PHENOMENOLOGY OF THE STANDARD MODEL PHY4208S

I will cover:

- Introduction to gauge theories
- Spontaneous symmetry breaking
- Weak interactions
- Strong interactions
- CP Violation
- Neutrino physics

Suggested Texts:

Main - Thomson Modern Particle Physics

Others
- Quigg
- Burgess and Moore
- Halzen Martin
- Griffiths
- Aitchison and Hey

Grading

- Weekly* problem sets 25% **
- Long problem sets 50% **
- Presentation (in April) 25%

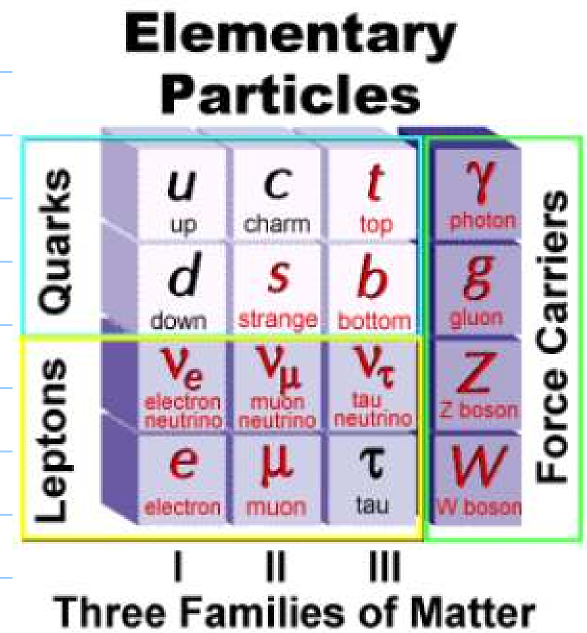
* almost weekly

** -20% per week late

The Standard Model

A quantum Field Theory.
Lagrangian obeys local gauge invariance

global $\psi \to \psi' = e^{i\theta}\psi$
local $\psi \to \psi' = e^{i\alpha(x)}\psi$



Lagrangian invariant under a continuous group of local transformations (gauge transformations). They form a Lie Group whose generators have associated vector fields (gauge fields)

- 12 Fermions
  - 6 quarks
  - 6 leptons

  + 1 scalar : Higgs

- 3 Forces → spin 1 bosons
  - EM — γ
  - Weak — W^+, W^-, Z^0
  - Strong — 8 gluons

In more detail: SM based on the Fields below and $SU(3) \times SU(2)_L \times U(1)_Y$ gauge symmetries.

					$SU(3)$	$SU(2)_L$	$U(1)_Y$
Q^i_L	=	$\begin{pmatrix} u_L \\ d_L \end{pmatrix}$	$\begin{pmatrix} c_L \\ s_L \end{pmatrix}$	$\begin{pmatrix} t_L \\ b_L \end{pmatrix}$	3	2	$1/6$
u^i_R		u_R	c_R	t_R	3	1	$2/3$
d^i_R		d_R	s_R	b_R	3	1	$-1/3$
L^i_L		$\begin{pmatrix} \nu_{eL} \\ e_L \end{pmatrix}$	$\begin{pmatrix} \nu_{\mu L} \\ \mu_L \end{pmatrix}$	$\begin{pmatrix} \nu_{\tau L} \\ \tau_L \end{pmatrix}$	1	2	$-1/2$
e^i_R		e_R	μ_R	τ_R	1	1	-1
φ	=	$\begin{pmatrix} \varphi^+ \\ \varphi^0 \end{pmatrix}$			1	2	$1/2$

Now we should add neutrinos above (and we will)

We can break the SM into the following:

$$\mathcal{L}_{SM} = \mathcal{L}_{GAUGE} + \mathcal{L}_{MATTER} + \mathcal{L}_{YUKAWA} + \mathcal{L}_{HIGGS}$$

A brief look ahead and an answer to a question sometimes asked to graduate students.

- in the late 80s, early 90s, physicists started designing machines to probe physics at the TeV scale. The argument:

  "we are sure to find something: either the Higgs or something else."

  why??

Let's look at $\mathcal{L}_{HIGGS}$:

$$\mathcal{L}_{Higgs} = (D^\mu \varphi)^\dagger D_\mu \varphi + \underbrace{\mu^2 \varphi^\dagger \varphi - \lambda (\varphi^\dagger \varphi)^2}_{\text{potential}}$$

μ^2 - is the only dimensionful parameter of the SM

- sign chosen to provided nonzero VEV

$$\langle \varphi_0 \rangle = \frac{\mu}{2\sqrt{2\lambda}} \equiv \frac{v}{\sqrt{2}}$$

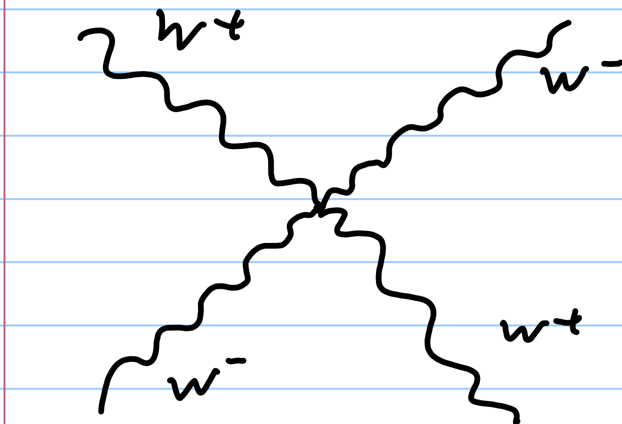
$$\boxed{v \simeq 246 \text{ GeV}}$$

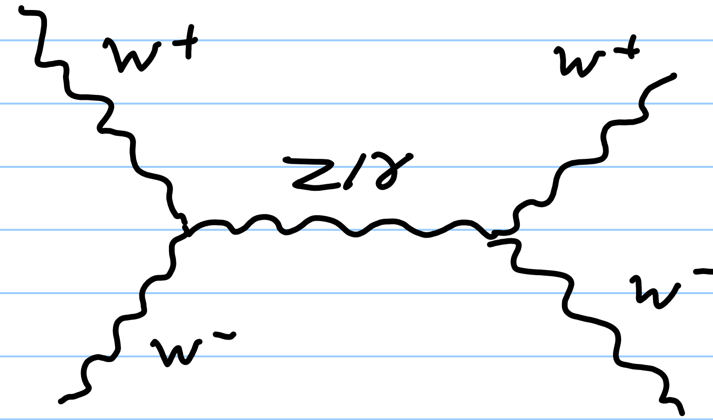
Higgs acquisition of non-zero VEV breaks electroweak symmetry and gives mass of W, Z bosons and fermions

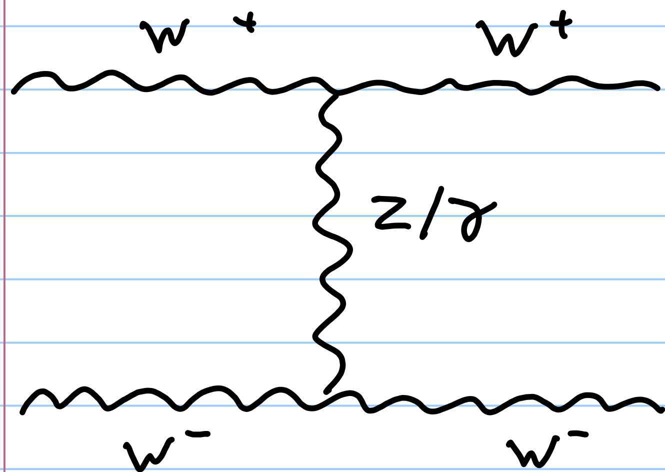
Now $SU(2) \times U(1)$ part of $\mathcal{L}_{GAUGE}$: $-\frac{1}{4} F^i_{\mu\nu} F^{\mu\nu i} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu}$

→ self interactions (non-Abelian theory)

Have diagrams for WW scattering:

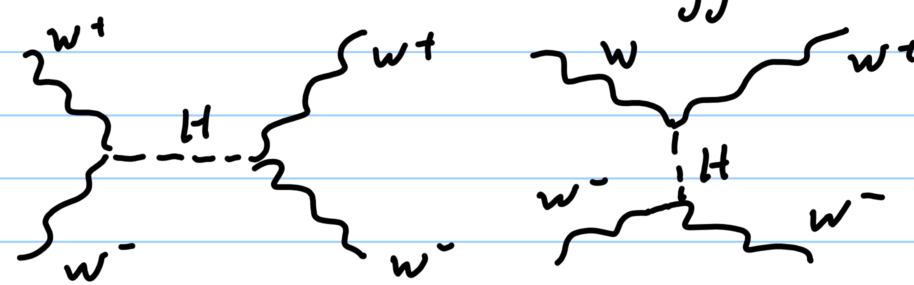






$\to$ σ grows with s (E_{cm}^2)

and violates unitarity unless we add the Higgs



$\Rightarrow$ $M_H \lesssim 1$ TeV

New Physics

→ problem with our fundamental scalar:

Higgs mass receives quadratically-divergent corrections from loop diagrams:

$$\delta m_H^2 \propto \Lambda^2$$

in contrast $\delta m_F \propto \ln\left(\frac{\Lambda}{m_F}\right)$

⇒ "Natural" value for Higgs mass is at Λ, the cutoff energy

⇒ Keeping Higgs mass at weak scale while setting Λ at GUT scale ($\sim 10^{16}$ GeV) requires very precise fine-tuning.

To prevent this fine tuning, new physics should be close to weak scale.