Search for a SM Higgs Decaying to ZZ to l^+l^-qq or $l^+l^-\nu\nu$ at CMS

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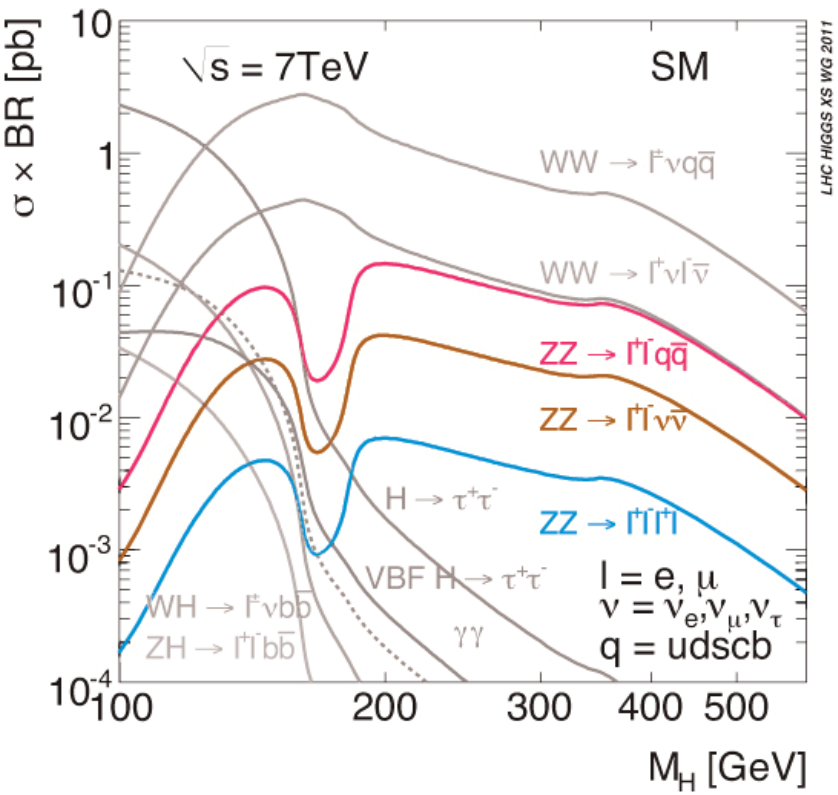
Two High Mass Explorers

- H→ZZ→2l2q/2l2ν specialized in **high mass** Higgs searches
  - Need energetic decay products to fight backgrounds
  - 'Natural' sensitivity range: $2\times M_Z \div 600$ GeV
- Pioneering high-mass searches in 2011
  - Large signal BR: **first analyses** to have results at high mass
  - Outrun by H→ZZ→4l in lumi race
- It doesn't end with a 95% CL
  - Still crucial to understand **vector boson scattering** at high mass
  - **VBF**-like signature under the spotlight

Compared to the Golden Channel



	Cross Section	Back-grounds
H→ZZ→2l2q	× 20	more
H→ZZ→2l2ν	× 6	
H→ZZ→4l	× 1	less

higher purity

larger yields

$H \rightarrow ZZ^{(*)} \rightarrow 2l2q$

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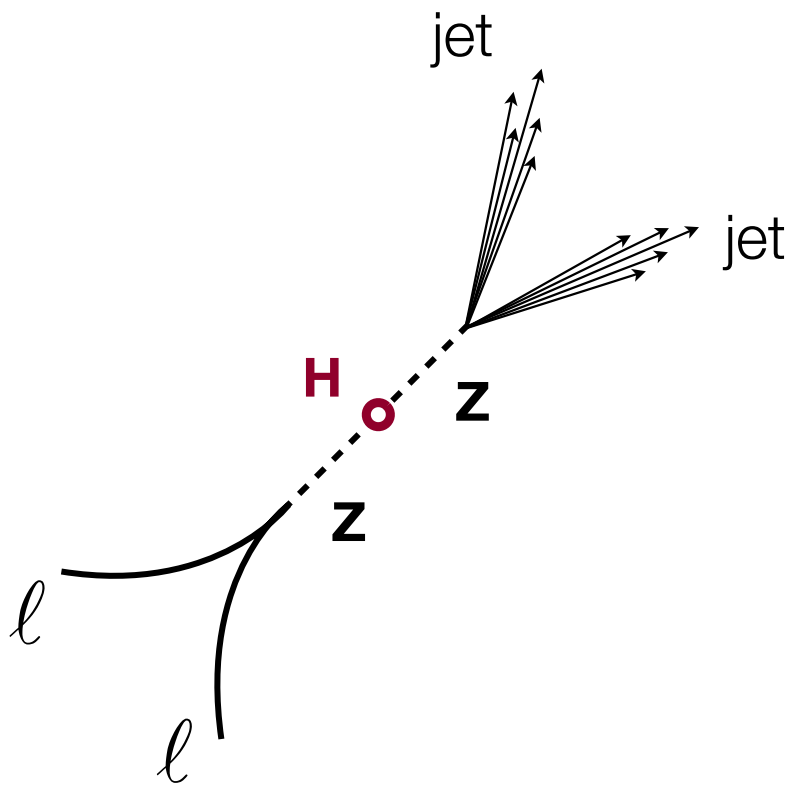
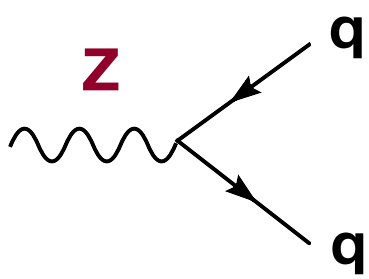
2011 Data

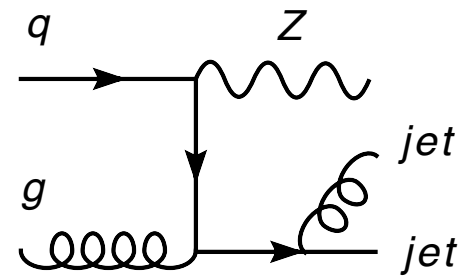
H→ZZ→2l2q at a Glance



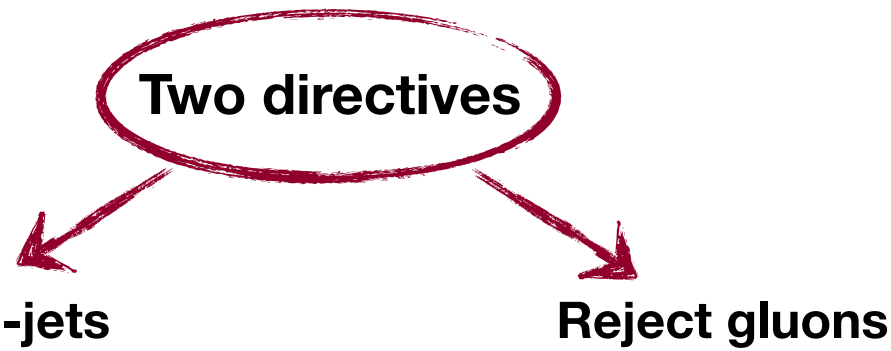
- Conceptually similar to 4 leptons
  - Fully reconstructed final state
  - Search for a mass peak
  - (Good for discovery)
- But:
  - High signal yield (×20)
  - Worse resolution (jets)
  - Larger backgrounds

Jet Flavour as Means of Discrimination

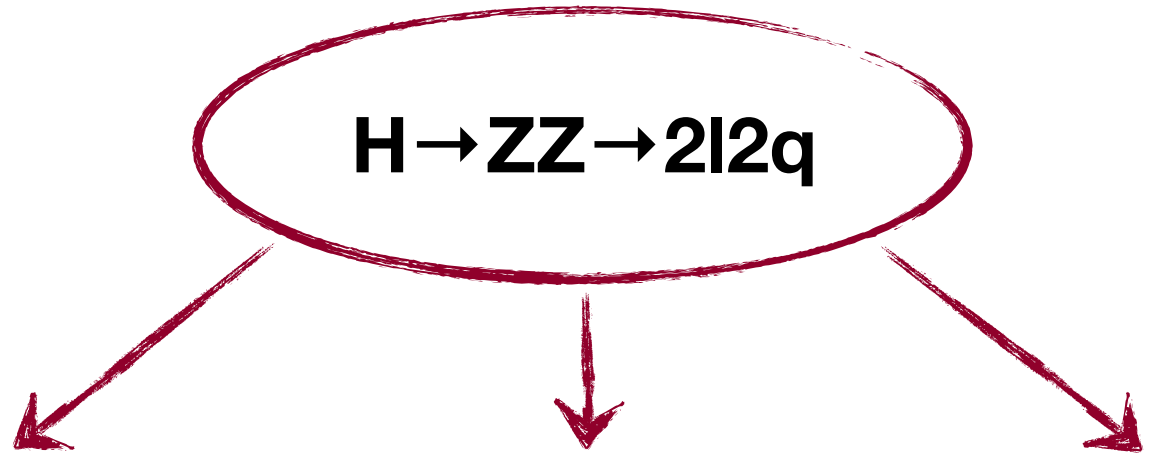




- **Signal:** decay of a Z boson
  - 100% quarks
  - 'Democratic' wrt flavor
- **Background:** Z + 2 jets
  - Lots of gluons (~50%)
  - Heavy flavors (*b*) suppressed



Isolating Heavy Flavors: Three Categories



2 b-tags

- Both jets b-tagged
- Purest category
- Lowest signal yield

1 b-tag

- One jet b-tagged
- Worst category
- Large background

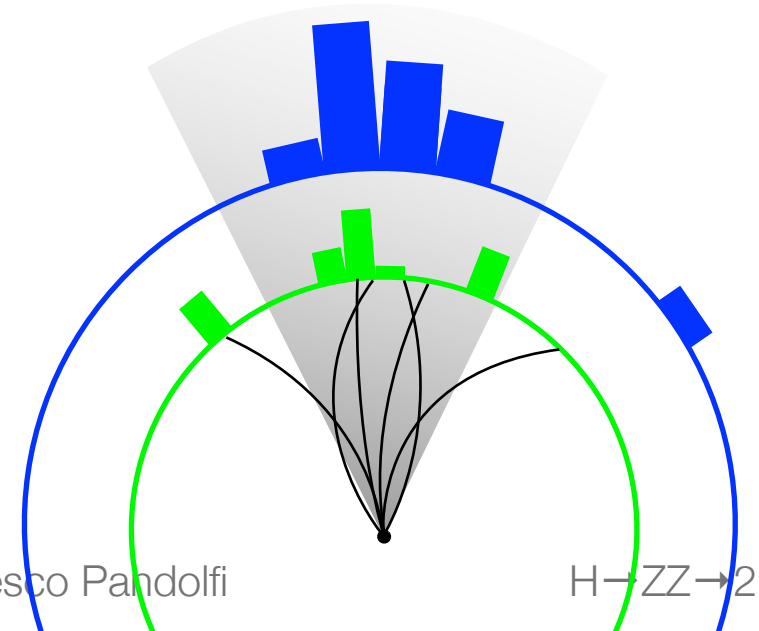
0 b-tags

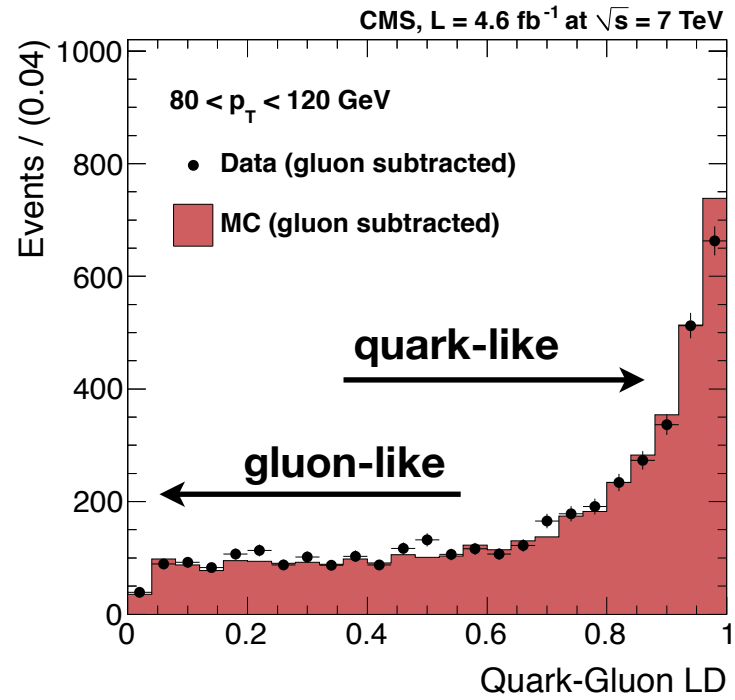
- No jet b-tagged
- Highest signal yield
- Large background

Discriminating Gluon Jets

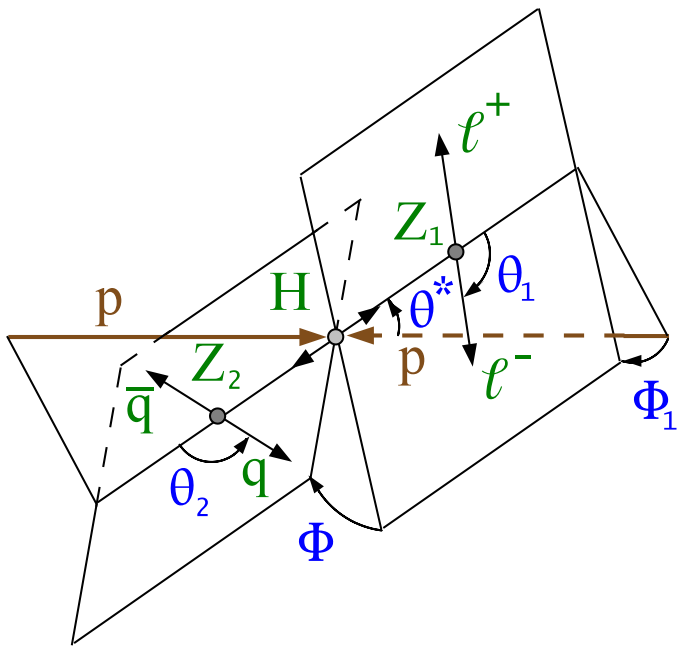
- Quarks and gluons: **different** hadronization
- Can discriminate thanks to Particle Flow
  - Particle-level info, sensitive to hadronization
  - Combined into a likelihood discriminant

γ+Jet Control Sample
~90% quark jets

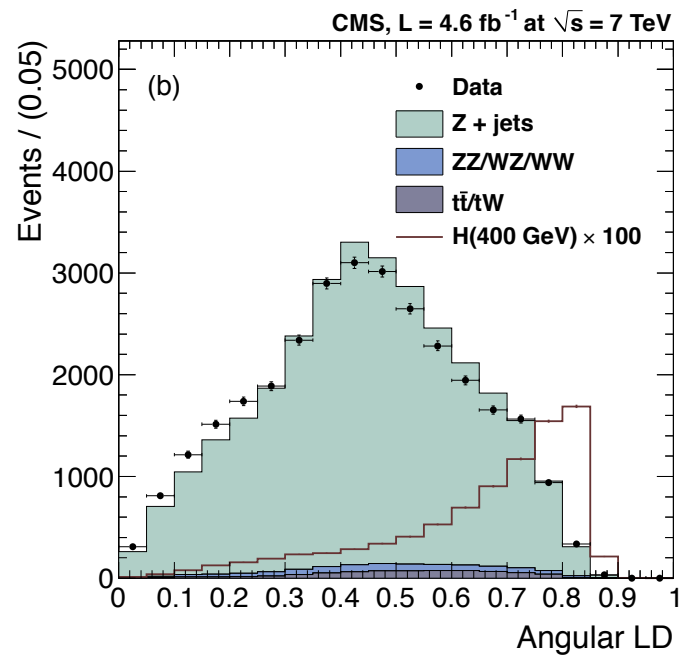




Angular Analysis



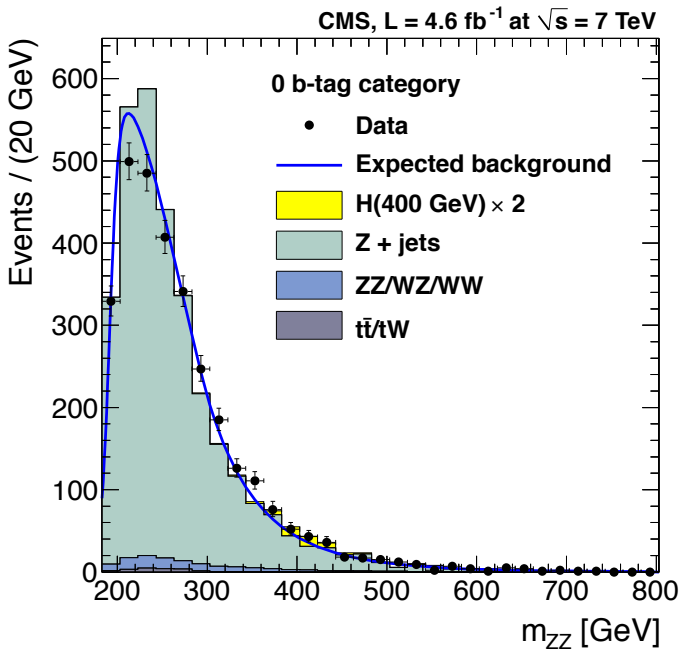
- **Signal:** (spin-0) → 2×(spin-1) → 2l2j
- **Background:** non-resonant
- Mirrors in final state angles



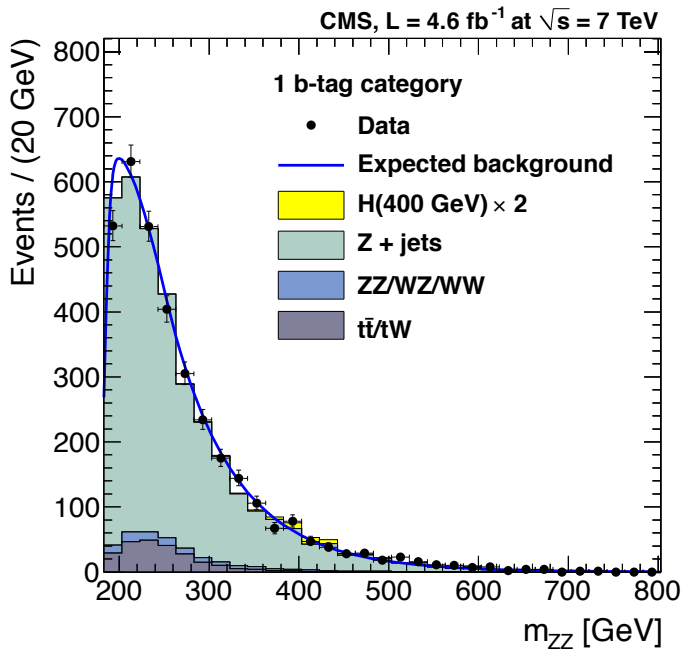
- Angles → Likelihood Discriminant
  - Optimized mass-dependent cut
- Angular selection preserves BG shape

Mass Spectra After Selection

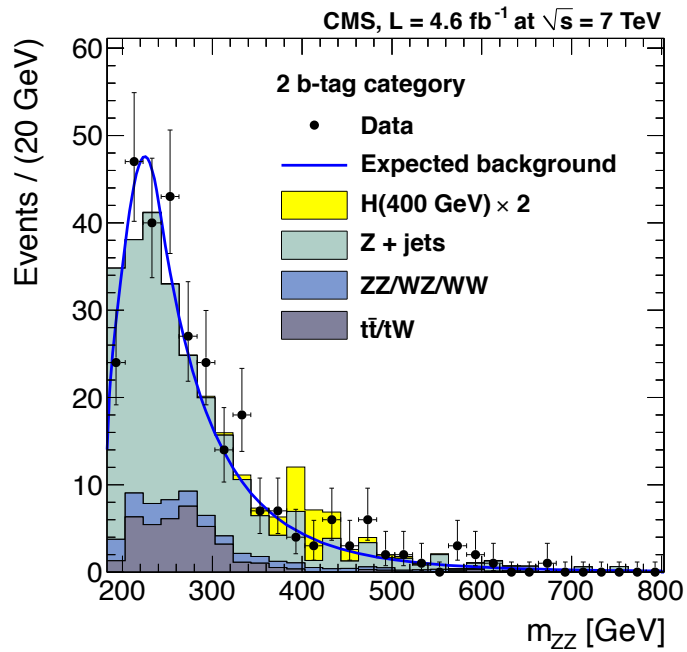
0 b-tag



1 b-tag



2 b-tag

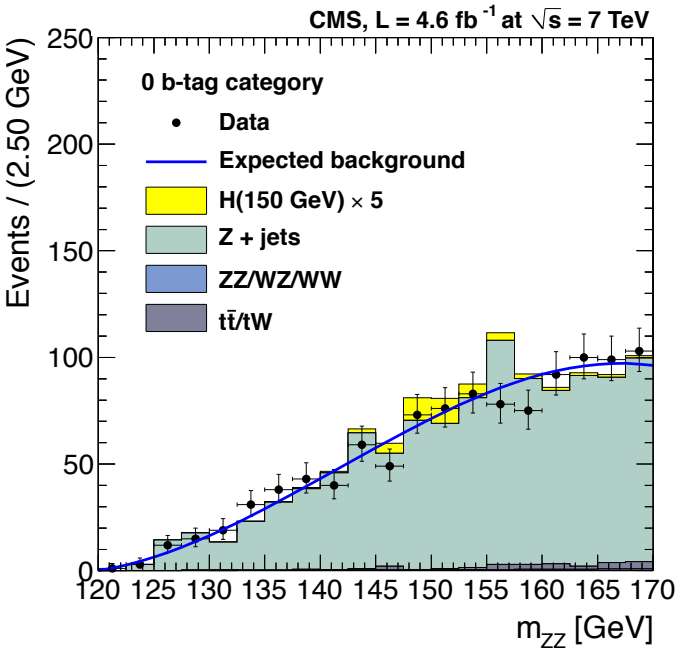


- Blue line is **not** a fit: background estimation from data sidebands
- Comparison to MC not relevant for results

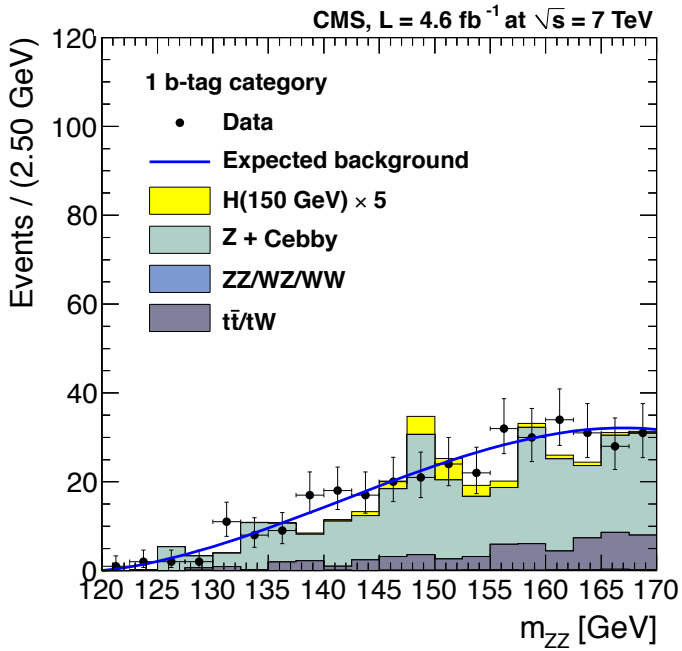
The Low Mass Analysis

- Analysis reach extended to low mass range 130-164 GeV
- Same as high mass but dropping angular and quark/gluon discriminants

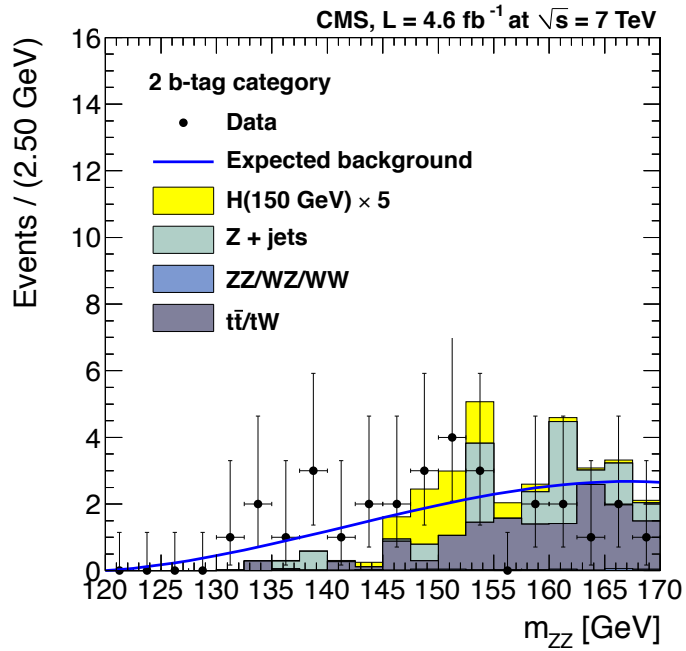
0 b-tag



1 b-tag

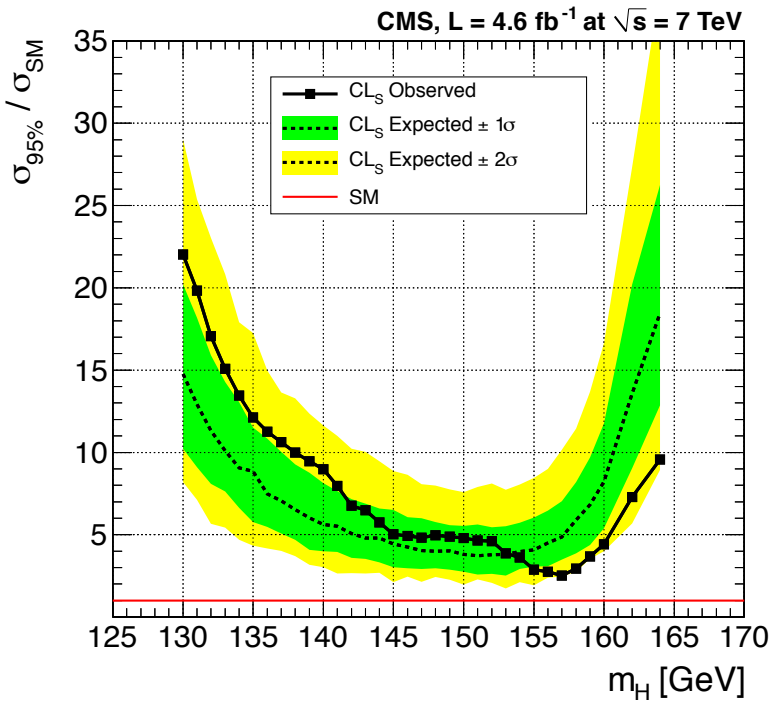


2 b-tag

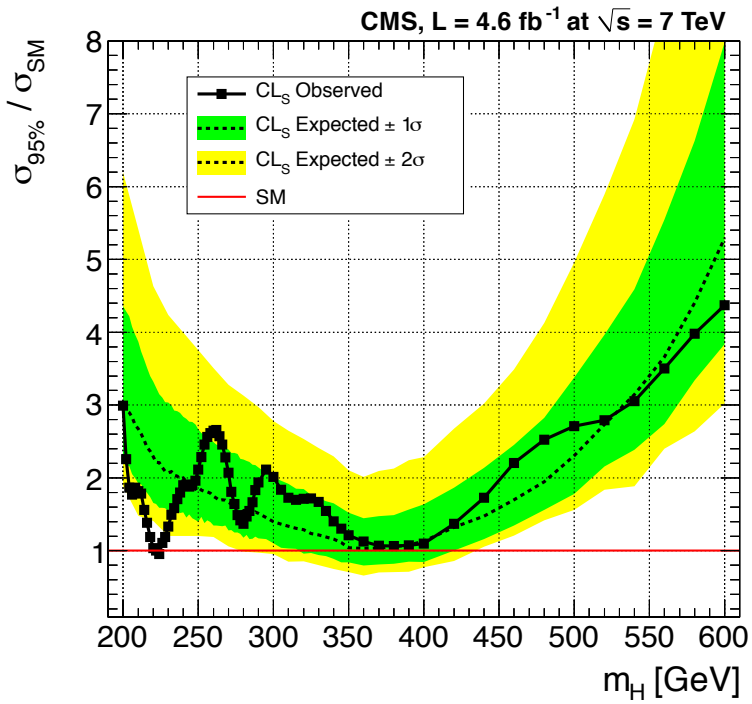


H→ZZ→2l2q Limits

Low Mass



High Mass



- Sensitive to 5×SM in 140 ÷ 155 GeV
  - Excluding 3×SM around 155 GeV
- Reached sensitivity to SM
  - At 1×SM in 370 ÷ 400 GeV

$H \rightarrow ZZ \rightarrow 2l2\nu$

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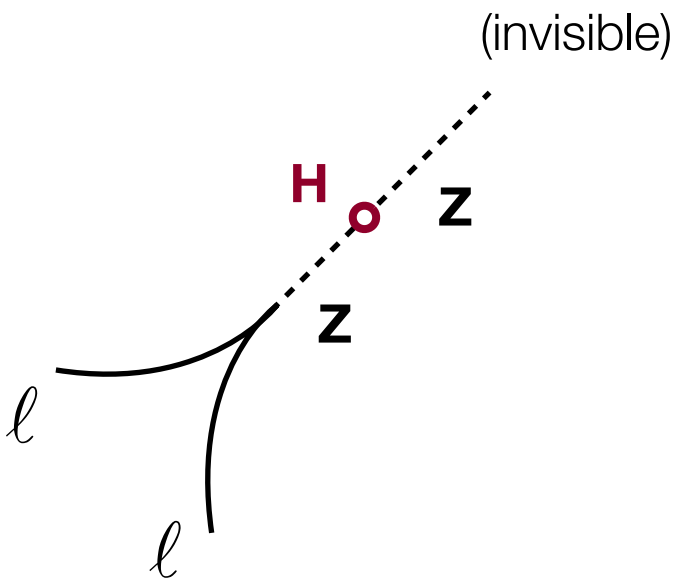
2011+2012 Data

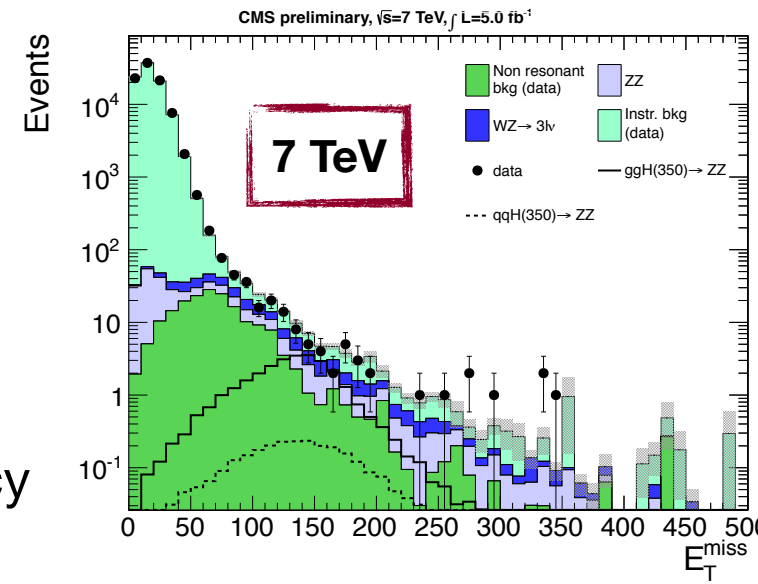
H→ZZ→2l2ν at a Glance

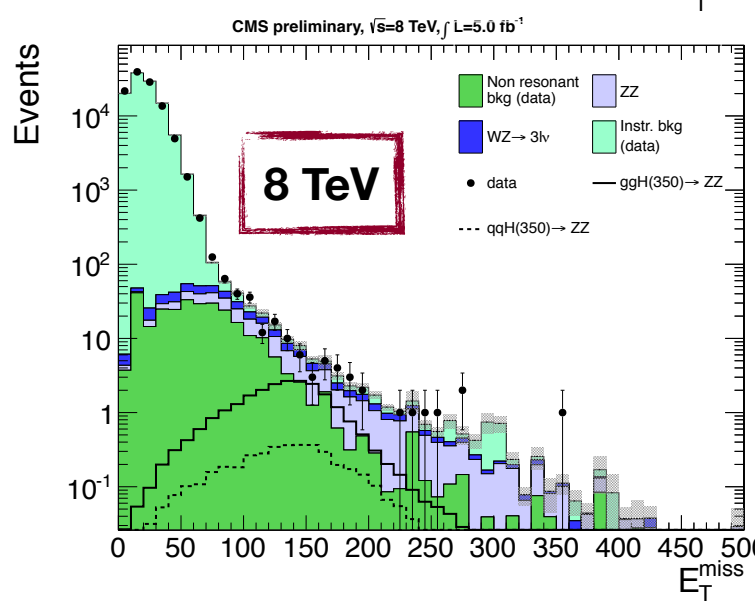


- Signal:
  - Z→ll + missing-E_T (massive H)
- Backgrounds:
  - Z→ll + (fake) missing-E_T
  - Non-resonant (top, WW, W+jets)
  - Irreducible ZZ/WZ

Drell-Yan Estimation with γ+ME_T

- Need to find control sample for Z + (fake)ME_T
  - Solution: use γ + (fake)ME_T
- Idea:
  - Z→ll/photon reconstructed w/ great accuracy
  - Similar (fake)ME_T distribution
  - Larger cross section
- Reweigh photon kinematics to match Z
- Good agreement in ME_T

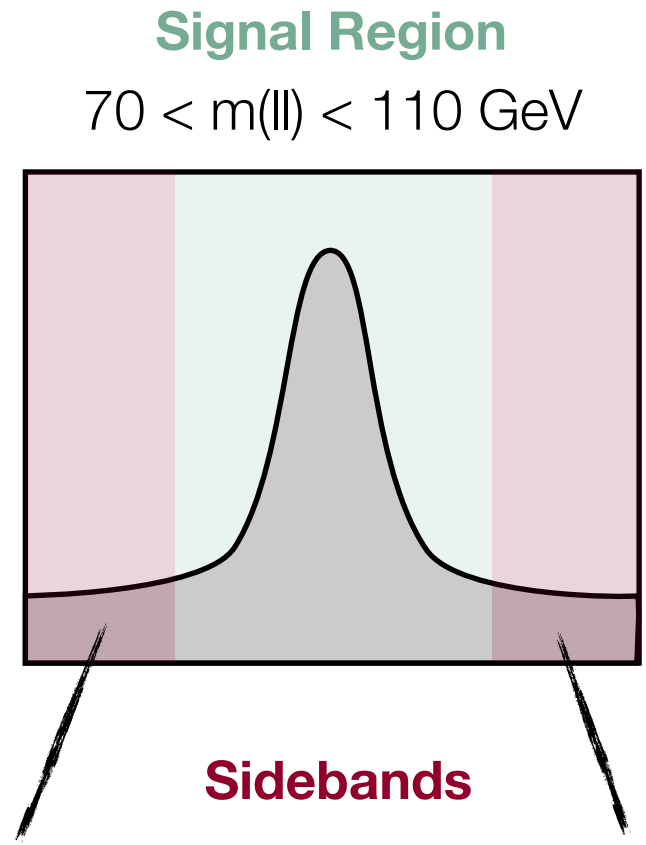




Non-Resonant and Irreducible Backgrounds

- **Non-resonant** (top, WW, W+jets) backgrounds estimated with eμ events
  - Scaled from m(ll) sidebands

$$N_{\ell\ell}^{SIG} = \left(\frac{{N_{\ell\ell}}^{SB}}{{N_{e\mu}}^{SB}} \right) \cdot N_{e\mu}^{SIG}$$



- **Irreducible** (ZZ and WZ) backgrounds taken from simulation

Differentiate Between Signatures

VBF Category

- Two jets
  - $\Delta\eta > 4$
  - M(jj) > 500 GeV
- Central jet veto
- Leptons between jets
- Flat kinematic cuts
  - $p_T(Z) > 55$ GeV, $ME_T > 70$ GeV

Non-VBF

- Veto VBF
- Categories in jet multiplicity

0 jet **1 jet** **≥2 jet**

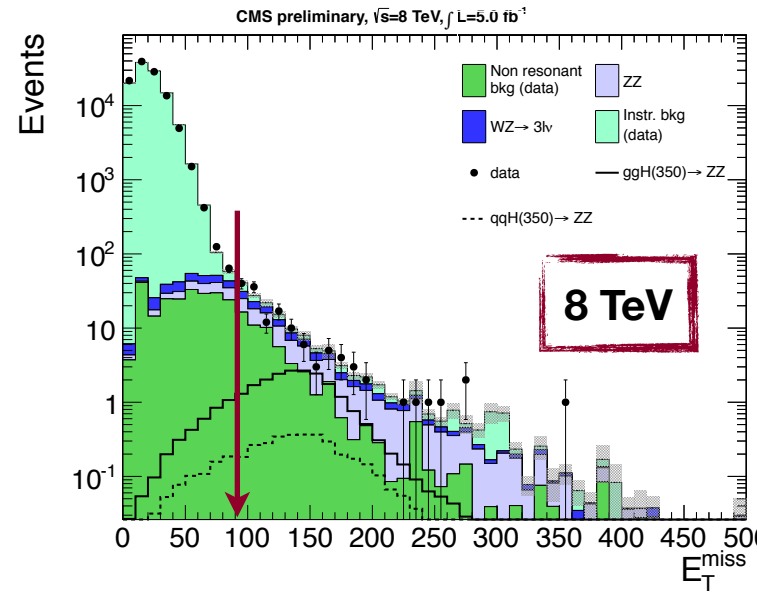
- Optimized cuts on ME_T and M_T
  - Tighter with higher m_H

$$M_T^2 = \left(\sqrt{p_{T,Z}^2 + M_Z^2} + \sqrt{E_{T,miss}^2 + M_Z^2}\right)^2 - \left(\vec{p}_{T,Z} + \vec{E}_{T,miss}\right)^2$$

An Example: The Analysis at 400 GeV

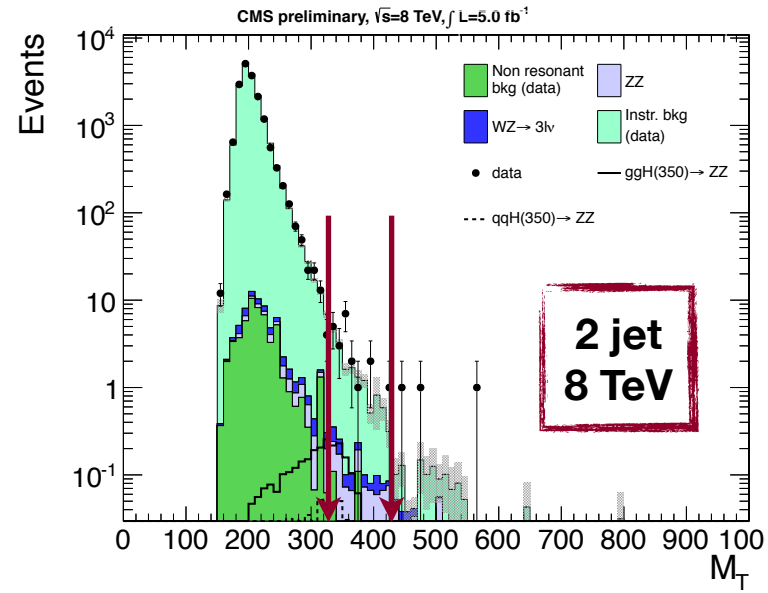
- Kinematic selections:

VBF	0/1/2 jets
$p_T(Z) > 55$ GeV	$p_T(Z) > 55$ GeV
$ME_T > 70$ GeV	$ME_T > 90$ GeV
	$325 < M_T < 425$ GeV

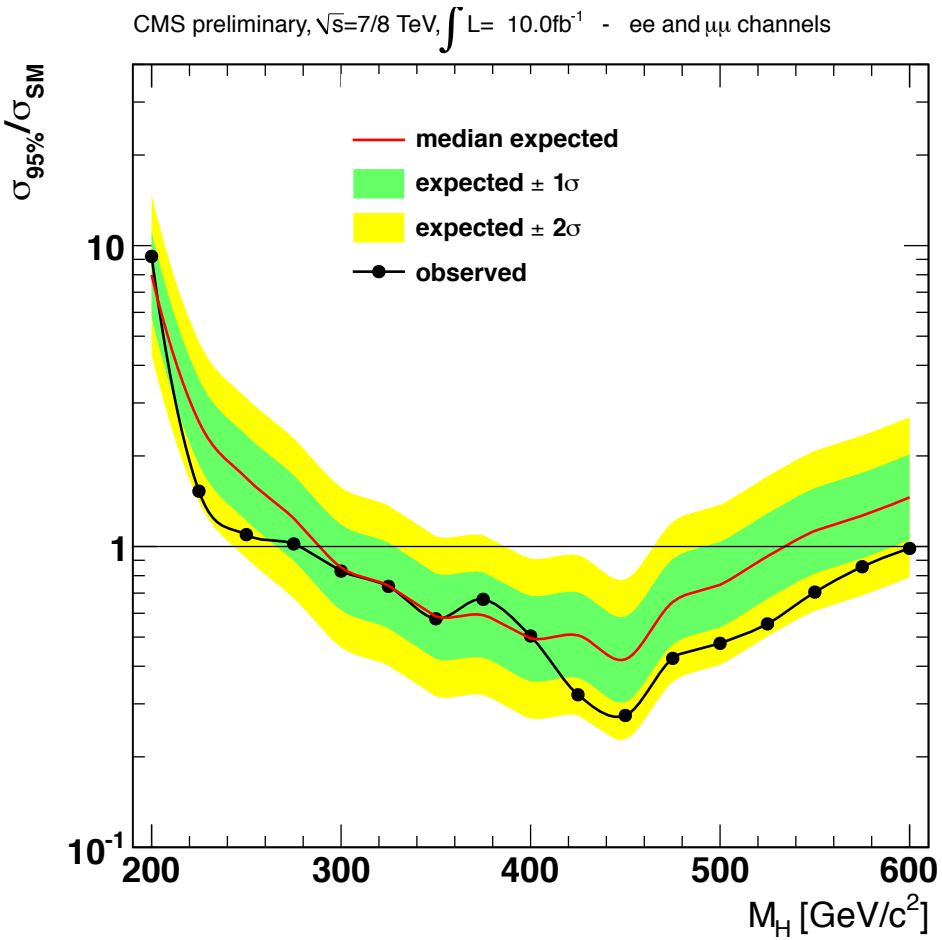


- Event yields (5 fb^{-1} @ 7 TeV + 5 fb^{-1} @ 8 TeV):

	Total BG	Signal	Observed
VBF	3.1	1.3	2
0 jet	14.9	11.3	13
1 jet	15.6	16.2	18
2 jet	6.1	6.1	6



H→ZZ→2l2ν Limit



- No excess found
- Excluding SM Higgs boson for masses in 278-600 GeV
  - Expected 291-534 GeV

Conclusions

- No evidence for a high mass SM Higgs

- H→ZZ→2l2q (2011 data only)
  - Three b-tag categories
  - Quark-gluon discrimination
  - Angluar analysis
  - Excluding around 370 ÷ 400 GeV

- H→ZZ→2l2ν (2011+2012 data)
  - VBF + 3 jet multiplicity categories
  - Photon+ME_T to estimate Z+ME_T
  - Excludes 278 < m_H < 600 GeV