Title: Standard Model-1

Date: Jan 07, 2015 09:00 AM

URL: http://pirsa.org/15010002

Abstract:

Standard Model PSI

Gordan Krnjaic (474) gkrnjaic@" ".ca
Stefania Gori (?) sgori@" ".ca

Overview:

- Introduction — Cast of Characters / Notation/Conventions
- Electroweak Sector
- Higgs Sector, flavor physics, QCD, Higgs Discovery

- SM @ 1-loop (EWPT)
- β (QED, QCD)
- Problems w/ SM (Hierarchy Problem)

0. Notation / Conventions

$$g_{\mu\nu} \equiv \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix} = \eta_{\mu\nu}$$

$\partial_\mu \equiv \frac{\partial}{\partial x^\mu}$, Natural Units.

$\hbar \equiv c = 1$

$c = 3\times10^8 \frac{m}{s} \equiv 1 \rightarrow \frac{m}{s} \equiv \frac{1}{3\times10^8}$ def of $m(s)$

$\hbar \equiv 1.05 \times 10^{-34}\ J\cdot s \sim 10^{-34}\ J\cdot s$

$= 10^{-34}\ \frac{kg\,m^2}{s^2}\cdot s = 10^{-34}\ kg\,m\left(\frac{m}{s}\right)$

$= \frac{10^{-34}\,(kg\,m)}{3\times 10^{8}}$

$m_p \simeq 0.938\ \frac{GeV}{c^2} \sim GeV$

$= 1.67 \times 10^{-27}\ kg$

$\hbar = \frac{10^{-34}}{3\times 10^{8}}\left(\frac{1}{1.67\times 10^{-27}}\right)(GeV\cdot m) \equiv 1$

$\frac{1}{GeV\cdot cm} = 2\times 10^{-14}$

def of cm (GeV)

Accounting:

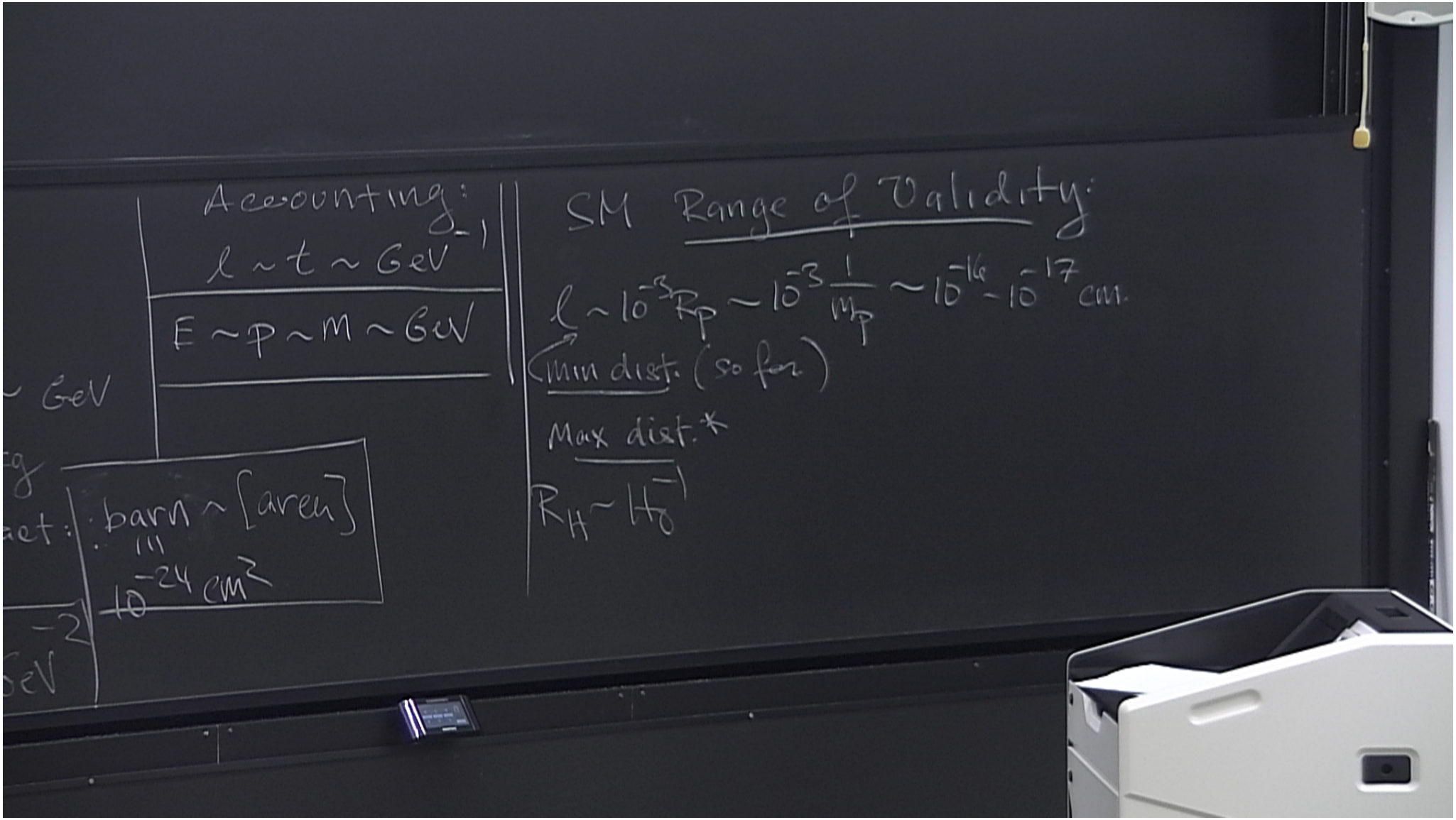
$\ell \sim t \sim GeV^{-1}$

$E \sim p \sim m \sim GeV$

fun fact: $\sigma \sim GeV^{-2}$

barn ~ [area]

$10^{-24}\ cm^2$


Accounting:
$\ell \sim t \sim GeV^{-1}$
$E \sim p \sim M \sim GeV$
barn ~ [area]
$10^{-24} cm^2$
SM Range of Validity:
$\ell \sim 10^{-3} R_p \sim 10^{-3} \frac{1}{M_p} \sim 10^{-16} - 10^{-17}$ cm.
Min dist. (so far)
Max dist.*
$R_H \sim H_0^{-1}$

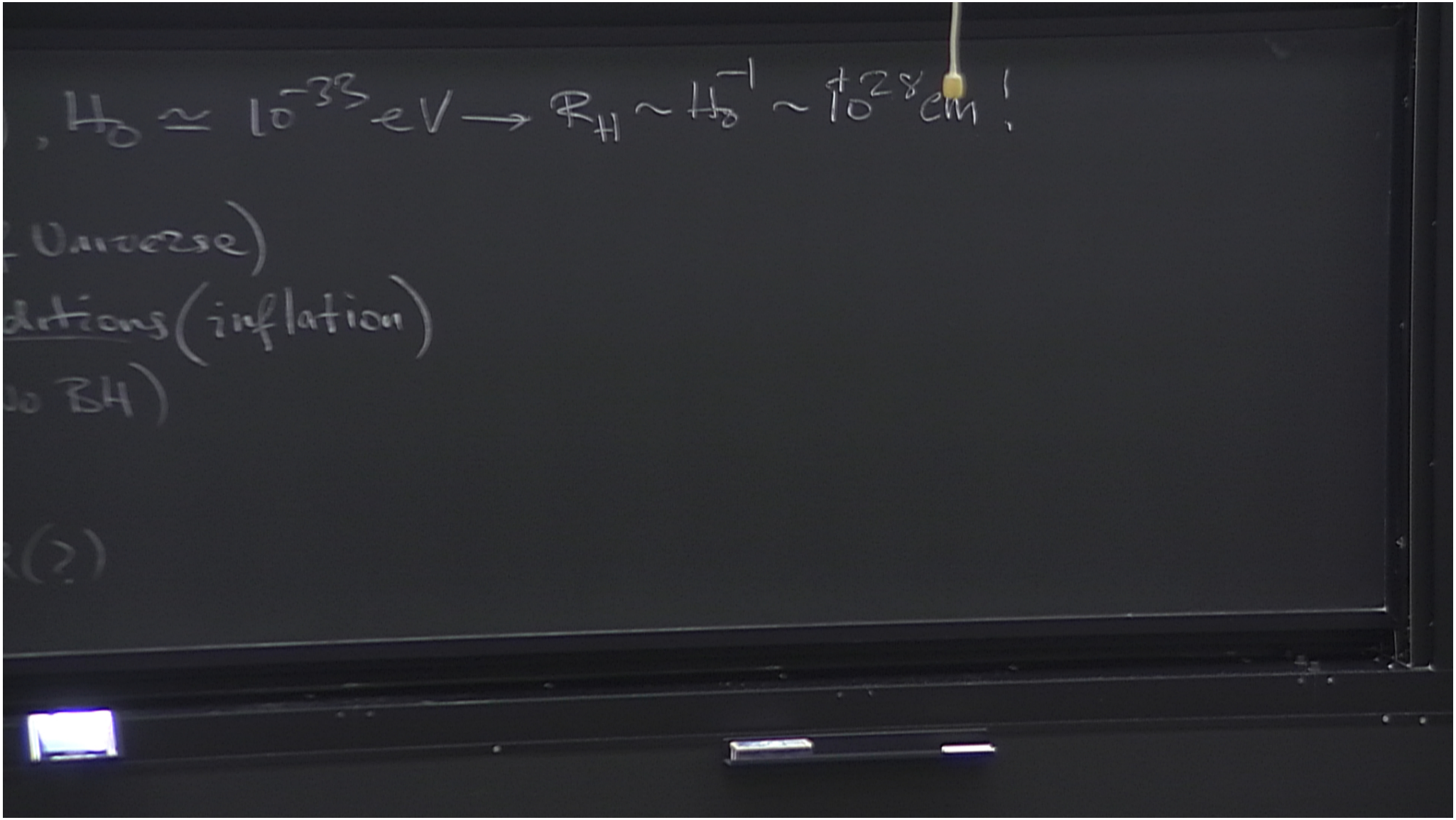
$R_{max} \sim R_H \sim H_0^{-1}$ (Inverse Hubble Radius), $H_0 \simeq 10^{-33}$ eV

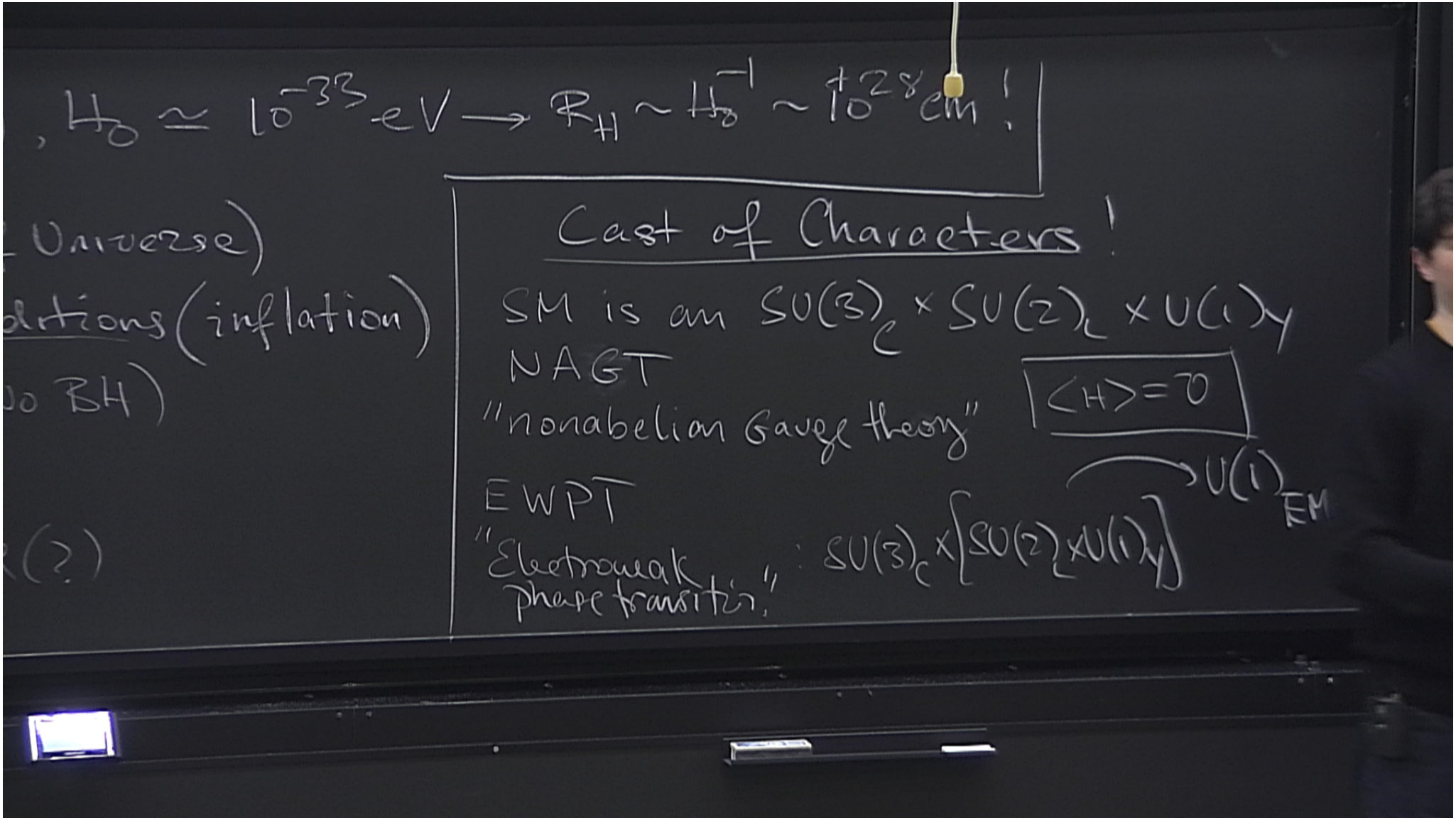
for Max we need: - Classical GR (exp. of Universe)
- DM + DE + Initial Conditions (inflation)
- No Quantum Gravity (No BH)

quant grav. ... $\leftarrow 10^{-17}$ cm $\leftarrow$ SM $\rightarrow 10^{28}$ cm. $\rightarrow$

BSM (how much Matter is Antimatter)

multiverse (?)


$H_0 \simeq 10^{-33}\,eV \rightarrow R_H \sim H_0^{-1} \sim 10^{28}\,cm$!
Universe)
ditions (inflation)
BH)
R(?)


$H_0 \simeq 10^{-33}\,eV \rightarrow R_H \sim H_0^{-1} \sim 10^{28}\,cm$!
Universe)
olutions (inflation)
o BH)
(?)
Cast of Characters !
SM is an $SU(3)_C \times SU(2)_L \times U(1)_Y$
NAGT
"nonabelian Gauge theory"
$\langle H \rangle = 0$
EWPT
"Electroweak phase transition"
$SU(3)_C \times [SU(2)_L \times U(1)_Y]$
$U(1)_{EM}$

GeV·cm = 2×10

cm (GeV) | $\sqrt{} \sim$ GeV

"familiar cast" ($h, W^{\pm} Z \cdots Q G, \ell, \nu \ldots$)

Energy Specific! Mainly Consider E (or Temp) $\gtrsim \Lambda_{QCD}$

- below this, QCD is Confined ($q, g \to p, n, \pi \ldots$)
- Need effective theory of (p, n, π-) (New dof)
- Numerically ele path Integral (lattice QCD)

also. $E \lesssim$ TeV (EWPT)
below this WZ bad. Dof ...

focus on TeV $> E > \Lambda_{QCD}$

(how much Matter vs. Antimatter)

multiverse (?)

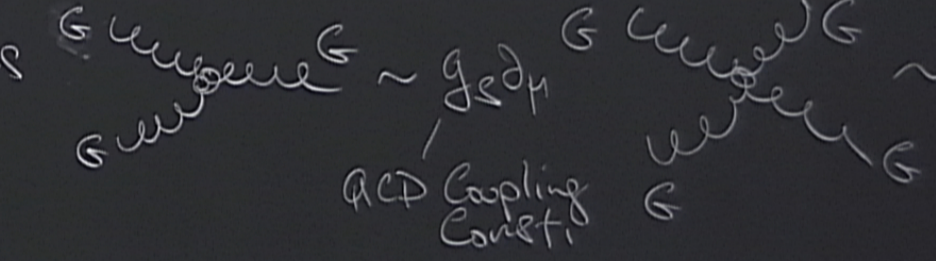
"Ele... ph...

Cast of Characters (for Real) — One by One..

Turn on QCD (quant. Chromodynamics) "like QED only more so"

$SU(3)_C$ gauge theory → $SU(N)$ → N^2-1 generators (i.e. gauge bosons)

G_μ (spin 1 gluons) & Interactions

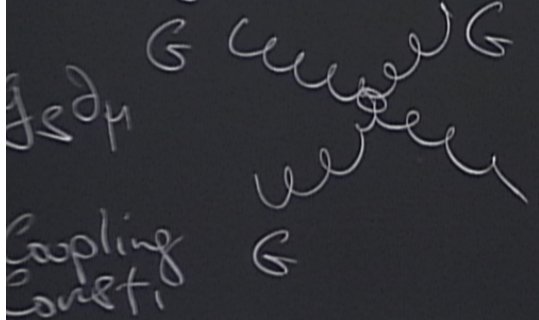


phase transition.

One..

QED only more so!!

(i.e. gauge bosons)



Leading coupling constant

$\alpha_s \equiv \frac{g_s^2}{4\pi}$, $\alpha_s(m_Z) \simeq 0.118$

vs. $\alpha_{QED}(m_Z) \simeq \frac{1}{128}$

$m_Z \simeq 90$ GeV.

Quarks [fundamental Repres. of SU(3)]

each quark has 3 "colors" (RGB)

3 generations

u	d
c	s
t	b

also. $E \lesssim$ TeV (EWPT)
below this WZ bad. Dof ...

focus on $\text{TeV} > E > \Lambda_{QCD}$

Quarks (each 3 colors)

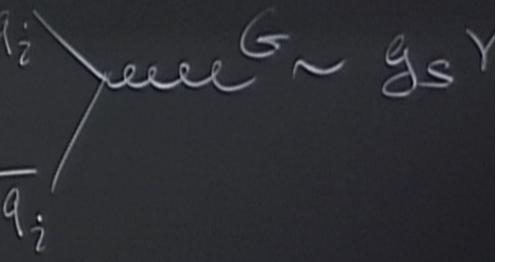
"up type" | "down type" ($-\frac{1}{3}$)

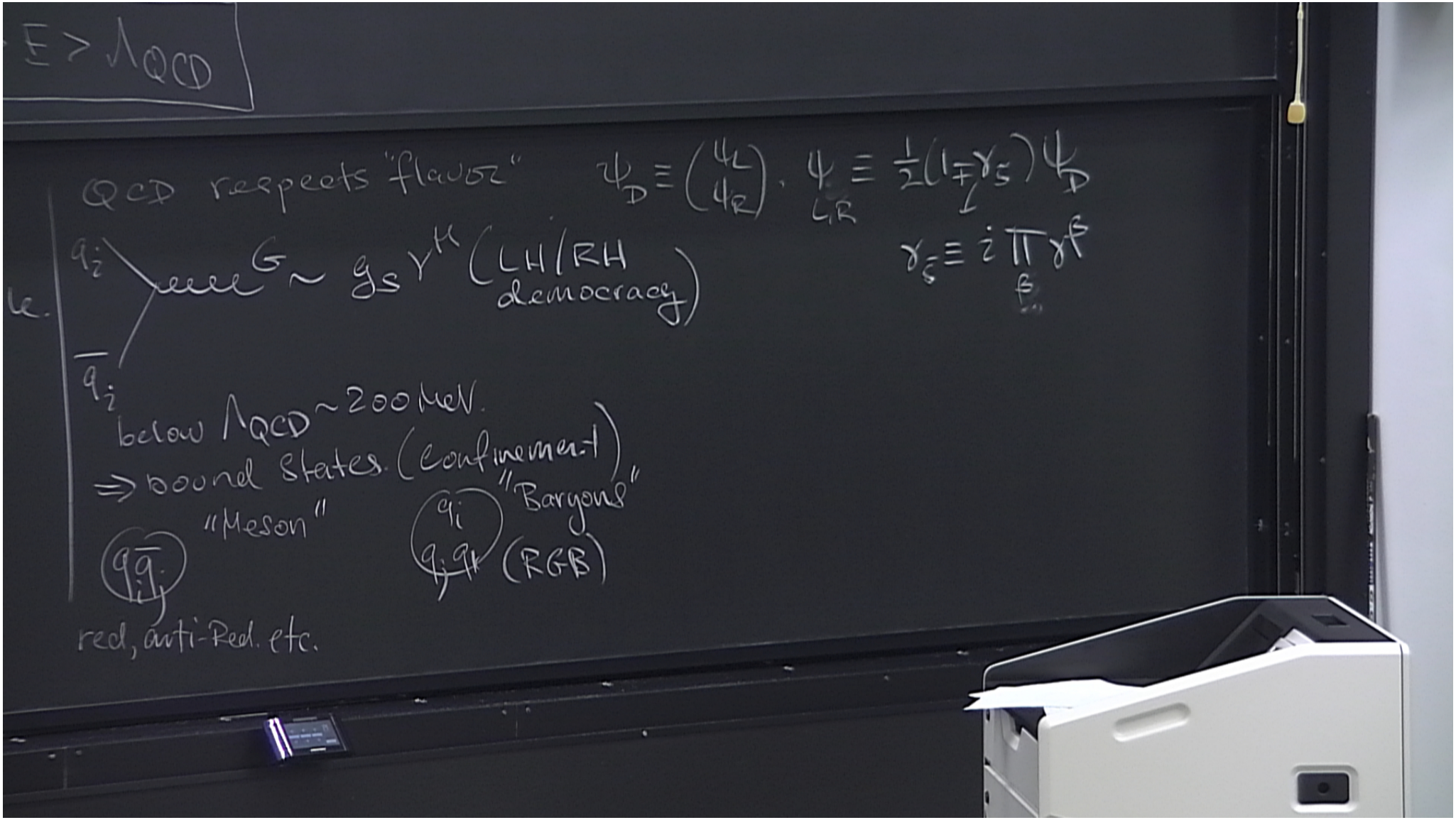
$u \sim 2$ MeV. | $d \sim 4.8$ MeV. → Stable.

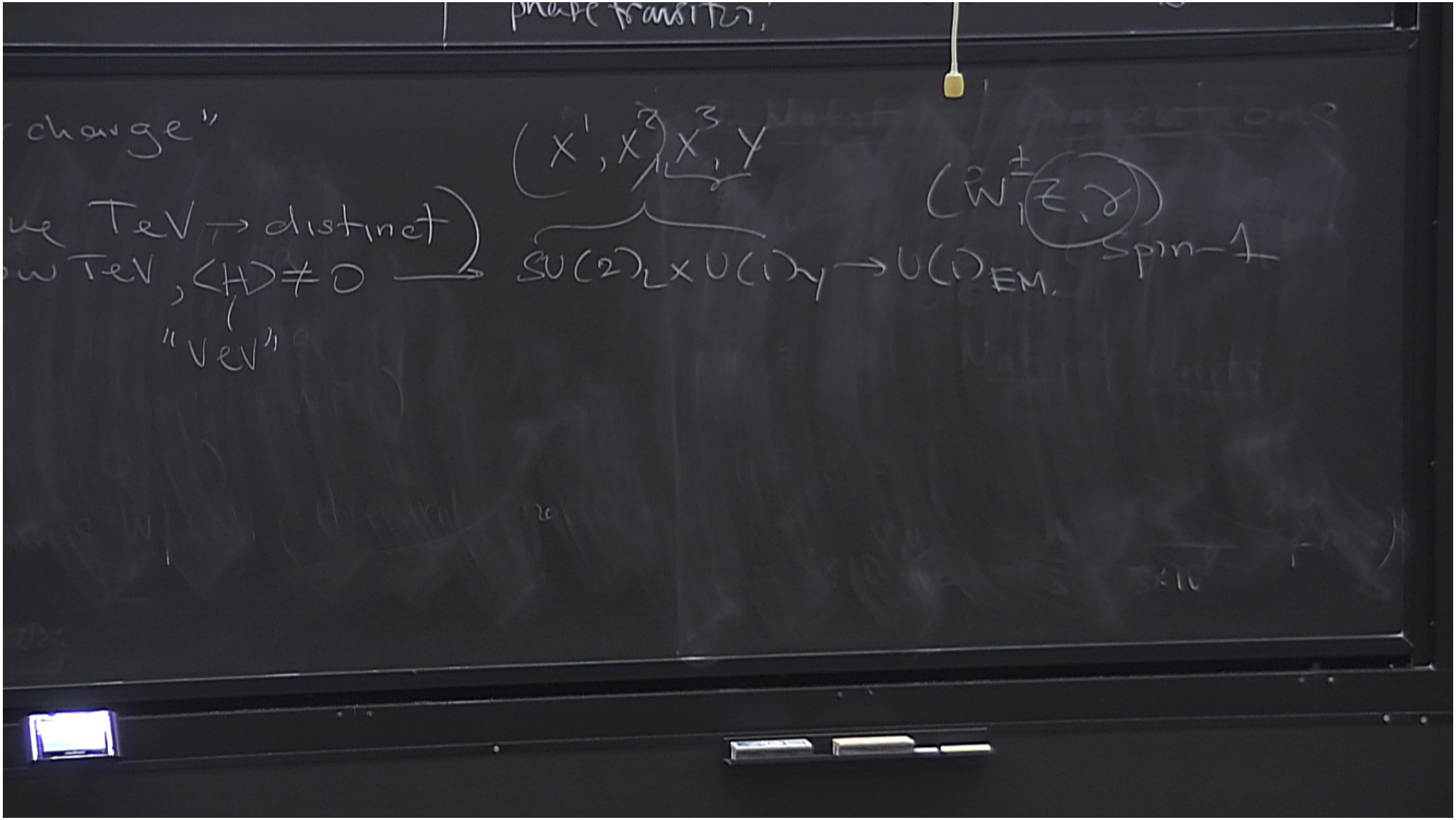
$+\frac{2}{3}$) $c \sim 1.2$ GeV. | $s \sim 95$ MeV.

$t \sim 175$ GeV (!) (why?) | $b \sim 4.2$ GeV.

QCD respects fl




E > Λ_QCD
QCD respects "flavor"
ψ_D ≡ (ψ_L, ψ_R)
ψ_L,R ≡ ½(1 ∓ γ_5) ψ_D
γ_5 ≡ i Π_β γ^β
q_i
q̄_i
G
~ g_s γ^μ (LH/RH democracy)
below Λ_QCD ~ 200 MeV.
⇒ bound states. (confinement)
"Meson"
"Baryons"
q_i q̄_i
q_i q_k (RGB)
red, anti-Red. etc.


phase transition.
charge"
TeV → distinct
w TeV, ⟨H⟩ ≠ 0
"VeV"
(x¹, x², x³, Y)
SU(2)L x U(1)Y → U(1)EM.
(W±, Z, γ)
spin-1

(How much Matter vs. Anti-matter?)

(Nobels) Turn On: $SU(2)_L \times U(1)_Y$ — "Hypercharge"

electroweak force (Above TeV → dist

below TeV, $\langle H \rangle \neq 0$

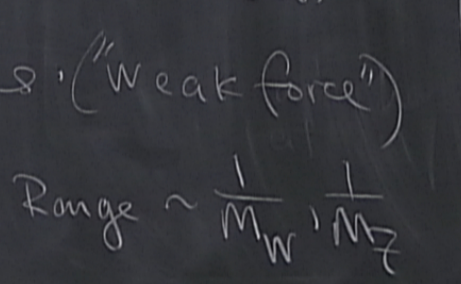
$\begin{cases} m_W = 80.385 \pm 0.015 \text{ GeV} \\ Z^0 = 91.187 \pm 0.0021 \text{ GeV} \end{cases}$

↳ Short range forces: ("Weak force")

$V \sim \frac{e^{-m_{W,Z} r}}{r}$, Range $\sim \frac{1}{m_W}, \frac{1}{m_Z}$

Weak

Quarks: (with W & Z) "VeV" q_i

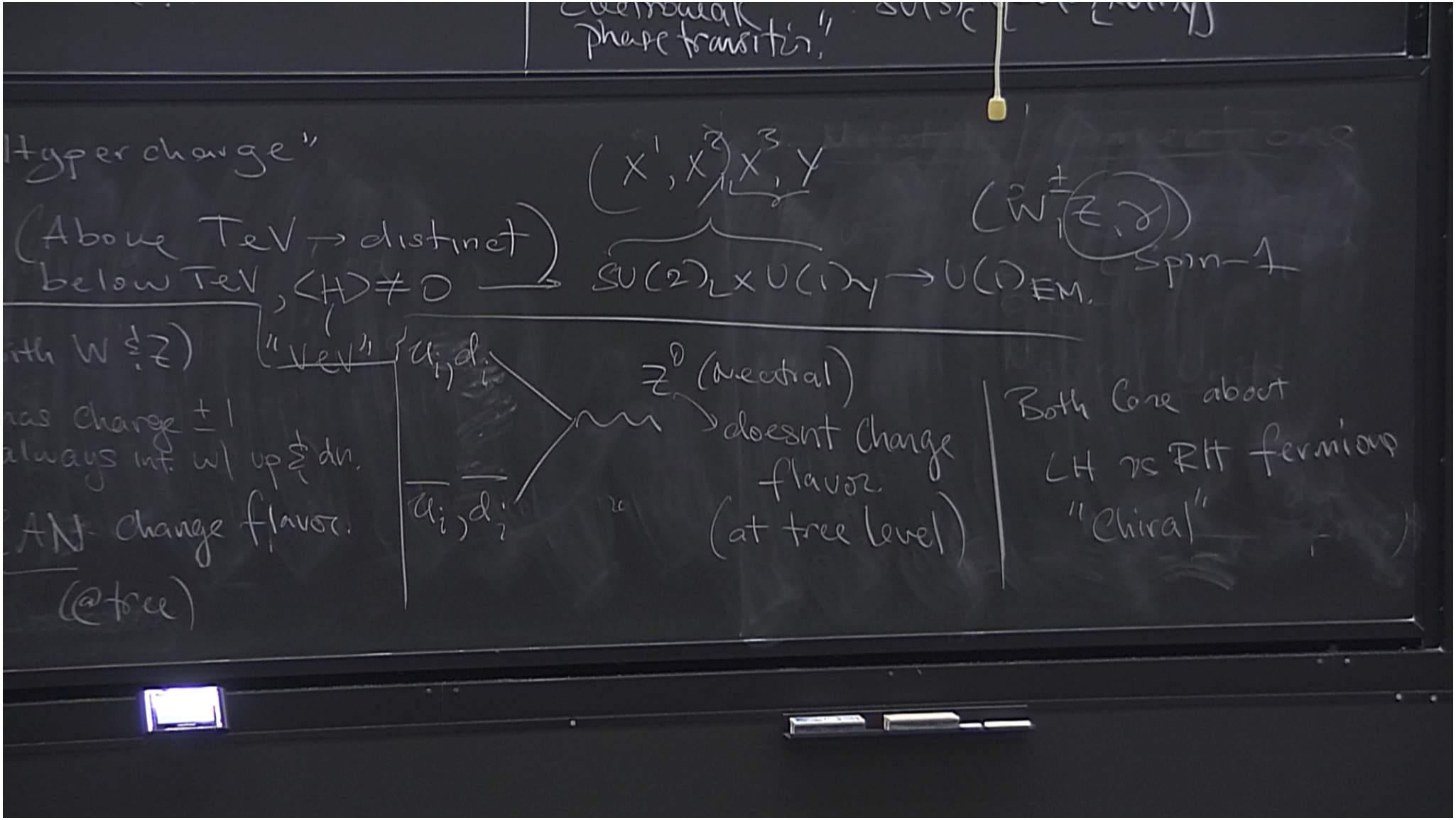


$W^\pm$ has charge ±1

always int. w/ up & dn.

CAN change flavor.

$\bar{q}_i$


phase transition"
hypercharge"
(Above TeV → distinct
below TeV, ⟨H⟩ ≠ 0
(X¹, X², X³, Y
SU(2)L × U(1)Y → U(1)EM.
(W±, Z, γ)
spin-1
"vev"
qi, di
Z⁰ (Neutral)
doesn't Change flavor.
(at tree level)
Both Core about
LH vs RH fermions
"Chiral"
with W ↕ Z)
has charge ±1
always int. w/ up & dn.
CAN change flavor.
(@tree)

Also $E \lesssim$ TeV (EWPT)
below this WZ bad. Dof

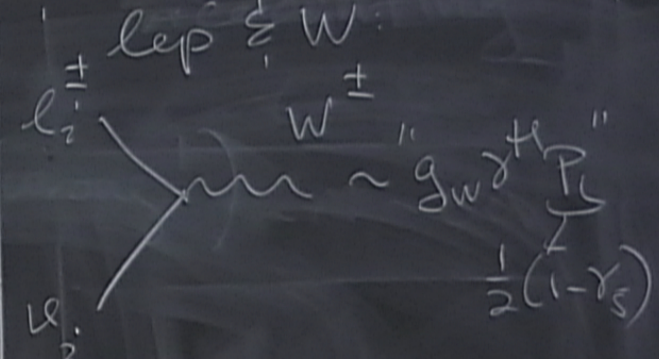
focus on $\text{TeV} > E > \Lambda_{QCD}$

Add leptons: Dont feel QCD

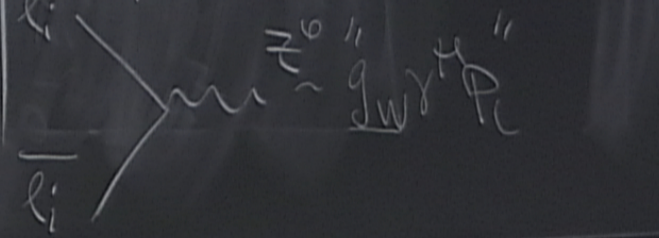
± 1

1. $e^{\pm} \sim 0.511$ MeV. ν_e $(m_\nu = 0)$
2. $\mu^{\pm} \sim 106$ MeV. ν_μ $m = 0$
3. $t^{\pm} \sim 1776$ MeV (USA) ν_t $m = 0$

lep & W:



lep + Z:



Focus On $TeV > E > \Lambda_{QCD}$

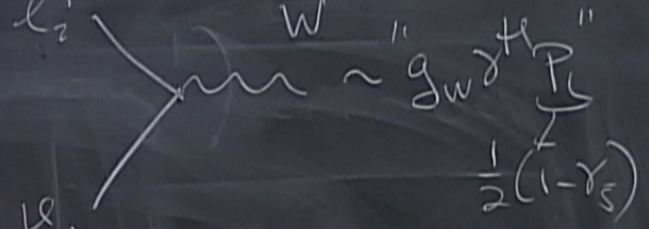
Real QCD

$(m_R = 0)$

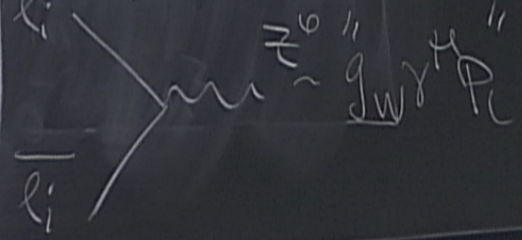
$m = 0$

$m = 0$

lep & W:



lep + Z:



$\psi_D \equiv P_L \psi_D + P_R \psi_D$

$P_{L,R} \equiv \frac{1}{2}(1 \mp \gamma_5)$

$\gamma_5 \equiv i\gamma^0\gamma^1\gamma^2\gamma^3$

$P_L = \begin{pmatrix} \mathbb{1}_{2\times 2} & 0 \\ 0 & 0 \end{pmatrix}$

$P_L \begin{pmatrix} \psi_L \\ \psi_R \end{pmatrix} = \begin{pmatrix} \psi_L \\ 0 \end{pmatrix}$