

# 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

---

日本物理学会 第58回年次大会

3月29日

宮城教育大学 福田 善之

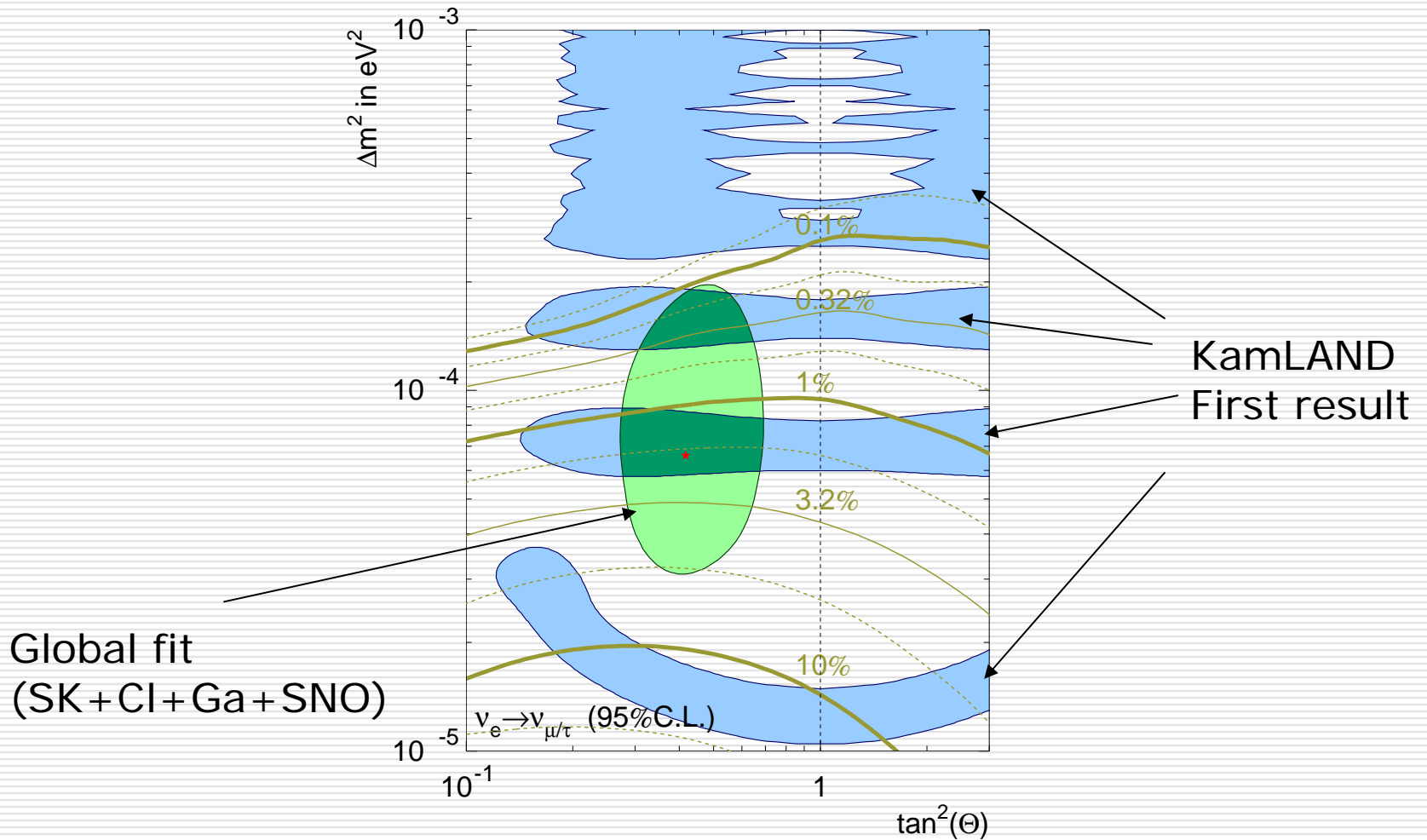
東大宇宙線研 小汐 祐介、森山 茂栄、

塩澤 真人、竹内 康雄

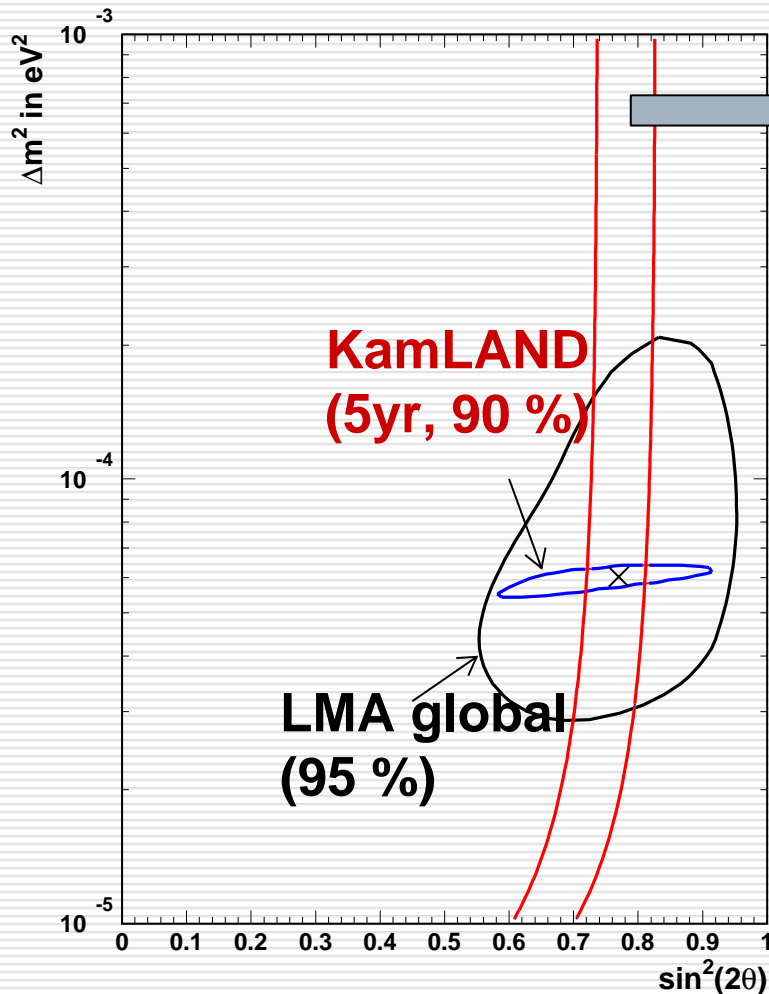
浜松ホトニクス(株) 犬塚 智也

---

# 太陽ニュートリノ振動の現状



# ニュートリノ振動の解の制限



- pp neutrino flux measurement (90 % C.L.) by :
  - 10 ton detector
  - $\nu e$  scattering experiment
  - 5 years data
  - Statistical error + SSM flux error
- Accuracy of mixing angle :  
 $\sin^2 2\theta = 0.77 \pm 0.03$  (stat.+SSM)

Precise determination of oscillation parameters by KamLAND and pp experiments.

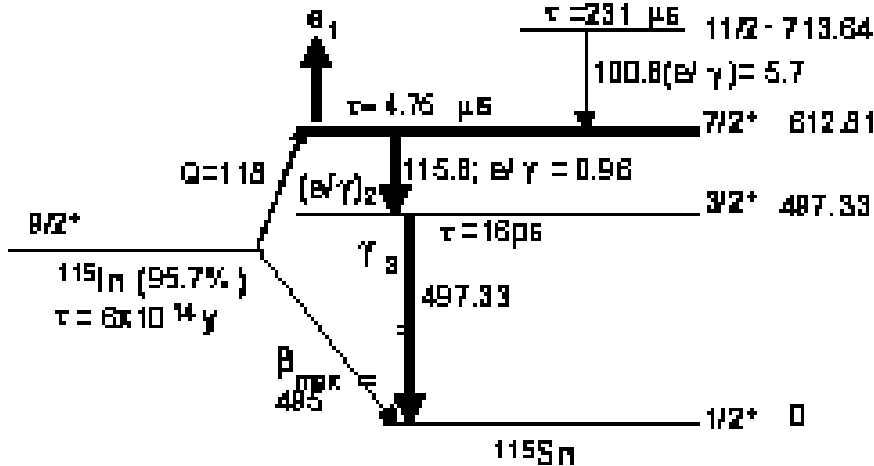
# 太陽ppニュートリノ検出計画の現状

---

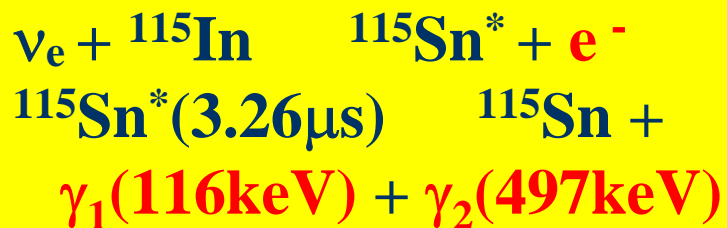
- $\nu_e$  elastic scattering experiment
    - XMASS (Liquid Xe scintillator) [see this conference](#)
    - CLEAN (Liquid Neon scintillator)
    - HERON (Liquid Helium at 50mK + scintillation)
    - TPC (Helium + CH<sub>4</sub> gas chamber)
    - Genius (Ge detector in LN<sub>2</sub>)
    - .....
  - $\nu_e$  charged current experiment
    - LENS (indium loaded liquid scintillator)
    - SIREN (<sup>160</sup>Gd loaded liquid scintillator)
    - MOON (<sup>100</sup>Mo)
    - .....
-

# インジウムによる太陽ニュートリノの検出

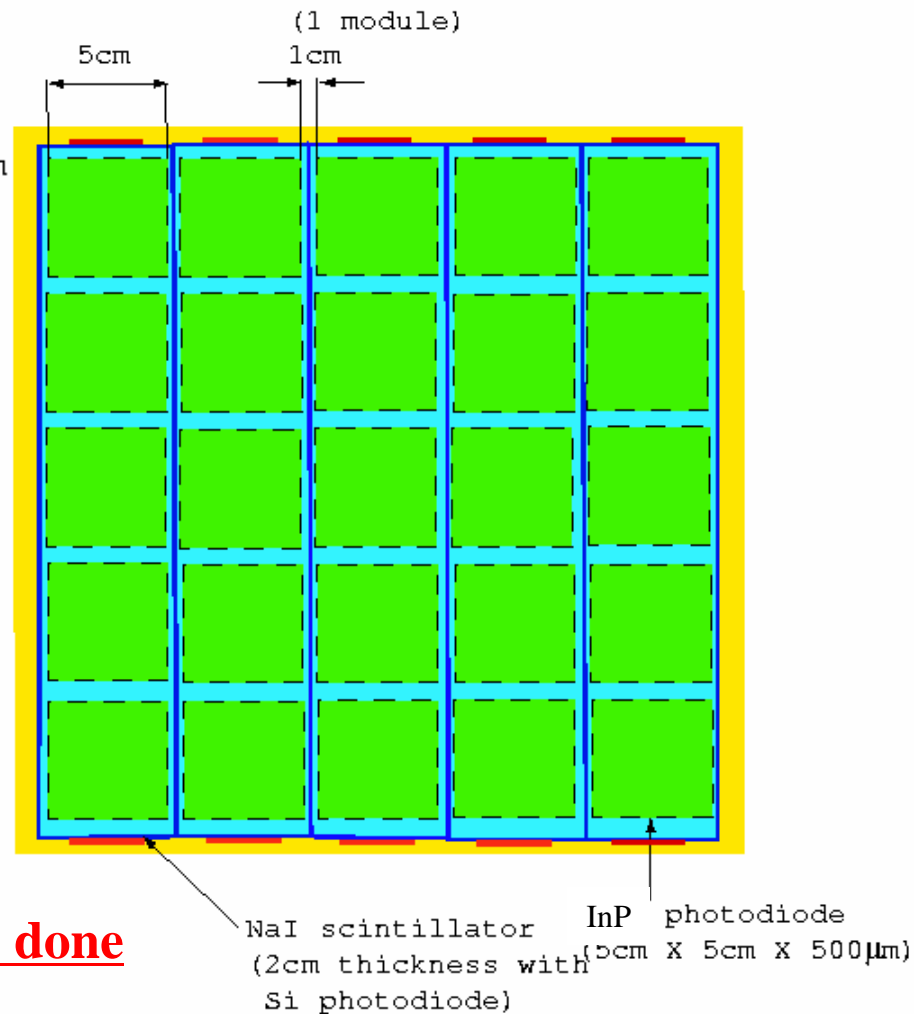
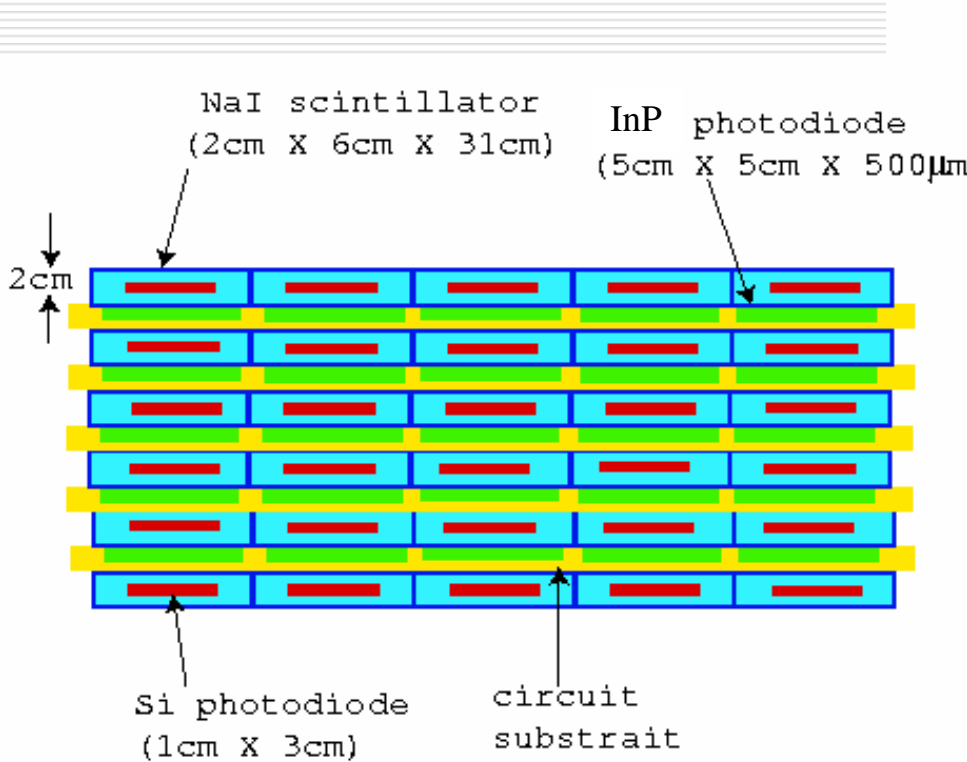
R.S.Raghavan Phs.Rev.Lett37(1976)259



- Real-time measurement
- $\nu$  energy measurable ( $E_e = E_\nu - 125\text{keV}$ )
- 3 fold coincidence to extract neutrino signal
- $\beta$ -decay from  $^{115}\text{In}$  ( $\tau_{1/2} = 6 \times 10^{14}\text{yr}$ )
- Correlated chance coincidence-Bremsstrahlung
- Correlated chance coincidence impurities



# InP solid state detector for solar neutrino measurements

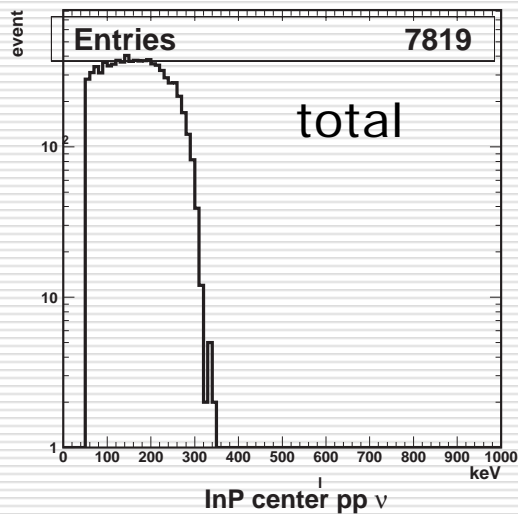
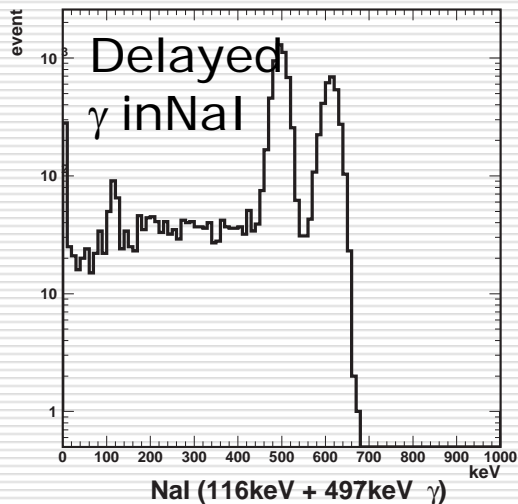
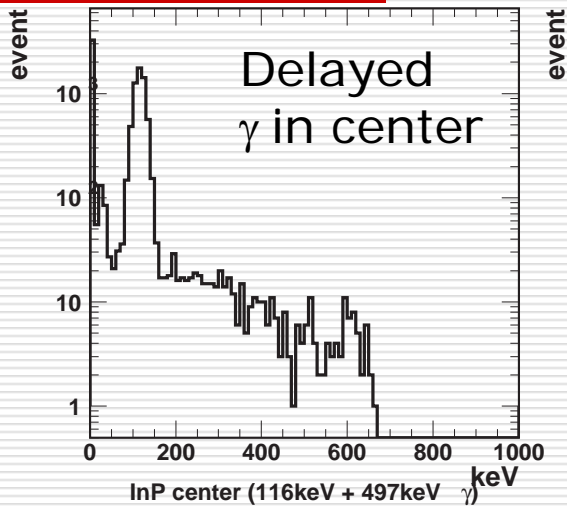
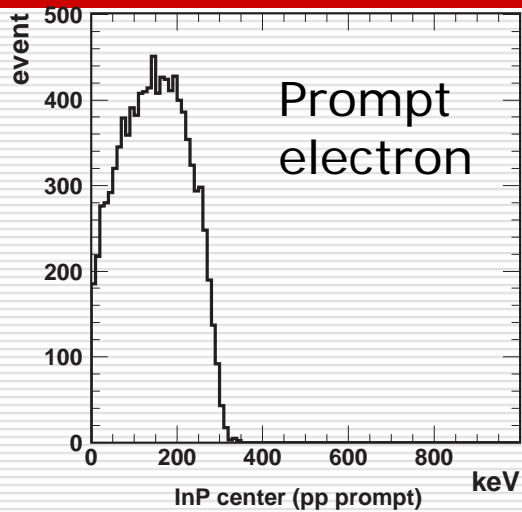


High energy resolution, high granularity  
High speed read out, No quenching

**High BG reduction could be done**



# InP検出器による太陽ppニュートリノシグナルのシミュレーション



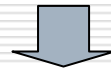
Efficiency  $\sim 80\%$

# Semi-Insulating (SI) InP検出器

---

## < 特徴 >

- well established material
- $\langle A \rangle \sim 80.2$  (same as Ge/GaAs)
- band gap 1.34eV (can be used in RT)
- high resistance  $(0.5 \sim 0.94) \times 10^8 \cdot \text{cm}$
- fast movirity  $2000 \sim 2200 \text{ cm}^2 / \text{V} \cdot \text{s}$



## バルク型の検出器の可能性

**8cm in radius + 500 $\mu\text{m}$  in thickness 48.2g**

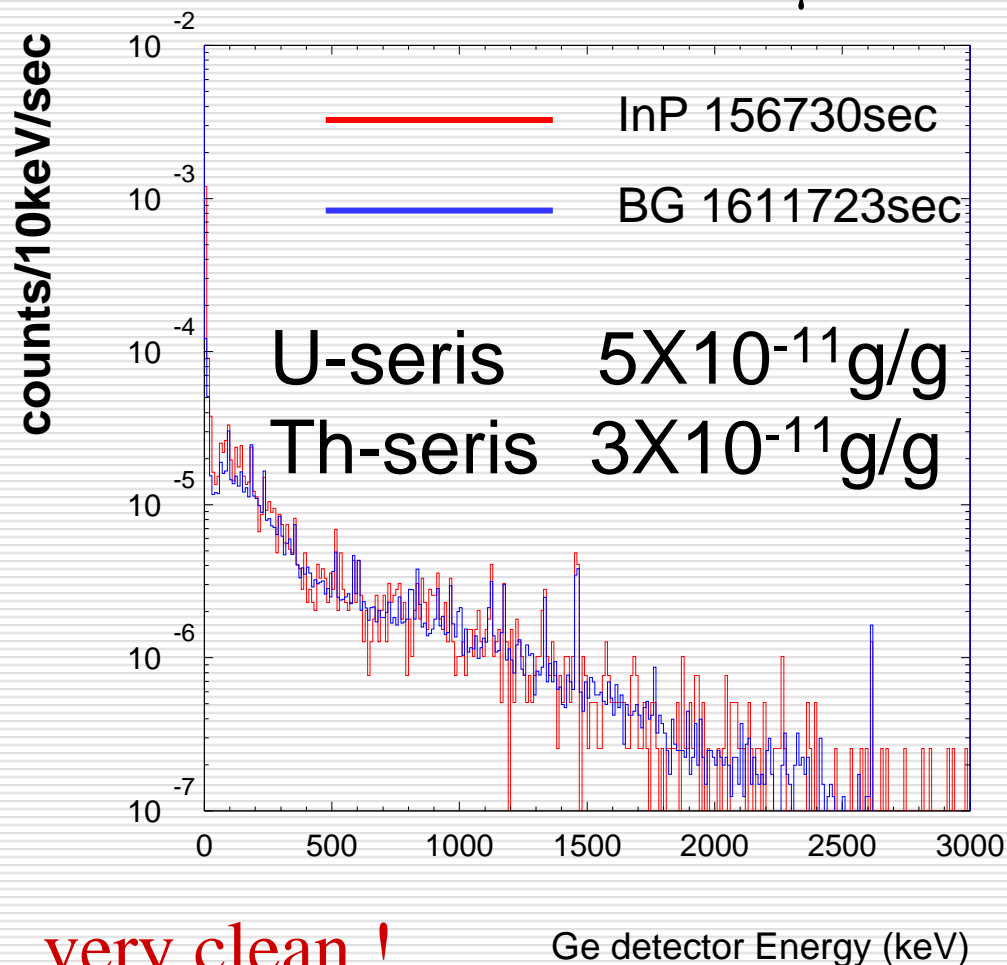


InP 5ton can capture **0.5ppve / day 100,000 units**



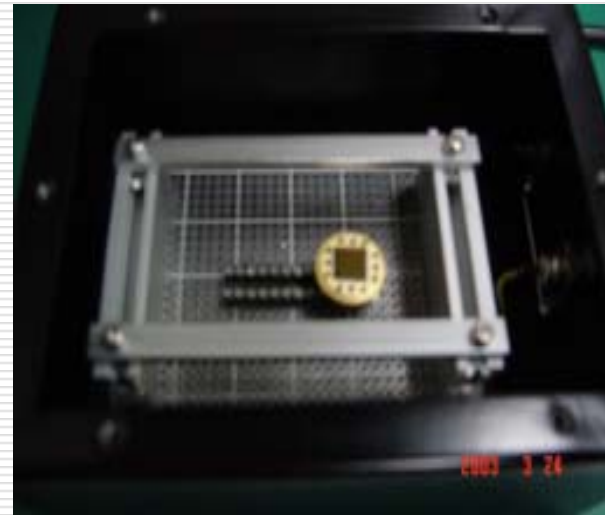
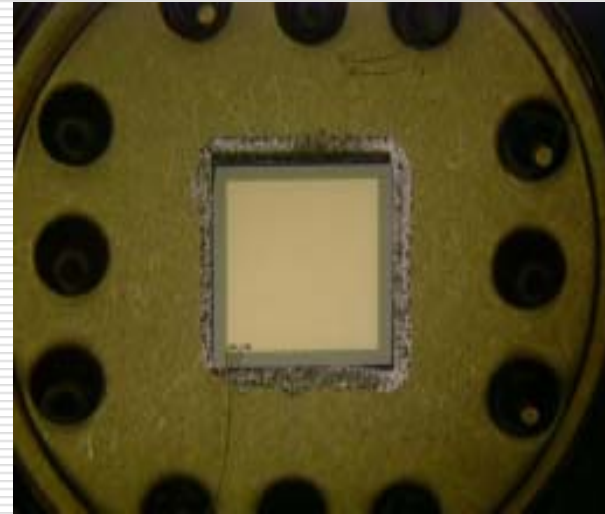
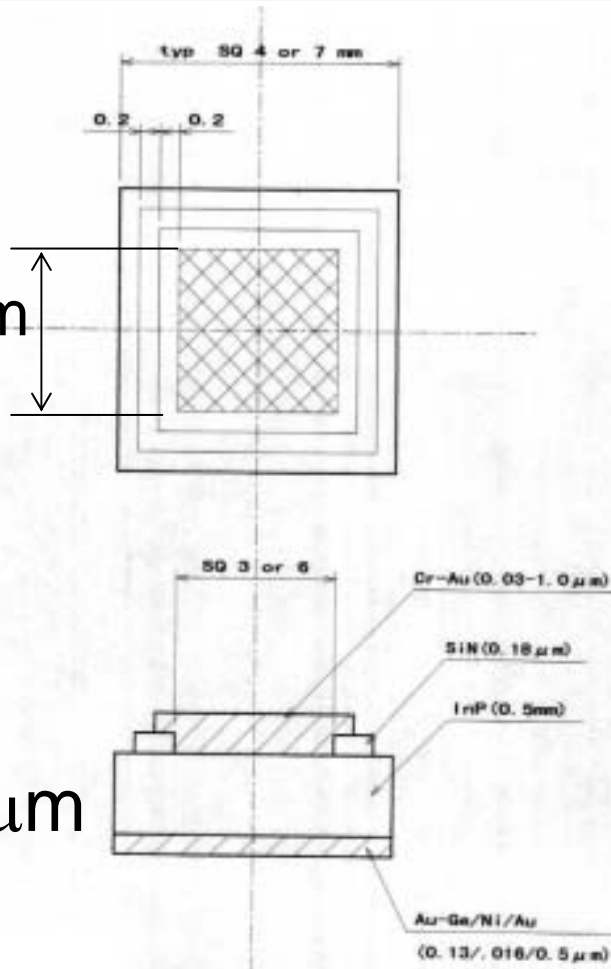
# Semi-insulating InP基盤のU/Thバックグラウンド

diameter 5cm thickness 450 $\mu$ m mass 1.5g



# InP SI proto-type 検出器

3mm or 6mm

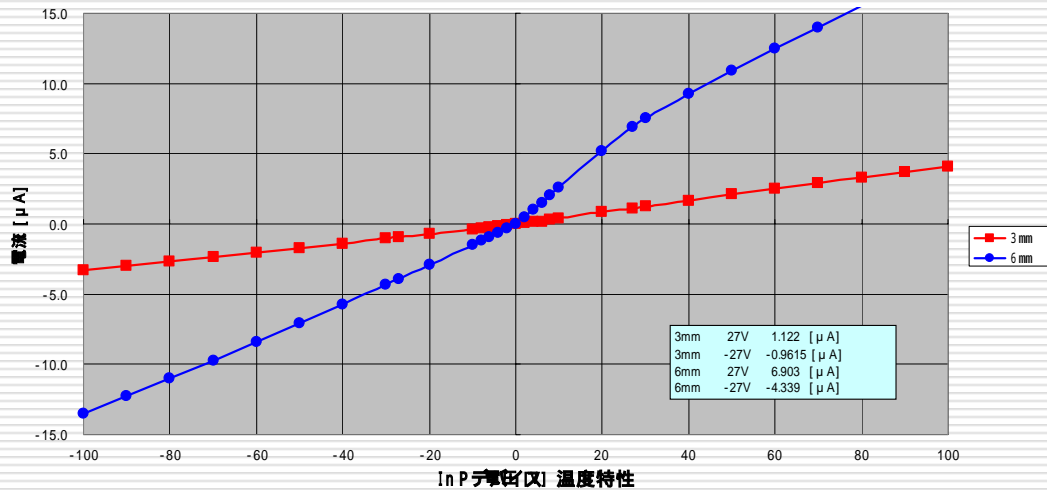


$D=450 \pm 25 \mu\text{m}$

( presented by Hamamatsu photonics )

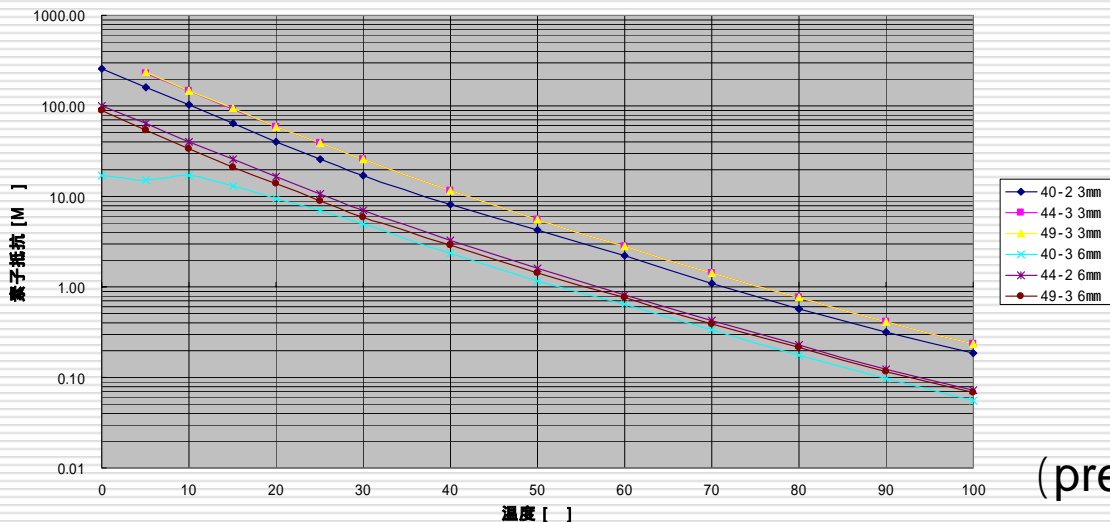
# 半導体特性の評価

InPデバイス V-I特性 25



Dark current can be reduced by lowering the temperature.

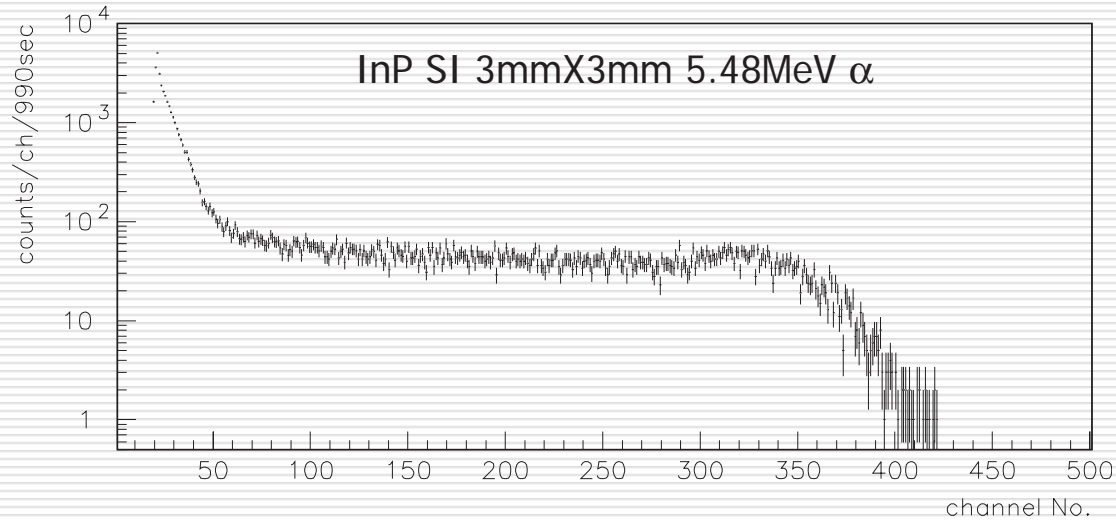
$$I[A] = T^{2/3} \exp(-E_g / 2k_B T)$$



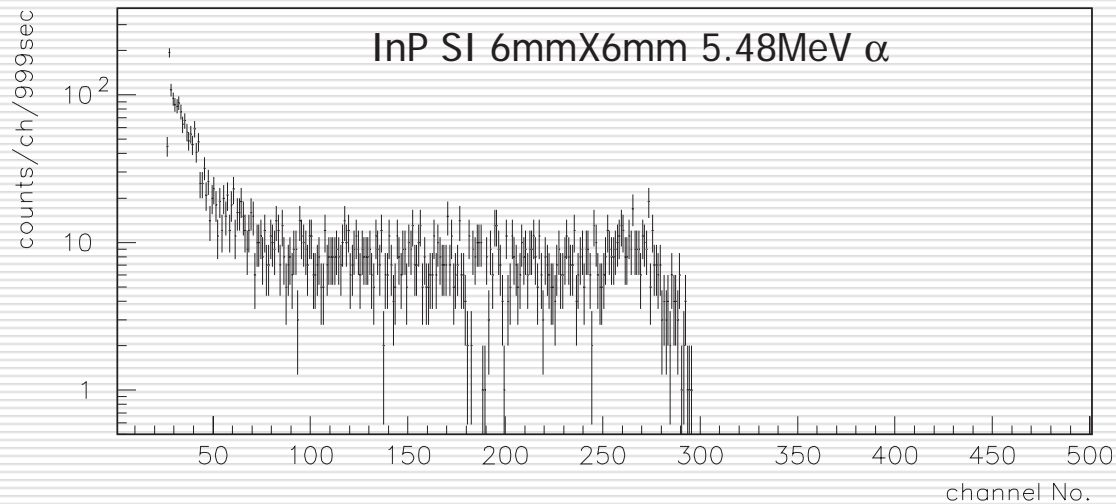
0.018μA for 6mm InP @ 100V and -40degree

(presented by Hamamatsu Photonics)

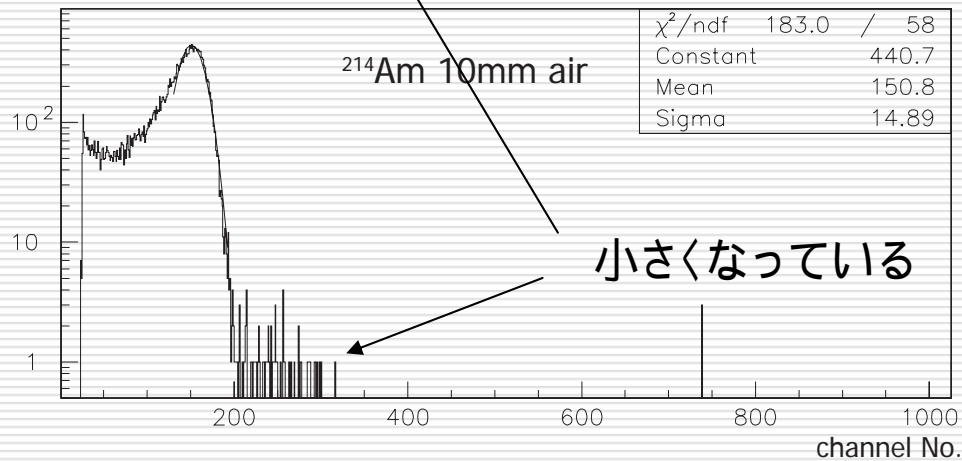
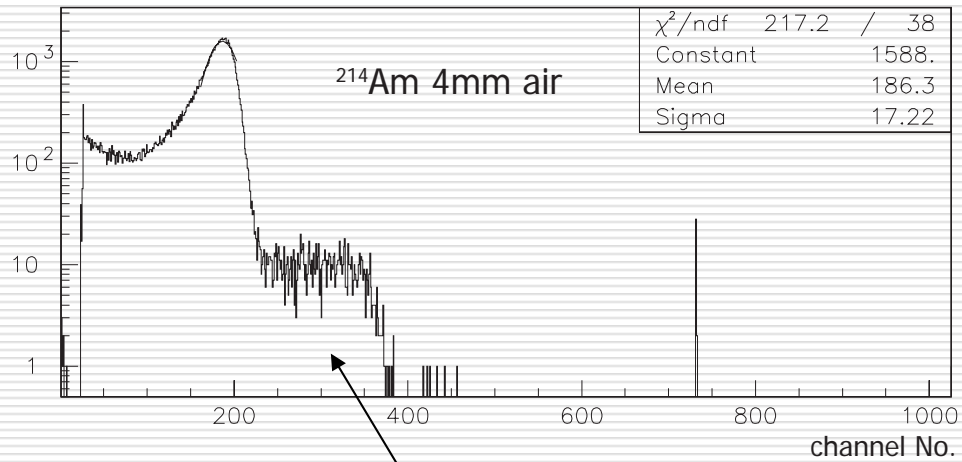
# 放射線( $\alpha$ 線) に対する反応



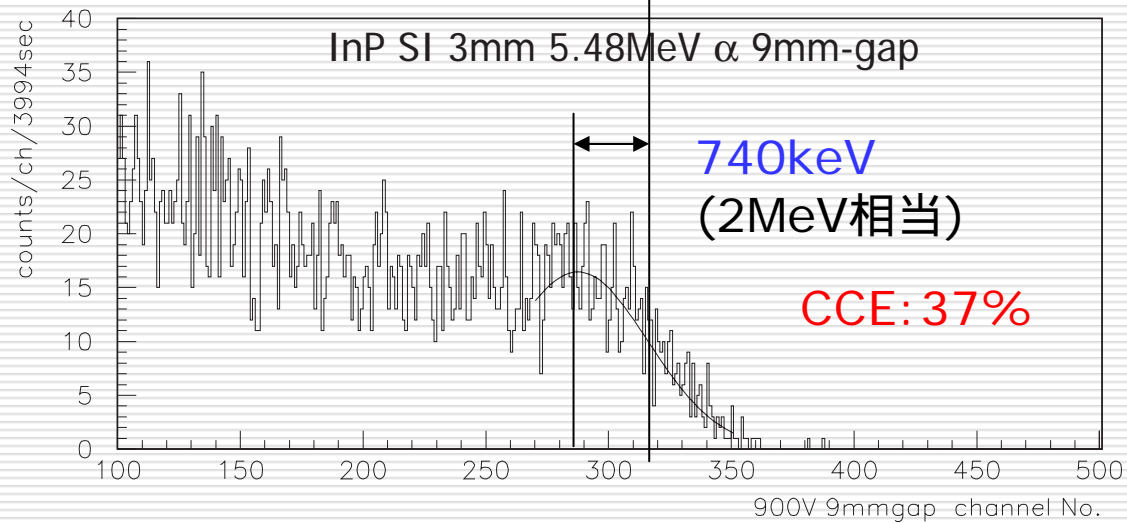
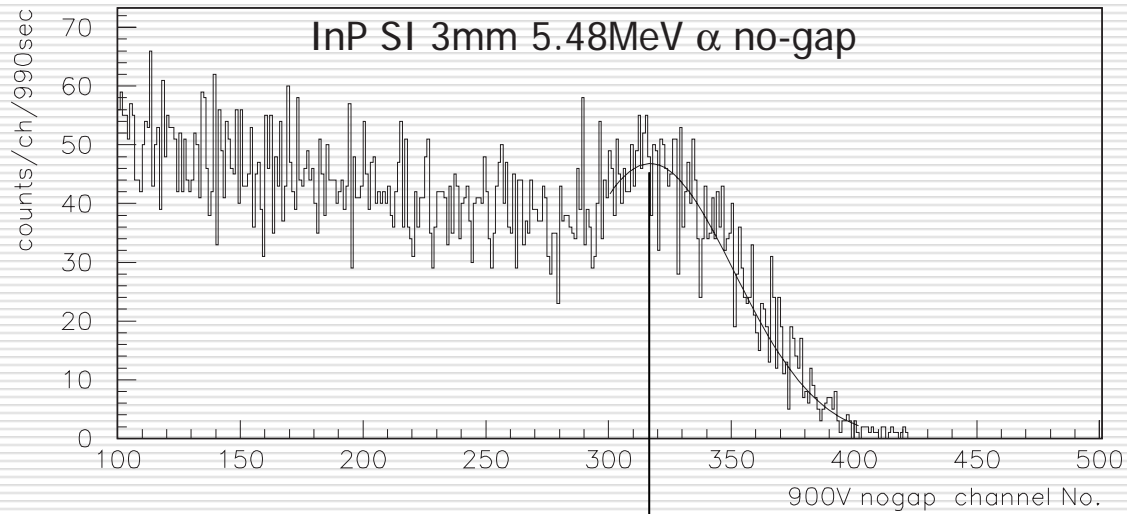
$\alpha$ 線の信号は見えて  
いるが、single peak  
は見えない。



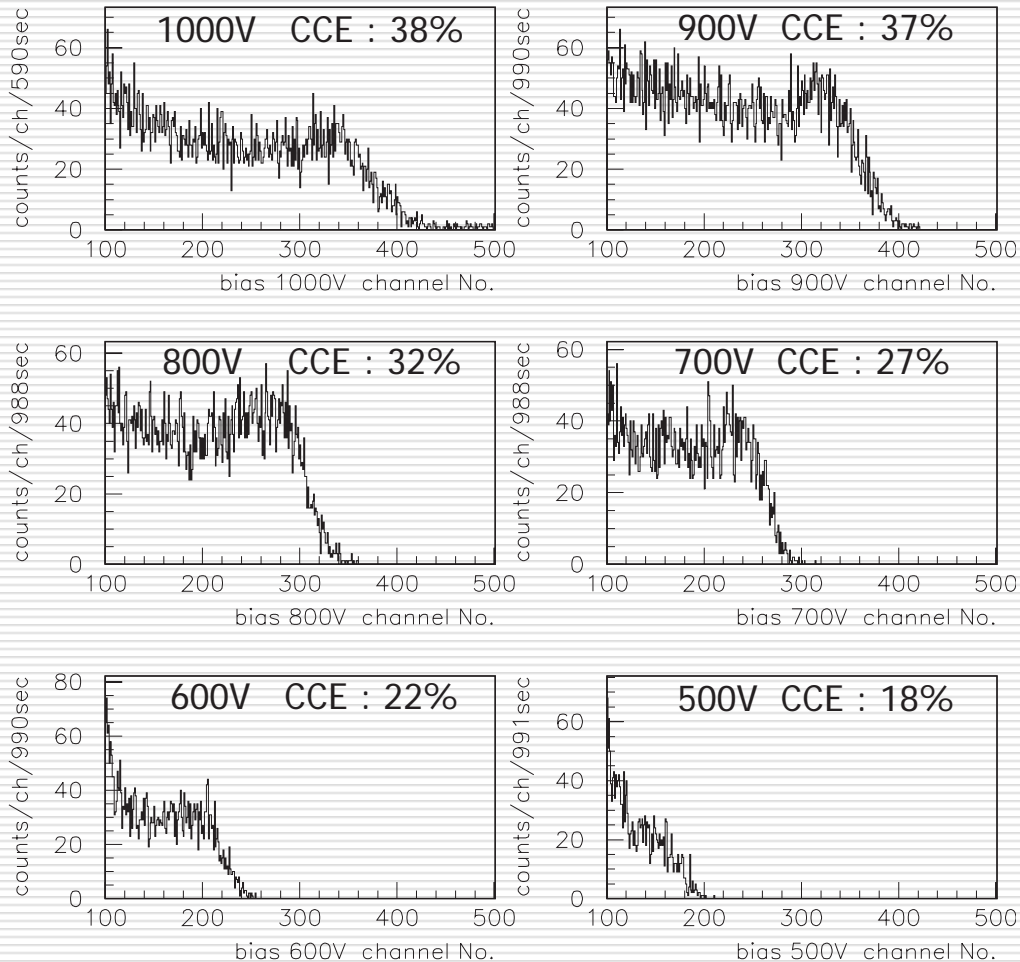
# シリコン検出器による $^{241}\text{Am}$ $\alpha$ 線スペクトル



# キャリブレーション



# 電荷収集効率 (Charge Collection Efficiency)



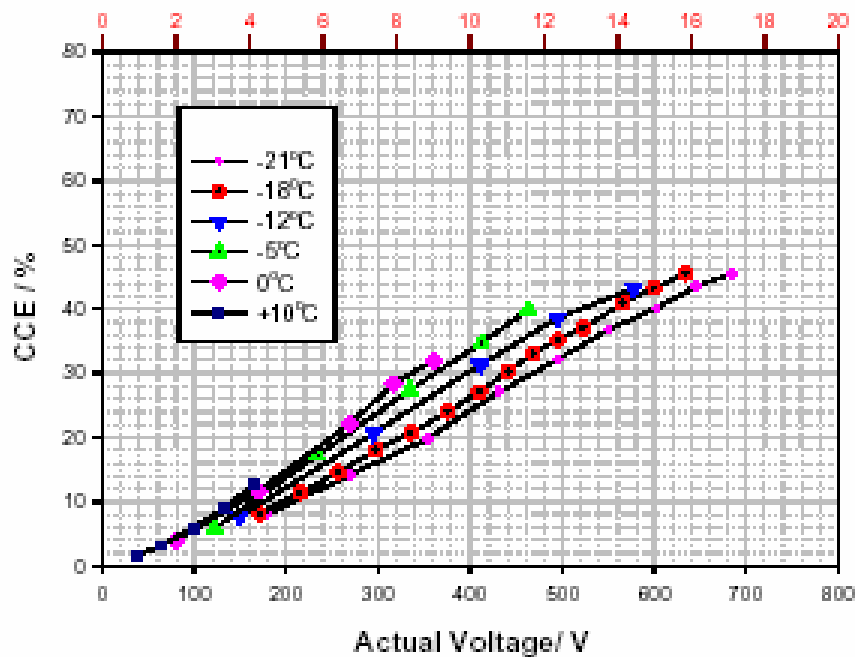
electron/hole pair production energy for InP : 4.2eV

# UKグループの結果と比較

[H.El-Abbassi et al., NIMA 466\(2001\)47](#)

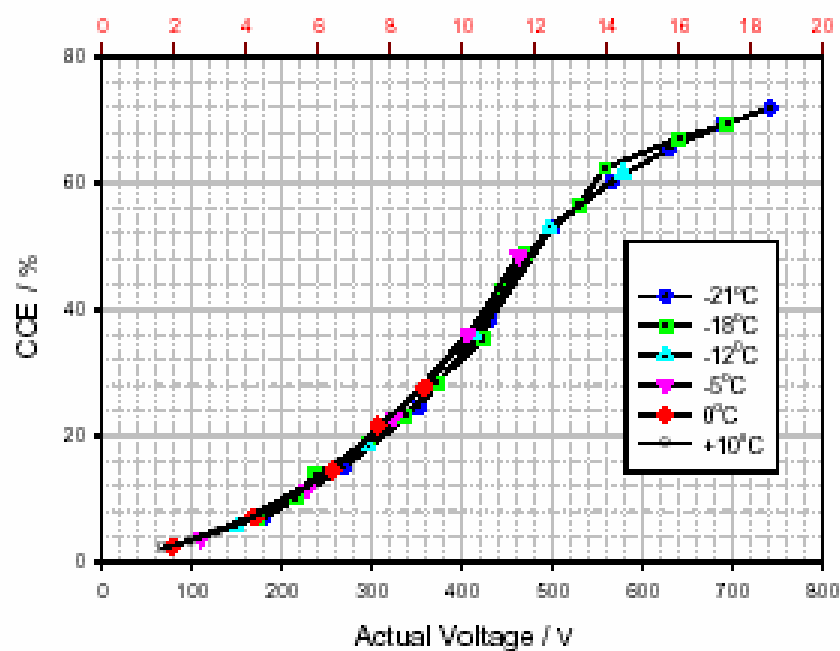
+ve bias (hole drift)

Electric Field kV/cm



-ve bias (electron drift)

Electric Field kV/cm



UKグループに対しCCEは半分程度  
厚さが関係しているか？



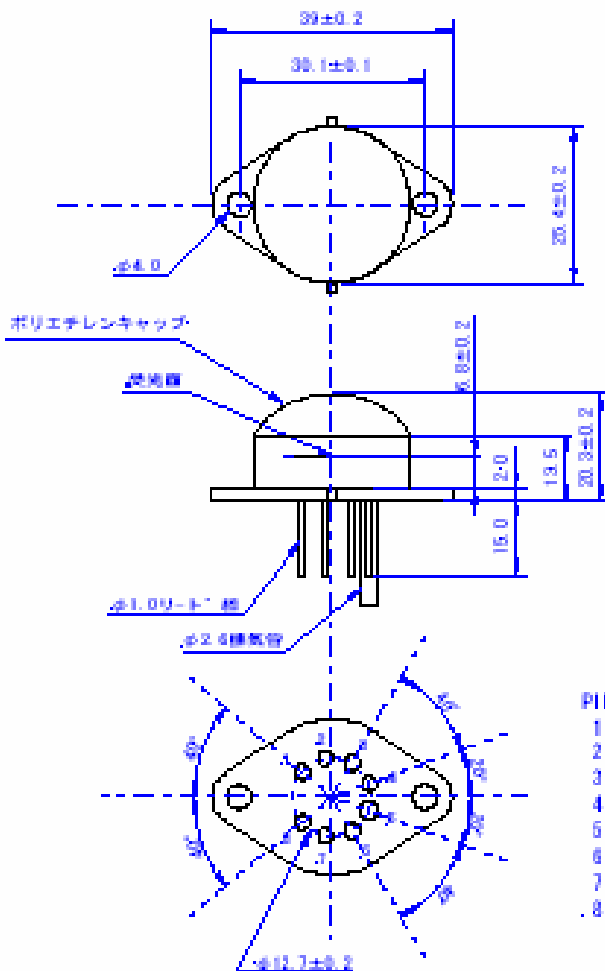
# 結論と今後の計画

---

- 3mmと6mm角のInP SI検出器を制作
  - $^{241}\text{Am}$ からの5.48MeV  $\alpha$ 線によるsingle peakは観測できなかった
  - 電荷収集効率(CCE)は最大でも約37%
  - $^{137}\text{Cs}$ からの662keV  $\gamma$ 線は観測できなかった。CCEが良くないためと思われる
  - 高いバイアス電圧を印可するため、素子を冷却する
  - ショットキ型3mm/6mm検出器の性能を見る(開発中) cf 38.5mm<sup>2</sup>X140 $\mu$ mが最大 NIMA458(2001)400
  - 3cm角プロトタイプ検出器を制作(今年度開発予定)
-

# ペルチェ冷却型InP SI半導体検出器

外形図 (単位: mm)



Pin No.

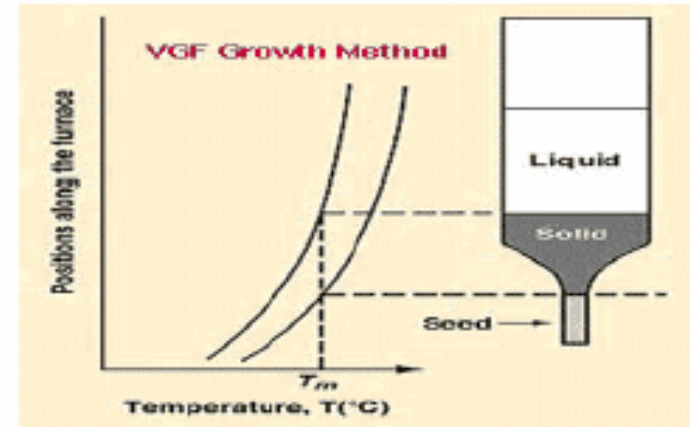
- 1 - InP(-) 素子表面
- 2 - InP(+) 素子表面
- 3 - thermistor
- 4 - thermistor
- 5 - 排気管
- 6 - cooler (-)
- 7 - cooler (+)
- 8 - NC



# Vertical Gradient Freeze (VGF) Technique

Comparison of VGF, LEC and HB growth method

	VGF	LEC	HB
SI Wafers	Yes	Yes	No
SC Wafers	Yes	No	Yes
EPD (Crystal Defects)	V. Low	High	Low
Stress	Low	High	Medium
Uniformity	Good	Fair	Poor
Diameter Scale Up	Good	Good	Poor



specifications as given by AXT

resistivity	$1.1 - 2.2 \times 10^7 \Omega\text{cm}$
mobility	2600-2700 $\text{cm}^2/\text{Vs}$
thickness	$350 \pm 25 \mu\text{m}$
Fe concentration	