InP crystal

Solid state detector using indium for pp/^{7}Be solar neutrino measurement

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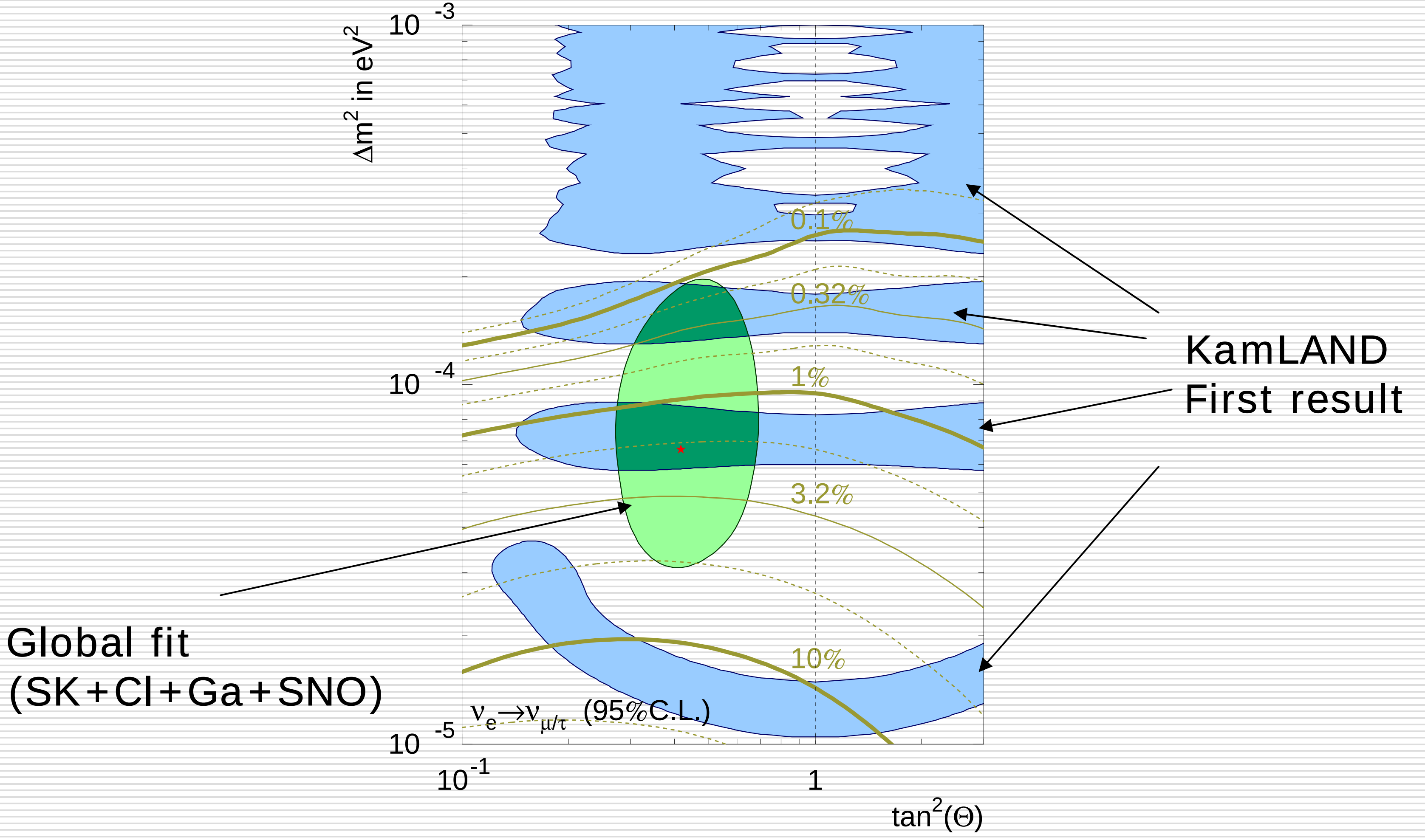
Status of Solar Neutrino Oscillation

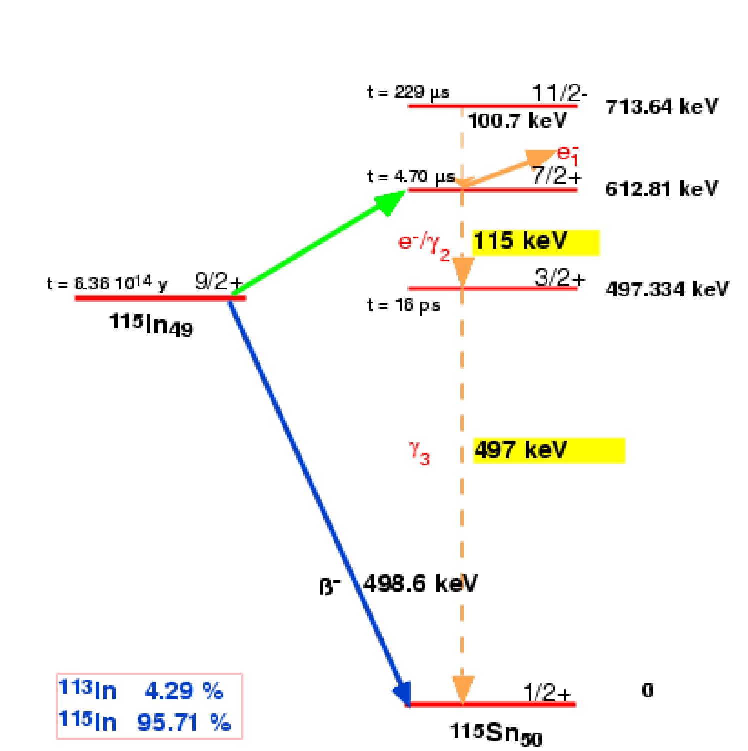


Projects to detect low energy solar neutrinos

- ν_e elastic scattering experiment
  - XMASS (Liquid Xe scintillator)
  - CLEAN (Liquid Neon scintillator)
  - HERON (Liquid Hellium at 50mK + scintillation)
  - TPC (Hellium + CH_4 gas chamber)
  - Genius (Ge detector in LN_2)
  - ……
- ν_e charged current experiment
  - LENS (In/Ye loaded liquid scintillator)
  - SIREN (^{160}Gd loaded liquid scintillator)
  - MOON (^{100}Mo)
  - …..

Neutrino capture using indium and their advantages

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



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

${}^{115}\mathrm{Sn}^*(4.70\mu s) \rightarrow {}^{115}\mathrm{Sn} +$

$\gamma_1(115\mathrm{keV}) + \gamma_2(497\mathrm{keV})$

- Real-time measurement
- ν energy measurable ($E_e=E_\nu$-114.2keV)
- 3 fold coincidence to extract neutrino signal
- β–decay from ^{115}In ($\tau_{1/2}=6\times10^{14}$yr)
- Correlated chance coincidence-Bremsstrahlung
- Correlated chance coincidence impurities

History of InP SSD development

- Y.Suzuki et al., Indium Phosphide solid state detector NIMA 275(1988)142

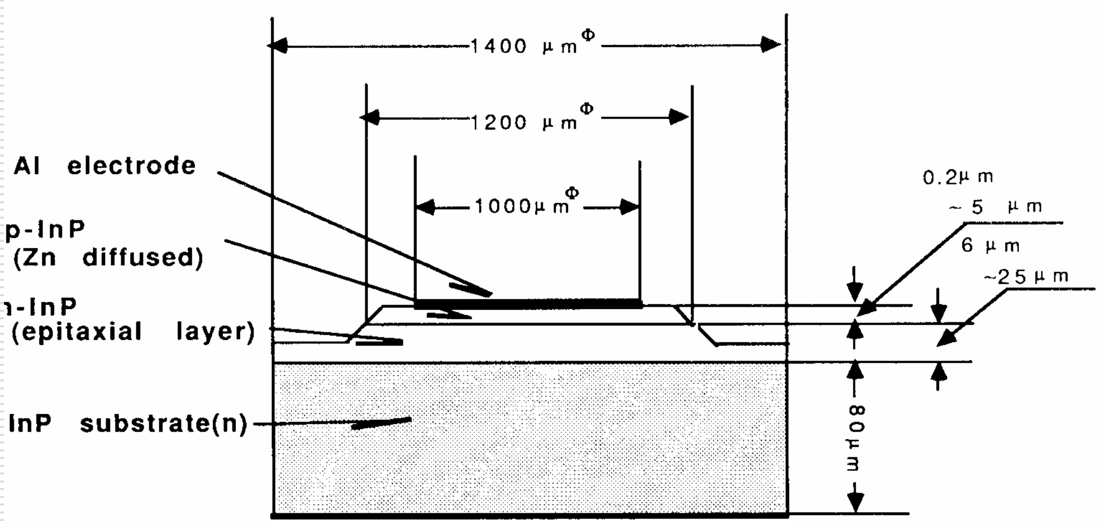


Fig. 1. Schematic view of the InP photodiode.

CCE is 60% for α particle and 76% for 60keV γ-ray

Detector size is small (limited by an epitaxial growth)

Current status of InP SSD development

- H.El-Abbassi et al., NIMA 466(2001)46

  VGF semi-insulating Fe-doped InP bulk detector

  CCE~72% for 5.46MeV alpha particle

- F.Dubecky et al., NIMA487(2002)27

  VGF SI InP with Schottky electrodes

  volume 0.25mm^3 CCE~82% with 14% (FWHM) of resolution for 60keV gamma

- A.Owens et al., NIMA 487(2002)435

  SI Fe-doped InP detector for X-ray measurement

  size 3mmx3mmx180mm P^+ contact

  2.5keV (FWHM) for 5.9keV and 12keV for 88keV of resolution at -60 degree

Semi-Insulating (SI) InP detector

- well established material
- <A> ~ 80.2 (almost same as Ge/GaAs)
- band gap 1.34eV (can be used in RT)
- high resistance (0.5～0.94) x 10^8 Ω·cm
- fast mobility 2000～2200 cm^2／V·s

⇩

Possible work as bulk type detector

cf. 10cm x 10cm **x** 500μm in thickness 24g

⬇

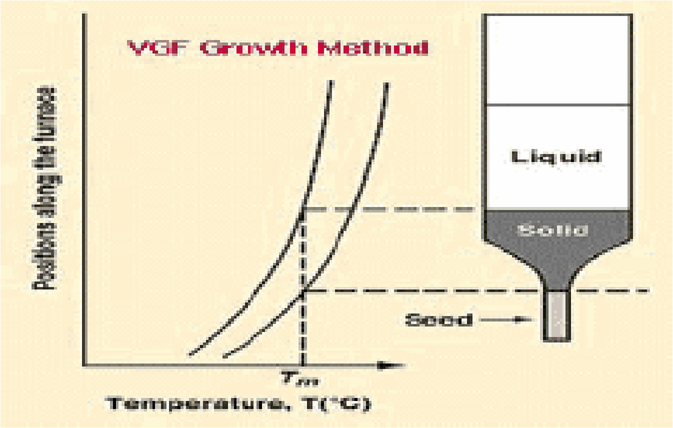
In 2ton would capture 0.5ppν_e／day **→**~100,000 units

InP crystal made by Vertical Gradient Freeze (VGF)

H.El-Abbassi *et al*., NIMA 466(2001)47

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

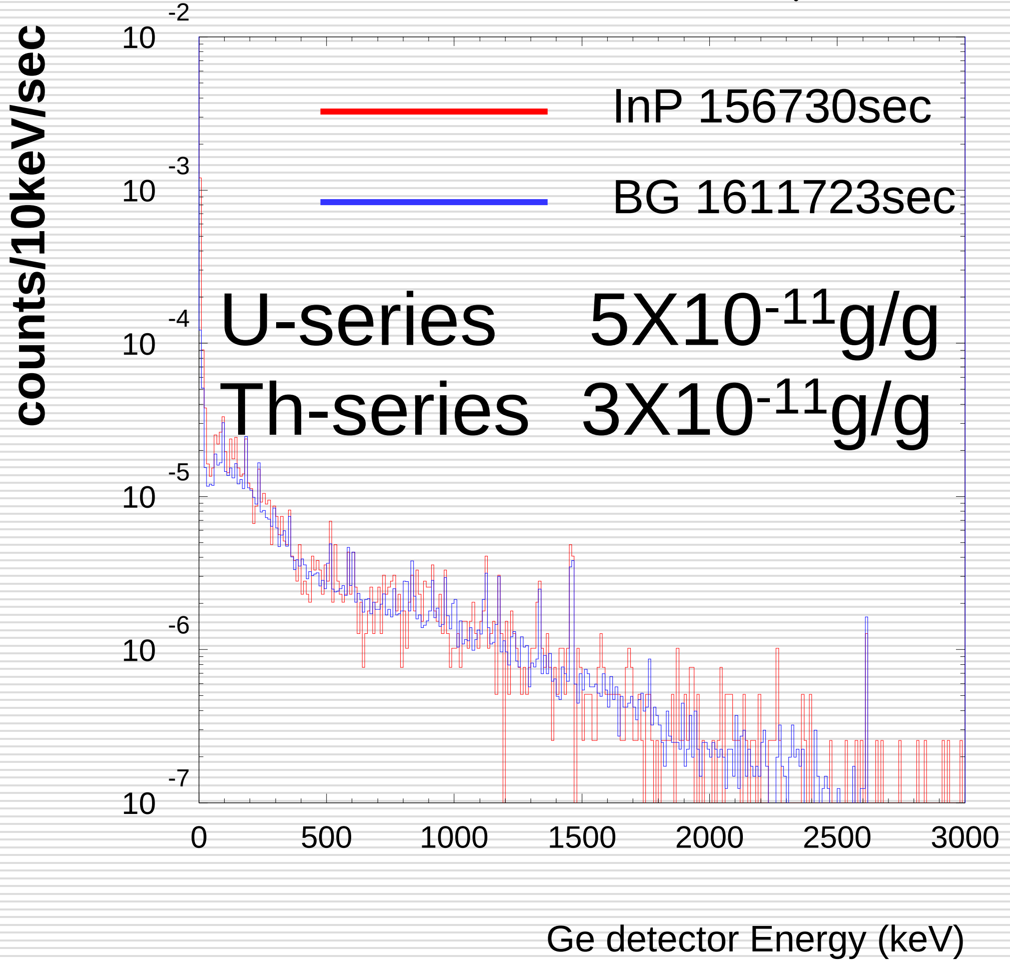


specifications as given by AXT

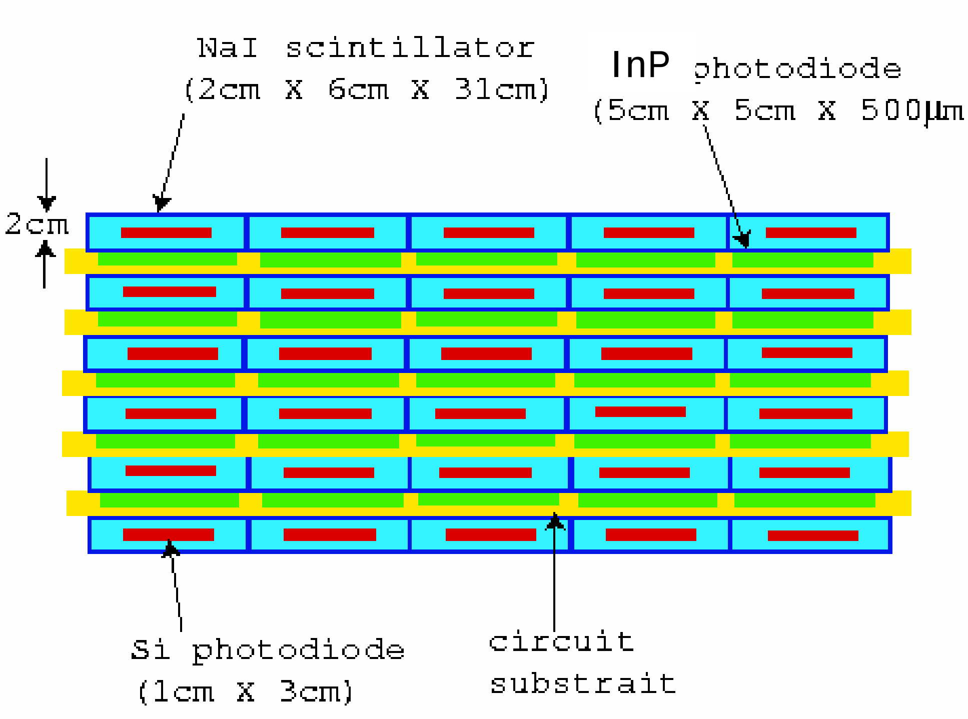
resistivity	1.1 – 2.2 x 10^7 Ωcm
mobility	2600-2700 cm^2/Vs
thickness	350±25 μm
Fe concentration	

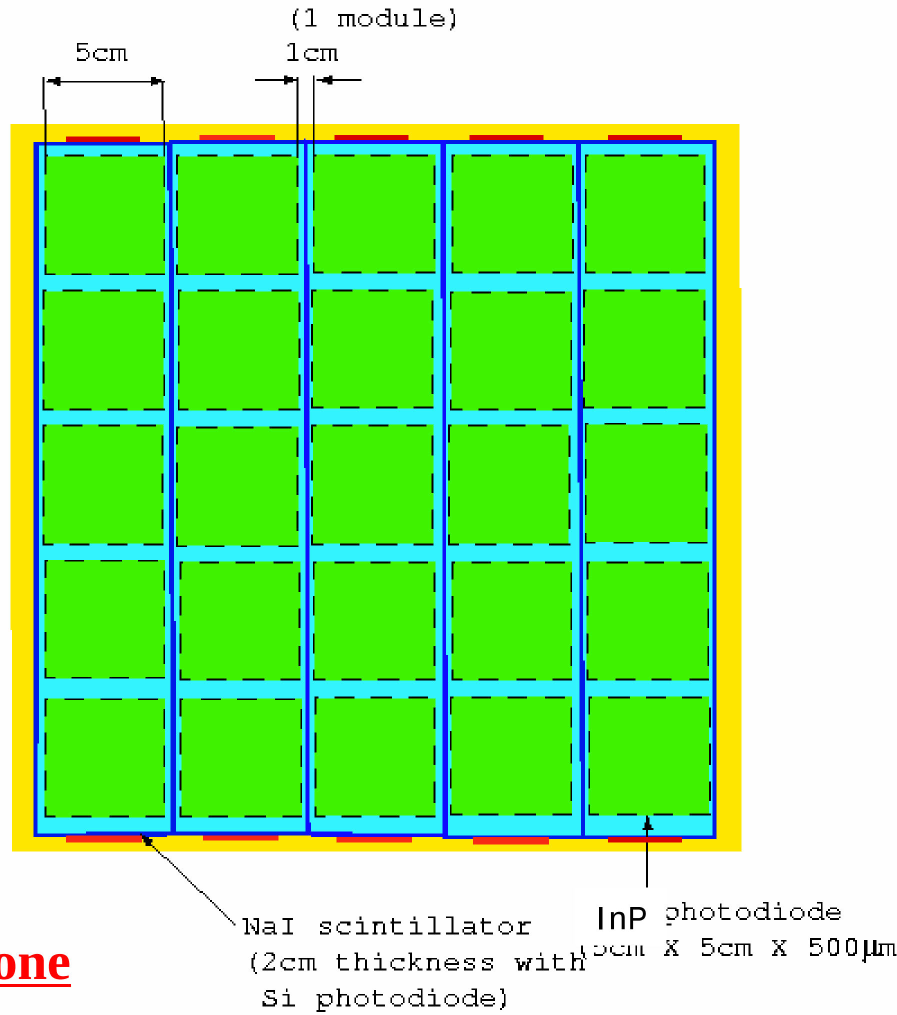
Background measurement of SI InP substrait

diameter 5cm thickness 500μm mass 1.5g



Basic idea of InP solid state detector for solar neutrino measurements

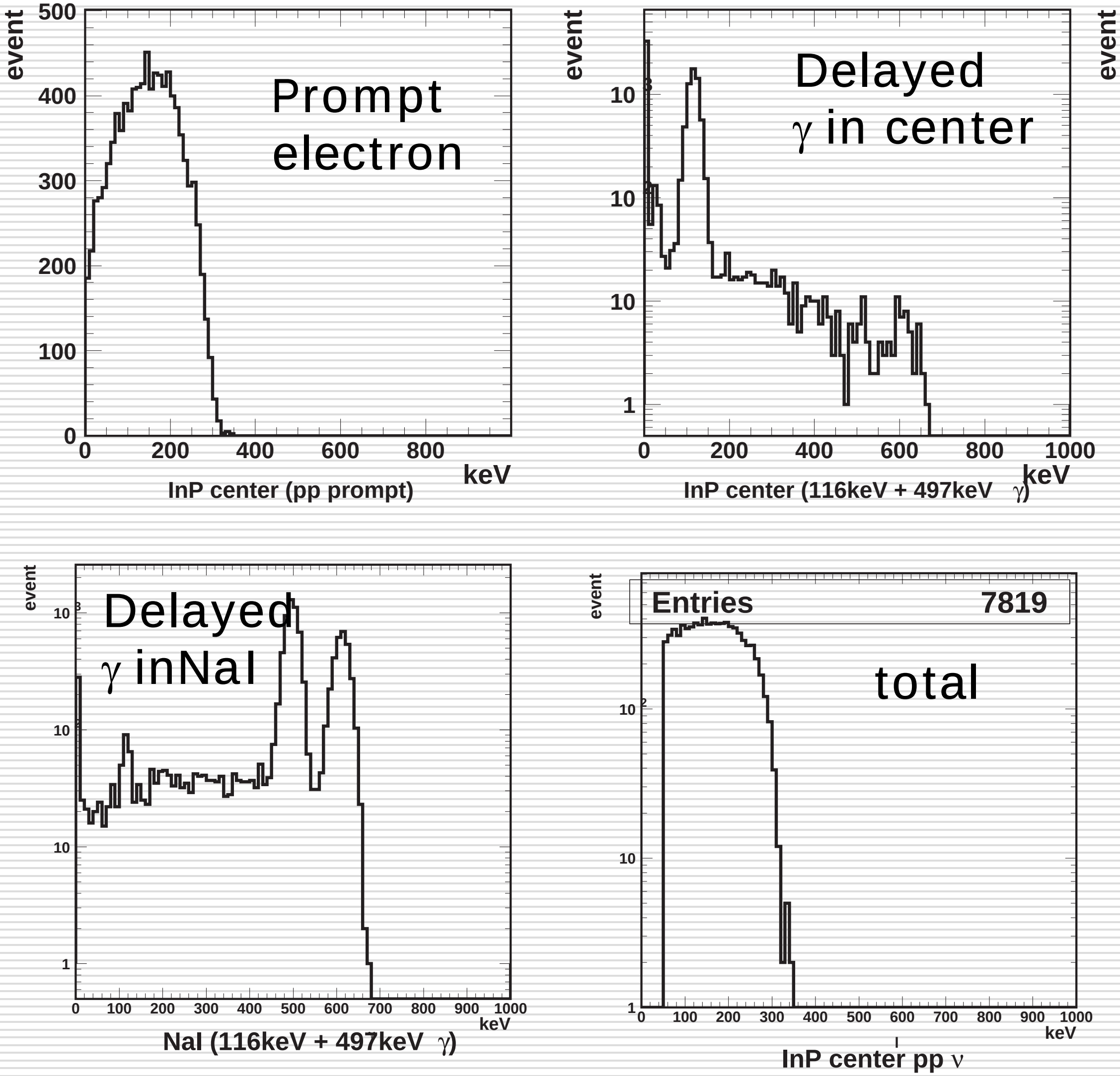




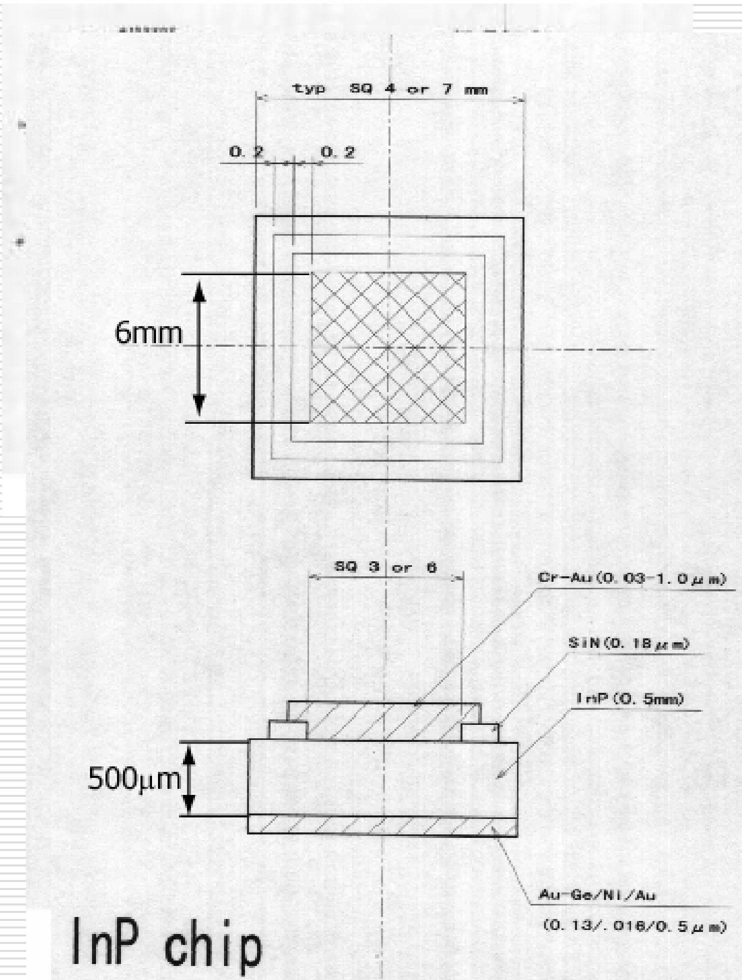
High energy resolution, high granularity
High speed read out, No quenching

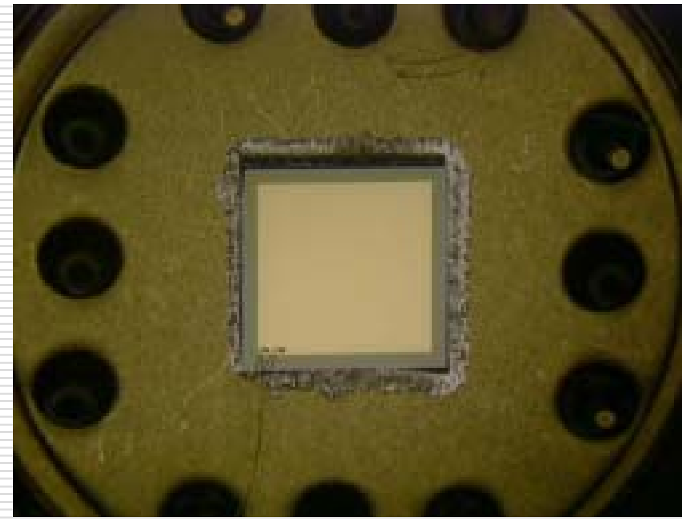
→ **High BG reduction could be done**

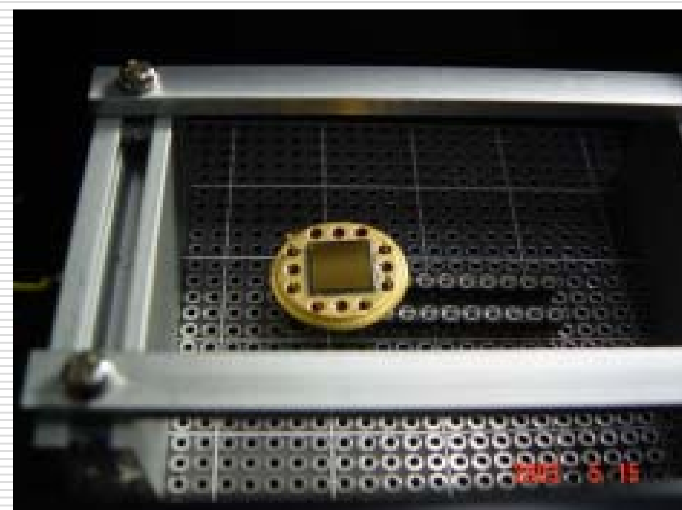
Monte Carlo signal simulation



InP SI proto-type detector (phase-I)

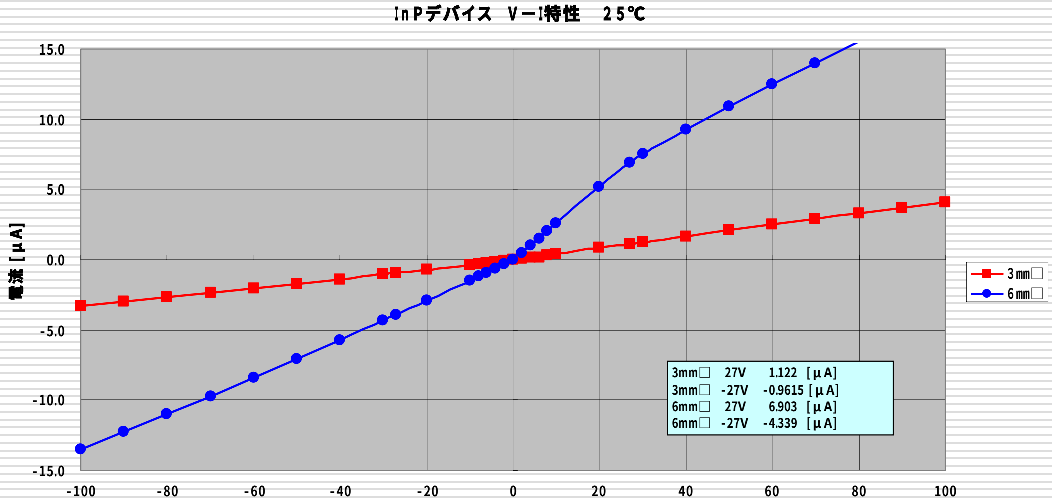


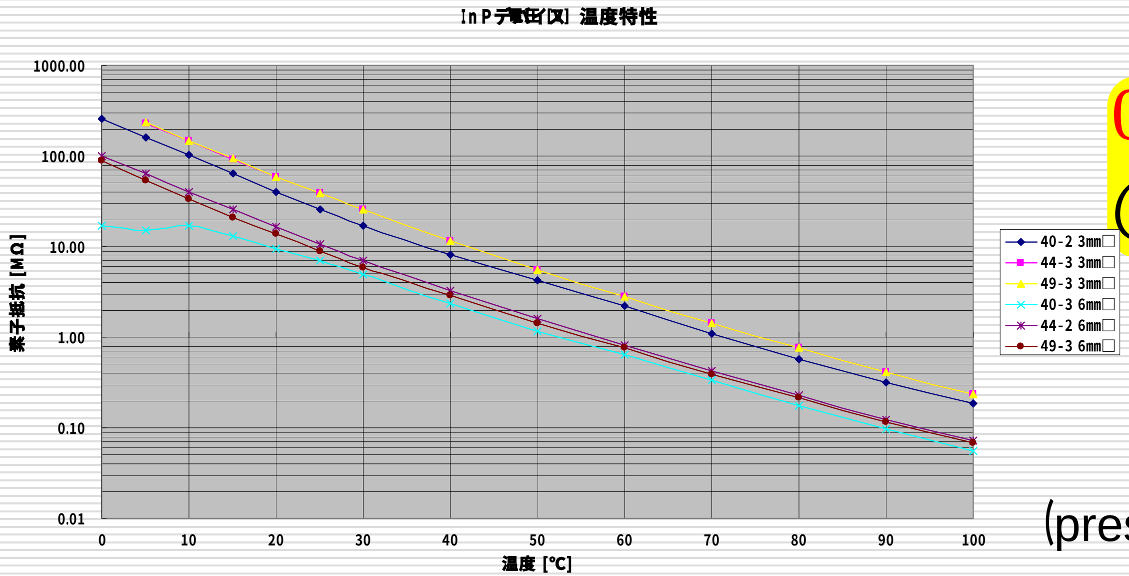




（presented by Hamamatsu photonics）

Property of proto-type detector





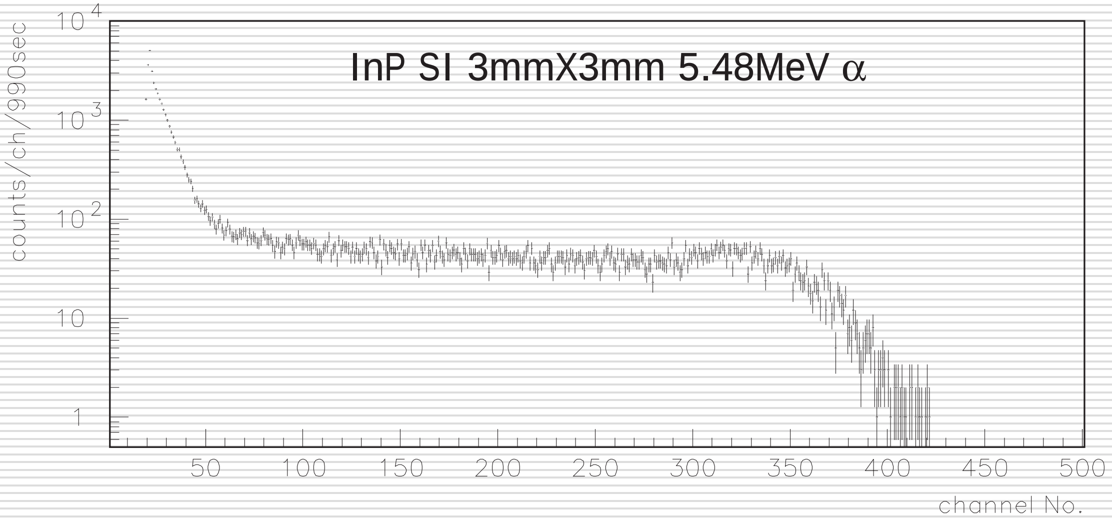
Dark current can be reduced by lowering the temperature.

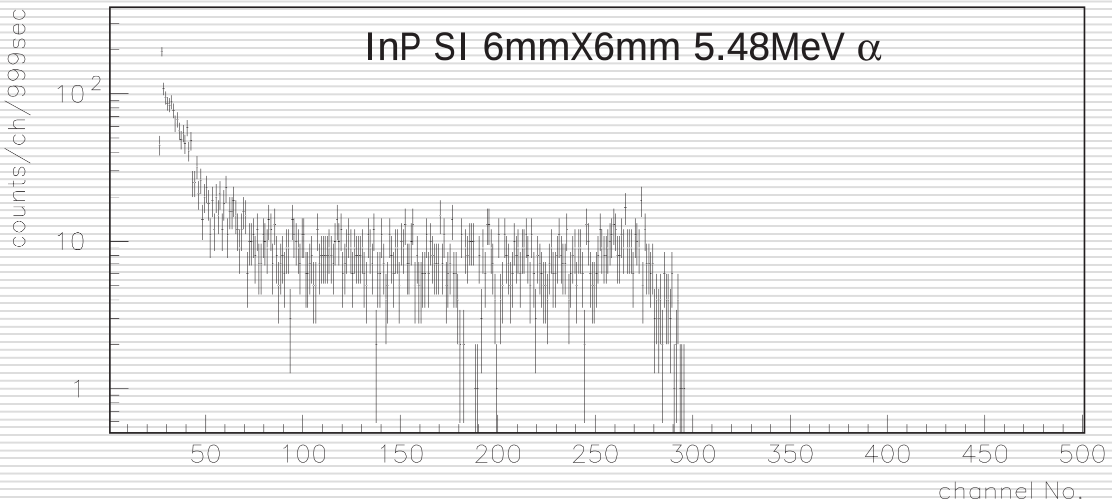
$$I[A]=T^{2/3}\exp(-E_g/2k_BT)$$

0.018μA for 36mm^2 InP @100V and -40degree

(presented by Hamamatsu Photonics)

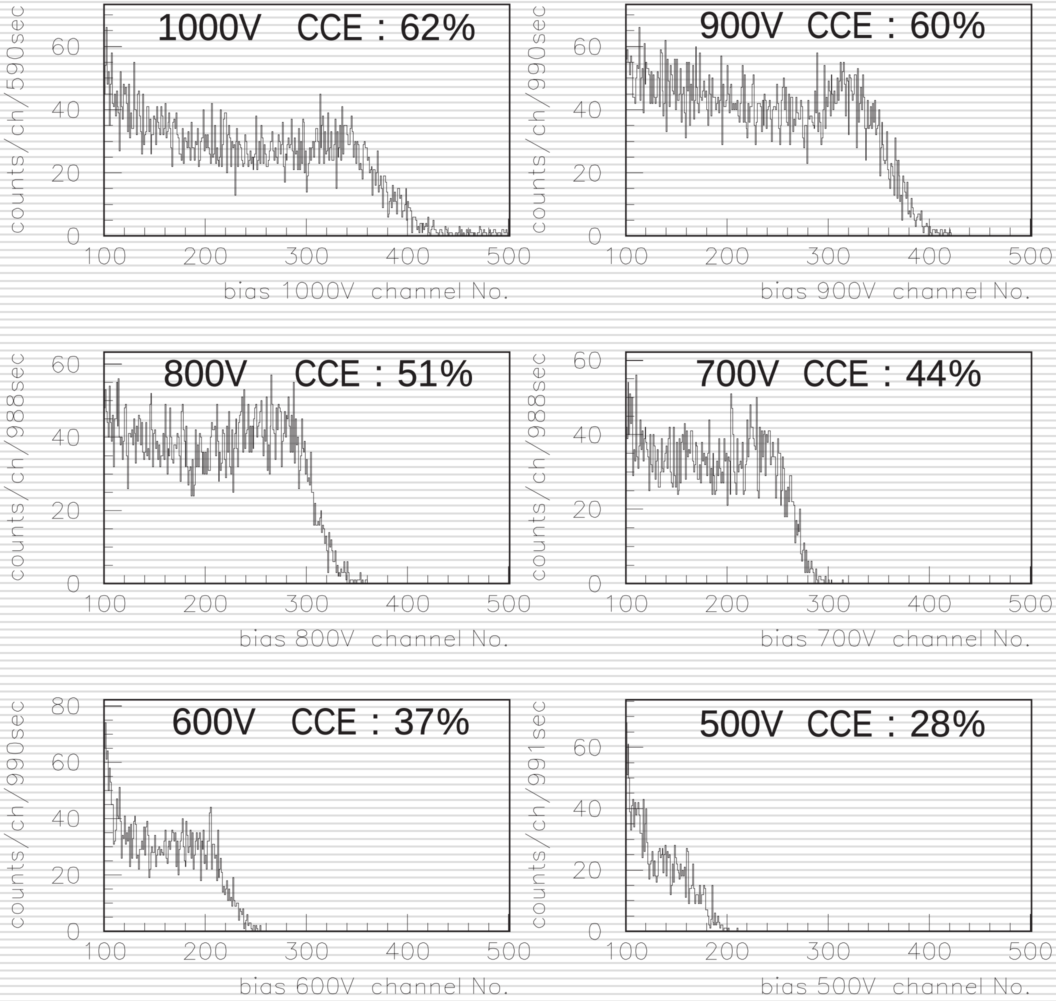
Response for alpha particle





signal could be seen, however no single peak

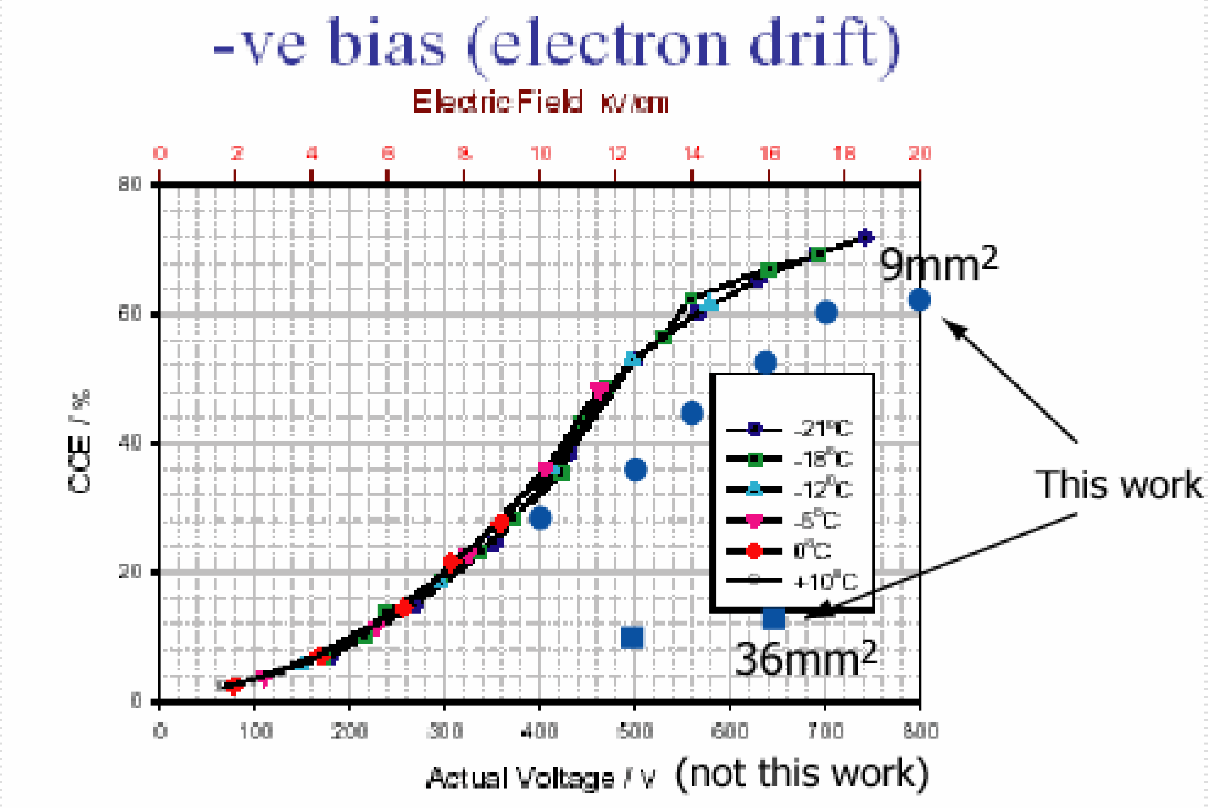
Charge Collection Efficiency



electron/hole pair production energy for InP : 4.2eV

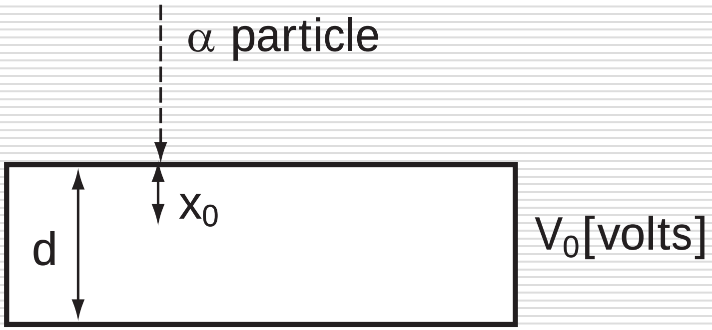
Comparison with UK group

H.El-Abbassi *et al.*, NIMA 466(2001)47



Maximum CCE is obtained by 60% for 9mm^2 InP (but 13% for 36mm^2 InP)

Explanation of CCE for SI InP



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 α particle

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

average length $L=\tau v=\mu\tau V_0/d$ τ : carrier lifetime [s]

$\mu\tau$ is measured by H.El-Abassi et al. NIMA466(2001)47

$\mu\tau = 5 - 8 \times 10^{-7}$ [cm^2V^{-1}] (@-21 to 19 degree)

Thus $L=5\times10^{-7}[cm^2V^{-1}] \times 1000[V]/500[\mu m]$
$=0.01$ [cm] >> x_0 (~16μm in InP 4MeV α)

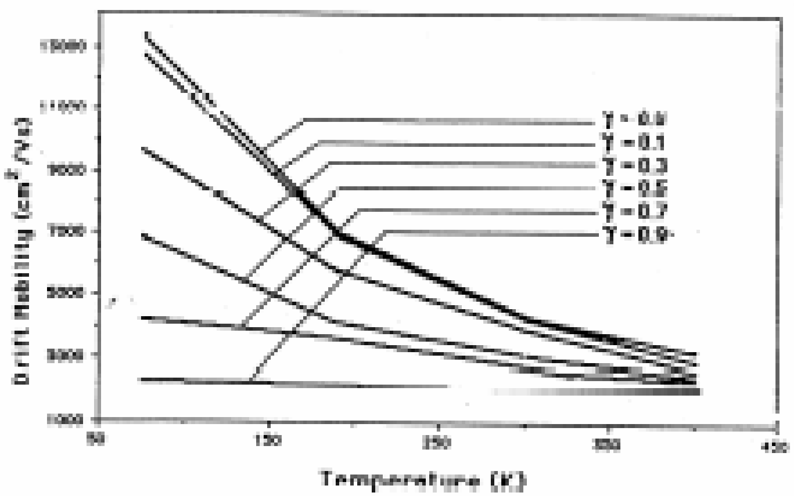
Howeve, it means not enough for the entire volume
to collect all charge

How to get higher CCE

For full depletion of detector volume,

- Increase bias voltage
- Lower temperature ($\mu\tau$ becomes large, and also BG should be reduced)

Extrapolated Low-Field Electron Drift Mobility for InP



Ref: J. Costa and A.Peczalski, ***J. Appl. Phys*. 66(2),** (1989) **p674-679**

Results and Future

- Active area $9mm^2$ and $36mm^2$ with $500\mu m$ thickness proto-type InP detector were tested
- Alpha particle signal was clearly seen
- CCE is obtained by 60% for $9mm^2$ and 13% for $36mm^2$
- New proto-type detectors (phase-II) will come soon
  - $36mm^2$ SI InP with a peltier cooler
  - $36mm^2$ SI InP applied by schottky barrier

    cf $38.5mm^2 X 140\mu m$ detector NIMA458(2001)400
- If CCE achieve over 80%, then large active area with $900mm^2$ detector (phase-III) will be tested within this year

Proto-type InP detector (phase-II) with Peltier cooler