

Searching for Ultra Rare Processes with the Large Hadron Collider

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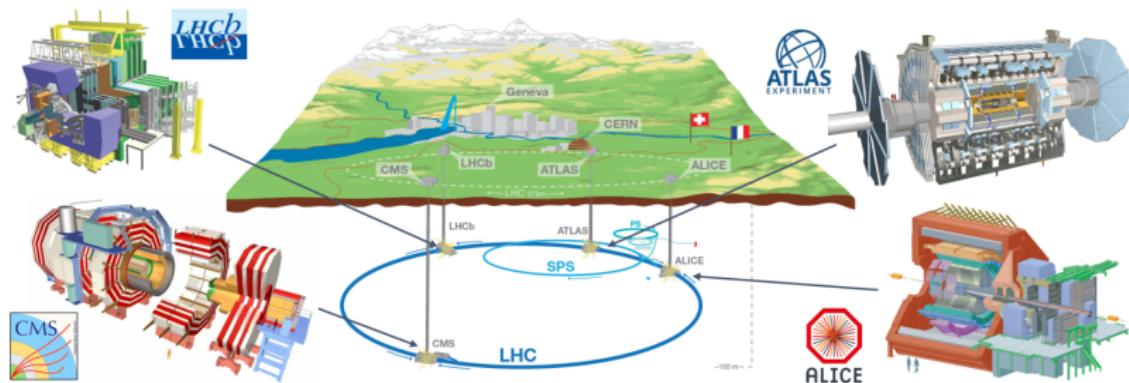
Overview

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

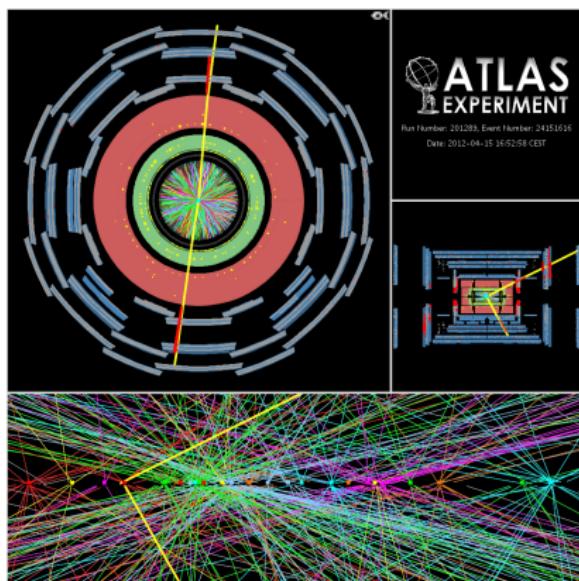
Results and Conclusions
Work In Progress - Results

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

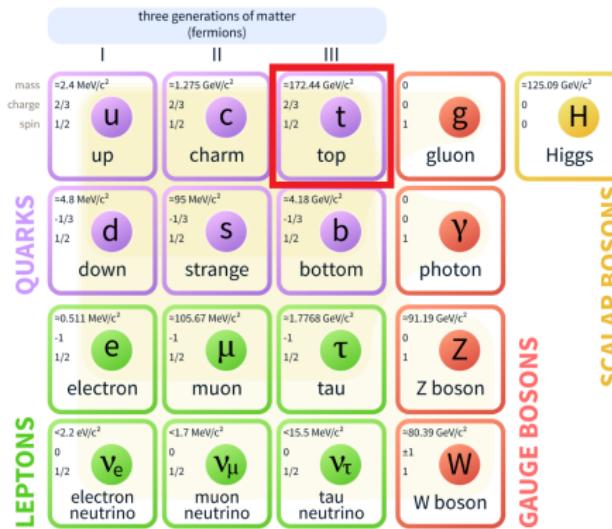
Events in ATLAS



- ▶ 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

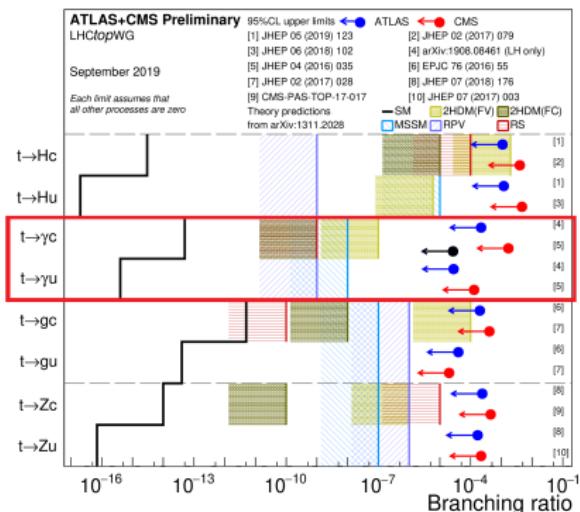
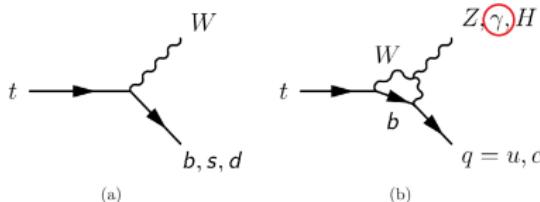
Standard Model of Elementary Particles



- ▶ 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 5×10^{-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

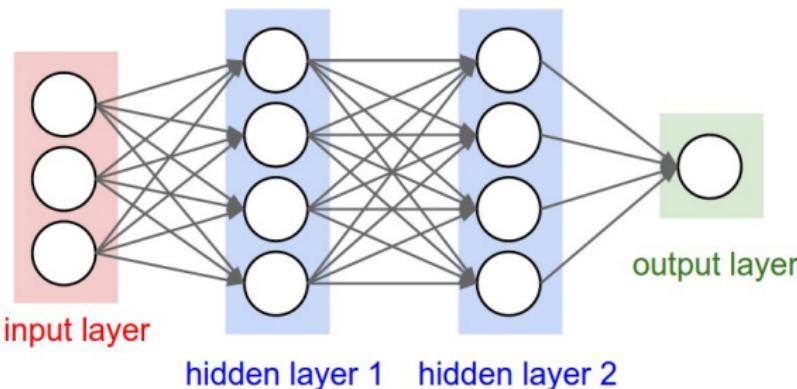
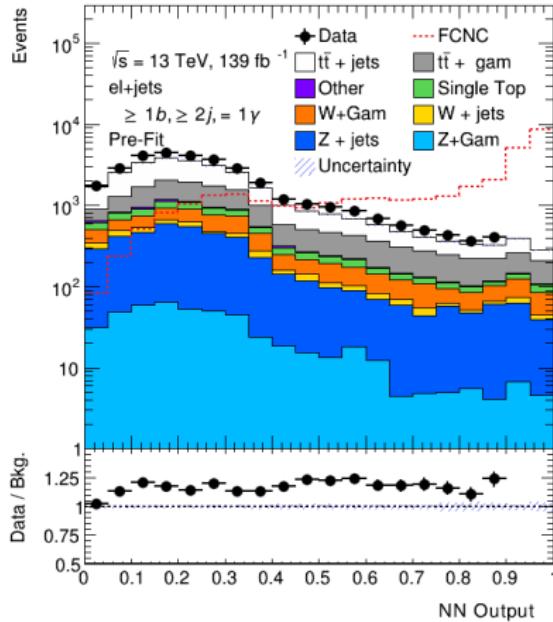


Figure: [Ref: Neural Network]

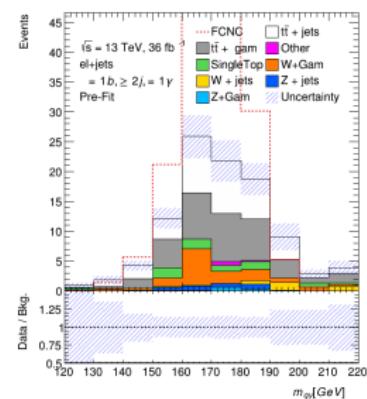
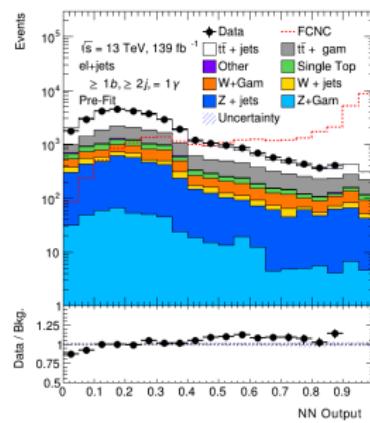
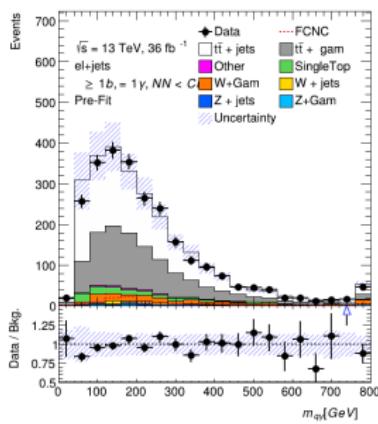
Neural Network Outputs



- Excellent signal/background separation achieved

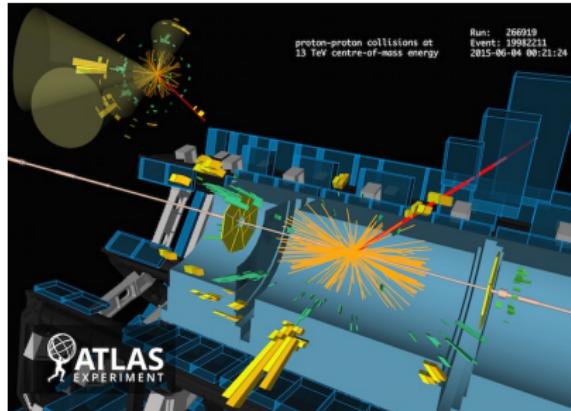
Work In Progress - Results

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



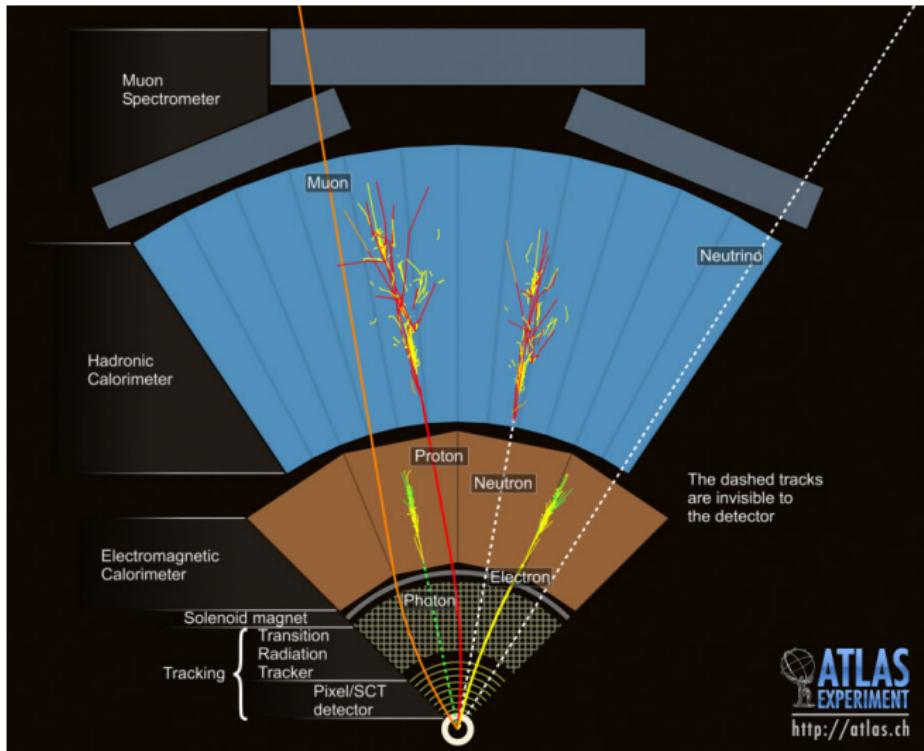
Conclusions

- ▶ 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 $\text{BR}(t \rightarrow q\gamma) \leq 4 \times 10^{-5}$

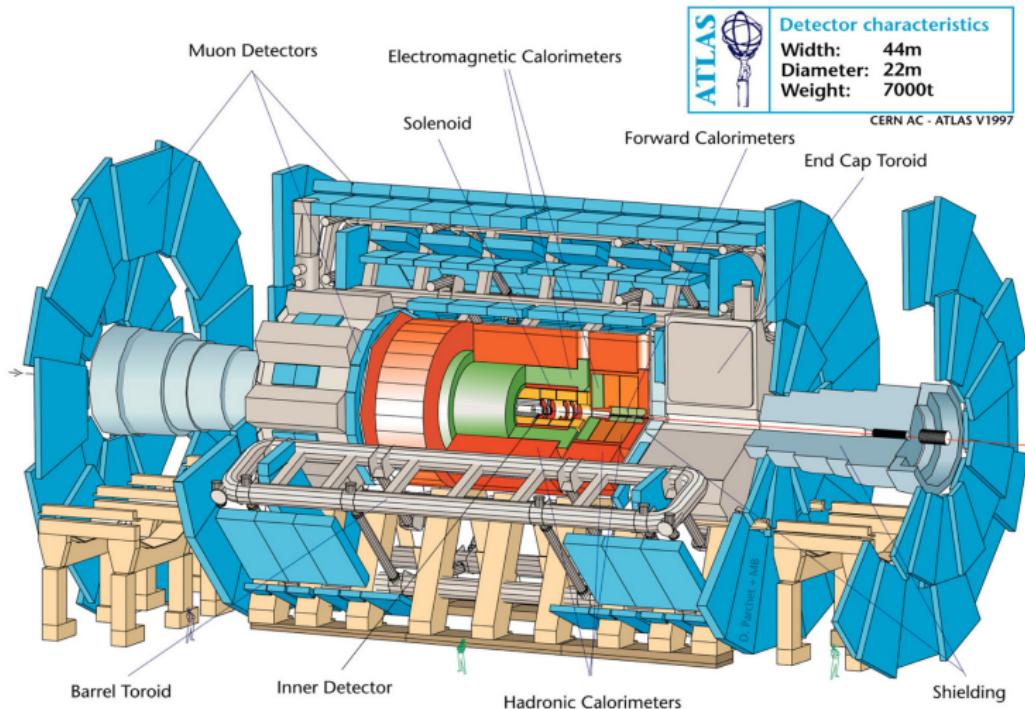


Backup

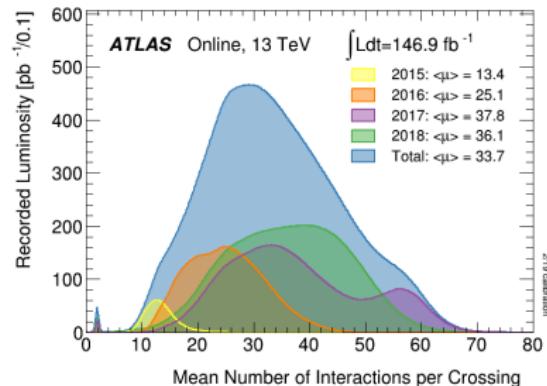
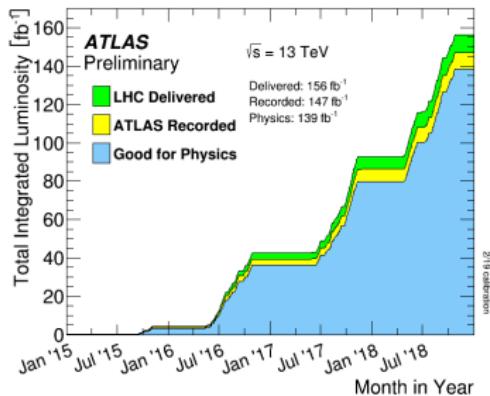
Particles in ATLAS



The ATLAS Detector



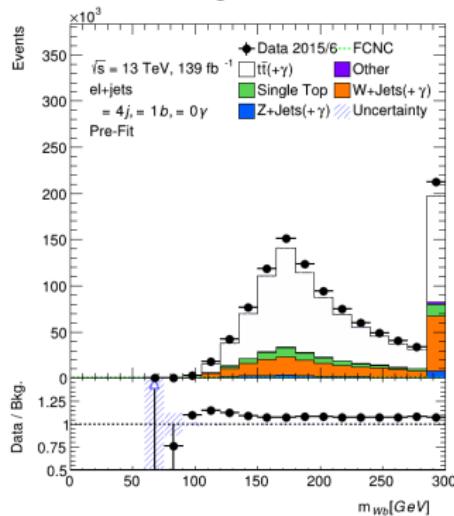
Luminosity and Pile-up



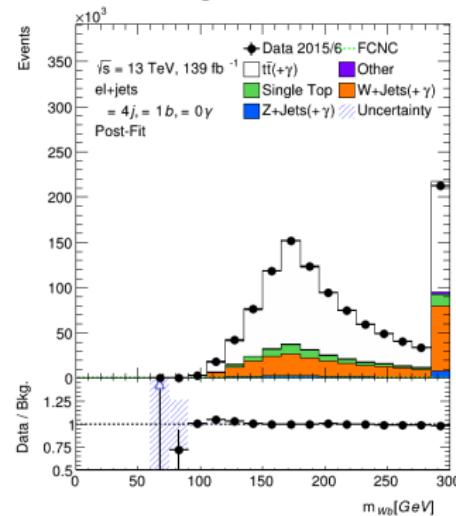
Data Driven Backgrounds

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

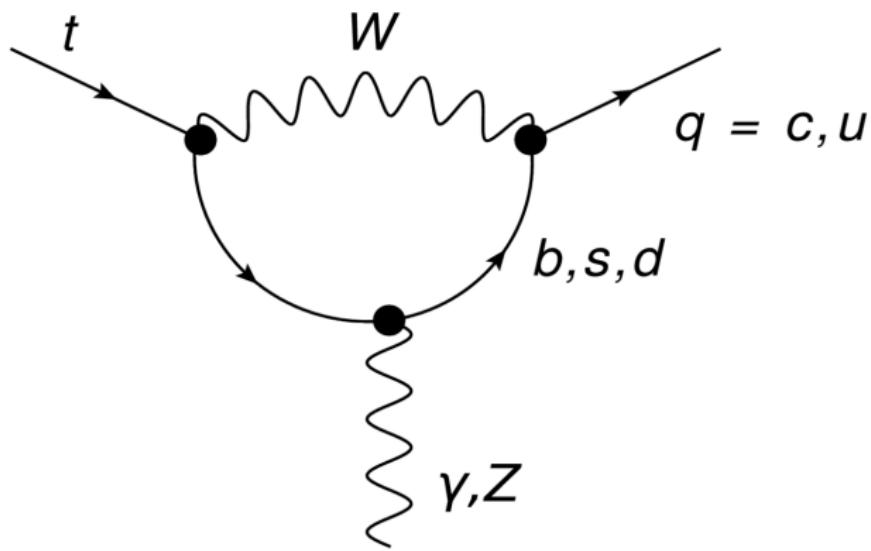
Before Scaling



After Scaling



FCNC Diagrams



Neural Network Model Inputs

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

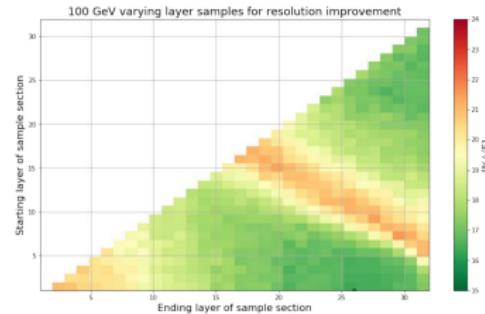
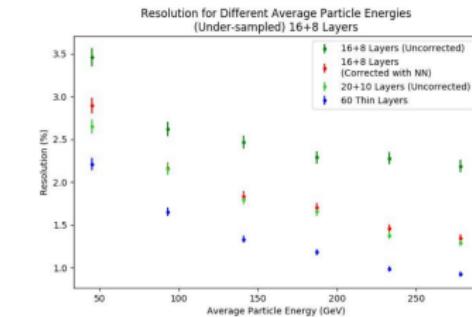
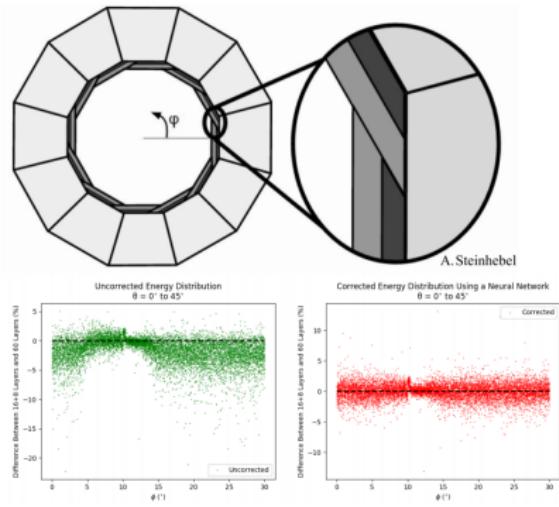
mu+jets channel

| 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 |

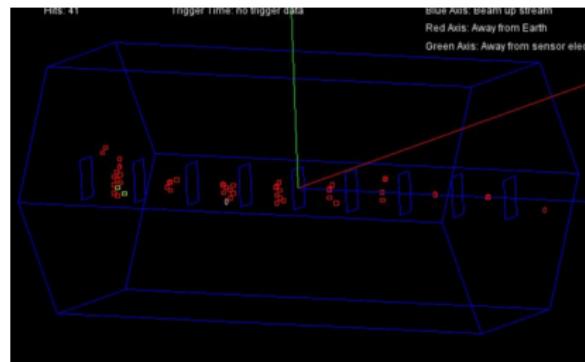
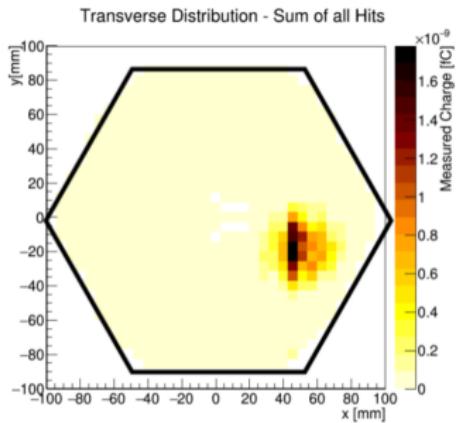
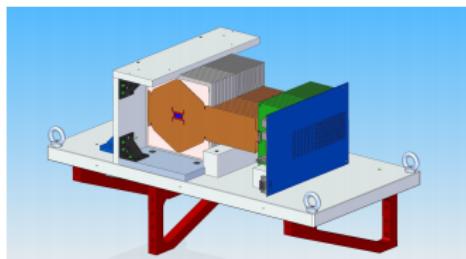
e+jets channel

| 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

