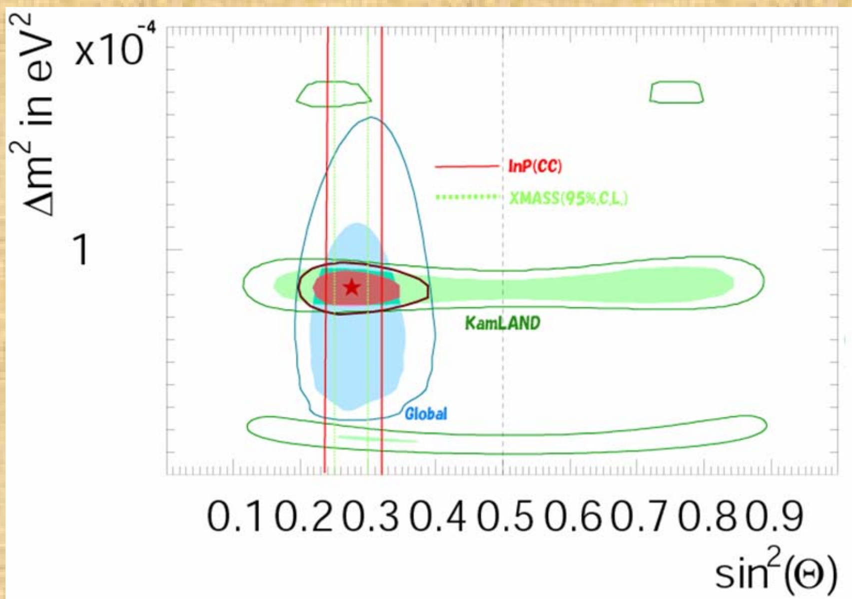
InP solid state detector for a measurement of low energy solar neutrinos

TAUP2009 conference
Solar, Reactor and other Low-Energy Neutrino Physics
July 1st, 2009

Miyagi University of Education Y.Fukuda
ICRR, Univ. of Tokyo S.Moriyama, M.Shiozawa, Y.Koshio
ICEPP, Univ. of Tokyo T.Namba
Hamamatsu Photonics K.K. S.S.div. T.Izawa, M.Asakura

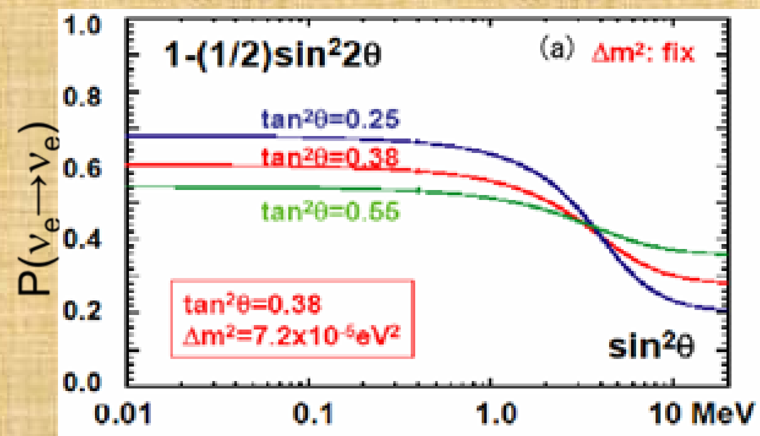
Motivation

Allowed region obtained by combined results and KamLAND



Survival probability for solar matter oscillation below 1MeV

Y.Suzuki@Neutrino2004



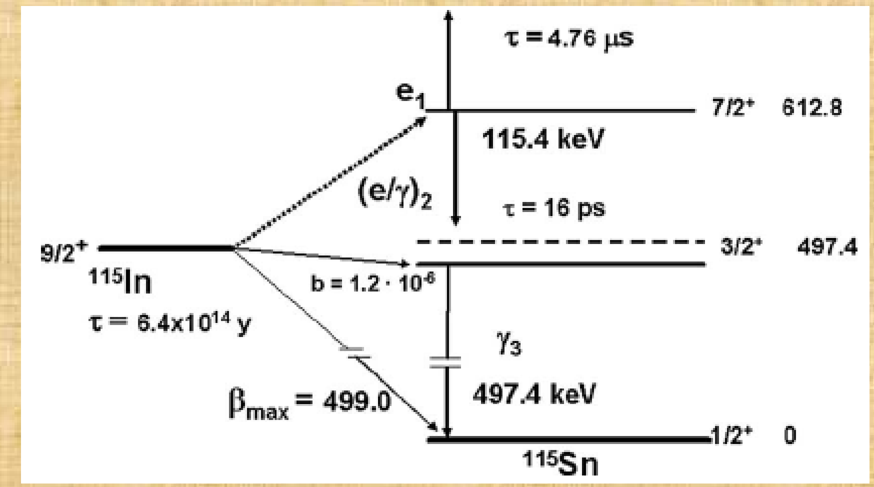
Neutrino energy

- 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

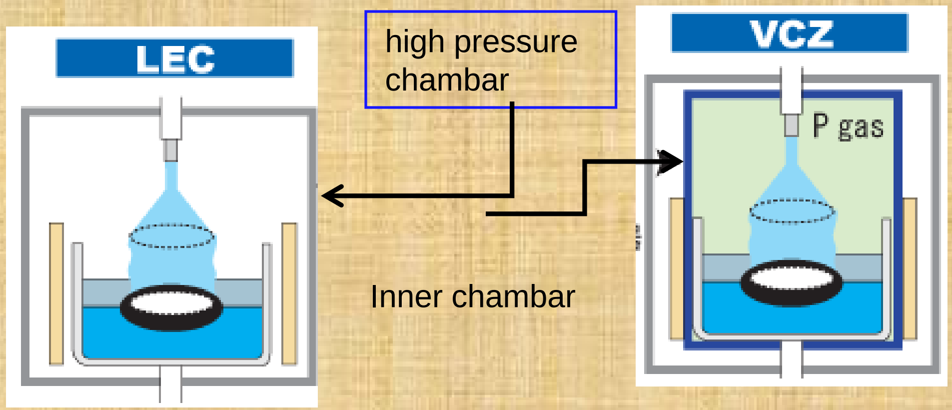
^{115}In + $\nu_e \rightarrow$ ^{115}Sn* + e$^-$
^{115}Sn*(4.76μs) $\rightarrow$ ^{115}Sn +
γ_1(115keV) + γ_2(497keV)

- Advantage
  - large cross section (~640SNU)
  - direct counting for solar neutrinos
  - sensitive to low energy region ($E_\nu \geqq$ 125keV)
  - energy measurement ($E_e = E_\nu -$ 125keV)
  - 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 × 10^{14} yr , Ee≧498keV)
  - possible BG due to correlated coincidence by radiative Bremsstrahlung

Requirement for the detector

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

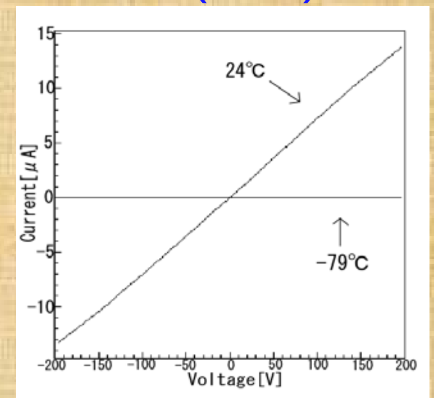
Semi-Insulating InP semi-conductor

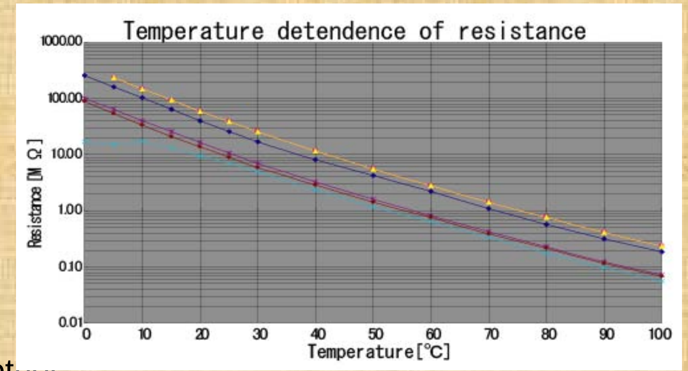


http://www.sei.co.jp/sc/technical/inp.html

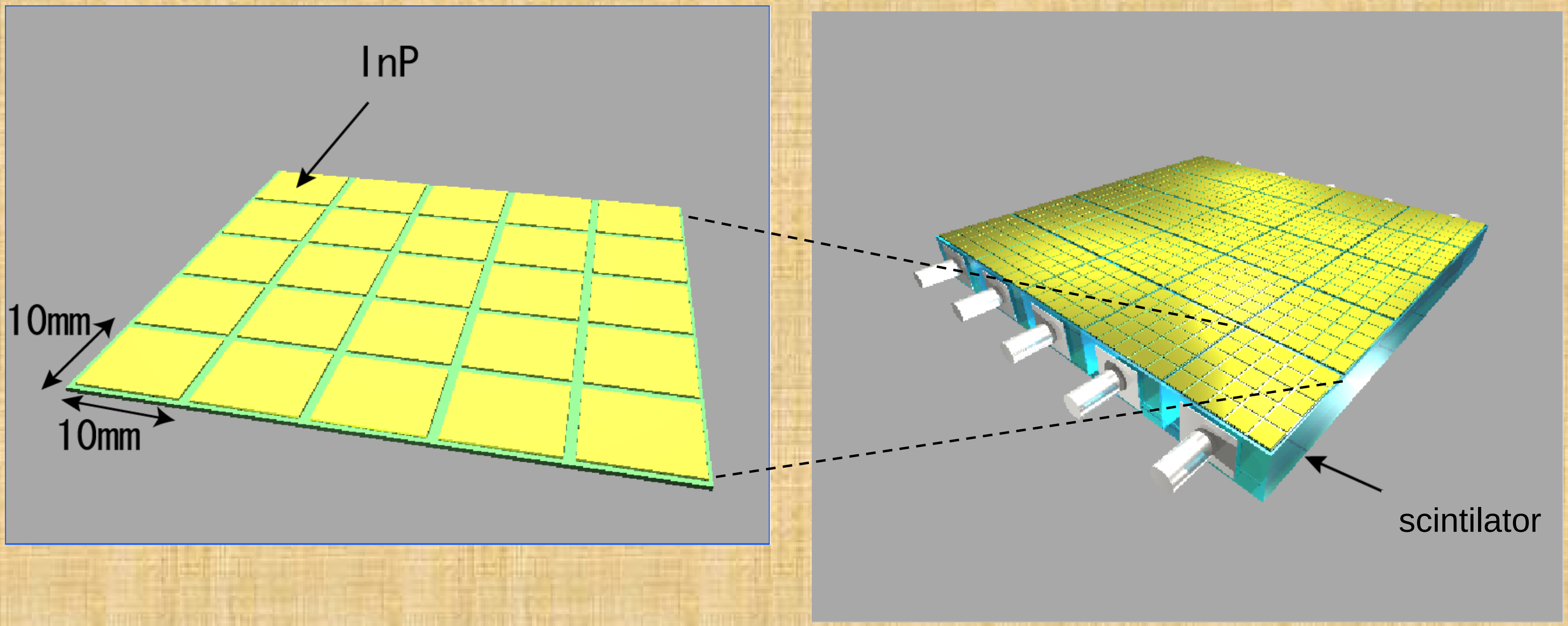
Product :
Sumitomo Electric Industries, Ltd.
Crystal growth method:
Vapor Pressure controlled Czochralski (VCZ)

EPD	～5,000cm^{-2}
Conduct	Semi-insulation
Dopant	InP(Fe)
Resistivity	(4.9～5.2)×10^{7}Ωcm
Mobility	(2.8～2.7)×10^{3}cm^{2}V^{-1}s^{-1}
Thickness	456～459μm
Diameter	50.00mm
Orientation	(100)±0.03°





Possible InP detector for solar neutrinos

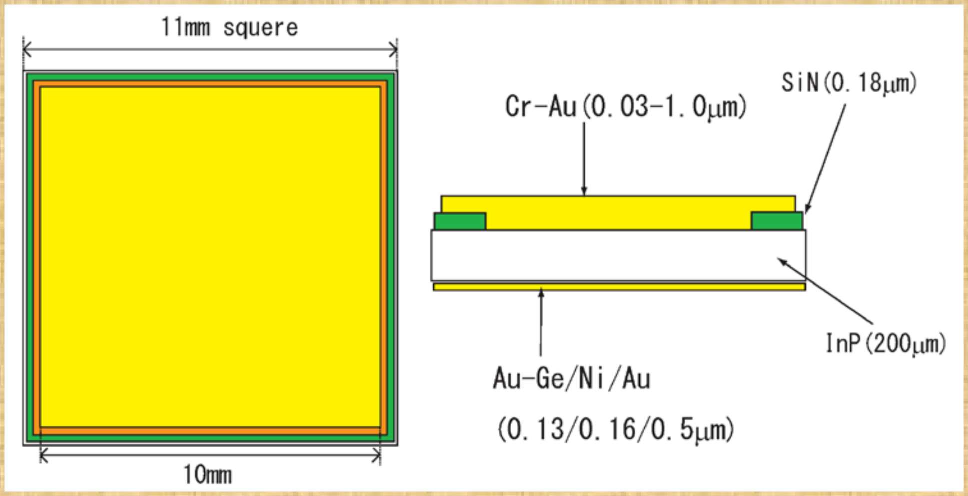


- Multi-pixel structure for large area detector
- High Z scintillator surrounding InP detector detect γs
- 4tons of ^{115}In detector for low energy solar ν

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

Semi-insulating InP cell detector

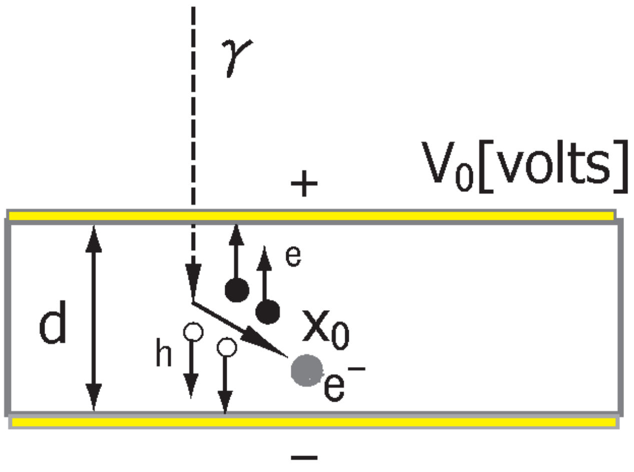
Mounted in vacuum chamber



- 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 : $L_d=\tau v=\mu\tau V_0/d$

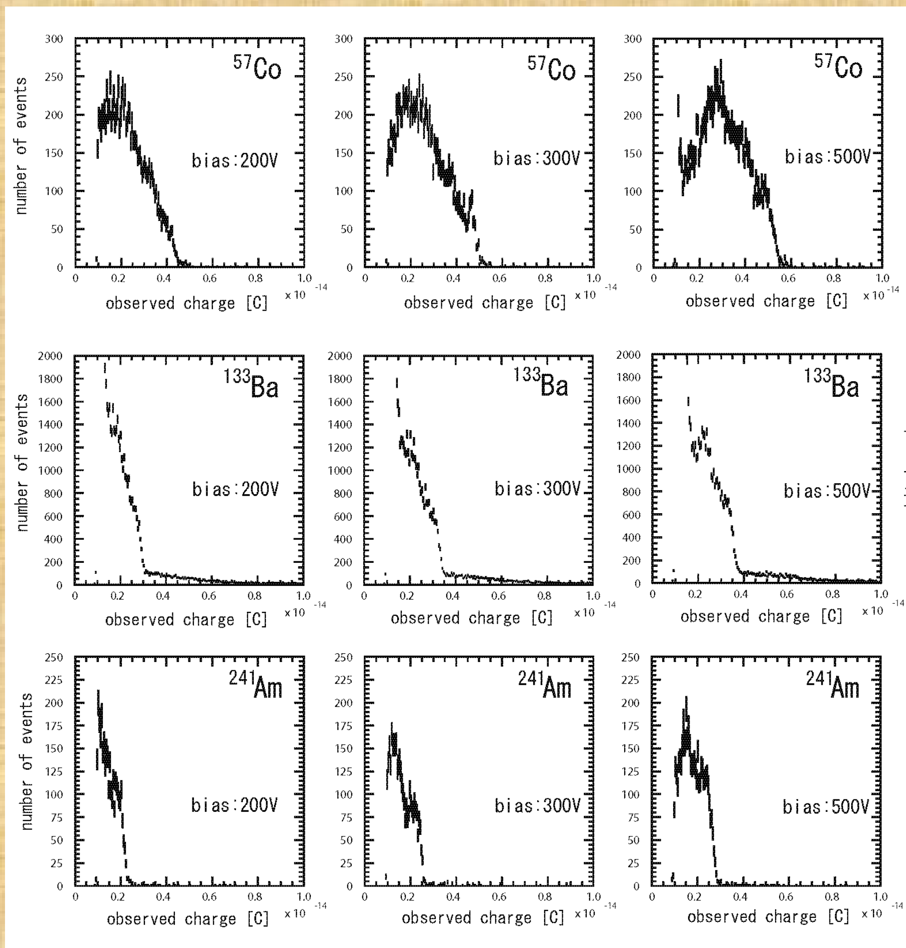
τ : carrier lifetime [s]

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

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

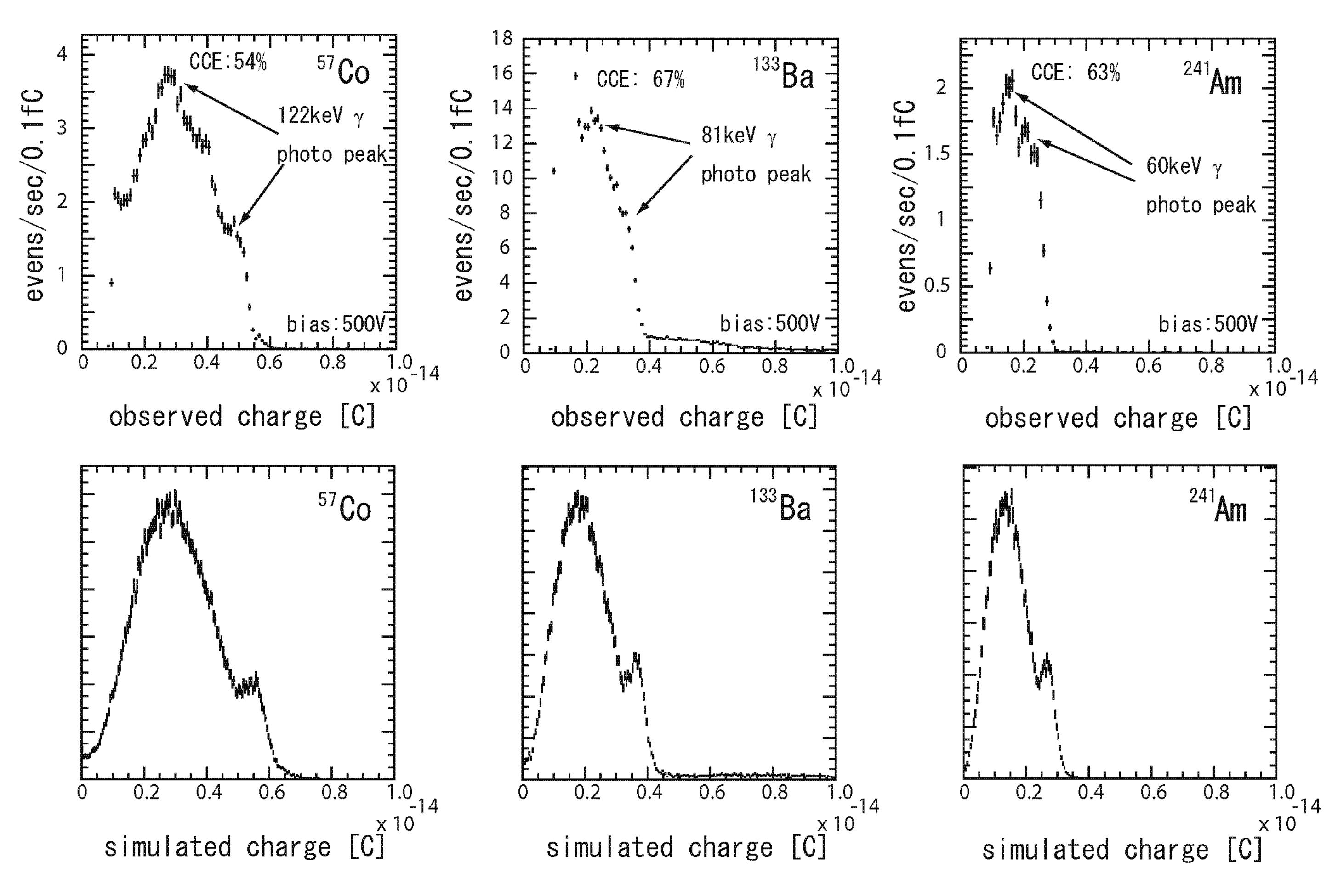
- For full collection (Le+Lh∼d) $Q=Q_0$

γ spectrum measured by InP detector



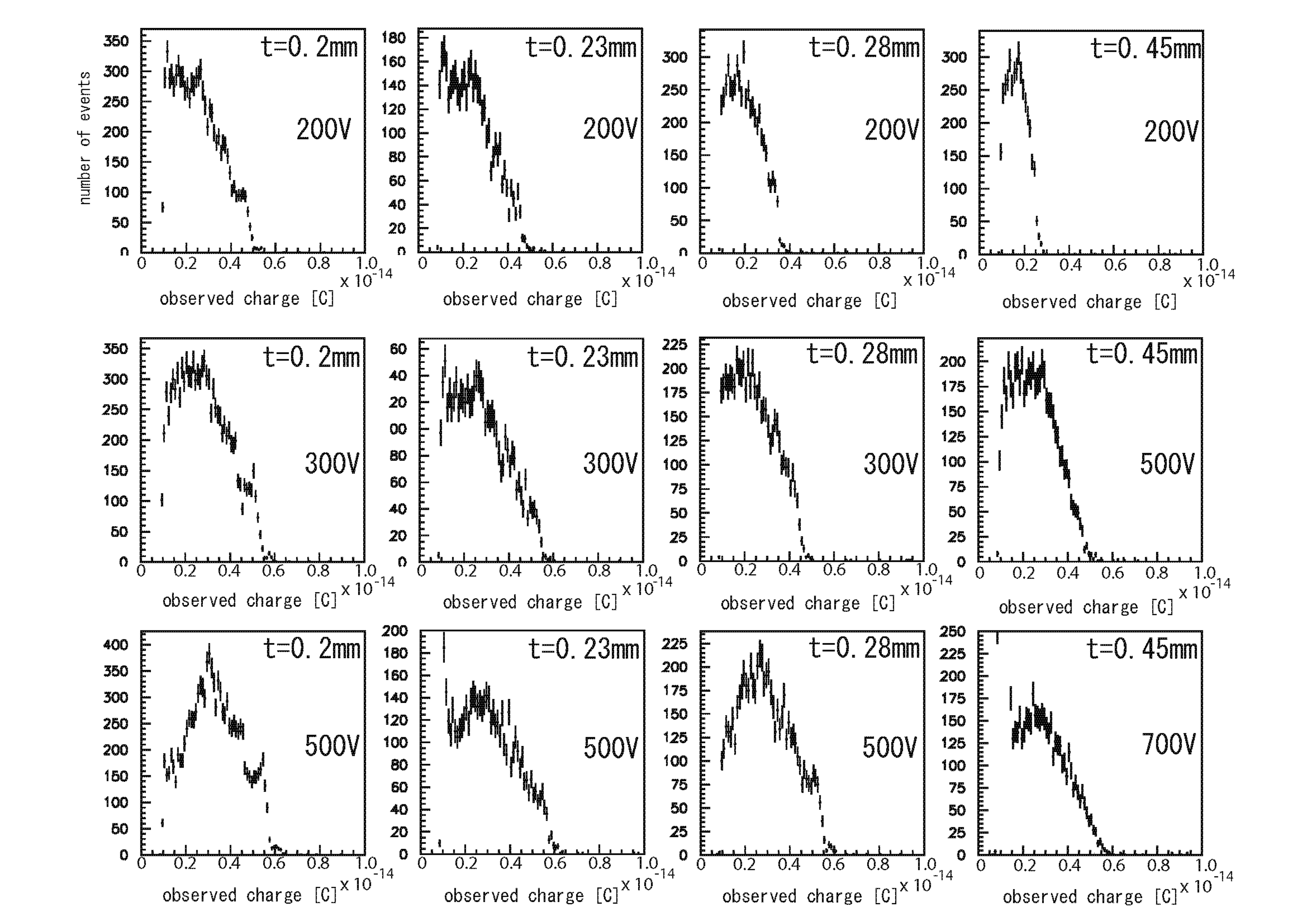
- InP detector should be cooled (-79 degree using Dry-Ice)
- Clear photo-peak was observed, but two peak structure
- Lower peak: induced charge generated by drift of carrier (electron and hole)
- Higher peak: full charge collection
- Energy of electron-hole pair production : 3.5eV
- Energy resolution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

Spectral shape and simulation

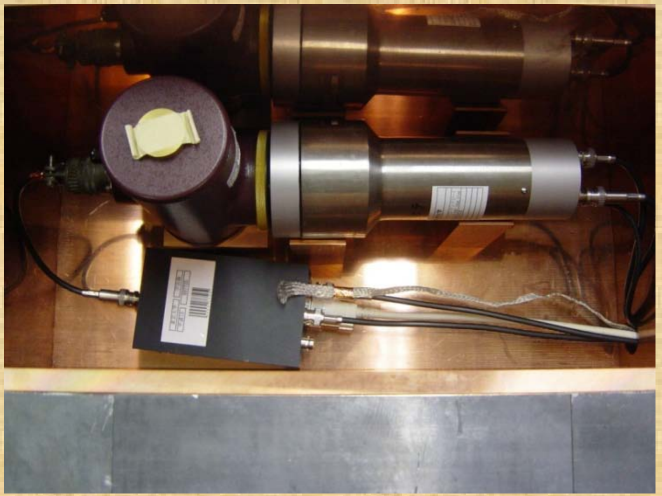


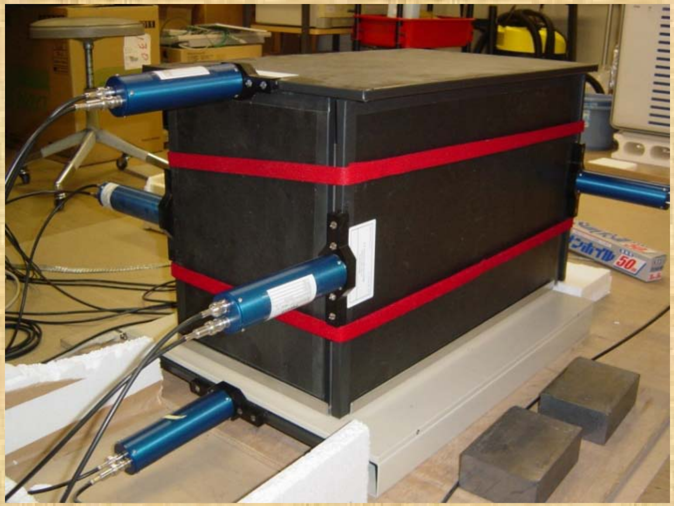
- Assuming, L_e~200μm and L_h~30μm, two peak structure could be reproduced by induced charge and full charge collection.

Optimization for detector thickness



Observation of internal ^{115}In β decay and correlated backgrounds

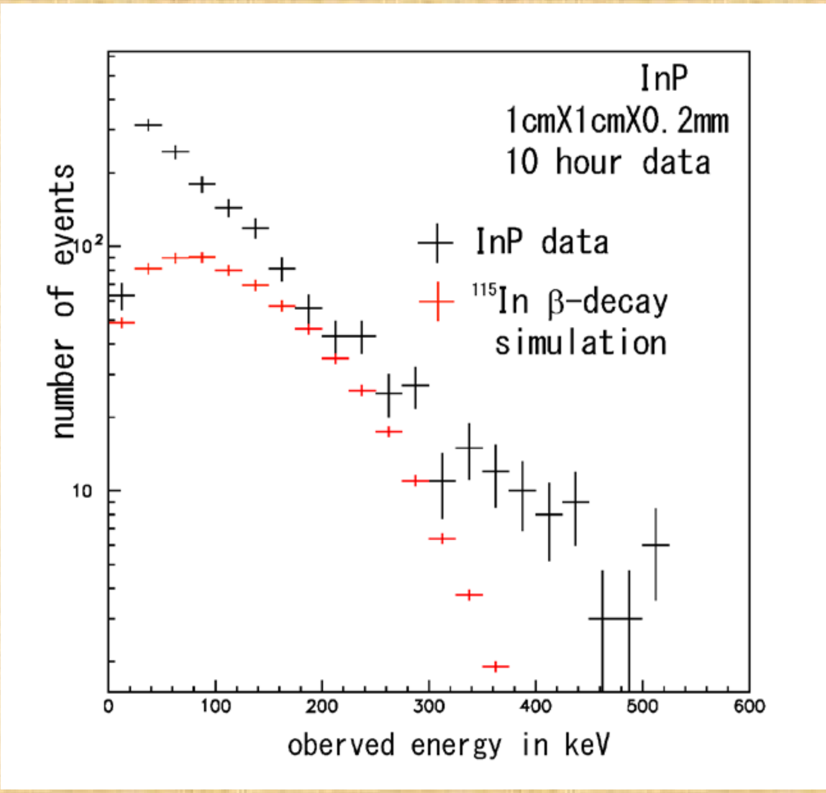




- CsI(Tl) scintillator : detect radiative Bremsstrahlung and other coincidence events with InP detector
- CsI crystal size : 50mm×50mm×20mm
- radiation shield : lead in 5cm thickness and oxygen free copper in 1cm thickness
- 4-π active veto plastic counter : veto cosmic ray muon

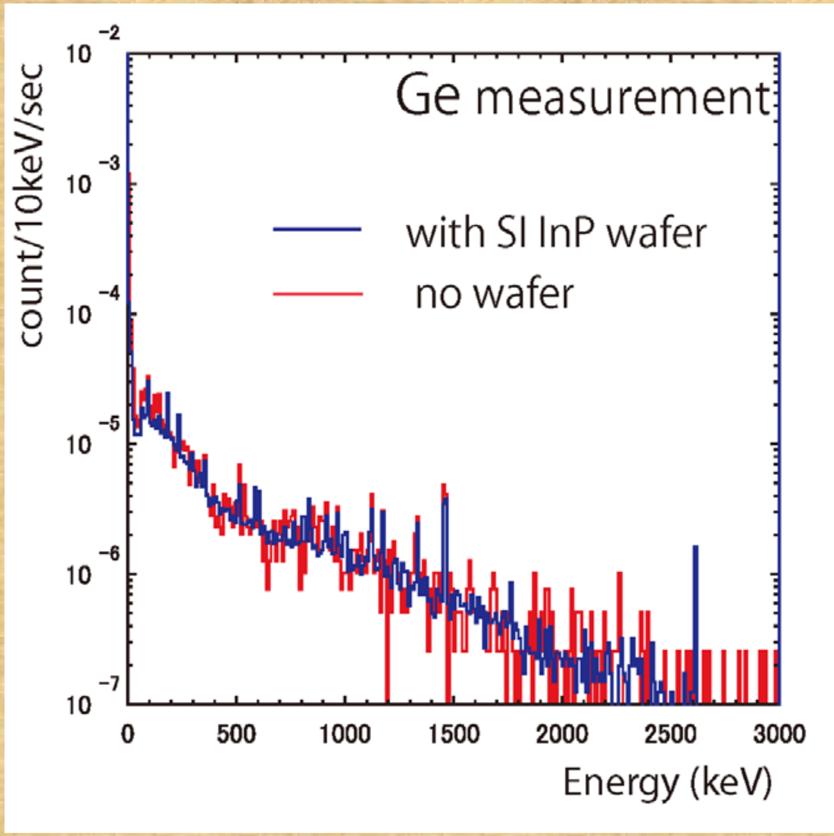
^{115}In β-decay signal in InP detector

- Observed spectrum has different shape from the expected one by β decay of ^{115}In.
- Events with E<100keV seem to be noise due to the vibration
- Events with E>300keV seems to be another backgrounds



U/Th contamination in SI InP wafer

- According to BG measurement using low-BG Ge detector, amount of U/Th contamination are evaluated by 5×10^{-11} g/g and 3×10^{-11} g/g, respectively .

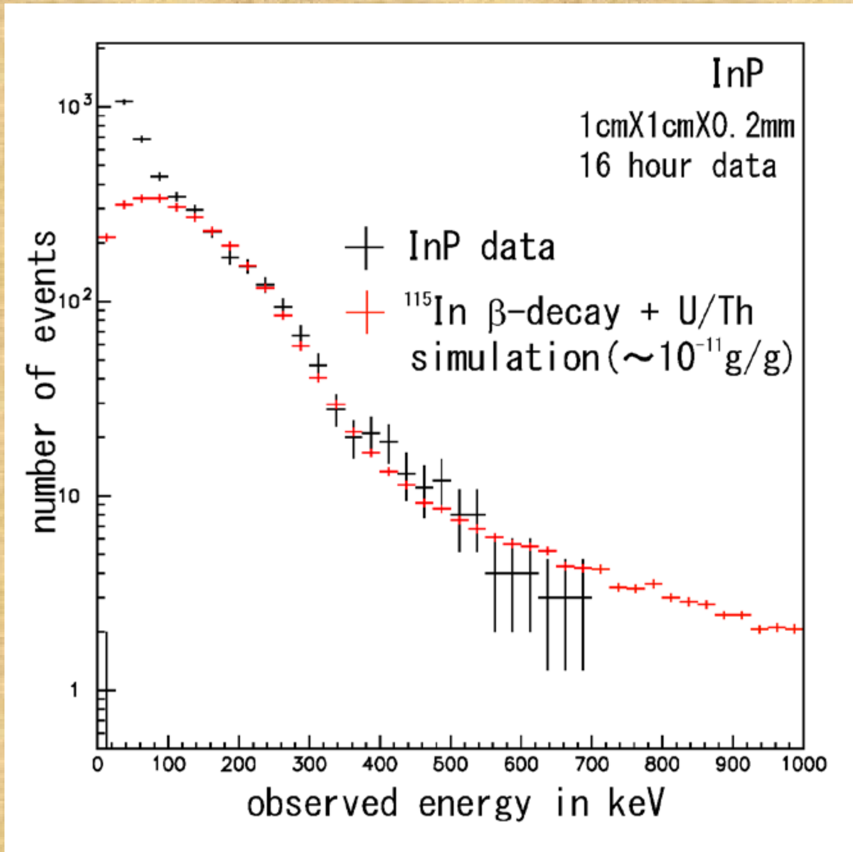


β–decay spectrum with U/Th backgrounds

- Assuming U/Th backgrounds, the spectral shape with E>300keV seems to be consistent with the observed spectrum.

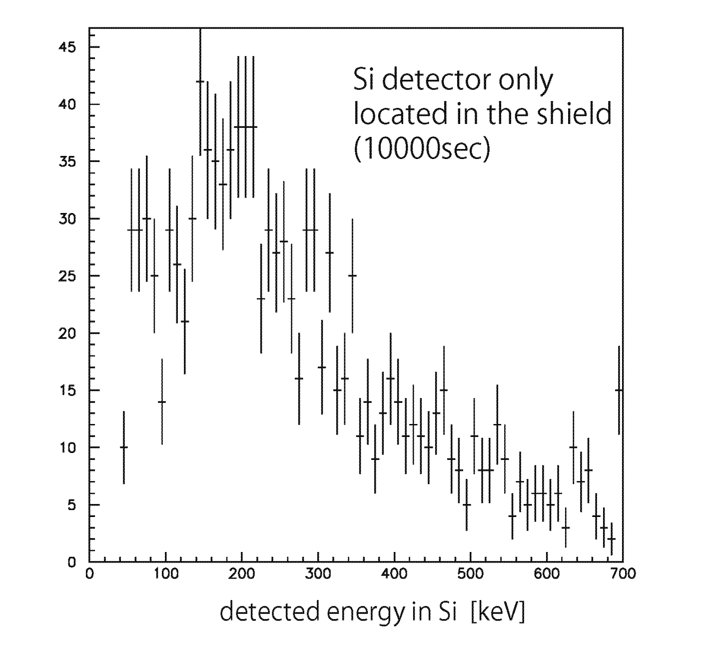
  ^{214}Pb(E_{max}=670keV)
  ^{214}Pb(E_{max}=730keV)
  ^{212}Pb(E_{max}=334keV)
  ^{234}Th(E_{max}=106keV)

- Another source of β–decay with E>300keV?



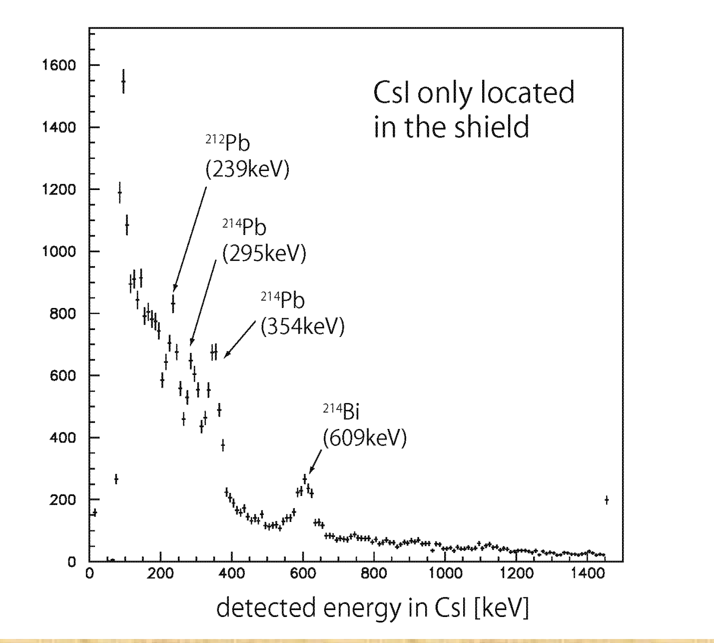
Backgrounds inside of Shield

Measurement of large area Si detector



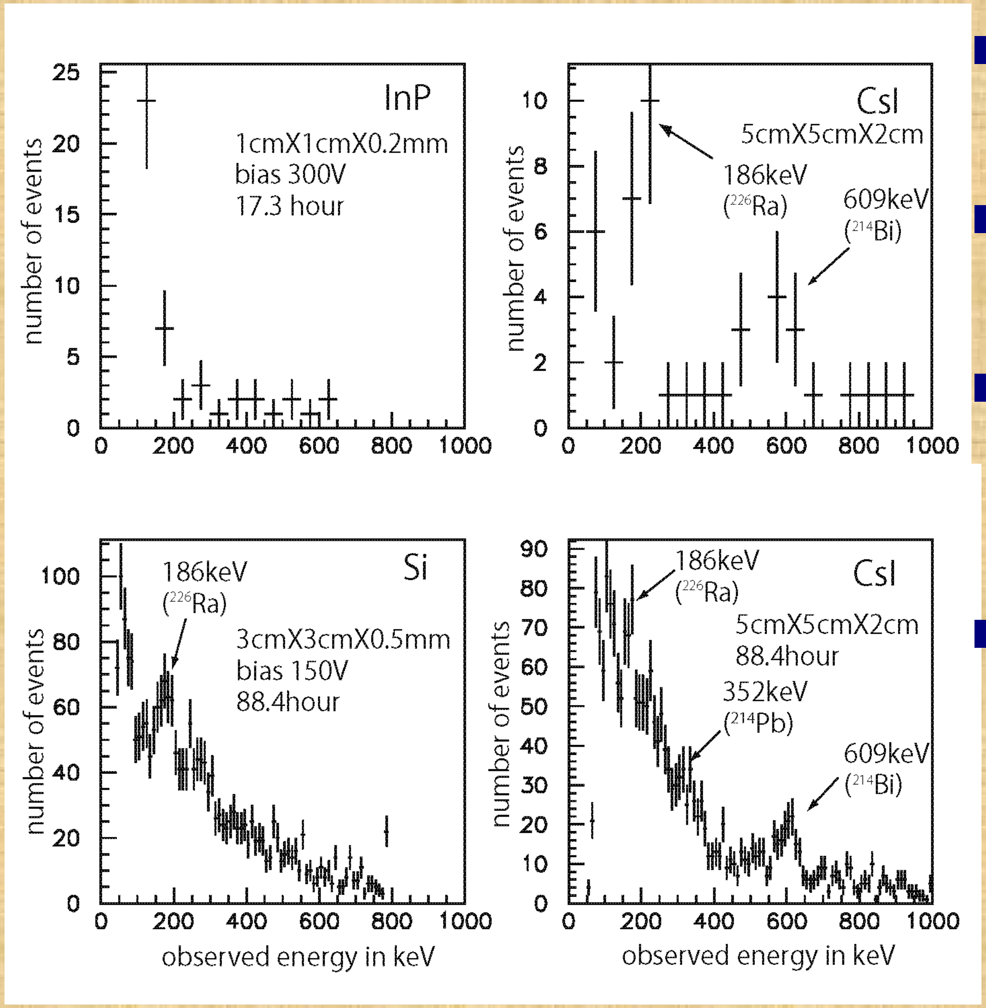
No peak of gammas（β spectrum of U/th?）

Measurement of CsI scintillator detector



Several peaks of gammas from U/Th decay

Observed coincidence backgrounds



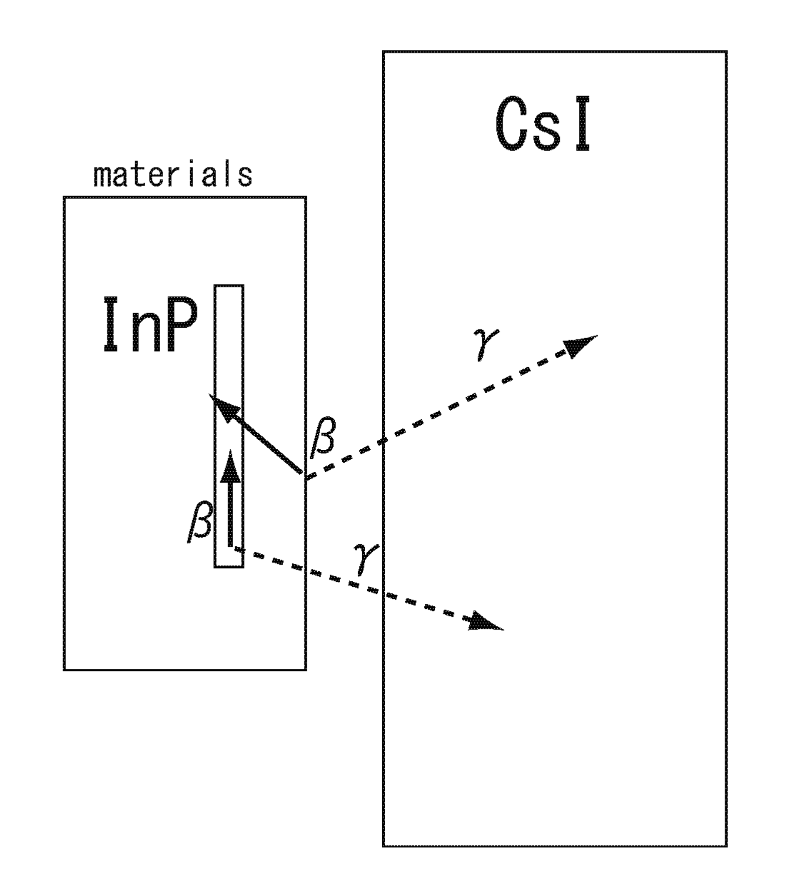
- Coincidence background was observed.
- CsI scint. detects external gammas from U/Th decay
- InP (Si as a reference) detects internal/external βs from U/Th decay.
- No significant radiative Bremsstrahlung from ^{115}In β decay was observed.

need more statistics

Uncorrelated BG for solar ν experiment

- InP signal (ev#1) and scintillator signals (ev#2 with E~116keV and ev#3 with E~497keV) within 10ms Gate
- Uncorrelated BG: 5×10^{-6} events/day/module

  = 10 events /day/whole detector =$2.0X10^{6}$ modules
- U/Th in InP wafer should be reduced ~1/10



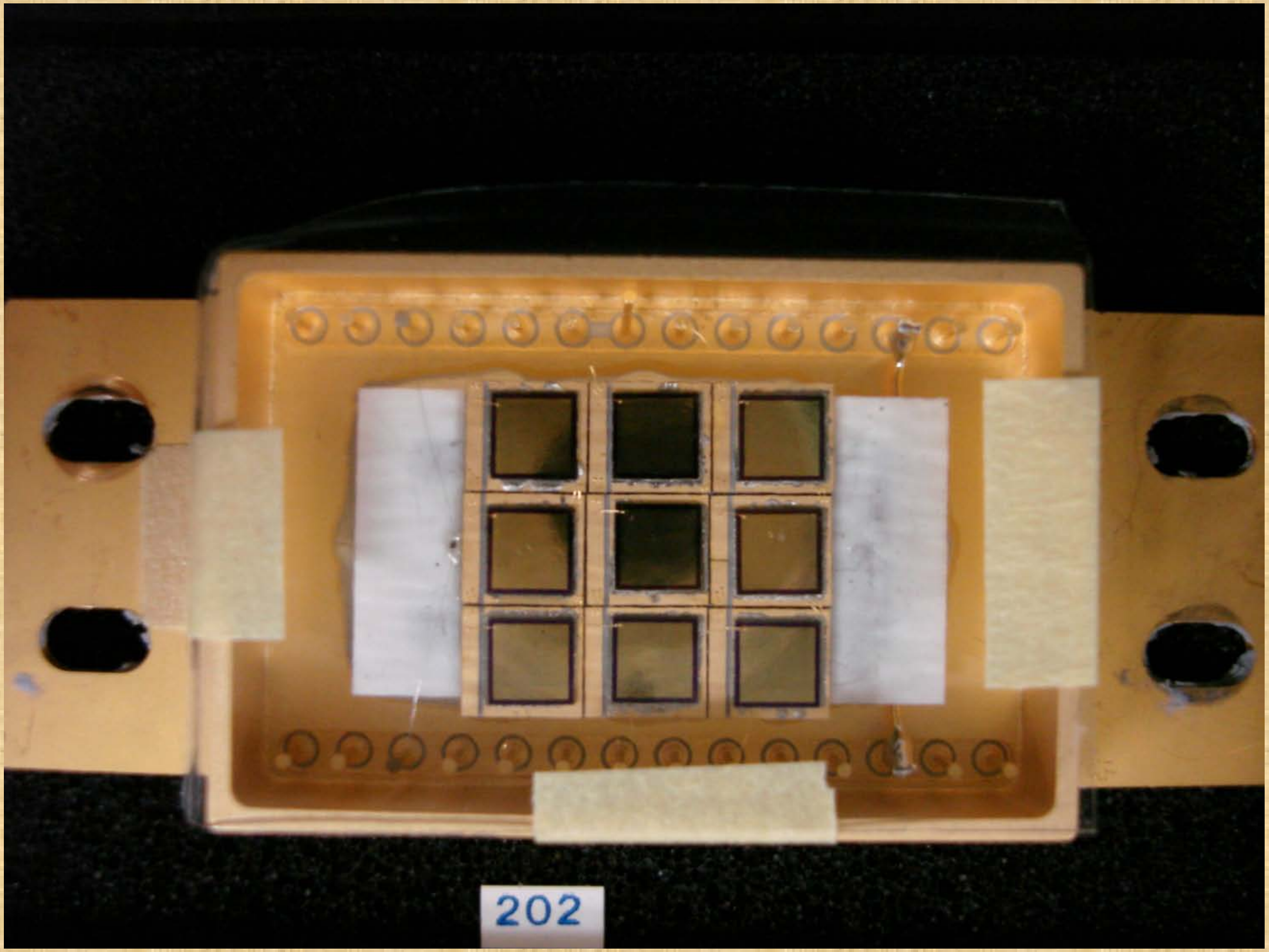
Conclusion

- InP detector observed clear peak of γs
- Induced charge due to drift of carrier (electron and hole) generated by radiation.
- Average energy of carrier production : 3.5eV
- Energy resolution : 25% → Vertical Bridgeman method
- No significant backgrounds related to radiative Bremsstralung of ^{115}In → need more statistics
- Amount of Internal U/Th contamination should be reduced by 1/10 in order to keep S/N~1

Next step : 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

Prototype of multi-pixel InP detector



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