Search for the higgs boson decays $\mathrm{H} \longrightarrow ZZ^* \longrightarrow 4l$

4. Februar 2009

Outline

1. Higgs particle
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   - Higgs boson production
   - Higgs boson decays
   - Higgs to $ZZ^{(*)}$ Decay
2. Detection of the Higgs Bosons
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   - Event selection results
   - Significance

Higgs-Brout-Englert-Guralnik-Hagen-Kibble mechanism

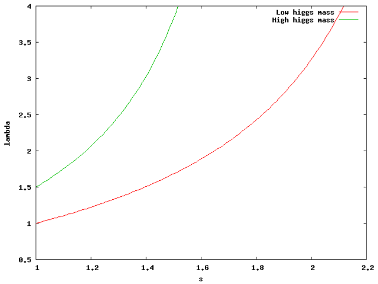
- $SU(2)_L \times U(1)_Y$ gauge invariance of the electroweak theory forbids massive gauge bosons and fermion masses.
- Solution: spontaneous symmetry breaking: $SU(2)_l \times U(1)_Y \rightarrow U(1)_{em}$ by inserting a complex scalar field with negative mass term.
  $V = -\mu^2 \phi^+ \phi + \lambda(\phi^+ \phi)^2$
- The coupling of the scalar field to the fermions and bosons allows to insert boson mass terms into the Standard Model Lagrangian.
- Predicts the mass relation between the W and Z gauge bosons.

Higgs boson properties

- The gauge boson of the scalar field is called the Higgs particle.
- Higgs boson self coupling gives mass to the boson: $m_H = \sqrt{2\lambda}v$; with vacuum expectation value $v = 246 GeV$
- Higgs self coupling parameter λ is a free parameter which needs to be determined by experiment.

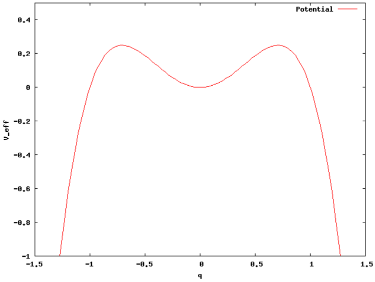
Upper boundary

- The upper boundary for the higgs boson mass given by the renormalization group equation:
  $\frac{d\lambda}{d \ln \frac{s}{s_0}} = 1/2\beta = \frac{1}{16\pi^2}\left(12\lambda^2 + 12\lambda g_t^2 - 12 g_t^4 + gaugeterms\right)$
  - Landau pole Λ dependent of higgs mass
    $m_H = 114 GeV : \Lambda \approx 10^{19} GeV$
    $m_H \geq 800 GeV : \Lambda \approx 1 TeV$

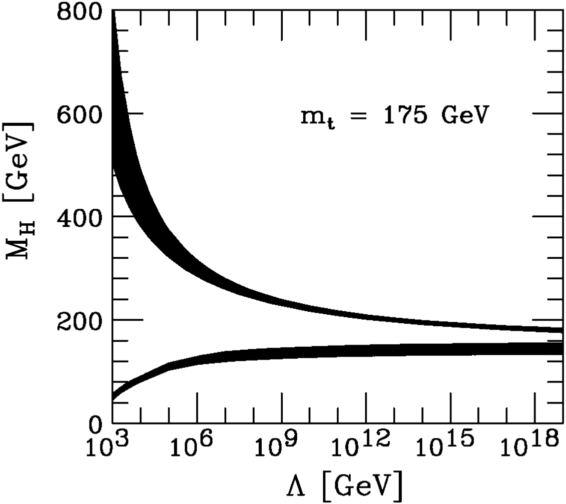


Lower boundary

- $\frac{d\lambda}{d\ln\frac{s}{s_0}} = 1/2\beta = \frac{1}{16\pi^2}\left(12\lambda^2 + 12\lambda g_t^2 - 12g_t^4 + gaugeterms\right)$
- For small λ the running coupling is dominated by the yukawa term of the top quark.
- λ must remain positive at all scales or else the vacuum potential has no lower bound.

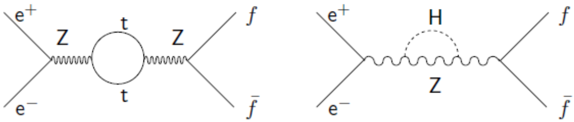


Theoretical boundaries

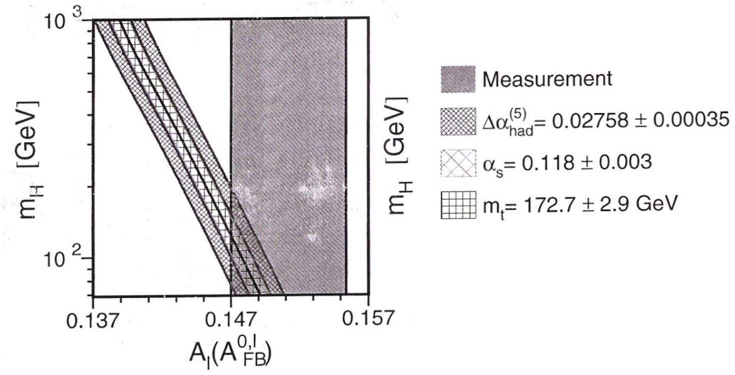


Experimental boundaries

- Experimental boundaries available through direct LEP and Tevatron searches.
- Lower bound by direct search: $m_H = 114 GeV$ (LEP)
- Standard Model observables influenced by higgs mass per radiative corrections.

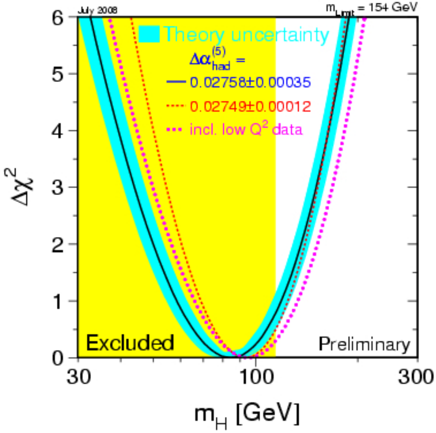


Experimental boundaries

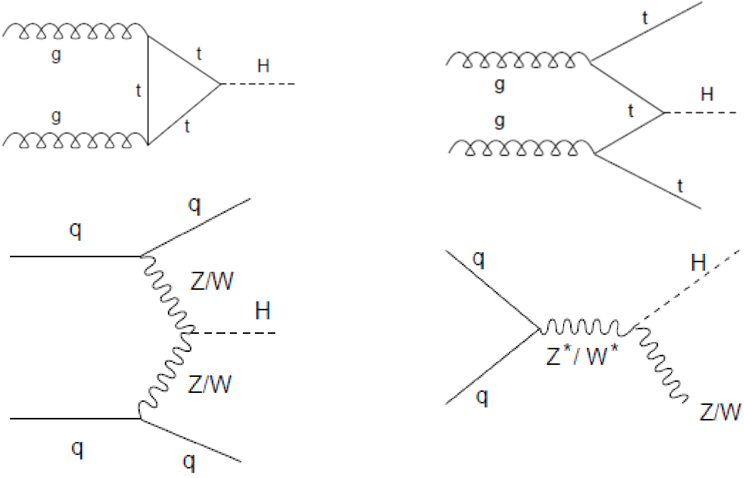


Experimental boundaries

- Combination of all measured parameters give a probable higgs mass: $m_H = 84^{+34}_{-26} GeV$ at 68% confidence level.

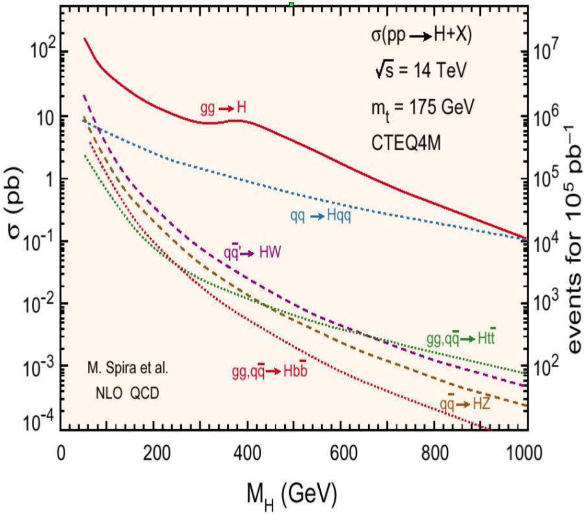


Production processes at the LHC

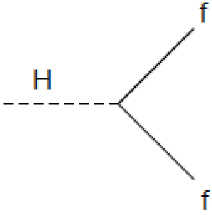


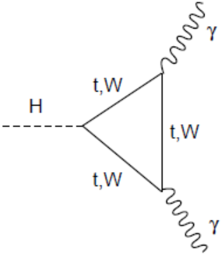
Production processes at the LHC

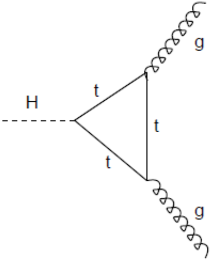
- Cross section computable in terms of higgs mass.

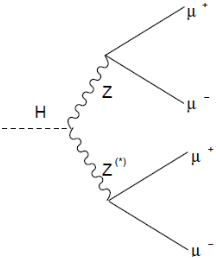


Higgs boson decay processes



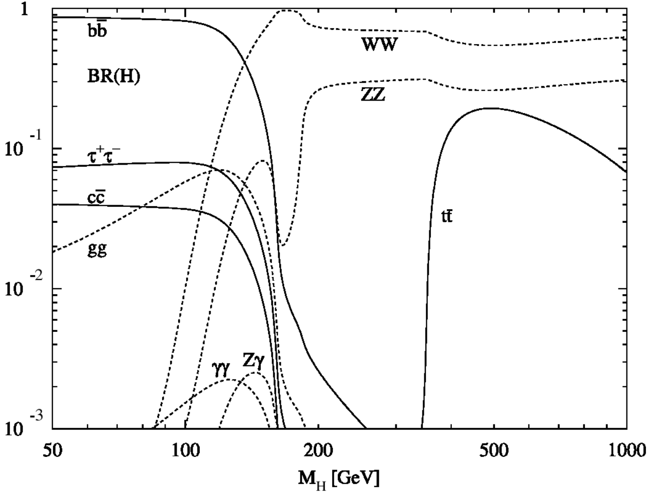




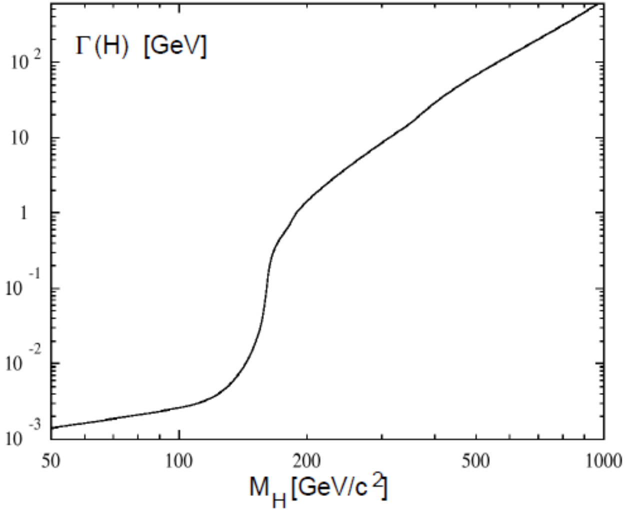


Branching rations

- Branching ratios computable in terms of m_H

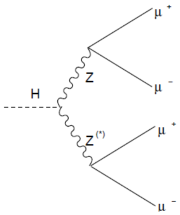


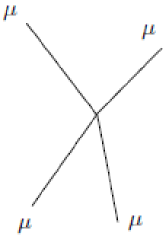
Higgs decay width



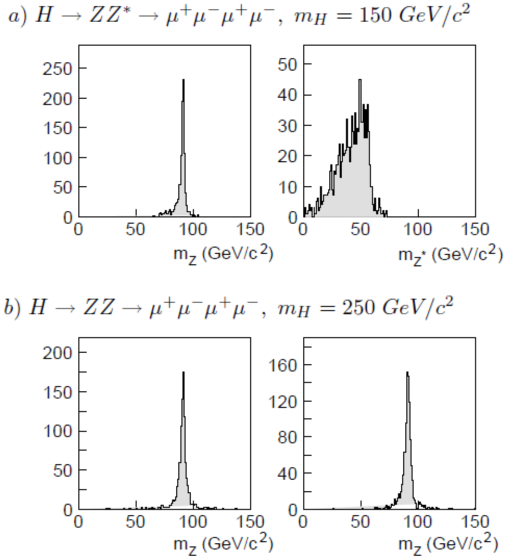
Higgs to $ZZ^{(*)}$ Decay

- Higgs decay in two Z bosons has high branching ration for higgs masses $> 114 GeV$
- Decay of Z bosons to electron and muon pairs have a clear signature in the detector.
- If higgs mass $< 2M_Z$ it can decay over one real and one virtual Z boson.



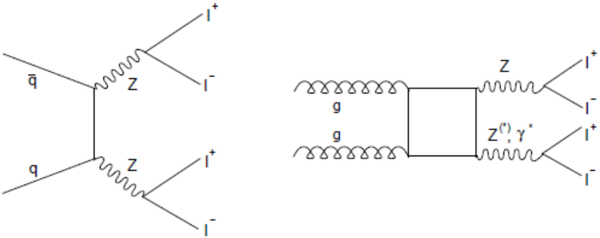


$ZZ^{(*)}$ invariant mass



Irreducible background

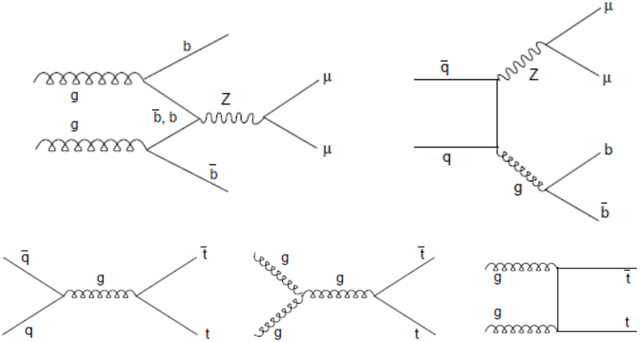
- ZZ background which isn't distinguishable from a higgs signal.



- Cross section higher than higgs cross section but evenly distributed over a wide energy range.
- Events in expected higgs region are an order of magnitude lower than the higgs events.

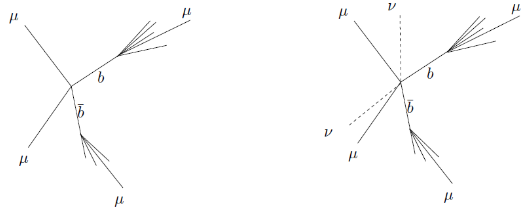
Reducible background

- Background processes with lepton end states have non neglible cross sections in the higgs region.



Background reduction

- Reducible background processes have a different signature than the higgs decays.

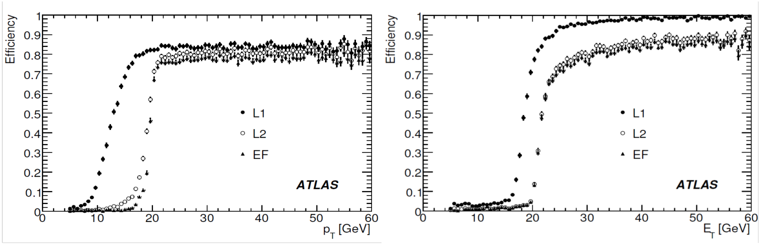


i) $Zb\bar{b} \rightarrow (\mu\mu)(b\bar{b}) \rightarrow (\mu\mu)(\mu j)(\mu j)$ *ii)* $t\bar{t} \rightarrow (Wb)(W\bar{b}) \rightarrow (\mu\nu)(\mu j)(\mu\nu)(\mu j)$

- Possible reduction by data analysis and triggers.

Trigger efficiency

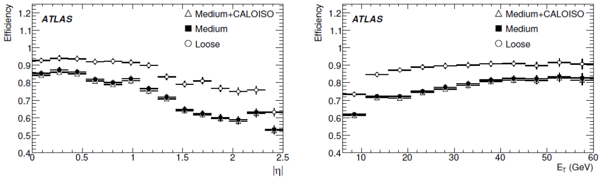
- Trigger selects events with at least one muon with $p_T > 20 GeV$ or at least one isolated electron with $p_T > 22$.



- Trigger captures higgs and background events with an efficiencies greater than 95%.

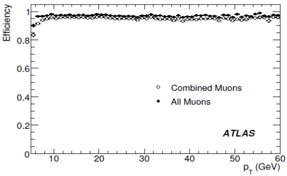
Electron offline reconstruction

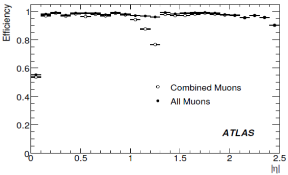
- The electron reconstruction sets certain quality restraints on the electron signals:
  cluster shape, shower shape, track association with clusters, track quality.
- LooseElectron definition less strict than MediumElectron. Used for electrons from heavz higgs decays with high p_T.



Muon offline reconstruction

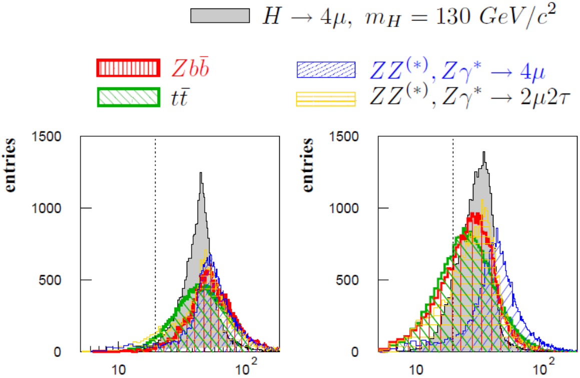
- Muon reconstruction combines hits in the muon spectrometer and the inner detector.
- Tracks which can't be reconstructed completely in the muon spectrometer are extrapolated from the inner detector.



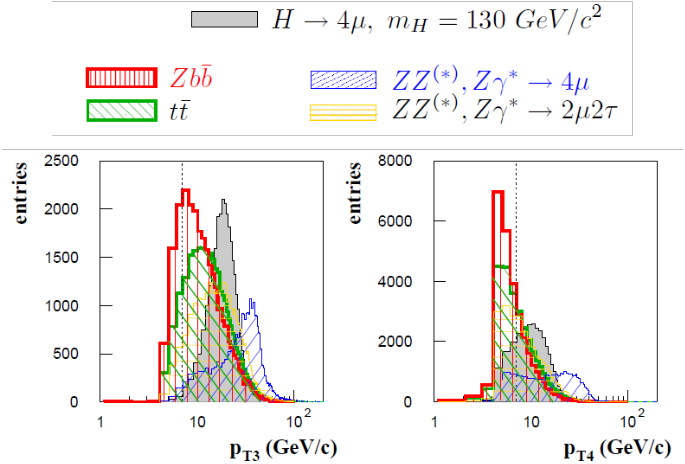


Event preselection

- Electrons must satisfy MediumElectron conditions. If higgs mass is greater than $180 GeV/c^2$ the LooseElectron condition is enough.
- Require two Leptons pairs of same flavour and opposite charge which have $p_T > 7 GeV/c$ and at least two leptons must have $p_T > 20 GeV/c$.



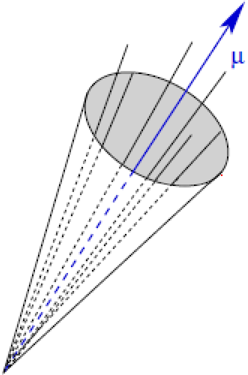
Event preselection



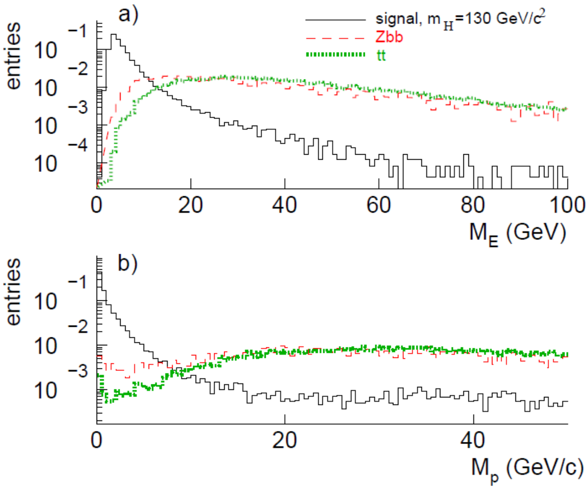
Track isolation

- In $Zb\bar{b}$ and $t\bar{t}$ background processes muons originate from semileptonic b quark decays.
- These leptons are surrounded by jets.
- The leptons from Z decays are isolated.

  - Calculate the sum of the energy and momenta in a cone excluding the lepton.
  - Cone size $\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2}$
  - $M_E = max_{i=1..N}\left(\sum E_T\right)_i$
  - $M_p = max_{i=1..N}\left(\sum p_T\right)_i$

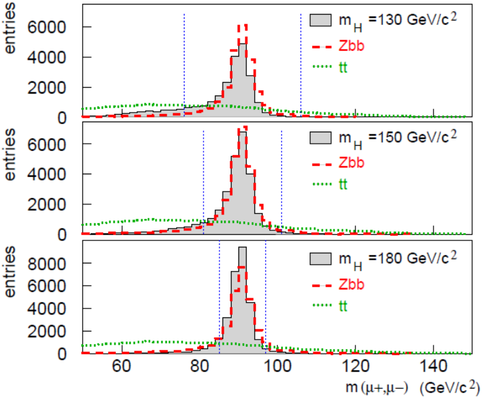


Track isolation



Invariant mass selection

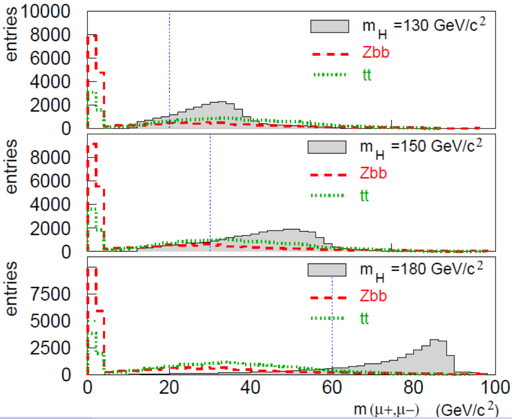
- Invariant mass of at least two leptons from real Z decays are distributed around 91GeV.



- Allows cut to reduce $t\bar{t}$ background. $Zb\bar{b}$ not reducible because of real Z boson involved.

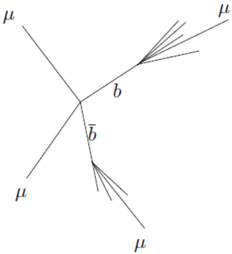
Invariant mass selection

- Invariant mass of other lepton pair reduces background further because jet leptons have lower energies.
- If the higgs mass allows two real Z bosons, reduction increases due of the sharper mass distribution.

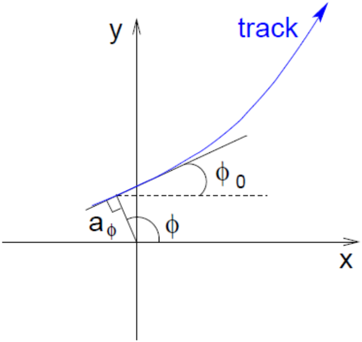


Impact parameter

- Background processes involving b quark jets come from displaced vertices because of the comparably high lifetime of the b quarks.

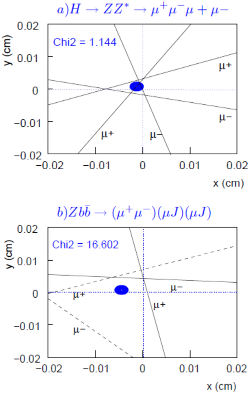


$Zb\bar{b} \rightarrow (\mu\mu)(b\bar{b}) \rightarrow (\mu\mu)(\mu j)(\mu j)$

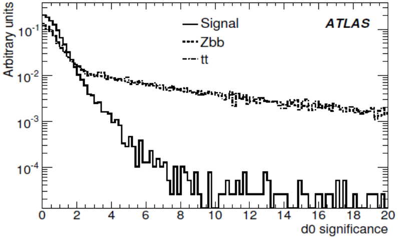


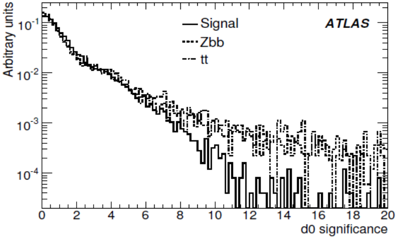
Impact parameter

- Knowledge of primary vertex not known and impact parameter measurement is imprecise.
- A fit of the lepton tracks to a primary vertex increases precision.
- Background rejection possible by discriminating at certain values of the distance of tracks to the vertex.



Impact parameter

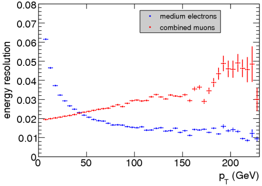


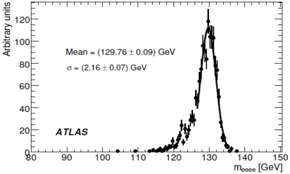


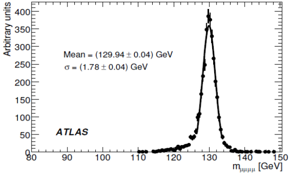
- Electron impact parameter measurement is less precise because of higher bremsstrahlung.

Higgs mass reconstruction

- Invariant mass of lepton quadruplet equals higgs mass distribution.
- Invariant mass of electron quadruplet biased to lower masses because of Bremsstrahlung and lower E_T resolution.







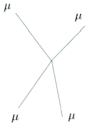
- Further background reduction possible by defining a signal region around higgs mass.
- $|M_{ll1} - M_Z| < \Delta M_{12}, \quad M_{ll2} > M_{34}$

Event selection results

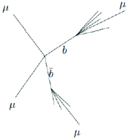
- Combination of all methods allow it to decrease the reducible background to values lower than the irreduclibe background.

Selection cut	Signal [%]		
	$4e$	4μ	$2e4\mu$
Trigger selection	94.7	95.3	95.7
Lepton preselection	57.0	73.8	66.8
Lepton quality & p_T	24.7	60.5	39.7
Z mass cuts	17.1	42.9	27.6
Track isolation	16.5	38.1	24.7
Impact parameter	15.1	36.5	23.2
H mass cut	12.5 ± 0.3	31.4 ± 0.5	19.2 ± 0.4

Event selection results



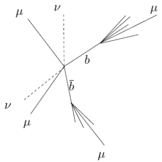
$ZZ^{(*)}, Z\gamma^* \to 4\mu$



$Zb\bar{b} \to (\mu\mu)(b\bar{b}) \to (\mu\mu)(\mu j)(\mu j)$

Selection cut	ZZ [%]			$Zb\bar{b}$ [%]		
	$4e$	4μ	$2e4\mu$	$4e$	4μ	$2e4\mu$
Trigger selection	96.6	96.6	96.6	91.4	91.4	91.4
Lepton preselection	13.8	17.6	31.4	2.6	9.4	12.0
Lepton quality & p_T	7.3	16.0	21.9	0.11	2.1	1.7
Z mass cuts	6.9	14.8	20.2	0.047	0.085	0.12
Track isolation	6.8	13.6	19.2	0.013	0.033	0.044
Impact parameter	6.2	13.0	17.8	0.0056	0.011	0.018
H mass cut	0.052	0.13	0.12	0.0016	0.0012	0.030

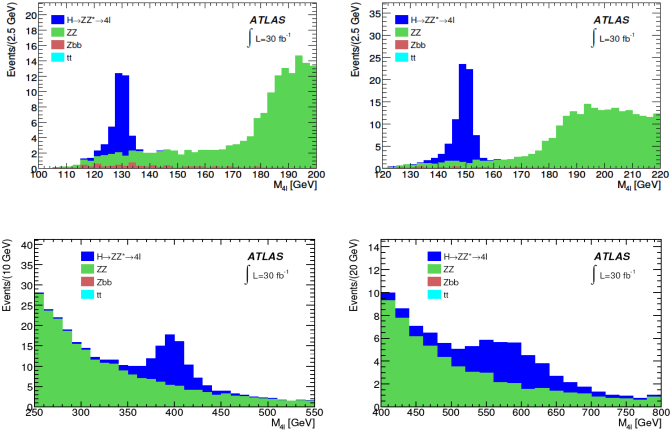
Event selection results



$t\bar{t} \rightarrow (Wb)(W\bar{b}) \rightarrow (\mu\nu)(\mu j)(\mu\nu)(\mu j)$

Selection cut	$t\bar{t}$ [%]		
	$4e$	4μ	$2e4\mu$
Trigger selection	75.1	75.1	75.1
Lepton preselection	1.0	4.7	10.1
Lepton quality & p_T	0.0068	0.73	0.58
Z mass cuts	0.0016	0.20	0.10
Track isolation	0.00026	0.00025	0.001
Impact parameter	0.00026	< 0.0006	0.00026
H mass cut	< 0.0006	< 0.0006	< 0.0006

Event selection result



Significance

- Around 20 higgs signals expected with $30fb^{-1}$ (about 3 years)
- Significance greater 5 expected for most higgs masses.
  160GeV significance low because of the decrease in the branching ratio due to the W resonanz.