

Search for a high mass SM-like Higgs boson at CMS in the decay channel $H \rightarrow ZZ \rightarrow llqq$ at 8 TeV

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on behalf of the CMS Collaboration

Young Scientists Forum
50th Rencontres de Moriond

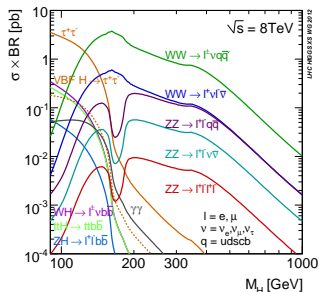
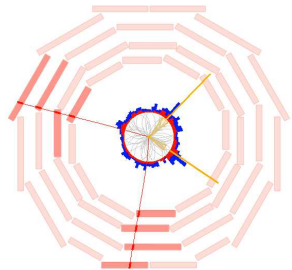
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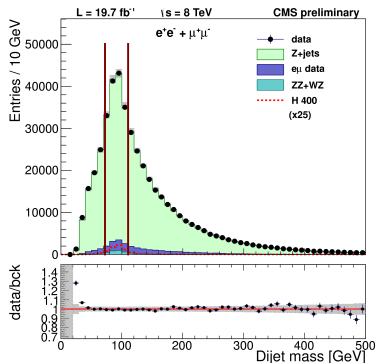
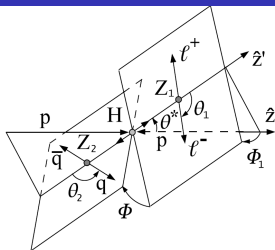
Introduction

- Search for Higgs-like particles
 $m_H > 200$ GeV
- pp collisions at 8 TeV collected by CMS
($L \sim 20 \text{ fb}^{-1}$)
- $H \rightarrow ZZ \rightarrow 2\ell 2q$ decay channel
 - Identify two high momenta leptons and two high momenta jets
 - Reconstruct both Z bosons
 - Largest yields within ZZ decay channels
 - Huge backgrounds



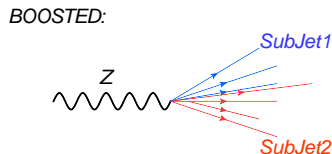
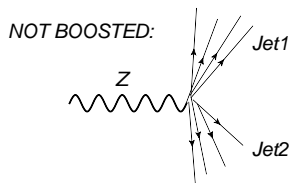
H \rightarrow ZZ \rightarrow 2 ℓ 2q analysis

- Reduce overwhelming backgrounds (mainly **Z+jets**)
 - Dijet around Z mass:
 $71 < m_{jj} \text{ (GeV)} < 111$
 - **Angular analysis** for a spin-0 resonance
 - Exploit **Z \rightarrow b \bar{b}** (b-tagging)
- Two production mechanisms considered: **gluon fusion** and **VBF**
- Fully reconstructed **ZZ mass**
- Sensitivity up to **600 GeV**

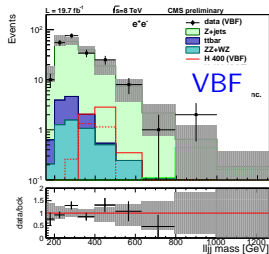
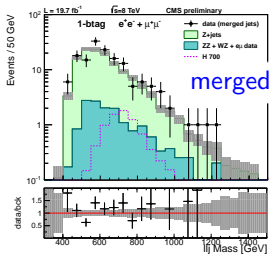
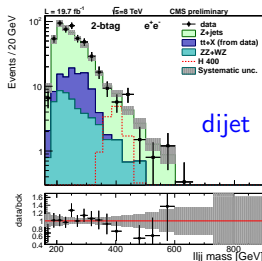


$H \rightarrow ZZ \rightarrow 2\ell 2q$ high mass analysis

- Above 500 GeV: boosted Z implies **merging** of the jets
- Identified using **jet substructure** techniques (see John Stupak's talk)
 - Pruned mass and τ_{21}
 - Angular analysis and b-tagging on the **subjets**
- Increased sensitivity up to **1000 GeV**

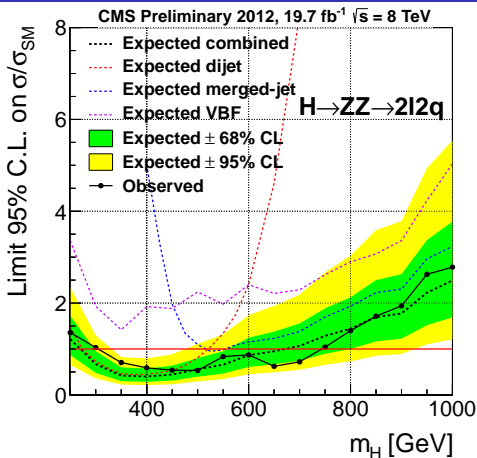


- Use m_{ZZ} spectra to perform hypothesis testing
- Normalisation constrained by dijet mass **sidebands**



The analysis is split into **14 exclusive categories**, separating into dielectron/dimuon, dijet/merged, 0,1,2-btag and ggH/VBF

Results - SM-like Higgs



- Consistent with SM expectations
- SM-like Higgs directly excluded in the range 305 to 744 GeV
- Included in the full ZZ and WW high mass combined search (see Mario Pelliccioni's talk)

Results - EWK singlet interpretation

EWK singlet in a nutshell

- Additional scalar H
- Mixed with h(125) state
- Properties are SM-like
- Signal strengths and widths of both h(H) are modified by $C(C')$. For the heavy Higgs state:

$$\mu' = C'^2(1 - B_{\text{new}})$$

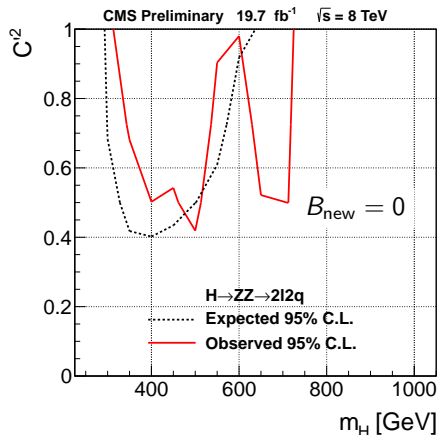
$$\Gamma' = \Gamma_{\text{SM}} \cdot C'^2 / (1 - B_{\text{new}})$$

with:

$$C^2 + C'^2 = 1 \text{ (unitarity)}$$

$$B_{\text{new}} \equiv \text{non-SM decays}$$

- Scan in C'^2 and B_{new} parameters



- $H \rightarrow ZZ \rightarrow 2\ell 2q$ analysis (CMS-PAS-HIG-14-007)
- Results **compatible with SM**
- **Excluded** SM-like Higgs in the mass range between **305 and 744 GeV**
- Additional EWK singlet interpretation
- Part of the **ZZ and WW combined** search for high mass Higgs

BACKUP

Muon selection

- Tight ID working point
- $p_T > 40/20$ GeV for leading/subleading leptons
- $|\eta| < 2.4$
- $I_{PF}(\Delta\beta_{corr})/p_T < 0.12$
($\Delta R < 0.4$ cone)

Electron selection

- Loose ID working point
- $p_T > 40/20$ GeV for leading/subleading leptons
- $|\eta| < 2.5$ (excluding $1.44 < |\eta| < 1.57$)
- $I_{PF}(Eff.A_{corr})/p_T < 0.15$
($\Delta R < 0.3$ cone)

Each pair of oppositely charged leptons is considered to be a **Z candidate**

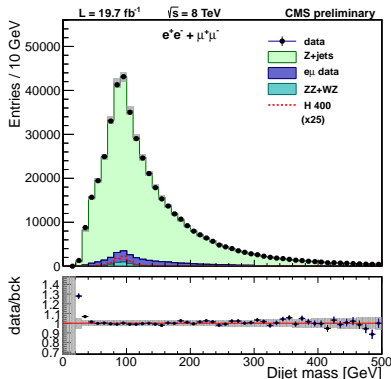
Restricting dilepton invariant mass: $76 < m_{\ell\ell}$ (GeV) < 106

Two algorithms to reconstruct jets: AK5 and CA8

AK5 jets

- PF jets reconstructed with anti- k_T ($R=0.5$)
- $p_T > 30$ GeV, $|\eta| < 2.4$
- $\Delta R(\text{lepton}, \text{jet}) < 0.5$
- Pile-up removal: $\beta > 0.2$
- Standard jet-quality cuts

Each pair of AK5 jets (**dijet**) is considered as a **Z candidate**.

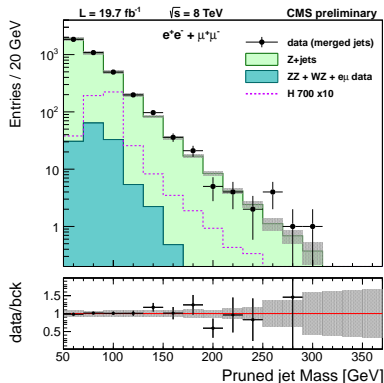


Jet selection - Boosted hadronic Z

Boosted high mass resonances: $Z \rightarrow q\bar{q}$ expected to be reconstructed as a single jet

CA8 jets

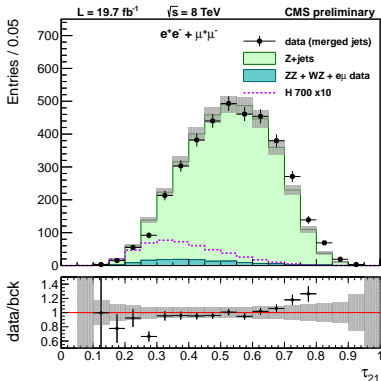
- PF jets reconstructed with Cambridge-Aachen algorithm ($R=0.8$)
- $p_T > 100$ GeV
- $|\eta| < 2.4$
- $\Delta R(\text{lepton}, \text{jet}) < 0.8$
- Jet pruning: improve background rejection and mass resolution
- $M_J^{\text{pruned}} > 50$ GeV



A single CA8 jet (**merged jet**) is considered as a boosted **Z candidate**.

Boosted Z-tagging

- Use jet substructure techniques to identify the boosted hadronic Z (see JME-13-006)
- τ_N = compability of a jet having N **subjets**
- Discriminate between merged Z jets with 2 subjets and QCD background using $\tau_{21} = \tau_2/\tau_1$



Categorisation

Classify candidates into exclusive categories according to:

- Production mechanism: VBF or ggH
- Hadronic Z: dijet or merged jet
- Lepton flavour and number of b-tagged jets (subjects)

VBF category

The event is tagged as VBF if contains an additional pair of AK5 jets satisfying:

- $p_T(j_{add}) > 30 \text{ GeV}$, $\eta(j_{add}) < 4.7$
- $M(j_{add}j_{add}) > 500 \text{ GeV}$, $\Delta\eta(j_{add}j_{add}) > 3.5$, MVA-PUId

Merged-jet category

Events are considered for the merged-jet category when contains a CA8 jet with:

- $p_T(ll) > 200 \text{ GeV}$, $p_T(J) > 100 \text{ GeV}$
- $\tau_{21} < 0.5$

Dijet category

Remaining events are considered for the ggH dijet category

Event categories

The analysis is split into **14 exclusive categories**:

VBF category

- Two channels split by **lepton flavour**: $eejj$ and $\mu\mu jj$
- Combining merged jets and dijets

Merged-jet category

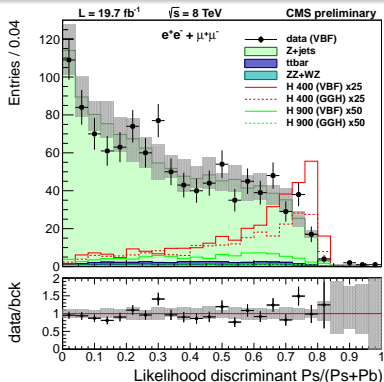
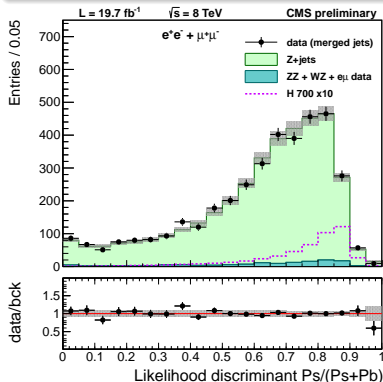
- Six high mass channels split by **lepton flavour** and number of **btagged** jets: $(eejj \text{ and } \mu\mu jj) \otimes (0,1,2)\text{-btags}$
- Vetoing VBF categories

Dijet category

- Six low mass channels split by **lepton flavour** and number of **btagged** jets: $(eejj \text{ and } \mu\mu jj) \otimes (0,1,2)\text{-btags}$
- Vetoing VBF and merged-jet categories

Angular analysis

- Five angles fully describe the kinematics of $H \rightarrow ZZ \rightarrow 2\ell 2q$:
(θ^* , θ_1 , θ_2 , Φ_1 , Φ)
- Build a variable to discriminate signal from background, angular likelihood discriminant $LD = \frac{P_s}{P_b + P_s}$
- Merged-jets: use angles between the subjects



Restricting invariant mass of dijet/pruned jet forming two regions:

Signal region

Mass around nominal Z mass to reduce backgrounds

- Dijet category:
 $71 < m_{jj} \text{ (GeV)} < 111$
- Merged jet category:
 $71 < m_J^{\text{pruned}} \text{ (GeV)} < 111$

Perform a **shape analysis** on $M_{\ell\ell jj}$ system

Sidebands

Signal-depleted region

- Dijet category:
ISR &
 $60 < m_{jj} \text{ (GeV)} < 130$
- Merged jet category:
ISR & $60 < m_J^{\text{pruned}} \text{ (GeV)} < 130$

Used to **validate** the analysis and **constrain** the normalization

VBF category

The event is tagged as VBF if contains an additional pair of AK5 jets satisfying:

- $p_T(j_{add}) > 30$ GeV, $\eta(j_{add}) < 4.7$
- $M(j_{add}j_{add}) > 500$ GeV,
 $\Delta\eta(j_{add}j_{add}) > 3.5$
- MVA discriminant exploiting the VBF topology reduce backgrounds
- Cut on 0.4

