# The Search for Dark Matter Via Higgs Boson Decays

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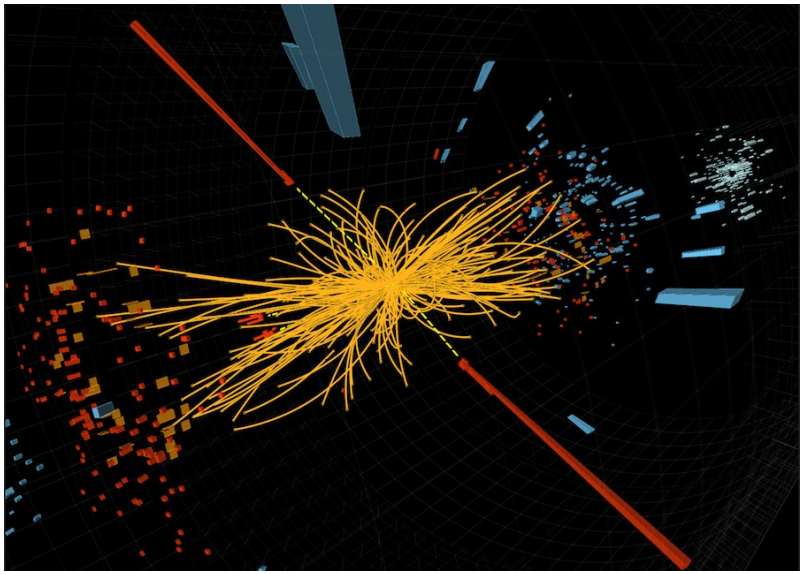
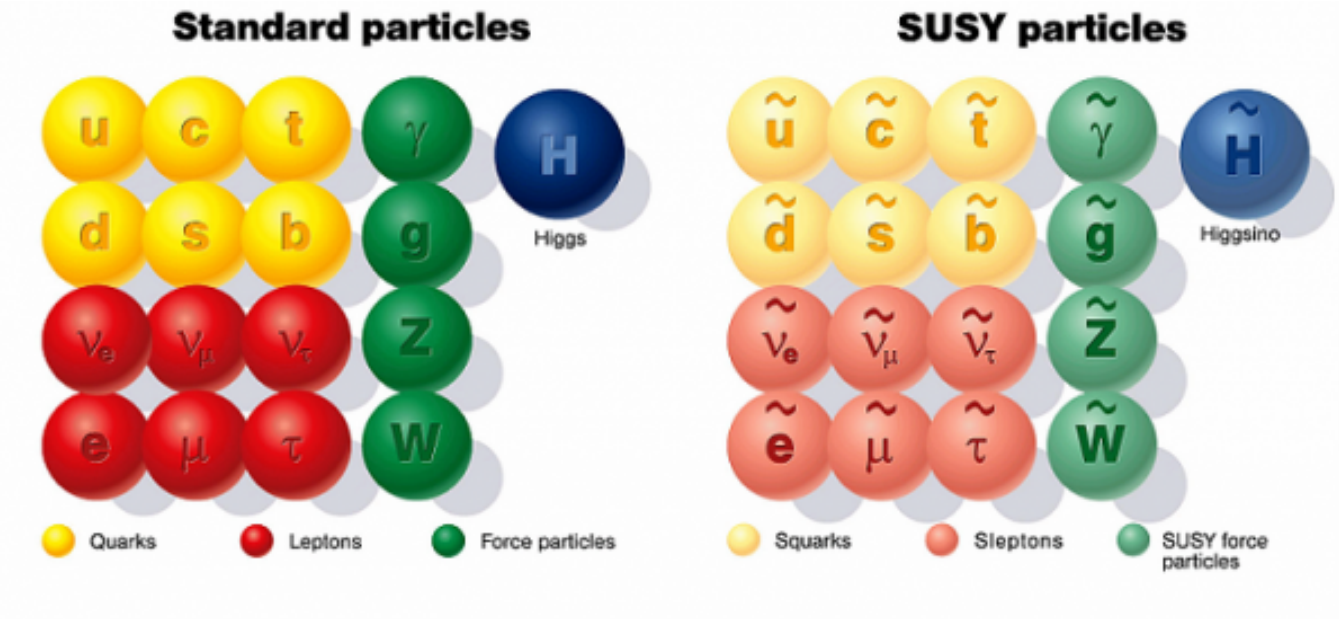
Abstract: With the discovery of a new boson, suspected to be the Standard Model Higgs, scientists at CERN are turning their attention to physics beyond the Standard Model. One possibility is that the Higgs decays into massive dark matter. This talk will briefly describe jet selection criteria that will detect a vector boson capable of producing a Higgs. This is done by looking at the jet substructure and grooming the jets.



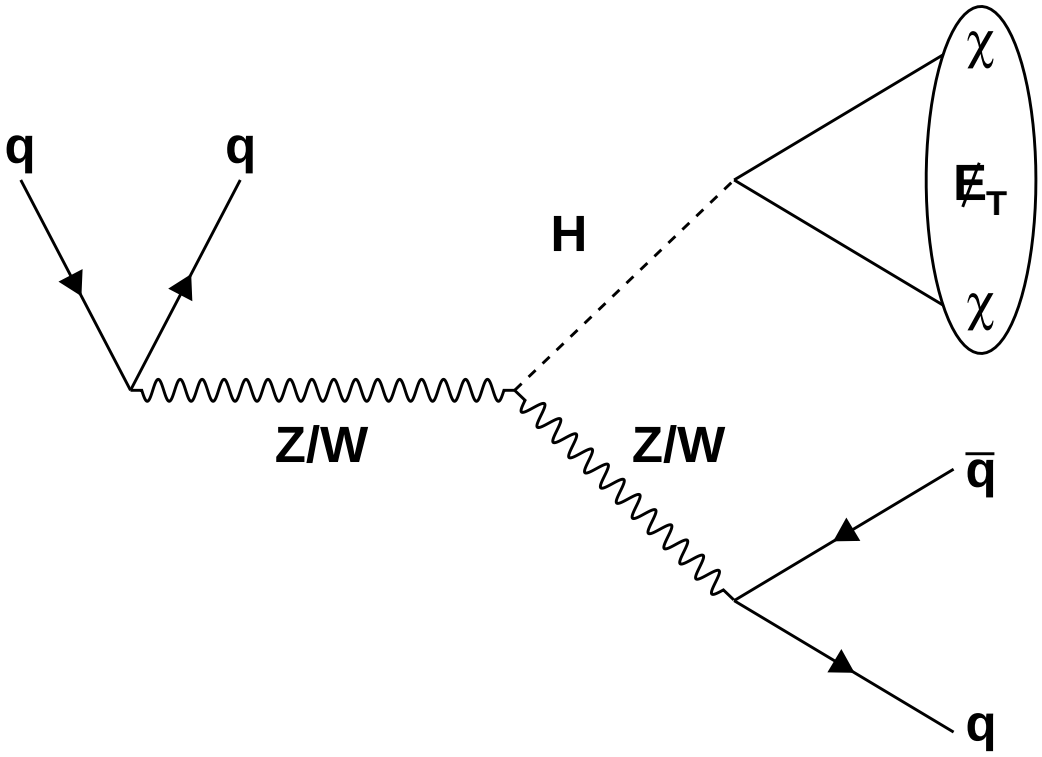
# The Particle Zoo




- There are fermions, gauge bosons, and the Higgs
- Dark matter is believed to be "supersymmetric" particles by some

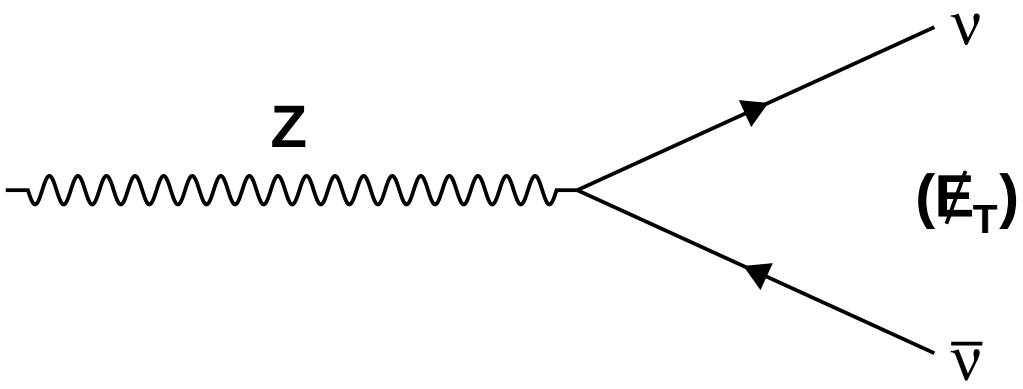
# The Desired Process

- The Higgs couples to massive particles

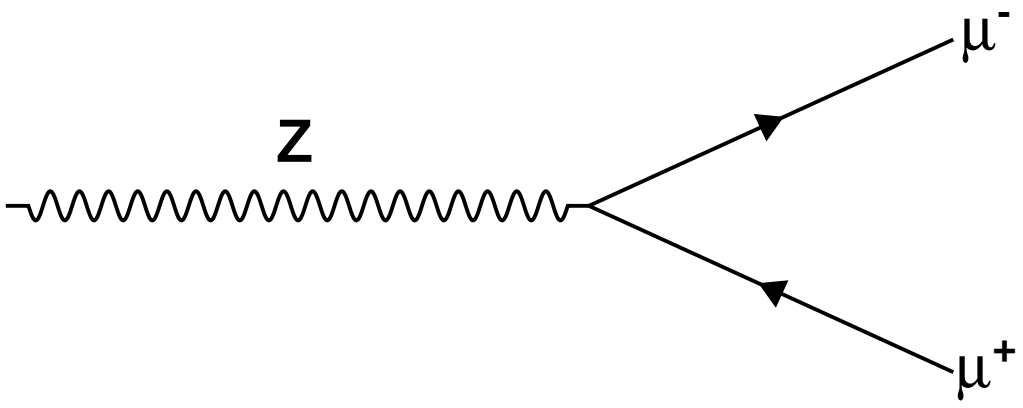



- The Higgs decaying into dark matter will appear as missing transverse energy ($\not{E}_T$).

# The Dominant $Z \to \nu\bar{\nu}$ Background




- Most of the background will be missing energy from neutrinos
- $Z$ events can be characterized using decay into muons



# Isolated Quarks Make Jets

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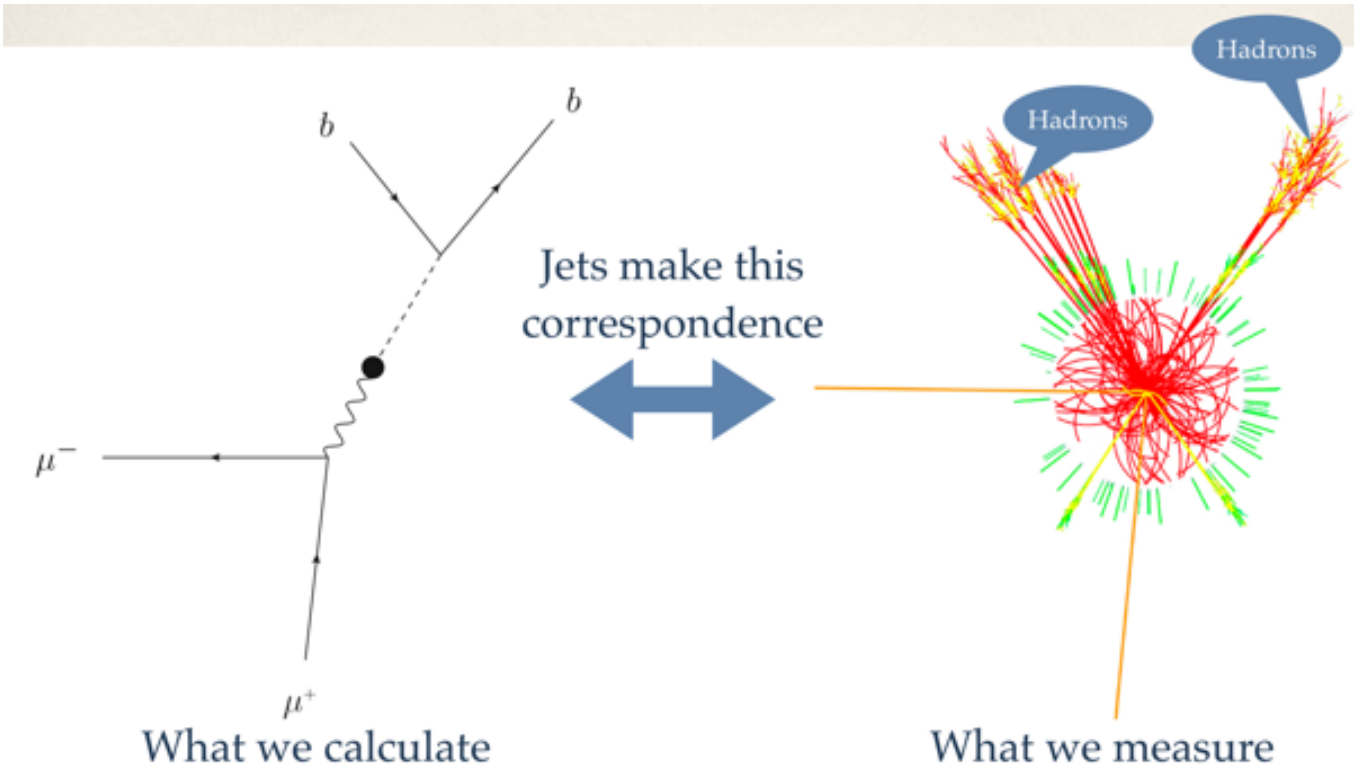
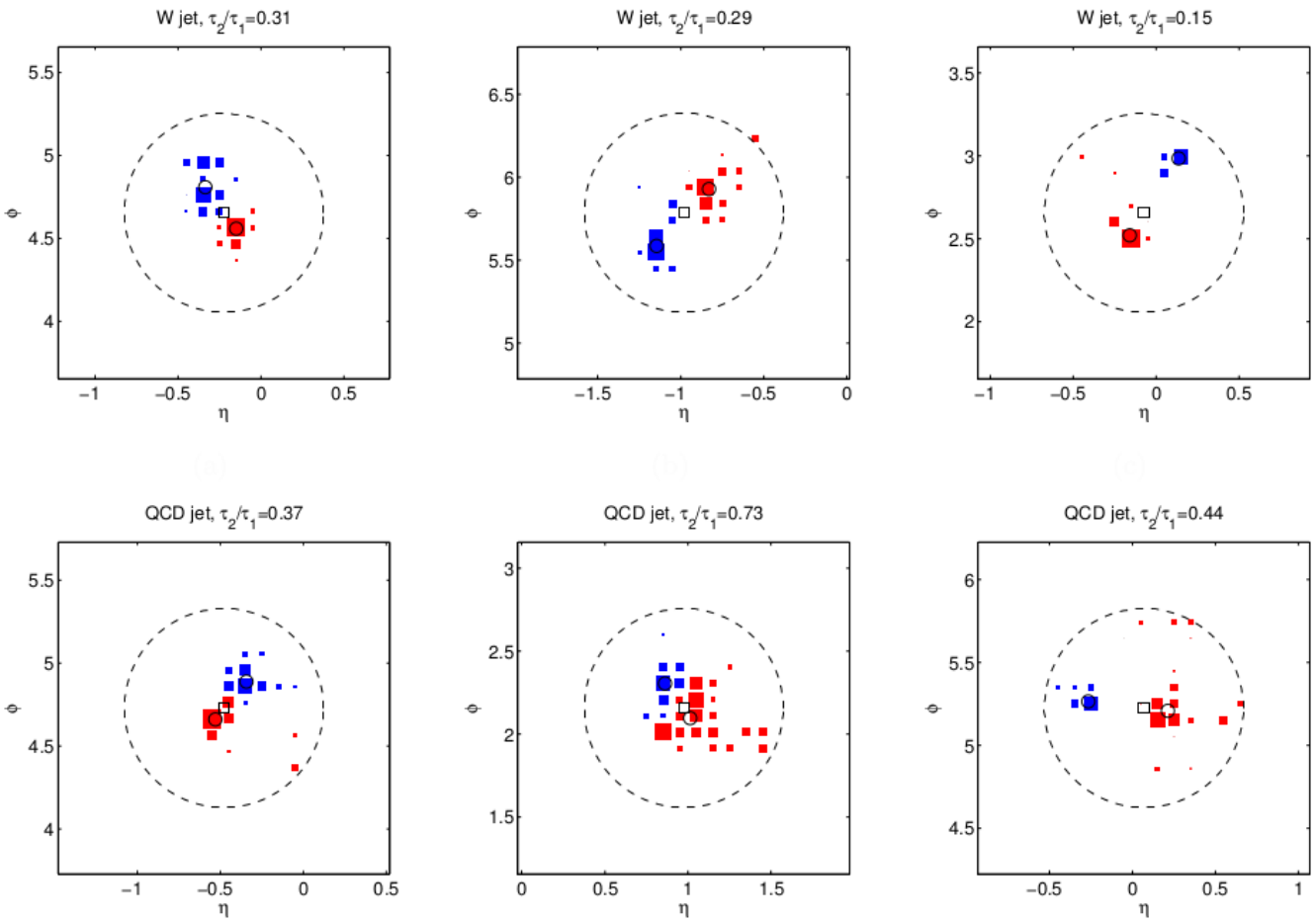



- Cannot measure isolated quarks, but we have bunches of particles called jets

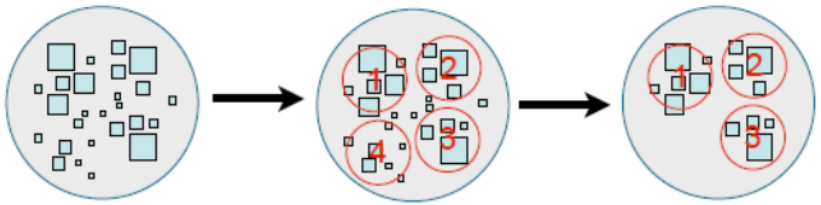
# Substructure Using N-Subjettiness



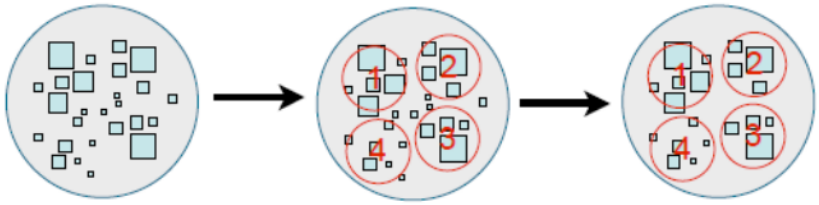

- Using ratios of $\tau_2/\tau_1$, $W$ jets are distinguished from gluon jets

# Grooming Algorithms

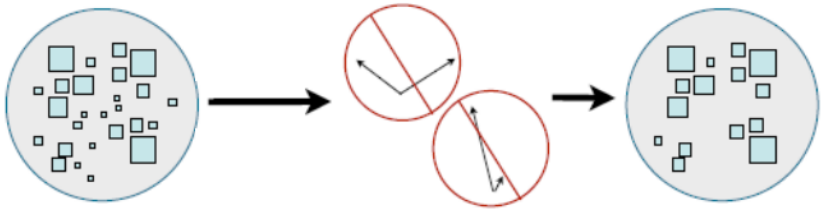
- Filtering
  - Smaller clusters gathered
  - Set number is kept




- Trimming
  - Smaller clusters gathered
  - Low fractional $p_T$ is cut




- Pruning
  - Each vertex is considered
  - Large angles or extreme $p_T$ ratios cut



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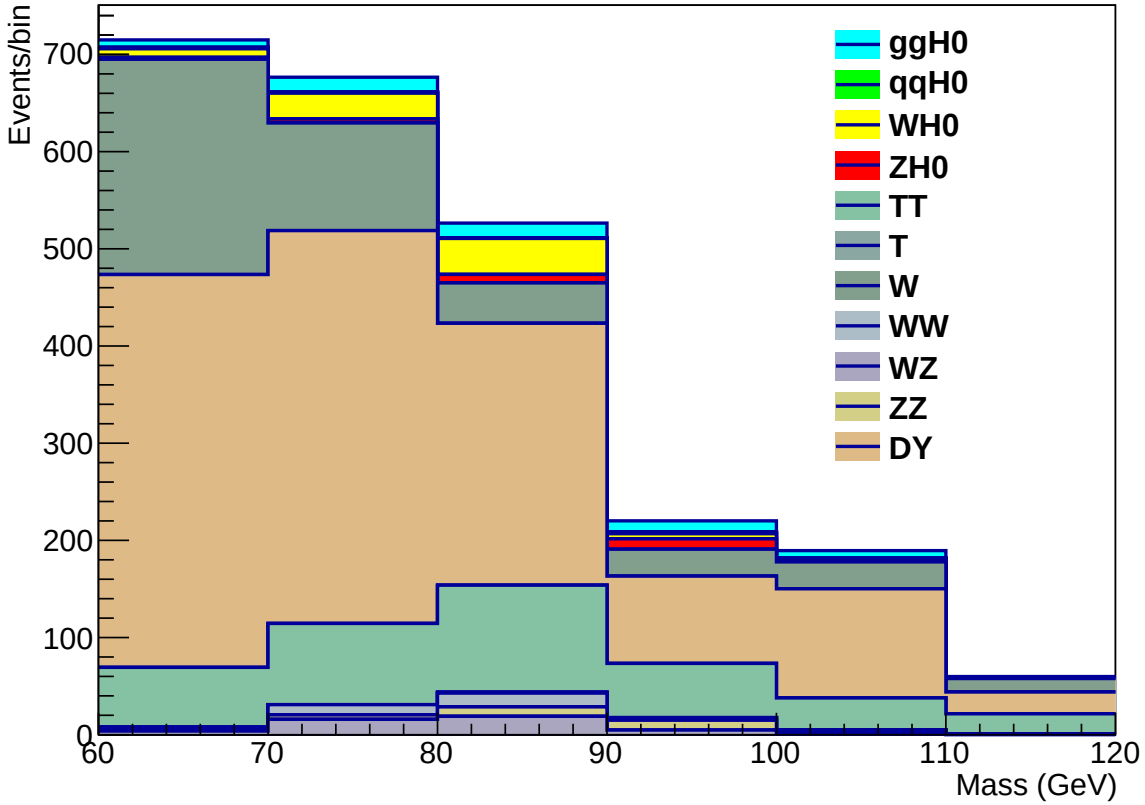
# Jet Mass Distribution

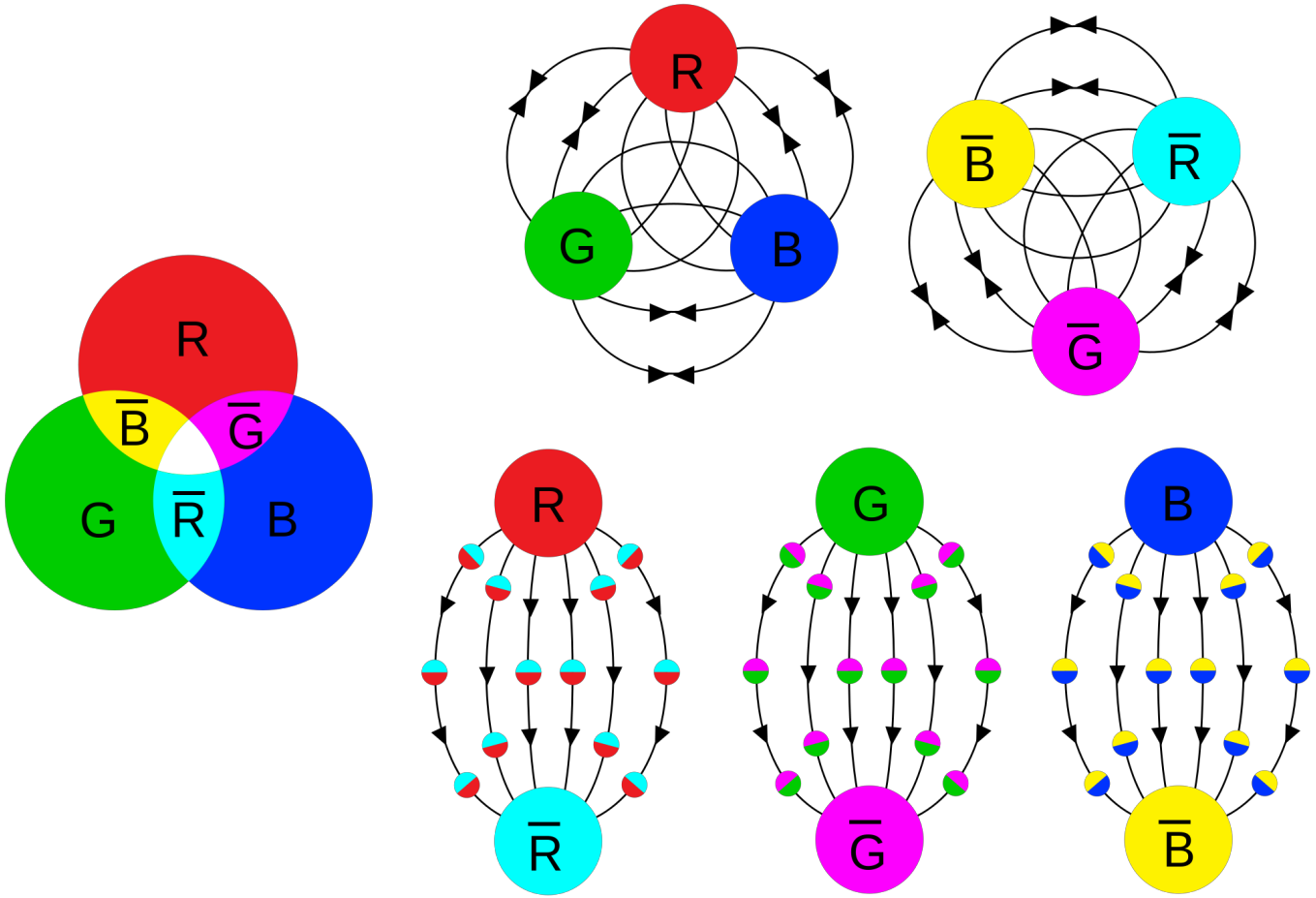
- $\not{E}_T > 300\,\text{GeV}$
- $\Delta R = 0.6$
- $(\tau_2/\tau_1) < 0.50$
- Grooming Algorithm; Filtering ($f_1$)




- If data is in blue, yellow, and red region, the Higgs is most likely decaying into invisible particles

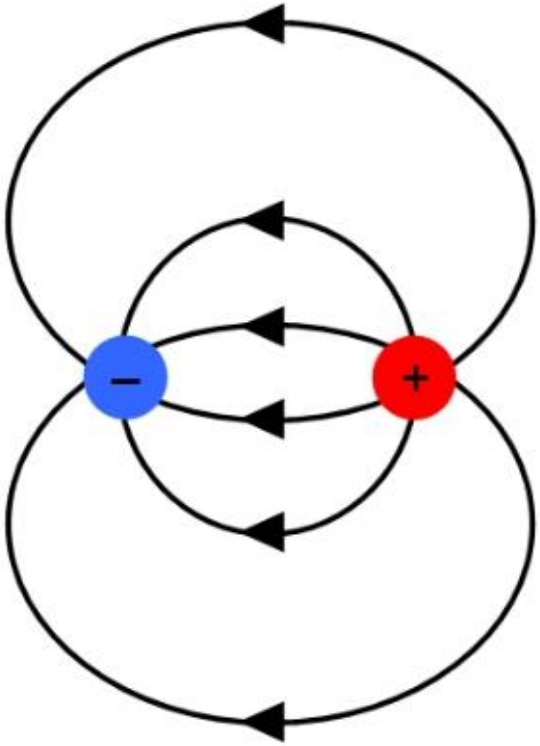
# Backup Slides

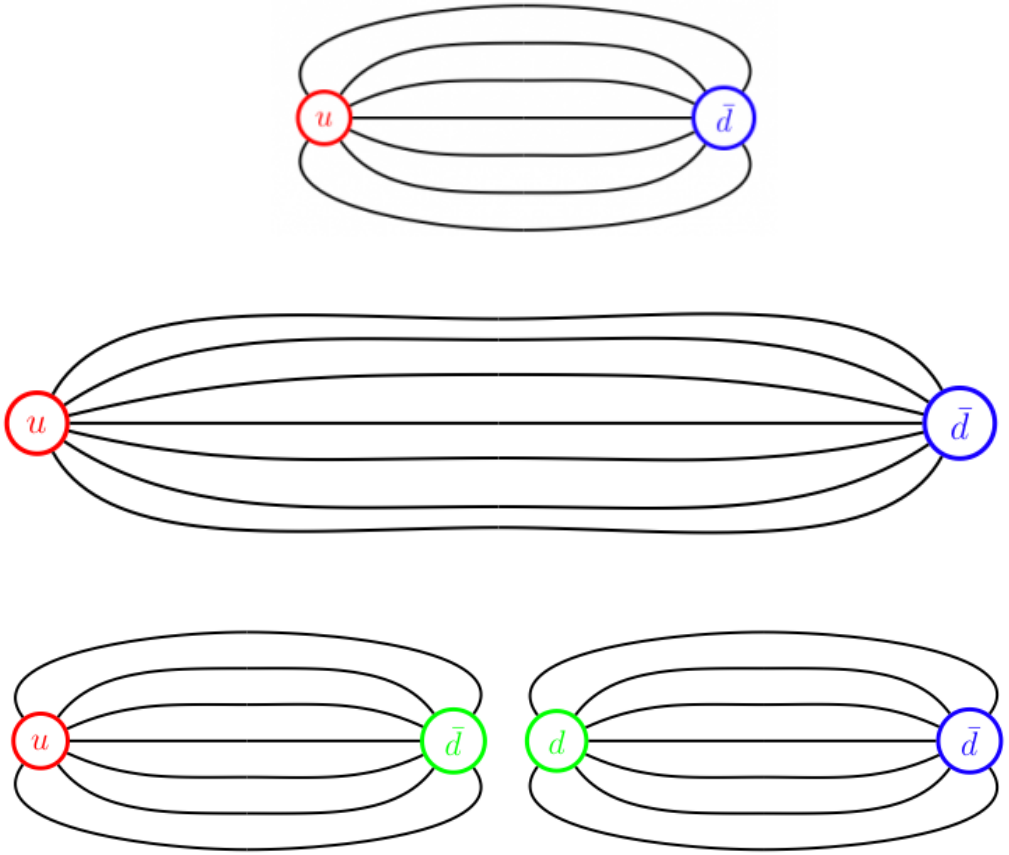
# Quantum Chromodynamics




- There are three colors and three anti-colors
- All observable particles are "colorless"

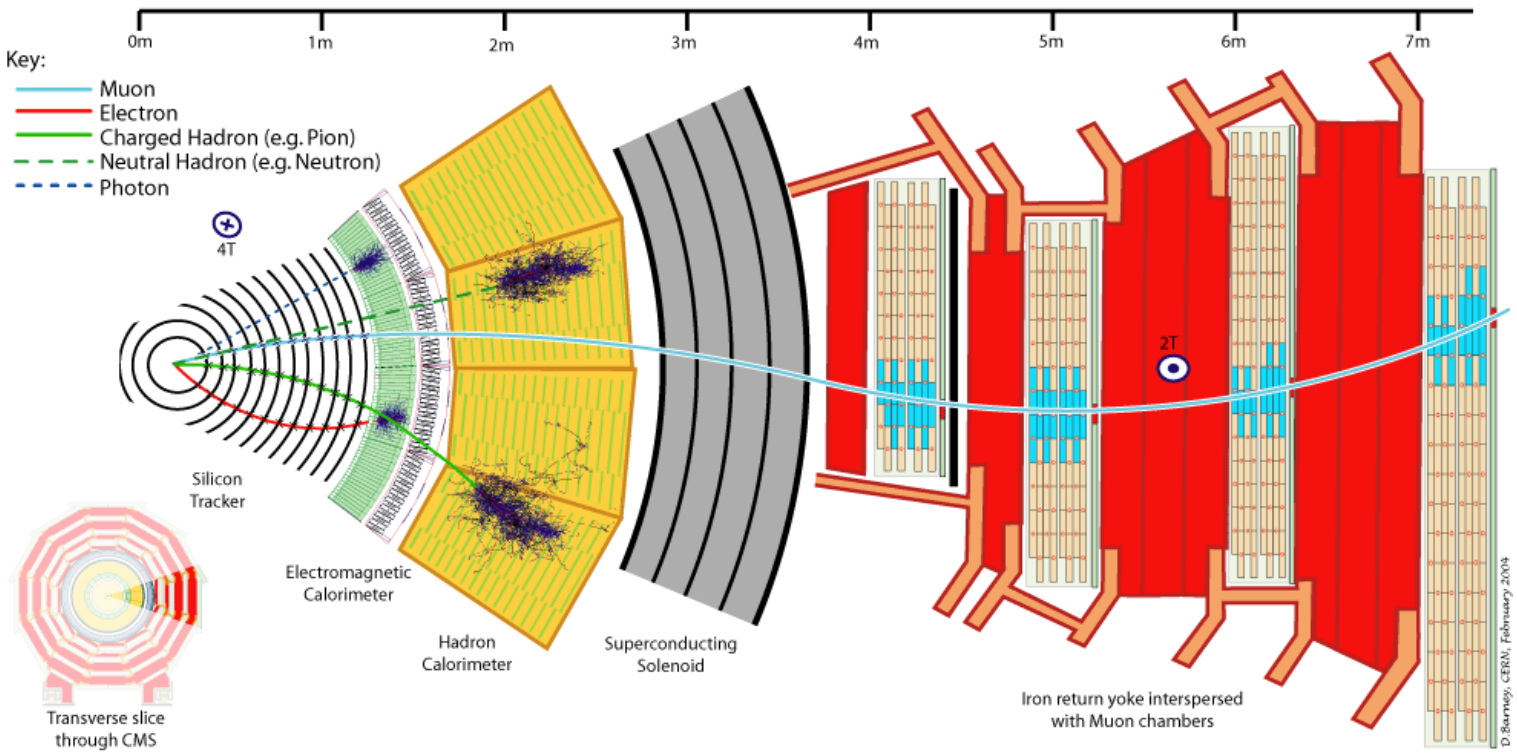
# Trying to Separate Quarks



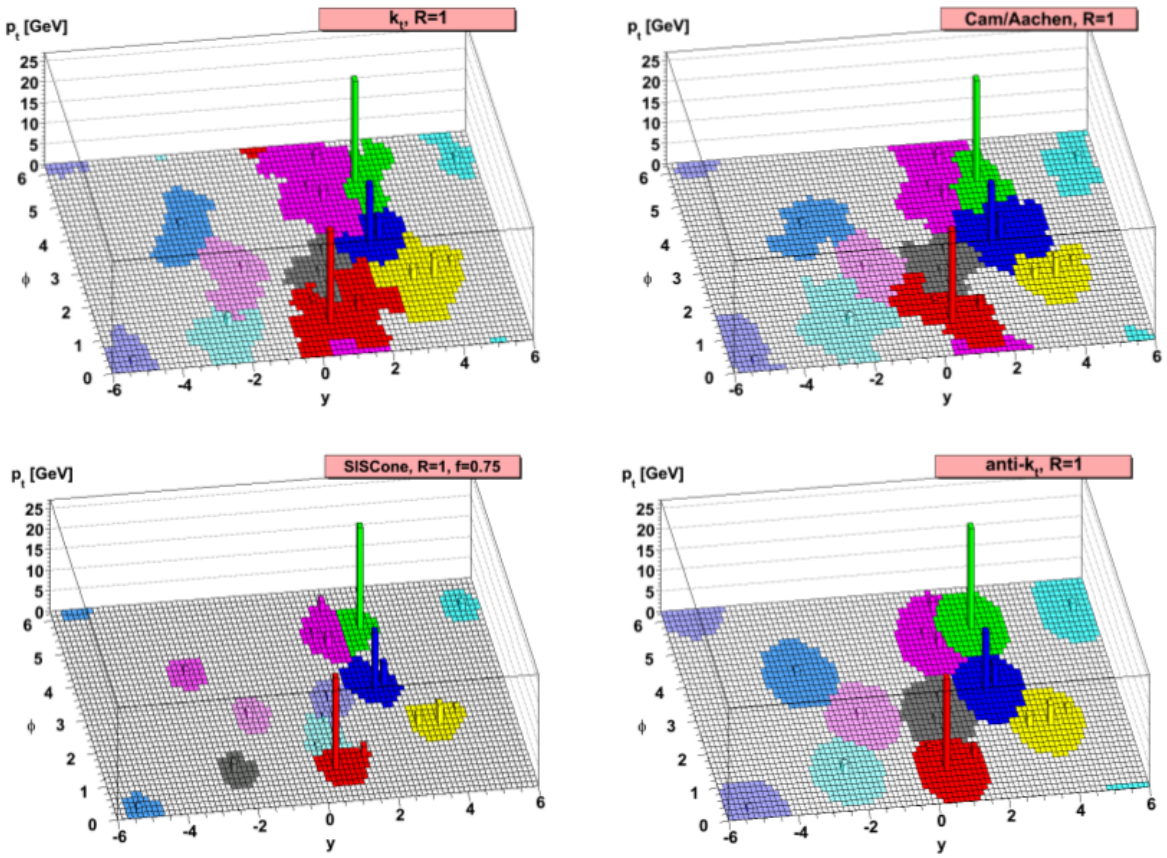

- Electric fields weaken farther from charged particles
- The strong force "gluon fields" becomes constant when color is unshielded
- It becomes energetically favorable to create particles

# A Cross Section




- There are five main components of the Compact Muon Solenoid (CMS).
  - Superconducting Solenoid
  - Silicon Tracker
  - Electromagnetic Calorimeter
  - Hadron Calorimeter
  - Muon Chambers

# Jet Reconstruction




$$\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$$

- The Anti-$k_T$ algorithm is used to gather quarks
- High energy jets get most conical shape

# N-Subjettiness Definition

$$\tau_N = \frac{1}{d_0} \sum_k p_{T,k} \min\{\Delta R_{1,k}, \Delta R_{2,k} ... \Delta R_{N,k}\}$$

The normalization $d_0$ is defined as follows.

$$d_0 = \sum_k p_{T,k} R_0$$

The summation takes place over the $k$ particles that make up a jet. $\Delta R_{i,k}$ between a candidate subjet and the particle in question. $R_0$ is the cone size of the larger jet.

# Grooming Algorithms

- Pruning:
  $p_1 \rightarrow n_{subjets} = 2; z_{cut} = 0.1; d_{cut_factor} = 0.5$, algo = CA
  $p_2 \rightarrow n_{subjets} = 2; z_{cut} = 0.1; d_{cut_factor} = 0.2$, algo = CA
- Filtering:
  $f_1 \rightarrow r_{filt} = 0.2; n_{filt} = 3$, algo = CA
  $f_2 \rightarrow r_{filt} = 0.3; n_{filt} = 3$, algo = CA
- Trimming:
  $t_1 \rightarrow r_{trim} = 0.2; p_{T,frac} = 0.05$, algo = CA
  $t_2 \rightarrow r_{trim} = 0.2; p_{T,frac} = 0.03$, algo = CA
  $t_3 \rightarrow r_{trim} = 0.1; p_{T,frac} = 0.03$, algo = CA
  $t_4 \rightarrow r_{trim} = 0.05; p_{T,frac} = 0.03$, algo = CA

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