Title: Standard Model Theory 4

Date: Jul 10, 2018 01:00 PM

URL: http://pirsa.org/18070021

Abstract:

complex scaler

$$\mathcal{L}_\phi = \partial_\mu \phi \, \partial^\mu \phi^* - V(\phi, \phi^*)$$

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if $V(|\phi|)$ global $\phi : e^{i\alpha} \phi$

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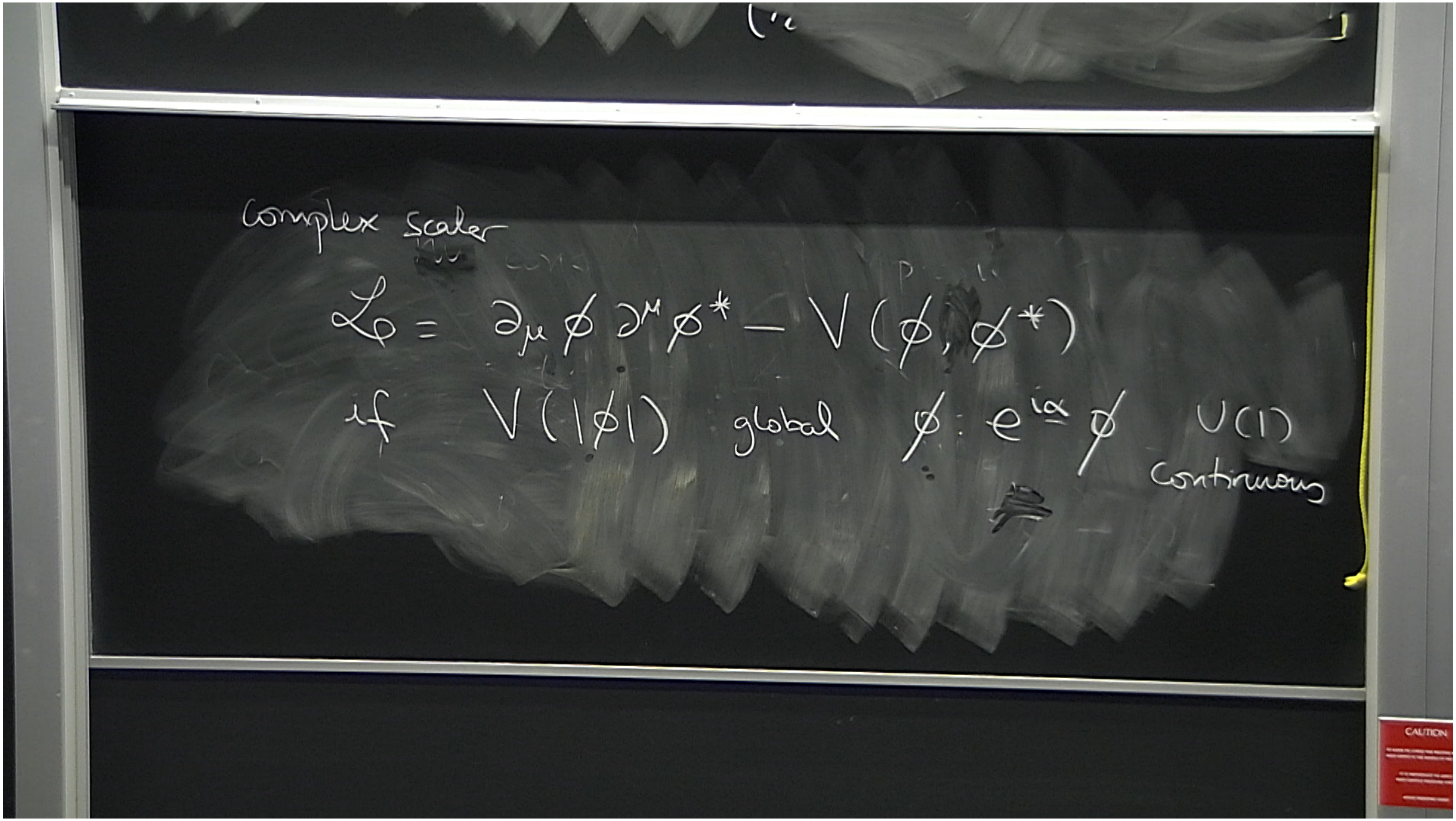
complex scalar
$\mathcal{L}_\phi = \partial_\mu \phi \, \partial^\mu \phi^* - V(\phi, \phi^*)$
if $V(|\phi|)$ global $\phi : e^{i\alpha} \phi$ $U(1)$
continuous

$$V(|\phi|) = m^2 |\phi|^2 + \lambda |\phi|^4$$

$$\partial_\phi V \,, \quad \partial_{\phi^*} V$$

$$V(|\phi|) = m^2|\phi|^2 + \lambda|\phi|^4$$

$$\partial_\phi V \, , \; \partial_{\phi^*} V = 0$$

$$\text{Hessian} \quad \begin{vmatrix} \partial_\phi^2 V & \partial_\phi V \partial_{\phi^*} V \\ \cdot & \partial_{\phi^*}^2 V \end{vmatrix}$$

$$V(|\phi|) = m^2|\phi|^2 + \lambda|\phi|^4$$

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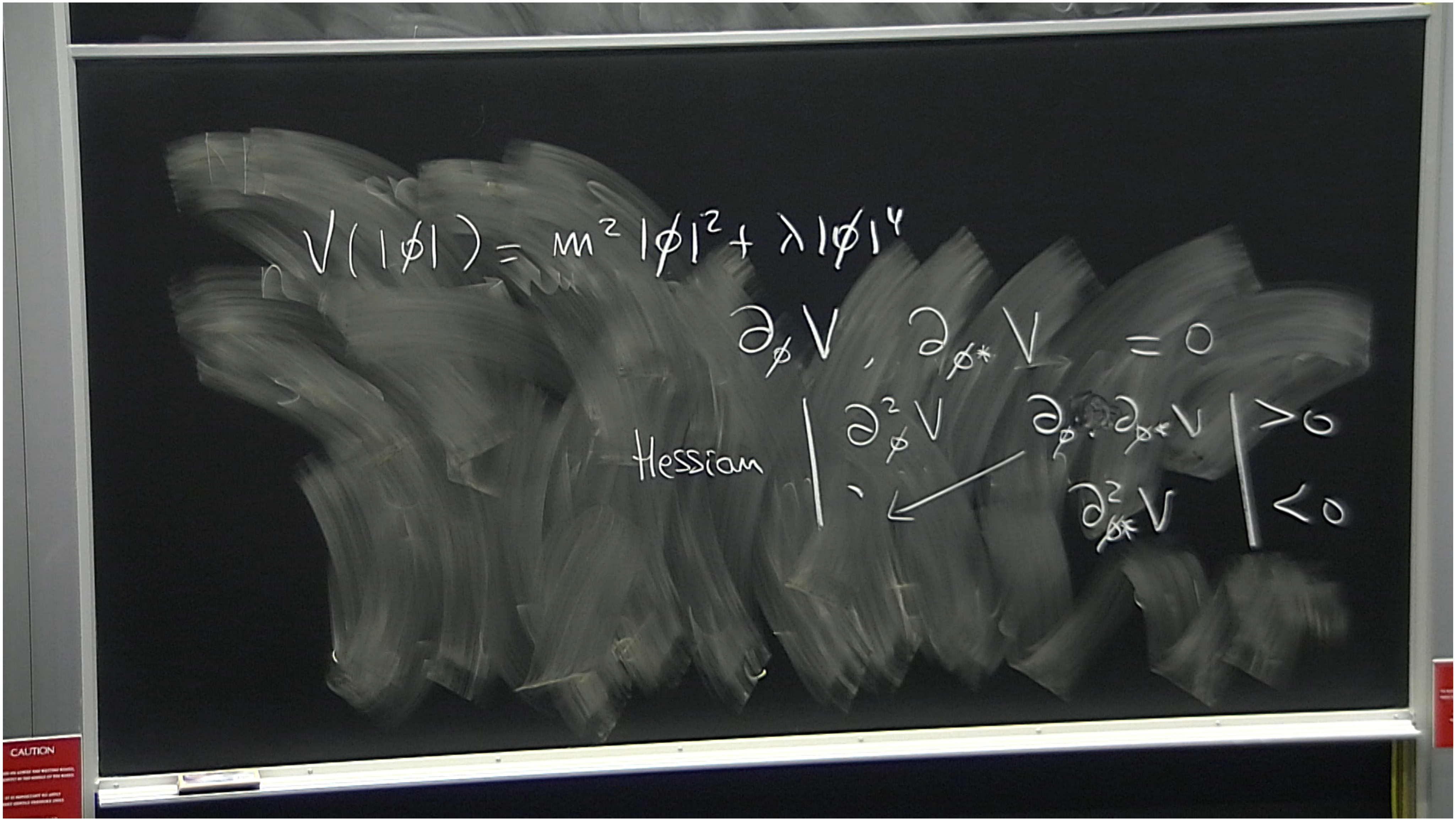
$$\text{Hessian}\quad \begin{vmatrix} \partial_\phi^2 V & \partial_\phi \partial_{\phi^*} V \\ \cdot & \partial_{\phi^*}^2 V \end{vmatrix}$$


$V(|\phi|) = m^2|\phi|^2 + \lambda|\phi|^4$
$\partial_\phi V, \partial_{\phi^*} V = 0$
Hessian
$\partial_\phi^2 V$
$\partial_\phi \partial_{\phi^*} V$
$\partial_{\phi^*}^2 V$
>0
<0

$V(|\phi|^2) = m^2|\phi|^2 + \lambda|\phi|^4$

$\partial_\phi V, \ \partial_{\phi^*} V = 0$

Hessian $\begin{vmatrix} \partial_\phi^2 V & \partial_\phi \partial_{\phi^*} V \\ \cdot & \partial_{\phi^*}^2 V \end{vmatrix} \begin{matrix} >0 \\ <0 \end{matrix}$

(1) $\phi = 0$

(2) if $m^2 < 0$ $\quad |\phi| = \sqrt{\frac{-m^2}{2\lambda}}$

$V(\phi)$

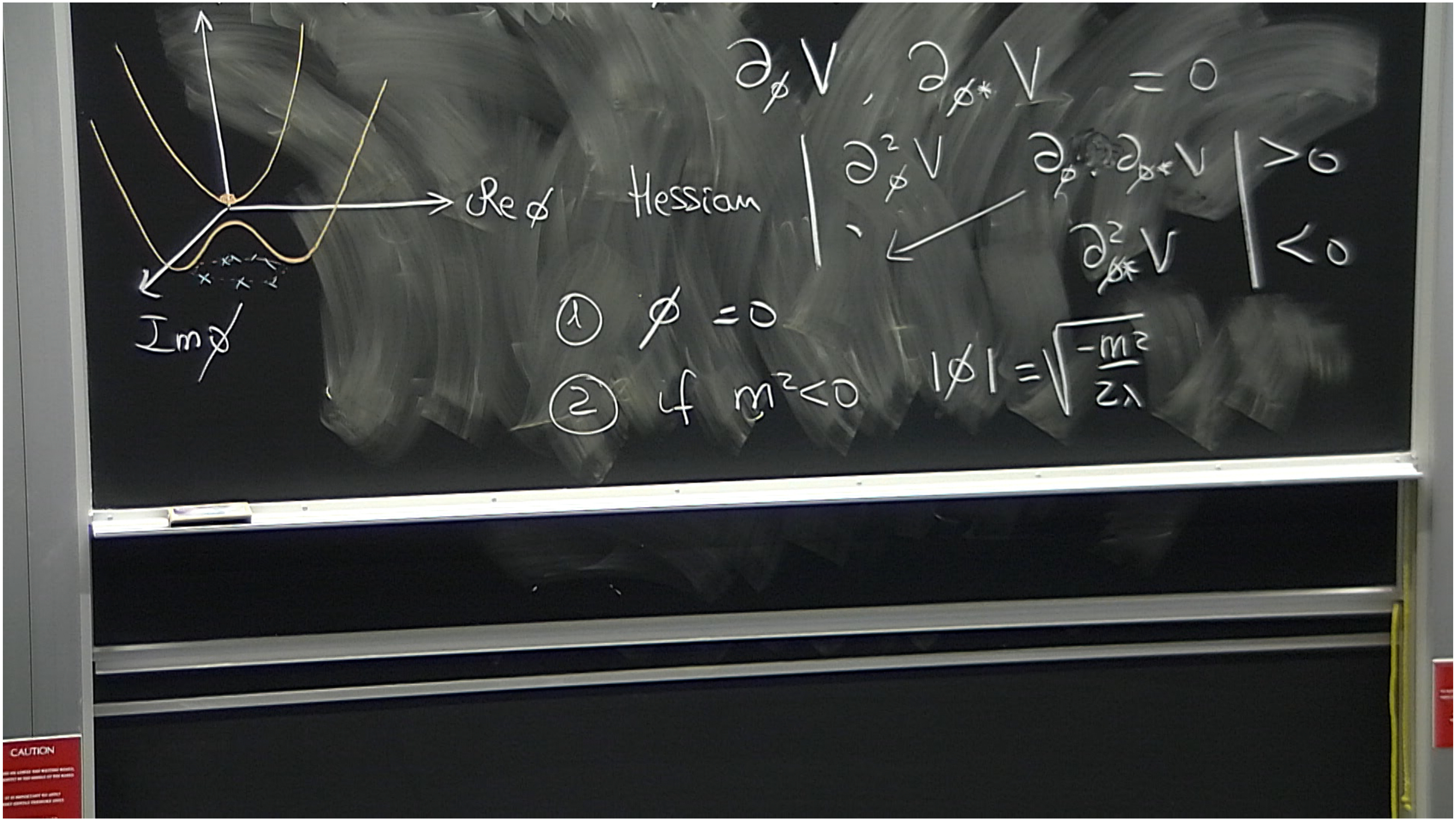
$$V(|\phi|) = m^2|\phi|^2 + \lambda|\phi|^4$$

$$\partial_\phi V, \ \partial_{\phi^*} V = 0$$

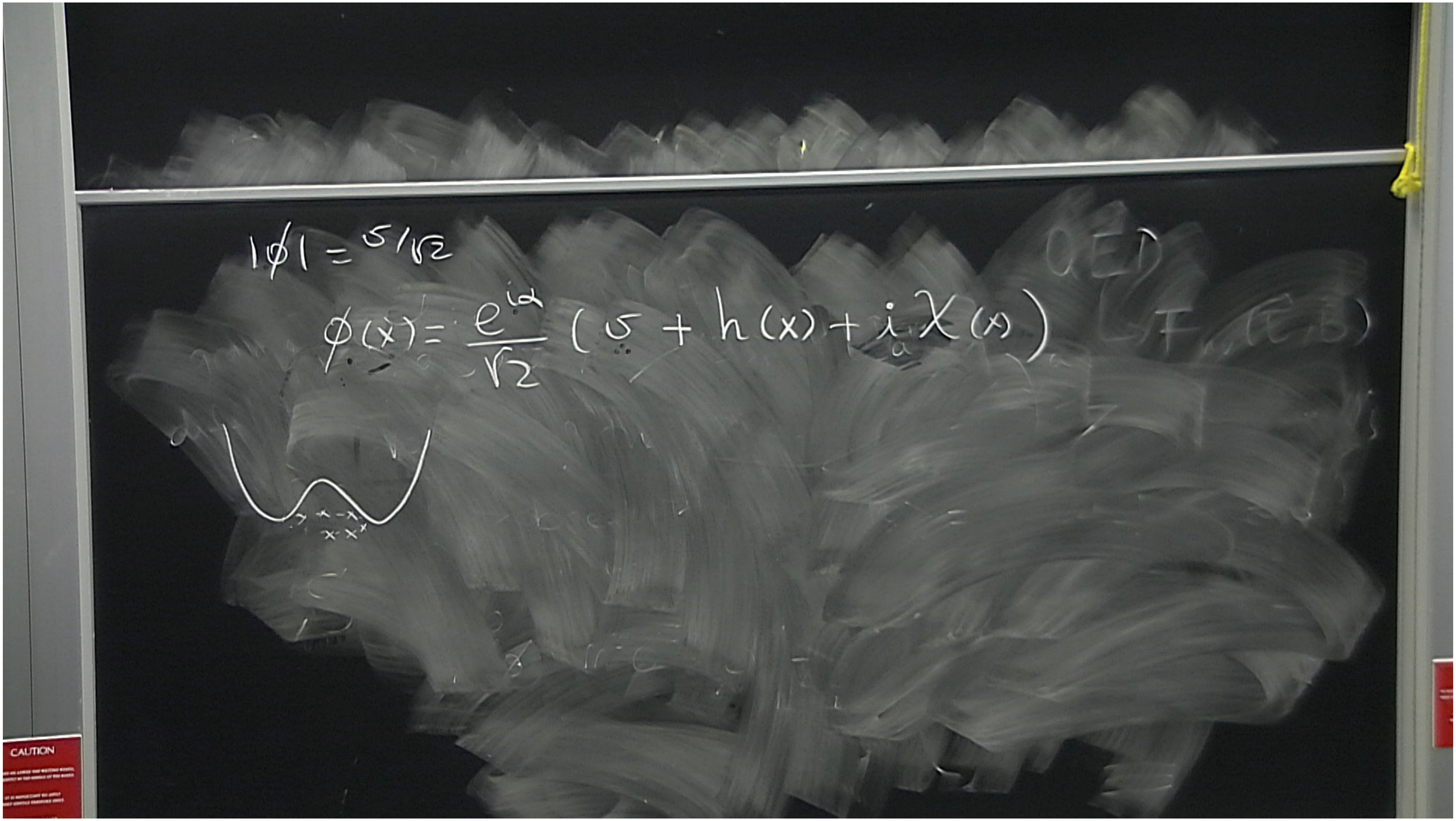
Hessian $\begin{vmatrix} \partial^2_\phi V & \partial_\phi \partial_{\phi^*} V \\ \cdot & \partial^2_{\phi^*} V \end{vmatrix} \begin{matrix} > 0 \\ < 0 \end{matrix}$

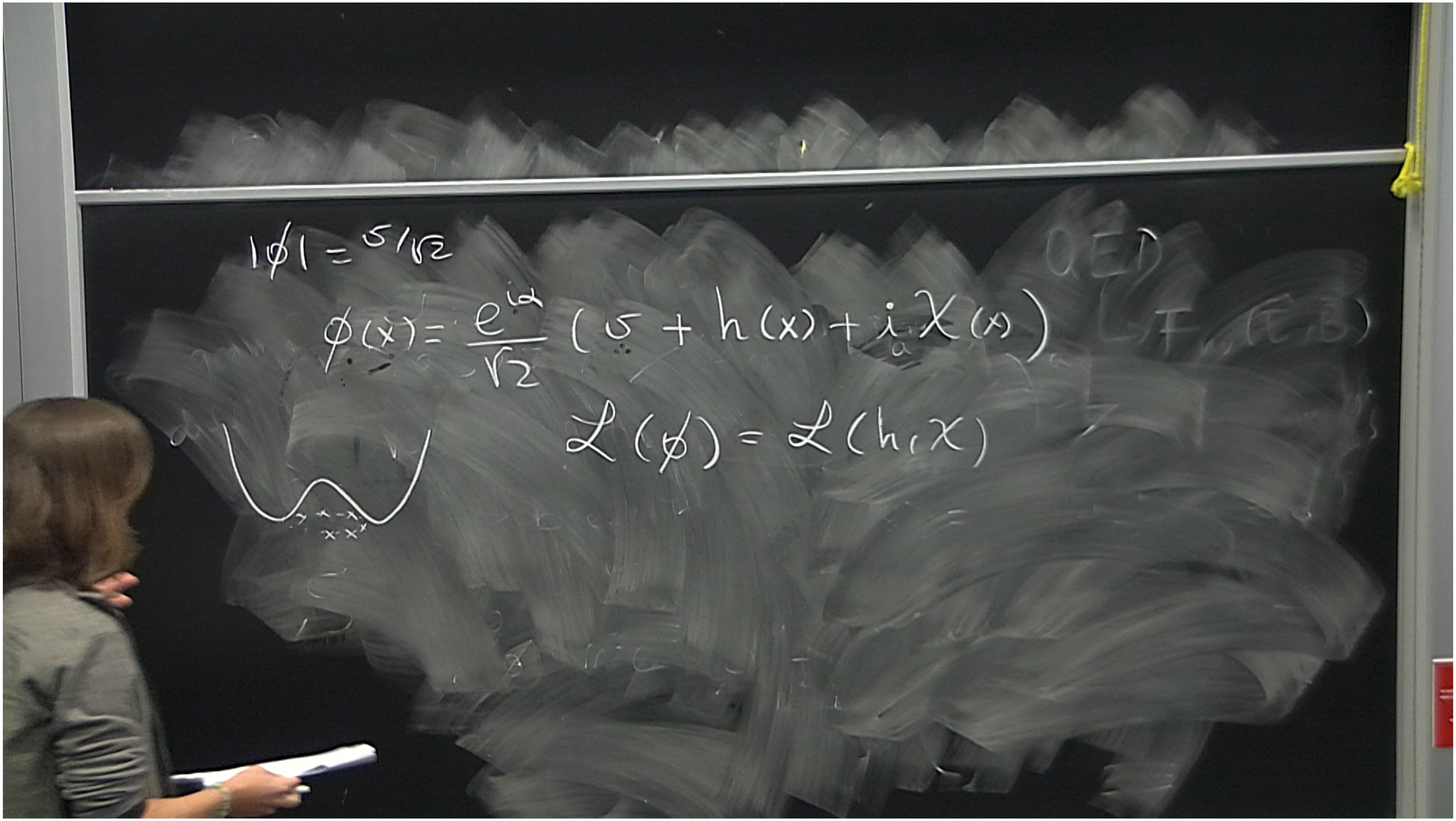
① $\phi = 0$

② if $m^2 < 0$ $\quad |\phi| = \sqrt{\frac{-m^2}{2\lambda}}$



$\mathrm{Re}\,\phi$
$\mathrm{Im}\,\phi$
$\partial_\phi V \,,\ \partial_{\phi^*} V = 0$
Hessian
$\begin{vmatrix} \partial_\phi^2 V & \partial_\phi \partial_{\phi^*} V \\ \cdot & \partial_{\phi^*}^2 V \end{vmatrix}$
>0
<0
① $\phi = 0$
② if $m^2 < 0$ $\quad |\phi| = \sqrt{\frac{-m^2}{2\lambda}}$


$|\phi| = v/\sqrt{2}$
$\phi(x) = \frac{e^{i\alpha}}{\sqrt{2}}\left(v + h(x) + i\chi(x)\right)$
QED


$|\phi| = v/\sqrt{2}$
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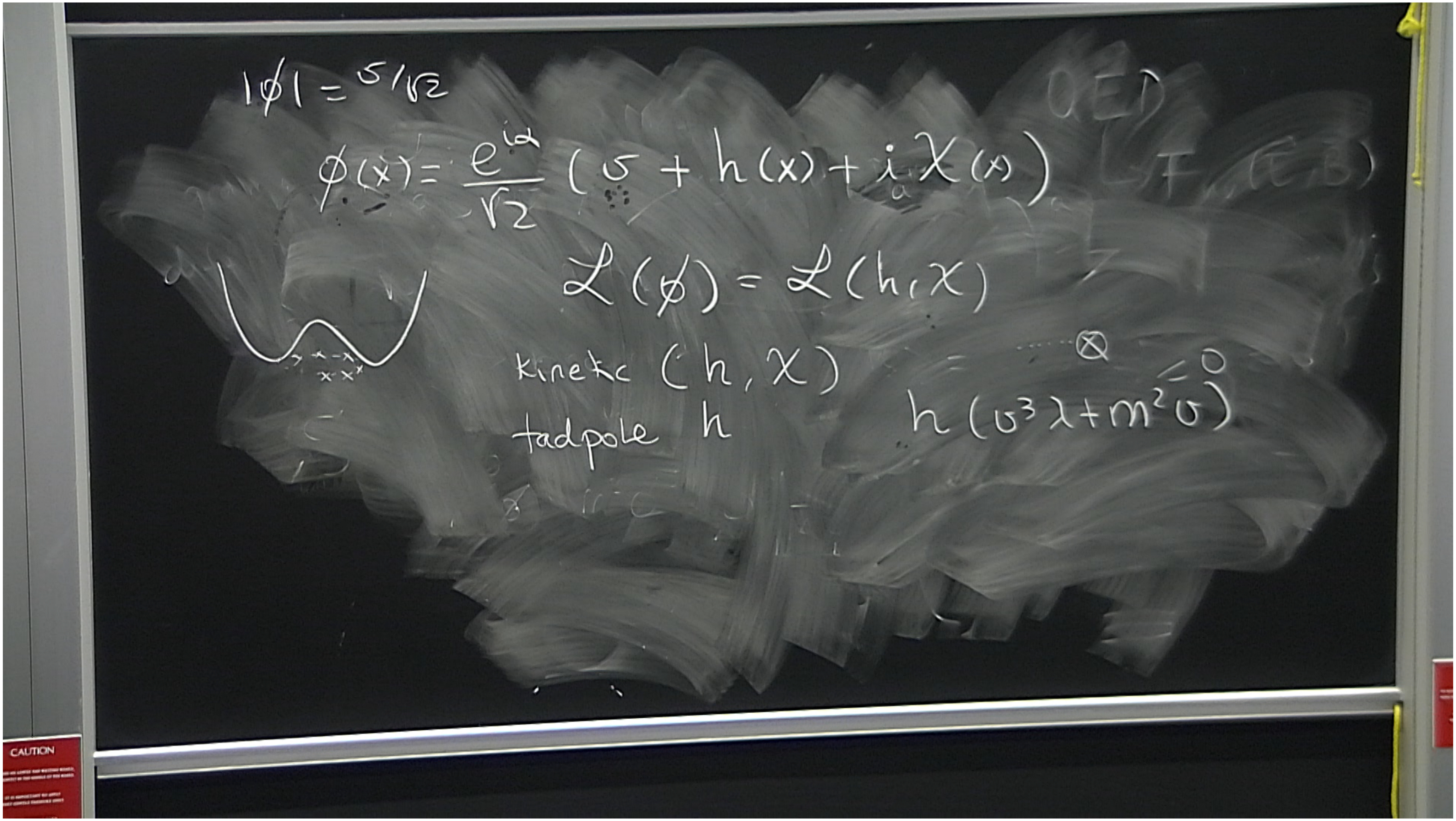
$\phi(x) = \frac{e^{i\alpha}}{\sqrt{2}}\left(v + h(x) + i\chi(x)\right)$
$\mathcal{L}(\phi) = \mathcal{L}(h, \chi)$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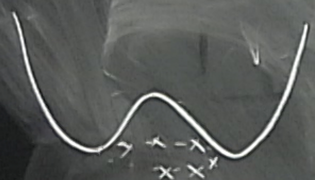
QED
$\mathcal{L}(\phi) = \mathcal{L}(h, \chi)$
kinetic (h, χ)
tadpole h
$h(v^3\lambda + m^2 v) = 0$

$|\phi| = v/\sqrt{2}$

$$\phi(x) = \frac{e^{i\alpha}}{\sqrt{2}}\left(v + h(x) + i\,\chi(x)\right)$$



$$\mathcal{L}(\phi) = \mathcal{L}(h, \chi)$$

kinetic (h, χ)

tadpole h $\qquad h(v^3\lambda + m^2 v) = 0$

mass term h $\qquad h^2\left(\frac{1}{2}m^2 + \frac{3}{2}\lambda v^2\right) > 0$

$|\phi| = v/\sqrt{2}$

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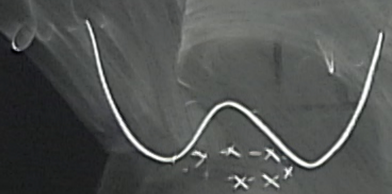

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kinetic (h, χ)

tadpole h $\quad h(v^3\lambda + m^2 v) = 0$

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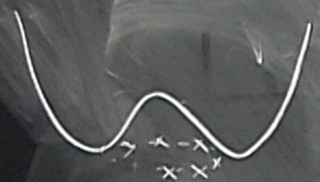
massless χ $\quad \left(\frac{1}{2}m^2 + \frac{1}{2}\lambda v^2\right)$

interactions

$|\phi| = v/\sqrt{2}$

$$\phi(x) = \frac{e^{i\alpha}}{\sqrt{2}}\left(v + h(x) + i\chi(x)\right)$$



$$\mathcal{L}(\phi) = \mathcal{L}(h,\chi)$$

kinetic (h,χ) $\otimes$

$= 0$

tadpole h $\quad h(v^3\lambda + m^2 v)$

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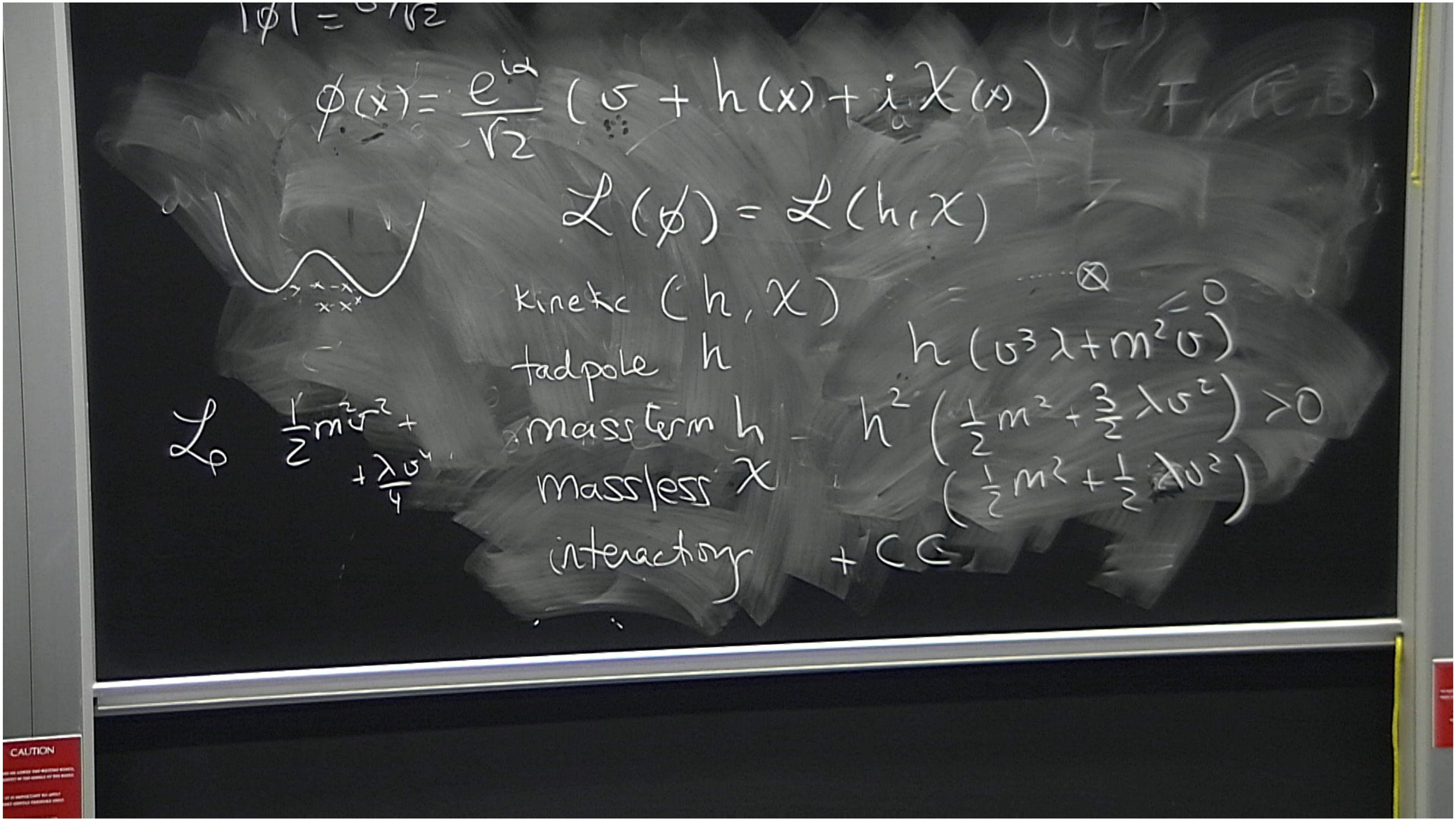
interaction $\quad + CC$



$|\phi| = v/\sqrt{2}$
$\phi(x) = \frac{e^{i\alpha}}{\sqrt{2}} (v + h(x) + i\chi(x))$
$\mathcal{L}(\phi) = \mathcal{L}(h, \chi)$
kinetic (h, χ)
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interactions $\quad$ + CC
$\mathcal{L}_\phi \quad \frac{1}{2}m^2 v^2 + \frac{\lambda v^4}{4}$

$|\phi| = v/\sqrt{2}$

Goldstone boson

$$\phi(x) = \frac{e^{i\alpha}}{\sqrt{2}}\left(v + h(x) + i\,\chi(x)\right)$$

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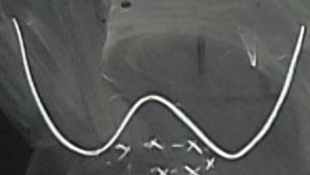

Kinetic (h, χ)

tadpole h $\quad h(v^3\lambda + m^2 v) = 0$

mass term h $\quad h^2\left(\frac{1}{2}m^2 + \frac{3}{2}\lambda v^2\right) > 0$

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$\mathcal{L}_\phi \quad \frac{1}{2}m^2 v^2 + \frac{\lambda v^4}{4}$

$|\phi| = v/\sqrt{2}$

Goldstone boson

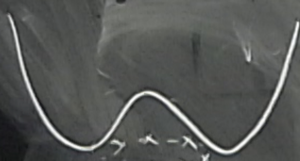
$\phi(x) = \frac{e^{i\alpha}}{\sqrt{2}}\left(v + h(x) + i\chi(x)\right)$

accidental

$\chi \mapsto \chi + c$

$\partial\chi$

$\mathcal{L}(\phi) = \mathcal{L}(h,\chi)$



kinetic (h,χ) $= \otimes$ $= 0$

tadpole h $\quad h(v^3\lambda + m^2 v)$

mass term h $\quad h^2\left(\frac{1}{2}m^2 + \frac{3}{2}\lambda v^2\right) > 0$

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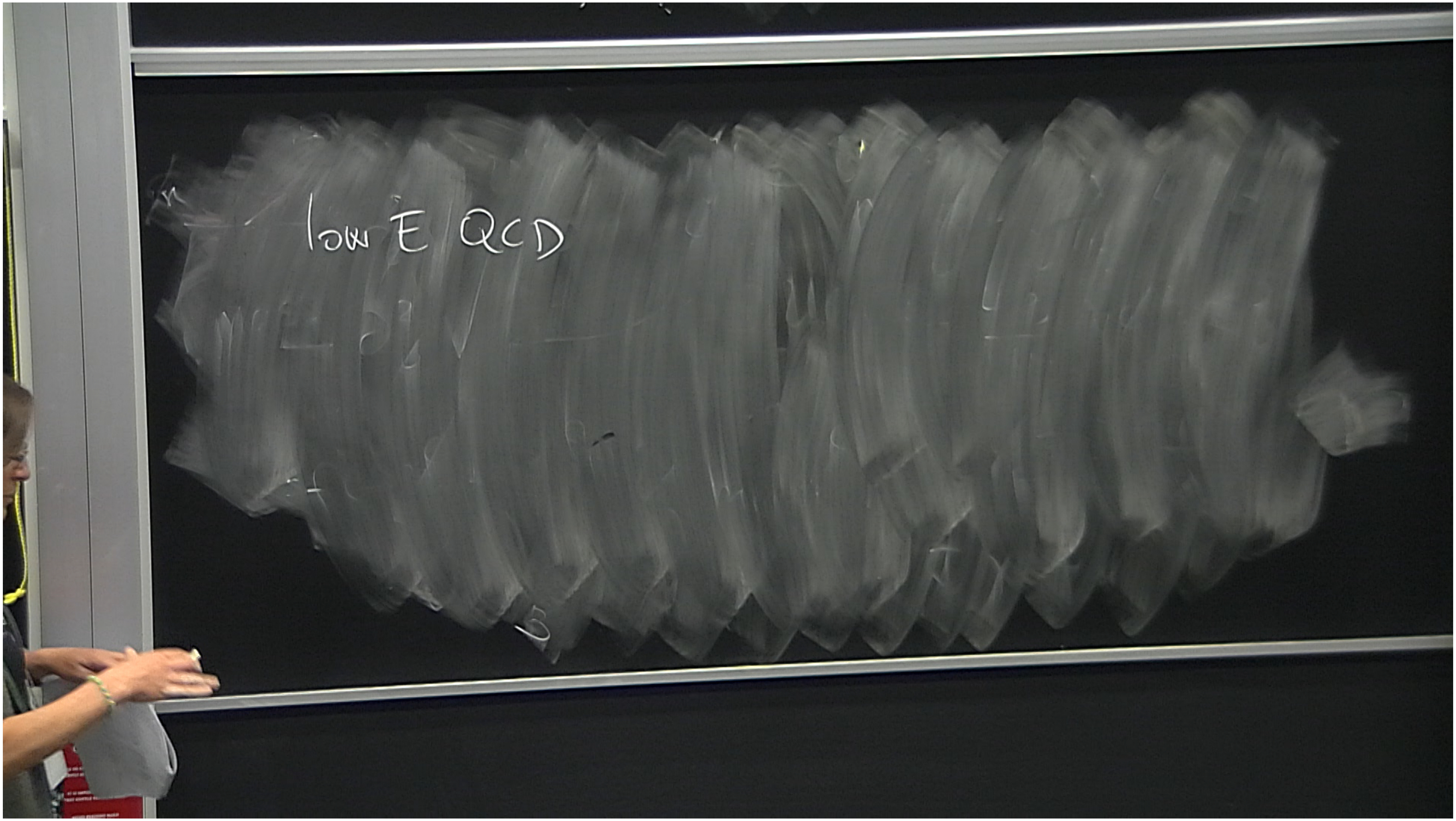
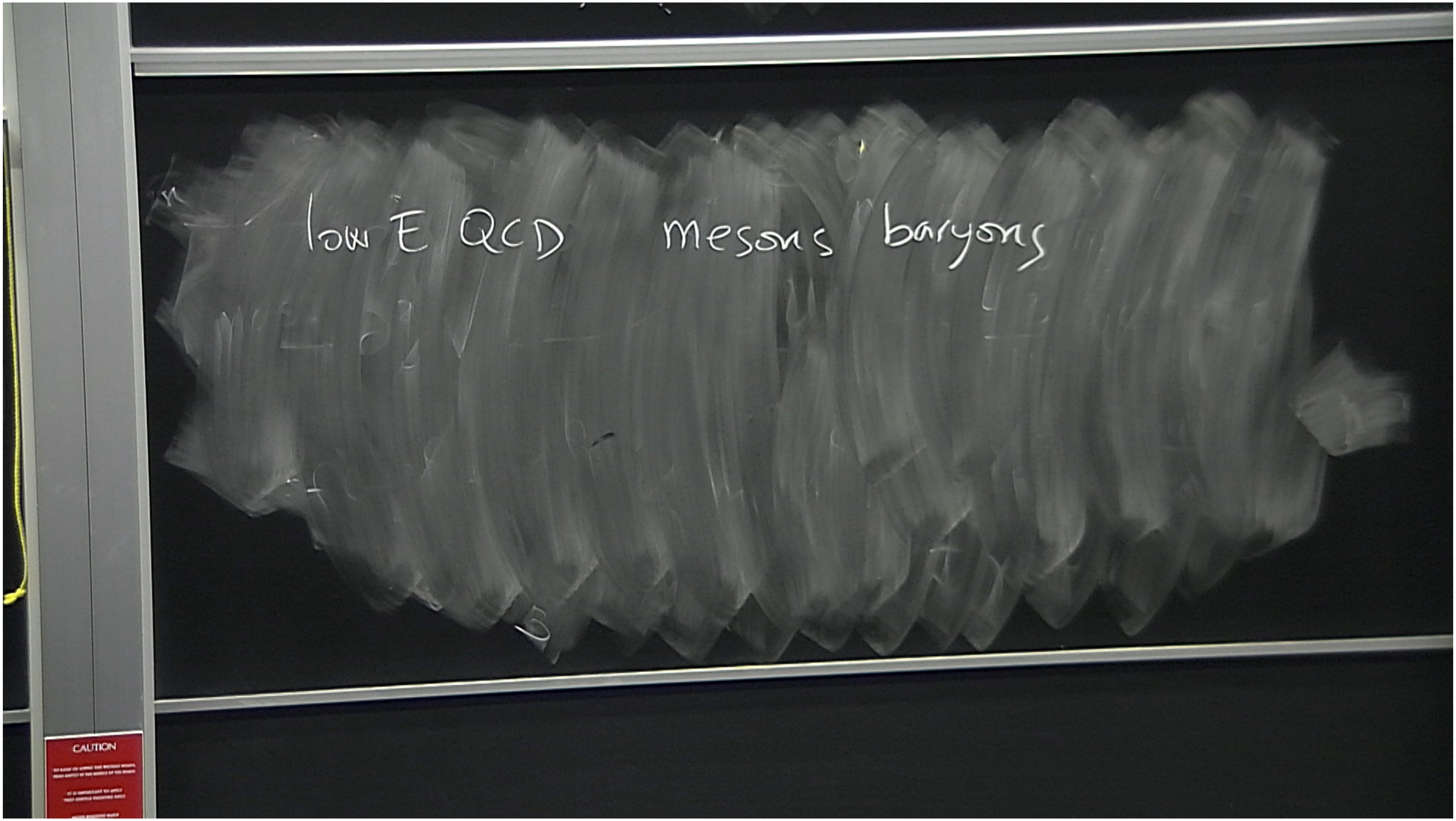
$\mathcal{L}_\phi \quad \frac{1}{2}m^2 v^2 + \frac{\lambda v^4}{4}$


low E QCD


low E QCD mesons baryons
CAUTION

low E $\underbrace{QCD}_{SU(3)_c}$ mesons baryons

$m_u \simeq m_d \approx 0$

$\bar{\psi}\not{\partial}\psi - m\bar{\psi}\psi$ fermions $m=0$ chiral symm

$\psi \to e^{i\alpha}\psi$

low E $\underbrace{\text{QCD}}_{SU(3)_c}$ mesons baryons

$m_u \simeq m_d \approx 0$

$\bar\psi \underset{LL\;RR}{\not\partial} \psi - \underset{LR}{\cancel{m\bar\psi\psi}}$ fermions $m=0$ chiral symm

$\langle \bar\psi_L \psi_R \rangle$

$\psi_{\substack{L\\R}} \to e^{i\alpha_{\substack{L\\R}}} \psi_{\substack{L\\R}}$

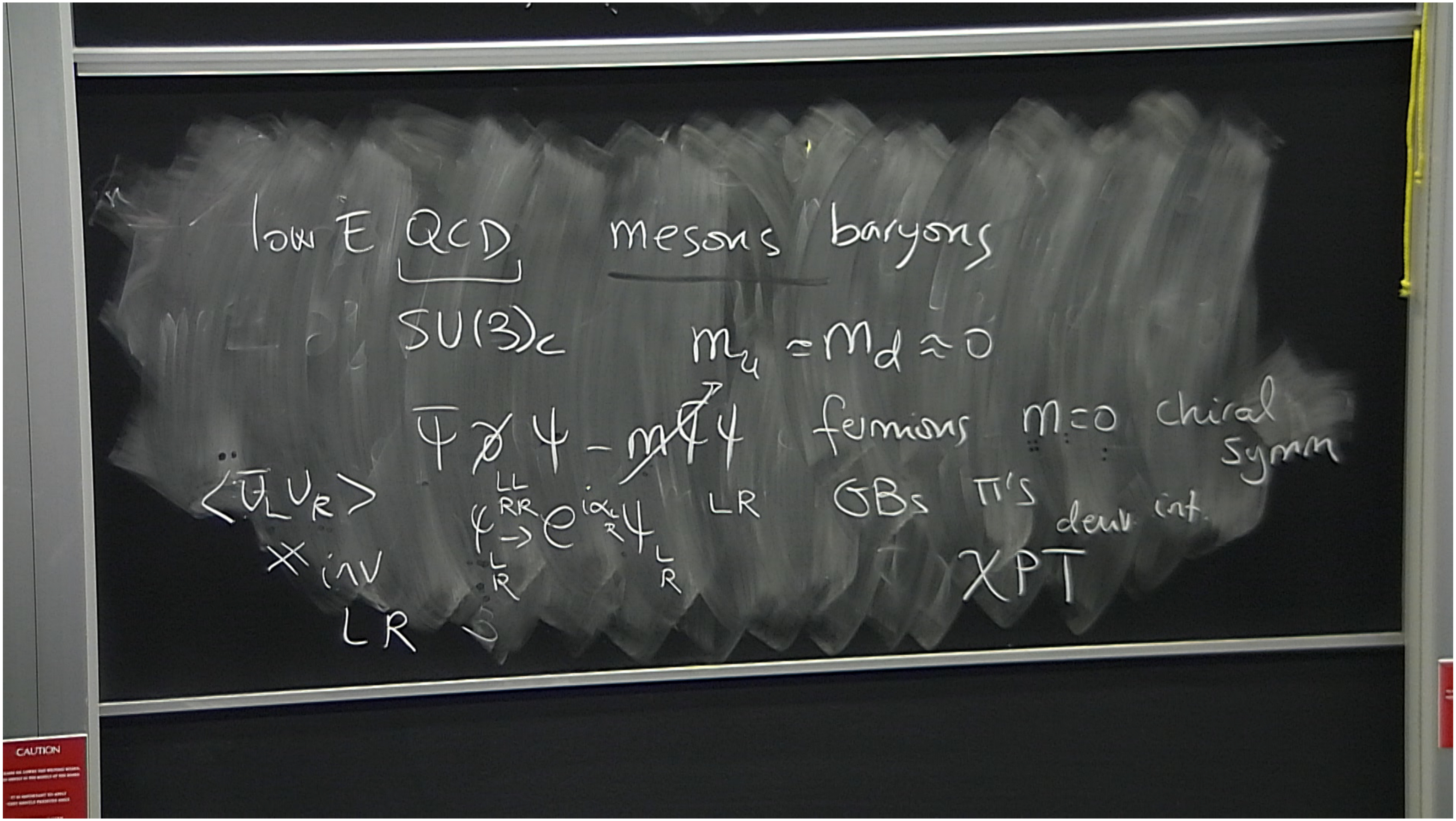
low E $\underbrace{\text{QCD}}_{SU(3)_c}$ mesons baryons

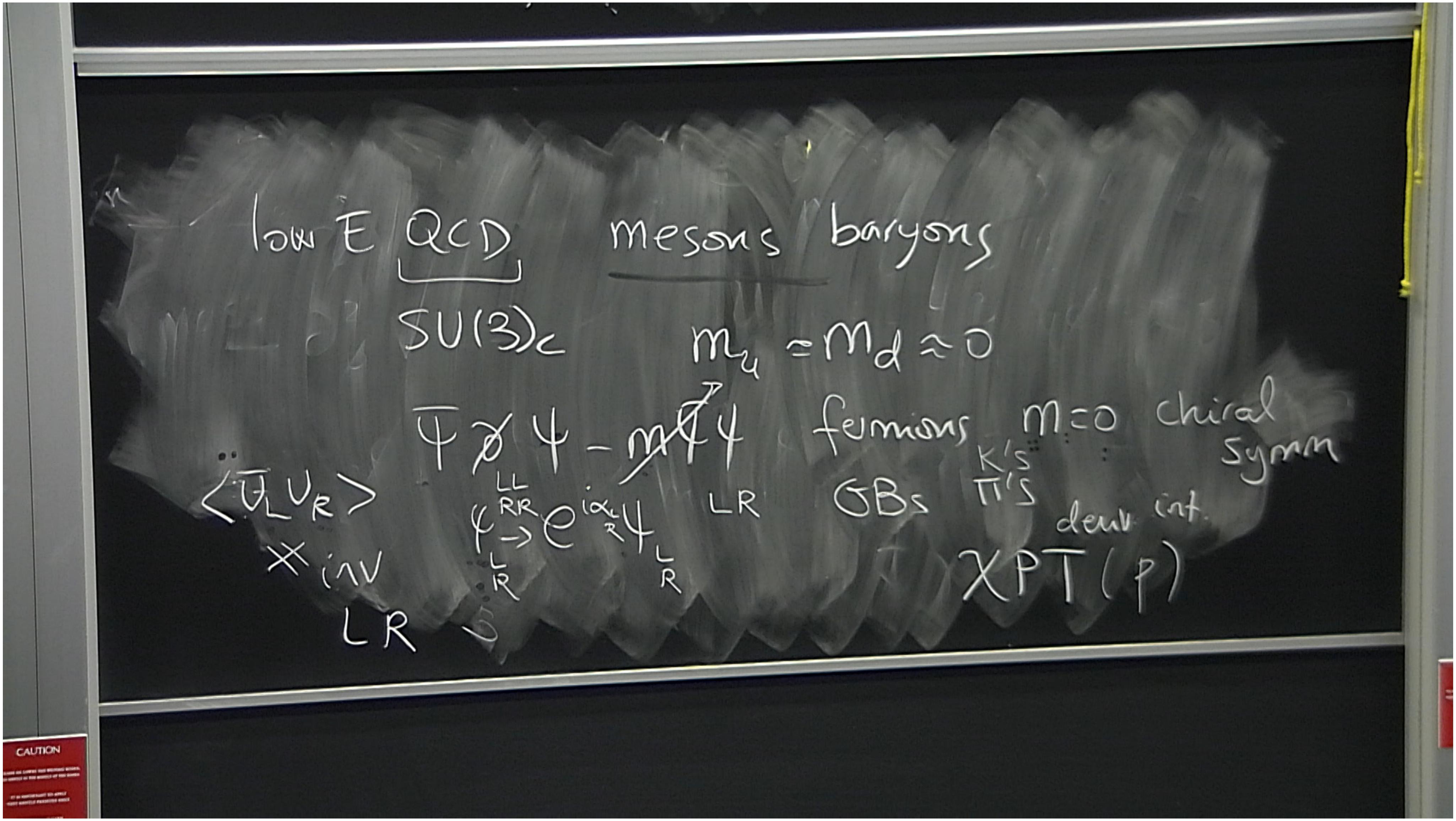
$m_u \simeq m_d \approx 0$

$\underbrace{\bar\psi \not\partial \psi}_{LL\;RR} - \underbrace{\cancel{m\bar\psi\psi}}_{LR}$ fermions $m=0$ chiral symm

$\langle \bar\psi_L \psi_R \rangle$ $\not\!\times$ inv LR

$\psi_{L,R} \to e^{i\alpha_{L,R}} \psi_{L,R}$


low E QCD
mesons baryons
$SU(3)_c$
$m_u \simeq m_d \approx 0$
$\bar\Psi \not\partial \Psi - \cancel{m \bar\Psi \Psi}$
fermions m=0 chiral symm
$\langle \bar\Psi_L \Psi_R \rangle$
✗ inv
LR
LL RR
$\psi_{L,R} \to e^{i\alpha_{L,R}} \psi_{L,R}$
LR
GBs π's
deriv. int.
χPT


low E QCD mesons baryons
SU(3)$_c$
$m_u \simeq m_d \approx 0$
$\bar\psi \not\partial \psi - \cancel{m \bar\psi \psi}$
fermions $m=0$ chiral symm
K's π's
GBs
LL RR LR
$\langle \bar\psi_L \psi_R \rangle$
$\psi_{L,R} \to e^{i\alpha_{L,R}} \psi_{L,R}$
deriv int.
χPT(p)
✗ inv
LR

low E QCD   mesons   baryons   pseudo-GBs

$\underbrace{\text{QCD}}_{SU(3)_c}$

$m_u \simeq m_d \approx 0$

$\bar{\psi} \not{\partial} \psi - \cancel{m \bar{\psi} \psi}$ fermions $m=0$ chiral symm

$\langle \bar{\psi}_L \psi_R \rangle$ $\psi_{L,R} \to e^{i\alpha_{L,R}} \psi_{L,R}$ LL RR   LR   GBs   K's π's   deriv int.

✗ inv $\chi PT(p)$

LR

low E $\underbrace{\text{QCD}}_{SU(3)_c}$ mesons baryons pseudo-GBs

$\mathcal{L}(\partial_\mu \pi)$

$m_u \approx m_d \approx 0$

$\bar{\psi} \gamma \psi - \cancel{m \bar{\psi} \psi}$ fermions $m=0$ chiral symm

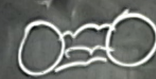
$\langle \bar{\psi}_L \psi_R \rangle$ ✗ inv LR

$\overset{LL}{\underset{RR}{}}$ $\psi_{L,R} \to e^{i\alpha_{L,R}} \psi_{L,R}$ LR

GBs K's π's deriv int.

$\chi PT(p)$

low E $\underbrace{\text{QCD}}_{SU(3)_c}$



mesons

baryons

pseudo-GBs

$m_u \simeq m_d \approx 0$

$\mathcal{L}(\partial\pi)$

$\bar{\psi} \not{\partial} \psi - \cancel{m\bar{\psi}\psi}$

LL RR LR

fermions $m=0$ chiral symm

$\psi_{L,R} \to e^{i\alpha_{L,R}} \psi_{L,R}$

GBs π's K's

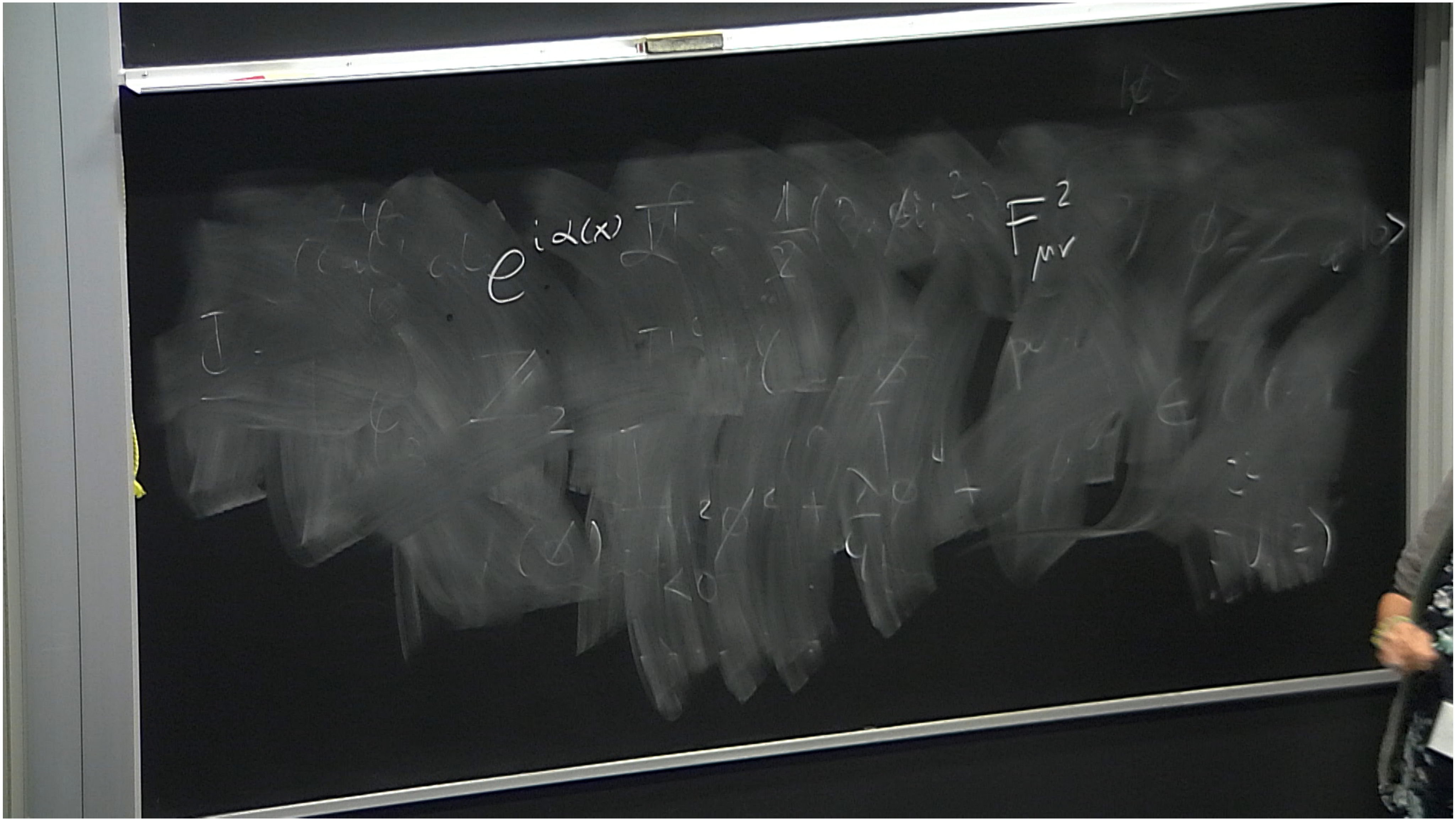
deriv. int.

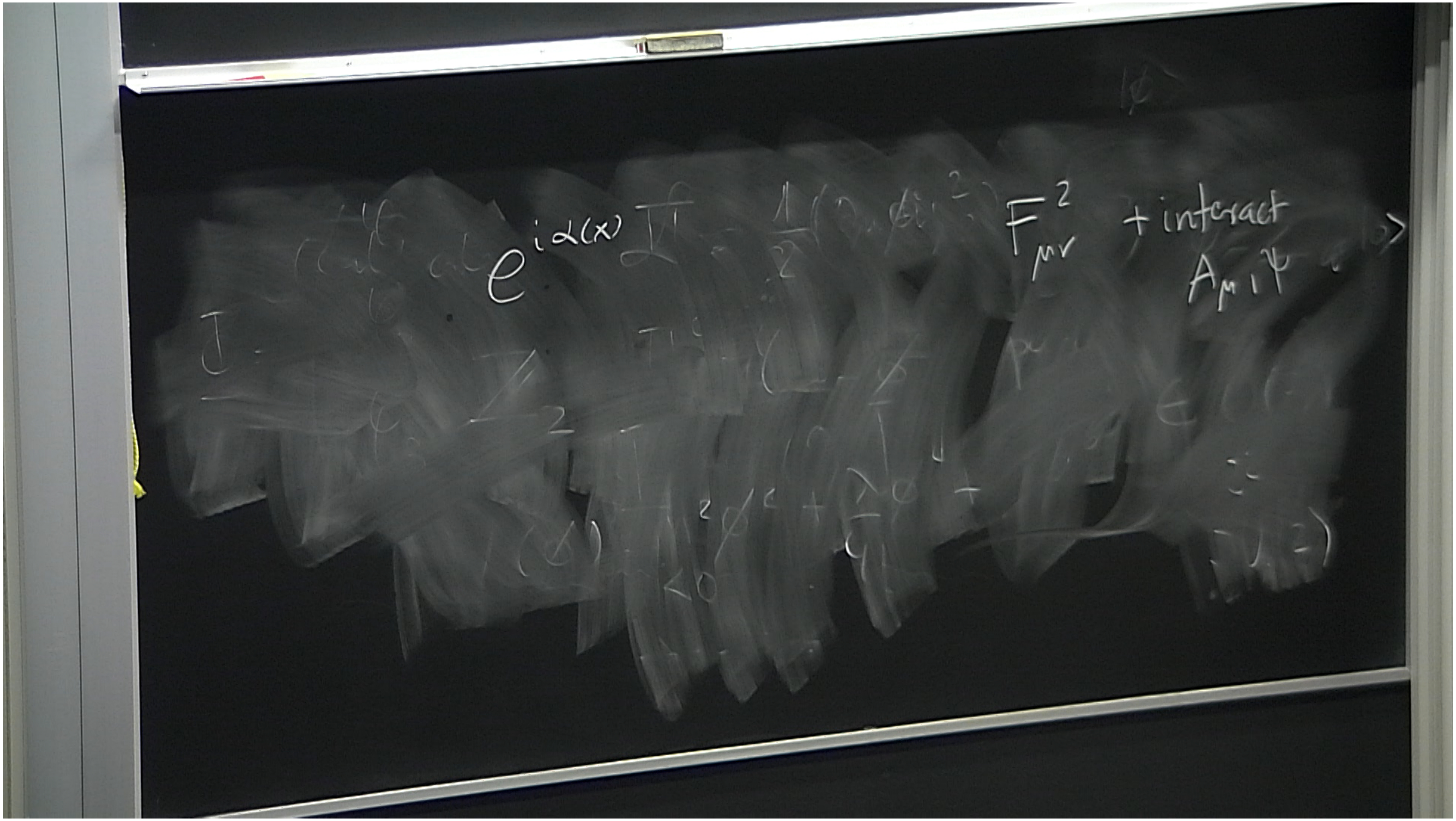
$\langle \bar{\psi}_L \psi_R \rangle$

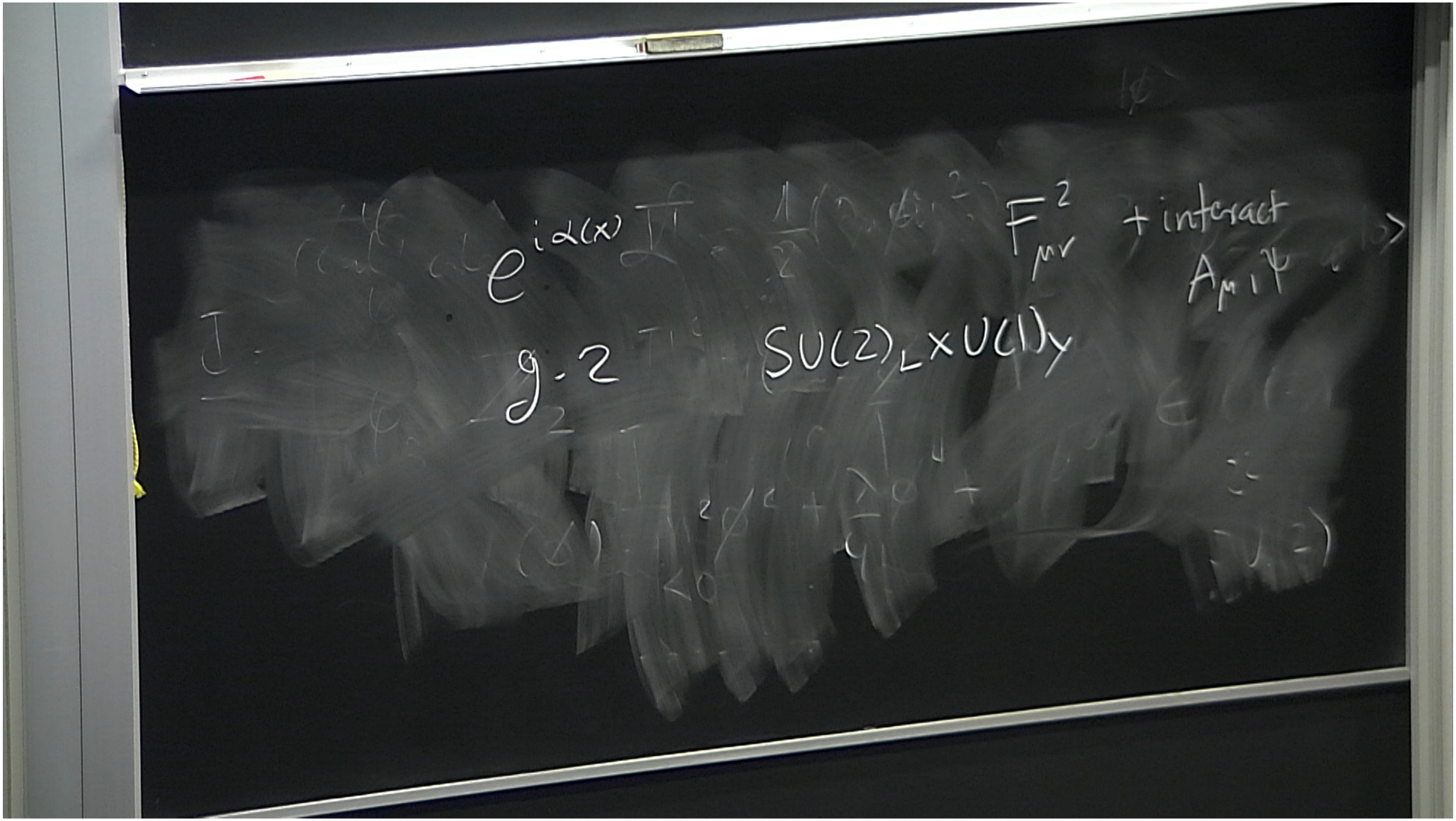
✗ inv

LR

$\chi PT(p)$


$e^{i\alpha(x)}$
$F_{\mu\nu}^2$


e^{iα(x)}
F_{μν}^2 + interact
A_μ ψ


$e^{i\alpha(x)}$
$F_{\mu\nu}^2$ + interact
A_μ, ψ
$g-2$
$SU(2)_L \times U(1)_Y$

$e^{i\alpha(x)}$

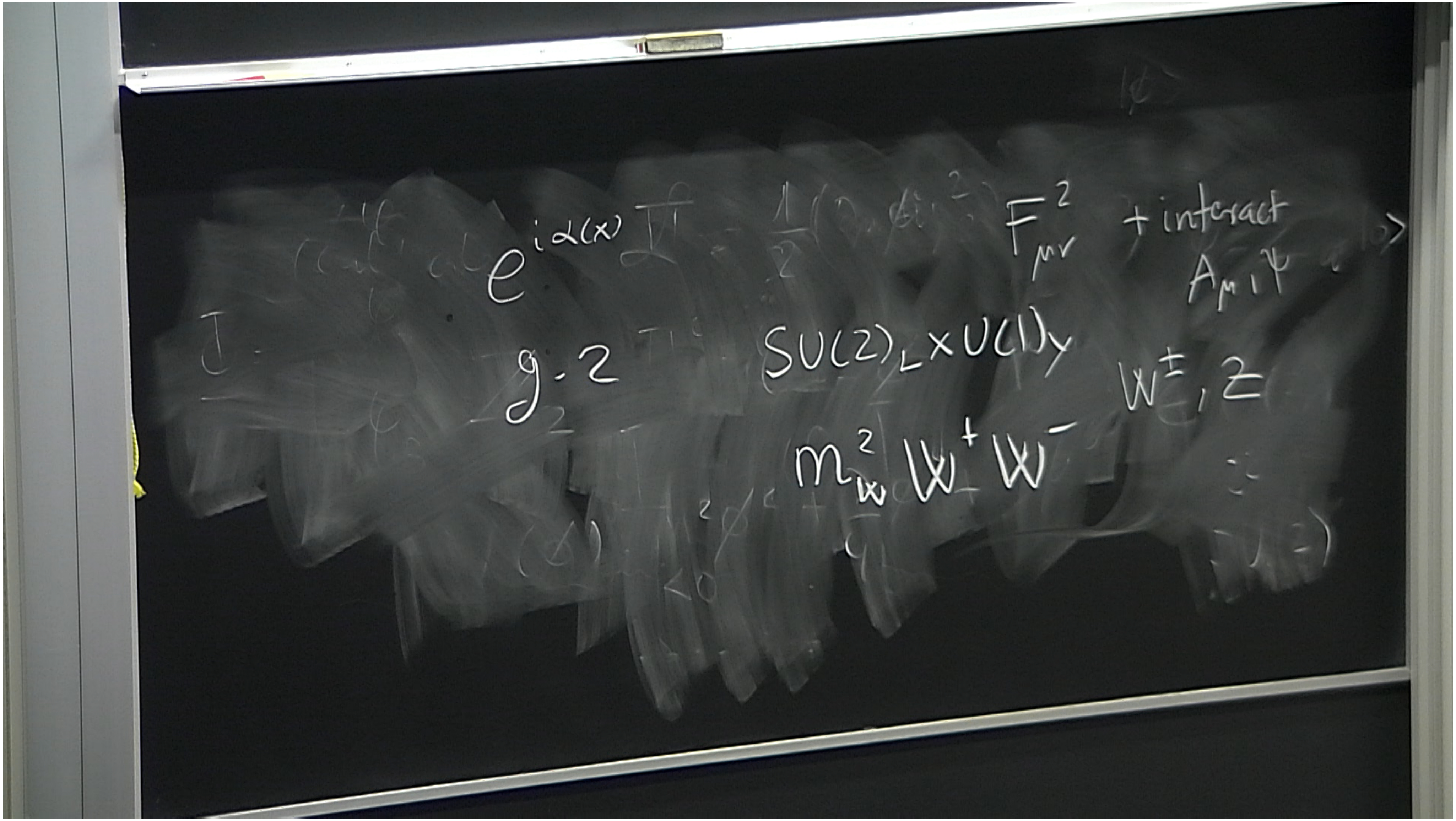
$F_{\mu\nu}^2$ + interact

A_μ, ψ

$g-2$

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

$W^\pm, Z$



e^{iα(x)}
F_{μν}^2 + interact
A_μ, ψ
g-2
SU(2)_L × U(1)_Y
W^±, Z
m_W^2 W^+ W^-

$e^{i\alpha(x)}$

$F_{\mu\nu}^2$ + interact

A_μ, ψ

$g-2$

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

$W^\pm, Z$

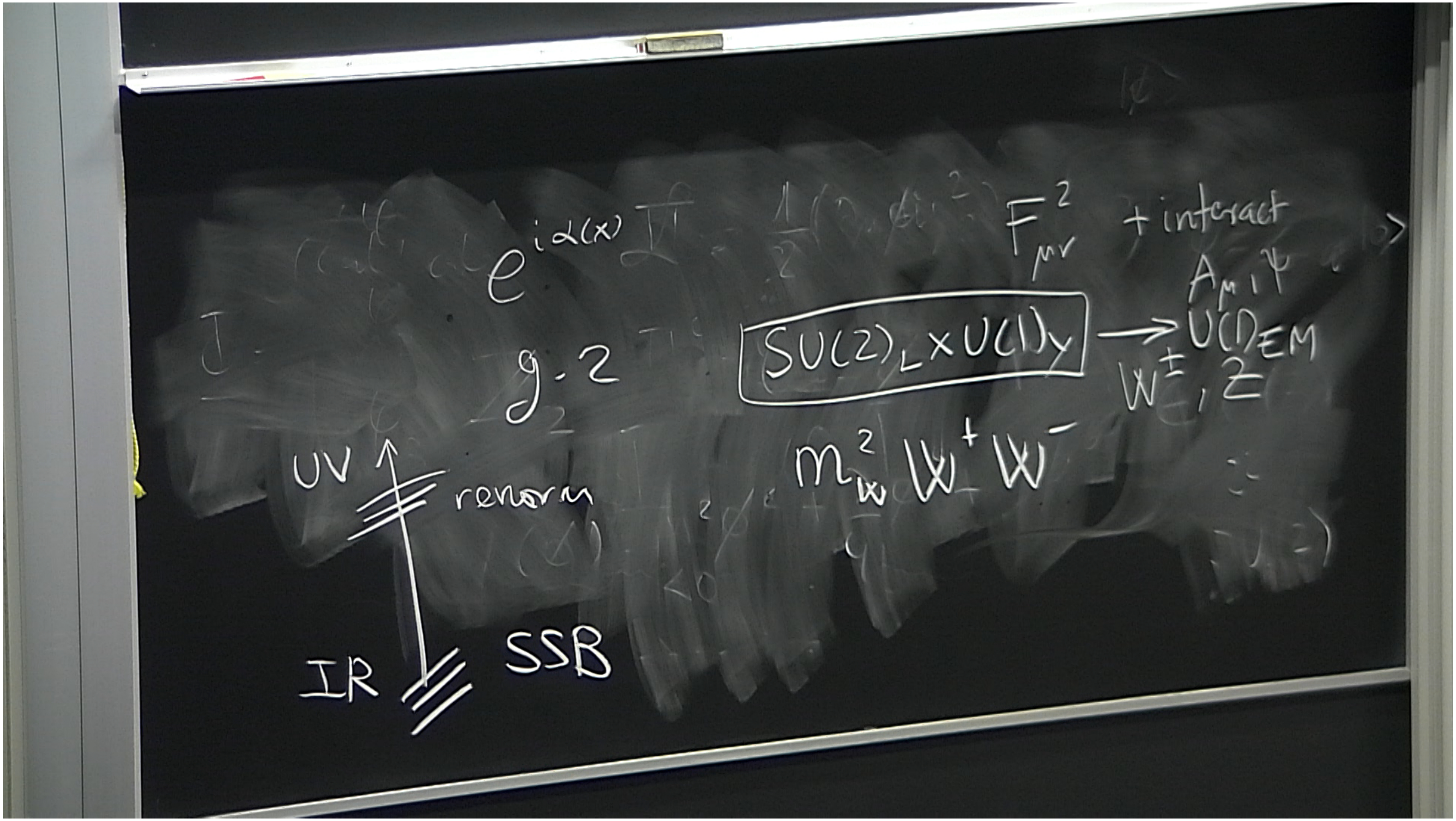
$m_W^2 W^+ W^-$

UV

renorm

IR

SSB


$e^{i\alpha(x)}$
$F_{\mu\nu}^2$ + interact
A_μ, ψ
$g-2$
$\boxed{SU(2)_L \times U(1)_Y} \to U(1)_{EM}$
$W^\pm, Z$
$m_W^2 W^+ W^-$
UV
renorm
IR
SSB

Abelian Higgs

$$\mathcal{L}_\Phi = D_\mu \Phi^* D^\mu \Phi - V(\Phi) - \frac{1}{4} F_{\mu\nu}^2$$

$$D_\mu = \partial_\mu - ieA_\mu$$

Abelian Higgs

$$\mathcal{L}_\phi = D_\mu \Phi^* D^\mu \Phi - V(\Phi) - \frac{1}{4} F_{\mu\nu}^2$$

$$D_\mu = \partial_\mu - ieA_\mu$$

$$V = m|\phi|^2 + \lambda|\phi|^4$$

Abelian Higgs

$$\mathcal{L}_\phi = D_\mu \Phi^* D^\mu \Phi - V(\Phi) - \frac{1}{4} F_{\mu\nu}^2$$

scalar QED

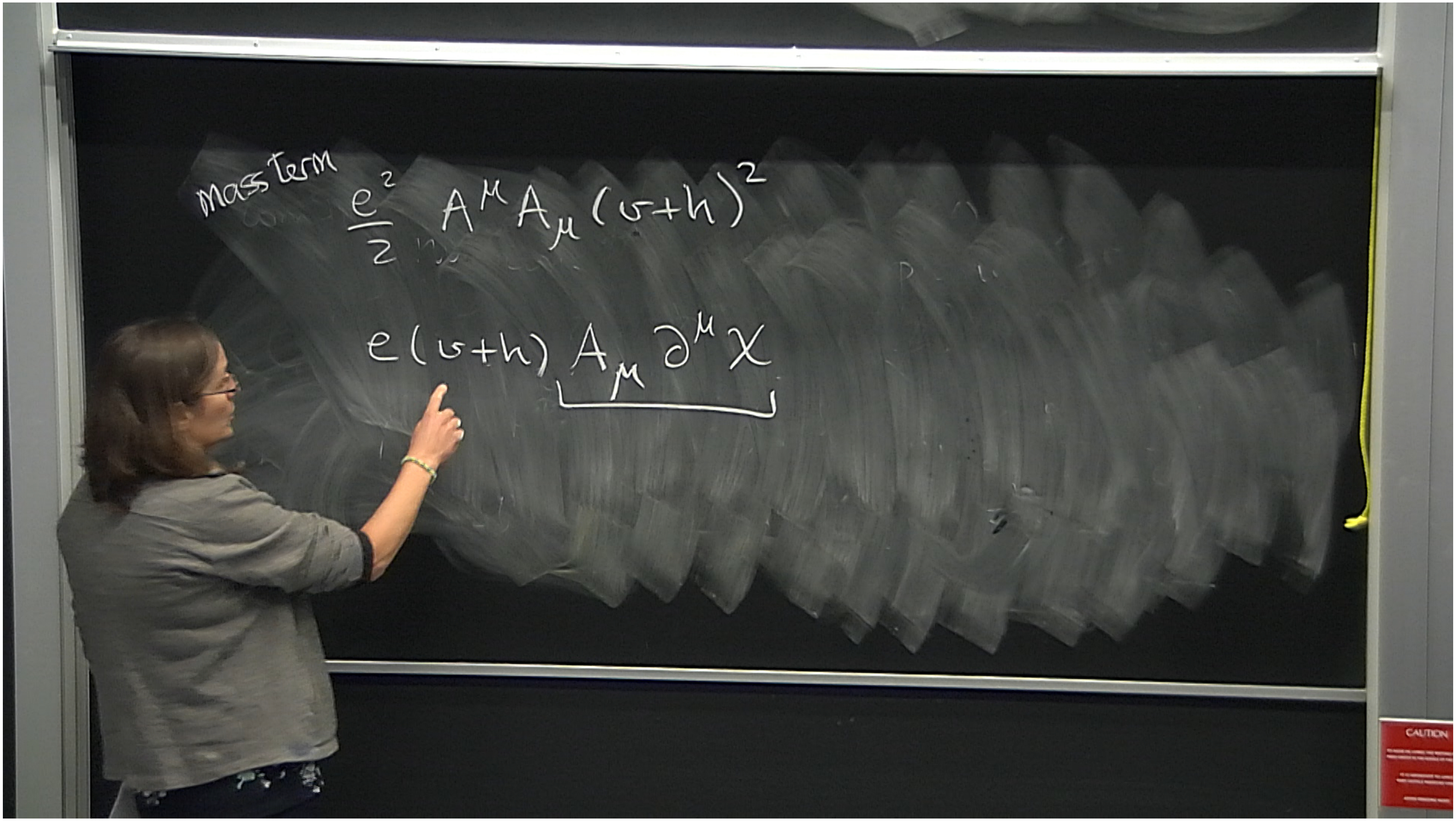
$$D_\mu = \partial_\mu - ieA_\mu$$

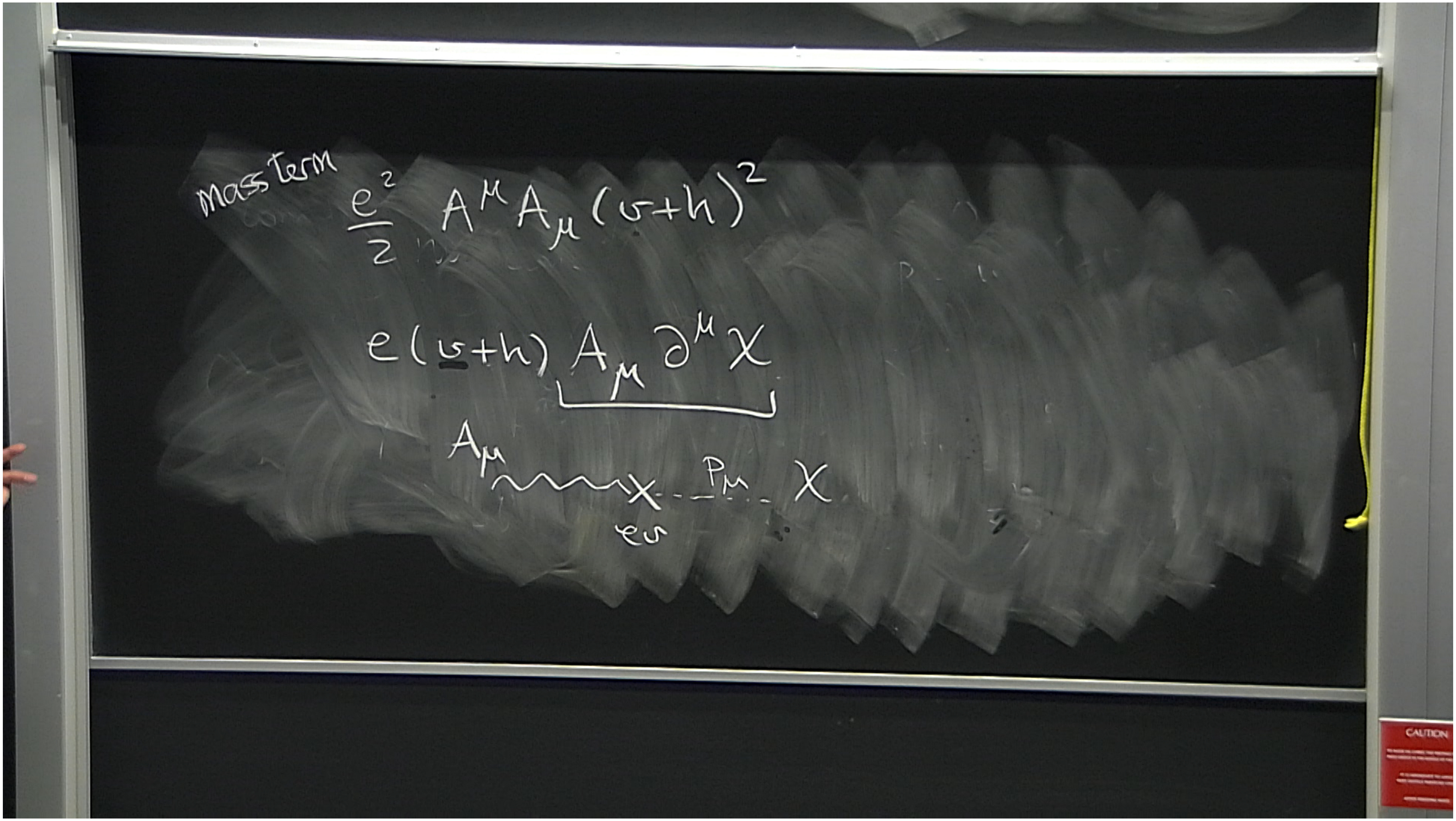
$$V = m^2|\phi|^2 + \lambda|\phi|^4$$

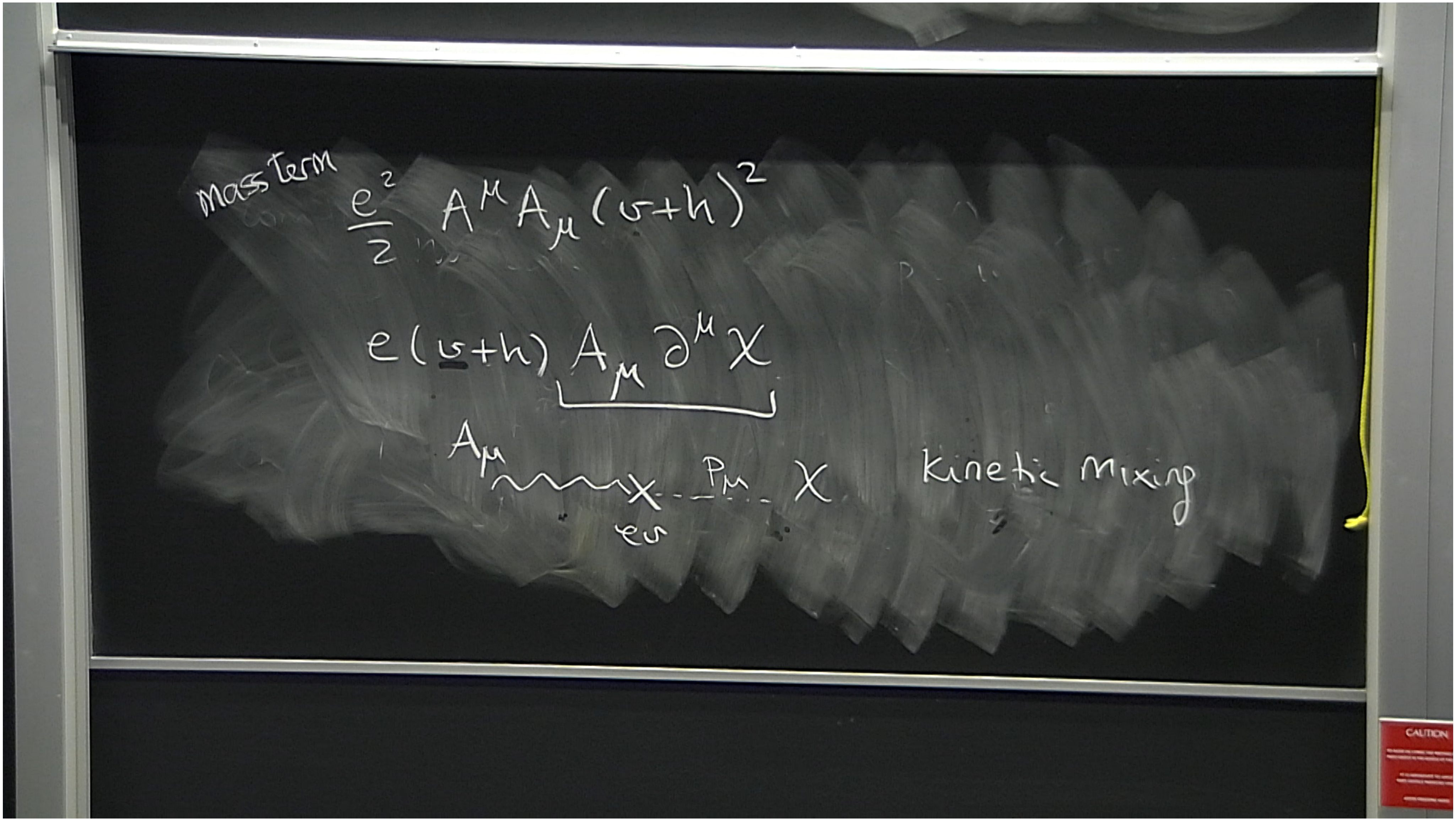
mass term $\frac{e^2}{2} A^\mu A_\mu (v+h)^2$

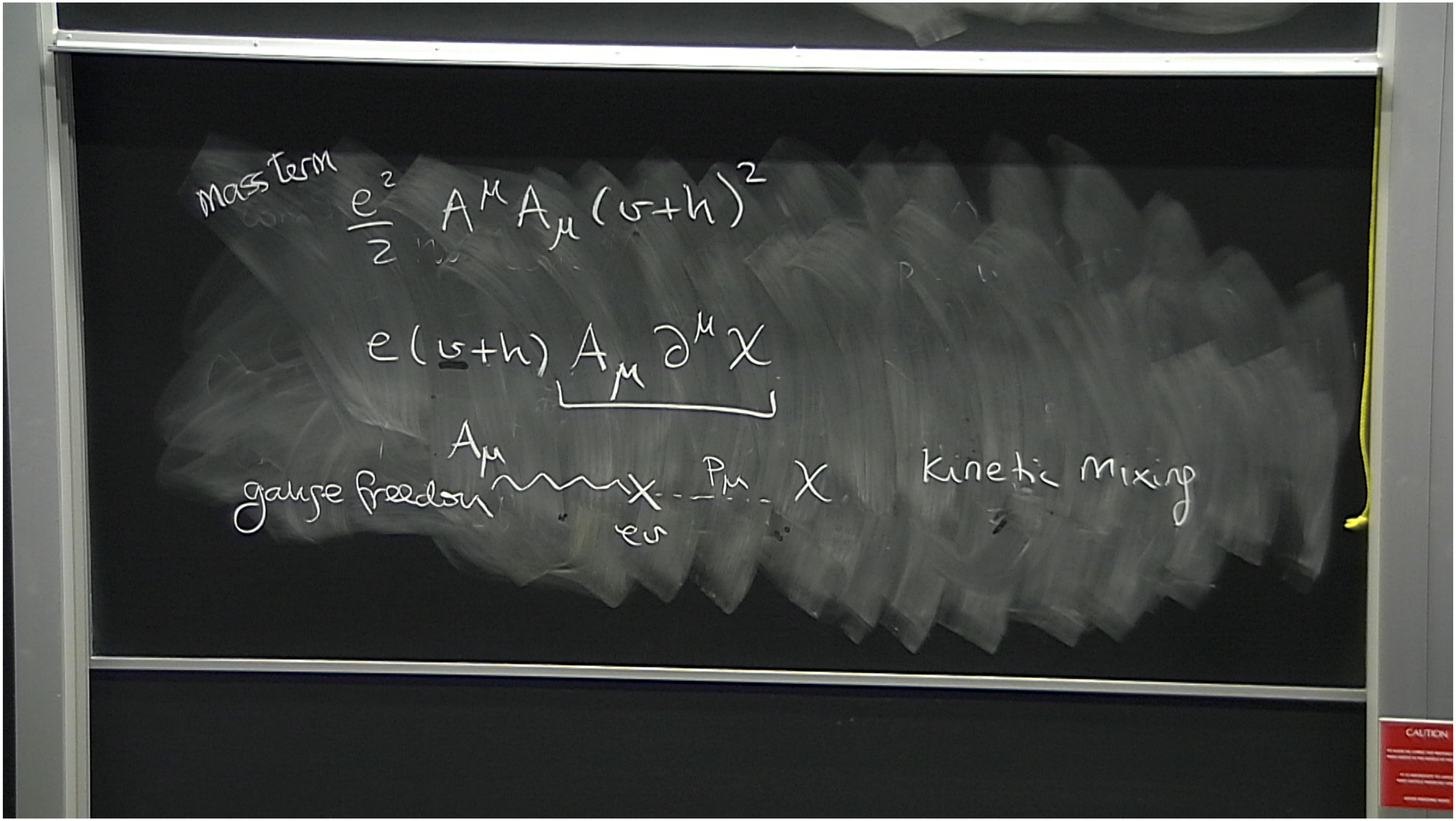
Mass term $\frac{e^2}{2} A^\mu A_\mu (v+h)^2$

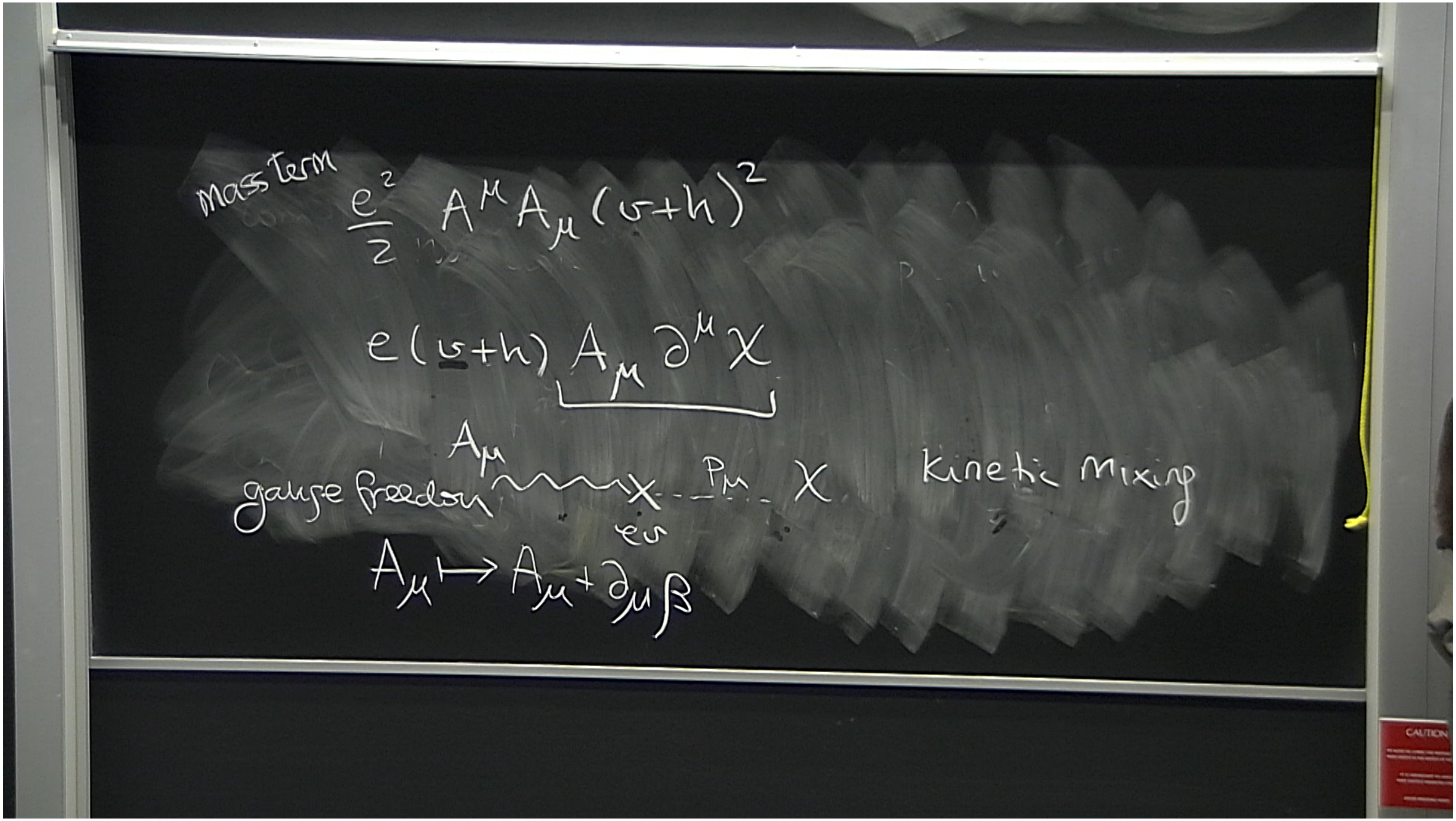
$$e(v+h)A_\mu \partial^\mu \chi$$


Mass term
$\frac{e^2}{2} A^\mu A_\mu (v+h)^2$
$e(v+h) \underbrace{A_\mu \partial^\mu \chi}$
CAUTION


Mass term
$\frac{e^2}{2} A^\mu A_\mu (v+h)^2$
$e(v+h) \underbrace{A_\mu \partial^\mu \chi}$
A_μ
ev
p_μ
χ


Mass Term
$\frac{e^2}{2} A^\mu A_\mu (v+h)^2$
$e(v+h) A_\mu \partial^\mu \chi$
A_μ
P_μ
χ
ev
Kinetic Mixing


mass term
$\frac{e^2}{2} A^\mu A_\mu (v+h)^2$
$e(v+h) \underbrace{A_\mu \partial^\mu \chi}$
gauge freedom
A_μ
ev
p_μ
χ
kinetic mixing


mass term
$\frac{e^2}{2} A^\mu A_\mu (v+h)^2$
$e(v+h) \underbrace{A_\mu \partial^\mu \chi}$
A_μ
gauge freedom
P_μ
χ
ev
kinetic mixing
$A_\mu \mapsto A_\mu + \partial_\mu \beta$

mass term $\frac{e^2}{2} A^\mu A_\mu (v+h)^2$

$$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$$

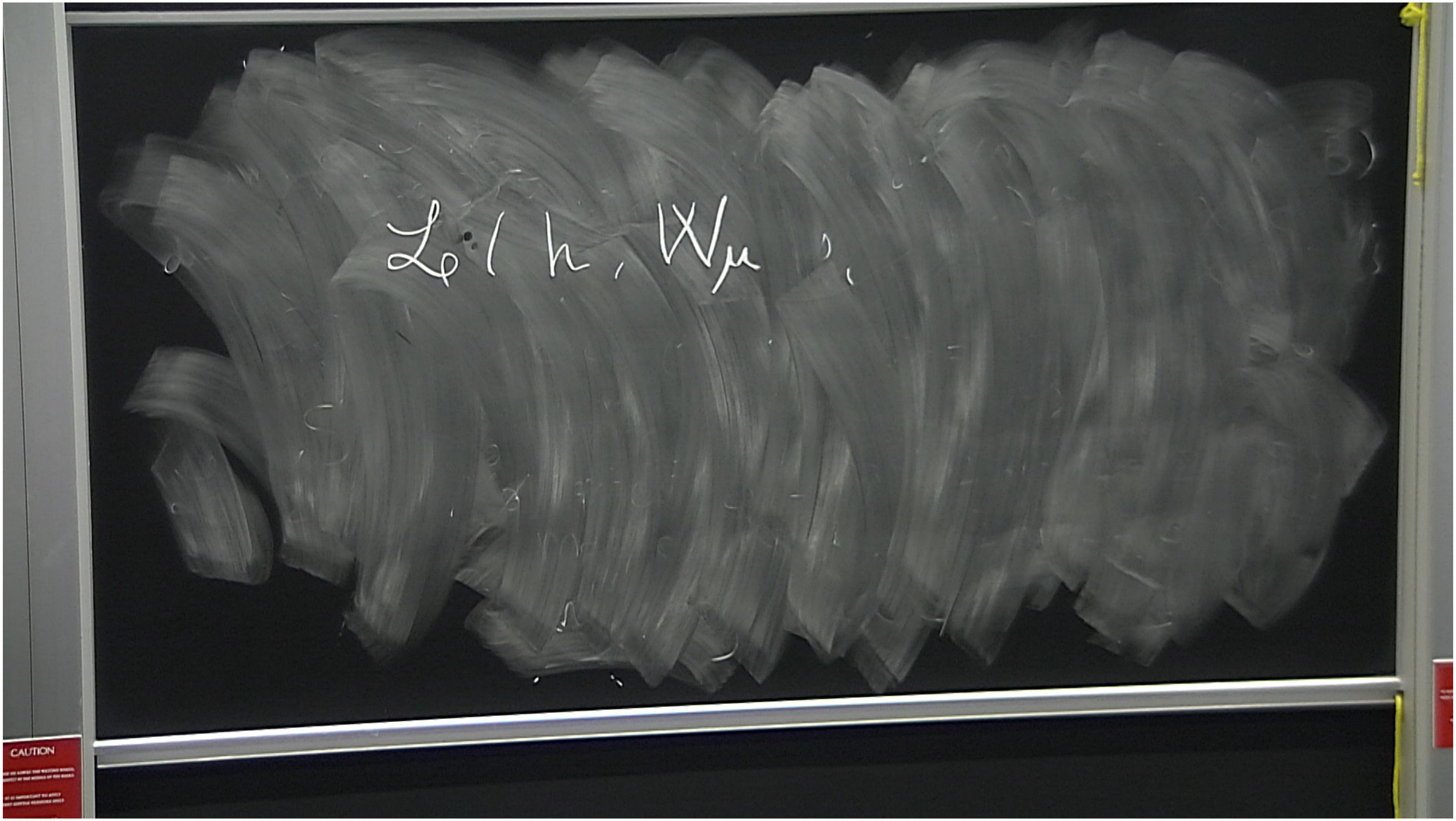
$$e(\underline{v}+h)\, \underbrace{A_\mu \partial^\mu \chi}$$

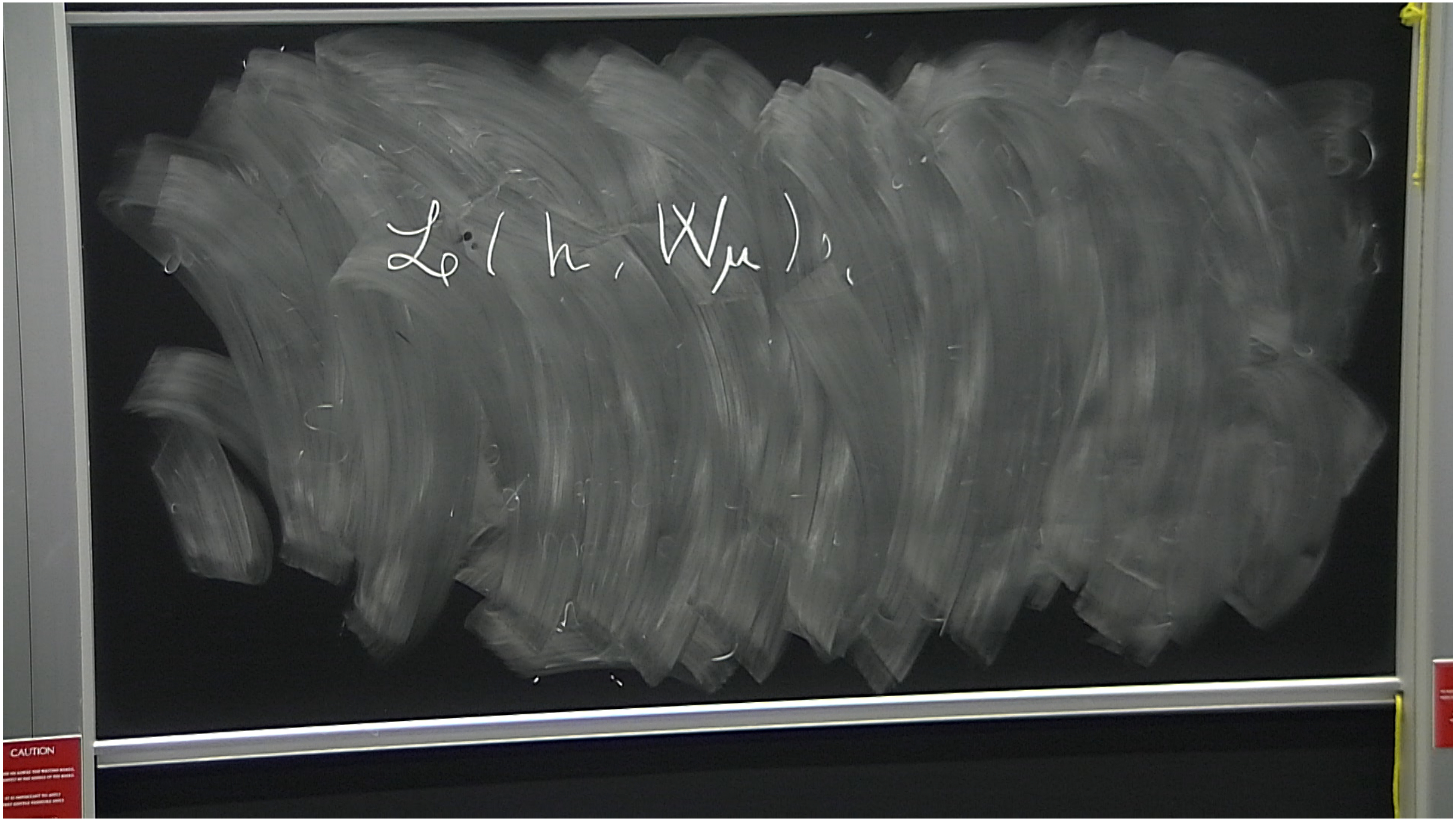
A_μ $\sim\sim\sim \times$ - - - p_μ - - - χ kinetic mixing

ev

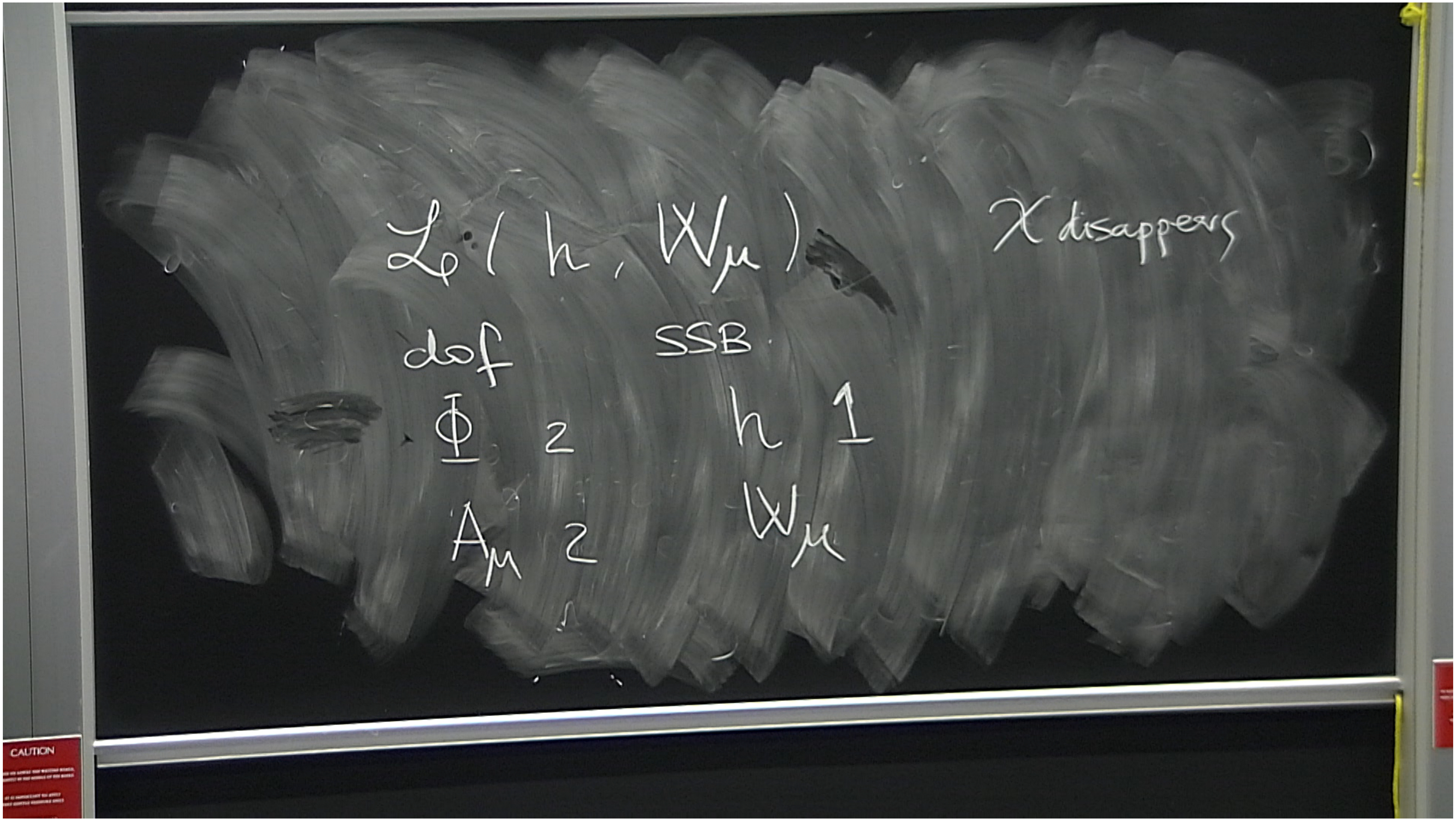
gauge freedom

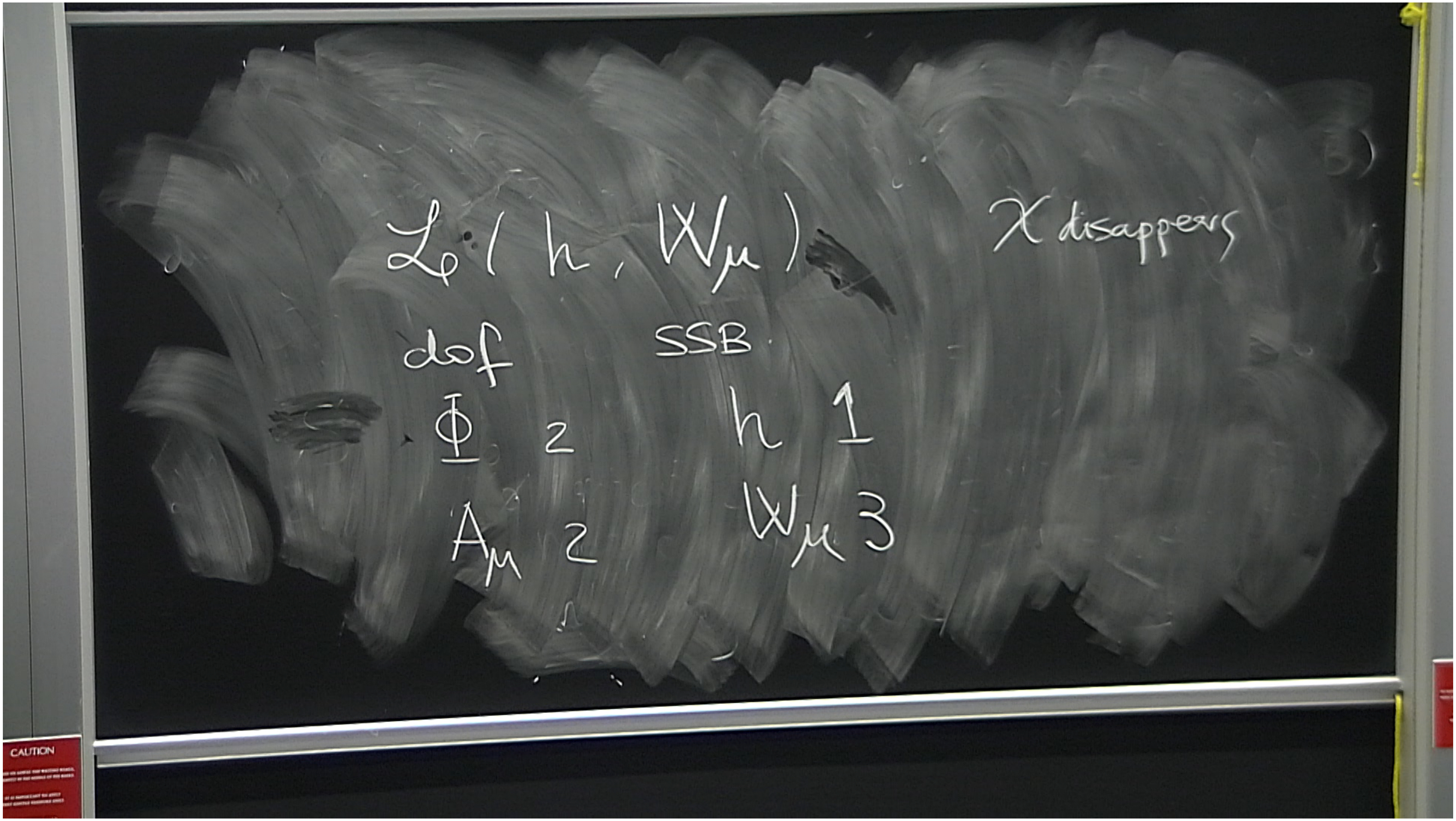
$$A_\mu \mapsto A_\mu + \partial_\mu \beta$$


L(h, Wμ ,

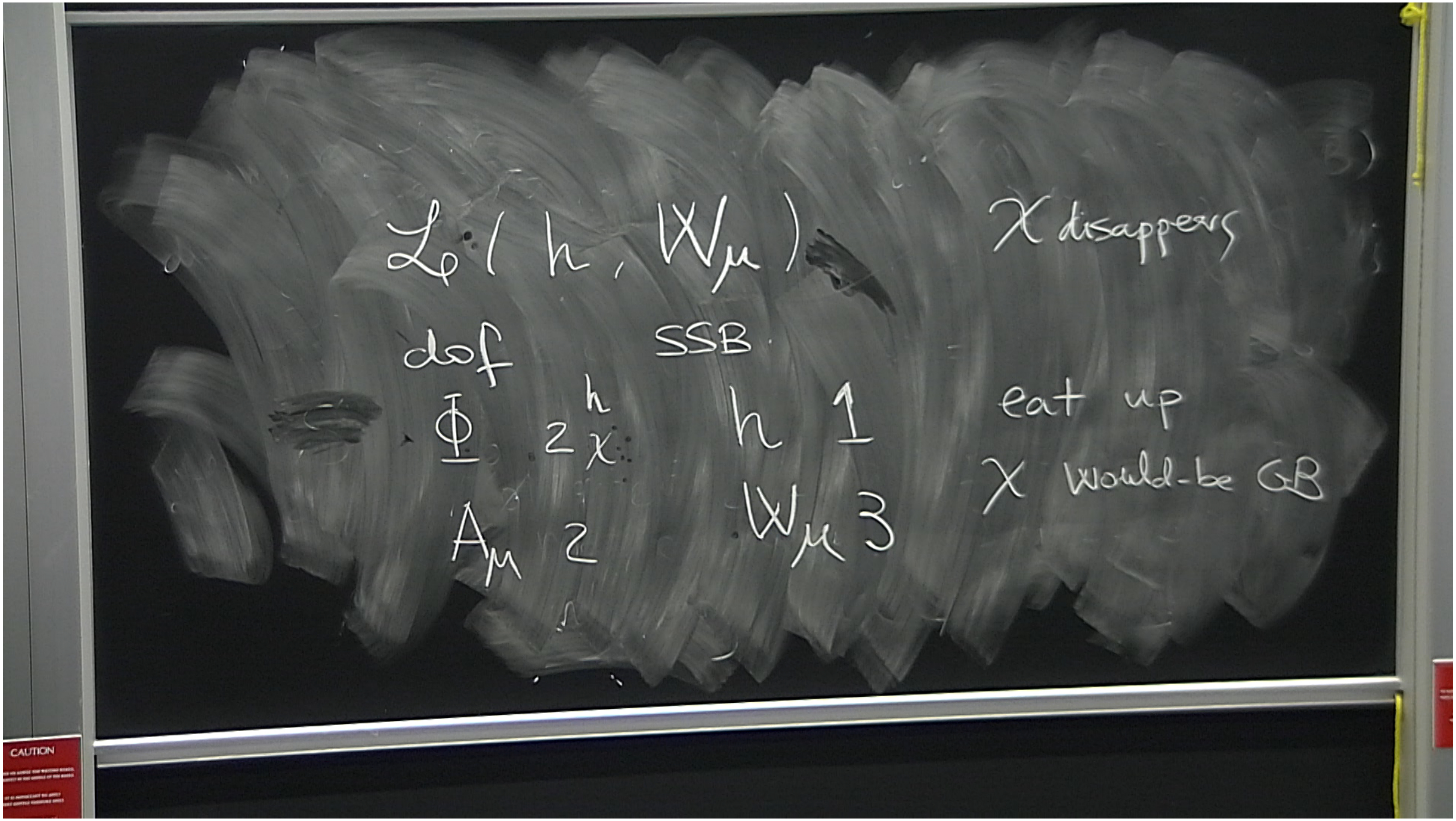

$\mathcal{L}(h, W_\mu),$

$\mathcal{L}_0(h, W_\mu)$, X disappears


$\mathcal{L}_\phi(h, W_\mu)$
χ disappears
dof
SSB
Φ 2
h 1
A_μ 2
W_μ



$\mathcal{L}_\phi (h , W_\mu)$
χ disappears
dof
SSB
Φ 2
h 1
A_μ 2
W_μ 3
CAUTION


$\mathcal{L}_\phi(h, W_\mu)$
χ disappears
dof
SSB
Φ 2 h χ
h 1
eat up
χ would-be GB
A_μ 2
W_μ 3
CAUTION

$\mathcal{L}_\phi(h, W_\mu)$

χ disappears

dof | SSB

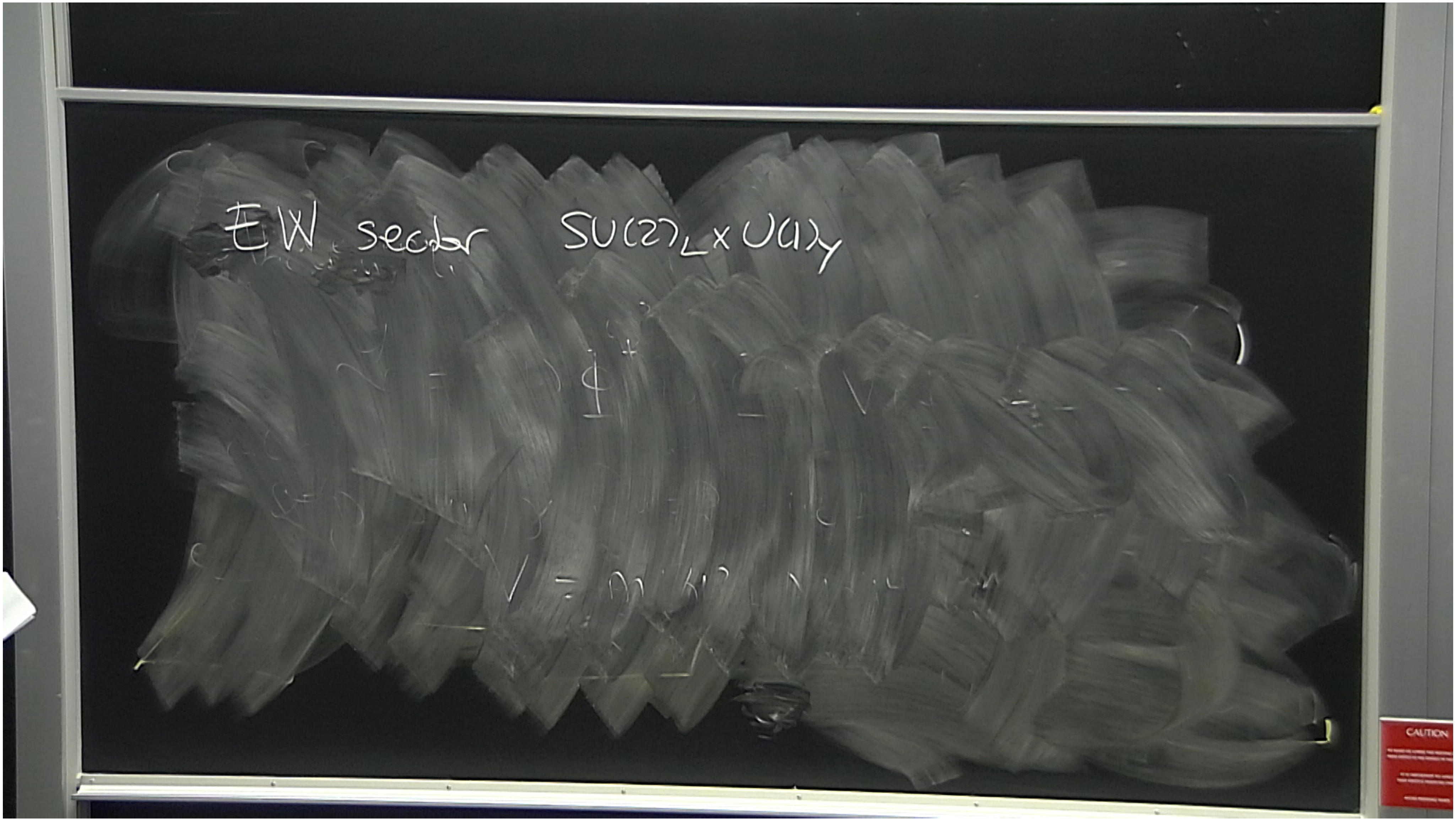
Φ 2 $\begin{matrix} h \\ \chi \end{matrix}$ | h 1

A_μ 2 | W_μ 3

longitudinal

eat up

χ would-be GB


EW sector $SU(2)_L \times U(1)_Y$

EW sector $SU(2)_L \times U(1)_Y$

Higgs sector

EW sector $SU(2)_L \times U(1)_Y$

	$SU(2)_L$
Higgs sector	$\Phi = \begin{pmatrix} \phi_1 \\ \phi_2 \end{pmatrix}^{\mathbb{C}}$

EW sector $SU(2)_L \times U(1)_Y$

	$SU(2)_L$	$U(1)_Y$
Higgs sector	$\Phi = \begin{pmatrix} \phi_1 \\ \phi_2 \end{pmatrix}$ $\mathbb{C}$ 4 dof	$Y_\phi = +1$

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	$SU(2)_L$	$U(1)_Y$
Higgs sector	$\Phi = \begin{pmatrix} \phi_1 \\ \phi_2 \end{pmatrix}$ $\mathbb{C}$ 4 dof	$Y_\phi = +1$
Fermion sector	$L_1 = \Big(\; e_L$	

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	$SU(2)_L$	$U(1)_Y$
Higgs sector	$\Phi = \begin{pmatrix} \phi_1 \\ \phi_2 \end{pmatrix}$ $\mathbb{C}$ 4 dof	$Y_\phi = +1$
Fermion sector	$L_1 = \begin{pmatrix} \nu \\ e_L \end{pmatrix}$ L_2 μ	

EW sector $SU(2)_L \times U(1)_Y$

	$SU(2)_L$	$U(1)_Y$
Higgs sector	$\Phi = \begin{pmatrix}\phi_1 \\ \phi_2\end{pmatrix}$ $\mathbb{C}$ 4dof	$Y_\phi = +1$
Fermion sector	$L_1 = \begin{pmatrix}\nu \\ e_L\end{pmatrix}$ L_2 μ e_R μ_R τ_R	

EW sector $SU(2)_L \times U(1)_Y$

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Fermion sector	$L_1 = \begin{pmatrix}\nu \\ e_L\end{pmatrix}$ L_2 μ	$Y_{L_i} = -1$
	e_R μ_R τ_R singlet	$Y_R = -2$

Electroweak SM $\quad SU(2)_L \times U(1)_Y$

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu}^{a} F^{\mu\nu, a} - \frac{1}{4} F_{\mu\nu} F^{\mu\nu}$$

Electroweak SM $\quad SU(2)_L \times U(1)_Y$

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu}^{a} F^{\mu\nu, a} - \frac{1}{4} F_{\mu\nu} F^{\mu\nu}$$

$$+ |D_\mu \Phi|^2 - m^2 |\Phi|^2 - \lambda |\phi|^4$$

3

Electroweak SM $\quad SU(2)_L \times U(1)_Y$

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu}^{a} F^{\mu\nu,a} - \frac{1}{4} F_{\mu\nu} F^{\mu\nu}$$

$$+ |D_\mu \Phi|^2 - m^2 |\Phi|^2 - \lambda |\phi|^4$$

$$+ i \bar{L}_i \not{D} L_i$$

$$D = \partial - i g \frac{\tau^a}{2} A_\mu^a - i g' B_\mu \frac{Y}{2}$$

Electroweak SM $SU(2)_L \times U(1)_Y$

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu}^{a} F^{\mu\nu,a} - \frac{1}{4} F_{\mu\nu} F^{\mu\nu}$$

$$+ |D_\mu \Phi|^2 - m^2 |\Phi|^2 - \lambda |\phi|^4$$

$$+ i \bar{L}_i \not{D} L_i + i \bar{E}_i \not{D} E_i$$

$$D = \partial - i g \frac{\tau^a}{2} A_\mu^a - i g' B_\mu \frac{Y}{2}$$

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	$SU(2)_L$	$U(1)_Y$
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	e_R – μ_R τ_R singlet	$Y_R = -2$

E_i

Electroweak SM $\quad SU(2)_L \times U(1)_Y$

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu}^{a} F^{\mu\nu,a} - \frac{1}{4} F_{\mu\nu} F^{\mu\nu}$$

$$+ |D_\mu \Phi|^2 - m^2 |\Phi|^2 - \lambda |\phi|^4 + f_{ij} \bar{L}_i \Phi E_j + h.c.$$

$$+ i \bar{L}_i \not{D} L_i + i \bar{E}_i \not{D} E_i$$

$$D = \partial - i g \frac{\tau^a}{2} A^a_\mu - i g' B_\mu \frac{Y}{2}$$

Electroweak SM $\quad SU(2)_L \times U(1)_Y$

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu}^{a} F^{\mu\nu,a} - \frac{1}{4} F_{\mu\nu} F^{\mu\nu}$$

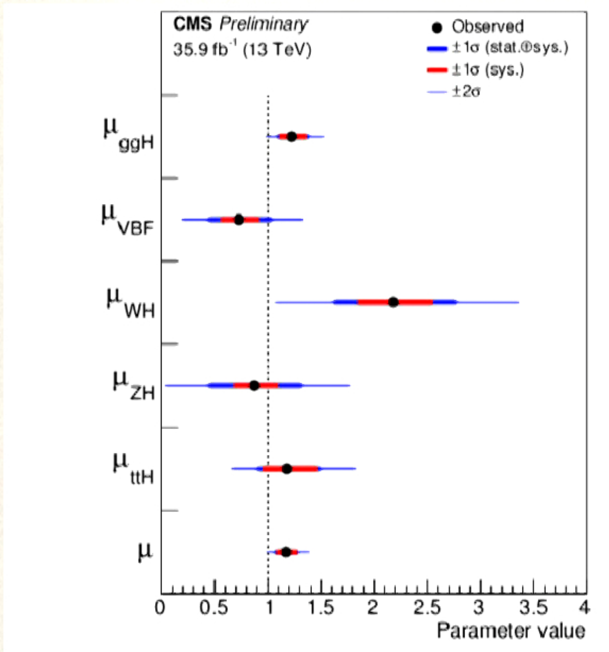
$$+|D_\mu \Phi|^2 - m^2 |\Phi|^2 - \lambda |\phi|^4 + f_{ij} \overbrace{\overbrace{\bar{L}_i \Phi}^{\text{singlet}} E_j}^{\text{singlet}} + h.c.$$

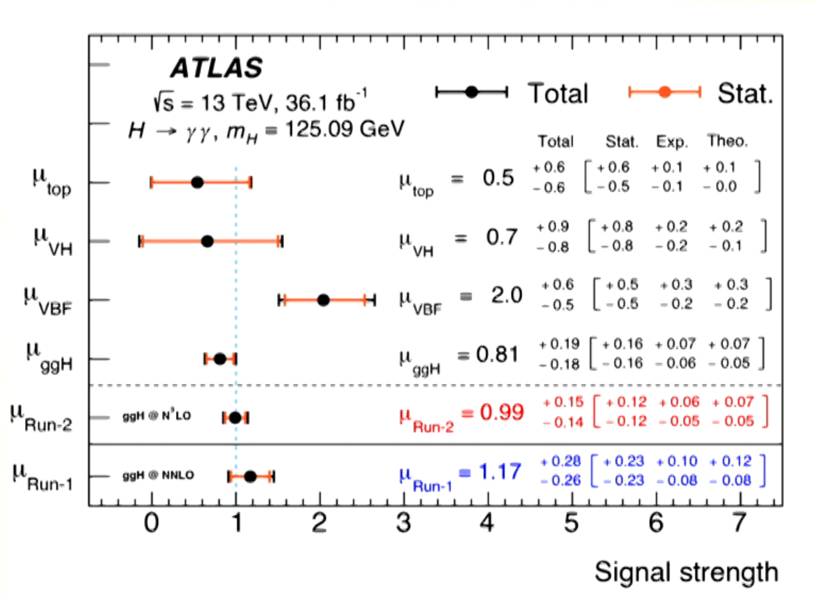
$$+ i \bar{L}_i \not{D} L_i + i \bar{E}_i \not{D} E_i$$

$$D = \partial - i g \frac{\tau^a}{2} A^a_\mu - i g' B_\mu \frac{Y}{2}$$

SM Higgs — an LHC snapshot

Run2 indicates a *SM-like* Higgs





Before we get very technical

Why the Higgs?

A cosmological Higgs

HIGGS

Dark Matter
Higgs portal
Higgs DM mediator

UV sensitivity
Naturalness
heavy new physics
Relaxation

Inflation
Higgs inflation
Inflaton vs Higgs

Phase transitions
Baryogenesis
gravitational waves

Fate of the Universe
Stability

The LHC provides the most precise, controlled way of studying the Higgs and direct access to TeV scales
Exploiting complementarity with cosmo/astro probes

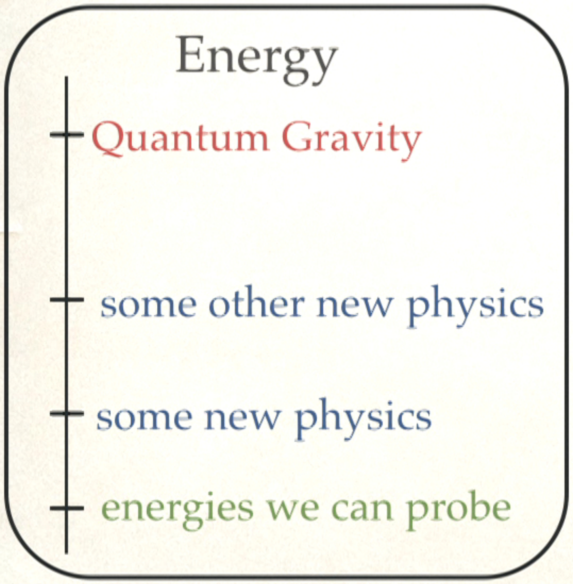
Similar story for Axions and ALPs, scalars are versatile

Naturalness

Predictive theory: quantum mechanical. In QFT, physical quantities *run*

mass term in a Lagrangian, quantum corrections

$$\mathcal{L}_m = -m_\Psi \bar{\Psi}\Psi - m_\phi^2 \phi^2$$

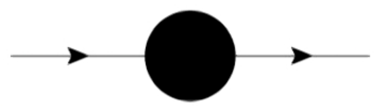


Fermions

Massless fermion, additional symmetry

$$\Psi \to e^{-i\gamma_5 \theta}\Psi$$

if this chiral symmetry is preserved QM



$$\delta m_\Psi \propto m_\Psi \, \log(\mu_1/\mu_2)$$

chiral symmetry protects fermions masses from large UV corrections

Light fermions are technically natural

Naturalness

Predictive theory: quantum mechanical. In QFT, physical quantities *run*

mass term in a Lagrangian, quantum corrections

$$\mathcal{L}_m = -m_\Psi \bar{\Psi}\Psi - m_\phi^2 \phi^2$$

Energy

- Quantum Gravity
- some other new physics
- some new physics
- energies we can probe

Scalars

Massless scalar, scale invariance

Classical symmetry is not preserved QM (anomalous)

$$\delta m_\phi^2 \propto c_1\, \Lambda_{NP}^2 + c_2\, M_{Pl}^2$$

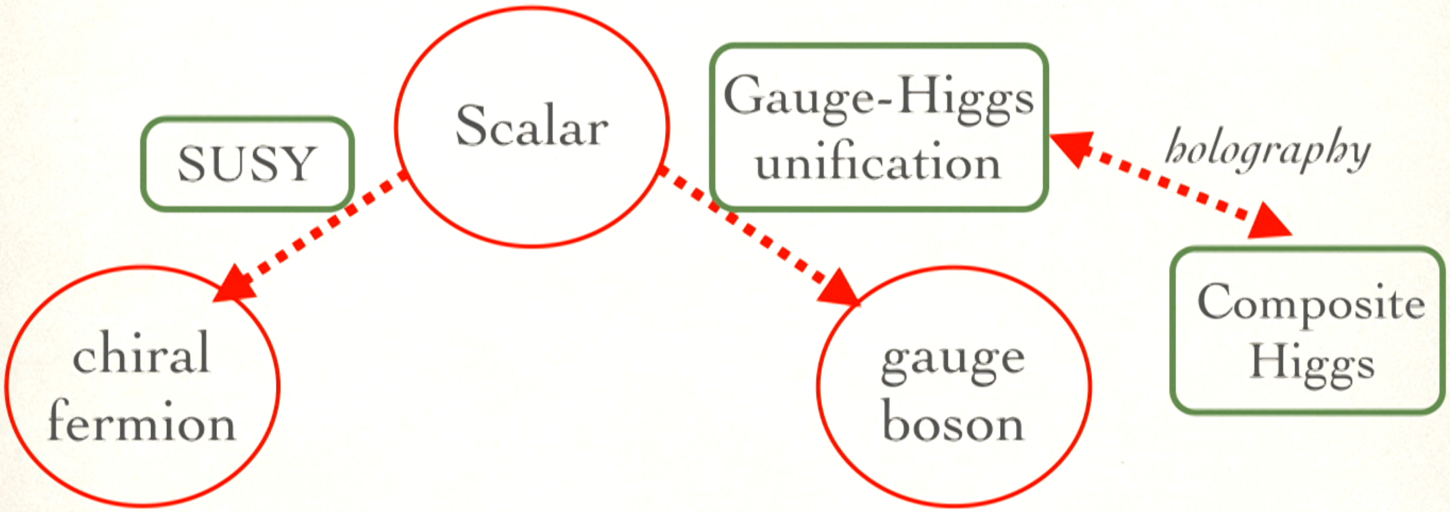
scalars are not protected by a symmetry, are UV sensitive, natural value for the mass is the highest scale it couples to

Light scalars are **unnatural**

Light scalars

The light Higgs is a reality

symmetry / duality arguments to explain its nature



Many, many possible realizations (phenomenology)

Predict new states, to be discovered

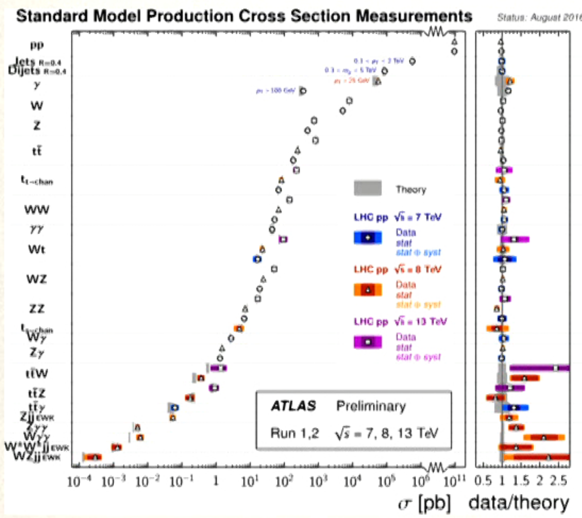
(SUSY partners, techni-baryons and mesons, spin-two…)

AND induce deviations in the Higgs behaviour

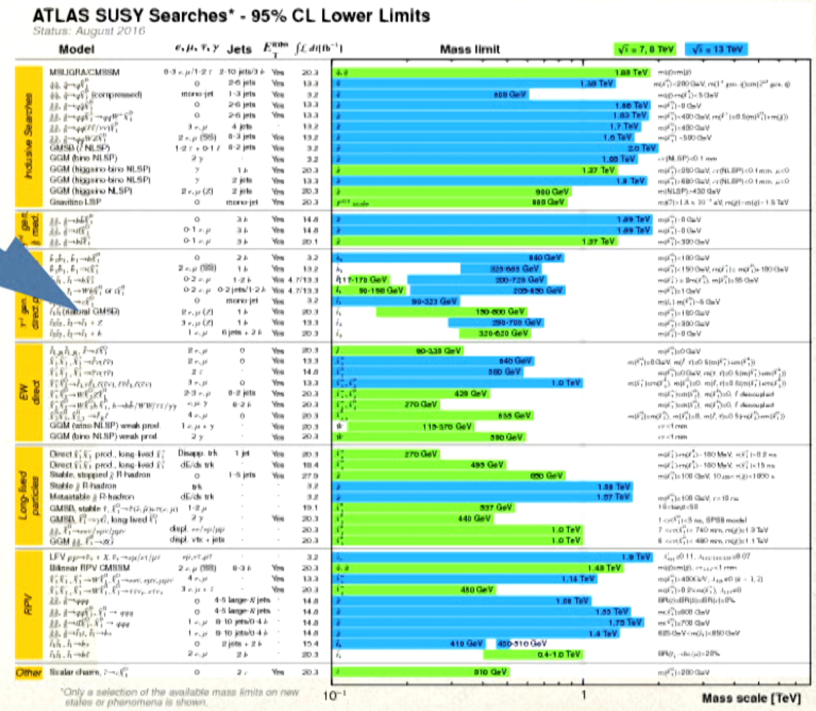
Direct versus indirect searches

Direct searches for new phenomena

consistency of data vs
SM predictions



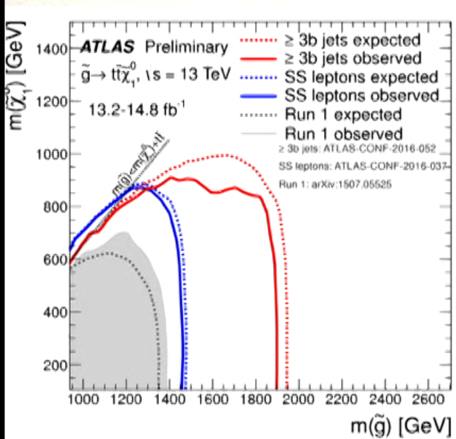
Interpretation in models:
exclusion regions

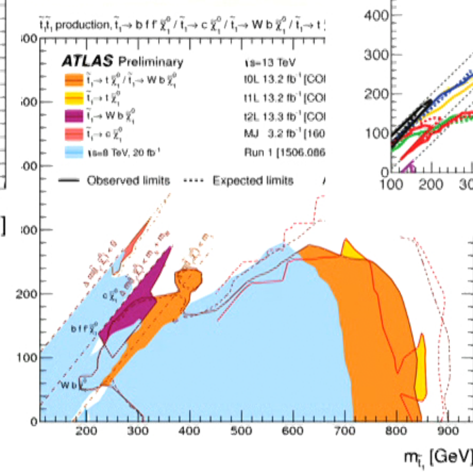


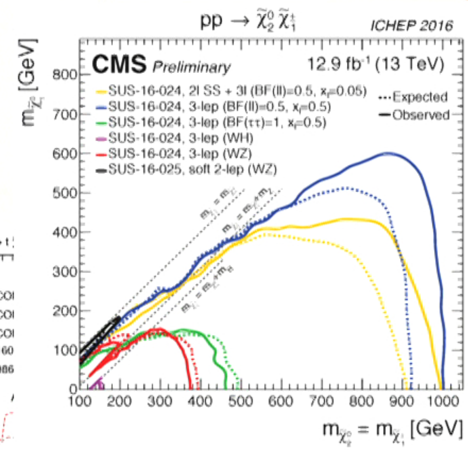
Example: coloured SUSY

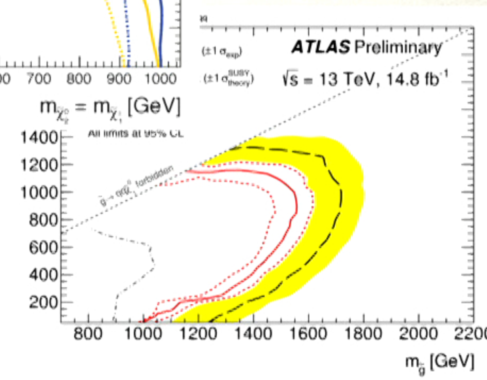
The 13 TeV data pushing hard the limits on coloured states

Vanilla SUSY | **Natural SUSY** | **EW SUSY** | **some-SUSY**







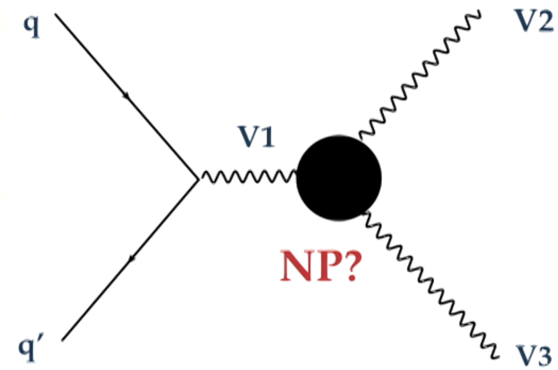


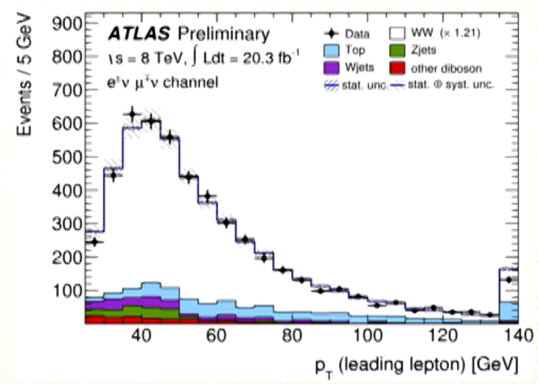
Indirect searches

Focus on SM particles' behaviour
precise determination of couplings
and kinematics
comparison with SM,
search for deviations

Indirect searches using the Higgs
since 2012, relatively new
Higgs as a window to NP
expect deviations in its behaviour
Run2 data and beyond
precision Higgs Physics

e.g. Anomalous trilinear gauge couplings, aka **TGCs**





LEP, Tevatron, LHC

The EFT approach

Looking for small deviations from the SM

EFT approach

Well-defined theoretical approach
Assumes New Physics states are heavy
Write Effective Lagrangian with only light (SM) particles
BSM effects can be incorporated as a momentum expansion

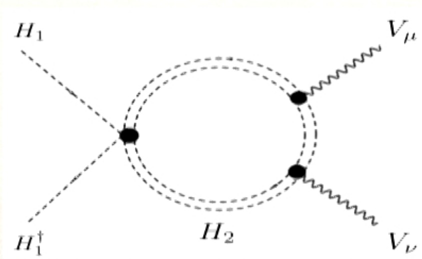
dimension-6 dimension-8

$$\mathcal{L} = \mathcal{L}_{SM} + \sum \frac{c_i}{\Lambda^2} \mathcal{O}_i^{d=6} + \sum \frac{c_i}{\Lambda^4} \mathcal{O}_i^{d=8} + \ldots$$

BSM effects SM particles

example:

2HDM



$$\boxed{\frac{ig}{2m_W^2}\bar{c}_W}\left[\Phi^\dagger T_{2k} \overleftrightarrow{D}_\mu \Phi\right] D_\nu W^{k,\mu\nu}$$

where $\bar{c}_W = \dfrac{m_W^2\,(2\,\tilde{\lambda}_3 + \tilde{\lambda}_4)}{192\,\pi^2\,\tilde{\mu}_2^2}$