HZZ Analysis at CMS

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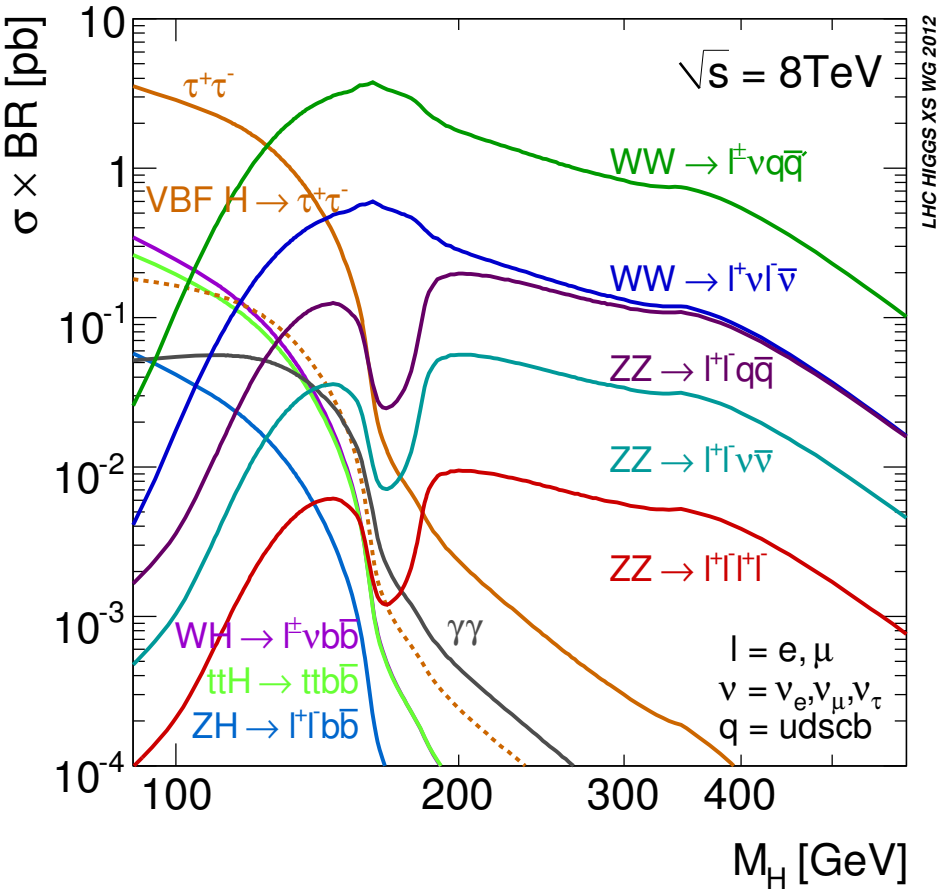
Outline

Motivations

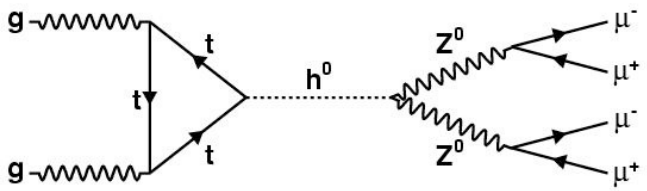
- SM Higgs is expected to decay through ZZ coupling with a large BR.
- Several final states combinations are available:
  - H→ZZ→ 4*l* (2011-12)
  - H→ZZ→ 2*l*2τ (2011-12)
  - H→ZZ→ 2*l*2*q* (2011)
  - H→ZZ→ 2*l*2ν (2011-12)
- 2*l*2*q* and 2*l*2ν have large BR but low purity. They are well suited for the search of high mass Higgs bosons.

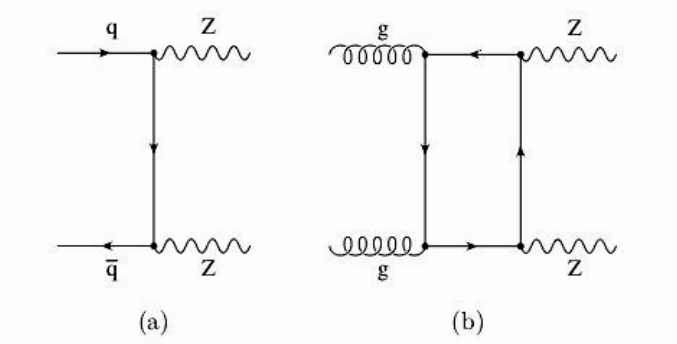


- 4*l* final state has low BR, but very clean signature and excellent resolution, **golden channel** for Higgs analysis. It allows spin/parity study from the angular distribution of decay products.

H→ZZ→ 4l: The golden channel

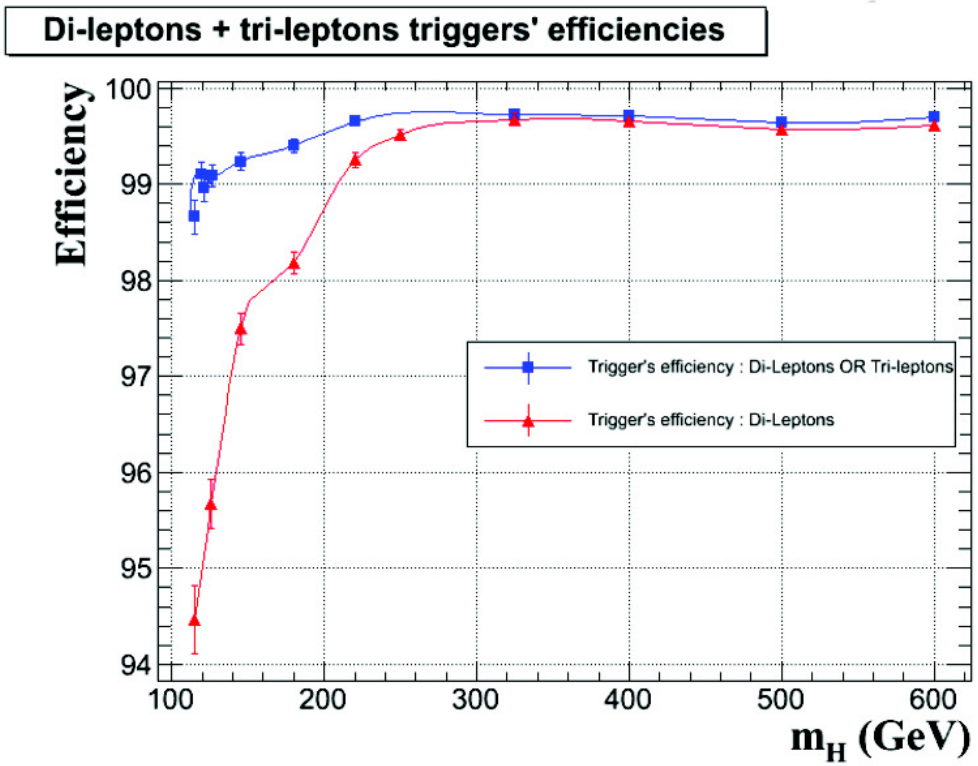
- Very clean signal: search for a narrow peak in the 4l invariant mass spectra
- Flat and small background
  - Reducible: Z+jets; Z+tt; WZ
  - Irreducible: ZZ*
- Sensitivity with 2011+2012 statistics: $110 < m_H < 1000$ GeV
- Very small number of expected events, high efficiency required!
- Event properties from lepton angular distribution





Event selection

- Events selected by di-lepton (18, 8 Gev) or tri-electron (15, 8, 5 GeV) trigger. Electron-muon trigger in 2012 only.
- High trigger efficiency: $> 99\%(> 99\%, > 98\%)$ for 4μ ($4e$, $2e2\mu$) for $m_H > 120$ GeV and $> 99\%$ for $2l2\tau$ for $m_H > 180$ GeV



- HCP statistics: 5.26fb^{-1} at 7 TeV, 12.21fb^{-1} at 8 TeV

Lepton selection

Leptons are required to be isolated and coming from the primary vertex:

- $R^{l}_{\text{iso}} < 0.4$ ($4l$ analysis), $R^{ll}_{\text{iso}} < 0.25$ and $R^{\tau\tau}_{\text{iso}} < 0.1$ ($2l2\tau$)
- $|\text{SIP}_{3D} = \frac{\text{IP}}{\sigma_{\text{IP}}}| < 4$

e/μ selection efficiency measured via tag-and-probe using Z and J/Ψ inclusive events.

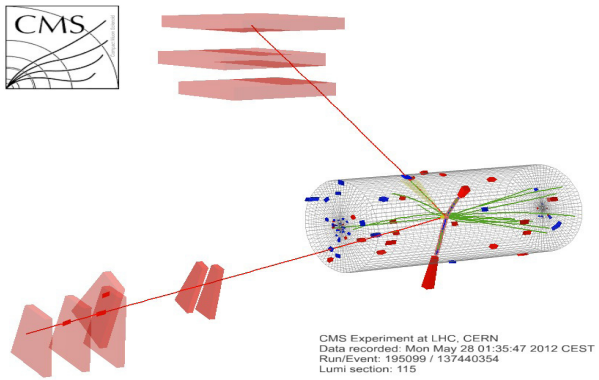
- ϵ^{e} is 71% (65%) at low p_t and reaches 90% (85%) for $p_t \sim 20$ GeV/c in the barrel (endcaps)
- ϵ^{μ} is above 98% in the full range

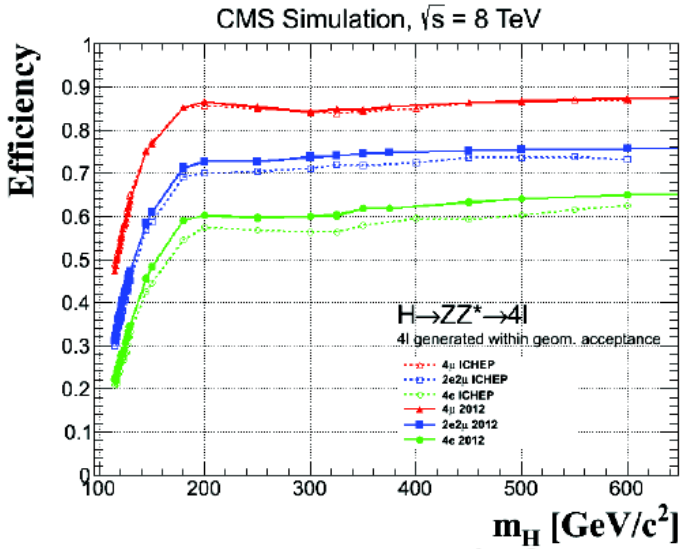
FSR corrections applied when an isolated photon is found close to a selected lepton. FSR candidates must satisfy:

- $p_t^{\gamma} > 2$ GeV/c, $\Delta R^{l} < 0.07$ OR $p_t^{\gamma} > 4$ GeV/c, $0.07 < \Delta R^{l} < 0.5$
- $R^{\gamma}_{\text{iso}} < 1$
- $|\eta^{\gamma}| < 2.4$

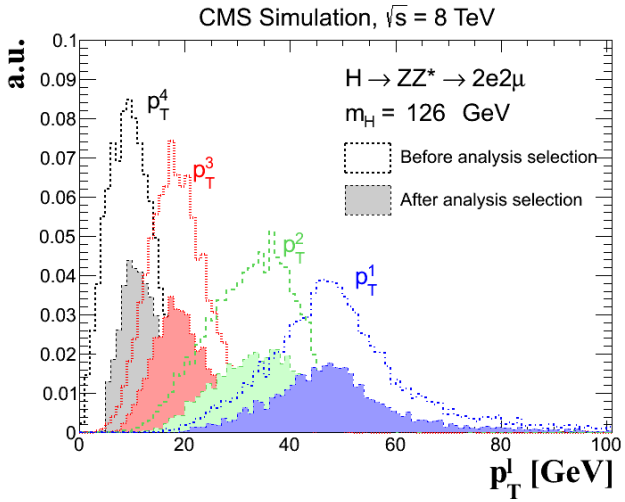
FSR corrections improve efficiency by 3%. FSR photon selection efficiency is about 50% with 80% mean purity

Kinematics





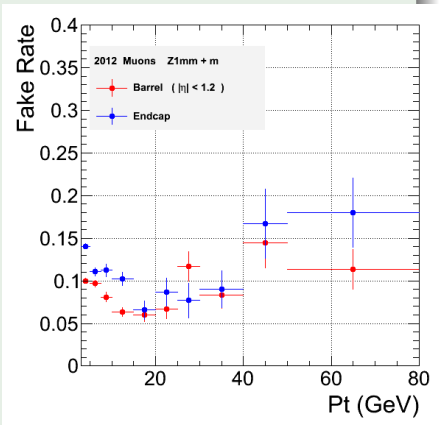
- Two pairs of OS/SF leptons. Z_1 closest to the Z mass, Z_2 the remaining with highest p_t
- $40 < m_{Z_1} < 120$GeV
  $12 < m_{Z_2} < 120$GeV
- One lepton with $p_t > 20$ GeV/c, another with $p_t > 10$ GeV/c.
- $m_{4l} > 100$ GeV, any $m_{l^+l^-} > 4$ GeV
- Tighter cuts for $2l2\tau$ analysis



Background and Systematic uncertainties

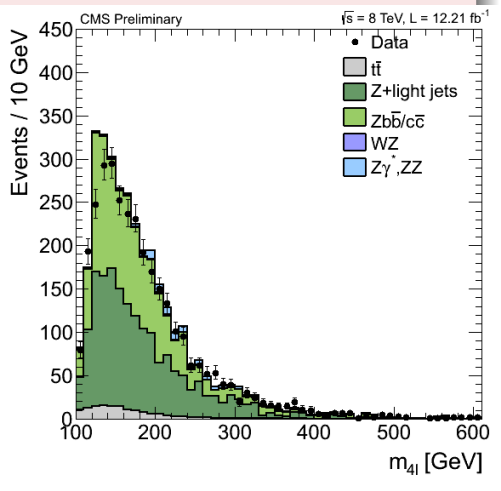
Reducible

- Zbb, Ztt, Z+jets, WZ+jets
- Estimated in Z_1+X and $Z_1 + l_{rec}$ control regions
- "fake rate"=tight/loose estimated using loose selection on leptons
- syst + stat uncertainties $\sim$ 50%

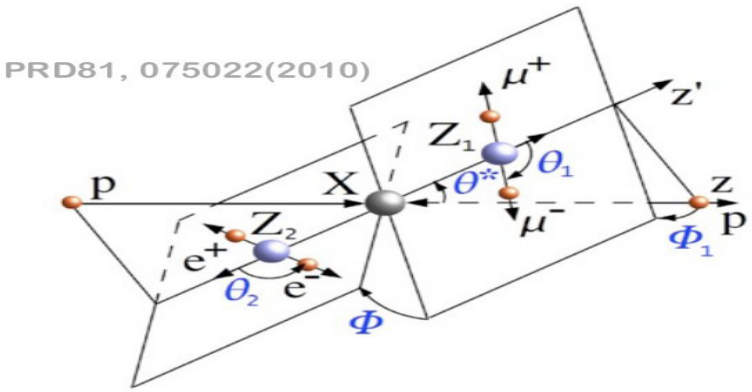


Irreducible

- Calculated from MC, including $q\bar{q}$ annihilation (POWHEG) and gluon fusion (GG2ZZ)
- Phenomenological model for the shape
- 2-6% (24-44%) syst. from QCD scale and 5% (10%) from parton luminosity unc. for qq→ZZ (gg→ZZ)



MELA

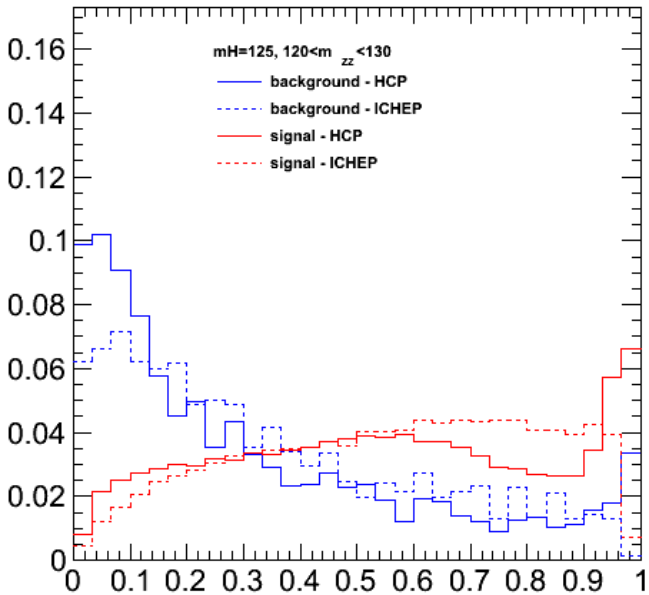


5 angles and 2 masses fully describe the H→ZZ→ 4*l* decay

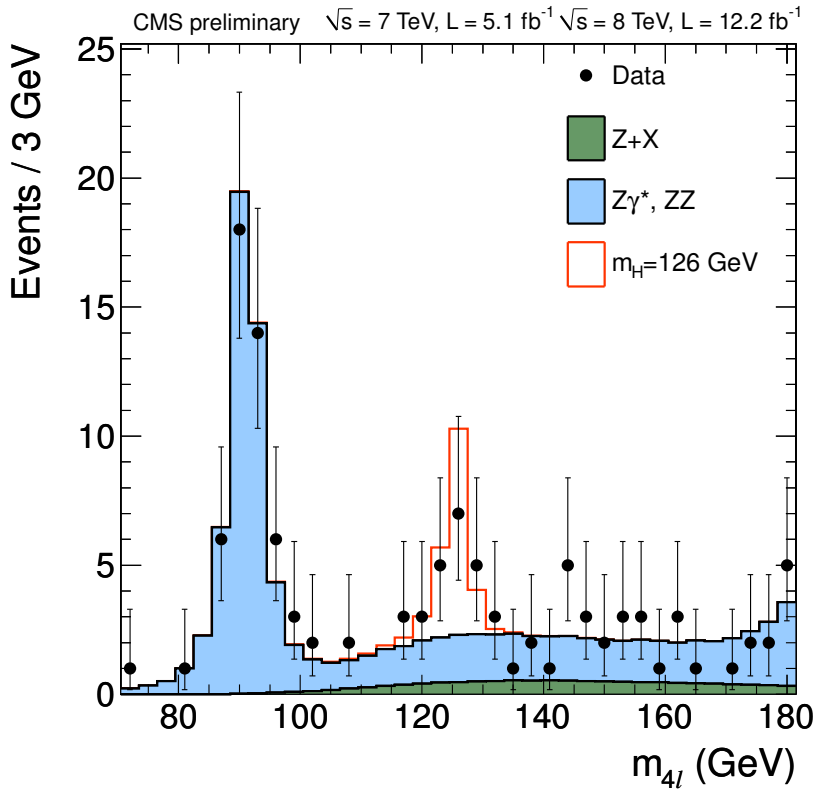
Matrix Element Likelyhood Analysis: build a discriminant (KD) based on signal/bkg probabilities.

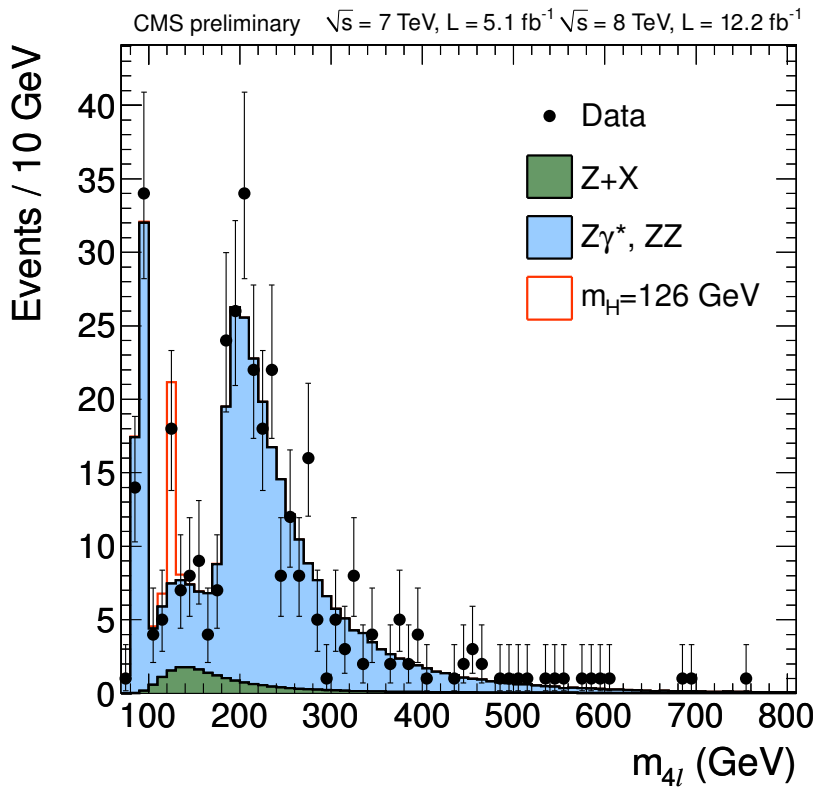
$$KD = \frac{P_{sig}}{P_{sig}+P_{bkg}} = \left(1 + \frac{P_{bkg}(m_1, m_2, \Omega | m_{4l})}{(m_1, m_2, \Omega | m_{4l})}\right)^{-1}$$

- Use angles and masses to discriminate
  - between signal/background hypothesis
  - between spin/parity hypothesis
- Analytical parametrization of the background
- Alternative parametrization (MEKD) has been tested, performance are similar



Mass distribution

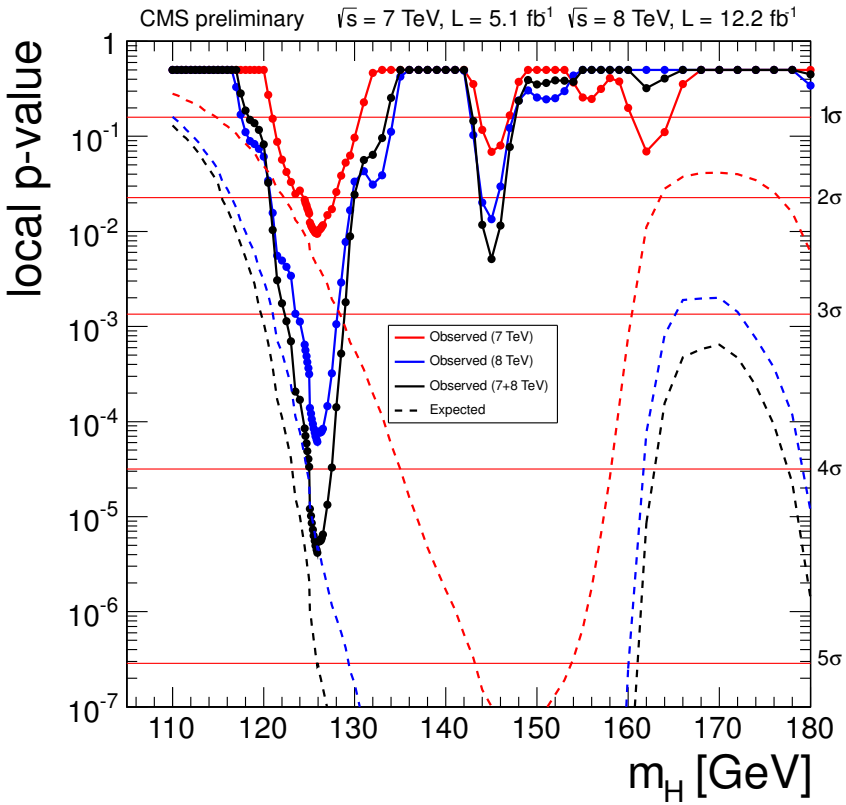


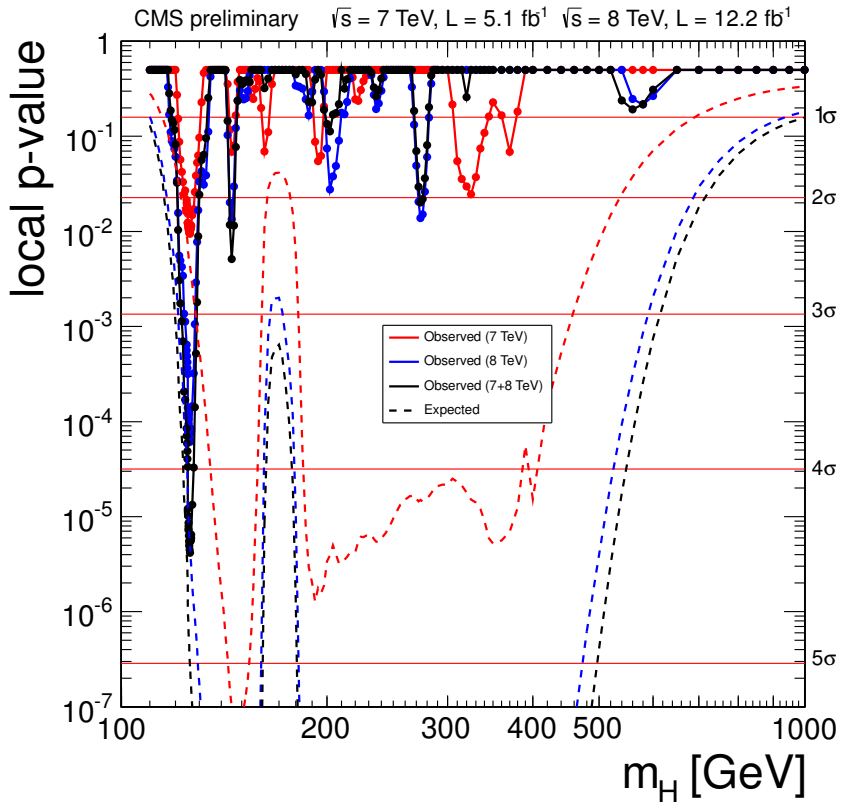


A clear peak is visible in the 4l invariant mass spectra, suggesting the presence of a new particle around 126 GeV

P-values

The peak significance can be evaluated. A 2D likelihood fit on m_{4l};KD is performed for each m_H hypothesis

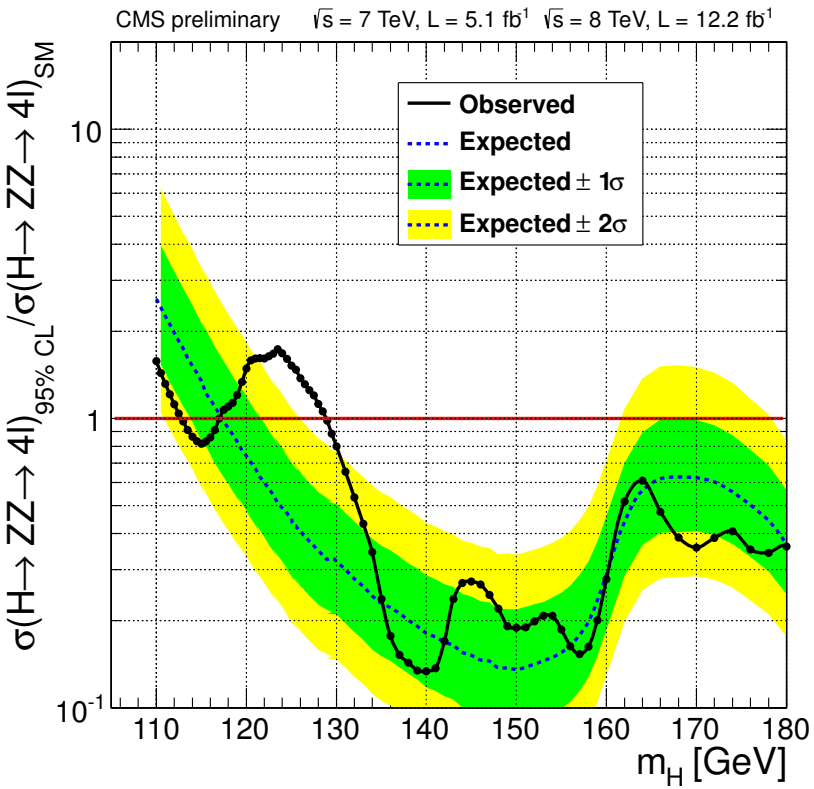


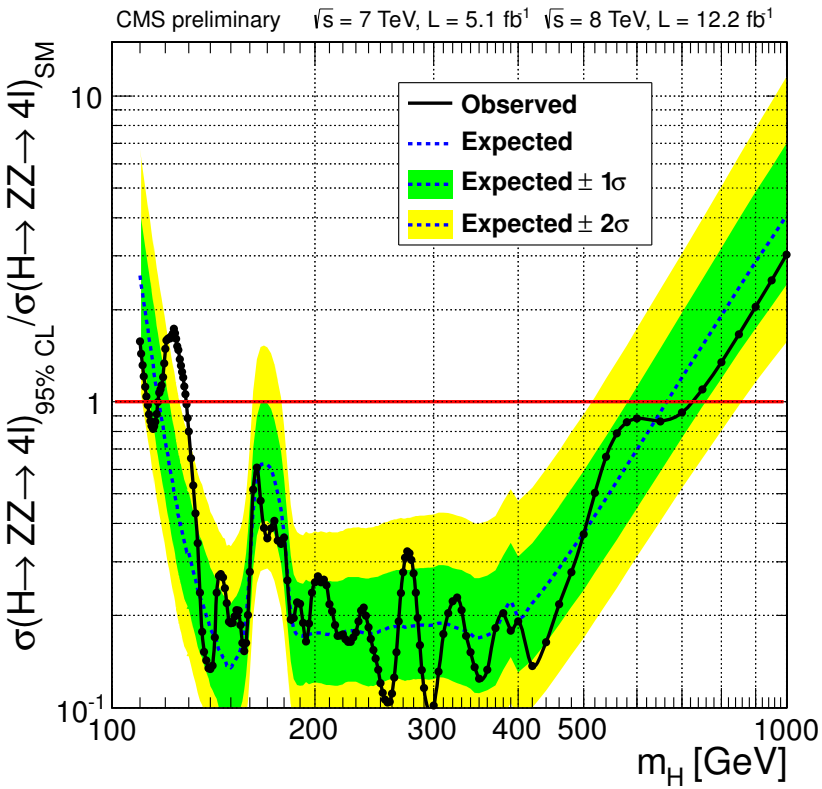


$\sim$ 4.5 significance for the 126 GeV peak (5 expected)!

Other 2 peaks with significance > 2. Particularly interesting the one around 145 GeV. We need more data if we want to look into it!

Limits

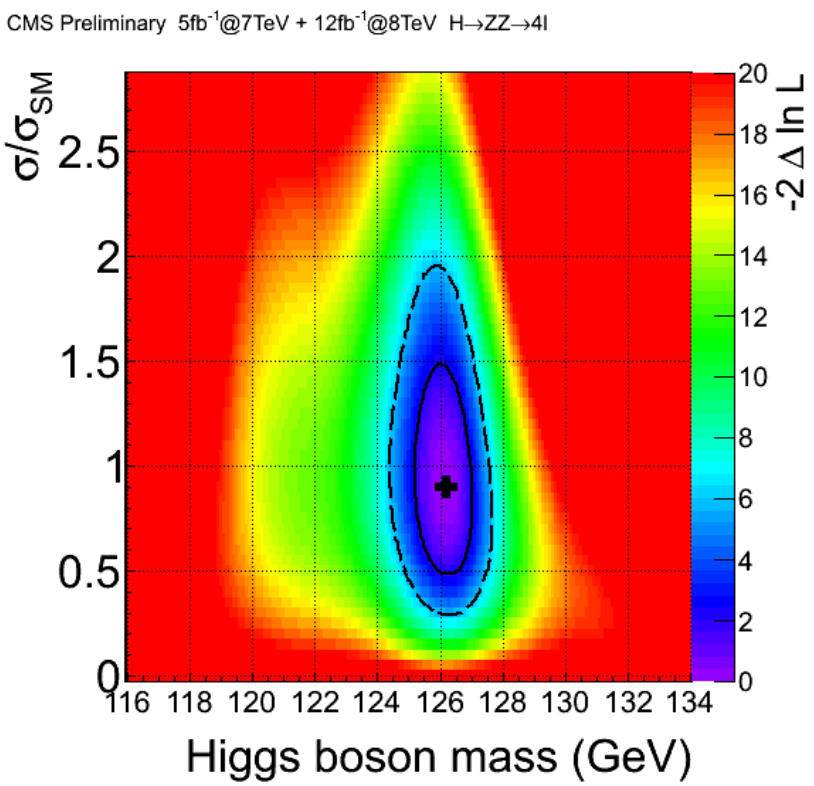


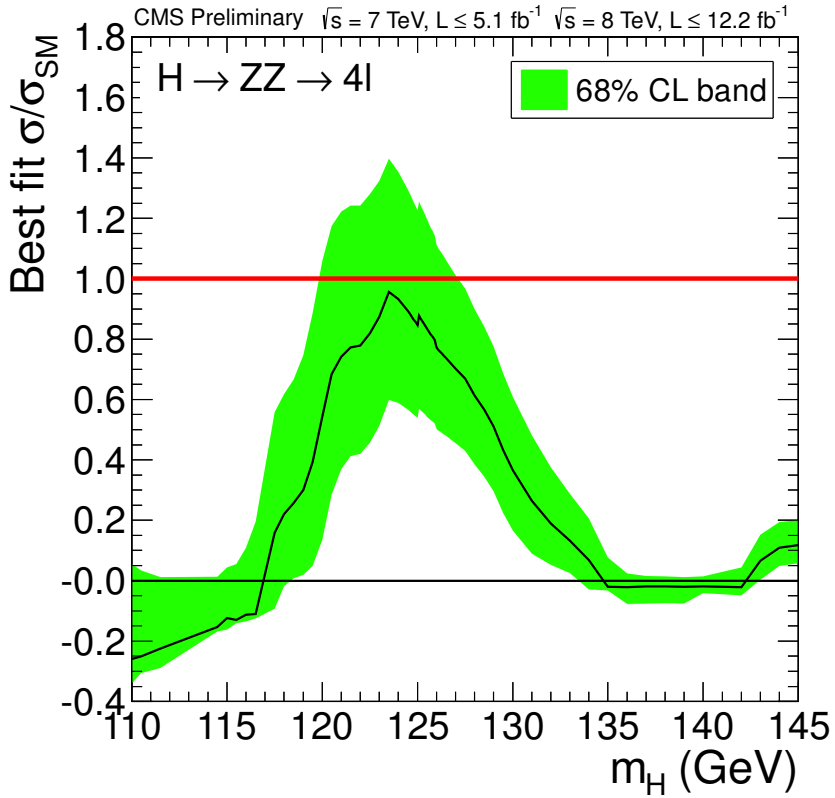


The H→ZZ→ 4l channel excludes a SM Higgs up to 700 GeV!

Observed exclusion in the range [113 – 117] GeV and [129 – 700] GeV

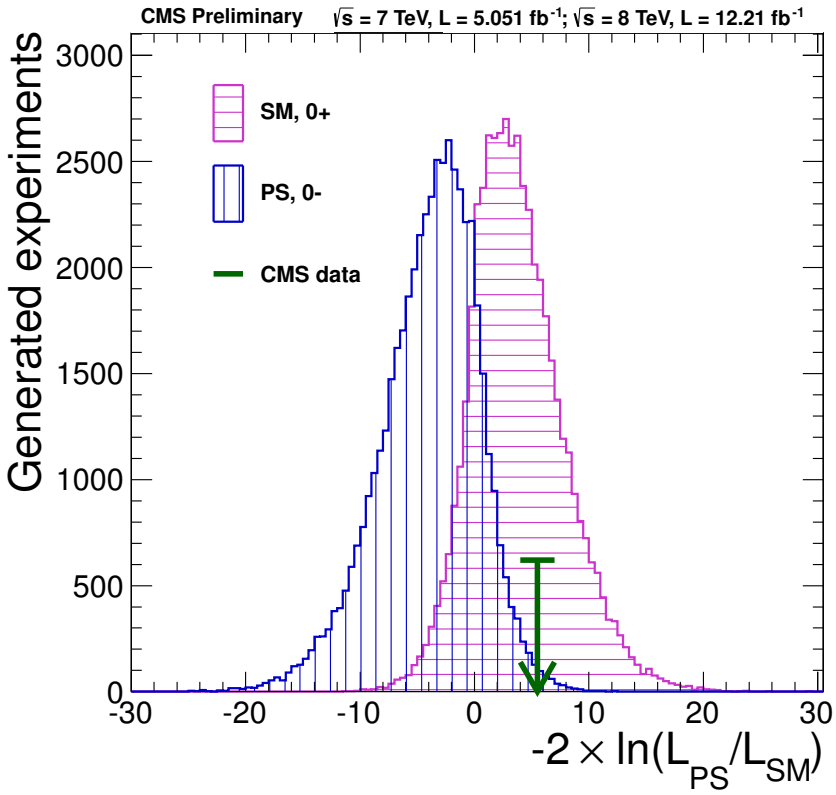
Signal strenght



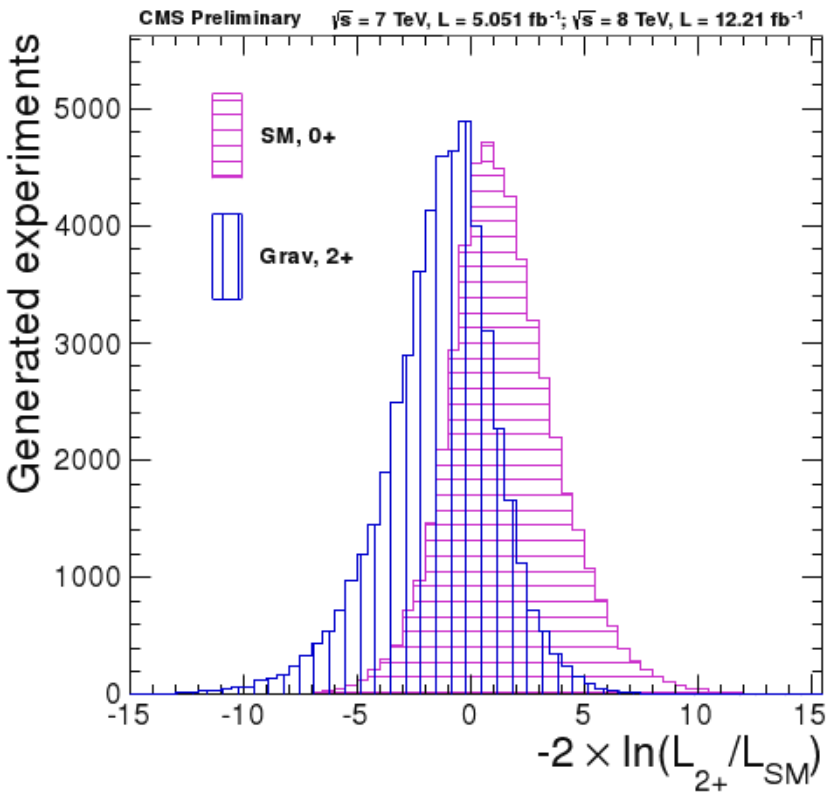


Local μ value compatible with the one of a SM Higgs within uncertainties

Spin and Parity



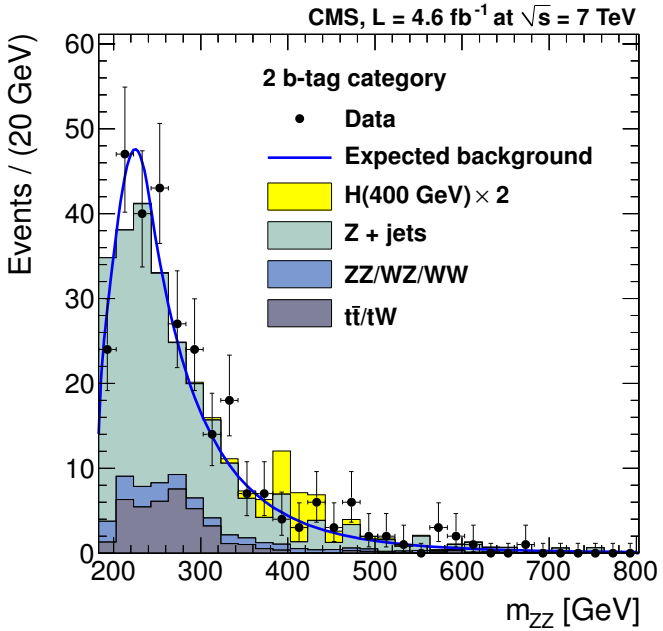
1.97σ expected, 2.45σ observed (0^-), 0.53σ observed (0^+)



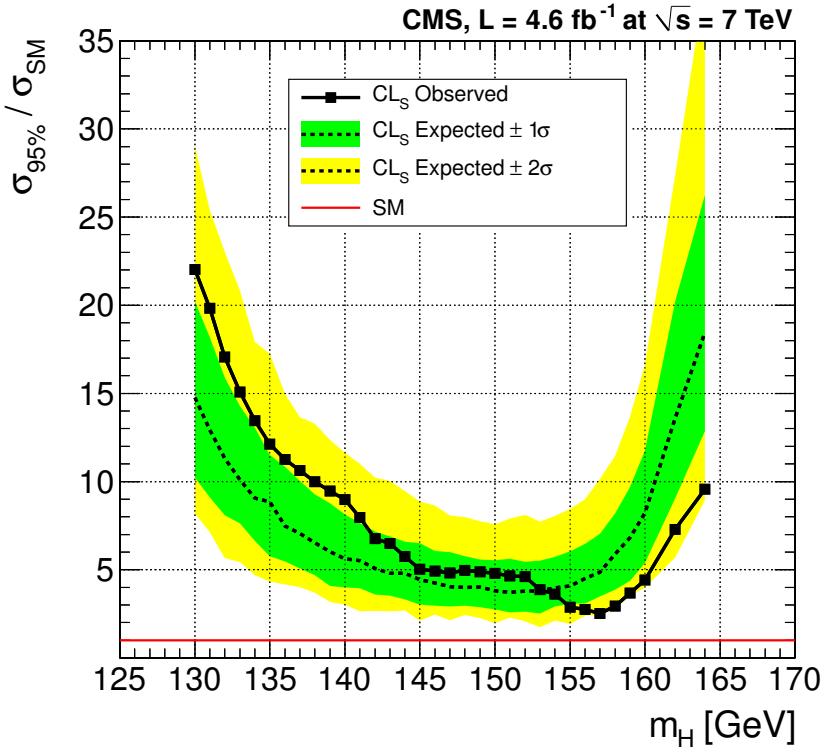
1.2σ expected, 0.6σ observed (2^+), 0.4σ observed (0^+)

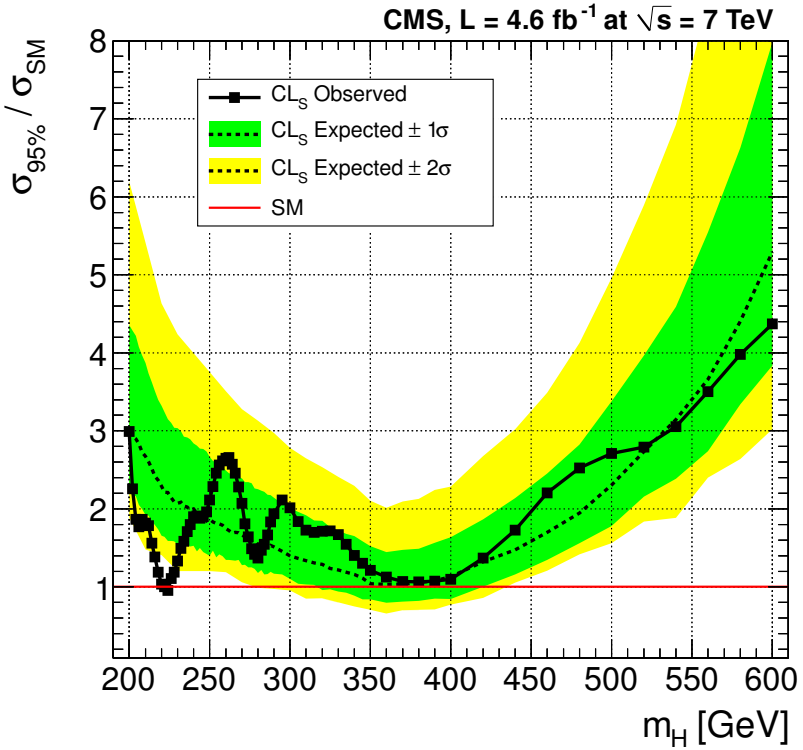
H→ ZZ→ 2l2q in a nutshell

- 2 opposite charge leptons and 2 jets in the same events
- Analysis is conceptually similar to 4*l*: build invariant mass and look for a peak.
- Much larger yields ($\times 20$) than 4*l*
- Worse resolution on jet energy than lepton
- Large background
- jet b-tagging
- Angular discriminant to separate signal and background



Results on 2011 data

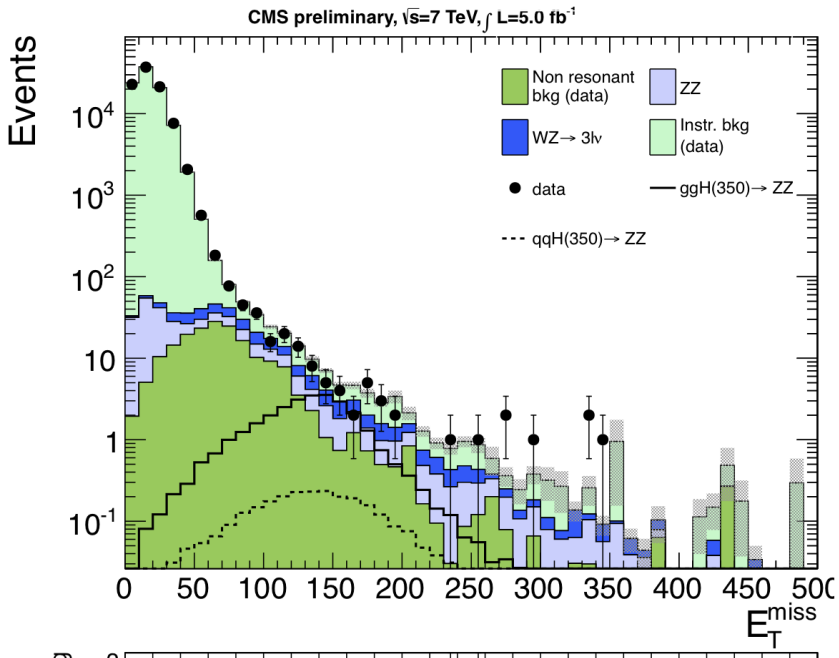




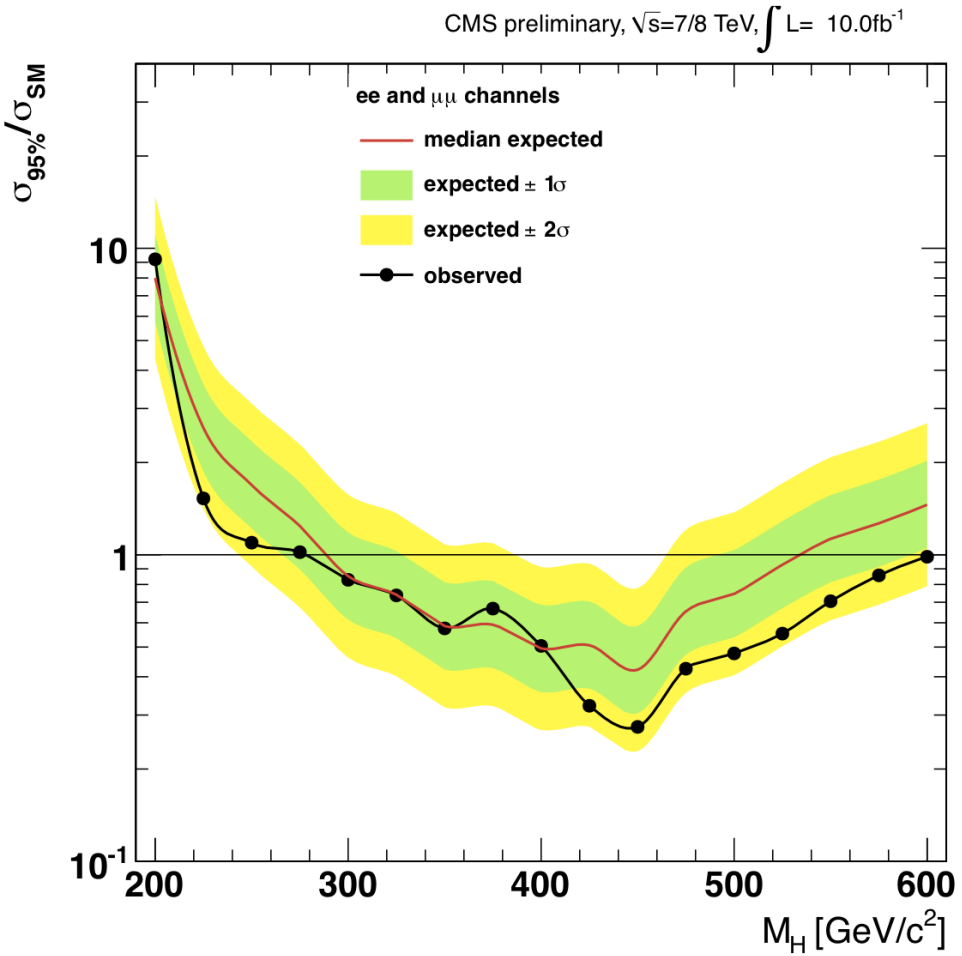
Reaches sensitivity at the SM level for high mass.

H→ ZZ→ 2l2ν in a nutshell

- Signature given by $Z \to ll+$ missing energy
- Main background sources: fake missing energy, Non-resonant bkg (top, WW, W+jets), irreducible ZZ/WZ
- Control sample: $\gamma+$ missing energy
- Non-resonant background: $e\mu$ events in the control region ($55 < m_{ll} < 70$GeV and $110 < m_{ll} < 200$GeV)
- Irreducible bacground estimated from MC simulations
- Sample divided in VBF or jets categories (0,1,$\geq$ 2 jets)



Results (2011+2012 data)



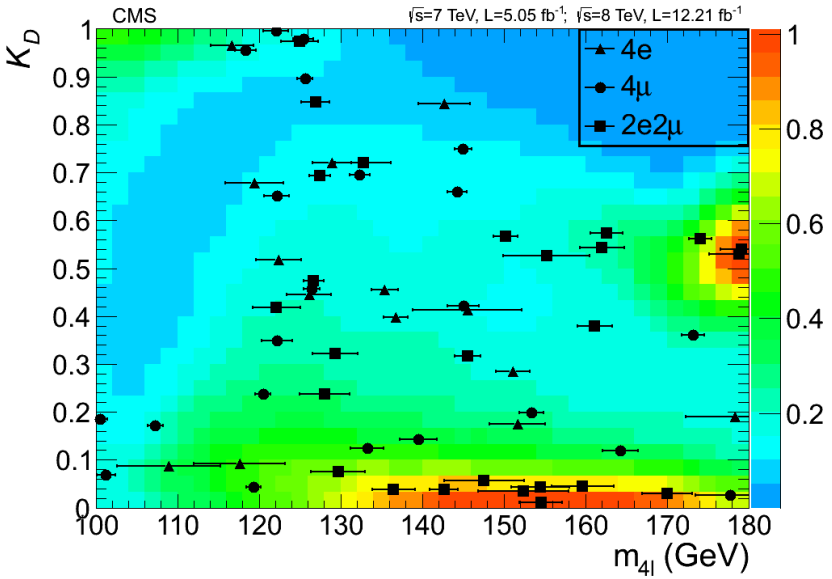
No significant excess has been found. The $2l2\nu$ channel excludes a SM Higgs up to 600 GeV using $5+5fb^{-1}$.

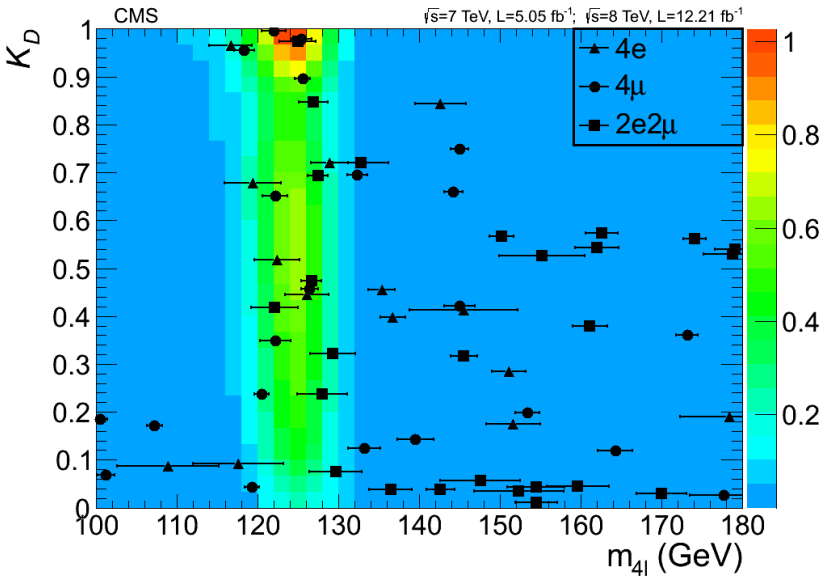
Conclusions

- The status of the $H \rightarrow ZZ$ analysis at CMS was presented
- Evidence for a new SM Higgs-like particle at 126 GeV in the H→ZZ→ 4*l* channel
  - 4.5 statistical significance observed (5 expected)
- Decay characteristics favour SM over alternative hypothesis so far
- Other SM Higgs excluded up to 700 GeV
- No evidence for other unpredicted particles with the current statistics
- $2l2q$ and $2l2\nu$ channels can contribute to the analysis in the high mass region

BACKUP

MELA distribution





The cluster of events at 126 GeV have large KD values.