Title: Astroparticle Physics â€“ Theory: Direct detection

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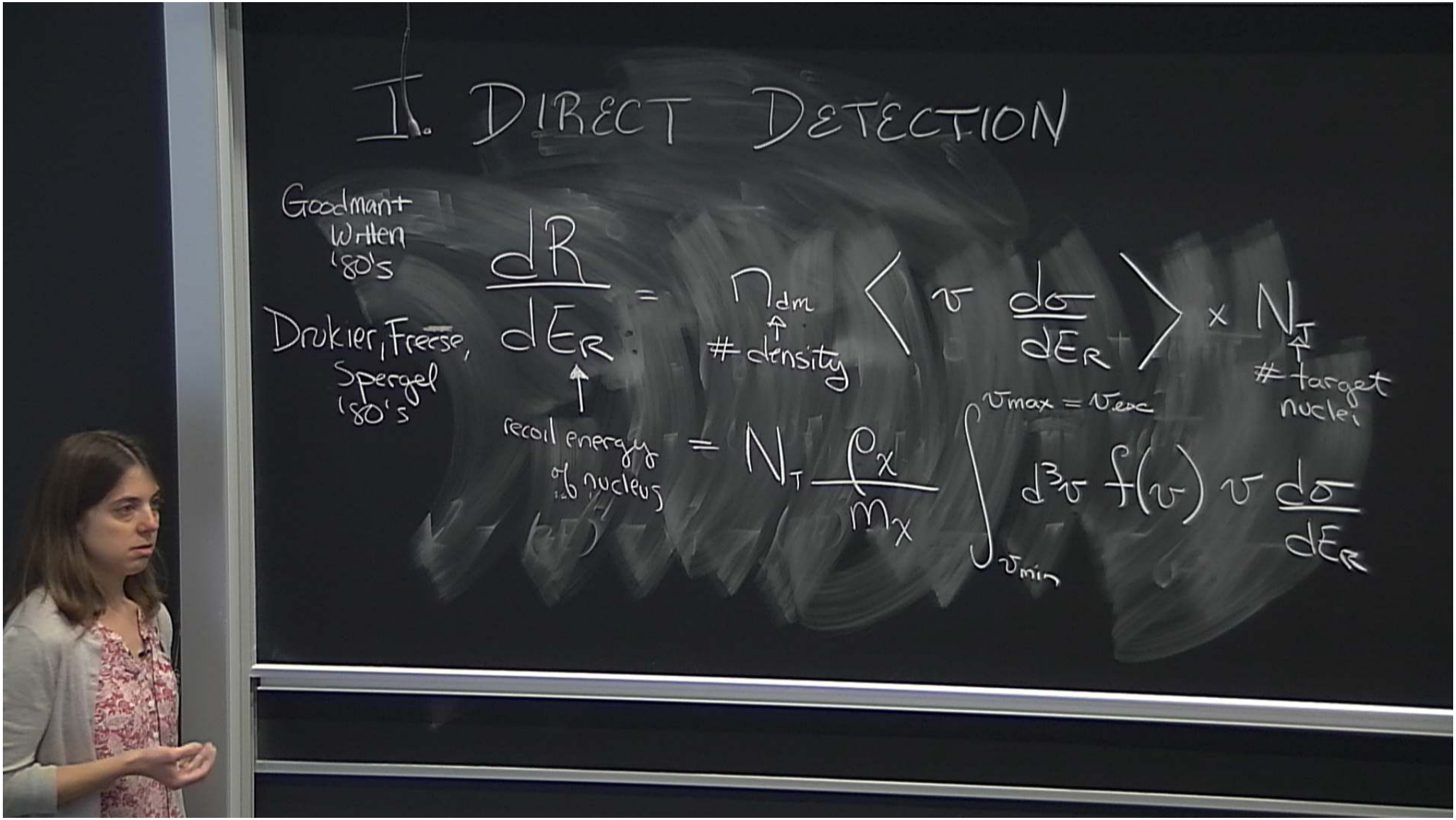
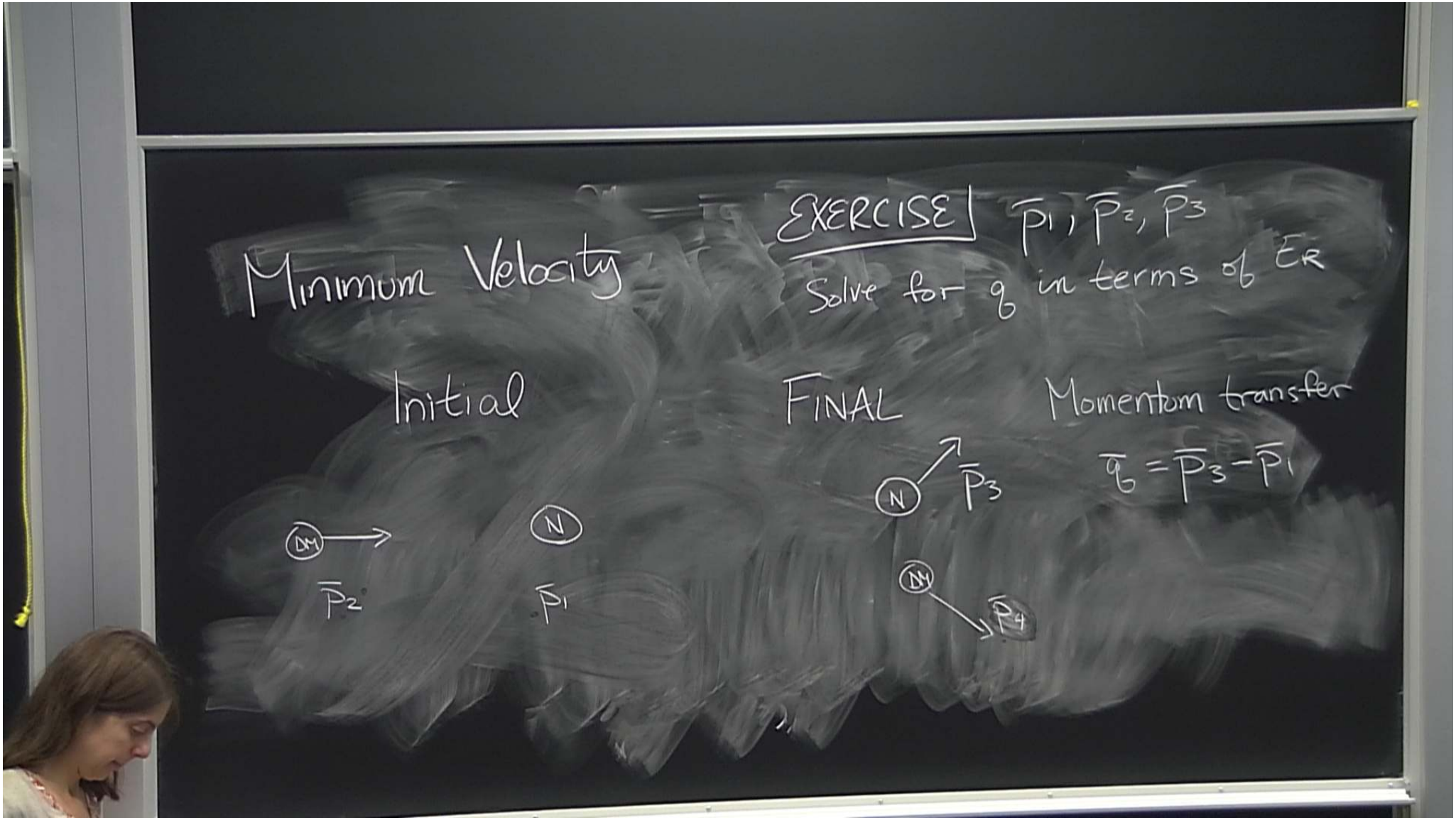
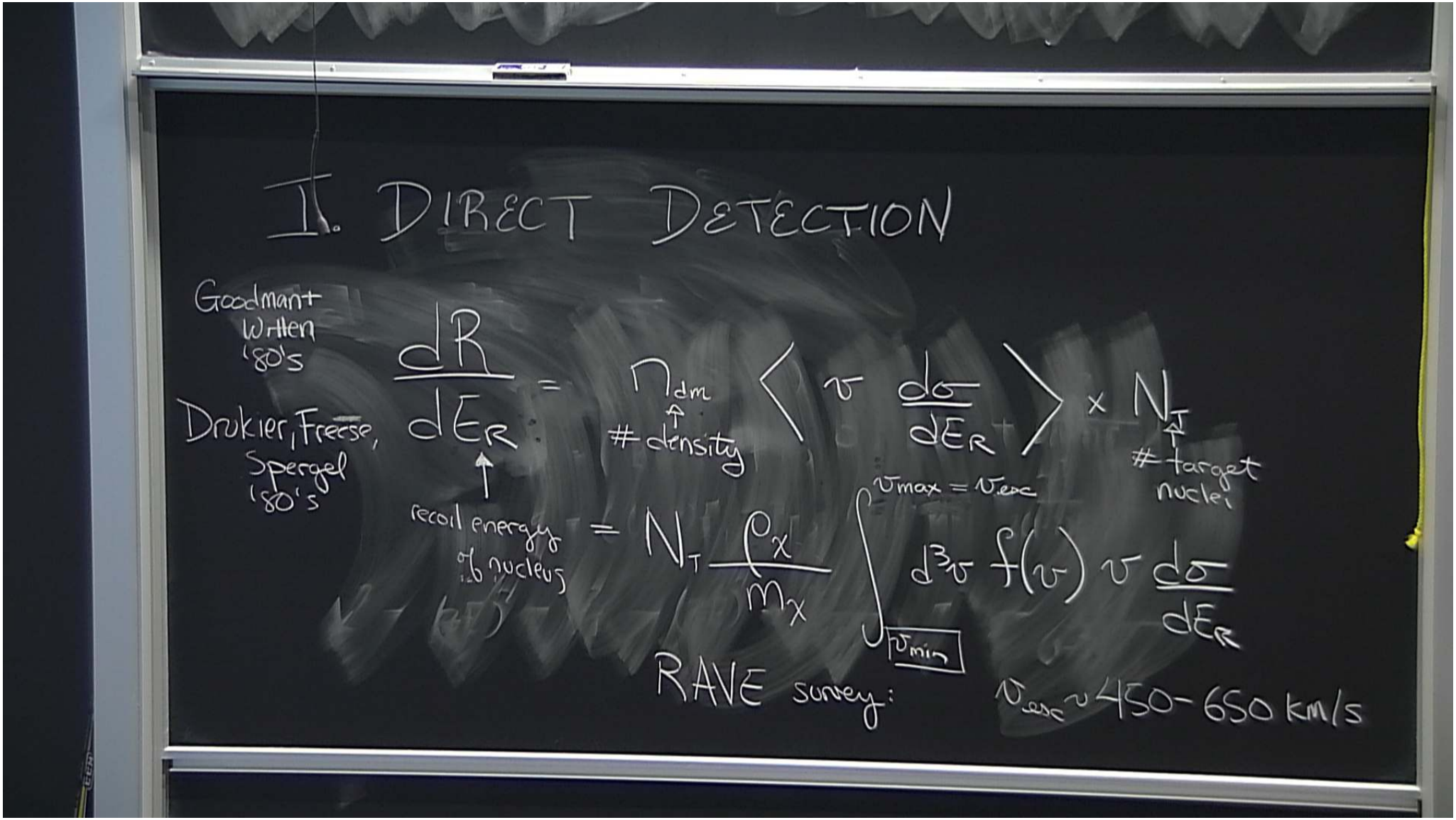
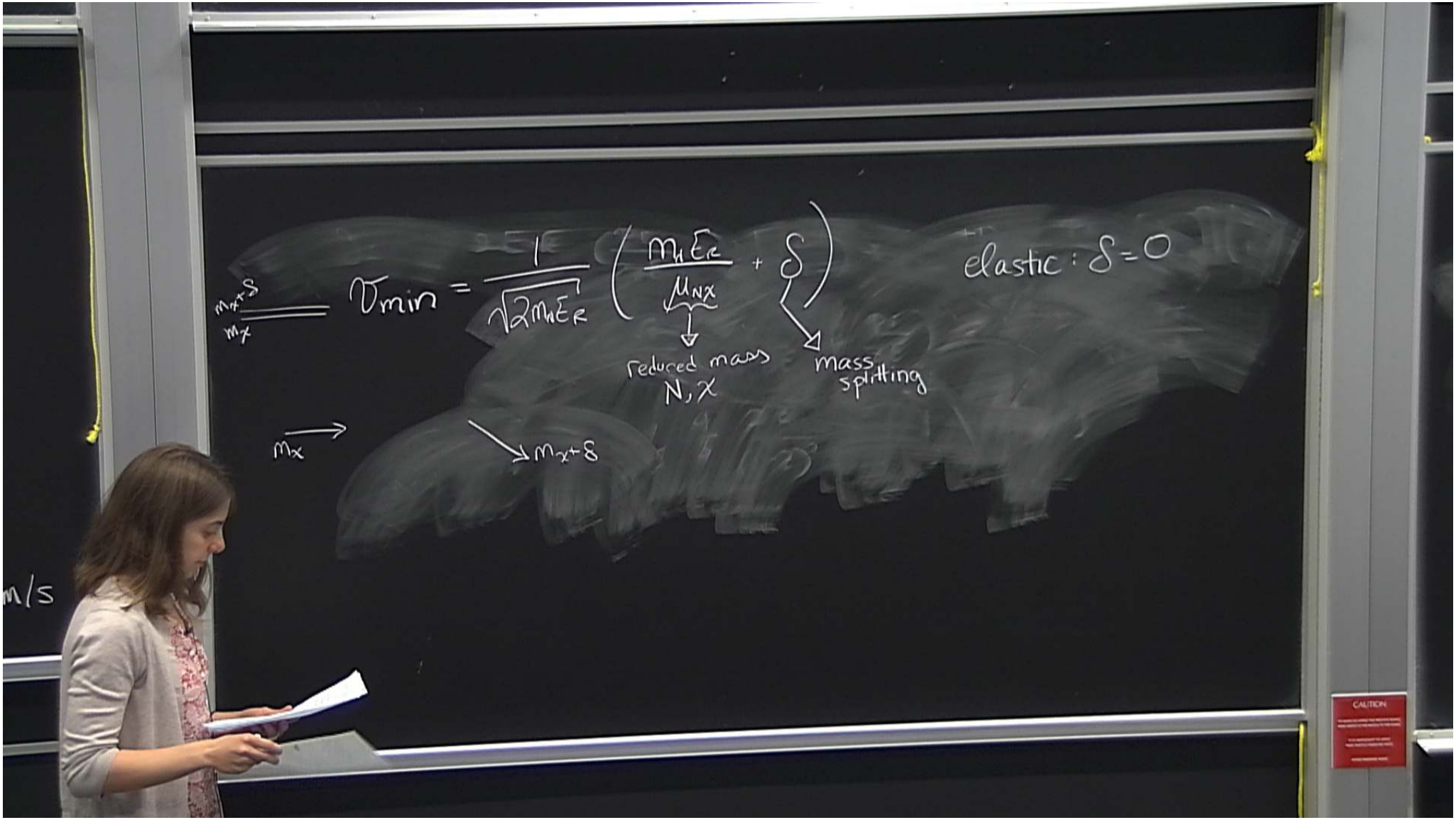
URL: http://pirsa.org/15070018

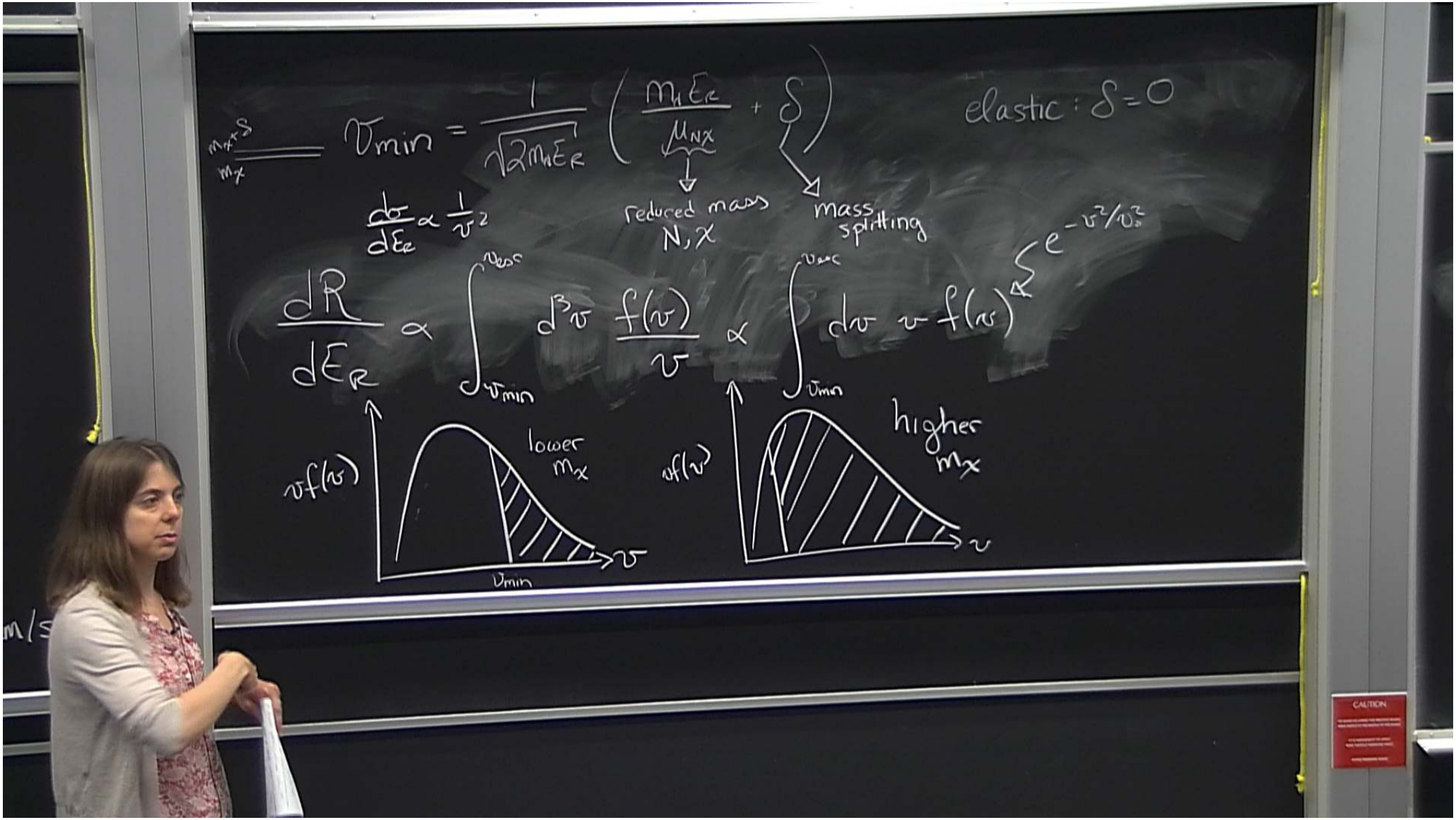
Abstract:

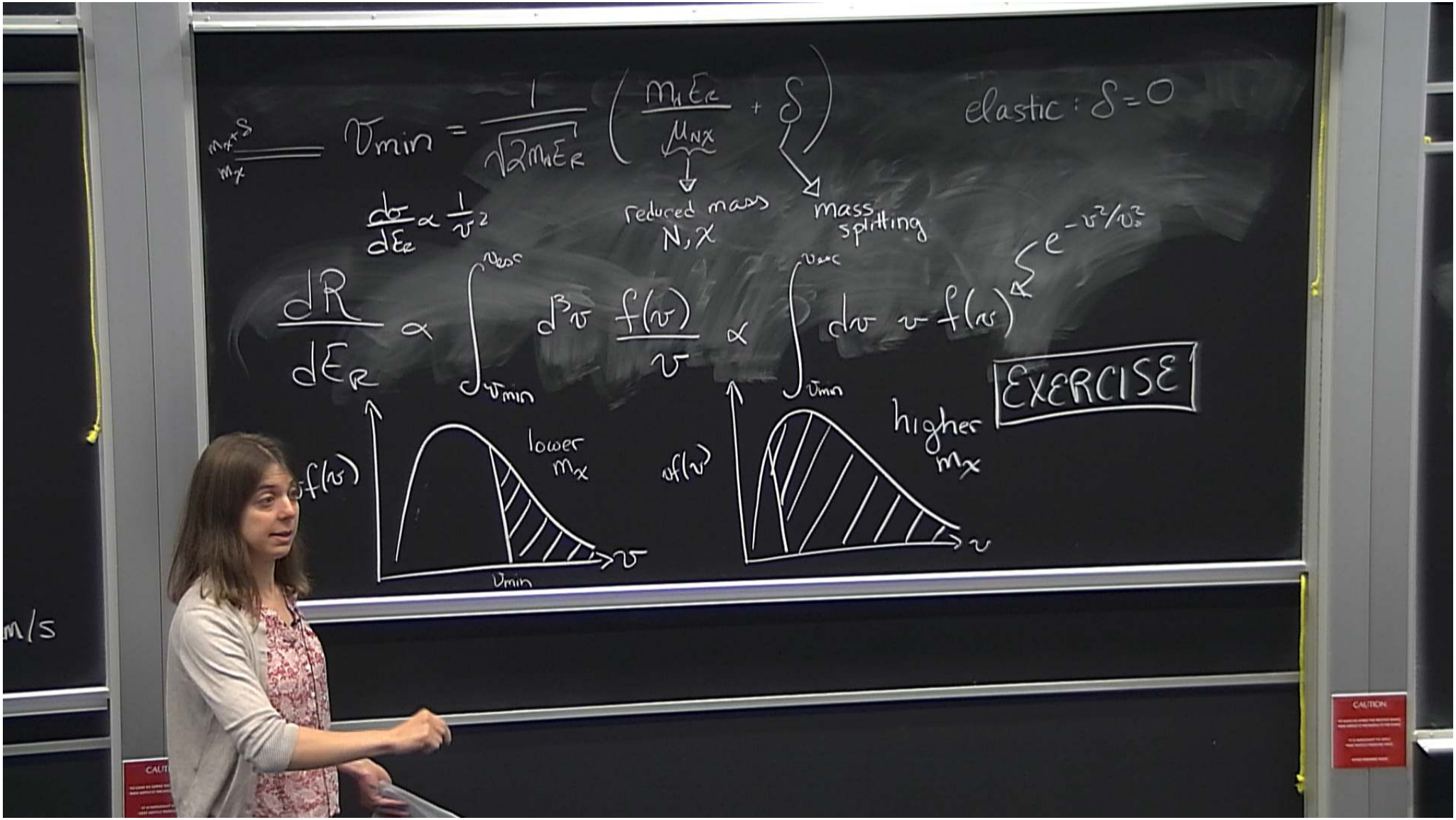

I. DIRECT DETECTION
Goodman + Witten '80's
Drukier, Freese, Spergel '80's
dR/dE_R = n_dm/m_χ ⟨ v dσ/dE_R ⟩ × N_T
density
target nuclei
recoil energy of nucleus
= N_T ρ_χ/m_χ ∫_{v_min}^{v_max = v_esc} d³v f(v) v dσ/dE_R

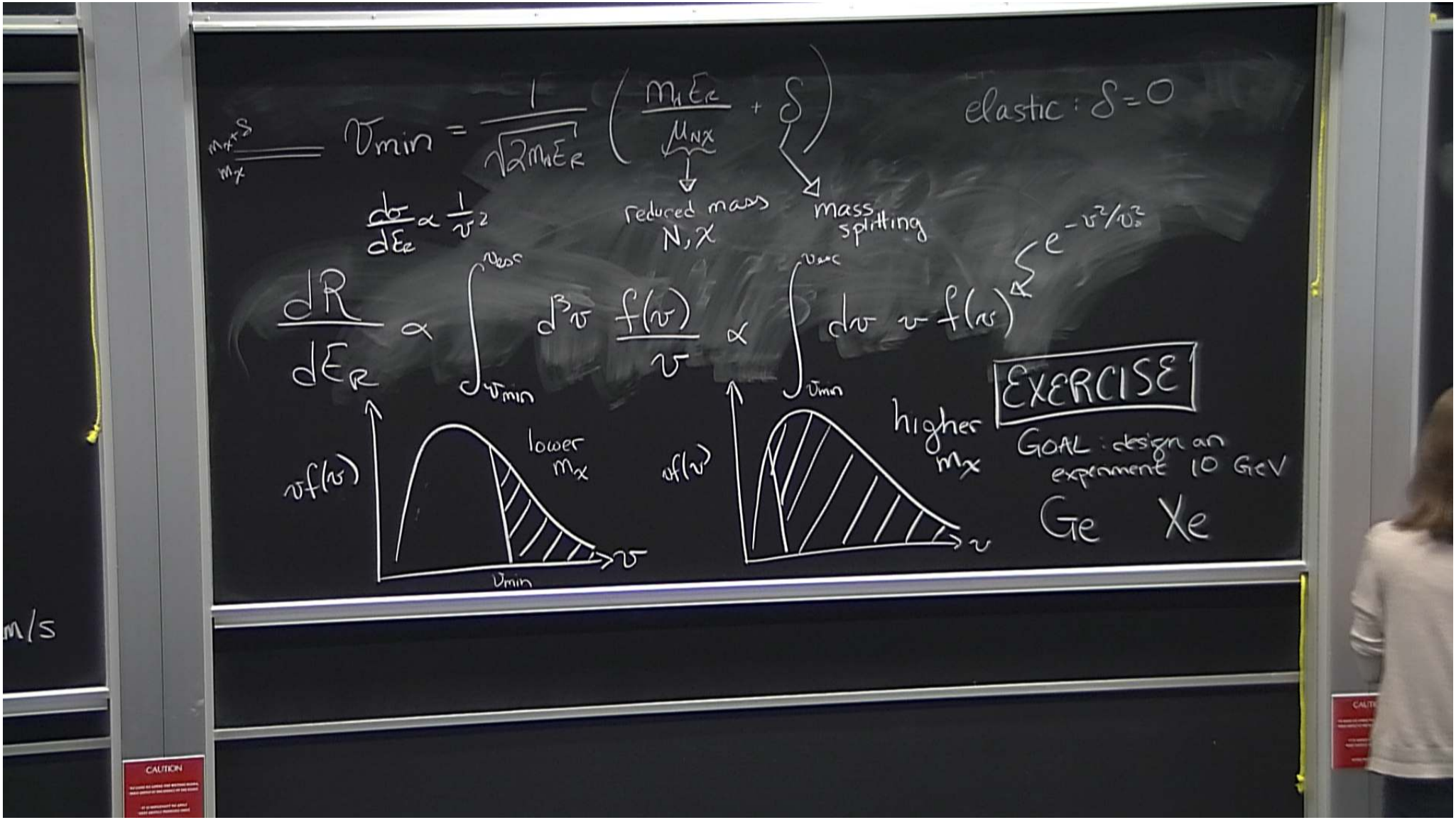

Minimum Velocity
EXERCISE
$\bar{p}_1, \bar{p}_2, \bar{p}_3$
Solve for q in terms of E_R
Initial
FINAL
Momentum transfer
$\bar{q} = \bar{p}_3 - \bar{p}_1$
DM
$\bar{p}_2$
N
$\bar{p}_1$
N
$\bar{p}_3$
DM
$\bar{p}_4$

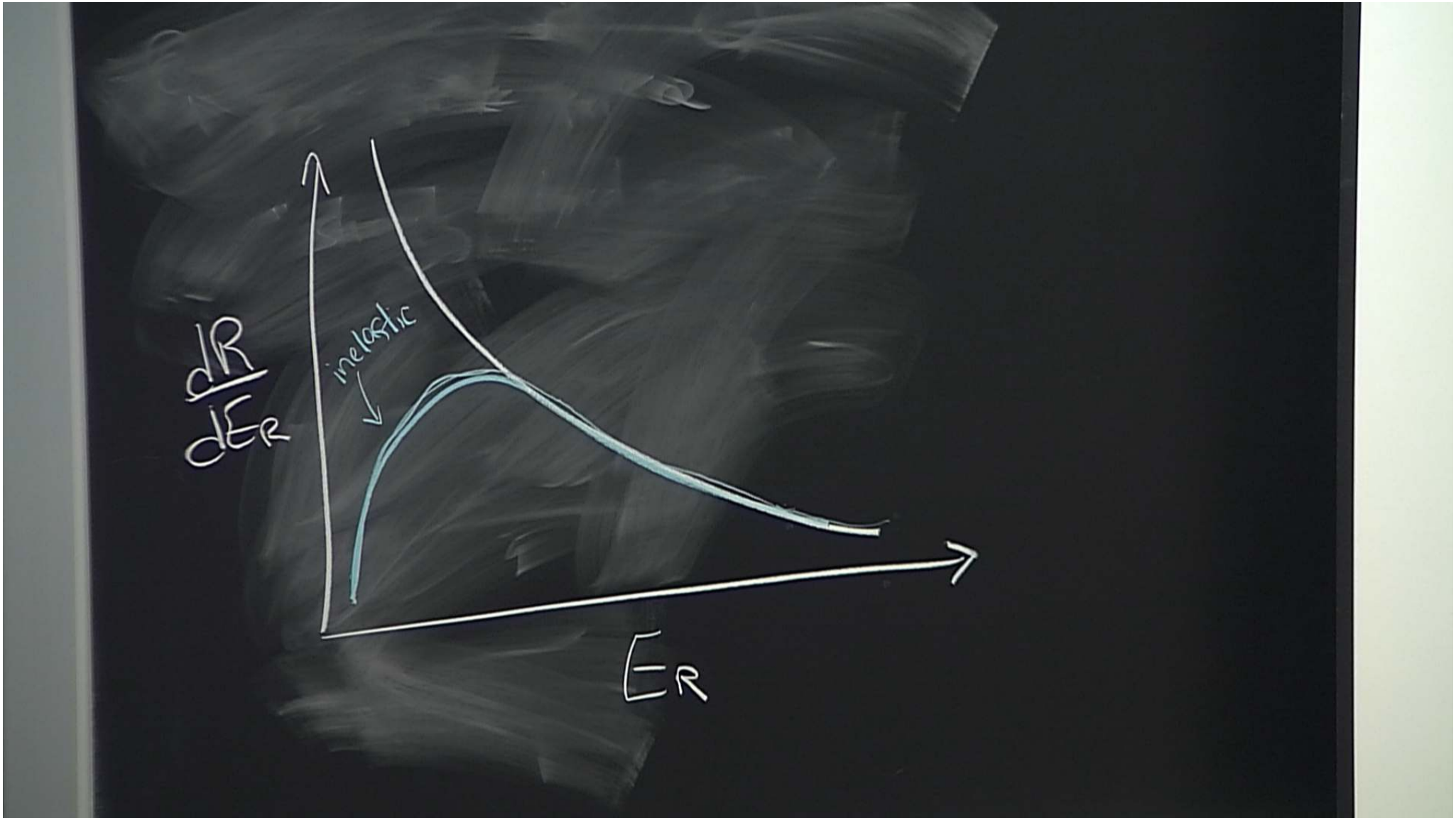

I. DIRECT DETECTION
Goodman+ Witten '80's
Drukier, Freese, Spergel '80's
$\frac{dR}{dE_R} = n_{dm} \left\langle v \frac{d\sigma}{dE_R} \right\rangle \times N_T$
density
target nuclei
recoil energy of nucleus
$= N_T \frac{\rho_\chi}{m_\chi} \int_{v_{min}}^{v_{max}=v_{esc}} d^3v\, f(v)\, v \frac{d\sigma}{dE_R}$
RAVE survey: $v_{esc} \sim 450\text{-}650$ km/s

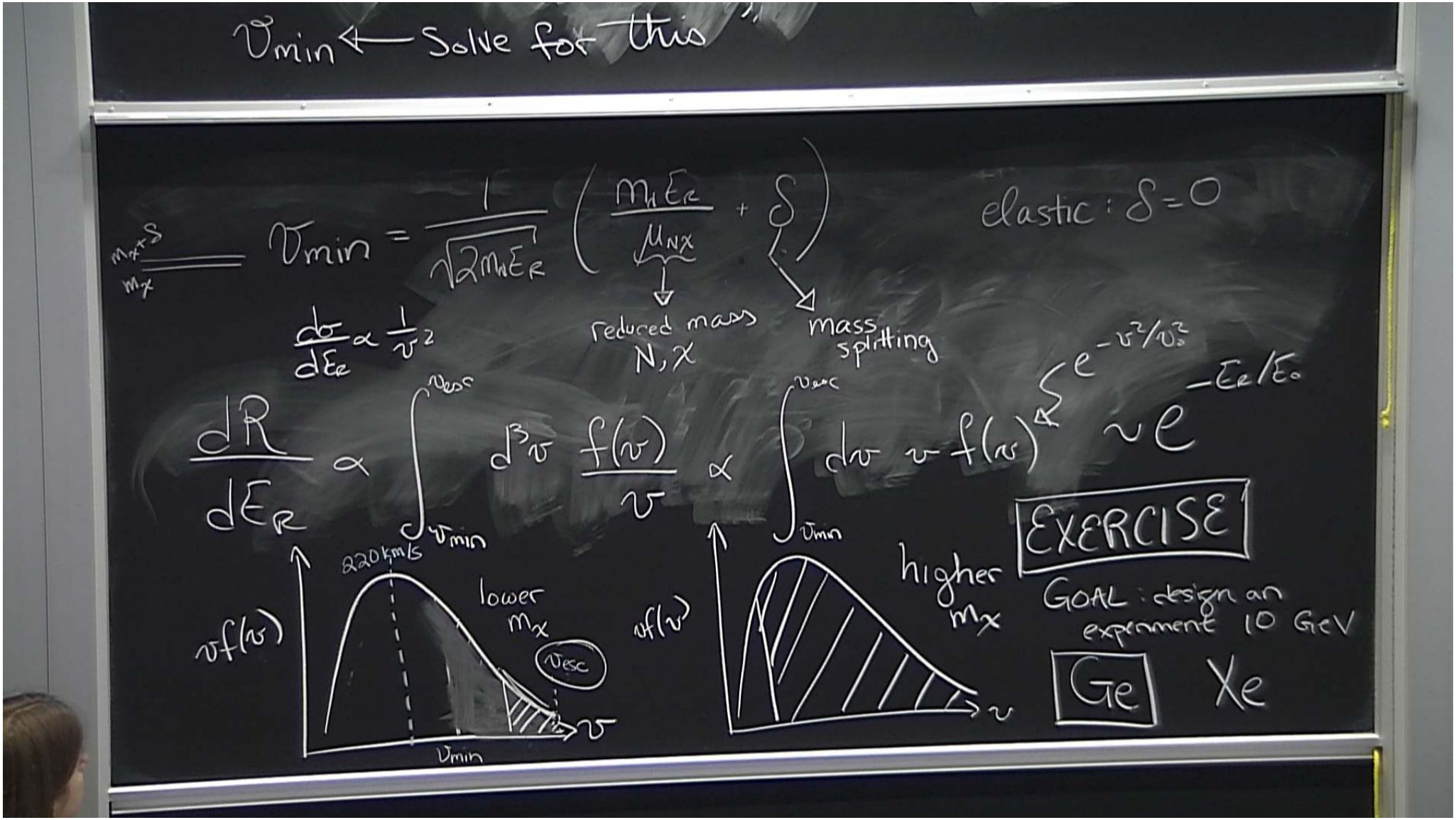

$m_{\chi}+\delta$
m_{χ}
$v_{min} = \frac{1}{\sqrt{2 m_N E_R}} \left(\frac{m_N E_R}{\mu_{N\chi}} + \delta \right)$
reduced mass
N, χ
mass splitting
elastic : $\delta = 0$
m_{χ}
$m_{\chi}+\delta$
m/s
CAUTION


$v_{min} = \frac{1}{\sqrt{2 m_x E_R}} \left(\frac{m_x E_R}{\mu_{Nx}} + \delta \right)$
elastic: $\delta = 0$
reduced mass
N, χ
mass splitting
$\frac{d\sigma}{dE_R} \propto \frac{1}{v^2}$
$\frac{dR}{dE_R} \propto \int_{v_{min}}^{v_{esc}} d^3v \, \frac{f(v)}{v} \propto \int_{v_{min}}^{v_{esc}} dv \, v f(v) \, e^{-v^2/v_0^2}$
$vf(v)$
lower m_x
v_{min}
v
higher m_x


elastic : δ = 0
reduced mass
N, χ
mass splitting
EXERCISE
lower m_χ
higher m_χ
v_{min}


$v_{min} = \frac{1}{\sqrt{2 m_N E_R}} \left(\frac{m_N E_R}{\mu_{NX}} + \delta \right)$
elastic: $\delta = 0$
reduced mass
N, X
mass splitting
$\frac{d\sigma}{dE_R} \propto \frac{1}{v^2}$
$\frac{dR}{dE_R} \propto \int_{v_{min}}^{v_{esc}} d^3v \, \frac{f(v)}{v} \propto \int_{v_{min}}^{v_{esc}} dv \, v f(v) \, e^{-v^2/v_0^2}$
$v f(v)$
lower m_X
v_{min}
higher m_X
EXERCISE
GOAL: design an experiment 10 GeV
Ge Xe

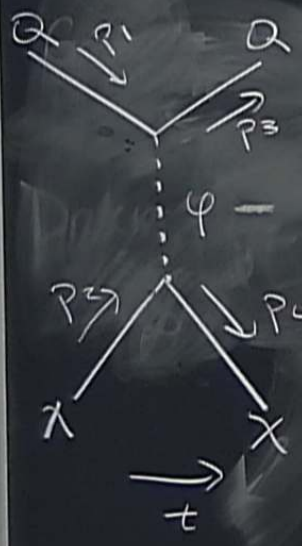

dR/dER
inelastic
ER


v_{min} ← Solve for this
$v_{min} = \frac{1}{\sqrt{2 m_N E_R}} \left(\frac{m_N E_R}{\mu_{NX}} + \delta \right)$
$\frac{m_X + \delta}{m_X}$
elastic: $\delta = 0$
reduced mass N, X
mass splitting
$\frac{d\sigma}{dE_R} \propto \frac{1}{v^2}$
$\frac{dR}{dE_R} \propto \int_{v_{min}}^{v_{esc}} d^3v \frac{f(v)}{v} \propto \int_{v_{min}}^{v_{esc}} dv \, v f(v) \xi e^{-v^2/v_0^2} \sim e^{-E_R/E_0}$
$v f(v)$
220 km/s
lower m_X
v_{esc}
v_{min}
v
higher m_X
EXERCISE
GOAL: design an experiment 10 GeV
Ge
Xe

ex

$\mathcal{L}_{eff} = G(q^2, m_\varphi^2)\,\bar{\chi}\,\Gamma_\chi\,\chi\,\bar{Q}\,\Gamma_Q\,Q$

$G(q^2, m_\varphi^2)$ → propagator

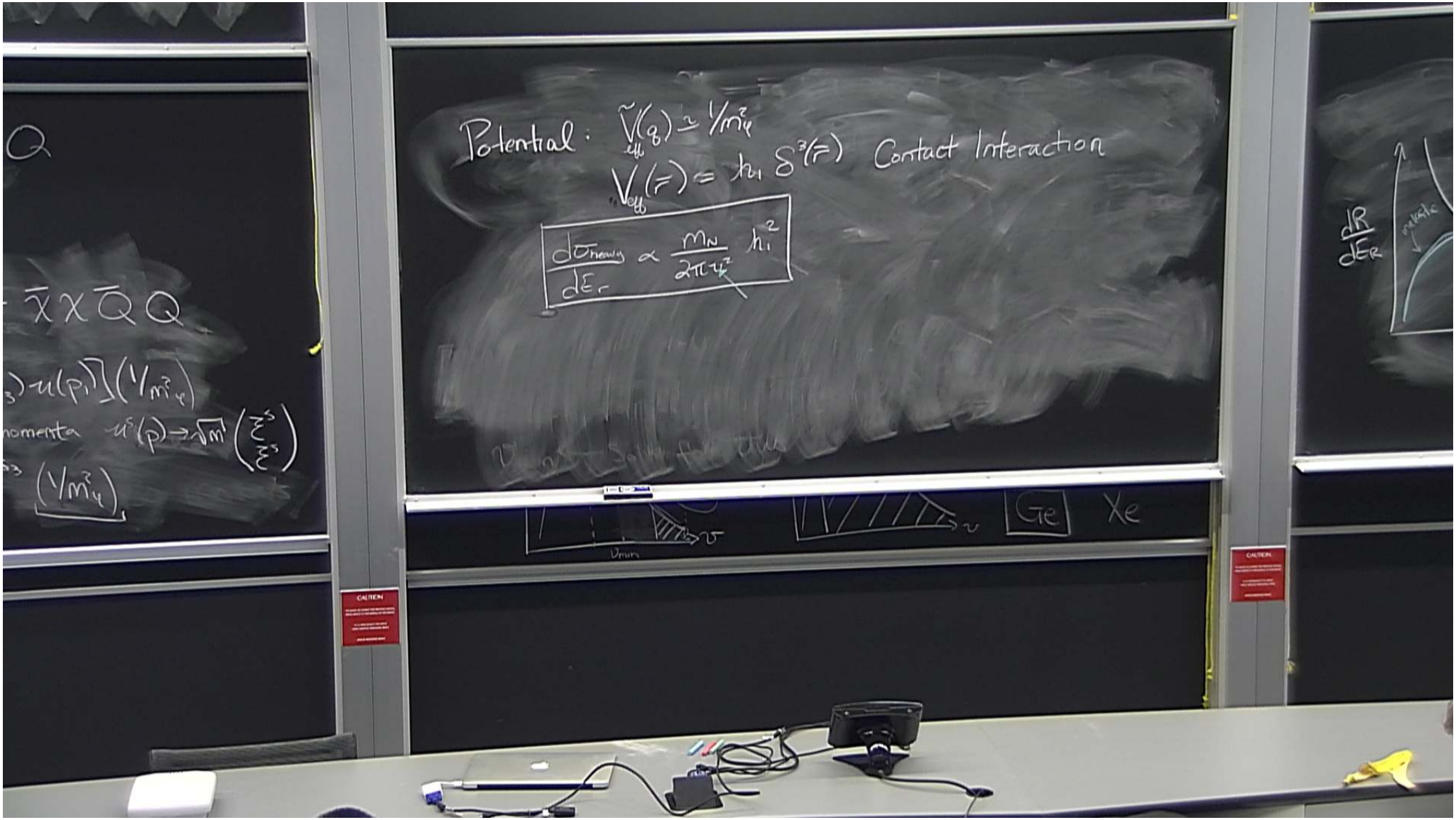


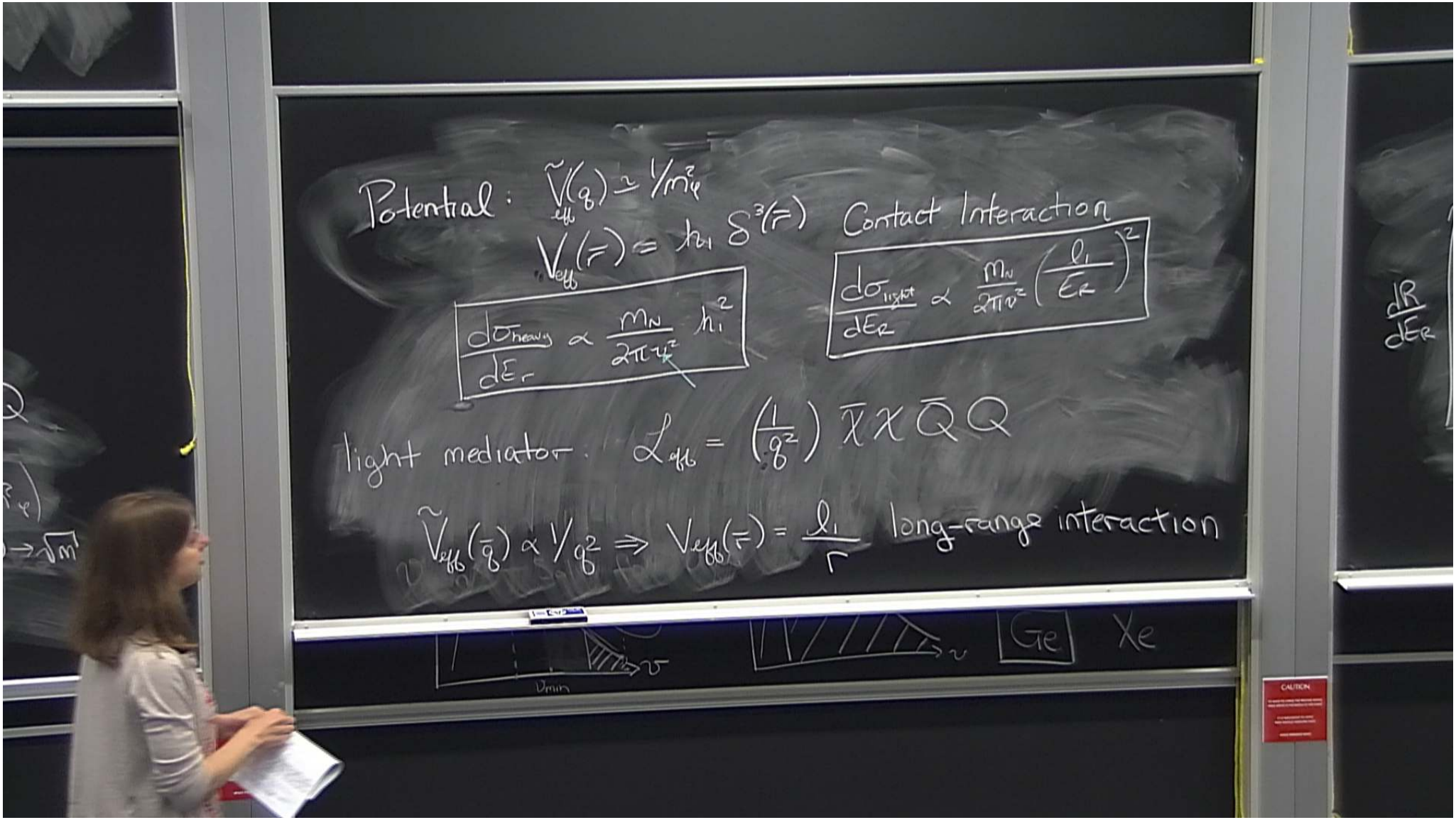
heavy mediator $\mathcal{L}_{eff} = \frac{1}{m_\varphi^2}\,\bar{\chi}\chi\bar{Q}Q$

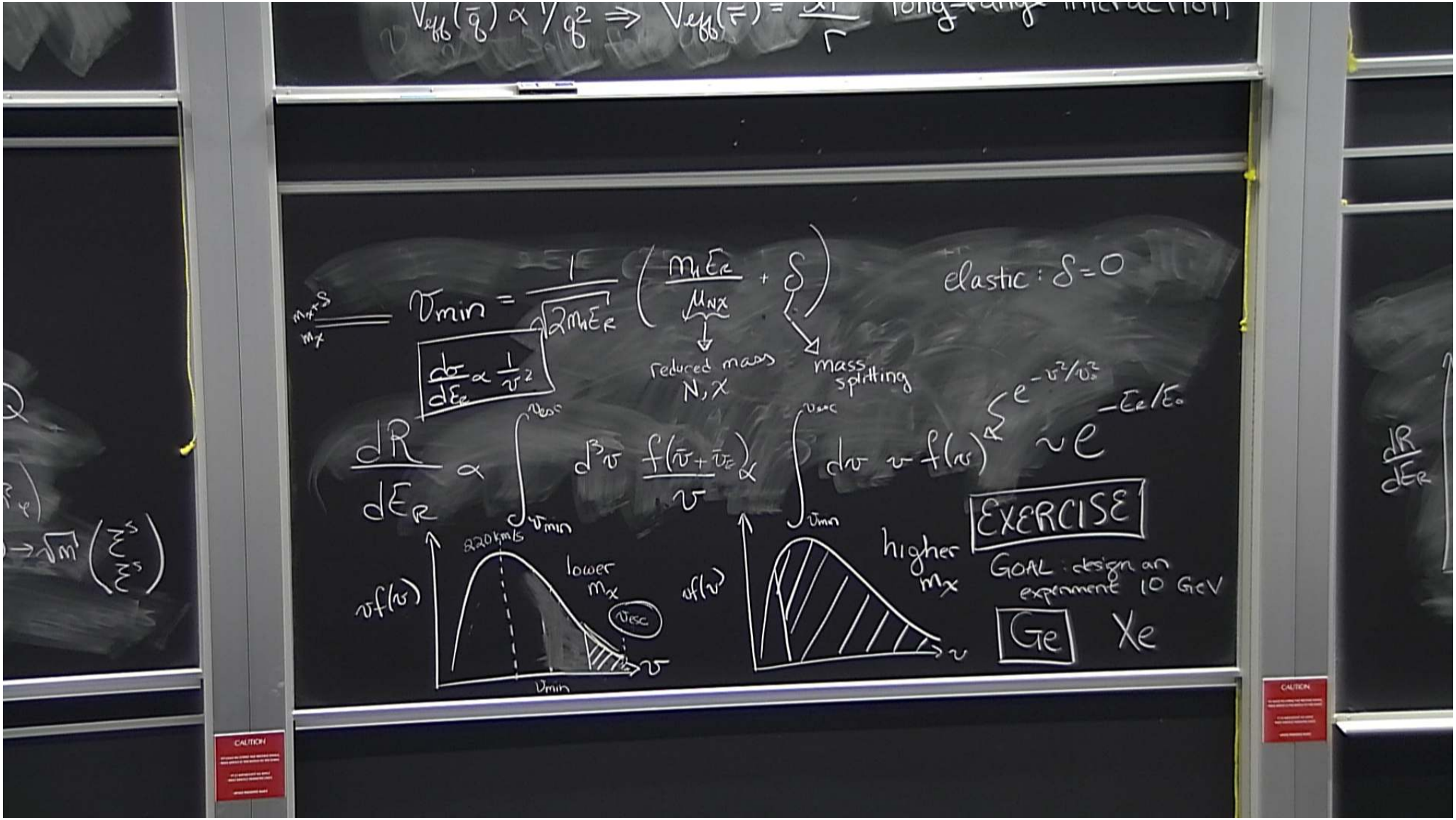
$i\mathcal{M} = [\bar{u}(p_4)u(p_2)][\bar{u}(p_3)u(p_1)]\left(1/m_\varphi^2\right)$

lowest order 3-momenta $u^s(p) \to \sqrt{m}\begin{pmatrix}\xi^s\\ \xi^s\end{pmatrix}$

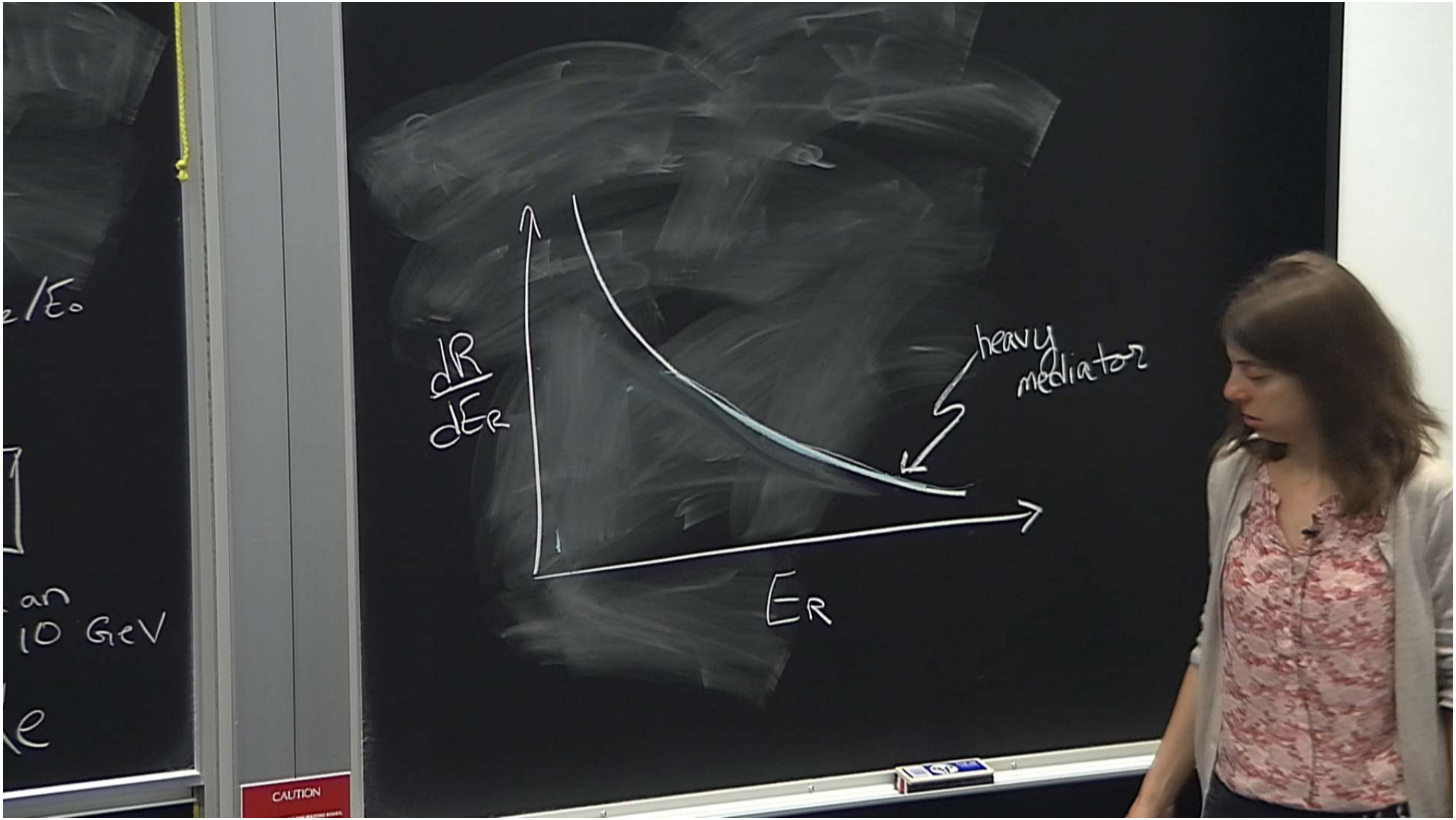
$\to 2m_\chi\,\delta^{s_2 s_4}\; 2m_N\,\delta^{s_1 s_3}\left(1/m_\varphi^2\right)$


Potential: $\tilde{V}_{eff}(q) \simeq 1/m_\psi^2$
$V_{eff}(\vec{r}) = h_i\, \delta^3(\vec{r})$ Contact Interaction
$\frac{d\sigma_{heavy}}{dE_r} \propto \frac{m_N}{2\pi v^2} h_i^2$
Ge
Xe
$\frac{dR}{dE_R}$

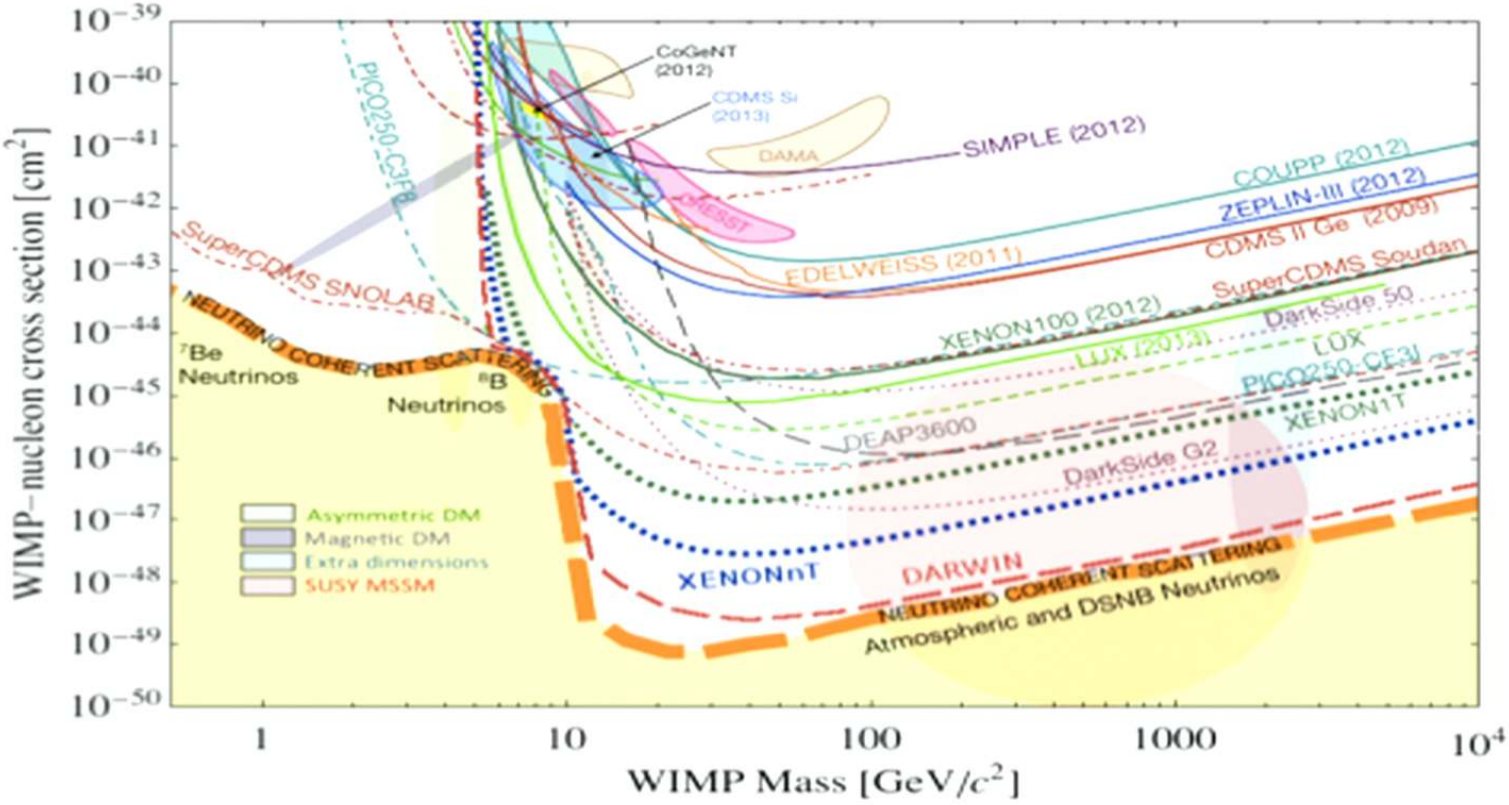

Potential: $\tilde{V}_{eff}(q) \simeq 1/m_\phi^2$
$V_{eff}(\vec{r}) = h_1 \delta^3(\vec{r})$
Contact Interaction
$\frac{d\sigma_{heavy}}{dE_r} \propto \frac{m_N}{2\pi v^2} h_1^2$
$\frac{d\sigma_{light}}{dE_R} \propto \frac{m_N}{2\pi v^2}\left(\frac{f_1}{E_R}\right)^2$
light mediator. $\mathcal{L}_{eff} = \left(\frac{1}{q^2}\right) \bar{\chi}\chi\bar{Q}Q$
$\tilde{V}_{eff}(\vec{q}) \propto 1/q^2 \Rightarrow V_{eff}(\vec{r}) = \frac{f_1}{r}$ long-range interaction
v_{min}
Ge
Xe
$\frac{dR}{dE_R}$



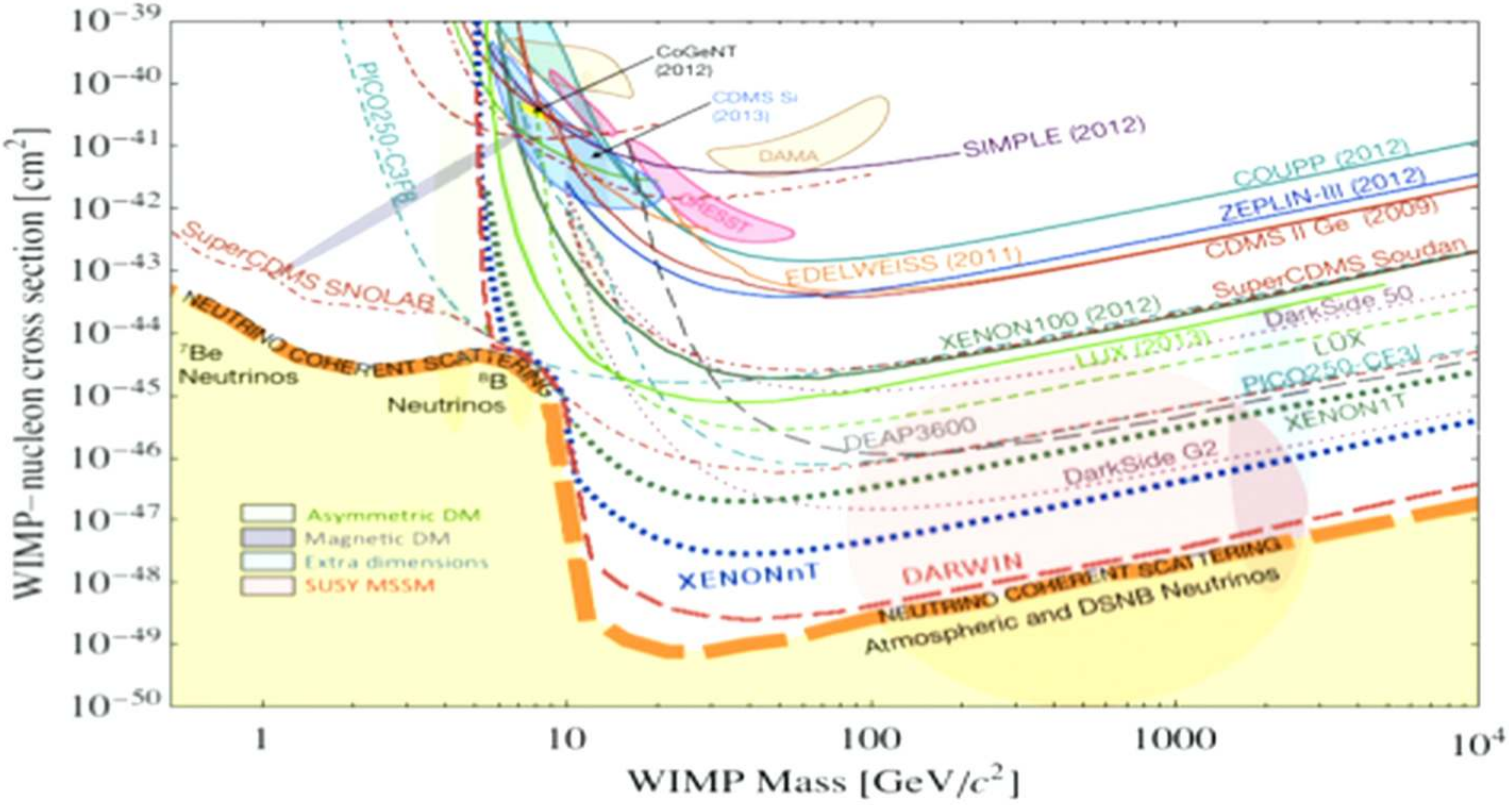
$V_{eff}(\bar{q}) \propto 1/q^2 \Rightarrow V_{eff}(\bar{r}) = \frac{\alpha r}{r}$ long-range interaction
$v_{min} = \frac{1}{\sqrt{2m_N E_R}} \left(\frac{m_N E_R}{\mu_{N\chi}} + \delta \right)$
elastic : $\delta = 0$
reduced mass N, χ
mass splitting
$\frac{d\sigma}{dE_R} \propto \frac{1}{v^2}$
$\frac{dR}{dE_R} \propto \int_{v_{min}}^{v_{esc}} d^3v \, \frac{f(\bar{v}+\bar{v}_E)}{v} \propto \int_{v_{min}}^{v_{esc}} dv \, v f(v) \sim e^{-E_R/E_0}$
e^{-v^2/v_0^2}
EXERCISE
GOAL : design an experiment 10 GeV
Ge
Xe
220 km/s
lower m_χ
higher m_χ
$v f(v)$
v_{esc}
v_{min}

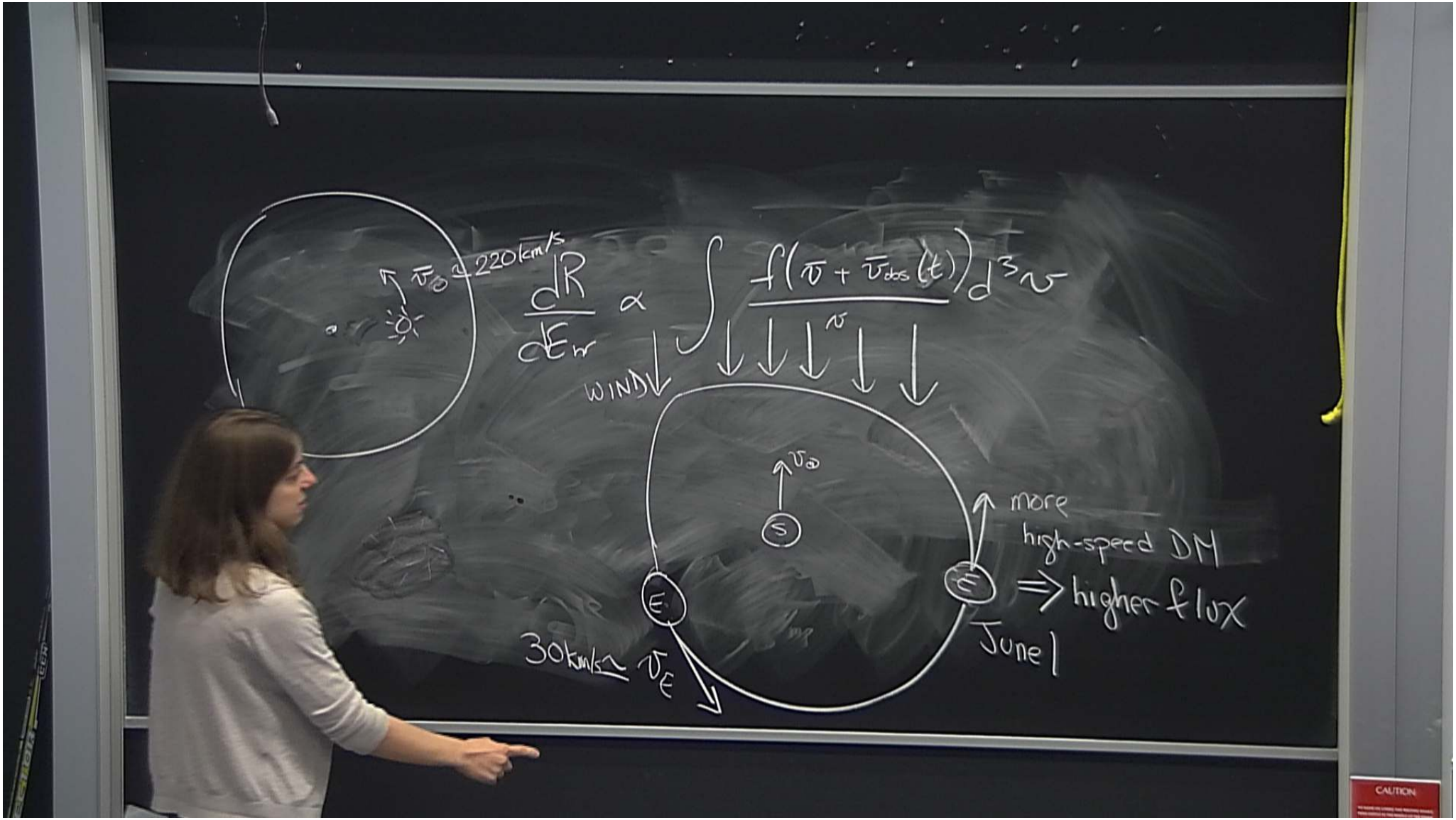

dR
dER
heavy mediator
ER
10 GeV
CAUTION

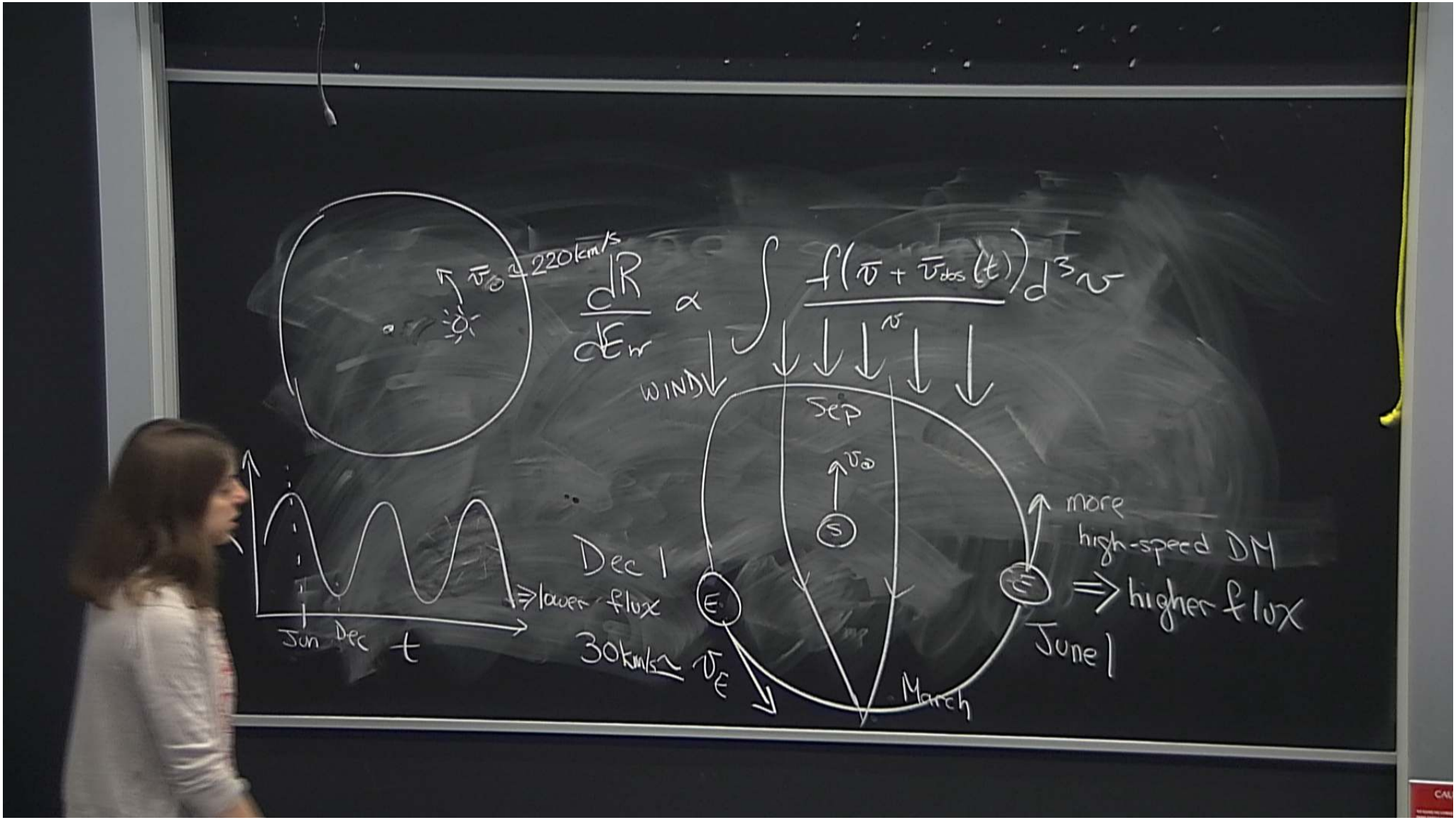
Direct Detection



Direct Detection




$\vec{v}_\odot \simeq 220\,km/s$
$\frac{dR}{dE_{nr}} \propto \int \frac{f(\vec{v}+\vec{v}_{obs}(t))}{v} d^3v$
WIND
$\vec{v}_\odot$
more high-speed DM
$\Rightarrow$ higher flux
June 1
30 km/s $\simeq \vec{v}_\oplus$



$\bar{v}_\odot \simeq 220$ km/s
$\frac{dR}{dE_{nr}} \propto \int \frac{f(\bar{v} + \bar{v}_{obs}(t))}{v} d^3v$
WIND
Sep
$v_\odot$
S
E
more
high-speed DM
⇒ higher flux
June 1
March
Dec 1
⇒ lower flux
30 km/s ≃ v_E
Jun
Dec
t