Title: PSI 2019/2020 - Standard Model and Beyond - Part 1 - Lecture 11

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Collection: PSI 2019/2020 - Standard Model and Beyond - Part 1

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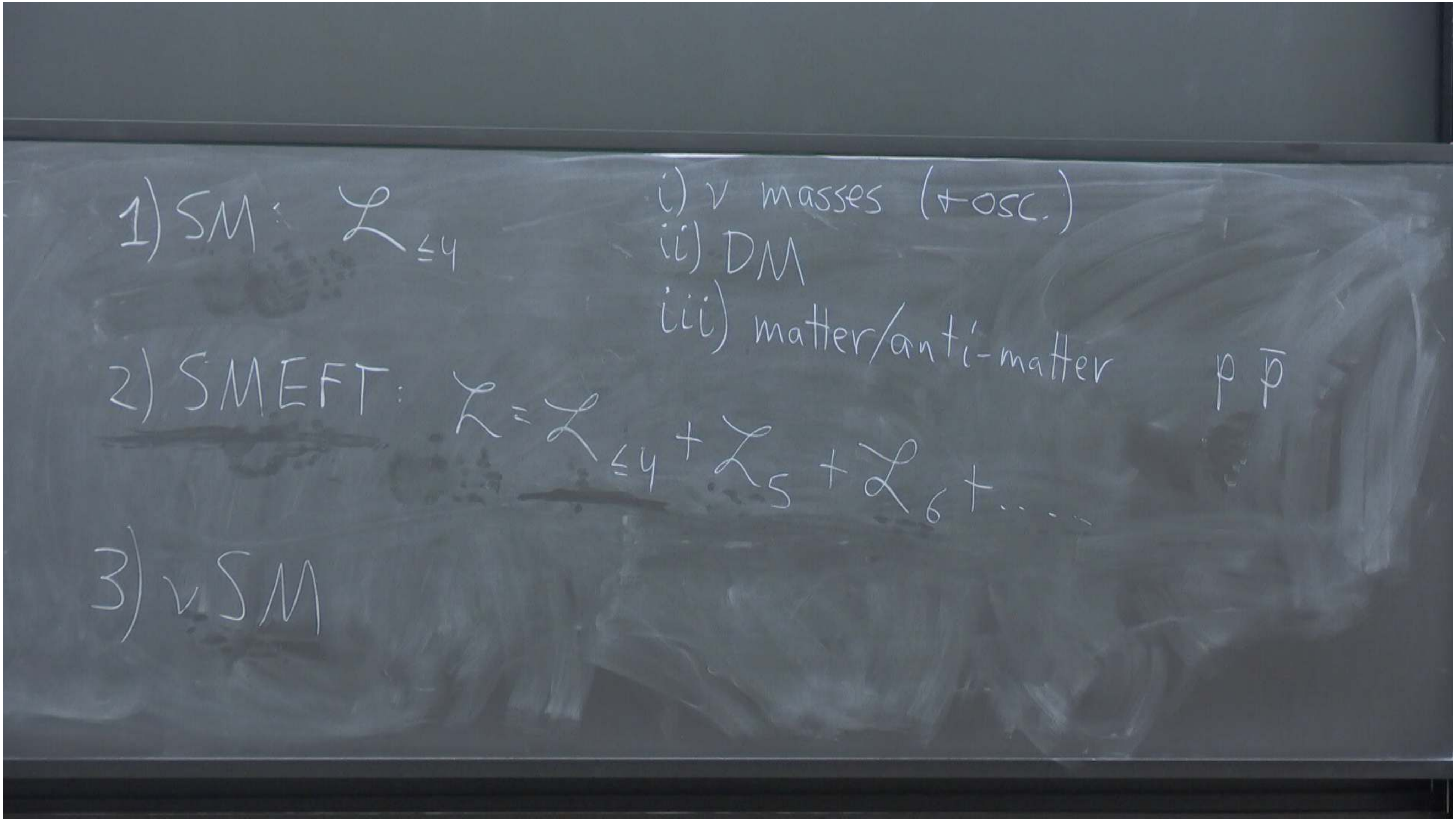
Lecture 11

	$SU(3)$	$SU(2)$	$U(1)_Y$	$U(1)_L$	$U(1)_B$
q_L	3	2	$1/6$	0	$1/3$
u_R	3	1	$2/3$	0	$1/3$
d_R	3	1	$-1/3$	0	$1/3$
ℓ_L	1	2	$-1/2$	1	0
ν_R	1	1	0	1	0
e_R	1	1	-1	1	0
h	1	2	$1/2$	0	0


1) SM: $\mathcal{L}_{\leq 4}$
i) ν masses (+osc.)
ii) DM
iii) matter/anti-matter
$p\ \bar{p}$
2) SMEFT: $\mathcal{L} = \mathcal{L}_{\leq 4} + \mathcal{L}_5 + \mathcal{L}_6 + \ldots$
3) νSM

SMEFT: $\mathcal{L} = \underbrace{\mathcal{L}_{\le 4}}_{SM} + \mathcal{L}_5 + \mathcal{L}_6 + \dots$ $\qquad \psi \equiv \tilde{h}^{\dagger} l_L$

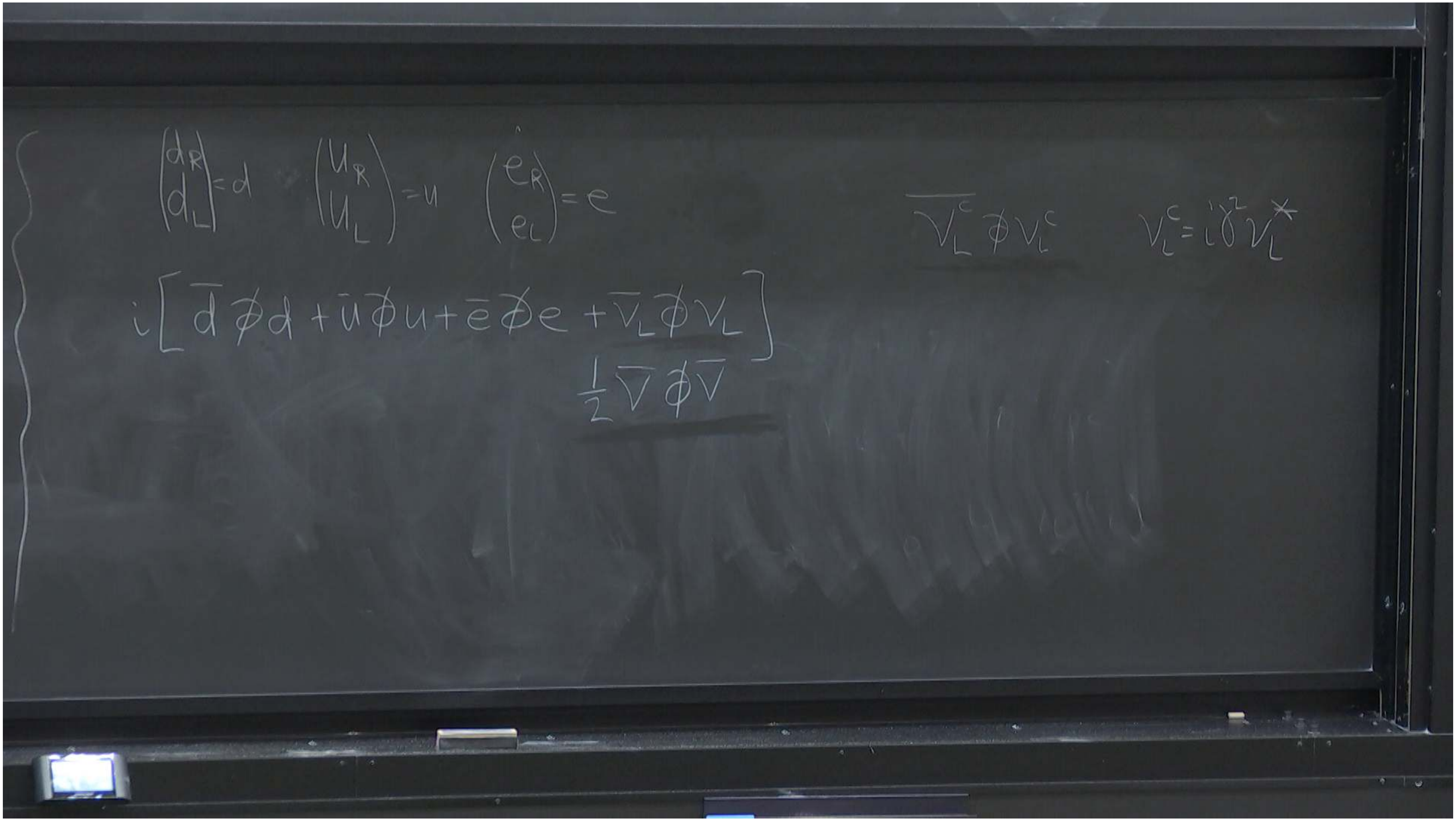
Weinberg term: $-\frac{1}{2\Lambda}\left[\overline{\psi_c}^{\,i} y^{ij} \psi^{j} + h.c.\right] \simeq -\frac{1}{2}\bar{\nu} M \nu$

$$\psi \equiv \tilde{h}^{\dagger} \ell_L$$

$$)^{j} + h.c.\Big] \simeq -\frac{1}{2}\bar{\nu} M \nu \qquad \nu = \begin{pmatrix} \nu_L^c \\ \nu_L \end{pmatrix}$$

- $L + B$ "accidental syms"
- no DM + no expl. $M/\bar{M}$ asym. $\cancel{B}$, $\cancel{C}$, $\cancel{CP}$, $\cancel{T.E.}$
  (no new d.o.f.)

νSM



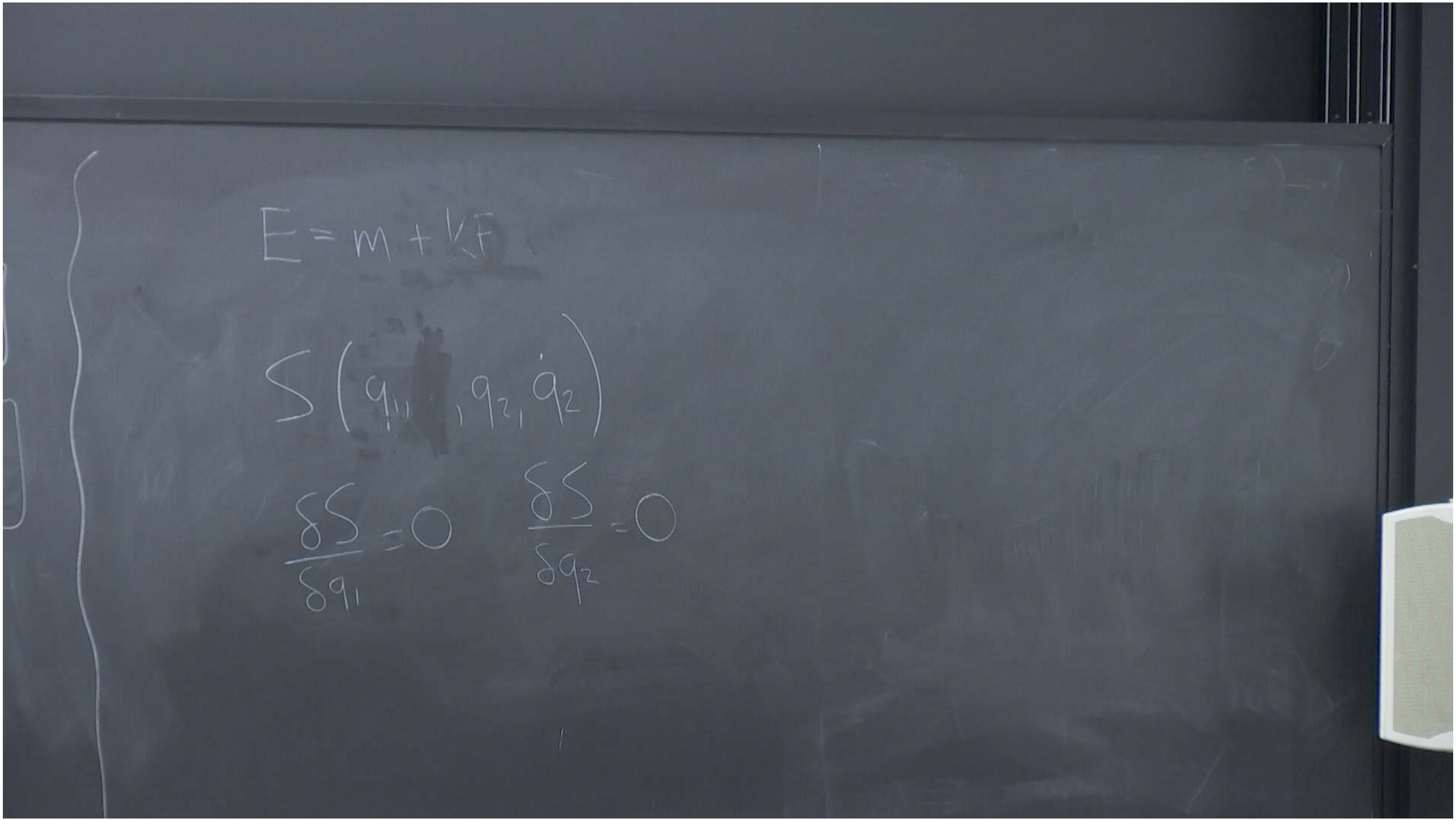
$\begin{pmatrix} d_R \\ d_L \end{pmatrix} = d$
$\begin{pmatrix} u_R \\ u_L \end{pmatrix} = u$
$\begin{pmatrix} e_R \\ e_L \end{pmatrix} = e$
$\overline{\nu_L^c} \not{\partial} \nu_L^c$
$\nu_L^c = i\gamma^2 \nu_L^*$
$i\left[\bar{d} \not{\partial} d + \bar{u} \not{\partial} u + \bar{e} \not{\partial} e + \bar{\nu}_L \not{\partial} \nu_L\right]$
$\frac{1}{2} \bar{\nu} \not{\partial} \bar{\nu}$

$$L = \text{same bosonic terms} \ldots$$

$$- \left[\bar{q}_L Y_d h d_R + \bar{q}_L Y_u \tilde{h} u_R + \bar{l}_L Y_e h e_R + \bar{l}_L Y_\nu \tilde{h} \nu_R + h.c. \right]$$

$$+ i \left[\bar{q}_L \not{D} q_L + \bar{u}_R \not{D} u_R + \bar{d}_R \not{D} d_R + \bar{l}_L \not{D} l_L + \bar{e}_R \not{D} e_R + \bar{\nu}_R \not{D} \nu_R \right]$$

$$\underbrace{- \frac{1}{2} \left[\bar{\nu}_{R,c}^{\,i} M^{ij} \nu_R^j + h.c. \right]}_{-\frac{1}{2} \bar{\nu}' M \nu'} \qquad \nu' = \nu_R + \nu_R^c = \begin{pmatrix} \nu_R \\ \nu_R^c \end{pmatrix}$$


$E = m + KE$
$S(q_1, \ , q_2, \dot{q}_2)$
$\frac{\delta S}{\delta q_1} = 0$ $\frac{\delta S}{\delta q_2} = 0$

$\mathcal{L} =$ same bosonic terms...

$$- \left[\bar{q}_L Y_d h d_R + \bar{q}_L Y_u \tilde{h} u_R + \bar{l}_L Y_e h e_R + \bar{l}_L Y_\nu \tilde{h} \nu_R + h.c. \right]$$

$$+ i \left[\bar{q}_L \not{D} q_L + \bar{u}_R \not{D} u_R + \bar{d}_R \not{D} d_R + \bar{l}_L \not{D} l_L + \bar{e}_R \not{D} e_R + \bar{\nu}_R \not{D} \nu_R \right]$$

$$\underbrace{- \frac{1}{2} \left[\overline{\nu_{R,c}^{\,i}} M_m^{ij} \nu_R^j + h.c. \right]}_{-\frac{1}{2} \bar{\nu}' M_m \nu'}$$

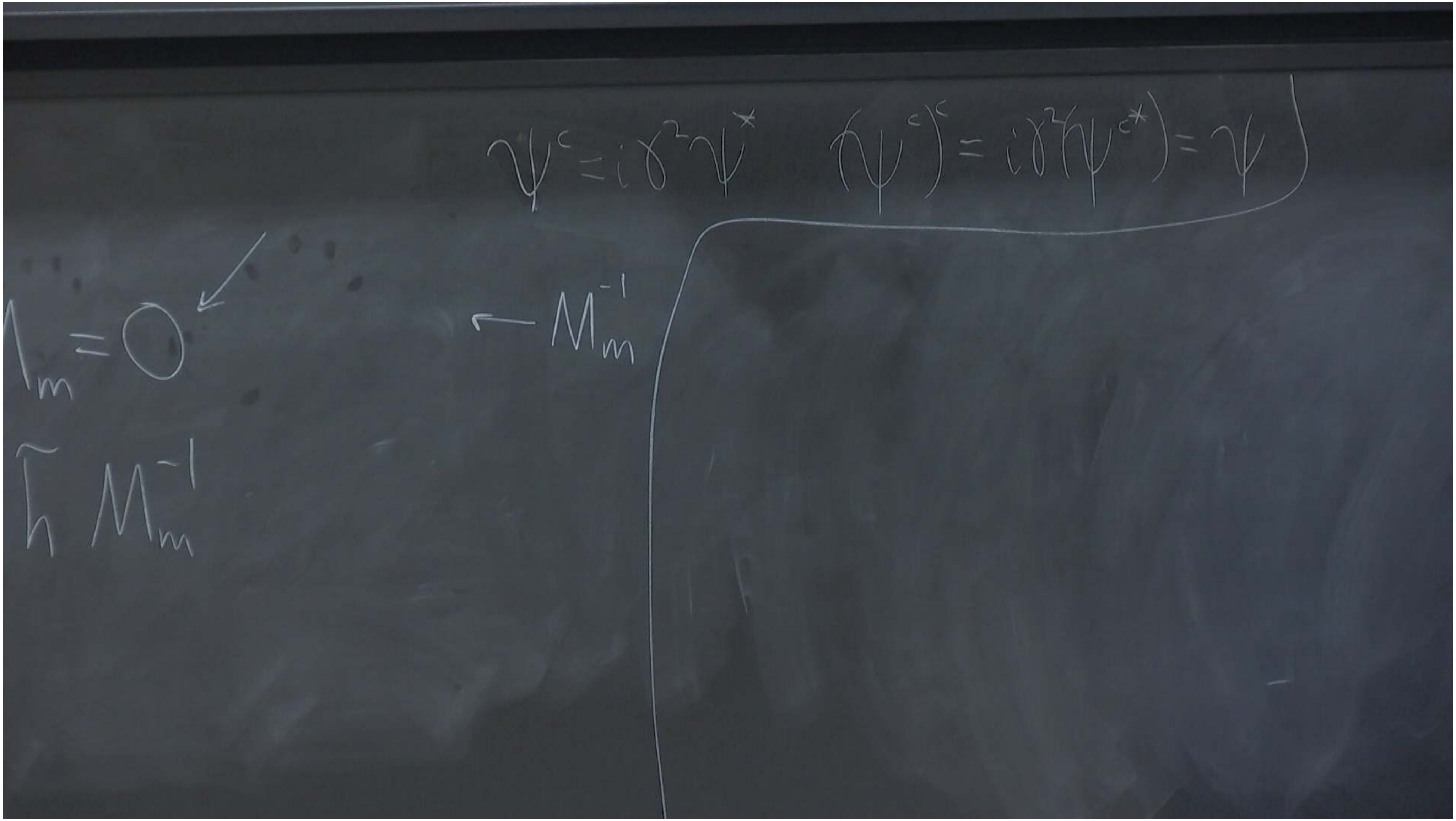
$$\nu' = \nu_R + \nu_R^c = \begin{pmatrix} \nu_R \\ \nu_R^c \end{pmatrix}$$

E-L eq for $\nu_R^{\,i}$

$$-\bar{\ell}_L Y_\nu \tilde{h} - \overline{\nu_R^c} M_m = 0$$

$$\overline{\nu_R^c} = -\bar{\ell}_L Y_\nu \tilde{h} M_m^{-1}$$

ν_R


$\psi^c = i\gamma^2\psi^*$
$(\psi^c)^c = i\gamma^2(\psi^{c*}) = \psi$
$M_m = 0$
$\leftarrow M_m^{-1}$
$\sim h\, M_m^{-1}$

$$-\frac{1}{2}\bar{\nu}' M_m \nu'$$

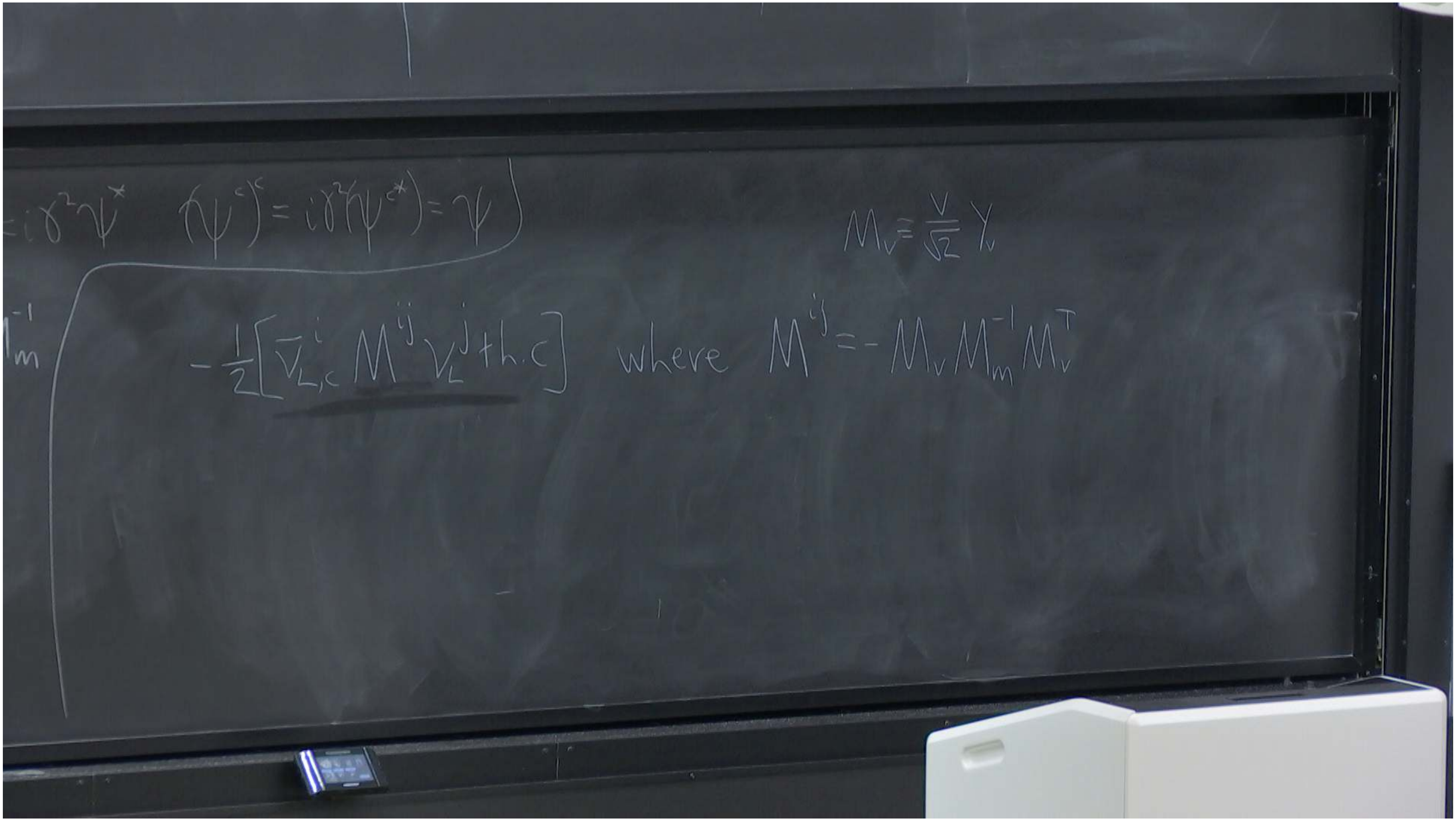
$$\psi^c = i\gamma^2\psi^* \qquad (\psi^c)^c = i\gamma^2(\psi^{c*}) = \psi$$

E-L eq for ν_R^i

$$-\bar{\ell}_L Y_\nu \tilde{h} - \overline{\nu_R^c} M_m = 0 \qquad \leftarrow M_m^{-1}$$

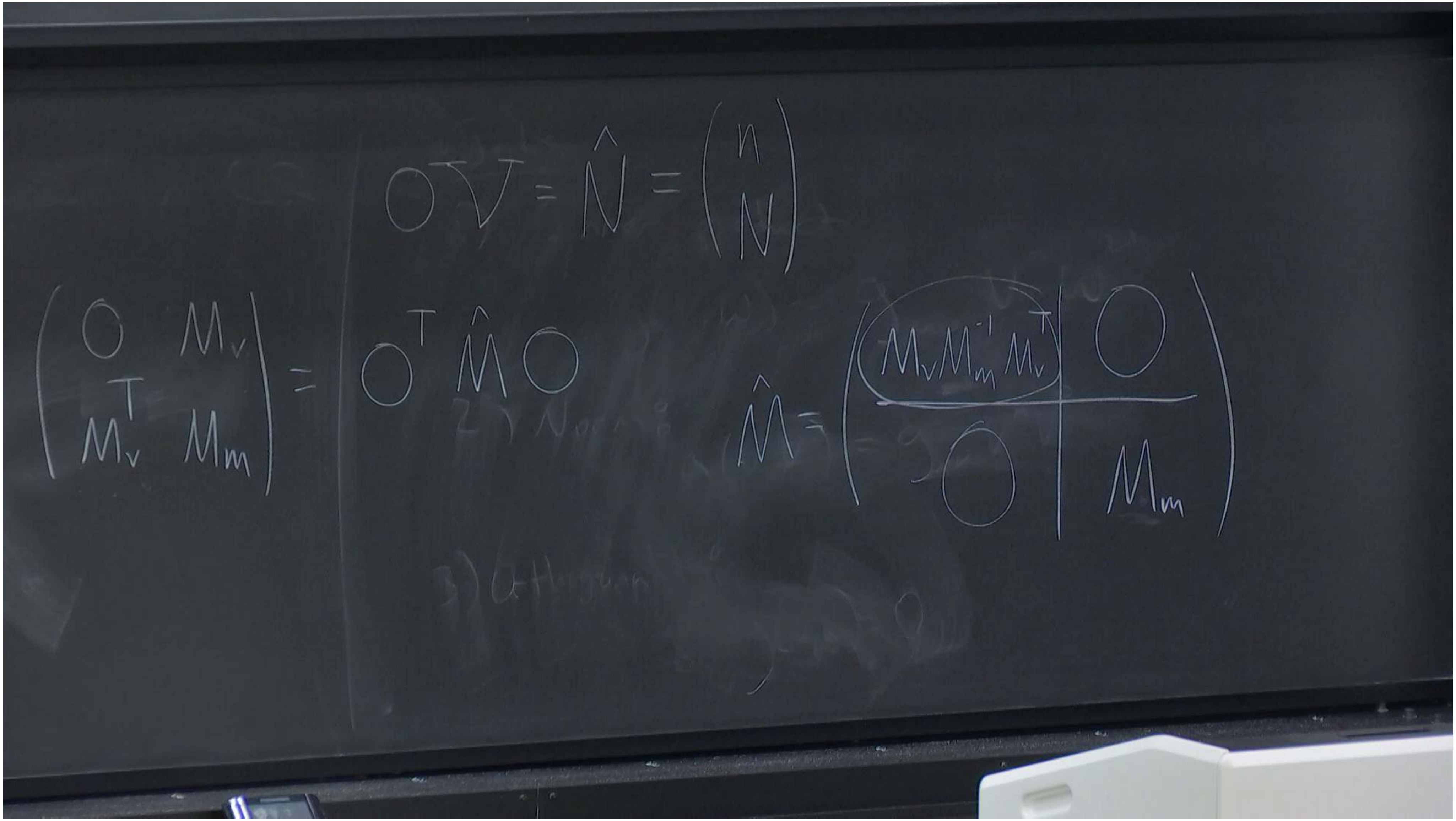
$$\overline{\nu_R^c} = -\bar{\ell}_L Y_\nu \tilde{h} M_m^{-1}$$

ν_R


$= i\gamma^2\psi^*$ $(\psi^c)^c = i\gamma^2(\psi^{c*}) = \psi$
$M_\nu = \frac{v}{\sqrt{2}} Y_\nu$
M_m^{-1}
$-\frac{1}{2}[\bar{\nu}^i_{L,c} M^{ij} \nu^j_L + h.c]$ where $M^{ij} = -M_\nu M_m^{-1} M_\nu^T$

$$\nu' = \begin{pmatrix} \nu_L^c \\ \nu_L \end{pmatrix} \qquad \nu' = \begin{pmatrix} \nu_R \\ \nu_R^c \end{pmatrix} \qquad \mathcal{V} = \begin{pmatrix} \nu \\ \nu' \end{pmatrix}$$

$$L = \frac{1}{2} i \bar{\mathcal{V}} \partial\!\!\!/ \mathcal{V} - \frac{1}{2} \bar{\mathcal{V}} \begin{pmatrix} 0 & M_\nu \\ M_\nu^T & M_m \end{pmatrix} \mathcal{V}$$


$O^T V = \hat{N} = \begin{pmatrix} n \\ N \end{pmatrix}$
$\begin{pmatrix} 0 & M_v \\ M_v^T & M_m \end{pmatrix} = O^T \hat{M} O$
$\hat{M} = \left(\begin{array}{c|c} M_v M_m^{-1} M_v^T & 0 \\ \hline 0 & M_m \end{array}\right)$