

# Internal Amplification $Ge(GeIA)$

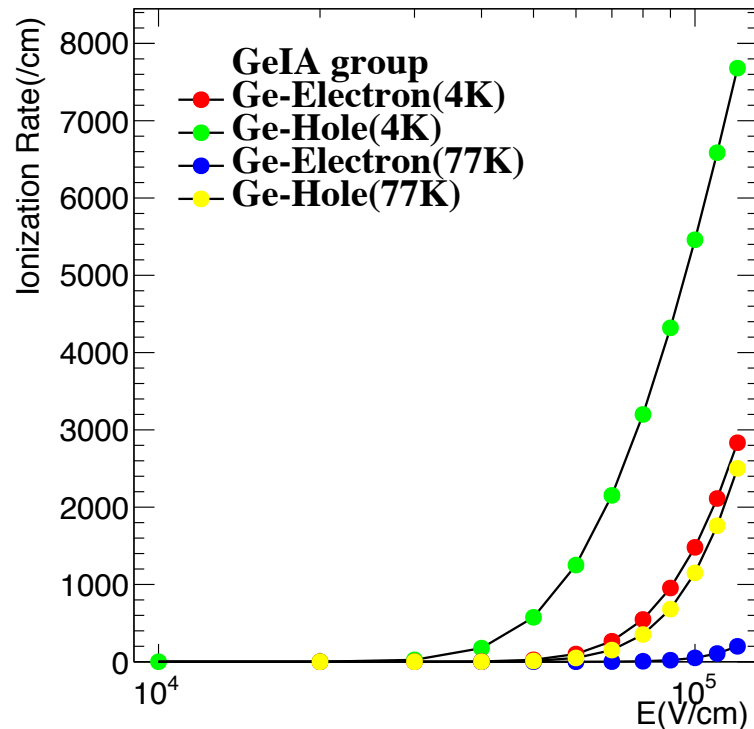
## Theory of predicting the necessary gain

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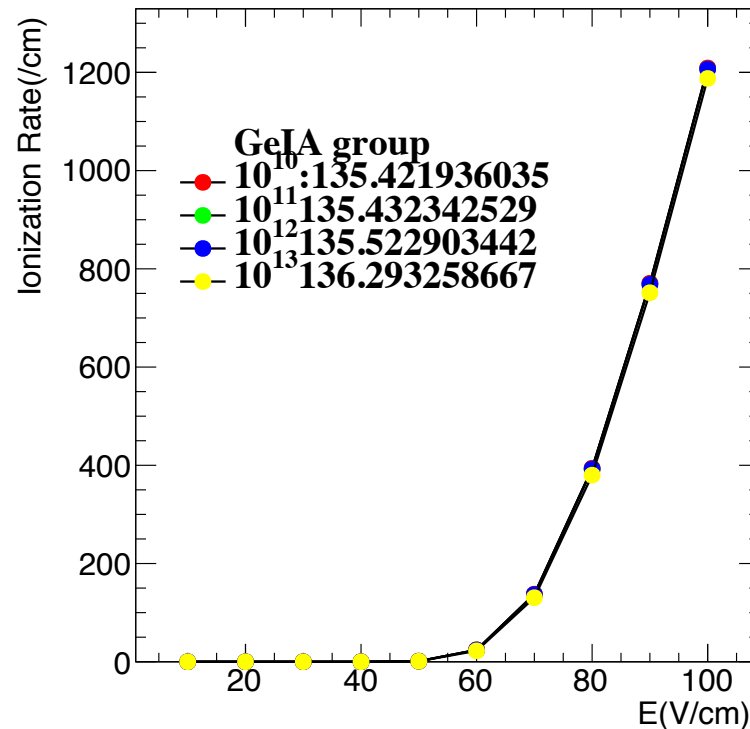
# The reminder of the previous results

- 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



**Ionization rate**  
**Gain(E,T)**



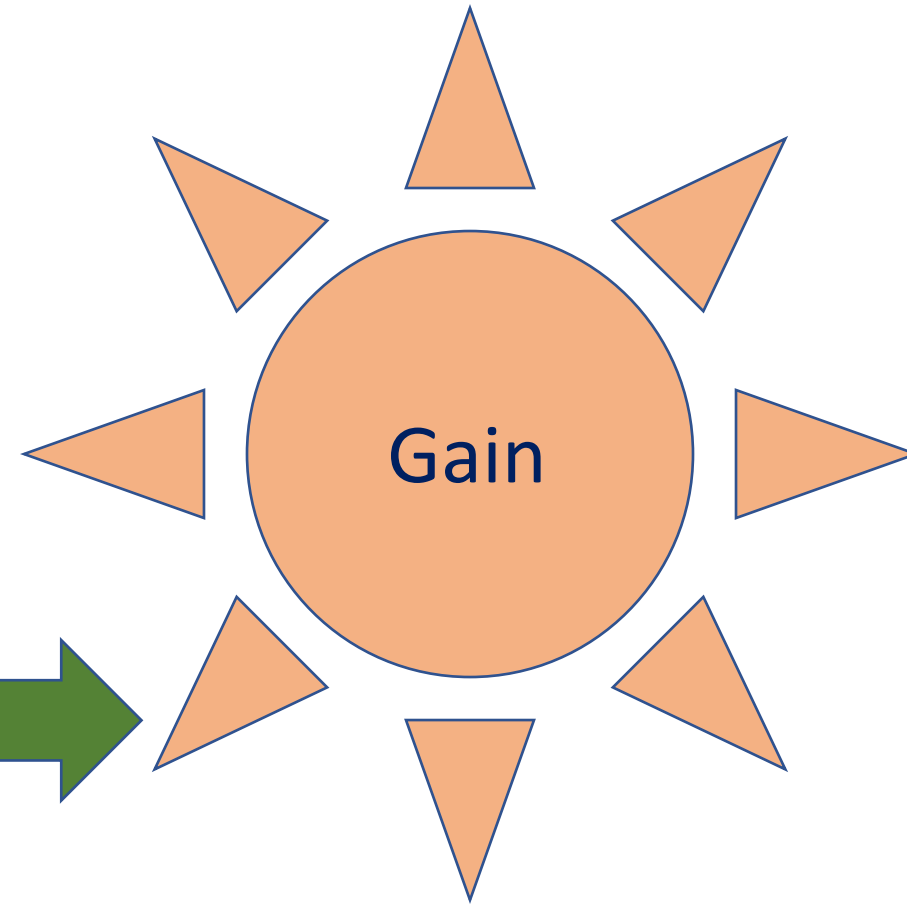
**Know our predicted gain for signal**  
**Under the certain T and E**



**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



S

B



$S * G$

$B * G$

$$(SIG) > (3 * \text{sigma of BKG})$$

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

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

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

$$(SIG) > (3 * \text{sigma of BKG})$$

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

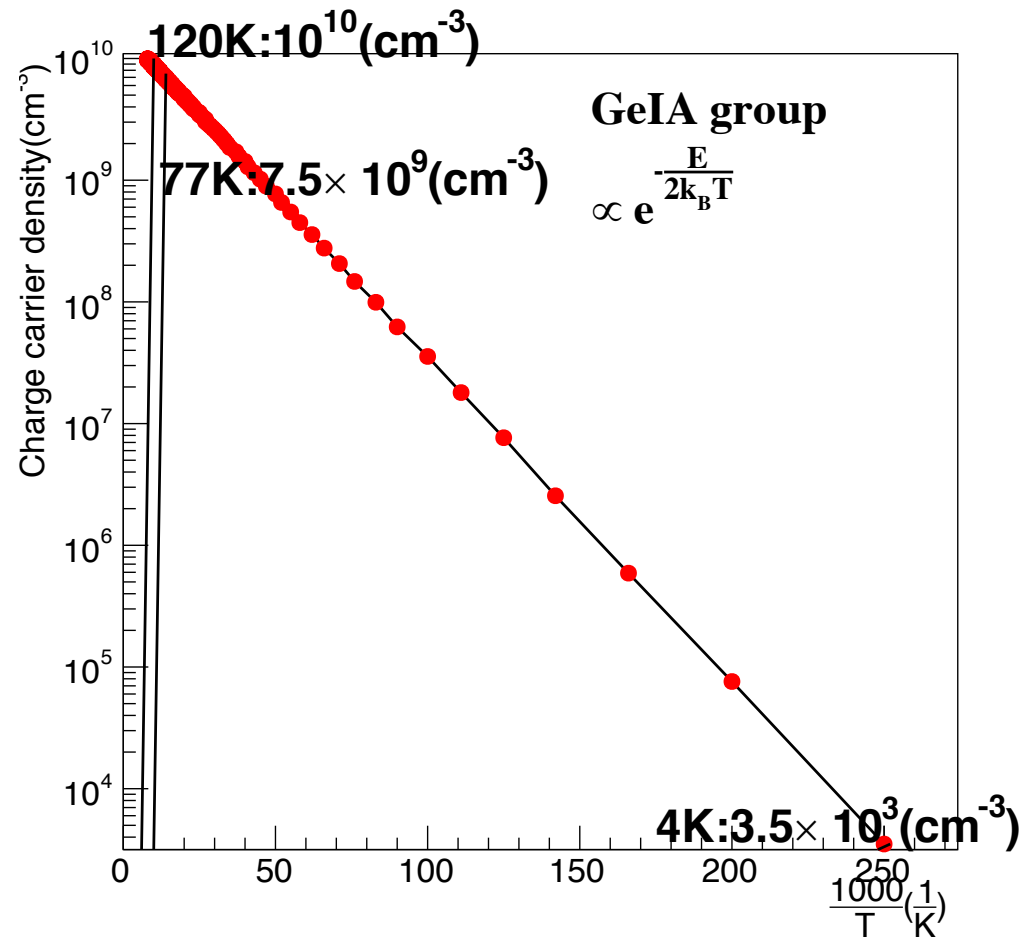
$$S > \frac{3 * \sqrt{(B * G)}}{G}$$

# 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.

$$\propto \frac{1}{e^{\frac{E}{2k_B T}}}$$

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

**We can get the charged concentration correlated with the temperature!**



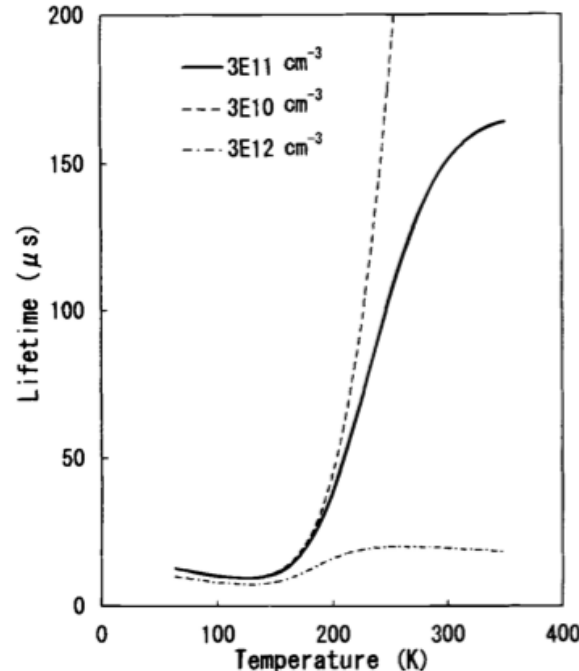
# BKG contribution

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

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

# Carrier lifetime

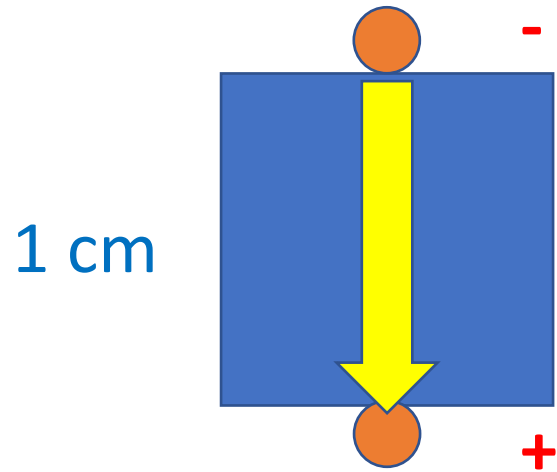
- Normal concentration ( Level:  $10^{10} - 10^{15} \text{ (cm}^3\text{) } )$
- ➔ Lifetime won't be changed under the low temperature
- Below 100K, The  $\tau$  of the material will remain the same value.



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

# The standard Germanium

- $1 \times 1 \times 1 \text{ (cm}^2\text{)}$
- To see if the threshold of the detector is reasonable



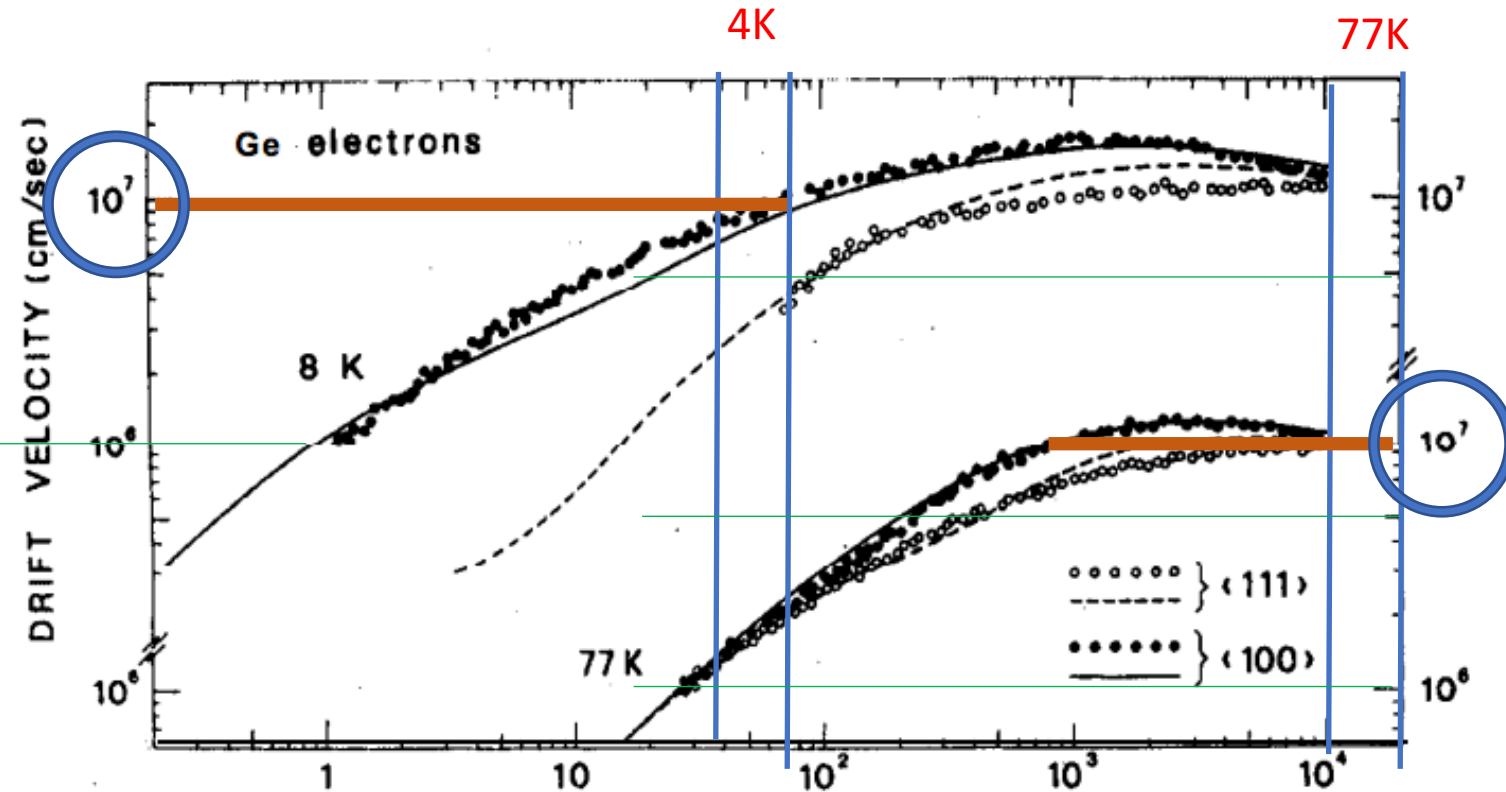
Velocity?

➔ The next one we need to know

# The velocity of the electron in Ge

Gain: 0-1000 case

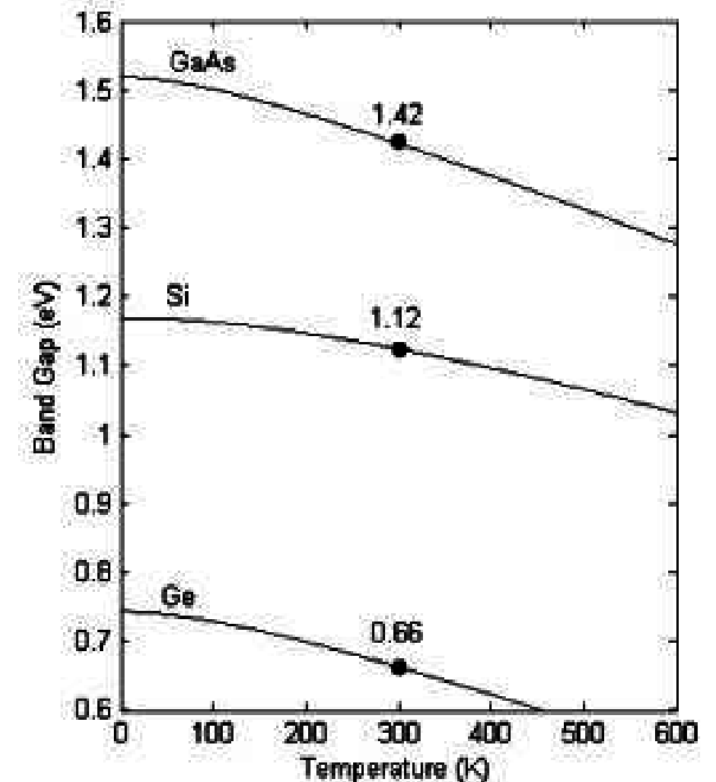
$$\frac{1 \text{ cm}}{10^7 \frac{\text{cm}}{\text{s}}} = 0.1 \mu\text{s}$$



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. Heavily doping
- ➔ Not for our case.
- 3. 77K,4K
- ➔ Bandgap~0.75eV



# E-h pair extension- consider the phonon

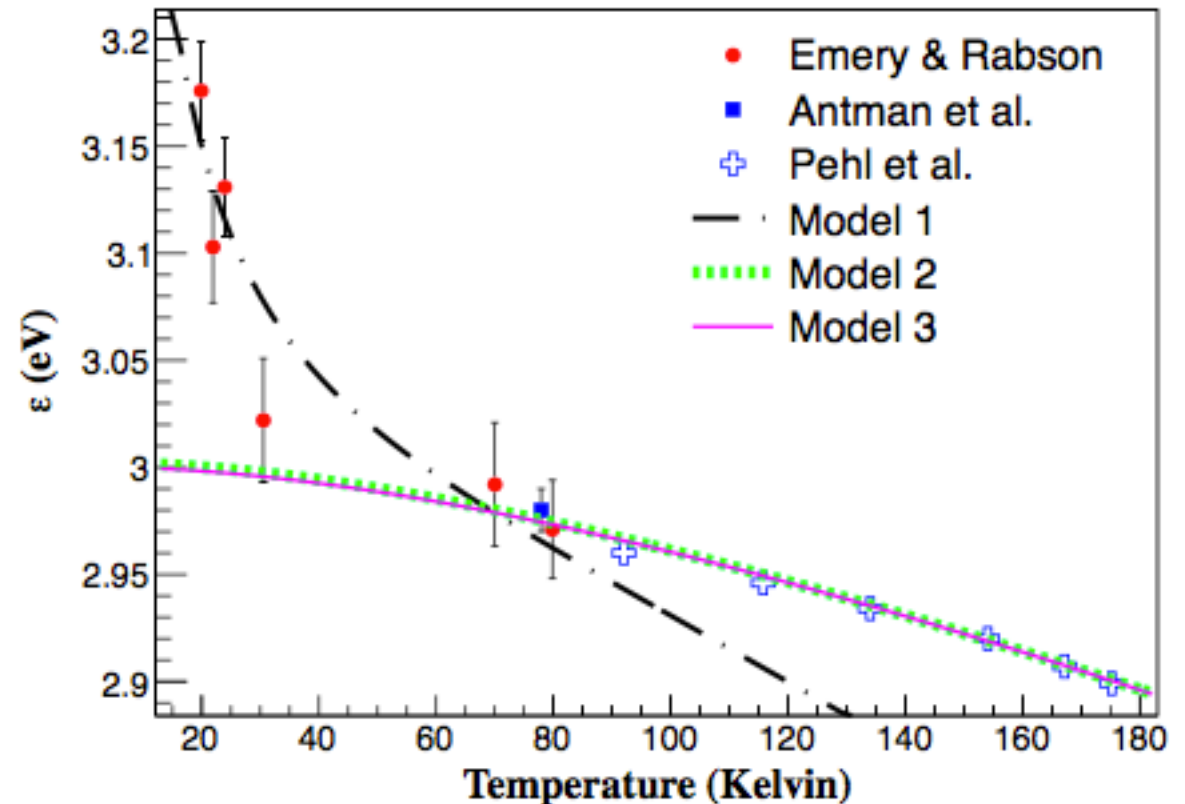
- Consider the phonon – Losing the energy by the phonon

- $E_{detectable} = E_{real} * \frac{E_g}{\varepsilon}$

- $E_g = 0.75eV$

- $\varepsilon(77K) = 3eV$

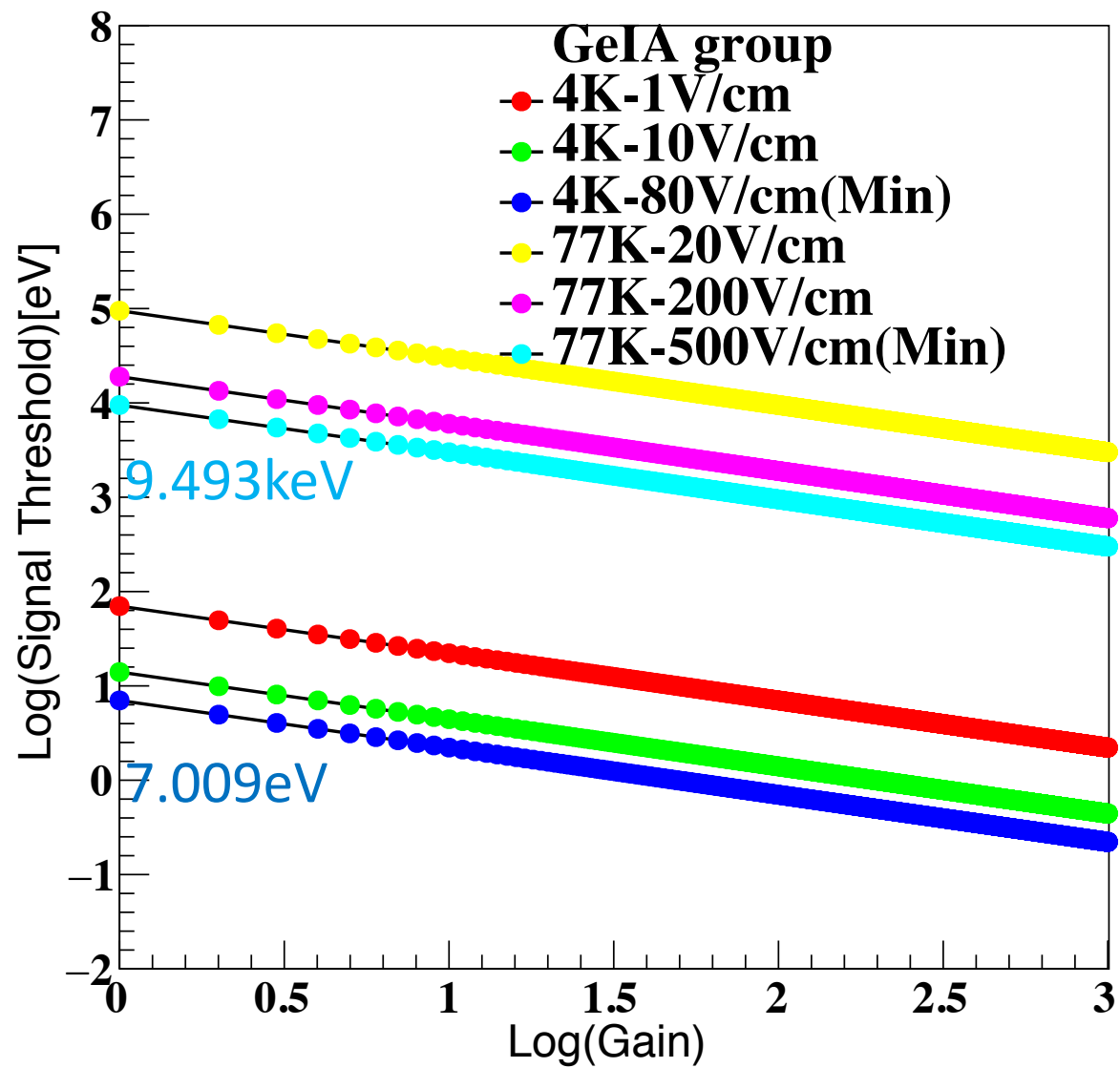
- $\varepsilon(4K) = 3.5eV$



# New material ( e-h pair )

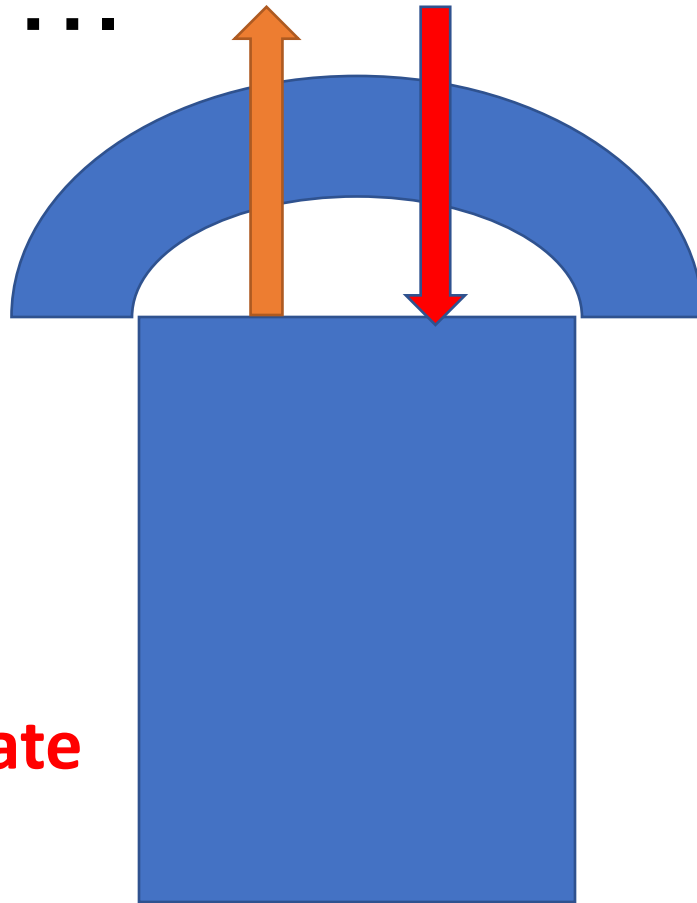
- 77K :  $\left( S * G * \frac{0.75}{3} \right) > 3 * \sqrt{\left( B * G * \frac{0.75}{3} \right)}$
- 4K :  $\left( \left( S * G * \frac{0.75}{3.5} \right) \right) > 3 * \sqrt{\left( B * G * \frac{0.75}{3.5} \right)}$





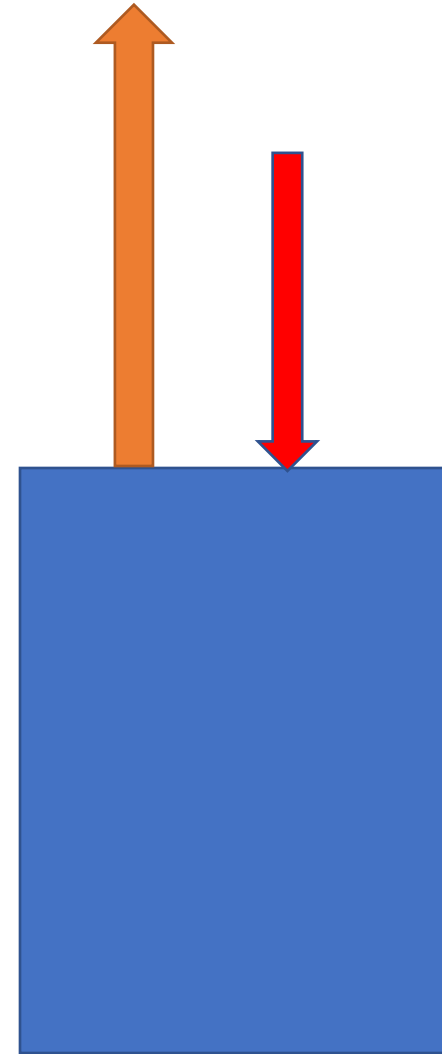
# Backup

Image....



T equilibrium

$$G=R$$



Take off the cover

$$G>R$$

The same as our experiment!

Generate rate  
(Evaporate)

Recombination rate  
(Condensate)

Water

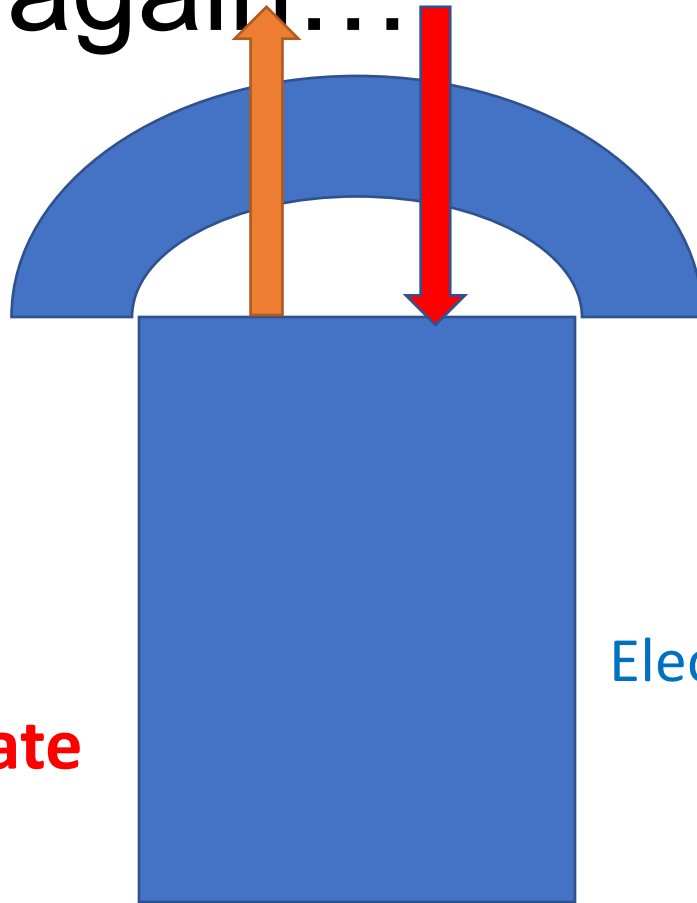
*Net impurity concentration =  $\Delta n$*   
*Carrier lifetime =  $T$*

Image again...

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

Generate rate  
(e pop up)

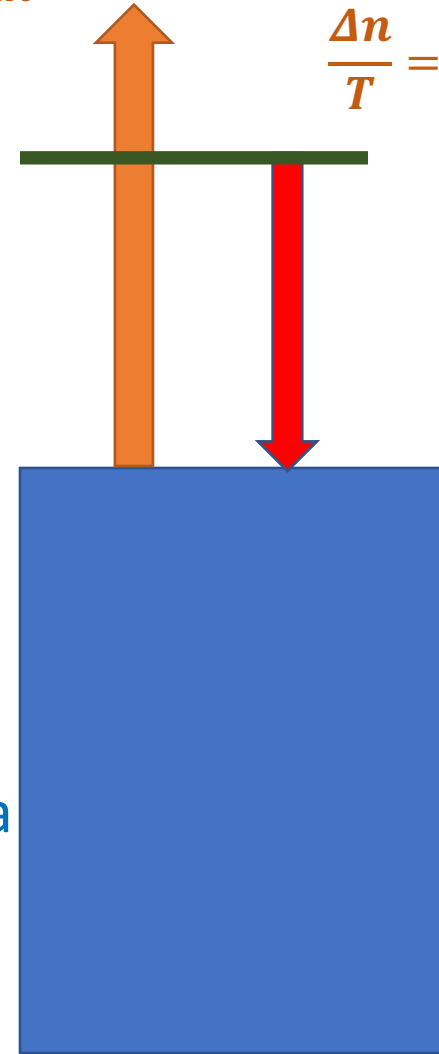
Recombination rate  
(e absorbed)



T equilibrium  
(Electric field off)

$G=R$

Electron sea



Take off the cover  
(Electric field on)

$G>R$

# Give us the sense

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

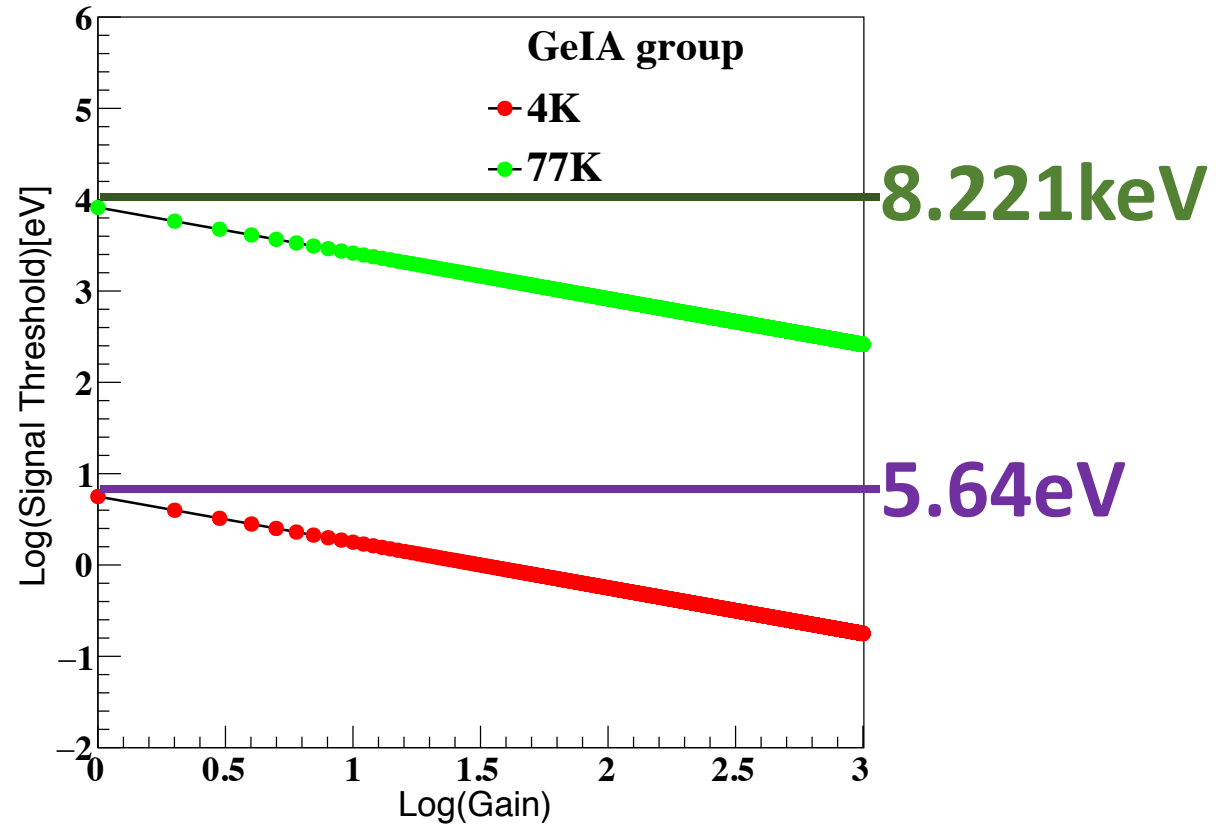
- Since we don't know the explicit physics in the detector
- → Do some approximation.
- We suppose the whole crystal can give us the BKG estimation.
- → In  $\mu s$

- $7.5 \times 7.5 \times 3 (cm^3)$ 
$$\frac{\Delta n}{T} = \frac{(F)}{100\mu s} = \frac{0.01 * F}{cm^3 * \mu s} = \frac{10^{-3} * F}{cm^3 * 0.1\mu s} = 10^{-3} * F (/cm^3 * 0.1\mu s)$$

# Threshold

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

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



# 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](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](https://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&xsrf=ACYBGNRX-wf-0\\_XGePwPz3r-STAx-jnXw:1572081781847&source=Inms&tbm=isch&sa=X&ved=0ahUKEwissaiBzbnIAhVRI6YKHd8gCPAQ\\_AUIEigB&biw=1280&bih=605#imgrc=ZFkOn2ay1IHZ9M:](https://www.google.com/search?q=Carrier+lifetime+concentration&xsrf=ACYBGNRX-wf-0_XGePwPz3r-STAx-jnXw:1572081781847&source=Inms&tbm=isch&sa=X&ved=0ahUKEwissaiBzbnIAhVRI6YKHd8gCPAQ_AUIEigB&biw=1280&bih=605#imgrc=ZFkOn2ay1IHZ9M:)
- Normal concentration (Level:  $10^{10} \sim 10^{15}$  ) → Lifetime won't be changed