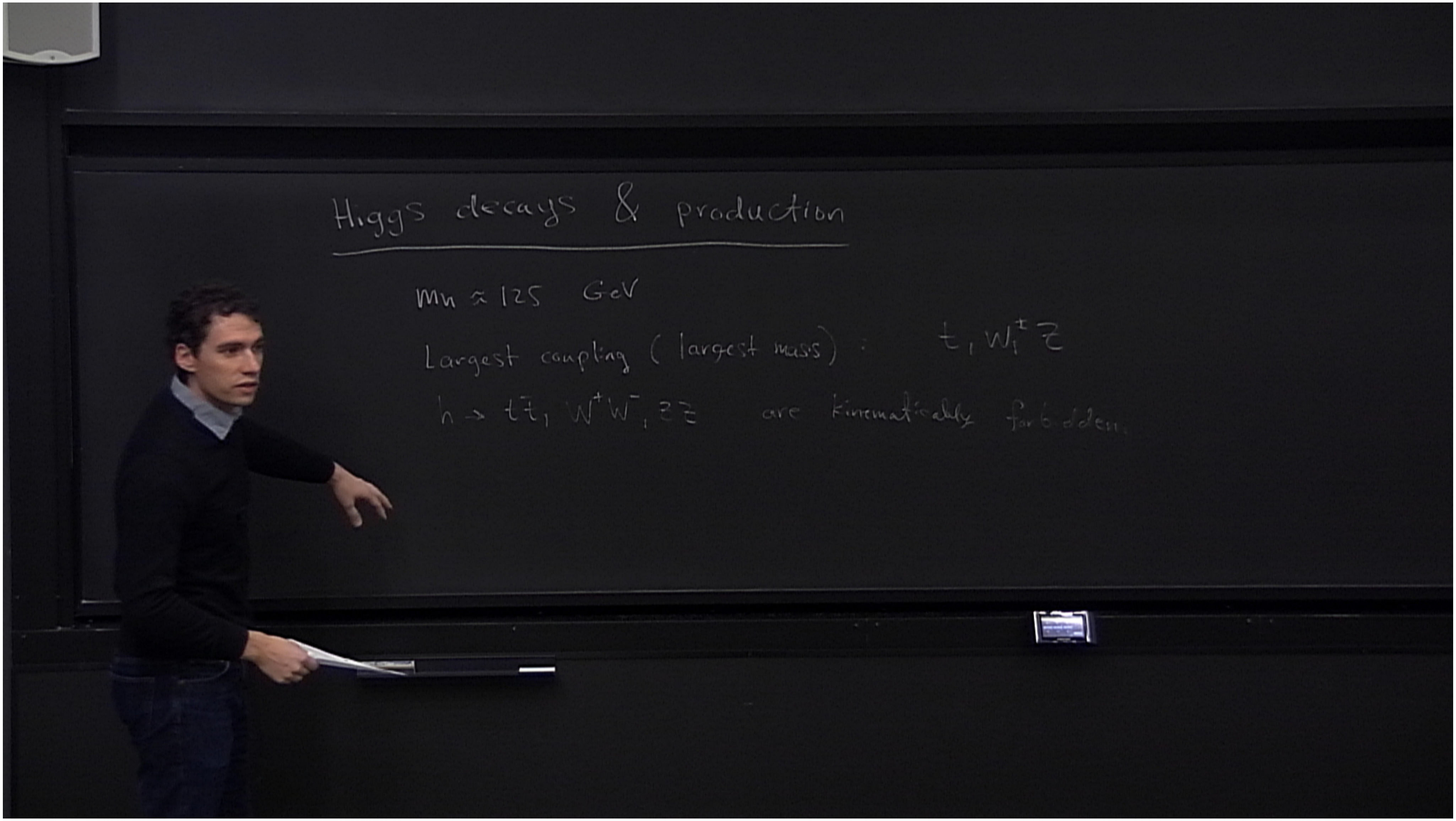
Title: PSI 2016/2017 Standard Model (Review) - Lecture 9

Date: Jan 13, 2017 09:00 AM

URL: http://pirsa.org/17010013

Abstract:


Higgs decays & production
mh ≈ 125 GeV
Largest coupling (largest mass) : t, W±, Z
h → tt̄, W+W−, ZZ are kinematically forbidden.

Higgs decays & production

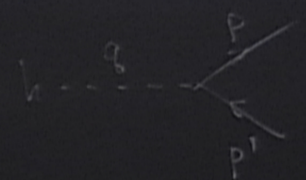
$m_h \approx 125$ GeV

Largest coupling (largest mass) : $t, W^\pm, Z$

$h \to t\bar{t}, W^+W^-, ZZ$ are kinematically forbidden.

Tree-level decays:

• $h \to$ fermions $\qquad \mathcal{L}_{int} = -\frac{m_\psi}{v}\, h\,\bar{\psi}\psi$



$= -i\,\frac{m_\psi}{v}$

$$i\mathcal{M} = -\,i\,\frac{m_\psi}{v}\,\bar{u}(p)\,v(p') \qquad 2m_\psi \ll m_h$$

$$\sum_{\text{spins}} |\mathcal{M}|^2 = \frac{m_\psi^2}{v^2}\,4\,p\cdot p' = \frac{2m_\psi^2 m_h^2}{v^2} \qquad q^2 = m_h^2 = 2p\cdot p'$$

$$\Gamma(h\to \psi\bar{\psi}) = \frac{1}{16\pi m_h}\sum|\mathcal{M}|^2 = \frac{m_\psi^2 m_h}{8\pi v^2}$$

(after doing 2-bod

$\Gamma(h \to \tau$ … m

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$$\Gamma(h \to \tau\bar{\tau}) = \frac{m_\tau^2 m_h}{8\pi v^2} \approx 0.26 \text{ MeV}$$

$$\Gamma(h \to b\bar{b}) = \frac{m_b^2 m_h}{8\pi v^2}$$

(after doing 2-body integral w/ $m_\psi = 0$)

$$\sum_{\text{spins}} |\mathcal{M}|^2 = \frac{m_\psi^2}{v^2} 4 p\cdot p' = \frac{2 m_\psi^2 m_h^2}{v^2} \qquad q^2 = m_h^2 = 2 p\cdot p'$$

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$$\Gamma(h \to b\bar{b}) = \frac{3 m_b^2 m_h}{8\pi v^2} \approx 4.3 \text{ MeV}^* \quad (58\%)$$

* RGE of m_b, m_c (or y_b, y_c) reduces m_b, m_c by factor of ~ 2 (b), ~

$$\Gamma(h \to c\bar{c}) = \frac{3 m_c^2 m_h}{8\pi v^2} \approx 0.4 \text{ MeV}^* \quad (2.9\%)$$

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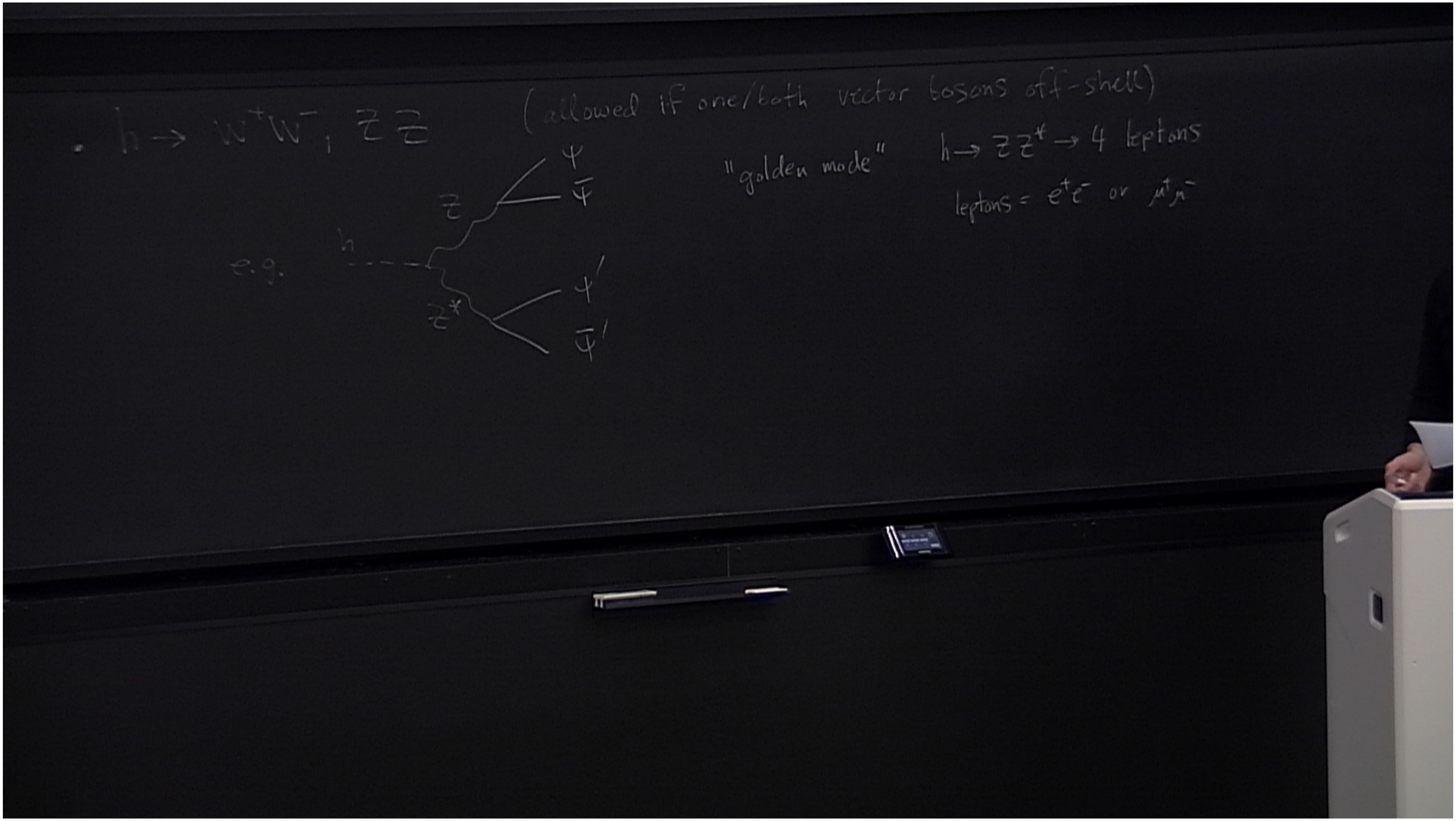
• $h \to W^+W^-, ZZ$
(allowed if one/both vector bosons off-shell)
e.g.
h
Z
Z^*
ψ
$\bar{\psi}$
ψ'
$\bar{\psi}'$
"golden mode" $h \to ZZ^* \to 4$ leptons
leptons = e^+e^- or $\mu^+\mu^-$

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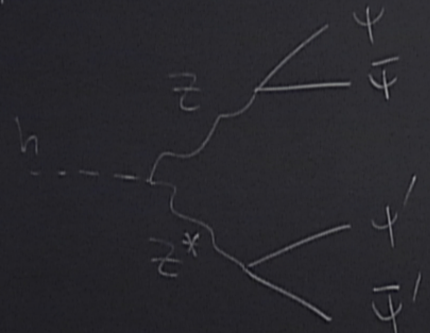


$\Gamma(h \to ZZ^*) \simeq 0.11$ MeV (2.6%)

$\Gamma(h \to WW^*) \simeq 0.88$ MeV (22%)

Loop decays: very important

$$\Gamma(h \to gg) \simeq 0.35 \text{ MeV} \quad (8.8\%)$$

$$\Gamma(h \to \gamma\gamma) \simeq 6 \times 10^{-3} \text{ MeV} \quad (0.15\%)$$

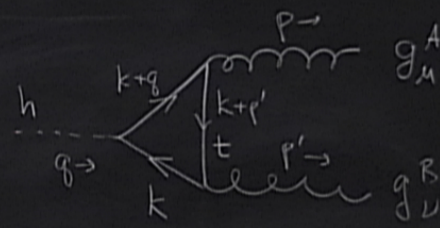
$h \to \gamma\gamma$ is rare, but experimentally clean (other "golden mode")

$h \to gg$ easier to compute (difficult to measure)

$$\sum_{\text{spins}} |\mathcal{M}|^2 = \frac{m_t^2}{v^2}\, 4\, p\cdot p' = \frac{2 m_t^2 m_h^2}{v^2} \qquad q^2 = m_h^2 = 2p\cdot p'$$

Compute $h \to gg$:

$$i\mathcal{M} = i\mathcal{M}_1 + i\mathcal{M}_2 =$$



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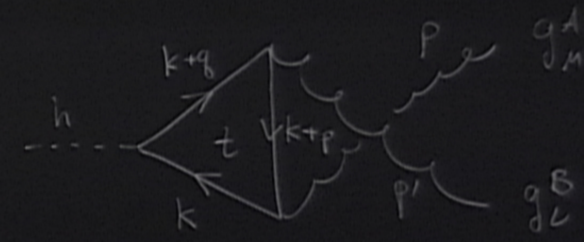
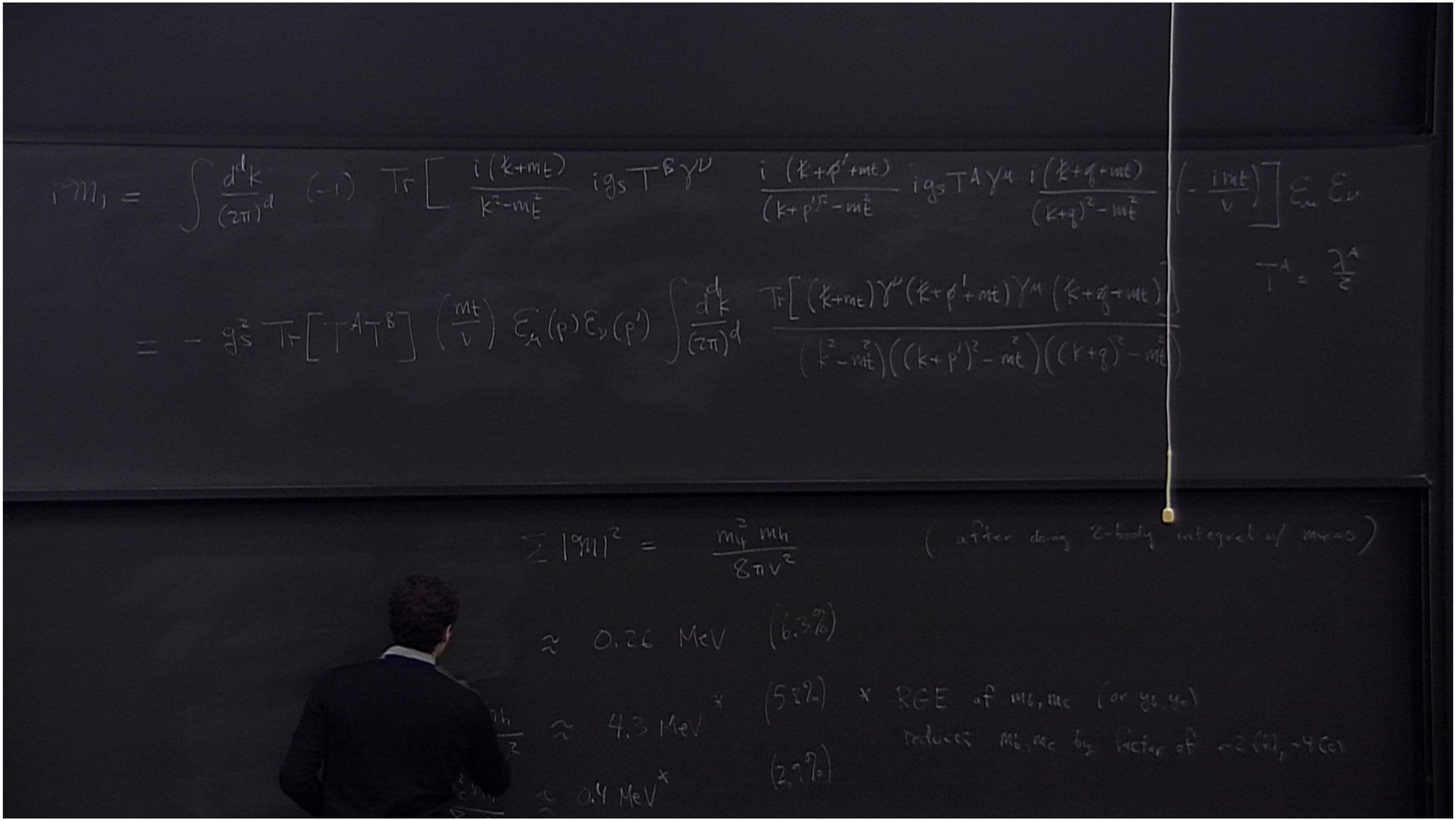



$i\mathcal{M}_1 = \int \frac{d^dk}{(2\pi)^d} (-1)\, \mathrm{Tr}\left[\frac{i(\not k + m_t)}{k^2 - m_t^2}\, i g_s T^B \gamma^\nu\, \frac{i(\not k + \not p' + m_t)}{(k+p')^2 - m_t^2}\, i g_s T^A \gamma^\mu\, \frac{i(\not k + \not q + m_t)}{(k+q)^2 - m_t^2} \left(-\frac{i m_t}{v}\right)\right] \varepsilon_\mu \varepsilon_\nu$
$T^A = \frac{\lambda^A}{2}$
$= -g_s^2\, \mathrm{Tr}[T^A T^B] \left(\frac{m_t}{v}\right) \varepsilon_\mu(p)\varepsilon_\nu(p') \int \frac{d^dk}{(2\pi)^d} \frac{\mathrm{Tr}[(\not k + m_t)\gamma^\nu(\not k + \not p' + m_t)\gamma^\mu(\not k + \not q + m_t)]}{(k^2 - m_t^2)((k+p')^2 - m_t^2)((k+q)^2 - m_t^2)}$
$\sum |\mathcal{M}|^2 = \frac{m_\tau^2 m_h}{8\pi v^2}$
(after doing 2-body integral w/ $m_\tau \to 0$)
≈ 0.26 MeV (6.3%)
≈ 4.3 MeV* (58%) * RGE of m_b, m_c (or y_b, y_c)
reduces m_b, m_c by factor of ~ 2 (b), ~ 4 (c)
≈ 0.4 MeV* (2.9%)

Use Feynman parameters:

$$i\mathcal{M}_1 = -g_s^2\,\mathrm{Tr}\left[T^A T^B\right] \frac{m_t}{v}\,\varepsilon_\mu \varepsilon_\nu$$

$$\times \int dx\,dy\,dz\;2\;\delta(1-x-y-z)\,\frac{\mathrm{Tr}\left[\ldots\right]}{\left[(k^2-m_t^2)x+\left((k+p)^2-m_t^2\right)y+\left((k+q)^2-m_t^2\right)z\right]^3}$$

Use Feynman parameters:

$$\int \frac{d^d k}{(2\pi)^d}$$

$$i\mathcal{M}_1 = -g_s^2 \,\mathrm{Tr}[T^A T^B] \frac{m_t}{v} \varepsilon_\mu \varepsilon_\nu$$

$$\times \int dx\, dy\, dz \;\; 2 \;\; \delta(1-x-y-z) \frac{\mathrm{Tr}[\ldots]}{\left[(k^2-m_t^2)x + ((k\right.}$$

$$= \underbrace{(k + y p' + z q)^2}_{l^2} - (y p' + z q)^2 + m_h^2 z - m_t^2$$

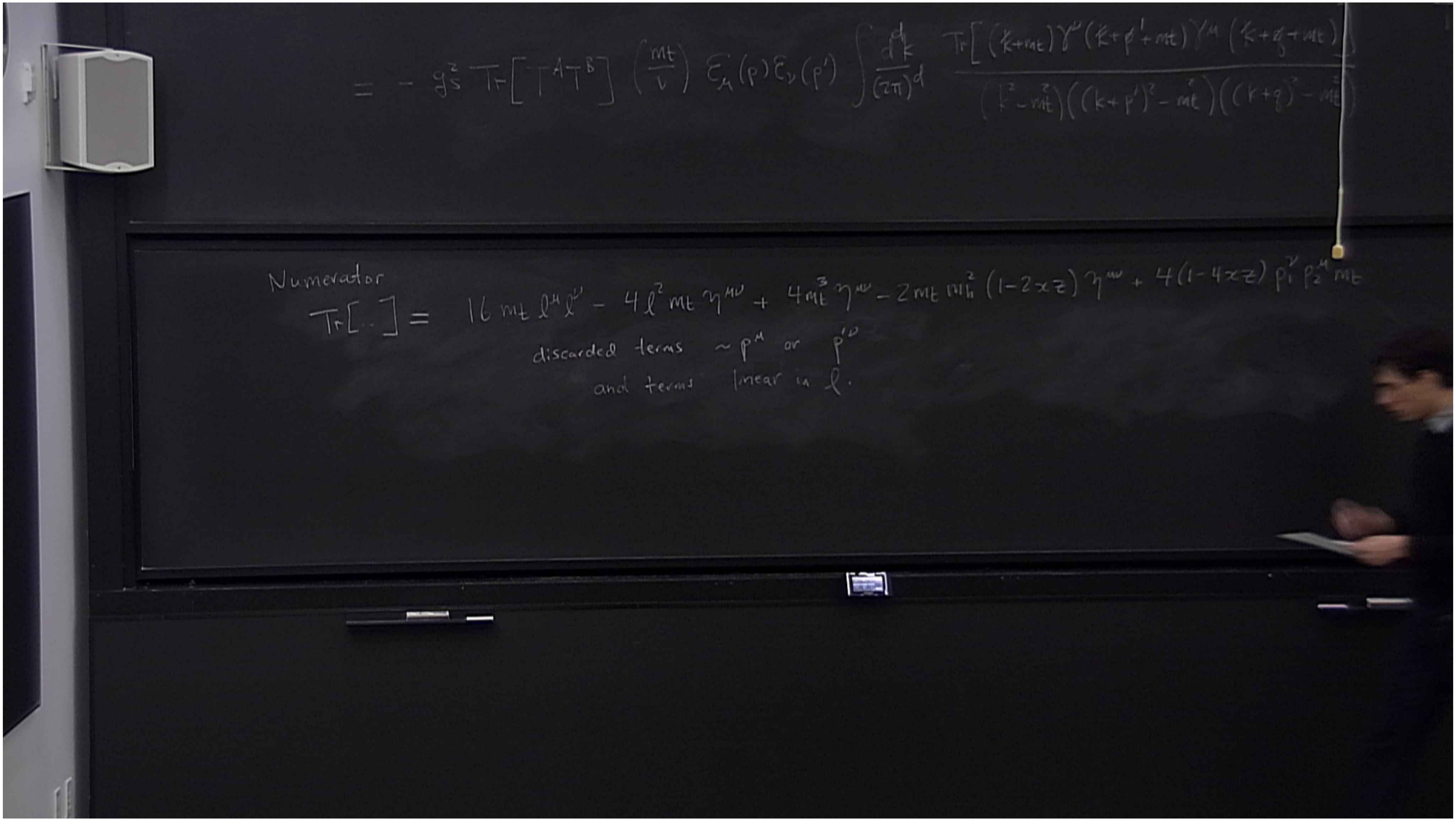
$$= l^2 - \underbrace{\left(z^2 m_h^2 - m_h^2 z + m_t^2 + 2yz\, p' \cdot q \right)}_{M^2}$$

$$p'\cdot q = p'\cdot(p+p') = p\cdot p' = \frac{1}{2}q^2 = \frac{1}{2}m_h^2$$

$$M^2 = m_t^2 + (z^2 - z)m_h^2 + yz\,m_h^2$$

$$= m_t^2 - m_h^2\underbrace{(1-y-z)}_{x}z = m_t^2 - zx\,m_h^2$$

$$l = k + yp' + zq = k + (1-x)p' + zp$$



$= -g_s^2 \, \mathrm{Tr}[T^A T^B] \left(\frac{m_t}{v}\right) \epsilon_\mu(p)\epsilon_\nu(p') \int \frac{d^dk}{(2\pi)^d} \frac{\mathrm{Tr}[(\not{k}+m_t)\gamma^\nu(\not{k}+\not{p}'+m_t)\gamma^\mu(\not{k}+\not{q}+m_t)]}{(k^2-m_t^2)((k+p')^2-m_t^2)((k+q)^2-m_t^2)}$
Numerator
$\mathrm{Tr}[\ldots] = 16 m_t \ell^\mu \ell^\nu - 4\ell^2 m_t \eta^{\mu\nu} + 4m_t^3 \eta^{\mu\nu} - 2m_t m_h^2 (1-2xz)\eta^{\mu\nu} + 4(1-4xz) p_1^\nu p_2^\mu m_t$
discarded terms $\sim p^\mu$ or p'^ν
and terms linear in ℓ.

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In d-dimensions $\quad \ell^\mu \ell^\nu \to \frac{1}{d}\,\eta^{\mu\nu}\ell^2 \quad$ under the integral.

$$\eta^{\mu\nu}\ell_\mu \ell_\nu = \ell^2 = \frac{1}{\cancel{d}}\cancel{d}\,\ell^2$$

$$i\mathcal{M}_1 = -g^2\,\mathrm{Tr}\left[T^A T^B\right]\frac{m_t^2}{v}\,\varepsilon_\mu \varepsilon_\nu$$

$$\times \int \frac{d^d\ell}{(2\pi)^d}\int dx\,dy\,dz\; 2\,\delta(1-x-y-z)\,\frac{1}{\left(\ell^2 - M^2\right)^3}$$

$$\times \left(\left(\frac{16}{d}-4\right)\ell^2\eta^{\mu\nu} + 2\left(2m_t^2 - m_h^2(1-2xz)\right)\eta^{\mu\nu} + 4(1-4xz)\,p_1^\nu p_2^\mu\right)$$

Momentum integrals:

$$(1) = \int \frac{d^d \ell}{(2\pi)^d} \frac{\ell^2}{(\ell^2 - M^2)^3} = \frac{-i}{(4\pi)^{d/2}} \frac{d}{2} \frac{\Gamma(3 - \frac{d}{2} - 1)}{\Gamma(3)} \left(\frac{1}{M^2}\right)^{3 - \frac{d}{2} - 1}$$

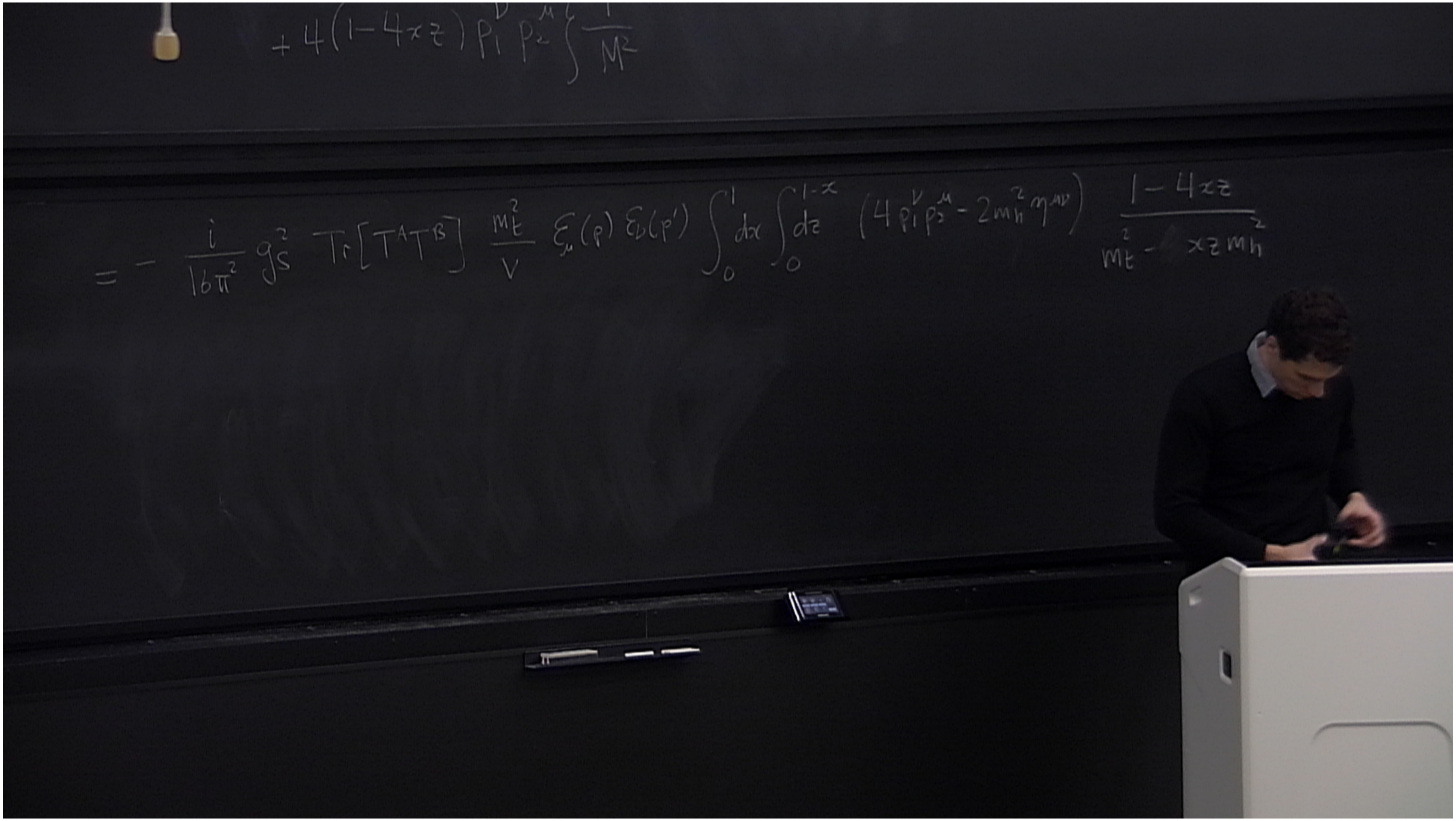
$$(2) = \int \frac{d^d \ell}{(2\pi)^d} \frac{1}{(\ell^2 - M^2)^3} = \frac{i}{(4\pi)^{d/2}} \frac{\Gamma(3 - \frac{d}{2})}{\Gamma(3)} \left(\frac{1}{M^2}\right)^{3 - d/2}$$

$$
i\mathcal{M}_1 = -\frac{i}{16\pi^2}\, g_s^2\, \mathrm{Tr}\left[T^A T^B\right] \frac{m_t^2}{v}\, \varepsilon_\mu \varepsilon_\nu \int_0^1 dx \int_0^{1-x} dz
$$

$$
\times \Big\{ -\cancel{4} \left(\frac{\cancel{4-d}}{\cancel{d}}\right) \frac{2}{\cancel{4-d}}\, 2\left(m_t^2 - xz\, m_h^2\right)\eta^{\mu\nu}
$$

$$
+ \left(4 m_t^2 - 2 m_h^2 + 4xz\, m_h^2\right)\eta^{\mu\nu}
$$

$$
+ 4\left(1 - 4xz\right) p_1^\nu p_2^\mu \Big\} \frac{1}{M^2}
$$


$+4(1-4xz)\,p_1 p_2$
$= -\frac{i}{16\pi^2} g_s^2 \,\mathrm{Tr}[T^A T^B]\, \frac{m_t^2}{v}\, \epsilon_\mu(p)\, \epsilon_\nu(p') \int_0^1 dx \int_0^{1-x} dz \,(4 p_1^\nu p_2^\mu - 2 m_h^2 \eta^{\mu\nu})\, \frac{1-4xz}{m_t^2 - xz m_h^2}$