Search for the Standard Model Higgs at LHC (Part III)

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September 2009

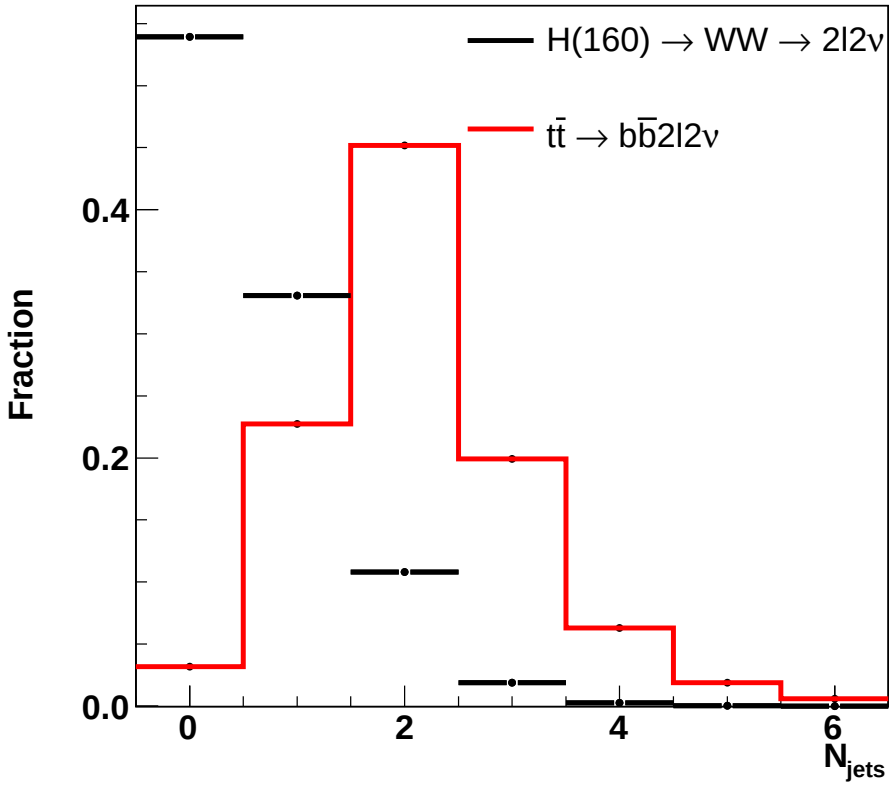
Taller de Altas Energías

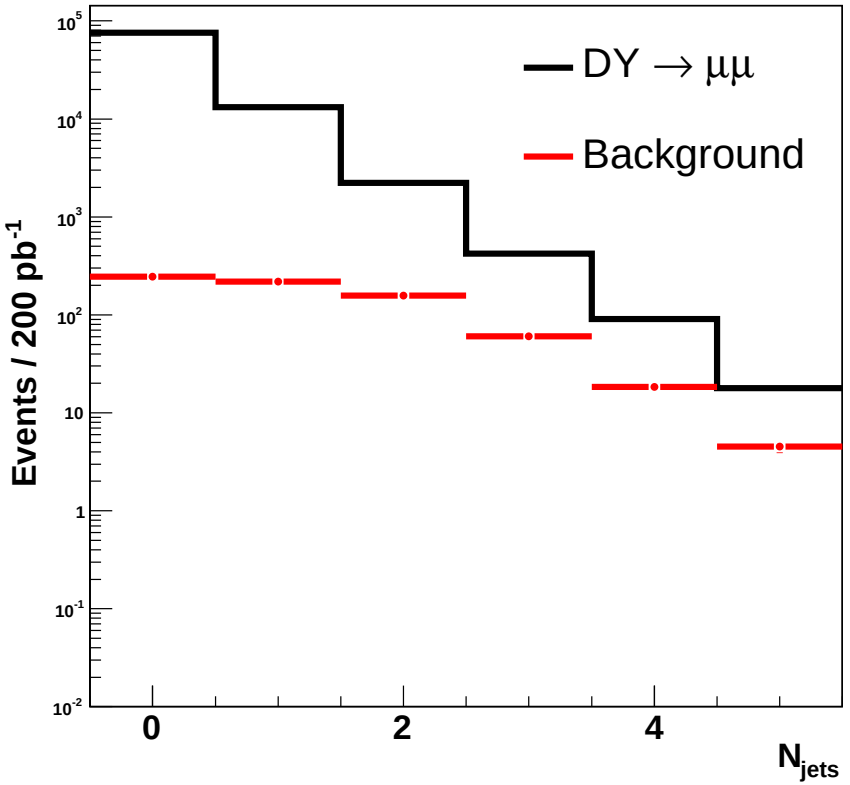
$H(+0/1\ jet) \rightarrow WW \rightarrow 2l2\nu$

$H \to WW \to 2l2\nu$ (Summary)

- Main features:
  - 2 high energetic leptons
  - large $E_{\mathrm{T}}^{\mathrm{miss}}$
  - little jet activity
  - low $\Delta\phi_{\ell\ell}$ and $m_{\ell\ell}$ values
- Backgrounds: main discriminating variables
  - WW: $\Delta\phi_{\ell\ell}/m_{\ell\ell}$
  - $t\bar{t}$: no central jets, $\Delta\phi_{\ell\ell}/m_{\ell\ell}$
  - $Z \to \ell\ell$: $E_{\mathrm{T}}^{\mathrm{miss}}$, $\Delta\phi_{\ell\ell}/m_{\ell\ell}$
  - $W + jets$: lepton id
  - WZ/ZZ: more than 2 leptons in the final state, $E_{\mathrm{T}}^{\mathrm{miss}}$
- Analysis:
  - pros: large signal cross-section
  - cons: no mass peak, systematics play very important role

$H \rightarrow WW \rightarrow 2l2\nu$ (Jets)

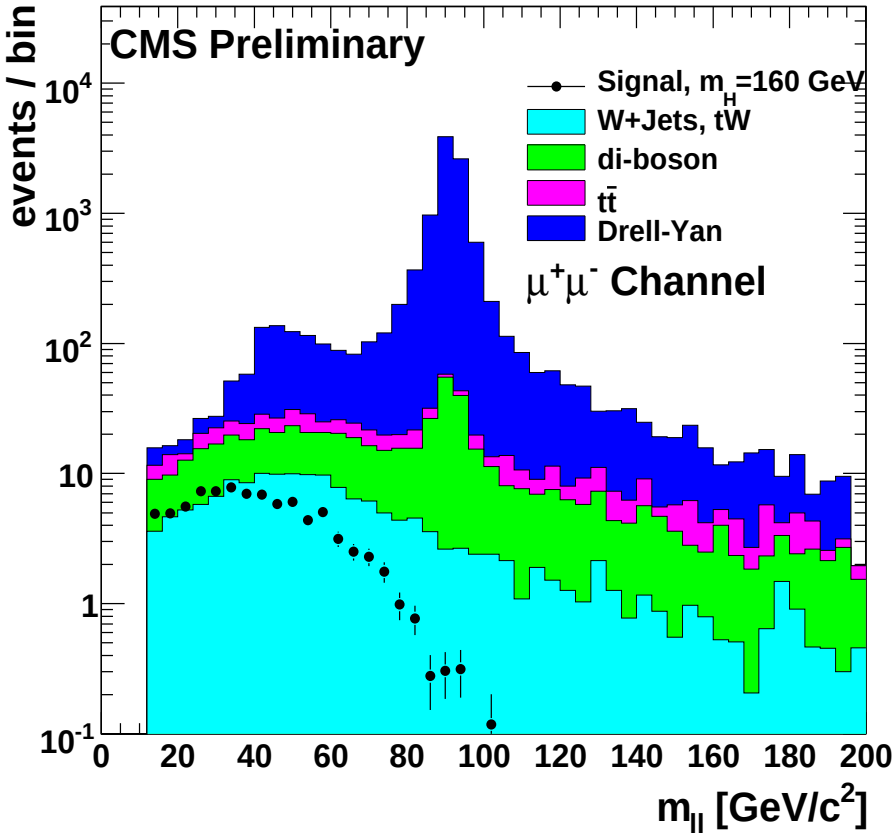


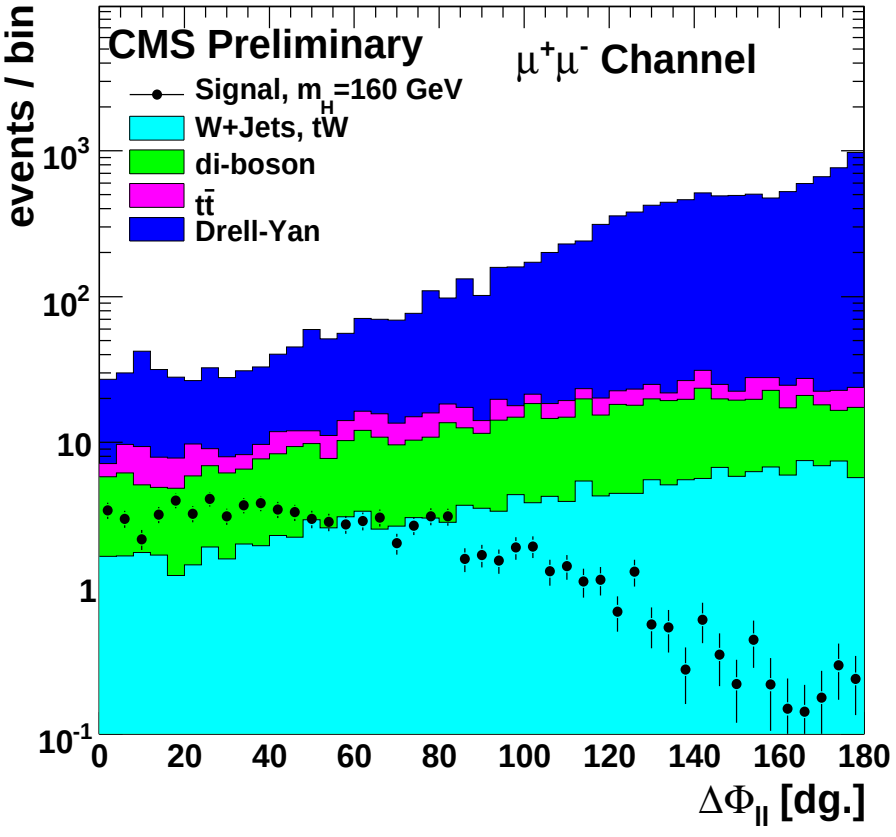


- Clear difference between signal and $t\bar{t}$
- Can be studied in data by looking at $Z + jets$ events

$H \rightarrow WW \rightarrow 2l2\nu$ (Preselection-I)

$\Delta\phi_{\ell\ell}$ & $m_{\ell\ell}$ after some preselection + jet veto

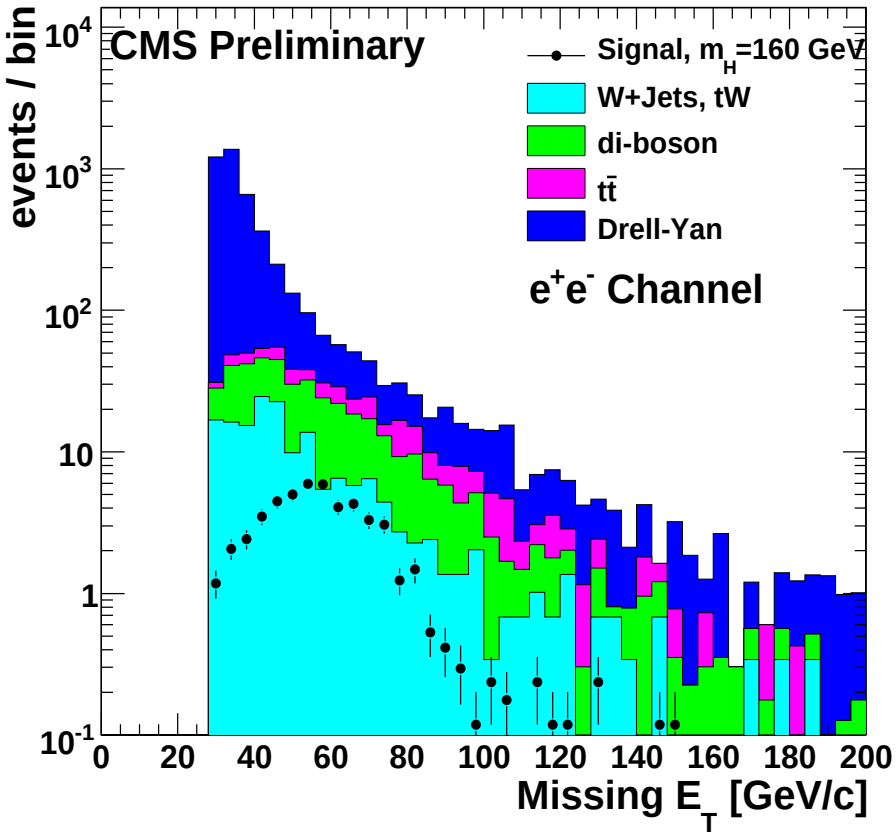


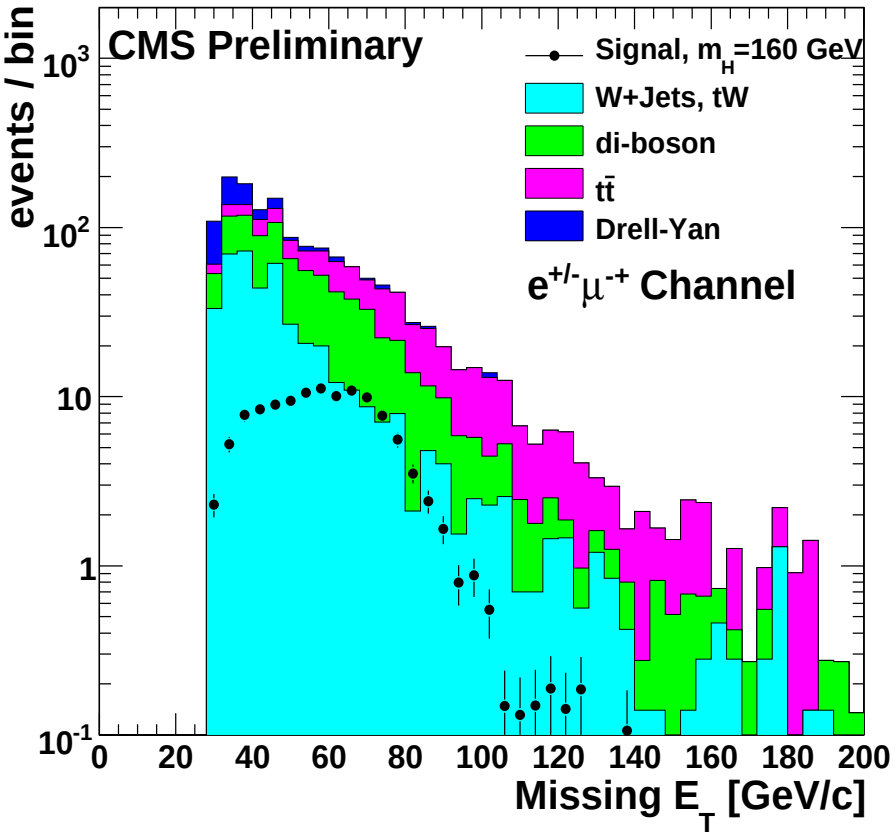


Distributions normalized at 1 fb^{-1} at $\sqrt{s} = 14TeV$

$H \rightarrow WW \rightarrow 2l2\nu$ (Preselection-II)

E_T^{miss} for ee and $e\mu$ channels after some preselection + jet veto

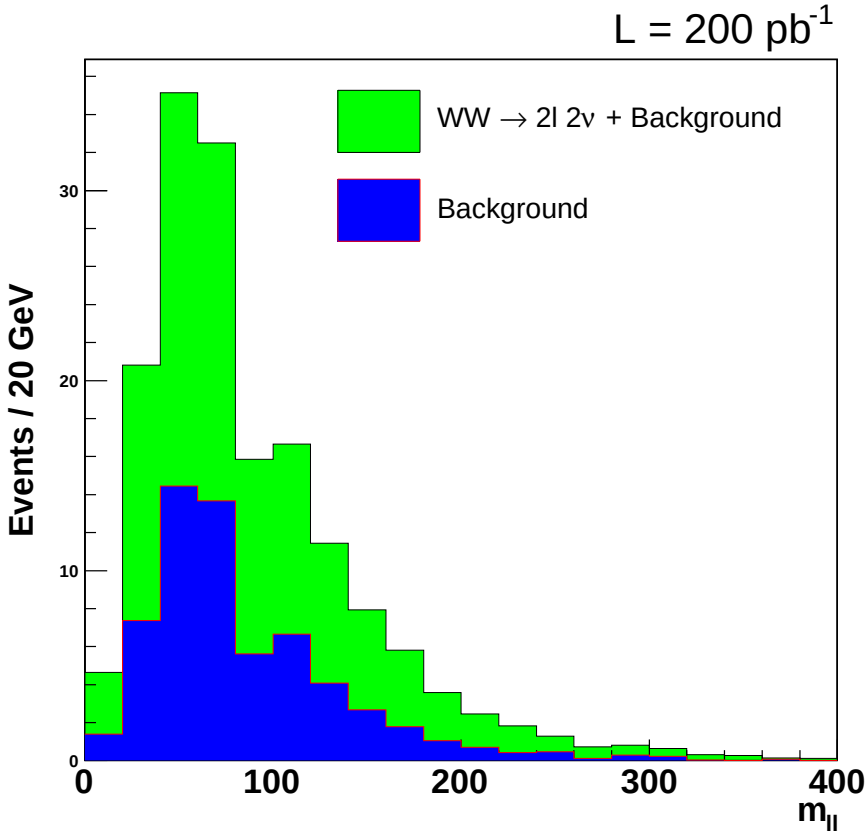




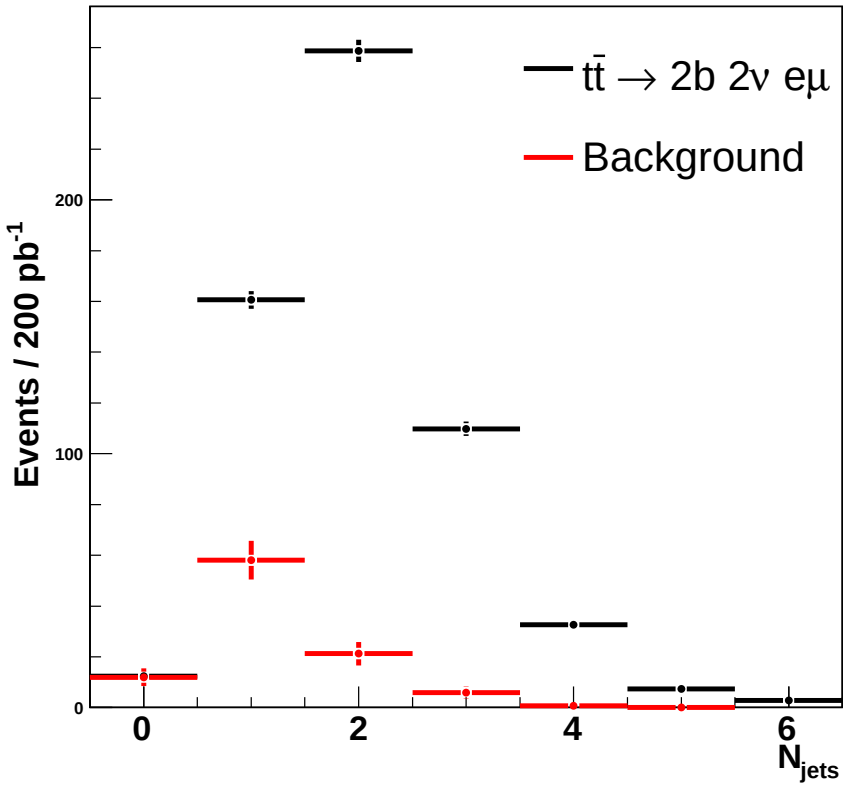
Distributions normalized at 1 fb^{-1} at $\sqrt{s} = 14TeV$

$H \rightarrow WW \rightarrow 2l2\nu$ (Control Regions)

$WW \rightarrow 2l2\nu$



$t\bar{t} \rightarrow 2\ell 2\nu 2b$

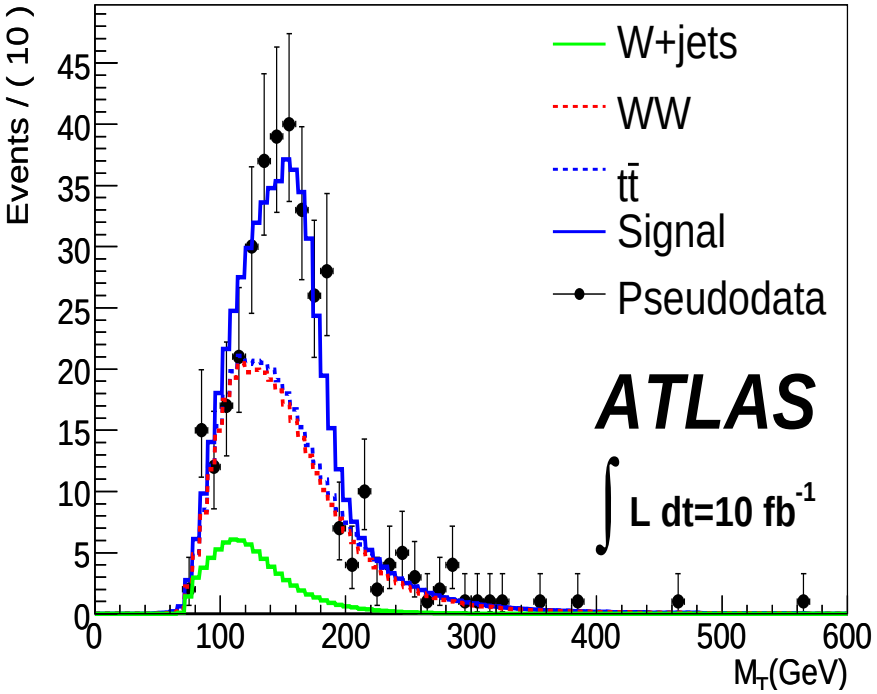


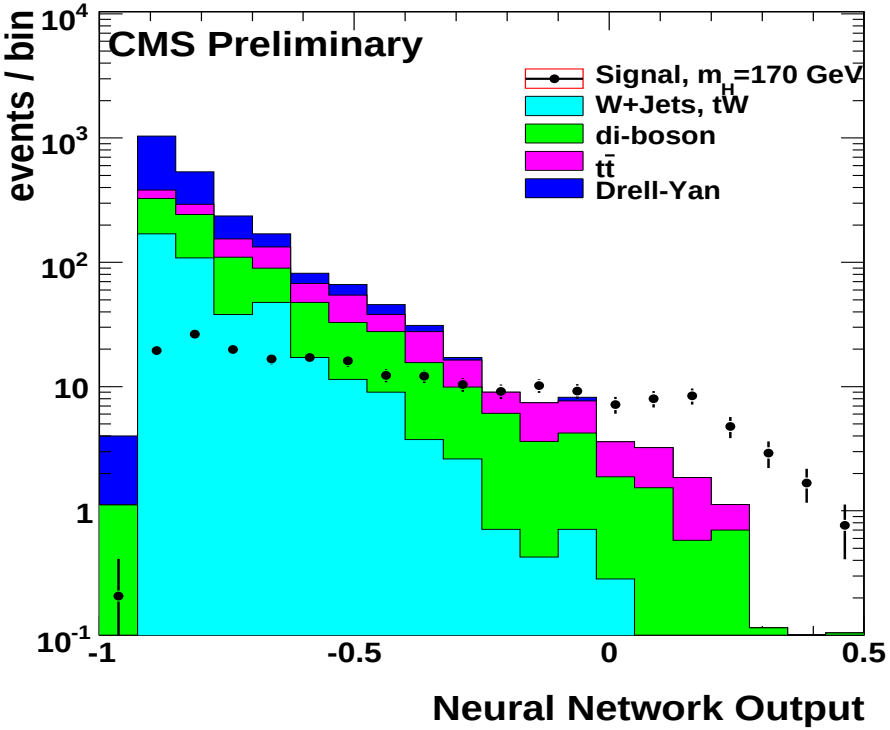
Be aware, they maybe be 'contaminated' from Higgs signal

- for WW, $m_{\ell\ell} < 80$ GeV/c^2
- for $t\bar{t}$, $N_{jet} = 0$

$H \rightarrow WW \rightarrow 2l2\nu$ (Final Selection)

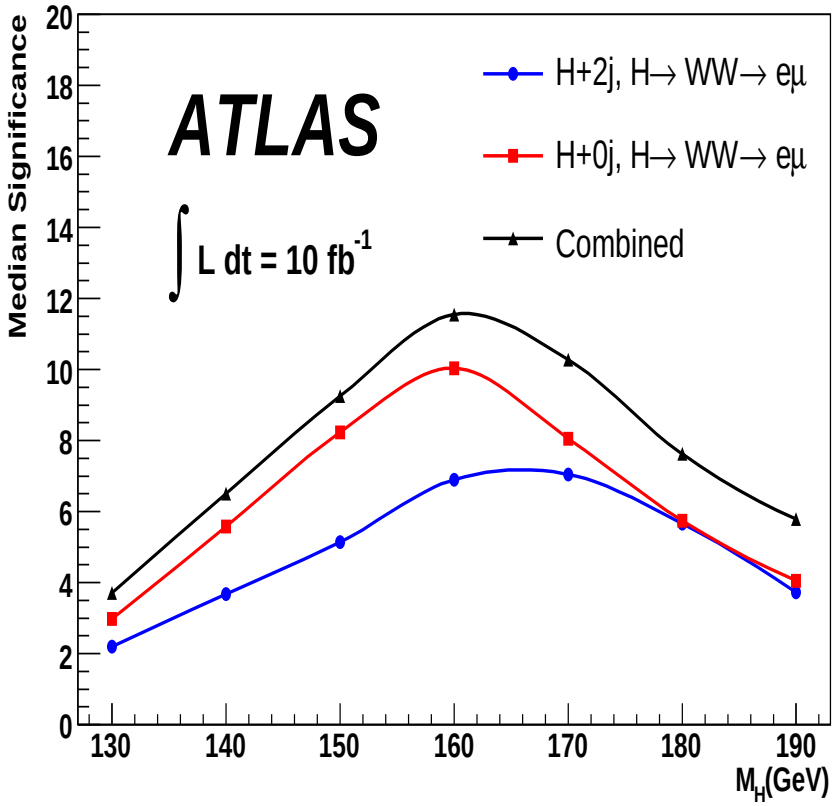
- Different approaches:
  - (1) cut based
  - (2) multivariate analysis
  - (3) multidimensional fits
- (1) is the safest approach, but with a (very?) limited sensitivity

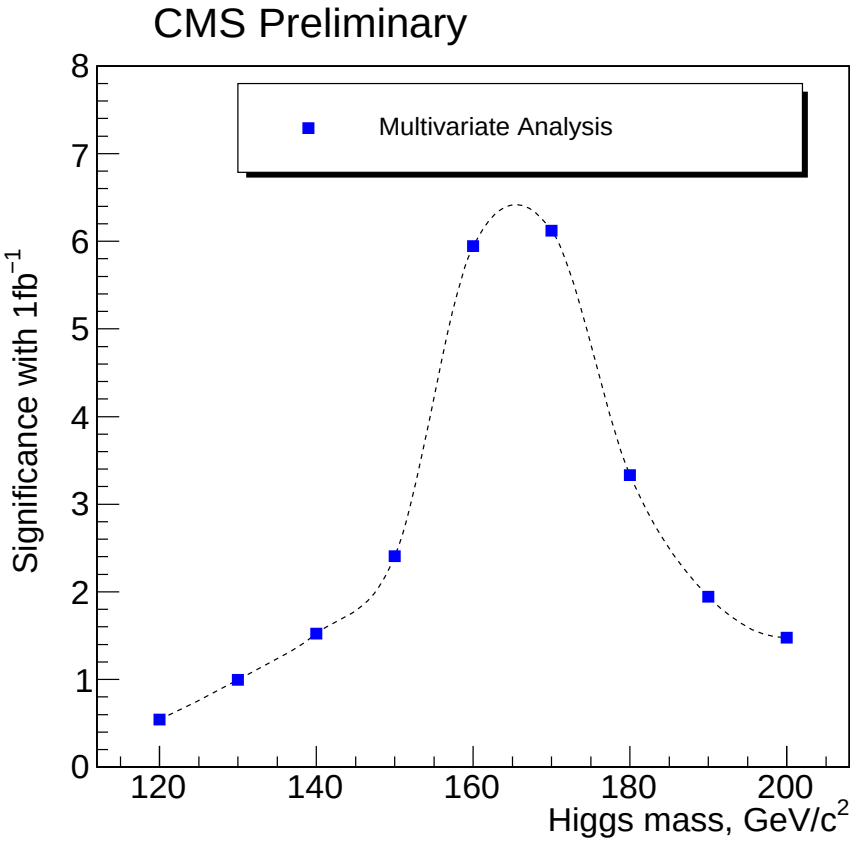




$H \rightarrow WW \rightarrow 2l2\nu$ (Results)

Results for $\sqrt{s} = 14TeV$





Improvements are still possible to be added into these analyses

On the other hand real data may be more difficult

~50-100 signal events after all requirements

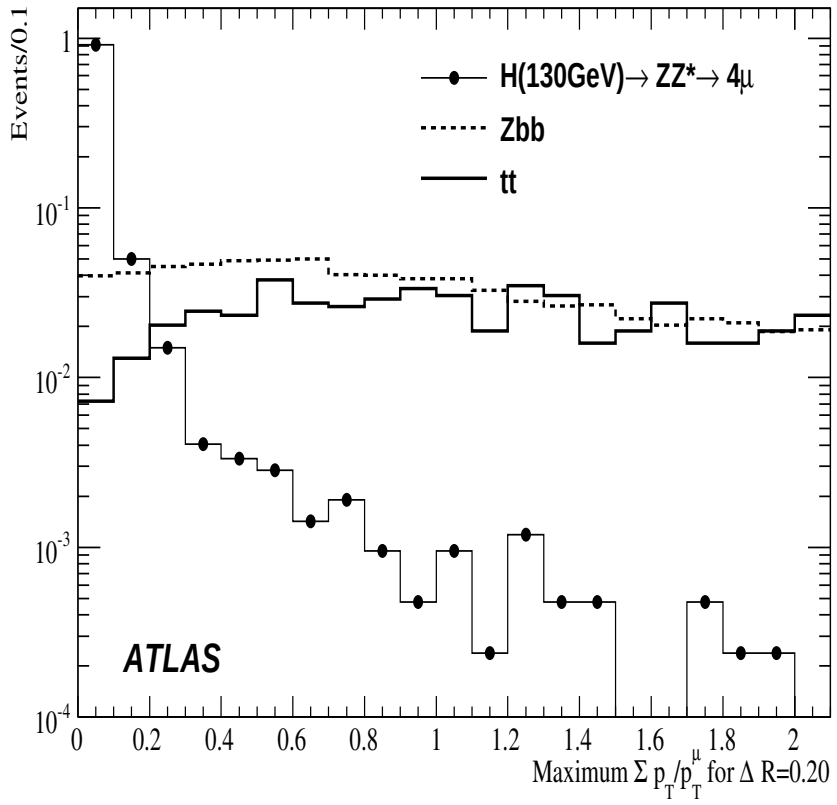
$$H \rightarrow ZZ \rightarrow 4l$$

$H \rightarrow ZZ \rightarrow 4l$ (Summary)

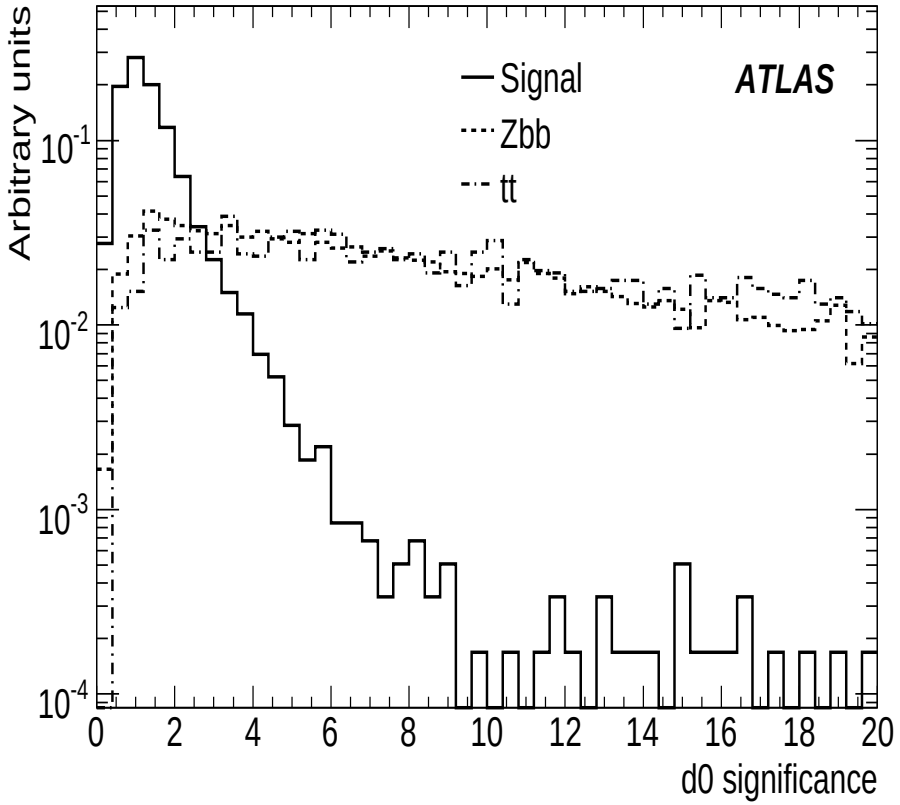
- Main features:
  - ☞ 4 high energetic leptons
  - ☞ low E_T^{miss}, little jet activity (in principle no need to use it)
- Backgrounds: main discriminating variables
  - ☞ ZZ: almost irreducible, just different mass shape
  - ☞ $t\bar{t}$ & Zbb: lepton id (only two prompt leptons in the final state)
- Analysis:
  - ☞ pros: mass peak, very low backgrounds
  - ☞ cons: low signal yield, need to push the lepton id to the limit

$H \rightarrow ZZ \rightarrow 4l$ (Discriminant Variables)

$Iso^{\mu}_{Trk}/p^{\mu}_{T}$

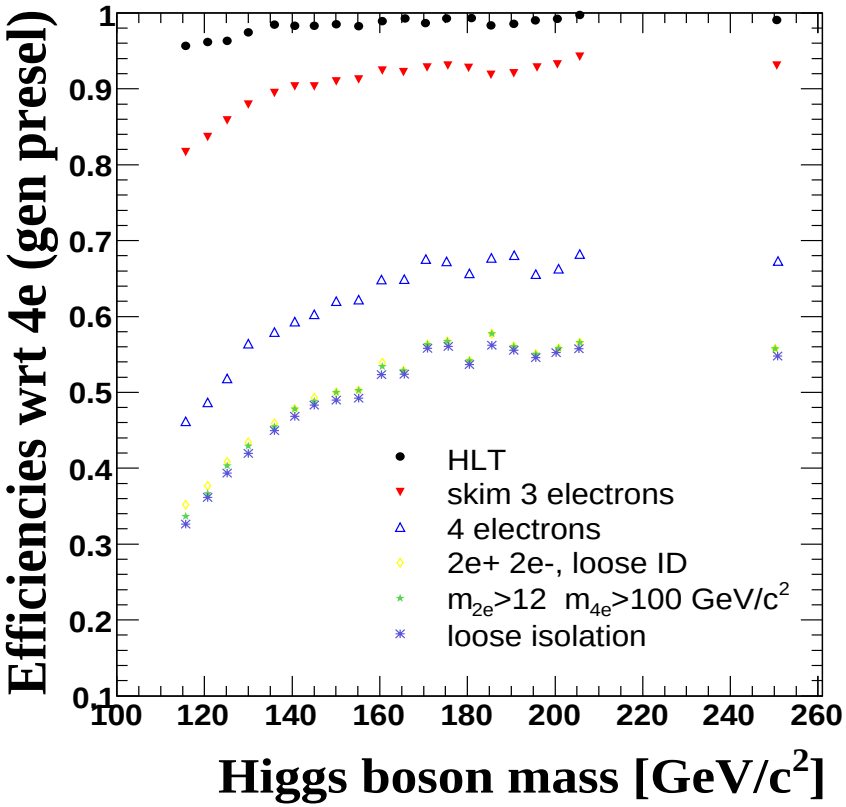


$d0^{\mu}/\sigma^{\mu}_{d0}$

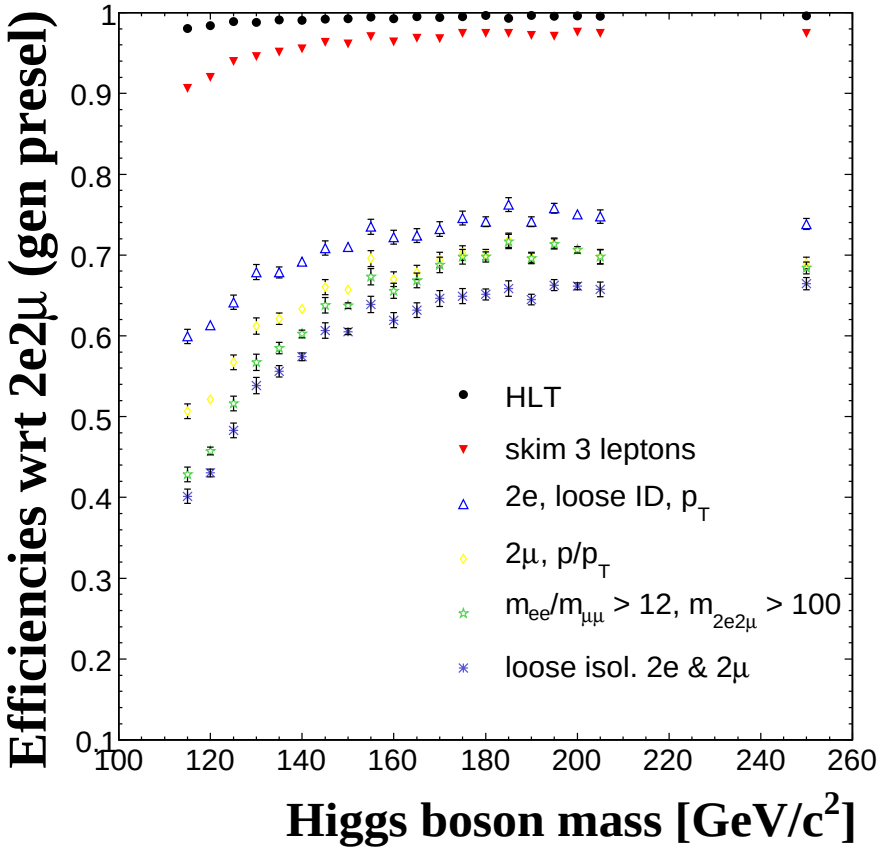


$H \rightarrow ZZ \rightarrow 4l$ (Preselection-I)

4e

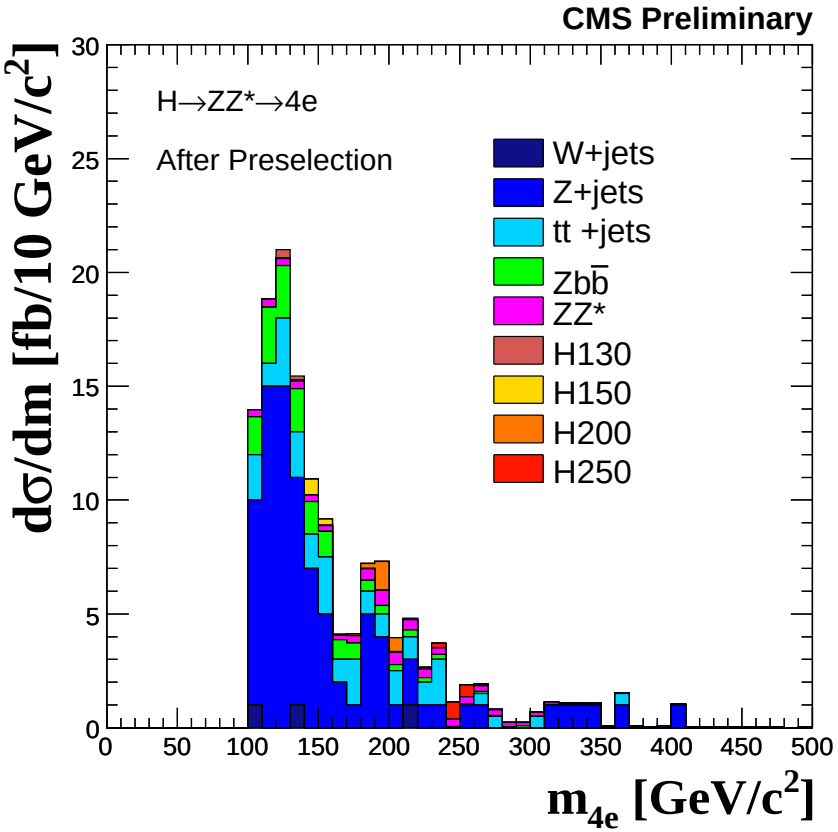


2e2μ

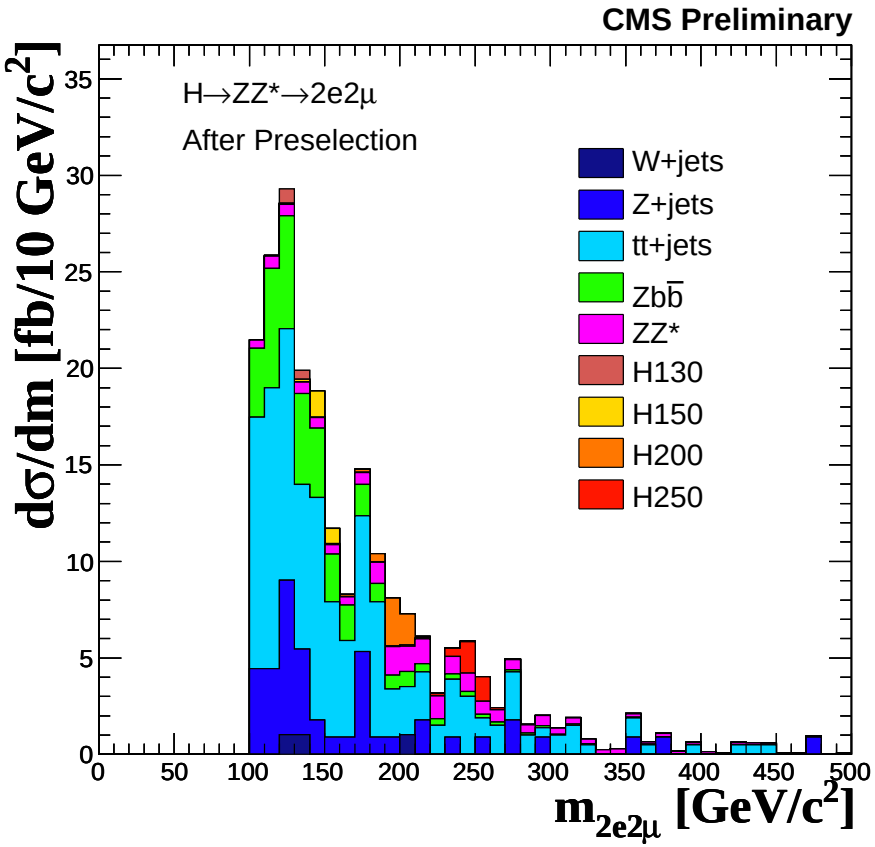


$H \rightarrow ZZ \rightarrow 4l$ (Preselection-II)

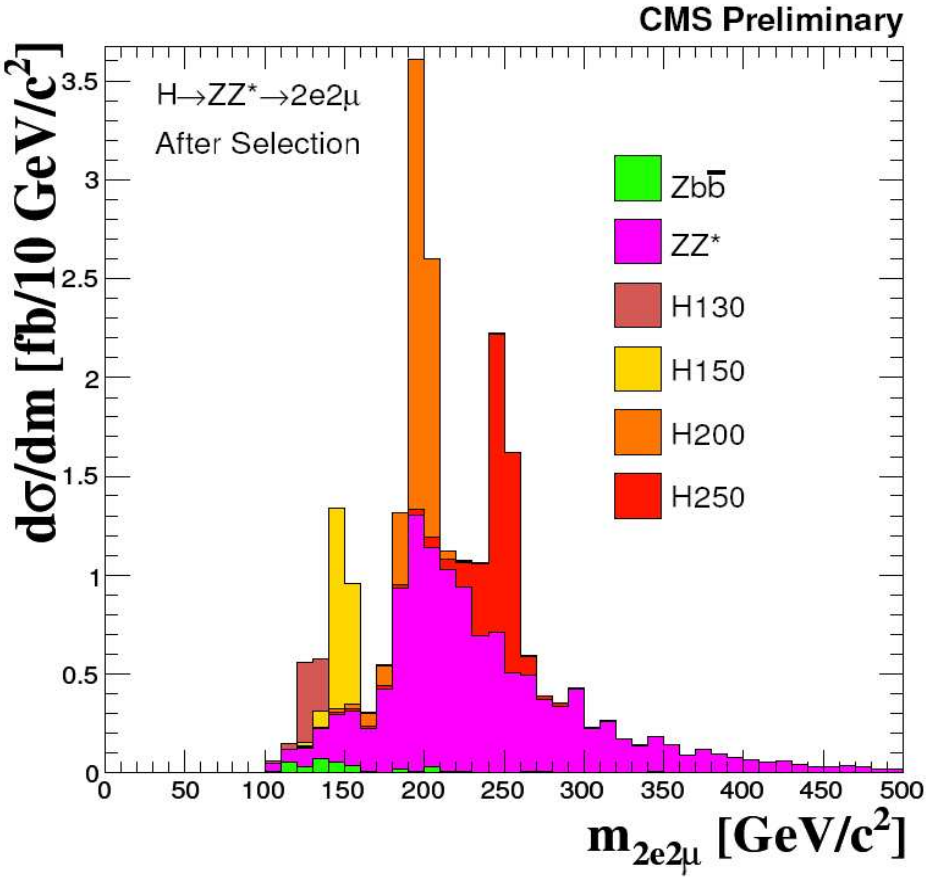
4μ

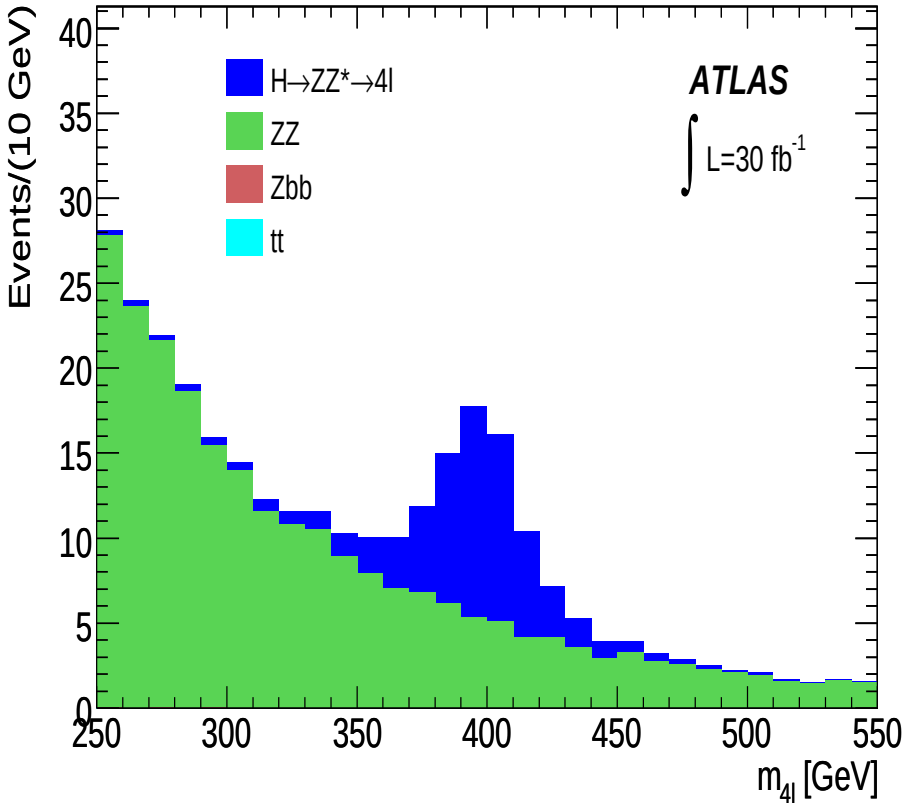


$2e2\mu$



$H \rightarrow ZZ \rightarrow 4l$ (Mass Distributions)

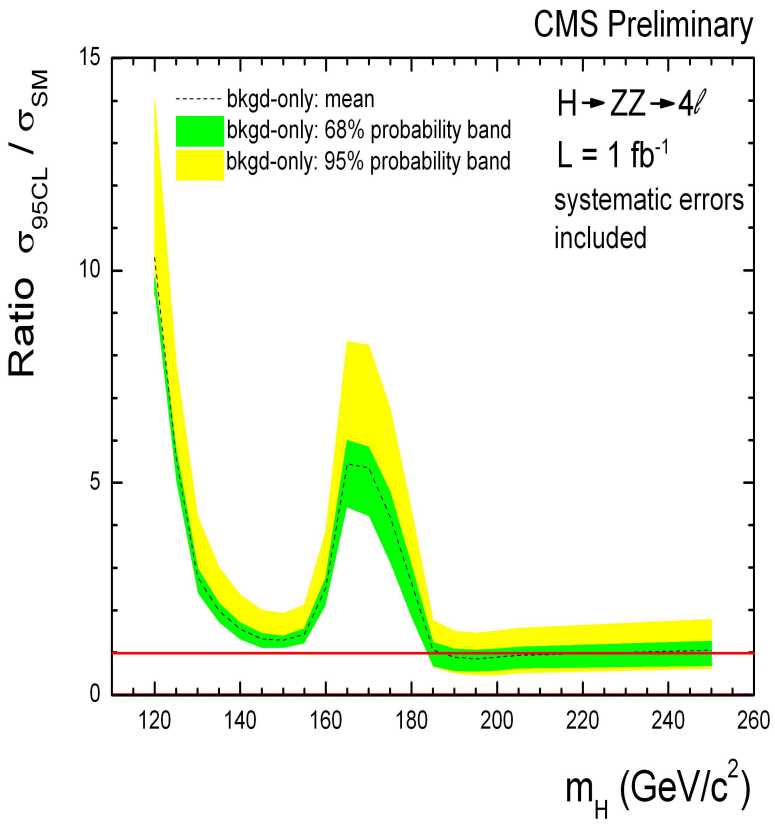


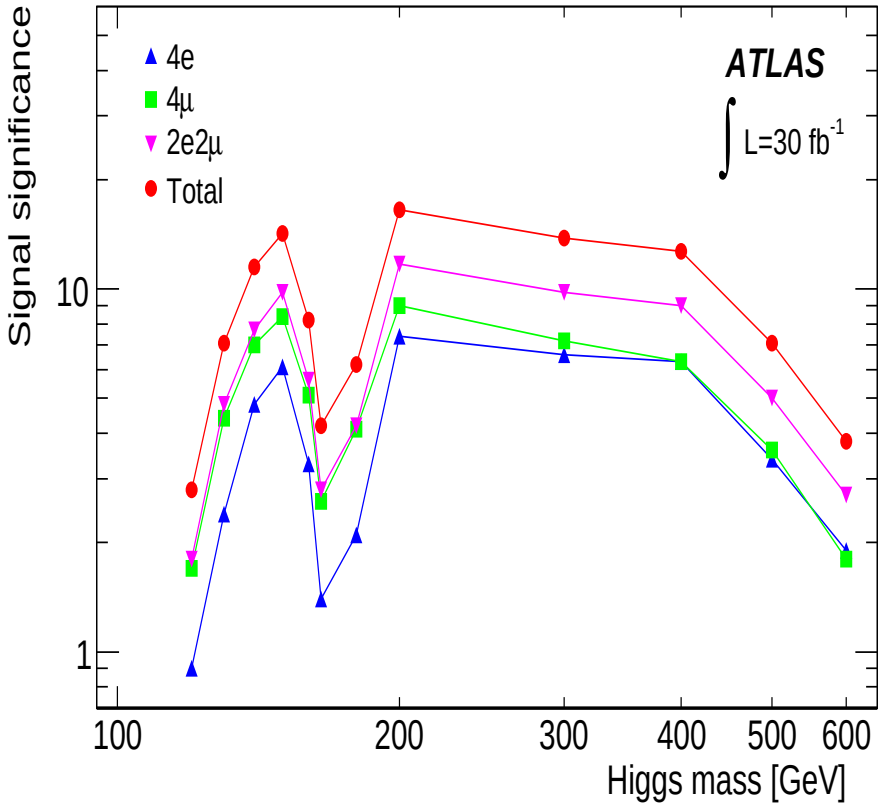


Higgs mass distributions wider for larger masses:

- worse resolution
- Higgs natural width becomes relevant

$H \rightarrow ZZ \rightarrow 4l$ (Results)





- Cross-section limits for “low” luminosity
- Signal significance for “high” luminosity

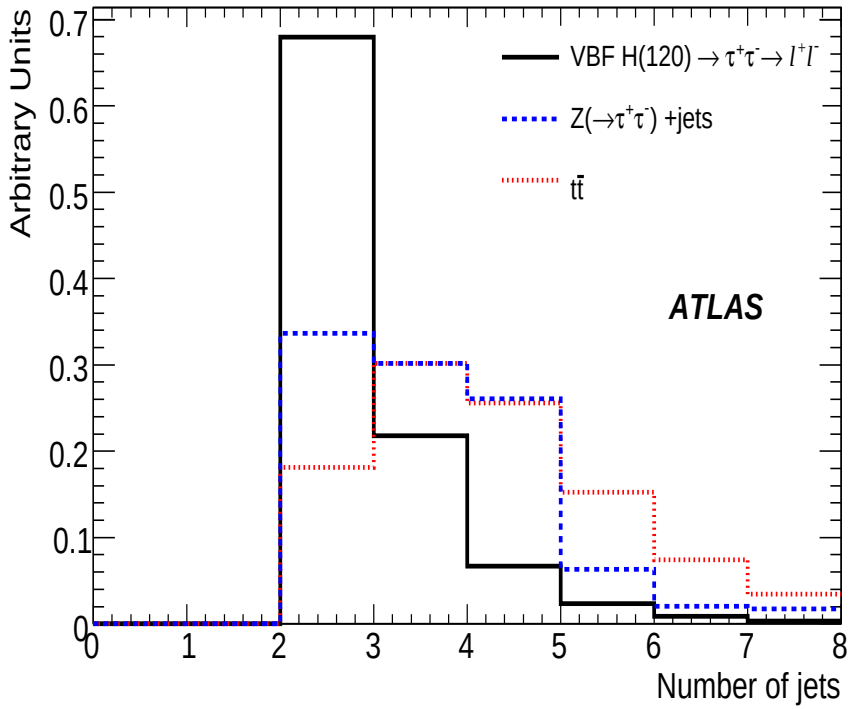
~5-10 signal events after all requirements with 1 fb^{-1}

$qqH,\ H \rightarrow \tau\tau$

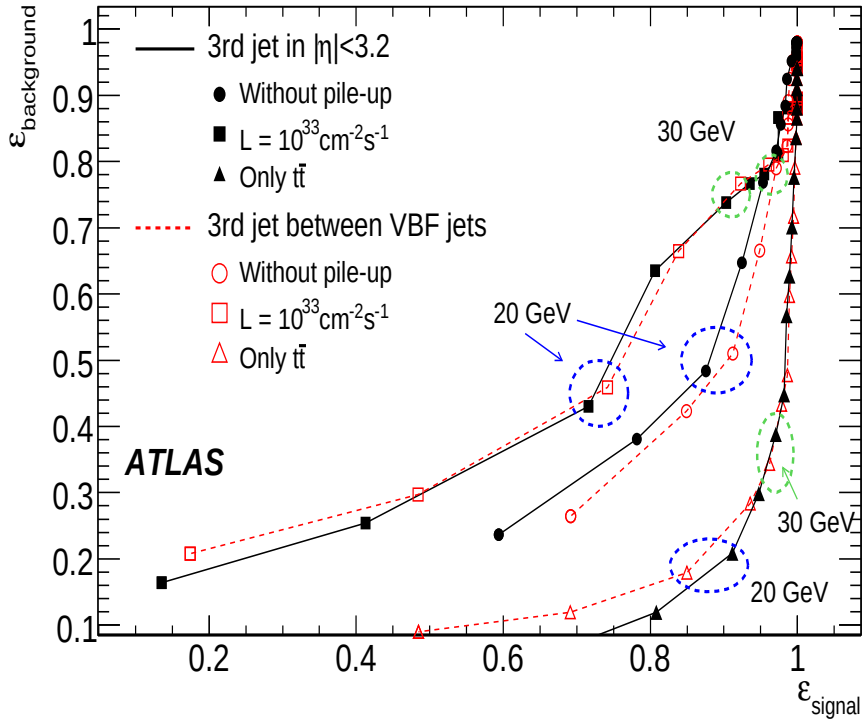
$qqH,\ H \to \tau\tau$ (Summary)

- Main features:
  - 2 energetic forward-backward jets
  - 1 hadronic τ decay and 1 leptonic τ decays (or 2 leptonic τ decays)
  - little central jet activity
- Backgrounds: main discriminating variables (in addition to forward jets and mass shape)
  - $Z \to \tau\tau$: almost irreducible
  - $W + jets$: lepton id
  - $t\bar{t}$: lepton id, central jet veto
  - QCD (2 “fakes”): lepton id
- Analysis:
  - pros: mass peak
  - cons: large backgrounds

$qqH,\ H \rightarrow \tau\tau$ (Jet Veto)

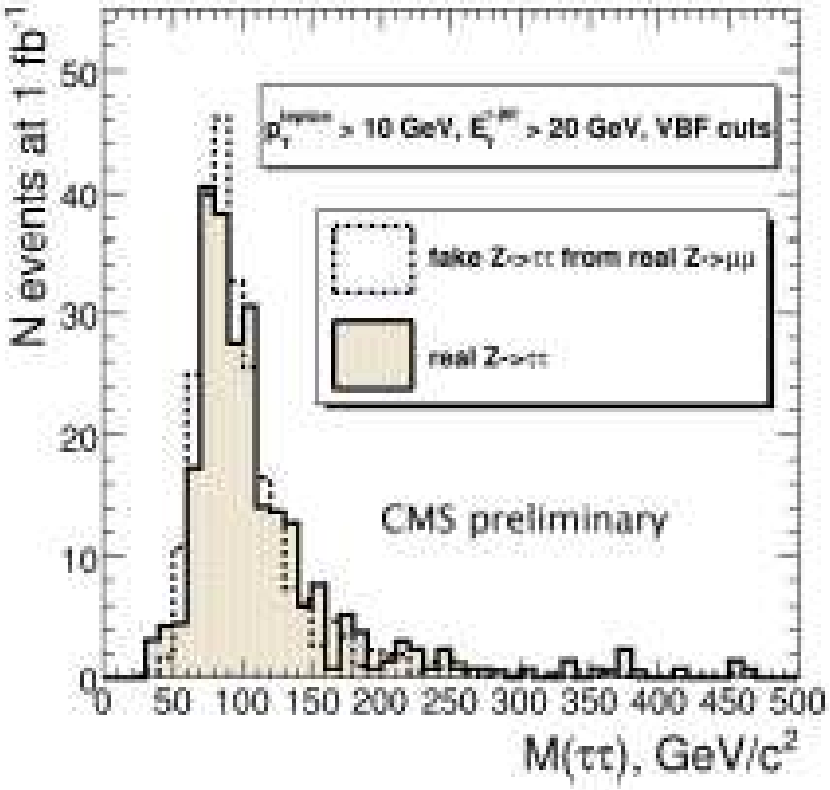


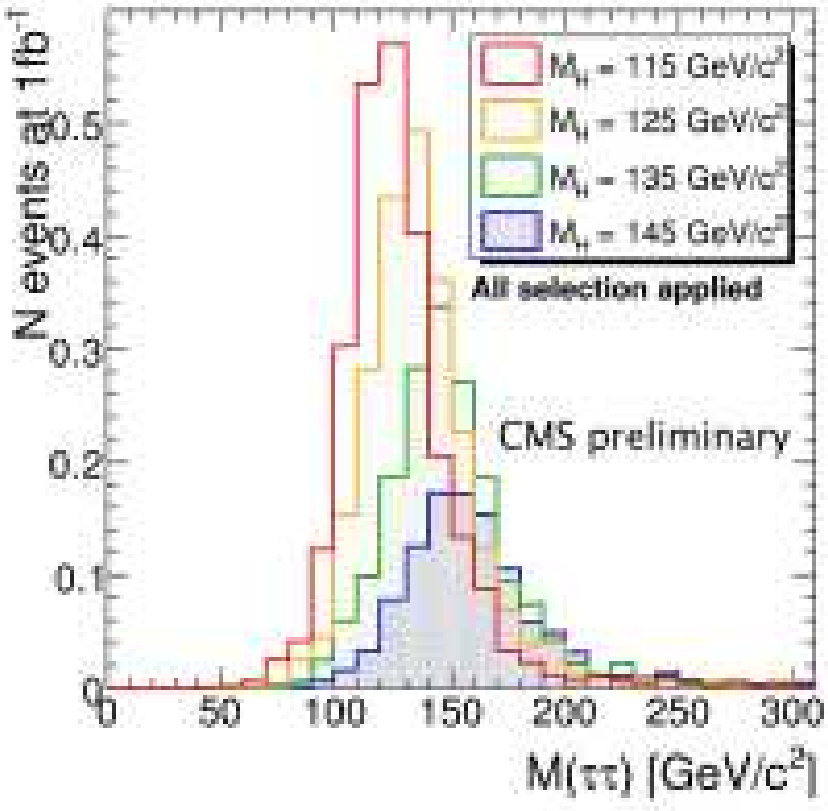
Jet multiplicity distribution after requiring $N_{jets} \geq 2$



Background rejection versus signal sensitivity for the central jet veto with and without pile-up

$qqH,\ H \to \tau\tau$ (Mass Reconstruction)

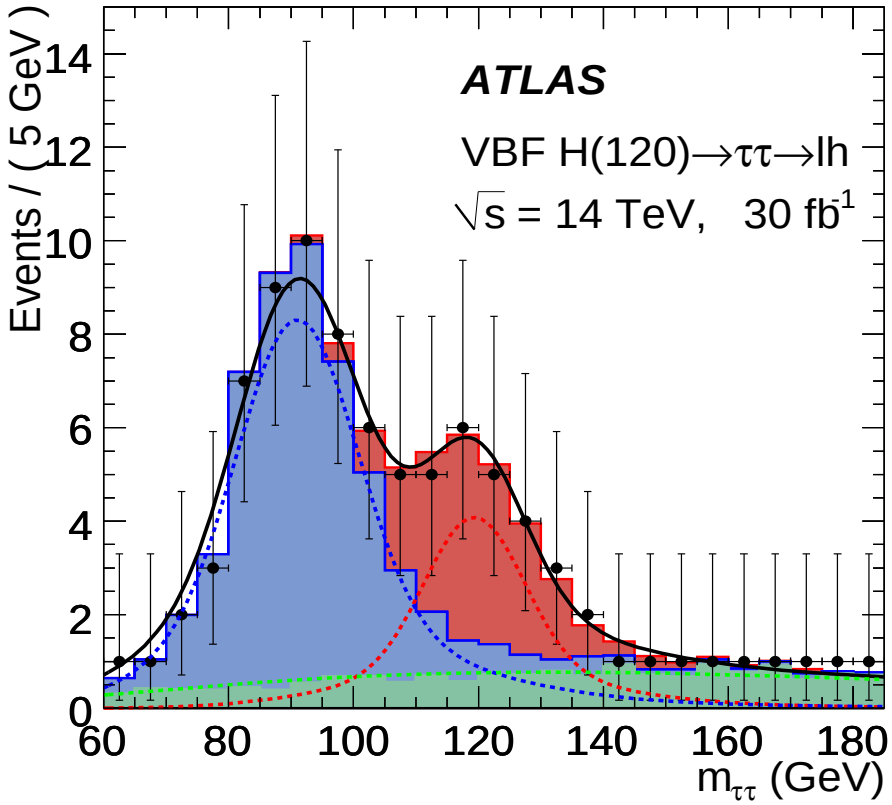


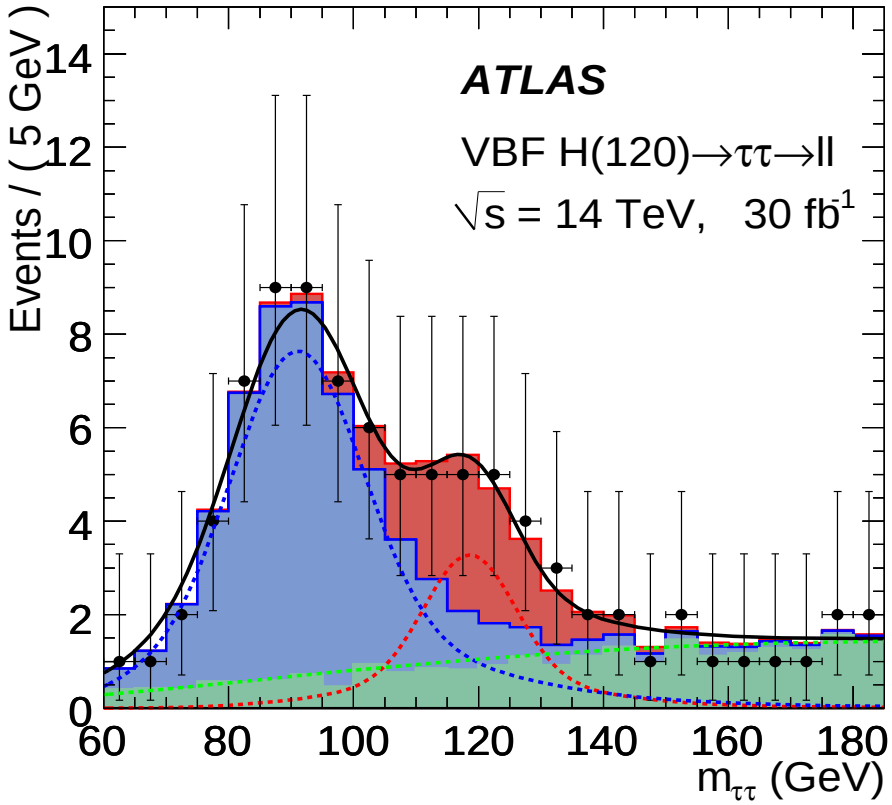


Reconstructed mass distribution for real and "fake" $Z \to \tau\tau \to h\ell X$ events

Reconstructed mass distribution using the collinear approximation for several Higgs masses

$qqH,\ H \rightarrow \tau\tau$ (Mass Distributions)

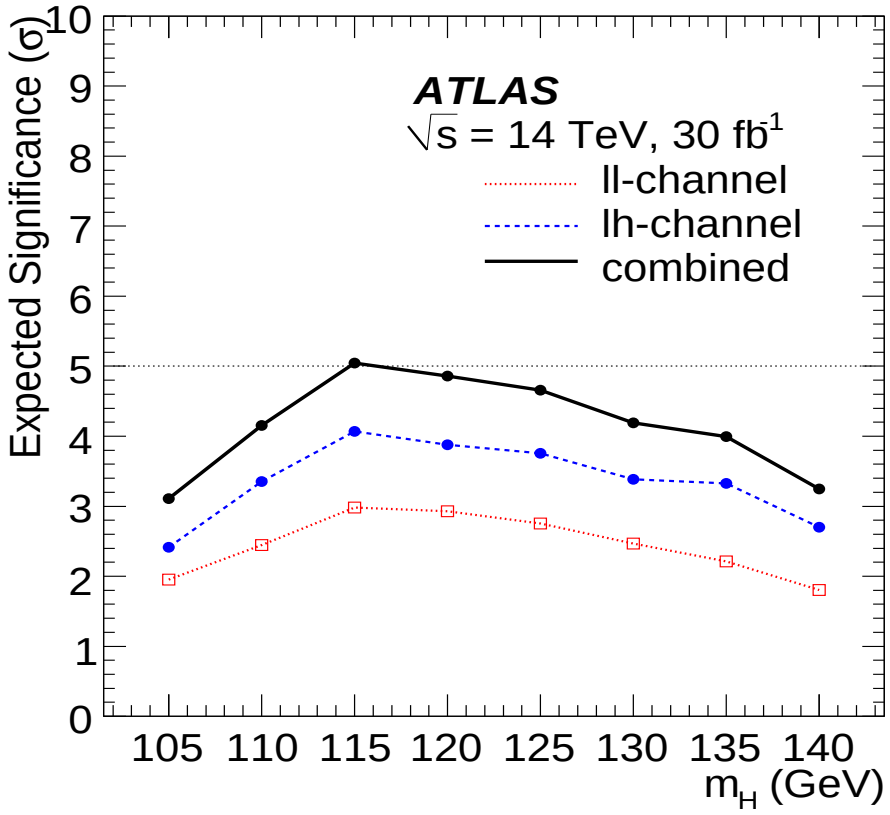


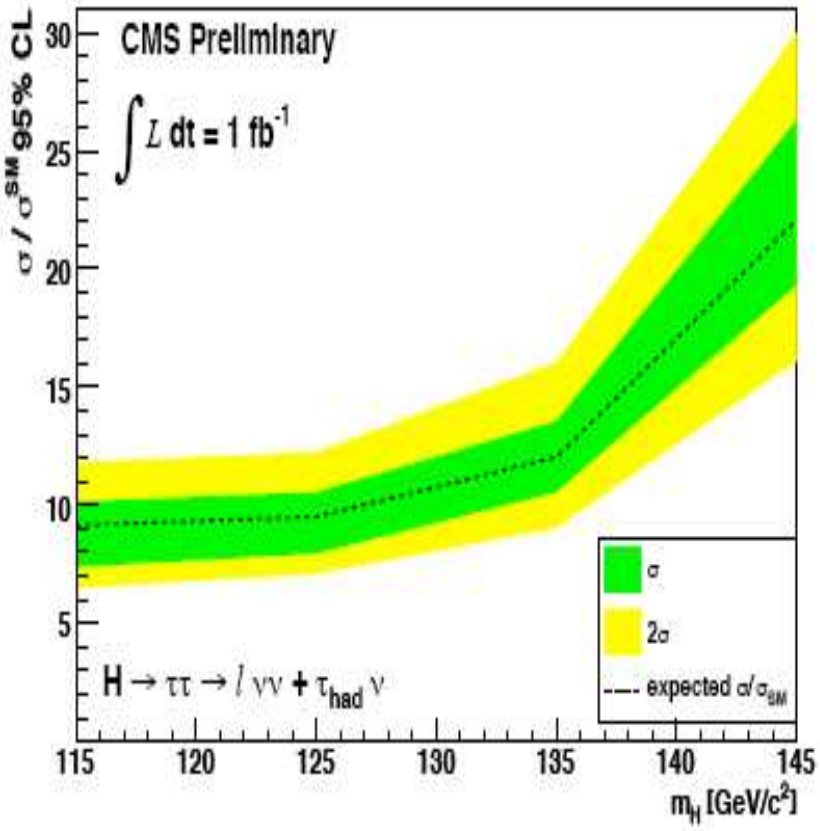


- ☞ Stringent cuts are needed
- ☞ high luminosity is needed to get a meaningful number of events

~10 signal events after all requirements with 10 fb^{-1}

$qqH,\ H \rightarrow \tau\tau$ (Results)



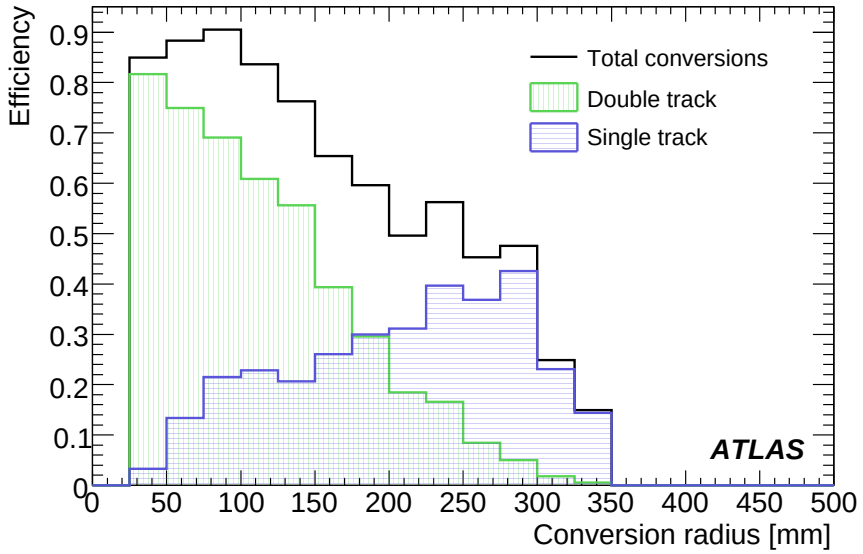


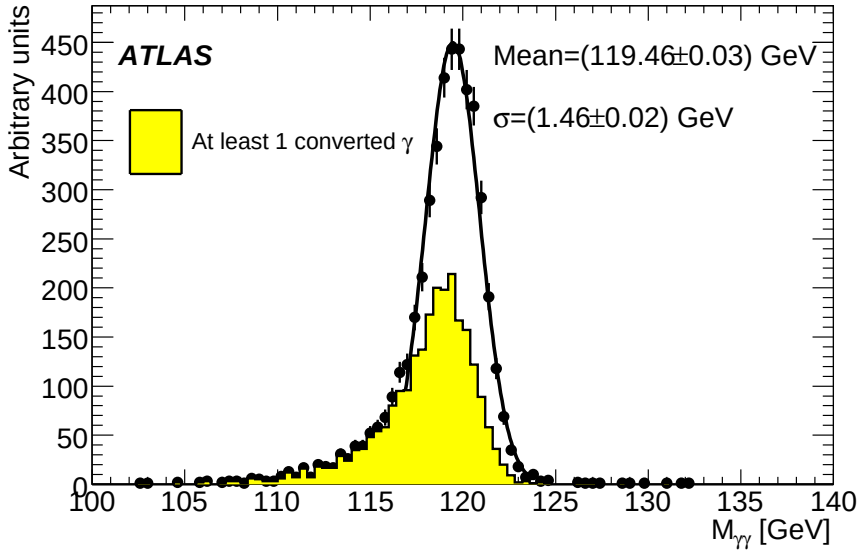
$$H \rightarrow \gamma\gamma$$

$H \rightarrow \gamma\gamma$ (Summary)

- Main features:
  - ☞ 2 energetic and isolated photons
  - ☞ ECAL resolution is the name of the game
- Backgrounds: main discriminating variables
  - ☞ QCD: γ id, mass
- Analysis:
  - ☞ pros: mass peak
  - ☞ cons: low yields, large backgrounds

$H \rightarrow \gamma\gamma$ (Mass Reconstruction)

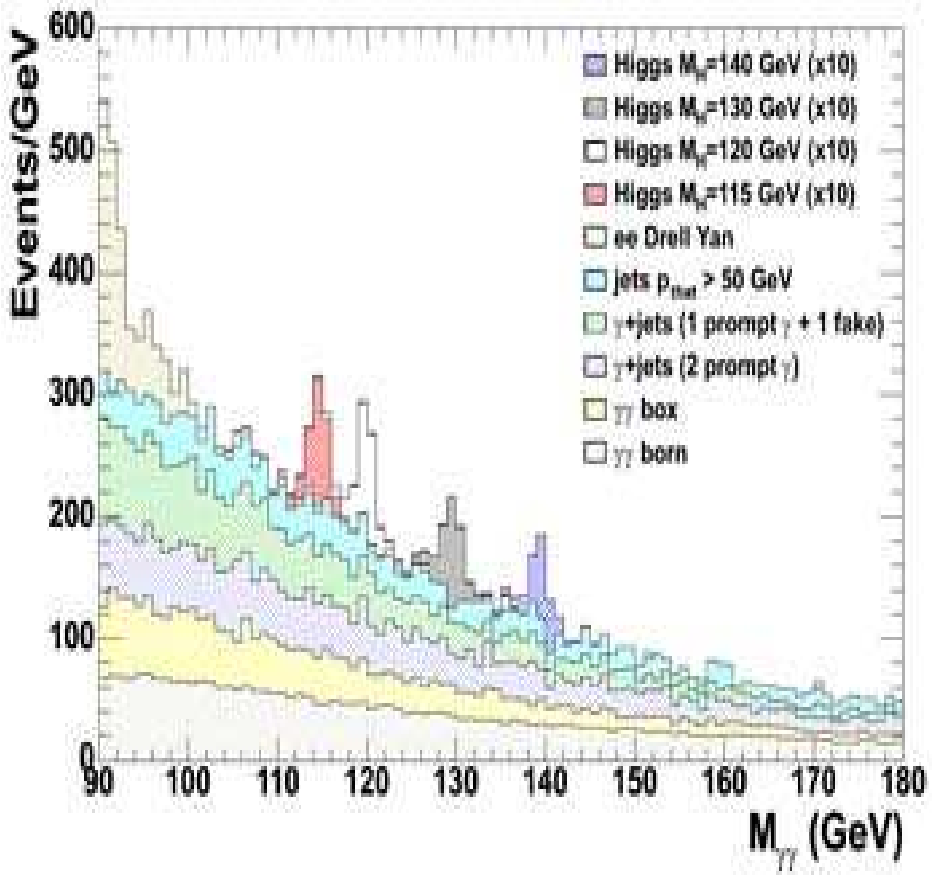


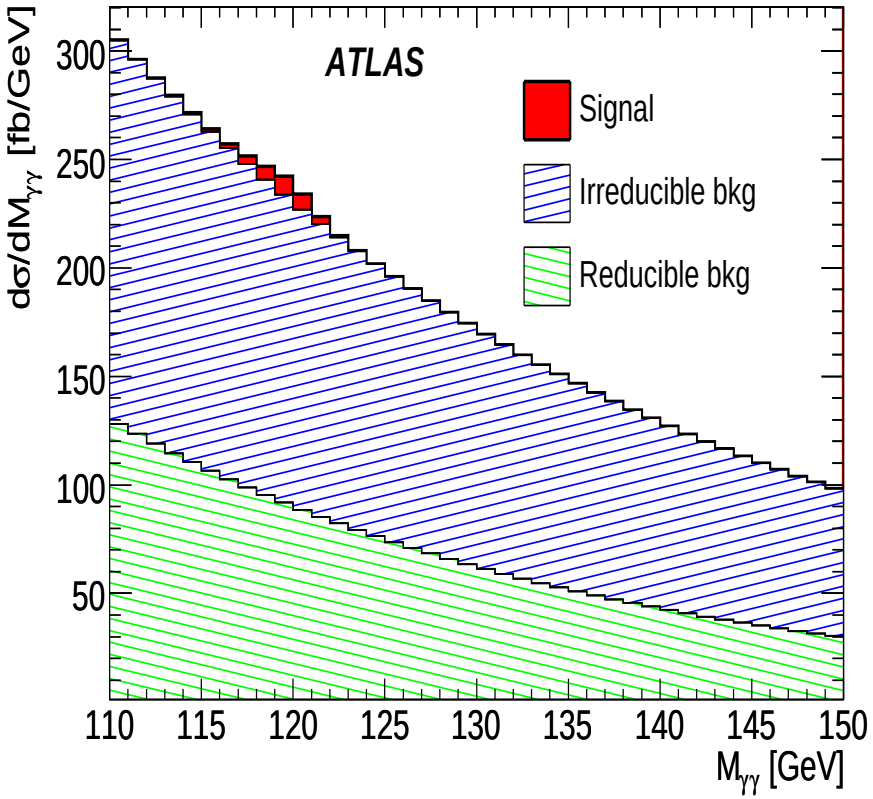


Effi ciency of single-track and double-track conversion reconstruction as a function of the conversion radius

Invariant mass distributions for photons pairs from Higgs boson decays with $m_H = 120$ GeV/c^2, after trigger and identifi cation cuts

$H \rightarrow \gamma\gamma$ (Mass Distribution-I)

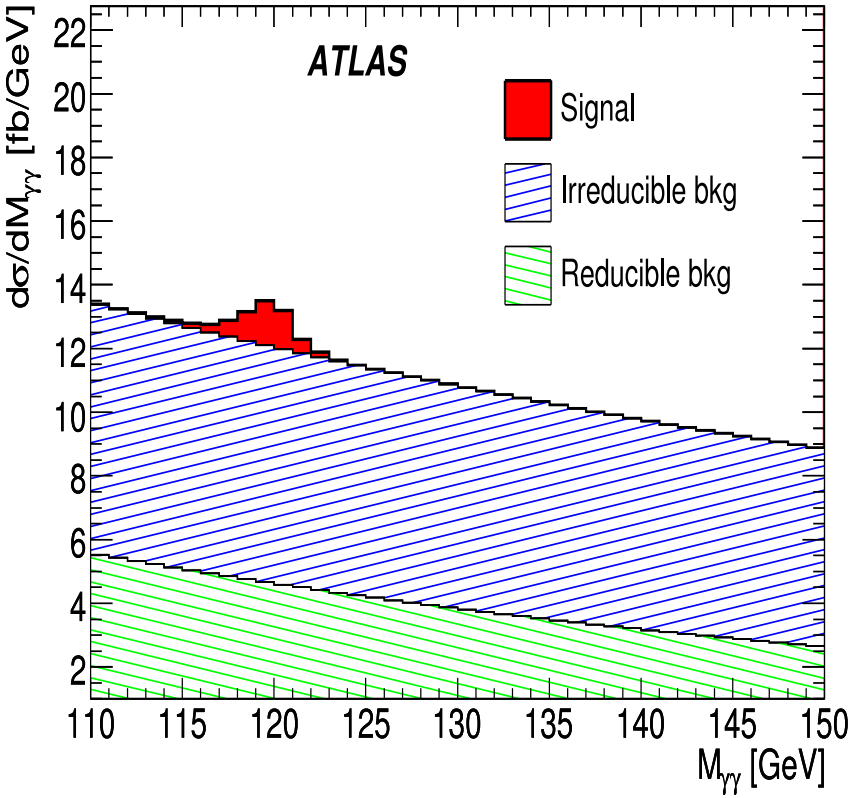




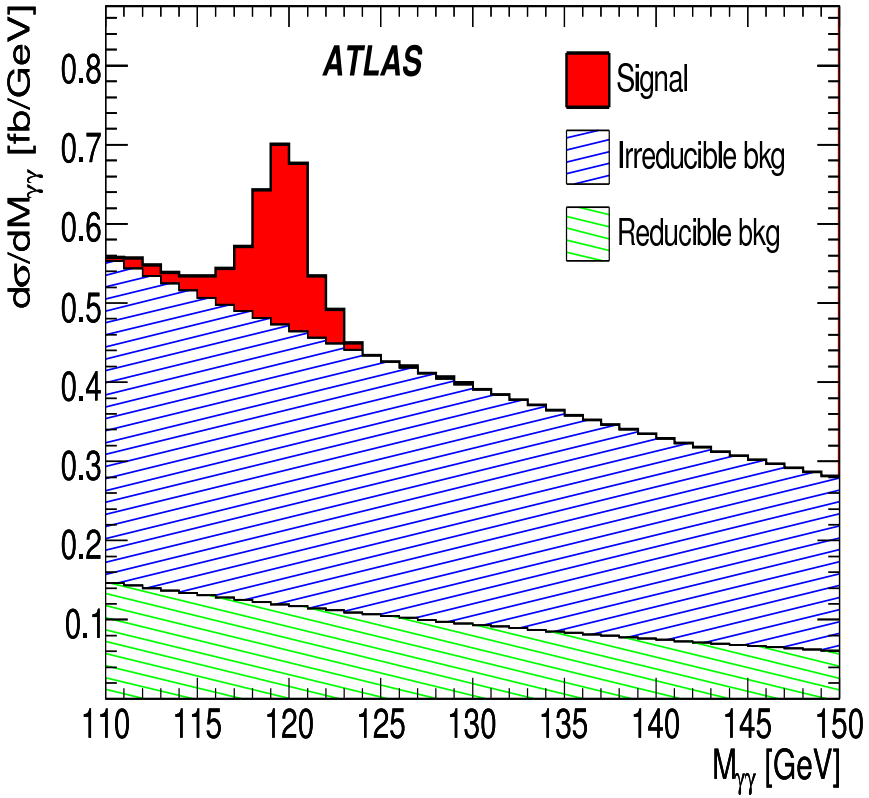
- Small peak in a large background environment
- Background shape must be very weel understood
- Splitting in several categories help a lot (see next slide)

$H \to \gamma\gamma$ (Mass Distribution-II)

$H \to \gamma\gamma + 1 - jet$

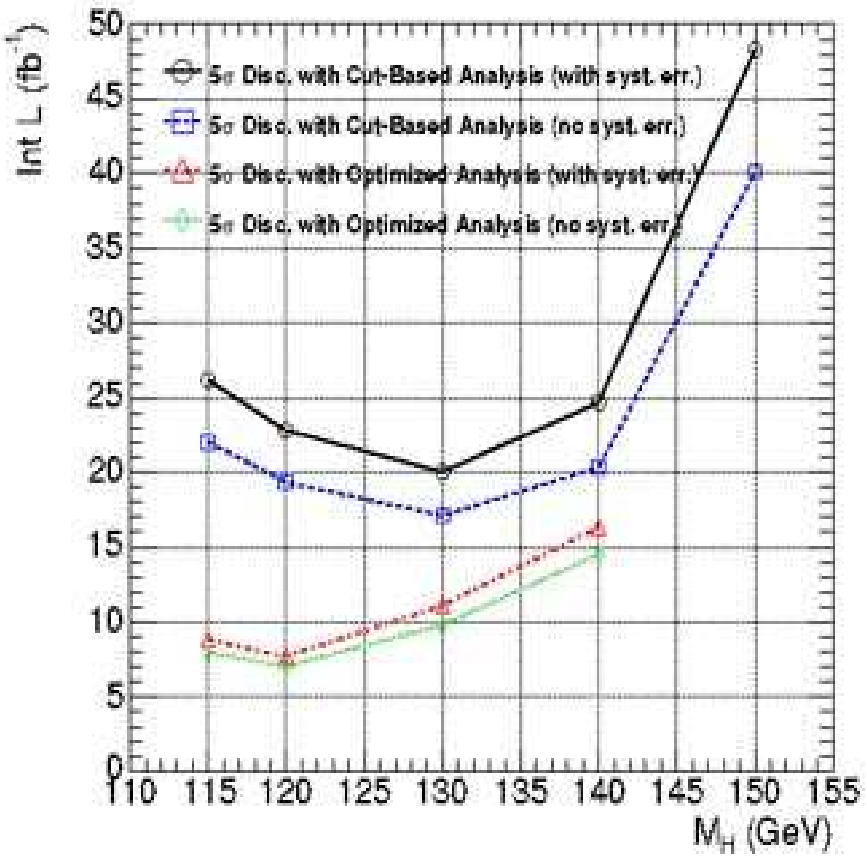


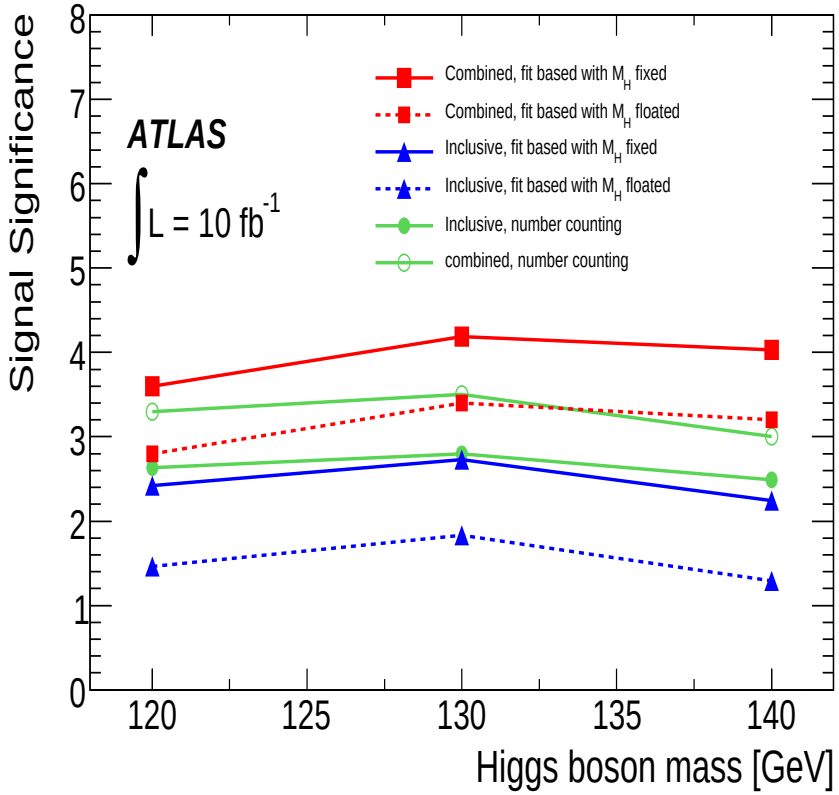
$H \to \gamma\gamma + 2 - jets$



- Much better S/B
- Much lower signal yield

$H \rightarrow \gamma\gamma$ (Results)

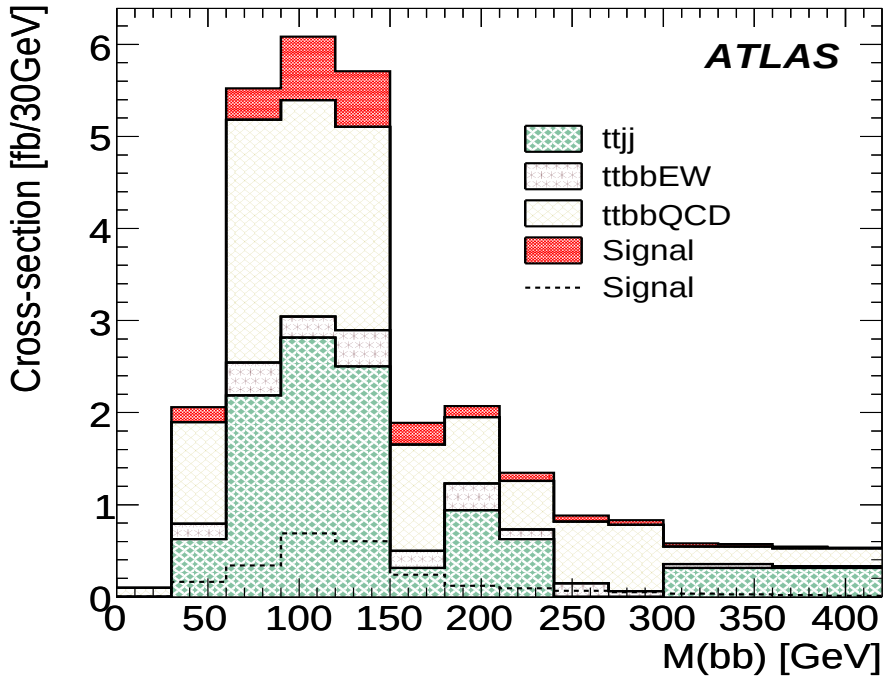


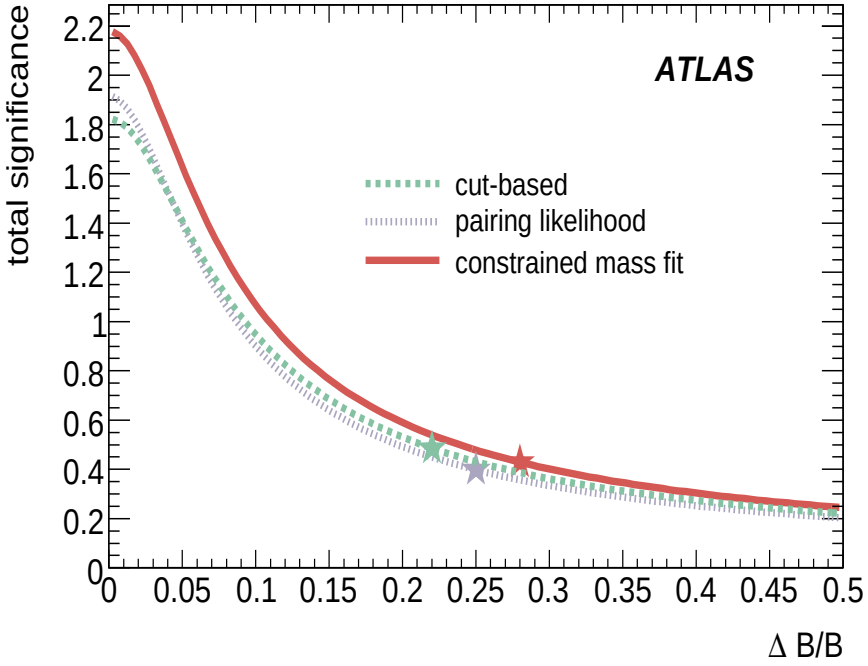


- May discover Higgs with ~10 fb^{-1}
- Slightly (expected) better performance at CMS due to better ECAL resolution

Other (More “Exotic”) Channels

$t\bar{t}H,\ H \to b\bar{b}$

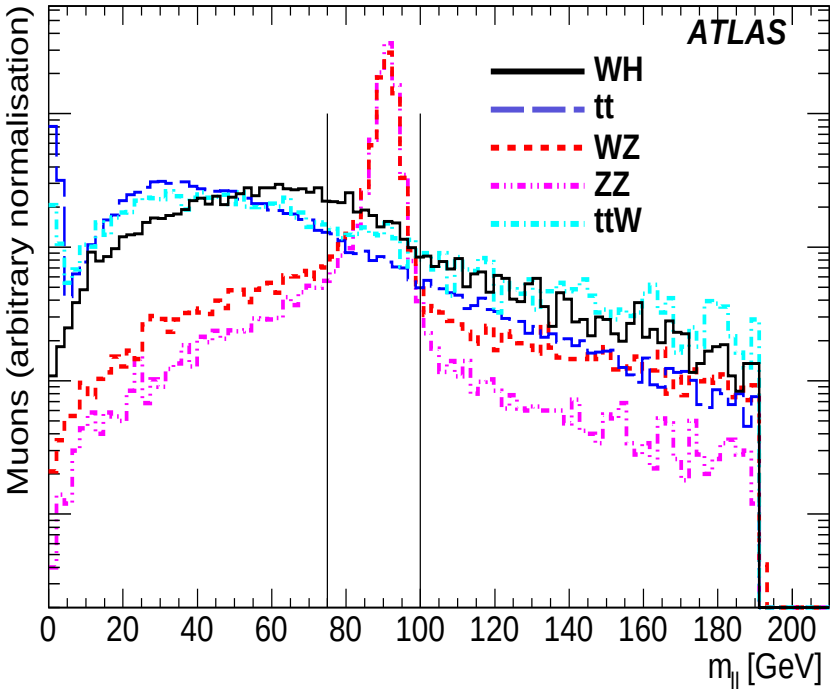




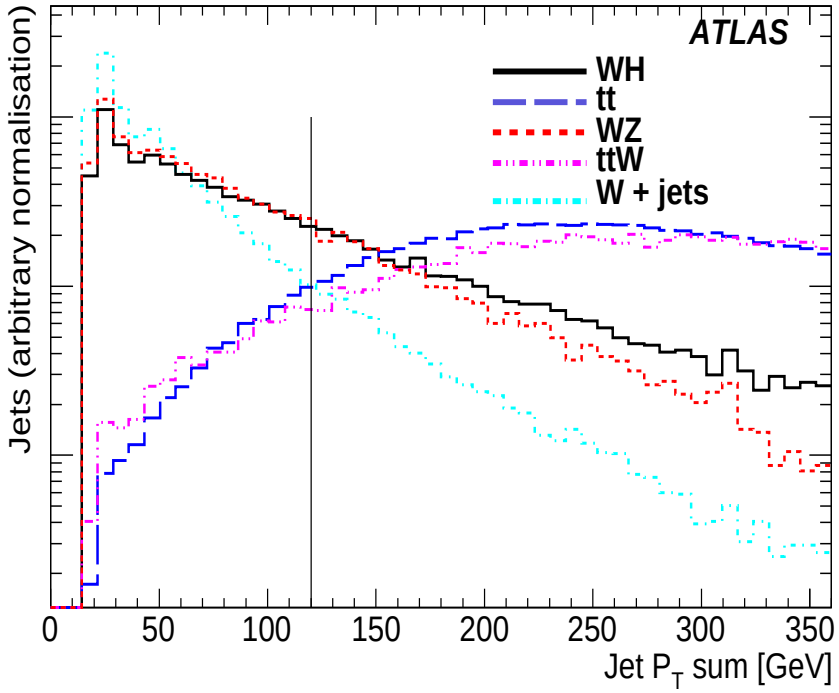
- Very difficult, but important, analysis
- Keep in mind: easier analysis if the Higgs mass is known

$t\bar{t}H/WH,\ H \rightarrow WW \rightarrow 2l2\nu$

$m_{\ell\ell}$

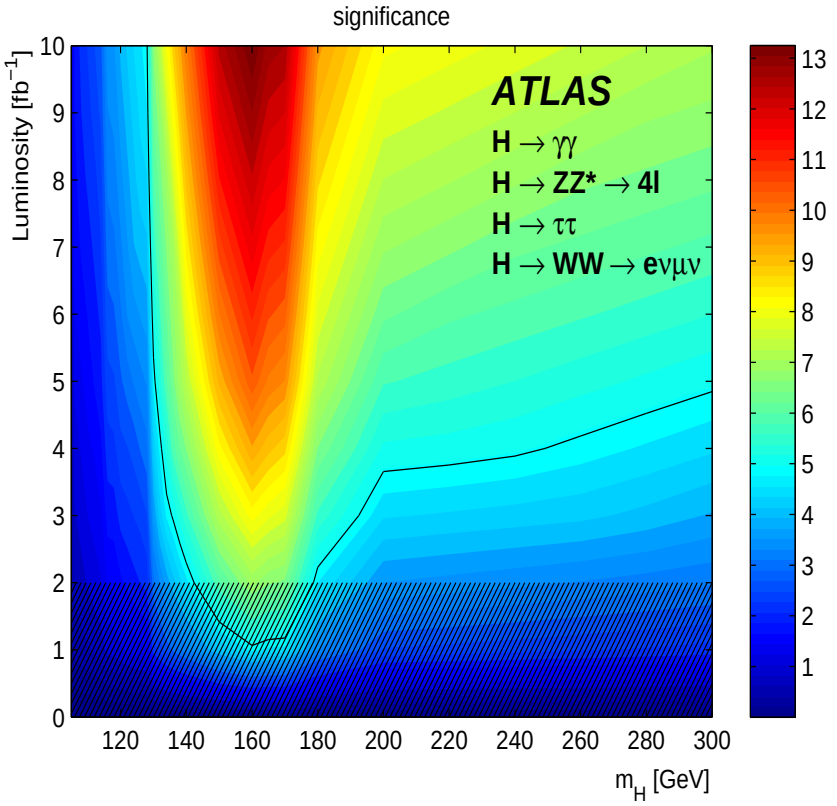


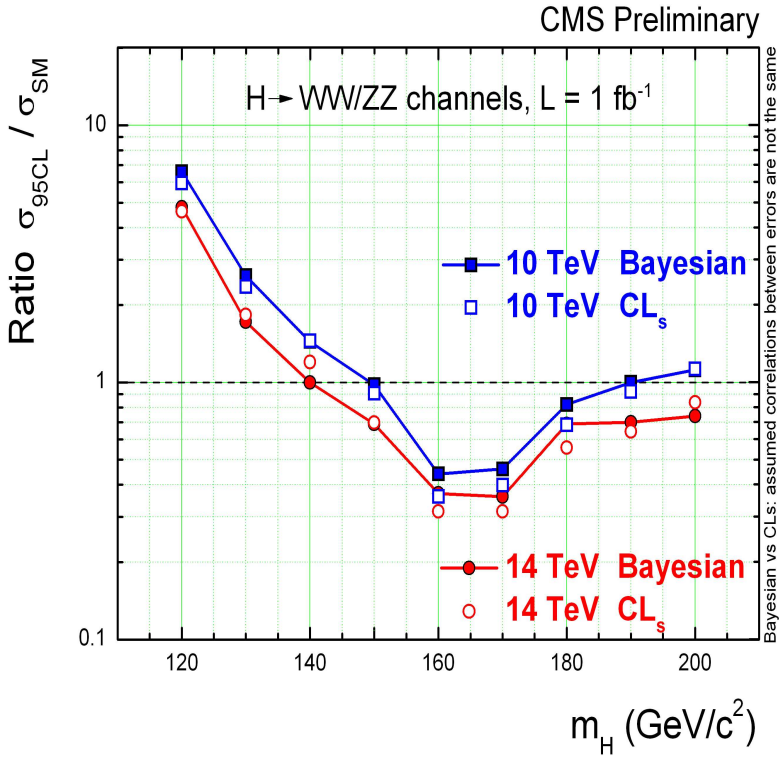
$\sum_i p_T^{jet_i}$



- At least 3 leptons in the final state
- Low background, but very low signal yield

Combined Results





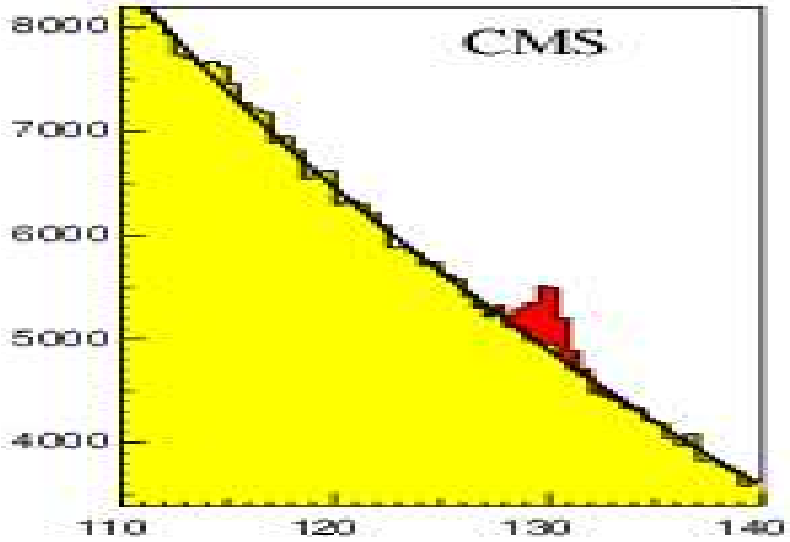
Measurements After The Higgs Discovery

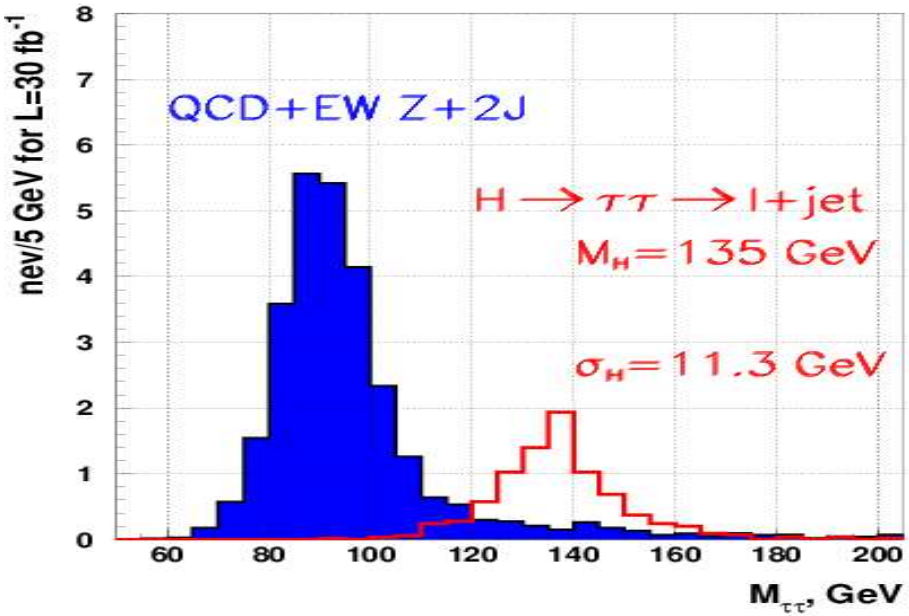
Measurements

All done after found it?: No!

- Cross-sections
- Mass
- Couplings
- Spin & CP Measurements

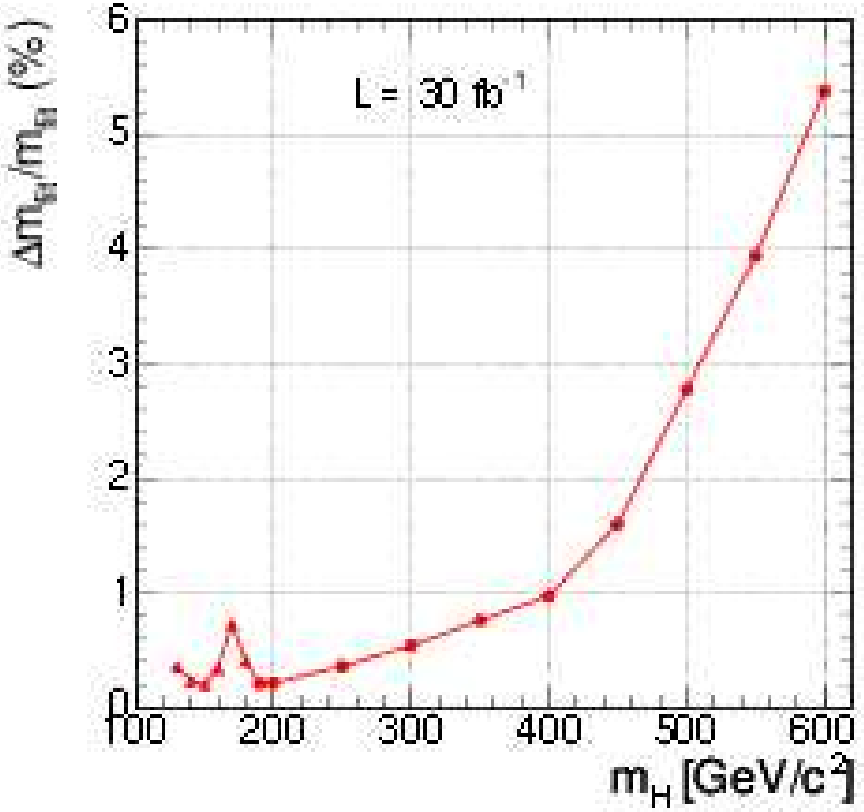
Measuring the Higgs Mass



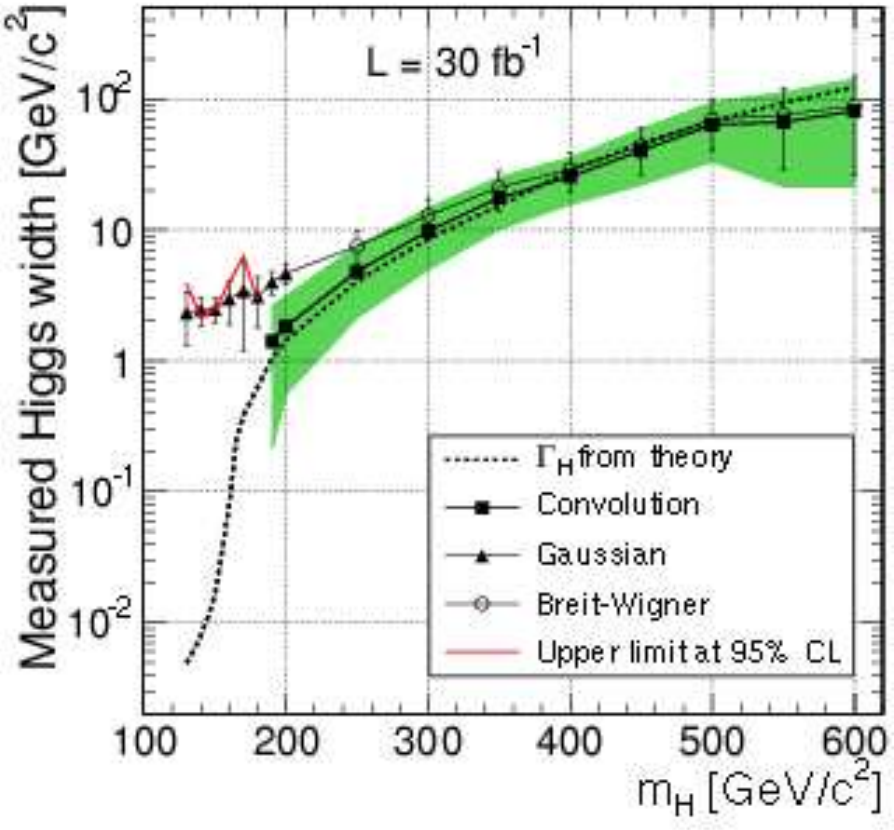


- $H \to ZZ/\gamma\gamma$: easy to measure the mass
- $H \to \tau\tau/WW$: not so easy to measure the mass

Mass Measurement in $H \rightarrow ZZ \rightarrow 4\mu$ Decays

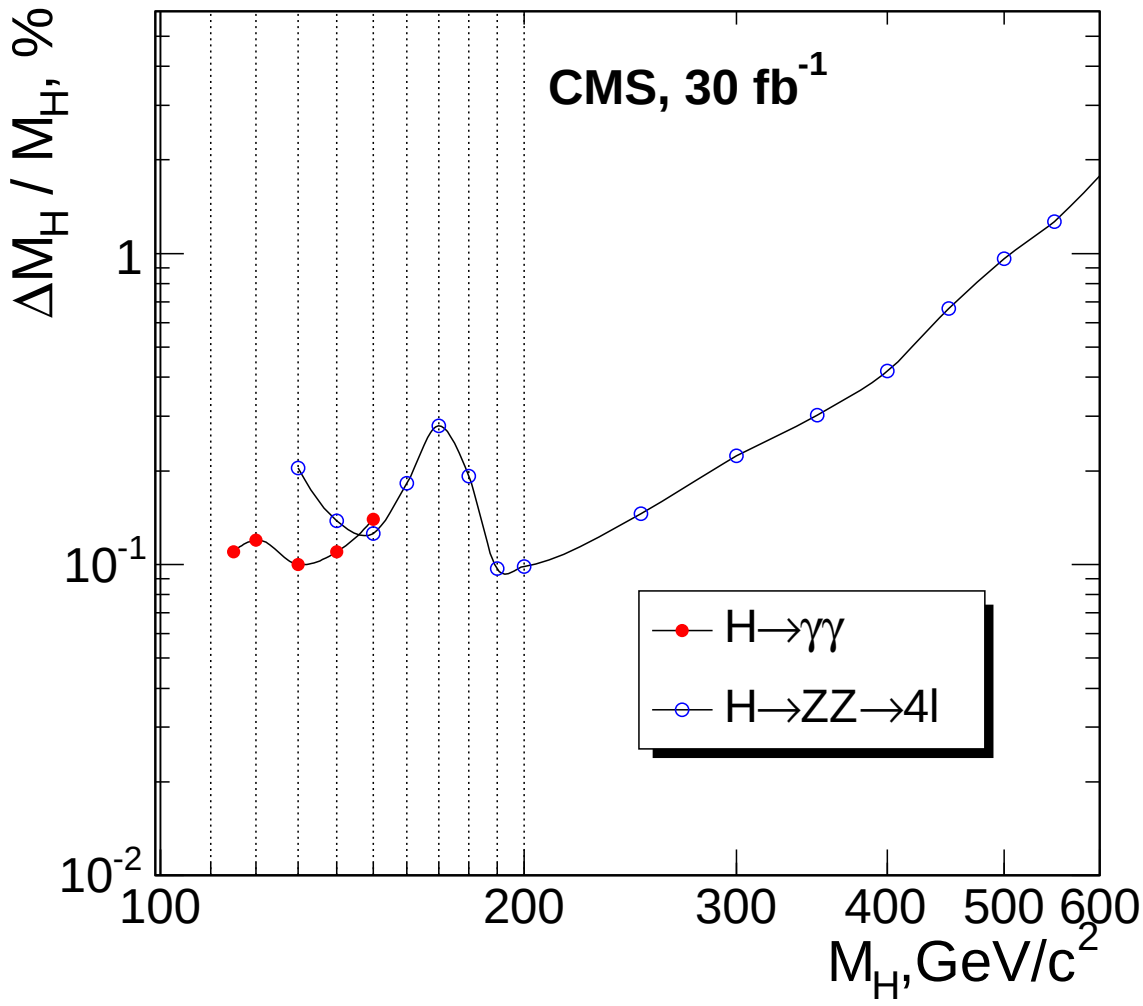


Relative error in the determination of the peak value as a function of the Higgs mass



Measured Higgs boson width from a fit to the signal plus background distribution as a function of the Higgs mass

Combined Mass Measurement



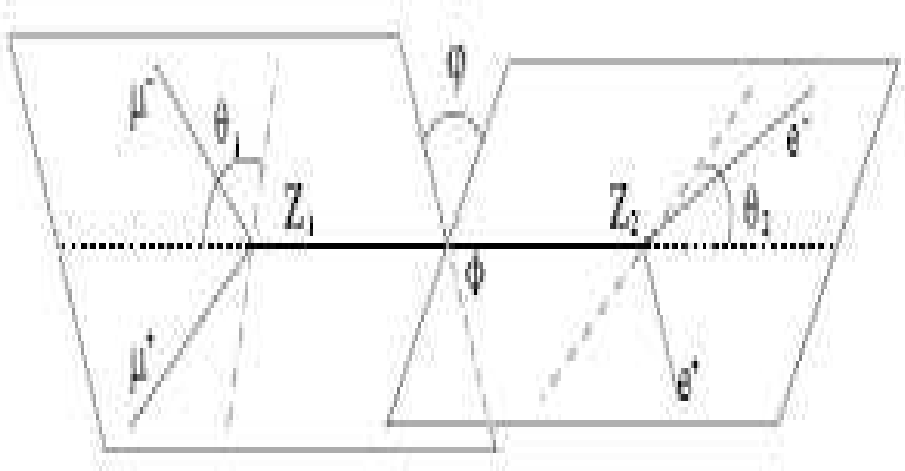
Accuracy of the Higgs boson mass measurement for 30 fb^{-1}

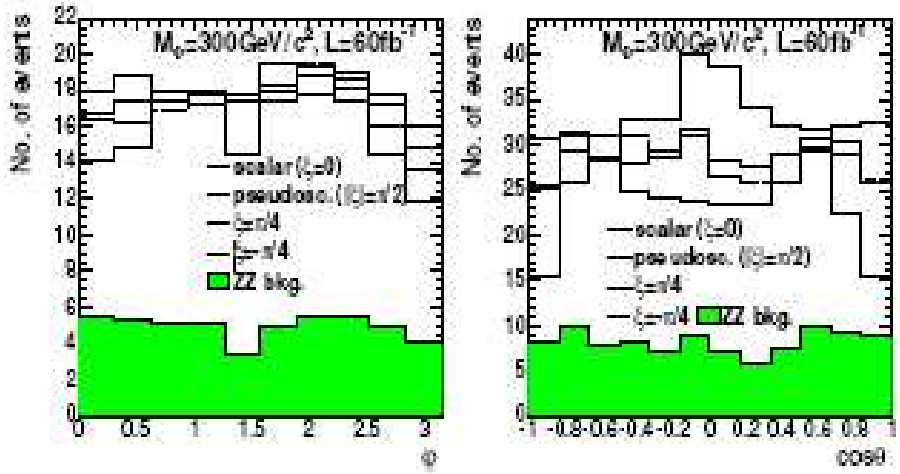
Spin & CP Measurements

- Spin:
  - ☞ Spin 1: excluded if $H \to \gamma\gamma$ or $gg \to H$ are seen
  - ☞ possible to test spin 0 in $qqH,\ H \to WW \to 2\ell 2\nu$ decays
  - ☞ angular correlations from $H \to ZZ \to 4\ell$ decays

- CP:
  - ☞ angular correlations from $H \to ZZ \to 4\ell$ decays
  - ☞ angular correlations from $qqH,\ H \to WW \to 2\ell 2\nu / H \to \tau\tau$ decays

Angular Measurements in $H \rightarrow ZZ \rightarrow 4l$ Decays





Defi nitions of the angles ϕ and θ

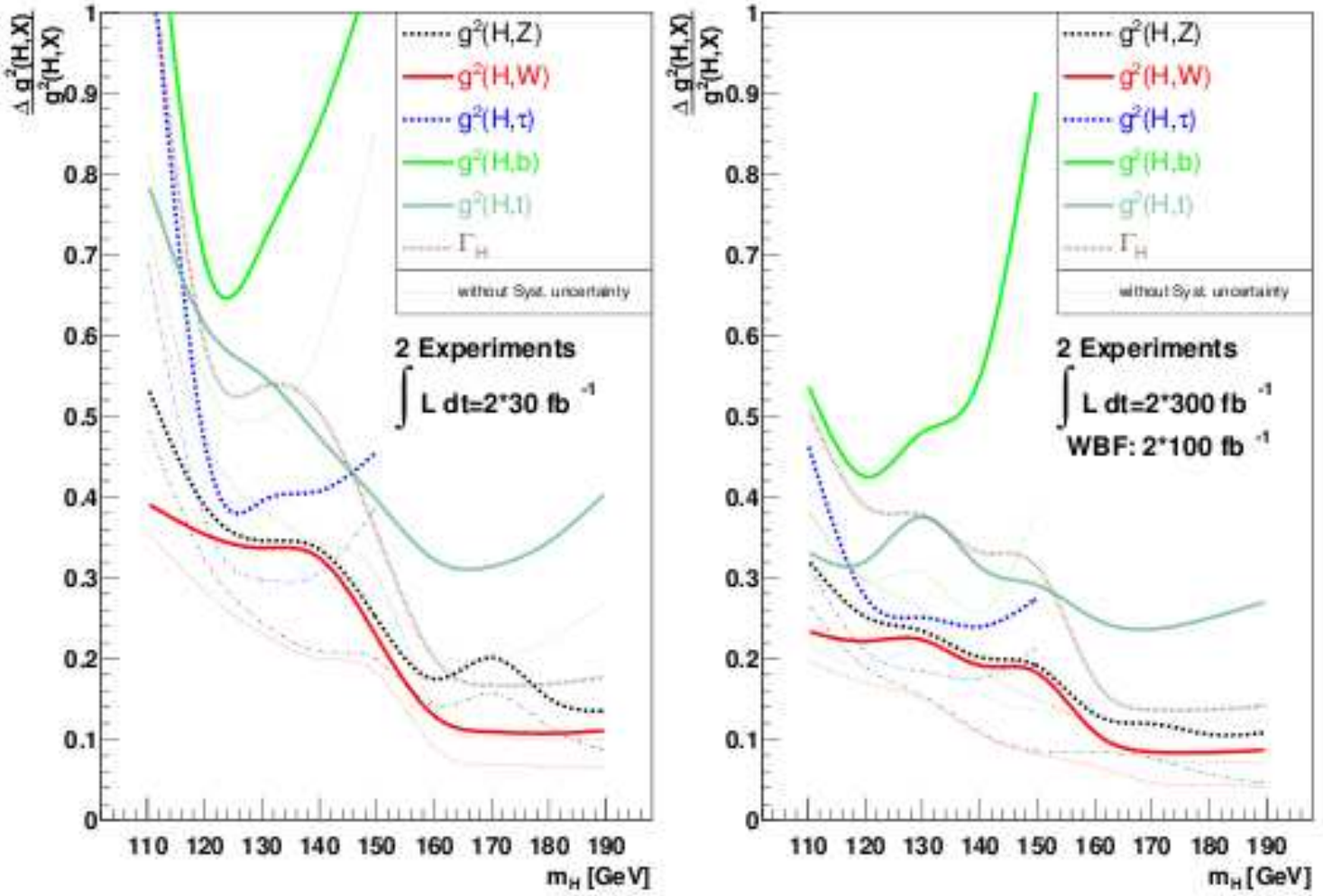
$\rightarrow d\Gamma \sim (scalar\ term) + \eta(CP-violating\ term) +$

$\eta^2(pseudo-scalar\ term)$

$\rightarrow tan\xi = \eta$

Distributions of the angles ϕ and θ for several values of the parameter ξ for 60 fb^{-1}

Coupling Measurements



Relative precision of Higgs couplings-squared as a function of the Higgs boson mass from LHC data only

Conclusions

- Higgs Physics is -the- major topic at LHC
- But it will take time “just” to discover it!
- Higgs “precision” measurements will only happen at high luminosity
- All assuming it exists :-)