低エネルギー太陽ニュートリノ観測を目的としたインジウム・リン半導体検出器の開発研究

平成21年度共同利用研究成果発表研究会

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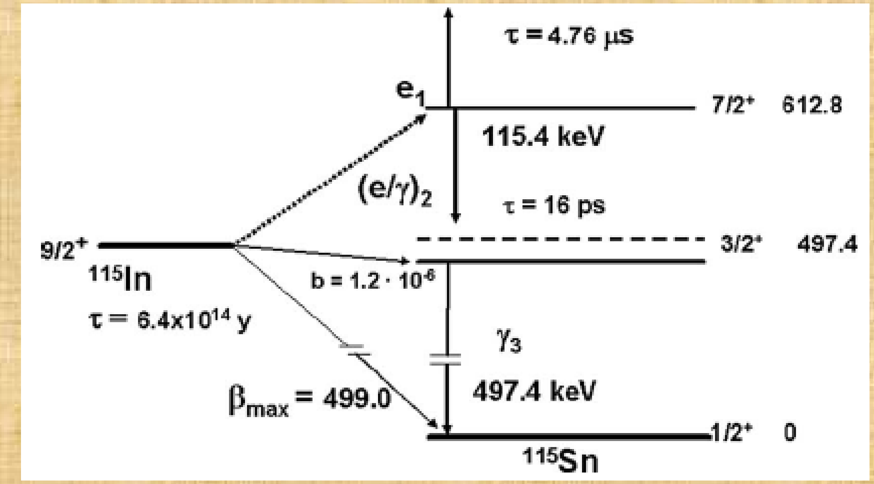
今年度の研究開発状況

- 検出器の検出電荷量の理解とシミュレーションによる評価
- MIS構造による暗電流低減化
- ^{115}Inの自然β崩壊事象と原子核起因の制動輻射事象の観測
- Multi-pixel型検出器の試験
- シンチレーション光の観測試験

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)

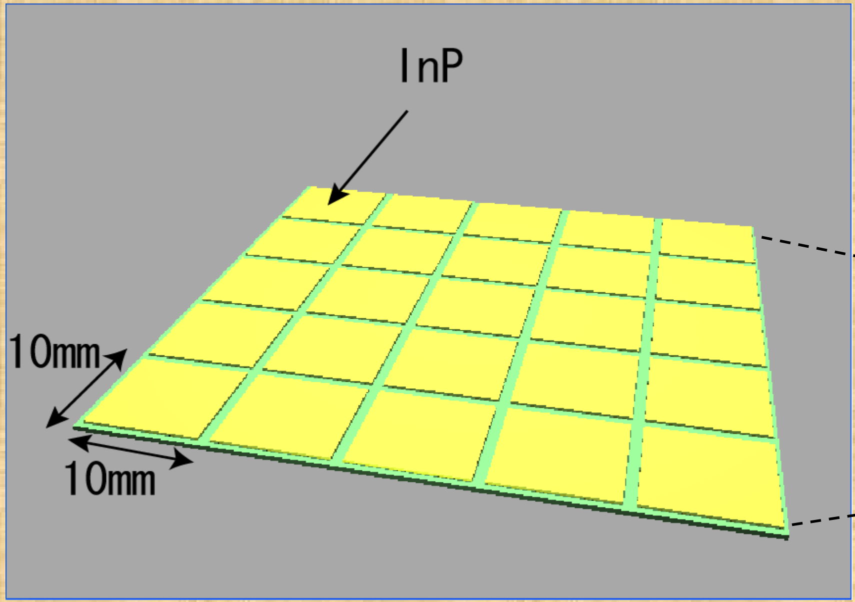
● Advantage
- large cross section (~640SNU)
- direct counting for solar neutrinos
- sensitive to low energy region ($E_\nu \geqq$ 125keV)
- energy measurement ($E_e = E_\nu$ − 125keV)
- triple fold coincidence to extract neutrino signal from huge BG ($e_1 + \gamma_2 + \gamma_3$)

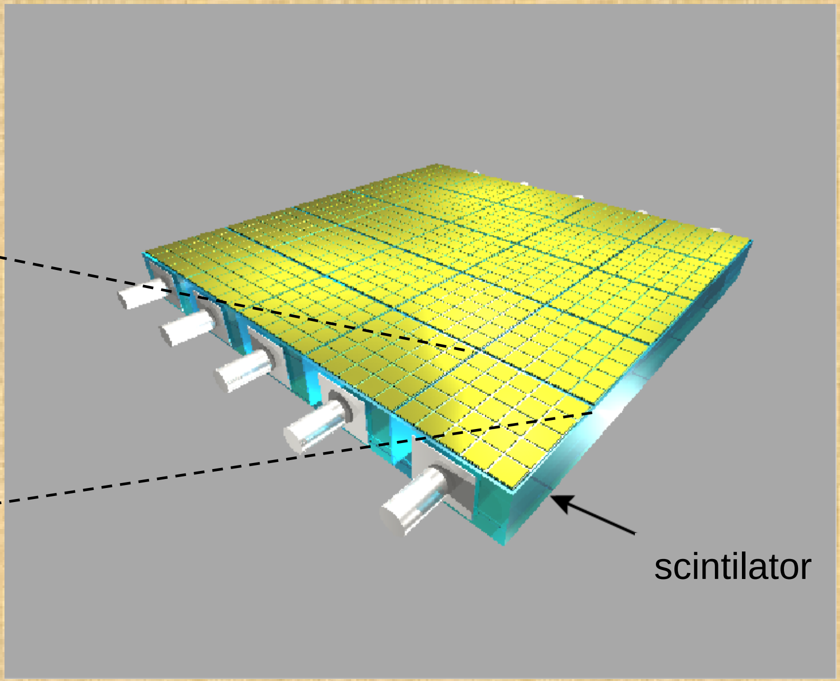
● Disadvantage
- natural β-decay of ^{115}In ($\tau_{1/2}$ = 4.4 × 10^{14} yr , Ee≧498keV)
- possible BG due to correlated coincidence by radiative Bremsstrahlung

Requirement for the detector

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

Possible InP detector for solar neutrinos

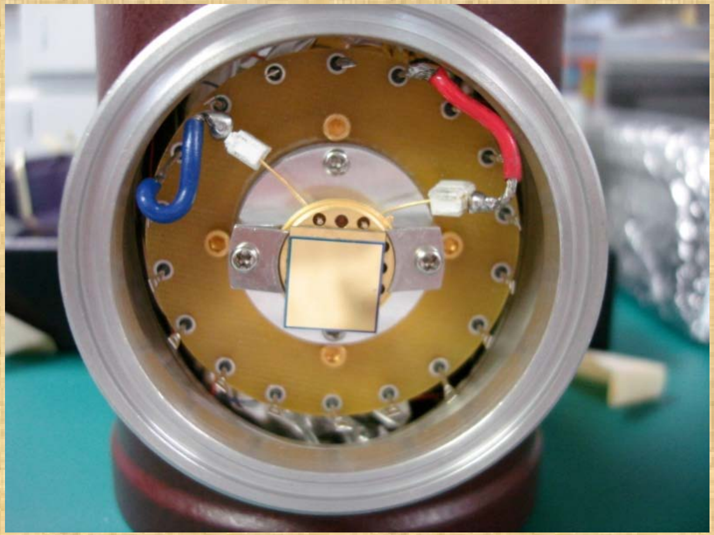




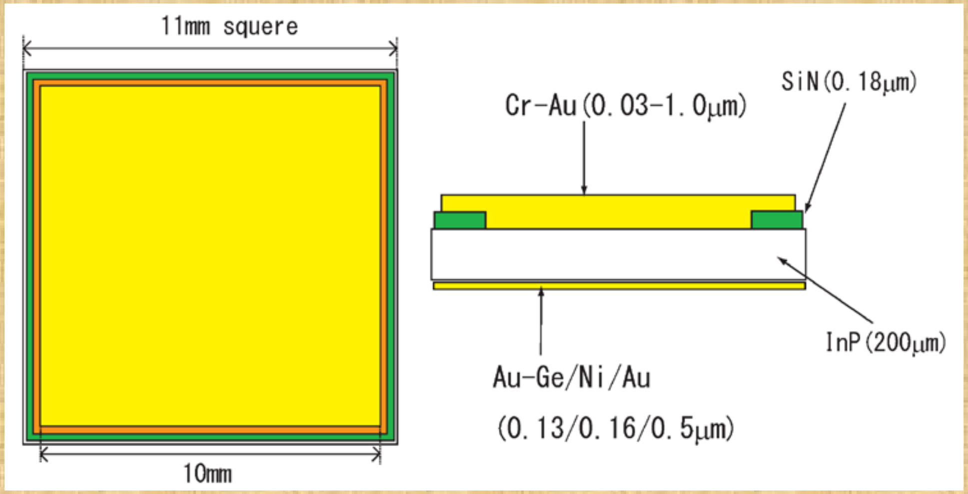
- Multi-pixel structure for large area detector
- High Z scintillator surrounding InP detector detect γs
- 4tons of ^{115}In detector for low energy solar ν

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

Semi-insulating InP cell detector



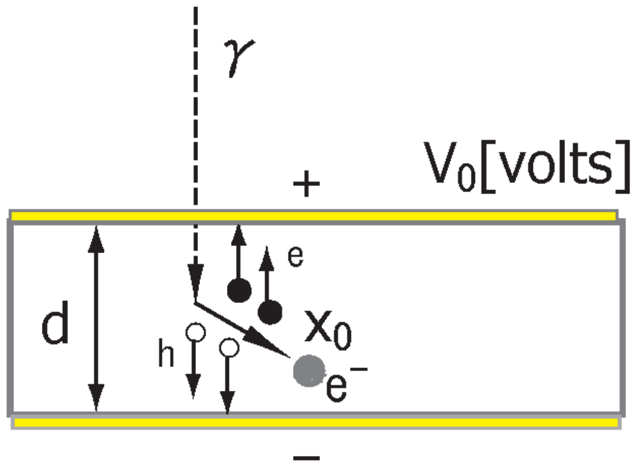
Mounted in vacuum chamber



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

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

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

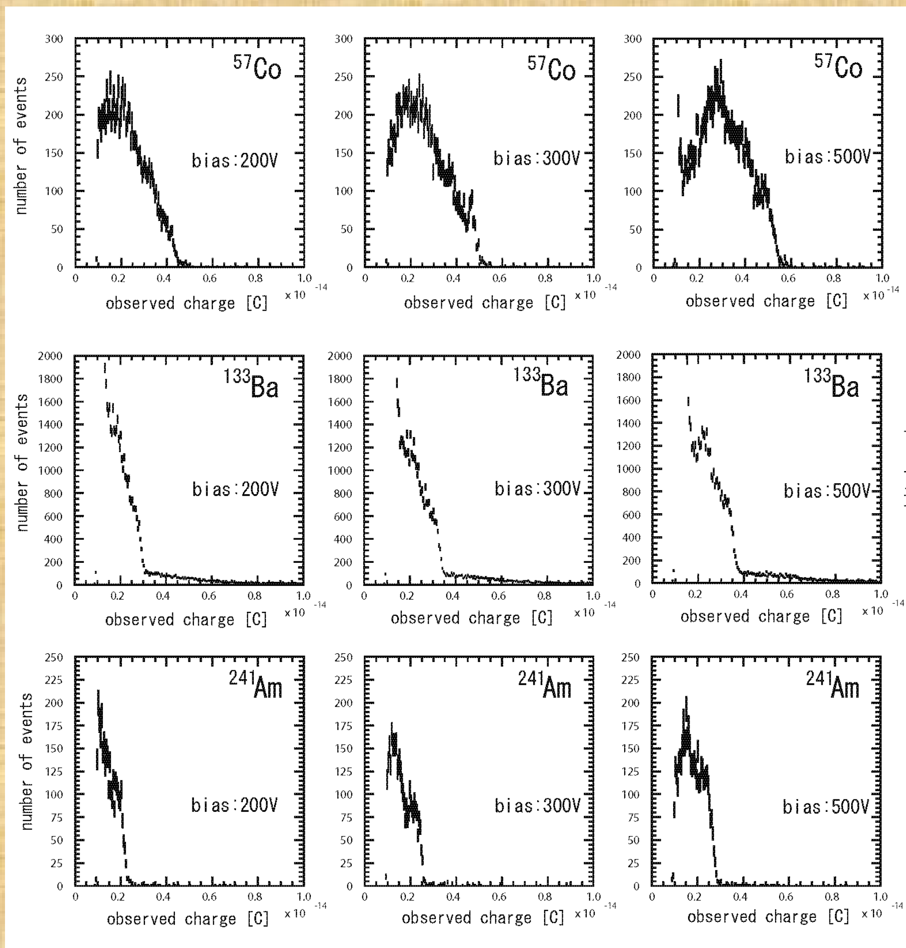
τ : carrier lifetime [s]

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

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

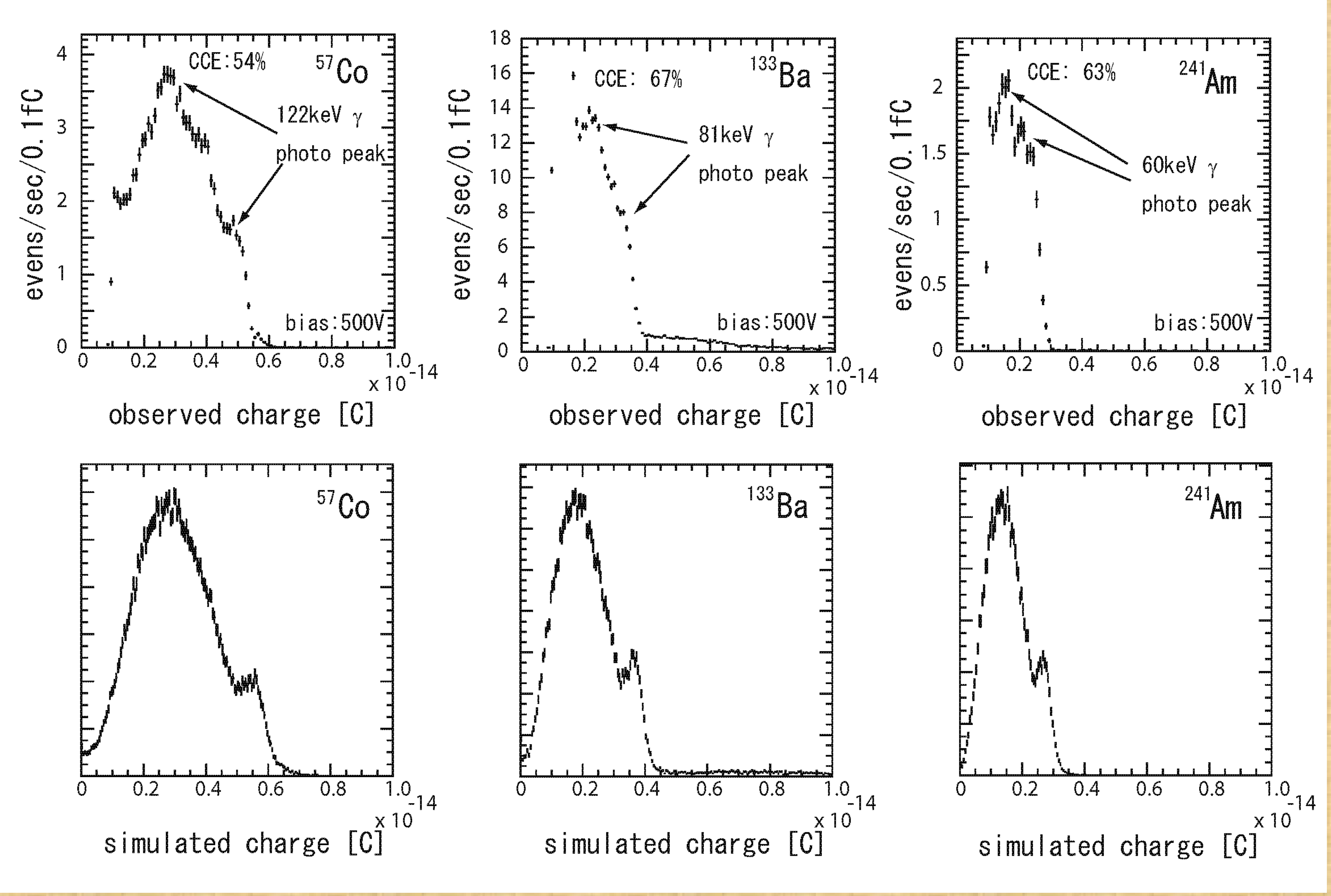
- For full collection (Le+Lh～d) $Q = Q_0$

γ spectrum measured by InP detector



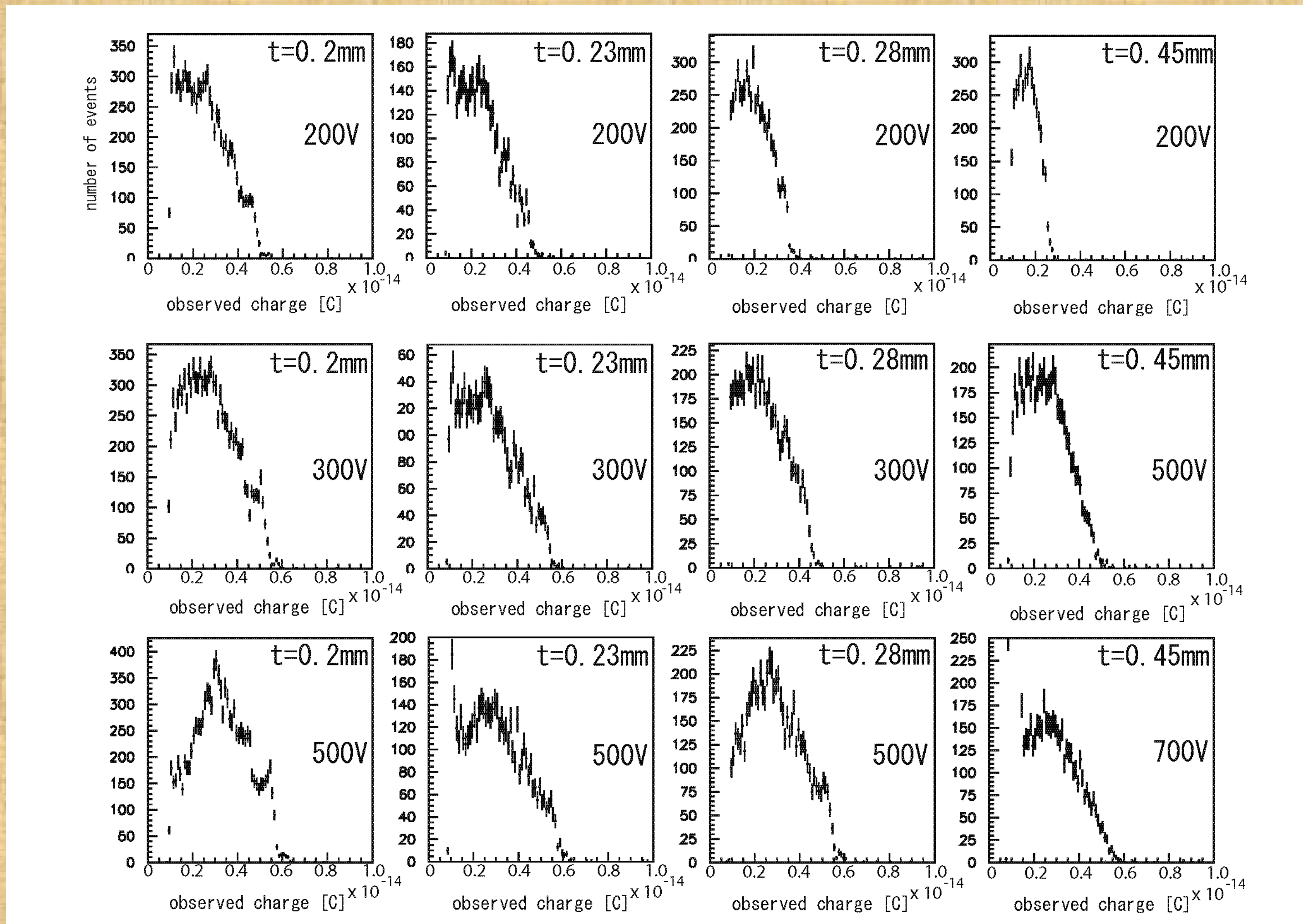
- InP detector should be cooled (-79 degree using Dry-Ice)
- Clear photo-peak was observed, but two peak structure
- Lower peak: induced charge generated by drift of carrier (electron and hole)
- Higher peak: full charge collection
- Energy of electron-hole pair production : 3.5eV
- Energy resolution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

Spectral shape and simulation



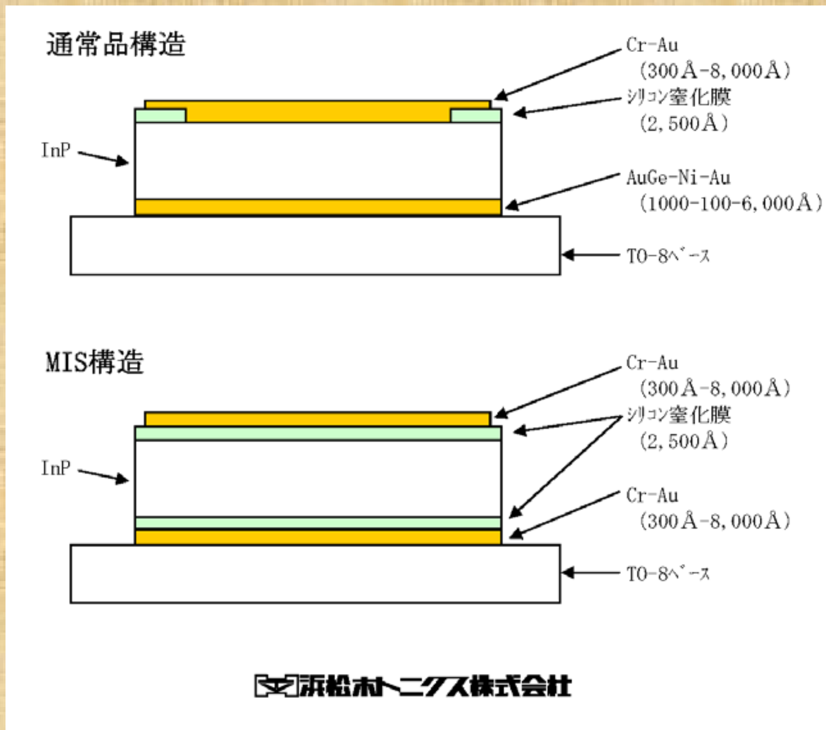
- Assuming, L_e~200μmand L_h~30μm, two peak structure could be reproduced by induced charge and full charge collection.

Optimization for detector thickness

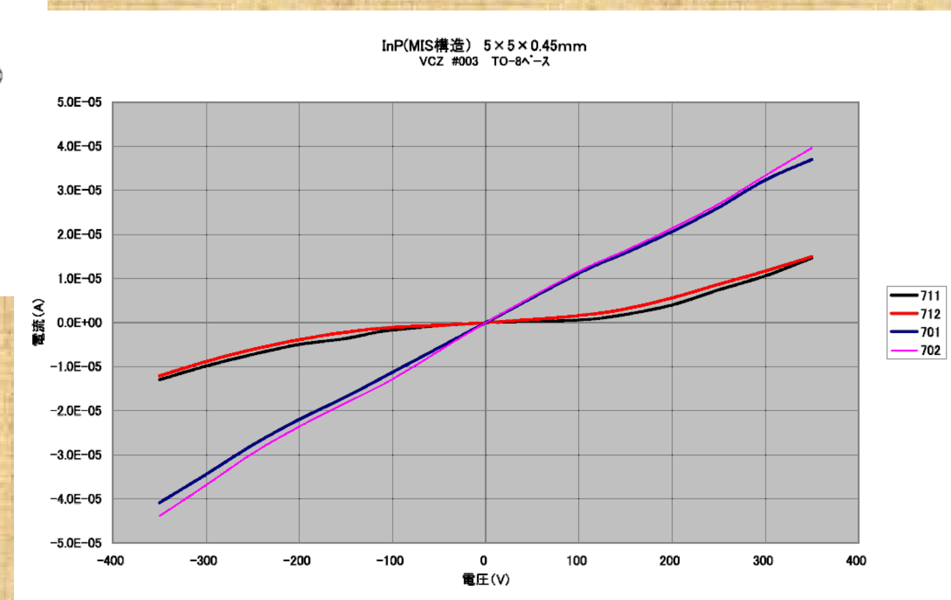


Thickness < 300μm is best

MIS structure detector

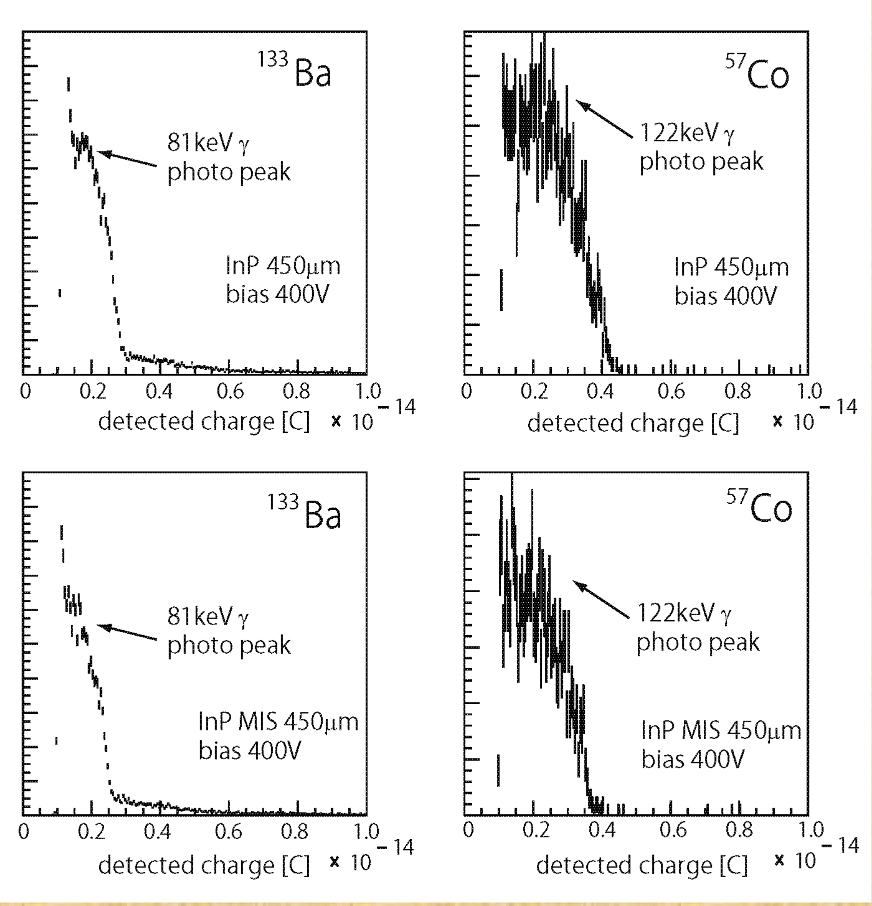


- ■purpose
  Obtain better energy resolution due to low dark I
- ■Metal-insulator-semiconductor (MIS structure)



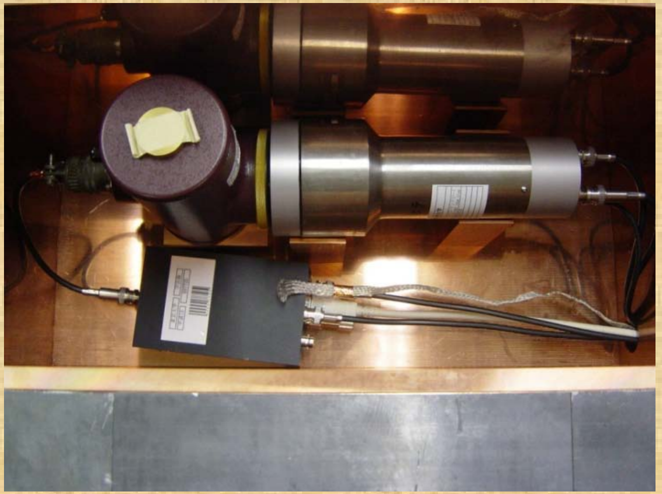
V-I indicates MIS-detector has lower dark current

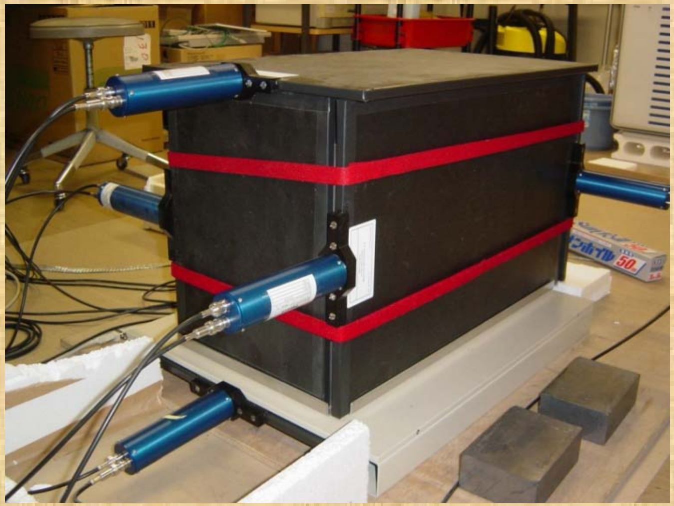
γ–response for MIS-detector



- Same charge as usual detector
- Induced charge collection was confirmed
- Lower dark current might not affect the energy resolution
- Longer drift length (or life time) will improve energy resolution (need much uniform wafer)

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

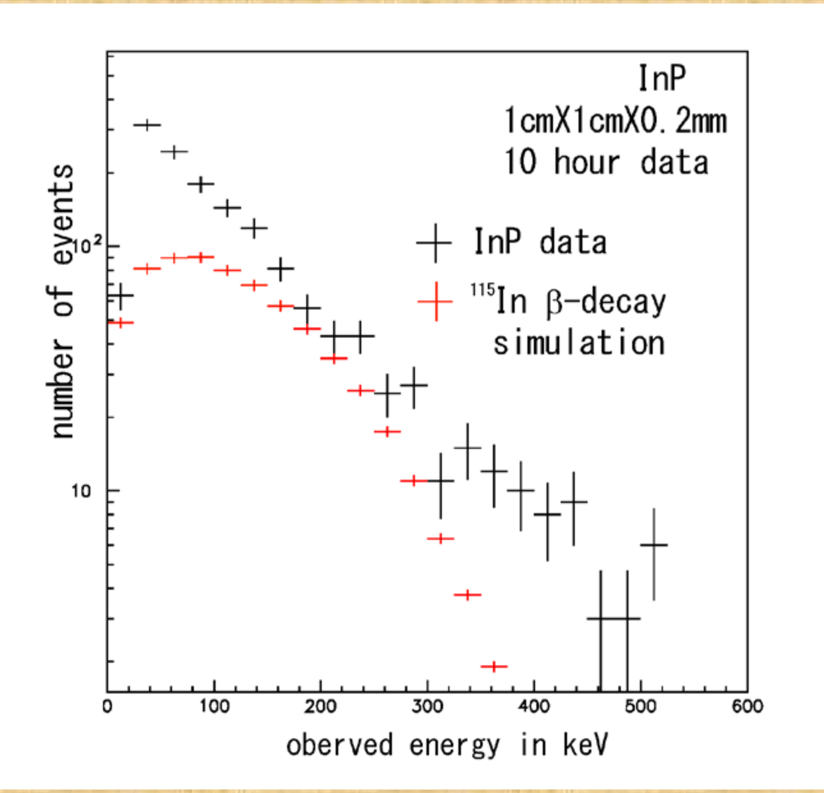




- CsI(Tl) scintillator : detect radiative Bremsstrahlung and other coincidence events with InP detector
- CsI crystal size : 50mm×50mm×20mm
- radiation shield : lead in 5cm thickness and oxygen free copper in 1cm thickness
- 4-π active veto plastic counter : veto cosmic ray muon

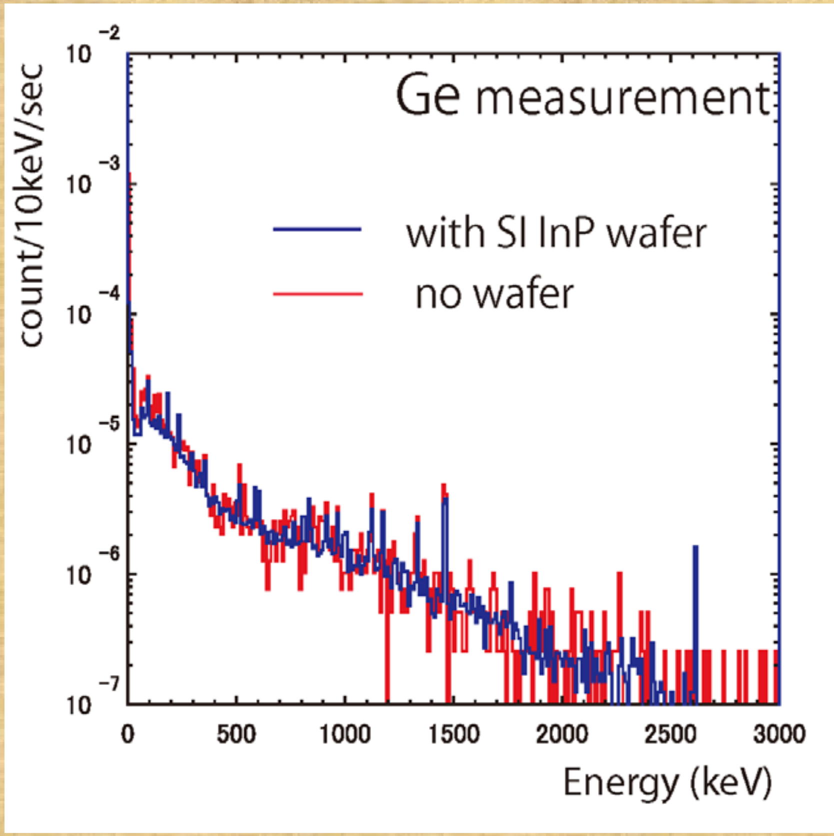
^{115}In β-decay signal in InP detector

- 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 .

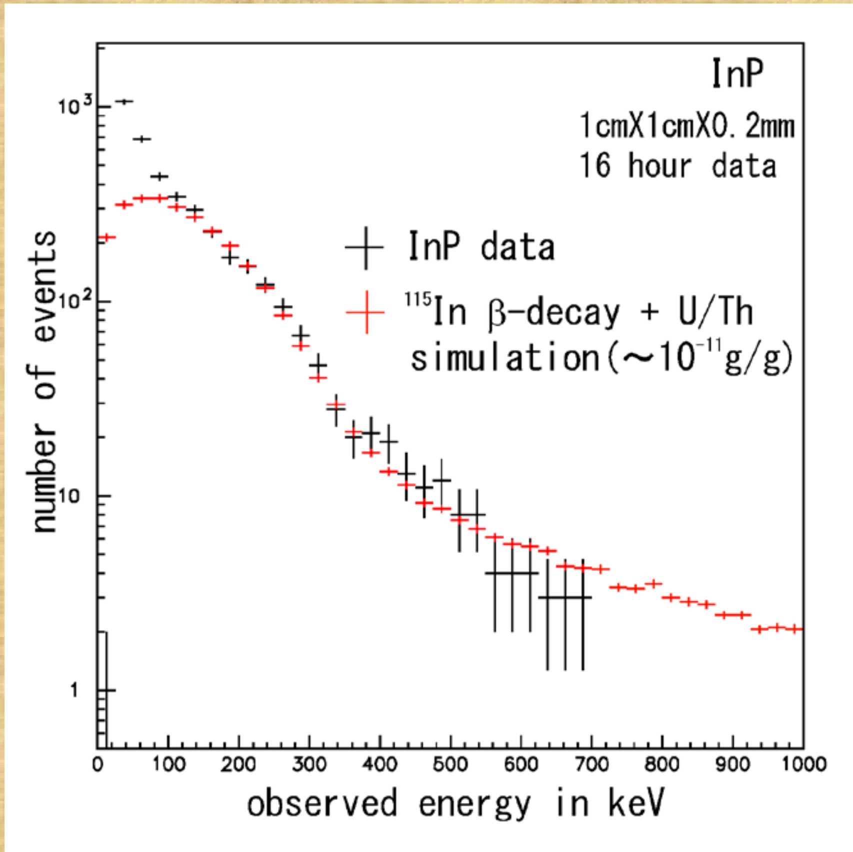


β–decay spectrum with U/Th backgrounds

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

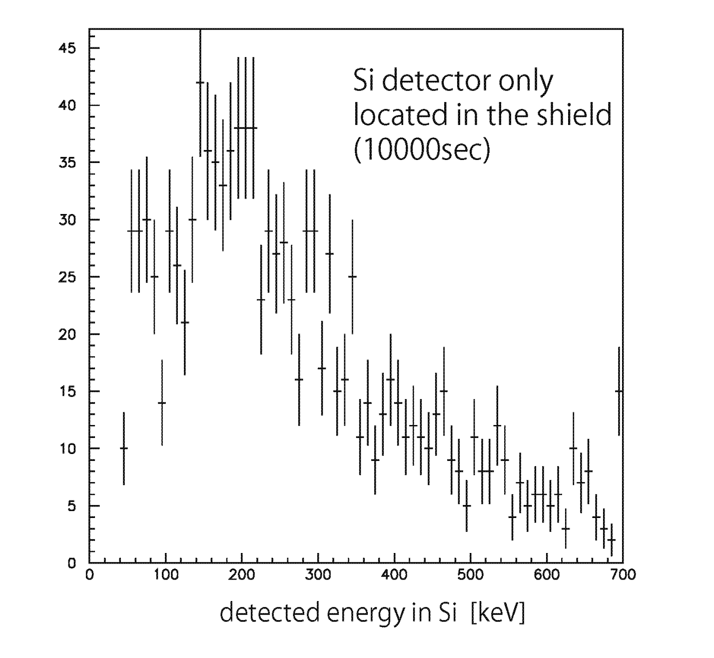
  ^{214}Pb(E_{max}=670keV)
  ^{214}Pb(E_{max}=730keV)
  ^{212}Pb(E_{max}=334keV)
  ^{234}Th(E_{max}=106keV)

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



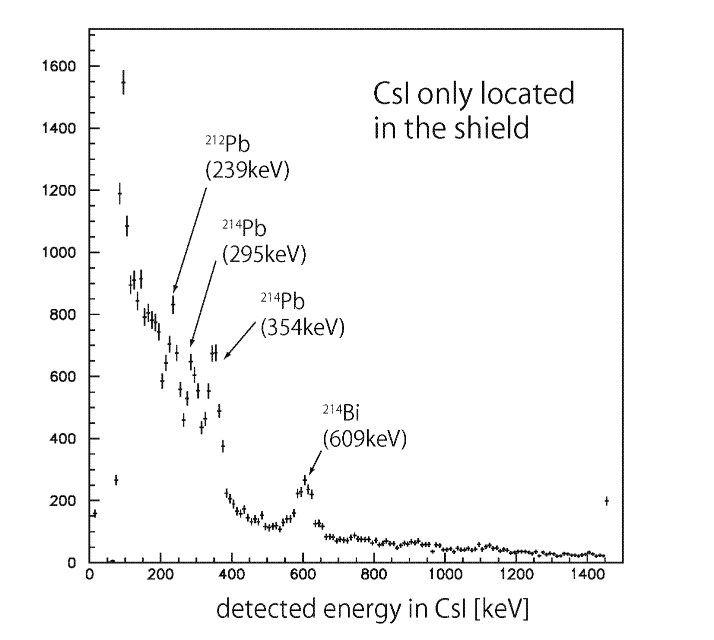
Backgrounds inside of Shield

Measurement of large area Si detector



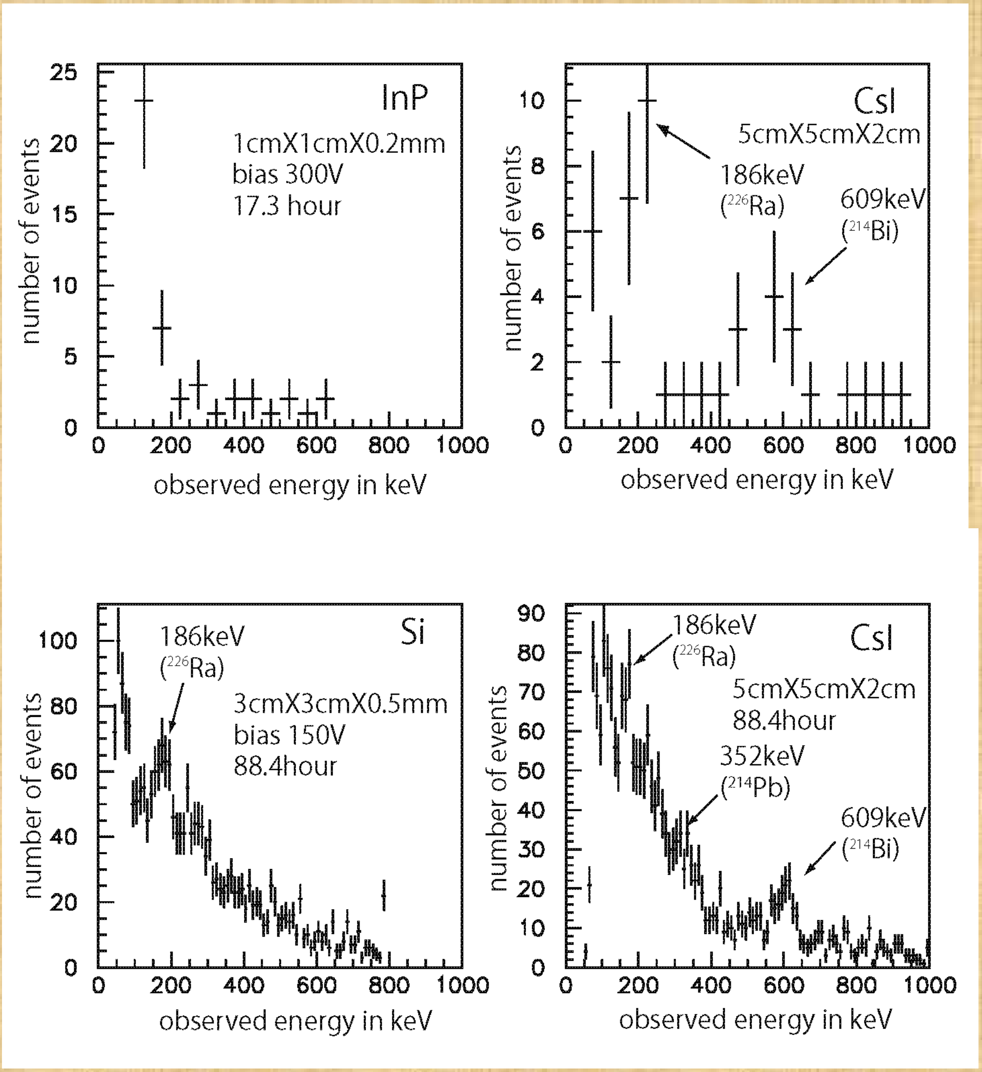
No peak of gammas（β spectrum of U/th?）

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.

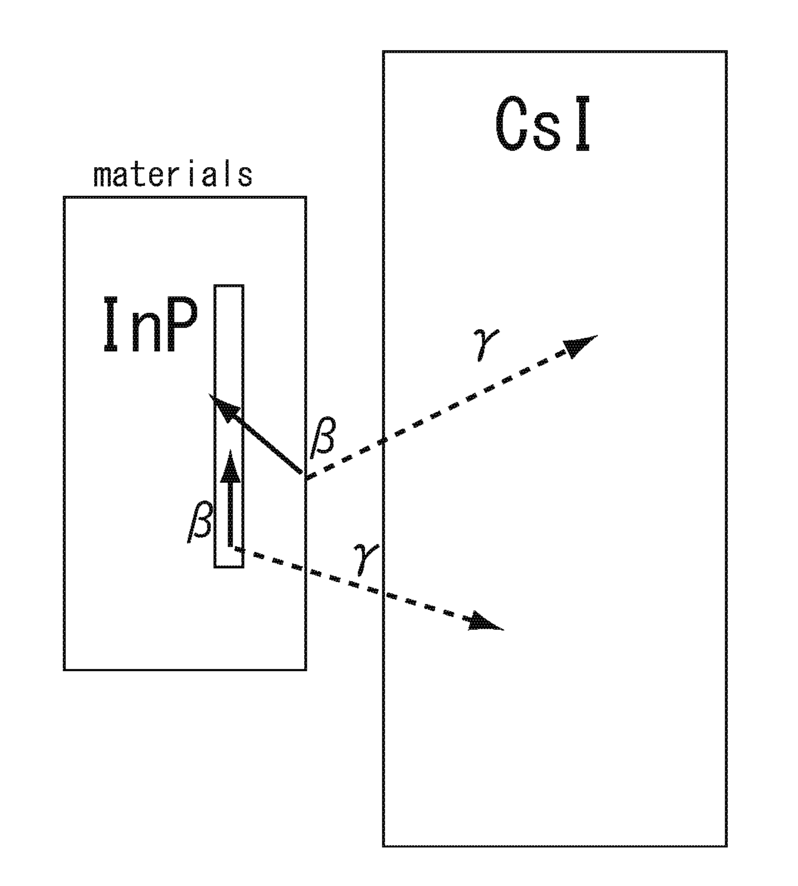
⇓

need more statistics to confirm

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 10μs Gate
- Uncorrelated BG: 5×10^{-6} events/day/module

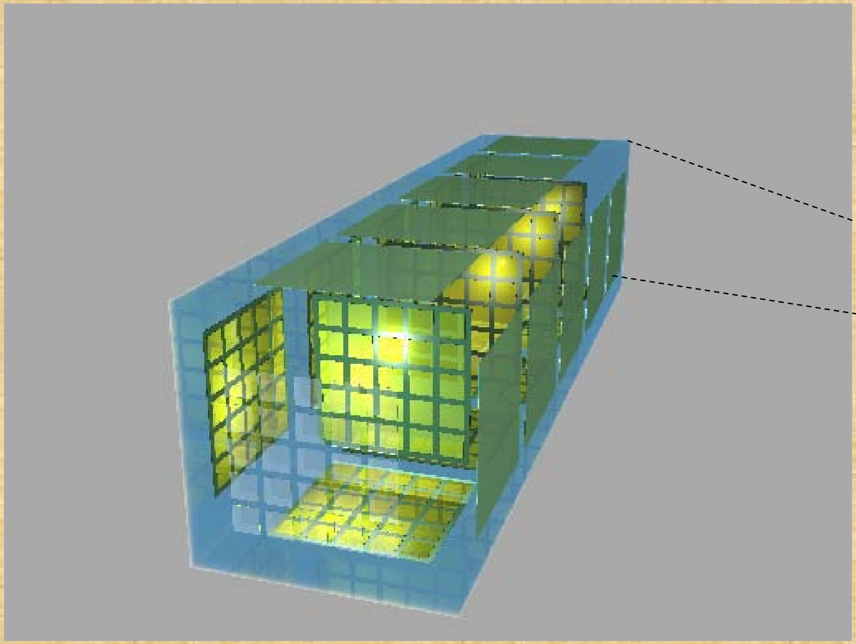
  = 10 events /day/whole detector =$2.0X10^{6}$ modules
- U/Th in InP wafer should be reduced by ~1/10

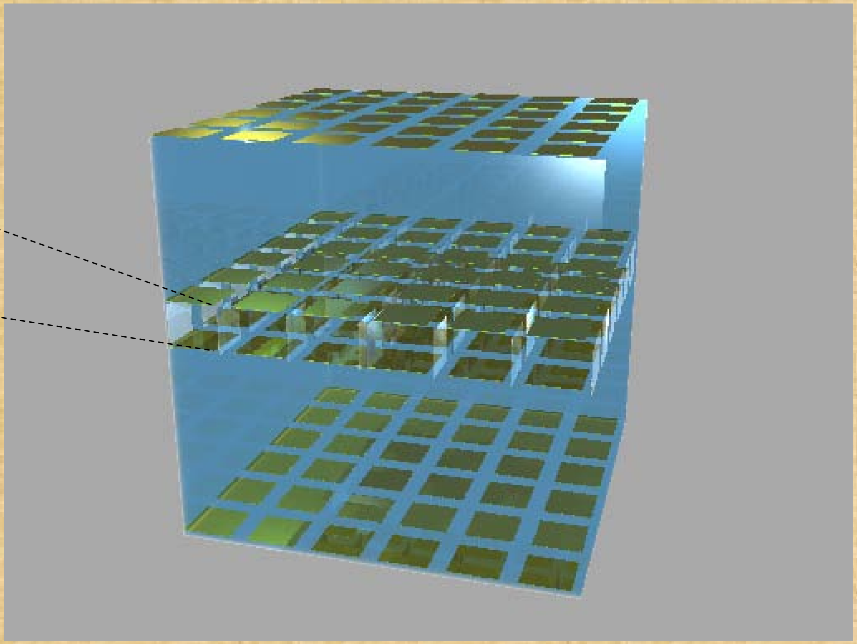


New concept for IPNOS phase-I experiment

InP multi-pixel detector inside of Liquid Xenon.

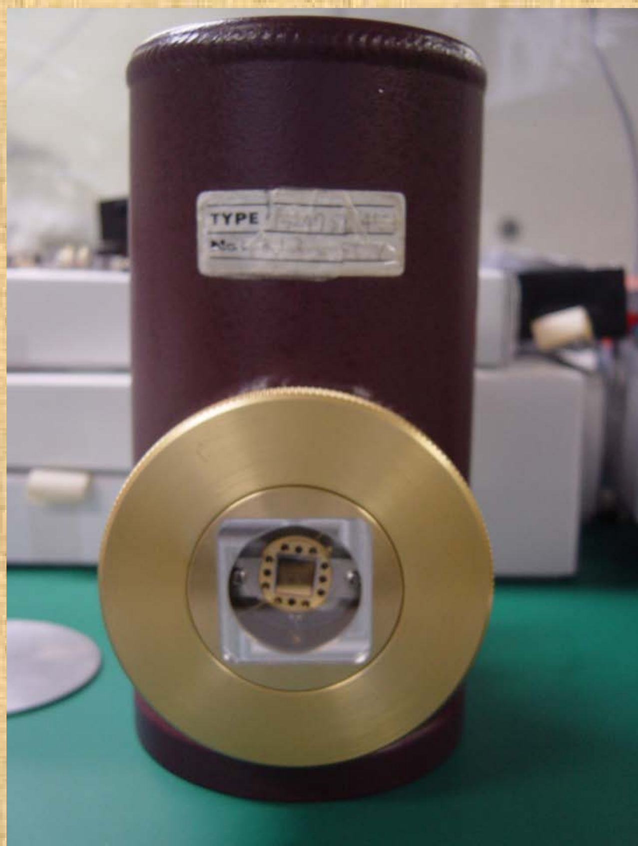
30cm cubic chamber (like XMASS 100kg prototype) includes ~10kg InP detector





Measurement of scintillation light by InP

Transparent window using Sapphire glass

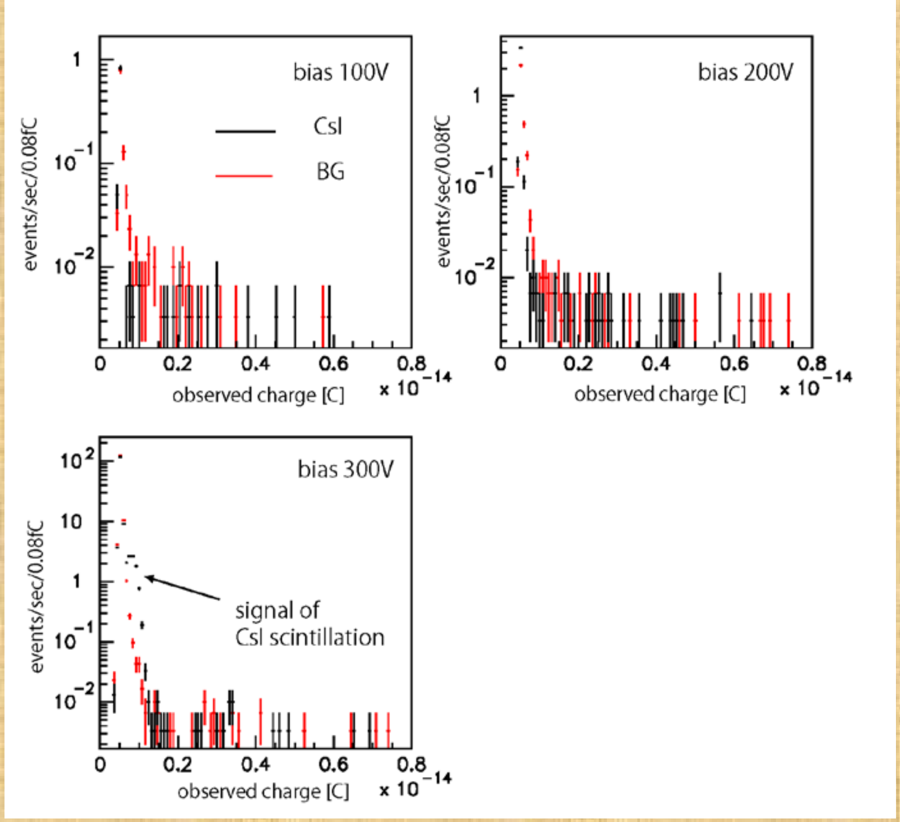


Scintillation from CsI crystal

Spectrum of scintillation light

- Band Gap : 1.35eV

  corresponds to λsci. < 930nm
- InP detector observed signals from CsI : ~1×10^{-15}C
- expected charge : 5×10^{-16}C



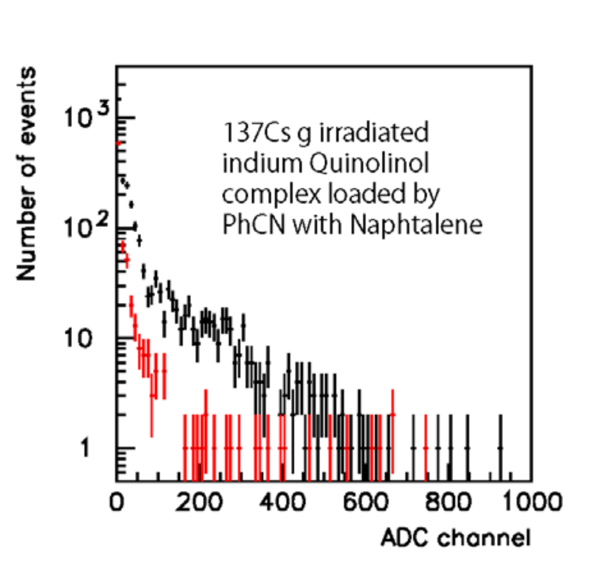
Conclusion

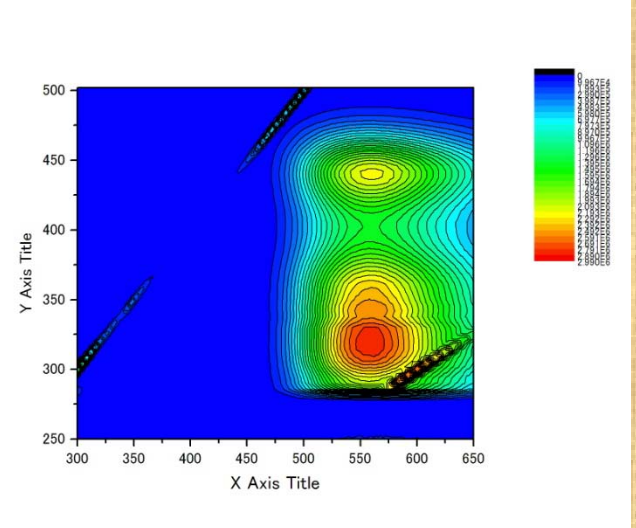
- InP detector observed clear peak of γs
- Induced charge due to drift of carrier (electron and hole) generated by radiation.
- Averaged energy of carrier production : 3.5eV
- Energy resolution : 25% ➡ Vertical Bridgeman method
- No significant backgrounds related to radiative Bremsstralung of ^{115}In ➡ 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
- ✓ Response of scintillation light has been checked byusing CsI. Must detect scintillation light from Liq.Xenon.

Development of indium complex loaded liquid scintillator





- Indium-complex could be solved by organic Liq-scintillator.
- Quinolinol and tropolone ligand have light emission.

Requirement : 10%wt solubility and Energy res. 10%@100keV