Carbon Nanotubes in Directional Dark Matter Searches

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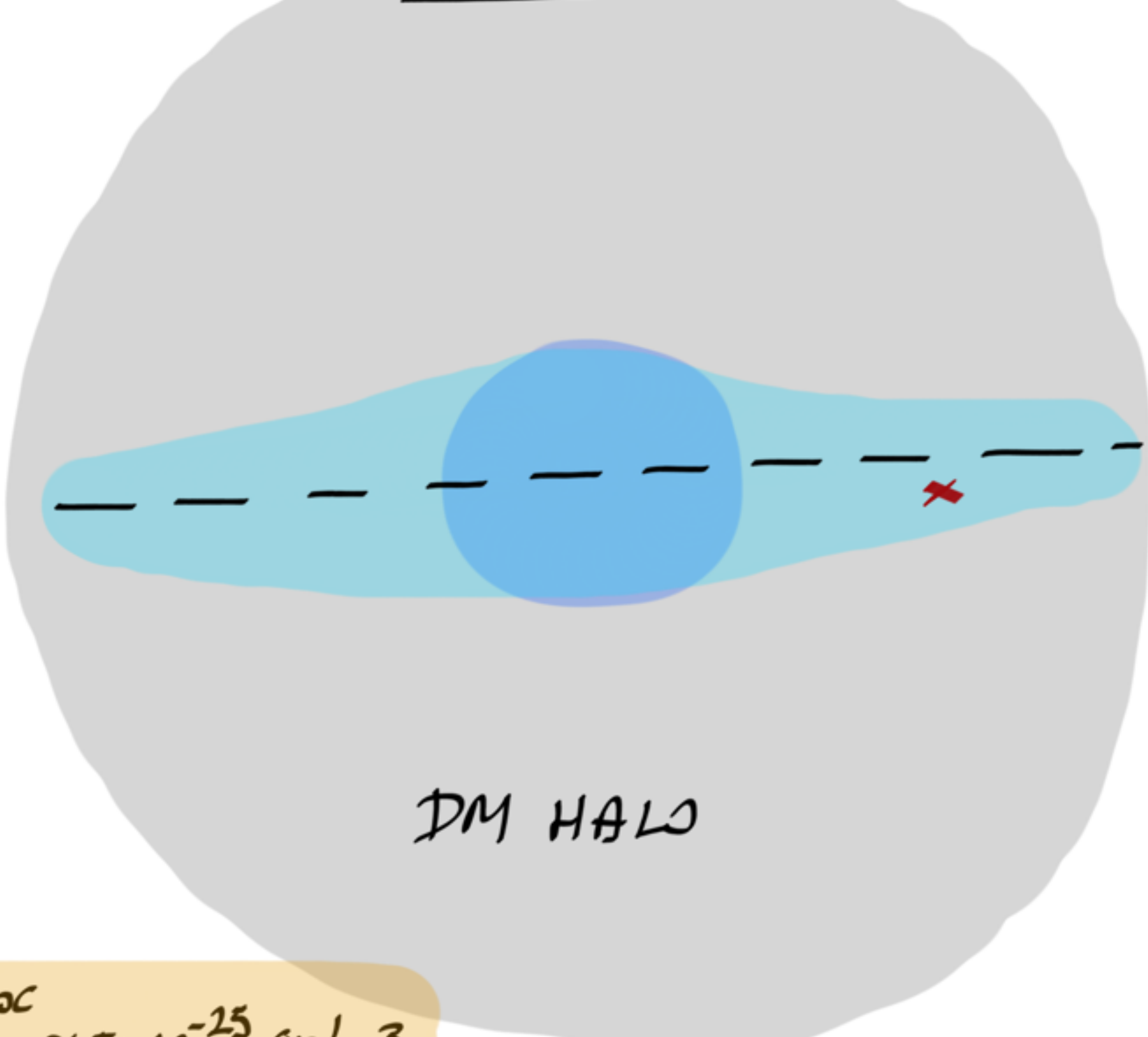
DARK MATTER



$$\rho_{DM}^{Loc} \approx 5\times10^{-25}\ gr/cm^3$$

IDENTIKIT

1. Interacts gravitationally
2. Does not emit UV, IR, X, RADIO, ...
3. Probably pervades universe
   ~ uniformly
4. Should be cold
5. No planets // Rocks // Dust

   (distant objects would look more opaque)

Dark Matter particles?

1. Interacts gravitationally
2. Stable
3. Massive
4. Neutral
5. "Cold"

Neutrinos?

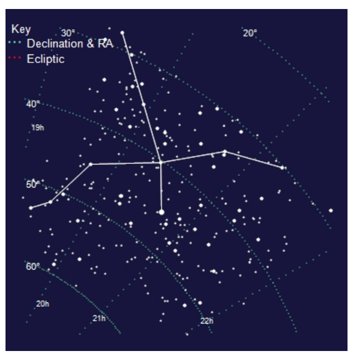
Early Universe: hot & dense

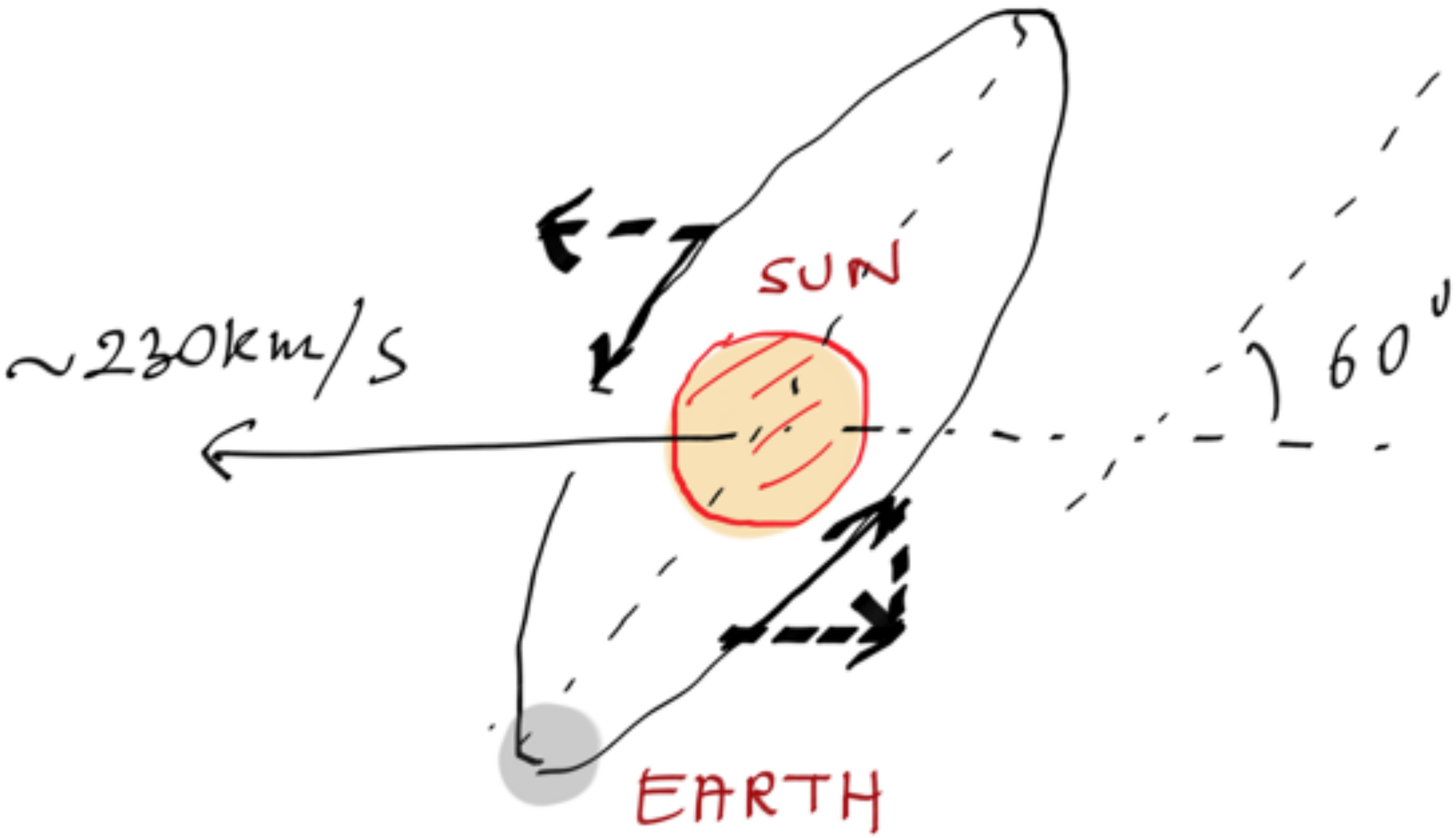
$$e^- p \rightleftarrows n \nu$$

Expansion & Cooling: few leftover ν's

relic ν's $\simeq 100/cm^3$

WIMP WIND





$$\vec{w}(t) = [232 + 15\cos\psi(t)]\,\hat{k}$$

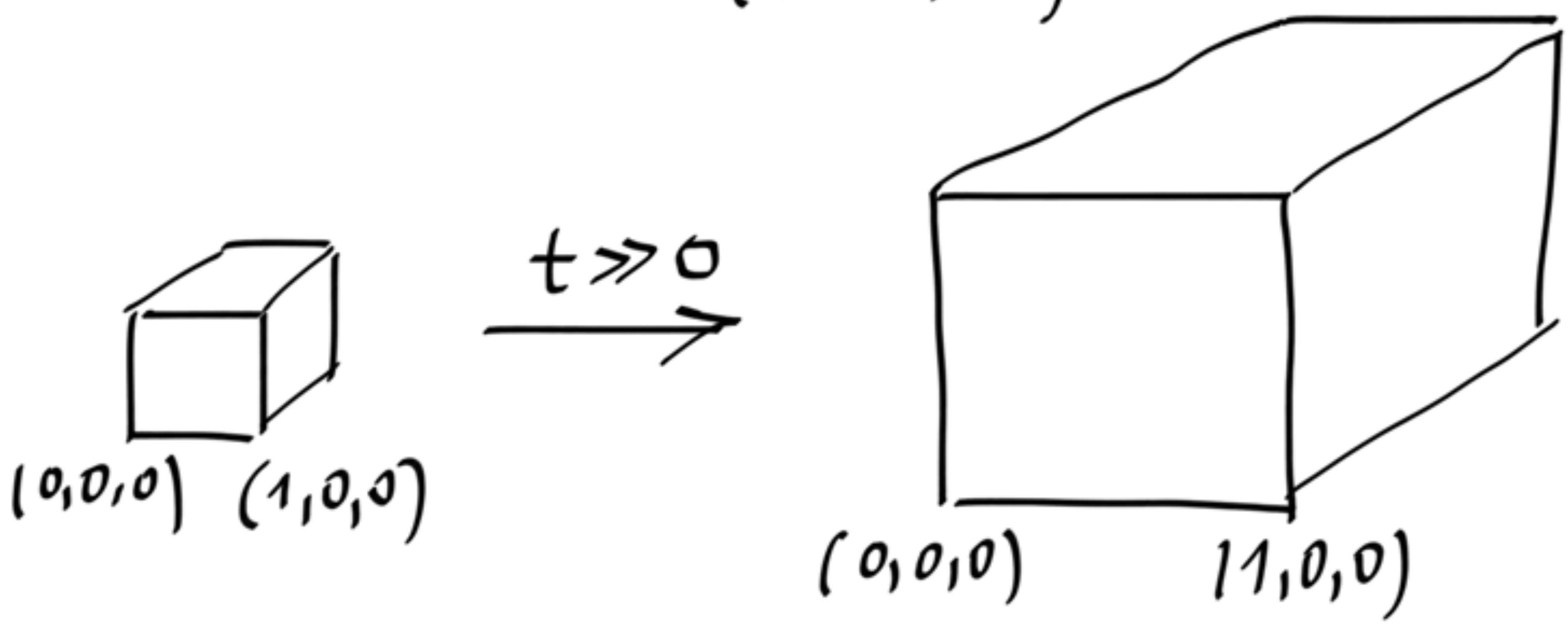
$$\psi(t) = 2\pi\,\frac{t - 152.5}{365.25}$$

WIMPS

$t \approx 0 \qquad n_\chi \sim n_{\bar{\chi}}$

$\chi\bar{\chi} \rightleftharpoons$ STANDARD PART.

$$n_\chi = \frac{\#}{(1 \cdot a(t)\,\mathrm{cm})^3}$$



NUMBER DENSITY DROPS W/ TIME

WIMPS II

$$n(t)\,a^3(t) = n(t_0)\,a^3(t_0) \quad ?$$

$$n(t)\,a^3(t) = \frac{n(t_0)\,a^3(t_0)}{1 + n(t_0)\,a^3(t_0)\displaystyle\int_{t_0}^{t} \frac{\langle v\sigma\rangle_T}{a^3(t')}\,dt'}$$

$t \to \infty$

— If $I = 0$ the number of particles in a COMOVING VOLUME does not change

— If $I = \infty$ THERE ARE NO LEFT-OVER WIMPS

WIMPS III

$\chi\bar{\chi} \rightarrow$ STANDARD PART. EXOTHERMIC

— $k \to 0$, $k' \to$ const.

$$v\sigma \to k \cdot \frac{k^{2\ell+1} \cdot \text{const}}{k^2} \sim \text{const.}$$

S-wave

— $$\langle v\sigma \rangle_T \sim \int_0^\infty dE\, e^{-E/T}\, v\sigma \sim \text{const.}$$

low T (later t)

— $$\int_{t_0}^{t} \frac{\langle v\sigma \rangle_T}{a^3(t')} dt' \sim \text{const.} \int_{t_0}^{t} \frac{dt'}{(t'/\tau)^2}$$

I finite even if $t \to \infty$

RELIC WIMPS

χ with $M_\chi \approx 100\,\mathrm{GeV}$ and

$$\langle v\sigma \rangle \sim 10^{-26}\,\mathrm{cm}^3/\mathrm{sec}$$

gives a

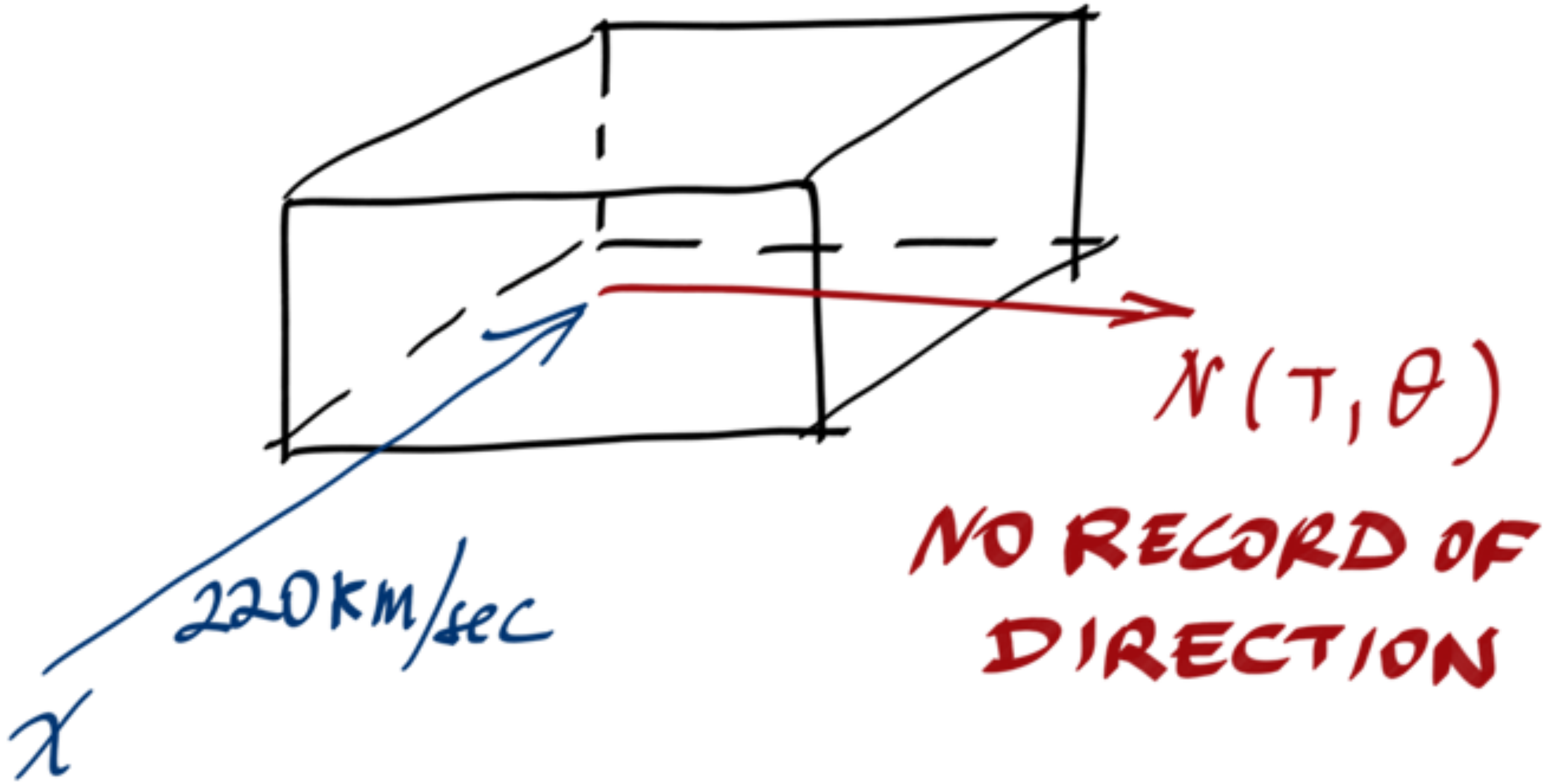
$$\Omega_{DM} = \frac{\rho_{DM}}{\rho_{crit}} \approx 0{,}2$$

$$\frac{\rho_\gamma + \rho_b + \rho_\nu + \rho_{DM}}{\rho_{crit}} + \Omega_\Lambda = 1$$ FLAT UNIVERSE

ON LARGE SCALES DM DOMINATES

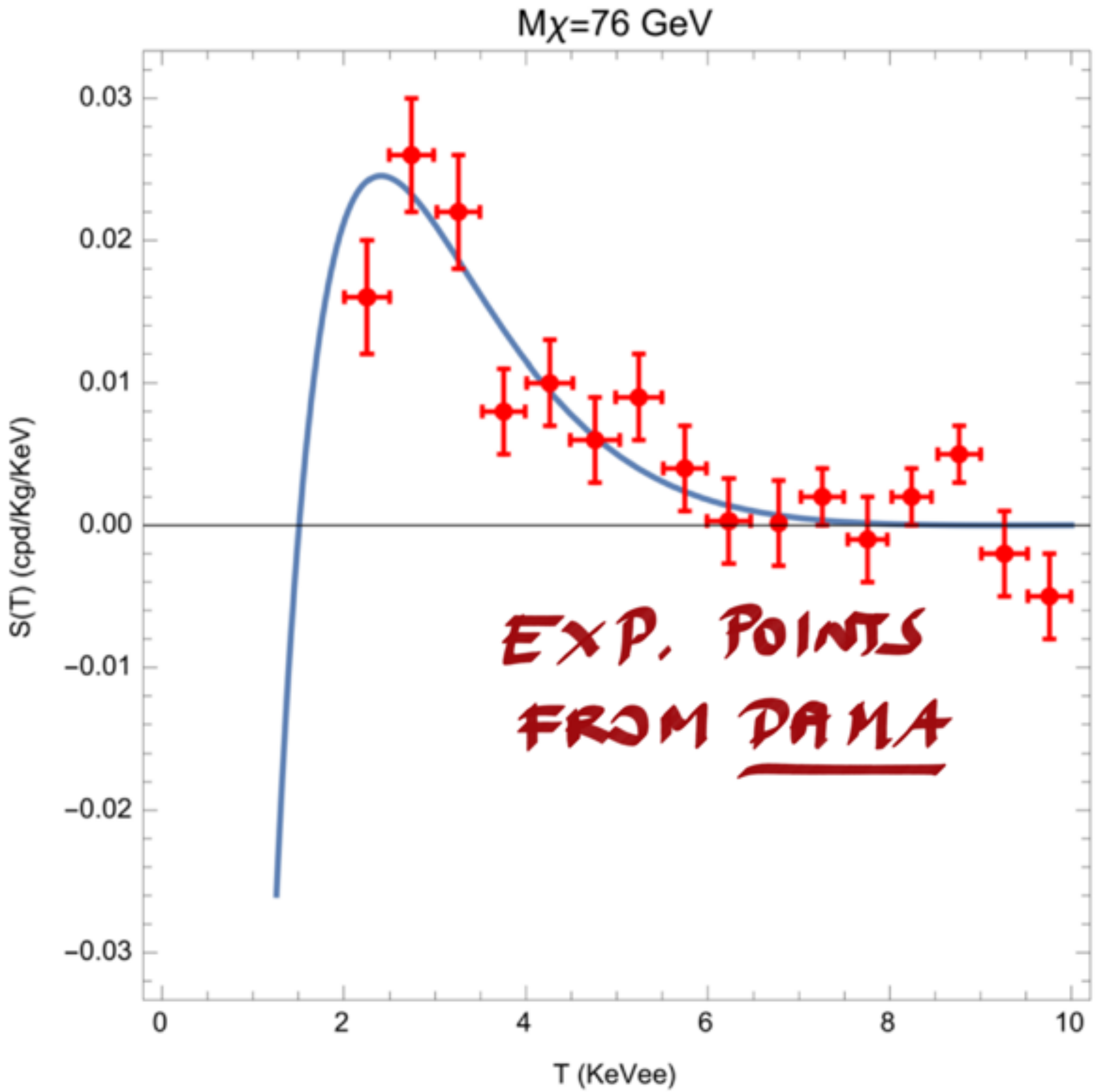
84.5%

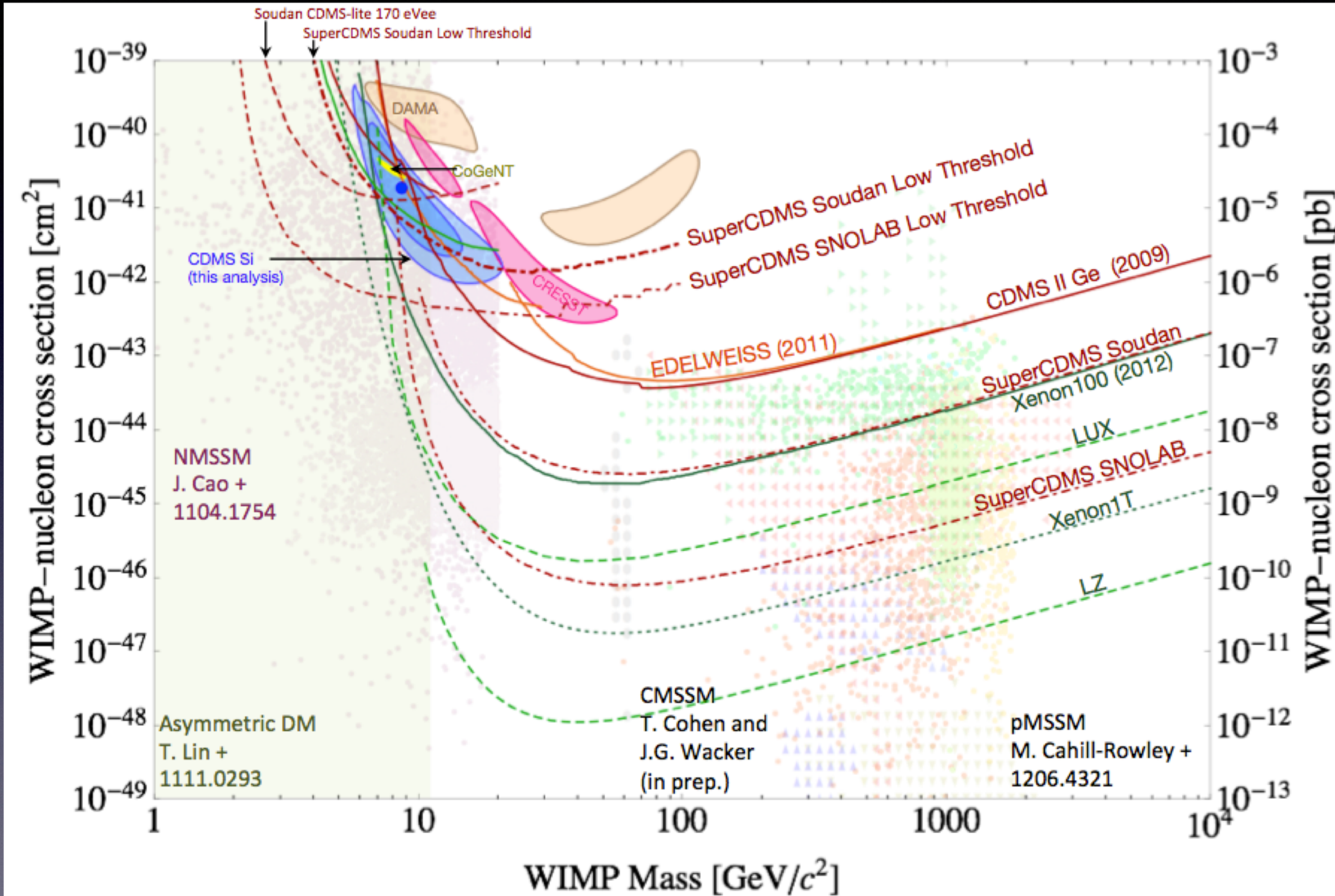
RECOILS BY RELIC WIMPS



$$\frac{d\Gamma}{dT} = A(T) + S(T)\cos(\omega t + \varphi)$$

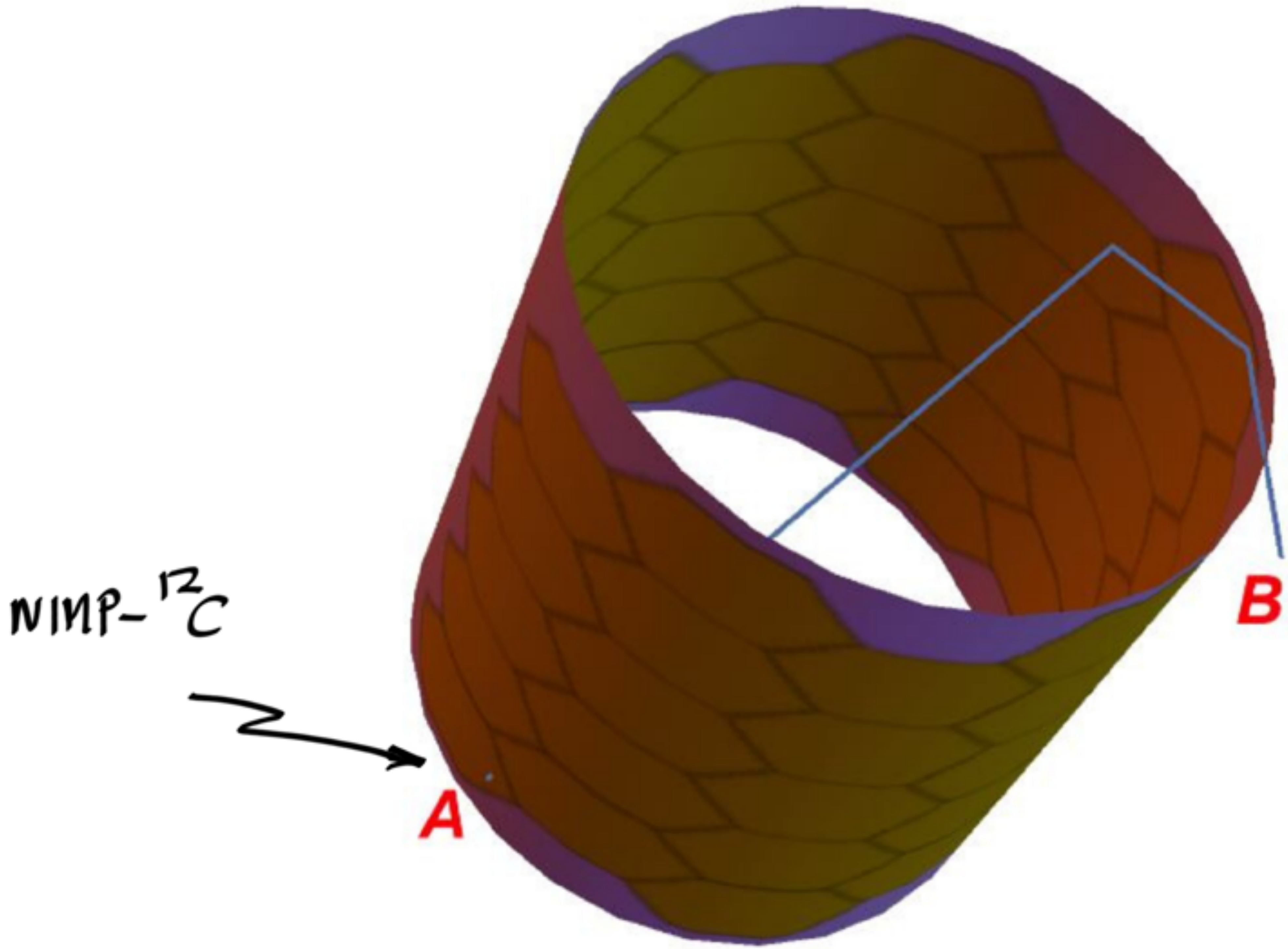
THE S(T) AMPLITUDE

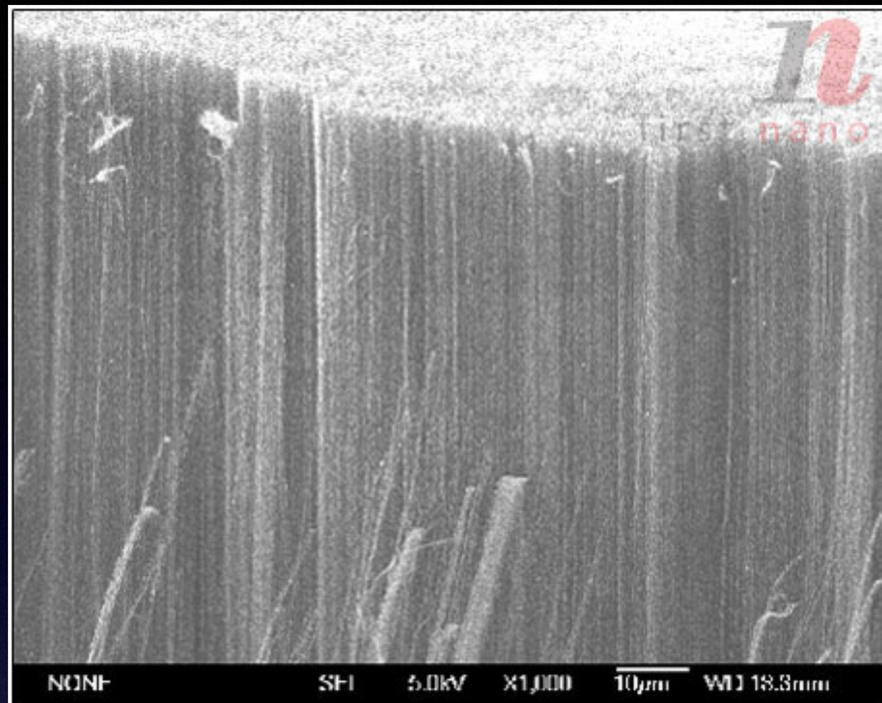


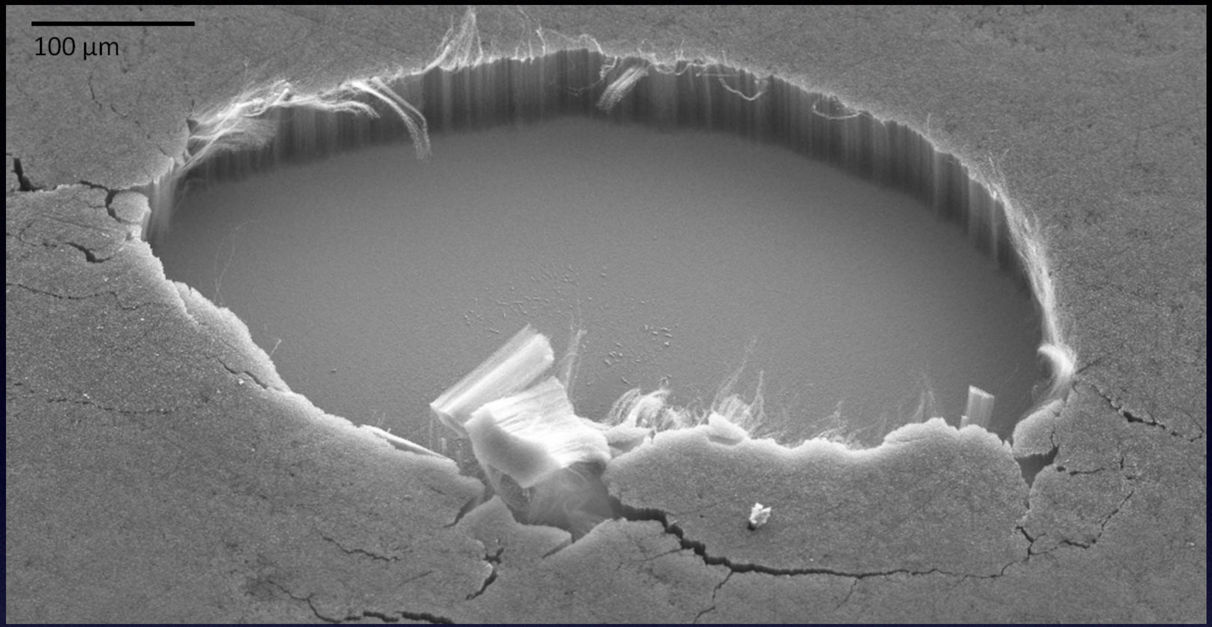


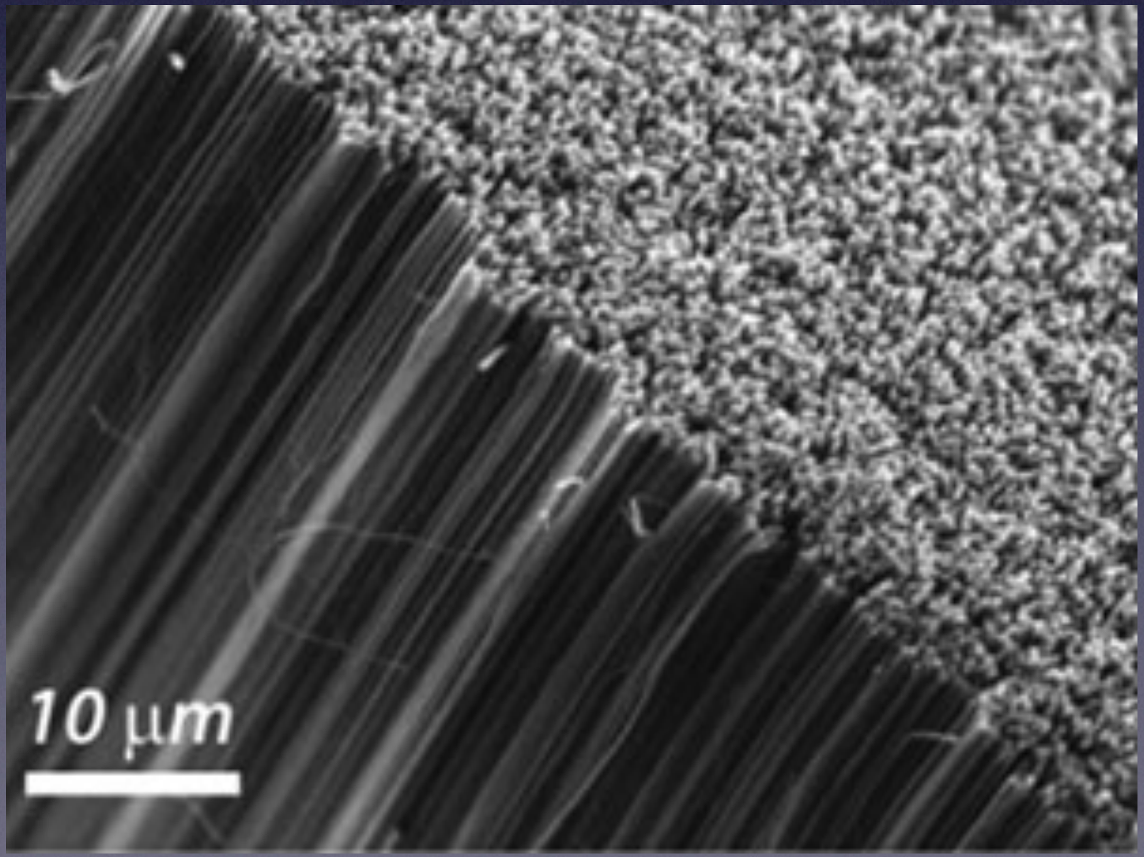
Soudan CDMS-lite 170 eVee
SuperCDMS Soudan Low Threshold
DAMA
CoGeNT
CDMS Si
(this analysis)
CRESST
SuperCDMS Soudan Low Threshold
SuperCDMS SNOLAB Low Threshold
CDMS II Ge (2009)
EDELWEISS (2011)
SuperCDMS Soudan
Xenon100 (2012)
LUX
SuperCDMS SNOLAB
Xenon1T
LZ
NMSSM
J. Cao +
1104.1754
Asymmetric DM
T. Lin +
1111.0293
CMSSM
T. Cohen and
J.G. Wacker
(in prep.)
pMSSM
M. Cahill-Rowley +
1206.4321
WIMP–nucleon cross section [cm^2]
WIMP–nucleon cross section [pb]
WIMP Mass [GeV/c^2]
10^{-39}
10^{-40}
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
10^{-49}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
1
10
100
1000
10^4

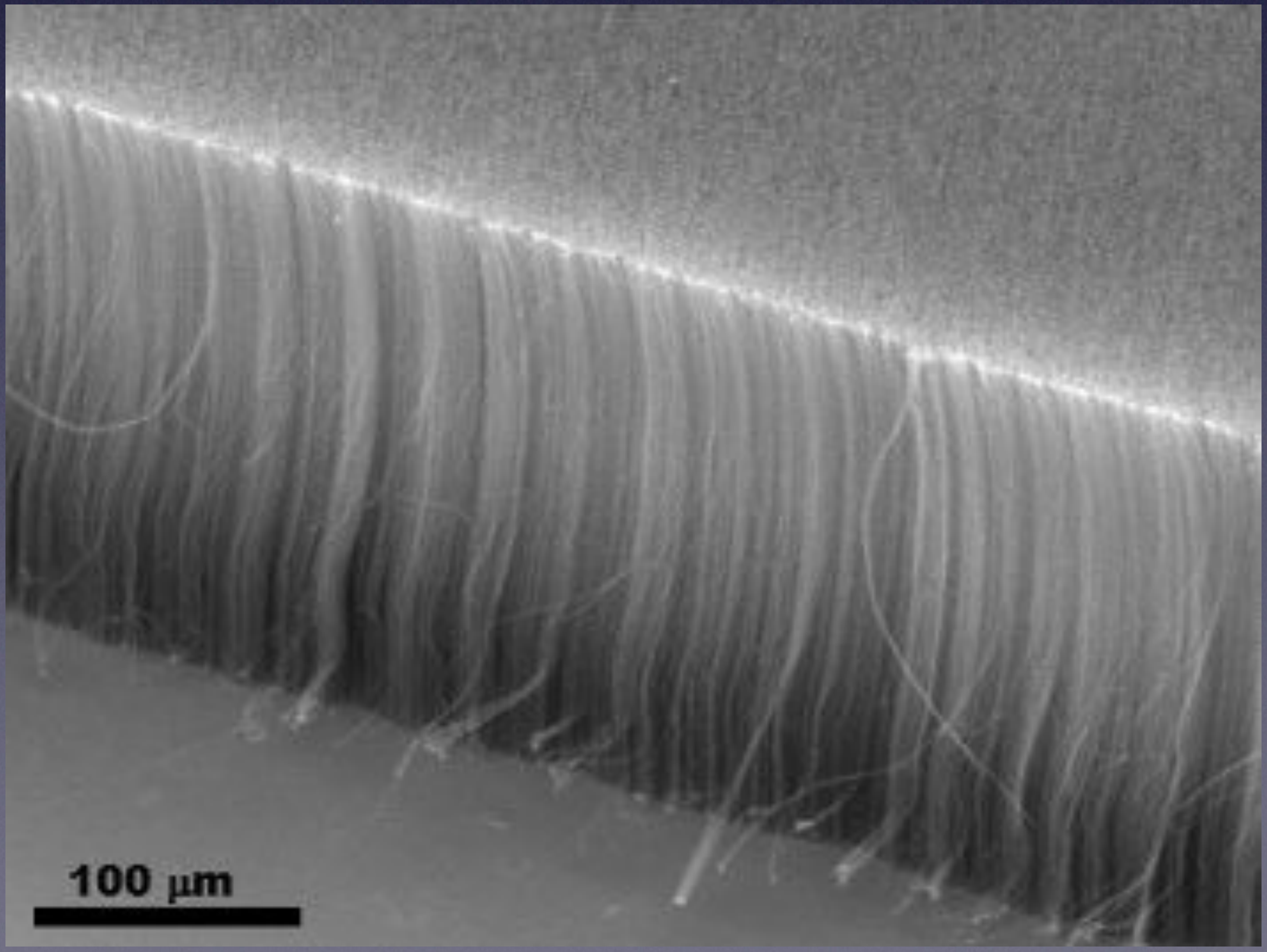
DIRECTIONALITY



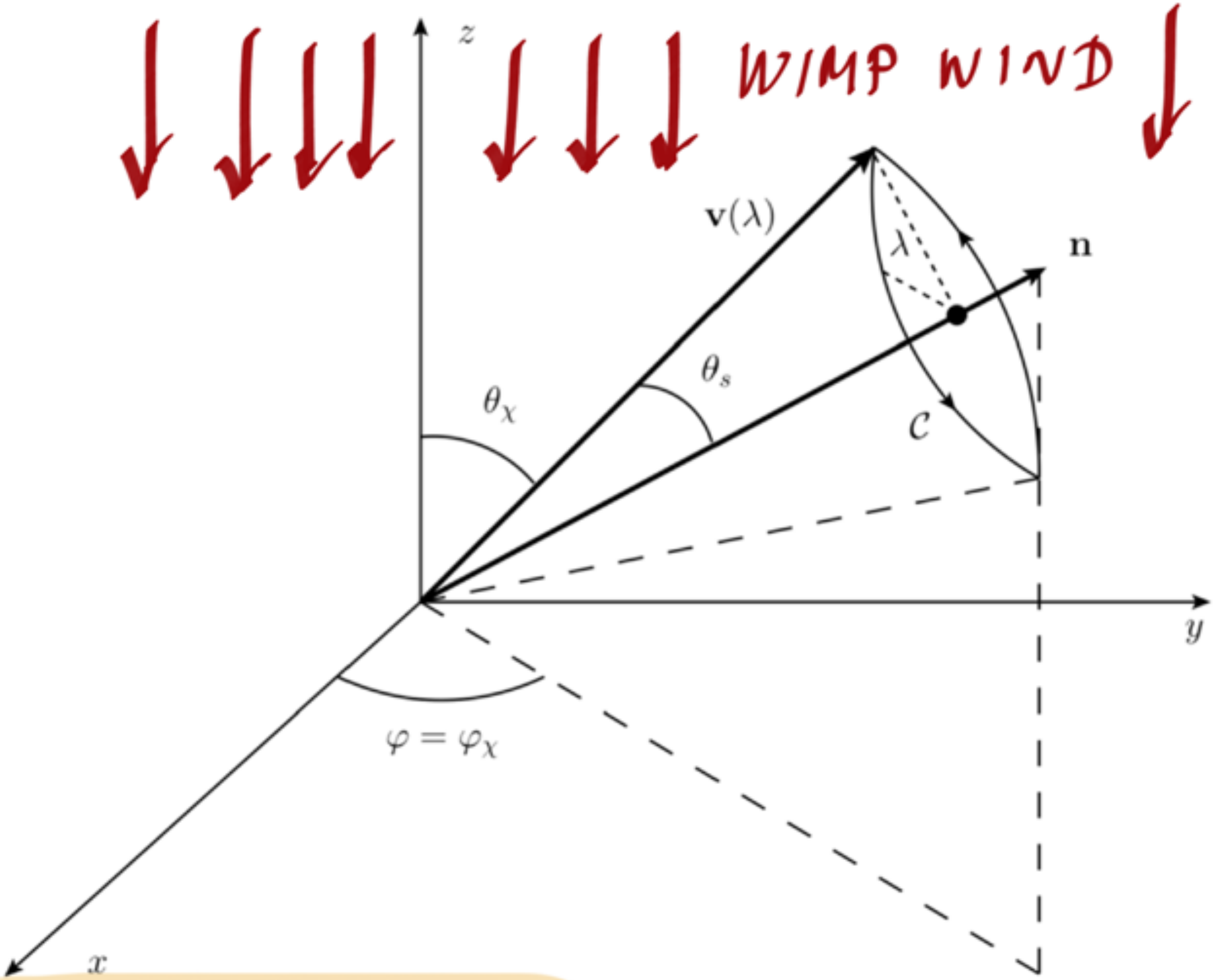

5.0kV
X1,000
10μm


100 µm


10 µm


100 µm

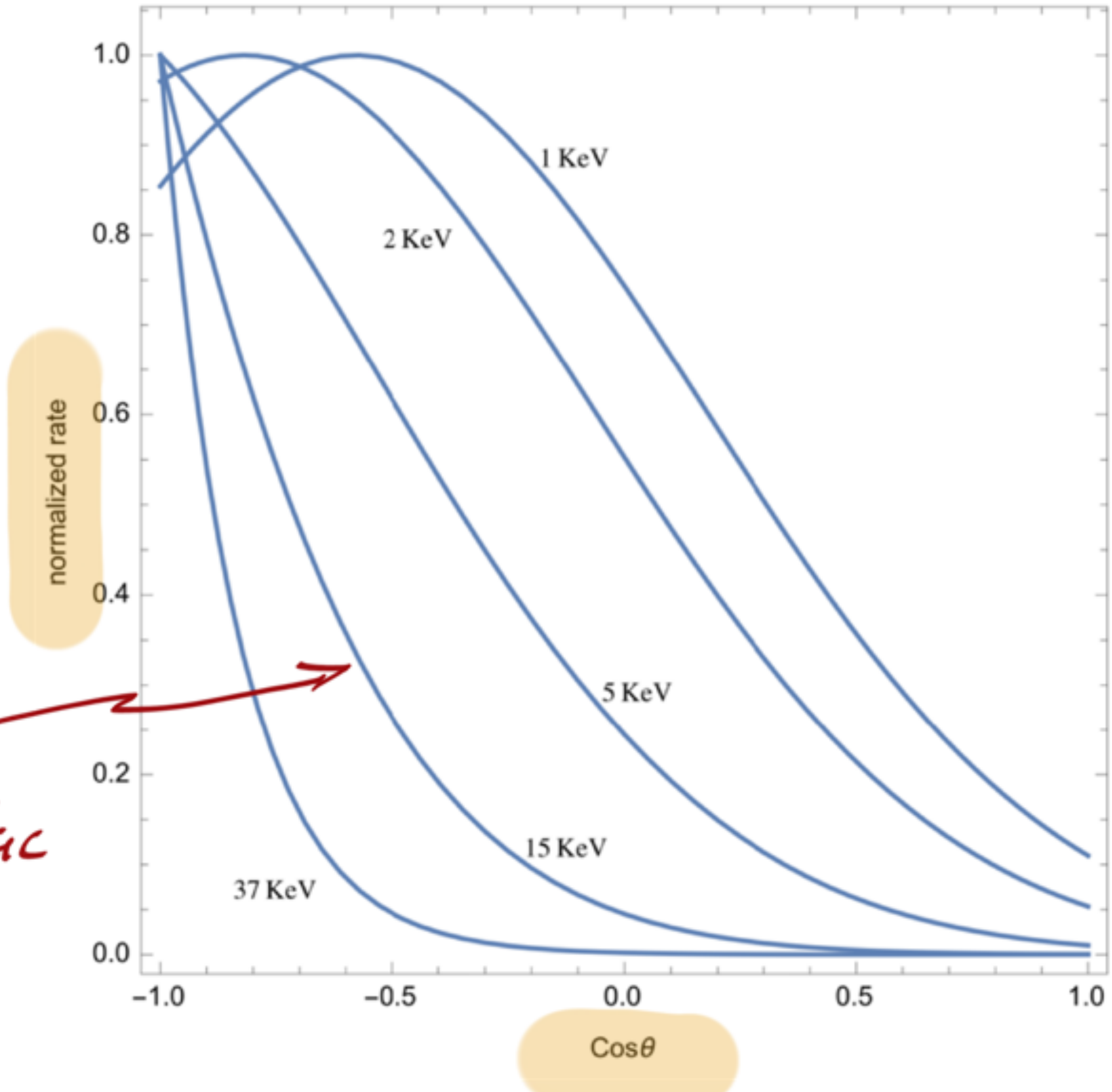
NUCLEAR RECOIL



$$f(\mathbf{v}') = \beta e^{-\alpha \mathbf{v}'^2}$$

$$\mathbf{v}' = \mathbf{v} + \mathbf{w}$$

CARBON NUCLEI RECOILS



$M_\chi \gg M_N$

$v \sim 230$ km/sec

RECOIL RATES

$$\frac{d\Gamma}{dT\,d\cos\theta} = \frac{m_\chi G_A^2 F_A^2 (2M_N T)}{16 M_\chi^2 \sqrt{2M_N T}} \int_{\sqrt{\frac{2T}{\mu}}}^{v_{max}} dv \cdot v\beta e^{-\alpha A(t)} I_0(\alpha B(t))$$

$$A(t) = v^2 + w^2(t) + 2v\cos\theta_s \cos\theta\, w_z(t)$$

$$B(t) = 2v \sin\theta_s \sin\theta\, w_z(t)$$

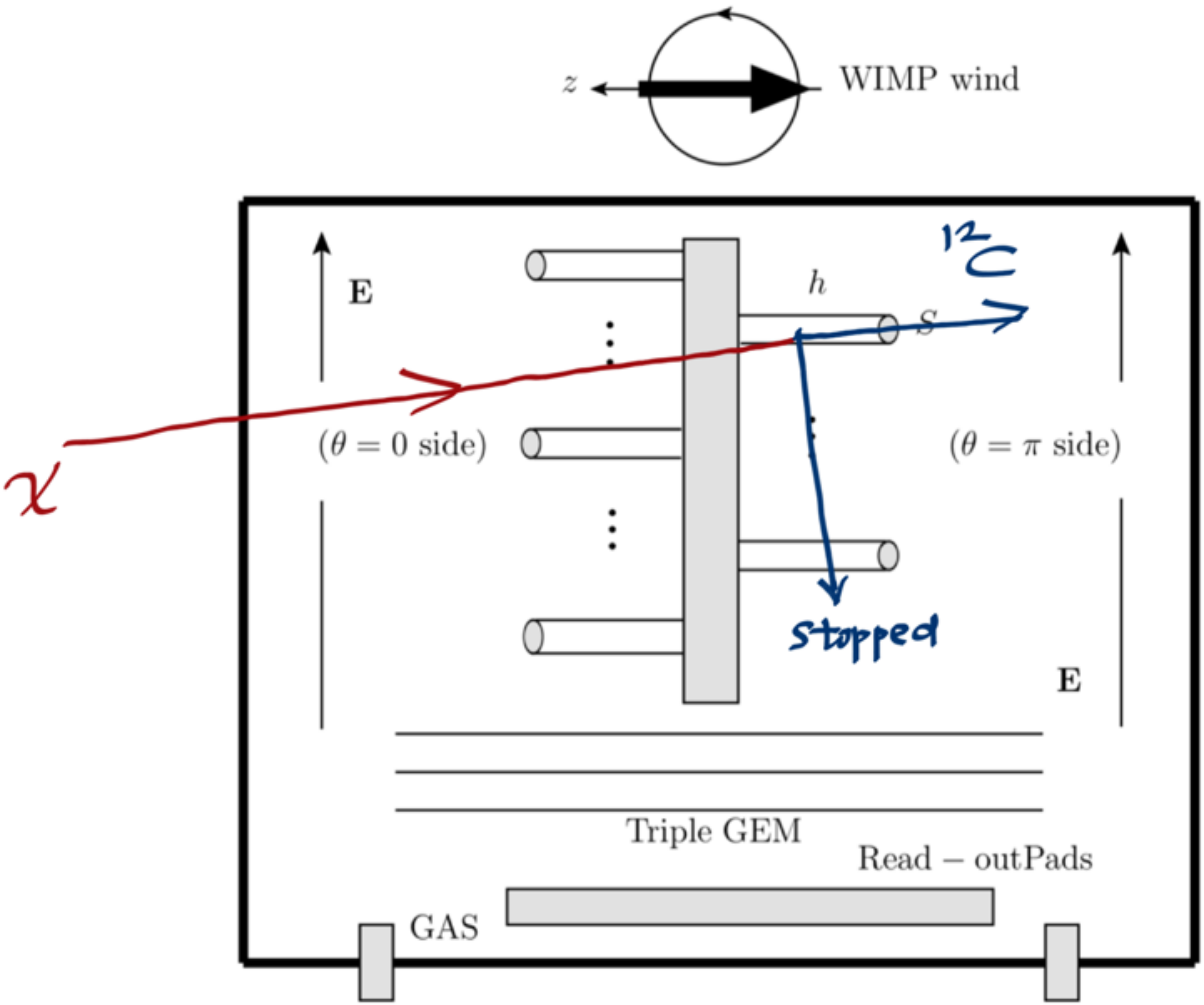
$$\cos\theta_s = \sqrt{2T/\mu v^2}$$

$$\mu = \frac{4M_\chi^2 M_N}{(M_\chi + M_N)^2}$$

SCATTERING INJECTS AN ION ^{12}C IN A WITH

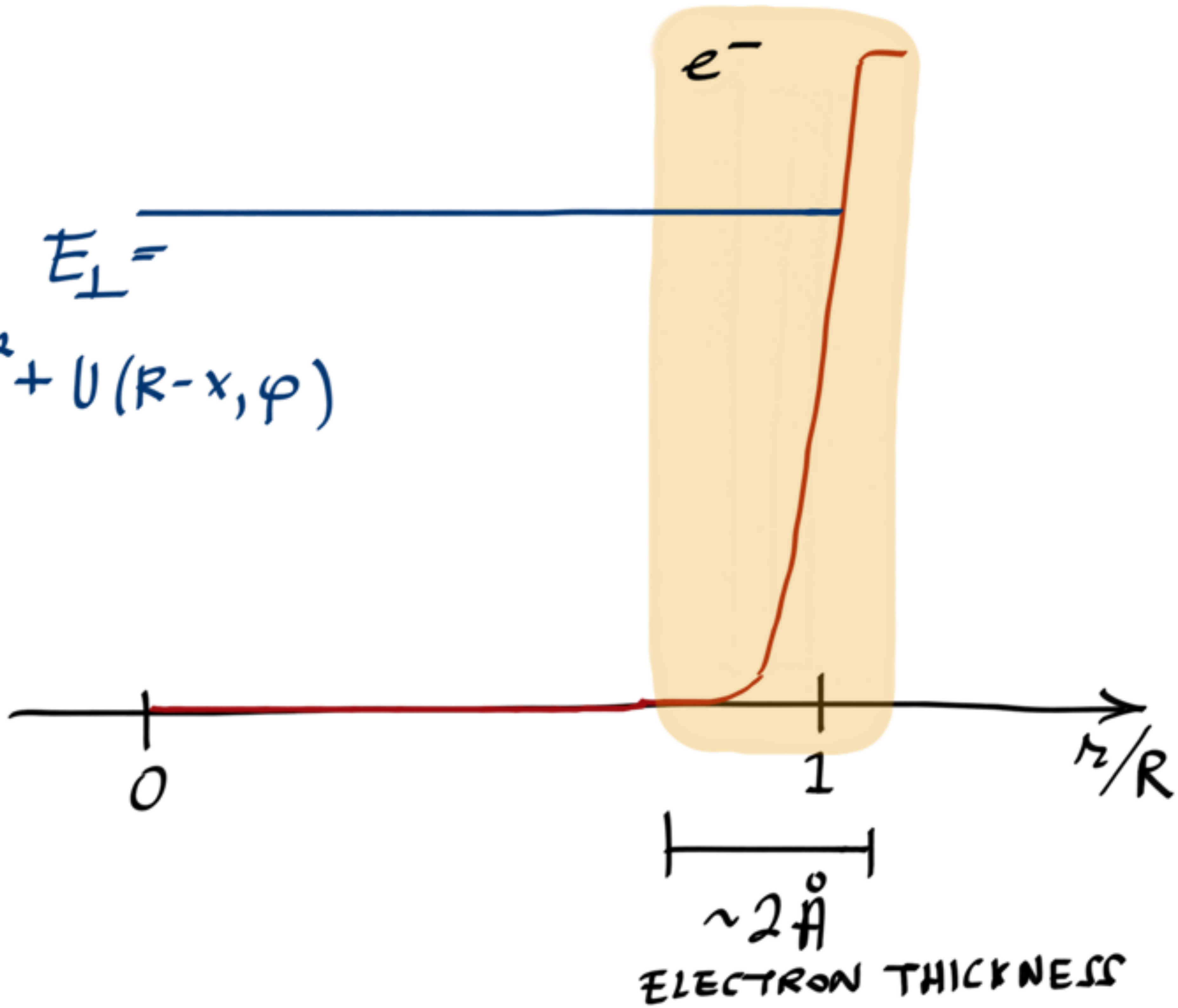
(T, θ)

DIRECTIONAL DETECTOR

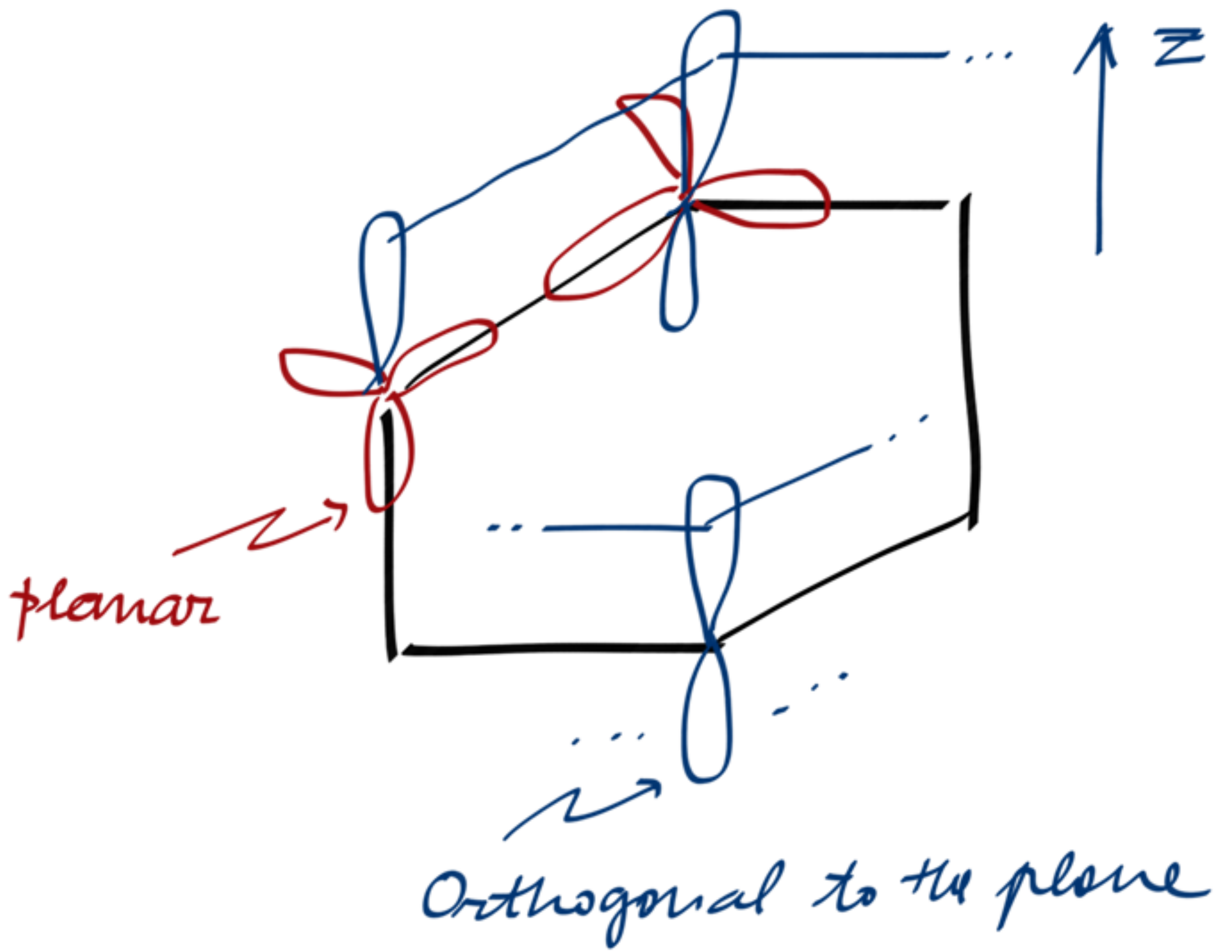


CHANNELS

$$E_\perp = T\theta^2 + U(R-x, \varphi)$$



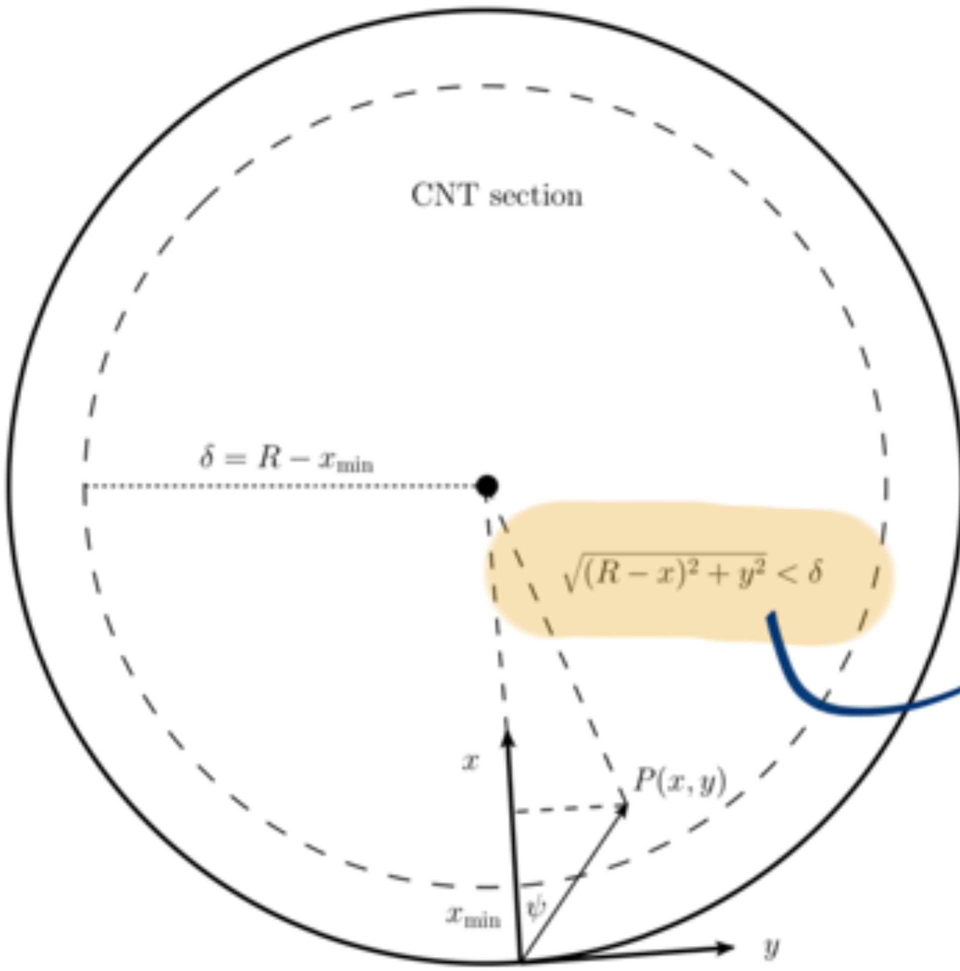
ELECTRONS & DECHANNELING



~CONSERVATION OF $E_\perp$

$$E_\perp = T\theta^2 + U(R-x,\phi) \lesssim \min_\phi U(R,\phi)$$

$\Rightarrow x_{min}$

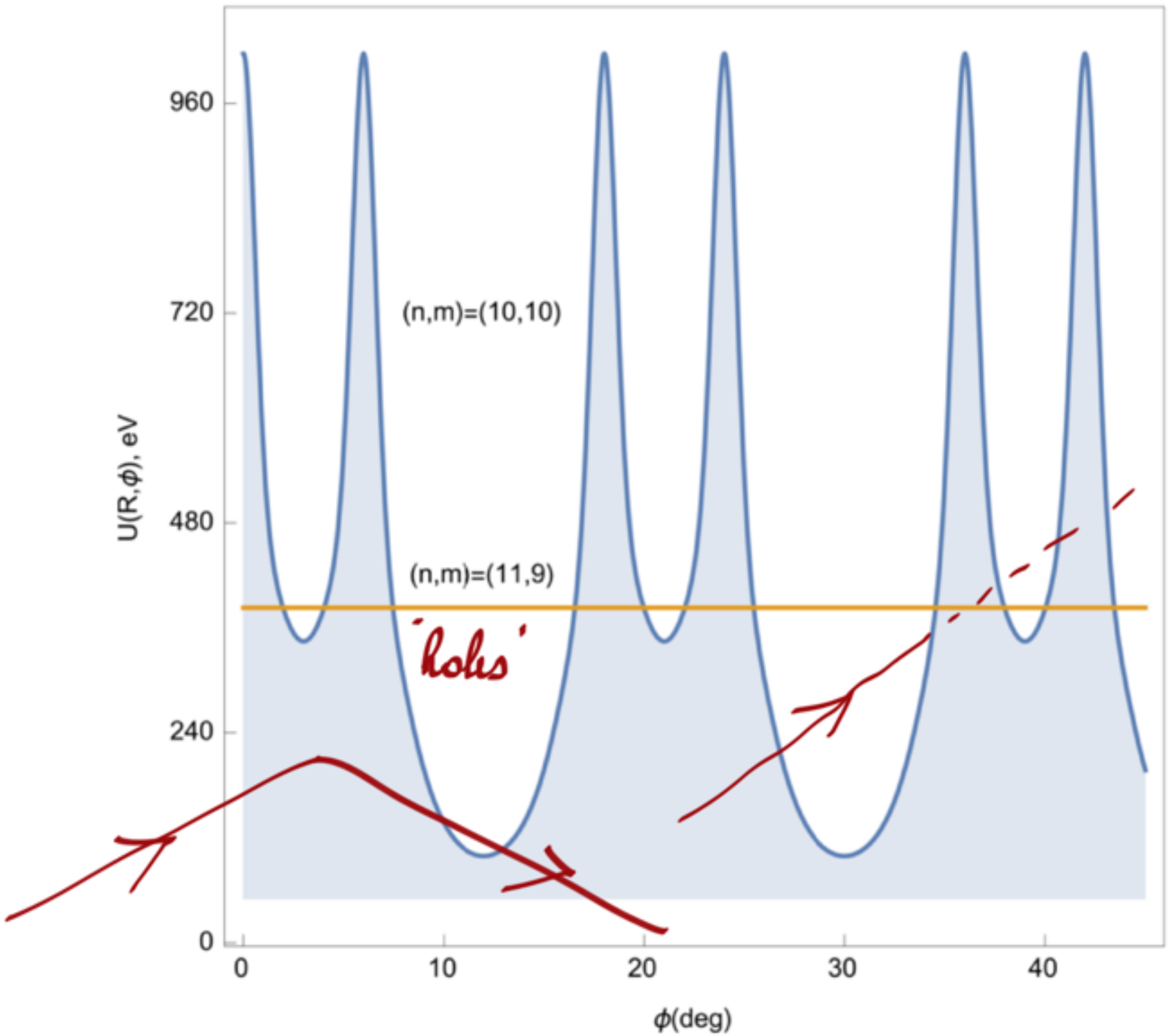


$$W(T,\theta) = \int_{x,y\in\mathcal{R}} \frac{e^{-x^2/2u_\perp^2(T^*)}}{\sqrt{2\pi}\,u_\perp(T^*)} \frac{e^{-y^2/2u_\parallel^2}}{\sqrt{2\pi}\,u_\parallel}$$

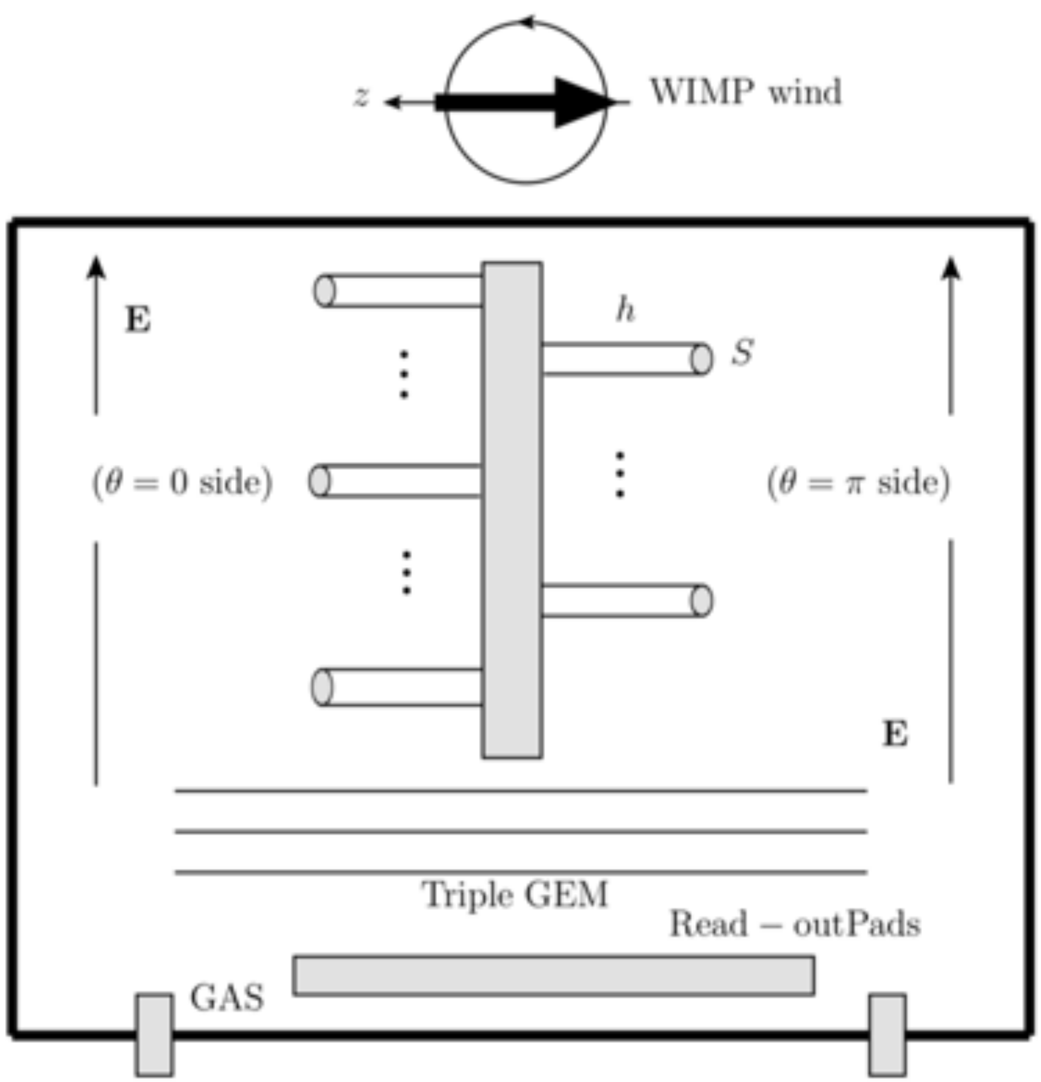
$\rightarrow$ defines $\mathcal{R}$

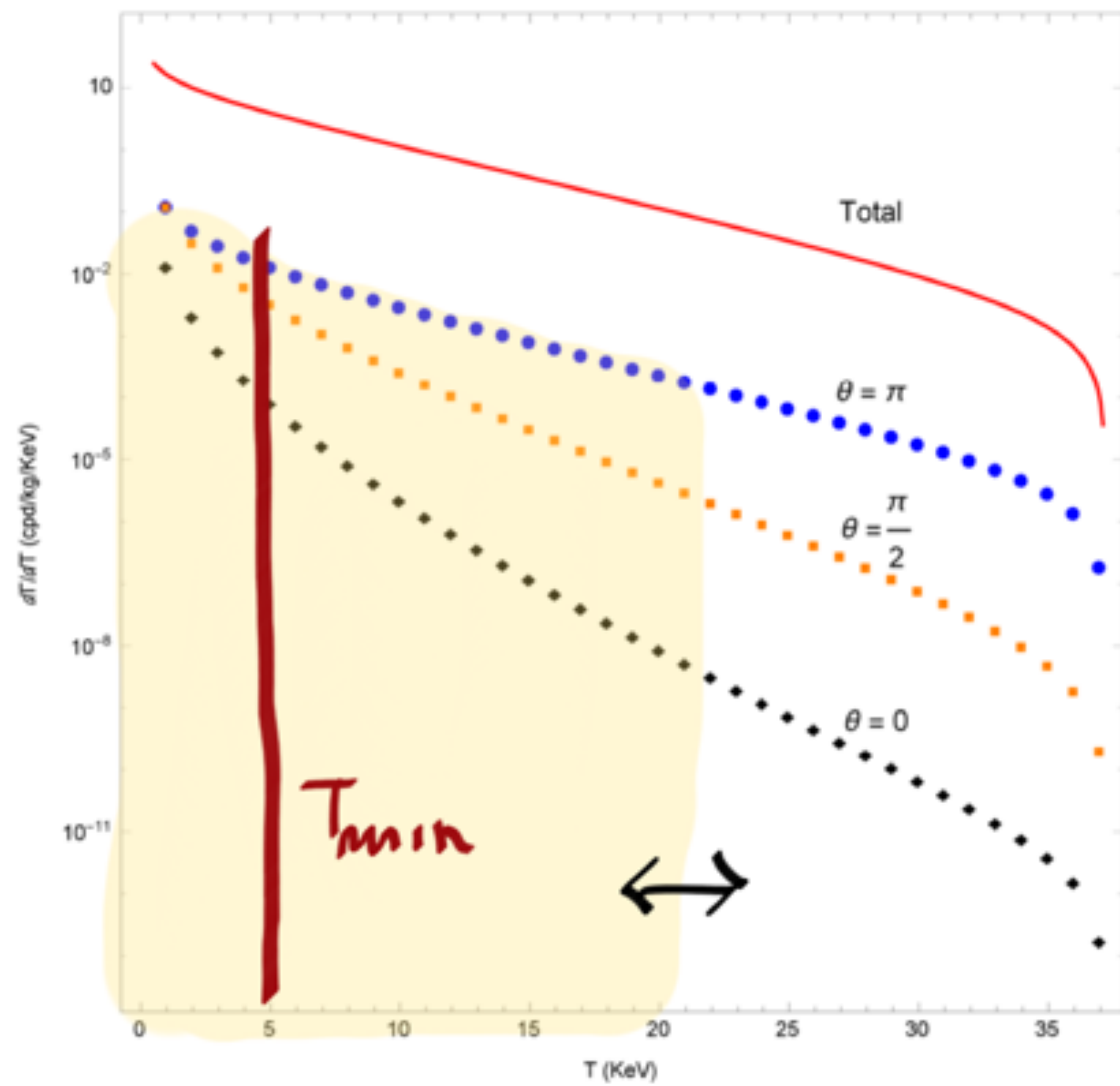
$$\left.\begin{aligned} u_\perp &= 0.0085\ \text{nm} \\ u_\parallel &= 0.0035\ \text{nm} \end{aligned}\right\} @\ \text{room}\ T^*$$

ϕ-DEPENDENCE IN POTENTIALS

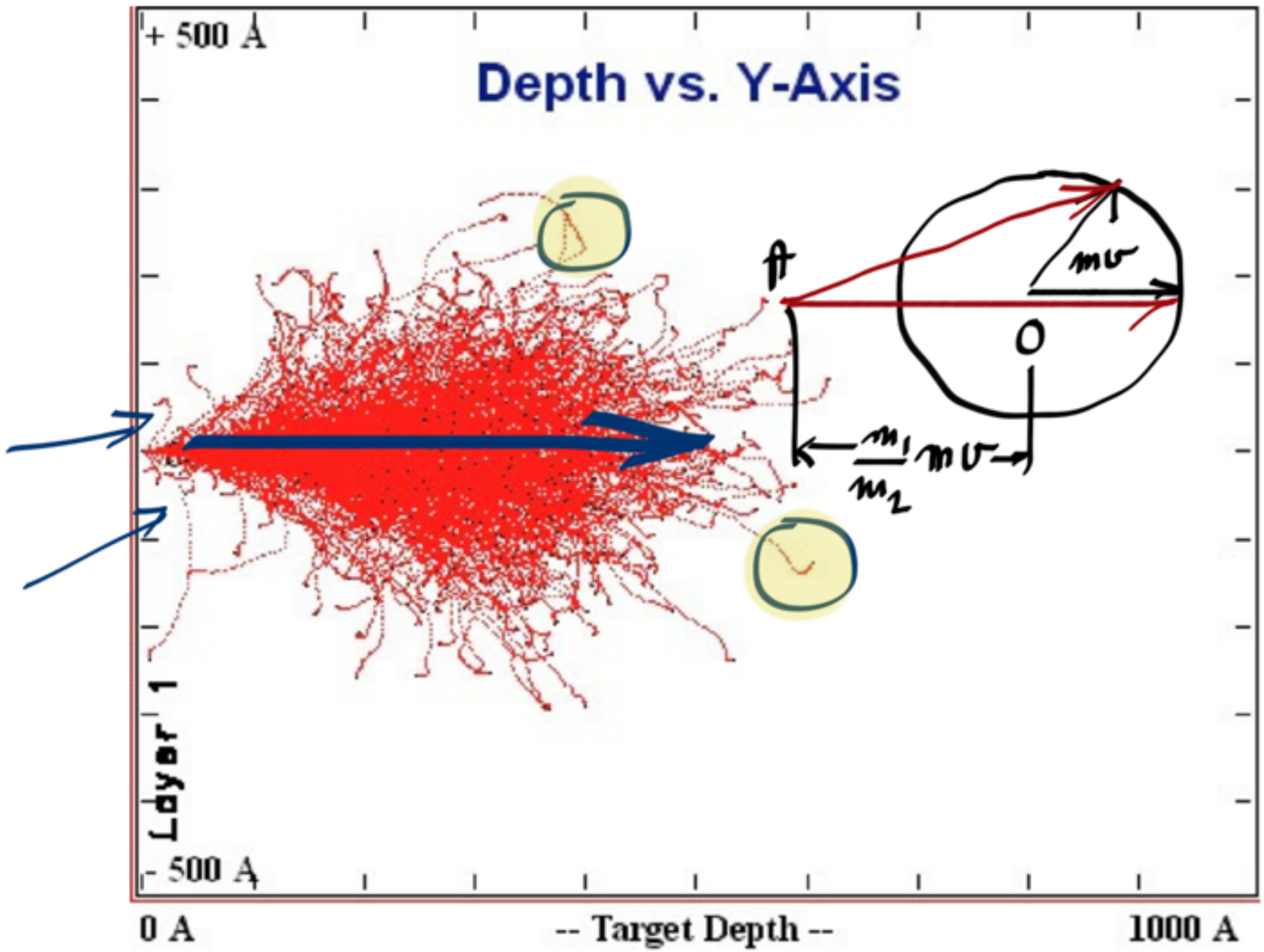


SINGLE CNT CHANNELS

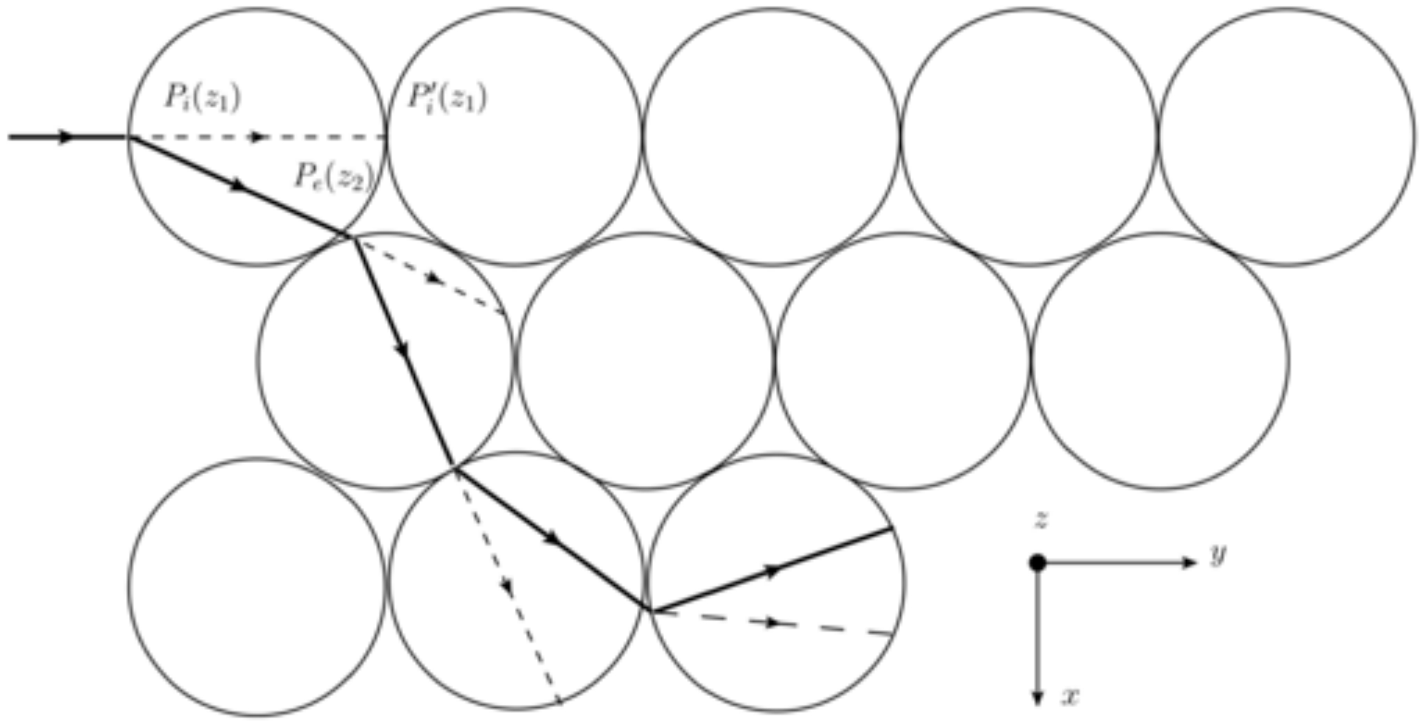


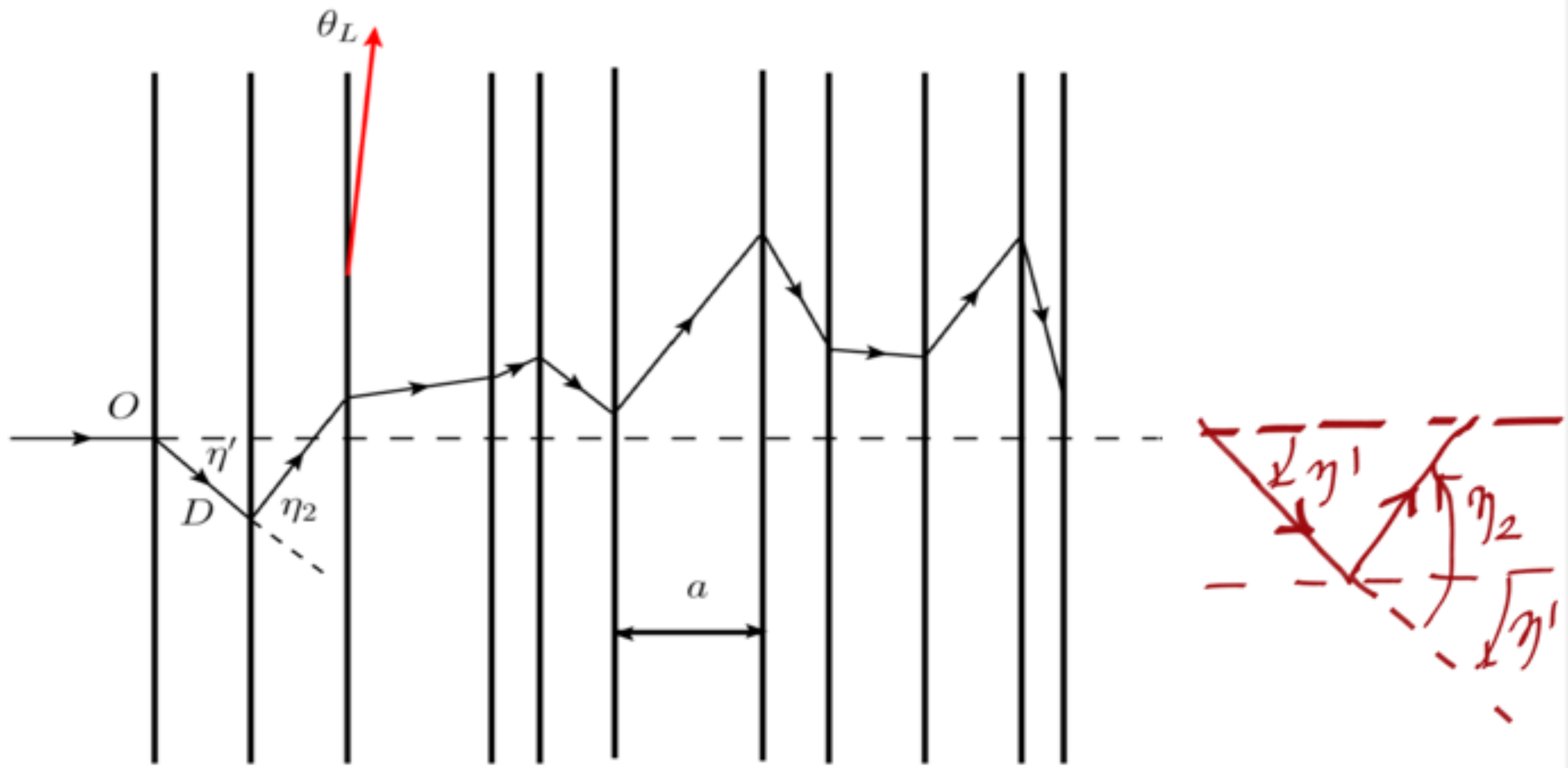


RE-CHANNELINGS



RE-CHANNELINGS





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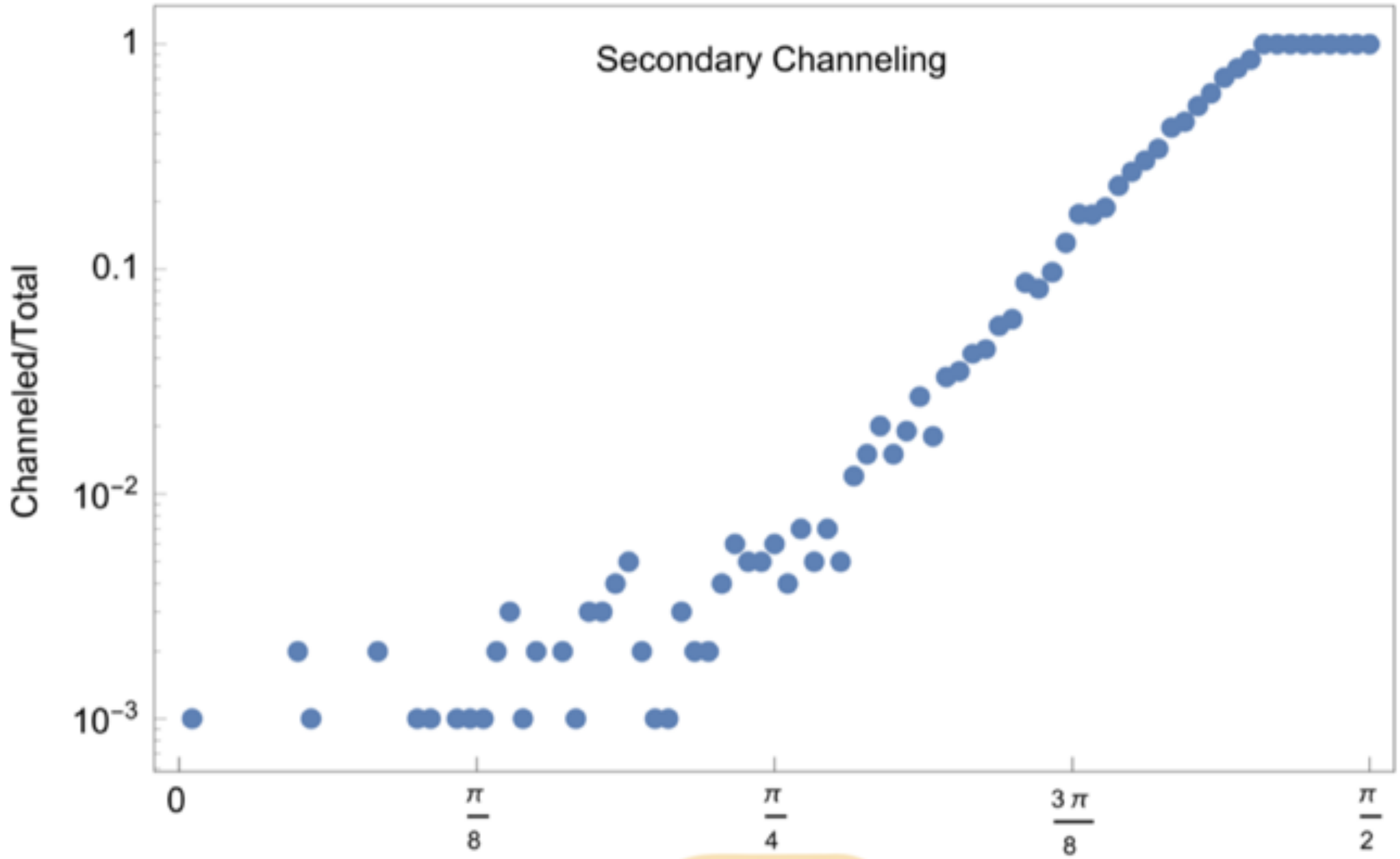

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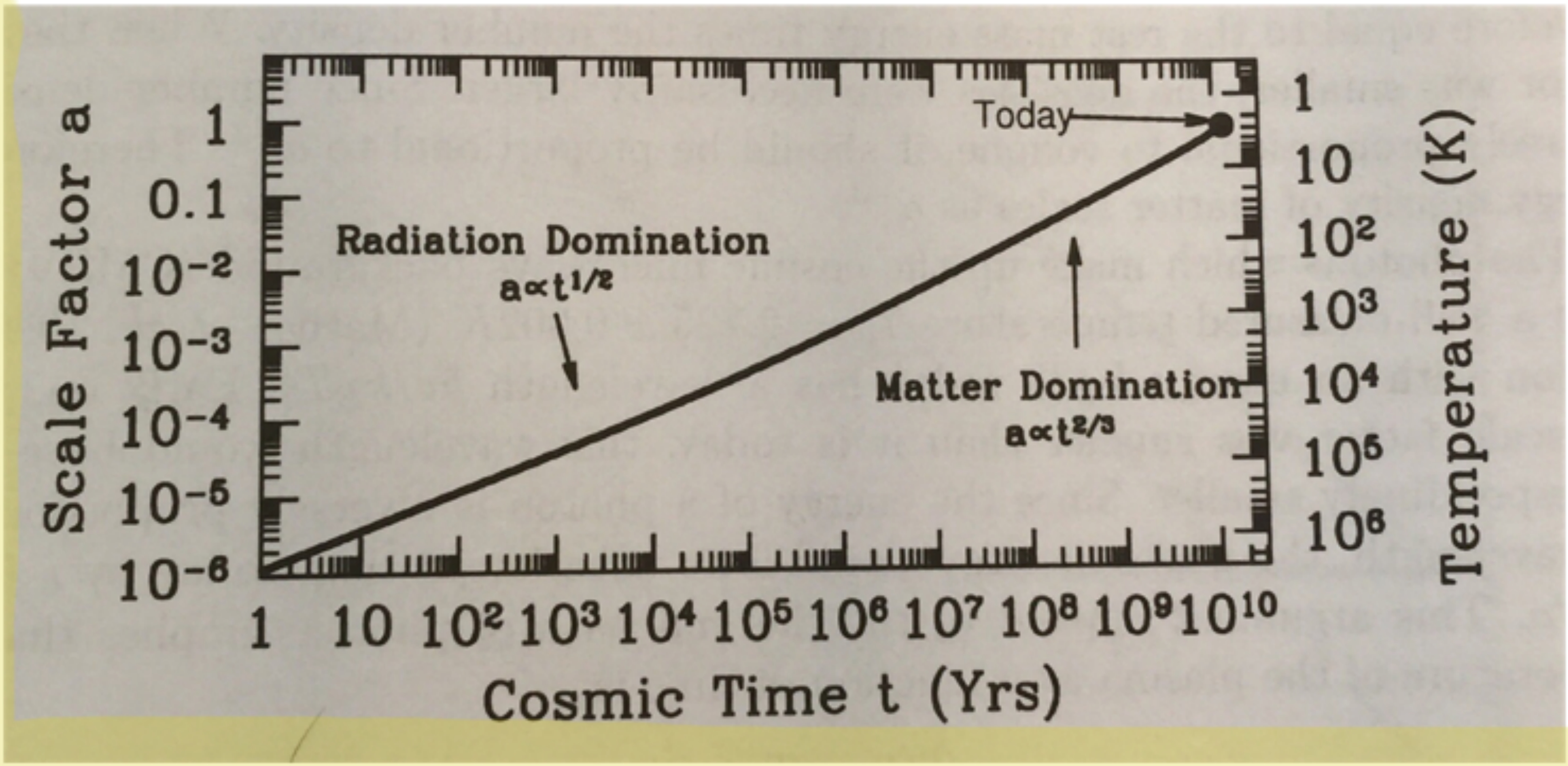
Backup

Evolution of a(t)



$$\rho_b \sim m_b \, n_b \sim 1/a^3$$

$$\rho_\gamma \sim \mathcal{E}_\gamma \, n_\gamma \sim 1/\lambda \cdot 1/a^3 \sim 1/a^4$$