Title: Explorations in Particle Theory - Lecture 9

Date: Apr 13, 2012 09:00 AM

URL: http://pirsa.org/12040011

Abstract:

$$\mathcal{M} = \langle \chi | \gamma^\mu \gamma^5 | \chi \rangle \langle N | S^\mu | N \rangle \, 2\sqrt{2}\, G_F \Lambda_N$$

$\hookrightarrow q^2 \to 0 : S^\mu = (0, \vec{J})$

$$\text{"}|\mathcal{M}|^2\text{"} = 8 G_F^2 \Lambda_N^2 J(J+1) \rightsquigarrow \text{only applies for } q^2 \to 0$$

$q^2 = 2 m_N E_R$

$$\frac{d\sigma_N}{dE_R} = \frac{4}{\pi} m_N \frac{G_F^2}{v^2} \Lambda_N^2 J(J+1)\, \mathcal{F}^2_{SD}(E_R)$$

$\mathcal{F}_{SD}$ = Form factor

$$\tilde{\sigma}_N = \frac{2\mu_N^2 v^2}{m_N} \frac{d\sigma_N}{dE_R}(E_R \to 0) = \frac{8}{\pi} G_F^2 \mu_N^2 \Lambda_N^2 J(J+1)$$

$$O_{SD}^{p} := \left(\frac{\mu_p}{\mu_N}\right)^2 \tilde{O}_N \left[\frac{\Lambda_p^2 J_p(J_p+1)}{\Lambda_N^2 J(J+1)}\right]$$

, assuming all spin is from protons.

$$\sigma_{SD}^{p} = \left(\frac{\mu_p}{\mu_N}\right)^2 \tilde{\sigma}_N \left[\frac{\Lambda_p^2 J_p(J_p+1)}{\Lambda_N^2 J(J+1)}\right]$$, assuming all spin is from protons

$$\sigma_{SD}^{n} = \left(\frac{\mu_n}{\mu_N}\right)^2 \tilde{\sigma}_N \left[\frac{\Lambda_n^2 J_n(J_n+1)}{\Lambda_N^2 J(J+1)}\right]$$, assuming all spin from neutrons

$$\sigma_{SD}^{p} = \left(\frac{\mu_p}{\mu_N}\right)^2 \tilde{\sigma}_N \left[\frac{\Lambda_p^2 J_p(J_p+1)}{\Lambda_N^2 J(J+1)}\right]$$, assuming all spin is from protons.

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$$\frac{dR}{dE_R} = n_T \left(\frac{\rho_\chi}{m_\chi}\right) \int \underbrace{d^3v}_{\text{lab frame}} \, v \, f_{lab}(\vec{v}, \vec{v}_e) \frac{d\sigma_N}{dE_R}$$

$$\sigma^{p}_{SD} = \left(\frac{\mu_p}{\mu_N}\right)^2 \tilde{\sigma}_N \left[\frac{\Lambda_p^2 J_p(J_p+1)}{\Lambda_N^2 J(J+1)}\right]$$, assuming all spin is from protons.

$$\sigma^{n}_{SD} = \left(\frac{\mu_n}{\mu_N}\right)^2 \bar{\sigma}_N \left[\frac{\Lambda_n^2 J_n(J_n+1)}{\Lambda_N^2 J(J+1)}\right]$$, assuming all spin from neutrons.

$$\frac{dR}{dE_R} = n_T\left(\frac{\rho_\chi}{m_\chi}\right)\int \underbrace{d^3v}_{\text{lab frame}}\; v \cdot f_{lab}(\vec{v}, \vec{v}_e)\, \frac{d\sigma_N}{dE_R}$$

$$\sigma_{SI} =$$

$$\sigma_{SD}^{p} = \left(\frac{\mu_p}{\mu_N}\right)^2 \tilde{\sigma}_N \left[\frac{\Lambda_p^2 J_p(J_p+1)}{\Lambda_N^2 J(J+1)}\right]$$, assuming all spin is from protons

$$\sigma_{SD}^{n} = \left(\frac{\mu_n}{\mu_N}\right)^2 \tilde{\sigma}_N \left[\frac{\Lambda_n^2 J_n(J_n+1)}{\Lambda_N^2 J(J+1)}\right]$$, assuming all spin from neutrons

$$\frac{dR}{dE_R} = n_T \left(\frac{\rho_\chi}{m_\chi}\right) \int d^3v \, v \cdot f_{lab}(\vec{v}, \vec{v}_e) \, \frac{d\sigma_N}{dE_R}$$

lab frame

$$\sigma_{SI} = \left(\frac{\mu_p}{\mu_N}\right)^2 \tilde{\sigma}_N \frac{1}{A^2}$$

$$\sigma_{SD}^{p} = \left(\frac{\mu_p}{\mu_N}\right)^2 \tilde{\sigma}_N \left[\frac{\Lambda_p^2 J_p(J_p+1)}{\Lambda_N^2 J(J+1)}\right]$$, assuming all spin is from protons

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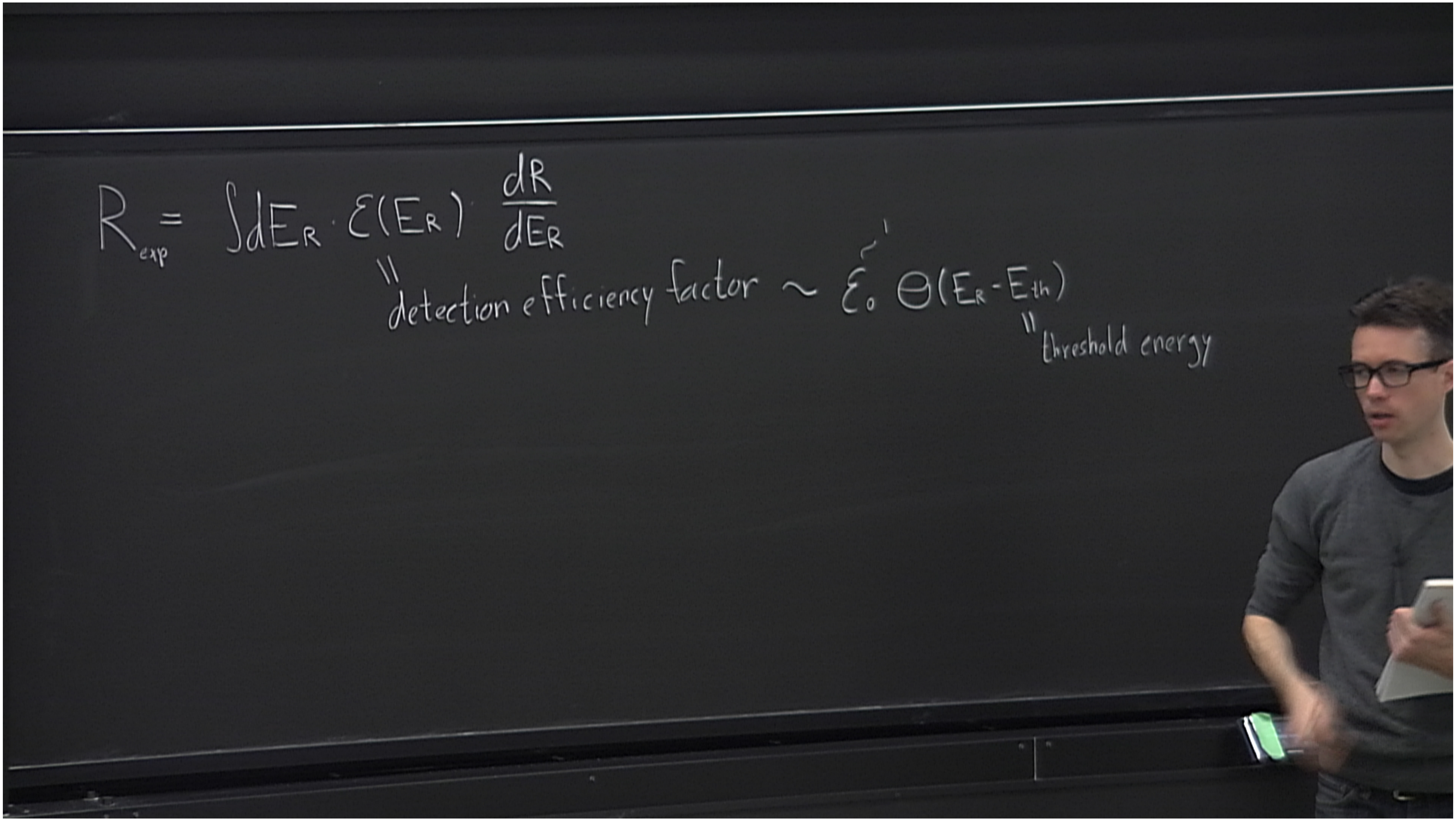
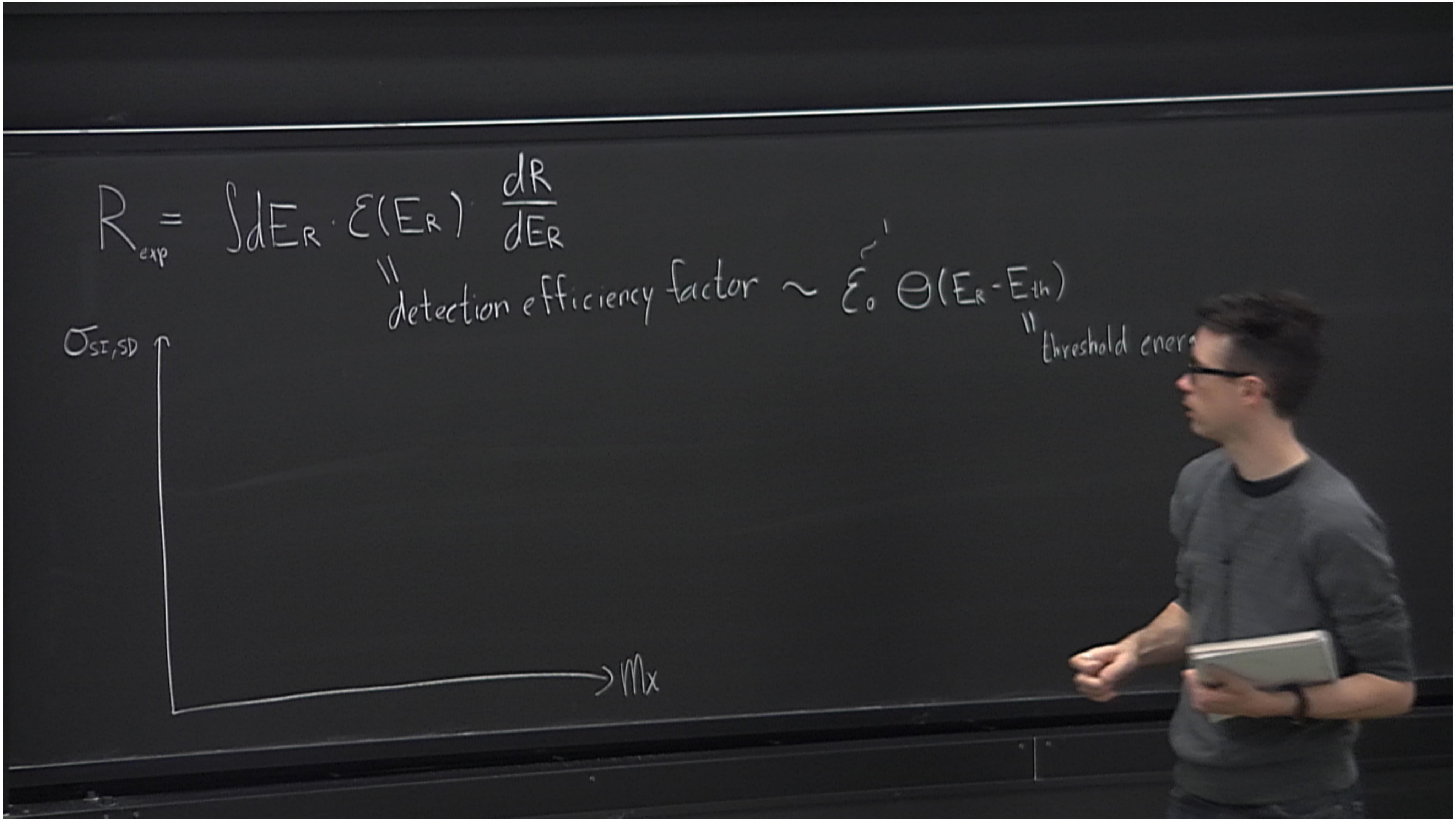
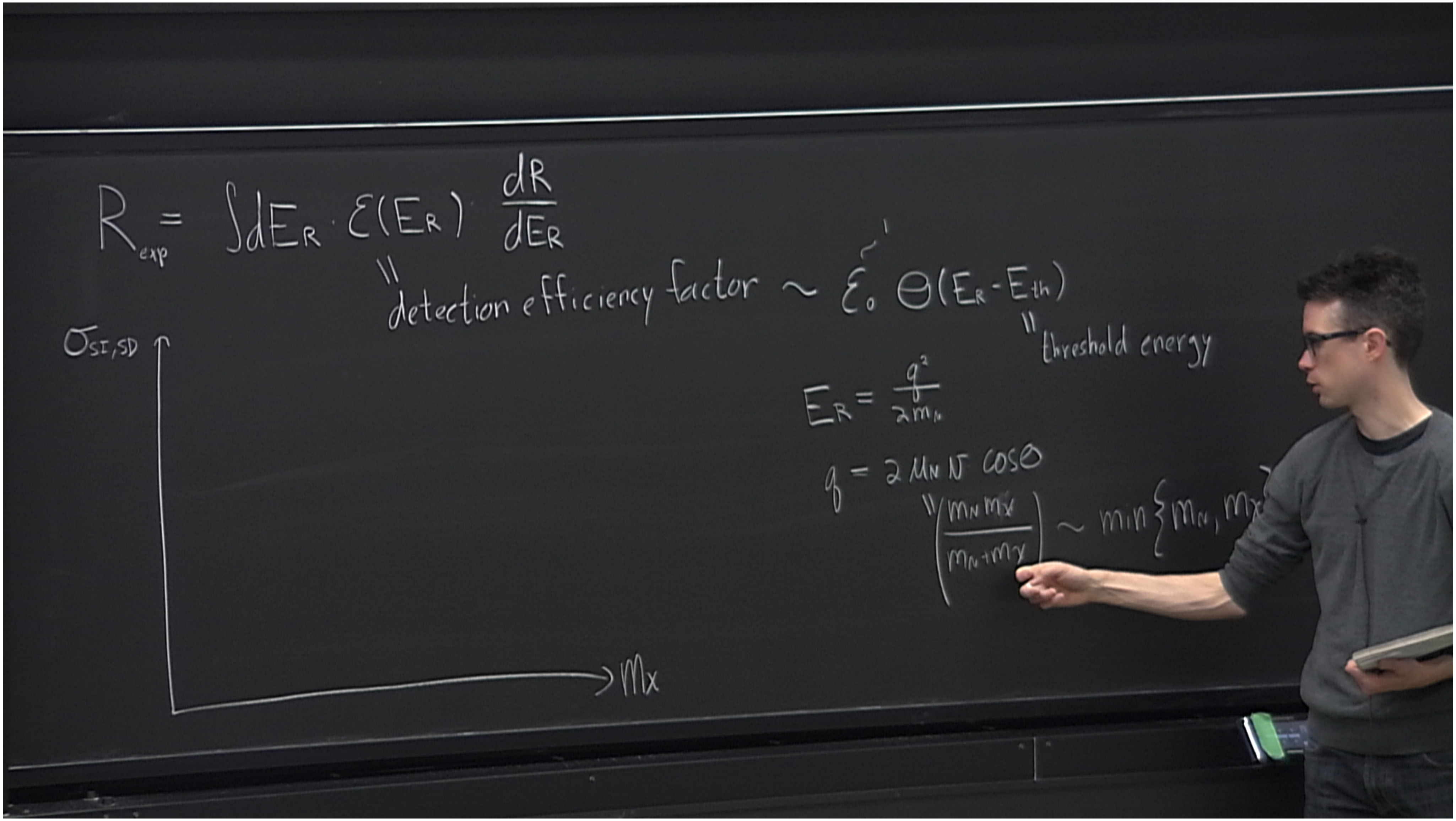
lab frame

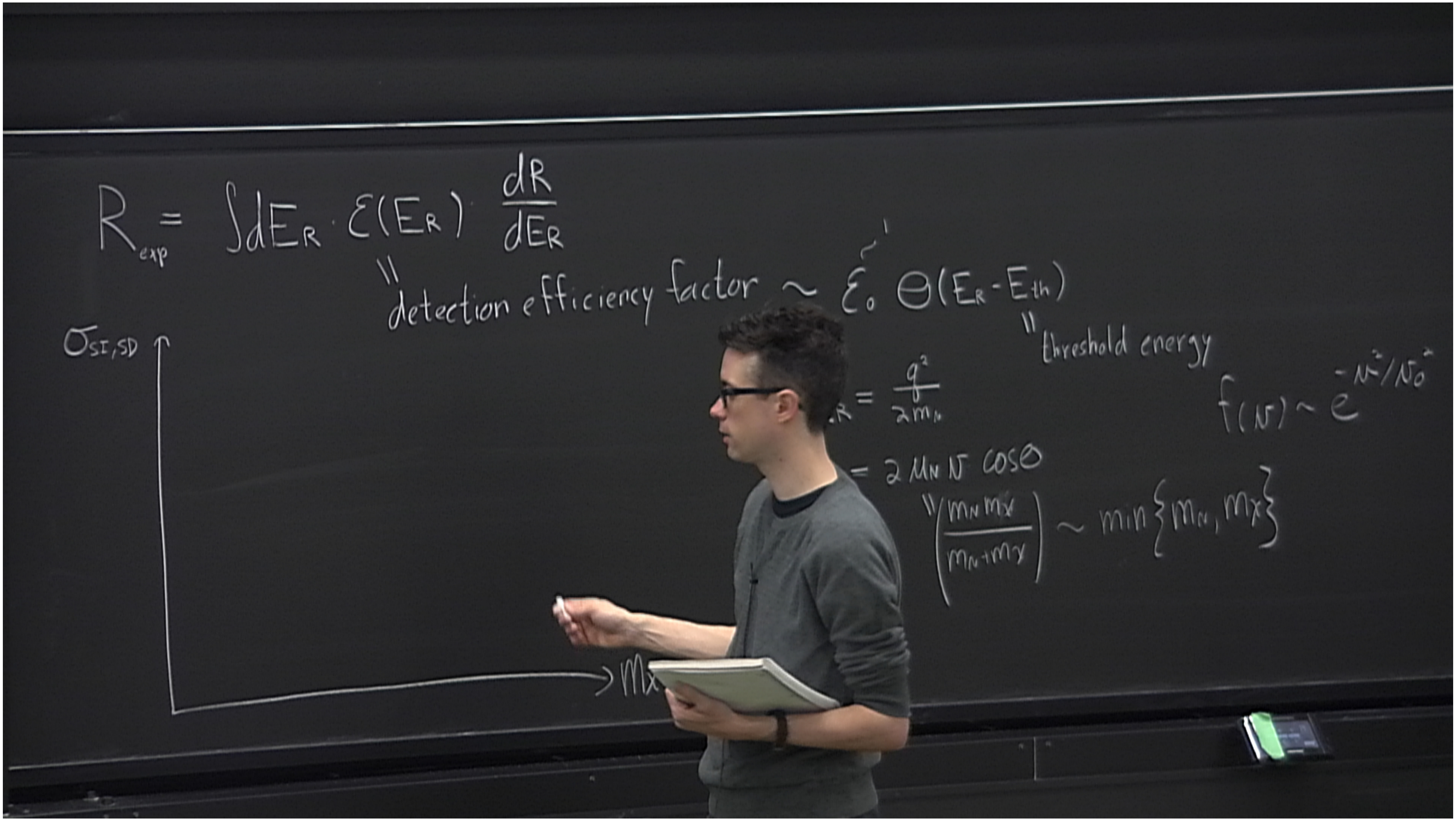
$$\sigma_{SI} = \left(\frac{\mu_p}{\mu_N}\right)^2 \tilde{\sigma}_N \frac{1}{A^2}$$

$$\tilde{\sigma}_N = (\ldots) \frac{\mu_N^2}{m_N} \sigma_p \left[f_p Z + (A-Z) f_n\right]^2 / f_p$$


$R_{exp} = \int dE_R \cdot \varepsilon(E_R) \frac{dR}{dE_R}$
detection efficiency factor $\sim \varepsilon_0 \, \Theta(E_R - E_{th})$
threshold energy


$R_{exp} = \int dE_R \cdot \varepsilon(E_R) \frac{dR}{dE_R}$
detection efficiency factor $\sim \varepsilon_0 \, \Theta(E_R - E_{th})$
threshold ener
$\sigma_{SI,SD}$
m_χ


$R_{exp} = \int dE_R \cdot \varepsilon(E_R) \frac{dR}{dE_R}$
detection efficiency factor $\sim \varepsilon_0 \, \Theta(E_R - E_{th})$
threshold energy
$\sigma_{SI,SD}$
m_χ
$E_R = \frac{q^2}{2m_N}$
$q = 2\mu_N v \cos\theta$
$\left(\frac{m_N m_\chi}{m_N + m_\chi}\right) \sim \min\{m_N, m_\chi\}$


R_exp = ∫dE_R · ε(E_R) dR/dE_R
detection efficiency factor ~ ε_0 Θ(E_R - E_th)
threshold energy
σ_SI,SD
m_χ
q²/2m_N
= 2 μ_N v cosθ
m_N m_χ / m_N+m_χ ~ min{m_N, m_χ}
f(v) ~ e^{-v²/v_0²}

$$\sigma^{p}_{SD} = \left(\frac{\mu_p}{\mu_N}\right)^2 \tilde{\sigma}_N \left[\frac{\Lambda_p^2 J_p(J_p+1)}{\Lambda_N^2 J(J+1)}\right]$$

, assuming all spin is from protons

$$\sigma^{n}_{SD} = \left(\frac{\mu_n}{\mu_N}\right)^2 \tilde{\sigma}_N \left[\frac{\Lambda_n^2 J_n(J_n+1)}{\Lambda_N^2 J(J+1)}\right]$$

, assuming all spin from neutrons

$$\frac{dR}{dE_R} = n_T \left(\frac{\rho_\chi}{m_\chi}\right) \int d^3v \cdot v \cdot f_{lab}(\vec{v}, \vec{v}_e) \frac{d\sigma_N}{dE_R}$$

lab frame

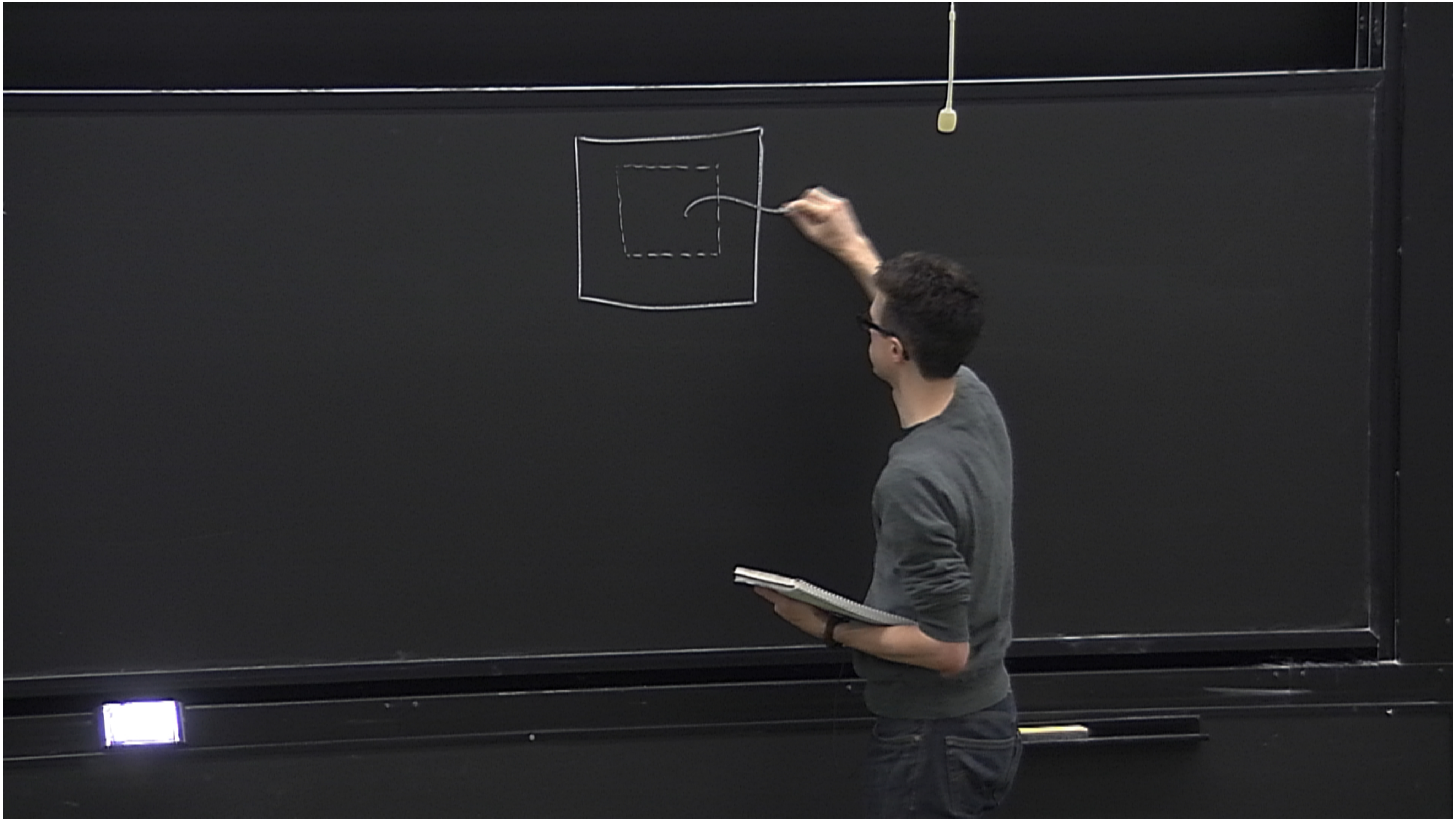
$$\rho_\chi = 0.3 \ \mathrm{GeV/cm^3}$$

$$\sigma_{SI} = \left(\frac{\mu_p}{\mu_N}\right)^2 \tilde{\sigma}_N \cdot \frac{1}{A^2}$$

$$\tilde{\sigma}_N = (\ldots) \frac{\mu_N^2}{m_N} \sigma_p \left[f_p Z + (A-Z) f_n\right]^2 / f_p \ .$$

Current Experiments: SI : XENON100 : ~50 kg of Xe

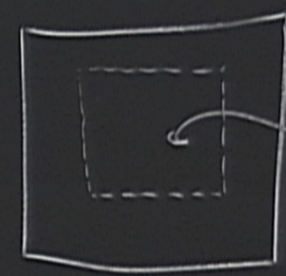
↳ $\begin{matrix}126-132\\54\end{matrix}$



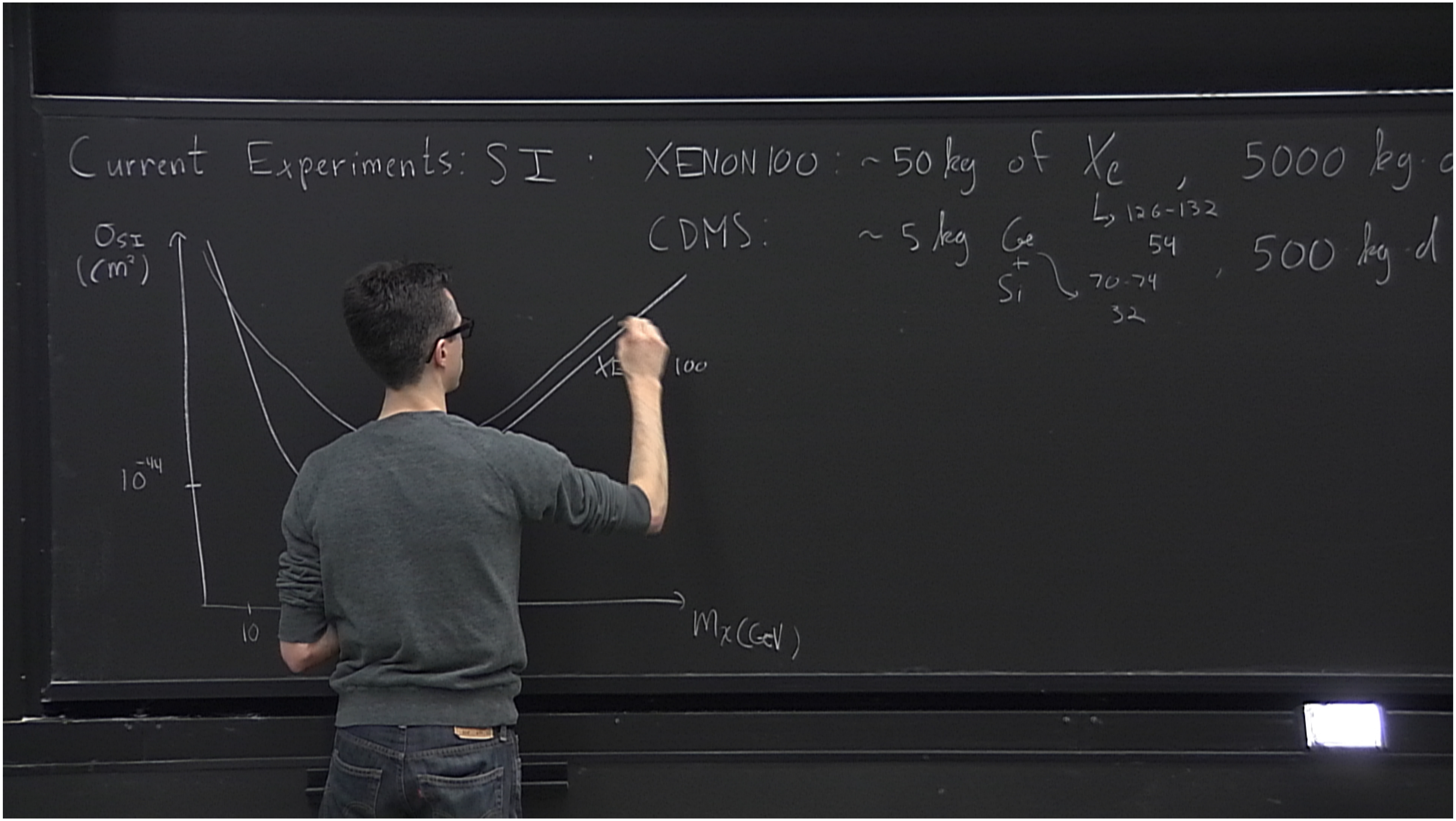
o : ~50 kg of Xe , 5000 kg·d.

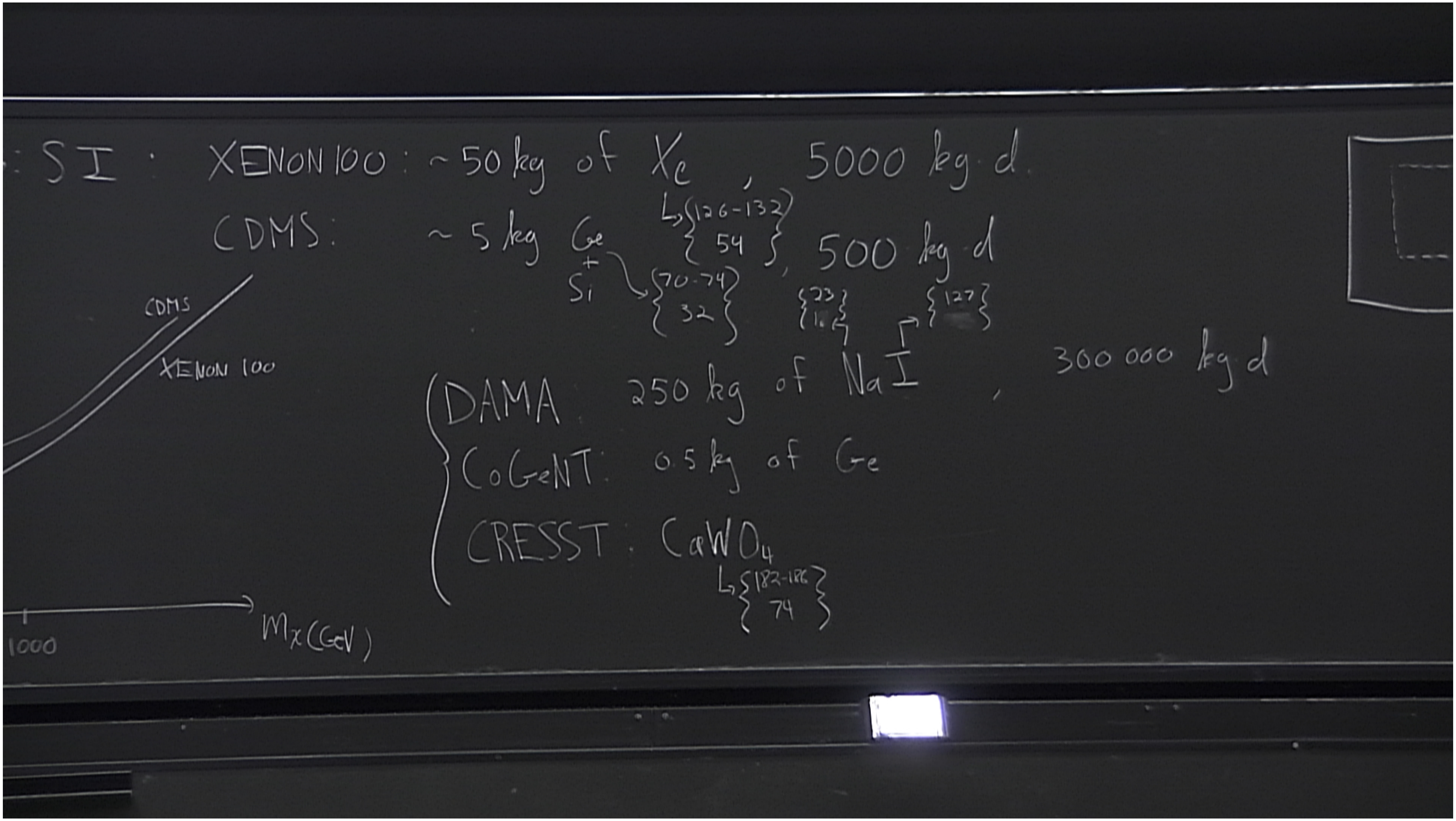
$\hookrightarrow$ 126-132

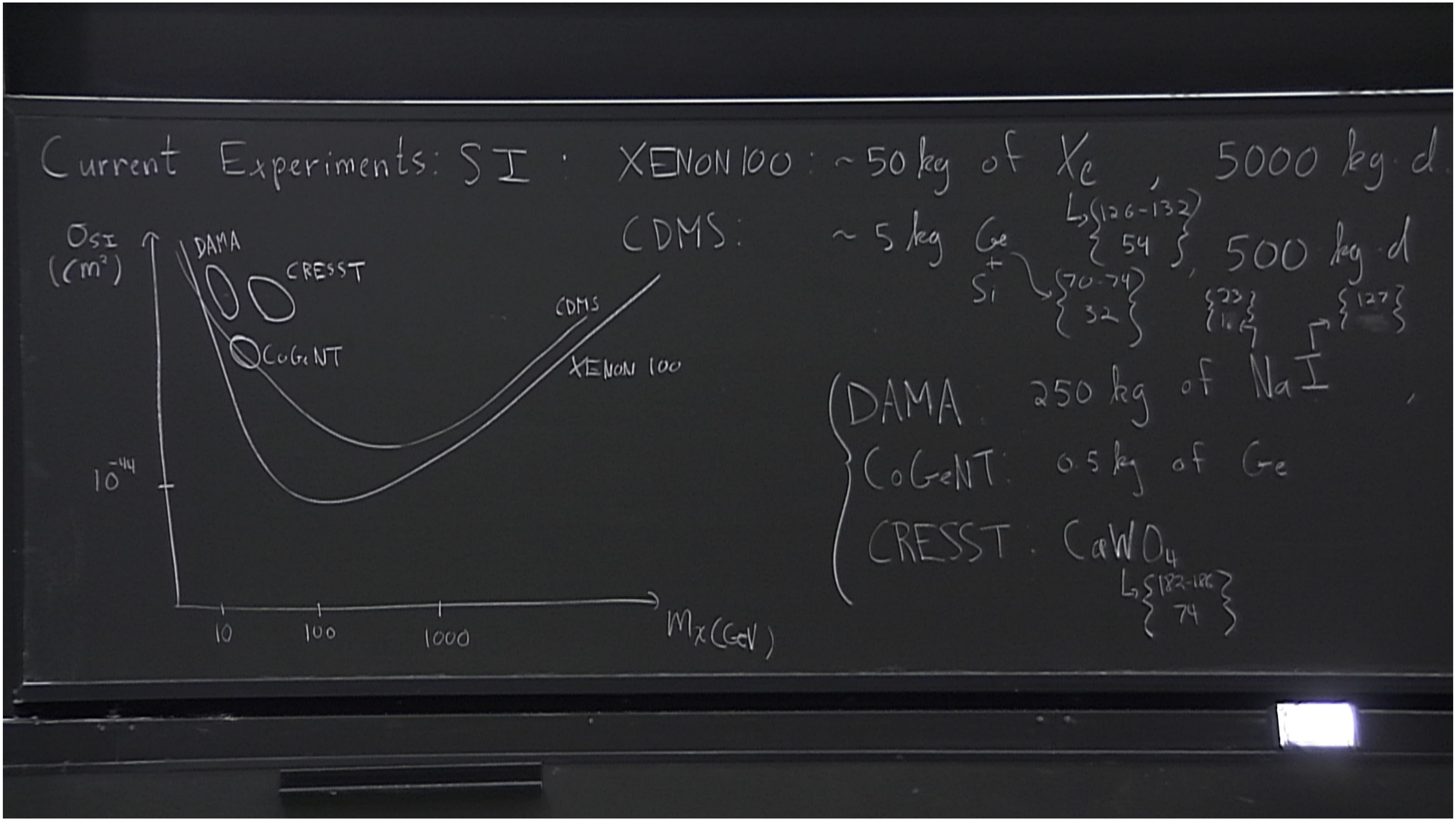
54



fiducial region


Current Experiments: SI : XENON100 : ~50 kg of Xe , 5000 kg·d
CDMS: ~5 kg Ge + Si , 500 kg·d
126-132
54
70-74
32
σSI (cm²)
10^-44
10
XE 100
mχ (GeV)


SI : XENON100 : ~50 kg of Xe , 5000 kg·d
126-132
54
CDMS: ~5 kg Ge + Si , 500 kg·d
70-74
32
23
DAMA: 250 kg of NaI , 300 000 kg·d
CoGeNT: 0.5 kg of Ge
CRESST: CaWO4
182-186
74
CDMS
XENON 100
1000
mχ (GeV)


Current Experiments: SI : XENON100 : ~50 kg of Xe , 5000 kg·d
(126-132)
54
CDMS : ~5 kg Ge + Si , 500 kg·d
70-74
32
23
127
DAMA 250 kg of NaI
CoGeNT 0.5 kg of Ge
CRESST CaWO4
182-186
74
σSI (cm²)
DAMA
CRESST
CoGeNT
CDMS
XENON 100
10^-44
10
100
1000
mχ (GeV)

100 : ~50 kg of Xe $\left\{ {126-132 \atop 54} \right\}$, 5000 kg·d

~5 kg Ge + Si $\left\{ {70-74 \atop 32} \right\}$, 500 kg·d

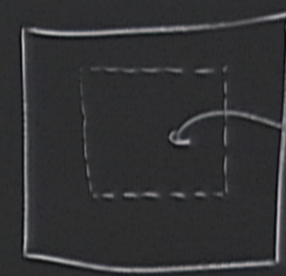
$\left\{ {23 \atop 11} \right\}$ $\left\{ {127 \atop 53} \right\}$

DAMA : 250 kg of NaI , 300 000 kg·d

CoGeNT : 0.5 kg of Ge

CRESST : $CaWO_4$ $\left\{ {182-186 \atop 74} \right\}$

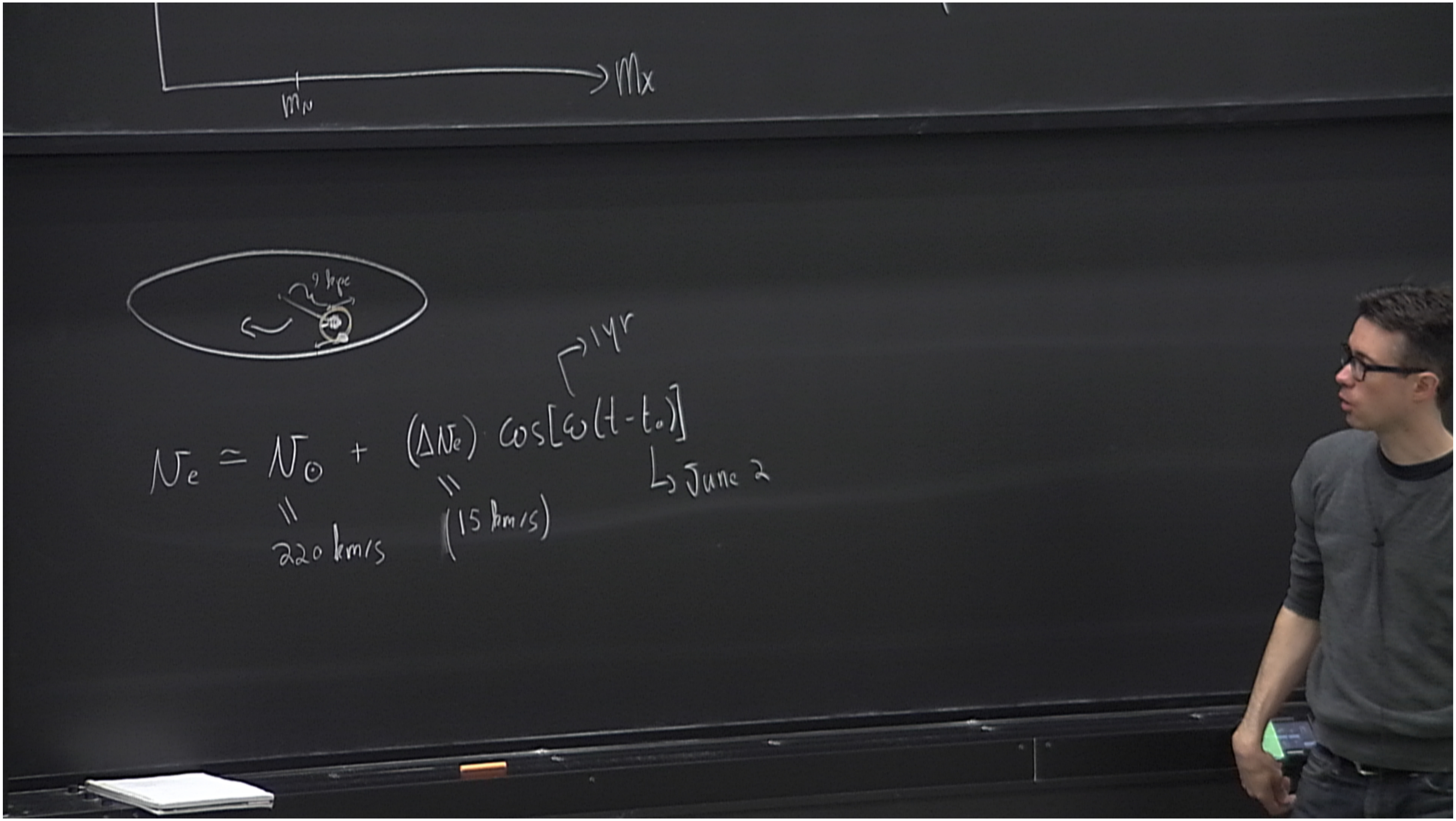
(GeV)

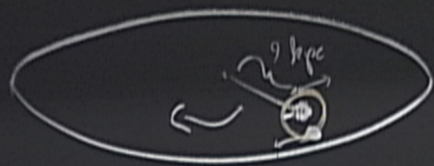


fiducial region

SI : $f_n = f_p$

$\left[f_n (A-Z) + f_p Z \right]$


m_N
m_X
9 kpc
1 yr
$v_e \simeq v_\odot + (\Delta v_e) \cdot \cos[\omega(t-t_0)]$
220 km/s
(15 km/s)
June 2

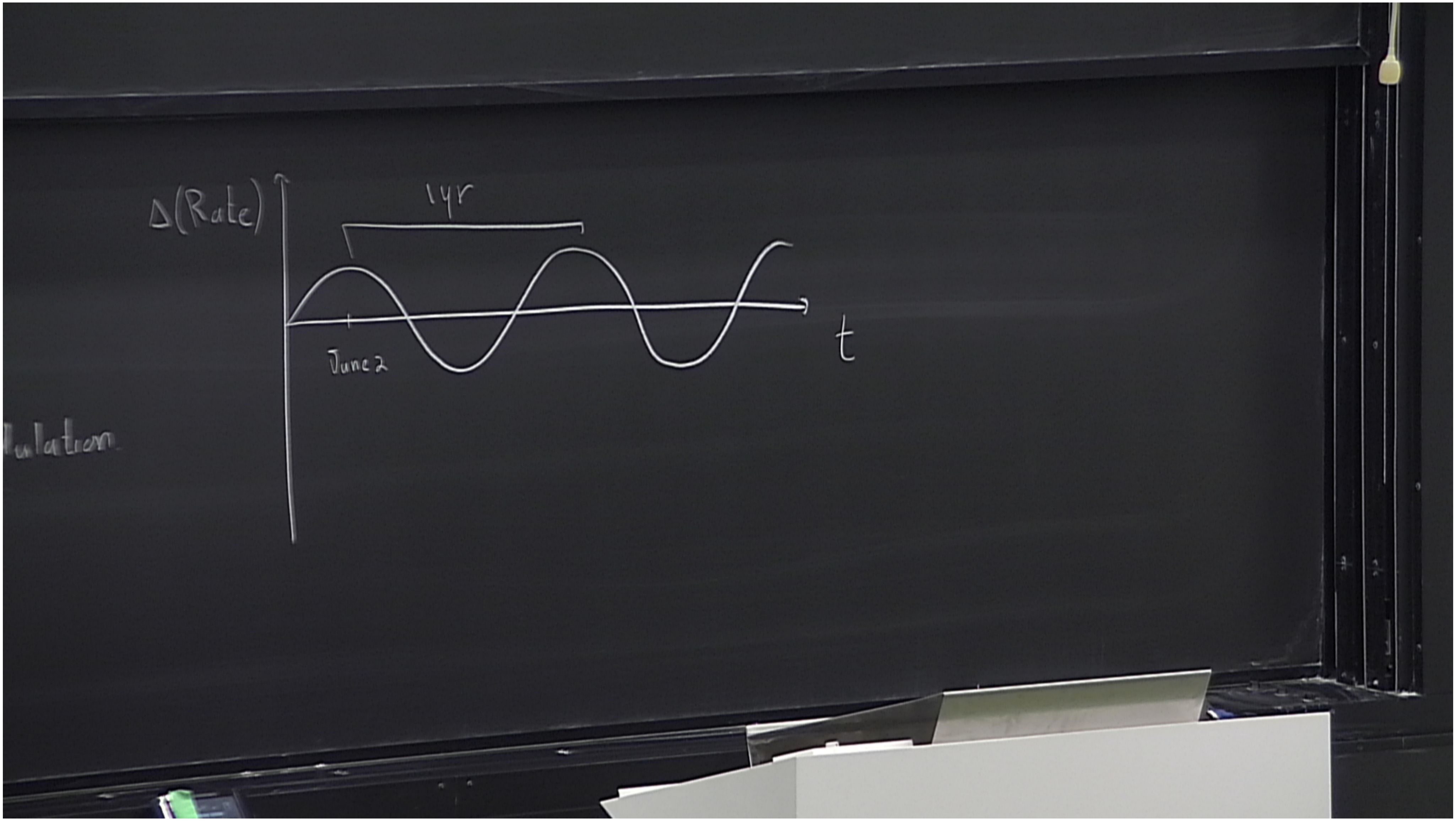


$$v_e \simeq v_\odot + (\Delta v_e)\cos[\underbrace{\omega}_{\to 1\,\text{yr}}(t-\underbrace{t_0}_{\to \text{June 2}})]$$

$\Rightarrow$ DM scattering will have an annual modulation

$v_\odot = 220$ km/s

$\Delta v_e = (15$ km/s$)$

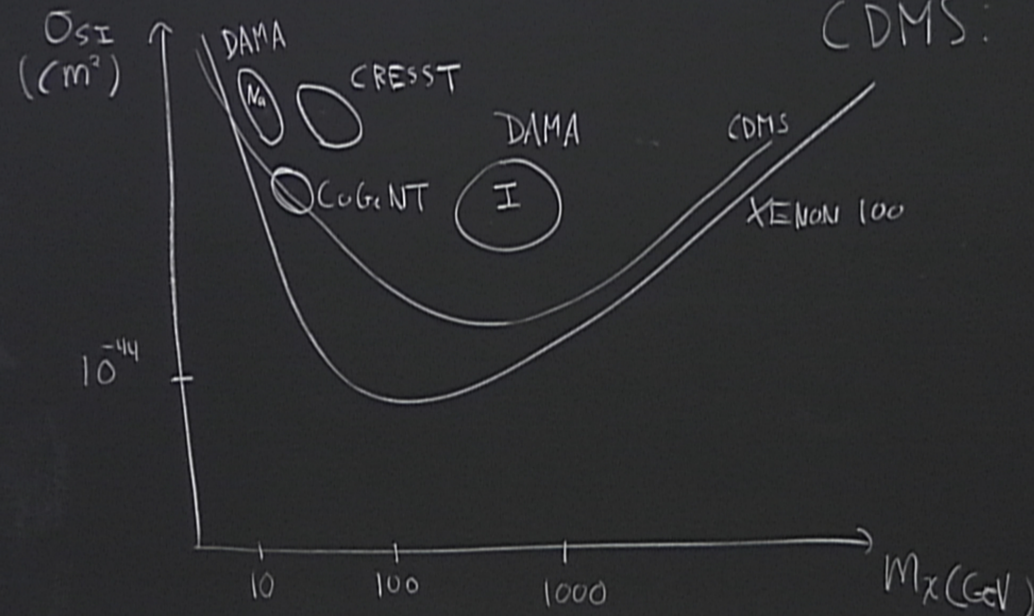

Δ(Rate)
1yr
June 2
t
dulation

Current Experiments: SI : XENON 100 : ~ 50 kg of Xe , 5000 kg

$\left\{ {126-132 \atop 54} \right\}$

CDMS: ~ 5 kg Ge + Si , 500 kg

$\left\{ {70-74 \atop 32} \right\}$ $\left\{ {23 \atop 11} \right\}$ $\left\{ {127 \atop 53} \right\}$

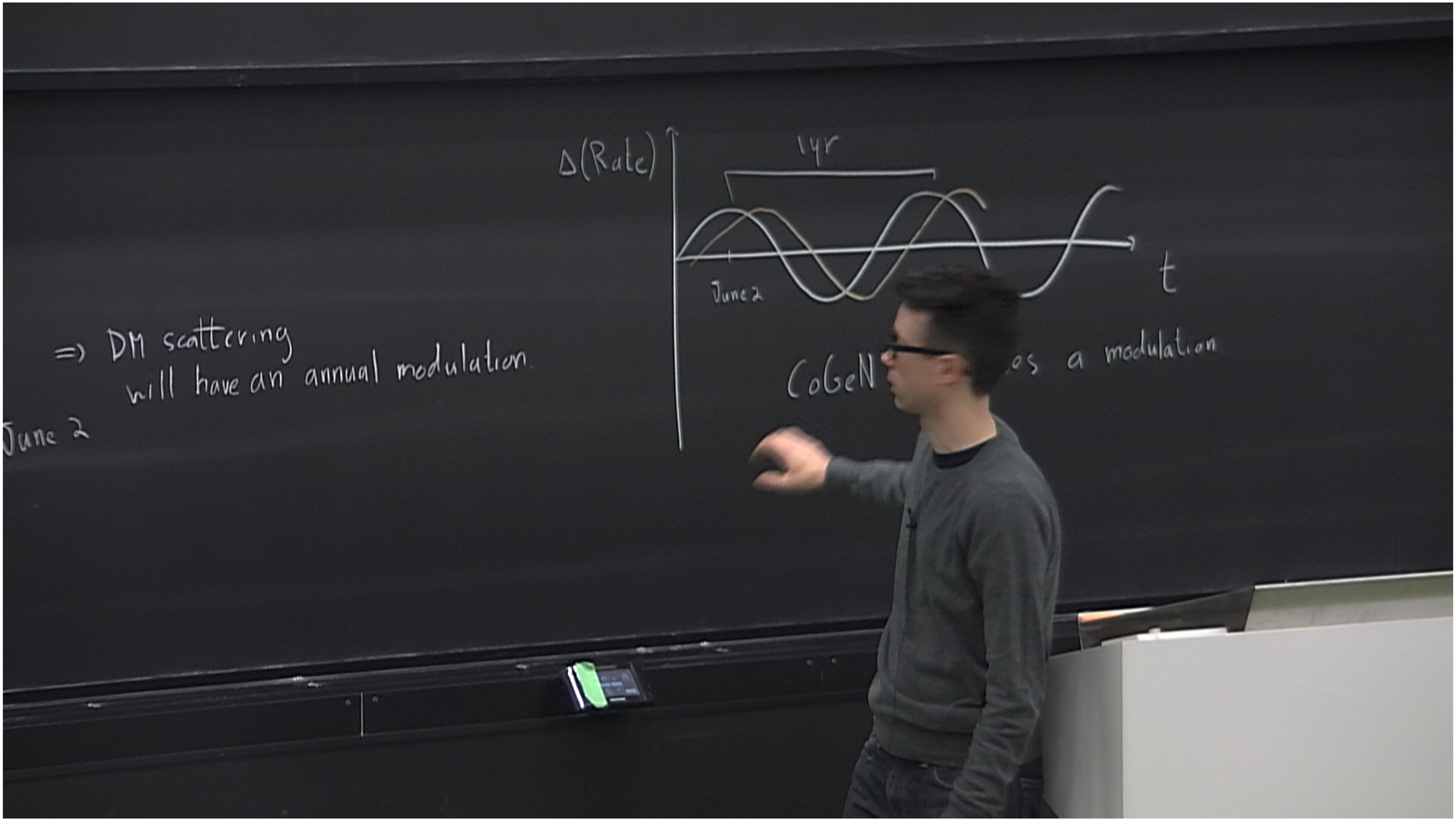


DAMA: 250 kg of NaI

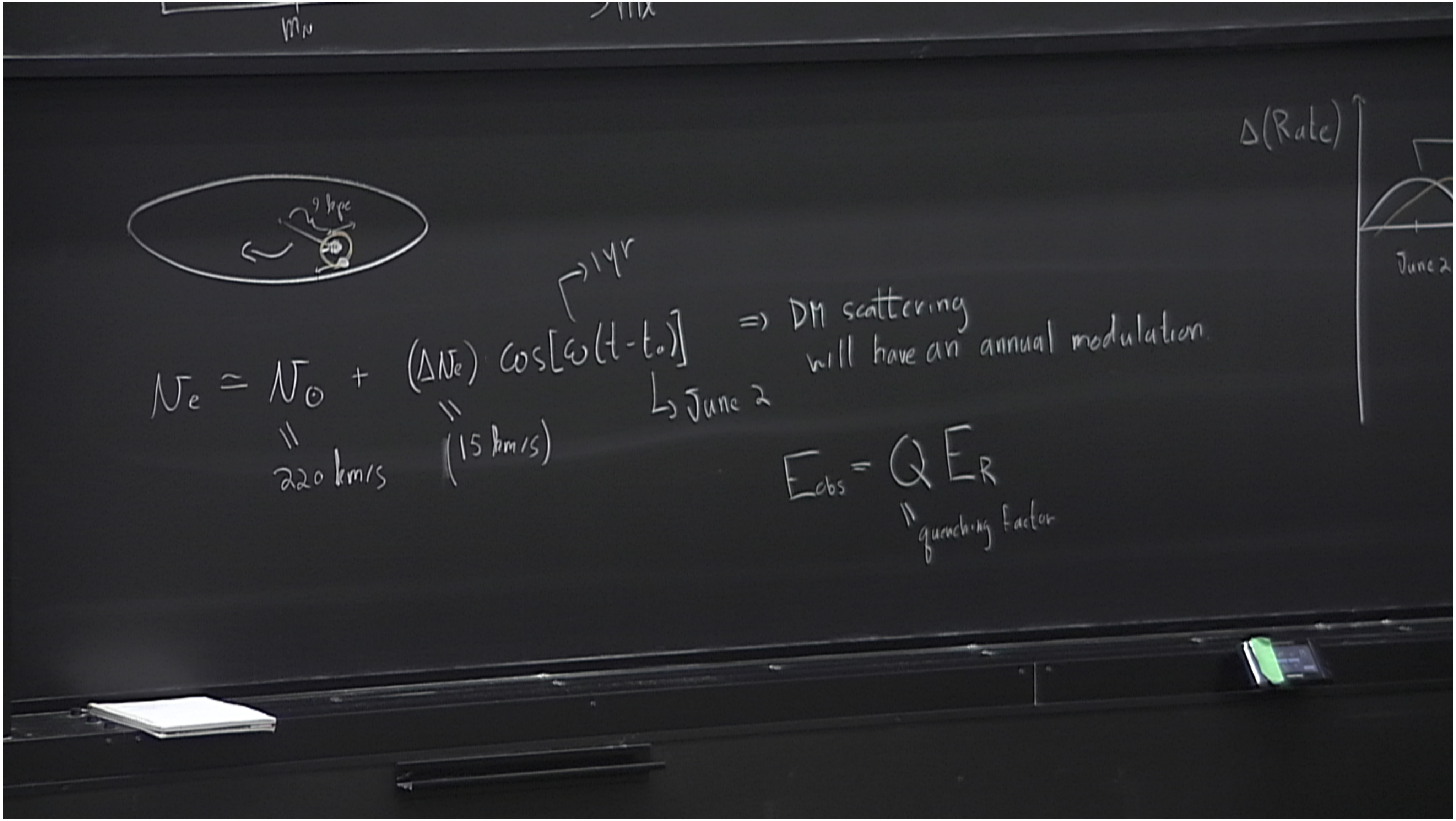
CoGeNT: 0.5 kg of Ge

CRESST: $CaWO_4$

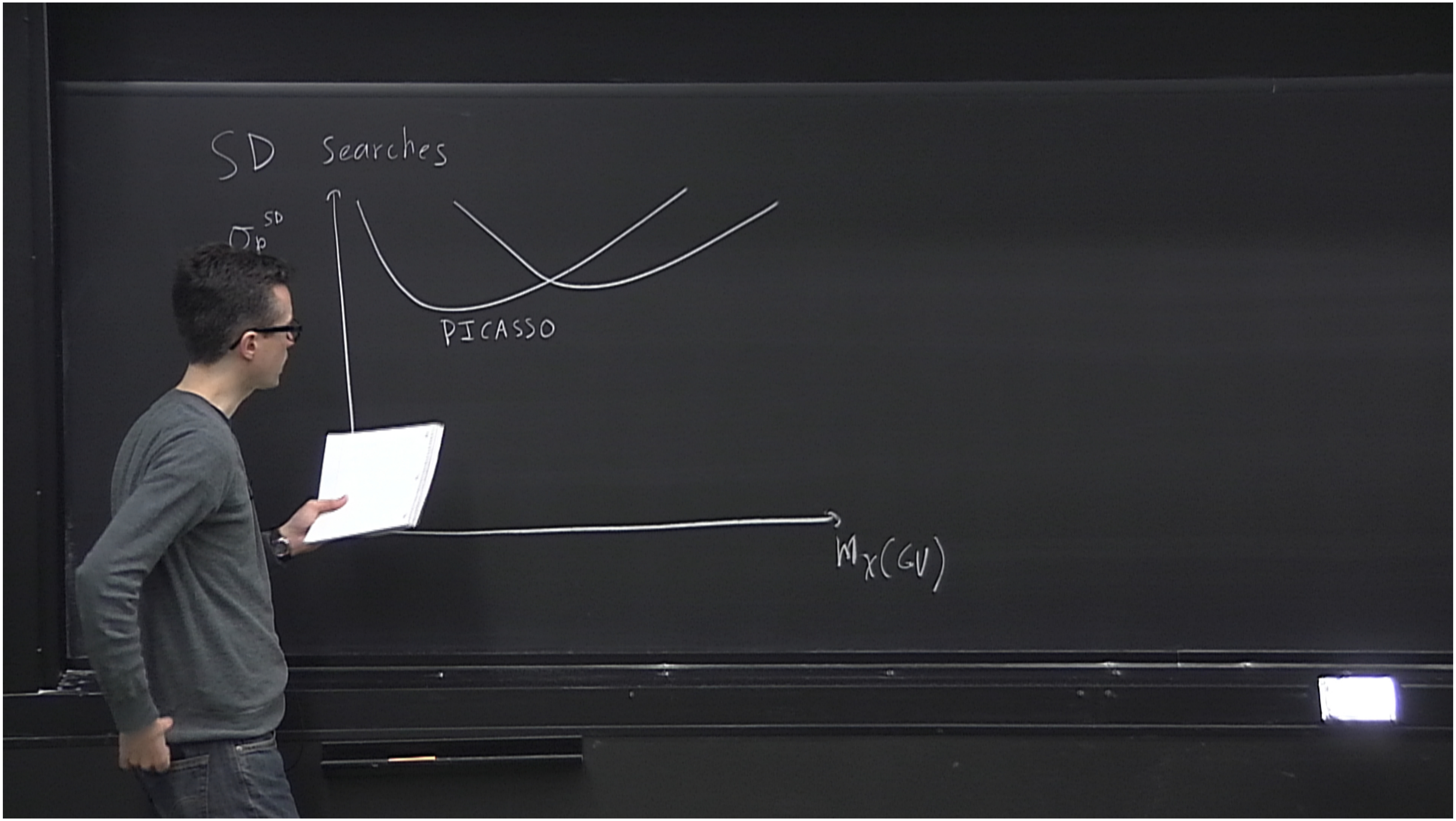
$\left\{ {182-186 \atop 74} \right\}$

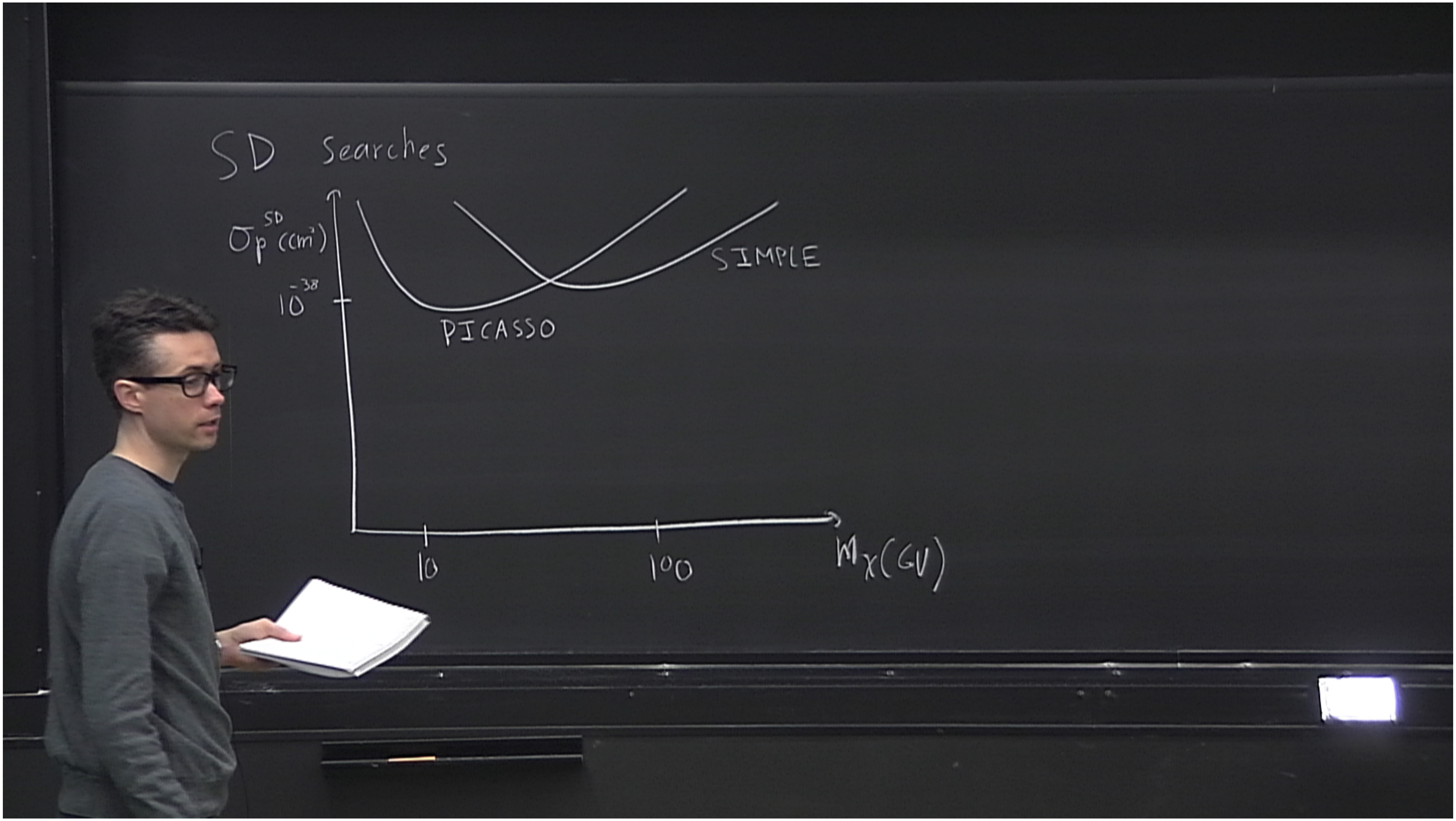


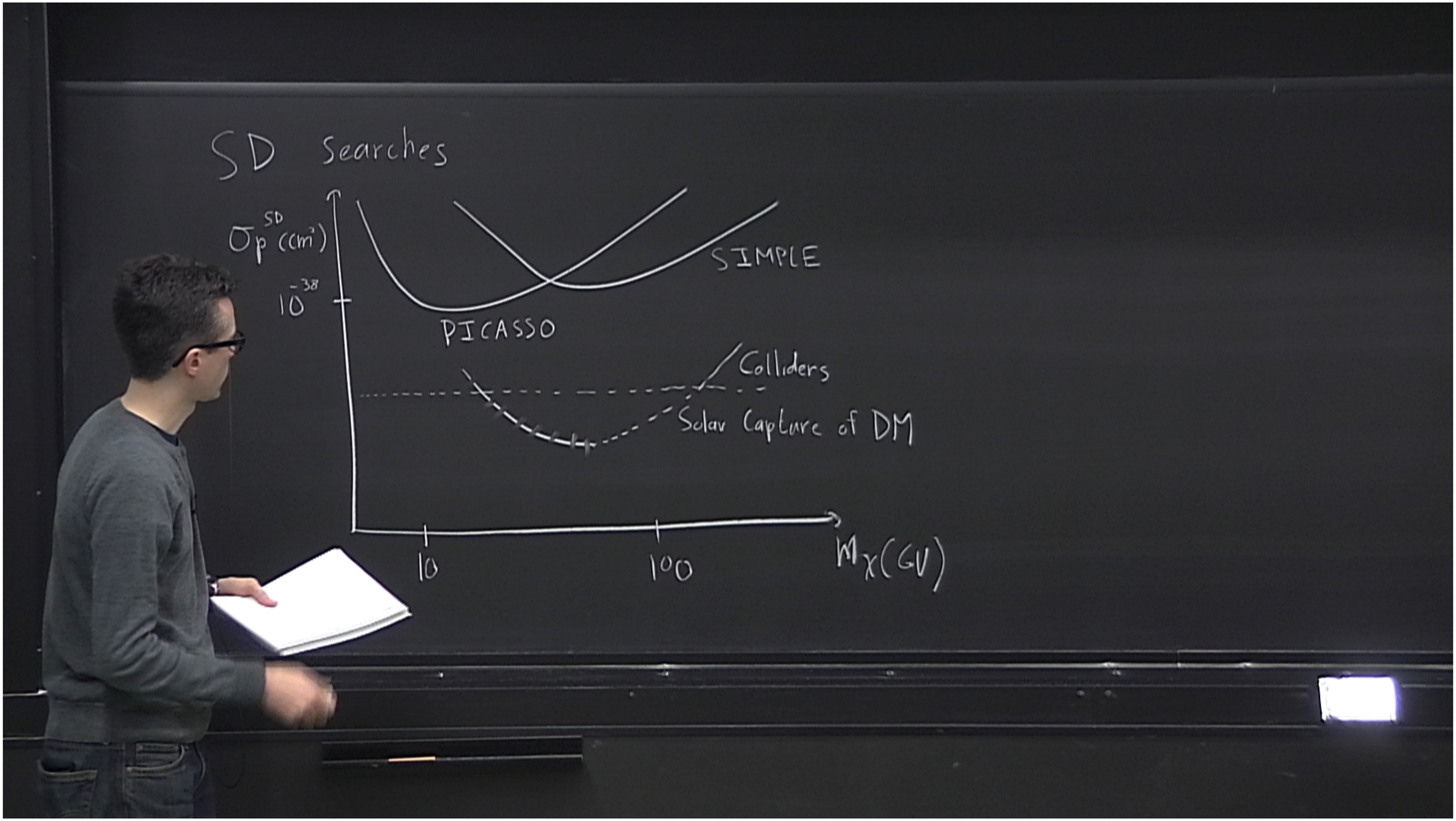
Δ(Rate)
1yr
June 2
t
⇒ DM scattering
will have an annual modulation.
June 2
CoGeN
a modulation

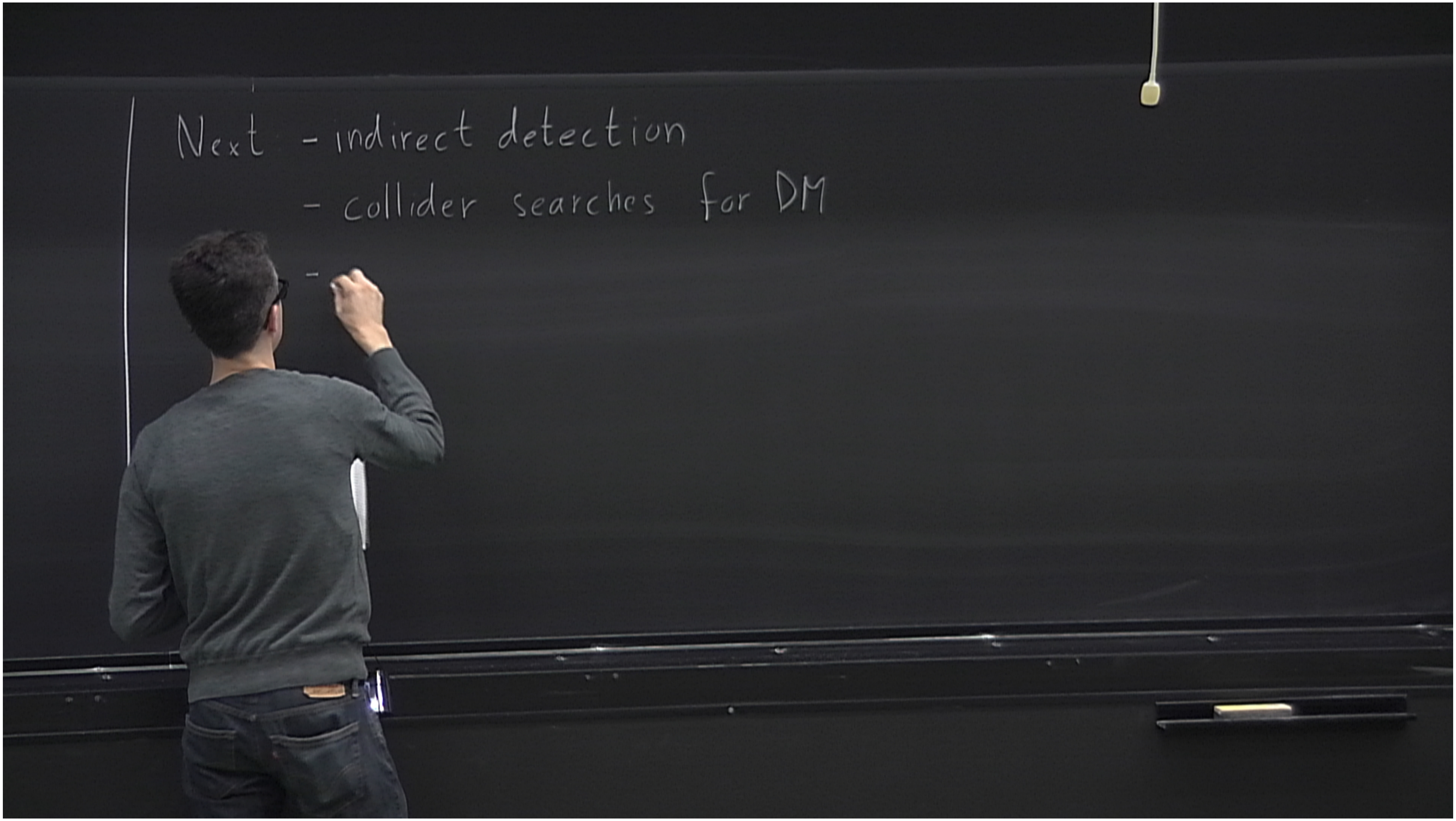


9 kpc
1 yr
$N_e \simeq N_\odot + (\Delta N_e) \cos[\omega(t-t_0)]$
⇒ DM scattering will have an annual modulation
June 2
220 km/s
(15 km/s)
$E_{obs} = Q E_R$
quenching factor
Δ(Rate)
June 2


SD Searches
σ_p^{SD}
PICASSO
m_χ (GV)


SD searches
σ_p^{SD} (cm²)
10^{-38}
SIMPLE
PICASSO
10
100
m_χ (GV)

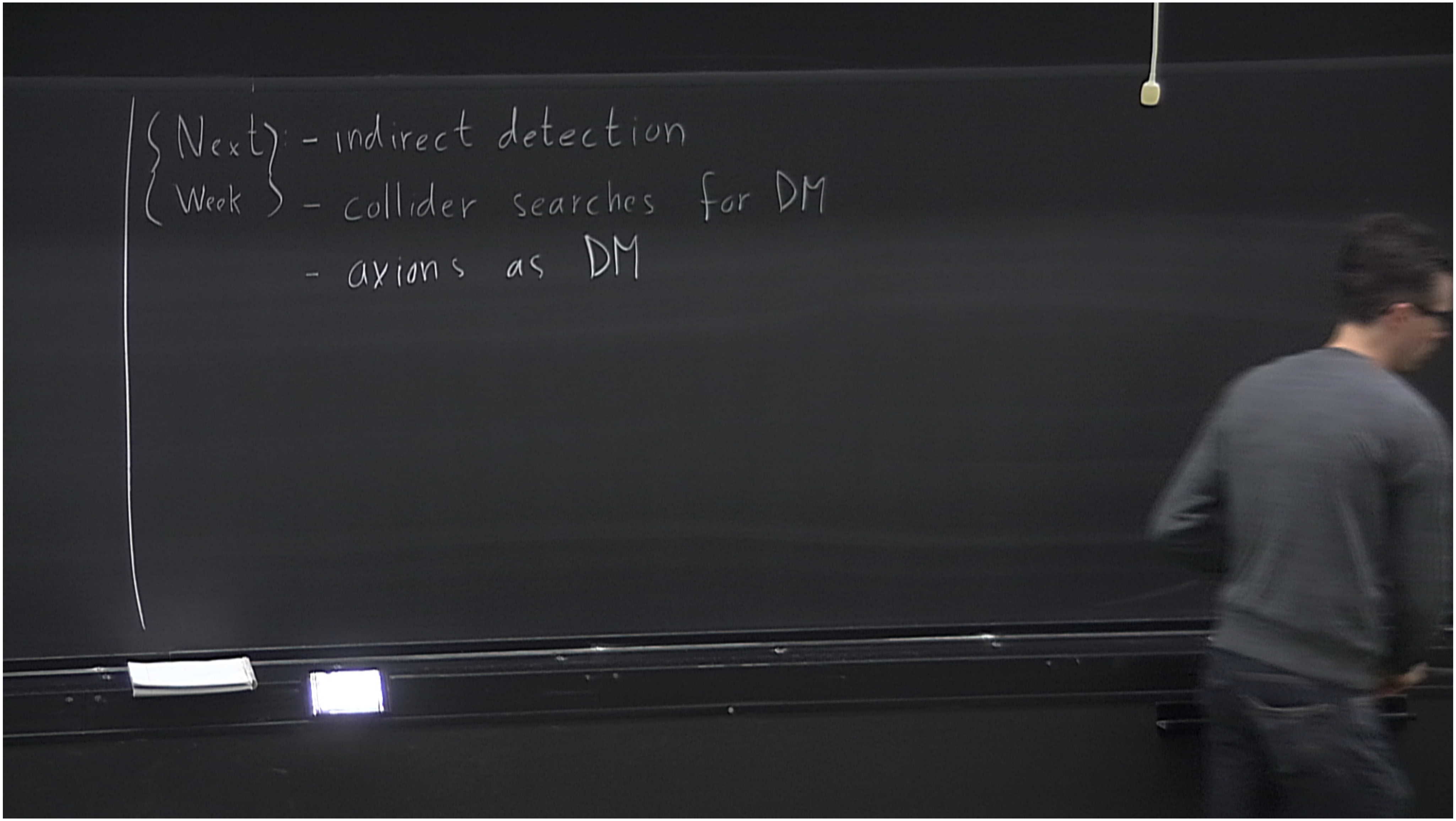

SD Searches
σp^SD (cm²)
10^-38
SIMPLE
PICASSO
Colliders
Solar Capture of DM
10
100
mχ (GeV)


Next - indirect detection
- collider searches for DM
-

Next - indirect detection

- collider searches for DM

- axions as DM


Next Week
- indirect detection
- collider searches for DM
- axions as DM