Title: PSI 17/18 - Beyond Standard Model - lecture 8

Date: Feb 27, 2018 02:00 PM

URL: http://pirsa.org/18020108

Abstract:

$\mathcal{L} = \mathcal{L}_0 + \mathcal{L}_2 + \mathcal{L}_4 + \mathcal{L}_5 + \mathcal{L}_6 + \cdots$

$[\mathcal{L}_n] = n$

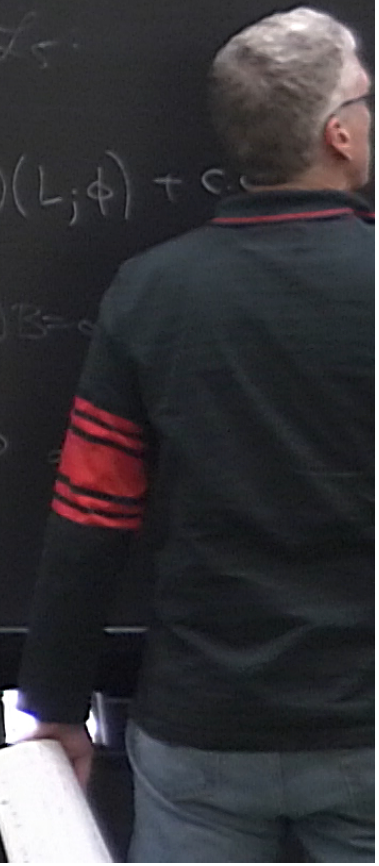
→ what is most general $\mathcal{L}_5$ consistent with $SU_3 \times SU_2 \times U_1$ containing only $B_\mu, W^a_\mu, G^a_\mu, L, E, D, U, Q, \phi$

Claim: unique $\mathcal{L}_5$.

$\mathcal{L}_5 = \frac{c_{ij}}{\Lambda}(L_i \phi)(L_j \phi) + c.c.$

$\Delta L = +2$

$\phi = \begin{pmatrix} 0 \\ v \end{pmatrix} \rightarrow$



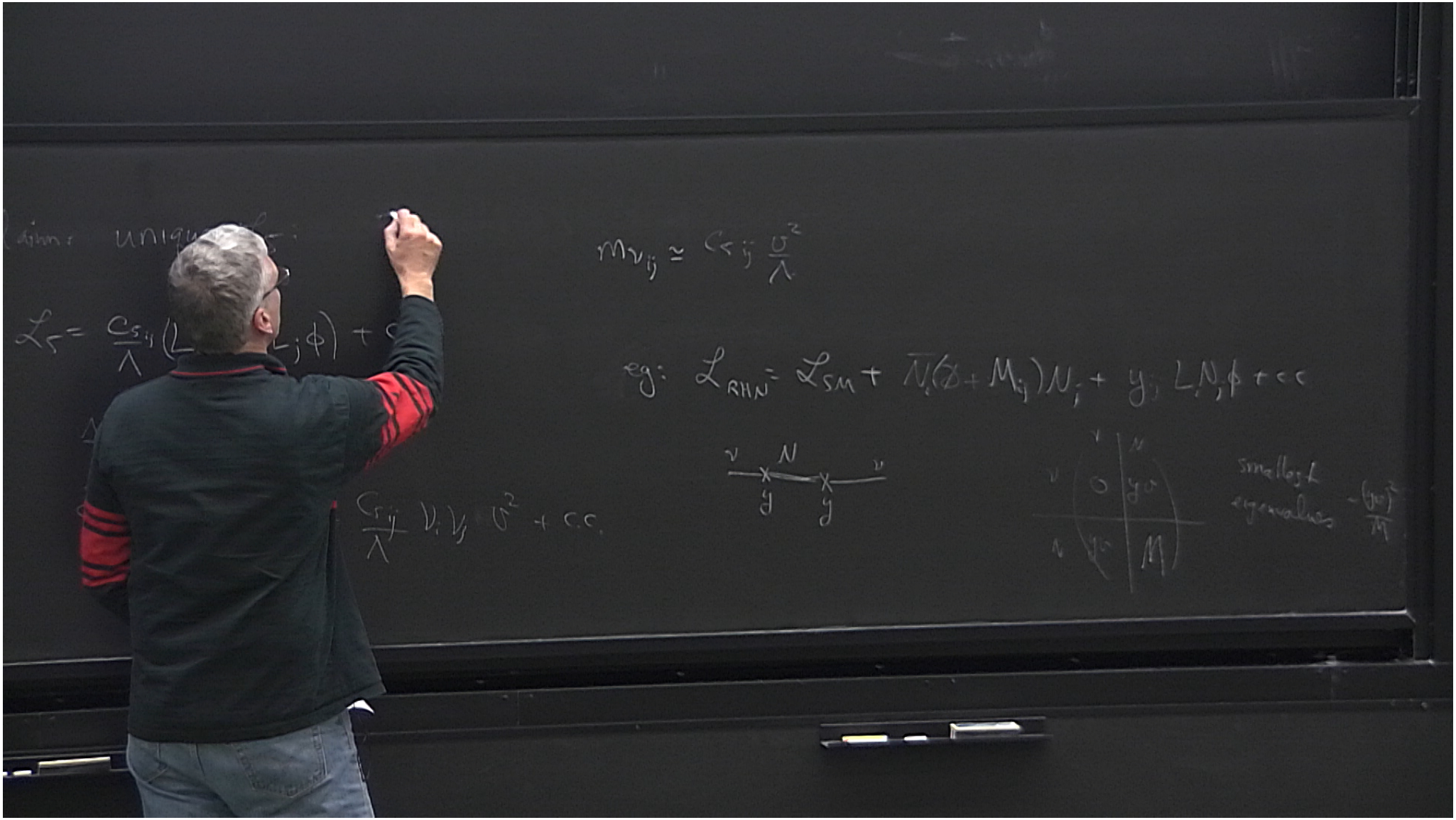
Claim: unique $\mathcal{L}_5$:

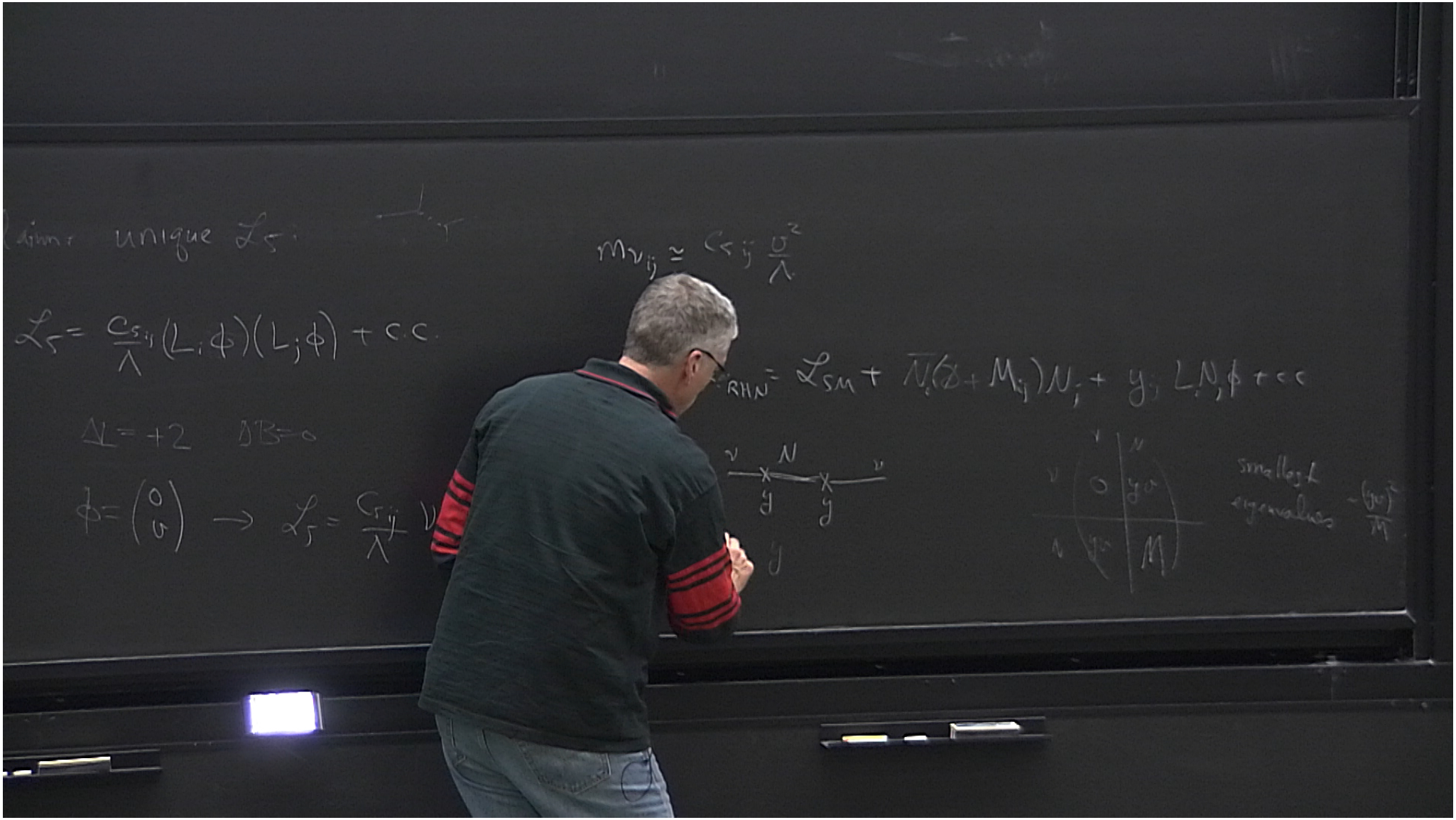
$$m_{\nu_{ij}} \simeq c_{5ij} \frac{v^2}{\Lambda}$$

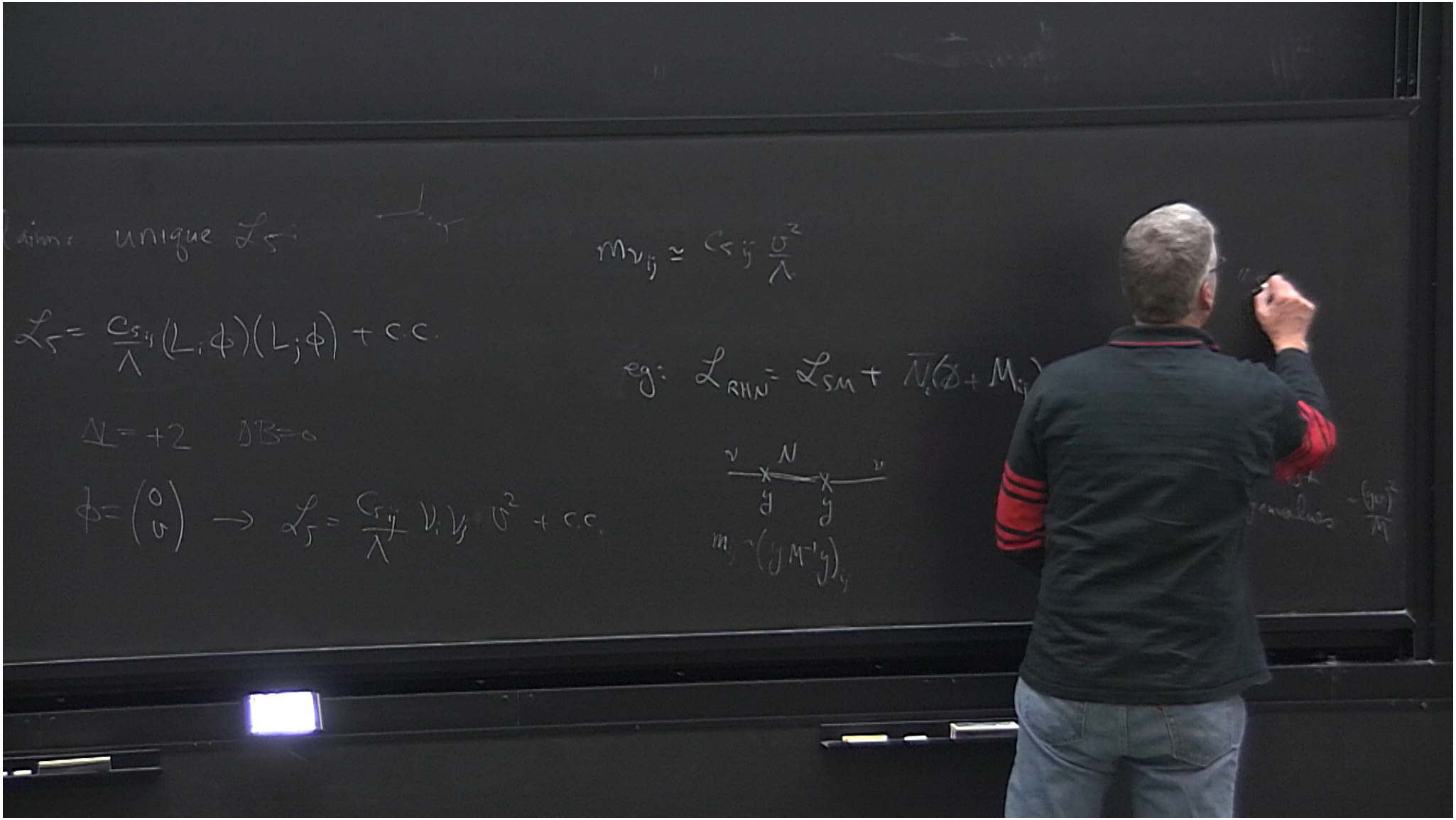
$$\mathcal{L}_5 = \frac{c_{5ij}}{\Lambda} (L_i \phi)(L_j \phi) + \text{c.c.}$$

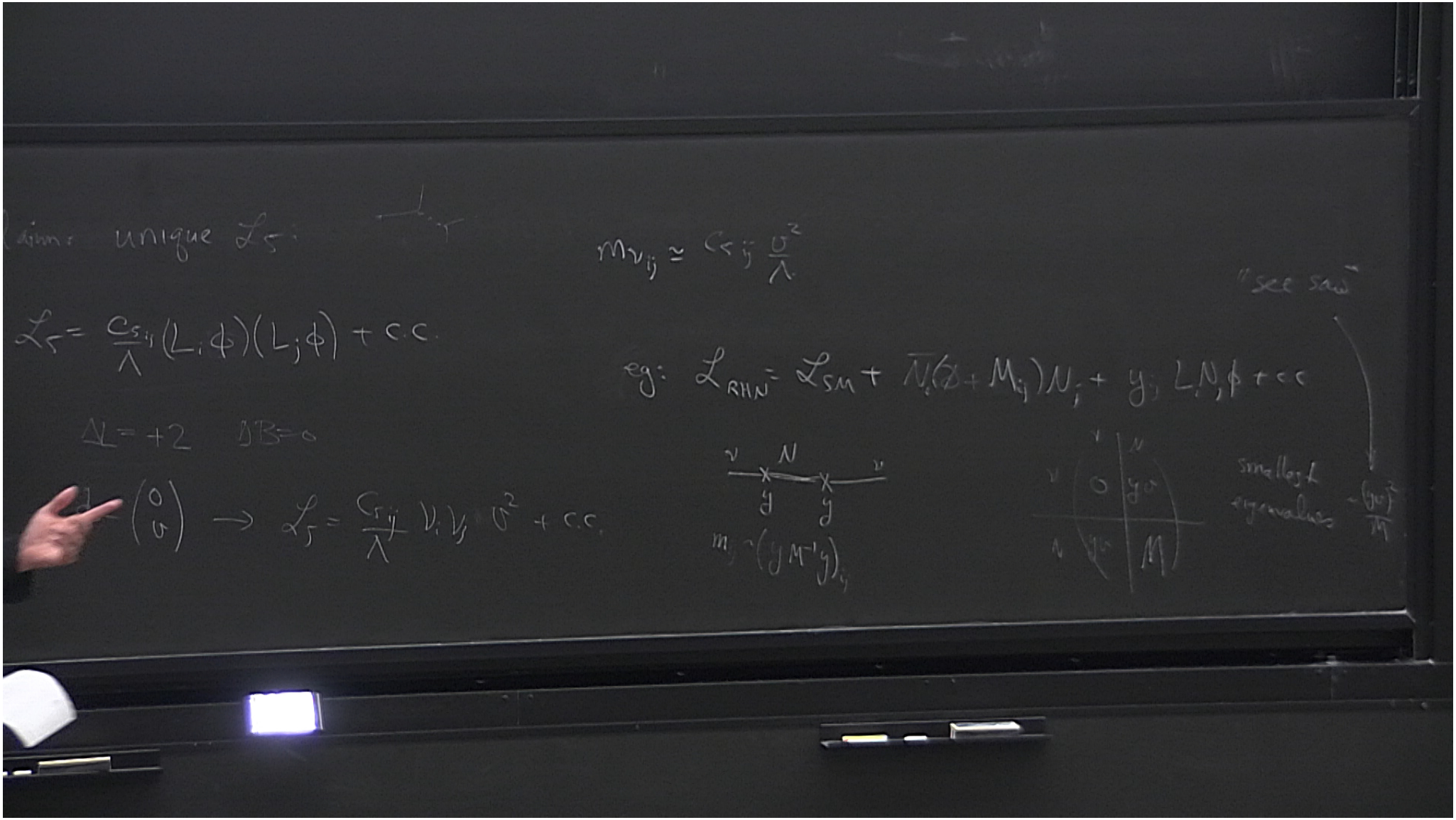
$\Delta L = +2 \quad \Delta B = 0$

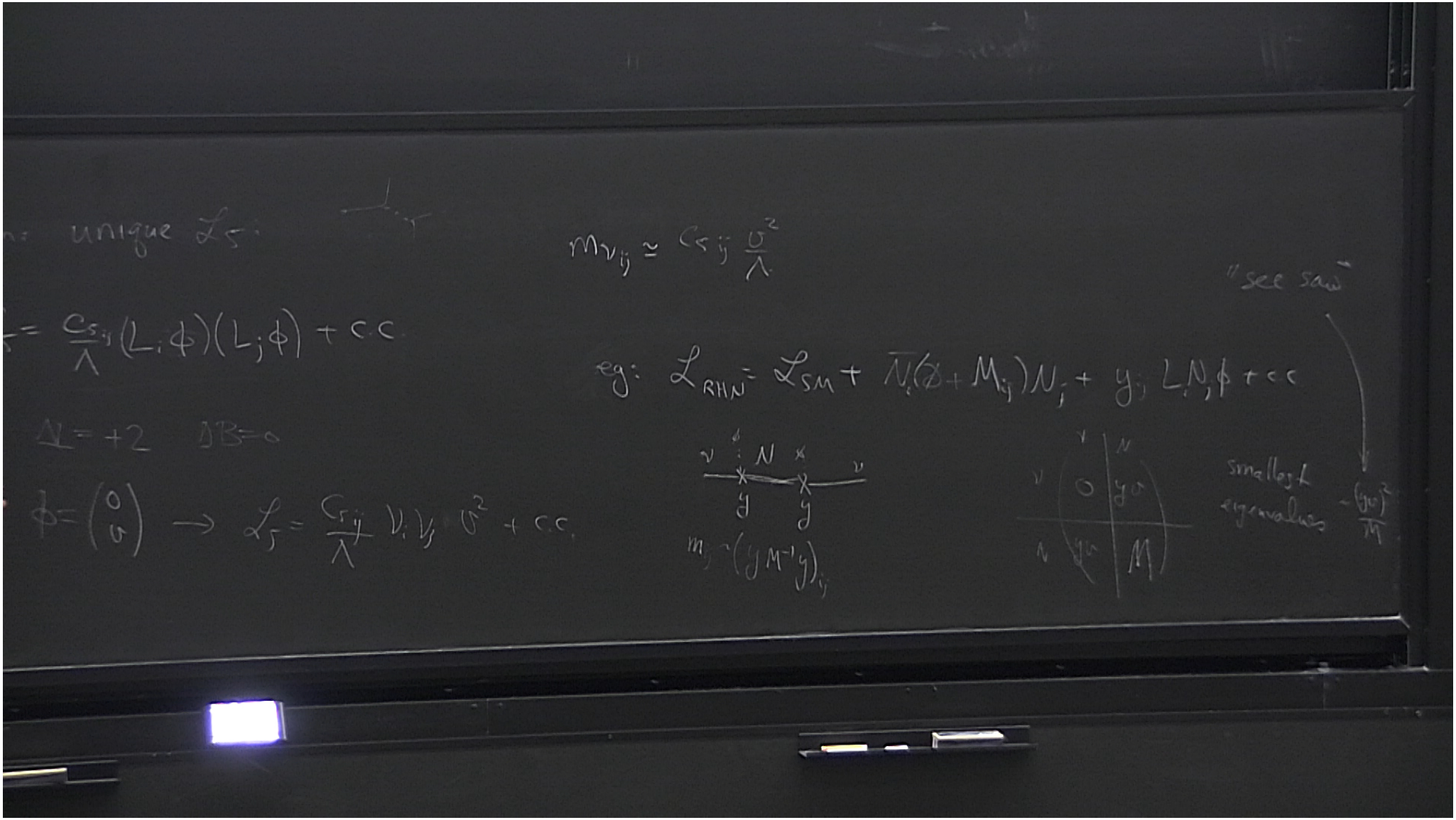
$$\phi = \begin{pmatrix} 0 \\ v \end{pmatrix} \rightarrow \mathcal{L}_5 = \frac{c_{5ij}}{\Lambda} \nu_i \nu_j v^2 + \text{c.c.}$$

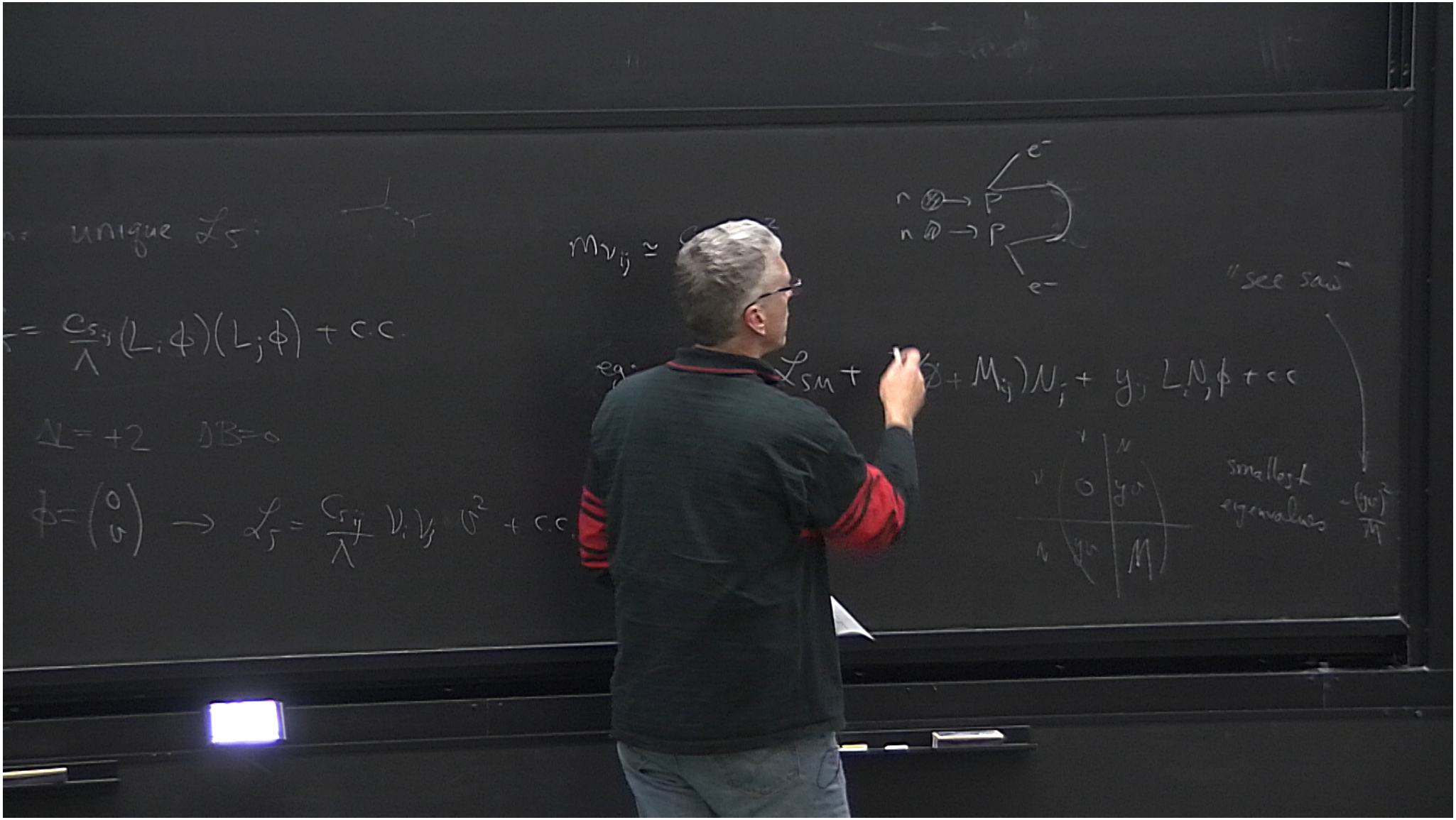

$m_{\nu_{ij}} \simeq c_{ij} \frac{v^2}{\Lambda}$
$\mathcal{L}_{RHN} = \mathcal{L}_{SM} + \bar{N}_i(\partial\!\!\!/ + M_{ij})N_j + y_{ij} L N_j \phi + cc$
ν N ν
y y
ν N
ν 0 $y v$
N $y v$ M
smallest eigenvalue $\sim \frac{(yv)^2}{M}$

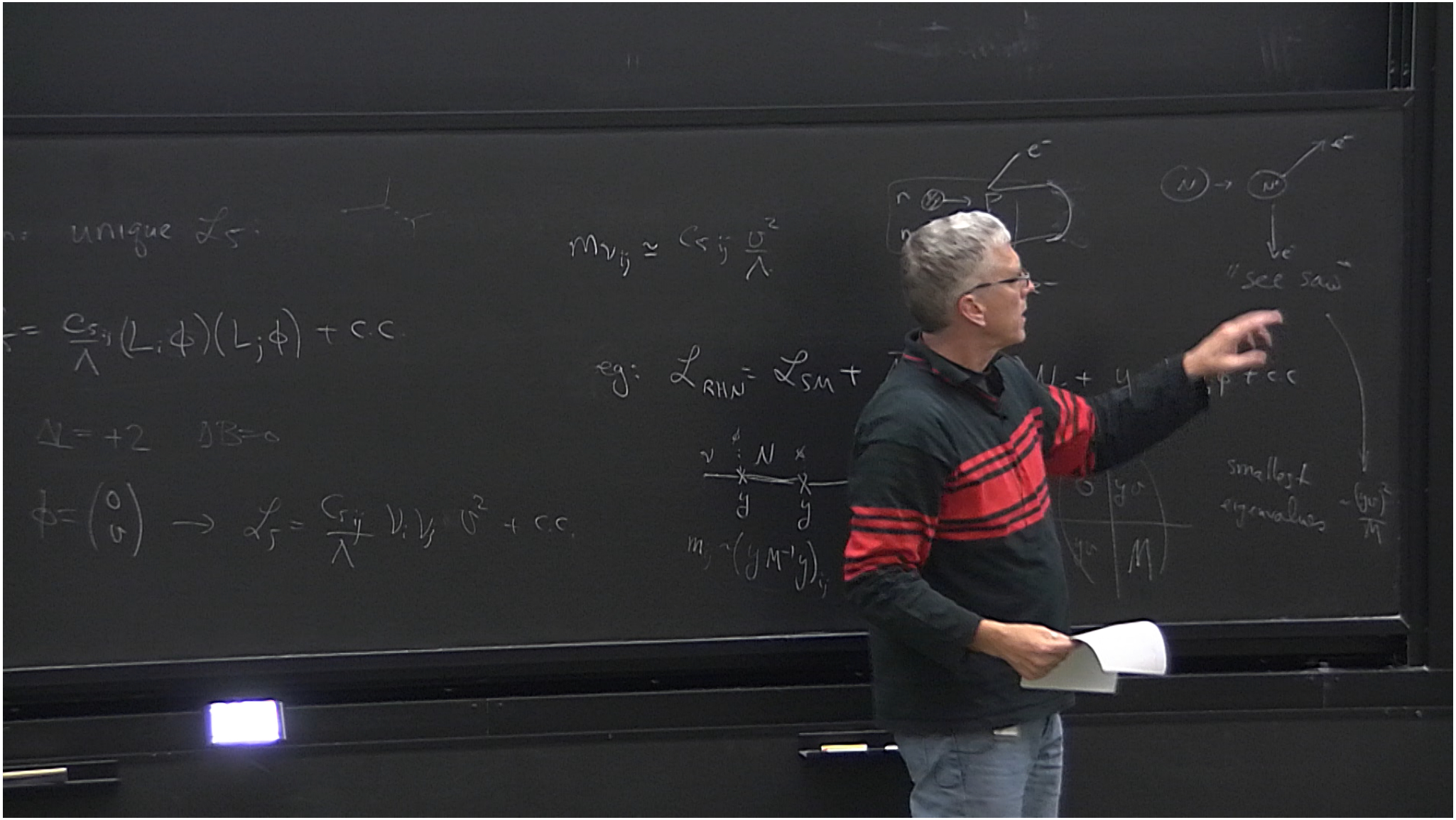

unique $\mathcal{L}_5$:
$m_{\nu_{ij}} \simeq c_{ij} \frac{v^2}{\Lambda}$
$\mathcal{L}_5 = \frac{c_{5ij}}{\Lambda}(L_i \phi)(L_j \phi) + c.c.$
$\mathcal{L}_{RHN} = \mathcal{L}_{SM} + \bar{N}_i(\partial + M_{ij})N_j + y_{ij} L_i N_j \phi + c.c$
$\Delta L = +2 \quad \Delta B = 0$
$\phi = \begin{pmatrix} 0 \\ v \end{pmatrix} \rightarrow$
$\nu \quad N \quad \nu$
$y \quad y$
$\nu \quad N$
$\nu \quad 0 \quad y v$
$N \quad y v \quad M$
smallest eigenvalues $-\frac{(yv)^2}{M}$

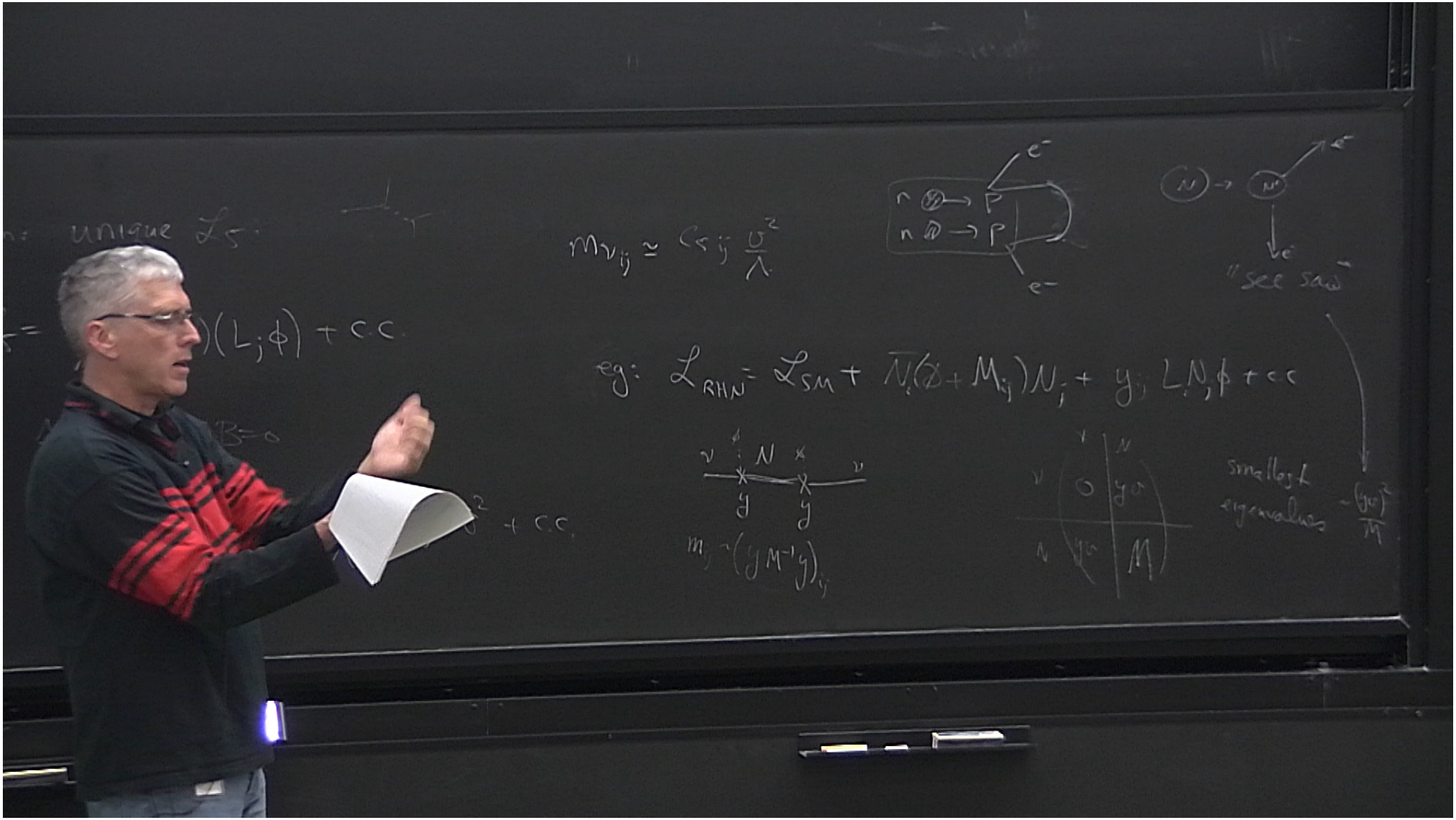

unique $\mathcal{L}_5$:
$\mathcal{L}_5 = \frac{C_{5ij}}{\Lambda}(L_i\phi)(L_j\phi) + c.c.$
$\Delta L = +2 \quad \Delta B = 0$
$\phi = \begin{pmatrix} 0 \\ v \end{pmatrix} \rightarrow \mathcal{L}_5 = \frac{C_{5ij}}{\Lambda} Y_i Y_j v^2 + c.c.$
$m_{\nu_{ij}} \simeq C_{5ij}\frac{v^2}{\Lambda}$
eg: $\mathcal{L}_{RHN} = \mathcal{L}_{SM} +$
ν N ν
y y
$m_\nu \sim (yM^{-1}y)_{ij}$

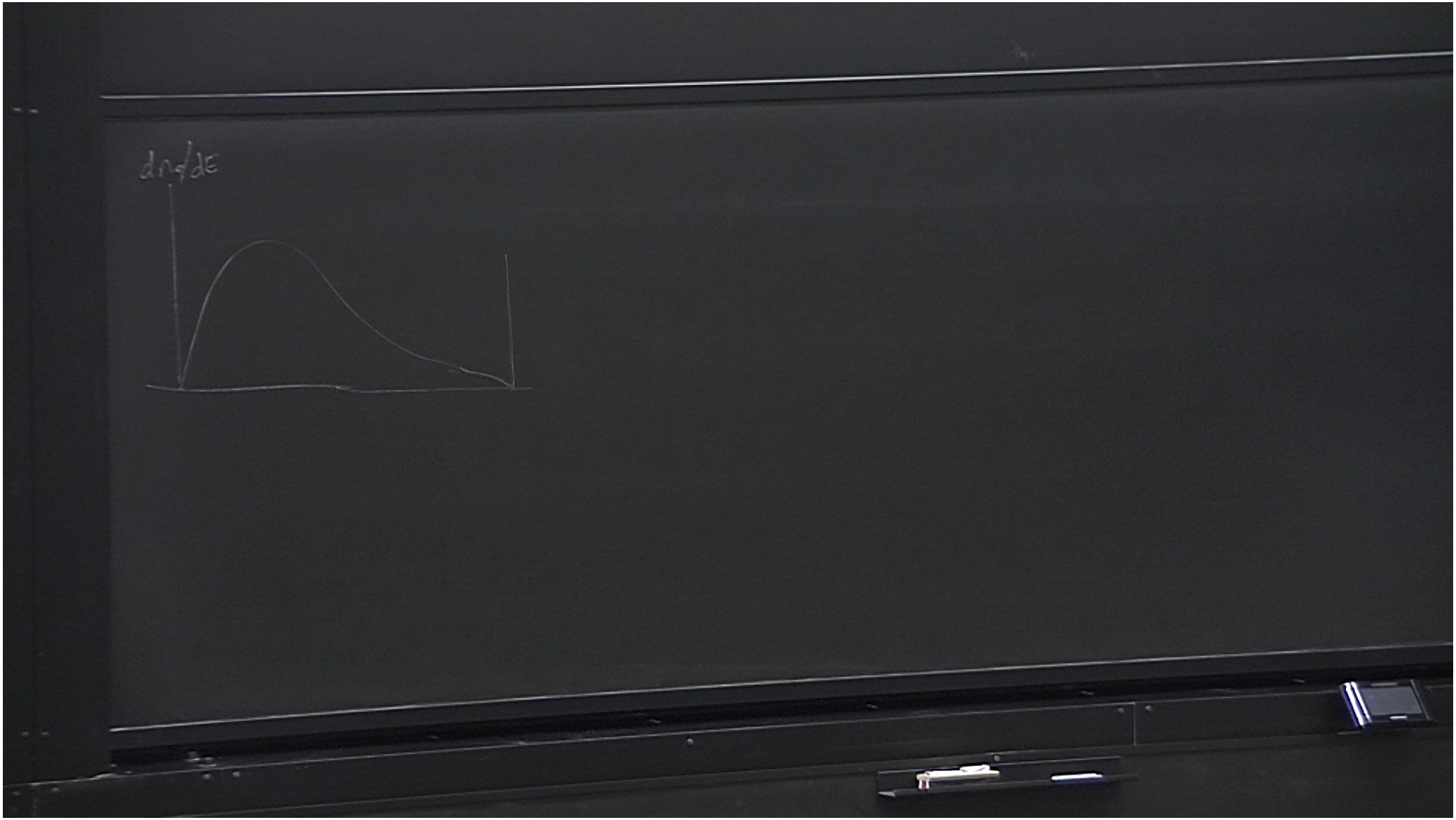

dim 5 unique $\mathcal{L}_5$:
$\mathcal{L}_5 = \frac{C_{5ij}}{\Lambda}(L_i\phi)(L_j\phi) + c.c.$
$\Delta L = +2 \quad \Delta B = 0$
$\langle\phi\rangle = \begin{pmatrix}0\\ v\end{pmatrix} \rightarrow \mathcal{L}_5 = \frac{C_{5ij}}{\Lambda} \nu_i \nu_j v^2 + c.c.$
$m_{\nu_{ij}} \simeq C_{5ij}\frac{v^2}{\Lambda}$
"see saw"
eg: $\mathcal{L}_{RHN} = \mathcal{L}_{SM} + \bar{N}_i(\partial\!\!\!/ + M_{ij})N_j + y_{ij} L N_j \phi + c.c$
ν N ν
y y
$m_\nu \sim (y M^{-1} y)_{ij}$
ν N
ν 0 yv
N yv M
smallest eigenvalue $\sim \frac{(yv)^2}{M}$

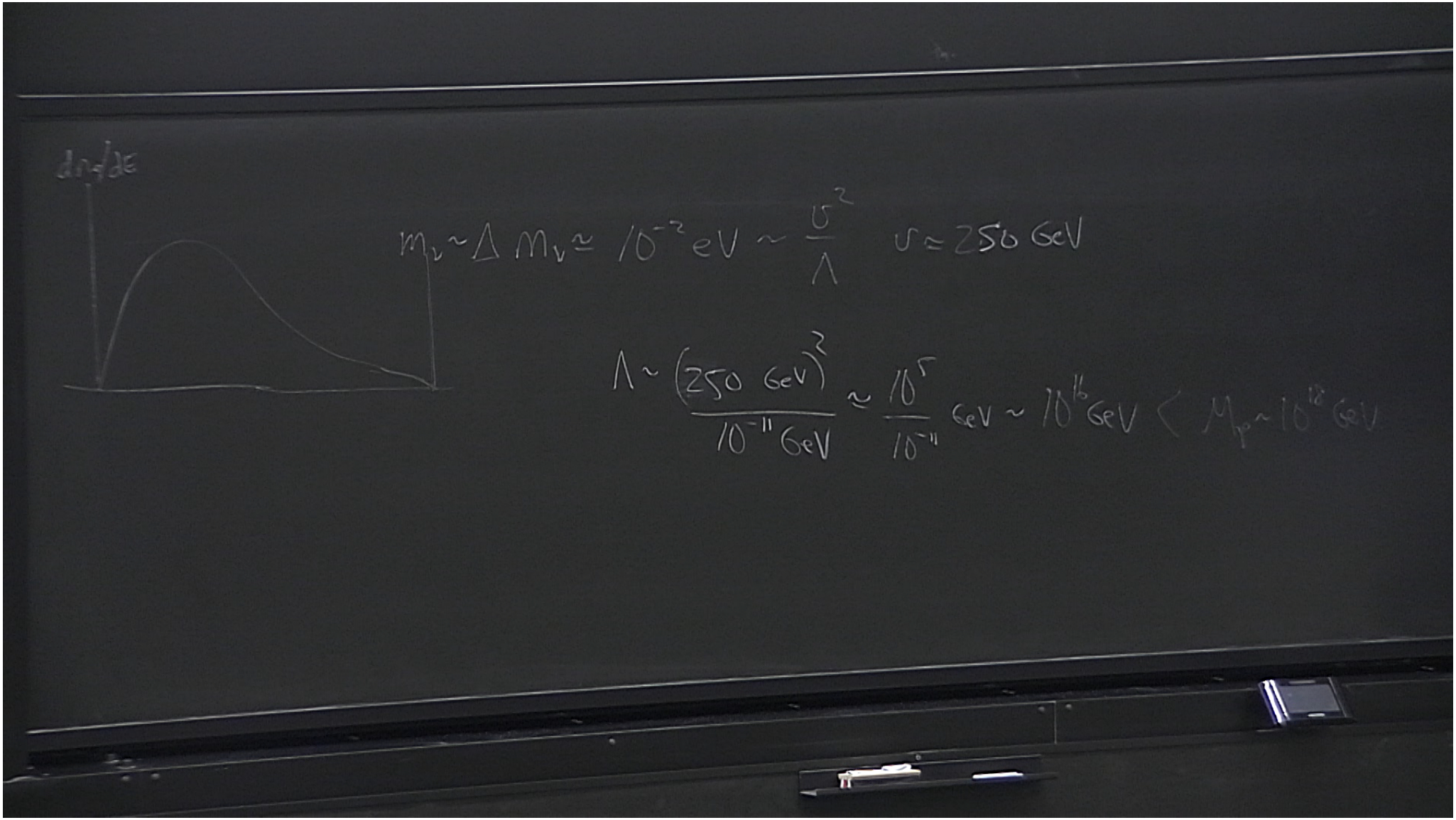

unique $\mathcal{L}_5$:
$\mathcal{L}_5 = \frac{C_{5ij}}{\Lambda}(L_i\phi)(L_j\phi) + c.c.$
$\Delta L = +2 \quad \Delta B = 0$
$\phi = \begin{pmatrix} 0 \\ v \end{pmatrix} \rightarrow \mathcal{L}_5 = \frac{C_{5ij}}{\Lambda} \nu_i \nu_j v^2 + c.c.$
$m\nu_{ij} \simeq C_{5ij}\frac{v^2}{\Lambda}$
"see saw"
eg: $\mathcal{L}_{RHN} = \mathcal{L}_{SM} + \bar{N}_i(\partial + M_{ij})N_j + y_{ij} L_i N_j \phi + c.c.$
ν N N ν
y y
$m_\nu \sim (yM^{-1}y)_{ij}$
ν N
ν 0 yv
N yv M
smallest eigenvalue $\sim \frac{(yv)^2}{M}$

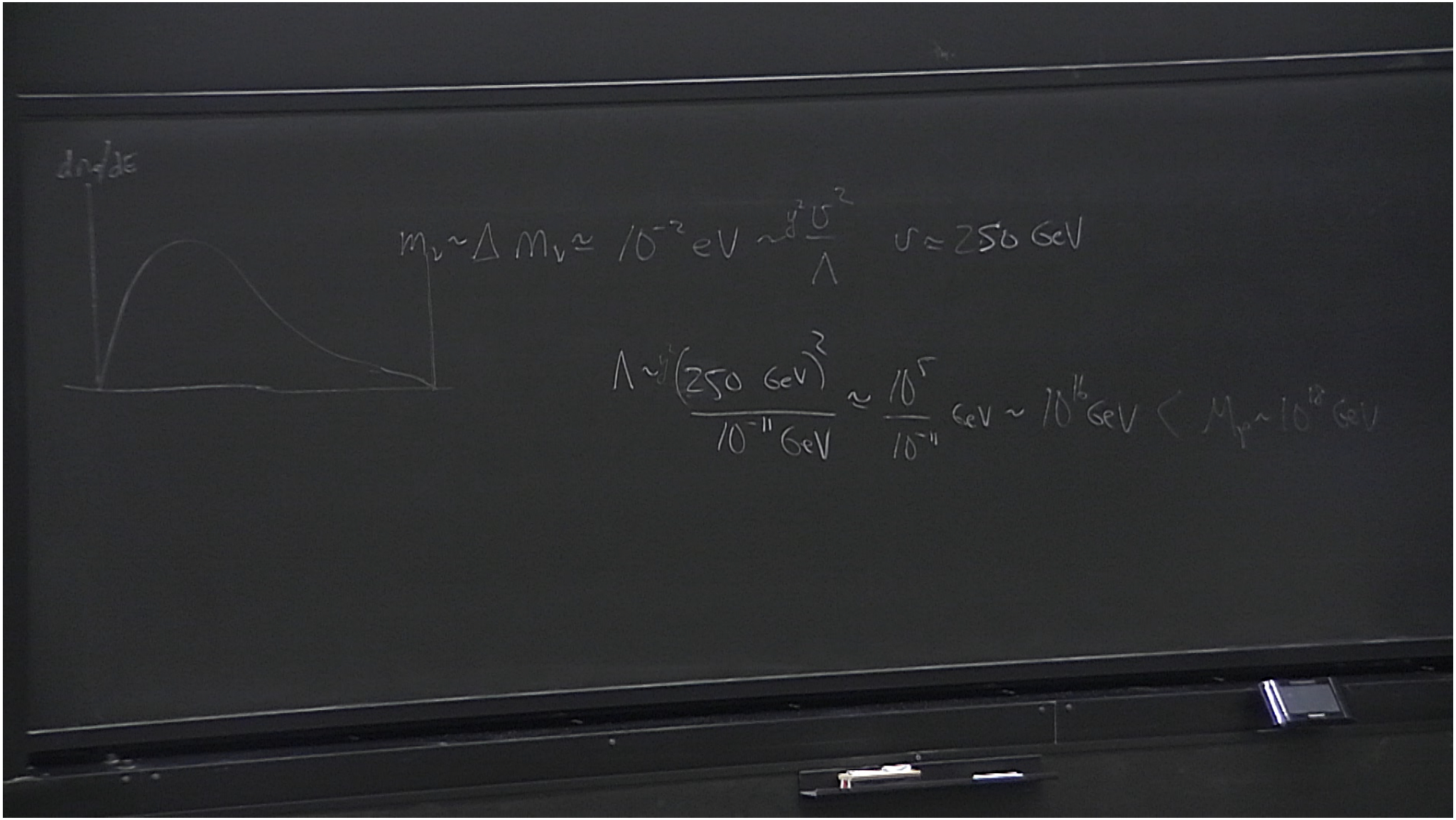

unique $\mathcal{L}_5$:
$m_{\nu_{ij}} \simeq$
$\mathcal{L} = \frac{C_{5,ij}}{\Lambda}(L_i\phi)(L_j\phi) + c.c.$
$\Delta L = +2 \quad \Delta B = 0$
$\phi = \begin{pmatrix} 0 \\ v \end{pmatrix} \rightarrow \mathcal{L}_5 = \frac{C_{5,ij}}{\Lambda} \nu_i \nu_j v^2 + c.c.$
$\mathcal{L}_{SM} + (\not{D} + M_{ij})N_j + y_{ij} L_i N_j \phi + c.c$
n → p + e⁻
n → p + e⁻
"see saw"
smallest eigenvalues
$-\frac{(yv)^2}{M}$

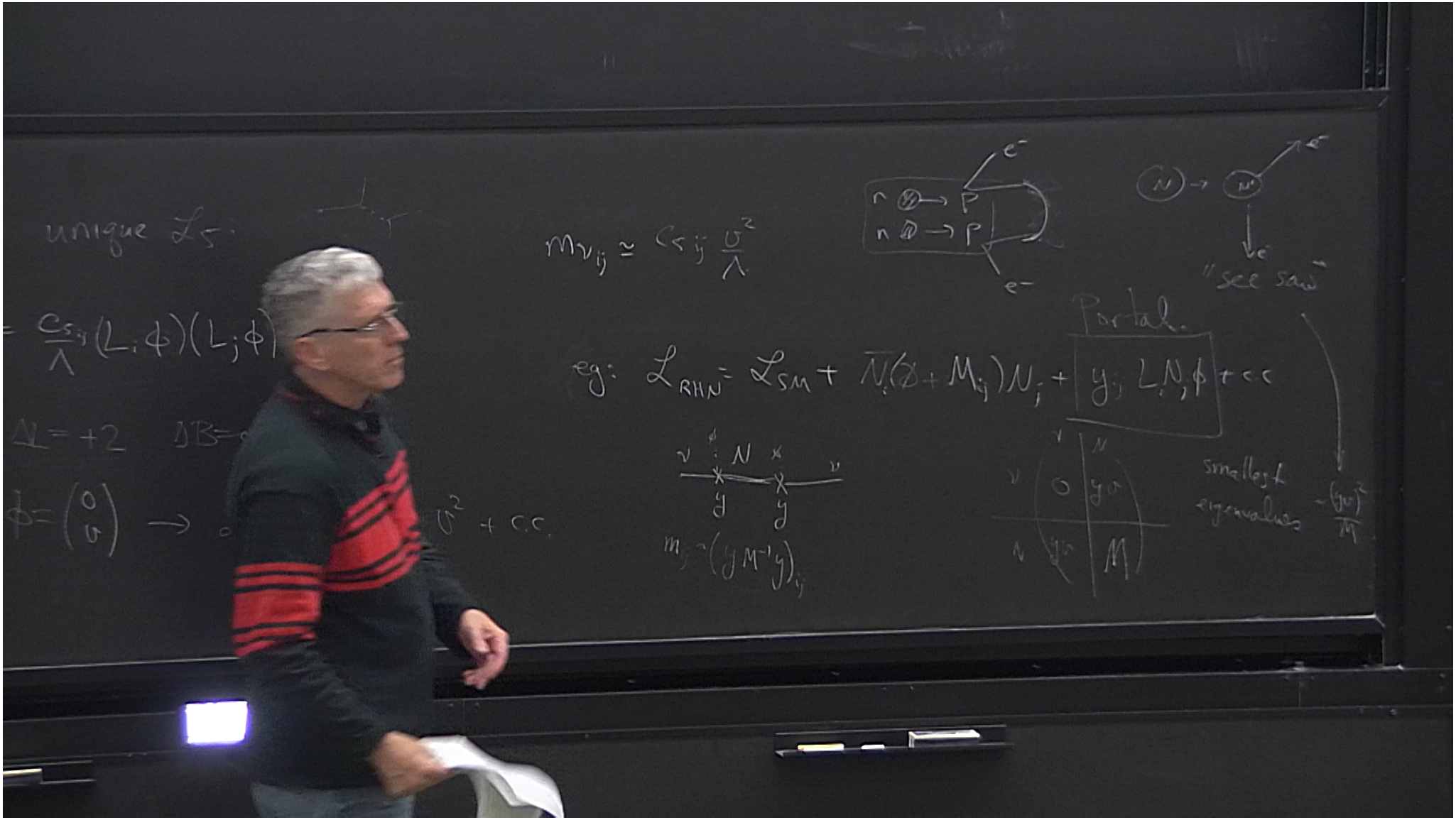

unique $\mathcal{L}_5$:
$m_{\nu_{ij}} \simeq c_{5ij} \frac{v^2}{\Lambda}$
$= \frac{c_{5ij}}{\Lambda}(L_i\phi)(L_j\phi) + c.c.$
eg: $\mathcal{L}_{RHN} = \mathcal{L}_{SM} +$
$\Delta L = +2 \quad \Delta B = 0$
$\phi = \begin{pmatrix} 0 \\ v \end{pmatrix} \rightarrow \mathcal{L}_5 = \frac{c_{5ij}}{\Lambda} \nu_i \nu_j v^2 + c.c.$
$m_\nu \sim (y M^{-1} y)_{ij}$
"see saw"
smallest eigenvalues
$\sim \frac{(yv)^2}{M}$

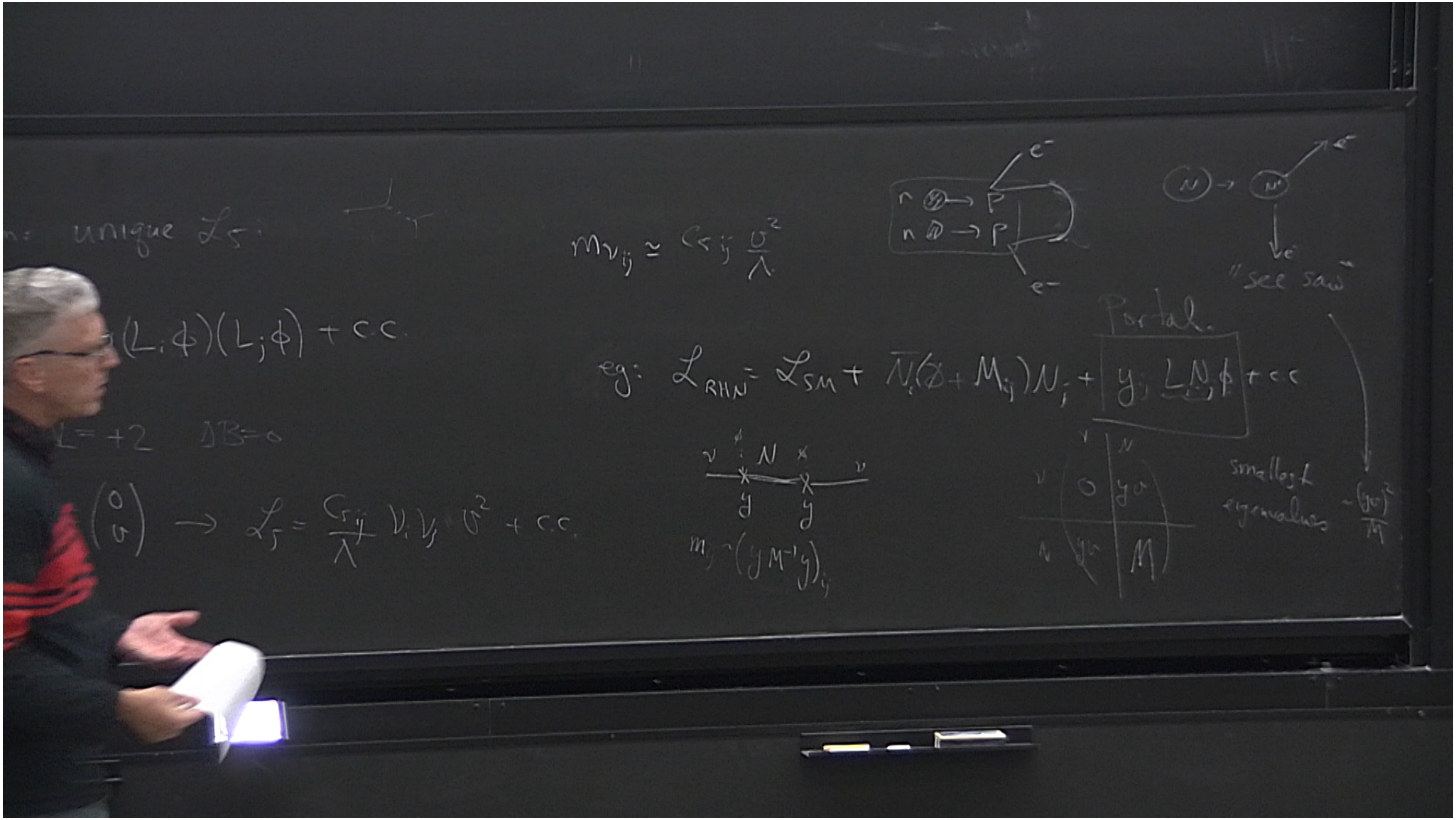

unique $\mathcal{L}_5$:
$m_{\nu_{ij}} \simeq c_{ij} \frac{v^2}{\Lambda}$
$n \to p + e^- + \bar{\nu}_e$
$N \to \nu + e^- + \bar{\nu}_e$
"see saw"
eg: $\mathcal{L}_{RHN} = \mathcal{L}_{SM} + \bar{N}_i(\partial\!\!\!/ + M_{ij})N_j + y_{ij} L N_j \phi + c.c.$
$m_\nu \sim (y M^{-1} y)_{ij}$
smallest eigenvalue $\sim \frac{(yv)^2}{M}$

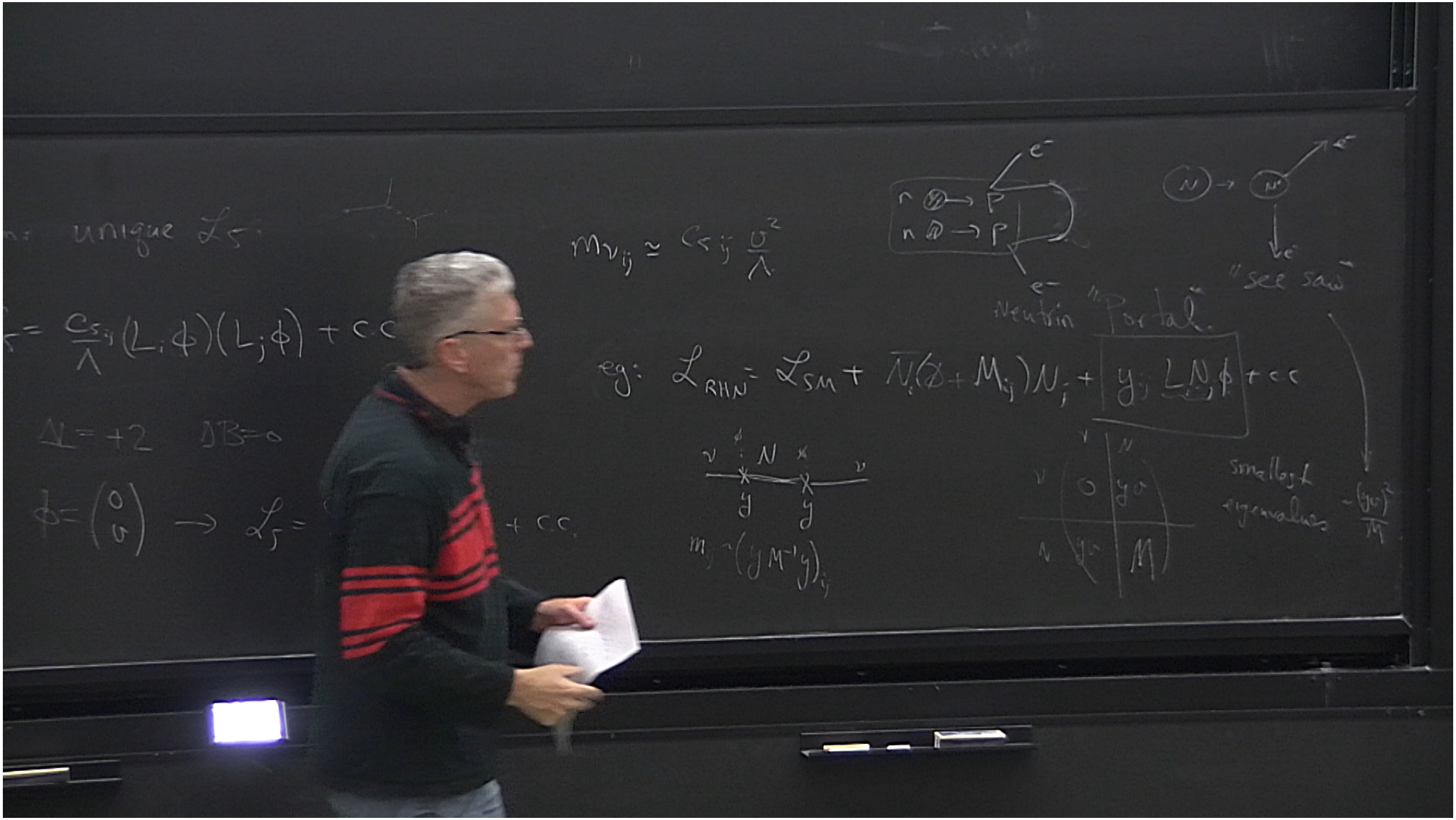

dn/dE

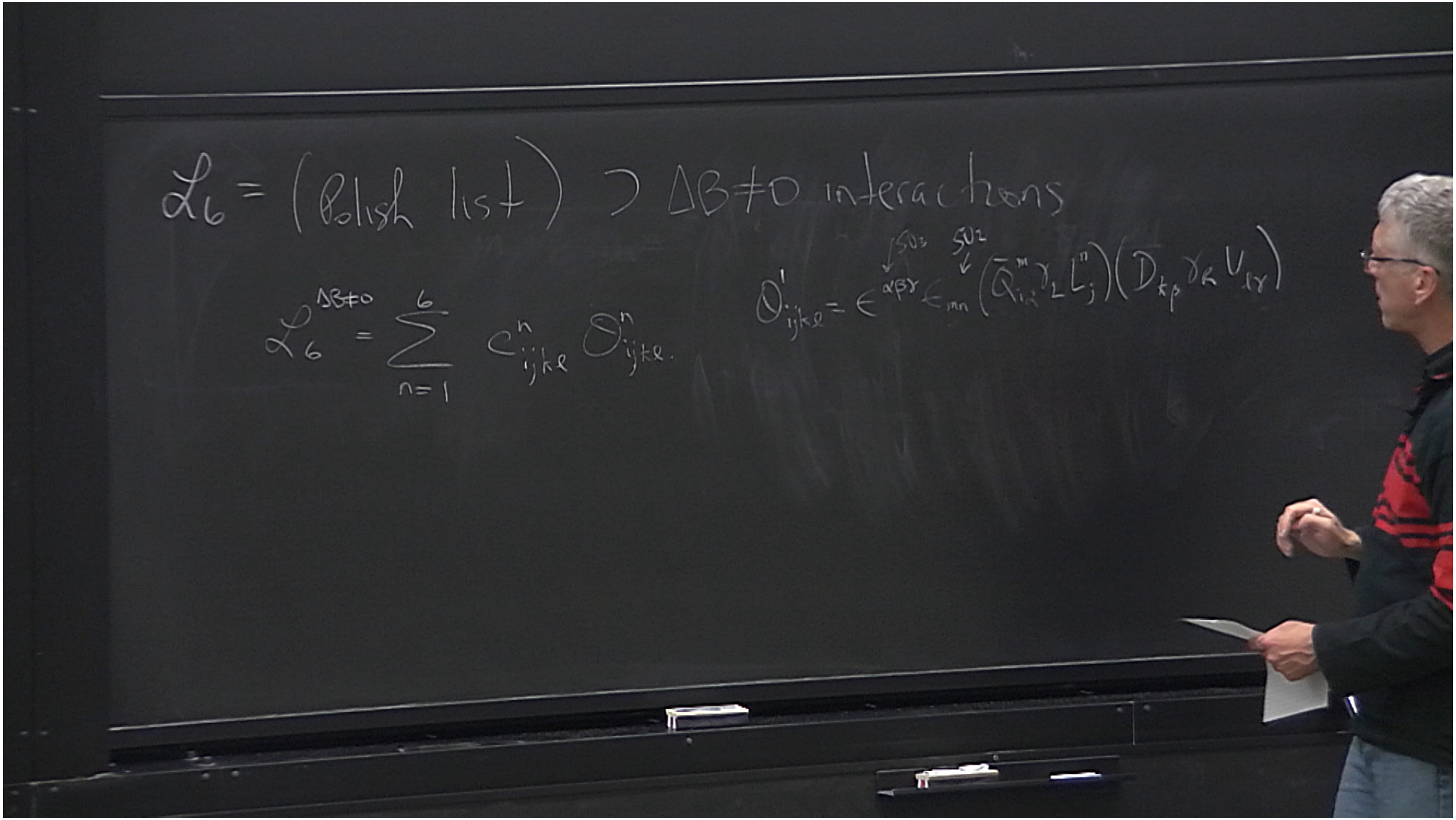

dn/dE
$m_\nu \sim \Delta m_\nu \simeq 10^{-2}\,eV \sim \frac{v^2}{\Lambda}$ $v \simeq 250\,GeV$
$\Lambda \sim \frac{(250\,GeV)^2}{10^{-11}\,GeV} \simeq \frac{10^5}{10^{-11}}\,GeV \sim 10^{16}\,GeV < M_p \sim 10^{18}\,GeV$

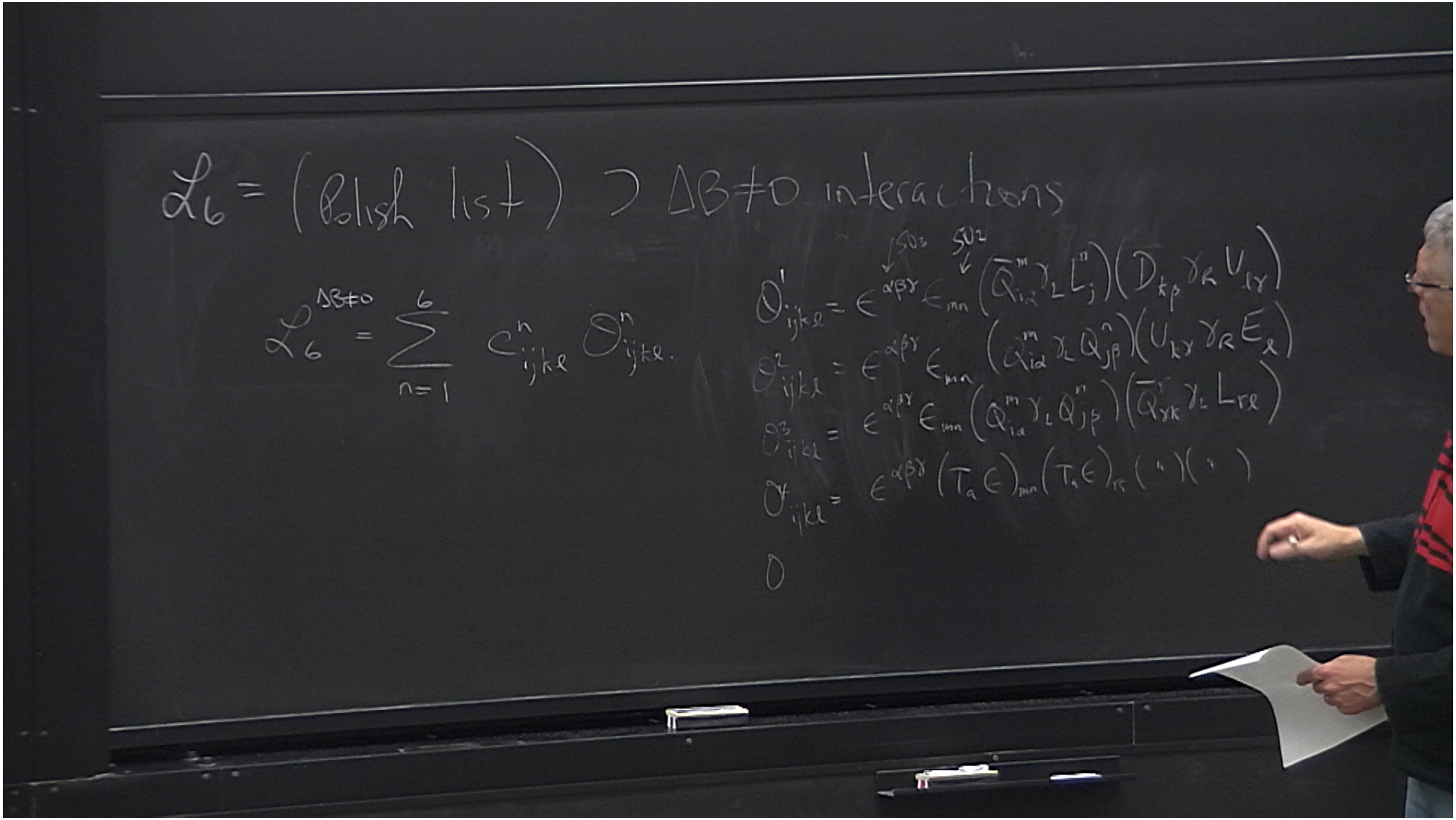

dn/dE
$m_\nu \sim \Delta m_\nu \simeq 10^{-2}\,\mathrm{eV} \sim y^2 \frac{v^2}{\Lambda}$ $v \simeq 250\,\mathrm{GeV}$
$\Lambda \sim y^2 \frac{(250\,\mathrm{GeV})^2}{10^{-11}\,\mathrm{GeV}} \simeq \frac{10^5}{10^{-11}}\,\mathrm{GeV} \sim 10^{16}\,\mathrm{GeV} < M_P \sim 10^{18}\,\mathrm{GeV}$

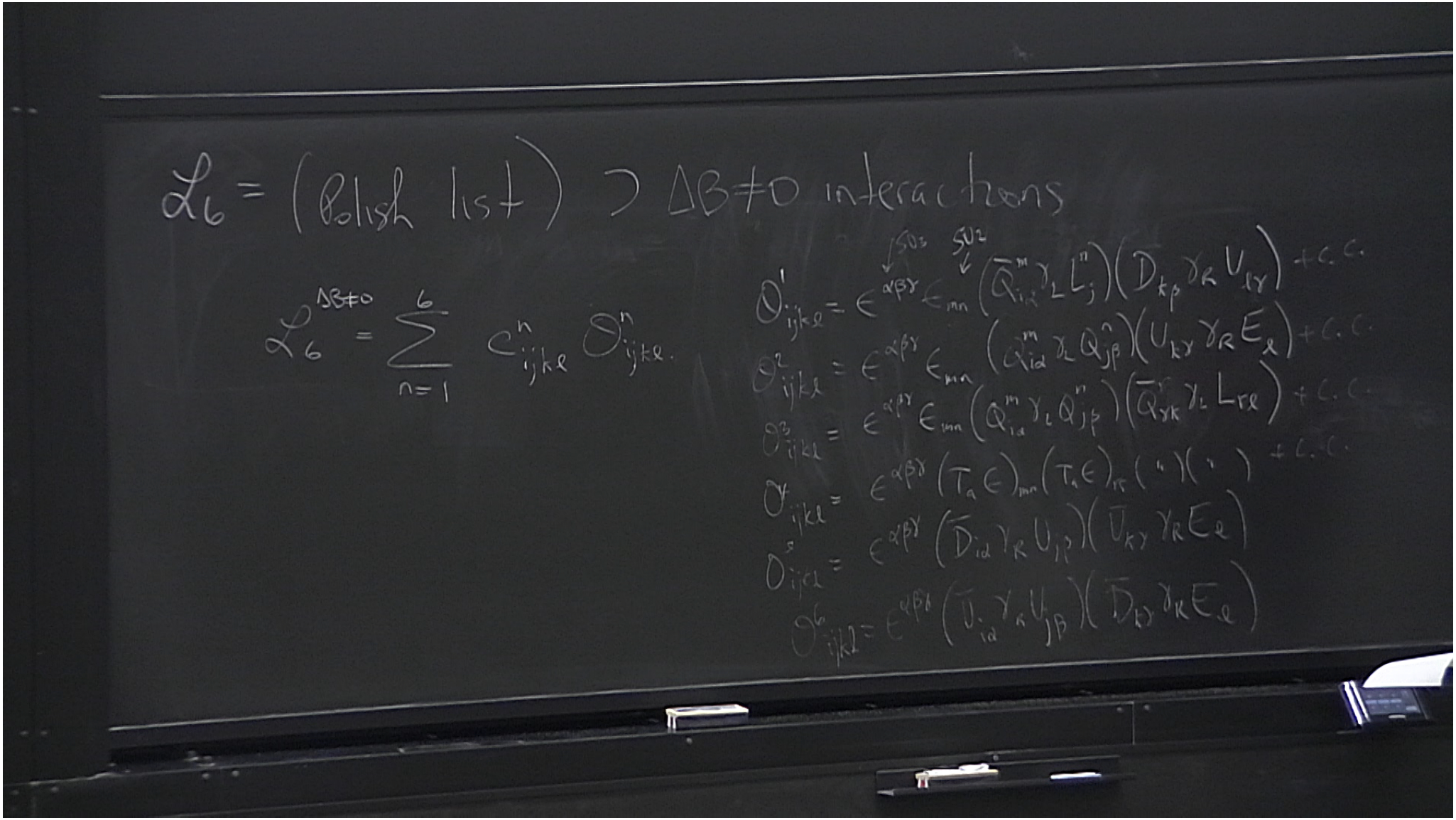

unique $\mathcal{L}_5$:
$m_{\nu_{ij}} \simeq c_{5ij} \frac{v^2}{\Lambda}$
$\frac{c_{5ij}}{\Lambda}(L_i\phi)(L_j\phi)$
$\Delta L = +2$
$\phi = \begin{pmatrix} 0 \\ v \end{pmatrix}$
v^2 + c.c.
$\mathcal{L}_{RHN} = \mathcal{L}_{SM} + \bar{N}_i(\partial\!\!\!/ + M_{ij})N_j +$ Portal $y_{ij} L_i N_j \phi$ + c.c
$m_\nu \sim (yM^{-1}y)_{ij}$
"see saw"
smallest eigenvalues
$\sim \frac{(yv)^2}{M}$

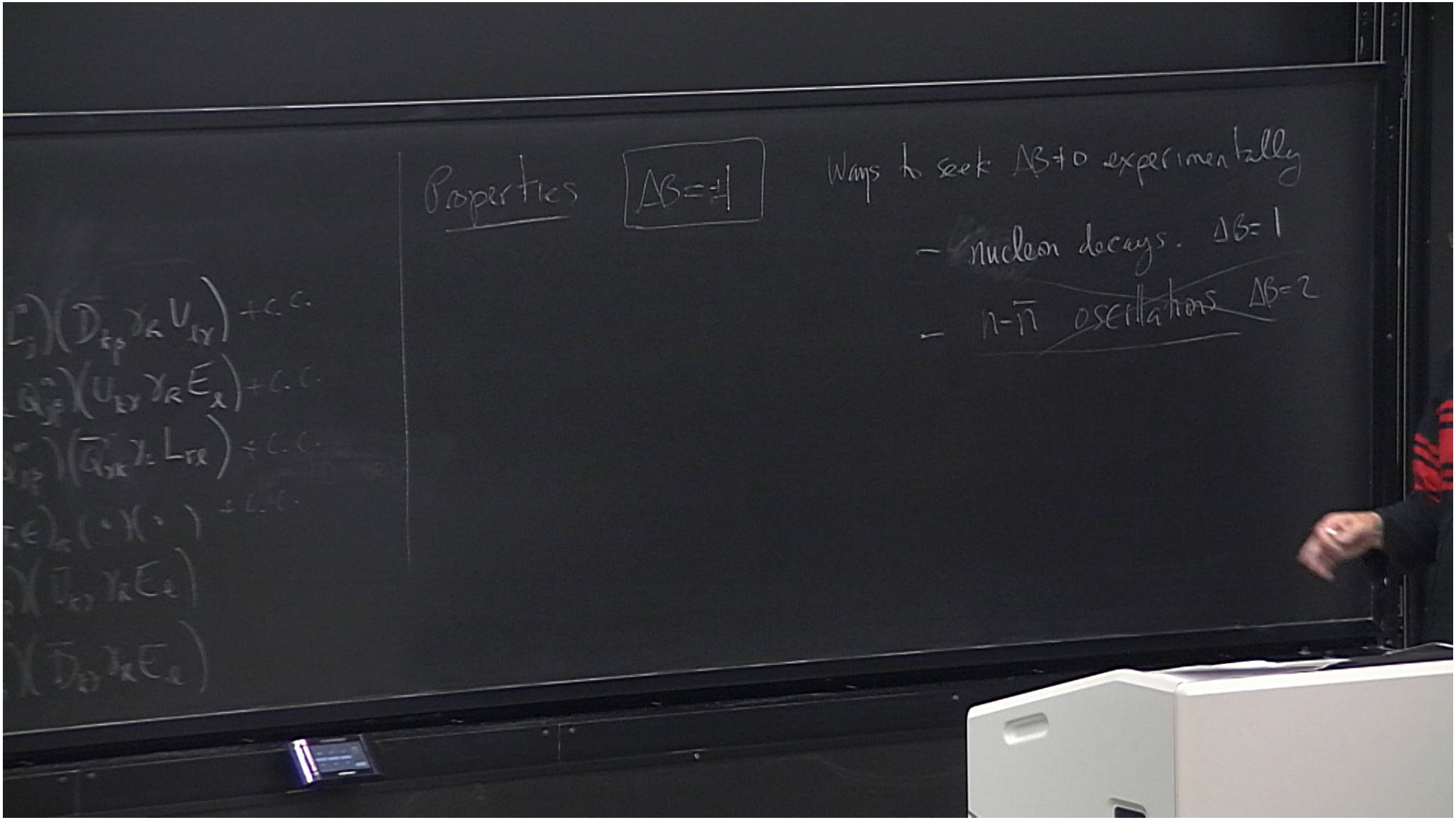

unique $\mathcal{L}_5$:
$m_{\nu_{ij}} \simeq c_{ij} \frac{v^2}{\Lambda}$
$(L_i \phi)(L_j \phi) + c.c.$
$L = +2 \quad \Delta B = 0$
$\begin{pmatrix} 0 \\ v \end{pmatrix} \rightarrow \mathcal{L}_5 = \frac{c_{ij}}{\Lambda} \nu_i \nu_j v^2 + c.c.$
e^-
e^-
"see saw"
Portal
eg: $\mathcal{L}_{RHN} = \mathcal{L}_{SM} + \bar{N}_i (\not{\partial} + M_{ij}) N_j + y_{ij} L_i N_j \phi + c.c.$
$m_\nu \sim (y M^{-1} y)_{ij}$
smallest eigenvalue
$\sim \frac{(yv)^2}{M}$

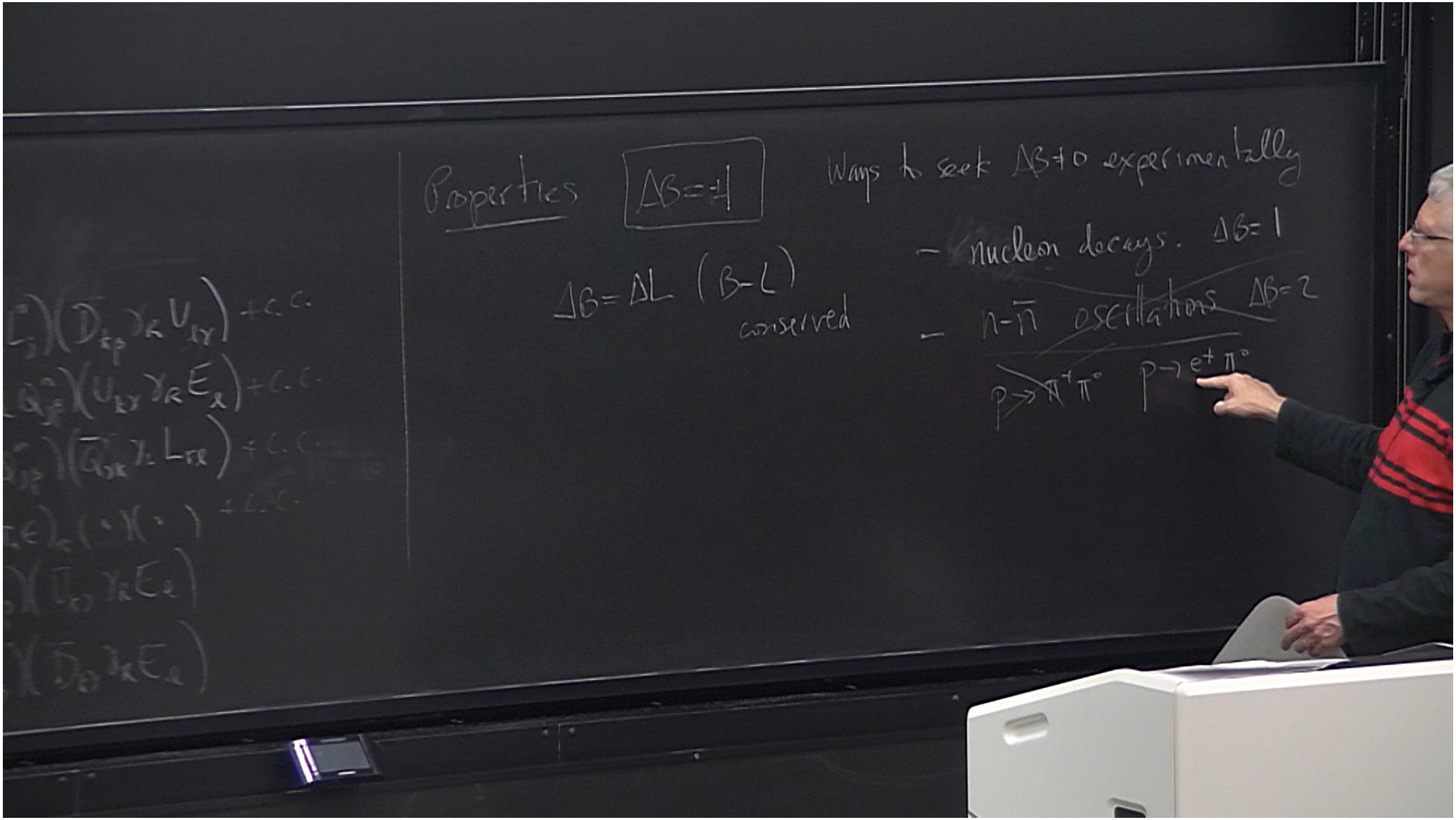

unique $\mathcal{L}_5$:
$m_{\nu_{ij}} \simeq c_{5ij} \frac{v^2}{\Lambda}$
$\mathcal{L}_5 = \frac{c_{5ij}}{\Lambda}(L_i\phi)(L_j\phi) + c.c$
$\Delta L = +2 \quad \Delta B = 0$
$\phi = \begin{pmatrix} 0 \\ v \end{pmatrix} \rightarrow \mathcal{L}_5 =$ + c.c.
$m_\nu \sim (y M^{-1} y)_{ij}$
e.g.: $\mathcal{L}_{RHN} = \mathcal{L}_{SM} + \bar{N}_i(\partial\!\!\!/ + M_{ij})N_j + y_{ij} L N_j \phi + c.c$
Neutrino "Portal"
"see saw"
smallest eigenvalues
$-\frac{(yv)^2}{M}$

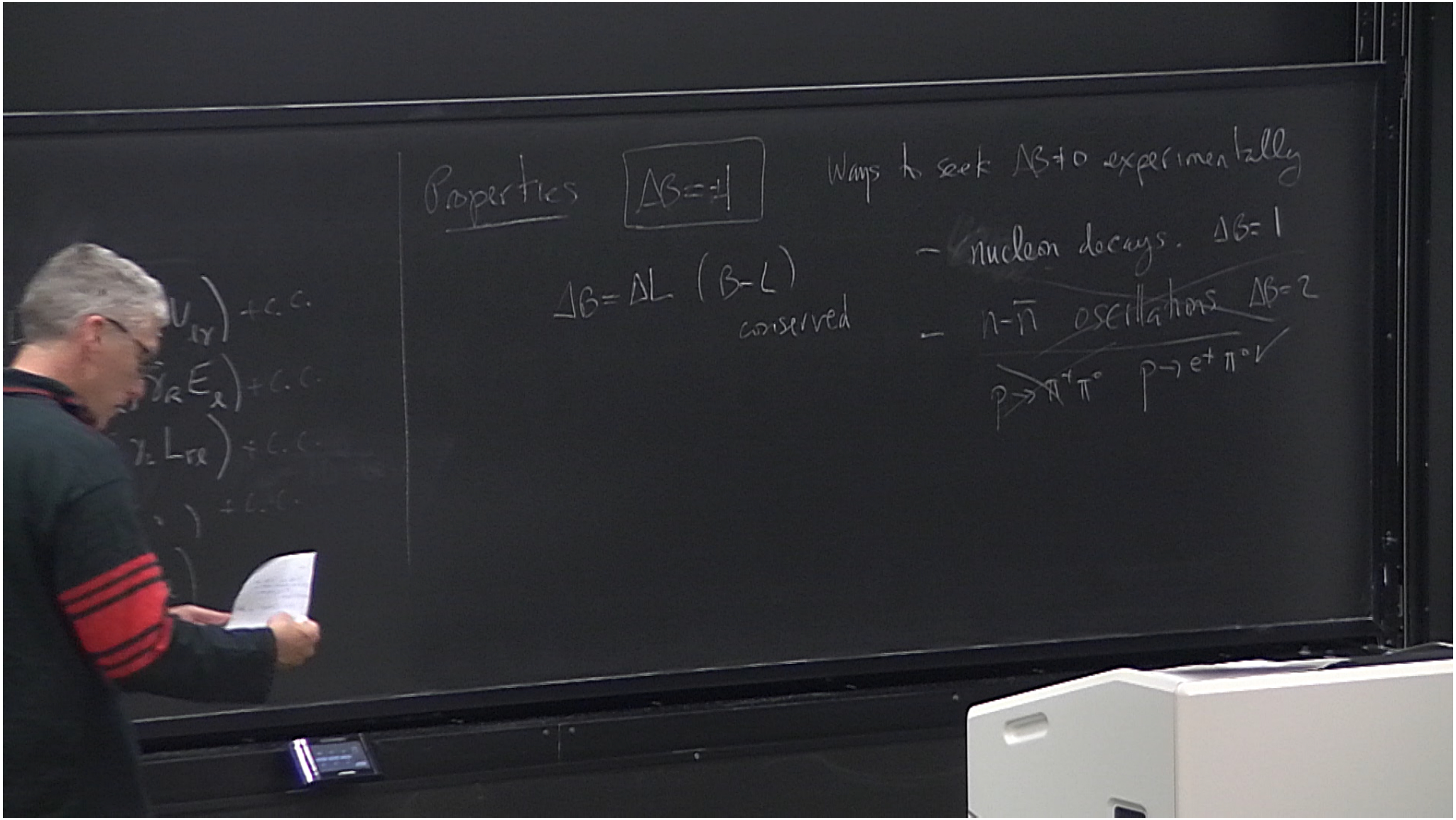

$\mathcal{L}_6 = (\text{Polish list}) \supset \Delta B \neq 0$ interactions
$\mathcal{L}_6^{\Delta B \neq 0} = \sum_{n=1}^{6} c^n_{ijkl} O^n_{ijkl}$.
$O'_{ijkl} = \epsilon^{\alpha\beta\gamma} \epsilon_{mn} (\bar{Q}^m_{i\alpha} \gamma_L L^n_j)(D_{k\beta} \gamma_R U_{l\gamma})$
SU3
SU2

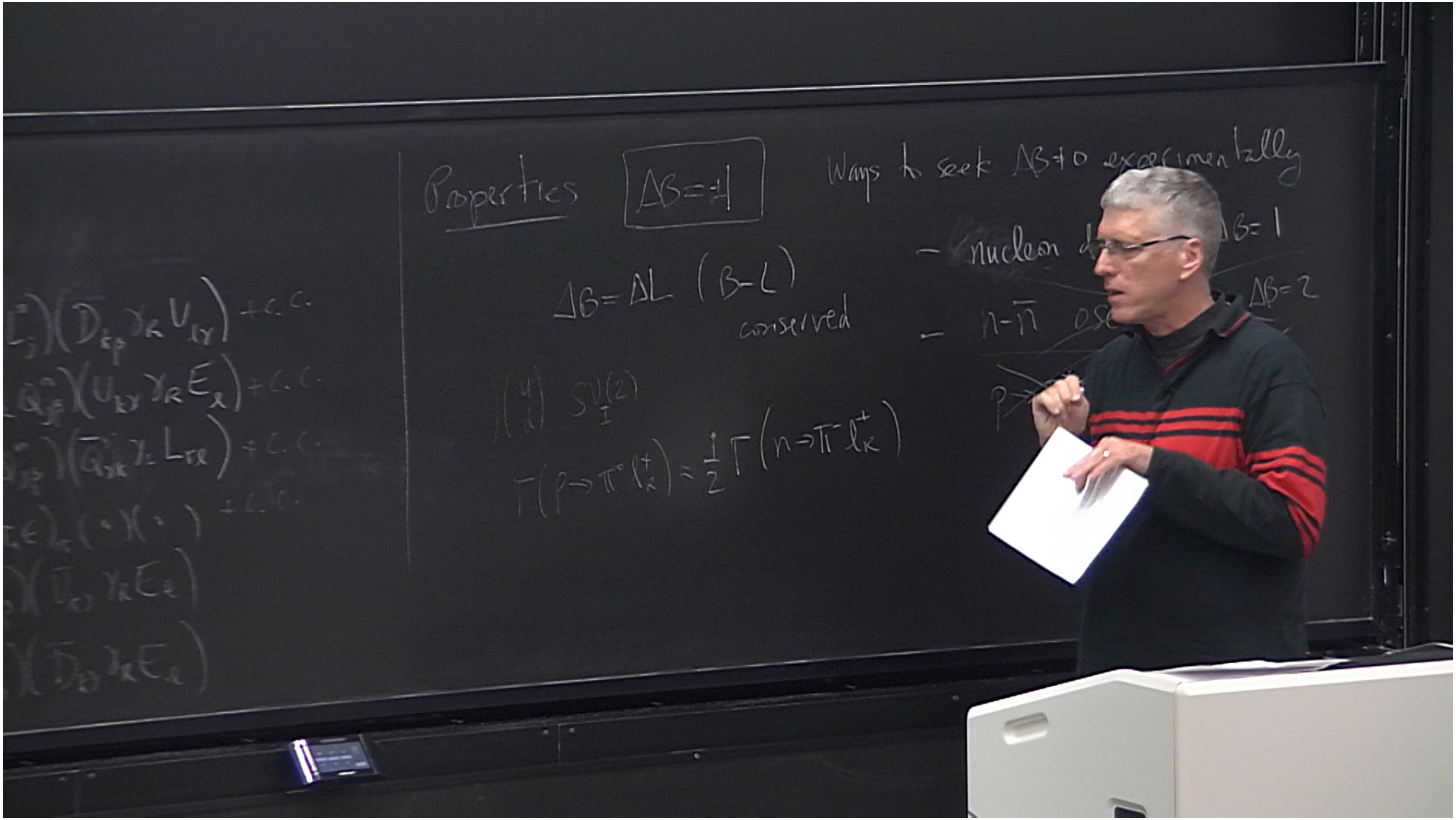

$\mathcal{L}_6 = (\text{Polish list}) \supset \Delta B \neq 0$ interactions
$\mathcal{L}_6^{\Delta B \neq 0} = \sum_{n=1}^{6} c^n_{ijkl} O^n_{ijkl}$.
$O^1_{ijkl} = \epsilon^{\alpha\beta\gamma} \epsilon_{mn} (\bar{Q}^m_{i\alpha} \gamma_L L^n_j)(D_{k\beta} \gamma_R U_{l\gamma})$
$O^2_{ijkl} = \epsilon^{\alpha\beta\gamma} \epsilon_{mn} (Q^m_{i\alpha} \gamma_L Q^n_{j\beta})(U_{k\gamma} \gamma_R E_l)$
$O^3_{ijkl} = \epsilon^{\alpha\beta\gamma} \epsilon_{mn} (Q^m_{i\alpha} \gamma_L Q^n_{j\beta})(\bar{Q}^r_{\gamma k} \gamma_L L_{rl})$
$O^4_{ijkl} = \epsilon^{\alpha\beta\gamma} (T_a \epsilon)_{mn} (T_a \epsilon)_{rs} (\quad)(\quad)$
0

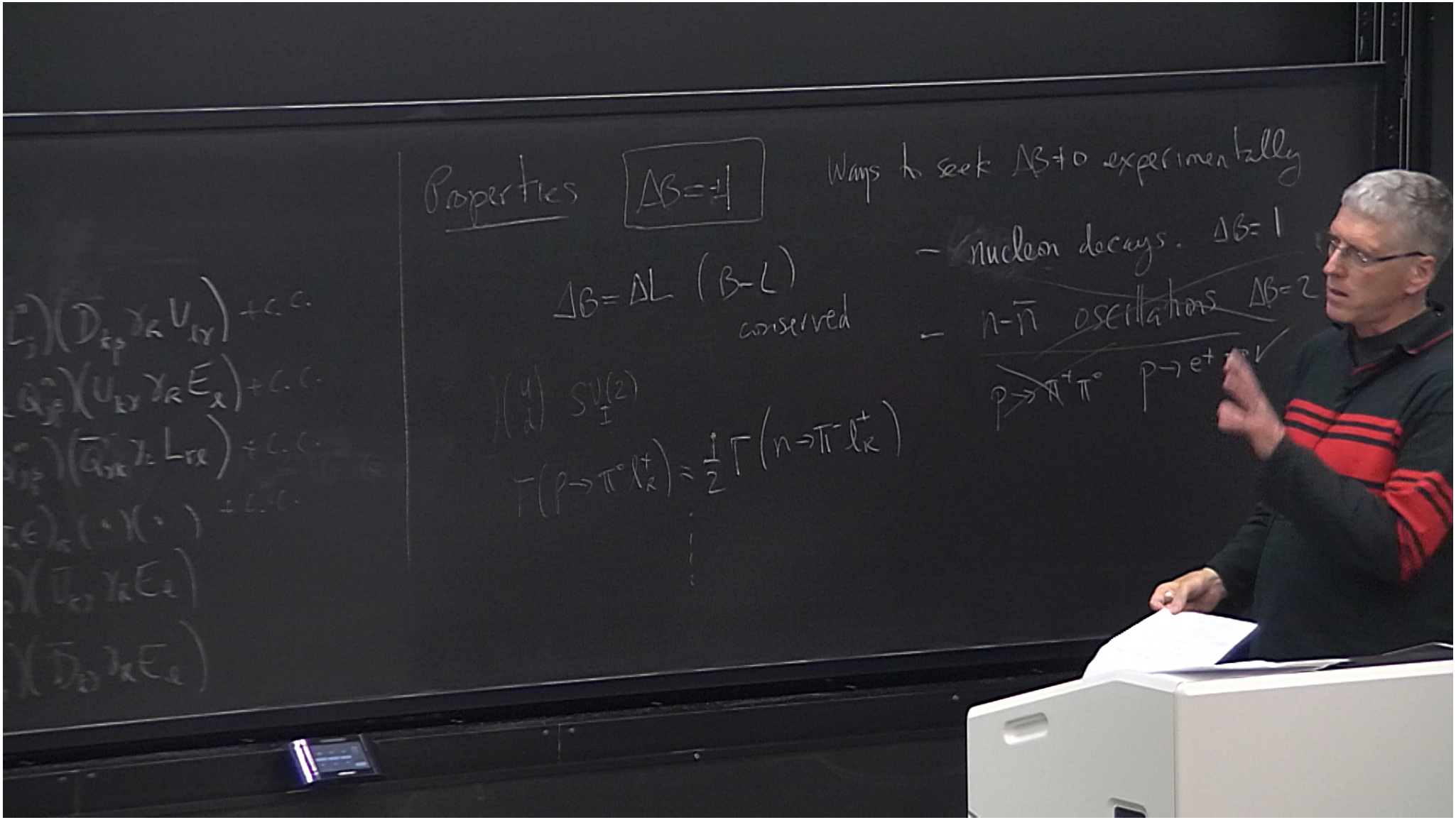

$\mathcal{L}_6 = (\text{Polish list}) \supset \Delta B \neq 0$ interactions
$\mathcal{L}_6^{\Delta B \neq 0} = \sum_{n=1}^{6} c^n_{ijkl} \mathcal{O}^n_{ijkl}$.
SU_3
SU_2
$\mathcal{O}^1_{ijkl} = \epsilon^{\alpha\beta\gamma} \epsilon_{mn} (\bar{Q}^m_{i\alpha} \gamma_L L^n_j)(D_{k\beta} \gamma_R U_{l\gamma}) + c.c.$
$\mathcal{O}^2_{ijkl} = \epsilon^{\alpha\beta\gamma} \epsilon_{mn} (\bar{Q}^m_{i\alpha} \gamma_L Q^n_{j\beta})(U_{k\gamma} \gamma_R E_l) + c.c.$
$\mathcal{O}^3_{ijkl} = \epsilon^{\alpha\beta\gamma} \epsilon_{mn} (Q^m_{i\alpha} \gamma_L Q^n_{j\beta})(\bar{Q}^r_{\gamma k} \gamma_L L_{rl}) + c.c.$
$\mathcal{O}^4_{ijkl} = \epsilon^{\alpha\beta\gamma} (T_a \epsilon)_{mn} (T_a \epsilon)_{rs} (\quad)(\quad) + c.c.$
$\mathcal{O}^5_{ijkl} = \epsilon^{\alpha\beta\gamma} (\bar{D}_{i\alpha} \gamma_R U_{j\beta})(\bar{U}_{k\gamma} \gamma_R E_l)$
$\mathcal{O}^6_{ijkl} = \epsilon^{\alpha\beta\gamma} (\bar{U}_{i\alpha} \gamma_R U_{j\beta})(\bar{D}_{k\gamma} \gamma_R E_l)$

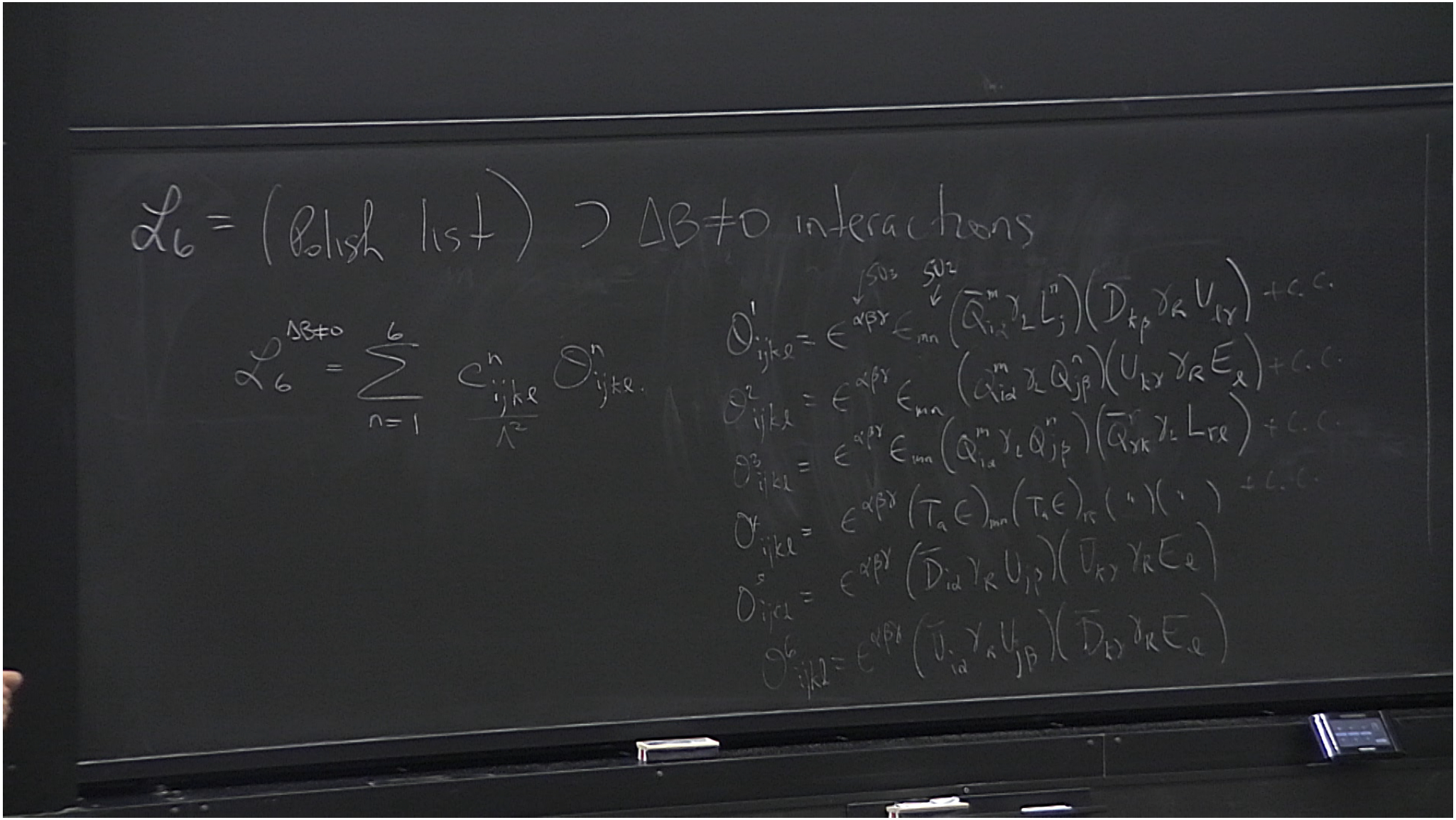

Properties
ΔB=±1
Ways to seek ΔB≠0 experimentally
- nucleon decays. ΔB=1
- n-n̄ oscillations ΔB=2

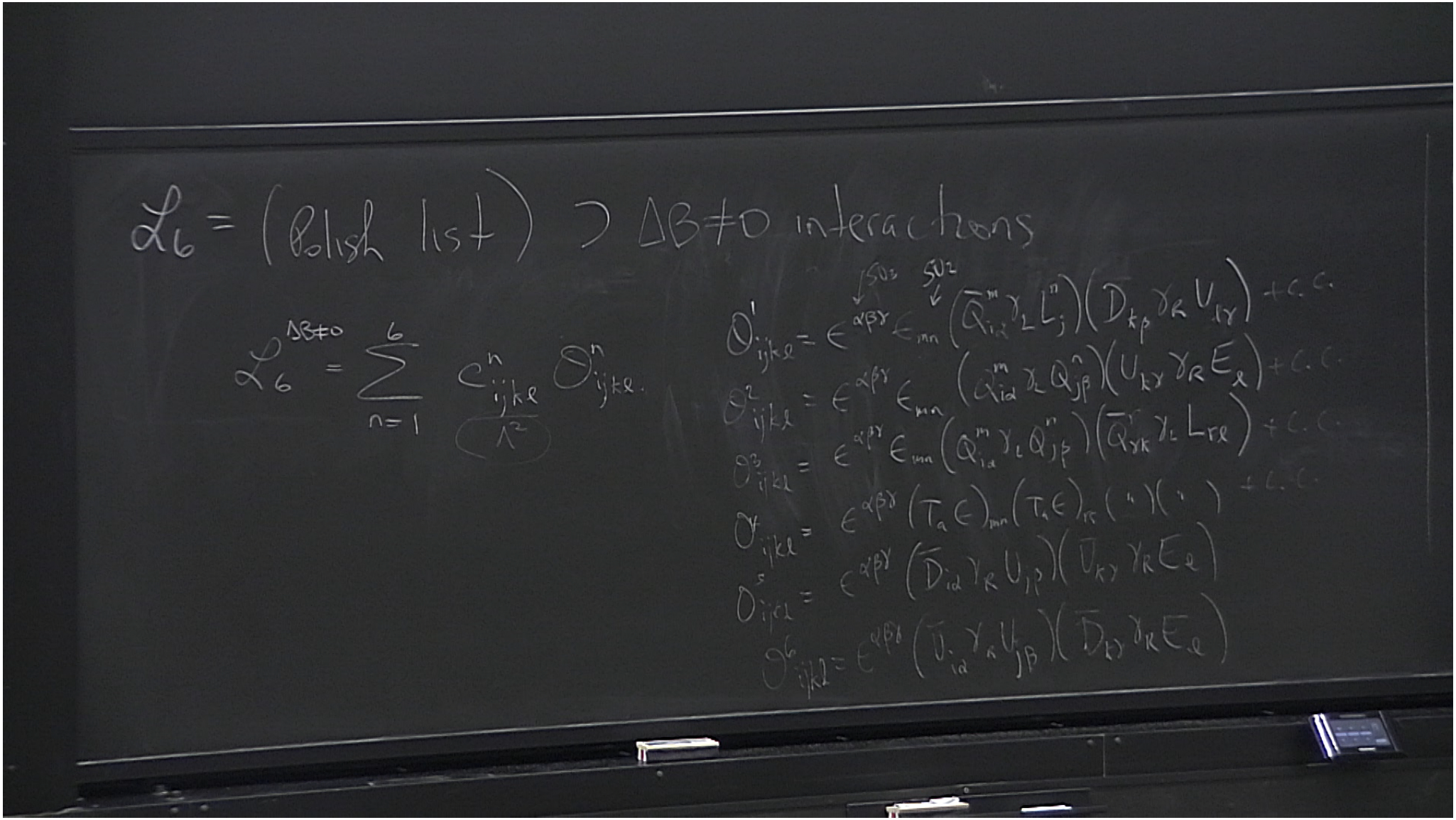

Properties
ΔB=±1
ΔB=ΔL (B-L)
conserved
Ways to seek ΔB≠0 experimentally
- nucleon decays. ΔB=1
- n-n̄ oscillations ΔB=2
p→π⁺π⁰
p→e⁺π⁰

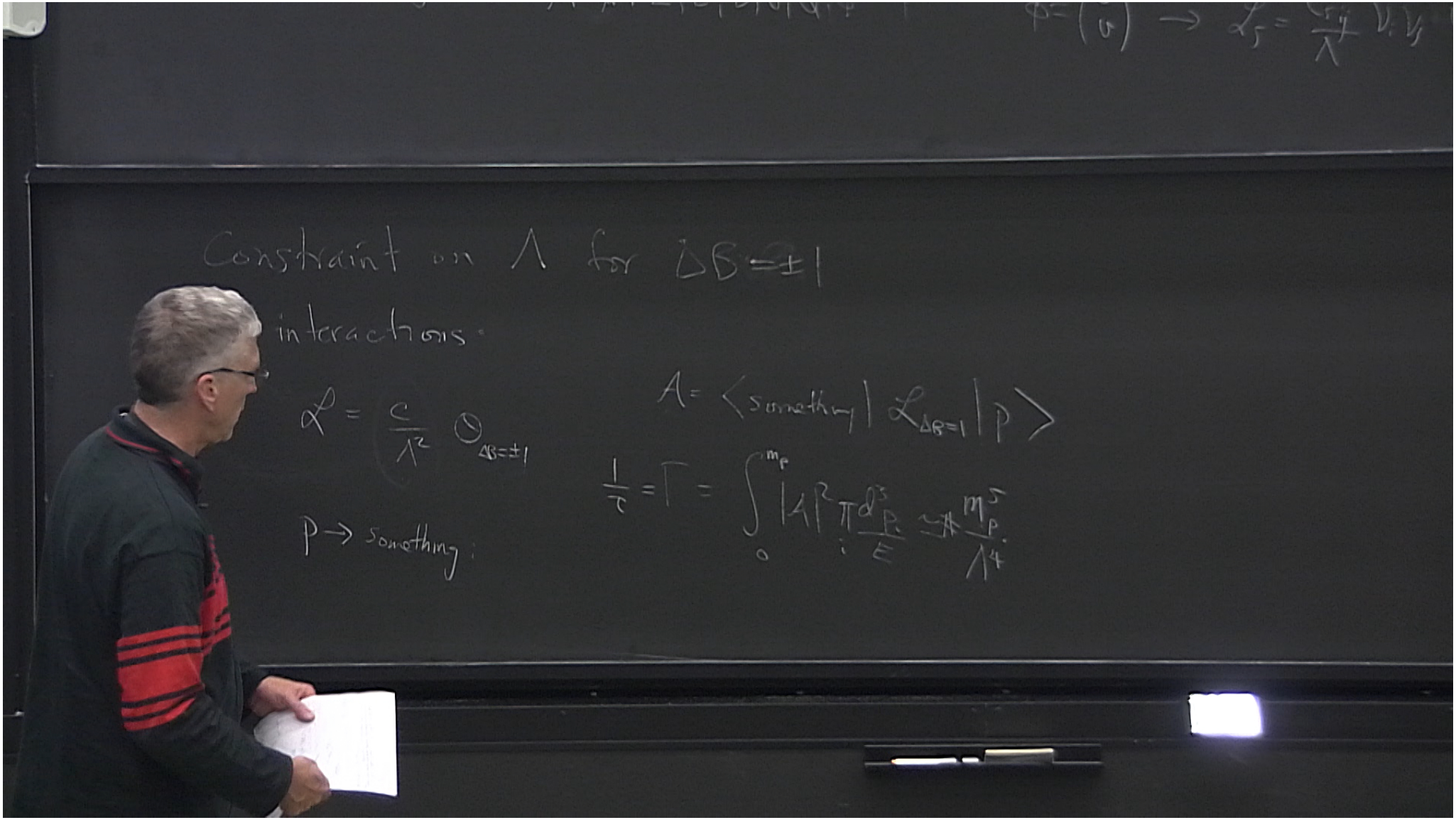

Properties
ΔB=±1
Ways to seek ΔB≠0 experimentally
- nucleon decays. ΔB=1
ΔB=ΔL (B-L) conserved
- n-n̄ oscillations ΔB=2
p→π⁺π⁰ p→e⁺π⁰

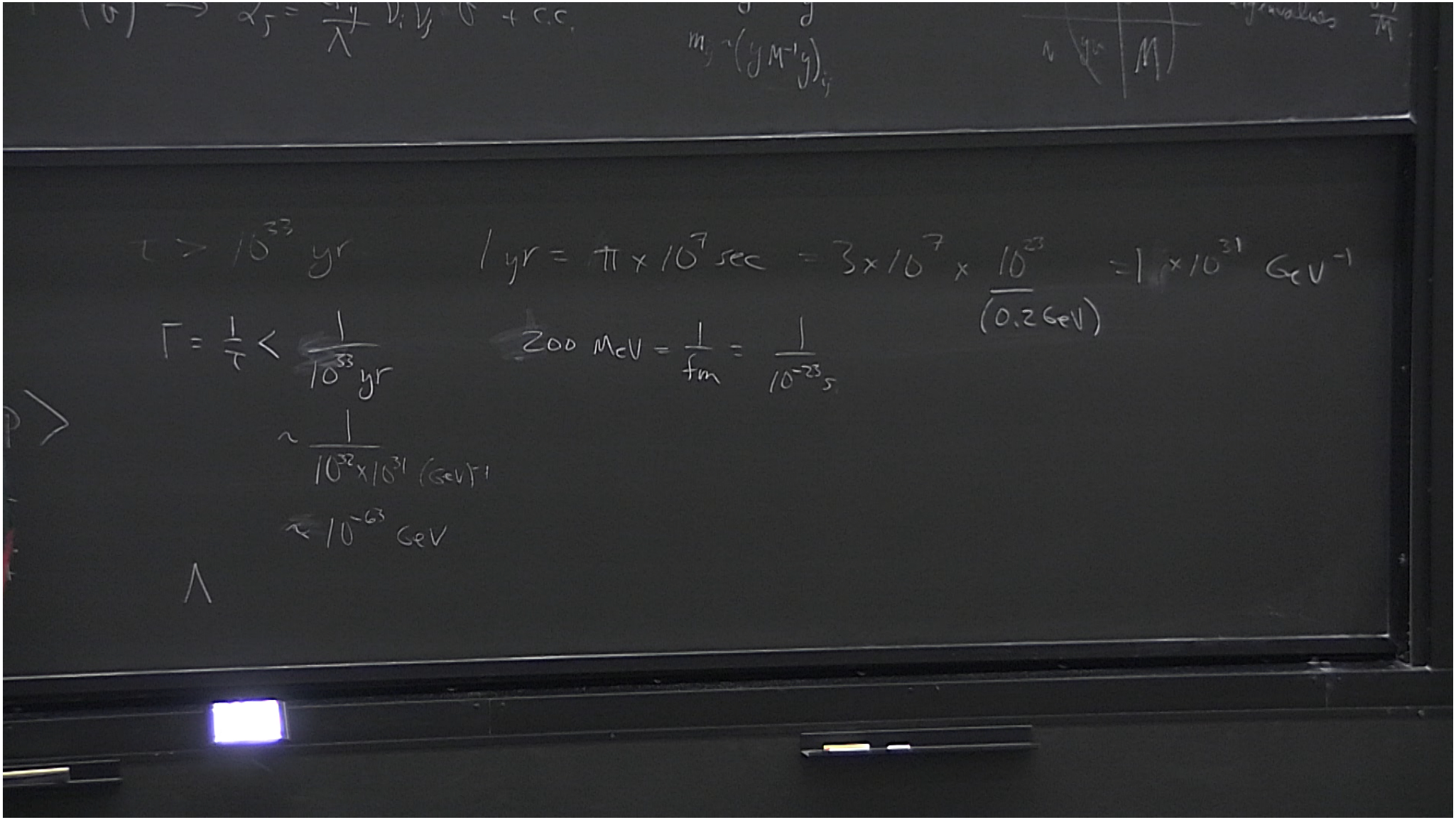

Properties
ΔB=±1
Ways to seek ΔB≠0 experimentally
ΔB=ΔL (B-L)
conserved
ΔB=1
ΔB=2
SU(2)

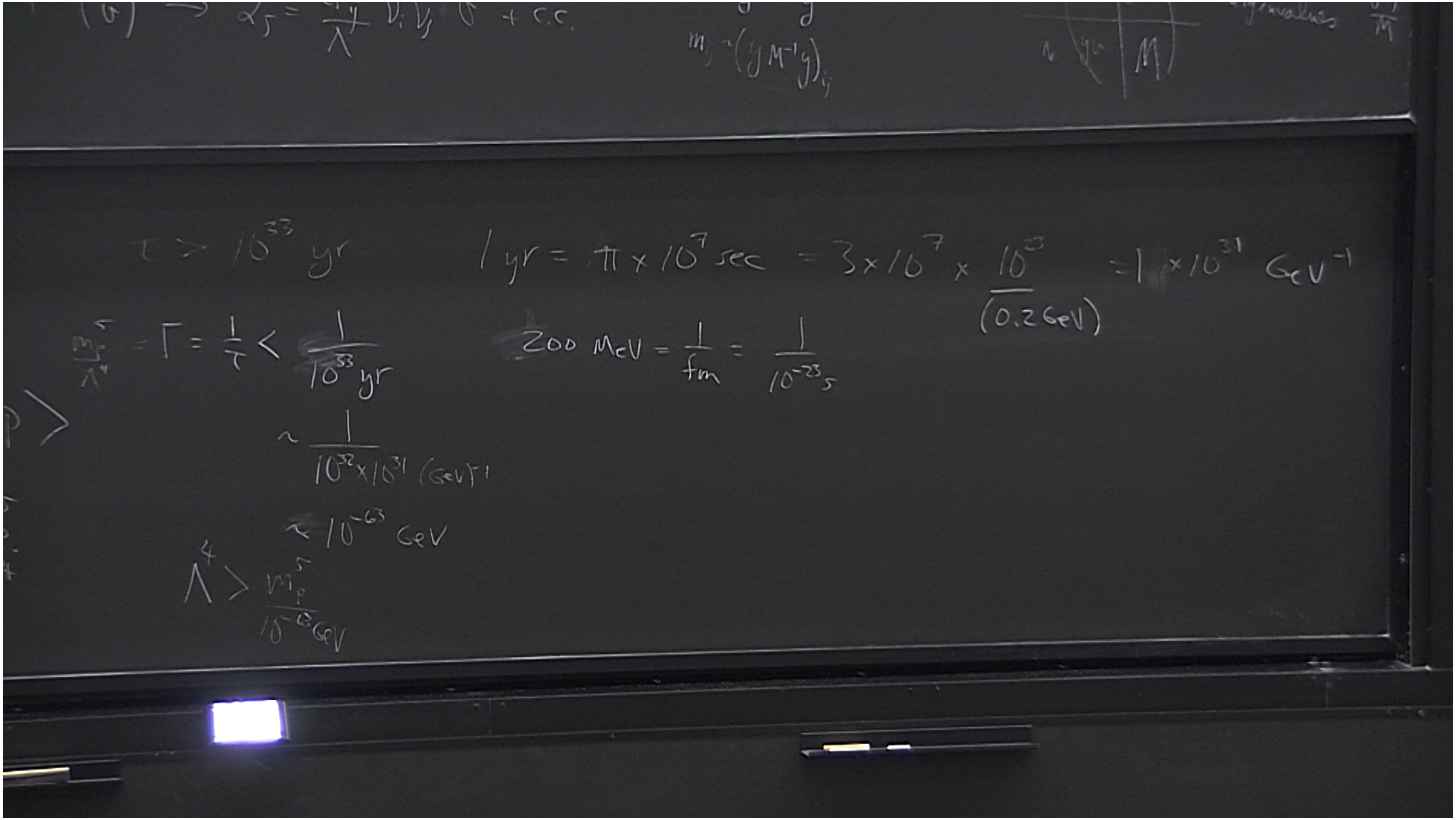

Properties
ΔB=±1
Ways to seek ΔB≠0 experimentally
- nucleon decays. ΔB=1
- n-n̄ oscillations ΔB=2
ΔB=ΔL (B-L) conserved
p→π⁺π⁰
p→e⁺
Γ(p→π⁰l_R⁺) = 1/2 Γ(n→π⁻l_R⁺)

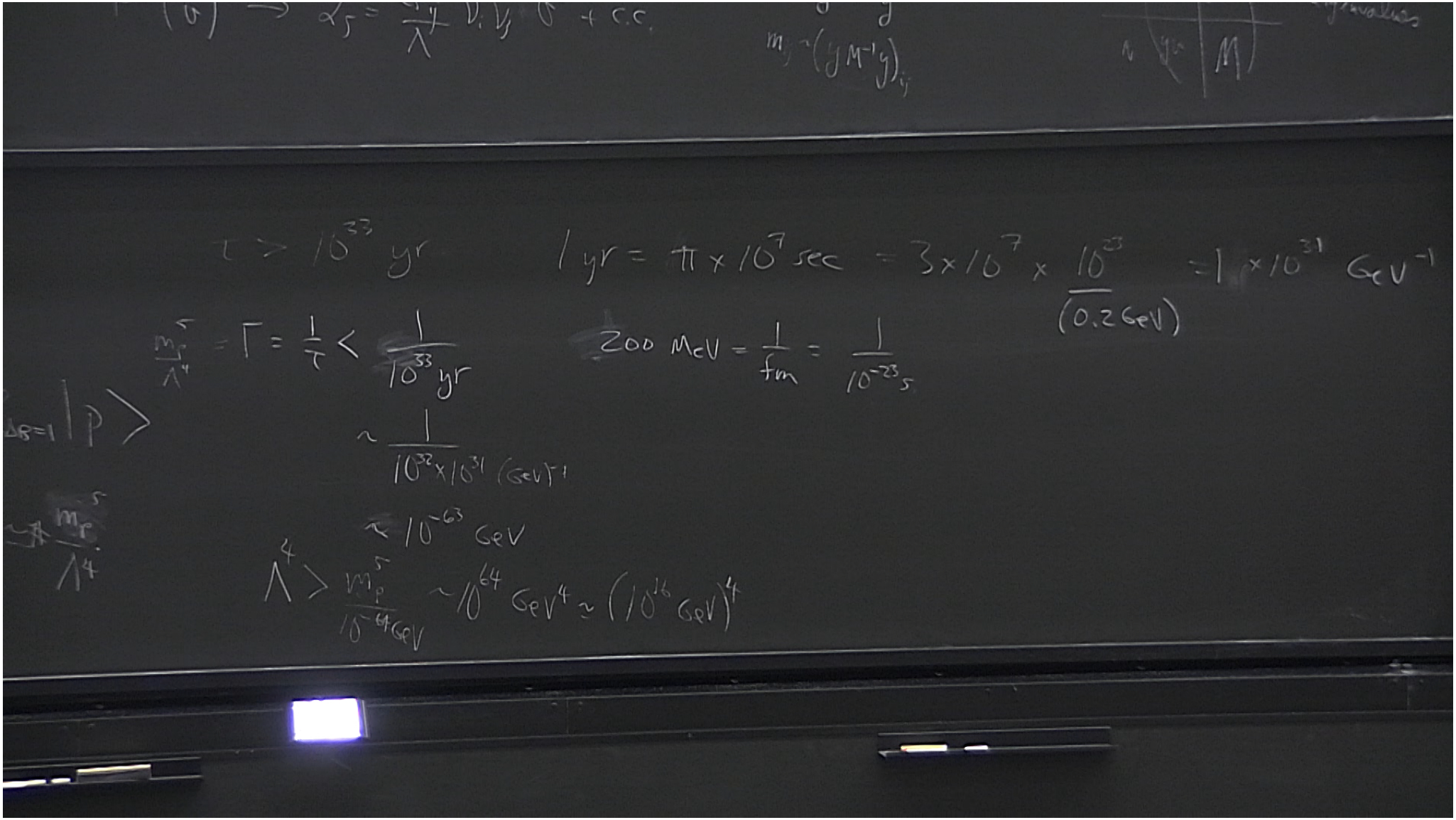

$\mathcal{L}_6 = (\text{Polish list}) \supset \Delta B \neq 0$ interactions
$\mathcal{L}_6^{\Delta B \neq 0} = \sum_{n=1}^{6} \frac{c^n_{ijkl}}{\Lambda^2} O^n_{ijkl}$.
$O^1_{ijkl} = \epsilon^{\alpha\beta\gamma} \epsilon_{mn} (\bar{Q}^m_{i\alpha} \gamma_L L^n_j)(D_{k\beta} \gamma_R U_{l\gamma}) + \text{c.c.}$
$O^2_{ijkl} = \epsilon^{\alpha\beta\gamma} \epsilon_{mn} (\bar{Q}^m_{i\alpha} \gamma_L Q^n_{j\beta})(U_{k\gamma} \gamma_R E_l) + \text{c.c.}$
$O^3_{ijkl} = \epsilon^{\alpha\beta\gamma} \epsilon_{mn} (Q^m_{i\alpha} \gamma_L Q^n_{j\beta})(\bar{Q}^r_{\gamma k} \gamma_L L_{rl}) + \text{c.c.}$
$O^4_{ijkl} = \epsilon^{\alpha\beta\gamma} (T_a \epsilon)_{mn} (T_a \epsilon)_{rs} (\quad)(\quad) + \text{c.c.}$
$O^5_{ijkl} = \epsilon^{\alpha\beta\gamma} (\bar{D}_{i\alpha} \gamma_R U_{j\beta})(\bar{U}_{k\gamma} \gamma_R E_l)$
$O^6_{ijkl} = \epsilon^{\alpha\beta\gamma} (\bar{U}_{i\alpha} \gamma_R U_{j\beta})(\bar{D}_{k\gamma} \gamma_R E_l)$
SU_3
SU_2


$\mathcal{L}_6 = (\text{Polish list}) \supset \Delta B \neq 0$ interactions
$\mathcal{L}_6^{\Delta B \neq 0} = \sum_{n=1}^{6} \frac{c^n_{ijkl}}{\Lambda^2} O^n_{ijkl}$.
$O^1_{ijkl} = \epsilon^{\alpha\beta\gamma} \epsilon_{mn} (\bar{Q}^m_{i\alpha} \gamma_L L^n_j)(D_{k\beta} \gamma_R U_{l\gamma}) + c.c.$
$O^2_{ijkl} = \epsilon^{\alpha\beta\gamma} \epsilon_{mn} (\bar{Q}^m_{i\alpha} \gamma_L Q^n_{j\beta})(U_{k\gamma} \gamma_R E_l) + c.c.$
$O^3_{ijkl} = \epsilon^{\alpha\beta\gamma} \epsilon_{mn} (Q^m_{i\alpha} \gamma_L Q^n_{j\beta})(\bar{Q}^r_{k\gamma} \gamma_L L_{rl}) + c.c.$
$O^4_{ijkl} = \epsilon^{\alpha\beta\gamma} (T_a \epsilon)_{mn} (T_a \epsilon)_{rs} (\quad)(\quad) + c.c.$
$O^5_{ijkl} = \epsilon^{\alpha\beta\gamma} (\bar{D}_{i\alpha} \gamma_R U_{j\beta})(\bar{U}_{k\gamma} \gamma_R E_l)$
$O^6_{ijkl} = \epsilon^{\alpha\beta\delta} (\bar{U}_{i\alpha} \gamma_\mu U_{j\beta})(\bar{D}_{k\delta} \gamma_R E_l)$
SU_3
SU_2


Constraint on Λ for ΔB=±1
interactions:
$\mathcal{L} = \frac{c}{\Lambda^2} \mathcal{O}_{\Delta B=\pm 1}$
$A = \langle \text{something} | \mathcal{L}_{\Delta B=1} | p \rangle$
$p \to \text{something}$
$\frac{1}{\tau} = \Gamma = \int_0^{m_p} |A|^2 \pi \frac{d^3 p}{E} \sim \frac{m_p^5}{\Lambda^4}$


$\tau > 10^{33}$ yr
$1\,\text{yr} = \pi \times 10^7\,\text{sec} = 3 \times 10^7 \times \frac{10^{23}}{(0.2\,\text{GeV})} = 1 \times 10^{31}\,\text{GeV}^{-1}$
$\Gamma = \frac{1}{\tau} < \frac{1}{10^{33}\,\text{yr}}$
$200\,\text{MeV} = \frac{1}{\text{fm}} = \frac{1}{10^{-23}\,\text{s}}$
$\sim \frac{1}{10^{32} \times 10^{31}\,(\text{GeV})^{-1}}$
$\sim 10^{-63}\,\text{GeV}$


$\tau > 10^{33}$ yr
$1\,\text{yr} = \pi \times 10^7\,\text{sec} \approx 3 \times 10^7 \times \frac{10^{23}}{(0.2\,\text{GeV})} \approx 1 \times 10^{31}\,\text{GeV}^{-1}$
$\frac{m_p^5}{\Lambda^4} \sim \Gamma = \frac{1}{\tau} < \frac{1}{10^{33}\,\text{yr}}$
$200\,\text{MeV} = \frac{1}{\text{fm}} = \frac{1}{10^{-23}\,\text{s}}$
$\sim \frac{1}{10^{32} \times 10^{31}\,(\text{GeV})^{-1}}$
$\sim 10^{-63}\,\text{GeV}$
$\Lambda^4 > \frac{m_p^5}{10^{-63}\,\text{GeV}}$


$\tau > 10^{33}$ yr
$1\,\mathrm{yr} = \pi \times 10^7\,\mathrm{sec} = 3 \times 10^7 \times \frac{10^{23}}{(0.2\,\mathrm{GeV})} = 1 \times 10^{31}\,\mathrm{GeV}^{-1}$
$\frac{m_p^5}{\Lambda^4} = \Gamma = \frac{1}{\tau} < \frac{1}{10^{33}\,\mathrm{yr}}$
$200\,\mathrm{MeV} = \frac{1}{\mathrm{fm}} = \frac{1}{10^{-23}\,\mathrm{s}}$
$\Delta B = 1 \; |p\rangle$
$\sim \frac{1}{10^{32} \times 10^{31}\,(\mathrm{GeV})^{-1}}$
$\frac{m_p^5}{\Lambda^4}$
$\approx 10^{-63}\,\mathrm{GeV}$
$\Lambda^4 > \frac{m_p^5}{10^{-64}\,\mathrm{GeV}} \sim 10^{64}\,\mathrm{GeV}^4 \simeq (10^{16}\,\mathrm{GeV})^4$

$\mathcal{L}_6 = (\text{Polish list}) \supset \Delta B \neq 0$ interactions

$$\mathcal{L}_6^{\Delta B \neq 0} = \sum_{n=1}^{6} \frac{c^n_{ijkl}}{\Lambda^2} O^n_{ijkl}$$

$$O^1_{ijkl} = \epsilon^{\alpha\beta\gamma} \epsilon_{mn} \left(\bar{Q}^m_{i\alpha} \gamma_L L^n_j\right)\left(D_{k\beta} \gamma_R U_{l\gamma}\right) + \text{c.c.}$$

(SO_3, SO_2)

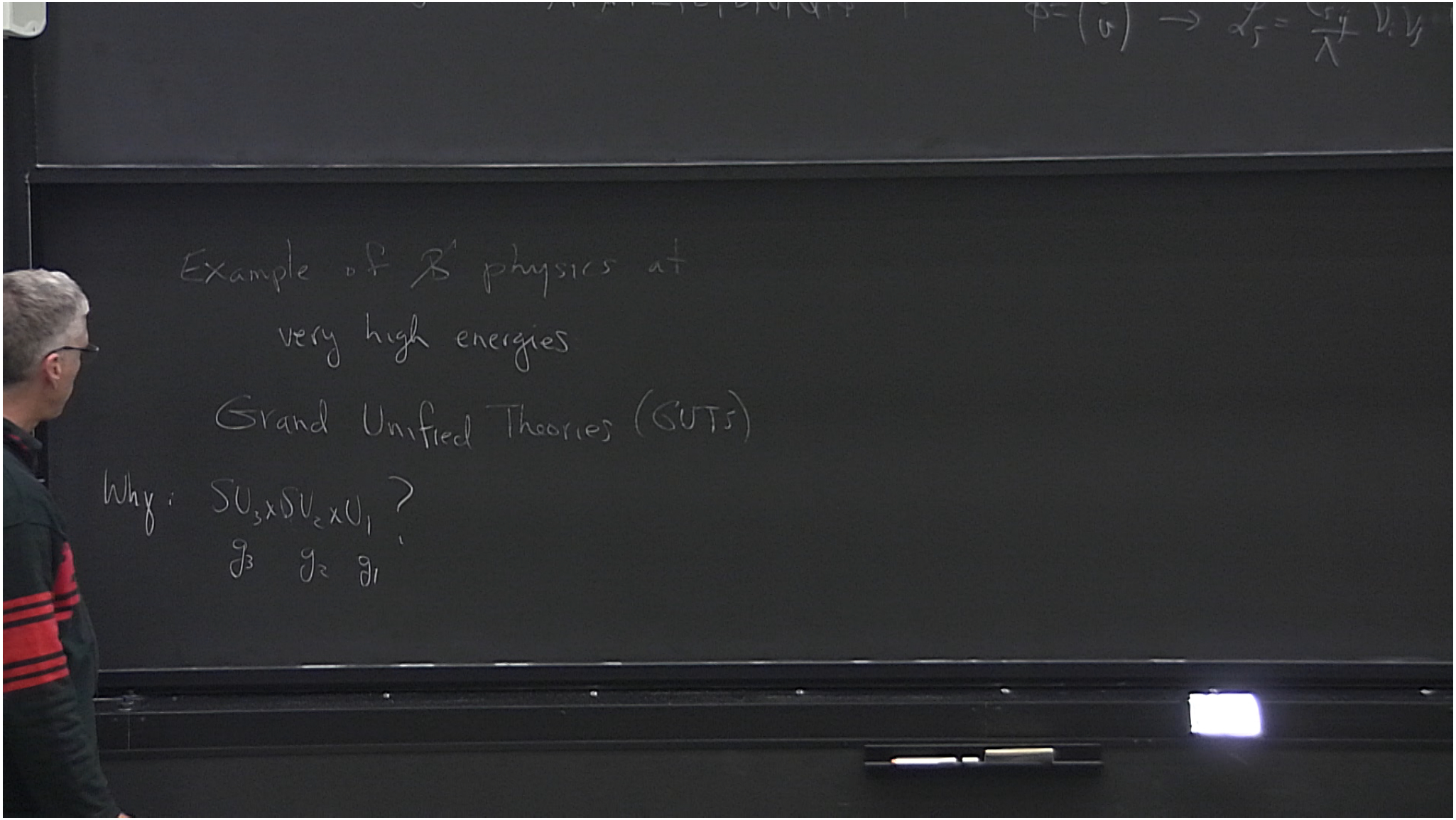
$$O^2_{ijkl} = \epsilon^{\alpha\beta\gamma} \epsilon_{mn} \left(\bar{Q}^m_{i\alpha} \gamma_L Q^n_{j\beta}\right)\left(U_{k\gamma} \gamma_R E_l\right) + \text{c.c.}$$

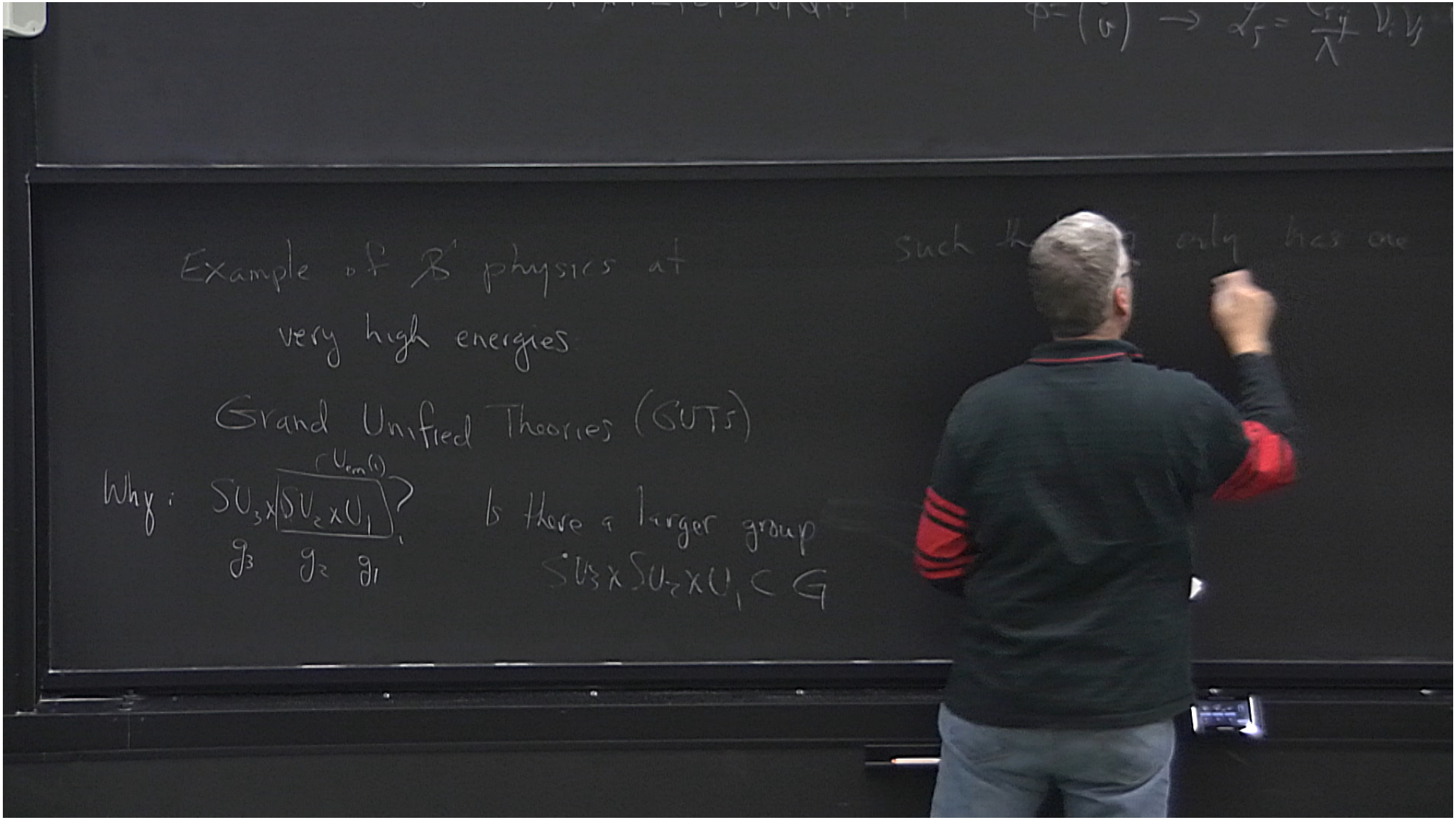
$$O^3_{ijkl} = \epsilon^{\alpha\beta\gamma} \epsilon_{mn} \left(Q^m_{i\alpha} \gamma_L Q^n_{j\beta}\right)\left(\bar{Q}^r_{\gamma k} \gamma_L L_{rl}\right) + \text{c.c.}$$

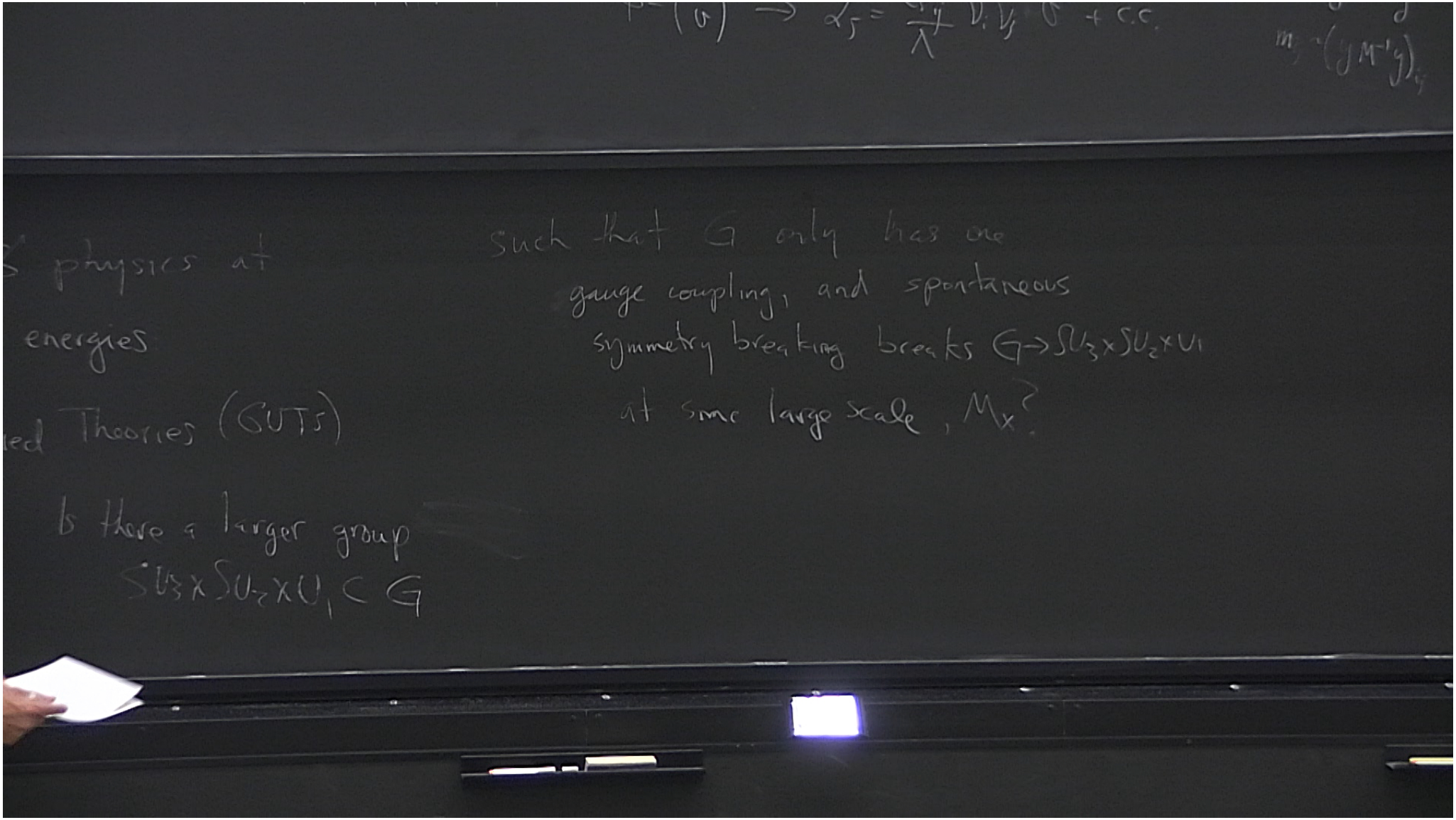
$$O^4_{ijkl} = \epsilon^{\alpha\beta\gamma} \left(T_a \epsilon\right)_{mn} \left(T_a \epsilon\right)_{rs} (\,)(\,) \pm \text{c.c.}$$

$$O^5_{ijkl} = \epsilon^{\alpha\beta\gamma} \left(\bar{D}_{i\alpha} \gamma_R U_{j\beta}\right)\left(\bar{U}_{k\gamma} \gamma_R E_l\right)$$

$$O^6_{ijkl} = \epsilon^{\alpha\beta\gamma} \left(\bar{U}_{i\alpha} \gamma_\kappa U_{j\beta}\right)\left(\bar{D}_{k\gamma} \gamma_R E_l\right)$$


Example of $\mathcal{R}^1$ physics at
very high energies
Grand Unified Theories (GUTs)
Why: $SU_3 \times SU_2 \times U_1$?
g_3 g_2 g_1


Example of BSM physics at
very high energies:
Grand Unified Theories (GUTs)
Why: $SU_3 \times \overbrace{SU_2 \times U_1}^{\text{Weak}}$?
g_3 g_2 g_1
Is there a larger group
$SU_3 \times SU_2 \times U_1 \subset G$


physics at
energies
ied Theories (GUTs)
Is there a larger group
$SU_3 \times SU_2 \times U_1 \subset G$
such that G only has one
gauge coupling, and spontaneous
symmetry breaking breaks $G \to SU_3 \times SU_2 \times U_1$
at some large scale, M_X?

physics at

energies

ied Theories (GUTs)

Is there a larger group

$SU_3 \times SU_2 \times U_1 \subset G$

such that G only has one gauge coupling, and spontaneous symmetry breaking breaks $G \to SU_3 \times SU_2 \times U_1$ at some large scale, M_X?

Ans: Yes: SU(5), SO(10), E_8, ...

SU(5): SM fermions exactly fit

SO(10): ν_R + SM exactly fits

physics at

energies

ied Theories (GUTs)

Is there a larger group

$SU_3 \times SU_2 \times U_1 \subset G$

such that G only has one

gauge coupling, and spontaneous

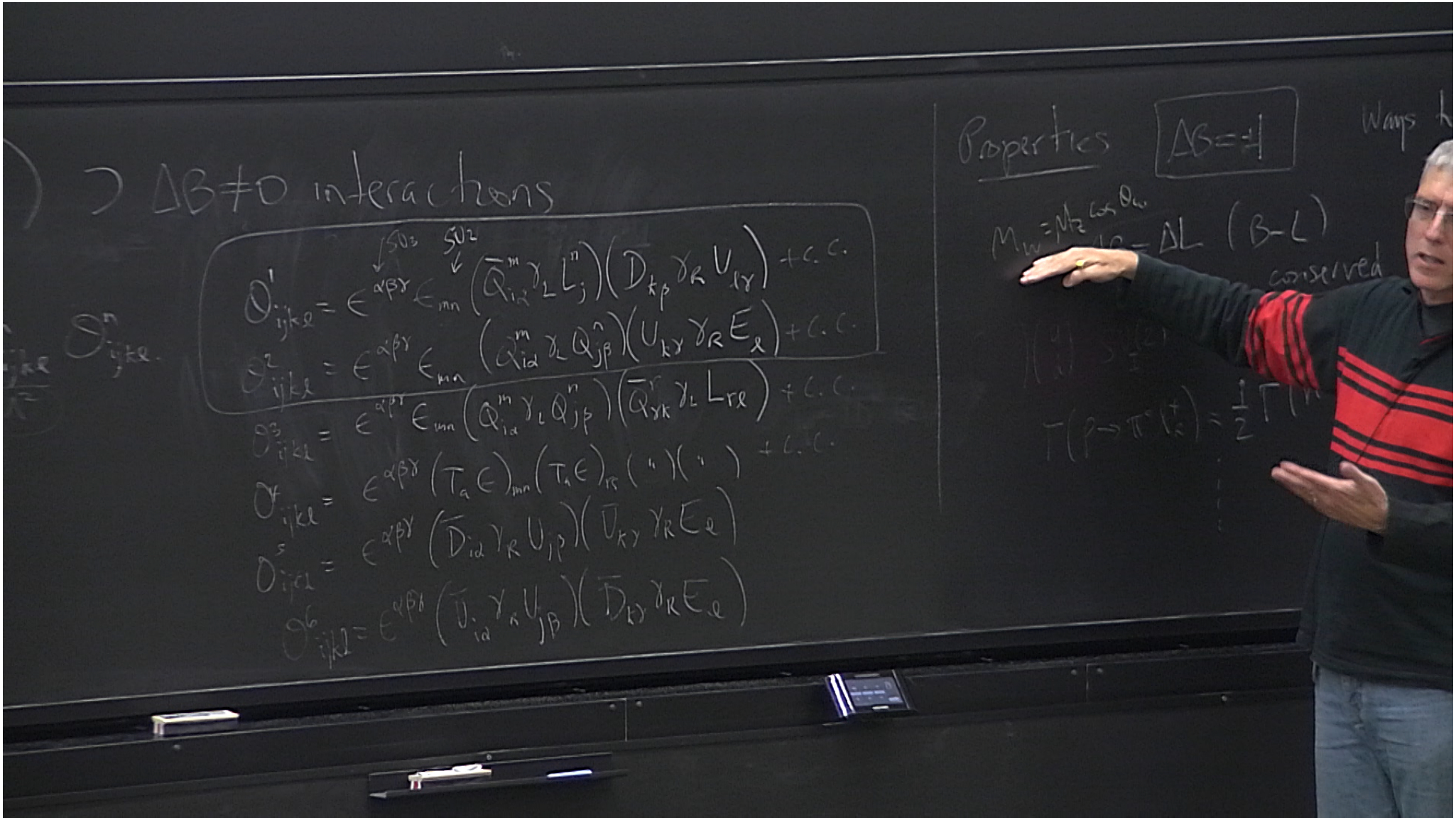
symmetry breaking breaks $G \to SU_3 \times SU_2 \times U_1$

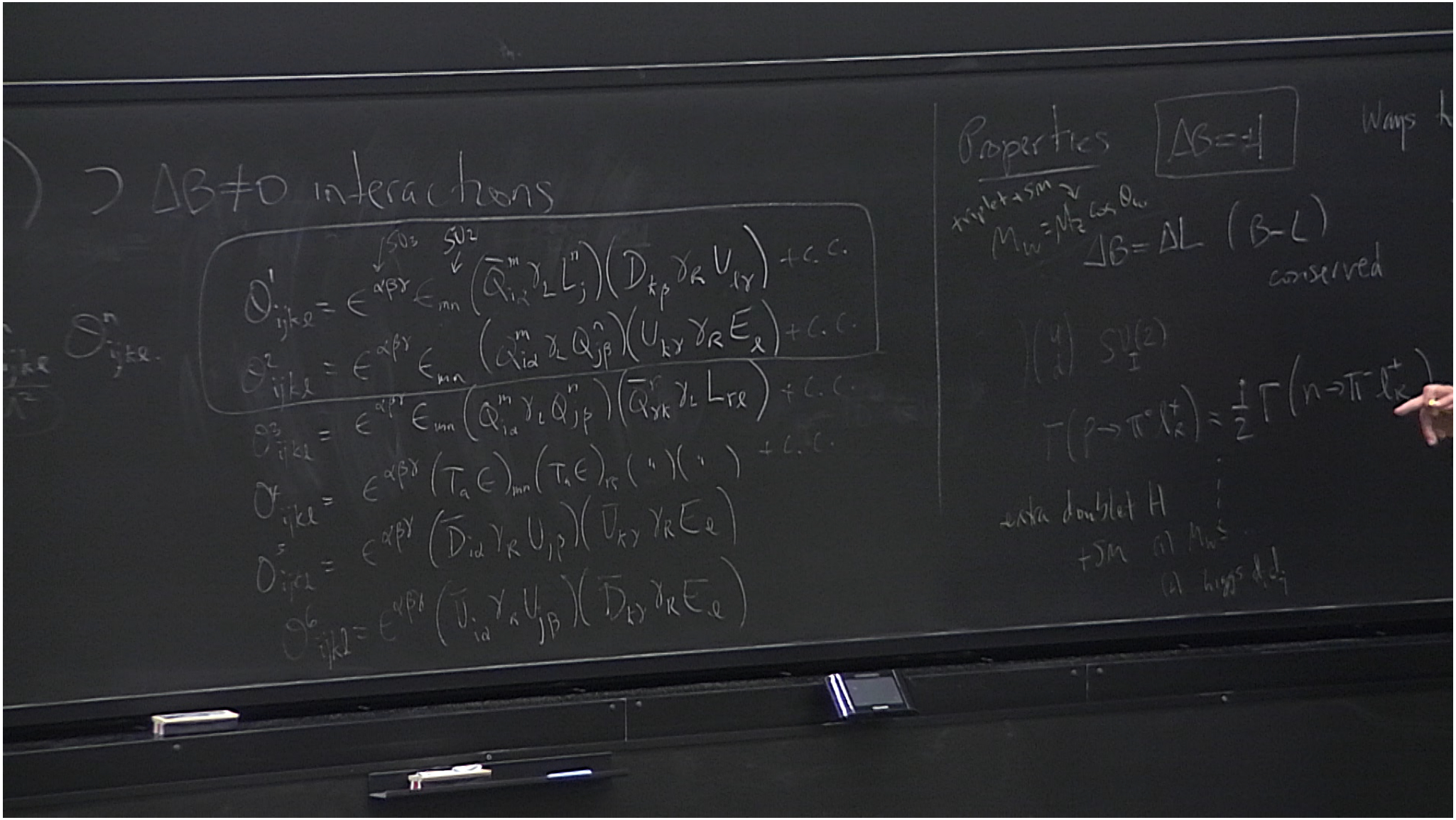
at some large scale, M_X?

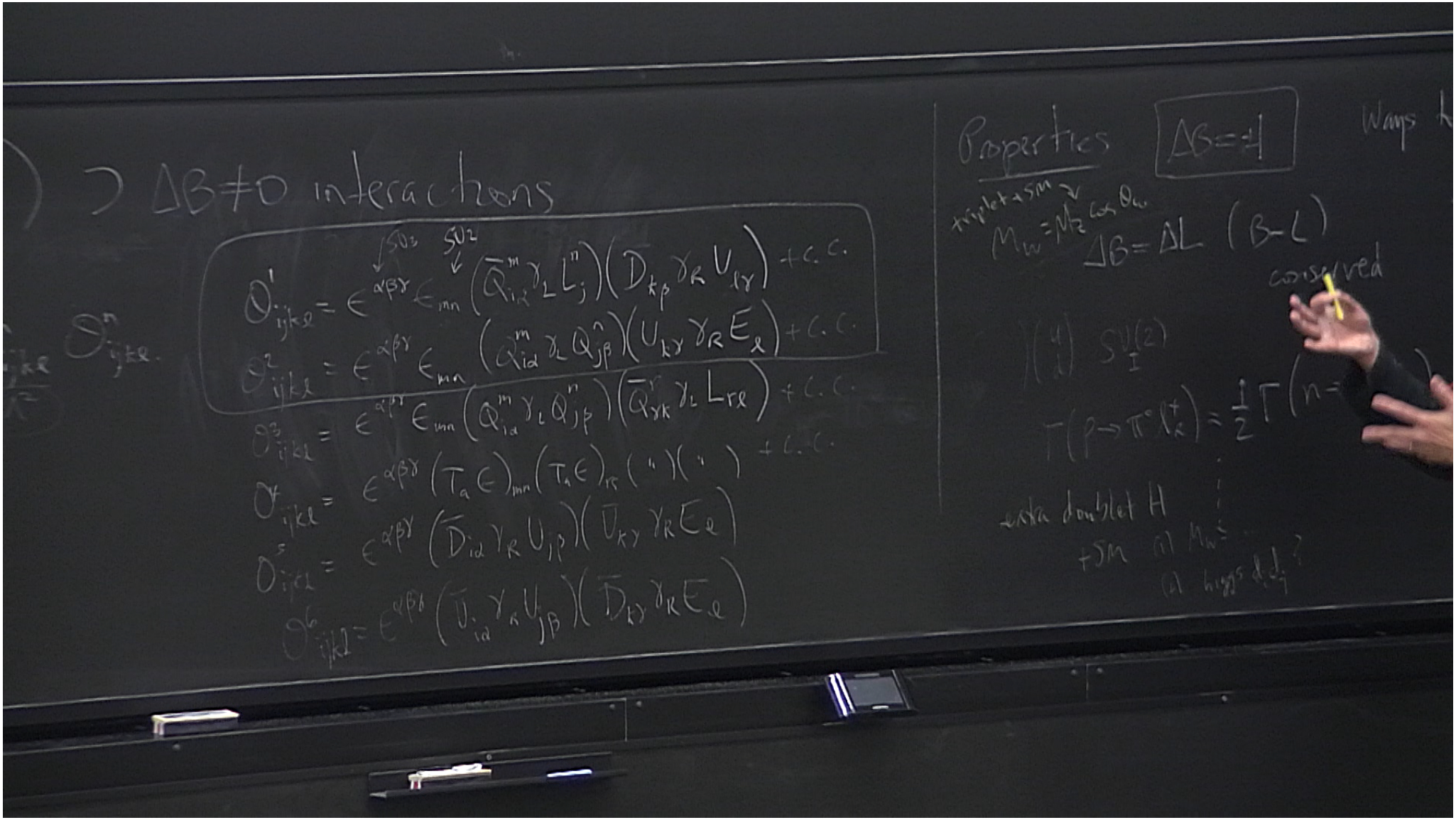
Ans: Yes: SU(5) SO(10), E_8, ...

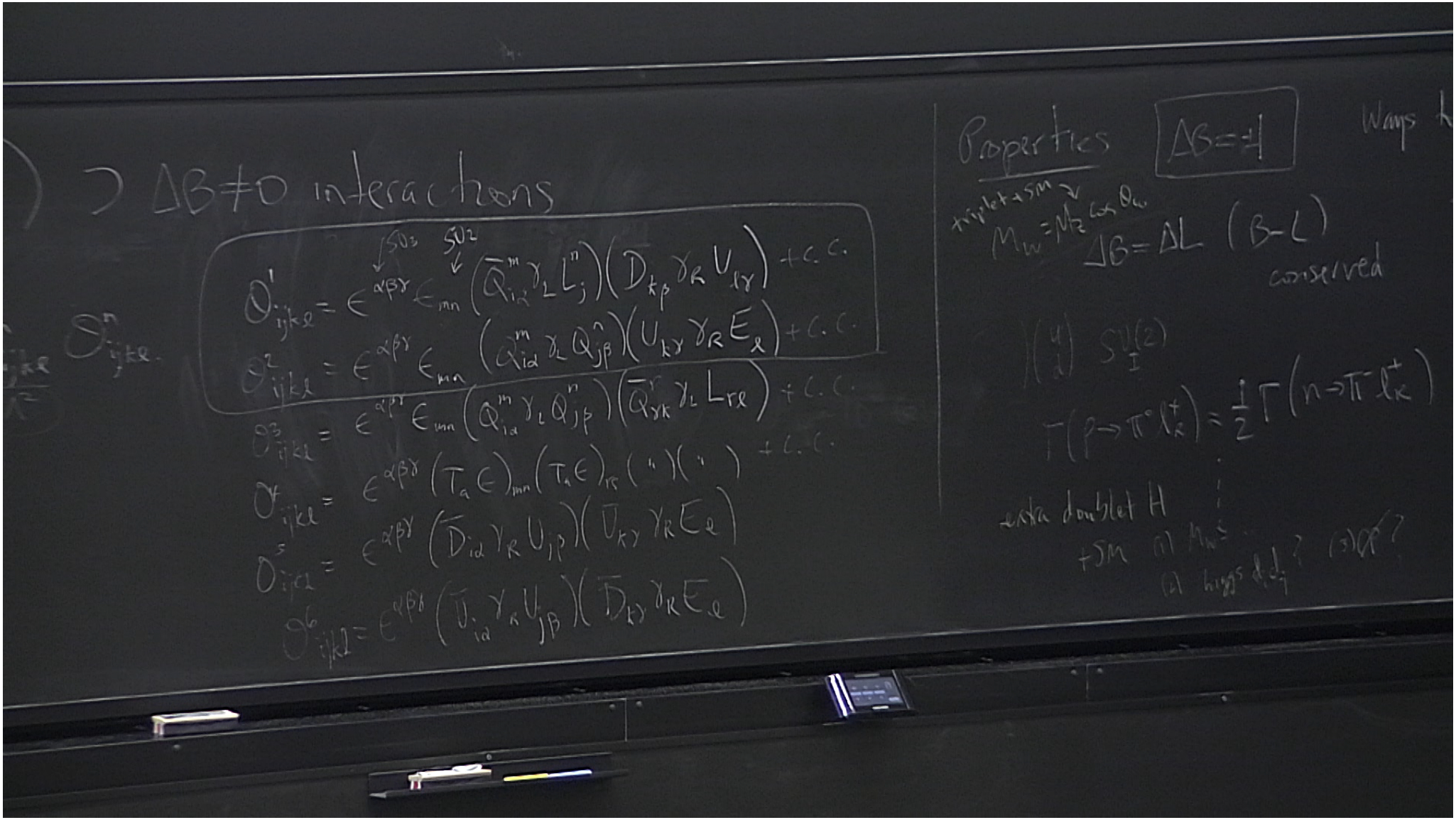
SM fermions exactly fit

N=1 SM exactly fits


ΔB≠0 interactions
Properties
ΔB=1
conserved


ΔB≠0 interactions
Properties
ΔB=ΔL (B-L) conserved
extra doublet H


ΔB≠0 interactions
Properties
ΔB=±1
ΔB=ΔL (B-L)
conserved
extra doublet H
+SM at M_W=
at higgs &


ΔB≠0 interactions
Properties
ΔB=ΔL (B-L)
conserved
extra doublet H