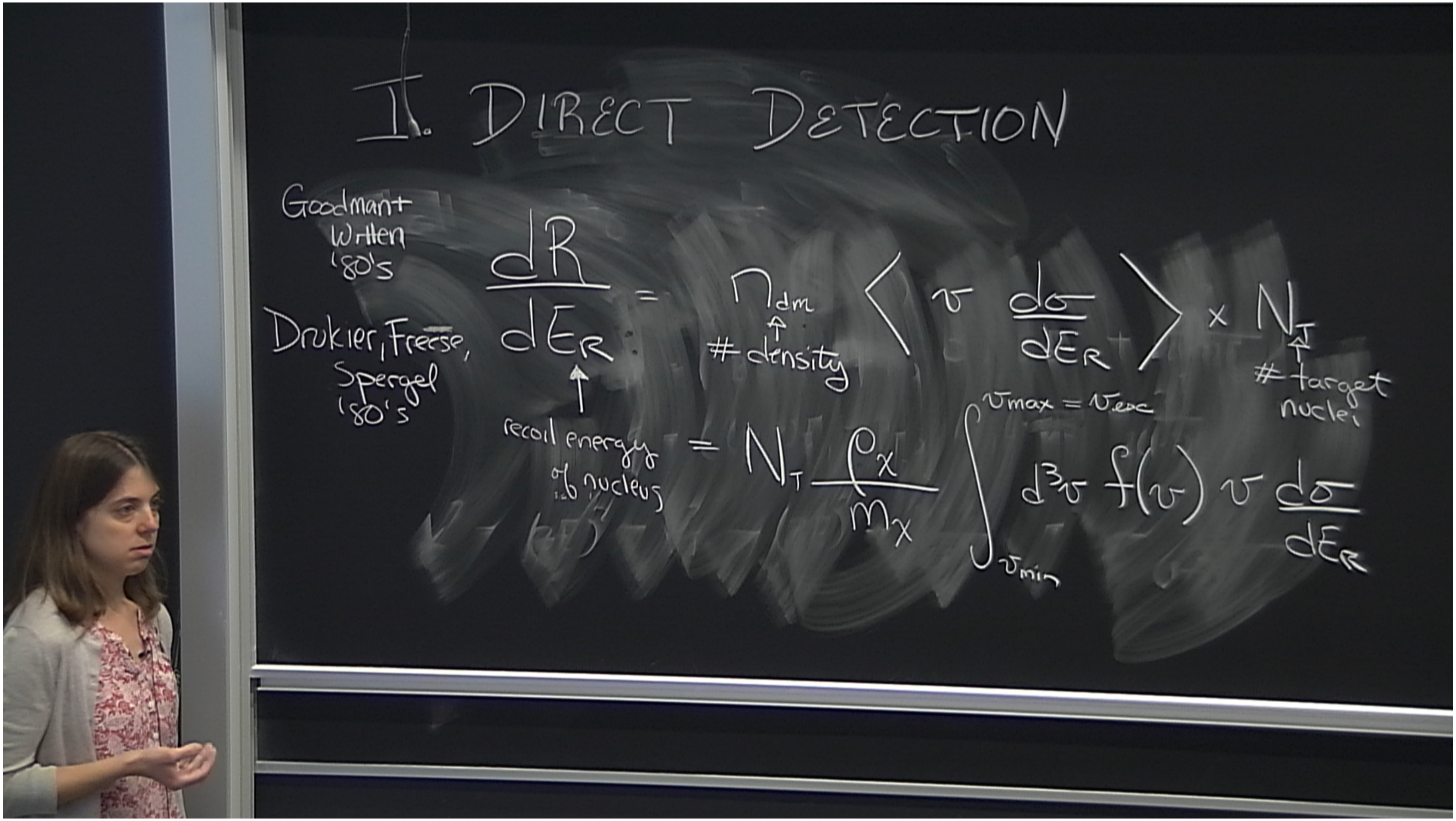
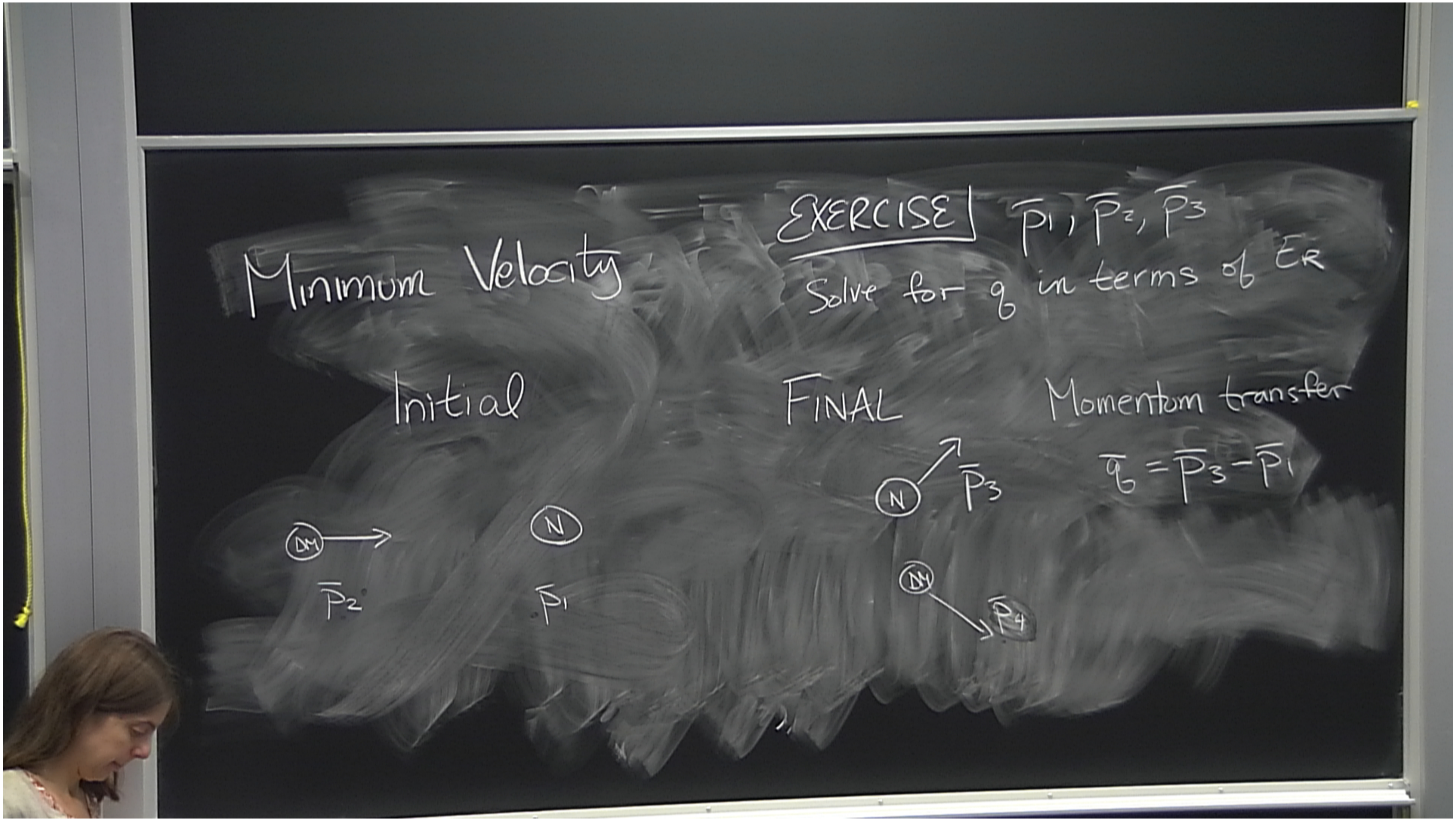
Title: Astroparticle Physics â€“ Theory: Direct detection

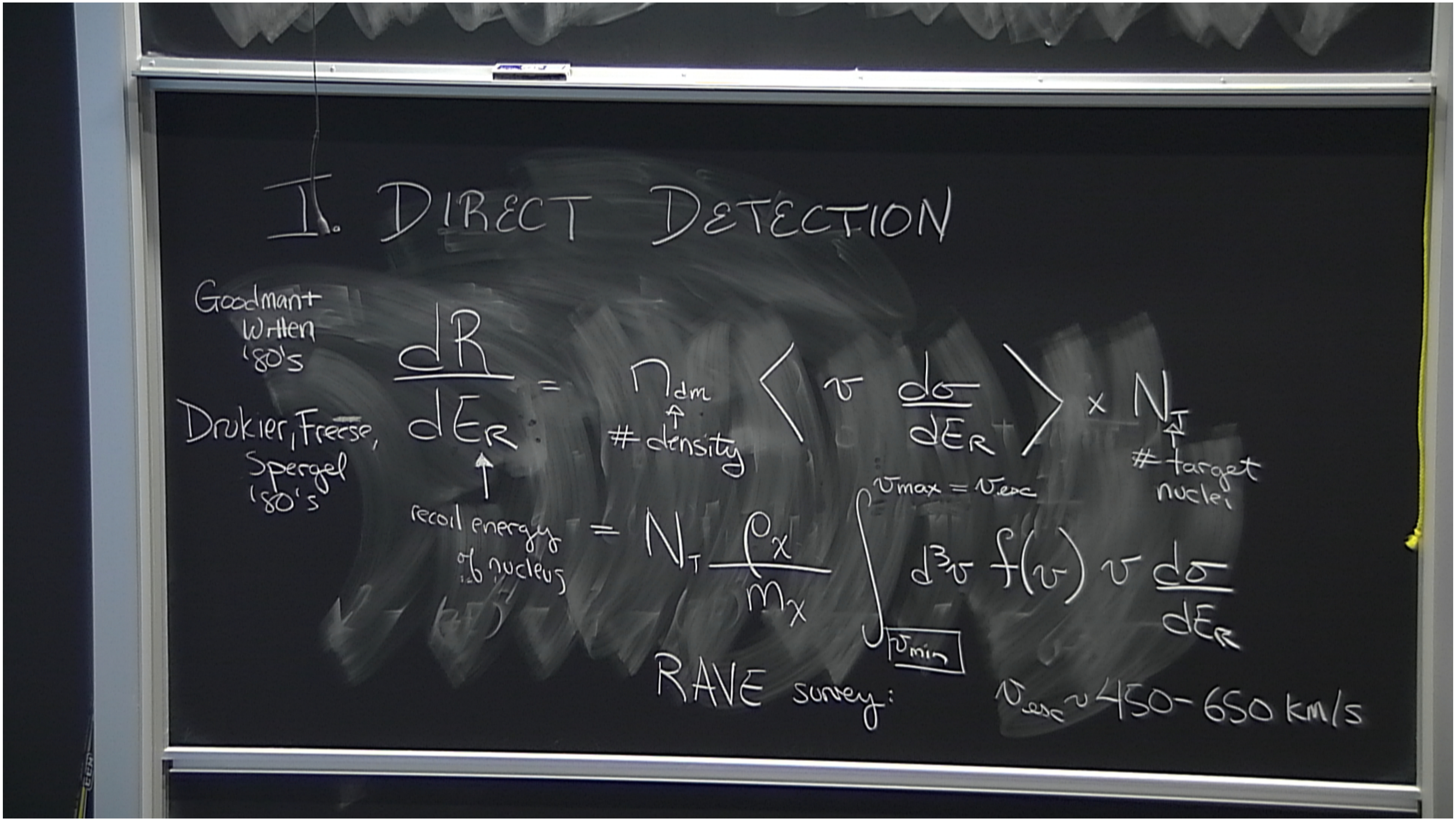
Date: Jul 07, 2015 10:30 AM

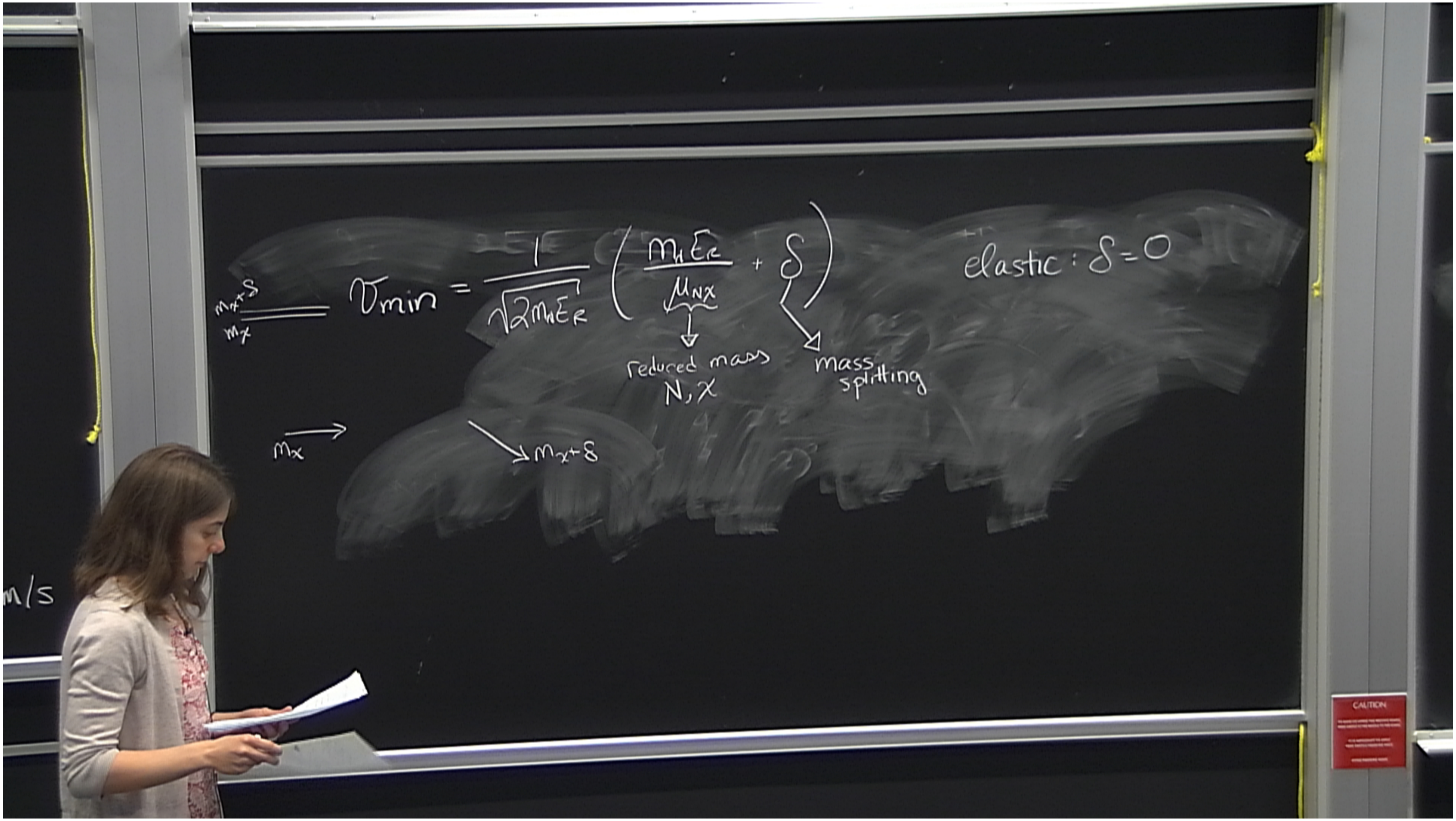
URL: http://pirsa.org/15070018

Abstract:

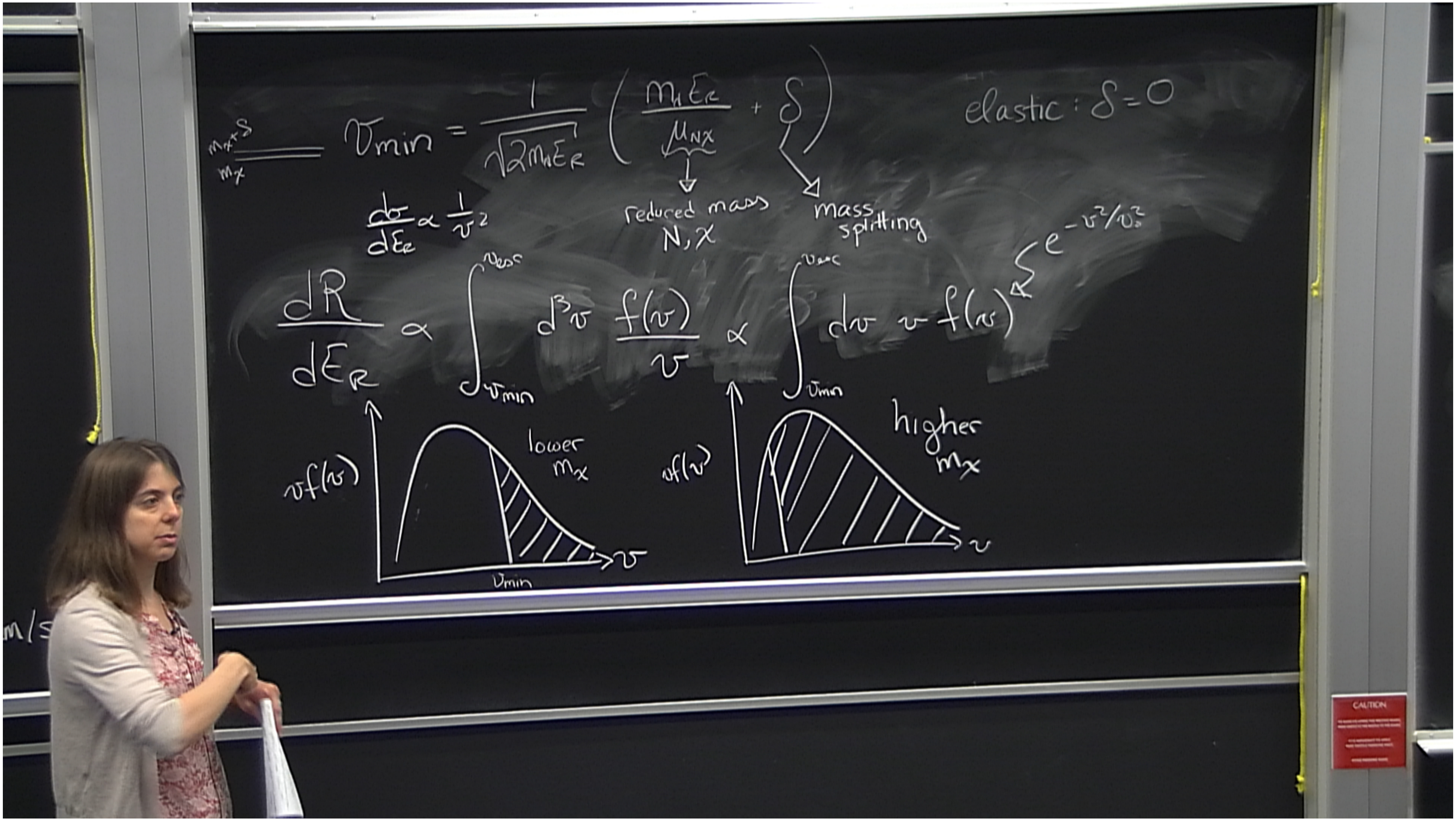

I. DIRECT DETECTION
Goodman + Witten '80's
Drukier, Freese, Spergel '80's
dR/dE_R = n_dm ⟨v dσ/dE_R⟩ × N_T
density
recoil energy of nucleus
target nuclei
= N_T ρ_χ/m_χ ∫_{v_min}^{v_max = v_esc} d³v f(v) v dσ/dE_R


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
N
$\bar{p}_2$
$\bar{p}_1$
$\bar{p}_3$
$\bar{p}_4$

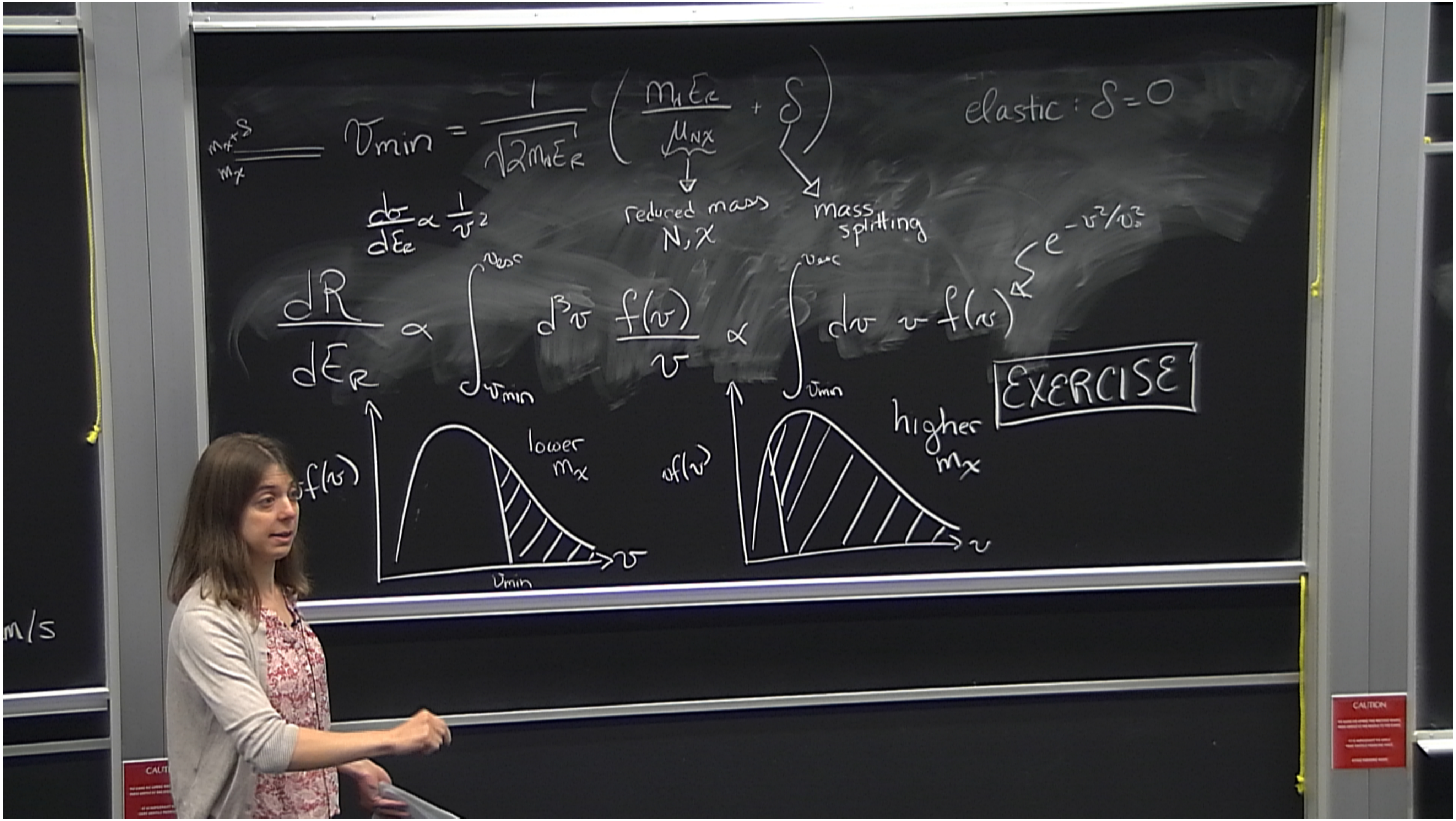

I. DIRECT DETECTION
Goodman+ Witten '80's
Drukier, Freese, Spergel '80's
$\frac{dR}{dE_R} = n_{dm} \left\langle v \frac{d\sigma}{dE_R} \right\rangle \times N_T$
density
target nuclei
recoil energy of nucleus
$= N_T \frac{\rho_\chi}{m_\chi} \int_{v_{min}}^{v_{max} = v_{esc}} d^3v \, f(v) \, v \frac{d\sigma}{dE_R}$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



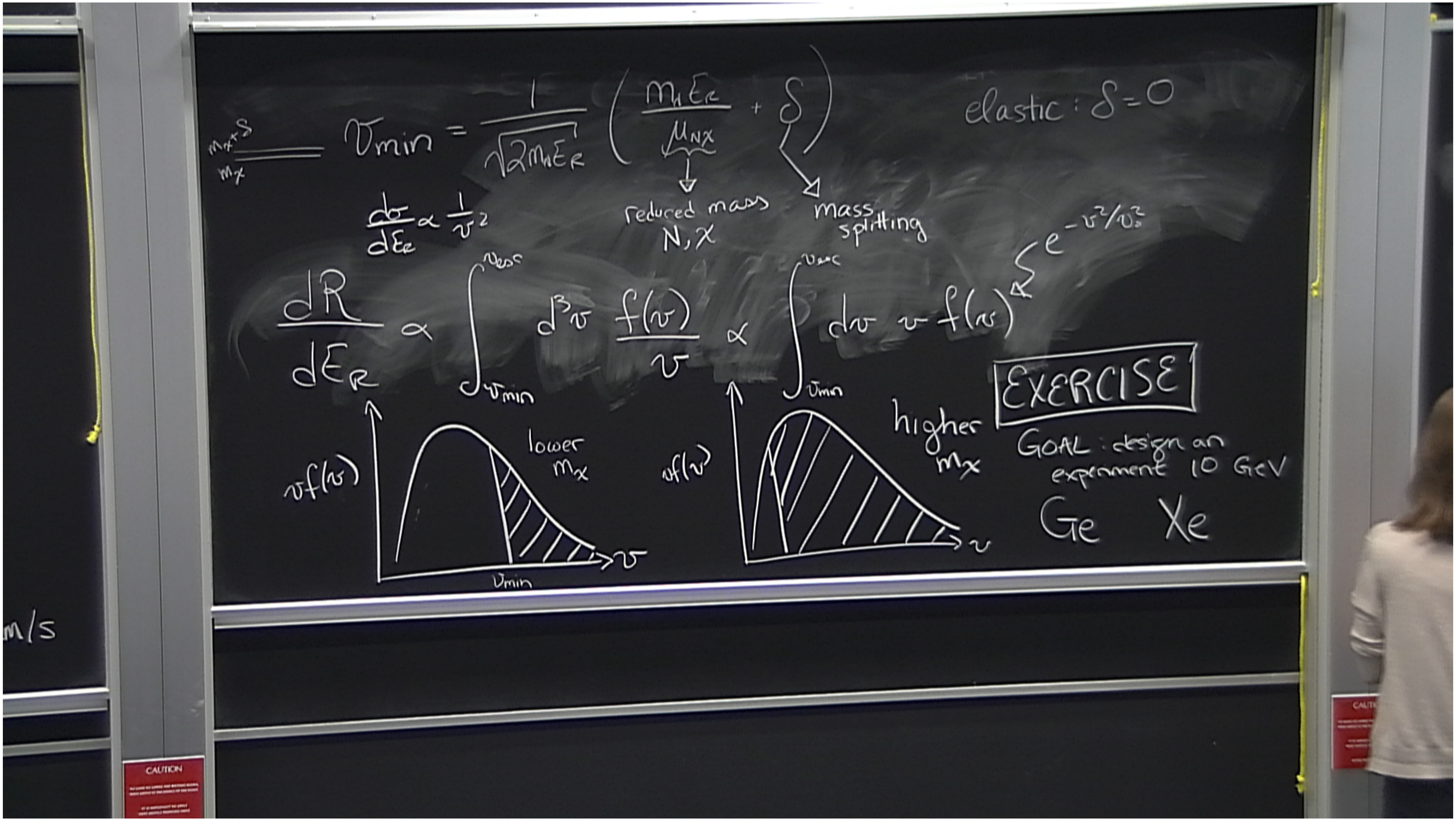
$v_{min} = \frac{1}{\sqrt{2 m_N E_R}} \left(\frac{m_N E_R}{\mu_{N\chi}} + \delta \right)$
reduced mass
N, χ
mass splitting
elastic : δ = 0
$m_\chi + \delta$
m_χ
m_χ
$m_\chi + \delta$

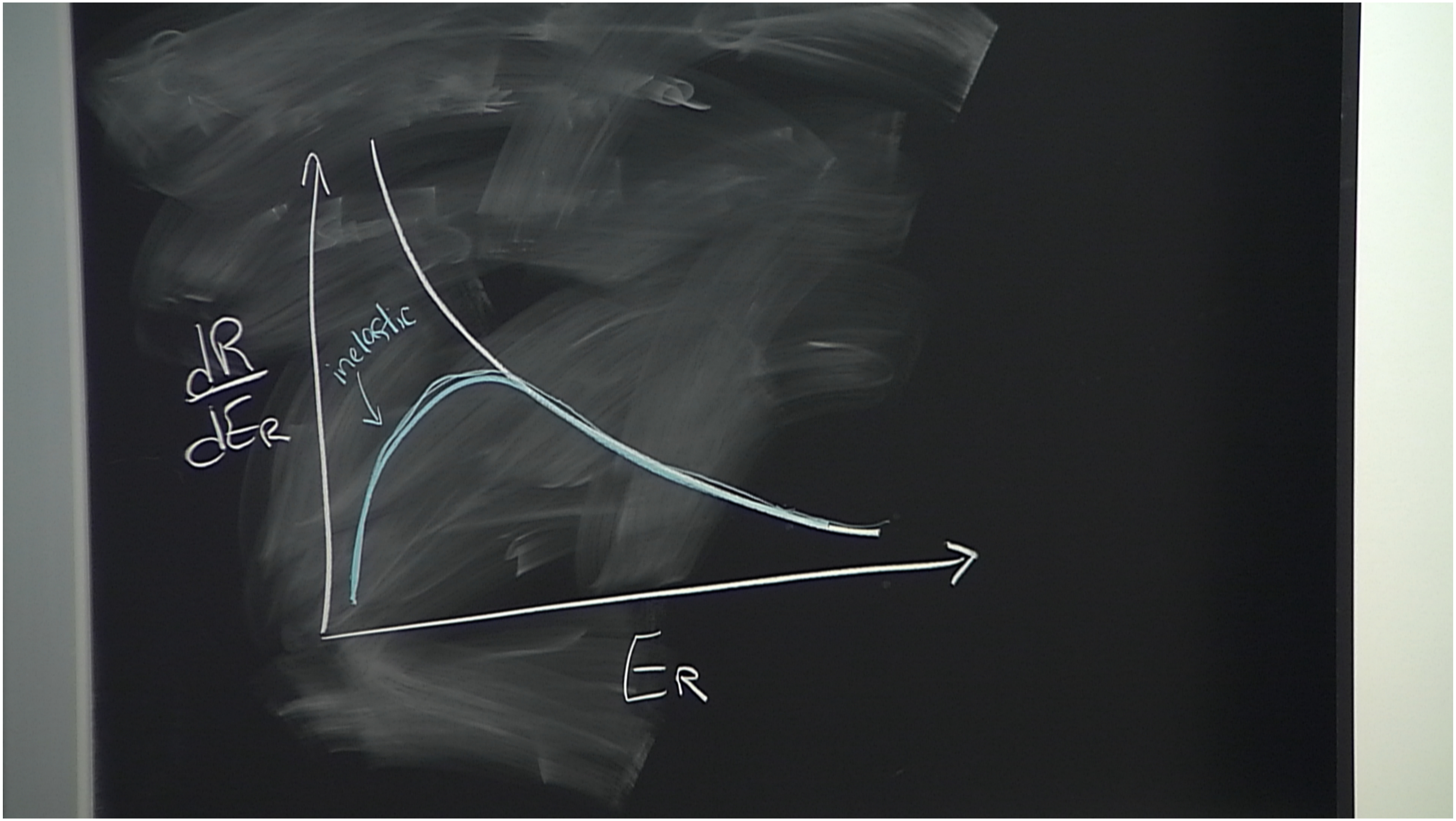


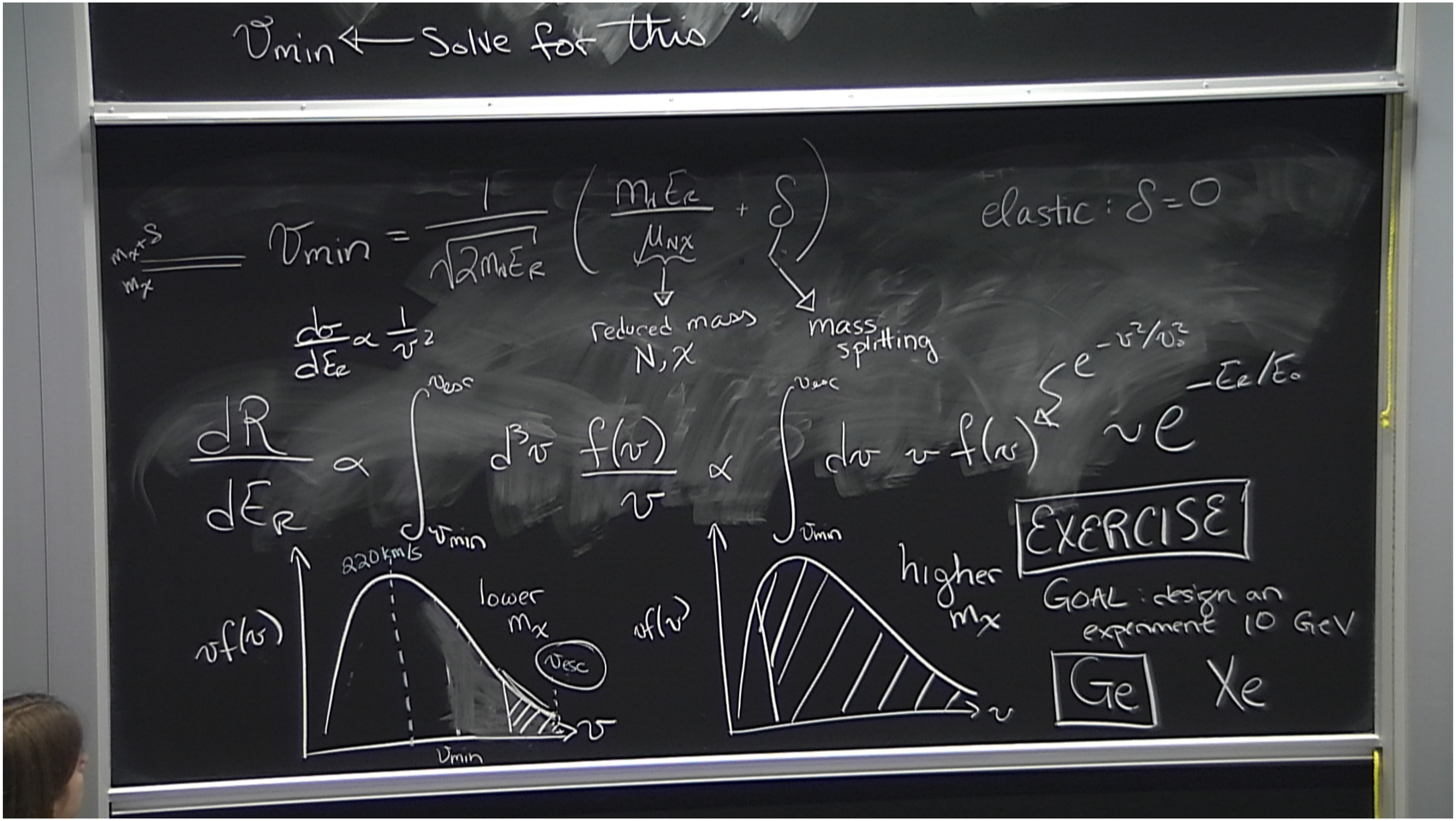
$v_{min} = \frac{1}{\sqrt{2 m_N E_R}} \left(\frac{m_N E_R}{\mu_{N\chi}} + \delta \right)$
elastic: $\delta = 0$
reduced mass N, χ
mass splitting
$\frac{d\sigma}{dE_R} \propto \frac{1}{v^2}$
$\frac{dR}{dE_R} \propto \int_{v_{min}}^{v_{esc}} d^3v \frac{f(v)}{v} \propto \int_{v_{min}}^{v_{esc}} dv\, v f(v)$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

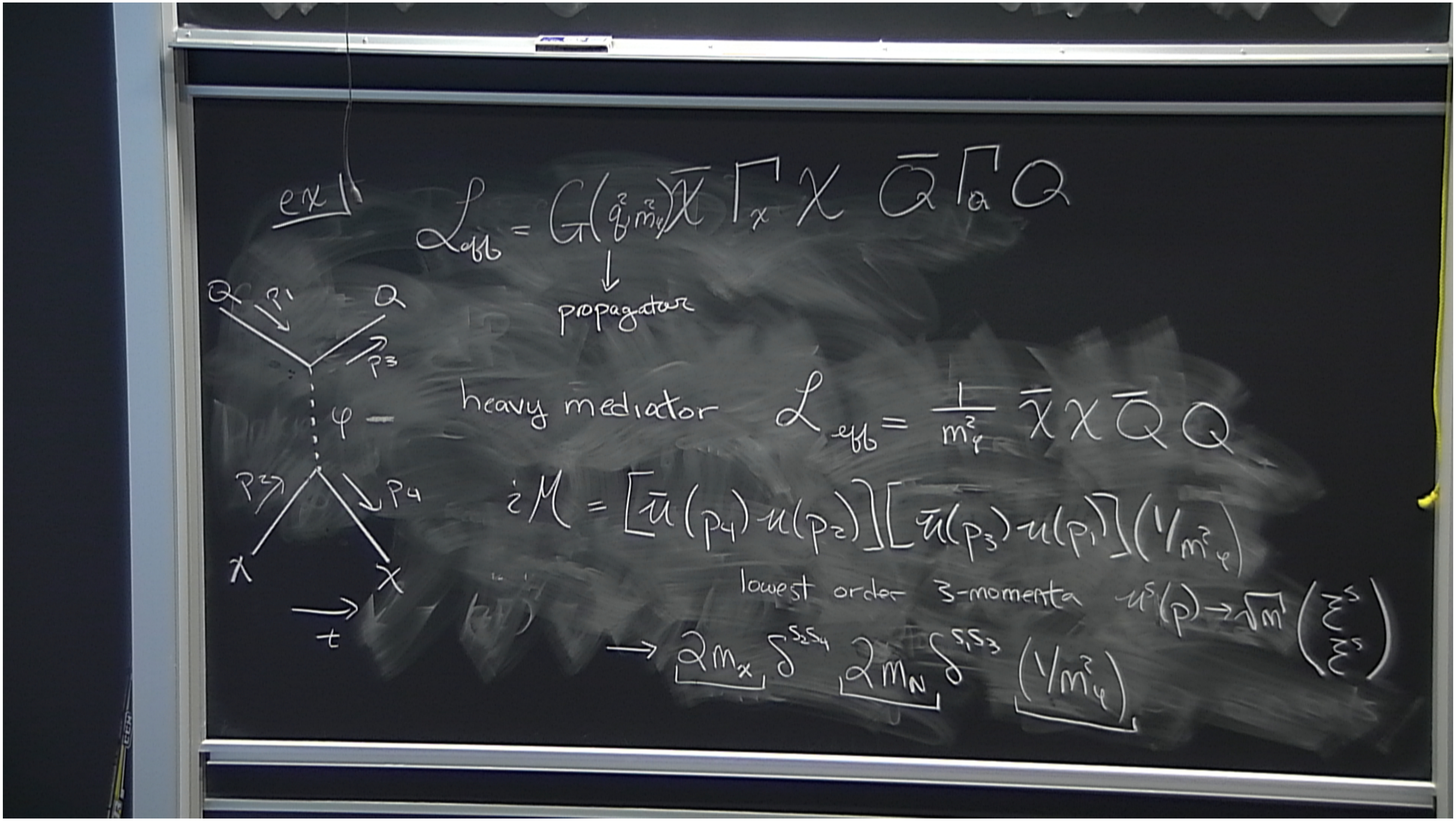


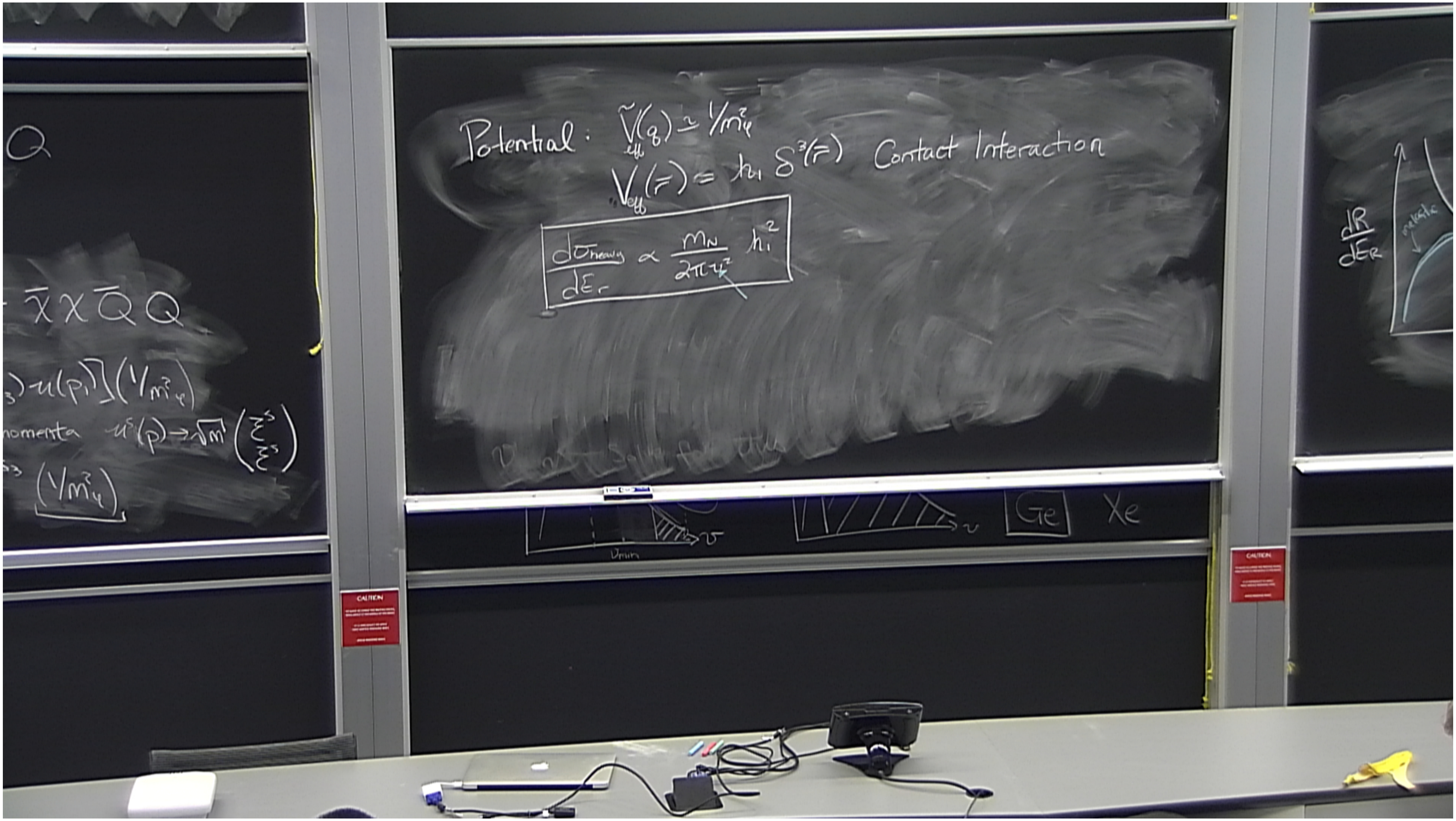
v_min = 1/√(2m_N E_R) (m_N E_R/μ_NX + δ)
elastic: δ = 0
reduced mass N, χ
mass splitting
dσ/dE_R ∝ 1/v²
dR/dE_R ∝ ∫ d³v f(v)/v ∝ ∫ dv v f(v)
e^{-v²/v_0²}
EXERCISE
lower m_χ
higher m_χ
v_min

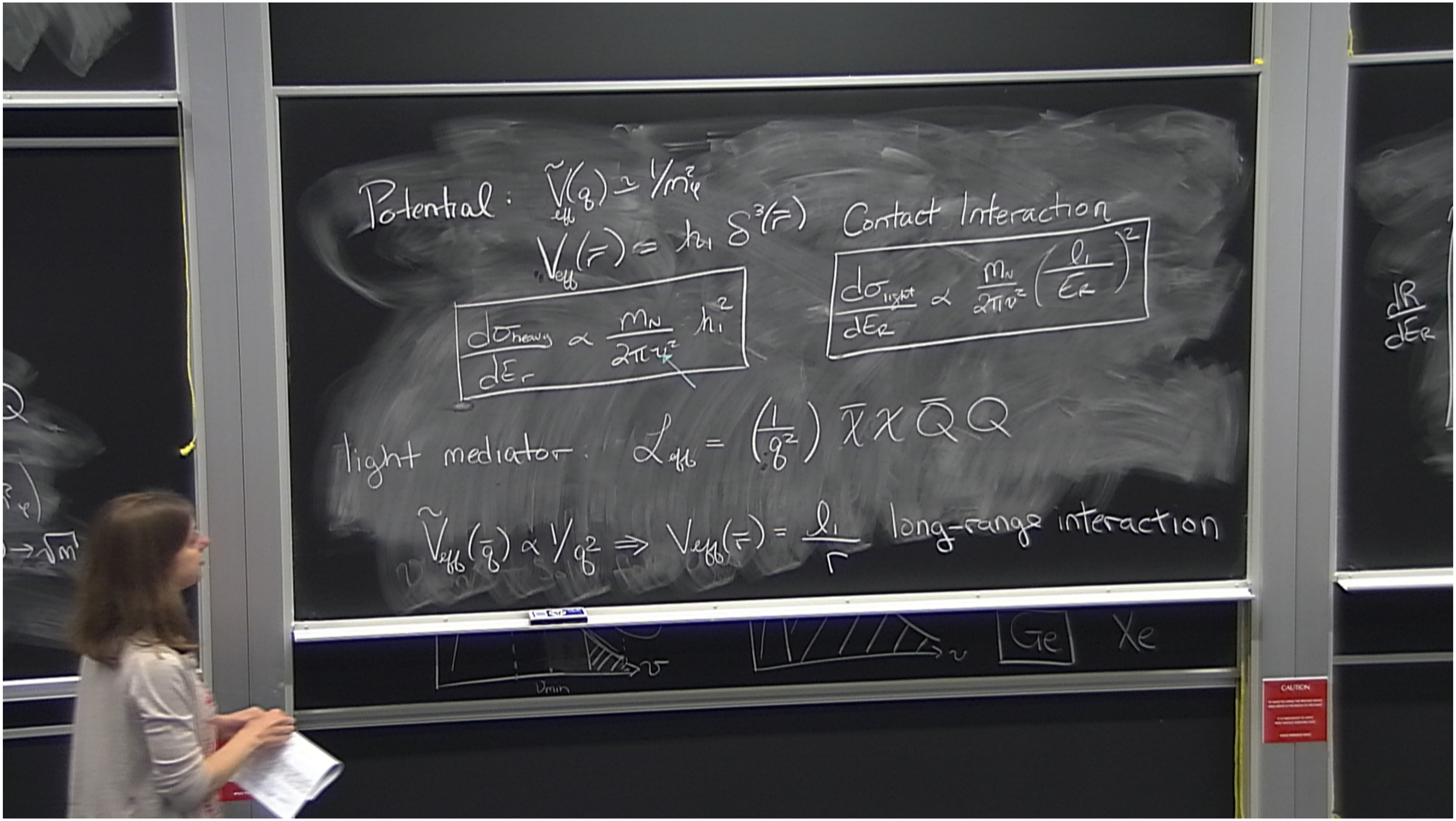

v_min = 1/√(2 m_N E_R) (m_N E_R/μ_Nχ + δ)
elastic : δ = 0
reduced mass N, χ
mass splitting
dσ/dE_R ∝ 1/v²
dR/dE_R ∝ ∫_{v_min}^{v_esc} d³v f(v)/v ∝ ∫_{v_min}^{v_esc} dv v f(v)
e^{-v²/v_0²}
vf(v)
lower m_χ
v_min
higher m_χ
EXERCISE
GOAL : design an experiment 10 GeV
Ge Xe
CAUTION

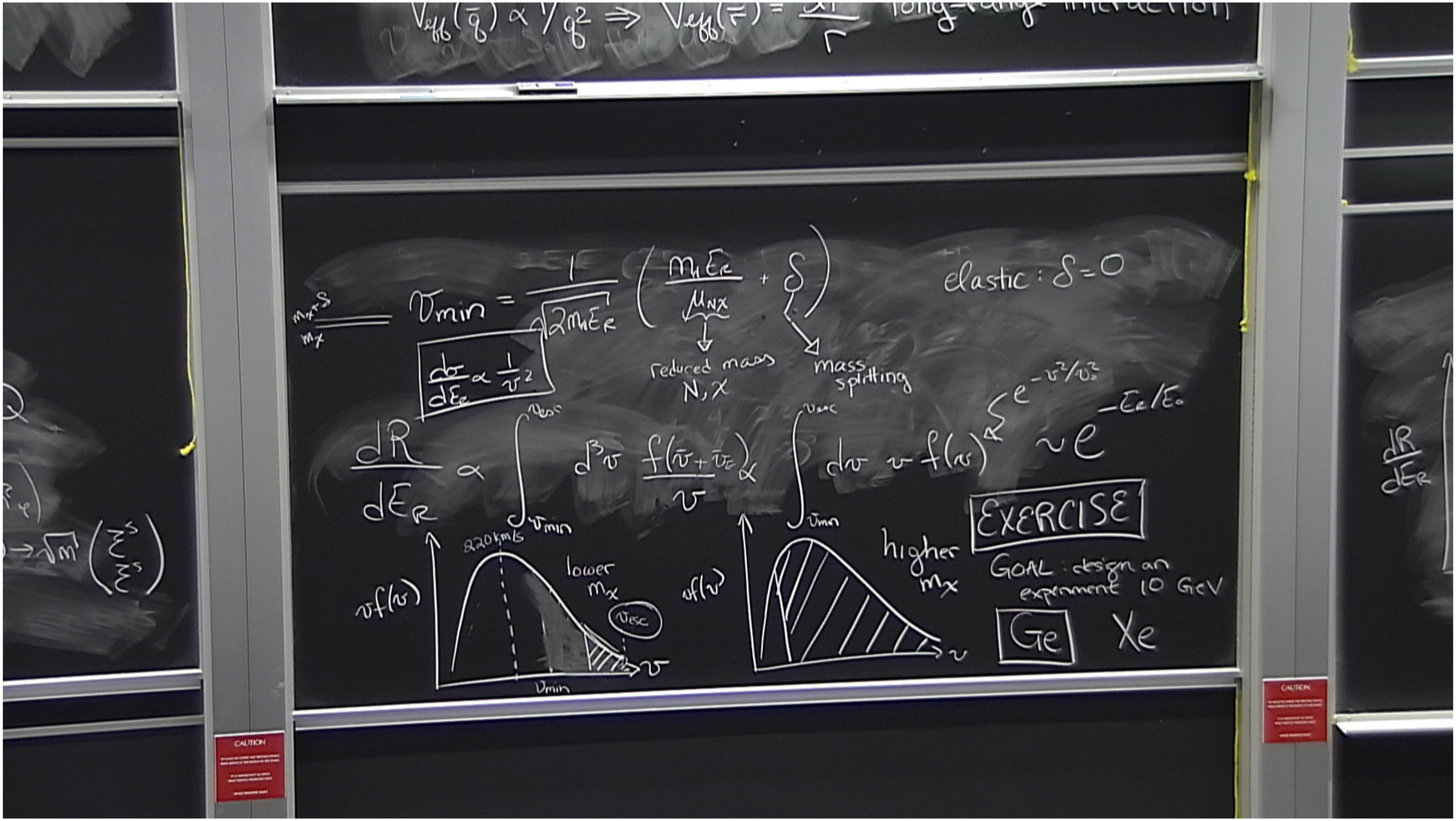

dR
dE_R
inelastic
E_R

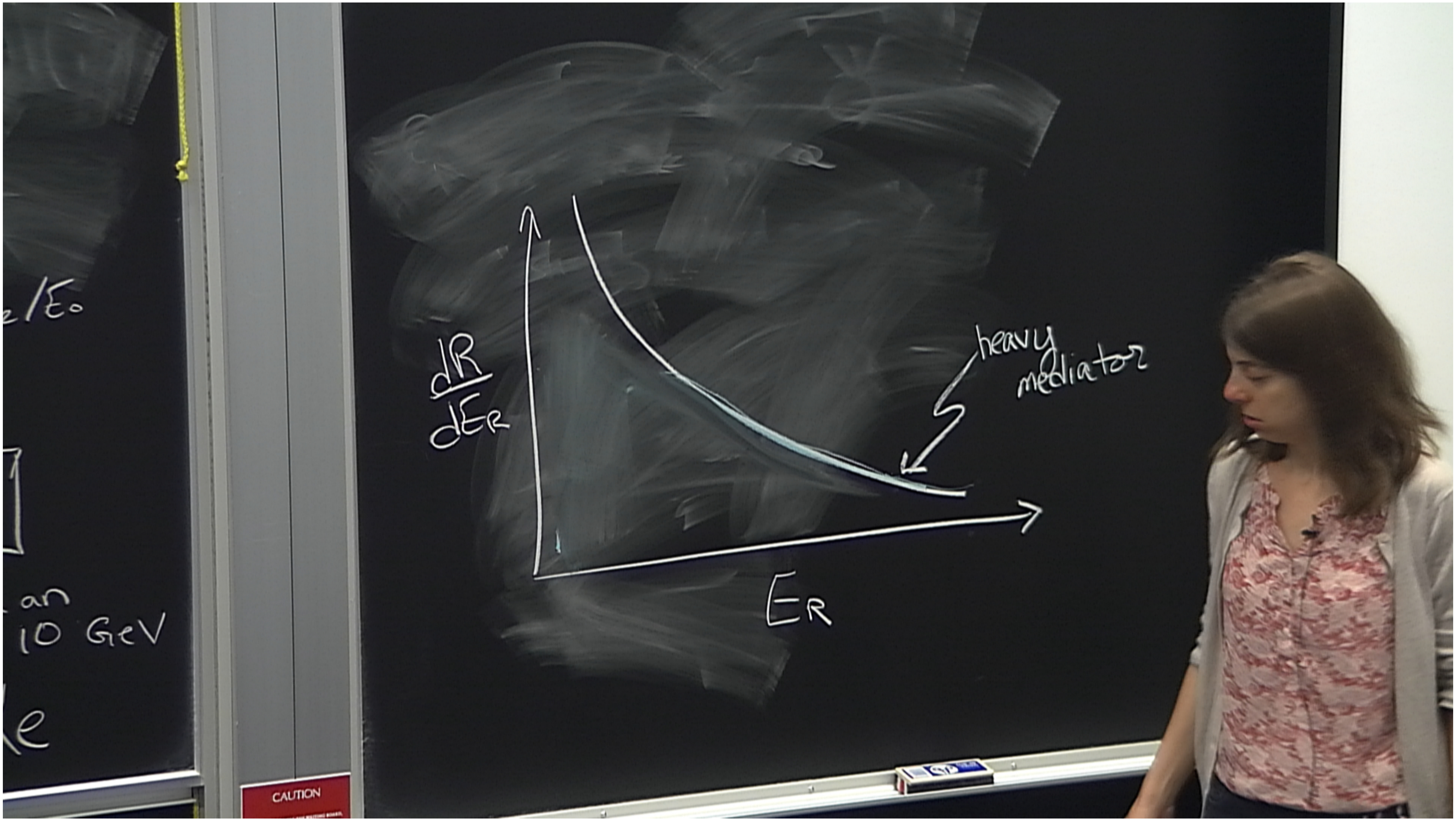

v_min ← Solve for this
v_min = 1/√(2 m_N E_R) (m_N E_R / μ_NX + δ)
elastic: δ = 0
reduced mass N, χ
mass splitting
dσ/dE_R ∝ 1/v²
dR/dE_R ∝ ∫_{v_min}^{v_esc} d³v f(v)/v ∝ ∫_{v_min}^{v_esc} dv v f(v)
e^{-v²/v₀²}
~ e^{-E_R/E₀}
220 km/s
v f(v)
lower m_χ
v_esc
v_min
higher m_χ
EXERCISE
GOAL: design an experiment 10 GeV
Ge
Xe


ex
$\mathcal{L}_{eff} = G(q^2, m_\varphi^2)\bar{\chi}\Gamma_\chi \chi \bar{Q}\Gamma_Q Q$
propagator
heavy mediator $\mathcal{L}_{eff} = \frac{1}{m_\varphi^2}\bar{\chi}\chi\bar{Q}Q$
$iM = [\bar{u}(p_4)u(p_2)][\bar{u}(p_3)u(p_1)](1/m_\varphi^2)$
lowest order 3-momenta $u^s(p) \to \sqrt{m}\begin{pmatrix}\xi^s \\ \xi^s\end{pmatrix}$
$\to 2m_\chi \delta^{s_2 s_4}\, 2m_N \delta^{s_1 s_3}\, (1/m_\varphi^2)$
Q
p1
Q
p3
φ
p2
p4
χ
χ
t


Potential: Ṽeff(q) ≃ 1/mφ²
Veff(r) = h1 δ³(r) Contact Interaction
dσheavy/dEr ∝ mN/2πv² h1²
Ge
Xe
dR/dER

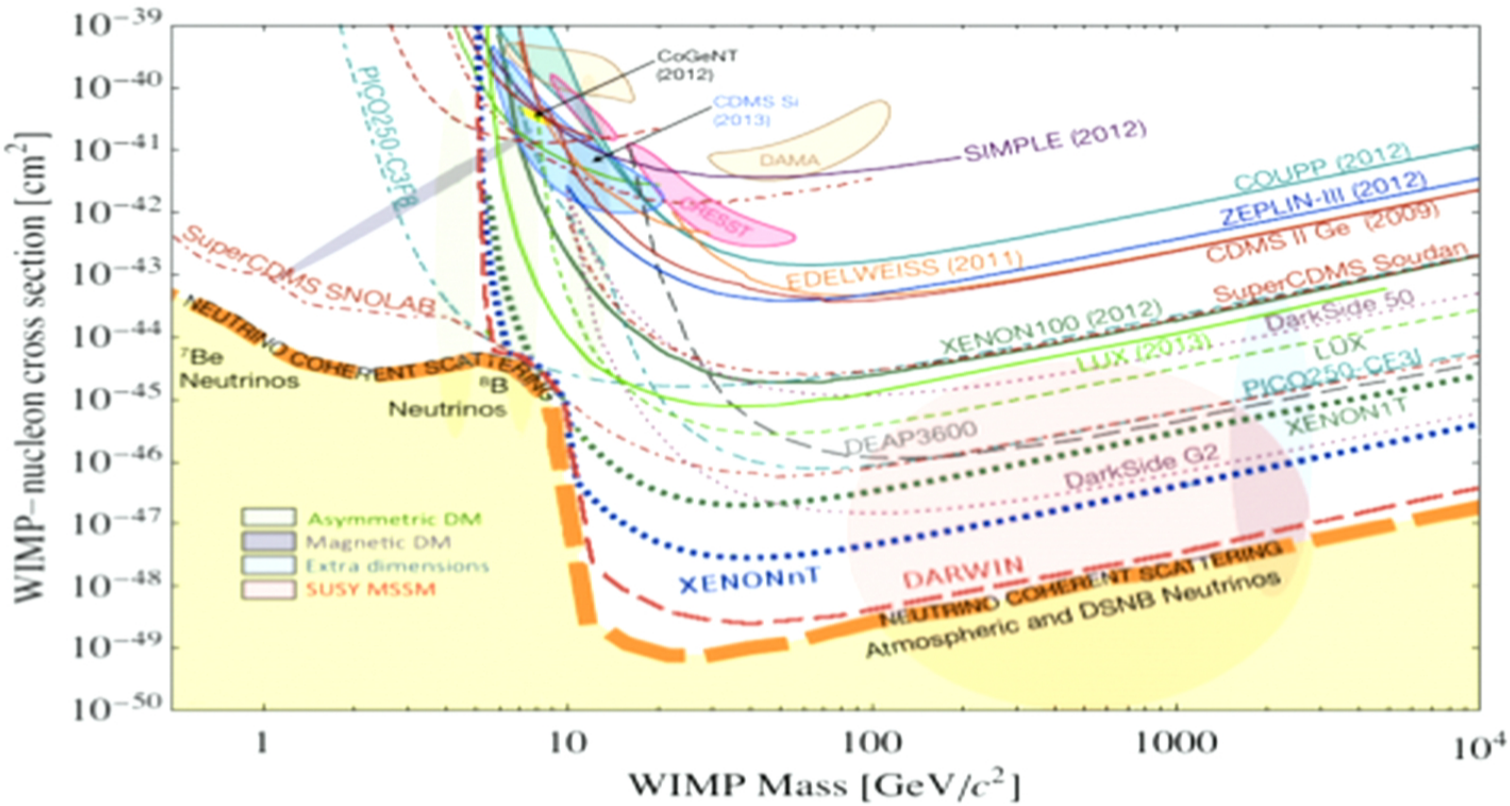

Potential: $\tilde{V}_{eff}(q) \simeq 1/m_\varphi^2$
$V_{eff}(\bar{r}) = h_1 \delta^3(\bar{r})$
Contact Interaction
$\frac{d\sigma_{heavy}}{dE_r} \propto \frac{m_N}{2\pi v^2} h_1^2$
$\frac{d\sigma_{light}}{dE_R} \propto \frac{m_N}{2\pi v^2} \left(\frac{l_1}{E_R}\right)^2$
light mediator: $\mathcal{L}_{eff} = \left(\frac{1}{q^2}\right) \bar{\chi}\chi\bar{Q}Q$
$\tilde{V}_{eff}(\bar{q}) \propto 1/q^2 \Rightarrow V_{eff}(\bar{r}) = \frac{l_1}{r}$ long-range interaction
v_{min}
Ge
Xe
$\frac{dR}{dE_R}$
CAUTION


elastic : δ = 0
reduced mass
N, χ
mass splitting
EXERCISE
GOAL : design an experiment 10 GeV
Ge
Xe
220 km/s
lower m_χ
higher m_χ
v_{esc}
v_{min}

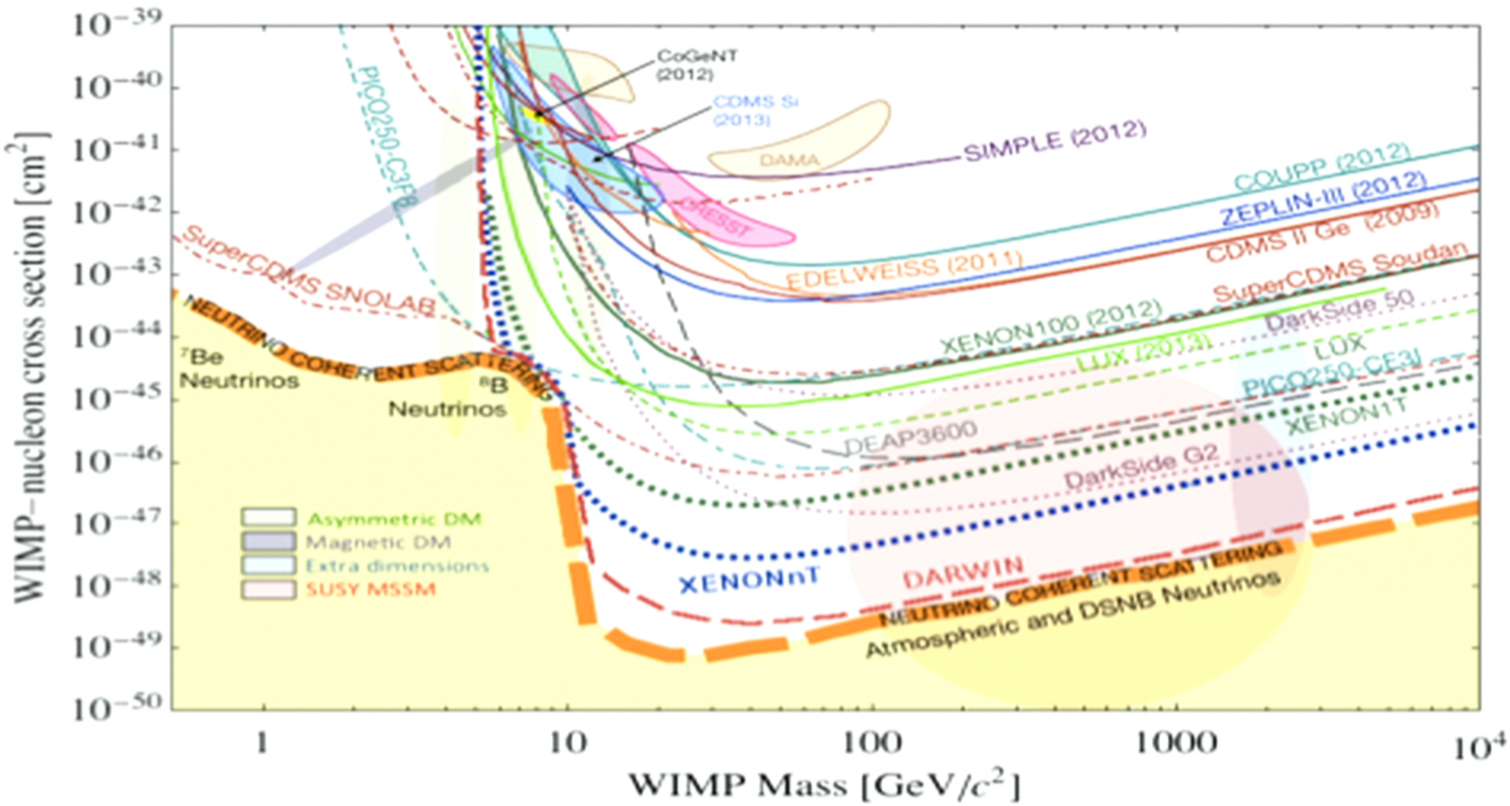


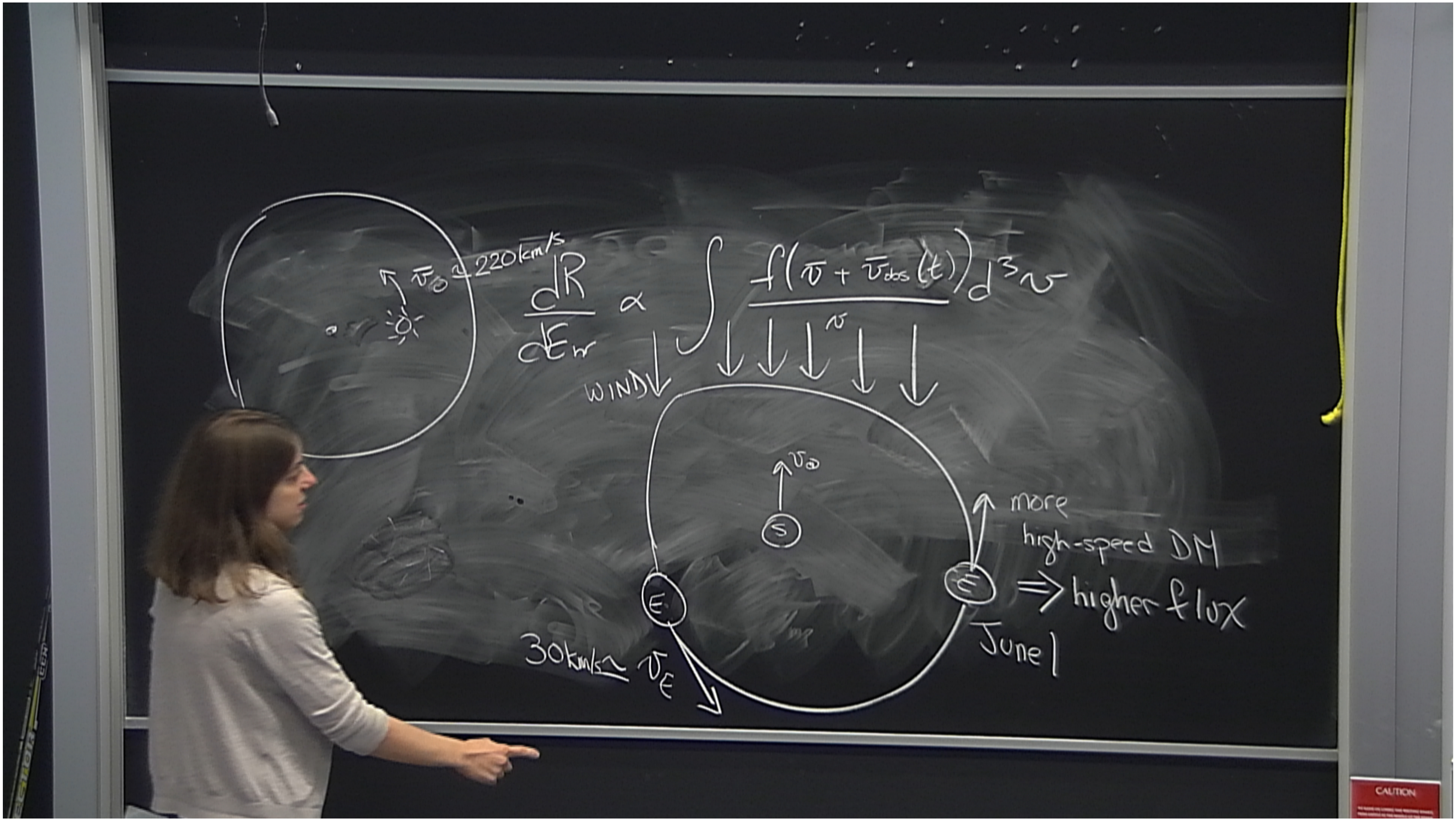
dR/dE_R
E_R
heavy mediator
10 GeV

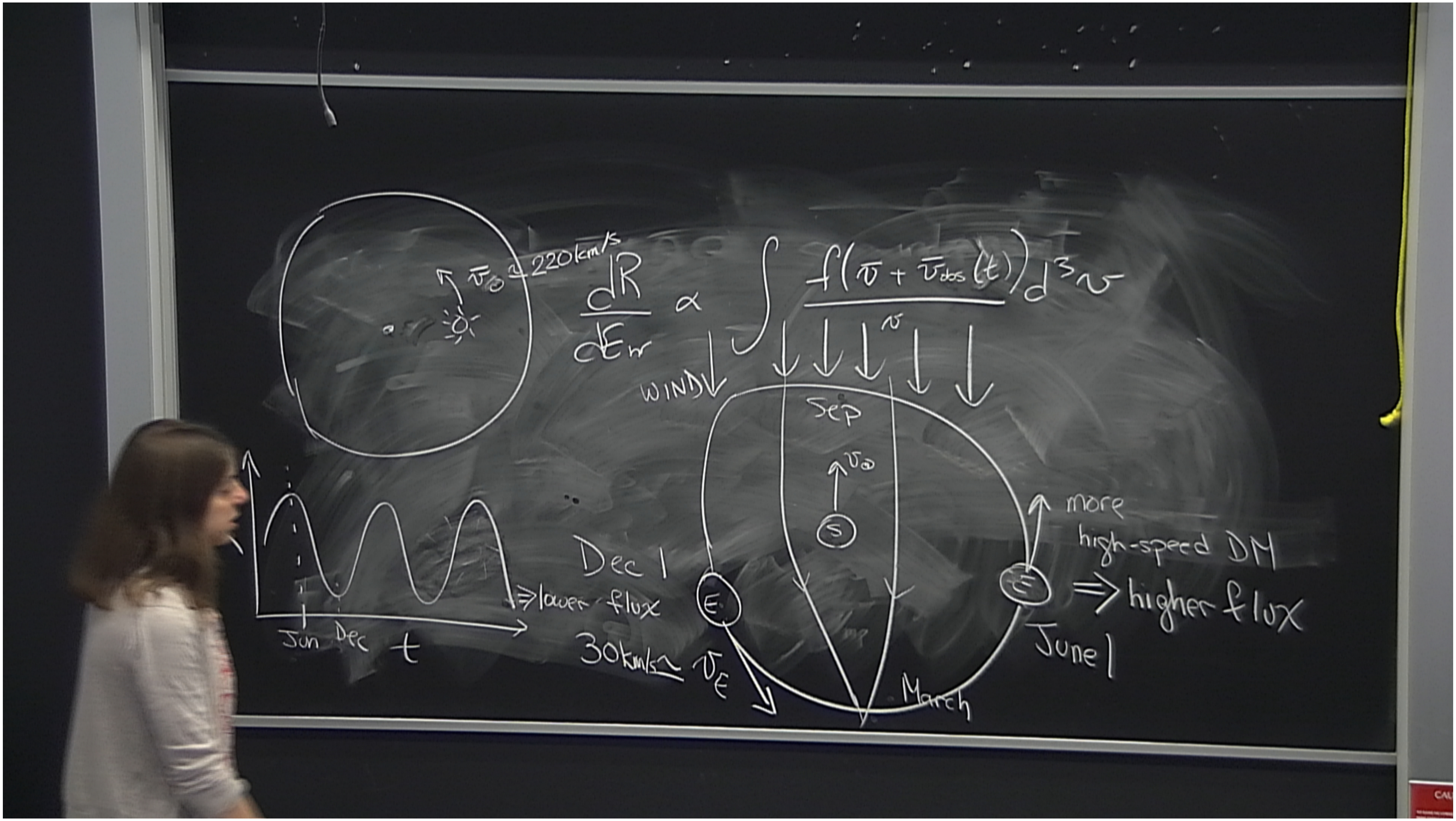
Direct Detection



Direct Detection




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


v⊙ ≃ 220 km/s
dR/dE_nr ∝ ∫ f(v + v_obs(t))/v d³v
WIND
Sep
v⊙
S
E
E
Dec 1
June 1
March
30 km/s ≃ v_E
more
high-speed DM
⇒ higher flux
⇒ lower flux
Jun
Dec
t