Title: Lecture - Standard Model, PHYS 622

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Collection/Series: Standard Model (Elective), PHYS 622, January 6 - February 5, 2025

Subject: Particle Physics

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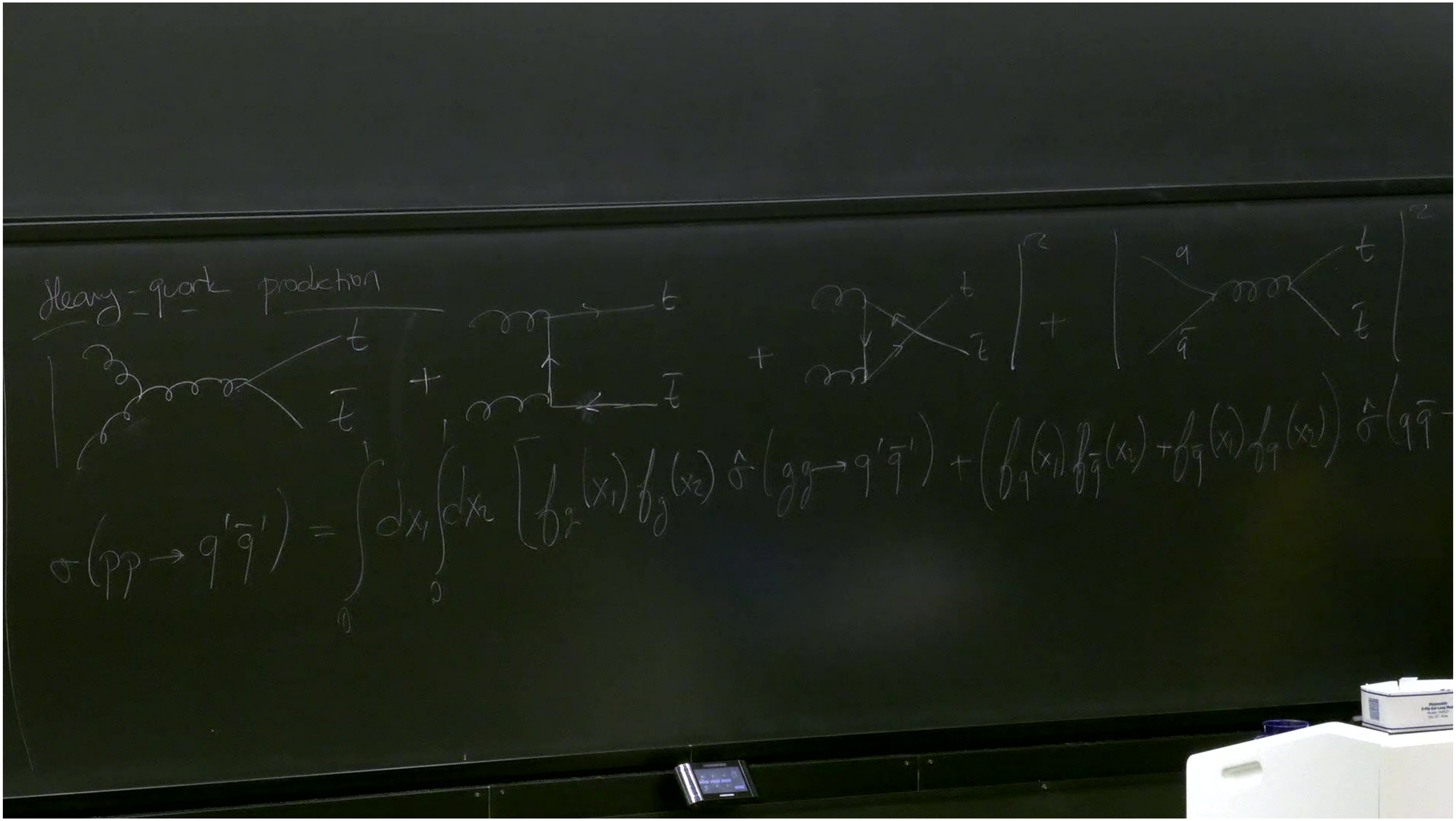
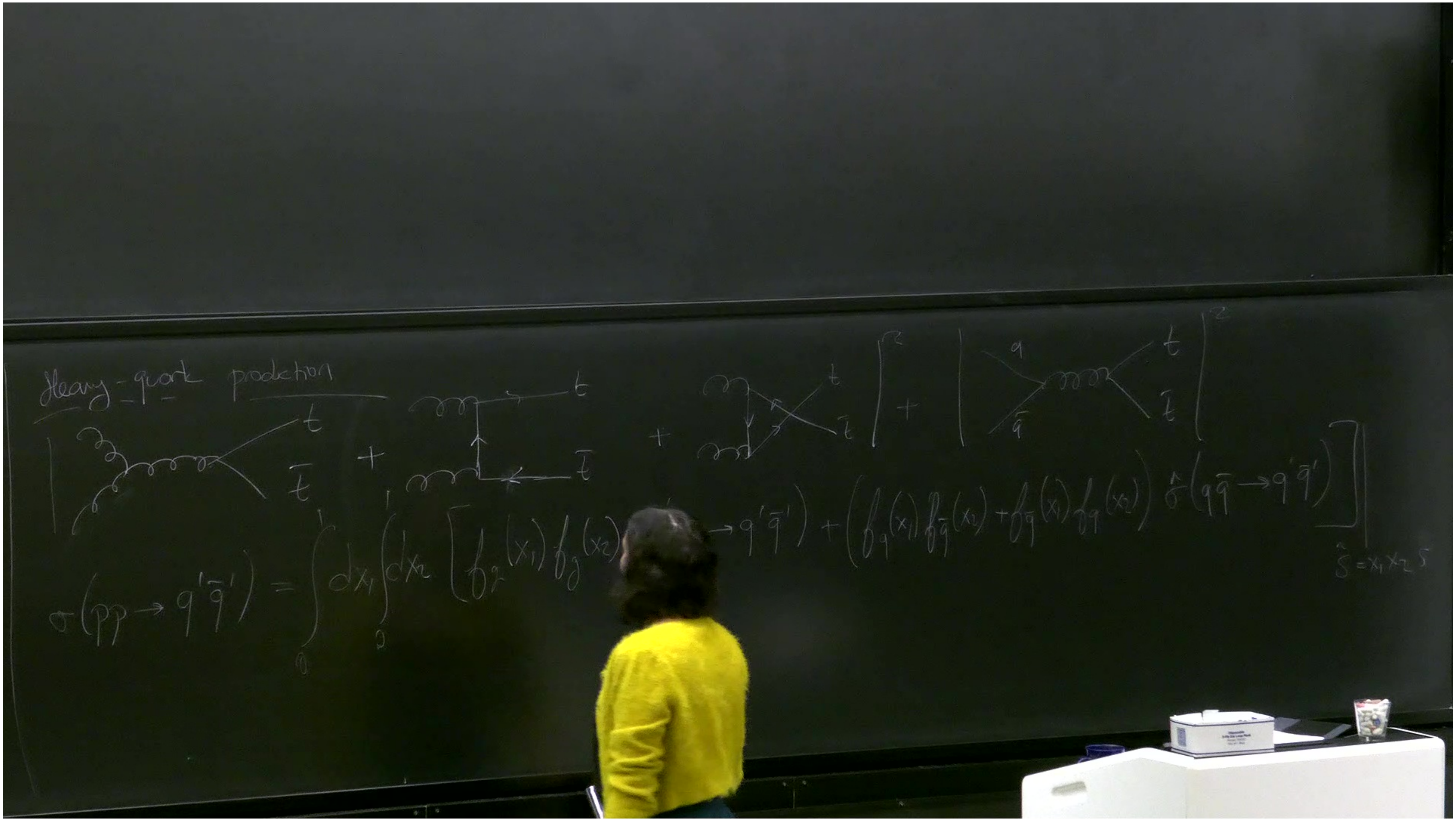
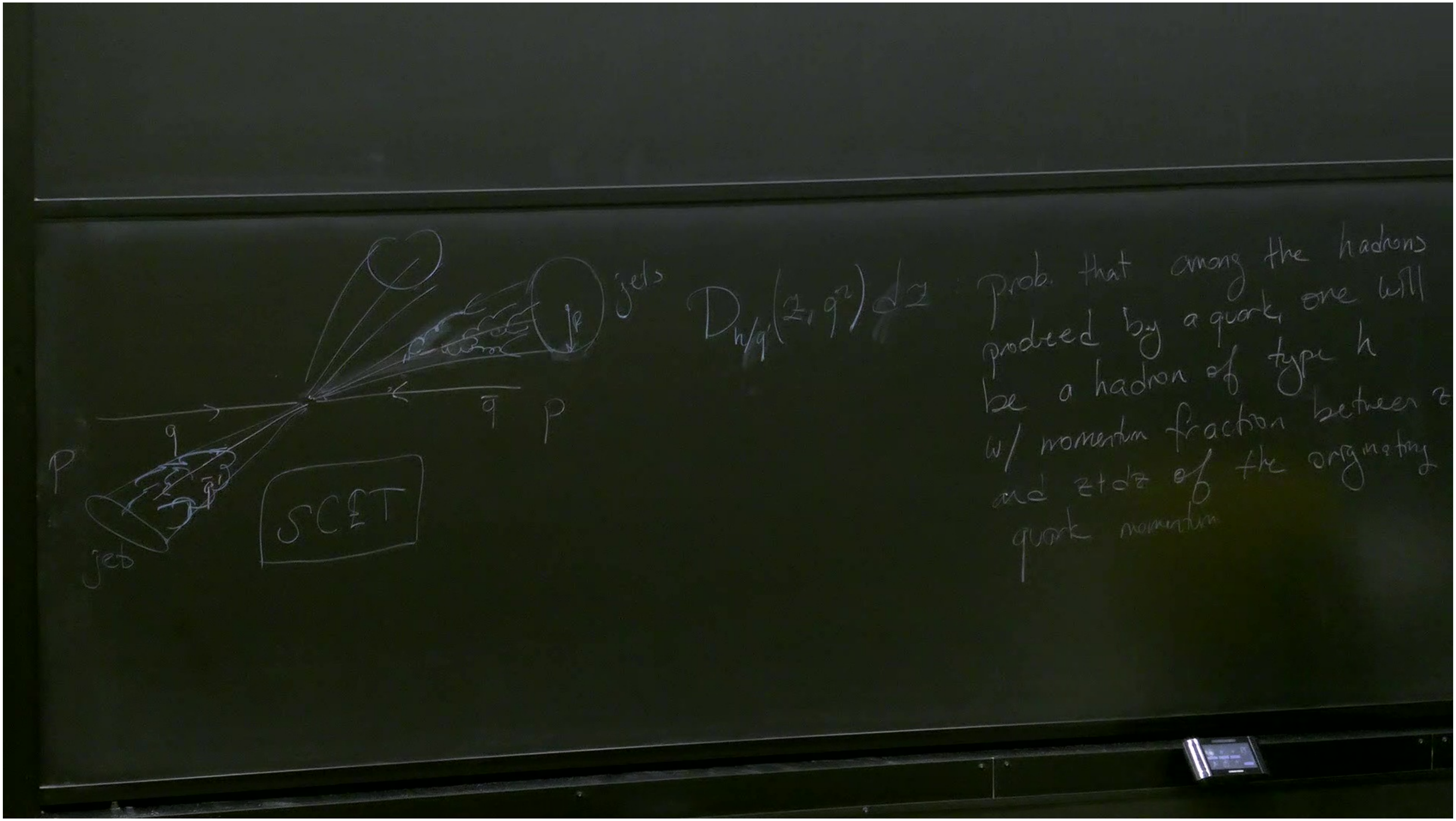
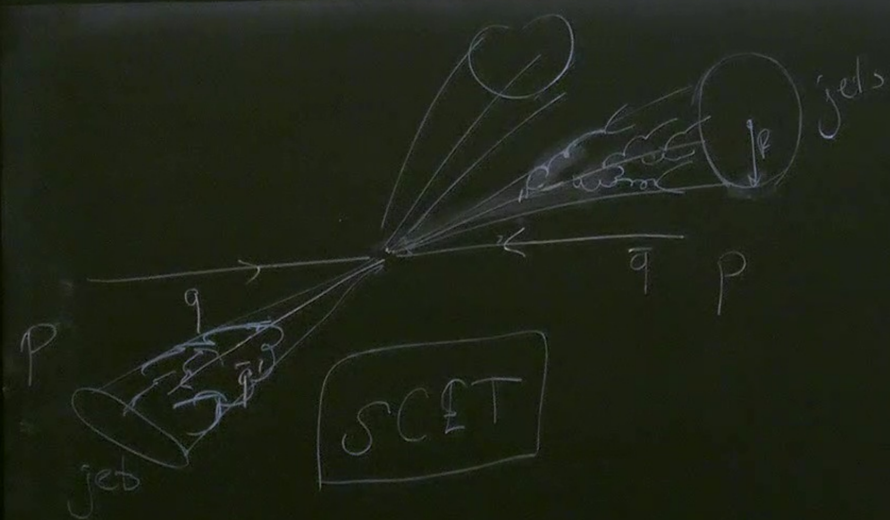

Heavy-quark production
t
t̄
+
t
t̄
+
t
t̄
+
q
q̄
t
t̄
σ(pp → q'q̄') = ∫₀¹ dx₁ ∫₀¹ dx₂ [f_g(x₁) f_g(x₂) σ̂(gg → q'q̄') + (f_q(x₁) f_q̄(x₂) + f_q̄(x₁) f_q(x₂)) σ̂(qq̄


Heavy-quark production
σ(pp → q'q̄') = ∫dx1 ∫dx2 [f_g(x1) f_g(x2) ... → q'q̄') + (f_q(x1) f_q̄(x2) + f_q̄(x1) f_q(x2)) σ̂(qq̄ → q'q̄')]
ŝ = x1 x2 s


jets
jet
p
q
q̄
p
SCET
$D_{h/q}(z, q^2)\, dz$: prob. that among the hadrons produced by a quark, one will be a hadron of type h w/ momentum fraction between z and z+dz of the originating quark momentum



$D_{h/q}(z, q^2)\,dz$: prob. that among the hadrons produced by a quark, one will be a hadron of type h w/ momentum fraction between z and z+dz of the originating quark momentum

fragmentation function.

measured, mostly in e^+e^- collisions

jets

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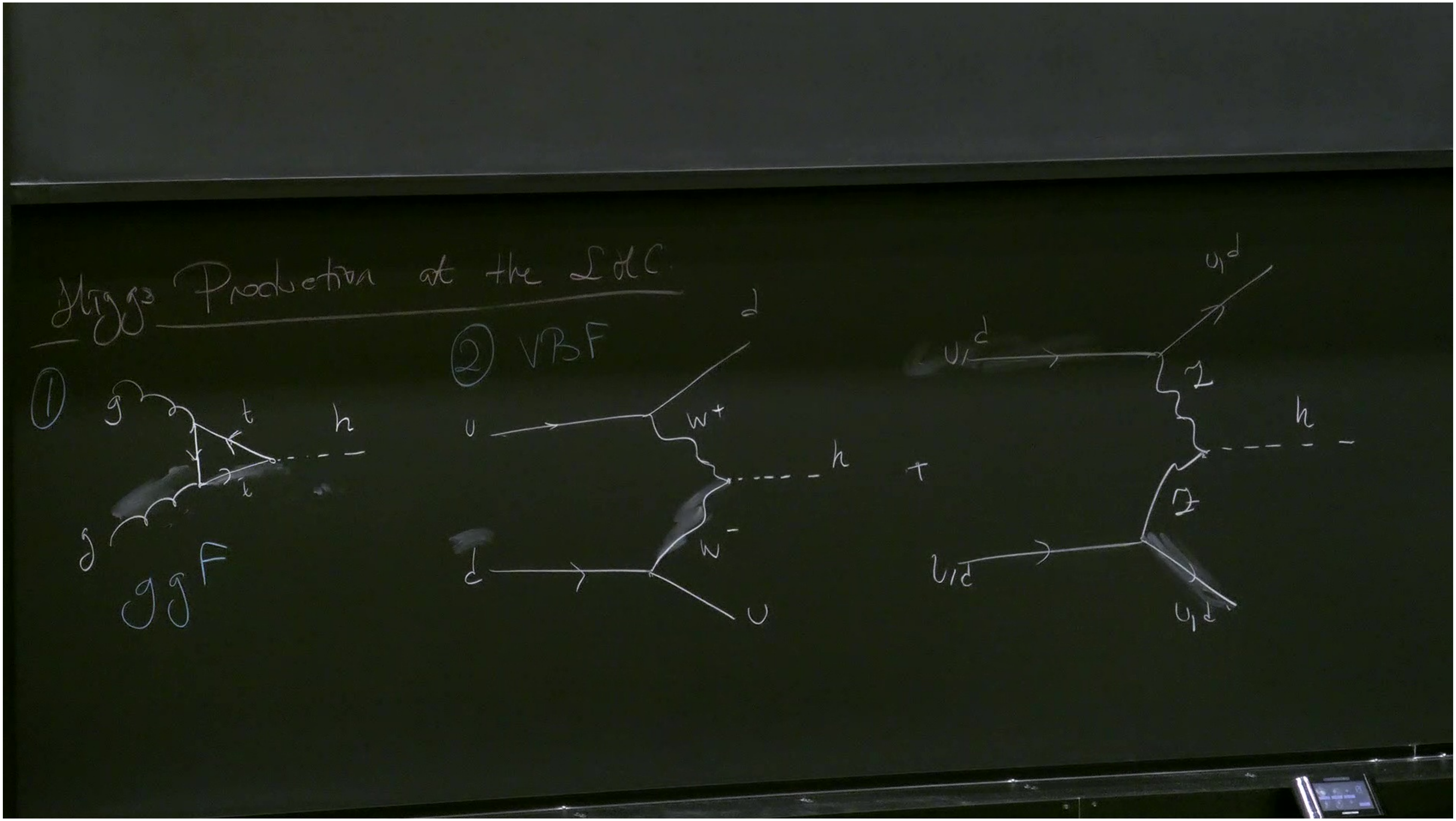
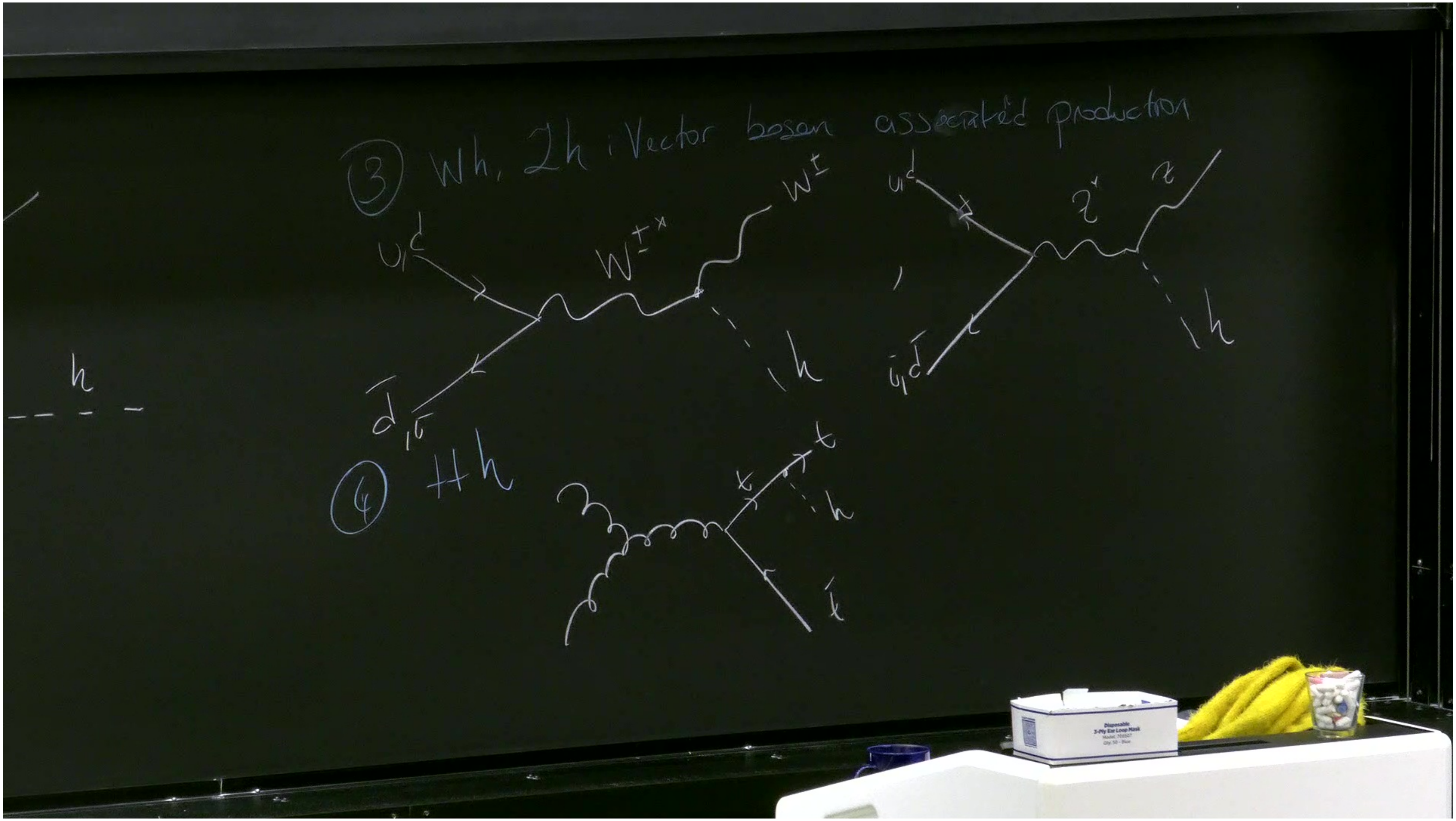
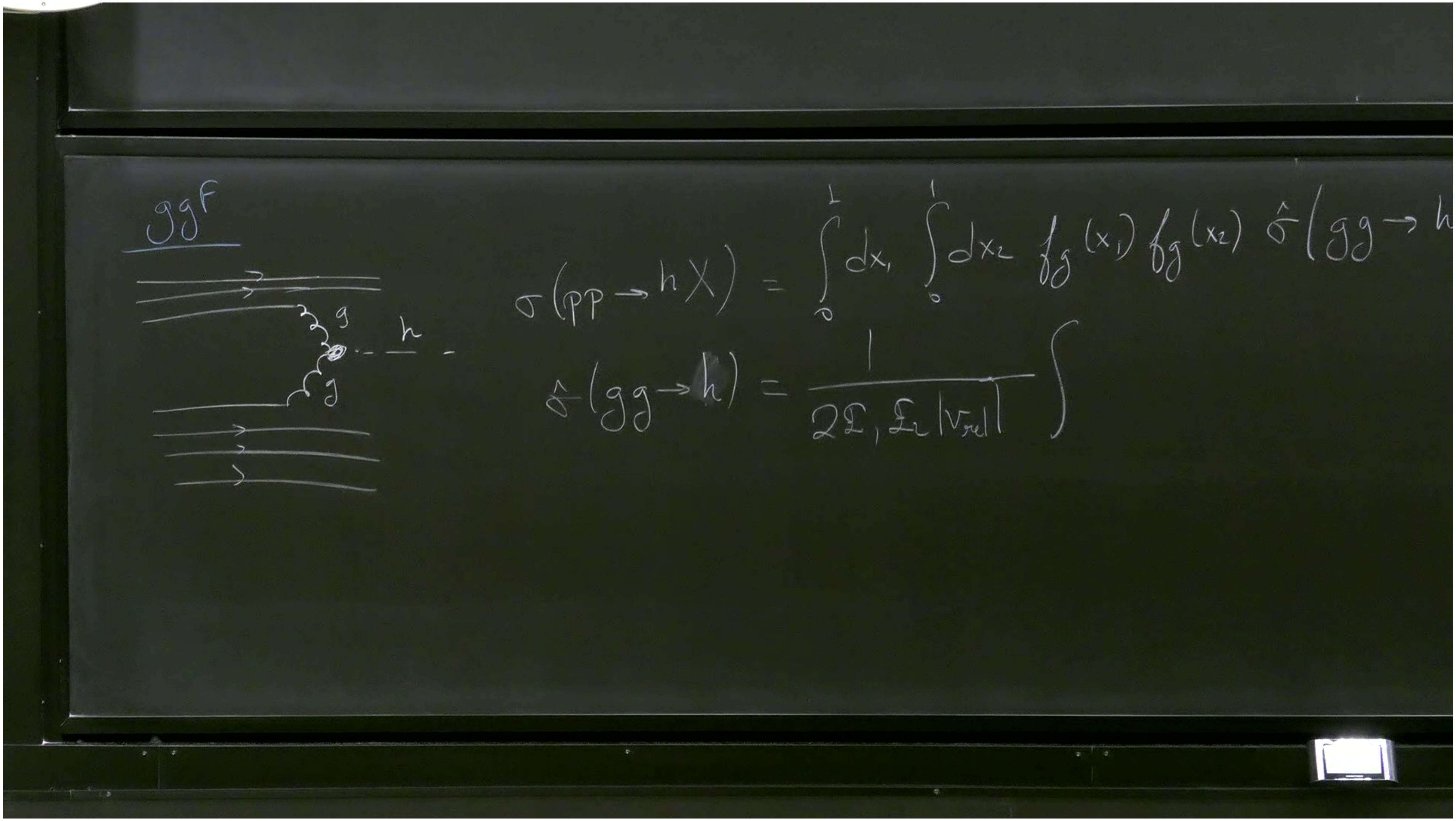

Higgs Production at the LHC
① ggF
g
t
h
g
② VBF
u
d
W+
W−
h
d
u
+
u,d
Z
Z
h
u,d
u,d
u,d


③ Wh, Zh : Vector boson associated production
$W^{\pm *}$
$W^{\pm}$
u, d
$\bar{d}, \bar{u}$
h
Z^*
Z
④ tth
t
$\bar{t}$


ggF
g
h
g
$\sigma(pp \to hX) = \int_0^1 dx_1 \int_0^1 dx_2\, f_g(x_1) f_g(x_2)\, \hat{\sigma}(gg \to h$
$\hat{\sigma}(gg \to h) = \frac{1}{2E_1 E_2 |v_{rel}|} \int$

$$f_g(x_1)\, f_g(x_2)\, \hat{\sigma}(gg \to h)$$

$$\int \frac{d^3 q}{(2\pi)^3} \frac{1}{2E_q} (2\pi)^4 \delta^4(q - p_1 - p_2) \frac{1}{8^2} \cdot \frac{1}{2^2} \sum |\mathcal{M}(gg \to h)|$$

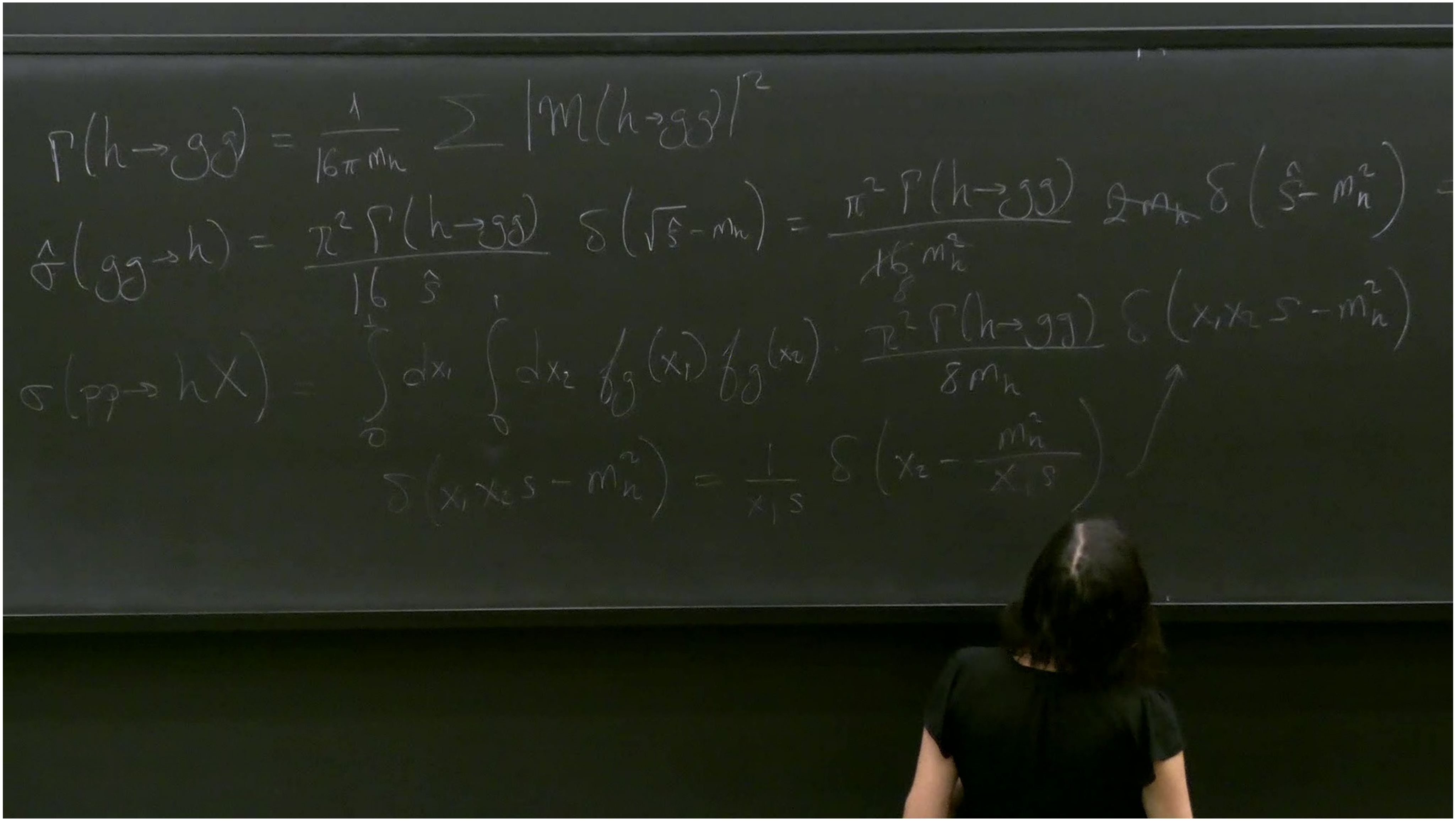
$$\cdot 2 \sum |\mathcal{M}(h \to gg)|^2$$

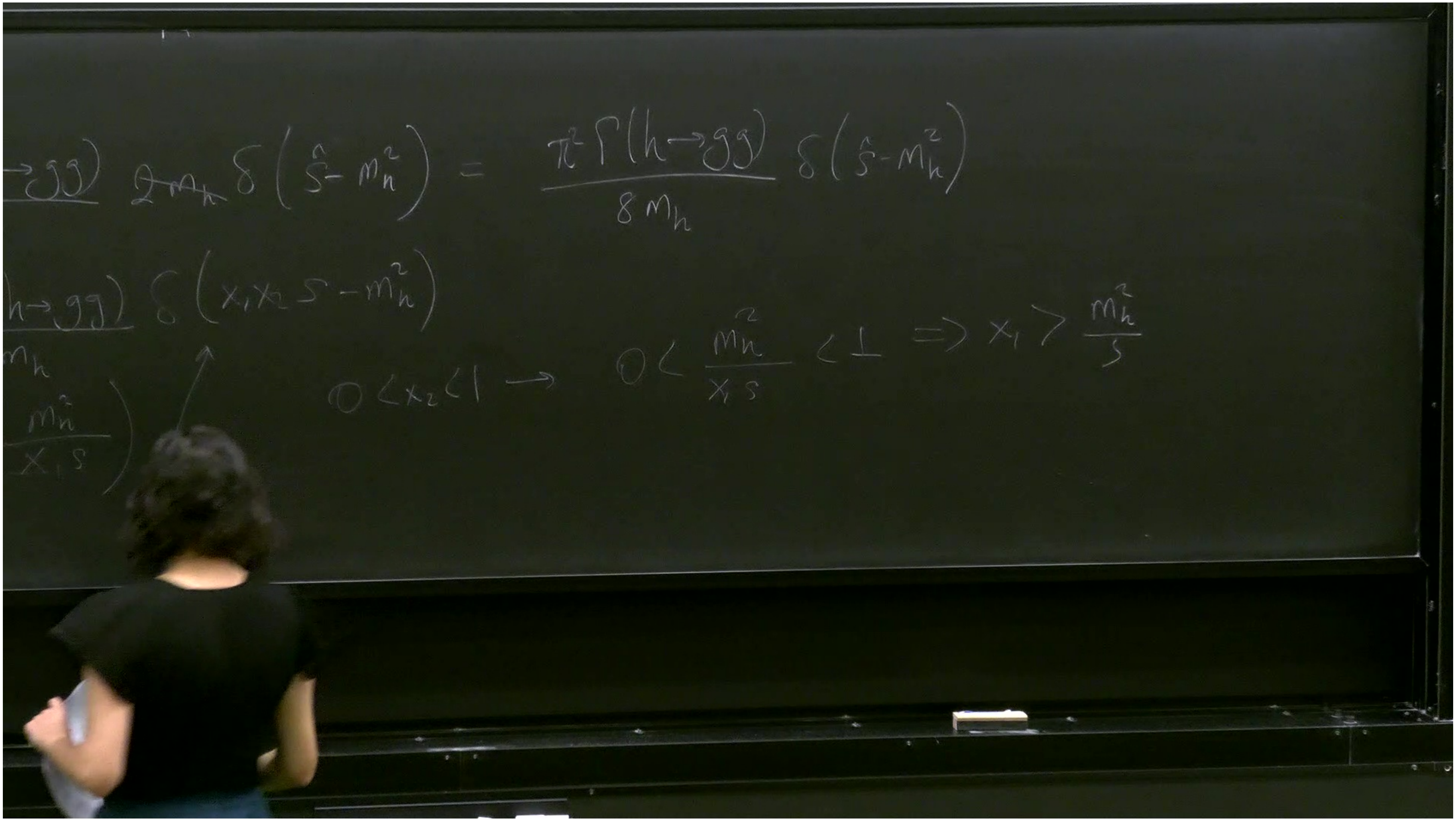
$$\hat{\sigma}(gg \to h) = \frac{1}{2\hat{s}} \frac{1}{2m_h} (2\pi)\, \delta(m_h - \underbrace{E_1 - E_2}_{\sqrt{\hat{s}}}) \frac{1}{(16)^2}$$

$$\Gamma(h \to gg) = \frac{1}{16\pi m_h} \sum |\mathcal{M}(h \to gg)|^2$$

$$\hat{\sigma}(gg \to h) = \frac{\pi^2 \Gamma(h \to gg)}{16\, \hat{s}} \delta\left(\sqrt{\hat{s}} - m_h\right) = \frac{\pi^2 \Gamma(h \to gg)}{\cancel{16}_{8}\, m_h^2} \cancel{2 m_h}\, \delta\left(\hat{s} - m_h^2\right) =$$

$$\cancel{2 m_h}\, \delta\left(\hat{s} - m_h^2\right) = \frac{\pi^2 \Gamma(h \to gg)}{8 m_h}\, \delta\left(\hat{s} - m_h^2\right)$$


$\Gamma(h\to gg) = \frac{1}{16\pi m_h} \sum |\mathcal{M}(h\to gg)|^2$
$\hat{\sigma}(gg\to h) = \frac{\pi^2 \Gamma(h\to gg)}{16\,\hat{s}} \delta(\sqrt{\hat{s}} - m_h) = \frac{\pi^2 \Gamma(h\to gg)}{8\, m_h^2} 2m_h\, \delta(\hat{s} - m_h^2) =$
$\sigma(pp\to hX) = \int_0^1 dx_1 \int_0^1 dx_2\, f_g(x_1) f_g(x_2) \cdot \frac{\pi^2 \Gamma(h\to gg)}{8 m_h} \delta(x_1 x_2 s - m_h^2)$
$\delta(x_1 x_2 s - m_h^2) = \frac{1}{x_1 s} \delta\left(x_2 - \frac{m_h^2}{x_1 s}\right)$


→gg) 2mh δ(ŝ − mh²) = π² Γ(h→gg) / 8mh δ(ŝ − mh²)
h→gg) δ(x1x2 s − mh²)
mh
mh² / x1 s
0 < x2 < 1 → 0 < mh² / x1 s < 1 ⇒ x1 > mh² / s

$$\delta(x_1 x_2 s - m_h^2) = \frac{1}{x_1 s}\,\delta\left(x_2 - \frac{m_h^2}{x_1 s}\right)$$

$$\sigma(pp \to hX) = \int_{m_h^2/s}^{1} \frac{dx_1}{x_1}\, f_g(x_1)\, f_g\!\left(\frac{m_h^2}{x_1 s}\right) \frac{\pi^2\, \Gamma(h \to gg)}{8 m_h s}$$

$$f_g(x) = \frac{8}{x}(1-x)^7 \qquad \text{(fit to data)}$$

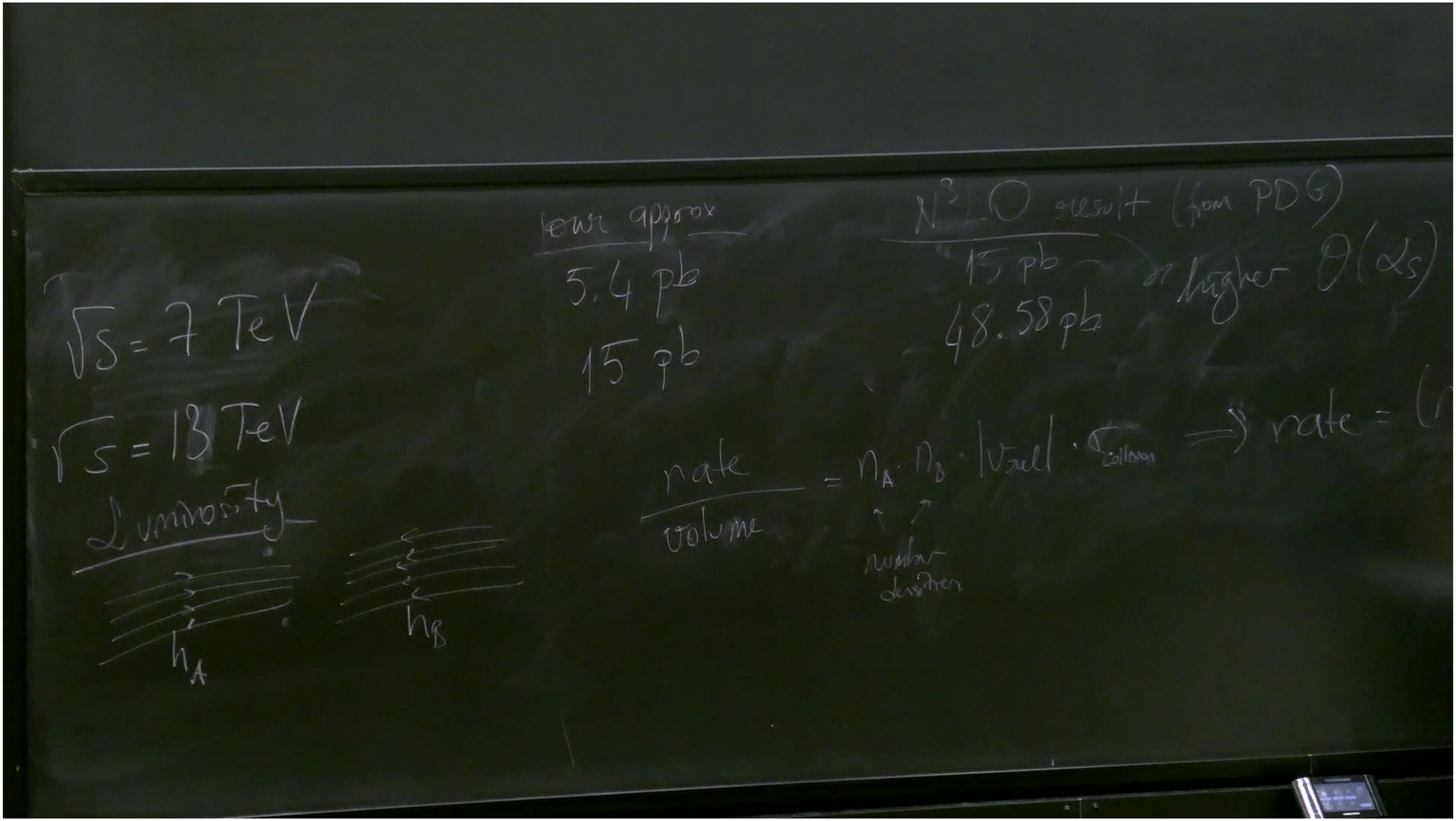
$$\Gamma(h \to gg) = \frac{\alpha_s^2 m_h^3}{64 \pi^3 v^2} \qquad \text{for } m_t \gg m_h$$

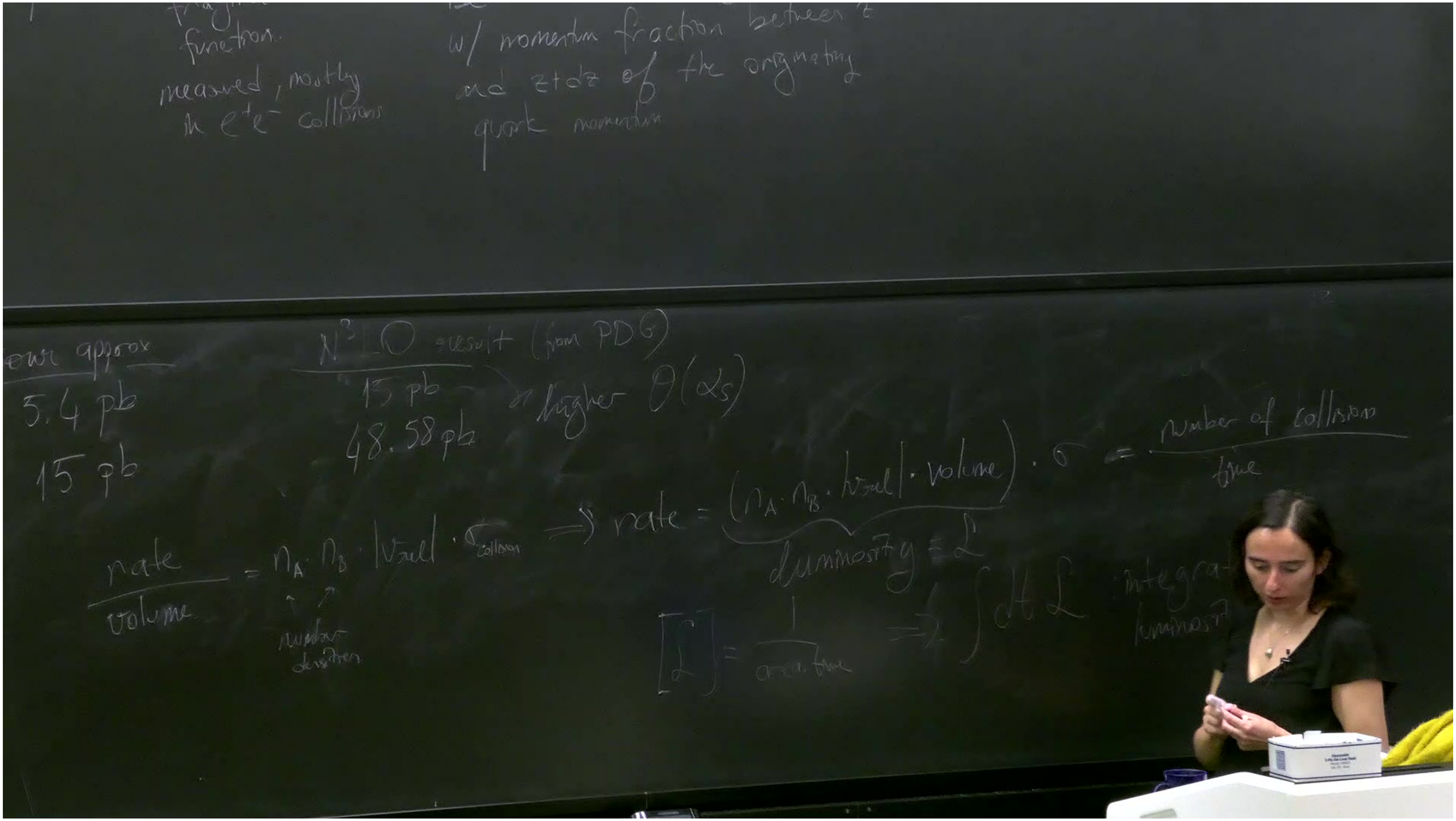
$$\left(\text{for } m_q \ll m_h,\ |M|^2 \sim m_q\right)$$

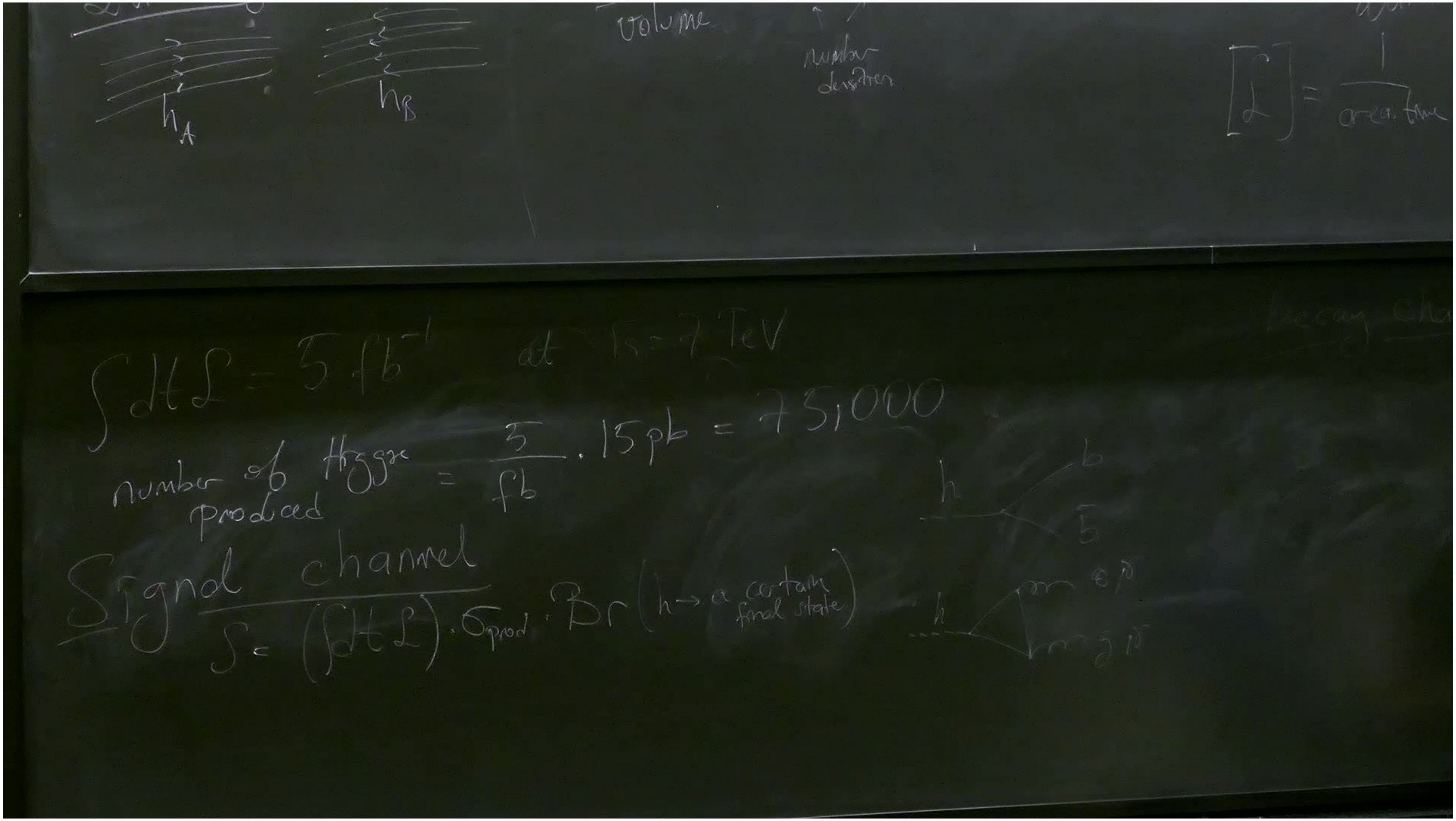
$\frac{m_h^2}{s} \ll 1$:

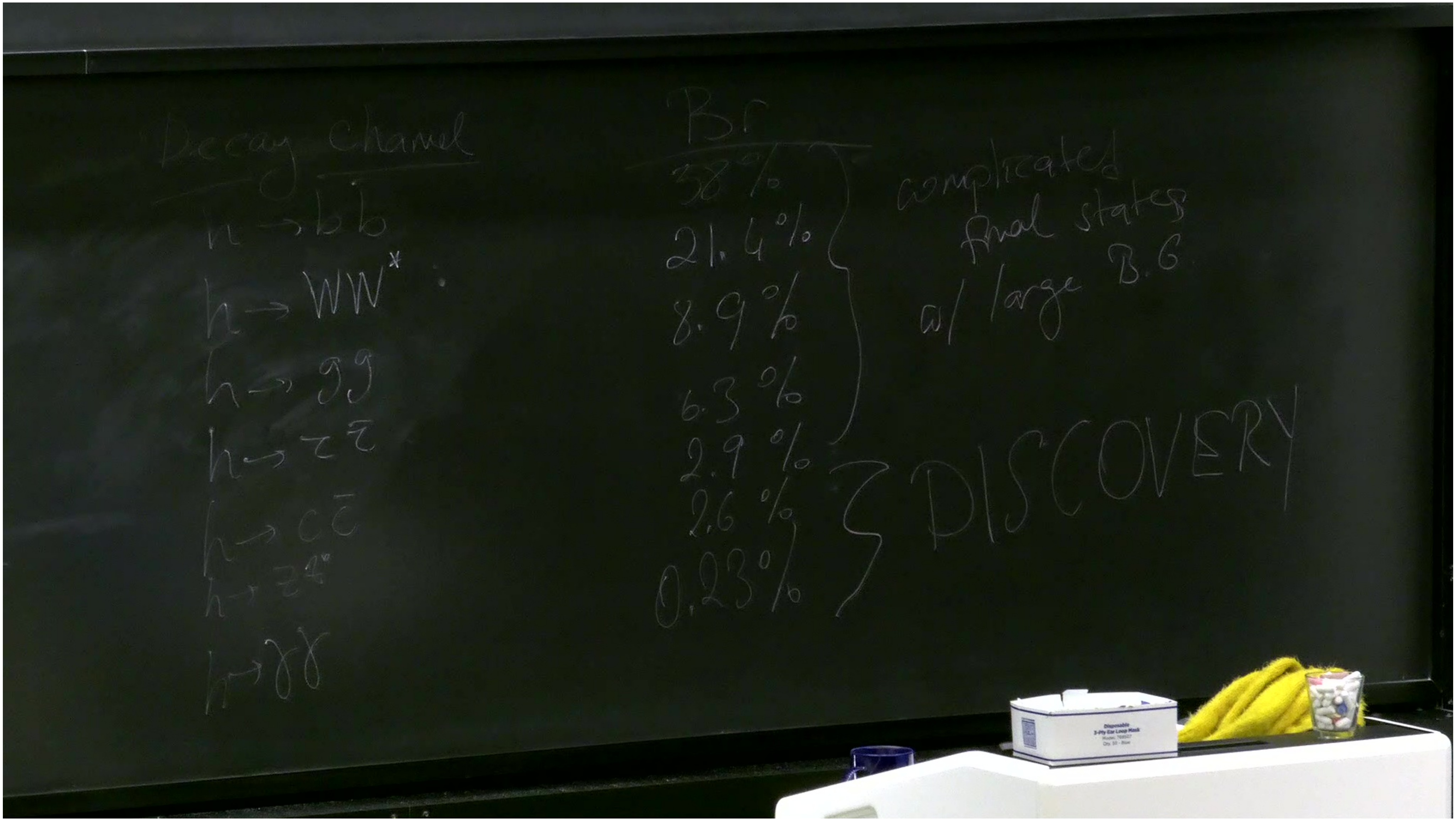
$$\int_{m_h^2/s}^{1} \frac{dx}{x} \frac{8}{x} (1-x)^7 \frac{8sx}{m_h^2} \left(1 - \frac{m_h^2}{sx}\right)^7 \simeq \left[\ln\left(\frac{s}{m_h^2}\right) - 5\right] \frac{64\, s}{m_h^2}$$

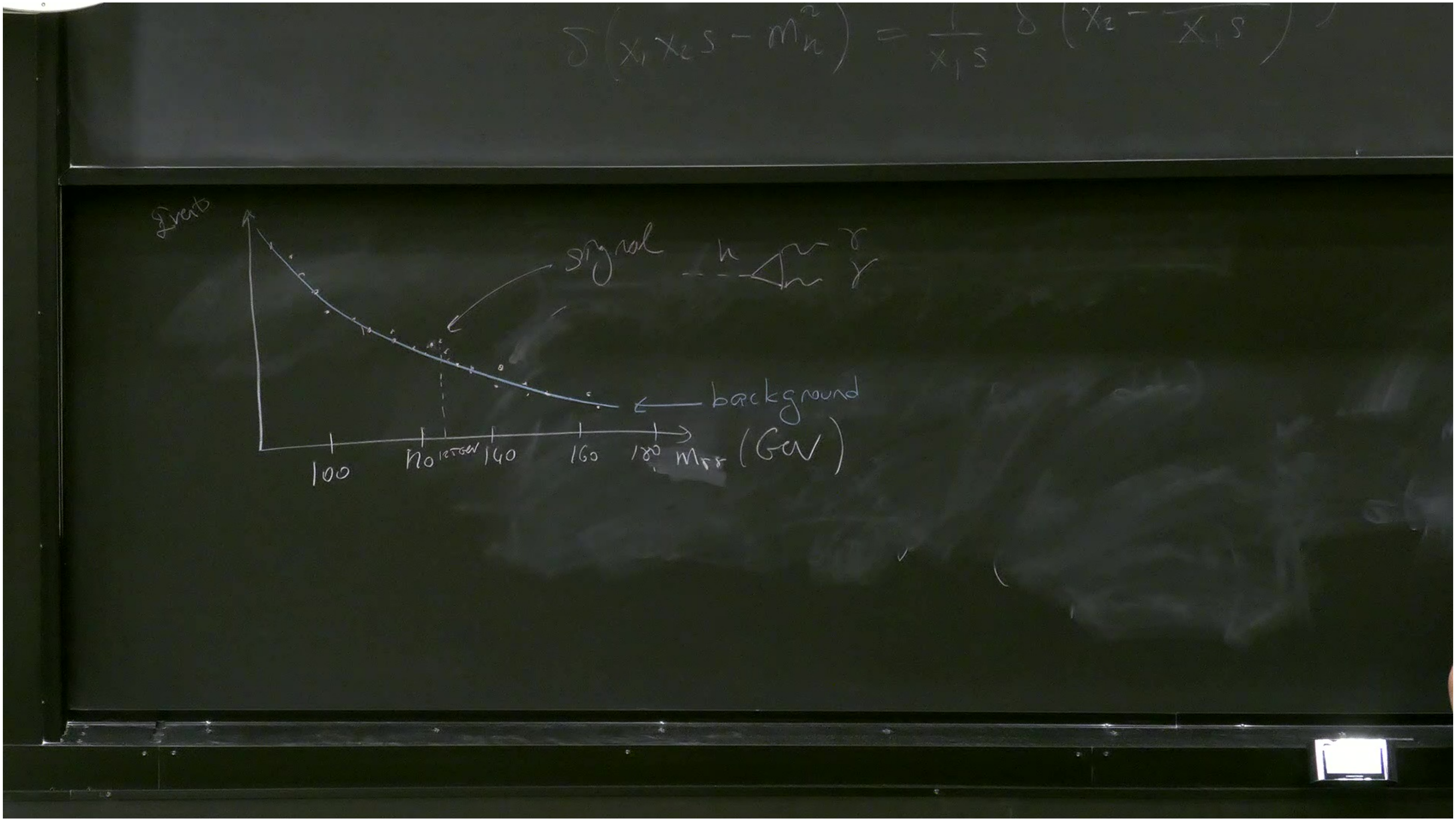
$$\sigma(pp \to hX) \simeq \frac{\alpha_s^2}{8\pi v^2} \left(\ln\left(\frac{s}{m_h^2}\right) - 5\right)$$


√s = 7 TeV
√s = 13 TeV
Luminosity
n_A
n_B
lowest approx
5.4 pb
15 pb
N^3LO result (from PDG)
15 pb
48.58 pb
higher O(αs)
rate / volume = n_A · n_B · |v_rel| · σ_collision ⟹ rate =
number densities

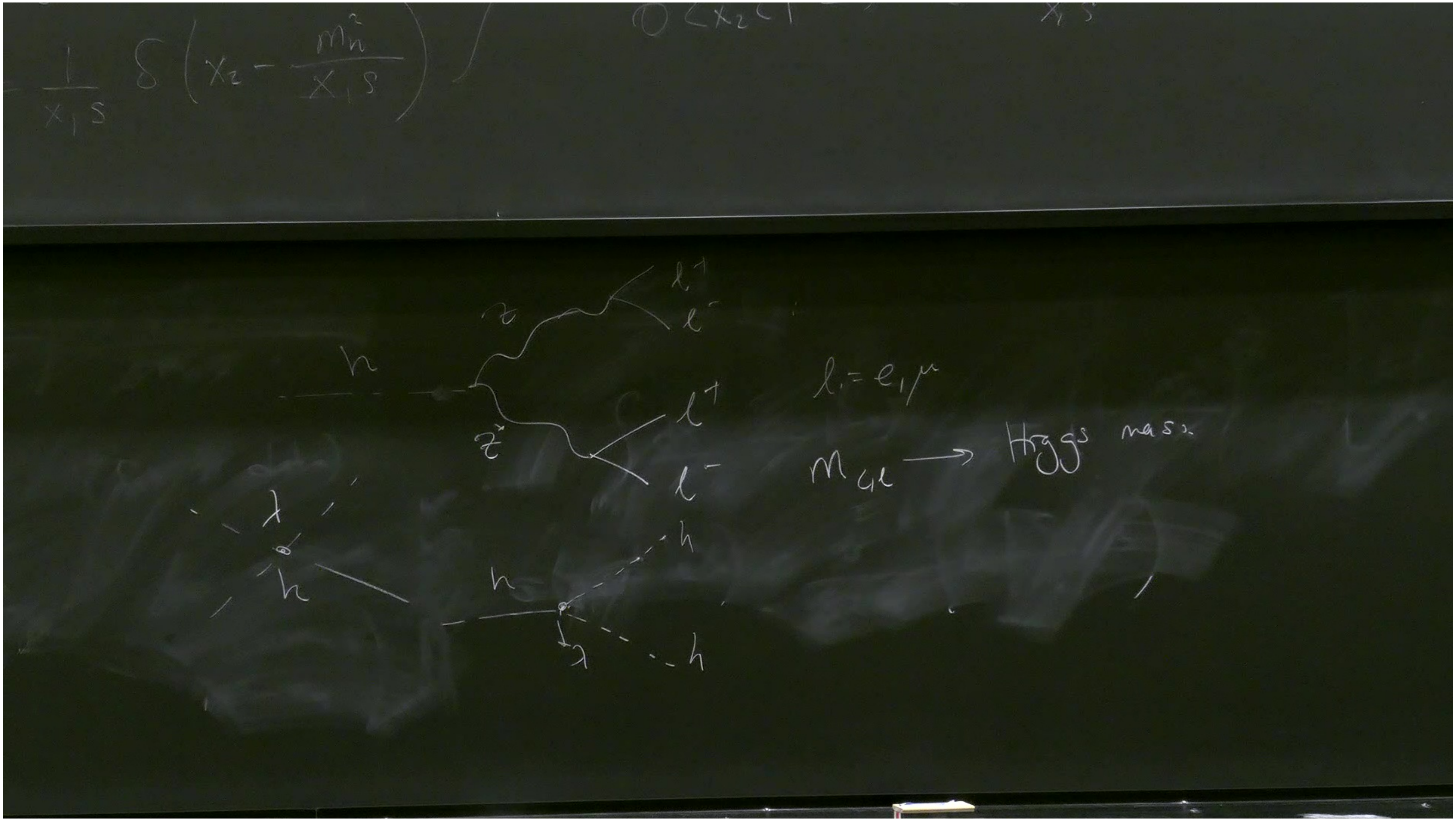

function.
measured, mostly
in e+e- collisions
w/ momentum fraction between z
and z+dz of the originating
quark momentum
N3LO result (from PDG)
5.4 pb
15 pb
15 pb
48.58 pb
higher O(αs)
number of collisions
time
rate
volume
= nA · nB · |vrel| · σcollision
number densities
⟹ rate = (nA · nB · |vrel| · volume) · σ
luminosity = L
[L] = 1 / area · time
⟹ ∫ dt L
integrat
luminosi


volume
number densities
h_A
h_B
$[\mathcal{L}] = \frac{1}{\text{area} \cdot \text{time}}$
$\int dt \mathcal{L} = 5 fb^{-1}$ at $\sqrt{s} = 7$ TeV
number of Higgs produced $= \frac{5}{fb} \cdot 15 pb = 75{,}000$
Signal channel
$S = (\int dt \mathcal{L}) \cdot \sigma_{prod} \cdot Br(h \to$ a certain final state$)$
h
b
$\bar{b}$


Decay chanel
Br
h → bb̄
58%
h → WW*
21.4%
h → gg
8.9%
h → ττ̄
6.3%
h → cc̄
2.9%
h → ZZ*
2.6%
h → γγ
0.23%
complicated final states w/ large B.G
DISCOVERY



$\delta(x_1 x_2 s - m_h^2) = \frac{1}{x_1 s}\,\delta\left(x_2 - \frac{\quad}{x_1 s}\right)$
Events
signal
h
γ
γ
background
100
120
125 GeV
140
160
180
$m_{\gamma\gamma}$ (GeV)


h
Z
Z*
l+
l-
l = e, μ
m4l → Higgs mass
λ