Direct Detection of the Dark Matter:
Germanium detector Internal Amplification(GeIA)
(Battle between “liquid Ne-77K” and “He-4K”)

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Before the talk….

- Detector project – Cryogenic knowledge
- Filled with “Solid-State Physics”
- Try my best to explain the jargon well.

Outline – Qualitative and Quantitative

- The principles of our experiment
- The issues we are engaging in
- The conclusion and prospect

WIMPs

Predicted by gravitation:

The velocity of the stars
➔Inconsistent with the existing law
➔Missing mass in our universe!

➔Weakly Interacting Massive Particles(WIMPs)

Reach through region
(Low E region)

Avalanche region
(High E region)

E-h generated
Mechanism:
(1)Excitation
(2)Ionization

electron

hole

Drifted in the crystal

+

Give out many electrons

G(T,E...)

-

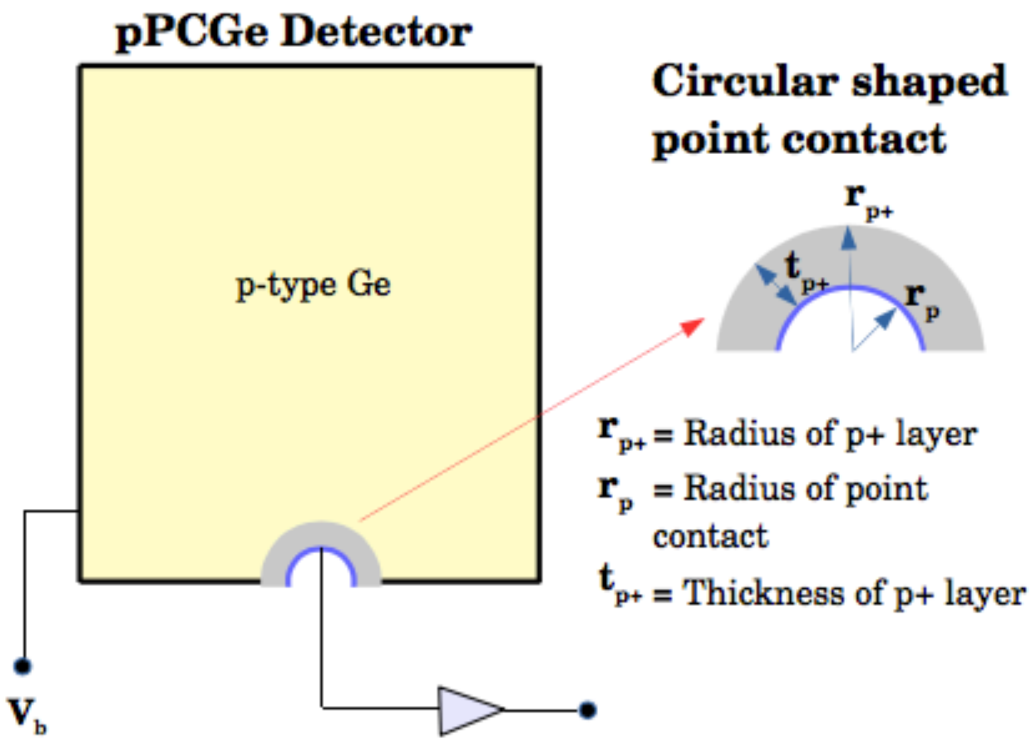
Amplification

Purity: Ge

Impurity: Be, Al, Ga, (3A)-hole. “**P-type detector**”

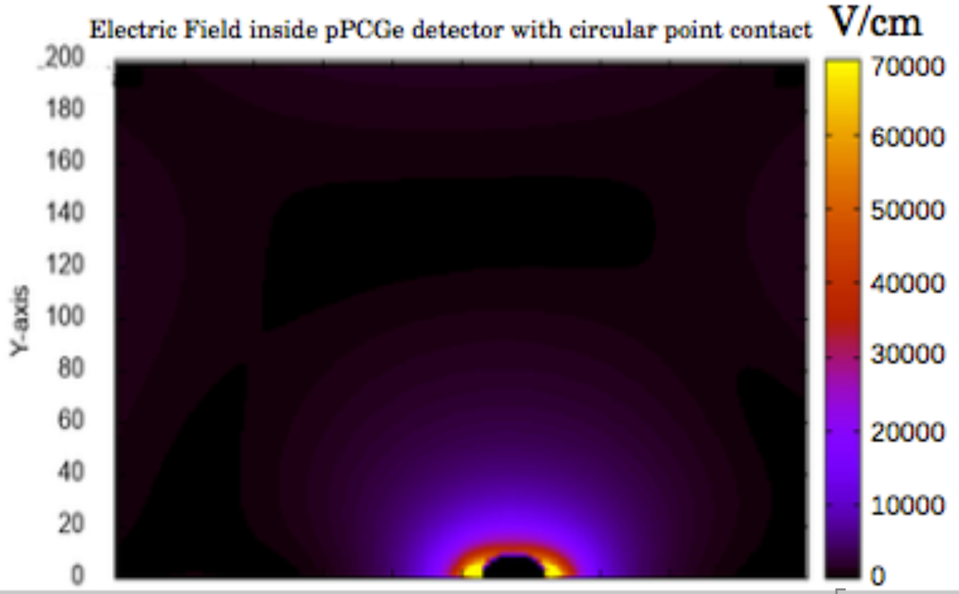
Examples from other people

Shape of point contact and p+layer under Circular Geometry for pPCGe detector

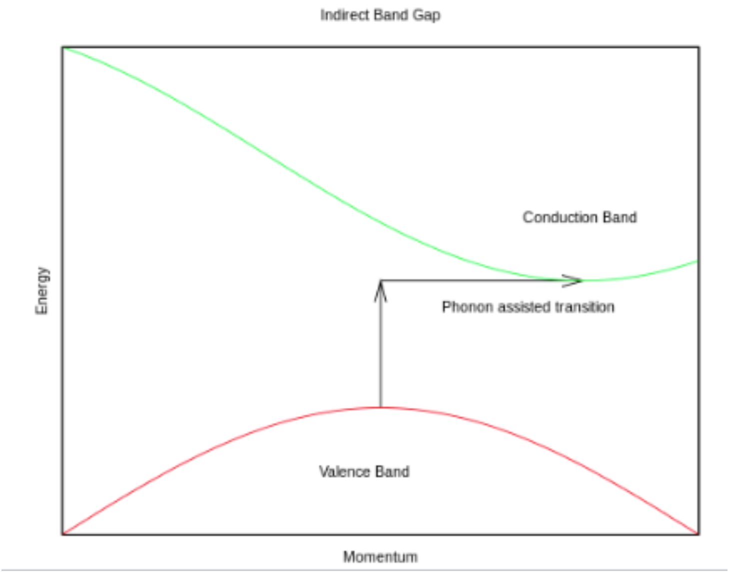


Electric Field

- Detector dimension : 1cm x 1cm
- Bias voltage : 3500 V
- Impurity concentration : 5 x 10^{10} cm^{-3}
- Radius of point contact r_P : 0.4997 mm
- Radius of p+ layer r_{p+} : 0.5 mm
- Thickness of p+ layer t_{p+} : 0.0003 mm (300 nm)

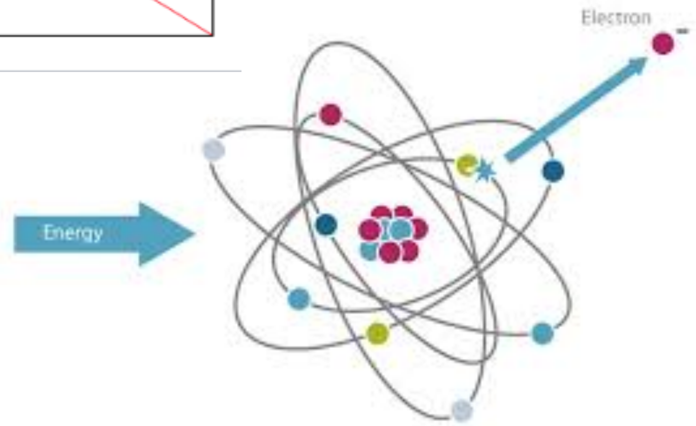


Clarification(Solid-State Physics)



e-h pair

e-ion pair
(e-h pair)



The energy to produce E-h pair

	Excitation (Ionization) **-Ge**	**Ionization** **-Impurities**
4K	3.3eV	0.01eV
77K	3.0eV	0.01eV

*In our topic, we call them “Ionization” and “e-h pair” totally
➔ The one energy that can produce e-h pair

Issue?

I have the low background!

4K

Liquid Helium

Winner or Loser?

Versus

I'm easy to be achieved!

77K

Liquid Nitrogen

(Beijing Tsing-Hua University)

$$\frac{Signal}{Noise}$$

Non-trivial issues

- Breakdown voltage
- Leakage current
- …….
- Many issues at there!

- At the beginning, we start at “Gain” without other noises!

Gain factor

- How do we know about the gain?
- ➔ We need to know about the number of e-h pair we can produce!

- *Ionization rate
- ➔ How many e-h pairs will be produced during the avalanche region?

Parameter(1): Mean free path

- *Definition:
- How far the electron(hole) can run without colliding with others

- (Relaxation time) * (velocity)

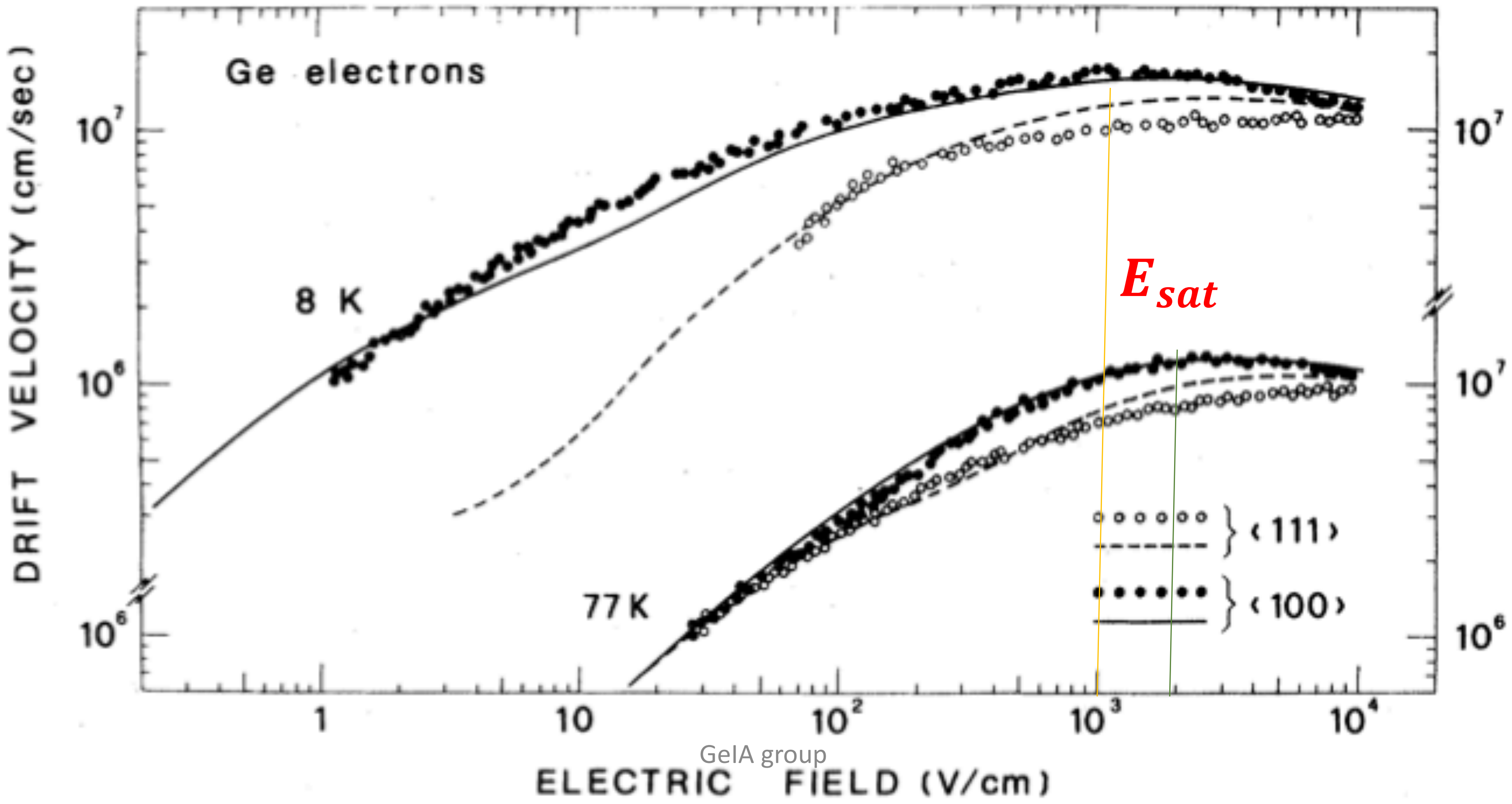
Parameter(2): Relaxation time

- How long the electron(hole) can run without colliding with others
- Formula: $\frac{\mu \times m*}{e} = \tau$
- (1)μ(mobility) = $\frac{v_d(1+\frac{E}{E_{sat}})}{E}$

- (2)m* (Effective mass): bounded electron (F=m*a)
- ➔ Use effective mass to do the approximation
- ➔ electron* = 0.21*(free e- mass), hole* = 0.12*(free e- mass)
- (3)e(Charge constant)

Parameter(3): Velocity

PhysRevB.24.1014



Parameter(4): Ionization rate

$$\alpha_s = \frac{a_s}{z}\exp\left(-\frac{b_s}{E(x)}\right) \quad \text{with} \quad s = \{n, p\} \qquad (20a)$$

and

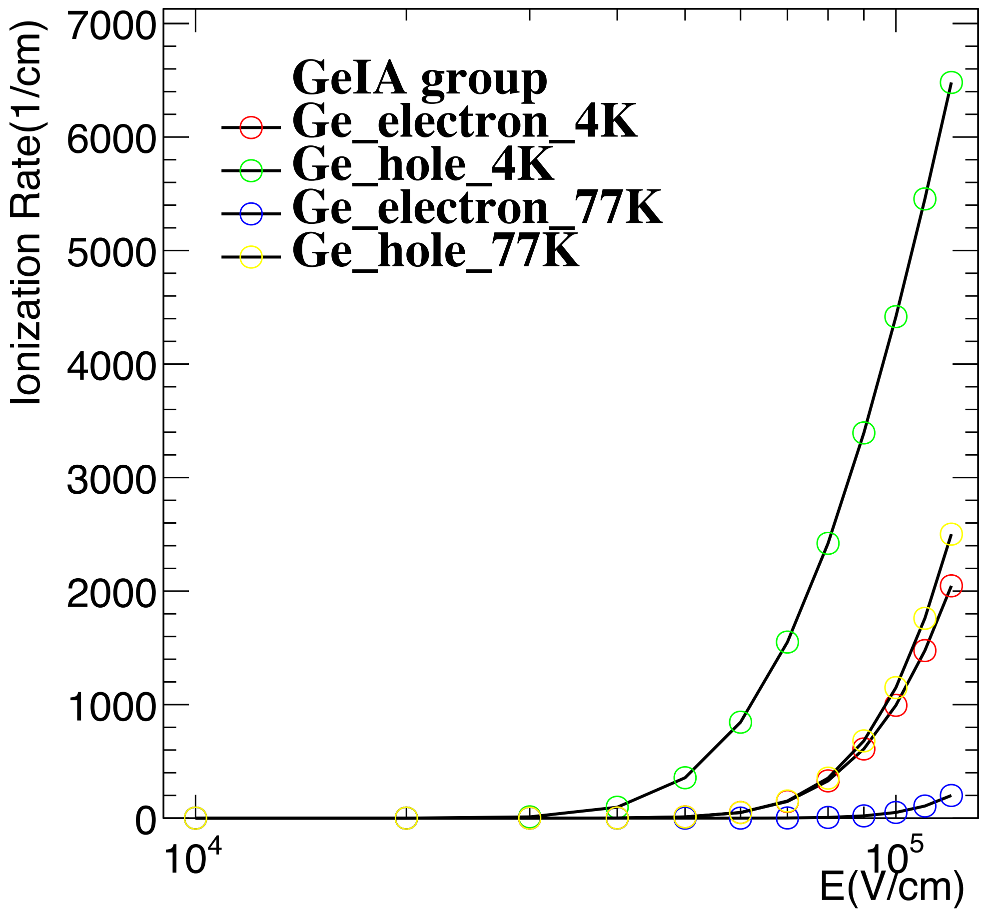
$$z(x) = 1 + \frac{b_n}{E(x)}\exp\left(-\frac{b_n}{E(x)}\right) + \frac{b_p}{E(x)}\exp\left(-\frac{b_p}{E(x)}\right) \qquad (20b)$$

and

$$a_s = \gamma_s = \frac{1}{L_s} \quad \text{and} \quad b_s = \frac{U_c^s \gamma_s}{q} \qquad (20c)$$

Important point: (1) Mean free path (2)Ionization energy

Results – Ionization rate(1/cm)



How many e-h can be produced per centimeter?

(1) Hole's rate is bigger than electron's for both of the temperature

➔ *P-type detector (Benefit)

(2) At 4K, the rates of both electron and hole are bigger than 77K individually.

➔ *4K is the winner in this case.

(3) We need to use at least $3\times10^4(\frac{V}{cm})$ to drive the Ge electron and hole if this case happens.

Conclusion and Prospect

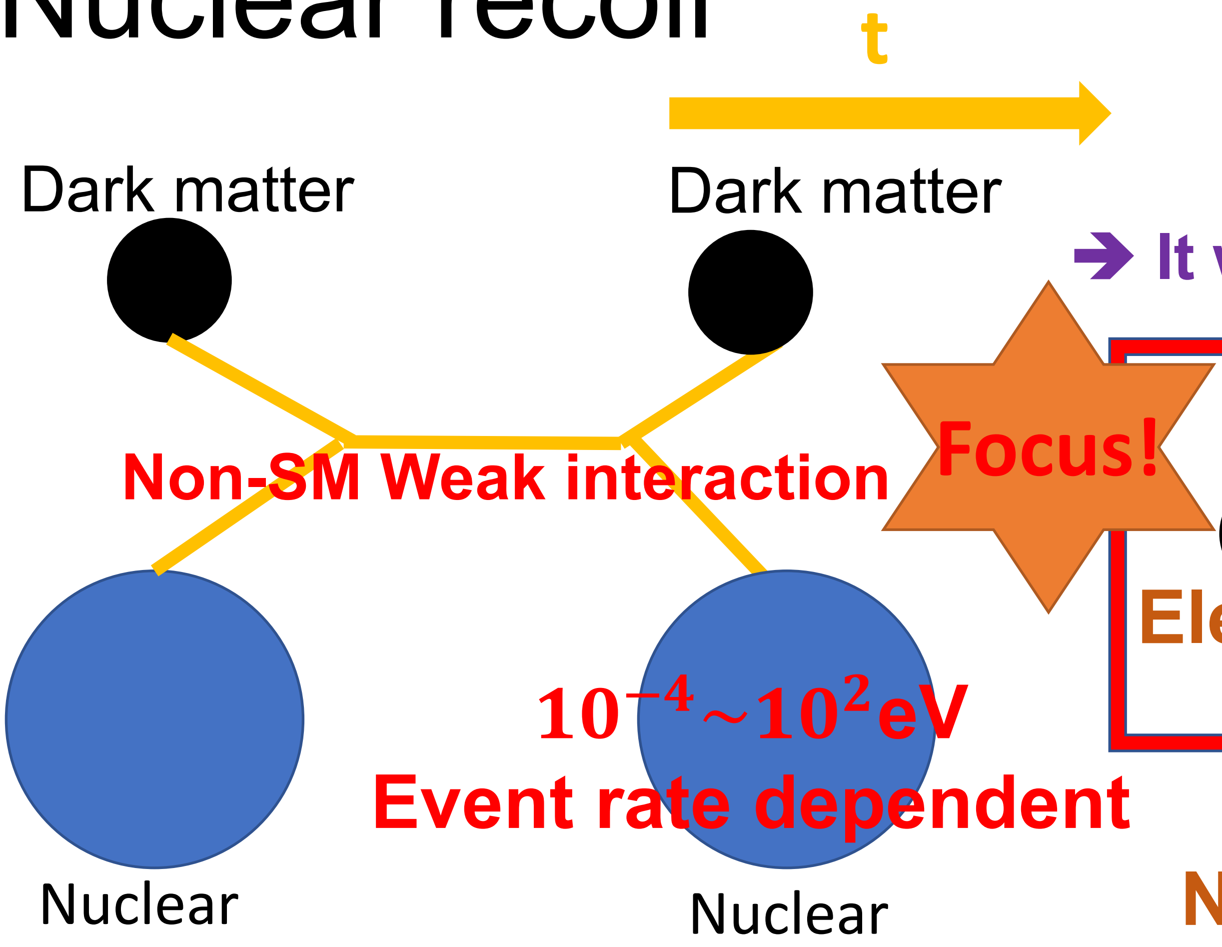
- For the ionization rate of the Ge electron and hole
- ➔ 4K is bigger than 77K for both of them.

- We need to use more than $\mathbf{3 \times 10^4}(\frac{\boldsymbol{V}}{\boldsymbol{cm}})$ to drive the Ge electron and hole

- Next step:
- (1) Figure out the ionization rate of the impurities
- (2) Jump into the real point contact detector
- ➔ Use the real electric field in the detector to figure out the gain.

BackUp

Nuclear recoil



Fake-Feynman diagram of DM-Nuclear scattering

After nuclear recoil

➔ It will collide with electrons and atoms

Electrons ➔ e-h pairs

(Effective ionization energy)

Electronic stopping of heavy ion

Atoms➔ phonons

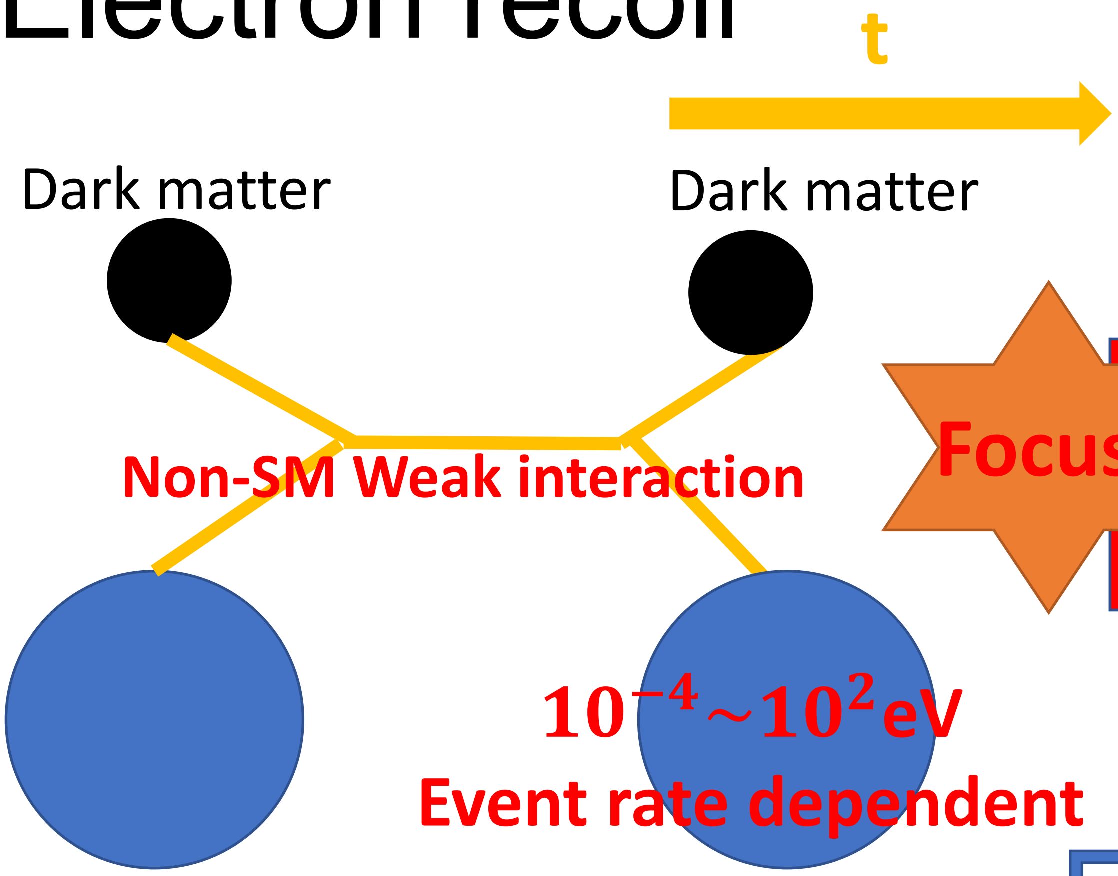
Nuclear stopping of heavy ion

Nuclear recoil (scattering off)

NR

$\frac{dE}{dX}$ **- dependent**

Electron recoil



Fake-Feynman diagram of DM-electron scattering

Electron recoil (scattering off)

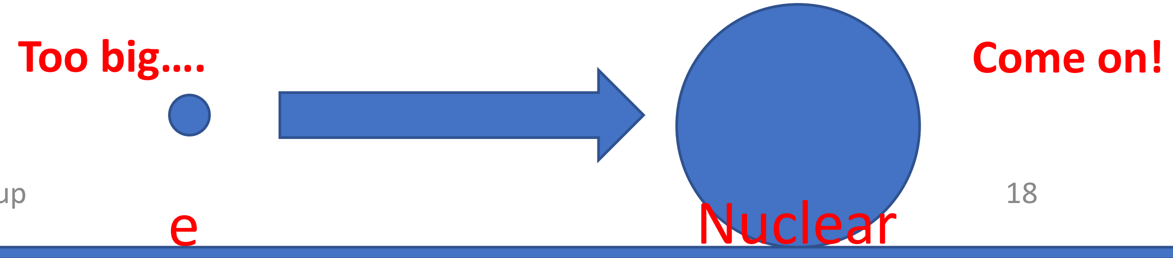
ER

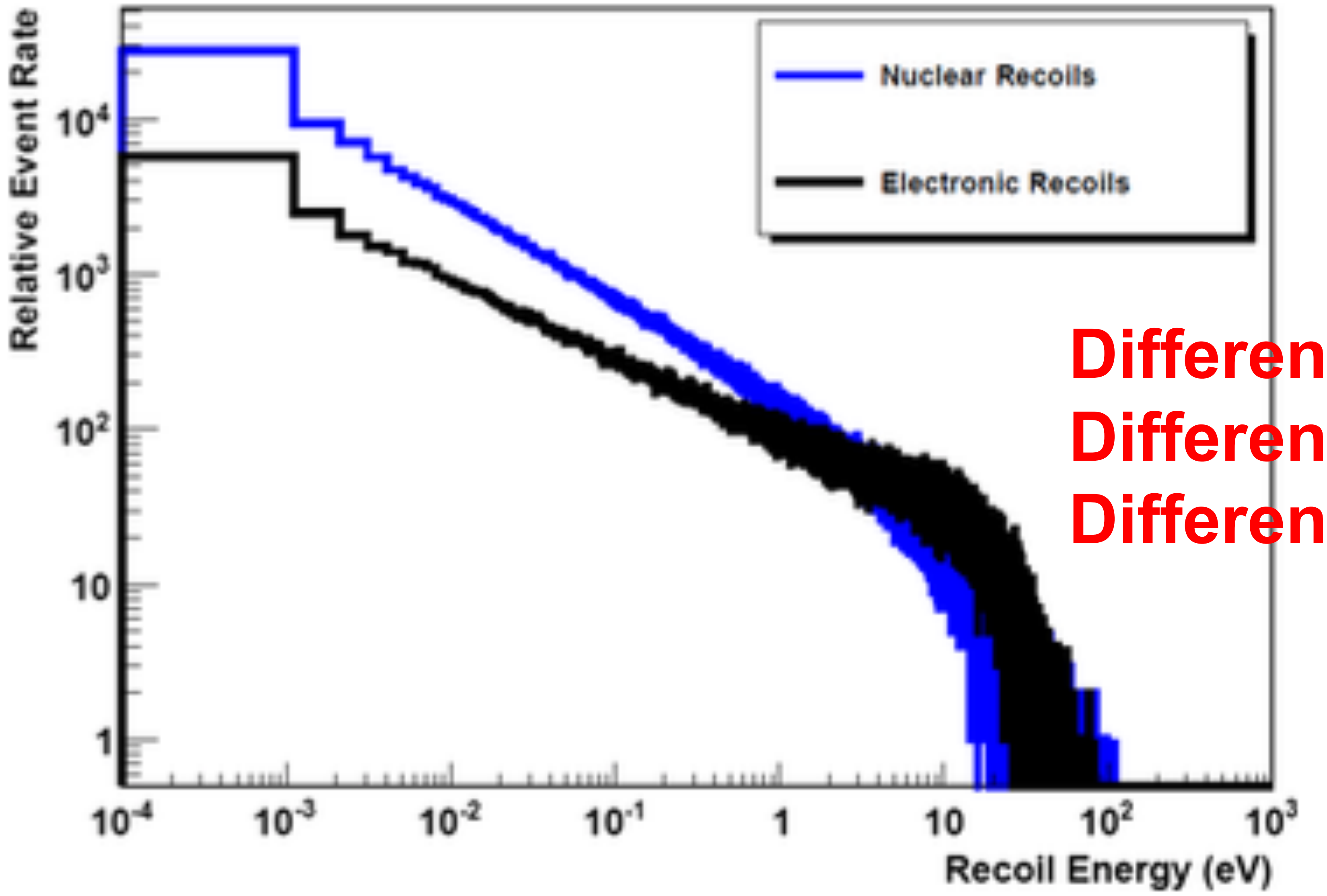
After the electron recoil
➔ It will collide with electrons

Focus!

Electrons ➔ e-h pairs
(Effective ionization energy)

No phonon basically! Can't give nuclear much energy





Different DM Mass
Different Recoil energy
Different Relative event rate!

GeV to MeV dark matters

Fig. 1 The relative event rate as a function of recoil energy for DM with masses between 0.1 MeV/c^2 to 1 GeV/c^2