Search for a Heavy Higgs Boson in ZZ→2l2ν channel in pp collisions with CMS detector at the LHC

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On behalf of the CMS Collaboration

Recontres de Moriond
Electroweak Session
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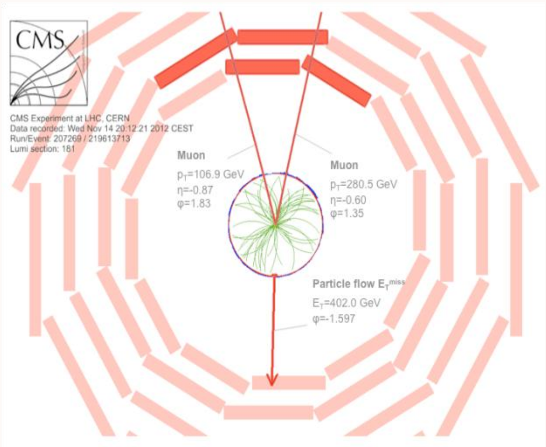
Introduction and Motivation

- Is boson @126 GeV is alone responsible for full unitarization of theory?
- Searches for Narrow width heavy scalar Electroweak Singlet partner to low mass Higgs – Motivated by hidden sector field theories: arxiv:hep-ph/0701035v1
- Study Vector Boson Scattering at high energy scale.
- Search for Anomalous ZZ production → aTGC & Bounding Higgs Width
- B.R.($H \rightarrow ZZ \rightarrow 2l2\nu$) ~ 6 x B.R.($H \rightarrow ZZ \rightarrow 4l$): worse resolution because of MET.

Signature

- Two isolated leptons (e,μ) from Z boson decay and large MET.
- Mass Range: 200 GeV – 1000 GeV
- Gluon fusion and Vector Boson Fusion production modes.



Backgrounds

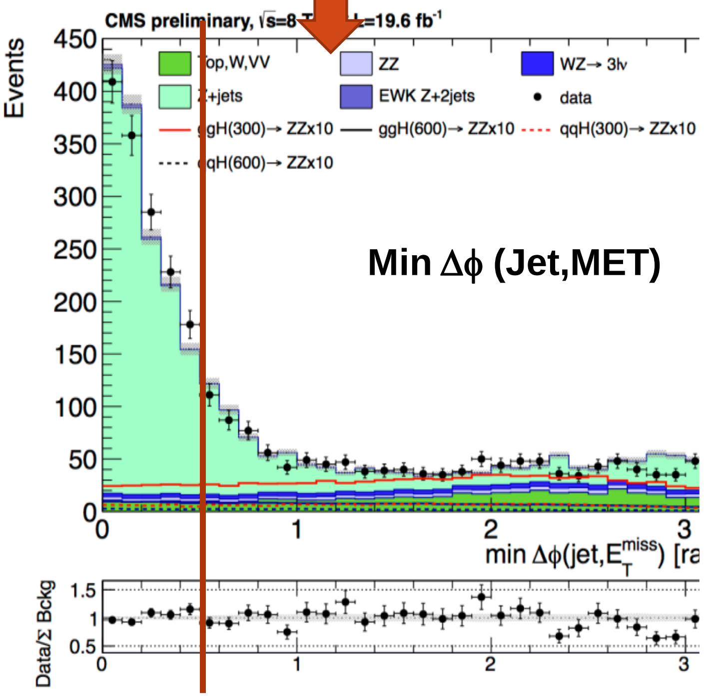
- **Z+Jets** – (Instrumental MET) Most dominant at pre-selection
- **TT-Jets, Single Top** – real leptons, MET and jets.
- **SM di-Boson backgrounds** – ZZ, WZ, WW

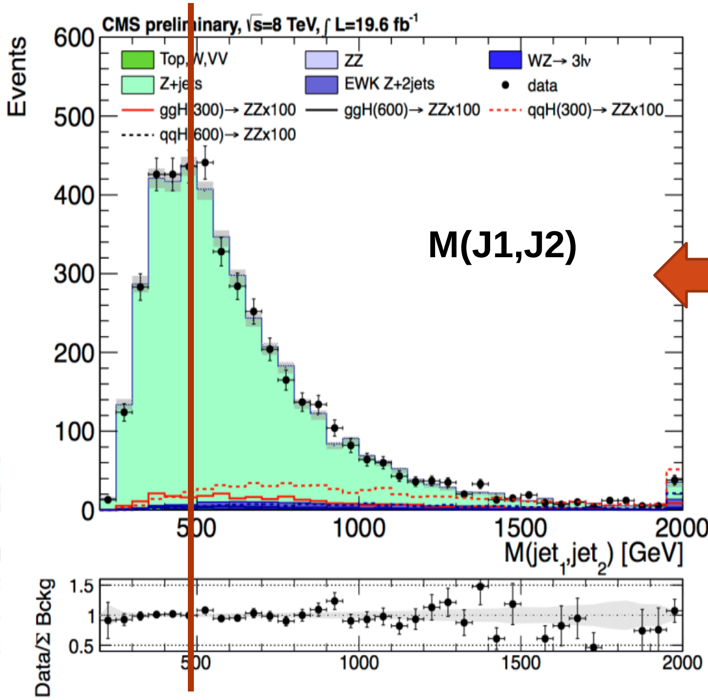
Analysis Strategy(1/2)

- Analysis is optimized separately for Gluon-Gluon and VBF categories.
  - Events categorized based on jet multiplicity.

Pre-Selection:

- Select lepton for Boosted Z decay → $|M_{ll} - M_Z| < 15$ GeV & $P_T(ll) > 55$ GeV
- Third Lepton Veto: → to suppress WZ background.
- Veto on b-jets and Soft Muons → to suppress Top related backgrounds.
- Min $\Delta\phi$(Jet,MET) > 0.5 → to reduce the Instrumental Background.





VBF Selection:

- Jet PT > 30 GeV
- M(J1,J2) > 500 GeV
- $\Delta\eta$ (J1,J2) > 4.0
- Central Jet Veto

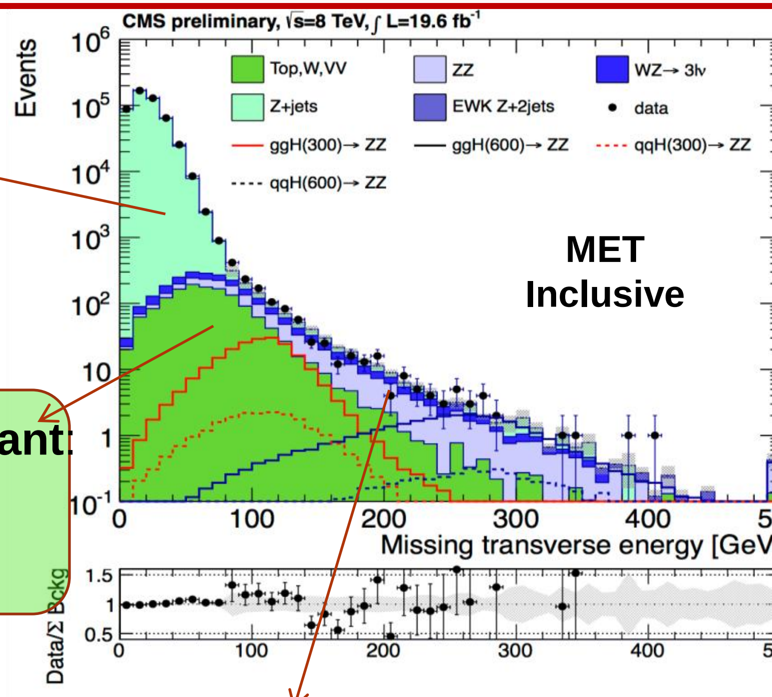
Analysis Strategy(2/2)

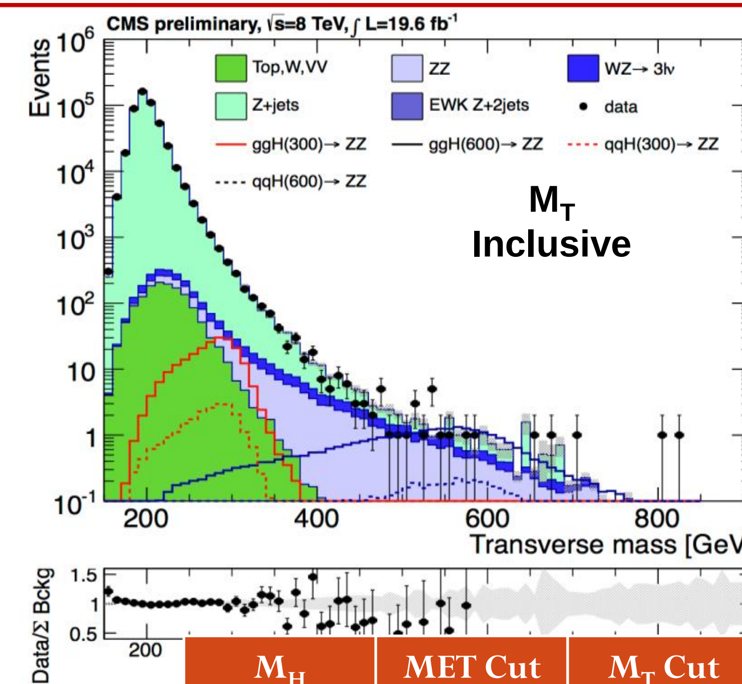
Final Selection:

- Two variables chosen for final selection MET and Transverse Mass of Higgs (M_T)

$$M_T^2 = \left[\sqrt{p_{T,\ell\ell}^2 + m_{\ell\ell}^2} + \sqrt{E_T^{miss,2} + m_{\ell\ell}^2}\right]^2 - \left[\vec{p}_{T,\ell\ell} + \vec{E}_T^{miss}\right]^2$$

- **Z+Jets:** Estimated from data using γ+jets events.
- **Non-Resonant:** Estimated from data using e-μ events.



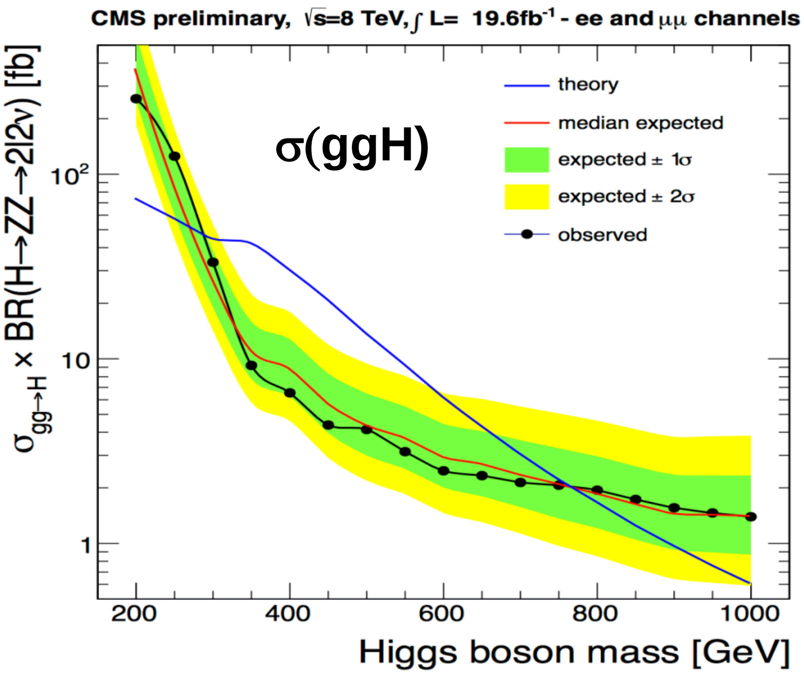


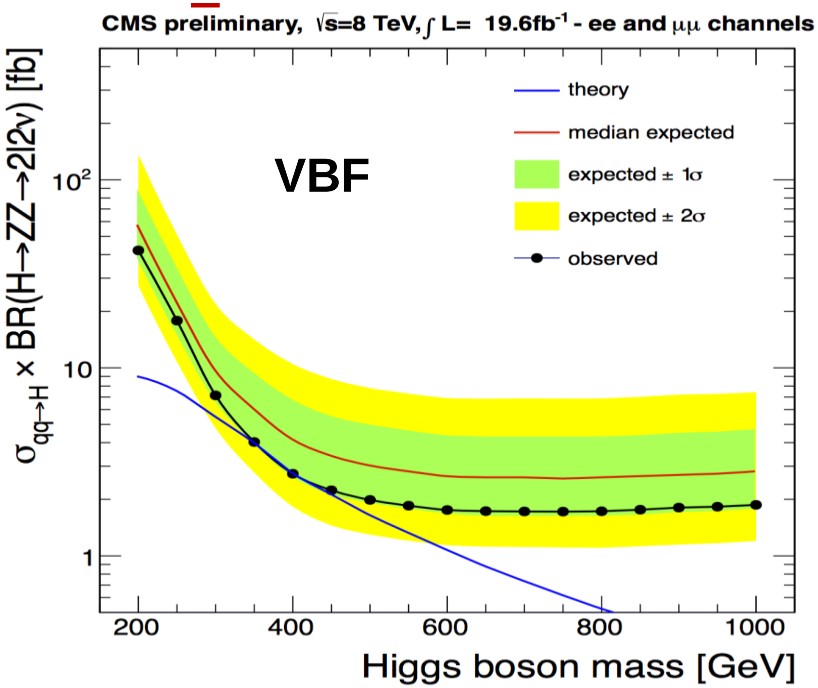
WZ, ZZ from MC

- Higgs mass dependent cuts applied.
- M_T Shape analysis carried out. (No M_T Cut)
- Cross-checked with Cut-Count analysis.

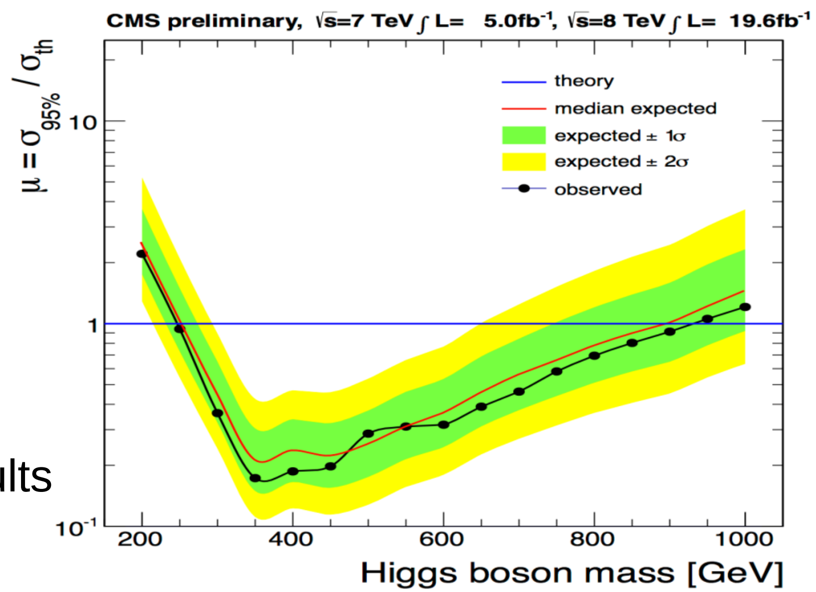
M_H	MET Cut	M_T Cut
200	> 80	180 – 220
300	>100	180 – 270
400	>110	350 – 450
500	>110	400 – 600
600 ≤	>110	500 – ∞

Results for SM-like Higgs: M_T Shape Analysis





- ➢ Cross-section calculated exclusively for both production modes.
  - ❑ **Expected:**
    - ❑ **254 – 898 GeV (Shape)**
    - ❑ 265 – 761 GeV (Cut-Count)
  - ❑ **Observed:**
    - ❑ **248 – 930 GeV (Shape)**
    - ❑ 268 – 756 GeV (Cut-Count)
- ➢ Cross-checked with Cut-Count: Similar Results



CMS-PAS-HIG-13-014

Search for ElectroWeak Singlet Partner of the h(126)

- The new, heavy Higgs boson, may decay to different channels
  - e.g. H→hh , where, h = Higgs at 126 GeV, H = new heavy Higgs.
  - Introduce branching ratio to new states : BR_{new}
- Assuming the 2 Singlets mix with each other like:

$$\phi_{SM} = \cos\omega h + \sin\omega H$$
$$\phi_{H} = -\sin\omega h + \cos\omega H$$

  - h(126) signal strength is reduced by $\mu = C^2$
  - The heavy Higgs signal strength: $\mu' = C'^2 (1-BR_{new})$
  - Unitarity implies : $C^2 + C'^2 = 1$
- Decay width is related to the SM case by $\Gamma' = C'^2 \Gamma_{SM}/(1-BR_{new})$
  - $\Gamma' \leq \Gamma_{SM}$ studied.

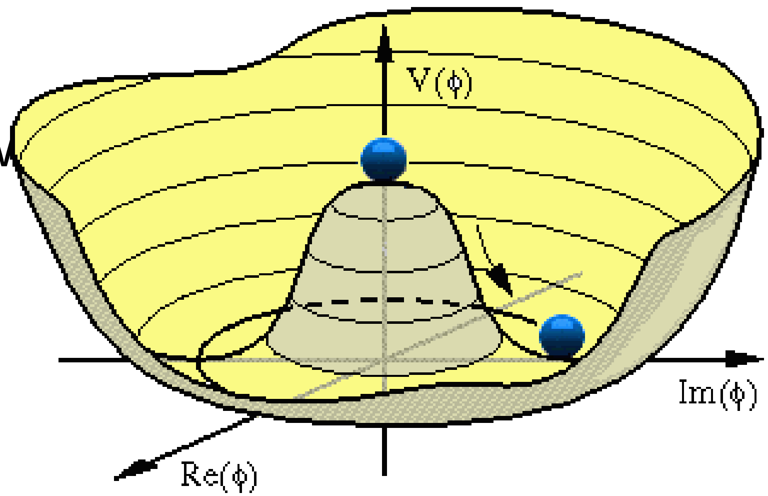
Implementation

- Reweight the signal line-shapes to relativistic BW

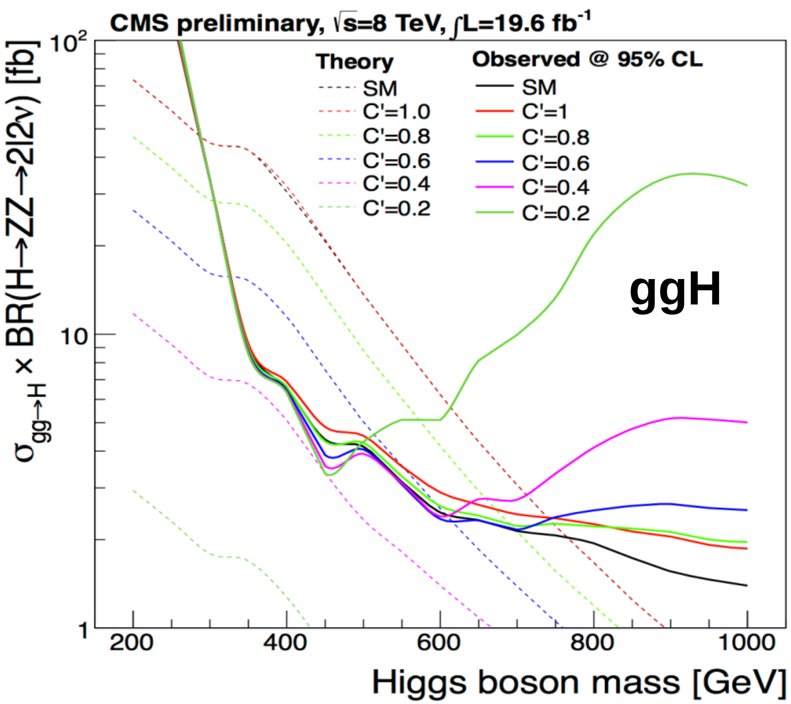
$$f(m_{ZZ}) = \frac{m_{ZZ}^2 \Gamma / m_H}{(m_{ZZ}^2 - m_H^2)^2 + (m_{ZZ}^2 \Gamma / m_H)^2}$$

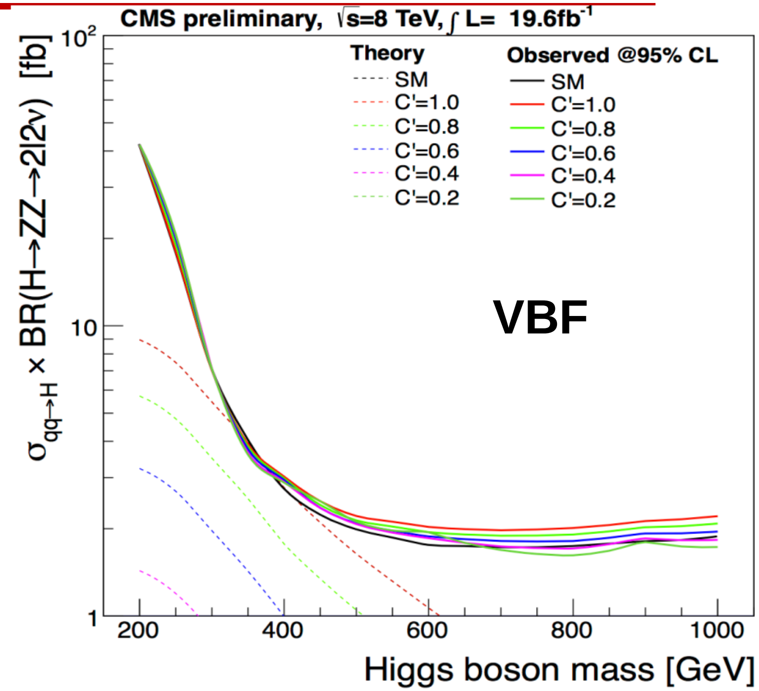
- Rescaling SM interference effects as:

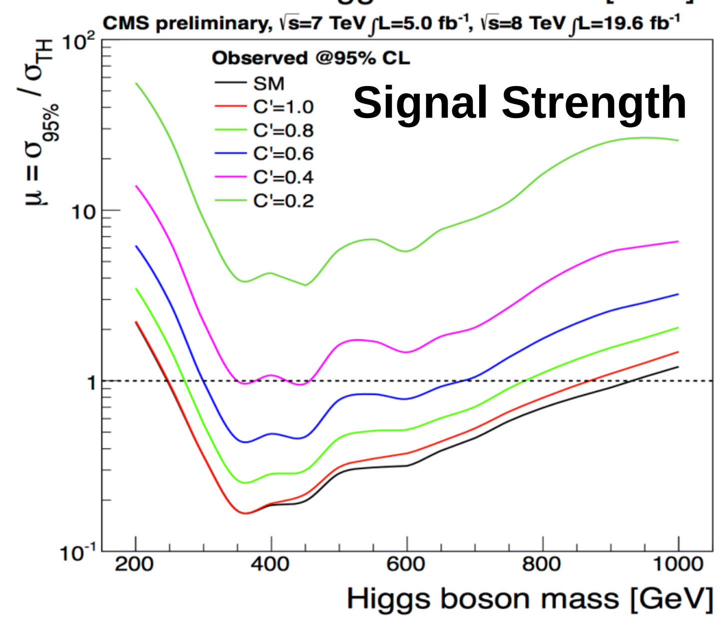
$$(\mu+I)_{BSM} = \mu_{SM} C'^2 + I_{SM} C'$$



Results – Limits on Production Cross-section





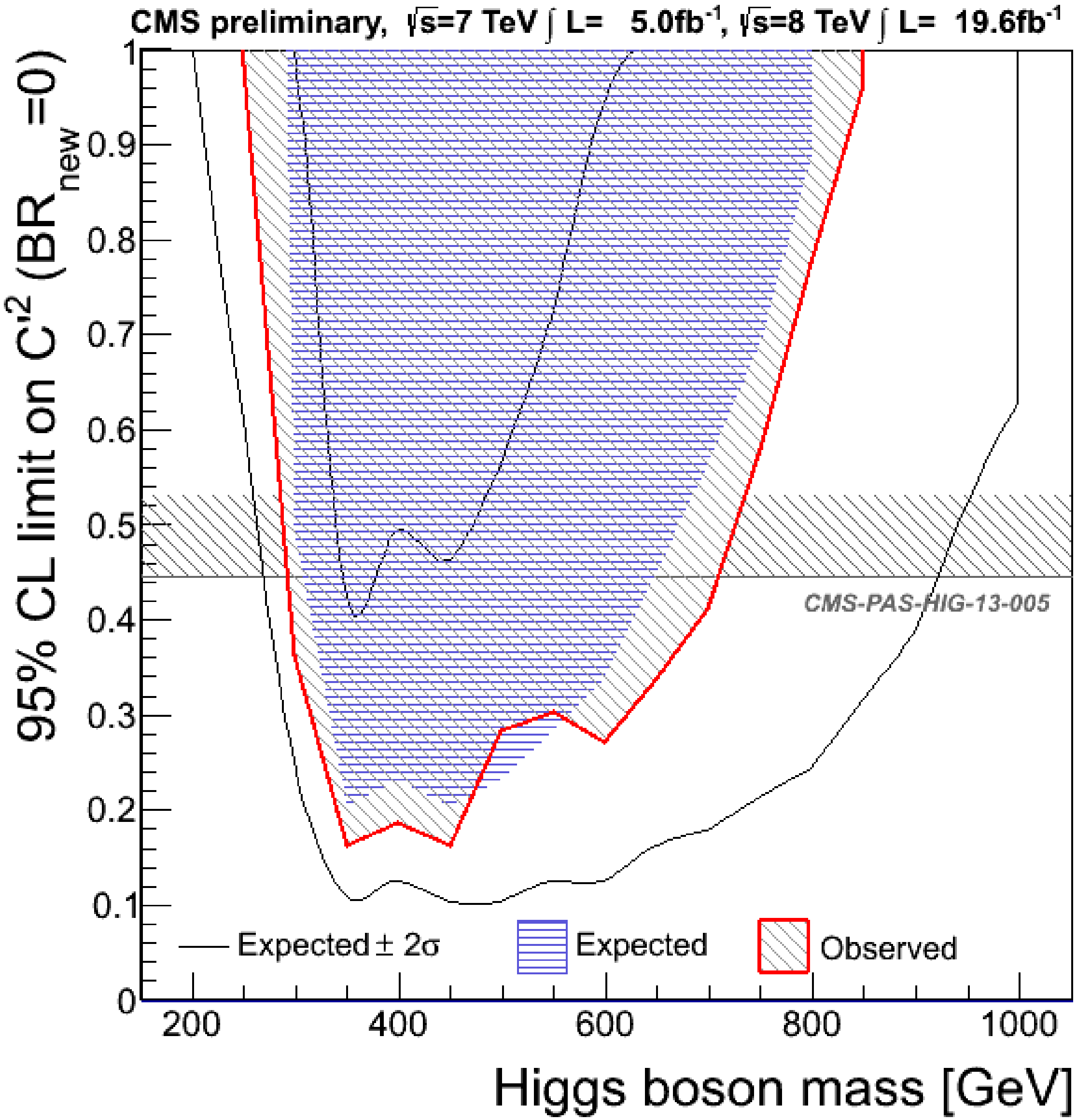


Assumptions:

- No decay to any new particles: $BR_{new} = 0$
- While combining 7 and 8 TeV results:
  - Same glu-glu/VBF ratio as SM.

CMS-PAS-HIG-13-014

Results – Limits on Coupling Modifier : C'²



CMS-PAS-HIG-13-014

- Evolution of 95% CL limit on the scale (C'^2) of the coupling of the EW singlet as function of its mass.

$C'^2 < 0.446$: In-direct limit by signal strength fit of h(126) CMS-PAS-HIG-13-005

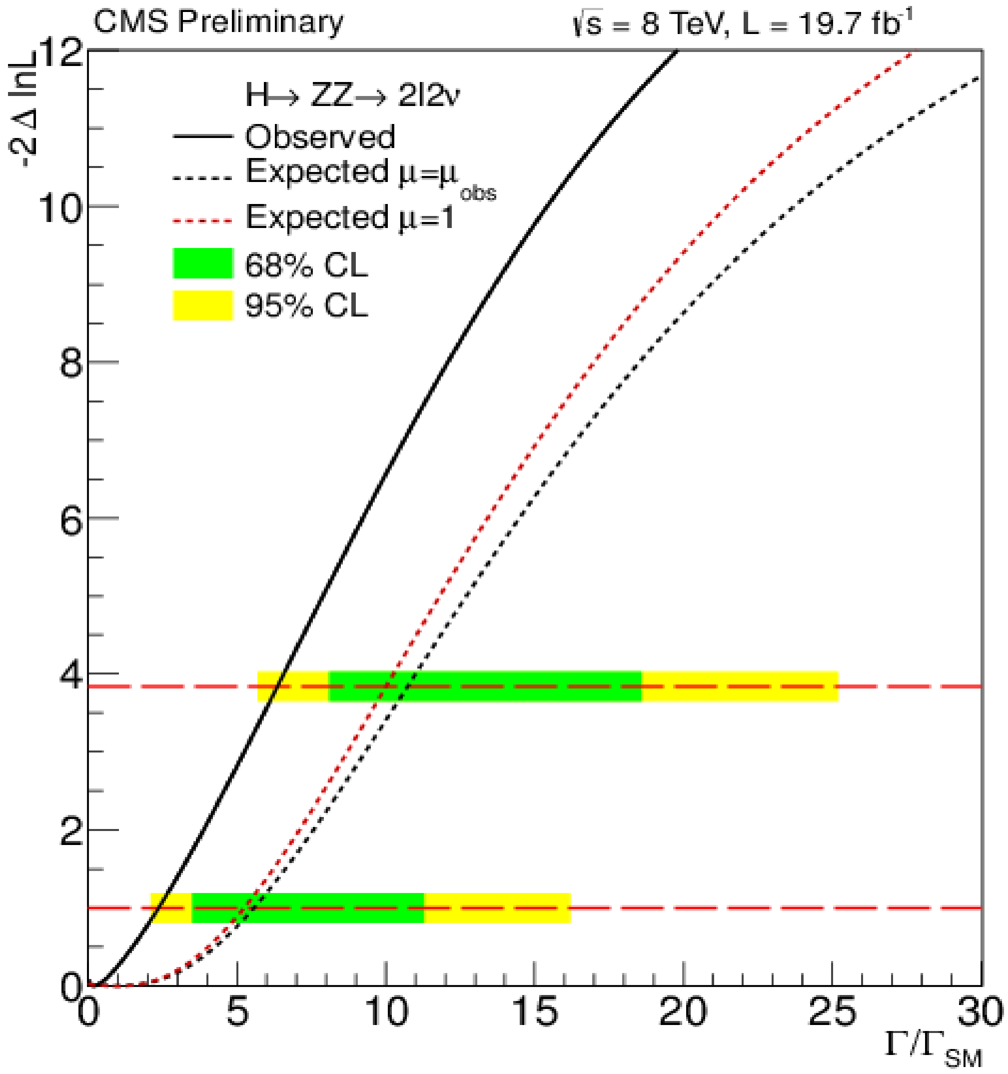
- Long path to follow to reach the exclusion of trans-TeV bosons.

- Also scanned $BR_{new} \neq 0$ cases: limit on C' gets weaker with BR_{new} ↑

Constraints Higgs boson Width from Off-shell Production

- Upper limit were set on total Higgs decay width from off-shell production.
- See R. Covarelli's Talk for Details.

arxiv:1307.4935



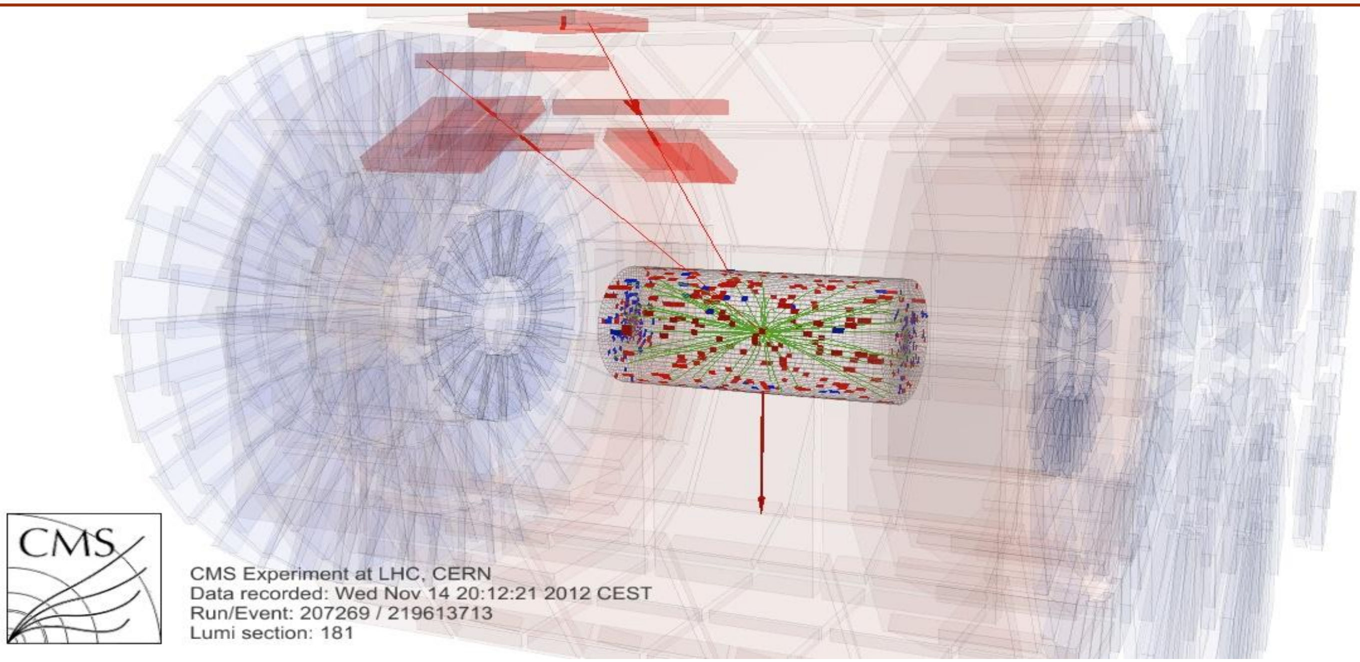
- Using ZZ→2l2ν channel in off-shell production alone: limits @95%CL
- **Expected: $\Gamma_H \leq 10.7x\ \Gamma_H^{SM}$**
- **Observed: $\Gamma_H \leq 6.4x\ \Gamma_H^{SM}$**

- Combined limits with ZZ→ 4l $\Gamma_H \leq 4.2$ x Γ_H^{SM} assuming Γ_H^{SM} = 4.15 MeV

CMS-PAS-HIG-14-002

Summary

- ✓ Results are presented for H→ZZ→2l2ν channel with full data from CMS.
- ✓ SM-like Higgs boson excluded in 248 – 930 GeV mass range
  - ✓ Best Individual Channel High mass limit in CMS.
- ✓ Results shown for search of EW Singlet Partner of h(126)
  - ✓ Expanding significantly exclusion from indirect constrain.
- ✓ Limits on the Higgs boson width from ZZ→2l2ν off-shell production: $\Gamma_H \leq 6.4 \times \Gamma_H^{SM}$



Back Up

Systematic Uncertainties

Source	Uncertainty [%]
Luminosity	2.2 (7 TeV), 5.0 (8 TeV)
pdf, gluon-gluon initial state	6-11
pdf, quark-quark initial state	3.3-7.6
QCD scale, gluon-gluon initial state (ggH)	7.6-11
QCD scale, quark-quark initial state (VBF)	0.2-2
QCD scale, gluon-gluon initial state (ggZZ)	20
QCD scale, quark-quark initial state (qqVV)	5.8-8.5
Higgs boson line shape	10-30
Signal rescaling (from 7 TeV)	25 (8 TeV VBF)
Anti b-tagging	1-3
Lepton ID+Isolation	2
Lepton momentum scale	1-2
Jet energy scale	1
PU effects, MET	1-3
Trigger	2
non-resonant background estimation from data	25
$Z + jets$ estimation from data	100

Z+Jets Background Estimation

- γ+jets events are used to model Z+Jets from data.
  - γ+jets has similar kinematic distributions as Z+Jets
  - Larger Statistics

- **Procedure**
  - PT distribution of γ's reweighted to match to Z's
  - Number of primary vertex distribution in γ's is reweighted to match to Z's
  - Each photon is assigned a mass by sampling Z line shape from data
  - done separately for each event category

Final estimate is taken as half of the prediction from photon events with 100% systematic error on prediction

Non-Resonant Background Estimation

- Estimation of non-resonant backgrounds is performed with standard technique, using eμ events passing analysis selection ($N_{e\mu}^{SIG}$)

- Using sidebands (55 < m_{ll} < 70 and 110 < m_{ll} < 200 GeV) of the Z peak a scale factor a is determined from ratio of ee/μμ and eμ events passing MET > 70 GeV and requiring at least one b-tagged jet.

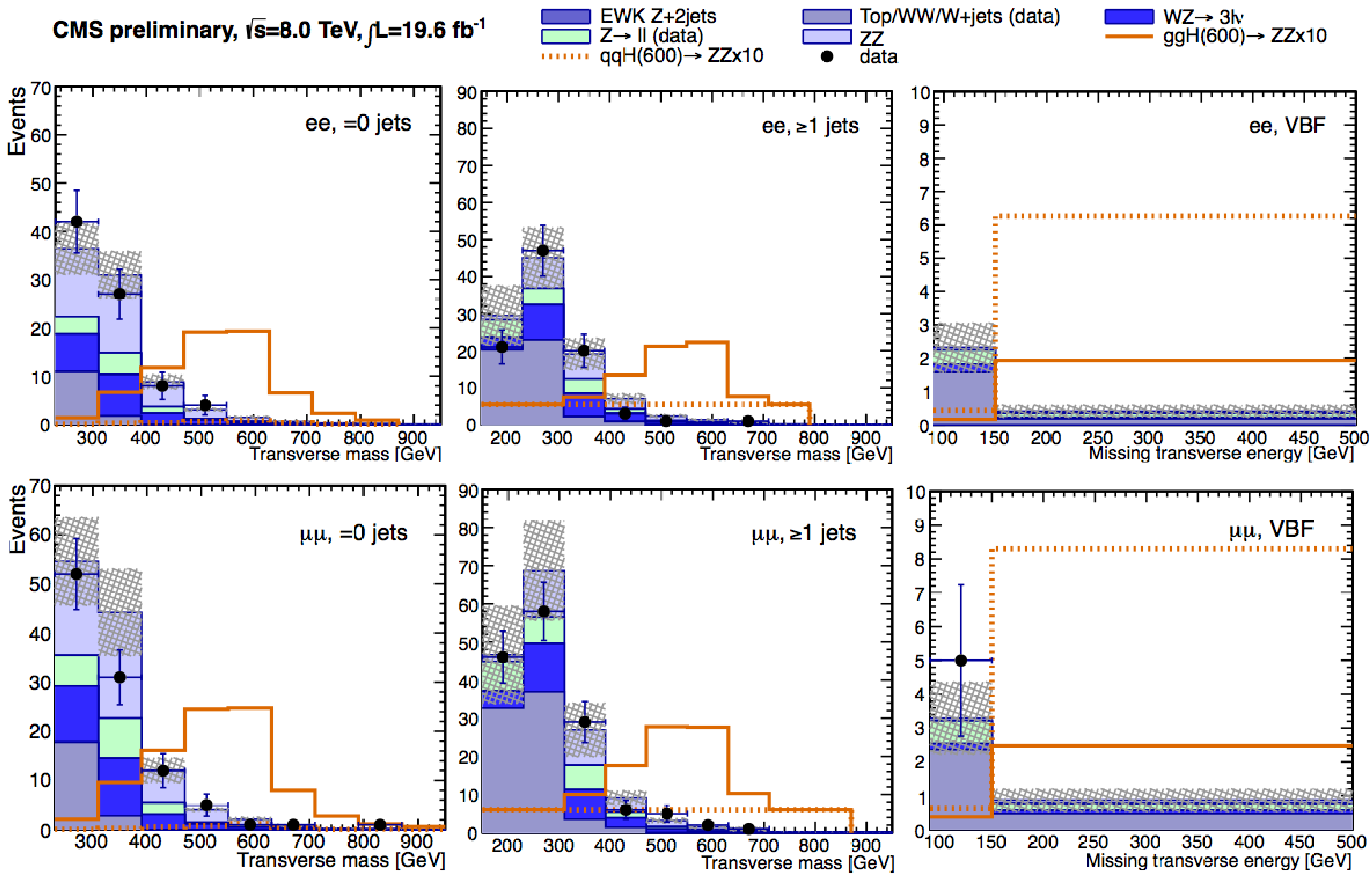
$$\alpha_e = \frac{N_{ee}^{SB}}{N_{e\mu}^{SB}}; \quad \alpha_\mu = \frac{N_{\mu\mu}^{SB}}{N_{e\mu}^{SB}}$$

- Predicted number of background events is given then as

$$N_{ee}^{SIG} = \alpha_e \cdot N_{e\mu}^{SIG}; \quad N_{\mu\mu}^{SIG} = \alpha_\mu \cdot N_{e\mu}^{SIG}$$

- We treat contribution from $H \rightarrow WW^* \rightarrow 2l2\nu$ as background and properly accounts on it.

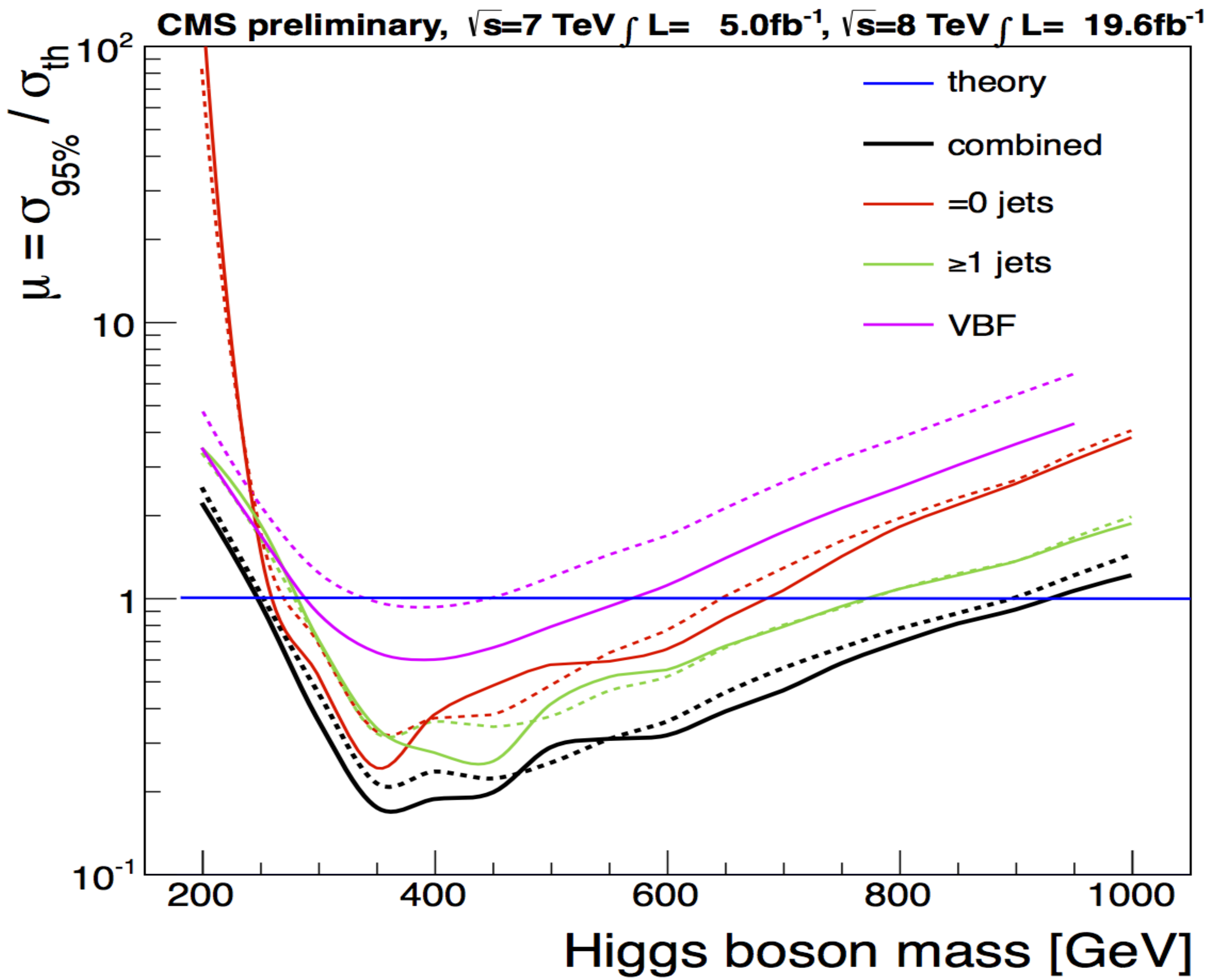
Final M_T Shapes



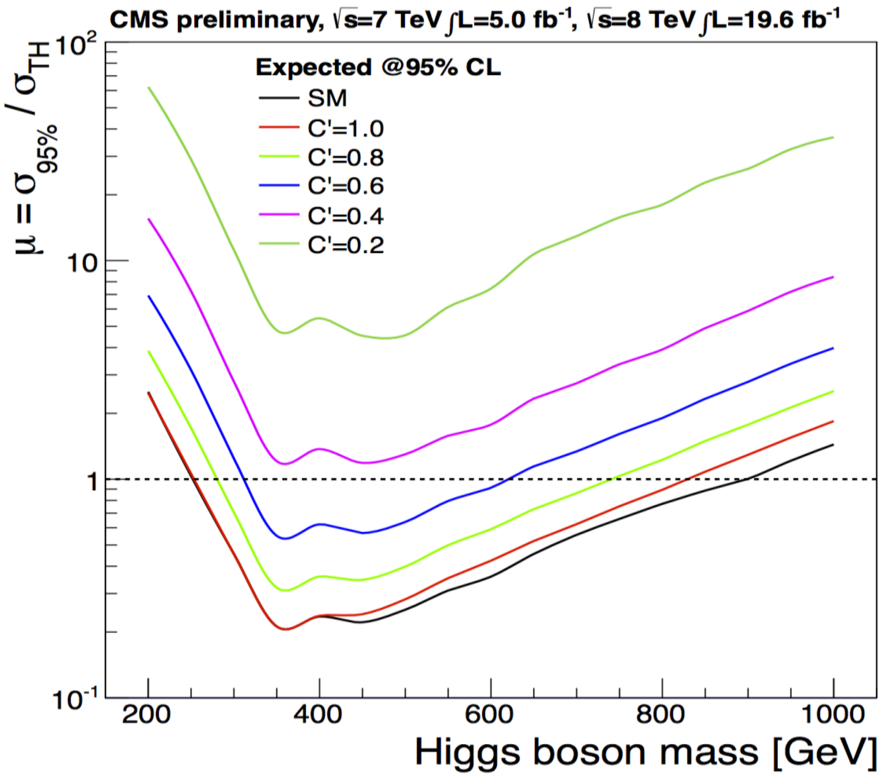
Event Yields at 8 TeV

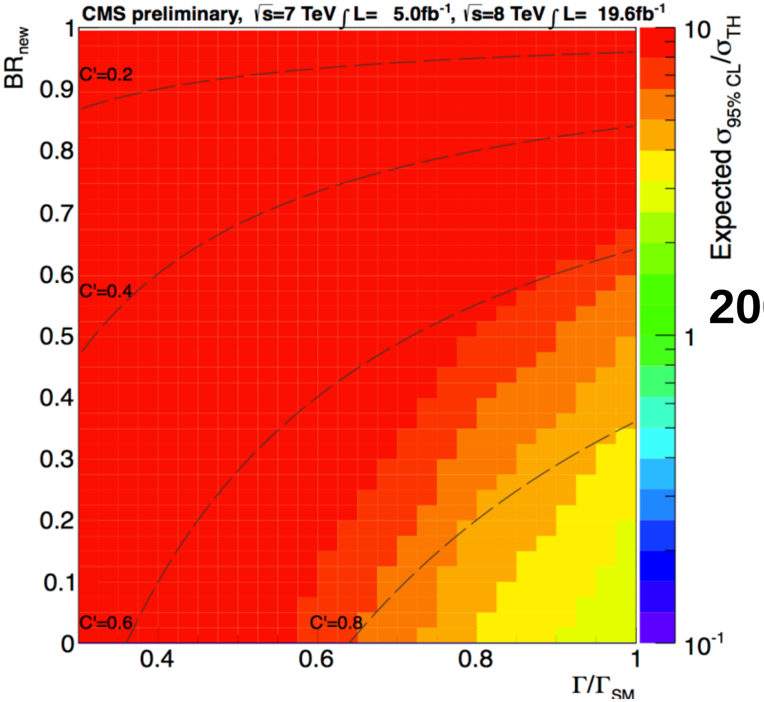
ZZ	$WZ \rightarrow 3\ell\nu$	$Z \rightarrow \ell\ell$	Top/WW/ W+jets	Total	ggH	qqH	Data
200 GeV (0jets, ≥1jet, VBF : 7 TeV, 8 TeV)							
0.09 ± 0.02 0.54 ± 0.06	0.21 ± 0.04 1.0 ± 0.1	0.03 ± 0.02 ± 0.02 2.5 ± 1.1 ± 1.5	1.1 ± 0.8 ± 0.2 12.6 ± 2.8 ± 2.0	**1.5 ± 0.8 ± 0.2** **16.7 ± 3.0 ± 2.4**	0.016 ± 0.006 0.16 ± 0.03	0.004 ± 0.002 0.012 ± 0.007	**4** **19**
0.89 ± 0.07 5.8 ± 0.2	3.6 ± 0.2 16.0 ± 0.4	3.5 ± 1.4 ± 2.2 39.7 ± 14.7 ± 23.4	17.2 ± 3.3 ± 2.7 86.2 ± 7.6 ± 13.3	**25.2 ± 3.6 ± 3.5** **148.1 ± 16.6 ± 26.9**	1.61 ± 0.06 8.7 ± 0.2	0.59 ± 0.02 2.64 ± 0.10	**53** **146**
0.04 ± 0.02 0.31 ± 0.05	0.13 ± 0.03 0.56 ± 0.08	0.04 ± 0.03 ± 0.03 1.4 ± 0.5 ± 0.9	1.1 ± 0.6 ± 0.2 4.6 ± 0.6 ± 0.7	**1.4 ± 0.6 ± 0.2** **6.9 ± 0.8 ± 1.1**	0.028 ± 0.007 0.24 ± 0.04	0.24 ± 0.01 1.16 ± 0.07	**1** **5**
400 GeV (0jets, ≥1jet, VBF : 7 TeV, 8 TeV)							
4.1 ± 0.2 23.5 ± 0.4	1.7 ± 0.1 11.4 ± 0.4	1.06 ± 0.41 ± 0.03 7.9 ± 2.2 ± 5.0		**6.88 ± 0.45 ± 0.03** **42.8 ± 2.3 ± 5.0**	9.3 ± 0.1 48.7 ± 0.3	0.172 ± 0.007 0.93 ± 0.04	**8** **37**
1.31 ± 0.09 11.8 ± 0.3	2.2 ± 0.1 9.2 ± 0.3	0.5 ± 0.2 ± 0.2 7.1 ± 2.0 ± 4.2	 3.5 ± 1.4 ± 0.5	**4.0 ± 0.2 ± 0.2** **31.4 ± 2.5 ± 4.2**	7.3 ± 0.1 40.6 ± 0.3	0.82 ± 0.02 4.35 ± 0.08	**5** **23**
0.04 ± 0.02 0.31 ± 0.05	0.13 ± 0.03 0.56 ± 0.08	0.04 ± 0.03 ± 0.03 1.4 ± 0.5 ± 0.9	1.1 ± 0.6 ± 0.2 4.6 ± 0.6 ± 0.7	**1.4 ± 0.6 ± 0.2** **6.9 ± 0.8 ± 1.1**	0.20 ± 0.02 1.53 ± 0.06	0.59 ± 0.01 3.37 ± 0.08	**1** **5**
600 GeV (0jets, ≥1jet, VBF : 7 TeV, 8 TeV)							
1.23 ± 0.09 5.9 ± 0.2	0.33 ± 0.05 2.6 ± 0.2	0.145 ± 0.102 ± 0.001 1.2 ± 0.3 ± 0.8		**1.705 ± 0.143 ± 0.001** **9.6 ± 0.4 ± 0.8**	1.67 ± 0.02 9.72 ± 0.07	0.076 ± 0.005 0.46 ± 0.03	**1** **9**
0.58 ± 0.06 4.3 ± 0.2	0.43 ± 0.06 2.3 ± 0.2	0.198 ± 0.074 ± 0.006 2.1 ± 0.6 ± 1.2		**1.214 ± 0.112 ± 0.006** **8.7 ± 0.6 ± 1.2**	1.92 ± 0.02 11.37 ± 0.08	0.35 ± 0.01 2.15 ± 0.06	**2** **9**
0.04 ± 0.02 0.31 ± 0.05	0.13 ± 0.03 0.56 ± 0.08	0.04 ± 0.03 ± 0.03 1.4 ± 0.5 ± 0.9	1.1 ± 0.6 ± 0.2 4.6 ± 0.6 ± 0.7	**1.4 ± 0.6 ± 0.2** **6.9 ± 0.8 ± 1.1**	0.065 ± 0.004 0.48 ± 0.02	0.241 ± 0.008 1.56 ± 0.05	**1** **5**
800 GeV (0jets, ≥1jet, VBF : 7 TeV, 8 TeV)							
1.23 ± 0.09 5.9 ± 0.2	0.33 ± 0.05 2.6 ± 0.2	0.145 ± 0.102 ± 0.001 1.2 ± 0.3 ± 0.8		**1.705 ± 0.143 ± 0.001** **9.6 ± 0.4 ± 0.8**	0.416 ± 0.005 2.92 ± 0.02	0.039 ± 0.002 0.30 ± 0.02	**1** **9**
0.58 ± 0.06 4.3 ± 0.2	0.43 ± 0.06 2.3 ± 0.2	0.198 ± 0.074 ± 0.006 2.1 ± 0.6 ± 1.2		**1.214 ± 0.112 ± 0.006** **8.7 ± 0.6 ± 1.2**	0.578 ± 0.006 4.02 ± 0.02	0.162 ± 0.005 1.18 ± 0.03	**2** **9**
0.04 ± 0.02 0.31 ± 0.05	0.13 ± 0.03 0.56 ± 0.08	0.04 ± 0.03 ± 0.03 1.4 ± 0.5 ± 0.9	1.1 ± 0.6 ± 0.2 4.6 ± 0.6 ± 0.7	**1.4 ± 0.6 ± 0.2** **6.9 ± 0.8 ± 1.1**	0.0168 ± 0.0010 0.141 ± 0.004	0.094 ± 0.004 0.75 ± 0.03	**1** **5**

Event Category based Limit – SM Case

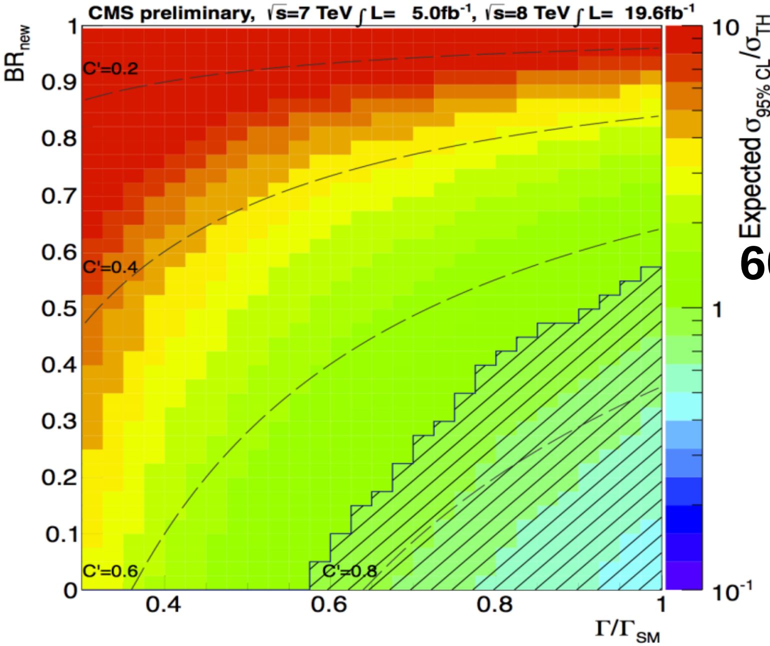


Expected Limits



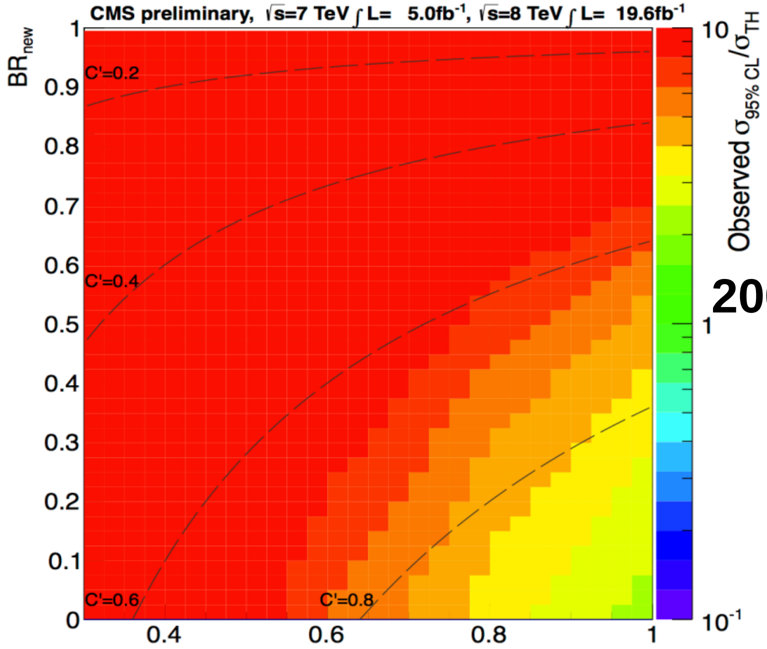


200 GeV

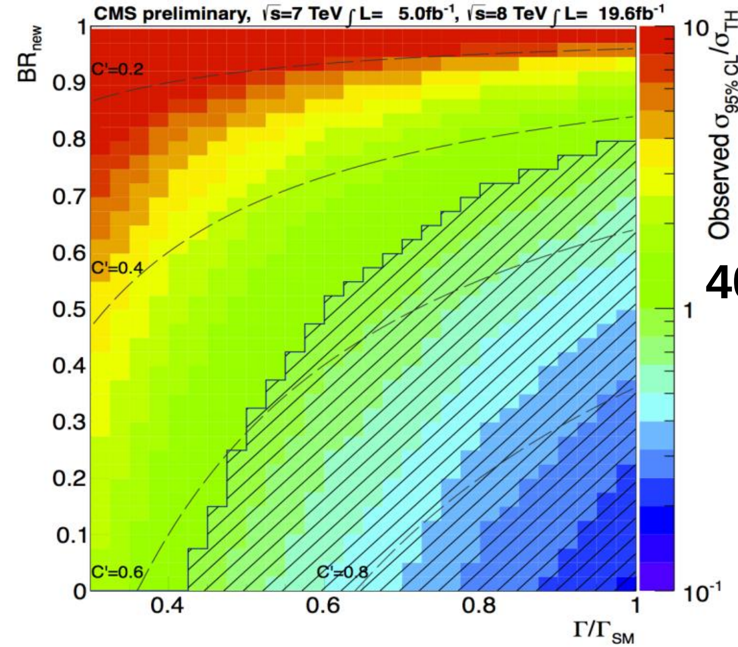


600 GeV

Results – 2D Limits on BR_{new} vs Γ/Γ_{SM}

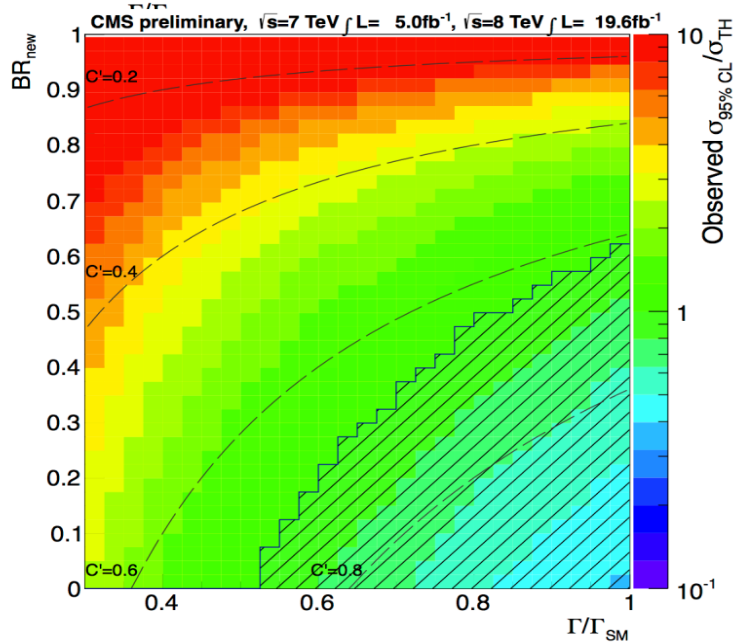


200 GeV



400 GeV

600 GeV



- Limit gets weaker with increasing BR_{new}