Searching for Ultra Rare Processes With the Large Hadron Collider

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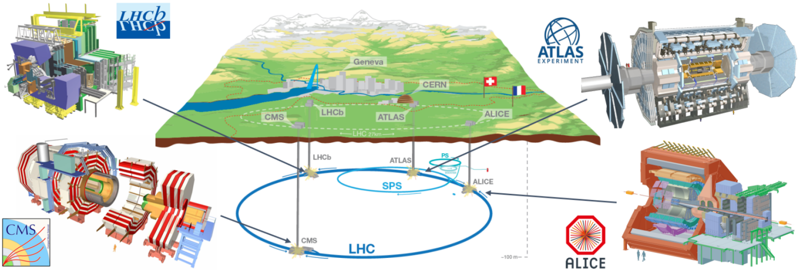
February 6, 2020

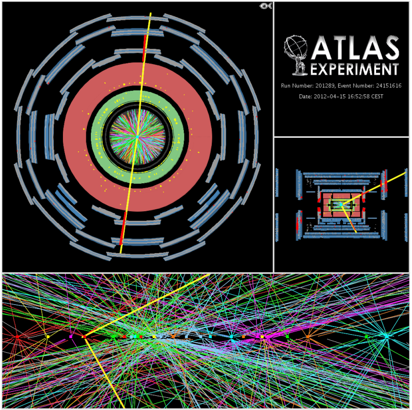
Overview

The Large Hadron Collider



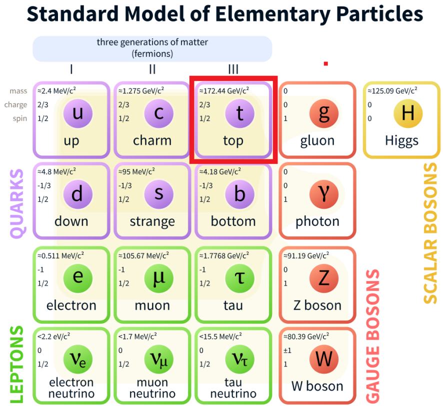
- 27km ring beneath Franco-Swiss Border
- Collides protons at center of mass energy 13TeV
  - Proton Therapy Machines around 100MeV (5 orders of magnitude smaller!)
- Over 10 Quadrillion (10^{15}) events produced within the ATLAS detector so far

Events in ATLAS



- LHC Provides around 600 million interactions/second
- Save compelling events $\rightarrow$ 10s of PB/year
- Extremely large, messy data sets
- Detector well modeled with GEANT4
- Monte Carlo techniques used for background event generation

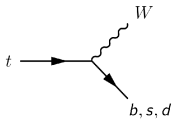
The Standard Model of Particle Physics



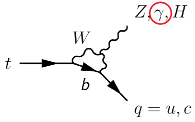
- Our current best theory that attempts to explain the building blocks of nature
  - Experimentally precise and well behaved
  - Very few exceptions (i.e. Dark Matter Abundance)

The Top Quark and Flavor Changing Neutral Currents

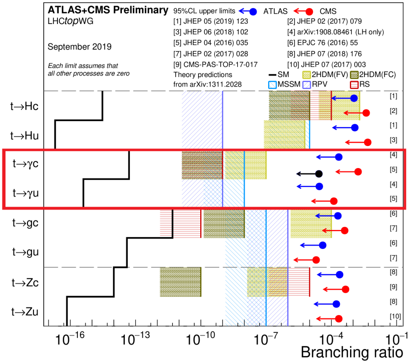
- Heaviest fundamental particle
- Lifetime 5×10^{-25}s
  - Allows study of single quark decay
- Top decays to bW 100% of the time
- Expect $\approx 10^8$ top pair events



(a)



(b)



Neural Networks

- Advanced pattern recognition used to classify events
- A dense neural network is used with various low and high level variable inputs
- Supervised learning used to approximate any multidimensional function

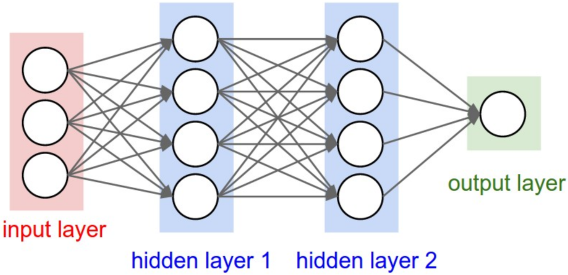
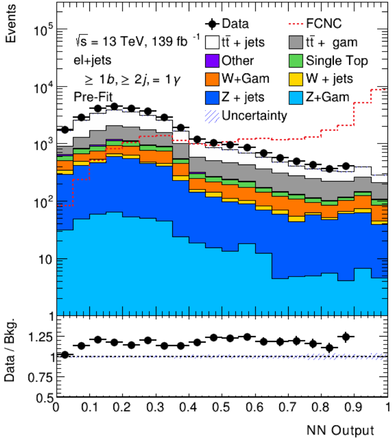


Figure: [Ref: Neural Network]

Neural Network Outputs

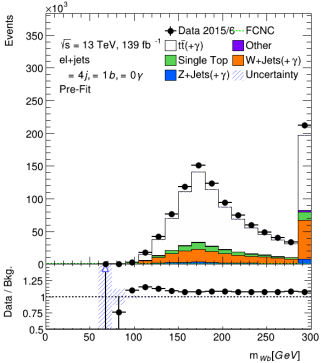


- Excellent signal/background separation achieved

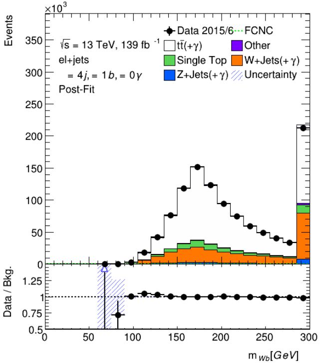
Data Driven Backgrounds

- Various physics processes are known to be difficult to model, especially at the high energies and interaction rates of the LHC

Before Scaling

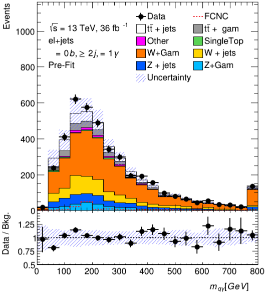


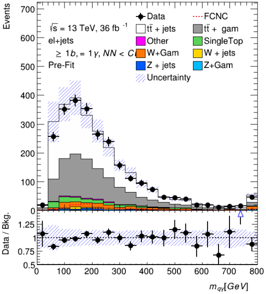
After Scaling

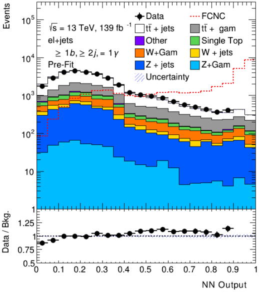


Work In Progress - Results

- Regions to check background modeling behavior compared with data while not unblinding the signal region are used

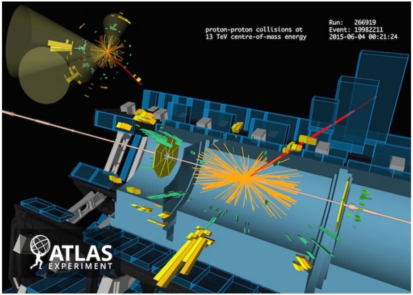






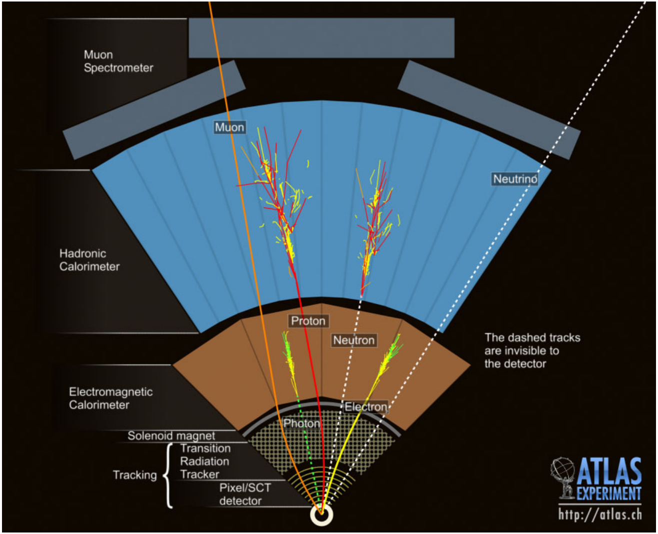
Conclusions

- I have created model independent signal samples to search for new physics with flavor changing neutral current decays in top pair events
- Developed and implemented a neural network for signal classification
- Currently working to ensure well modeled backgrounds and account for systematic errors
- Any excess in signal data events it is a strong indication of physics beyond the Standard Model
- Expected statistics only limit $\mathrm{BR}(t \to q\gamma) \leq 4 \times 10^{-5}$

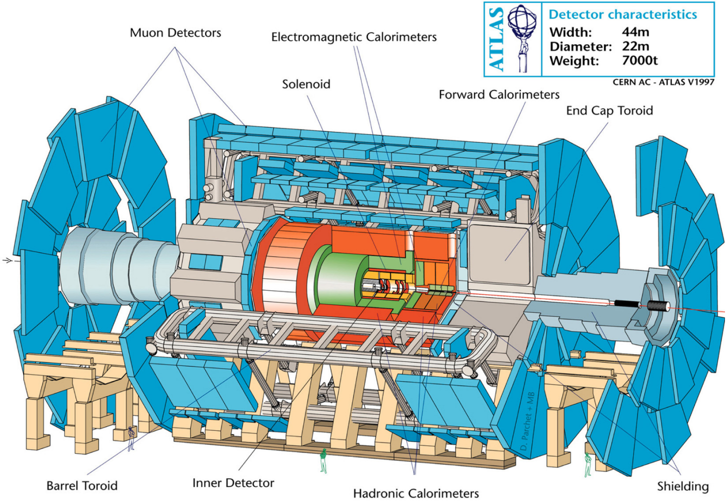


Backup

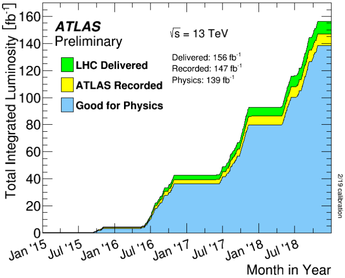
Particles in ATLAS

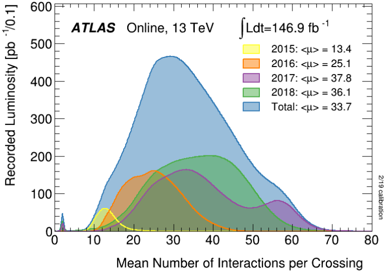


The ATLAS Detector

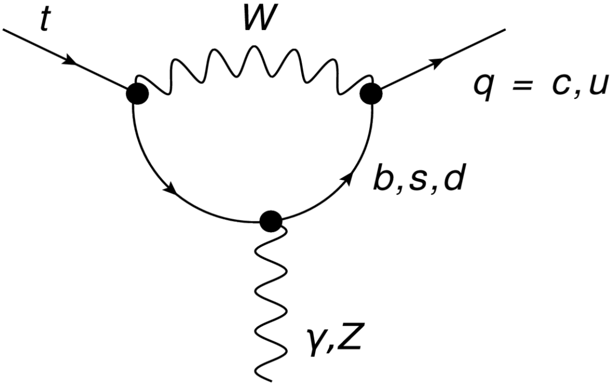


Luminosity and Pile-up





FCNC Diagrams



Neural Network Model Inputs

$$\text{Separation} = \sum_{i}^{bins} \frac{n_{si} - n_{bi}}{n_{si} + n_{bi}}$$

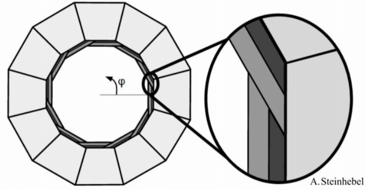
mu+jets channel

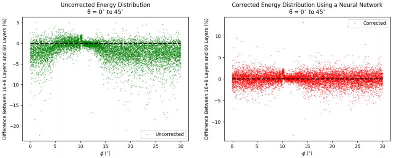
Variable	Separation
photon0iso	41.18
mqgam	28.27
photon0pt	24.07
mtSM	11.60
mlgam	7.56
deltaRjgam	5.64
deltaRbl	4.42
MWT	3.34
ST	3.30
nuchi2	3.12
jet0pt	2.81
njets	2.07
smchi2	1.89
wchi2	1.87
jet0e	1.52
deltaRlgam	1.17
leptone	0.87
deltaRjb	0.86
met	0.68
bjet0pt	0.52
leptoniso	0.27

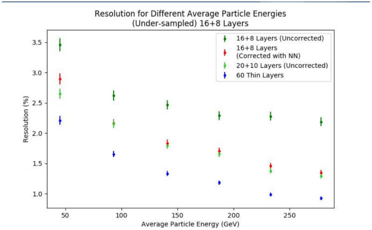
e+jets channel

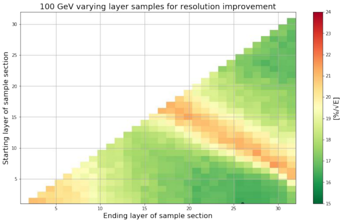
Variable	Separation
photon0pt	23.14
mqgam	22.73
photon0iso	18.70
mtSM	11.02
mlgam	9.53
deltaRbl	5.00
deltaRjgam	4.60
ST	3.83
MWT	3.16
jet0pt	2.47
njets	1.70
nuchi2	1.59
deltaRlgam	1.40
wchi2	1.33
smchi2	1.09
deltaRjb	0.88
leptone	0.85
leptoniso	0.56
bjet0pt	0.50
met	0.47

ILC ECAL1

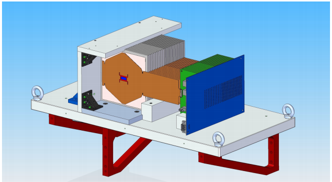

φ
A. Steinhebel

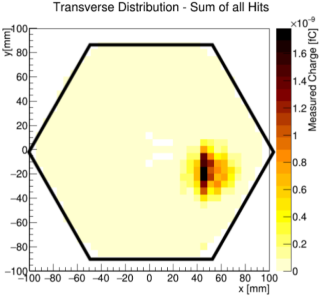

Uncorrected Energy Distribution
θ = 0° to 45°
Difference Between 16+8 Layers and 60 Layers (%)
Uncorrected
ϕ (°)
Corrected Energy Distribution Using a Neural Network
θ = 0° to 45°
Difference Between 16+8 Layers and 60 Layers (%)
Corrected
ϕ (°)

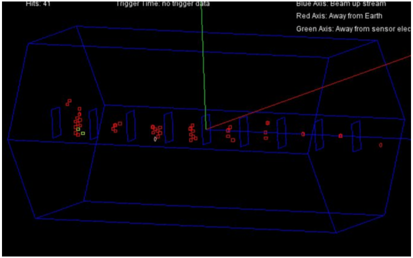

Resolution for Different Average Particle Energies
(Under-sampled) 16+8 Layers
16+8 Layers (Uncorrected)
16+8 Layers
(Corrected with NN)
20+10 Layers (Uncorrected)
60 Thin Layers
Resolution (%)
Average Particle Energy (GeV)

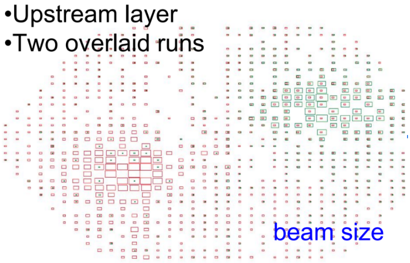

100 GeV varying layer samples for resolution improvement
Starting layer of sample section
Ending layer of sample section
[%/√E]

ILC ECAL2




Transverse Distribution - Sum of all Hits
y[mm]
x [mm]
Measured Charge [fC]
×10^-9
100
80
60
40
20
0
−20
−40
−60
−80
−100
−100 −80 −60 −40 −20 0 20 40 60 80 100
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0


Hits: 41
Trigger Time: no trigger data
Blue Axis: Beam up stream
Red Axis: Away from Earth
Green Axis: Away from sensor elec


•Upstream layer
•Two overlaid runs
beam size