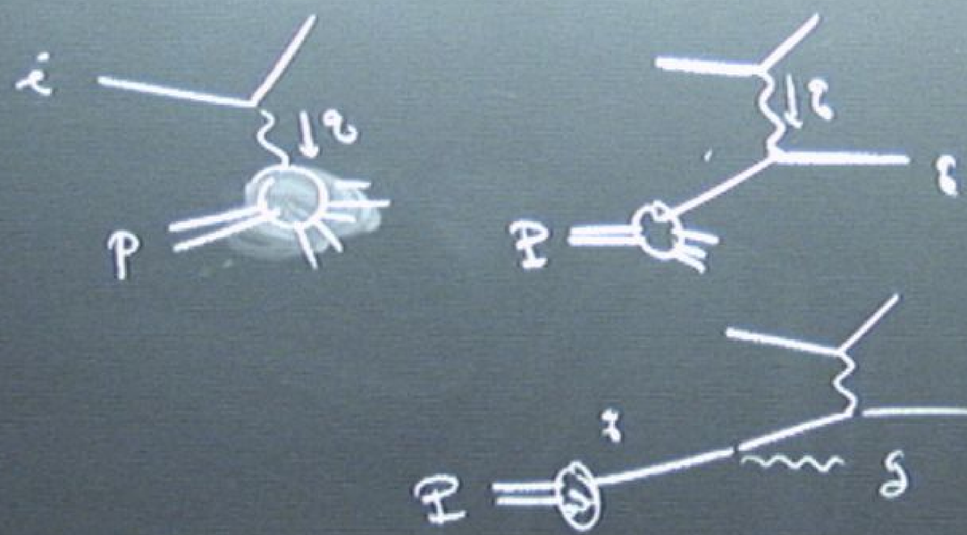
Title: Standard Model - Review (PHYS 622) - Lecture 9

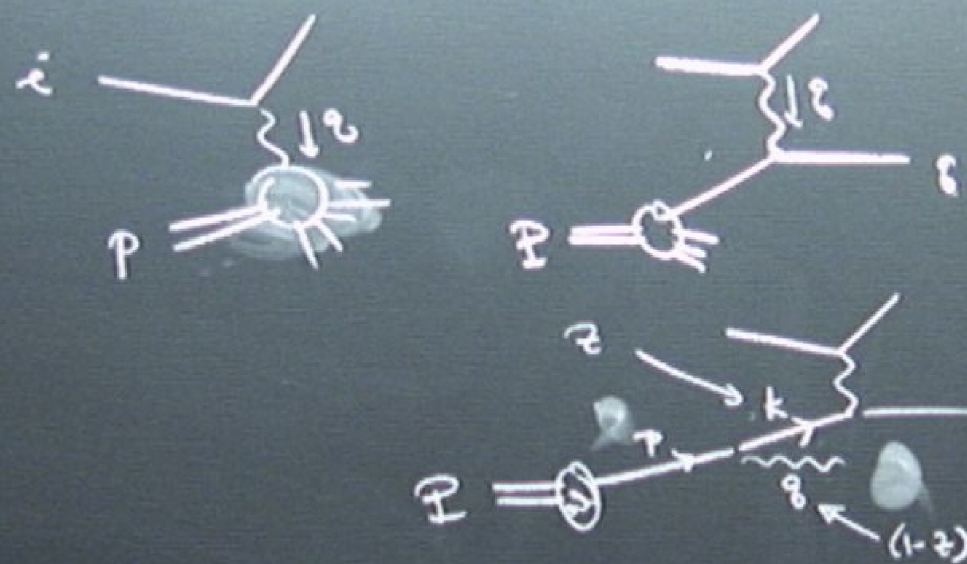
Date: Dec 10, 2009 09:00 AM

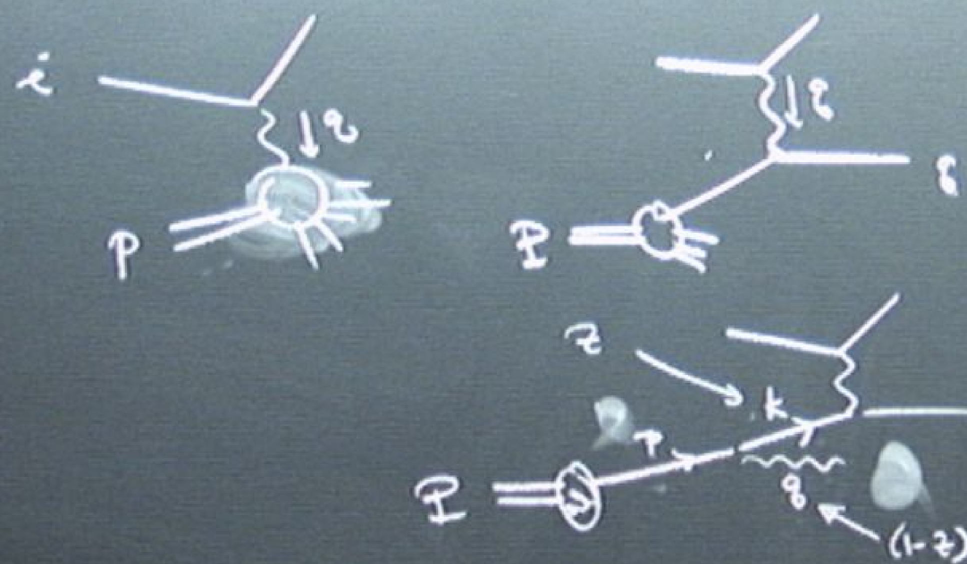
URL: http://pirsa.org/09120041

Abstract:

perimeter scholars
international

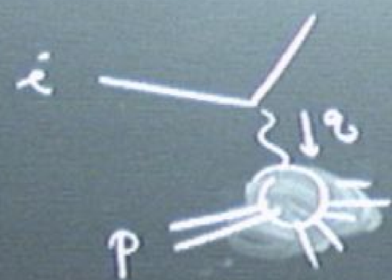


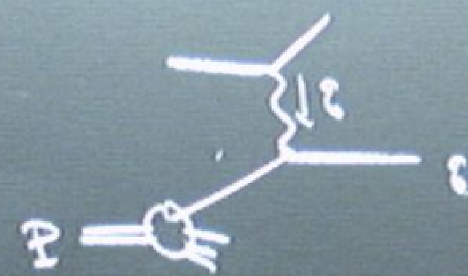

e
q
P
q
P
z
k
p
q
P
(1-z)

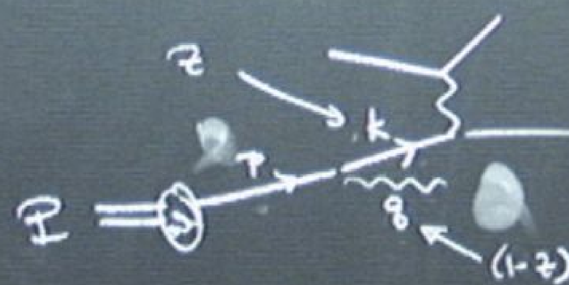


$$p = (E, 0, 0, E)$$

$$q = \left((1-z)E,\ k_T,\ 0,\ (1-z)E - \frac{k_T^2}{2(1-z)E} \right)$$







$$p = (E, 0, 0, E)$$

$$q = \left((1-z)E,\ k_T,\ 0,\ (1-z)E - \frac{k_T^2}{2(1-z)E} \right)$$

$$k = \left(zE,\ -k_T,\ 0,\ zE + \frac{k_T^2}{2(1-z)E} \right)$$

$$k^2 = -\left(k_T^2 + \frac{z k_T^2}{(1-z)}\right) = -\frac{k_T^2}{(1-z)}$$

$$k^2 = -\left(k_T^2 + \frac{z k_T^2}{(1-z)}\right) = -\frac{k_T^2}{(1-z)}$$

$$\sigma(P e^- \to e^- q g X) = \int dx \; f_q(x) \; \frac{1}{2xs}$$

$$k^2 = -\left(k_T^2 + \frac{z k_T^2}{(1-z)}\right) = -\frac{k_T^2}{(1-z)}$$

$$\sigma(P e^- \to e^- q g X) = \int dx \, f_q(x) \, \frac{1}{2xs} \int \frac{d^3 q}{(2\pi)^3} \frac{1}{2q} \int d\Pi_2 \, |\mathcal{M}|^2$$

$$k^2 = -\left(k_T^2 + \frac{z k_T^2}{(1-z)}\right) = -\frac{k_T^2}{(1-z)}$$

$$\sigma(P e^- \to e^- q g X) = \int dx\, f_q(x)\, \frac{1}{2xs} \int \frac{d^3 q}{(2\pi)^3} \frac{1}{2q} \int d\Pi_2\, |\hat{m}|^2$$

$$\hat{m} = \quad i\,\frac{u(p)\,\bar{u}(k)}{k^2}$$

$$k^2 = -\left(k_T^2 + \frac{z k_T^2}{(1-z)}\right) = -\frac{k_T^2}{(1-z)}$$

$$\sigma(P e^- \to e^- q g X) = \int dx\, f_f(x)\ \frac{1}{2xs} \int \frac{d^3 q}{(2\pi)^3}\frac{1}{2q} \int d\Pi_2\ |\hat{m}|^2$$

$$\hat{m} = \quad \frac{u(k)\bar{u}(k)}{k^2}$$

$$= \int dx\ f_f(x)\ \frac{1}{2xs}$$

$$\int d\Pi_2\ |m(e^- q \to e^- q)|^2\ \frac{(1-z)^2}{k_T^4}\ |m|^2$$

$$= -\left(k_T^2 + \frac{z k_T^2}{(1-z)}\right) = -\frac{k_T^2}{(1-z)}$$

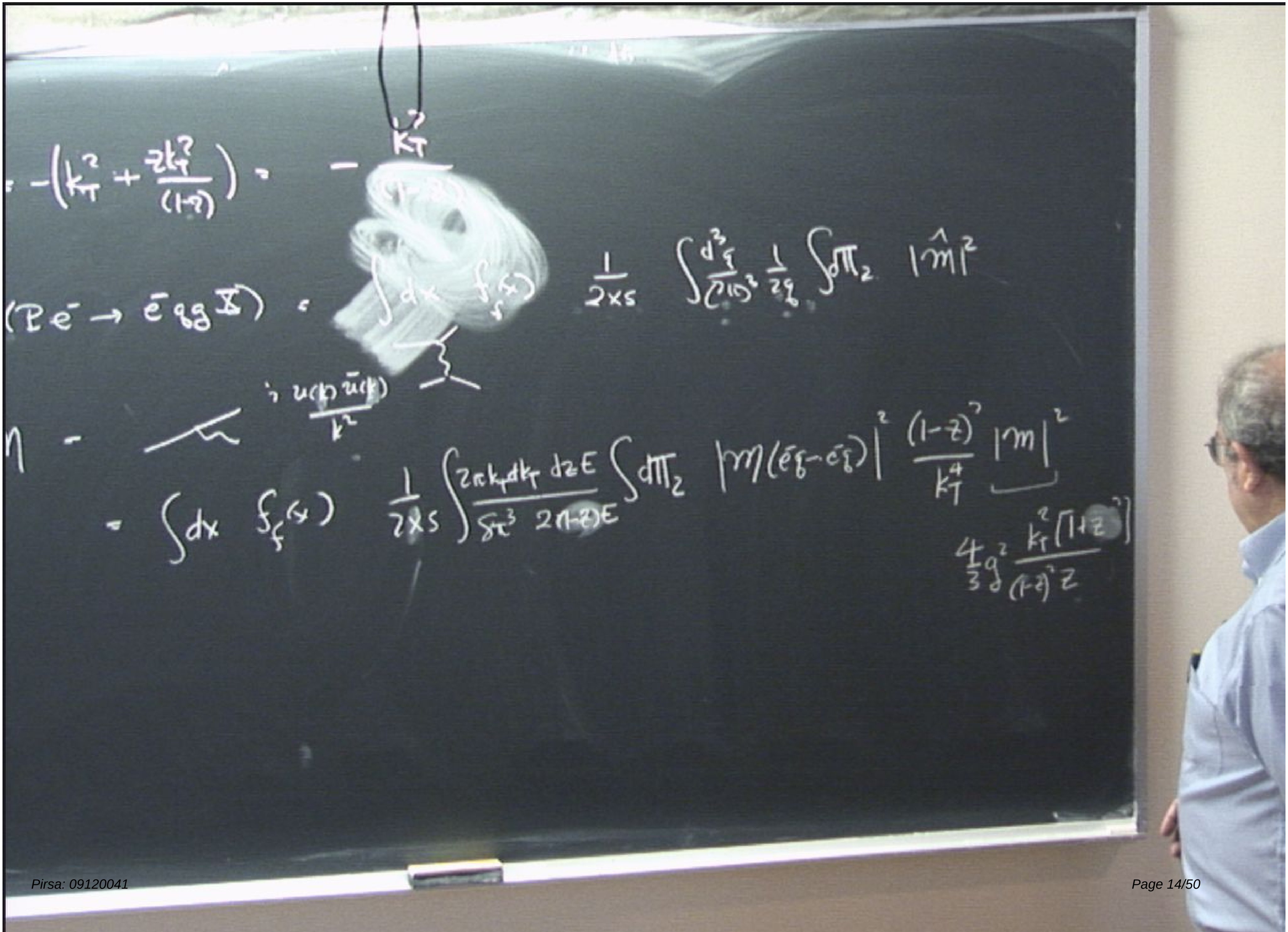
$$(Pe^- \to e^- q g X) = \int dx\, f_q(x) \quad \frac{1}{2xs} \int \frac{d^3 q}{(2\pi)^3} \frac{1}{2q} \int d\Pi_2 \; |\hat{\mathcal{M}}|^2$$

$$\mathcal{M} = \quad \frac{u(k)\bar{u}(k)}{k^2}$$

$$= \int dx\; f_q(x) \quad \frac{1}{2xs}$$

$$\int d\Pi_2 \; |\mathcal{M}(e^- q \to e^- q)|^2 \; \frac{(1-z)^2}{k_T^4} \, \underbrace{|\mathcal{M}|^2}_{}$$

$$\frac{4}{3} g^2 \frac{k_T^2 \left[1+z^2\right]}{(1-z)^2 z}$$


(P e⁻ → e⁻ q g X)
∫dx f_f(x) 1/(2xs) ∫ d³q/(2π)³ 1/(2q) ∫dΠ₂ |M̂|²
= ∫dx f_f(x) 1/(2xs) ∫ 2πk_T dk_T dz E / (8π³ 2(1−z)E) ∫dΠ₂ |M(eq→eq)|² (1−z)²/k_T⁴ |M|²
4/3 g² k_T² [1+z²] / ((1−z)² z)

$$= -\left(k_T^2 + \frac{z k_T^2}{(1-z)}\right) = -\frac{k_T^2}{(1-z)}$$

$$\sigma(P e^- \to e^- q g X) = \int dx\, f_f(x)\ \frac{1}{2xs} \int \frac{d^3 q}{(2\pi)^3}\frac{1}{2q} \int d\Pi_2\ |\hat{\mathcal{M}}|^2$$

$$\sim \frac{u(k)\bar{u}(k)}{k^2}$$

$$\mathcal{M} =$$

$$= \int dx\ f_f(x)\ \frac{1}{2xs} \int \frac{2\pi k_T dk_T\, dz E}{8\pi^3\ 2(1-z)E} \int d\Pi_2\ |\mathcal{M}(e^-q \to e^-q)|^2\ \frac{(1-z)^2}{k_T^4}\ \underbrace{|\mathcal{M}|^2}$$

$$\frac{4}{3} g^2 \frac{k_T^2 [1+z^2]}{(1-z)^2 z}$$

$$\frac{1}{2xzs} \int d\Pi_2 \left|\mathcal{M}(e^- q(xzP) \to e^- q)\right|^2$$

$$= -\left(k_T^2 + \frac{z k_T^2}{(1-z)}\right) = -\frac{k_T^2}{(1-z)}$$

$$\sigma(P e^- \to e^- q g X) = \int dx\, f_f(x) \frac{1}{2xs} \int \frac{d^3 q}{(2\pi)^3} \frac{1}{2q} \int d\Pi_2 \, |\hat{m}|^2$$

$$m = \frac{i\, u(k)\bar{u}(k)}{k^2}$$

$$= \int dx\, f_f(x) \frac{1}{2xs} \int \frac{2\pi k_T dk_T\, dz E}{8\pi^3\, 2(1-z)E} \int d\Pi_2 \, |m(e^- q \to e^- q)|^2 \, \frac{(1-z)^2}{k_T^4} \underbrace{|m|^2}_{\frac{4}{3} g^2 \frac{2k_T^2 [1+z^2]}{(1-z)^2 z}}$$

$$\int dx\, f_f(x) \frac{4}{3} \frac{\alpha_s}{\pi} \int \frac{dk_T}{k_T} \int dz \quad \frac{1}{2xzs} \int d\Pi_2 \, |m(e^- q(xzP) \to e^- X)|^2$$

$$= -\left(k_T^2 + \frac{z k_T^2}{(1-z)}\right) = -\frac{k_T^2}{(1-z)}$$

$$\sigma(Pe^- \to e^- q g X) = \int dx\, f_f(x)\, \frac{1}{2xs} \int \frac{d^3q}{(2\pi)^3}\frac{1}{2q} \int d\Pi_2\, |\hat{\mathcal{M}}|^2$$

$$\frac{i\, u(k)\bar{u}(k)}{k^2}$$

$$\mathcal{M} = \ldots \qquad |\mathcal{M}(e^-q \to e^-q)|^2\, \frac{\cancel{(1-z)}}{k_T^4}\, |m|^2$$

$$= \int dx\, f_f(x)\, \frac{1}{2xs} \int \frac{2\pi k_T\, dk_T\, dz\, E}{8\pi^3\, 2(1-z)E} \int d\Pi_2\, |\mathcal{M}(e^-q \to e^-q)|^2$$

$$\frac{4}{3} g^2 \frac{2k_T^2\,[1+z^2]}{(1-z)^2 z}$$

$$\int dx\, f_f(x)\, \frac{4}{3}\frac{\alpha_s}{\pi} \int \frac{dk_T}{k_T} \int dz\, \frac{1+z^2}{(1-z)}\, \frac{1}{2xzs} \int d\Pi_2\, |\mathcal{M}(e^-q(xzP) \to e^-q)|^2$$

$$= -\left(k_T^2 + \frac{z k_T^2}{(1-z)}\right) = -\frac{k_T^2}{(1-z)}$$

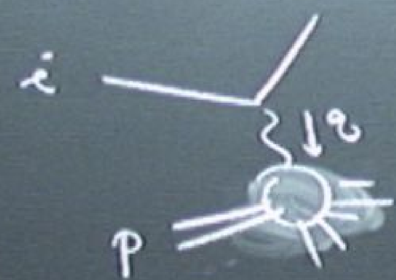
$$\sigma(P e^- \to e^- q g X) = \int dx\, f_f(x)\, \frac{1}{2xs} \int \frac{d^3 q}{(2\pi)^3} \frac{1}{2q} \int d\Pi_2\, |\hat{\mathcal{M}}|^2$$

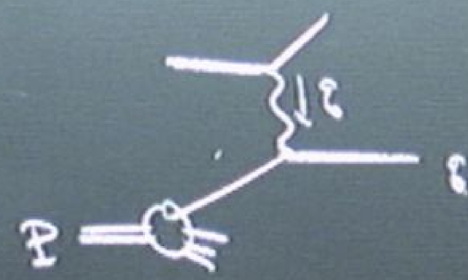
$$\mathcal{M} =$$

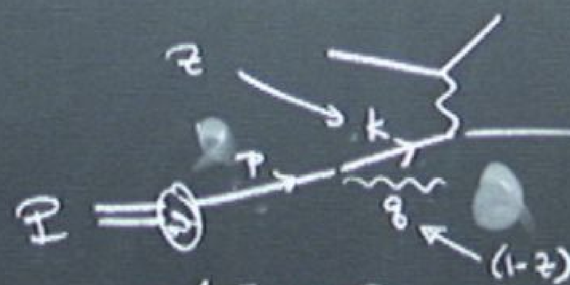
$$\frac{i\, u(k)\bar{u}(k)}{k^2}$$

$$= \int dx\, f_f(x)\, \frac{1}{2xs} \int \frac{2\pi k_T dk_T\, dz E}{8\pi^3\, 2(1-z)E} \int d\Pi_2\, |\mathcal{M}(e^- q \to e^- q)|^2\, \frac{(1-z)}{k_T^4}\, \underbrace{|m|^2}_{\frac{4}{3} g^2 \frac{2k_T^2 [1+z^2]}{(1-z)^2 z}}$$

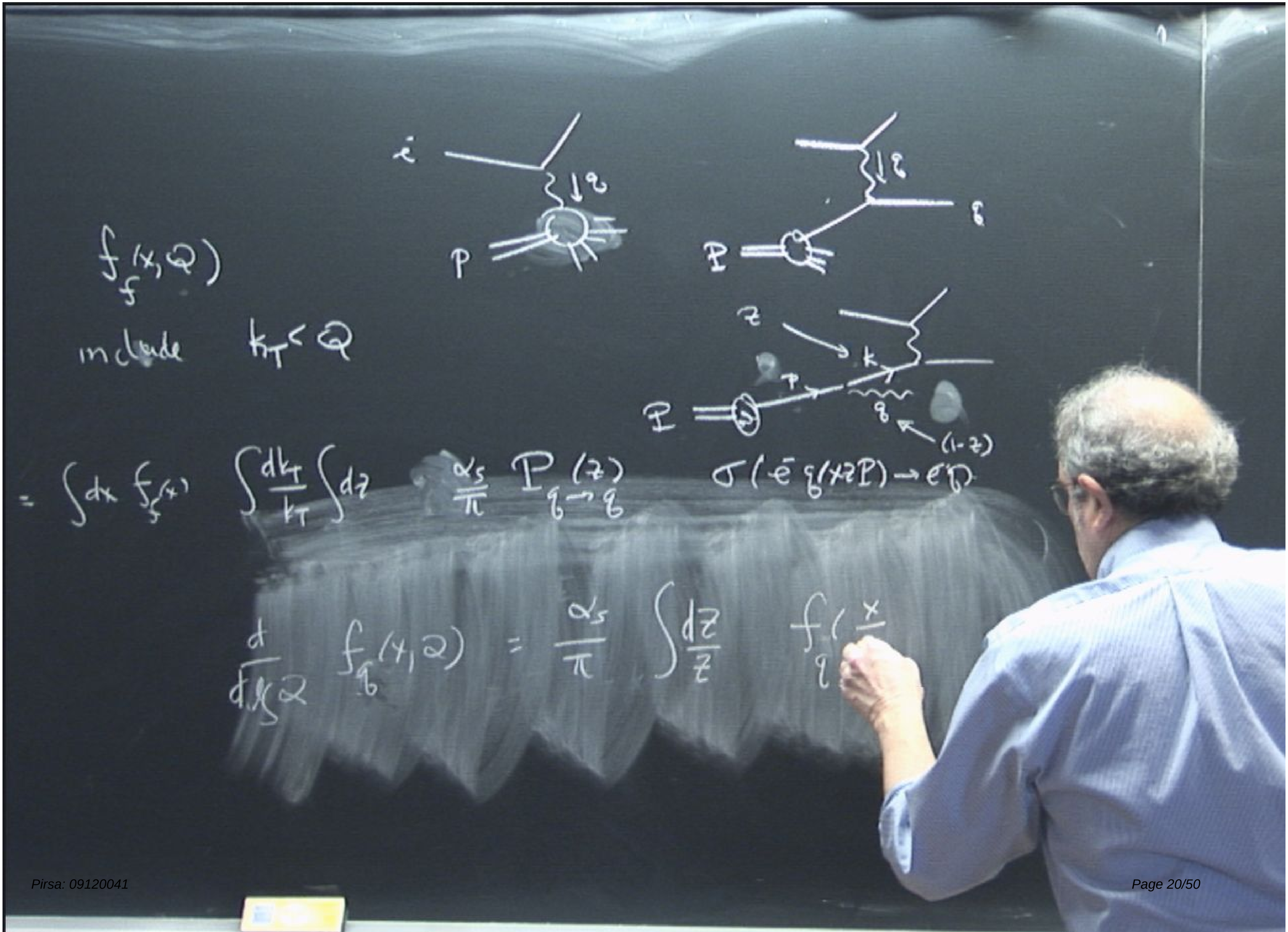
$$\int dx\, f_f(x)\, \frac{4}{3}\frac{\alpha_s}{\pi} \int \frac{dk_T}{k_T} \int dz\, \frac{1+z^2}{(1-z)}\, \frac{1}{2xzs} \int d\Pi_2\, |\mathcal{M}(e^- q(xzP) \to e^- q)|^2$$





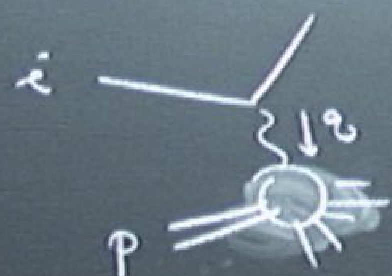


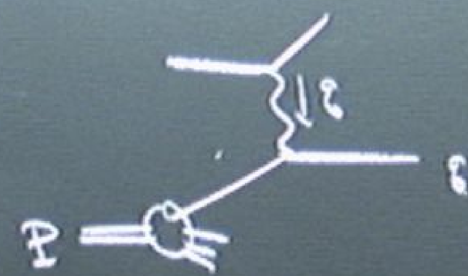
$$= \int dx\, f_q(x) \int \frac{dk_T}{k_T} \int dz\, \frac{\alpha_s}{\pi}\, P_{q\to q}(z)\; \sigma(e\, q(xzP) \to e\, q)$$

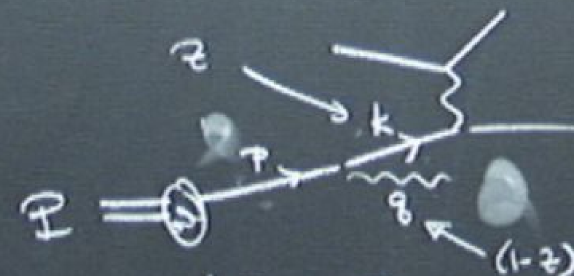

$f_f(x,Q)$
include $k_T < Q$
$= \int dx\, f_f(x) \int \frac{dk_T}{k_T} \int dz \frac{\alpha_s}{\pi} P_{q\to q}(z)\ \sigma(e\, q(xzP) \to e\, q)$
$\frac{d}{d\log Q} f_q(x,Q) = \frac{\alpha_s}{\pi} \int \frac{dz}{z}\ f_q(\frac{x}{\ }$
e
q
P
z
k
p
(1-z)

$f_f(x, Q)$

include $k_T < Q$



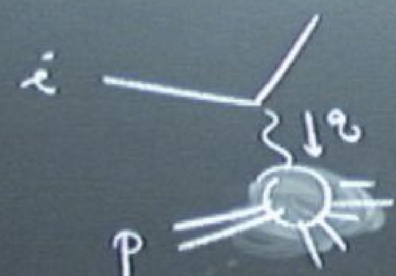


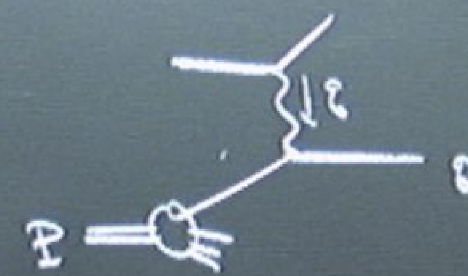


$$= \int dx\, f_f(x) \int \frac{dk_T}{k_T} \int dz \; \frac{\alpha_s}{\pi} \; P_{q\to q}(z) \qquad \sigma(\bar{e}\, q(xzP) \to e\, q)$$

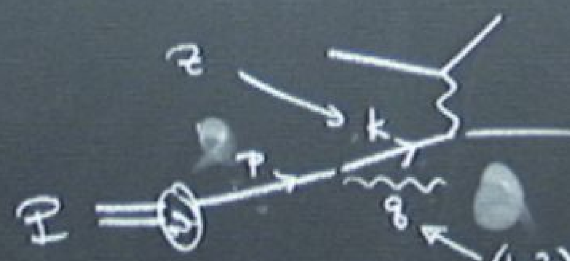
$$\frac{d}{d\log Q} f_q(x, Q) = \frac{\alpha_s}{\pi} \int \frac{dz}{z} \; f_q\left(\frac{x}{z}, Q\right) P_{q\to q}(z)$$

$f_f(x,Q)$



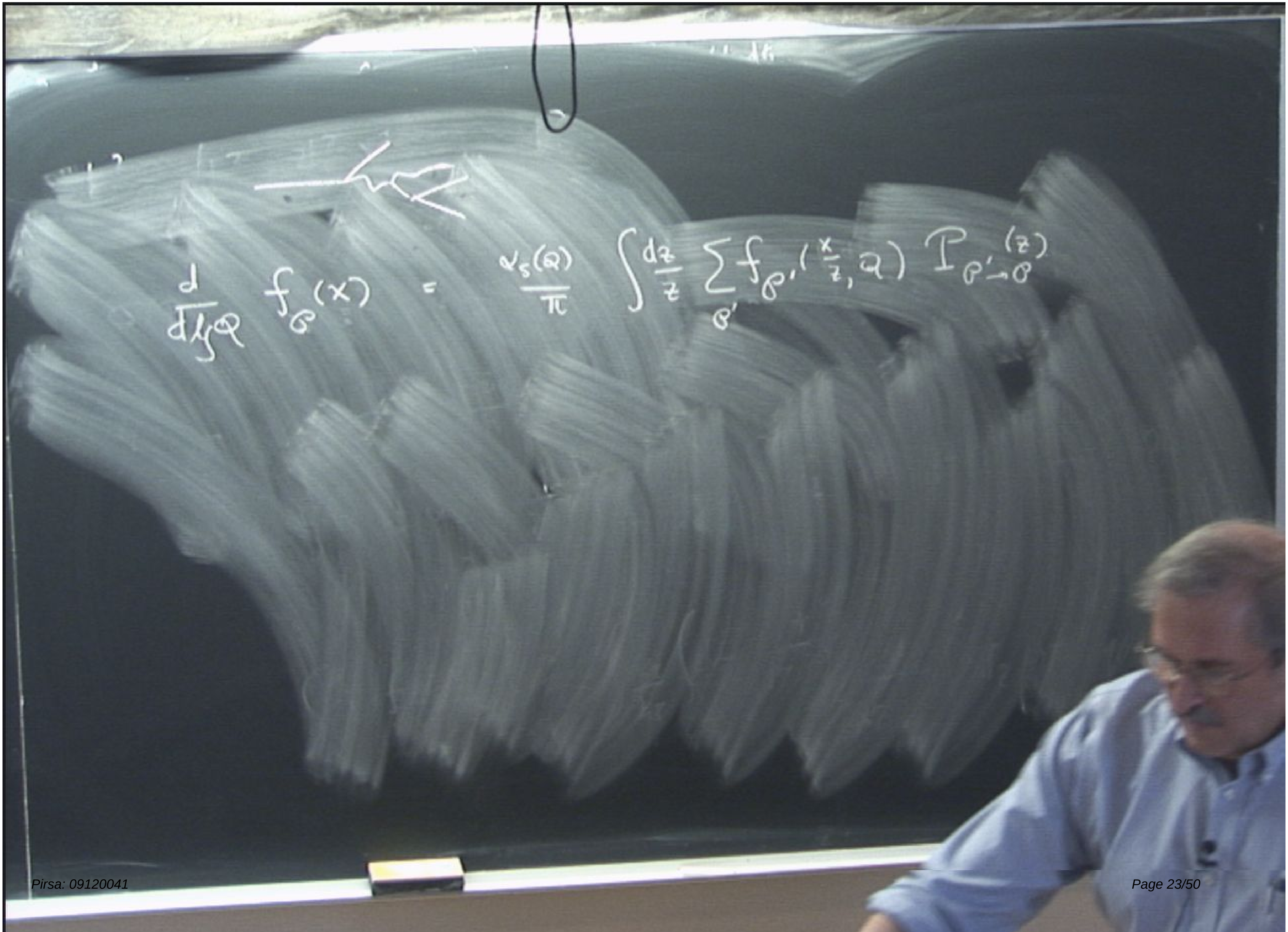


include $k_T < Q$



$$= \int dx\, f_f(x) \int \frac{dk_T}{k_T} \int dz\, \frac{\alpha_s}{\pi} P_{q\to q}(z) \quad \sigma(\bar{e}\, q(xzP) \to e\, q)$$

$$\frac{d}{d\log Q} f_q(x,Q) = \frac{\alpha_s}{\pi} \int \frac{dz}{z}\, f_q\!\left(\frac{x}{z}, Q\right) P_{q\to q}(z)$$


$\frac{d}{d\ln Q} f_a(x) = \frac{\alpha_s(Q)}{\pi} \int \frac{dz}{z} \sum_{a'} f_{a'}(\frac{x}{z}, Q)\, P_{a' \to a}(z)$

$$\frac{d}{d\ln Q} f_g(x,Q) = \frac{\alpha_s(Q)}{\pi} \int \frac{dz}{z} \sum_{g'} f_{g'}\left(\frac{x}{z}, Q\right) P_{g' \to g}(z)$$

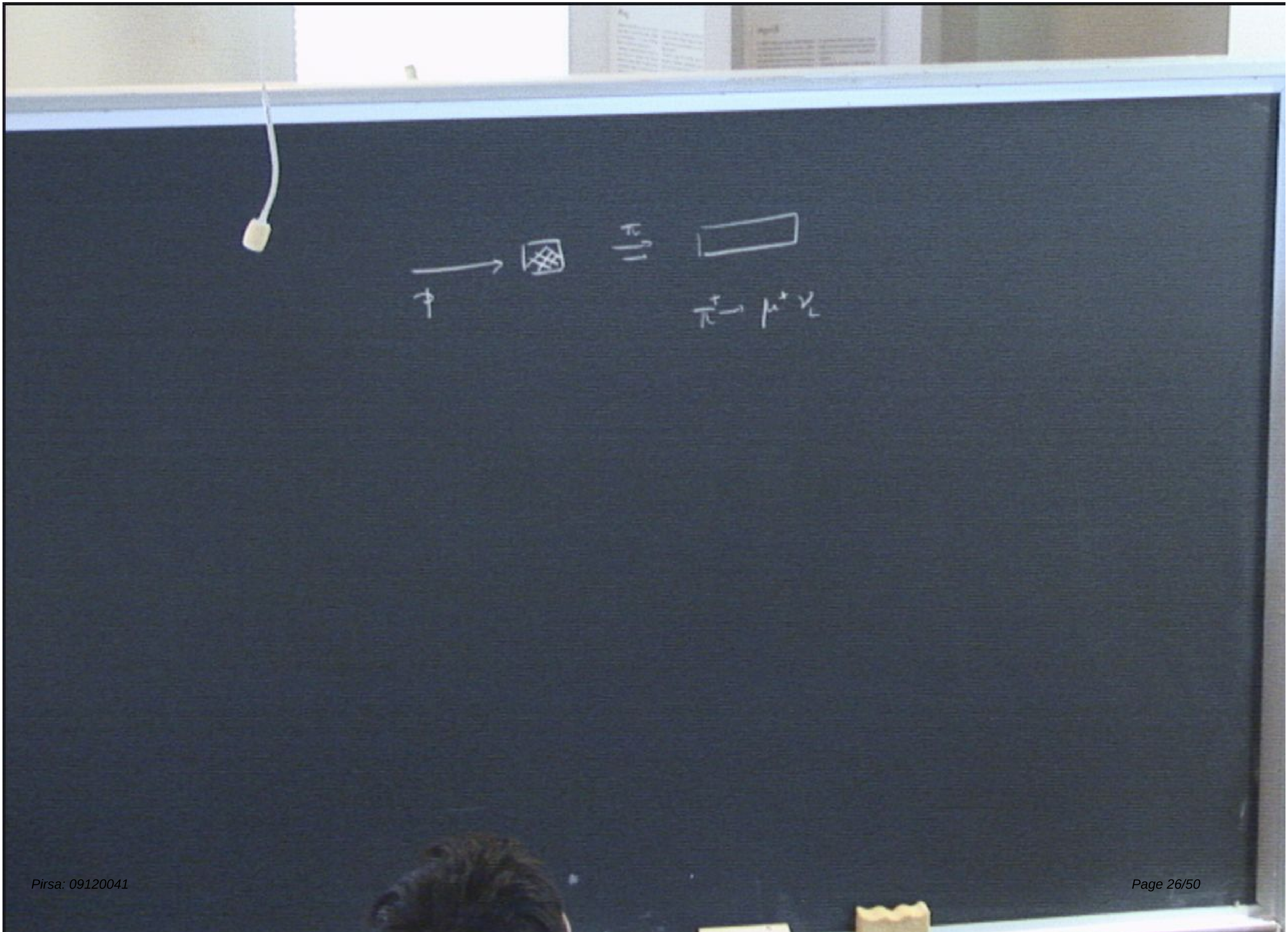
$f_g(x)$

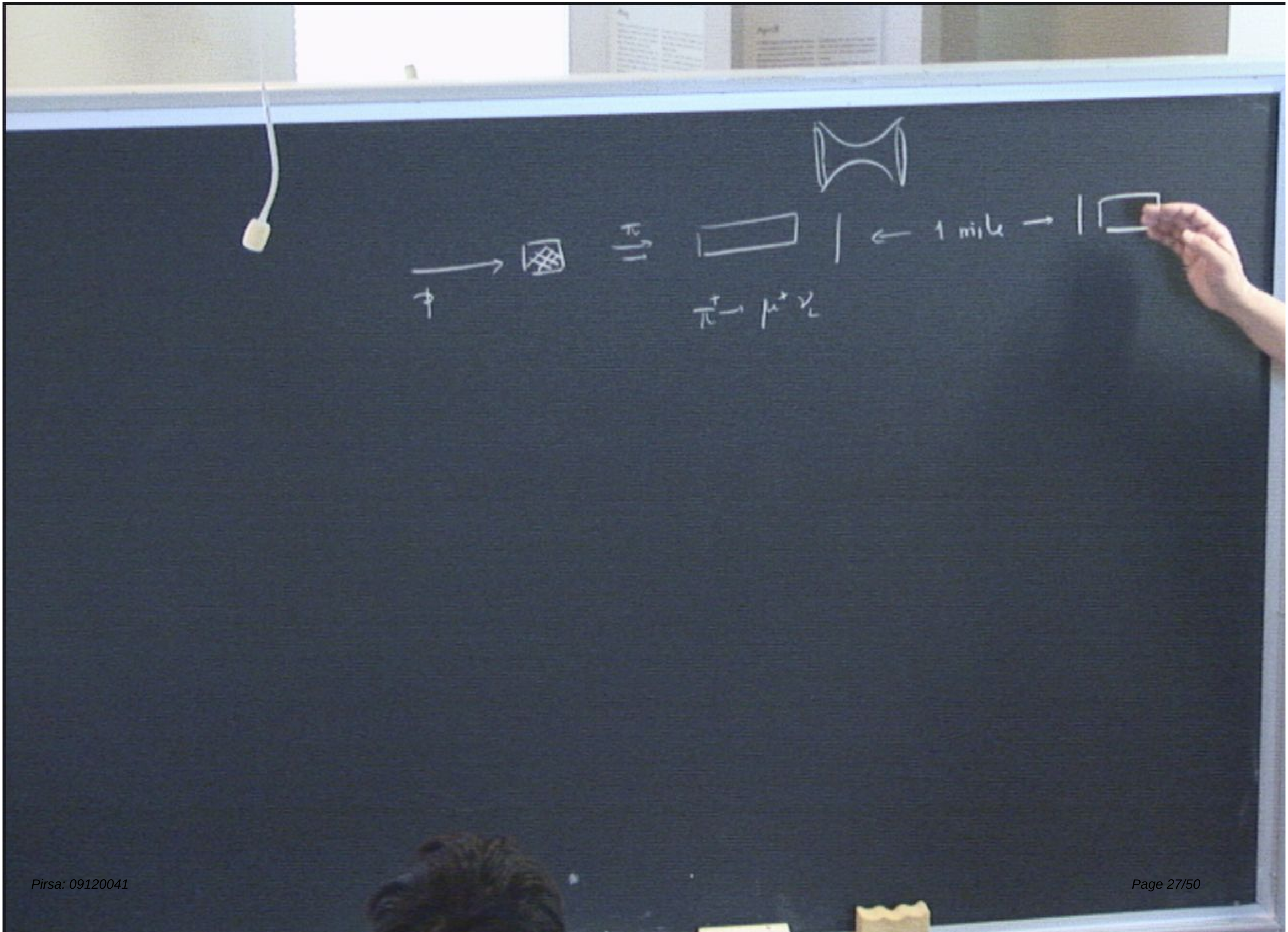
$$P_{g \to g}(z) = \frac{6}{z} \qquad z \to 0$$

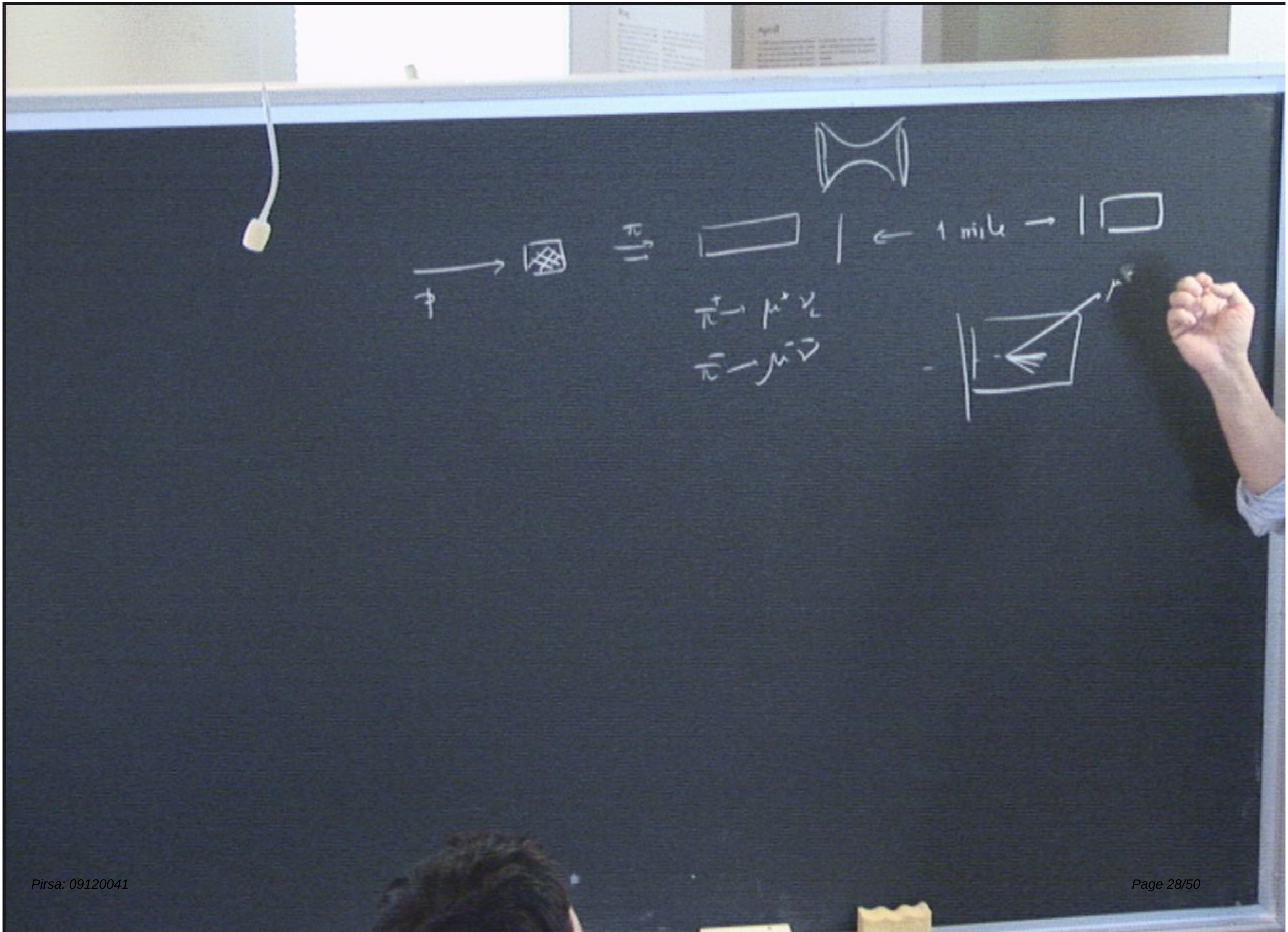
$$\frac{d}{d\log Q} f_q(x,Q) = \frac{\alpha_s(Q)}{\pi}\int \frac{dz}{z}\sum_{q'} f_{q'}\left(\frac{x}{z},Q\right) P_{q'\to q}(z)$$

$$P_{g\to g}(z) = \frac{6}{z} \qquad z \to 0$$

$$F_2 = \sum_f Q_f^2 \, x\,\left(f_f(x) + f_{\bar f}(x)\right)$$


π
p
π⁺ → μ⁺ ν_L

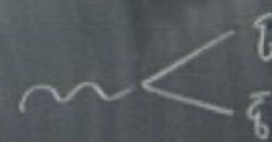

p
π
← 1 mile →
$\pi^+ \to \mu^+ \nu$


p
π
1 mile
$\pi^+ \to \mu^+ \nu_\mu$
$\pi^- \to \mu^- \bar{\nu}$
μ

$$\frac{d}{d\log Q} f_g(x,Q) = \frac{\alpha_s(Q)}{\pi} \int \frac{dz}{z} \sum_{g'} f_{g'}\left(\frac{x}{z}, Q\right) P_{g' \to g}(z)$$

$$P_{g \to g}(z) = \frac{6}{z} \qquad z \to 0$$

$f_g(x)$

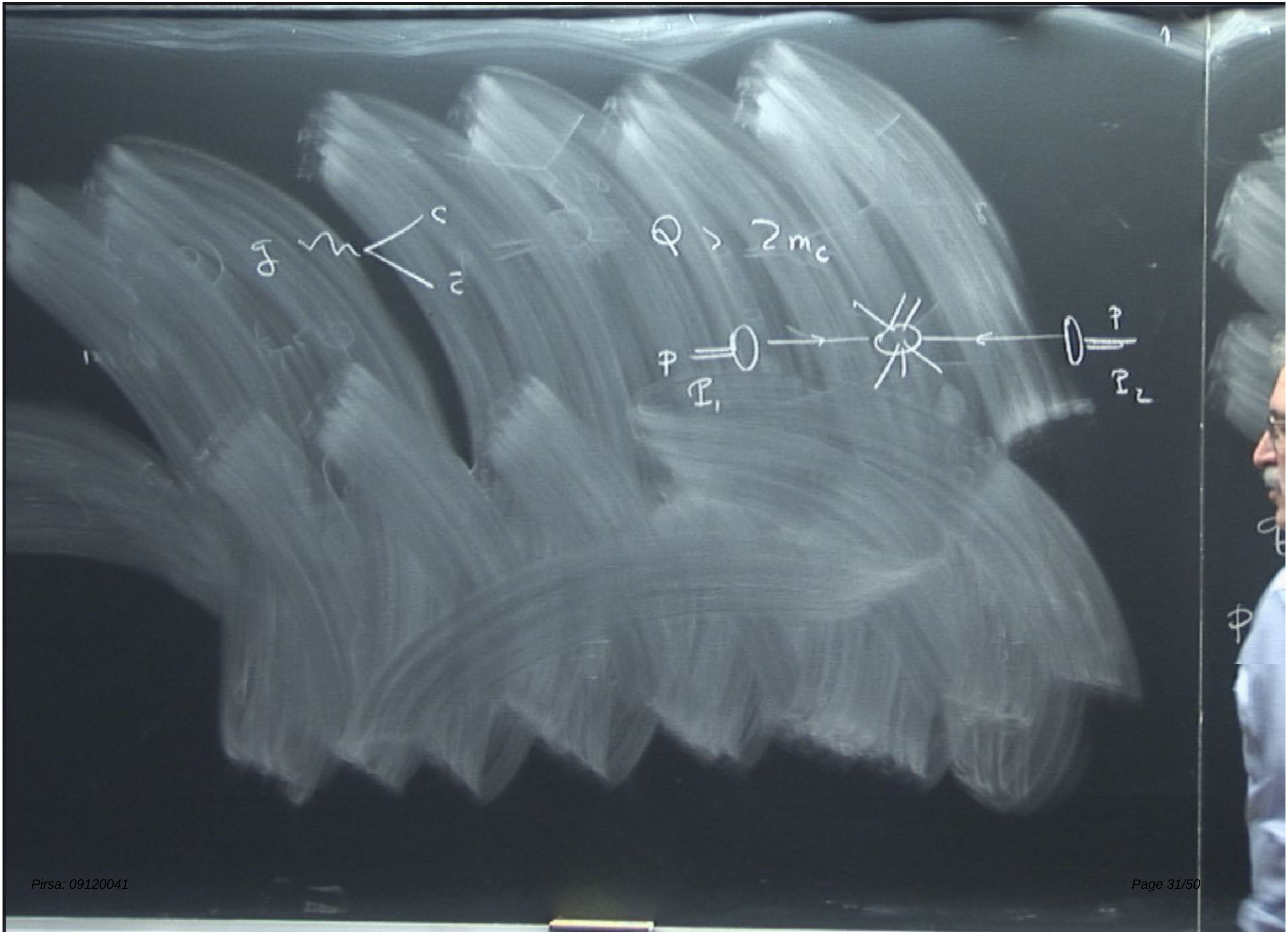


$q\bar{q} \to \mu^+\mu^-$

$pp \to \mu^+\mu^- + X$

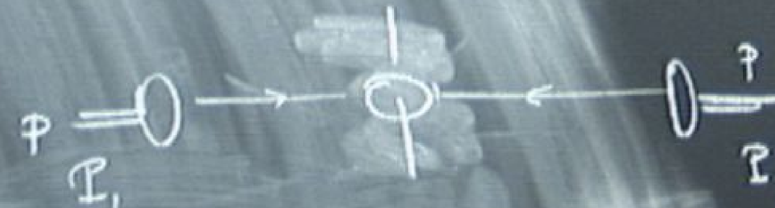
$$F_2 = \sum_f Q_f^2\, x \left(f_f(x) + f_{\bar{f}}(x)\right)$$

$Q > 2m_c$


g
c
c̄
Q > 2m_c
p
P_1
p
P_2

$g \rightsquigarrow c\bar{c}$

$Q > 2m_c$



q

pp

$Q > 2m_c$

$Q > 2m_c$

$$\sigma(pp \to X) = \int dx_1 \sum_{\mathcal{P}_1} f_{\mathcal{P}_1}(x_1, Q) \int dx_2 \sum_{\mathcal{P}} f_{\mathcal{P}_2}(x_2, Q)$$

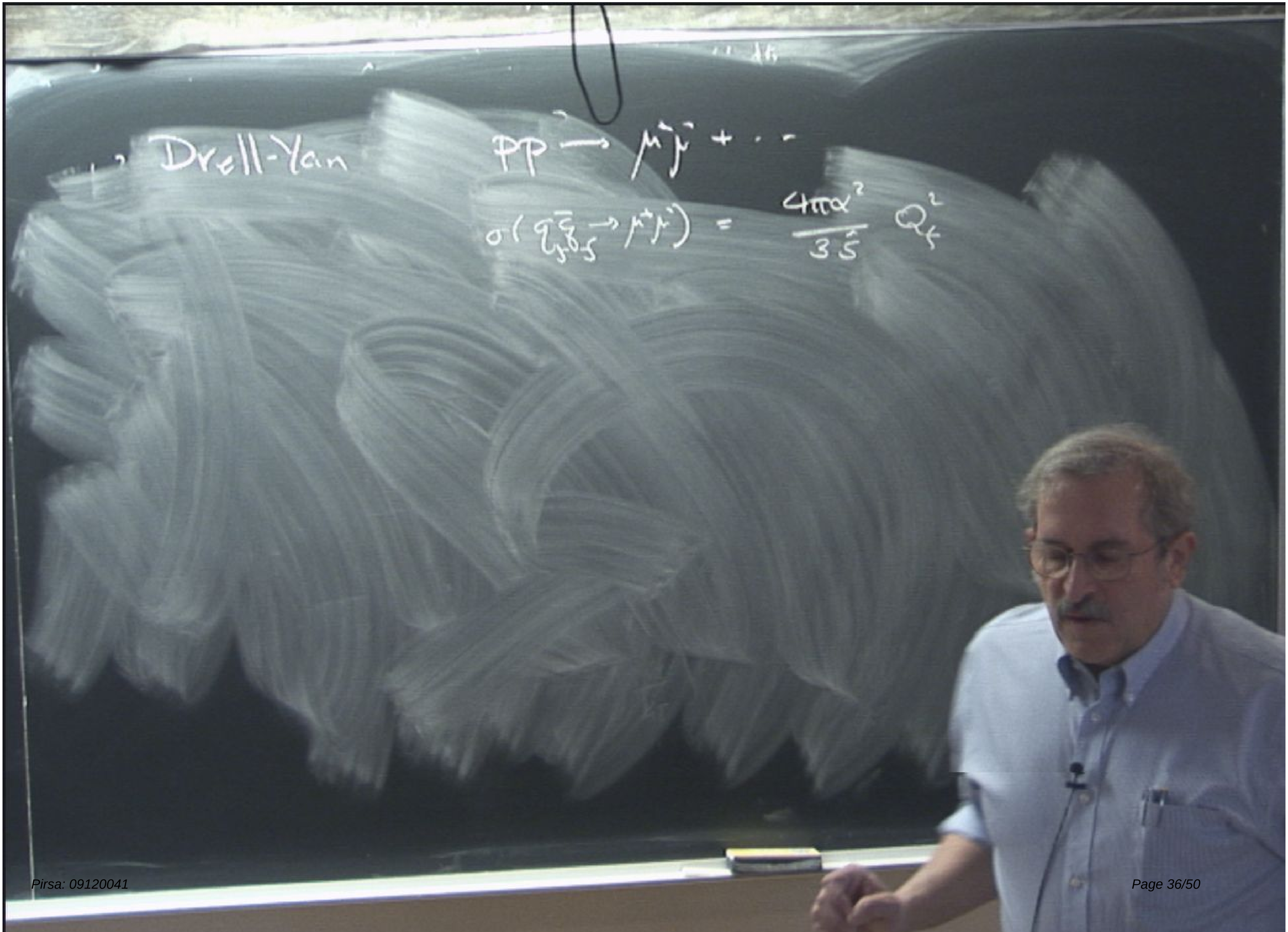
$$\cdot\, \sigma\big(\mathcal{P}_1(x_1 P_1)\, \mathcal{P}_2(x_2 P_2) \to X\big)$$

$g \sim\!\!< \begin{matrix} c \\ \bar{c} \end{matrix}$ $\qquad Q > 2m_c$

$$\sigma(pp \to X) = \int dx_1 \sum_{p_1} f_{p_1}(x_1, Q) \int dx_2 \sum_{p} f_{p_2}(x_2, Q) \cdot \sigma\left(p_1(x_1 P_1)\, p_2(x_2 P_2) \to X\right)$$

$$\hat{s} = (p_1 + p_2)^2 = (x_1 P_1 + x_2 P_2)^2 = 2\, x_1 x_2\, P_1 \cdot P_2$$

$$= x_1 x_2\, s$$


Drell-Yan
pp → μ⁺μ⁻ + ...
σ(q_f q̄_f → μ⁺μ⁻) = 4πα² / 3ŝ Q_f²

Drell-Yan $\quad pp \to \mu^+\mu^- + \cdots$

$$\sigma(q_f\bar{q}_f \to \mu^+\mu^-) = \frac{4\pi\alpha^2}{3\hat{s}} Q_f^2 \cdot \frac{1}{3}$$

$$\sigma \sim \delta_{ij} \qquad \frac{1}{3}\,\frac{1}{3}\sum_{ij}\delta_{ij} = \frac{1}{3}$$

Drell-Yan $\quad pp \to \mu^+\mu^- + \cdots$

$$\sigma(q_f \bar{q}_f \to \mu^+\mu^-) = \frac{4\pi\alpha^2}{3\hat{s}} Q_f^2 \cdot \frac{1}{3}$$

$$\sigma \sim \delta_{ij} \qquad \frac{1}{3}\,\frac{1}{3}\sum_{ij}\delta_{ij} = \frac{1}{3}$$

$$\sigma = \sum_f \int dx_1\, dx_2 \left[f_f(x_1) f_f(x_2) + f_{\bar{f}}(x_1) f_f(x_2) \right] \frac{Q_f^2}{3}\, \frac{4\pi\alpha^2}{3}$$

Drell-Yan $\quad pp \longrightarrow \mu^+\mu^- + \cdots$

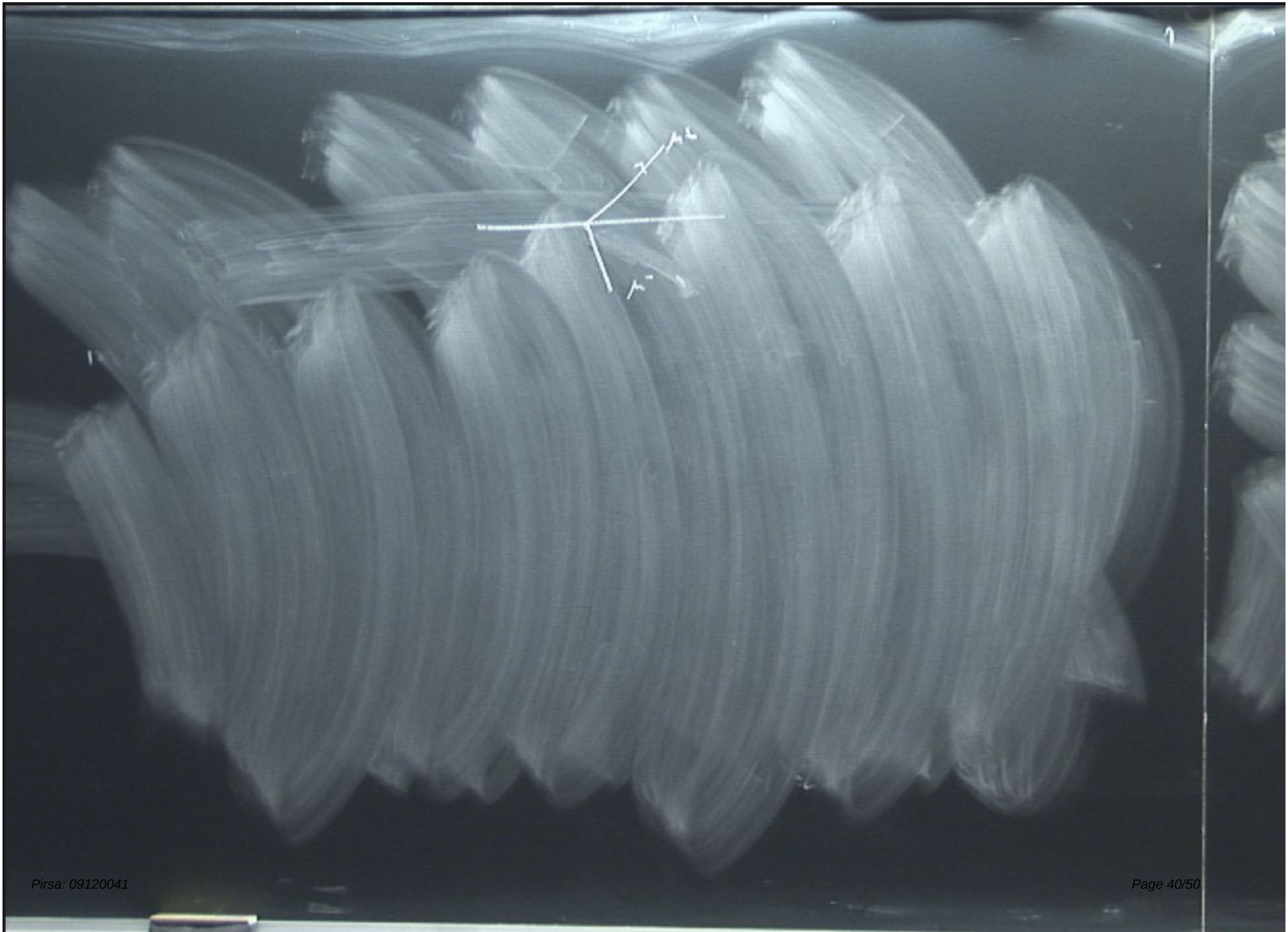
$$\sigma(q_{f_i}\bar{q}_{f_j} \to \mu^+\mu^-) = \frac{4\pi\alpha^2}{3\hat{s}} Q_f^2 \cdot \frac{1}{3}$$

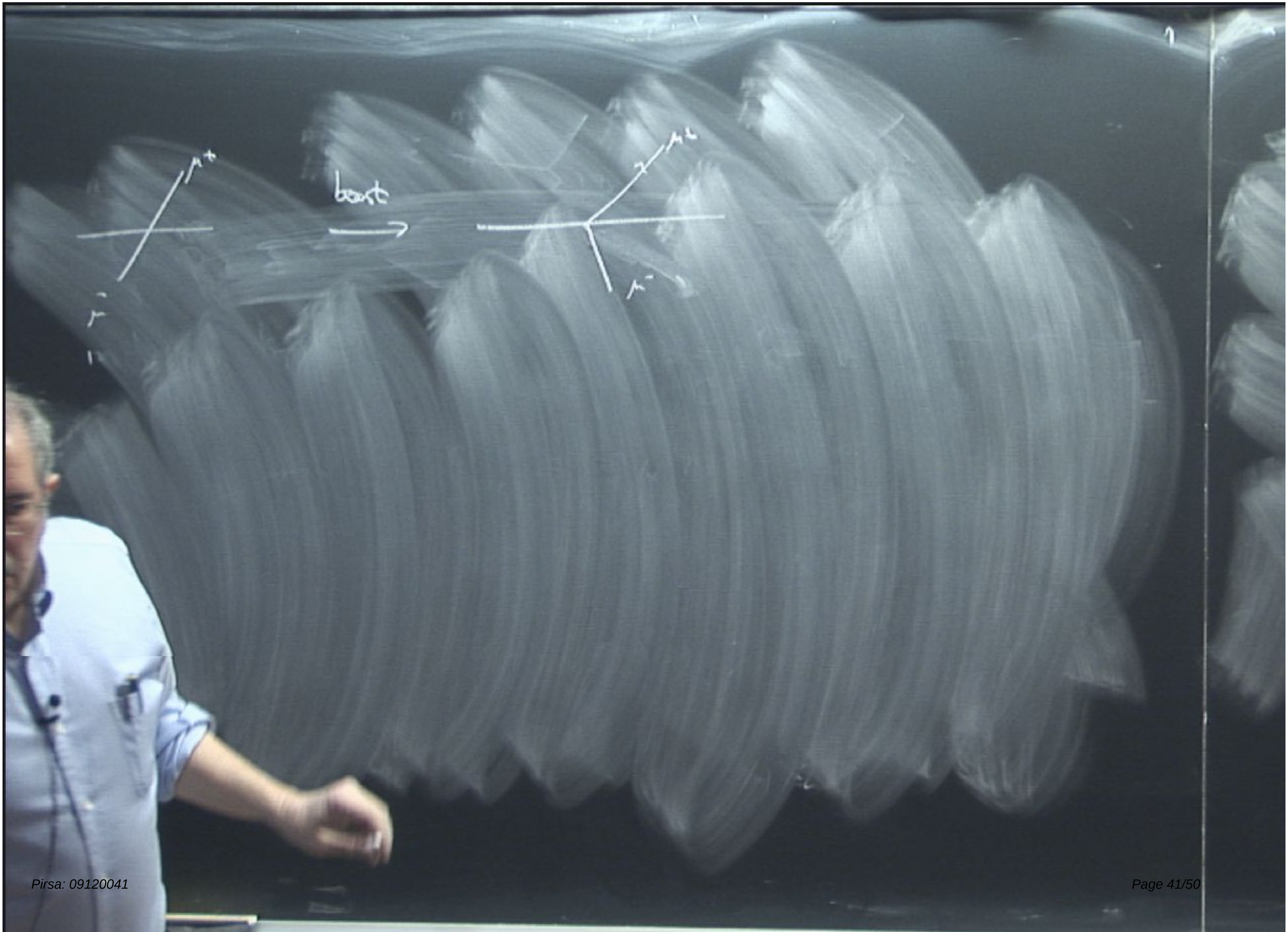
$$Q^2 = m^2(\mu^+\mu^-)$$

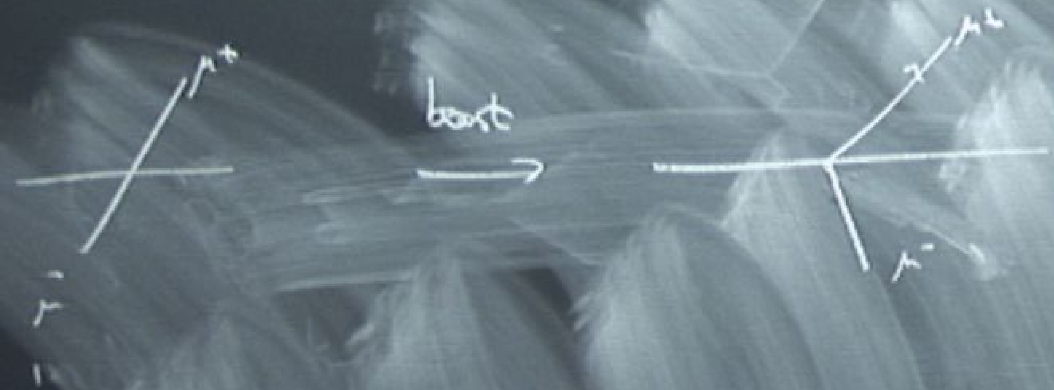
$$\sigma \sim \delta_{ij} \qquad \frac{1}{3}\,\frac{1}{3}\sum_{ij}\delta_{ij} = \frac{1}{3}$$

$$\sigma = \sum_f \int \frac{dx_1}{x_1}\frac{dx_2}{x_2}\left[x_1 f_f(x_1)\, x_2 f_{\bar{f}}(x_2) + x_1 f_{\bar{f}}(x_1)\, x_2 f_f(x_2)\right] \frac{Q_f^2}{3} \frac{4\pi\alpha^2}{3Q^2}$$

$$Q^2 = x_1 x_2 s$$




boost



E_b beam energy.

$P_1 = (E_b, 0\ 0\ E_b)$

$P_2 = (E_b\ 0\ 0\ -E_b)$

$$Q = ((x_1+x_2)E_b,\ 0,\ 0,\ (x_1-x_2)E_b)$$

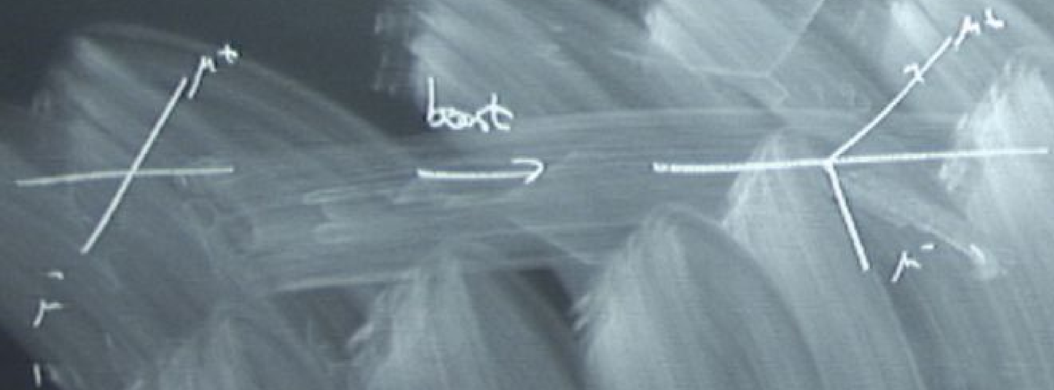
E_b beam engy.

$P_1 = (E_b, 0\ 0\ E_b)$

$P_2 = (E_b\ 0\ 0\ -E_b)$

$$Q = ((x_1+x_2)E_b\ ,\ 0\ ,0\ ,(x_1-x_2)E_b)$$

$$Q^2 = 4x_1x_2E_b^2 = x_1x_2\ s$$



E_b beam energy.

$P_1 = (E_b, 0\ 0\ E_b)$

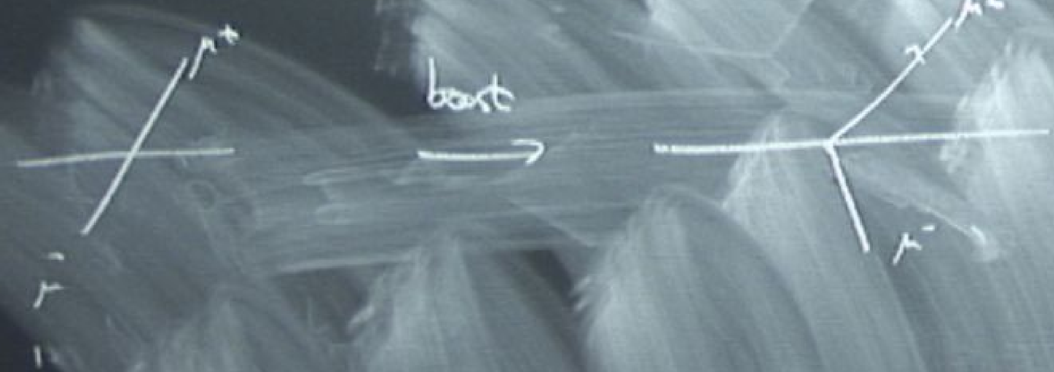
$P_2 = (E_b\ 0\ 0\ -E_b)$

$$Q = ((x_1+x_2)E_b,\ 0,\ 0,\ (x_1-x_2)E_b)$$

$$Q^2 = 4x_1x_2E_b^2 = x_1x_2\, s$$

$$(Q\cosh y,\ 0,\ 0,\ Q\sinh y)$$

y = rapidity



E_b beam engy.

$P_1 = (E_b, 0\ 0\ E_b)$

$P_2 = (E_b\ 0\ 0\ -E_b)$

$$Q = ((x_1+x_2)E_b,\ 0,\ 0,\ (x_1-x_2)E_b)$$

$$Q^2 = 4x_1x_2E_b^2 = x_1x_2\, s$$

y = rapidity

$$(Q\cosh y,\ 0,\ 0,\ Q\sinh y)$$

$$\tanh y = \frac{x_1-x_2}{x_1+x_2} \qquad y = \frac{1}{2}\log\frac{x_1}{x_2}$$

Drell-Yan $pp \to \mu^+\mu^- + \cdots$

$$\sigma(q_f \bar{q}_f \to \mu^+\mu^-) = \frac{4\pi\alpha^2}{3\hat{s}} Q_f^2 \cdot \frac{1}{3}$$

$$Q^2 = m^2(\mu^+\mu^-)$$

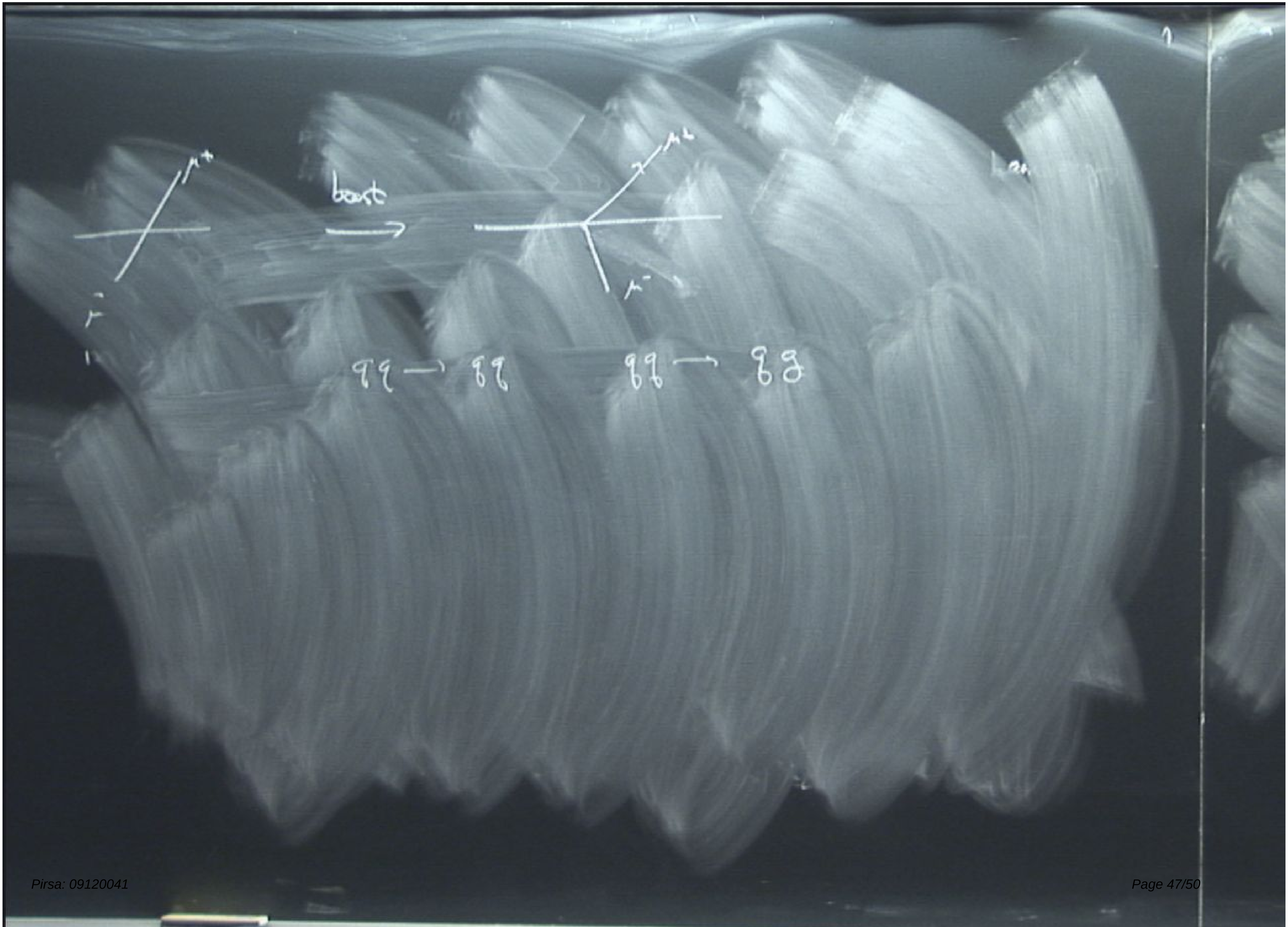
$$\sigma \sim \delta_{ij} \qquad \frac{1}{3}\,\frac{1}{3} \sum_{ij} \delta_{ij} = \frac{1}{3}$$

$$\sigma = \sum_f \int \frac{dx_1}{x_1}\frac{dx_2}{x_2} \left[x_1 f_f(x_1) x_2 f_{\bar{f}}(x_2) + x_1 f_{\bar{f}}(x_1) x_2 f_f(x_2)\right] \frac{Q_f^2}{3} \frac{4\pi\alpha^2}{3Q^2}$$

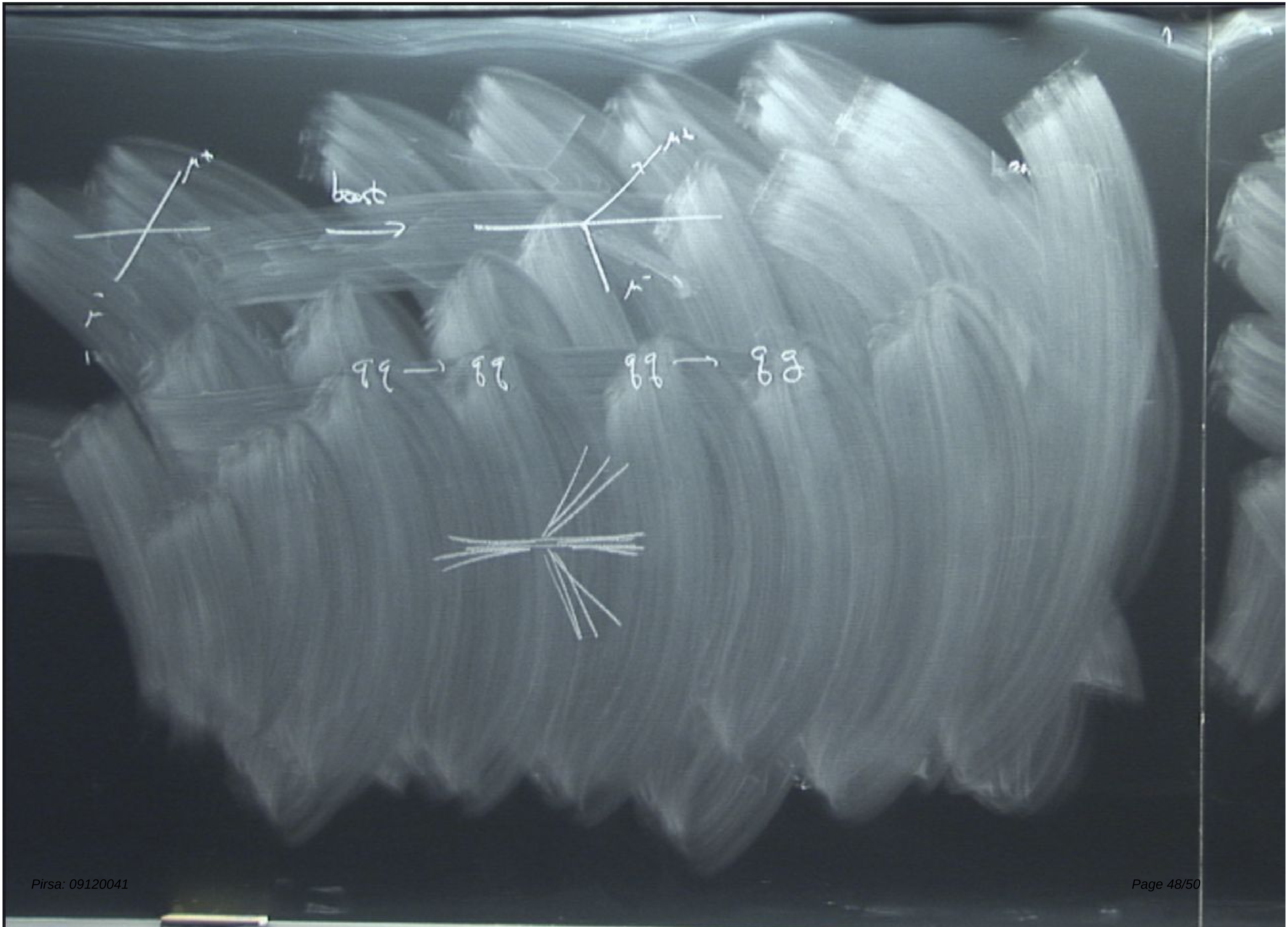
$$\frac{\partial(Q^2 y)}{\partial(x_1, x_2)} = s$$

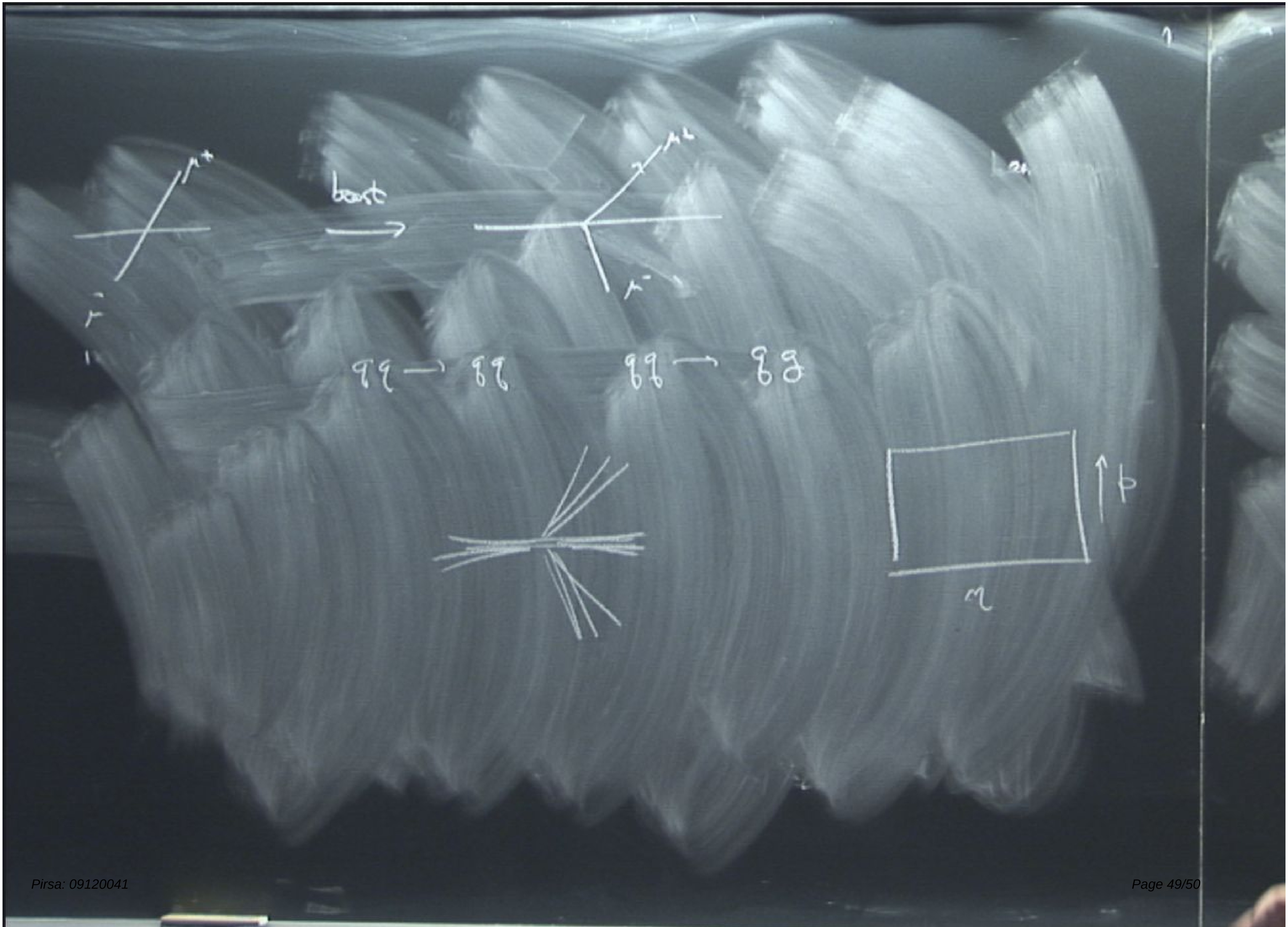
$$Q^2 = x_1 x_2 s$$

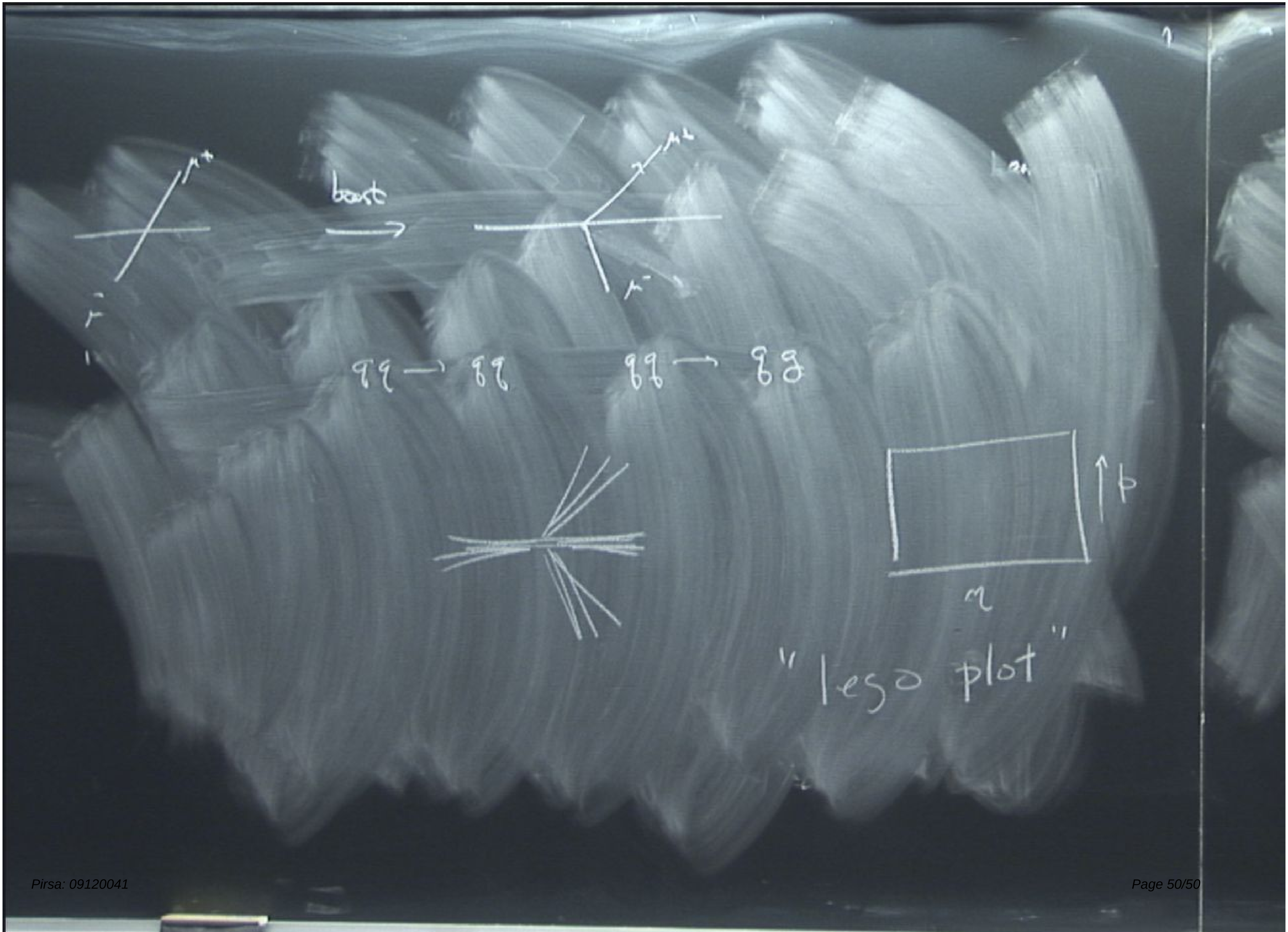
$$\frac{d\sigma(pp \to \mu^+\mu^-)}{dy\, dQ^2} = \sum_{f,\bar{f}} \left(x_1 f_f(x_1)\, x_2 f_f(x_2)\right) \frac{Q_f^2}{3} \frac{4\pi\alpha^2}{3Q^4}$$



μ^+
boost
μ^+
μ^-
qq → qq
qg → qg


boost


boost
p
η


boost
μ+
μ-
p
η
"lego plot"