Title: Beyond the Standard Model (TeV Physics)

Date: Aug 10, 2007 09:00 AM

URL: http://pirsa.org/07080014

Abstract:

$$M_{Pl}^2 = M_*^{n+2} \underbrace{(2\pi r)^n}_{V_n}$$

~~$n=1,\ M_* = 1\ \text{TeV}$~~ $\quad r \sim 10^{12}\ m$

~~$n=2,\ M_* = 1\ \text{TeV}$~~

$n \gtrsim 3$

$$V(r') = -G_N^{(4+n)} \frac{m_1 m_2}{(r')^{1+n}}$$

$\downarrow$

$50\ \mu m$

LHC:

$$g_{\mu\nu} = \eta_{\mu\nu} + \frac{h_{\mu\nu}}{M_{Pl}}$$

$$g_{MN} = \eta_{MN} + \frac{h_{MN}}{M_*^{\frac{n+2}{2}}}$$

$$h_{MN}(x;y) = \sum_{m_1=-\infty}^{\infty} \cdots \sum_{m_n=-\infty}^{\infty} \frac{h^{(m)}_{MN}(x)}{\sqrt{V_n}} e^{i\frac{m\cdot y}{r}}$$

KALUZA-KLEIN

LHC :

$$g_{\mu\nu} = \eta_{\mu\nu} + \frac{h_{\mu\nu}}{M_{Pl}}$$

$$g_{MN} = \eta_{MN} + \frac{h_{MN}}{M_*^{\frac{n+2}{2}}}$$

$$h_{MN}(x;y) = \sum_{m_1=-\infty}^{\infty} \cdots \sum_{m_n=-\infty}^{\infty} \frac{h_{MN}^{(m)}(x)}{\sqrt{V_n}} e^{i\frac{m\cdot y}{r}}$$

KALUZA-KLEIN

LHC:

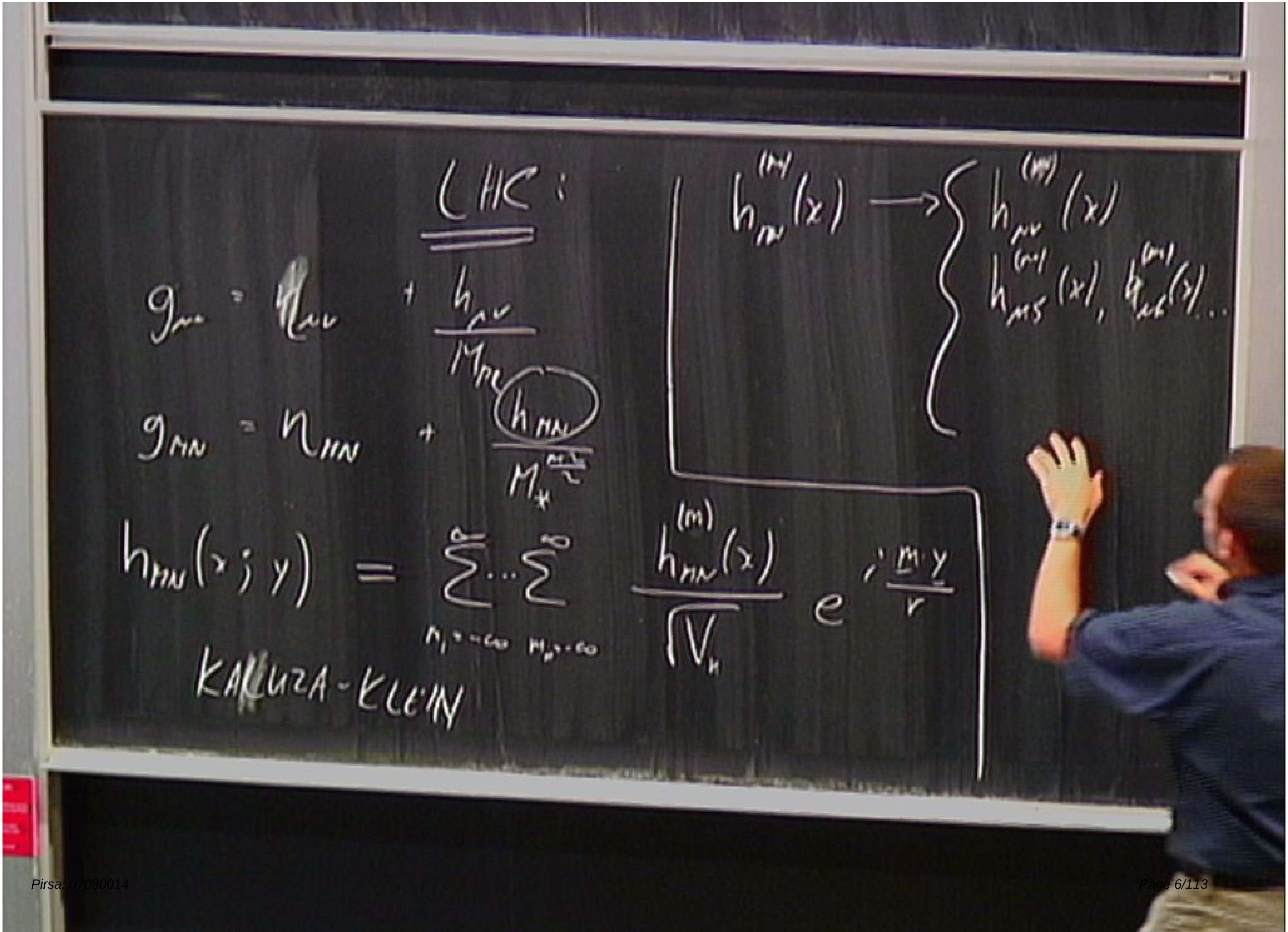
$$g_{\mu\nu} = \eta_{\mu\nu} + \frac{h_{\mu\nu}}{M_{Pl}}$$

$$g_{MN} = \eta_{MN} + \frac{h_{MN}}{M_*^{\frac{n+2}{2}}}$$

$$h_{MN}(x;y) = \sum_{m_1=-\infty}^{\infty}\cdots\sum_{m_n=-\infty}^{\infty} \frac{h^{(m)}_{MN}(x)}{\sqrt{V_n}}\, e^{i\frac{\underline{m}\cdot y}{r}}$$

KALUZA-KLEIN

$$h^{(m)}_{\mu\nu}(x) \longrightarrow \left\{ h^{(m)}_{\mu\nu}(x) \right.$$


LHC:
$g_{\mu\nu} = \eta_{\mu\nu} + \frac{h_{\mu\nu}}{M_{Pl}}$
$g_{MN} = \eta_{MN} + \frac{h_{MN}}{M_*^{\frac{n+2}{2}}}$
$h_{MN}(x;y) = \sum_{n_1=-\infty}^{\infty} \cdots \sum_{n_k=-\infty}^{\infty} \frac{h^{(n)}_{MN}(x)}{\sqrt{V_n}} e^{i\frac{n\cdot y}{r}}$
KALUZA-KLEIN
$h^{(n)}_{MN}(x) \rightarrow \begin{cases} h^{(n)}_{\mu\nu}(x) \\ h^{(n)}_{\mu 5}(x),\ h^{(n)}_{\mu 6}(x) \ldots \end{cases}$

$\underline{\underline{\text{LHC:}}}$

$$g_{\mu\nu} = \eta_{\mu\nu} + \frac{h_{\mu\nu}}{M_{Pl}}$$

$$g_{MN} = \eta_{MN} + \frac{h_{MN}}{M_*^{\frac{n+2}{2}}}$$

$$h_{MN}(x;y) = \sum_{n_1=-\infty}^{\infty}\cdots\sum_{n_n=-\infty}^{\infty} \frac{h^{(m)}_{MN}(x)}{\sqrt{V_n}}\, e^{i\frac{m\cdot y}{r}}$$

KALUZA-KLEIN

$$h^{(m)}_{MN}(x) \longrightarrow \begin{cases} h^{(m)}_{\mu\nu}(x) \\ h^{(m)}_{\mu 5}(x),\ h^{(m)}_{\mu 6}(x) \ldots \\ h^{(m)}_{ij}(x) \quad i,j = 5,6,\ldots \end{cases}$$

LHC :

$$g_{\mu\nu} = \eta_{\mu\nu} + \frac{h_{\mu\nu}}{M_{Pl}}$$

$$g_{MN} = \eta_{MN} + \frac{h_{MN}}{M_*^{\frac{n+2}{2}}}$$

$$h_{MN}(x;y) = \sum_{n_1=-\infty}^{\infty} \cdots \sum_{n_n=-\infty}^{\infty} \frac{h^{(m)}_{MN}(x)}{\sqrt{V_n}} e^{i\frac{m\cdot y}{r}}$$

KALUZA-KLEIN

$$h^{(m)}_{MN}(x) \longrightarrow \begin{cases} h^{(m)}_{\mu\nu}(x) \\ h^{(m)}_{\mu 5}(x),\ h^{(m)}_{\mu 6}(x) \ldots \\ h^{(m)}_{ij}(x) \end{cases}$$

$i,j = 5, 6, \ldots$

LHC:

$$g_{\mu\nu} = \eta_{\mu\nu} + \frac{h_{\mu\nu}}{M_{Pl}}$$

$$g_{MN} = \eta_{MN} + \frac{h_{MN}}{M_*^{\frac{n+2}{2}}}$$

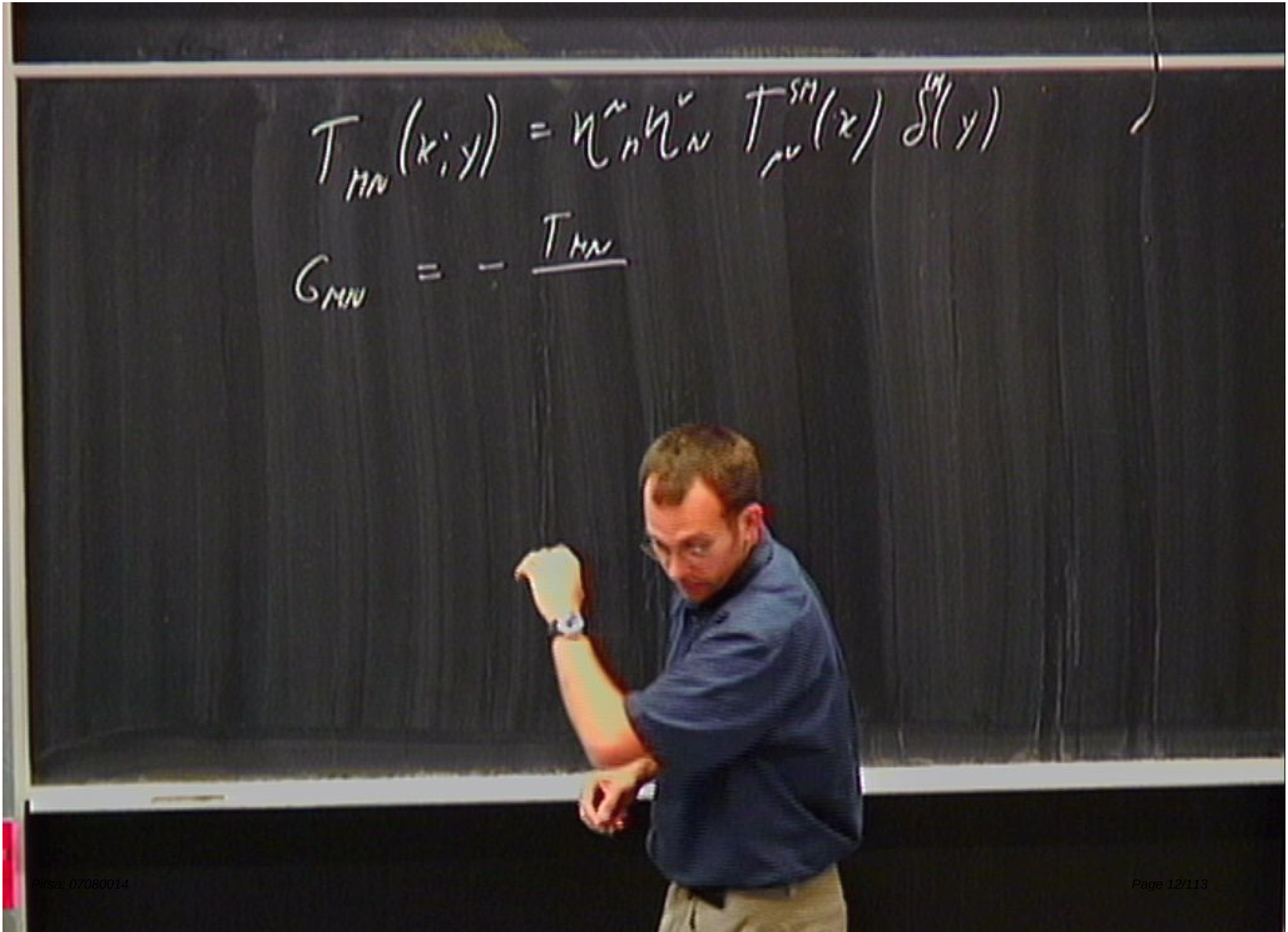
$$h_{MN}(x;y) = \sum_{n_1=-\infty}^{\infty}\cdots\sum_{n_n=-\infty}^{\infty} \frac{h^{(m)}_{MN}(x)}{\sqrt{V_n}}\, e^{i\frac{m\cdot y}{r}}$$

KALUZA-KLEIN

$$h^{(m)}_{MN}(x) \longrightarrow \begin{cases} h^{(m)}_{\mu\nu}(x) \\ h^{(m)}_{\mu 5}(x),\ h^{(m)}_{\mu 6}(x)\ldots \\ h^{(m)}_{ij}(x) \quad i,j = 5,6,\ldots \end{cases}$$

$$T_{MN}(x;y) = T^{SM}_{\mu\nu}(x)\,\delta^{(n)}(y)$$

$$T_{MN}(x;y) = \eta^{\mu}{}_{M}\,\eta^{\nu}{}_{N}\; T^{SM}_{\mu\nu}(x)\,\delta^{(n)}(y)$$


$T_{MN}(x;y) = \eta^{\mu}{}_{M}\eta^{\nu}{}_{N}\, T^{SM}_{\mu\nu}(x)\,\delta^{(n)}(y)$
$G_{MN} = -\ \frac{T_{MN}}{\ }$

$$T_{MN}(x;y) = \eta^{\mu}{}_{M}\eta^{\nu}{}_{N}\, T^{SM}_{\mu\nu}(x)\, \delta^{(n)}(y)$$

$$G_{MN} = -\frac{T_{MN}}{M_*^{2+n}}$$

$$G_{\mu\nu} = -\frac{T_{\mu\nu}}{M_*^{2+n}}$$

$$G_{\mu j} = 0$$

$$G_{ij} = 0$$

$$T_{MN}(x;y) = \eta^{\mu}{}_{M}\,\eta^{\nu}{}_{N}\; T^{SM}_{\mu\nu}(x)\,\delta^{(n)}(y)$$

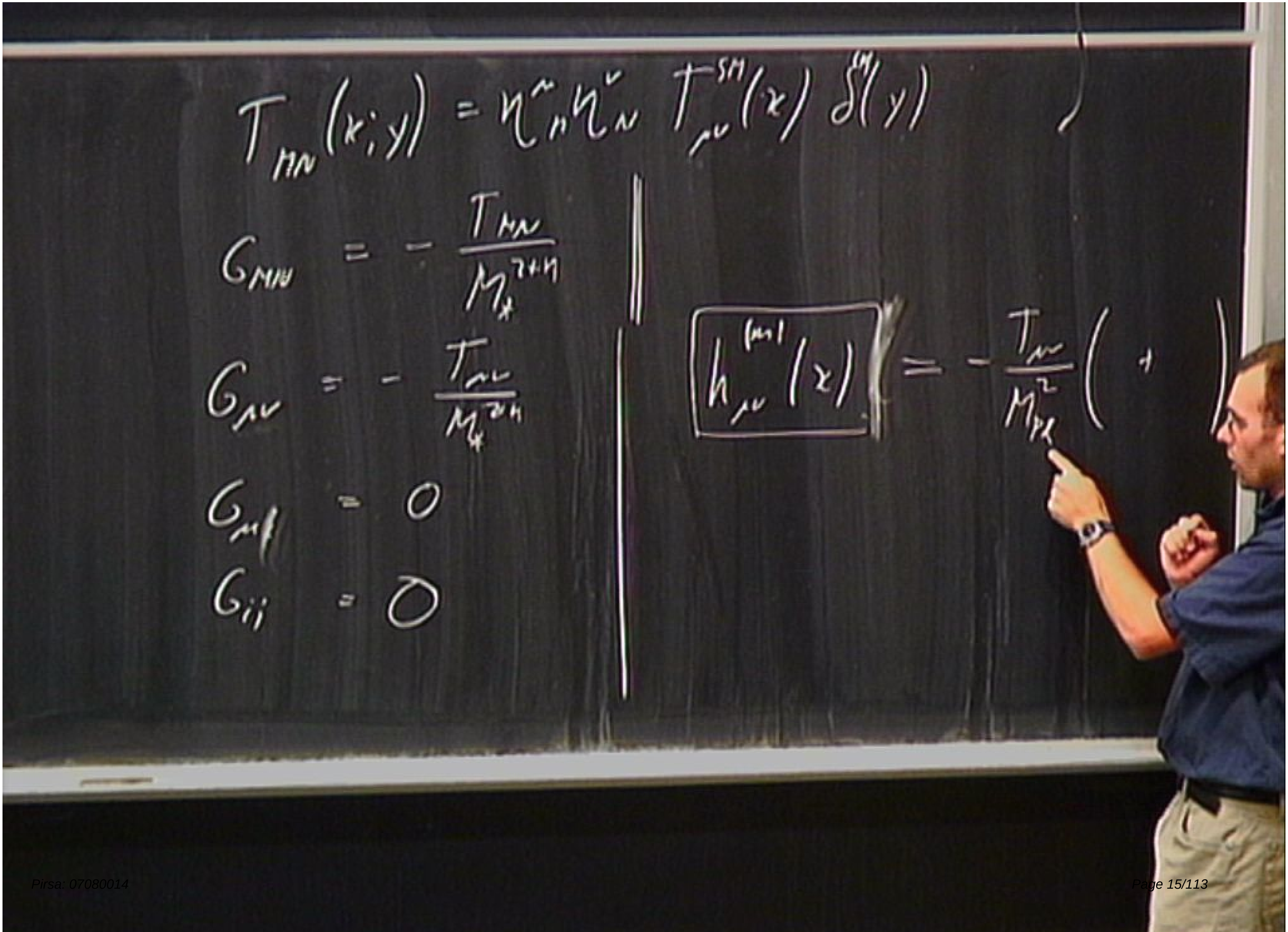
$$G_{MN} = -\frac{T_{MN}}{M_*^{2+n}}$$

$$G_{\mu\nu} = -\frac{T_{\mu\nu}}{M_*^{2+n}}$$

$$G_{\mu j} = 0$$

$$G_{ij} = 0$$

$$\underline{h^{(m)}_{\mu\nu}(x)}$$


$T_{MN}(x;y) = \eta^{\mu}{}_{M}\eta^{\nu}{}_{N}\, T^{SM}_{\mu\nu}(x)\, \delta^{(n)}(y)$
$G_{MN} = -\frac{T_{MN}}{M_*^{2+n}}$
$G_{\mu\nu} = -\frac{T_{\mu\nu}}{M_*^{2+n}}$
$G_{\mu i} = 0$
$G_{ij} = 0$
$\boxed{h^{(m)}_{\mu\nu}(x)} = -\frac{T_{\mu\nu}}{M_{Pl}^2}\left(\; + \; \right)$

$$T_{MN}(x;y) = \eta^{\mu}{}_{M}\,\eta^{\nu}{}_{N}\,T^{SM}_{\mu\nu}(x)\,\delta^{(n)}(y)$$

$$G_{MN} = -\frac{T_{MN}}{M_*^{2+n}}$$

$$G_{\mu\nu} = -\frac{T_{\mu\nu}}{M_*^{2+n}}$$

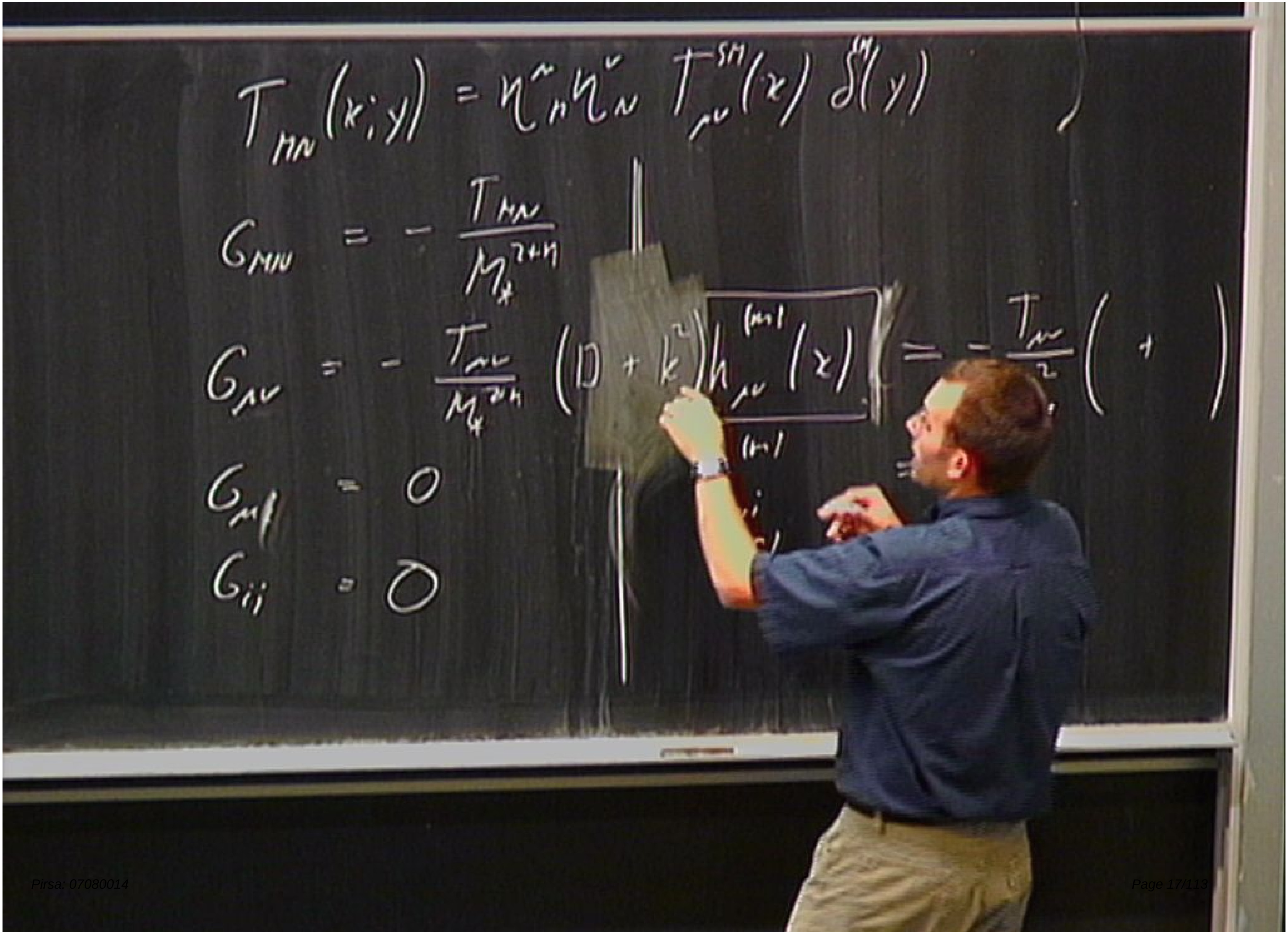
$$G_{\mu j} = 0$$

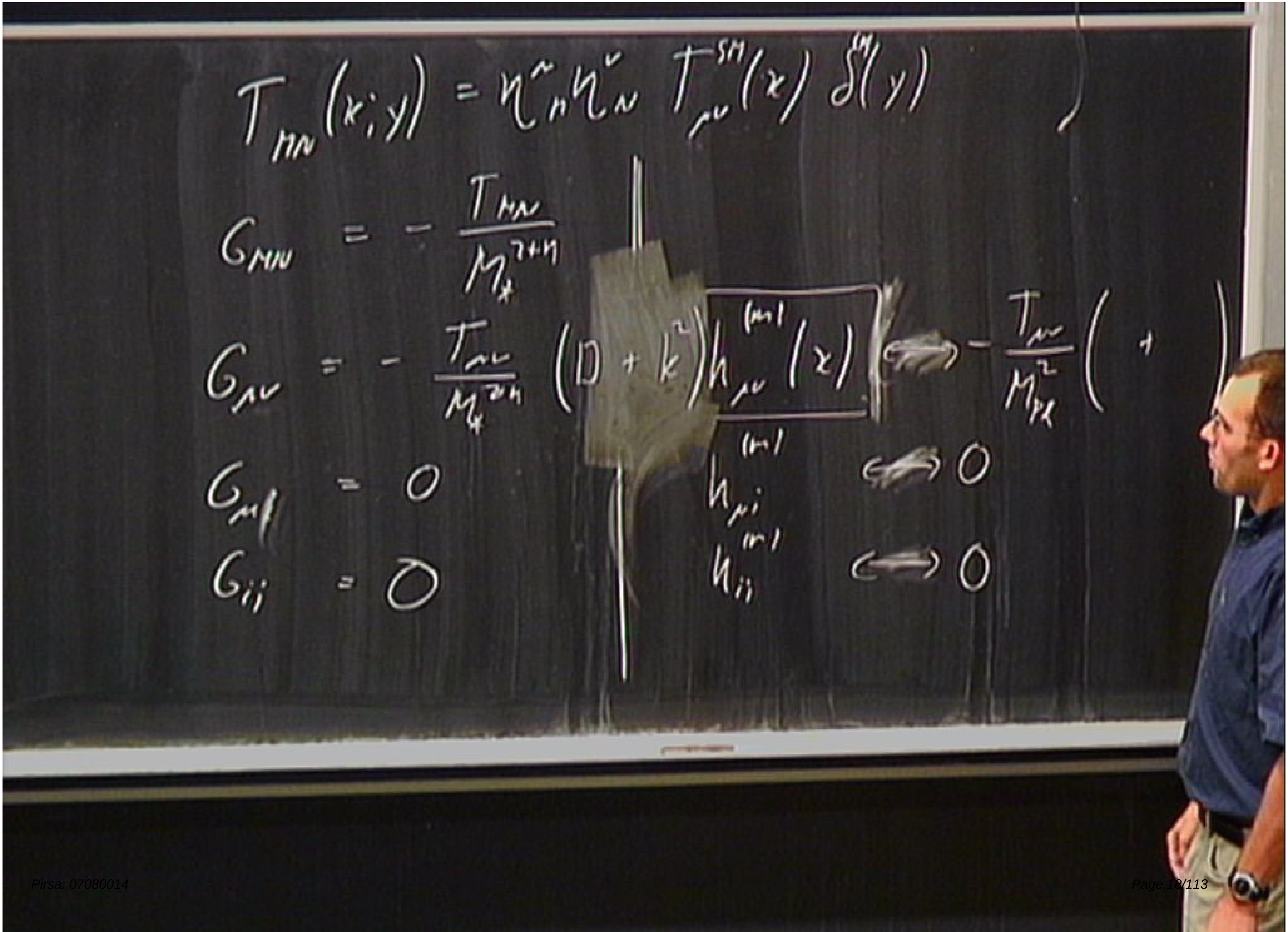
$$G_{ij} = 0$$

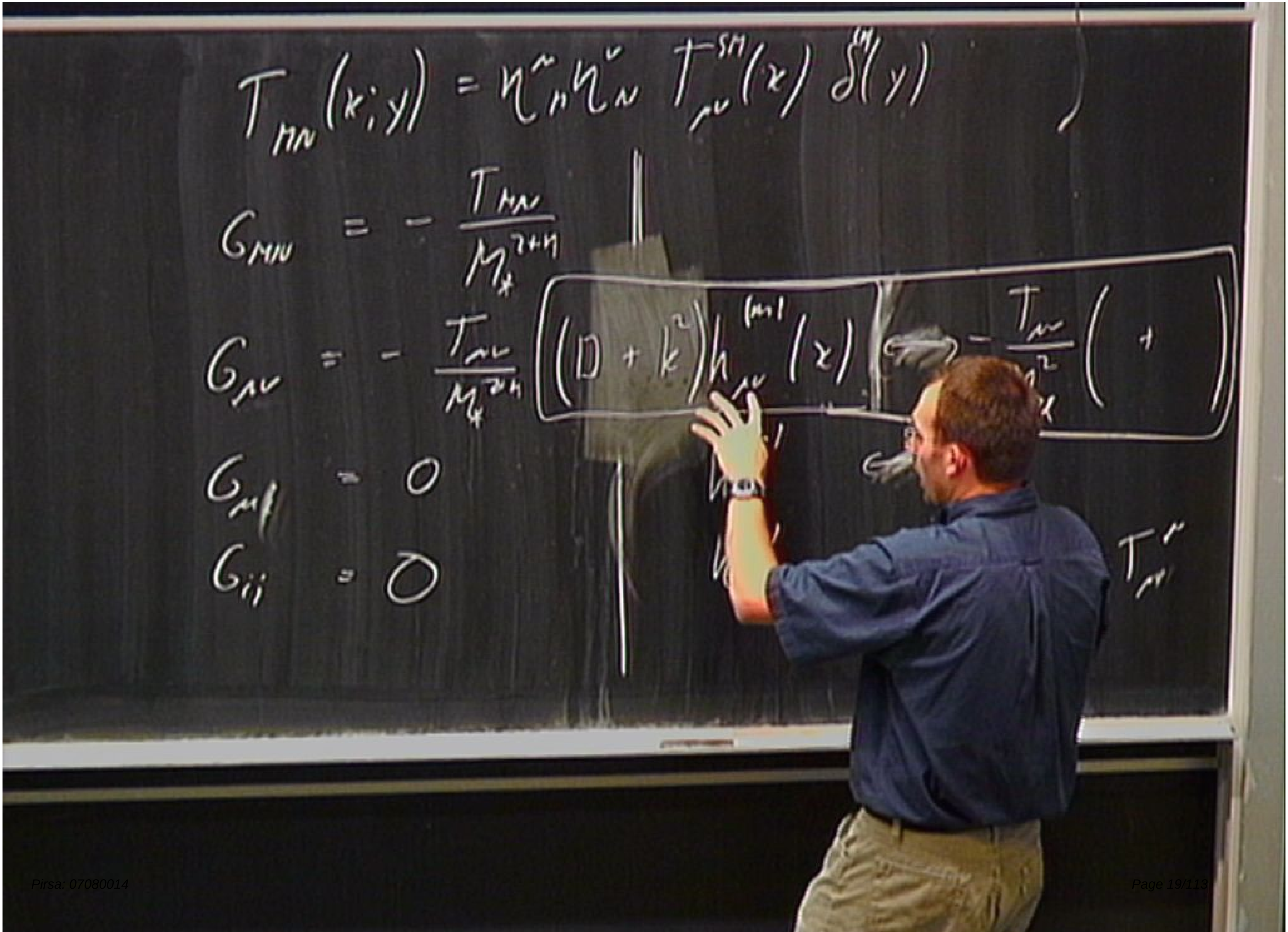
$$\boxed{h^{(m)}_{\mu\nu}(x)} = -\frac{T_{\mu\nu}}{M_{Pl}^2}\left(\quad + \quad \right)$$

$$h^{(m)}_{\mu i} = 0$$

$$h^{(m)}_{ij} = 0$$


$T_{MN}(x;y) = \eta^{\mu}_{M}\eta^{\nu}_{N}\, T^{SM}_{\mu\nu}(x)\,\delta^{(n)}(y)$
$G_{MN} = -\frac{T_{MN}}{M_*^{2+n}}$
$G_{\mu\nu} = -\frac{T_{\mu\nu}}{M_*^{2+n}}$
$(\Box + k^2)\, h^{(m)}_{\mu\nu}(x)$
$G_{\mu j} = 0$
$G_{ij} = 0$


$T_{MN}(x;y) = \eta^{\mu}{}_{M}\eta^{\nu}{}_{N}\, T^{SM}_{\mu\nu}(x)\, \delta^{(n)}(y)$
$G_{MN} = -\frac{T_{MN}}{M_*^{2+n}}$
$G_{\mu\nu} = -\frac{T_{\mu\nu}}{M_*^{2+n}}(\Box + k^2)\, \boxed{h^{(m)}_{\mu\nu}(x)} \Longleftrightarrow -\frac{T_{\mu\nu}}{M_{Pl}^2}(\ \ +\ \ )$
$G_{\mu i} = 0$ $h^{(m)}_{\mu i} \Longleftrightarrow 0$
$G_{ij} = 0$ $h^{(m)}_{ij} \Longleftrightarrow 0$



$T_{MN}(x;y) = \eta^{\mu}{}_{M}\eta^{\nu}{}_{N}\, T^{SM}_{\mu\nu}(x)\, \delta^{(n)}(y)$
$G_{MN} = -\frac{T_{MN}}{M_*^{2+n}}$
$G_{\mu\nu} = -\frac{T_{\mu\nu}}{M_*^{2+n}}$
$(\Box + k^2) h^{(m)}_{\mu\nu}(x)$
$-\frac{T_{\mu\nu}}{M_*^2}(\quad + \quad)$
$G_{\mu j} = 0$
$G_{ij} = 0$
T^{μ}_{μ}

$$T_{MN}(x;y) = \eta^{\mu}{}_{M}\,\eta^{\nu}{}_{N}\,T^{SM}_{\mu\nu}(x)\,\delta^{(n)}(y)$$

$$G_{MN} = -\frac{T_{MN}}{M_*^{2+n}}$$

$$G_{\mu\nu} = -\frac{T_{\mu\nu}}{M_*^{2+n}} \qquad \boxed{(\Box + k^2)\,h^{(m)}_{\mu\nu}(x)} \Longleftrightarrow -\frac{T_{\mu\nu}}{M_{Pl}^2}\left(\quad + \quad \right)$$

$$G_{\mu i} = 0 \qquad h^{(m)}_{\mu i} \Longleftrightarrow 0$$

$$G_{ij} = 0 \qquad h^{(m)}_{ij} \Longleftrightarrow 0 \qquad T^{\mu}_{\mu}$$

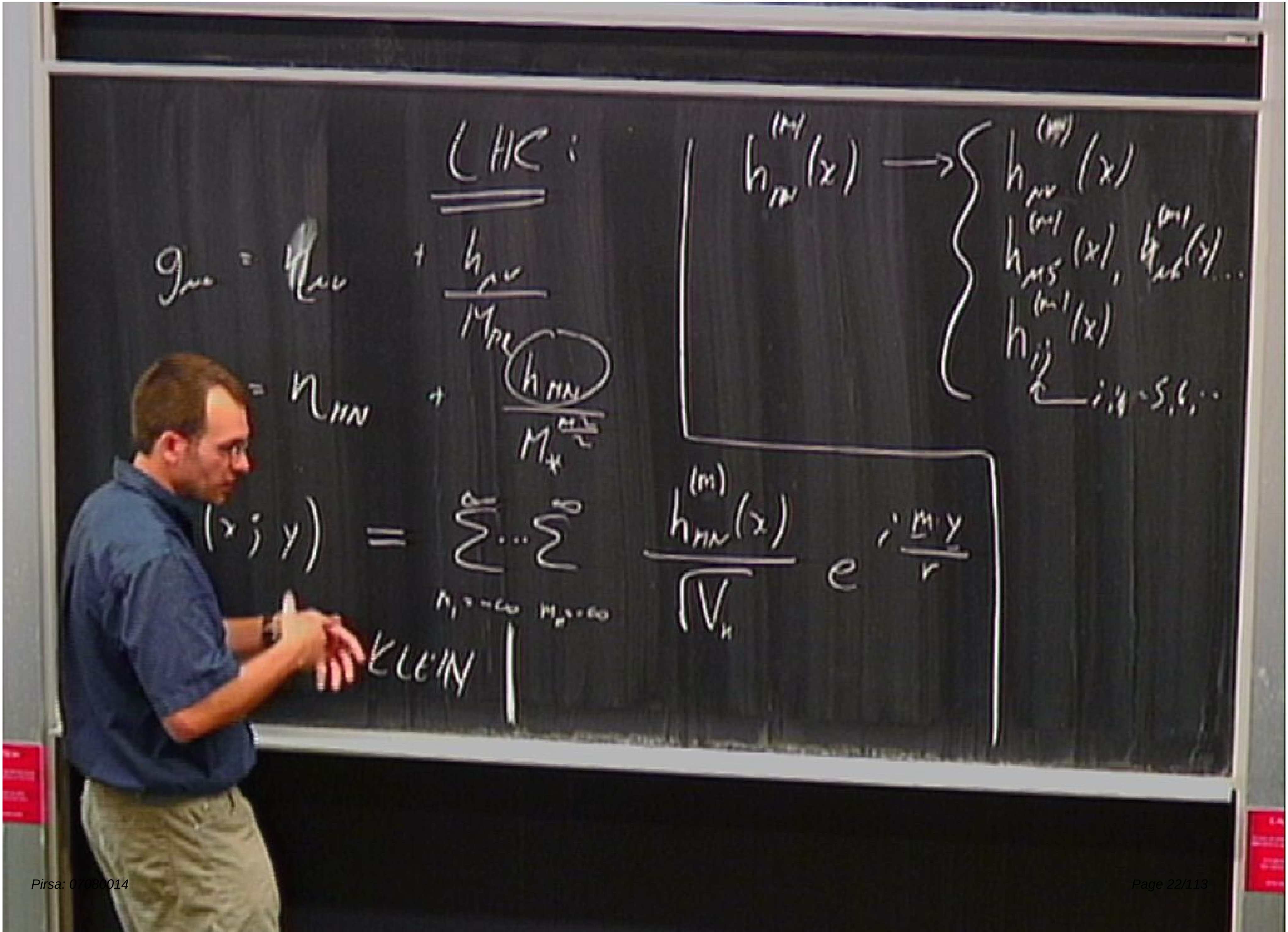
$$T_{MN}(x;y) = \eta^{\mu}{}_{M}\eta^{\nu}{}_{N}\, T^{SM}_{\mu\nu}(x)\,\delta^{(n)}(y)$$

$$G_{MN} = -\frac{T_{MN}}{M_*^{2+n}}$$

$$G_{\mu\nu} = -\frac{T_{\mu\nu}}{M_*^{2+n}} \qquad \boxed{(\Box + k^2)\, h^{(m)}_{\mu\nu}(x) \Longleftrightarrow -\frac{T_{\mu\nu}}{M_{Pl}^2}\left(\quad + \quad \right)}$$

$$G_{\mu j} = 0 \qquad h^{(m)}_{\mu i} \Longleftrightarrow 0$$

$$G_{ij} = 0 \qquad h^{(m)}_{ij} \Longleftrightarrow 0 \qquad T^{\mu}{}_{\mu}$$


LHC:
KLEIN
i,j = 5,6, ...

LHC:

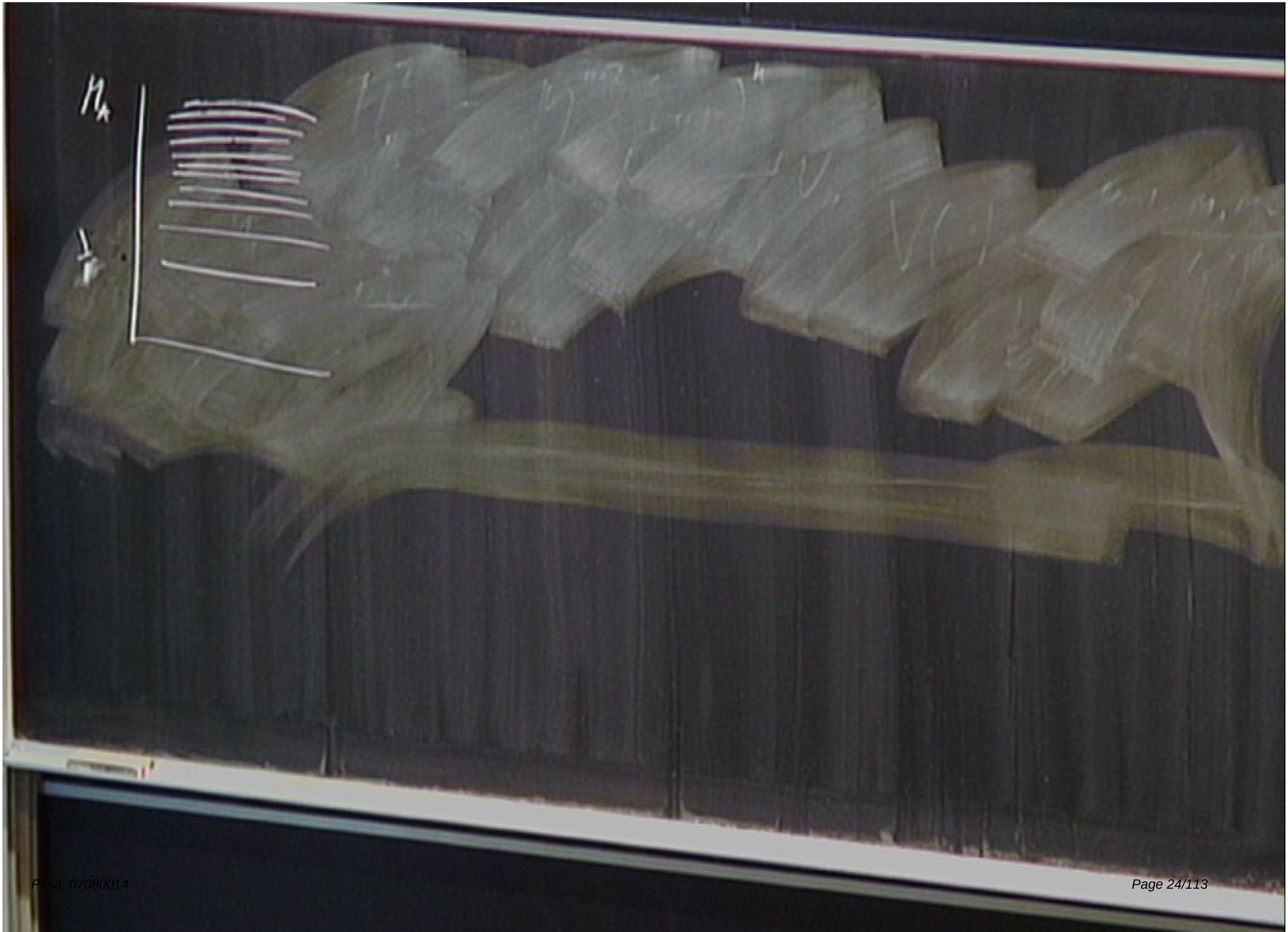
$$g_{\mu\nu} = \eta_{\mu\nu} + \frac{h_{\mu\nu}}{M_{Pl}}$$

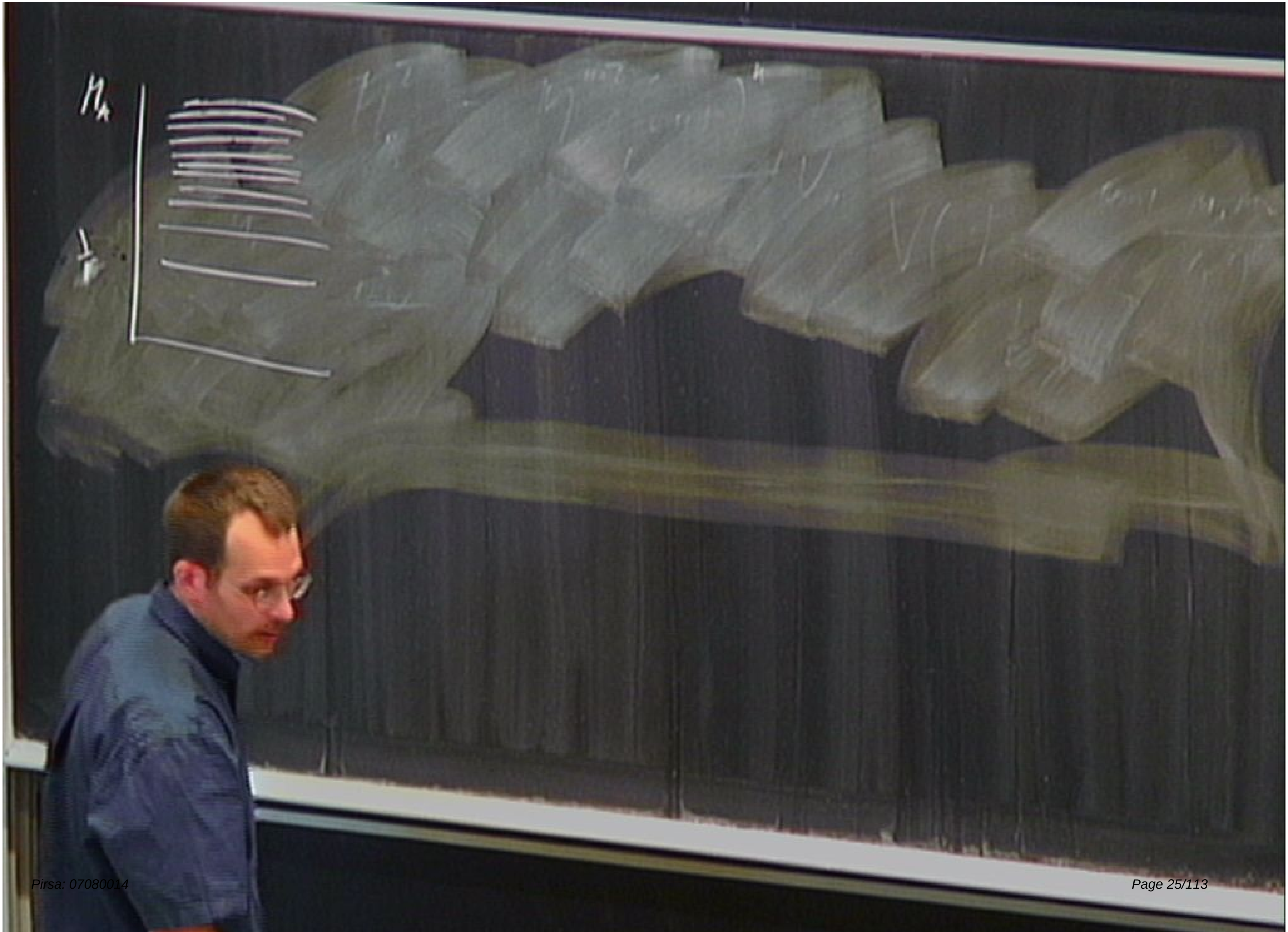
$$g_{MN} = \eta_{MN} + \frac{h_{MN}}{M_*^{\frac{n+2}{2}}}$$

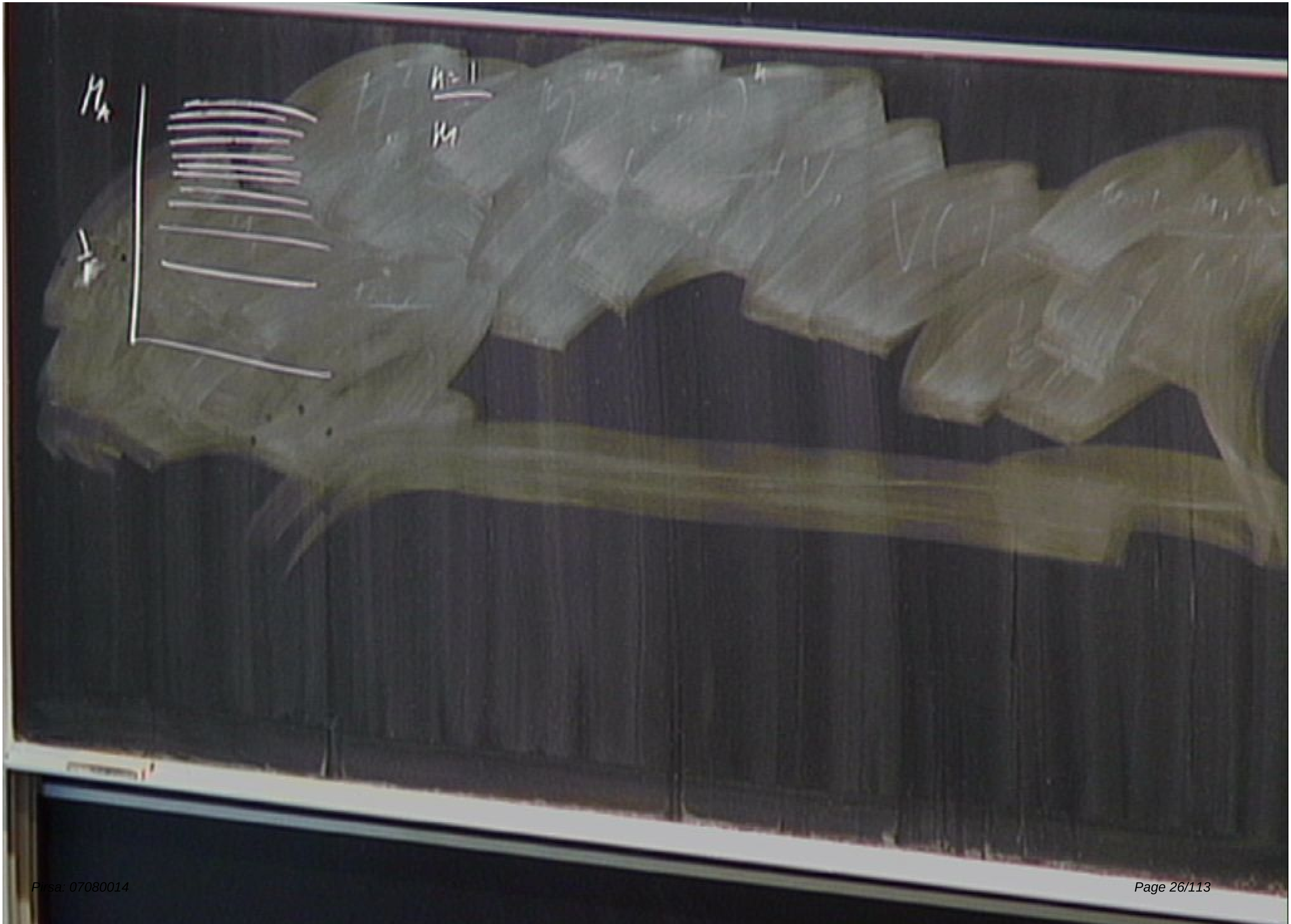
$$h_{MN}(x;y) = \sum_{n_1=-\infty}^{\infty}\cdots\sum_{n_n=-\infty}^{\infty} \frac{h^{(m)}_{MN}(x)}{\sqrt{V_n}}\, e^{i\frac{m\cdot y}{r}}$$

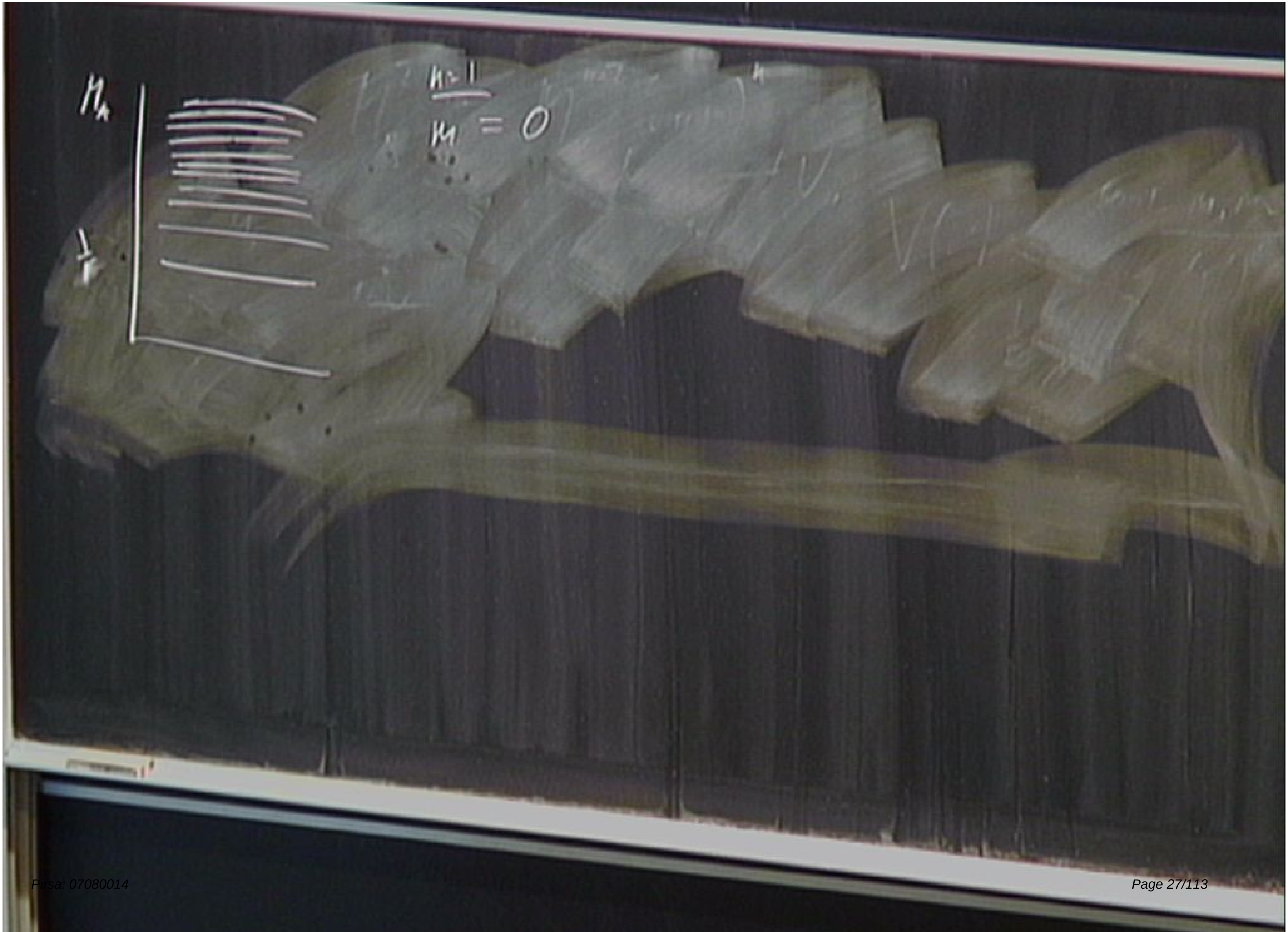
KALUZA-KLEIN

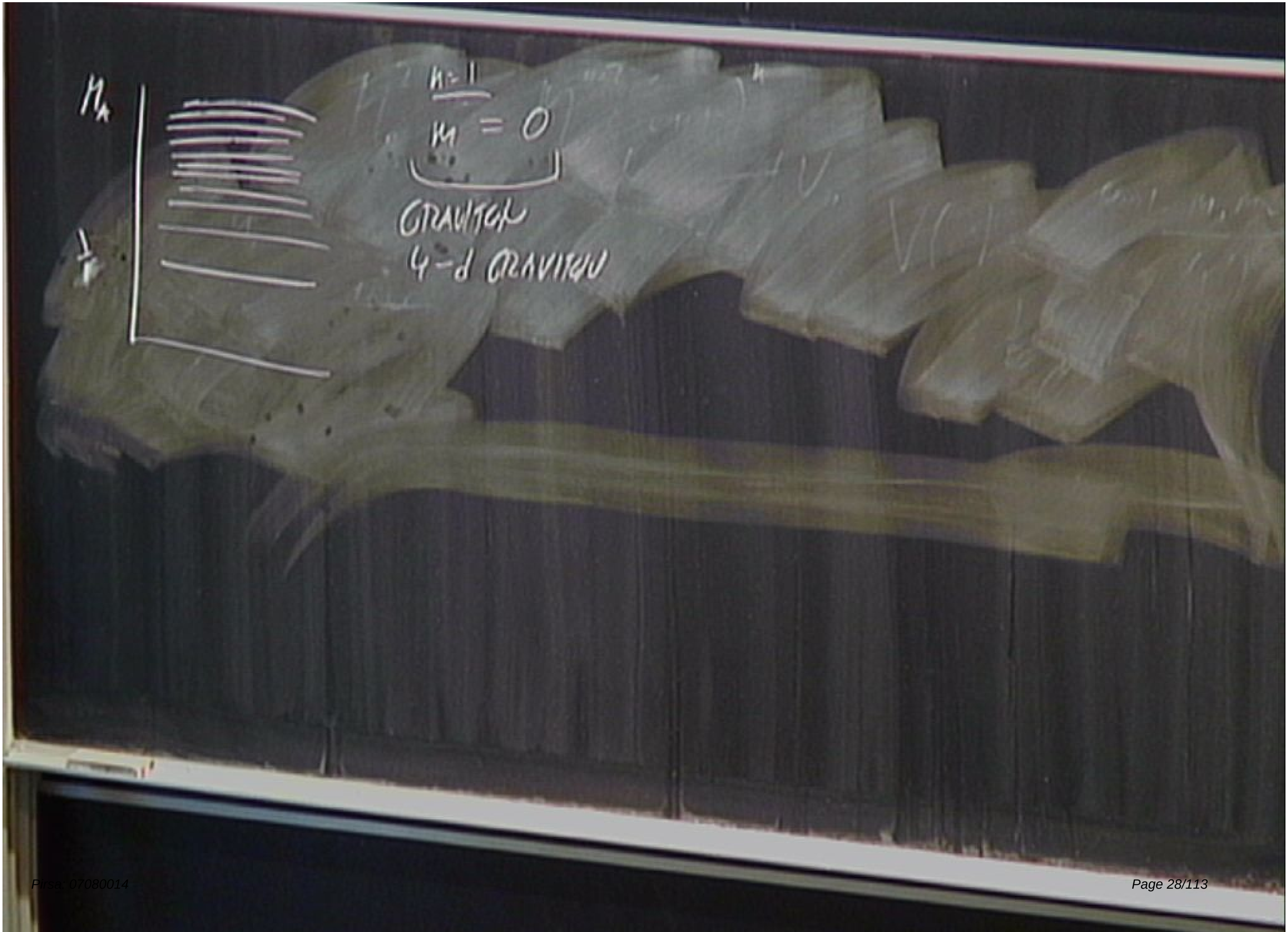
$$h^{(m)}_{MN}(x) \longrightarrow \begin{cases} h^{(m)}_{\mu\nu}(x) \\ h^{(m)}_{\mu 5}(x),\ h^{(m)}_{\mu 6}(x)\ldots \\ h^{(m)}_{ij}(x) \quad i,j = 5,6,\ldots \end{cases}$$

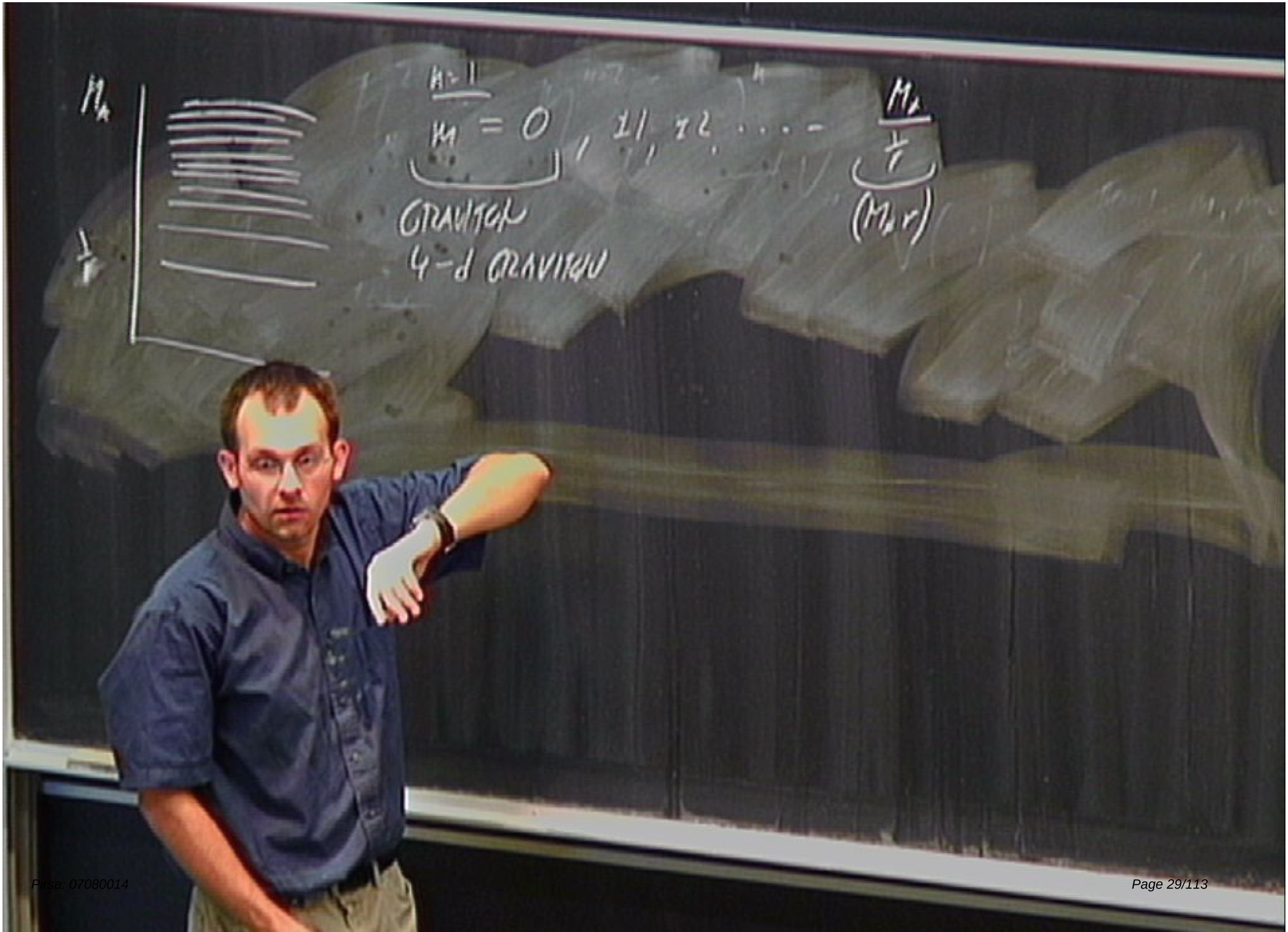


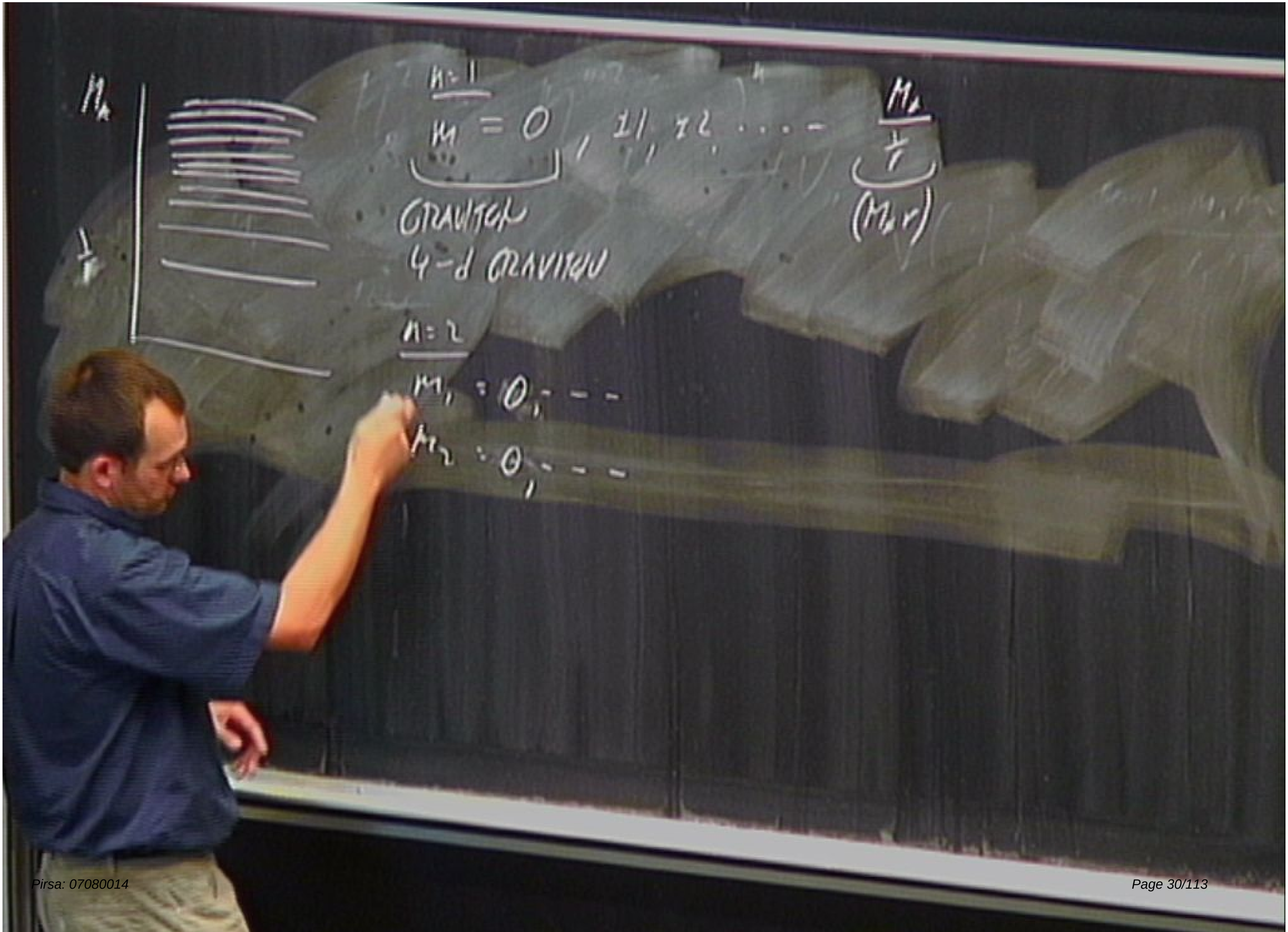


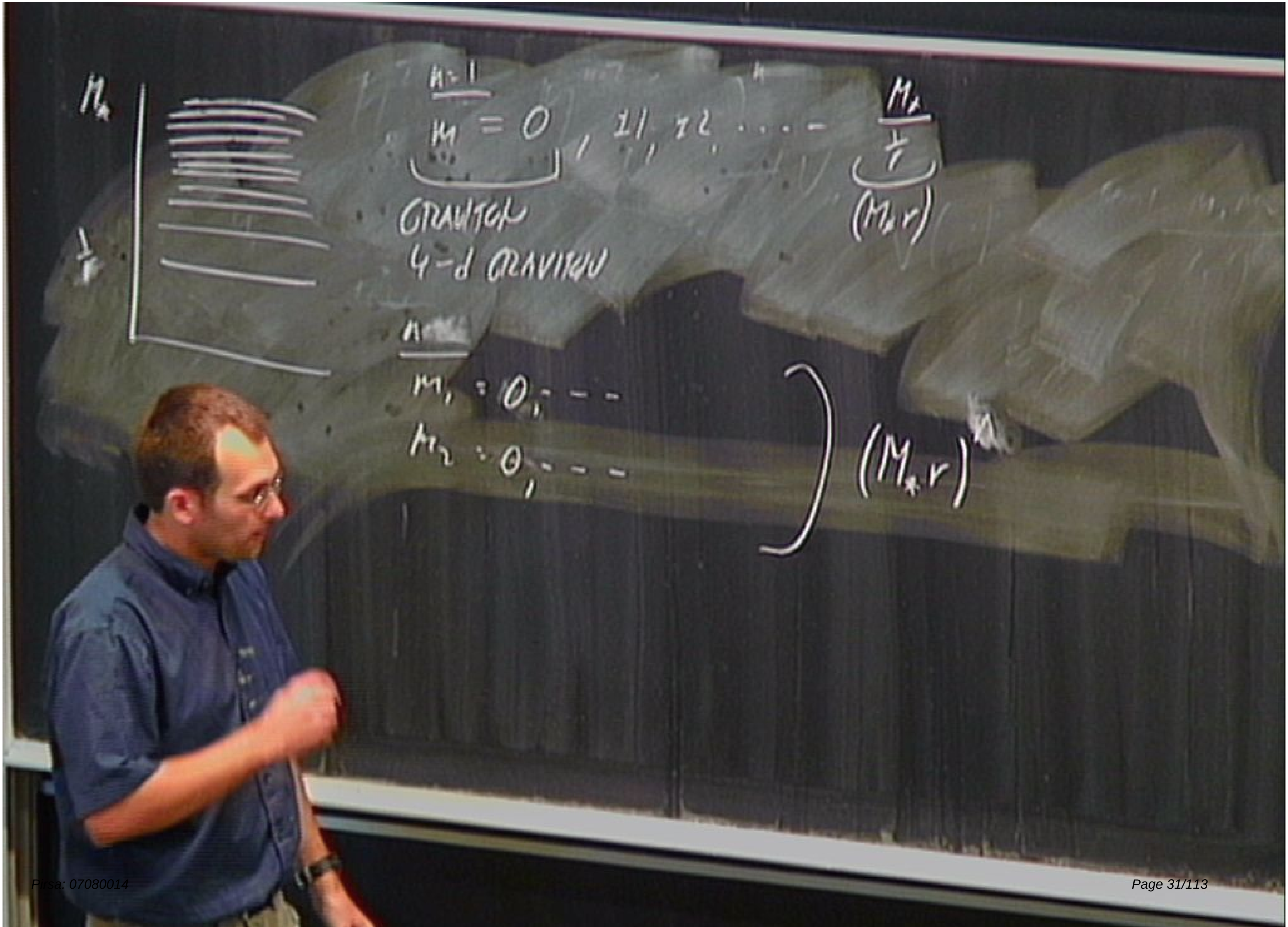

H_n
n=1

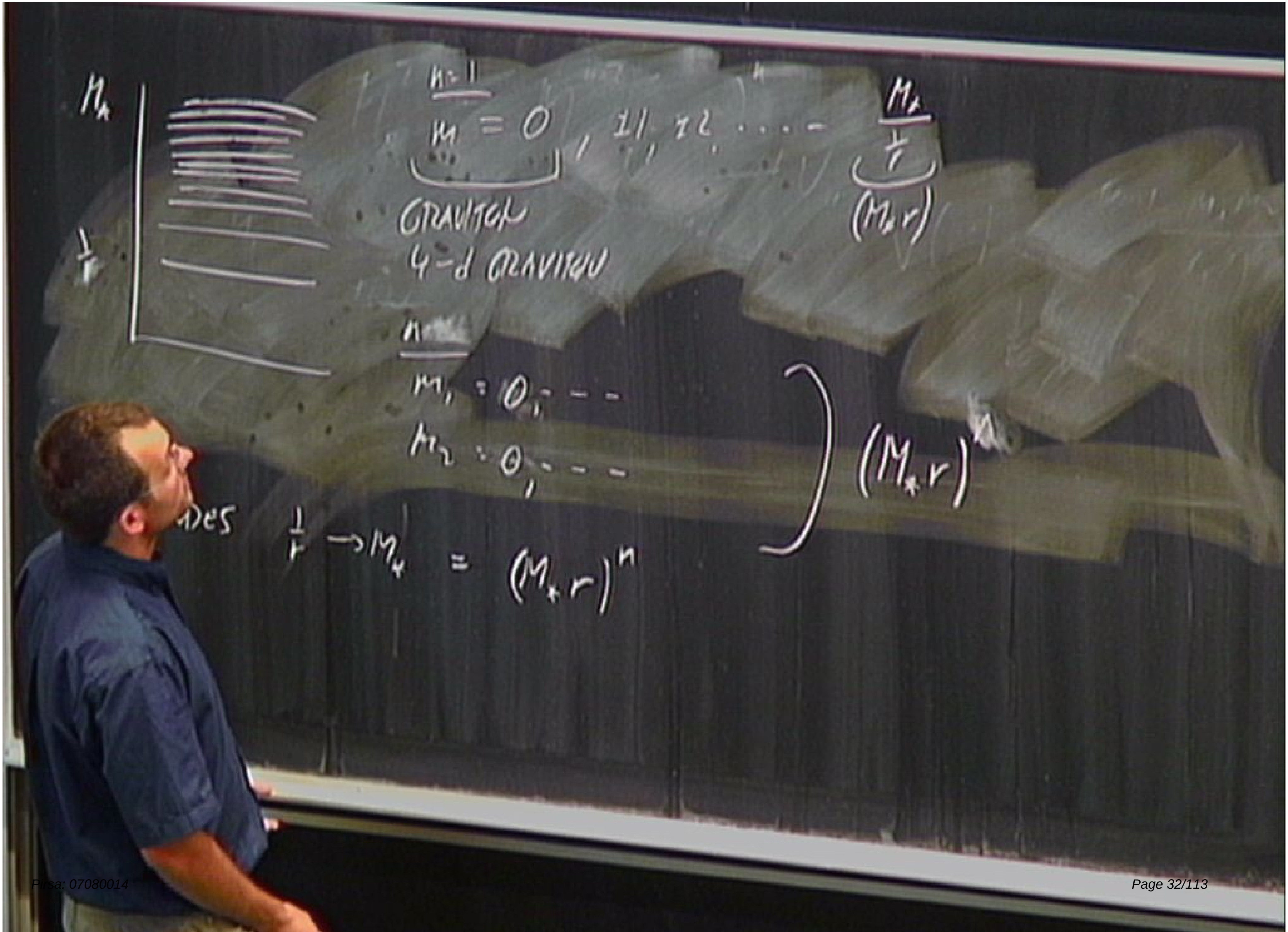

n_k
k=1
m = 0

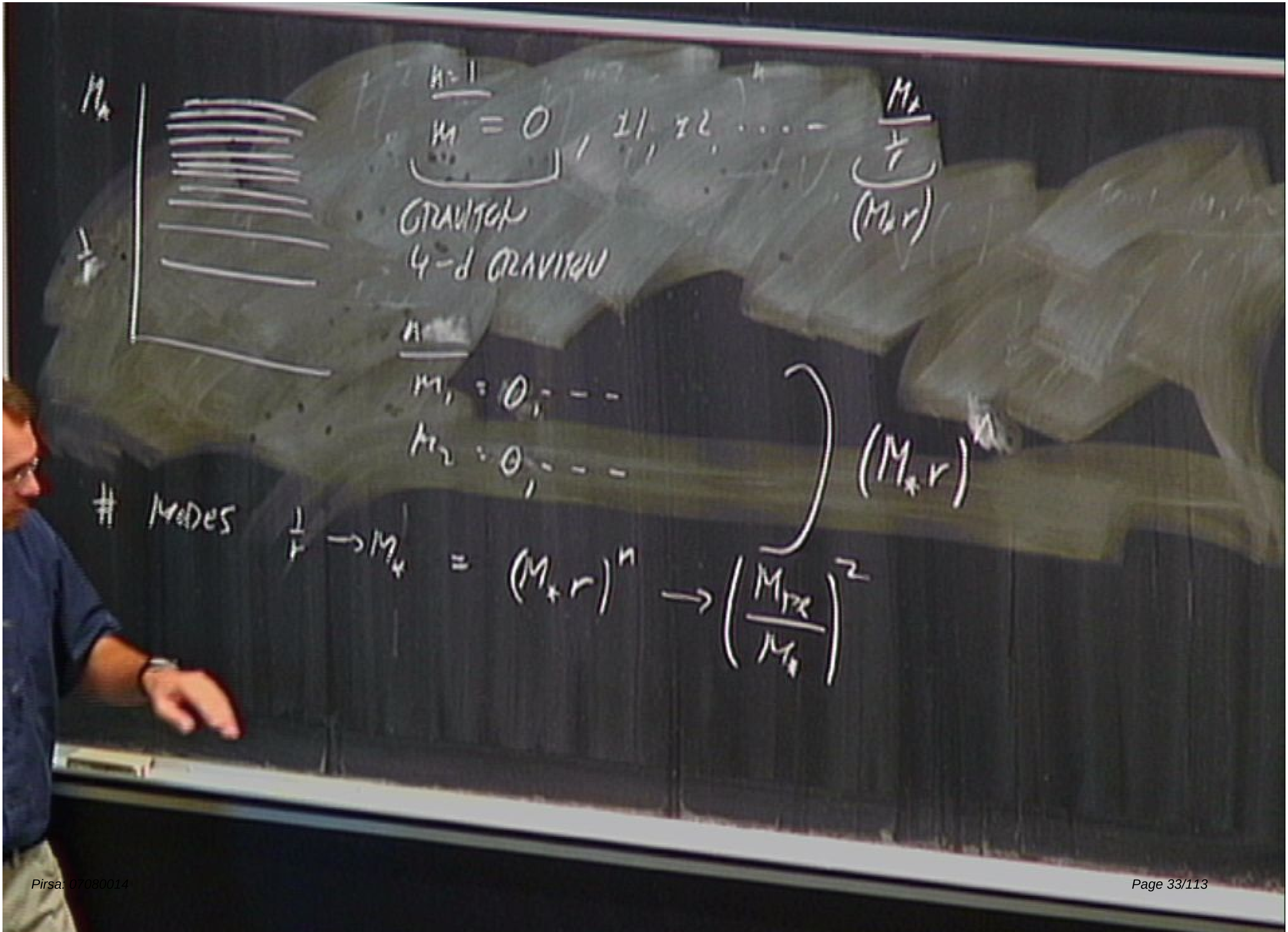

m_n
n=1
m = 0
GRAVITON
4-d GRAVITON


GRAVITON
4-d GRAVITON


n=1
GRAVITON
4-d GRAVITY
n=2


GRAVITON
4-d GRAVITY


M_*
n=1
m = 0, ±1, ±2, ...
$\frac{1}{r}$
GRAVITON
4-d GRAVITY
$(M_* r)$
$m_1 = 0, ---$
$m_2 = 0, ---$
$(M_* r)^n$
$\frac{1}{r} \rightarrow M_* = (M_* r)^n$


n=1
m = 0, ±1, ±2, ... M_*
GRAVITON
4-d GRAVITON
$\frac{1}{r}$
$(M_* r)$
$m_1 = 0, ---$
$m_2 = 0, ---$
$(M_* r)^n$
MODES
$\frac{1}{r} \to M_* = (M_* r)^n \to \left(\frac{M_{PL}}{M_*}\right)^2$

$n=2$

$\nu \quad | \quad 1 \quad mm$

$\hookrightarrow \frac{1}{r} = 0{,}003 \ eV$

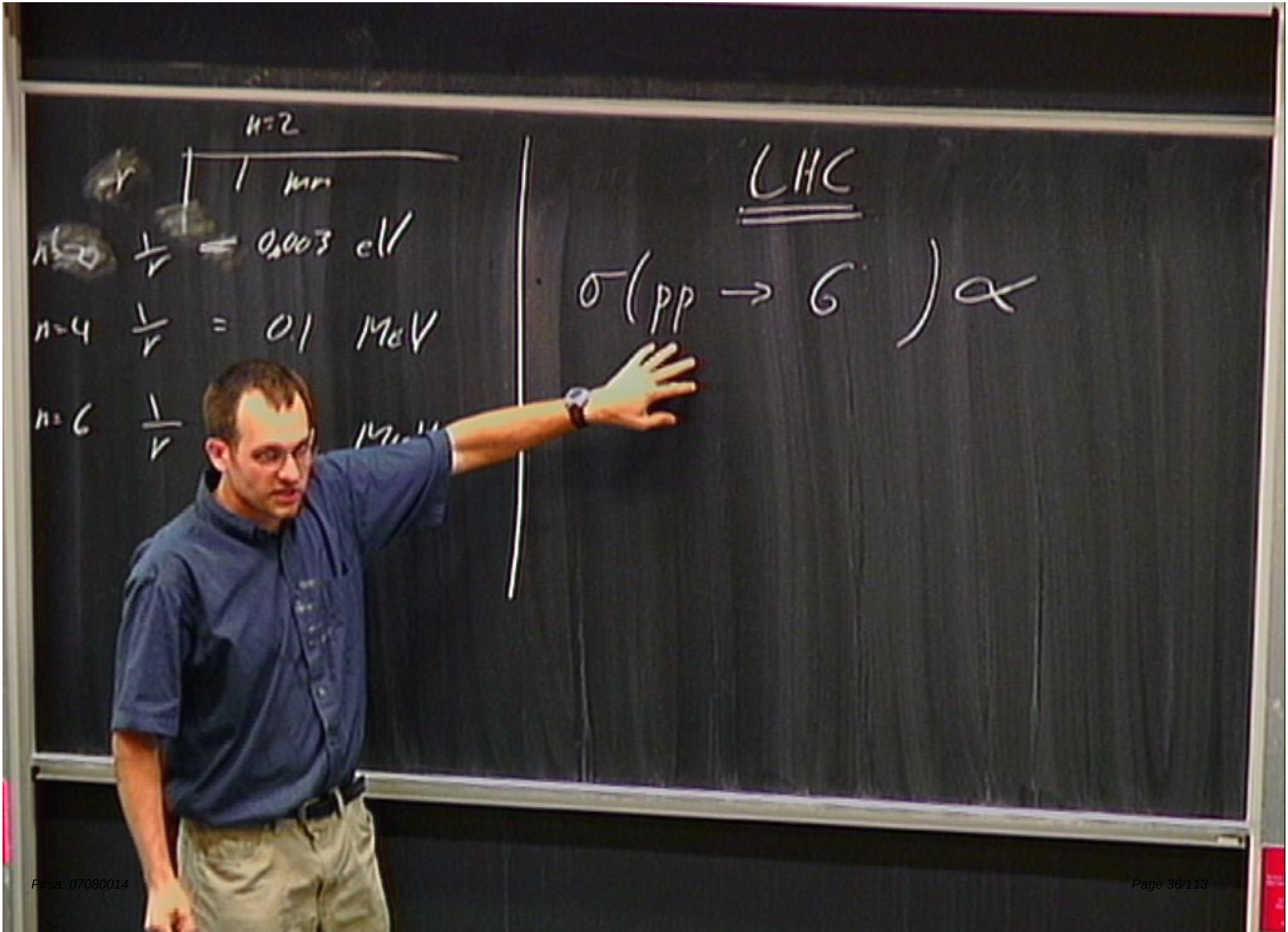
$n=2$

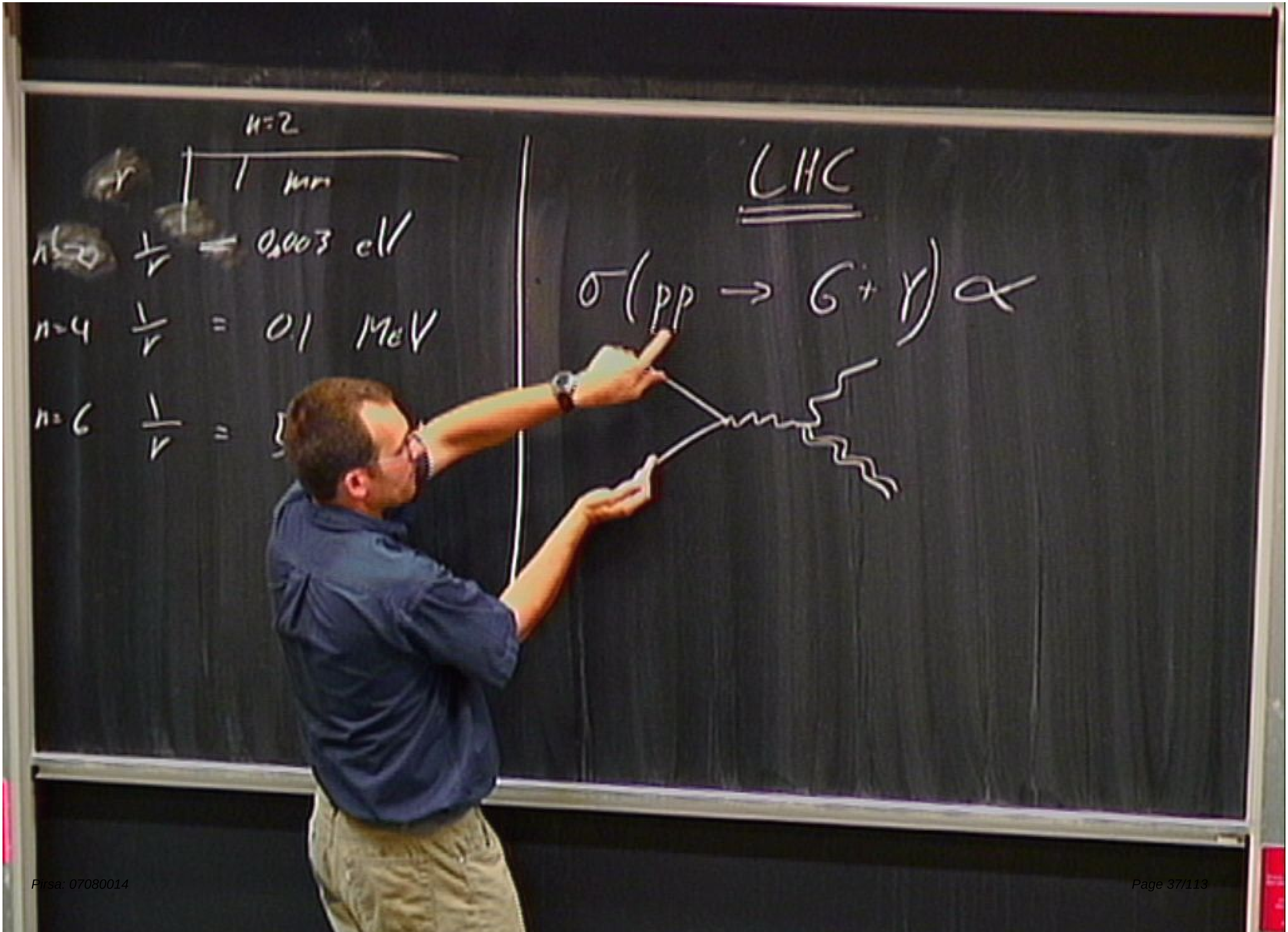
r | 1 mm

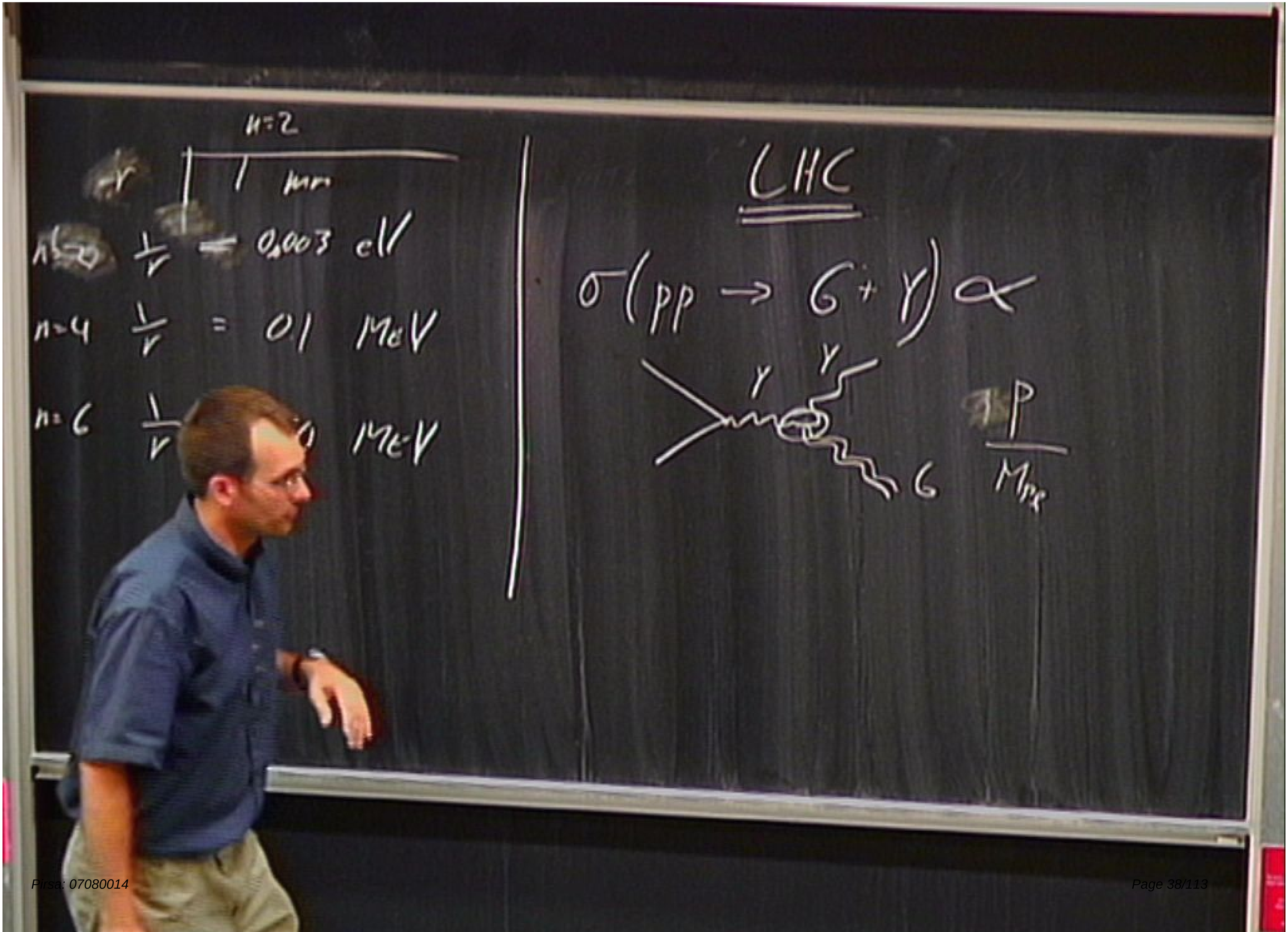
$n=2$ $\frac{1}{r} = 0.003$ eV

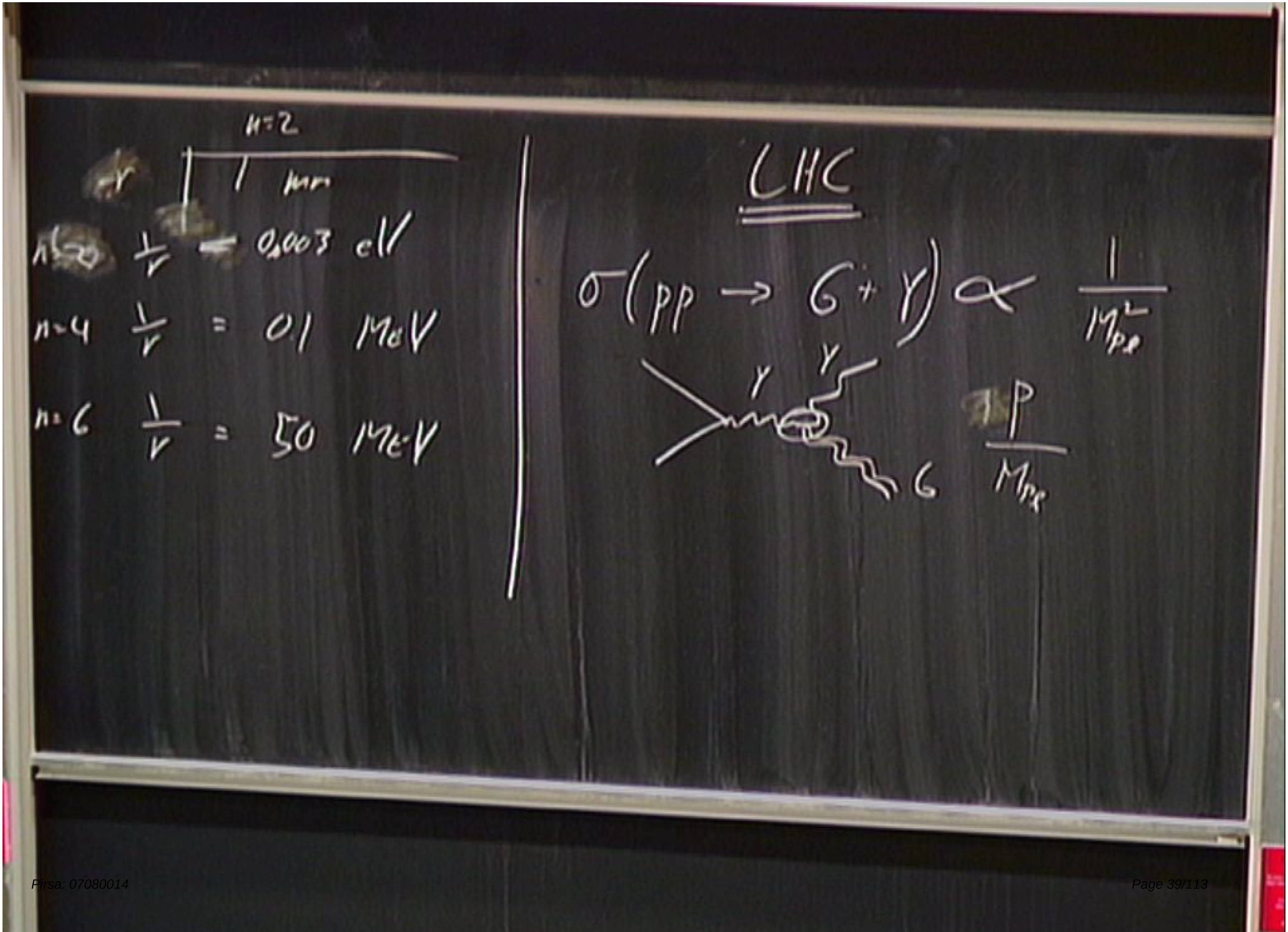
$n=4$ $\frac{1}{r} = 0.1$ MeV

$n=6$ $\frac{1}{r} = 50$ MeV


n=2
1 mm
0,003 eV
n=4 1/r = 0.1 MeV
n=6 1/r
MeV
LHC
σ(pp → G) ∝


n=2
1 mm
0.003 eV
n=4 1/r = 0.1 MeV
n=6 1/r =
LHC
σ(pp → G + γ) ∝


n=2
1 mm
1/r = 0,003 eV
n=4 1/r = 01 MeV
n=6 1/r MeV
LHC
σ(pp → G + γ) ∝
γ
γ
G


n=2
1 mm
n=2 1/r = 0,003 eV
n=4 1/r = 0.1 MeV
n=6 1/r = 50 MeV
LHC
σ(pp → G + γ) ∝ 1/M_pl^2
γ
γ
G
P/M_pl

$n=2$

$r \quad 1 \text{ mm}$

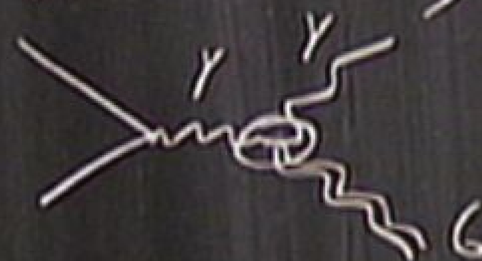
$n=2 \quad \frac{1}{r} = 0.003 \text{ eV}$

$n=4 \quad \frac{1}{r} = 0.1 \text{ MeV}$

$n=6 \quad \frac{1}{r} = 50 \text{ MeV}$

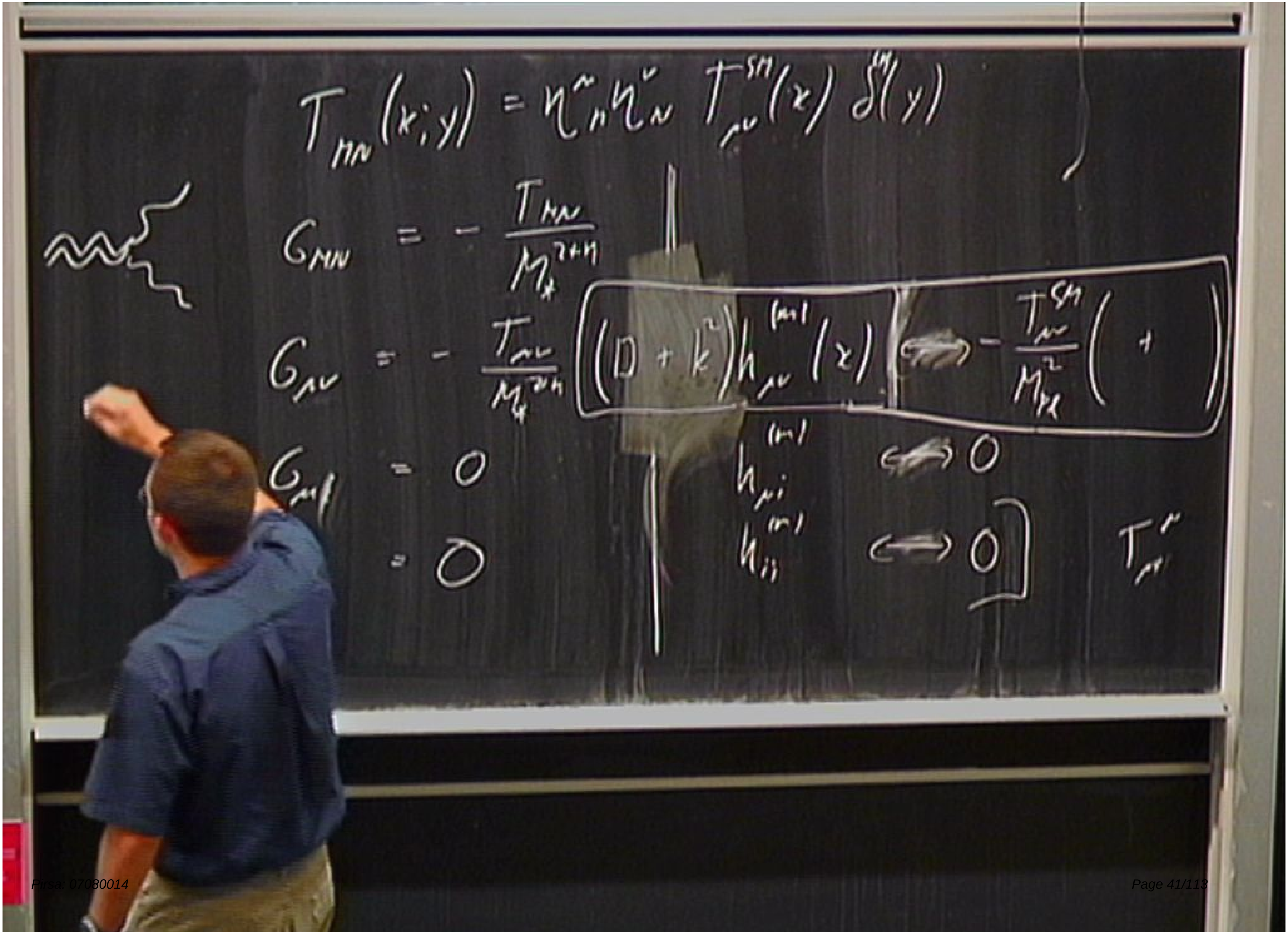
LHC

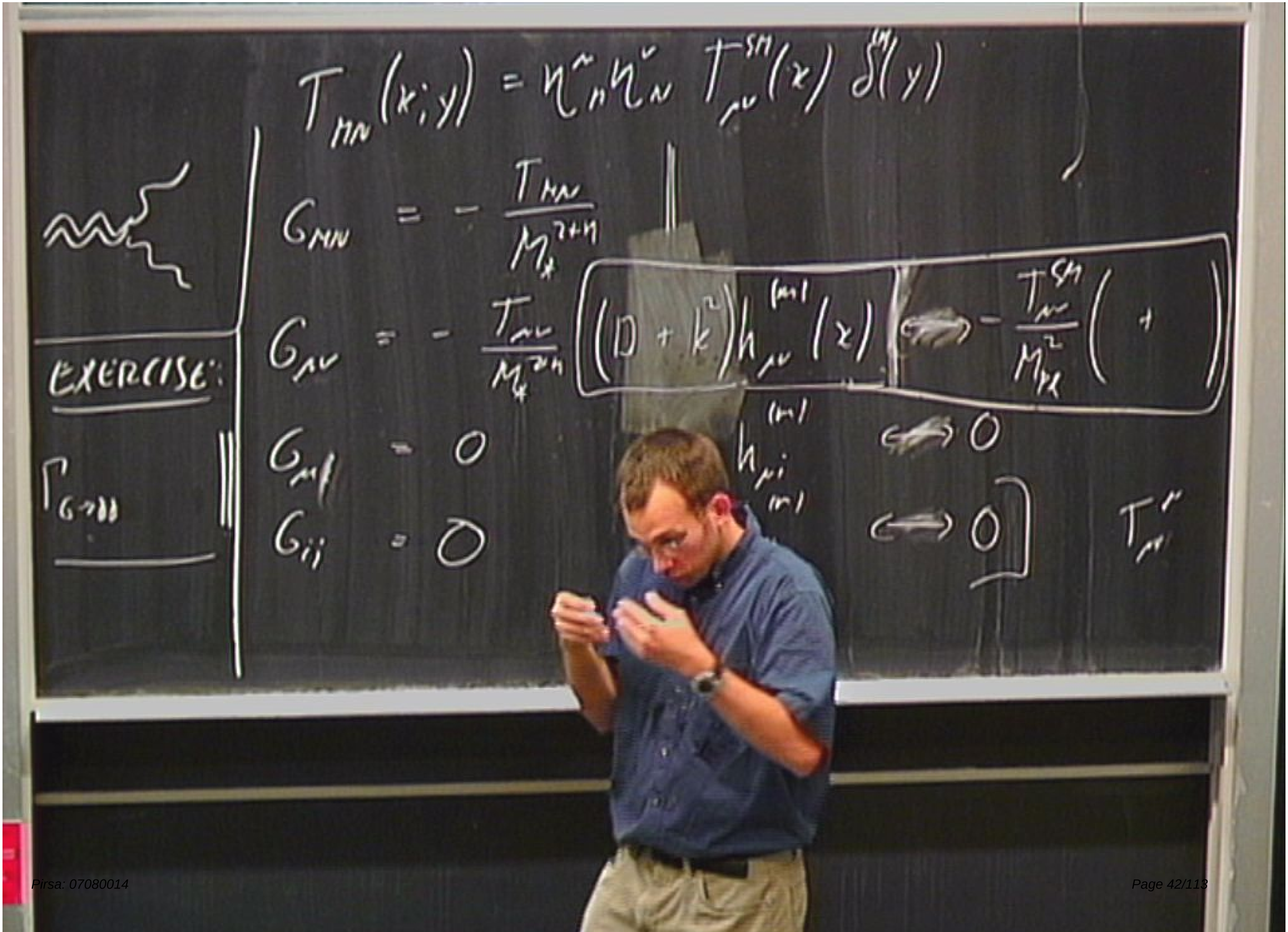
$$\sigma_i(pp \to G_i + \gamma) \propto \frac{1}{M_{pl}^2}$$



$$\frac{p}{M_{pl}}$$

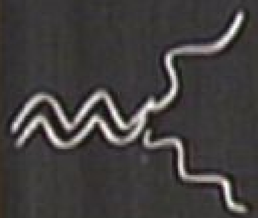
$$\sum_i \sigma_i \longrightarrow \frac{1}{M_{pl}^2} \times \left(\frac{M_{pl}}{M_*}\right)^2 \to \frac{1}{M_*^2}$$


$T_{MN}(x;y) = \eta^{\mu}_{M}\eta^{\nu}_{N}\, T^{SM}_{\mu\nu}(x)\, \delta^{(n)}(y)$
$G_{MN} = -\frac{T_{MN}}{M_*^{2+n}}$
$G_{\mu\nu} = -\frac{T_{\mu\nu}}{M_*^{2+n}}$
$(\Box + k^2) h^{(m)}_{\mu\nu}(x) \Longleftrightarrow -\frac{T^{SM}_{\mu\nu}}{M_{Pl}^2}(\; + \;)$
$G_{\mu i} = 0$
$h^{(m)}_{\mu i} \Longleftrightarrow 0$
$= 0$
$h^{(m)}_{ij} \Longleftrightarrow 0$
T^{μ}_{μ}



$T_{MN}(x;y) = \eta^\mu{}_M \eta^\nu{}_N T^{SM}_{\mu\nu}(x)\,\delta^{(n)}(y)$
$G_{MN} = -\frac{T_{MN}}{M_*^{2+n}}$
$G_{\mu\nu} = -\frac{T_{\mu\nu}}{M_*^{2+n}}$
$((\Box + k^2) h^{(m)}_{\mu\nu}(x) \Longleftrightarrow -\frac{T^{SM}_{\mu\nu}}{M_{Pl}^2}(\quad + \quad))$
$G_{\mu i} = 0$
$h^{(m)}_{\mu i} \Longleftrightarrow 0$
$G_{ij} = 0$
$h^{(m)} \Longleftrightarrow 0$
$T_\mu{}^\mu$
EXERCISE:
$\Gamma_{G\to\gamma\gamma}$

$$T_{MN}(x;y) = \eta^{\mu}_{M}\eta^{\nu}_{N}\, T^{SM}_{\mu\nu}(x)\, \delta^{(n)}(y)$$



EXERCISE:

$\Gamma_{G\to\gamma\gamma}$

$$G_{MN} = -\frac{T_{MN}}{M_*^{2+n}}$$

$$G_{\mu\nu} = -\frac{T_{\mu\nu}}{M_*^{2+n}} \qquad \boxed{(\Box + k^2)\, h^{(m)}_{\mu\nu}(x) \Longleftrightarrow -\frac{T^{SM}_{\mu\nu}}{M_{Pl}^2}\left(\quad + \quad \right)}$$

$$G_{\mu j} = 0 \qquad h^{(m)}_{\mu i} \Longleftrightarrow 0$$

$$G_{ij} = 0 \qquad h^{(m)}_{ij} \Longleftrightarrow 0 \qquad T^{\mu}_{\mu}$$

$n=2$

r | $1\ \mathrm{mm}$

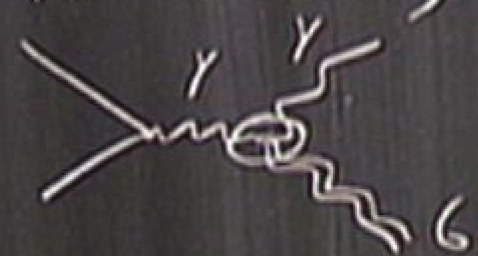
$n=2 \quad \frac{1}{r} = 0.003\ \mathrm{eV}$

$n=4 \quad \frac{1}{r} = 0.1\ \mathrm{MeV}$

$n=6 \quad \frac{1}{r} = 50\ \mathrm{MeV}$

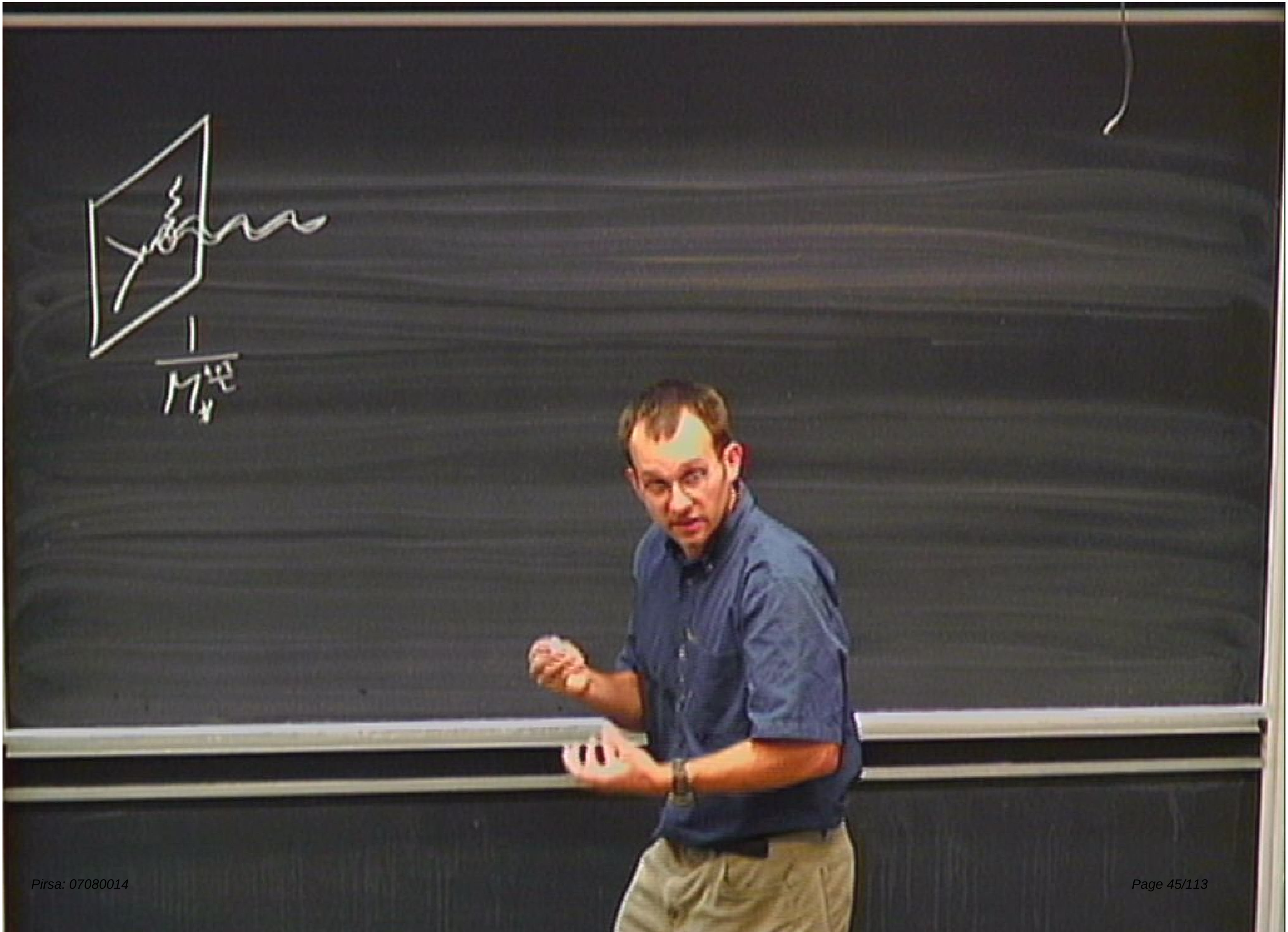
LHC

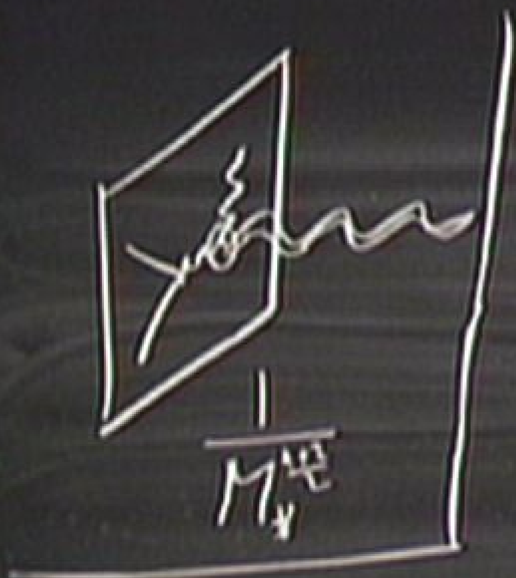
$$\sigma_i(pp \to G_i + \gamma) \propto \frac{1}{M_{pl}^2}$$



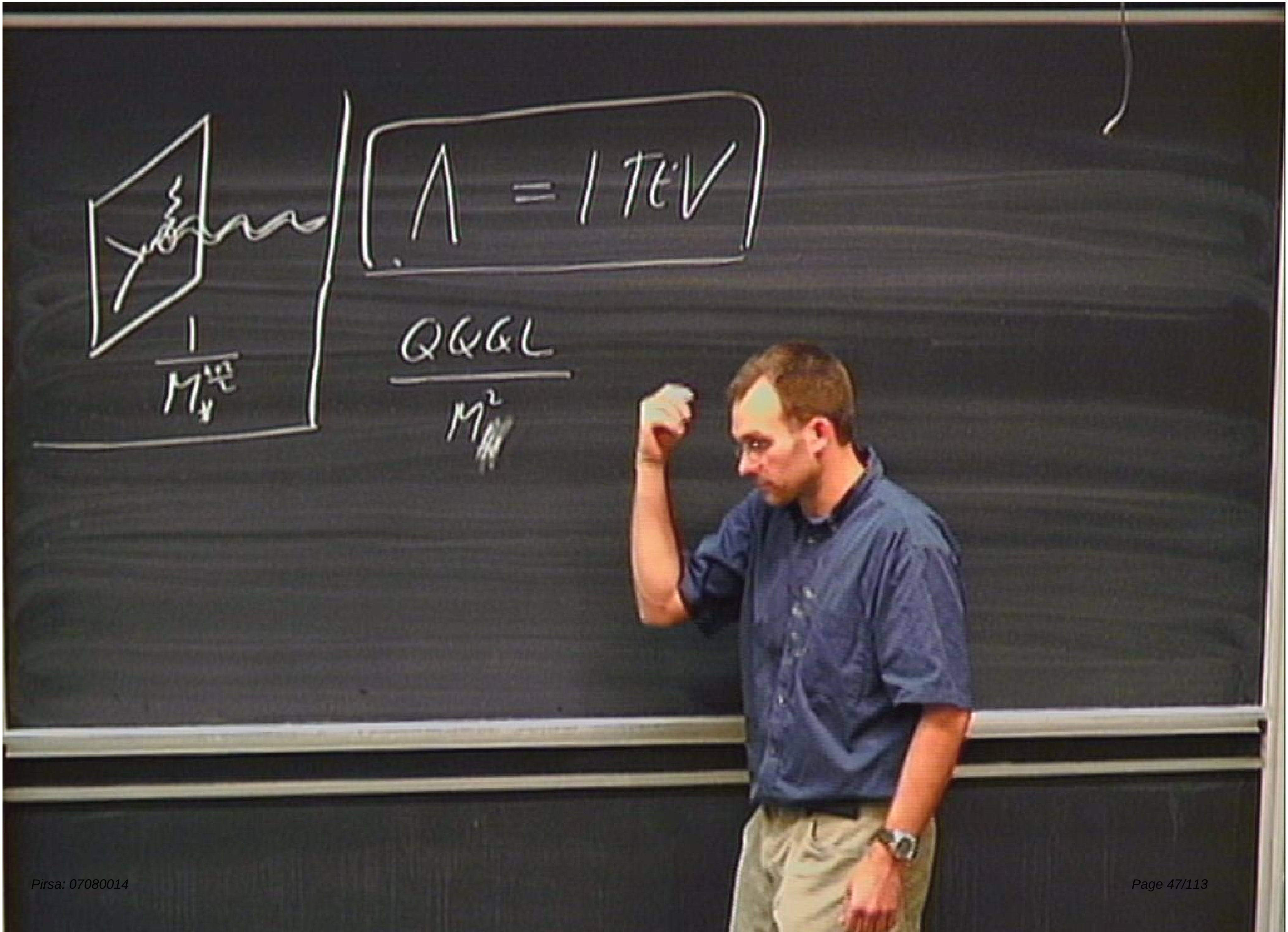
$$\frac{P}{M_{pl}}$$

$$\sum_i \sigma_i \longrightarrow \frac{1}{M_{pl}^2} \times \left(\frac{M_{pl}}{M_*}\right)^2 \Rightarrow \frac{1}{M_*^2}$$

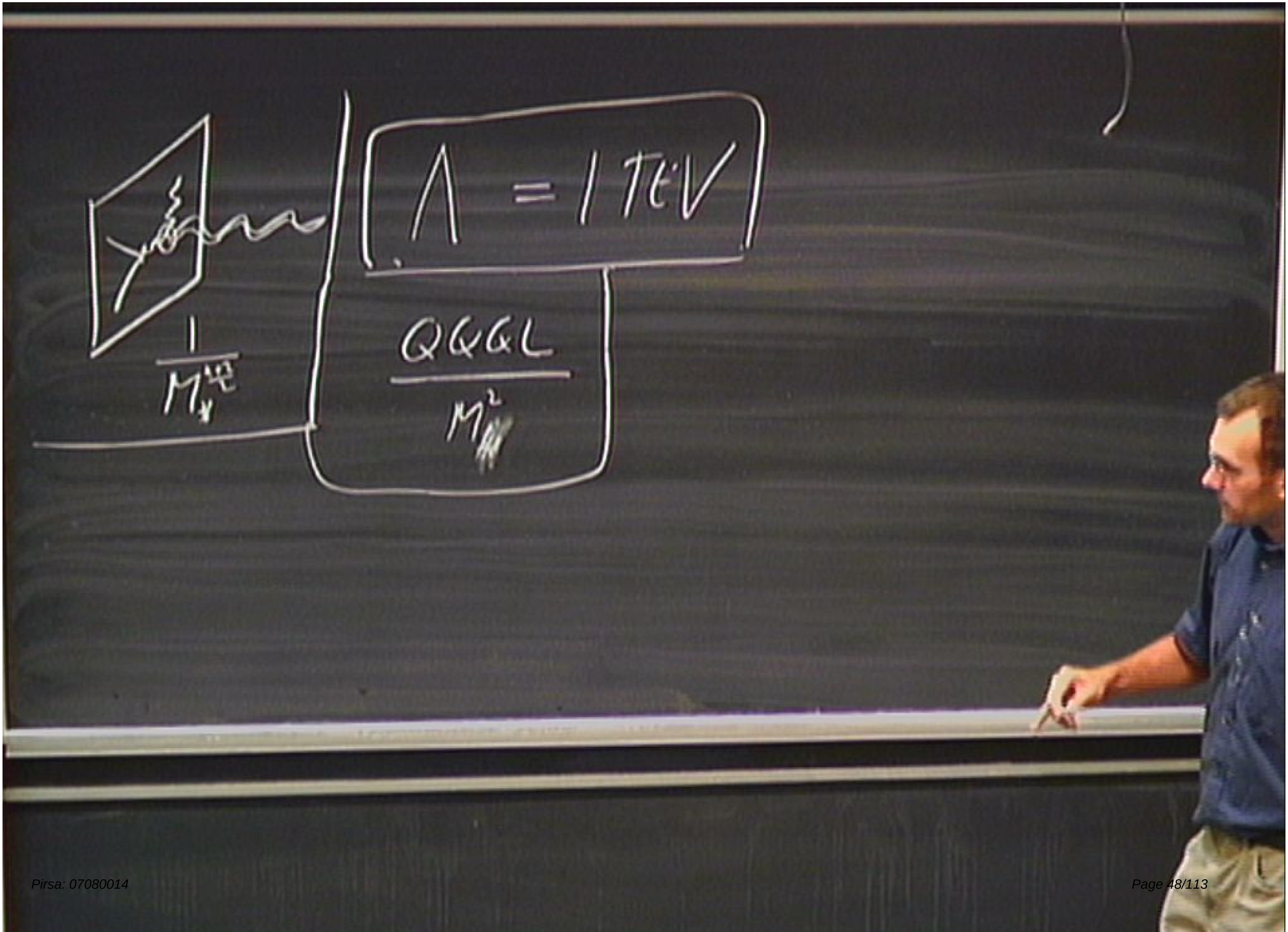


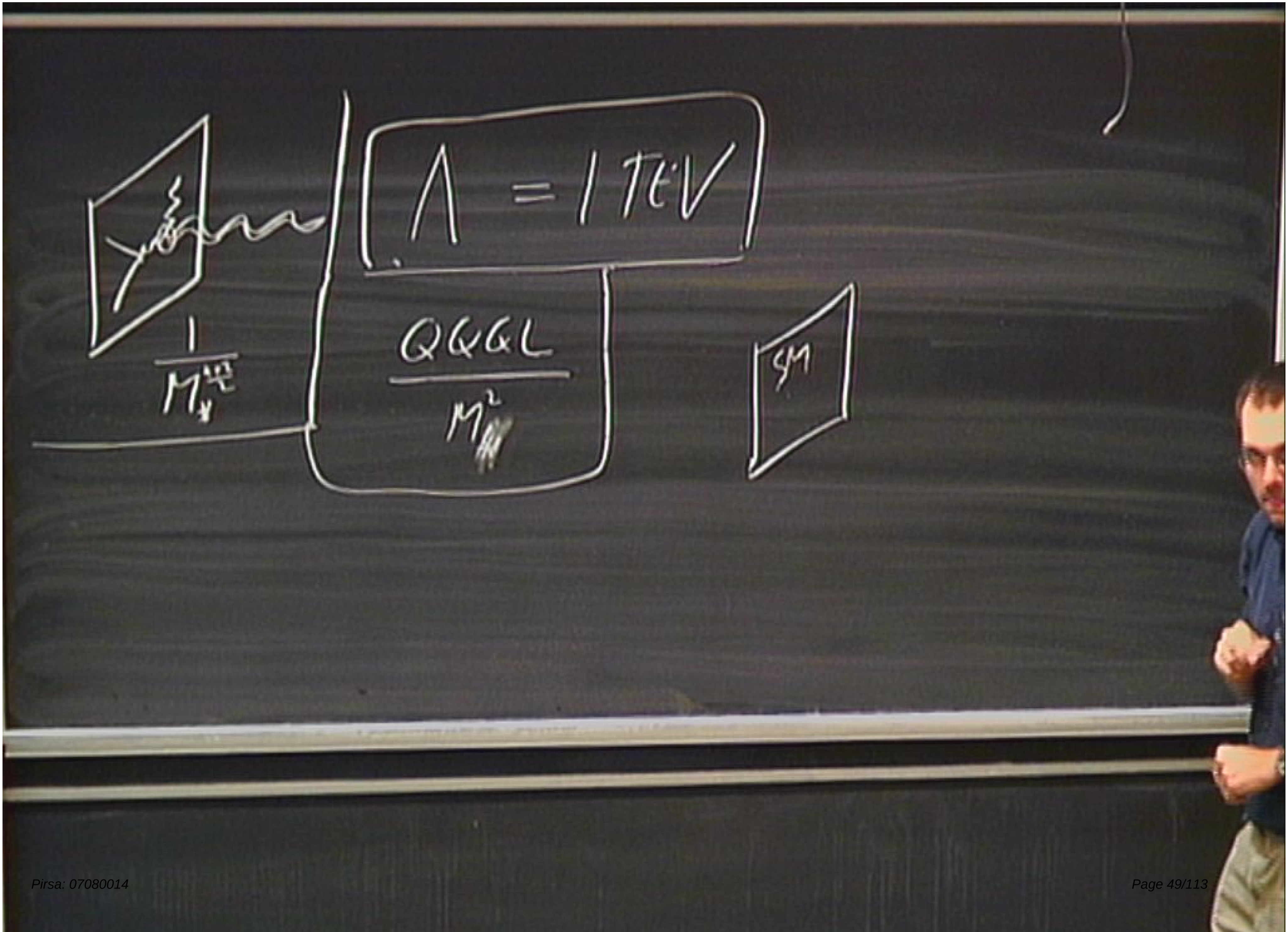


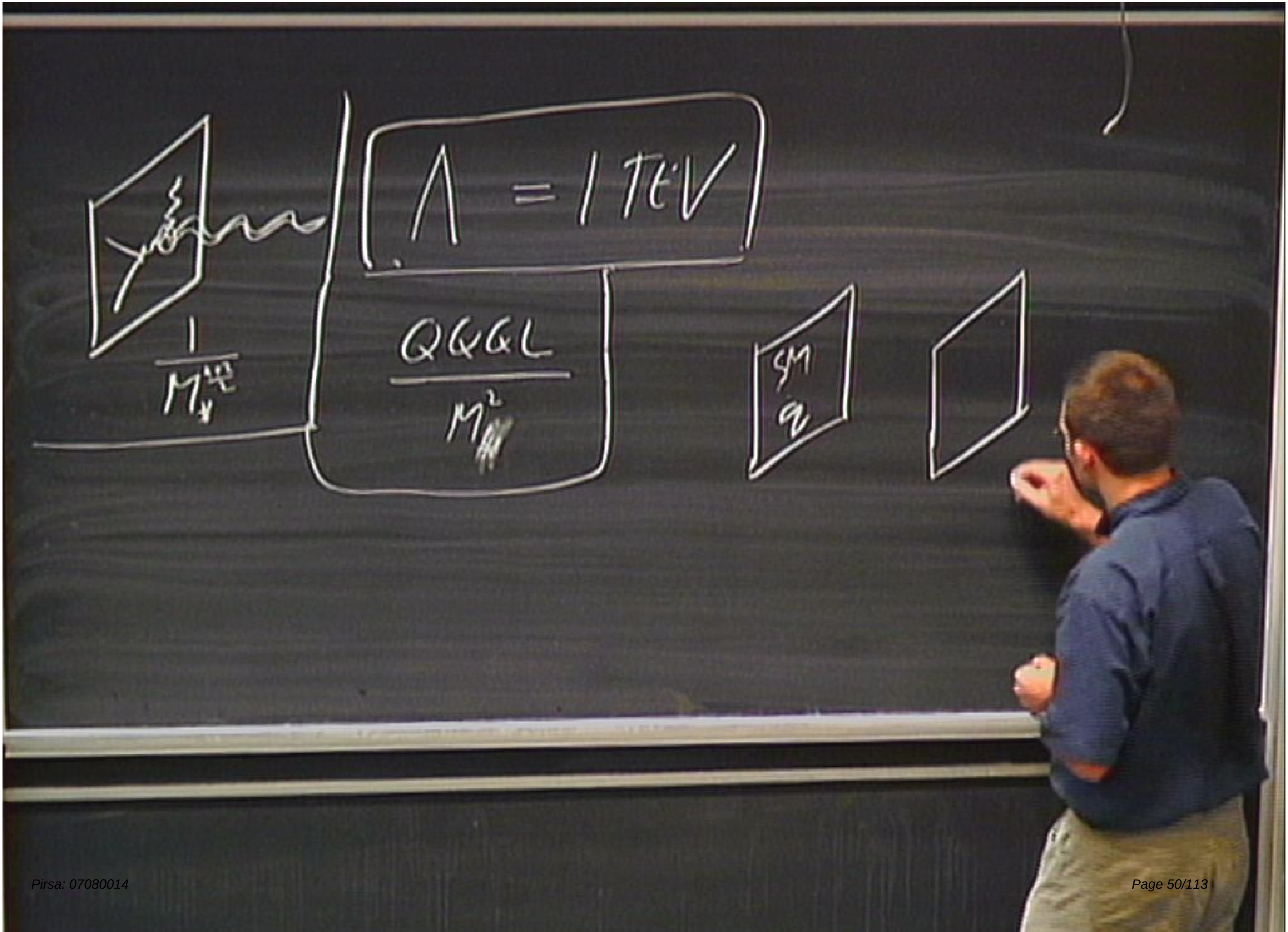
$$\Lambda = 1 \text{ TeV}$$

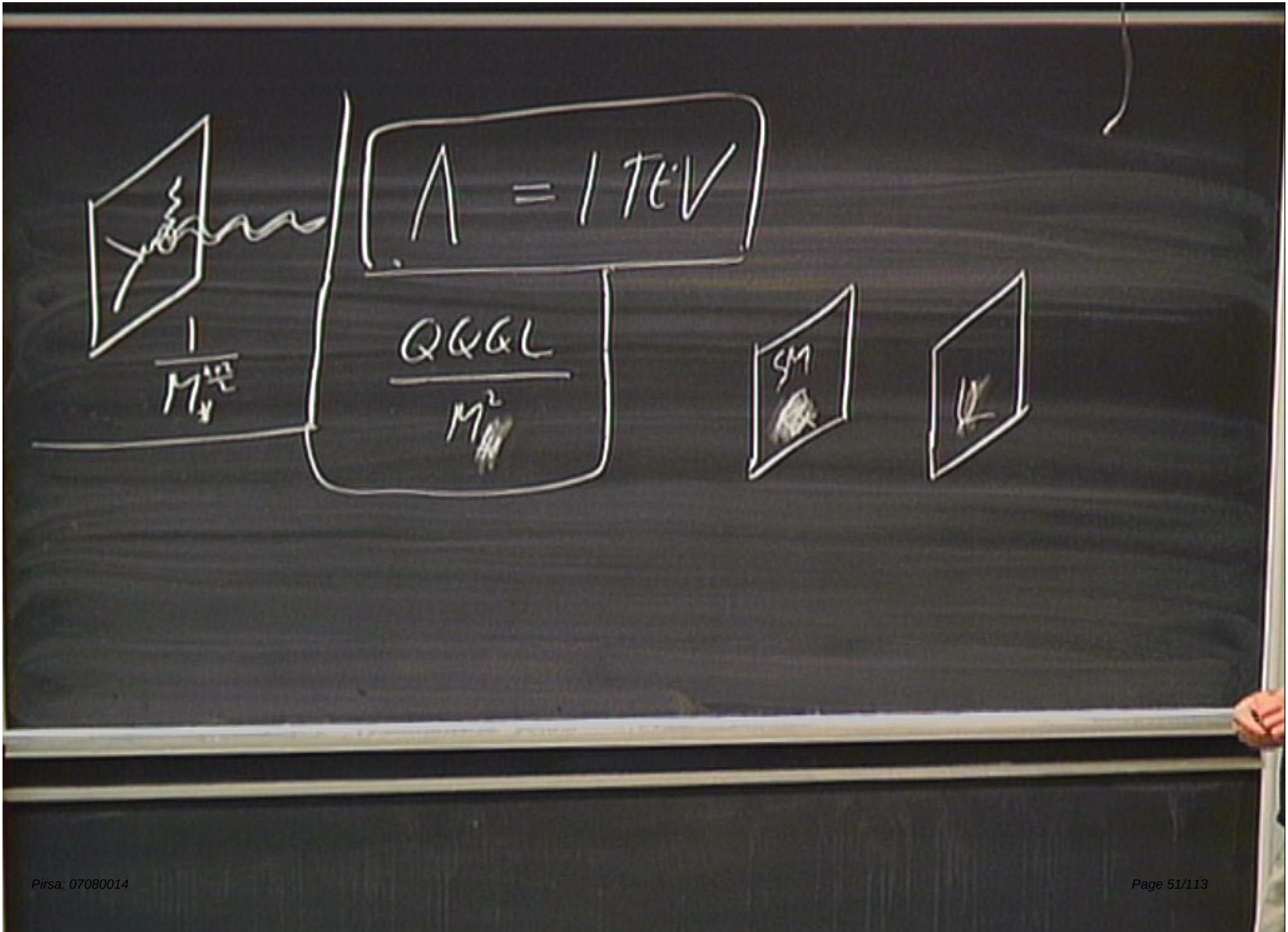


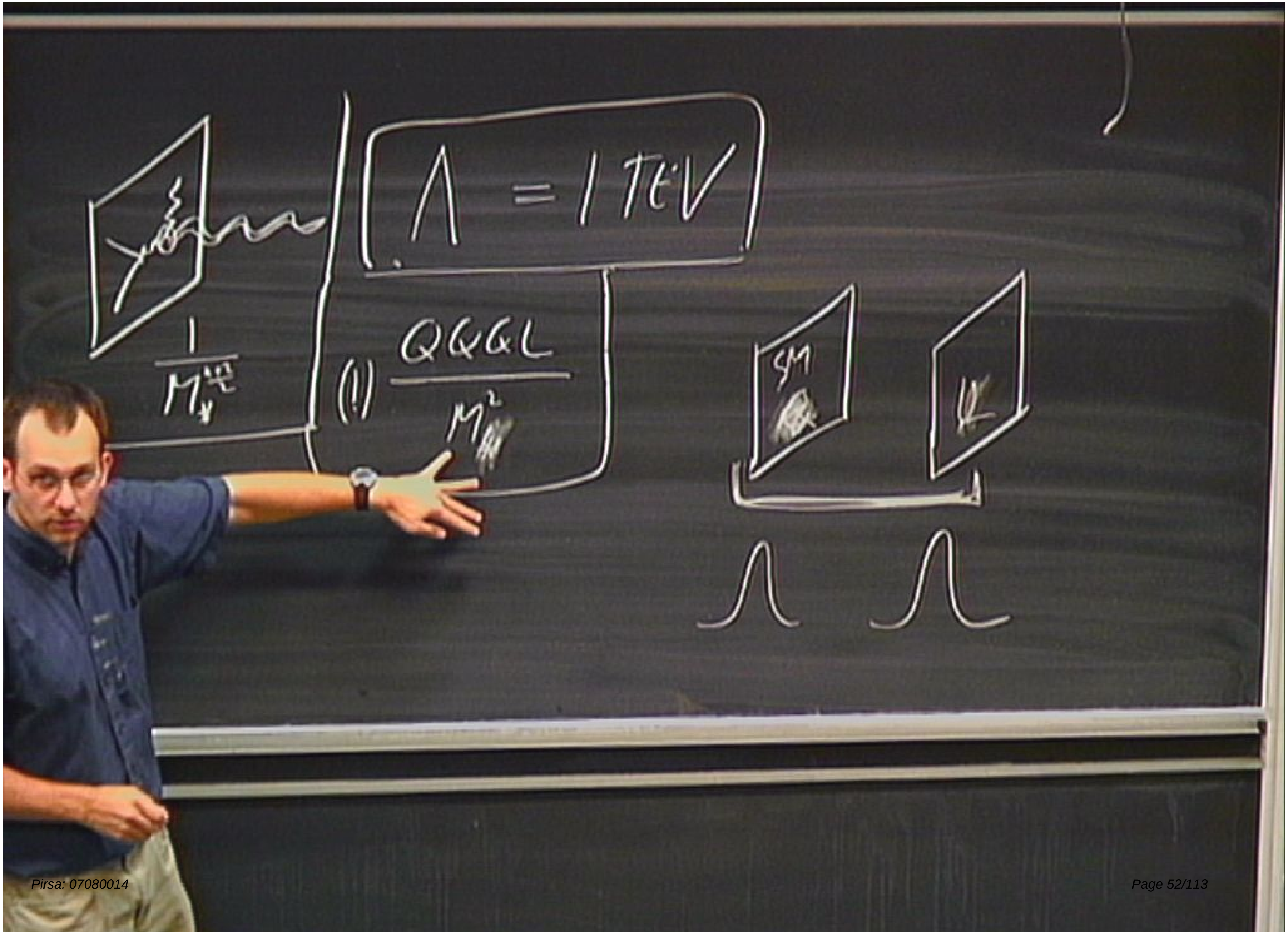
Λ = 1 TeV
QQQL

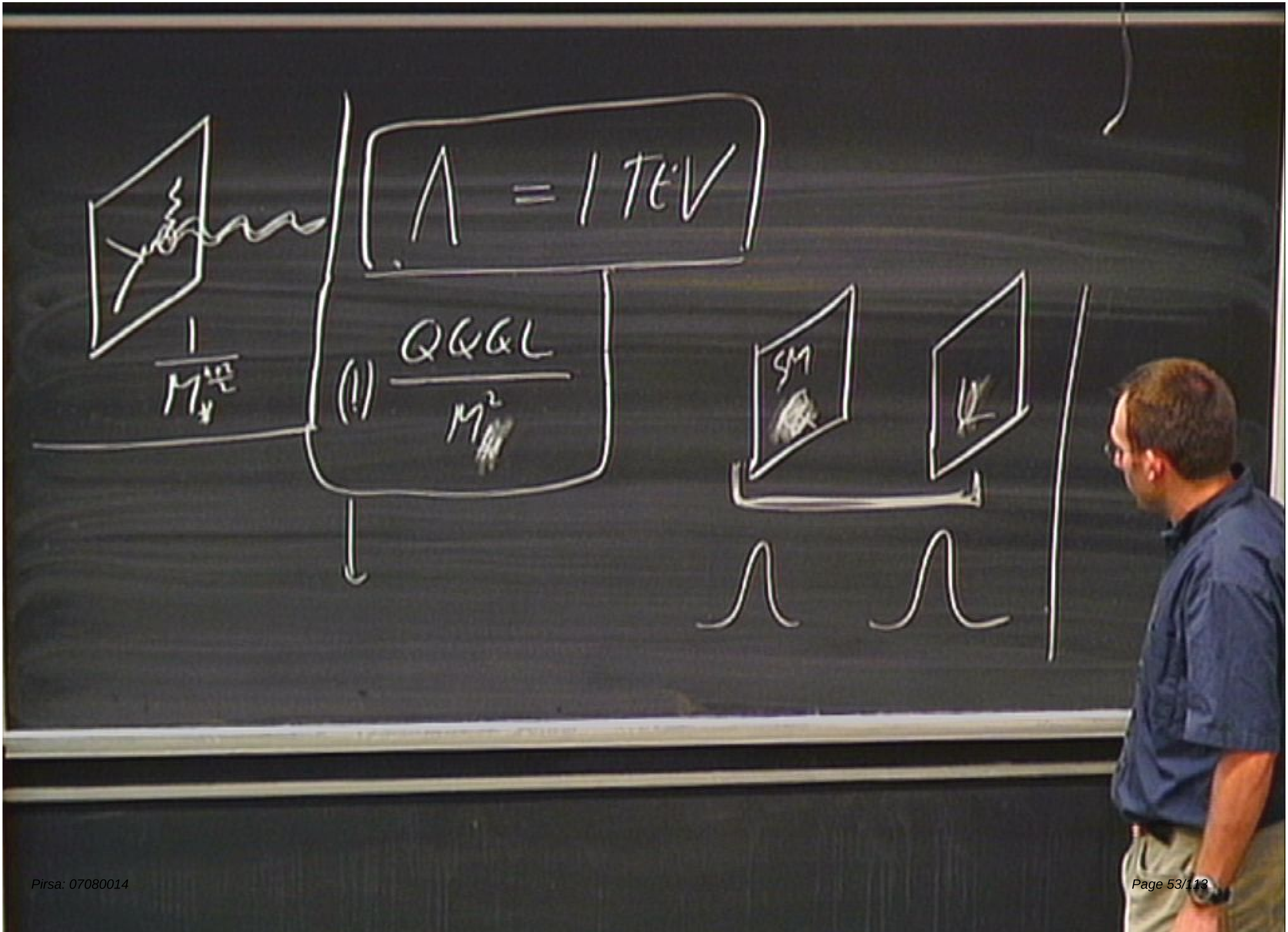

Λ = 1 TeV
QQQL

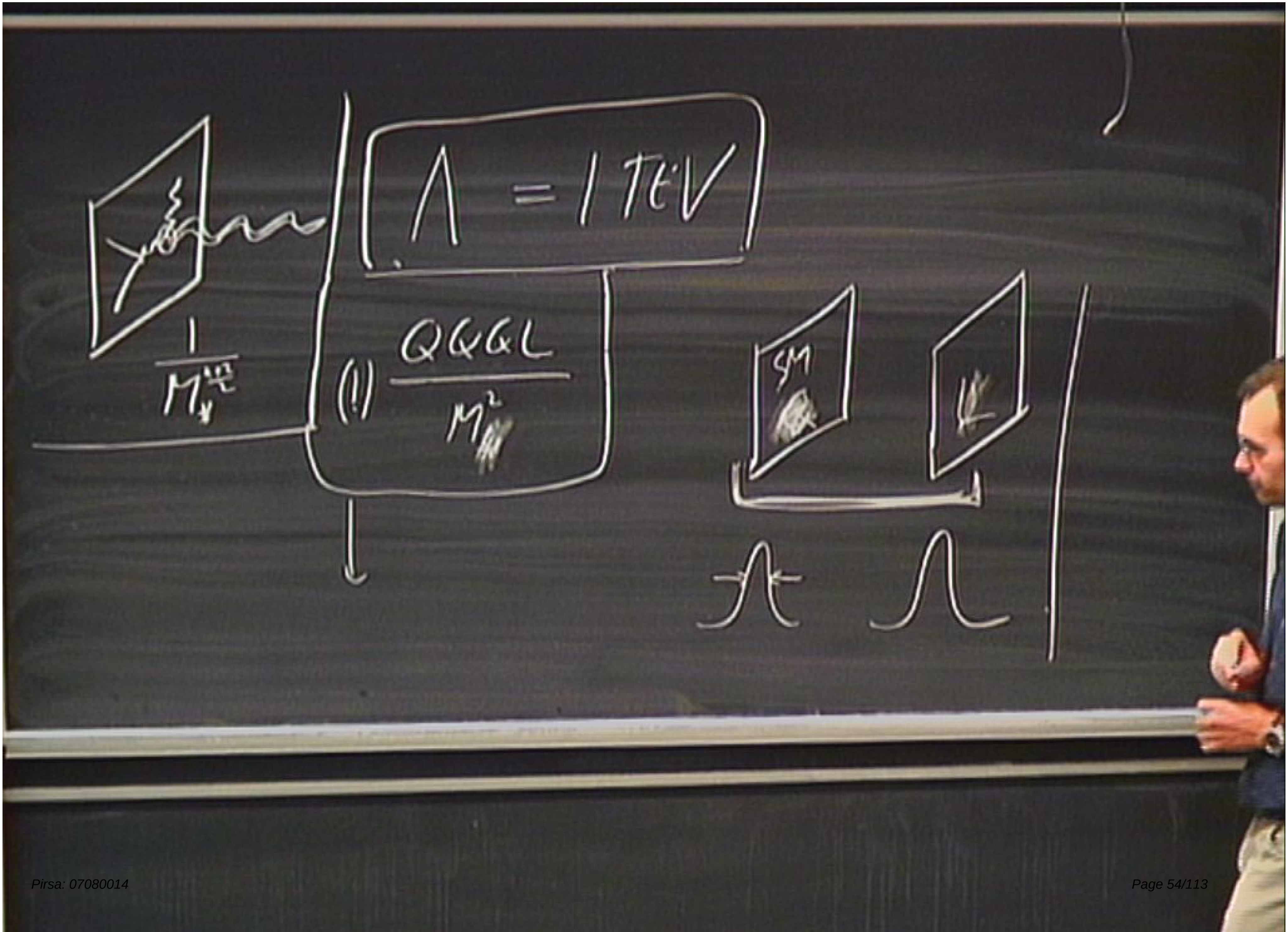

Λ = 1 TeV
QQQL
M²
1
M
SM

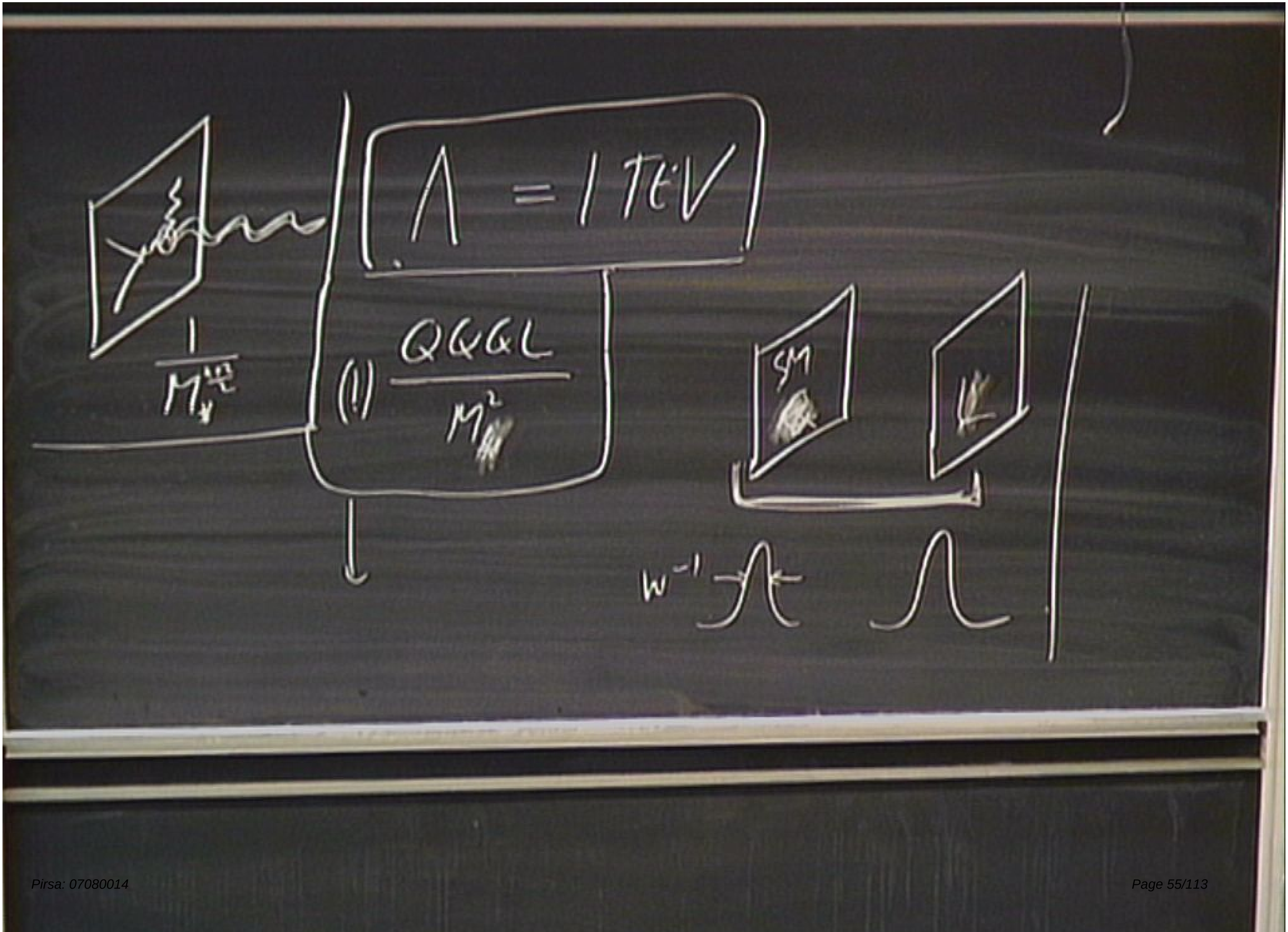

Λ = 1 TeV
QQQL
SM

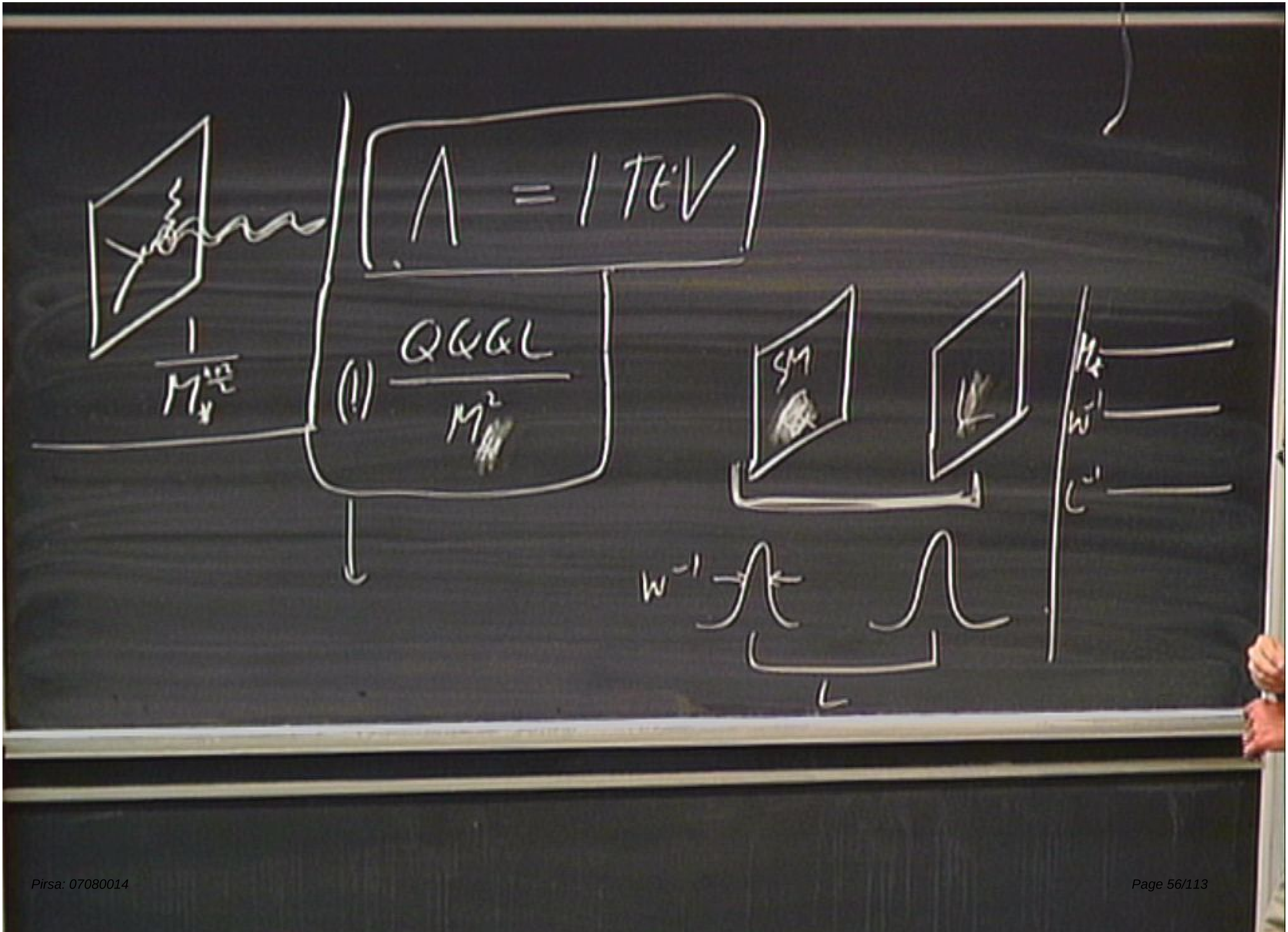

Λ = 1 TeV
QQQL
SM

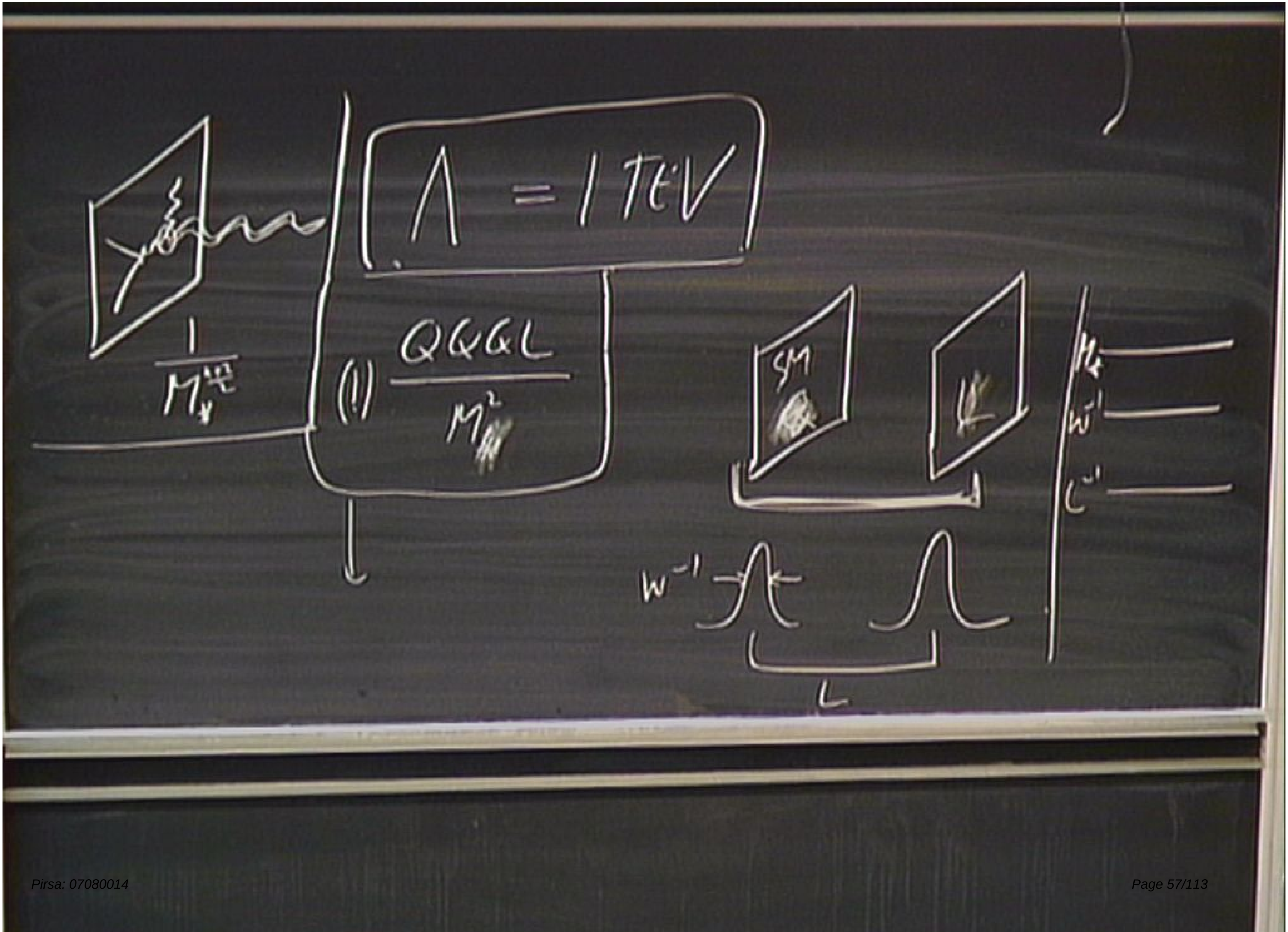

Λ = 1 TeV
QQQL
SM

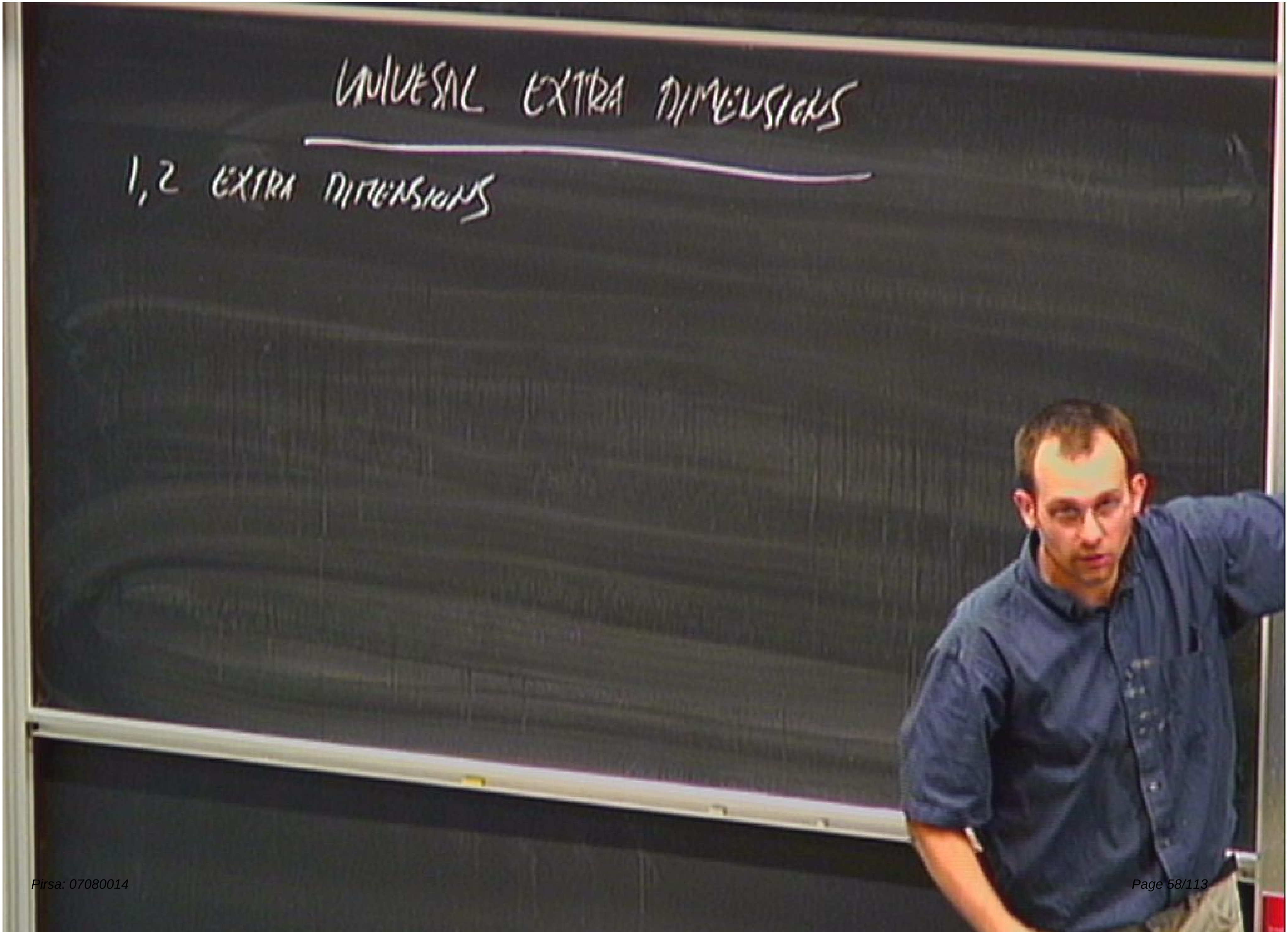

Λ = 1 TeV
QQQL
SM


Λ = 1 TeV
QQQL
SM


Λ = 1 TeV
(1) QQQL / M²
1 / M
SM
w⁻¹


Λ = 1 TeV
QQQL
SM
L


Λ = 1 TeV
QQQL
SM
w⁻¹
L

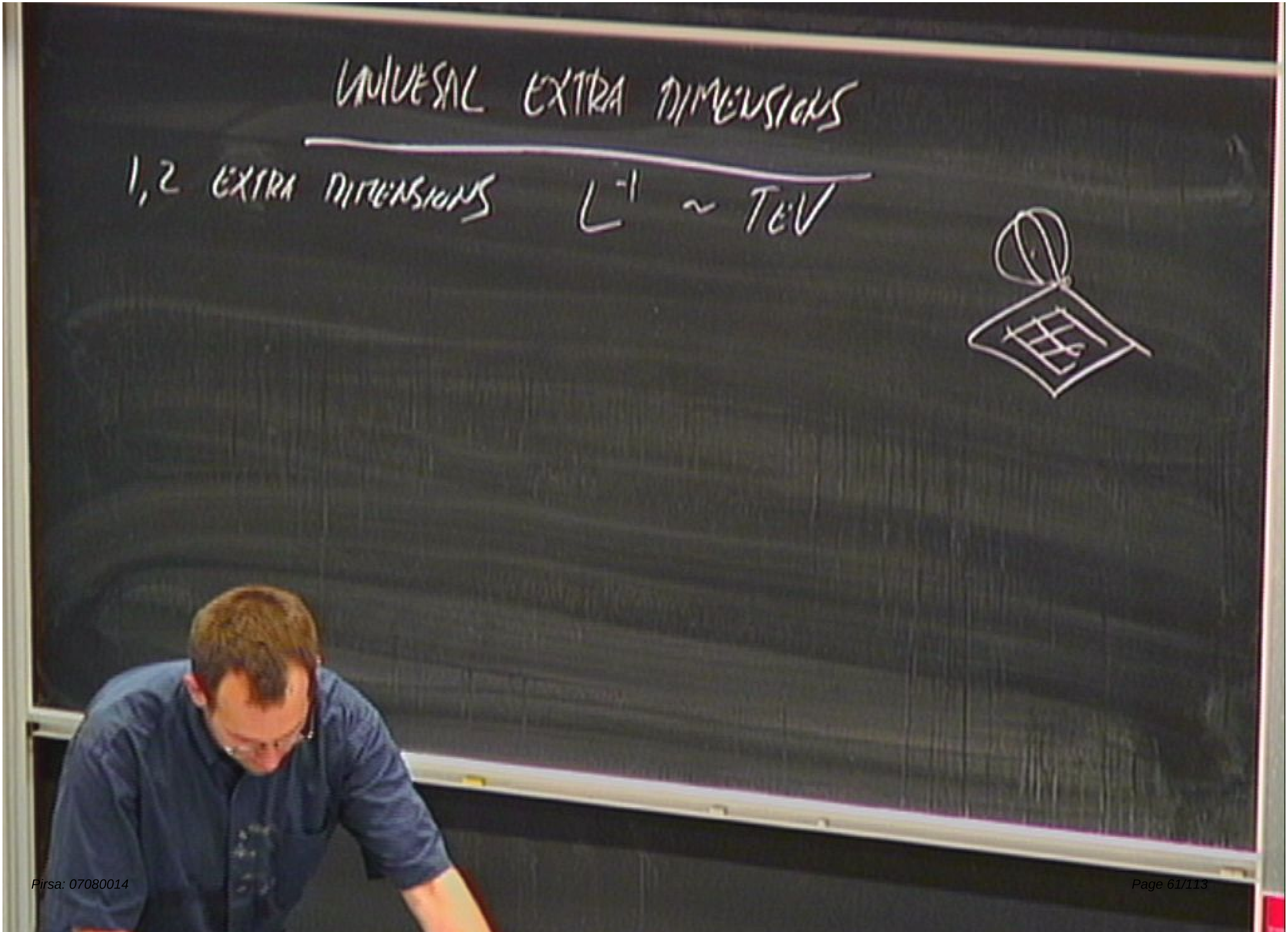

UNIVERSAL EXTRA DIMENSIONS
1, 2 EXTRA DIMENSIONS

UNIVERSAL EXTRA DIMENSIONS

1, 2 EXTRA DIMENSIONS

UNIVERSAL EXTRA DIMENSIONS

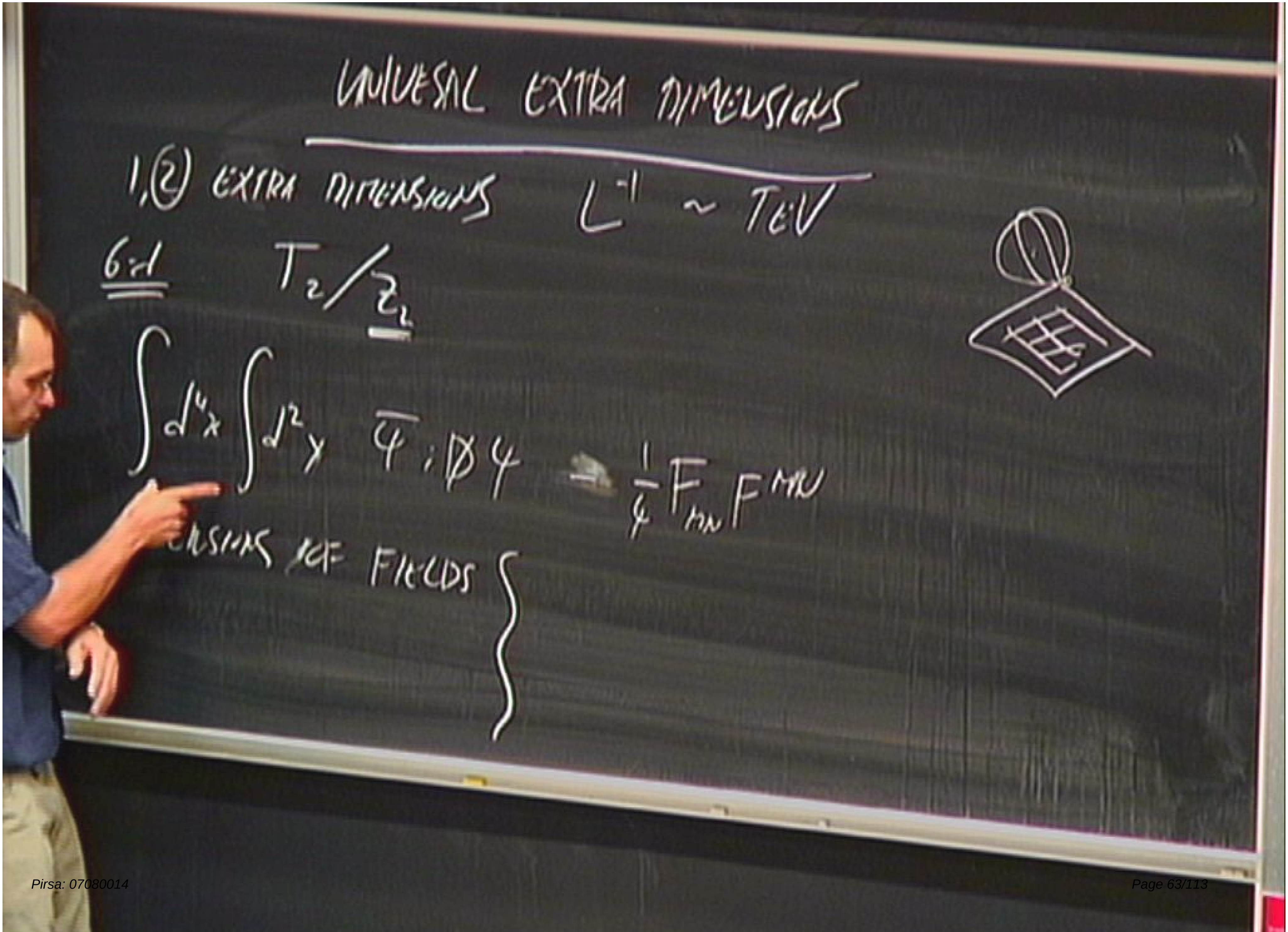
1, 2 EXTRA DIMENSIONS $L^{-1} \sim \text{TeV}$


UNIVERSAL EXTRA DIMENSIONS
1,2 EXTRA DIMENSIONS $L^{-1} \sim$ TeV

UNIVERSAL EXTRA DIMENSIONS

1, 2 EXTRA DIMENSIONS $L^{-1} \sim \text{TeV}$

6-d T_2/Z_2


UNIVERSAL EXTRA DIMENSIONS
1, 2 EXTRA DIMENSIONS $L^{-1} \sim$ TeV
6-d
T_2/Z_2
$\int d^4x \int d^2y \; \bar{\psi} \, i \not{D} \psi - \frac{1}{4} F_{MN} F^{MN}$
NSIONS OF FIELDS

UNIVERSAL EXTRA DIMENSIONS

1, (2) EXTRA DIMENSIONS $\quad L^{-1} \sim TeV$

6-d $\quad T_2/Z_2$

$$S = \int d^4x \int d^2y \; \bar{\psi}\, i \not{D} \psi - \frac{1}{4} F_{MN} F^{MN}$$

$\partial_\mu \phi^\dagger \partial^\mu \phi$

$0 \quad -4 \quad -2$

DIMENSIONS OF FIELDS $\begin{cases} \text{FERMIONS } \frac{5}{2} \\ \text{BOSONS} \end{cases}$

UNIVERSAL EXTRA DIMENSIONS

1, 2 EXTRA DIMENSIONS $\quad L^{-1} \sim \mathrm{TeV}$

6-d $\quad T_2/Z_2$

$$\underset{0}{S} = \int \underset{-4}{d^4x} \int \underset{-2}{d^2y}\; \bar{\psi}\, i \not{D}\, \psi - \frac{1}{4} F_{MN} F^{MN}$$

$\partial_\mu \phi^\dagger \partial^\mu \phi$

DIMENSIONS OF FIELDS
- FERMIONS $\frac{5}{2}$
- BOSONS 2

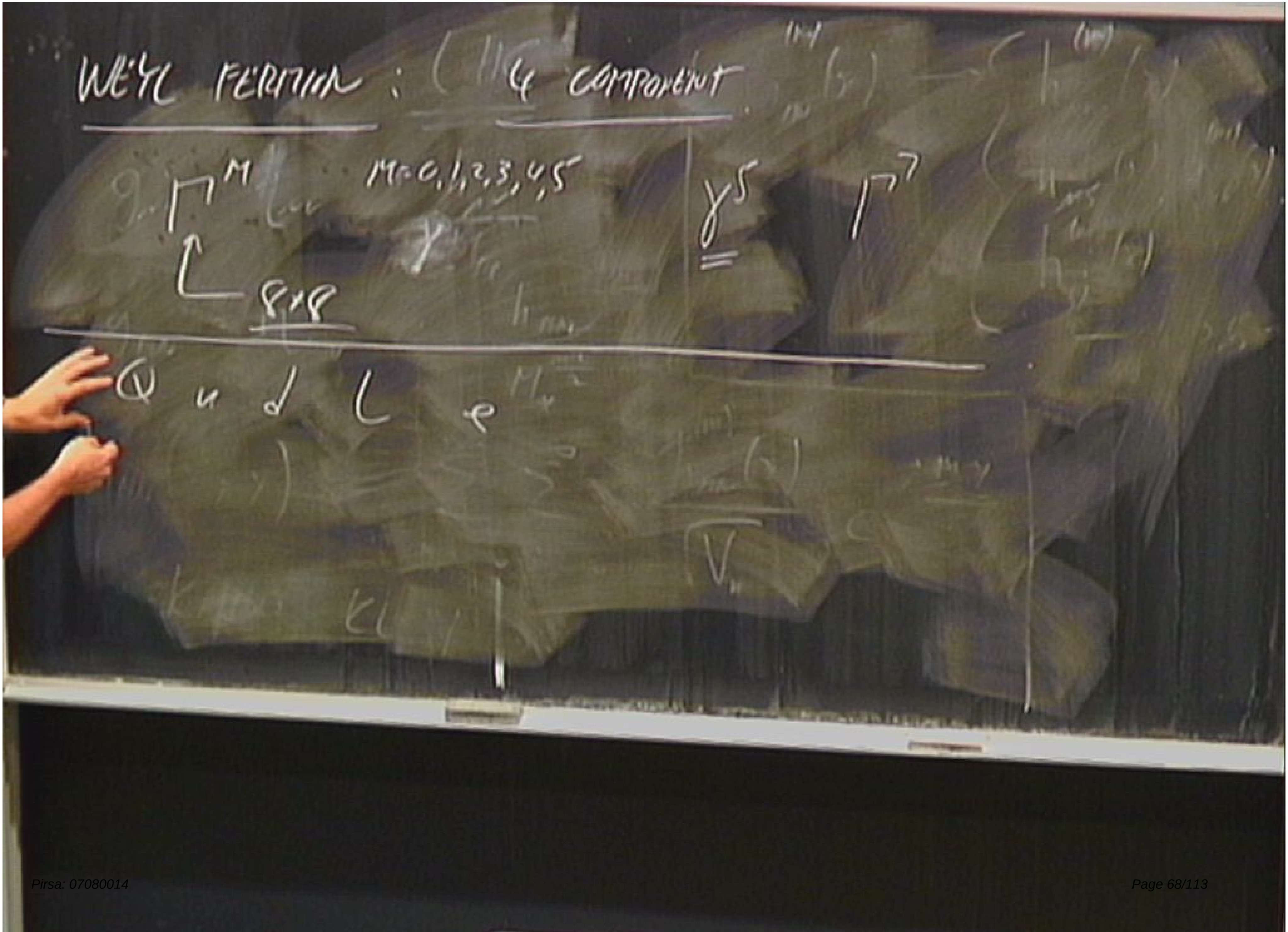
WEYL FERMION : 4 COMPONENT

WEYL FERMION : 4 COMPONENT

Γ^M $\quad M = 0,1,2,3,4,5$

8×8

$\gamma^5 \quad \Gamma^7$


WEYL FERMION : 4 COMPONENT
Γ^M   M=0,1,2,3,4,5
8×8
γ^5
Γ^7
Q u d L e

WEYL FERMION : 4 COMPONENT

Γ^M $M = 0,1,2,3,4,5$ γ^5 Γ^7

8×8

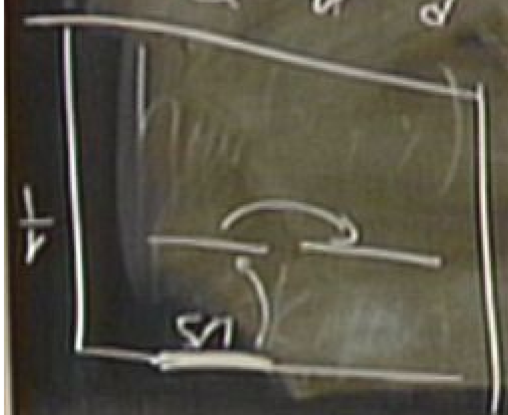
Q u d L e

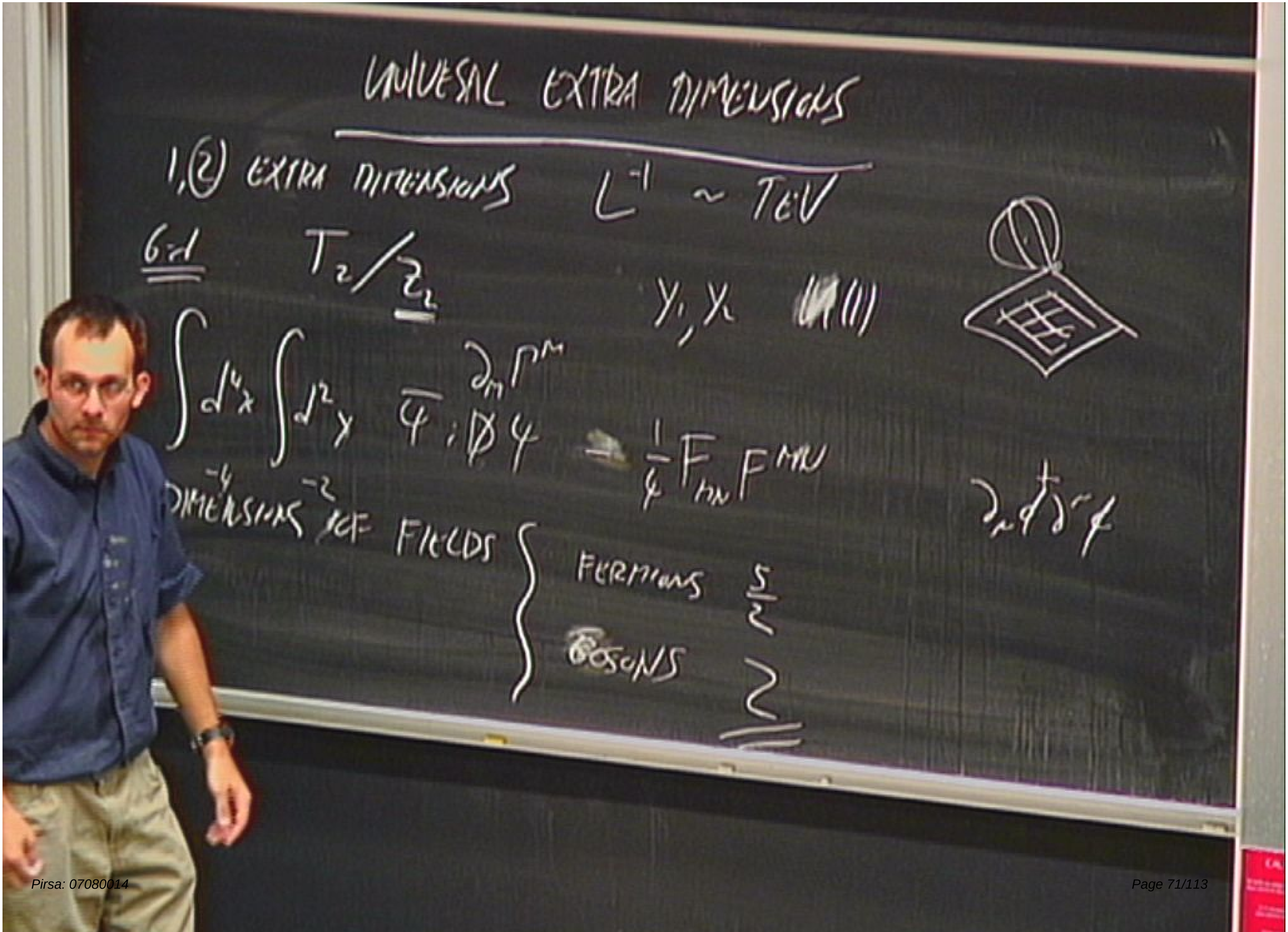
WEYL FERMION : 4 COMPONENT

Γ^M $\quad M=0,1,2,3,4,5$ $\quad \gamma^5$ $\quad \Gamma^7$

8×8

$Q \quad u \quad d \quad L \quad e$




UNIVERSAL EXTRA DIMENSIONS
1, 2 EXTRA DIMENSIONS
L^-1 ~ TeV
6-d
T2/Z2
y1, x2
∫d^4x ∫d^2y ψ̄ i D ψ
∂m Γ^m
-1/4 F_MN F^MN
∂_M φ† ∂^M φ
DIMENSIONS OF FIELDS
FERMIONS 5/2
BOSONS 2

UNIVERSAL EXTRA DIMENSIONS

1, 2 EXTRA DIMENSIONS $\quad L^{-1} \sim \text{TeV}$

6-d $\quad T_2/Z_2 \quad\quad y_1, y_2$

$$S = \int d^4x \int d^2y \;\; \bar{\psi}\, i \not{D} \psi \qquad \partial_m \Gamma^m$$

$$-\frac{1}{4} F_{mn} F^{mn} \qquad \partial_\mu \phi^\dagger \partial^\mu \phi$$

$-4 \quad -2$

DIMENSIONS OF FIELDS $\begin{cases} \text{FERMIONS} & \frac{5}{2} \\ \text{BOSONS} & 2 \end{cases}$

WEYL FERMION : 4 COMPONENT

Γ^M $M = 0,1,2,3,4,5$ $\quad \underline{\underline{\gamma^5}}$ $\quad \Gamma^7$

$\underline{8 \times 8}$

$Q \quad u_R \quad d_R \quad L \quad e_R \quad \Big\| \quad -\frac{1}{2}$

$\frac{1}{2}$

SU

WEYL FERMION : 4 COMPONENT

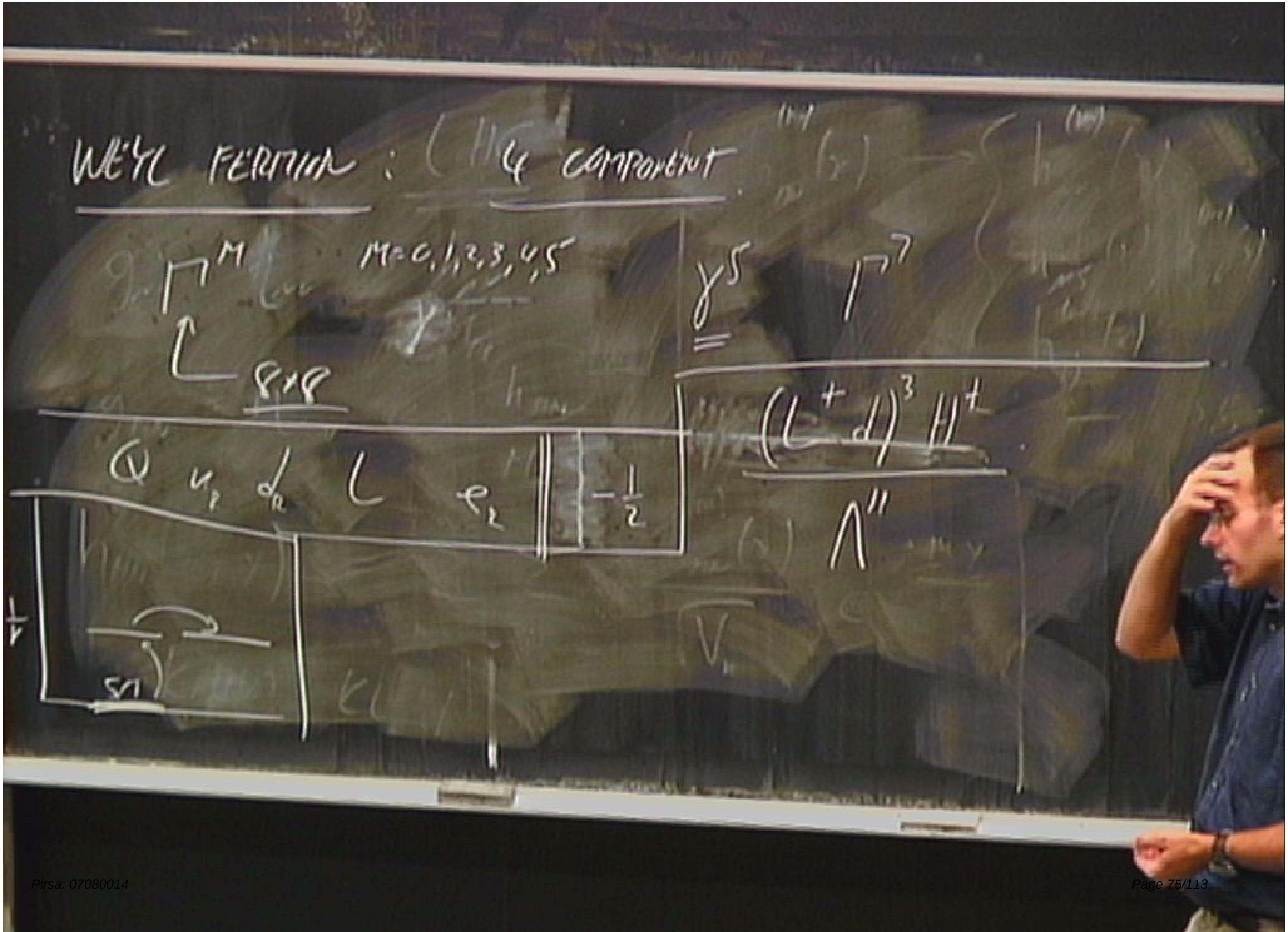
Γ^M $\quad M = 0,1,2,3,4,5$ $\quad \underline{\underline{\gamma^5}}$ $\quad \Gamma^7$

$\underline{8 \times 8}$

Q	u_R	d_R	L	e_R		$-\frac{1}{2}$

$\frac{1}{2}$

SU


WEYL FERMION : 4 COMPONENT
Γ^M
M=0,1,2,3,4,5
8×8
γ5
Γ7
(L⁺d)³ H⁺
Λ''
Q u_R d_R L e_R
−1/2
SM

WEYL FERMION : 4 COMPONENT

Γ^M $M = 0,1,2,3,4,5$

8×8

γ^5 Γ^7

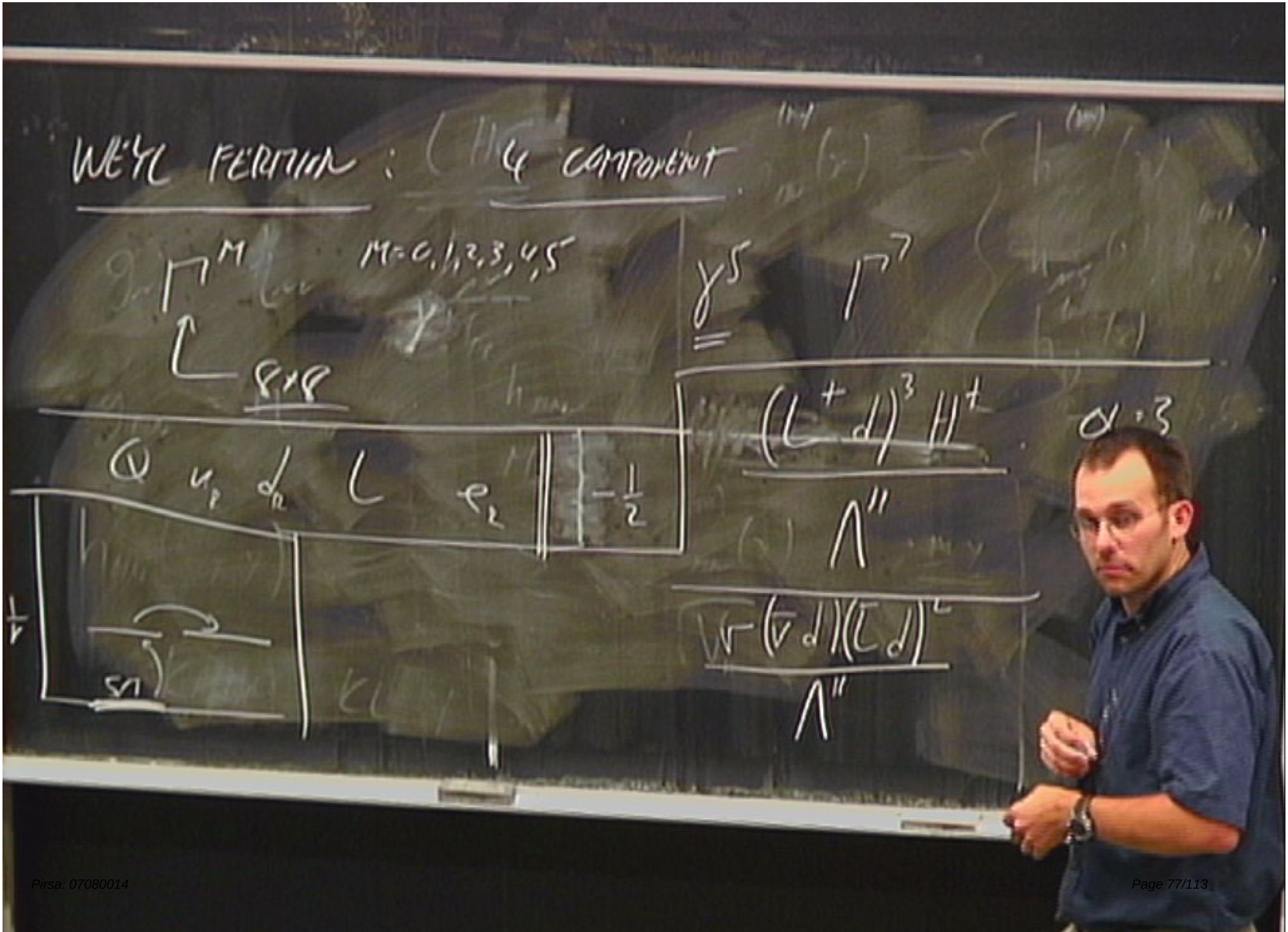
$(L^+ d)^3 H^+$ $\alpha = 3$

$\Delta B = 1$

Λ''

Q	u_R	d_R	L	e_R	$-\frac{1}{2}$

S^1


WEYL FERMION : 4 COMPONENT
M=0,1,2,3,4,5
8×8
Q
L
−1/2
Λ''
Λ''

WEYL FERMION : 4 COMPONENT

$\Gamma^M \quad M = 0,1,2,3,4,5$

8×8

$\gamma^5 \quad \Gamma^7$

$Q \quad u_R \quad d_R \quad L \quad e_R \quad \| \quad -\frac{1}{2}$

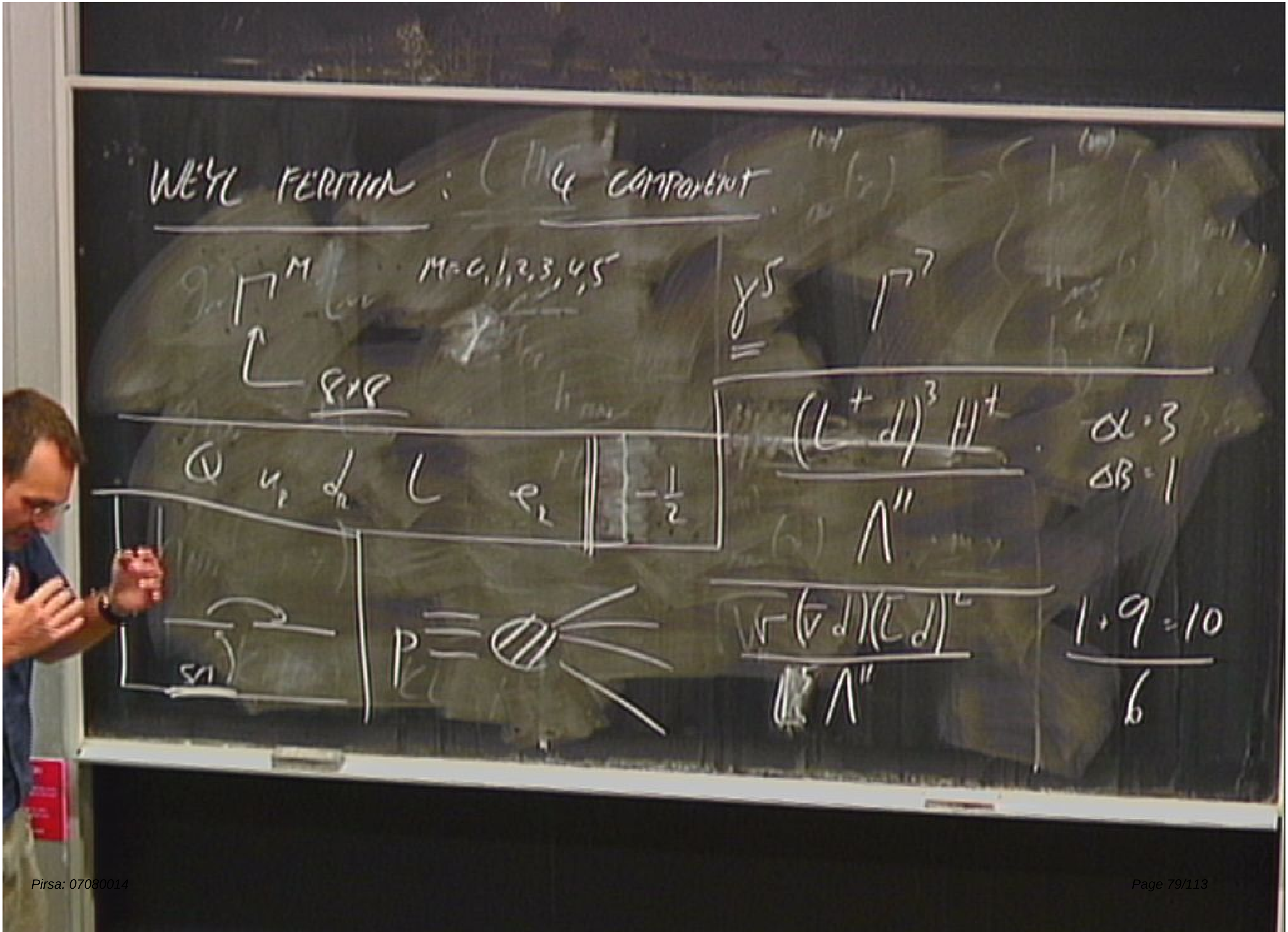
$\frac{(\bar{L}^+ d)^3 H^+}{\Lambda''}$ $\quad \alpha = 3, \ \Delta B = 1$

$\frac{\nu (\bar{\nu} d)(\bar{L} d)^2}{\Lambda''}$

$\frac{1 + 9 = 10}{6}$

SM

$p \equiv$


WEYL FERMION : 4 COMPONENT
M=0,1,2,3,4,5
8×8
Q u_R d_R L e_R
-1/2
P
γ5
Γ7
α·3
ΔB·1
Λ''
1·9=10
6

WEYL FERMION : 4 COMPONENT

Γ^M $\quad M=0,1,2,3,4,5$

8×8

$\gamma^5 \quad \Gamma^7$

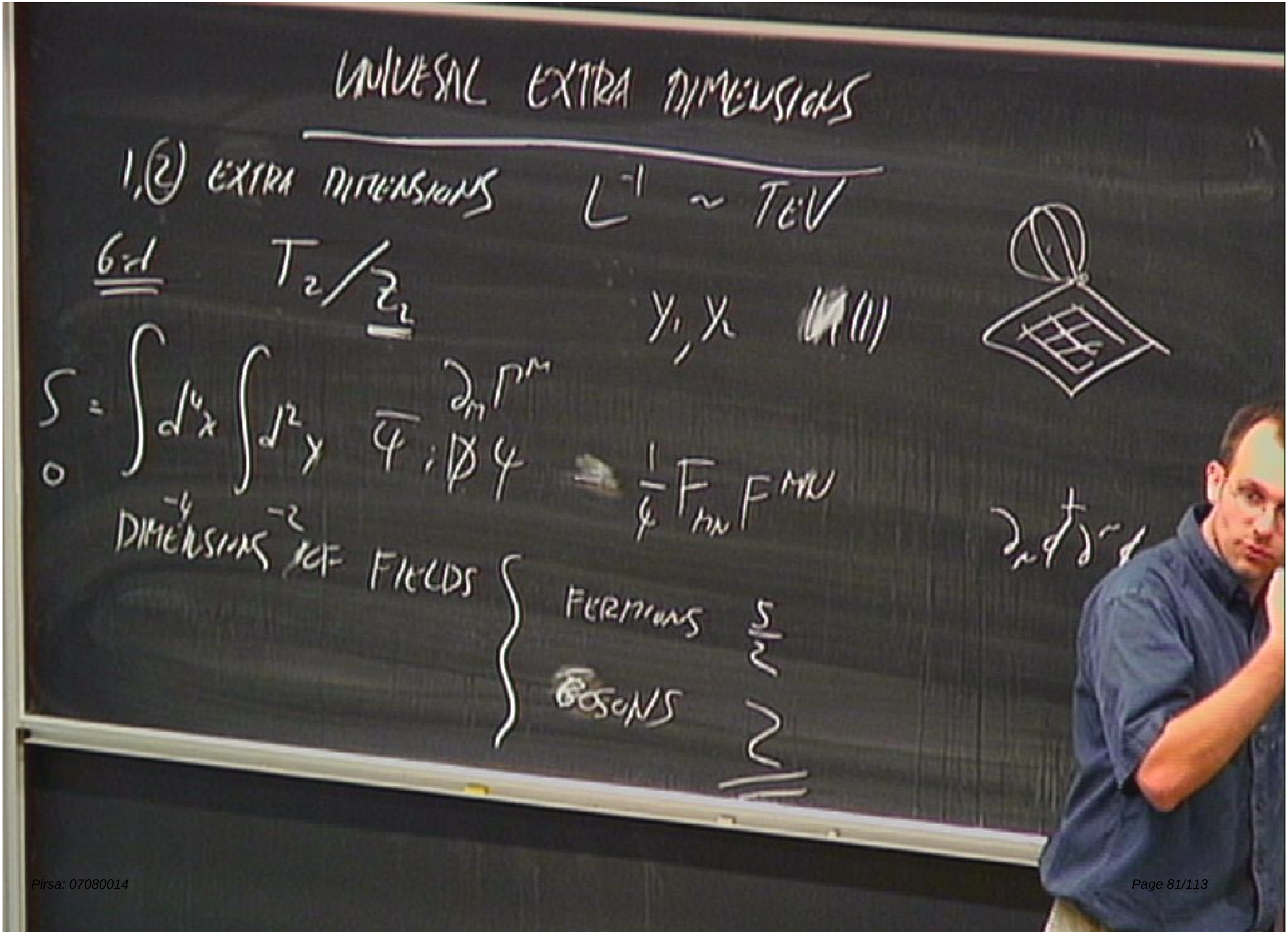
$Q \quad u_R \quad d_R \quad L \quad e_R \quad \| \quad -\frac{1}{2}$

$$\frac{(L^+ d)^3 H^+}{\Lambda^{11}} \qquad \alpha = 3, \quad \Delta B = 1$$

$$\frac{\nu(\bar{\nu} d)(\bar{L} d)^2}{\Lambda^{11}} \qquad \frac{1+9=10}{6}$$

SM

$P \equiv$


UNIVERSAL EXTRA DIMENSIONS
1, 2 EXTRA DIMENSIONS
L^-1 ~ TeV
6-d
T2/Z2
y1, y2
U(1)
S = ∫d^4x ∫d^2y ψ̄ i∂̸ψ
∂m Γ^m
1/4 F_MN F^MN
∂_M φ† ∂^M φ
-4
-2
DIMENSIONS OF FIELDS
FERMIONS 5/2
BOSONS 2

UNIVERSAL EXTRA DIMENSIONS

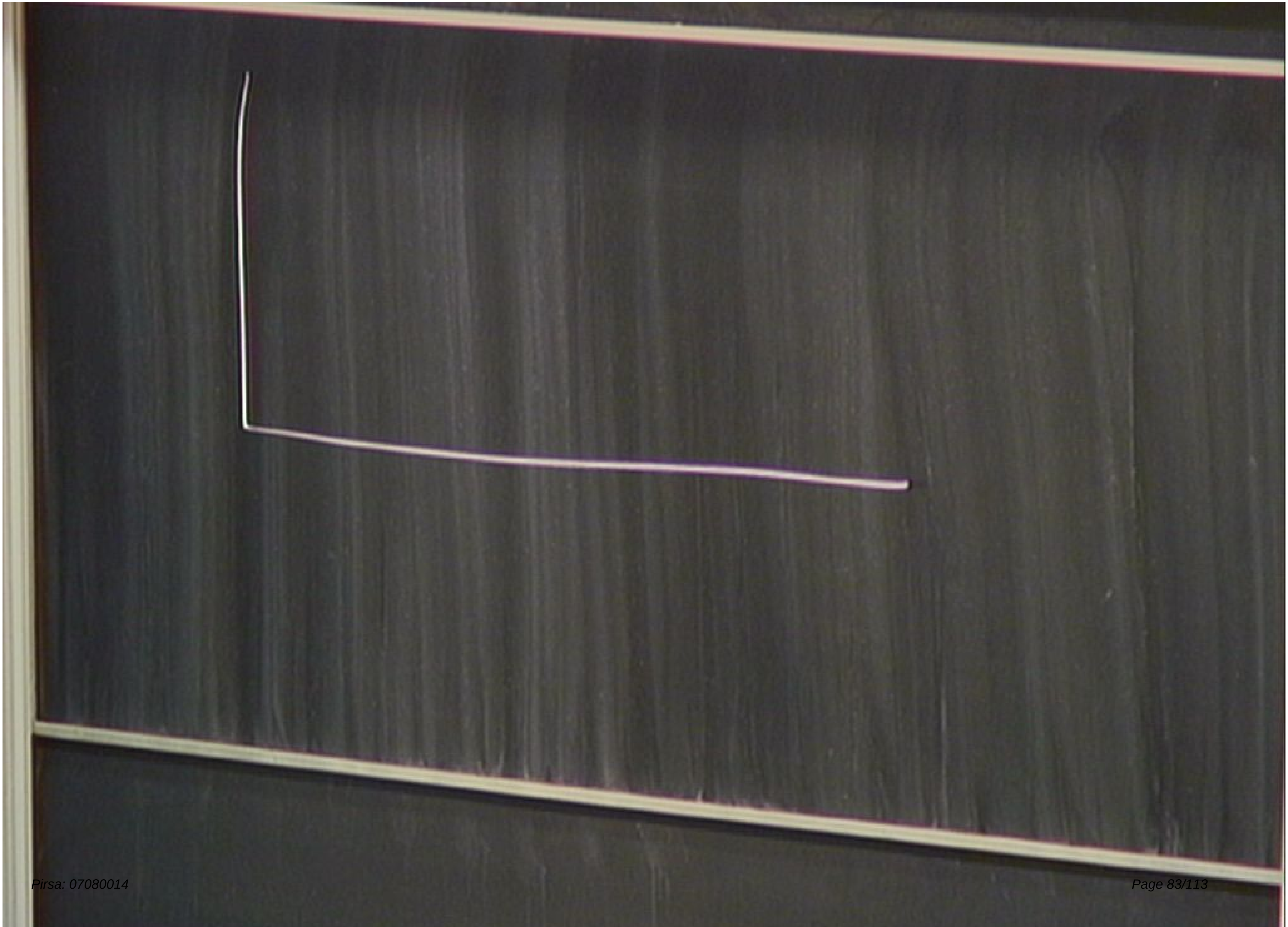
1, 2 EXTRA DIMENSIONS $L^{-1} \sim \text{TeV}$

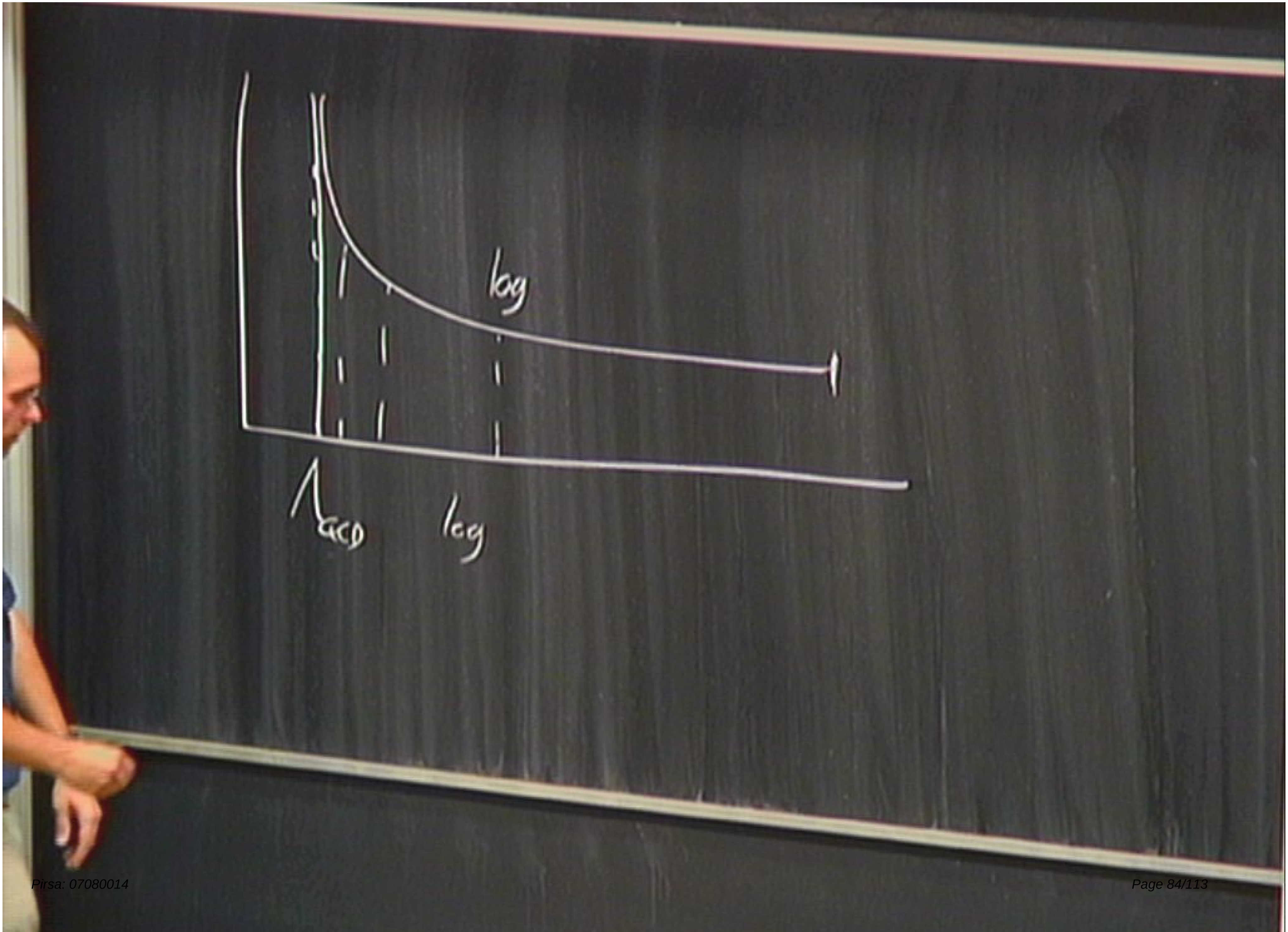
6-d T_2 / Z_2 y_1, y_2

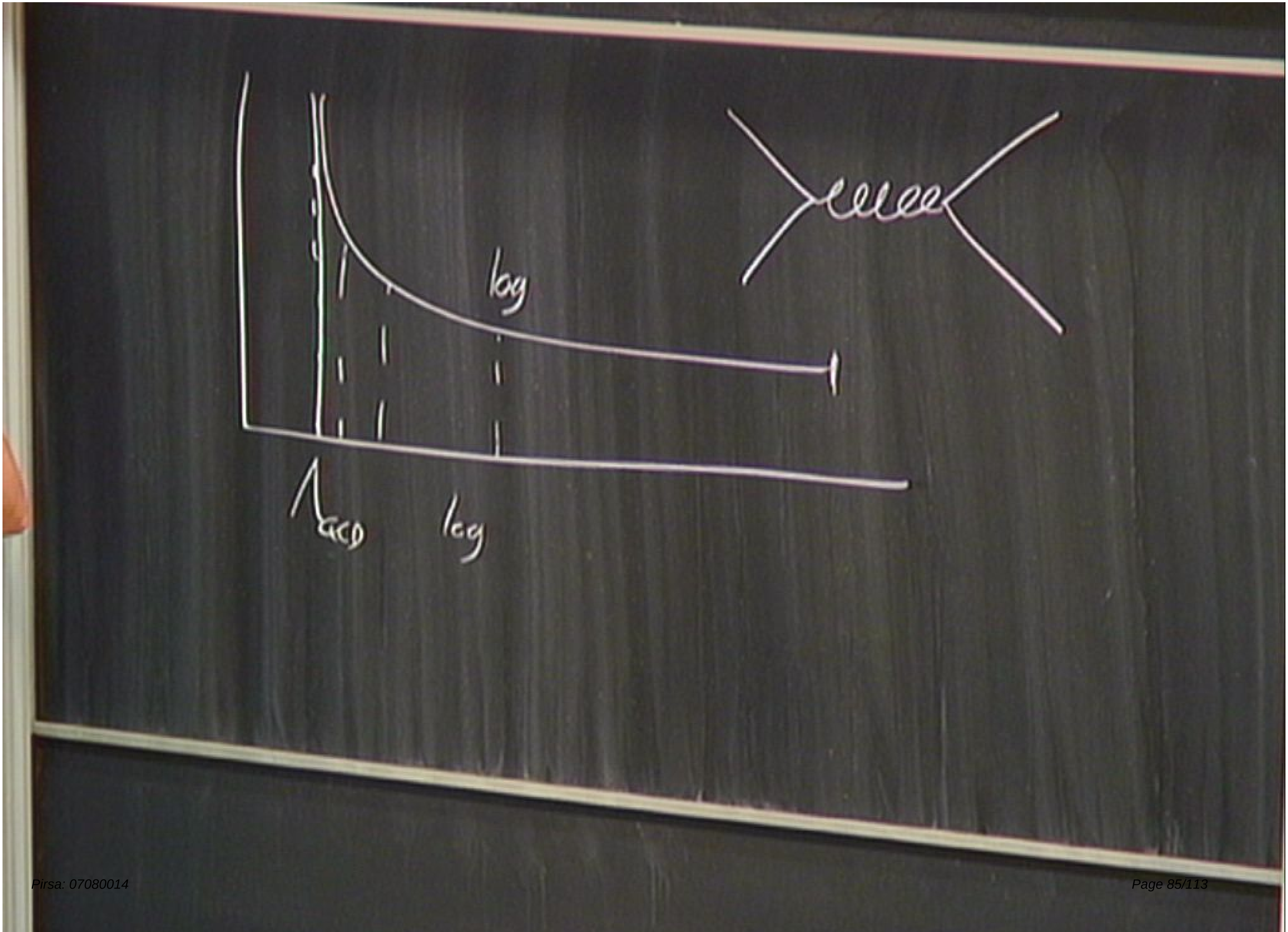
$$S_0 = \int d^4x \int d^2y \; \bar{\psi}\, i \not{D} \psi \qquad \partial_m \Gamma^m \qquad -\frac{1}{4} F_{MN} F^{MN} \qquad \partial_\mu \phi^\dagger \partial^\mu \phi$$

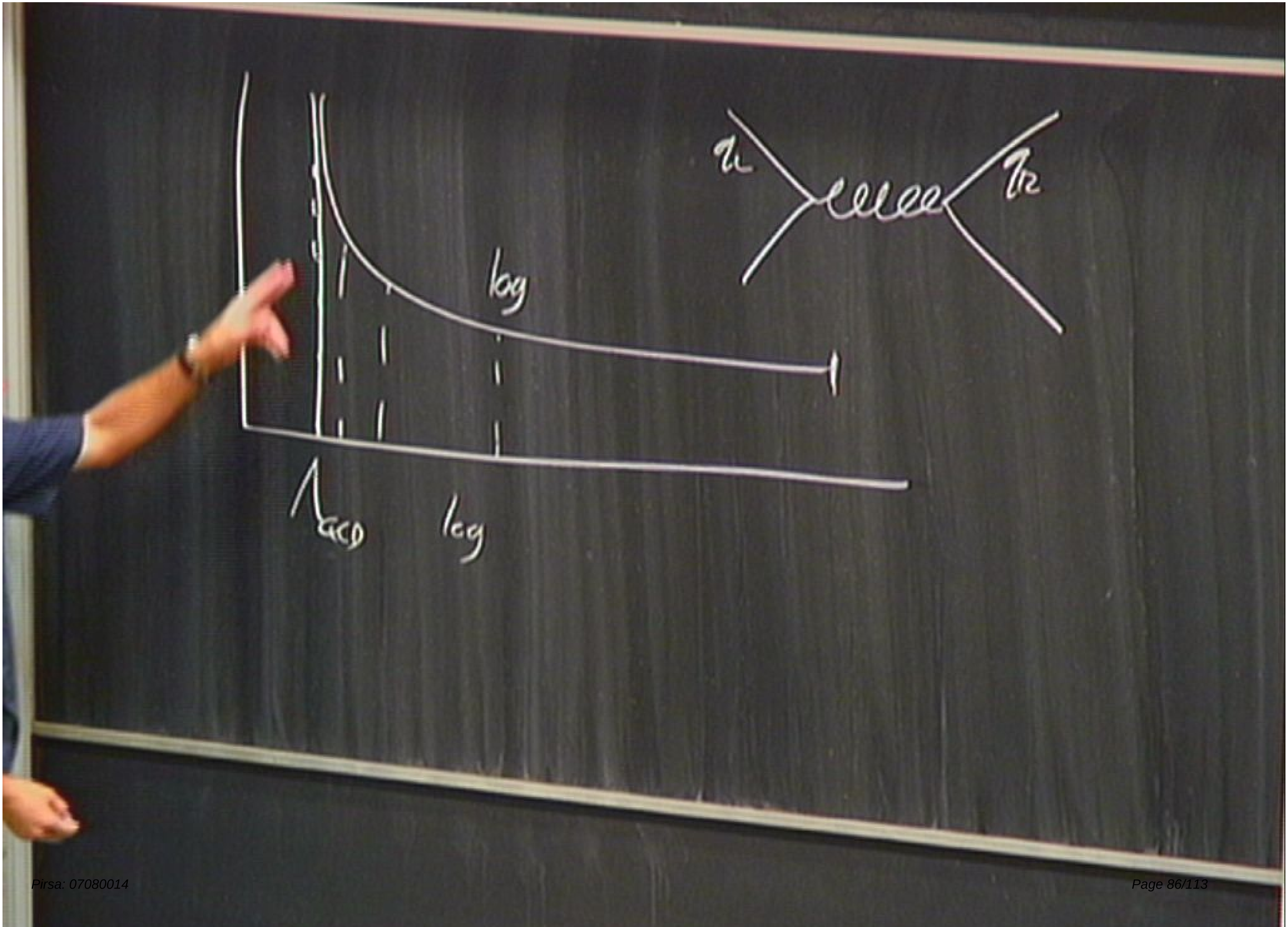
$-4 \quad -2$

DIMENSIONS OF FIELDS
$$\begin{cases} \text{FERMIONS} & \frac{5}{2} \\ \text{BOSONS} & 2 \end{cases}$$

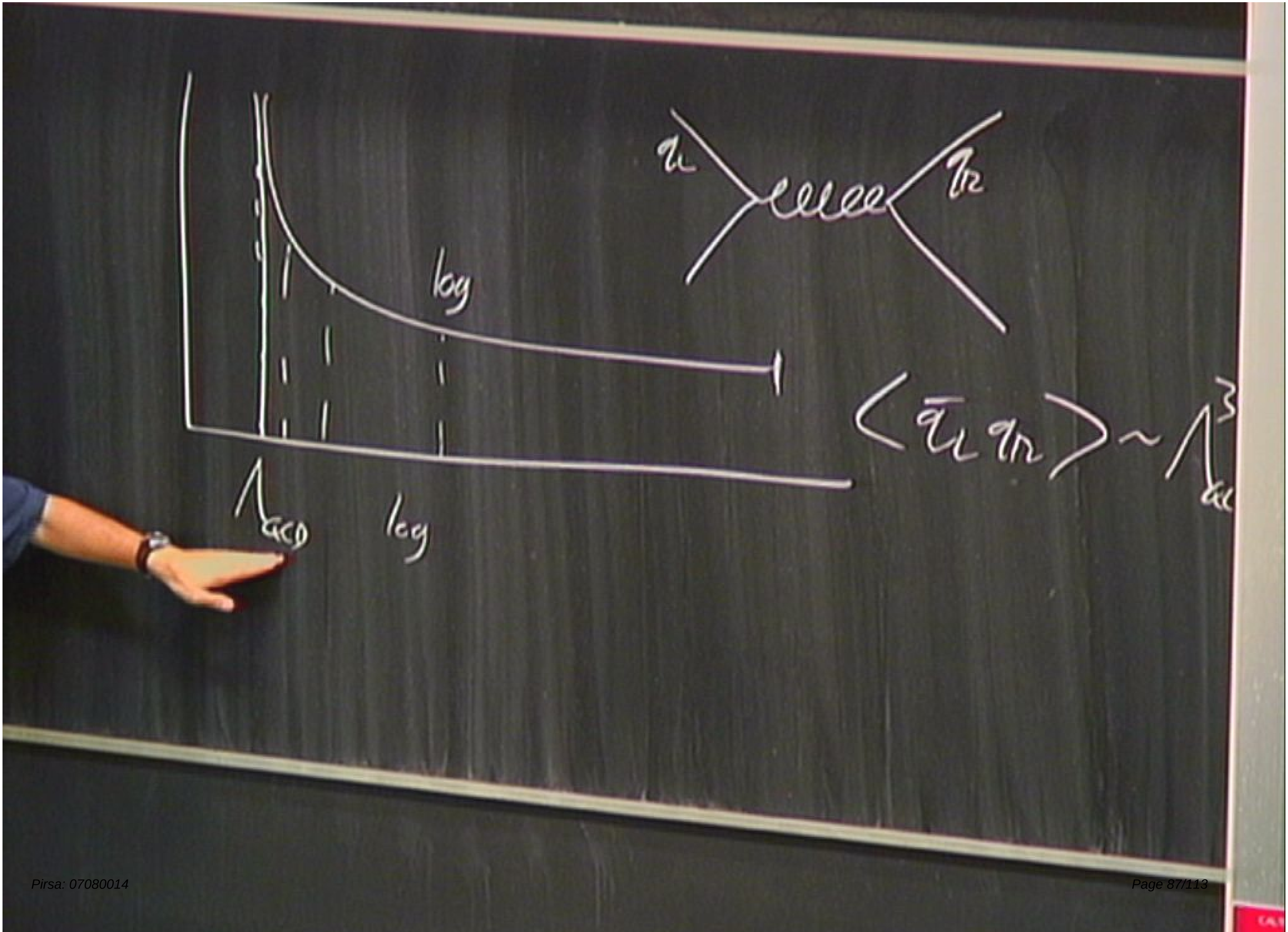



log
Λ_{QCD}
log

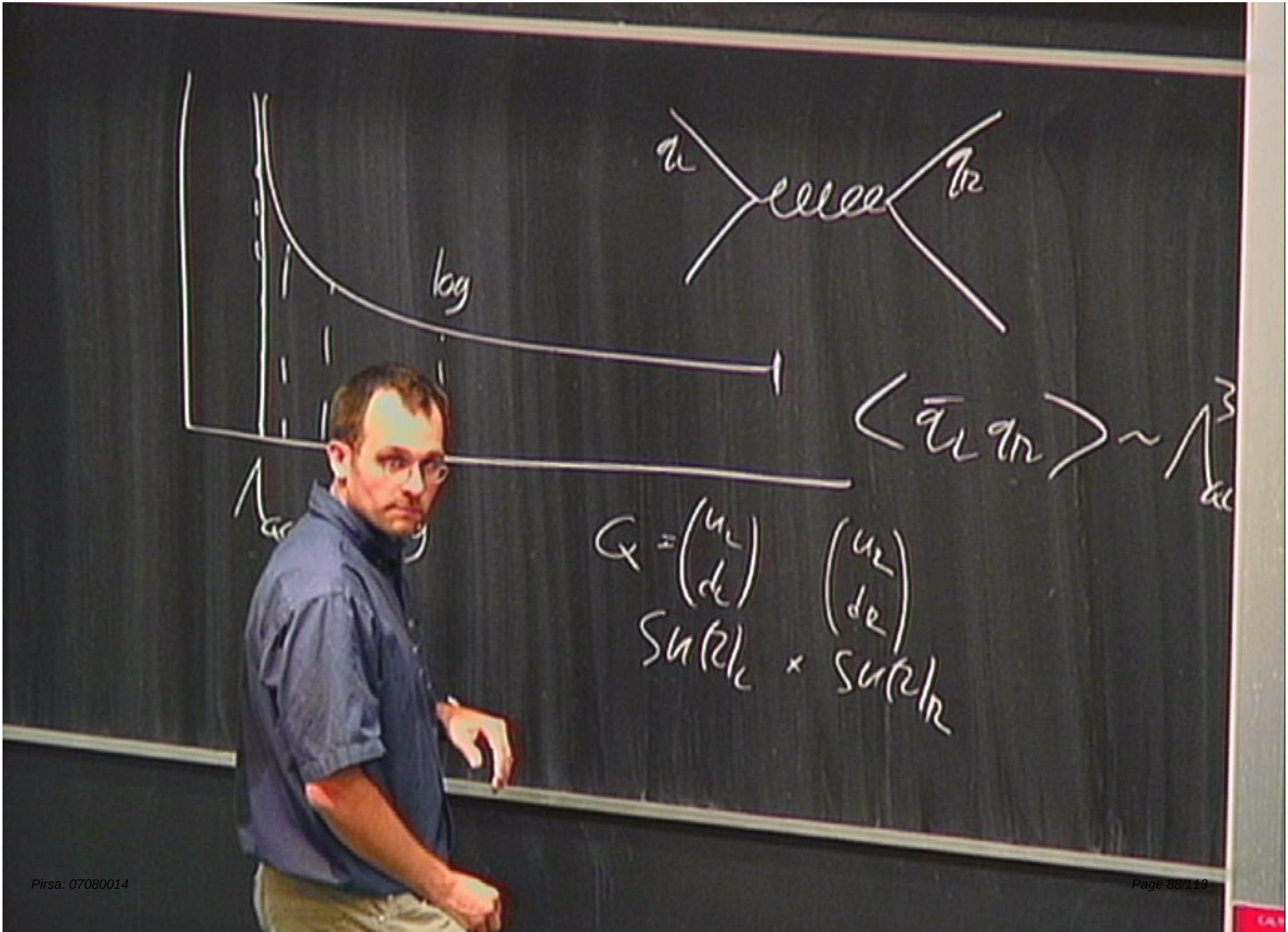

log
Λ_{QCD}
log

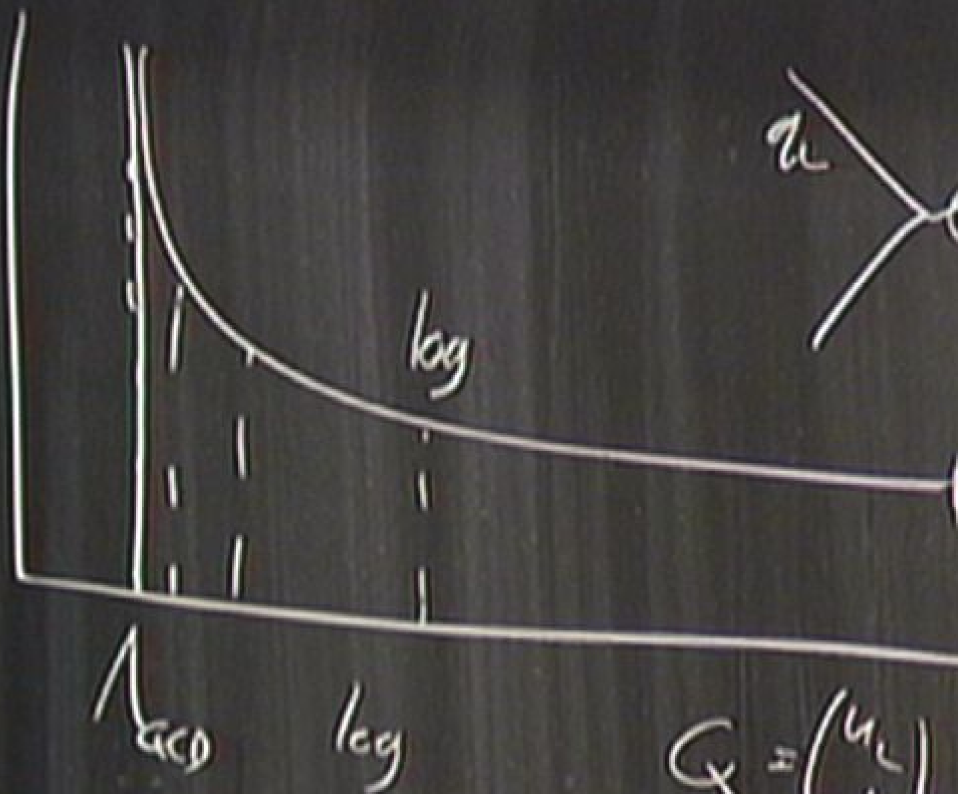


log
Λ_{QCD}
log
q_1
q_2



q_L
q_R
log
$\langle \bar{q}_L q_R \rangle \sim \Lambda^3$
Λ_{QCD}
log

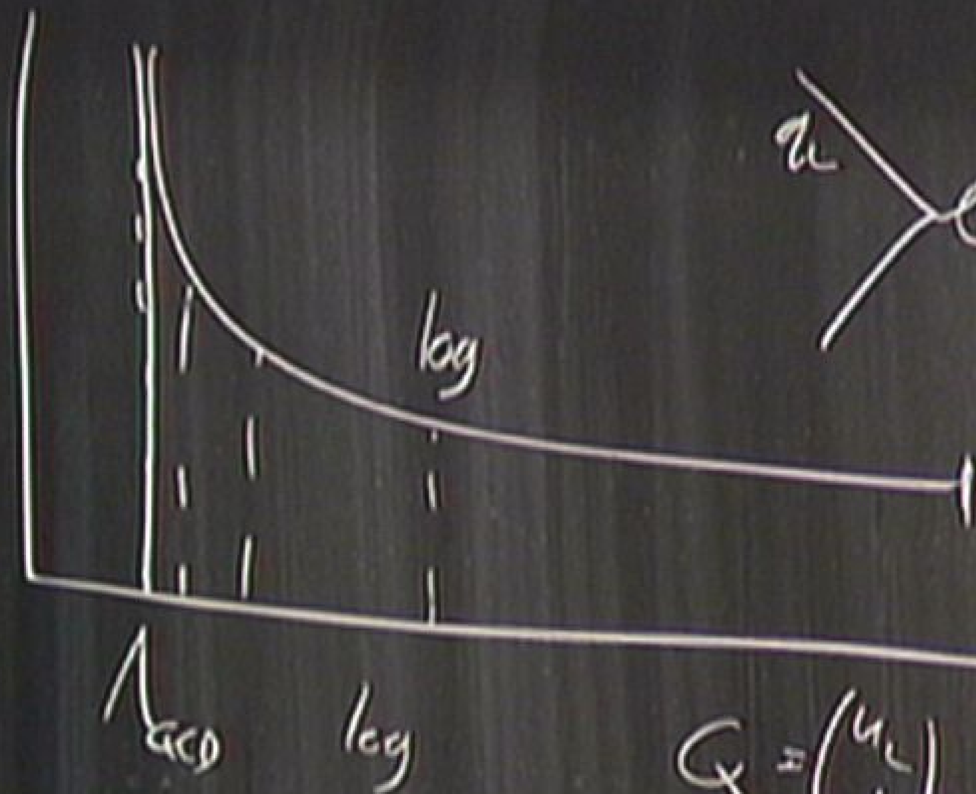

log
q_L
q_R
$\langle \bar{q}_L q_R \rangle \sim \Lambda^3_{QCD}$
$Q = \begin{pmatrix} u_L \\ d_L \end{pmatrix} \quad \begin{pmatrix} u_R \\ d_R \end{pmatrix}$
$SU(2)_L \times SU(2)_R$



$$\langle \bar{q}_L q_R \rangle \sim \Lambda_{QCD}^3$$

$$Q = \begin{pmatrix} u_L \\ d_L \end{pmatrix} \quad \begin{pmatrix} u_R \\ d_R \end{pmatrix}$$

$$SU(2)_L \times SU(2)_R \longrightarrow SU(2)_D$$

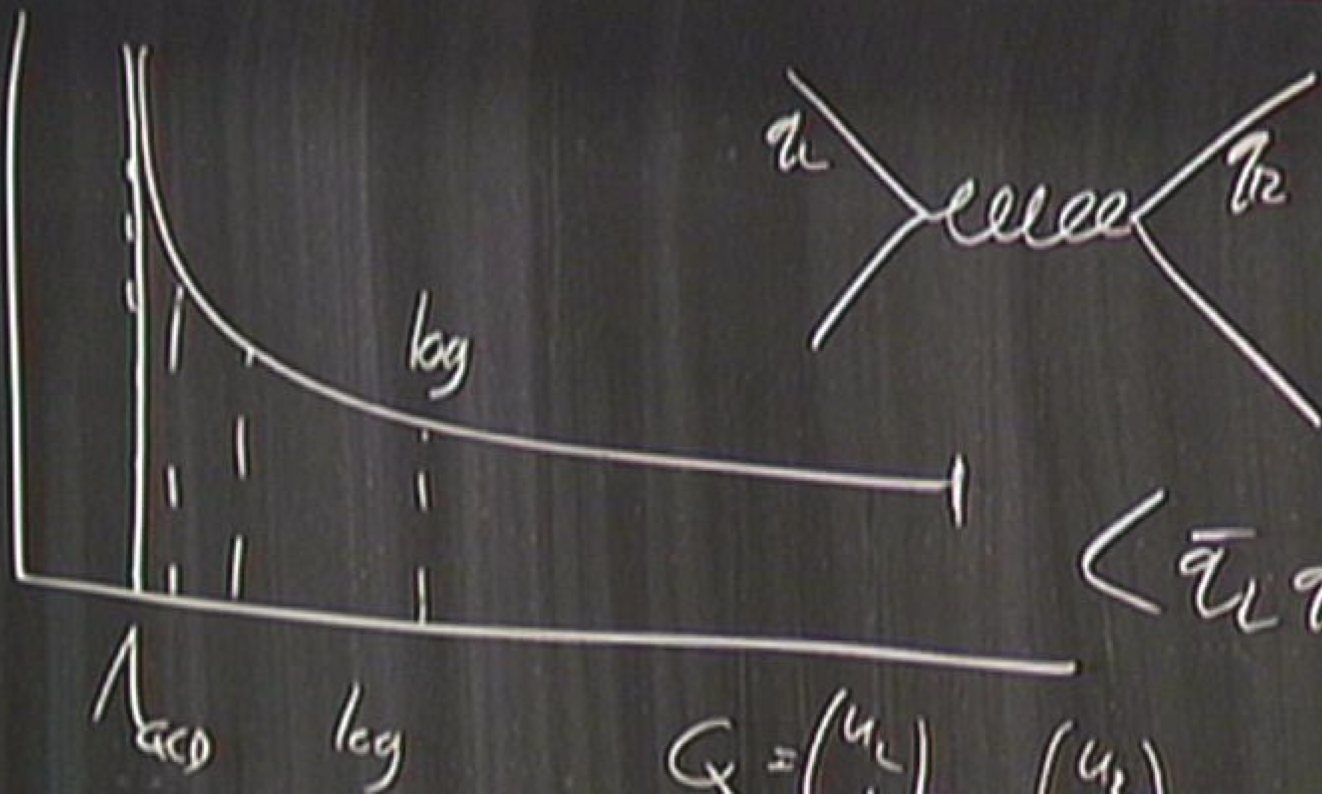


$$\langle \bar{q}_L q_R \rangle \sim \Lambda_{QCD}^3$$

$$Q = \begin{pmatrix} u_L \\ d_L \end{pmatrix} \quad \begin{pmatrix} u_R \\ d_R \end{pmatrix}$$

$$SU(2)_L \times SU(2)_R \to SU(2)_D$$

GOLDSTONES (π^+, π^0, π^-)



$$\langle \bar{q}_L q_R \rangle \sim \Lambda_{QCD}^3$$

$$Q = \begin{pmatrix} u_L \\ d_L \end{pmatrix} \quad \begin{pmatrix} u_R \\ d_R \end{pmatrix}$$

$$\underline{SU(2)_L \times SU(2)_R} \to SU(2)_D$$

<u>GOLDSTONES</u> (π^+, π^0, π^-)

ELECTROWEAK

W^+, Z_0, W^-

W^+, Z_0, W^-

ELECTROWEAK

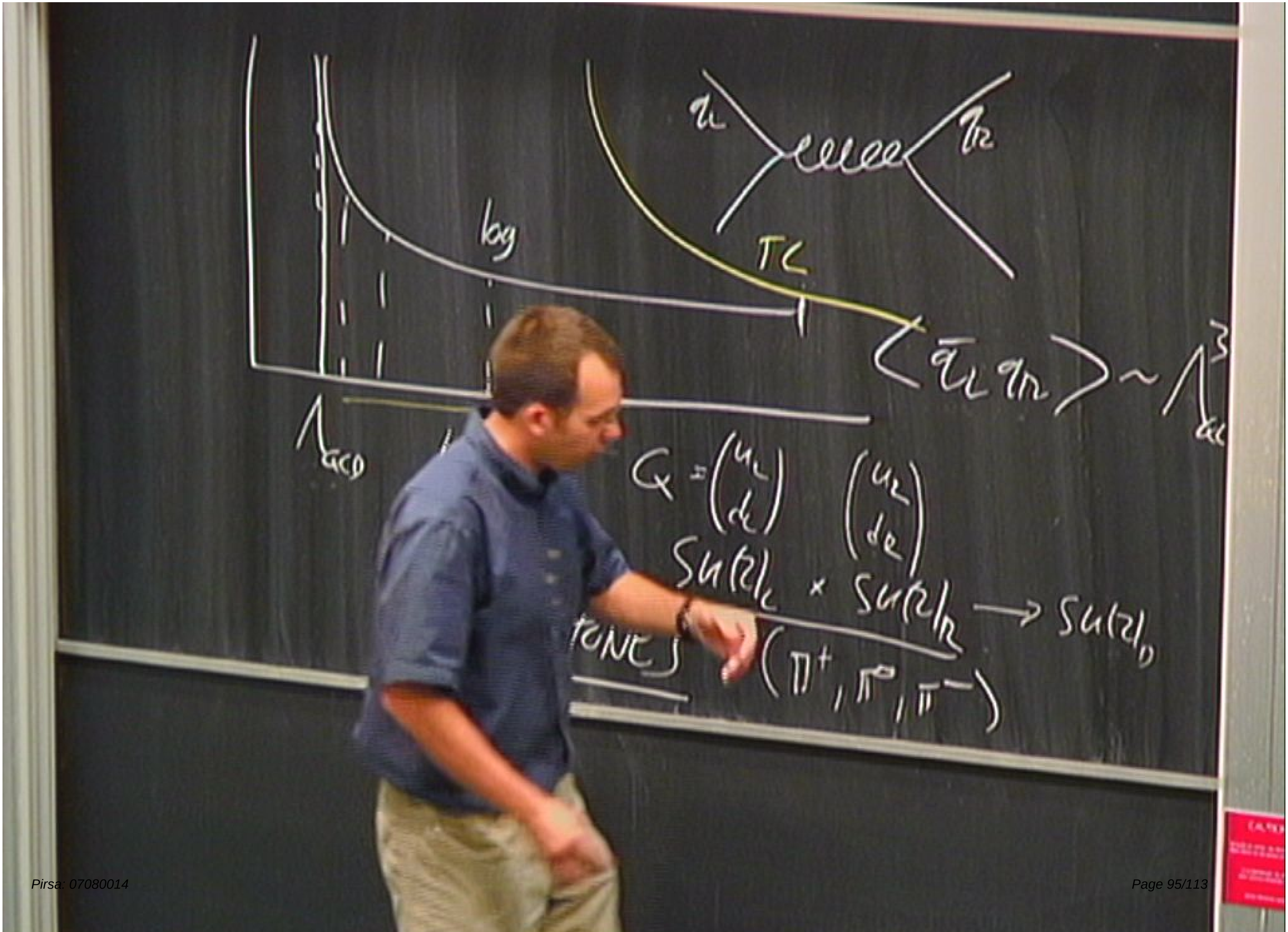
W^+ , Z_0 , W^-

$(w^+ , \; z_0 , \; w^-)$

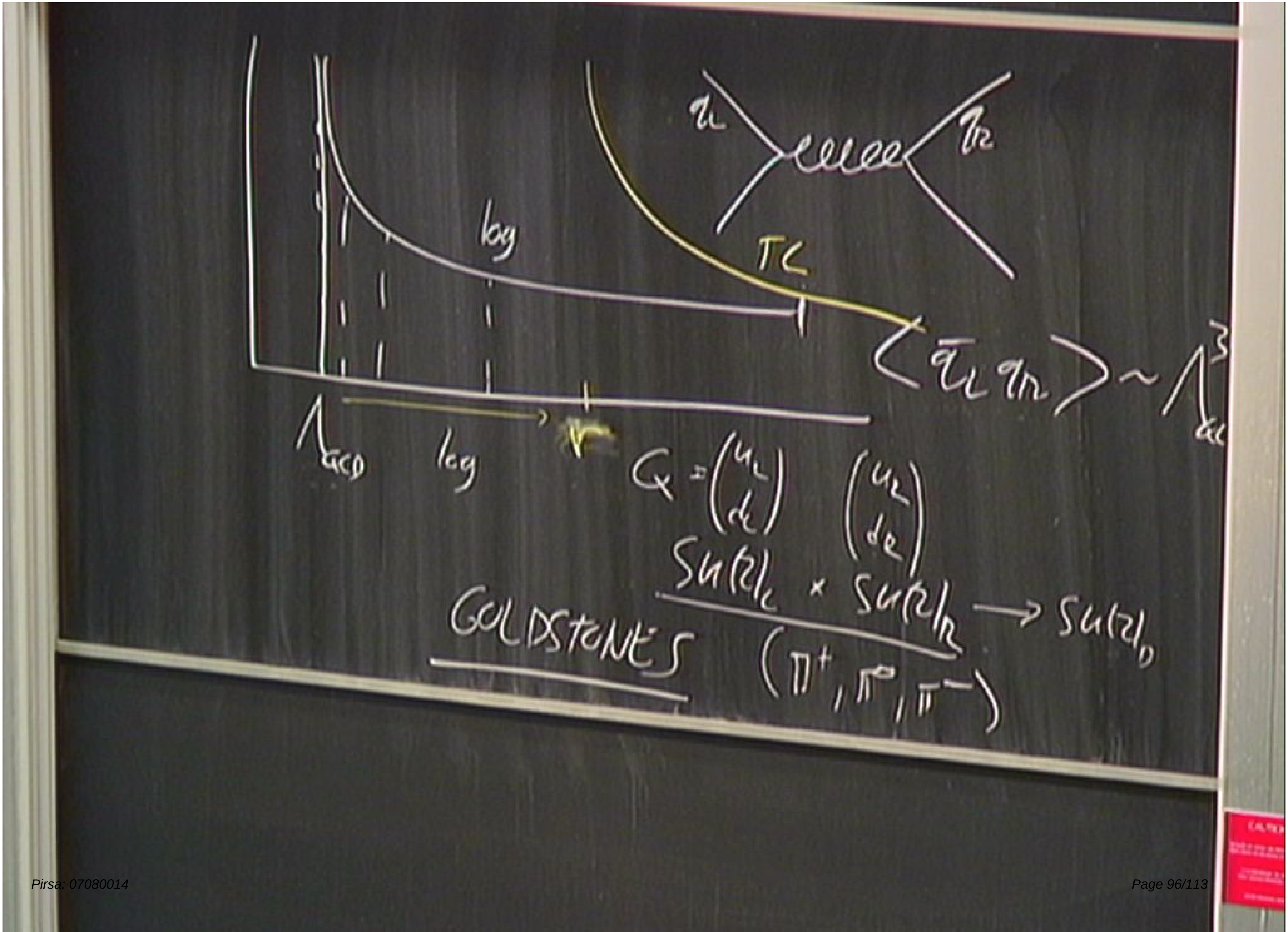
ELECTROWEAK / TECHNICOLOR

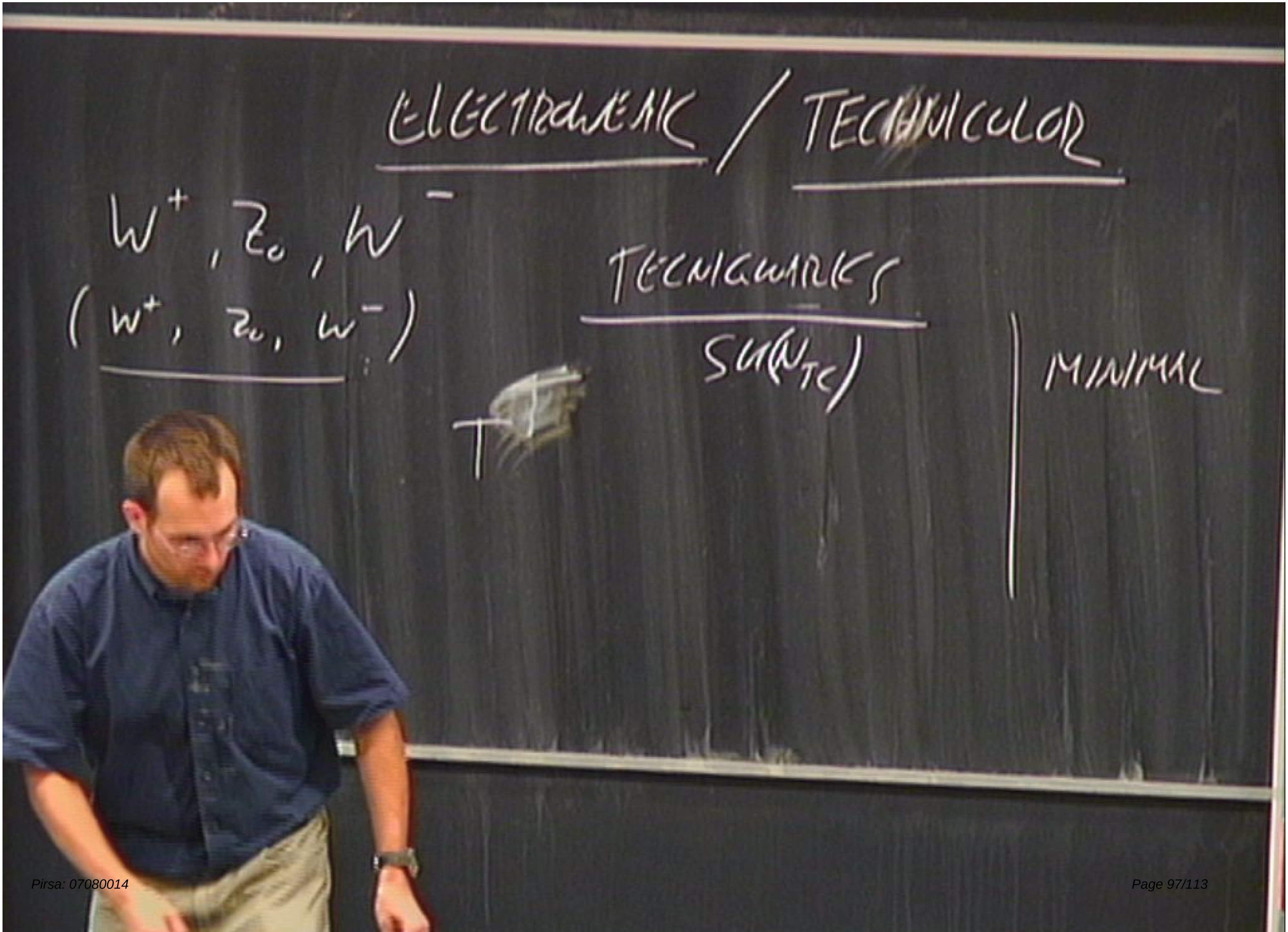
W^+, Z_0, W^-

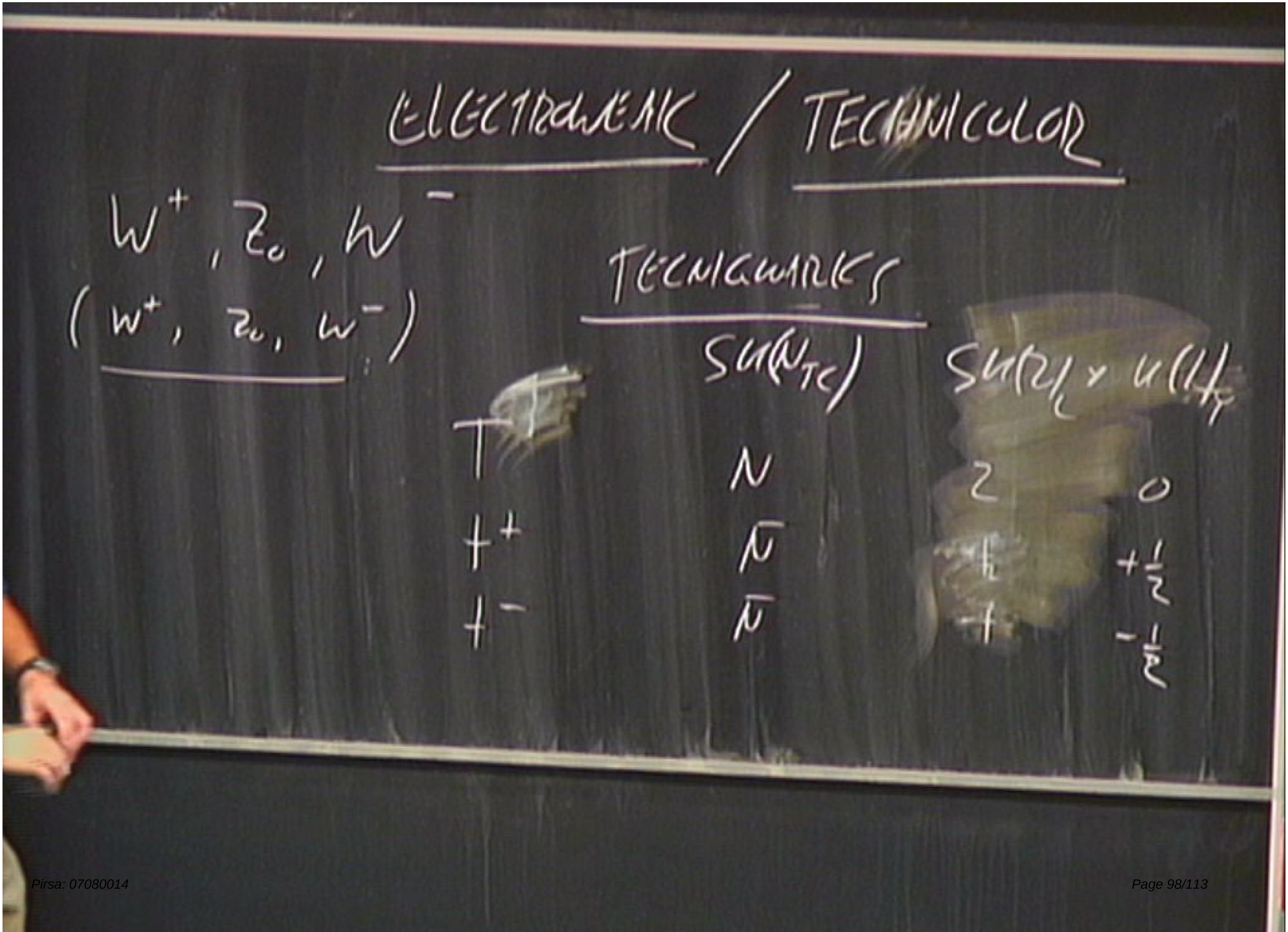
(w^+, z_0, w^-)

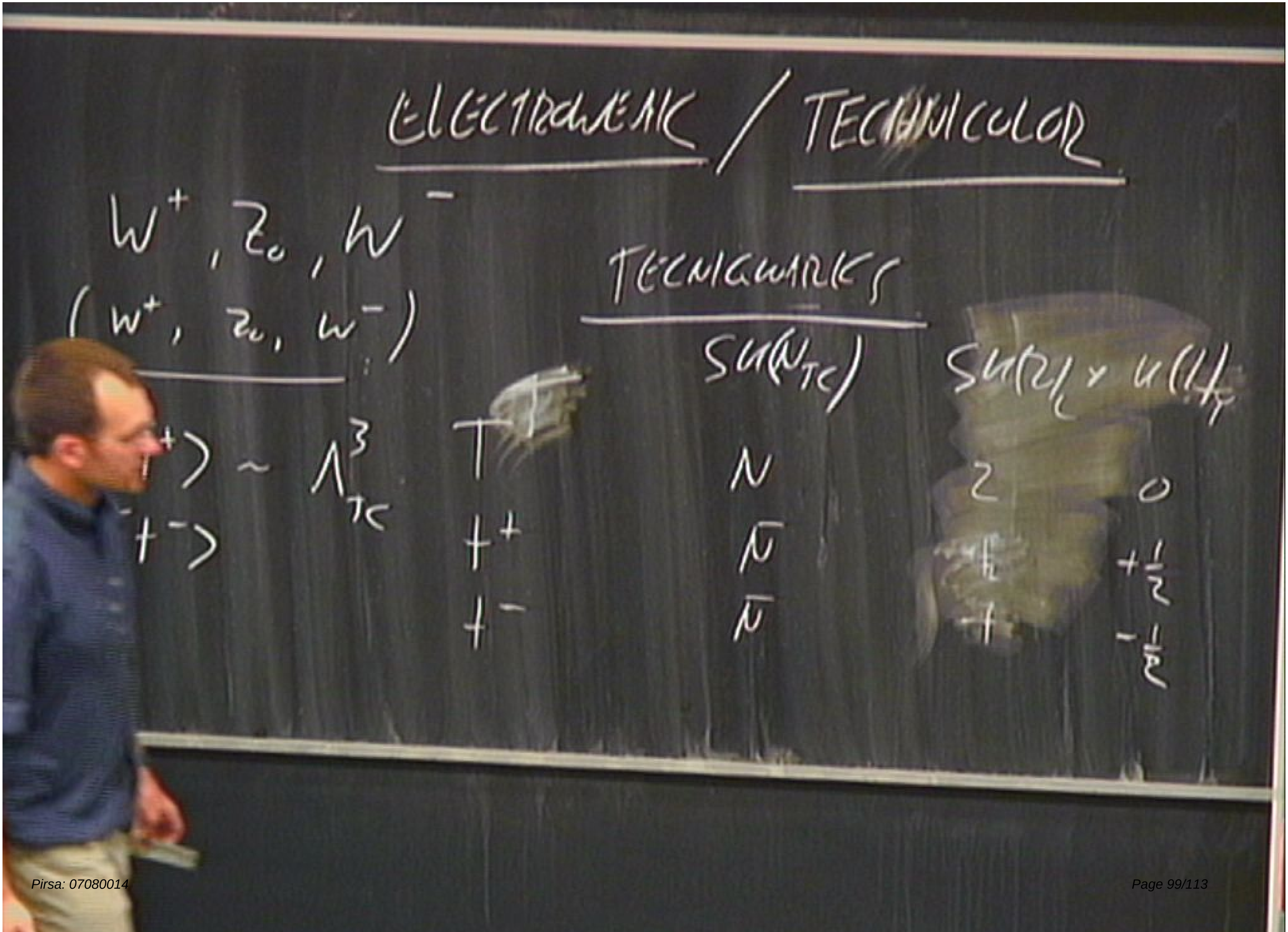


q_L
q_R
log
TC
Λ_{QCD}
$\langle \bar{q}_L q_R \rangle \sim \Lambda^3$
$Q = \begin{pmatrix} u_L \\ d_L \end{pmatrix}$ $\begin{pmatrix} u_R \\ d_R \end{pmatrix}$
$SU(2)_L \times SU(2)_R \rightarrow SU(2)_D$
(π^+, π^0, π^-)


q_L
q_R
log
TC
$\langle \bar{q}_L q_R \rangle \sim \Lambda^3_{QCD}$
Λ_{QCD}
log
$Q = \begin{pmatrix} u_L \\ d_L \end{pmatrix} \quad \begin{pmatrix} u_R \\ d_R \end{pmatrix}$
$SU(2)_L \times SU(2)_R \rightarrow SU(2)_D$
GOLDSTONES (π^+, π^0, π^-)


ELECTROWEAK / TECHNICOLOR
W^+, Z_0, W^-
(w^+, z_0, w^-)
TECNIQUARKS
$SU(N_{TC})$
MINIMAL


ELECTROWEAK / TECHNICOLOR
W+, Z0, W−
(w+, z0, w−)
TECHNIQUARKS
SU(N_TC)
SU(2)_L × U(1)_Y
T N 2 0
t+ N̄ +1/2
t− N̄ −1/2


ELECTROWEAK / TECHNICOLOR
W+, Z0, W−
(w+, z0, w−)
TECNIQUARKS
SU(NTC)
SU(2)L × U(1)Y
T
N
0
t+
N̄
+1/2
t−
N̄
−1/2

ELECTROWEAK / TECHNICOLOR

W^+, Z_0, W^-

(w^+, z_0, w^-)

$\langle T t^+ \rangle \sim \Lambda_{TC}^3$

$\langle T t^- \rangle$

TECHNIQUARKS

	$SU(N_{TC})$	$SU(2)_L \times U(1)_Y$	
T	N	2	0
t^+	$\bar{N}$	1	$+\frac{1}{2}$
t^-	$\bar{N}$	1	$-\frac{1}{2}$

ELECTROWEAK / TECHNICOLOR

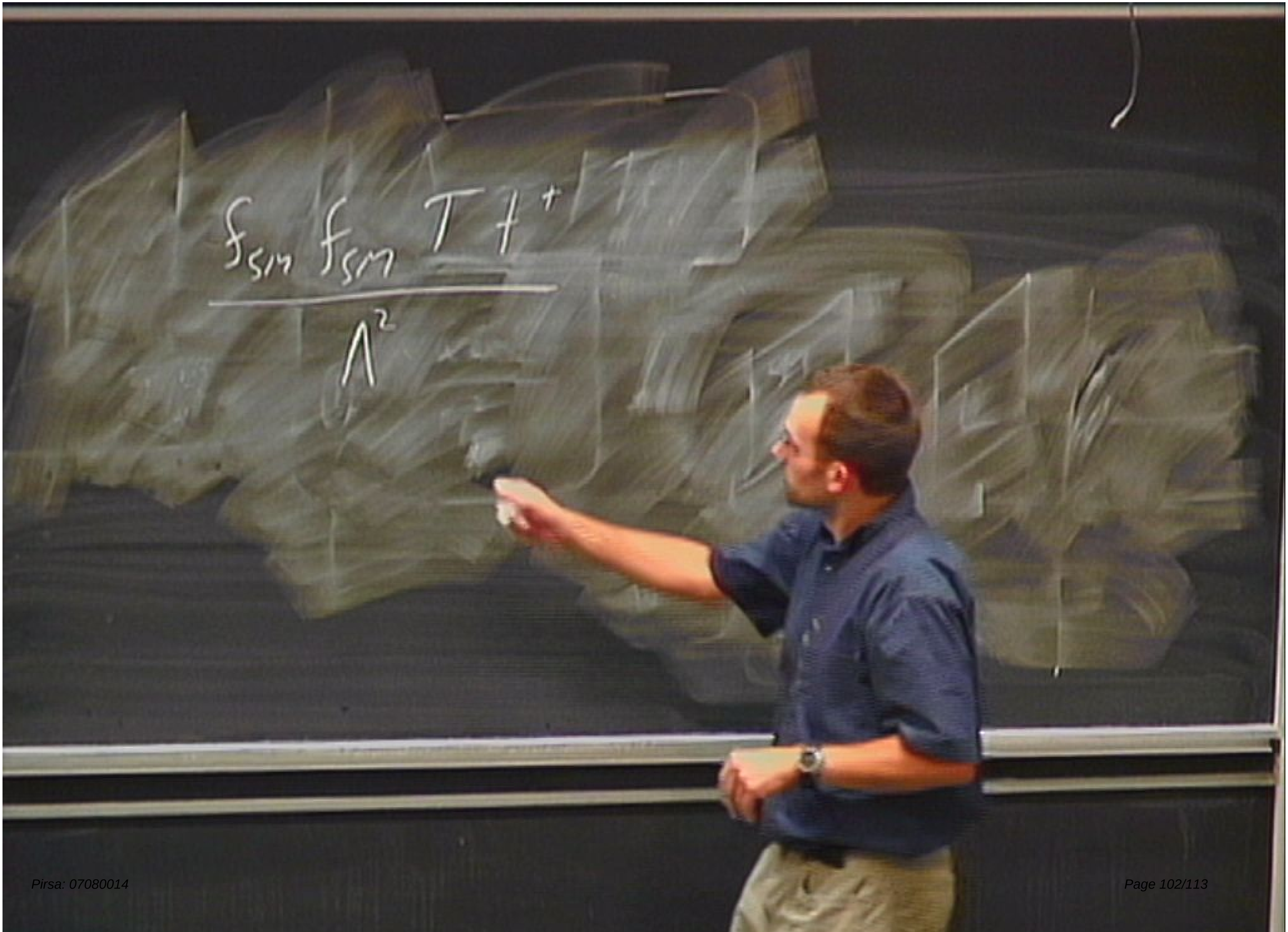
W^+ , Z_0 , W^-

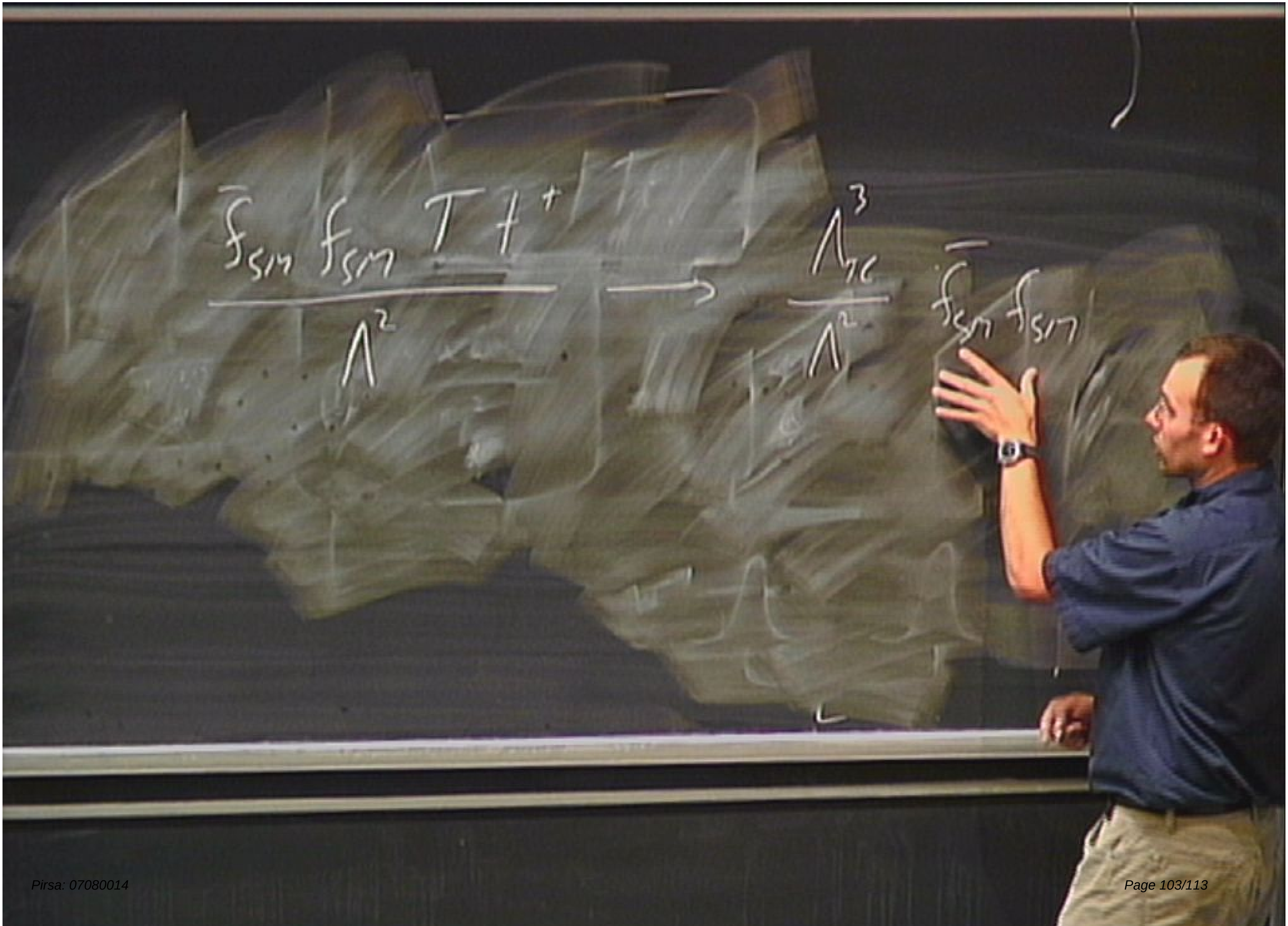
(w^+ , z_0 , w^-)

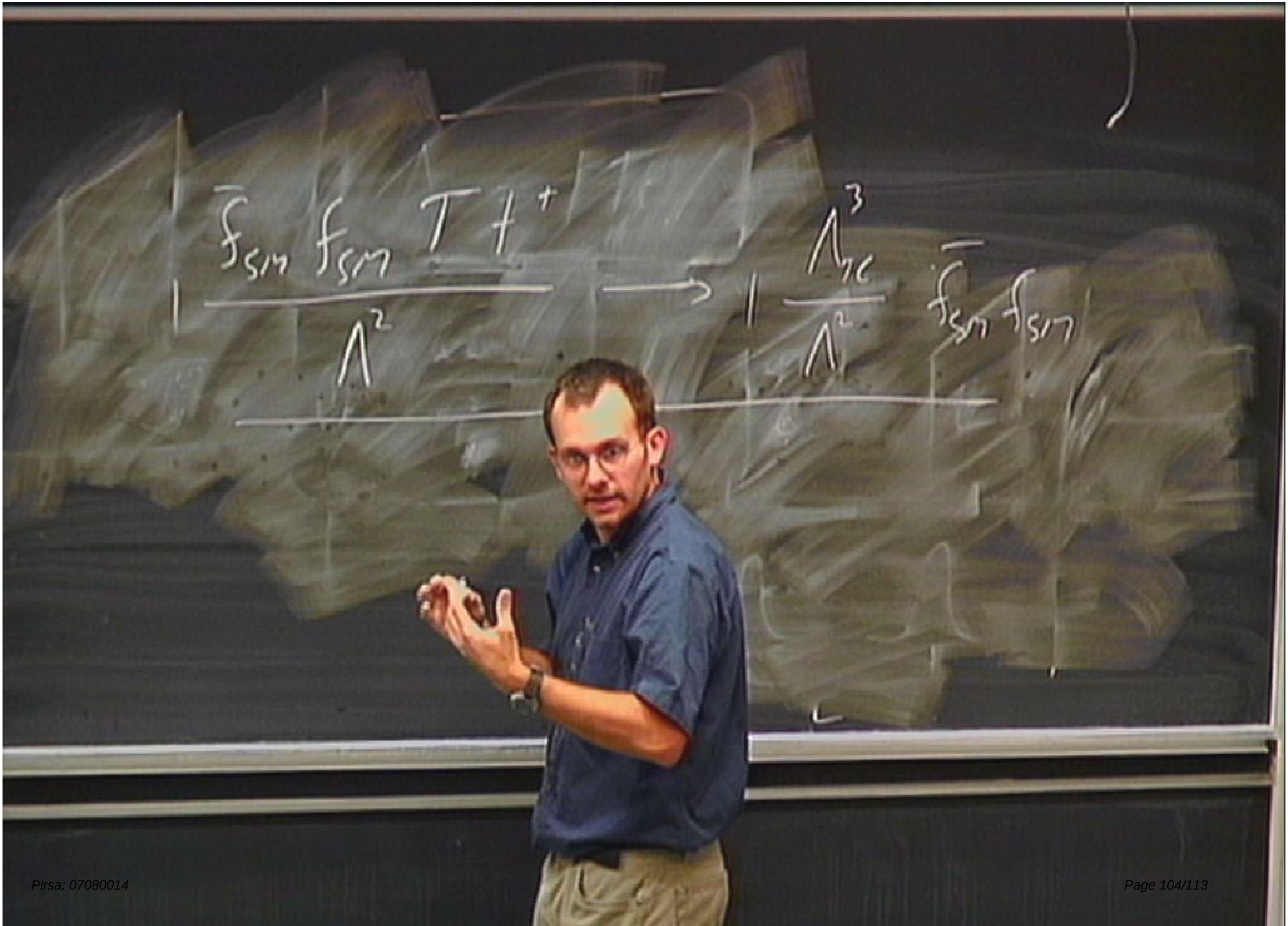
$\langle T t^+ \rangle \sim \Lambda_{TC}^3$

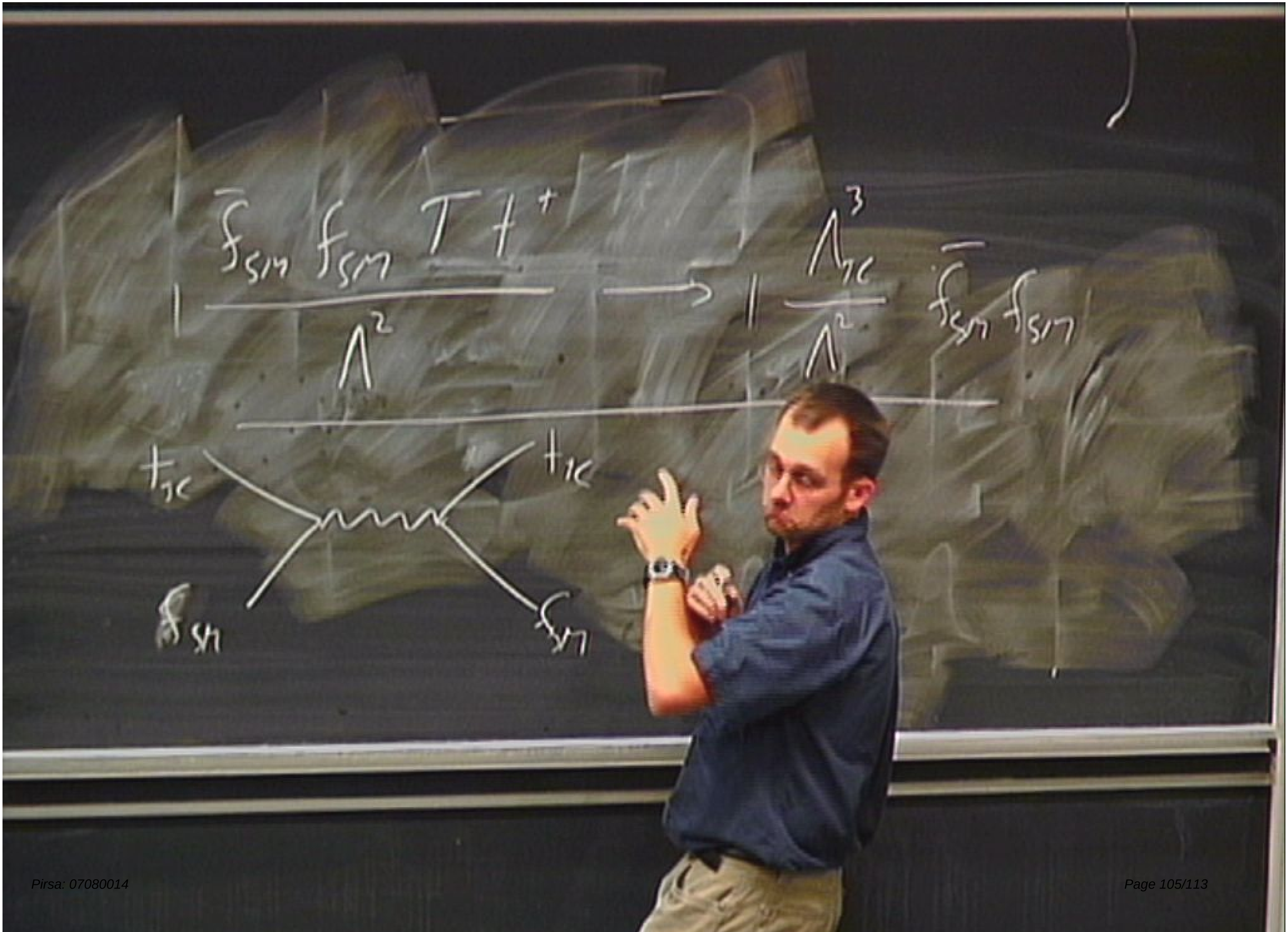
$\langle T t^- \rangle$

TECHNIQUARKS	$SU(N_{TC})$	$SU(2)_L \times U(1)_Y$	
T	N	2	0
t^+	$\bar{N}$	1	$+\frac{1}{2}$
t^-	$\bar{N}$	1	$-\frac{1}{2}$

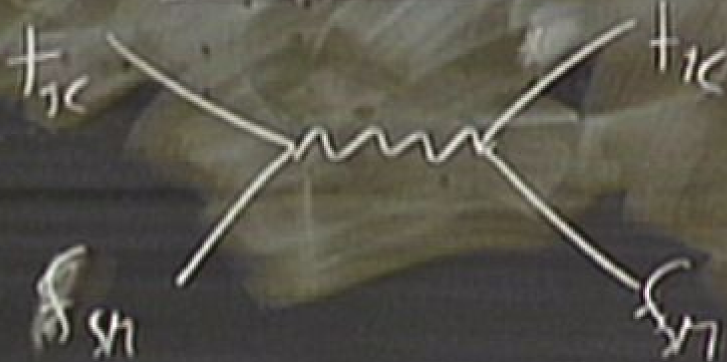

$\frac{f_{SM}\, f_{SM}\, T\, T^{+}}{\Lambda^2}$


$\frac{\bar{f}_{SM} f_{SM} T T^{+}}{\Lambda^2} \longrightarrow \frac{\Lambda_{TC}^3}{\Lambda^2} \bar{f}_{SM} f_{SM}$


$\frac{\bar{f}_{SM} f_{SM} T T^+}{\Lambda^2} \to \frac{\Lambda_{TC}^3}{\Lambda^2} \bar{f}_{SM} f_{SM}$


$\bar{f}_{SM} f_{SM} T T^{+}$
Λ^2
Λ_{TC}^3
Λ^2
$\bar{f}_{SM} f_{SM}$
t_{TC}
t_{TC}
f_{SM}
f_{SM}

$$\frac{\bar{f}_{SM} f_{SM} T T^{+}}{\Lambda^2} \longrightarrow \frac{\Lambda_{TC}^3}{\Lambda^2} \bar{f}_{SM} f_{SM}$$



$$\bar{f}_{SM} f_{SM} T T^{+} \frac{1}{\Lambda^2} \longrightarrow \frac{\Lambda_{TC}^3}{\Lambda^2} \bar{f}_{SM} f_{SM}$$

ELECTROWEAK / TECHNICOLOR

W^+, Z_0, W^-

(w^+, z_0, w^-)

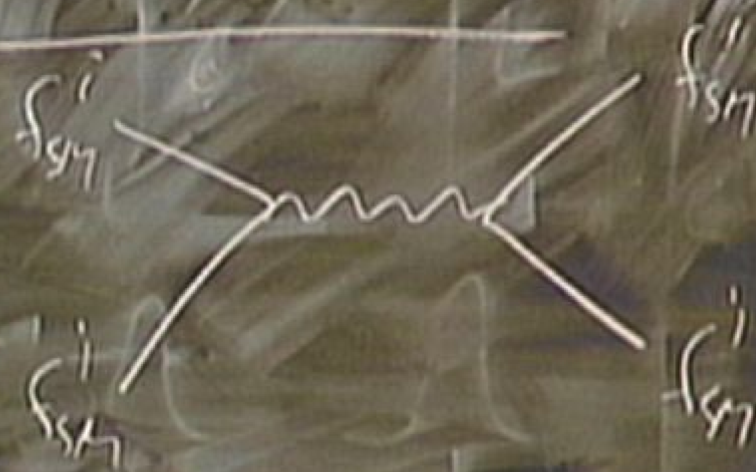
$\langle T t^+ \rangle \sim \Lambda_{TC}^3$

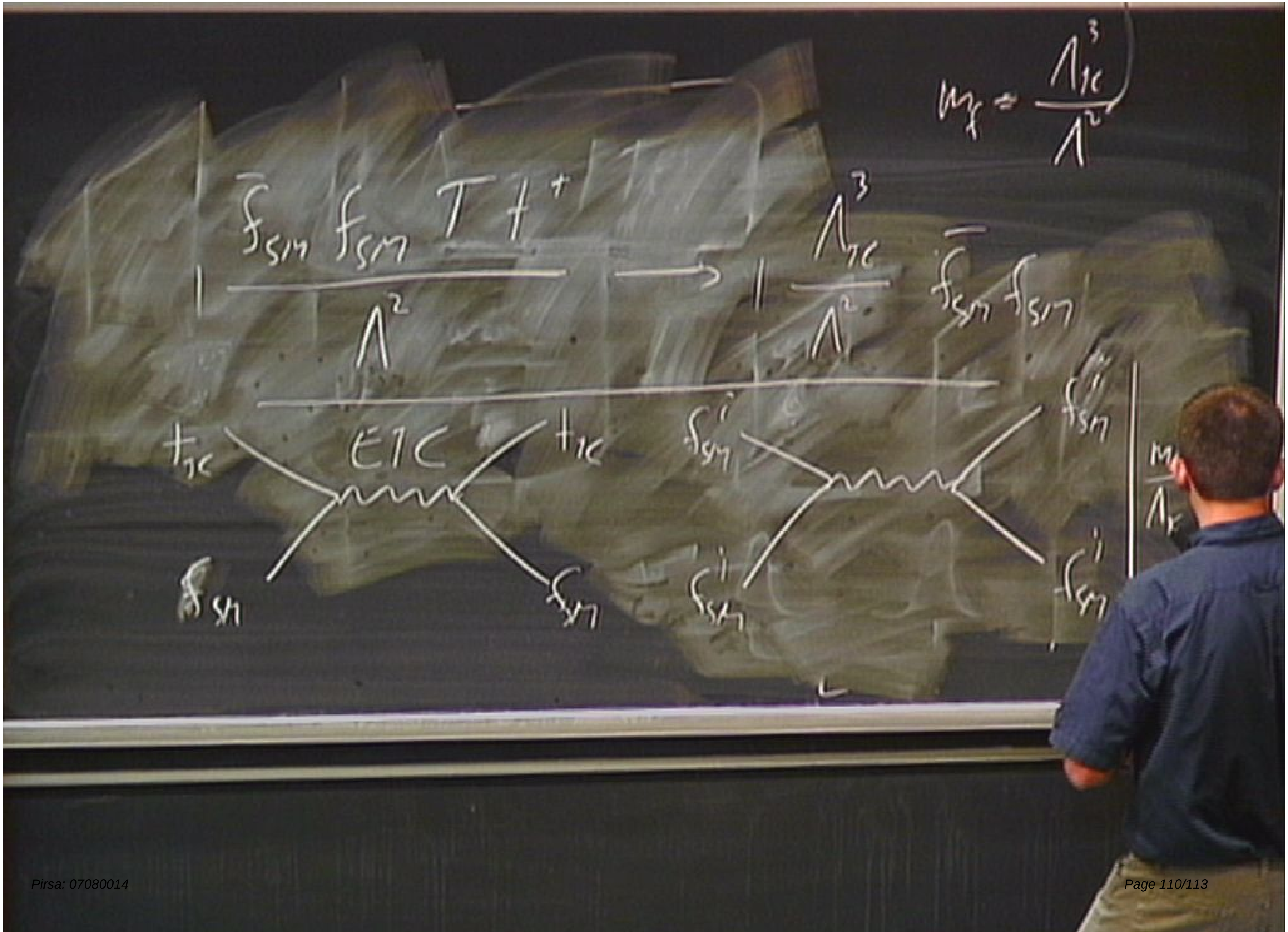
$\langle T t^- \rangle$

TECHNIQUARKS

	$SU(N_{TC})$	$SU(2)_L \times U(1)_Y$	
T	N	2	0
t^+	$\bar{N}$	1	$+\frac{1}{2}$
t^-	$\bar{N}$	1	$-\frac{1}{2}$

$$\frac{\bar{f}_{SM} f_{SM} T T^{\dagger}}{\Lambda^2} \longrightarrow \frac{\Lambda_{TC}^3}{\Lambda^2} \bar{f}_{SM} f_{SM}$$

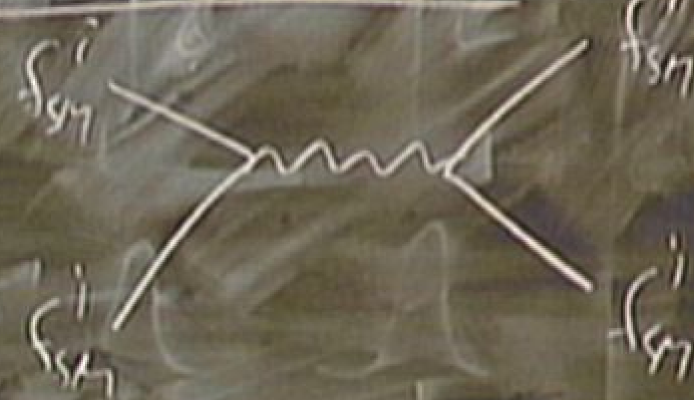




$m_f \simeq \frac{\Lambda_{TC}^3}{\Lambda^2}$
$\frac{\bar{f}_{SM} f_{SM} T T^+}{\Lambda^2} \longrightarrow \frac{\Lambda_{TC}^3}{\Lambda^2} \bar{f}_{SM} f_{SM}$
f_{TC}
ETC
f_{TC}
f_{SM}
f_{SM}
f_{SM}^i
f_{SM}^i
f_{SM}^j
f_{SM}^j

$$m_f \simeq \frac{\Lambda_{TC}^3}{\Lambda^2}$$

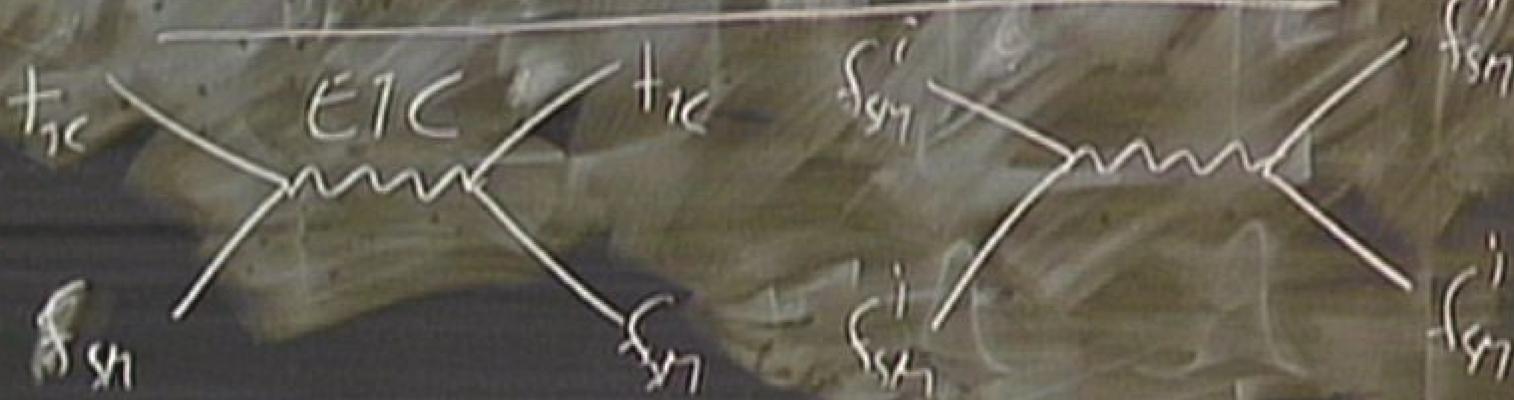
$$\frac{\bar f_{SM} f_{SM} T T^{+}}{\Lambda^2} \longrightarrow \frac{\Lambda_{TC}^3}{\Lambda^2} \bar f_{SM} f_{SM}$$



$$\frac{m_f}{\Lambda_F} \cdot \frac{ffff}{\Lambda_{TC}^2}$$

$$m_f \approx \frac{\Lambda_{TC}^3}{\Lambda^2}$$

$$\frac{\bar{f}_{SM} f_{SM} \bar{T} T}{\Lambda^2} \longrightarrow \frac{\Lambda_{TC}^3}{\Lambda^2} \bar{f}_{SM} f_{SM}$$



$$\left(\frac{m_f}{\Lambda_{TC}}\right)^2 \frac{ffff}{\Lambda_{TC}^2}$$

ELECTROWEAK / TECHNICOLOR

W^+, Z_0, W^-

(w^+, z_0, w^-)

$\langle T t^+ \rangle \sim \Lambda_{TC}^3$

$\langle T t^- \rangle$

TECHNIQUARKS

	$SU(N_{TC})$	$SU(2)_L \times U(1)_Y$	
T	N	2	0
t^+	$\bar{N}$	1	$+\frac{1}{2}$
t^-	$\bar{N}$	1	$-\frac{1}{2}$