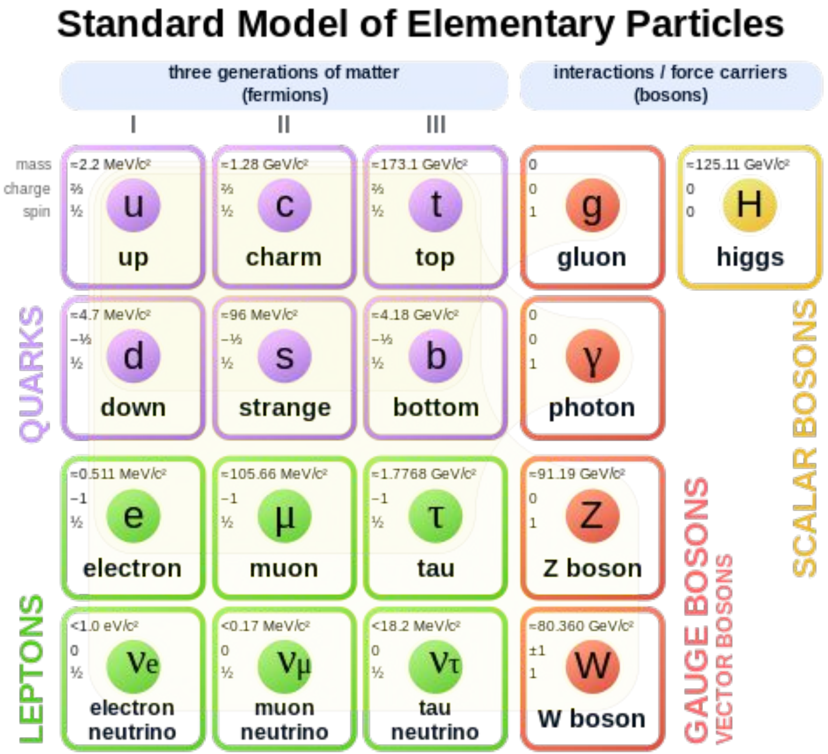
Neural network classification of top quark production at the LHC

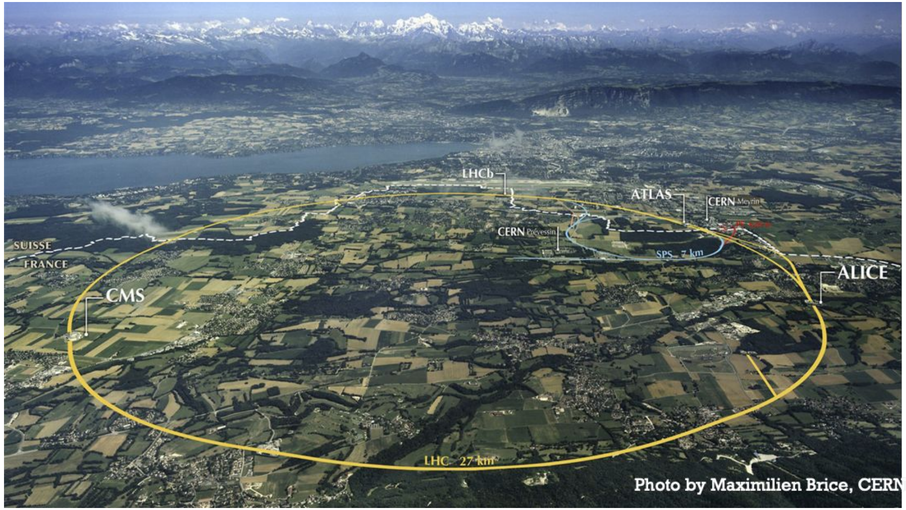
The Standard Model of Particle Physics

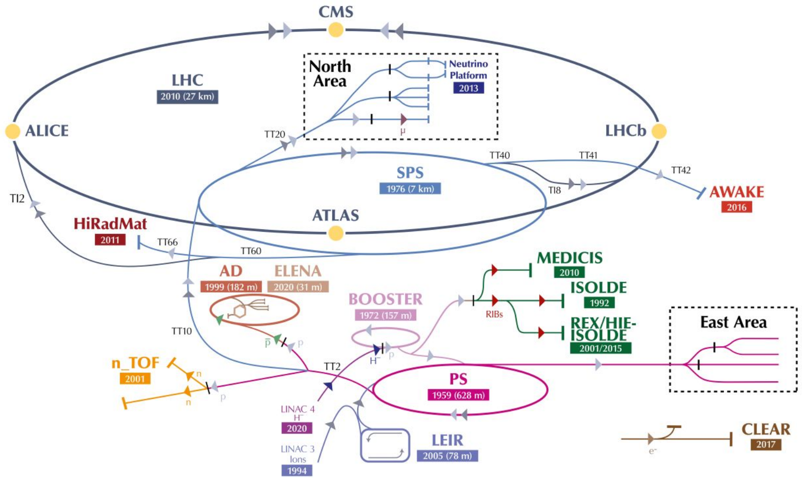
- Matter particles
  - Quarks and leptons: spin ½
  - Three generations
- Force carriers
  - Vector bosons: spin 1
  - Strong force: gluons
  - Weak force: W and Z bosons
  - Electromagnetic force: photons
- Higgs bosons
  - Scalar spin 0
  - Generate masses for fermions and bosons via Spontaneous Symmetry Breaking



The Large Hadron Collider

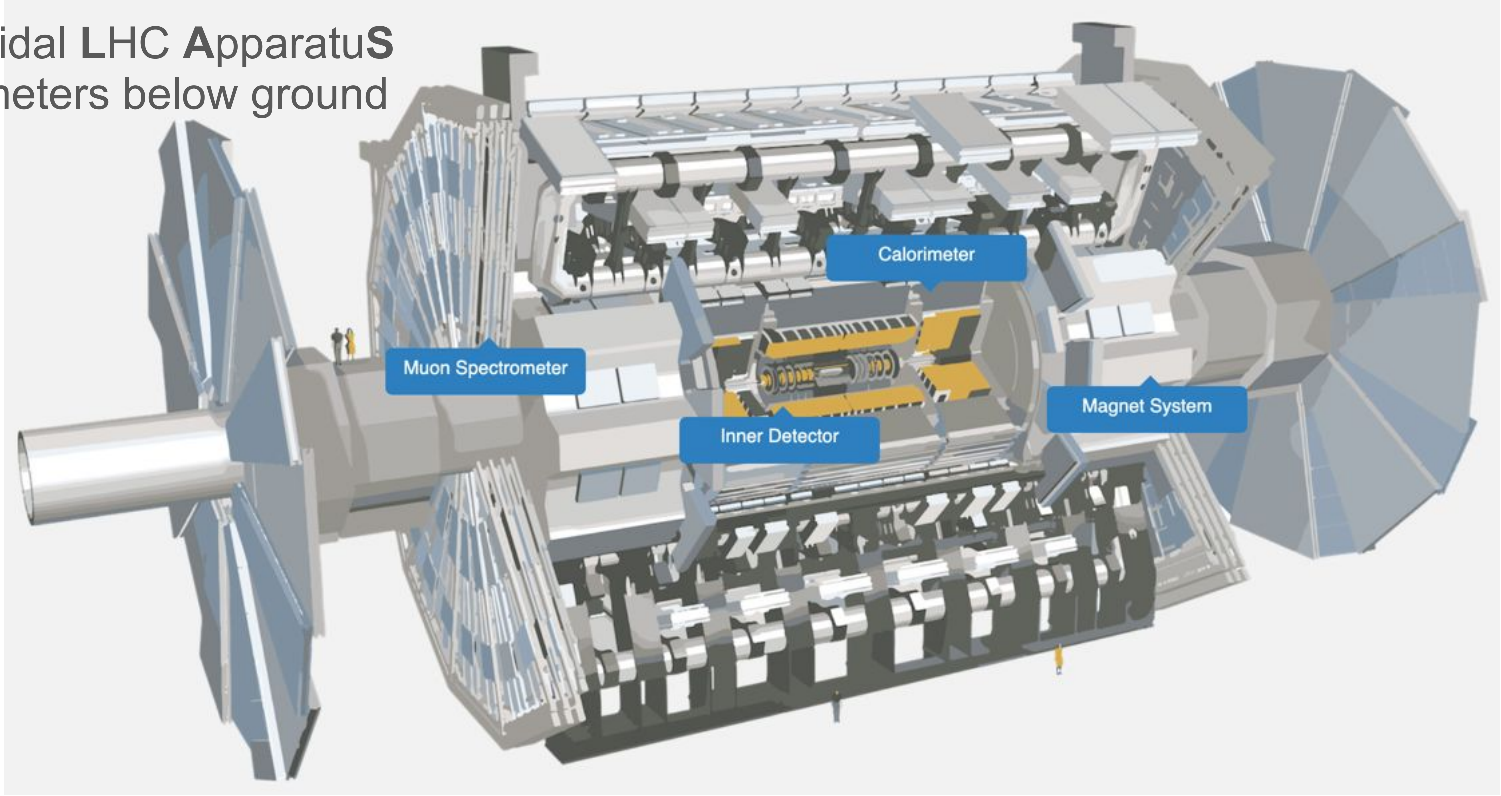
- A proton-proton circular collider
  - 27 km in circumference
  - Colliding protons at the center of mass energy of 13 TeV (2015 - 2018), 13.6 TeV (2022 -)
  - At a rate of 40 MHz



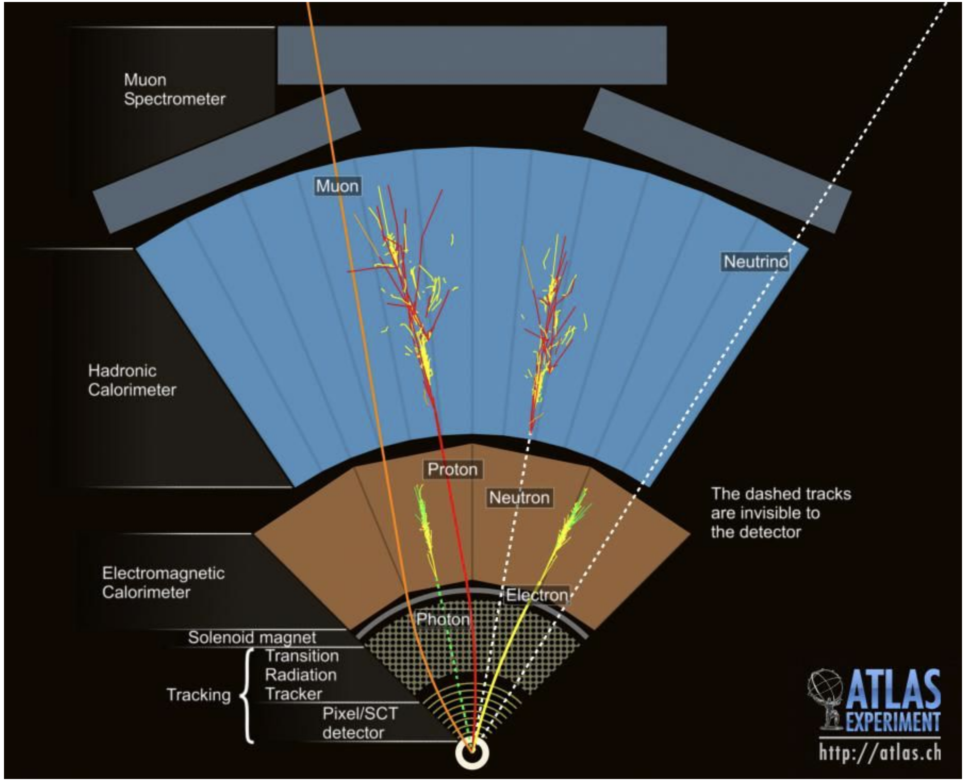


The ATLAS Experiment

- **A T**oroidal **L**HC **A**pparatu**S**
- ~100 meters below ground



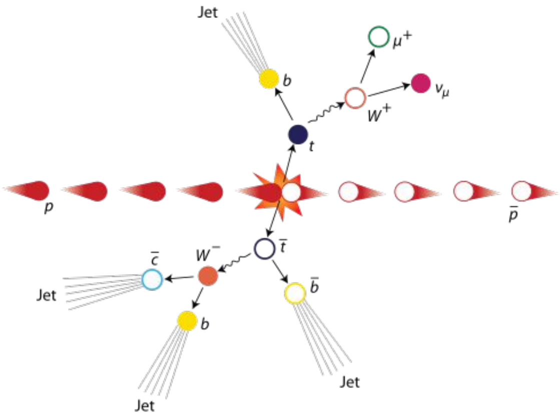
ATLAS Particle Identification

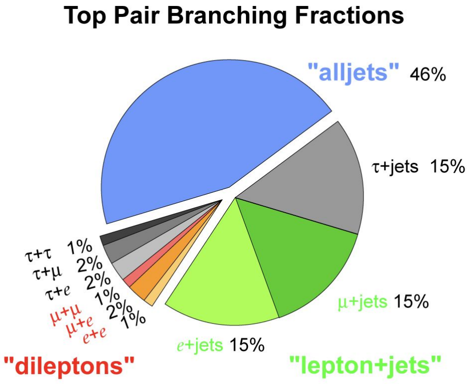


- **Electrons & Photons**
  - Energy deposit mostly in the Electromagnetic Calorimeter
  - **Electrons**: tracks in the Inner Detector
  - **Photons**: no tracks
- **Hadrons**
  - Energy deposit mostly in the Hadronic Calorimeter
  - **Charged hadrons**: tracks in the Inner Detector
  - **Neutral hadrons**: no tracks
- **Muons**
  - Tracks in both Inner Detector and Muon Spectrometer
  - Litter energy deposit in the Calorimeters
- **Neutrinos**
  - Escape from the detector
  - Inferred based on the conservation of transverse momentum

Top quark

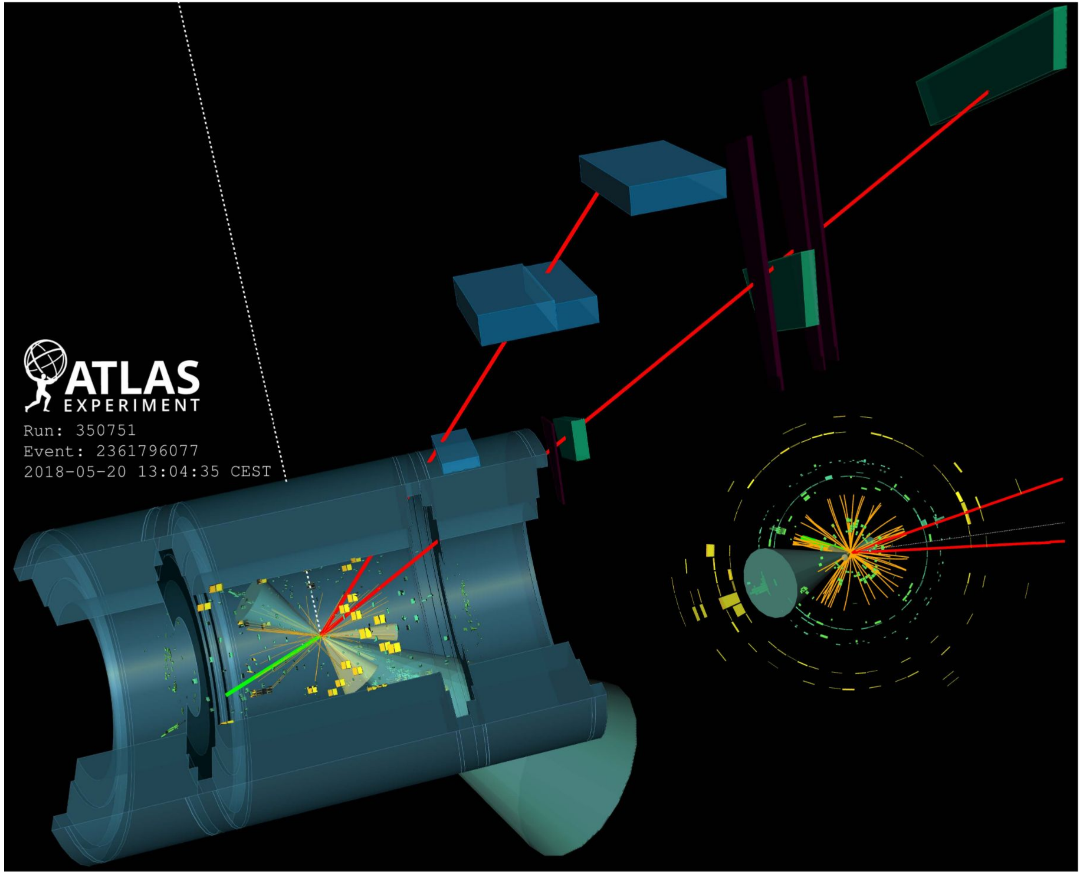
- Heaviest known fundamental particle
  - ~173 GeV/c^2
- An up-type quark
  - Charge ⅔ e
  - Spin ½
- Produced by strong and weak interactions
  - More likely to produce a pair of top quarks compare to a single top quark at the LHC
- Decay almost exclusively to a W boson and a bottom quark
  - W boson can then decay to various light quarks or leptons
- Only place to study the properties of a bare quark
  - It decays before hadronization





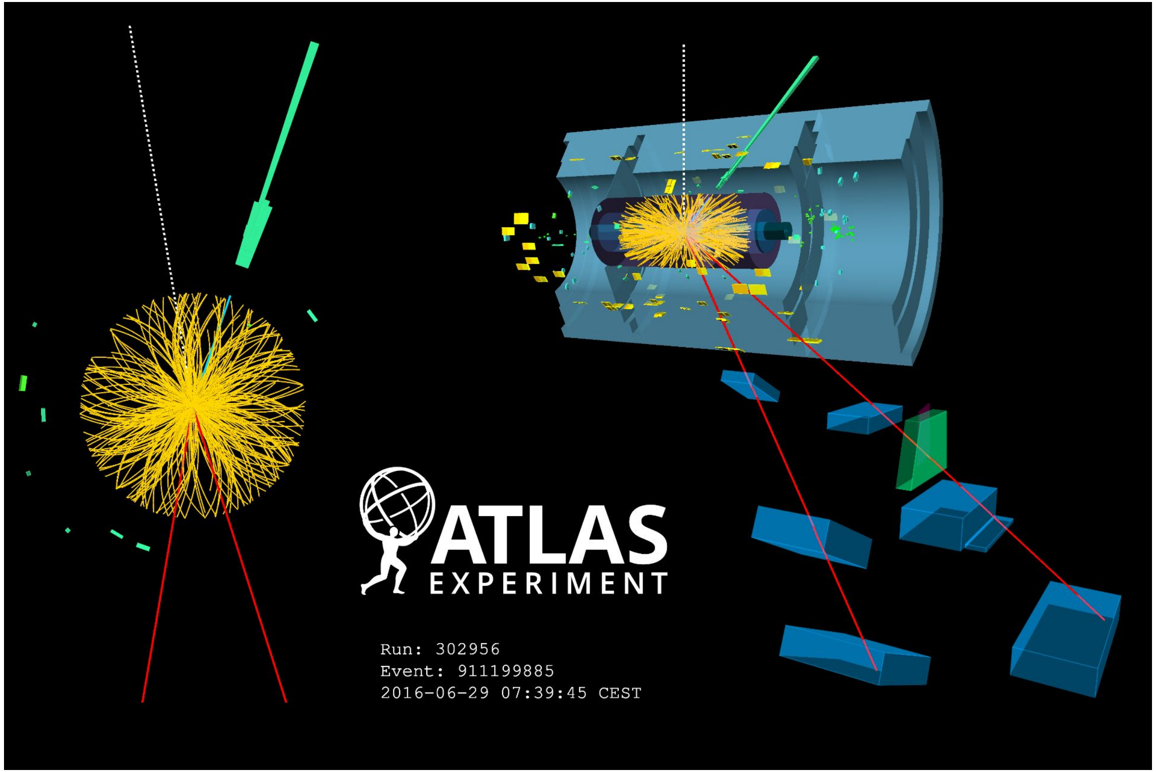
ttZ

- An ttZ event candidate
  - Top quark + anti-top quark + Z boson
  - One top decays hadronically
  - The other top decays leptonically
  - The Z boson decays into two muons
- Can try to select these events based on their expected detector signatures
- But …



WZ

- Some other processes could potentially give similar detector signatures
- The rate of these background events can also be some orders of magnitude higher than the process of interest



Classify Signal and Background

- We can simulate the signal (ttZ) and major background (WZ) events using the Monte Carlo method
- Features that could be useful to separate the signal and background:
    - The number of reconstructed objects: muons, electrons, jets
    - The momentum and energy of the particle
    - The direction of the particles: azimuthal (φ) and polar angle (measured as pseudo-rapidity η)
    - Missing transverse momentum
- Individual feature may not be too different between signal and background, but we can combine them by training a neural network classifier
    - Trained using the simulated events with known labels
- Trained classifier can then be applied to the recorded data