Probing the nature of Electroweak Symmetry breaking at the LHC with the ATLAS detector

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Overview

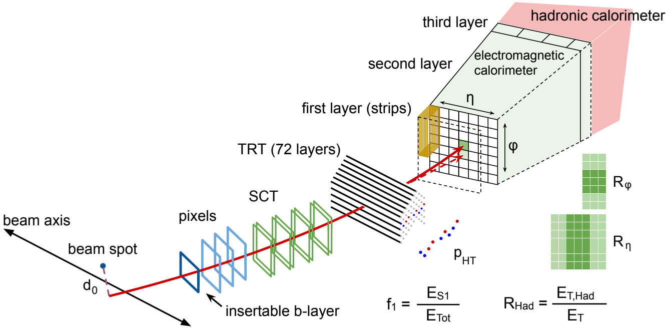
- **Part-1:**Optimization of cut-based electron identification menu.
- **Part-2:**Overview of theoretical, phenomenological, and experimental work on doublet-triplet Higgs models.

Optimization of Electron Identification: Motivation and Necessity

- Electrons are at the centre of a lot of analyses, such as Higgs to multi-lepton decays, $Z \rightarrow ee$ etc.
- The ATLAS detector also use the identification of electrons to trigger on events of interest.
- Optimization of the electrons needed for Run-2:
  - New run conditions such as higher collision energy, and higher luminosity.
  - Changes in detectors such as the addition of the new Insertable B-layer, replacement of Xenon by a mixture of Xenon-Argon in the Transition Radiation Tracker etc.
    - Changes in the identification variables.

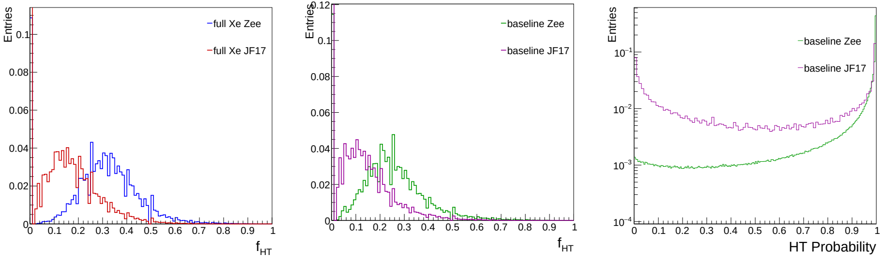
The Detector

- ElectronID attempts to make optimal use of the tracking and calorimetric detectors.
- This includes shower widths, ratios of various energy deposits, tracking hits, track-cluster matching, etc.



Changes in the TRT

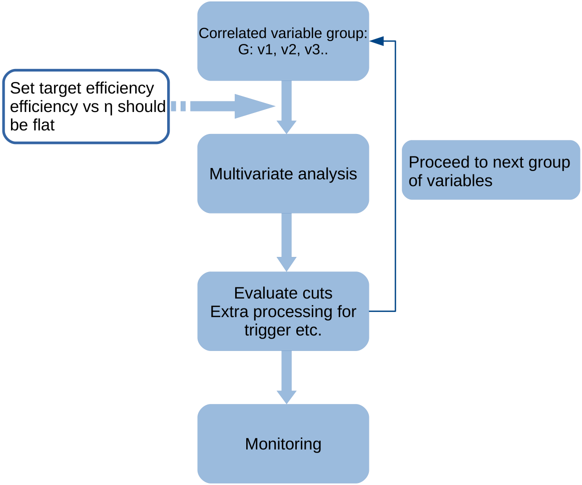
Due to increased cost caused by leakage of the Xenon gas in the TRT, the full Xe gas(left) has now been replaced by a Xenon-Argon mixture(right). This affects the variables which depend on the High Threshold hits.



This variable is now replaced by a likelihood variable, eProbabilityHT.

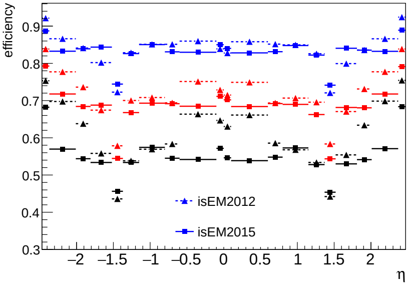
Multivariate Optimization flow

TMVA cuts method was used for optimization with some post-TMVA processing to cope with various constraints such as the trigger.



Results of Optimization

Cuts were optimized for Run-2 conditions, including the change in the gas mixtures in the TRT. Flatter efficiencies with more pileup robustness were obtained.



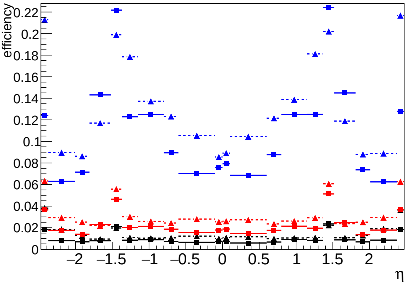
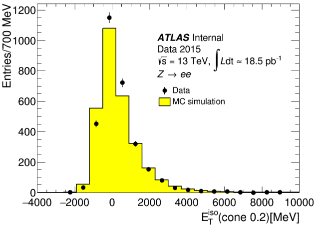


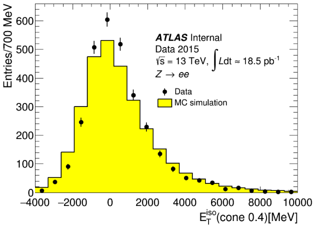
Figure: Efficiency vs η for signal(left), and background(right): **Loose**, **Medium**, **Tight**

Data vs MC using early 50ns data

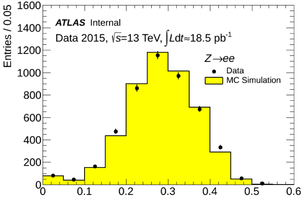
Data vs MC comparison of variable shapes using $Z \to ee$ events were shown in EPS-HEP 2015 conference.

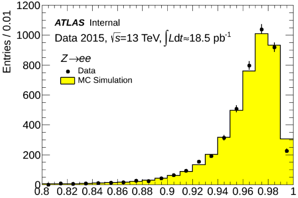
Calorimeter isolation variables with different cone sizes, left: cone 0.2, right: cone 0.4





Layer 1 EM calorimeter variables: f_1(left) and E_{ratio}(right)





The doublet-triplet extension of the Scalar Sector of the SM

- Massless neutrinos in Standard Model. Neutrino oscillation discovered. Implication: Neutrinos have mass.
- Fixed by type II seesaw by introducing a scalar triplet.
- Model naturally gives a SM-like Higgs and a rich scalar structure $(H^{\pm\pm}, H^{\pm}, A^0, H^0, h^0)$. If triplet hypercharge, $\mathrm{Y} = 2$ $(Q = I_3 + \frac{Y}{2})$, doubly charged Higgs is a unique feature with clean decay channels.
- Easy to find/rule out this model. It has very unique experimental signatures.
- Direct searches at LHC for light Higgs are possible.

The main reference can be found here: arxiv 1105.1925

The potential

The most general Lagrangian in the scalar sector can then be written as,

$$\mathcal{L} = (D_\mu H)^\dagger (D^\mu H) + Tr(D_\mu \Delta)^\dagger (D^\mu \Delta) - V(H,\Delta) + \mathcal{L}_{Yukawa} \quad (1)$$

where $V(H,\Delta)$ is given by,

$$V(H,\Delta) = -m_H^2 H^\dagger H + \frac{\lambda}{4}(H^\dagger H)^2 + m_\Delta^2 Tr(\Delta^\dagger \Delta) + [\mu(H^\dagger i\sigma^2 \Delta^\dagger H) + h.c.]$$
$$+ \lambda_1 (H^\dagger H) Tr(\Delta^\dagger \Delta) + \lambda_2 (Tr \Delta^\dagger \Delta)^2 + \lambda_4 H^\dagger \Delta \Delta^\dagger H$$

With the extra Yukawa term, $\mathcal{L}_{Yukawa} \supset -Y_\nu L^T C \otimes i\sigma^2 \Delta L$

Constraints from precision measurements

Custodial symmetry:

- The fact the potential $V = V(H^\dagger H)$ ensures $\rho \equiv \frac{M_W^2}{M_Z^2 \cos^2\theta_W} = 1$ at tree level within the SM.
- At tree level, in the limit $v_d \ggg v_t$, modified $\rho \approx 1 - 2\frac{v_t^2}{v_d^2}$.
- At 2σ level, $\rho_0 = 1.0004 \pm 0.00048$. This puts an upper bound on v_t of about 1.6 GeV.
- This bound can be loosened by considering radiative corrections in the DTHM model.

Production Modes

Possible production mechanisms include

- $p\bar{p}/pp \to \gamma^*, Z^* \to H^{\pm\pm}H^{\mp\mp}X$
- $p\bar{p}/pp \to W^{\pm*}W^{\pm*} \to H^{\pm\pm}X$

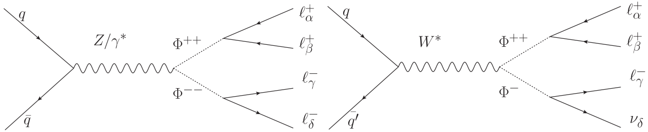
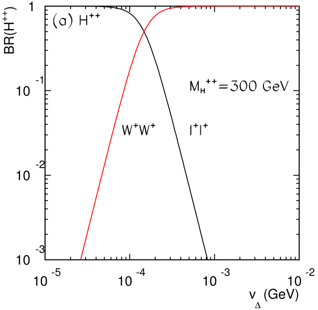


Figure 1: Feynman diagrams for pair and associated production of Φ^{++}.

Decay Modes

Two main modes of decay to choose from:

- $H^{\pm\pm} \to l^{\pm}l^{\pm}$. Searches for this mode have been performed at L3, OPAL, Delphi, CDF, ATLAS, CMS .. assuming 100% BR. Some results from ATLAS and CMS later!
- $H^{\pm\pm} \to W^{\pm}W^{\pm} \to l^{\pm}l^{\pm}\nu\nu$. In some part of the parameter space, this is substantial and the previous mode is suppressed.

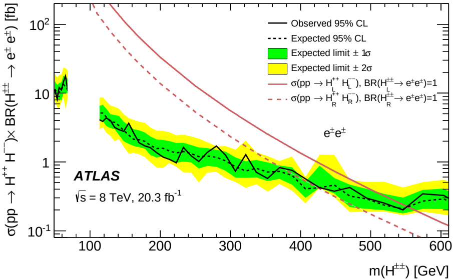


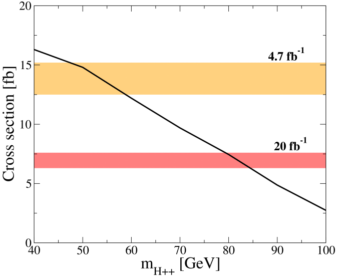
$H^{\pm\pm}H^{\mp\mp} \to 4W$	BR (in %)
$\to 0l + 8$ jets	20.1
$\to 1l + \not{E}_T + 6$ jets	39.7
$\to 2l + \not{E}_T + 4$ jets	29.3
$\to 3l + \not{E}_T + 2$ jets	9.6
$\to 4l + \not{E}_T +$ no jets	1.2

$H^{\pm\pm} \to W^{\pm}W^{\pm}$ at LHC: sensitivity estimate

Study region in parameter space where $H^{++} \to W^{\pm *}W^{\pm *}$ is dominant i.e. $v_t > 0.1$ MeV.

- Experimental searches in $H^{\pm\pm} \to l^{+}l^{+}$ decays.
- Results reinterpreted for the $H^{\pm\pm} \to W^{\pm}W^{\pm}$ case.
- **Mass bounds reduced from 450 GeV to 85 GeV**.





Towards the analysis..

- Implementation of the model in FeynRules to enable use of MadGraph to generate Monte Carlo simulations.
- Using the ttH data anaylsis framework in CPPM.
- Regular meetings within PESBLADE have begun.
  Gilbert Moultaka, Cristinel Diaconu, Lorenzo Feligioni, Lorenzo Basso and Venugopal Ellajosyula

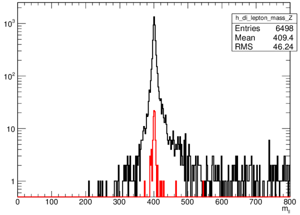


Figure: Available ATLAS pythia8 file with $m_{H^{++}} = 400$ GeV used, leptonic couplings suppressed and WW channel enhanced. Increase by a factor of 100 observed!

Work Plan

- Sensitivity studies with a realistic simulation of the signal and background within ATLAS framework; control analysis with 2015 data.
- Mid 2016: first optimised analysis and phenomenology study (paper/internal note)
- End 2016: first search using 50 fb^{-1} 13 TeV Data
- Mid 2017: publication experimental result