

# Searching for Ultra Rare Processes with the Large Hadron Collider

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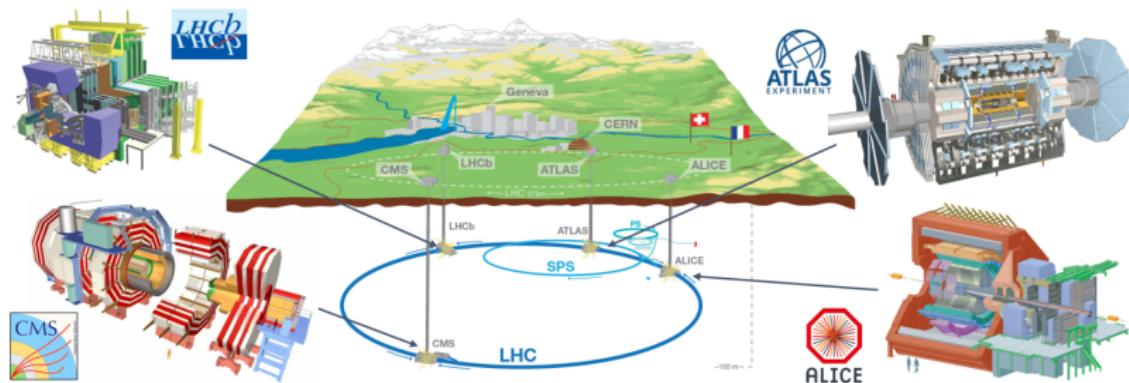
# Overview

The Large Hadron Collider and The Standard Model of Particle Physics  
LHC and ATLAS  
The Standard Model of Particle Physics

Search For Ultra Rare Decays  
The Top Quark  
Machine Learning

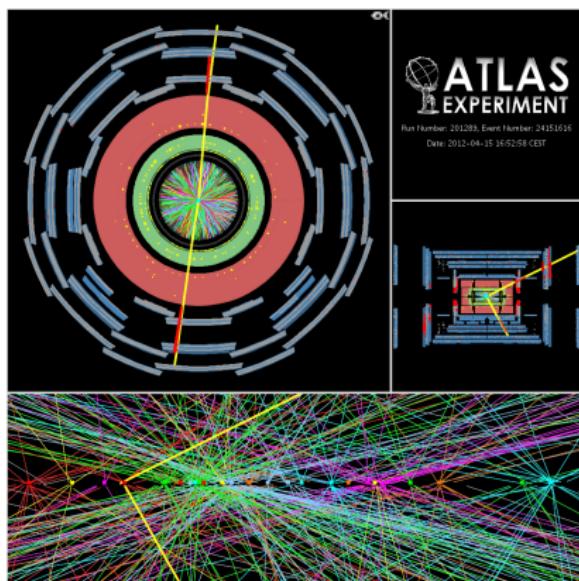
Results and Conclusions  
Work In Progress - Results

# 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

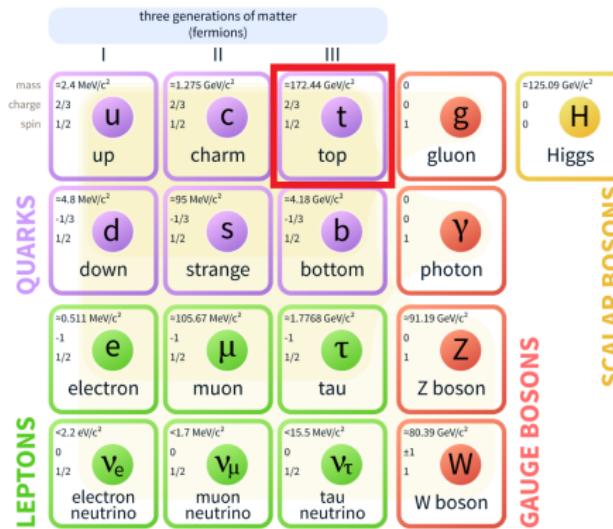
# Events in ATLAS



- ▶ LHC provides around 600 million interactions/second
- ▶ Save compelling events → 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

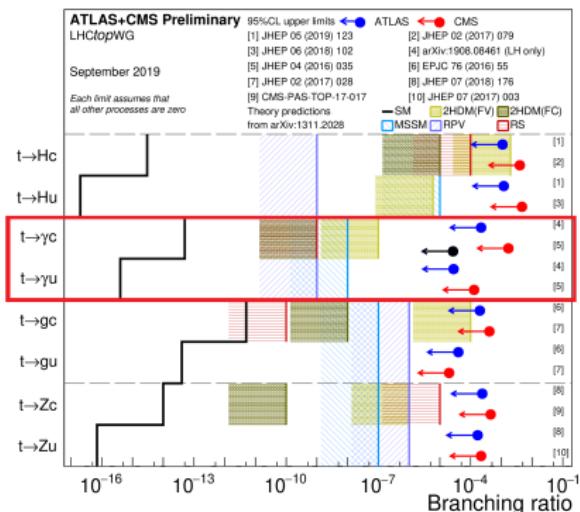
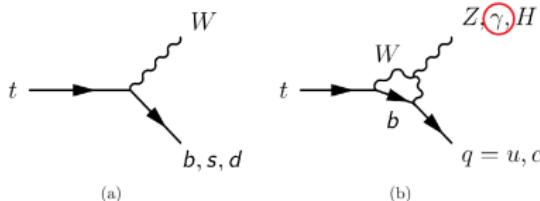
## Standard Model of Elementary Particles



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



# 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

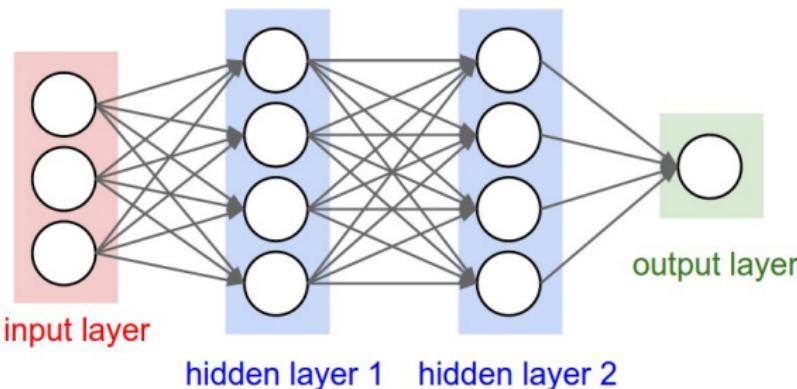
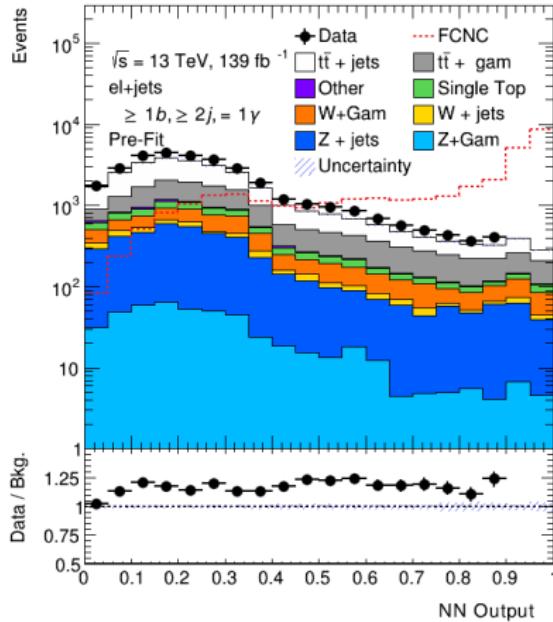


Figure: [Ref: Neural Network]

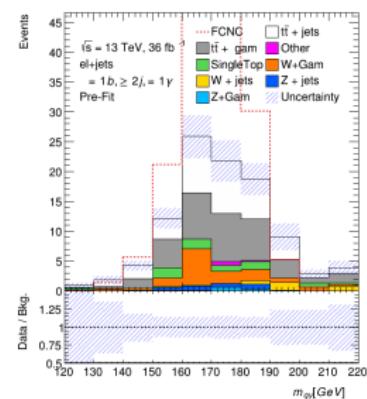
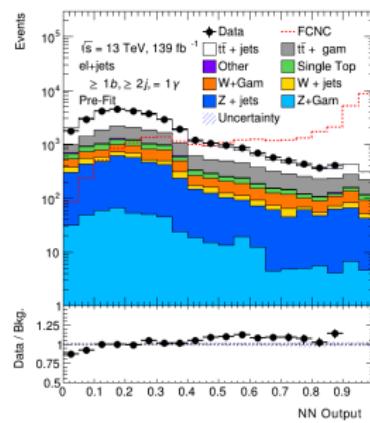
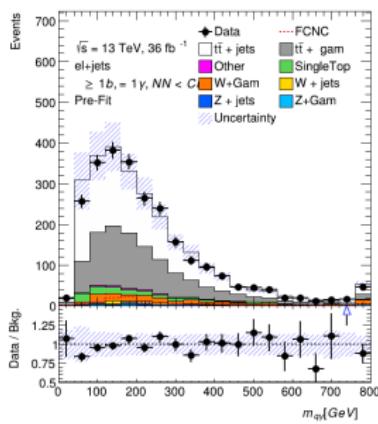
# Neural Network Outputs



- Excellent signal/background separation achieved

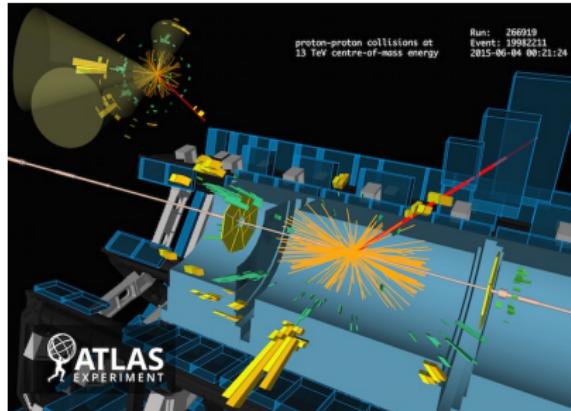
# Work In Progress - Results

- Regions are used to compare background modeling behavior and data while not unblinding the signal region



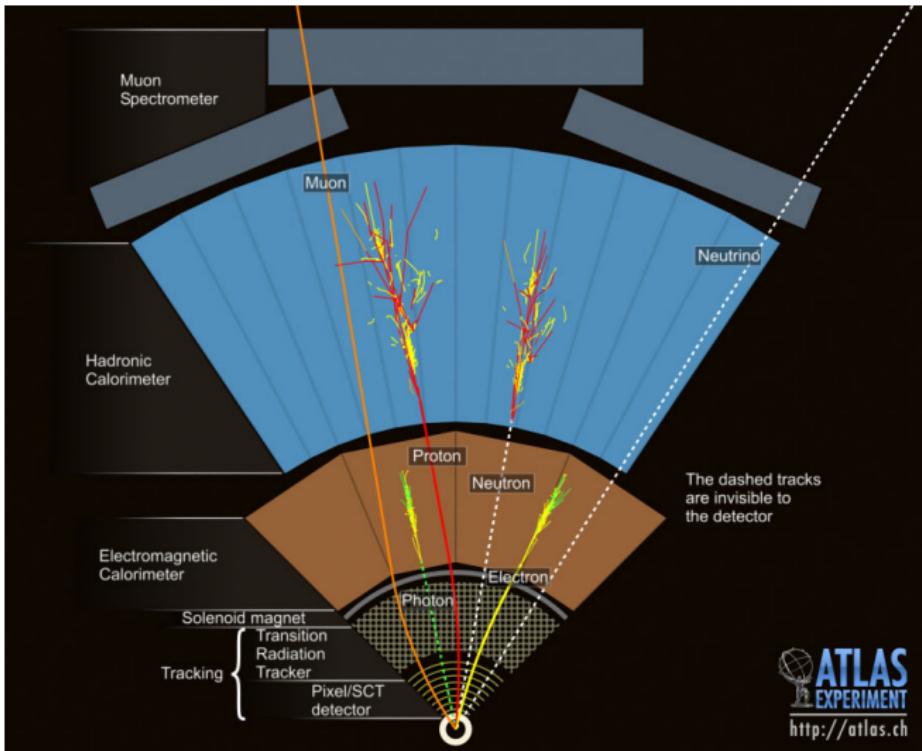
# Conclusions

- ▶ I have created model independent signal samples to search for 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
- ▶ Any excess in signal data events is a strong indication of physics beyond the Standard Model
- ▶ Expected statistics only limit  $\text{BR}(t \rightarrow q\gamma) \leq 4 \times 10^{-5}$

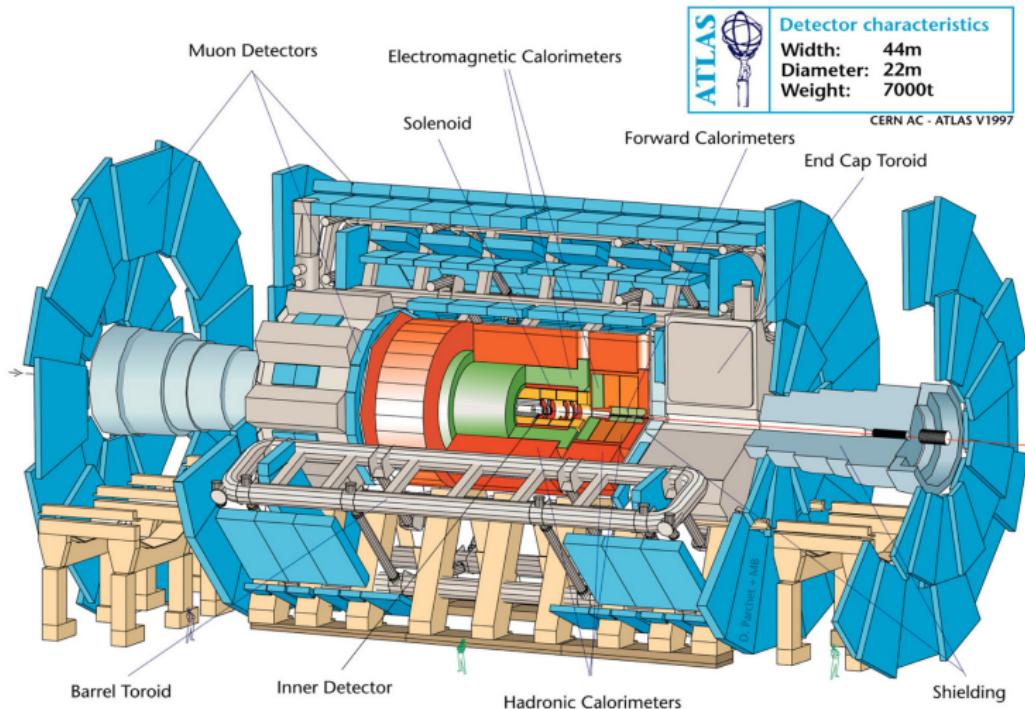


# Backup

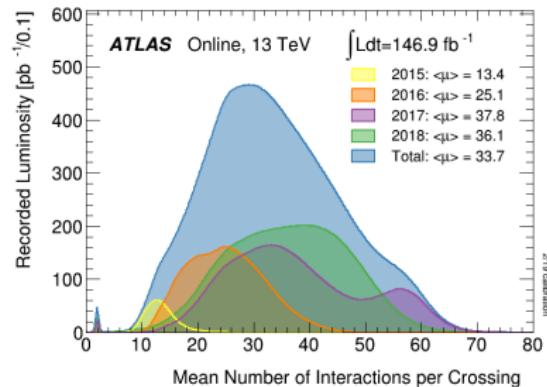
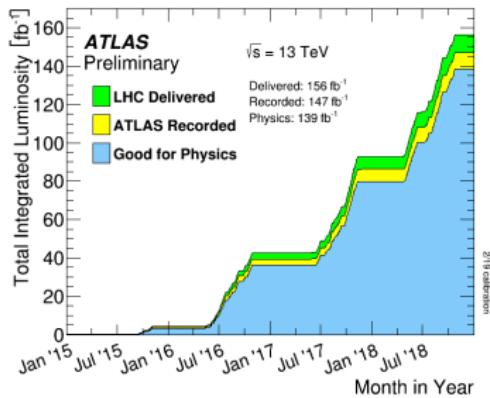
# Particles in ATLAS



# The ATLAS Detector



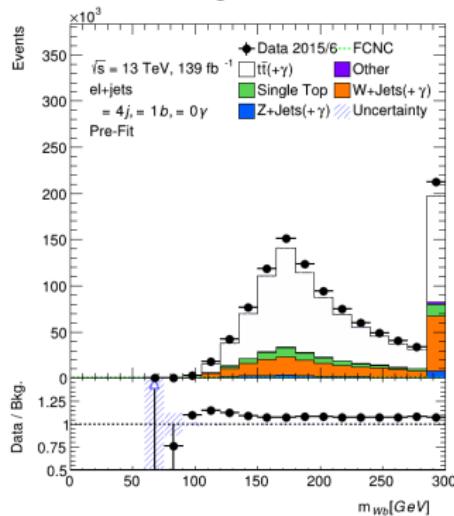
# Luminosity and Pile-up



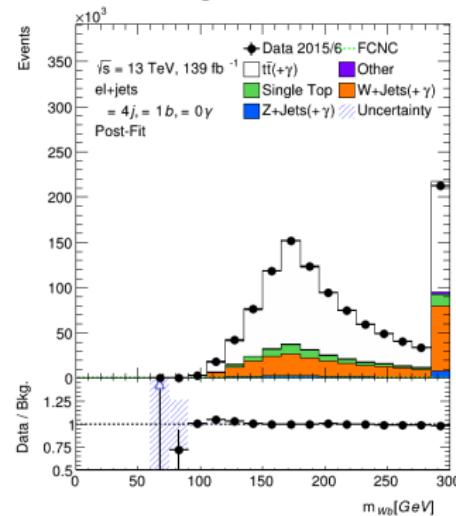
# Data Driven Backgrounds

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

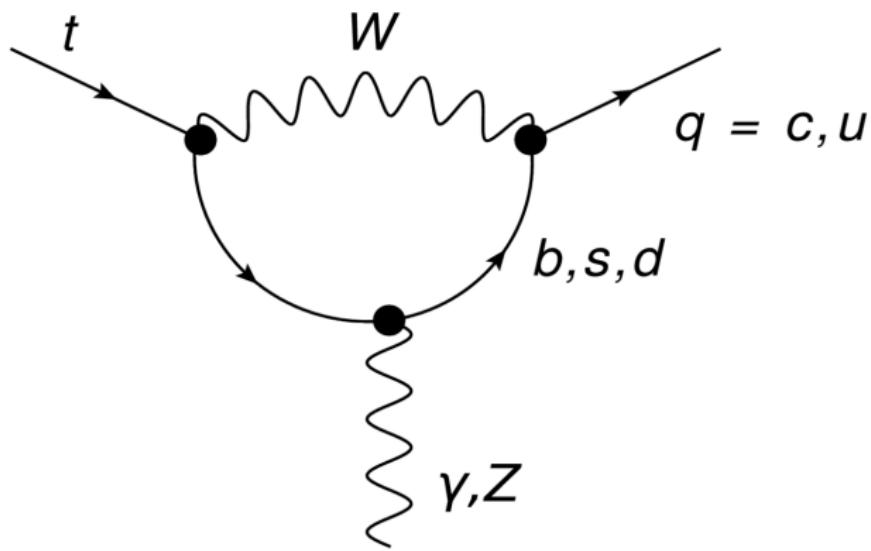
## Before Scaling



## After Scaling



# FCNC Diagrams



# Neural Network Model Inputs

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

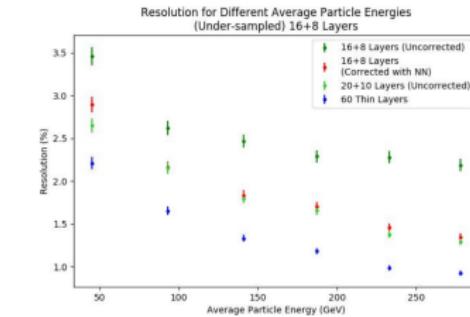
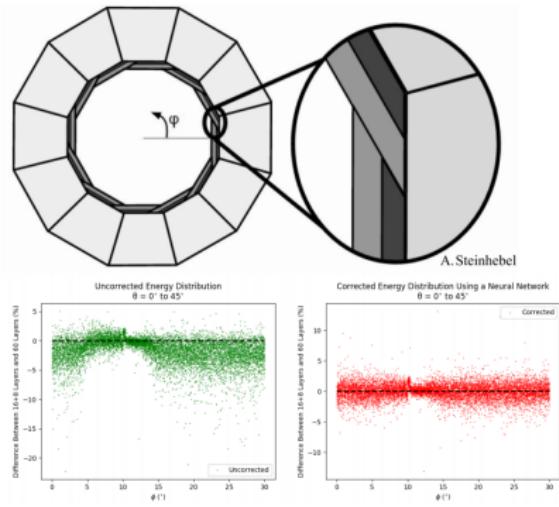
**mu+jets channel**

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

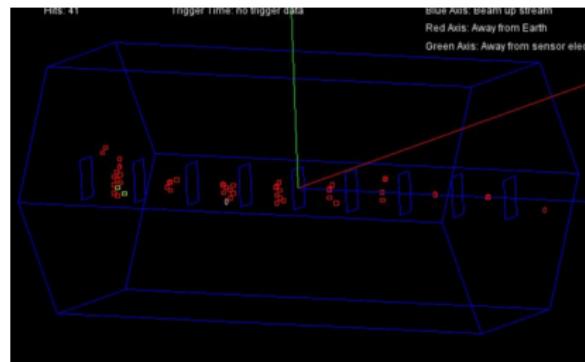
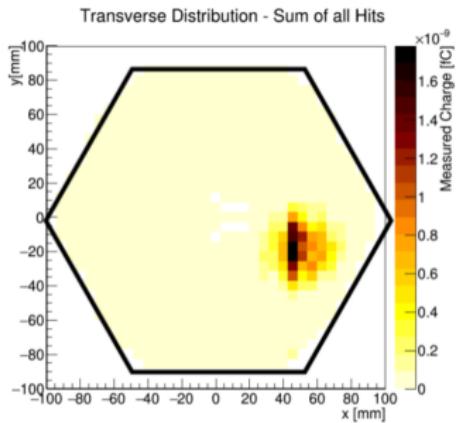
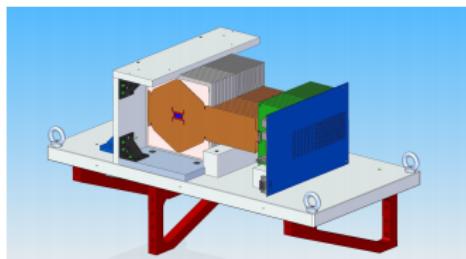
**e+jets channel**

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



# ILC ECAL2



- Upstream layer
- Two overlaid runs

