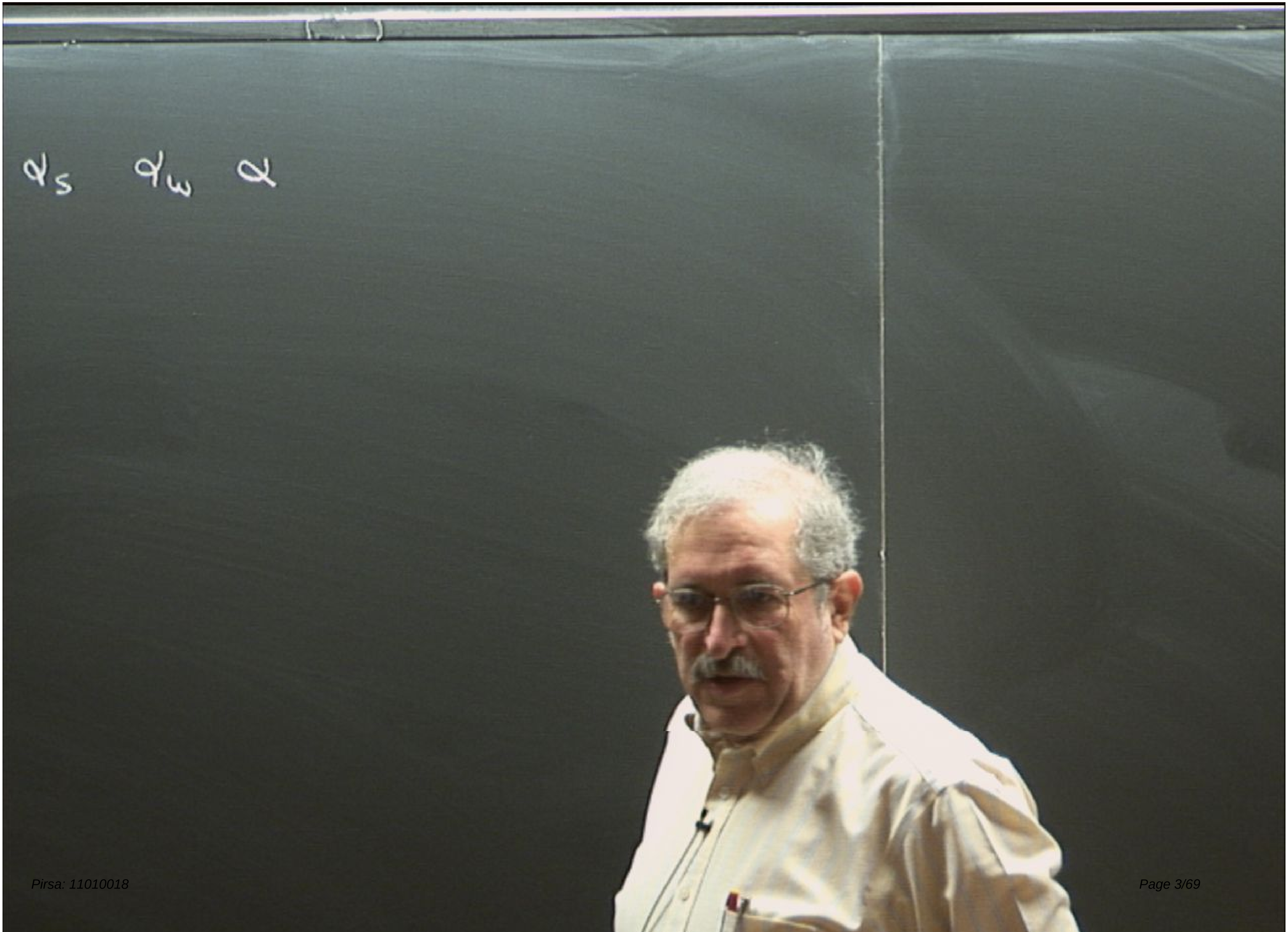
Title: Standard Model - Lecture 15

Date: Jan 21, 2011 09:00 AM

URL: http://pirsa.org/11010018

Abstract:

perimeter scholars
international


α_s α_w α

$\alpha_s \quad \alpha_w \quad \alpha$

λ^{ij}_f

$18 \times 3 \longrightarrow$

$\alpha_s \quad \alpha_w \quad \alpha$

λ^{ij}_f

$18 \times 3 \longrightarrow$ masses, 4 CKM angles.

$\alpha_s \quad \alpha_w \quad \alpha$

λ_f^{ij}

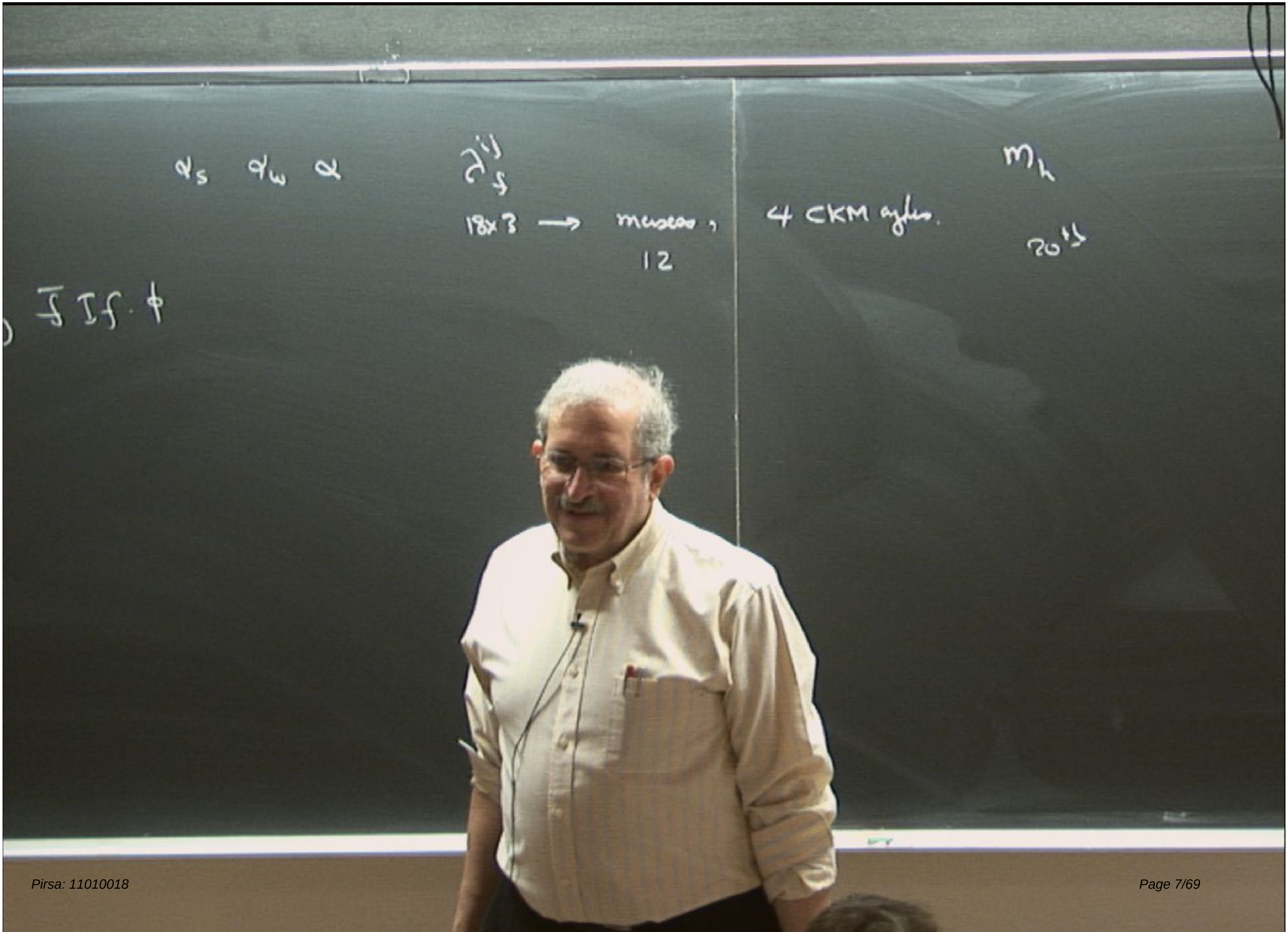
$18 \times 3 \longrightarrow$ masses, 12

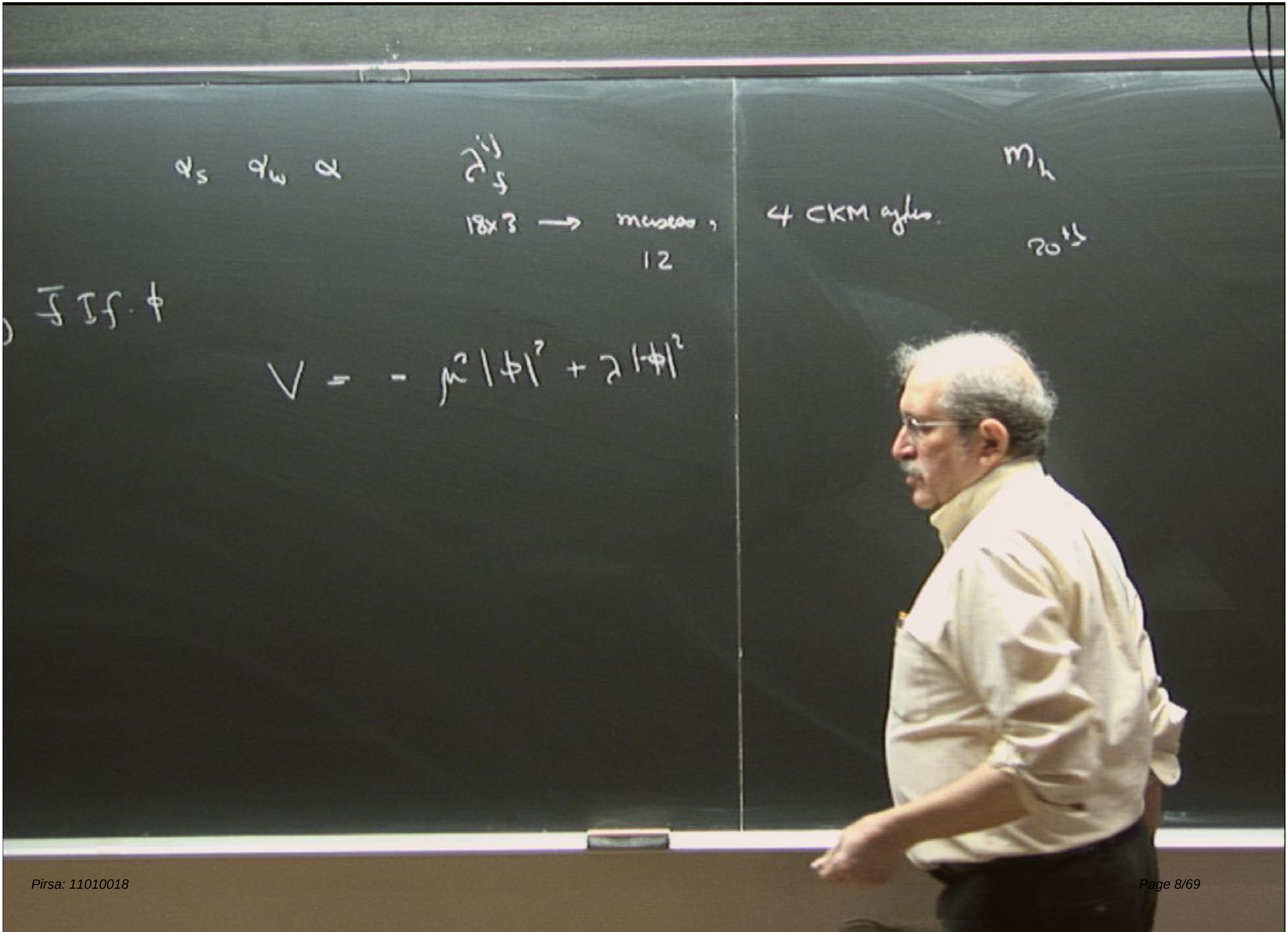
4 CKM angles.

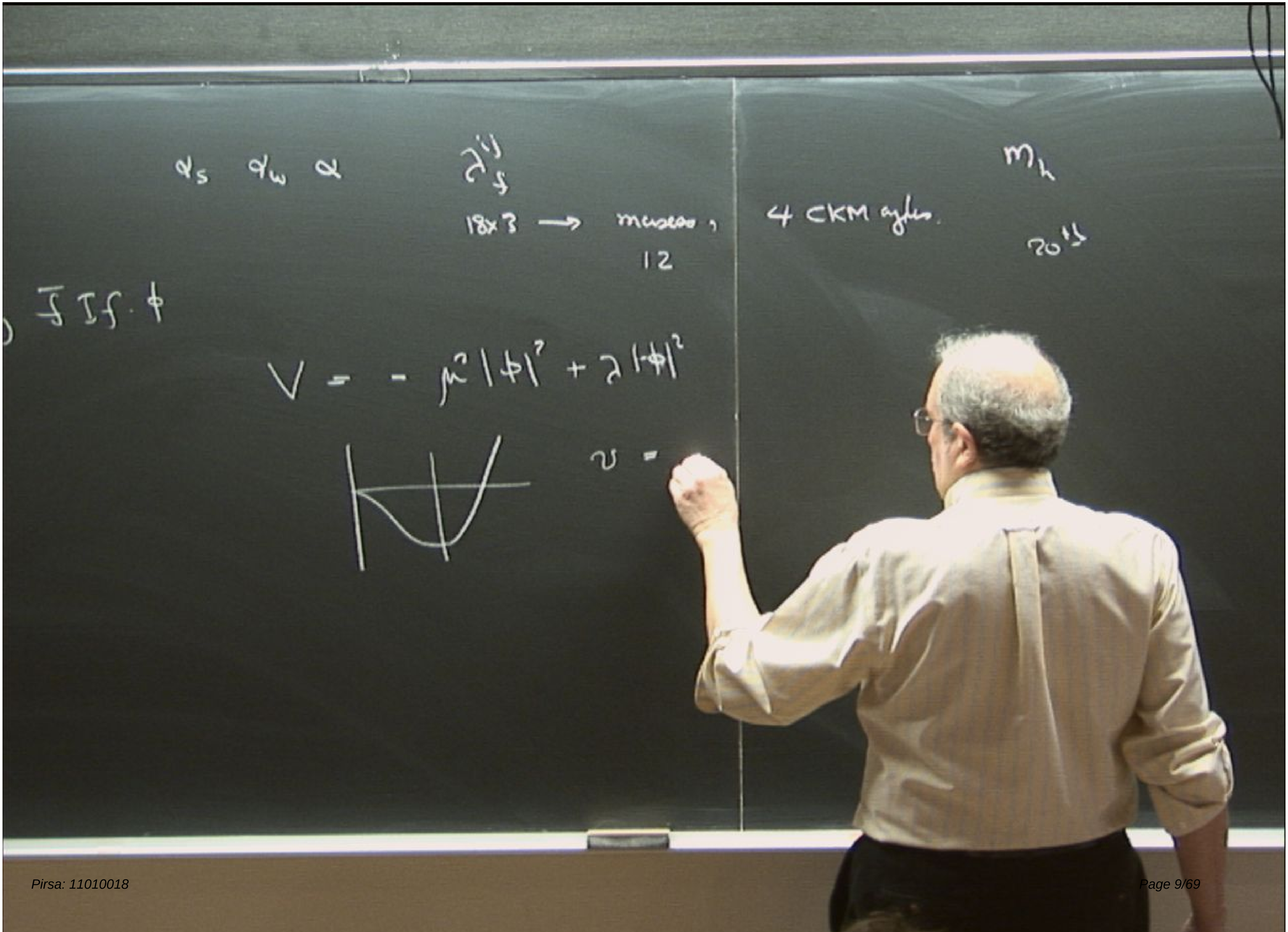
m_h

20

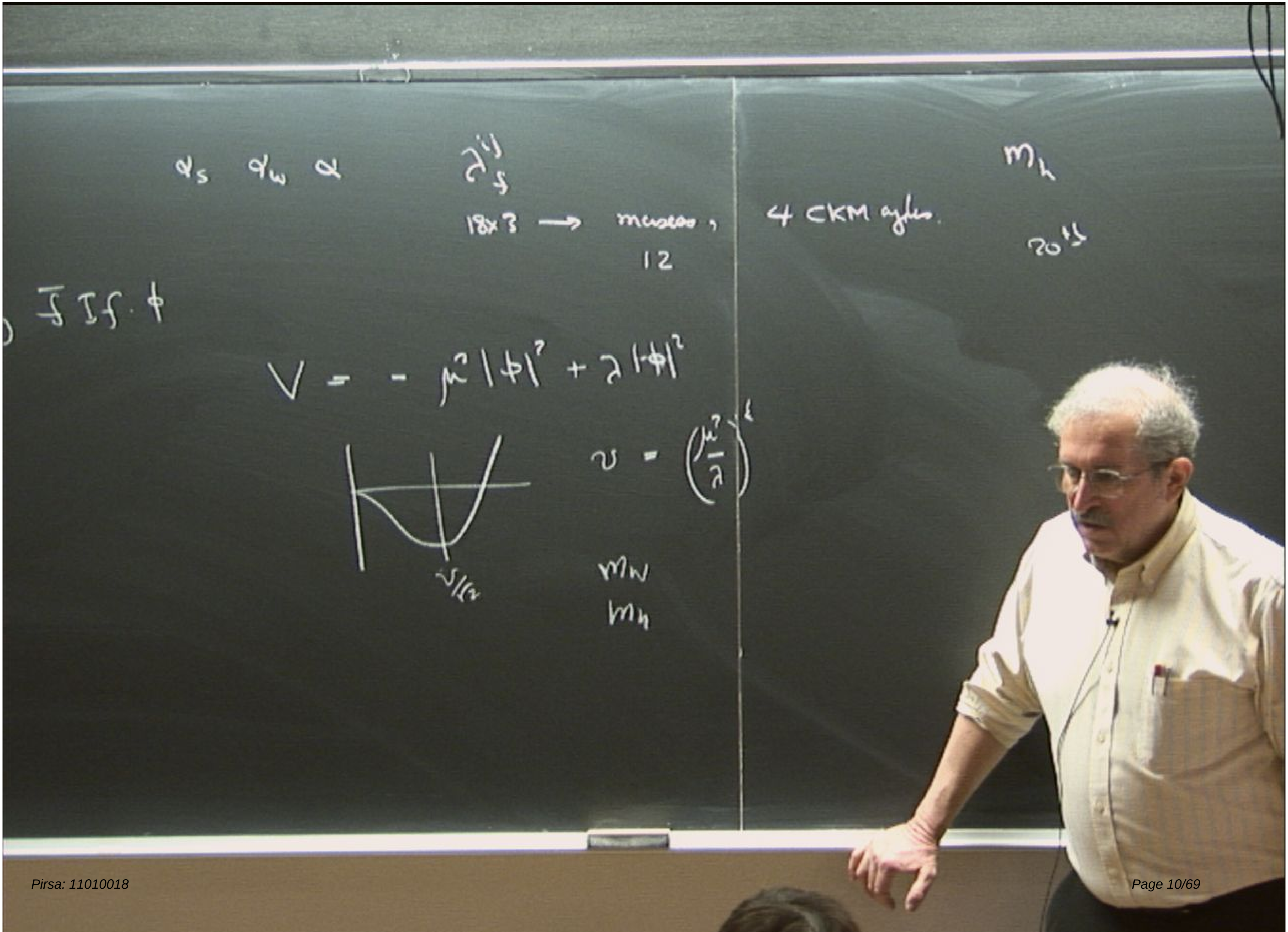
$y\, \bar{f} I f \cdot \phi$

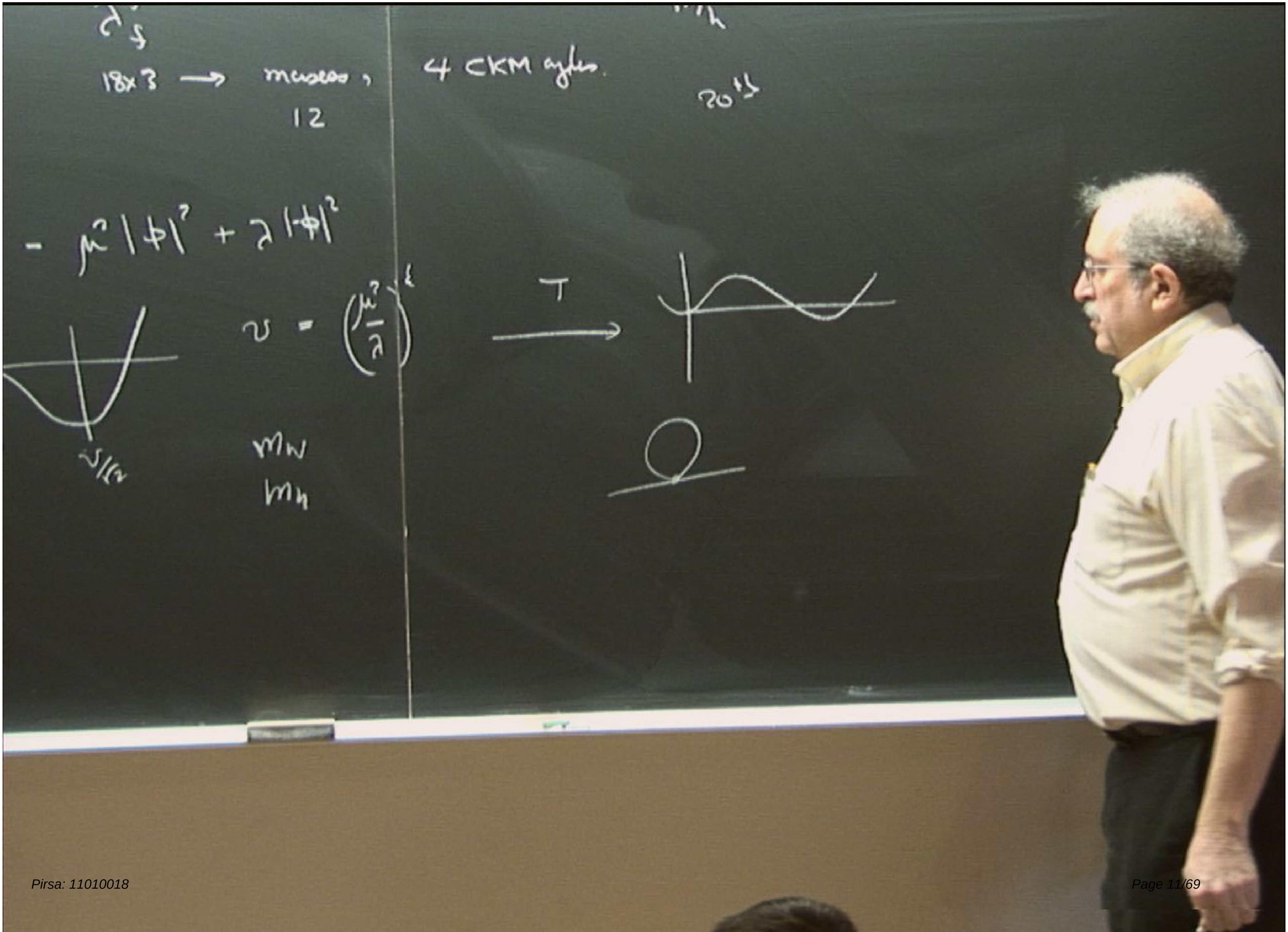

α_s α_w α
λ^{ij}_f
m_h
18x3 → masses,
12
4 CKM angles.

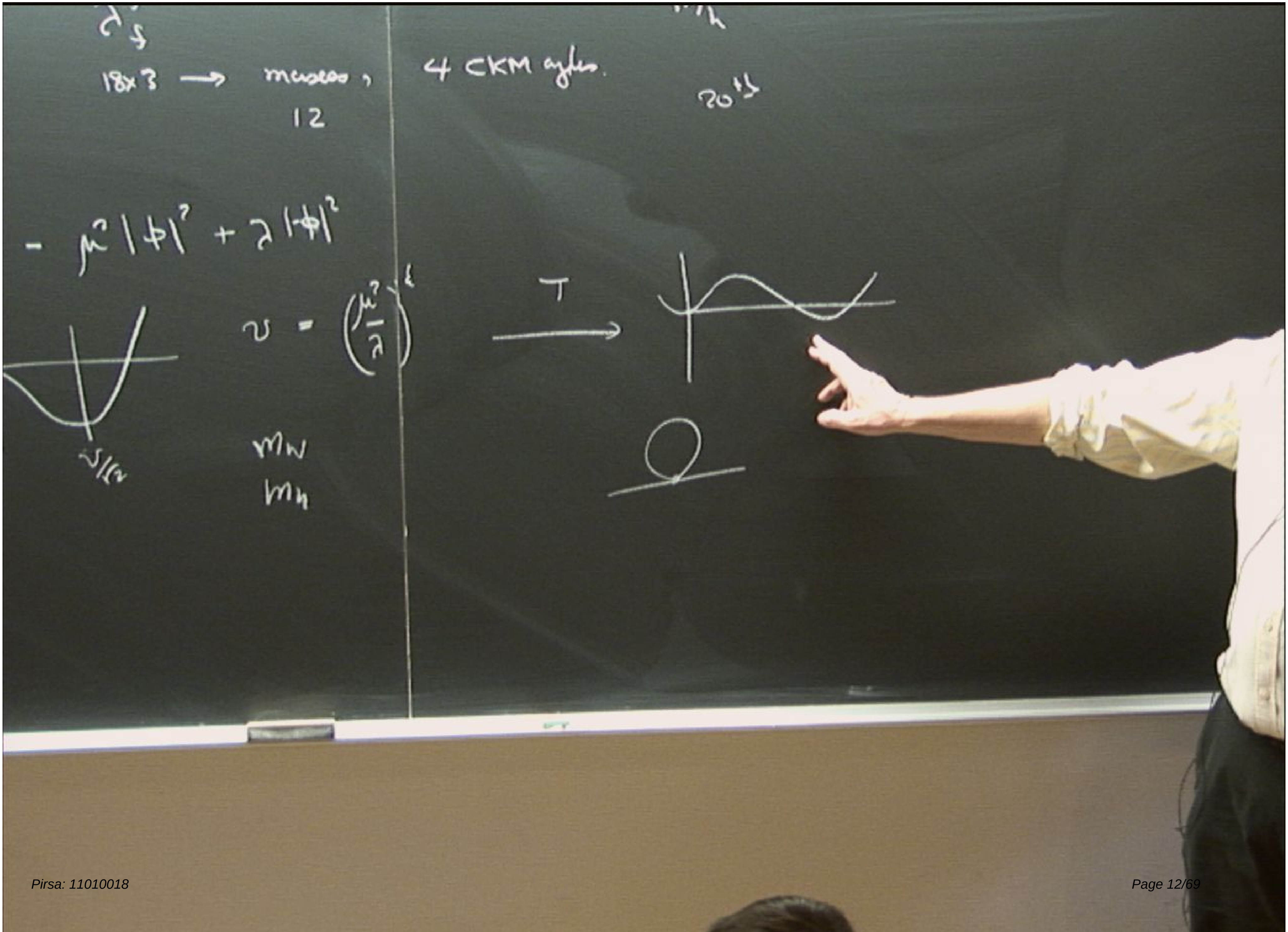

αs αw α
λf ij
mh
18x3 → masses,
12
4 CKM agles.
20's
f̄ I f · φ
V = - μ²|φ|² + λ|φ|²



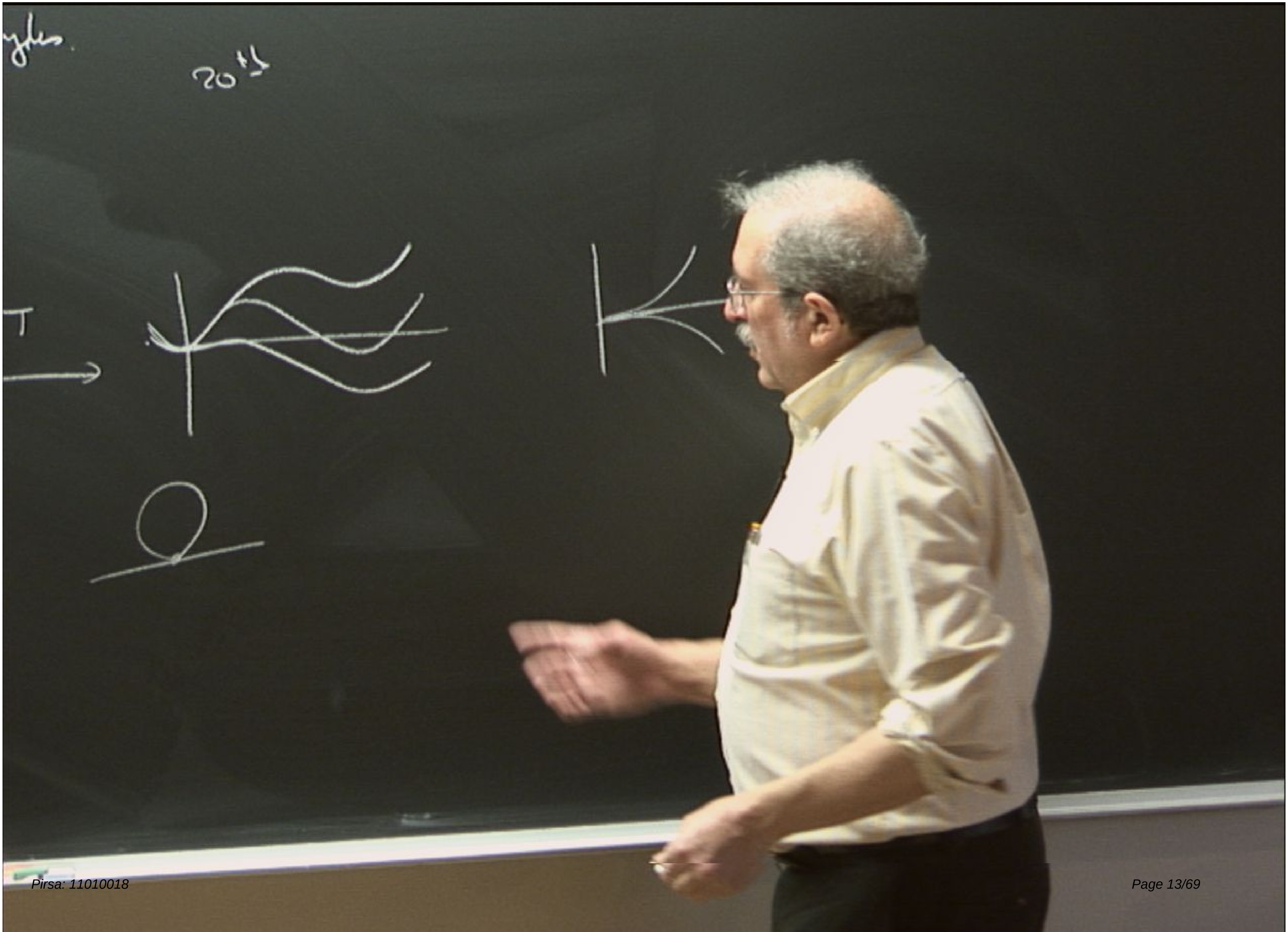
αs αw α
λf ij
mh
18×3 → masses,
12
4 CKM angles.
20's
f̄ I f · φ
V = - μ² |φ|² + λ |φ|²
v =

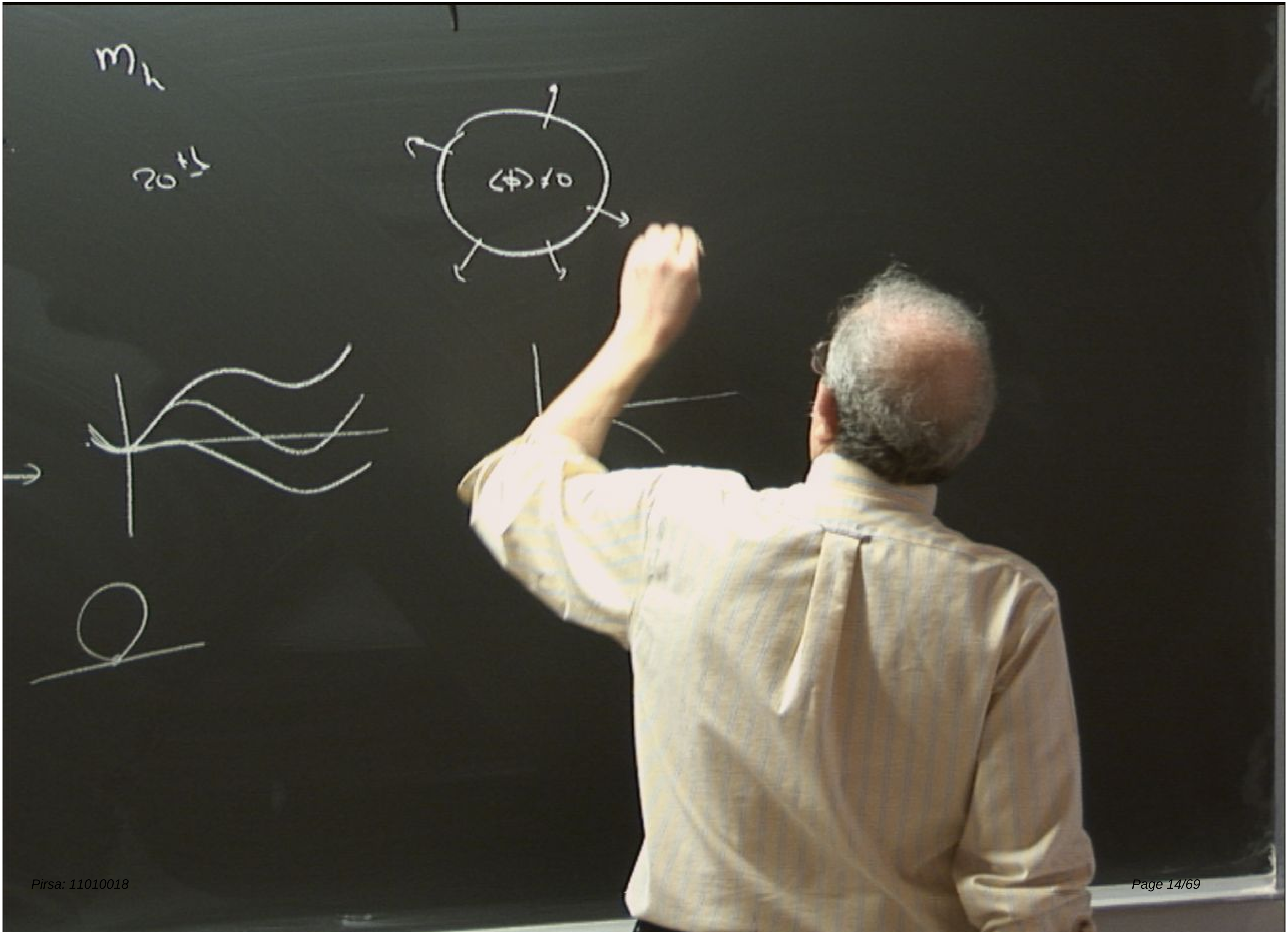

αs αw α
λf^ij
mh
18x3 → masses, 4 CKM angles.
12
20's
V = - μ²|φ|² + λ|φ|²
v = (μ²/λ)
v/√2
mW
mh

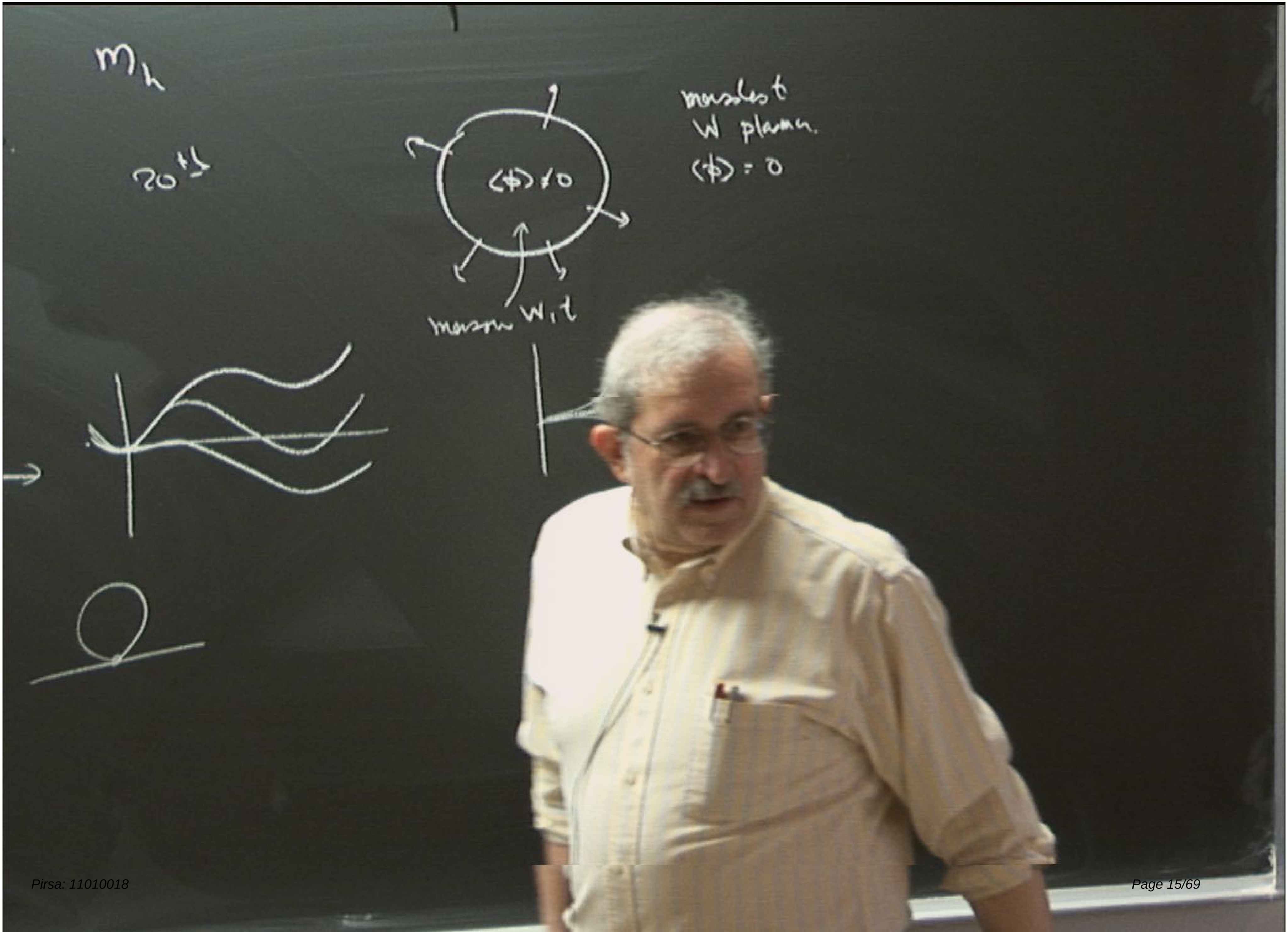

18x3 → masses, 12
4 CKM angles.
- μ²|φ|² + λ|φ|⁴
v = (μ²/λ)^½
v/√2
mW
mH
T

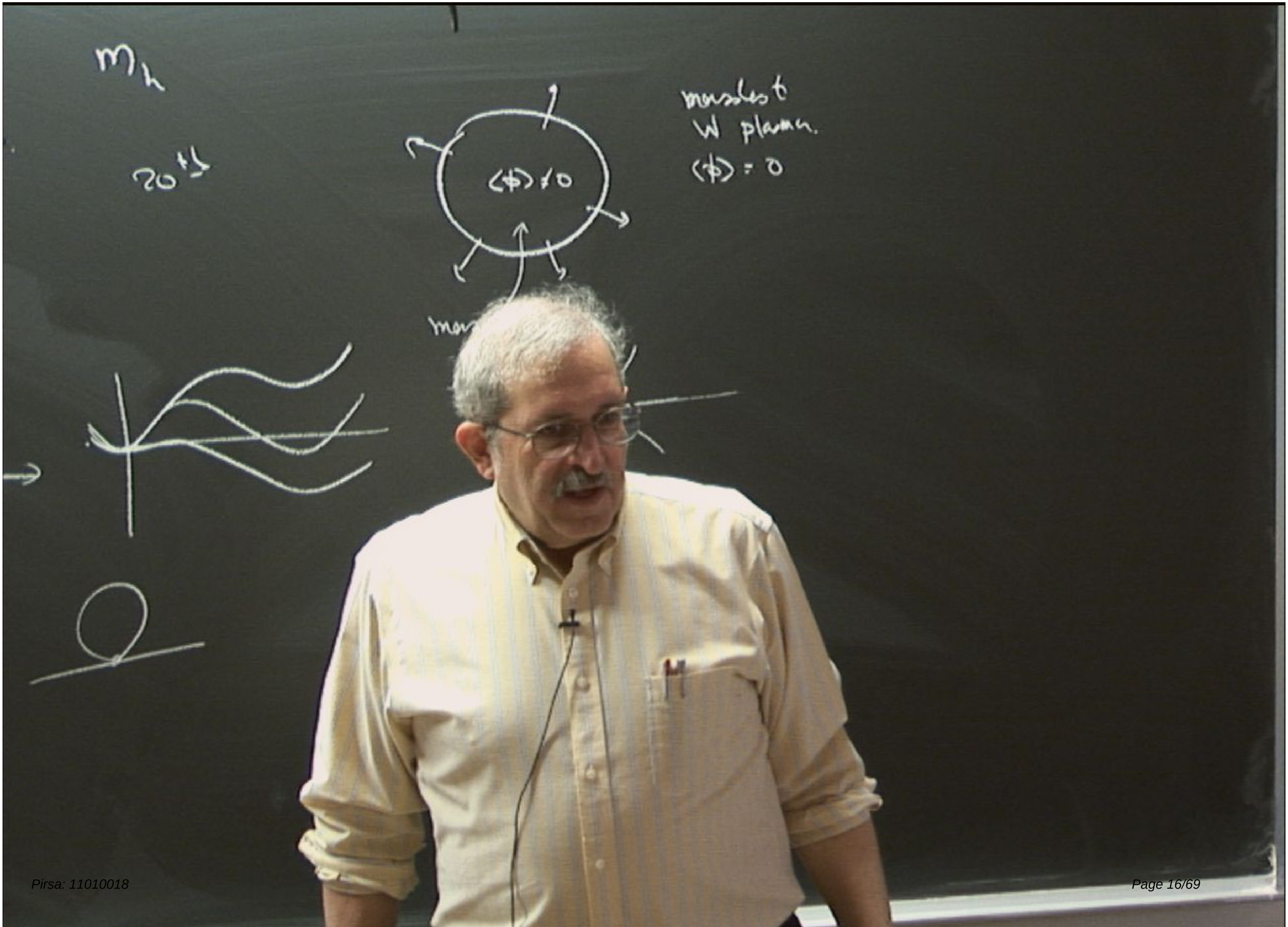


18x3 → masses,
12
4 CKM angles.
20's
- μ²|φ|² + λ|φ|⁴
v = (μ²/λ)^½
T
v/√2
mW
mh

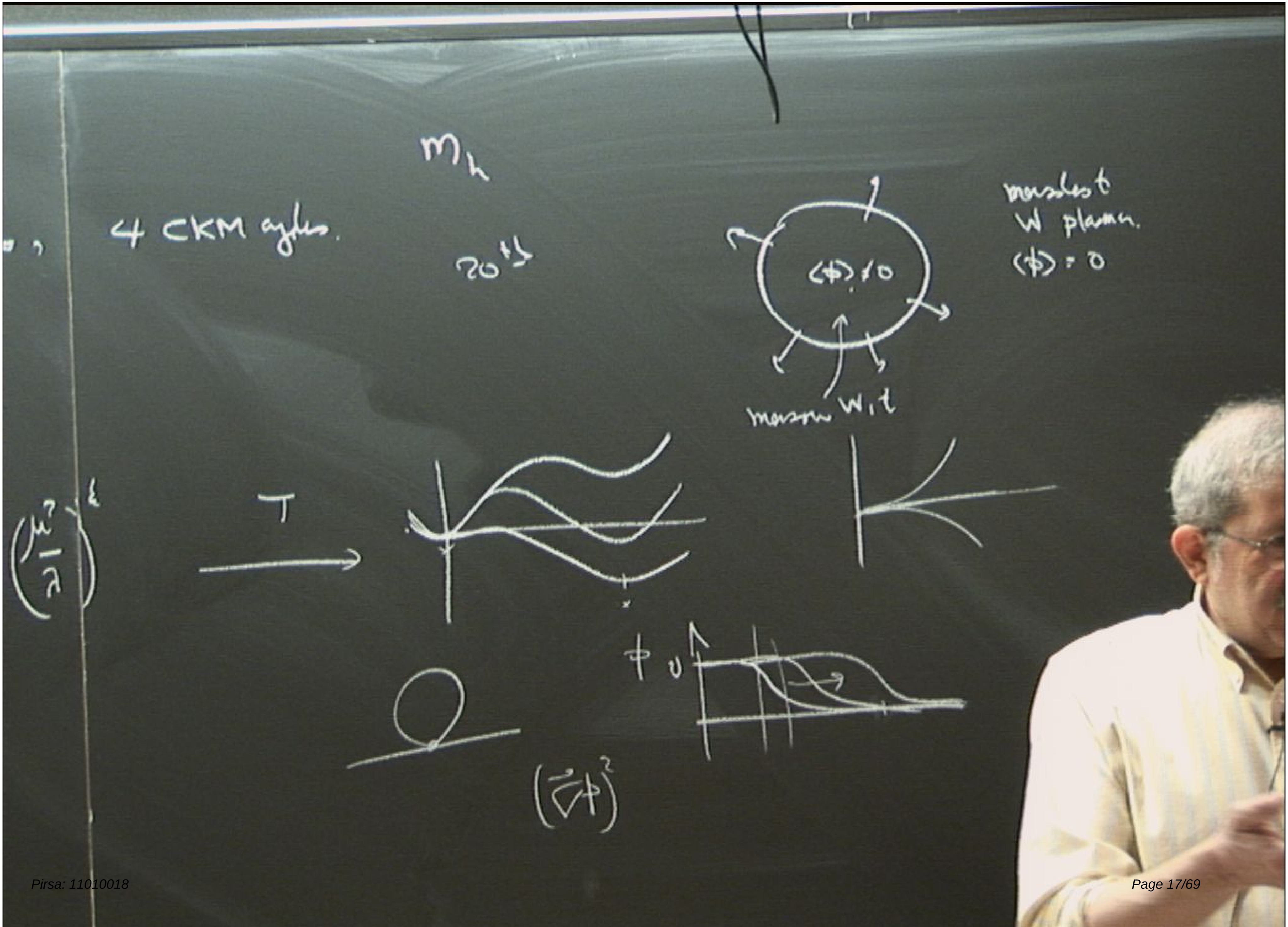

20th


m_h
$\langle\phi\rangle \neq 0$

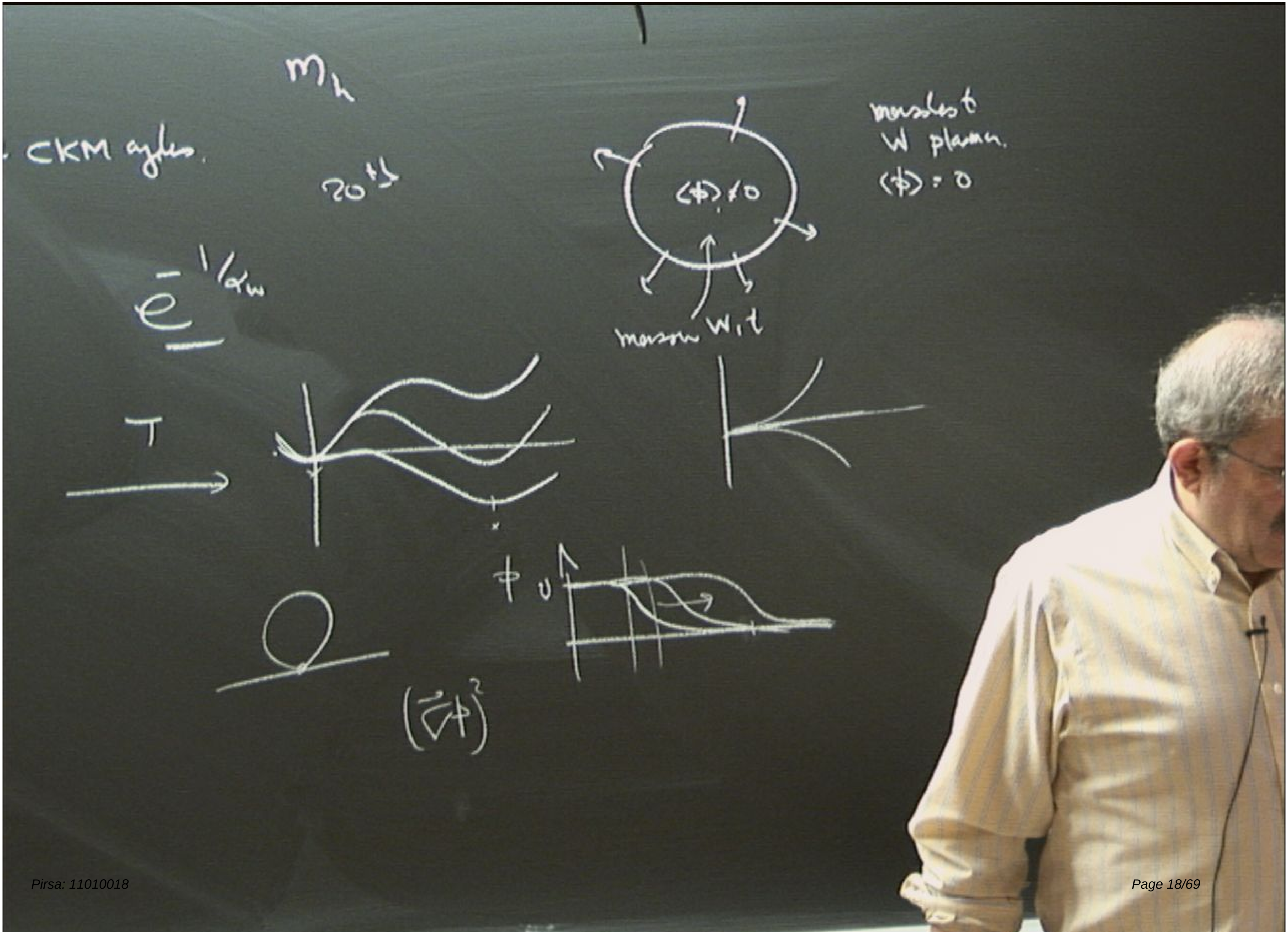

m_h
20^{th}
$\langle\phi\rangle \neq 0$
massless t
W plasma.
$\langle\phi\rangle = 0$
massive W, t



m_h
$\langle\phi\rangle \neq 0$
massless
W plasma.
$\langle\phi\rangle = 0$



4 CKM angles.
m_h
massless t
W plasma.
$\langle\phi\rangle = 0$
$\langle\phi\rangle \neq 0$
massive W, t
T
$\left(\frac{\mu^2}{\lambda}\right)$
ϕ v
$(\vec{\nabla}\phi)^2$



m_h
CKM angles.
20 th
e^{-1/α_w}
T
⟨φ⟩ ≠ 0
massless t
W plasma.
⟨φ⟩ = 0
massive W, t
φ v
(∇φ)^2

$\alpha_s \quad \alpha_w \quad \alpha$

λ^{ij}_f

$18 \times 3 \longrightarrow$ masses, 4 CKM angles.

12

e^{-1/α_w}

Pb Pb.

T

$\longrightarrow$

$\alpha_s \quad \alpha_w \quad \alpha$

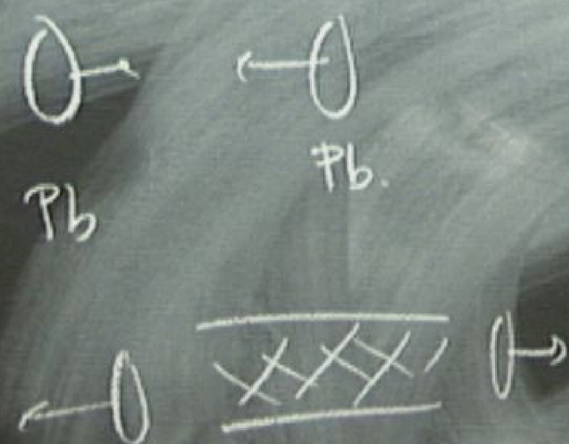
λ^{ij}_f

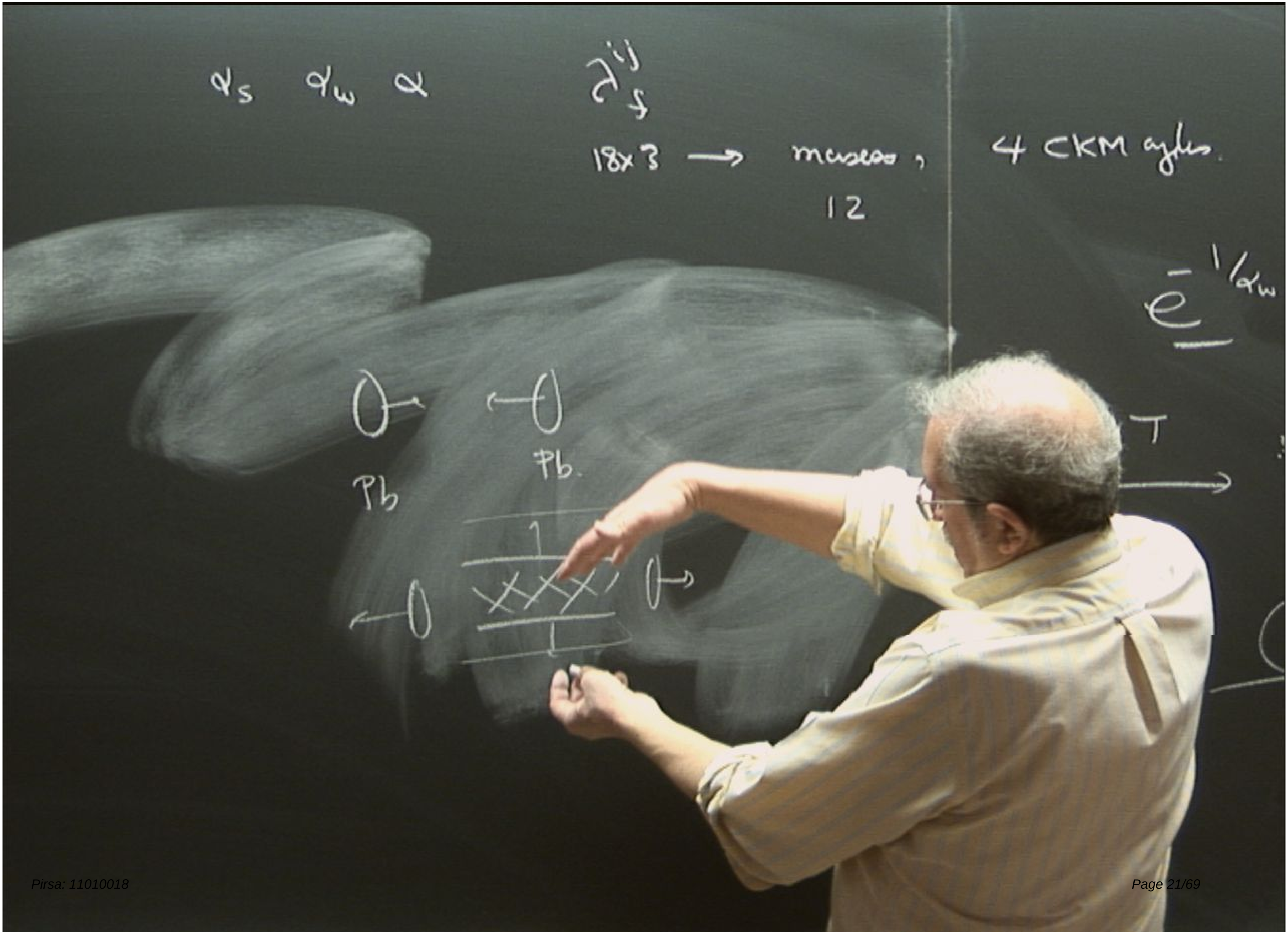
$18\times 3 \longrightarrow$ masses, 4 CKM angles.

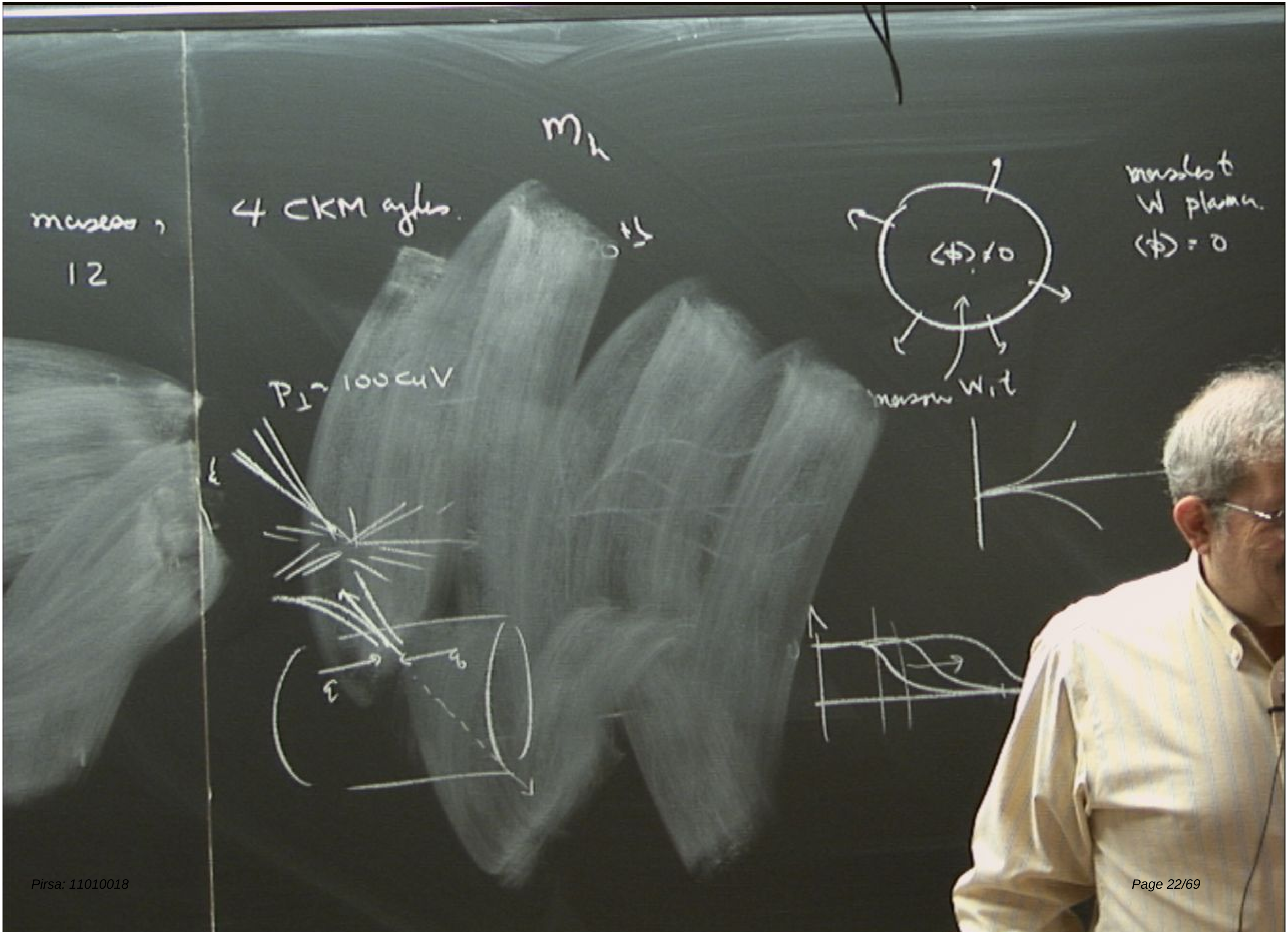
12

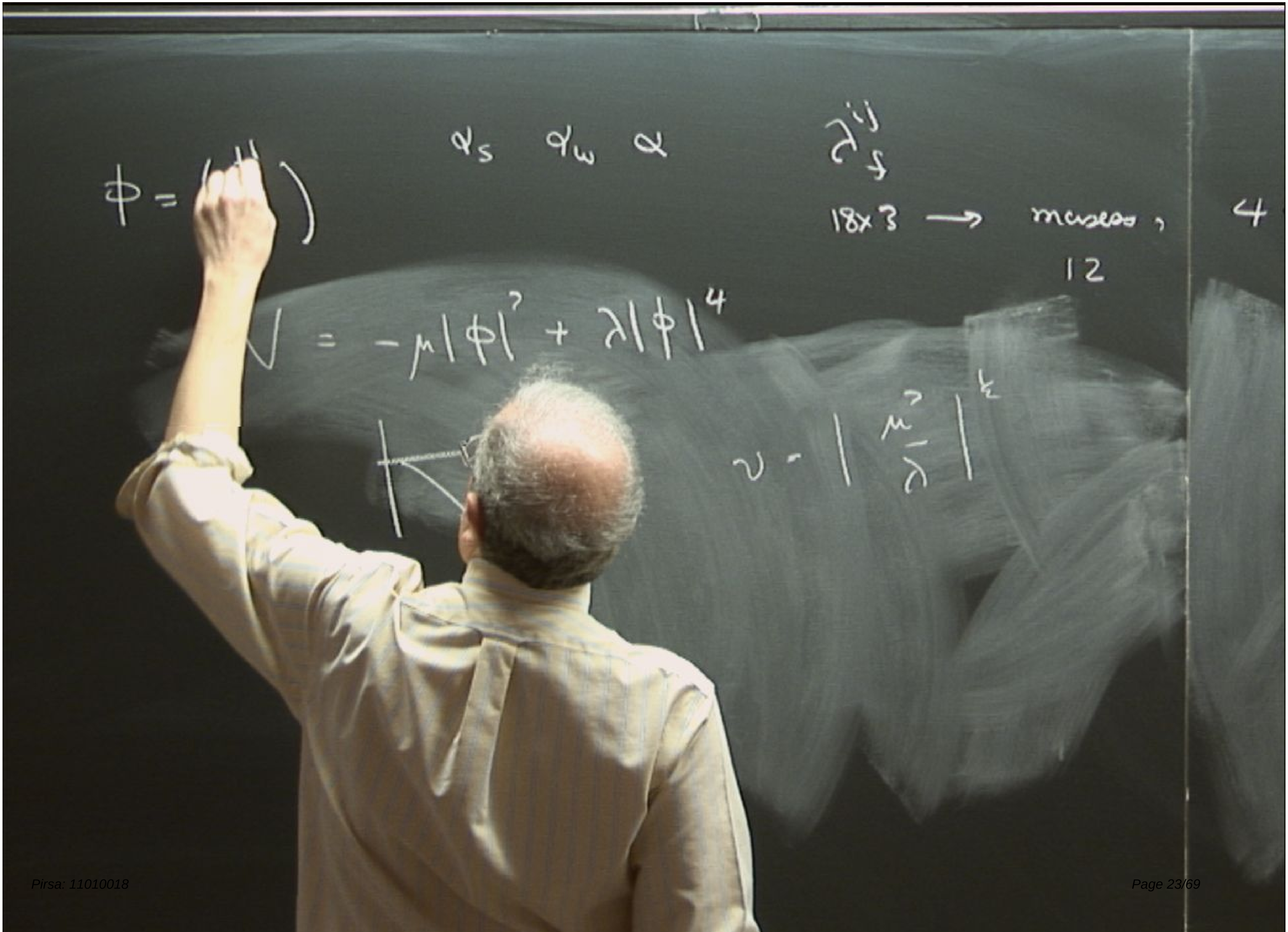
e^{-1/α_w}

$\xrightarrow{T}$




α_s α_w α
λ^{ij}_f
18x3 → masses,
12
4 CKM angles.
e^{-1/α_w}
Pb
Pb.
T


masses,
12
4 CKM angles
m_h
$\langle\phi\rangle \neq 0$
massless t
W plasma
$\langle\phi\rangle = 0$
$p_\perp \sim 100$ GeV
massive W, t


α_s α_w α
λ_f^{ij}
$\phi = (\ )$
18x3 → masses, 4
12
$V = -\mu|\phi|^2 + \lambda|\phi|^4$
$v = |\frac{\mu^2}{\lambda}|^{1/2}$

$$\Phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix}$$

$\alpha_s \quad \alpha_w \quad \alpha$ $\qquad$ λ_f^{ij}

$18 \times 3 \longrightarrow$ masses, $\quad 4$

12

$$V = -\mu|\phi|^2 + \lambda|\phi|^4$$

$$v = \left|\frac{\mu^2}{\lambda}\right|^{1/2}$$

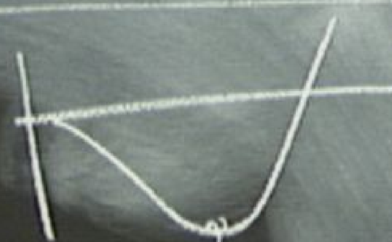
$\alpha_s \quad \alpha_w \quad \alpha$ $\qquad \lambda_f^{ij}$

$\Phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix}$

$18 \times 3 \longrightarrow$ masses, $\quad 4$

12

$$\underbrace{V = -\mu^2|\phi|^2 + \lambda|\phi|^4}$$



$$v = \left| \frac{\mu^2}{\lambda} \right|^{\frac{1}{2}}$$

$$\phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix}$$

$\alpha_s \quad \alpha_w \quad \alpha$

λ_f^{ij}

$18 \times 3 \longrightarrow$ masses, $\quad 4$

12

$$\underline{V = -\mu^2 |\phi|^2 + \lambda |\phi|^4}$$

$$v = \left| \frac{\mu^2}{\lambda} \right|^{1/2}$$

250 GeV

$$m_W = \frac{g v}{2}$$

$\alpha_s \quad \alpha_w \quad \alpha$ $\qquad \lambda_f^{ij}$

$$\phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix}$$

$18 \times 3 \longrightarrow$ masses, $\quad 4$

12

$$V = -\mu^2|\phi|^2 + \lambda|\phi|^4$$

$$v = \left| \frac{\mu^2}{\lambda} \right|^{1/2}$$

250 GeV

$$m_W = \frac{gv}{2}$$

$$\phi \rightarrow \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v + h(x) \end{pmatrix}$$

$\alpha_s \quad \alpha_w \quad \alpha \qquad \lambda_f^{ij}$

$$\Phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix}$$

$18 \times 3 \longrightarrow$ masses, $\quad 4$

12

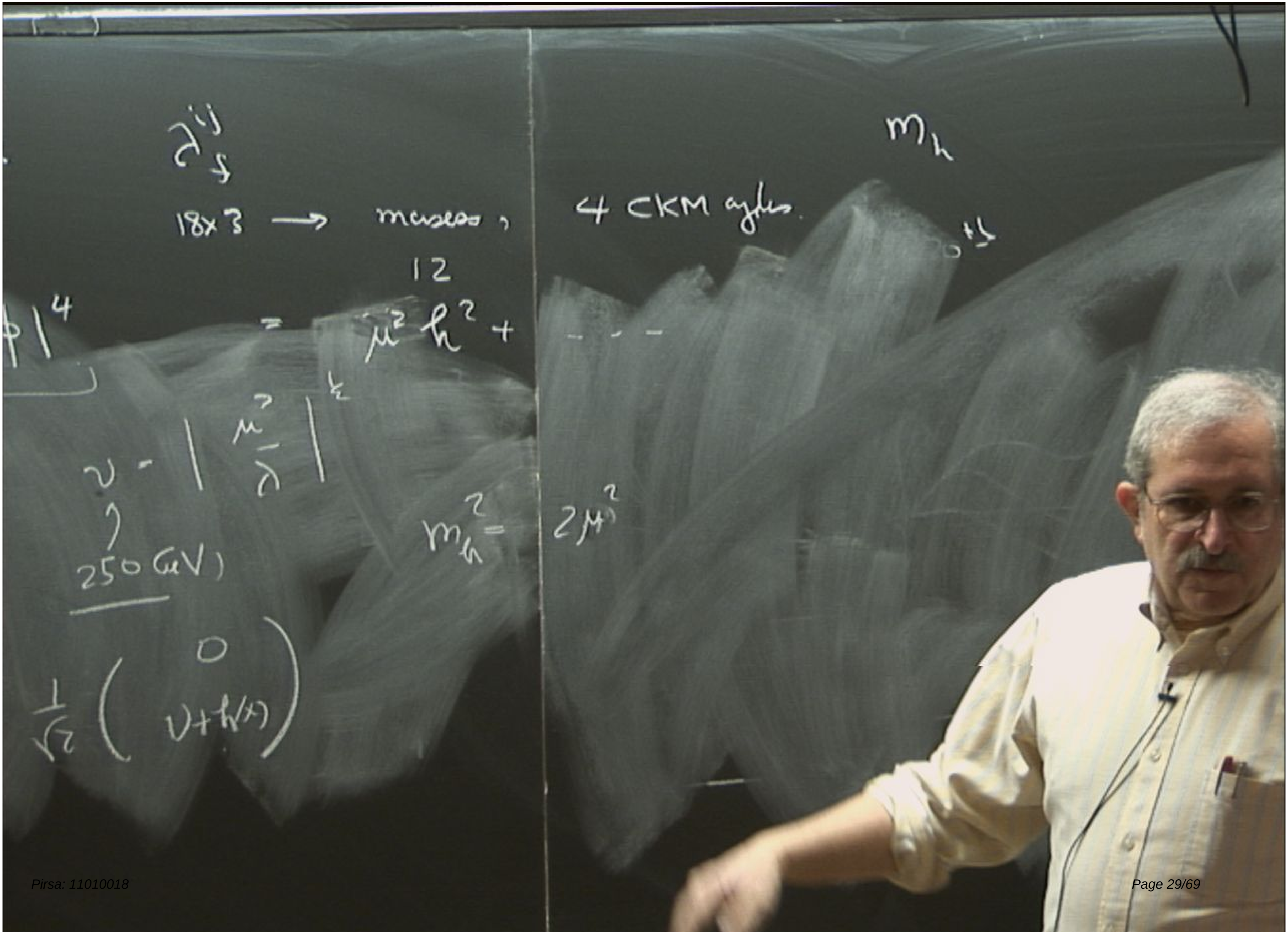
$$\underline{V = -\mu^2 |\phi|^2 + \lambda |\phi|^4} \quad = \quad \mu^2 h^2 + \ldots$$

$$v = \left| \frac{\mu^2}{\lambda} \right|^{\frac{1}{2}}$$

250 GeV

$$m_W = \frac{g v}{2}$$

$$\phi \longrightarrow \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v + h(x) \end{pmatrix}$$


λ_f^ij
m_h
18x3 → masses, 4 CKM angles
12
= μ² h² + - - -
v = |μ²/λ|^½
250 GeV
m_h² = 2μ²
1/√2 (0, v+h(x))

$18 \times 3 \longrightarrow$ masses, 4 CKM angles.

12

$\lambda|\phi|^4$

$= \mu^2 h^2 + \dots$

$v = \left|\frac{\mu^2}{\lambda}\right|^{\frac{1}{2}}$

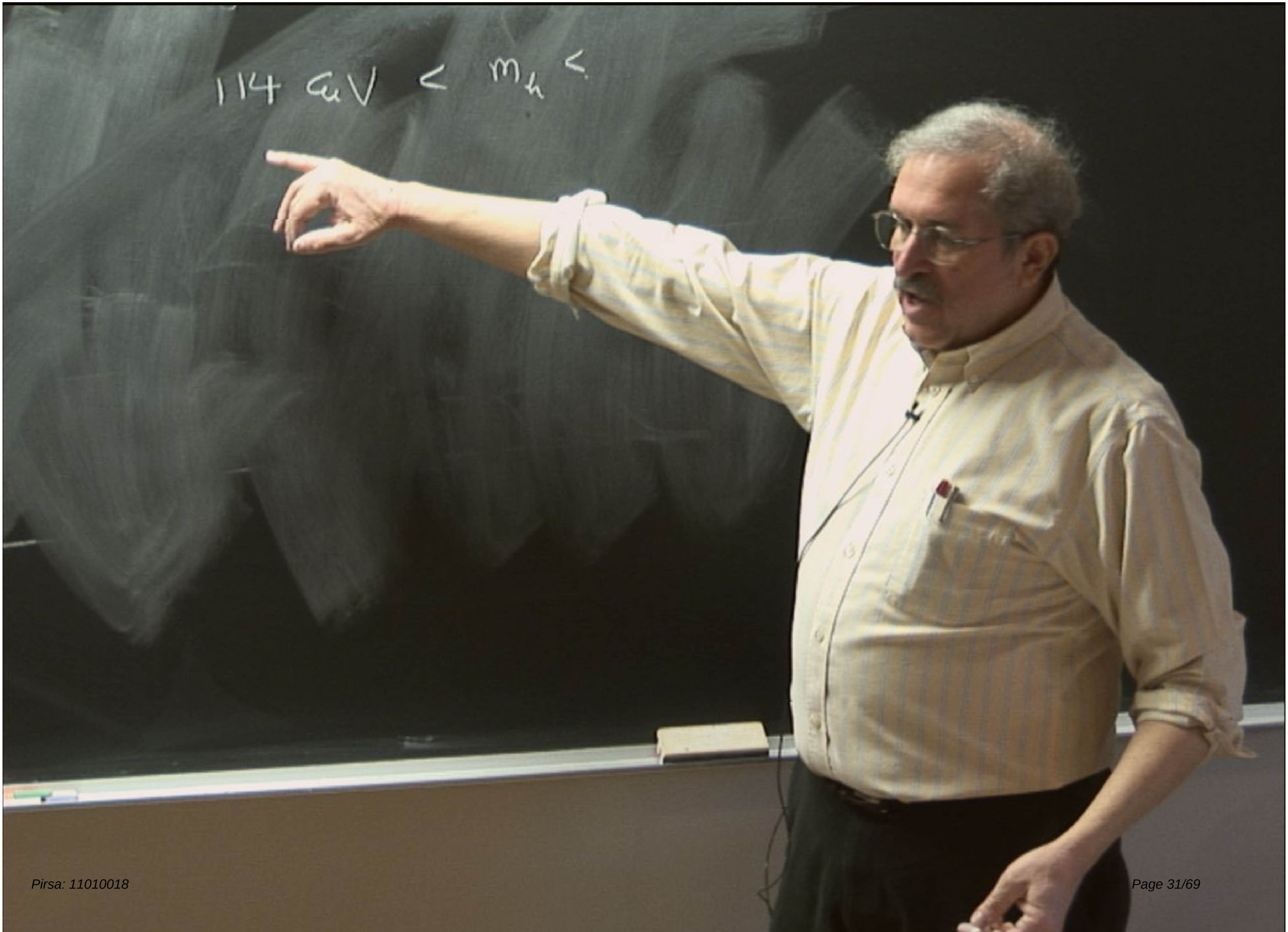
≈ 250 GeV

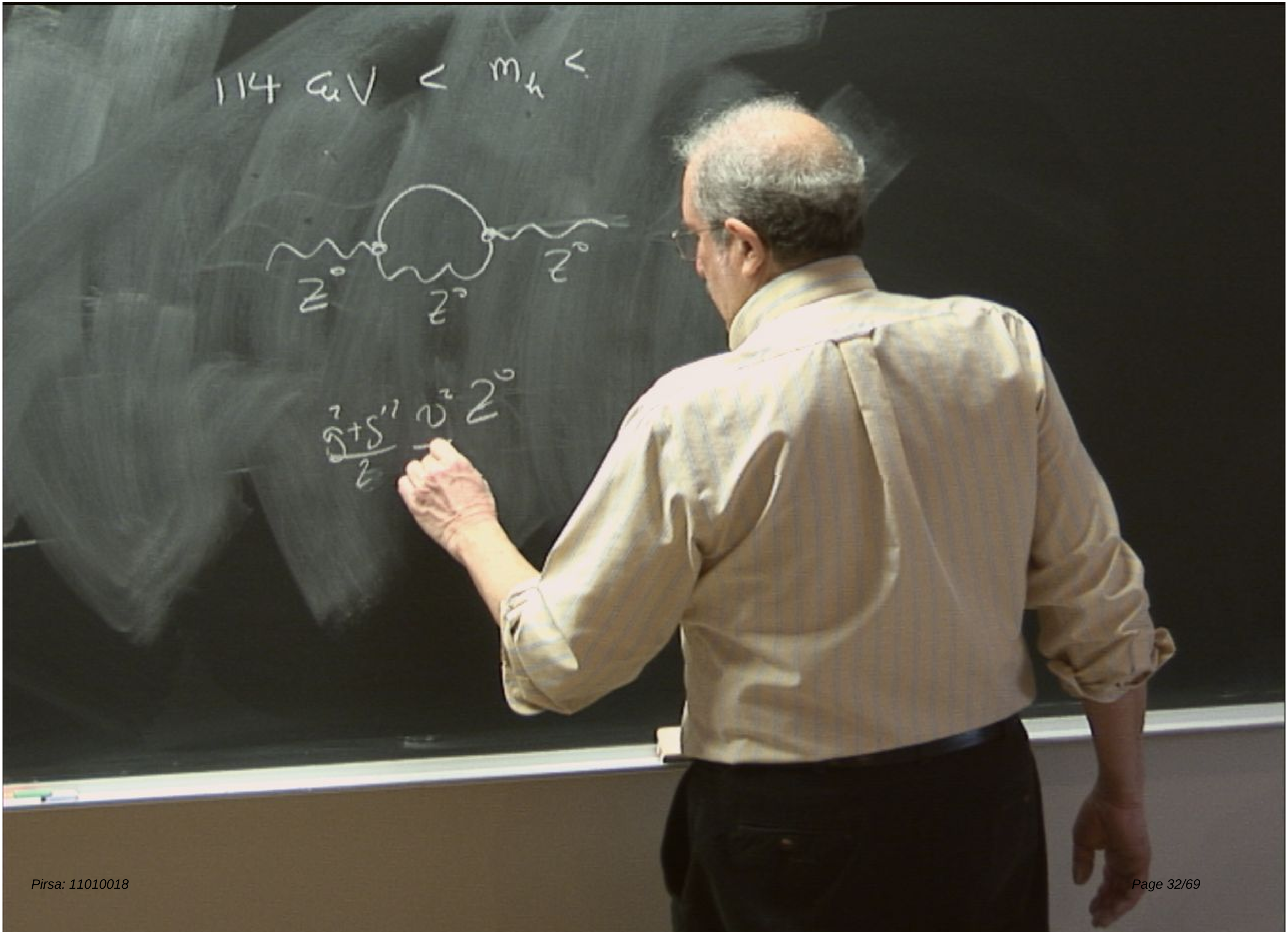
$\rightarrow \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ v + h(x) \end{pmatrix}$

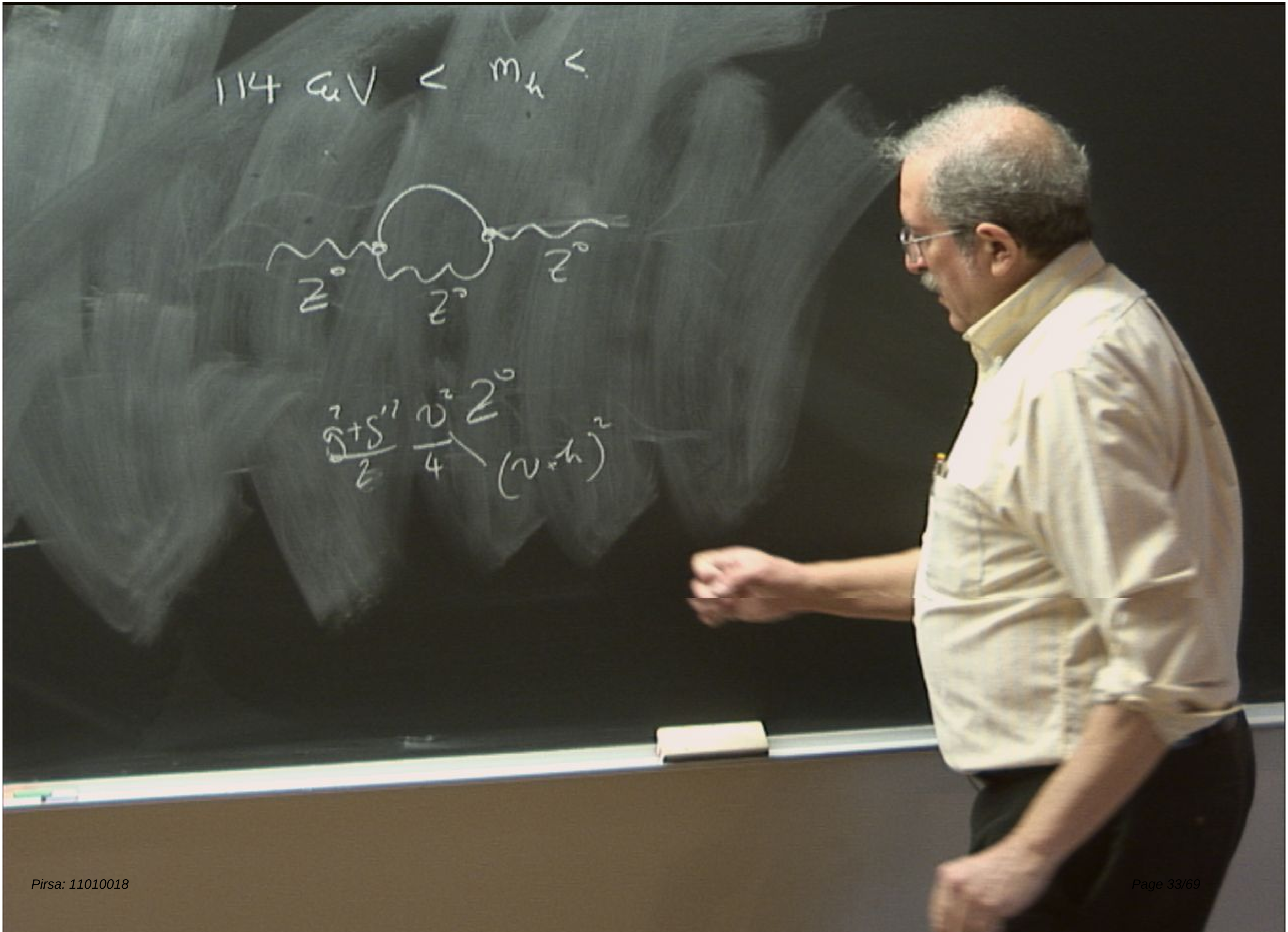
$m_h^2 = 2\mu^2$

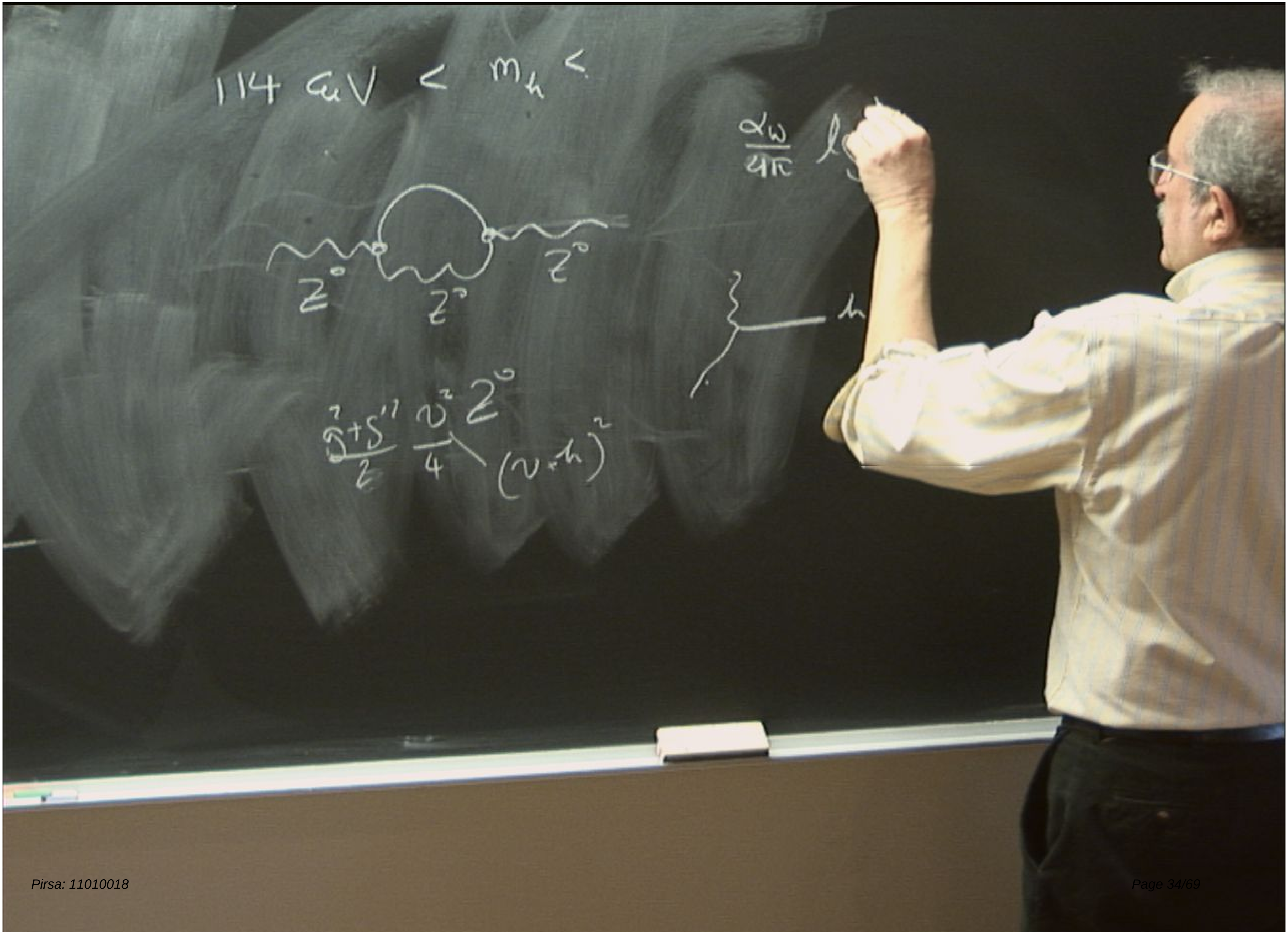
$\lambda = \frac{1}{2}\frac{m_h^2}{v^2}$

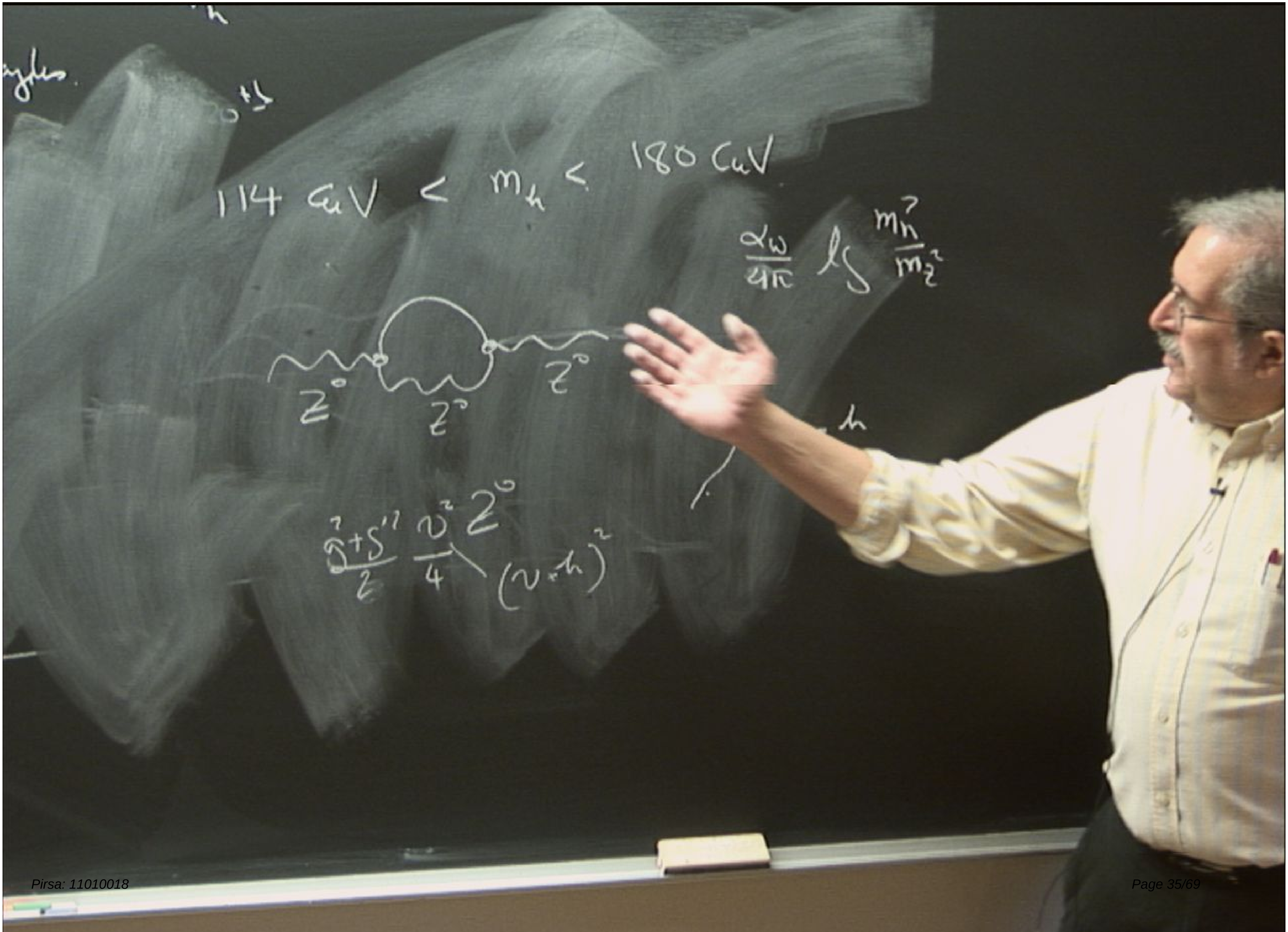
$\frac{\lambda}{4\pi} = \frac{m^2}{8\pi v^2}$


$114\ \text{GeV} < m_h <$


114 GeV < m_h <
Z^0
Z^0
Z^0
$\frac{S'+S''}{2}$ v^2 Z^0


114 GeV < m_h <
Z°
Z°
Z°
v² Z°
4
(v+h)²


114 GeV < m_h <
$\frac{\alpha_w}{4\pi}$
Z^0
Z^0
Z^0
h
v^2 Z^0
$(v+h)^2$



114 GeV < m_h < 180 GeV
αw/4π lg m_h²/m_z²
Z°
Z°
Z°
h

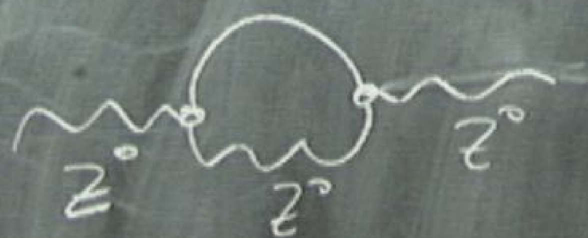
h

ngles.

$+1$

$$114 \text{ GeV} < m_h < 180 \text{ GeV}$$

$$\frac{\alpha_W}{4\pi} \log \frac{m_h^2}{m_Z^2}$$

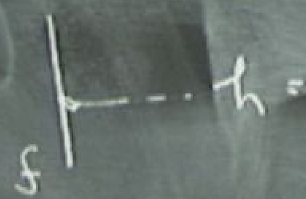


$$\frac{g^2+g'^2}{2} \frac{v^2}{4} Z^0 \quad (v+h)^2$$

$$v \to v + h(x)$$

$$\overset{f}{|}\text{-----} h = -i\,\frac{m_f}{v}$$

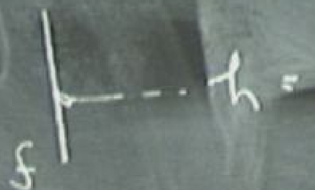
$$v \to v + h(x)$$



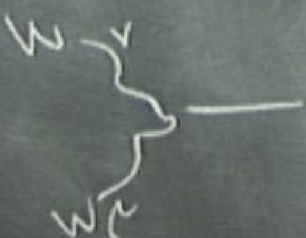
$$= -i\,\frac{m_f}{v}\,\mathbb{1}$$

$$= i\,2\,\frac{m_W^2}{v}\,g^{\mu\nu}$$

$v \to v + h(x)$



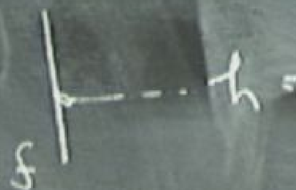
$= \quad -i \frac{m_f}{v} \mathbb{1}$



$= \quad i\, 2 \frac{m_W^2}{v} g^{\mu\nu}$

$= \quad -3i \frac{m_h^2}{v}$

$$v \to v + h(x)$$



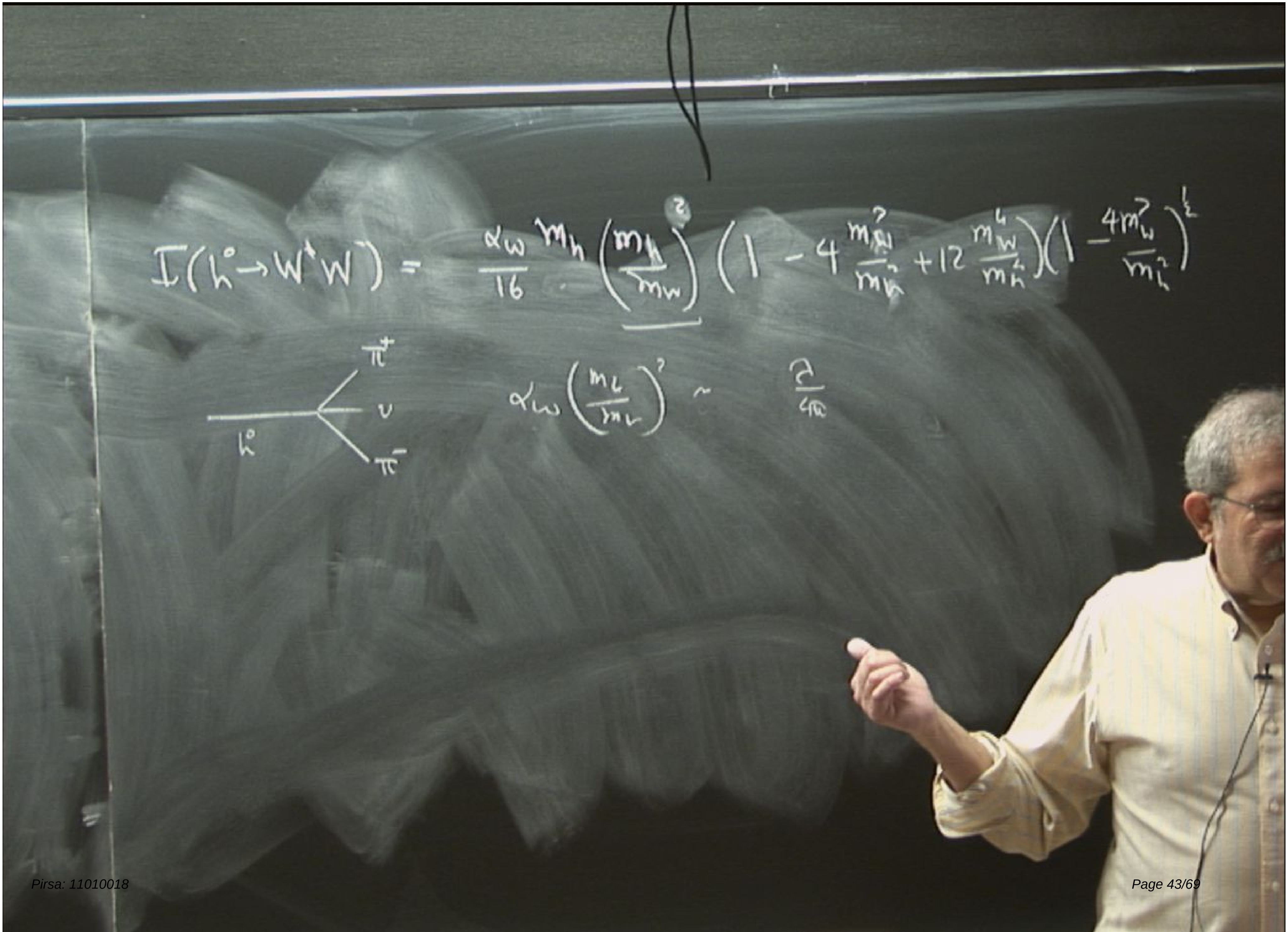
$$= -i \frac{m_f}{v} \mathbb{1}$$

$$= i\, 2 \frac{m_W^2}{v} g^{\mu\nu}$$

$$= -3i \frac{m_h^2}{v}$$

$$\Gamma(h^0 \to W^+W^-) = \frac{\alpha_w}{16}\, m_h \left(\frac{m_h}{m_W}\right)^2$$

$$\Gamma(h^0 \to W^+W^-) = \frac{\alpha_W}{16}\, m_h \left(\frac{m_h}{m_W}\right)^2 \left(1 - 4\frac{m_W^2}{m_h^2} + 12\frac{m_W^4}{m_h^4}\right)\left(1 - \frac{4m_W^2}{m_h^2}\right)^{\frac{1}{2}}$$



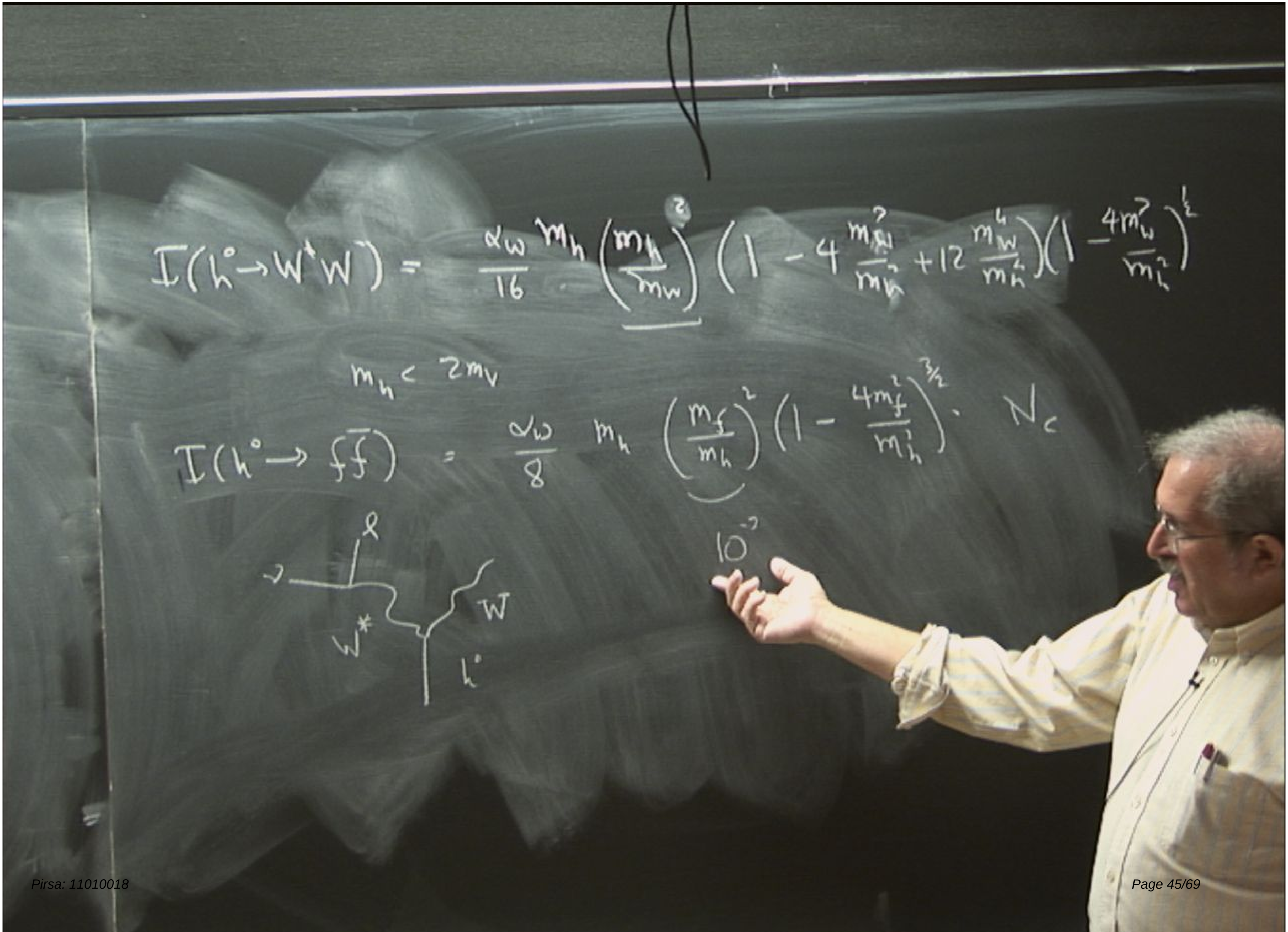
$\Gamma(h^0 \to W^+W^-) = \frac{\alpha_W}{16} m_h \left(\frac{m_h}{m_W}\right)^2 \left(1 - 4\frac{m_W^2}{m_h^2} + 12\frac{m_W^4}{m_h^4}\right)\left(1 - \frac{4m_W^2}{m_h^2}\right)^{\frac{1}{2}}$
π^+
ν
h^0
π^-
$\alpha_W \left(\frac{m_h}{m_W}\right)^2 \sim \frac{\alpha}{4\pi}$

$$\Gamma(h^0 \to W^+W^-) = \frac{\alpha_w}{16} m_h \left(\frac{m_h}{m_w}\right)^2 \left(1 - 4\frac{m_w^2}{m_h^2} + 12\frac{m_w^4}{m_h^4}\right)\left(1 - \frac{4m_w^2}{m_h^2}\right)^{\frac{1}{2}}$$

$m_h < 2m_V$

$$\Gamma(h^0 \to f\bar{f}) = \frac{\alpha_w}{8} m_h \left(\frac{m_f}{m_h}\right)^2 \left(1 - \frac{4m_f^2}{m_h^2}\right)^{3/2} \cdot N_c$$

10^{-7}



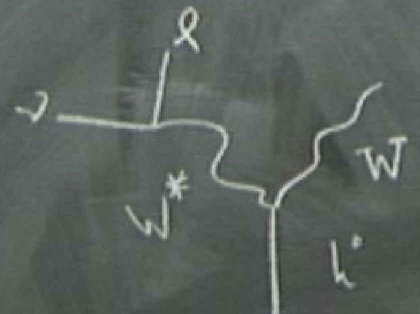
$\Gamma(h^\circ \to W^+W^-) = \frac{\alpha_w}{16} m_h \left(\frac{m_h}{m_w}\right)^2 \left(1 - 4\frac{m_W^2}{m_h^2} + 12\frac{m_W^4}{m_h^4}\right)\left(1 - \frac{4m_W^2}{m_h^2}\right)^{\frac{1}{2}}$
$m_h < 2m_V$
$\Gamma(h^\circ \to f\bar{f}) = \frac{\alpha_w}{8} m_h \left(\frac{m_f}{m_h}\right)^2 \left(1 - \frac{4m_f^2}{m_h^2}\right)^{3/2} \cdot N_c$
10
ℓ
ν
W^*
W
h°

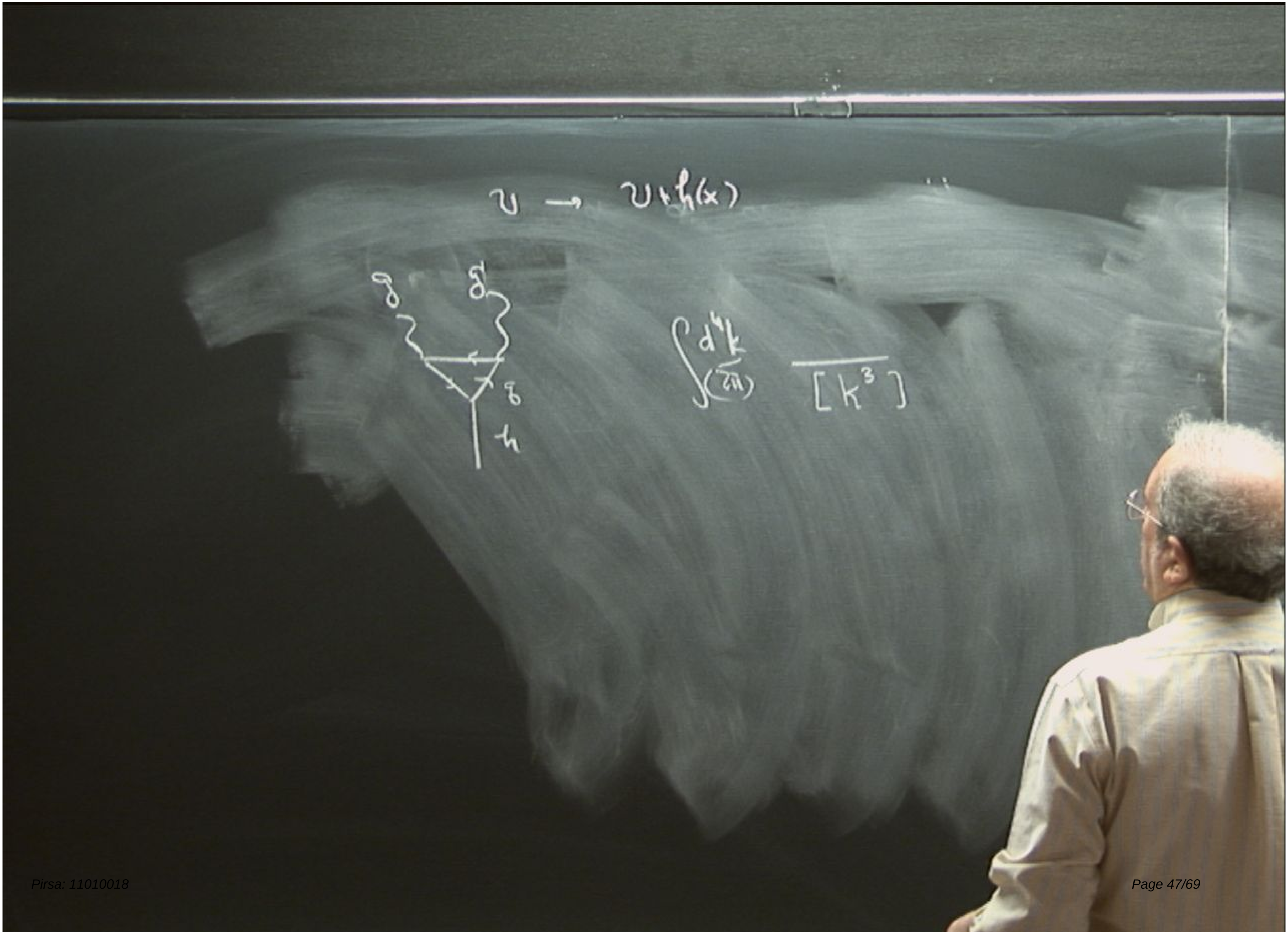
$$\Gamma(h^\circ \to W^+W^-) = \frac{\alpha_w}{16} m_h \left(\frac{m_h}{m_w}\right)^2 \left(1 - 4\frac{m_W^2}{m_h^2} + 12\frac{m_W^4}{m_h^4}\right)\left(1 - \frac{4m_W^2}{m_h^2}\right)^{\frac{1}{2}}$$

$m_h < 2m_V$

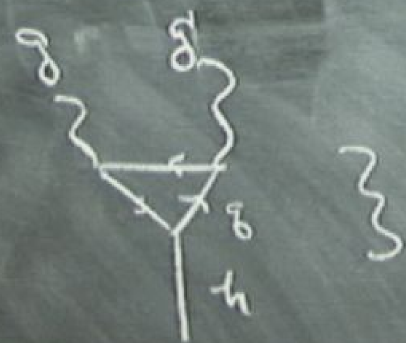
$$\Gamma(h^\circ \to f\bar{f}) = \frac{\alpha_w}{8} m_h \left(\frac{m_f}{m_h}\right)^2 \left(1 - \frac{4m_f^2}{m_h^2}\right)^{3/2} \cdot N_c$$

10^{-7}

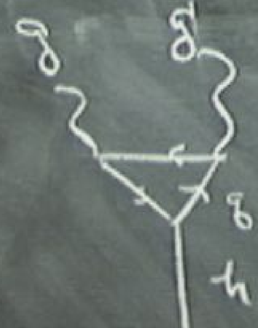



v → v + h(x)
γ
γ
γ
h
∫ d⁴k / (2π)
[k³]

$$v \to v + h(x)$$

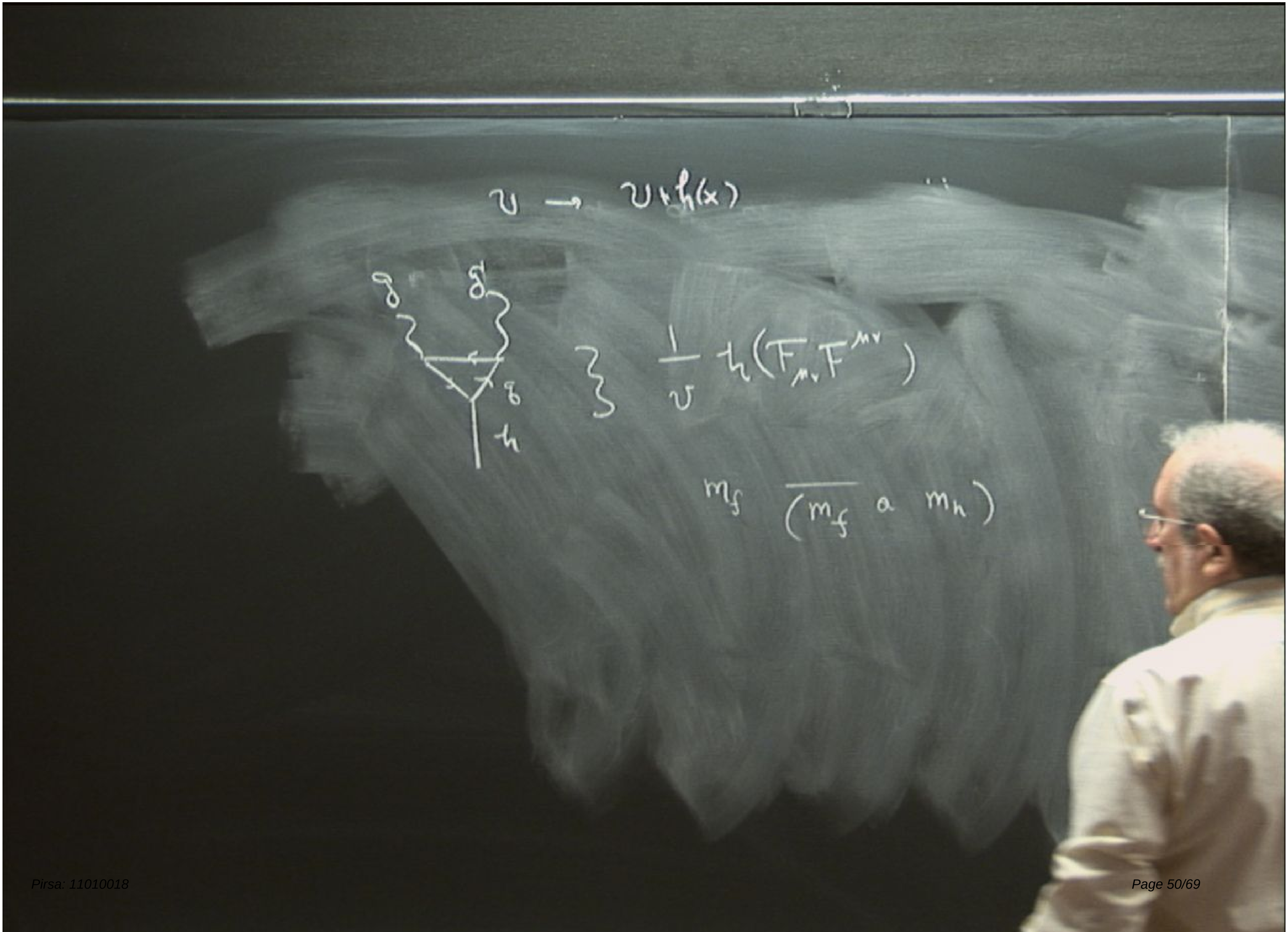


$$v \to v + h(x)$$



$$\sim \frac{1}{v}\, h\left(F_{\mu\nu}F^{\mu\nu}\right)$$

m_f

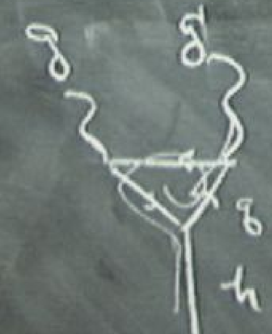

v → v + h(x)
g
g
t
h
1/v h (F_{μν} F^{μν})
m_f (m_f ≪ m_h)

$$v \to v + h(x)$$

$$\sim \frac{1}{v}\, h \left(F_{\mu\nu} F^{\mu\nu} \right)$$

$$\frac{m_f}{v} \frac{1}{(m_f \quad a \quad m_h)}$$

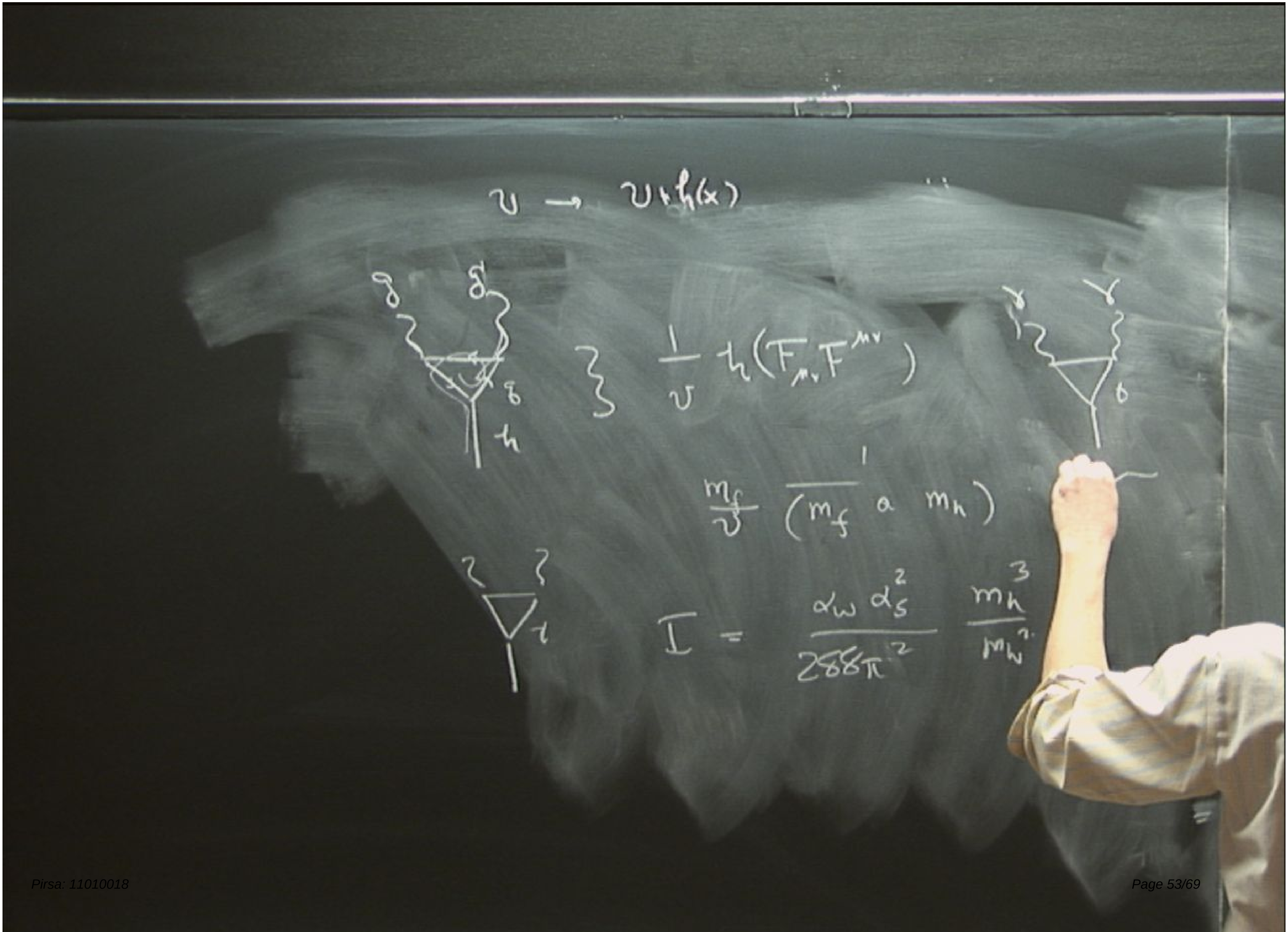
$$v \to v + h(x)$$



$$\frac{1}{v}\, h\left(F_{\mu\nu}F^{\mu\nu}\right)$$

$$\frac{m_f}{v}\;\frac{1}{(m_f \;\; a \;\; m_h)}$$

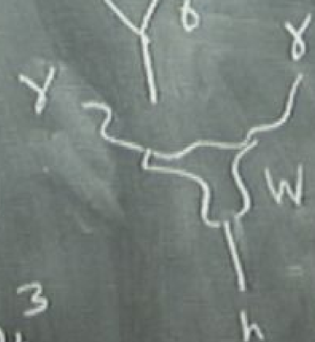
$$I = \frac{\alpha_w\,\alpha_s^2}{288\pi^2}\;\frac{m_h^3}{m_w^2}$$



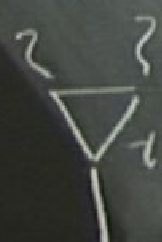
$v \to v + h(x)$
$\frac{1}{v} h (F_{\mu\nu} F^{\mu\nu})$
$\frac{m_f}{v} \frac{1}{(m_f \, a \, m_h)}$
$I = \frac{\alpha_W \alpha_s^2}{288\pi^2} \frac{m_h^3}{m_W^2}$

$v \to v + h(x)$

$\frac{1}{v} h (F_{\mu\nu} F^{\mu\nu})$



$\frac{m_f}{v} \quad \frac{1}{(m_f \;\; a \;\; m_h)}$



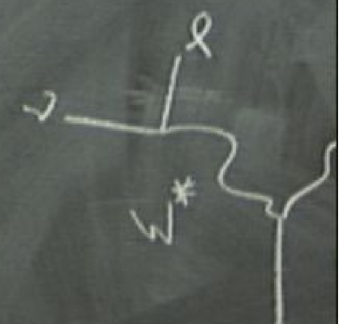
$\Gamma = \frac{\alpha_w \alpha_s^2}{288\pi^2} \frac{m_h^3}{m_W^2}$

$BR \sim 2 \times 10^{-3}$

$\Gamma(h^0 \to W^+ W^-) =$

$m_h <$

$\Gamma(h^0 \to f\bar{f})$



$$\Gamma(h^\circ \to W^+W^-) = \frac{\alpha_W}{16} m_h \left(\frac{m_h}{m_W}\right)^2 \left(1 - 4\frac{m_W^2}{m_h^2} + 12\frac{m_W^4}{m_h^4}\right)\left(1 - \frac{4m_W^2}{m_h^2}\right)^{\frac{1}{2}}$$

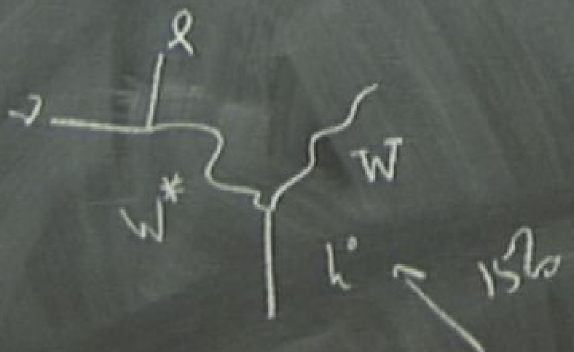
$m_h < 2m_V$

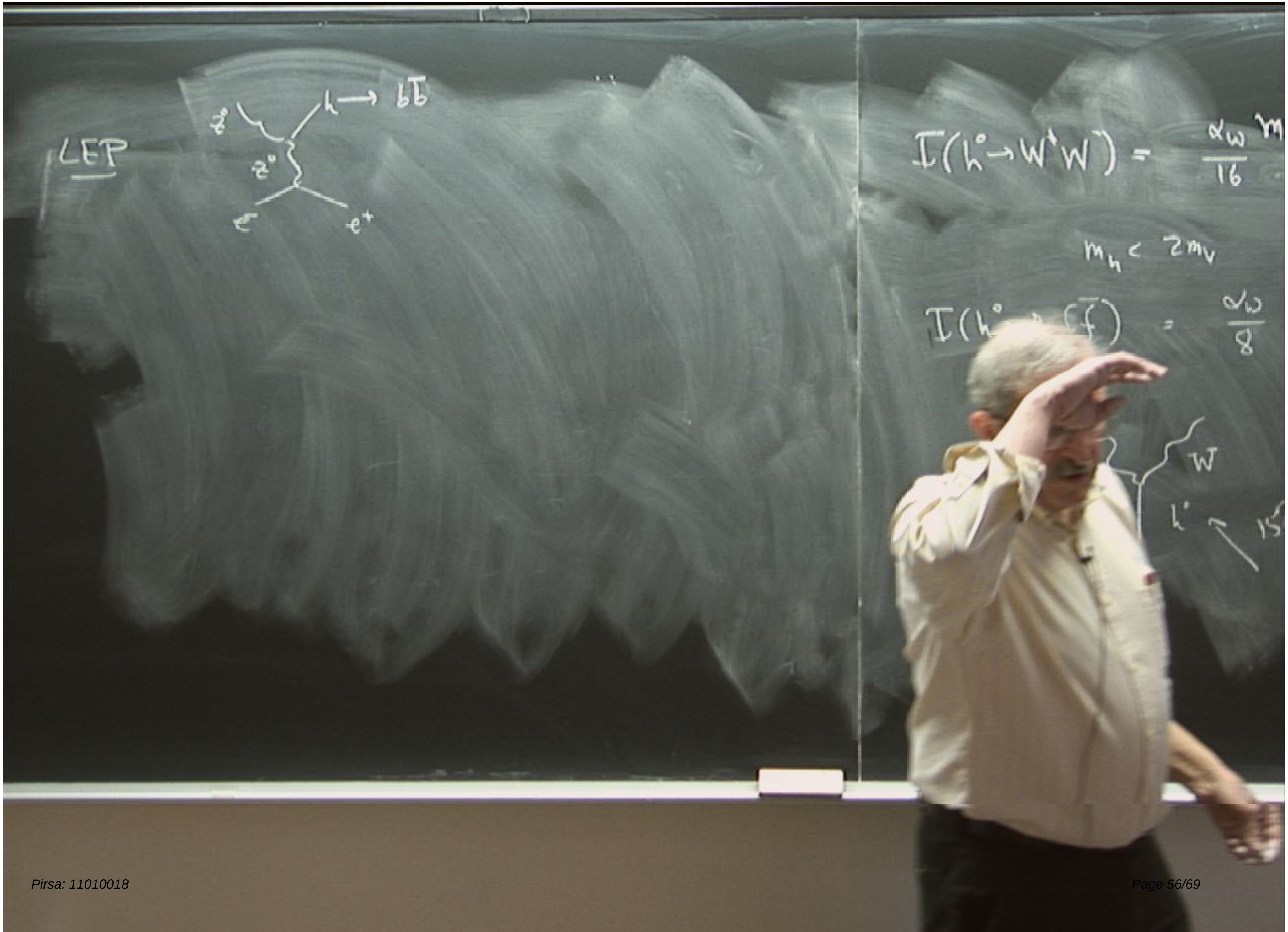
$$\Gamma(h^\circ \to f\bar{f}) = \frac{\alpha_W}{8} m_h \left(\frac{m_f}{m_h}\right)^2 \left(1 - \frac{4m_f^2}{m_h^2}\right)^{3/2} \cdot N_c$$

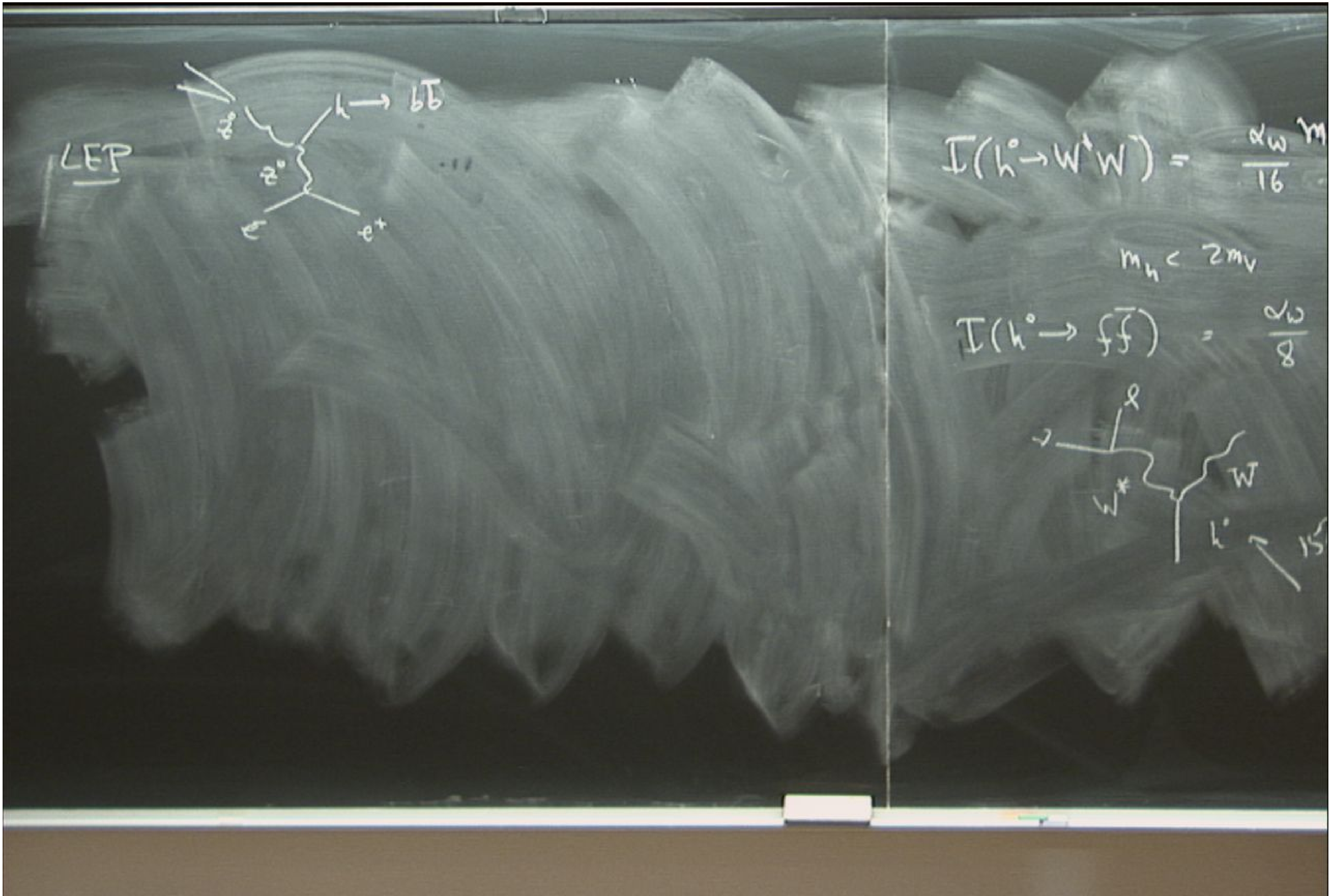
$10^{-?}$ $m_h = 120$ GeV

domin

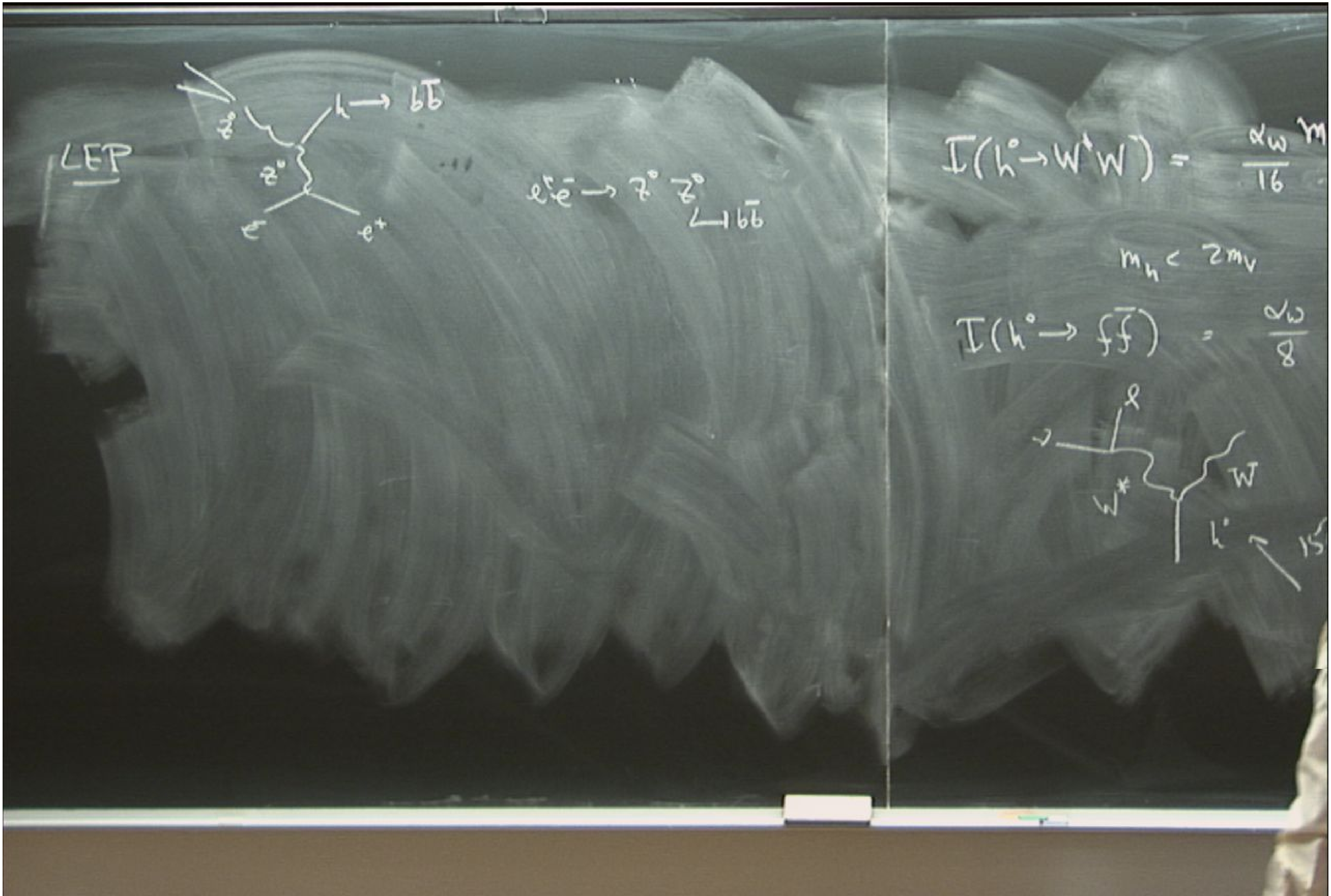
0^{-3}



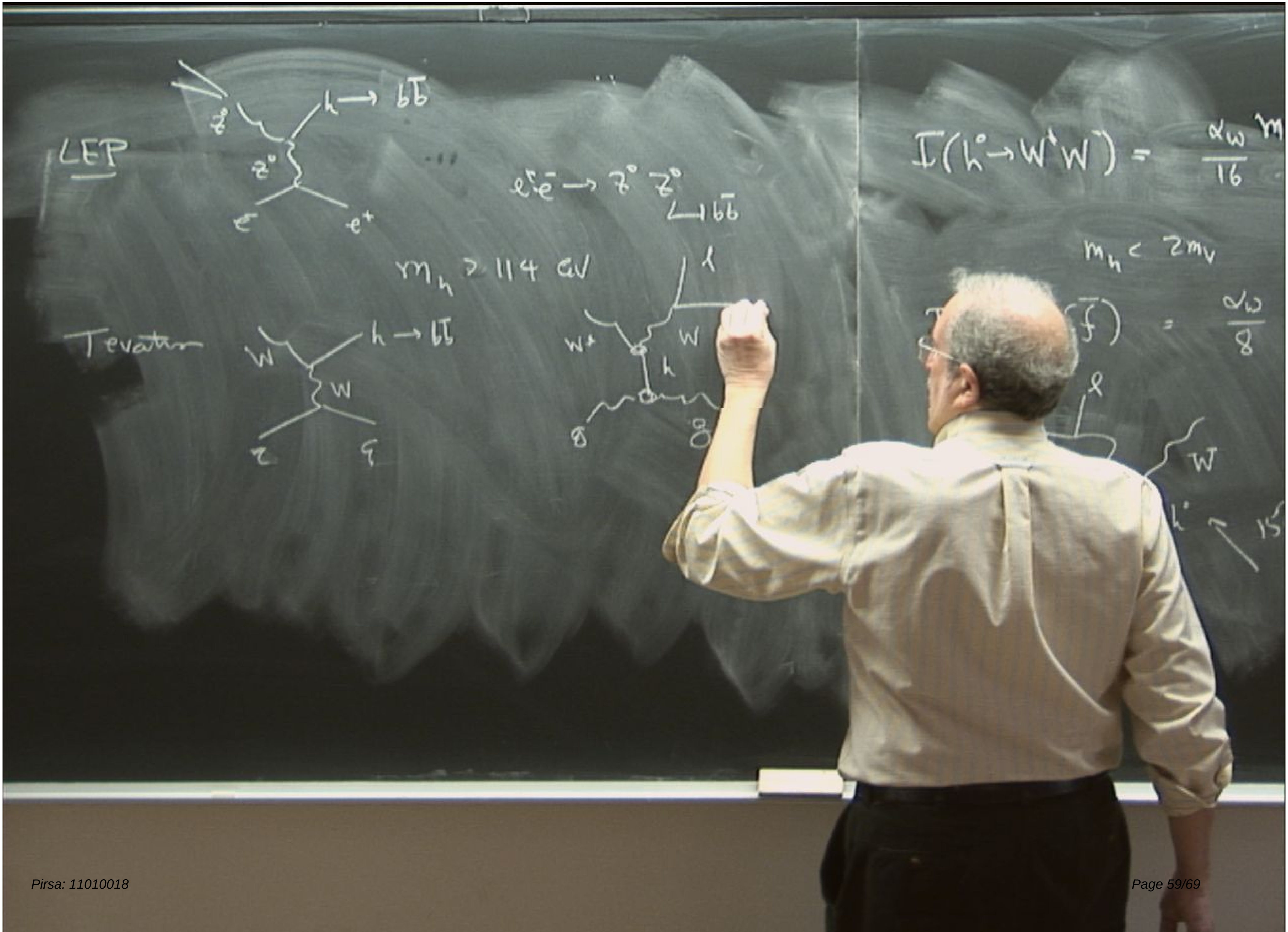

LEP
h → b b̄
Z°
Z°
e⁻
e⁺
Γ(h° → W⁺W⁻) = α_w / 16
m_h < 2m_V
Γ(h° → f f̄) = α_w / 8
W
h°



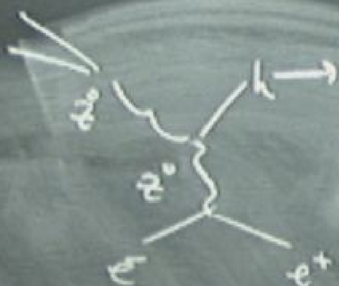
LEP
$h \rightarrow b\bar{b}$
Z^0
e^-
e^+
$\Gamma(h^0 \rightarrow W^+W^-) = \frac{\alpha_w}{16}$
$m_h < 2m_V$
$\Gamma(h^0 \rightarrow f\bar{f}) = \frac{\alpha_w}{8}$
W^*
W
h^0



LEP
$h \to b\bar{b}$
Z^0
e^-
e^+
$e^+e^- \to Z^0 Z^0$
$\hookrightarrow b\bar{b}$
$\Gamma(h^0 \to W^+W^-) = \frac{\alpha_W}{16}$
$m_h < 2m_V$
$\Gamma(h^0 \to f\bar{f}) = \frac{\alpha_W}{8}$
ℓ
ν
W^*
W
h^0


LEP
h → bb̄
e⁺e⁻ → Z⁰ Z⁰
↳ bb̄
m_h > 114 GeV
Tevatron
h → bb̄
Γ(h⁰ → W⁺W⁻) =
αw/16
m_h < 2m_V
αw/8

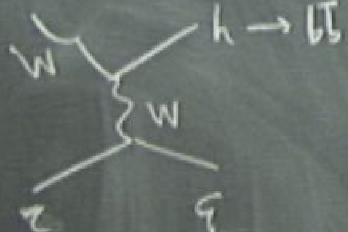
LEP

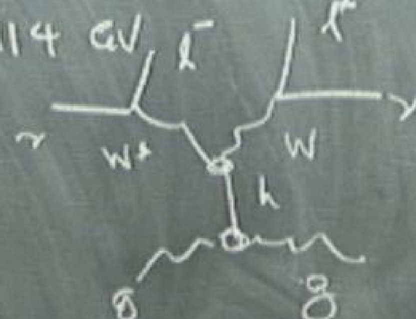


$e^+e^- \to Z^0 Z^0$
$\hookrightarrow b\bar b$

$m_h > 114$ GeV

Tevatron



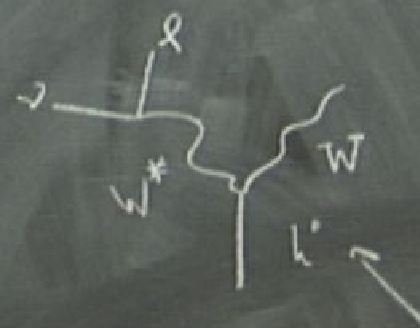


excluded range around 160 GeV

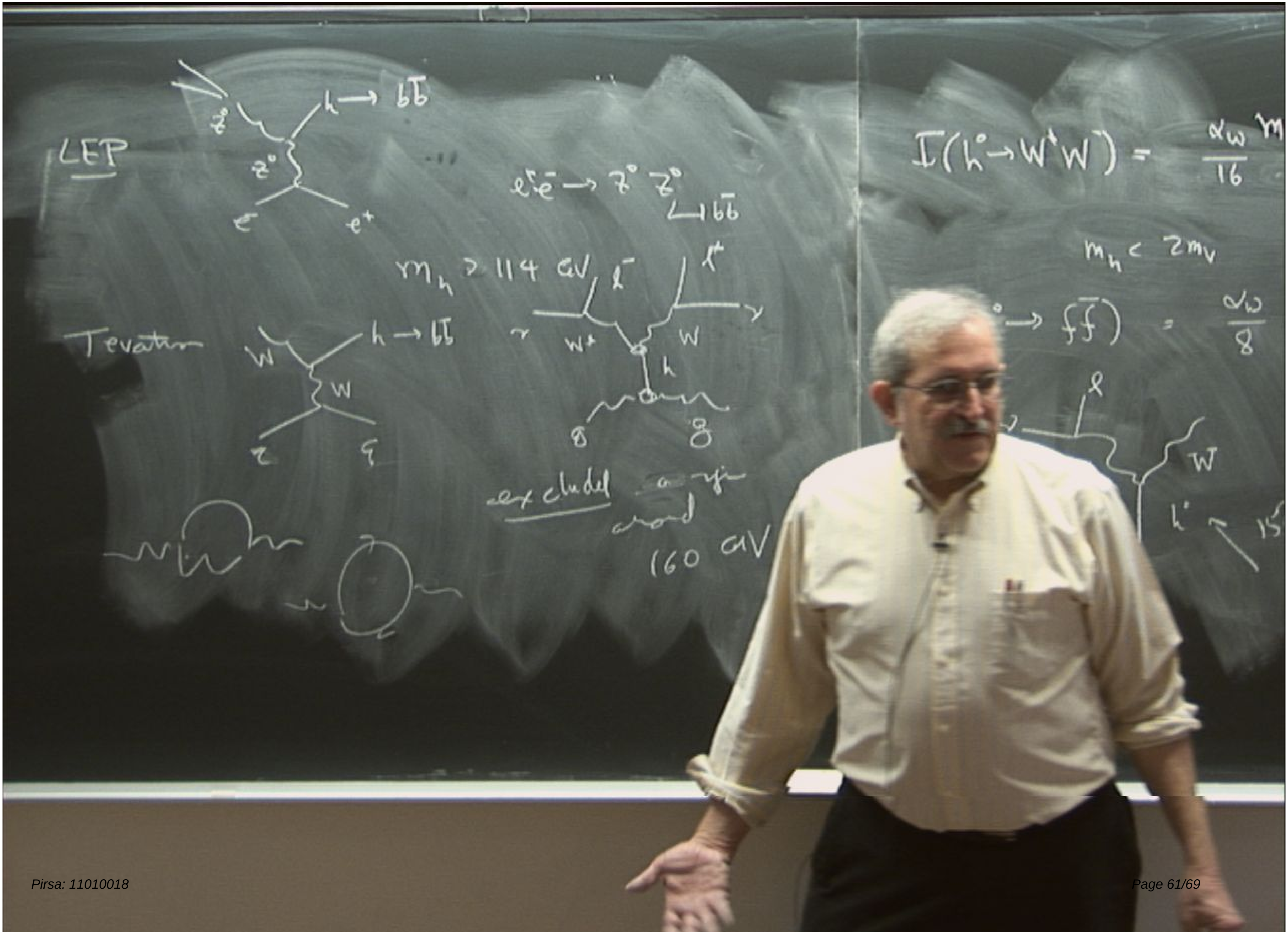
$$\Gamma(h^0 \to W^+W^-) = \frac{\alpha_w}{16} m$$

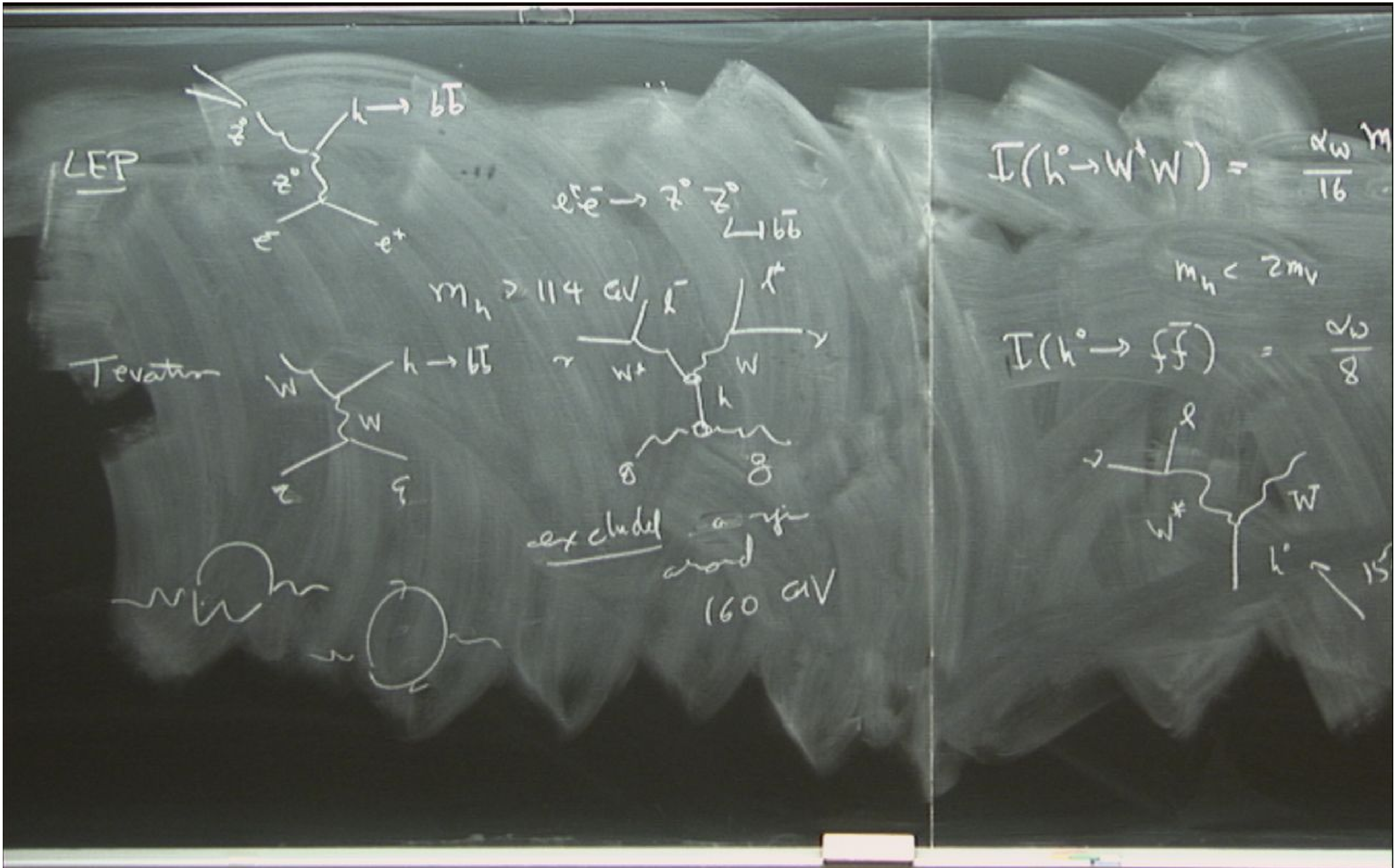
$m_h < 2m_V$

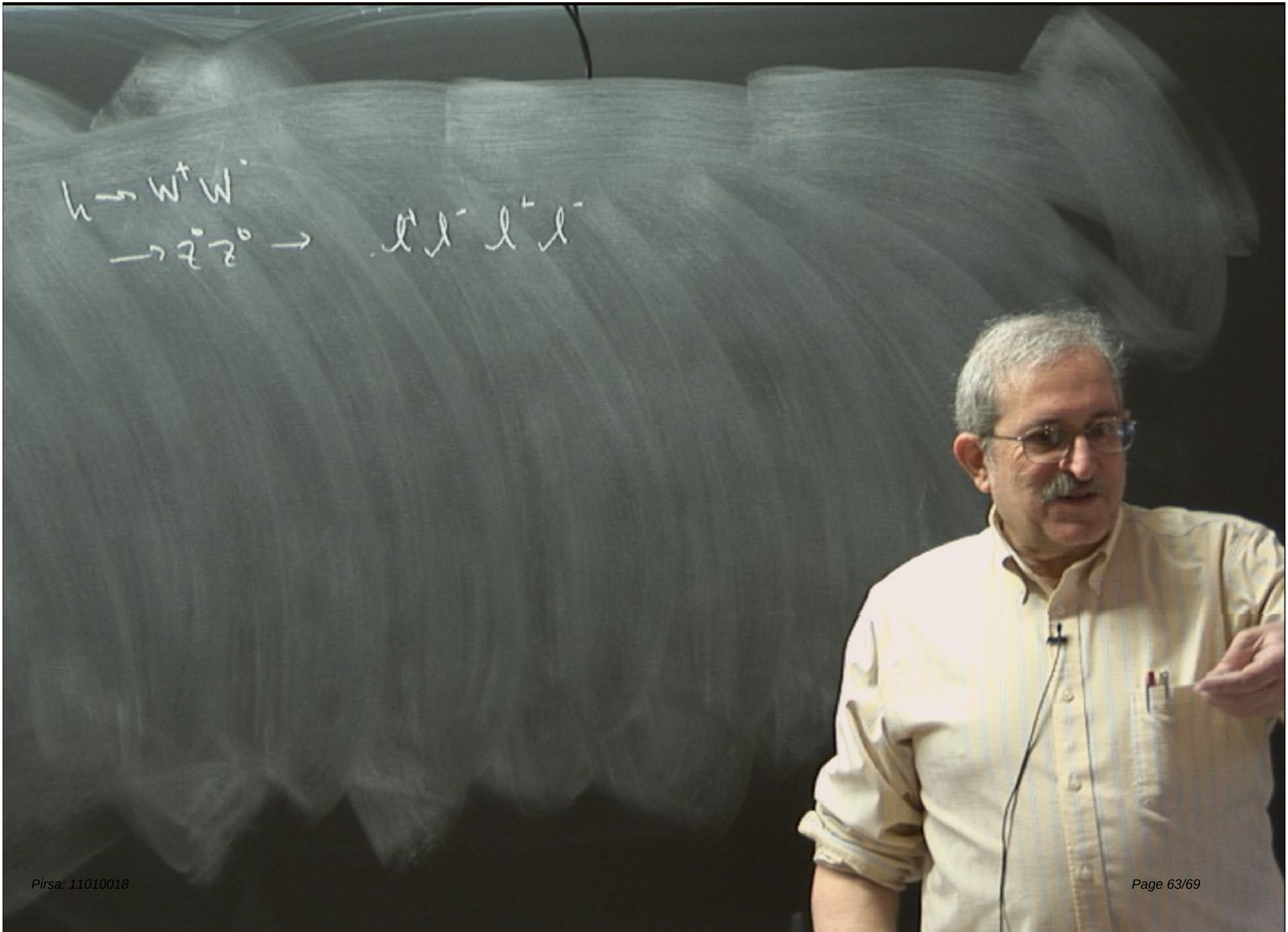
$$\Gamma(h^0 \to f\bar f) = \frac{\alpha_w}{8}$$

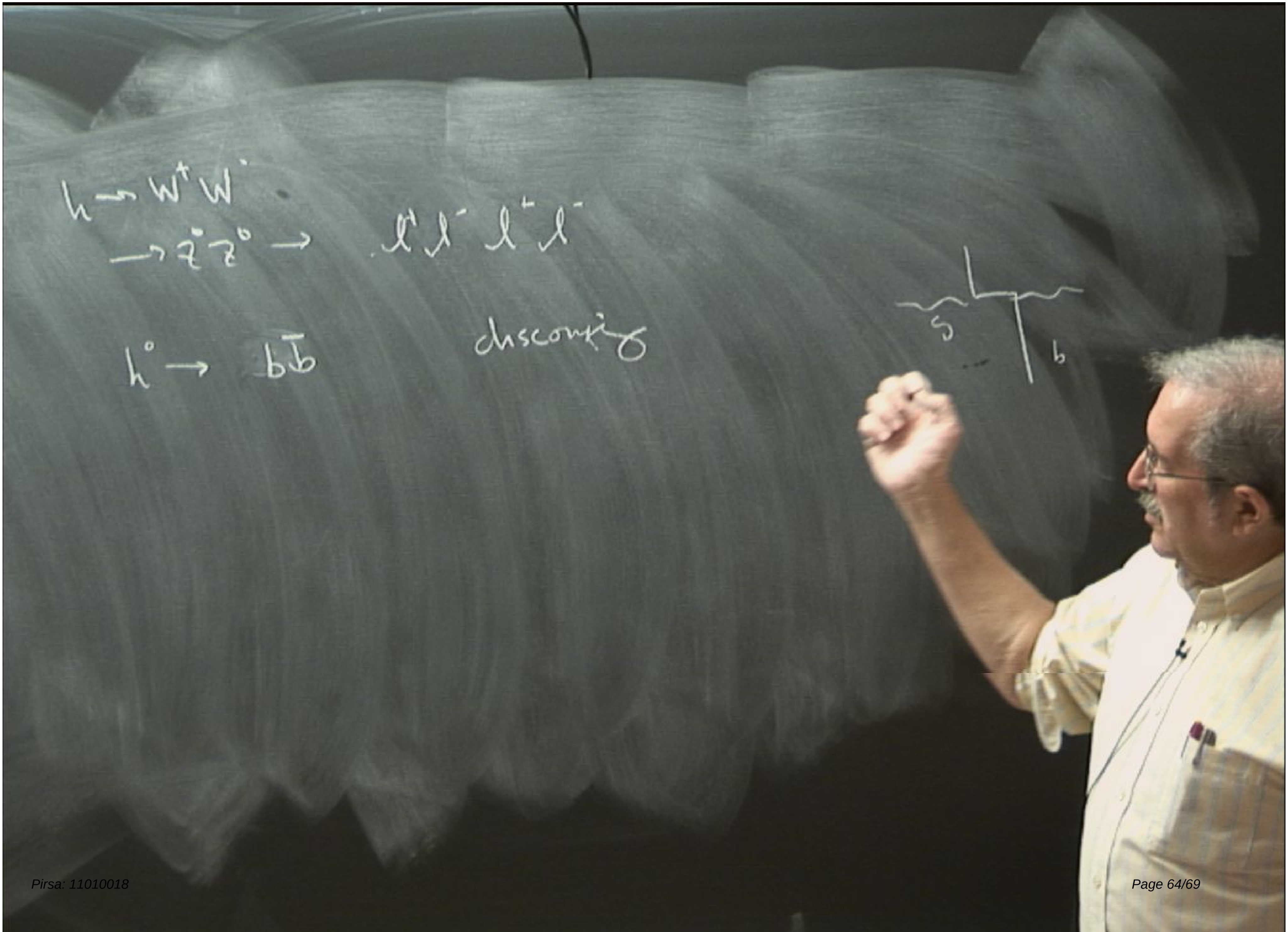


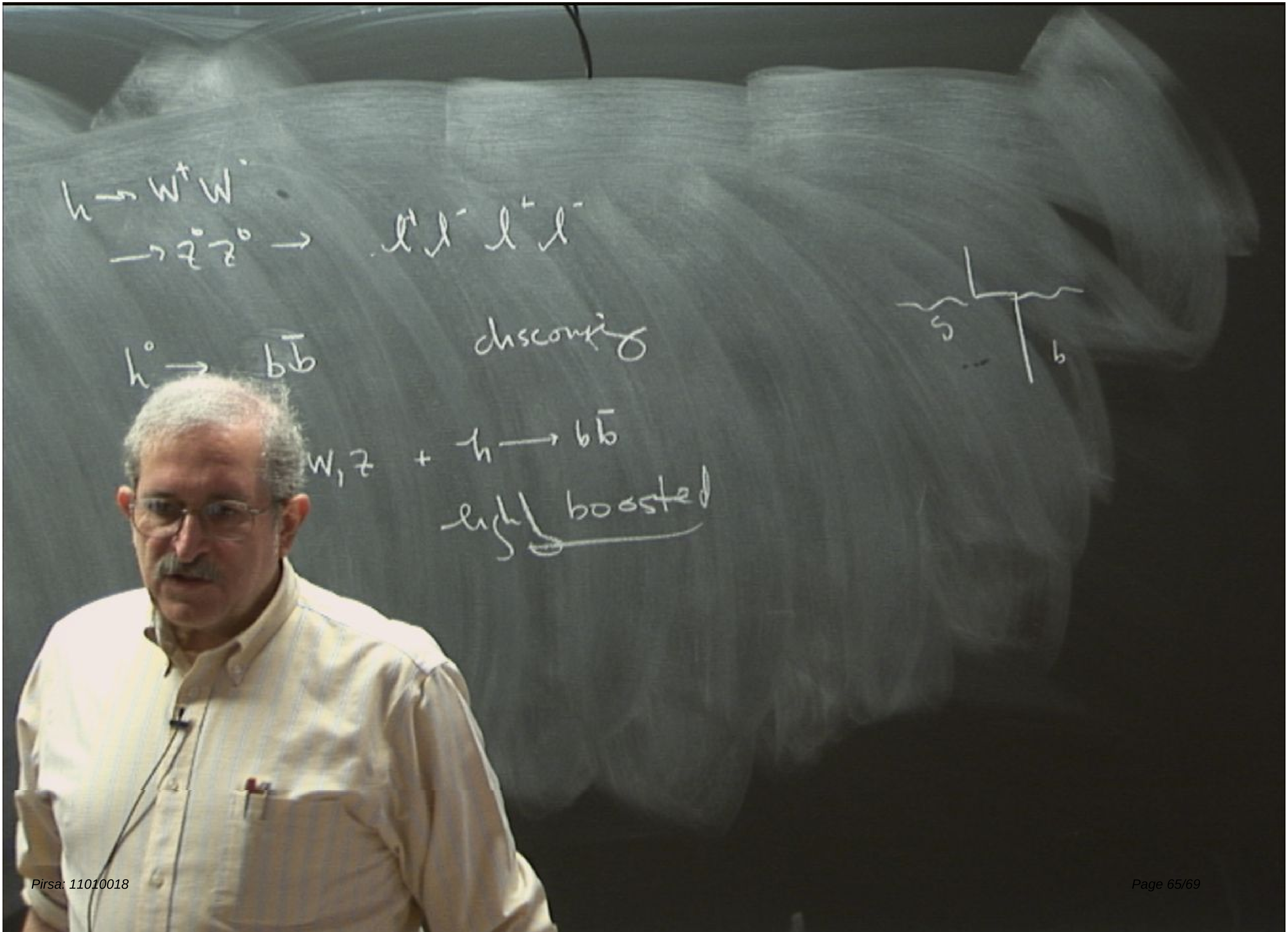
15

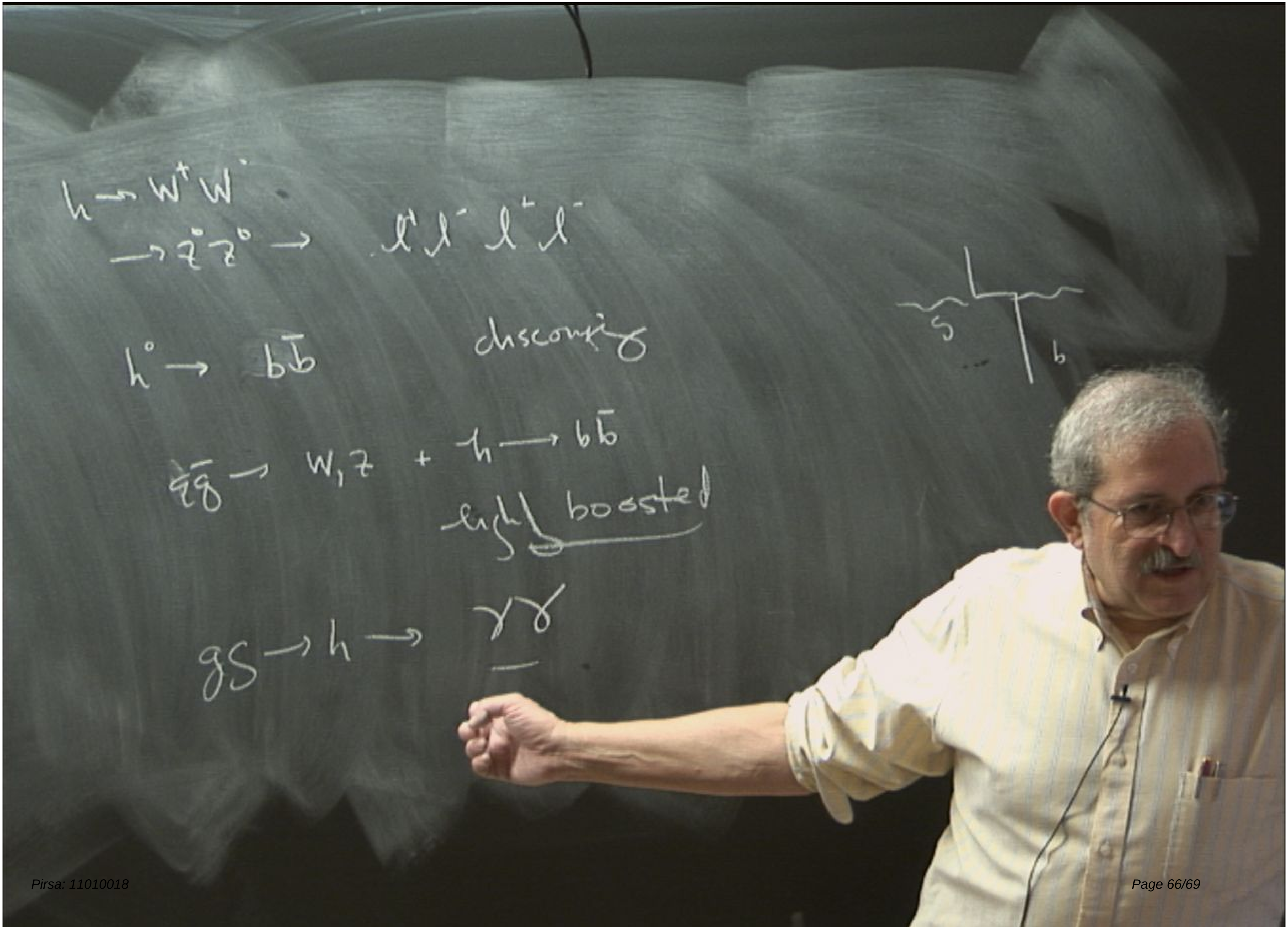

LEP
Tevatron
$e^+e^- \to Z^0 Z^0$
$m_h > 114$ GeV
excluded
160 GeV
$\Gamma(h^0 \to W^+W^-) = \frac{\alpha_W}{16}$
$m_h < 2m_V$

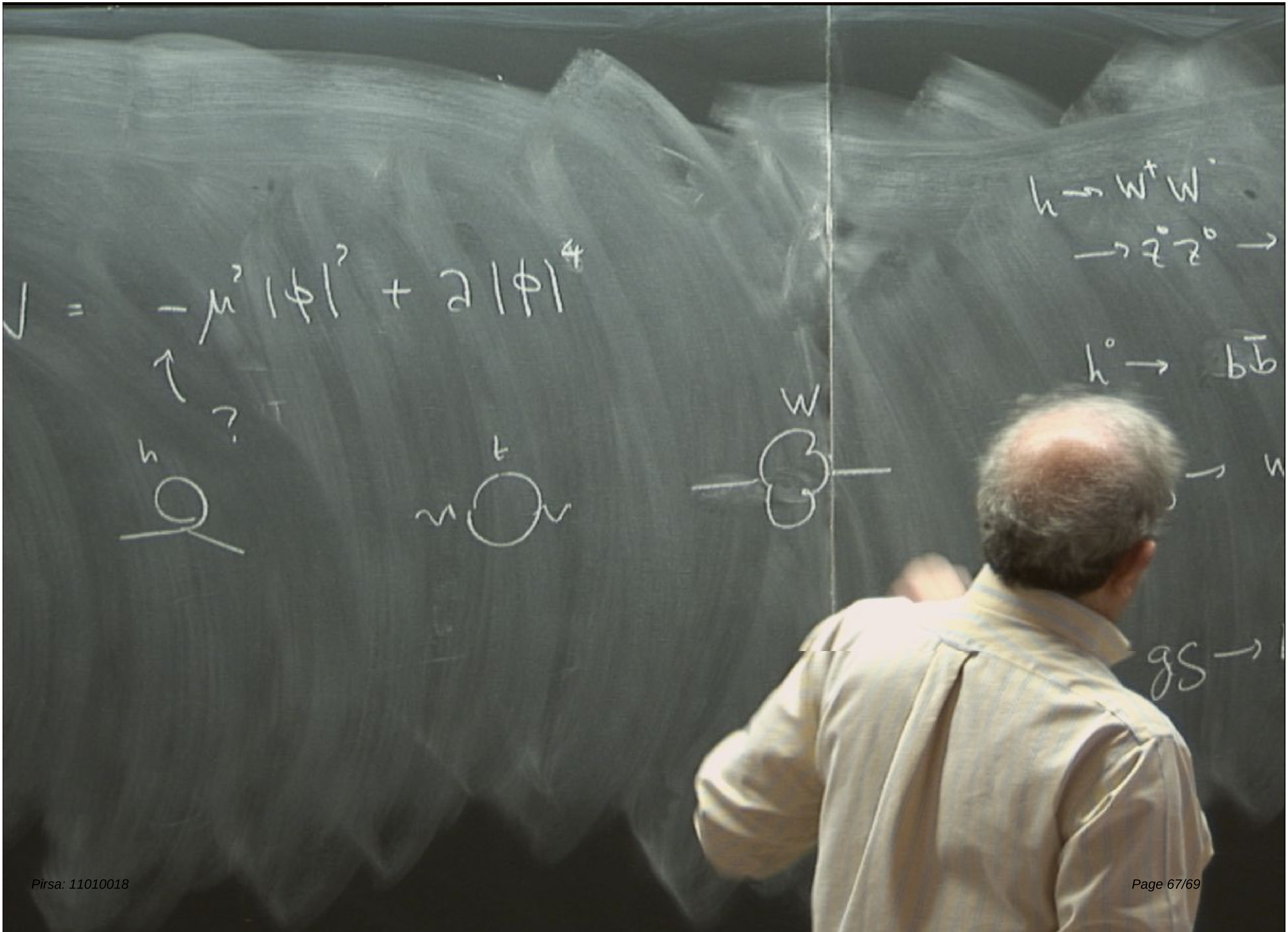

LEP
h → bb̄
Z°
e⁻ e⁺
e⁺e⁻ → Z° Z°
↳ bb̄
m_h > 114 GeV
Tevatron
h → bb̄
W
W
ℓ⁻ ℓ⁺
W⁺ W
h
g g
excluded
around
160 GeV
Γ(h° → W⁺W⁻) = α_W/16
m_h < 2m_V
Γ(h° → ff̄) = α_W/8
ℓ
W*
W
h°

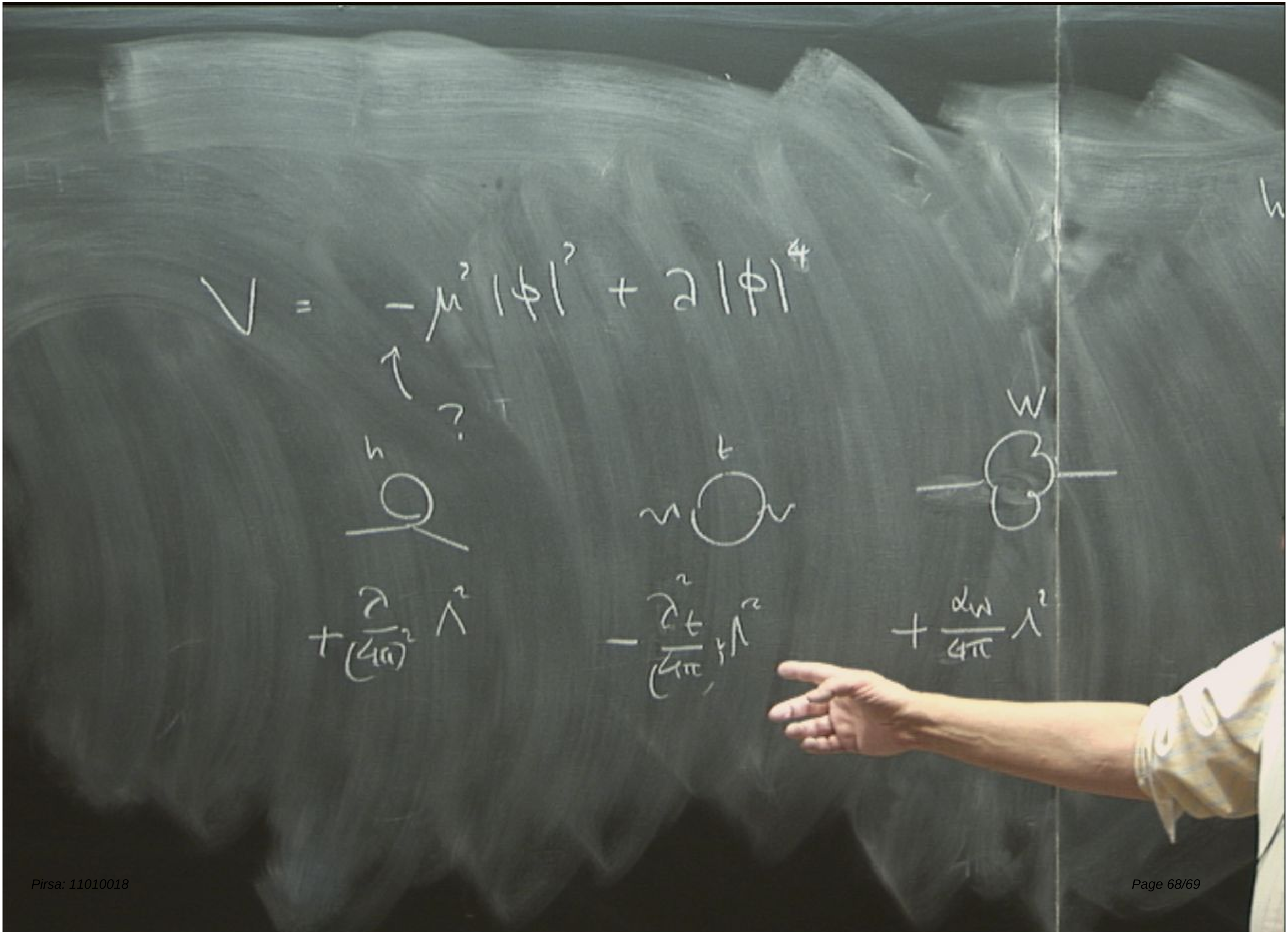

$h \to W^+W^-$
$\to Z^0Z^0 \to \ell^+\ell^-\ell^+\ell^-$


$h \to W^+W^-$
$\to Z^0 Z^0 \to l^+l^-l^+l^-$
$h^0 \to b\bar{b}$


h → W+W-
→ Z0Z0 → l+l- l+l-
h0 → bb̄
W, Z + h → bb̄
light boosted


$h \to W^+W^-$
$\to Z^0Z^0 \to l^+l^-l^+l^-$
$h^0 \to b\bar{b}$
discovering
$q\bar{q} \to W, Z + h \to b\bar{b}$
light boosted
$gg \to h \to \gamma\gamma$
g
b


V = −μ²|φ|² + λ|φ|⁴
?
h
t
W
h → W⁺W⁻
→ Z⁰Z⁰ →
h⁰ → b b̄
gs →


$V = -\mu^2 |\phi|^2 + \lambda |\phi|^4$
?
h
t
W
$+\frac{\lambda}{(4\pi)^2}\Lambda^2$
$-\frac{\lambda_t^2}{(4\pi)^2}\Lambda^2$
$+\frac{\alpha_W}{4\pi}\Lambda^2$

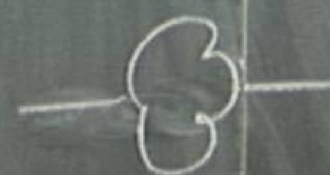
$$V = -\mu^2 |\phi|^2 + \lambda |\phi|^4$$

?

h

t

W



$$+\frac{\lambda}{(4\pi)^2}\Lambda^2 \qquad -\frac{\lambda_t^2}{(4\pi)^2}\Lambda^2 \qquad +\frac{\alpha_W}{4\pi}\Lambda^2$$

$$0 > \mu_{ren}^2 = \mu_b^2 + (\quad)\Lambda^2$$