Internal Amplification Ge(GeIA)

Theory of predicting the necessary gain

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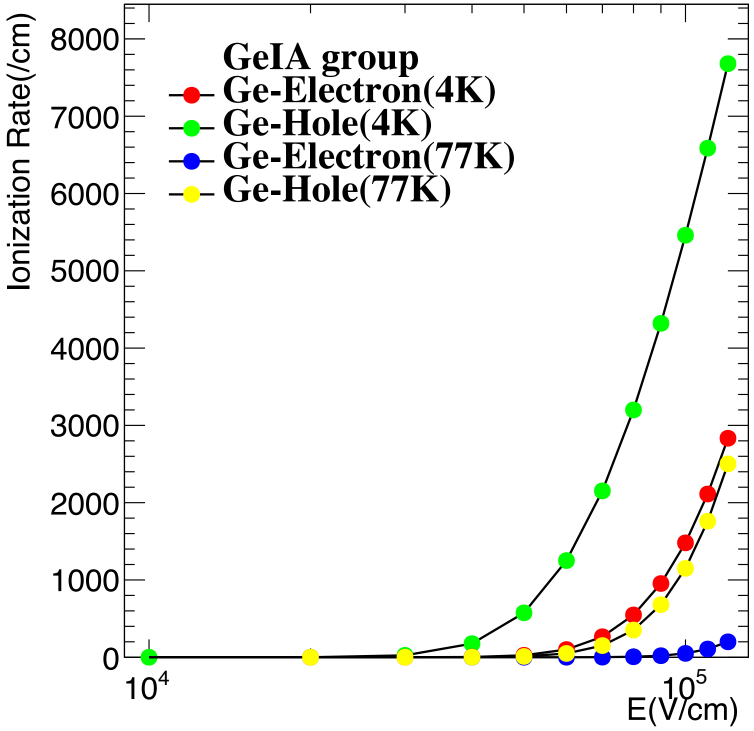
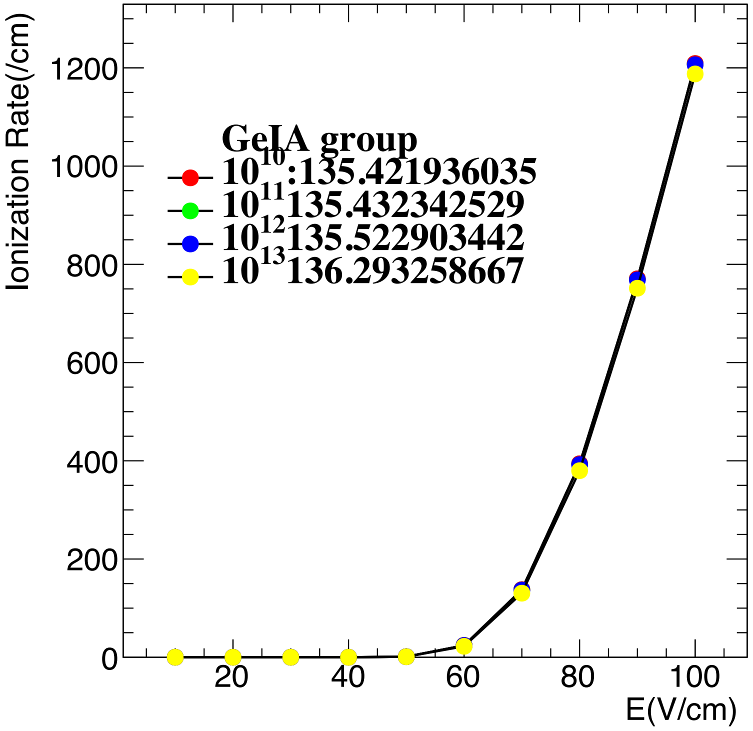
The reminder of the previous results

- At the first place, the ionization rates of electron and hole were predicted by some of the formulae:

Signal(Ge)



Signal(Impurities)



Ionization rate

➔ Give us the "Gain" in the end.

➔ Great! But what's the next?

➔ Debut of our "BKG"!!

➔ Umm…It seems complicated!

➔ Let me map out the blueprint first!

Three steps

SIG estimation

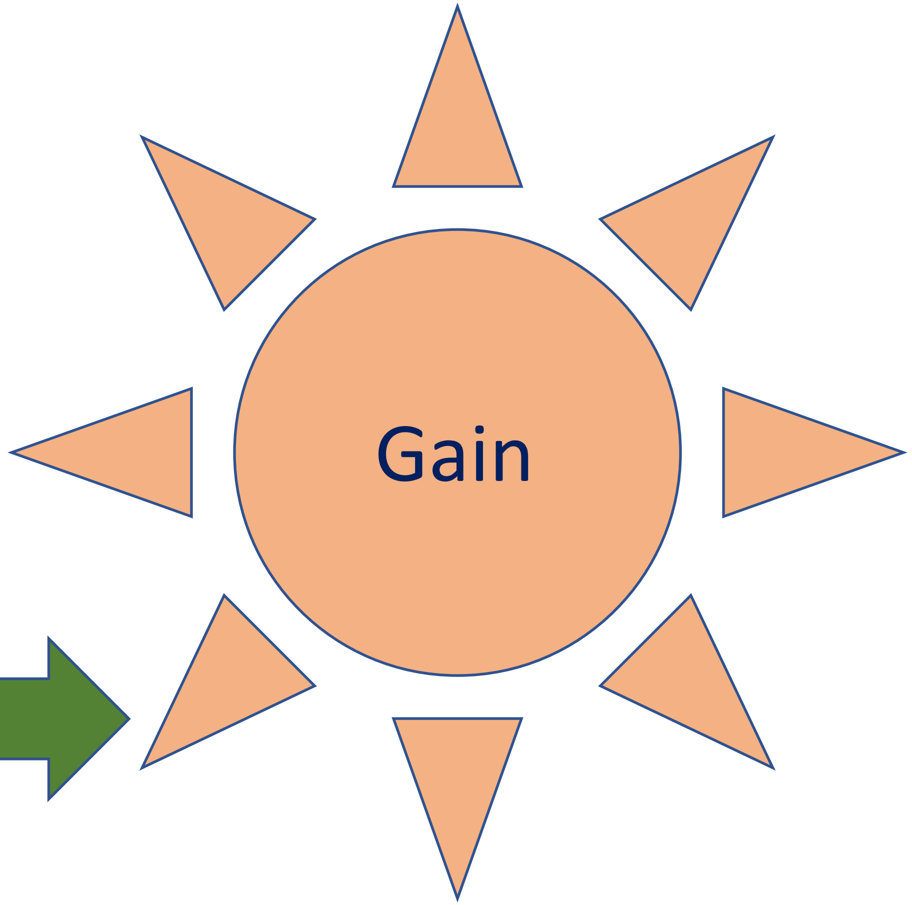
Ionization rate
Gain(E,T)

Know our predicted gain for signal
Under the certain T and E

BKG estimation

Theory of BKG
Signal threshold

Know the threshold of the signal
(Signal ➔ Gain)
Predicted by BKG (Theory)



Type of the detector?
Temperature?
Electric field?

Raw/Observable

No Amplification
Raw SIG/BKG

With Amplification
Obs SIG/BKG

(SIG) > (3 * sigma of BKG)

$$(S * G) > 3 * \sqrt{(B * G)}$$

S

S*G

B

B*G

$$S > \frac{3 * \sqrt{(B * G)}}{G}$$

Various thresholds (Given the dark matter energy) ➔ All can be predicted.

Confirm the circumstance

	G	S(GS)	B(GB)	Threshold
(1)USD	1	1(1)	1(1)	3
(2)China-THU	100	1(100)	100(10000)	3

(SIG) > (3 * sigma of BKG)

$$(S * G) > 3 * \sqrt{(B * G)}$$

$$S > \frac{3 * \sqrt{(B * G)}}{G}$$

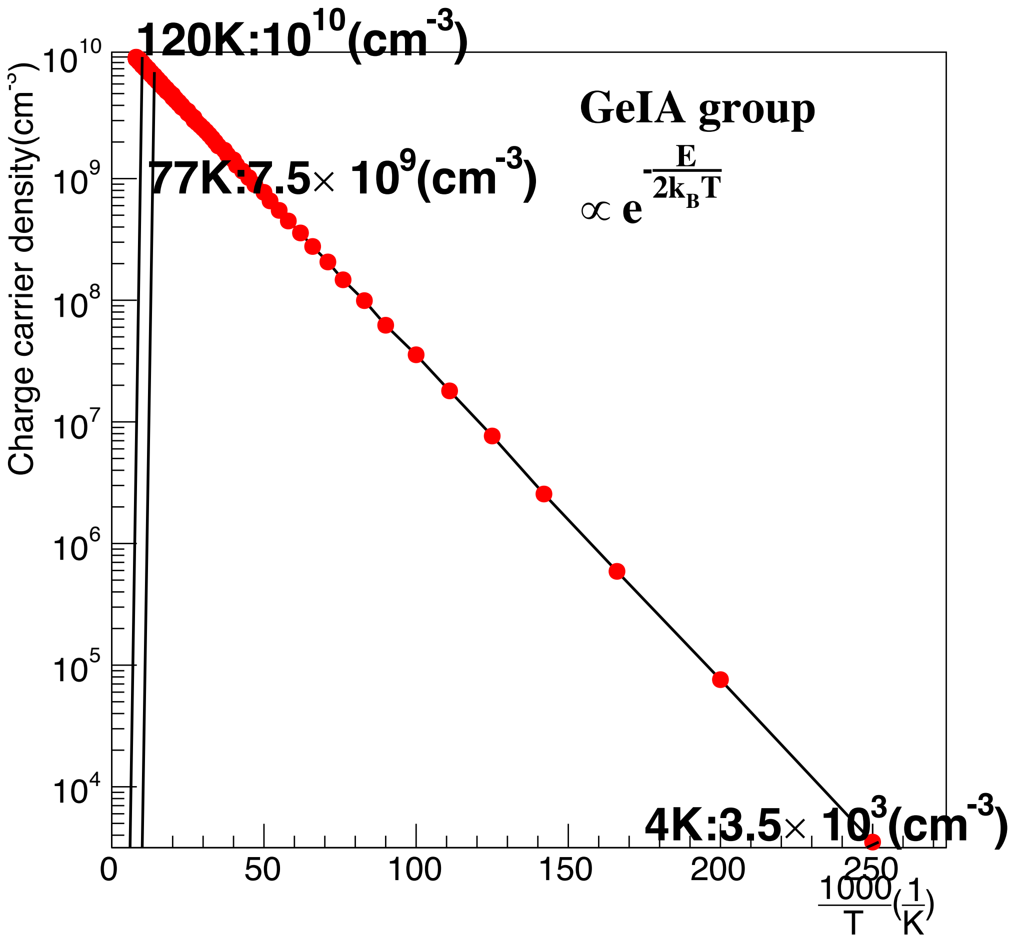
Purpose of this study

- *The important issue:
- Can we predict “the necessary gain” by the signal we expect?

- Next step:
- Find out the right BKG and find out the right threshold plots.
- → Then, we can apply it on our detector
- → Even design the different type of the detector compared with other people.

Theory of BKG

Charged concentration density



Temperature-dependent
charged concentration density

Lower than "ionization energy"
120K
Density of the charged concentration will get smaller since the insufficient fluctuation.

$$\propto \frac{1}{e^{\frac{E}{2k_BT}}}$$

Net impurity(cm^3) : $\frac{1}{e^{\frac{0.0106}{2k_B*120}}}$ = $x(cm^3)$: $\frac{1}{e^{\frac{0.0106}{2k_BT}}}$

We can get the charged concentration correlated with the temperature!

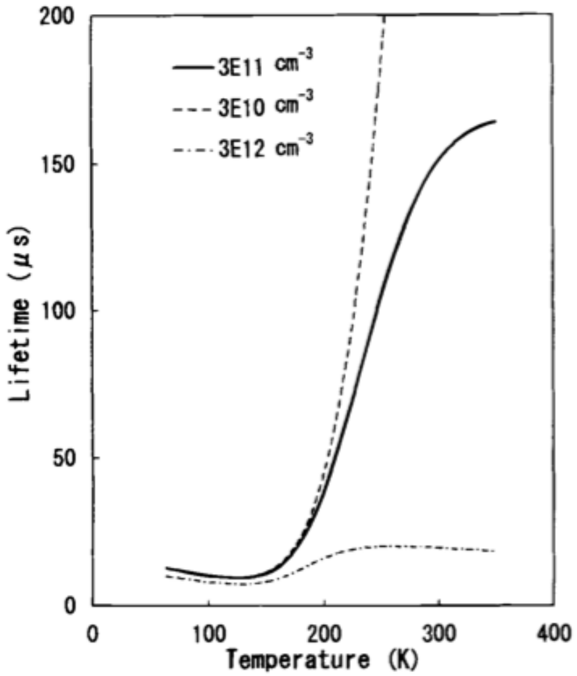
BKG contribution

- $\boldsymbol{\frac{\Delta n(T)}{\tau} = \frac{x\ (cm^3)}{100\mu(s)}}$

- $\Delta n\ (T)$: $Net\ Impurity\ concentration$
- τ: $Carrier\ Lifetime$

Carrier lifetime

- Normal concentration (Level:$10^{10} - 10^{15}\ (cm^3)$)
- ➔ Lifetime won't be changed under the low temperature
- Below 100K, The τ of the material will remain the same value.

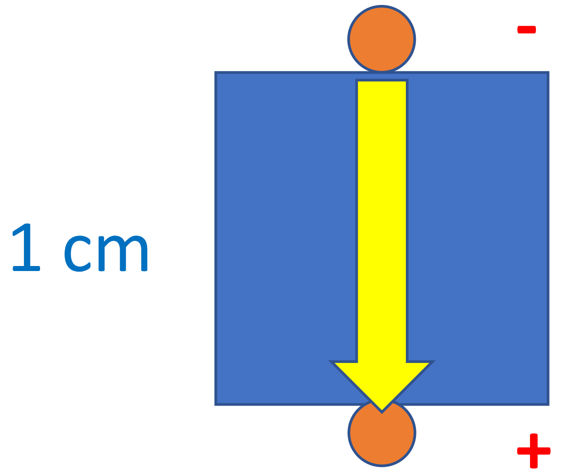


How do we know we are right?
The standard case as follows:

The standard Germanium

- **1 x 1 x 1 (cm^2)**

- **To see if the threshold of the detector is reasonable**



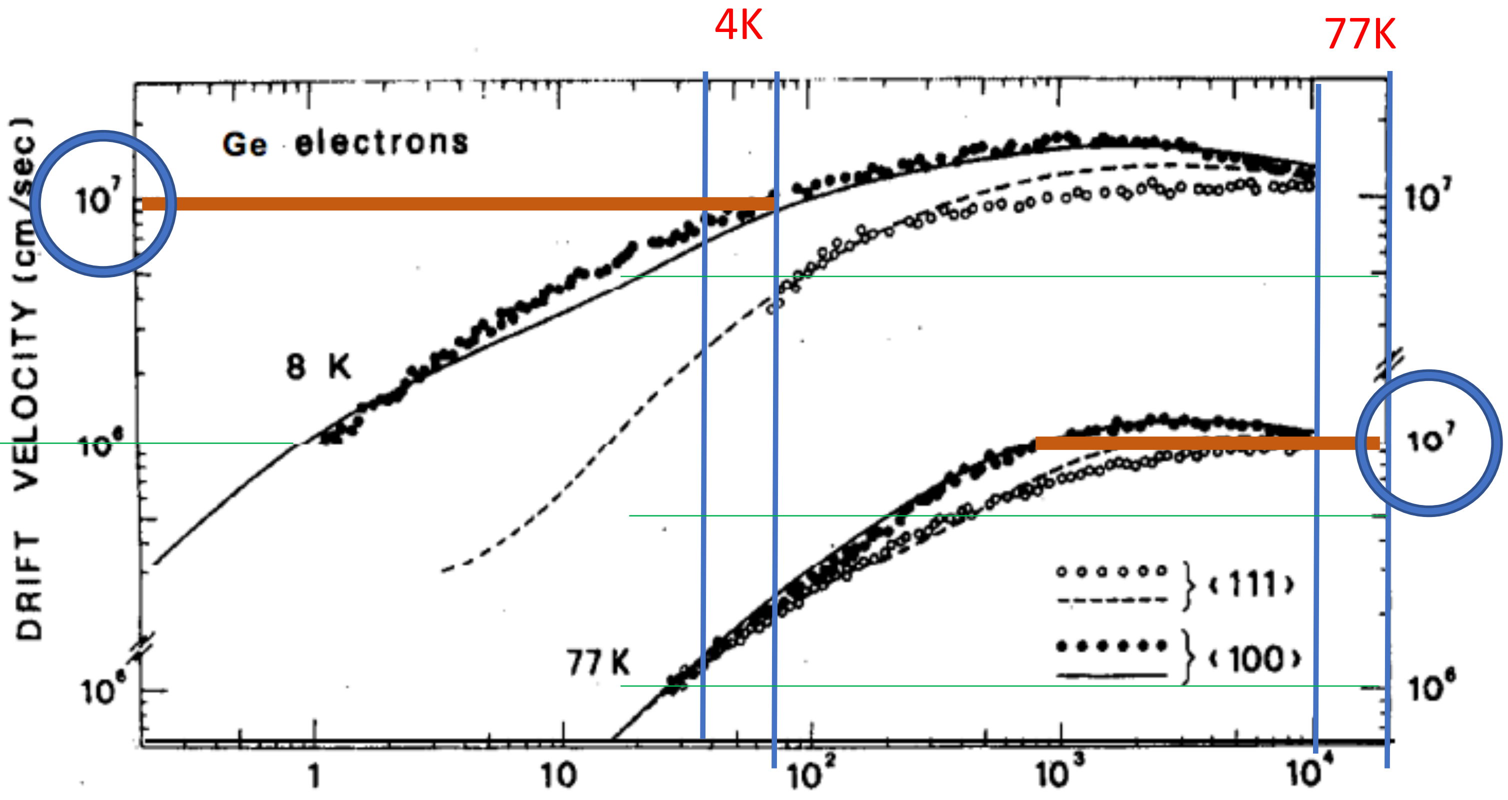
Velocity?

➔ The next one we need to know

The velocity of the electron in Ge

Gain: 0-1000 case

$$\frac{1\,cm}{10^7\,\frac{cm}{s}} = \mathbf{0.1\mu s}$$



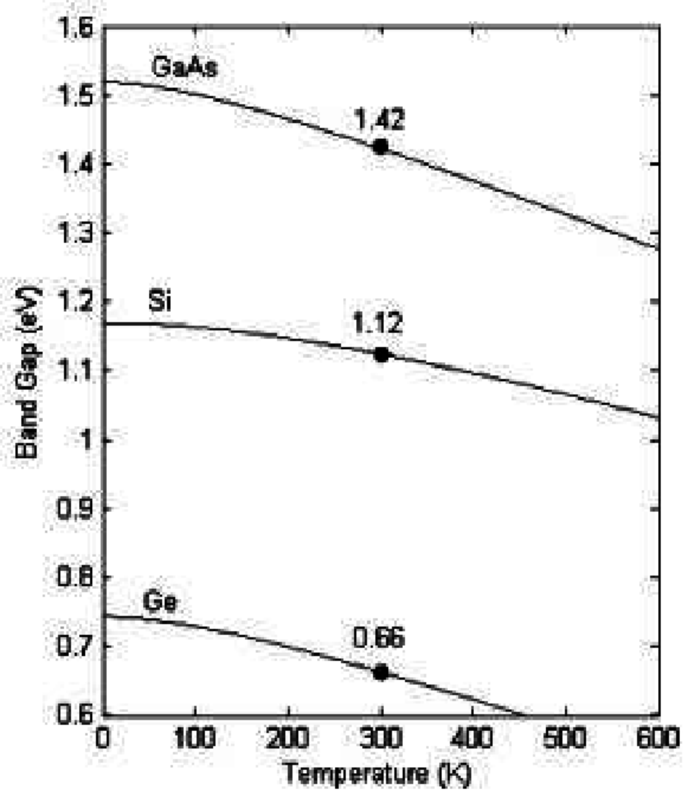
The electron crosses the detector within 1cm

Band gap (E, T, dopant)

- 1. Electric field:
- ➔It is not related to the band gap "Less than $10^9(\frac{V}{cm})$"

- 2. Heavy doping
- ➔ Not for our case.

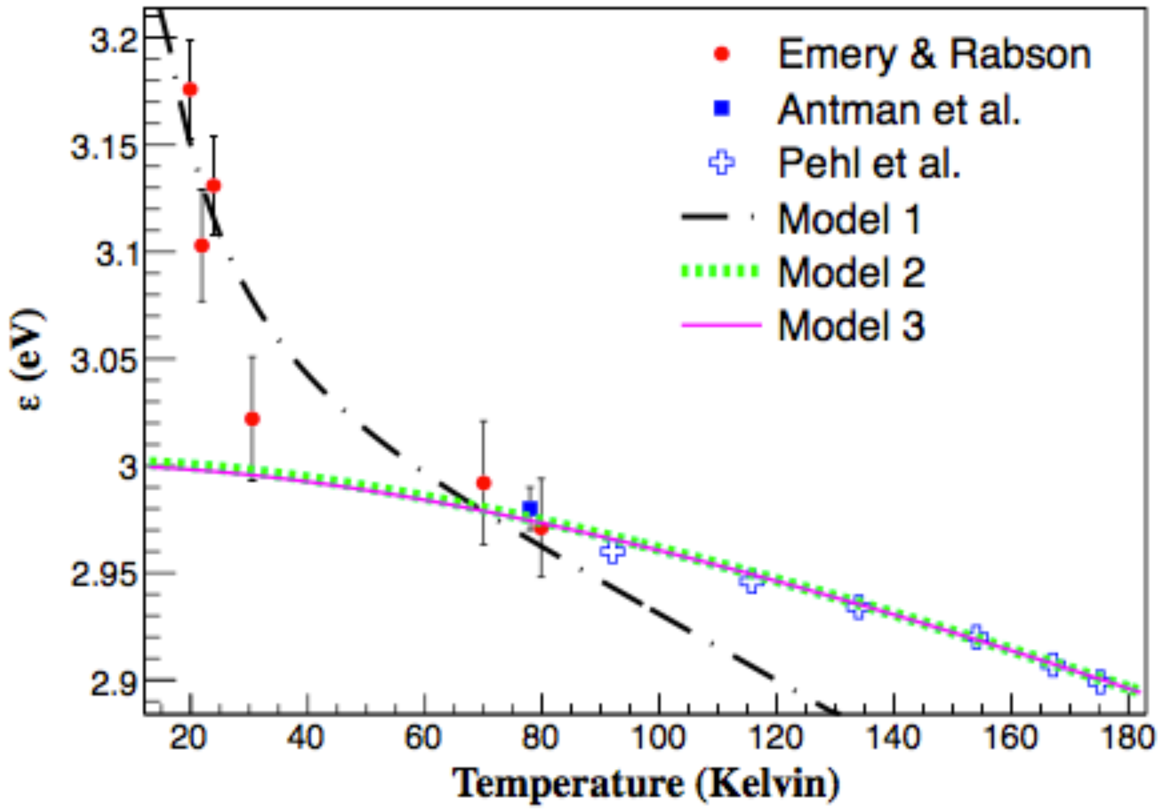
- 3. 77K,4K
- ➔ Bandgap~0.75eV



E-h pair extension- consider the phonon

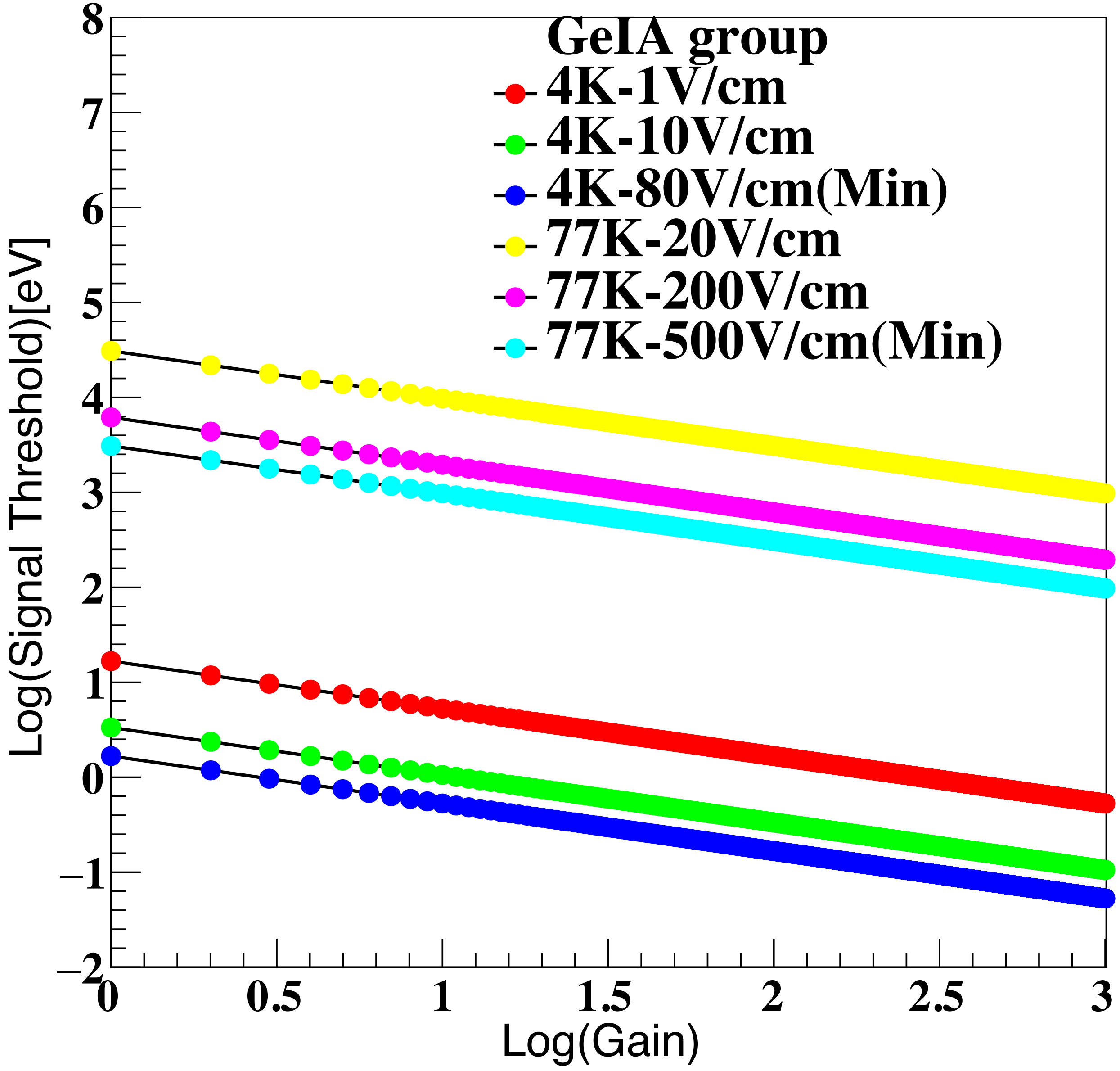
- Consider the phonon – Losing the energy by the phonon
- $E_{detectable} = E_{real} * \frac{E_g}{\varepsilon}$

- $E_g = 0.75eV$
- $\varepsilon(77K) = 3eV$
- $\varepsilon(4K) = 3.5eV$



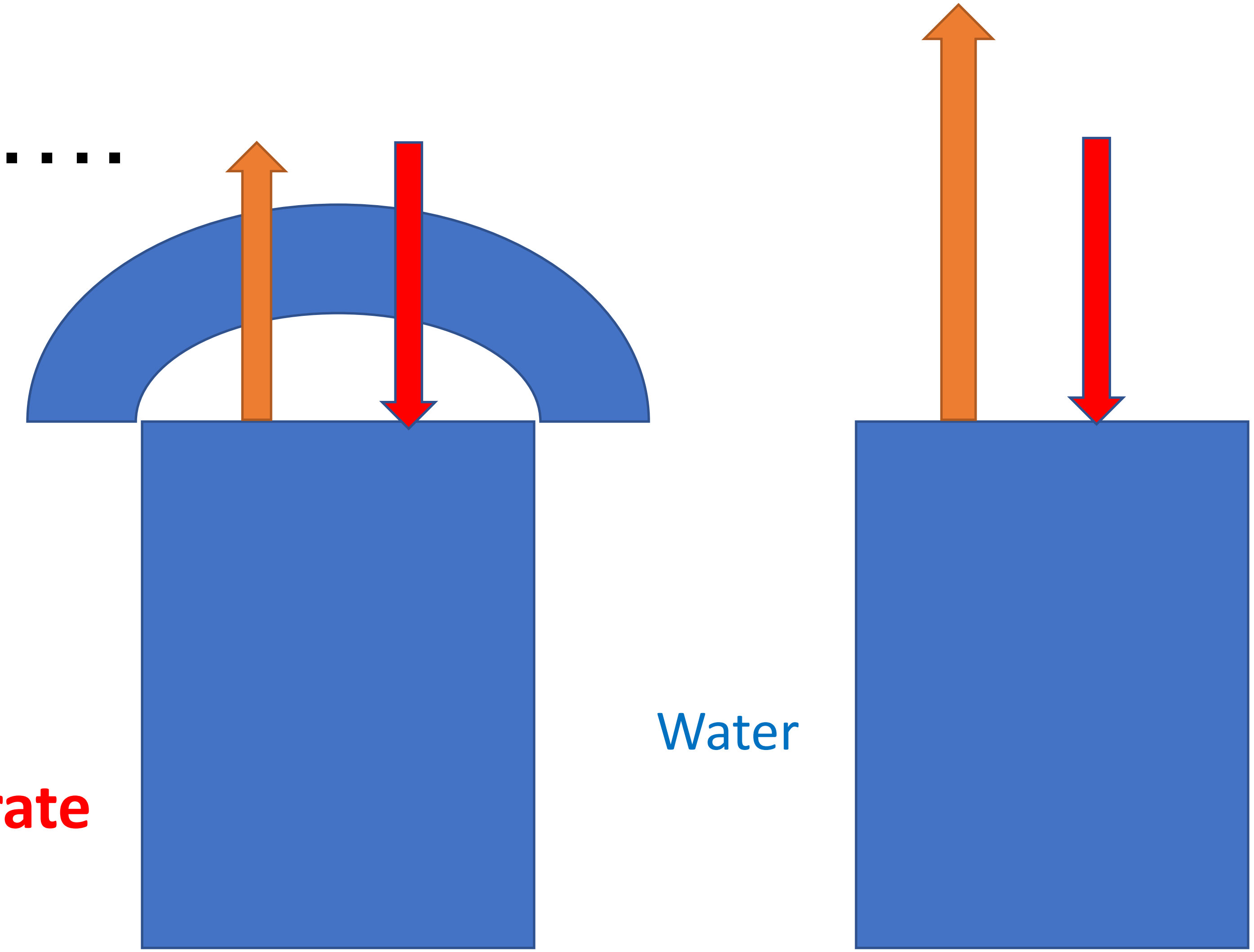
New material (e-h pair)

- 77K : $\left(S\ * G * \frac{0.75}{3}\right) > 3\ *\ \sqrt{\left(B\ * G * \frac{0.75}{3}\right)}$
- 4K : $(\left(S\ * G * \frac{0.75}{3.5})\right) > 3\ *\ \sqrt{\left(B\ * G * \frac{0.75}{3.5}\right)}$


GeIA group
4K-1V/cm
4K-10V/cm
4K-80V/cm(Min)
77K-20V/cm
77K-200V/cm
77K-500V/cm(Min)
Log(Signal Threshold)[eV]
Log(Gain)
8
7
6
5
4
3
2
1
0
−1
−2
0
0.5
1
1.5
2
2.5
3

Backup

Image....



Generate rate (Evaporate)

Recombination rate (Condensate)

T equilibrium

G=R

Take off the cover

G>R

The same as our experiment!

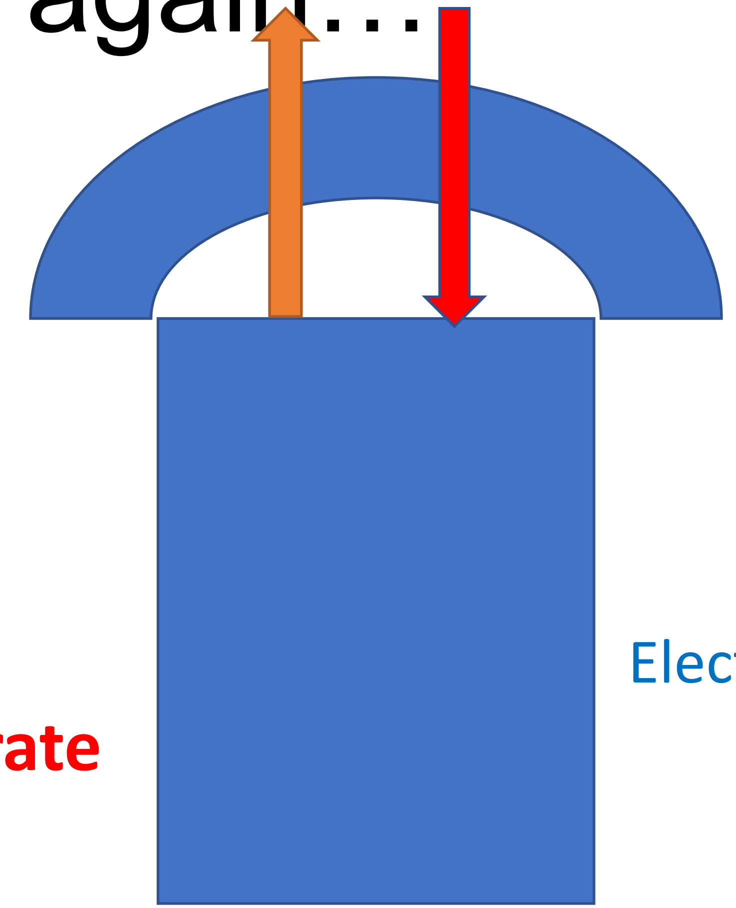
$$Net\ impurity\ concentration = \Delta n$$
$$Carrier\ lifetime = T$$

$$\frac{\Delta n}{T} = \frac{\frac{10^{10}}{cm^3} * (F)}{100\mu s} = \frac{10^8 * F}{cm^3 * \mu s}$$

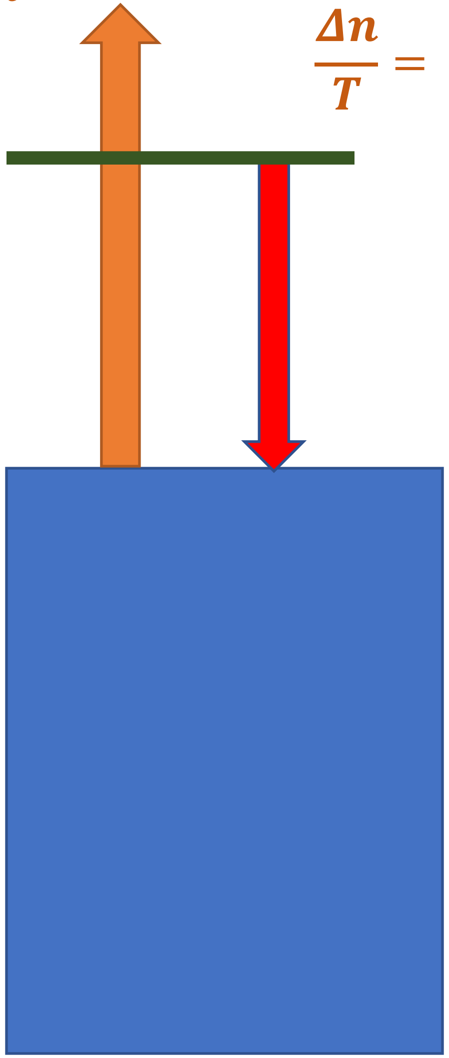
Image again…

Generate rate
(e pop up)

Recombination rate
(e absorbed)



Electron sea



T equilibrium
(Electric field off)

G=R

Take off the cover
(Electric field on)

G>R

Give us the sense

$$\frac{\Delta n}{T} = \frac{\frac{10^{10}}{cm^3} * (F)}{100\mu s} = \frac{10^8 * F}{cm^3 * \mu s}$$

- Since we don't know the explicit physics in the detector
- ➔ Do some approximation.

- We suppose the whole crystal can give us the BKG estimation.
- ➔ In μs

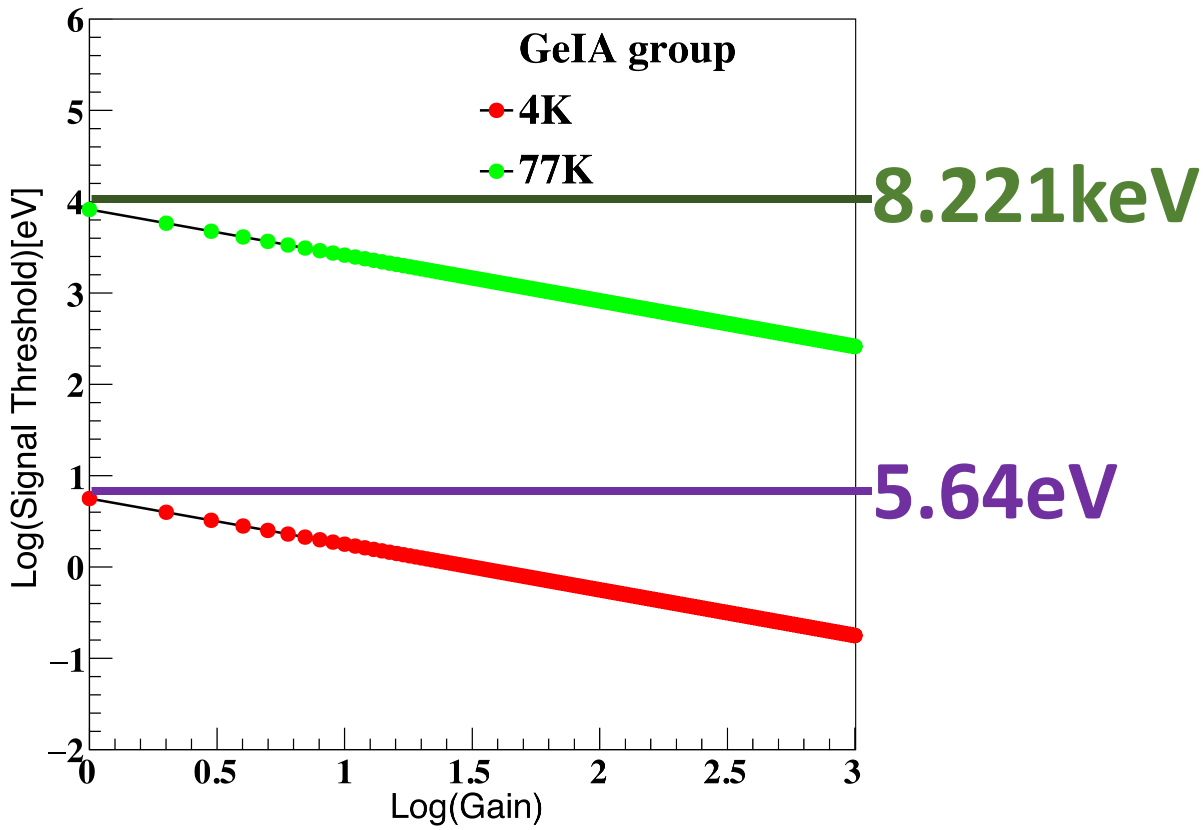
- $7.5 \times 7.5 \times 3 (cm^3)$

$$\frac{\Delta n}{T} = \frac{(F)}{100\mu s} = \frac{0.01 * F}{cm^3 * \mu s} = \frac{10^{-3} * F}{cm^3 * 0.1\mu s} = 10^{-3} * F \ (/cm^3 * 0.1\mu s)$$

Threshold

$$(S \ast G) > 3 \ast \sqrt{(B \ast G)}$$

$$S > \frac{3 \ast \sqrt{(B \ast G)}}{G}$$



Band gap (E, T, dopant)

- 1. For the electric field:
- ➔It is not related to the band gap “Less than $10^9(\frac{V}{cm})$”
- ➔Also there is no case related to our experiment directly.
- ➔ https://www.researchgate.net/figure/Relationship-between-external-electrical-field-and-band-gap-energy-on-pristine-germanene_fig2_282357381

Band gap (E, T, dopant)

- 2. For the dopant and temperature:
- sci-hub.tw/10.1103/PhysRevB.24.1971 (dopant)
- https://ecee.colorado.edu/~bart/book/eband5.htm (temperature)
- http://folk.uio.no/ravi/cutn/semiphy/21.Borstein-Moss.pdf (dopant)

- Heavy doping ➔ Not for our case.
- 77K,4K ➔ Bandgap~0.75eV

Carrier lifetime

- The period of the time that
- "The electron pops up and is absorbed by the atom"
- https://arxiv.org/pdf/1907.05067.pdf

http://jes.ecsdl.org/content/145/9/3265.full.pdf+html

- https://www.google.com/search?q=Carrier+lifetime+concentration&sxsrf=ACYBGNRX_-wf-0_XGePwPz3r-STAx-jnXw:1572081781847&source=lnms&tbm=isch&sa=X&ved=0ahUKEwissaiBzbnlAhVRI6YKHd8gCPAQ_AUIEigB&biw=1280&bih=605#imgrc=ZFkOn2ay1IHZ9M:
- Normal concentration (Level: 10^10~15) ➔ Lifetime won't be changed