Phenomenology of the Standard Model (PHY2408S)

I hope to cover the following:

- Review of cross section calculations in QED
- Review of Electrodynamics of Quarks and Hadrons
- Non-Abelian Gauge Theories
- Spontaneous Symmetry Breaking
- Weak Interactions
- QCD
- CP violation

I propose to present an overview of the topics on the previous page, perform important calculations and relate those calculations to experimental measurements.

The Standard Model is our theory of fundamental particles and interactions. It has been tested to a high degree of precision (work is ongoing). I would like you to understand:

- what is the prediction?
- how was it tested, what is the result?
  - need to understand what can be measured before doing the calculations
- It's the basis for H_0, the null hypothesis for any new physics.
  - need to understand predictions very well before we claim new physics

I propose to present an overview of the topics on the previous page, perform important calculations and relate those calculations to experimental measurements.

- I will post my notes online. Other suggested texts include:

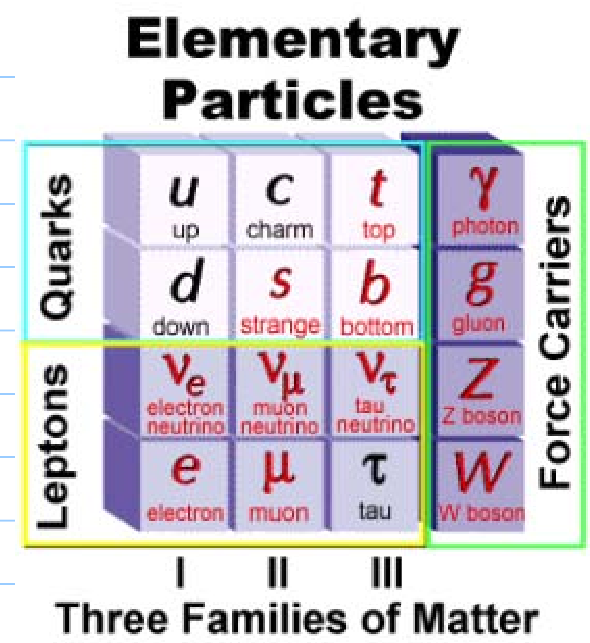
  - Burgess and Moore (Standard Model: a Primer)
  - Quigg (Gauge Theories of the Strong, Weak,...)
  - Halzen Martin (Quarks and Leptons)
  - Griffiths (Introdution to Elementary Particles)
  - Aitchison and Hey (Gauge Theories in Particle Physics)

Grading: 4 problem sets 15% each (Penalty for being late 20% per week. No marks if more than 3 weeks late).
Final Exam: 40% (mid-April)

The Standard Model

A quantum field theory.
Lagrangian obeys local gauge invariance

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



- 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
$\varphi =$	$\begin{pmatrix} \varphi^+ \\ \varphi^0 \end{pmatrix}$				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 $\mathcal{L}_{HIGGS}$:

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

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

- sign chosen to provided nonzero VEV

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

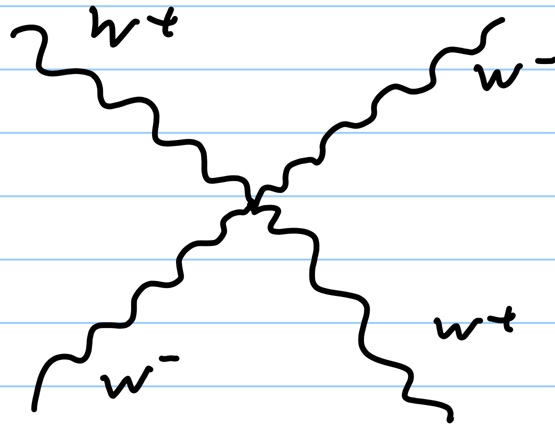
Higgs acquisition of non-zero VEV breaks electroweak symmetry and gives mass of W, Z bosons and fermions

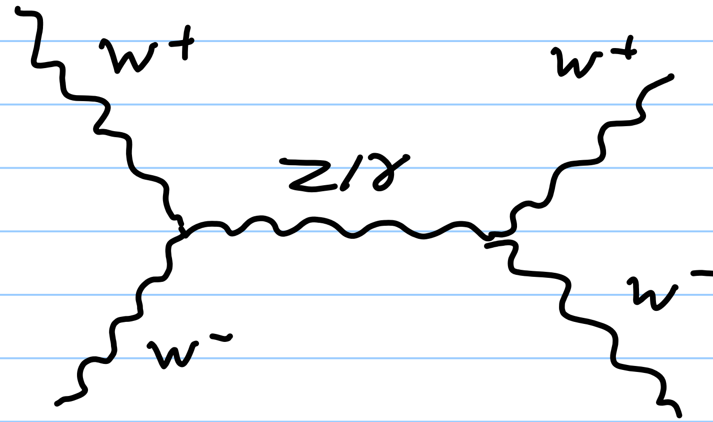
$$\boxed{v \simeq 246 \text{ GeV}}$$

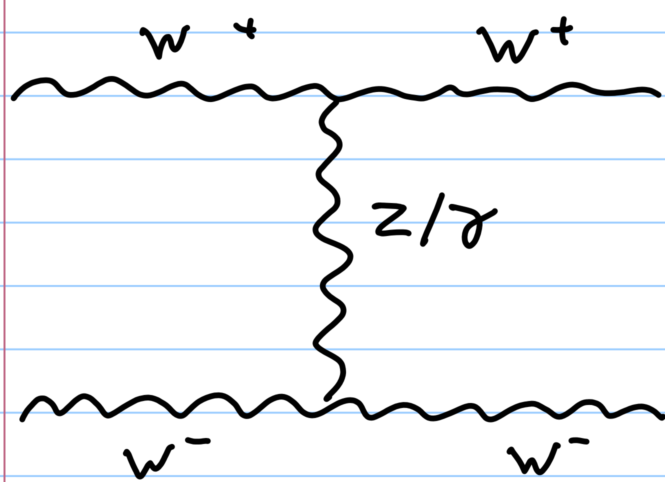
Now $SU(2) \times U(1)$ part of $\mathcal{L}_{\text{GAUGE}}$: $-\frac{1}{4} F^i_{\mu\nu} F^{\mu\nu i} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu}$

→ self interactions (non-Abelian theory)

Have diagrams for WW scattering:

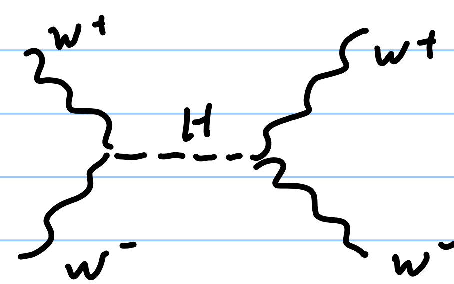


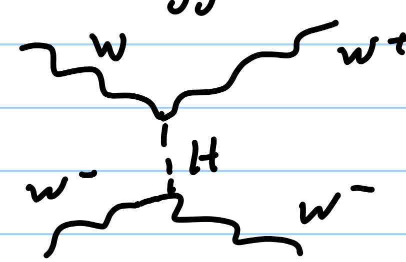




→ σ grows with s (E_{cm}^2)

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.