インジウムを用いた太陽ニュートリノ半導体検出器の開発XI

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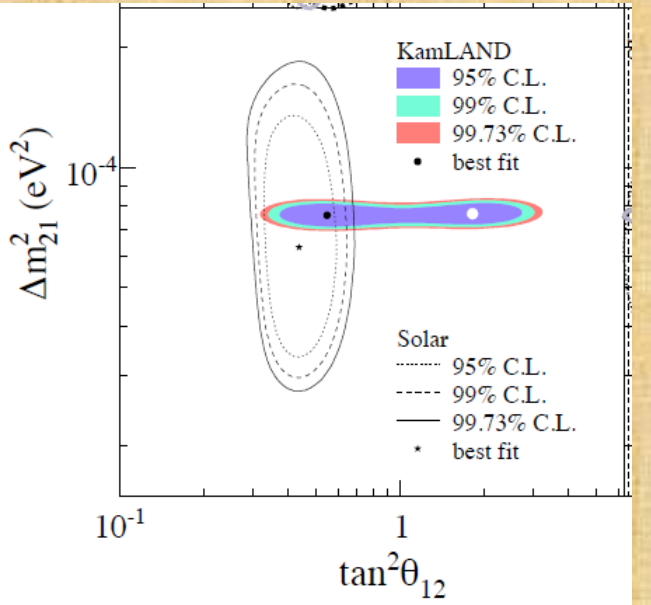
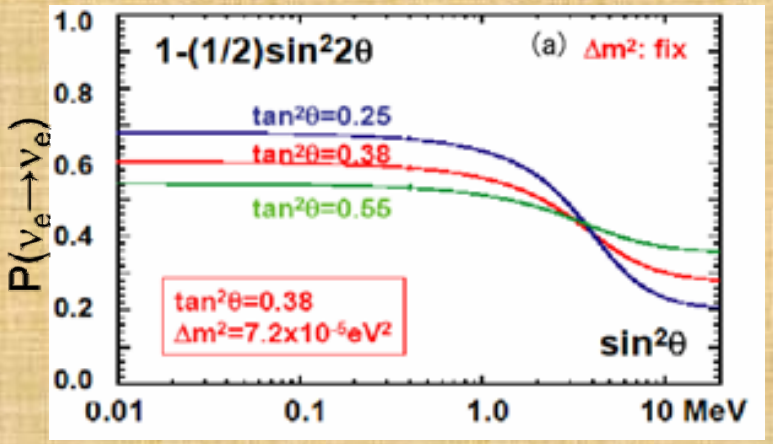
Motivation

Allowed region obtained by combined results and KamLAND



Survival probability for solar matter oscillation below 1MeV

Y.Suzuki@Neutrino2004



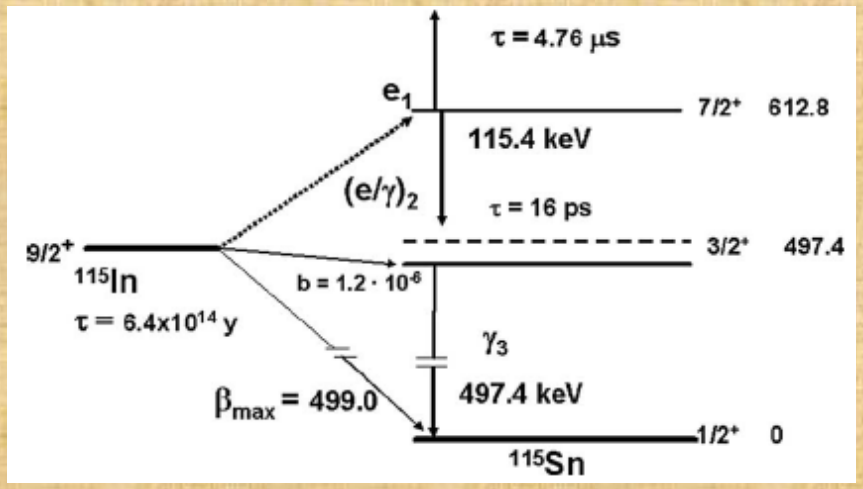
Neutrino energy

- mixing angle θ_{12} is not well determined compared with θ_{23} obtained by Atm. ν.
- Survival probability could increase at 5MeV or less in case of LMA solution, and the value of probability depends on θ_{12}.

pp/^{7}Be solar neutrino spectrum gives us precise θ_{12}

Capture of low energy solar neutrinos by ^{115}In

R.S.Raghavan Phs.Rev.Lett37(1976)259



Nuclear Physics A 748 (2005) 333-347

- Advantage
  - large cross section (~640SNU)
  - direct counting for solar neutrinos
  - sensitive to low energy region ($E_\nu \geqq 125$keV)
  - energy measurement ($E_e = E_\nu - 125$keV)
  - triple fold coincidence to extract neutrino signal from huge BG ($e_1 + \gamma_2 + \gamma_3$)
- Disadvantage
  - natural β-decay of ^{115}In ($\tau_{1/2} = 4.4 \times 10^{14}$ yr , Ee≧498keV)
  - possible BG due to correlated coincidence by radiative Bremsstrahlung

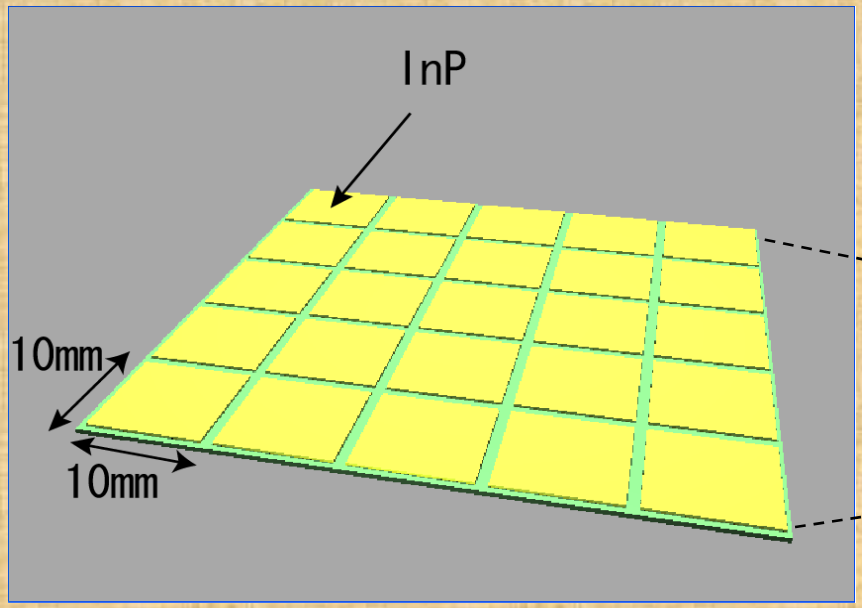
$^{115}In + \nu_e \rightarrow {}^{115}Sn^* + e^-$

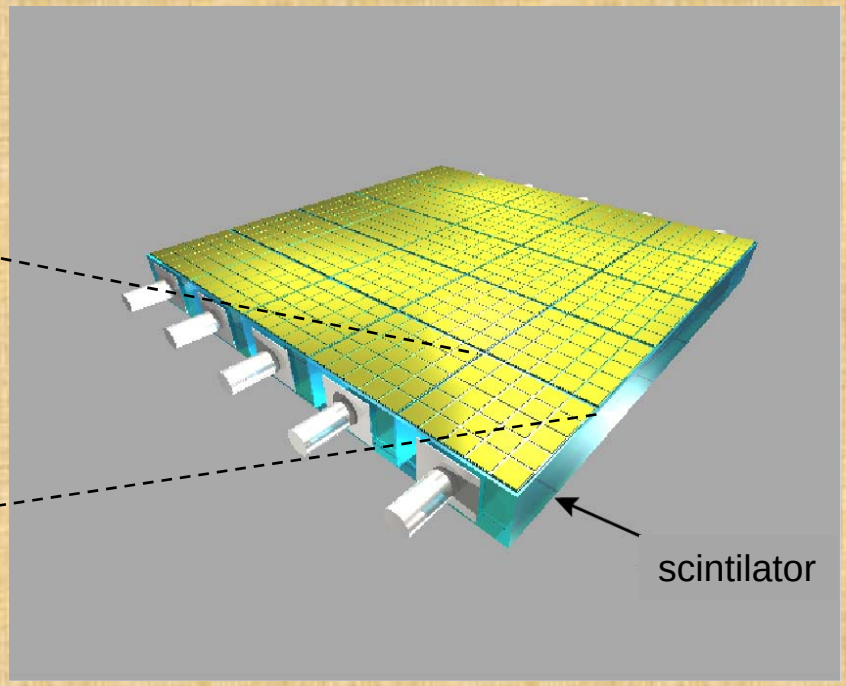
$^{115}Sn^*(4.76\mu s) \rightarrow {}^{115}Sn + \gamma_1(115keV) + \gamma_2(497keV)$

Requirement for the detector

1. Good energy resolution : 10%(FWHM)
2. Fine segmentation (10^4–10^5)
3. High efficiency γ detection

Possible InP detector for solar neutrinos

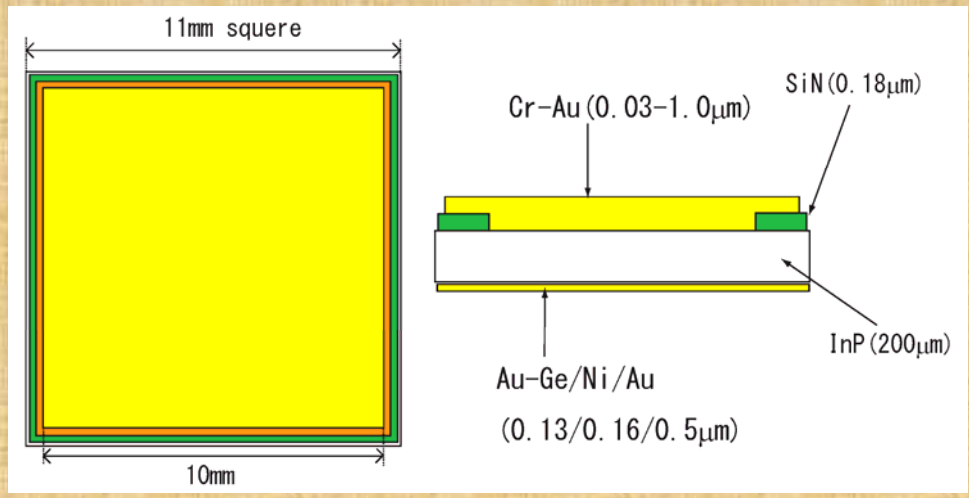




- Multi-pixel structure for large area detector
- High Z scintillator surrounding InP detector detect γs
- 4tons of ^{115}In detector for low energy solar ν

Indium Project on Neutrino Observation for Solar interior (IPNOS) experiment

Semi-insulating InP cell detector

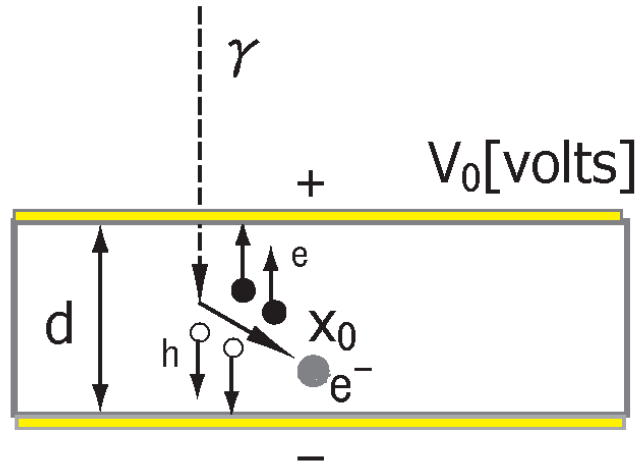


Mounted in vacuum chamber

- SI InP cell detector using VCZ-InP wafer (product of Sumitomo Electric K.K.)
- Cooled by dry-ice (T = -79 degree)
- Response for gammas from radio-active sources

Surface size:
10mm × 10mm × 0.2mm
(6mm × 6mm × 0.2/0.23/0.28/0.45mm)
Electrode :
- Ohmic contact
- evaporated Au base metal
- Insulator (SiN) to avoid leak current

Principle of charge collection



μ : mobility [$m^2v^{-1}s^{-1}$]
v : carrier velocity [ms^{-1}]
E : electric field [vm^{-1}]
d : thickness of SI InP
x_0 : range of electron

$E=V_0/d$ $v=\mu E=\mu V_0/d$

drift length : $L_d=\tau v=\mu\tau V_0/d$

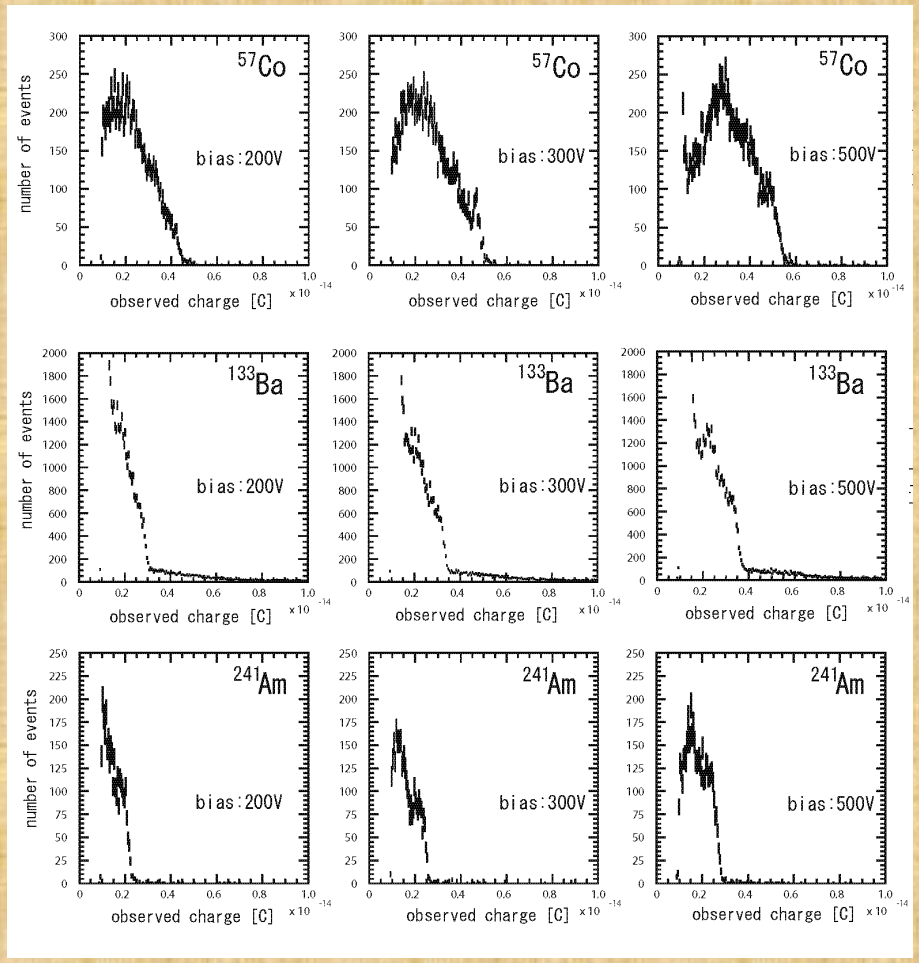
τ : carrier lifetime [s]

- Induced charge : $dQ = (q/d)\,dx$
- Using Hecht formula,

$$Q = Q_0 \left\{ \left(\frac{L_e}{d}\right)\left(1 - e^{-\frac{x}{L_e}}\right) + \left(\frac{L_h}{d}\right)\left(1 - e^{-\frac{(d-x)}{L_h}}\right) \right\}$$

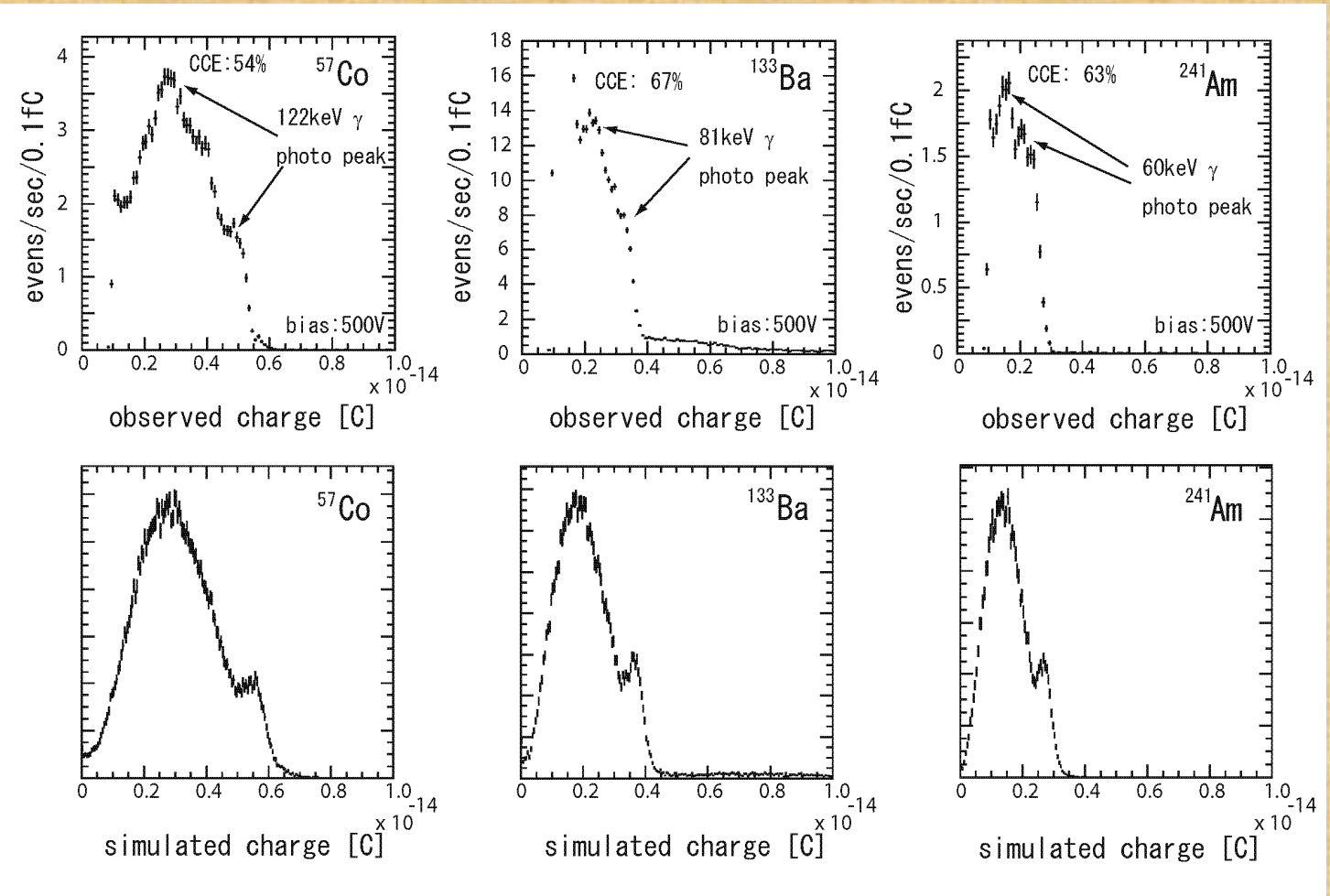
- For full collection : ($L_e+L_h \sim d$) $Q=Q_0$

γ spectrum measured by InP detector



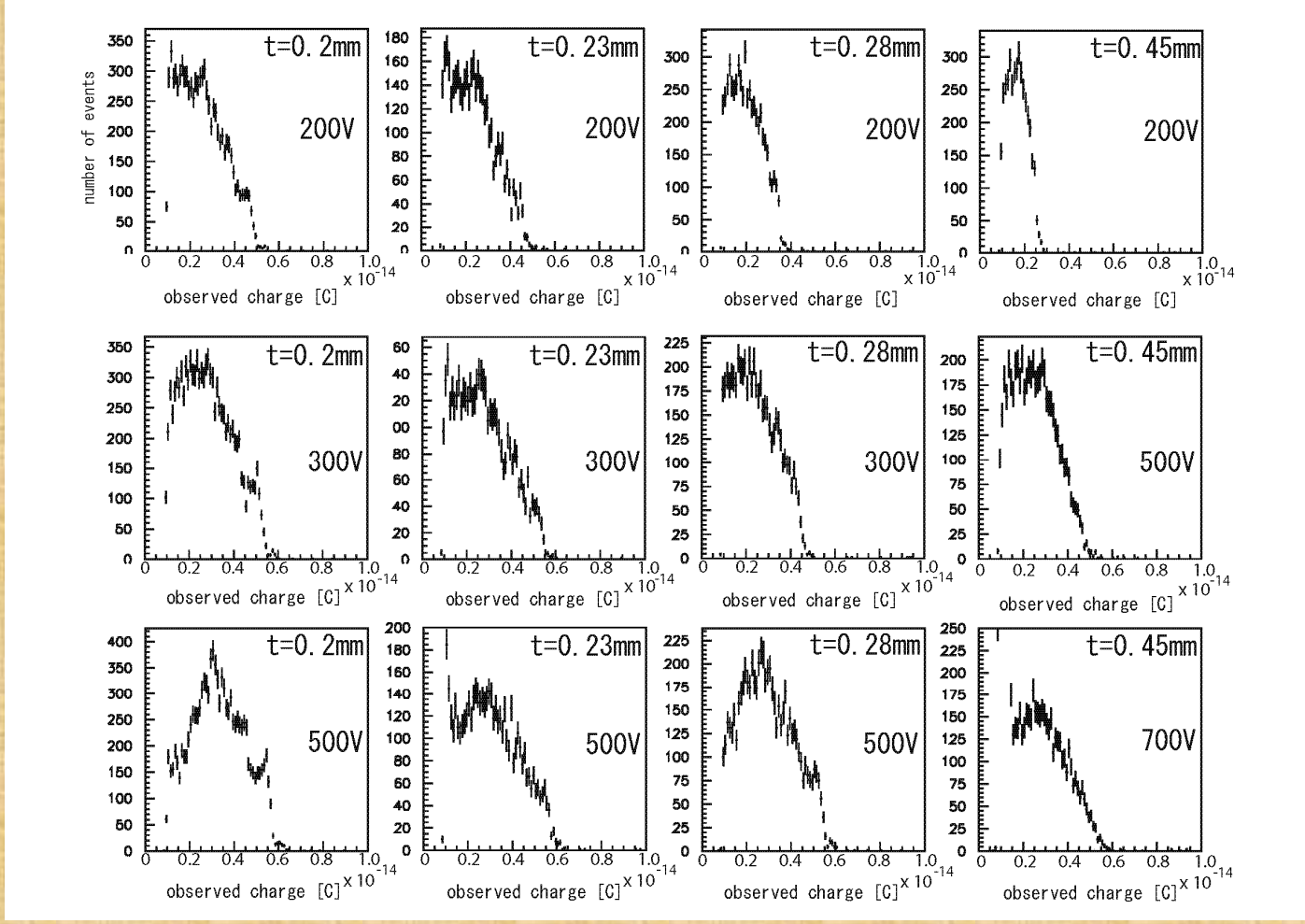
- InP detector should be cooled (-79 degree using Dry-Ice)
- Clear photo-peak was observed, but two peak structure
- Lower peak: induced charge generated by drift of carrier (electron and hole)
- Higher peak: full charge collection
- Energy of electron-hole pair production : 3.5eV
- Energy resolution : 25%@122keV for induced charge peak (intrinsic : 3%)

Spectral shape and simulation



- Assuming, L_e~200μm and L_h~30μm, two peak structure could be reproduced by induced charge and full charge collection.

Optimize detector thickness (using ^{57}Co)

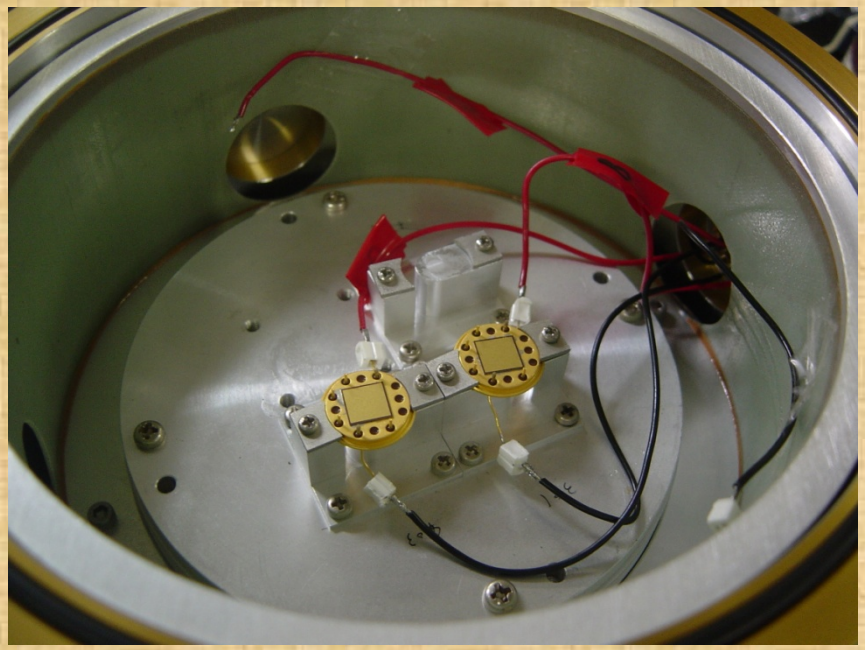


~280μm is best select for thickness

Development for multi-pixel detector

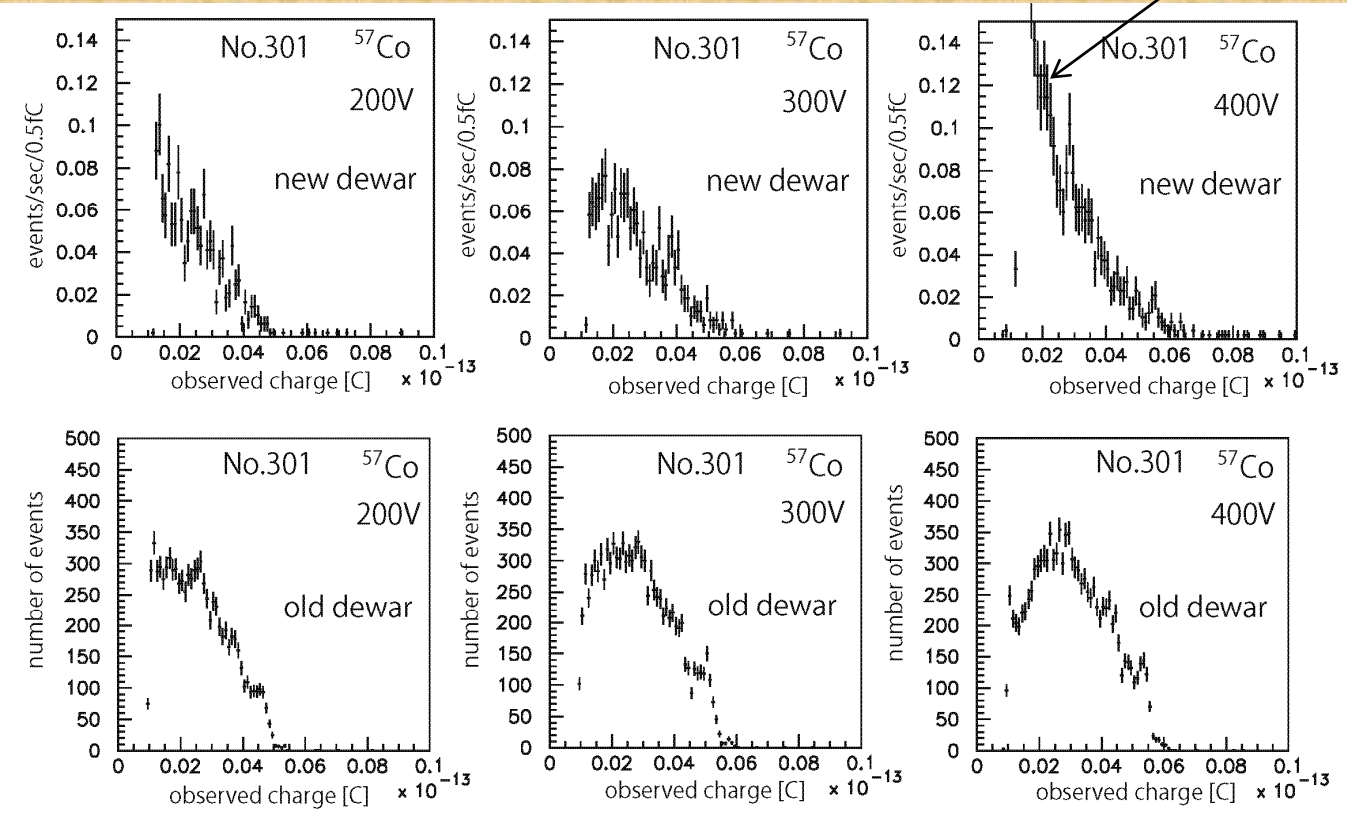
New dewar for parallel connection

Inside of new dewar for parallel connection



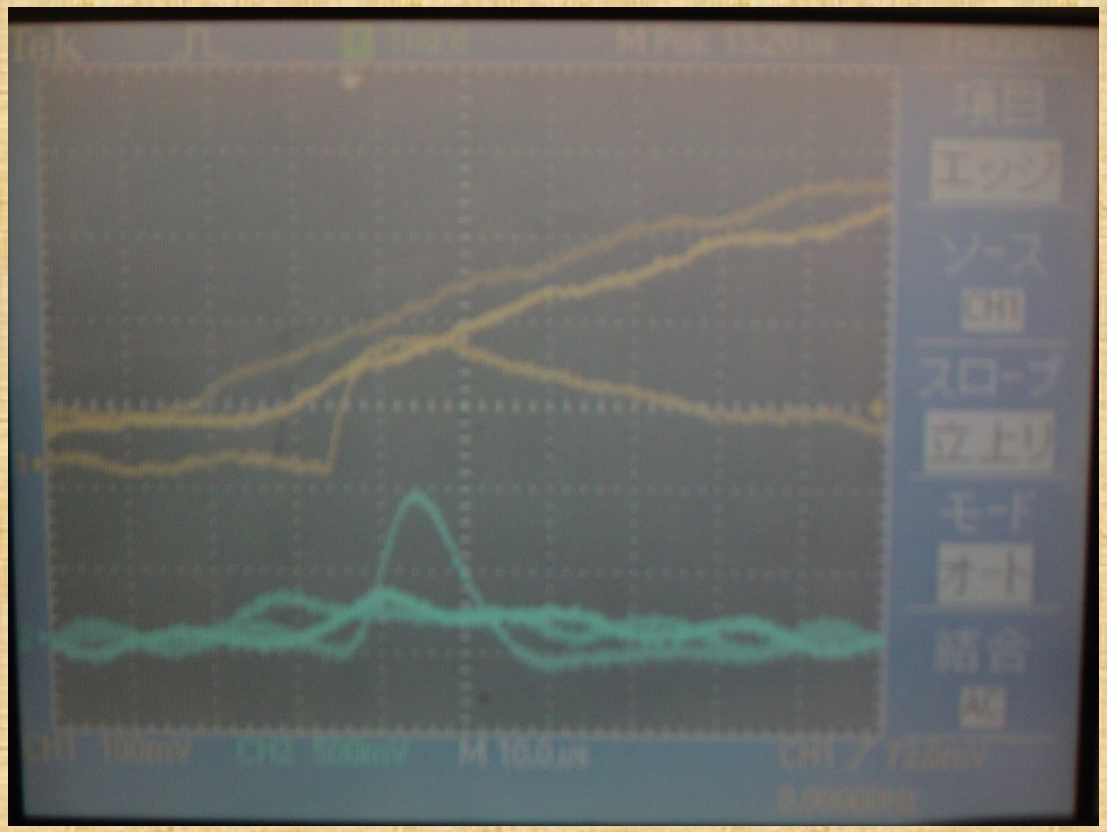
Observation of γ-rays for old and new dewar

- ^{57}Co (Serial # 301)



Same peak and structure was observed.

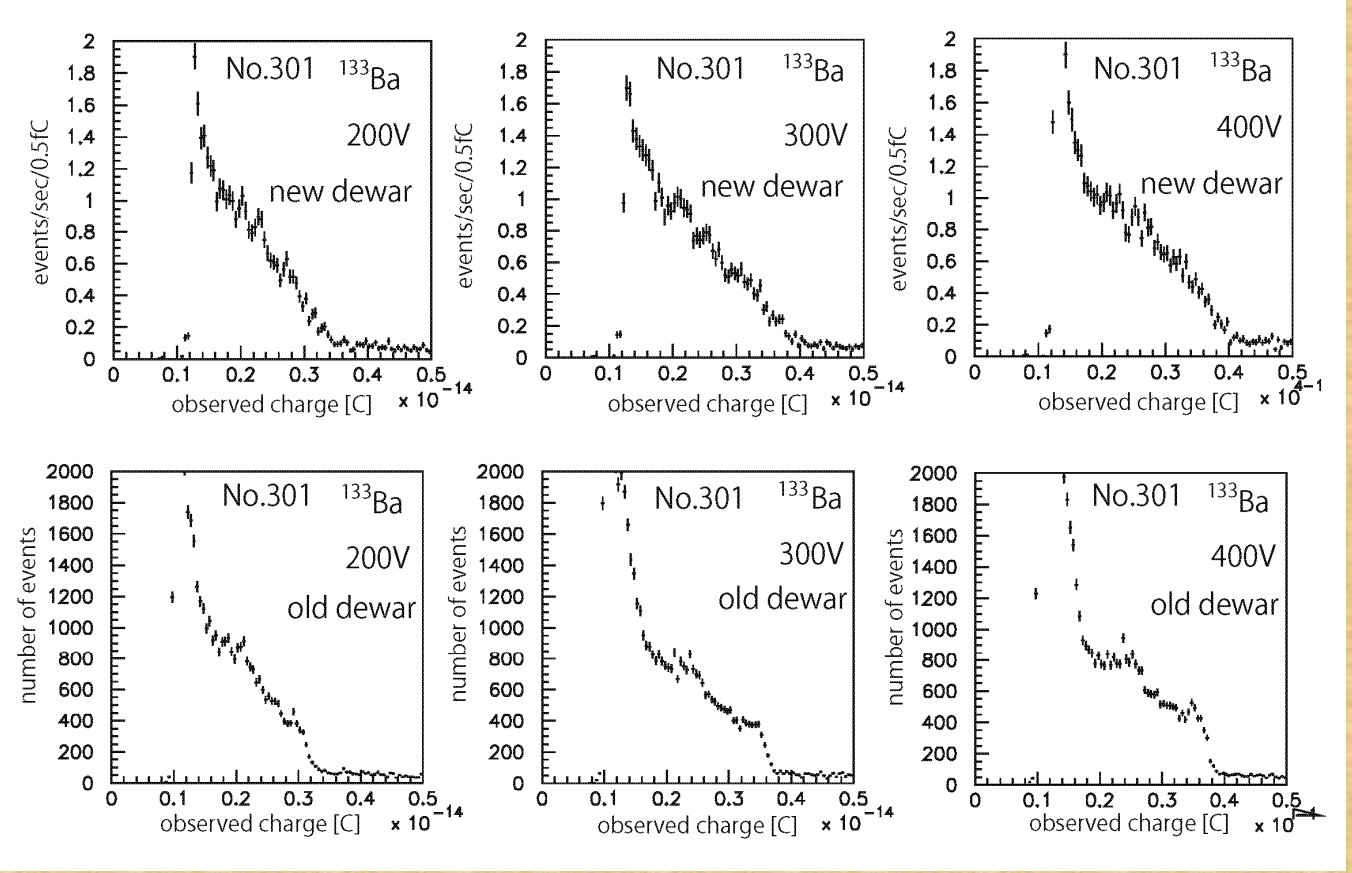
Pulse-like noise



Unstable pulse-like noise sometimes happened in new dewar measurement.

Observation of γ-rays for old and new dewar

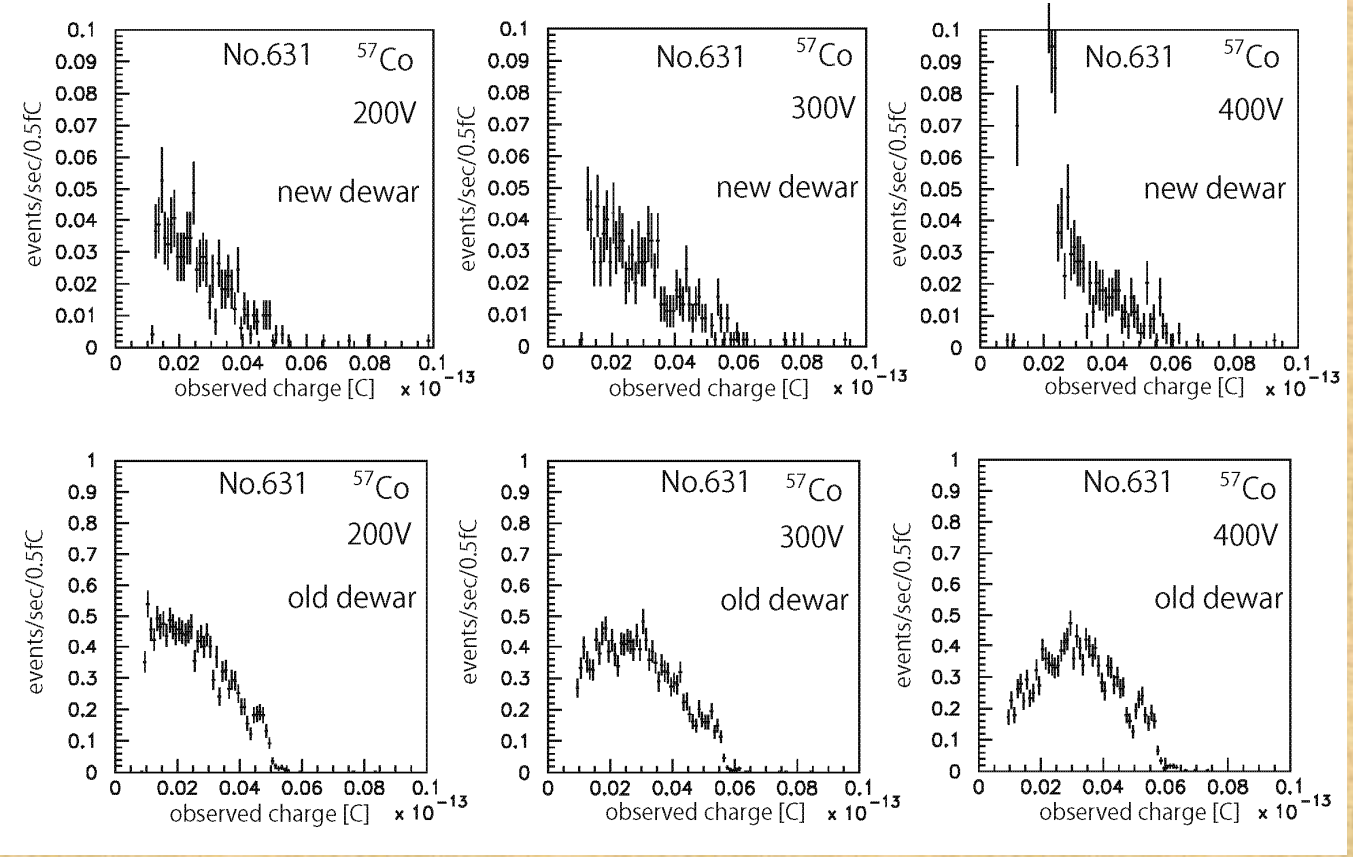
- ^{133}Ba (Serial # 301)



Same structure, but worse resolution

Observation of γ-rays for old and new dewar

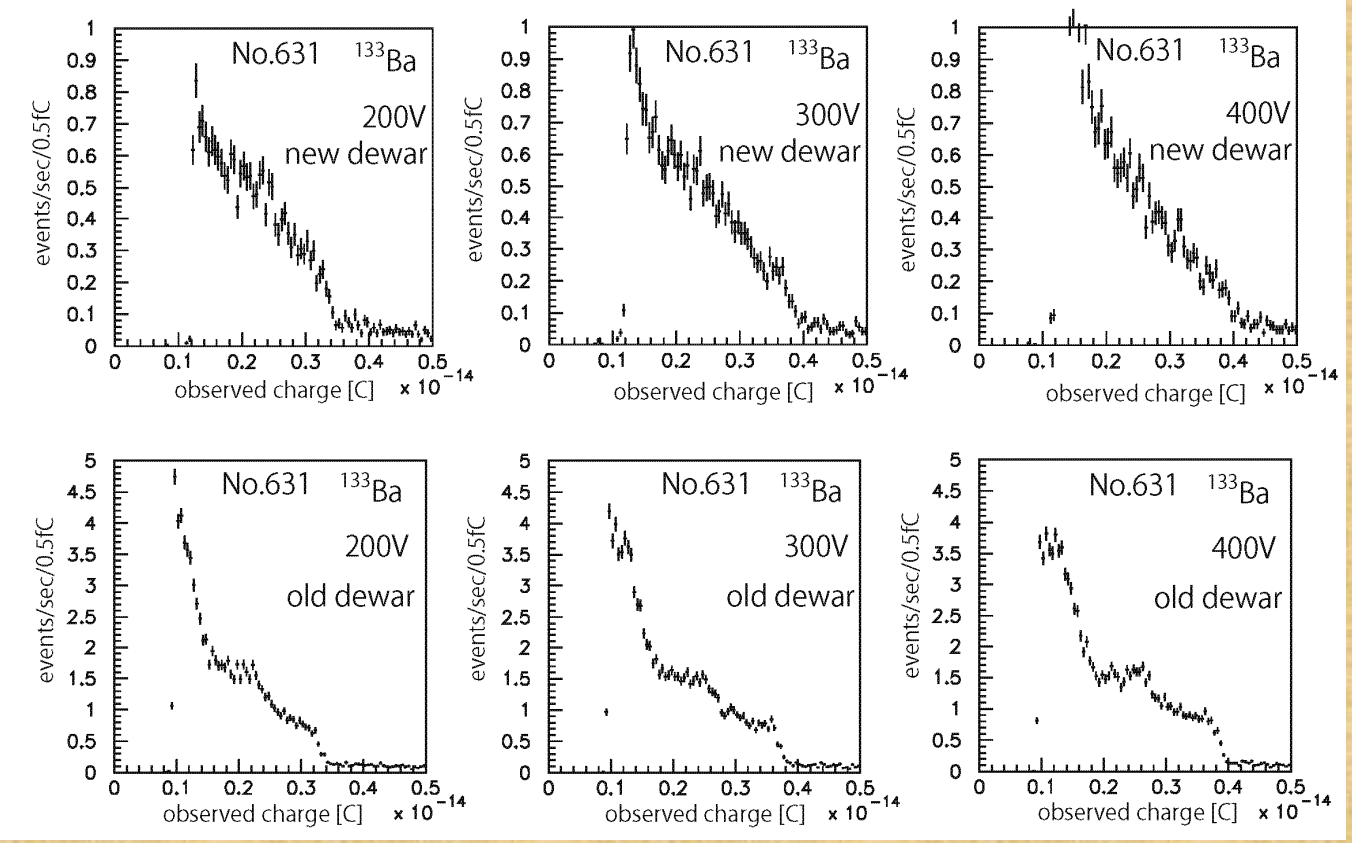
- ^{57}Co (Serial # 631)



Also same structure, but more worth resolution

Observation of γ-rays for old and new dewar

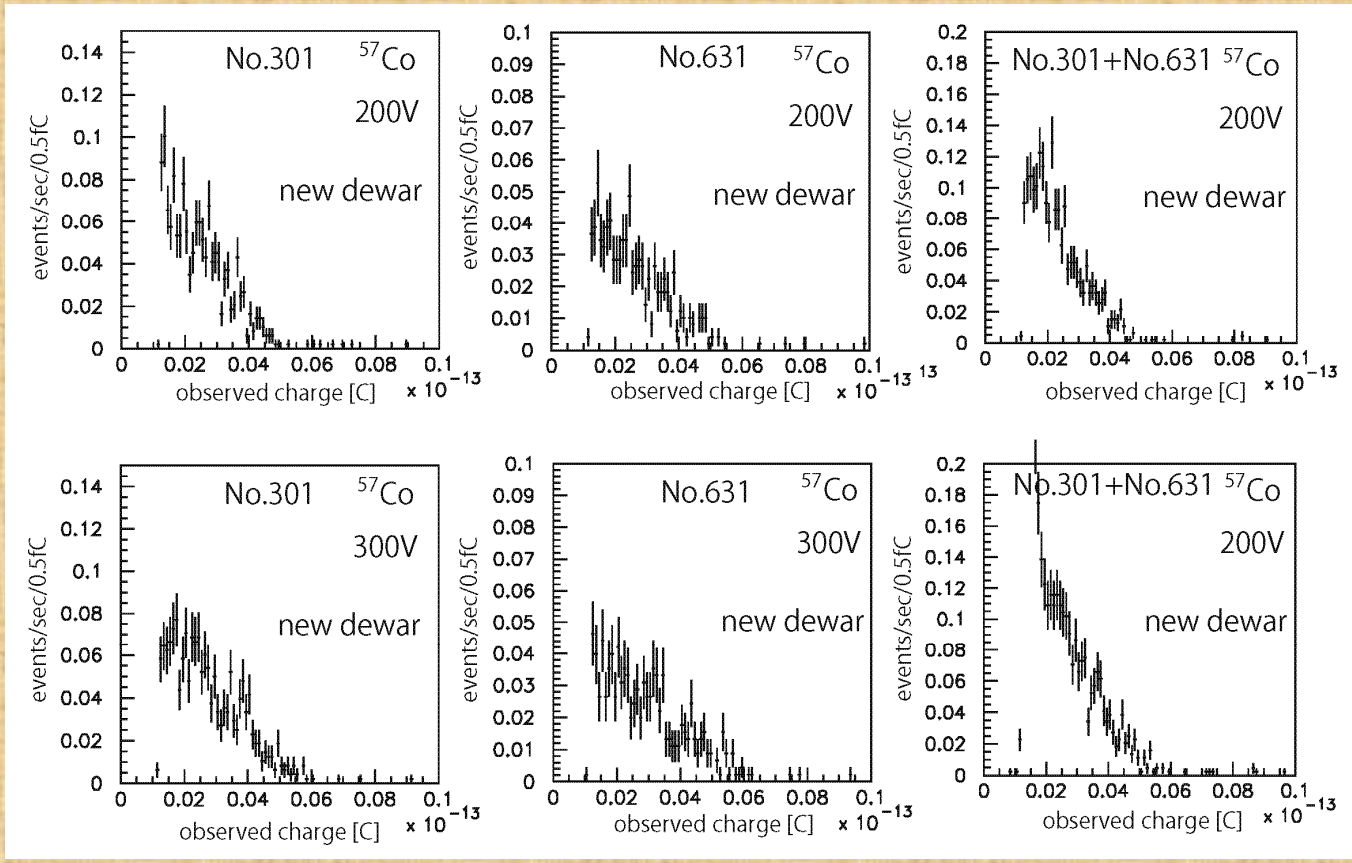
- ^{133}Ba (Serial # 631)



Same structure, but more worse resolution

Observation of γ-rays for parallel connection

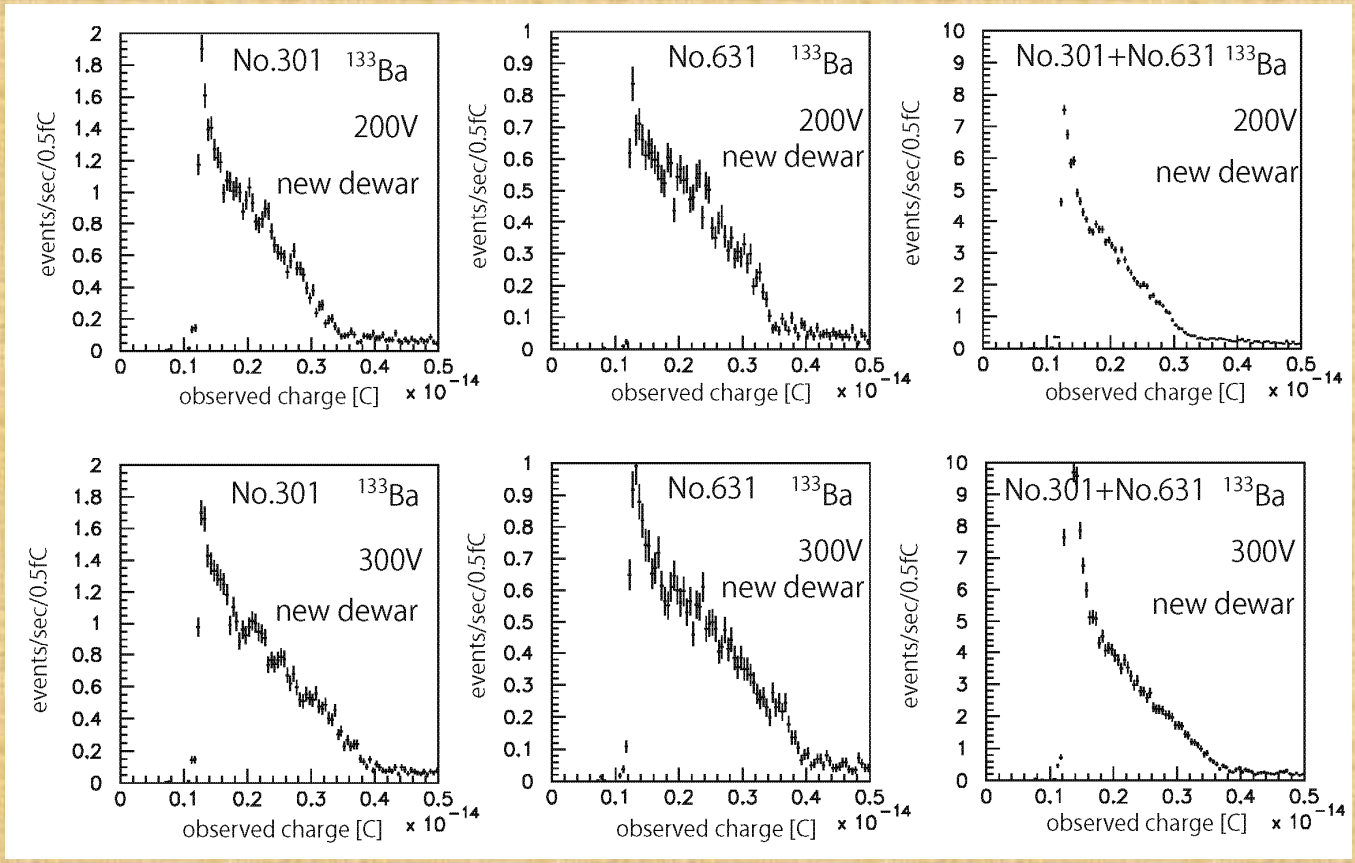
- ^{57}Co (Serial #301 + Serial #631)



Events rate increased and same resolution

Observation of γ-rays for parallel connection

- ^{133}Ba (Serial #301 + Serial #631)



Events rate increased and same resolution

Conclusion

- Induced charge due to drift of carrier (electron and hole) generated by radiation.
- Charge distribution depends on thickness of detector.
- Parallel connection for multi-pixel detector was tested using NEW dewar.
- Charge distribution has same structure but worse resolution → fix pulse-like noise problem
- Events rate increased as expected (or more)
- More multi-pixel detector connection will be tested.

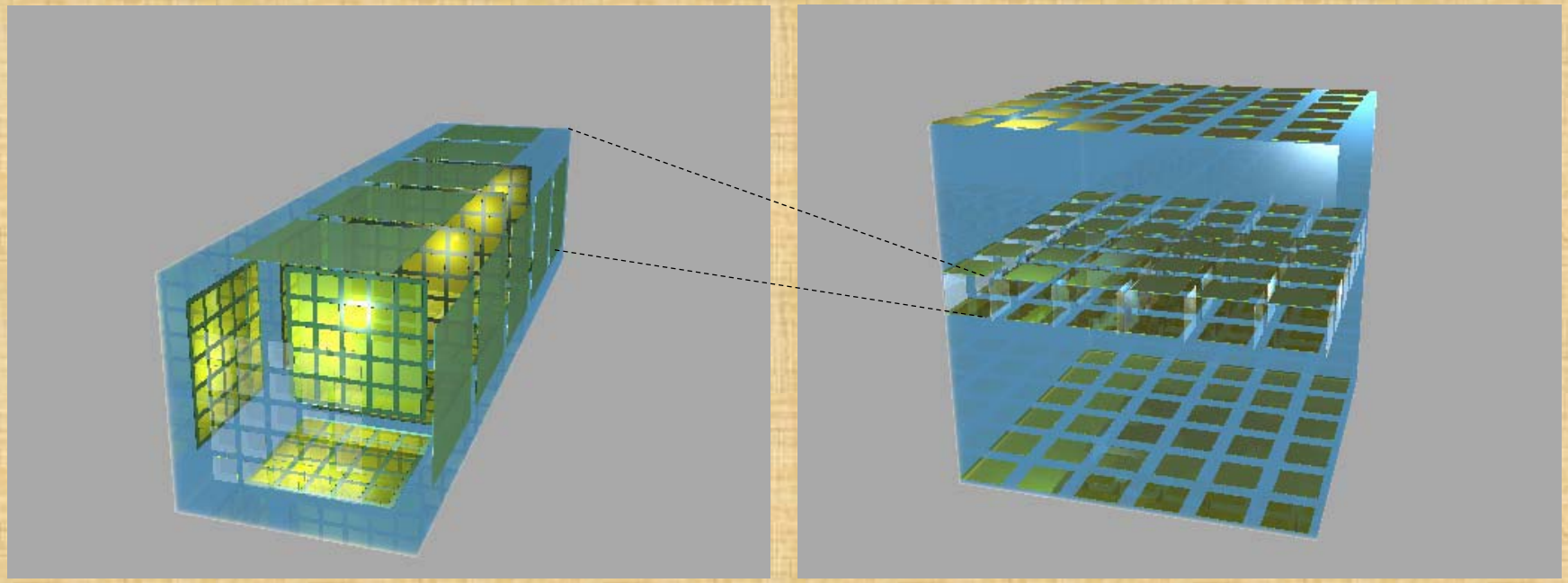
IPNOS phase-I (10kg InP in LXe)

- ✓ Low background (&low temperature) environment inside of LXe
- ✓ A few events per year for pp solar neutrinos, but…
- ✓ Demonstrate actual performance for low energy solar ν

New concept for IPNOS phase-I experiment

InP multi-pixel detector inside of Liquid Xenon.

30cm cubic chamber (like XMASS 100kg prototype) includes ~10kg InP detector



new detector to measure scintillation light from LXe

Prototype of multi-pixel InP detector