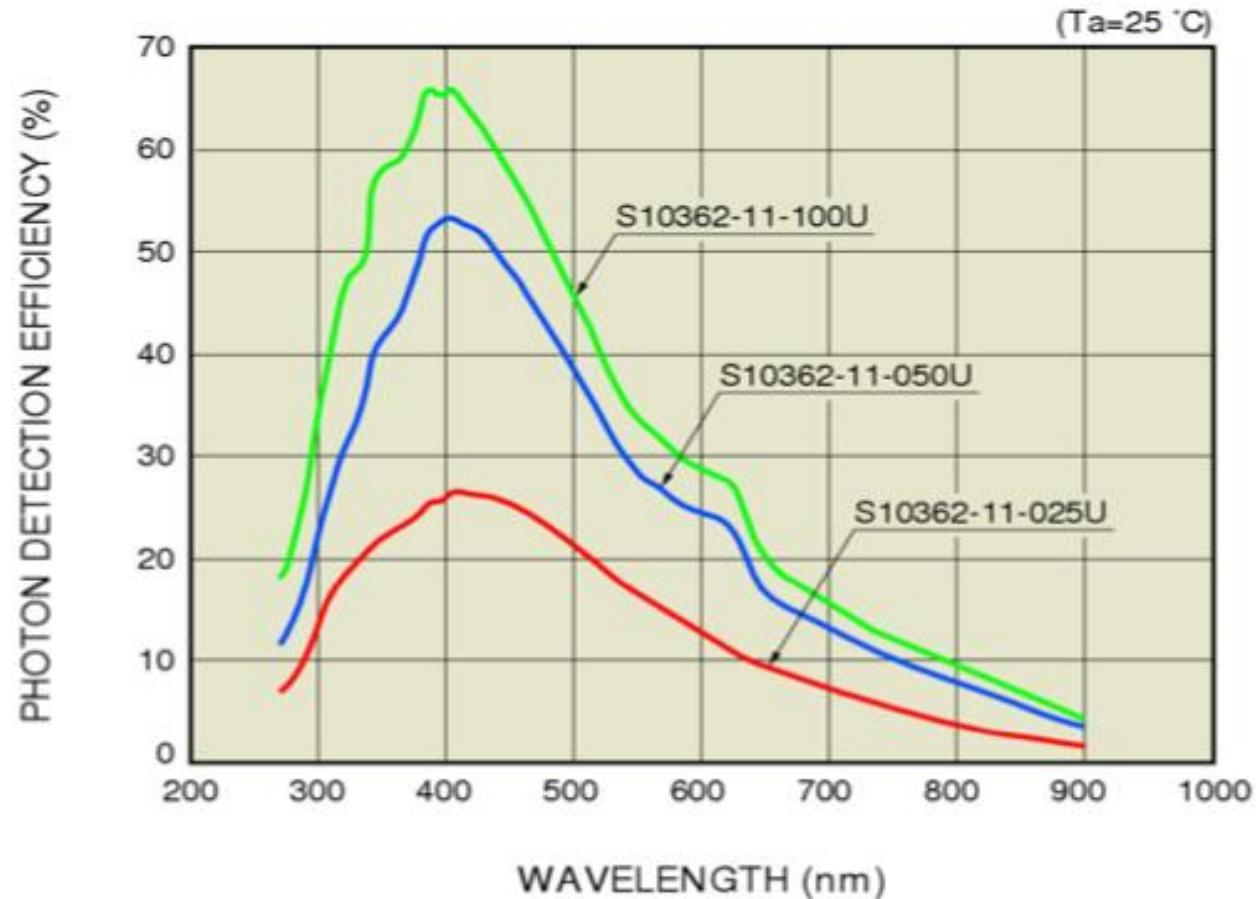
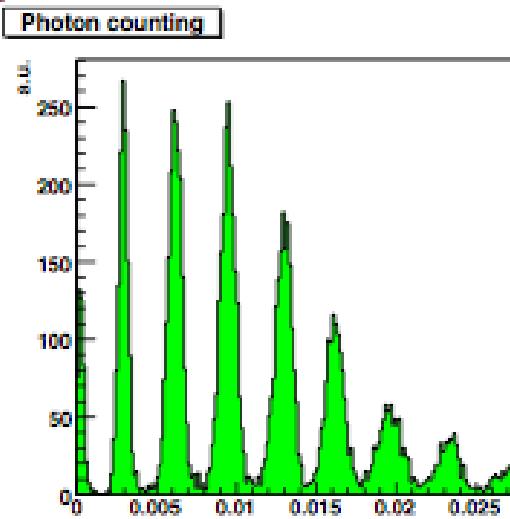
22% from Stainless-
Steel vessel

(courtesy of Xenon100 collab.)

BG from PMT
2.61 MeV γ ray
 $Q=2.467$ MeV

silicon avalanche photo-diode array

SiPM vs. PMT

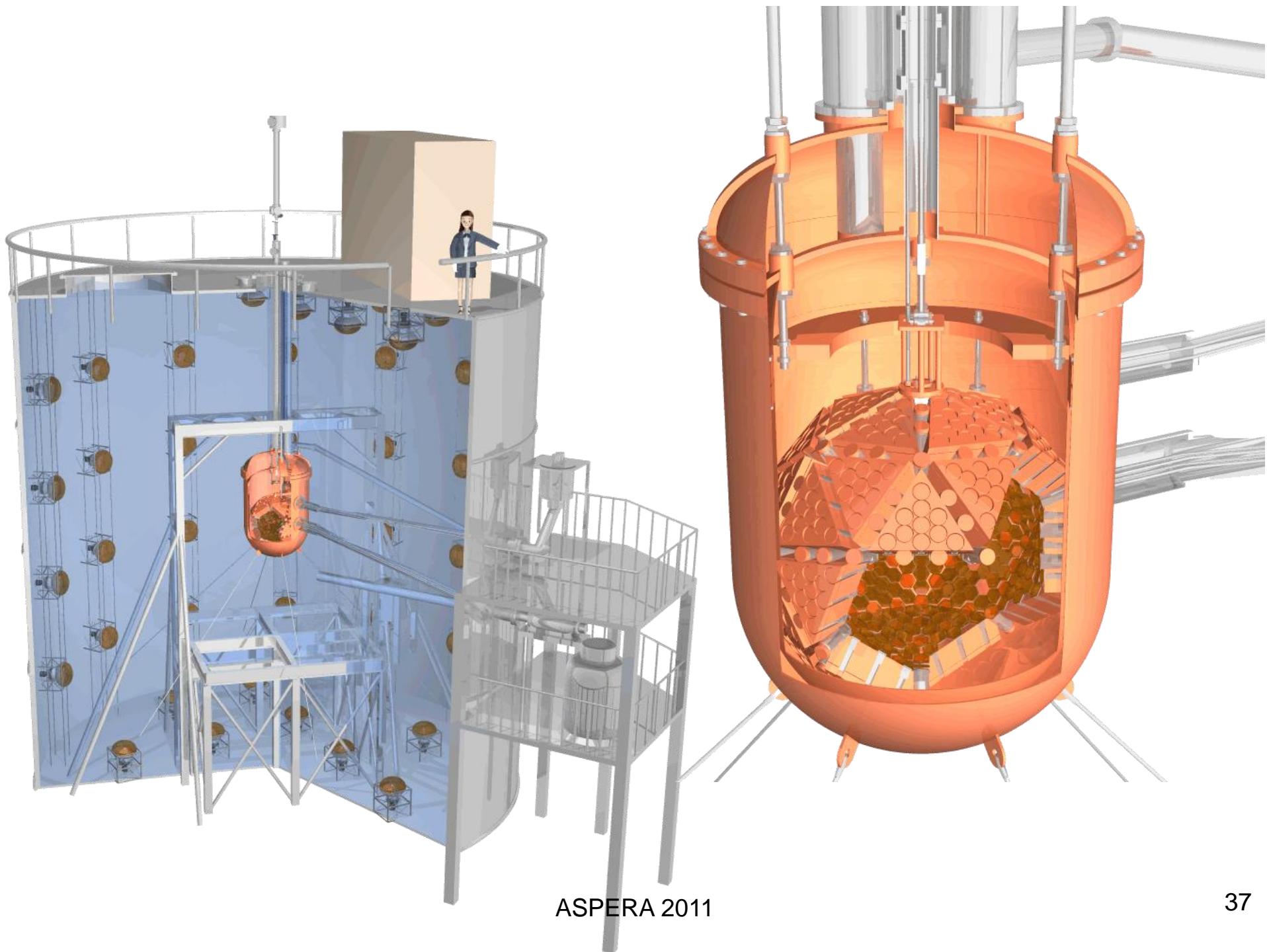


Hamamatsu MPPC,
To detect 178nm,
wavelength shifter needed

XMASS

^{136}Xe

Liquid Xe self-shield



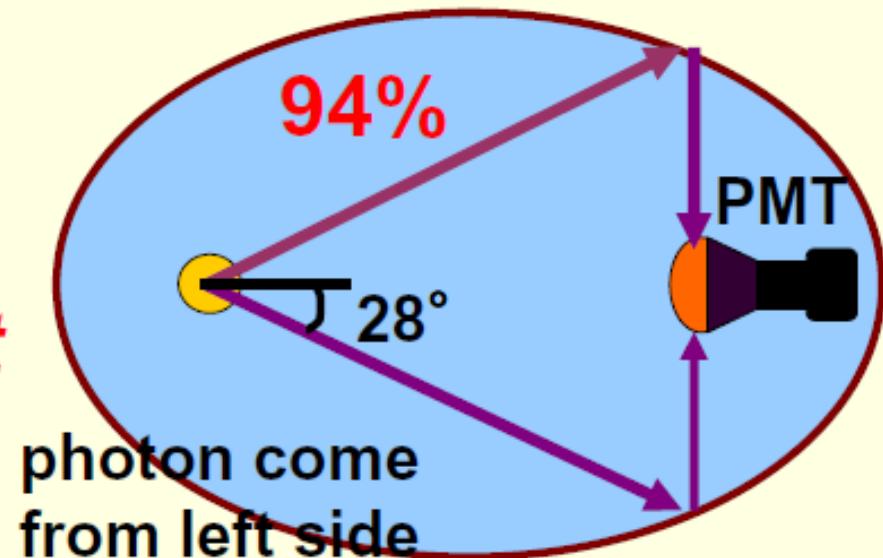
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Optics of the elliptic water tank

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

$$1 - (1 - \cos(28 \text{ deg.})) / 2 \sim 0.94$$

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

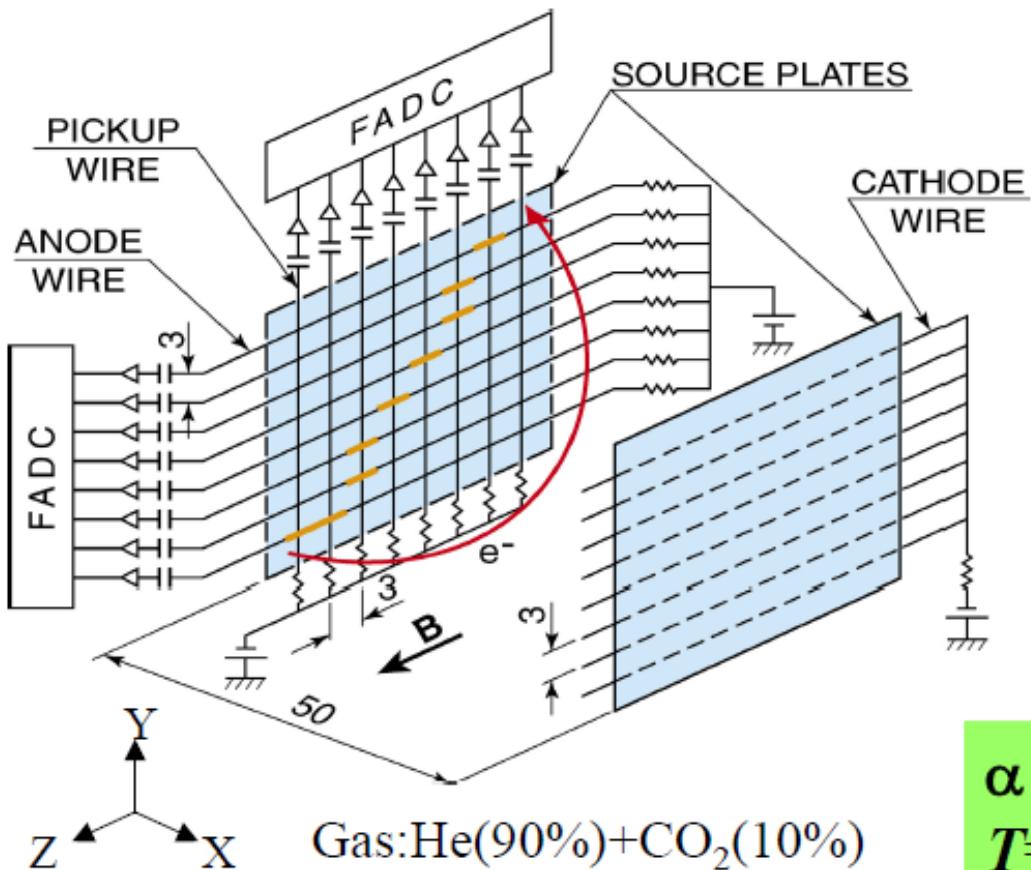


DCBA

^{150}Nd

Thin foil + Drift Chamber

Principle of electron detection in DCBA



Momentum Acceptance

$$p(\text{MeV}/c) = 0.3r(\text{cm})B(\text{kG})$$

$$B \approx 2 \text{ kG}$$

$$2 \text{ cm} < r < 5 \text{ cm}$$



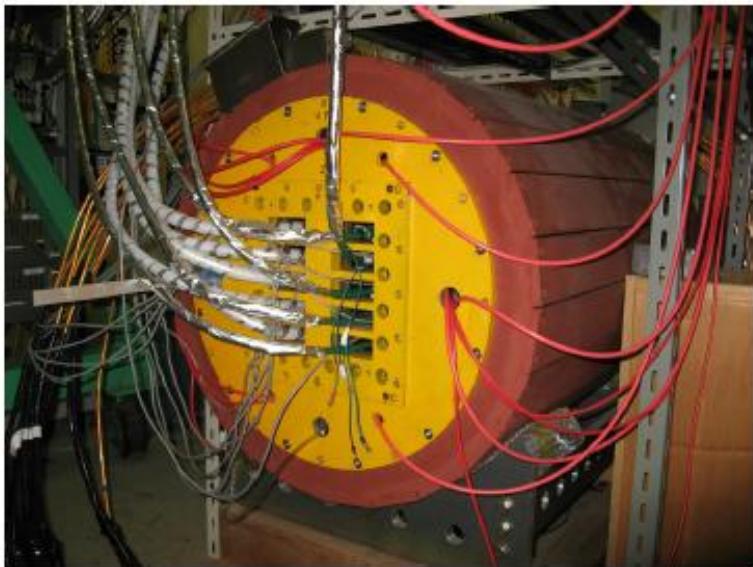
$$1.2 \text{ MeV}/c < p < 3 \text{ MeV}/c$$

Energy Acceptance for e⁻

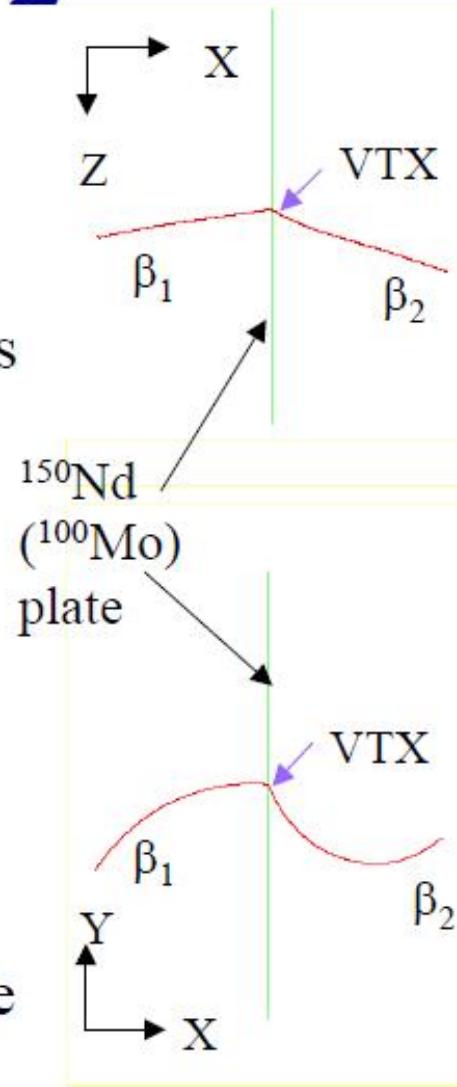
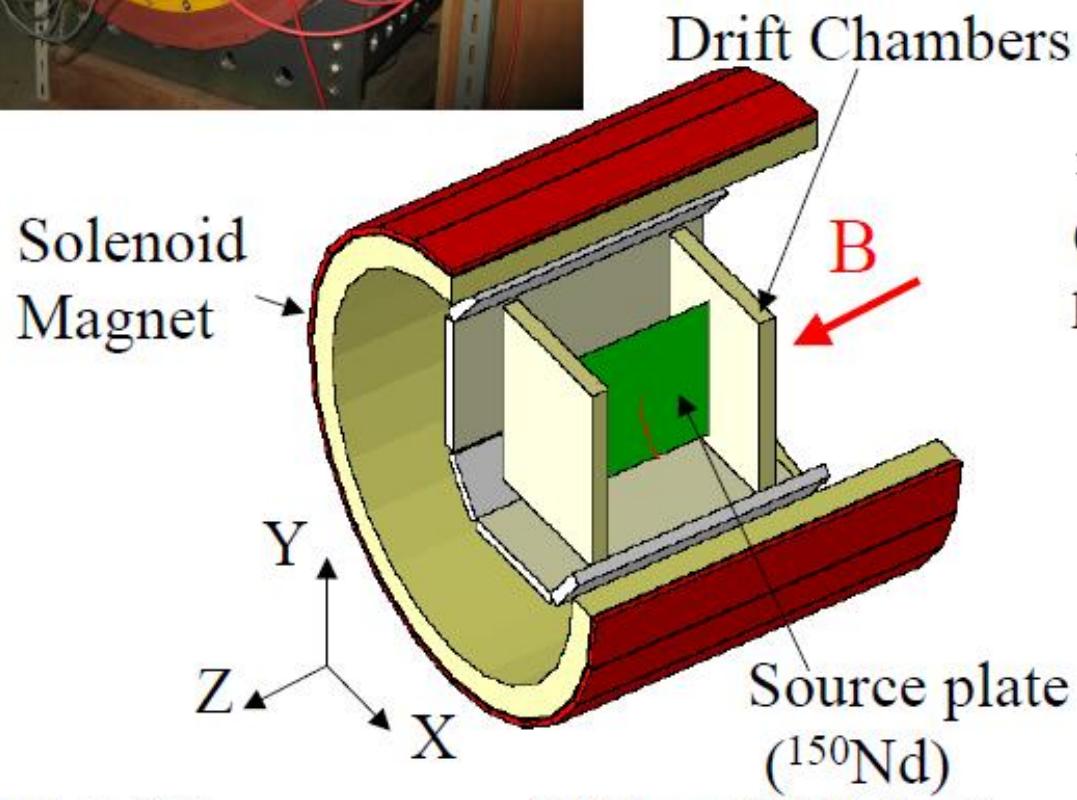
$$0.8 \text{ MeV} < T < 2.5 \text{ MeV}$$

α is automatically rejected

$$T = 1 \text{ MeV} \rightarrow p \approx 87 \text{ MeV}/c$$



DCBA-T2



summary

- Japan
 - Experiments about to run
 - CANDLES: commissioning
 - KamLAND-Zen: August
 - R&D
 - DCBA
 - XMASS
- Korea
 - AMoRE: R&D
- China
 - PandaX: R&D

International workshop on Double Beta Decay and Neutrino (DBD11)

- The main purpose of this workshop is an open discussion of current and future directions in the study of double beta decay and related neutrino physics.
- The workshop, DBD11 is hosted by Department of Physics and Research Center for Nuclear Physics, Osaka University, KEK, and Tohoku University.
- Date: Nov 15-17, 2011
- Place: Osaka, Crystal Tower (In front of Osaka Castle)