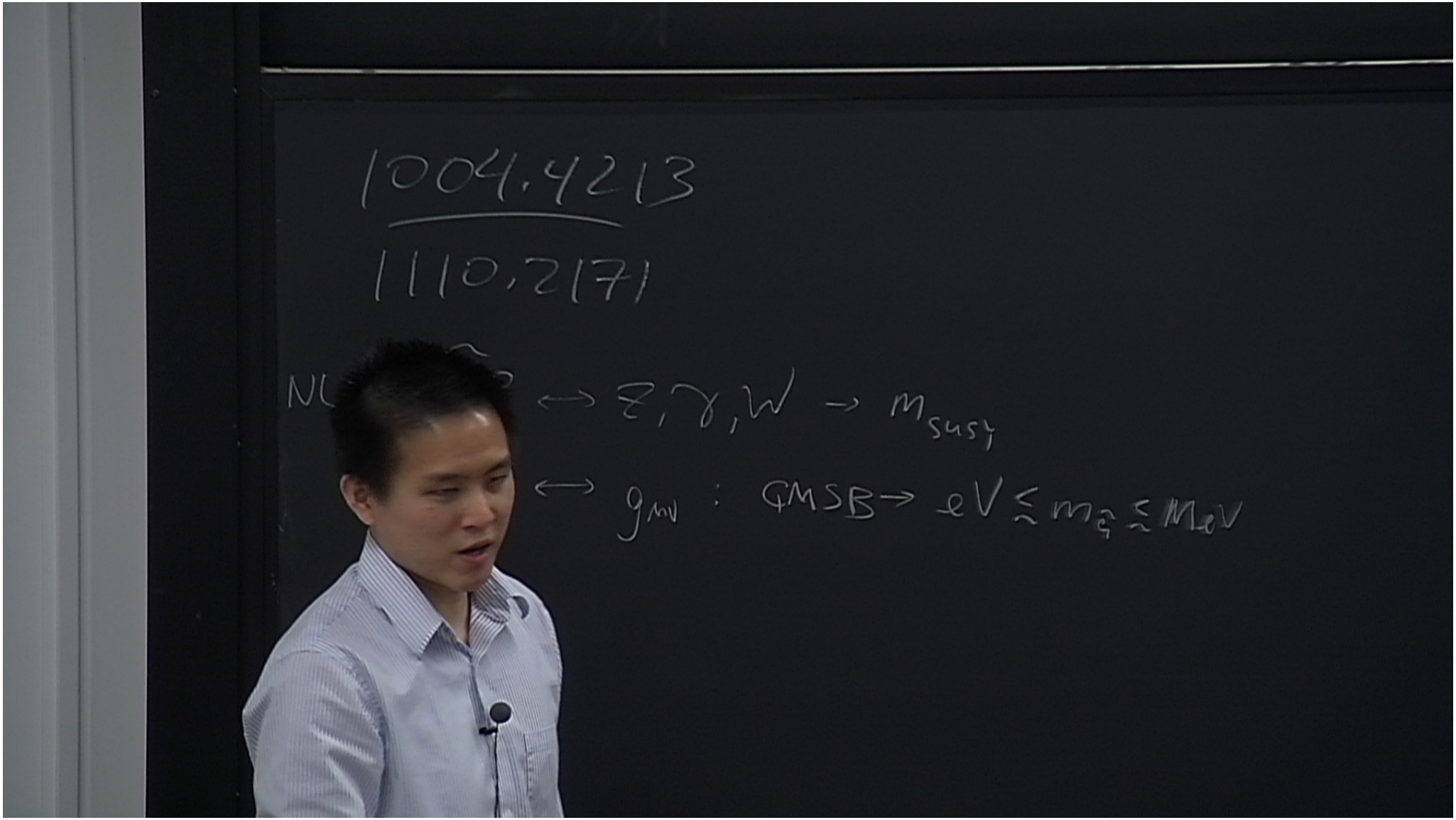
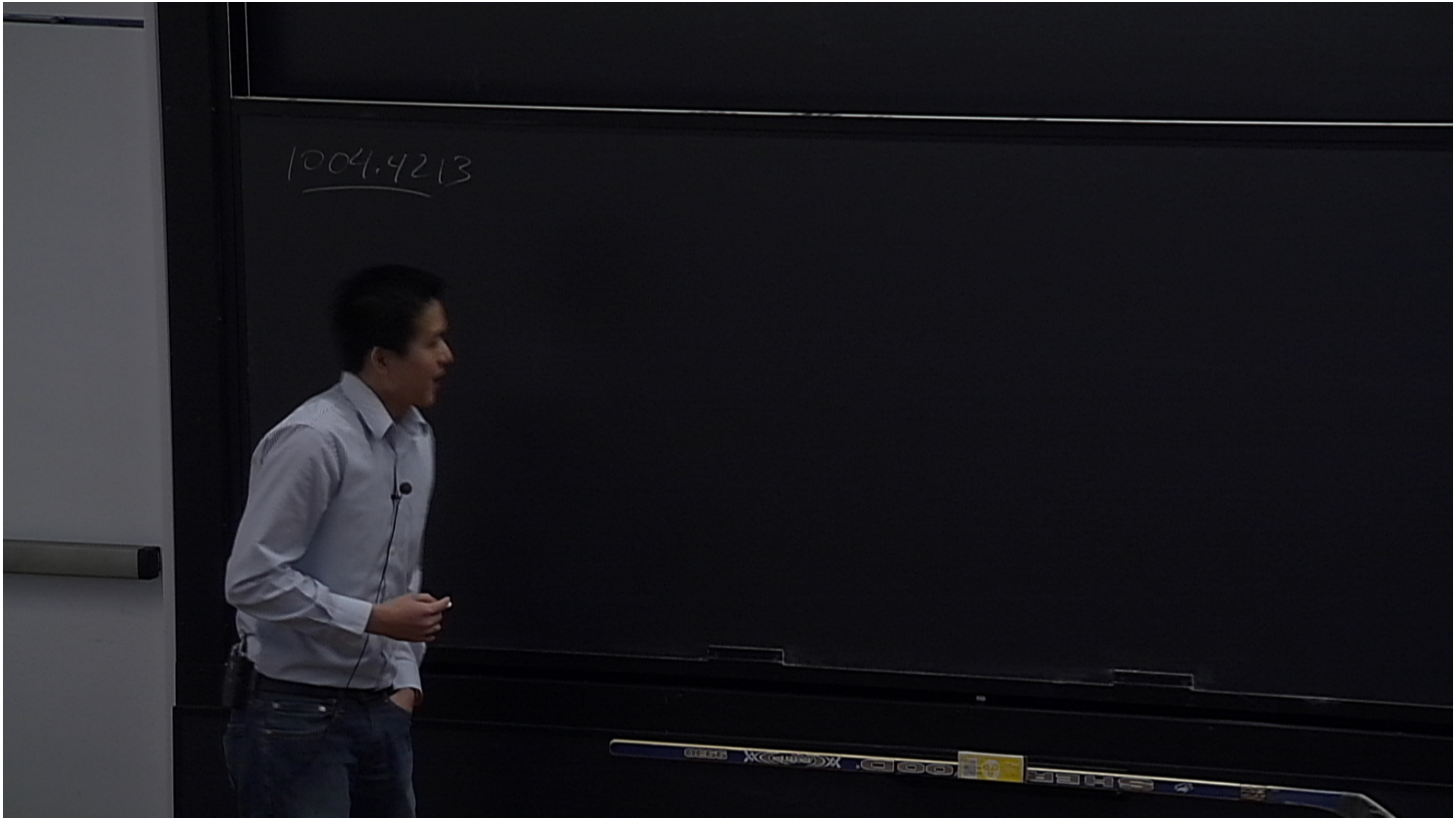
Title: The Phenomenology of Light Gravitino Dark Matter

Date: Dec 13, 2011 11:00 AM

URL: http://pirsa.org/11120039

Abstract: I will discuss some work on the collider phenomenology and cosmology of light gravitino dark matter, and will touch on some related issues concerning infrared divergences in charged-particle decay at finite temperature.
Light gravitinos, with mass in the eV to MeV range, are well-motivated in particle physics, but their status as dark-matter candidates is muddled by early-Universe uncertainties.


1004.4213
1110.2171
↔ Z, γ, W → m_susy
↔ g_mν : GMSB → eV ≲ m_g̃ ≲ MeV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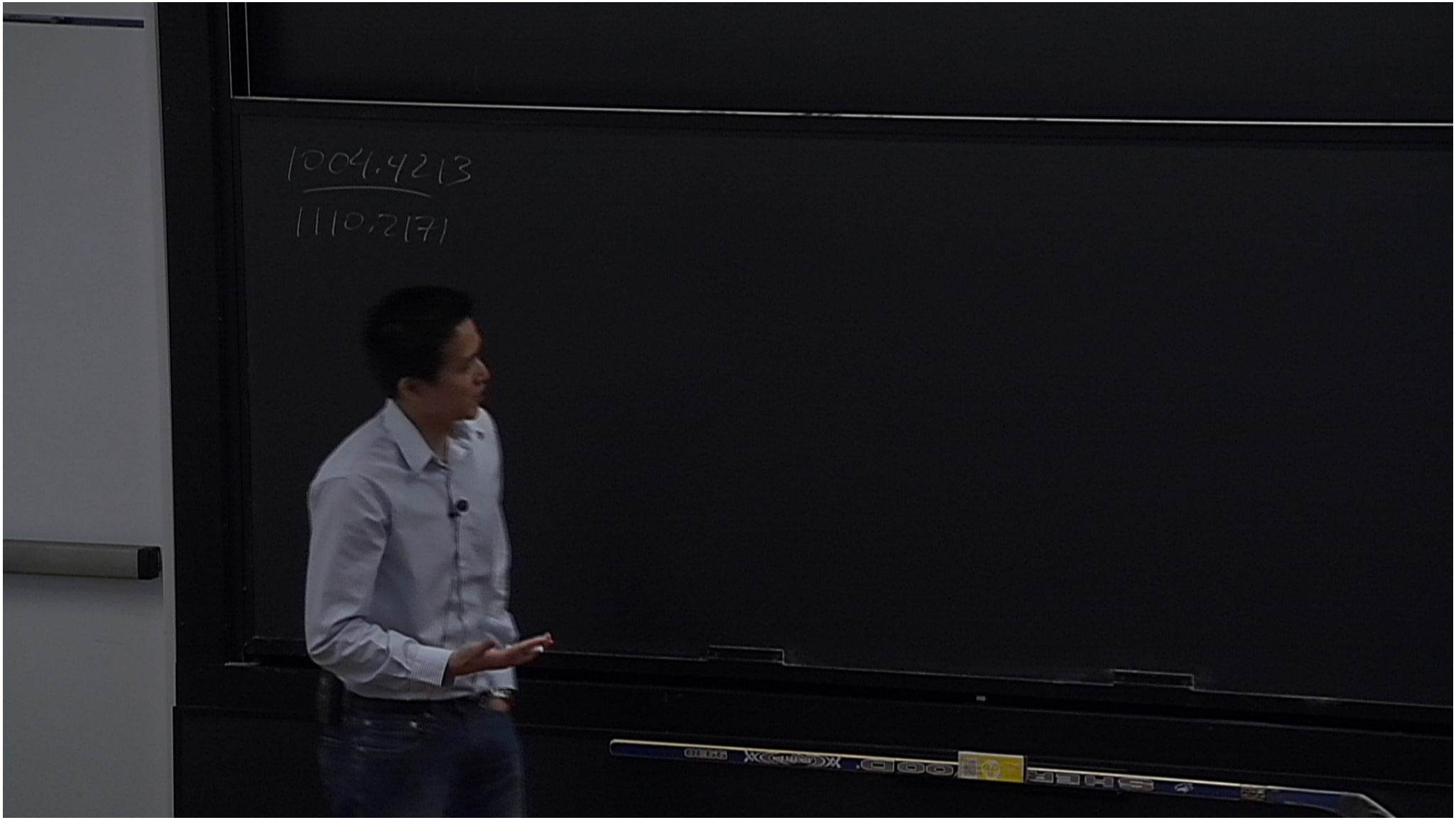
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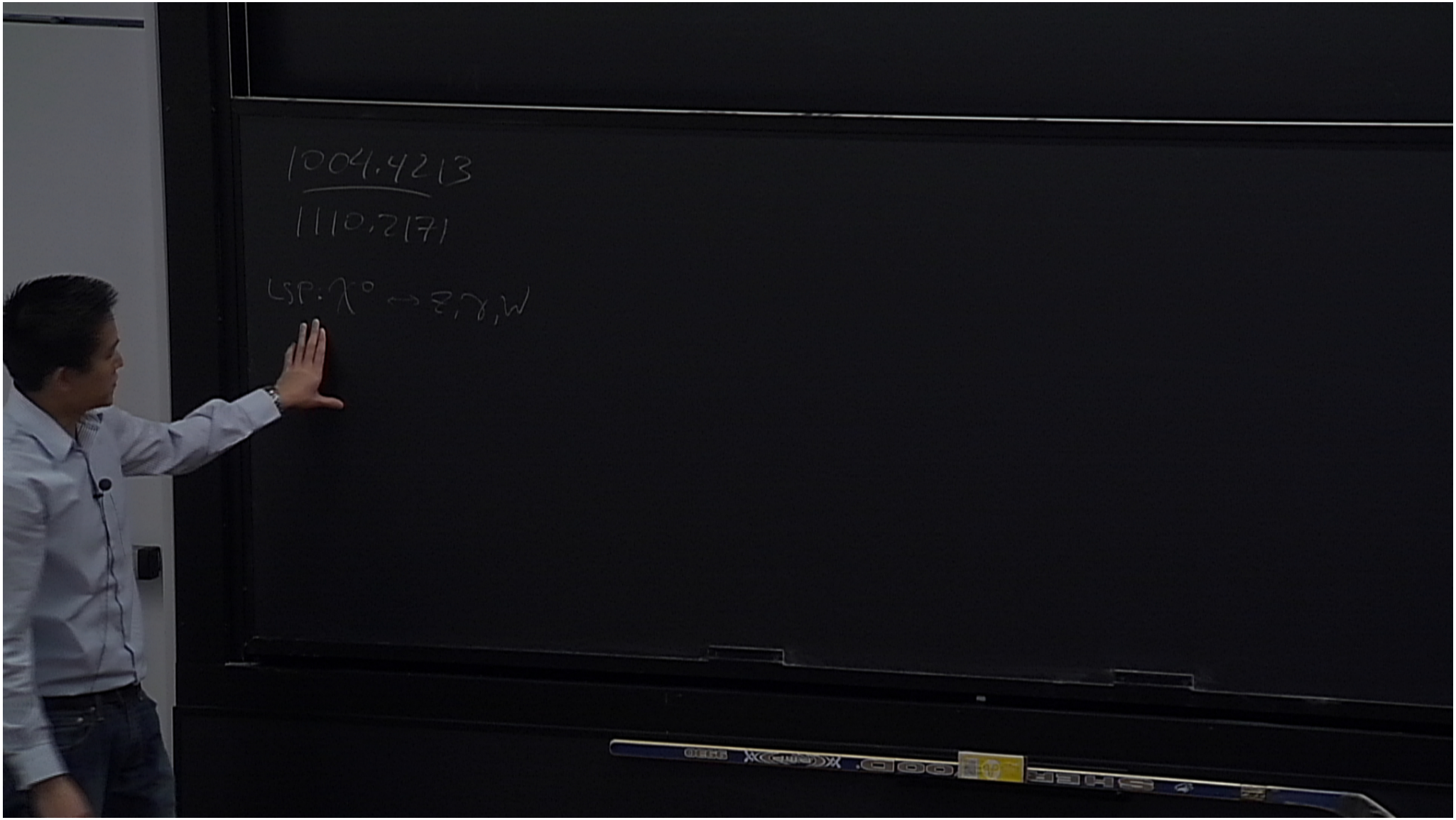
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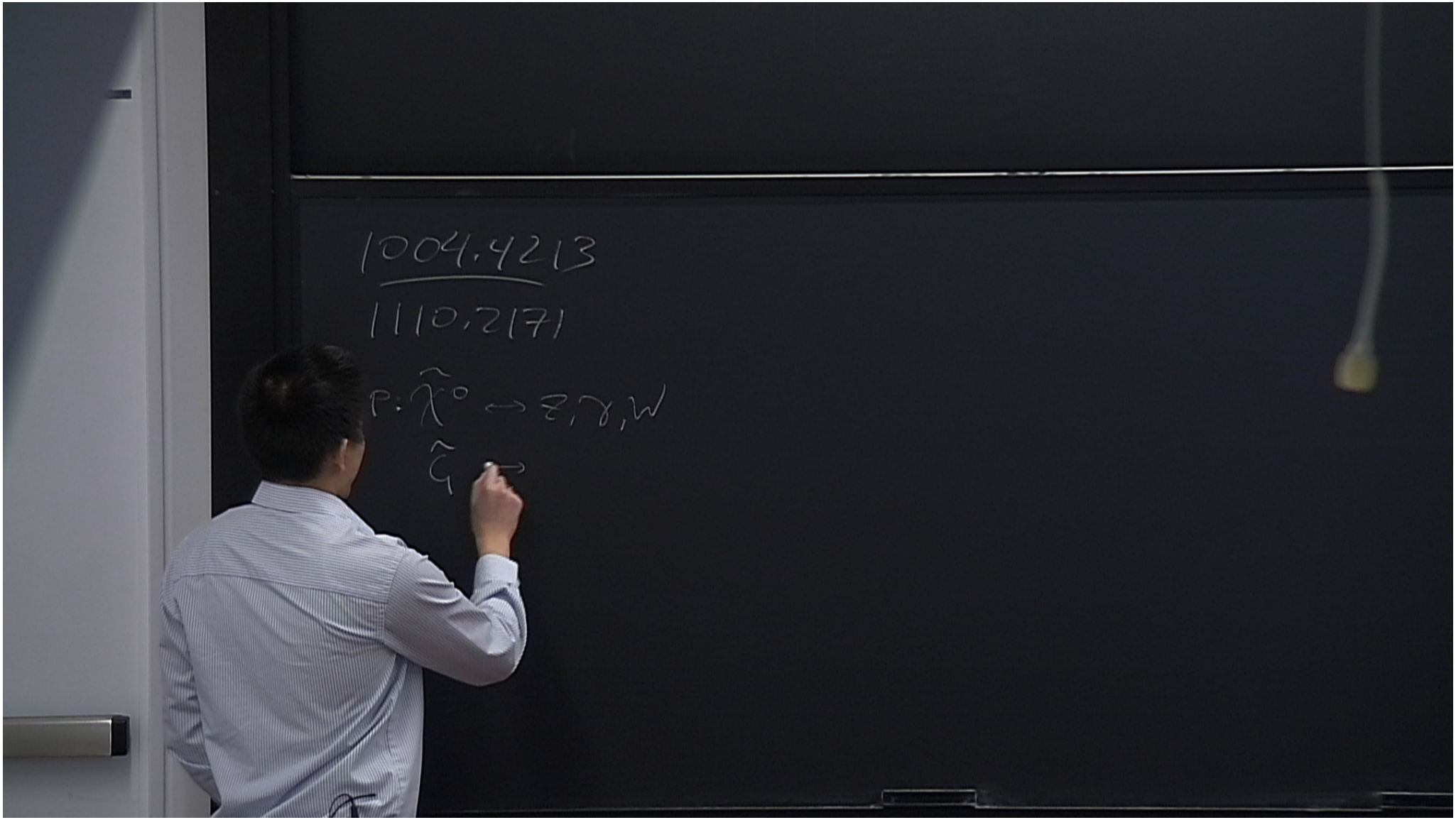
LSP: 7° → 8,7,W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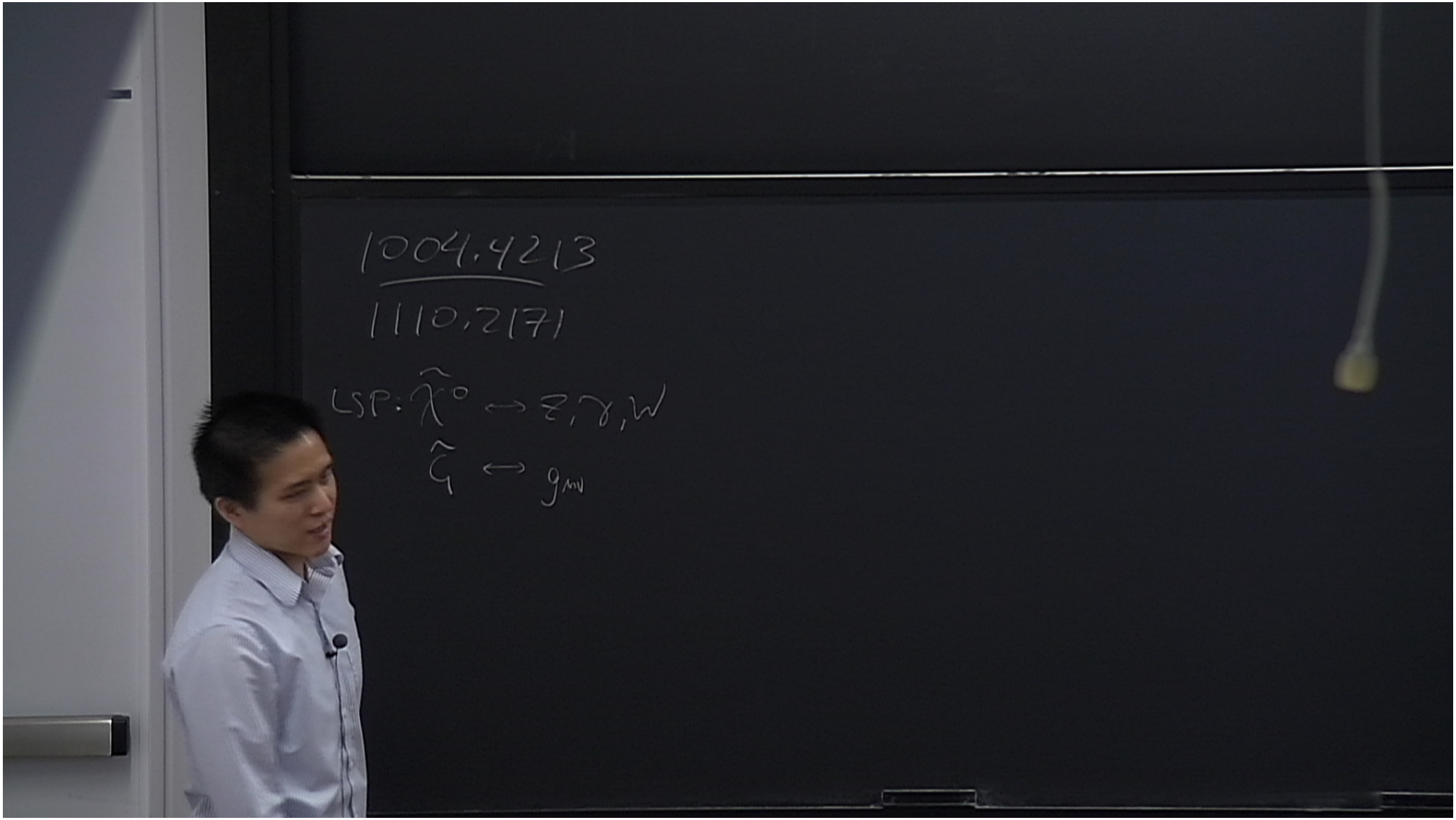
P: $\tilde{\chi}^0 \to Z, \gamma, W$
$\tilde{G}$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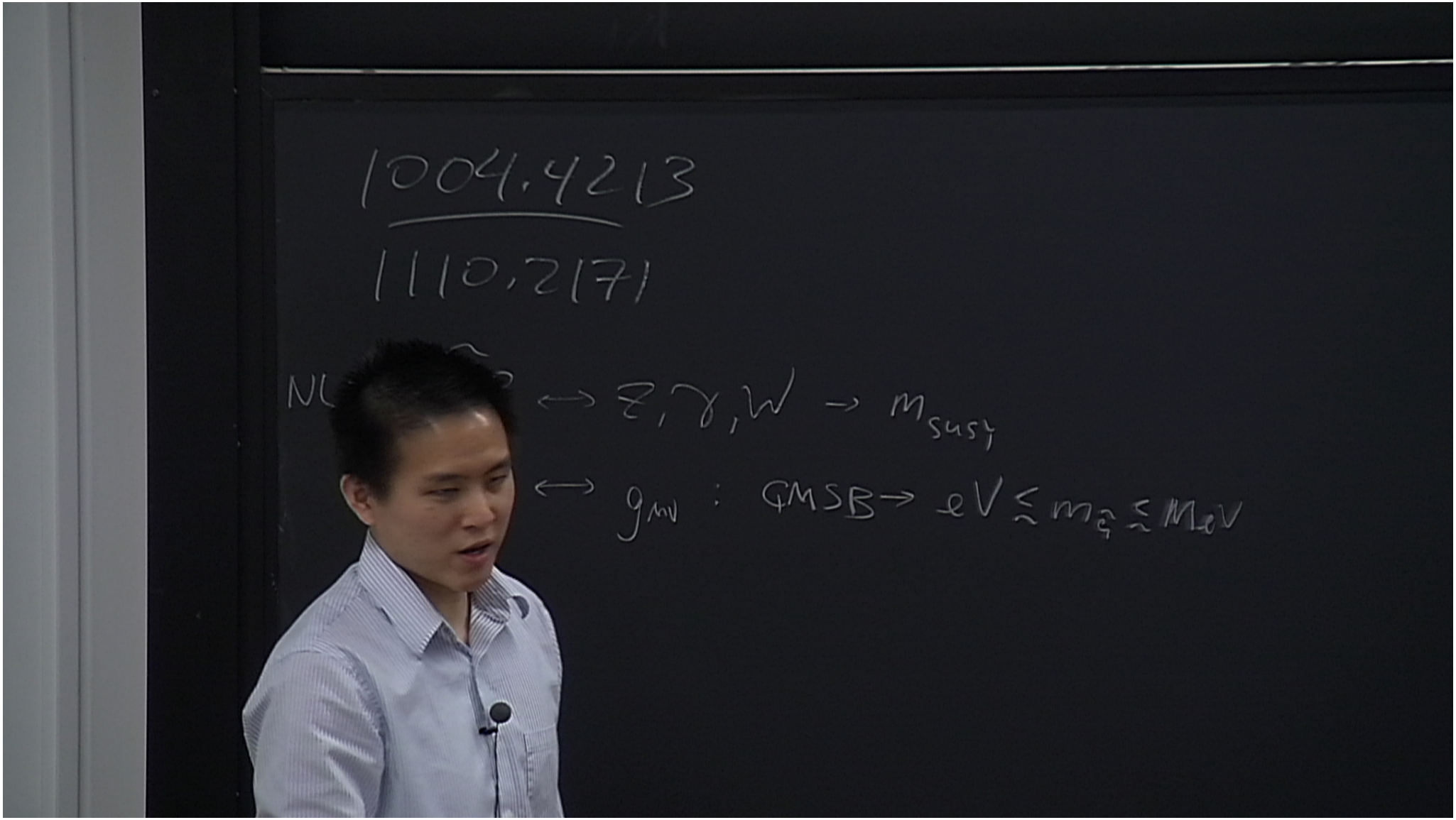
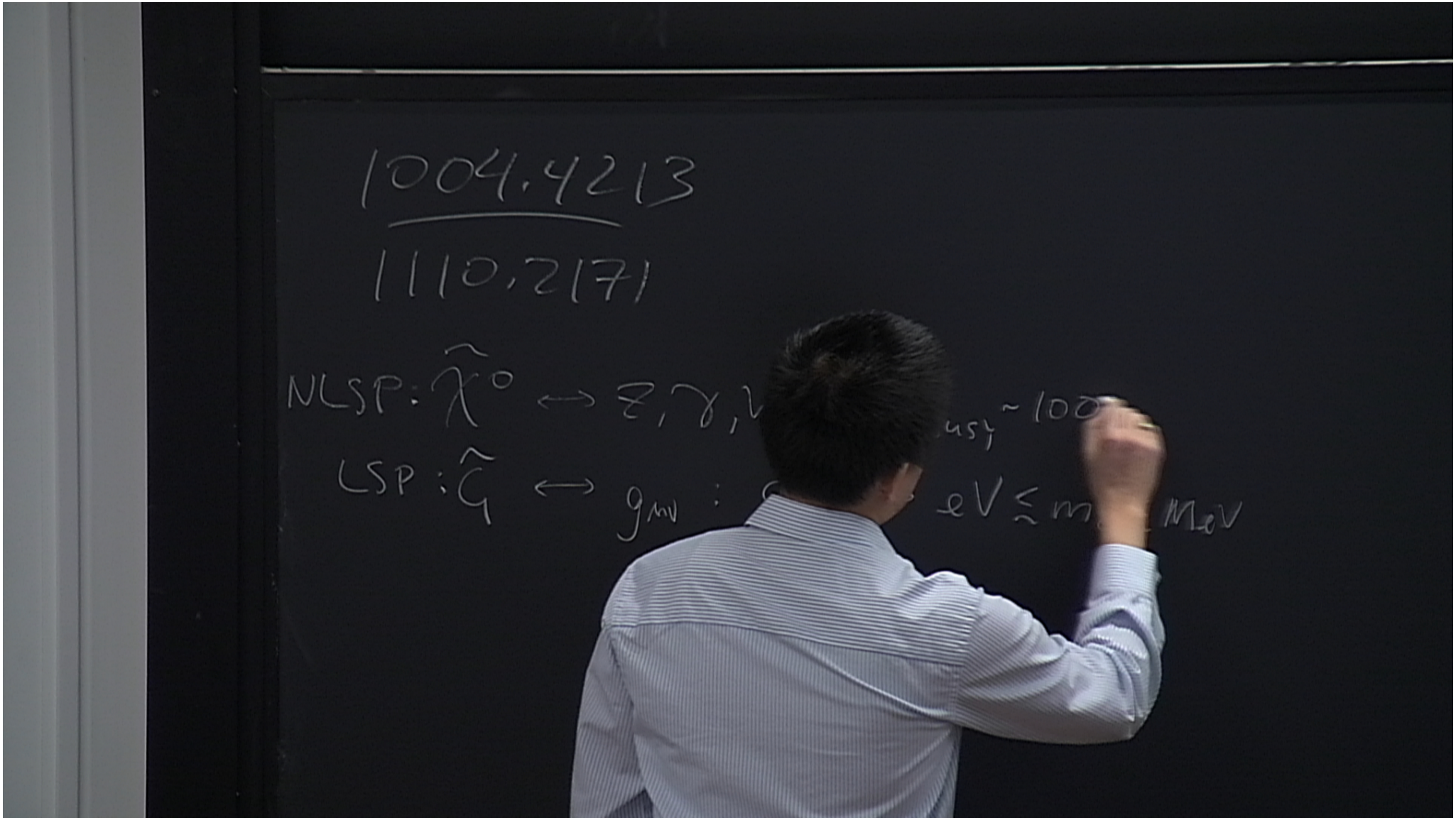
LSP: $\tilde{\chi}^0 \leftrightarrow Z, \gamma, W$
$\tilde{G} \leftrightarrow g_{\mu\nu}$


1004.4213
1110.2171
↔ Z, γ, W → m_susy
↔ g_mν : GMSB → eV ≲ m_g̃ ≲ MeV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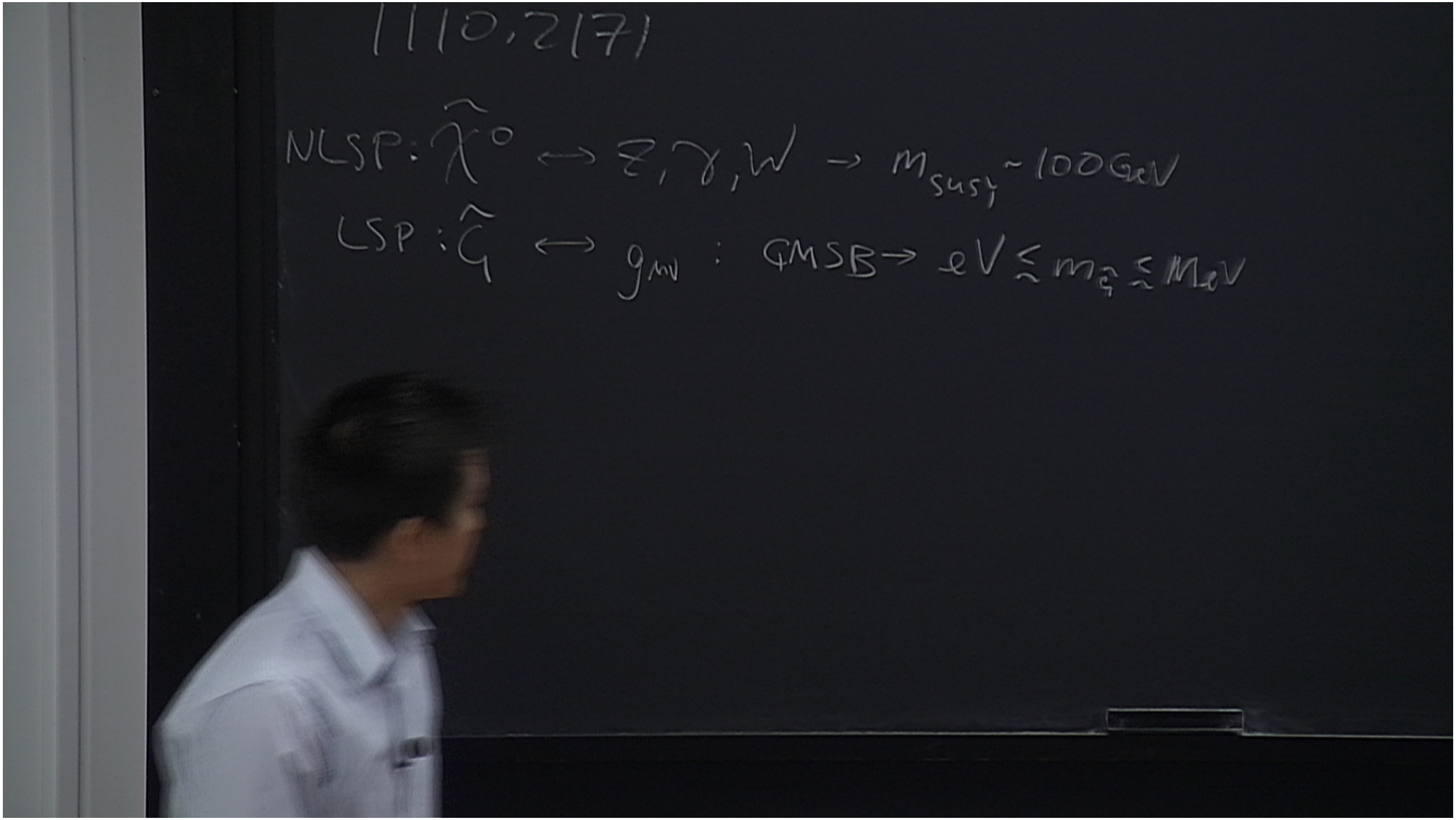
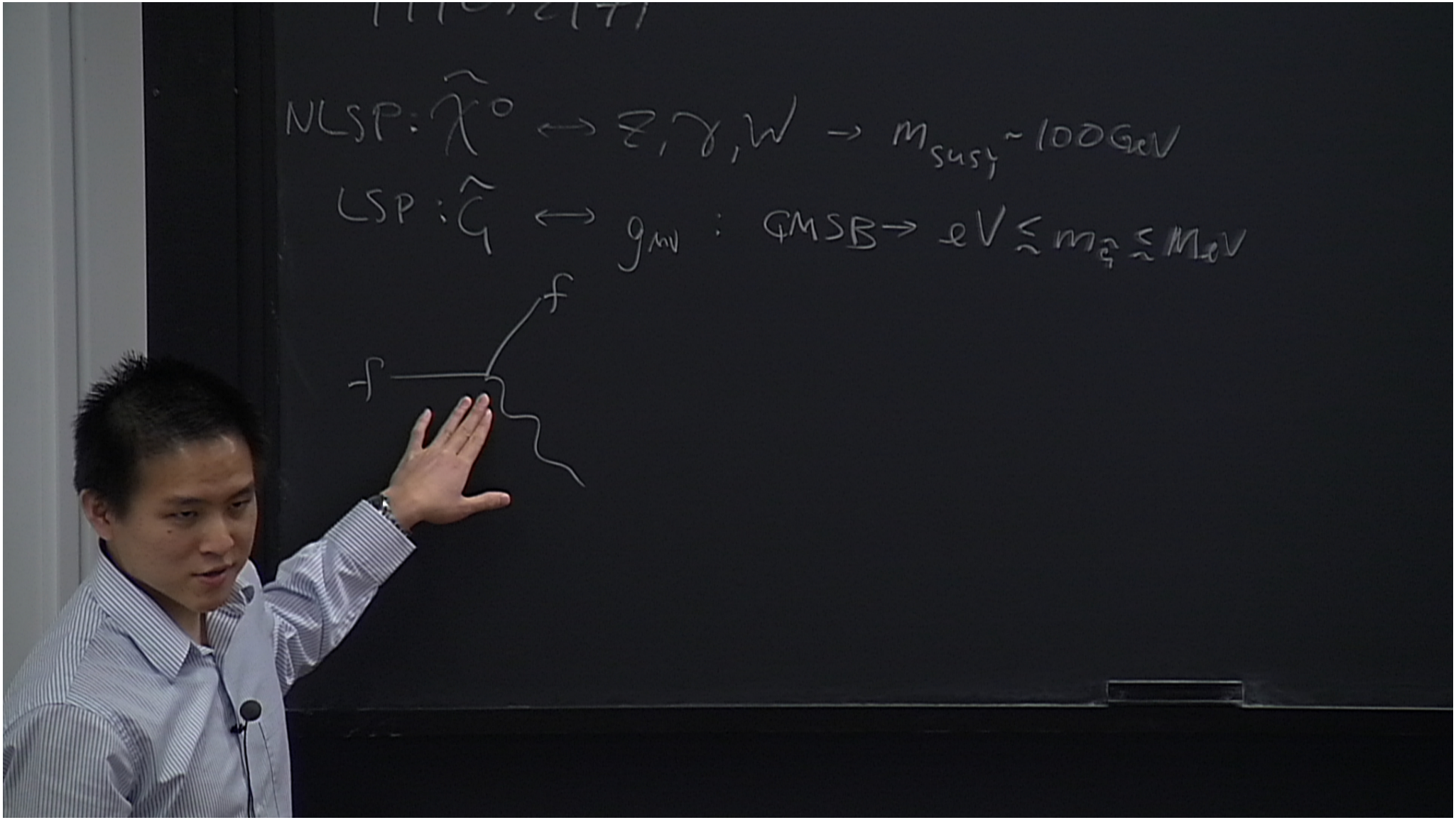
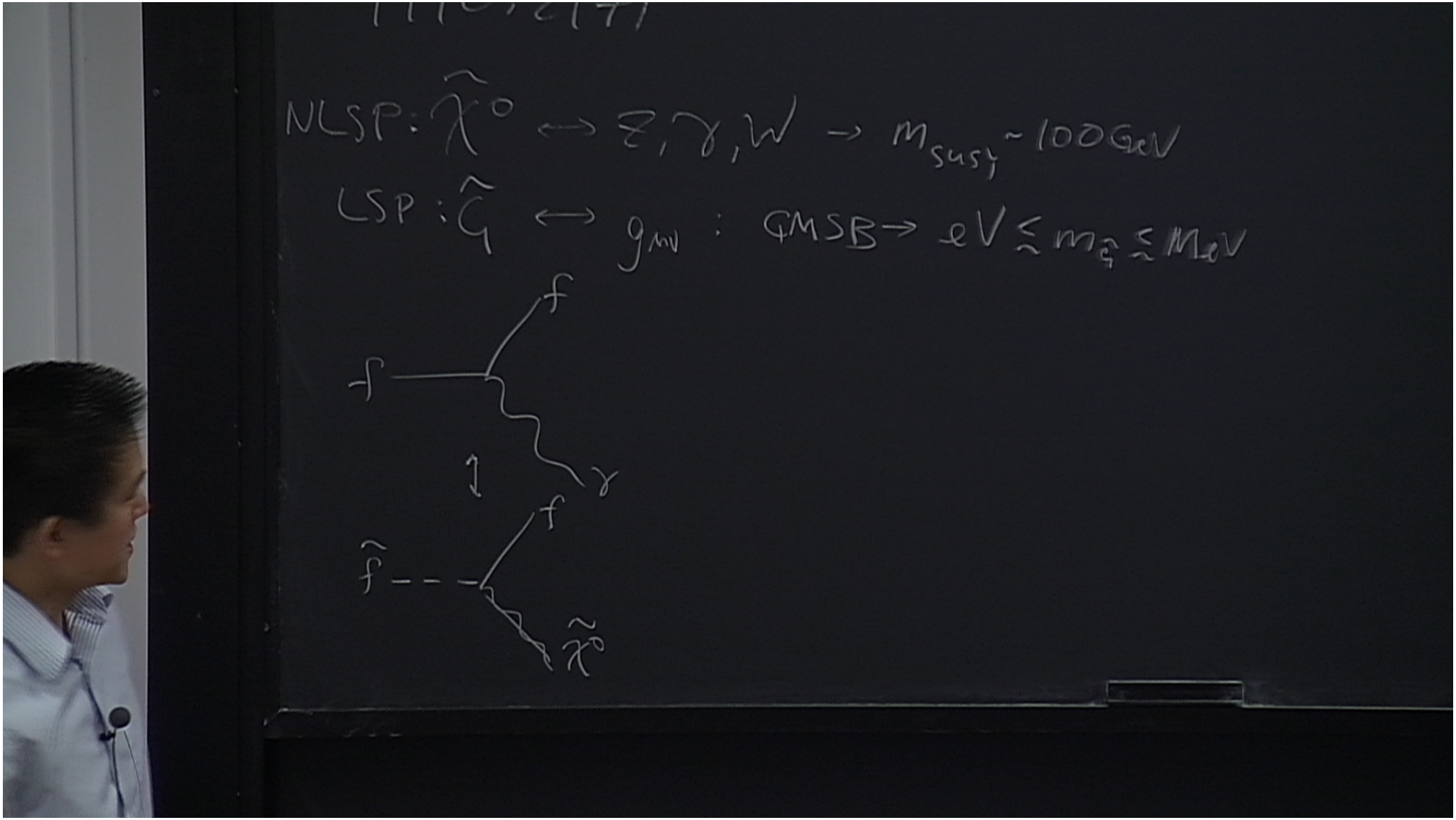
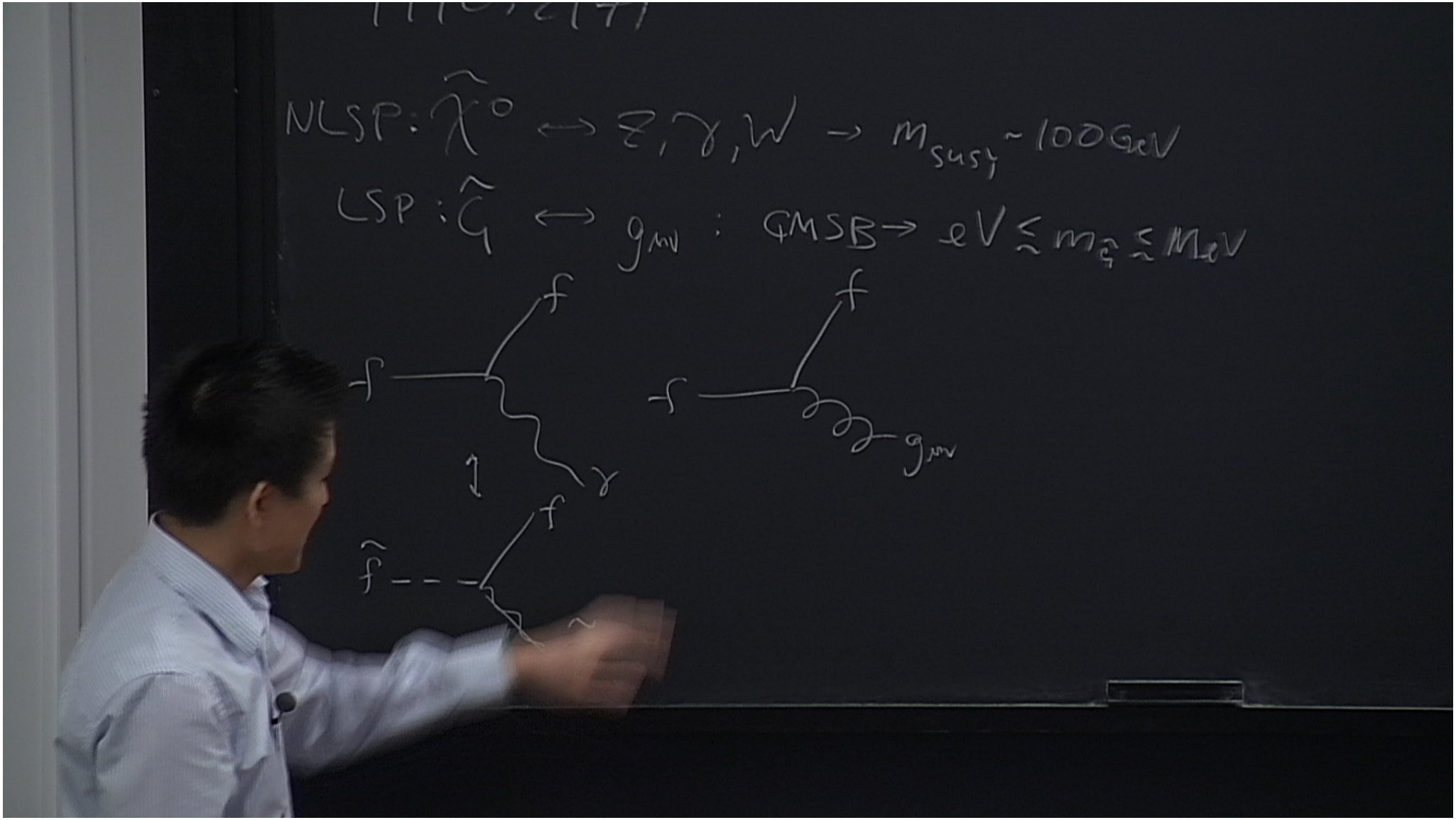
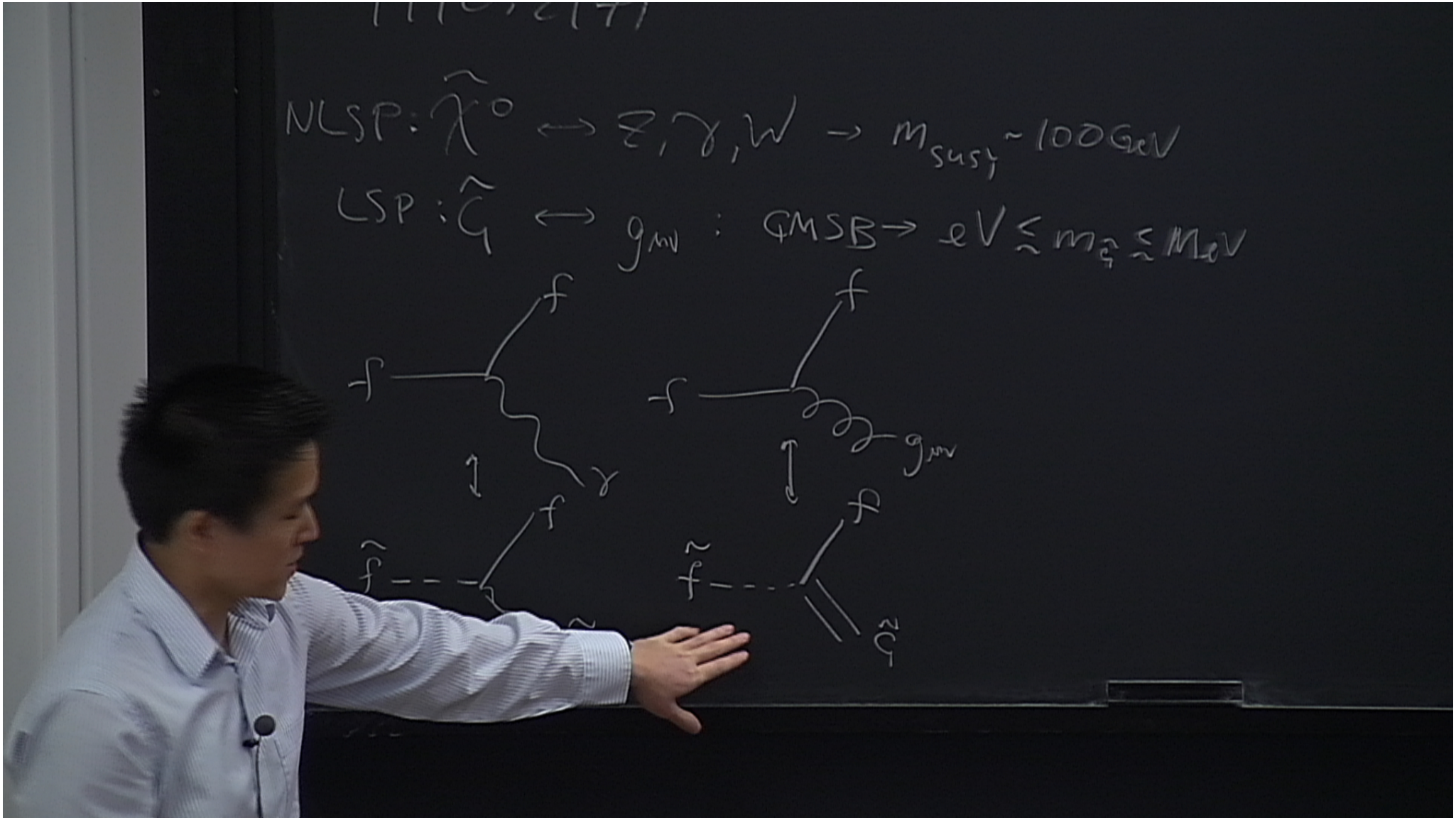
NLSP: $\tilde{\chi}^0$ ↔ $\tilde{e}, \tilde{\gamma}, \tilde{\nu}$
LSP: $\tilde{G}$ ↔ $g_{\mu\nu}$

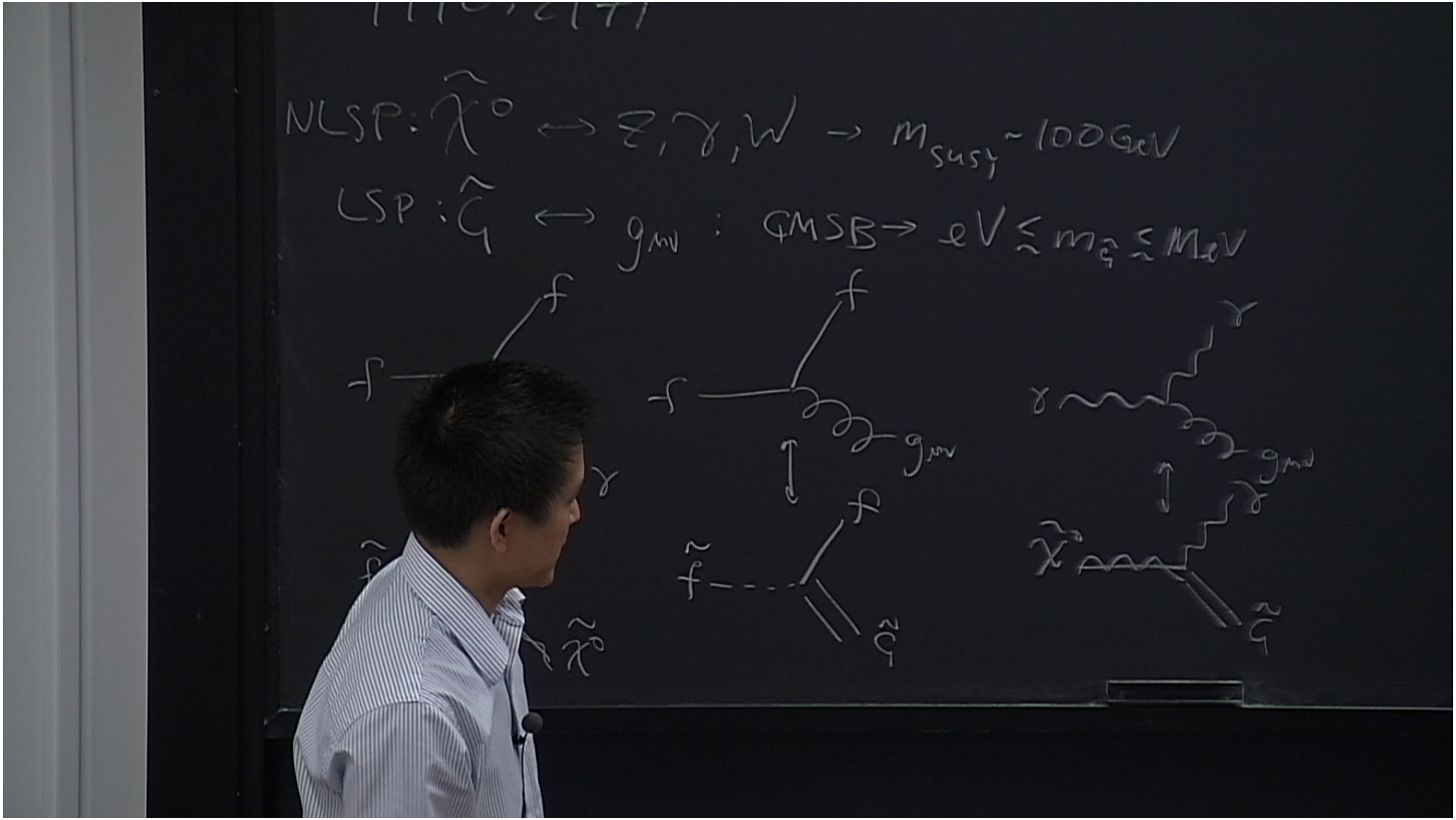

1110.2171
NLSP: $\tilde{\chi}^0 \leftrightarrow Z, \gamma, W \rightarrow m_{susy} \sim 100\,GeV$
LSP: $\tilde{G} \leftrightarrow g_{MV}$: GMSB $\rightarrow eV \lesssim m_{\tilde{G}} \lesssim MeV$

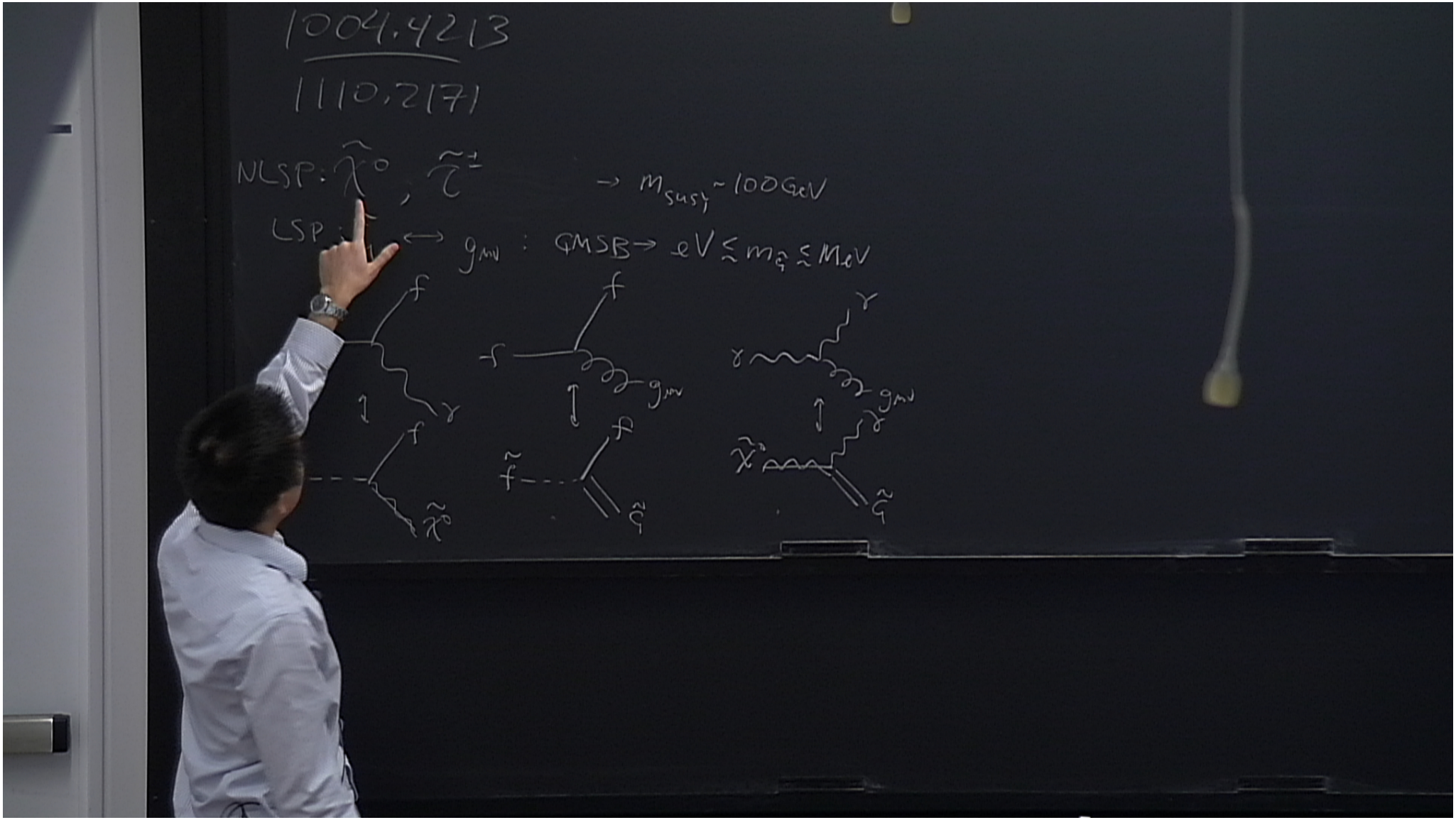

NLSP: $\tilde{\chi}^0 \leftrightarrow Z, \gamma, W \rightarrow m_{susy} \sim 100\,GeV$
LSP: $\tilde{G} \leftrightarrow g_{MV}$: GMSB $\rightarrow eV \lesssim m_{\tilde{G}} \lesssim MeV$
f
f


NLSP: $\tilde{\chi}^0 \leftrightarrow Z, \gamma, W \rightarrow m_{susy} \sim 100\,GeV$
LSP: $\tilde{G} \leftrightarrow g_{mv}$: GMSB $\rightarrow eV \lesssim m_{\tilde{G}} \lesssim MeV$
f
f
1
γ
f
$\tilde{f}$
$\tilde{\chi}^0$


NLSP: $\tilde{\chi}^0 \leftrightarrow Z, \gamma, W \rightarrow m_{susy} \sim 100\,GeV$
LSP: $\tilde{G} \leftrightarrow g_{\mu\nu}$: GMSB $\rightarrow eV \lesssim m_{\tilde{G}} \lesssim MeV$
f
f
$\tilde{f}$
f
f
γ
$g_{\mu\nu}$


NLSP: $\tilde{\chi}^0 \leftrightarrow \ell, \gamma, W \rightarrow m_{susy} \sim 100\,GeV$
LSP: $\tilde{G} \leftrightarrow g_{\mu\nu}$: GMSB $\rightarrow eV \lesssim m_{\tilde{G}} \lesssim MeV$
f
f
γ
$g_{\mu\nu}$
$\tilde{f}$
$\tilde{G}$


NLSP: $\tilde{\chi}^0 \leftrightarrow \ell, \gamma, W \rightarrow m_{susy} \sim 100\,GeV$
LSP: $\tilde{G} \leftrightarrow g_{\mu\nu}$: GMSB $\rightarrow eV \lesssim m_{\tilde{G}} \lesssim MeV$
f
f
$g_{\mu\nu}$
$\tilde{f}$
$\tilde{\chi}^0$
$\tilde{G}$
γ
γ
$g_{\mu\nu}$
$\tilde{\chi}^0$
$\tilde{G}$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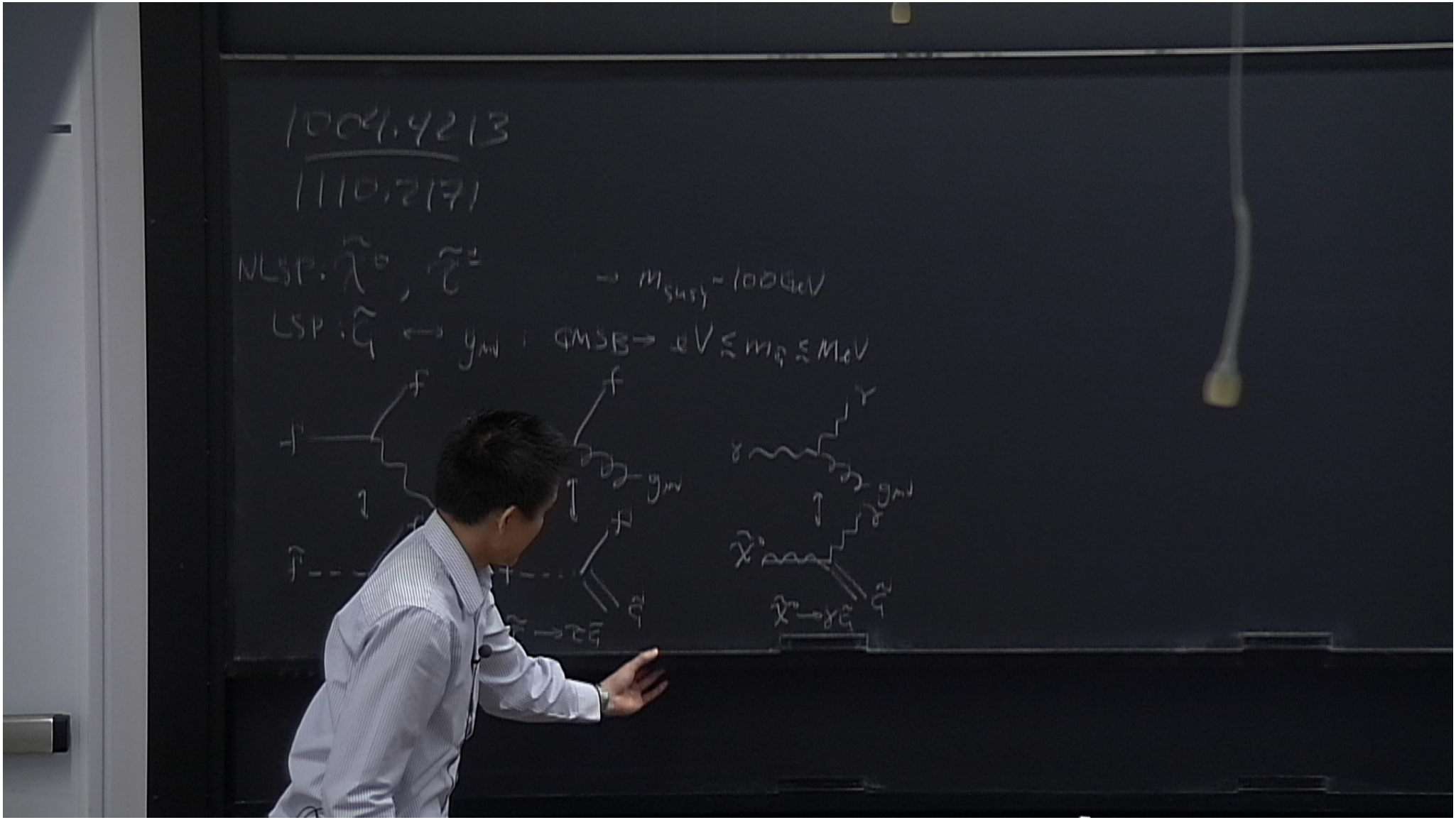
NLSP: $\tilde{\chi}^0$, $\tilde{\tau}^{\pm}$
$\rightarrow M_{susy} \sim 100\,GeV$
LSP: $\tilde{G}$ $\leftrightarrow$ $g_{\mu\nu}$: GMSB $\rightarrow$ $eV \lesssim m_{\tilde{G}} \lesssim MeV$
f
f
γ
γ
γ
$g_{\mu\nu}$
$g_{\mu\nu}$
f
$\tilde{f}$
$\tilde{\chi}^0$
$\tilde{\chi}^0$
$\tilde{G}$
$\tilde{G}$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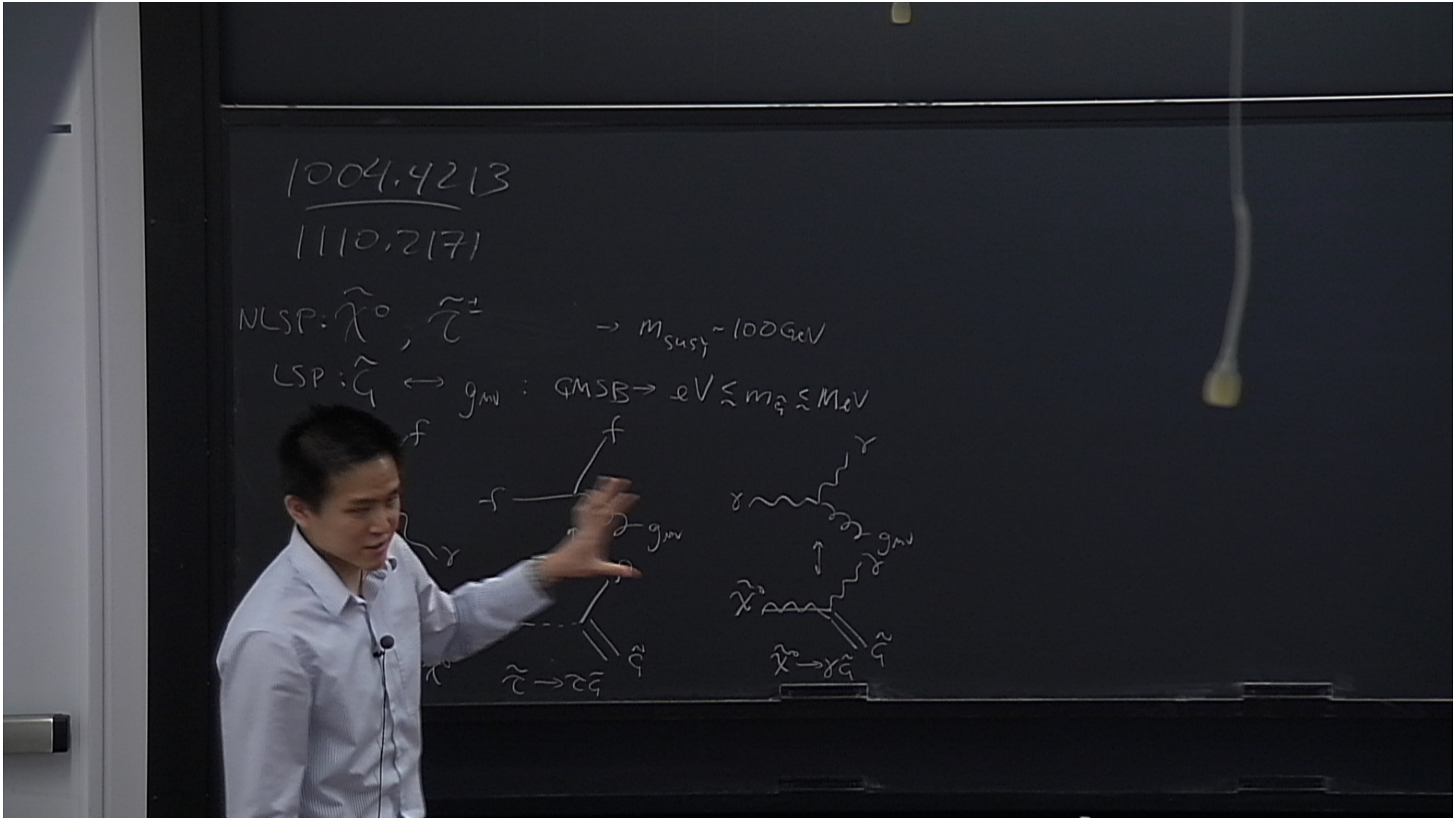
NLSP: $\tilde{\chi}^0$, $\tilde{e}^-$
$\rightarrow M_{susy} \sim 100$GeV
LSP: $\tilde{G}$ $\leftrightarrow$ y_{MN} ; GMSB $\rightarrow$ eV $\lesssim M_{\tilde{G}} \lesssim$ MeV
$\tilde{\chi}^0 \rightarrow \gamma\tilde{G}$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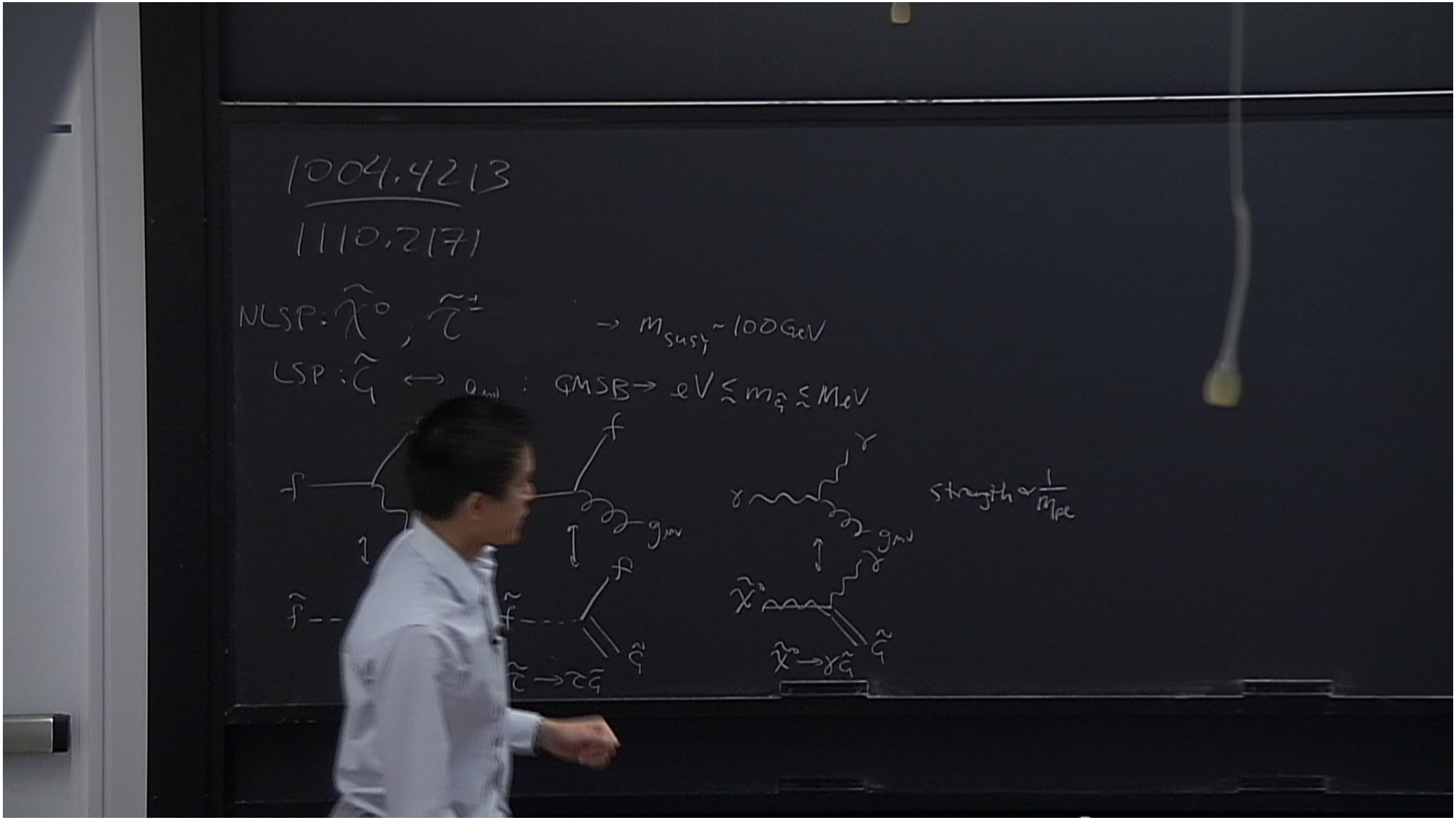
NLSP: $\tilde{\chi}^0$, $\tilde{\tau}^{\pm}$ → $M_{susy} \sim 100$GeV
LSP: $\tilde{G} \leftrightarrow g_{\mu\nu}$: GMSB → $eV \lesssim m_{\tilde{G}} \lesssim MeV$
f
f
γ
$g_{\mu\nu}$
$\tilde{\tau} \to \tau\tilde{G}$
$\tilde{G}$
γ
γ
γ
$g_{\mu\nu}$
$\tilde{\chi}^0$
$\tilde{\chi}^0 \to \gamma\tilde{G}$
$\tilde{G}$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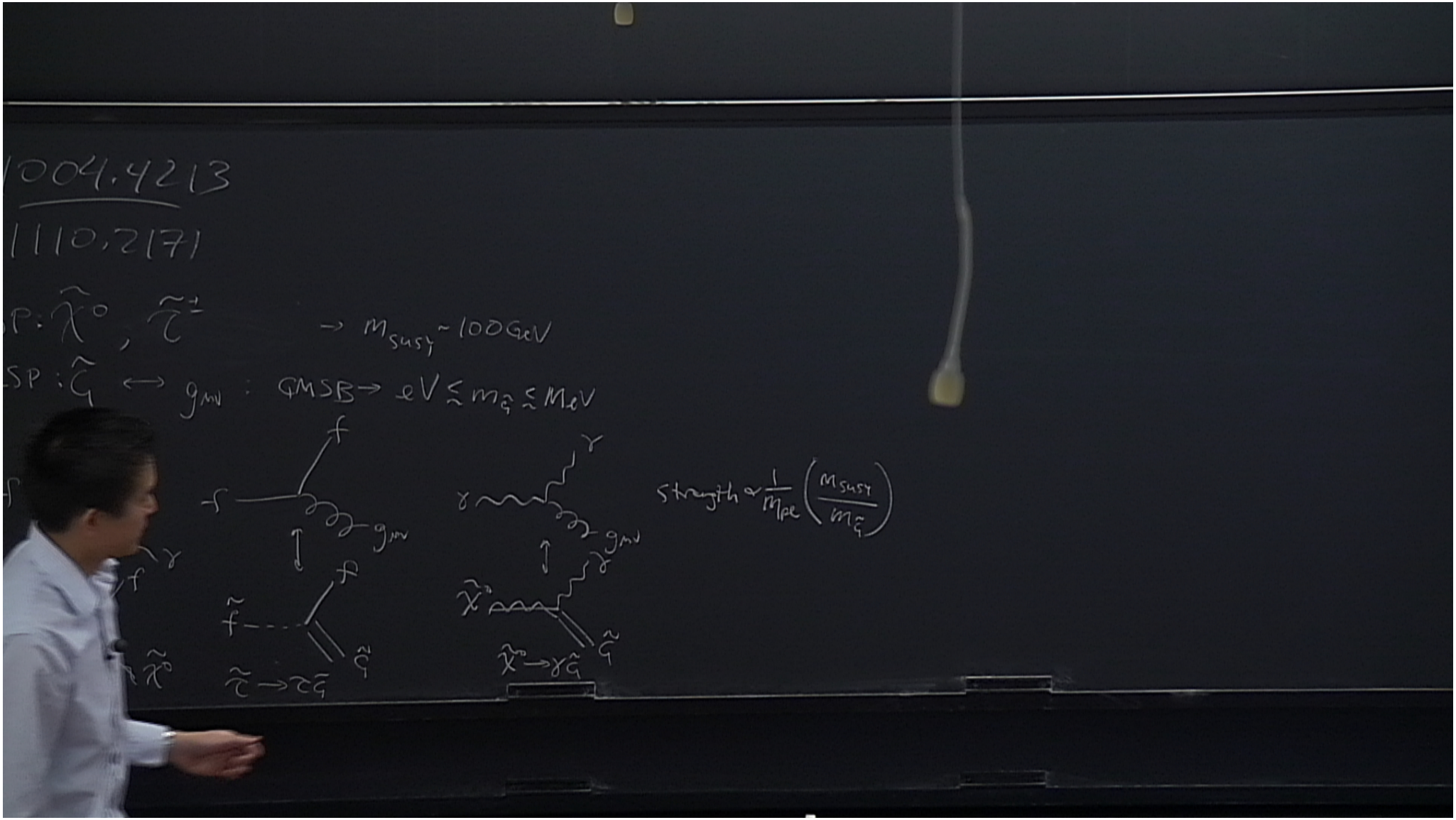
NLSP: $\tilde{\chi}^0$, $\tilde{\tau}^{\pm}$
$\rightarrow M_{susy} \sim 100\,GeV$
LSP: $\tilde{G}$
GMSB $\rightarrow$ $eV \lesssim m_{\tilde{G}} \lesssim MeV$
strength $\propto \frac{1}{M_{Pl}}$
$\tilde{\tau} \rightarrow \tau \tilde{G}$
$\tilde{\chi}^0 \rightarrow \gamma \tilde{G}$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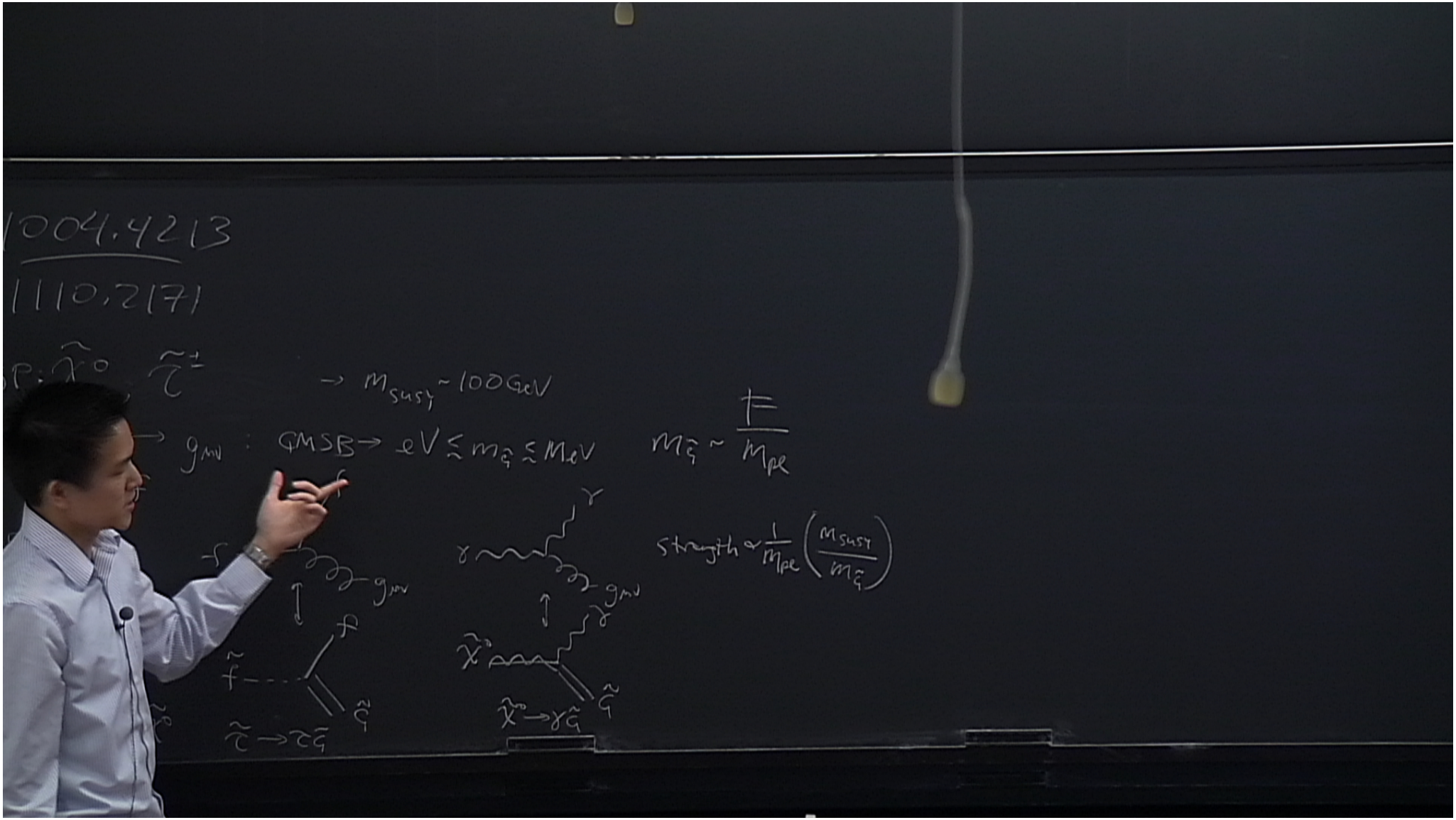
$\rightarrow m_{Susy} \sim 100\,GeV$
$\tilde{G} \leftrightarrow g_{\mu\nu}$: GMSB $\rightarrow eV \lesssim m_{\tilde{G}} \lesssim MeV$
$\tilde{f} \rightarrow f \tilde{G}$
$\tilde{\tau} \rightarrow \tau \tilde{G}$
$\tilde{\chi}^0 \rightarrow \gamma \tilde{G}$
strength $\propto \frac{1}{m_{pl}} \left(\frac{m_{Susy}}{m_{\tilde{G}}} \right)$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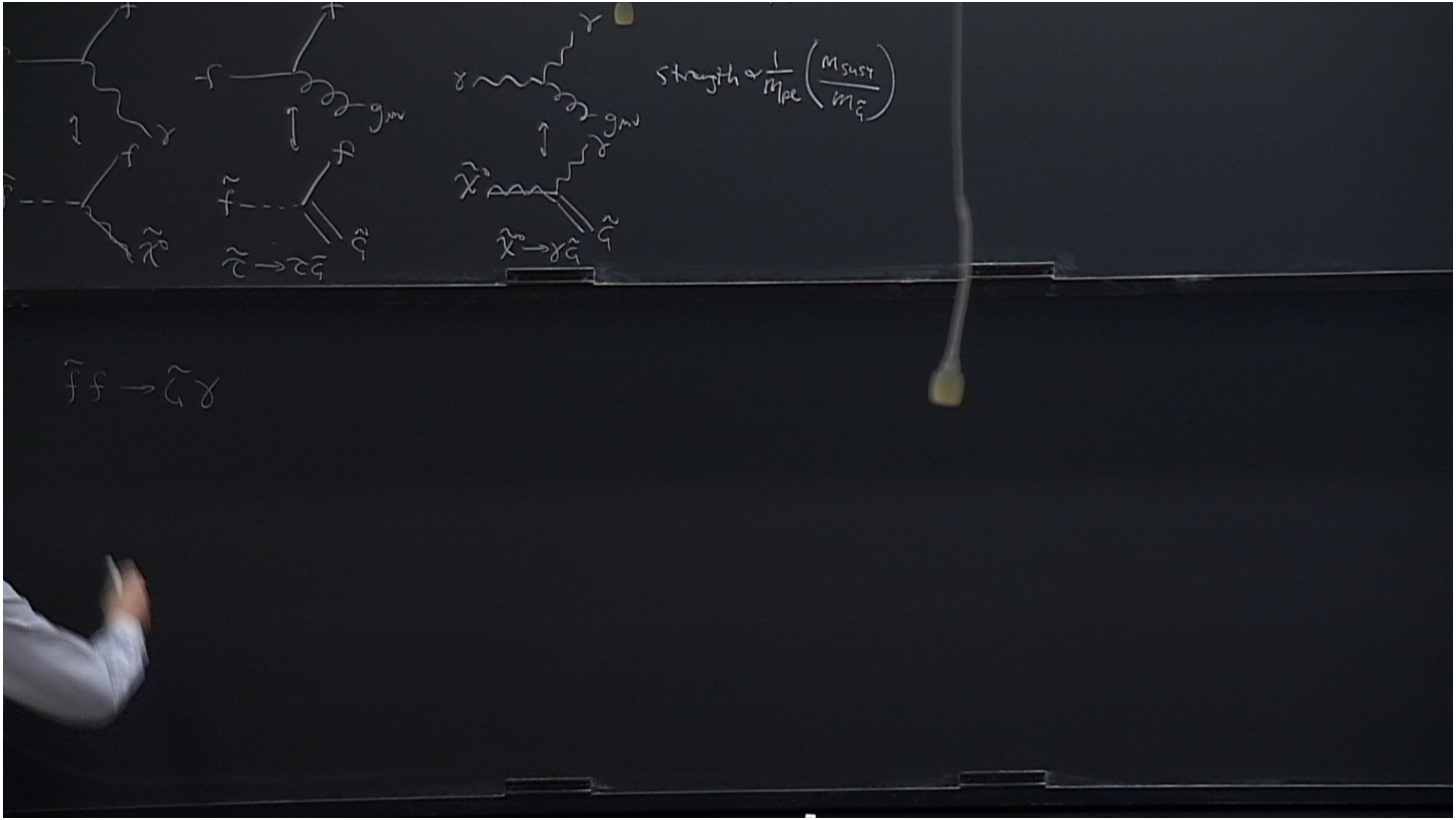
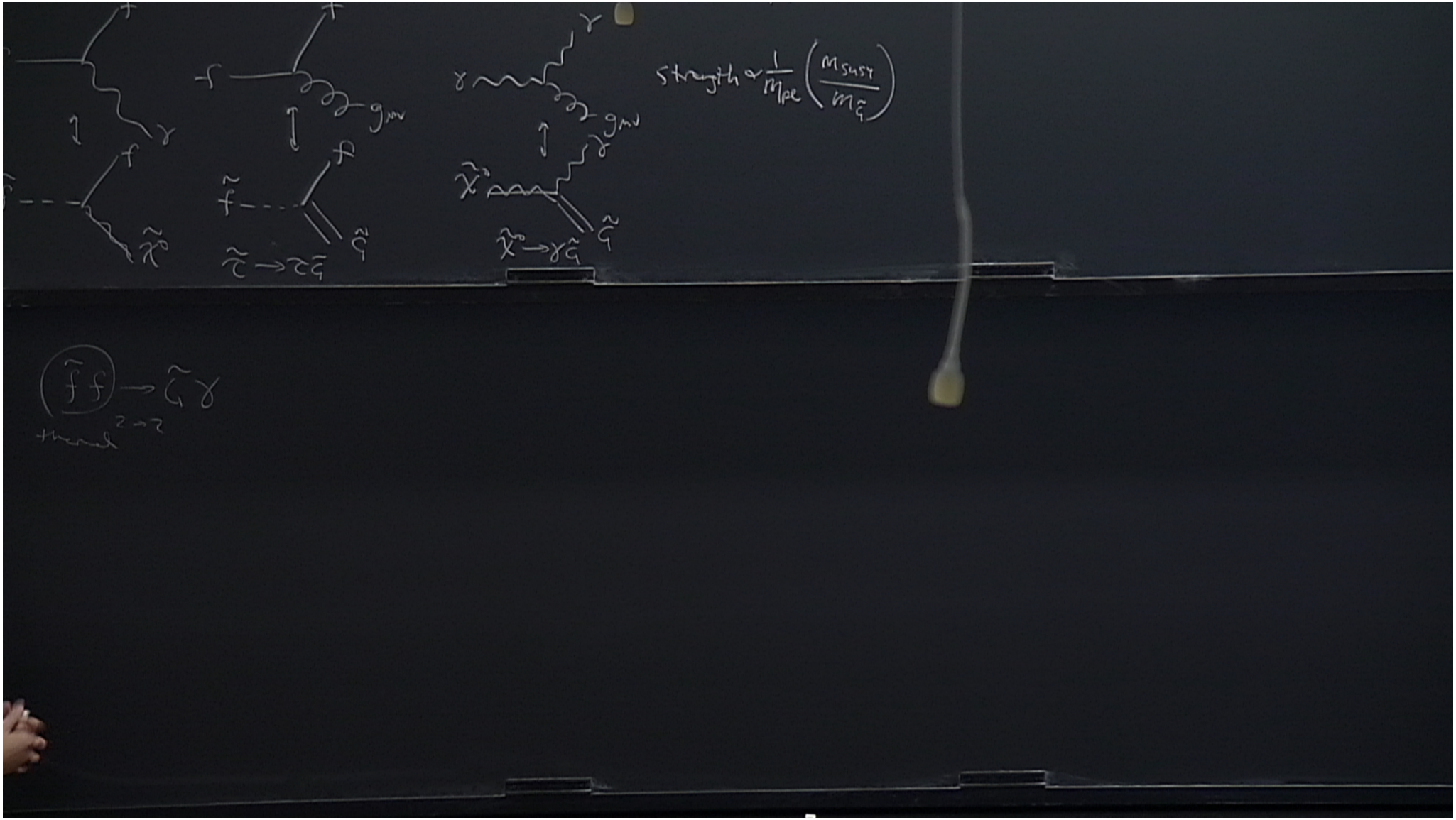
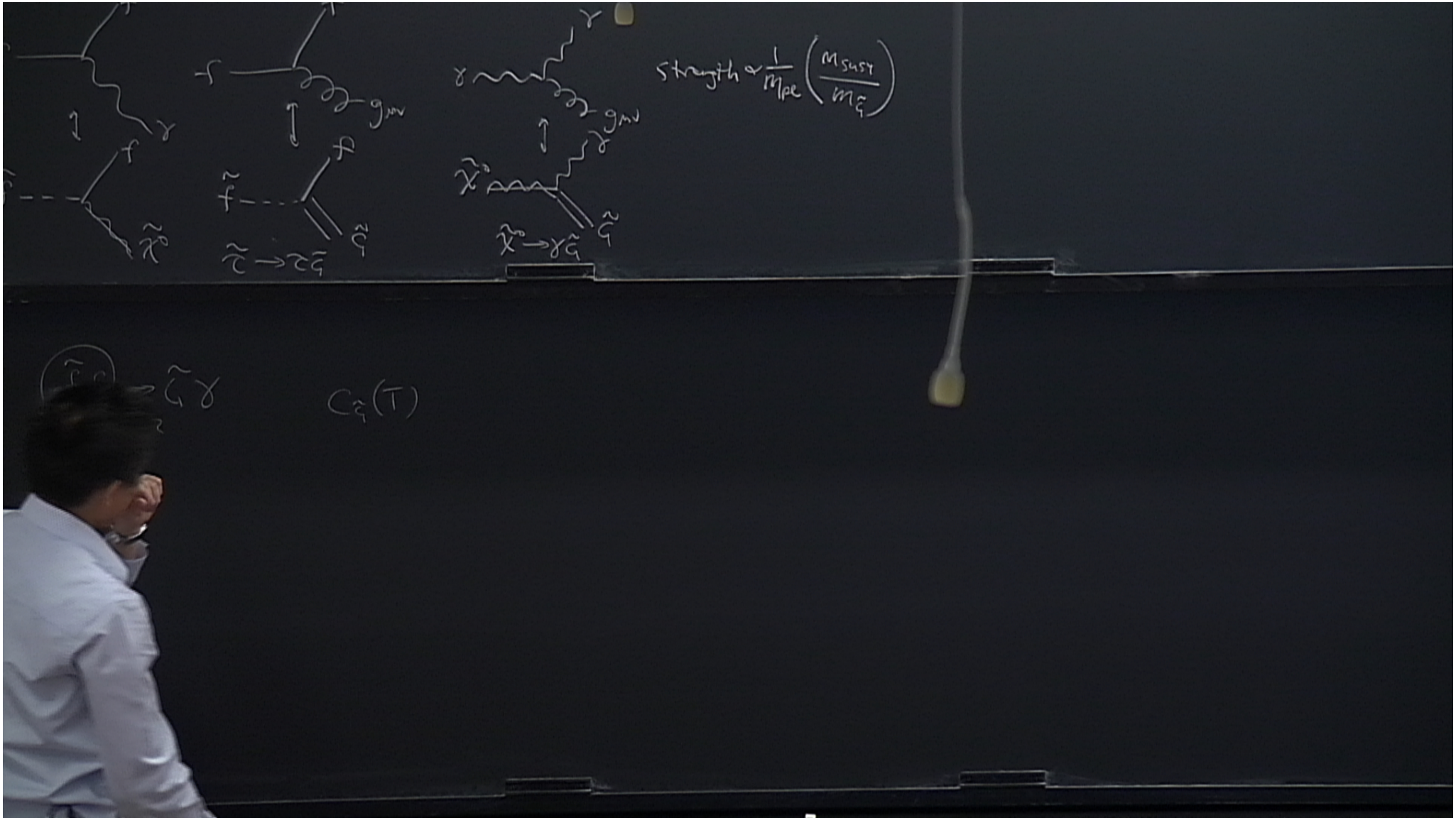
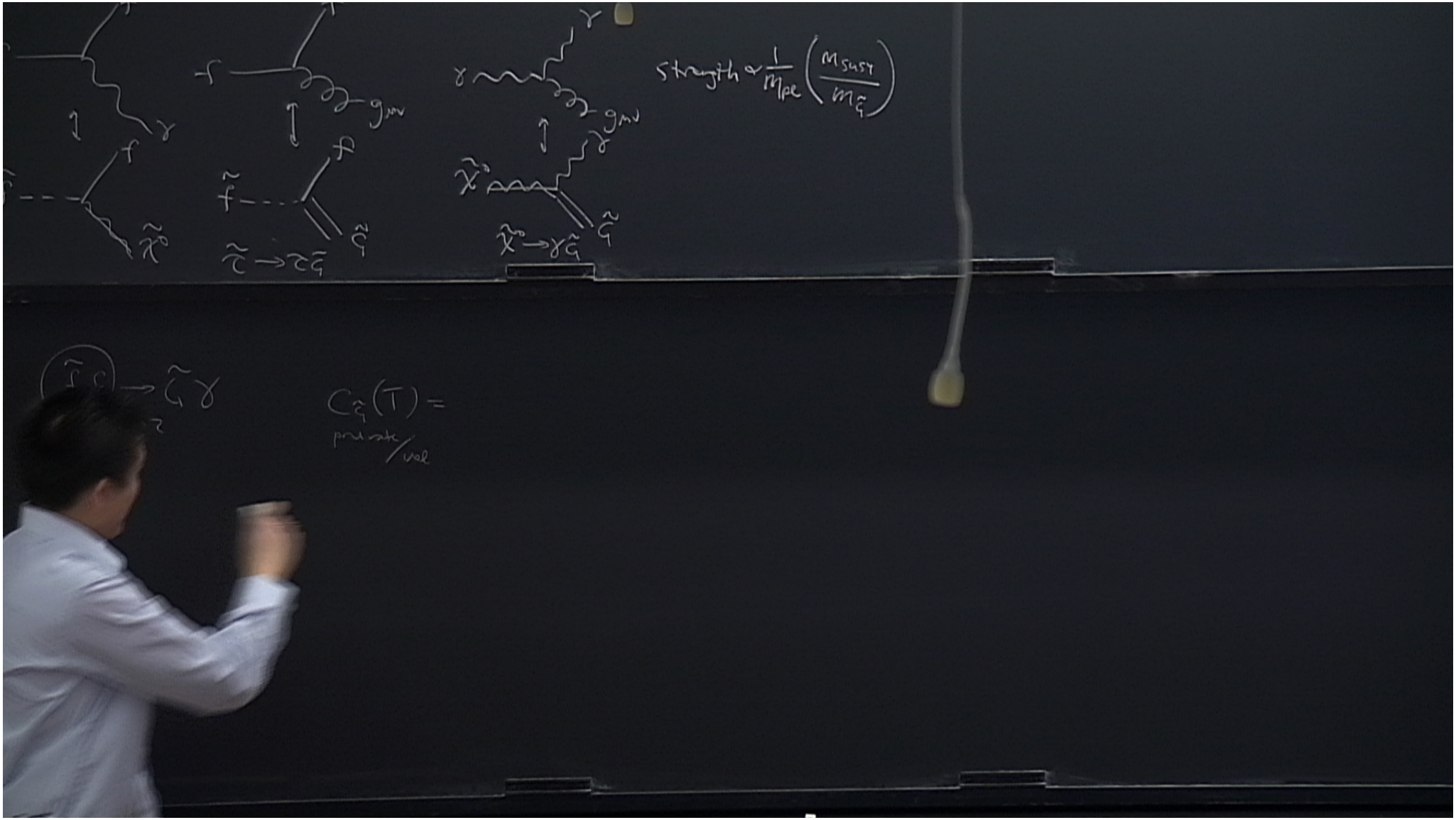
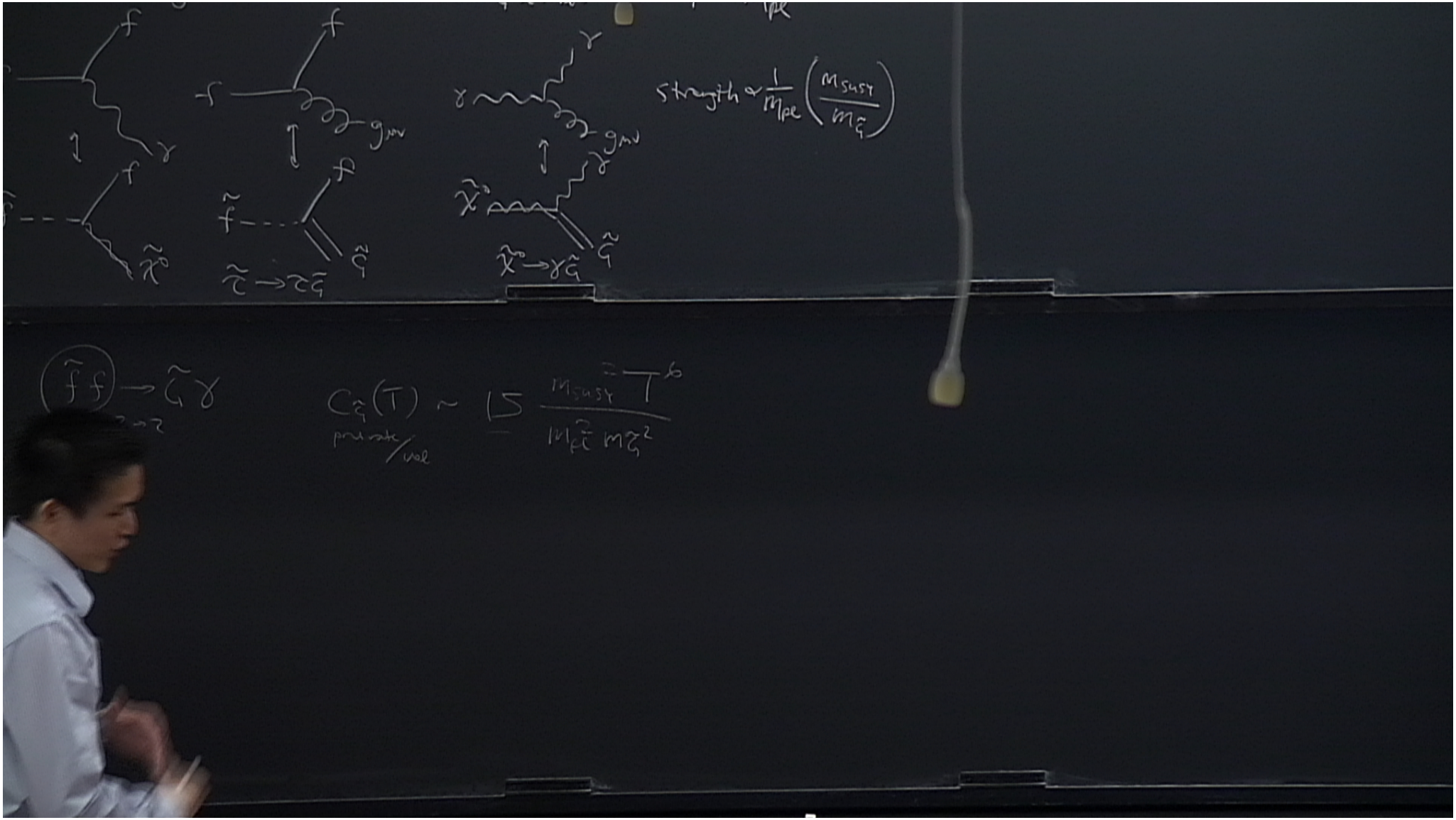
$\tilde{\chi}^0$, $\tilde{\tau}^\pm$
$\rightarrow m_{susy} \sim 100\,GeV$
$g_{\mu\nu}$: GMSB $\rightarrow$ $eV \lesssim m_{\tilde{G}} \lesssim MeV$
$m_{\tilde{G}} \sim \frac{F}{M_{PL}}$
strength $\propto \frac{1}{M_{PL}} \left(\frac{M_{susy}}{m_{\tilde{G}}}\right)$
$g_{\mu\nu}$
$\tilde{\tau} \rightarrow \tau \tilde{G}$
$\tilde{\chi}^0 \rightarrow \gamma \tilde{G}$

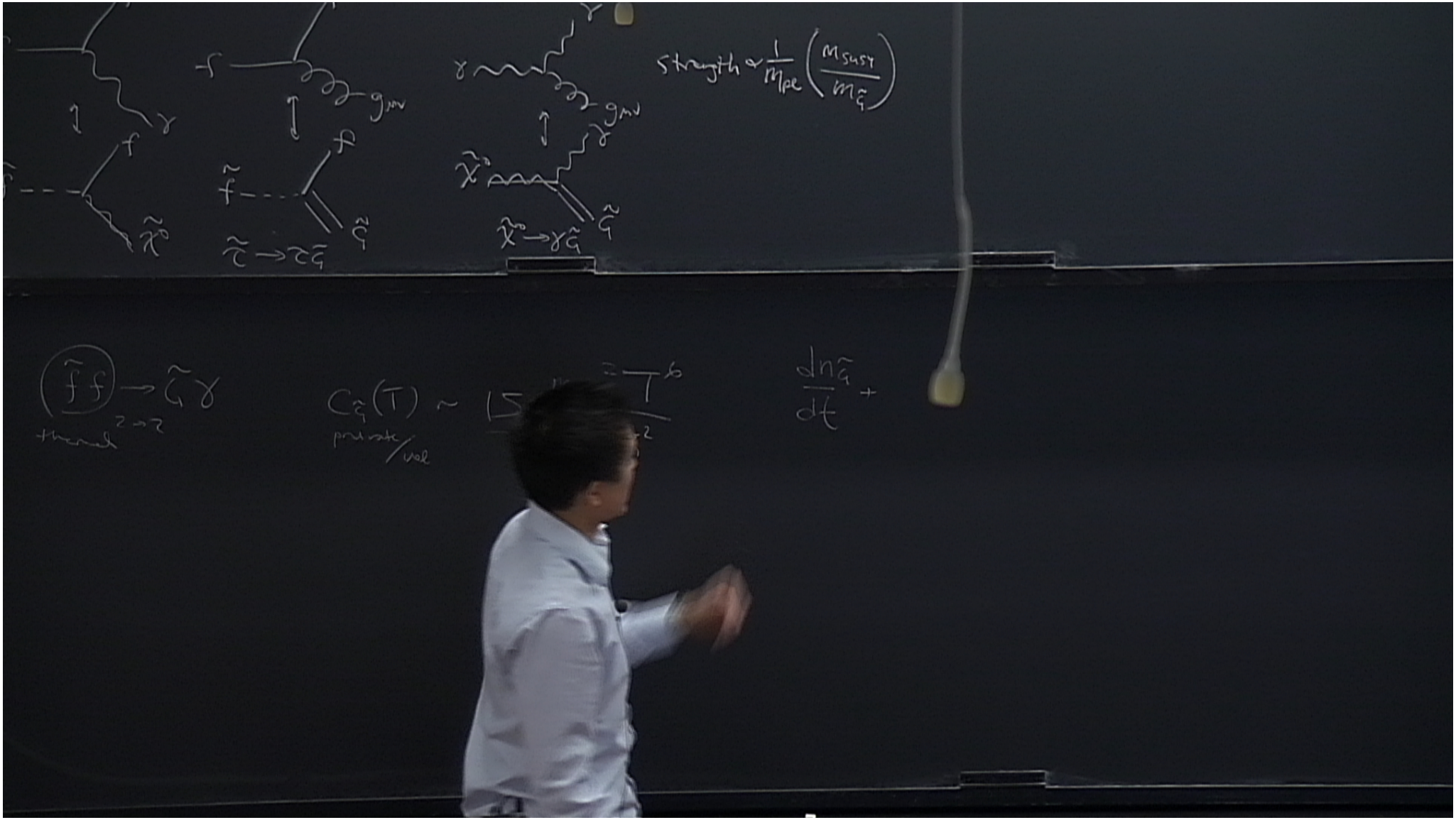

strength $\propto \frac{1}{M_{Pl}} \left(\frac{M_{SUSY}}{m_{\tilde{G}}}\right)$
$g_{\mu\nu}$
$\tilde{\chi}^0 \to \gamma\tilde{G}$
$\tilde{\tau} \to \tau\tilde{G}$
$\tilde{f}f \to \tilde{G}\gamma$

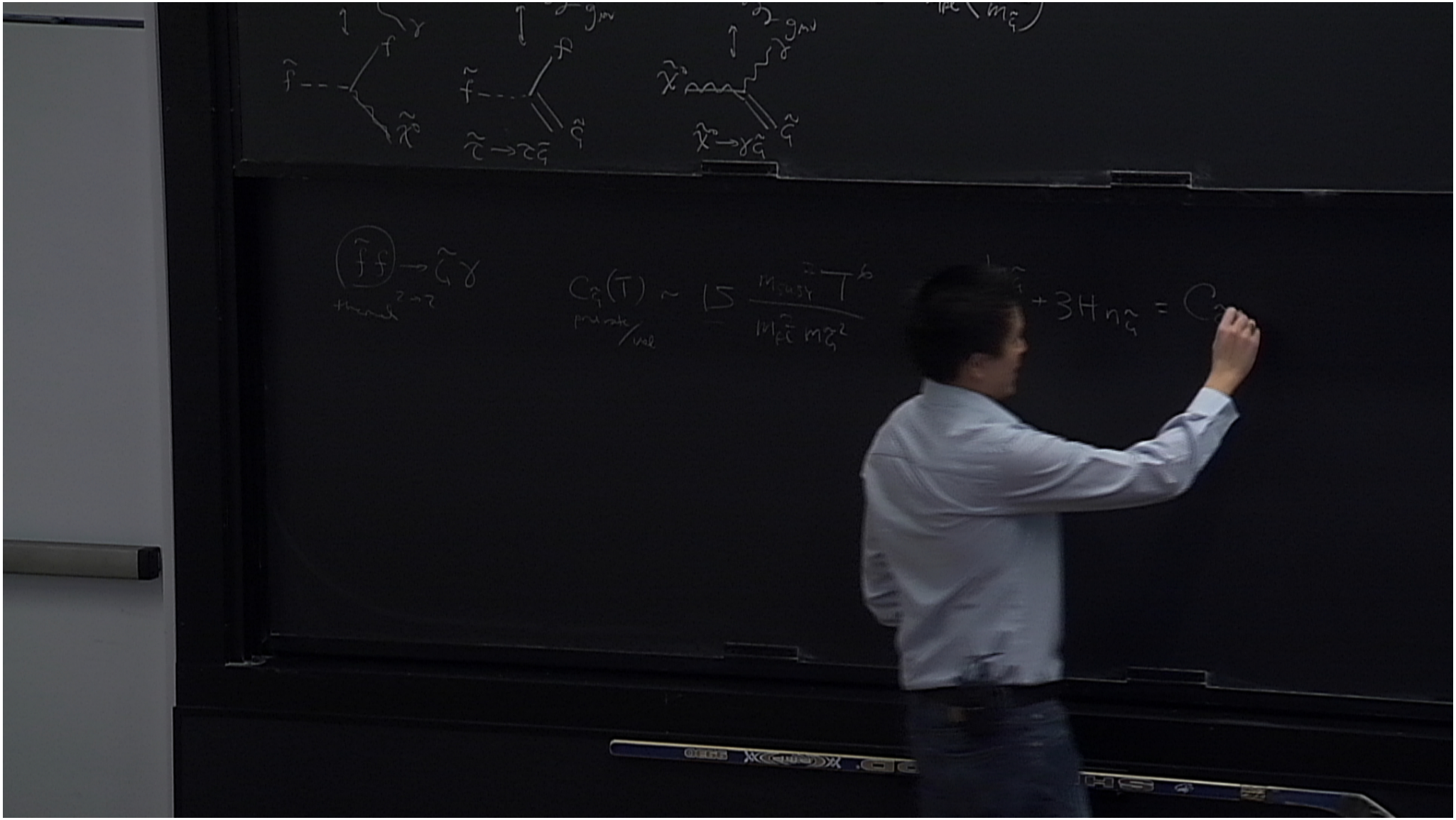

strength $\propto \frac{1}{M_{Pl}^2}\left(\frac{M_{SUSY}}{m_{\tilde{G}}}\right)^4$
$g_{\mu\nu}$
$\tilde{\chi}^0 \to \gamma\tilde{G}$
$\tilde{\tau} \to \tau\tilde{G}$
$\tilde{f}f \to \tilde{G}\gamma$
2→2

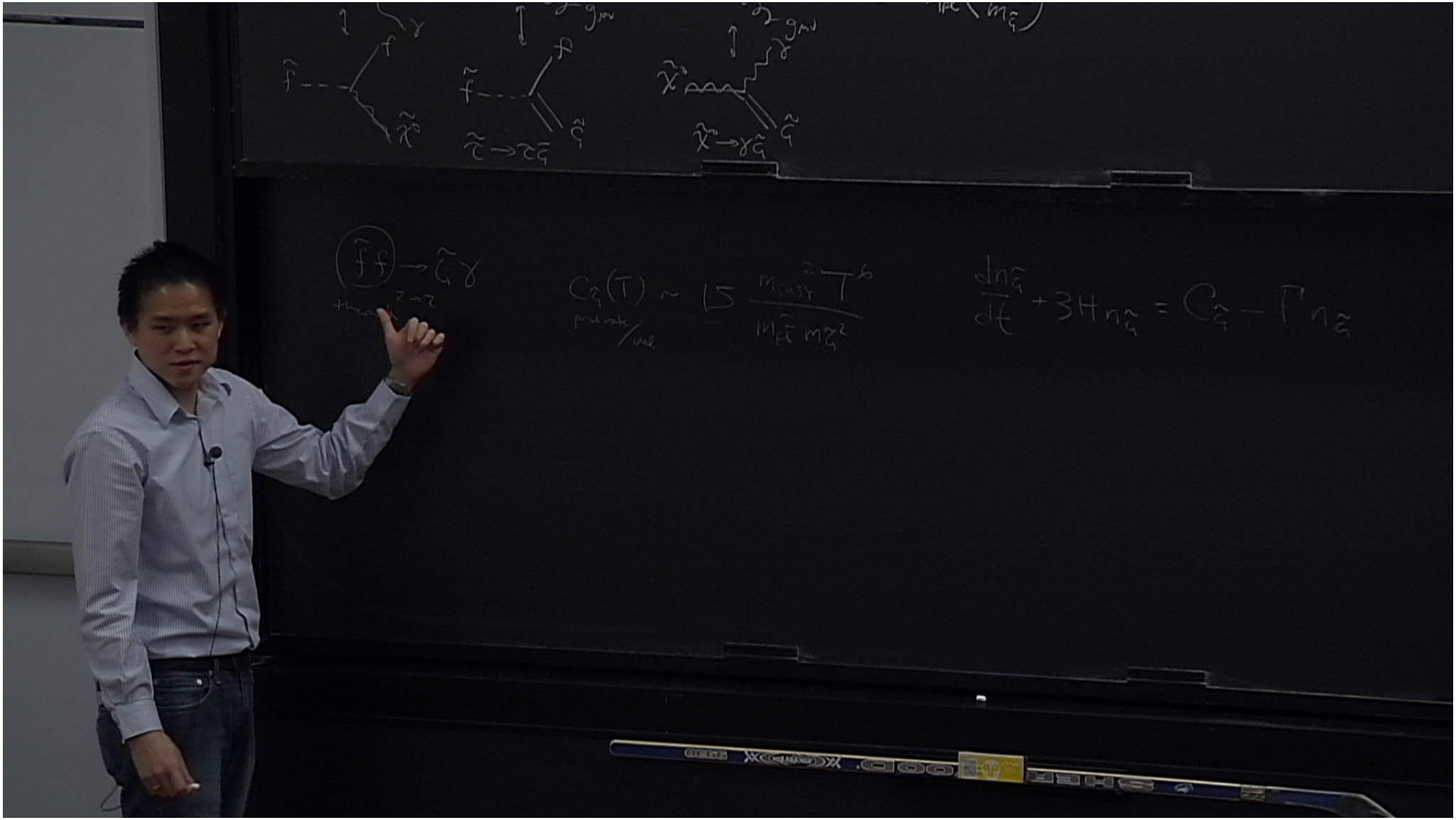

strength $\propto \frac{1}{m_{pl}} \left(\frac{M_{SUSY}}{m_{\tilde{G}}} \right)$
$\tilde{\tau} \to \tau \tilde{G}$
$\tilde{\chi}^0 \to \gamma \tilde{G}$
$C_{\tilde{G}}(T)$

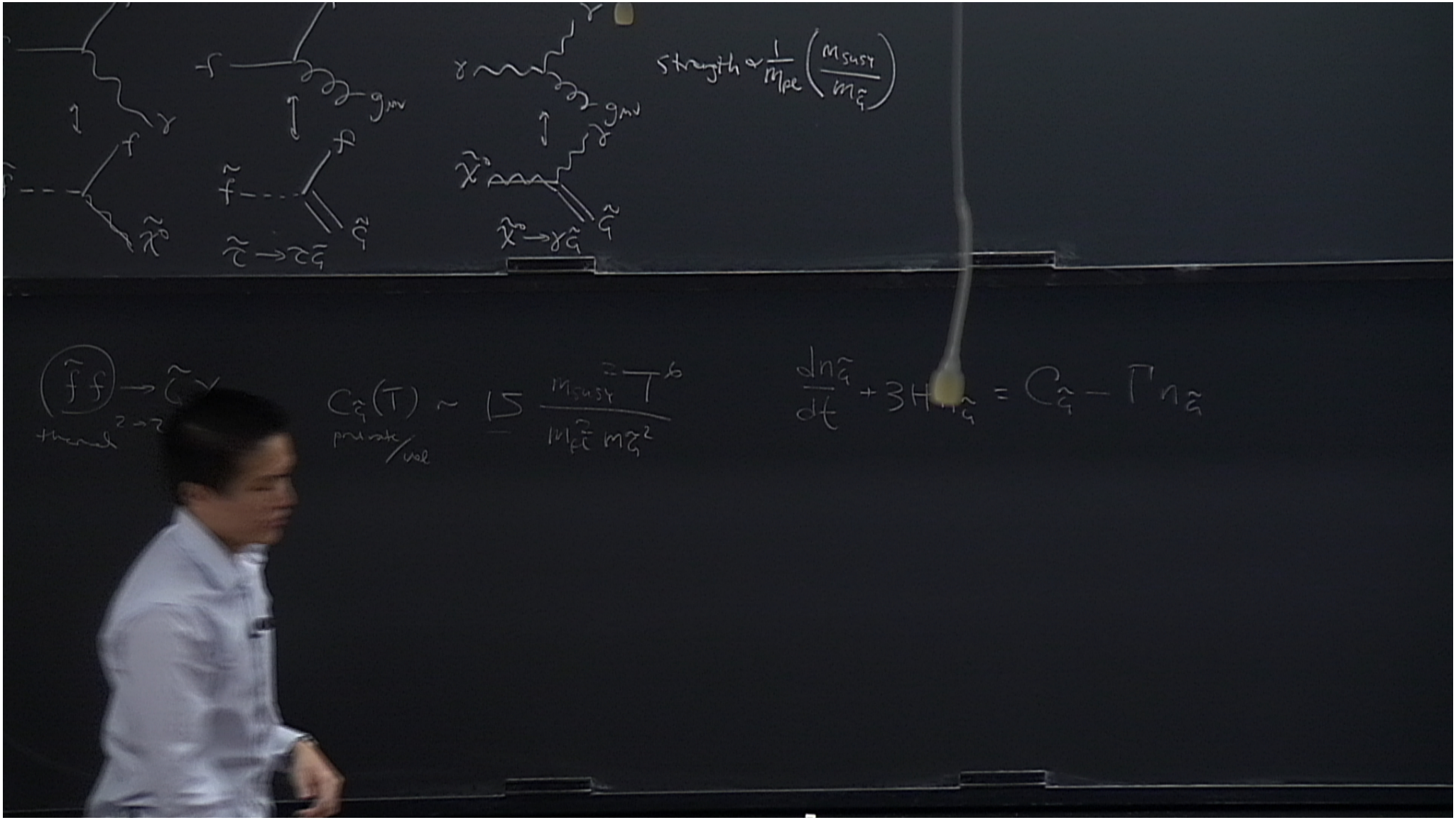

strength $\propto \frac{1}{m_{pl}} \left(\frac{m_{susy}}{m_{\tilde{G}}} \right)$
$\tilde{\tau} \to \tau \tilde{G}$
$\tilde{\chi}^0 \to \gamma \tilde{G}$
$C_{\tilde{G}}(T) =$
prod rate / vol

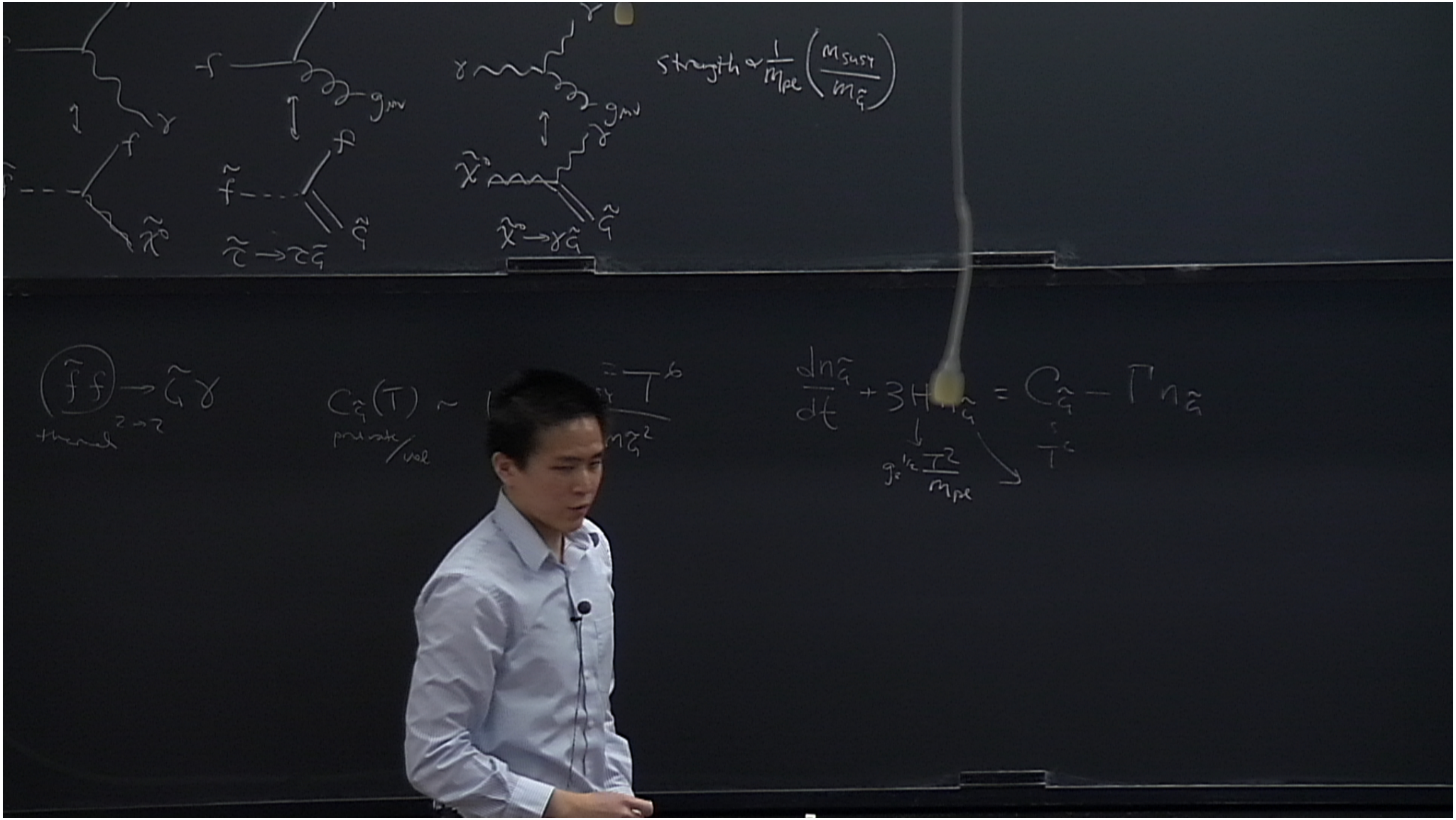

strength $\propto \frac{1}{M_{pl}} \left(\frac{M_{SUSY}}{m_{\tilde{G}}}\right)$
$\tilde{\tau} \to \tau \tilde{G}$
$\tilde{\chi}^0 \to \gamma \tilde{G}$
$\tilde{f}f \to \tilde{G}\gamma$
$C_{\tilde{G}}(T) \sim 15 \frac{M_{SUSY}^2 T^6}{M_{pl}^2 m_{\tilde{G}}^2}$
prob rate / vol

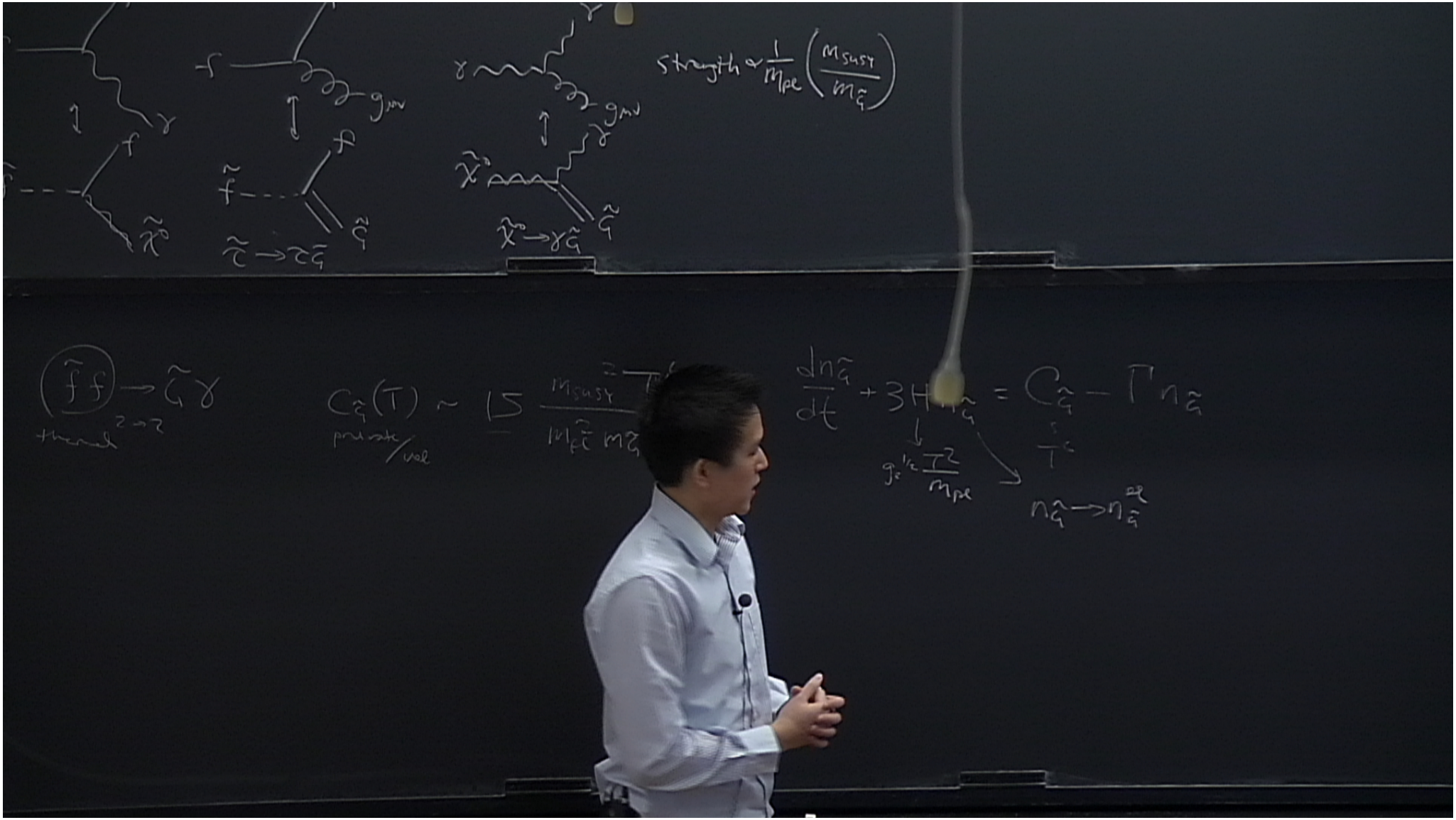

strength $\propto \frac{1}{M_{pl}} \left(\frac{M_{susy}}{m_{\tilde{G}}}\right)$
$\tilde{f}f \to \tilde{G}\gamma$
thermal
$2 \to 2$
$C_{\tilde{G}}(T) \sim$
$\frac{dn_{\tilde{G}}}{dt}$ +

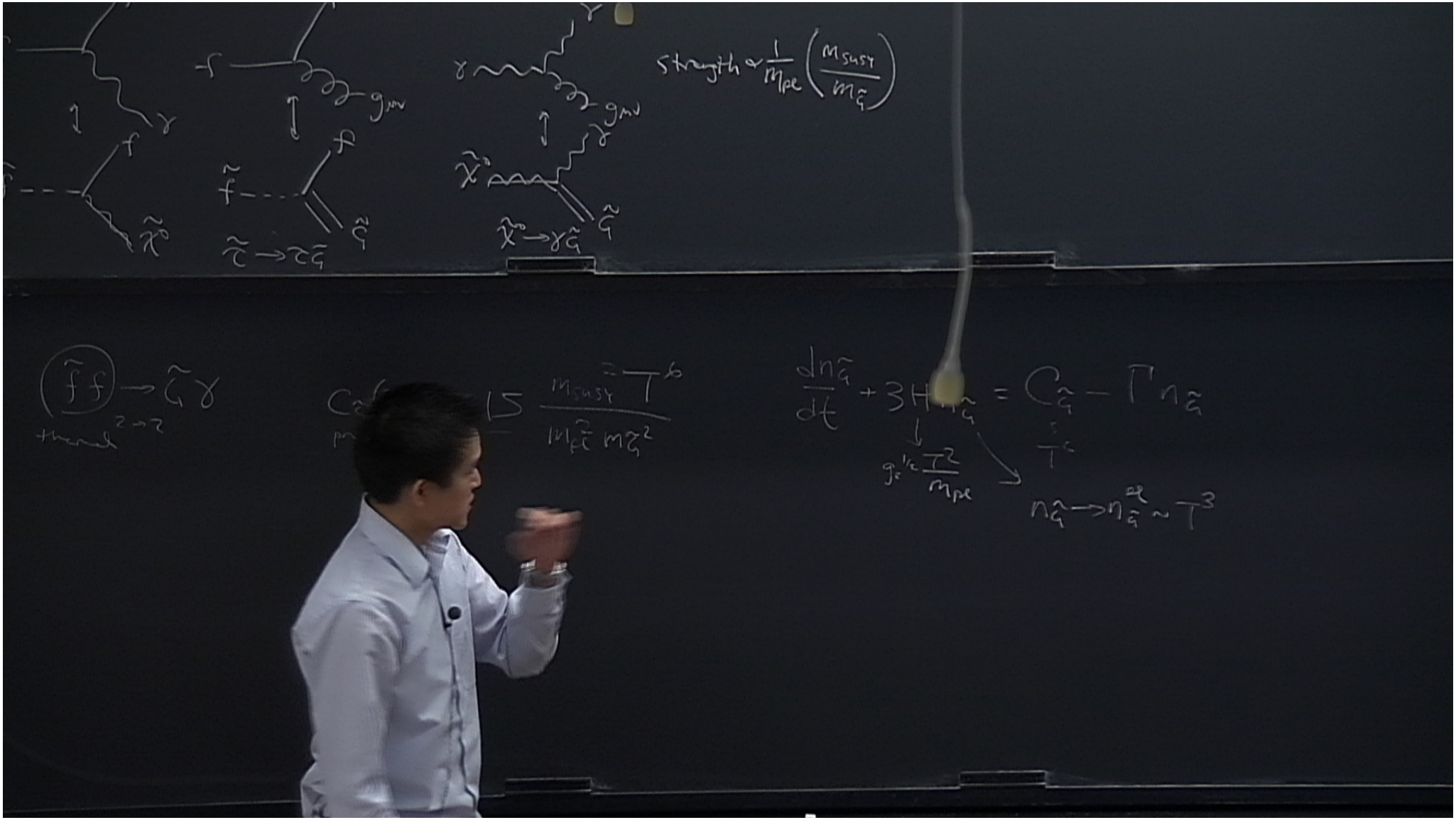

$\tilde{f} \to f \tilde{\chi}^0$
$\tilde{f} \to \tilde{c} \bar{c}$
$\tilde{\chi}^0 \to \gamma \tilde{G}$
$\tilde{f}\tilde{f} \to \tilde{G}\gamma$
$C_{\tilde{G}}(T) \sim 15 \frac{M_{reduced}}{M_{Pl}^2 m_{\tilde{G}}^2} T^6$
$+3H n_{\tilde{G}} = C_{\tilde{G}}$

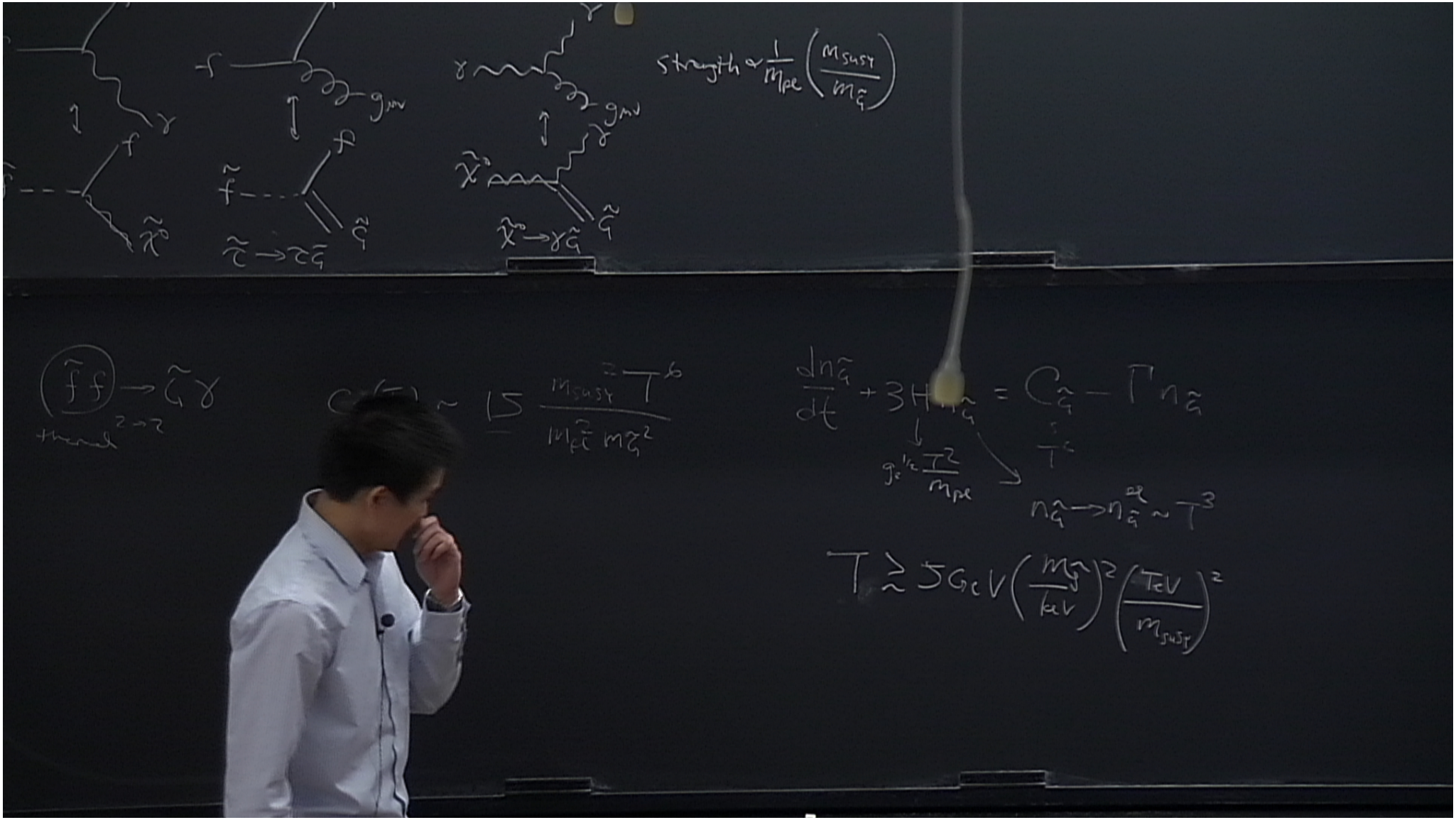

$\tilde{f}\tilde{f} \to \tilde{G}\gamma$
$C_{\tilde{G}}(T) \sim 15 \frac{M_{susy}}{M_{\tilde{F}} m_{\tilde{G}}^2} T^6$
$\frac{dn_{\tilde{G}}}{dt} + 3Hn_{\tilde{G}} = C_{\tilde{G}} - \Gamma n_{\tilde{G}}$
$\tilde{f} \to f \tilde{\chi}^0$
$\tilde{f} \to f \tilde{G}$
$\tilde{\tau} \to \tau \tilde{G}$
$\tilde{\chi}^0 \to \gamma \tilde{G}$

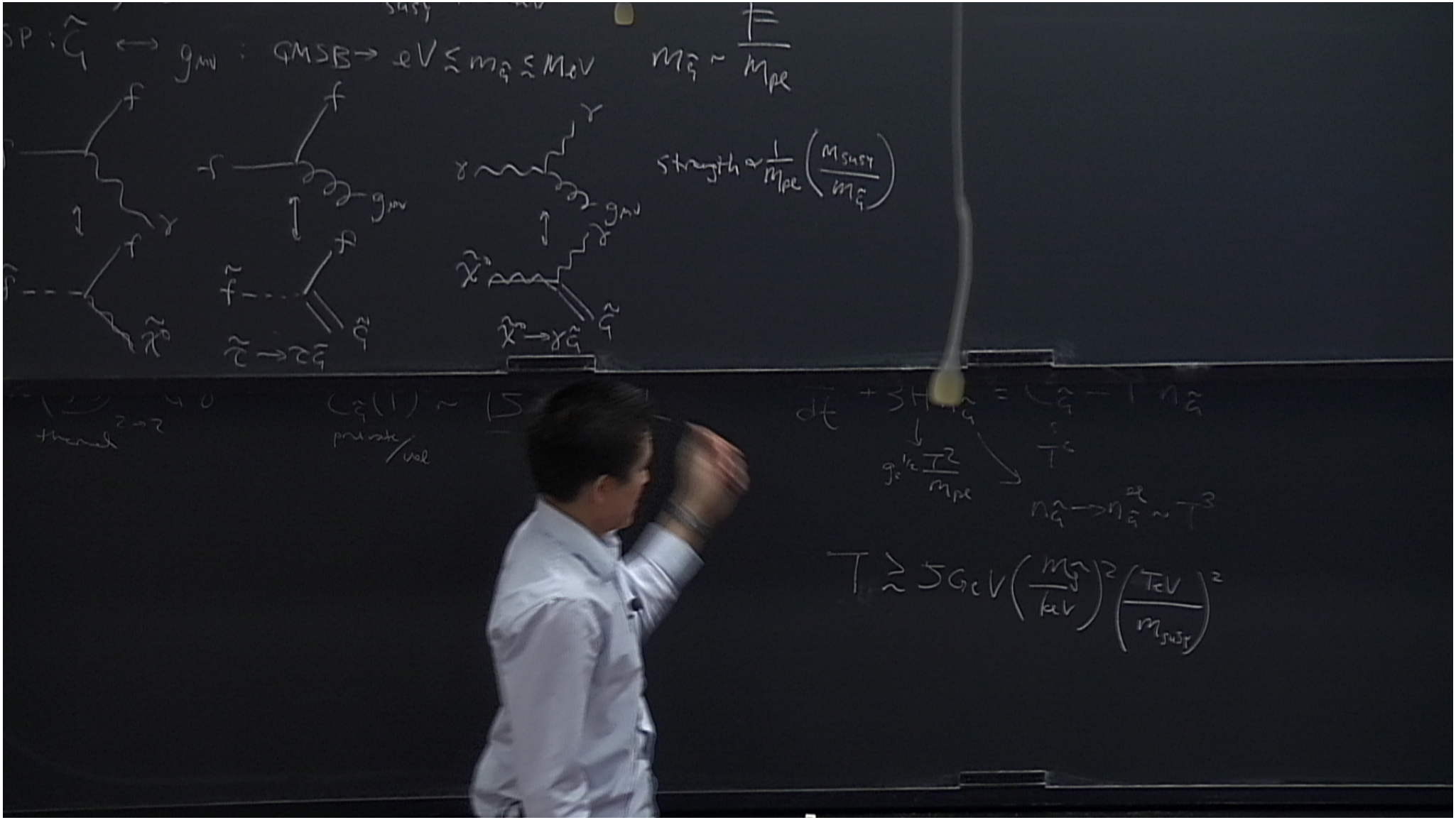

strength $\propto \frac{1}{M_{pl}} \left(\frac{M_{susy}}{m_{\tilde{G}}} \right)$
$\tilde{f}f \to \tilde{G}\gamma$
$C_{\tilde{G}}(T) \sim 15 \frac{M_{susy}^2 T^6}{M_{pl}^2 m_{\tilde{G}}^2}$
$\frac{dn_{\tilde{G}}}{dt} + 3H n_{\tilde{G}} = C_{\tilde{G}} - \Gamma n_{\tilde{G}}$

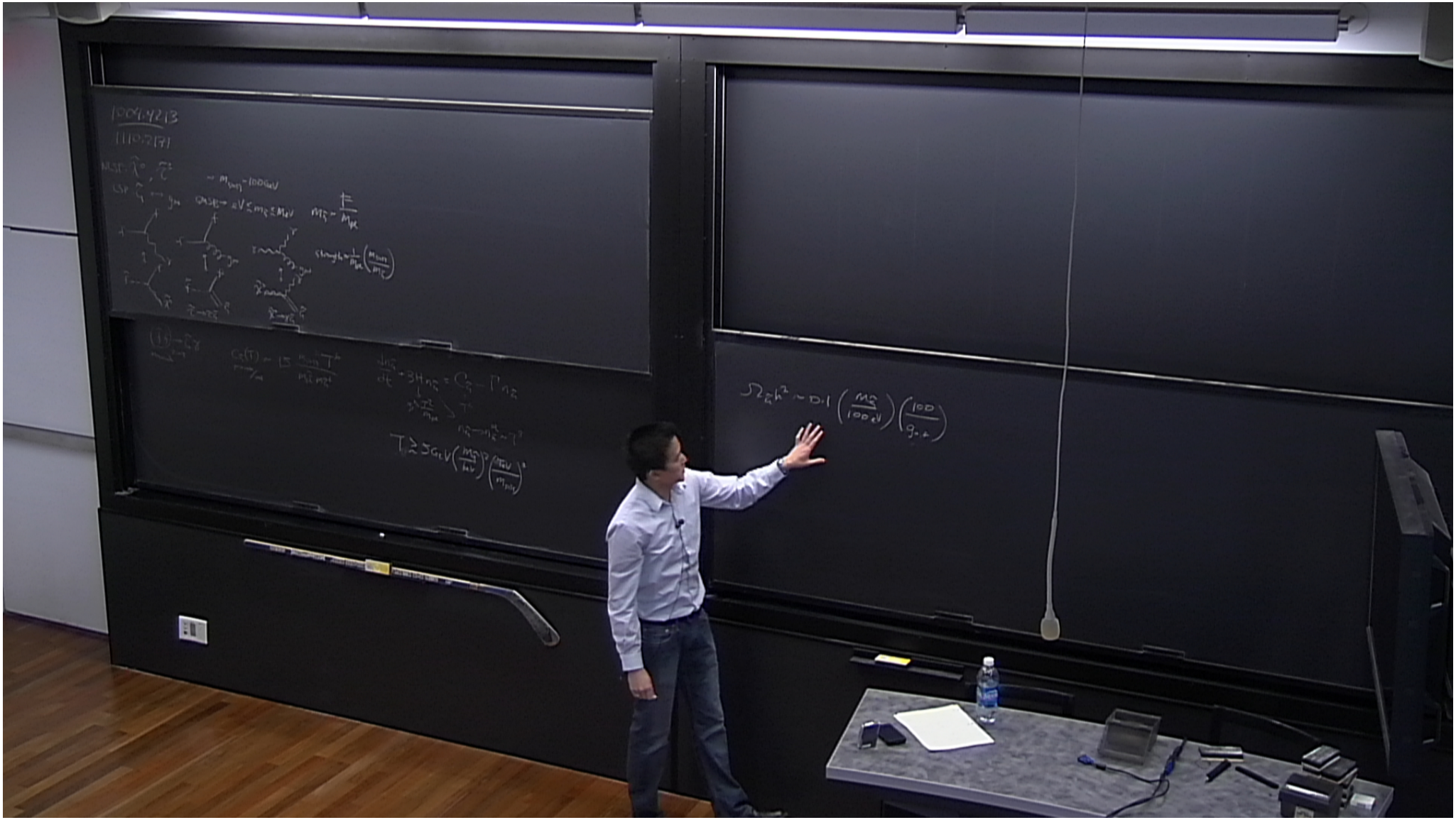

strength $\propto \frac{1}{m_{pl}}\left(\frac{m_{susy}}{m_{\tilde{q}}}\right)$
$\tilde{f}f \to \tilde{G}\gamma$
$\frac{dn_{\tilde{G}}}{dt} + 3Hn_{\tilde{G}} = C_{\tilde{G}} - \Gamma n_{\tilde{G}}$

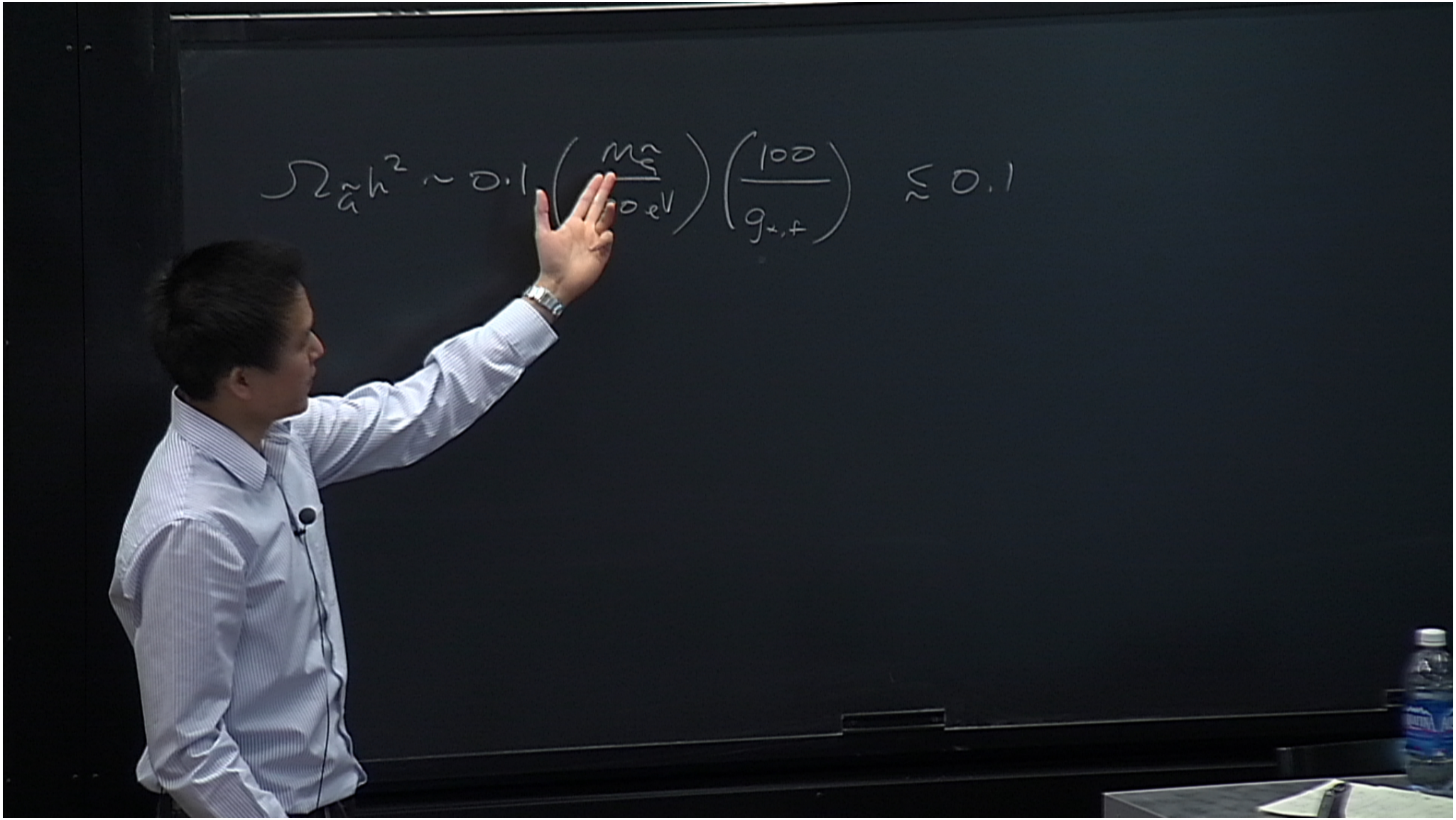

strength $\propto \frac{1}{m_{pl}}\left(\frac{m_{susy}}{m_{\tilde{q}}}\right)$
$\tilde{f}f \to \tilde{G}\gamma$
thermal
$2 \to 2$
$C_{\tilde{q}}(T) \sim 15 \frac{m_{susy}}{m_{\tilde{f}\tilde{f}} m_{\tilde{q}}}$
prob rate / vol
$\frac{dn_{\tilde{q}}}{dt} + 3Hn_{\tilde{q}} = C_{\tilde{q}} - \Gamma n_{\tilde{q}}$
$g_*^{1/2}\frac{T^2}{m_{pl}}$
T^5
$n_{\tilde{q}} \to n_{\tilde{q}}^{eq}$

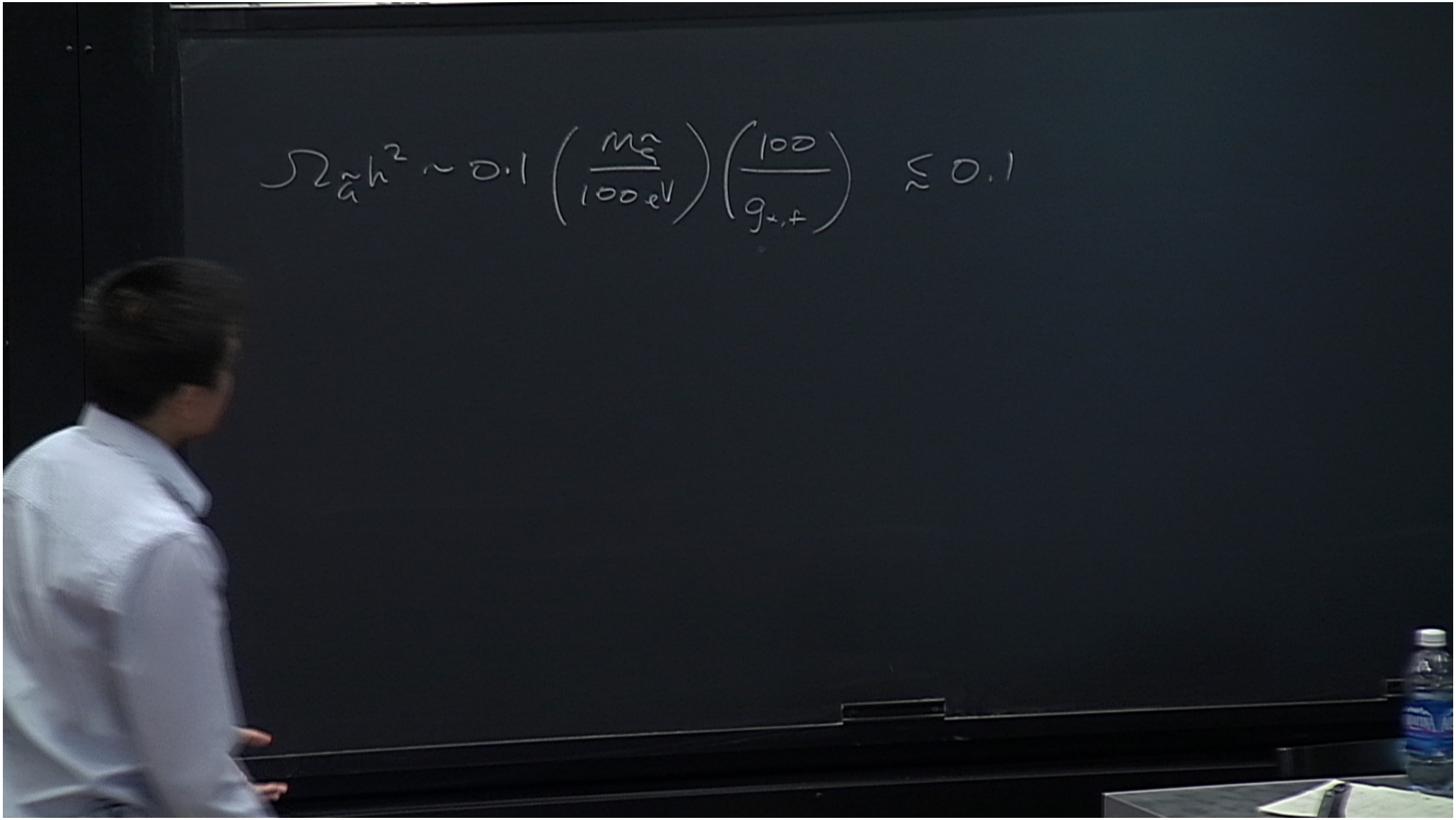

strength $\propto \frac{1}{m_{pl}}\left(\frac{m_{susy}}{m_{\tilde{G}}}\right)$
$\tilde{f}f \to \tilde{G}\gamma$
$\frac{dn_{\tilde{G}}}{dt} + 3Hn_{\tilde{G}} = C_{\tilde{G}} - \Gamma n_{\tilde{G}}$
$n_{\tilde{G}} \to n_{\tilde{G}}^{eq} \sim T^3$

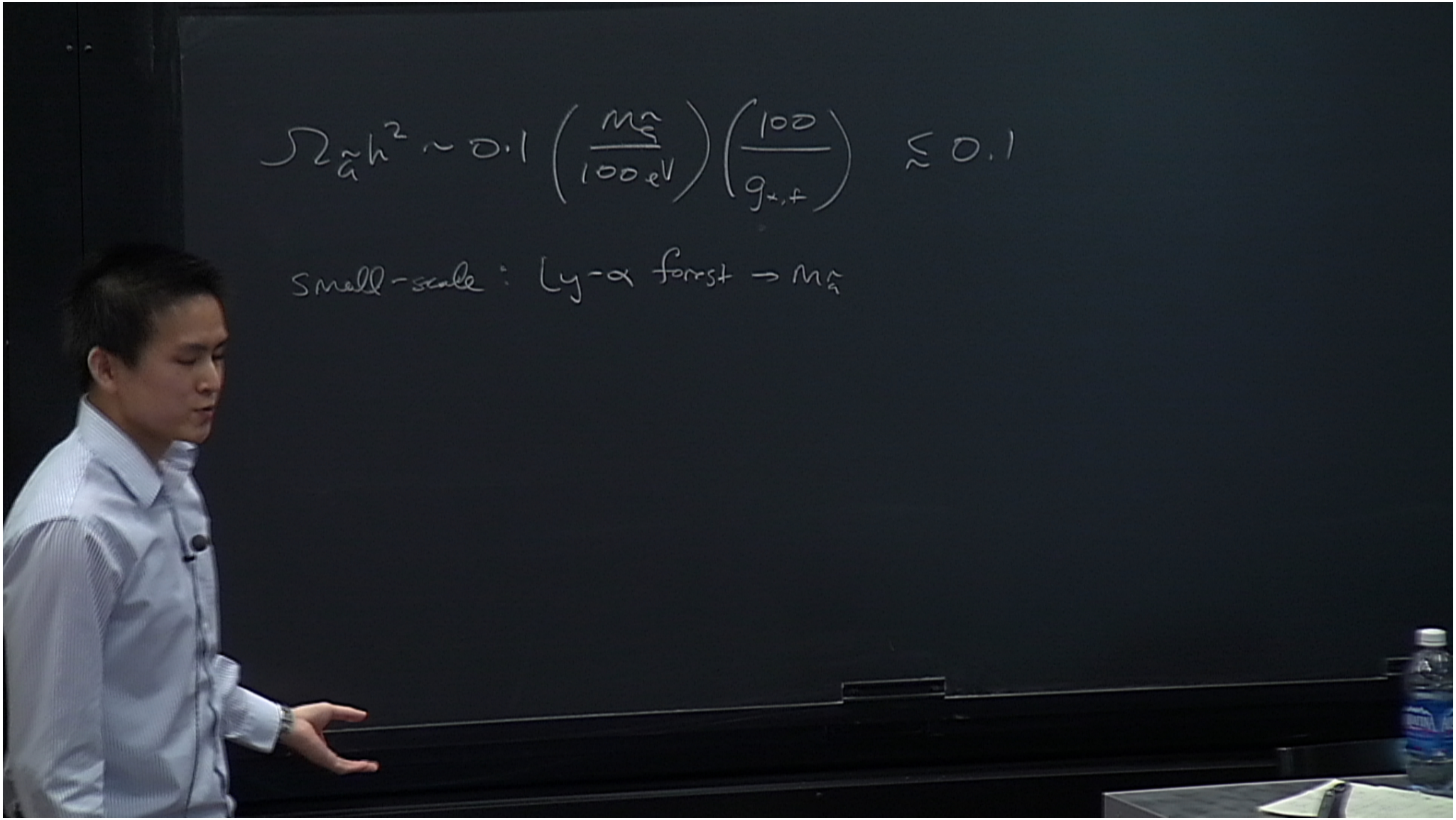

strength $\propto \frac{1}{m_{pl}}\left(\frac{m_{susy}}{m_{\tilde{G}}}\right)$
$\tilde{f}f \to \tilde{G}\gamma$
$\frac{dn_{\tilde{G}}}{dt} + 3Hn_{\tilde{G}} = C_{\tilde{G}} - \Gamma n_{\tilde{G}}$
$g_* \sim \frac{T^2}{m_{pl}}$
$n_{\tilde{G}} \to n_{\tilde{G}}^{eq} \sim T^3$
$T \gtrsim 5\,GeV\left(\frac{m_{\tilde{G}}}{keV}\right)^2\left(\frac{TeV}{m_{susy}}\right)^2$

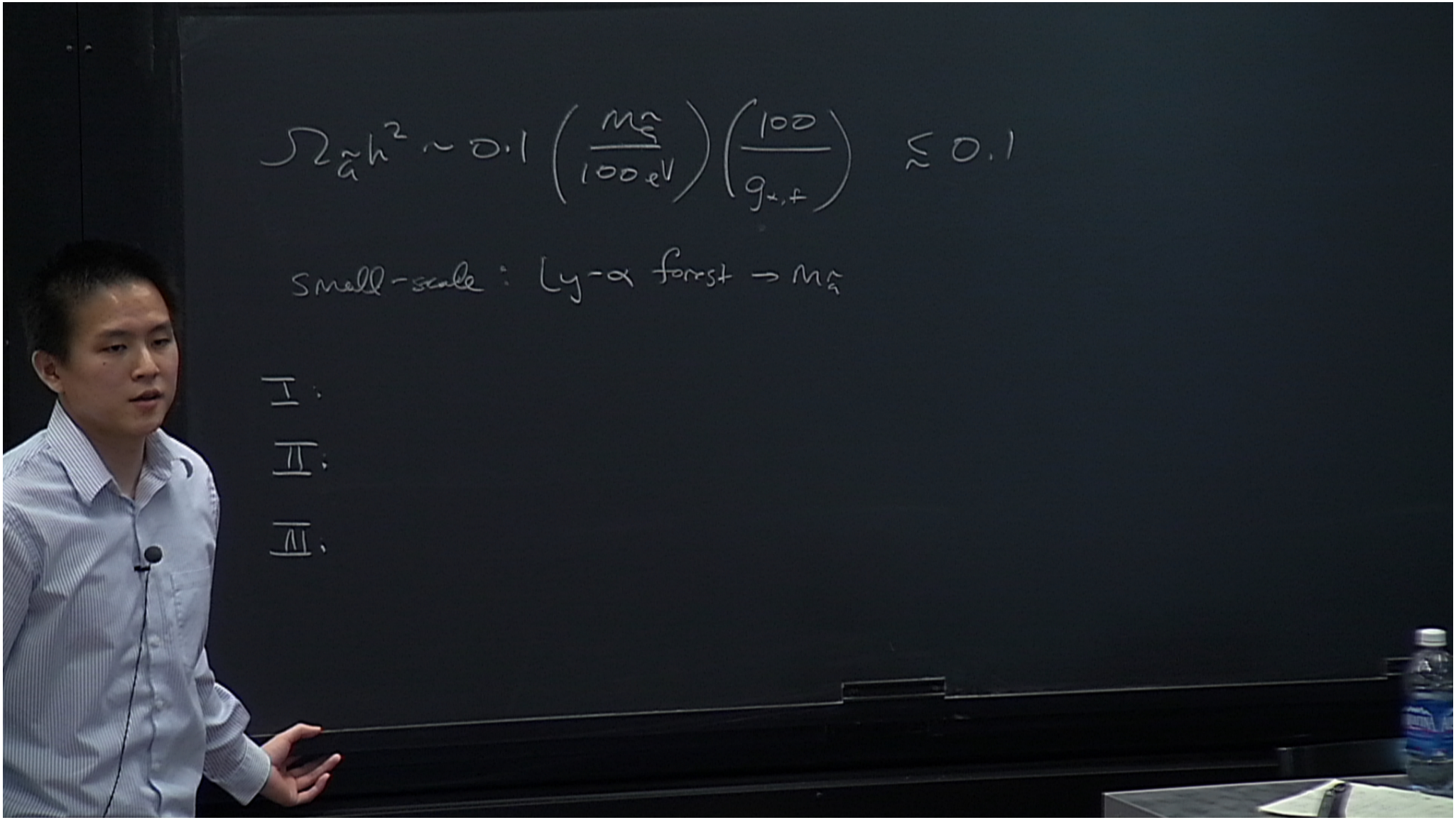

$\tilde{G}$: $g_{\mu\nu}$: GMSB → eV ≲ $m_{\tilde{G}}$ ≲ MeV
$m_{\tilde{G}} \sim \frac{F}{M_{Pl}}$
strength ∼ $\frac{1}{M_{Pl}}\left(\frac{M_{SUSY}}{m_{\tilde{G}}}\right)$
$\tilde{\chi}^0 \to \gamma\tilde{G}$
$\tilde{\tau} \to \tau\tilde{G}$
$g_c^{1/2}\frac{T^2}{M_{Pl}}$
$T \gtrsim 5\,GeV\left(\frac{m_{\tilde{G}}}{keV}\right)^2\left(\frac{TeV}{M_{SUSY}}\right)^2$

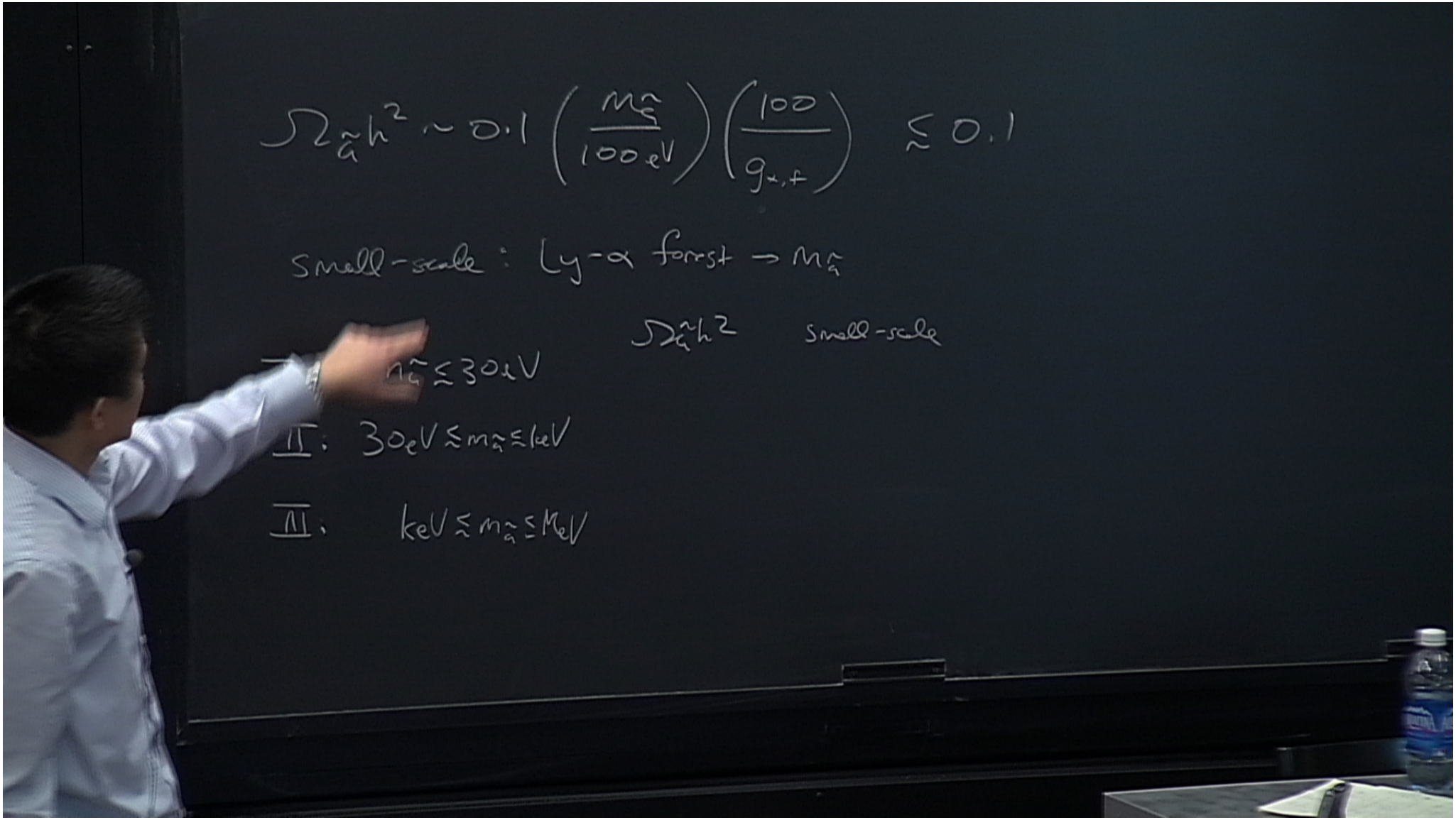

$\Omega_{\tilde{\chi}} h^2 \sim 0.1 \left(\frac{m_{\tilde{\chi}}}{100\,\mathrm{GeV}}\right)\left(\frac{100}{g_*}\right)$


$\Omega_{\tilde{a}} h^2 \sim 0.1 \left(\frac{m_{\tilde{a}}}{10\,eV}\right)\left(\frac{100}{g_{*,f}}\right) \lesssim 0.1$


$\Omega_{\tilde{G}} h^2 \sim 0.1 \left(\frac{m_{\tilde{G}}}{100\,\mathrm{eV}}\right)\left(\frac{100}{g_{*,f}}\right) \lesssim 0.1$


$\Omega_{\tilde{G}} h^2 \sim 0.1 \left(\frac{m_{\tilde{G}}}{100\,\mathrm{eV}}\right)\left(\frac{100}{g_{*,f}}\right) \lesssim 0.1$
small-scale: Ly-α forest → $m_{\tilde{G}}$


$\Omega_{\tilde{G}} h^2 \sim 0.1 \left(\frac{m_{\tilde{G}}}{100\,eV}\right)\left(\frac{100}{g_{*,f}}\right) \lesssim 0.1$
small-scale: Ly-α forest → $m_{\tilde{G}}$
I:
II:
III:


$\Omega_{\tilde{a}} h^2 \sim 0.1 \left(\frac{m_{\tilde{a}}}{100\,eV}\right)\left(\frac{100}{g_{*,f}}\right) \lesssim 0.1$
small-scale : Ly-α forest → $m_{\tilde{a}}$
$\Omega_{\tilde{a}} h^2$ small-scale
I: $m_{\tilde{a}} \lesssim 30\,eV$
II: $30\,eV \lesssim m_{\tilde{a}} \lesssim keV$
III. $keV \lesssim m_{\tilde{a}} \lesssim MeV$

$$\Omega_{\tilde{a}} h^2 \sim 0.1 \left(\frac{m_{\tilde{a}}}{100\,eV}\right)\left(\frac{100}{g_{*,f}}\right) \lesssim 0.1$$

small-scale: Ly-α forest $\rightarrow m_{\tilde{a}}$

$\Omega_{\tilde{a}} h^2$ small-scale

I: $eV \lesssim m_{\tilde{a}} \lesssim 30\,eV$ $\sqrt{}$ ~% DM

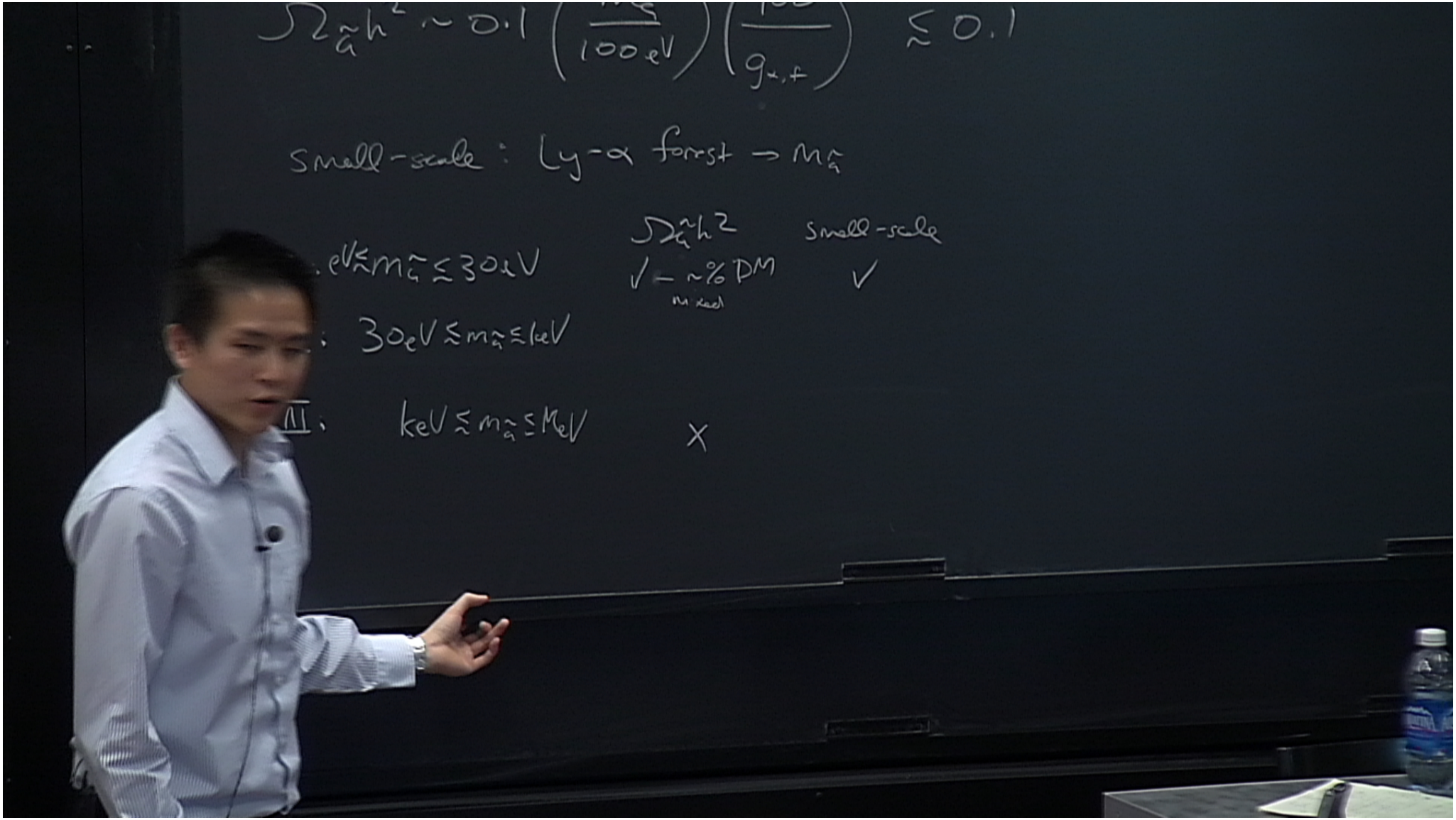
II: $30\,eV \lesssim m_{\tilde{a}} \lesssim keV$

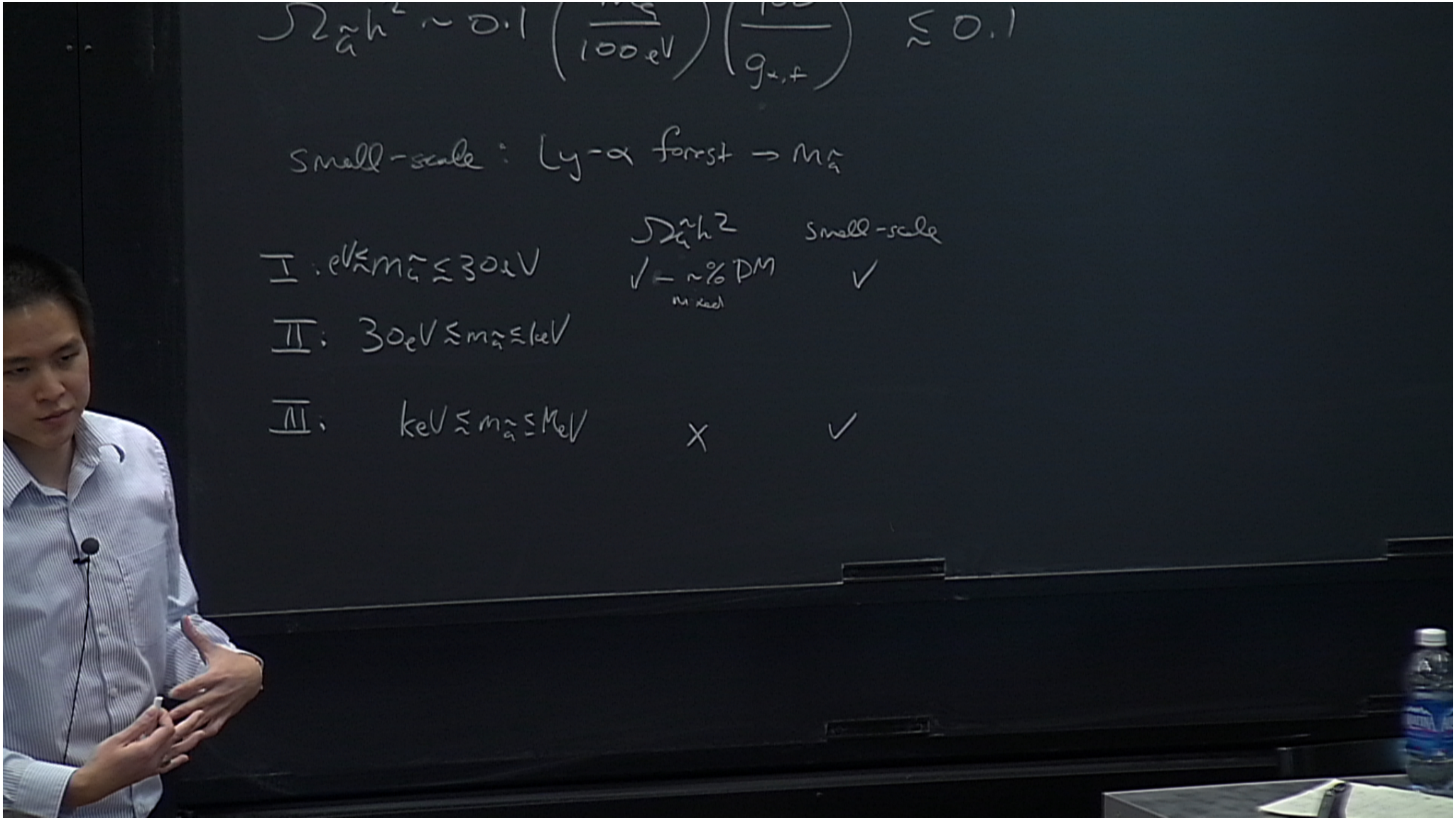
III: $keV \lesssim m_{\tilde{a}} \lesssim MeV$

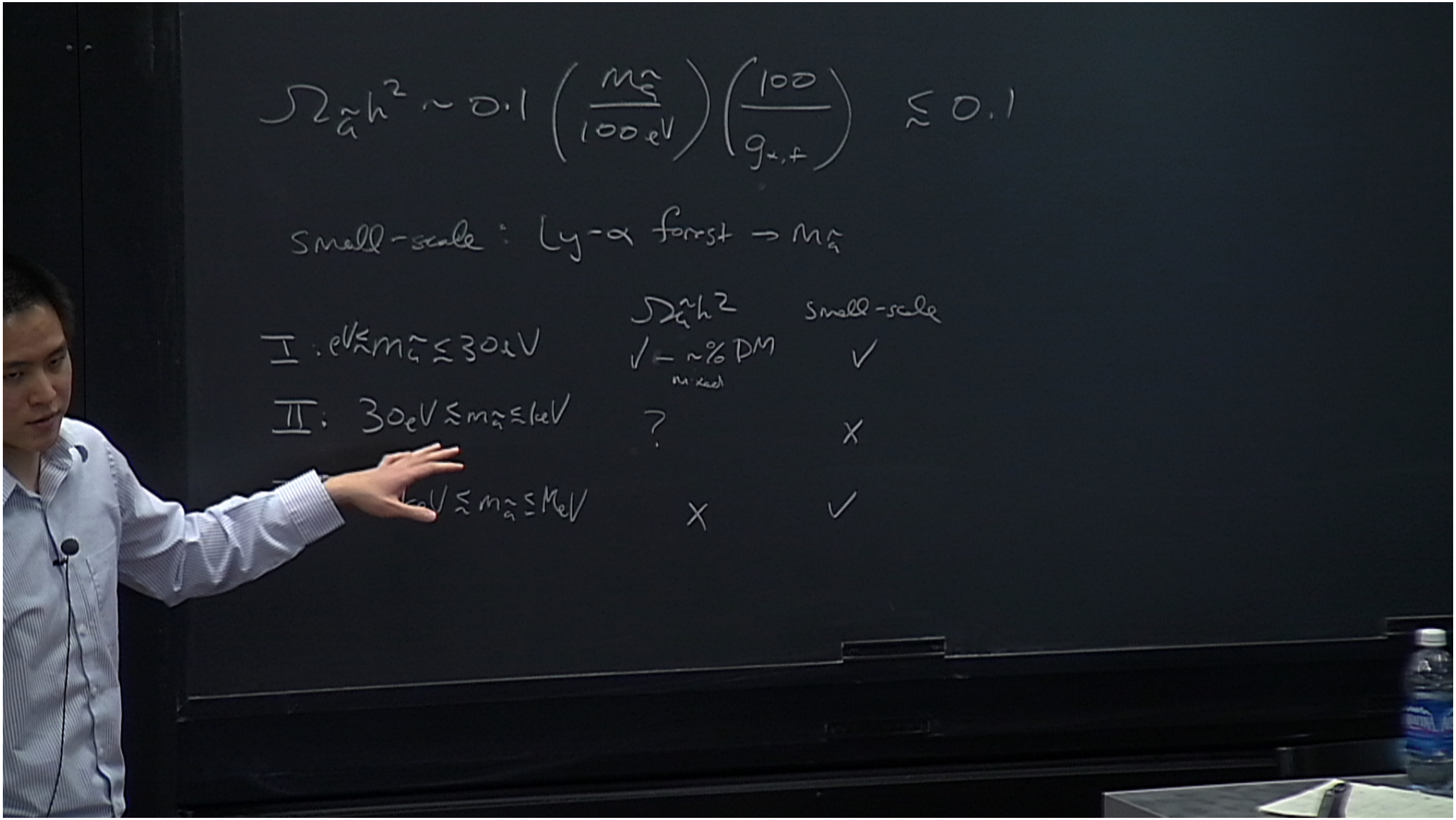
$$\Omega_{\tilde{a}} h^2 \sim 0.1 \left(\frac{m_{\tilde{a}}}{100\,eV}\right)\left(\frac{100}{g_{*,f}}\right) \lesssim 0.1$$

small-scale: Ly-α forest $\rightarrow m_{\tilde{a}}$

	$\Omega_{\tilde{a}} h^2$	small-scale
I: $eV \lesssim m_{\tilde{a}} \lesssim 30\,eV$	✓ — $\sim$% DM (no need)	✓
II: $30\,eV \lesssim m_{\tilde{a}} \lesssim keV$		
III: $keV \lesssim m_{\tilde{a}} \lesssim MeV$		

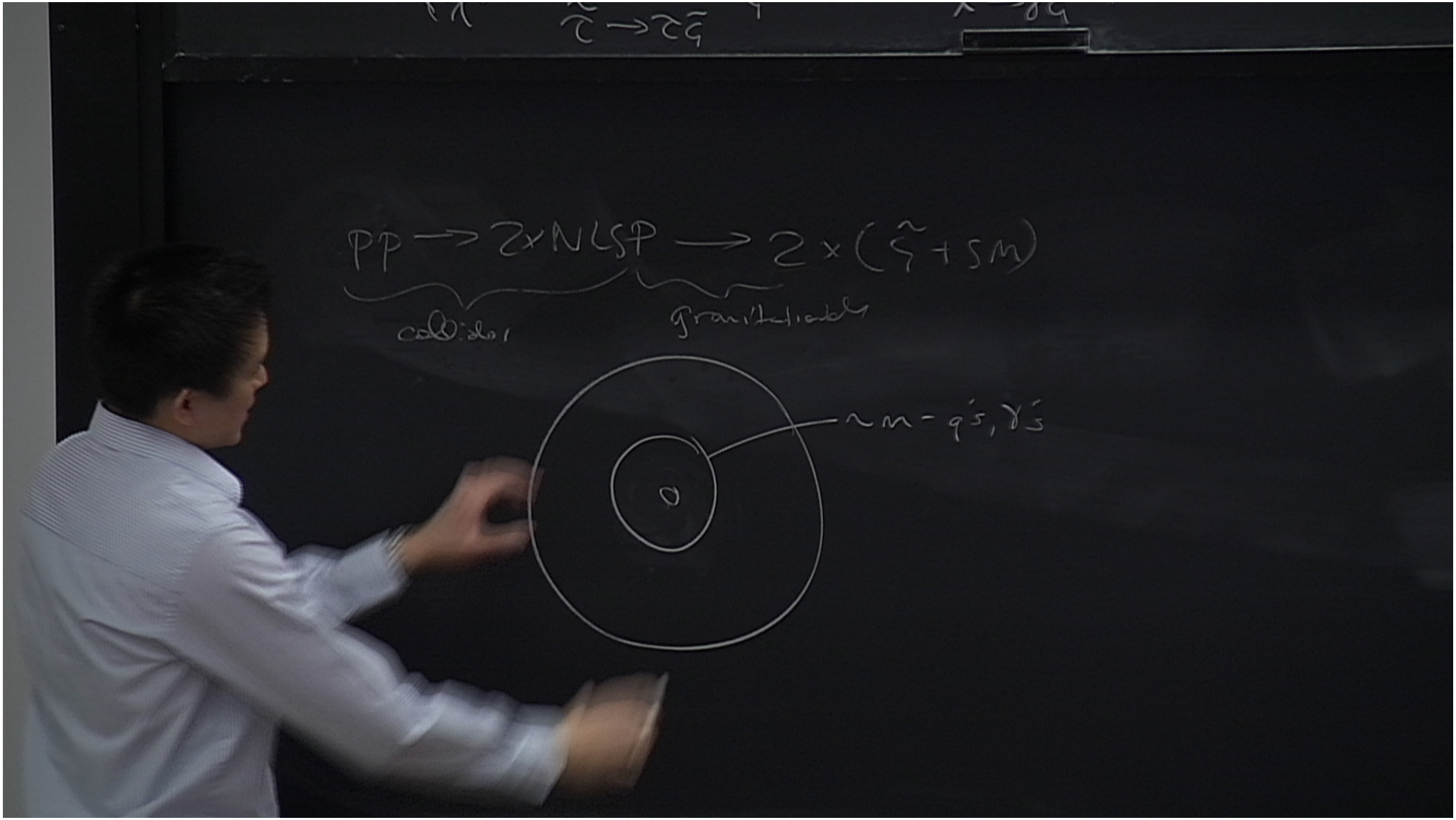

small-scale : Ly-α forest → $m_{\tilde{a}}$
$\Omega_{\tilde{a}}h^2$ small-scale
✓ ~% DM ✓
mixed
keV ≲ $m_{\tilde{a}}$ ≲ 30 eV
30 eV ≲ $m_{\tilde{a}}$ ≲ keV
keV ≲ $m_{\tilde{a}}$ ≲ MeV
×

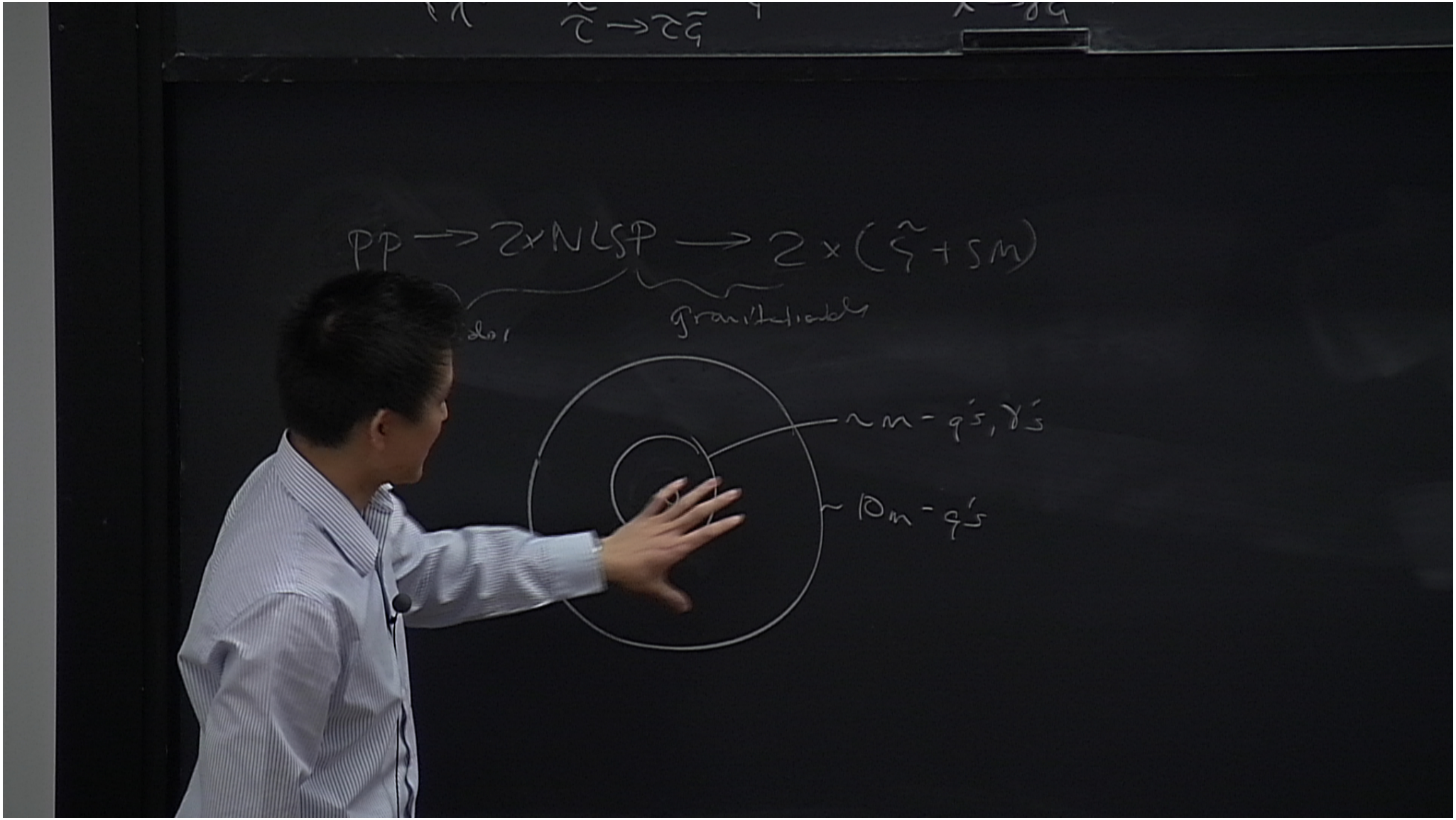

small-scale : Ly-α forest → $m_{\tilde{a}}$
$\Omega_{\tilde{a}}h^2$ small-scale
I. $eV \lesssim m_{\tilde{a}} \lesssim 30eV$ ✓ ~% DM ✓
mixed
II. $30eV \lesssim m_{\tilde{a}} \lesssim keV$
III. $keV \lesssim m_{\tilde{a}} \lesssim MeV$ ✗ ✓

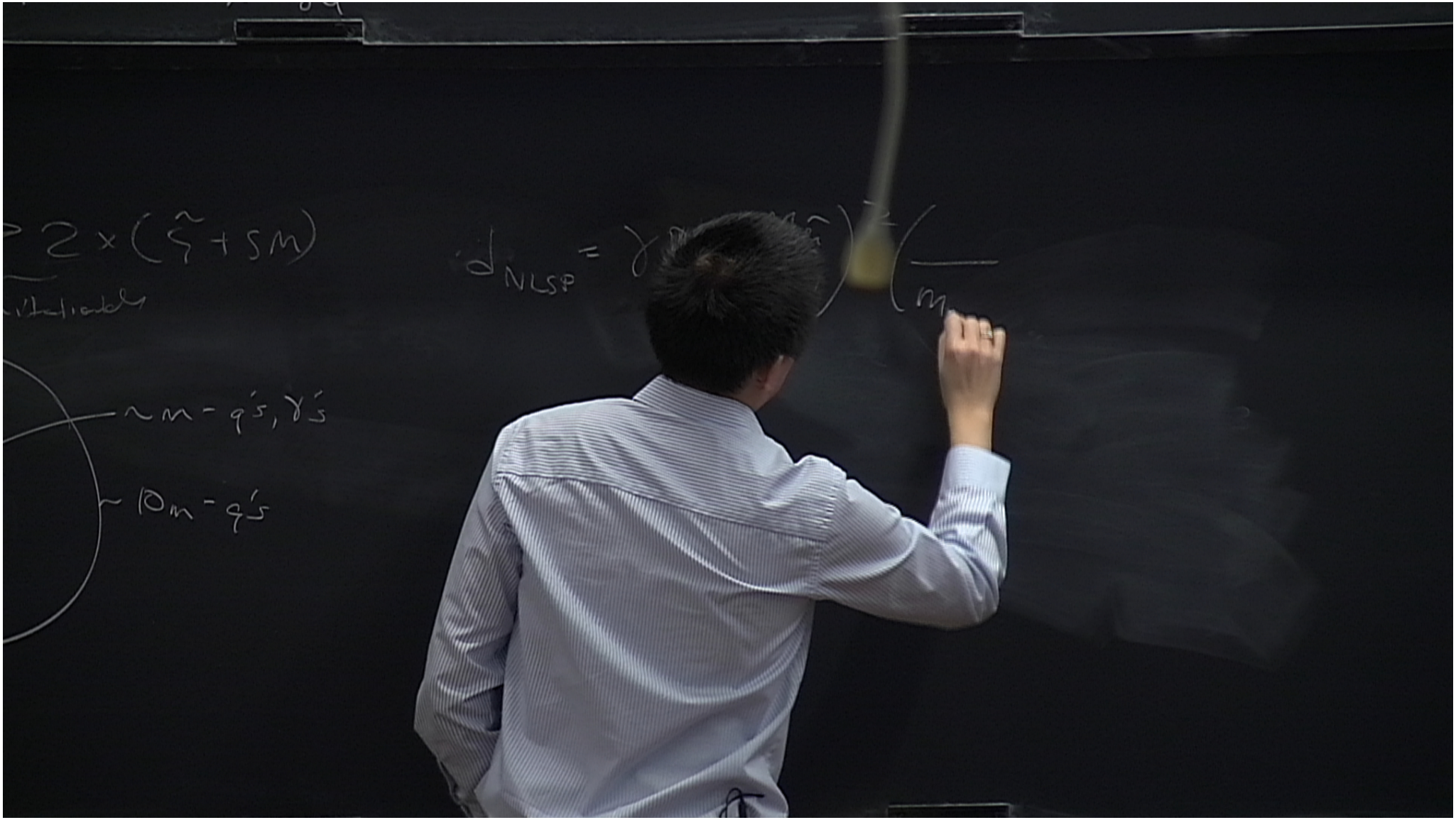

$\Omega_{\tilde{a}} h^2 \sim 0.1 \left(\frac{m_{\tilde{a}}}{100\,eV}\right)\left(\frac{100}{g_{*,f}}\right) \lesssim 0.1$
small-scale: Ly-α forest → $m_{\tilde{a}}$
$\Omega_{\tilde{a}} h^2$ small-scale
I: $eV \lesssim m_{\tilde{a}} \lesssim 30\,eV$ ✓ – ~% DM (mixed) ✓
II: $30\,eV \lesssim m_{\tilde{a}} \lesssim keV$? ×
$keV \lesssim m_{\tilde{a}} \lesssim MeV$ × ✓

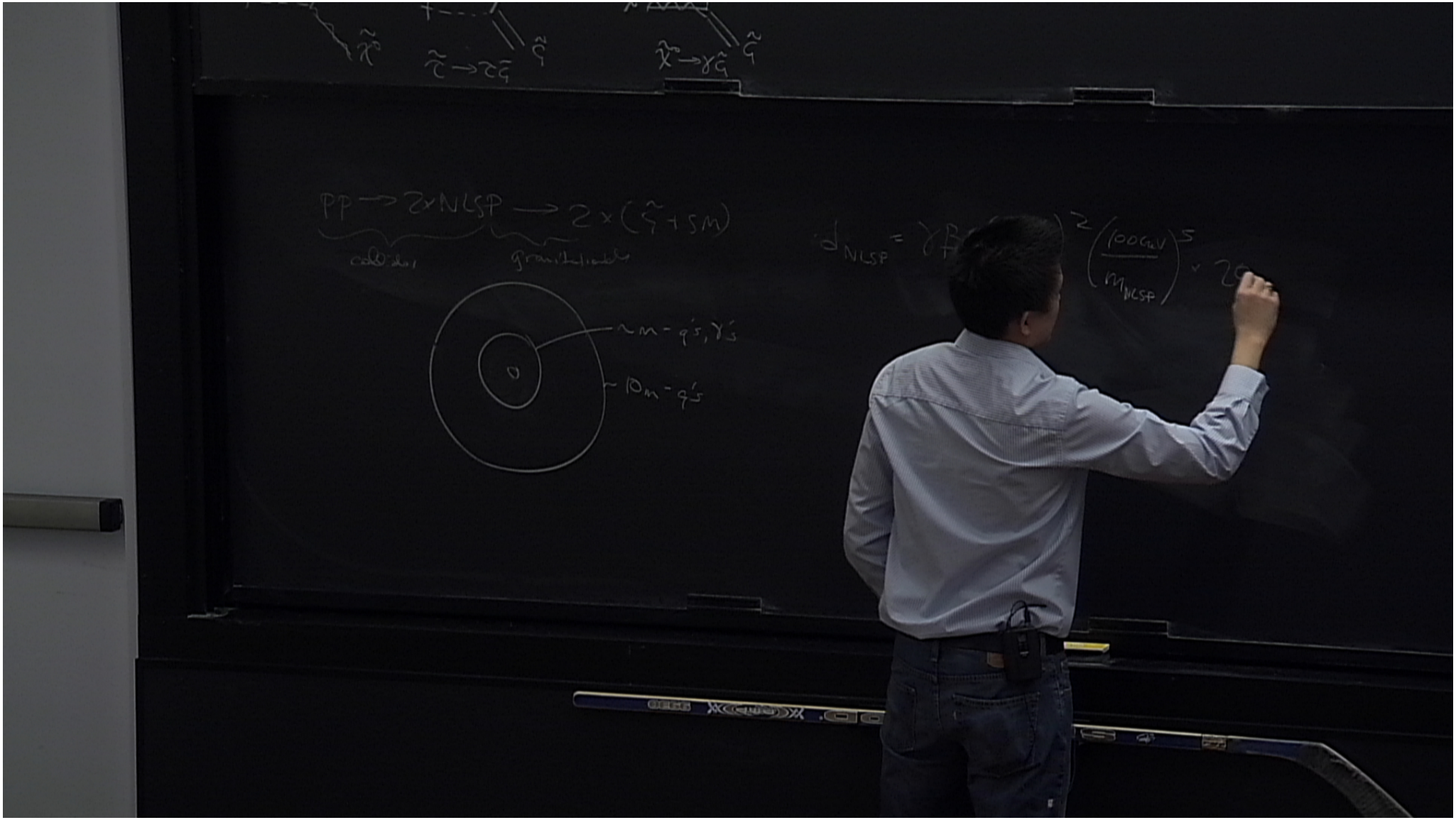

pp → 2×NLSP


$\tilde{\tau} \to \tau \tilde{G}$
$pp \to 2 \times NLSP \to 2 \times (\tilde{G} + SM)$
collider
gravitinos
0

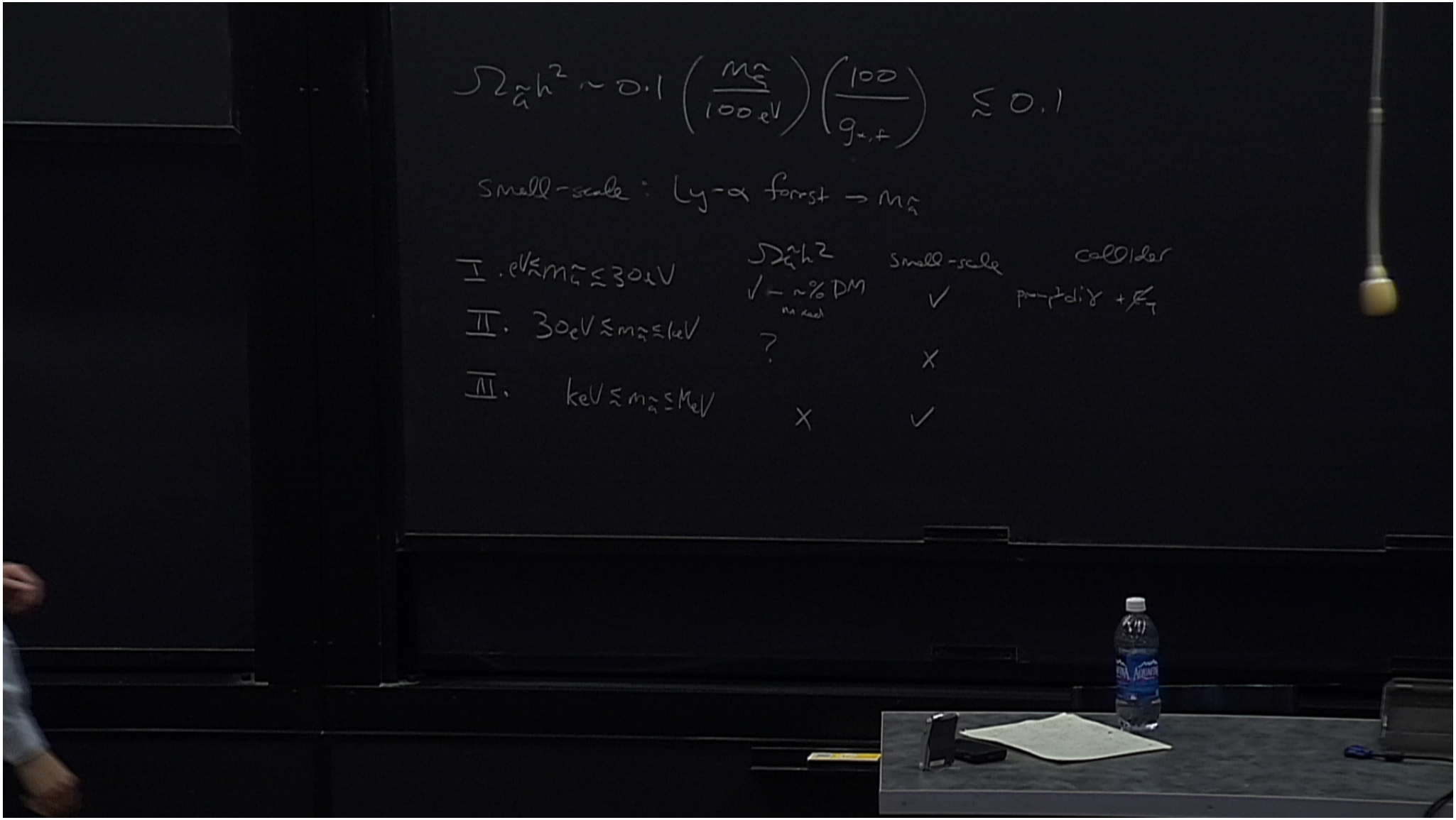

$\tilde{\tau} \to \tau \tilde{G}$
$pp \to 2 \times NLSP \to 2 \times (\tilde{G} + SM)$
collider
gravitational
$\sim m - q^5, \gamma^5$

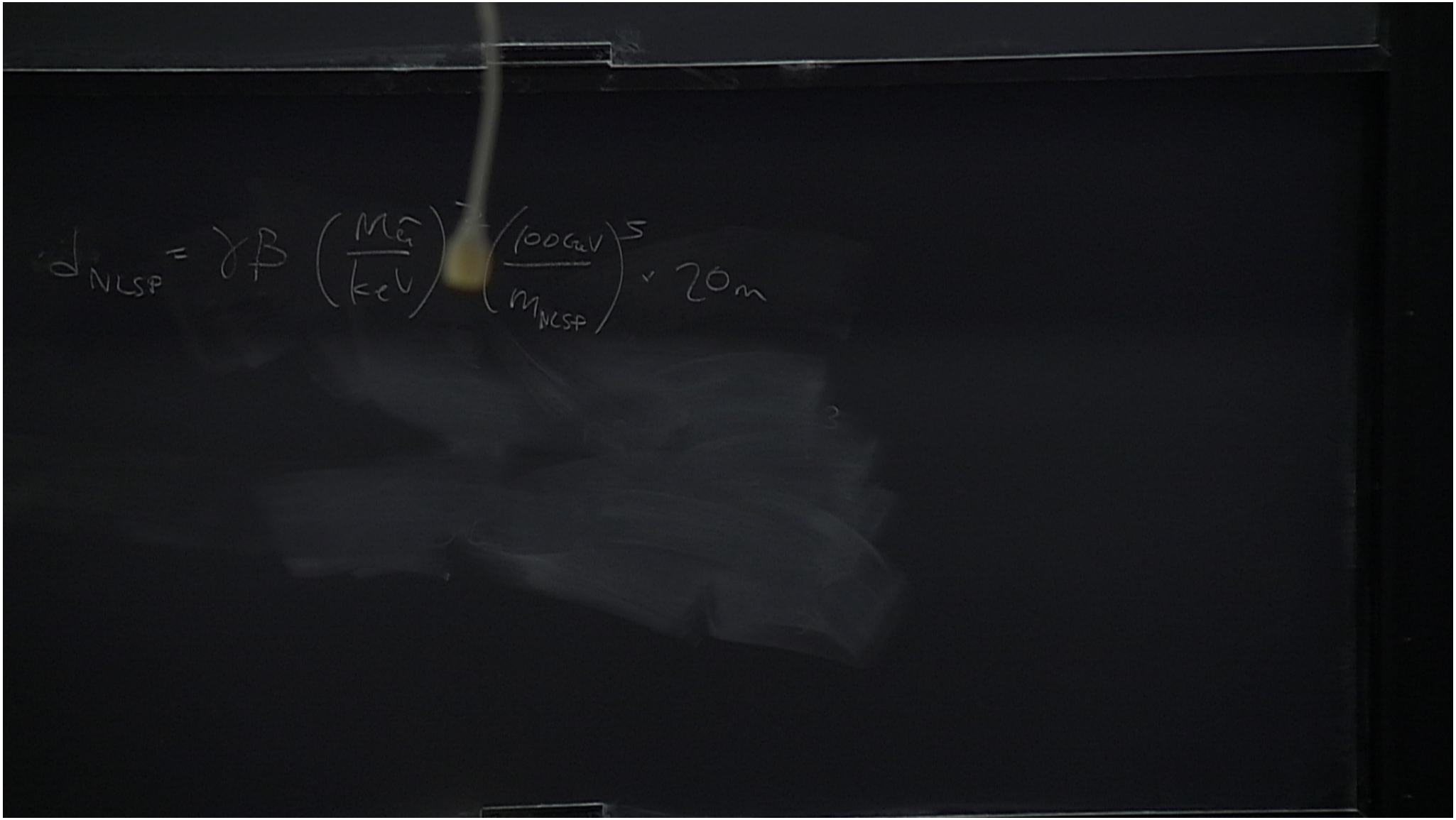

$\tilde{\tau} \to \tau \tilde{G}$
$PP \to 2 \times NLSP \to 2 \times (\tilde{\chi} + SM)$
gravitationally
$\sim m - q's, \gamma's$
$\sim 10m - q's$


$\sim M - q's, \gamma's$
$\sim 10m - q's$
$d_{NLSP} =$


$\tilde{\chi}^0$
$\tilde{\tau} \to \tau\tilde{G}$
$\tilde{q}$
$\tilde{\chi}^0 \to \gamma\tilde{G}$
$\tilde{G}$
$PP \to 2 \times NLSP \to 2 \times (\tilde{G} + SM)$
collider
gravitino
$\sim M - q's, \gamma's$
$\sim Pm - q's$
$d_{NLSP} =$
$\left(\frac{100 GeV}{m_{NLSP}}\right)^5$


π^0
$\tilde{\tau} \to \tau\tilde{G}$
$\chi \to \gamma G$
$PP \to 2 \times NLSP \to 2 \times (\tilde{G} + SM)$
gravitational
$\sim m - q^5, \gamma^5$
$\sim Dm - q^5$


$\Omega_{\tilde{a}} h^2 \sim 0.1 \left(\frac{m_{\tilde{a}}}{100\,eV}\right)\left(\frac{100}{g_{a\gamma}}\right) \lesssim 0.1$
small-scale: Ly-α forest → $m_{\tilde{a}}$
I. $eV \lesssim m_{\tilde{a}} \lesssim 30\,eV$
II. $30\,eV \lesssim m_{\tilde{a}} \lesssim keV$
III. $keV \lesssim m_{\tilde{a}} \lesssim MeV$
$\Omega_{\tilde{a}} h^2$
small-scale
collider
✓ – ~% DM
mixed
✓
prompt γ + $\not{E}_T$
?
×
×
✓


$d_{NLSP} = \gamma\beta \left(\frac{M_{\tilde{G}}}{keV}\right)^2 \left(\frac{100\,GeV}{m_{NLSP}}\right)^5 \times 20m$

$\tilde{\tau} \to \tau \tilde{G}$

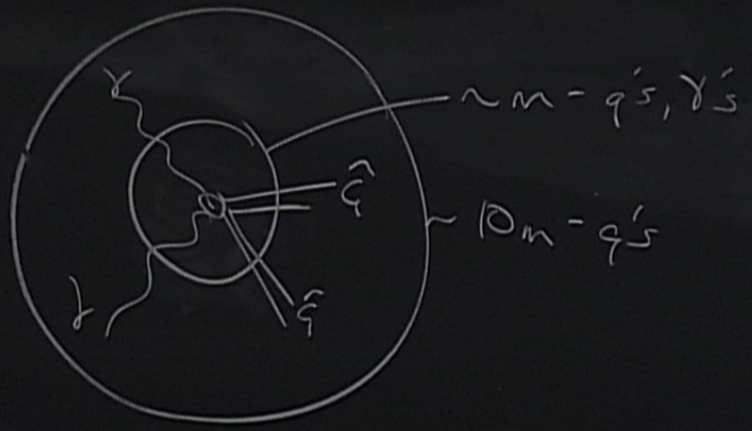
$\tilde{\chi}^0 \to \gamma \tilde{G}$

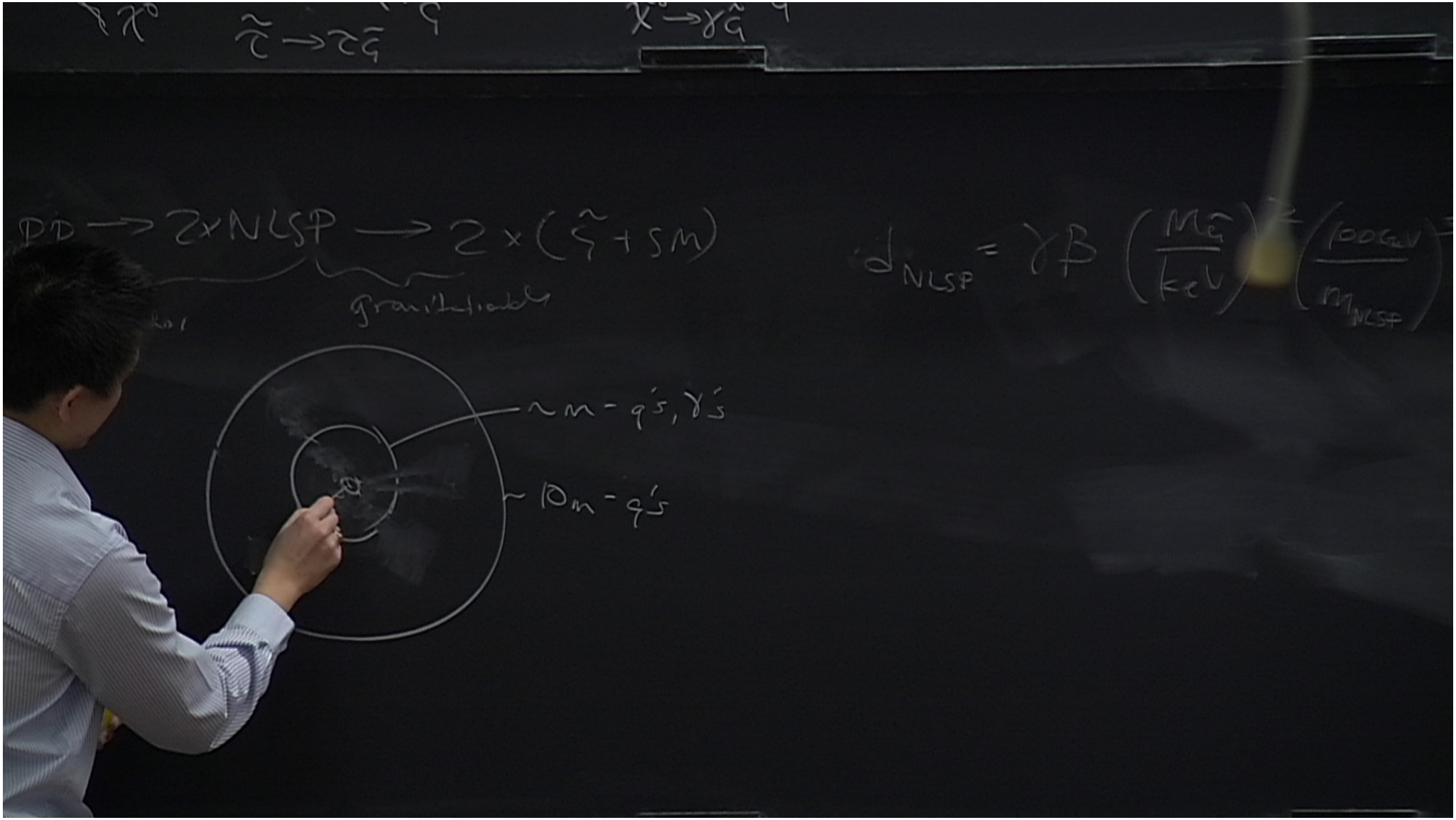
$pp \to 2 \times NLSP \to 2 \times (\tilde{G} + SM)$

collider

gravitationally

$d_{NLSP} = \gamma \beta \left(\frac{M_{\tilde{G}}}{keV}\right)$




$\tilde{\tau} \to \tau \tilde{G}$
$\chi^0 \to \gamma \tilde{G}$
$PP \to 2 \times NLSP \to 2 \times (\tilde{\chi} + SM)$
gravitationally
$d_{NLSP} = \gamma \beta \left(\frac{M_{\tilde{G}}}{keV}\right)^2 \left(\frac{100 GeV}{m_{NLSP}}\right)^5$
$\sim m - q's, \gamma's$
$\sim 10m - q's$

$\tilde{\tau} \to \tau \tilde{G}$

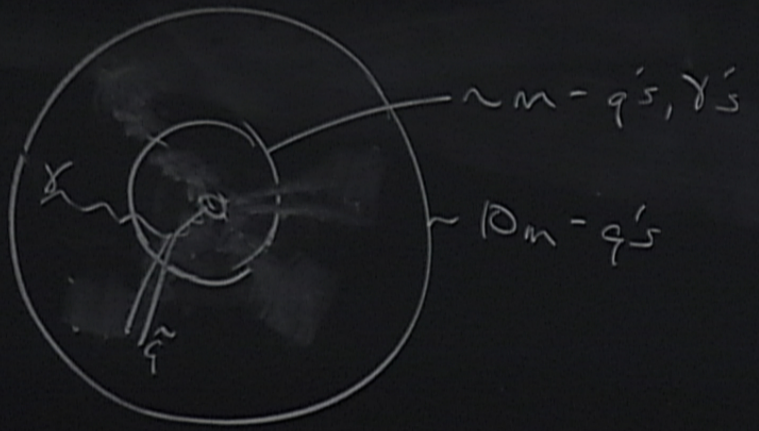
$\chi^0 \to \gamma \tilde{G}$

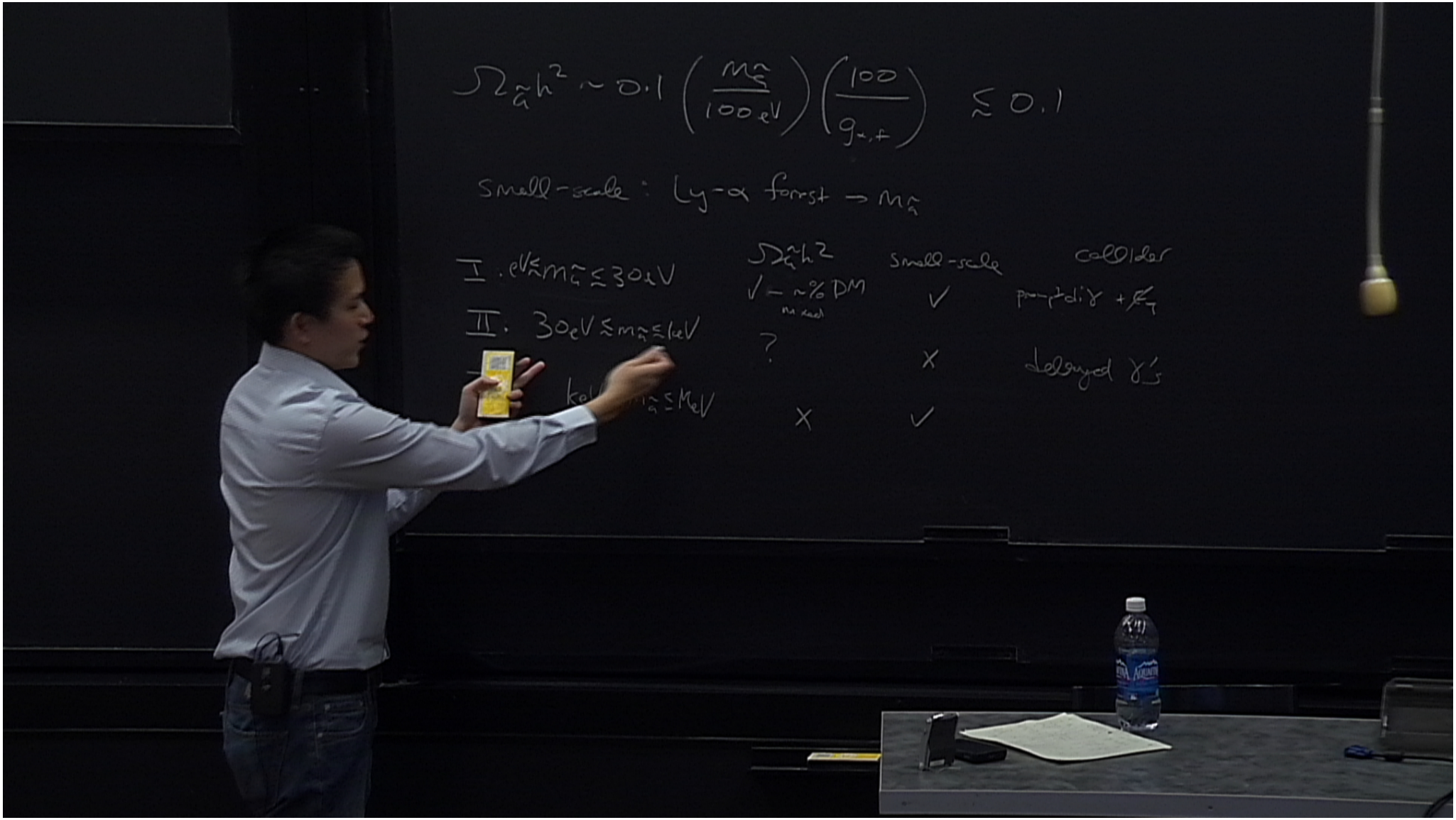
$pp \to 2 \times NLSP \to 2 \times (\tilde{\gamma} + SM)$

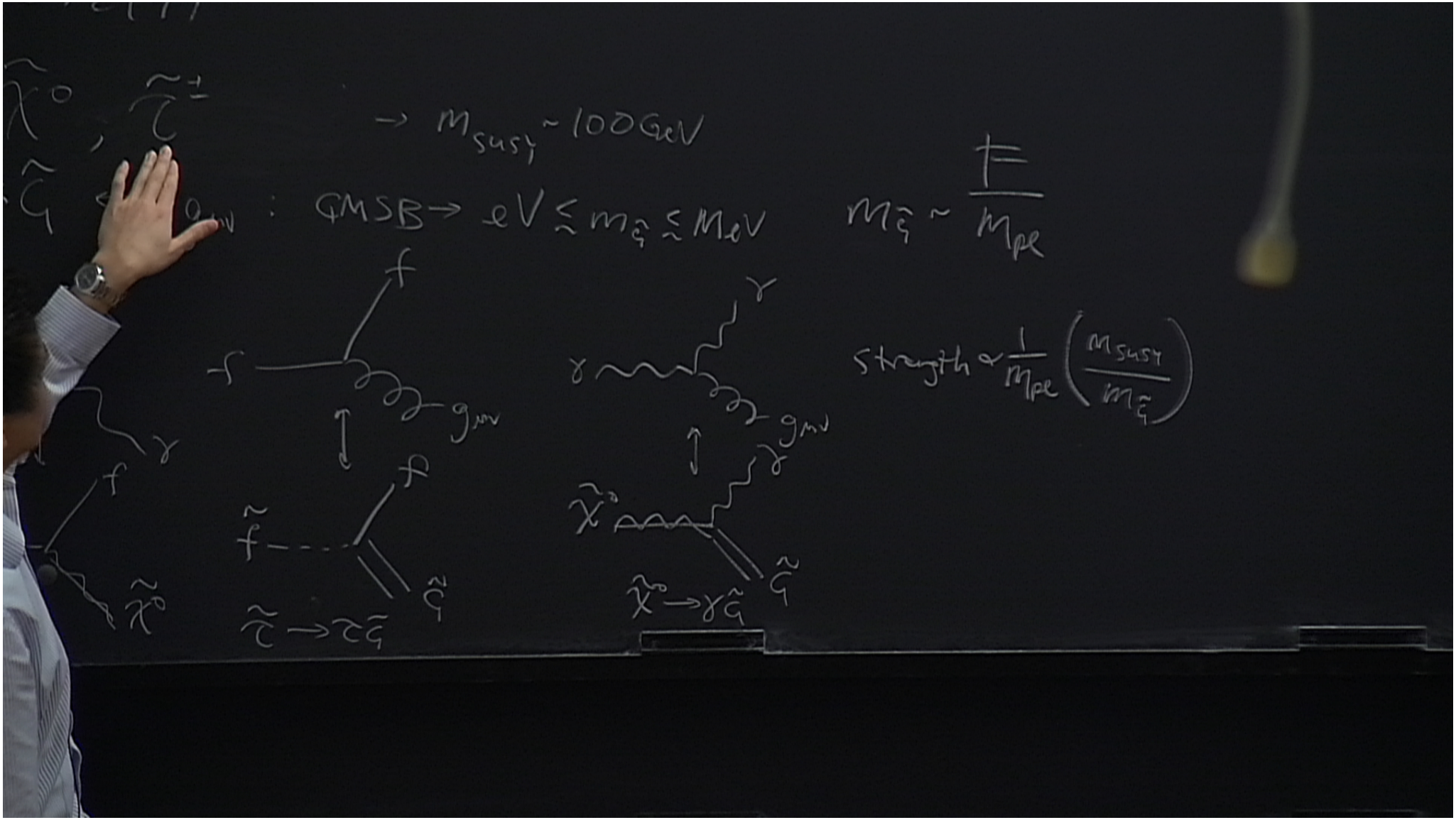
collider

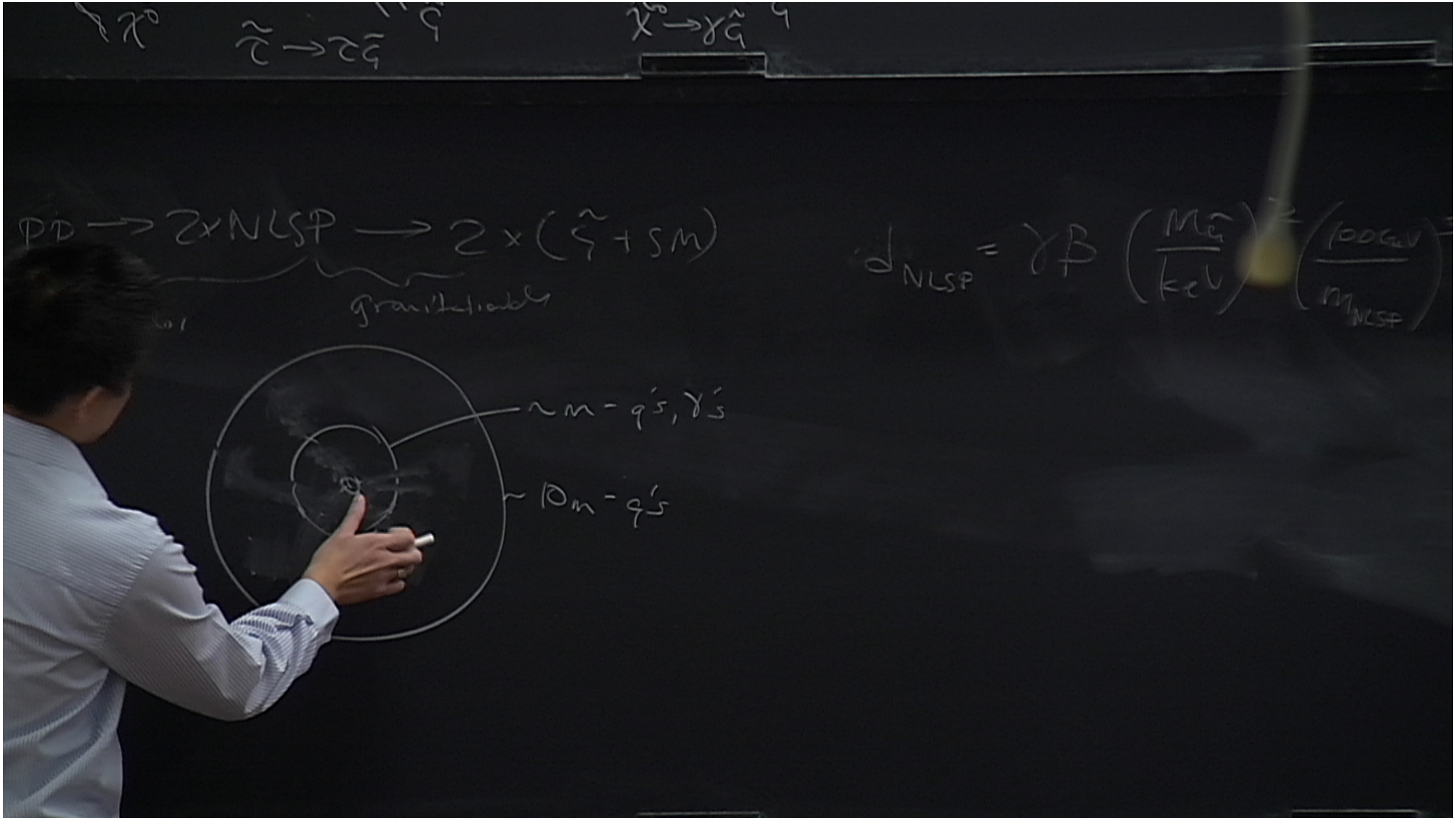
gravitationally

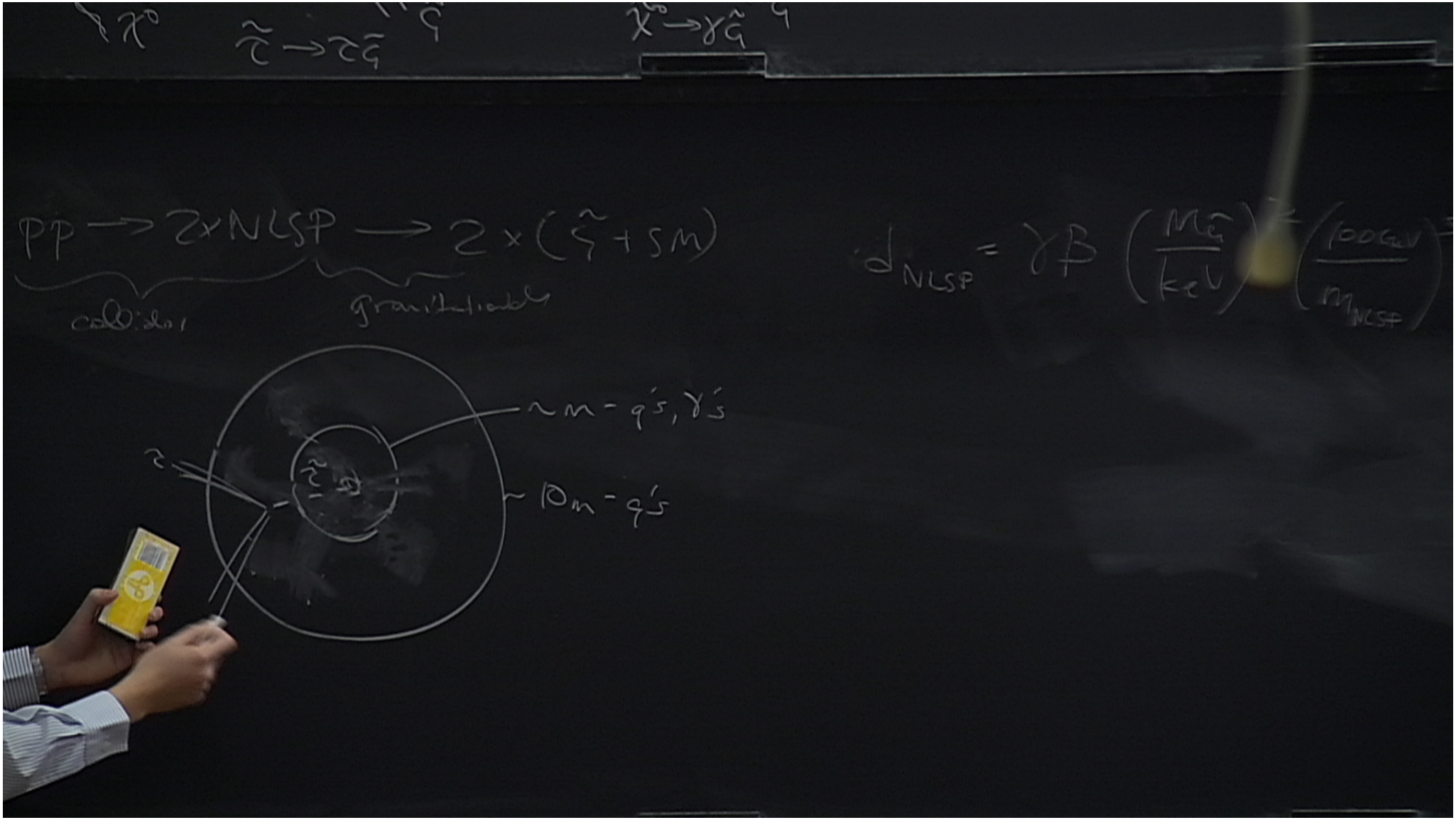
$d_{NLSP} = \gamma \beta \left(\frac{M_{\tilde{G}}}{keV}\right)^2 \left(\frac{100\,GeV}{m_{NLSP}}\right)^5$

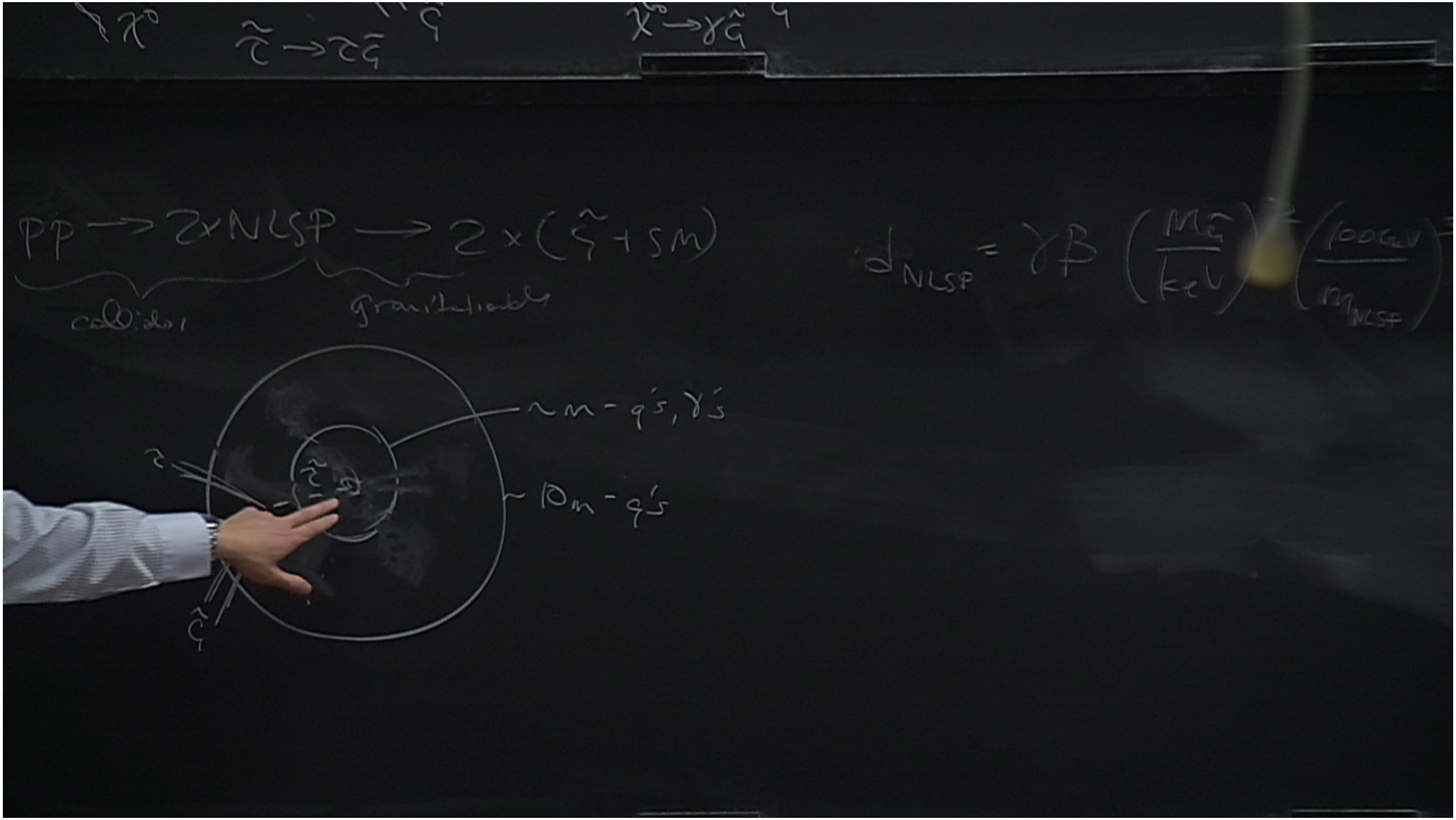


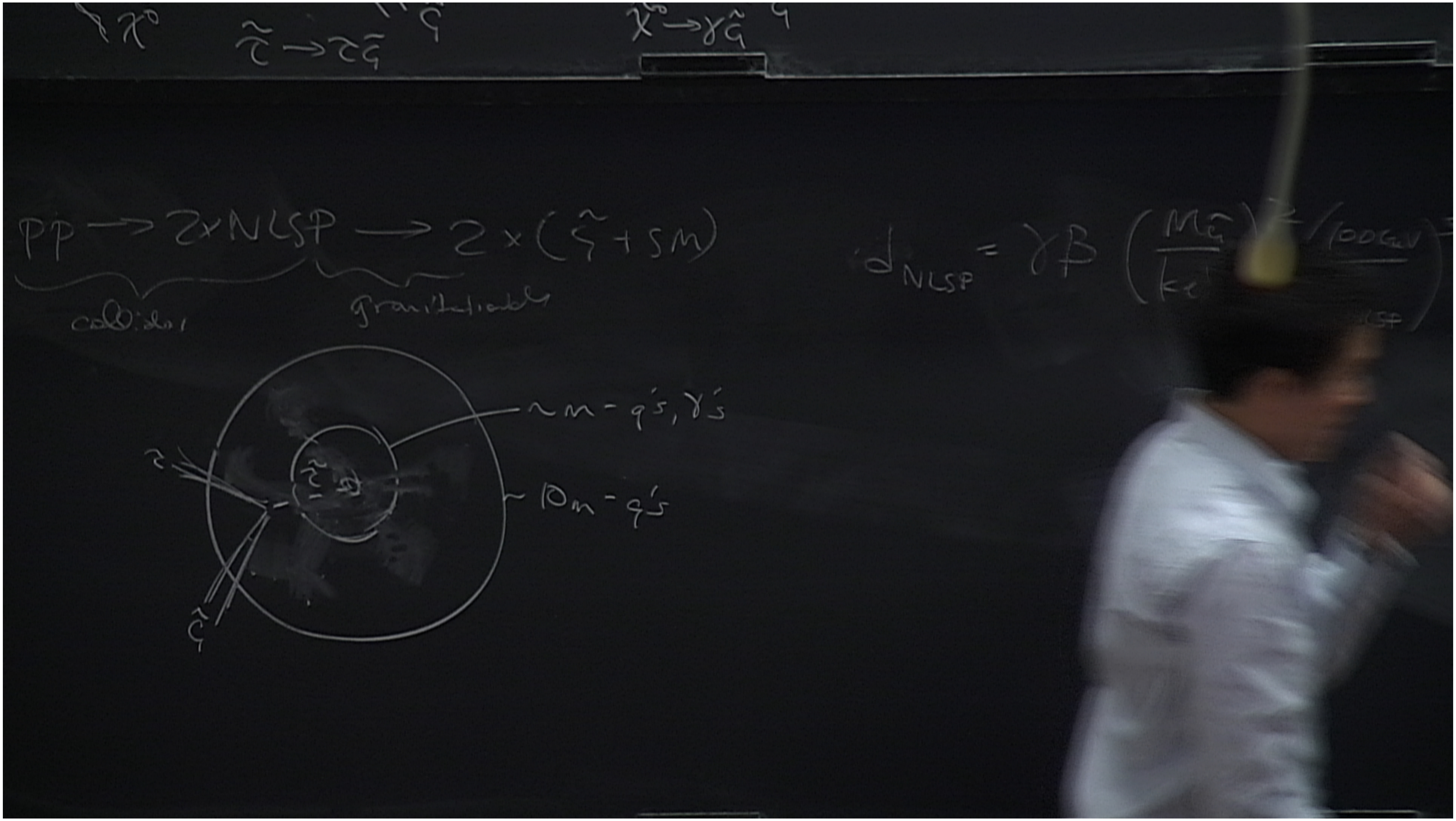

$\Omega_{\tilde{G}} h^2 \sim 0.1 \left(\frac{m_{\tilde{G}}}{100\,eV}\right)\left(\frac{100}{g_{*,f}}\right) \lesssim 0.1$
small-scale : Ly-α forest → $m_{\tilde{G}}$
I. $eV \lesssim m_{\tilde{G}} \lesssim 30\,eV$
II. $30\,eV \lesssim m_{\tilde{G}} \lesssim keV$
$\Omega_{\tilde{G}} h^2$
small-scale
collider
$\sim$% DM
prompt γ + $\not{E}_T$
delayed γ's
?
×
×
✓

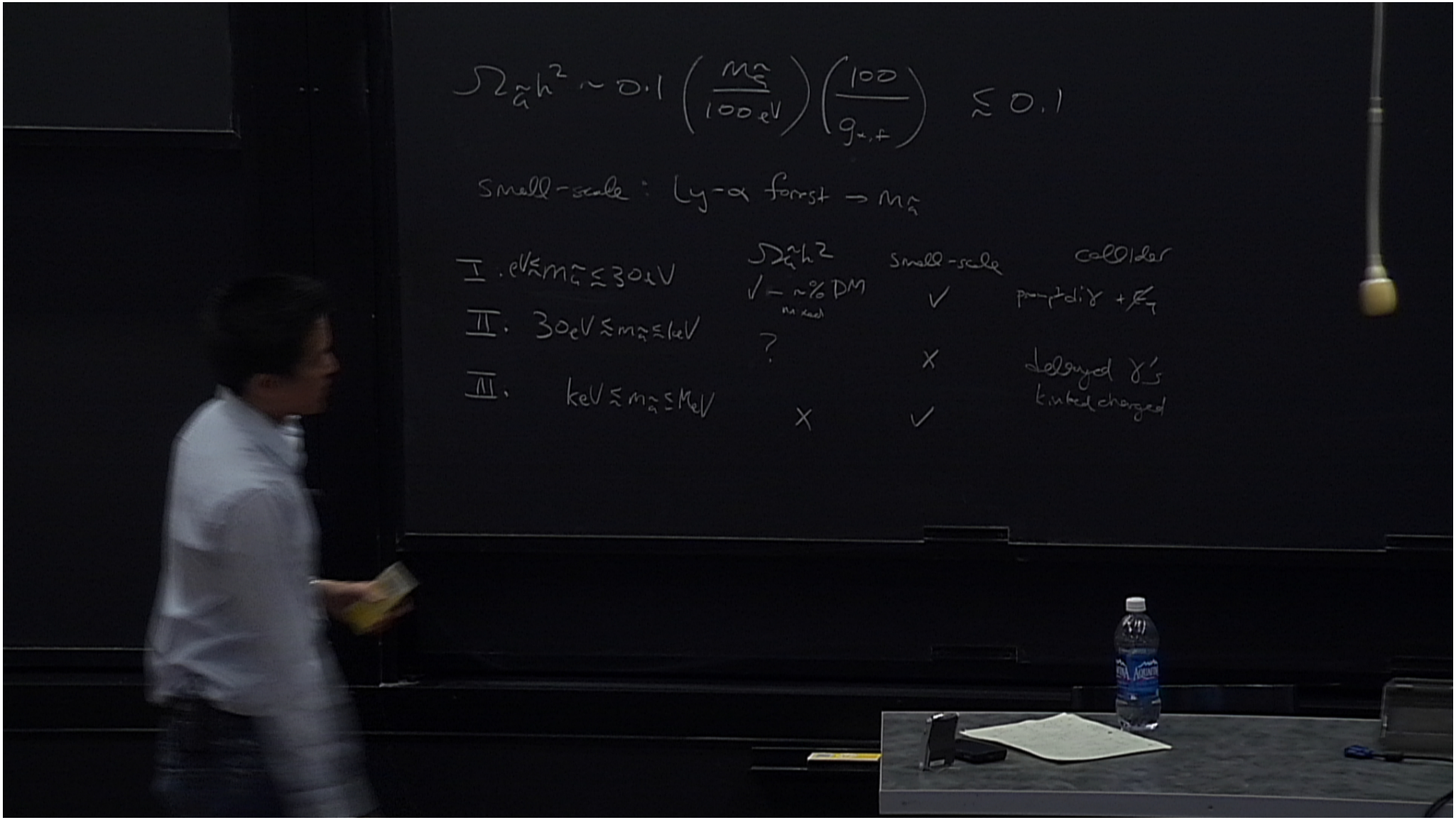

$\tilde{\chi}^0, \tilde{\tau}^{\pm}$
$\rightarrow m_{susy} \sim 100\,GeV$
$\tilde{G}$
$g_{\mu\nu}$: GMSB $\rightarrow$ $eV \lesssim m_{\tilde{G}} \lesssim MeV$
$m_{\tilde{G}} \sim \frac{F}{m_{pl}}$
strength $\propto \frac{1}{m_{pl}} \left(\frac{m_{susy}}{m_{\tilde{G}}} \right)$
f
γ
$g_{\mu\nu}$
$\tilde{f}$
$\tilde{\chi}^0$
$\tilde{\tau} \rightarrow \tau \tilde{G}$
$\tilde{\chi}^0 \rightarrow \gamma \tilde{G}$

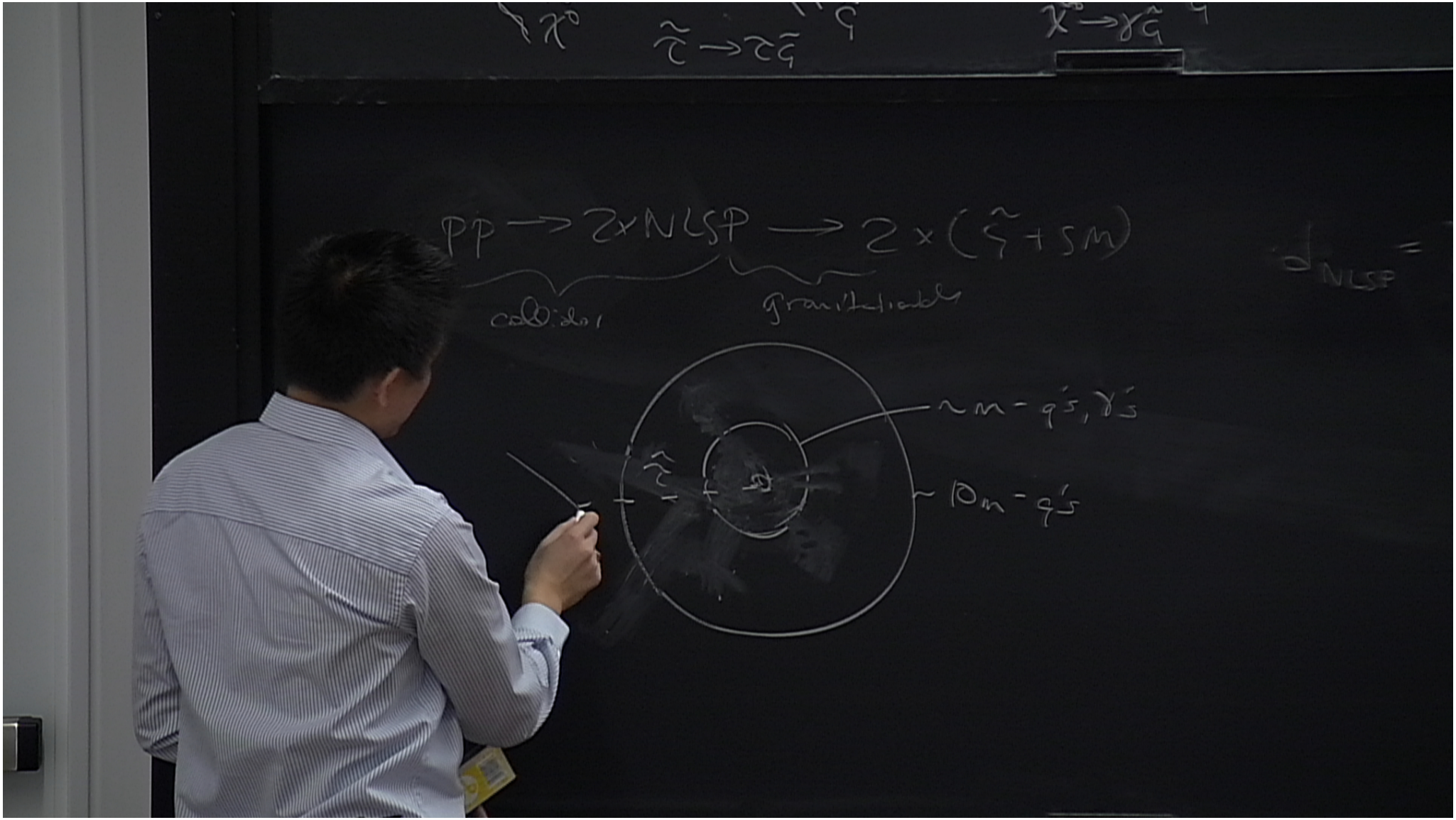

π^0
$\tilde{\tau} \to \tau \tilde{G}$
$\tilde{\chi}^0 \to \gamma \tilde{G}$
PD $\to$ 2×NLSP $\to$ 2×($\tilde{\chi}$ + SM)
gravitationally
$d_{NLSP} = \gamma\beta \left(\frac{M_{\tilde{G}}}{keV}\right)^2 \left(\frac{100\,GeV}{m_{NLSP}}\right)^5$
$\sim m$ - q's, γ's
$\sim 10m$ - q's

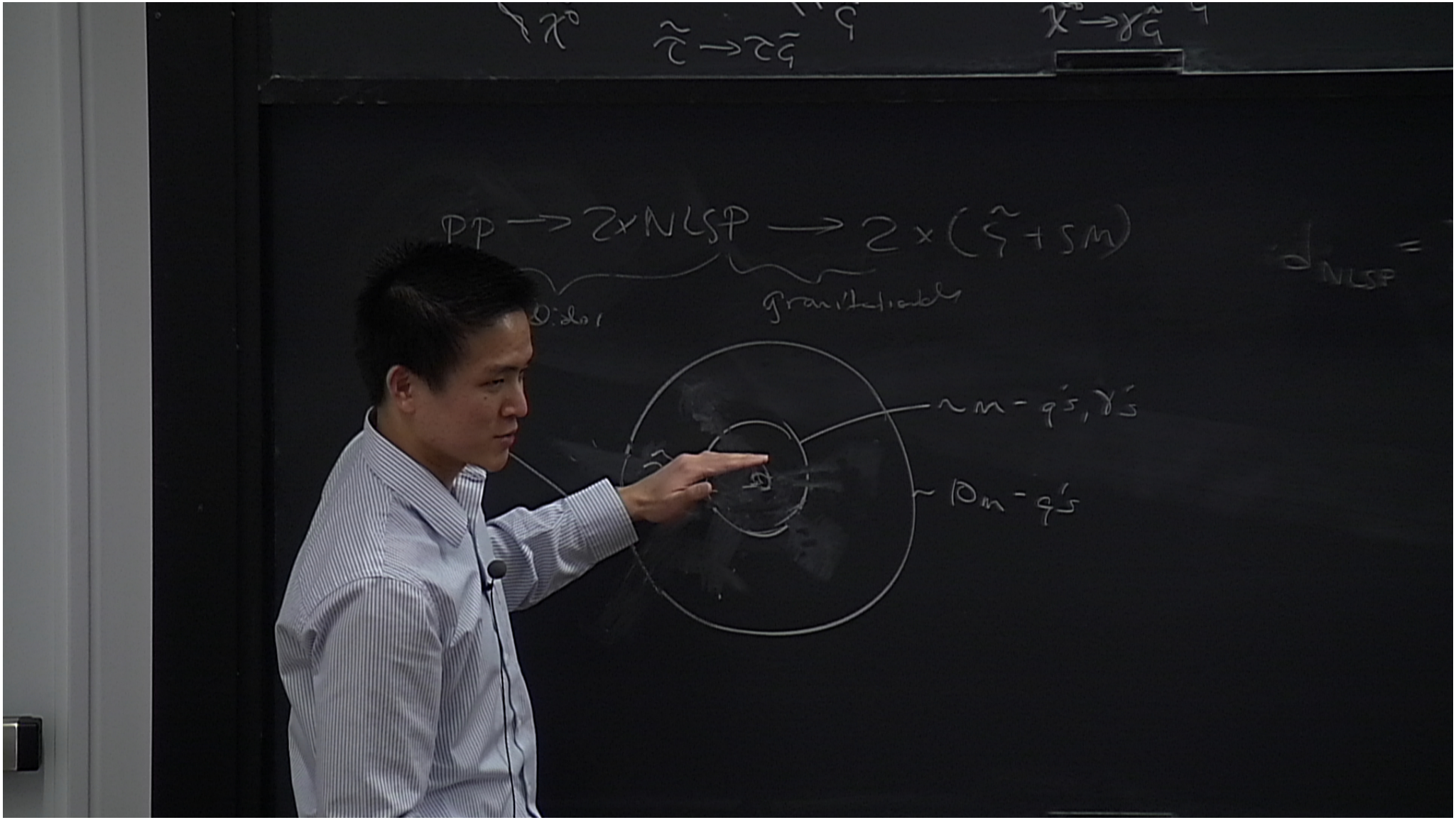

π^0
$\tilde{\tau} \to \tau \tilde{G}$
$\chi^0 \to \gamma \tilde{G}$
$pp \to 2 \times NLSP \to 2 \times (\tilde{\chi} + SM)$
collider
gravitino
$d_{NLSP} = \gamma \beta \left(\frac{M_{\tilde{G}}}{keV}\right)^2 \left(\frac{100 GeV}{m_{NLSP}}\right)^5$
$\sim m - q's, \gamma's$
$\sim 10m - q's$

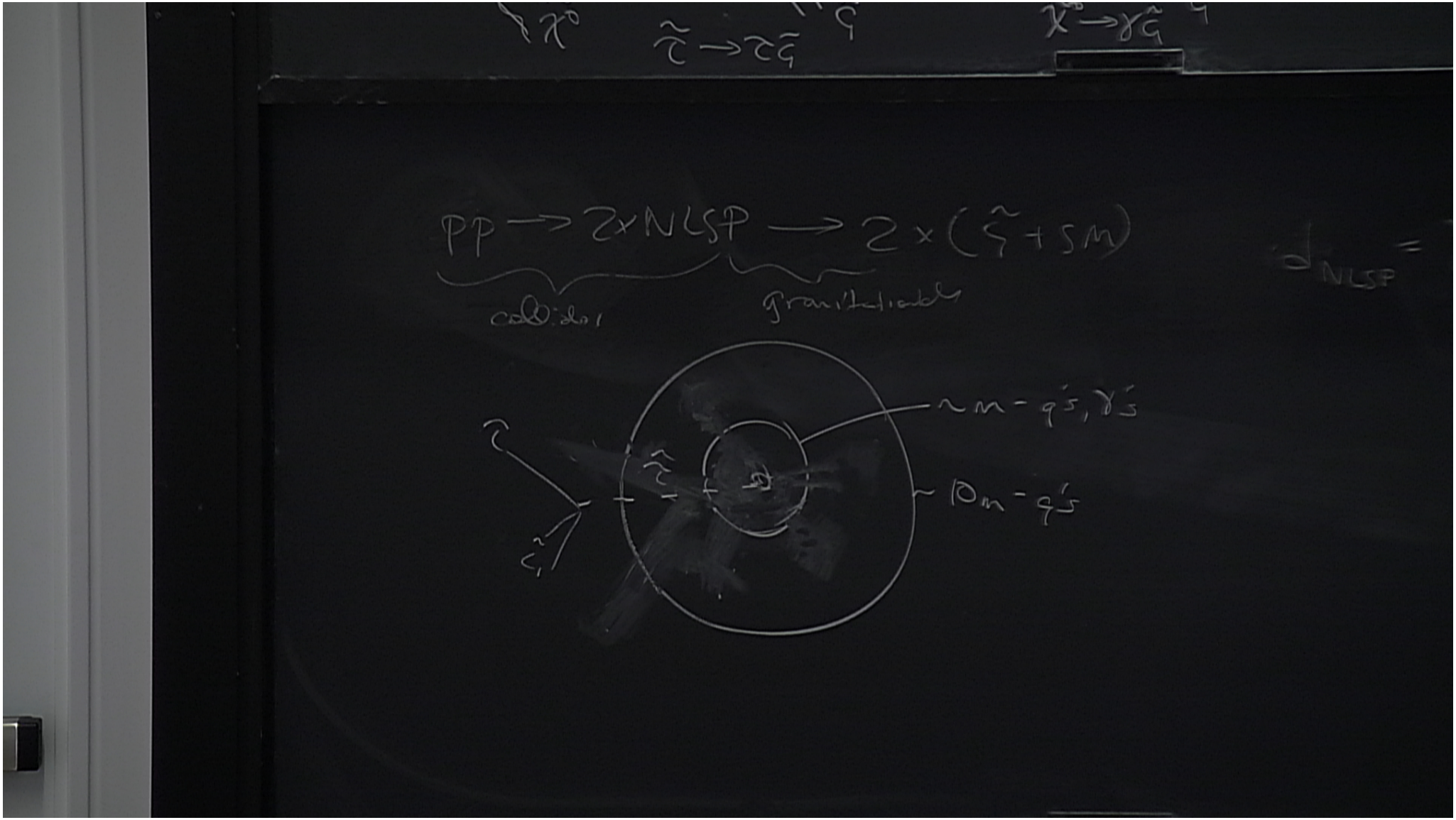

π^0
$\tilde{\tau} \to \tau \tilde{G}$
$\tilde{\chi}^0 \to \gamma \tilde{G}$
$pp \to 2 \times NLSP \to 2 \times (\tilde{\chi} + SM)$
collider
gravitational
$d_{NLSP} = \gamma\beta \left(\frac{M_{\tilde{G}}}{keV}\right)^2 \left(\frac{100\,GeV}{m_{NLSP}}\right)^5$
$\sim$ m - q's, γ's
$\sim$ 10m - q's
τ
$\tilde{\tau}$
$\tilde{\chi}$

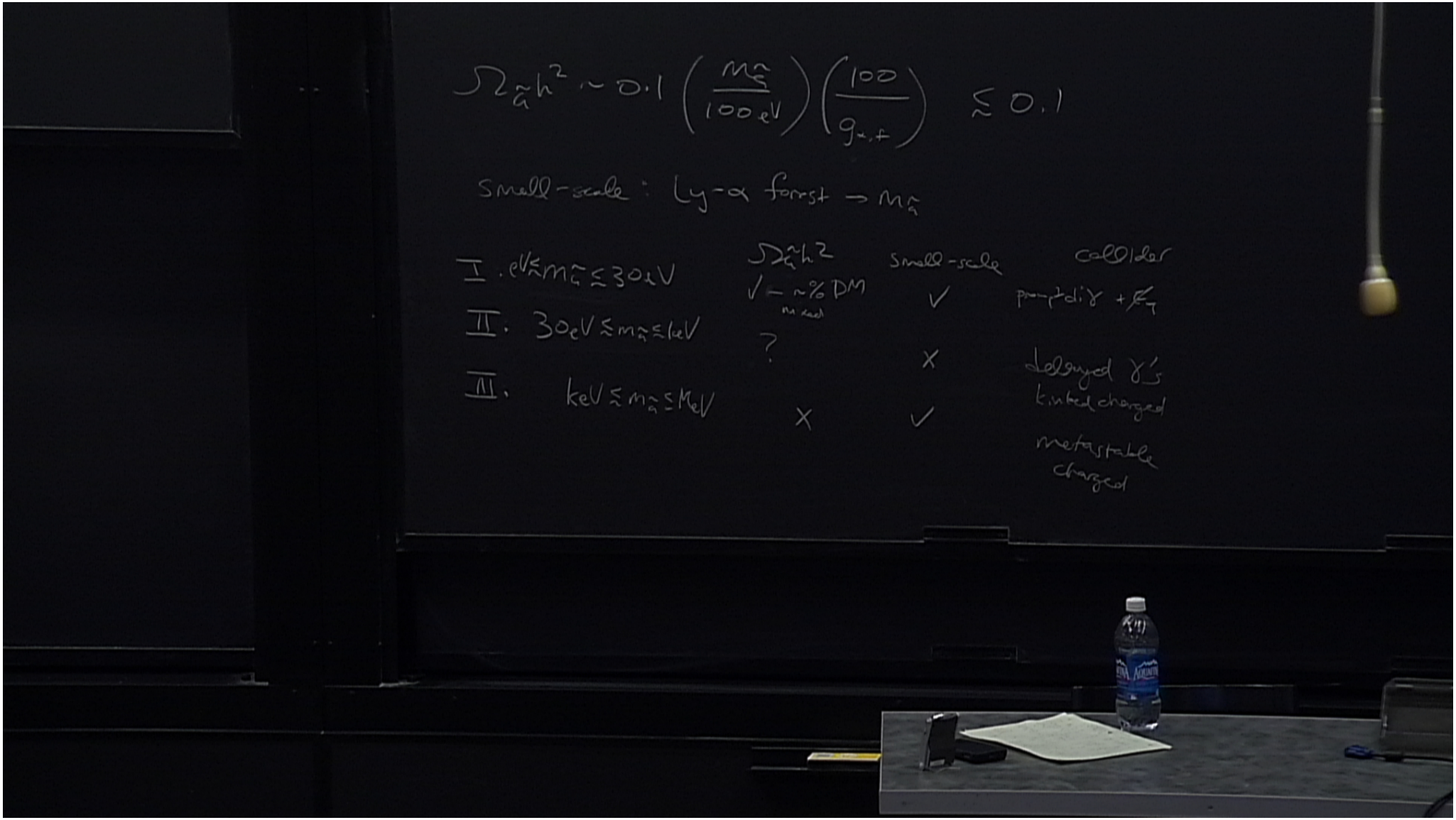

pp → 2×NLSP → 2×(G̃ + SM)
~m - q's, γ's
~10m - q's

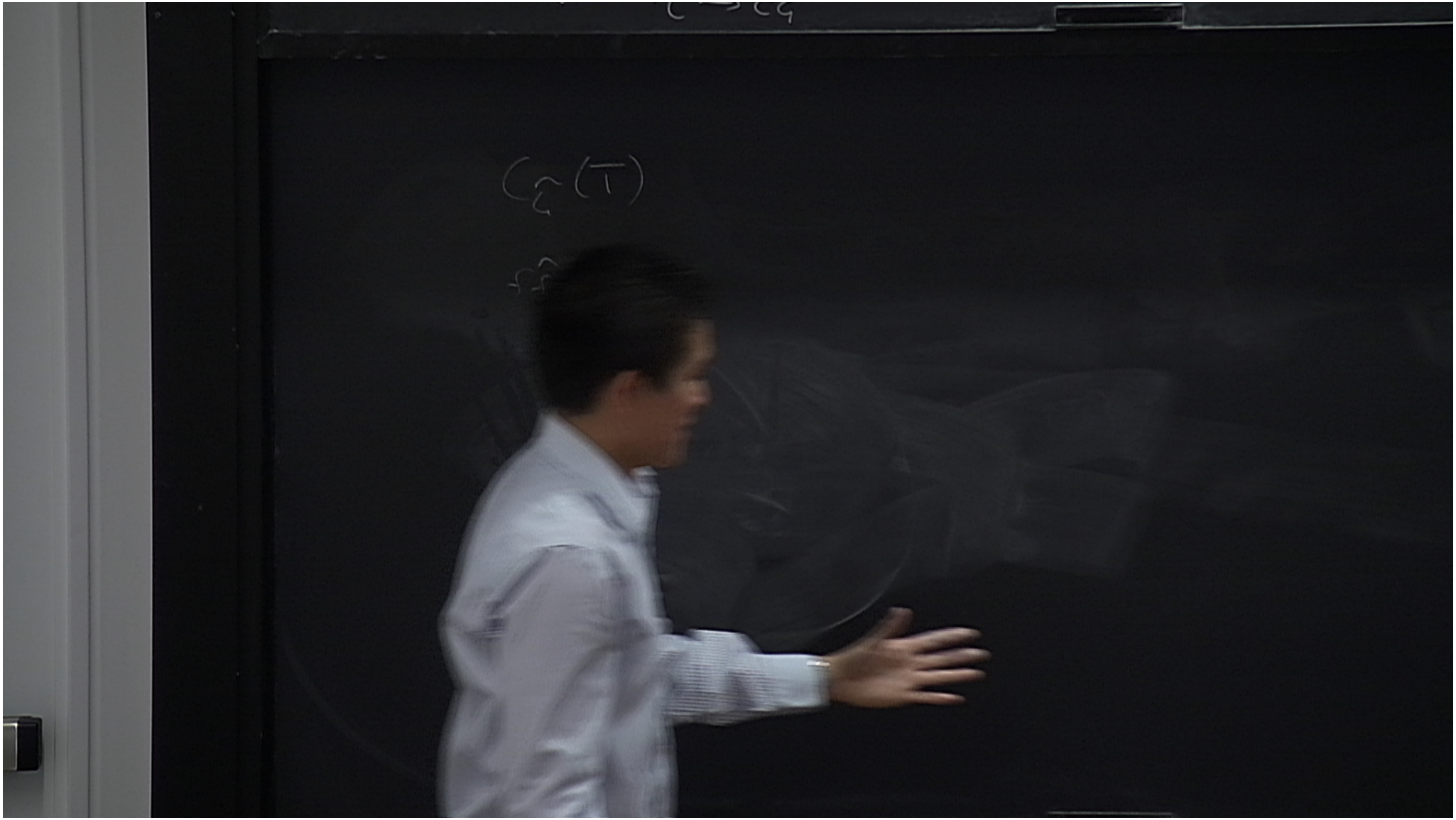

$\Omega_{\tilde{a}} h^2 \sim 0.1 \left(\frac{m_{\tilde{a}}}{100\,eV}\right)\left(\frac{100}{g_{a\gamma\gamma}}\right) \lesssim 0.1$
small-scale: Ly-α forest → $m_{\tilde{a}}$
I. $eV \lesssim m_{\tilde{a}} \lesssim 30\,eV$
II. $30\,eV \lesssim m_{\tilde{a}} \lesssim keV$
III. $keV \lesssim m_{\tilde{a}} \lesssim MeV$
$\Omega_{\tilde{a}} h^2$
$\sim$ % DM
small-scale
collider
prompt γ + $\not{E}_T$
?
delayed γ's
kinked charged

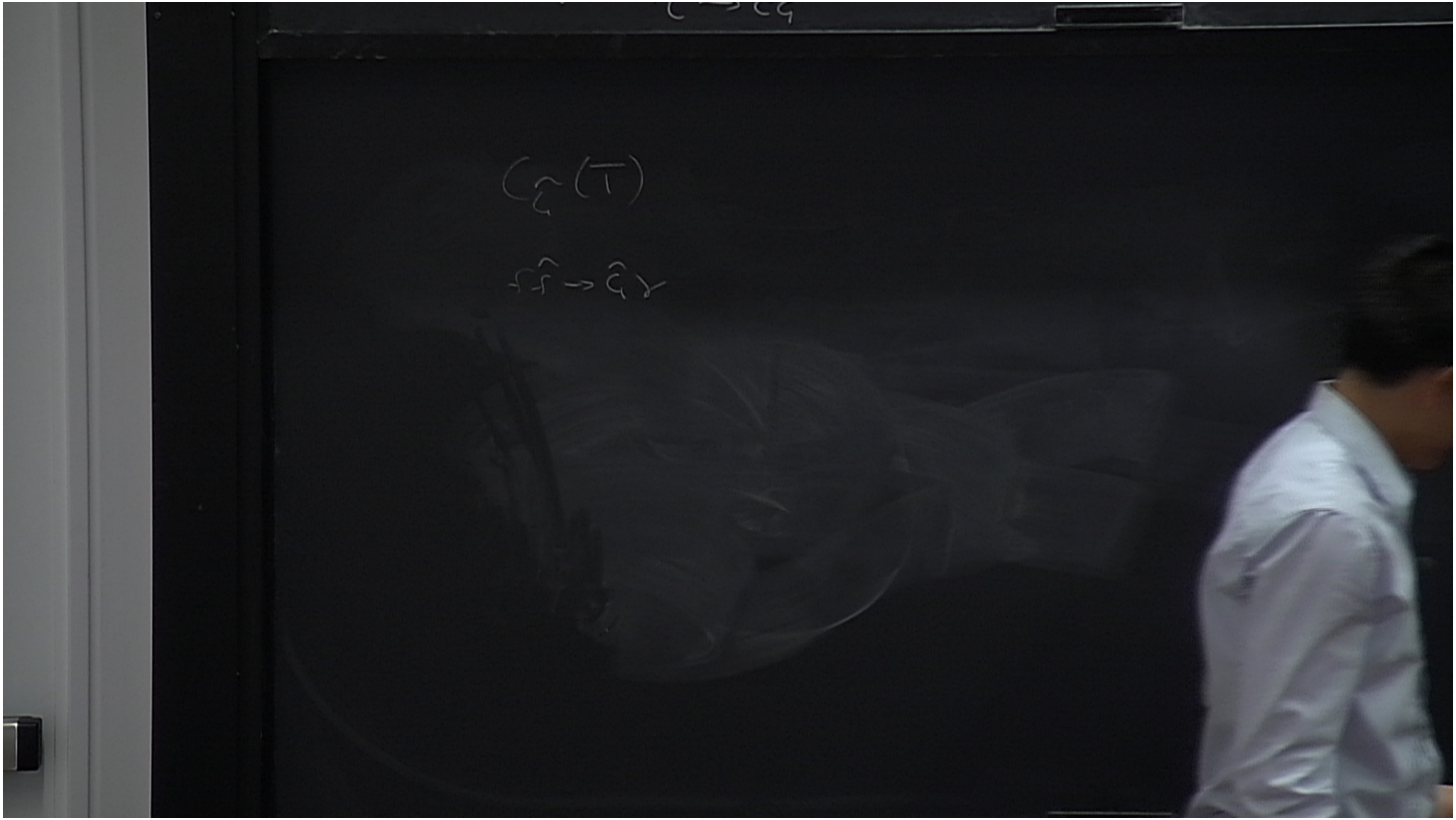

$\tilde{\tau} \to \tau \tilde{q}$
$\chi^0 \to \gamma \tilde{q}$
$PP \to 2 \times NLSP \to 2 \times (\tilde{\chi} + SM)$
$\sim m - q^5, \gamma^5$
$\sim 0m - q^5$

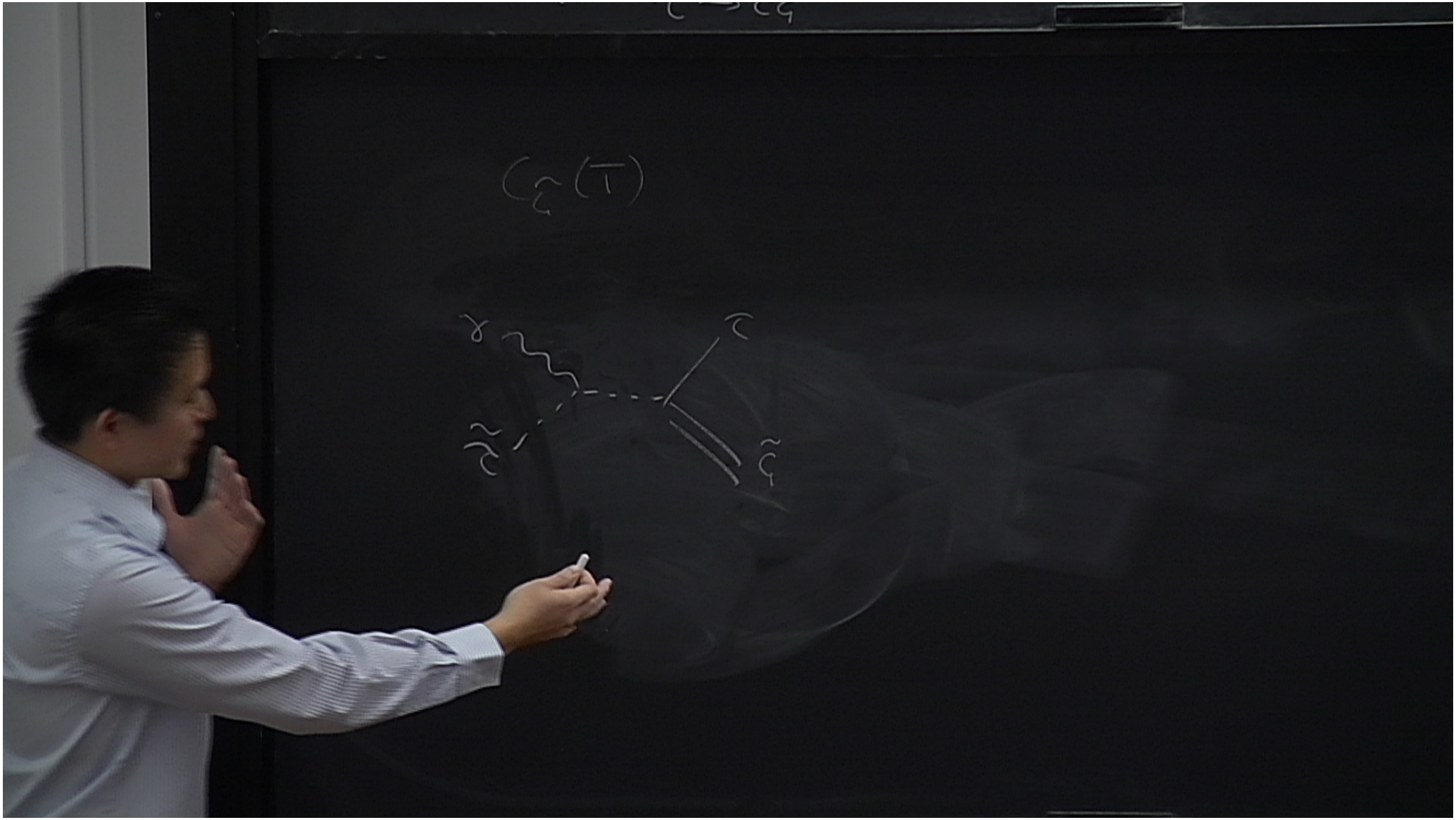

$\tilde{\tau} \to \tau \tilde{q}$
$\tilde{\chi}^0 \to \gamma \tilde{q}$
$pp \to 2 \times NLSP \to 2 \times (\tilde{\chi} + SM)$
d_{NLSP} =
Gravitational
$\sim m - q^5, \gamma^5$
$\sim 0m - q^5$

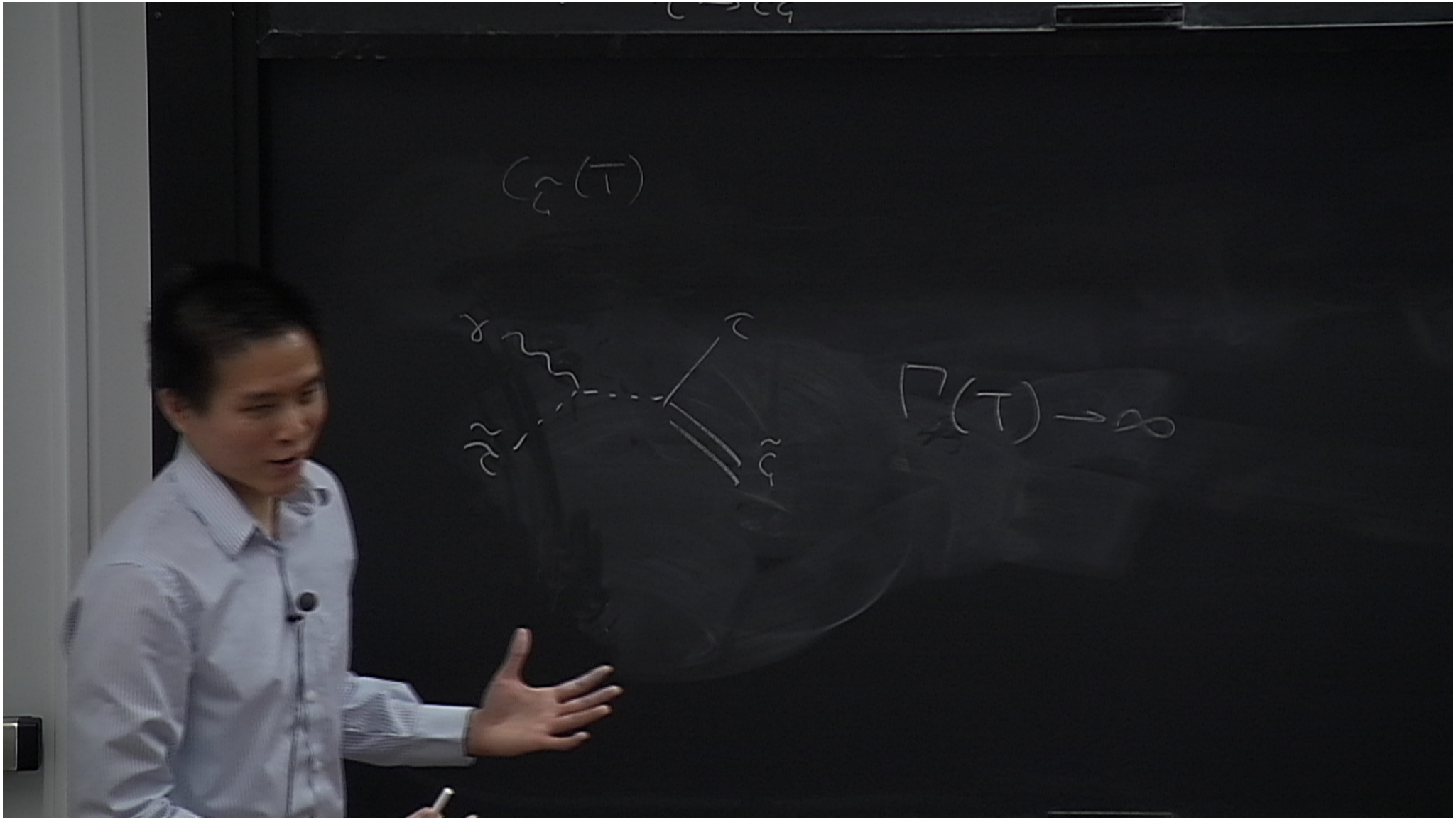

$\tilde{\tau} \to \tau \tilde{G}$
$\chi^0 \to \gamma \tilde{G}$
$PP \to 2 \times NLSP \to 2 \times (\tilde{G} + SM)$
collider
gravitational
d_{NLSP} =
$\sim M - q^5, \gamma^5$
$\sim 10m - q^5$


$\Omega_{\tilde{a}} h^2 \sim 0.1 \left(\frac{m_{\tilde{a}}}{100\,eV}\right)\left(\frac{100}{g_{a\gamma\gamma}}\right) \lesssim 0.1$
small-scale: Ly-α forest → $m_{\tilde{a}}$
I. $eV \lesssim m_{\tilde{a}} \lesssim 30\,eV$
II. $30\,eV \lesssim m_{\tilde{a}} \lesssim keV$
III. $keV \lesssim m_{\tilde{a}} \lesssim MeV$
$\Omega_{\tilde{a}} h^2$
$\sim$ % DM
small-scale
collider
prompt γ + $\not{E}_T$
?
delayed γ's
kinked charged
metastable
charged

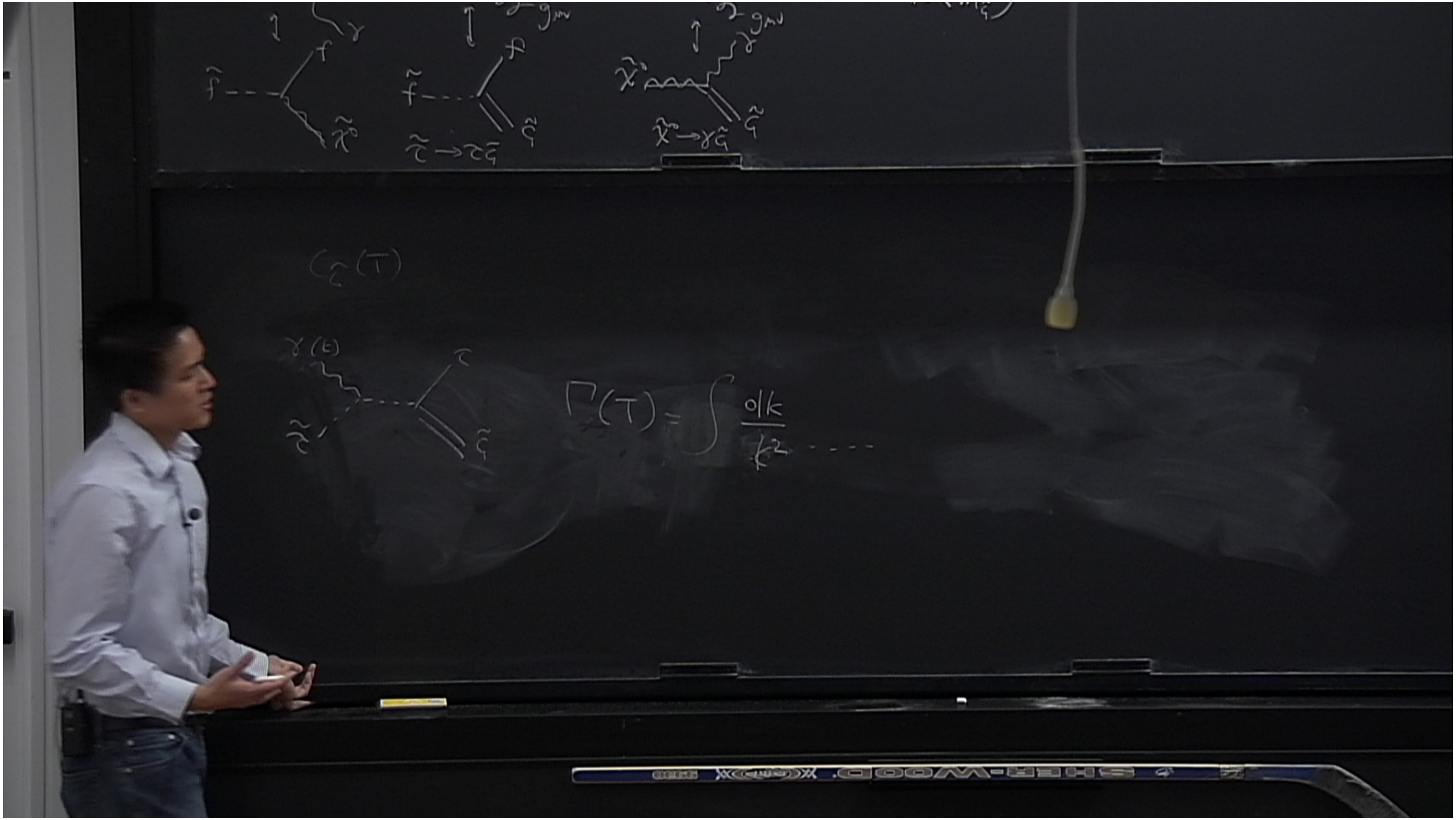


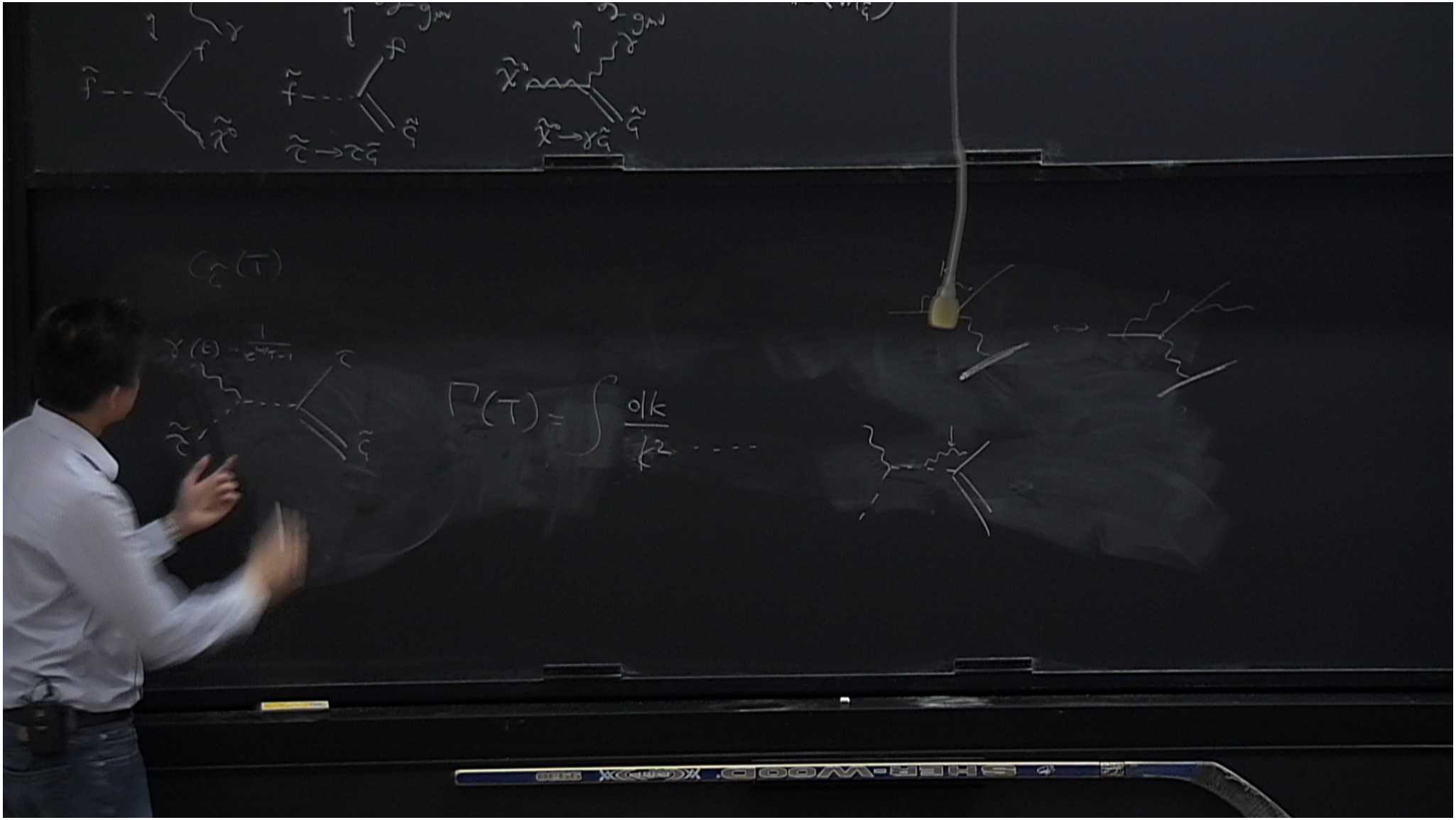


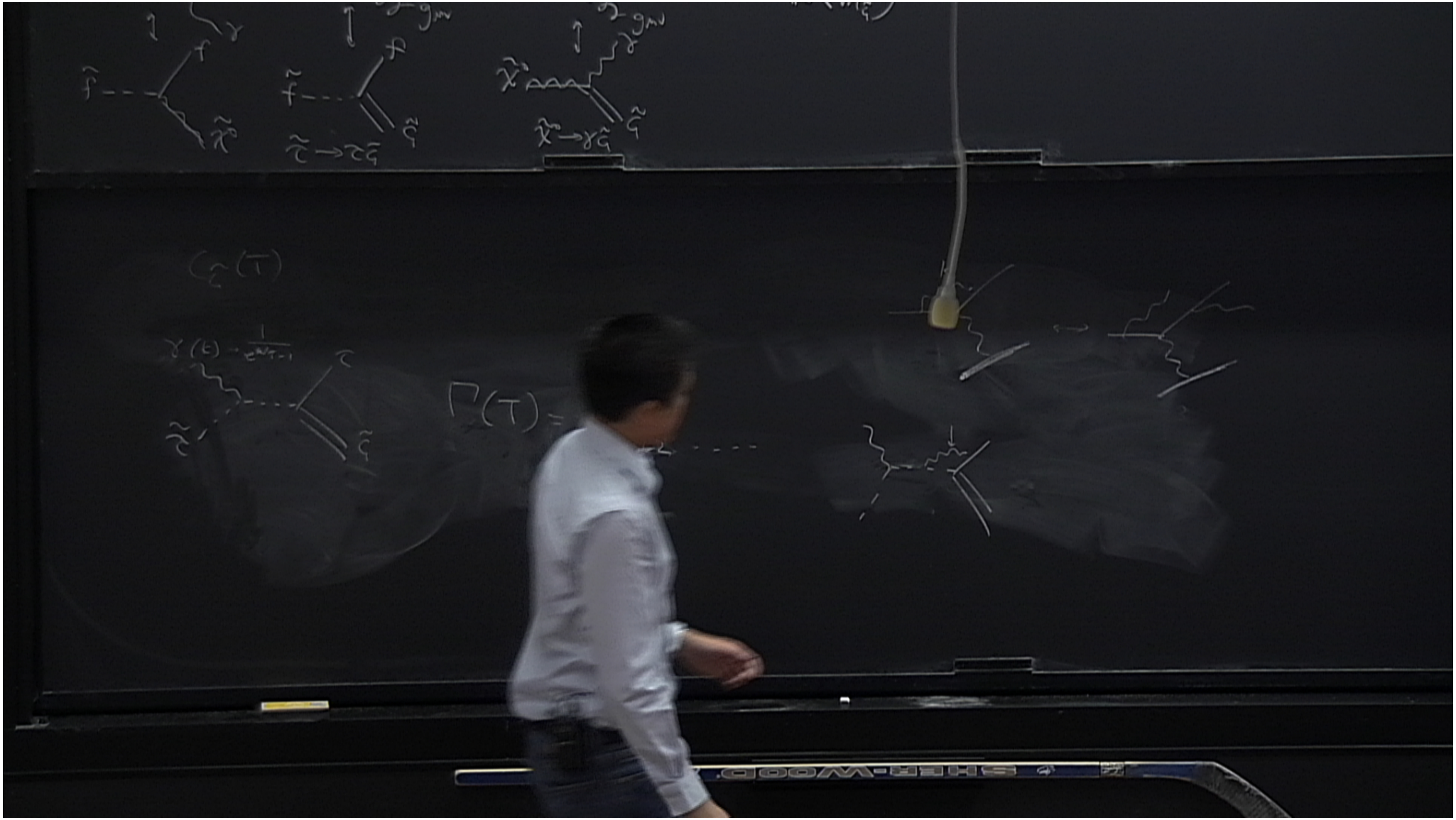

$\tilde{\chi}_2^0(\tau)$
γ
τ
$\tilde{\chi}_2^0$
$\tilde{\chi}_1^0$

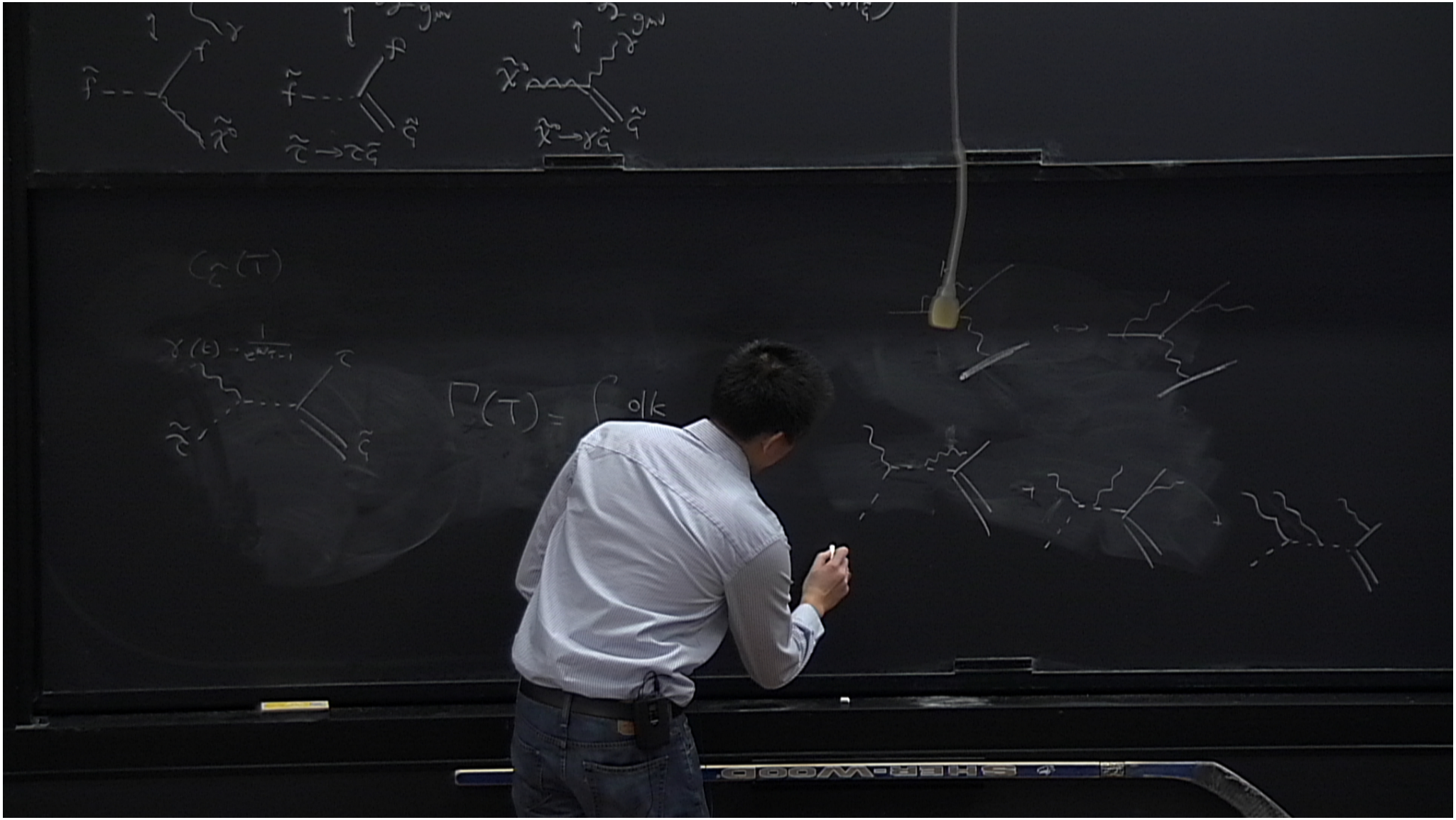

$\zeta(T)$
γ
$\tilde{\tau}$
τ
$\tilde{\zeta}$
$\Gamma(T) \to \infty$

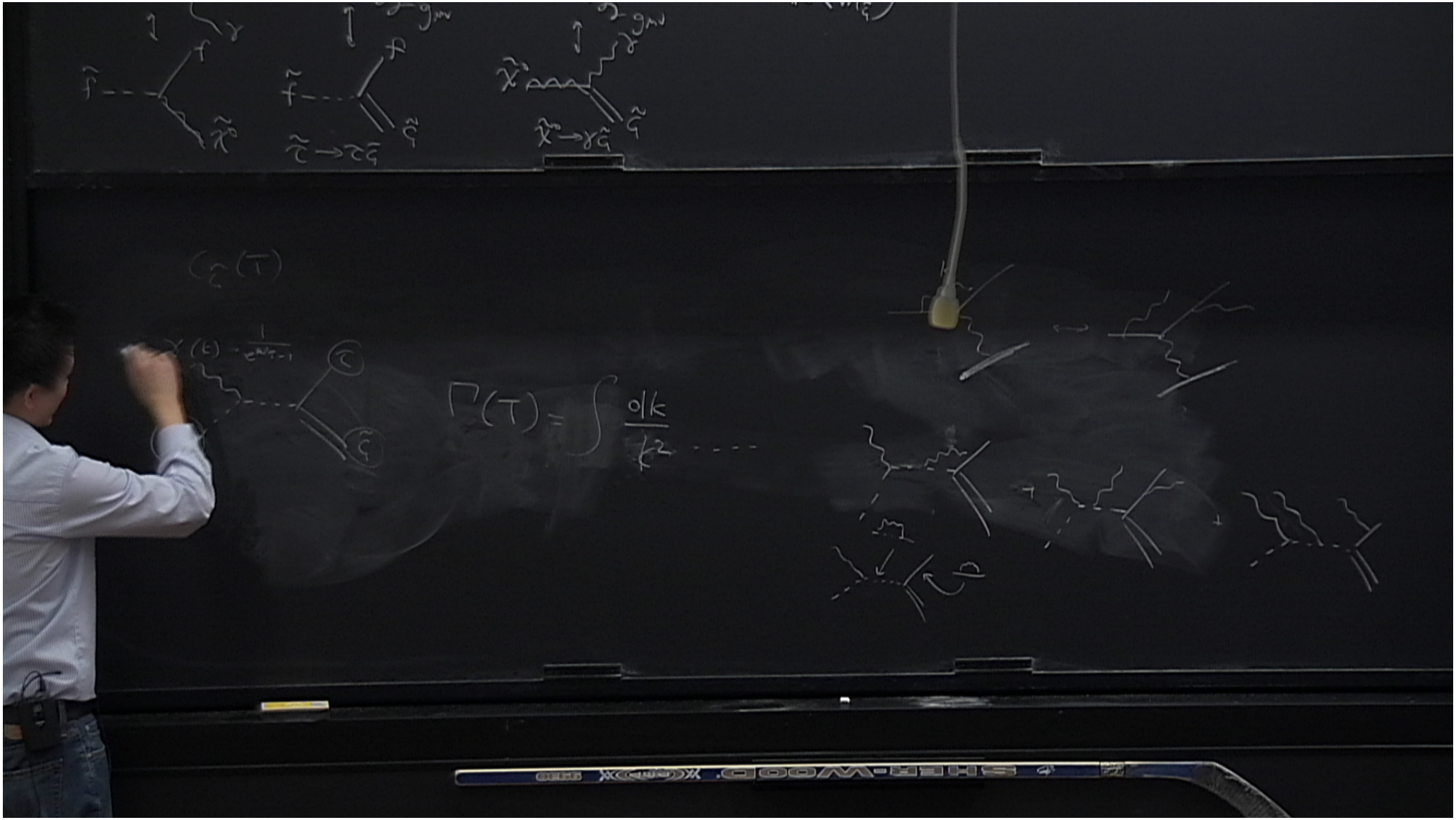

$\Gamma(T) = \int \frac{d|k}{k^2}$

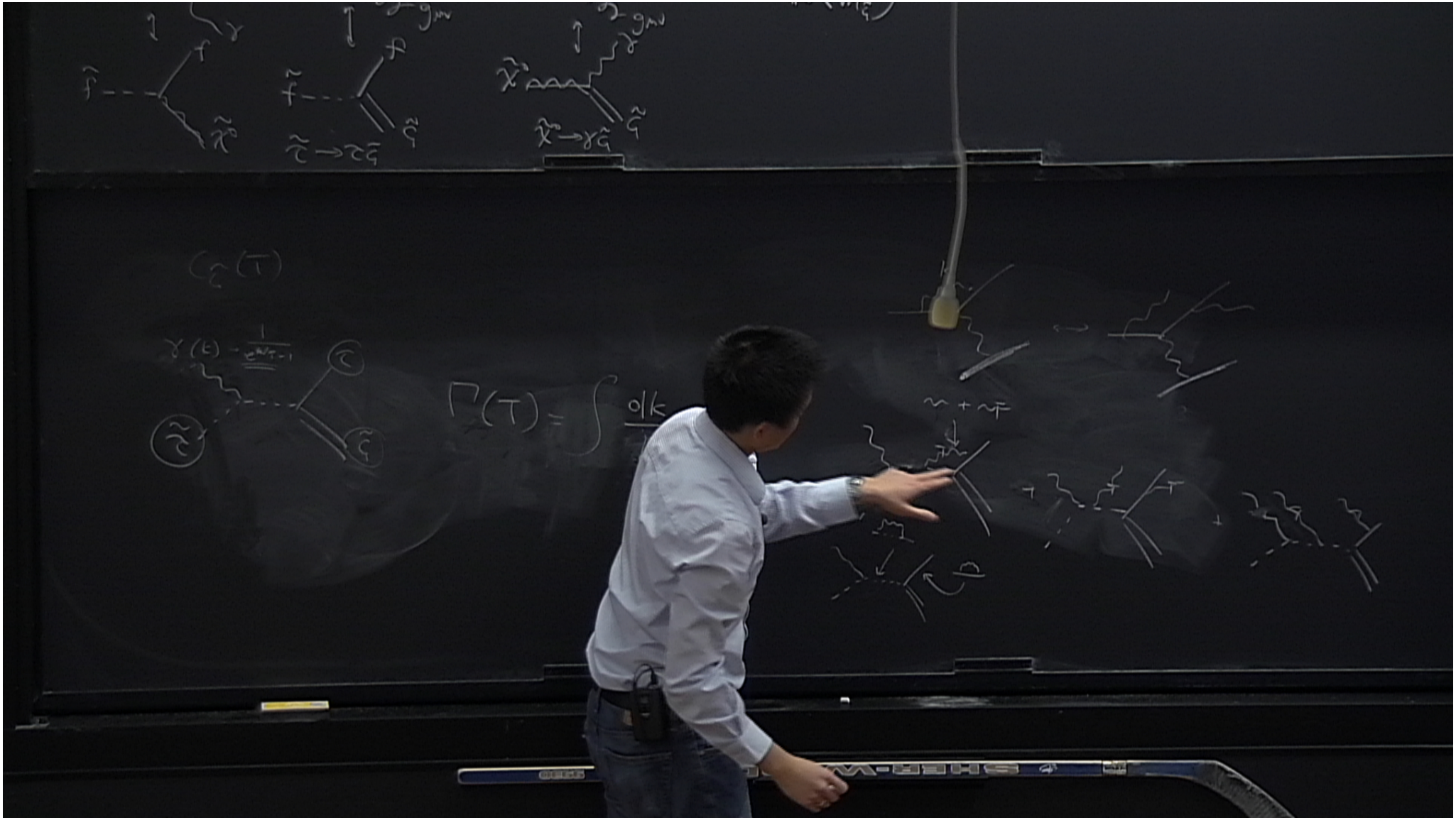

$\tilde{f}$
$\tilde{\chi}^0$
$\tilde{\tau} \to \tau \tilde{G}$
$\tilde{\chi}^0 \to \gamma \tilde{G}$
$g_{\mu\nu}$
$\zeta(T)$
$\gamma(E)$
$\tilde{\tau}$
$\Gamma(T) = \int \frac{d^3k}{k^2}$

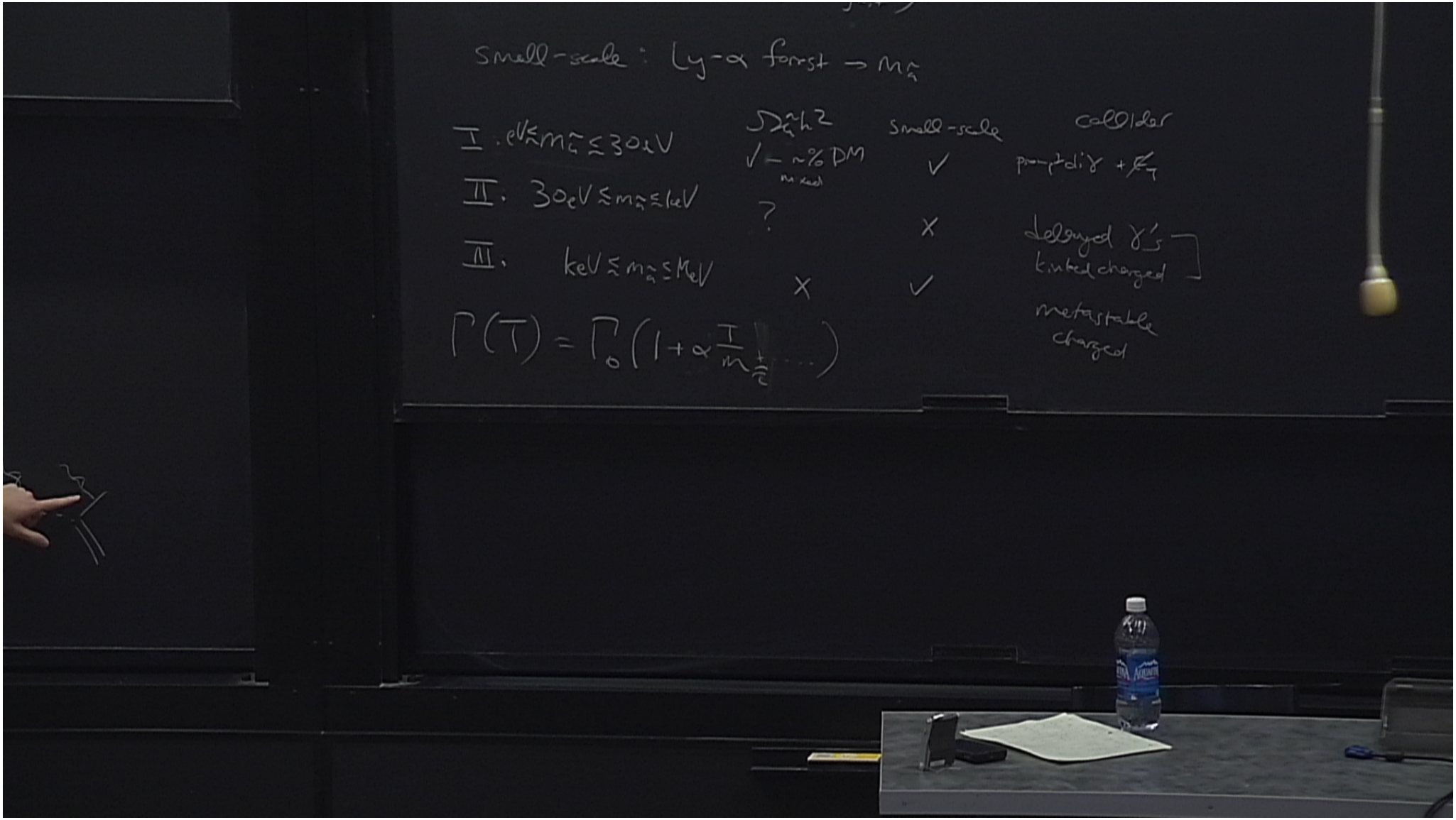

$\tilde{\tau} \to \tau \tilde{G}$
$\tilde{\chi}^0 \to \gamma \tilde{G}$
$\Gamma(T) = \int \frac{d|k|}{k^2}$

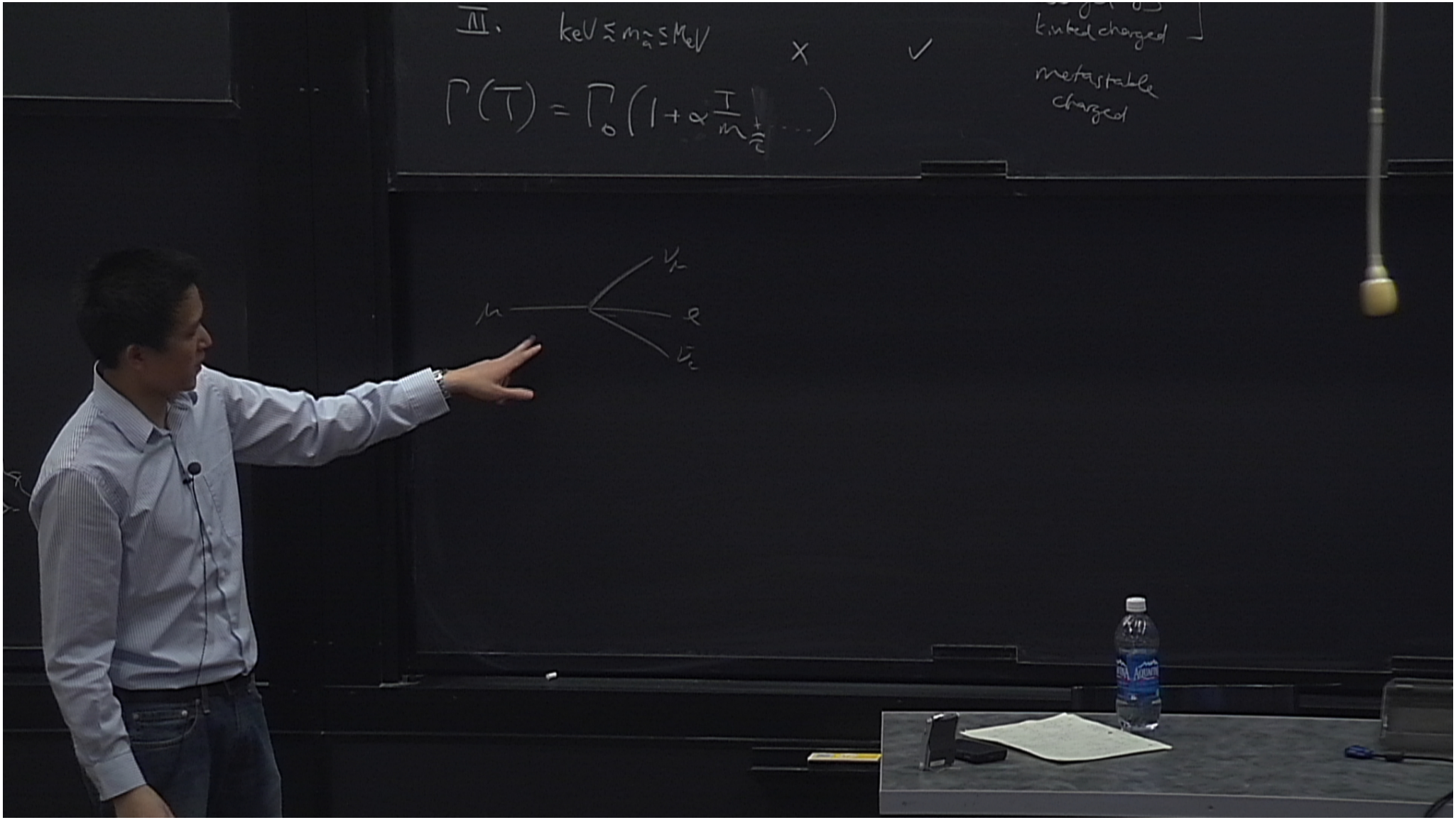

$\tilde{f} \to f \tilde{\chi}^0$
$\tilde{f} \to f \tilde{G}$
$\tilde{\chi}^0 \to \gamma \tilde{G}$
$\tilde{\tau} \to \tau \tilde{G}$
$\Gamma(T) =$

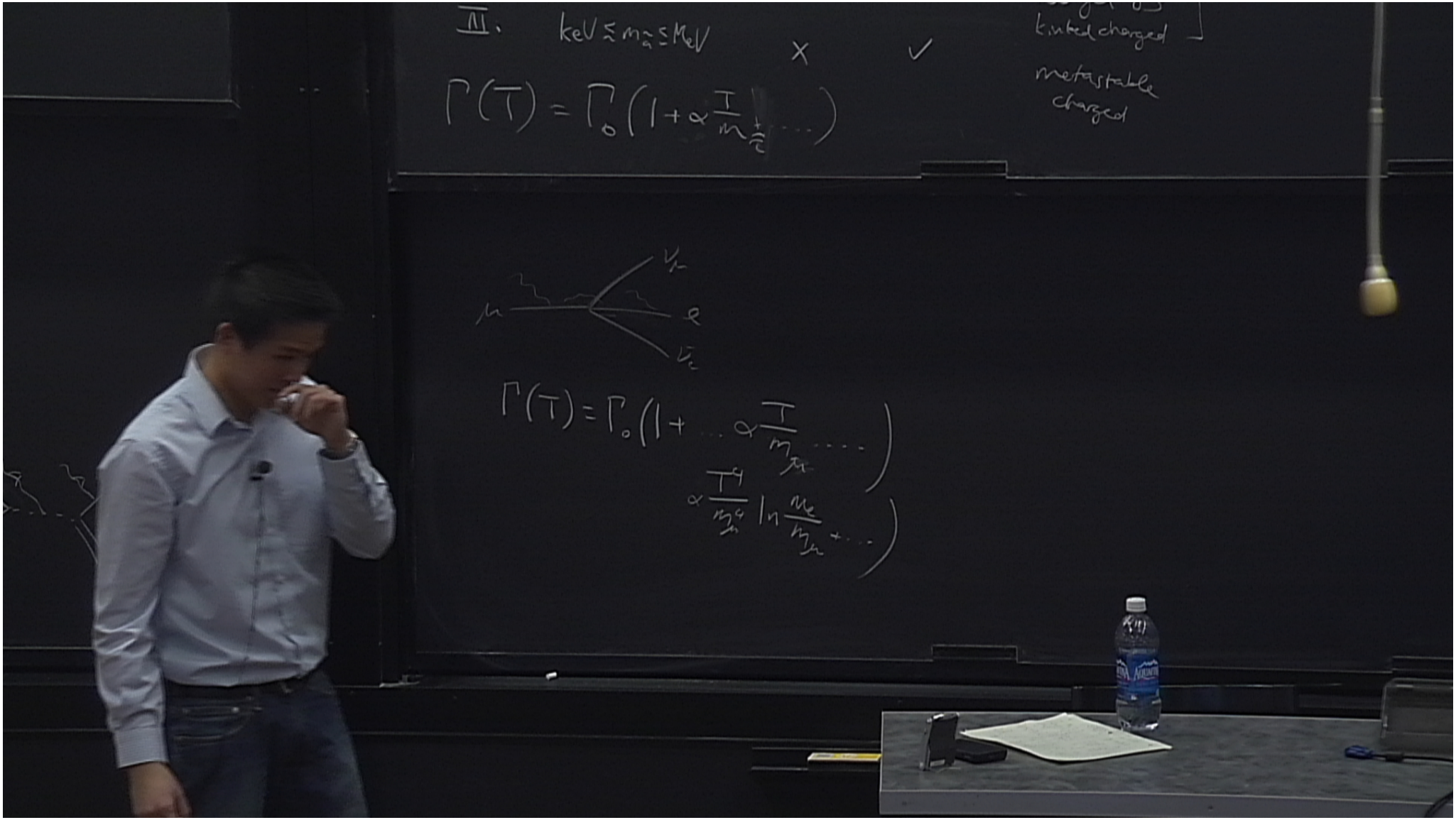



$\tilde{\tau} \to \tau \tilde{G}$
$\tilde{\chi}^0 \to \gamma \tilde{G}$
$\Gamma(T) = \int \frac{d|k}{k^2}$




small-scale: Ly-α forest → $m_{\tilde{\chi}}$
I. $eV \lesssim m_{\tilde{\chi}} \lesssim 30\,eV$
II. $30\,eV \lesssim m_{\tilde{\chi}} \lesssim keV$
III. $keV \lesssim m_{\tilde{\chi}} \lesssim MeV$
$\Omega_{\tilde{\chi}} h^2$
✓ – ~% DM
mixed
?
×
small-scale
✓
×
✓
collider
prompt diγ + $\not{E}_T$
delayed γ's
kinked charged
metastable
charged
$\Gamma(T) = \Gamma_0 \left(1 + \alpha \frac{T}{m_{\tilde{\chi}}} + \dots\right)$


II. keV ≲ m_a ≲ MeV
Γ(T) = Γ_0 (1 + α T/m_a^2 ...)
kinked charged
metastable charged


II. keV ≲ m_a ≲ MeV
×
✓
kinked charged
metastable
charged
Γ(T) = Γ_0 (1 + α T/m_e ...)
ν_μ
e
ν̄_e
Γ(T) = Γ_0 (1 + ... α T/m_μ ....
α T^4/m_μ^4 ln m_e/m_μ + ...)