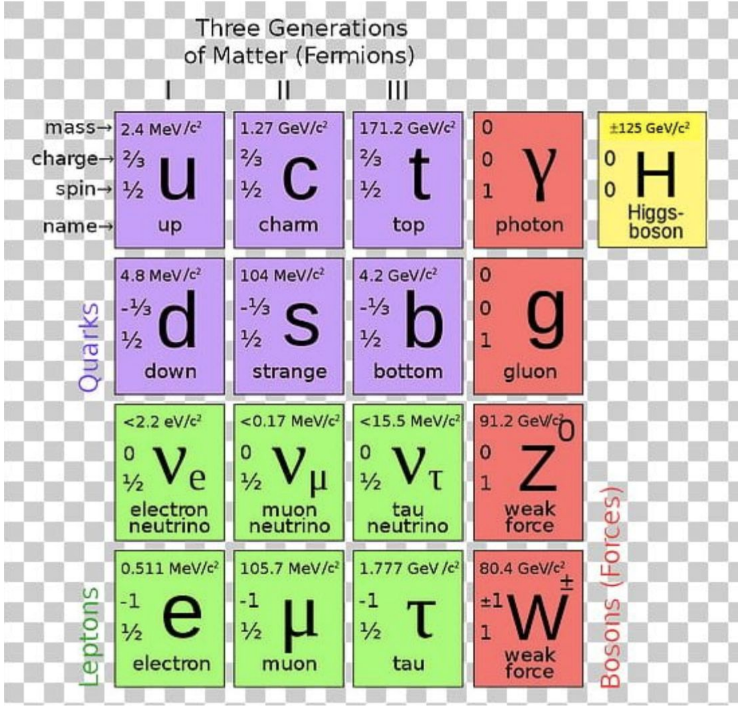
Analysis of the Charm Quark Higgs Decay Mode

Mrinal Bhatnagar
Physics REU 2024
Advised by Dr. Kao and Chenyu

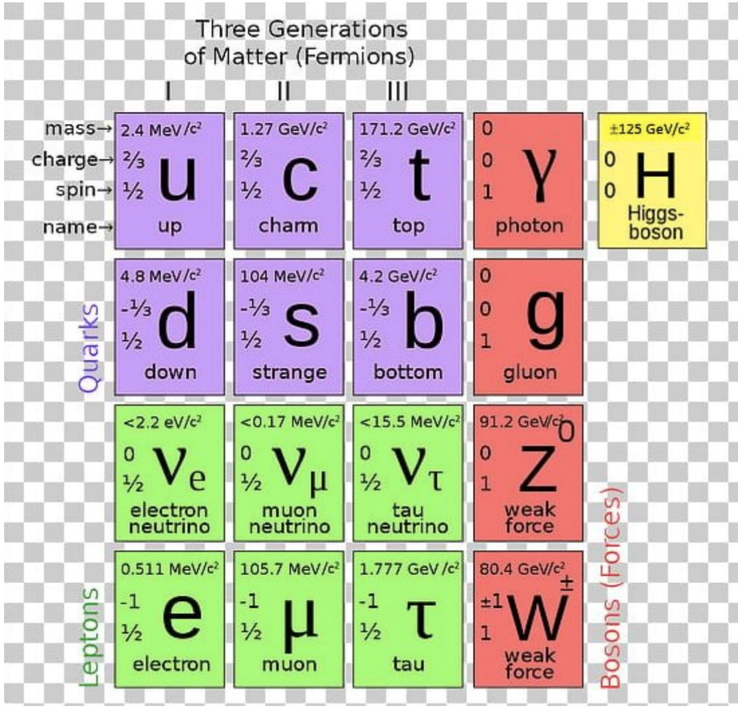
The Standard Model

- Goal: analyze the charm quark decay mode of the Higgs boson
- The most successful theory of physics
- Includes three of the four fundamental forces
- Bosons and fermions
- Interactions are mediated by gauge bosons



Isospin in the Standard Model

- Introduced by Heisenberg and Wigner
- Analogous to spin
- Similarities between protons and neutrons
- Conservation of isospin
- Doublets
- Bosons



Gauge Symmetry

- Gauge invariance
    - Local vs. global symmetry
- The mass problem

$$\vec{A} \rightarrow \vec{A} - \vec{\nabla} f(\vec{r}, t)$$

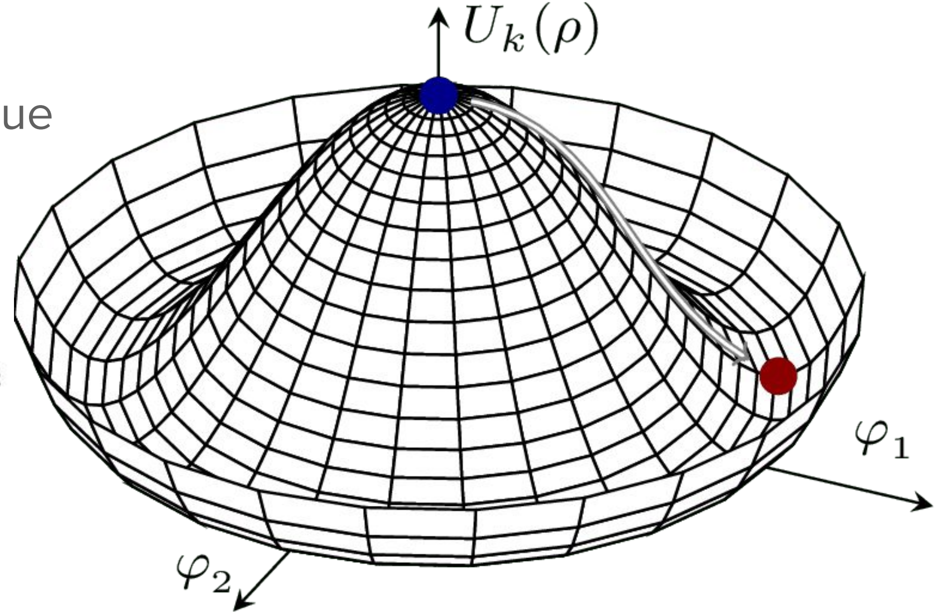
$$\phi \rightarrow \phi + \frac{1}{c}\frac{\partial f(\vec{r}, t)}{\partial t}$$

$$\psi(\vec{r}, t) \rightarrow e^{-i\frac{e}{\hbar c} f(\vec{r}, t)} \psi(\vec{r}, t)$$

- $\Psi' = U(\theta)\Psi$
- Gauge transformation: $U(\theta) = \exp\{-(i/h)\theta^a G^a\}$ if θ^a does not depend on spacetime, it's a global symmetry
- If θ^a depends on space and time, it's a local symmetry

Spontaneous Symmetry Breaking

- Symmetry of the Sombrero potential
- Broken by the vacuum expectation value
- Gauge principle



$$L = \tfrac{1}{2}(\partial_\mu \phi_1)(\partial^\mu \phi_1) + \tfrac{1}{2}(\partial_\mu \phi_2)(\partial^\mu \phi_2) + \tfrac{1}{2}\mu^2(\phi_1^2 + \phi_2^2) - \tfrac{1}{4}\lambda^2(\phi_1^2 + \phi_2^2)^2$$

$$V(\phi_1, \phi_2) = -\tfrac{1}{2}\mu^2(\phi_1^2 + \phi_2^2) + \tfrac{1}{4}\lambda^2(\phi_1^2 + \phi_2^2)^2$$

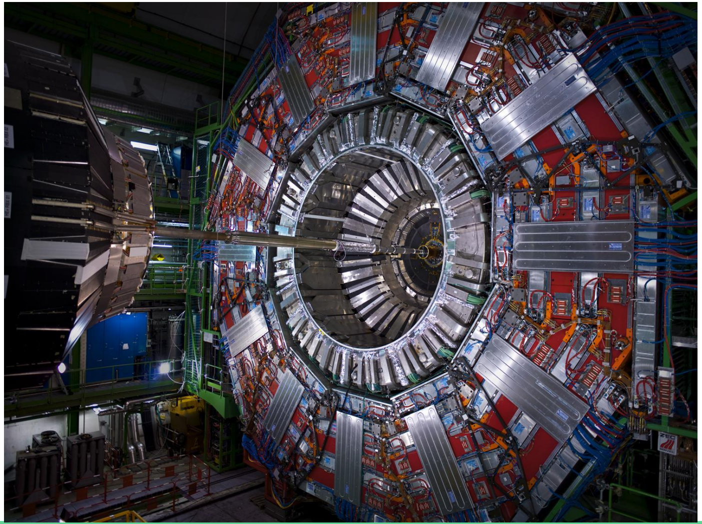
$$\phi_{1min}^2 + \phi_{2min}^2 = \frac{\mu^2}{\lambda^2}$$

$$\eta \equiv \phi_1 - \tfrac{\mu}{\lambda},\ \xi \equiv \phi_2$$

$$L = [\tfrac{1}{2}(\partial_\mu \eta)(\partial^\mu \eta) - \mu^2\eta^2] + [\tfrac{1}{2}(\partial_\mu \xi)(\partial^\mu \xi)] + \ldots$$

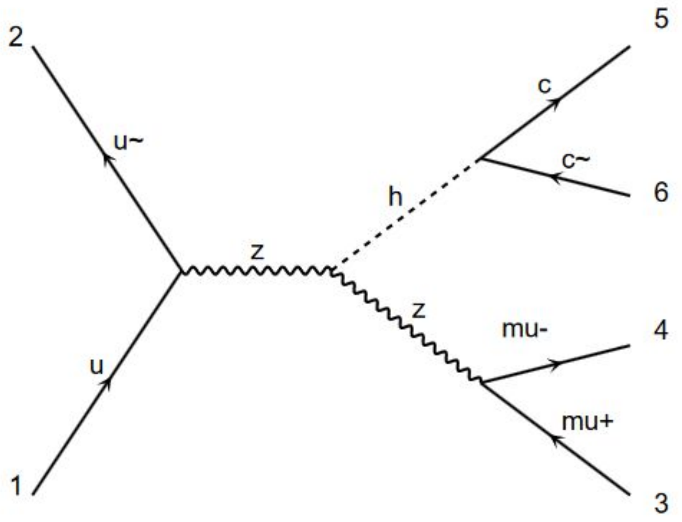
Discovery of the Higgs Boson

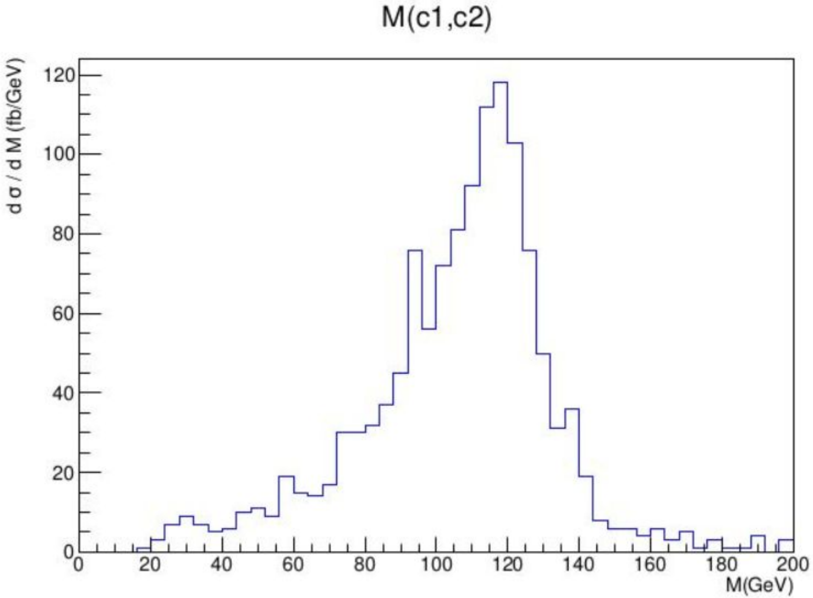
- Discovered in 2012
- First discovered in the ***γγ*** channel
- Low branching ratio of ***γγ*** with a low rate of background
- High mass resolution of ***γγ*** makes it easy to reconstruct the Higgs mass



Signal

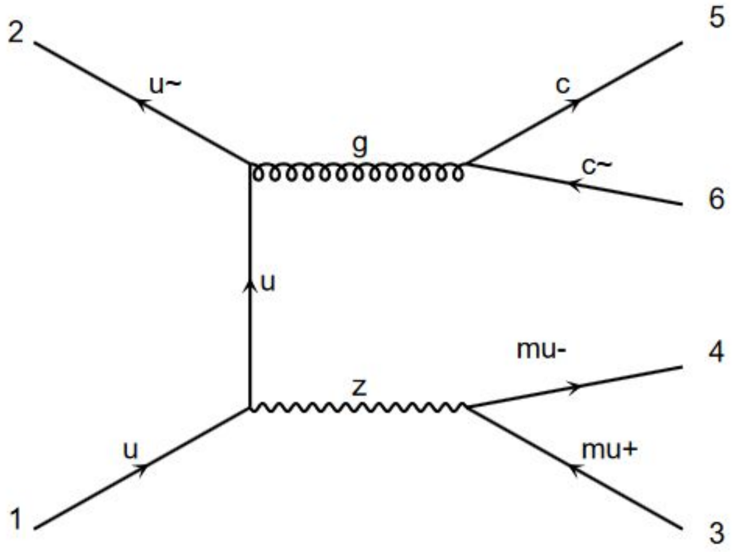
- It is now time to measure H to cc, H to $\mu\mu$, and the Higgs self couplings
- Z boson decay
- Higgs decay into charm quark and charm antiquark

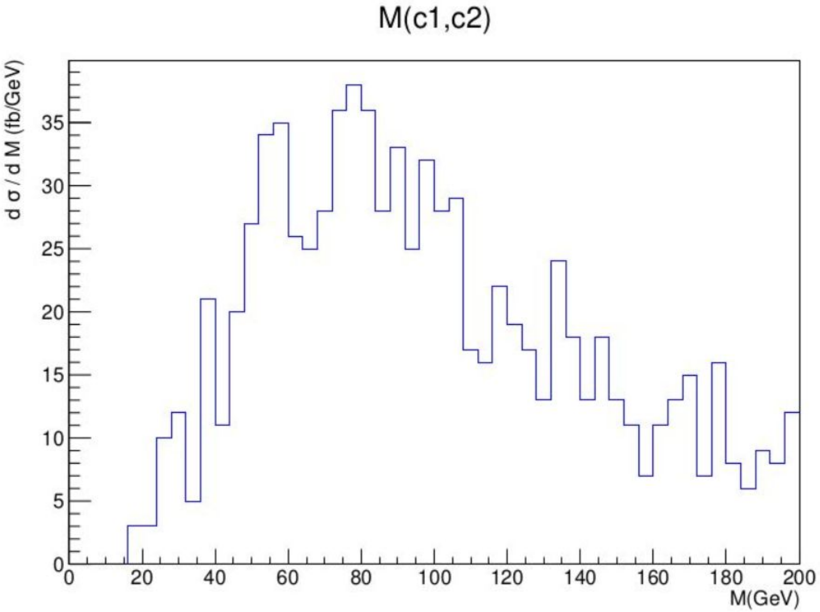




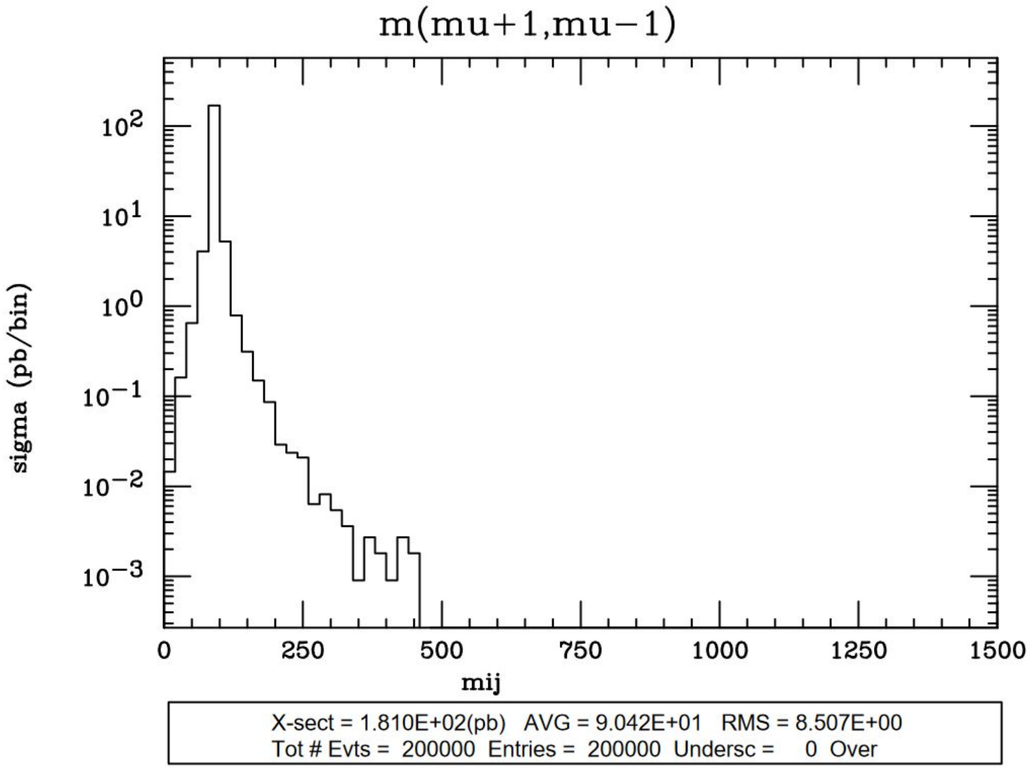
Background

- pp to ll cc, pp to ll bb, pp to ll jj
- j = g u d s





Mass Reconstruction for Z Boson



Discovery Potential

- N_S = # of signal events
- N_B = # of background events
- L = Luminosity
- N_{SS} = Statistical Significance
- Signal cross section: 3.433 fb
- Total background cross section: 1257 fb
- N_S = 2060 for L = 300 fb^{-1}, 20600 for L = 3000 fb^{-1}
- N_B = 754,200 for L = 300 fb^{-1}, 7,542,000 for L = 3000 fb^{-1}
- N_{SS} = 2.37**σ** for L = 300 fb^{-1}, 7.5**σ** for L = 3000 fb^{-1}

$$N_S = \sigma_S * L$$

$$N_B = \sigma_B * L$$

$$N_{SS} = \frac{NS}{\sqrt{NB}}$$

Conclusion/Future Avenues for Analysis

- Statistical significance crosses the discovery threshold for L = 3000 fb^{-1}
- A discovery at the LHC would be therefore be expected, consistent with ATLAS data
- A discovery of H to cc will help us to understand the interactions between the Higgs boson and fermions: tt, bb, $\tau\tau$, $\mu\mu$, cc

Questions?