Search for the Standard Model Higgs boson using the $H \to ZZ \to \ell^-\ell^+ q\bar{q}$ decay mode at the CMS

Roberto Castello (Università degli Studi di Torino/INFN, Italy)[1] on behalf of CMS collaboration

(1) now at Université Catholique de Louvain, Belgium

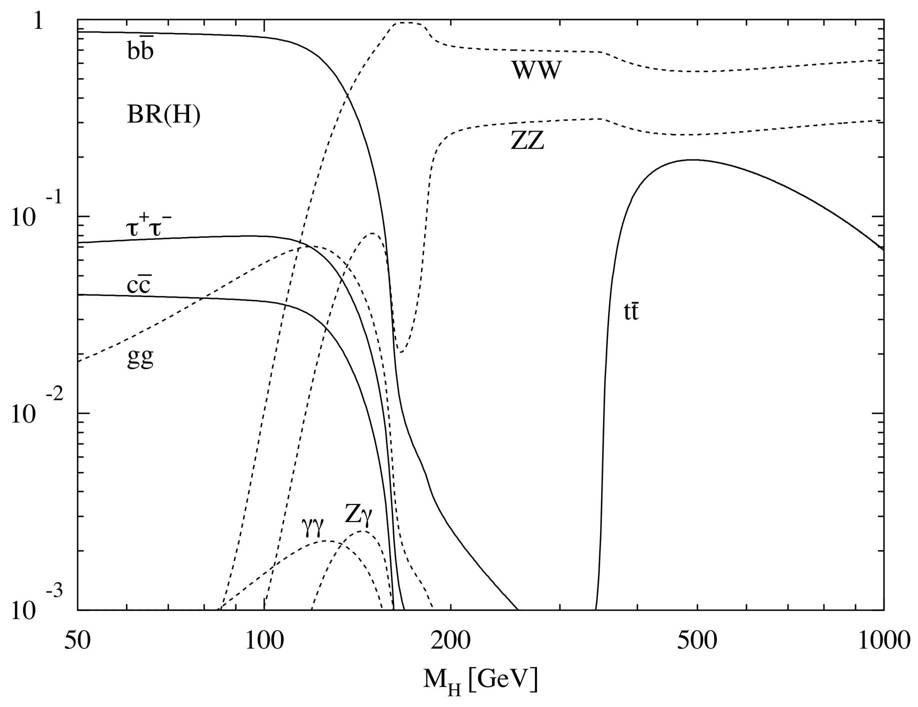
Abstract

A search for the standard model Higgs boson decaying to two Z bosons with subsequent decay to a final state with two leptons and two quark-jets is presented. Data corresponding to an integrated luminosity of 1.6 fb^{-1} of LHC proton-proton collisions at the center-of-mass energy of 7 TeV were collected and analyzed by the CMS experiment. No evidence for a Higgs boson is found and upper limits on the Higgs boson production cross section are set in the range of masses between 226 GeV and 600 GeV.

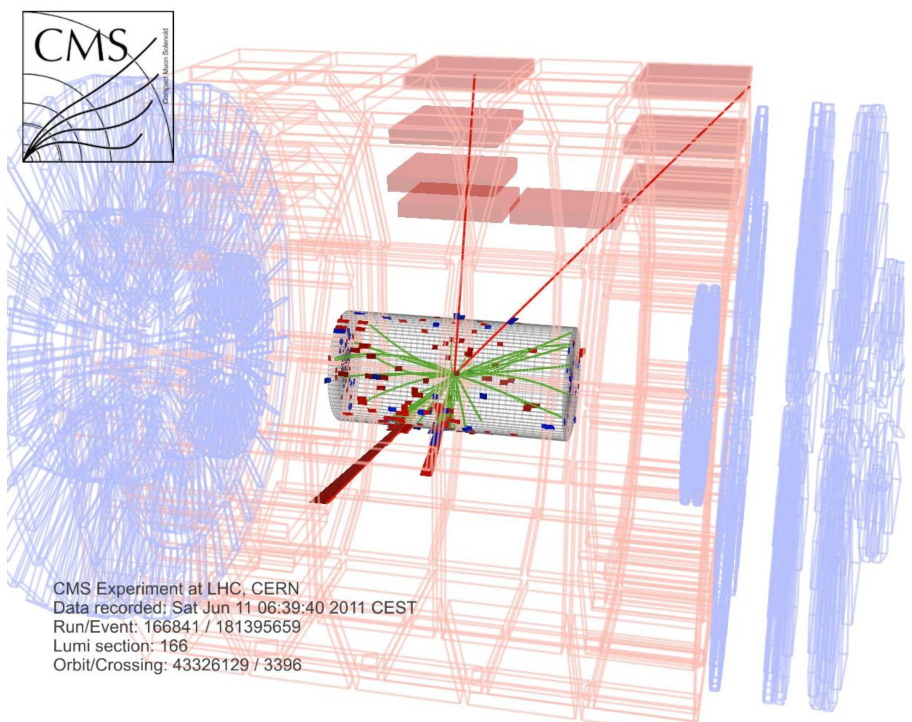
The Higgs sector

The primary Higgs boson production mechanism at LHC (pp collider) is gluon fusion (GF), with small but measureable contribution from vector boson fusion (VBF). Most promising decay channels are:

- *low* Higgs mass: $H \to \gamma\gamma$ (rare channel, clean signature), $H \to WW^*(ZZ^*)$
- *high* Higgs mass: $H \to WW$ (largest cross section), $H \to ZZ$ (best for $M_H > 200 GeV$).



$H \to ZZ \to \ell^-\ell^+ q\bar{q}$ at the Compact Muon Solenoid



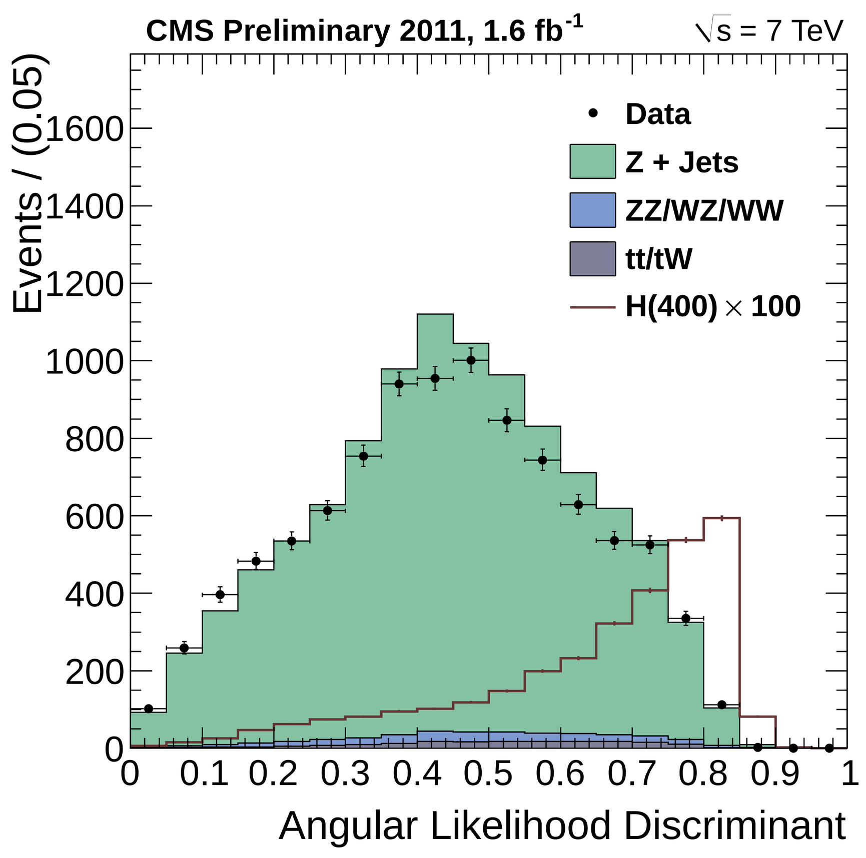
- Challenging process with respect to $H \to ZZ \to \ell\ell\ell\ell$: more complex signature, larger backgrounds ($100 \cdot \sigma_{4\ell}^{bkg}$), but larger signal yield ($20 \cdot \sigma_{4\ell}^{sig}$).
- Main backgrounds: Z+jets ($10^5 \cdot \sigma_{2\ell 2q}^{sig}$), $t\bar{t}$, ZZ,WW,WZ.
- Key ingredients: lepton reconstruction/identification efficiency (Tracker, muon system, Calorimeter), jet reconstruction (Particle Flow algorithm) and pile-up treatment.

$p_T(\ell^\pm)$	lowest $p_T > 20$ GeV, highest $p_T > 40$GeV
p_T(jets)	> 30 GeV/c
$\lvert\eta\rvert(\ell^\pm)$	$(e^\pm) < 2.5$, $(\mu^\pm) < 2.4$
$\lvert\eta\rvert$(jets)	< 2.5

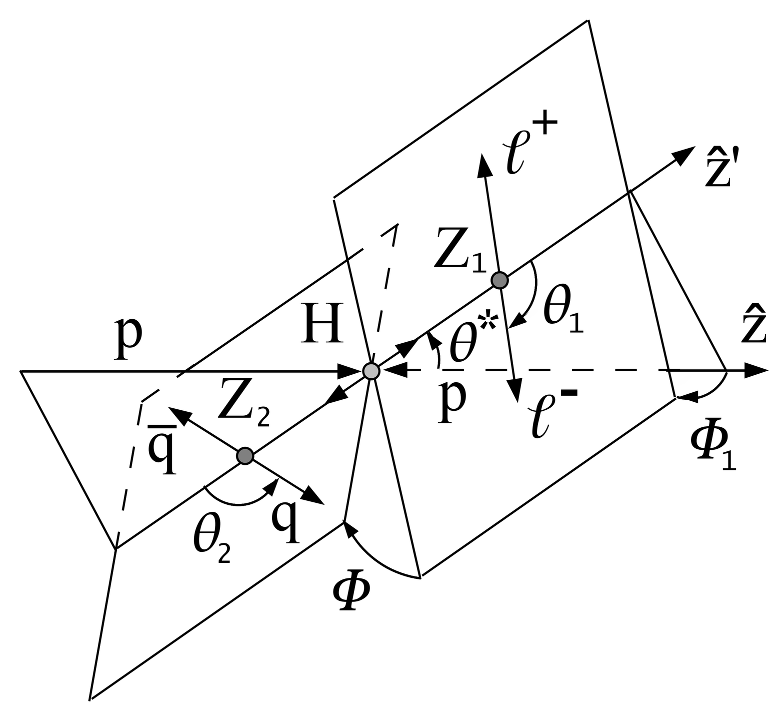
	0 b-tag	1 b-tag	2 b-tag
b-tag	none	one loose	medium & loose
angular LD	$> 0.55 + 2.5e^{-4}\, m_{ZZ}$	$> 0.302 + 6.5e^{-4}\, m_{ZZ}$	> 0.5
q-g LD	> 0.10	–	–
$2\ln\lambda(M_{E_T})$	–	–	< 10
m_{jj}	$\in$ [75, 105] GeV		
m_{ll}	$\in$ [70, 110] GeV		
m_{ZZ}	analyzed within [183, 800] GeV		

Table 1: Optimized kinematic and topological selection requirements.

The analysis strategy



- **Invariant mass cut**. m_{jj} and m_{ll} requirement to reduce background Z+jet and $t\bar{t}$.
- **Kinematic fit**. Forcing hadronic Z mass weighting jets with expected resolutions. Improve Higgs mass resolution in signal.
- **Angular likelihood discriminant**. Higgs boson is scalar: angular distribution of decay products independent from production mechanism. Final state kinematics univocally determined by 5 angles ($\theta^*\, \theta_1\, \theta_2\, \phi_1\, \phi$). LD based on the probability ratio between signal and background hypothesis [2].
- **Parton flavor of jets**. Z from signal decays democratically in u,d,s,c,b quark-jets. Background jets are mostly coming by gluon radiation. LD separates light-quark jets and gluon on a statistical basis.
- **Tagging of the b-flavour**. Identifying jets originating from the hadronization of b-quarks: optimization in 4 categories.



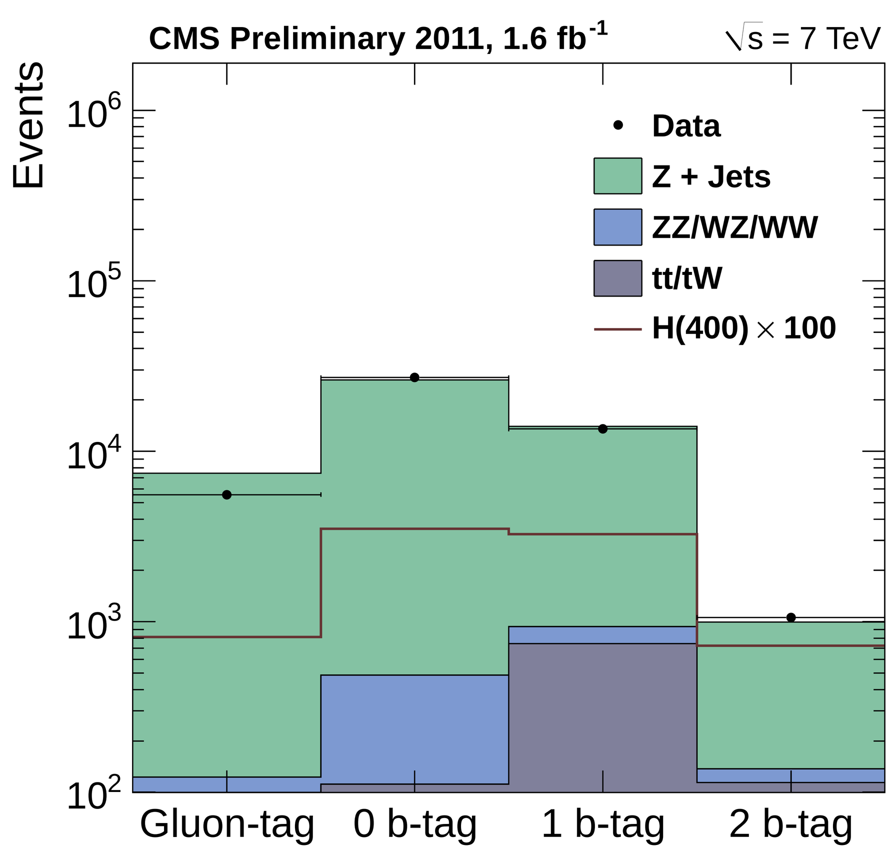
Event analysis

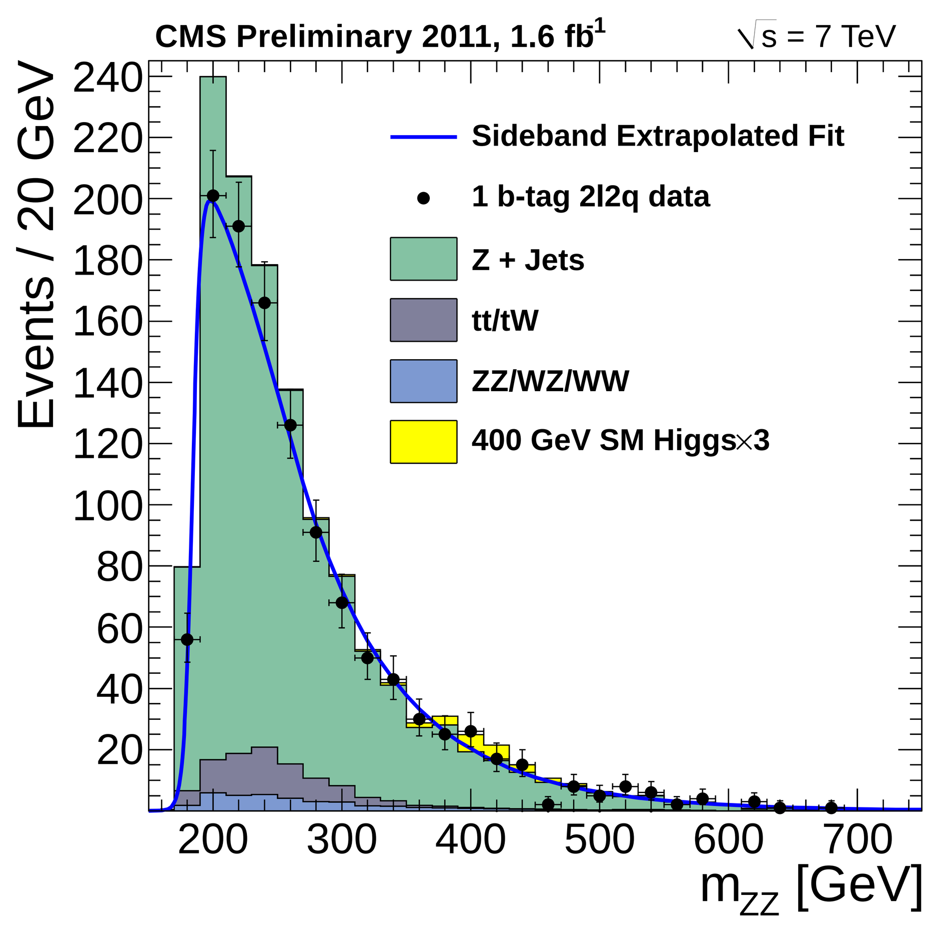
- **Background from sidebands**. $m_{jj} \in [60, 75] \bigcup [105; 130]$ GeV.

$$N_{\rm bkg}(m_{ZZ}) = N_{\rm sb}(m_{ZZ}) \times \frac{N_{\rm bkg}^{\rm sim}(m_{ZZ})}{N_{\rm sb}^{\rm sim}(m_{ZZ})} = N_{\rm sb}(m_{ZZ}) \times \alpha(m_{ZZ}), \quad (1)$$

Systematic uncertainties on background cancel in the ratios (theoretical cross-section prediction, b-tagging efficiency). Background fitted and extrapolated to the signal region.

- **Shape analysis for signal**. m_{ZZ} splitted in 6 categorie: 3 b-tag x 2 lepton flavors. Signal parametrized for 60 mass point (Breit-Wigner $\otimes$ Double Crystal-Ball fit)

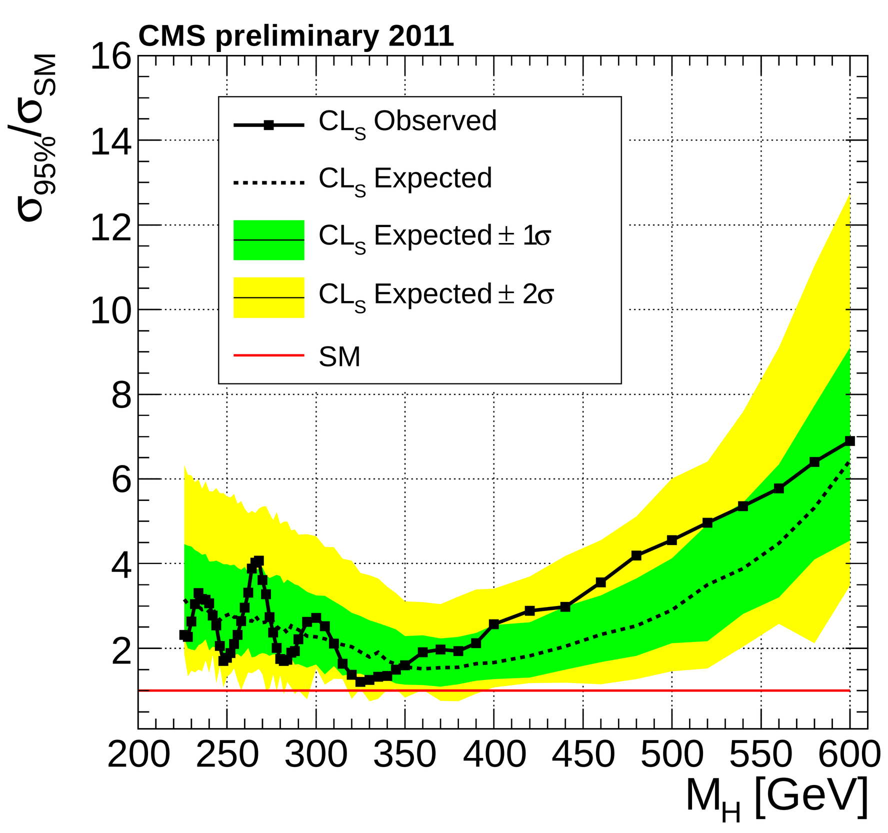




Systematic uncertainties

source	0 b-tag	1 b-tag	2 b-tag
muon reco	2.7%		
electron reco	4.5%		
jet reco	1–5%		
pileup	2%		
b-tagging	3–7%	3%	$+13\%/-18\%$
gluon-tagging	4.6%	–	–
M_{E_T}	–	–	3%
acceptance (PDF)	3%		
acceptance (HQT)	2%	5%	3%
acceptance (WBF)	1-2%		
luminosity	4.5%		
Higgs cross section	13–18%		

Table 2: Systematic uncertainties on signal normalization



Exclusion limits at 1.6 fb^{-1}

- No evidence for a SM-like Higgs boson has been found
- Upper limits on the production cross section for the SM Higgs boson have been set in the range of masses between 226 GeV and 600 GeV.
- The exclusion limits are approaching those of the SM expectation for the Higgs boson production (1.1 x SM at $m_{Higgs} \sim 330$ GeV)
- A range of SM4 Higgs mass hypotheses are excluded between 226 and 470 GeV at 95% CL

References

[1] CMS Collaboration, *Search for the standard model Higgs Boson in the decay channel H to ZZ to llqq at CMS*, CMS-PAS-HIG-11-017;

[2] Y. Gao at al., *Spin determination of single-produced resonances at hadron colliders*, Phys. Rev. D81 (2010) 075022, arXiv:1001.3396;