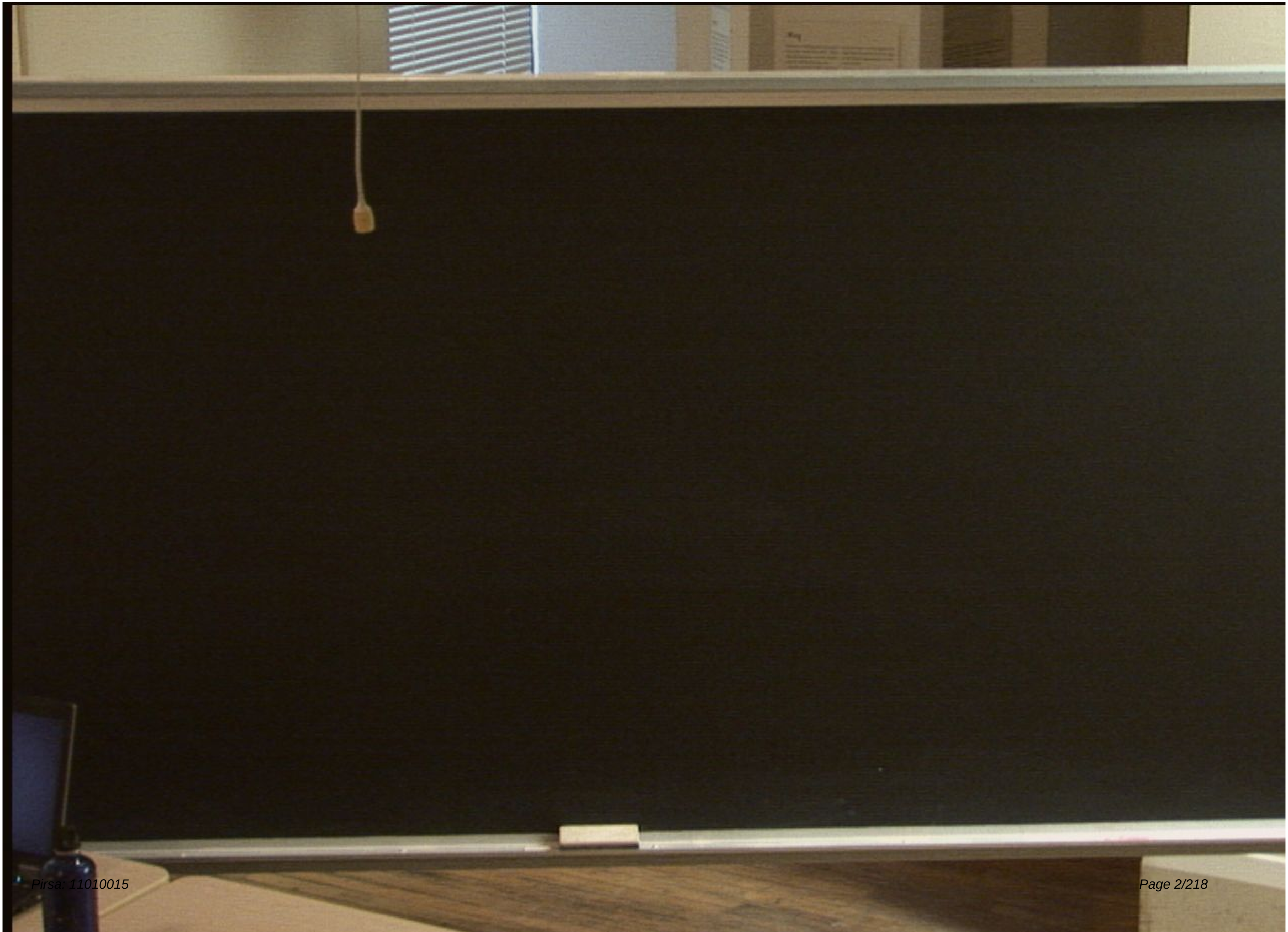
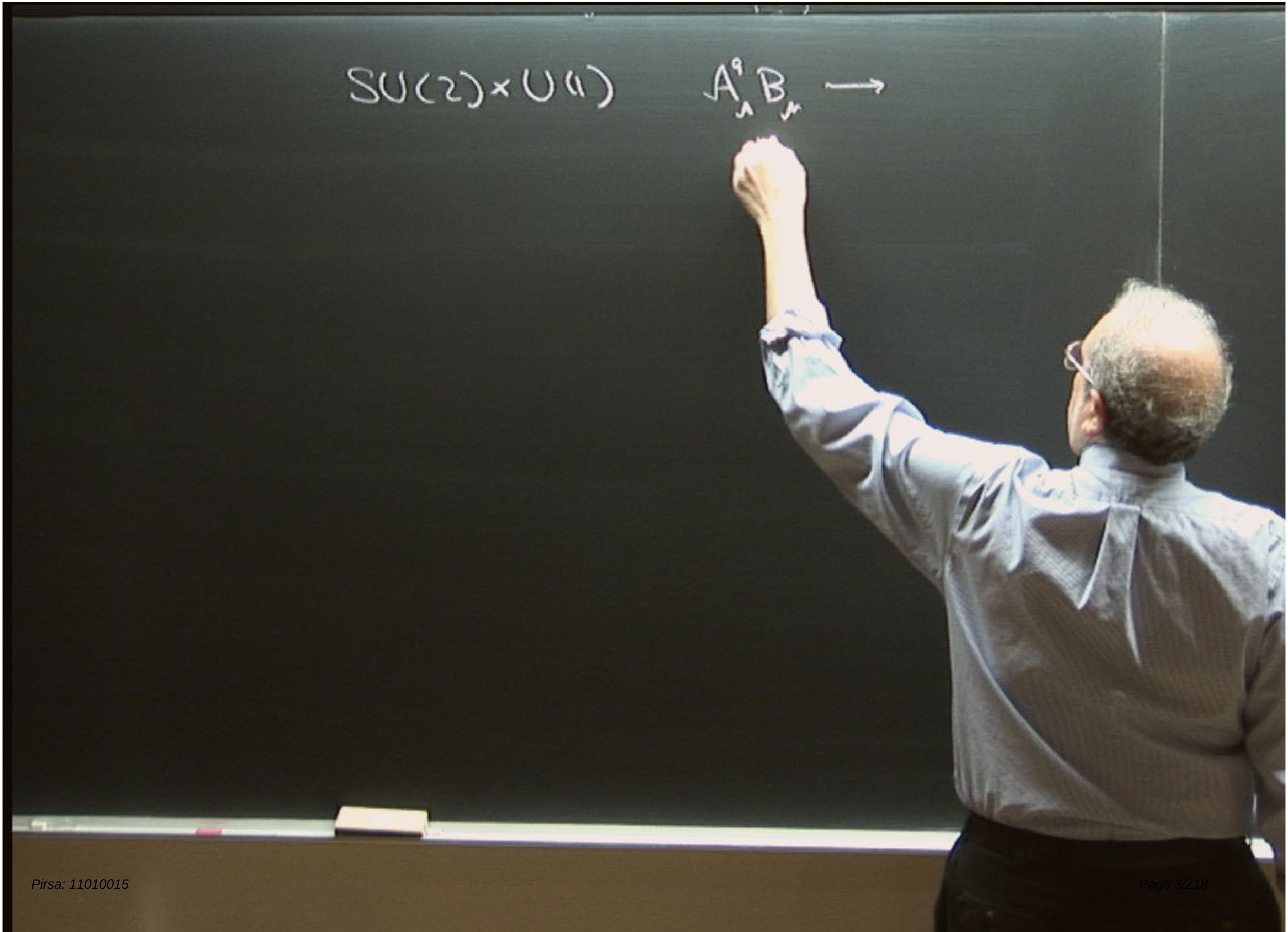
Title: Standard Model - Lecture 12

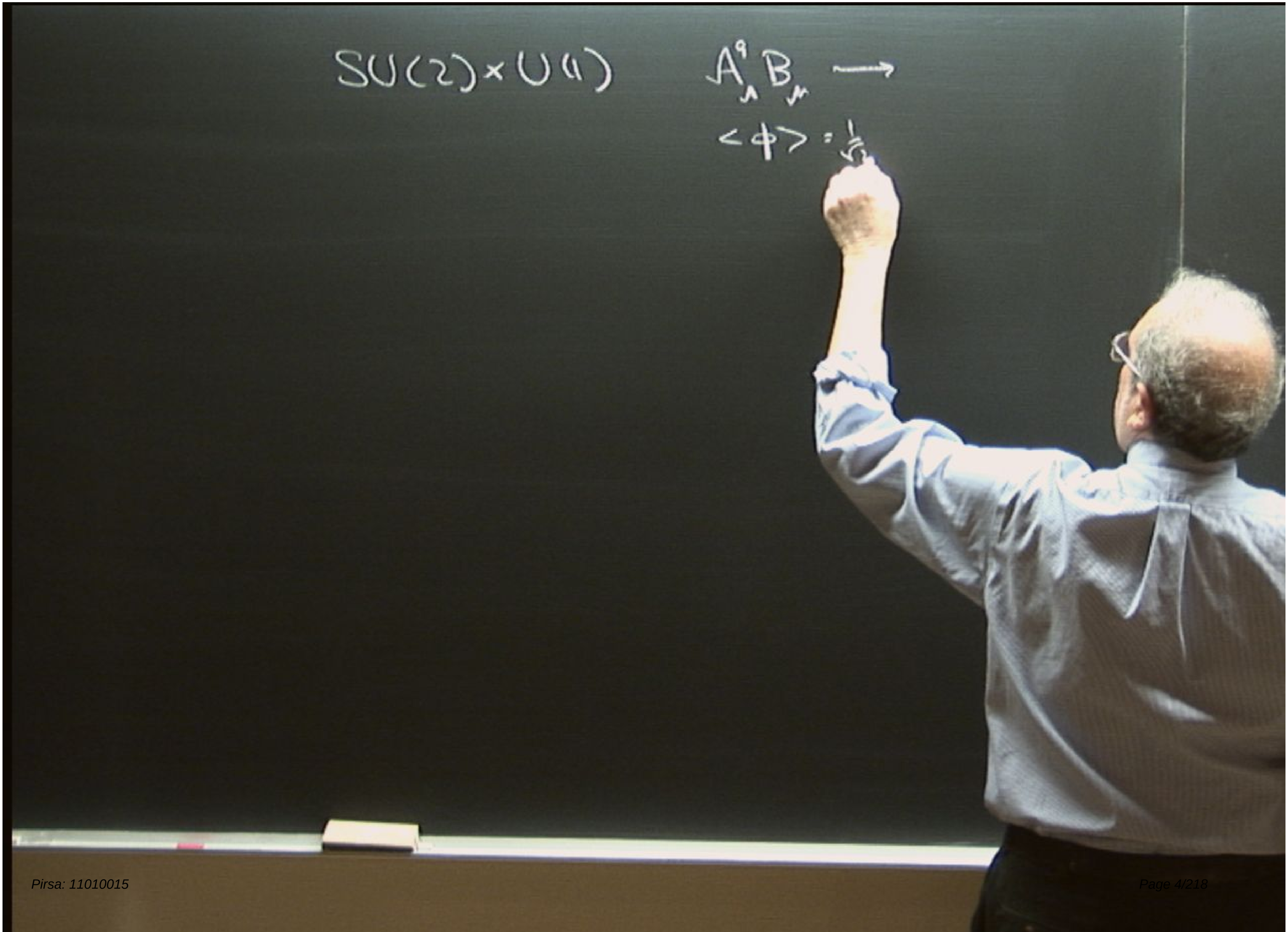
Date: Jan 18, 2011 09:00 AM

URL: http://pirsa.org/11010015

Abstract:



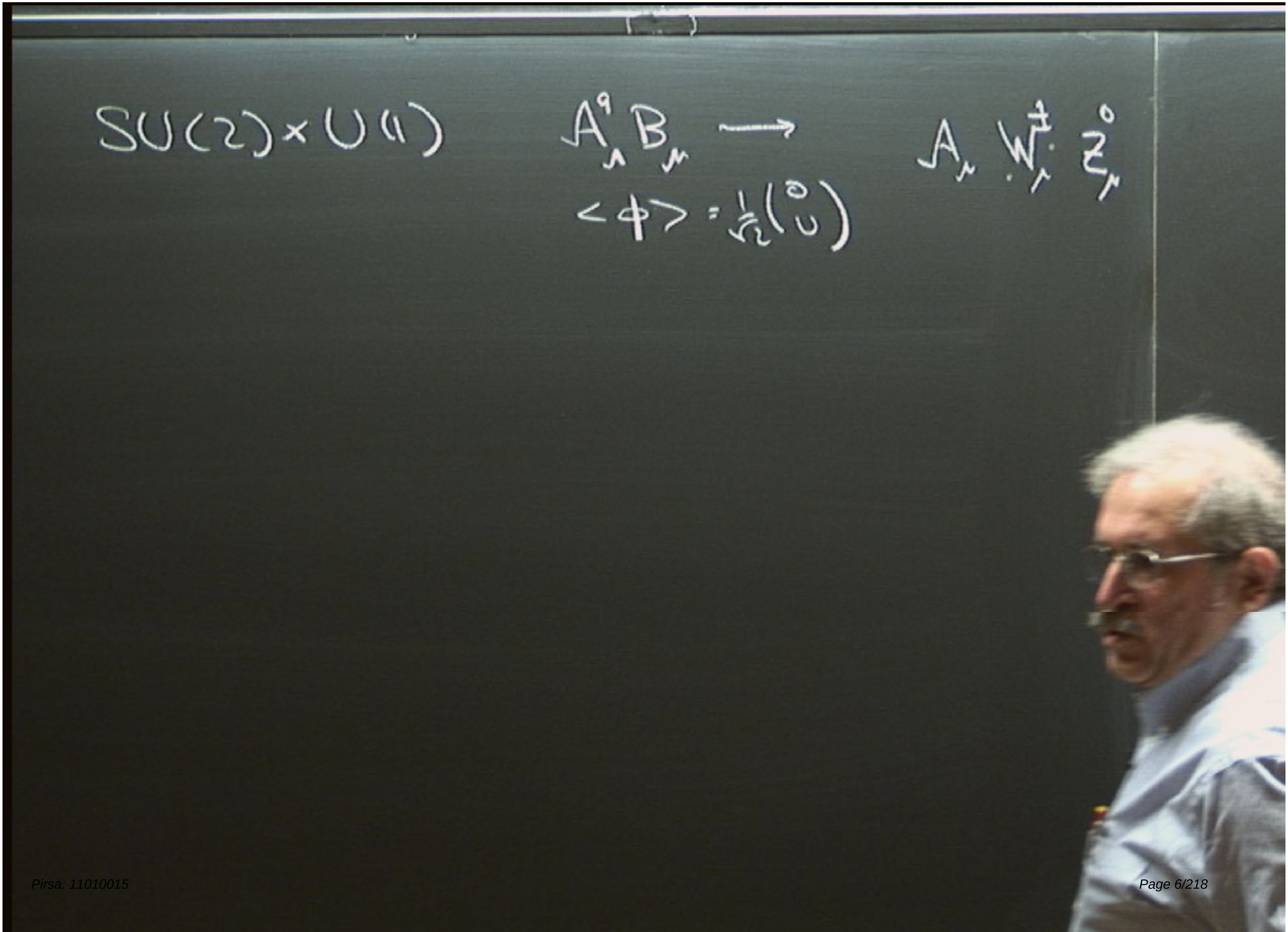

$SU(2) \times U(1)$
$A^a_\mu B_\mu \longrightarrow$


SU(2) × U(1)
A^a_μ B_μ ⟶
<φ> =

$SU(2) \times U(1)$

$$A^a_\mu \, B_\mu \longrightarrow A_\mu$$

$$\langle \phi \rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v \end{pmatrix}$$


$SU(2)\times U(1)$
$A^a_\mu\, B_\mu \longrightarrow A_\mu\, W^\pm_\mu\, Z^0_\mu$
$\langle\phi\rangle = \frac{1}{\sqrt{2}}\begin{pmatrix}0\\ v\end{pmatrix}$

$SU(2) \times U(1)$

$A^a_\mu \; B_\mu \longrightarrow A_\mu \; W^\pm_\mu \; Z^0_\mu$

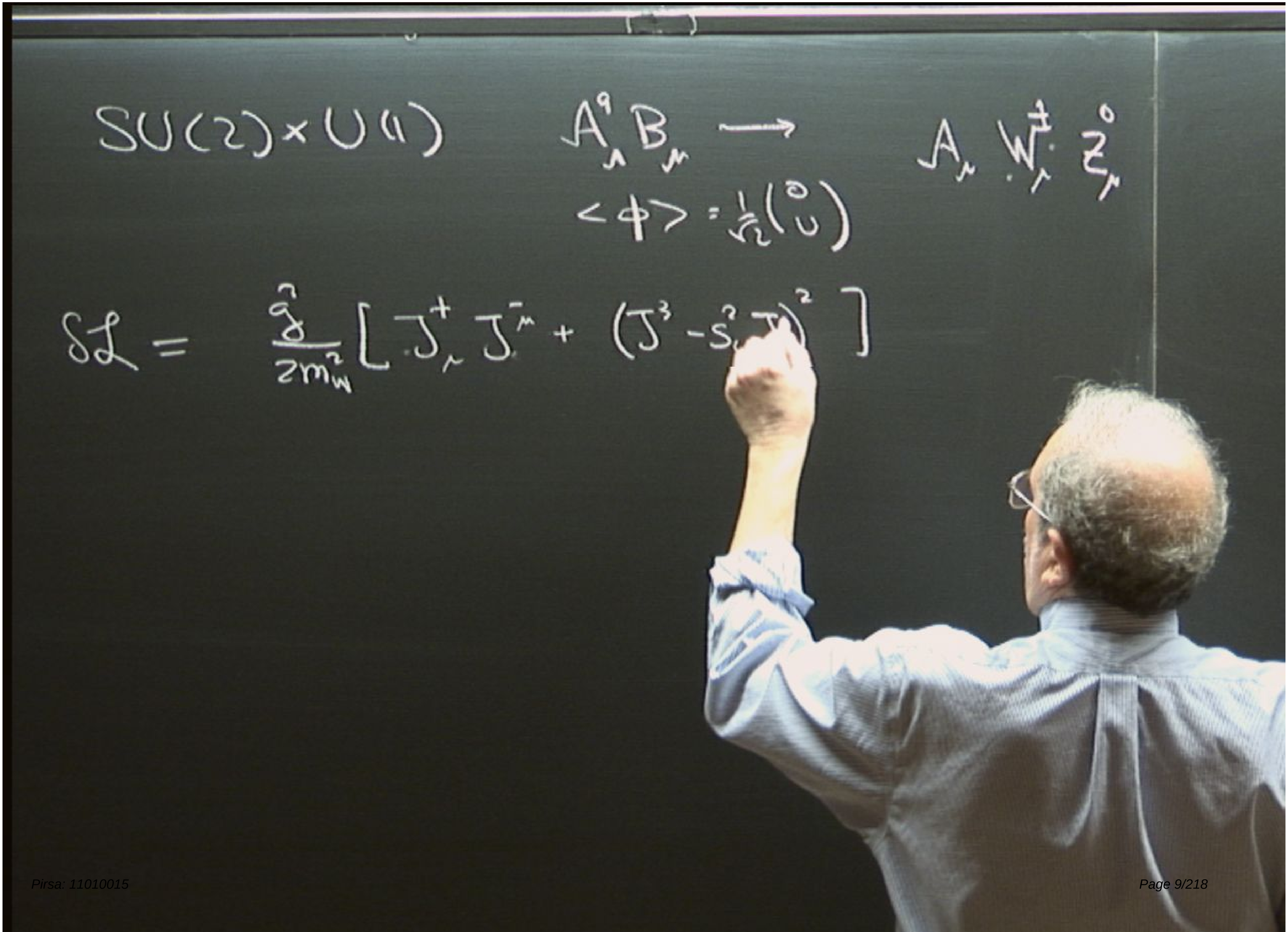
$\langle \phi \rangle = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ v \end{pmatrix}$

$\delta \mathcal{L} =$

$SU(2) \times U(1)$ $\quad A^a_\mu \, B_\mu \longrightarrow A_\mu \, W^\pm_\mu \, Z^0_\mu$

$\langle \phi \rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v \end{pmatrix}$

$$\delta \mathcal{L} = \frac{g^2}{2m_W^2} \left[J^+_\mu J^{-\mu} + (J^3 \qquad)^2 \right]$$


SU(2) × U(1)
$A^a_\mu \, B_\mu \longrightarrow A_\mu \, W^\pm_\mu \, Z^0_\mu$
$\langle \phi \rangle = \frac{1}{\sqrt{2}} \binom{0}{v}$
$\delta \mathcal{L} = \frac{g^2}{2 m_W^2} \left[J^+_\mu J^{-\mu} + (J^3 - s^2 J)^2 \right]$

$SU(2) \times U(1) \qquad A^a_\mu \, B_\mu \longrightarrow A_\mu \, W^\pm_\mu \, Z^0_\mu$

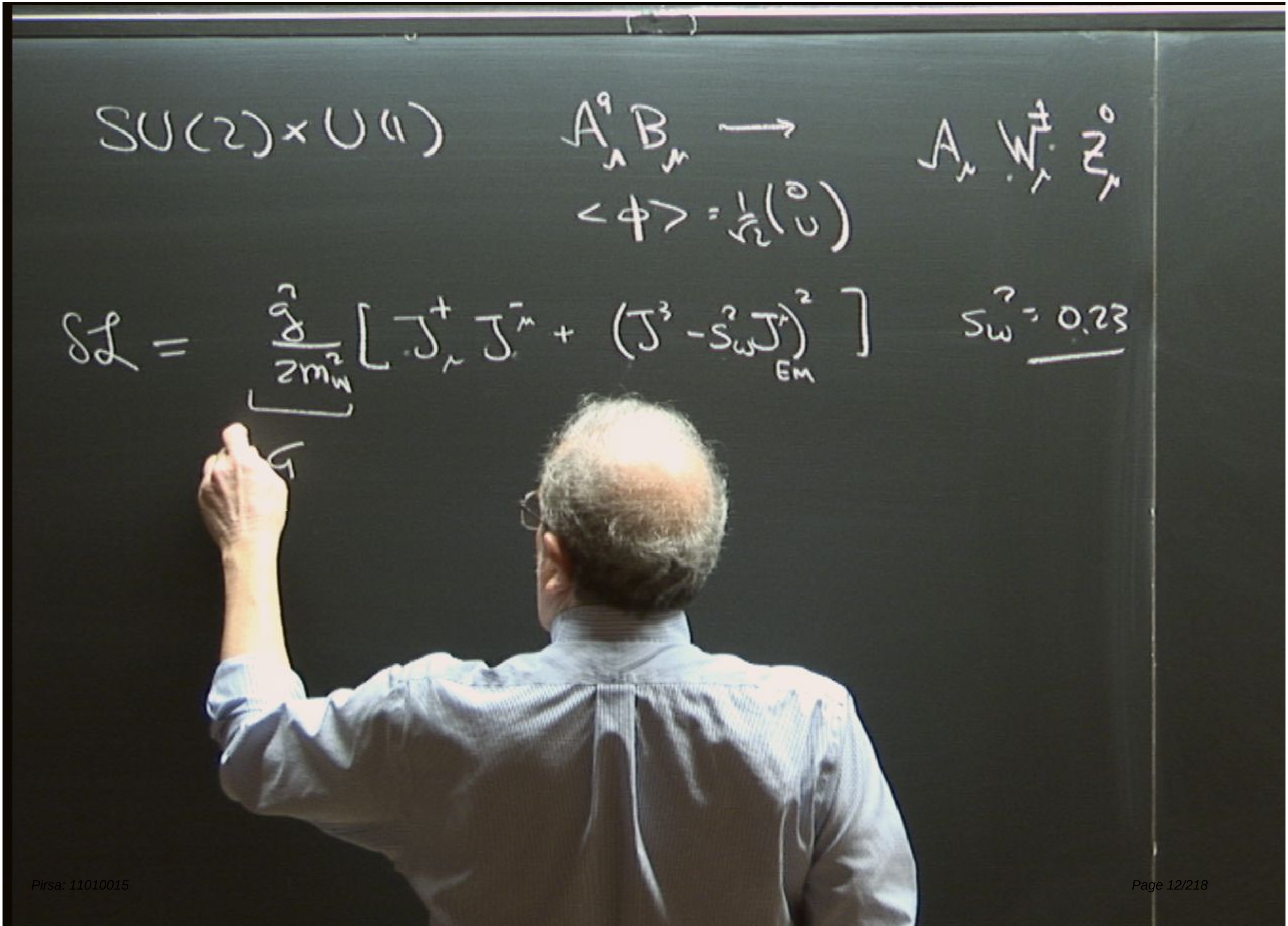
$\langle \phi \rangle = \frac{1}{\sqrt{2}} \binom{0}{v}$

$$\delta \mathcal{L} = \frac{g^2}{2 m_W^2} \left[J^+_\mu J^{-\mu} + \left(J^3 - s^2_W J^\mu_{EM} \right)^2 \right]$$

$SU(2)\times U(1)$ $\qquad A^a_\mu\, B_\mu \longrightarrow A_\mu\, W^{\pm}_\mu\, Z^0_\mu$

$$\langle\phi\rangle = \frac{1}{\sqrt{2}}\begin{pmatrix}0\\ v\end{pmatrix}$$

$$\delta\mathcal{L} = \frac{g^2}{2m_W^2}\left[J^+_\mu J^{-\mu} + \left(J^3 - s_W^2 J^\mu_{EM}\right)^2 \right]$$


$SU(2)\times U(1)$ $A^a_\mu B_\mu \longrightarrow A_\mu W^\pm_\mu Z^0_\mu$
$\langle\phi\rangle = \frac{1}{\sqrt{2}}\begin{pmatrix}0\\ v\end{pmatrix}$
$\delta\mathcal{L} = \underbrace{\frac{g^2}{2m_W^2}}_{G}\left[J^+_\mu J^{-\mu} + (J^3 - s_w^2 J_{EM})^2\right]$
$s_w^2 = 0.23$

$SU(2) \times U(1) \qquad A^a_\mu \, B_\mu \longrightarrow \qquad A_\mu \; W^\pm_\mu \; Z^0_\mu$

$\langle \phi \rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v \end{pmatrix}$

$$\delta \mathcal{L} = \underbrace{\frac{g^2}{2m_W^2}}_{\frac{4G_F}{\sqrt{2}}} \left[J^+_\mu J^{-\mu} + \left(J^3 - s_W^2 J_{EM} \right)^2 \right] \qquad \underline{s_W^2 = 0.23}$$

$SU(2)\times U(1)$ $\quad A^a_\mu\, B_\mu \longrightarrow A_\mu\, W^\pm_\mu\, Z^0_\mu$

$\langle\phi\rangle = \frac{1}{\sqrt{2}}\begin{pmatrix}0\\ v\end{pmatrix}$

$$\delta\mathcal{L} = \underbrace{\frac{g^2}{2m_W^2}}_{\frac{4G_F}{\sqrt{2}}}\left[J^+_\mu J^{-\mu} + \left(J^3 - s_w^2 J^\mu_{EM}\right)^2\right] \qquad \underline{s_w^2 = 0.23}$$

$$e = \frac{gg'}{\sqrt{g^2+g'^2}}$$

$SU(2)\times U(1)$ $\quad A^a_\mu\, B_\mu \longrightarrow A_\mu\, W^\pm_\mu\, Z^0_\mu$

$\langle\phi\rangle = \frac{1}{\sqrt{2}}\begin{pmatrix}0\\ v\end{pmatrix}$

$$\delta\mathcal{L} = \underbrace{\frac{g^2}{2m_W^2}}_{\frac{4G_F}{\sqrt{2}}}\left[J^+_\mu J^{-\mu} + \left(J^3 - s_w^2 J^\mu_{EM}\right)^2\right] \qquad s_w^2 = 0.23$$

$$e = \frac{gg'}{\sqrt{g^2+g'^2}} \qquad \alpha = \frac{g^2/4\pi}{\sin^2\theta_w} = \frac{g'^2/4\pi}{\cos\theta_w}$$

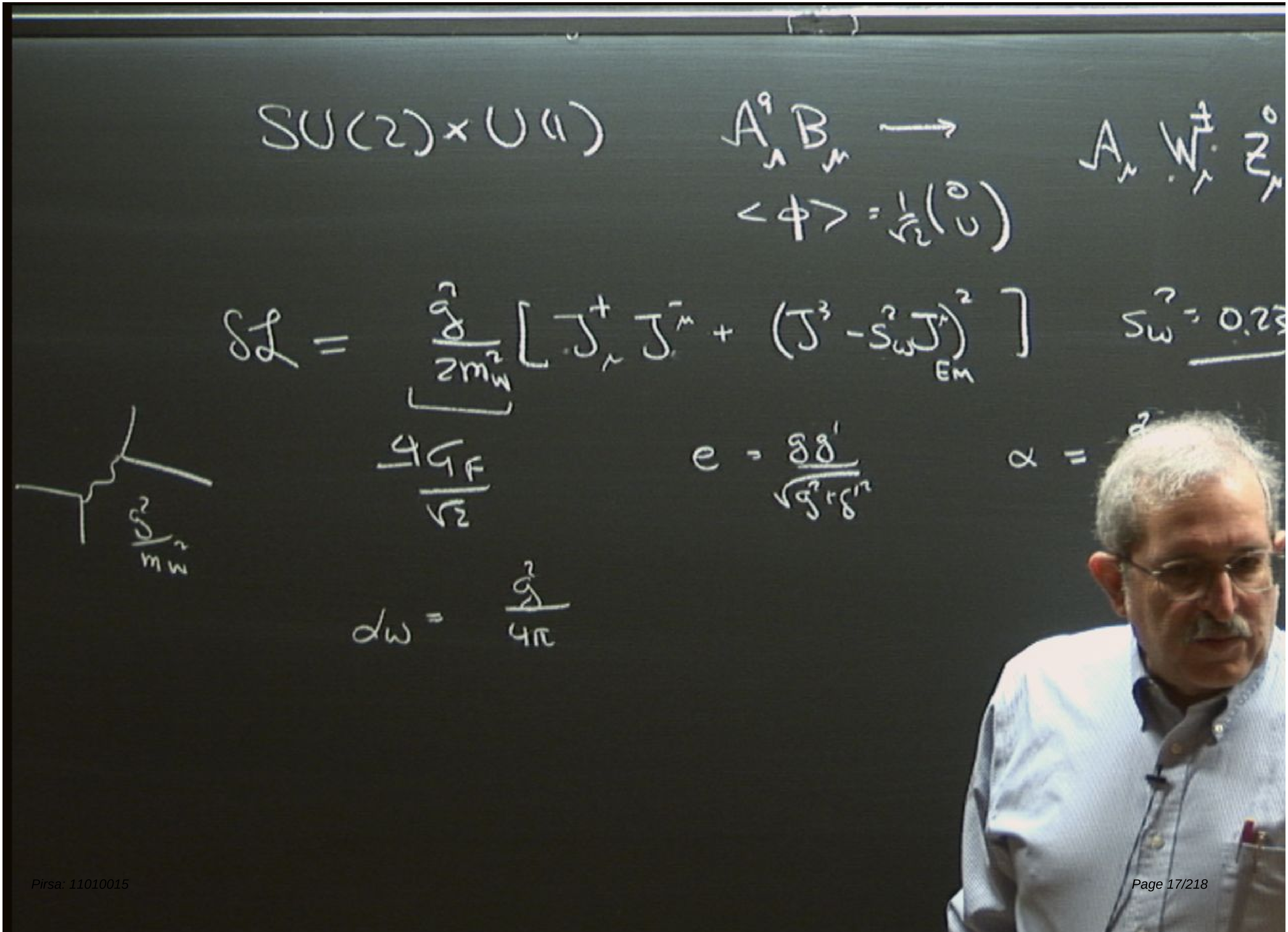
$SU(2) \times U(1)$ $\quad A^a_\mu B_\mu \longrightarrow A_\mu\ W^\pm_\mu\ Z^0_\mu$

$\langle \phi \rangle = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ v \end{pmatrix}$

$$\delta \mathcal{L} = \underbrace{\frac{g^2}{2m_W^2}}_{\frac{4G_F}{\sqrt{2}}}\left[J^+_\mu J^{-\mu} + (J^3 - s^2_W J^\mu_{EM})^2 \right] \qquad \underline{s^2_W = 0.23}$$

$$e = \frac{gg'}{\sqrt{g^2+g'^2}} \qquad \alpha = \frac{g^2/4\pi}{\sin^2\theta_W} = \frac{\frac{g'^2}{4\pi}}{\cos\theta_W}$$

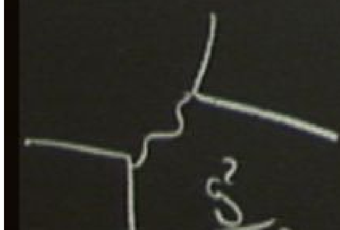
$$\alpha_W = \frac{g^2}{4\pi}$$


$SU(2)\times U(1)$
$A^a_\mu \; B_\mu \longrightarrow A_\mu \; W^\pm_\mu \; Z^0_\mu$
$\langle\phi\rangle = \frac{1}{\sqrt{2}}\binom{0}{v}$
$\delta\mathcal{L} = \underbrace{\frac{g^2}{2m_W^2}}\left[J^+_\mu J^{-\mu} + \left(J^3 - s_W^2 J^\mu_{EM}\right)^2\right]$
$s_W^2 = 0.23$
$\frac{4G_F}{\sqrt{2}}$
$e = \frac{gg'}{\sqrt{g^2+g'^2}}$
$\alpha =$
$\frac{g^2}{m_W^2}$
$\alpha_W = \frac{g^2}{4\pi}$

$SU(2) \times U(1) \qquad A^a_\mu\, B_\mu \longrightarrow A_\mu\ W^\pm_\mu\ Z^0_\mu$

$$\langle \phi \rangle = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ v \end{pmatrix}$$

$$\delta \mathcal{L} = \underbrace{\frac{g^2}{2m_W^2}}_{\frac{4G_F}{\sqrt{2}}}\left[J^+_\mu J^{-\mu} + \left(J^3 - s_W^2 J_{EM}\right)^2 \right] \qquad s_W^2 = 0.23$$



$\frac{g^2}{m_W^2}$

$$e = \frac{g g'}{\sqrt{g^2 + g'^2}} \qquad \alpha = \frac{g^2/4\pi}{\sin^2\theta_W}$$

$$\alpha_W = \frac{g^2}{4\pi} = \frac{\alpha}{s_W^2} \leftarrow \frac{1/}{0.23}$$

$SU(2)\times U(1)$ $\quad A^a_\mu B_\mu \longrightarrow A_\mu \; W^\pm_\mu \; Z^0_\mu$

$\langle\phi\rangle = \frac{1}{\sqrt{2}}\begin{pmatrix}0\\ v\end{pmatrix}$

$$\delta\mathcal{L} = \underbrace{\frac{g^2}{2m_W^2}}_{\frac{4G_F}{\sqrt{2}}}\left[J^+_\mu J^{-\mu} + \left(J^3 - s_W^2 J^\mu_{EM}\right)^2\right] \qquad \underline{s_W^2 = 0.23}$$

$$e = \frac{gg'}{\sqrt{g^2+g'^2}} \qquad \alpha = \frac{g^2/4\pi}{\sin^2\theta_W} = \frac{\frac{g'^2}{4\pi}}{\cos\theta_W}$$

$$\alpha_W = \frac{g^2}{4\pi} = \frac{\alpha}{s_W^2} \leftarrow \frac{1/129}{0.23} = \frac{1}{30.}$$

$SU(2) \times U(1) \qquad A^a_\mu \, B_\mu \longrightarrow A_\mu \; W^\pm_\mu \; Z^0_\mu$

$$\langle \phi \rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v \end{pmatrix}$$

$$\delta \mathcal{L} = \underbrace{\frac{g^2}{2m_W^2}}_{= \frac{4G_F}{\sqrt{2}}} \left[J^+_\mu J^{-\mu} + \left(J^3 - s_W^2 J^\mu_{EM}\right)^2 \right] \qquad s_W^2 = 0.23$$

$$e = \frac{g g'}{\sqrt{g^2 + g'^2}} \qquad \alpha = \frac{g^2/4\pi}{s \ldots} \qquad \frac{g'^2}{4\pi} \over \ldots \theta_W$$

$$\alpha_W = \frac{g^2}{4\pi} = \frac{\alpha}{s_W^2} \leftarrow \frac{1/129}{0.23} = \frac{1}{30.}$$

$$\frac{G_F}{\sqrt{2}} = \frac{g^2}{8 m_W^2}$$

$$SU(2)\times U(1) \qquad A^a_\mu \, B_\mu \longrightarrow A_\mu \, W^\pm_\mu \, Z^0_\mu$$

$$\langle \phi \rangle = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ v \end{pmatrix}$$

$$\delta \mathcal{L} = \underbrace{\frac{g^2}{2m_W^2}}_{=\frac{4G_F}{\sqrt{2}}}\left[J^+_\mu J^{-\mu} + \left(J^3 - s_w^2 J^\mu_{EM}\right)^2 \right] \qquad \underline{s_w^2 = 0.23}$$

$$e = \frac{gg'}{\sqrt{g^2+g'^2}} \qquad \alpha = \frac{g^2/4\pi}{\sin^2\theta_w} \cdot \frac{g'^2/4\pi}{\cos\theta_w}$$

$$\alpha_w = \frac{g^2}{4\pi} = \frac{\alpha}{s_w^2} \leftarrow \frac{1/129}{0.23} = \frac{1}{30}$$

$$\frac{G_F}{\sqrt{2}} = \frac{g^2}{8m_W^2} \qquad m_W =$$

$$SU(2)\times U(1) \qquad A^a_\mu\, B_\mu \longrightarrow A_\mu\ W^\pm_\mu\ Z^0_\mu$$

$$\langle\phi\rangle = \frac{1}{\sqrt{2}}\begin{pmatrix}0\\ v\end{pmatrix}$$

$$\delta\mathcal{L} = \underbrace{\frac{g^2}{2m_W^2}}_{\frac{4G_F}{\sqrt{2}}}\left[J^+_\mu J^{-\mu} + \left(J^3 - s_W^2 J^\mu_{EM}\right)^2\right] \qquad s_W^2 = 0.23$$

$$e = \frac{gg'}{\sqrt{g^2+g'^2}} \qquad \alpha = \frac{g^2/4\pi}{\sin^2\theta_W} = \frac{\frac{g'^2}{4\pi}}{\cos\theta_W}$$

$$\alpha_W = \frac{g^2}{4\pi} = \frac{\alpha}{s_W^2} \leftarrow \frac{1/129}{0.23} = \frac{1}{30}$$

$$\frac{G_F}{\sqrt{2}} = \frac{g^2}{8m_W^2} \qquad m_W = \frac{4\pi\alpha}{}$$

$SU(2)\times U(1)$ $\quad A^a_\mu B_\mu \longrightarrow A_\mu\ W^\pm_\mu\ Z^0_\mu$

$$\langle\phi\rangle = \frac{1}{\sqrt{2}}\begin{pmatrix}0\\ v\end{pmatrix}$$

$$\delta\mathcal{L} = \underbrace{\frac{g^2}{2m_W^2}}_{=\frac{4G_F}{\sqrt{2}}}\left[J^+_\mu J^{-\mu} + (J^3 - s_\omega^2 J^\mu_{EM})^2\right] \qquad \underline{s_\omega^2 = 0.23}$$

$$e = \frac{gg'}{\sqrt{g^2+g'^2}} \qquad \alpha = \frac{g^2/4\pi}{\sin^2\Theta_W} = \frac{g'^2/4\pi}{\cos\Theta_\omega}$$

$$\alpha_\omega = \frac{g^2}{4\pi} = \frac{\alpha}{s_\omega^2} \leftarrow \frac{1/129}{0.23} = \frac{1}{30.}$$

$$\frac{G_F}{\sqrt{2}} = \frac{g^2}{8m_W^2} \qquad m_W = \frac{4\pi\alpha}{4\sqrt{2}G_F}$$

$$SU(2)\times U(1) \qquad A^a_\mu B_\mu \longrightarrow A_\mu \; W^\pm_\mu \; Z^0_\mu$$

$$\langle\phi\rangle = \frac{1}{\sqrt{2}}\begin{pmatrix}0\\ v\end{pmatrix}$$

$$\delta\mathcal{L} = \underbrace{\frac{g^2}{2m_W^2}}_{\frac{4G_F}{\sqrt{2}}}\left[J^+_\mu J^{-\mu} + \left(J^3 - s_W^2 J^\mu_{EM}\right)^2\right] \qquad \underline{s_W^2 = 0.23}$$

$$e = \frac{gg'}{\sqrt{g^2+g'^2}} \qquad \alpha = \frac{g^2/4\pi}{\sin^2\theta_W} = \frac{\frac{g'^2}{4\pi}}{\cos\theta_W}$$

$$\alpha_W = \frac{g^2}{4\pi} = \frac{\alpha}{s_W^2} \leftarrow \frac{1/129}{0.23} = \frac{1}{30}$$

$$\frac{G_F}{\sqrt{2}} = \frac{g^2}{8m_W^2} \qquad m_W = \left[\frac{4\pi\alpha}{4\sqrt{2}G_F s_W^2}\right)^{1/2}$$

$SU(2) \times U(1) \qquad A^a_\mu \, B_\mu \longrightarrow A_\mu \, W^\pm_\mu \, Z^0_\mu$

$\langle \phi \rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v \end{pmatrix}$

$$\delta \mathcal{L} = \underbrace{\frac{g^2}{2m_W^2}}_{= \frac{4G_F}{\sqrt{2}}} \left[J^+_\mu J^{-\mu} + \left(J^3 - s_W^2 J^\mu_{EM} \right)^2 \right] \qquad \underline{s_W^2 = 0.23}$$

$$e = \frac{g g'}{\sqrt{g^2 + g'^2}} \qquad \alpha = \frac{g^2/4\pi}{\sin^2\theta_W} = \frac{g'^2/4\pi}{\cos\theta_W}$$

$$\alpha_W = \frac{g^2}{4\pi} = \frac{\alpha}{s_W^2} \leftarrow \frac{1/129}{0.23} = \frac{1}{30}$$

$$\frac{G_F}{\sqrt{2}} = \frac{g^2}{8m_W^2} \qquad m_W = \left[\frac{4\pi\alpha}{4\sqrt{2} G_F s_W^2} \right)^{1/2}$$

$$= 80 \text{ GeV}$$

$SU(2)\times U(1)$ $\quad A^a_\mu B_\mu \longrightarrow A_\mu\ W^\pm_\mu\ Z^0_\mu$

$$\langle\phi\rangle = \frac{1}{\sqrt{2}}\begin{pmatrix}0\\ v\end{pmatrix}$$

$$\mathcal{L} = \underbrace{\frac{g^2}{2m_W^2}}_{\frac{4G_F}{\sqrt{2}}}\left[J^+_\mu J^{-\mu} + (J^3 - s_W^2 J^\mu_{EM})^2\right] \qquad s_W^2 = 0.23$$

$$e = \frac{gg'}{\sqrt{g^2+g'^2}} \qquad \alpha = \frac{g^2/4\pi}{\sin^2\theta_W} = \frac{\frac{g'^2}{4\pi}}{\cos\theta_W}$$

$$\alpha_W = \frac{g^2}{4\pi} = \frac{\alpha}{s_W^2} \leftarrow \frac{1/129}{0.23} = \frac{1}{30}$$

$$\frac{G_F}{\sqrt{2}} = \frac{g^2}{8m_W^2} \qquad m_W = \left[\frac{4\pi\alpha}{4\sqrt{2}G_F s_W^2}\right]^{1/2} \qquad m_Z = \frac{m_W}{\cos\theta_W}$$

$$\doteq 90.\ \text{GeV}$$

$$= 80\ \text{GeV}$$

$SU(2)\times U(1)$ $\quad A^a_\mu\, B_\mu \longrightarrow A_\mu\, W^\pm_\mu\, Z^0_\mu$

$$\langle\phi\rangle = \frac{1}{\sqrt{2}}\begin{pmatrix}0\\ v\end{pmatrix}$$

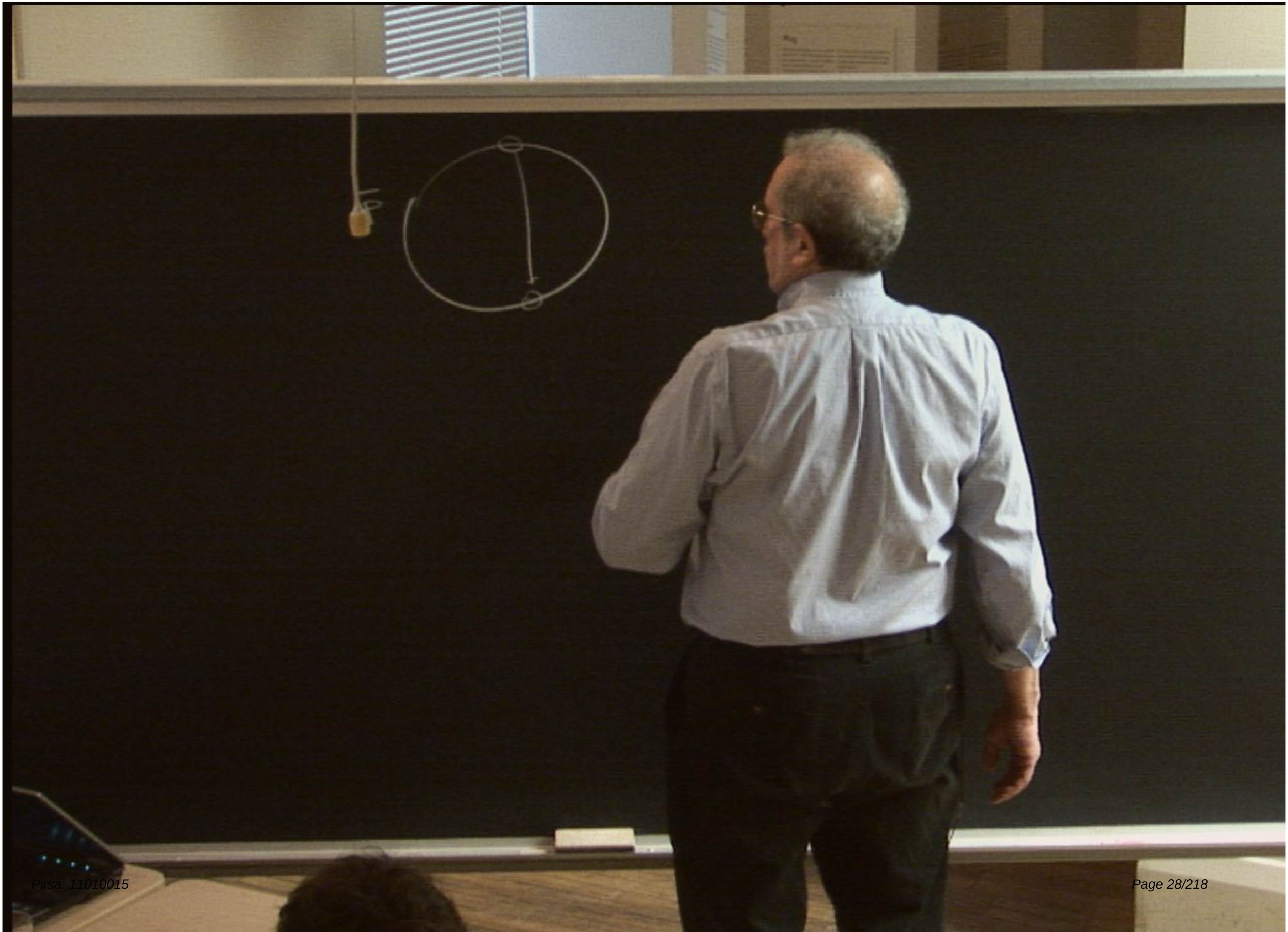
$$\mathcal{L} = \underbrace{\frac{g^2}{2m_W^2}}_{=\,\frac{4G_F}{\sqrt{2}}}\left[J^+_\mu J^{-\mu} + \left(J^3 - s_W^2 J^\mu_{EM}\right)^2\right] \qquad \underline{s_W^2 = 0.23}$$

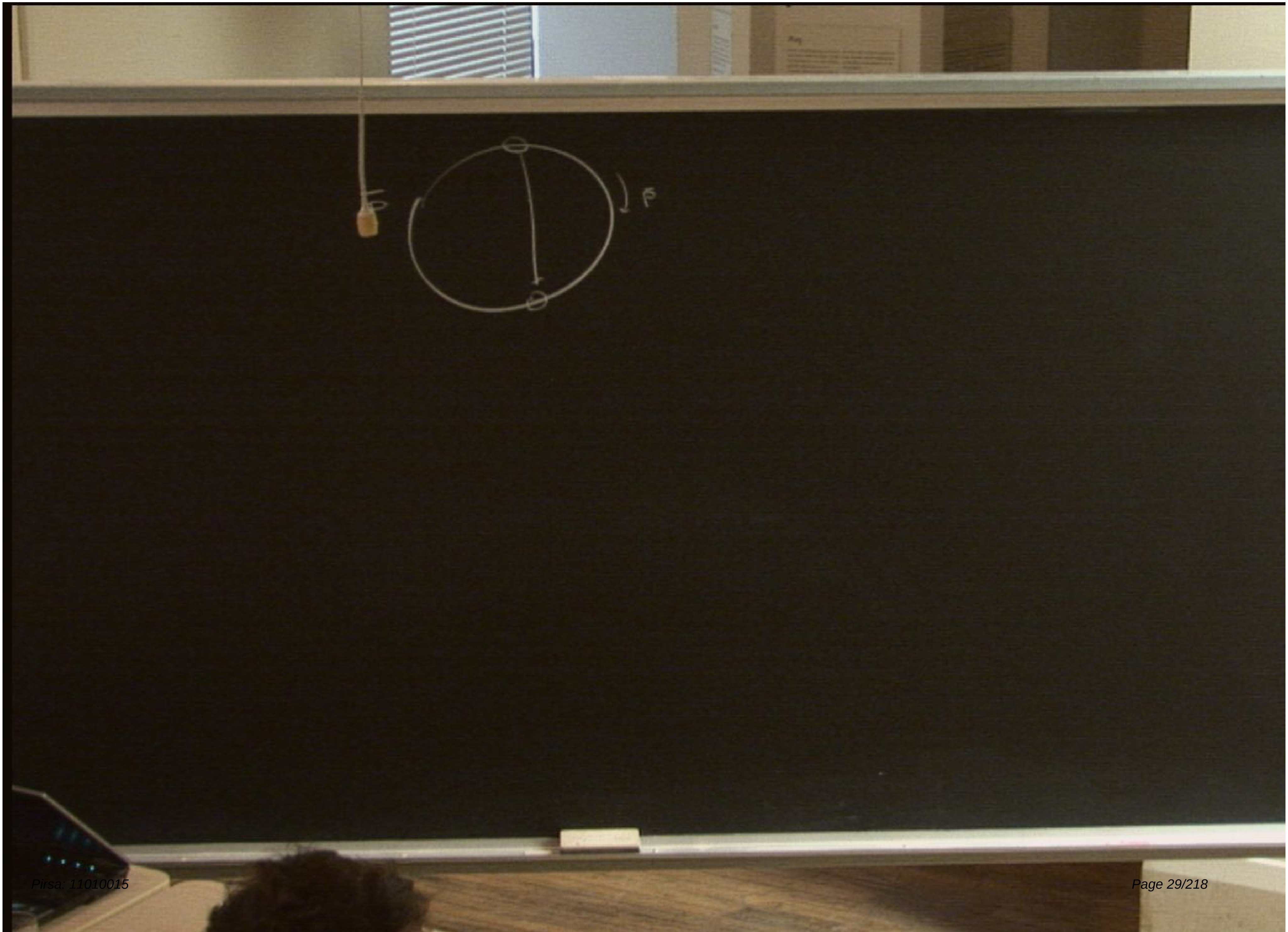
$$e = \frac{gg'}{\sqrt{g^2+g'^2}} \qquad \alpha = \frac{g^2/4\pi}{\sin^2\theta_W} = \frac{\frac{g'^2}{4\pi}}{\cos\theta_W}$$

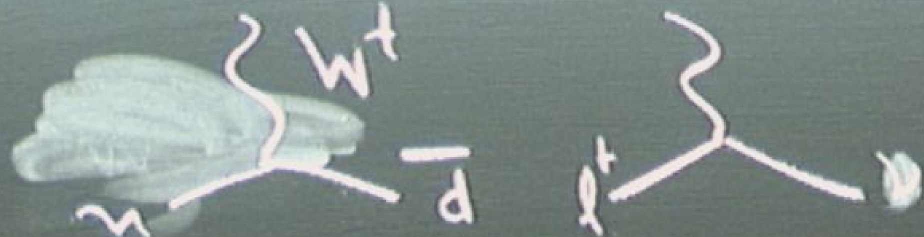
$$\alpha_W = \frac{g^2}{4\pi} = \frac{\alpha}{s_W^2} \leftarrow \frac{1/129}{0.23} = \frac{1}{30.}$$

$$\frac{G_F}{\sqrt{2}} = \frac{g^2}{8m_W^2} \qquad m_W = \left[\frac{4\pi\alpha}{4\sqrt{2}G_F s_W^2}\right]^{1/2} \qquad m_Z = \frac{m_W}{\cos\theta_W}$$

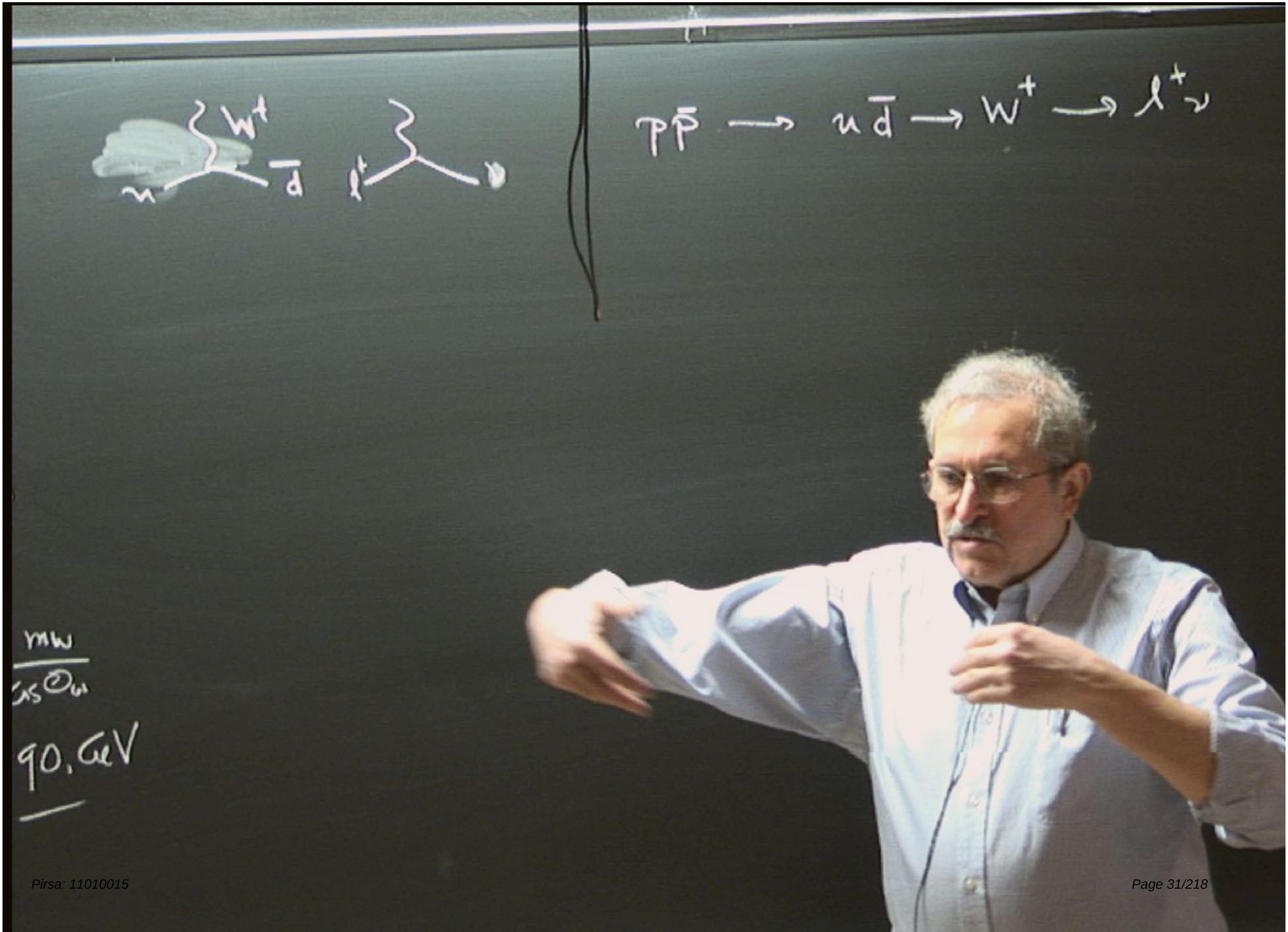
$$= 80\text{ GeV} \qquad \hat{=}\ \underline{90.\text{ GeV}}$$

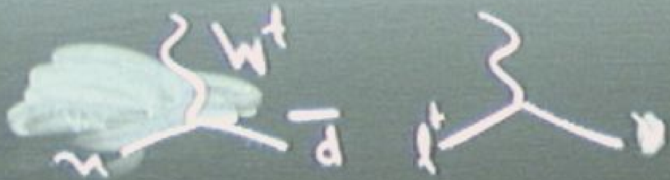






$p\bar{p} \longrightarrow u\bar{d} \longrightarrow$

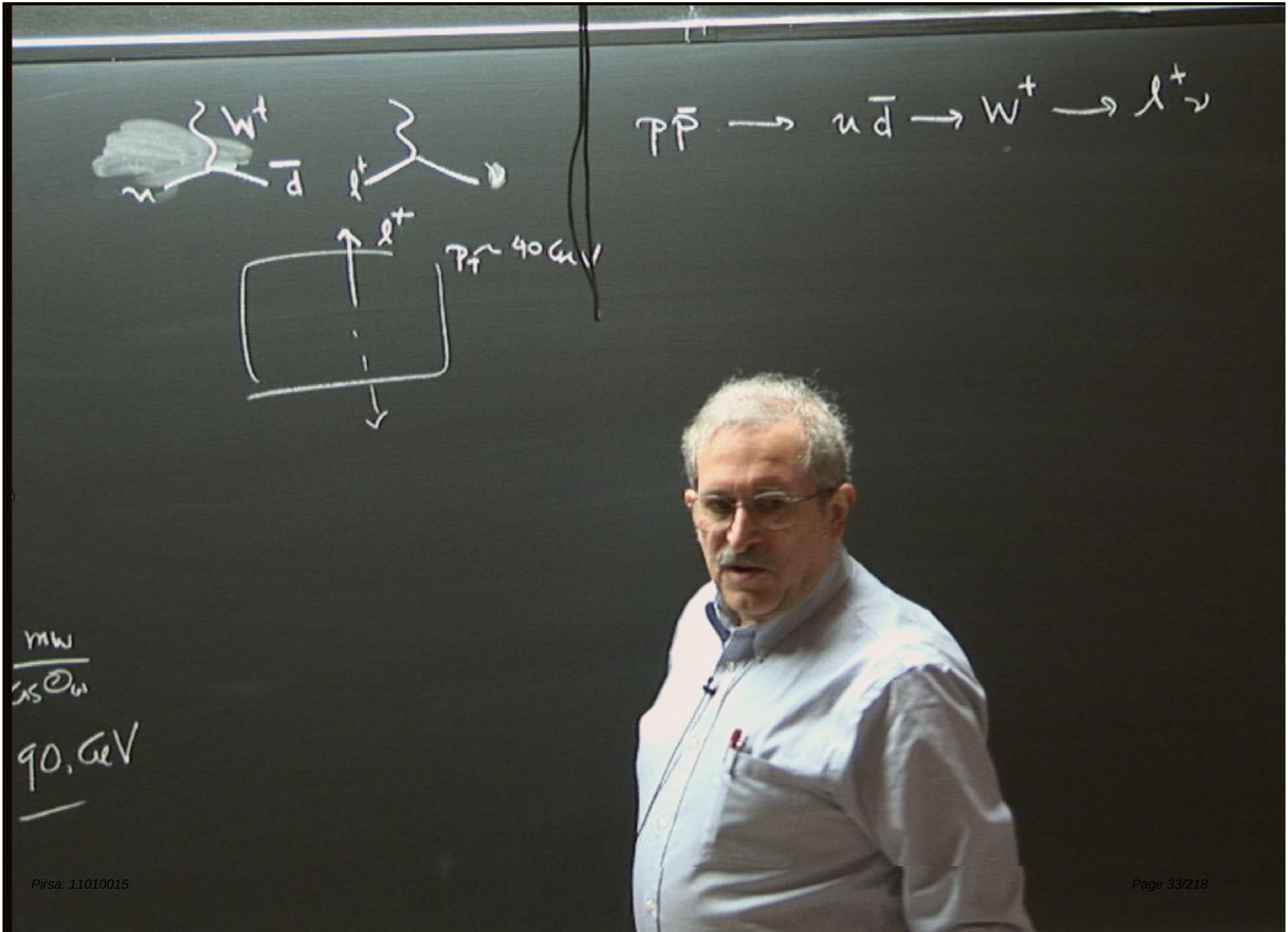

W+
u
d̄
l+
ν
pp̄ → ud̄ → W+ → l+ν
mw
cos θw
90. GeV

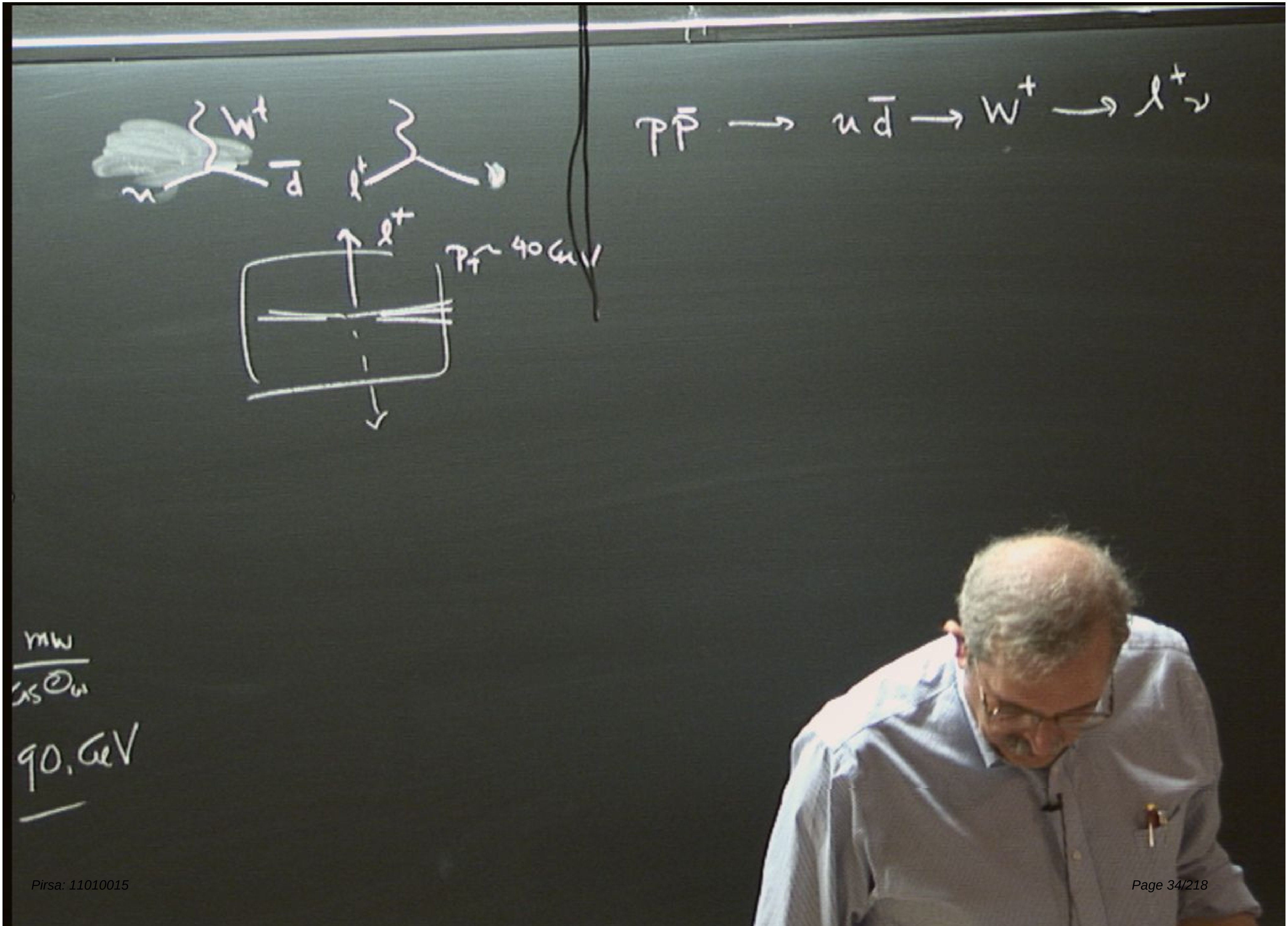


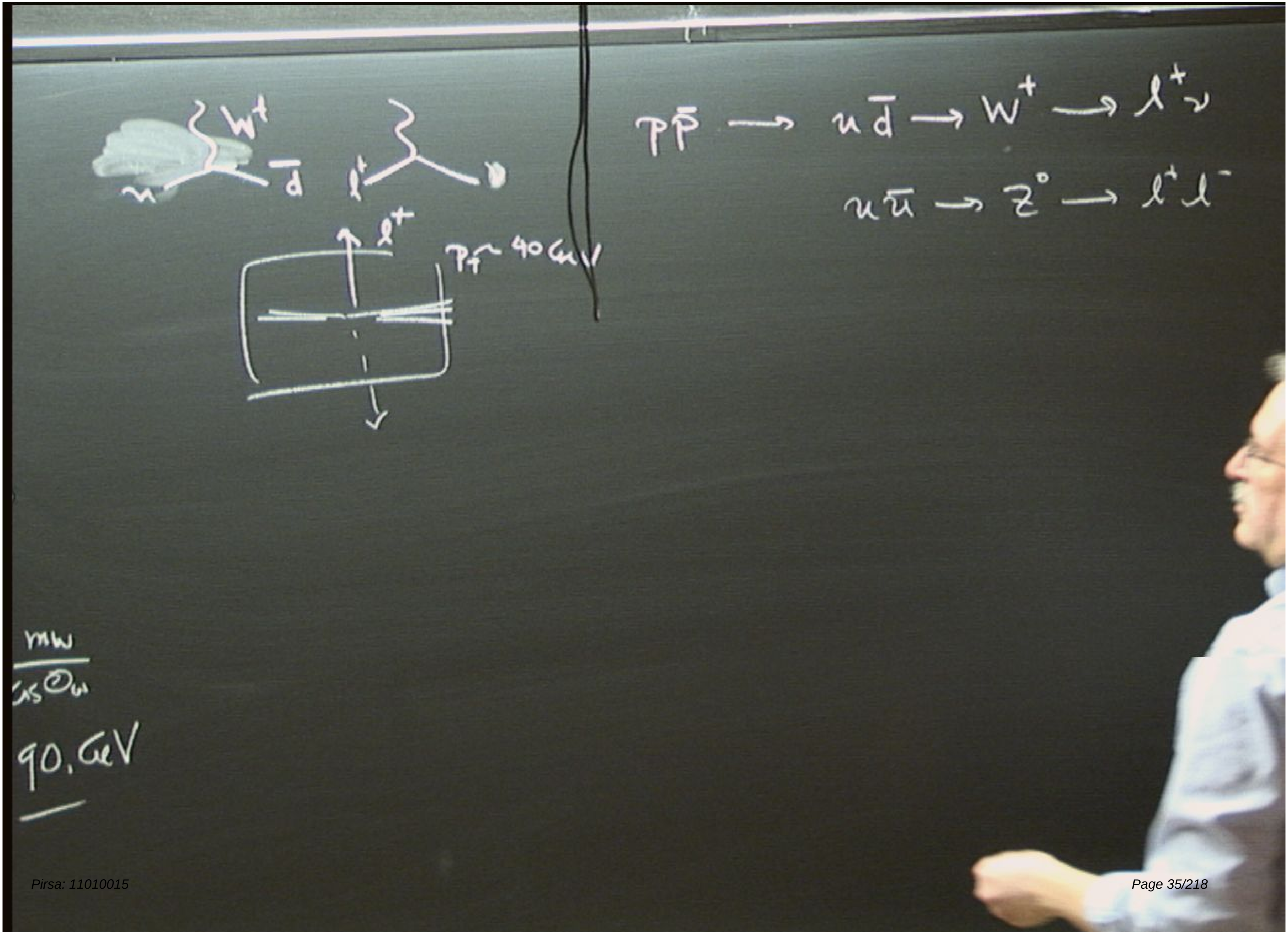
$p\bar{p} \longrightarrow u\bar{d} \longrightarrow W^+ \longrightarrow \ell^+\nu$

$\frac{m_W}{\cos\theta_W}$

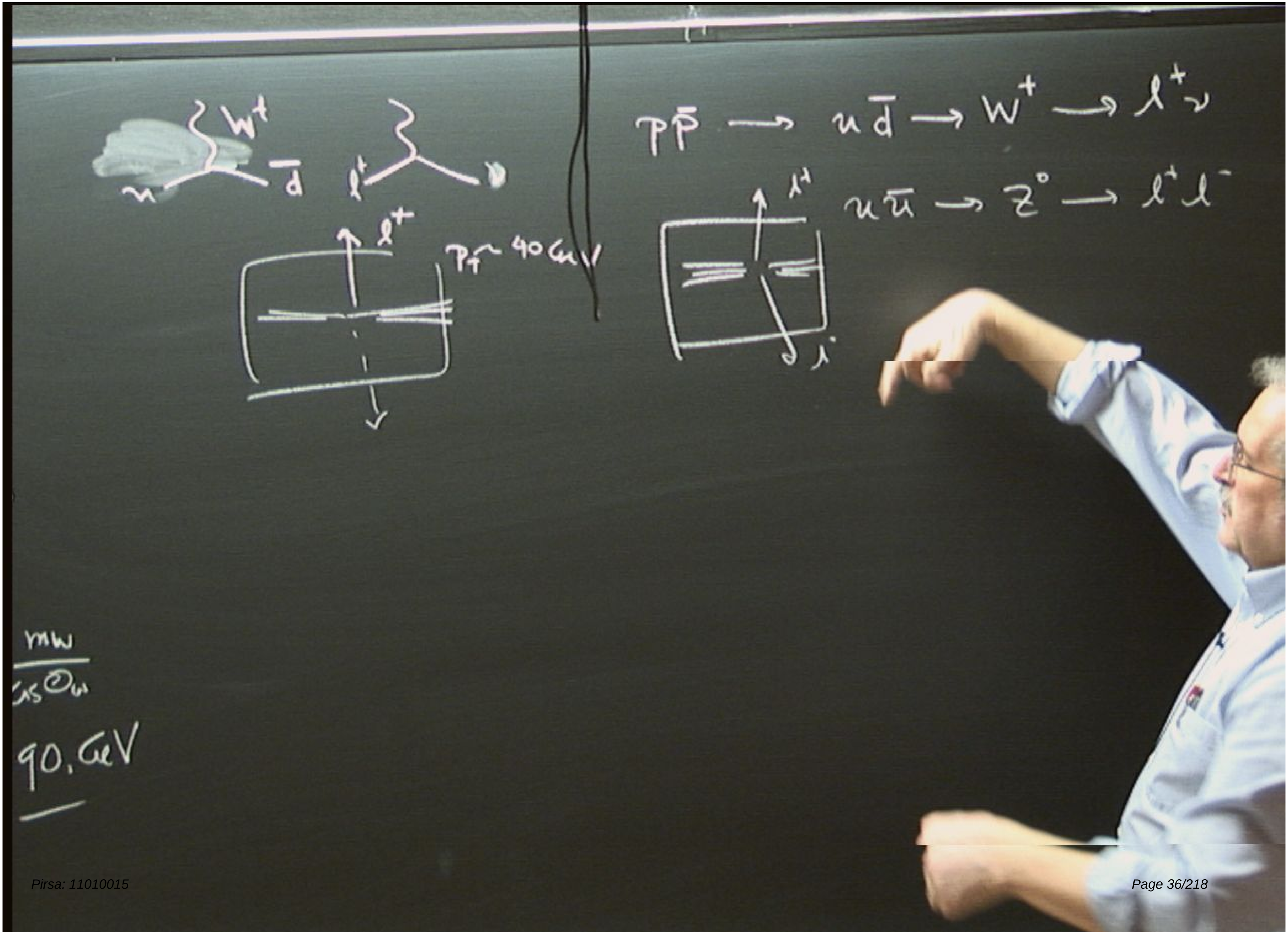
90. GeV

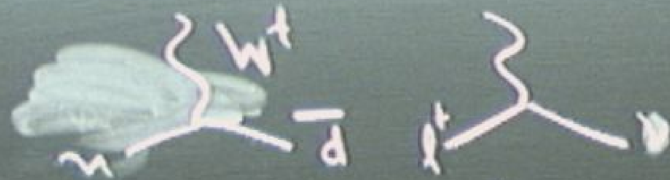

W+
d̄
u
l+
ν
l+
pT ~ 40 GeV
pp̄ → ud̄ → W+ → l+ν
mW
cos θW
90. GeV

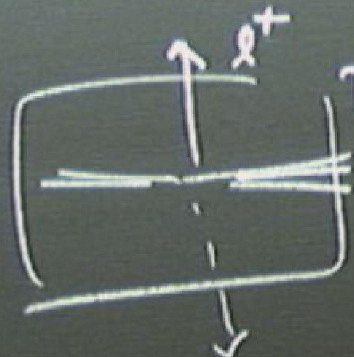

W+
d̄
u
ℓ+
ν
ℓ+
pT ~ 40 GeV
p p̄ → u d̄ → W+ → ℓ+ ν
mW
cos θW
90. GeV



W^+
$\bar{d}$ l^+ ν
$p\bar{p} \longrightarrow u\bar{d} \longrightarrow W^+ \longrightarrow l^+\nu$
$u\bar{u} \longrightarrow Z^0 \longrightarrow l^+l^-$
l^+
$p_T \sim 40$ GeV
$\frac{m_W}{\cos\theta_W}$
90. GeV

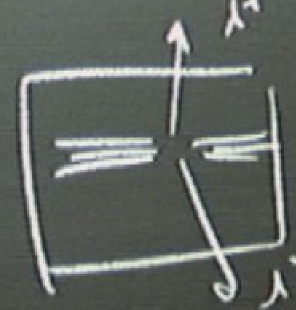

W+
d̄
u
l+
ν
pp̄ → ud̄ → W+ → l+ν
uū → Z° → l+l−
pT ~ 40 GeV
mw
cos θw
90. GeV





$p_T \sim 40$ GeV

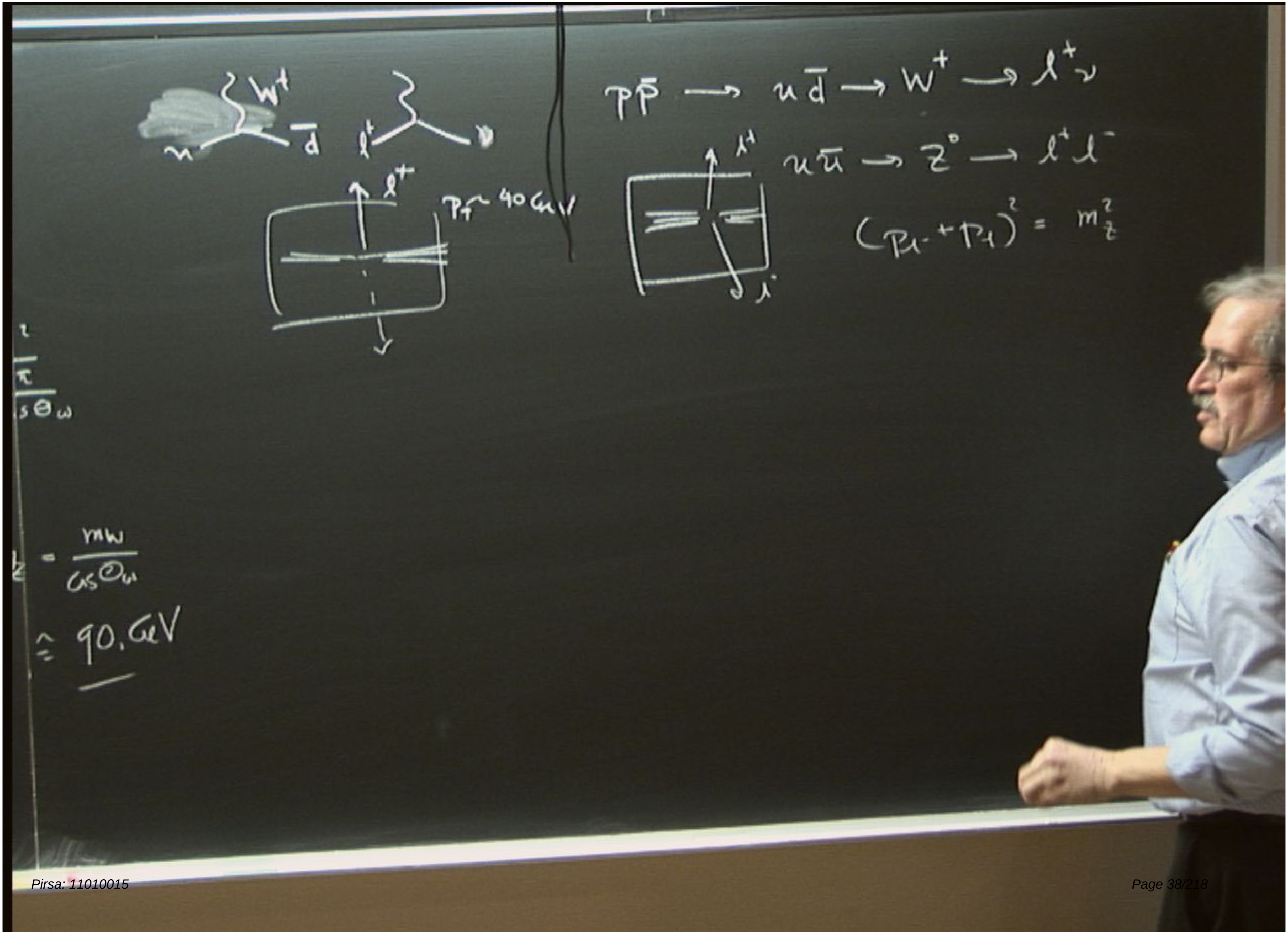
$p\bar p \longrightarrow u\bar d \longrightarrow W^+ \longrightarrow \ell^+\nu$



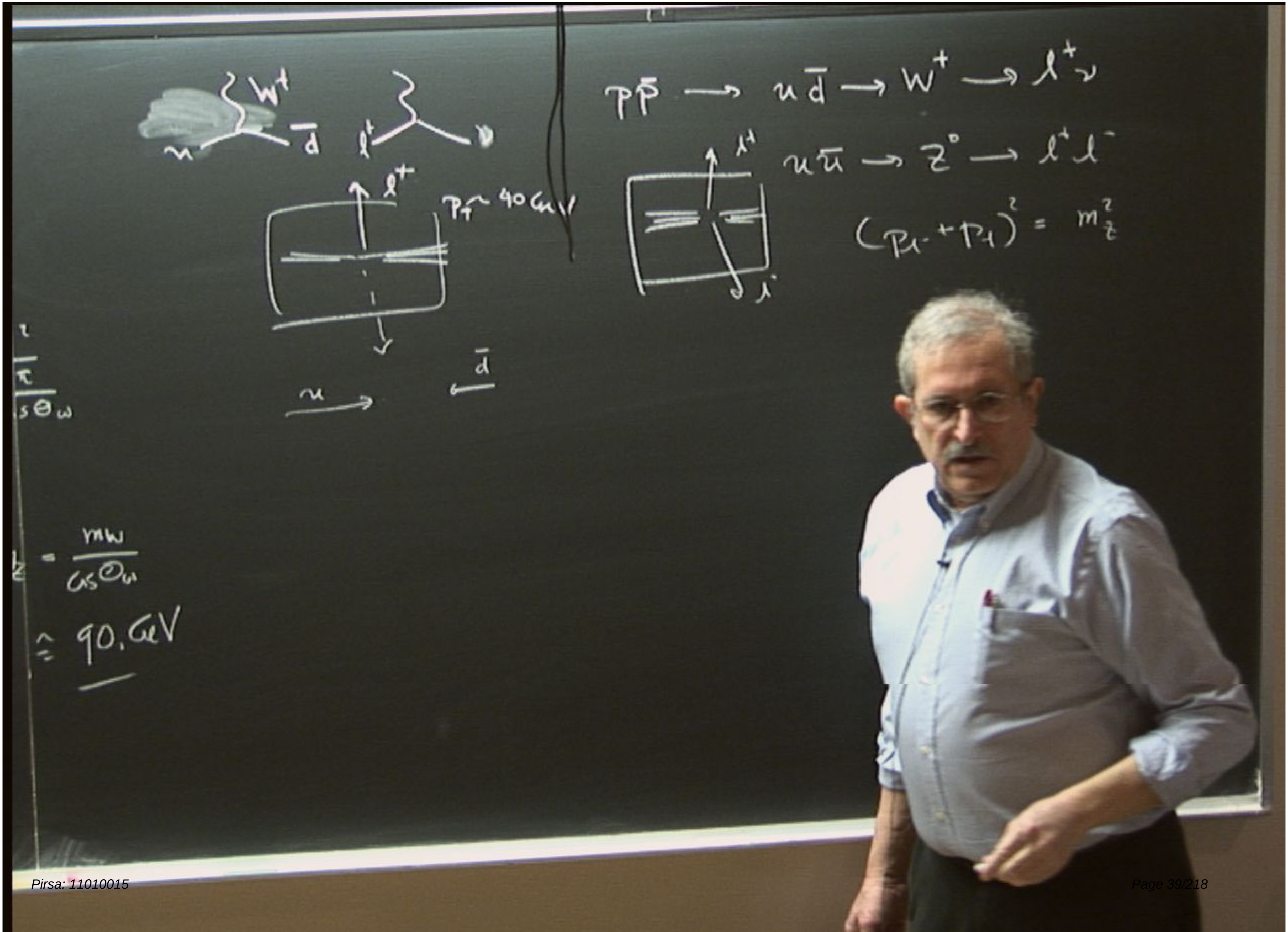
$u\bar u \longrightarrow Z^0 \longrightarrow \ell^+\ell^-$

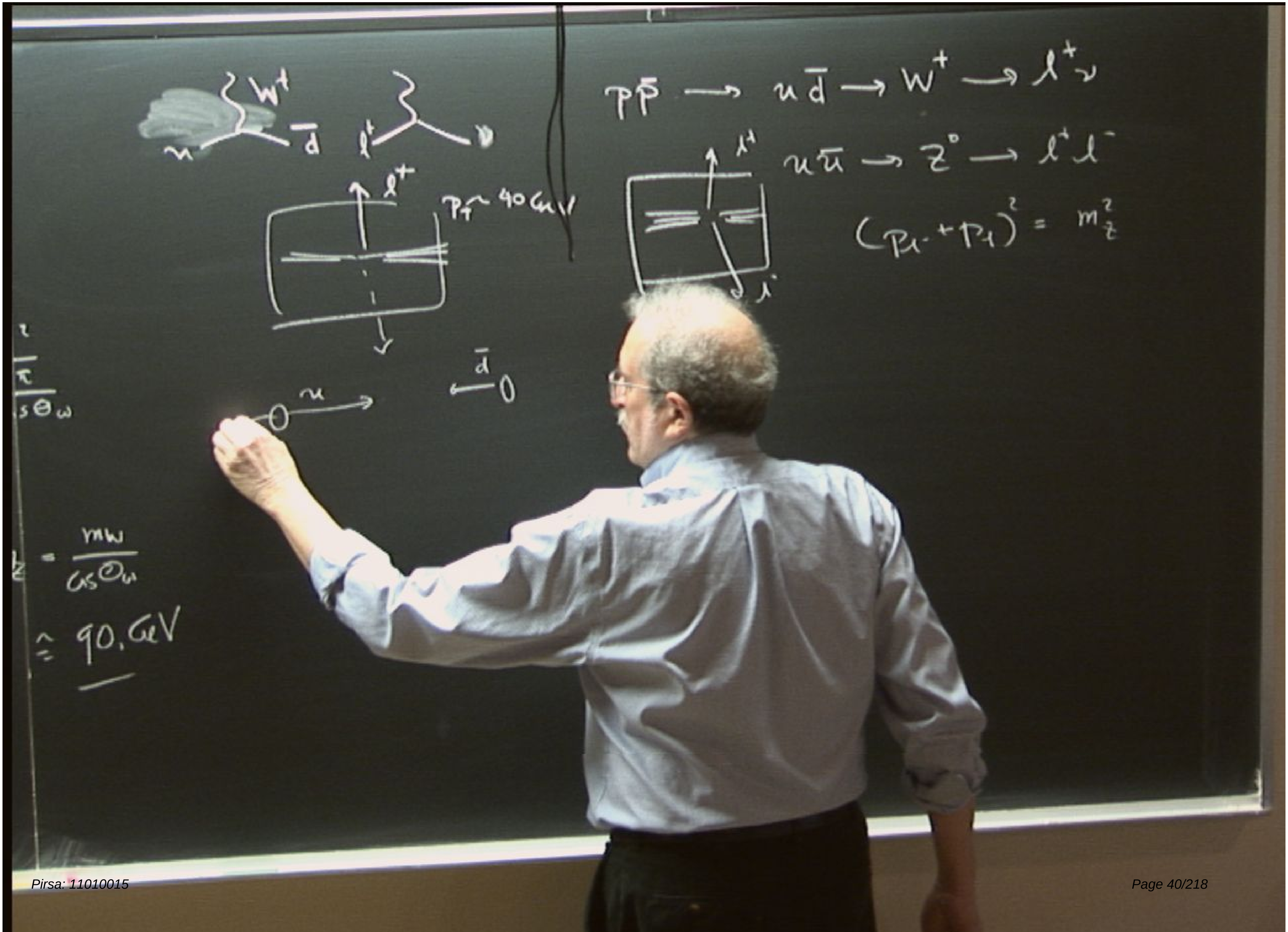
$\frac{m_W}{\cos\theta_W}$

90. GeV

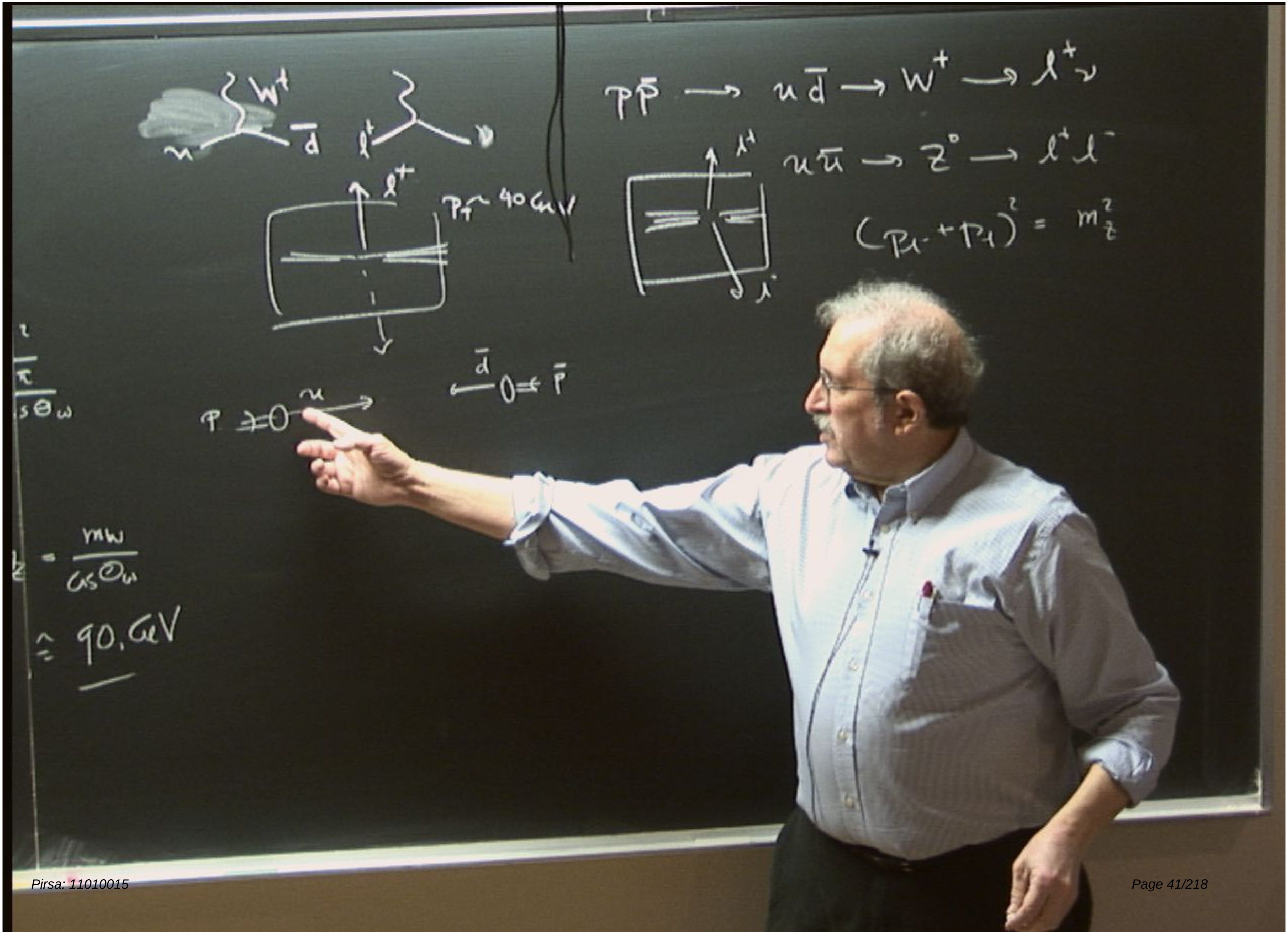


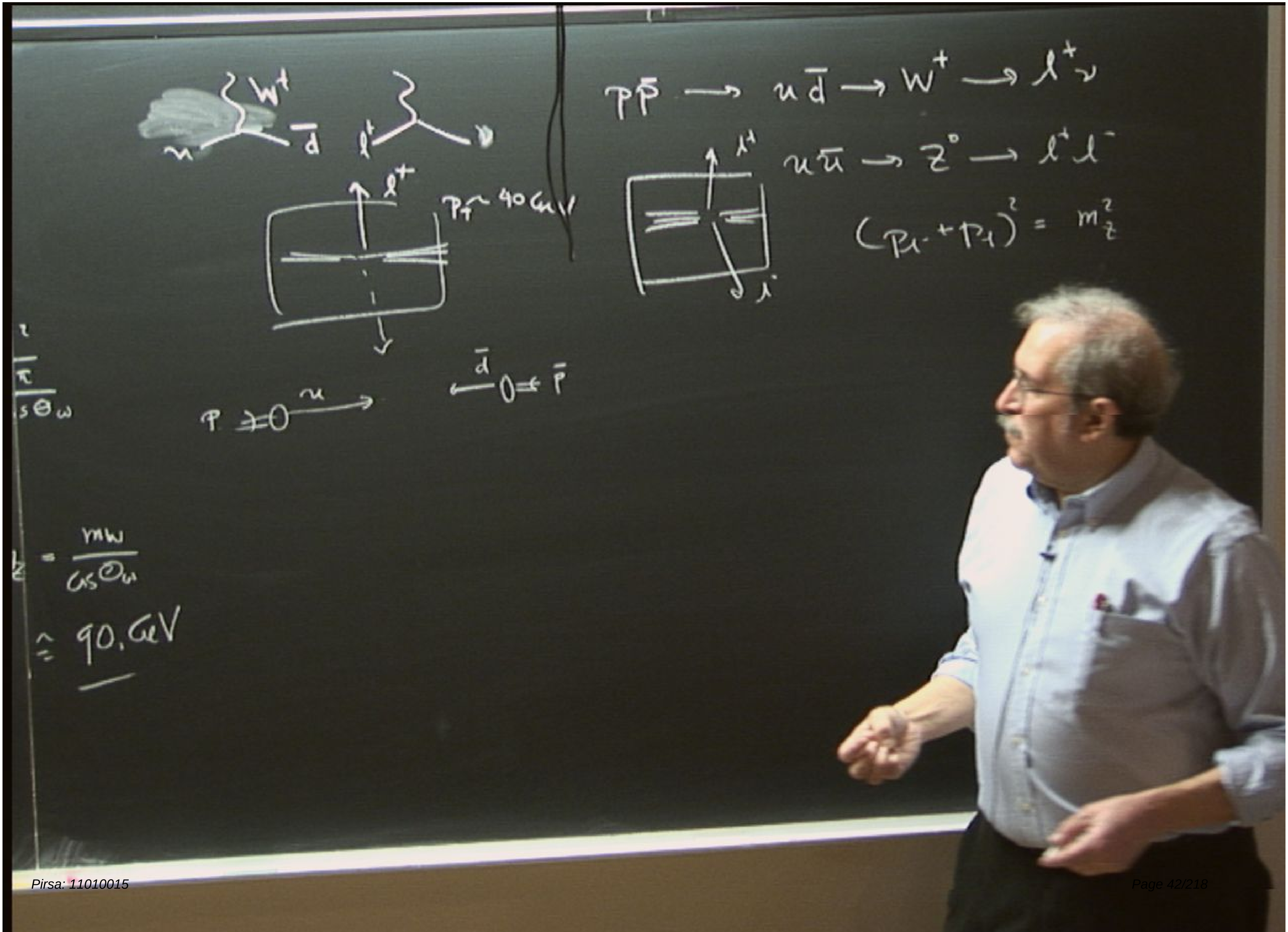
W+
d̄
l+
pp̄ → ud̄ → W+ → l+ν
uū → Z0 → l+ l−
(pl− + pl+)2 = m2Z
pT ~ 40 GeV
mW / cos θw
90. GeV

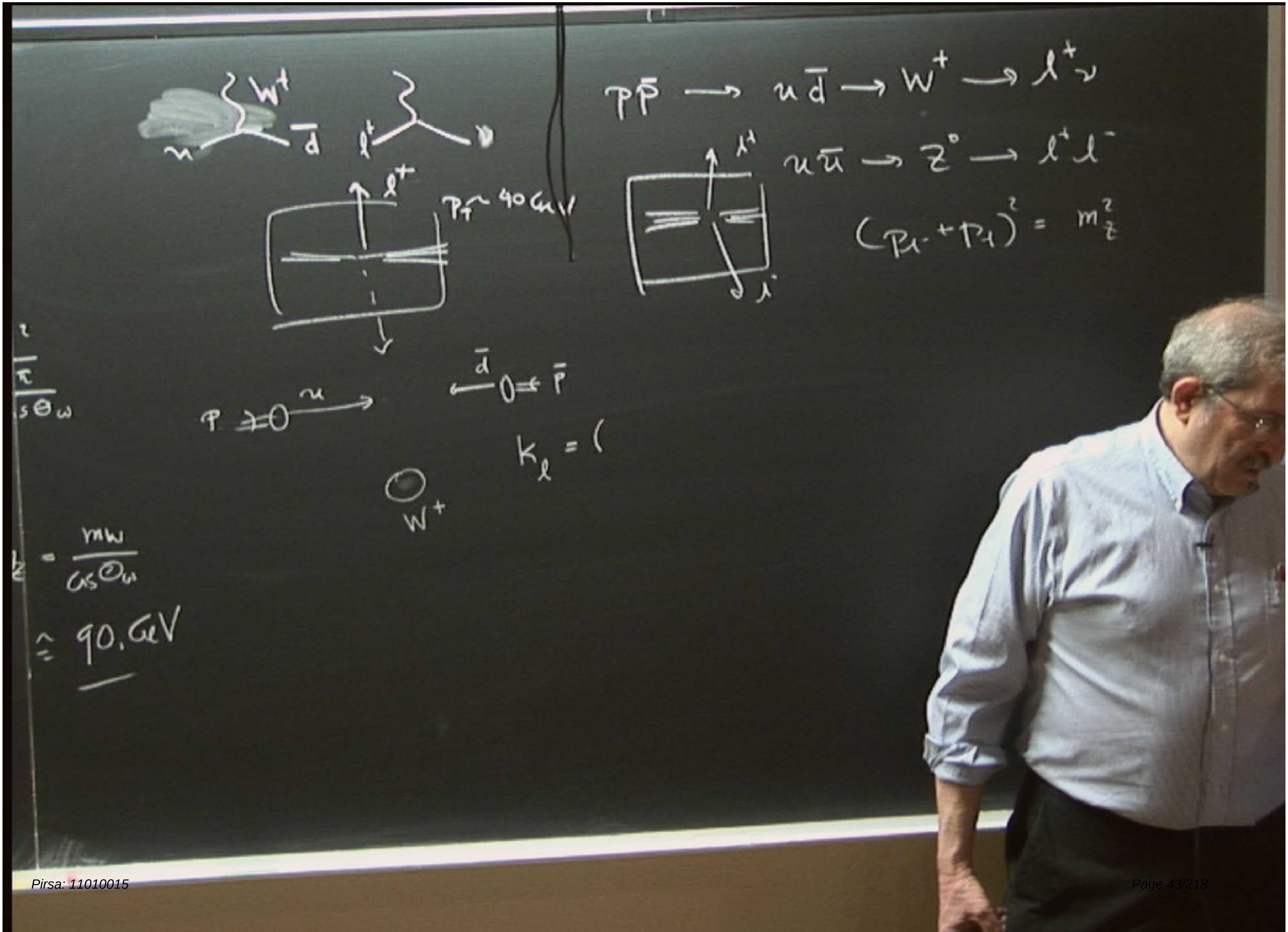

p p̄ → u d̄ → W⁺ → l⁺ ν
u ū → Z⁰ → l⁺ l⁻
(p_l⁻ + p_l⁺)² = m_Z²
p_T ~ 40 GeV
= mw / cos θw
≐ 90. GeV

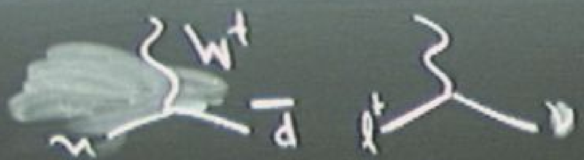


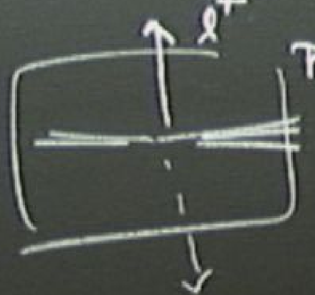
$p\bar{p} \longrightarrow u\bar{d} \longrightarrow W^+ \longrightarrow l^+\nu$
$u\bar{u} \longrightarrow Z^0 \longrightarrow l^+l^-$
$(p_{l^-} + p_{l^+})^2 = m_Z^2$
$p_T \sim 40$ GeV
$\frac{m_W}{\cos\theta_W}$
$\hat{=}$ 90. GeV


p p̄ → u d̄ → W+ → l+ ν
u ū → Z° → l+ l−
(p_l- + p_l+)² = m_Z²
W+
d̄
l+
p_T ~ 40 GeV
p
u
p̄
mW / cosθw
≐ 90. GeV

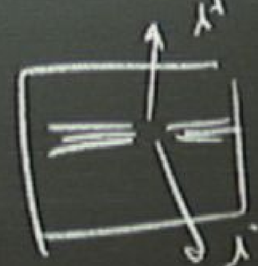

W+
l+
pp̄ → ud̄ → W+ → l+ν
uū → Z° → l+l−
(p_l− + p_l+)² = m_Z²
p_T ~ 40 GeV
m_W / cos θ_W
≃ 90. GeV


$p\bar{p} \longrightarrow u\bar{d} \longrightarrow W^+ \longrightarrow \ell^+\nu$
$u\bar{u} \longrightarrow Z^0 \longrightarrow \ell^+\ell^-$
$(p_{\ell^-} + p_{\ell^+})^2 = m_Z^2$
W^+
$\bar{d}$
ℓ^+
ν
u
$p_T \sim 40$ GeV
p
$\bar{p}$
$k_\ell = ($
W^+
$= \frac{m_W}{\cos\theta_W}$
$\hat{=}$ 90. GeV





$p_T \sim 40\,\mathrm{GeV}$



$p\bar{p} \longrightarrow u\bar{d} \longrightarrow W^+ \longrightarrow \ell^+ \nu$

$u\bar{u} \longrightarrow Z^0 \longrightarrow \ell^+ \ell^-$

$(p_{\ell^-} + p_{\ell^+})^2 = m_Z^2$

$p \rightarrow O \xrightarrow{u}$ $\qquad \xleftarrow{\bar{d}} O \leftarrow \bar{p}$

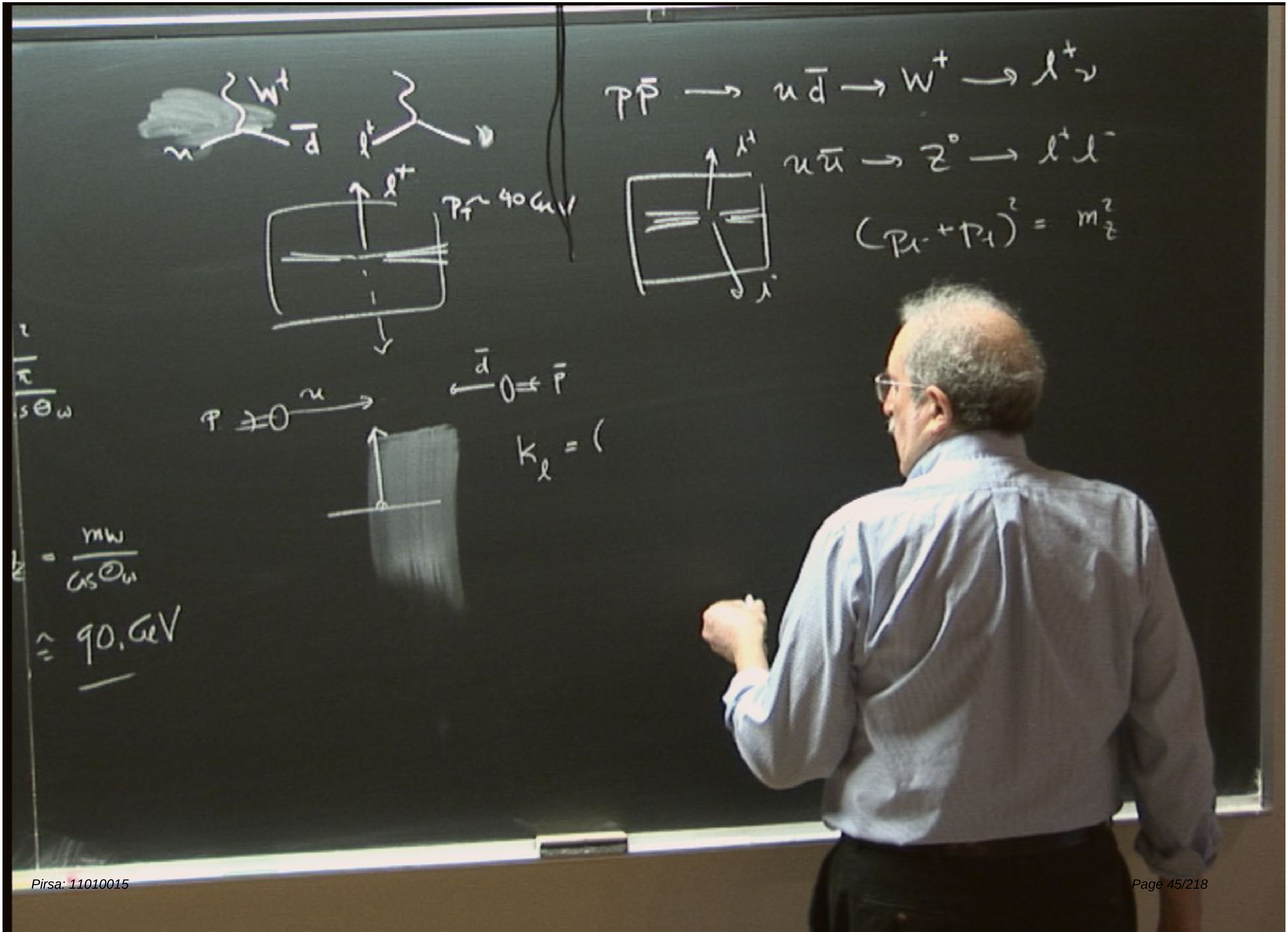
$k_\ell = ($

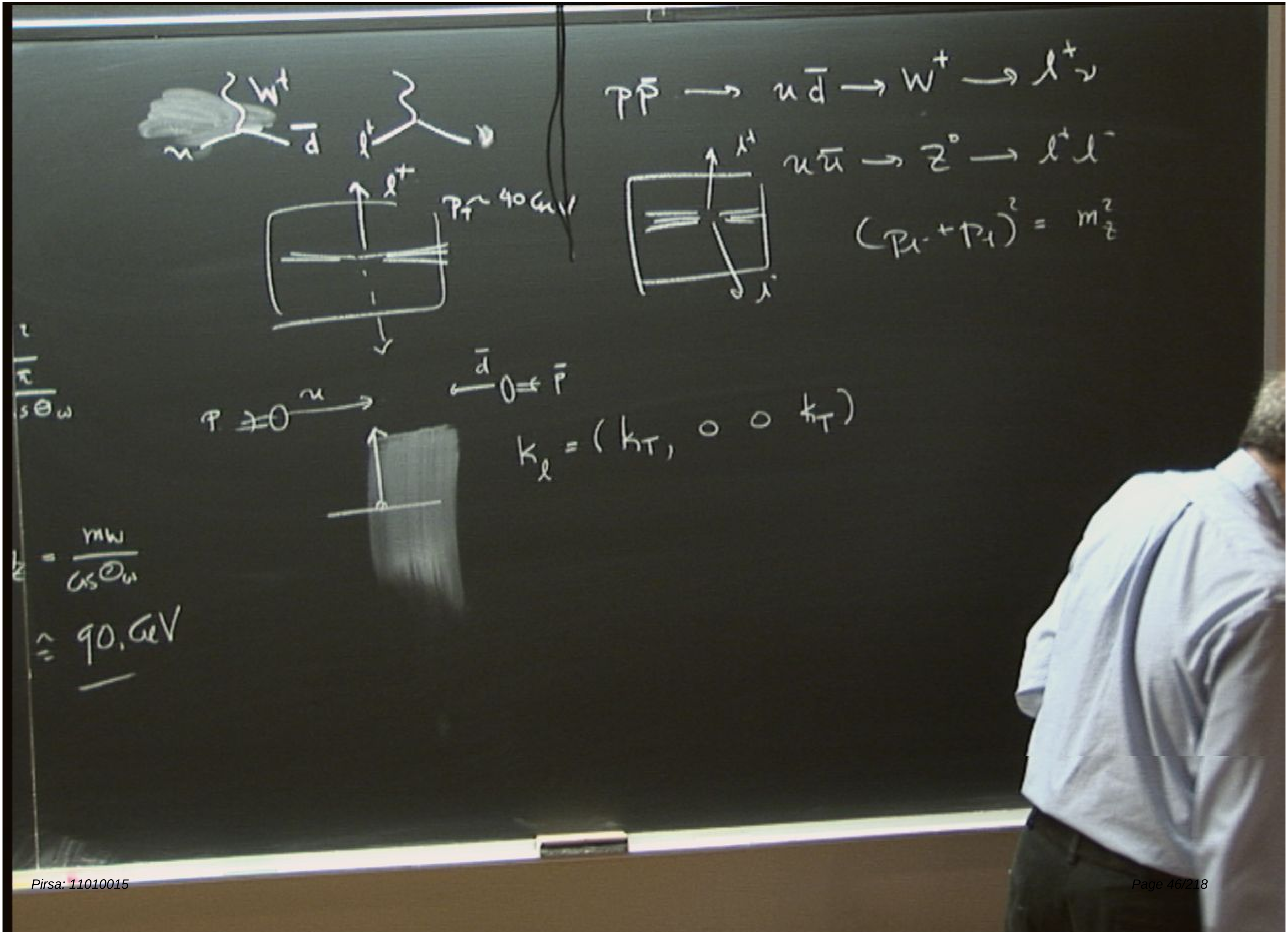
W^+

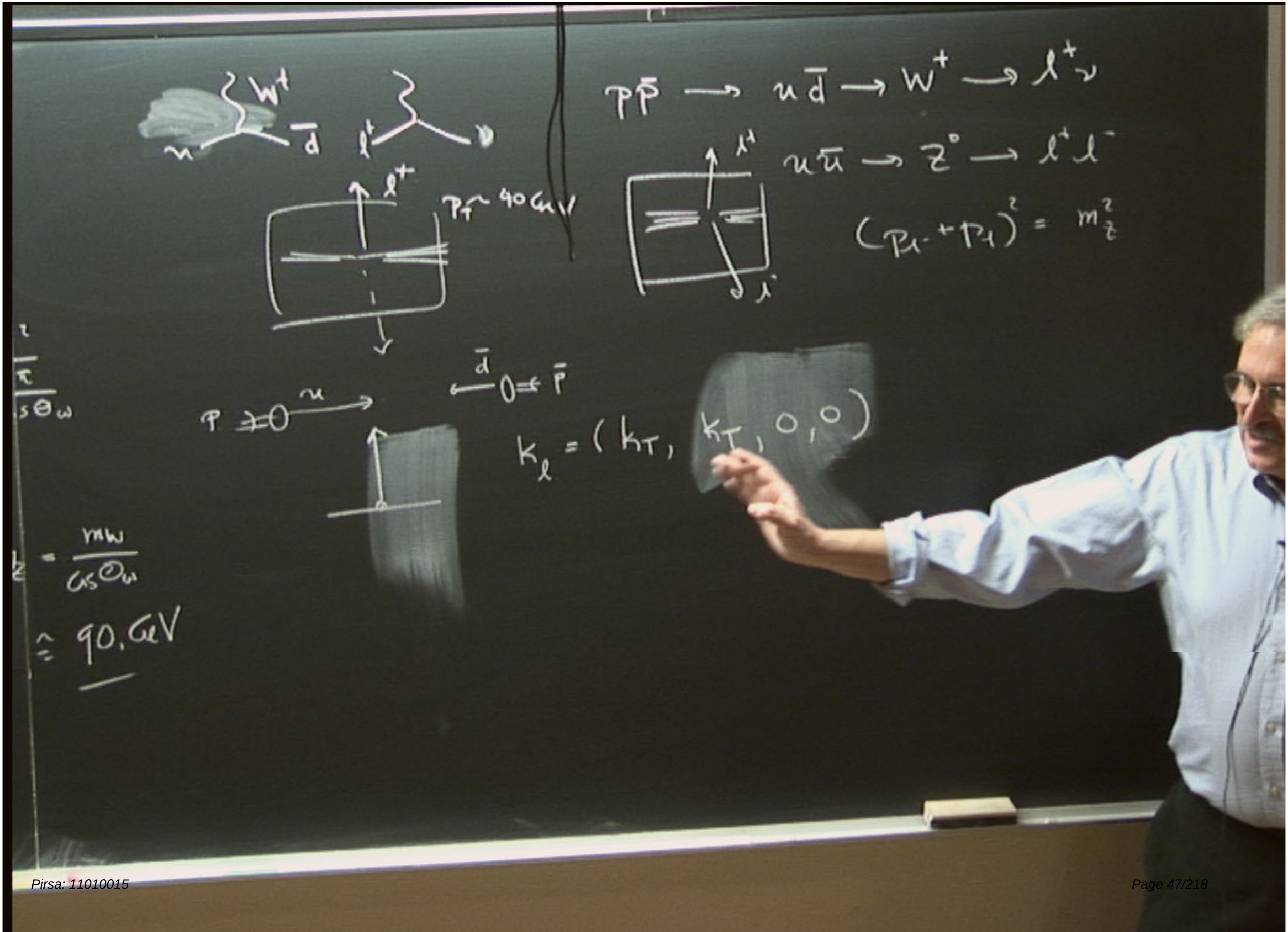
$\frac{\pi}{\cos\theta_W}$

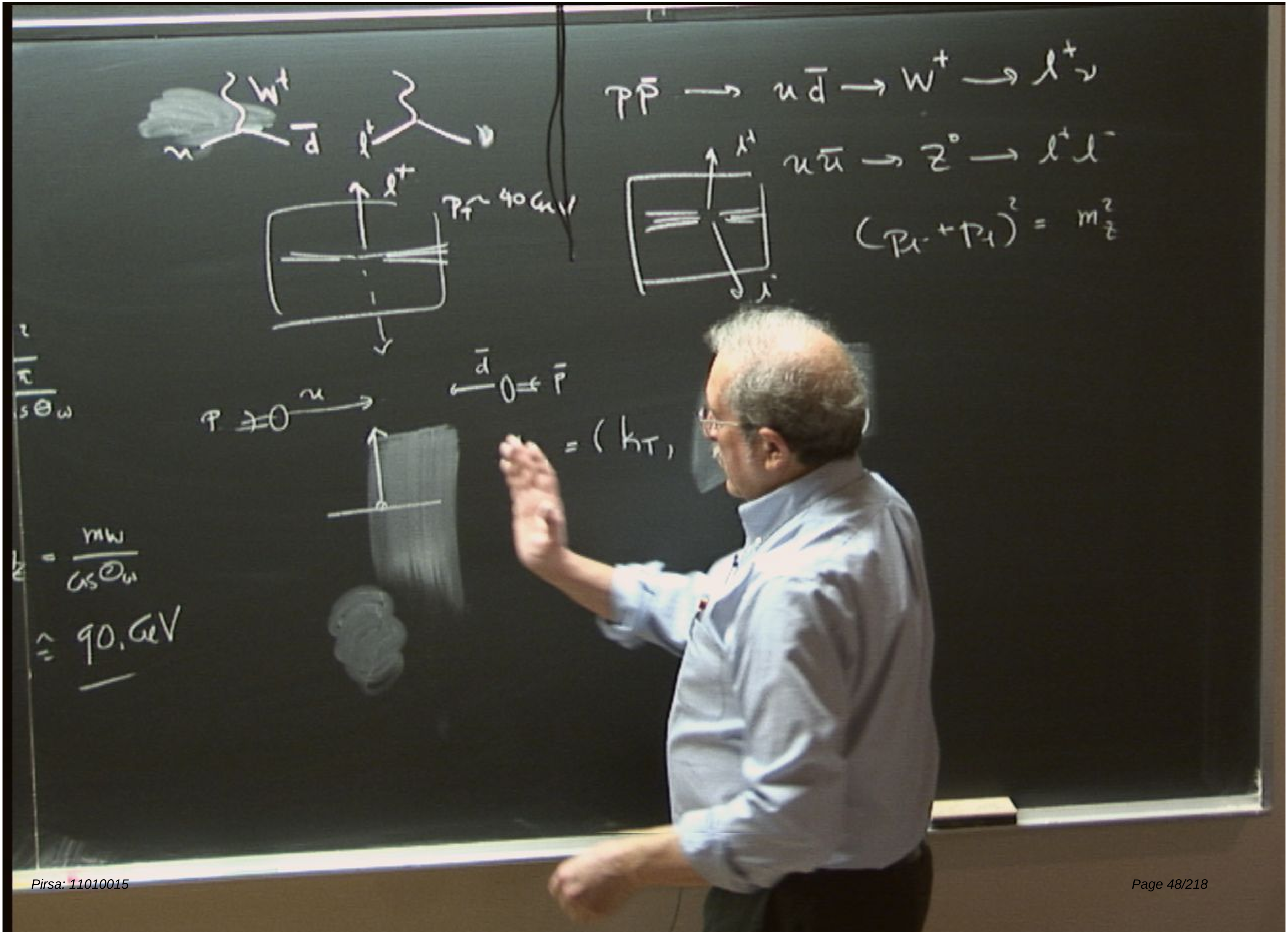
$m_Z = \frac{m_W}{\cos\theta_W}$

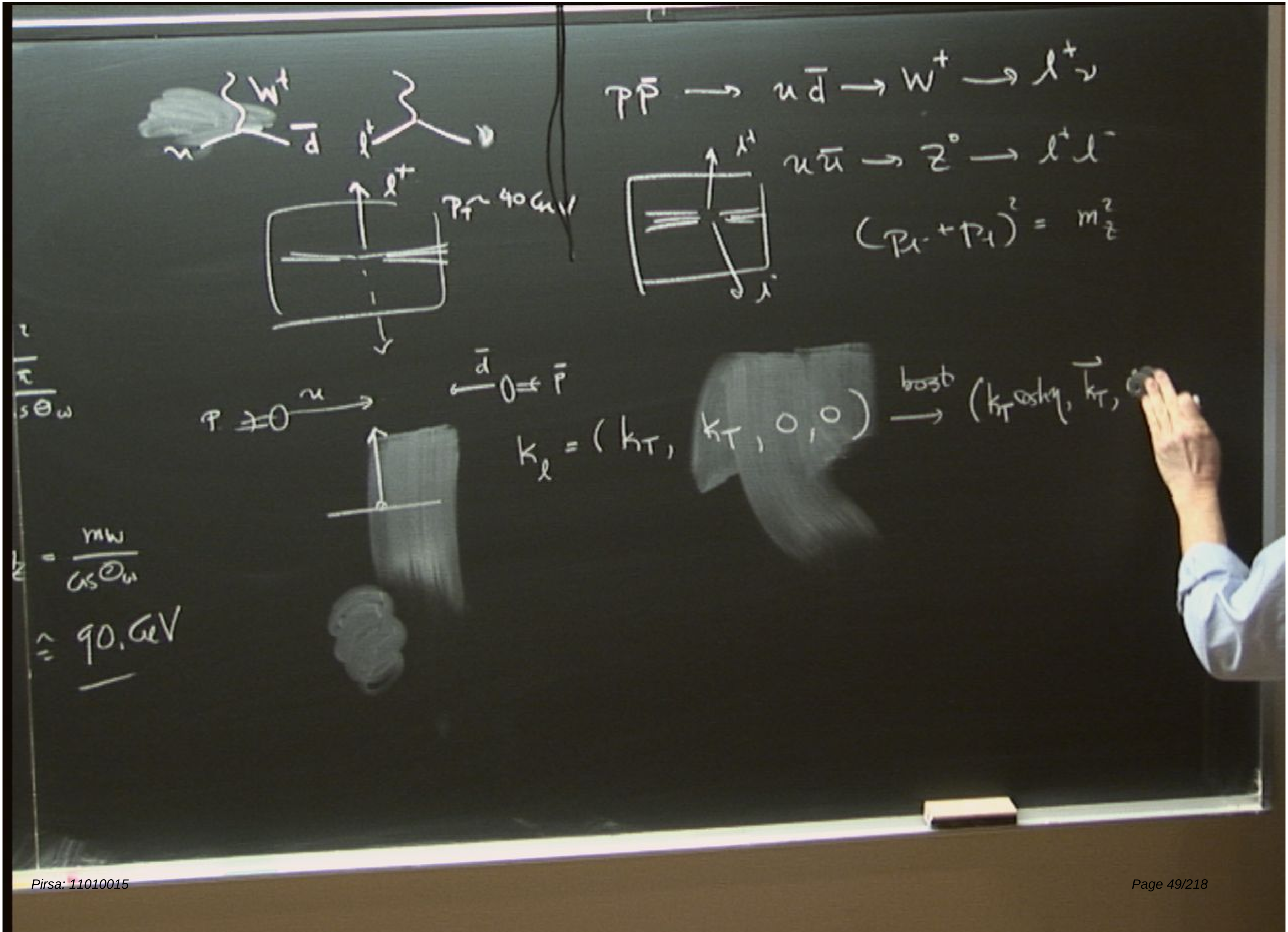
$\hat{=}\ \underline{90.\,\mathrm{GeV}}$


$p\bar{p} \longrightarrow u\bar{d} \longrightarrow W^+ \longrightarrow l^+\nu$
$u\bar{u} \longrightarrow Z^0 \longrightarrow l^+l^-$
$(p_{l^-} + p_{l^+})^2 = m_Z^2$
$p_T \sim 40$ GeV
$k_l = ($
$= \frac{m_W}{\cos\theta_W}$
$\simeq 90.$ GeV

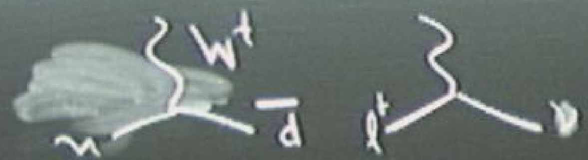

W+
u d̄ l+ ν
l+
pT ~ 40 GeV
p p̄ → u d̄ → W+ → l+ ν
l+
u ū → Z0 → l+ l−
(pl− + pl+)2 = mZ2
l−
d̄
p → u → ← p̄
kl = (kT, 0 0 kT)
cos θw
= mw / cos θw
≐ 90. GeV


p p̄ → u d̄ → W+ → l+ ν
u ū → Z° → l+ l−
(p_l− + p_l+)² = m_Z²
p_T ~ 40 GeV
k_l = (k_T, k_T, 0, 0)
≐ 90. GeV


W+
l+
pT ~ 40 GeV
p p̄ → u d̄ → W+ → l+ ν
u ū → Z0 → l+ l−
(pl− + pl+)² = mZ²
= (kT,
= 90. GeV

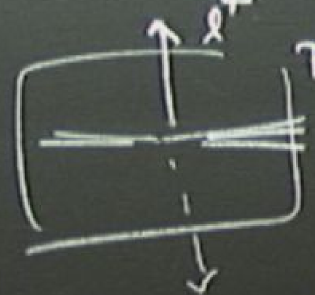


W+
d̄
u
l+
ν
p p̄ → u d̄ → W+ → l+ ν
u ū → Z° → l+ l−
(p_l- + p_l+)² = m_Z²
p_T ~ 40 GeV
l+
d̄
u
p
p̄
boost
k_l = (k_T, k_T, 0, 0) → (k_T cosh η, k_T,
= m_W / cos θ_W
≐ 90. GeV

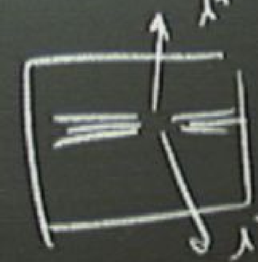


$$p\bar p \longrightarrow u\bar d \longrightarrow W^+ \longrightarrow l^+\nu$$

$$u\bar u \longrightarrow Z^0 \longrightarrow l^+ l^-$$

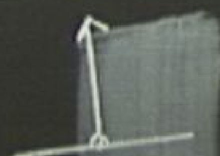


$p_T \sim 40$ GeV



$$(p_{l^-} + p_{l^+})^2 = m_Z^2$$

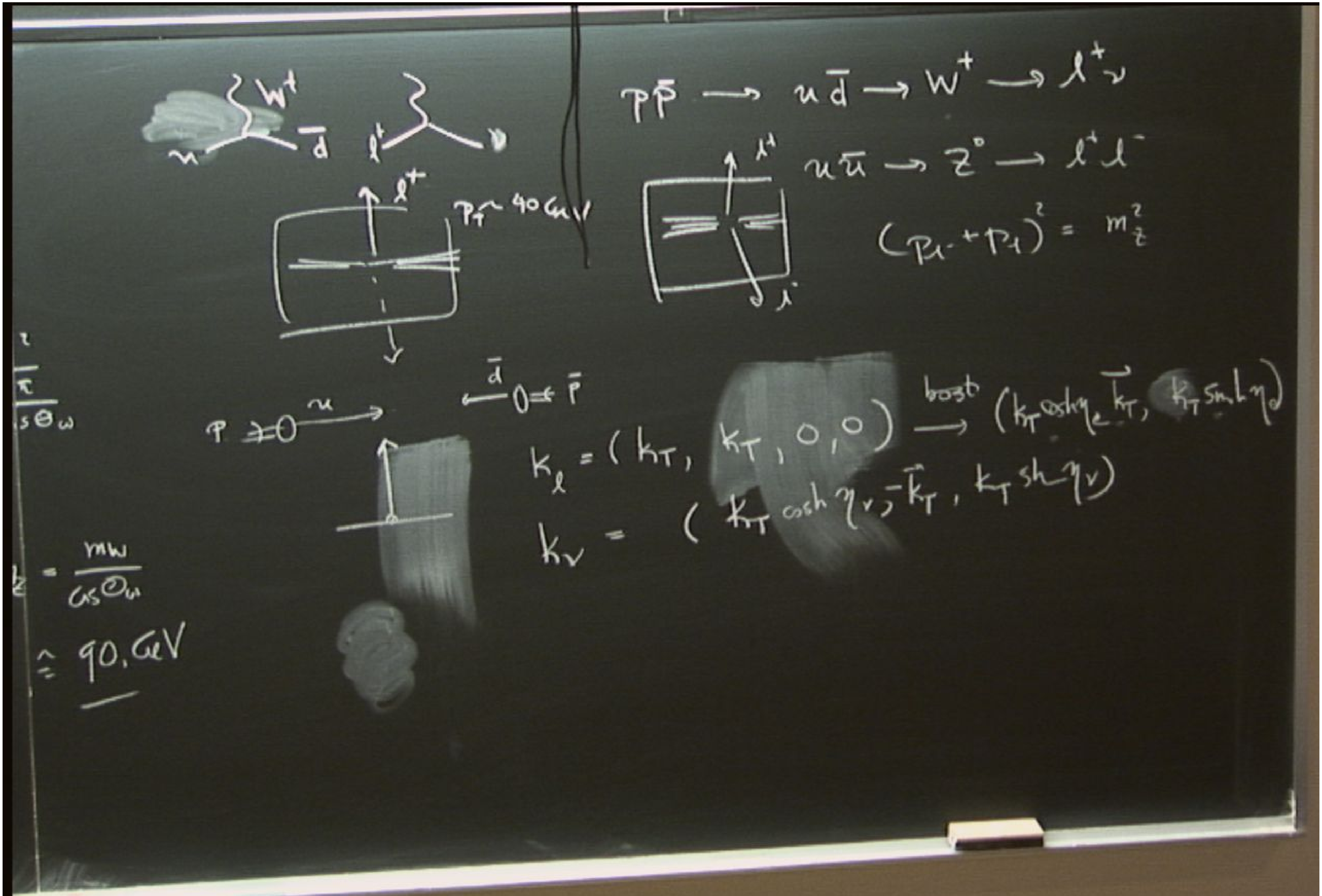
$p \rightarrow O \xrightarrow{u} \qquad \xleftarrow{\bar d} O \leftarrow \bar p$



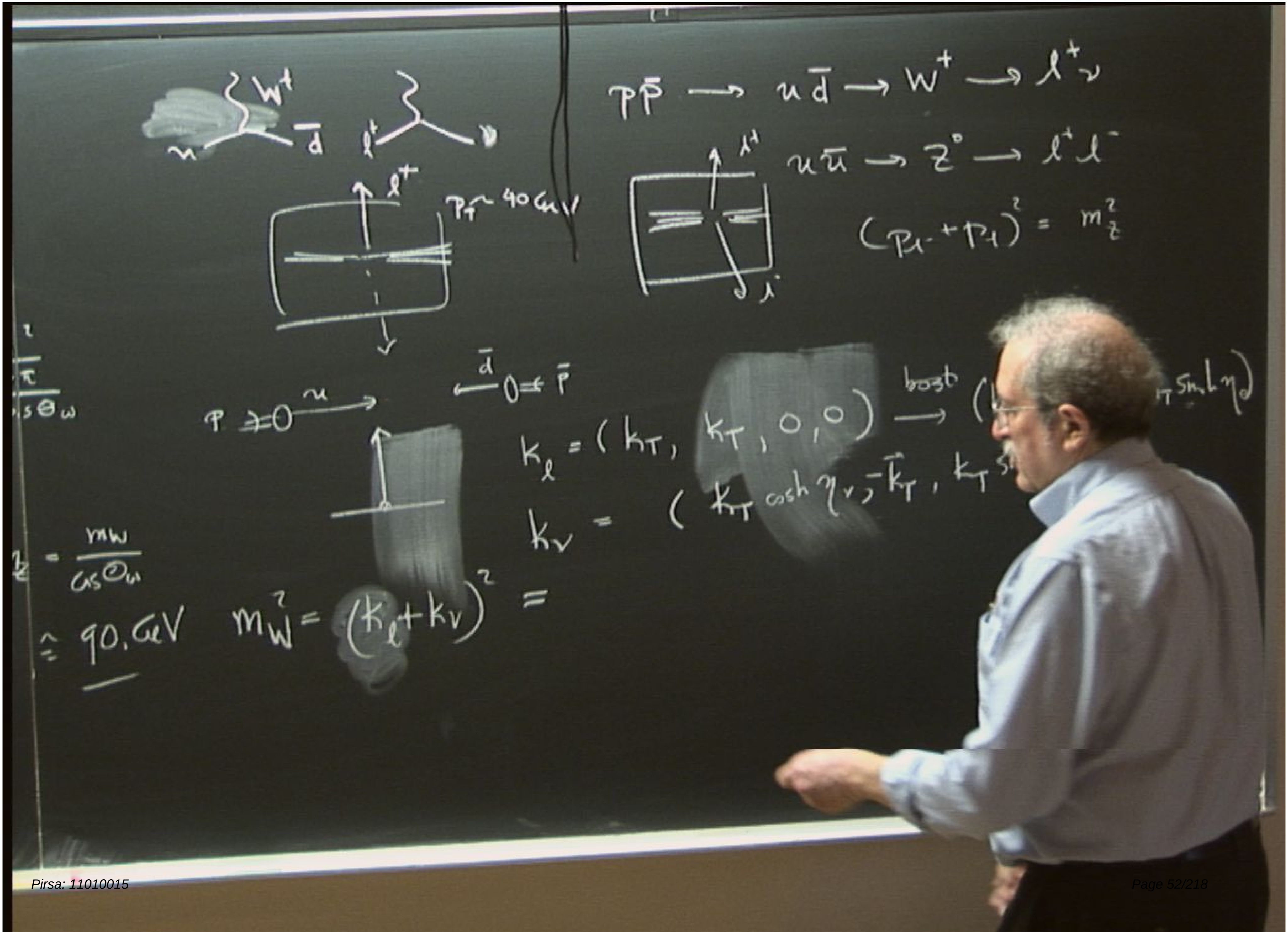
$$k_l = (k_T,\ k_T, 0, 0) \xrightarrow{\text{boost}} (k_T\cosh\eta,\ \vec{k}_T,\ k_T\sinh\eta)$$

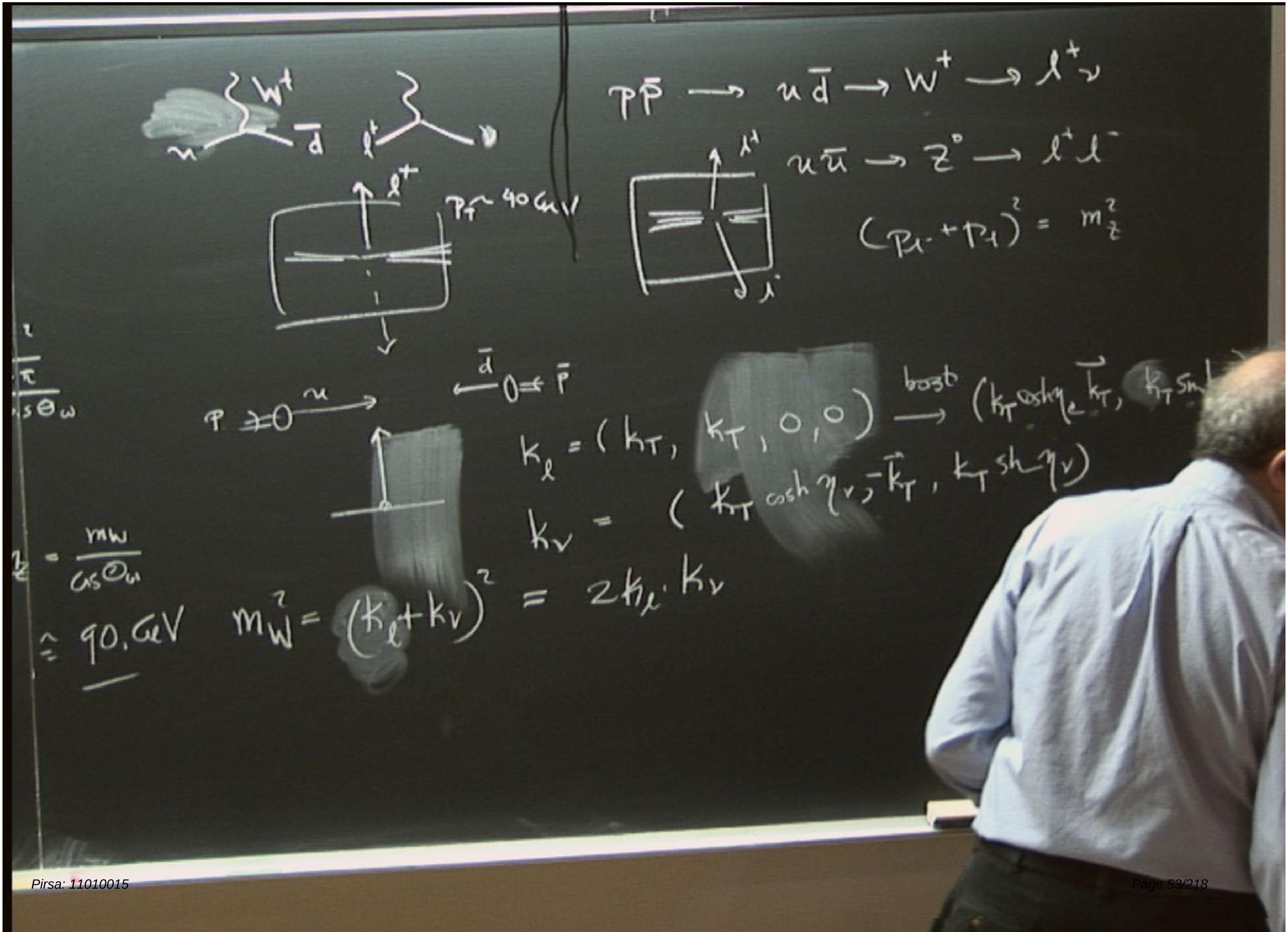
$$m_Z = \frac{m_W}{\cos\theta_W}$$

$$\hat{=}\ \underline{90.\,\text{GeV}}$$

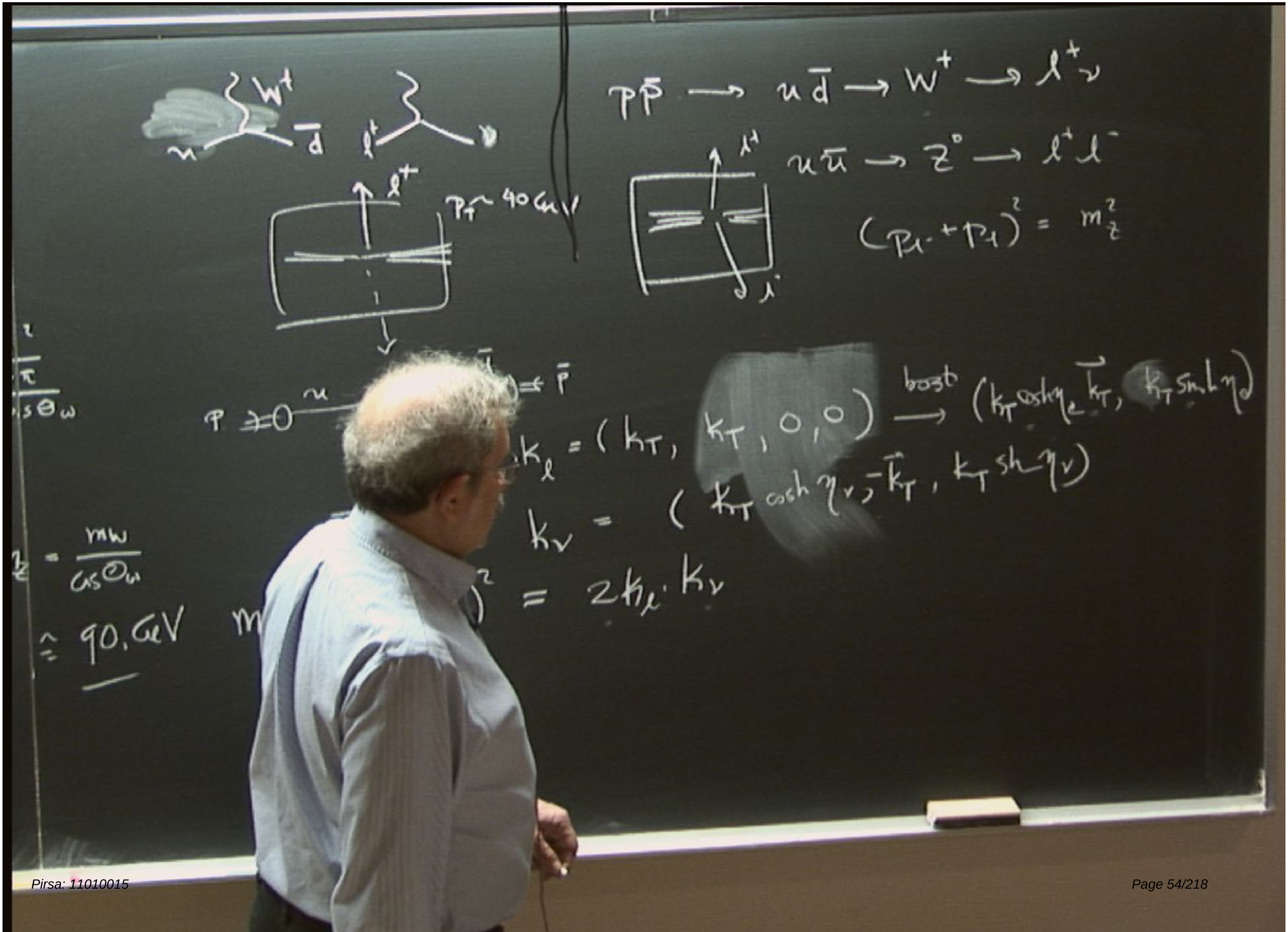


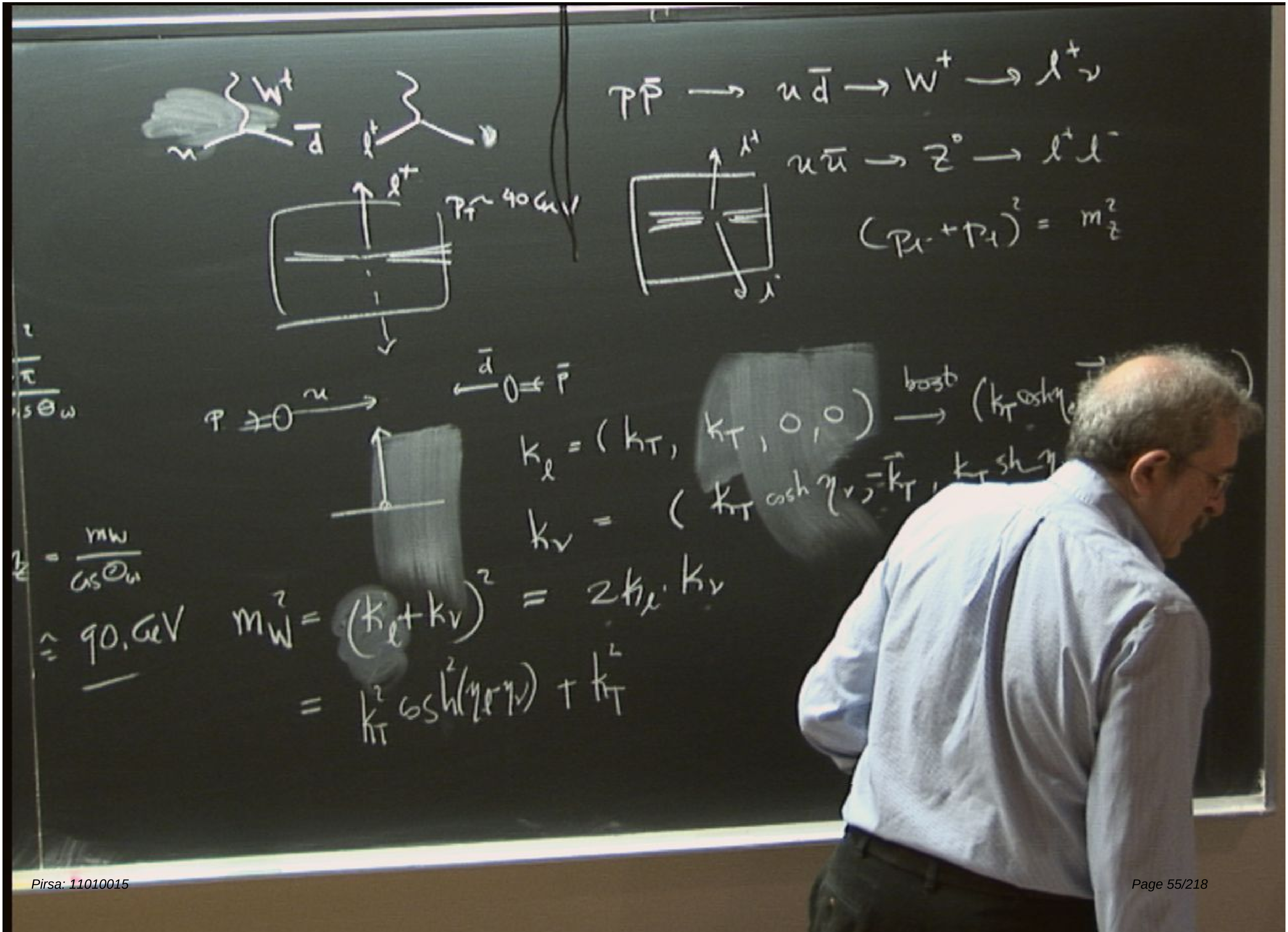
pp̄ → ud̄ → W⁺ → l⁺ν
uū → Z° → l⁺l⁻
(p_l⁻ + p_l⁺)² = m_Z²
p_T ~ 40 GeV
boost
k_l = (k_T, k_T, 0, 0) → (k_T cosh η_l, k_T, k_T sinh η_l)
k_ν = (k_T cosh η_ν, −k_T, k_T sh η_ν)
m_Z = m_W / cos θ_W
≃ 90. GeV

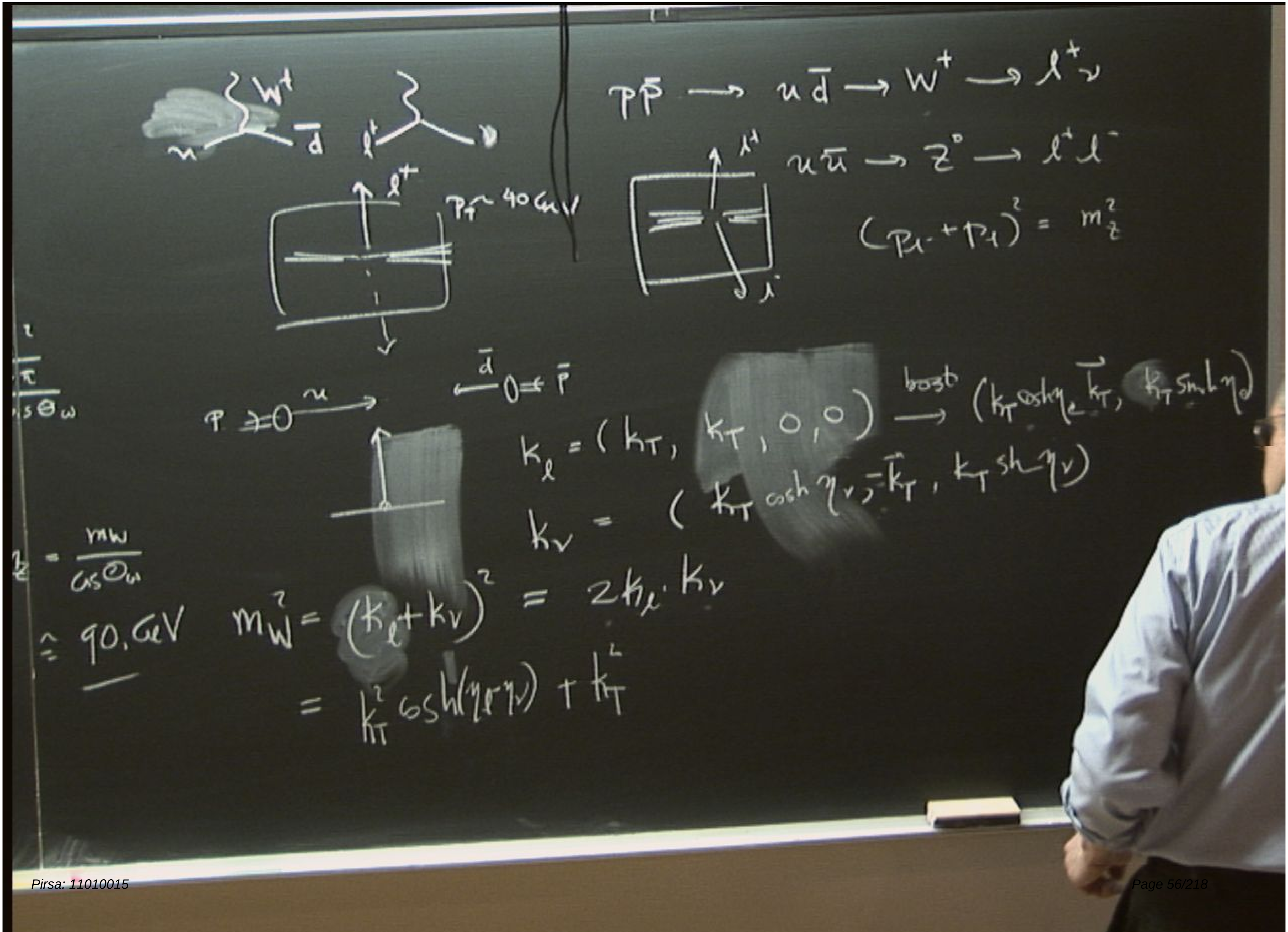

$p\bar{p} \longrightarrow u\bar{d} \longrightarrow W^+ \longrightarrow \ell^+\nu$
$u\bar{u} \longrightarrow Z^0 \longrightarrow \ell^+\ell^-$
$(p_{\ell^-} + p_{\ell^+})^2 = m_Z^2$
$p_T \sim 40\,\text{GeV}$
boost
$k_\ell = (k_T, k_T, 0, 0)$
$k_\nu = (k_T \cosh\eta_\nu, -\vec{k}_T, k_T \sinh\eta_\nu)$
$m_Z = \frac{m_W}{\cos\theta_W}$
$\hat{=}$ 90. GeV
$m_W^2 = (k_\ell + k_\nu)^2 =$



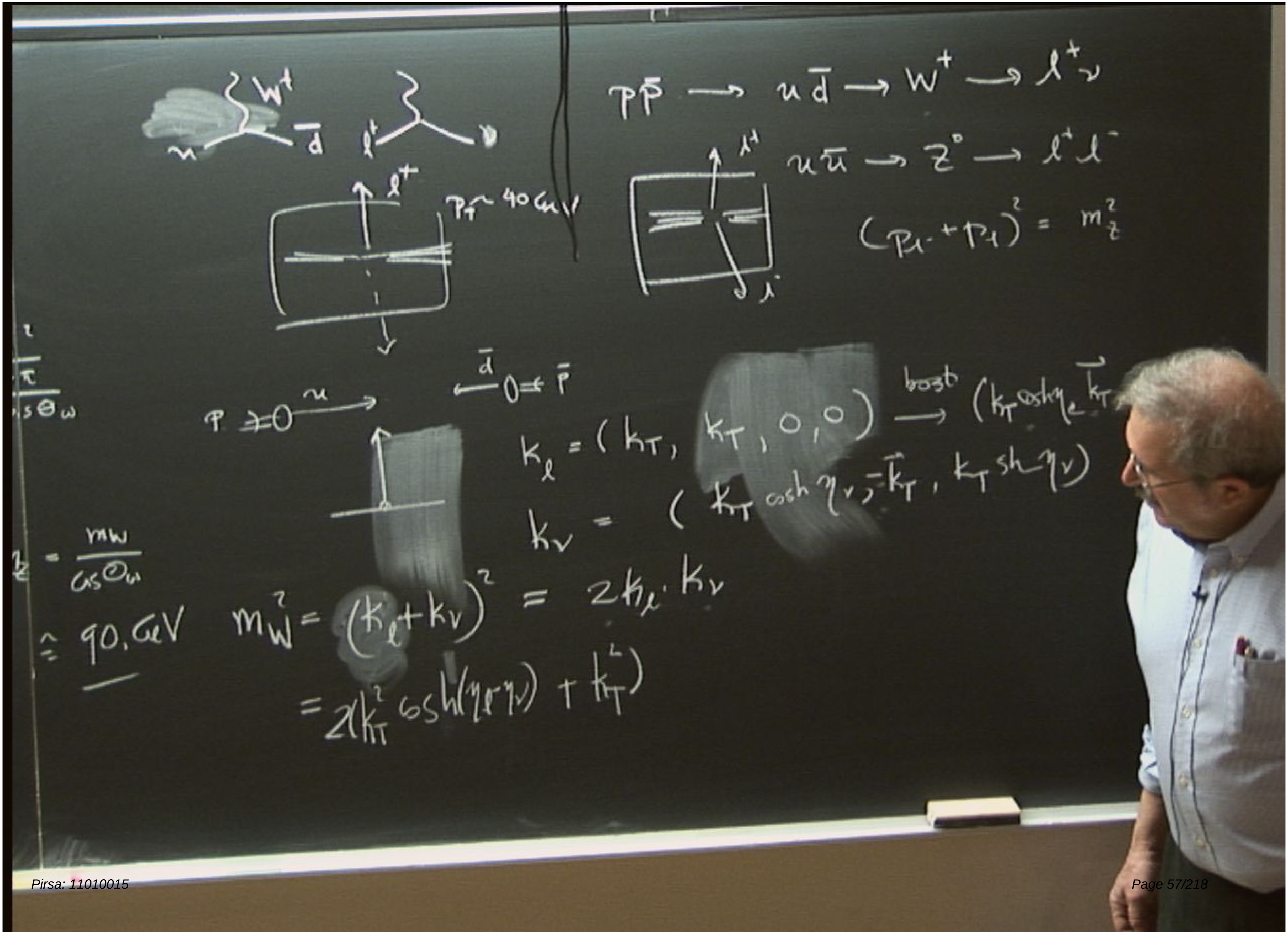
$p\bar{p} \longrightarrow u\bar{d} \longrightarrow W^+ \longrightarrow \ell^+\nu$
$u\bar{u} \longrightarrow Z^0 \longrightarrow \ell^+\ell^-$
$(p_{\ell^-} + p_{\ell})^2 = m_Z^2$
$p_T \sim 40$ GeV
boost
$k_\ell = (k_T, k_T, 0, 0)$
$k_\nu = (k_T \cosh\eta_\nu, -\vec{k}_T, k_T \sinh\eta_\nu)$
$m_W^2 = (k_\ell + k_\nu)^2 = 2k_\ell \cdot k_\nu$
$m_Z = \frac{m_W}{\cos\theta_w}$
$\hat{=}$ 90 GeV

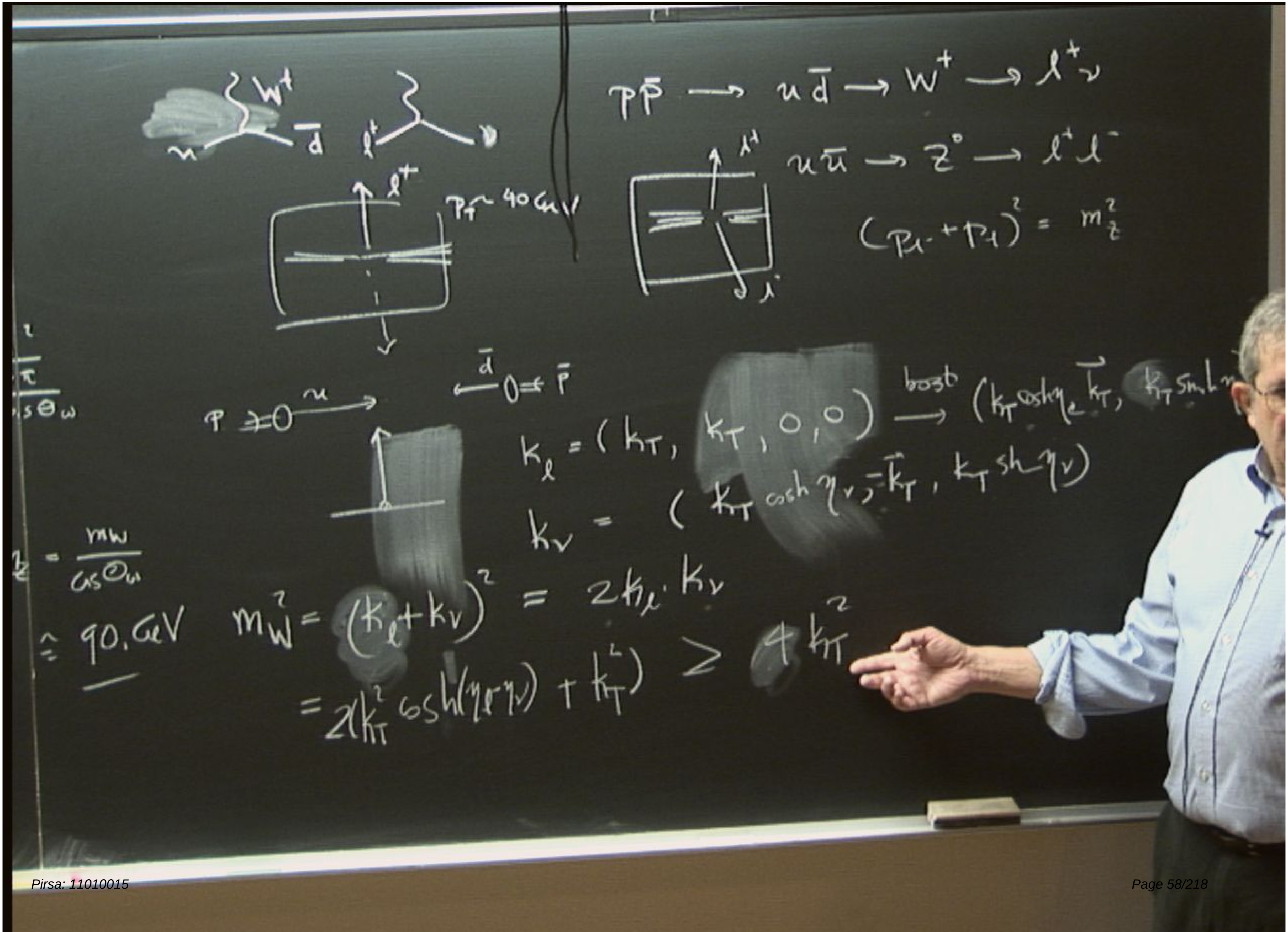

p p̄ → u d̄ → W+ → l+ ν
u ū → Z° → l+ l−
(p_l− + p_l+)² = m_Z²
p_T ~ 40 GeV
boost
k_l = (k_T, k_T, 0, 0)
k_ν =
= 2k_l · k_ν
m_W / cos θ_W
90. GeV


$p\bar{p} \longrightarrow u\bar{d} \longrightarrow W^+ \longrightarrow \ell^+\nu$
$u\bar{u} \longrightarrow Z^0 \longrightarrow \ell^+\ell^-$
$p_T \sim 40\,\text{GeV}$
$(p_{\ell^-} + p_{\ell^+})^2 = m_Z^2$
boost
$k_\ell = (k_T,\ k_T,\ 0,\ 0)$
$k_\nu = (k_T \cosh\eta_\nu,\ -\vec{k}_T,\ k_T \sinh\eta$
$= \frac{m_W}{\cos\theta_W}$
$\simeq 90\,\text{GeV}$
$m_W^2 = (k_\ell + k_\nu)^2 = 2k_\ell \cdot k_\nu$
$= k_T^2 \cosh^2(\eta_\ell - \eta_\nu) + k_T^2$

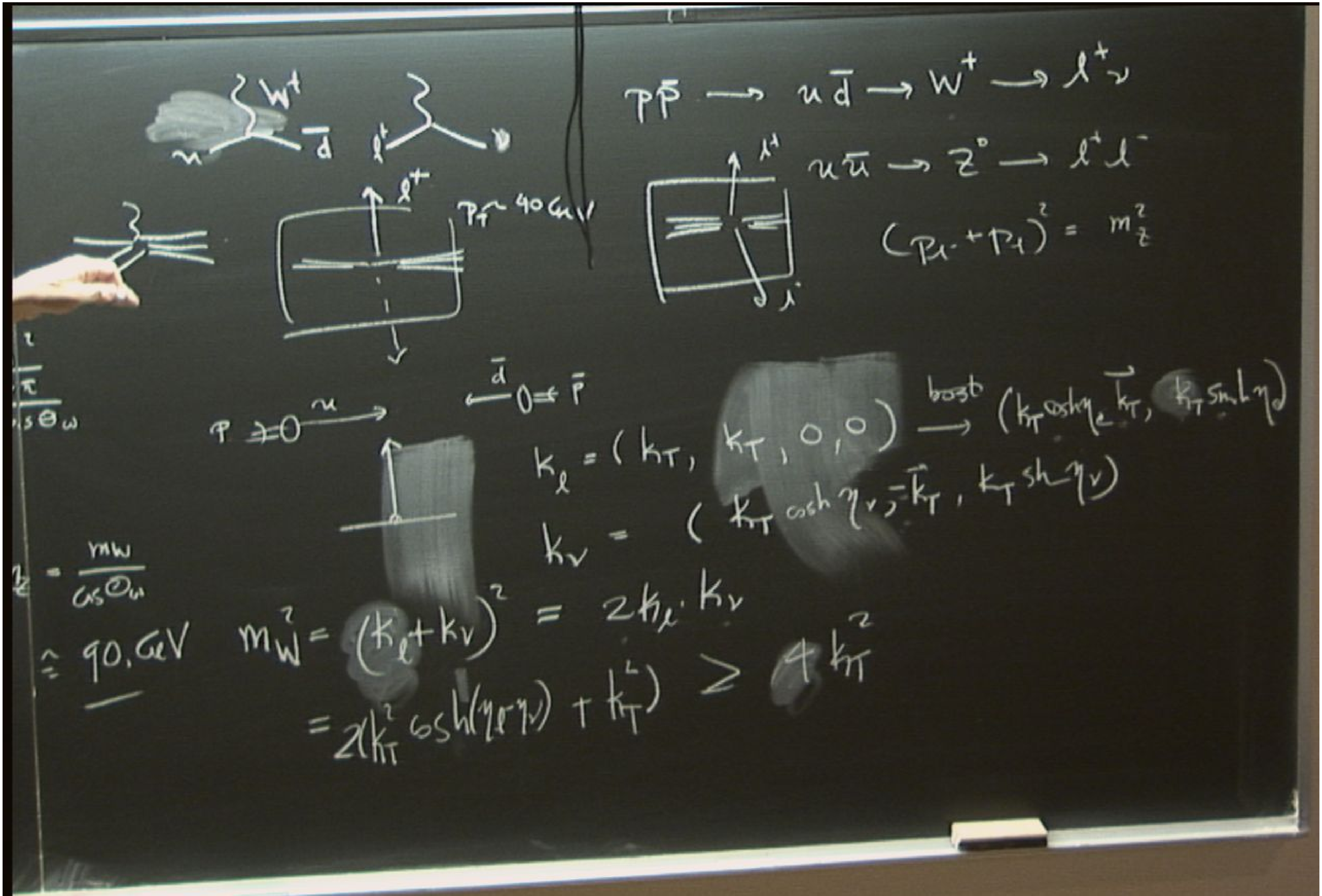


$p\bar{p} \longrightarrow u\bar{d} \longrightarrow W^+ \longrightarrow \ell^+\nu$
$u\bar{u} \longrightarrow Z^0 \longrightarrow \ell^+\ell^-$
$(p_{\ell^-} + p_{\ell^+})^2 = m_Z^2$
W^+
u $\bar{d}$ ℓ^+ ν
ℓ^+
$p_T \sim 40$ GeV
ℓ^+ ℓ^-
p u $\bar{d}$ $\bar{p}$
boost
$(k_T \cosh\eta_\ell, \vec{k}_T, k_T \sinh\eta_\ell)$
$k_\ell = (k_T, k_T, 0, 0)$
$k_\nu = (k_T \cosh\eta_\nu, -\vec{k}_T, k_T \sinh\eta_\nu)$
$m_W^2 = (k_\ell + k_\nu)^2 = 2k_\ell \cdot k_\nu$
$= k_T^2 \cosh(\eta_\ell - \eta_\nu) + k_T^2$
$= \frac{m_W}{\cos\Theta_W}$
$\doteq 90.$ GeV

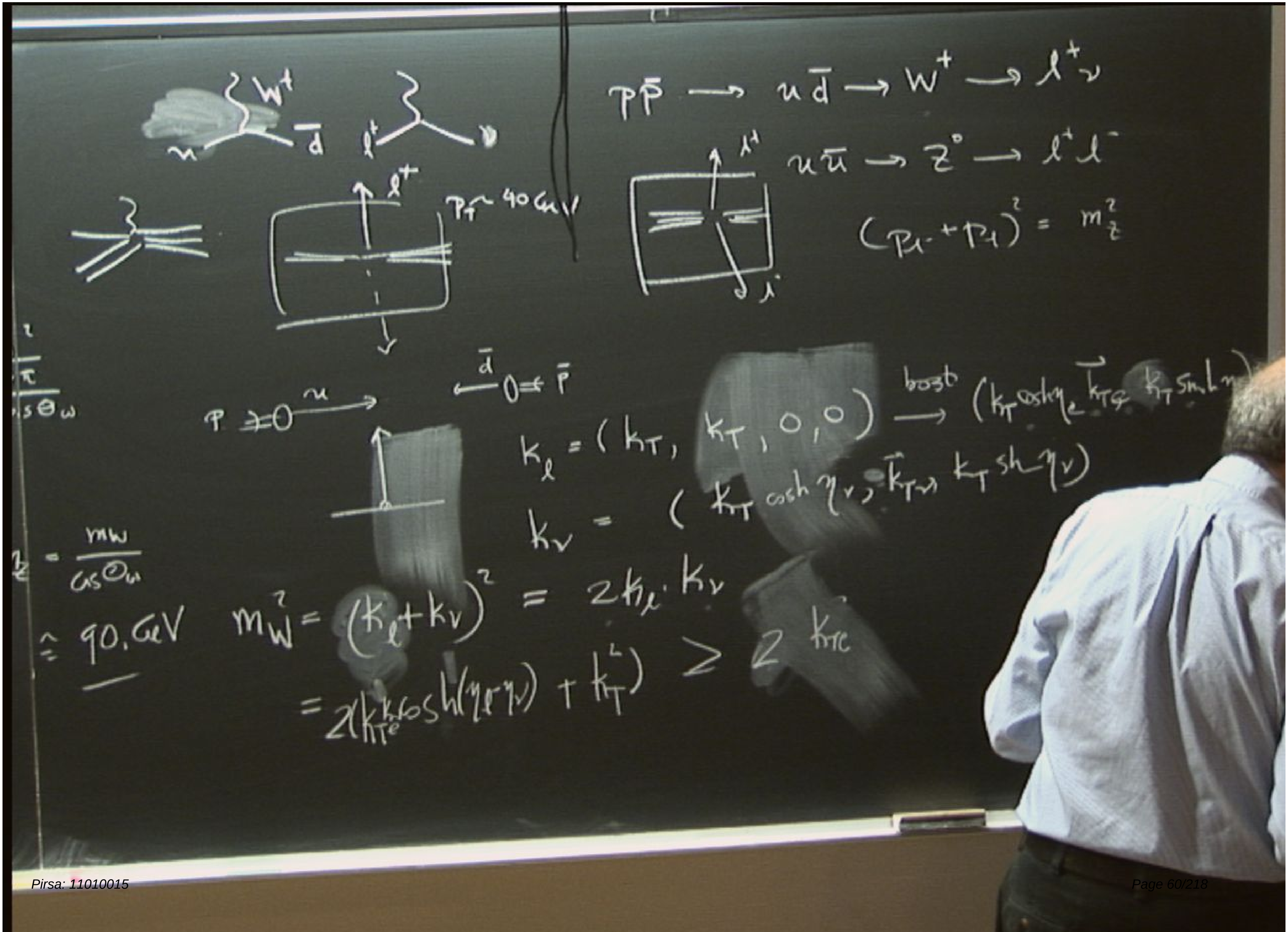

pp̄ → ud̄ → W+ → l+ν
uū → Z0 → l+l−
(pl- + pl)2 = mZ2
pT ~ 40 GeV
boost
kl = (kT, kT, 0, 0)
kν = (kT cosh ην, −kT, kT sinh ην)
mW2 = (kl + kν)2 = 2kl·kν
= 2(kT2 cosh(ηl − ην) + kT2)
≐ 90. GeV
mW / cos θW

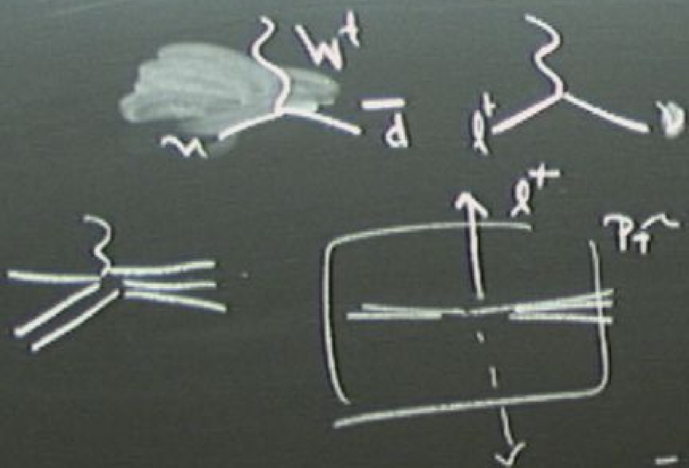


pp̄ → ud̄ → W⁺ → ℓ⁺ν
uū → Z° → ℓ⁺ℓ⁻
(p_{ℓ⁻} + p_{ℓ⁺})² = m_Z²
p_T ~ 40 GeV
boost
k_ℓ = (k_T, k_T, 0, 0)
k_ν = (k_T cosh η_ν, −k_T, k_T sinh η_ν)
m_Z = m_W / cos θ_W
≐ 90. GeV
m_W² = (k_ℓ + k_ν)² = 2k_ℓ · k_ν
= 2(k_T² cosh(η_ℓ − η_ν) + k_T²) ≥ 4 k_T²



W+
d̄
u
l+
ν
pp̄ → ud̄ → W+ → l+ν
uū → Z° → l+l−
l+
p_T ~ 40 GeV
(p_l− + p_l+)² = m_Z²
d̄
p
u
boost
k_l = (k_T, k_T, 0, 0) → (k_T cosh η_l, k_T, k_T sinh η_l)
k_ν = (k_T cosh η_ν, −k_T, k_T sinh η_ν)
m_W / cos θ_W
≅ 90. GeV
m_W² = (k_l + k_ν)² = 2 k_l · k_ν
= 2(k_T² cosh(η_l − η_ν) + k_T²) ≥ 4 k_T²


pp̄ → ud̄ → W⁺ → ℓ⁺ν
uū → Z⁰ → ℓ⁺ℓ⁻
(p_ℓ⁻ + p_ℓ)² = m_Z²
p_T ~ 40 GeV
boost
k_ℓ = (k_T, k_T, 0, 0)
k_ν = (k_T cosh η_ν, k_T, k_T sh η_ν)
m_W² = (k_ℓ + k_ν)² = 2k_ℓ · k_ν
= 2(k_Tℓ k_Tν cosh(η_ℓ − η_ν) + k_T²) ≥ 2 k_Tℓ
≅ 90. GeV

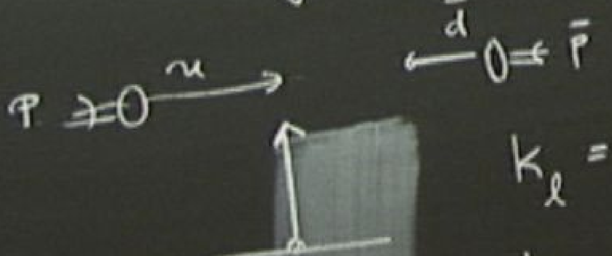


$$p\bar{p} \longrightarrow u\bar{d} \longrightarrow W^+ \longrightarrow \ell^+ \nu$$

$$u\bar{u} \longrightarrow Z^0 \longrightarrow \ell^+ \ell^-$$

$p_T \sim 40\,\mathrm{GeV}$

$$(p_{\ell^-} + p_{\ell^+})^2 = m_Z^2$$



$$k_\ell = (k_T,\ k_T,\ 0,\ 0) \xrightarrow{\text{boost}} (k_T\cosh\eta_\ell,\ \vec{k}_{T\ell},\ k_T \sinh\eta_\ell)$$

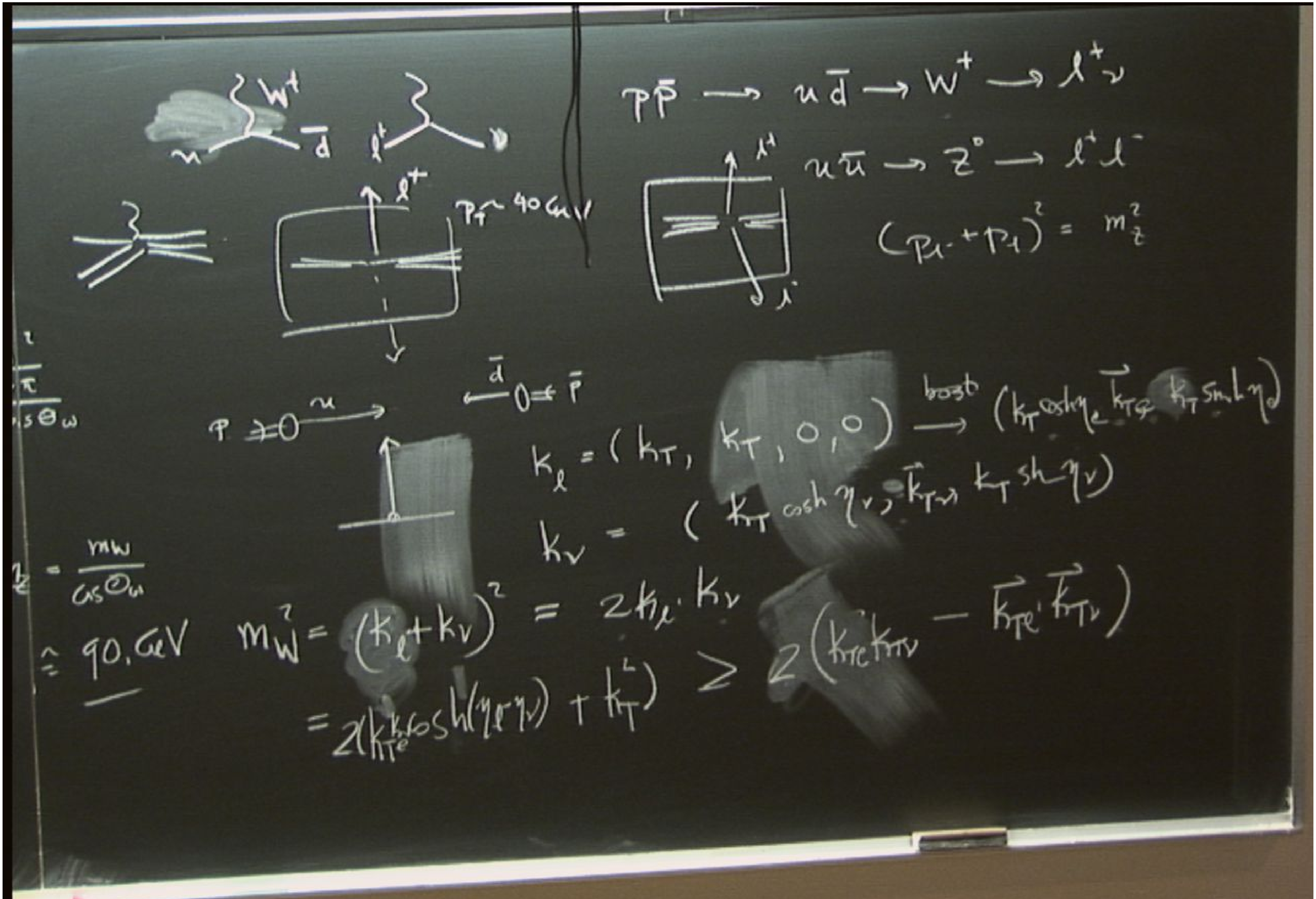
$$k_\nu = (k_T\cosh\eta_\nu,\ \vec{k}_{T\nu},\ k_T \sinh\eta_\nu)$$

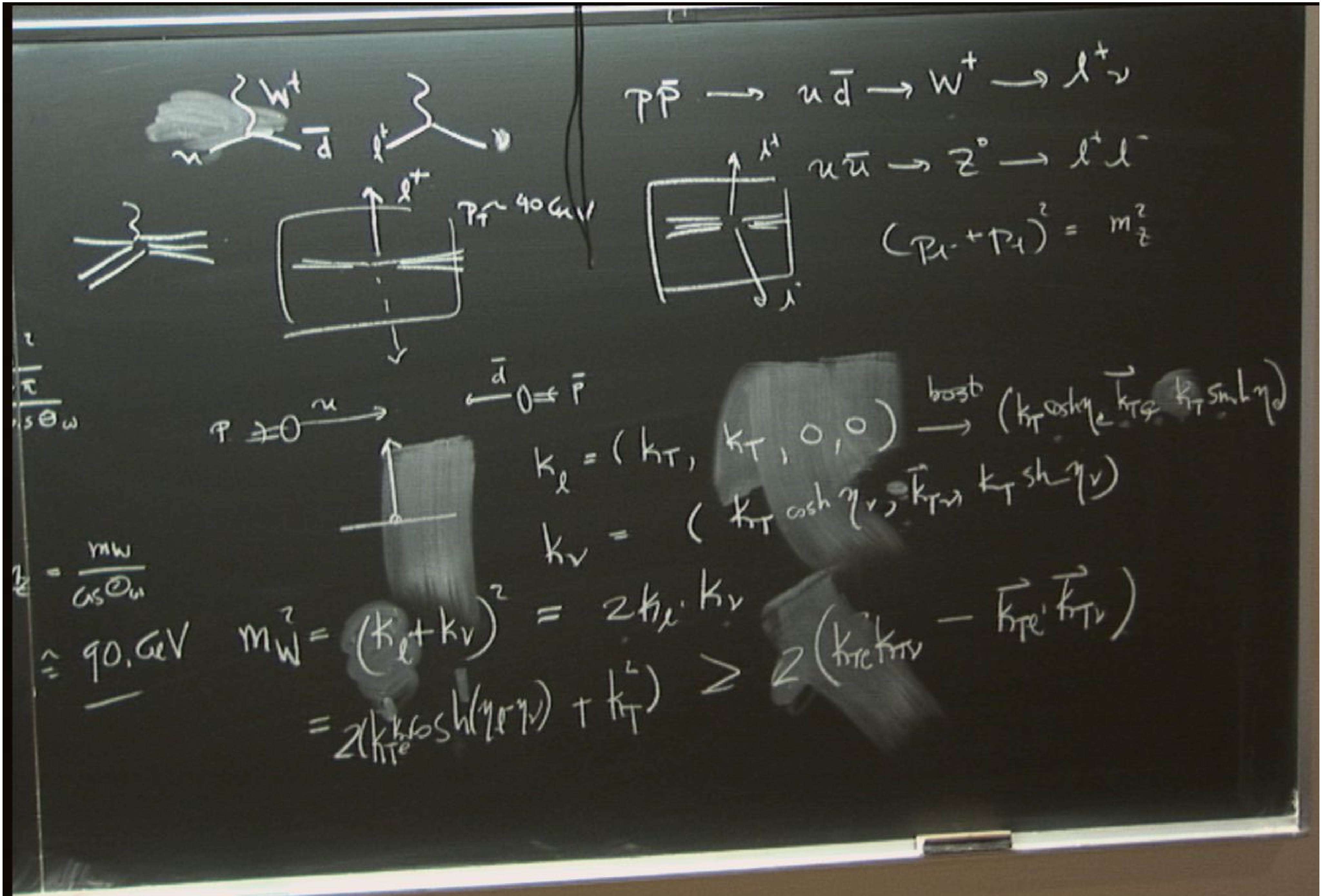
$$m_Z = \frac{m_W}{\cos\theta_W}$$

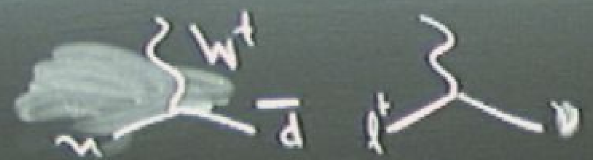
$\hat{=}\ \underline{90.\,\mathrm{GeV}}$

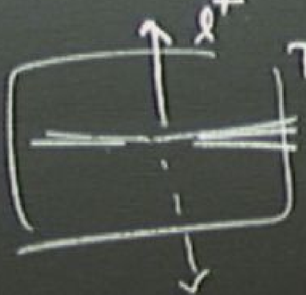
$$m_W^2 = (k_\ell + k_\nu)^2 = 2k_\ell \cdot k_\nu$$

$$= 2(k_{T\ell}k_{T\nu}\cosh(\eta_\ell - \eta_\nu) + k_T^2) \geq 2(k_{T\ell}k_{T\nu} - \vec{k}_{T\ell}\cdot\vec{k}_{T\nu})$$


$p\bar{p} \longrightarrow u\bar{d} \longrightarrow W^+ \longrightarrow \ell^+\nu$
$u\bar{u} \longrightarrow Z^0 \longrightarrow \ell^+\ell^-$
$(p_{\ell^-}+p_{\ell^+})^2 = m_Z^2$
$p_T \sim 40$ GeV
$k_\ell = (k_T, k_T, 0, 0) \xrightarrow{\text{boost}} (k_T\cosh\eta_\ell, \vec{k}_{T\ell}, k_T\sinh\eta_\ell)$
$k_\nu = (k_T\cosh\eta_\nu, \vec{k}_{T\nu}, k_T\sinh\eta_\nu)$
$m_W^2 = (k_\ell+k_\nu)^2 = 2k_\ell\cdot k_\nu$
$\geq 2(k_{T\ell}k_{T\nu} - \vec{k}_{T\ell}\cdot\vec{k}_{T\nu})$
$= 2(k_{T\ell}k_{T\nu}\cosh(\eta_\ell-\eta_\nu) + k_T^2)$
$= \frac{m_W}{\cos\theta_W}$
$\doteq 90.$ GeV


pp̄ → u d̄ → W+ → l+ ν
u ū → Z° → l+ l−
(p_l− + p_l+)² = m_Z²
p_T ~ 40 GeV
boost
k_l = (k_T, k_T, 0, 0) → (k_T cosh η_e, k_Tφ, k_T sinh η_e)
k_ν = (k_T cosh η_ν, k_Tν, k_T sh η_ν)
m_W² = (k_l + k_ν)² = 2 k_l · k_ν = 2(k_Te k_Tν − k_Te · k_Tν)
= 2(k_Te k_Tν cosh(η_e − η_ν) + k_T²) ≥ 2
m_Z = m_W / cos θ_W
≃ 90. GeV

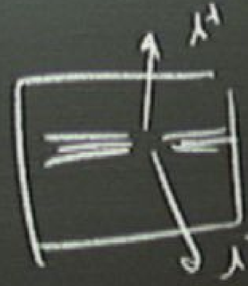




$p_T \sim 40$ GeV

$p\bar{p} \longrightarrow u\bar{d} \longrightarrow W^+ \longrightarrow \ell^+\nu$

$u\bar{u} \longrightarrow Z^0 \longrightarrow \ell^+\ell^-$



$(p_{\ell^-} + p_{\ell^+})^2 = m_Z^2$

$\xrightarrow{\text{boost}} (k_T\cosh\eta_\ell, \vec{k}_{T\ell}, k_T\sinh\eta_\ell)$

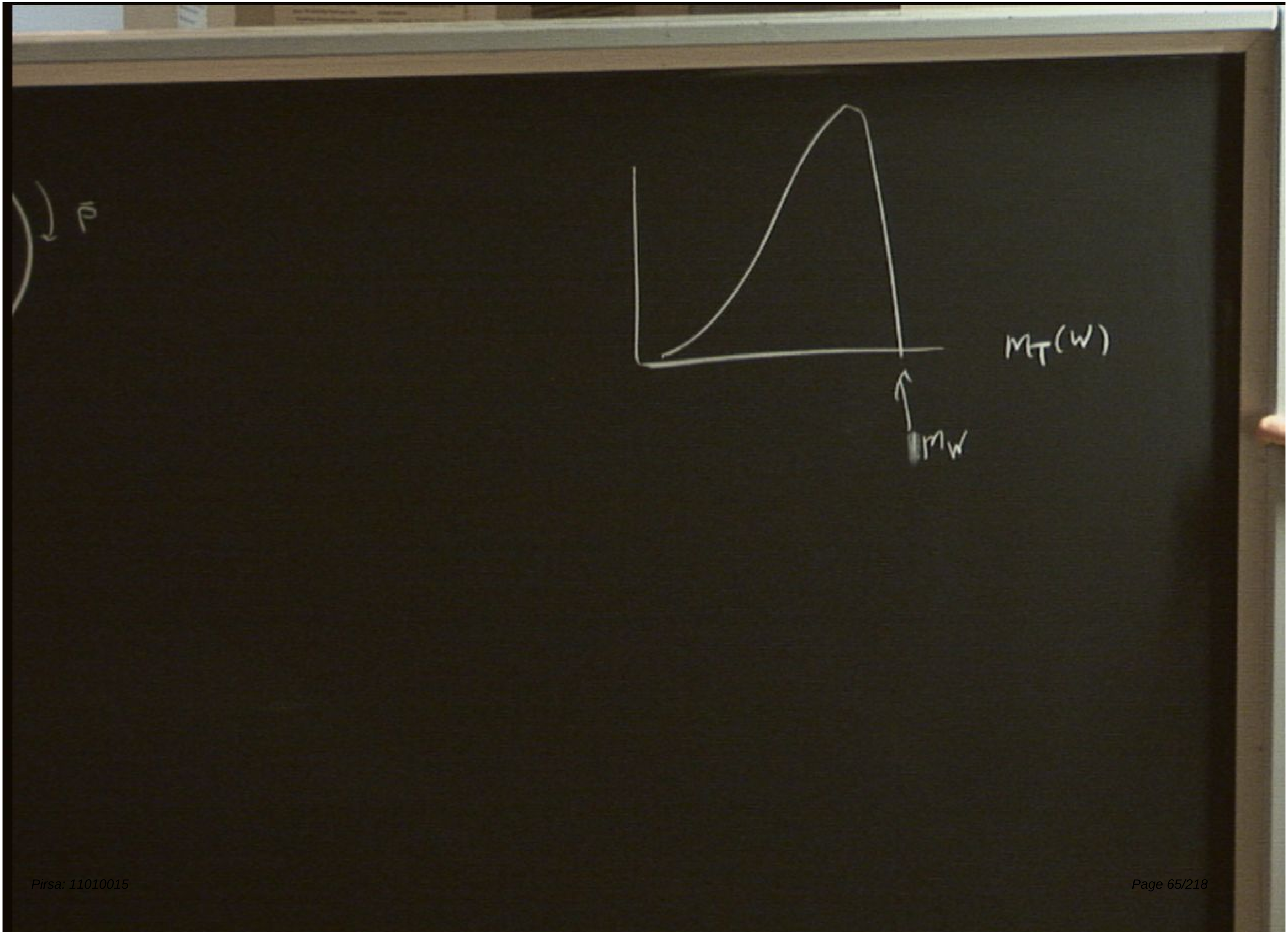
$k_\ell = (k_T, k_T, 0, 0)$

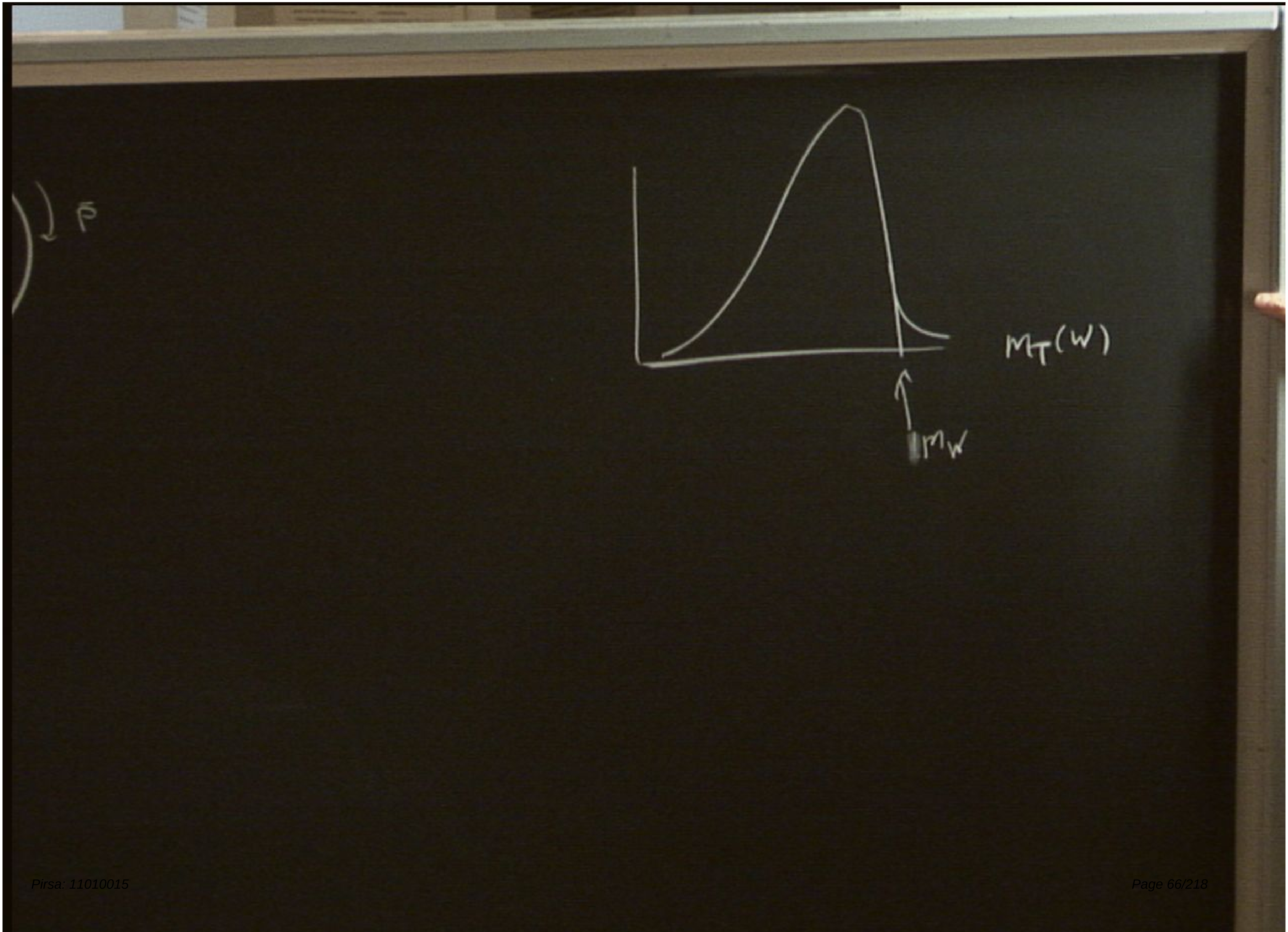
$k_\nu = (k_T\cosh\eta_\nu, \vec{k}_{T\nu}, k_T\sinh\eta_\nu)$

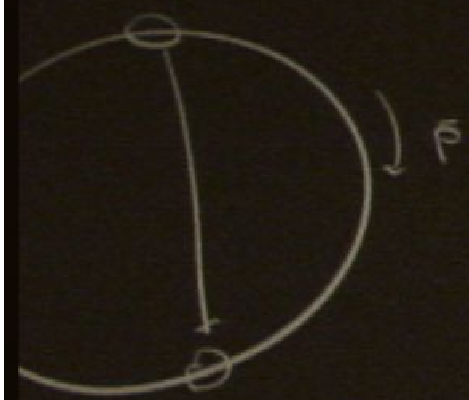
$m_Z = \frac{m_W}{\cos\theta_W} \doteq \underline{90.\text{GeV}}$

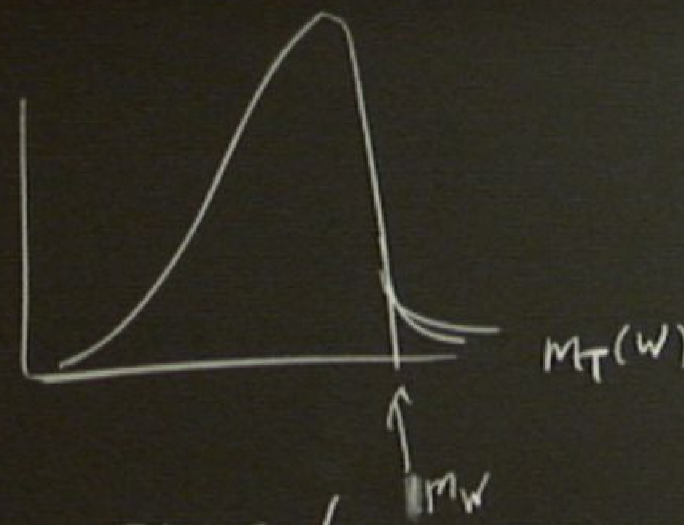
$m_W^2 = (k_\ell + k_\nu)^2 = 2k_\ell \cdot k_\nu$

$= 2(k_{T\ell}k_{T\nu}\cosh(\eta_\ell - \eta_\nu) + k_T^2) \geq \underbrace{2(k_{T\ell}k_{T\nu} - \vec{k}_{T\ell}\cdot\vec{k}_{T\nu})}_{m_T^2}$

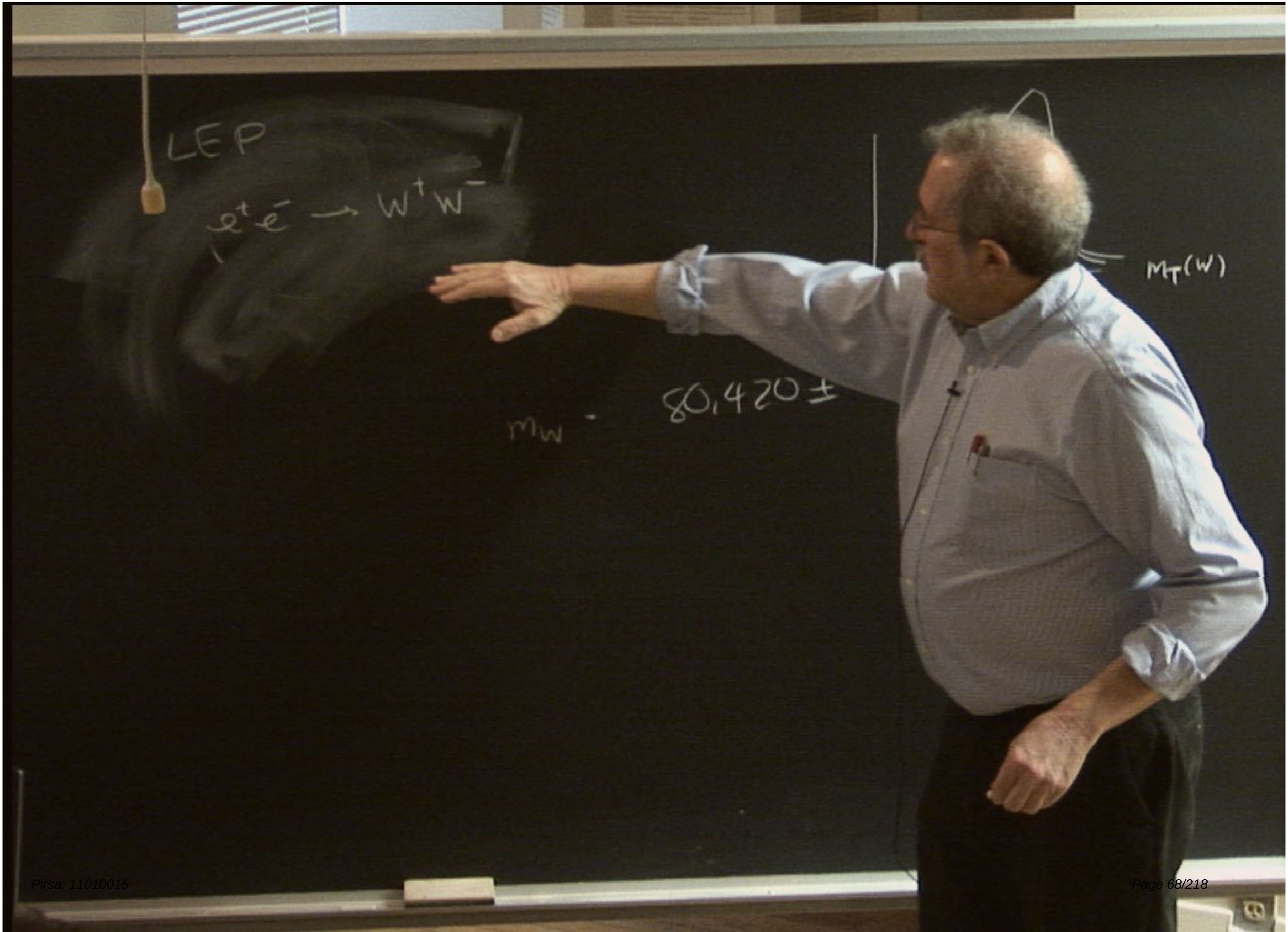

$\bar{p}$
$m_T(W)$
m_W


P
$M_T(W)$
m_W



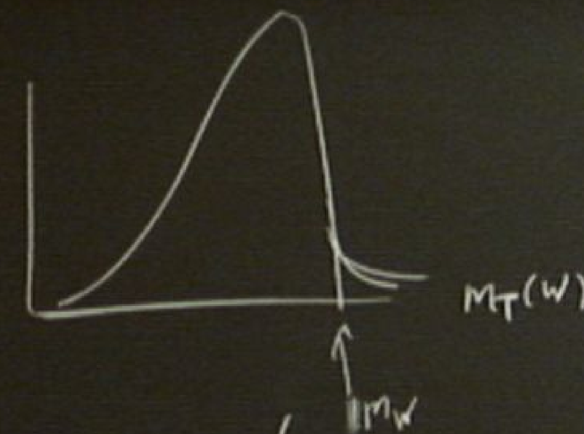


$$m_W = 80.420 \pm 0.031 \text{ GeV}$$


LEP
e+e- → W+W-
mW = 80,420 ±
MT(W)

LEP

$e^+e^- \to W^+ W^- \to (2\ \text{jets})$ or $\ell^+\nu$

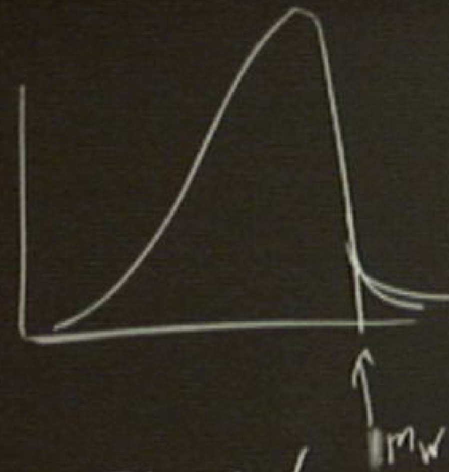


$m_W = 80.420 \pm 0.031$ GeV

LEP

$e^+e^- \to W^+ \longrightarrow (2\ \text{jets})$ or $\ell^+\nu$

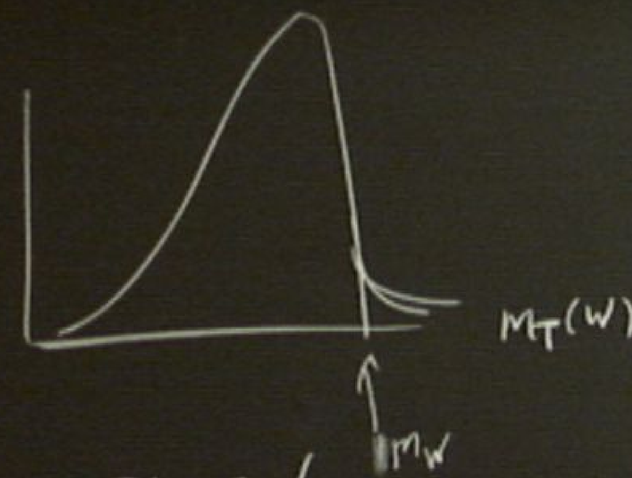
$\qquad\qquad\; W^-$



$m_W = 80.420 \pm 0.031$ GeV

LEP

$e^+e^- \to W^+ W^- \to (2 \text{ jets})$ or $\ell^+\nu$



$m_W = 80.420 \pm 0.031$ GeV

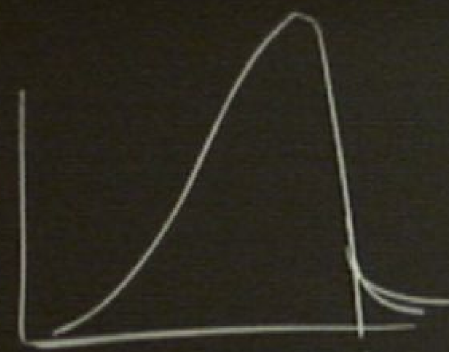
80.3

LEP

$e^+e^- \to W^+ \longrightarrow (2\text{ jets})$ or $\ell^+\nu$

W^-

m



$M_T(W)$

Tevatron

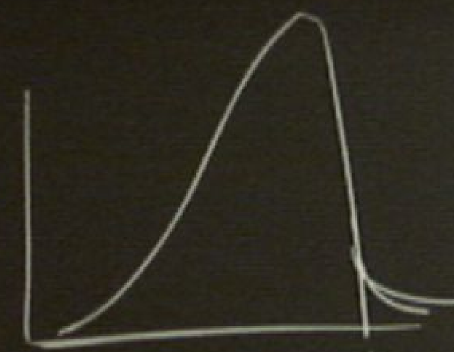
LEP

$m_W = 80.420 \pm 0.031$ GeV

80.376 ± 0.033 GeV

LEP

$e^+e^- \to W^+ W^- \longrightarrow$ (2 jets) or $l^+\nu$

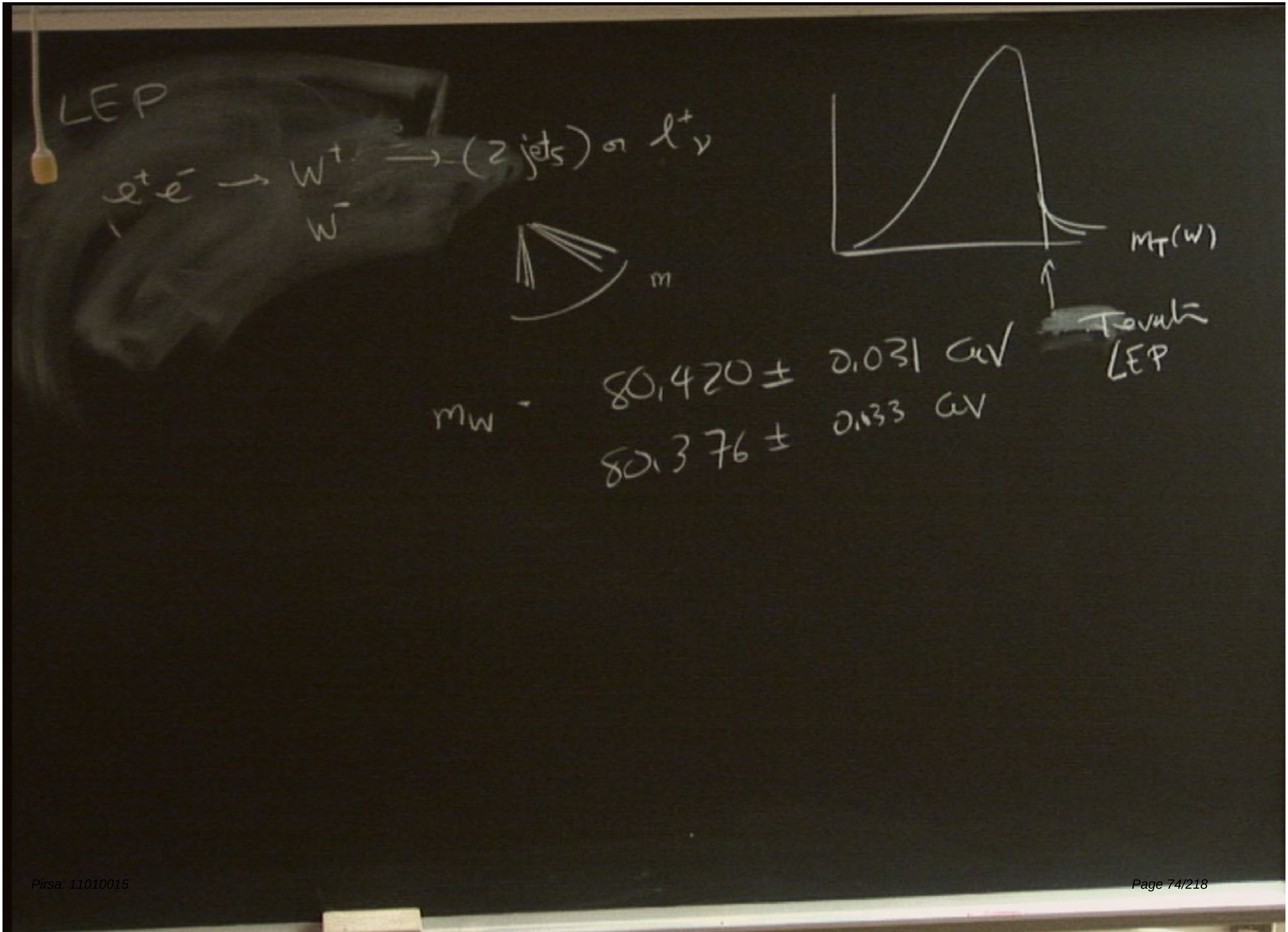


Tevatron

LEP

$m_W = 80.420 \pm 0.031$ GeV

80.376 ± 0.033 GeV

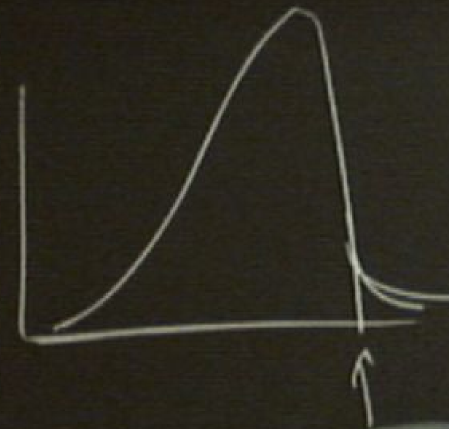

LEP
$e^+e^- \to W^+ W^- \to$ (2 jets) or $\ell^+\nu$
m
$M_T(W)$
Tevatron
LEP
m_W = 80.420 ± 0.031 GeV
80.376 ± 0.033 GeV

LEP

$e^+e^- \to W^+ W^-$

$W^+ \longrightarrow$ (2 jets) or $\ell^+\nu$

m



$M_T(W)$

Tevatron

LEP

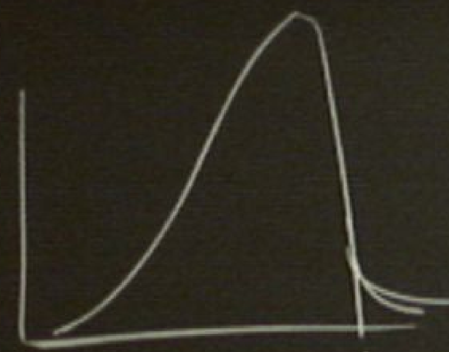
$m_W = 80.420 \pm 0.031$ GeV

80.376 ± 0.033 GeV

LEP

$e^+e^- \to W^+ W^- \longrightarrow$ (2 jets) or $l^+\nu$

m



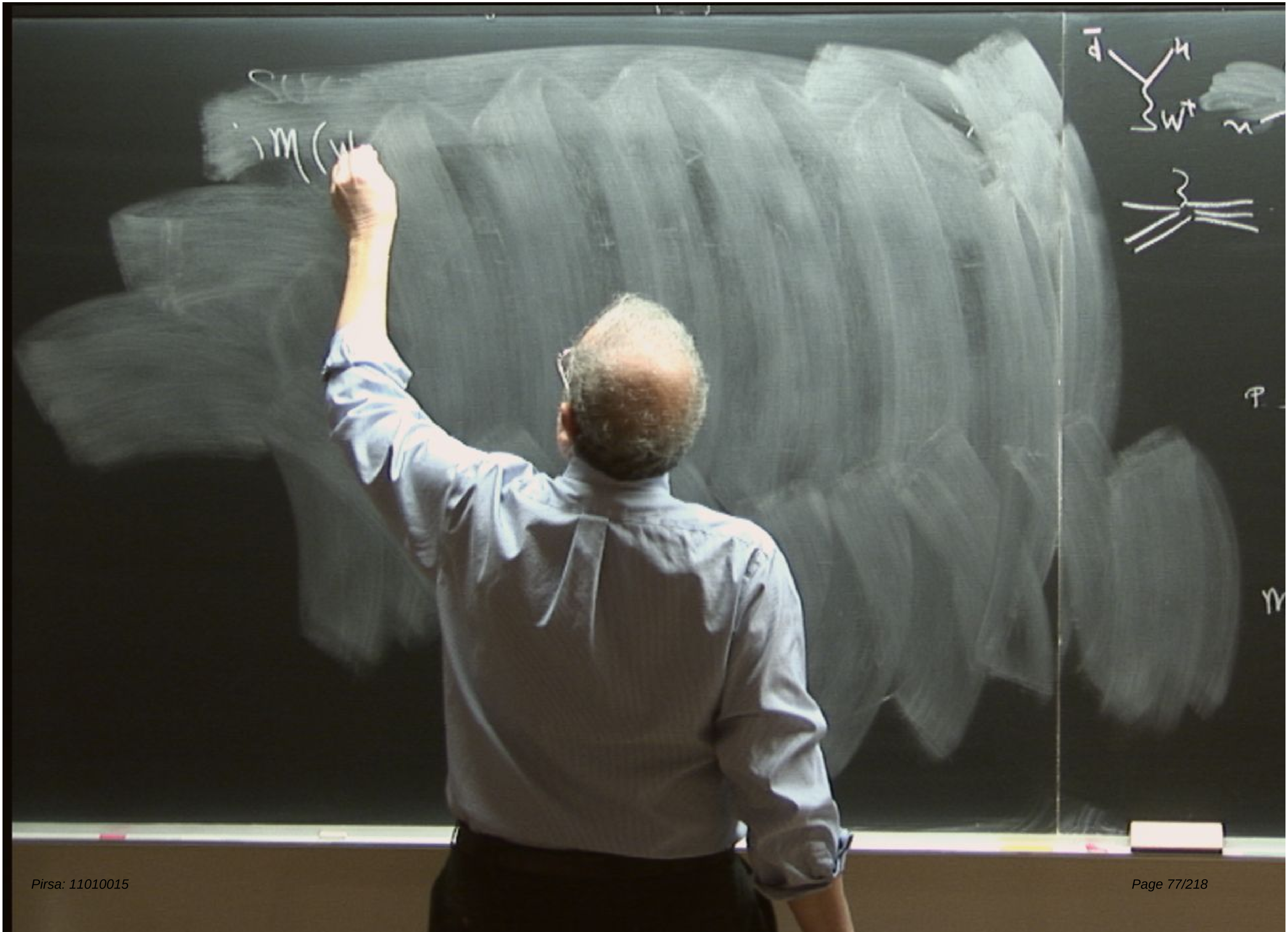
$M_T(W)$

Tevatron

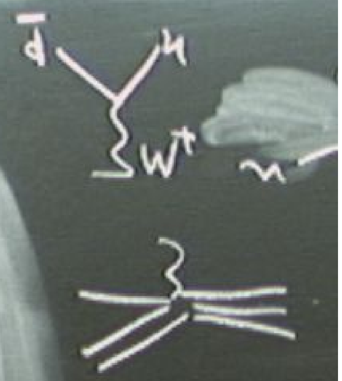
LEP

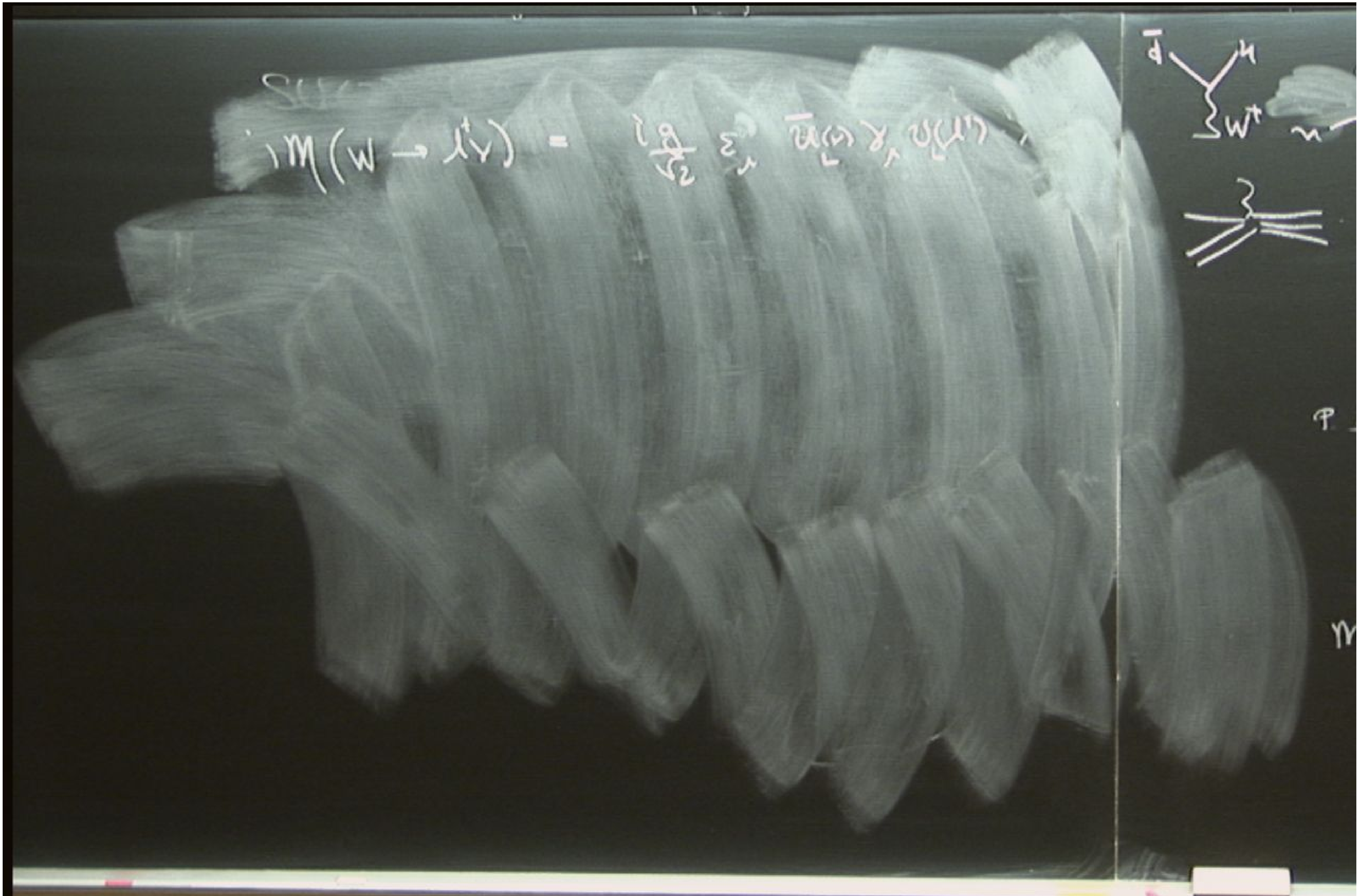
$m_W = 80.420 \pm 0.031$ GeV

80.376 ± 0.033 GeV



$$i\mathcal{M}(W \to \ell^+\nu) = \frac{ig}{\sqrt{2}}\,\varepsilon_\mu\,\bar{u}_L(\nu)\,\gamma^\mu\,v_L(\ell^+)$$

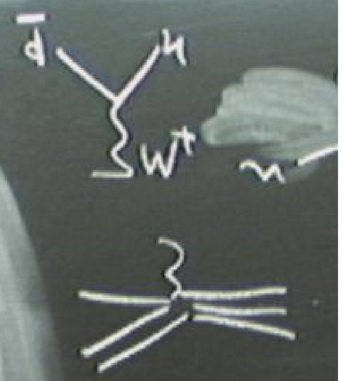




iM(W → l⁺ν) = (ig/√2) ε_μ ū_L(ν) γ_μ v_L(l⁺)
d̄
u
W⁺

$$i\mathcal{M}(W \to l^+\nu) = \frac{ig}{\sqrt{2}}\,\varepsilon_\mu\,\bar{u}_L(\nu)\,\gamma^\mu\,v_L(l^+)$$

$$= \frac{ig}{\sqrt{2}}\,\varepsilon_\mu(W)$$

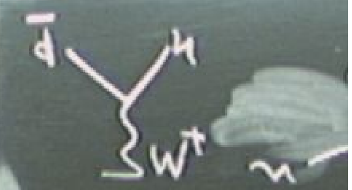


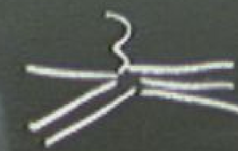
$$i\mathcal{M}(W \to \ell^+\nu) = \frac{ig}{\sqrt{2}}\,\varepsilon_\mu\;\bar{u}_L(\nu)\,\gamma^\mu\, v_L(\ell^+)$$

$$= \frac{ig}{\sqrt{2}}\,\varepsilon_\mu(W)\,\sqrt{2E}$$

$$i\mathcal{M}(W \to \ell^+\nu) = \frac{ig}{\sqrt{2}}\,\varepsilon_\mu\,\bar{u}_L(\nu)\,\gamma^\mu\,v_L(\ell)$$

$$= \frac{ig}{\sqrt{2}}\,\varepsilon_\mu(W)\,\sqrt{2E}$$





P

M

$$i\mathcal{M}(W \to l^+\nu) = \frac{ig}{\sqrt{2}}\,\varepsilon_\mu\,\bar{u}_L(\nu)\,\gamma^\mu\,v_L(l^+)$$

$$= \frac{ig}{\sqrt{2}}\,\varepsilon_\mu(W)\,\sqrt{2E}\,\varepsilon_\mu(l^+)$$

$$(0, 1, i, 0)^\mu$$

$$i\mathcal{M}(W \to l^+\nu) = \frac{ig}{\sqrt{2}}\,\varepsilon_\mu\,\bar{u}_L(\nu)\,\gamma_\mu\,v_L(l^+)$$

$$= \frac{ig}{\sqrt{2}}\,\varepsilon_\mu(W)\,\sqrt{2E}\,\varepsilon_\mu(l^+)$$

$$(0, 1, i, 0)^\mu$$

$$i\mathcal{M}(W \to l^+ \nu) = \frac{ig}{\sqrt{2}}\, \varepsilon_\mu\, \bar{u}_L(\nu)\, \gamma_\mu\, v_L(l^+)$$

$$= \frac{ig}{\sqrt{2}}\, \varepsilon_\mu(W)\, \sqrt{2E}\; \varepsilon_\mu(l^+)$$

$$(0, 1, i, 0)^\mu$$

$$\sum_{\text{pol.}} |\mathcal{M}|^2 =$$

$$i\mathcal{M}(W \to l^+\nu) = \frac{ig}{\sqrt{2}} \epsilon_\mu \, \bar{u}_L(\nu) \gamma^\mu v_L(l^+)$$

$$= \frac{ig}{\sqrt{2}} \epsilon_\mu(W) \underbrace{\sqrt{2E}}_{} \epsilon^\mu(l^+)$$

$$(0, 1, i, 0)^\mu$$

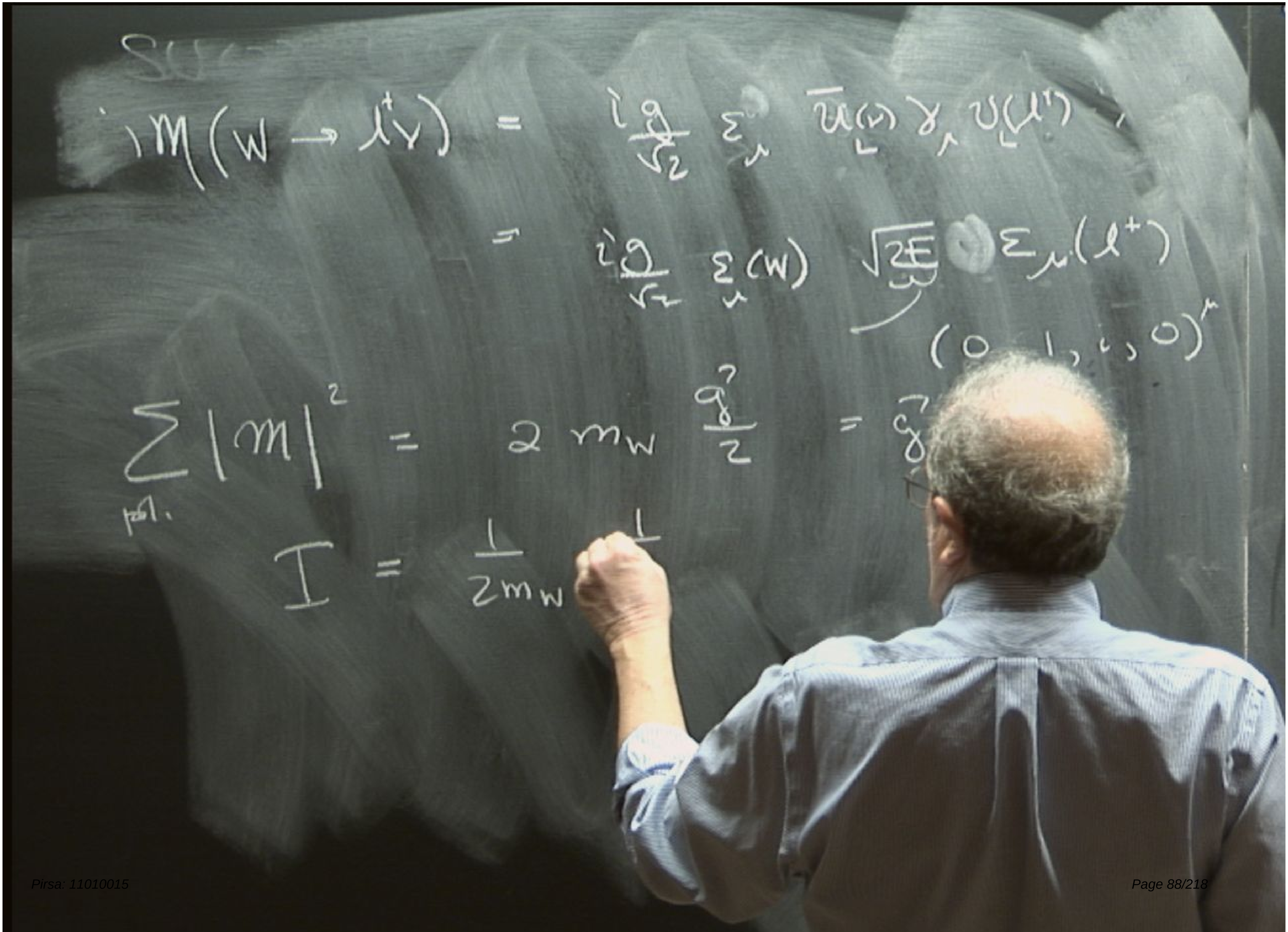
$$\sum_{\text{pol.}} |\mathcal{M}|^2 = 2 m_W \frac{g^2}{2}$$

$$i\mathcal{M}(W \to l^+\nu) = \frac{ig}{\sqrt{2}}\, \varepsilon_\mu\, \bar{u}_L(\nu)\, \gamma_\mu\, v_L(l^+)$$

$$= \frac{ig}{\sqrt{2}}\, \varepsilon_\mu(W)\, \sqrt{2E}\, \varepsilon_\mu(l^+)$$

$$(0, 1, i, 0)^\mu$$

$$\sum_{\text{pol.}} |\mathcal{M}|^2 = 2\, m_W\, \frac{g^2}{2}$$


$i\mathcal{M}(W \to l^+\nu) = \frac{ig}{\sqrt{2}} \varepsilon_\mu \, \bar{u}_L(\nu) \gamma_\mu v_L(l^+)$
$= \frac{ig}{\sqrt{2}} \varepsilon_\mu(W) \sqrt{2E} \, \varepsilon_\mu(l^+)$
$(0, 1, i, 0)^\mu$
$\sum_{pol} |\mathcal{M}|^2 = 2 m_W \frac{g^2}{2} = g^2$
$\Gamma = \frac{1}{2m_W} \frac{1}{}$

$$i\mathcal{M}(W \to l^+\nu) = \frac{ig}{\sqrt{2}}\,\varepsilon_\mu\, \bar{u}_L(\nu)\,\gamma_\mu\, v_L(l^+)$$

$$= \frac{ig}{\sqrt{2}}\,\varepsilon_\mu(W)\,\underbrace{\sqrt{2E}\,\varepsilon_\mu(l^+)}_{(0,\,1,\,i,\,0)^\mu}$$

$$\sum_{\text{pol.}} |\mathcal{M}|^2 = 2\, m_W \frac{g^2}{2} = g^2 m_W^2$$

$$\Gamma = \frac{1}{2m_W}\,\frac{1}{3}\,\frac{1}{8\pi}\, g^2 m_W^2$$

$$i\mathcal{M}(W \to l^+ \nu) = \frac{ig}{\sqrt{2}}\, \varepsilon_\mu\, \bar{u}_L(\nu)\, \gamma_\mu\, v_L(l^+)$$

$$= \frac{ig}{\sqrt{2}}\, \varepsilon_\mu(W)\, \sqrt{2E}\, \varepsilon_\mu(l^+)$$

$$(0, 1, i, 0)^\mu$$

$$\sum_{\text{pol.}} |\mathcal{M}|^2 = 2 m_W \frac{g^2}{2} = g^2 m_W^2$$

$$\Gamma = \frac{1}{2m_W} \frac{1}{3} \frac{1}{8\pi} g^2 m_W^2$$

$$= \frac{\alpha_W}{}$$

Sum

$$i\mathcal{M}(W \to l^+\nu) = \frac{ig}{\sqrt{2}}\, \varepsilon_\mu\, \bar{u}_L(\nu)\, \gamma^\mu\, v_L(l^+)$$

$$= \frac{ig}{\sqrt{2}}\, \varepsilon_\mu(W)\, \underbrace{\sqrt{2E}}_{}\, \varepsilon^\mu(l^+)$$

$$(0, 1, i, 0)^\mu$$

$$\sum_{pol.} |\mathcal{M}|^2 = 2 m_W \frac{g^2}{2} = g^2 m_W^2$$

$$\Gamma = \frac{1}{2m_W}\, \frac{1}{3}\, \frac{1}{8\pi}\, g^2 m_W^2$$

$$= \frac{\alpha_W}{12}\, m_W$$

$$i\mathcal{M}(W \to \ell^+\nu) = \frac{ig}{\sqrt{2}}\,\varepsilon_\mu\,\bar{u}_L(\nu)\,\gamma^\mu\, v_L(\ell^+)$$

$$= \frac{ig}{\sqrt{2}}\,\varepsilon_\mu(W)\,\sqrt{2E}\,\varepsilon^\mu(\ell^+)$$

$$(0,1,i,0)^\mu$$

$$\sum_{\text{pol.}} |\mathcal{M}|^2 = 2\,m_W\,\frac{g^2}{2} = g^2 m_W^2$$

$$\Gamma = \frac{1}{2m_W}\,\frac{1}{3}\,\frac{1}{8\pi}\,g^2 m_W^2$$

$$\Gamma(W^+\to e^+\nu) = \frac{\alpha_w}{12}\,m_W$$

$$i\mathcal{M}(W \to l^+ \nu) = \frac{ig}{\sqrt{2}}\, \varepsilon_\mu\, \bar{u}_L(\nu)\, \gamma_\mu\, v_L(l^+)$$

$$= \frac{ig}{\sqrt{2}}\, \varepsilon_\mu(W)\, \sqrt{2E}\, \varepsilon_\mu(l^+)$$

$$(0, 1, i, 0)^\mu$$

$$\sum_{\text{pol.}} |\mathcal{M}|^2 = 2\, m_W \frac{g^2}{2} = g^2 m_W^2$$

$$\Gamma = \frac{1}{2m_W} \frac{1}{3} \frac{1}{8\pi}$$

$$\Gamma(W^+ \to e^+ \nu) = \frac{\alpha_W}{12} m_W$$

$$\Gamma(W^+ \to u\bar{d}) = \frac{\alpha_W}{\ldots}$$

$$i\mathcal{M}(W \to l^+ \nu) = \frac{ig}{\sqrt{2}} \varepsilon_\mu \, \bar{u}_L(\nu) \gamma_\mu v_L(l^+)$$

$$= \frac{ig}{\sqrt{2}} \varepsilon_\mu(W) \, \underbrace{\sqrt{2E}}_{} \, \varepsilon_\mu(l^+)$$

$$(0, 1, i, 0)^\mu$$

$$\sum_{\text{pol.}} |\mathcal{M}|^2 = 2 m_W \frac{g^2}{2} = g^2 m_W^2$$

$$\Gamma = \frac{1}{2m_W} \frac{1}{3} \frac{1}{8\pi} g^2 m_W^2$$

$$\Gamma(W^+ \to e^+ \nu) = \frac{\alpha_W}{12} m_W$$

$$\Gamma(W^+ \to u\bar{d}) = \frac{\alpha_W}{12} m_W \; 3 \cdot$$

$$i\mathcal{M}(W \to l^+\nu) = \frac{ig}{\sqrt{2}}\, \varepsilon_\mu\, \bar{u}_L(\nu)\, \gamma^\mu\, v_L(l^+)$$

$$= \frac{ig}{\sqrt{2}}\, \varepsilon_\mu(W)\, \sqrt{2E}\, \varepsilon_\mu(l^+)$$

$$(0, 1, i, 0)^\mu$$

$$\sum_{\text{pol.}} |\mathcal{M}|^2 = 2\, m_W \frac{g^2}{2} = g^2 m_W^2$$

$$\Gamma = \frac{1}{2m_W}\, \frac{1}{3}\, \frac{1}{8\pi}\, g^2 m_W^2$$

$$\Gamma(W^+ \to e^+\nu) = \frac{\alpha_W}{12}\, m_W$$

$$\Gamma(W^+ \to u\bar{d}) = \frac{\alpha_W}{12}\, m_W\; 3 \cdot \left(1 + \frac{\alpha_s}{\pi} + \cdots\right)$$

$$i\mathcal{M}(W \to l^+\nu) = \frac{ig}{\sqrt{2}}\,\varepsilon_\mu\,\bar{u}_L(\nu)\,\gamma^\mu\,v_L(l^+)$$

$$= \frac{ig}{\sqrt{2}}\,\varepsilon_\mu(W)\,\sqrt{2E}\,\varepsilon^\mu(l^+)$$

$$(0,1,i,0)^\mu$$

$$\sum_{pol.}|\mathcal{M}|^2 = 2\,m_W\,\frac{g^2}{2} = g^2 m_W^2$$

$$\Gamma = \frac{1}{2m_W}\,\frac{1}{3}\,\frac{1}{8\pi}\,g^2 m_W^2$$

3

$$\Gamma(W^+ \to e^+\nu) = \frac{\alpha_W}{12}\,m_W$$

$$\Gamma(W^+ \to u\bar{d}) = \frac{\alpha_W}{12}\,m_W\quad 3\cdot\left(1+\frac{\alpha_s}{\pi}+\cdots\right)$$

2

$$i\mathcal{M}(W \to l^+\nu) = \frac{ig}{\sqrt{2}}\,\varepsilon_\mu\,\bar{u}_L(\nu)\,\gamma^\mu\,v_L(l^+)$$

$$= \frac{ig}{\sqrt{2}}\,\varepsilon_\mu(W)\,\sqrt{2E}\,\varepsilon_\mu(l^+)$$

$$(0,1,i,0)^\mu$$

$$\sum_{pol.}|\mathcal{M}|^2 = 2m_W\frac{g^2}{2} = g^2 m_W^2$$

$$\Gamma = \frac{1}{2m_W}\,\frac{1}{3}\,\frac{1}{8\pi}\,g^2 m_W^2$$

$$\Gamma(W^+\to e^+\nu) = \frac{\alpha_w}{12}\,m_W$$

$$\Gamma(W^+\to u\bar{d}) = \frac{\alpha_w}{12}\,m_W\;3\cdot\left(1+\frac{\alpha_s}{\pi}+\cdots\right)$$

$$(\quad c\bar{s})$$

3

$\Gamma_W = 2.1\ \mathrm{GeV}$ $\quad BR(\to \ell\nu) = 11\%$ $\quad B$

$\bar{d}$

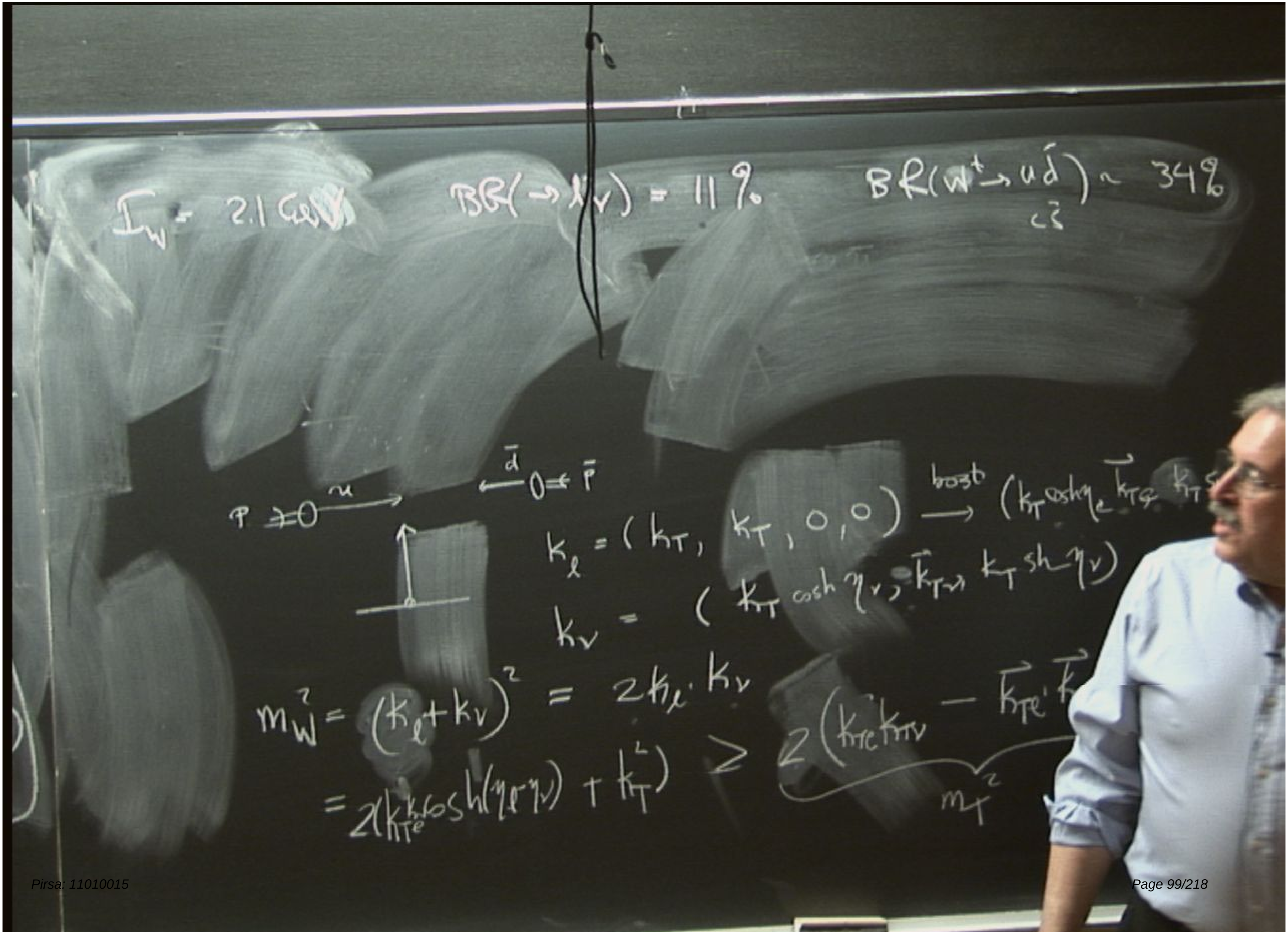
$p \;\to 0\; \xrightarrow{u} \qquad \longleftarrow 0 \leftarrow \bar{p}$

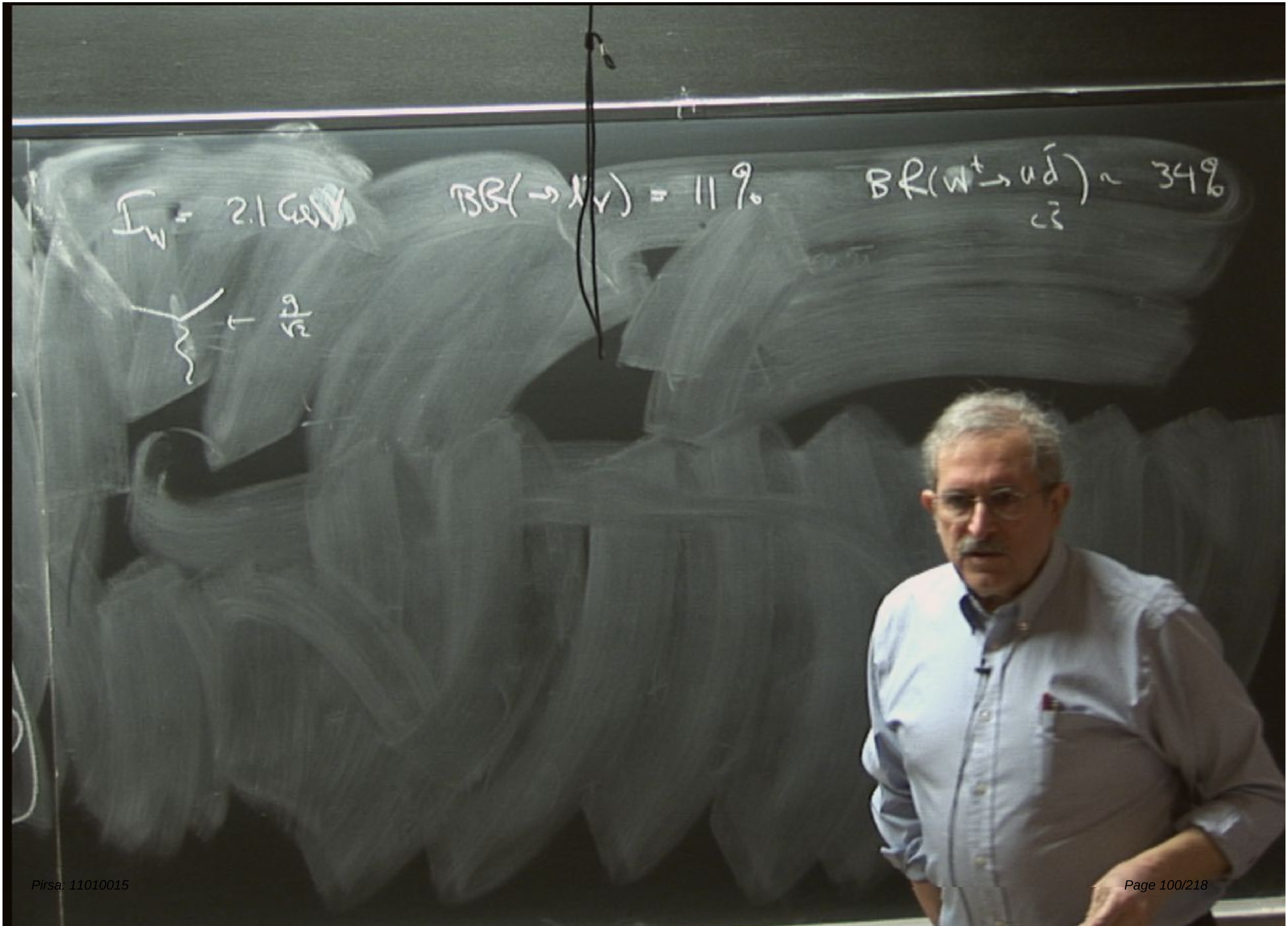
$k_\ell = (k_T,\ k_T,\ 0,\ 0)$

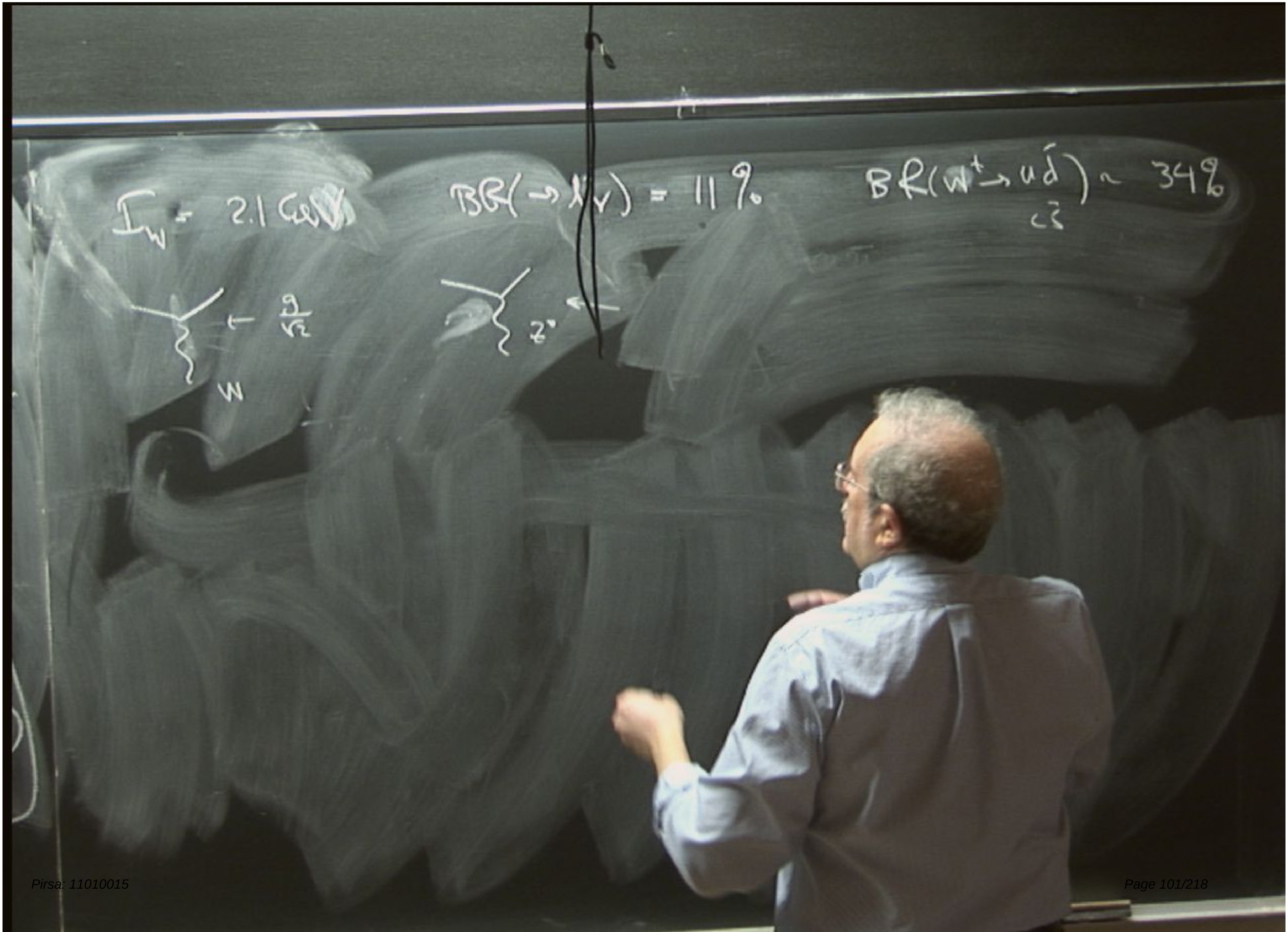
$k_\nu = (k_T \cosh \eta_\nu,\ \vec{k}_{T\nu}$

$m_W^2 = (k_\ell + k_\nu)^2 = 2 k_\ell \cdot k_\nu$

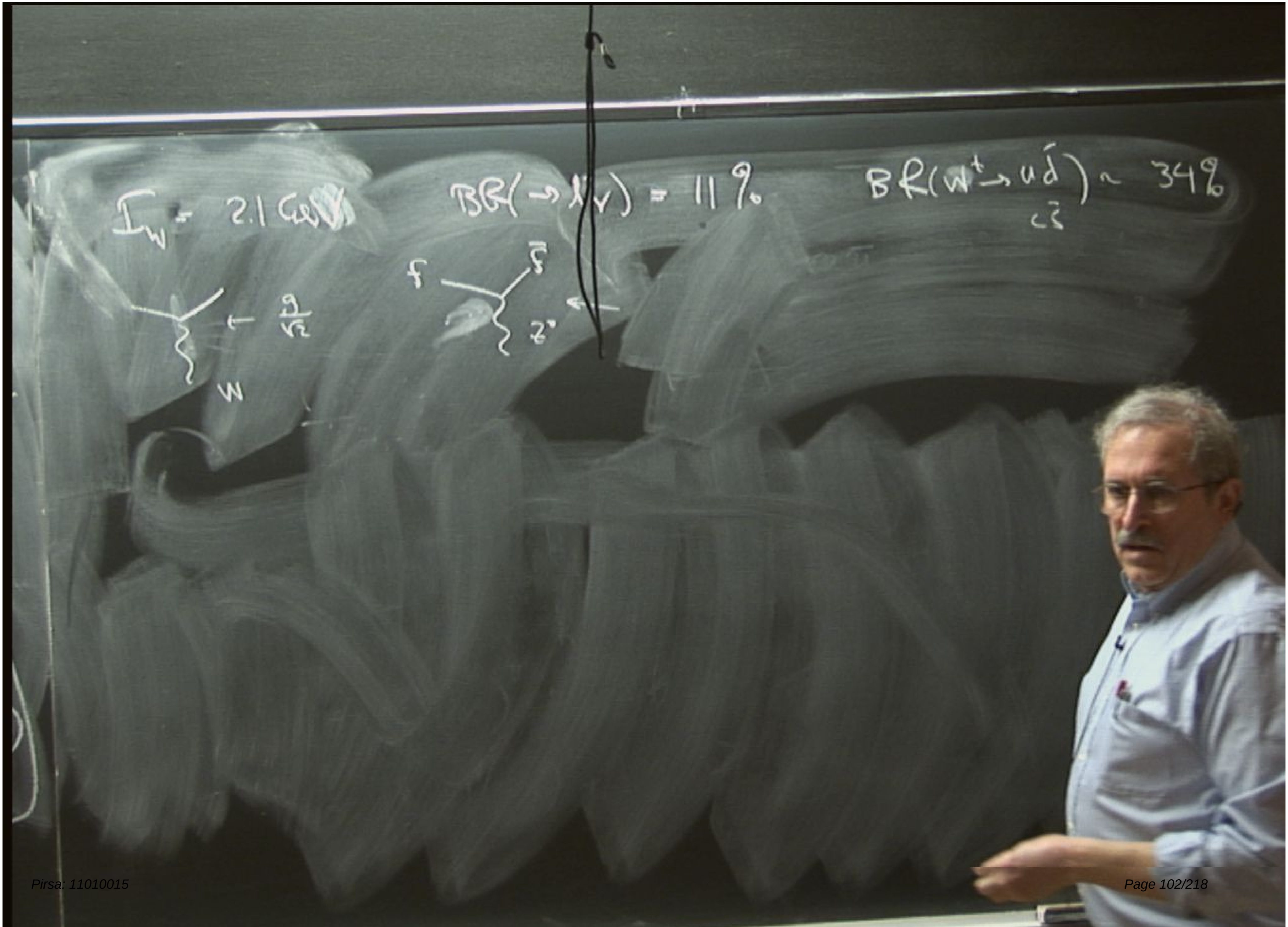
$\geq 2\,(k_{T\ell}\, k_{T\nu}$


$\Gamma_W = 2.1$ GeV
$BR(\to l\nu) = 11\%$
$BR(W^+ \to u\bar{d}) \approx 34\%$
$c\bar{s}$
$\bar{d}$
$p \to O \xrightarrow{u}$ $\leftarrow O \leftarrow \bar{p}$
$k_l = (k_T, k_T, 0, 0) \xrightarrow{boost} (k_T \cosh\eta_e, \vec{k}_{T}, k_T \sinh$
$k_\nu = (k_T \cosh\eta_\nu, \vec{k}_{T\nu}, k_T \sinh\eta_\nu)$
$m_W^2 = (k_l + k_\nu)^2 = 2k_l \cdot k_\nu$
$= 2(k_{Te} k_{T\nu} \cosh(\eta_e - \eta_\nu) + k_T^2) \geq 2(k_{Te} k_{T\nu} - \vec{k}_{Te} \cdot \vec{k}$
m_T^2

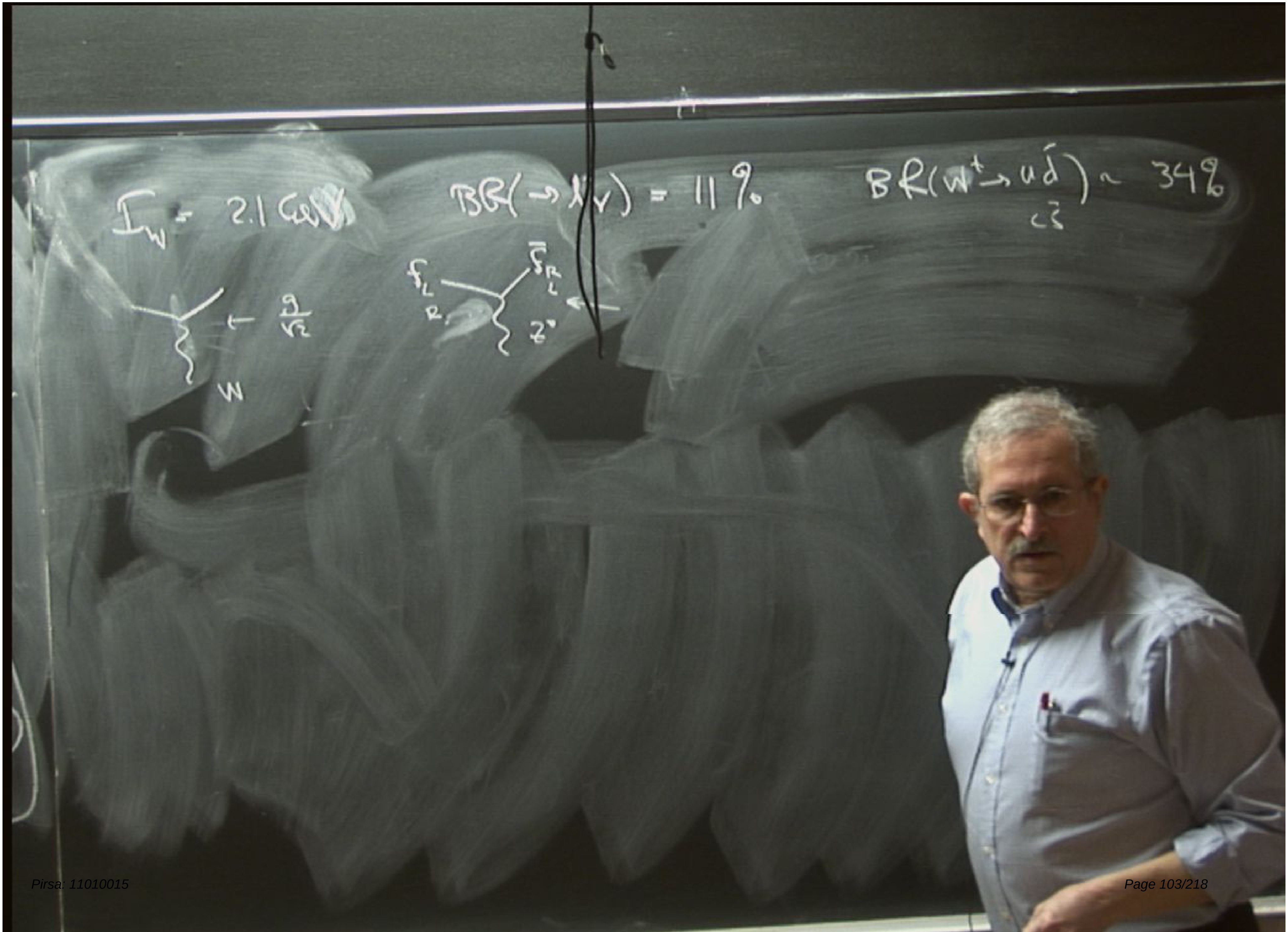

Γ_W = 2.1 GeV
BR(→ ℓν) = 11%
BR(W⁺ → ud̄) ~ 34%
cs̄
g/√2

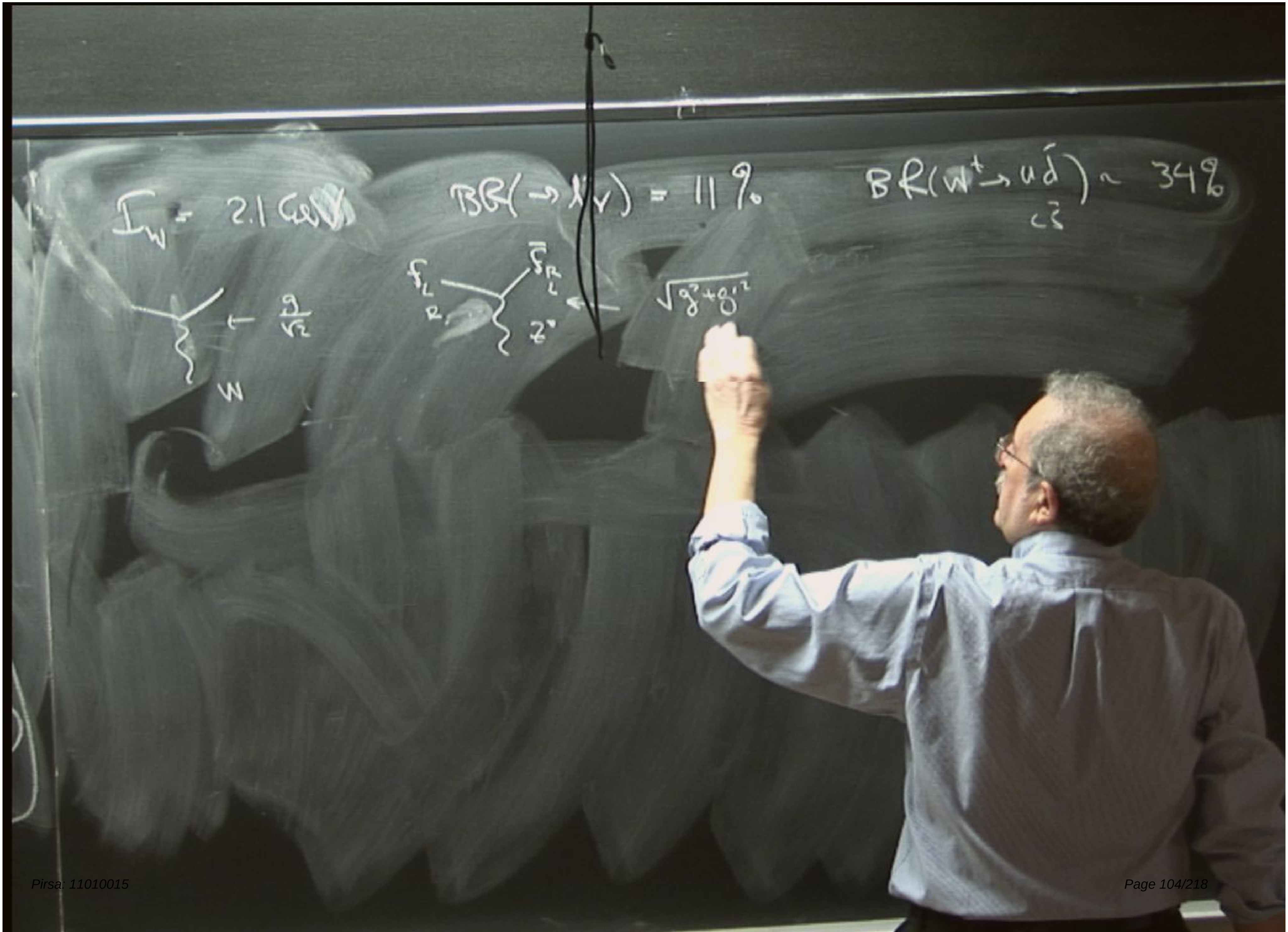


Γ_W = 2.1 GeV
BR(→ lν) = 11%
BR(W+ → ud̄) ~ 34%
×3
g/√2
W
Z°

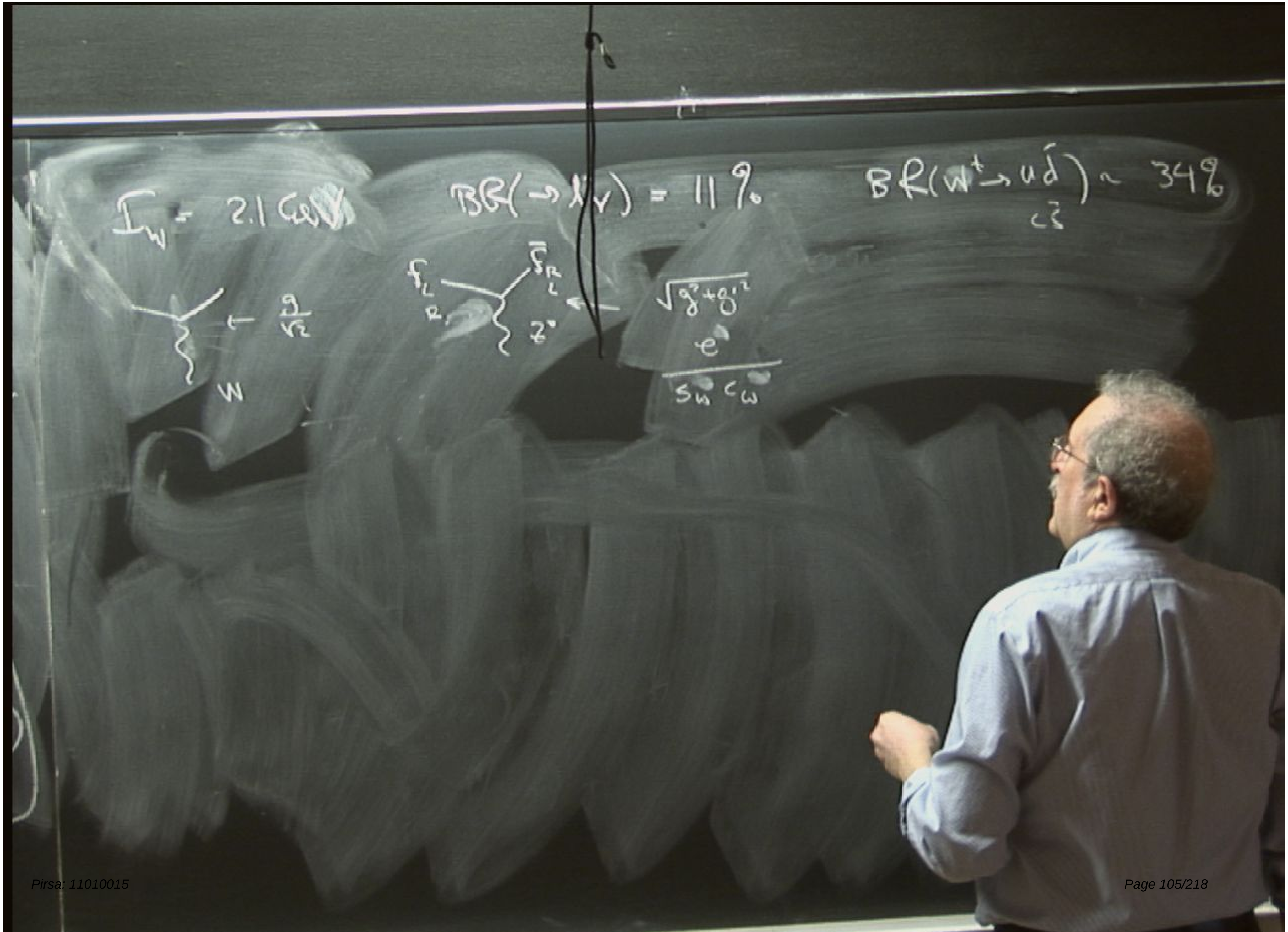


Γ_W = 2.1 GeV
BR(→ ℓν) = 11%
BR(W+ → u d̄) ≈ 34%
c s̄
f
f̄
g/√2
W
Z°


Γ_W = 2.1 GeV
BR(→ ℓν) = 11%
BR(W⁺ → ud̄) ≈ 34%
cs̄
g/√2
W
f_L
R
f̄_R
L
Z⁰

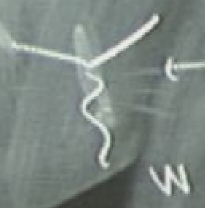


Γ_W = 2.1 GeV
BR(→ lν) = 11%
BR(W⁺→ ud̄) ≈ 34%
g/√2
W
f_L
f̄_R
Z°
√(g²+g'²)


$\Gamma_W = 2.1$ GeV
$BR(\to l\nu) = 11\%$
$BR(W^+ \to u\bar{d}) \approx 34\%$
$c\bar{s}$
f_L
R
$\bar{f}_R$
L
Z^0
$\frac{g}{\sqrt{2}}$
W
$\sqrt{g^2+g'^2}$
$\frac{e}{s_W c_W}$

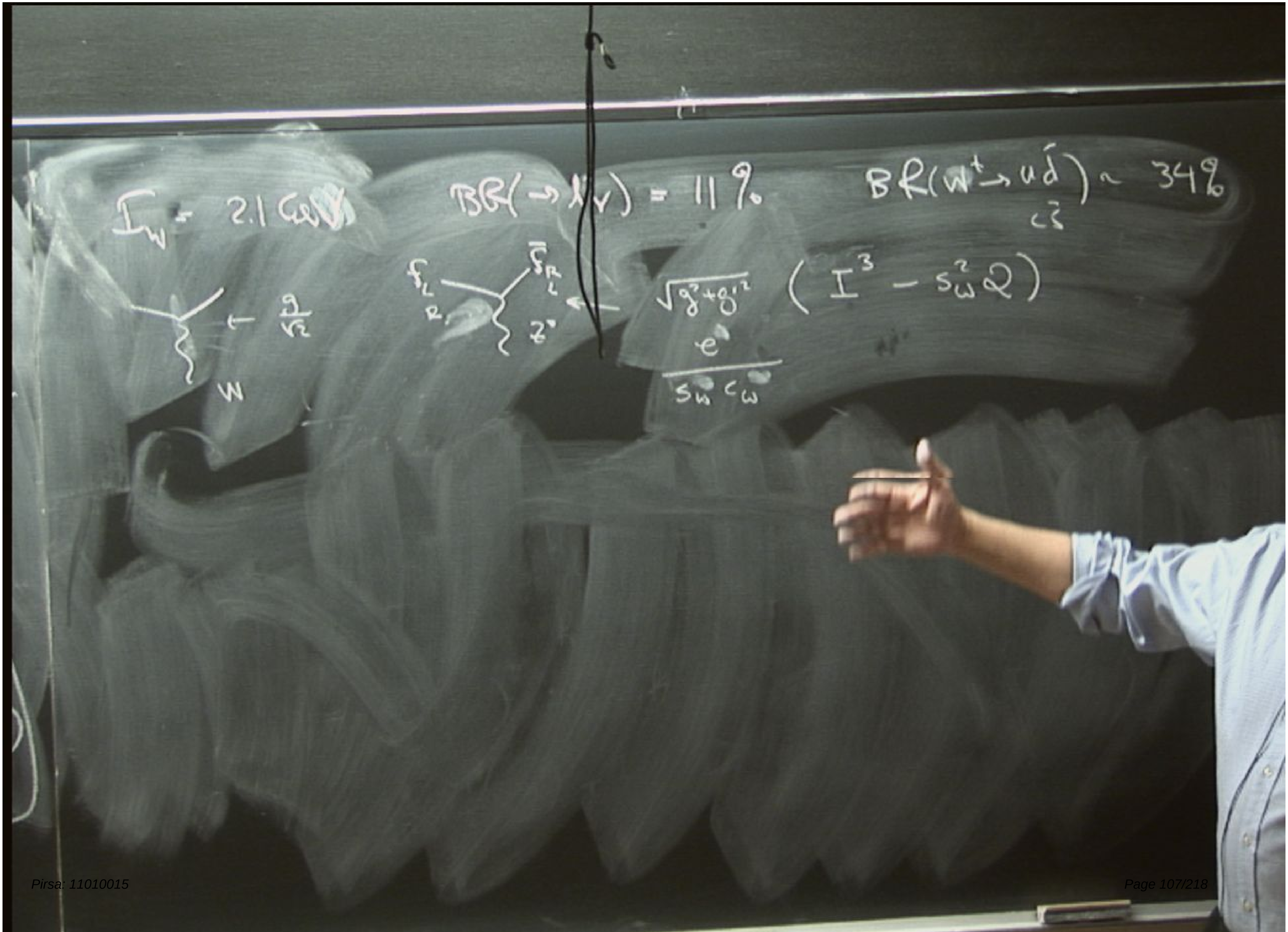
$\Gamma_W \approx 2.1\ \mathrm{GeV}$ $BR(\to \ell\nu) = 11\%$ $BR(W^+ \to u\bar{d}) \approx 34\%$

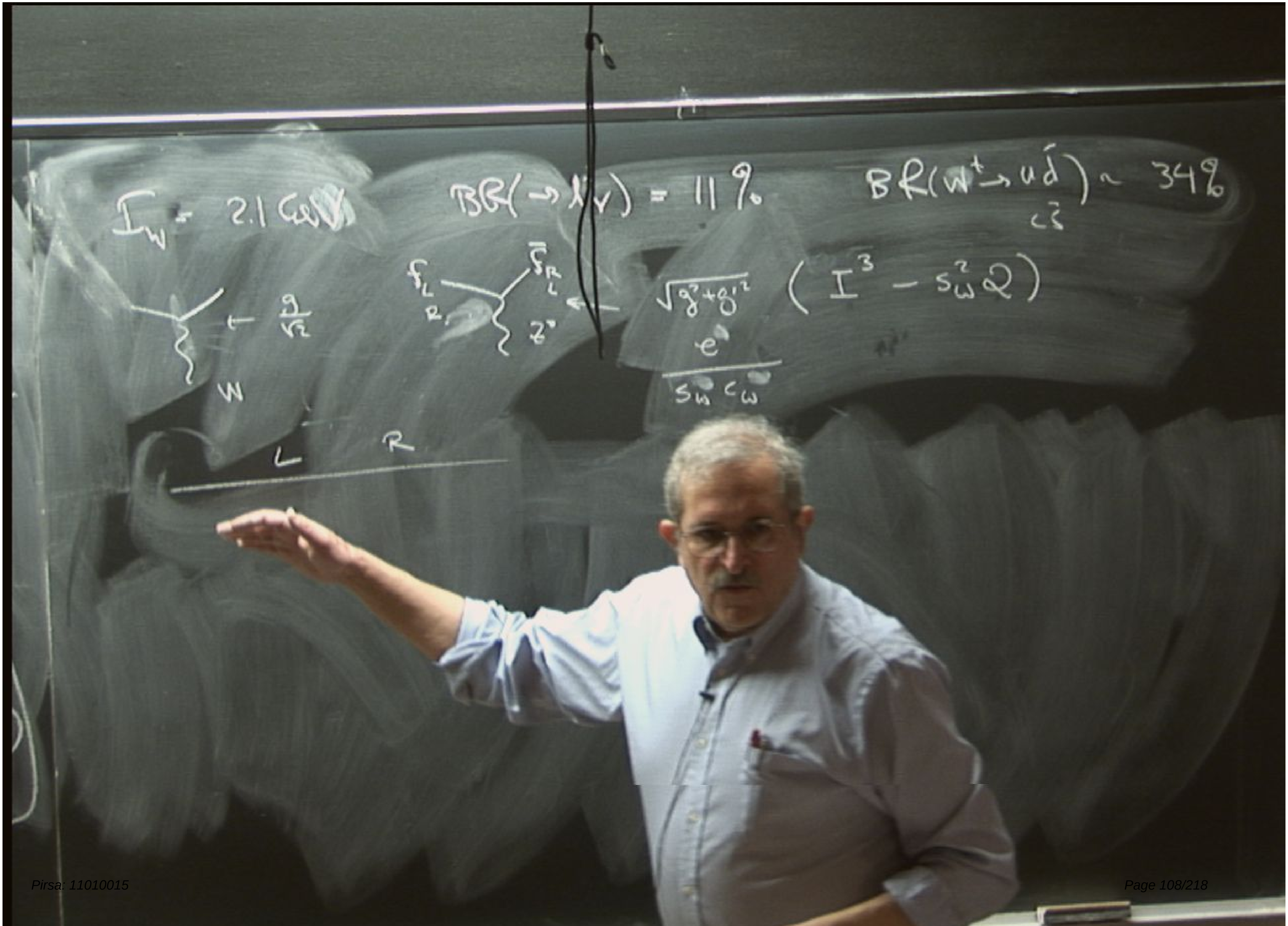
$c\bar{s}$



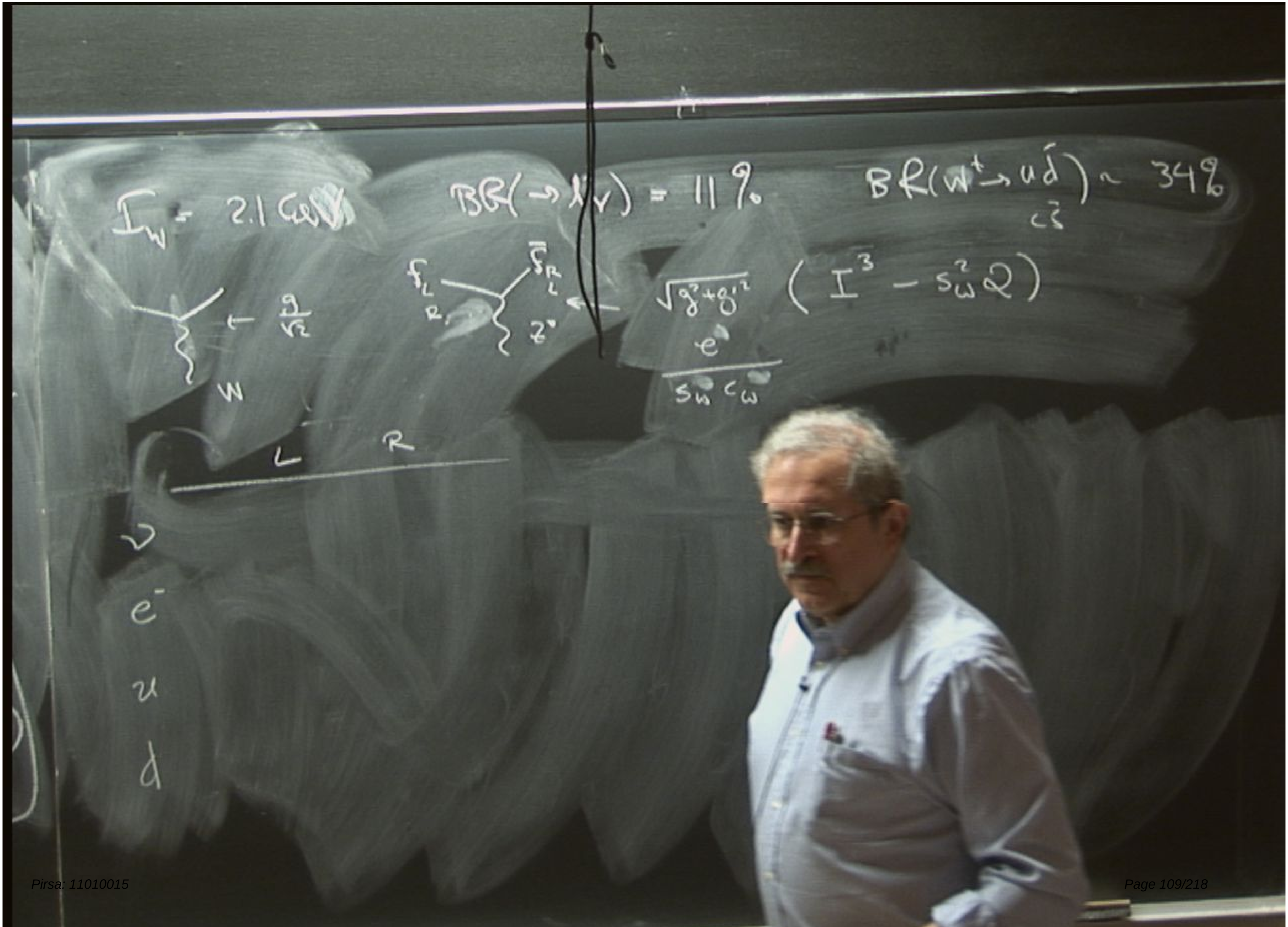
$\leftarrow \frac{g}{\sqrt{2}}$

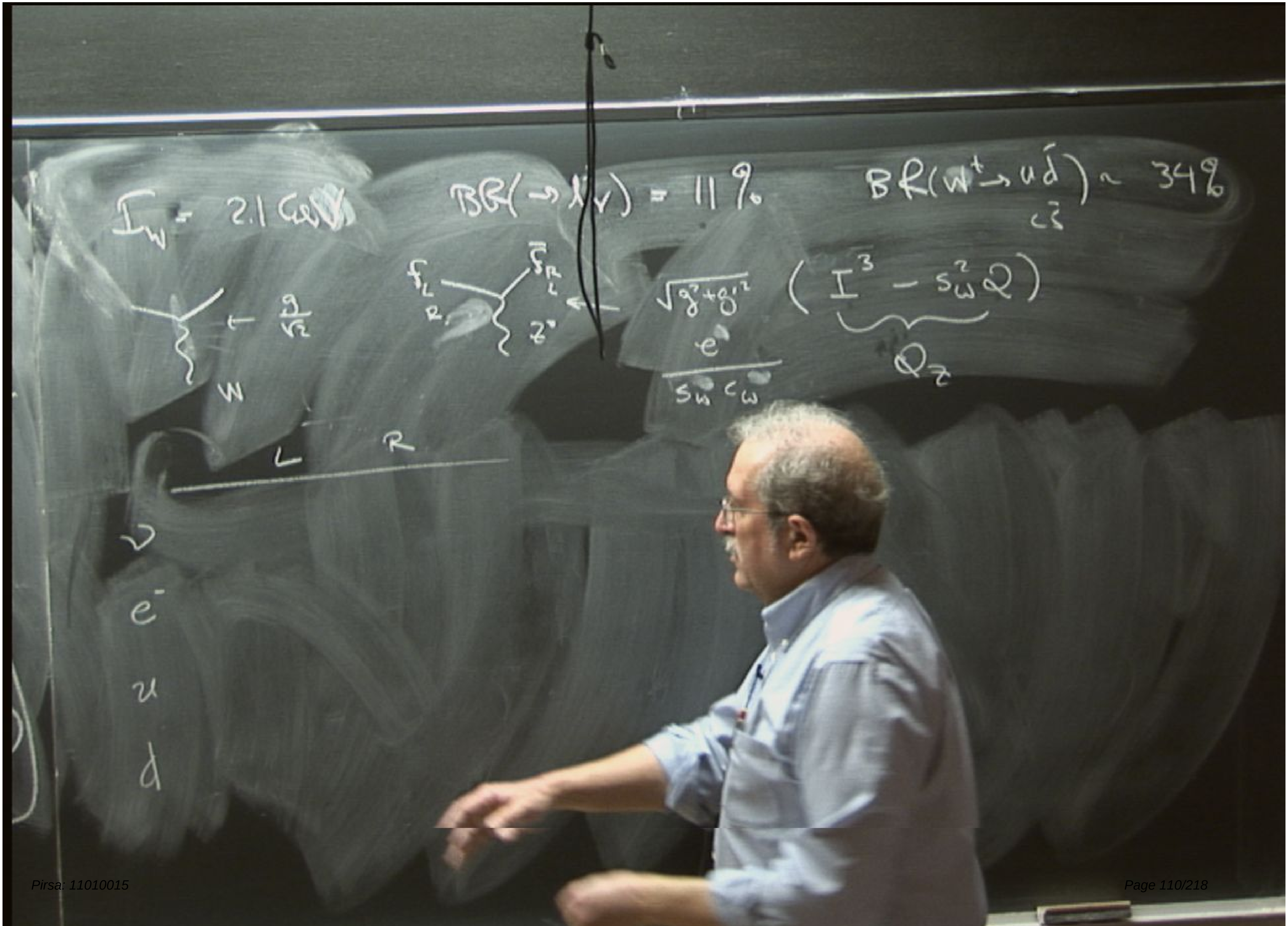
$\leftarrow \underbrace{\sqrt{g^2+g'^2}}_{\frac{e}{s_W c_W}} \left(I^3 - s_W^2 Q \right)$


Γ_W = 2.1 GeV
BR(→ lν) = 11%
BR(W⁺ → ud̄, cs̄) ≈ 34%
g/√2
W
f_L R
f̄_R L
Z°
√(g² + g'²) (I³ − s_w² Q)
e/(s_w c_w)

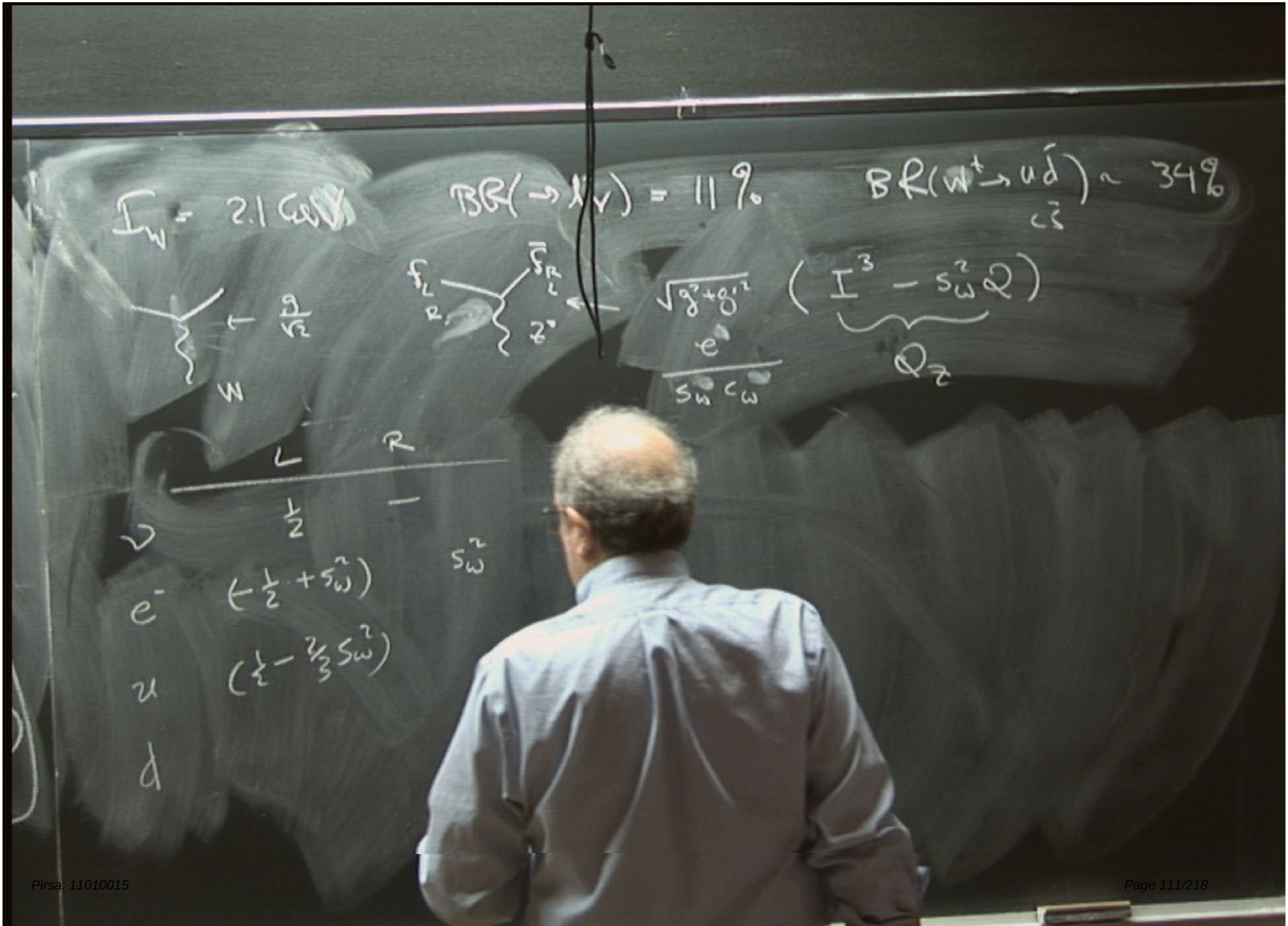


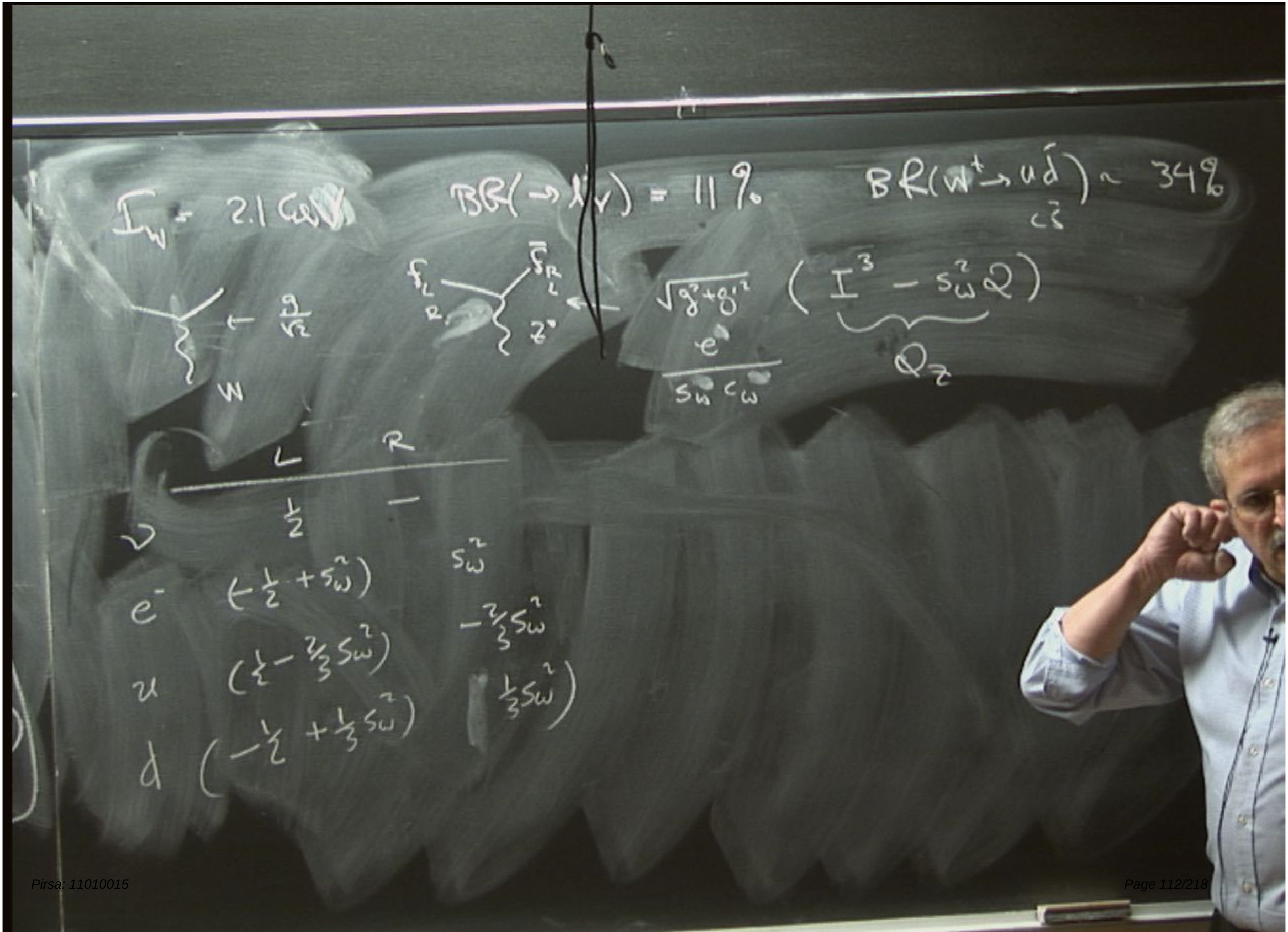
Γ_W = 2.1 GeV
BR(→ ℓν) = 11%
BR(W⁺ → u d̄) ≈ 34%
c s̄
g/√2
W
f_L R
f̄_R L
Z⁰
√(g²+g'²) (I³ − s_w² Q)
e / (s_w c_w)
L
R

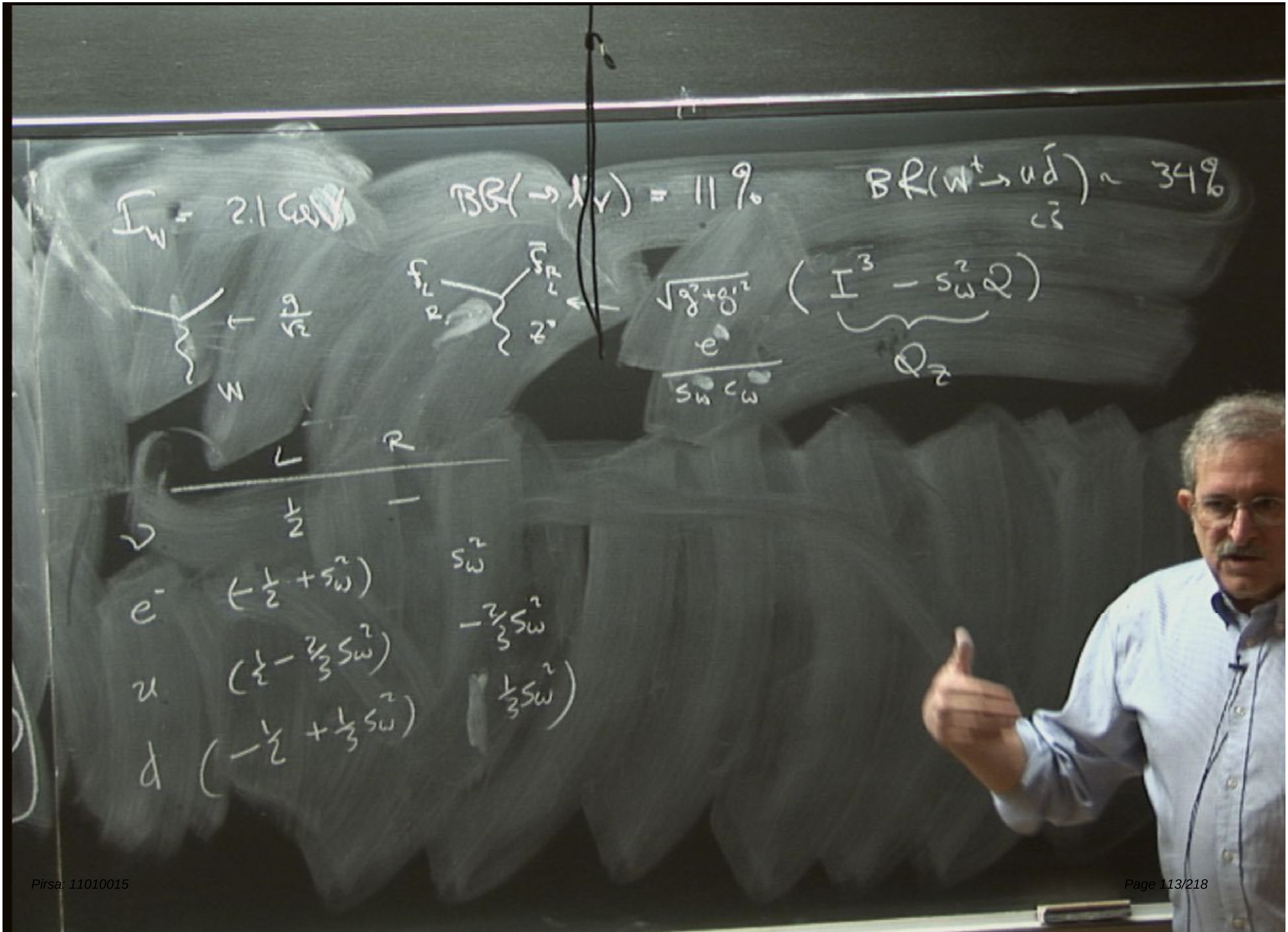

$\Gamma_W = 2.1$ GeV
$BR(\to l\nu) = 11\%$
$BR(W^+ \to u\bar{d}) \approx 34\%$
$c\bar{s}$
$\frac{g}{\sqrt{2}}$
W
f_L R
$\bar{f}_R$ L
Z^0
$\sqrt{g^2+g'^2}\,(I^3 - s_w^2 Q)$
$\frac{e}{s_w c_w}$
L R
ν
e^-
u
d

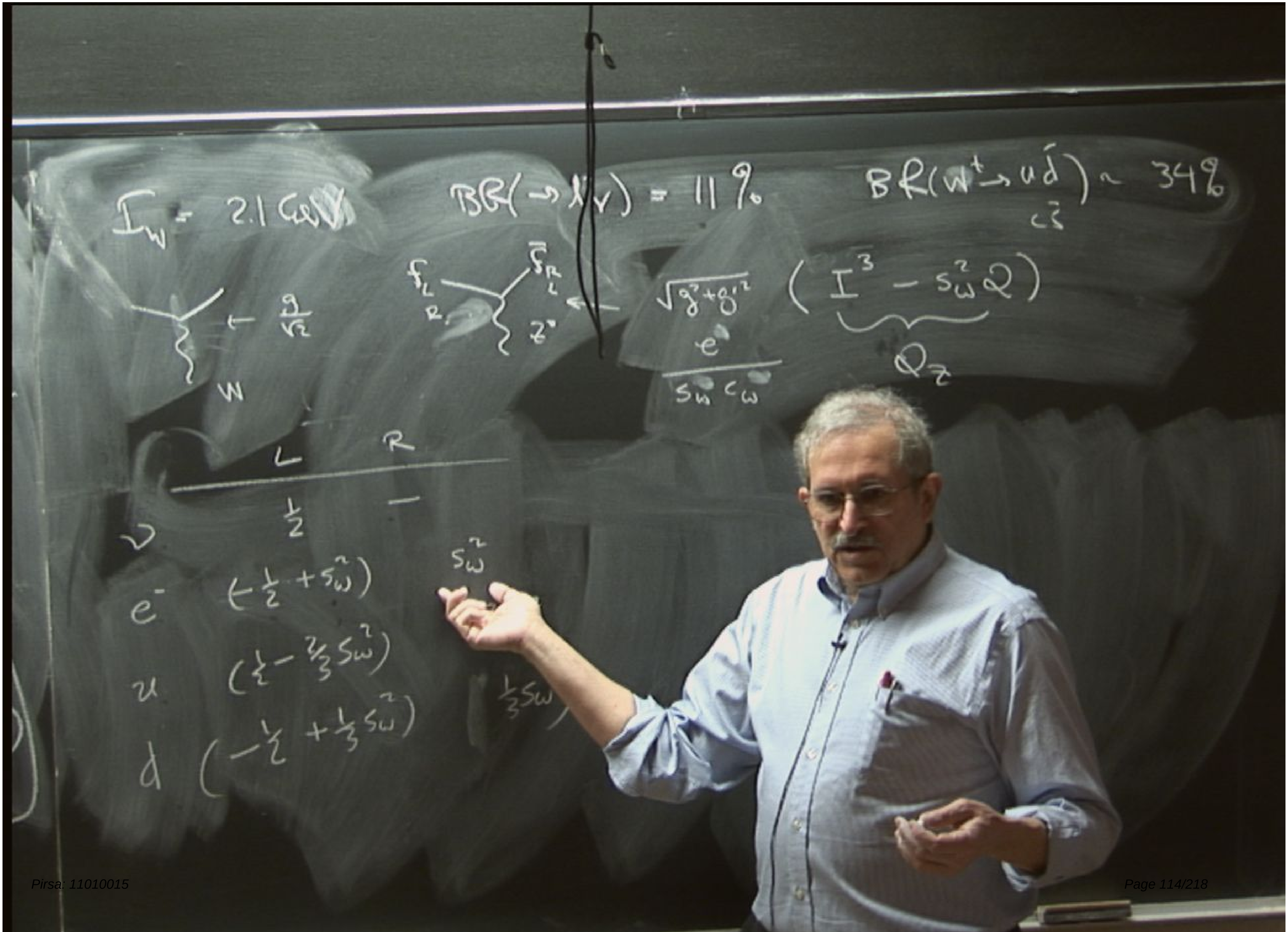


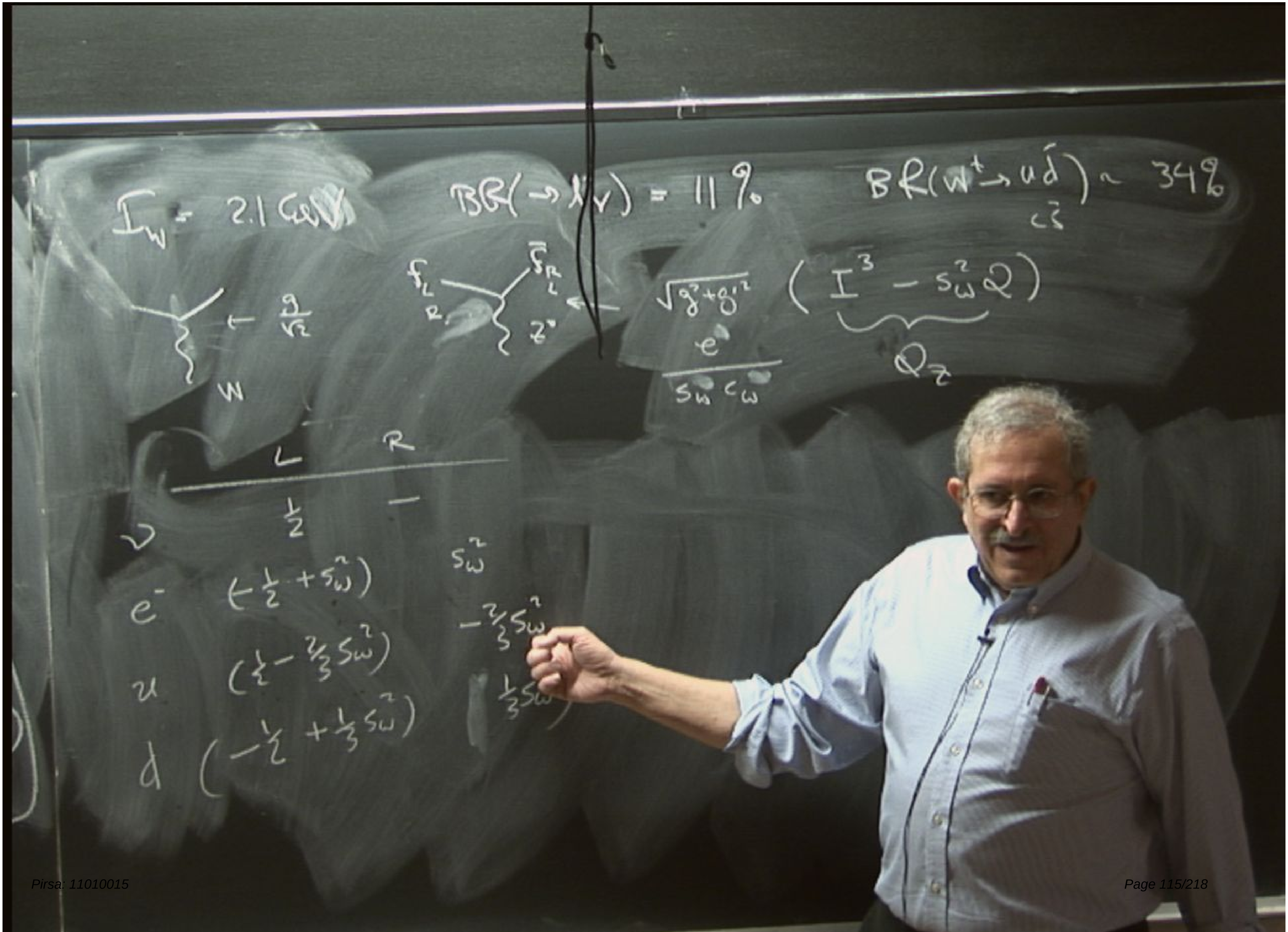
$\Gamma_W = 2.1$ GeV
$BR(\to l\nu) = 11\%$
$BR(W^+ \to u\bar{d}) \approx 34\%$
$c\bar{s}$
$\frac{g}{\sqrt{2}}$
W
f_L R
$\bar{f}_R$ L
Z^0
$\sqrt{g^2+g'^2}$
$\frac{e}{s_w c_w}$
$(\underbrace{I^3 - s_w^2 Q}_{Q_Z})$
L
R
ν
e^-
u
d

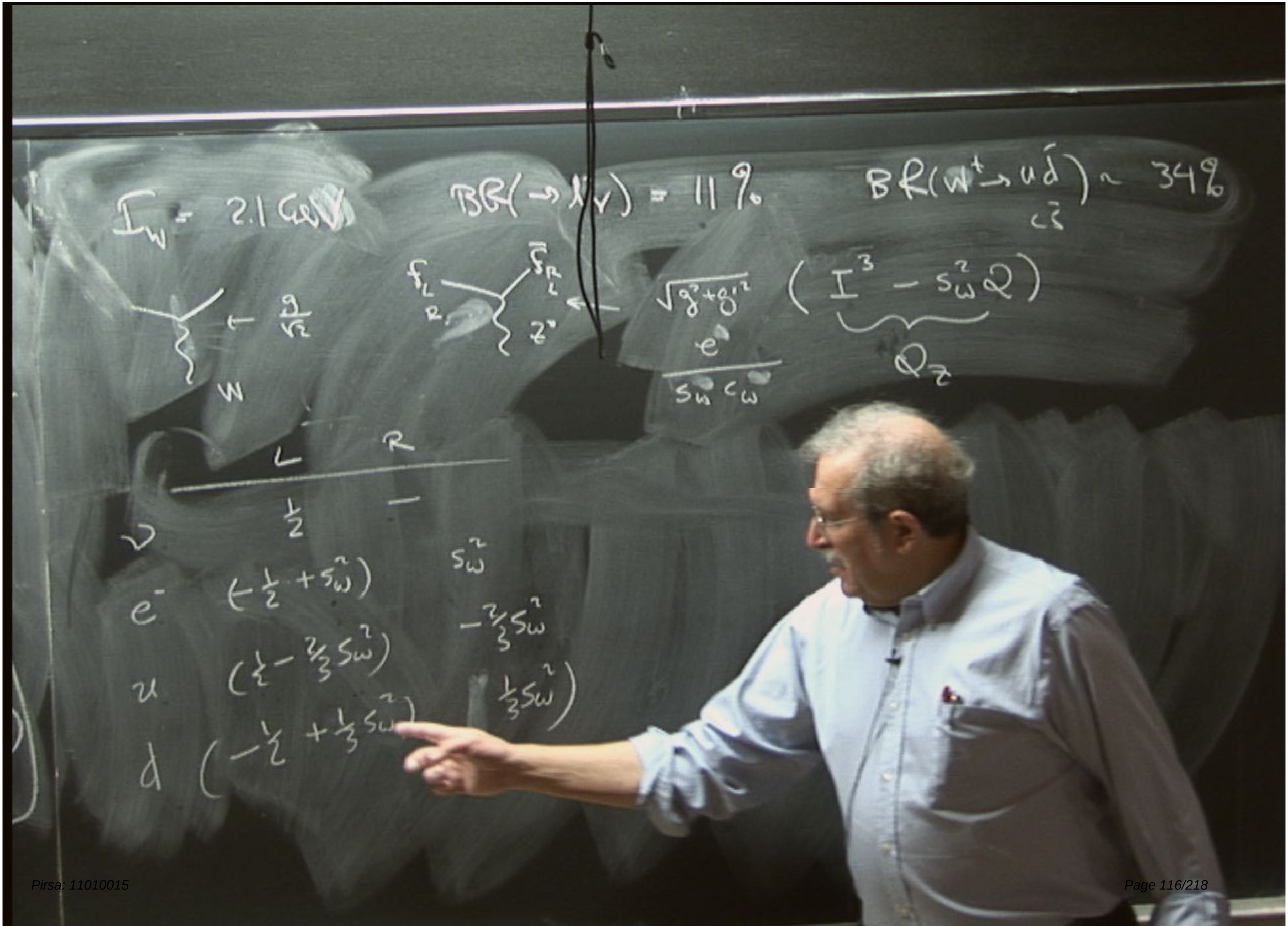

Γ_W = 2.1 GeV
BR(→ ℓν) = 11%
BR(W⁺→ ud̄) ≈ 34%
cs̄
f_L R
f̄_R L
Z°
g/√2
W
√(g²+g'²)
e / s_W c_W
(I³ − s_W² Q)
Q_Z
L
R
ν
1/2
s_W²
e⁻
(−1/2 + s_W²)
u
(1/2 − 2/3 s_W²)
d

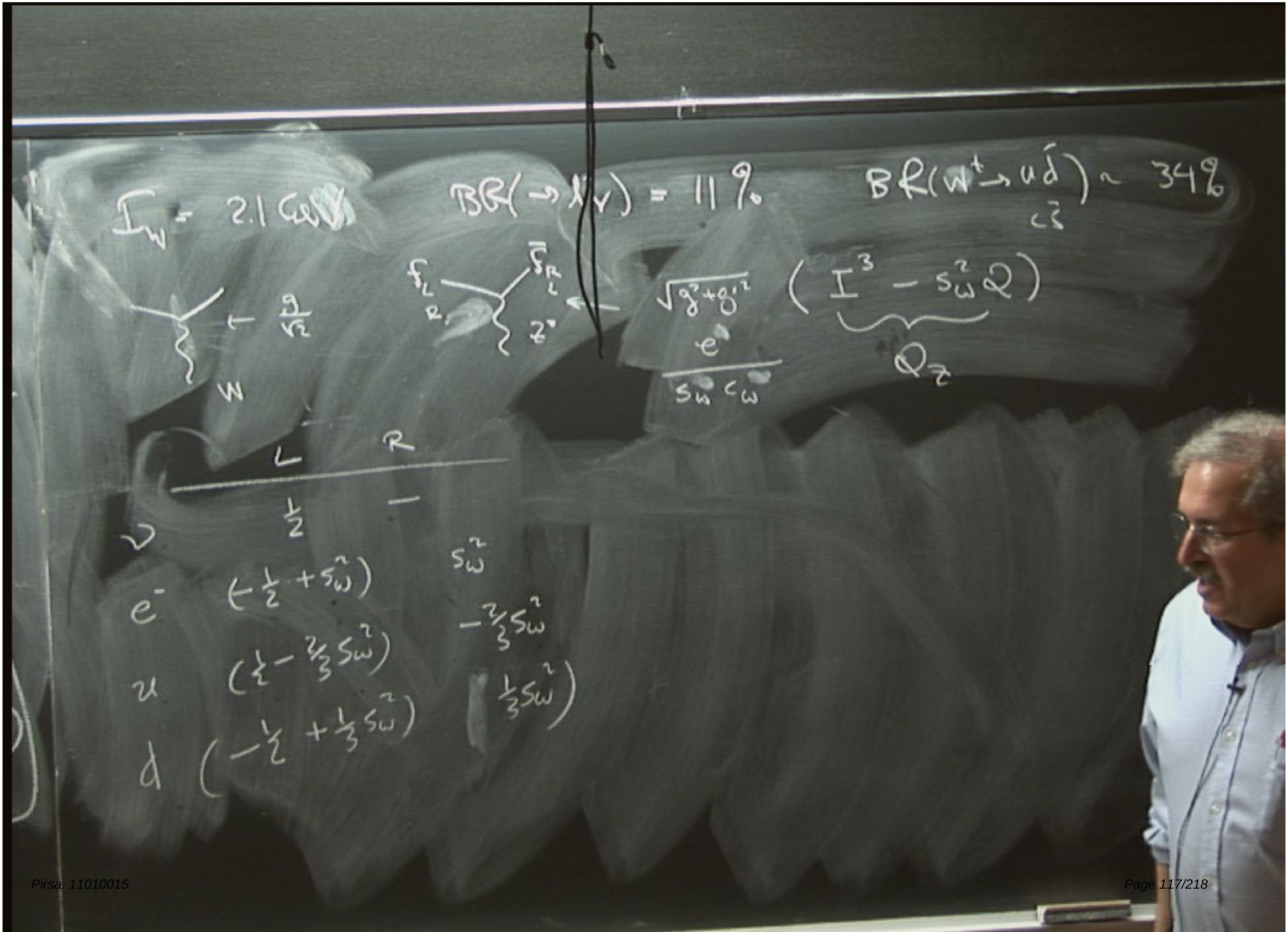

$\Gamma_W = 2.1$ GeV
$BR(\to l\nu) = 11\%$
$BR(W^+ \to u\bar{d}) \approx 34\%$
$c\bar{s}$
f_L $\bar{f}_R$
$\frac{g}{\sqrt{2}}$
W
Z^0
$\sqrt{g^2+g'^2}$
$\frac{e}{s_w c_w}$
$(\underbrace{I^3 - s_w^2 Q}_{Q_Z})$
L R
ν $\frac{1}{2}$ —
e^- $(-\frac{1}{2} + s_w^2)$ s_w^2
u $(\frac{1}{2} - \frac{2}{3}s_w^2)$ $-\frac{2}{3}s_w^2$
d $(-\frac{1}{2} + \frac{1}{3}s_w^2)$ $\frac{1}{3}s_w^2$


Γ_W = 2.1 GeV
BR(→ ℓν) = 11 %
BR(W⁺ → ud̄) ≈ 34 %
cs̄
f_L
f̄_R
g/√2
W
Z°
√(g²+g'²)
e/(s_W c_W)
(I³ − s_W² Q)
Q_Z
L
R
ν
1/2
e⁻
(−1/2 + s_W²)
s_W²
u
(1/2 − 2/3 s_W²)
−2/3 s_W²
d
(−1/2 + 1/3 s_W²)
1/3 s_W²

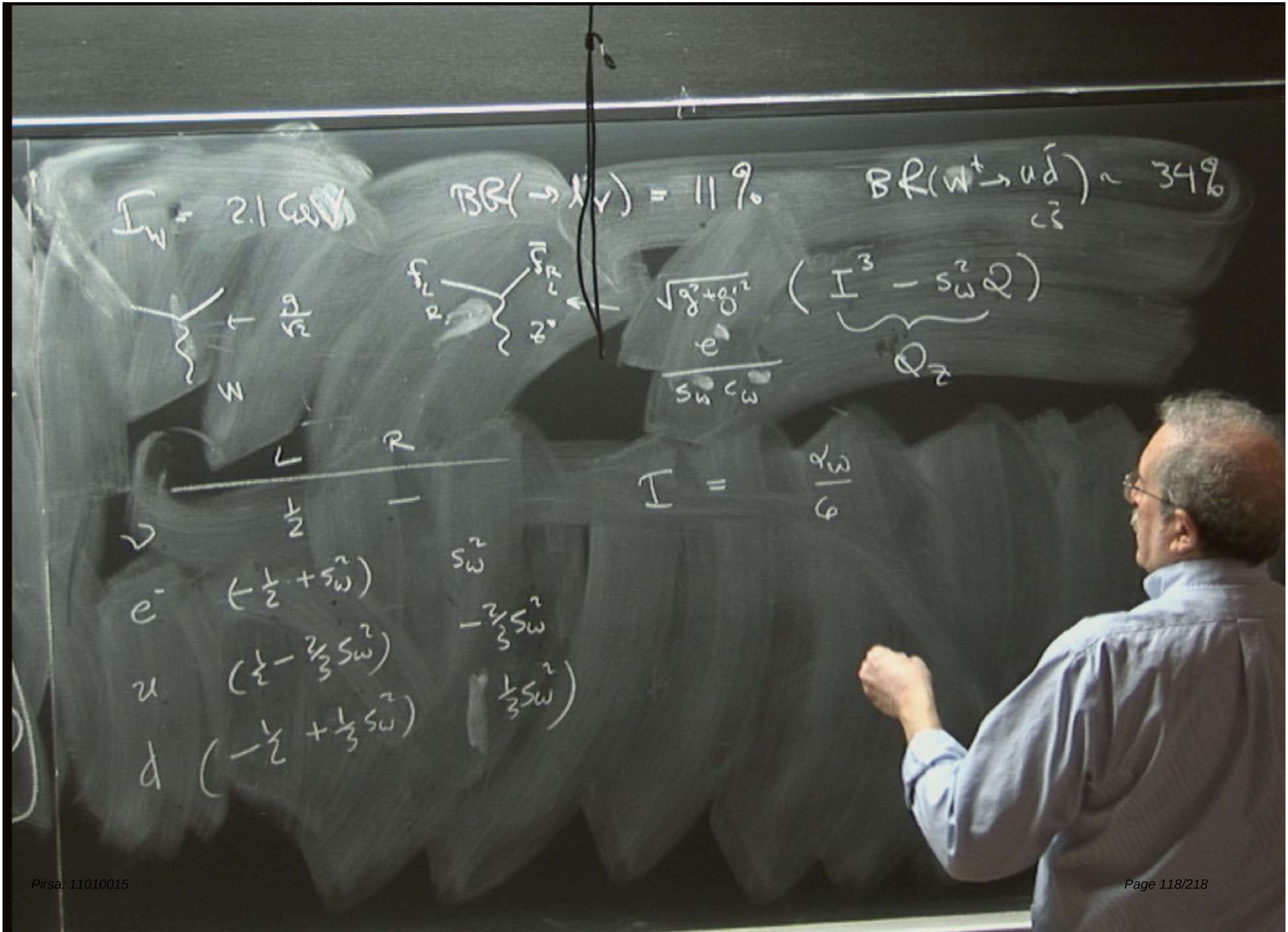

Γ_W = 2.1 GeV
BR(→ lν) = 11%
BR(W⁺ → ud̄) ≈ 34%
cs̄
g/√2
W
f_L
f̄_R
Z°
√(g²+g'²)
e/(s_W c_W)
(I³ − s_W² Q)
Q_Z
L
R
ν 1/2
e⁻ (−1/2 + s_W²)
s_W²
u (1/2 − 2/3 s_W²)
1/3 s_W
d (−1/2 + 1/3 s_W²)


Γ_W = 2.1 GeV
BR(→ ℓν) = 11 %
BR(W⁺ → u d̄) ≈ 34%
c s̄
g/√2
W
f_L
R
f̄_R
L
Z°
√(g²+g'²) (I³ − s_w² Q)
Q_Z
e/(s_w c_w)
L R
ν 1/2 —
e⁻ (−1/2 + s_w²) s_w²
u (1/2 − 2/3 s_w²) −2/3 s_w²
d (−1/2 + 1/3 s_w²) 1/3 s_w²


Γ_W = 2.1 GeV
BR(→ lν) = 11%
BR(W⁺→ ud̄) ≈ 34%
cs̄
g/√2
W
f_L
R
f̄_R
L
Z⁰
√(g²+g'²)
e / (s_W c_W)
(I³ − s_W² Q)
Q_Z
L
R
ν
1/2
e⁻
(−1/2 + s_W²)
s_W²
u
(1/2 − 2/3 s_W²)
−2/3 s_W²
d
(−1/2 + 1/3 s_W²)
1/3 s_W²

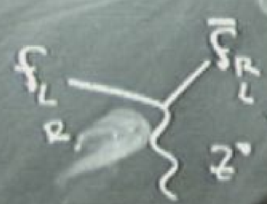


$\Gamma_W = 2.1$ GeV
$BR(\to \ell\nu) = 11\%$
$BR(W^+ \to u\bar{d}) \approx 34\%$
$c\bar{s}$
$\frac{g}{\sqrt{2}}$
W
f_L R, $\bar{f}_R$ L, Z^0
$\frac{\sqrt{g^2+g'^2}}{e} \cdot \frac{e}{s_W c_W}$
$\underbrace{(I^3 - s_W^2 Q)}_{Q_Z}$
L R
ν $\frac{1}{2}$ —
e^- $(-\frac{1}{2} + s_W^2)$ s_W^2
u $(\frac{1}{2} - \frac{2}{3} s_W^2)$ $-\frac{2}{3} s_W^2$
d $(-\frac{1}{2} + \frac{1}{3} s_W^2)$ $\frac{1}{3} s_W^2$


Γ_W = 2.1 GeV
BR(→ ℓν) = 11%
BR(W⁺ → ud̄) ≈ 34%
cs̄
g/√2
W
f_L
f̄_R
Z°
√(g²+g'²)
e
s_W c_W
(I³ − s_W² Q)
Q_Z
L
R
1/2
ν
e⁻
(−1/2 + s_W²)
s_W²
u
(1/2 − 2/3 s_W²)
−2/3 s_W²
d
(−1/2 + 1/3 s_W²)
1/3 s_W²
Γ =
α_W / 6

$\Gamma_W = 2.1\ \mathrm{GeV}$ $\qquad BR(\to \ell\nu) = 11\%$ $\qquad BR(W^+ \to u\bar{d}, c\bar{s}) \approx 34\%$

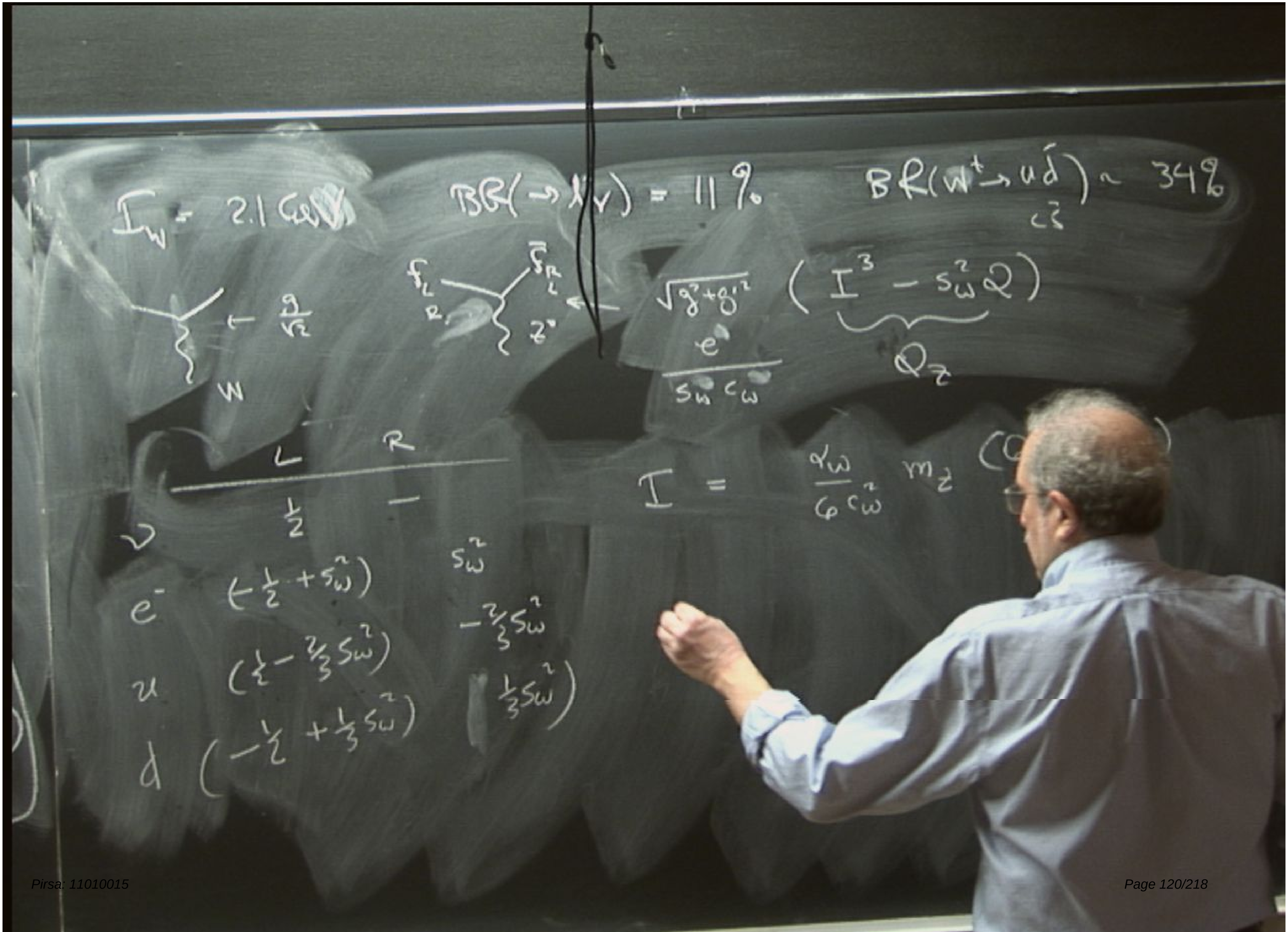
$W \qquad \leftarrow \frac{g}{\sqrt{2}}$



$f_{L,R}\ \ \bar{f}_{R,L}\ \ Z^0 \leftarrow \sqrt{g^2+g'^2} = \frac{e}{s_w c_w}\ \underbrace{(I^3 - s_w^2 Q)}_{Q_Z}$

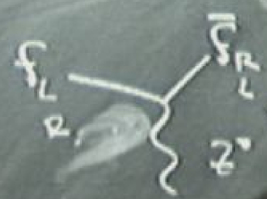
	L	R
ν	$\frac{1}{2}$	—
e^-	$(-\frac{1}{2} + s_w^2)$	s_w^2
u	$(\frac{1}{2} - \frac{2}{3} s_w^2)$	$-\frac{2}{3} s_w^2$
d	$(-\frac{1}{2} + \frac{1}{3} s_w^2)$	$\frac{1}{3} s_w^2$

$$\Gamma = \frac{\alpha_w}{6 c_w^2} m_Z$$


$\Gamma_W = 2.1$ GeV
BR($\to l\nu$) = 11%
BR($W^+ \to u\bar{d}$) ≈ 34%
$c\bar{s}$
$\frac{g}{\sqrt{2}}$
W
f_L $\bar{f}_R$
Z^0
$\frac{\sqrt{g^2+g'^2}}{e}$
$\frac{e}{s_w c_w}$
$(I^3 - s_w^2 Q)$
Q_Z
L R
ν $\frac{1}{2}$ —
e^- $(-\frac{1}{2} + s_w^2)$ s_w^2
u $(\frac{1}{2} - \frac{2}{3}s_w^2)$ $-\frac{2}{3}s_w^2$
d $(-\frac{1}{2} + \frac{1}{3}s_w^2)$ $\frac{1}{3}s_w^2$
$\Gamma = \frac{\alpha_w}{6 c_w^2} m_Z$

$\Gamma_W = 2.1\ \mathrm{GeV}$ $\quad BR(\to \ell\nu) = 11\%$ $\quad BR(W^+ \to u\bar{d},\ c\bar{s}) \approx 34\%$

$\leftarrow \frac{g}{\sqrt{2}}$

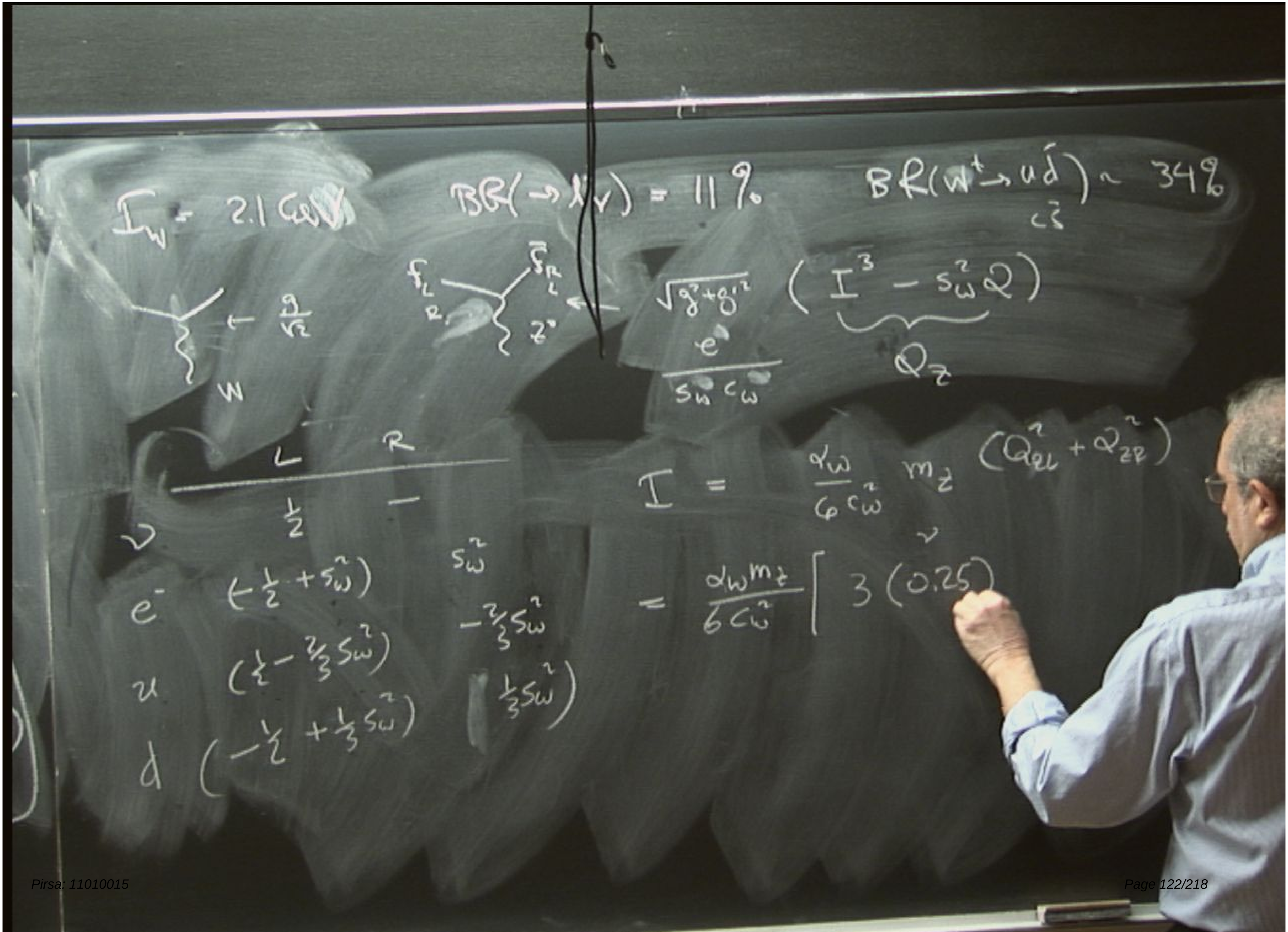


$$\leftarrow \sqrt{g^2+g'^2} = \frac{e}{s_w c_w} \left(\underbrace{I^3 - s_w^2 Q}_{Q_Z} \right)$$

	L	R
ν	$\frac{1}{2}$	—
e^-	$\left(-\frac{1}{2} + s_w^2\right)$	s_w^2
u	$\left(\frac{1}{2} - \frac{2}{3} s_w^2\right)$	$-\frac{2}{3} s_w^2$
d	$\left(-\frac{1}{2} + \frac{1}{3} s_w^2\right)$	$\frac{1}{3} s_w^2$

$$\Gamma = \frac{\alpha_w}{6 c_w^2}\, m_Z \left(Q_{ZL}^2 + Q_{ZR}^2\right)$$

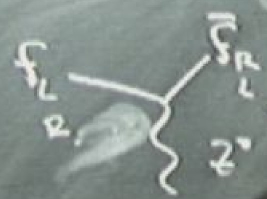
$$=$$



$\Gamma_W = 2.1\ \mathrm{GeV}$
$BR(\to \ell\nu) = 11\%$
$BR(W^+ \to u\bar{d}, c\bar{s}) \approx 34\%$
$\frac{g}{\sqrt{2}}$
W
f_L R, $\bar{f}_R$ L, Z^0
$\sqrt{g^2+g'^2}\,(\underbrace{I^3 - s_w^2 Q}_{Q_Z})$
$\frac{e}{s_w c_w}$
L R
ν $\frac{1}{2}$ —
e^- $(-\frac{1}{2} + s_w^2)$ s_w^2
u $(\frac{1}{2} - \frac{2}{3}s_w^2)$ $-\frac{2}{3}s_w^2$
d $(-\frac{1}{2} + \frac{1}{3}s_w^2)$ $\frac{1}{3}s_w^2$
$\Gamma = \frac{\alpha_w}{6c_w^2} m_Z (Q_{ZL}^2 + Q_{ZR}^2)$
$= \frac{\alpha_w m_Z}{6c_w^2}\left[\, 3\,(0.25)\right.$

$\Gamma_W = 2.1\ \mathrm{GeV}$ $\qquad BR(\to l\nu) = 11\%$ $\qquad BR(W^+ \to u\bar{d},\ c\bar{s}) \approx 34\%$

$\leftarrow \frac{g}{\sqrt{2}}$



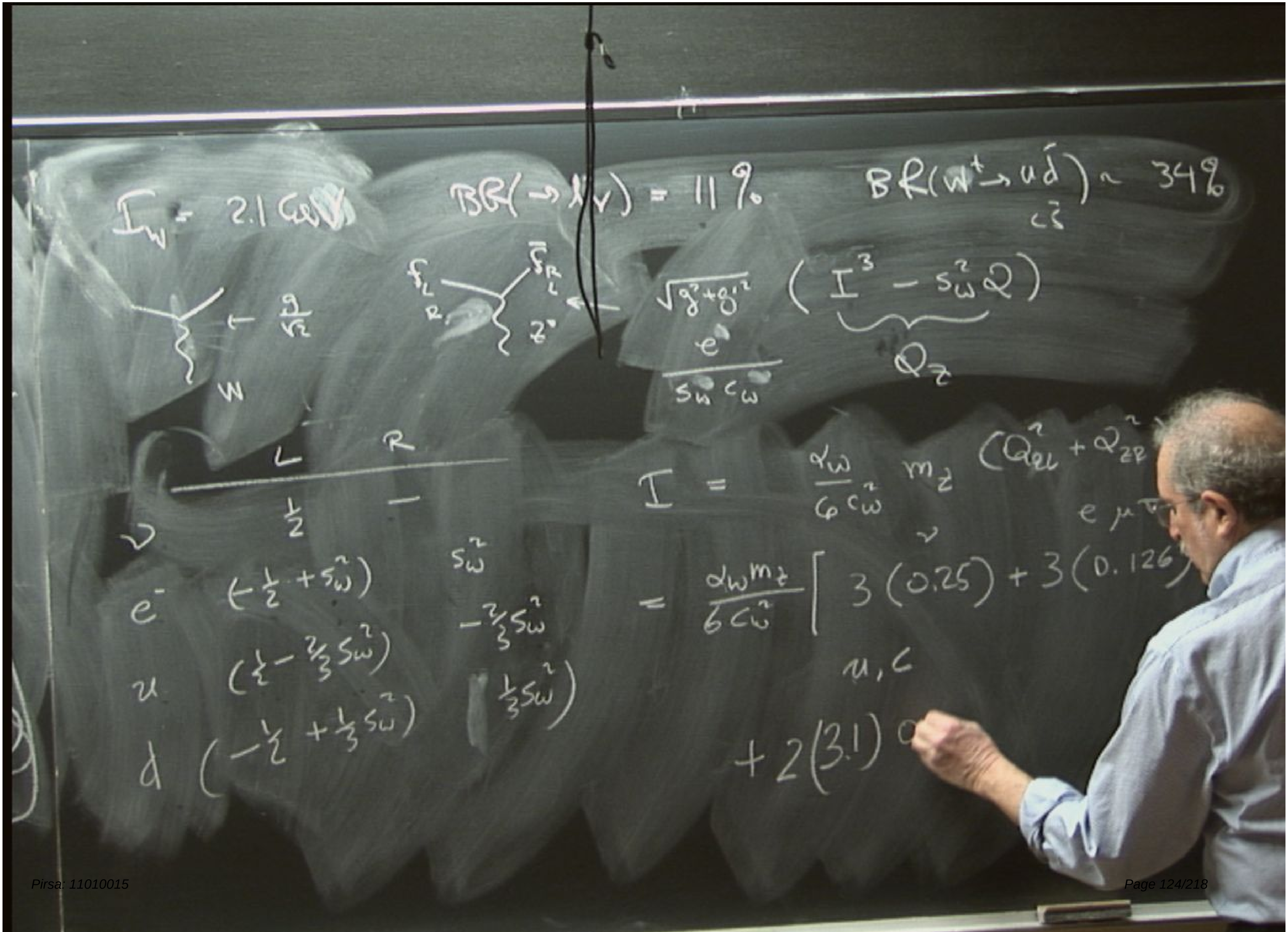
$\leftarrow \sqrt{g^2+g'^2} = \frac{e}{s_W c_W}\ \underbrace{\left(I^3 - s_W^2 Q\right)}_{Q_Z}$

	L	R
ν	$\frac{1}{2}$	—
e^-	$(-\frac{1}{2} + s_W^2)$	s_W^2
u	$(\frac{1}{2} - \frac{2}{3} s_W^2)$	$-\frac{2}{3} s_W^2$
d	$(-\frac{1}{2} + \frac{1}{3} s_W^2)$	$\frac{1}{3} s_W^2)$

$$\Gamma = \frac{\alpha_W}{6 c_W^2}\, m_Z \left(Q_{ZL}^2 + Q_{ZR}^2\right)$$

$$\nu$$

$$= \frac{\alpha_W m_Z}{6 c_W^2}\left[\, 3(0.25) + 3(0. \ldots\right.$$

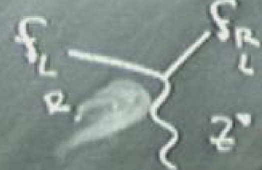

Γ_W = 2.1 GeV
BR(→ lν) = 11%
BR(W⁺ → u d̄) ≈ 34%
c s̄
g/√2
W
f_L, f̄_R
Z°
√(g²+g'²) (I³ − s_w² Q)
Q_Z
e / (s_w c_w)
L R
ν 1/2 —
e⁻ (−1/2 + s_w²) s_w²
u (1/2 − 2/3 s_w²) −2/3 s_w²
d (−1/2 + 1/3 s_w²) 1/3 s_w²
Γ = α_w/(6 c_w²) m_Z (Q_ZL² + Q_ZR²)
e μ τ
ν
= α_w m_Z/(6 c_w²) [3(0.25) + 3(0.126)
u, c
+ 2(3.1) 0

$\Gamma_W = 2.1\ \text{GeV}$ $\quad BR(\to \ell\nu) = 11\%$ $\quad BR(W^+ \to u\bar{d}) \approx 34\%$

$\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad c\bar{s}$

$\leftarrow \frac{g}{\sqrt{2}}$

W



$\leftarrow \sqrt{g^2+g'^2} = \dfrac{e}{s_w c_w}\left(\underbrace{I^3 - s_w^2 Q}_{Q_Z}\right)$

	L	R
ν	$\frac{1}{2}$	—
e^-	$\left(-\frac{1}{2} + s_w^2\right)$	s_w^2
u	$\left(\frac{1}{2} - \frac{2}{3}s_w^2\right)$	$-\frac{2}{3}s_w^2$
d	$\left(-\frac{1}{2} + \frac{1}{3}s_w^2\right)$	$\frac{1}{3}s_w^2$

$$\Gamma = \frac{\alpha_w}{6 c_w^2} m_Z \left(Q_{ZL}^2 + Q_{ZR}^2\right)$$

$$= \frac{\alpha_w m_Z}{6 c_w^2}\Big[\, \underset{\nu}{3(0.25)} + \underset{e\,\mu\,\tau}{3(0.126)} + \underset{u,c}{2(3.1)(0.144)} + $$

$\Gamma_W = 2.1\ \text{GeV}$ $\quad BR(\to l\nu) = 11\%$ $\quad BR(W^+ \to u\bar{d},\ c\bar{s}) \approx 34\%$

$\leftarrow \frac{g}{\sqrt{2}}$

$\leftarrow \sqrt{g^2+g'^2} \quad \frac{e}{s_w c_w} \left(\underbrace{I^3 - s_w^2 Q}_{Q_Z} \right)$

	L	R
ν	$\frac{1}{2}$	—
e^-	$(-\frac{1}{2} + s_w^2)$	s_w^2
u	$(\frac{1}{2} - \frac{2}{3} s_w^2)$	$-\frac{2}{3} s_w^2$
d	$(-\frac{1}{2} + \frac{1}{3} s_w^2)$	$\frac{1}{3} s_w^2$

$$\Gamma = \frac{\alpha_w}{6 c_w^2} m_Z \left(Q_{ZL}^2 + Q_{ZR}^2 \right)$$

$$= \frac{\alpha_w m_Z}{6 c_w^2} \Big[\underset{\nu}{3(0.25)} + \underset{e\,\mu\,\tau}{3(0.126)}$$

$$\underset{u,c}{+ 2(3.1)(0.144)} + \underset{d\,s\,b}{3(3.1)}$$

$\Gamma_W = 2.1\ \mathrm{GeV}$ $\quad BR(\to \ell \bar{\nu}) = 11\%$ $\quad BR(W^+ \to u\bar{d}, c\bar{s}) \approx 34\%$

 $\leftarrow \frac{g}{\sqrt{2}}$

W

f_L, R, $\bar{f}_R$, L, Z^0

 $\leftarrow \sqrt{g^2+g'^2} = \frac{e}{s_w c_w}$

$$\underbrace{\left(I^3 - s_w^2 Q\right)}_{Q_Z}$$

	L	R
ν	$\frac{1}{2}$	—
e^-	$\left(-\frac{1}{2} + s_w^2\right)$	s_w^2
u	$\left(\frac{1}{2} - \frac{2}{3} s_w^2\right)$	$-\frac{2}{3} s_w^2$
d	$\left(-\frac{1}{2} + \frac{1}{3} s_w^2\right)$	$\frac{1}{3} s_w^2$

$$\Gamma = \frac{\alpha_w}{6 c_w^2} m_Z \left(Q_{ZL}^2 + Q_{ZR}^2\right)$$

$$= \frac{\alpha_w m_Z}{6 c_w^2}\Big[\underset{\nu}{3(0.25)} + \underset{e\,\mu\,\tau}{3(0.126)} + \underset{u,c}{2(3.1)(0.144)} + \underset{d\,s\,b}{3(3.1)(0.185)}\Big]$$

SU

$\Gamma = 249 \text{ GeV}$

$BR(\to \nu\bar{\nu}) = 6.7\%$

$BR \to \mu^+\mu^- \cdot 3.1\%$

Γ = 249 GeV

$BR(\to \nu\bar{\nu}) = 6.7\%$

$BR \to \mu^+\mu^-$ · 3.3%

$BR(\longrightarrow c\bar{c}) =$

$\Gamma = 249$ GeV

$BR(\to \nu\bar{\nu}) = 6.7\%$ $BR \to \mu^{\pm}\mu^{-} \cdot 3.3\%$

$BR(\to c\bar{c}) = 11.9\%$ $BR(\to d\bar{d}) = 1$

Su

$\Gamma = 249 \text{ GeV}$

$BR \rightarrow \mu^{+}\mu^{-} \cdot 3.3\%$

$BR(\rightarrow \nu\bar{\nu}) = 6.7\%$

$BR(\rightarrow c\bar{c}) = 11.9\%$

$BR(\rightarrow d\bar{d}) = 15.3\%$

$BR(\rightarrow b\bar{b}) - 2\%$

$\Gamma = 249$ GeV

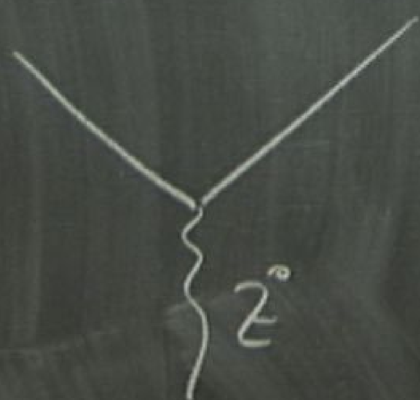
$BR(\to \nu\bar{\nu}) = 6.7\%$

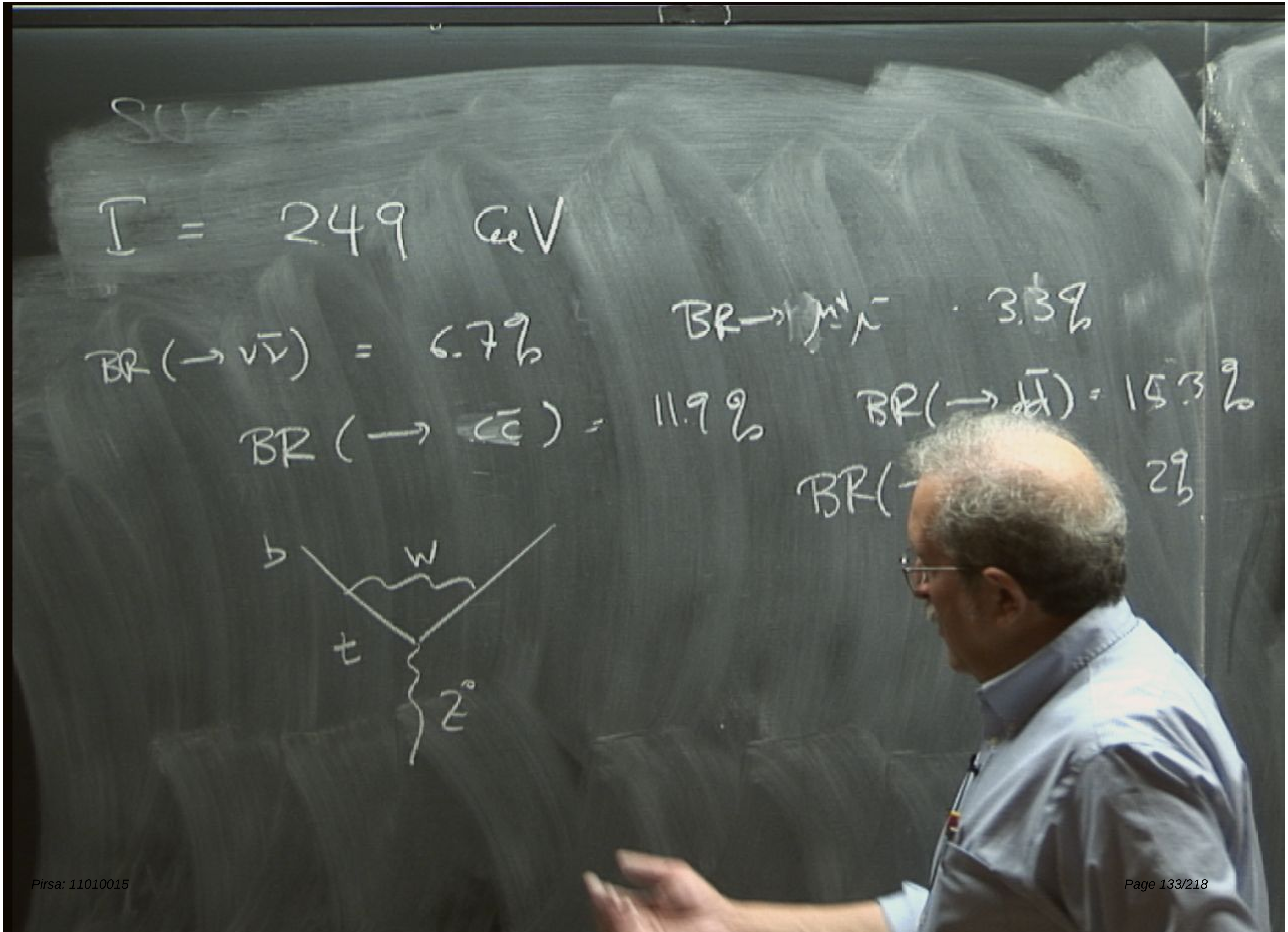
$BR \to \mu^+\mu^- \cdot 3.3\%$

$BR(\to c\bar{c}) = 11.9\%$

$BR(\to d\bar{d}) = 15.3\%$

$BR(\to b\bar{b}) - 2\%$




Γ = 249 GeV
BR(→ νν̄) = 6.7%
BR → μ⁺μ⁻ 3.3%
BR(→ cc̄) = 11.9%
BR(→ dd̄) = 15.3%
BR(2%
b
W
t
Z°

$\Gamma = 249$ GeV

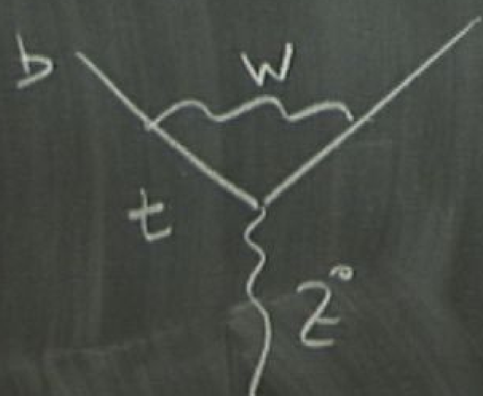
$BR(\to \nu\bar{\nu}) = 6.7\%$

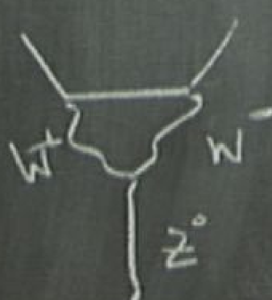
$BR \to \mu^+\mu^-$ · 3.3%

$BR(\to c\bar{c}) = 11.9\%$

$BR(\to d\bar{d}) = 15.3\%$

$BR(\to b\bar{b})$ —





$\Gamma = 249$ GeV

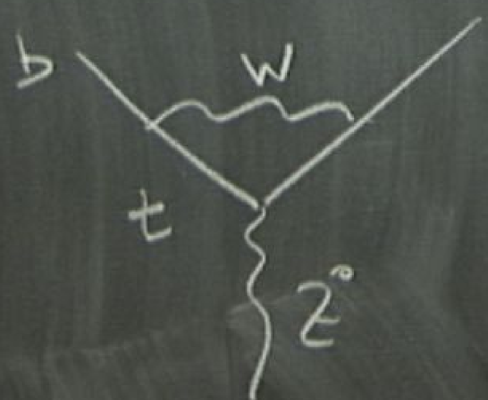
$BR(\to \nu\bar{\nu}) = 6.7\%$

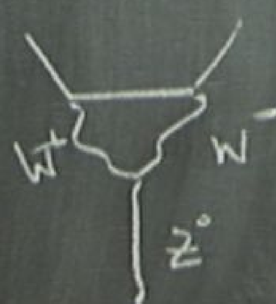
$BR \to \mu^+\mu^- \cdot 3.3\%$

$BR(\to c\bar{c}) = 11.9\%$

$BR(\to d\bar{d}) = 15.3\%$

$BR(\to b\bar{b}) - 2\%$





$\Gamma = 249\ \mathrm{GeV}$

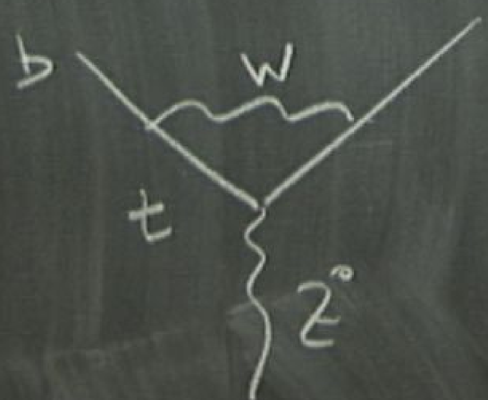
$BR(\to \nu\bar{\nu}) = 6.7\%$

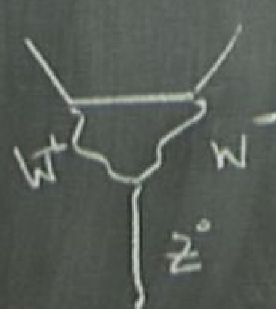
$BR \to \mu^+\mu^- \cdot 3.3\%$

$BR(\to c\bar{c}) = 11.9\%$

$BR(\to d\bar{d}) = 15.3\%$

$BR(\to b\bar{b}) - 2\%$





$$R_b = \frac{\Gamma(\to b\bar{b})}{\Gamma(\to \text{hadr})}$$

$$= 0.216$$

$\Gamma = 249$ GeV

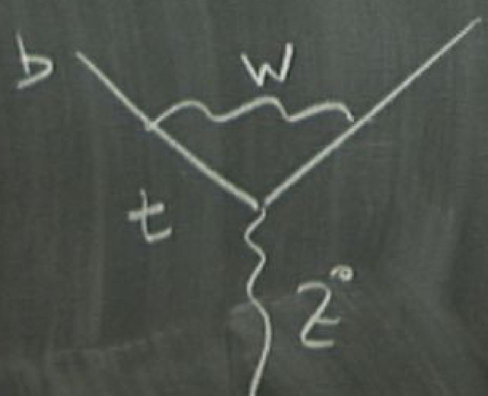
$BR(\to \nu\bar{\nu}) = 6.7\%$

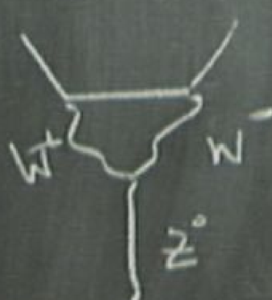
$BR \to \mu^+\mu^- \cdot 3.3\%$

$BR(\to c\bar{c}) = 11.9\%$

$BR(\to d\bar{d}) = 15.3\%$

$BR(\to b\bar{b}) - 2\%$





$$R_b = \frac{\Gamma(\to b\bar{b})}{\Gamma(\to \text{hadr.})}$$

$= 0.216$

(0.220)

$\Gamma = 249$ GeV

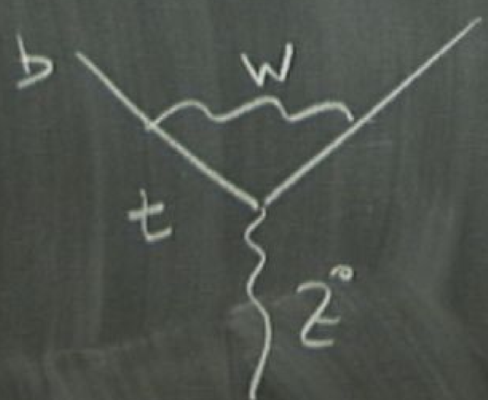
$BR(\to \nu\bar{\nu}) = 6.7\%$

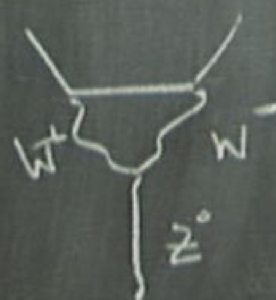
$BR \to \mu^+\mu^- \cdot 3.3\%$

$BR(\to c\bar{c}) = 11.9\%$

$BR(\to d\bar{d}) = 15.3\%$

$BR(\to b\bar{b}) - 2\%$

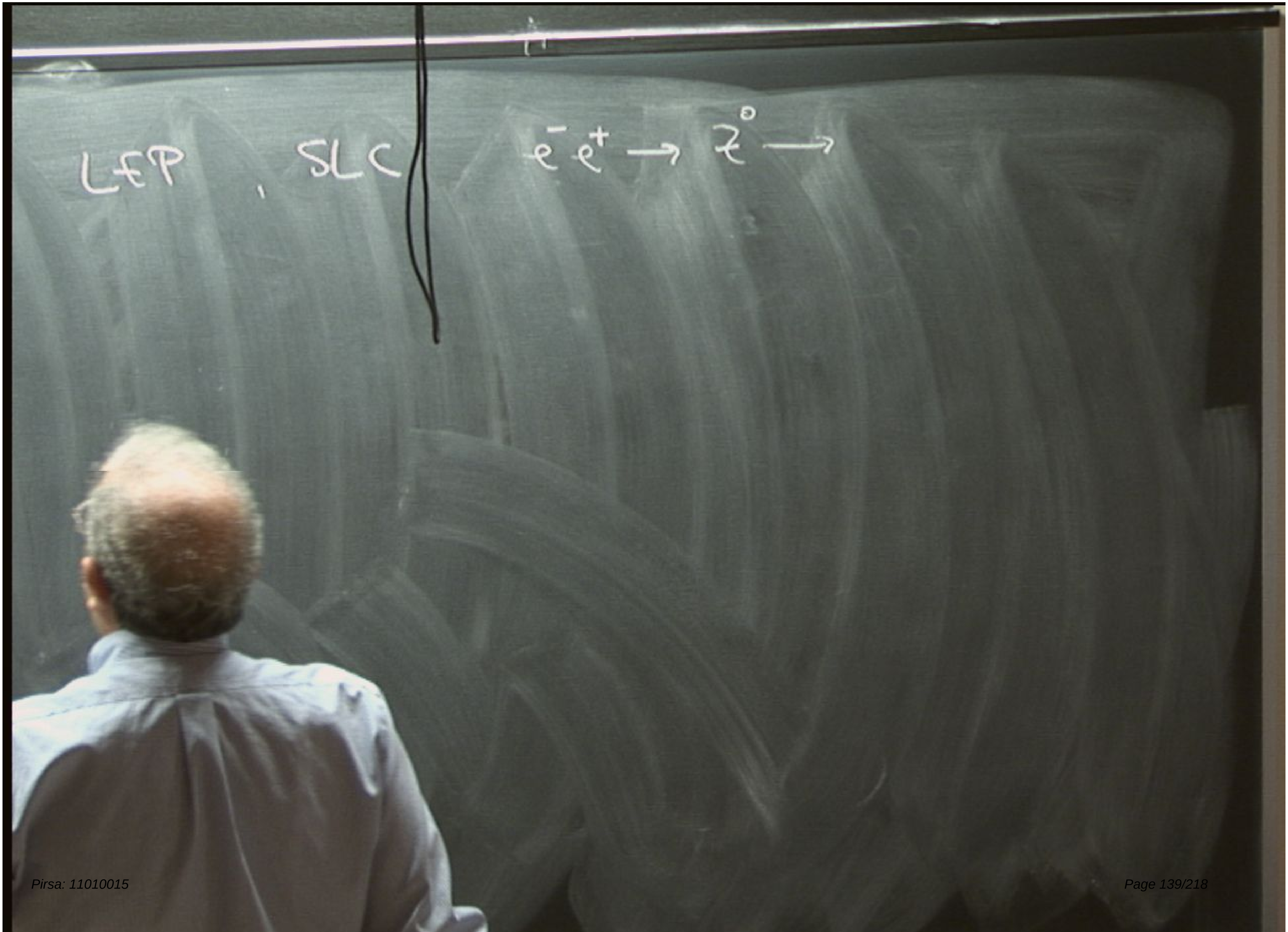


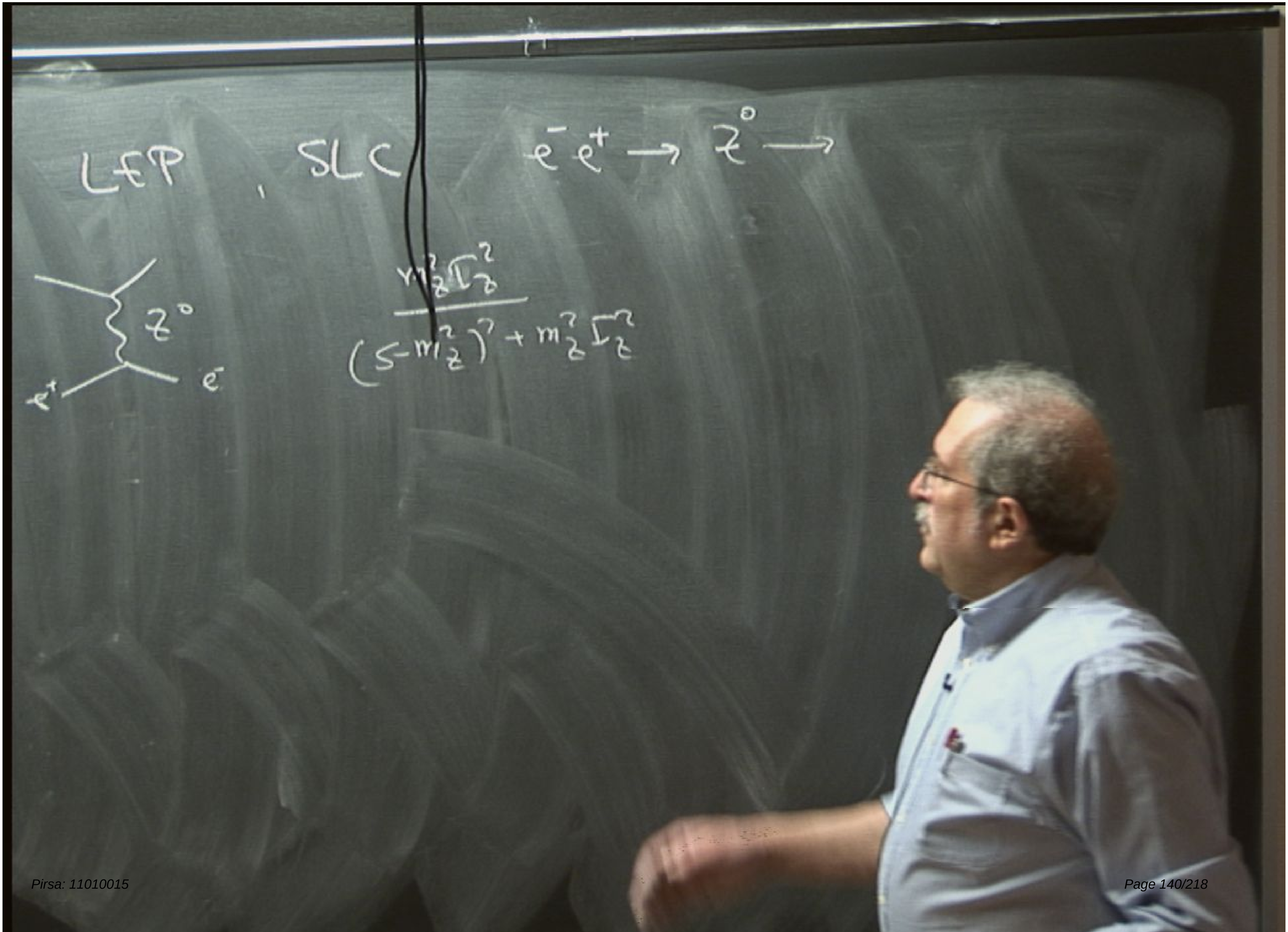


$$R_b = \frac{\Gamma(\to b\bar{b})}{\Gamma(\to \text{hadr})}$$

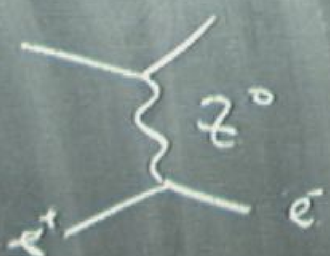
$= 0.216$

(0.220)


LEP , SLC $e^-e^+ \to Z^0 \to$

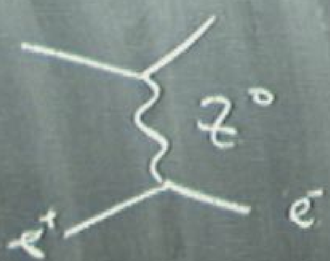

LEP , SLC $e^- e^+ \to Z^0 \to$
Z^0
e^+
e^-
$\frac{m_Z^2 \Gamma_Z^2}{(s-m_Z^2)^2 + m_Z^2 \Gamma_Z^2}$

LEP , SLC $e^-e^+ \longrightarrow Z^0 \longrightarrow$

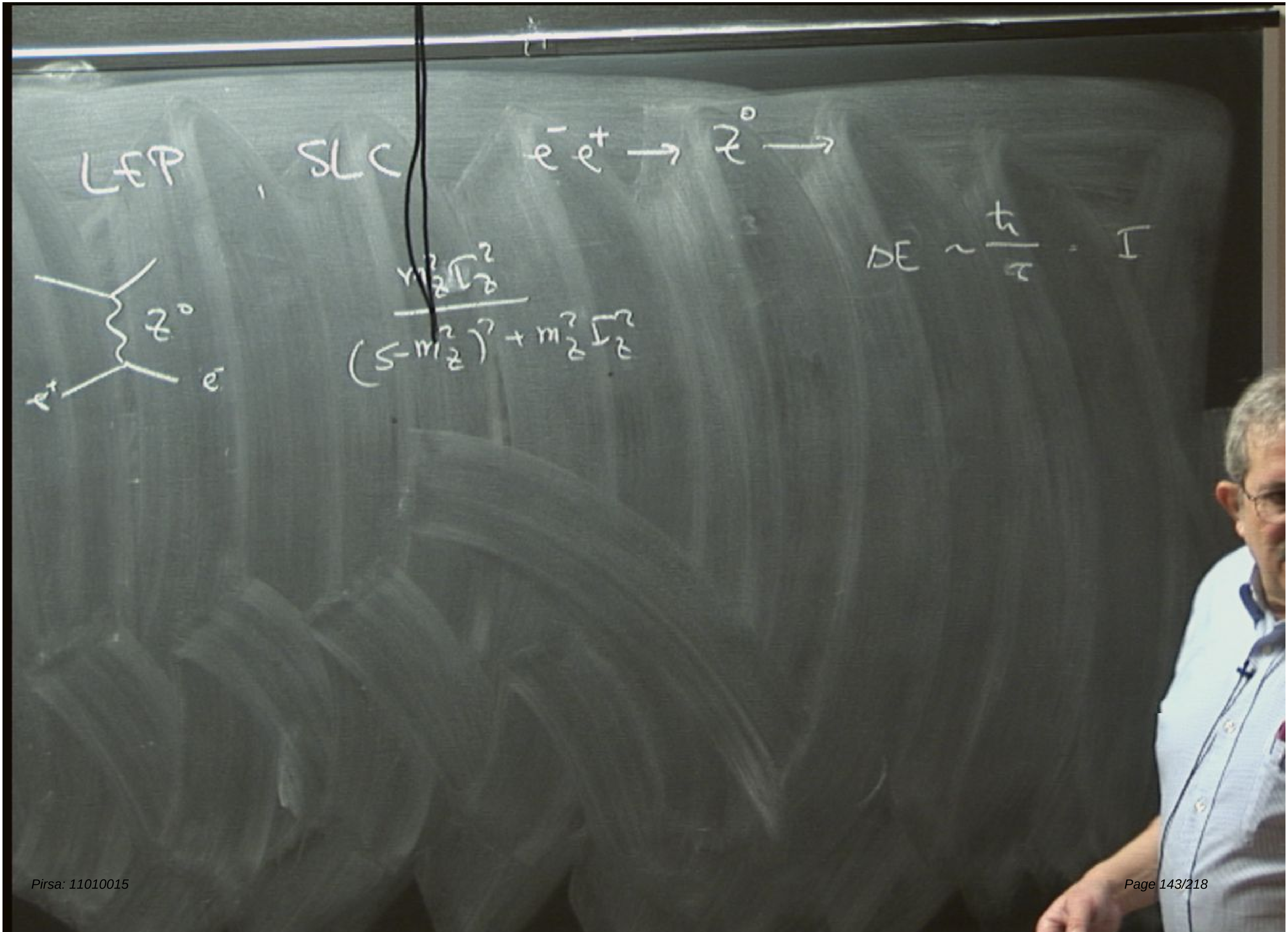


$$\frac{m_Z^2 \Gamma_Z^2}{(s-m_Z^2)^2 + m_Z^2 \Gamma_Z^2}$$

LEP, SLC $e^- e^+ \to Z^0 \to$

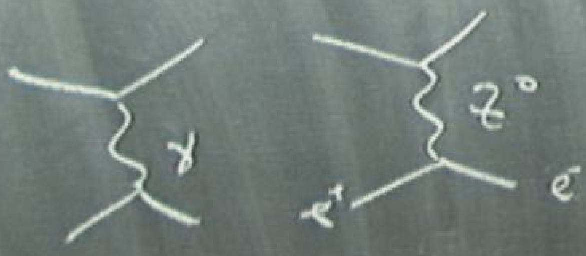


$$\frac{m_Z^2 \Gamma_Z^2}{(s - m_Z^2)^2 + m_Z^2 \Gamma_Z^2}$$


LEP , SLC
$e^- e^+ \longrightarrow Z^0 \longrightarrow$
Z^0
e^+
e^-
$\frac{m_Z^2 \Gamma_Z^2}{(s-m_Z^2)^2 + m_Z^2 \Gamma_Z^2}$
$\Delta E \sim \frac{\hbar}{\tau} \cdot I$

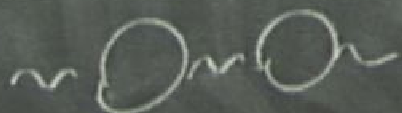
LEP, SLC $\quad e^-e^+ \to Z^0 \to$

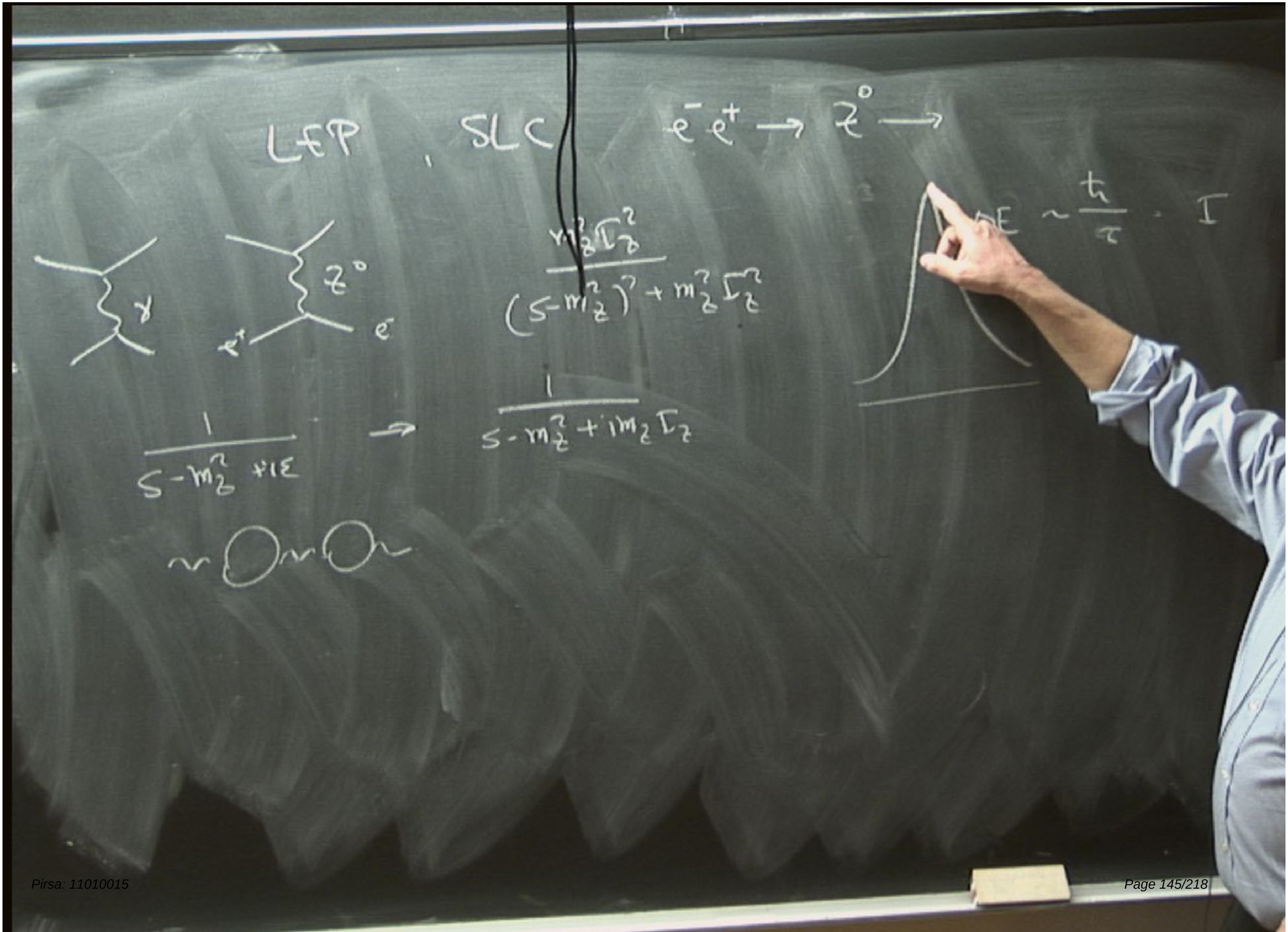
$$\Delta E \sim \frac{\hbar}{\tau} \cdot \Gamma$$



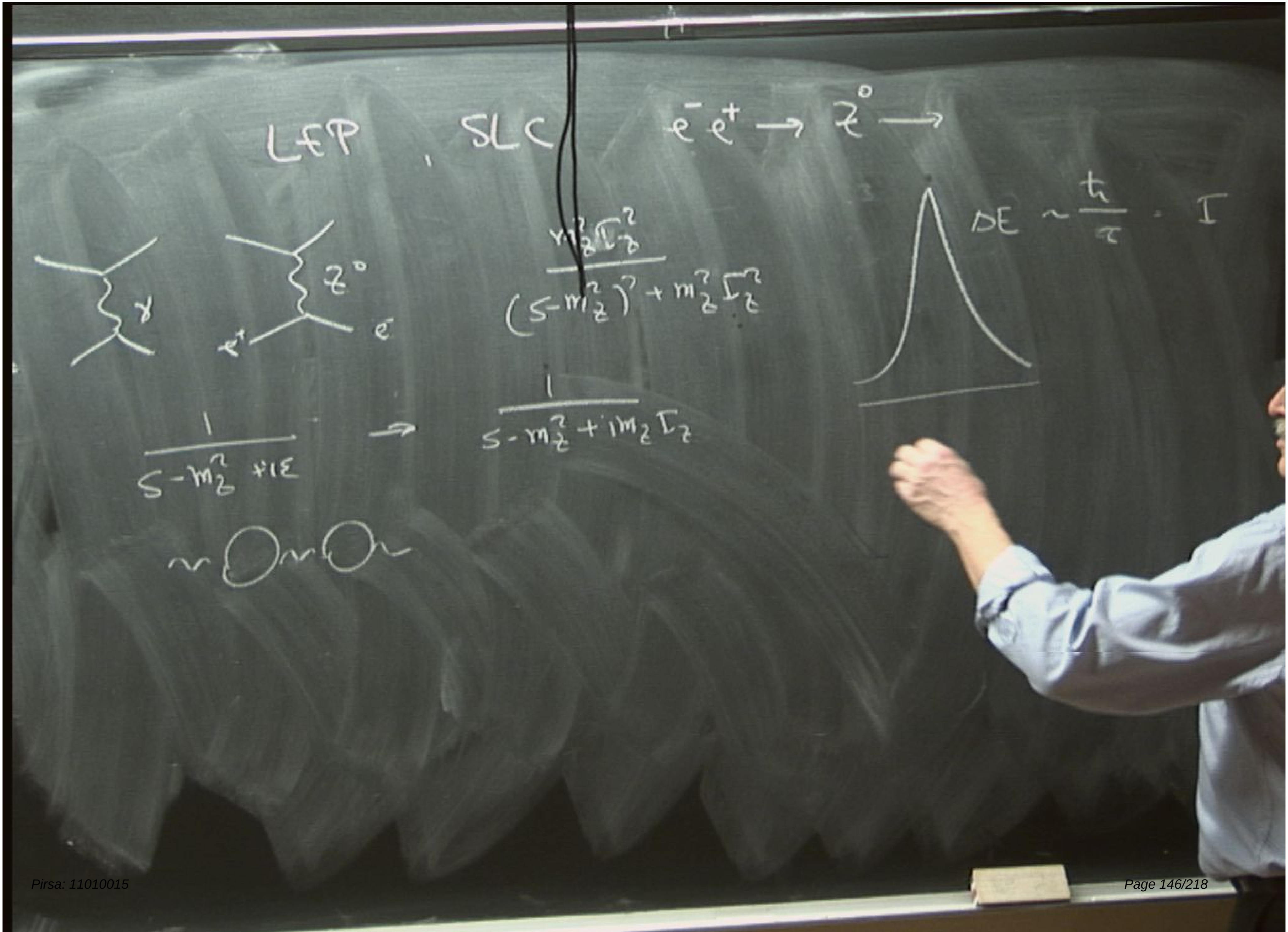
$$\frac{m_Z^2\Gamma_Z^2}{(s-m_Z^2)^2+m_Z^2\Gamma_Z^2}$$

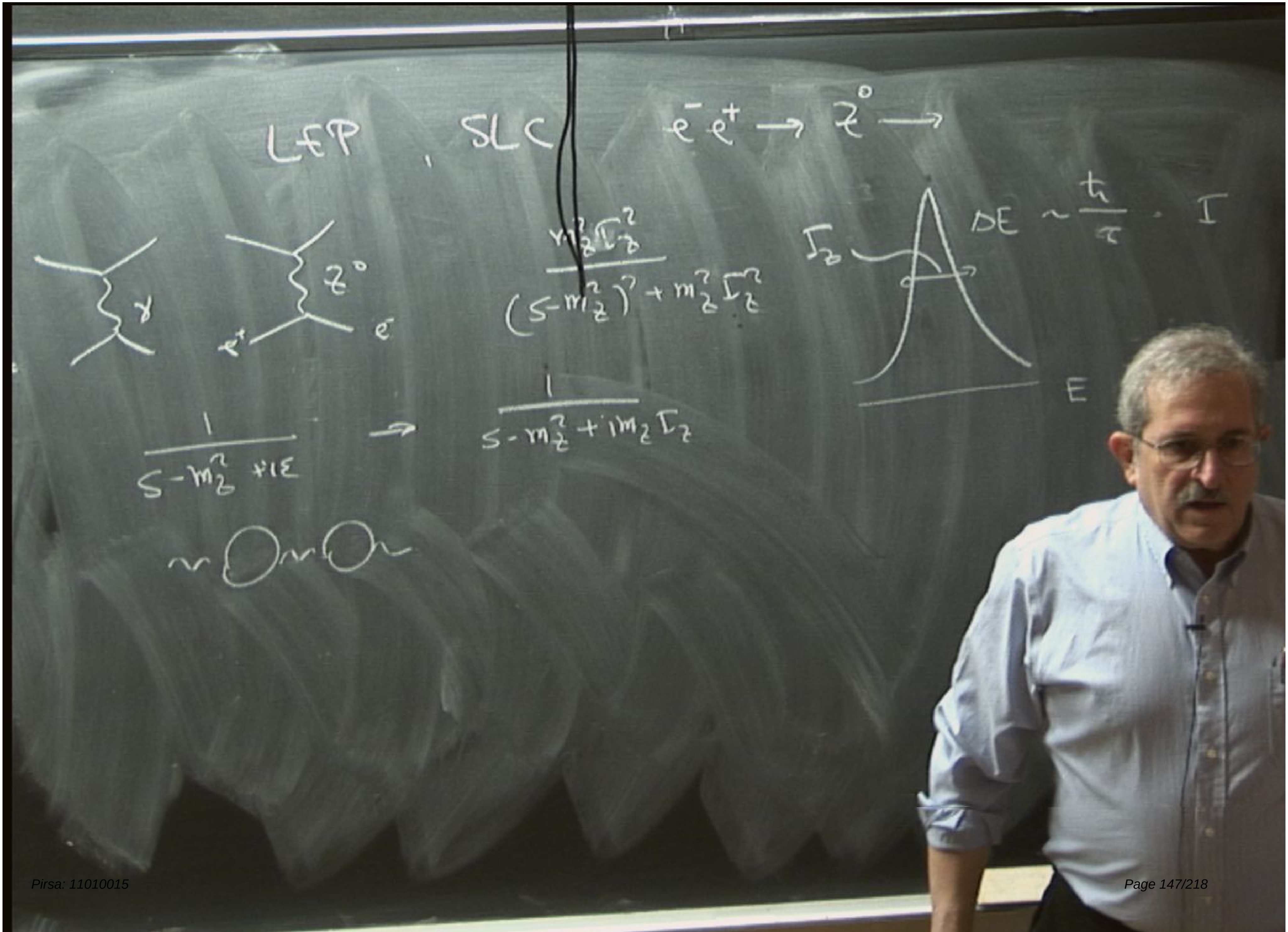
$$\frac{1}{s-m_Z^2+i\epsilon} \to \frac{1}{s-m_Z^2+im_Z\Gamma_Z}$$

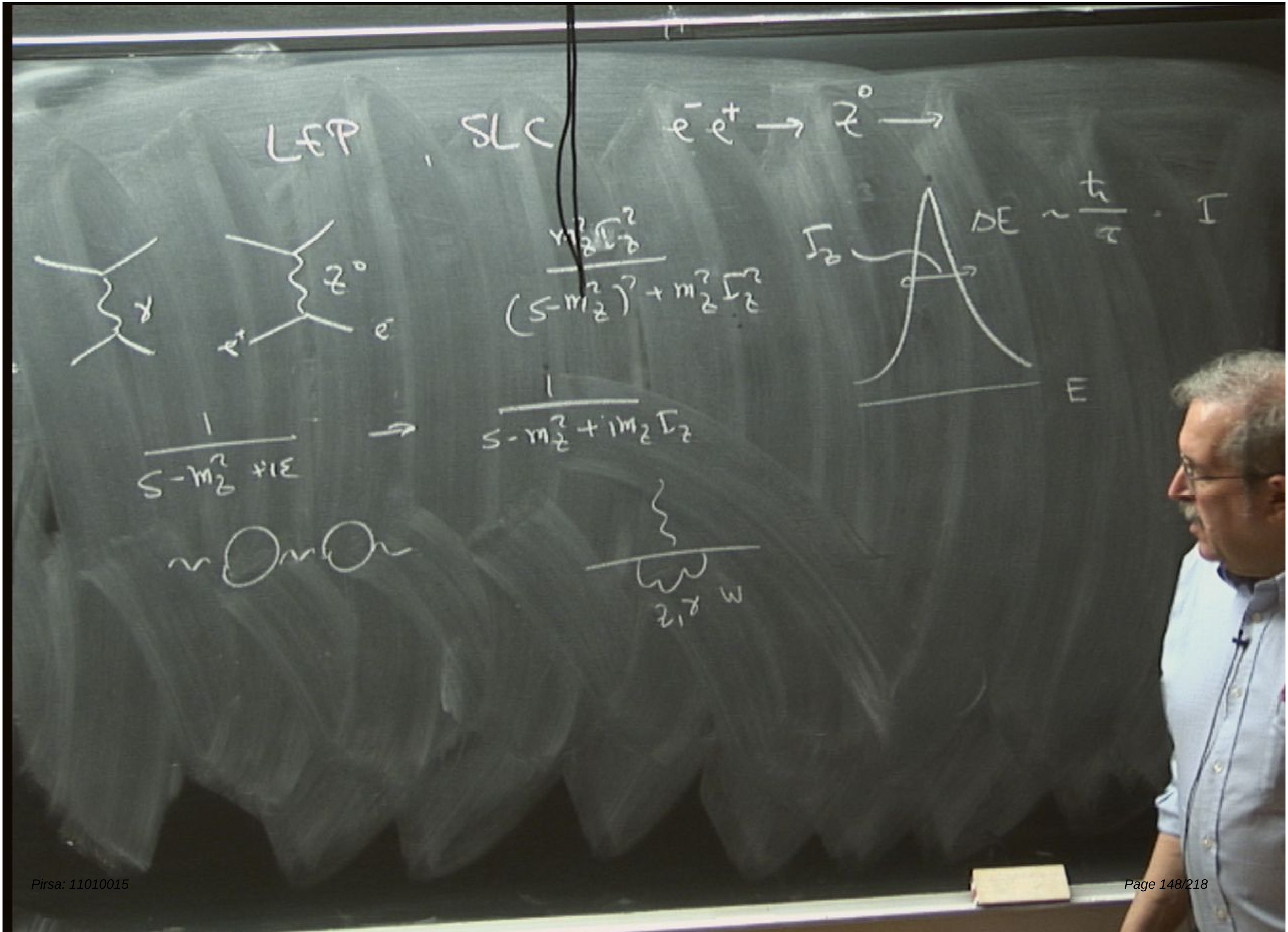


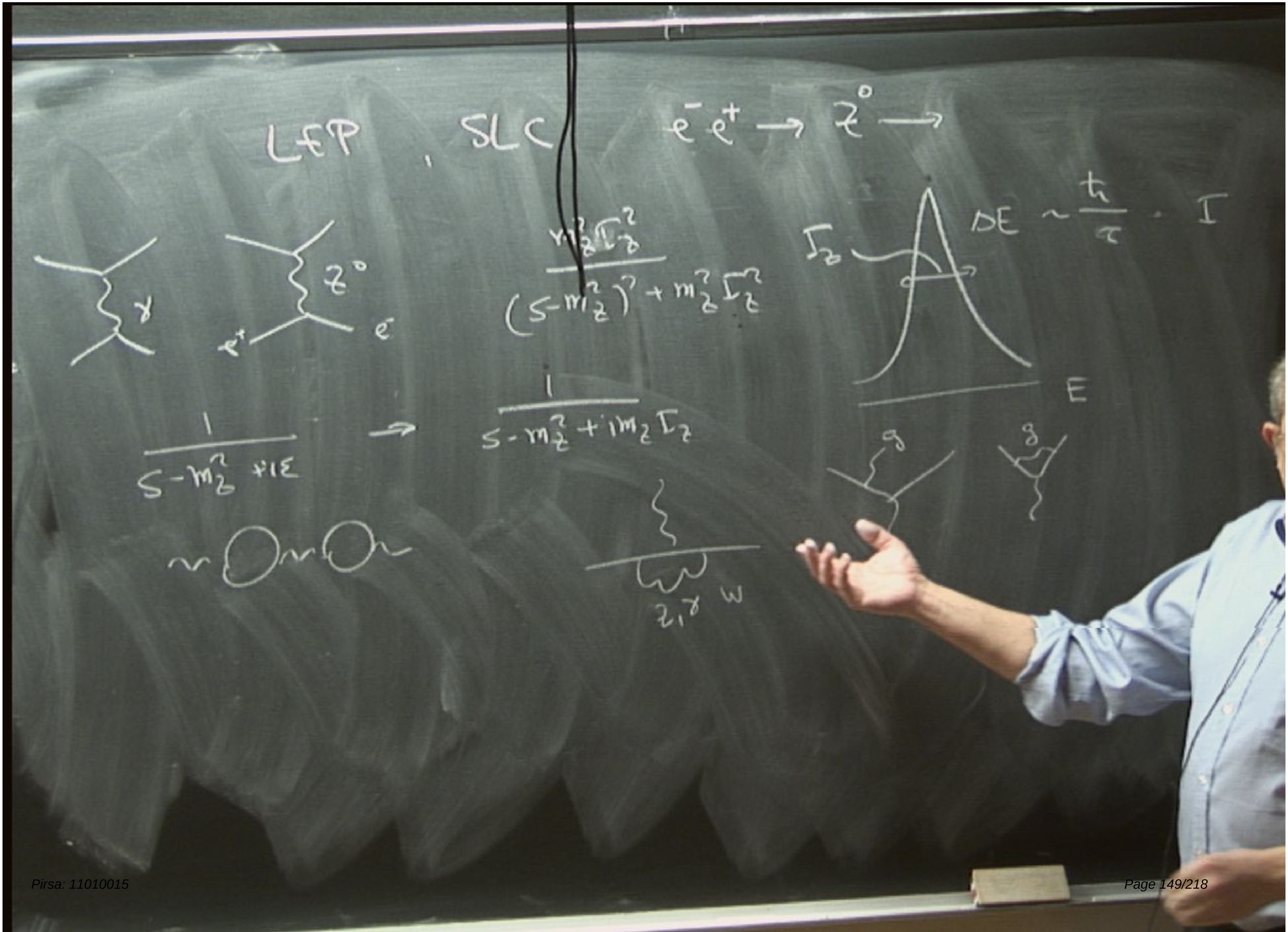


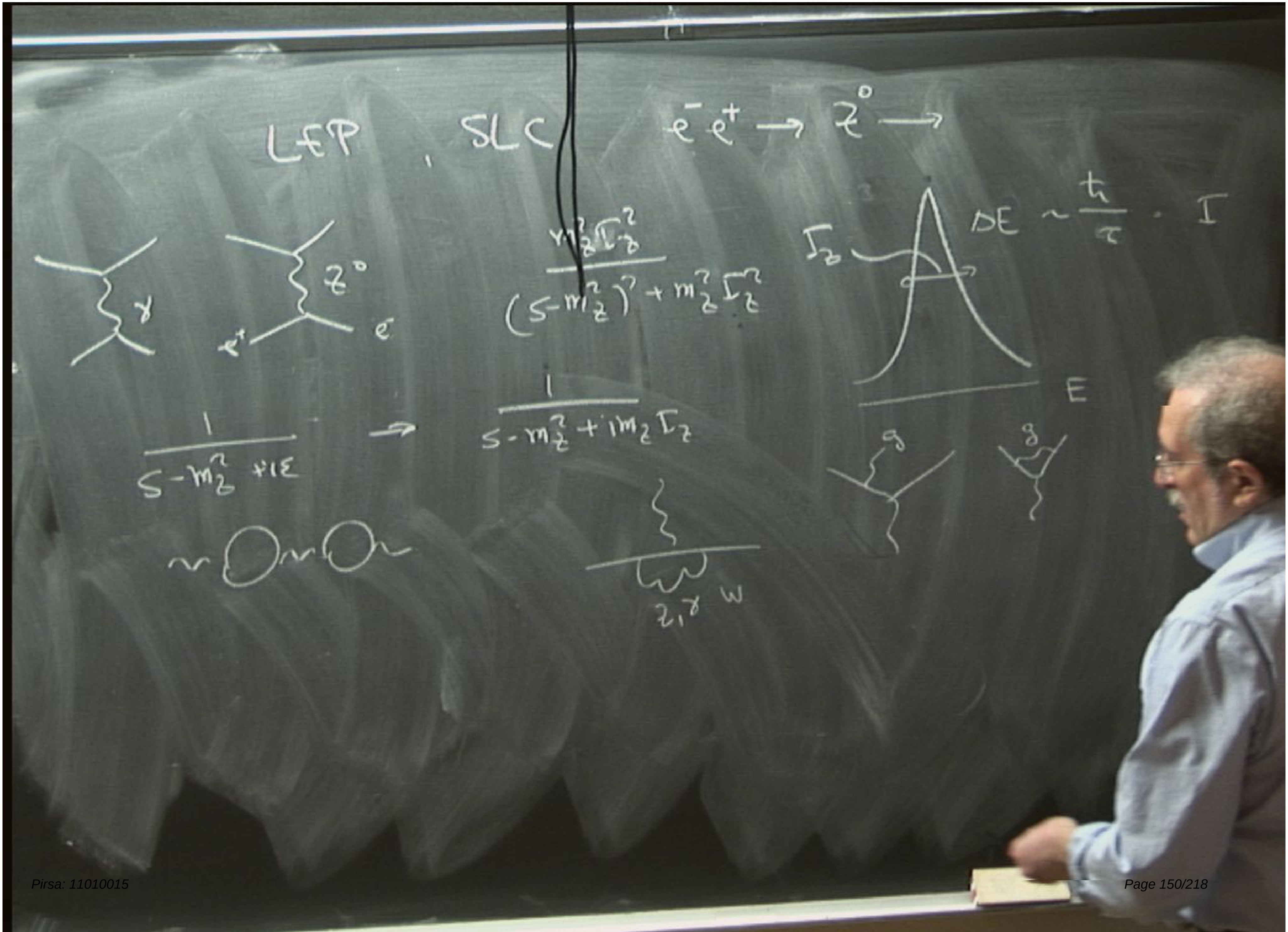
LEP , SLC
$e^- e^+ \to Z^0 \to$
$\Delta E \sim \frac{\hbar}{\tau} \cdot \Gamma$
γ
Z^0
e^+
e^-
$\frac{m_Z^2 \Gamma_Z^2}{(s-m_Z^2)^2 + m_Z^2 \Gamma_Z^2}$
$\frac{1}{s-m_Z^2+i\epsilon} \to \frac{1}{s-m_Z^2+im_Z\Gamma_Z}$

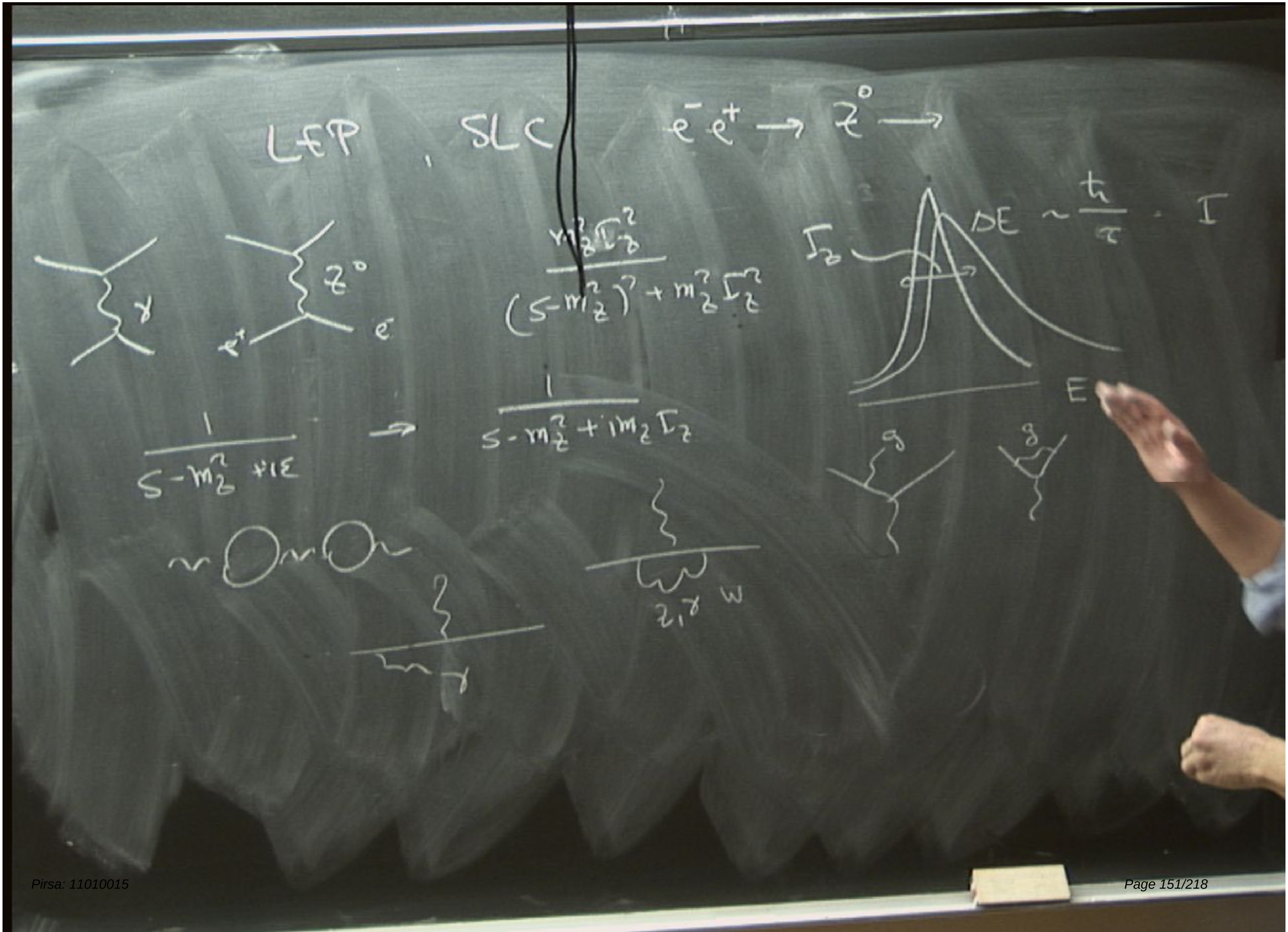

LEP , SLC
e⁻e⁺ → Z⁰ →
γ
Z⁰
e⁺
e
m²_Z Γ²_Z / ((s − m²_Z)² + m²_Z Γ²_Z)
ΔE ~ ħ/τ = Γ
1 / (s − m²_Z + iε) → 1 / (s − m²_Z + i m_Z Γ_Z)


LEP , SLC
$e^- e^+ \to Z^0 \to$
$\Delta E \sim \frac{\hbar}{\tau} \cdot \Gamma$
Γ_Z
E
Z^0
γ
e^+
e
$\frac{m_Z^2 \Gamma_Z^2}{(s-m_Z^2)^2 + m_Z^2 \Gamma_Z^2}$
$\frac{1}{s - m_Z^2 + i\varepsilon} \to \frac{1}{s - m_Z^2 + i m_Z \Gamma_Z}$


LEP , SLC
$e^- e^+ \to Z^0 \to$
γ
Z^0
e^+
e
$\frac{m_Z^2 \Gamma_Z^2}{(s-m_Z^2)^2 + m_Z^2 \Gamma_Z^2}$
Γ_Z
$\Delta E \sim \frac{\hbar}{\tau} \cdot \Gamma$
E
$\frac{1}{s - m_Z^2 + i\epsilon} \to \frac{1}{s - m_Z^2 + i m_Z \Gamma_Z}$
Z, γ W

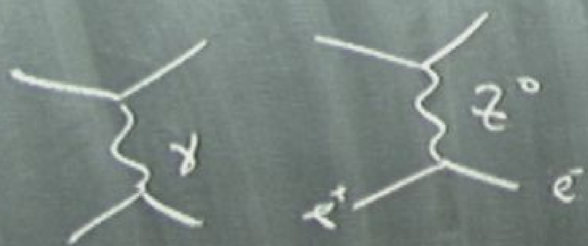

LEP , SLC
$e^- e^+ \to Z^0 \to$
$\frac{m_Z^2 \Gamma_Z^2}{(s-m_Z^2)^2 + m_Z^2 \Gamma_Z^2}$
Γ_Z
$\Delta E \sim \frac{\hbar}{\tau} \cdot \Gamma$
γ
Z^0
e^+
e
E
$\frac{1}{s-m_Z^2+i\epsilon} \to \frac{1}{s-m_Z^2+im_Z\Gamma_Z}$
g
g
Z, γ W


LEP , SLC
e⁻e⁺ → Z° →
Z°
γ
e⁺
e
ΔE ~ ħ/τ · Γ
Γ_Z
E
g
g
Z, γ
W

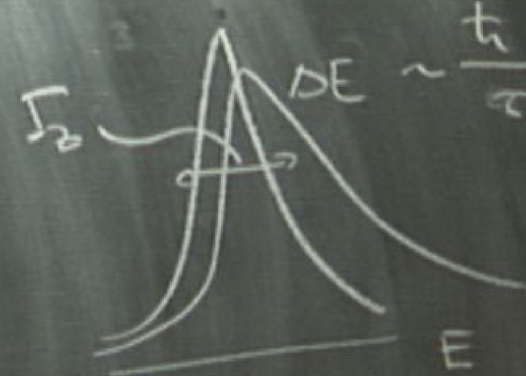


LEP , SLC
$e^- e^+ \to Z^0 \to$
Z^0
γ
e^+
e
$\frac{m_Z^2 \Gamma_Z^2}{(s-m_Z^2)^2 + m_Z^2 \Gamma_Z^2}$
Γ_Z
$\Delta E \sim \frac{\hbar}{\tau} \cdot \Gamma$
E
$\frac{1}{s - m_Z^2 + i\varepsilon} \to \frac{1}{s - m_Z^2 + i m_Z \Gamma_Z}$
g
g
Z, γ W
γ

LEP , SLC $e^-e^+ \to Z^0 \to$

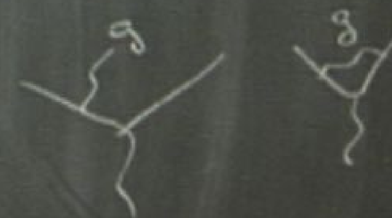


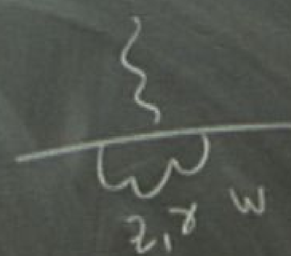
$$\frac{m_Z^2\Gamma_Z^2}{(s-m_Z^2)^2+m_Z^2\Gamma_Z^2}$$

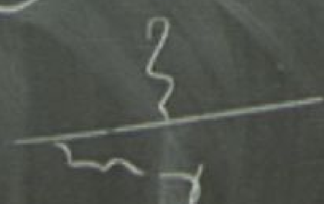


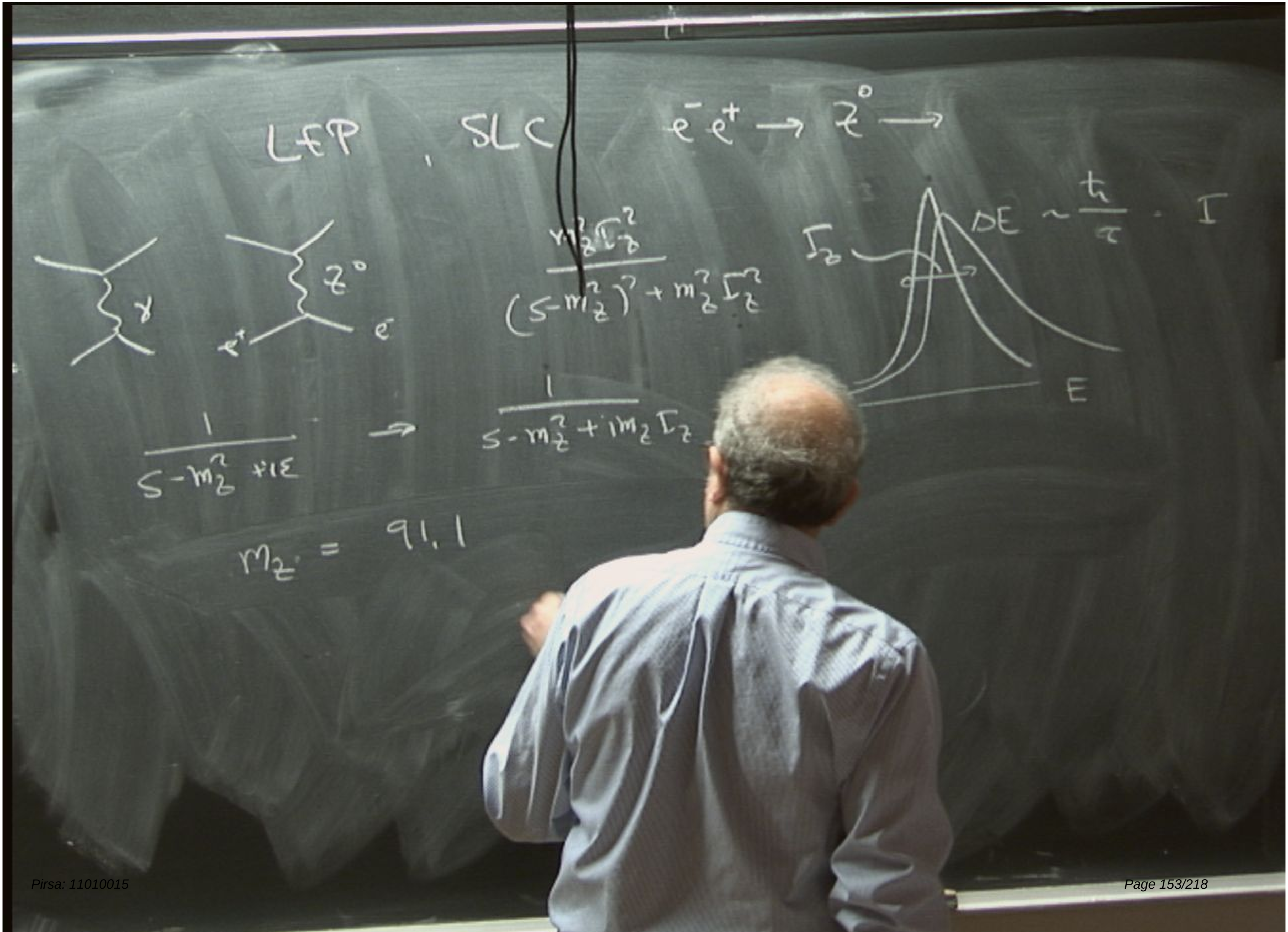
$$\Delta E \sim \frac{\hbar}{\tau} \cdot \Gamma$$

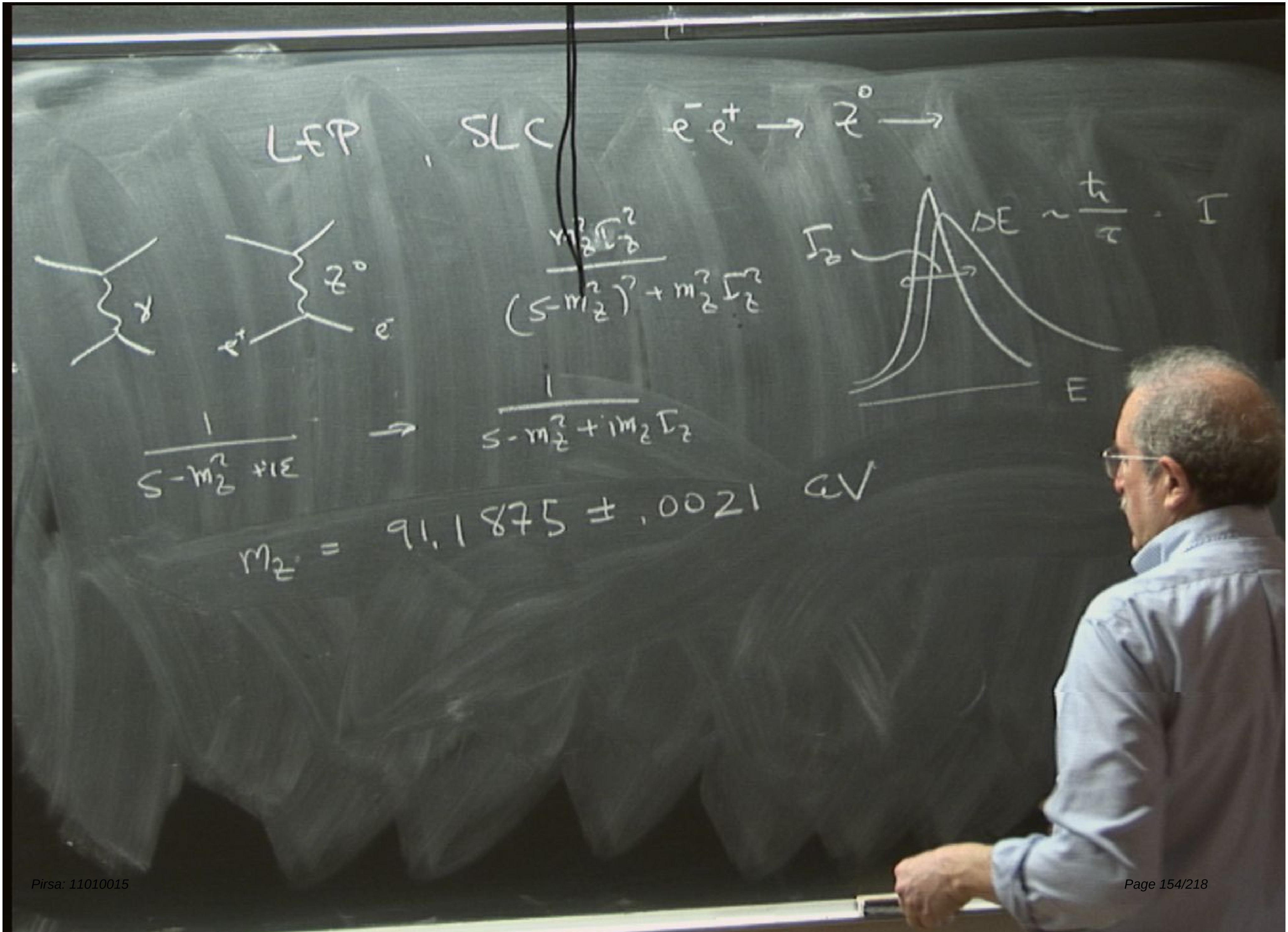
$$\frac{1}{s-m_Z^2+i\epsilon} \to \frac{1}{s-m_Z^2+im_Z\Gamma_Z}$$

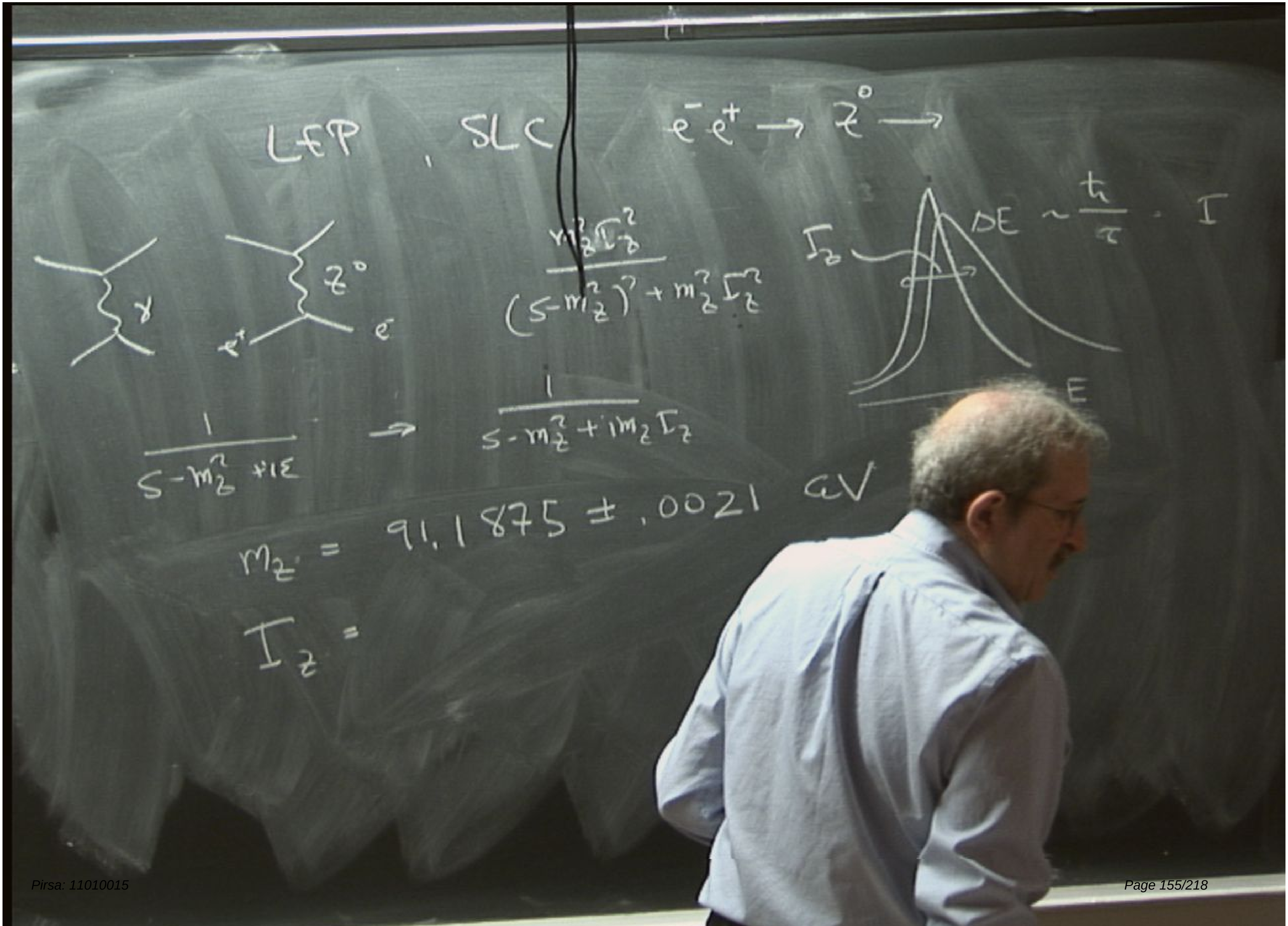


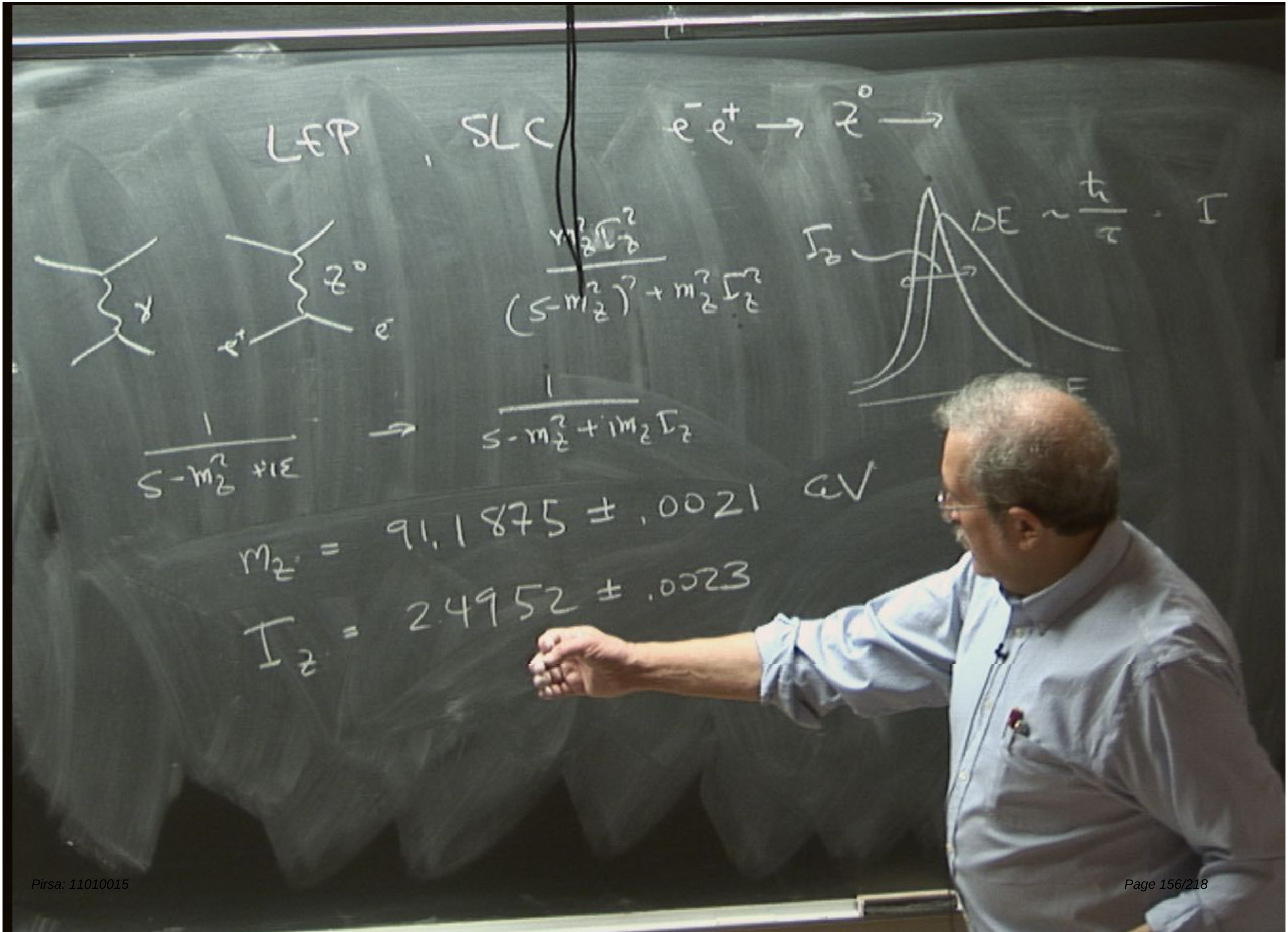




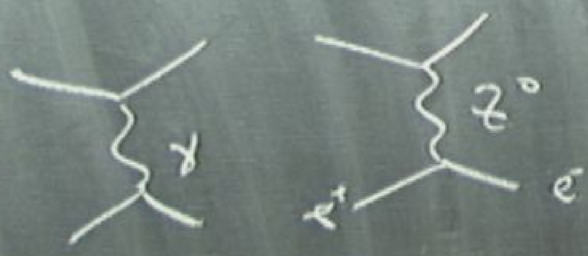

LEP, SLC
$e^- e^+ \to Z^0 \to$
γ
Z^0
e^+
e
$\frac{m_Z^2 \Gamma_Z^2}{(s-m_Z^2)^2 + m_Z^2 \Gamma_Z^2}$
Γ_Z
$\Delta E \sim \frac{\hbar}{\tau} \cdot \Gamma$
E
$\frac{1}{s - m_Z^2 + i\varepsilon} \to \frac{1}{s - m_Z^2 + i m_Z \Gamma_Z}$
$m_Z = 91.1$


LEP , SLC
e⁻e⁺ → Z⁰ →
γ
Z⁰
e⁺
e
m_Z² Γ_Z² / ((s − m_Z²)² + m_Z² Γ_Z²)
Γ_Z
ΔE ~ ħ/τ
E
1 / (s − m_Z² + iε) → 1 / (s − m_Z² + i m_Z Γ_Z)
m_Z = 91.1875 ± .0021 GeV

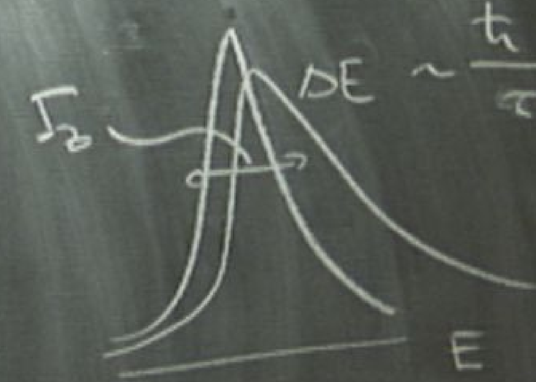

LEP , SLC
e⁻e⁺ → Z⁰ →
Z⁰
γ
e⁺
e
ΔE ~ ħ/τ · Γ
Γ_Z
E
m_Z² Γ_Z² / ((s − m_Z²)² + m_Z² Γ_Z²)
1 / (s − m_Z² + iε) → 1 / (s − m_Z² + i m_Z Γ_Z)
m_Z = 91.1875 ± .0021 GeV
Γ_Z =


LEP , SLC
$e^- e^+ \to Z^0 \to$
γ
Z^0
e^+
e
$\frac{m_Z^2 \Gamma_Z^2}{(s-m_Z^2)^2 + m_Z^2 \Gamma_Z^2}$
Γ_Z
$\Delta E \sim \frac{\hbar}{\tau} \cdot \Gamma$
$\frac{1}{s - m_Z^2 + i\epsilon} \to \frac{1}{s - m_Z^2 + i m_Z \Gamma_Z}$
$m_Z = 91.1875 \pm .0021$ GeV
$\Gamma_Z = 2.4952 \pm .0023$

LEP , SLC $e^-e^+ \to Z^0 \to$



$$\frac{m_Z^2\Gamma_Z^2}{(s-m_Z^2)^2+m_Z^2\Gamma_Z^2}$$

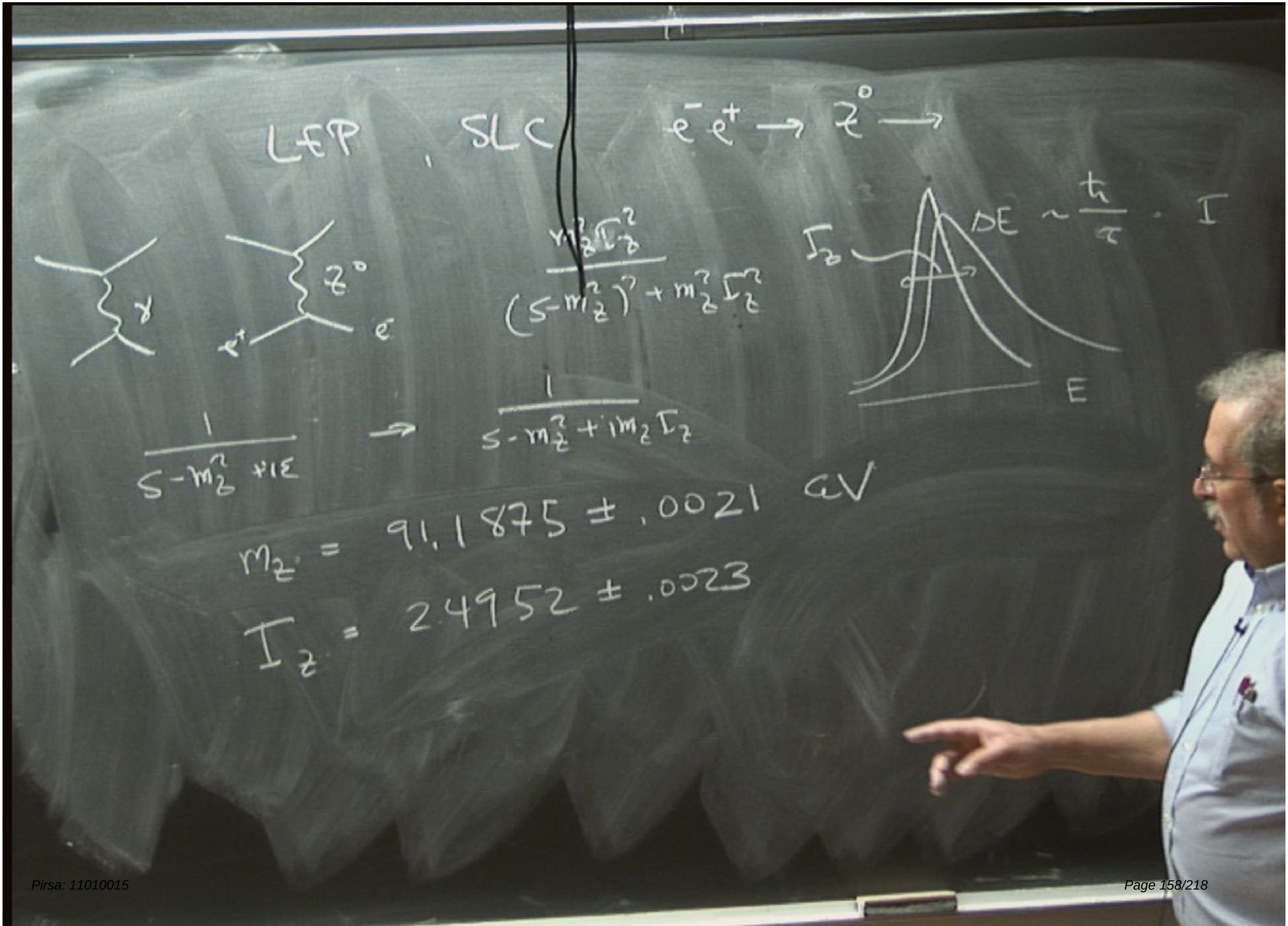


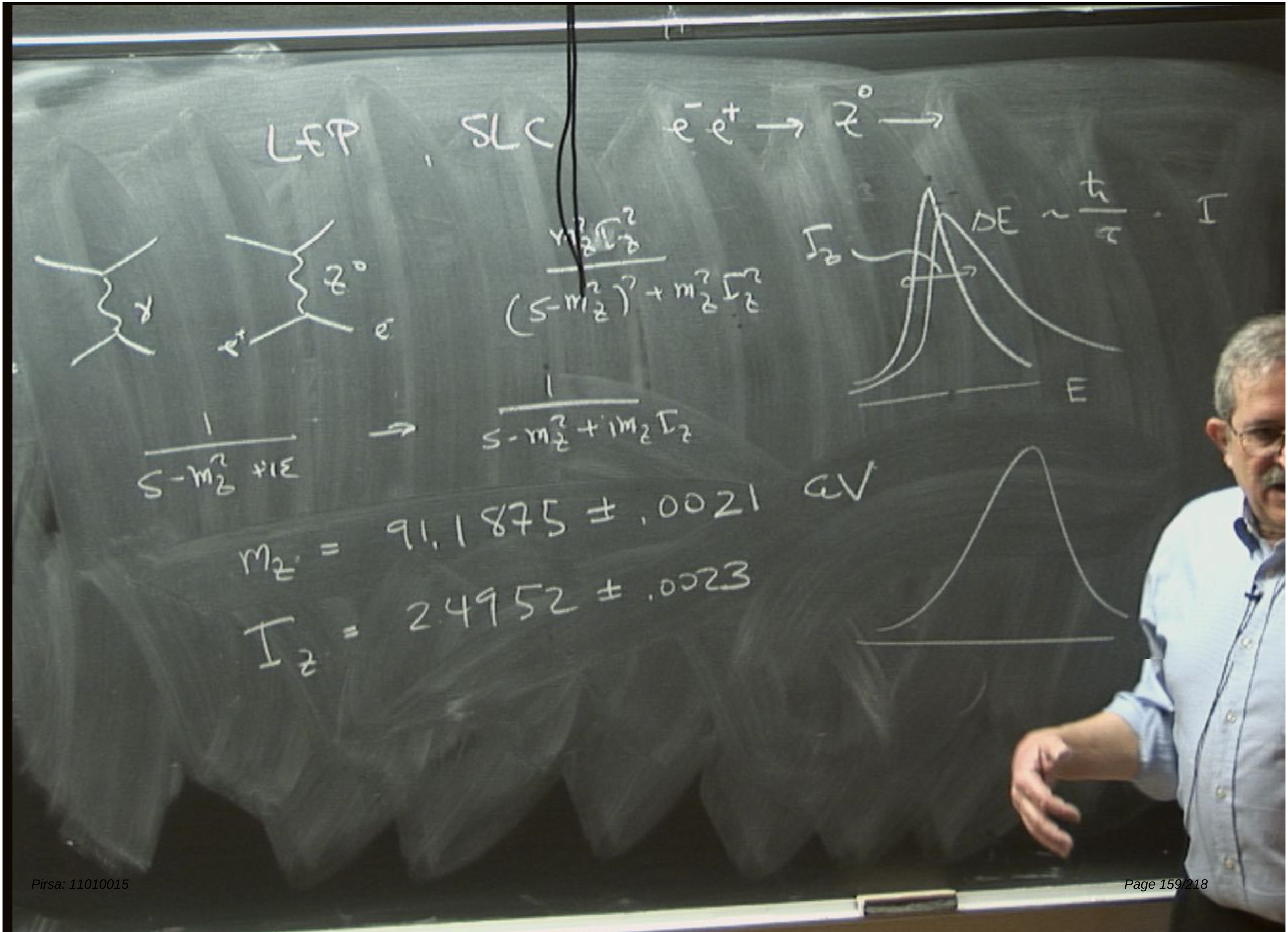
$$\Delta E \sim \frac{\hbar}{\tau} \cdot \Gamma$$

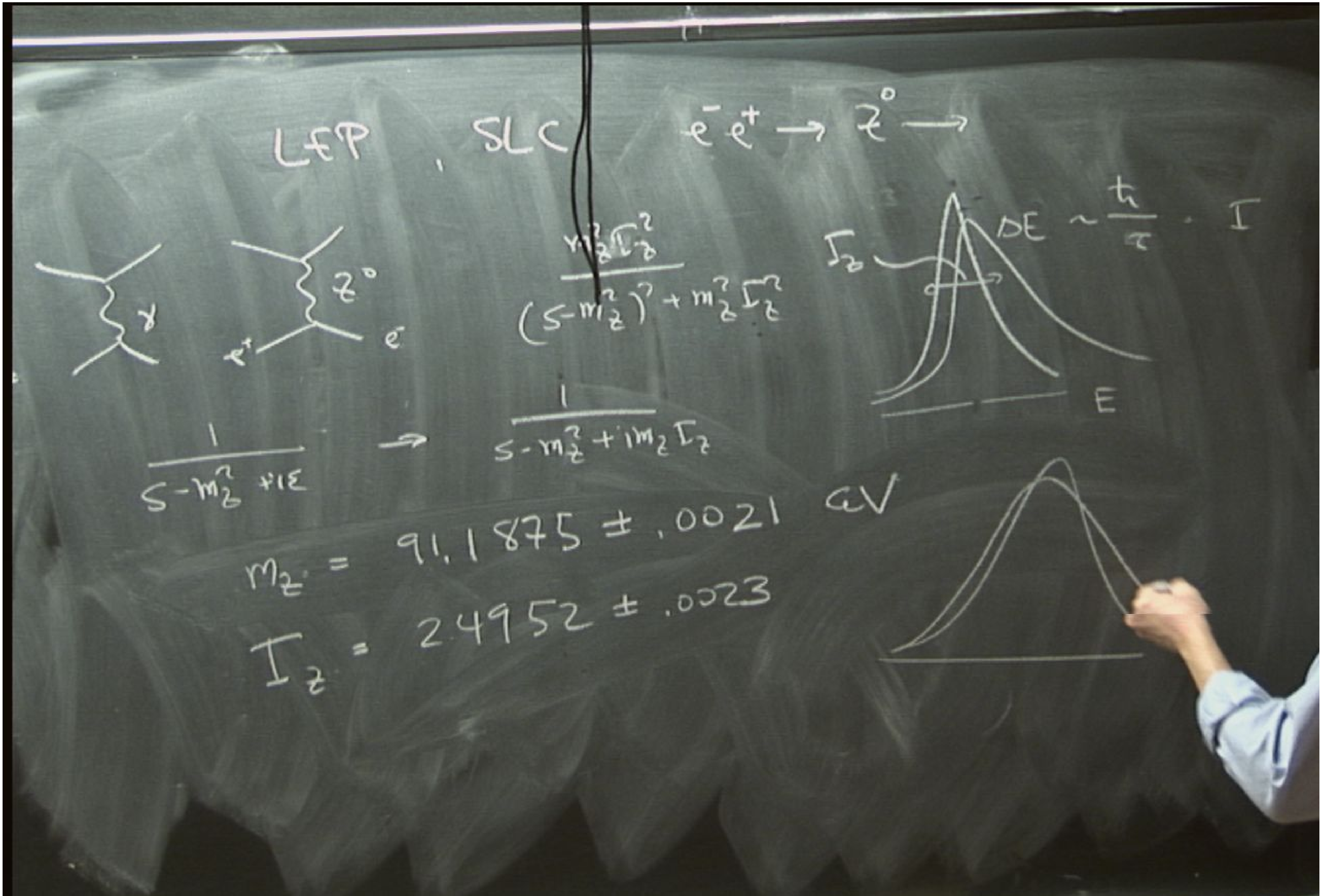
$$\frac{1}{s-m_Z^2+i\epsilon} \to \frac{1}{s-m_Z^2+im_Z\Gamma_Z}$$

$$m_Z = 91.1875 \pm .0021 \text{ GeV}$$

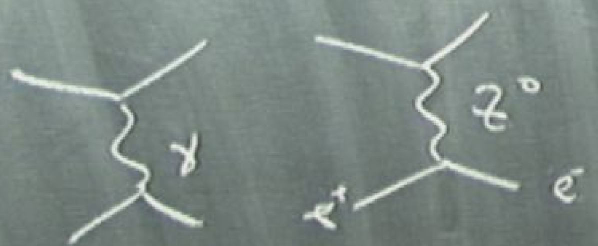
$$\Gamma_Z = 2.4952 \pm .0023$$


LEP, SLC $e^- e^+ \to Z^0 \to$
γ
Z^0
e^+
e
$\frac{m_Z^2 \Gamma_Z^2}{(s-m_Z^2)^2 + m_Z^2 \Gamma_Z^2}$
Γ_Z
$\Delta E \sim \frac{\hbar}{\tau} \cdot \Gamma$
E
$\frac{1}{s-m_Z^2+i\epsilon} \to \frac{1}{s-m_Z^2+im_Z\Gamma_Z}$
$m_Z = 91.1875 \pm .0021$ GeV
$\Gamma_Z = 2.4952 \pm .0023$

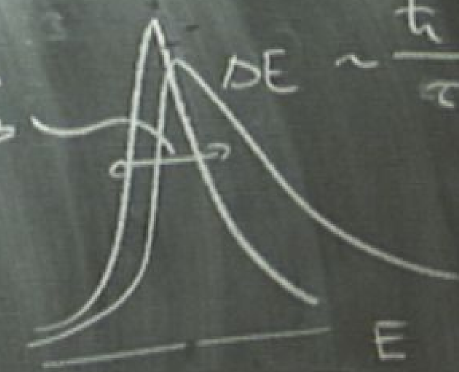

LEP , SLC
$e^- e^+ \to Z^0 \to$
γ
Z^0
e^+
e
$\frac{m_Z^2 \Gamma_Z^2}{(s-m_Z^2)^2 + m_Z^2 \Gamma_Z^2}$
Γ_Z
$\Delta E \sim \frac{\hbar}{\tau} \cdot \Gamma$
E
$\frac{1}{s - m_Z^2 + i\varepsilon} \to \frac{1}{s - m_Z^2 + i m_Z \Gamma_Z}$
$m_Z = 91.1875 \pm .0021$ GeV
$\Gamma_Z = 2.4952 \pm .0023$


LEP , SLC
e⁻e⁺ → Z⁰ →
γ
Z⁰
e⁺
e⁻
m_Z² Γ_Z² / ((s − m_Z²)² + m_Z² Γ_Z²)
Γ_Z
ΔE ~ ħ/τ · Γ
E
1 / (s − m_Z² + iε) → 1 / (s − m_Z² + i m_Z Γ_Z)
m_Z = 91.1875 ± .0021 GeV
Γ_Z = 2.4952 ± .0023

LEP, SLC $e^-e^+ \to Z^0 \to$



$$\frac{m_Z^2\Gamma_Z^2}{(s-m_Z^2)^2+m_Z^2\Gamma_Z^2}$$

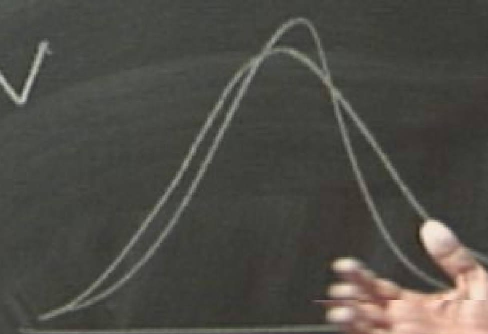


$\Delta E \sim \frac{\hbar}{\tau} \cdot \Gamma$

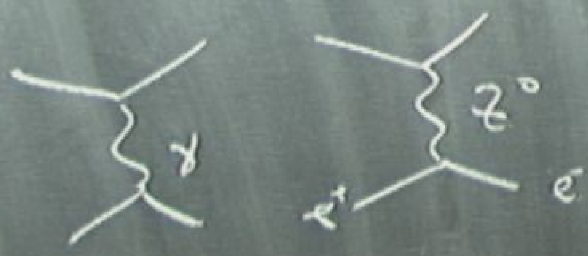
$$\frac{1}{s-m_Z^2+i\epsilon} \to \frac{1}{s-m_Z^2+im_Z\Gamma_Z}$$

$m_Z = 91.1875 \pm .0021$ GeV

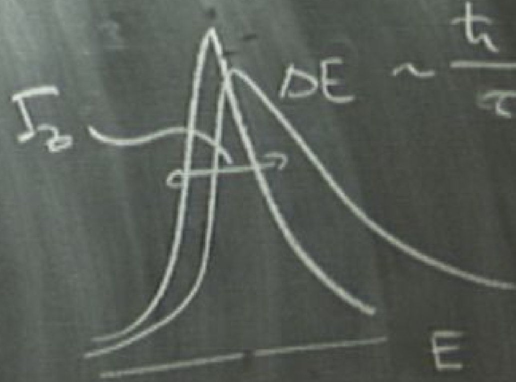
$\Gamma_Z = 2.4952 \pm .0023$



LEP, SLC $e^-e^+ \to Z^0 \to$



$$\frac{m_Z^2\Gamma_Z^2}{(s-m_Z^2)^2+m_Z^2\Gamma_Z^2}$$

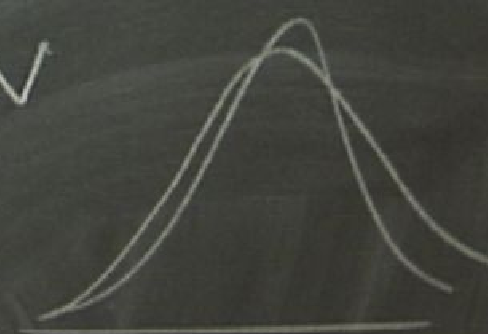


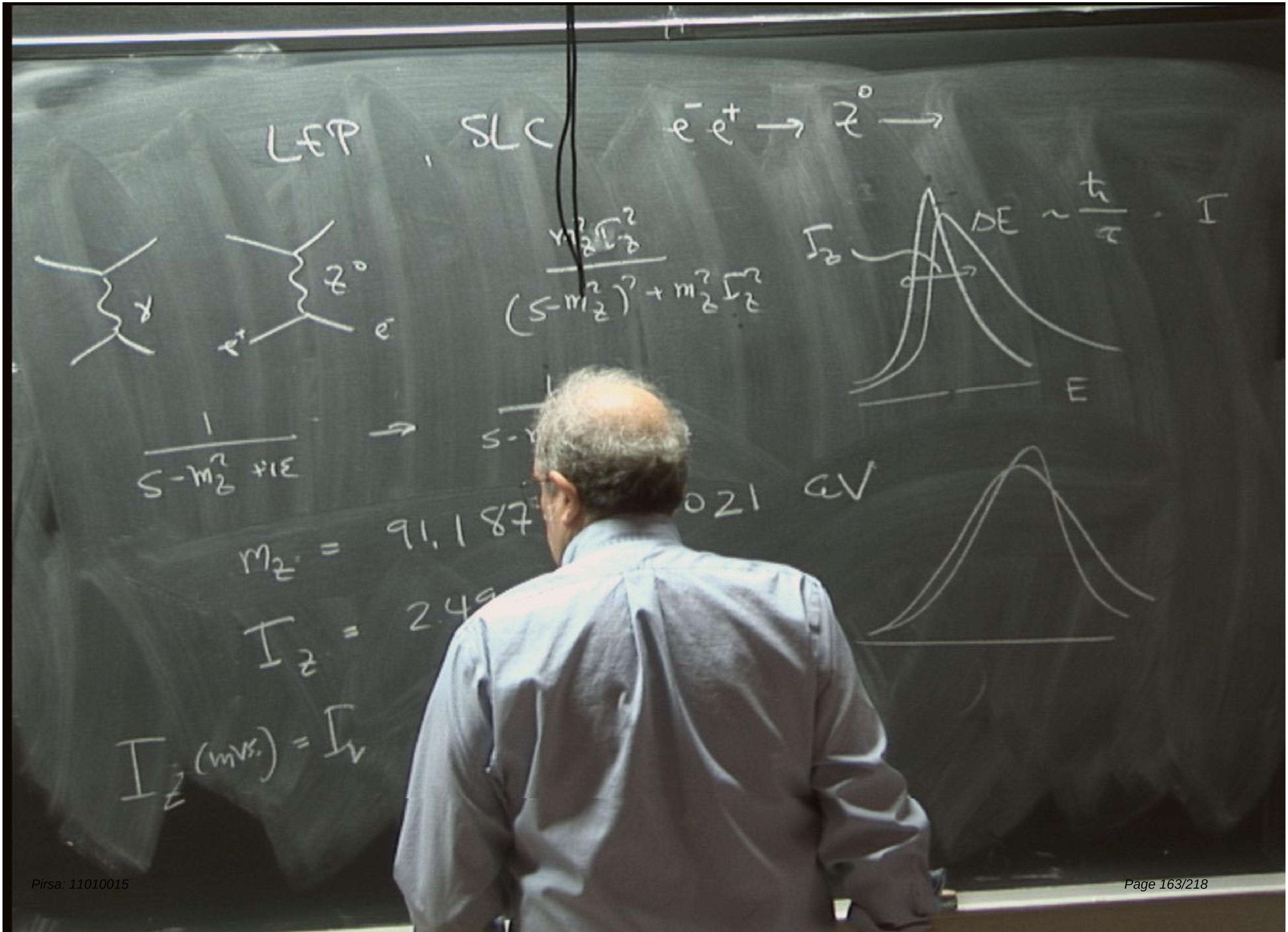
$\Delta E \sim \frac{\hbar}{\tau} \cdot \Gamma$

$$\frac{1}{s-m_Z^2+i\epsilon} \to \frac{1}{s-m_Z^2+im_Z\Gamma_Z}$$

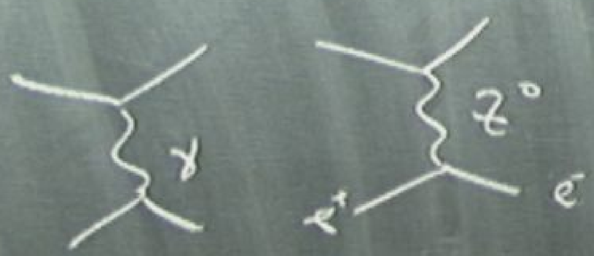
$m_Z = 91.1875 \pm .0021$ GeV

$\Gamma_Z = 2.4952 \pm .0023$

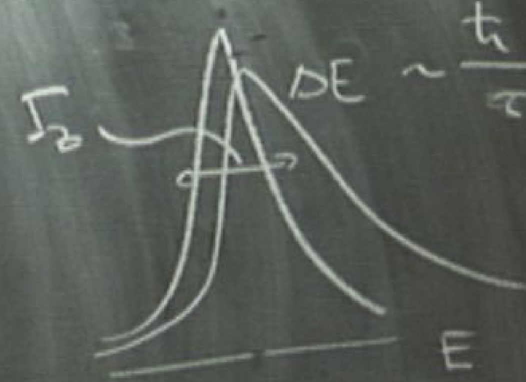



LEP , SLC
e⁻e⁺ → Z⁰ →
Z⁰
γ
e⁺
e
ΔE ~ ħ/τ · Γ
Γ_Z
E
1 / (s − m_Z² + iε) →
m_Z² Γ_Z² / ((s − m_Z²)² + m_Z² Γ_Z²)
GeV
m_Z = 91.187
Γ_Z = 2.49
Γ_Z (invis.) = Γ_ν

LEP, SLC $\quad e^-e^+ \to Z^0 \to$

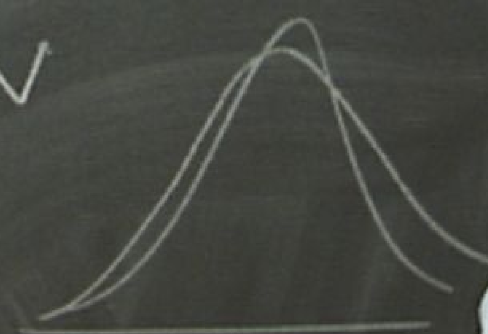


$$\frac{m_Z^2\Gamma_Z^2}{(s-m_Z^2)^2+m_Z^2\Gamma_Z^2}$$



$\Delta E \sim \frac{\hbar}{\tau} \cdot \Gamma$

$$\frac{1}{s-m_Z^2+i\epsilon} \to \frac{1}{s-m_Z^2+im_Z\Gamma_Z}$$



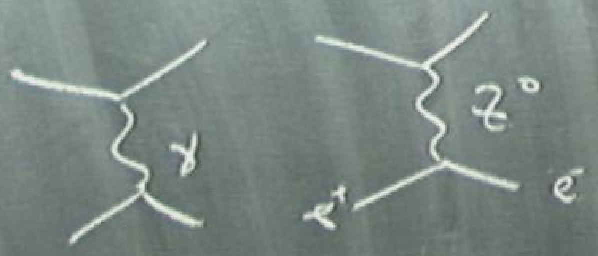
$m_Z = 91.1875 \pm .0021$ GeV

$\Gamma_Z = 2.4952 \pm .0023$

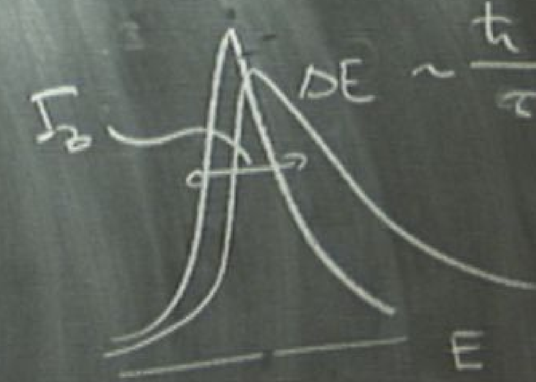
$N_\nu = 2.98$

$\Gamma_Z(\text{inv.}) = \Gamma_\nu \cdot N_\nu$

LEP, SLC $e^-e^+ \to Z^0 \to$



$$\frac{m_Z^2\Gamma_Z^2}{(s-m_Z^2)^2+m_Z^2\Gamma_Z^2}$$

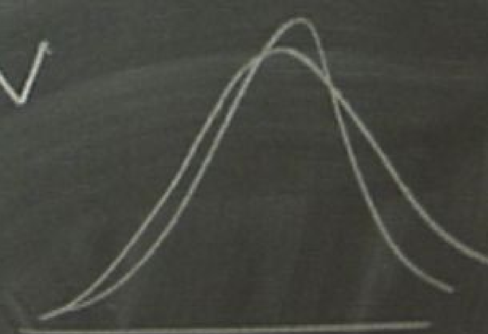


$\Delta E \sim \frac{\hbar}{\tau} \cdot \Gamma$

$$\frac{1}{s-m_Z^2+i\epsilon} \to \frac{1}{s-m_Z^2+im_Z\Gamma_Z}$$

$m_Z = 91.1875 \pm .0021$ GeV

$\Gamma_Z = 2.4952 \pm .0023$



$\Gamma_Z(\nu's) = \Gamma_\nu \cdot N_\nu$ $\quad N_\nu = 2.9840 \pm .0082$

$\Gamma = 2.49 \text{ GeV}$

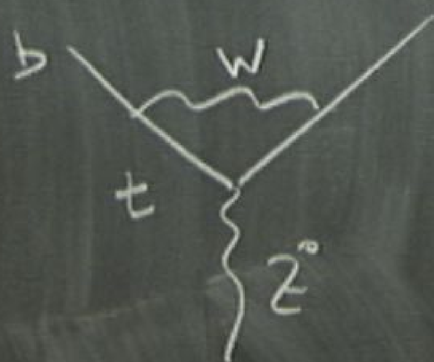
$BR(\to \nu\bar{\nu}) = 6.7\%$

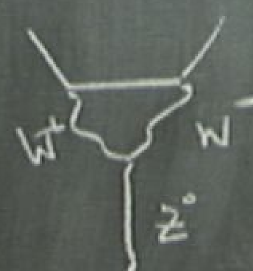
$BR \to \mu^+\mu^- \cdot 3.3\%$

$BR(\to c\bar{c}) = 11.9\%$

$BR(\to d\bar{d}) = 15.3\%$

$BR(\to b\bar{b}) - 2\%$

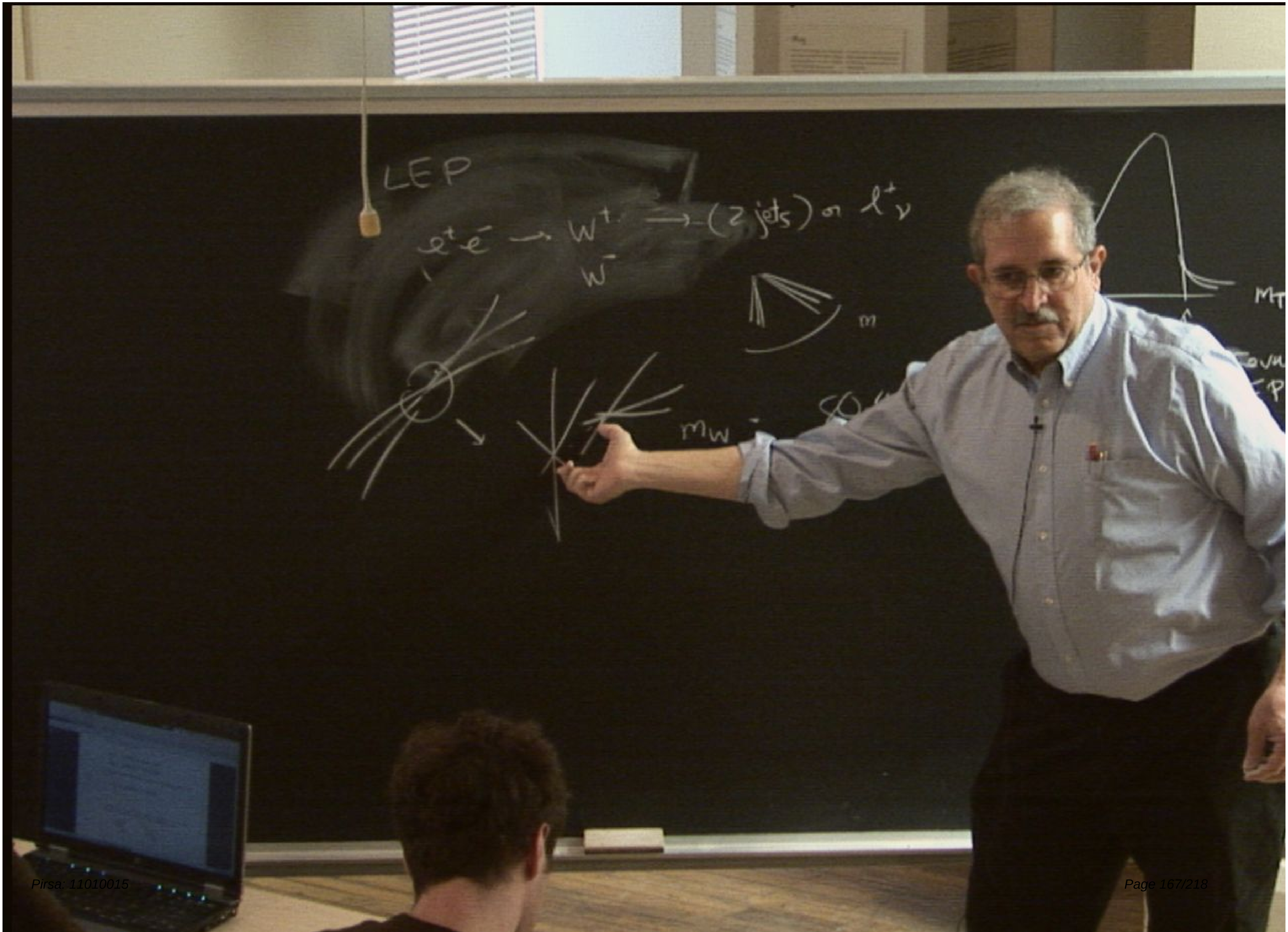


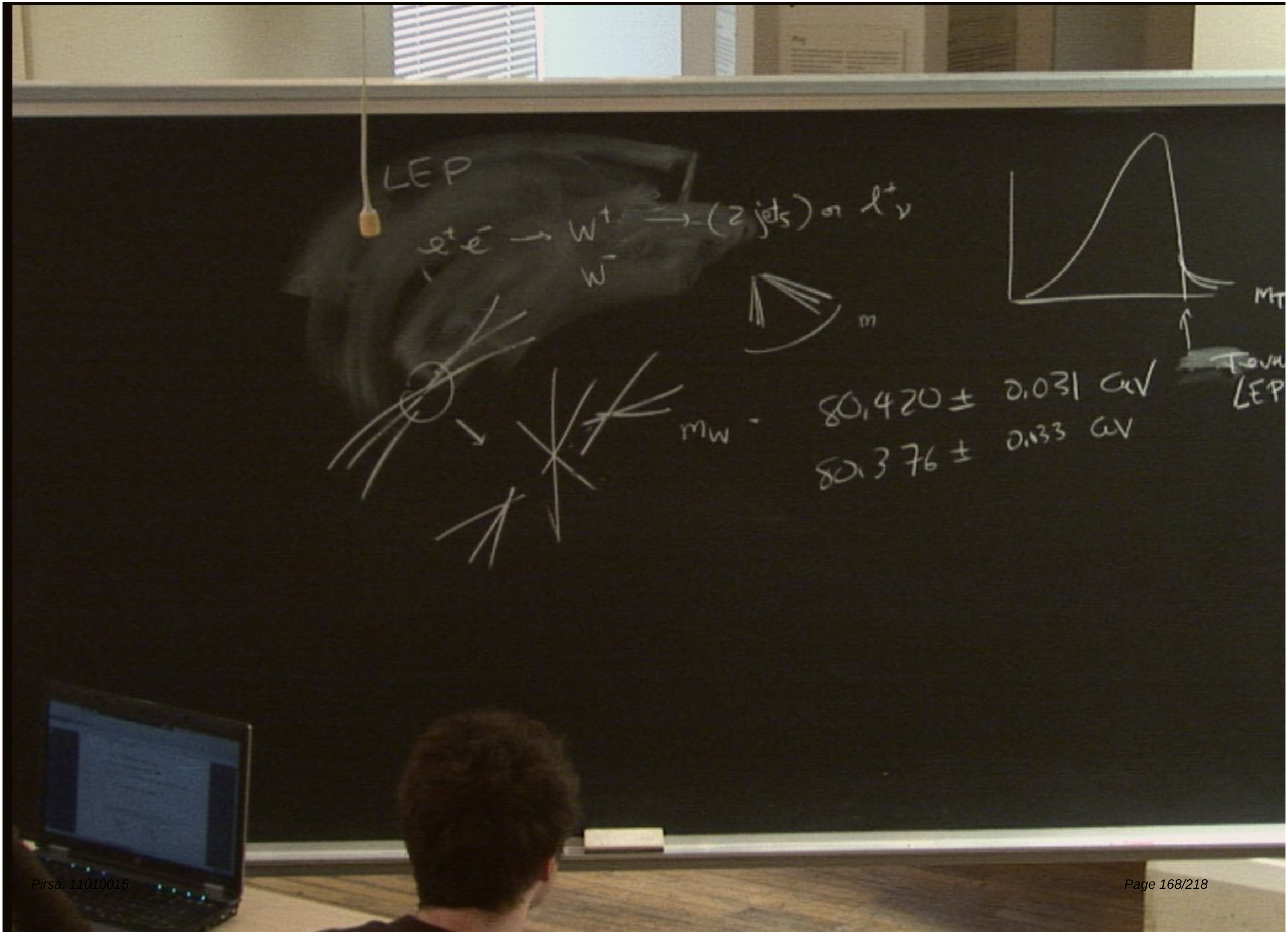


$$R_b = \frac{\Gamma(\to b\bar{b})}{\Gamma(\to \text{hadr})}$$

$= 0.216$

(0.220)


LEP
(2 jets) or $\ell^+\nu$
m_W

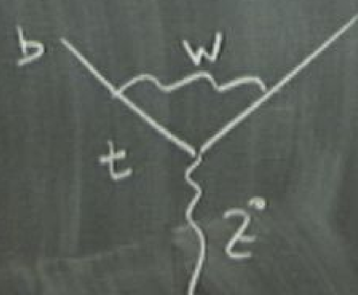

LEP
e+e- → W+ W- → (2 jets) or l+ν
m
mW = 80.420 ± 0.031 GeV
80.376 ± 0.033 GeV
LEP

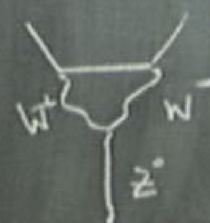
$\Gamma = 2.49 \text{ GeV}$

$\mathrm{BR}(\to \nu\bar{\nu}) = 6.7\%$ $\quad$ $\mathrm{BR}(\to \mu^+\mu^-) \cdot 3.3\%$

$\mathrm{BR}(\to c\bar{c}) = 11.9\%$ $\quad$ $\mathrm{BR}(\to d\bar{d}) \cdot 15.3\%$

$\mathrm{BR}(\to b\bar{b}) - 2\%$



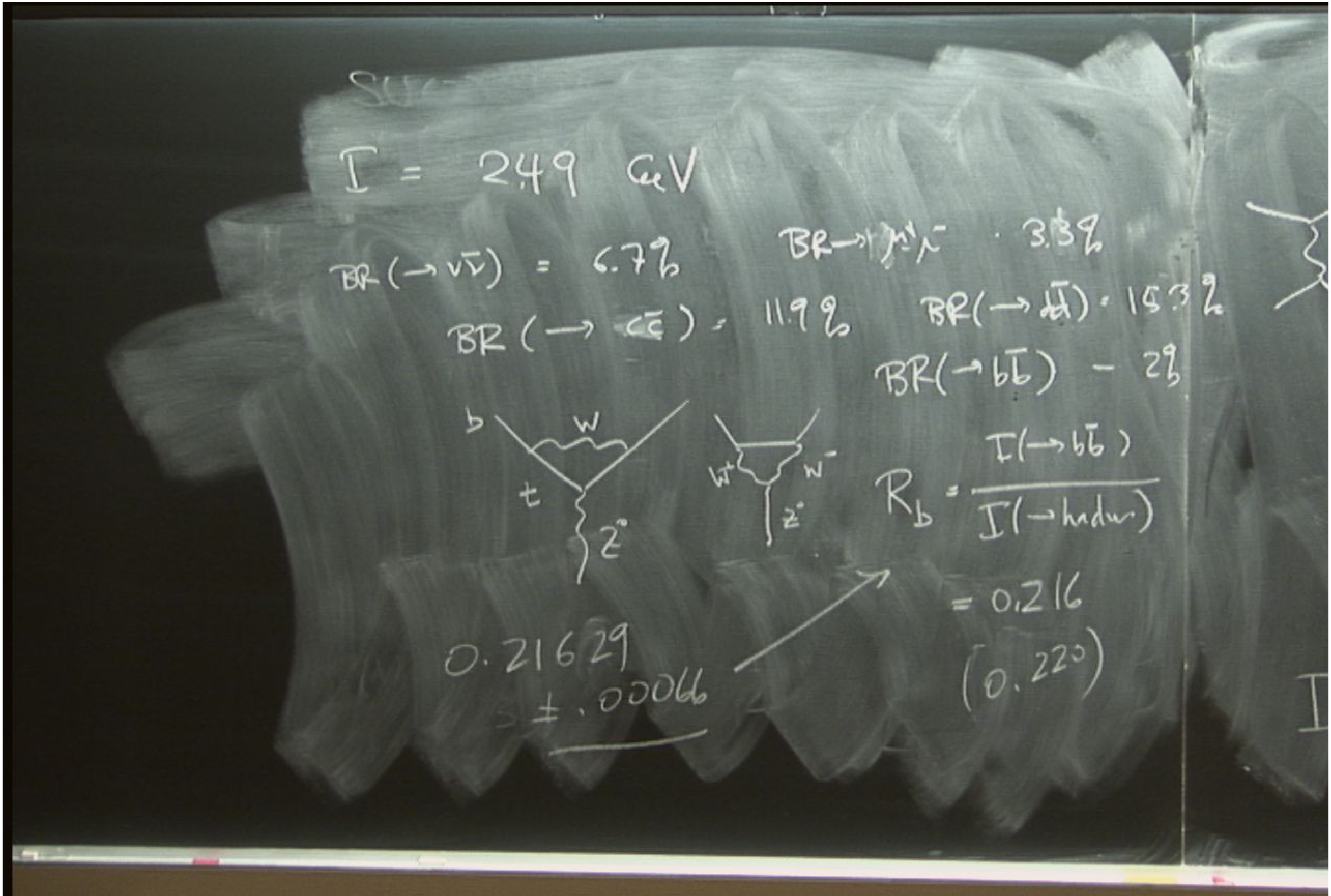


$$R_b = \frac{\Gamma(\to b\bar{b})}{\Gamma(\to \text{hadr.})}$$

$= 0.216$

(0.220)

0.2169



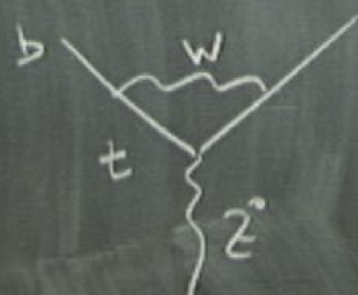
$\Gamma = 2.49$ GeV
$BR(\to \nu\bar{\nu}) = 6.7\%$
$BR \to \mu^+\mu^-$ 3.3%
$BR(\to c\bar{c}) = 11.9\%$
$BR(\to d\bar{d}) = 15.3\%$
$BR(\to b\bar{b}) - 2\%$
b
W
t
Z°
W^+
W^-
Z°
$R_b = \frac{\Gamma(\to b\bar{b})}{\Gamma(\to \text{hadr})}$
$= 0.216$
(0.220)
0.21629
$\pm .00066$

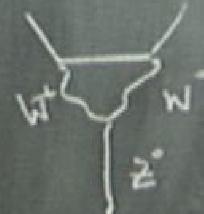
$\Gamma = 2.49 \text{ GeV}$

$BR(\to \nu\bar{\nu}) = 6.7\%$ $\quad BR \to \mu^+\mu^- \cdot 3.3\%$

$BR(\to c\bar{c}) = 11.9\%$ $\quad BR(\to d\bar{d}) = 15.3\%$

$BR(\to b\bar{b}) \sim 2\%$





$$R_b = \frac{\Gamma(\to b\bar{b})}{\Gamma(\to \text{hadr})}$$

$= 0.216$

$(\ldots 220)$

0.21629
$\pm .00066$

$\Gamma = 2.49$ GeV

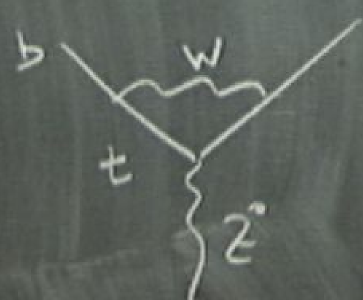
$BR(\to \nu\bar{\nu}) = 6.7\%$

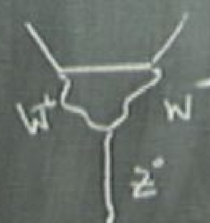
$BR(\to \mu^+\mu^-) \cdot 3.3\%$

$BR(\to c\bar{c}) = 11.9\%$

$BR(\to d\bar{d}) \cdot 15.3\%$

$BR(\to b\bar{b}) \sim 2\%$





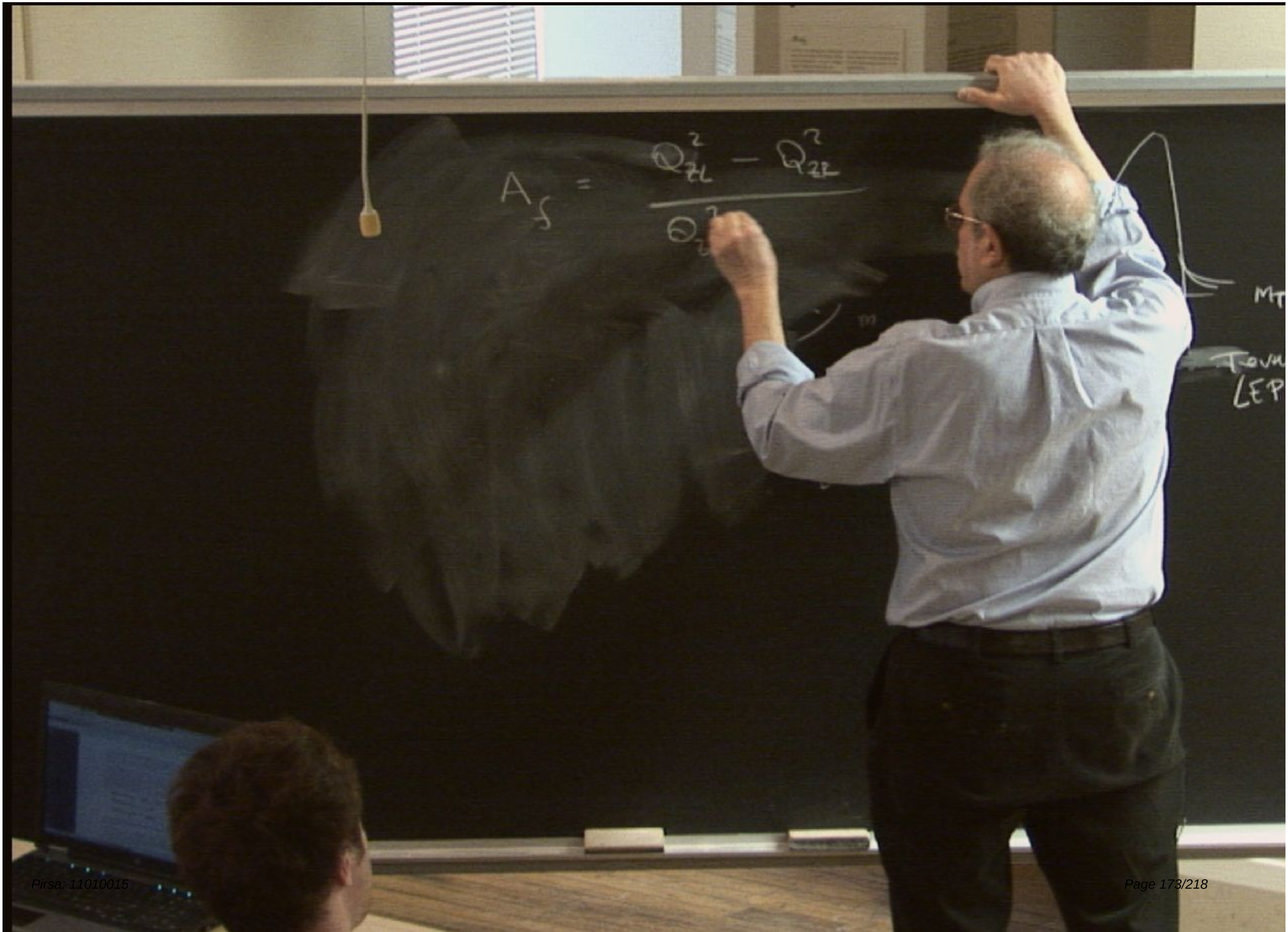
$$R_b = \frac{\Gamma(\to b\bar{b})}{\Gamma(\to \text{hadr.})}$$

$= 0.216$

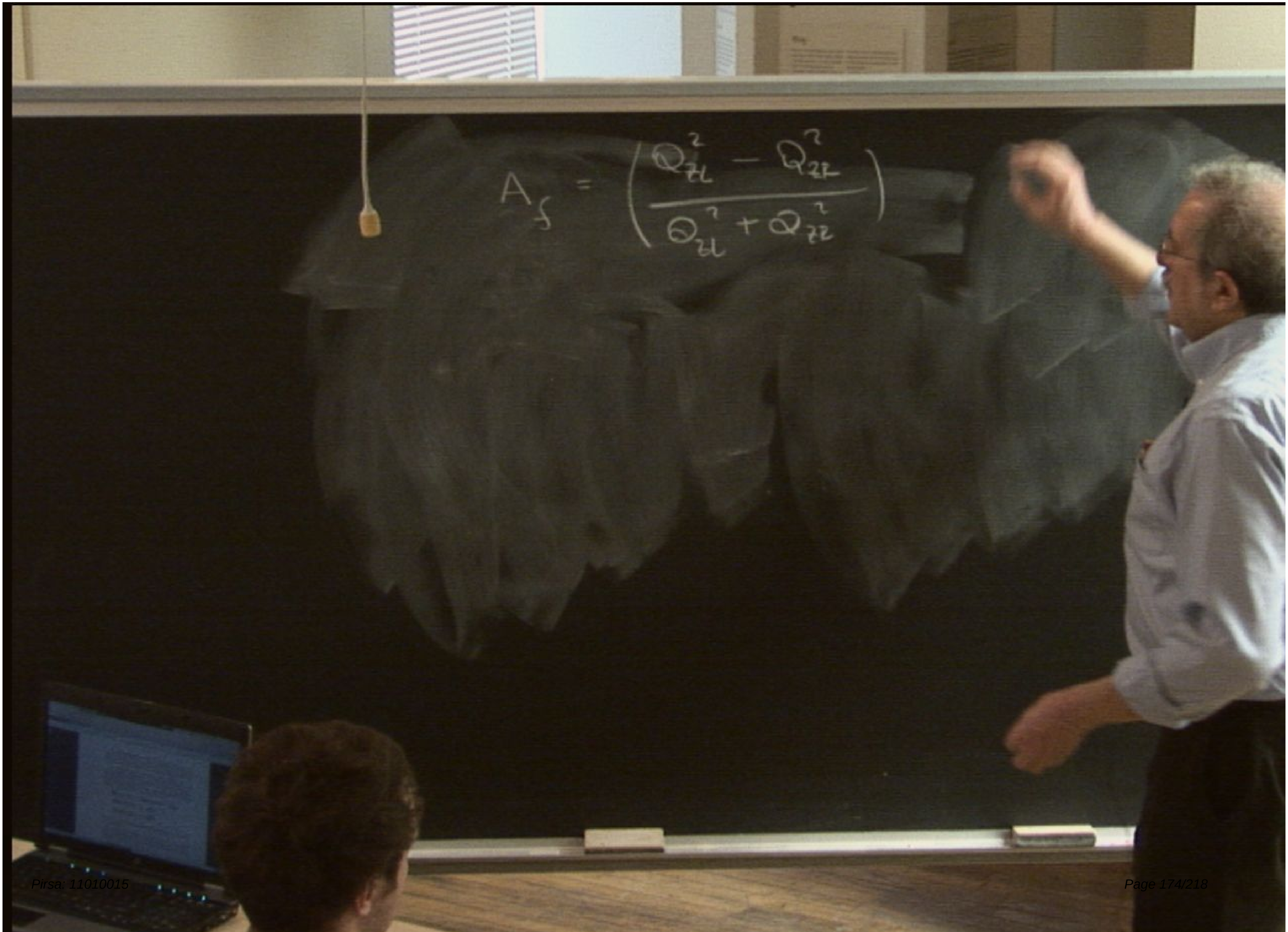
(0.220)

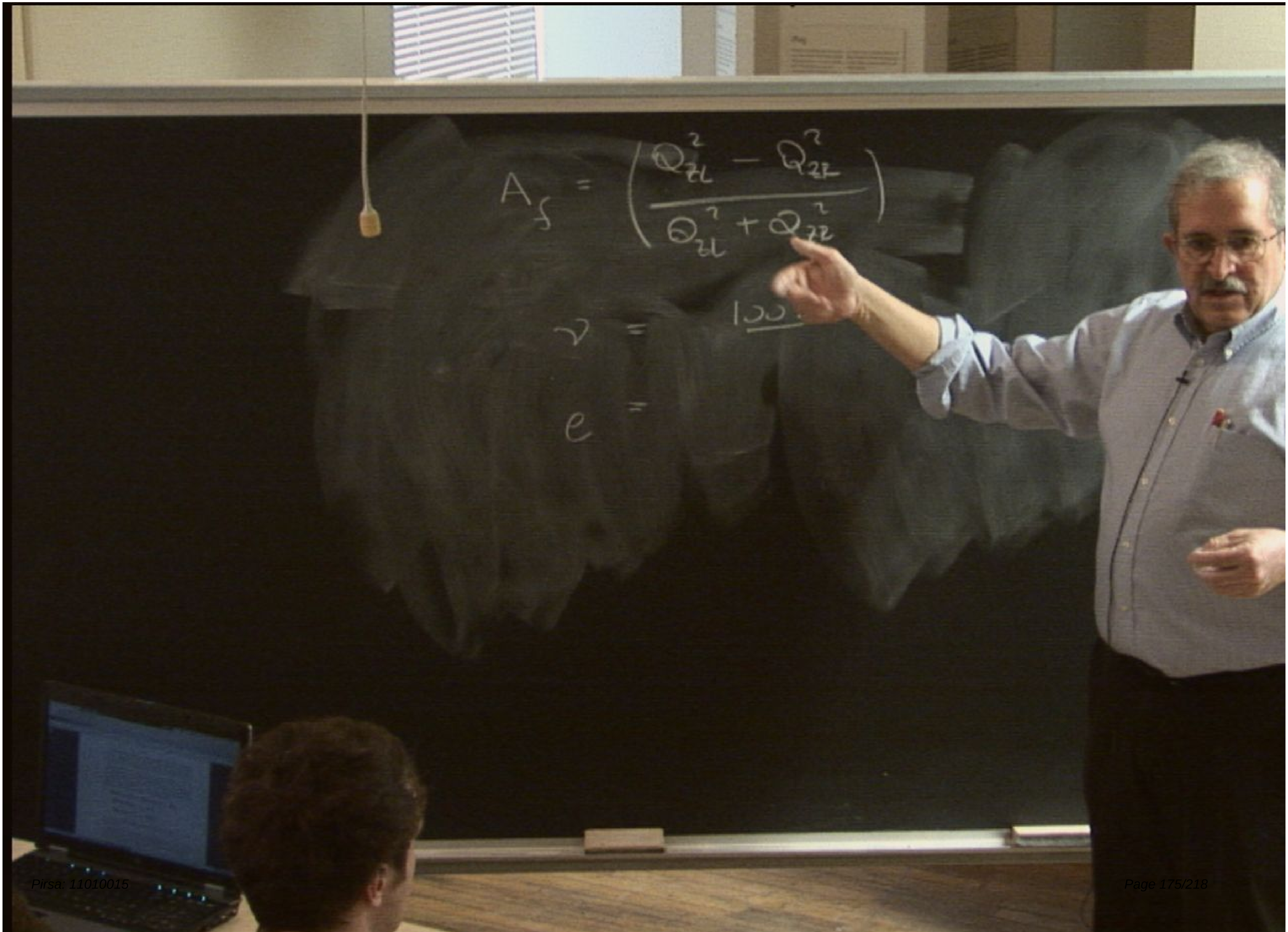
0.21629

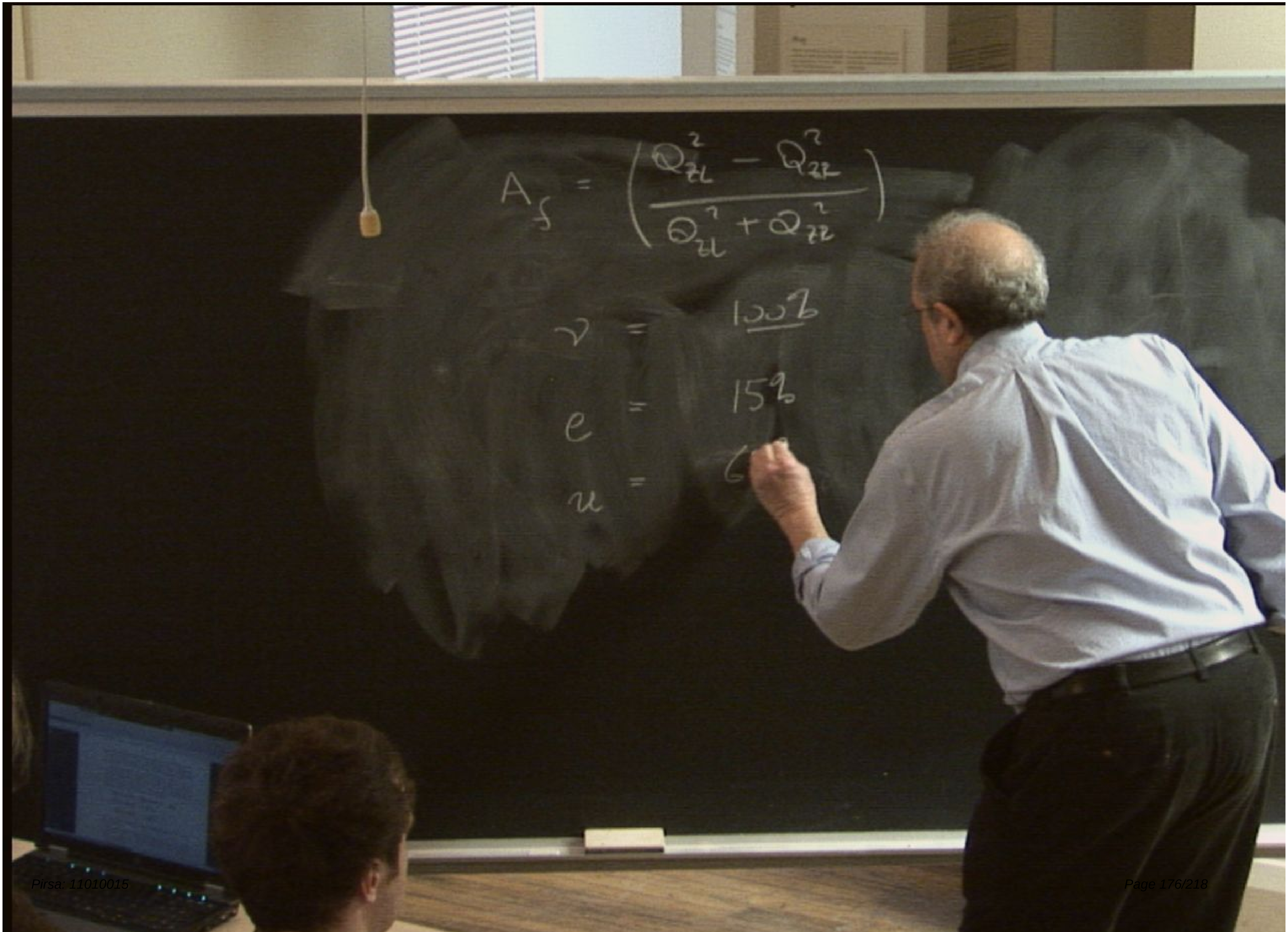
$\pm .00066$

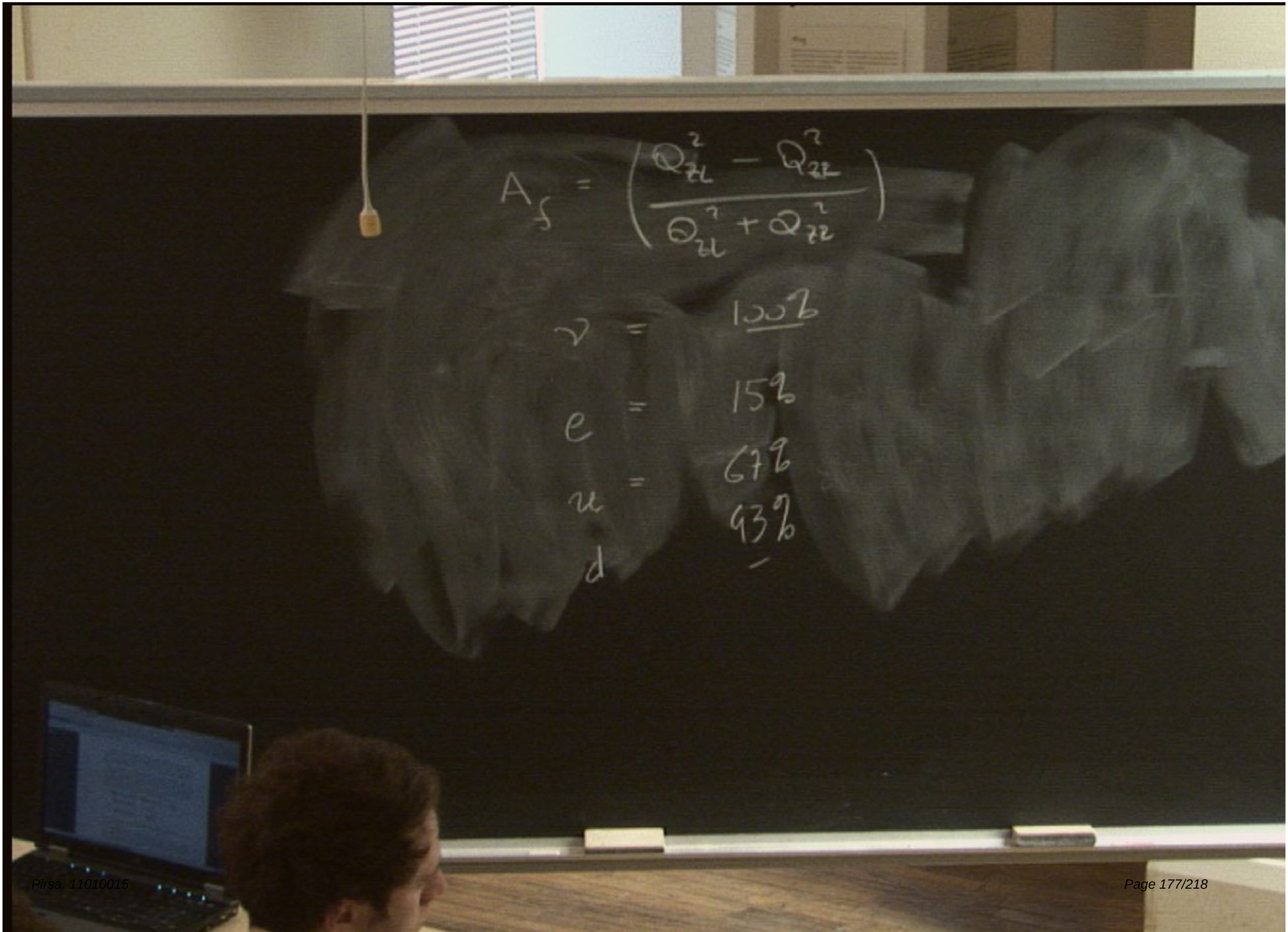


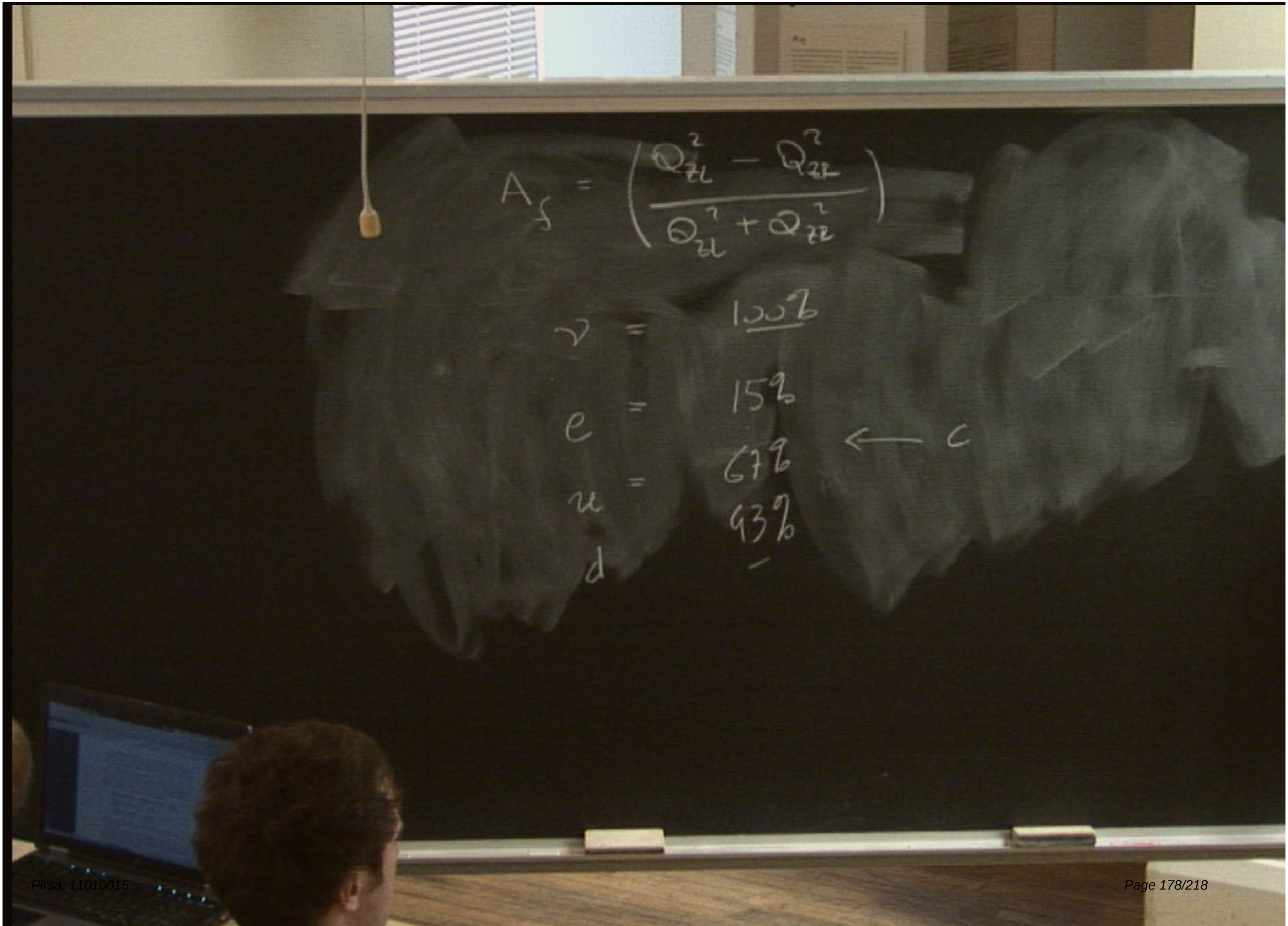
$A_f = \frac{Q_{ZL}^2 - Q_{ZR}^2}{Q_Z^2}$
LEP


$A_f = \left(\frac{Q_{zL}^2 - Q_{zR}^2}{Q_{zL}^2 + Q_{zR}^2} \right)$

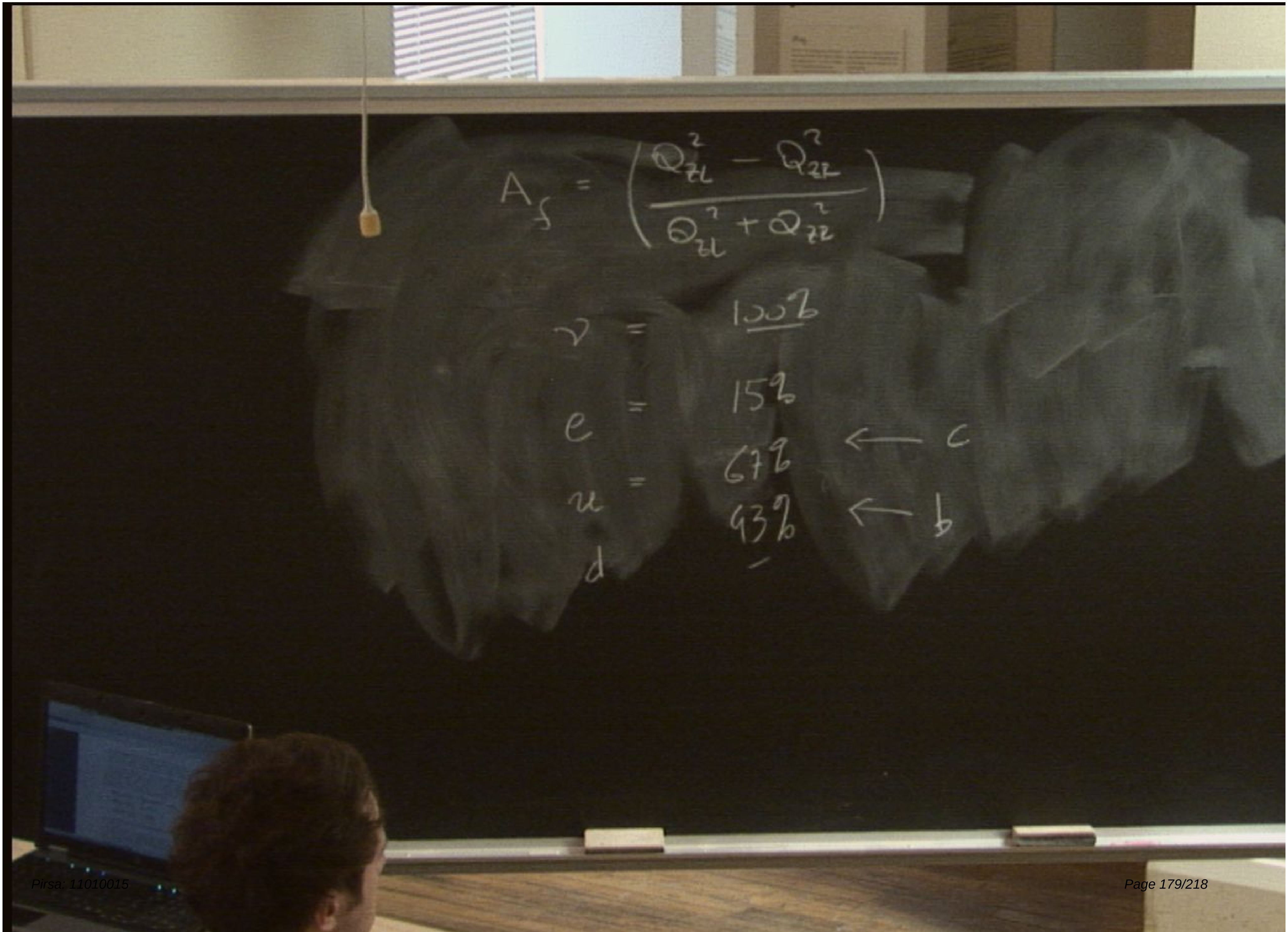

$A_f = \left(\frac{Q_{zL}^2 - Q_{zR}^2}{Q_{zL}^2 + Q_{zR}^2} \right)$
$\nu =$
100
$e =$

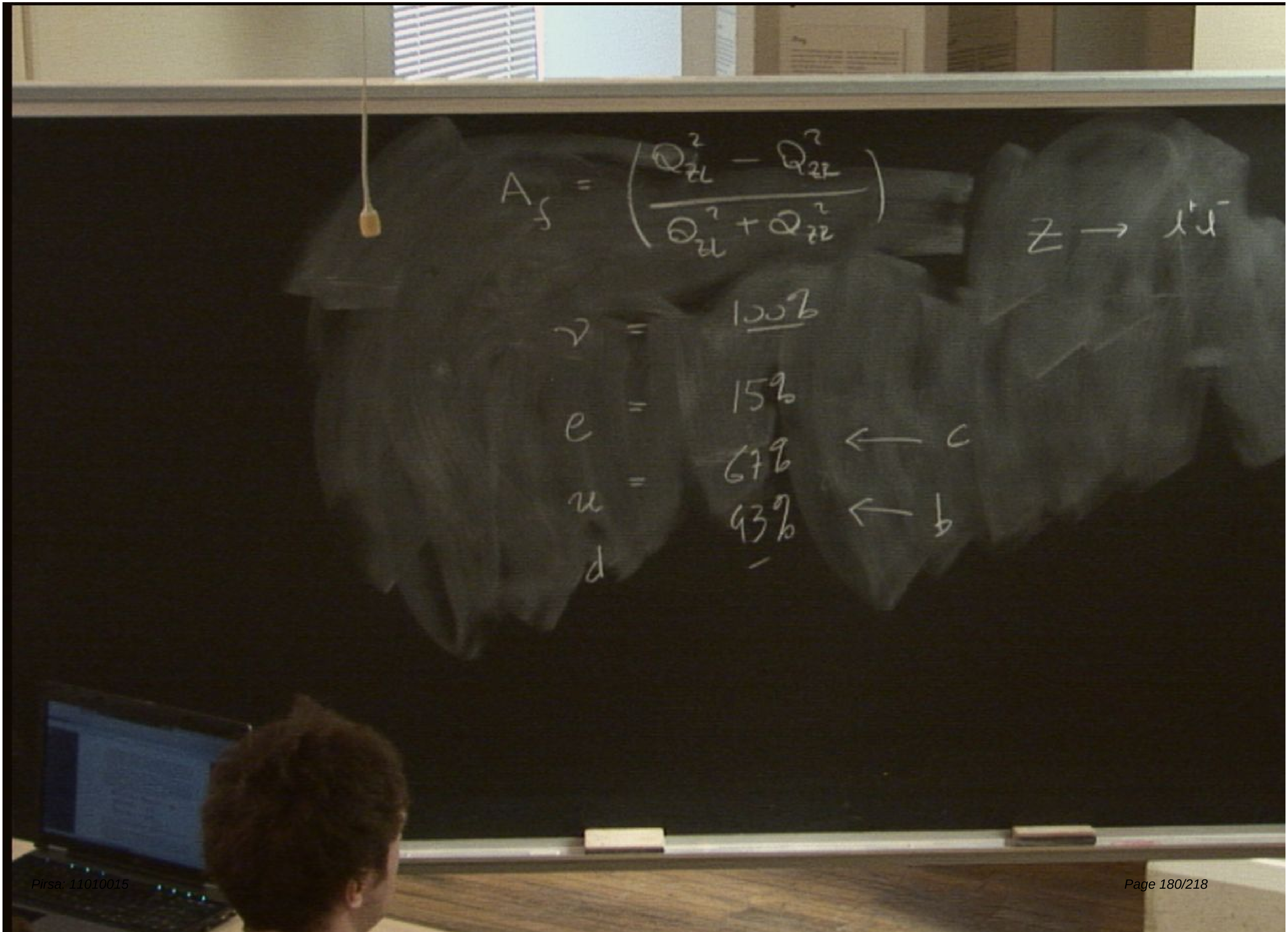

$A_f = \left(\frac{Q_{zL}^2 - Q_{zR}^2}{Q_{zL}^2 + Q_{zR}^2} \right)$
ν = 100%
e = 15%
μ =


$A_f = \left(\frac{Q_{zL}^2 - Q_{zR}^2}{Q_{zL}^2 + Q_{zR}^2} \right)$
ν = 100%
e = 15%
u = 67%
d = 93%



$A_f = \left(\frac{Q_{zL}^2 - Q_{zR}^2}{Q_{zL}^2 + Q_{zR}^2} \right)$
ν = 100%
e = 15%
u = 67%
d 93%
← c


$A_f = \left(\frac{Q_{zL}^2 - Q_{zR}^2}{Q_{zL}^2 + Q_{zR}^2} \right)$
ν = 100%
e = 15%
u = 67% ← c
d 93% ← b


$A_f = \left(\frac{Q_{Zl}^2 - Q_{Zr}^2}{Q_{Zl}^2 + Q_{Zr}^2} \right)$
$Z \to l^+ l^-$
ν = 100%
e = 15%
u = 67% ← c
d = 93% ← b

$$A_f = \left(\frac{Q_{ZL}^2 - Q_{ZR}^2}{Q_{ZL}^2 + Q_{ZR}^2} \right)$$

$Z \to l^+ l^-$

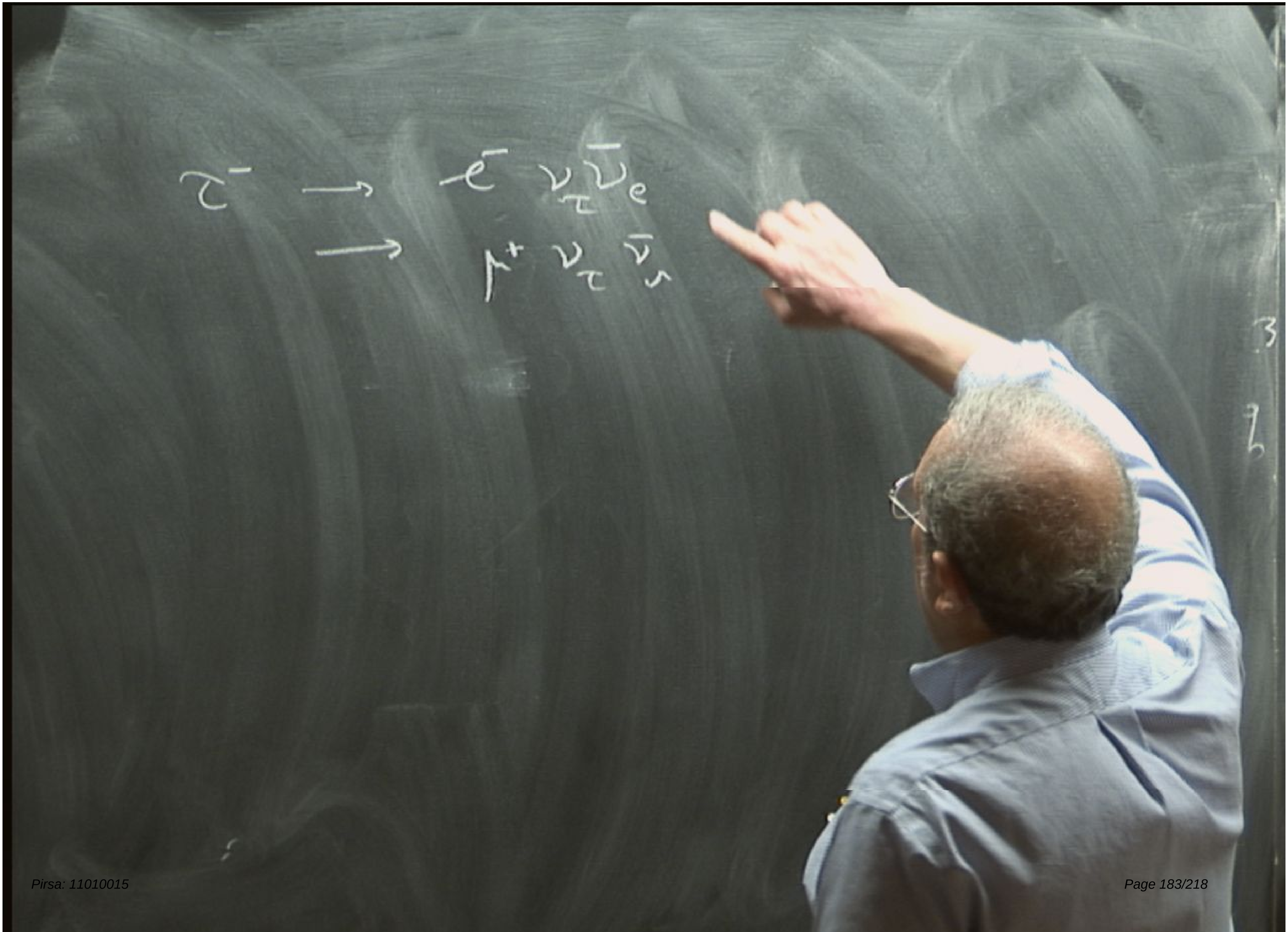
$\nu = \underline{100\%}$

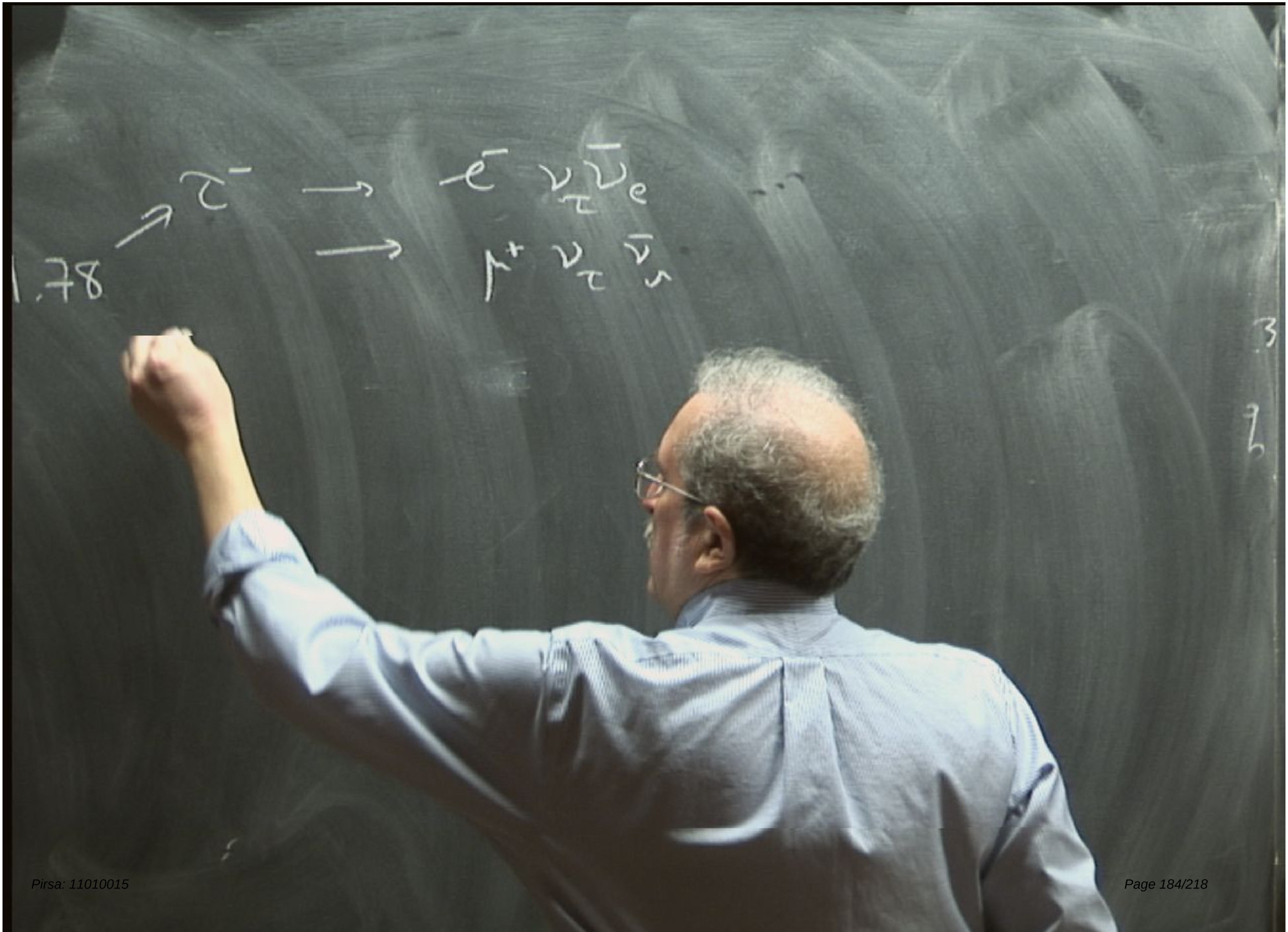
$e = 15\%$

$u = 67\% \leftarrow c$

$d \quad 93\% \leftarrow b$

τ^-

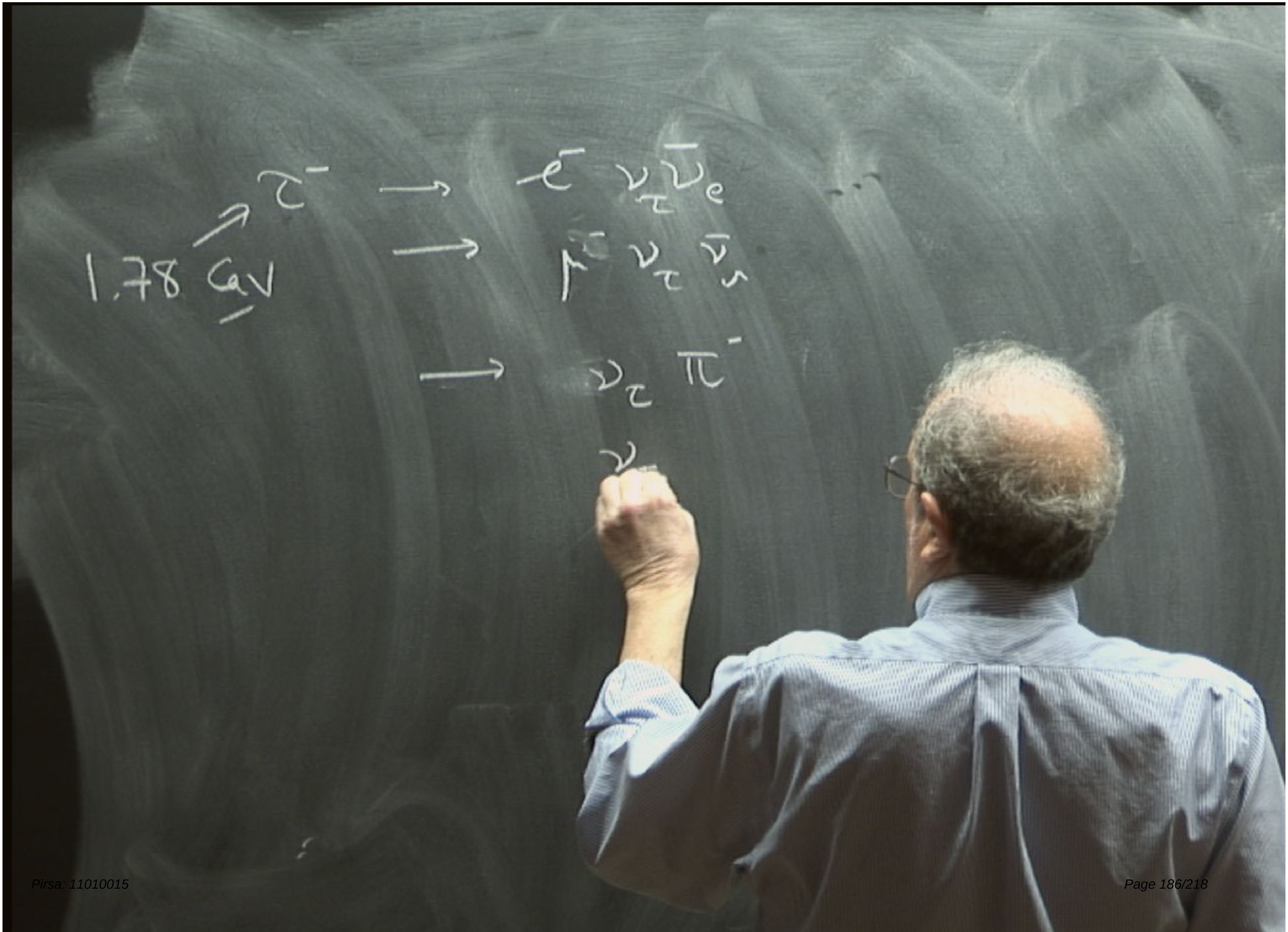

$\tau^- \longrightarrow e^- \nu_\tau \bar{\nu}_e$
$\longrightarrow \mu^+ \nu_\tau \bar{\nu}_\mu$


$\tau^- \longrightarrow e^- \nu_\tau \bar{\nu}_e$
$\longrightarrow \mu^+ \nu_\tau \bar{\nu}_\mu$
1.78

$$\tau^- \longrightarrow e^- \nu_\tau \bar{\nu}_e$$

$$\longrightarrow \mu^- \nu_\tau \bar{\nu}_\mu$$

1.78 GeV


$\tau^- \longrightarrow e^- \nu_\tau \bar{\nu}_e$
1.78 GeV
$\longrightarrow \mu^- \nu_\tau \bar{\nu}_\mu$
$\longrightarrow \nu_\tau \pi^-$
ν

$$1.78\ \mathrm{GeV} \nearrow \tau^- \longrightarrow e^- \nu_\tau \bar{\nu}_e$$

$$\longrightarrow \mu^- \nu_\tau \bar{\nu}_\mu$$

$$\longrightarrow \nu_\tau \pi^-$$

$$\nu_\tau e^-$$

$$\nu_\tau a_1^-$$

$$1.78\ \underline{GeV} \nearrow \tau^-$$

$$\longrightarrow e^- \nu_\tau \bar{\nu}_e$$

$$\longrightarrow \mu^- \nu_\tau \bar{\nu}_\mu$$

$$\longrightarrow \nu_\tau \pi^-$$

$$\nu_\tau e^-$$

$$\nu_\tau a_1^-$$

$$J^-_{V-A}$$

$1.78\ \underline{GeV} \nearrow \tau^-$

$\tau^- \longrightarrow e^-\, \nu_\tau\, \bar{\nu}_e$

$\longrightarrow \mu^-\, \nu_\tau\, \bar{\nu}_\mu$

$\longrightarrow \nu_\tau\, \pi^-$

$\nu_\tau\, \rho^-$

$\nu_\tau\, a_1^-$

J^-_{V-A}

$1.78\ \mathrm{GeV} \nearrow \tau^-$

$\tau^- \longrightarrow e^- \nu_\tau \bar{\nu}_e$

$\longrightarrow \mu^- \nu_\tau \bar{\nu}_\mu$

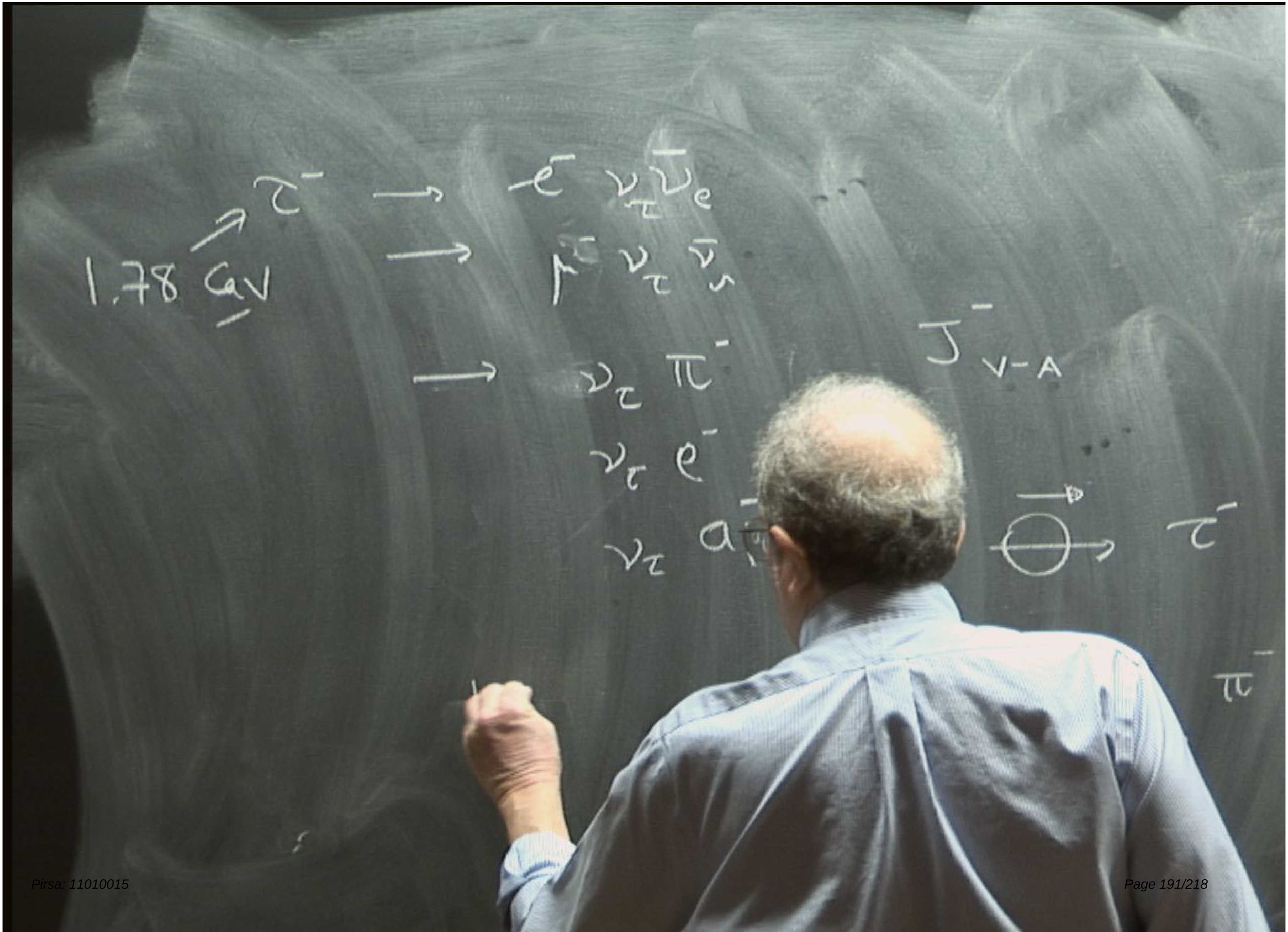
$\longrightarrow \nu_\tau \pi^-$

$\nu_\tau \rho^-$

$\nu_\tau a_1^-$

J^-_{V-A}

τ^-


$\tau^- \rightarrow e^- \nu_\tau \bar{\nu}_e$
1.78 GeV
$\rightarrow \mu^- \nu_\tau \bar{\nu}_\mu$
$\rightarrow \nu_\tau \pi^-$
$\nu_\tau e^-$
$\nu_\tau a^-$
J^-_{V-A}
τ^-
π^-

$$\tau^- \longrightarrow e^- \, \nu_\tau \bar{\nu}_e$$

1.78 GeV

$$\longrightarrow \mu^- \, \nu_\tau \, \bar{\nu}_\mu$$

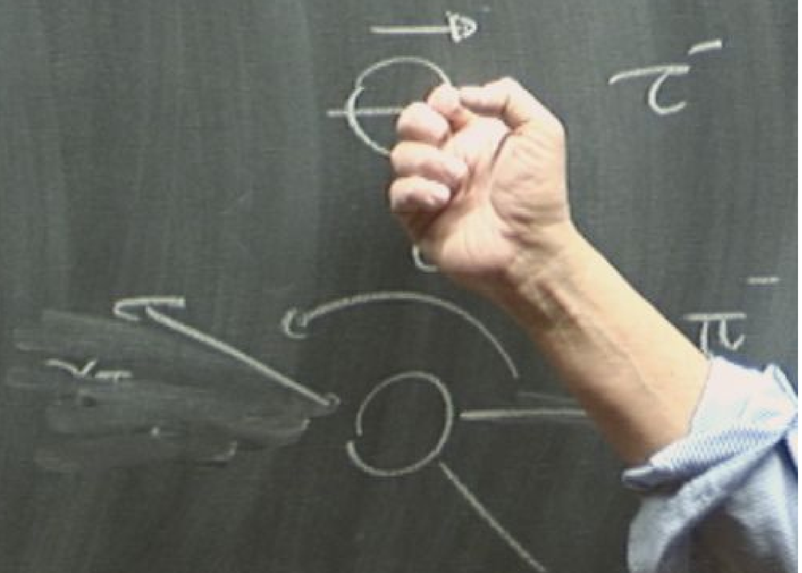
$$\longrightarrow \nu_\tau \, \pi^-$$

$$\nu_\tau \, e^-$$

$$\nu_\tau \, a_1^-$$

$$J^-_{V-A}$$

$$(1 - \cos\theta)$$



$$\tau^- \longrightarrow e^- \nu_\tau \bar{\nu}_e$$

1.78 GeV

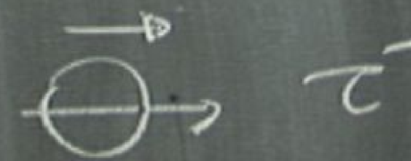
$$\longrightarrow \mu^- \nu_\tau \bar{\nu}_\mu$$

$$\longrightarrow \nu_\tau \pi^-$$

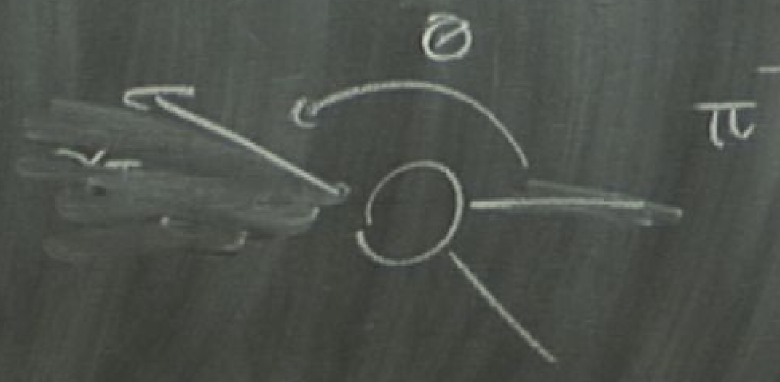
$$\nu_\tau e^-$$

$$\nu_\tau a_1^-$$

$$J^-_{V-A}$$



$$\frac{d\Gamma}{d\cos\theta} \sim (1 - \cos\theta)$$



$$\tau^- \to e^- \nu_\tau \bar{\nu}_e$$

$1.78\ \text{GeV}$

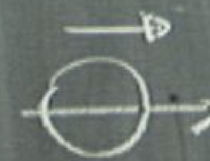
$$\to \mu^- \nu_\tau \bar{\nu}_\mu$$

$$\to \nu_\tau \pi^-$$

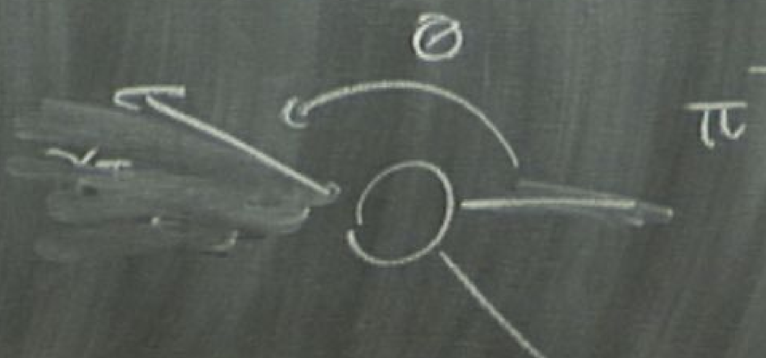
$$\nu_\tau e^-$$

$$\nu_\tau a_1^-$$

$$J^-_{V-A}$$



τ^-



$$\frac{d\Gamma}{d\cos\theta} \sim (1-\cos\theta)$$

$$\tau^- \longrightarrow e^- \nu_\tau \bar{\nu}_e$$

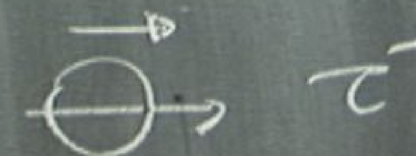
$$1.78\ \text{GeV} \qquad \longrightarrow \mu^- \nu_\tau \bar{\nu}_\mu$$

$$\longrightarrow \nu_\tau \pi^-$$

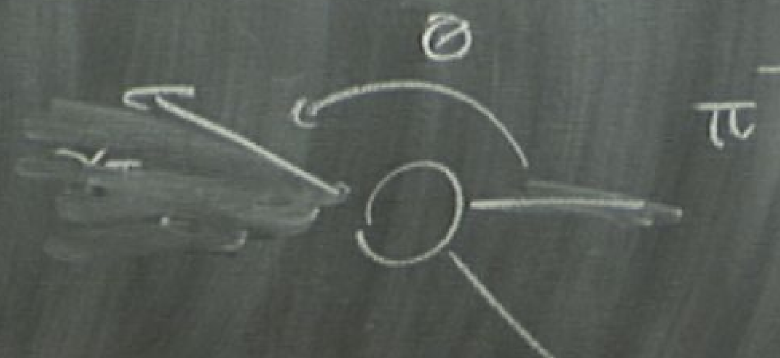
$$\nu_\tau \rho^-$$

$$\nu_\tau a_1^-$$

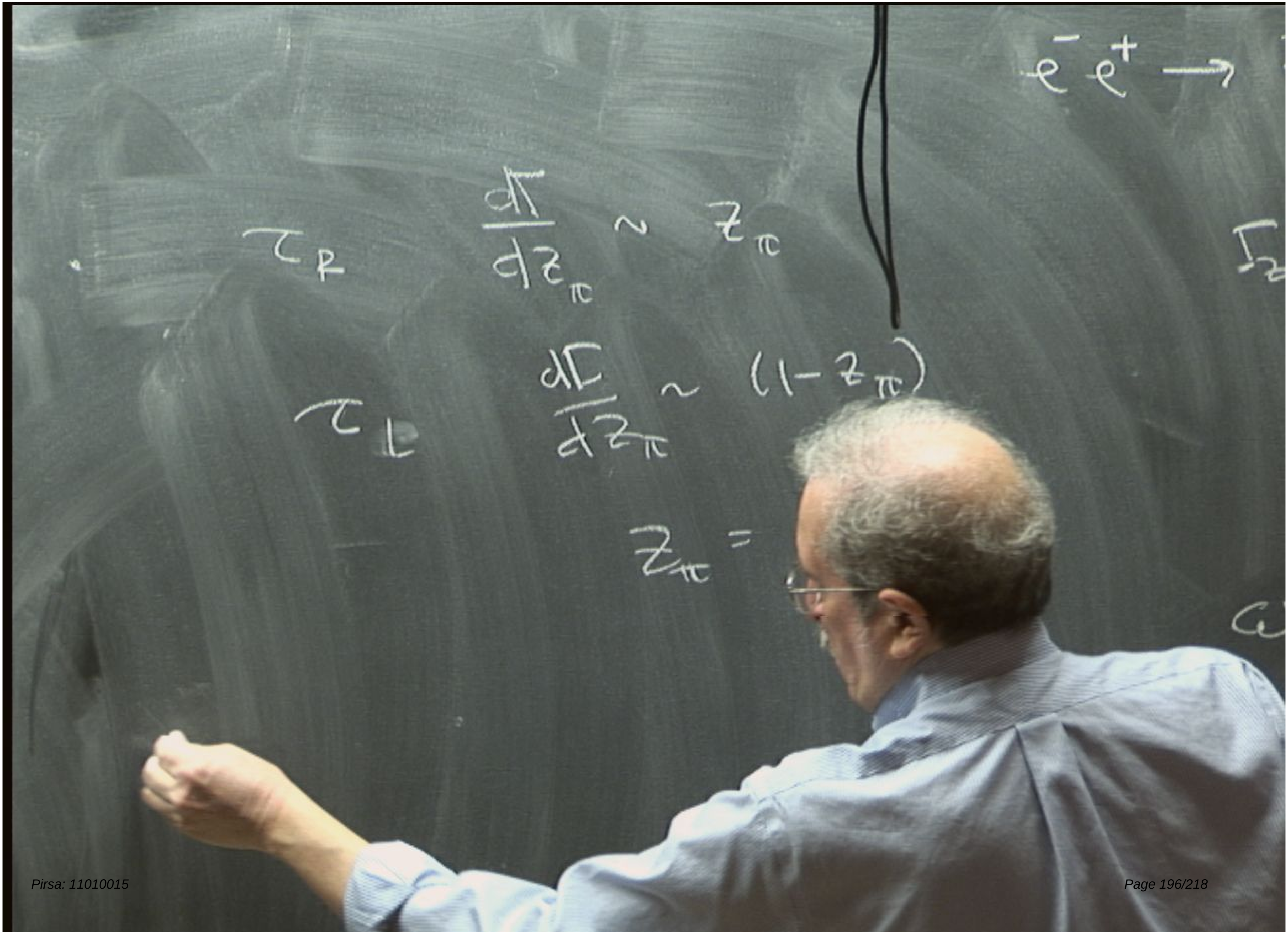
$$J^-_{V-A}$$



$$\frac{d\Gamma}{d\cos\theta} \sim (1-\cos\theta)$$



$$:\quad \frac{d\Gamma}{dz} \sim (1-z)$$

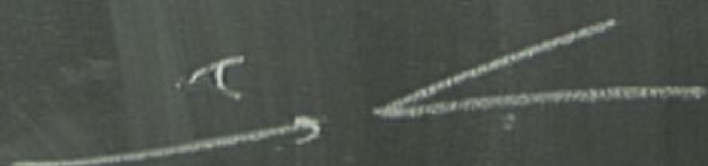

$e^- e^+ \longrightarrow$
$\tau_R \quad \frac{d\Gamma}{dz_\pi} \sim z_\pi$
$\tau_L \quad \frac{d\Gamma}{dz_\pi} \sim (1 - z_\pi)$
$z_\pi =$

$e^- e^+ \longrightarrow$

$\tau_R \qquad \frac{d\Gamma}{dz_\pi} \sim z_\pi$

$\tau_L \qquad \frac{d\Gamma}{dz_\pi} \sim (1 - z_\pi)$

$$z_\pi = \frac{E_\pi}{E_\tau}$$

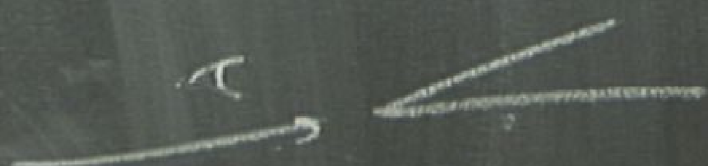


$e^- e^+ \longrightarrow$

$\tau_R \qquad \frac{d\Gamma}{dz_\pi} \sim z_\pi$

$\tau_L \qquad \frac{d\Gamma}{dz_\pi} \sim (1 - z_\pi)$

$$z_\pi = \frac{E_\pi}{E_\tau}$$



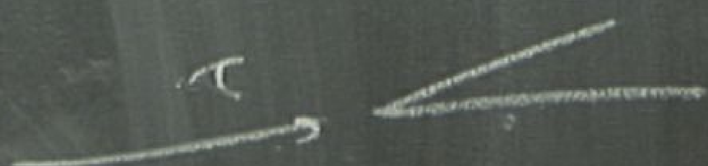
40

$e^- e^+ \longrightarrow$

$$\tau_R \qquad \frac{d\Gamma}{dz_\pi} \sim z_\pi$$

$$\tau_L \qquad \frac{d\Gamma}{dz_\pi} \sim (1 - z_\pi)$$

$$z_\pi = \frac{E_\pi}{E_\tau}$$



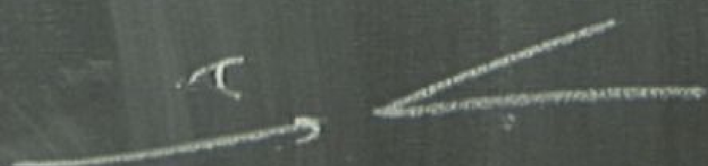
40

$e^- e^+ \longrightarrow$

$\tau_R \quad \frac{d\Gamma}{dz_\pi} \sim z_\pi$

$\tau_L \quad \frac{d\Gamma}{dz_\pi} \sim (1 - z_\pi)$

$z_\pi = \frac{E_\pi}{E_\tau}$



$A_\tau = 0.1465 \pm 0.0032$

40

$e^- e^+ \longrightarrow$

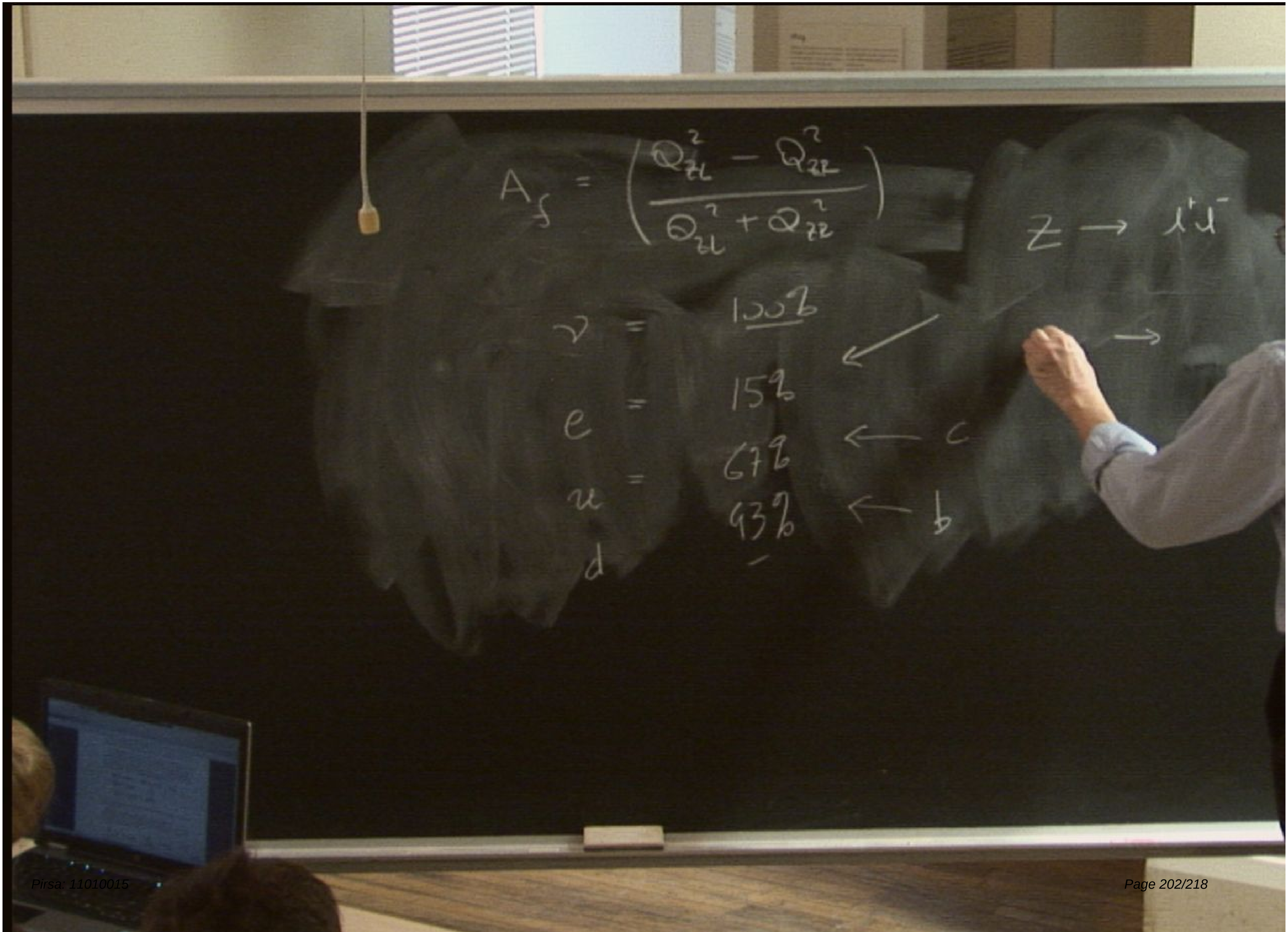
$\tau_R \quad \frac{d\Gamma}{dz_\pi} \sim z_\pi$

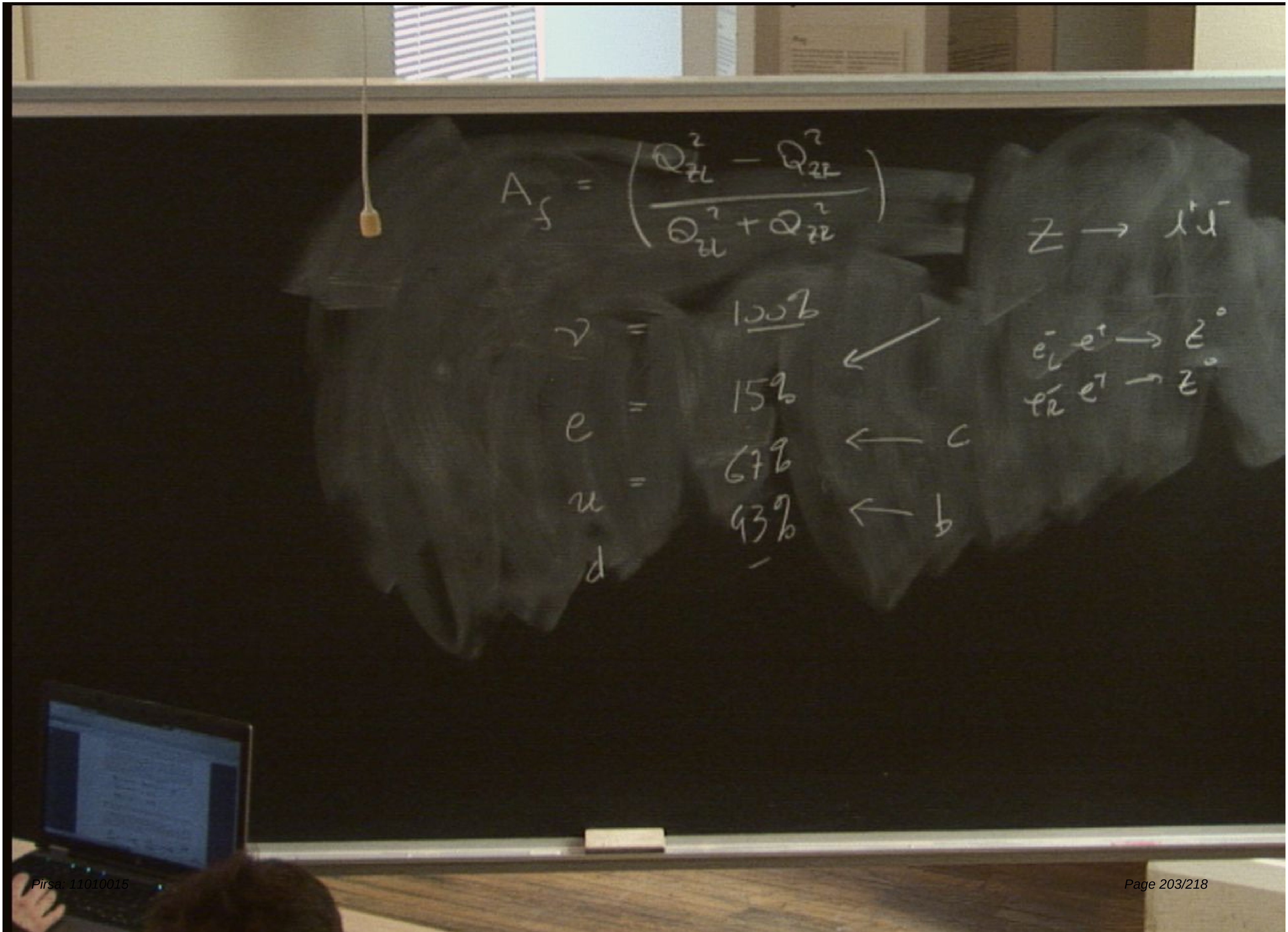
$\tau_L \quad \frac{d\Gamma}{dz_\pi} \sim (1 - z_\pi)$

$z_\pi = \frac{E_\pi}{E_\tau}$

τ

$A_\tau = 0.1465 \pm 0.0032$


$A_f = \left(\frac{Q_{zL}^2 - Q_{zR}^2}{Q_{zL}^2 + Q_{zR}^2}\right)$
$Z \to l^+ l^-$
$\nu = 100\%$
$e = 15\%$
$u = 67\%$
$d = 43\%$
c
b


$A_f = \left(\frac{Q_{zL}^2 - Q_{zR}^2}{Q_{zL}^2 + Q_{zR}^2}\right)$
$Z \to l^+ l^-$
$\nu =$ 100%
$e =$ 15%
$u =$ 67% ← c
$d =$ 93% ← b
$e_L^- e^+ \to Z^0$
$e_R^- e^+ \to Z^0$

$$A_f = \left(\frac{Q_{ZL}^2 - Q_{ZR}^2}{Q_{ZL}^2 + Q_{ZR}^2} \right)$$

$Z \longrightarrow l^+ l^-$

$\nu = 100\%$

$e_L^- e^+ \longrightarrow Z^0$

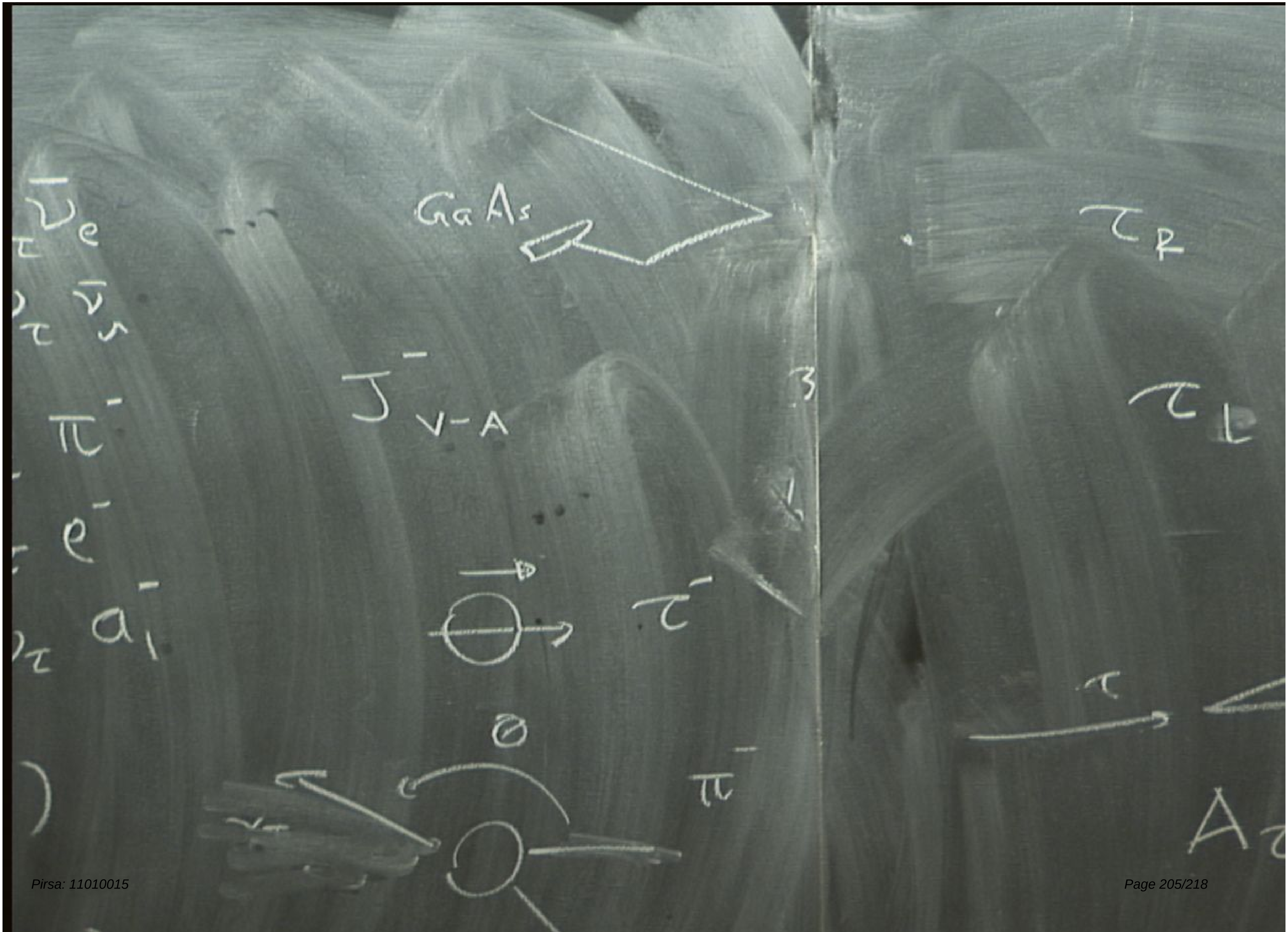
$e_R^- e^+ \longrightarrow Z^0$

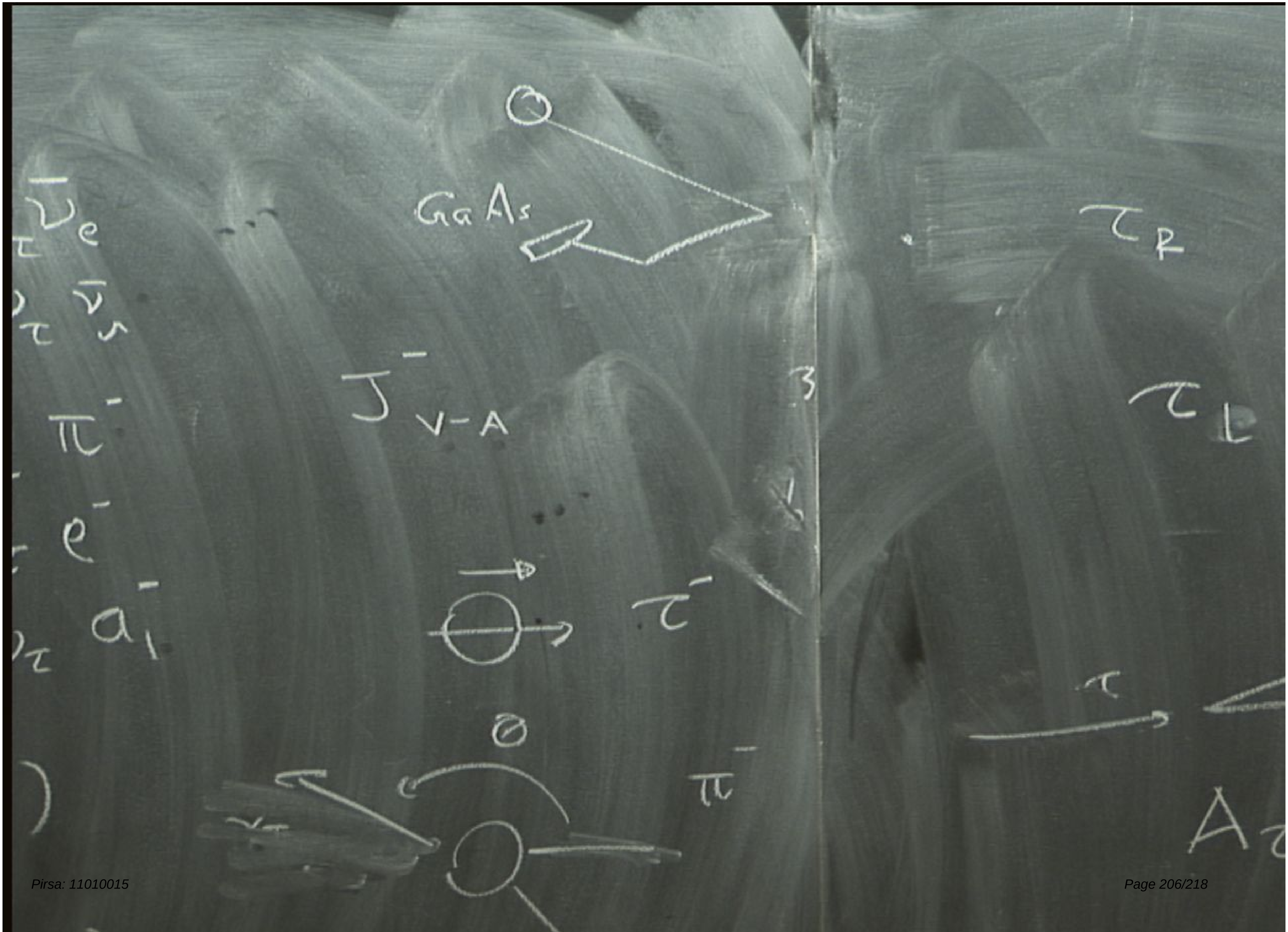
$e = 15\%$

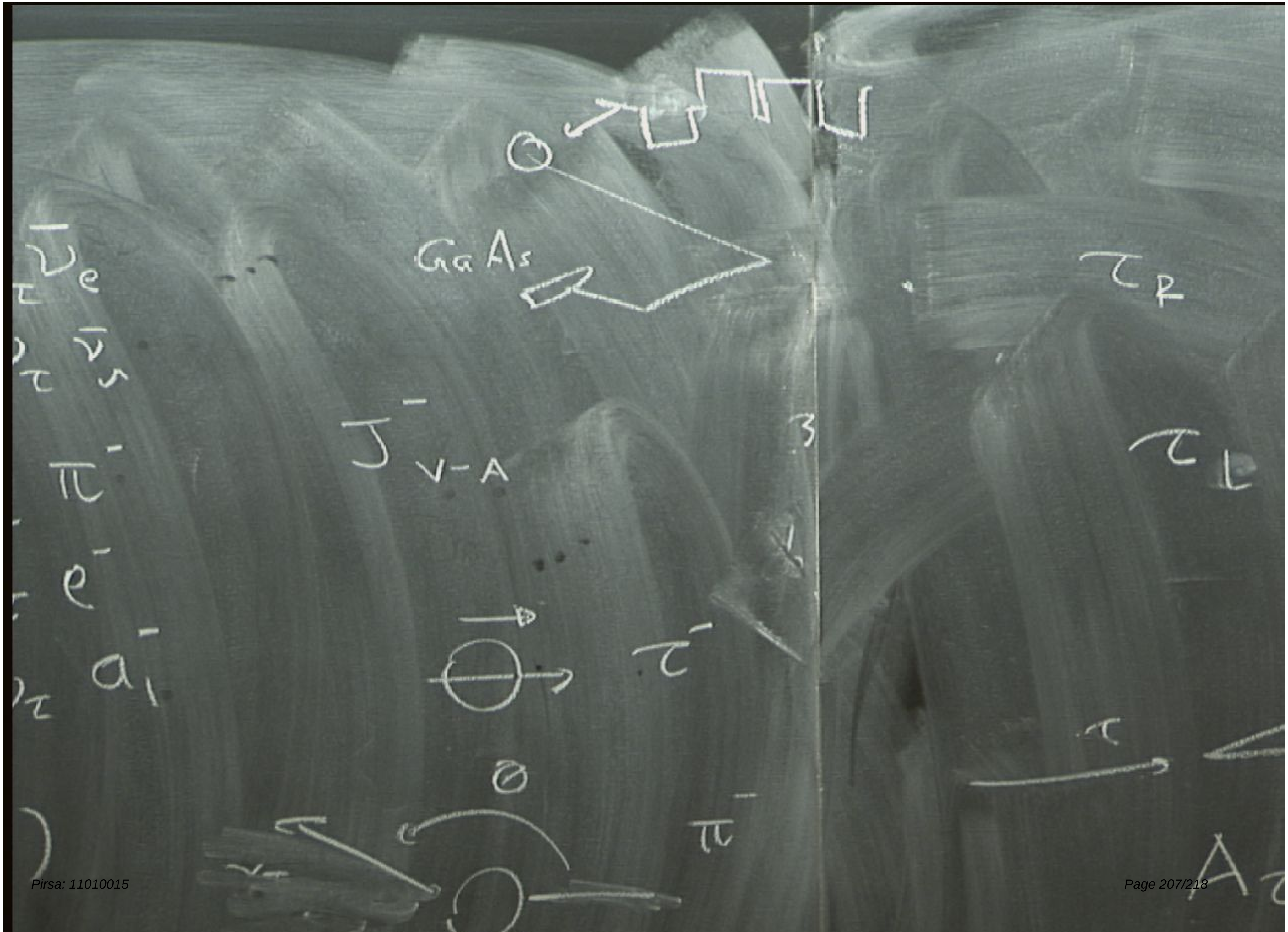
$67\% \longleftarrow c$

$u = 93\% \longleftarrow b$

d

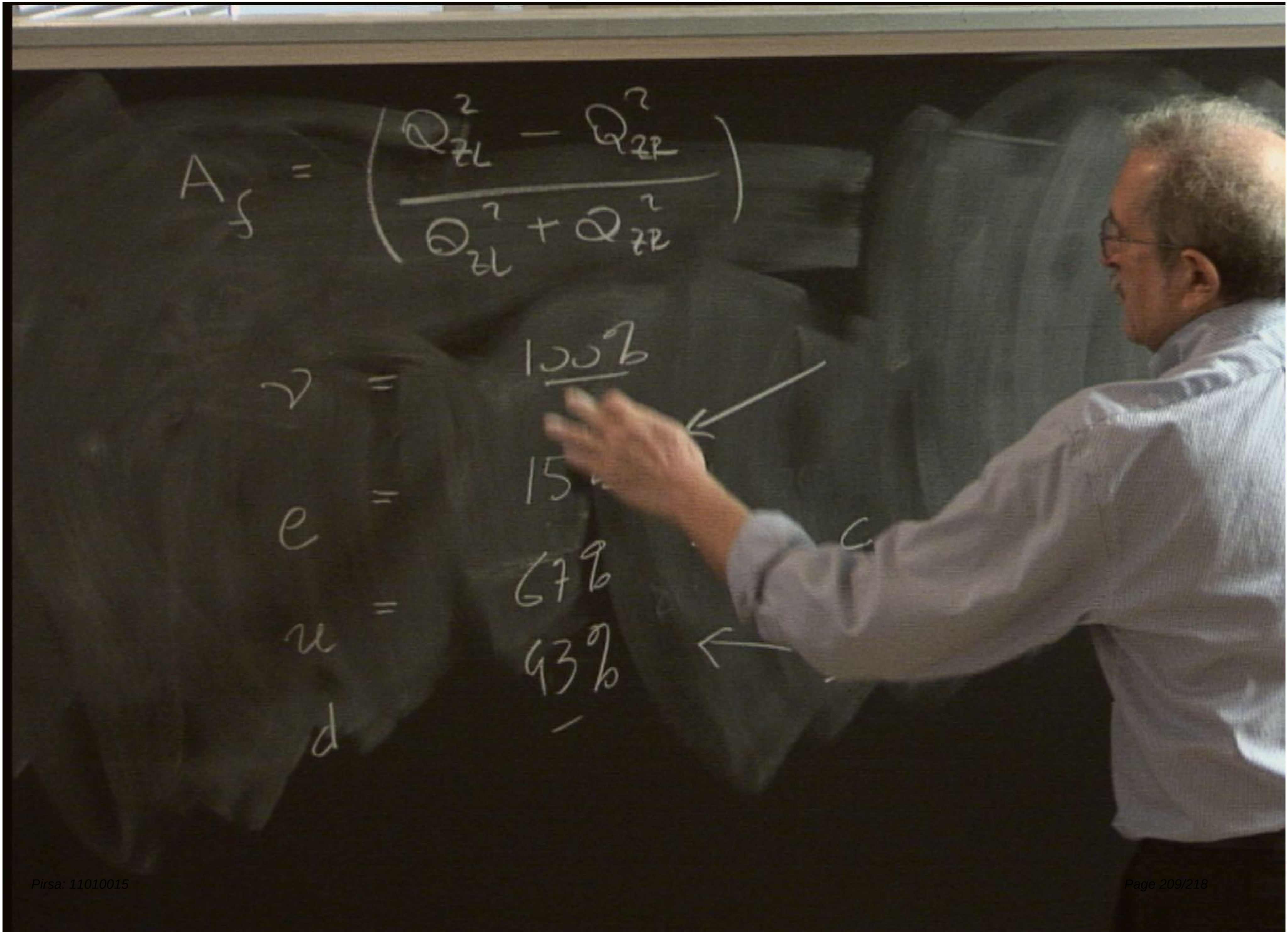

GaAs
$\bar{\nu}_e$
τ_R
ν_τ $\bar{\nu}_s$
J^-_{V-A}
τ_L
π^-
e^-
a_1^-
τ^-
θ
π^-
τ
A_τ


GaAs
$\bar{\nu}_e$
J^-_{V-A}
π^-
e^-
a_1^-
τ^-
θ
π^-
τ_R
τ_L
τ


GaAs
τ_R
$\bar{\nu}_e$
$\bar{\nu}_s$
J^-_{V-A}
π^-
e^-
a_1^-
τ^-
τ_L
τ
π^-
A

$e_R^- \quad e^- \quad e$

$$A_e = 0.1513 \pm .002$$


$A_f = \left(\frac{Q_{ZL}^2 - Q_{ZR}^2}{Q_{ZL}^2 + Q_{ZR}^2} \right)$
ν = 100%
e = 15
67%
u = 43%
d

$$A_f = \left(\frac{Q_{ZL}^2 - Q_{ZR}^2}{Q_{ZL}^2 + Q_{ZR}^2} \right)$$

$\nu = 100\%$

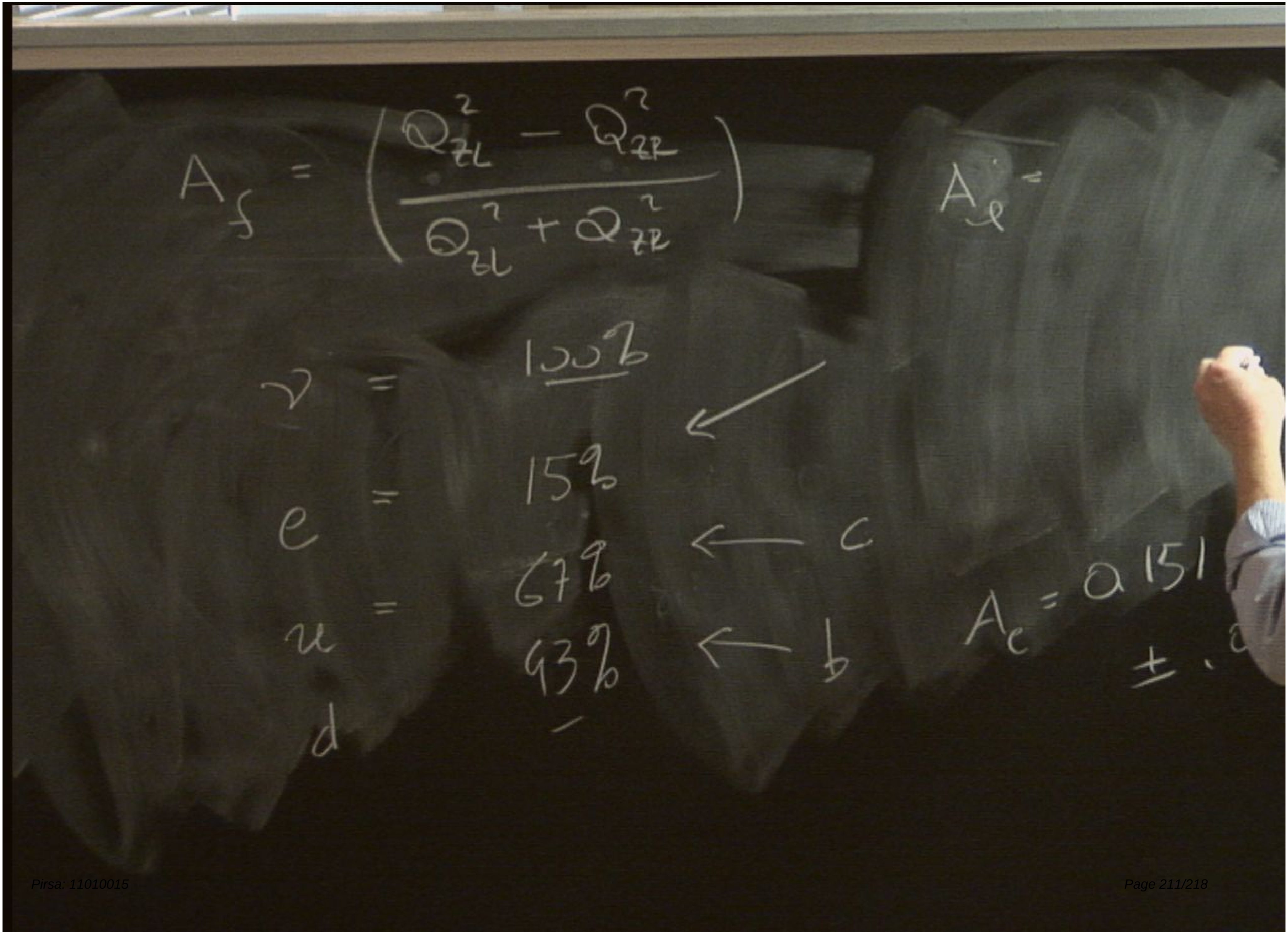
$e = 15\%$

$u = 67\% \leftarrow c$

$d = 93\% \leftarrow b$

$A_c = 0.1$

$\pm$


$A_f = \left(\frac{Q_{ZL}^2 - Q_{ZR}^2}{Q_{ZL}^2 + Q_{ZR}^2} \right)$
$A_e =$
100%
$\nu =$
15%
$e =$
67%
c
$u =$
93%
b
d
$A_c = 0.151$

$$= \left(\frac{Q_{ZL}^2 - Q_{ZR}^2}{Q_{ZL}^2 + Q_{ZR}^2} \right)$$

$$A_\ell = 8\left(\frac{1}{4} - s_W^2\right) + O(s_W^4)$$

$\nu = 100\%$

$e = 15\%$

$67\% \leftarrow c$

$u = 93\% \leftarrow b$

d

$$A_c = 0.1513$$

$$A_f = \left(\frac{Q_{ZL}^2 - Q_{ZR}^2}{Q_{ZL}^2 + Q_{ZR}^2} \right)$$

$$A_\ell = 8\left(\tfrac{1}{4} - s_W^2\right) + O(s_W^4)$$

$$s_W^2 = 0.2315 \pm$$

$\nu =$ 100%

$e =$ 15% $\leftarrow c$

$u =$ 67%

$d =$ 93% $\leftarrow b$

$$A_c = 0.1513 \pm .002$$

$$A_f = \left(\frac{Q_{ZL}^2 - Q_{ZR}^2}{Q_{ZL}^2 + Q_{ZR}^2} \right)$$

$$A_\ell = 8\left(\tfrac{1}{4} - s_w^2\right) + O(s_w^4)$$

$$s_w^2 = 0.23153 \pm .00016$$

$\nu =$ 100%

$e =$ 15%

$u =$ 67% $\leftarrow c$

d 93% $\leftarrow b$

$$A_c = 0.1513 \pm .002$$

$$A_f = \left(\frac{Q_{ZL}^2 - Q_{ZR}^2}{Q_{ZL}^2 + Q_{ZR}^2} \right)$$

$$A_\ell = 8\left(\tfrac{1}{4} - s_w^2\right) + O(s_w^4)$$

$$s_w^2 = 0.23153 \pm .00016$$

$\nu = 100\%$

$e = 15\%$ $\leftarrow c$

$u = 67\%$ $\leftarrow b$

d 93%

$$A_c = 0.1513 \pm .002$$

$e^- e^+ \longrightarrow Z^0$

$$\frac{d\sigma}{d\cos}\left(e^-_L e^+_R \longrightarrow b_L \bar{b}_R\right) \sim (1+\cos\theta)^2$$

I_3

$e^- e^+ \to Z^0$

$$\frac{d\sigma}{d\cos}(e^-_L e^+_R \to b_L \bar{b}_R) \sim (1+\cos\theta)^2 \qquad \Gamma_Z$$

$$(e^-_R e^+_L \to b_L \bar{b}_R) \sim (1-\cos\theta)^2$$

$e^- e^+ \longrightarrow Z^0$

$$\frac{d\sigma}{d\cos}(e^-_L e^+_R \longrightarrow b_L \bar{b}_R) \sim (1+\cos\theta)^2$$

$$(e^-_R e^+_L \longrightarrow b_L \bar{b}_R) \sim (1-\cos\theta)^2$$

Γ_Z

$$A_b = 0.923 \pm .020$$