H to 4 leptons

Outline:

- Introduction
- The work so far
- Possible improvements after the CSC note
- Ready for real data?

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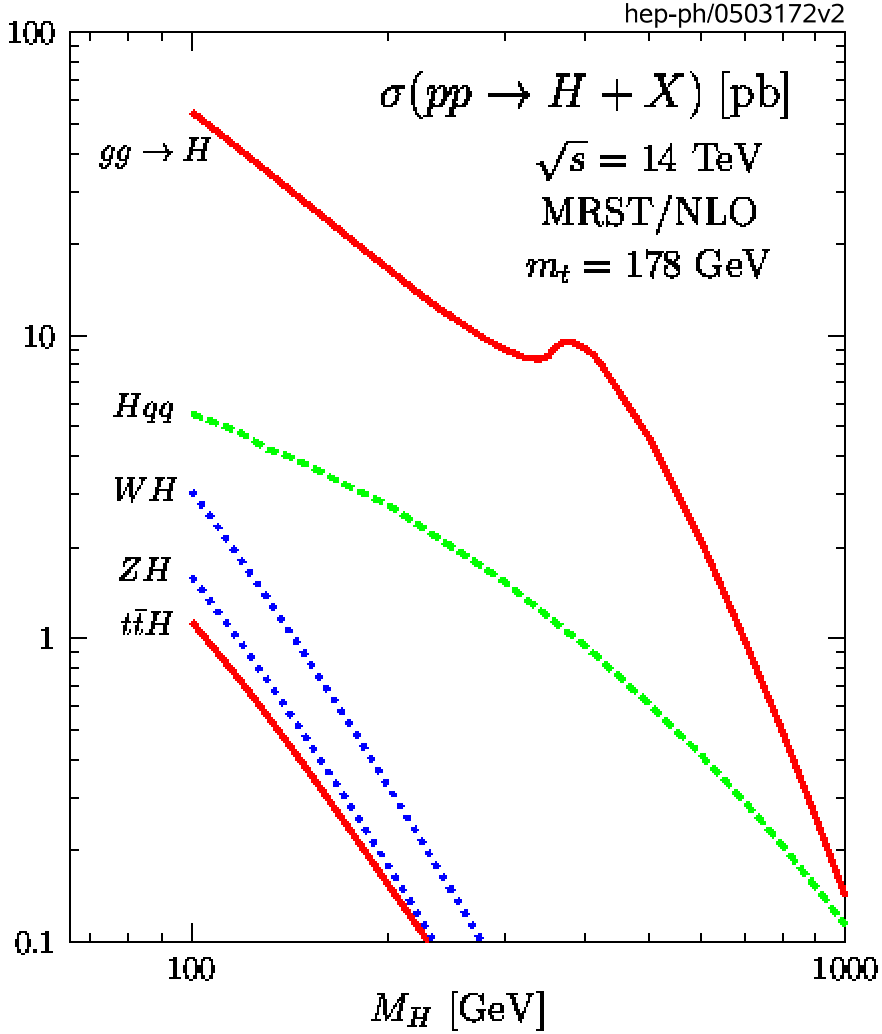
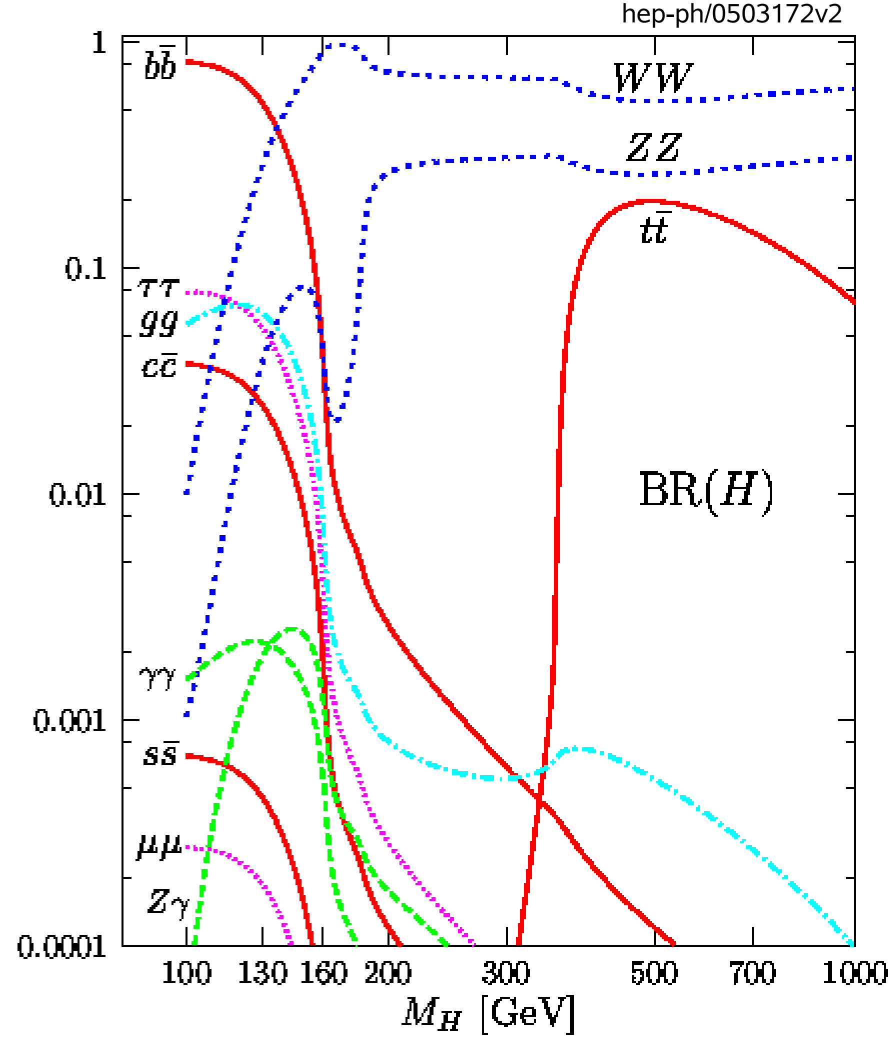
cea saclay

The University Of Sheffield.

Higgs Production and Decay at the LHC





- **Dominant process:** gluon-gluon fusion ~10-20% uncert.
- **LEP Direct Limit:** $M_H > 114.4$ GeV@ 95% CL

Higgs To Four Leptons

- The "golden channel"
  - Clean signal on top of smooth background
    - Narrow mass peak due to full event reconstruction
  - Only electrons and muons involved
    - Multiple sub-channels: 4e, 4μ, 2e2μ
    - Simple trigger set-up: high P_T single and di-lepton triggers
    - First objects to be understood in ATLAS
  - High branching ratio in a wide mass range
- Challenges
  - Low statistics ($Z \rightarrow \mu\mu$ and $Z \rightarrow ee$ BR ≈ 3.37%)
    - Good lepton identification required
  - Only one on-shell Z at low Higgs masses
    - Low P_T leptons required

Background Processes

	$\sigma_{NLO} \cdot BR$ [fb]
• **Irreducible**	
– $qq \rightarrow ZZ^*/\gamma^* \rightarrow 4l$	2×10^2
• NLO derived from LO PYTHIA + K-factor from MCFM	
– $gg \rightarrow ZZ^*/\gamma^* \rightarrow 4l$	6×10^1
• Added as 30% correction to qq→ZZ* LO x-section	
• **Reducible**	
– gg→Zbb→2lbb	7×10^4
• NLO derived from LO AcerMC + K-factor from MCFM	
– qq→Zbb→2lbb	1×10^4
• Added as 8.6pb correction to gg→Zbb LO x-section	
– gg,qq→tt	8×10^5
• NLO MC@NLO + Jimmy	
• **Additional possible sources of background**	
– qq→WZ	
– gg→Z+X	

The Analysis Framework

- ATLAS Software releases 13 and 14
  - Athena / AthenaROOTAccess
    - Use / validation of standard tools
    - AOD or DPD with in future maybe included user data
- Monte Carlo samples available on the Grid
  - Signal samples
    - Ideal geometry / misaligned / pile-up
    - Different mass points: 120 GeV up to 600 GeV
    - In this presentation: Higgs mass 130 GeV
  - Background samples
    - Misaligned
    - Sample sizes: 70k up to 500k events per channel

see tutorial by Bruno and Christos

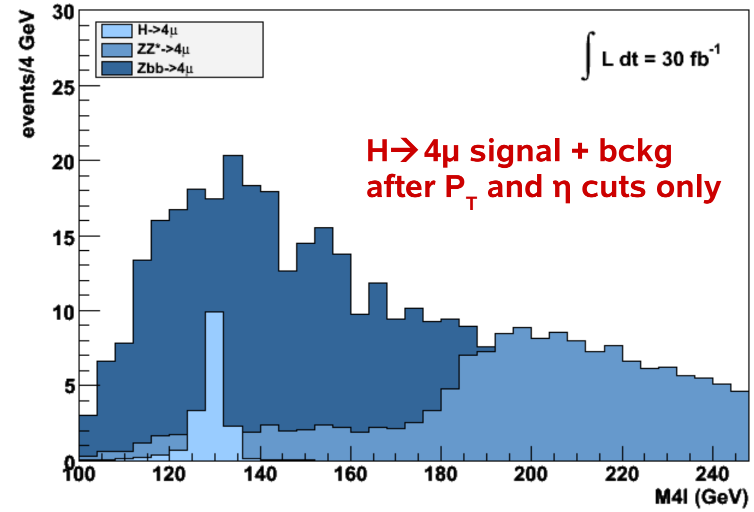
see talk by Alessia

The Analysis Strategy

- Signal selection
  - Aim: trigger on signal

    see talk by Tulay

    - Cuts on P_T distribution of leptons
    - Cuts on di-lepton mass m_{ll}



- Background Rejection
  - Aim: reject the reducible background well below the irreducible background (protection against theoretical uncertainties)
    - Isolation cuts
    - Impact parameter of leptons, χ^2 of common vertex of 4l
- Higgs mass reconstruction
  - Aim: improve mass resolution
    - Combined reconstruction (calo + ID, Muon Spectrometer + ID)
    - Z mass constraint (Breit-Wigner + Gaussian distribution)

Lepton Identification

- Good Lepton Identification essential
  - Electrons

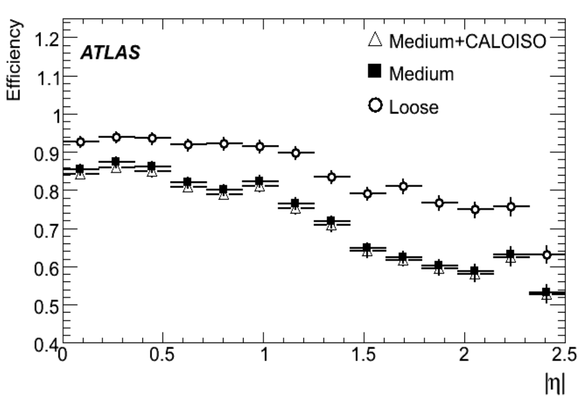
    see talk by Nicolas

    - Cluster in LAr EM-Calorimeter
    - Inner Detector track associated with the cluster
    - Consistency of shower shape of the cluster with an electron
    - Inconsistency of shower shape of the cluster with $\pi^0 \rightarrow \gamma\gamma$
    - Hits in the Pixel and SCT detector required
  - Muons

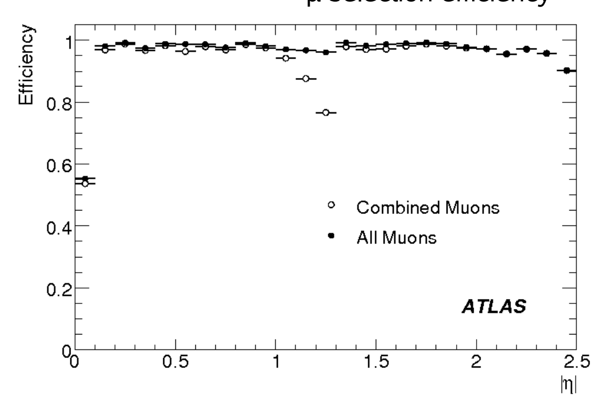
    see talk by Rosy

    - STACO: Combined reconstruction of tracks in ID and Muon Spectrometer
    - MuTag: Tagging ID tracks with track segments in the Muon Spectrometer

e selection efficiency

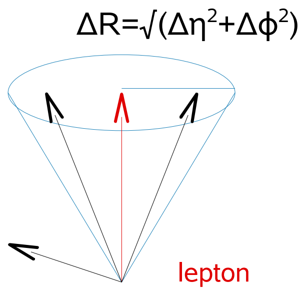


μ selection efficiency

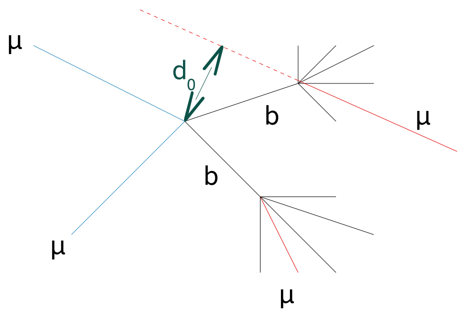


Background Rejection

- Track isolation
  - Zbb and tt background shows activity around leptons from heavy quark decays
    - Cut on $\Sigma P_T/P_T^{\mu}$ in cone ΔR (Inner Detector)
    - Cut on $\Sigma E_T/P_T^{\mu}$ in cone ΔR (Calorimeter)



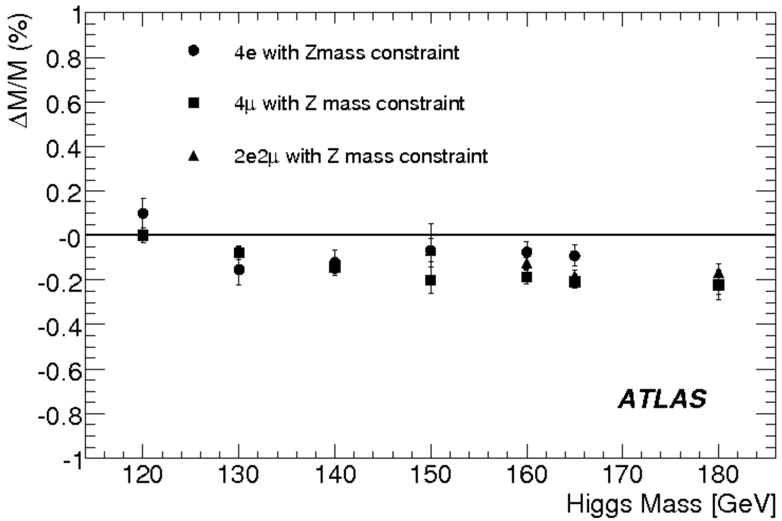
- Impact parameter (transverse distance of closest approach)
  - Leptons from b- and c-decays come from secondary vertices
    - Cut on significance: $d_0/\sigma(d_0)$

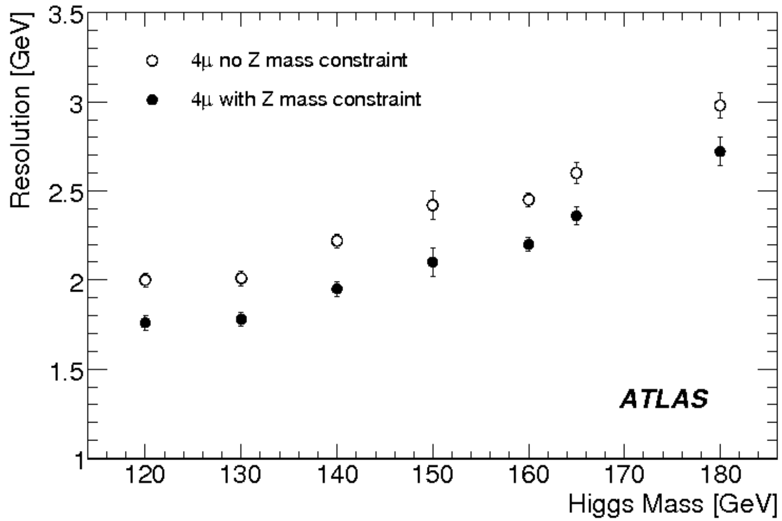


Higgs Mass Reconstruction

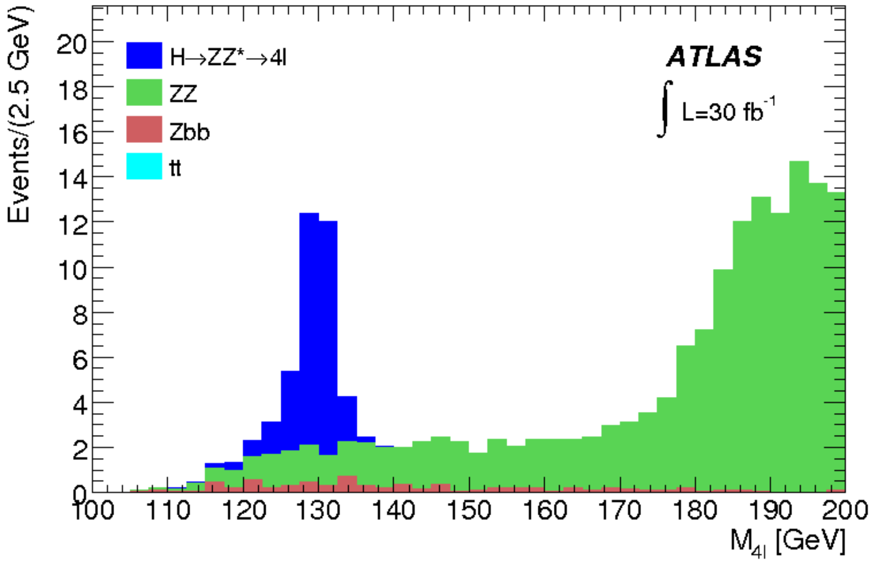
related to ARTEMIS deliverable month: 36

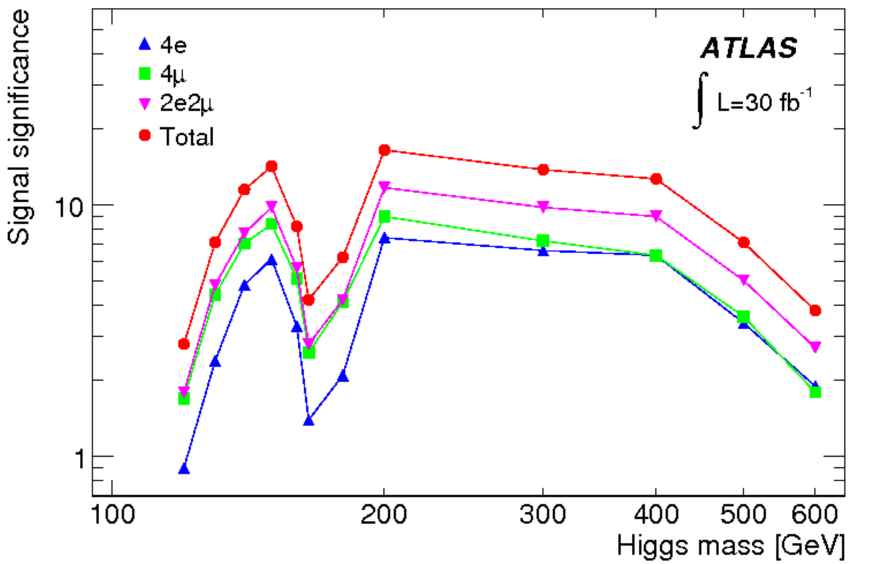
- Higgs mass reconstruction
  - Measurment of Higgs mass needs good lepton energy resolution
  - Calibration of lepton energy using Z→ll
    - Electron energy corrected by 1% to account for material effects
- Higgs width varies rapidly over mass range
  - Above ~200 GeV natural width exceeds detector resolution
  - For low masses good resolution is crucial for discovery
    - Use on-shell Z mass constrain fit





Higgs To Four Leptons CSC Note

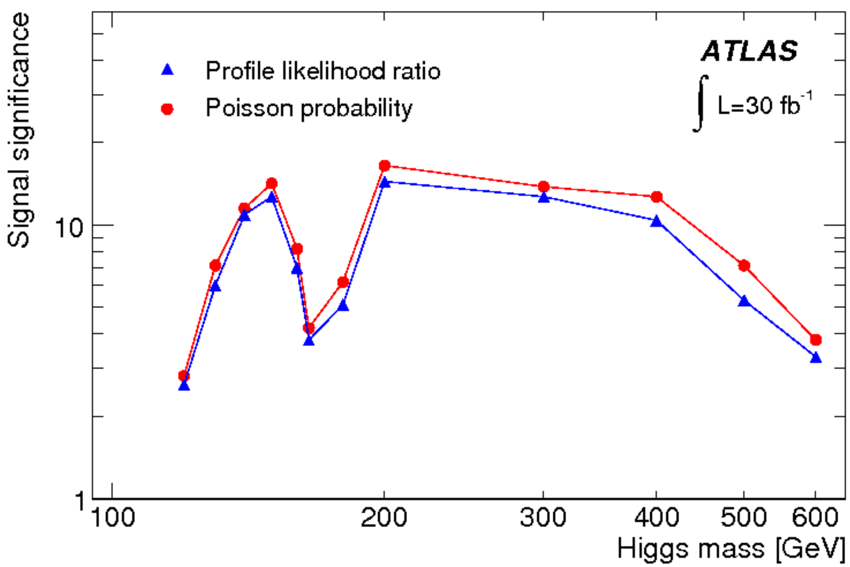




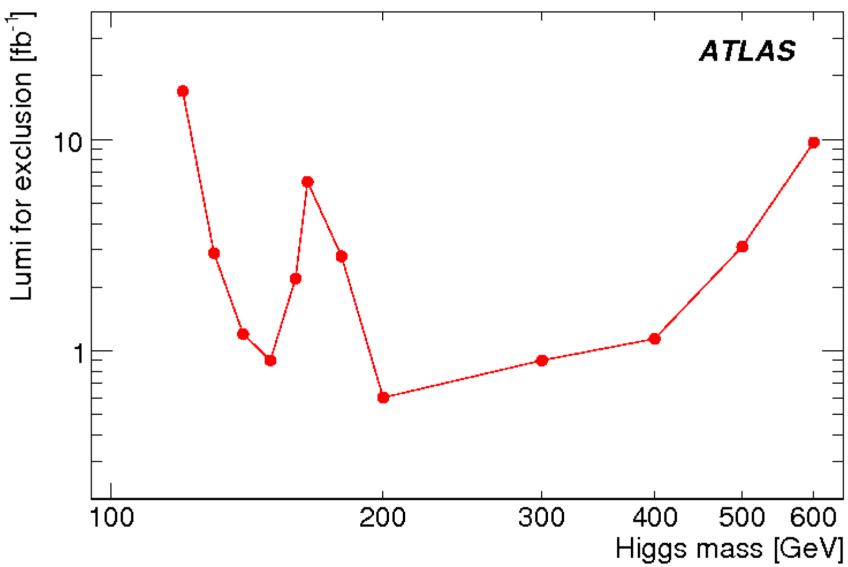
Selection cut	Signal (m_H=130 GeV)		
	4e	4μ	2e2μ
Trigger selection	94.7	95.3	95.7
Lepton preselection	57.0	73.8	66.8
Lepton quality and P_T	24.7	60.5	39.7
Z's mass cut	17.1	42.9	27.6
Calo Isolation	17.1	39.5	25.4
Tracker Isolation	16.5	38.1	24.7
IP cut	15.1	36.5	23.2
H mass cut	12.5±0.3	31.4±0.5	19.2±0.4

Significance Extraction

- Different ways how to extract the signal significance
  - Using Poisson statistics
    - Good description by Monte Carlo needed
  - Use sidebands to determine the background
    - Good description by fit function needed



- Sideband fit result
- Counting result



95% exclusion limit

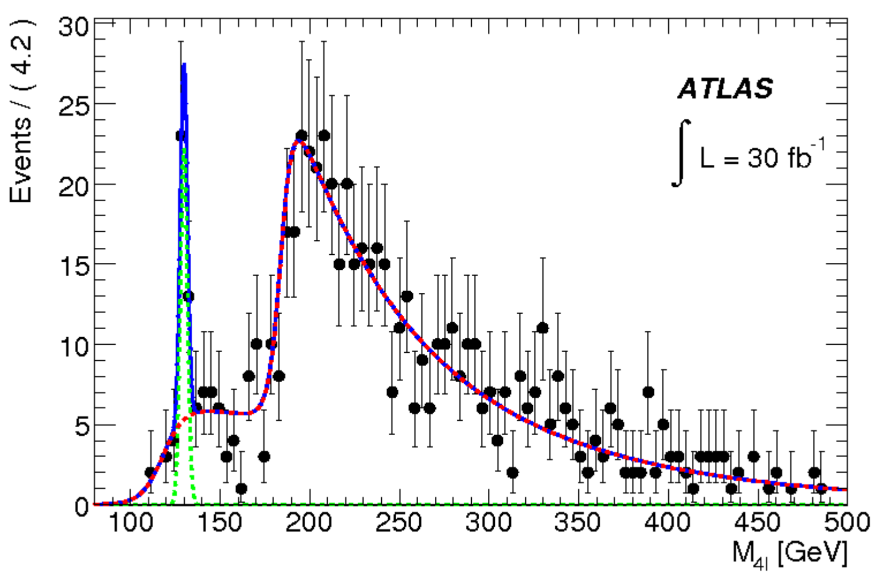
Significance Extraction From A Sideband Fit

- **Background normalization error depends on statistics in the sideband and knowledge of the shape**
  - When using the full sideband fit
    - \+ More statistics
    - \- Larger uncertainty due to complex shape
  - Only use near sideband for the fit
    - \+ Much simpler shape
    - \- Less statistics

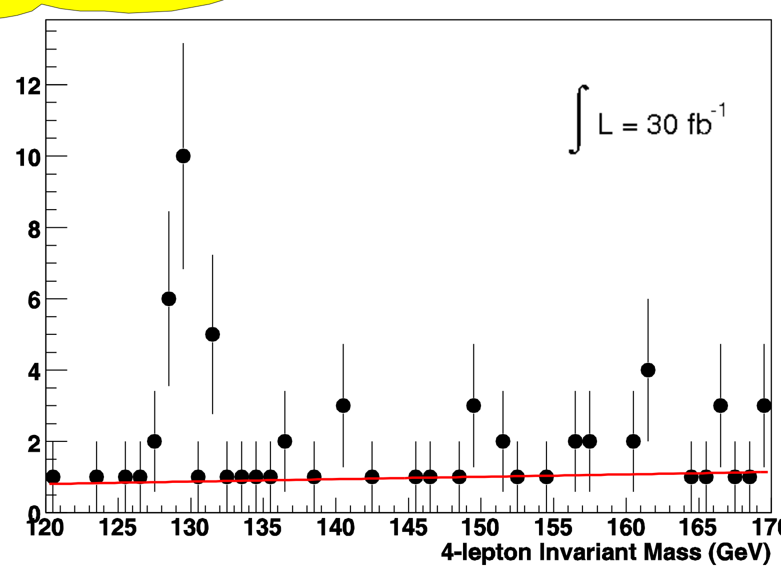
Method	Significance (m_H=130 GeV and ∫L=30 fb-1)
Poisson Statistics (no sys.)	7.1
Profile Likelihood (full sideband)	5.98
Profile Likelihood (near sideband)	4.62
Approx. frequentist	4.69
Numerical frequentist	4.6±0.2

"Background and Signal Estimation for a low mass Higgs Boson at the LHC" Paganis, Tovey EPJC (June/2008)

No look-elsewhere effect yet!



Background fit: Combination of Fermi functions



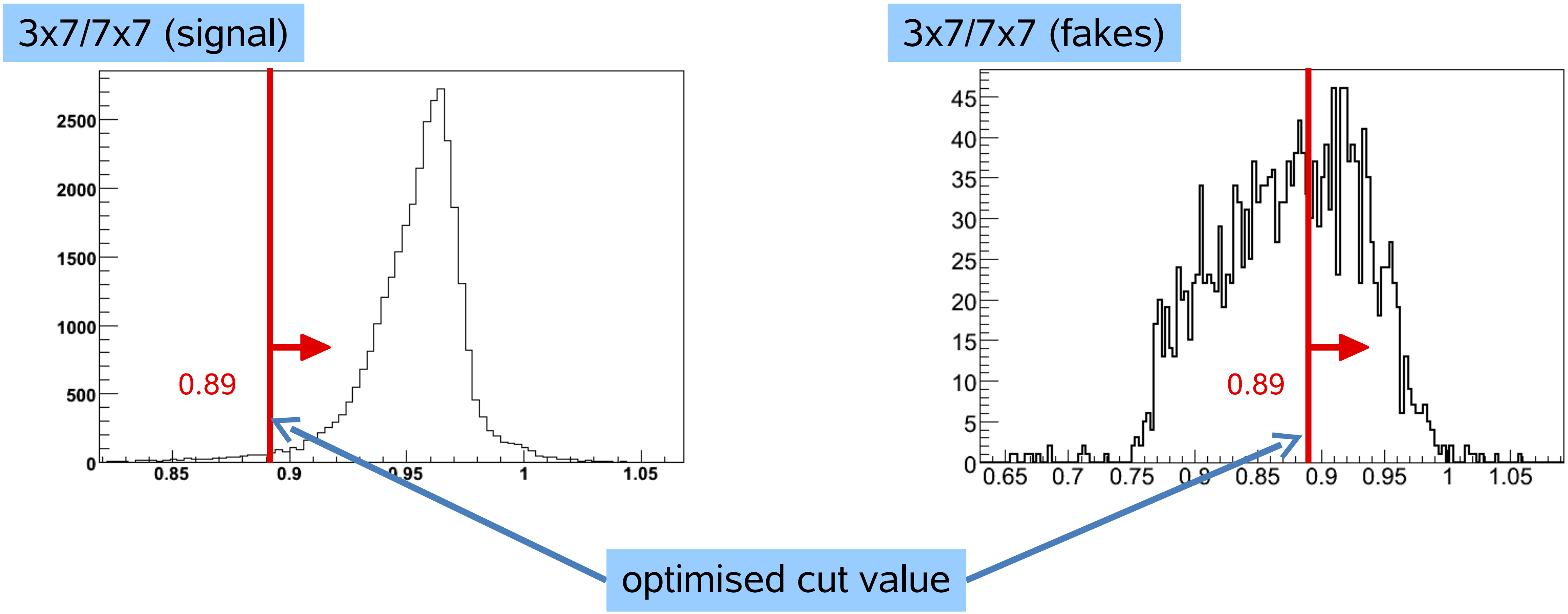
Background fit: straight line

Beyond CSC note

- CSC analysis is done, so are we done yet?
- There is room for improvements e.g.
  - Electron Identification
  - Impact parameter determination
  - Track χ^2
  - Track Isolation
  - ...

Studies On Z→ee Inclusive Sample

- **Problem with standard medium identification cuts on electrons**
  - Z inclusive background ~20 times higher than Zbb and ~2 times higher than ZZ
- **Test of IsEM cuts on signal electrons and fake electrons**
  - Signal electrons: electrons from Z, Z* in a Higgs sample
  - Fake electrons: hadrons passing cuts in the Z→ee inclusive sample



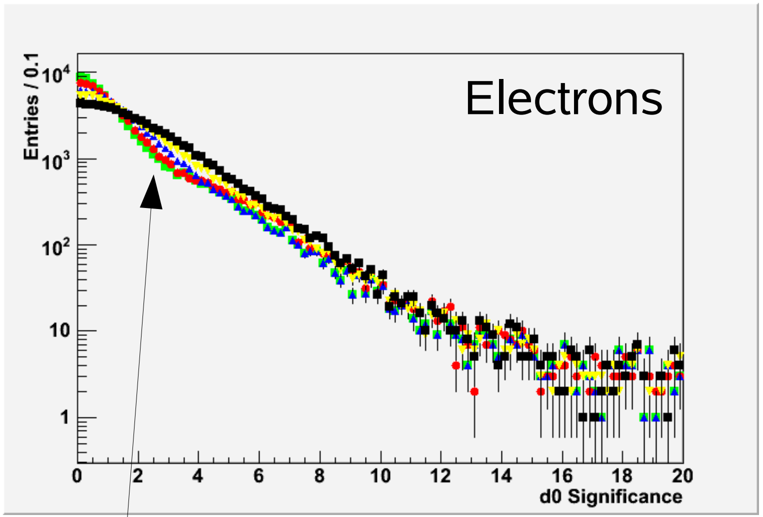
Estimate Of Required Fake Rejection

- We need to make sure, that we control the background
  - Aim: $Z \to ee$ below 10% of $ZZ^* \to 4e$
    - $Z \to ee$ cross section: 1.4 nb
    - $ZZ^* \to 4e$ cross section 8.5 fb with sel.efficiency ~30%
    - ➔ 8.5 fb x 30% x 10% = 1.4 nb x sel.efficiency x $(\text{rejection})^{-1}$
  - Required rejection before selection: ~ 5×10^6
  - Achieved rejection with medium cuts: ~2×10^5
- Composition of the remaining background after medium cuts:
  - ~60% 2 e from Z + 2 fakes
  - ~30% 2 e from Z + 1 fake + 1 e from photon conversion
  - ~10% 2 e from Z + 2 e from photon conversion
- Jet rejection for various IsEM settings is (for pT > 8 GeV):
  - Loose: ~180 (with electron efficiency of 86.9 %)
  - Medium: ~500 (with electron efficiency of 76.0 %)
  - Medium + CaloIso: ~900 (with electron efficiency of 75.8 %)
  - Tight: ~45000 (with electron efficiency of 67 %)

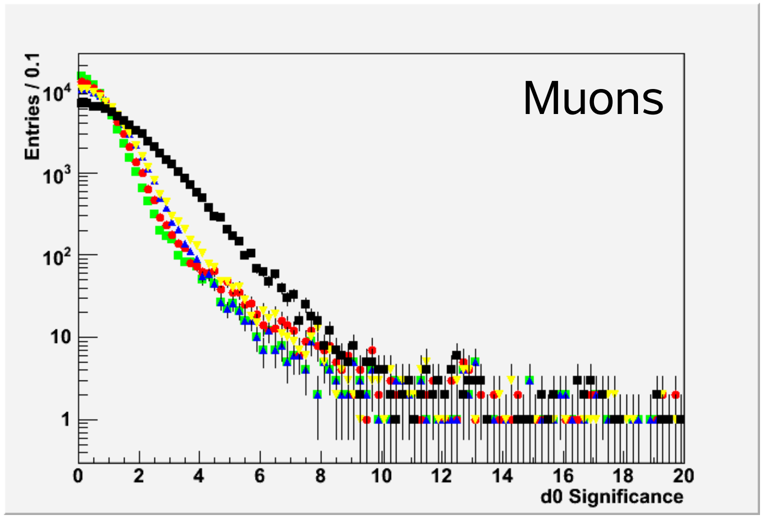
IsEM Optimisation

- Desired jet rejection: ~3200
  - Medium cut too low / tight cut too drastic
- Optimisation of electron cuts for the $H \rightarrow 4l$ analysis
  - Analysing $Z \rightarrow ee$ inclusive sample
  - Cut values derived using TMVA (multivariate analysis)
- Two sets of cuts:
  - Set optimised for high efficiency
    - jet rejection: 3801 → factor 8 improvement to 'medium'
    - Electron efficiency: 79.3% → 5% increase to 'medium'
  - Set optimised for high rejection
    - jet rejection: 8247
    - Electron efficiency: 74.5%
- Remark:
  - Currently this is all back-on-the-envelope estimation
  - Study ongoing with $Z \rightarrow ee$ inclusive sample with 5M events

Impact Parameter Studies

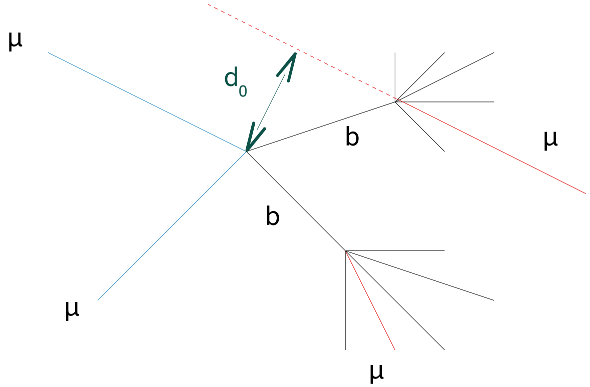


kinks observe in 3) and 4)

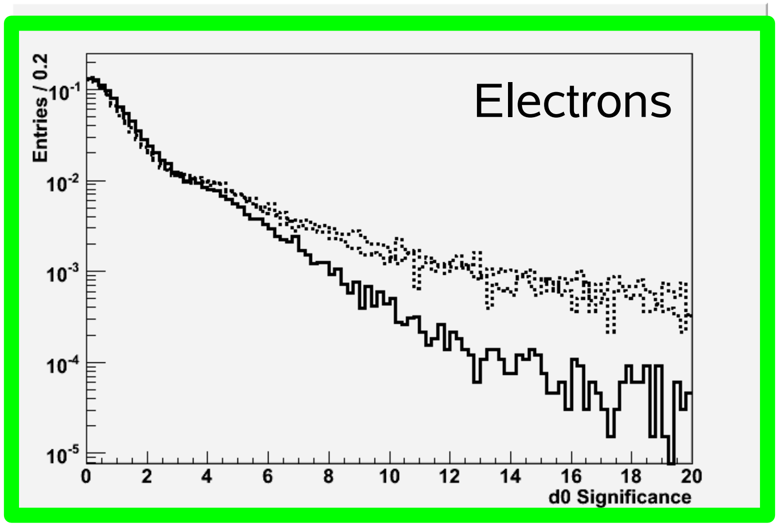


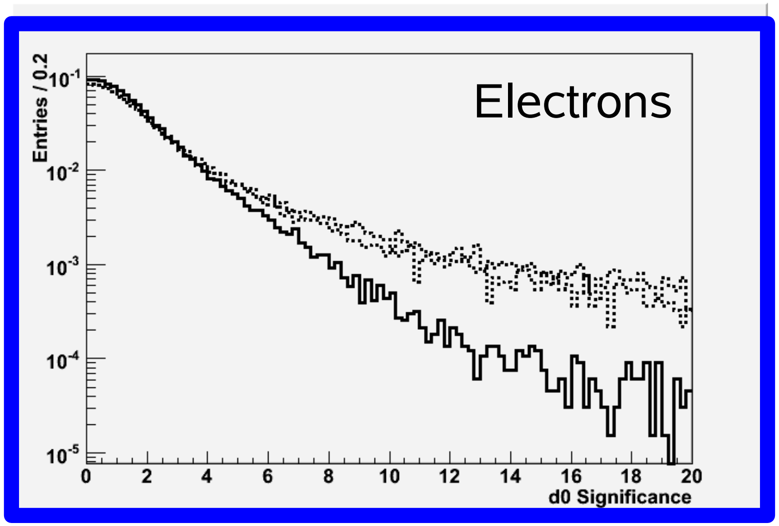
d_0 calculated with respect to...

1) ...nominal interaction point
   - $\sigma(d_0)$ uses only error on reconstructed track
2) ...simulated primary vertex
   - $\sigma(d_0)$ uses only error on reconstructed track
3) ...reconstructed primary vertex using all tracks
   - $\sigma(d_0)$ uses only error on reconstructed track
4) ...reconstructed primary vertex using all tracks (used in CSC note)
   - $\sigma(d_0)$ uses error on reconstructed track and error on primary vertex
5) ...reconstructed primary vertex using all tracks but current one
   - $\sigma(d_0)$ uses error on reconstructed track and error on primary vertex



Impact Parameter for Electrons





d_0 calculated with respect to...

4) ...reconstructed primary vertex using all tracks (used in CSC note)
   - $\sigma(d_0)$ uses error on reconstructed track and error on primary vertex

5) ...reconstructed primary vertex using all tracks but current one
   - $\sigma(d_0)$ uses error on reconstructed track and error on primary vertex

Solid line: signal

Dashed lines: ttbar and Zbbar backgrounds

Histograms are normalized to the individual total numbers of events and then superimposed.

Including the current track in the d_0 calculation can lead to a biased d_0 significance result $d_0/\sigma(d_0)$

First Data

related to ARTEMIS deliverable month: 48

- Verify that the detector works
  - analyse properties as close to the hardware as possible
- Verify lepton identification
  - use well known processes like $Z \to ll$
  - at $10pb^{-1}$ with $\sqrt{s}=14TeV$ about 5k $Z \to ll$ expected (after cuts)
- Prove that we understand the detector
  - verify Standard Model properties
- Prove that we have the background under control
  - Estimate the background from data
- Significances depend on m_H and knowledge of background
  - for $1fb^{-1}$: between 0.5 and 2.5
  - for $5fb^{-1}$: between 1.0 and 5.9

Outlook

- A first step has been done with the CSC note
  - We have seen, that it is feasible
- We have seen, that there is room for improvements
  - Improved electron identification cuts
  - Improved impact parameter treatment
  - Other studies ongoing
- Now we need to prepare ourselves for real data
  - The next months will be an exciting time