Analysis strategy for the Higgs boson search in the four lepton final state in CMS

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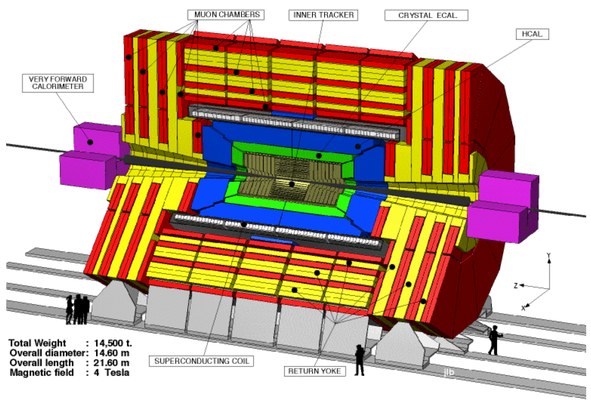
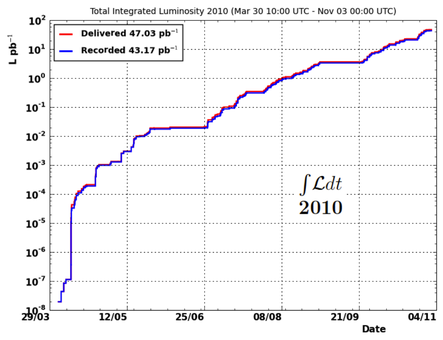
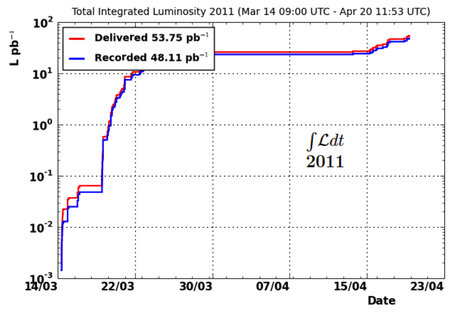
The CMS experiment

The CMS experiment at the LHC p-p collider at CERN has been taking high-quality data for more than one year nowadays.

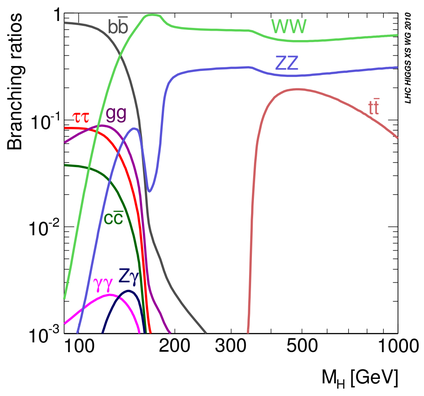






Signal and backgrounds

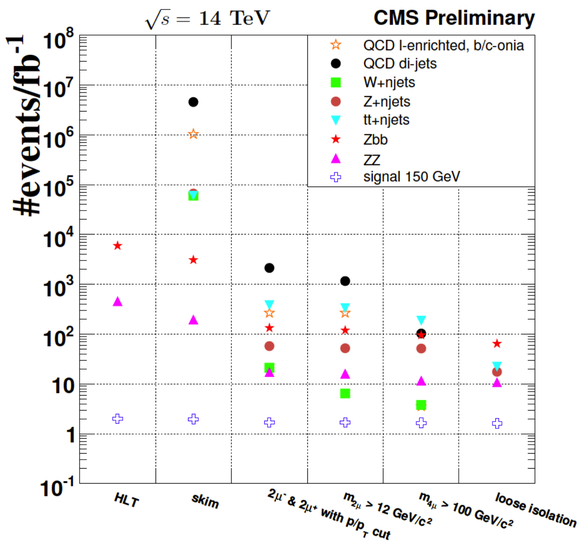
- The considered signal final states are 4μ, $4e$, $2e2\mu$
- The main backgrounds are ZZ, $t\bar{t}$, $Zb\bar{b}$, $Zc\bar{c}$, W+*jets*, Z+*jets*, *QCD*
- Very clean signature:
  - two pairs of same-flavour, opposite-sign, high-p_T isolated leptons pointing to the same vertex
  - at least one Z is on-shell $\rightarrow$ at least one pair of leptons has $m_{inv}(\ell\ell) \simeq m_Z$
  - the SM Higgs is a scalar particle $\rightarrow$ angular correlations among the final-state leptons



process ($\ell = e, \mu, \tau$)	$\sigma_{NLO} \cdot$ BR ($\sqrt{s} = 7$ *TeV*)
$H(130\ \text{GeV}) \rightarrow 4\ell$	6.87 fb (NNLO)
$H(150\ \text{GeV}) \rightarrow 4\ell$	10.41 fb (NNLO)
$H(200\ \text{GeV}) \rightarrow 4\ell$	15.93 fb (NNLO)
$Zb\bar{b} \rightarrow \ell^+\ell^- b\bar{b}$	2.93 pb (NLO)
$t\bar{t} \rightarrow 2\ell 2\nu b\bar{b}$	16.71 pb (NLO)
$ZZ^{(*)} \rightarrow 4\ell$	4.80 pb (NLO)

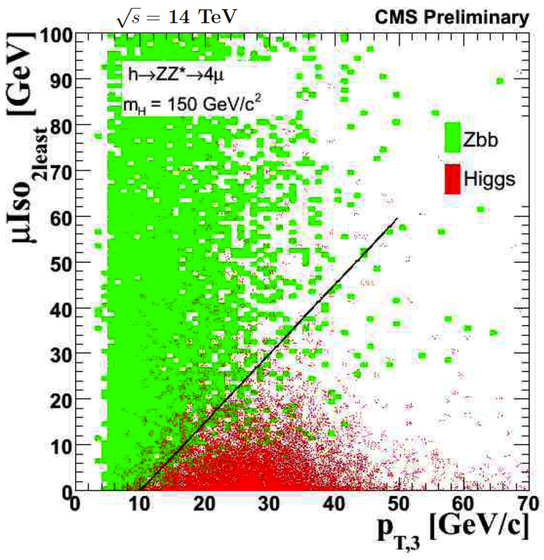
Event selection, part 1: 'Skimming' and 'Preselection'

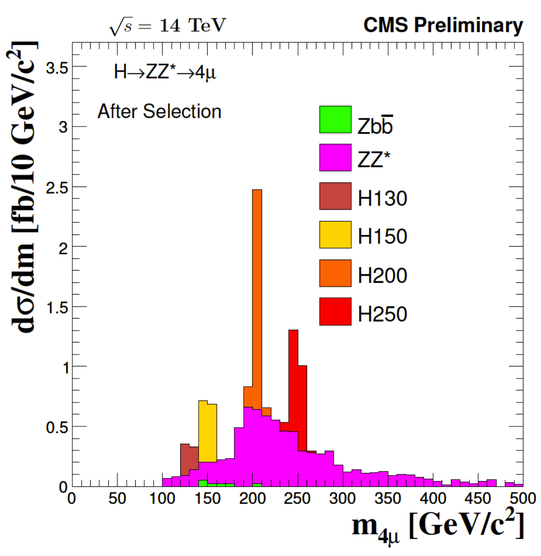
- Goals:
  - discarding the QCD events
  - bringing down the rate of W+*jets*, Z+*jets* events
  - keeping the signal and the most relevant backgrounds (ZZ, $Zb\bar{b}$, $t\bar{t}$) for bkg control studies
- Cuts:
  - trigger requirements for e and μ
  - p_T cuts on leptons
  - loose isolation requirements on all 4 leptons
- *'Best* 4ℓ*-candidate'* choice



Event selection, part 2: 'Selection'

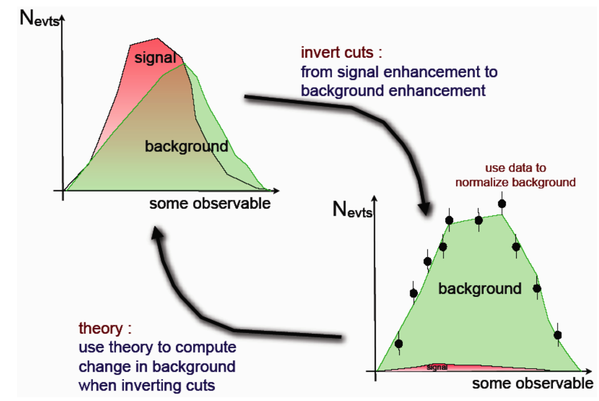
- Goals:
  - rejecting the $Zb\bar{b}$, $t\bar{t}$, $ZZ^{(*)}$ backgrounds
  - keeping the highest possible signal efficiency
- Cuts:
  - more isolation cuts
  - significance of the 3D impact parameter w.r.t. the beamline
  - invariant mass cuts on m_{Z1}, m_{Z2}





Background control: from a control region

- a control region is defined by inverting cuts, so that as few signal events as possible are there
- the background contribution is measured in this region
- the number of background events in the signal region is then evaluated from theory



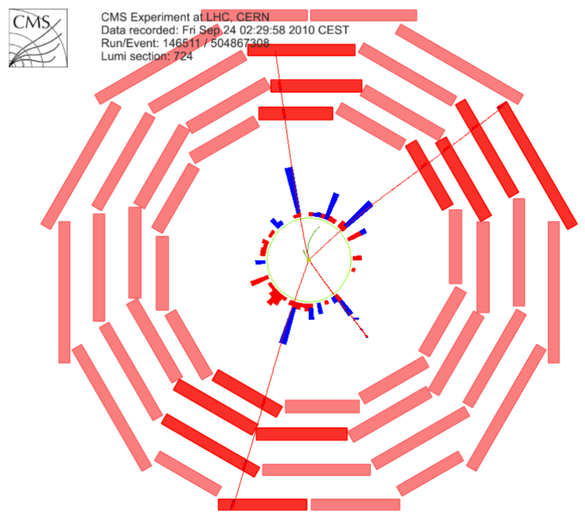
Background control: normalization of ZZ to single Z

$$N_{ZZ\rightarrow 4\ell} = \frac{\sigma^{NLO}_{pp\rightarrow ZZ\rightarrow 4\ell}}{\sigma^{NNLO}_{pp\rightarrow Z\rightarrow 2\ell}} \cdot \frac{\varepsilon^{MC}_{ZZ\rightarrow 4\ell}}{\varepsilon^{MC}_{Z\rightarrow 2\ell}} \cdot N^{observed}_{Z\rightarrow 2\ell}$$

$$\delta N_{ZZ\rightarrow 4\ell} = \pm\ stat. \pm syst. \pm theory$$

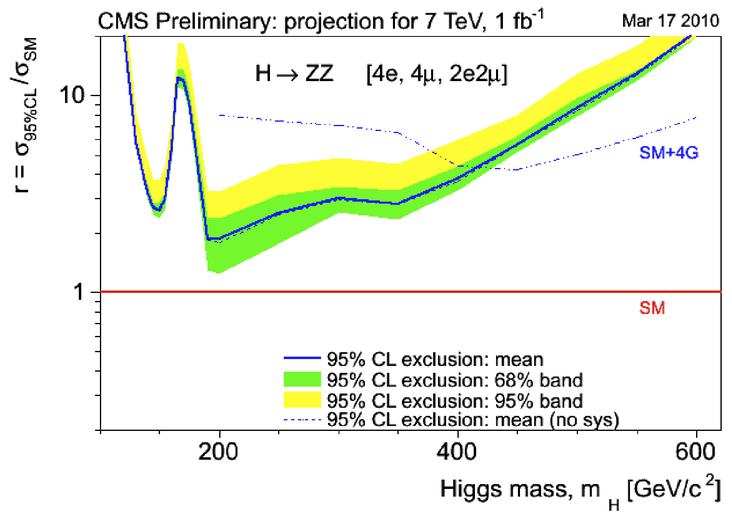
- most systematic uncertainties cancel out (e.g. those related to luminosity)
- most diagrams are shared by the two processes

The first $H \rightarrow ZZ \rightarrow 4\mu$ candidate

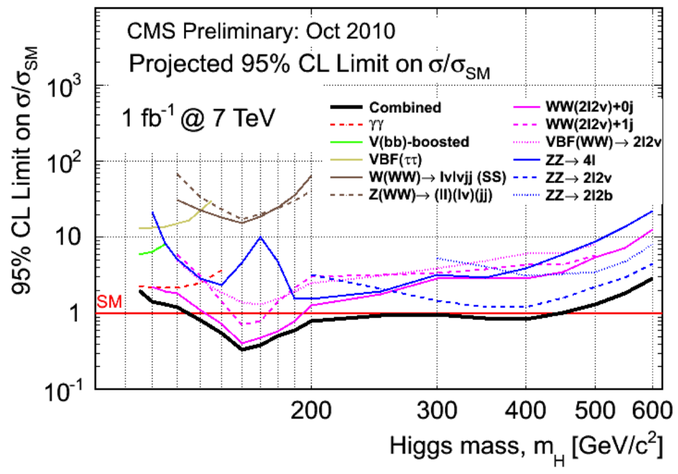


- the only event going through the whole selection so far
- two pairs of opposite-sign muons originating from a common vertex
- $p_T^{\mu 1} = 48.1$ GeV, $p_T^{\mu 2} = 43.4$ GeV, $p_T^{\mu 3} = 25.9$ GeV, $p_T^{\mu 4} = 19.6$ GeV
- two Z candidates can be reconstructed: $m_{Z1} = 92.2$ GeV, $m_{Z2} = 92.1$ GeV
- $m_{inv}(4\mu) = 201.7$ GeV

Exclusion reach for $\sqrt{s} = 7$ *TeV*, $L = 1$ fb^{-1}



- In the $\sqrt{s} = 7$ *TeV*, $L = 1$ fb^{-1} scenario, the exclusion is not possible in any mass range with the $H \rightarrow ZZ^{(*)} \rightarrow 4\ell$ channel only
- However, if a fourth generation of quarks exists, the Higgs boson could be excluded in the region $m_H \lesssim 420$ GeV



- Combining the individual subchannels would allow to exclude the mass range $155 < m_H < 450$ GeV with $\sqrt{s} = 7$ *TeV*, $L = 1$ fb^{-1}

References

- CMS AN 2010/237: S. Baffioni et al., "Search strategy for the Higgs boson in the $ZZ^{(*)}$ decay channel at $\sqrt{s}$=10 TeV with the CMS experiment"
- CMS Note 2010/008: The CMS Collaboration, "The CMS physics reach for searches at 7 TeV"
- CMS AN 2009/020: S. Baffioni et al., "Projected exclusion limits on the SM Higgs boson cross sections obtained by combining the $H \rightarrow WW^{(*)}$ and $ZZ^{(*)}$ decay channels"
- CMS PAS 2008/003: The CMS Collaboration, "Search strategy for the Higgs boson in the $ZZ^{(*)}$ decay channel with the CMS experiment"

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