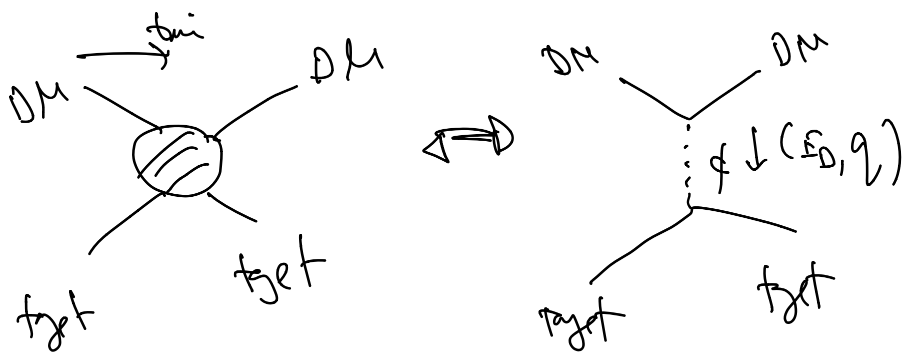
IV Direct Detection of Dark Matter:

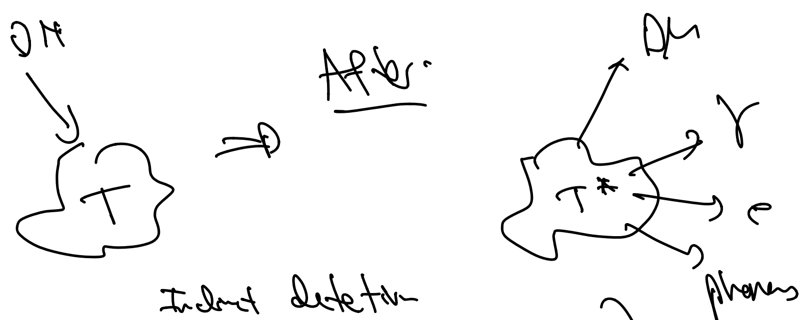
[Yonit Hochberg, HUJI]

DM interacts w/ target in a lab (typically deep underground)

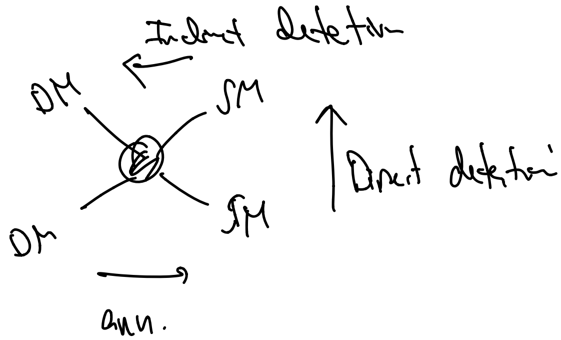


Before:

After:

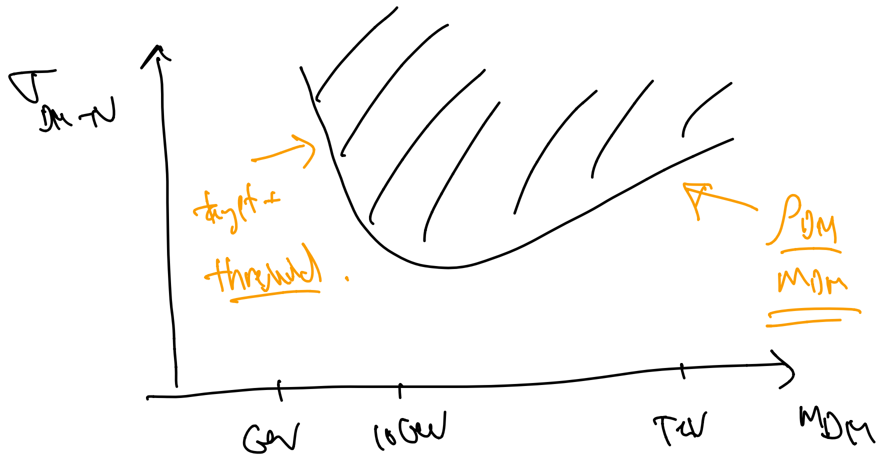


WIMP:



Many exp' searching for DM this way.

(Xenon1T, LUX, LZ.. PandaX, CRESST, DAMIC, DarkSide, CDMS ....)



$$\text{Rate} \sim \frac{1}{\rho_T} \cdot (\text{DM flux}) \, (\text{target properties}) \cdot \sigma_{int}$$

(DM flux) = $n_{DM} \cdot \underline{v}$

$$\int d^3v \, f(v)$$

↑ velocity dispersion ($\sim 10^{-3}$)

Standard Halo Model:

$$f(v) = \frac{4\pi v}{N_E} \, e^{-v^2/v_0^2} \, \Theta(v_{esc} - v_x)$$

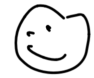
$v_0 = 220$ km/sec, $v_{esc} \sim 500$ km/sec.

$\rho_{DM} \sim 0.3$ GeV/cm^3

Experiments typically looking for Nuclear recoil:

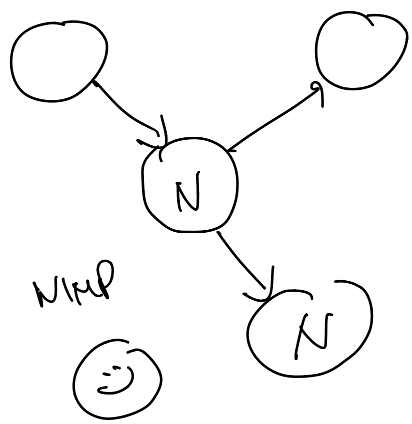
$$E_{NR} = \frac{q^2}{2m_T} \sim \frac{(m_\chi v)^2}{2m_T} \sim eV \left(\frac{m_\chi}{100\,MeV}\right)^2 \left(\frac{20\,GeV}{m_T}\right)$$

$$\overset{!}{\gtrsim} E_{th.} \sim keV$$

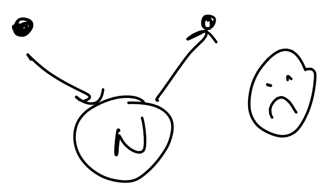
$m_\chi \sim 30$ GeV - $E_{NR} \sim 2$ keV 

$m_\chi <$ GeV $\longrightarrow$ 

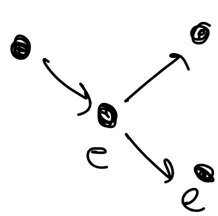
Billiard Balls:



≠ ping pong ball trying to kick a big bowling ball



⇒ Smarter to scatter off of something lighter!



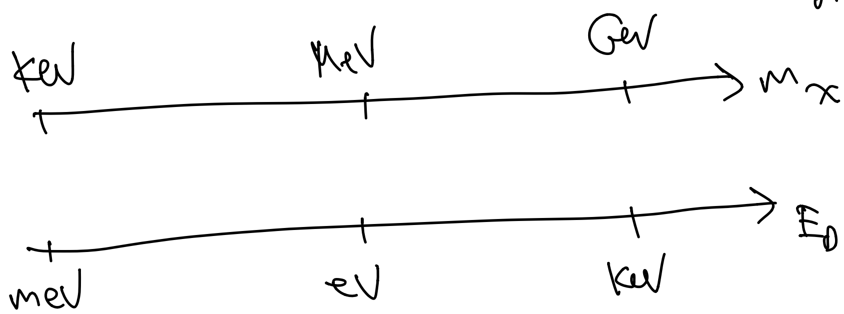
Scatter off electrons.

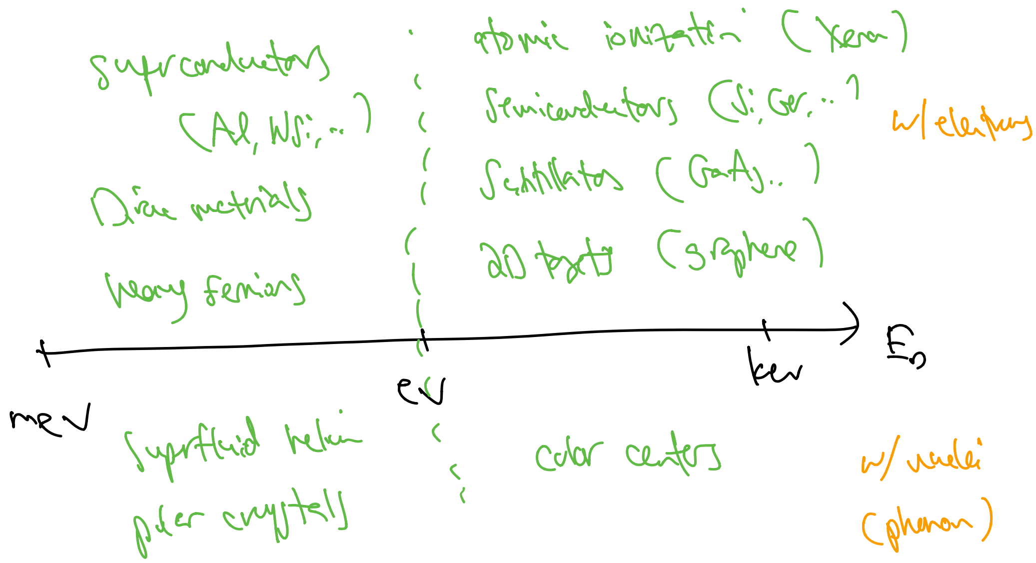
⇒ Basic notion behind new idea in the literature!

Energy guideline:

Scattering – $E_{D,max}$ = entire kinetic energy $\sim m_\chi v^2 \sim 10^{-6} m_\chi$

($v \sim 10^{-3}$)





Walk through a few of these.

<u>Sidenote (1)</u>: I Rate $\propto \sigma_{int}$, typically written as reference cross section, times form factor:

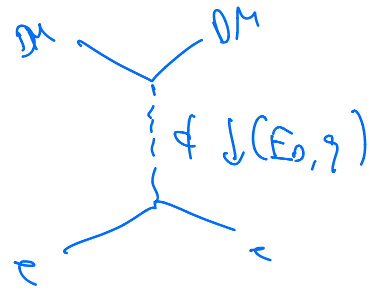
$$\bar{\sigma}_e \cdot |F_{DM}|^2$$

↑ cross section @ fixed momentum transfer

$q_{ref} = \alpha m_e$

(typical for semiconductors)

↖ Correct for momentum dependence:



propagator $\sim \frac{1}{m_\phi^2 + q^2}$ $\quad (E_D \ll q)$

$$\Rightarrow \quad |F_{DM}|^2 = \begin{cases} 1 & m_\phi \gg \alpha m_e \quad \text{heavy med.} \\ \frac{(\alpha m_e)^2}{q^2} & m_\phi \ll \alpha m_e \quad \text{light med.} \end{cases}$$

Sidenote ②: Rate $\propto$ target properties

Historically - computed using overlap of single particle excitations. More general method -

Dielectric function ↔ loss function:

$$\mathrm{Im}\left(- \frac{1}{\epsilon(q, E_D)} \right)$$

Measurable!

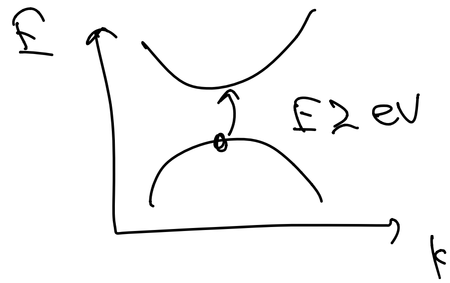
[YH et al, 2101.08263]

[Automatically includes many-body effects.]

Ex. #1 - First ideas:

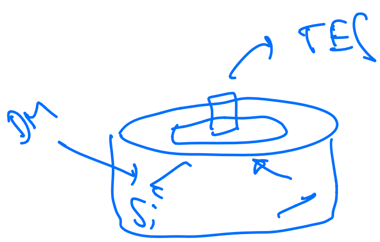
Atomic ionization / Semiconductors

$E \gtrsim 10$ eV



$\Rightarrow \quad m_\chi \gtrsim$ MeV [Essig et al 2012, 1509.01598 details]

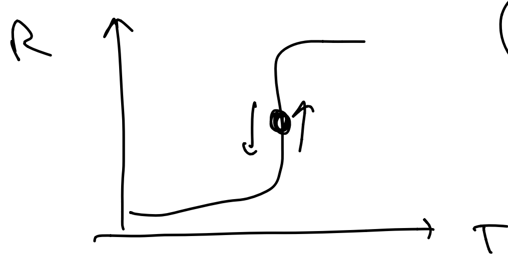
(SENSEI) SuperCDMS:



"Excitation concentration" philosophy.

Transition Edge Sensors (TES):

(Superconductor)



lower masses? $m < \text{MeV}$:

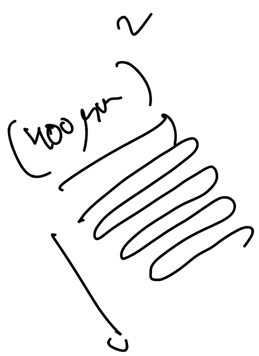
Ex #2: Superconductors ;

Ground state = Cooper pairs ~ $O(\text{meV})$

$\Rightarrow m \gtrsim \text{keV}$

"Target + sensor" philosophy: [YH et al 1903.05101]

Superconducting Nanowire Single Photon Detectors (SNSPDs) — mature technology from quantum sensing

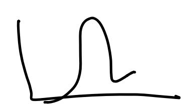


← DM

hotspot

resistive region across nanowire

$\Rightarrow$ voltage pulse

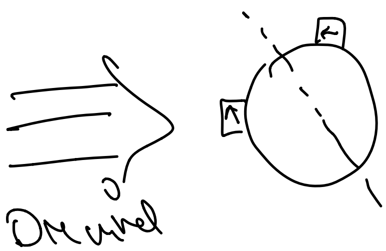


$E_{th} = 125\ \text{meV}$

(4.3 ng, 0.8 eV)

Ex #3: Directional information — Directional Detector?

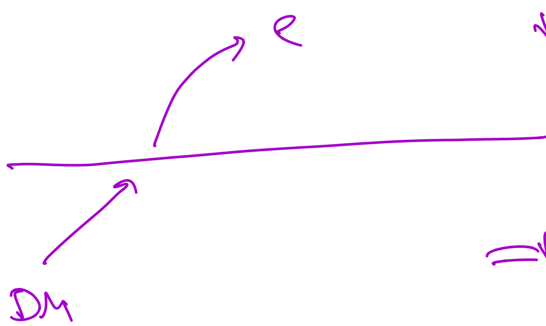
Directional detection long been recognized as powerful tool for DM detection — daily modulation rate & separate signal from backgrounds:



"Eject & detect" philosophy —

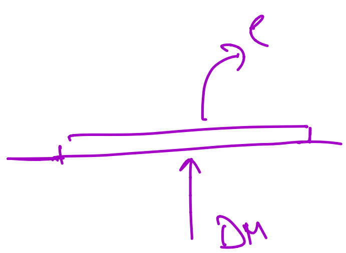
2D targets

graphene: ejected electron tracks the direction of DM!

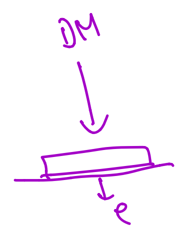


$E_{eject} \gtrsim \mathcal{O}(\text{few eV})$

$\Rightarrow m_\chi \gtrsim$ MeV

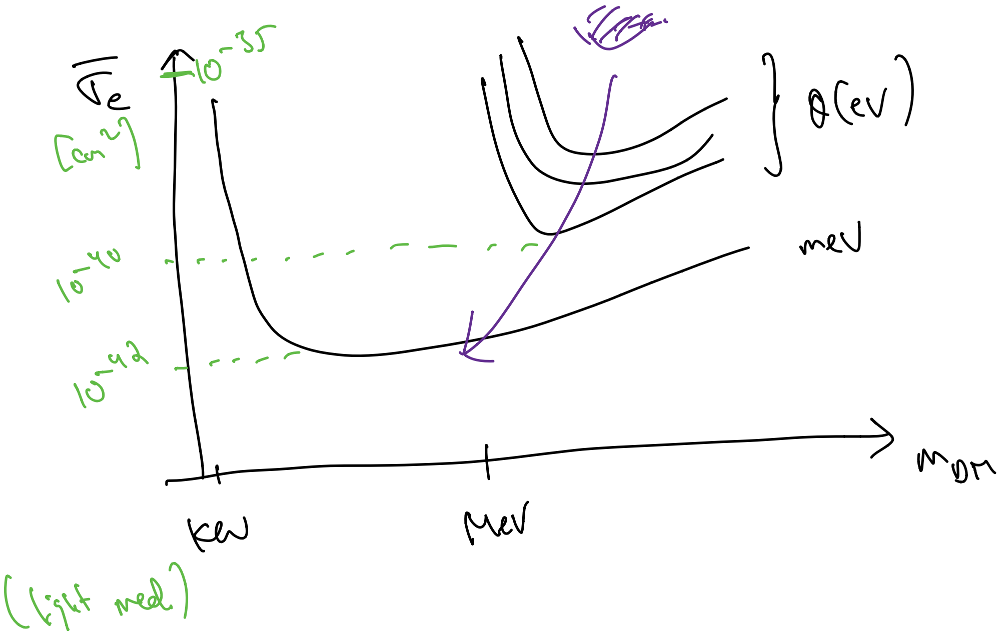


12h later:



Forward-Backward asym!

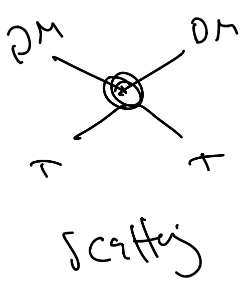
[PTOLEMY exp!] [1606.08849]

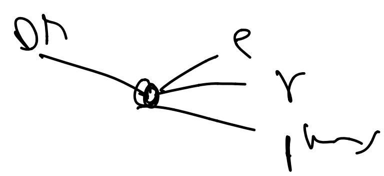


Any target material can go further:

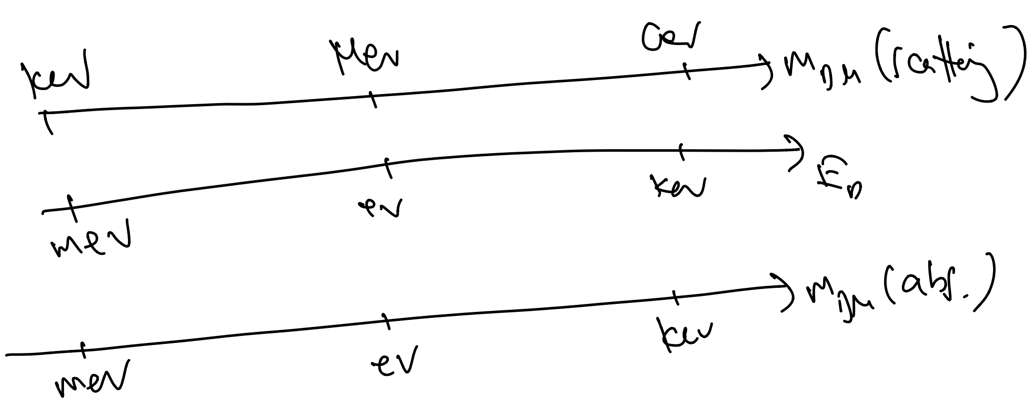
2 for the price of 1

DM absorption:





$E_D \sim m_{DM}$



⇒ Summary :

DM : existing – mechanisms
- models
- ways to detect.