Electron Reconstruction and Identification in CMS: an ECAL Perspective

featuring methods for discrimination of electrons from W decays and their QCD background

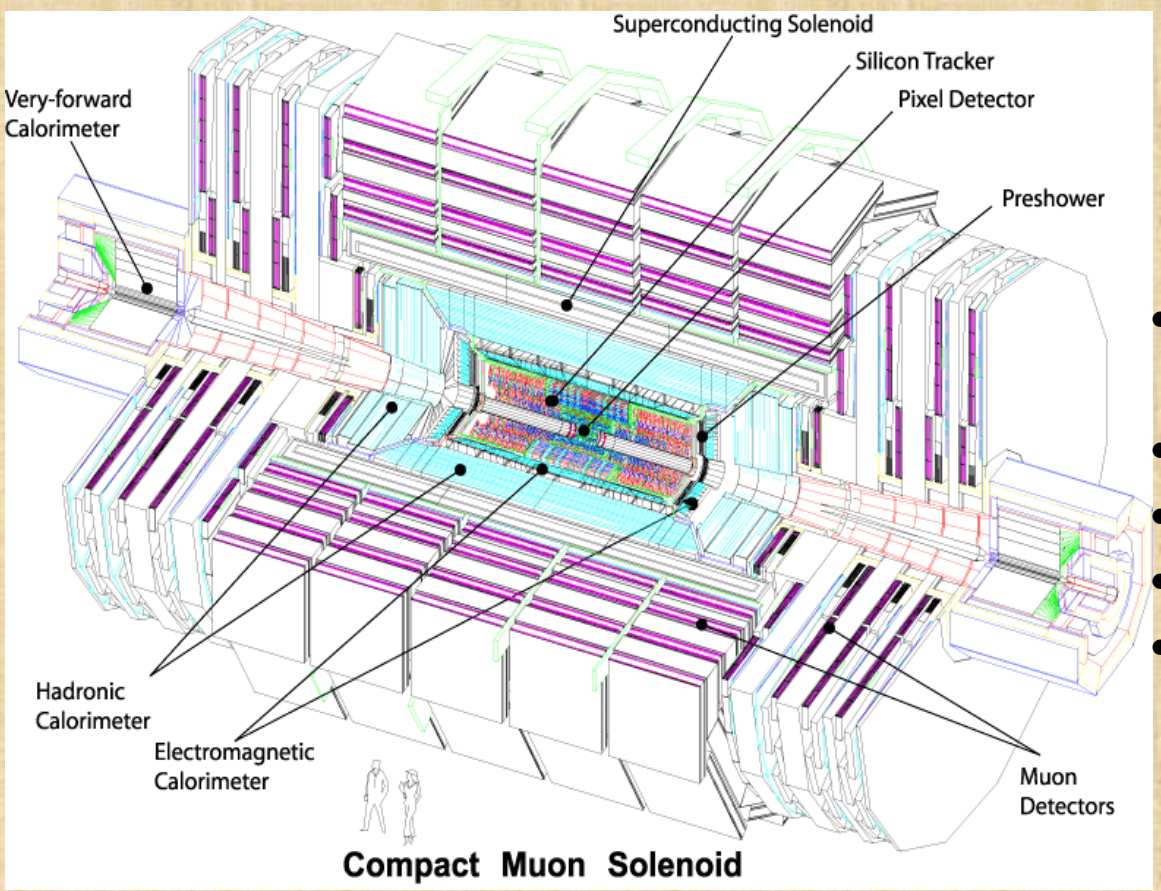
Nikolaos Rompotis

Outline of the talk

- CMS Detector and Electron Reconstruction
- Discrimination of W decay electrons from QCD background
  - Demonstration of a Cut Based Analysis: Robust Selection Criteria
  - Demonstration of a NN implementation
- Conclusions and future work

The CMS Experiment

Compact Muon Solenoid: a detector to study proton-proton collisions at 14TeV centre-of-mass energy with components built around a solenoid magnet.



Physics Goals:

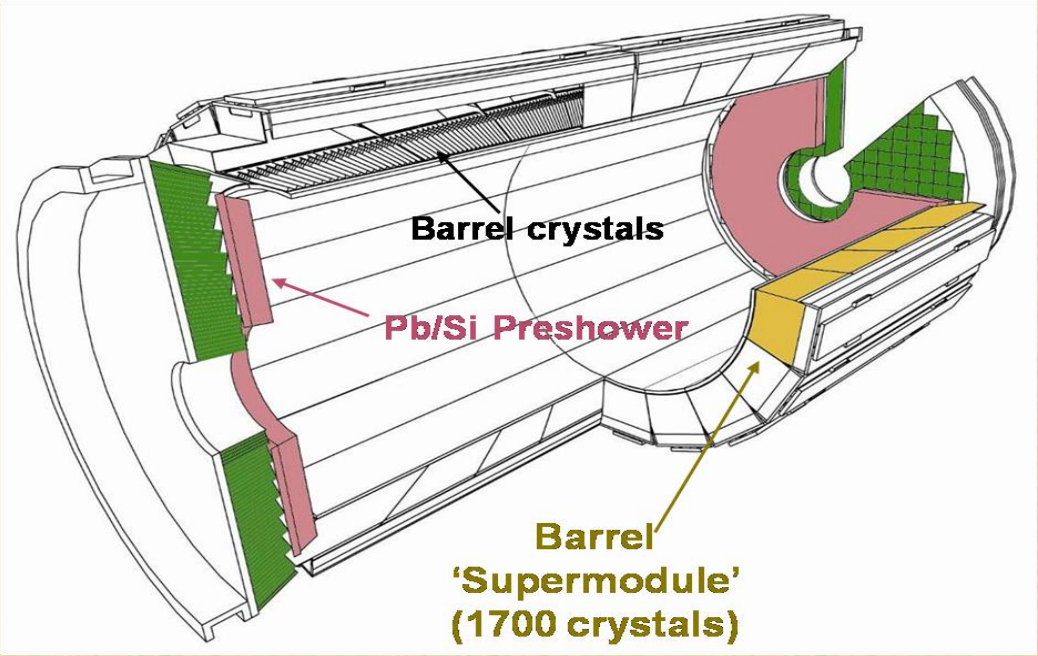
- Electroweak symmetry breaking mechanism (Higgs?)
- Supersymmetry (?)
- Extra Dimensions (?)
- New Massive Bosons (?)
- Heavy Ion Physics

Measuring Electrons in CMS

Electron measurements are particularly important:

- Higgs channels H→ ZZ→4e, H→WW→2e2v
- SUSY studies via dilepton production

The CMS electromagnetic calorimeter (ECAL) is a homogeneous calorimeter
made of $PbWO_4$ crystals.



The ECAL measures the energy of the electrons. The silicon tracker detector and the pixel detector are necessary to reconstruct their tracks.
Information from the hadronic calorimeter (HCAL) is also useful since electrons deposit all their energy in the ECAL – electron/jet discrimination.

An Outline of the Electron Reconstruction Procedure in CMS

- Level 1 trigger: selects electron/photon candidates without any discrimination between them using only ECAL-HCAL data. Most of the selected events are not from prompt photons/electrons, but mainly from neutral pions and other particles from jets.
- High Level Trigger (HLT): includes also tracker data in the analysis. Finds a track for the candidate that follows all the way to the ECAL.
- Offline Reconstruction: here no time restrictions as in the Trigger! A similar algorithm as in HLT, but candidates that may have been missed by HLT or they are below threshold are also reconstructed. The track is finally associated to an electron candidate if certain pre-selection requirements are satisfied.

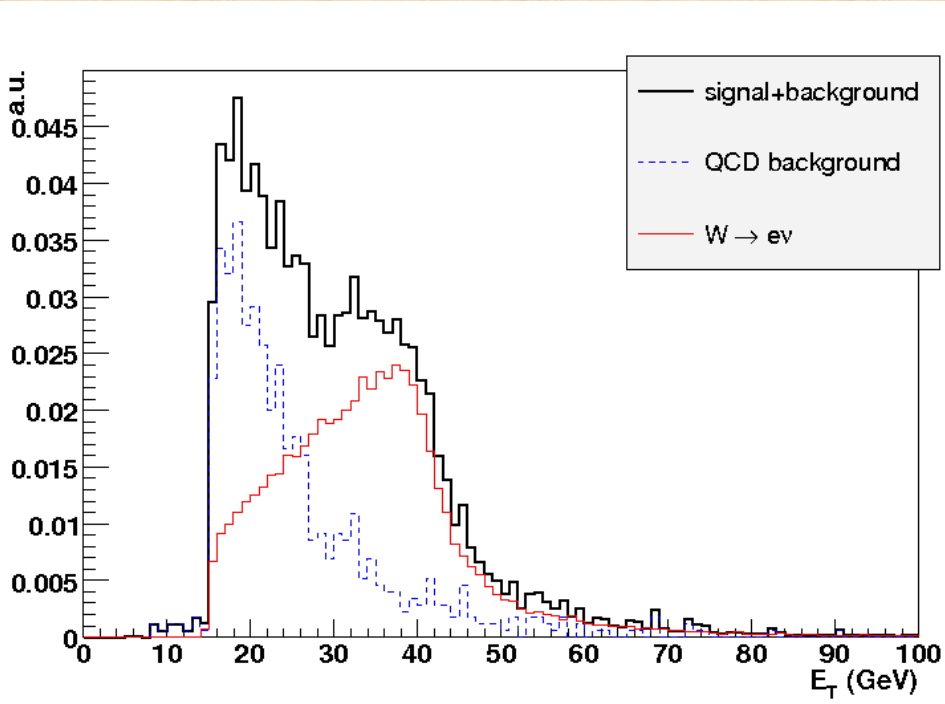
Electrons from W decays

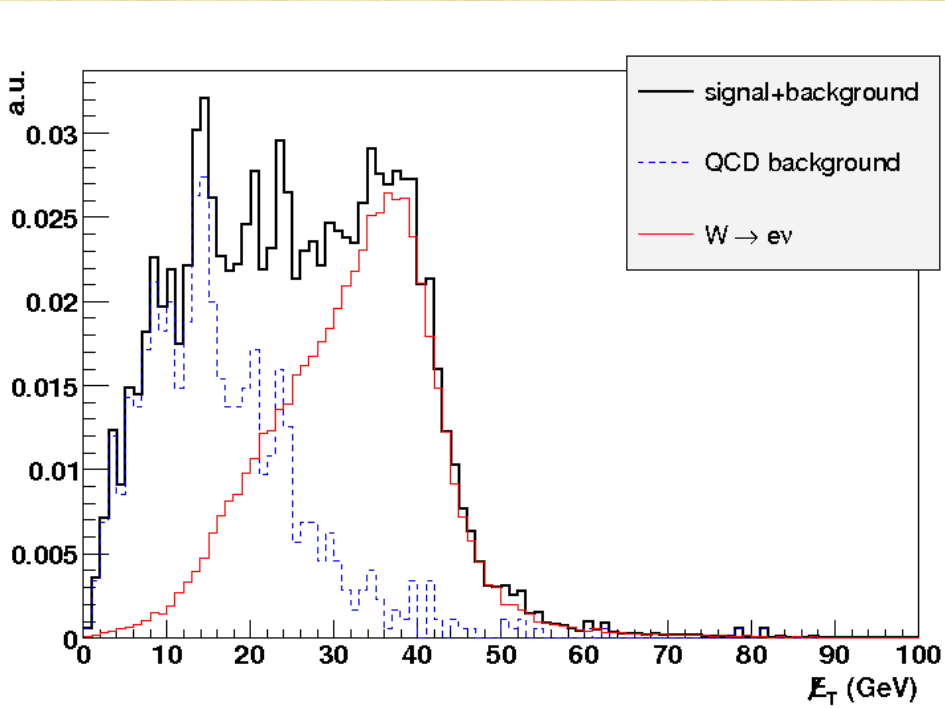
- Why? Large backgrounds, mainly from QCD with a jet misidentified as an electron and another one mismeasured.

- How?
  - Aim: demonstrate the procedure of separating W decay electrons from their QCD background.
  - Samples: Simulated events with CMSSW of offline reconstructed HLT events by D. Wardrope
  - Comments:
    - for simplicity only events in the ECAL barrel fiducial region have been considered
    - Only QCD events with jet p_T in the range 50-170GeV

Cut Based Analysis: Selection procedure (I)

- Start with events with at least one offline reconstructed HLT electron candidate and select the most high-energetic one.
- If the candidate is in the ECAL barrel fiducial region continue.





Cut Based Analysis: Selection procedure (II)

- Demand the candidate to be isolated:

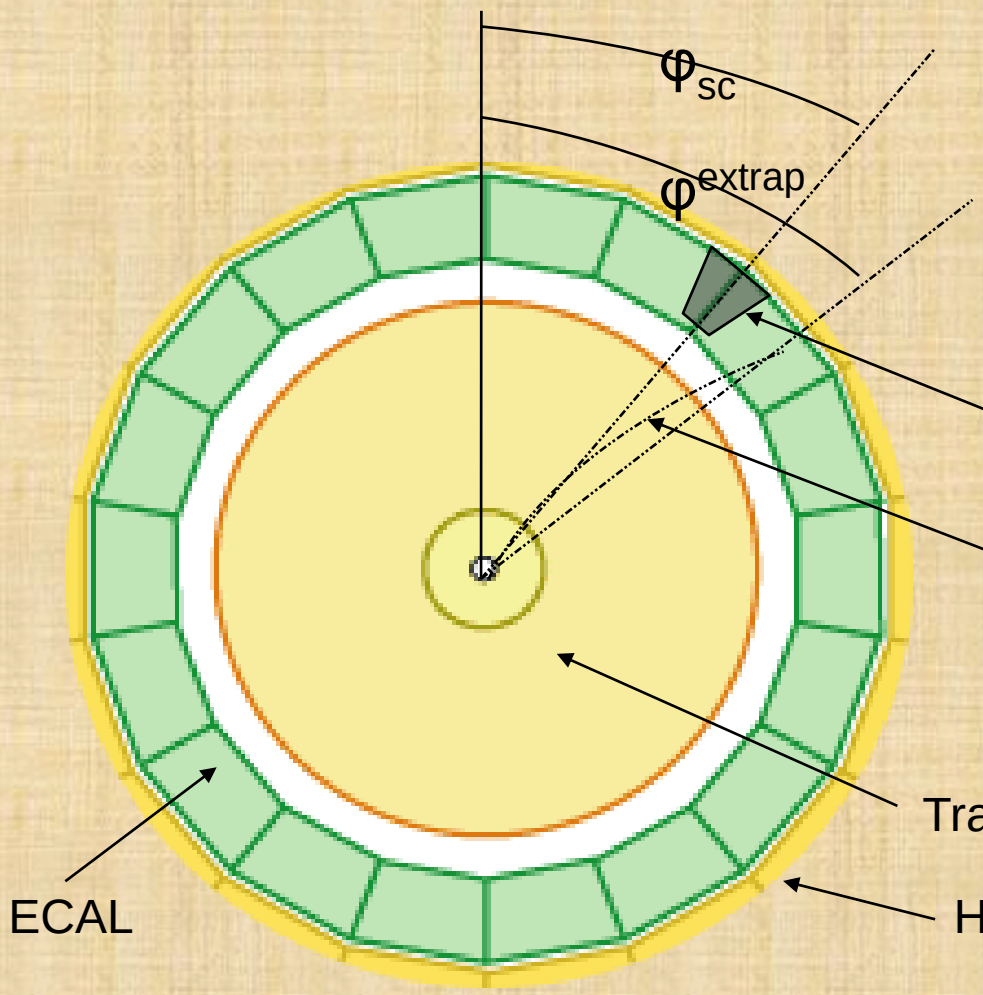
$$\sum_{tracks}\left(\frac{p_T^{track}}{p_T^{candidate}}\right)^2 < 0.02$$

- Robust selection criteria:

apply a set of cuts to the following variables:

- HoE : Ratio of the energy deposited in the HCAL behind the ECAL supercluster over the energy of the ECAL supercluster
- $\sigma_{\eta\eta}$: a measure of the η dispersion of the ECAL supercluster
- $|\Delta\eta_{in}|$: the absolute difference between the ECAL supercluster position in η and the extrapolated position in the ECAL using the track parameters at the interaction vertex (see picture in next slide)
- $|\Delta\varphi_{in}|$: similar to $|\Delta\eta_{in}|$

Cut Based Analysis: Selection procedure (III)



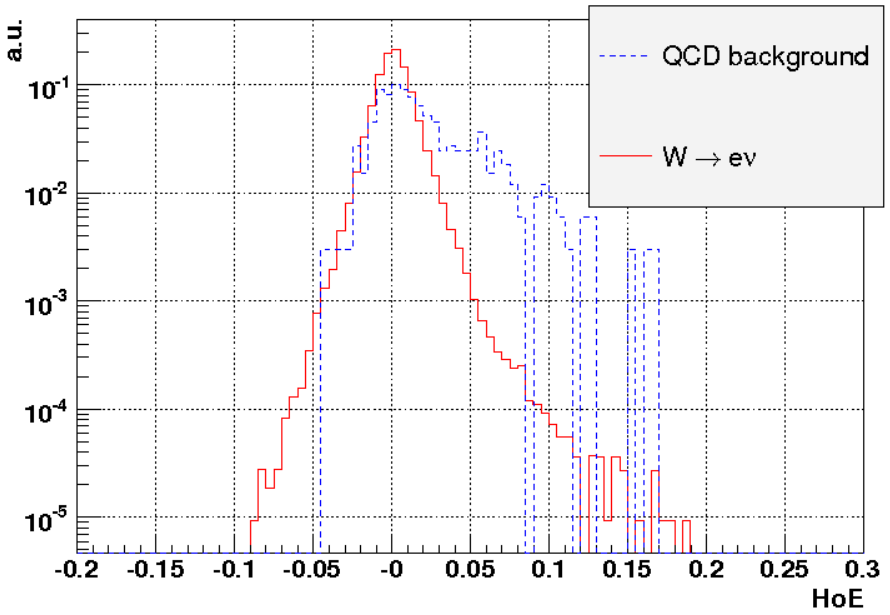
What exactly is $|\Delta\varphi_{in}|$, $|\Delta\eta_{in}|$?

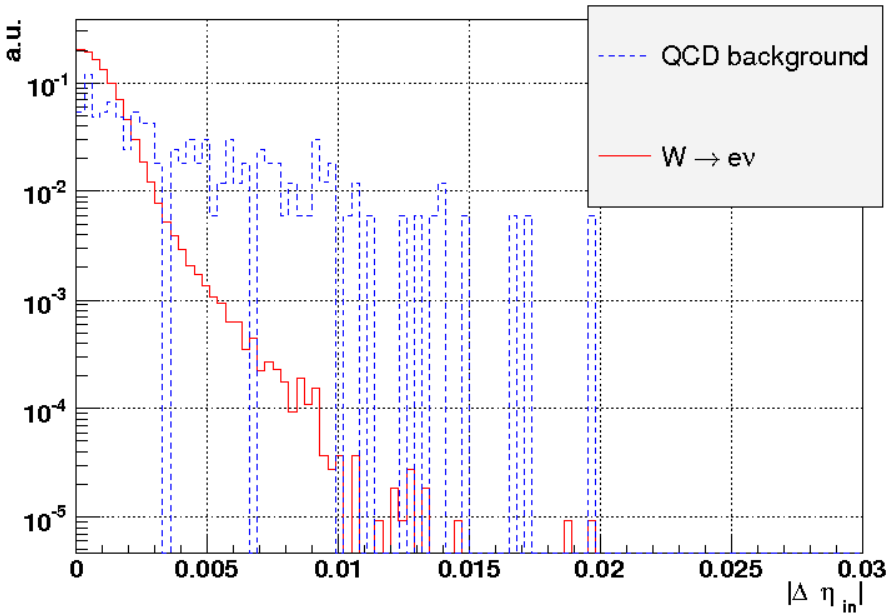
$|\Delta\varphi_{in}| = |\varphi_{sc} - \varphi^{extrap}|$

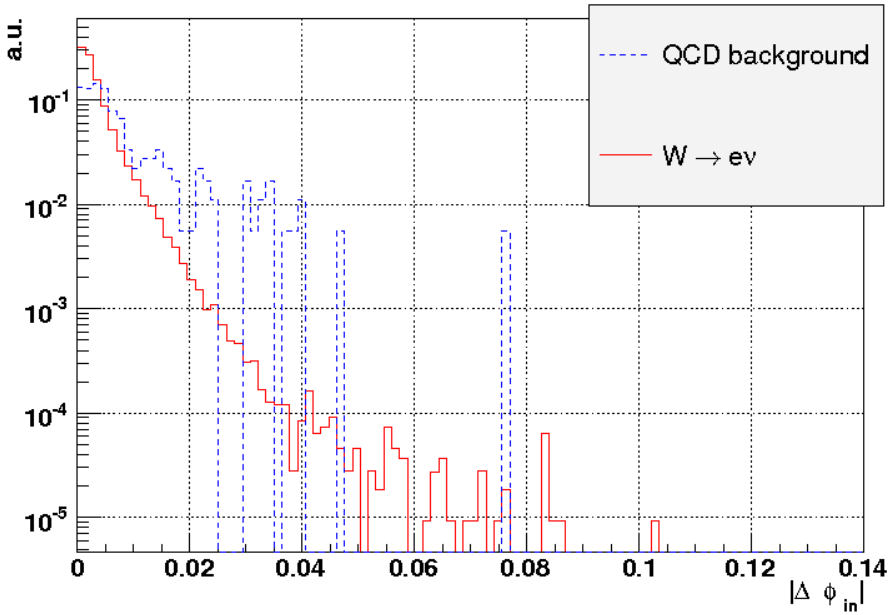
electromagnetic supercluster

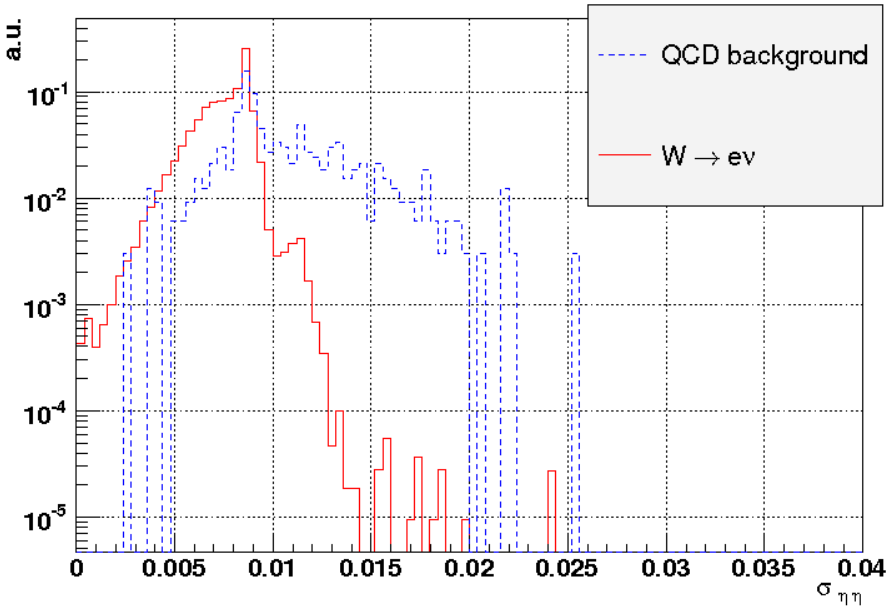
extrapolated electron track from track parameters at the interaction vertex

Cut Based Analysis: Robust Selection Variables (I)

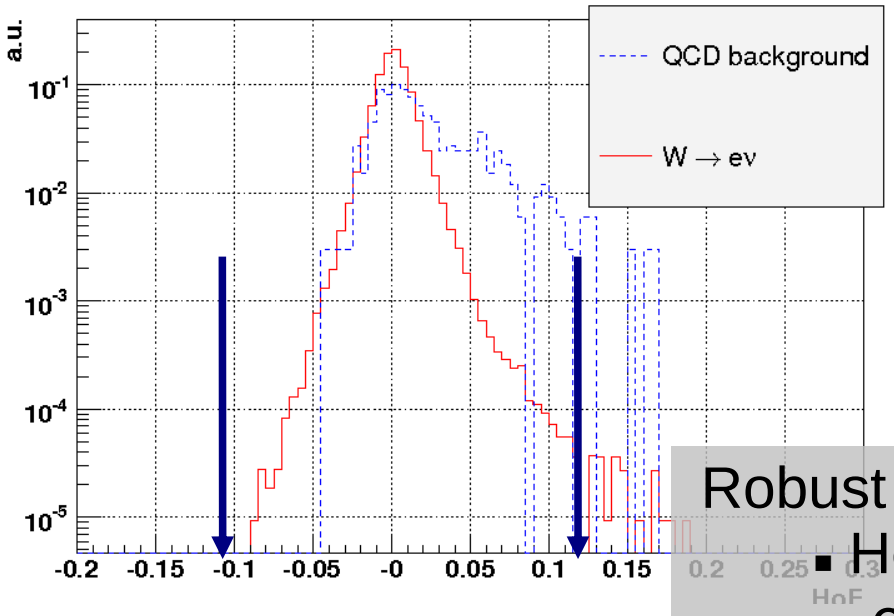


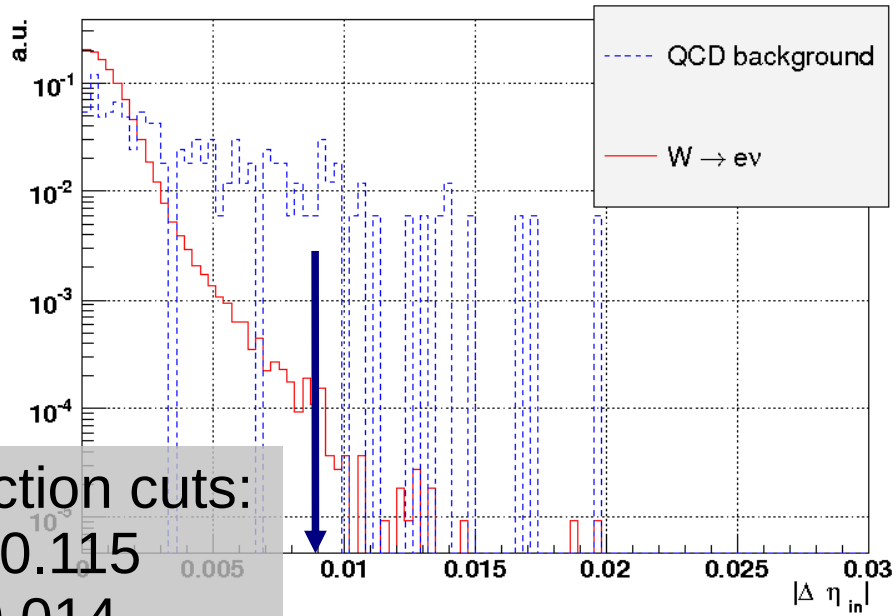






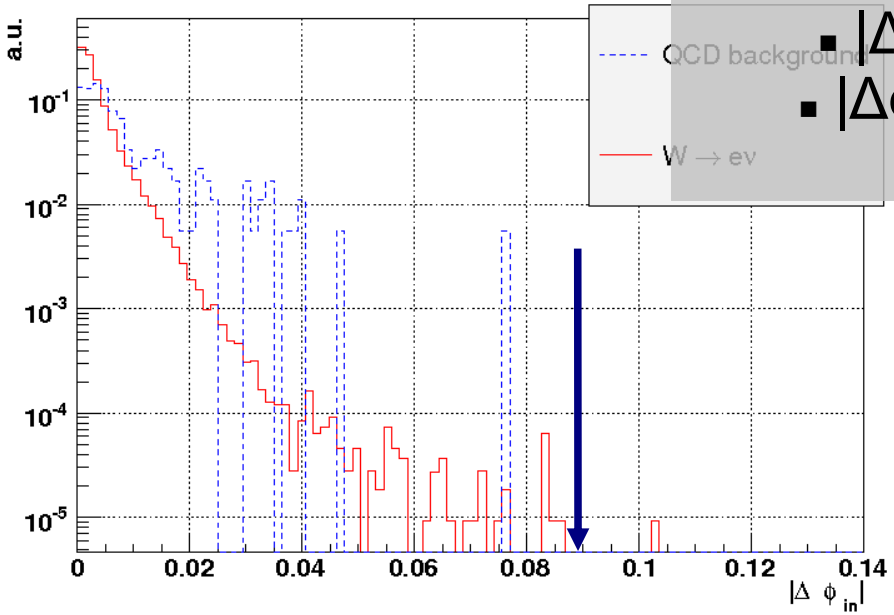
Cut Based Analysis: Robust Selection Variables (II)

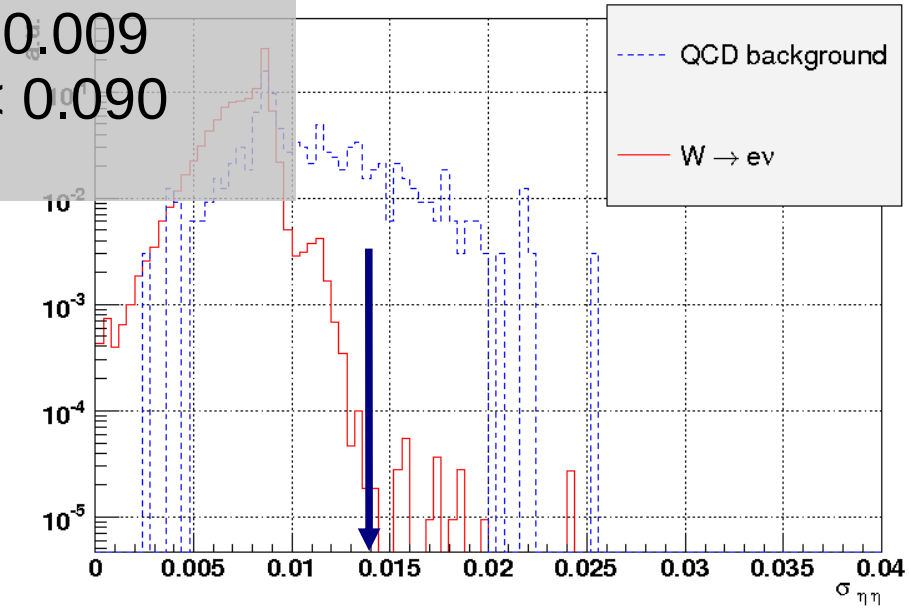




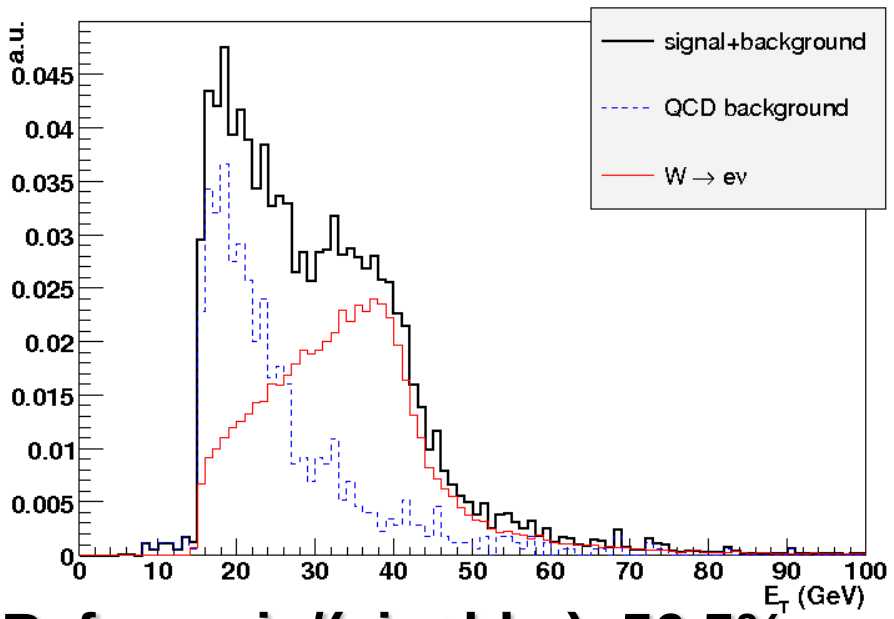
Robust Selection cuts:

- HoE < 0.115
- $\sigma_{\eta\eta} < 0.014$
- $|\Delta\eta_{in}| < 0.009$
- $|\Delta\varphi_{in}| < 0.090$

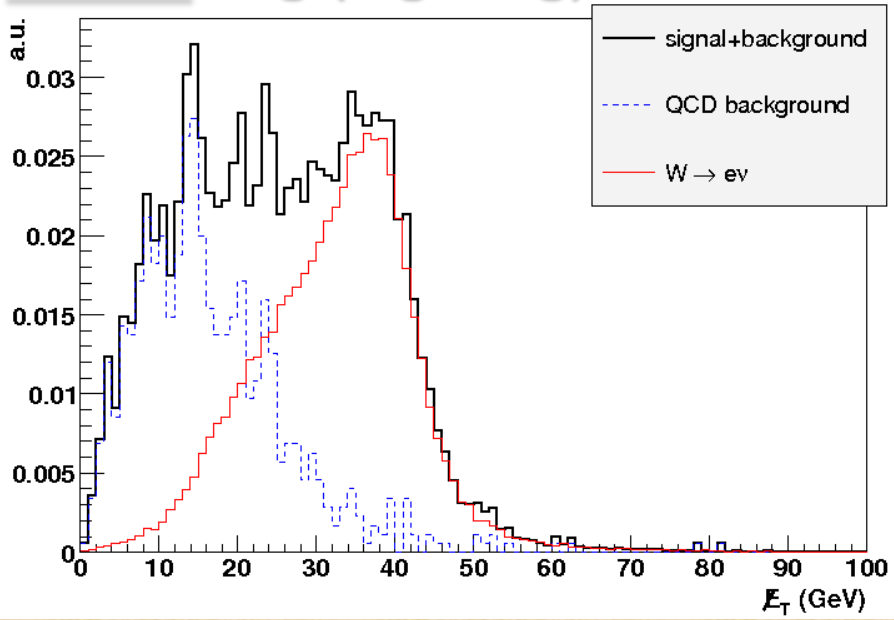


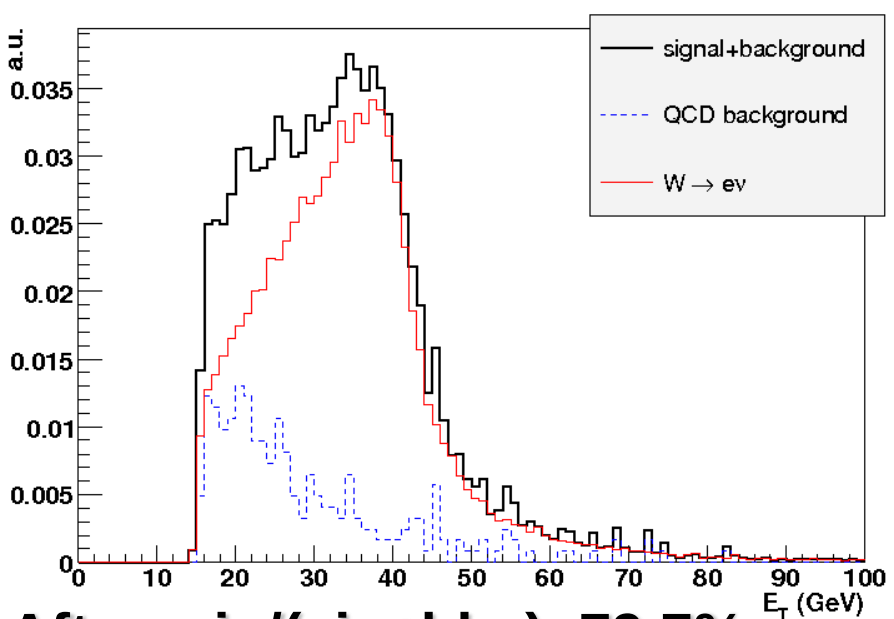


Cut Based Analysis: Applying the Selection Procedure

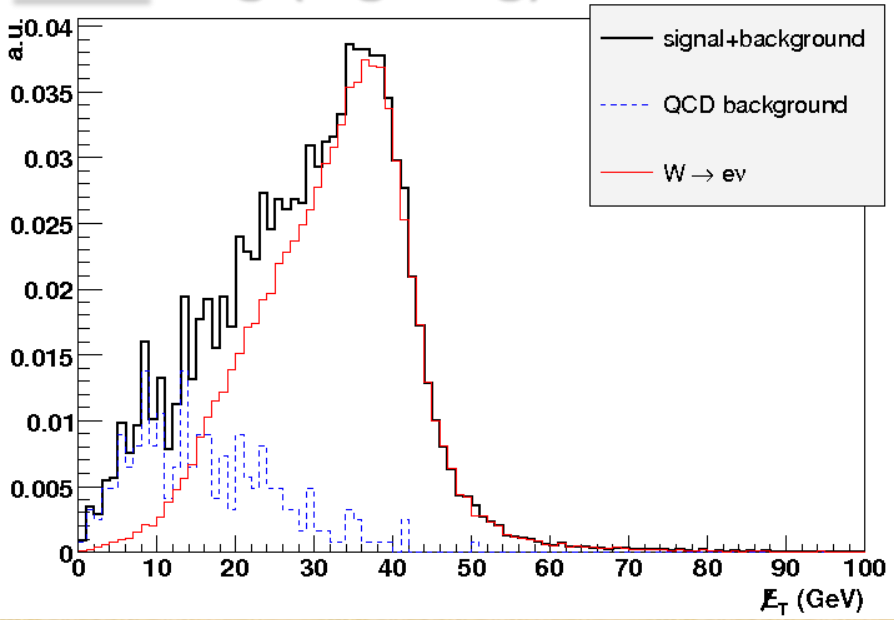


Before: sig/(sig+bkg)~56.5%





After: sig/(sig+bkg)~79.7%

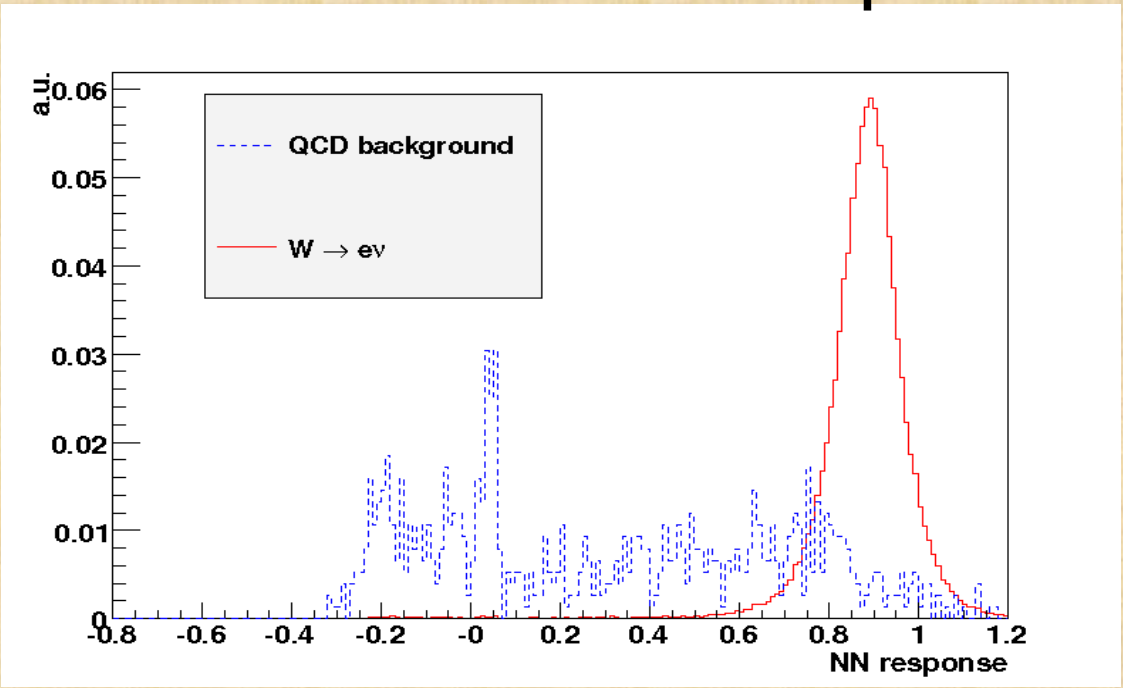


A Neural Network Analysis: Basics

Although there are no plans for a NN analysis in this stage of Electron ID I have developed one just for fun, influenced mainly by the D0 single top quark production analysis.
The NN is based on the following ideas:

- The input sample consists of offline reconstructed HLT candidate events, i.e. *exactly the same* set that was used in the cut based analysis before the application of the track isolation criterion
- The NN input variables are the track isolation variable and the 4 variables used in *robust selection cuts*.
- The number of hidden nodes is 12 – other choices have also been tested
- The training method was a gradient descent with the simplest possible choice of parameters – events were not weighted
- The training sample consisted of a small portion of the simulated events and the NN was tested to independent samples to show that no overtraining occurs.

A Neural Network Analysis: NN output and Performance Comparison



	HLT in Barrel	Cut Based Robust Selection	NN cut 0.5	NN cut 0.6	NN cut 0.7
W^+	62522	61823 (-1.1%)	61821 (-1.1%)	61505 (-1.6%)	60468 (-3.3%)
W^-	15782	15635 (-0.9%)	15627 (-1.0%)	15556 (-1.4%)	15248 (-3.4%)
QCD	762	250 (-67.2%)	277 (-63.6%)	229 (-69.9%)	171 (-77.6%)
sig/(sig+bkg) weighted	**56.5%**	**79.7%**	78.3%	81.0%	84.8%

Number of events and percent reduction with respect to offline reconstructed HLT events in the barrel

Summary and Conclusions

- By applying a set of selection cuts it was demonstrated than QCD background is reduced from 43.5% to 20.3% (factor of 2). However, it is still not fully optimized and further suppression is needed.

- Cut Based Analysis and NN were found to have similar performances

- Optimization of the selection cuts is the main target for the near future

Acknowledgements

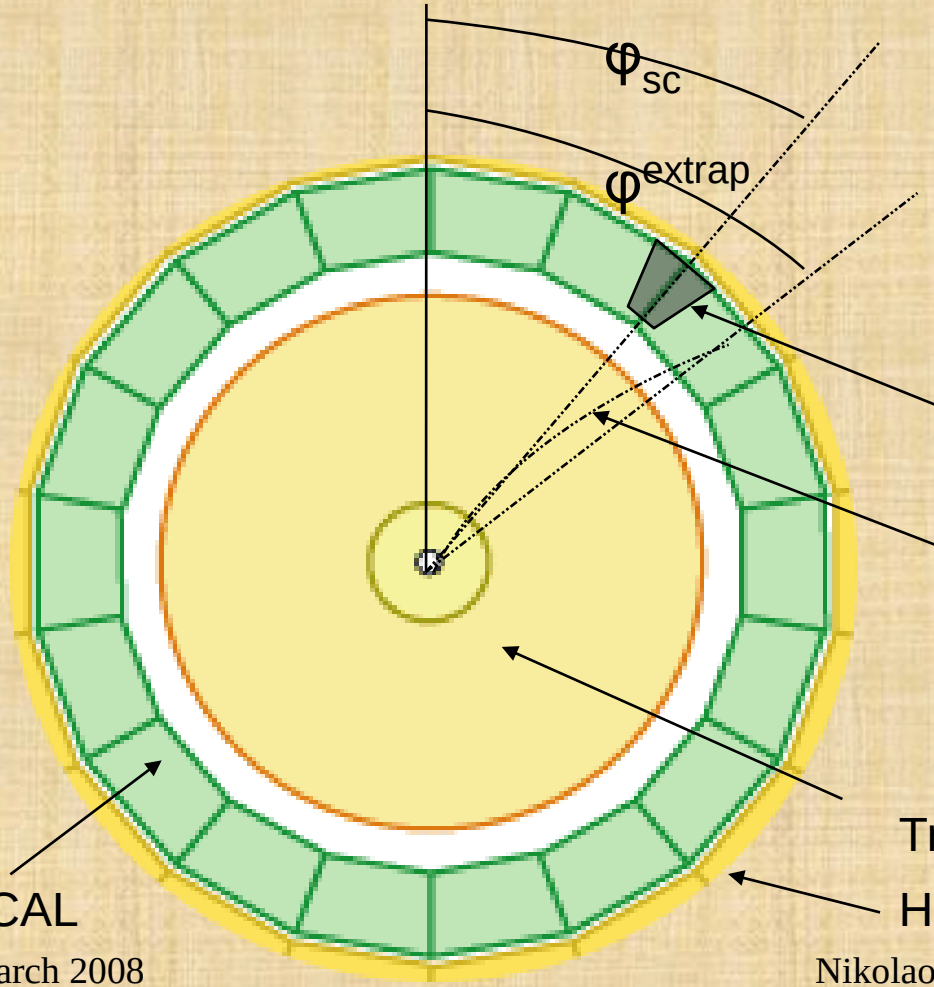
- Chris Seez – supervision
- David Wardope – simulation of electron candidates
- Kostas Petridis – discussions about CMS physics
- Louis Lyons – NN motivation and discussions

Thanks for your attention!

Backup Slides

Cut Based Analysis: Selection procedure (III)

HoE = the ratio of the energy deposited in the ECAL towers in a cone of radius $\Delta R < 0.1$ centred on the ECAL supercluster over the energy of the ECAL supercluster



$|\Delta\varphi_{in}| = |\varphi_{sc} - \varphi^{extrap}|$

electromagnetic supercluster

extrapolated electron track from track parameters at the interaction vertex

Cut Based Analysis: Selection procedure (IV)

Pseudorapidity of the "hottest" crystal in the seed cluster

$$\sigma_{\eta\eta} = \sum_{crystals} (\eta_i - \eta_s)^2 E_i / E_{seedcluster}$$

Pseudorapidity/Energy of the i-th crystal

Isolation variable definition:

$$\sum_{tracks} \left(\frac{p_T^{track}}{p_T^{candidate}} \right)^2 < 0.02$$

Transverse momentum of the candidate reconstructed at the vertex

Summation over tracks with $p_T > 1.5$GeV and within a cone $0.02<\Delta R<0.6$ centred at the candidate.