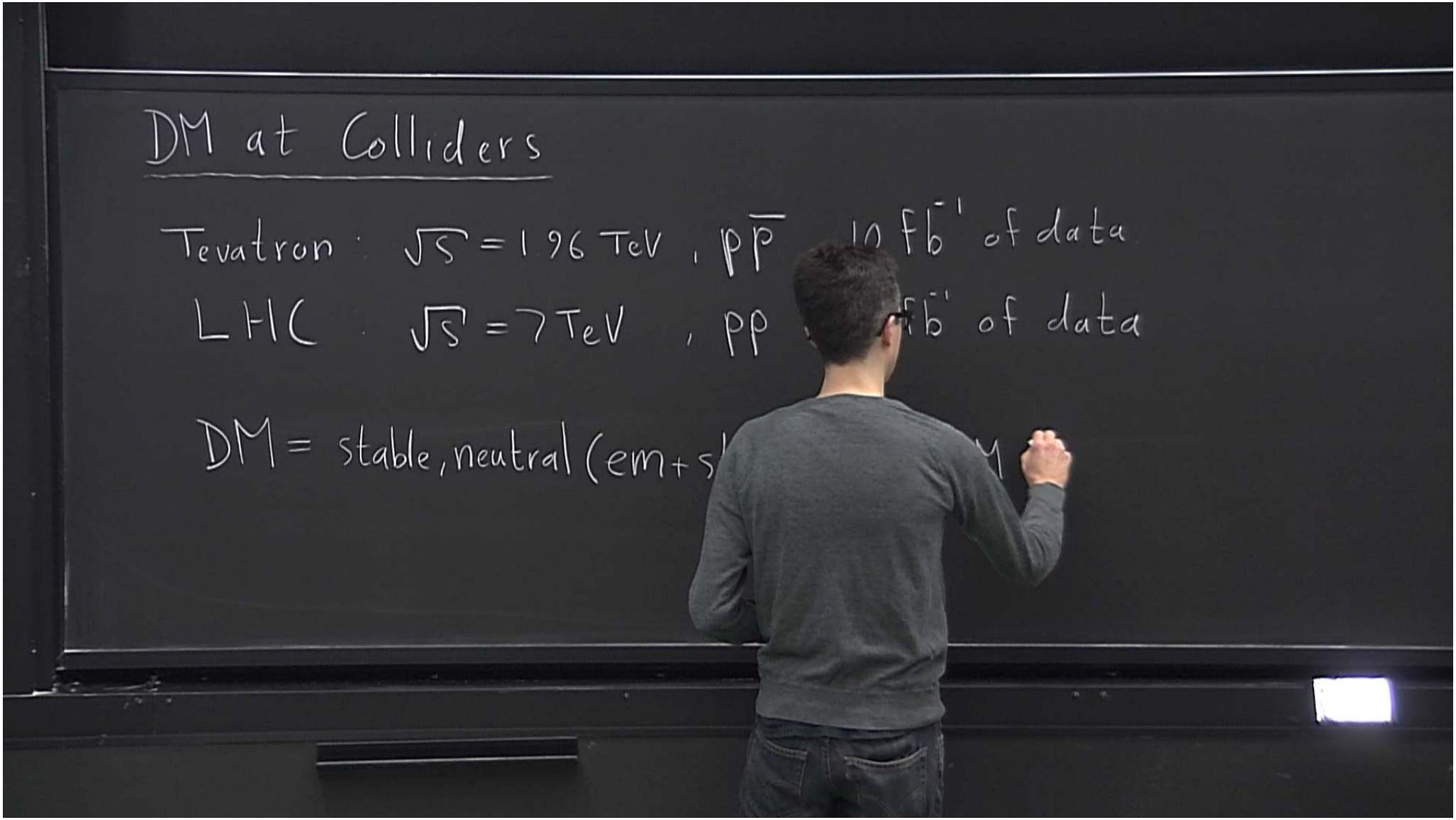
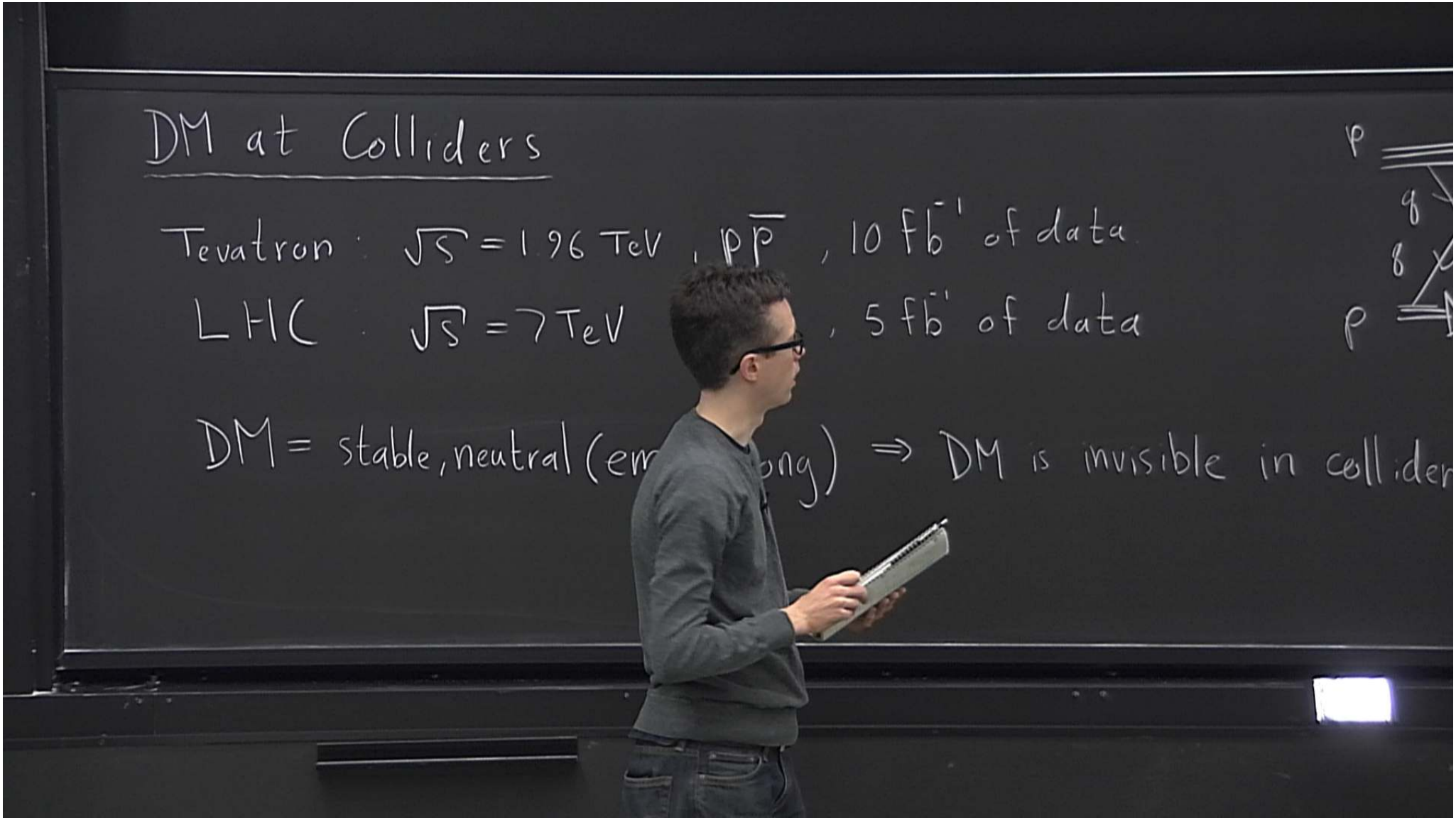
Title: Explorations in Particle Theory - Lecture 13

Date: Apr 19, 2012 09:00 AM

URL: http://pirsa.org/12040017

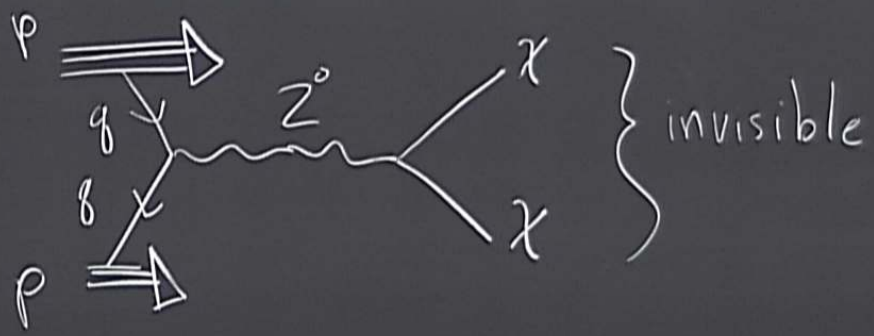
Abstract:


DM at Colliders
Tevatron : $\sqrt{s} = 1.96$ TeV , $p\bar{p}$ 10 fb^{-1} of data
LHC : $\sqrt{s} = 7$ TeV , pp fb^{-1} of data
DM = stable, neutral (em+s

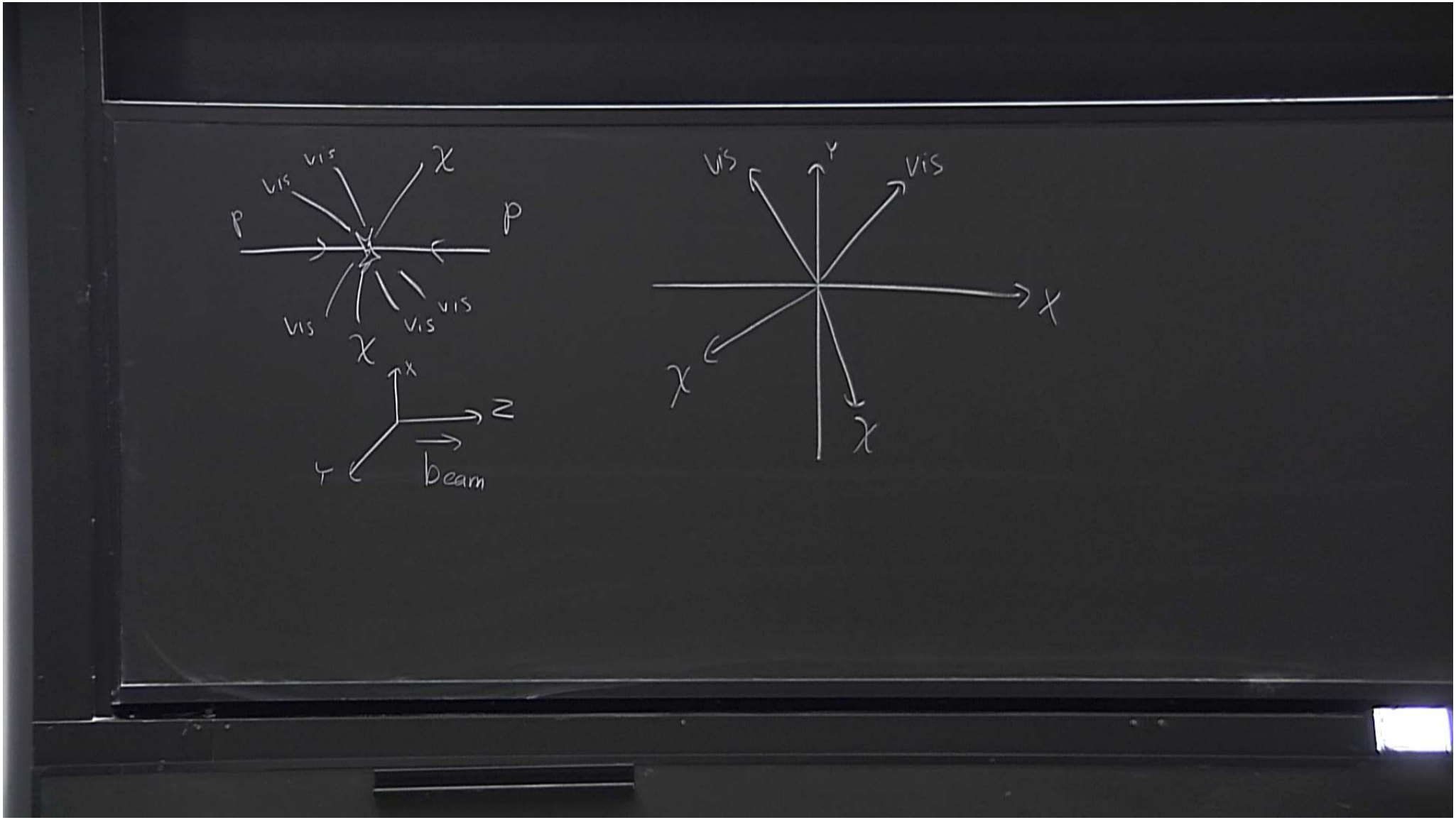

DM at Colliders
Tevatron : $\sqrt{s} = 1.96$ TeV , $p\bar{p}$, 10 fb^{-1} of data
LHC : $\sqrt{s} = 7$ TeV , 5 fb^{-1} of data
DM = stable, neutral (er ong) ⇒ DM is invisible in collider
p
q
g
p

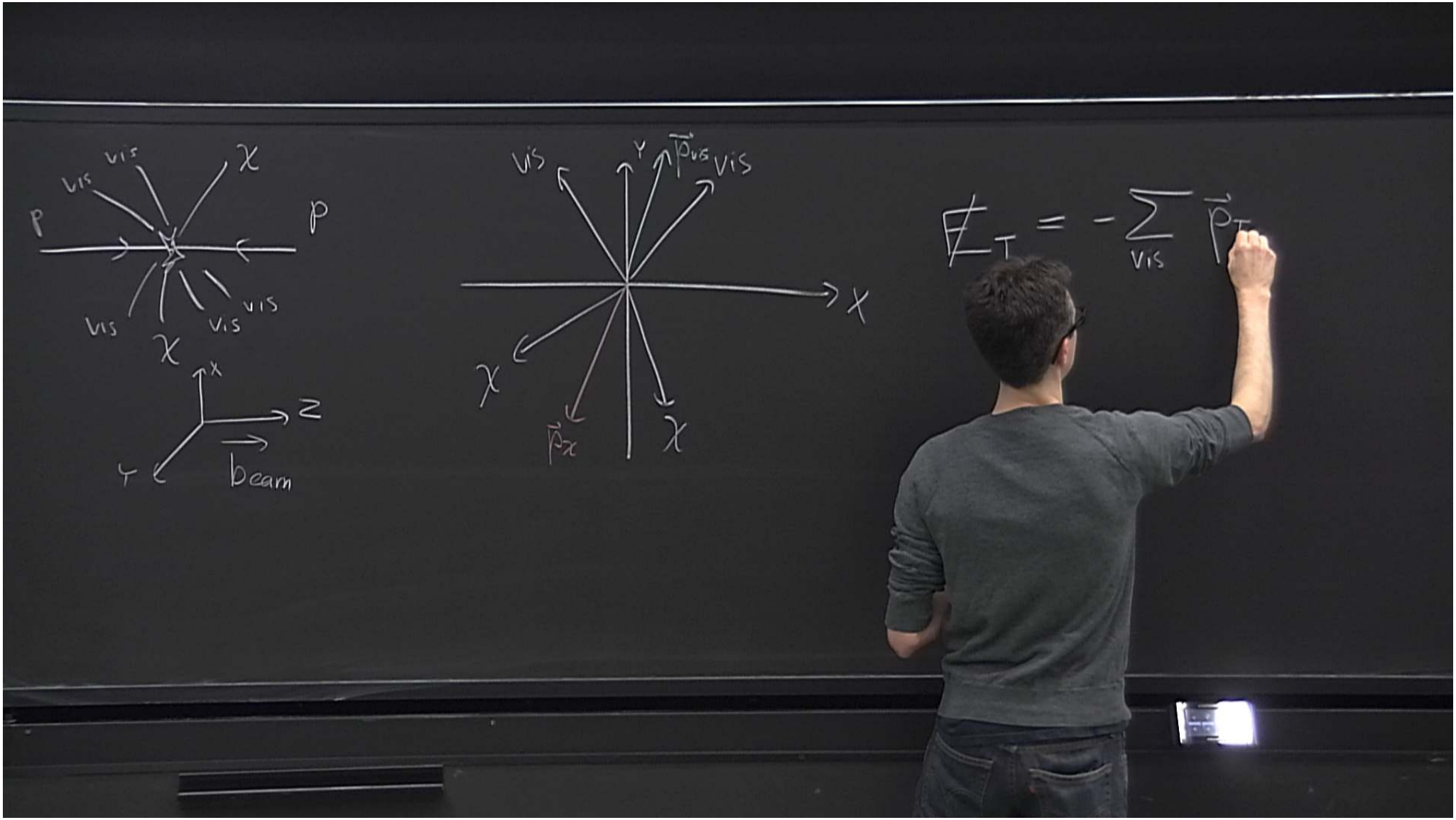
fb^{-1} of data

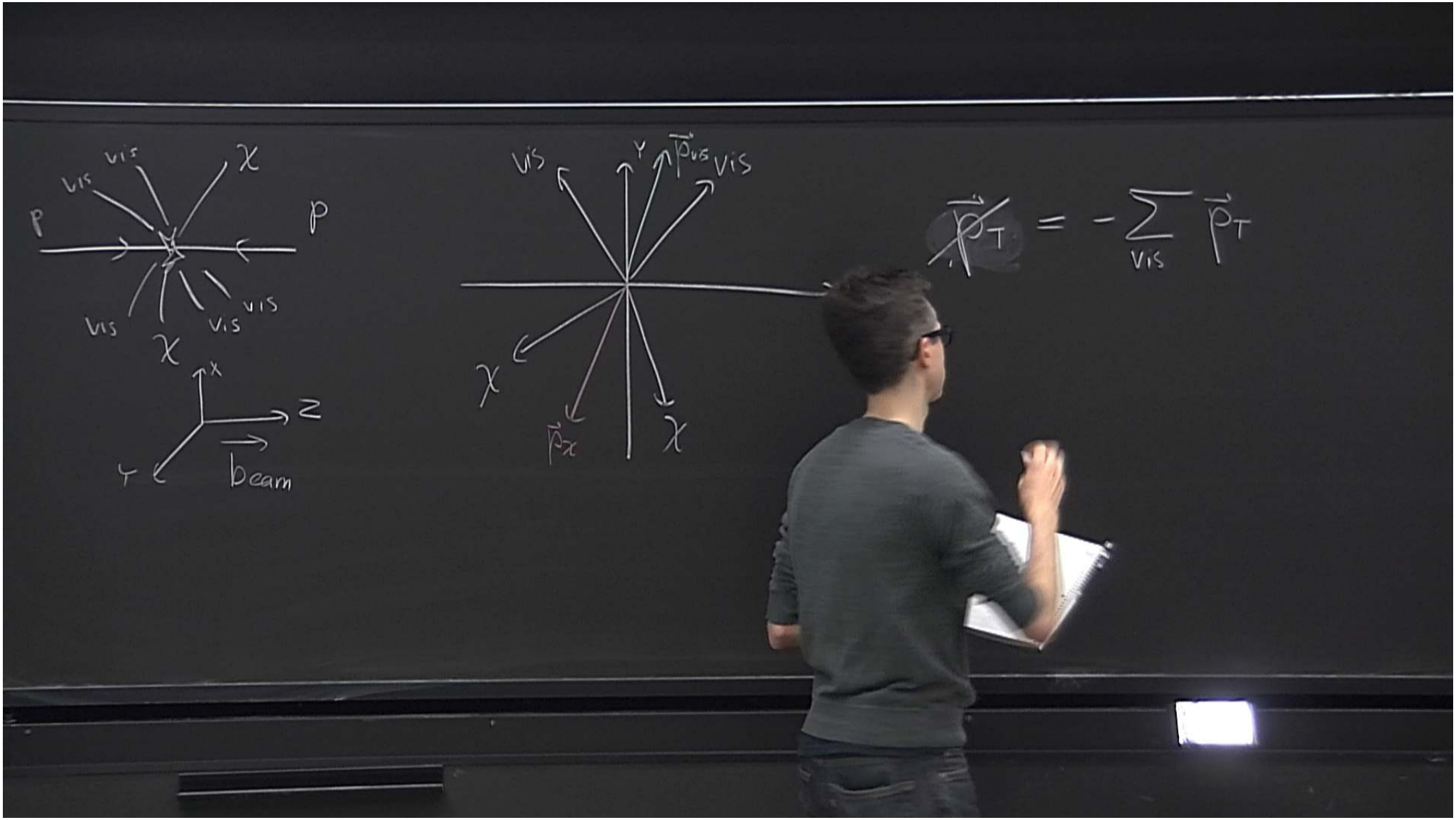
fb^{-1} of data

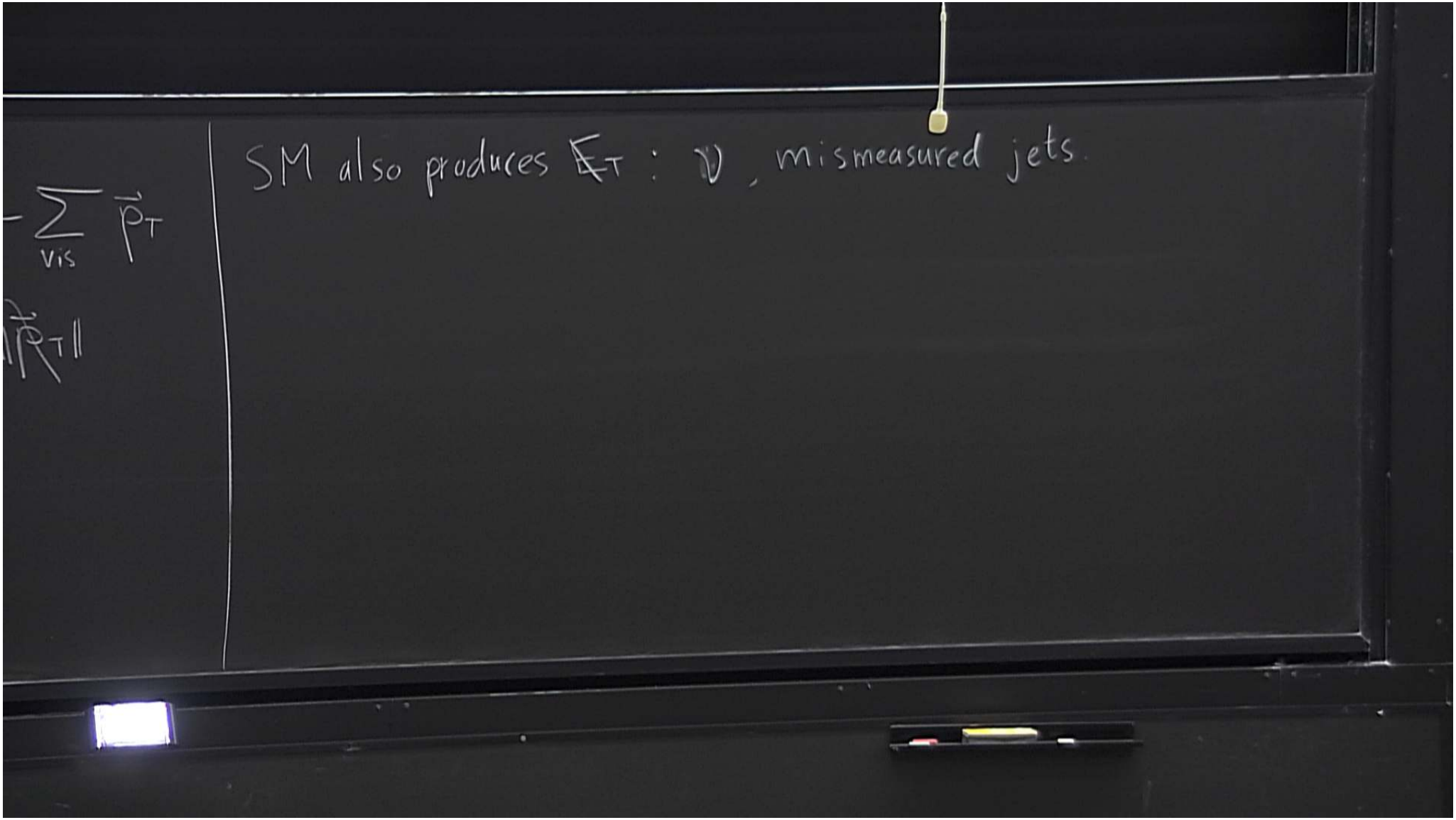


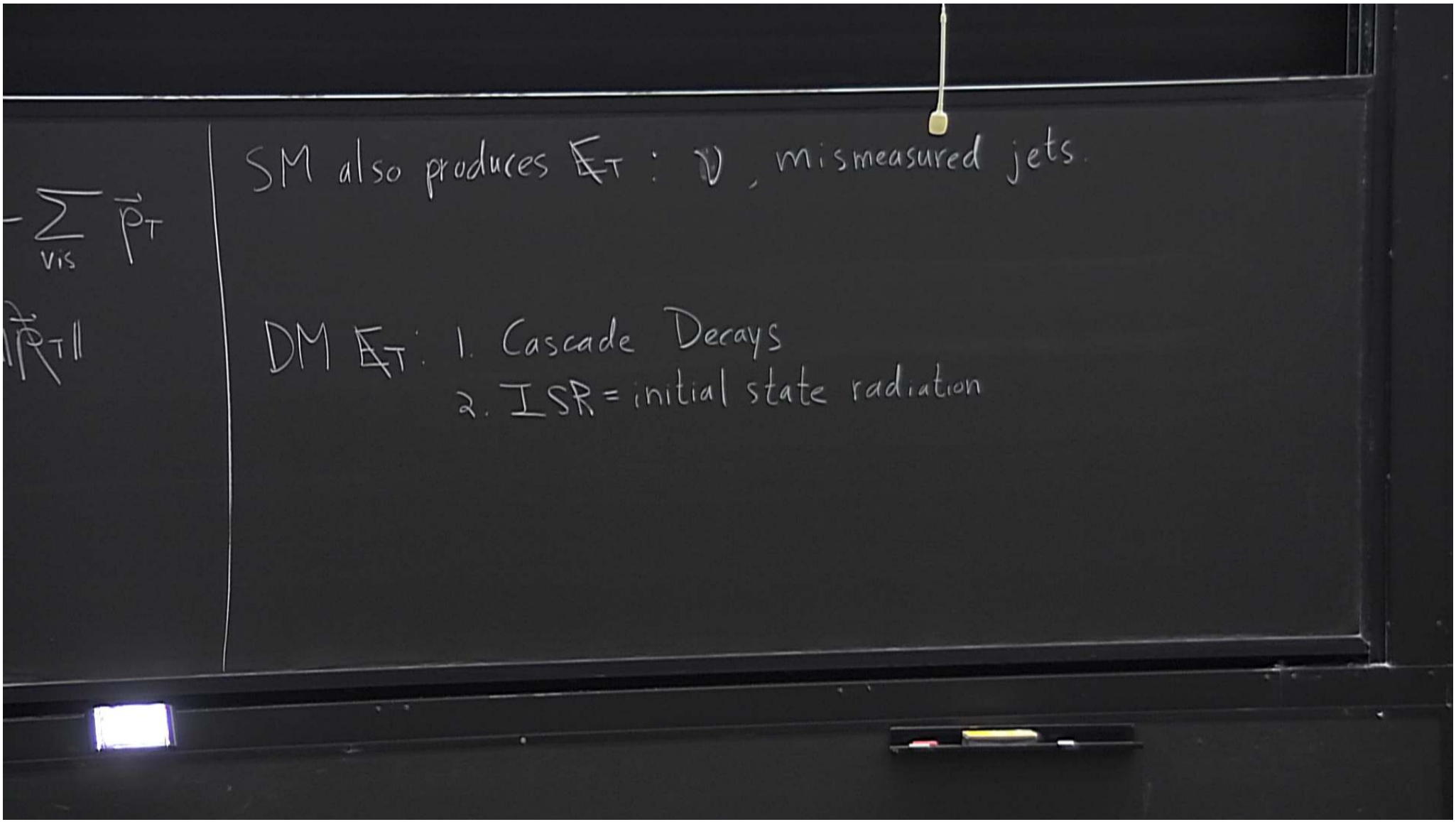
⇒ DM is invisible in collider detectors.

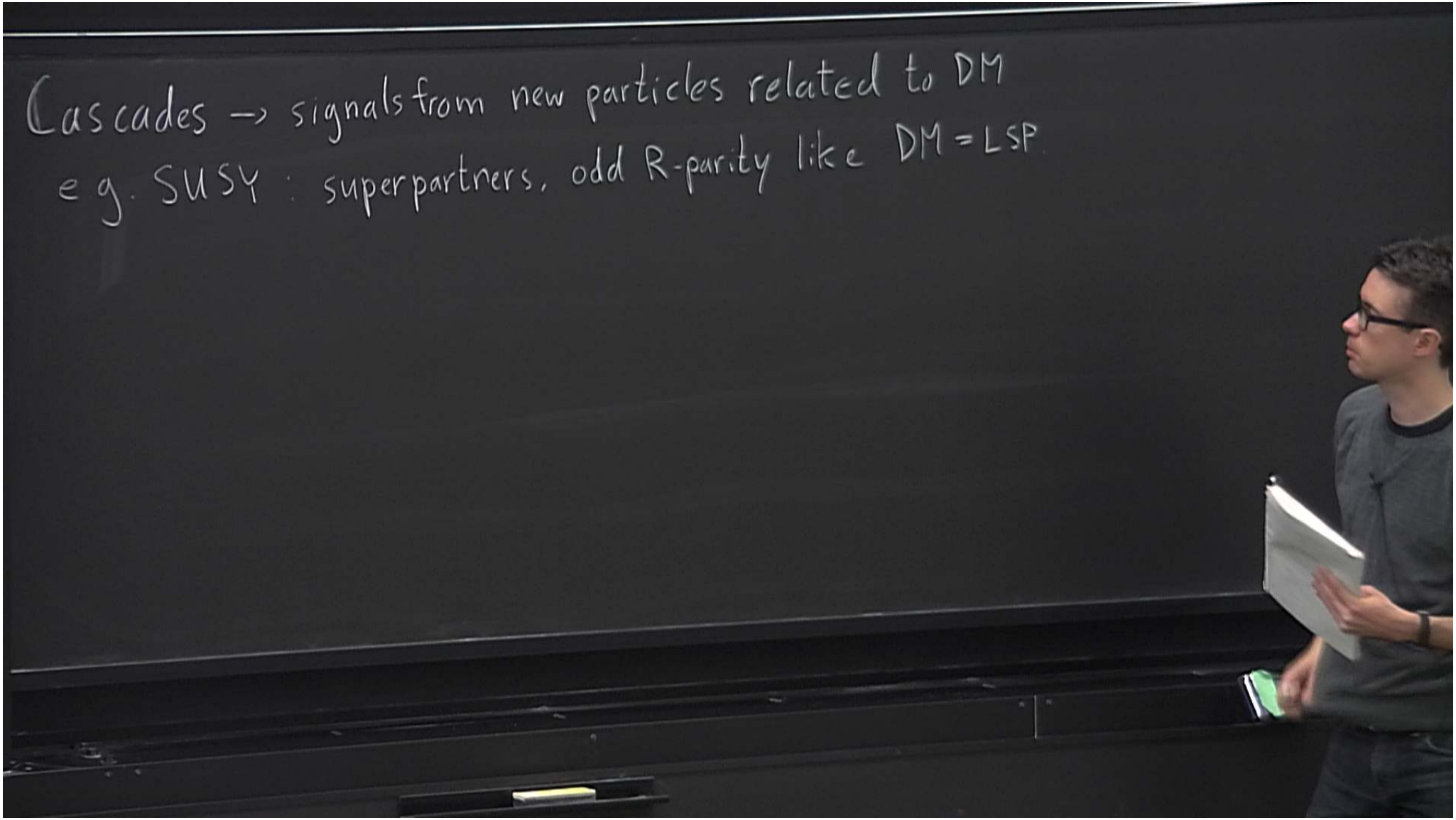

p
p
vis
vis
vis
vis
vis
χ
χ
Y
X
Z
beam
vis
vis
Y
X
χ
χ
χ

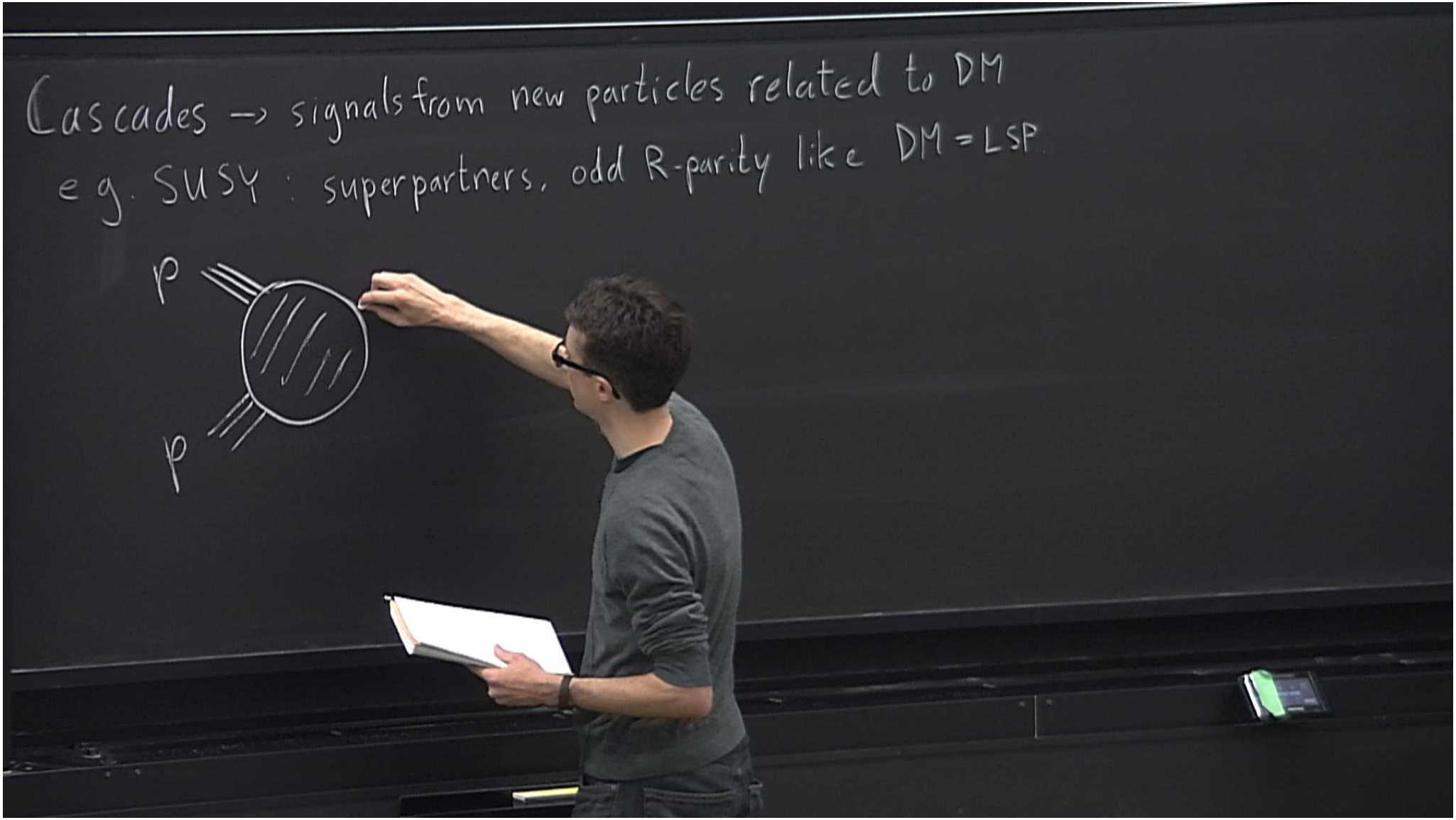

vis
vis
vis
χ
p
p
vis
vis
vis
vis
χ
x
z
y
beam
vis
y
$\vec{p}_{vis}$
vis
χ
χ
$\vec{p}_x$
χ
$\not{E}_T = -\sum_{vis} \vec{p}_T$


vis
vis
χ
p
p
vis
vis
vis
vis
χ
x
z
y
beam
vis
y
$\vec{p}_{vis}$
vis
χ
χ
$\vec{p}_x$
$\not{\vec{p}}_T = -\sum_{vis} \vec{p}_T$


$-\sum_{vis} \vec{p}_T$
$\|\vec{p}_T\|$
SM also produces $\not{E}_T$: ν, mismeasured jets.


$-\sum_{vis} \vec{p}_T$
$\|\vec{p}_T\|$
SM also produces $\not{E}_T$: ν, mismeasured jets.
DM $\not{E}_T$: 1. Cascade Decays
2. ISR = initial state radiation


Cascades → signals from new particles related to DM
e.g. SUSY: superpartners, odd R-parity like DM = LSP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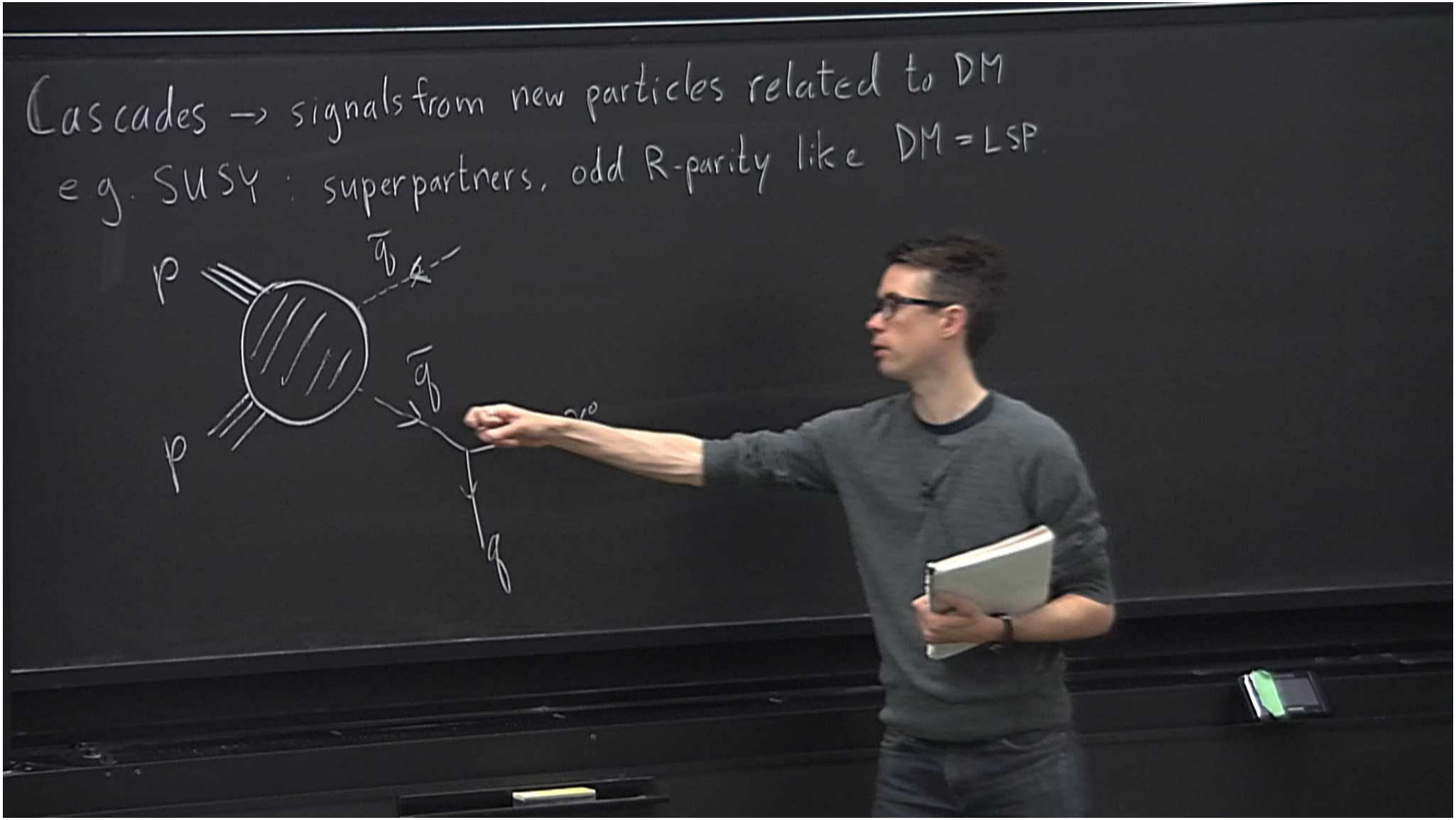
e.g. SUSY : superpartners, odd R-parity like DM = LSP
p
p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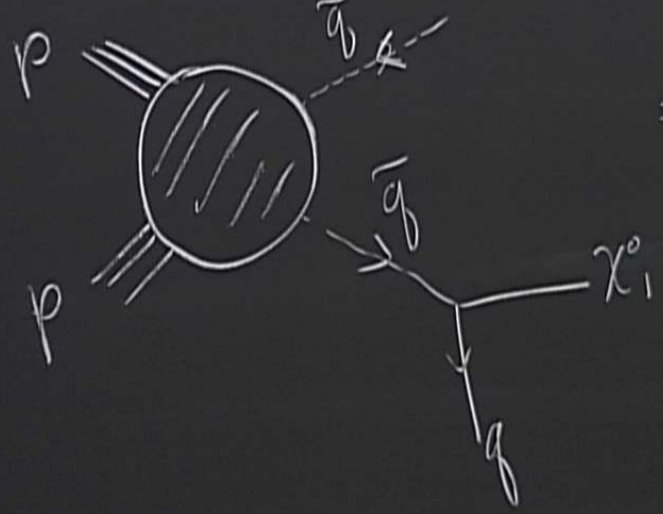
e.g. SUSY: superpartners, odd R-parity like DM = LSP
p
p
$\bar{q}$
$\bar{q}$
q

Cascades → signals from new particles related to DM

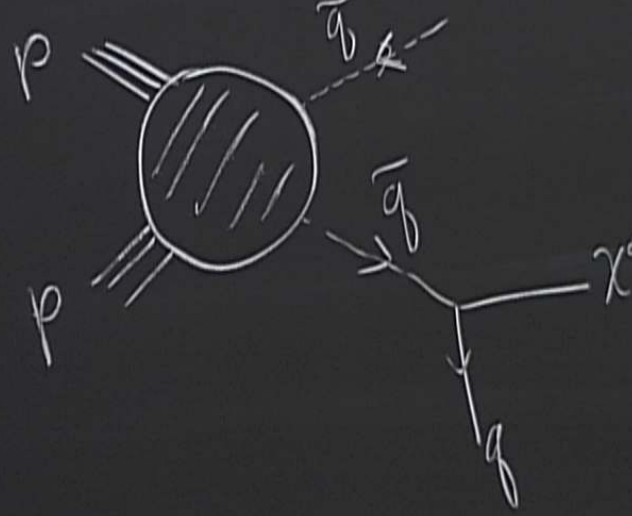
e.g. SUSY: superpartners, odd R-parity like DM = LSP



$\Rightarrow \{\text{SM stuff}\} + 2\chi^0_1$ from every even

Cascades → signals from new particles related to DM

e.g. SUSY: superpartners, odd R-parity like DM = LSP



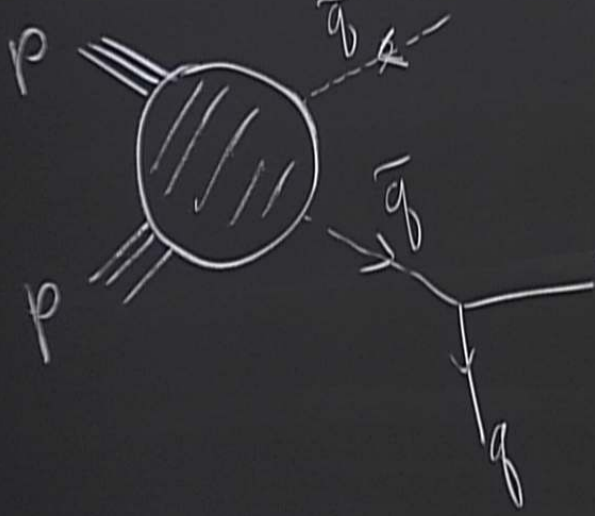
$\Rightarrow \{\text{SM stuff}\} + 2\chi_1^0$ from every event

Signals: $n\,j + m\,\ell + \not{E}_T$

j: QCD jets; ℓ: leptons

ades → signals from new particles related to DM

SUSY: superpartners, odd R-parity like DM = LSP



$\Rightarrow \{\text{SM stuff}\} + 2\chi_1^0$ from every event

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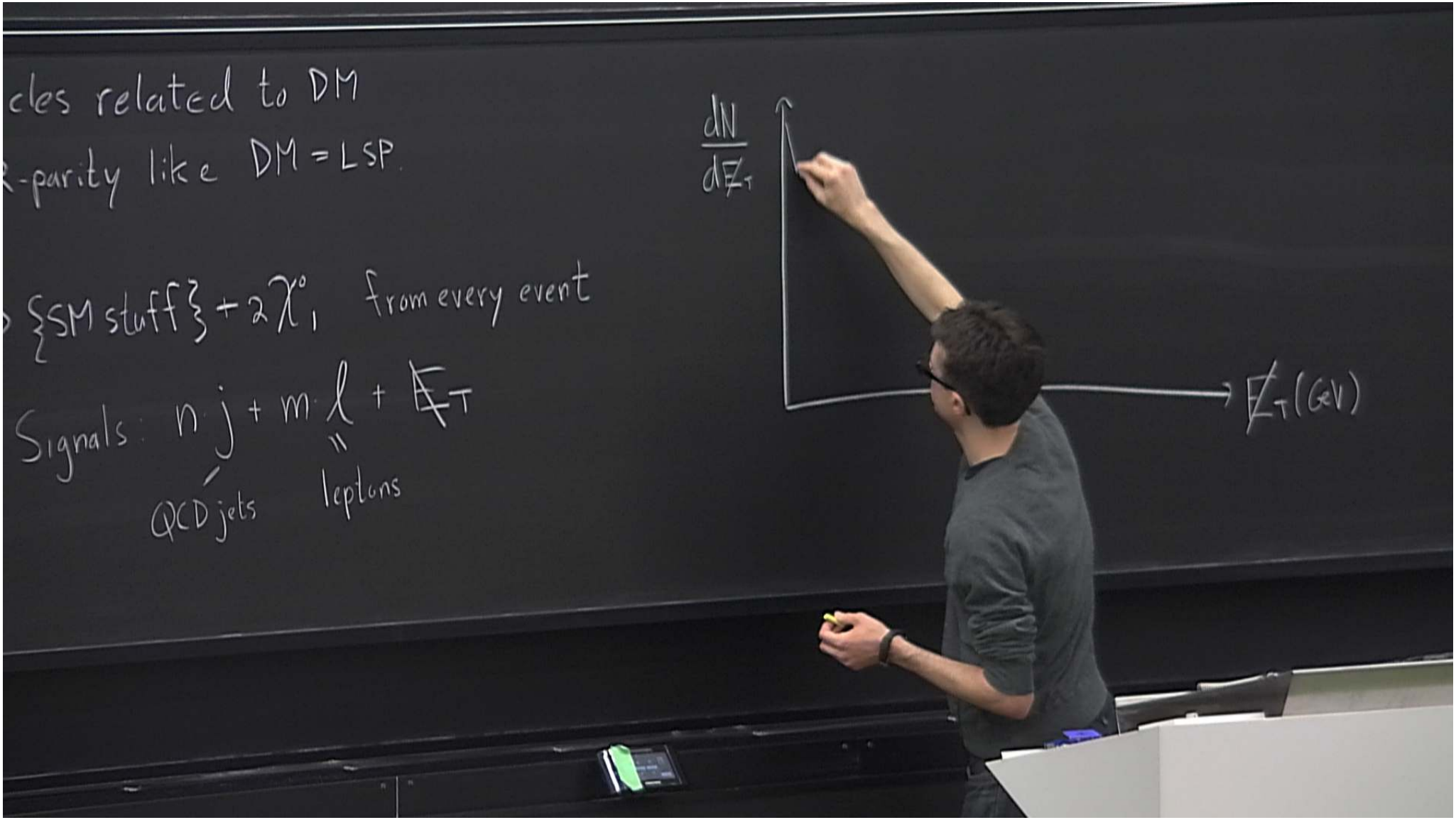

cles related to DM
-parity like DM = LSP
{SM stuff} + 2χ̃⁰₁ from every event
Signals: n j + m ℓ + E_T
QCD jets
leptons
dN/dE_T
E_T (GeV)

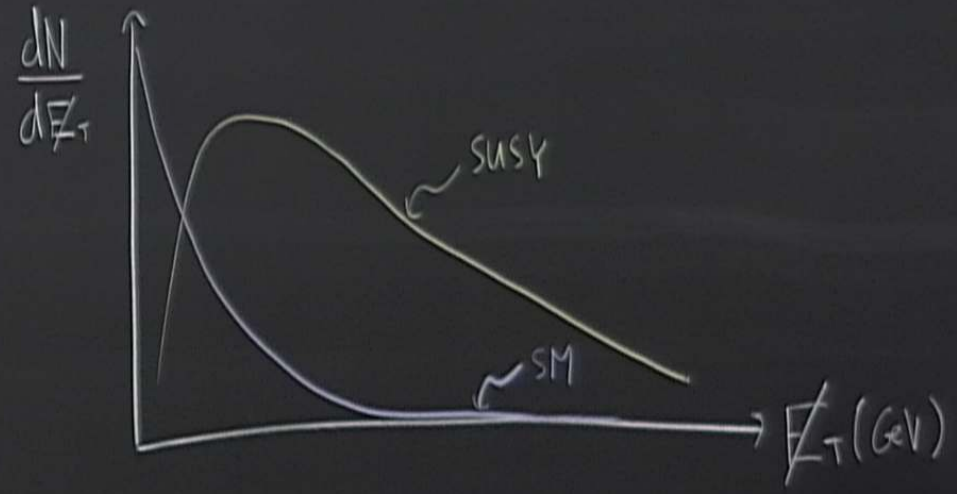
cles related to DM

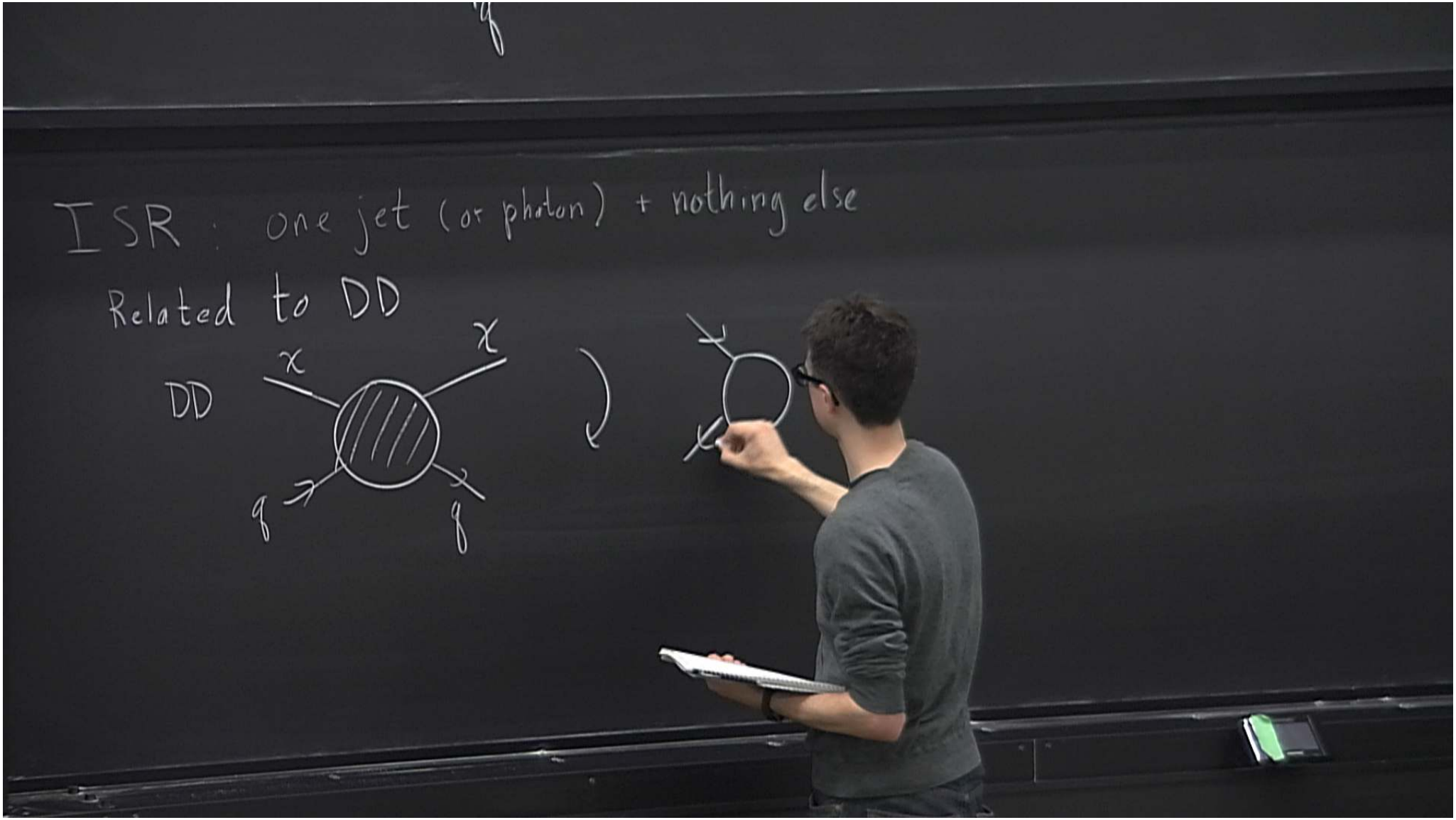
-parity like DM = LSP

{SM stuff} + $2\chi_1^0$ from every event

Signals: $n\,j + m\,\ell + \not{E}_T$

QCD jets leptons




ISR : one jet (or photon) + nothing else
Related to DD
DD
χ
χ
q
q

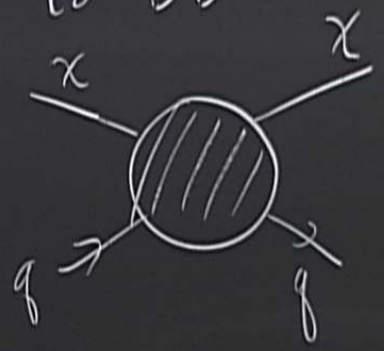
ISR: one jet (or photon) + nothing else

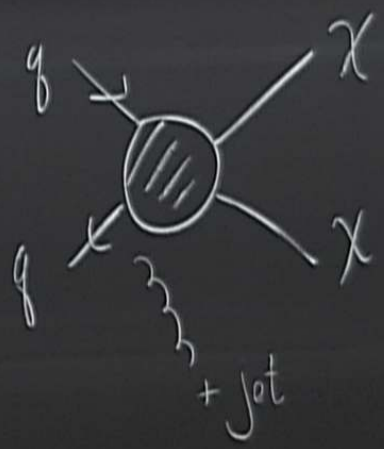
Related to DD

ISR: one jet (or photon) + nothing else

Related to DD

DD





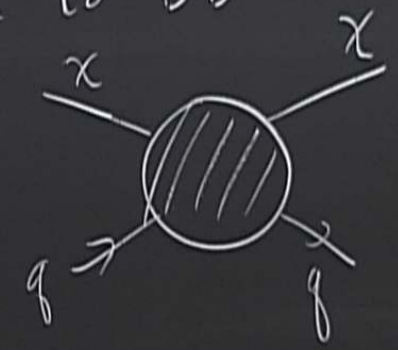
$\sigma_{ij} \sim \alpha_s \sigma_{0j}$

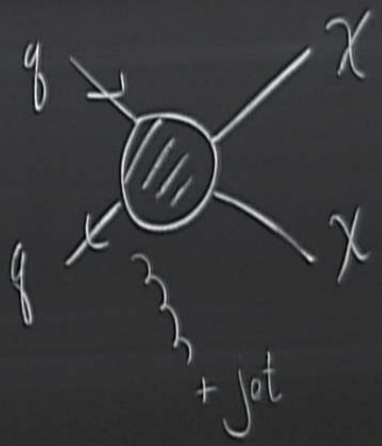
$\alpha_s = \frac{g_s^2}{4\pi}$

ISR : one jet (or photon) + nothing else

Related to DD

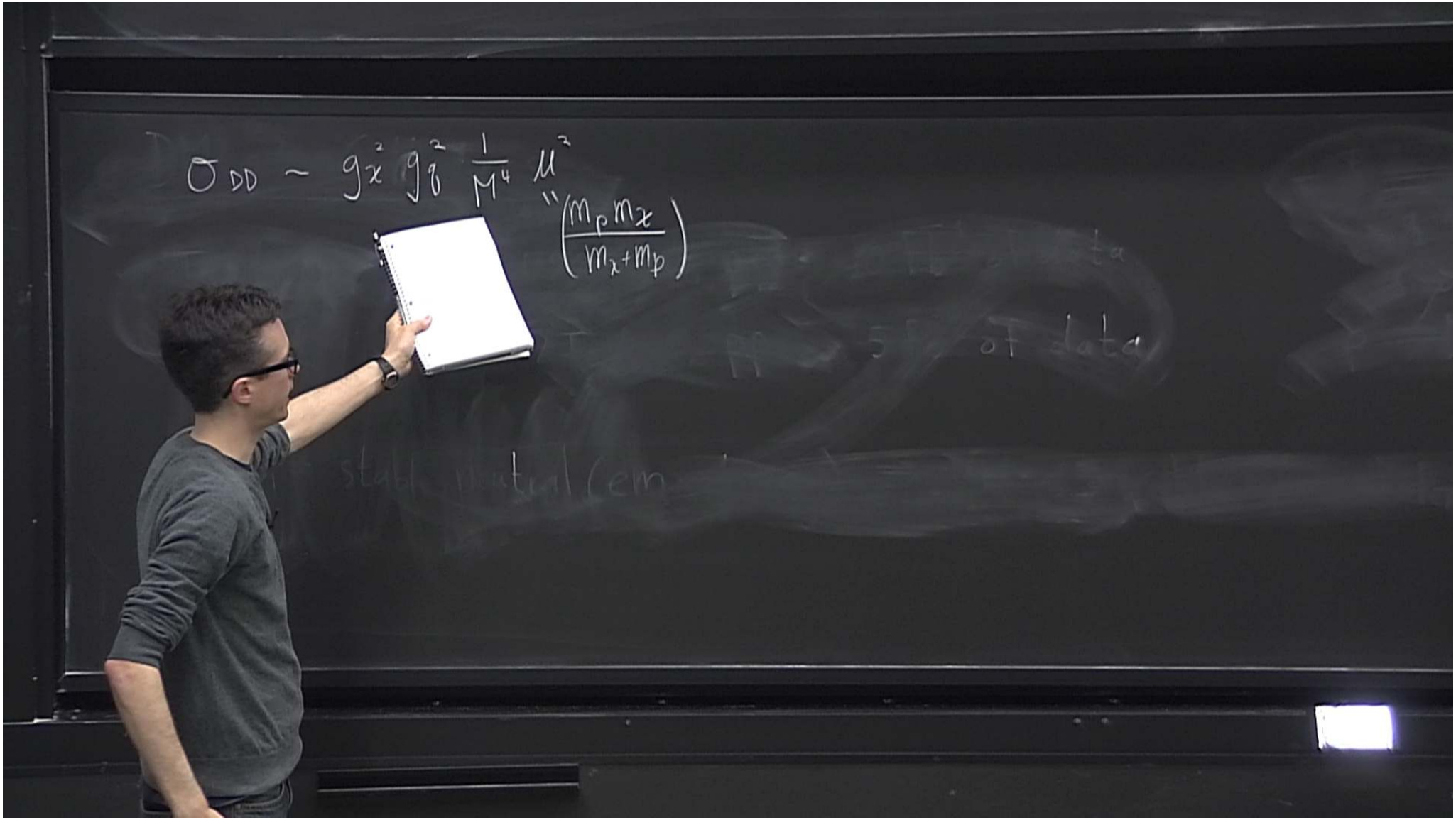
DD

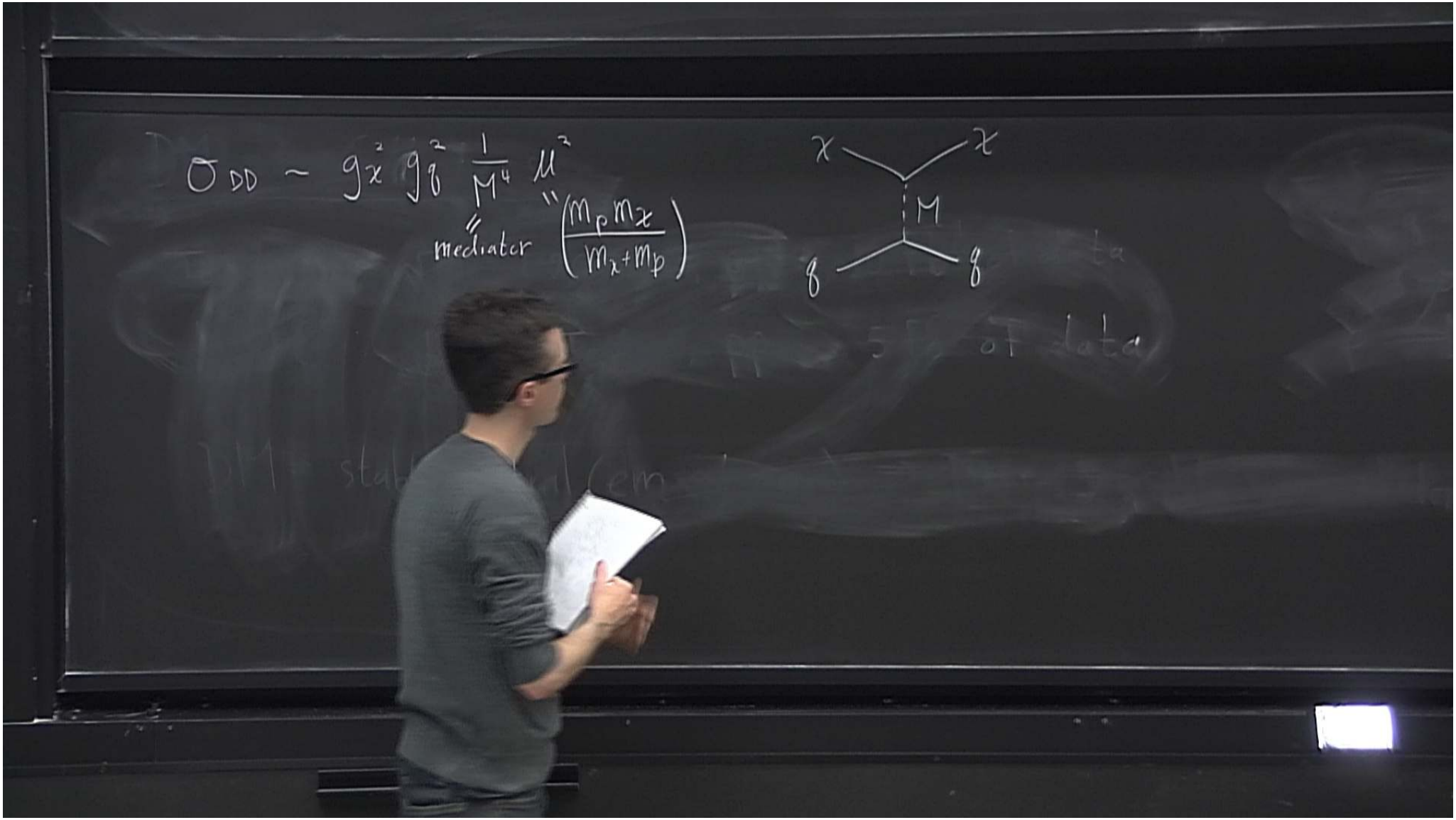


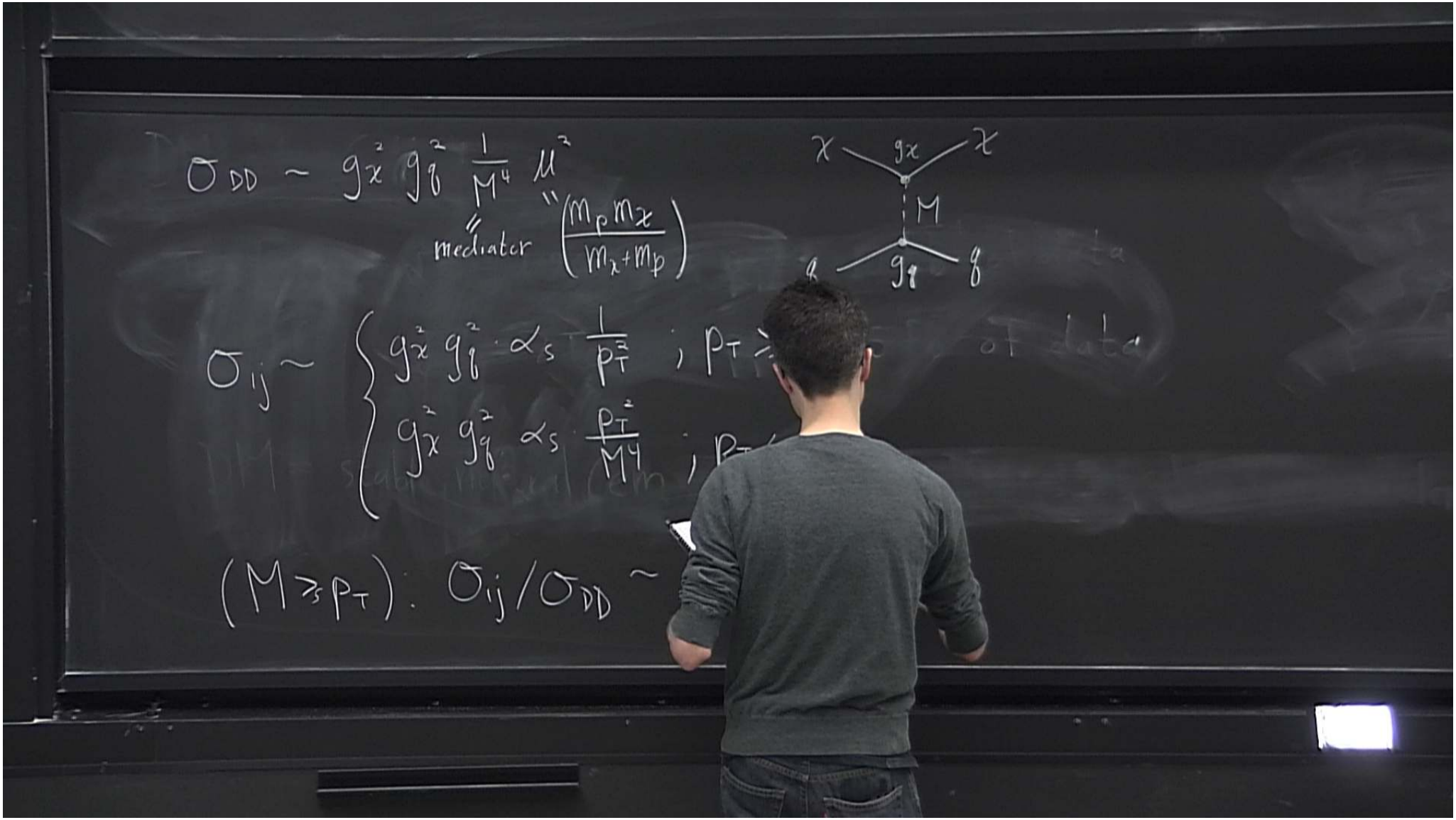


$\sigma_{1j} \sim \alpha_s \sigma_{0j}$

$= \frac{g_s^2}{4\pi}$

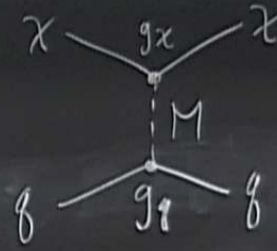

$\sigma_{DD} \sim g_\chi^2 g_q^2 \frac{1}{M^4} \mu^2$
$\left(\frac{m_p m_\chi}{m_\chi + m_p}\right)$


$\sigma_{DD} \sim g_\chi^2 g_q^2 \frac{1}{M^4} \mu^2$
mediator
$\left(\frac{m_p m_\chi}{m_\chi + m_p}\right)$
χ
χ
M
q
q


$\sigma_{DD} \sim g_\chi^2 g_q^2 \frac{1}{M^4} \mu^2$
mediator
$\left(\frac{m_p m_\chi}{m_\chi + m_p}\right)$
χ g_χ χ
M
q g_q g
$\sigma_{ij} \sim \begin{cases} g_\chi^2 g_q^2 \alpha_s \frac{1}{p_T^2} ; p_T \gtrsim \\ g_\chi^2 g_q^2 \alpha_s \frac{p_T^2}{M^4} ; p_T \end{cases}$
$(M \gtrsim p_T)$: $\sigma_{ij}/\sigma_{DD} \sim$

$$\sigma_{DD} \sim g_\chi^2 g_q^2 \frac{1}{M^4} \mu^2$$

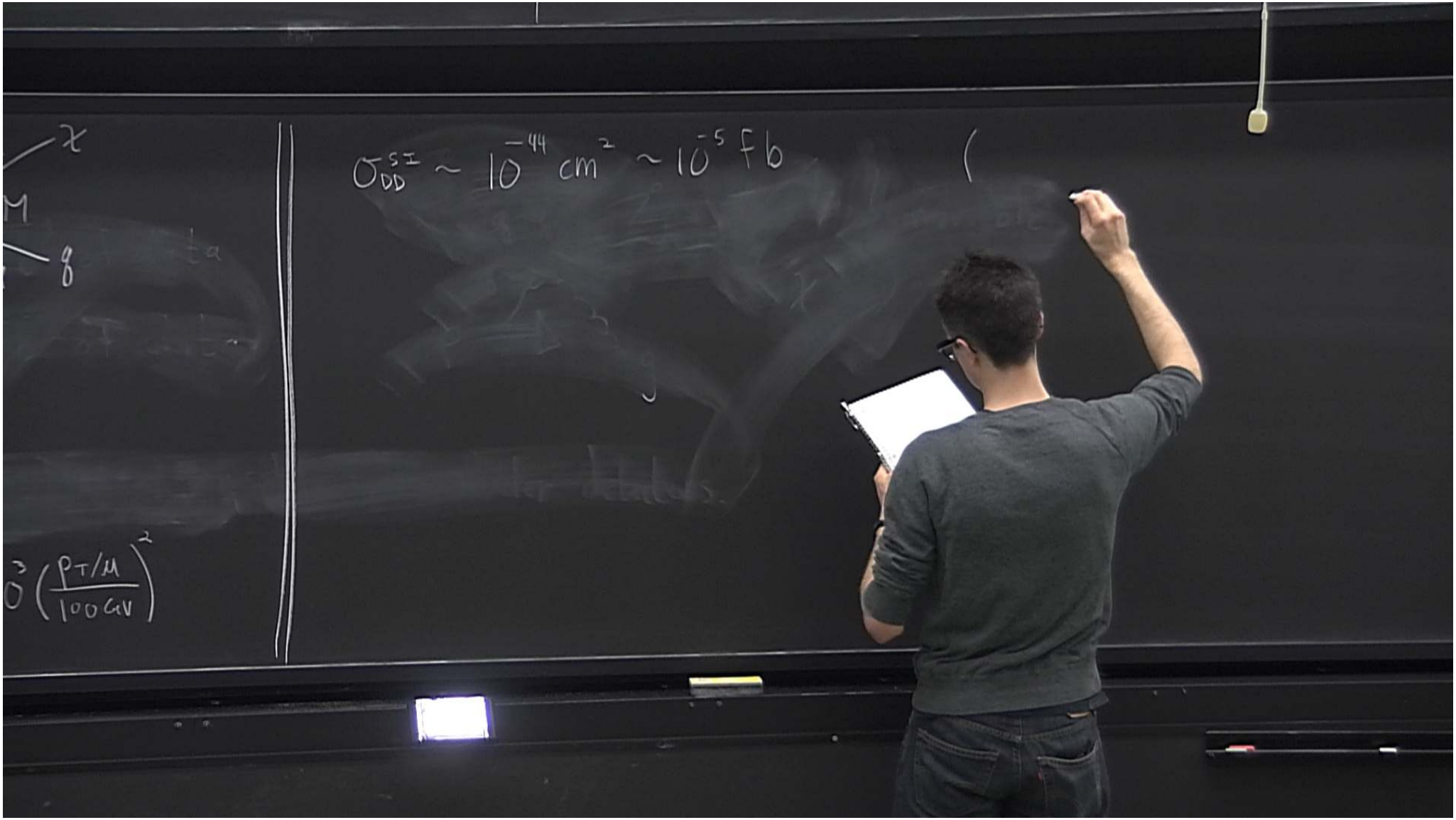
M = mediator, $\mu = \left(\frac{m_p m_\chi}{m_\chi + m_p}\right)$

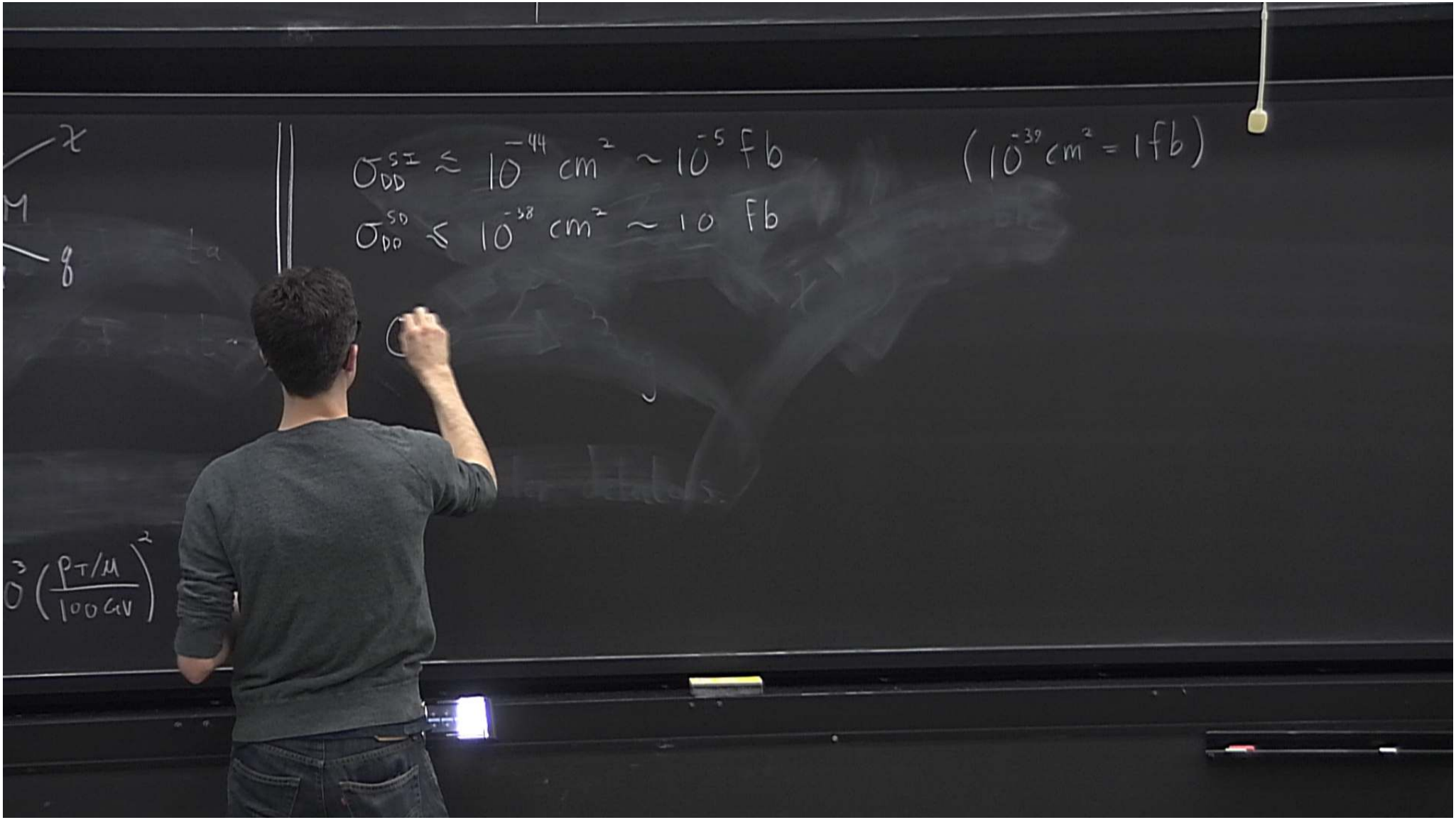


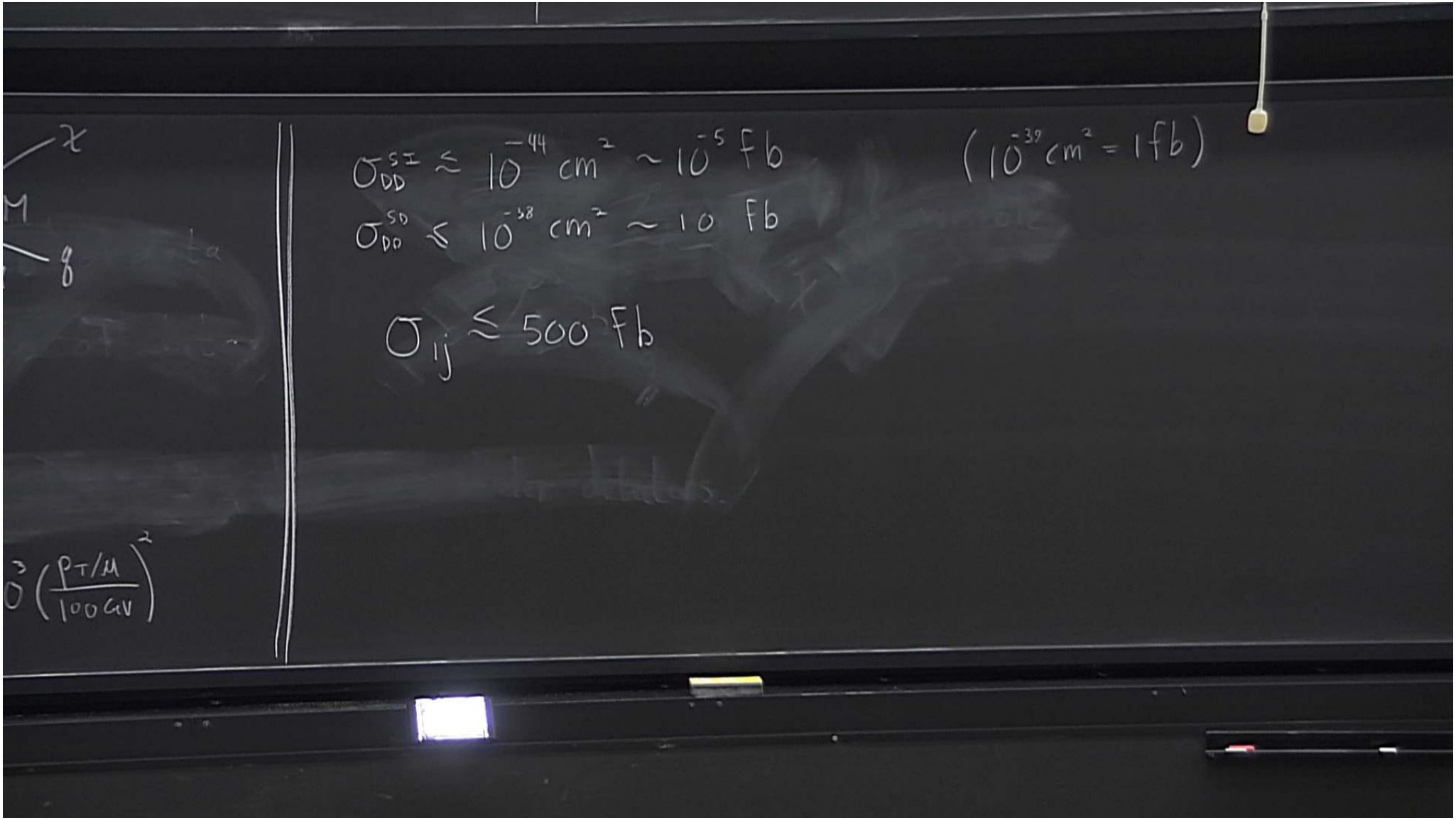
$$\sigma_{DD}^{SI} \sim 10^{-4}$$

$$\sigma_{ij} \sim \begin{cases} g_\chi^2 g_q^2 \alpha_s \frac{1}{p_T^2} & ; p_T \gg M \\ g_\chi^2 g_q^2 \alpha_s \frac{p_T^2}{M^4} & ; p_T \ll M \end{cases}$$

$$(M \gtrsim p_T): \quad \sigma_{ij}/\sigma_{DD} \sim \alpha_s p_T^2/M_T^2 \sim 10^3 \left(\frac{p_T/M}{100\,GV}\right)^2$$


$\sigma_{DD}^{SI} \sim 10^{-44}\,cm^2 \sim 10^{-5}\,fb$
$\left(\frac{p_T/M}{100\,GeV}\right)^2$


$\sigma_{DD}^{SI} \lesssim 10^{-44}\ cm^2 \sim 10^{-5}\ fb$
$(10^{-39}\ cm^2 = 1\ fb)$
$\sigma_{DD}^{SD} \lesssim 10^{-38}\ cm^2 \sim 10\ fb$
$\left(\frac{p_T/M}{100\,GV}\right)^2$

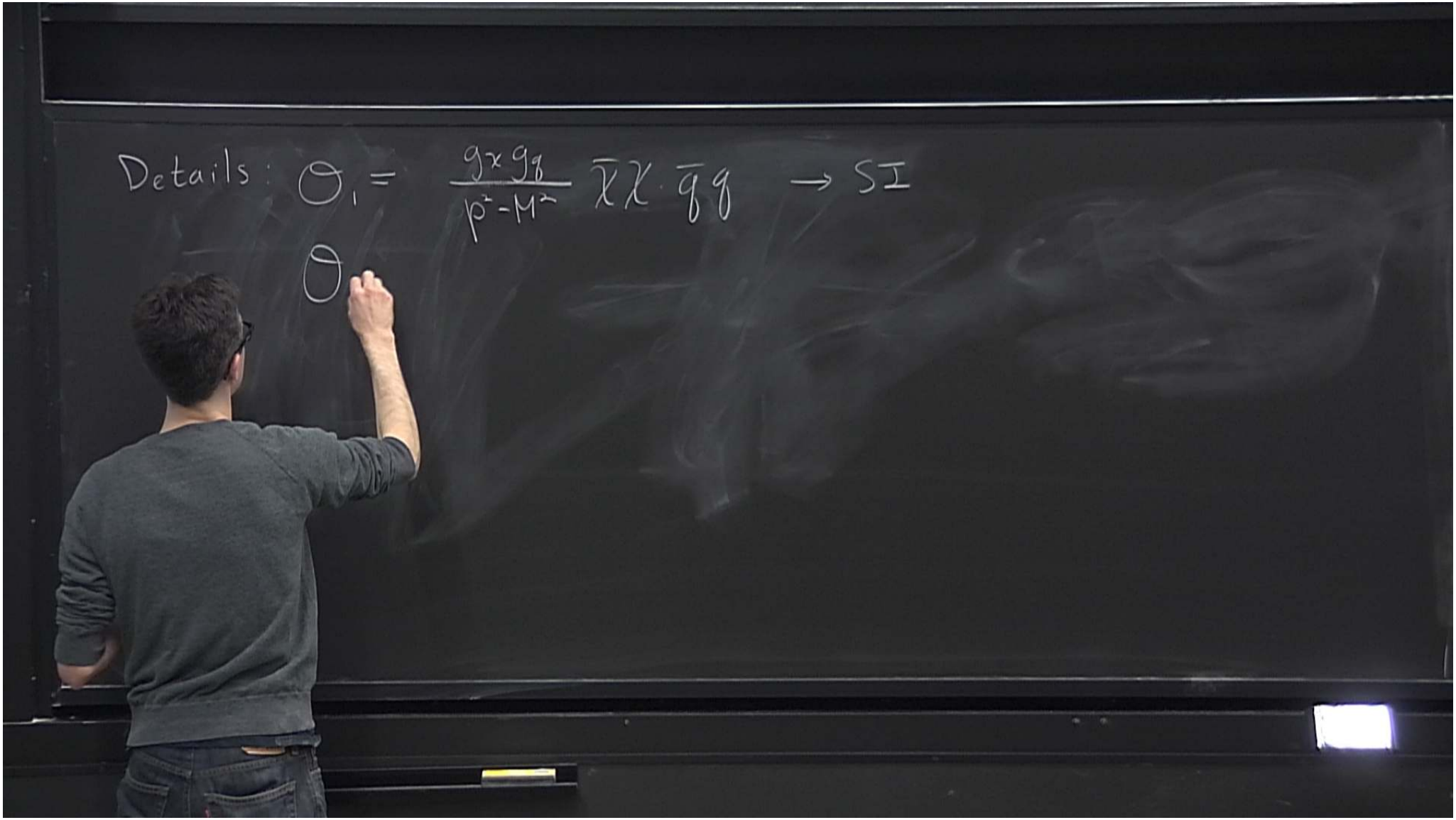

$\sigma_{DD}^{SI} \lesssim 10^{-44}\ cm^2 \sim 10^{-5}\ fb$
$(10^{-39}\ cm^2 = 1\ fb)$
$\sigma_{DD}^{SD} \lesssim 10^{-38}\ cm^2 \sim 10\ fb$
$\sigma_{ij} \lesssim 500\ fb$
$\left(\frac{p_T/M}{100\ GV}\right)^2$

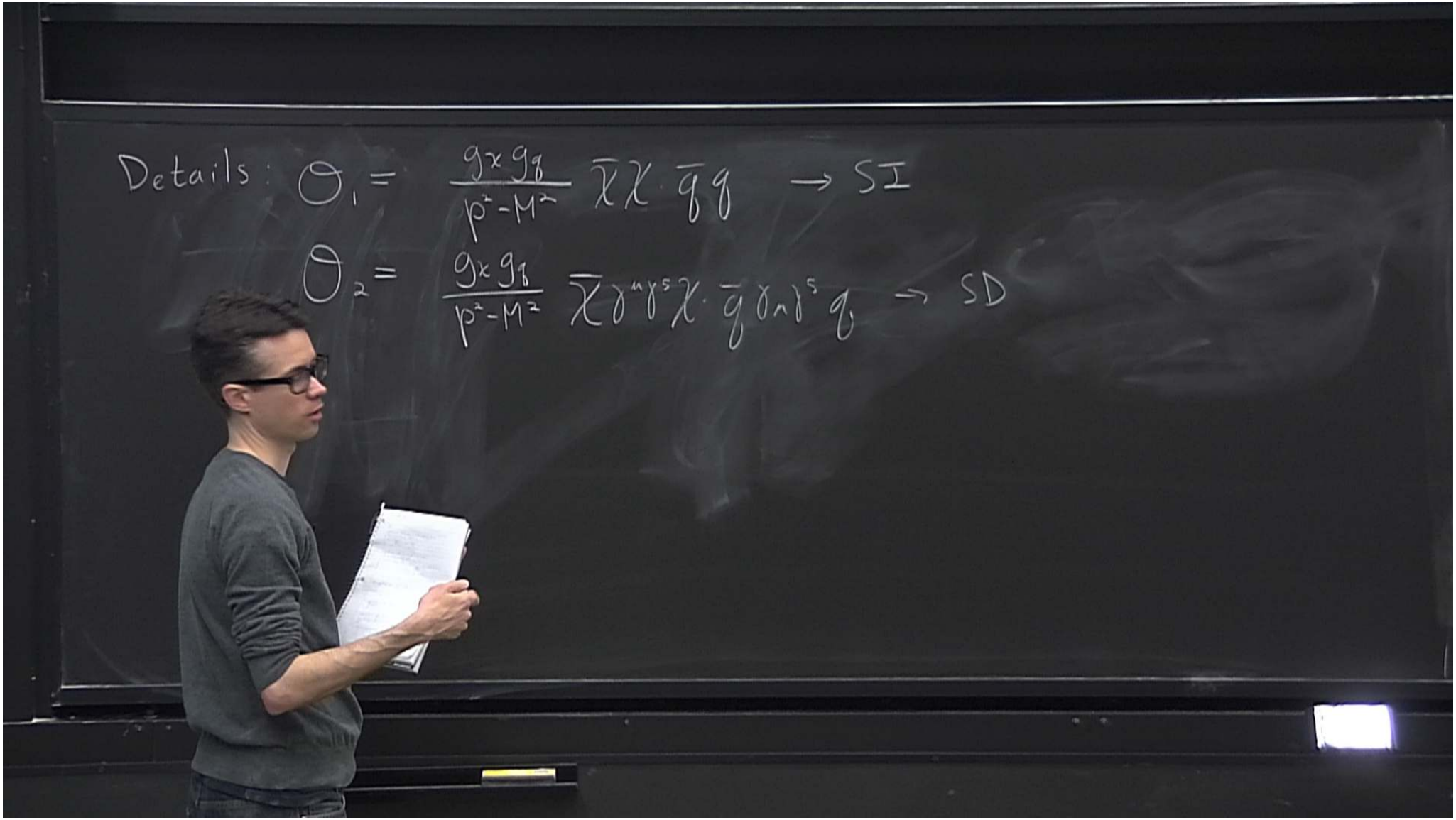
$= -\sum_{vis} \vec{p}_T$

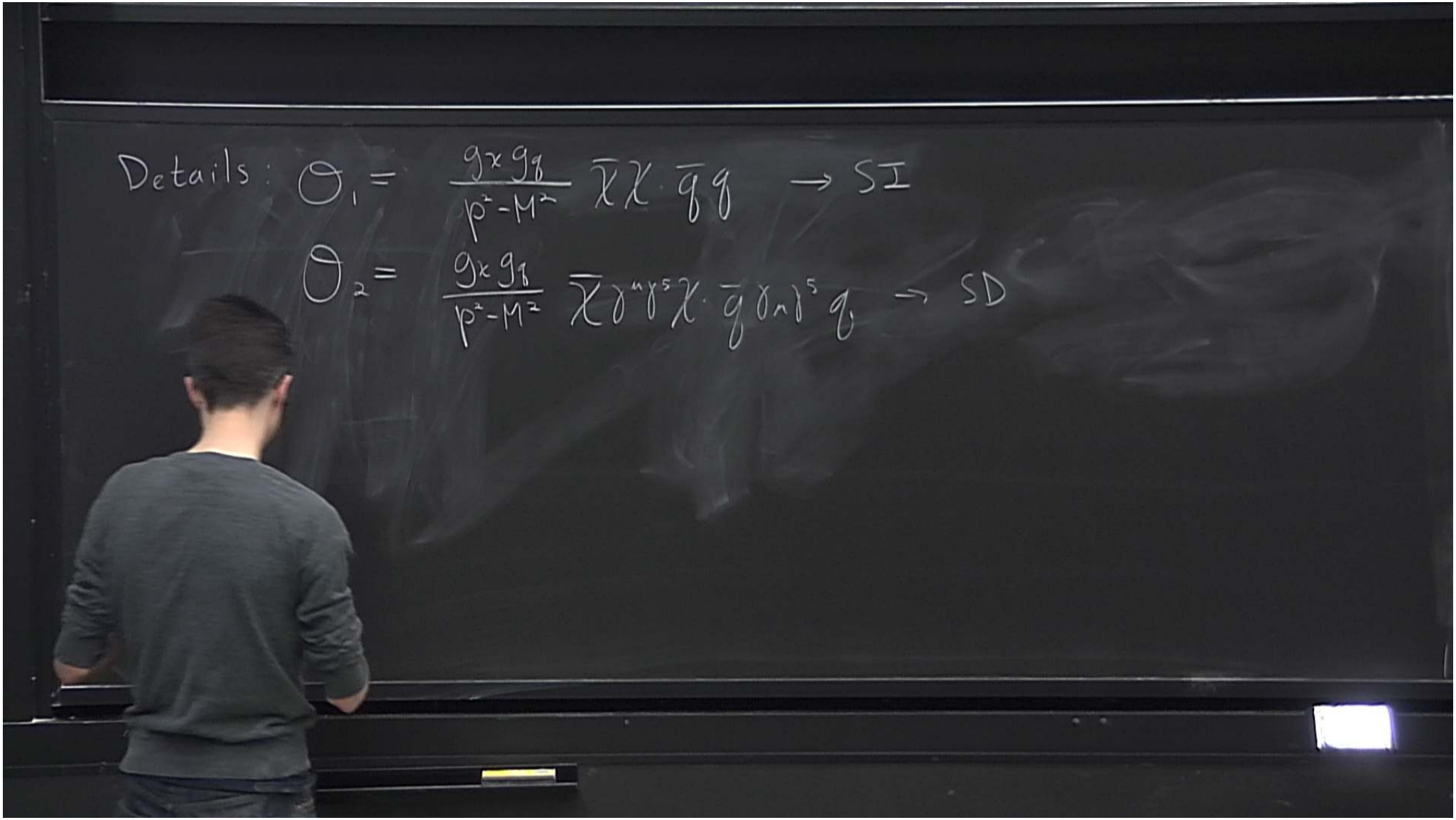
$= \|\vec{\not{p}}_T\|$

SM also produces $\not{E}_T$: ν, mismeasured jets.

DM $\not{E}_T$: 1. Cascade Decays
2. ISR = initial state radiation


Details: $\mathcal{O}_1 = \frac{g_\chi g_q}{p^2 - M^2} \bar{\chi}\chi\,\bar{q}q \rightarrow SI$
$\mathcal{O}$

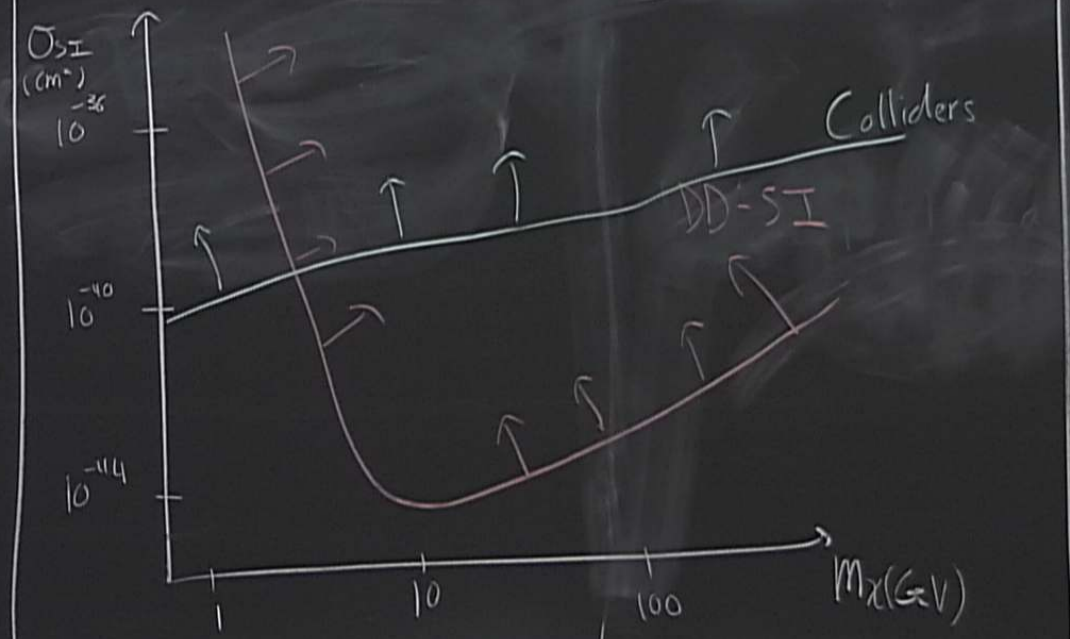

Details: $\mathcal{O}_1 = \frac{g_\chi g_q}{p^2 - M^2} \bar{\chi}\chi\,\bar{q}q \rightarrow SI$
$\mathcal{O}_2 = \frac{g_\chi g_q}{p^2 - M^2} \bar{\chi}\gamma^\mu\gamma^5\chi\,\bar{q}\gamma_\mu\gamma^5 q \rightarrow SD$

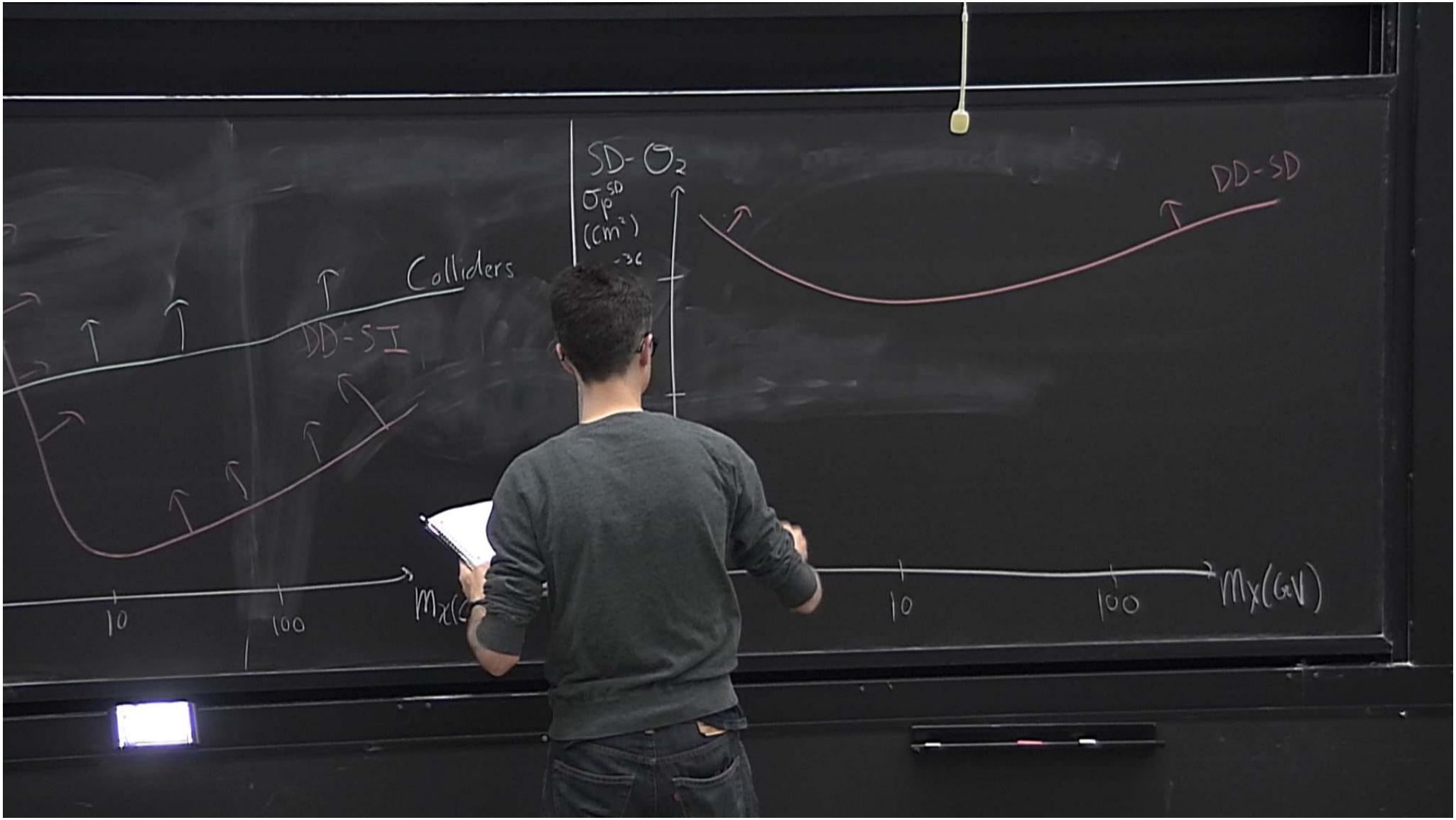

Details: $\mathcal{O}_1 = \frac{g_\chi g_q}{p^2 - M^2} \bar{\chi}\chi \cdot \bar{q}q \rightarrow SI$
$\mathcal{O}_2 = \frac{g_\chi g_q}{p^2 - M^2} \bar{\chi}\gamma^\mu\gamma^5\chi \cdot \bar{q}\gamma_\mu\gamma^5 q \rightarrow SD$

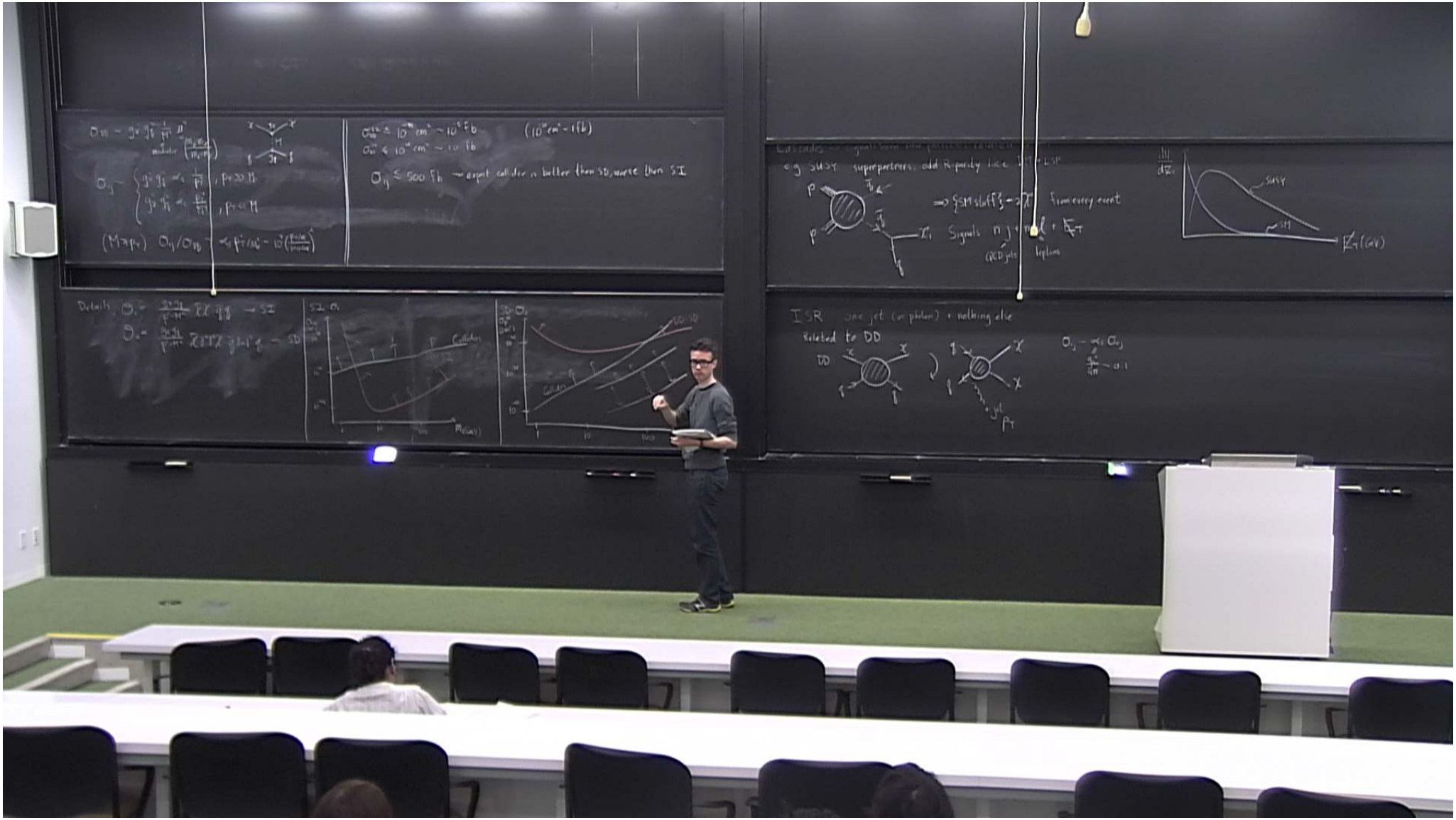
→ SI

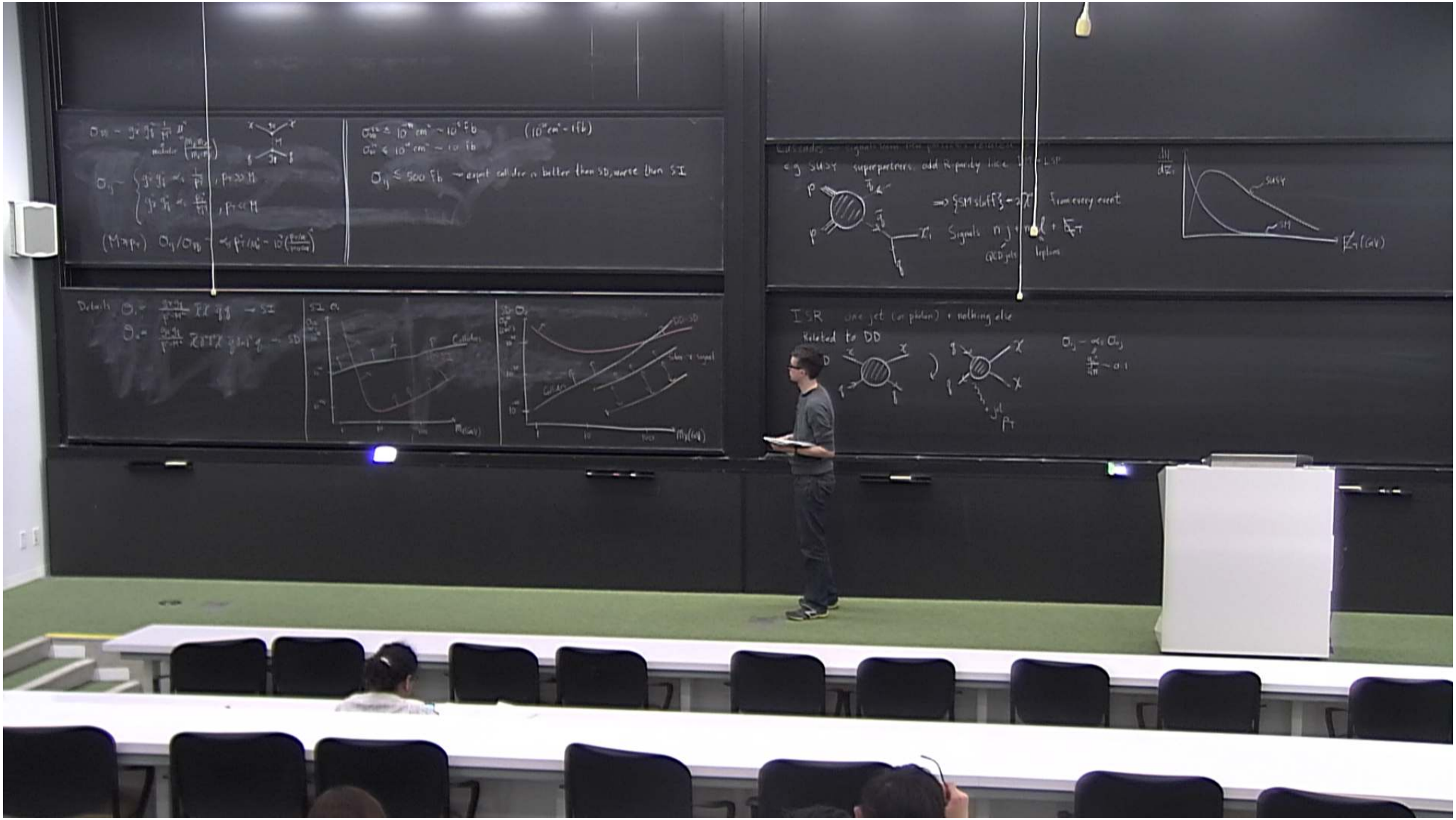
q^5 → SD

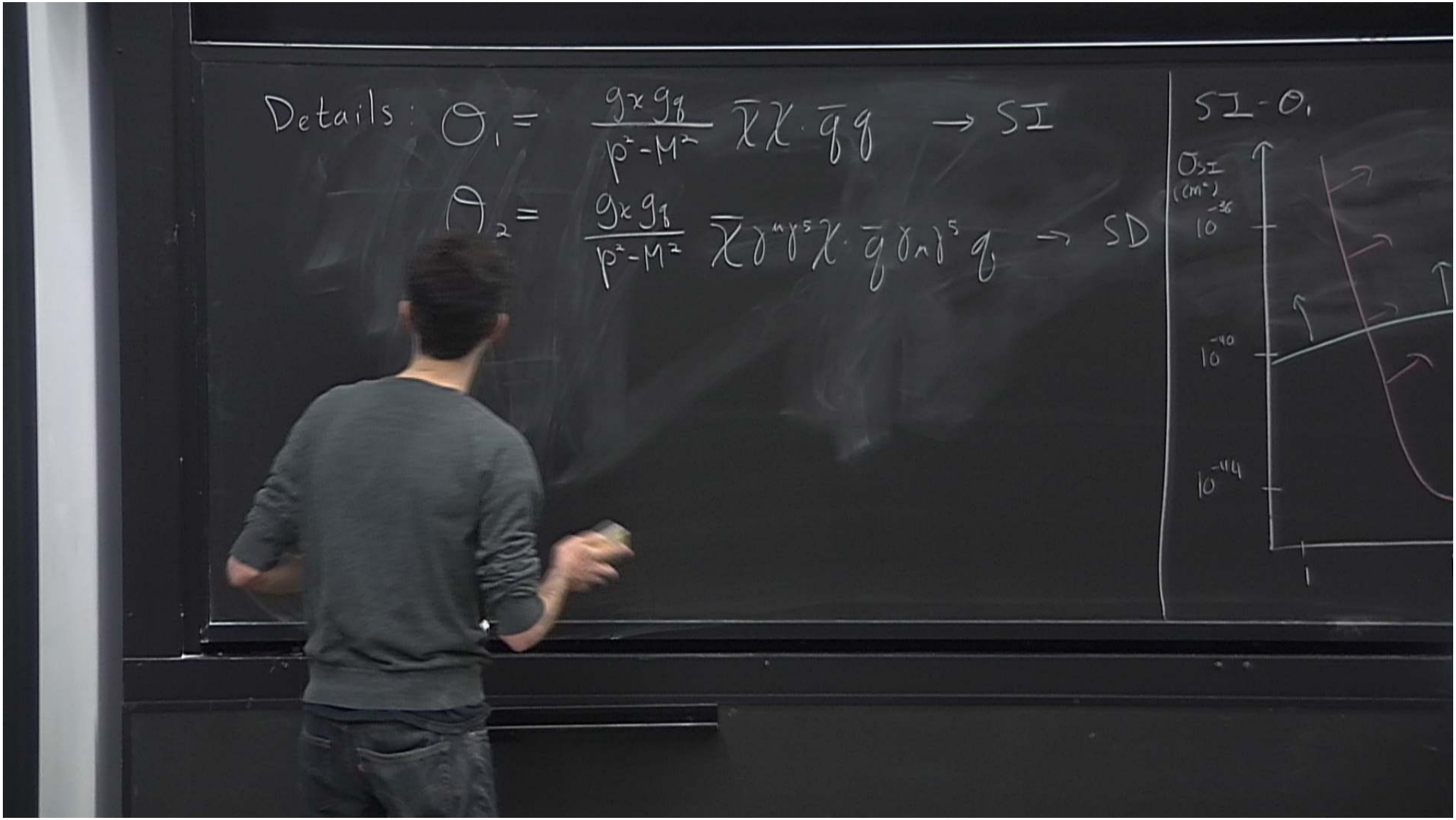
SI - θ_1

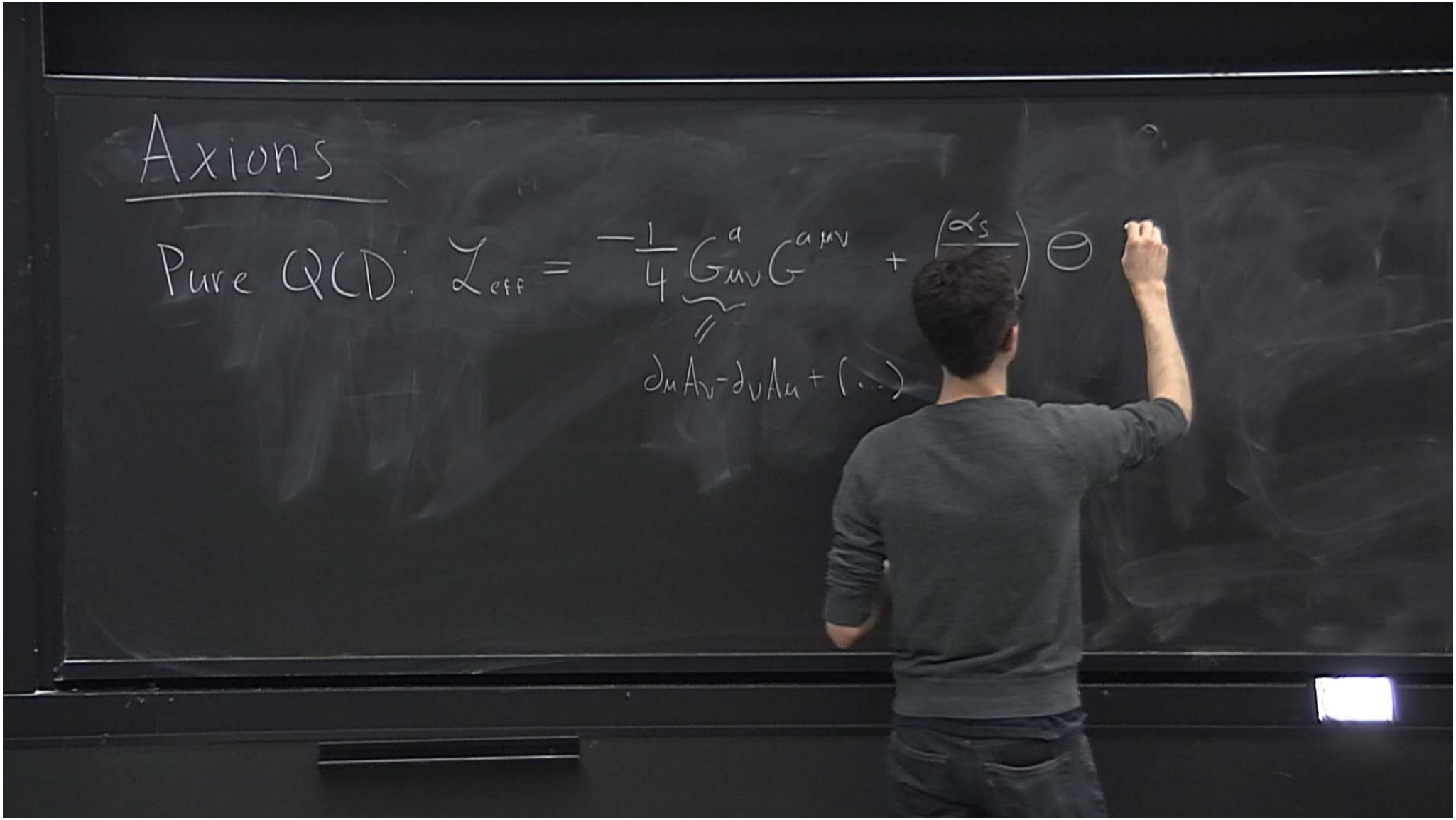


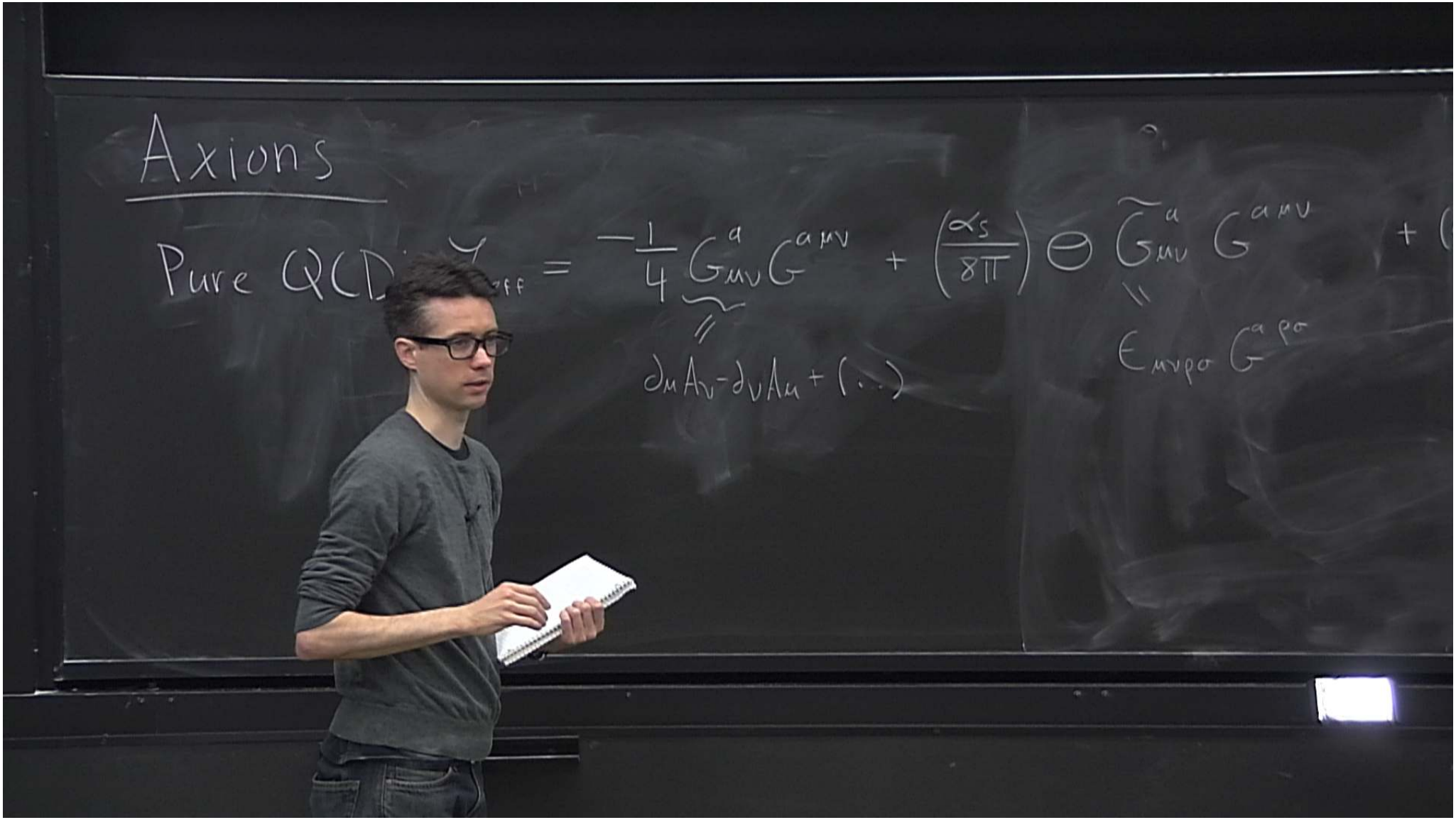

SD-$\mathcal{O}_2$
σ_p^{SD}
(cm^2)
-36
Colliders
DD-SI
DD-SD
10
100
m_χ(GeV)

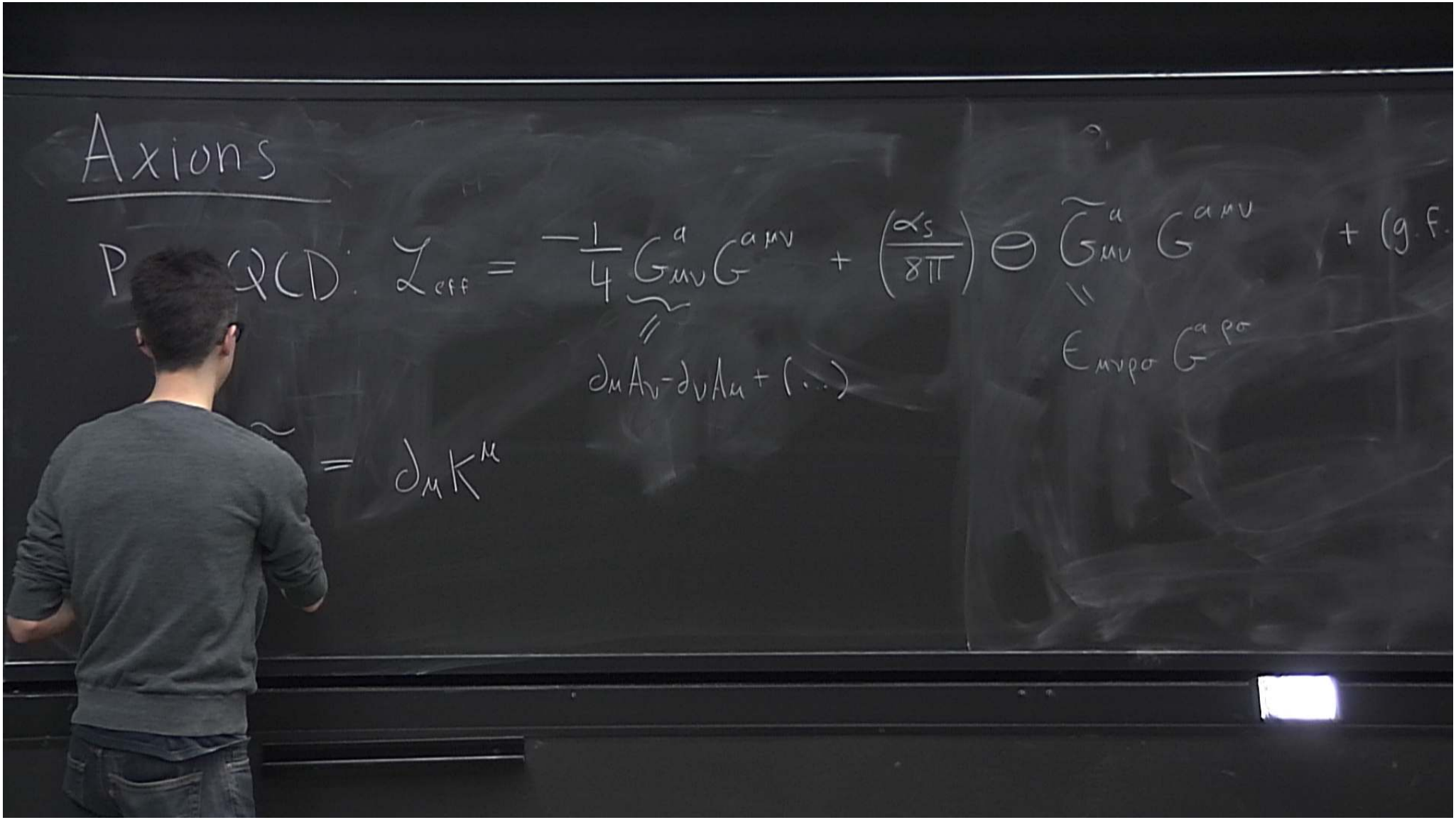

e.g. SUSY superpartners, odd R-parity like
from every event
Signals
QCD jets
leptons
SUSY
SM
ISR one jet (or photon) + nothing else
Related to DD
DD
Details
SI
Collider
DD-SD

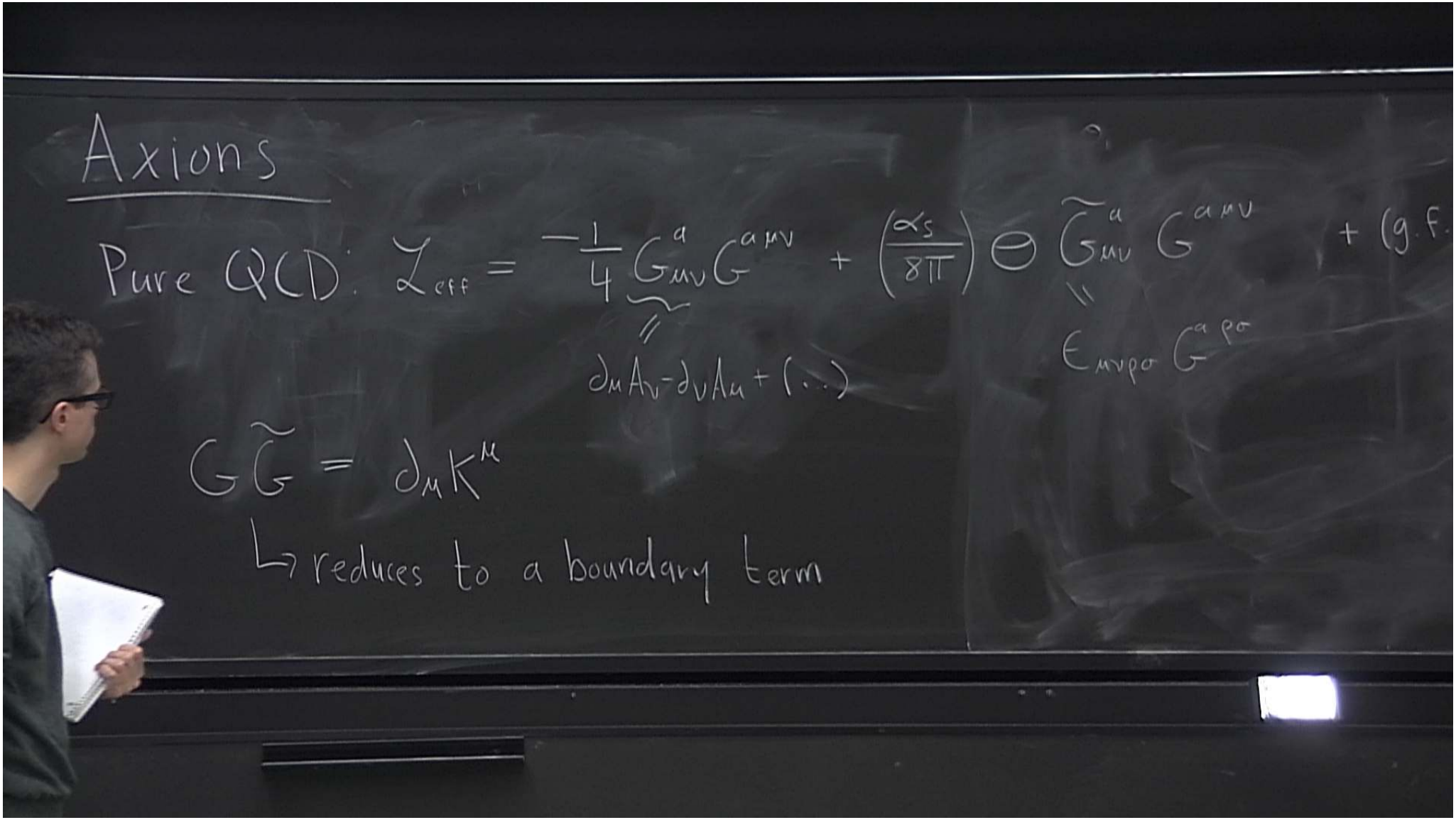

ISR
one jet (or photon) + nothing else
Related to DD
SUSY
SM


Details: $\mathcal{O}_1 = \frac{g_\chi g_q}{p^2 - M^2} \bar{\chi}\chi \cdot \bar{q}q \rightarrow SI$
$\mathcal{O}_2 = \frac{g_\chi g_q}{p^2 - M^2} \bar{\chi}\gamma^\mu\gamma^5\chi \cdot \bar{q}\gamma_\mu\gamma^5 q \rightarrow SD$
SI - $\mathcal{O}_1$
σ_{SI} (cm^2)
10^{-36}
10^{-40}
10^{-44}
1


Axions
Pure QCD: $\mathcal{L}_{eff} = -\frac{1}{4} G^a_{\mu\nu} G^{a\mu\nu} + \left(\frac{\alpha_s}{\quad}\right)\theta$
$\partial_\mu A_\nu - \partial_\nu A_\mu + (\ldots)$


Axions
Pure QCD
$\mathcal{L}_{\text{eff}} = -\frac{1}{4} G^a_{\mu\nu} G^{a\mu\nu} + \left(\frac{\alpha_s}{8\pi}\right) \theta \, \tilde{G}^a_{\mu\nu} G^{a\mu\nu}$
$G_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu + (\ldots)$
$\tilde{G}^a_{\mu\nu} = \epsilon_{\mu\nu\rho\sigma} G^{a\rho\sigma}$


Axions
QCD: $\mathcal{L}_{eff} = -\frac{1}{4} G^a_{\mu\nu} G^{a\mu\nu} + \left(\frac{\alpha_s}{8\pi}\right) \theta \tilde{G}^a_{\mu\nu} G^{a\mu\nu}$ + (g.F.
$G^a_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu + (..)$
$\tilde{G}^a_{\mu\nu} = \epsilon_{\mu\nu\rho\sigma} G^{a\rho\sigma}$
$= \partial_\mu K^\mu$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$G^a_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu + (..)$
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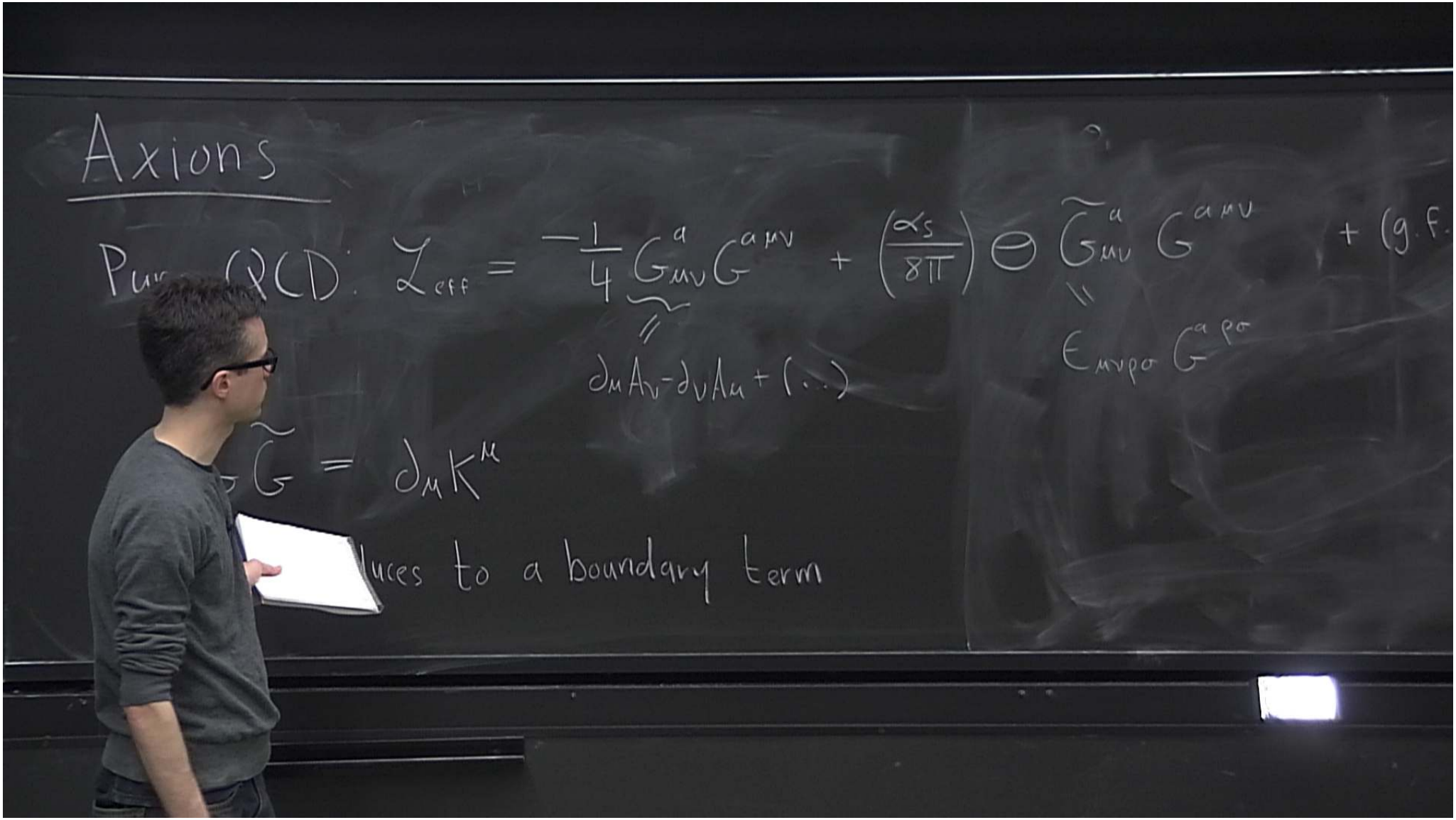
$G\tilde{G} = \partial_\mu K^\mu$
↳ reduces to a boundary term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Pure QCD: $\mathcal{L}_{eff} = -\frac{1}{4} G^a_{\mu\nu} G^{a\mu\nu} + \left(\frac{\alpha_s}{8\pi}\right) \theta \, \tilde{G}^a_{\mu\nu} G^{a\mu\nu} + (g.f.)$

$G^a_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu + (\ldots)$

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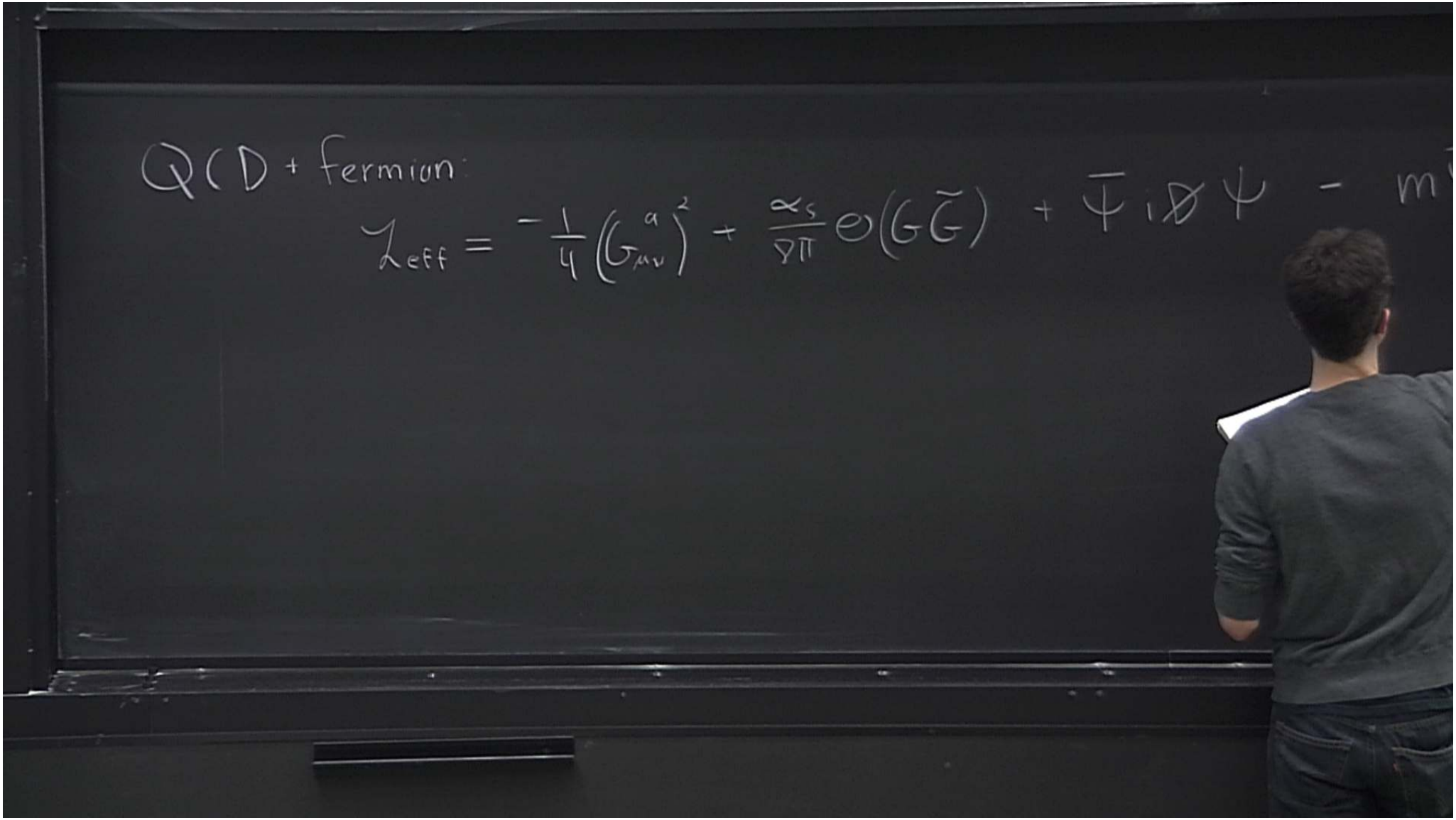
$G\tilde{G} = \partial_\mu K^\mu$

↳ reduces to a boundary term, but can't be completely ignored


QCD + fermion:
$\mathcal{L}_{eff} = -\frac{1}{4}(G^a_{\mu\nu})^2 + \frac{\alpha_s}{8\pi}\theta(G\tilde{G}) + \bar{\psi} i \not{D} \psi - m$

$$-\frac{1}{4}\left(G^{a}_{\mu\nu}\right)^2 + \frac{\alpha_s}{8\pi}\theta\left(G\tilde{G}\right) + \underbrace{\bar{\Psi} i \not{D} \Psi} - \left(m\bar{\Psi}_L \Psi_R + m^* \bar{\Psi}_R \Psi_L\right)$$

$$\bar{\Psi}_L i \not{D} \Psi_L + \bar{\Psi}_R i \not{D} \Psi_R$$

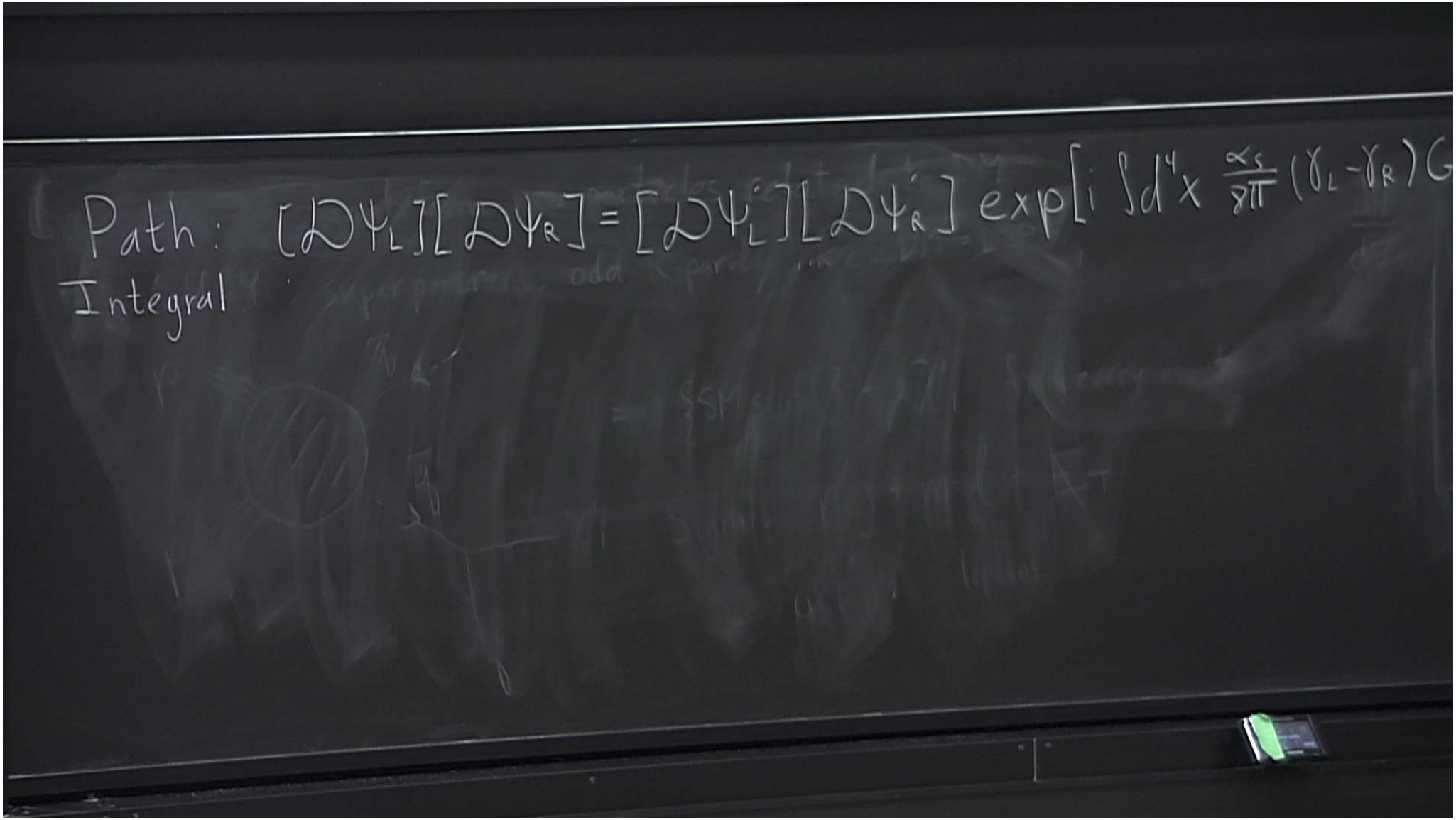
$$\Psi = \begin{pmatrix} \Psi_L \\ 0 \end{pmatrix} + \begin{pmatrix} 0 \\ \Psi_R \end{pmatrix}$$

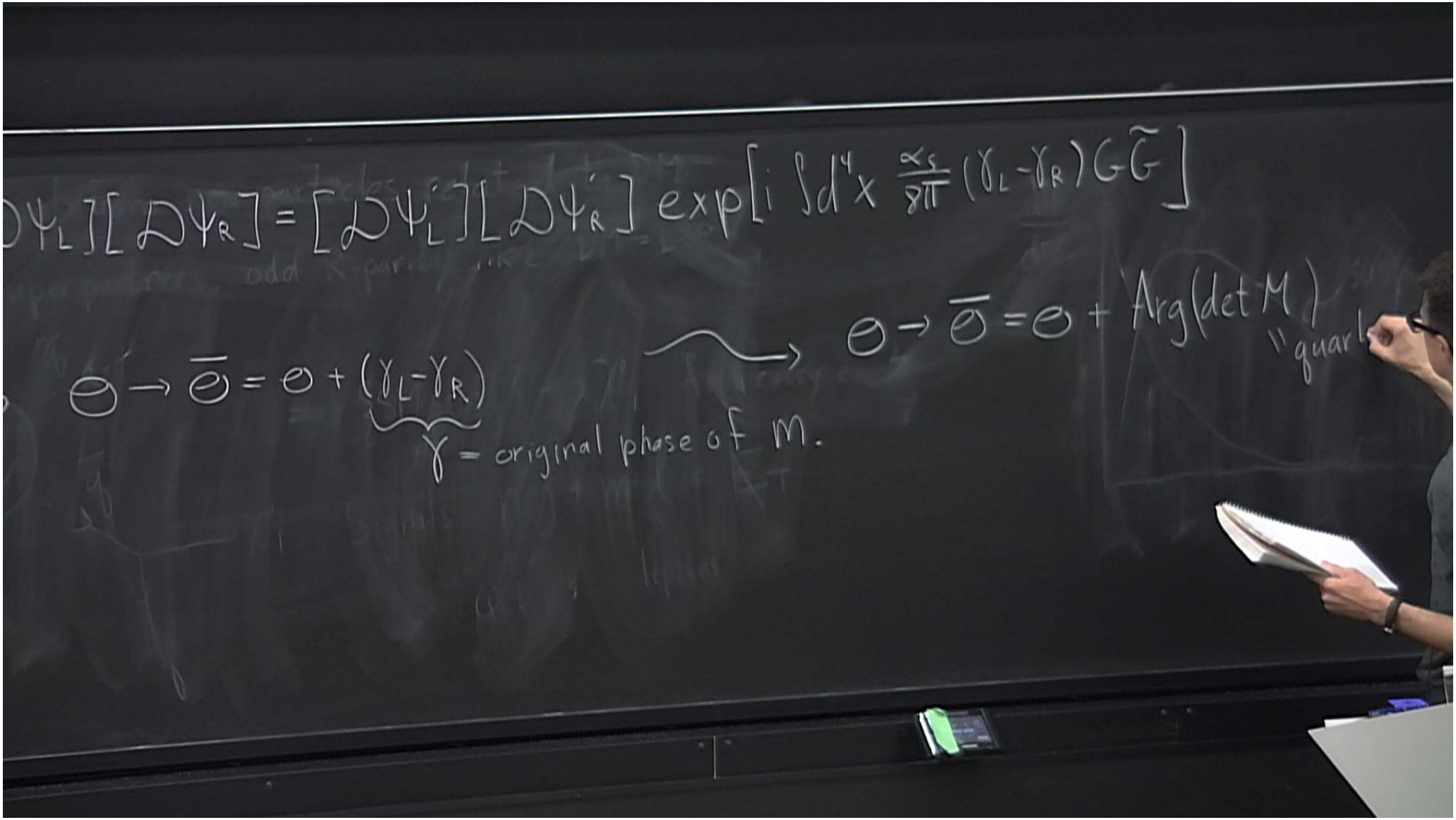
$$\frac{1}{4}\left(G^{a}_{\mu\nu}\right)^2 + \frac{\alpha_s}{8\pi}\theta\left(G\tilde{G}\right) + \bar{\Psi} i\not{D}\Psi - \left(m\bar{\Psi}_L\Psi_R + m^*\bar{\Psi}_R\Psi_L\right)$$

$$\Psi = \begin{pmatrix}\Psi_L\\ 0\end{pmatrix} + \begin{pmatrix}0\\ \Psi_R\end{pmatrix} \qquad \bar{\Psi}'_L i\not{D}\Psi'_L + \bar{\Psi}'_R i\not{D}\Psi'_R$$

$$|m|e^{i\gamma} \qquad \begin{cases}\Psi_L = e^{i\gamma_L}\Psi'_L \\ \Psi_R = e^{i\gamma_R}\Psi'_R\end{cases} \Rightarrow |m|e^{i(\gamma-\gamma_L+\gamma_R)}\bar{\Psi}_L\bar{\Psi}_R + h.c.$$

$\gamma_L - \gamma_R = \gamma \Rightarrow$ real mass term


Path: $[\mathcal{D}\psi_L][\mathcal{D}\psi_R] = [\mathcal{D}\psi_L'][\mathcal{D}\psi_R'] \exp\left[i \int d^4x \frac{\alpha_s}{8\pi}(\gamma_L - \gamma_R) G\right.$
Integral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$\theta \to \bar{\theta} = \theta + (\gamma_L - \gamma_R)$
γ = original phase of M.
$\theta \to \bar{\theta} = \theta + \mathrm{Arg}(\det M)$

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egral

↳ $\theta \to \bar{\theta} = \theta + (\gamma_L - \gamma_R)$ $\longrightarrow$ $\theta \to \bar{\theta} = \theta + \mathrm{Arg}(\det$

γ = original phase of m.

$|\eta| \sim 10^{-15} |\bar{\theta}| \lesssim 10^{-26}$

↳ $\bar{\theta} \lesssim 10^{-11}$ $\Rightarrow$ Strong CP problem.