

Title: PSI 2015/2016 Quantum Field Theory I - Daniel Wohns and Tibra Ali - Lecture 14

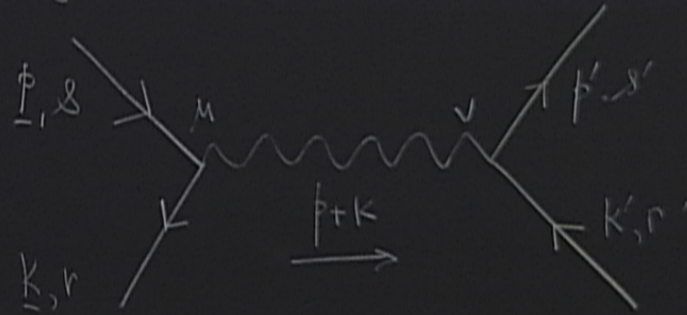
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Abstract:

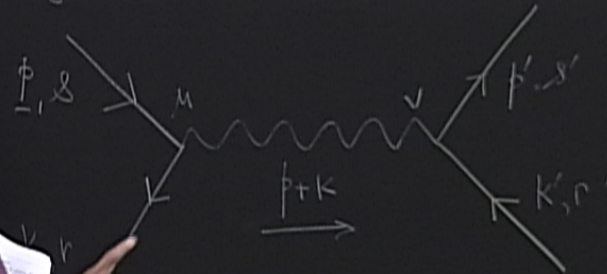
$$e^+e^- \rightarrow \mu^+\mu^-$$

$$\mathcal{L} = \bar{\psi}_e (i\not{D} - m_e) \psi_e + \bar{\psi}_\mu (i\not{D} - m_\mu) \psi_\mu + \mathcal{L}_{em}$$

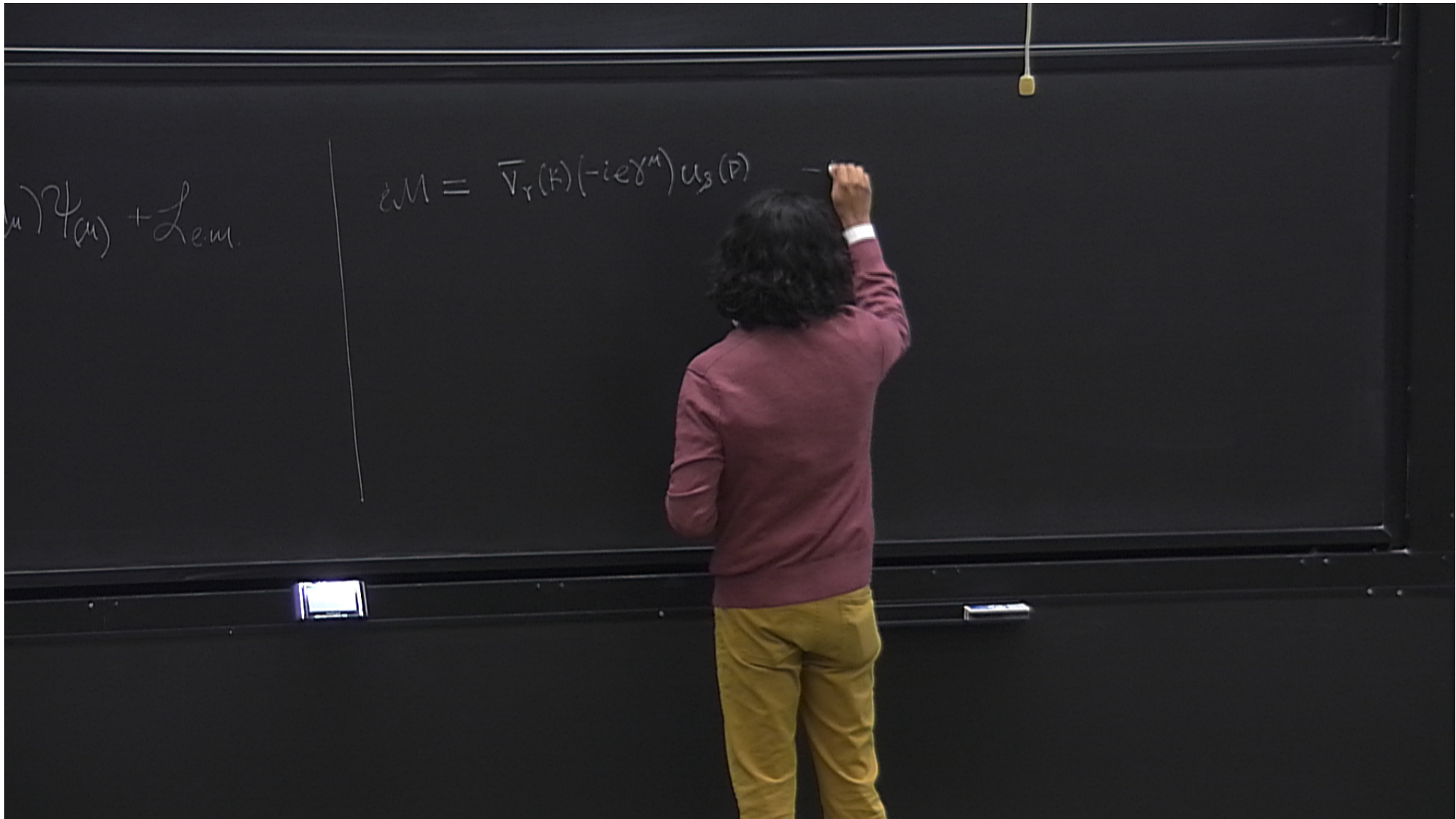


$$e^+e^- \rightarrow \mu^+\mu^-$$

$$\mathcal{L} = \bar{\psi}_e (i\not{D} - m_e) \psi_e + \bar{\psi}_\mu (i\not{D} - m_\mu) \psi_\mu + \mathcal{L}_{em}$$



$$\mathcal{M} =$$



$$\psi(u)\psi(u) + L_{em.}$$

$$\mathcal{M} = \bar{V}_r(k)(-ie\gamma^\mu)u_s(p)$$

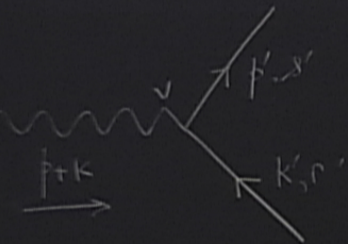
$u) \psi(u) + \text{Lem.}$

$$iM = \bar{V}_4(k) (-ie\gamma^\mu) u_3(p) \frac{-i \not{p}}{(p+k)^2 + i\epsilon}$$

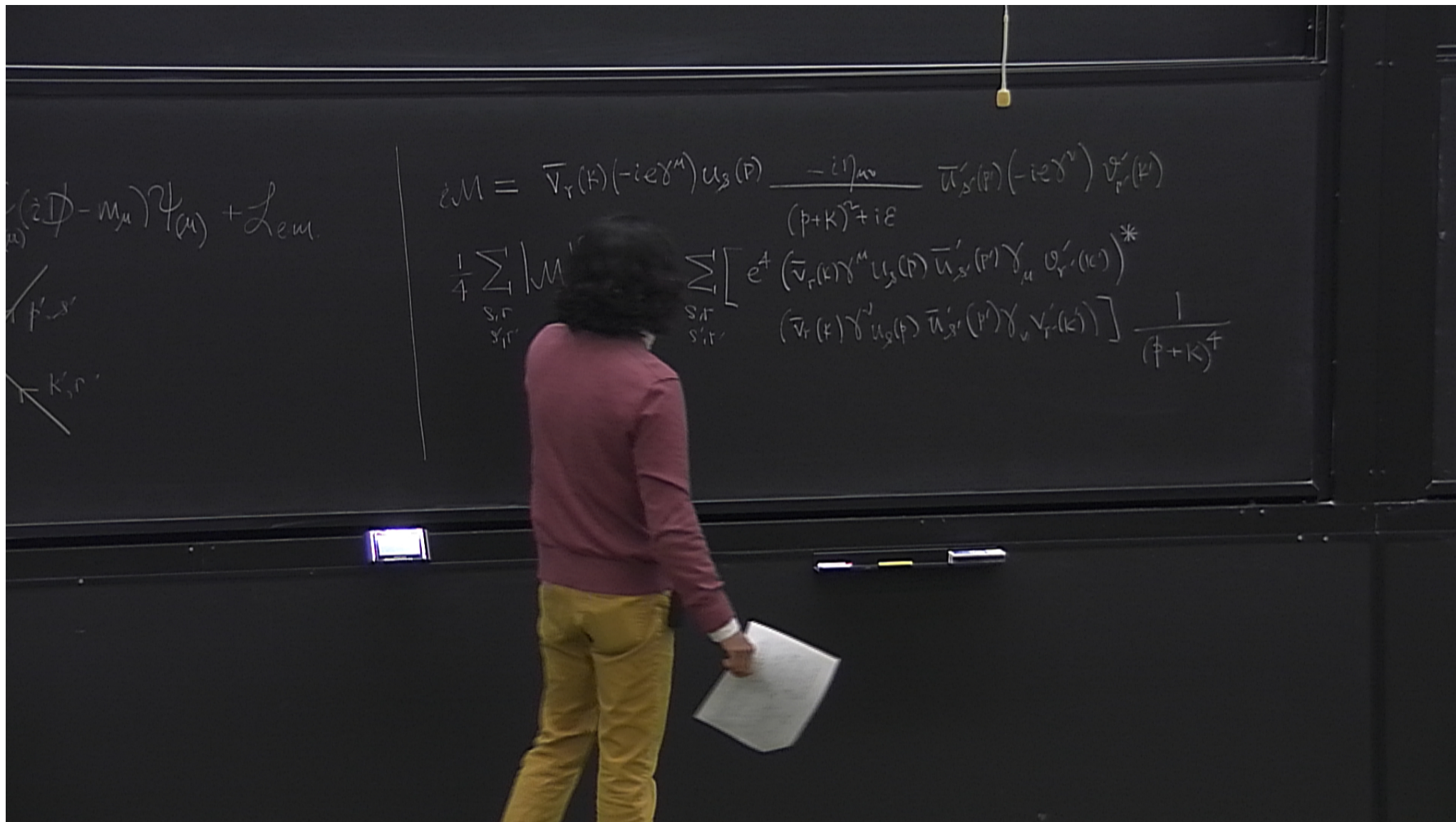
+ $\mathcal{L}_{em}$.

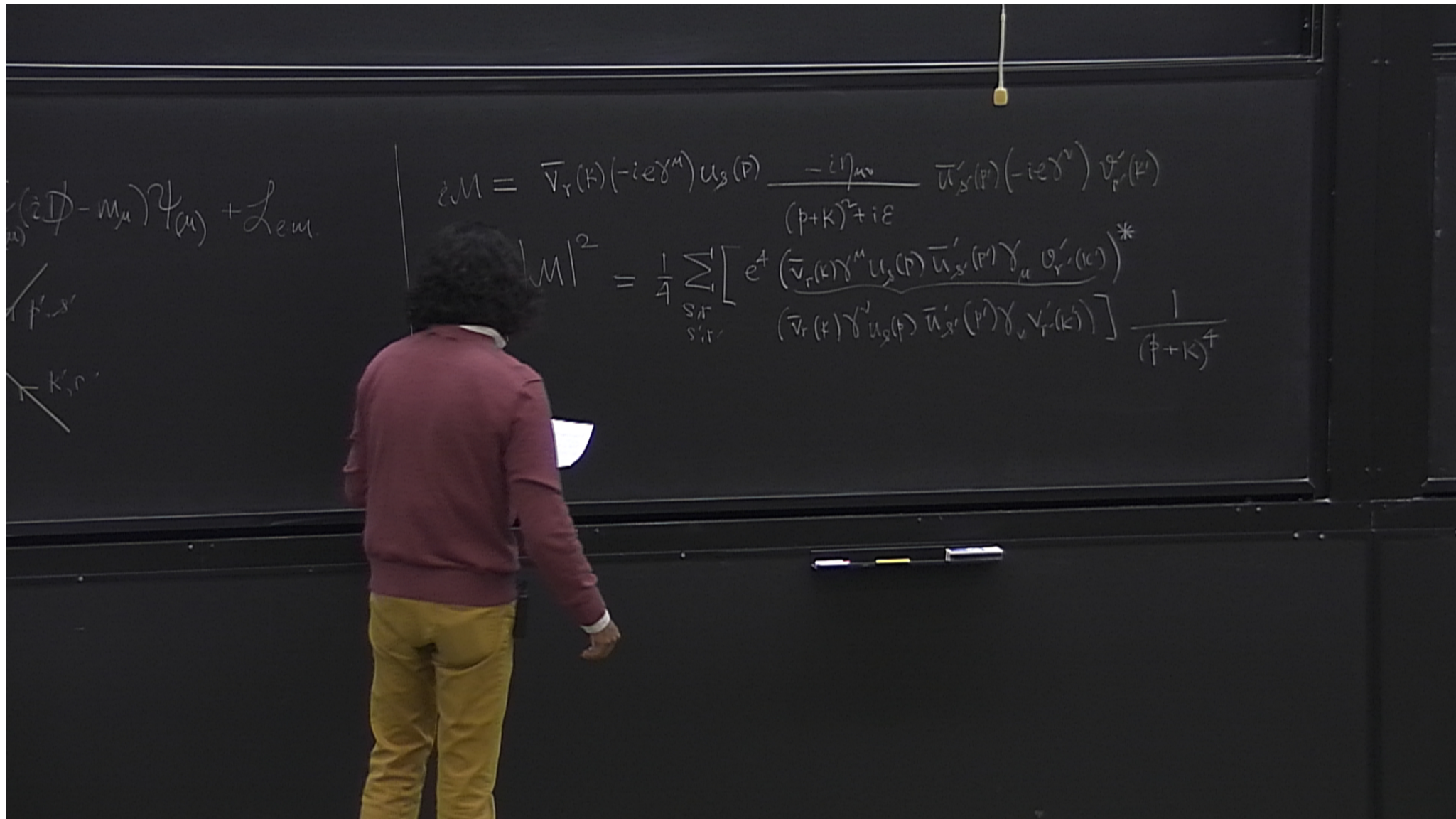
$$i\mathcal{M} = \bar{v}_r(k) (-ie\gamma^\mu) u_s(p) \frac{-i\eta_{\mu\nu}}{(p+k)^2 + i\epsilon} \bar{u}_{s'}(p') (-ie\gamma^\nu) v_{r'}(k')$$

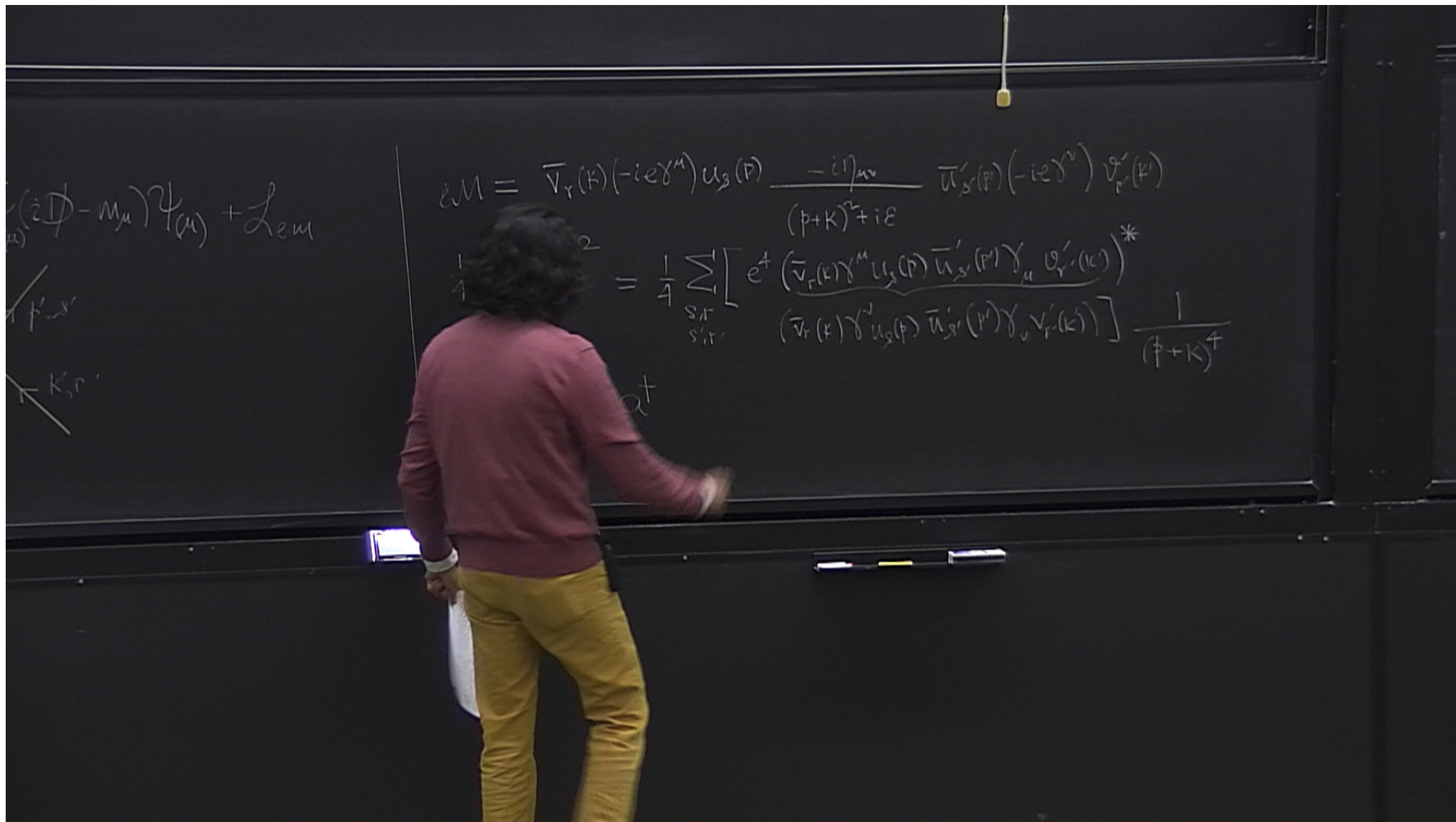
$$e) \psi_e + \bar{\psi}_{(\mu)} (i \not{D} - m_\mu) \psi_{(\mu)} + \mathcal{L}_{em}$$

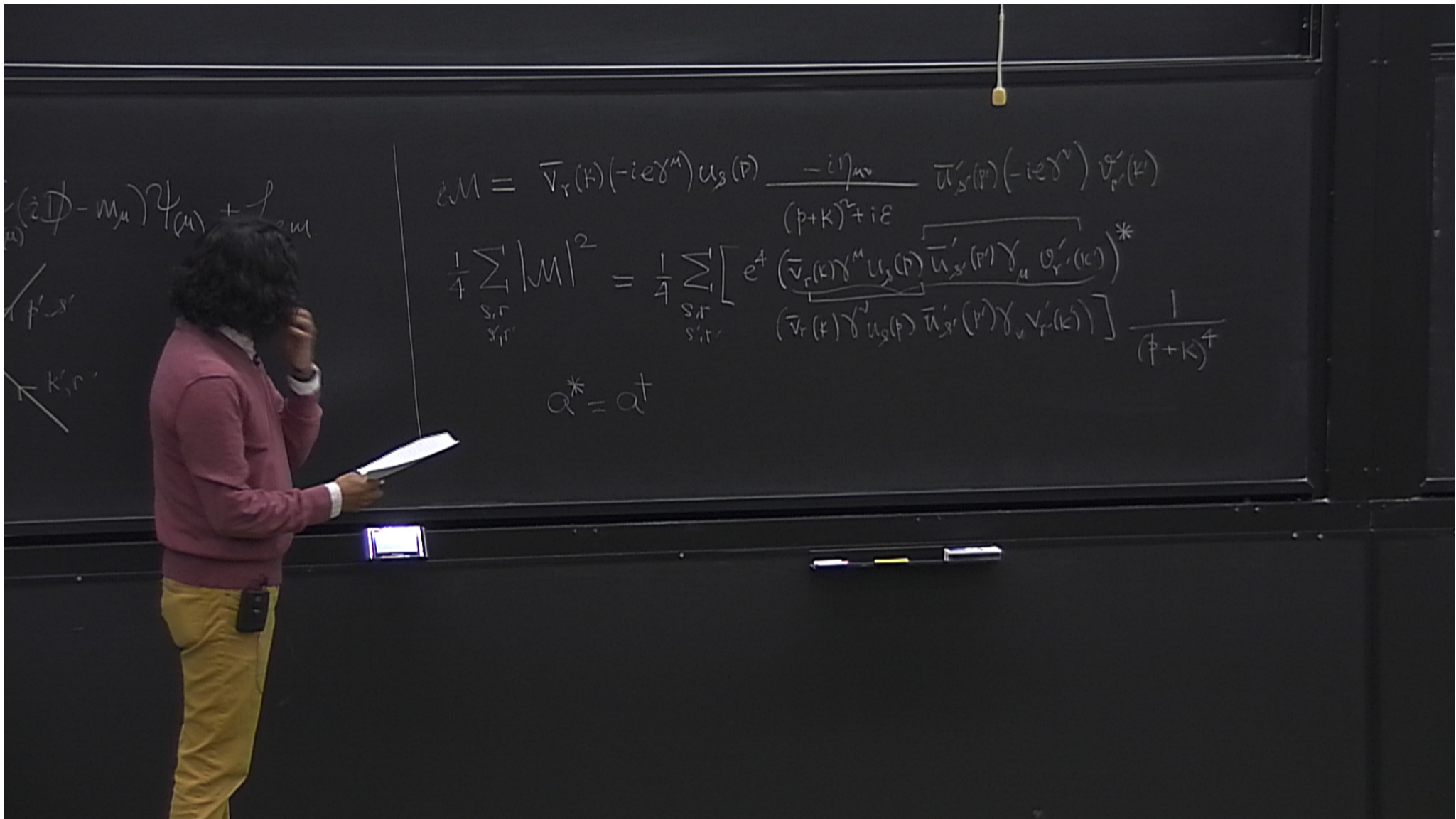


$$i\mathcal{M} = \bar{v}_r(k) (-ie\gamma^\mu) u_s(p) \frac{-i \not{\epsilon}_{\mu\nu}}{(p+k)^2 + i\epsilon} \bar{u}_{s'}(p') (-ie\gamma^\nu) v_{r'}(k')$$



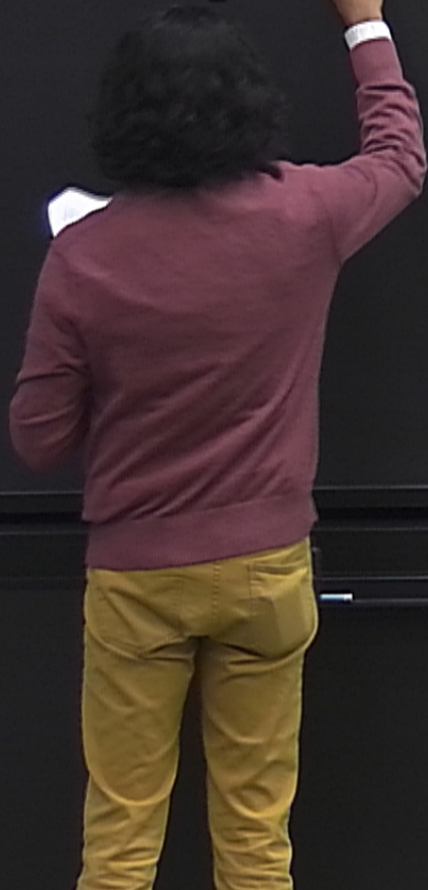






A person with dark curly hair, wearing a pink long-sleeved sweater and yellow trousers, stands with their back to the camera, holding a white sheet of paper in their left hand. They are positioned in front of a large blackboard. On the blackboard, the equation $(\bar{\psi} \gamma^\mu \psi)^\dagger = \psi^\dagger \gamma^\mu (\bar{\psi})^\dagger$ is written in white chalk. The blackboard has a horizontal ledge with a few markers and a small electronic device on it. The scene is dimly lit, focusing on the person and the equation.
$$(\bar{\psi} \gamma^\mu \psi)^\dagger = \psi^\dagger \gamma^\mu (\bar{\psi})^\dagger$$

$$\begin{aligned}
 (\bar{\psi} \gamma^\mu \psi)^\dagger &= \psi^\dagger \gamma^{\mu\dagger} (\bar{\psi})^\dagger \\
 &= \psi^\dagger \gamma^0 \gamma^0 \gamma^{\mu\dagger} (\gamma^0 \psi) \\
 &= \bar{\psi} \gamma^0 \gamma^{\mu\dagger} \gamma^0 \psi \\
 &= \bar{\psi} \gamma^\mu \psi
 \end{aligned}$$

A person with dark, curly hair, wearing a maroon long-sleeved shirt and yellow pants, is standing with their back to the camera. They are writing on a large blackboard with their right hand. The blackboard is dark and has some faint horizontal lines. The person's left hand is holding a small white object, possibly a piece of paper or a marker.
$$\frac{1}{4} \sum |\mathcal{M}|^2 = \left[e^4 \right]$$

$$\frac{1}{4} \sum |\mathcal{M}|^2 = \left[e^4 (\bar{v}_r(k) \gamma^\mu u_s(p) \bar{u}_s(p) \gamma^\nu v_r(k)) \right]$$

$$\frac{1}{4} \sum |\mathcal{M}|^2 = \left[e^4 (\bar{v}_r(k) \gamma^\mu u_s(p) \bar{u}_s(p) \gamma^\nu v_r(k)) (\bar{u}_{s'}(p') \gamma_\mu v_{r'}(k') \bar{v}_{r'}(k') \gamma_\nu u_{s'}(p')) \right]$$

$$\frac{1}{4} \sum |\mathcal{M}|^2 = \left[e^4 \underbrace{(\bar{v}_r(k) \gamma^\mu u_{\lambda}(p) \bar{u}_{\lambda}(p) \gamma^\nu v_r(k))}_{\text{fermion part}} (\bar{u}_{\lambda'}(p') \gamma_\mu v_{r'}(k') \bar{v}_{r'}(k') \gamma_\nu u_{\lambda'}(p')) \right] \frac{1}{(p+k)^4}$$

$$\frac{1}{4} \sum_{r,s} |M|_{\frac{1}{2} \rightarrow \frac{1}{2}}^2 = \left[e^4 \left(\bar{v}_r(k) \gamma^\mu u_{\frac{1}{2}}(p) \bar{u}_{\frac{1}{2}}(p) \gamma^\nu v_r(k) \right) \left(\bar{u}_{\frac{1}{2}}'(p') \gamma_\mu v_{r'}(k') \bar{v}_{r'}(k') \gamma_\nu u_{\frac{1}{2}}'(p') \right) \right] \frac{1}{(p+k)^4}$$

$$\sum_{r,s} \bar{v}_r(k)$$

b

$$\frac{1}{4} \sum_{r,s} |M|^2_{\frac{1}{4}} = \left[e^4 (\bar{v}_r(k) \gamma^\mu u_s(p) \bar{u}_s(p) \gamma^\nu v_r(k)) (\bar{u}_{s'}(p') \gamma_\mu v_{r'}(k') \bar{v}_{r'}(k') \gamma_\nu u_{s'}(p')) \right] \frac{1}{(p+k)^4}$$

$$\sum_{r,s} \bar{v}_r(k)_a \gamma^\mu_{ab} u_s(p)_b \bar{u}_s(p)_c \gamma^\nu_{cd} v_r(k)_d$$

$$\frac{1}{4} \sum_{r,s} |M|^2_{\frac{1}{4}} = \left[e^4 (\bar{\psi}_r(k) \gamma^\mu u_2(p) \bar{u}_2(p) \gamma^\nu \psi_r(k)) (\bar{u}_{2'}(p') \gamma_\mu \psi_{r'}(k') \bar{\psi}_{r'}(k') \gamma_\nu u_{2'}(p')) \right] \frac{1}{(p+k)^4}$$

$$\sum_{r,s} \bar{\psi}_r(k)_a \gamma^\mu_{ab} u_2(p)_b \bar{u}_2(p)_c \gamma^\nu_{cd} \psi_r(k)_d$$

$$\frac{1}{4} \sum_{r,s} |M|^2_{\frac{1}{2} \rightarrow \frac{1}{2}} = \left[e^4 \left(\bar{v}_r(k) \gamma^\mu u_s(p) \bar{u}_s(p) \gamma^\nu v_r(k) \right) \left(\bar{u}_{s'}(p') \gamma_\mu v_{r'}(k') \bar{v}_{r'}(k') \gamma_\nu u_{s'}(p') \right) \right] \frac{1}{(p+k)^4}$$

$$\sum_{r,s} \bar{v}_r(k) \gamma^\mu u_s(p) \bar{u}_s(p) \gamma^\nu v_r(k) = \sum_{r,s} \gamma^\mu_{ab} (u_s(p)_b \bar{u}_s(p)_c) \gamma^\nu_{cd} v_r(k)_d$$

$$\frac{1}{4} \sum_{\lambda, \lambda'} |M|_{\lambda, \lambda'}^2 = \left[e^4 \left(\bar{v}_r(k) \gamma^\mu u_\lambda(p) \bar{u}_\lambda(p) \gamma^\nu v_r(k) \right) \left(\bar{u}_{\lambda'}(p') \gamma_\mu v_{r'}(k') \bar{v}_{r'}(k') \gamma_\nu u_{\lambda'}(p') \right) \right] \frac{1}{(p+k)^4}$$

$$\sum_{r, s} \bar{v}_r(k)_a \gamma^\mu_{ab} u_\lambda(p)_b \bar{u}_\lambda(p)_c \gamma^\nu_{cd} v_r(k)_d$$

$$\sum_{r, s} v_r(k)_d \bar{v}_r(k)_a \gamma^\mu_{ab} (u_\lambda(p)_b \bar{u}_\lambda(p)_c) \gamma^\nu_{cd}$$

$$\sum_r v_r(k) \bar{v}_r(k) = \not{k} - m_e$$

$$\sum_r u_r(k) \bar{u}_r(k) = \not{k} + m_e$$

$$\frac{1}{4} \sum_{r,s} |M|_{\frac{1}{4}}^2 = \left[e^4 (\bar{v}_r(k) \gamma^\mu u_s(p) \bar{u}_s(p) \gamma^\nu v_r(k)) (\bar{u}_{s'}(p') \gamma_\mu v_{r'}(k') \bar{v}_{r'}(k') \gamma_\nu u_{s'}(p')) \right] \frac{1}{(p+k)^4}$$

$$\begin{aligned} & \sum_{r,s} \bar{v}_r(k)_a \gamma^\mu_{ab} u_s(p)_b \bar{u}_s(p)_c \gamma^\nu_{cd} v_r(k)_d \\ &= \sum_{r,s} v_r(k)_d \bar{v}_r(k)_a \gamma^\mu_{ab} (u_s(p)_b \bar{u}_s(p)_c) \gamma^\nu_{cd} \\ &= \end{aligned}$$

$$\begin{aligned} \sum_r v_r(k) \bar{v}_r(k) &= \not{k} - m_e \\ \sum_r u_r(k) \bar{u}_r(k) &= \not{k} + m_e \end{aligned}$$

$$\frac{1}{4} \sum_i |\mathcal{M}|^2 = \frac{1}{4} \sum_i \left[e^4 \left(\bar{v}_r(k) \gamma^\mu u_2(p) \bar{u}_2(p) \gamma^\nu v_r(k) \right) \left(\bar{u}_{2'}(p') \gamma_\mu v_{r'}(k') \bar{v}_{r'}(k') \gamma_\nu u_{2'}(p') \right) \right] \frac{1}{(p+k)^4}$$

$$\begin{aligned} & \sum_{r,s} \bar{v}_r(k)_a \gamma^\mu_{ab} u_2(p)_b \bar{u}_2(p)_c \gamma^\nu_{cd} v_r(k)_d \\ &= \sum_{r,s} v_r(k)_d \bar{v}_r(k)_a \gamma^\mu_{ab} (u_2(p)_b \bar{u}_2(p)_c) \gamma^\nu_{cd} \\ &= \text{Tr}[(\not{k} - m_e) \gamma^\mu (\not{p} + m_e) \gamma^\nu] \end{aligned}$$

$$\begin{aligned} \sum_r v_r(k) \bar{v}_r(k) &= \not{k} - m_e \\ \sum_r u_r(k) \bar{u}_r(k) &= \not{k} + m_e \end{aligned}$$

$$\left[\bar{u}_{s'}(p') \gamma_\mu u_{r'}(k') \bar{v}_{r'}(k') \gamma_\nu u_{s'}(p') \right] \frac{1}{(p+k)^4}$$

$$u_r(k)$$

$$\gamma_\nu$$

$$v_r(k)$$

$$\sum_r v_r(k) \bar{v}_r(k) = \not{k} - m_e$$

$$\sum_r u_r(k) \bar{u}_r(k) = \not{k} + m_e$$

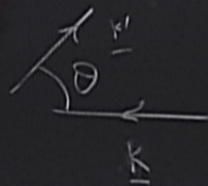
$$m_\mu = 105 \text{ MeV}$$

$$m_e = 0.5 \text{ MeV}$$

$$\frac{1}{4} \sum |\mathcal{M}|^2 = \frac{8e^4}{(p+k)^4} \left[(k \cdot p') (p \cdot k') + (k \cdot k') (p \cdot p') + 2(k \cdot p) m_\mu^2 \right]$$

$$\frac{1}{4} \sum |M|^2 = \frac{8e^4}{(P+K)^4} \left[(K \cdot P') (P \cdot K') + (K \cdot K') (P \cdot P') + 2(K \cdot P) m_\mu^2 \right]$$

$$\left(1 + \frac{m^2}{E^2} \right) + \left(1 - \frac{m^2}{E^2} \right) \cos^2 \theta$$



$$\vec{p} = (E, 0, 0, E)$$

$$(k \cdot k') (p \cdot p') + 2(k \cdot p) m_e^2]$$

$$\left(\frac{m^2}{E^2} \right) \cos^2 \theta]$$

$$(E, 0, 0, E)$$

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2}{4E_{\text{cm}}} \sqrt{1 - \frac{m^2}{E^2}} \left[\left(1 + \frac{m^2}{E^2} \right) + \left(1 - \frac{m^2}{E^2} \right) \cos^2 \theta \right]$$

$$E_{\text{cm}} = 2E, \quad \alpha = \frac{e^2}{4\pi\hbar c} = \frac{1}{137.04}$$

Fine structure
constant.

$$(k \cdot k') (p \cdot p') + 2(k \cdot p) m_e^2]$$

$$\left(\frac{m^2}{E^2} \right) \cos^2 \theta]$$

$$(E, 0, 0, E)$$

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2}{4E_{\text{cm}}} \sqrt{1 - \frac{m^2}{E^2}} \left[\left(1 + \frac{m^2}{E^2} \right) + \left(1 - \frac{m^2}{E^2} \right) \cos^2 \theta \right]$$

$$E_{\text{cm}} = 2E, \quad \alpha = \frac{e^2}{4\pi\hbar c} = \frac{1}{137.04}$$

Fine structure
constant.

$$(p \cdot p') + 2(k \cdot p) m_\mu^2]$$

$$(\cos^2 \theta)$$

$$, E)$$

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2}{4 E_{\text{cm}}} \sqrt{1 - \frac{m^2}{E^2}} \left[\left(1 + \frac{m^2}{E^2}\right) + \left(1 - \frac{m^2}{E^2}\right) \cos^2 \theta \right]$$

$$E_{\text{cm}} = 2E, \quad \alpha = \frac{e^2}{4\pi\hbar c} = \frac{1}{137.04}$$

Fine structure constant.

$$\sigma_{\text{total}} = \frac{4\pi\alpha^2}{3 E_{\text{cm}}} \times$$

$$\sqrt{1 - \frac{m^2}{E^2}} \left(1 + \frac{1}{2} \frac{m^2}{E^2}\right)$$

$$k'(p p') + 2(k p) m_e^2]$$

$$) \cos^2 \theta]$$

$$0, 0, E)$$

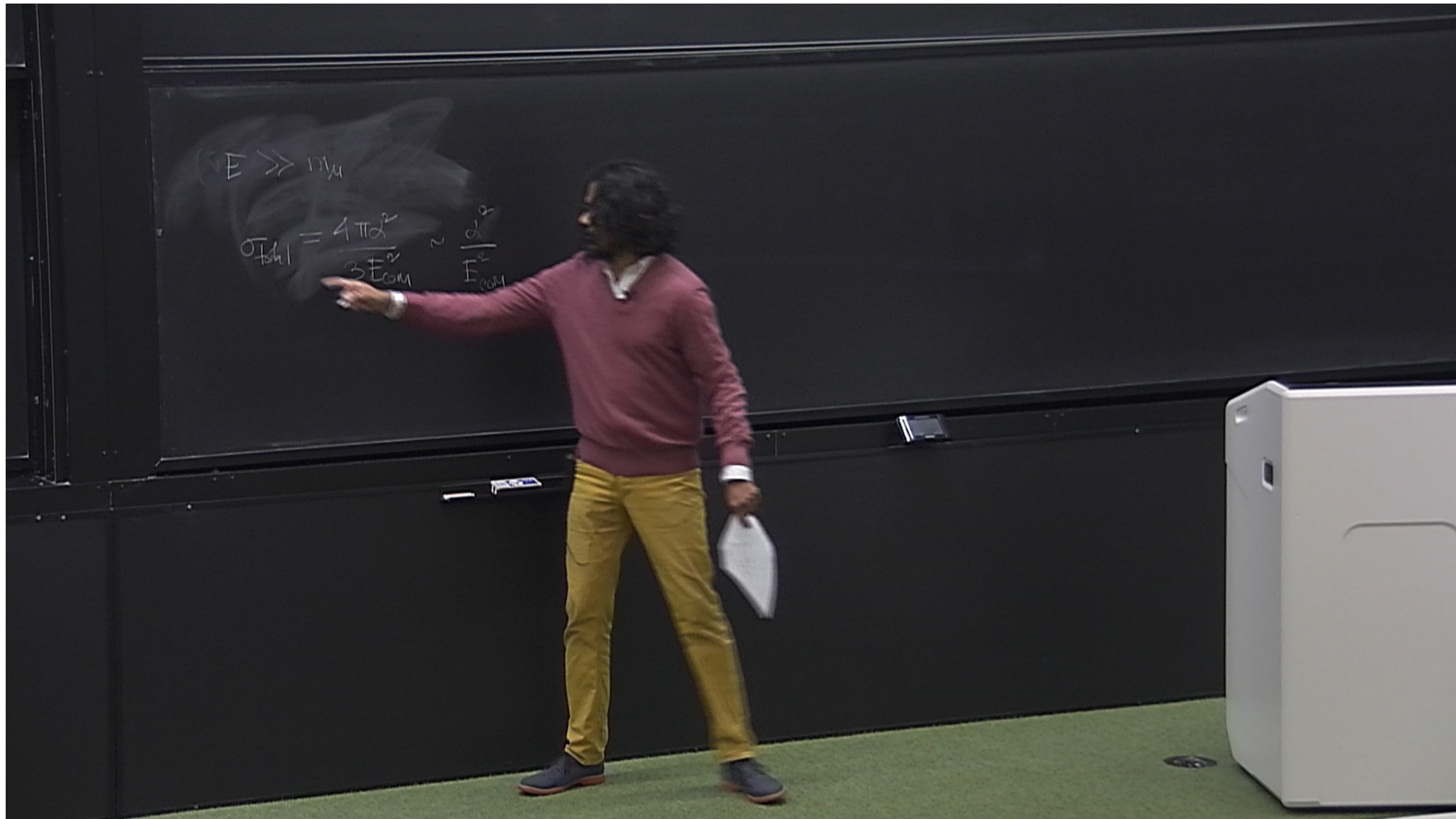
$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2}{4E_{\text{com}}} \sqrt{1 - \frac{m^2}{E^2}} \left[\left(1 + \frac{m^2}{E^2}\right) + \left(1 - \frac{m^2}{E^2}\right) \cos^2 \theta \right]$$

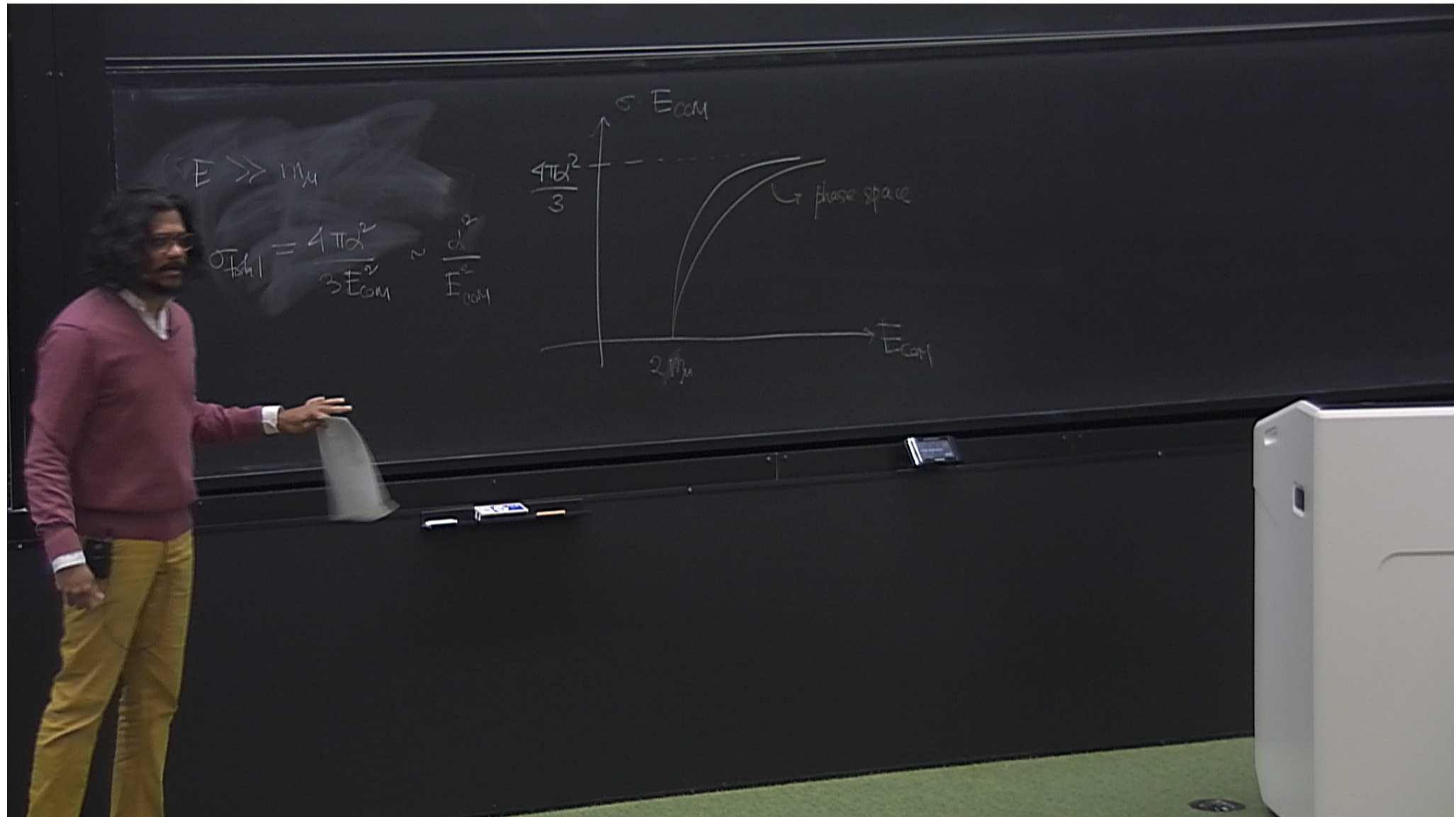
$$E_{\text{com}} = 2E, \quad \alpha = \frac{e^2}{4\pi\hbar c} = \frac{1}{137.04}$$

↙
Fine structure
constant.

$$= \frac{4\pi\alpha^2}{3E_{\text{com}}^2} \times$$

$$\left(1 - \frac{m^2}{E^2}\right) \left(1 + \frac{1}{2} \frac{m^2}{E^2}\right)$$

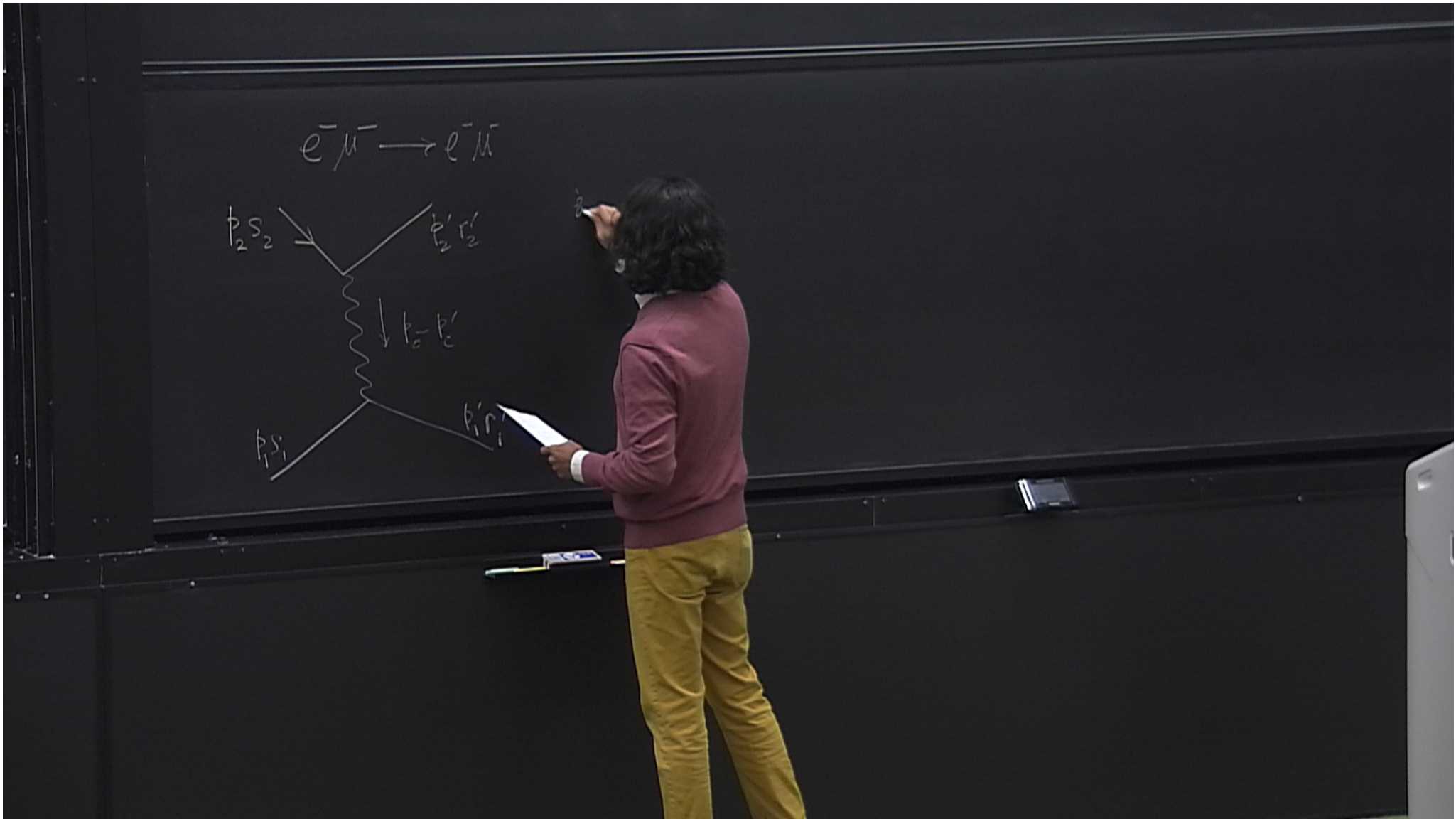


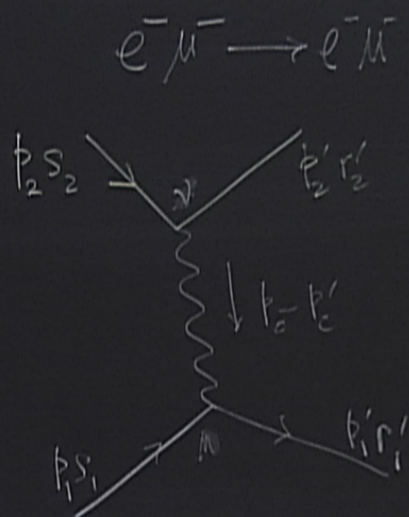


$$e^- \mu^- \rightarrow e^- \mu^-$$

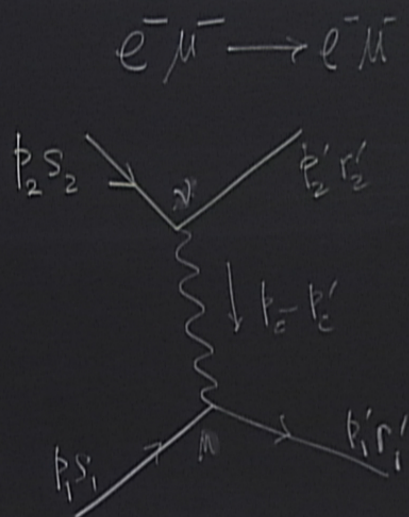
$$e^- \mu^- \rightarrow e^- \mu^-$$





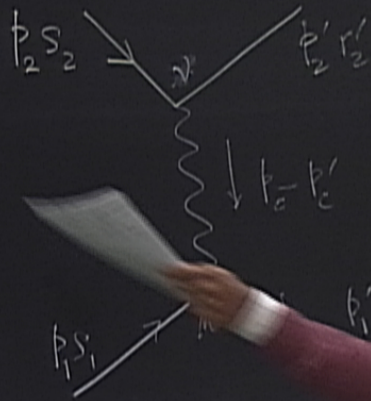


$$\hat{\mathcal{M}} = \bar{u}_{r_2'}(p_2') (-ie\gamma^\mu) u_{r_2}(p_2) \bar{u}_{r_1'}(p_1') (-ie\gamma_\mu) u_{r_1}(p_1)$$

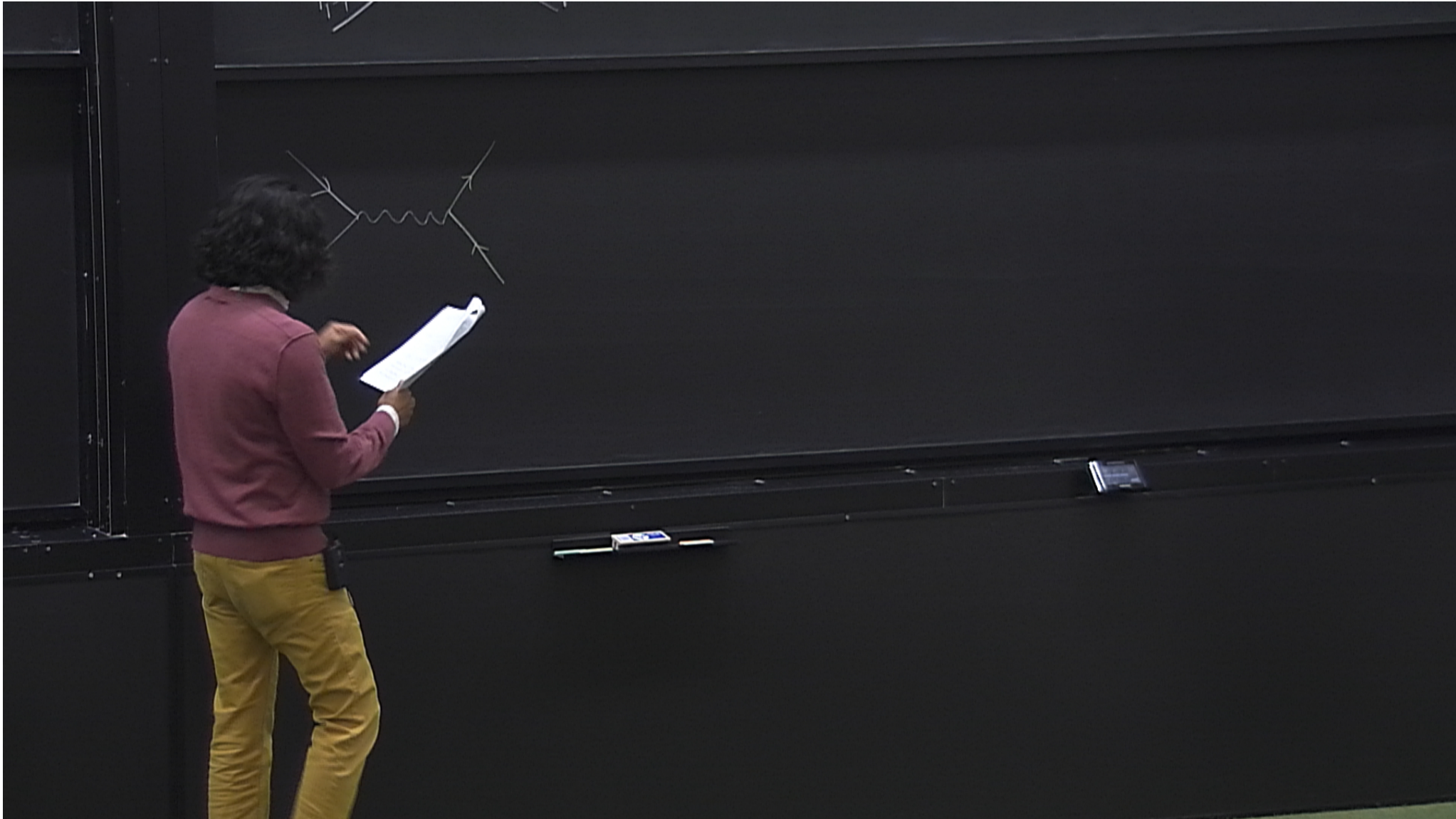


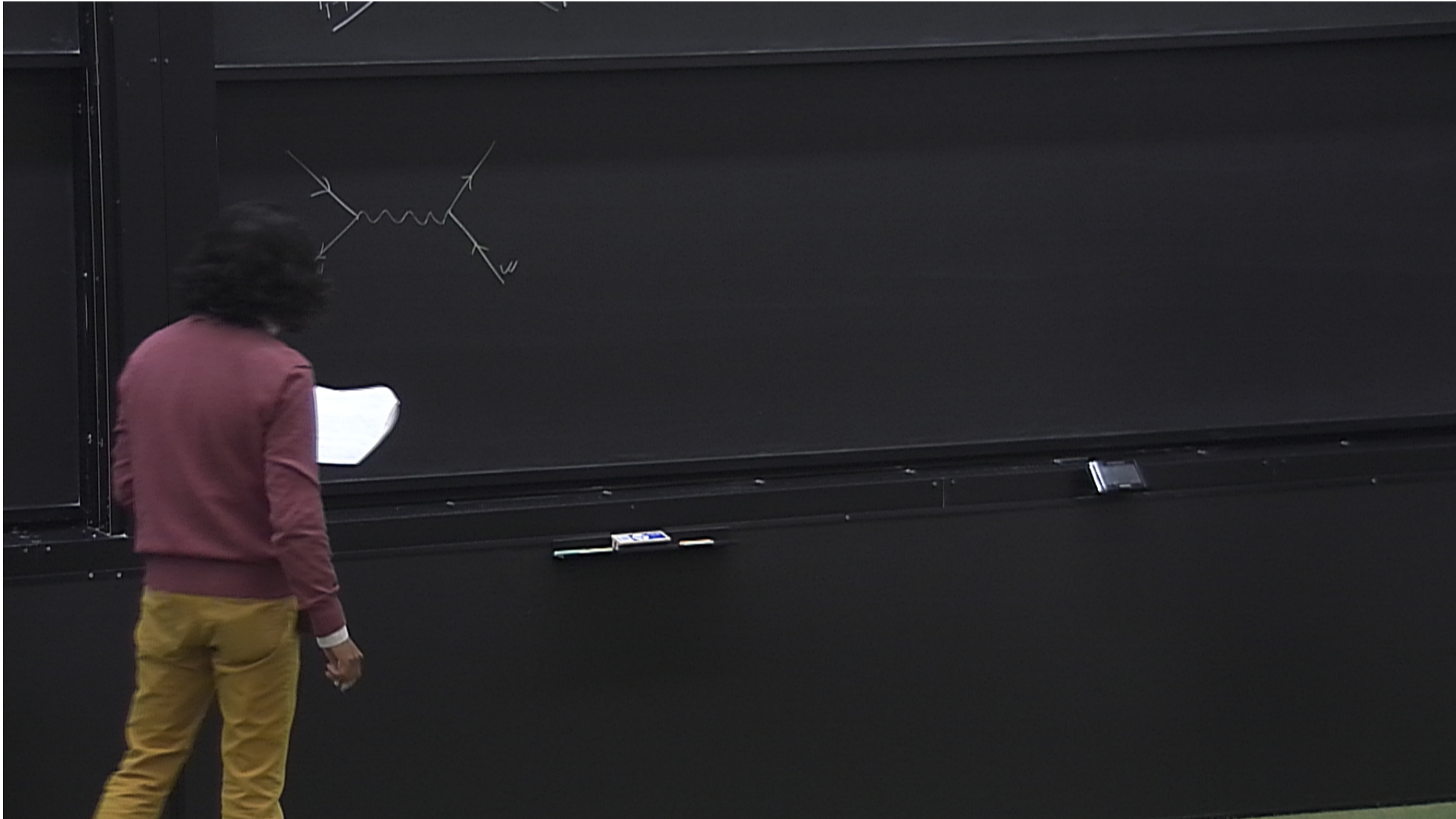
$$\mathcal{M} = \bar{u}_{r_2'}(p_2') (-ie\gamma^\mu) u_{s_2}(p_2) \frac{i\cancel{q}}{q^2} \bar{u}_{r_1'}(p_1') (-ie\gamma_\mu) u_{s_1}(p_1)$$

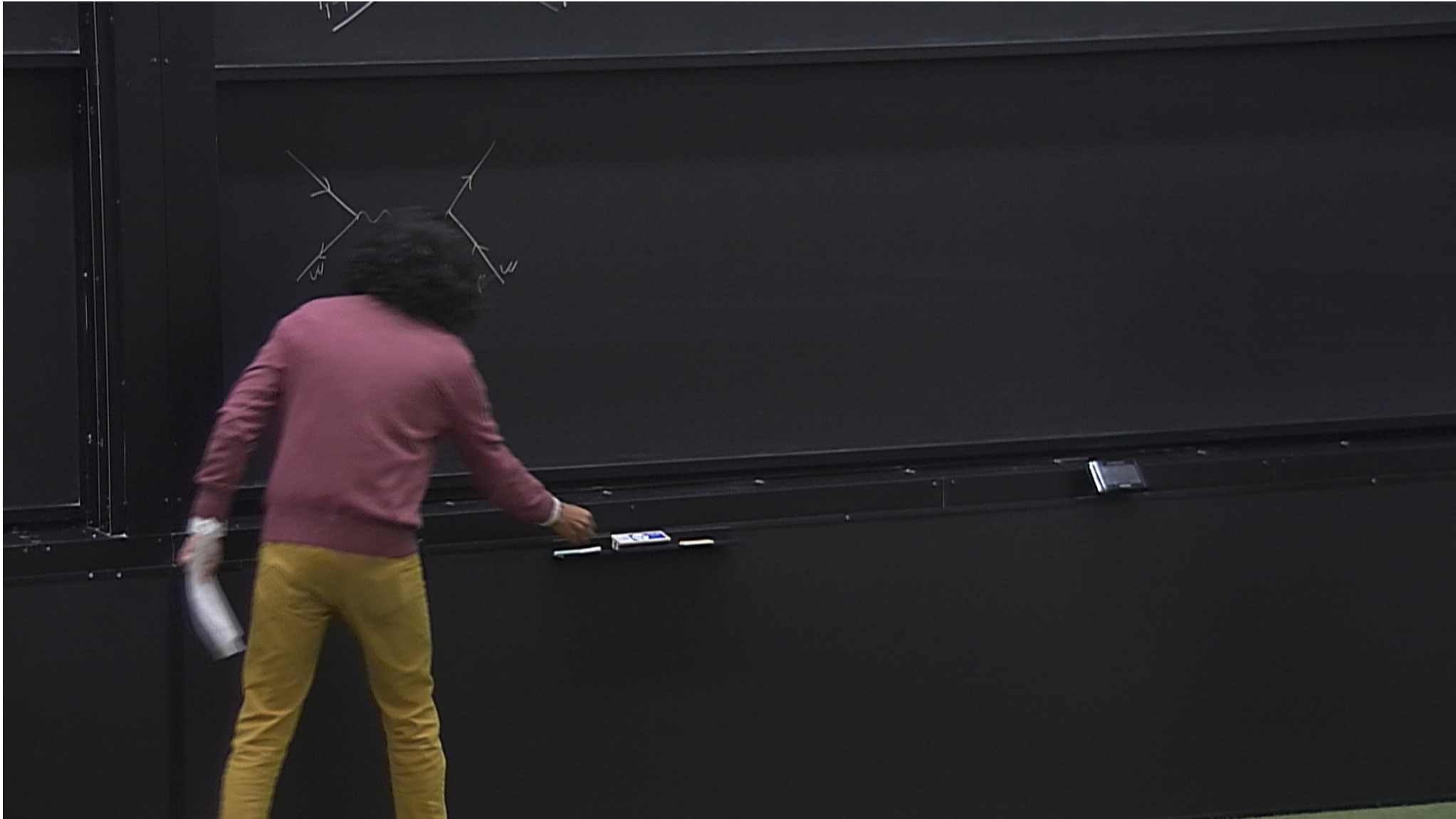
$$e^- \mu^- \rightarrow e^- \mu^-$$

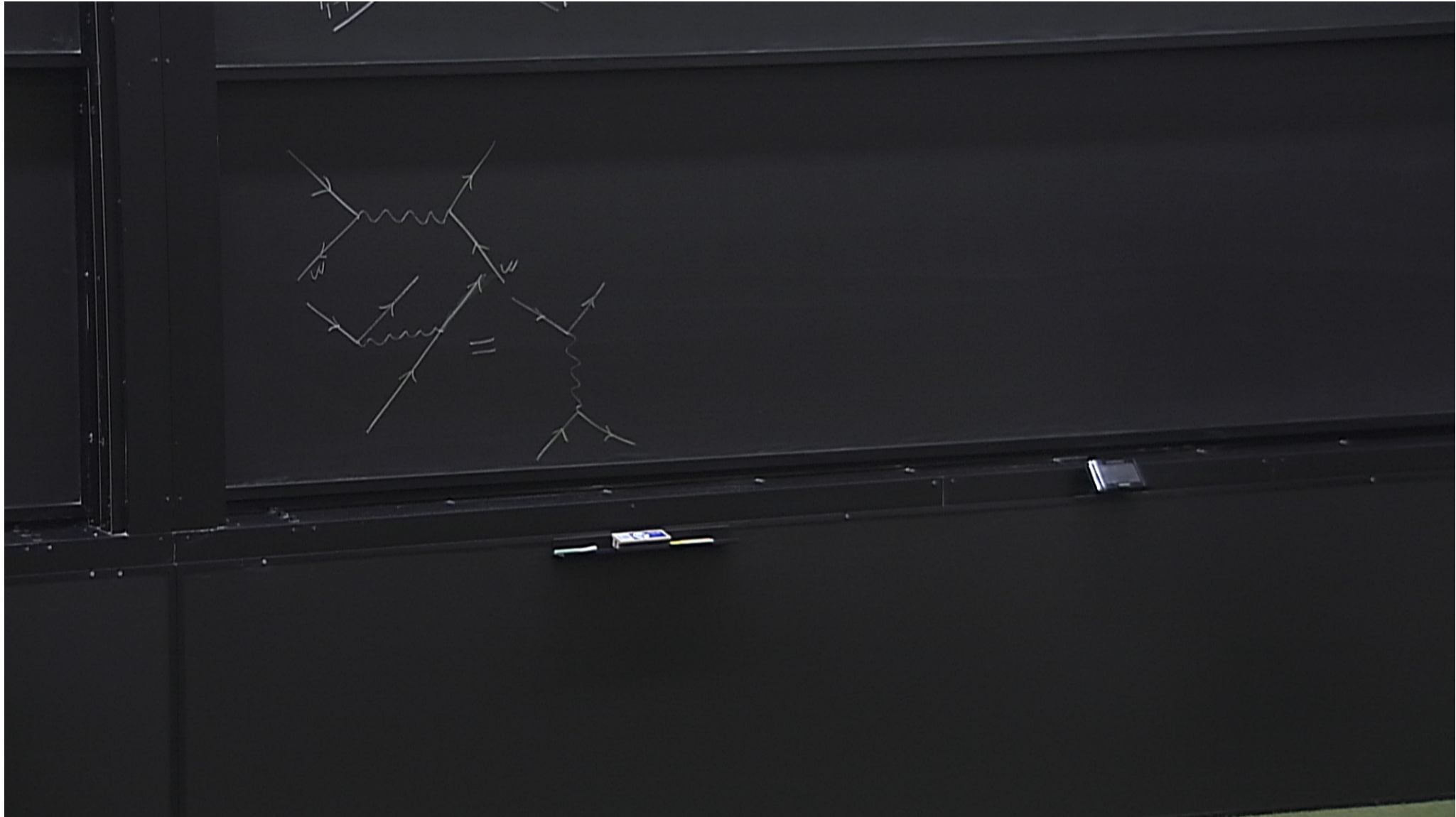


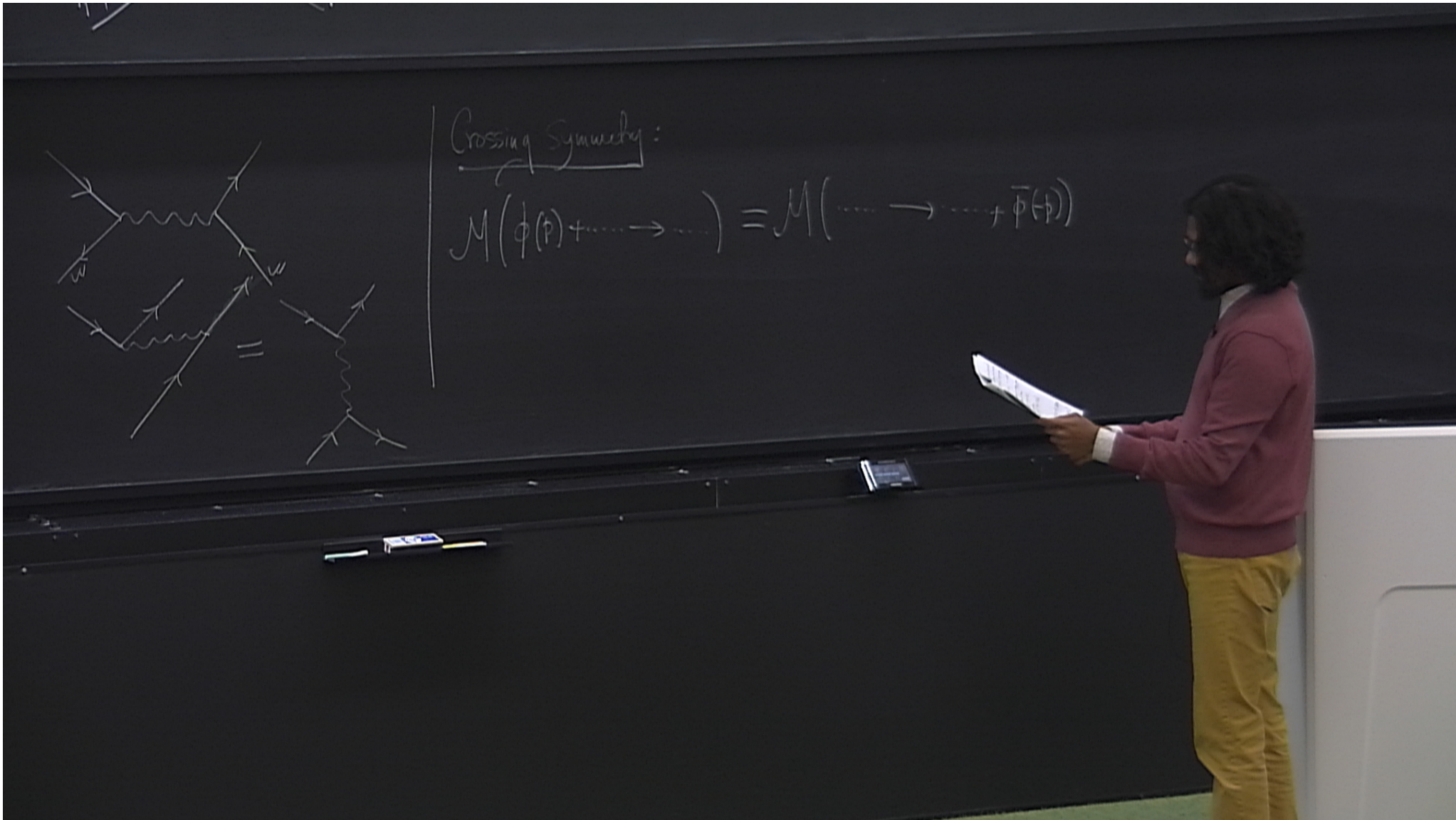
$$i\mathcal{M} = \bar{u}_{r_1'}(p_1')(-ie\gamma^\mu)u_{r_1}(p_1) \frac{-i\cancel{q}}{q^2} \bar{u}_{r_2'}(p_2')(-ie\gamma^\mu)u_{r_2}(p_2)$$









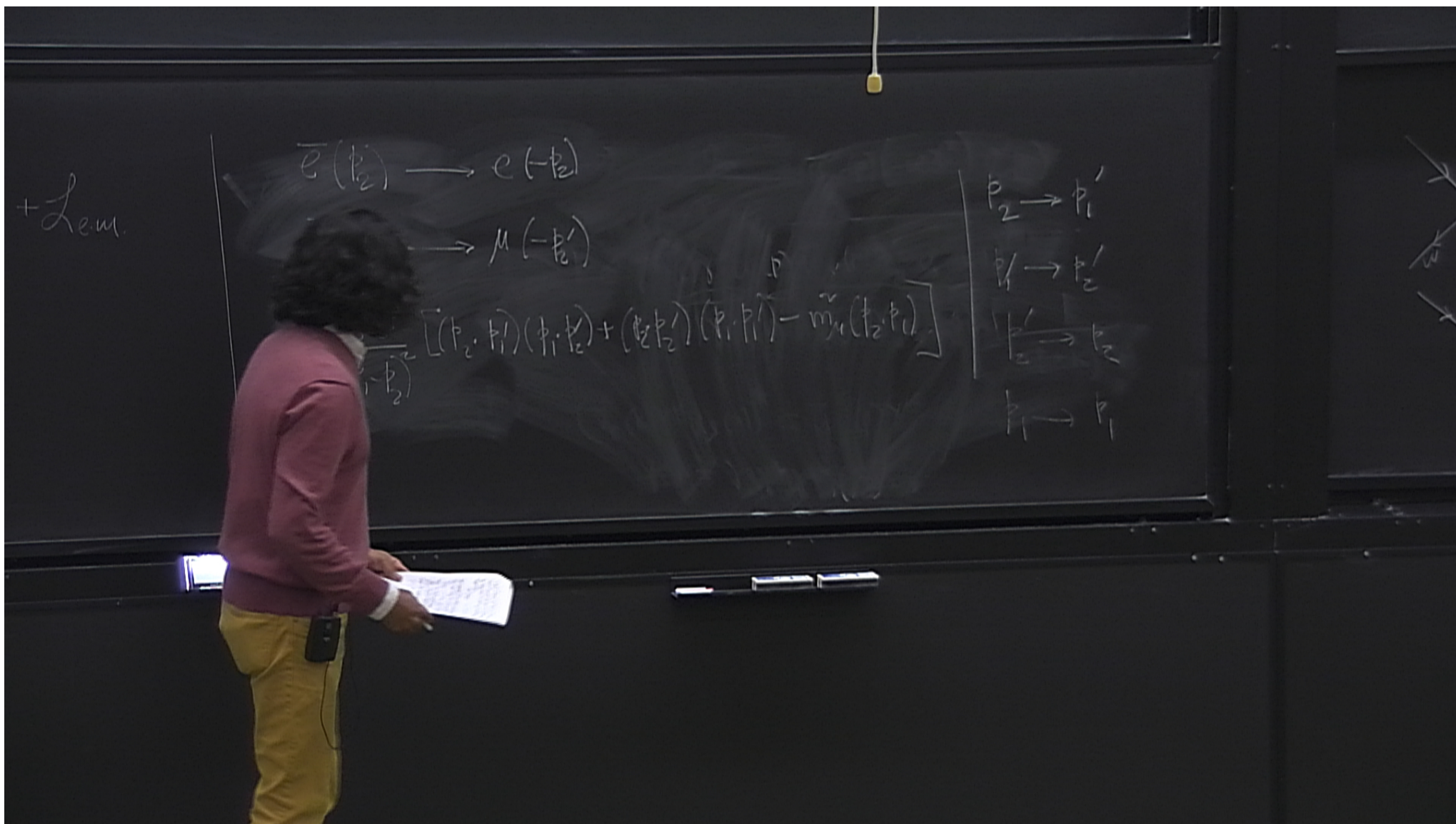


$$-m_\mu \bar{\psi}_\mu + \mathcal{L}_{em.}$$

$$\bar{e}(p_2) \longrightarrow e(-p_2)$$

$$\bar{\mu}(p'_2) \longrightarrow \mu(-p'_2)$$

$$\frac{8e^4}{(p_1 - p_2)^2} [(p_2 \cdot p'_1)(p_1 \cdot p'_2) + (p_2 \cdot p'_2)(p_1 \cdot p'_1)]$$



Polarization Sums

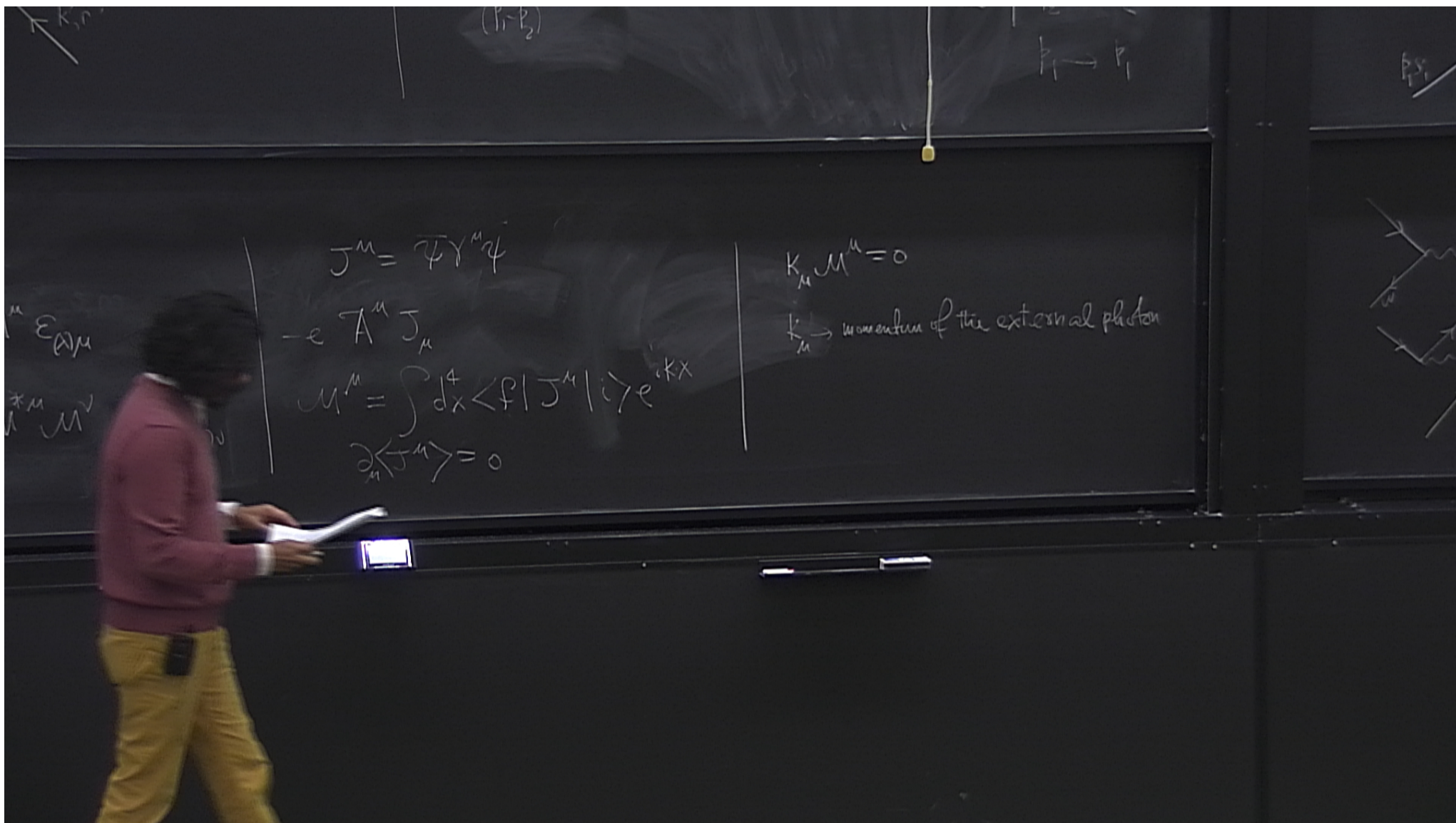
$$\epsilon_{(\lambda)}^\mu \quad \mathcal{M}_\lambda = \mathcal{M}^\mu \epsilon_{(\lambda)\mu}$$

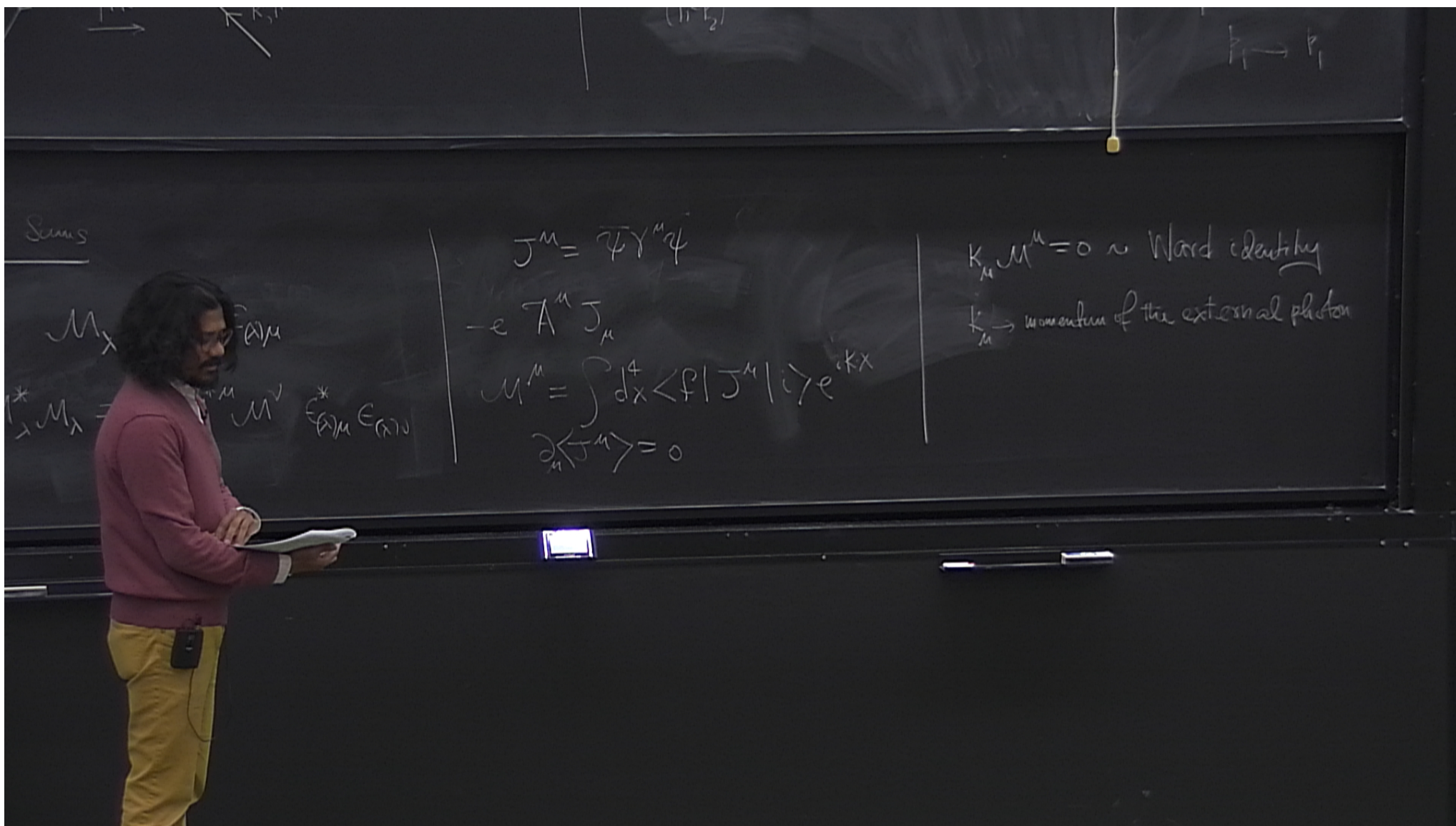
$$\sum_{\lambda=1}^2 \mathcal{M}_\lambda^* \mathcal{M}_\lambda = \sum_{\lambda=1}^2 \mathcal{M}^{\mu*} \mathcal{M}_\mu$$

$$J^\mu = \bar{\psi} \gamma^\mu \psi$$

$$-e \bar{A}^\mu J_\mu$$

$$\mathcal{M}^\mu = \int d^4x \langle f | J^\mu | i \rangle e^{ikx}$$





$$K^\mu = (K, 0, 0, K)$$

$$M^0 = M^3$$

$$\gamma^\mu \psi$$

$$\frac{d^4}{dx} \langle p | j^\mu | i \rangle e^{ik \cdot x}$$

$$= 0$$

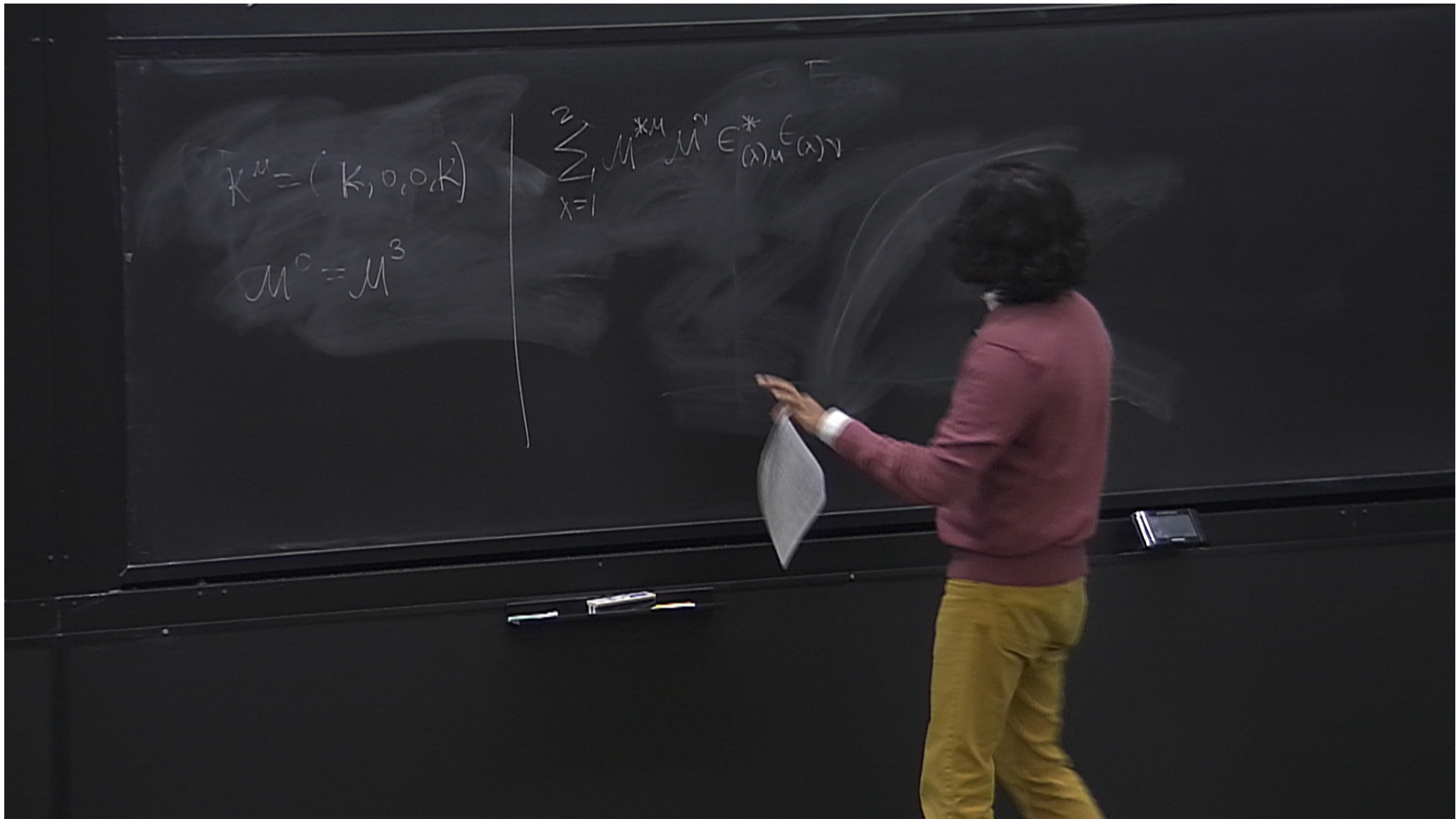
$$k_\mu M^\mu = 0 \sim \text{Ward identity}$$

$k_\mu \rightarrow$ momentum of the external photon

$$k^\mu M^\nu \eta_{\mu\nu} = k_\mu M^0 \eta_{00} + k_\mu M^3 \eta_{33} = 0$$

$$k^\mu =$$

$$M^0$$



$$K^\mu = (K, 0, 0, K)$$

$$M^0 = M^3$$

$$\sum_{\lambda=1}^2 M^{*\mu} \tilde{M}^\nu \epsilon_{(\lambda)\mu}^* \epsilon_{(\lambda)\nu} =$$

$$K^\mu = (K, 0, 0, K)$$

$$M^0 = M^3$$

$$E_{(0)}$$

$$\sum_{\lambda=1}^2 M^{*\mu} M^\nu E_{(\lambda)\mu}^* E_{(\lambda)\nu} = \sum_{\lambda=0}^2 M^{*\mu} M^\nu E_{(\lambda)\mu}^* E_{(\lambda)\nu}$$

$$K^\mu = (K, 0, 0, K)$$

$$= M^3$$

$$(1, 0, 0, 0)$$

$$(0, 0, 0, 1)$$

$$\sum_{\lambda=1}^2 M^{*\mu} \tilde{M}^\nu \epsilon_{(\lambda)\mu}^* \epsilon_{(\lambda)\nu} = \sum_{\lambda=0}^2 M^{*\mu} \tilde{M}^\nu \epsilon_{(\lambda)\mu}^* \epsilon_{(\lambda)\nu}$$

$$p_{\mu} = (E, \vec{p}) \quad p'_{\mu} = (E', \vec{p}')$$

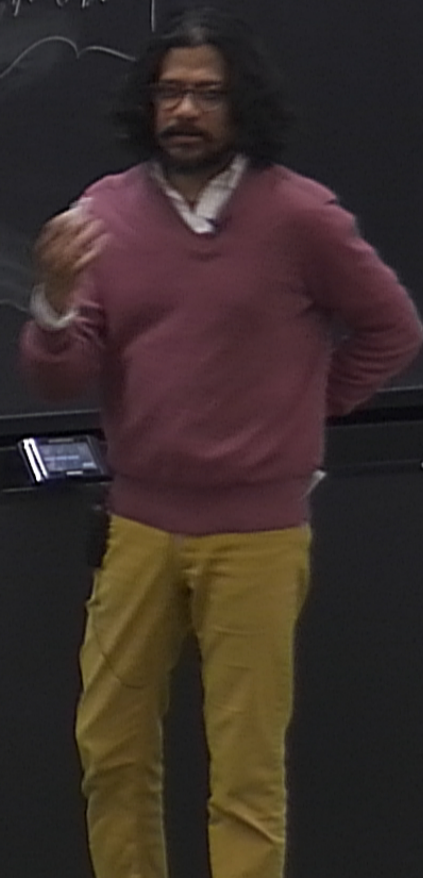
$$k^{\mu} = (k, 0, 0, k)$$

$$M^0 = M^3$$

$$E_{(0)} = (1, 0, 0, 0)$$

$$E_{(3)} = (0, 0, 0, 1)$$

$$\sum_{\lambda=1}^3 M^{*\mu} M^{\nu} \epsilon_{(\lambda)\mu}^* \epsilon_{(\lambda)\nu} = - \sum_{\lambda=0}^3 M^{*\mu} M^{\nu} \epsilon_{(\lambda)\mu}^* \epsilon_{(\lambda)\nu} \eta^{\lambda\lambda}$$



$$p_{\mu} \rightarrow p'_{\mu}$$

$$K^{\mu} = (K, 0, 0, K)$$

$$\mathcal{M}^0 = \mathcal{M}^3$$

$$\mathcal{E}_{(0)} = (1, 0, 0, 0)$$

$$\mathcal{E}_{(3)} = (0, 0, 0, 1)$$

$$\sum_{\lambda=1}^3 \mathcal{M}^{*\mu} \mathcal{M}^{\nu} \mathcal{E}_{(\lambda)\mu}^* \mathcal{E}_{(\lambda)\nu} = - \sum_{\lambda=0}^3 \mathcal{M}^{*\mu} \mathcal{M}^{\nu} \mathcal{E}_{(\lambda)\mu}^* \mathcal{E}_{(\lambda)\nu} \eta^{\lambda\lambda}$$

$$\sum_{\lambda=0}^3 \mathcal{E}_{(\lambda)\mu}^* \mathcal{E}_{(\lambda)\nu} \eta^{\lambda\lambda} = \eta_{\mu\nu}$$

$$\mathcal{E}_{(\lambda)\mu}^* \mathcal{E}_{(\lambda)\nu} \eta^{\lambda\lambda} = \eta_{\mu\nu}$$

$$p_{\mu} \rightarrow p'_{\mu}$$

$$K^{\mu} = (K, 0, 0, K)$$

$$M^0 = M^3$$

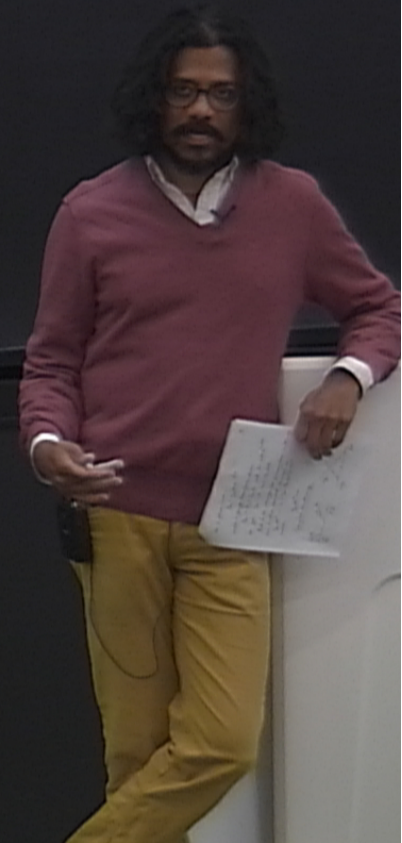
$$E_{(0)} = (1, 0, 0, 0)$$

$$E_{(3)} = (0, 0, 0, 1)$$

$$\sum_{\lambda=1}^3 M^{*\mu} M^{\nu} E_{(\lambda)\mu}^* E_{(\lambda)\nu} = \sum_{\lambda=0}^3 M^{*\mu} M^{\nu} E_{(\lambda)\mu}^* E_{(\lambda)\nu} \eta^{\lambda\lambda}$$

$$\sum_{\lambda=0}^3 E_{(\lambda)\mu}^* E_{(\lambda)\nu} \eta^{\lambda\lambda} = \eta_{\mu\nu}$$

$$E_{(\lambda)\mu}^* E_{(\lambda)\nu} \eta^{\lambda\lambda} = \eta_{\mu\nu}$$





$$K^\mu = (K, 0, 0, K)$$

$$\mathcal{M}^0 = \mathcal{M}^3$$

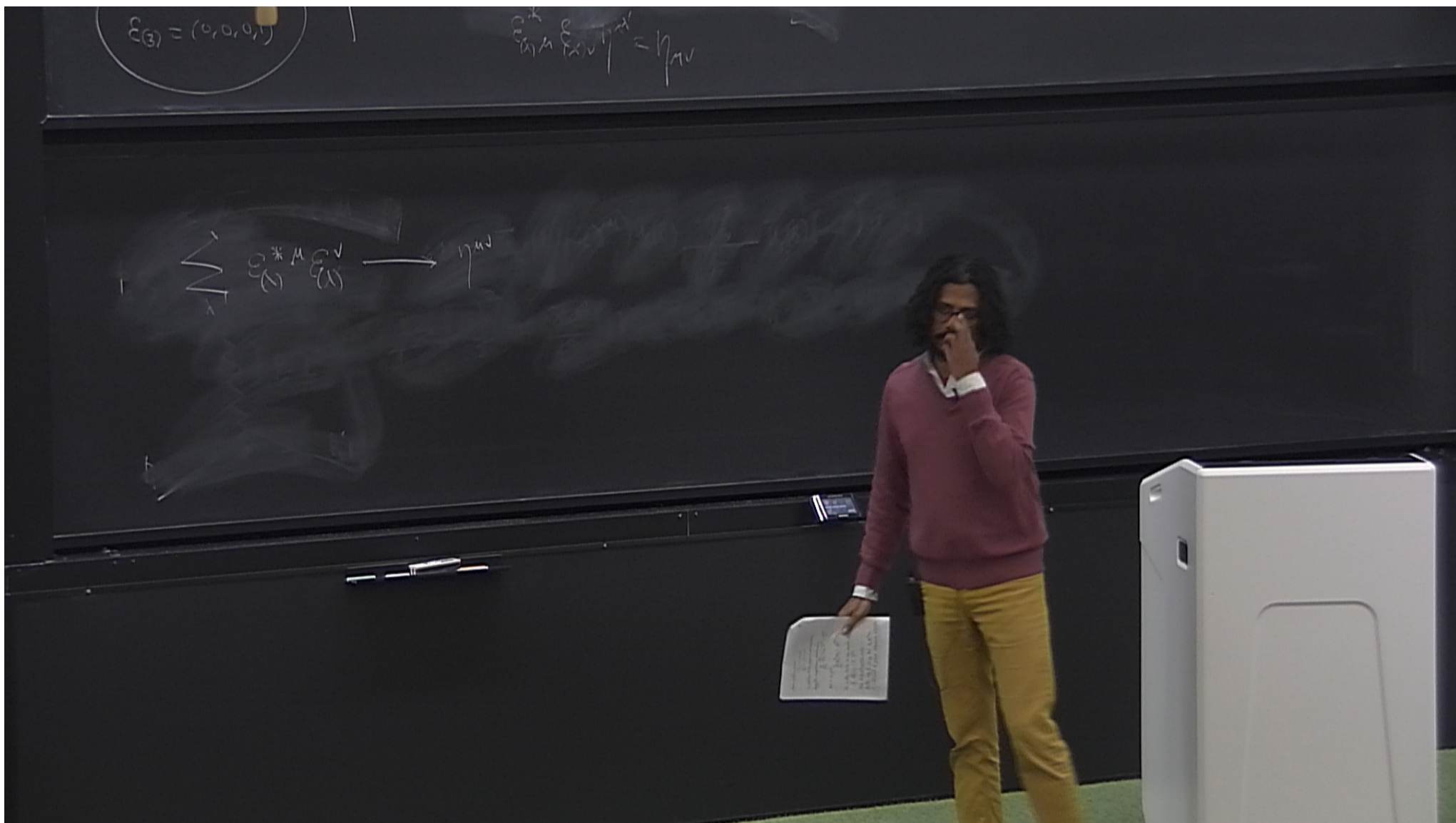
$$\epsilon_{(0)} = (1, 0, 0, 0)$$

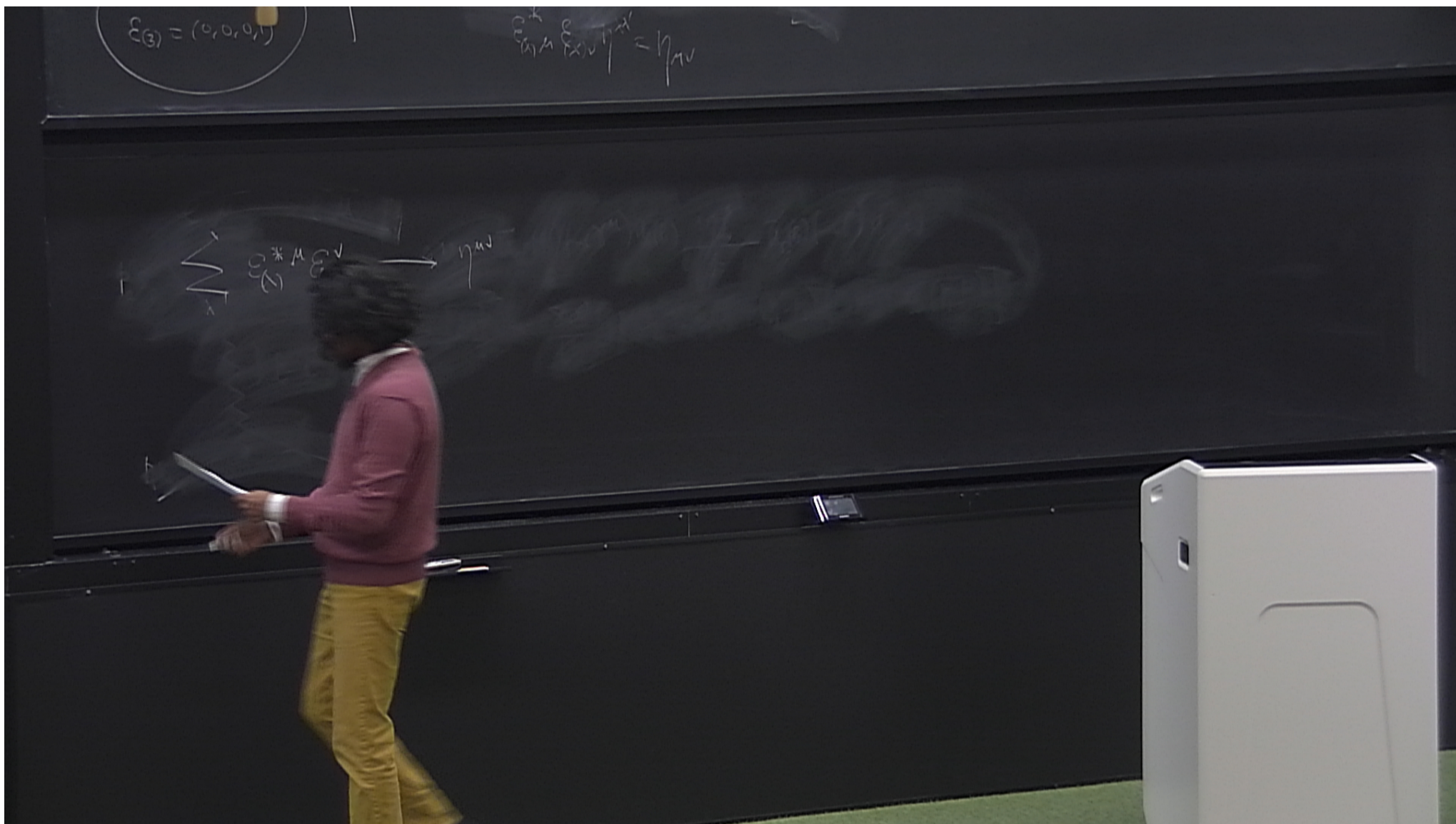
$$\epsilon_{(3)} = (0, 0, 0, 1)$$

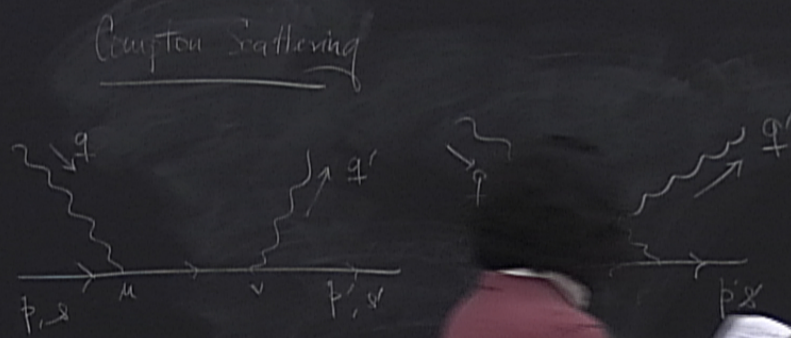
$$\sum_{\lambda=1}^3 \mathcal{M}^{*\mu} \mathcal{M}^\nu \epsilon_{(\lambda)\mu}^* \epsilon_{(\lambda)\nu} = \sum_{\lambda=0}^3 \mathcal{M}^{*\mu} \mathcal{M}^\nu \underbrace{\epsilon_{(\lambda)\mu}^* \epsilon_{(\lambda)\nu}}_{\eta^{\lambda\lambda}} = \mathcal{M}^{*\mu} \mathcal{M}^\nu \eta_{\mu\nu} = \mathcal{M}^{*\mu} \mathcal{M}_\mu$$

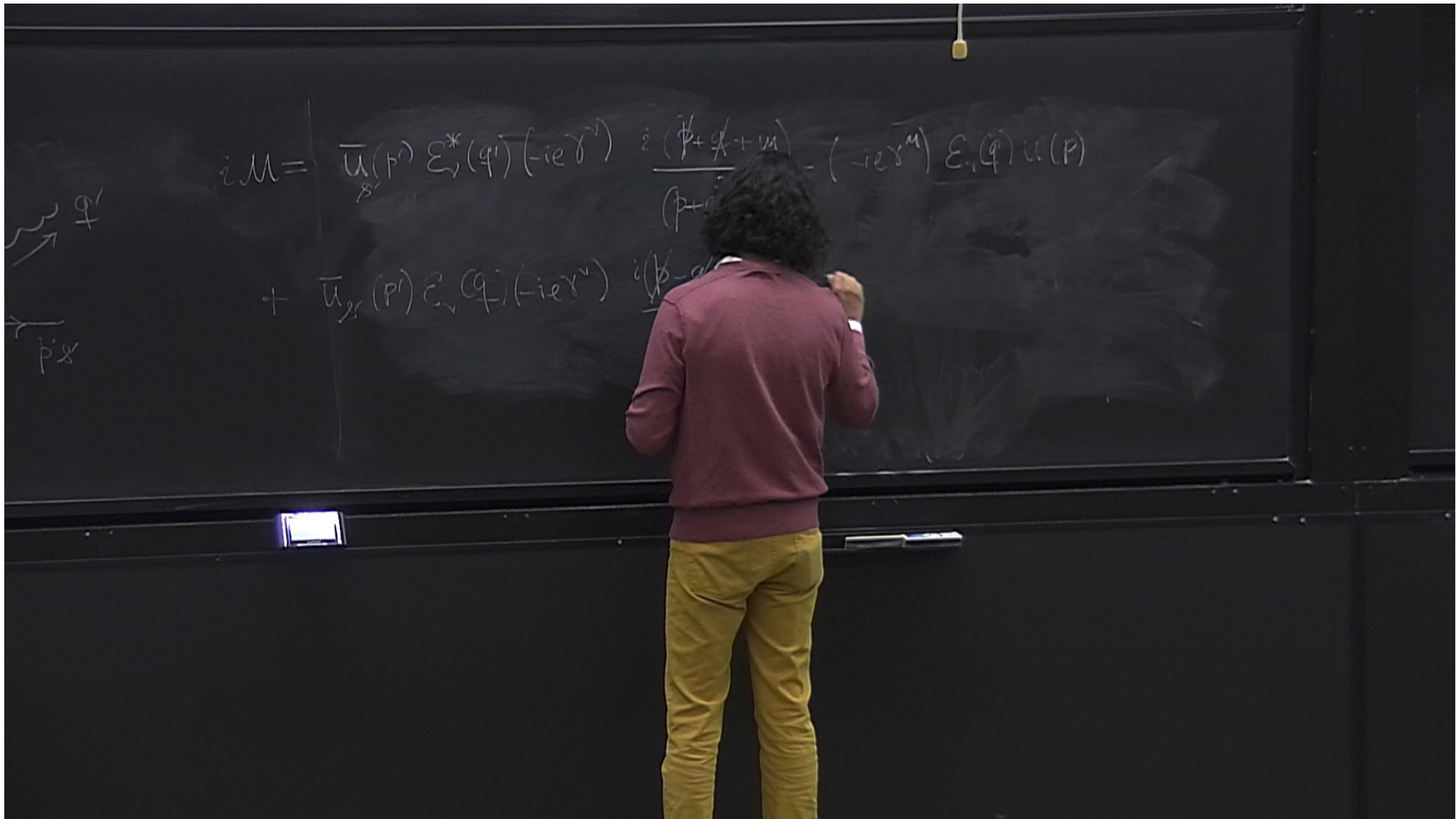
$$\sum_{\lambda=0}^3 \epsilon_{(\lambda)\mu}^* \epsilon_{(\lambda)\nu} \eta^{\lambda\lambda} = \eta_{\mu\nu}$$

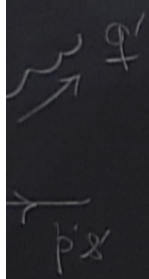
$$\epsilon_{(\lambda)\mu}^* \epsilon_{(\lambda)\nu} \eta^{\mu\mu} = \eta_{\mu\nu}$$











$$i\mathcal{M} = \overline{u}_1(p') \epsilon_\nu^*(q') (-ie\gamma^\nu) \frac{i(\not{p} + \not{q}' + m)}{(\not{p} + \not{q}')^2 - m^2} (-ie\gamma^\mu) \epsilon_\mu(q) u(p) \\ + \overline{u}_2(p') \epsilon_\nu(q) (-ie\gamma^\nu) \frac{i(\not{p} - \not{q}' + m)}{(\not{p} - \not{q}')^2 - m^2} \epsilon_\mu^*(q') (-ie\gamma^\mu) u_2(p)$$

$$\begin{aligned}
 i\mathcal{M} = & \bar{u}_{s'}(p') \epsilon_{\nu}^*(q') (-ie\gamma^{\nu}) \frac{i(\not{p} - \not{q}' + m)}{(p - q')^2 - m^2} (-ie\gamma^{\mu}) \epsilon_{\mu}(q) u(p) \\
 & + \bar{u}_{s'}(p') \epsilon_{\nu}(q) (-ie\gamma^{\nu}) \frac{i(\not{p} - \not{q}' + m)}{(p - q')^2 - m^2} \epsilon_{\mu}^*(q') (-ie\gamma^{\mu}) u_s(p)
 \end{aligned}$$