H → WW at CMS

ASPEN 2013 – *Higgs Quo Vadis?*

Maiko Takahashi (ETH Zürich)
on behalf of CMS Collaboration

H→WW

Dominant channel in wide mass range

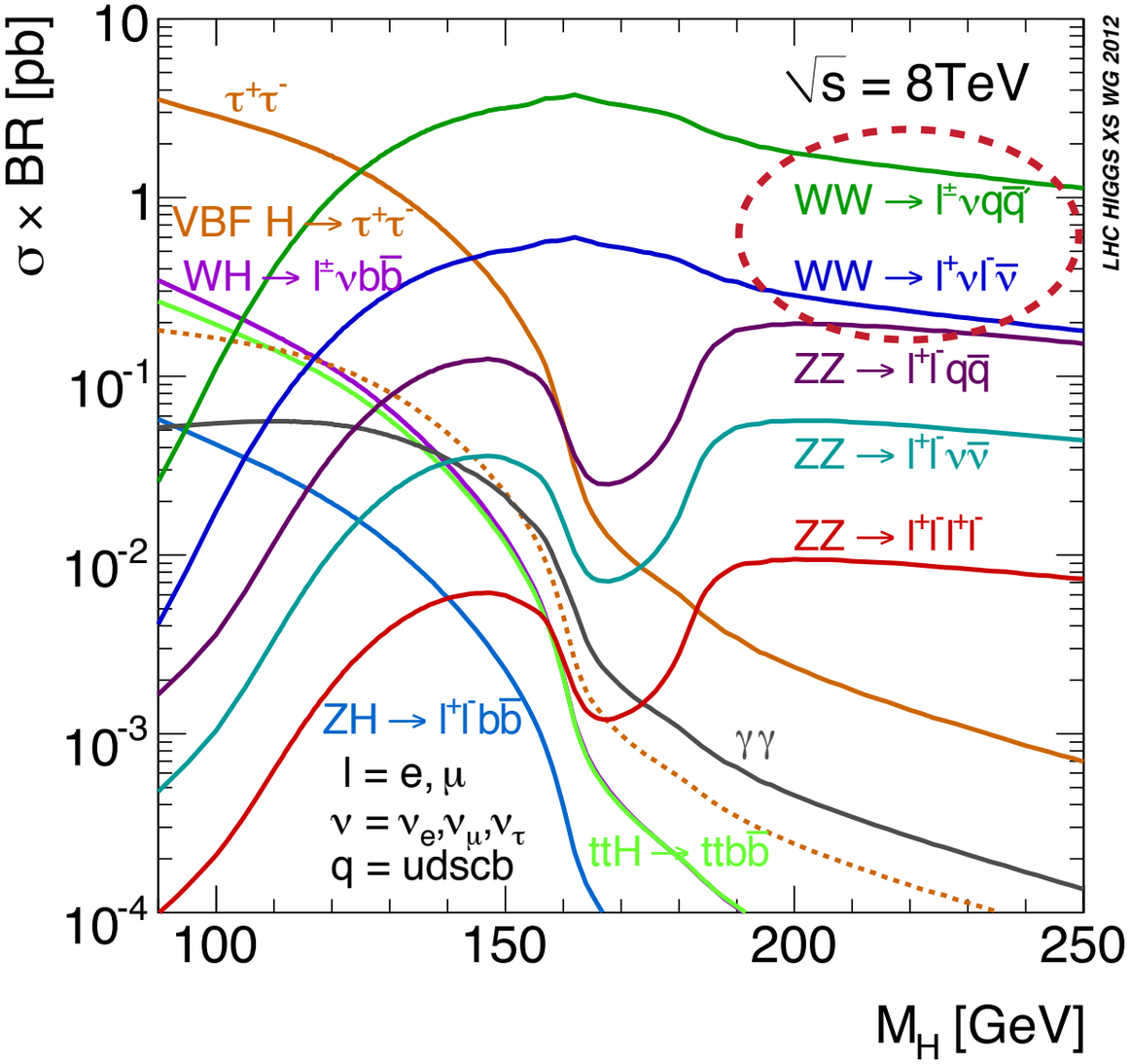
BR(H→WW) ~20% at m_H = 125 GeV

WW → lνlν :
clean signature, sensitivity to low m_H

WW → lνqq :
large BR, powerful at high m_H

Analyses optimised for final states

- Inclusive analysis dominated by gg→H
- 3-lepton from WH → W WW(ττ)
- 2-lepton + 2-jet from VH and VBF



Inclusive WW→ℓνℓν and WH in trilepton are updated using full luminosity = 4.9 + 19.5 fb^{-1} of 2011 and 2012 data

H → WW → ℓνℓν

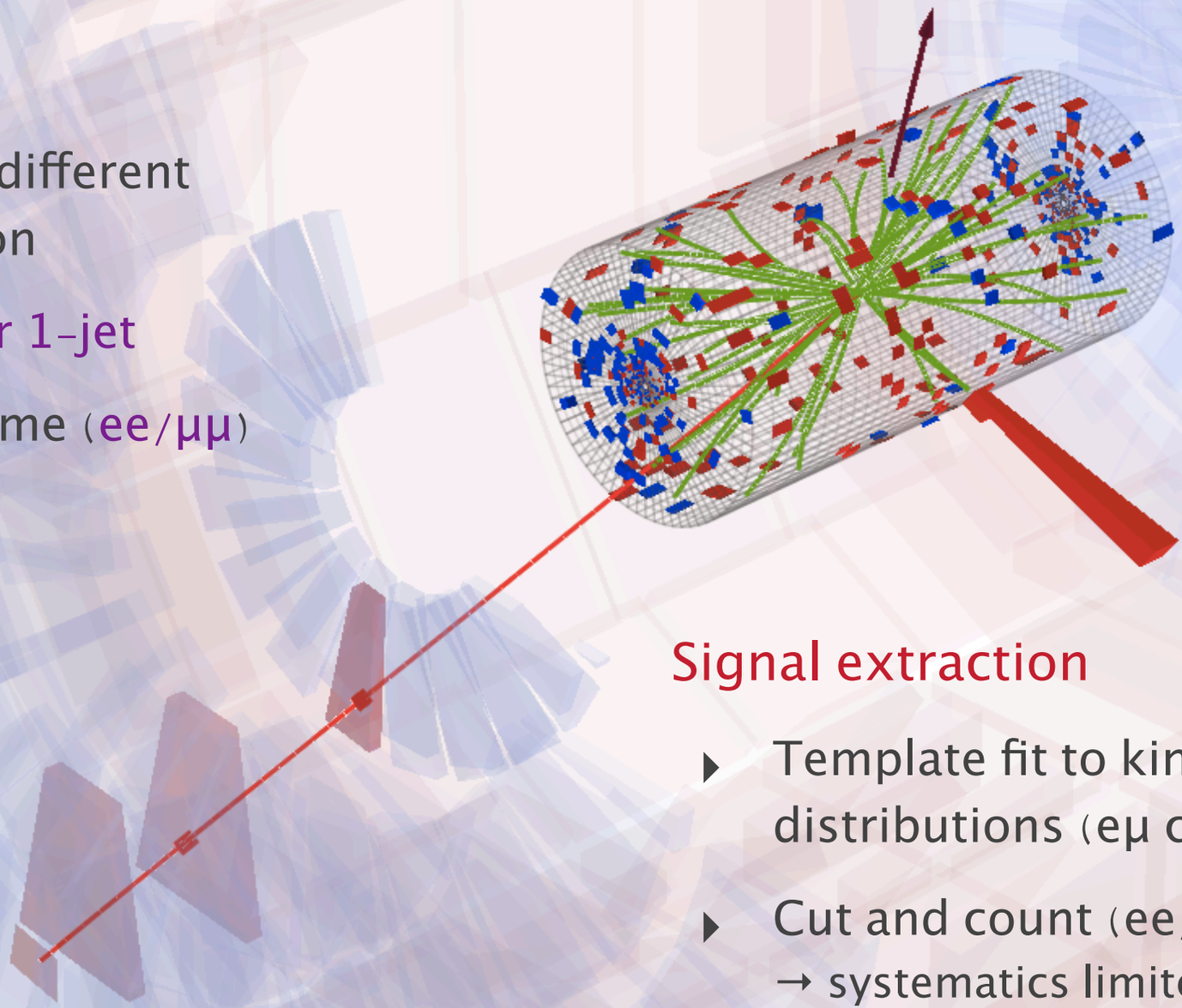
Signature of isolated leptons and large missing E_T

- 2 leptons with p_T > 20/10 GeV

Analysis strategies

Categorise events with different background composition

- jet multiplicity: 0 or 1-jet
- Different (eμ) or same (ee/μμ) lepton flavour pair

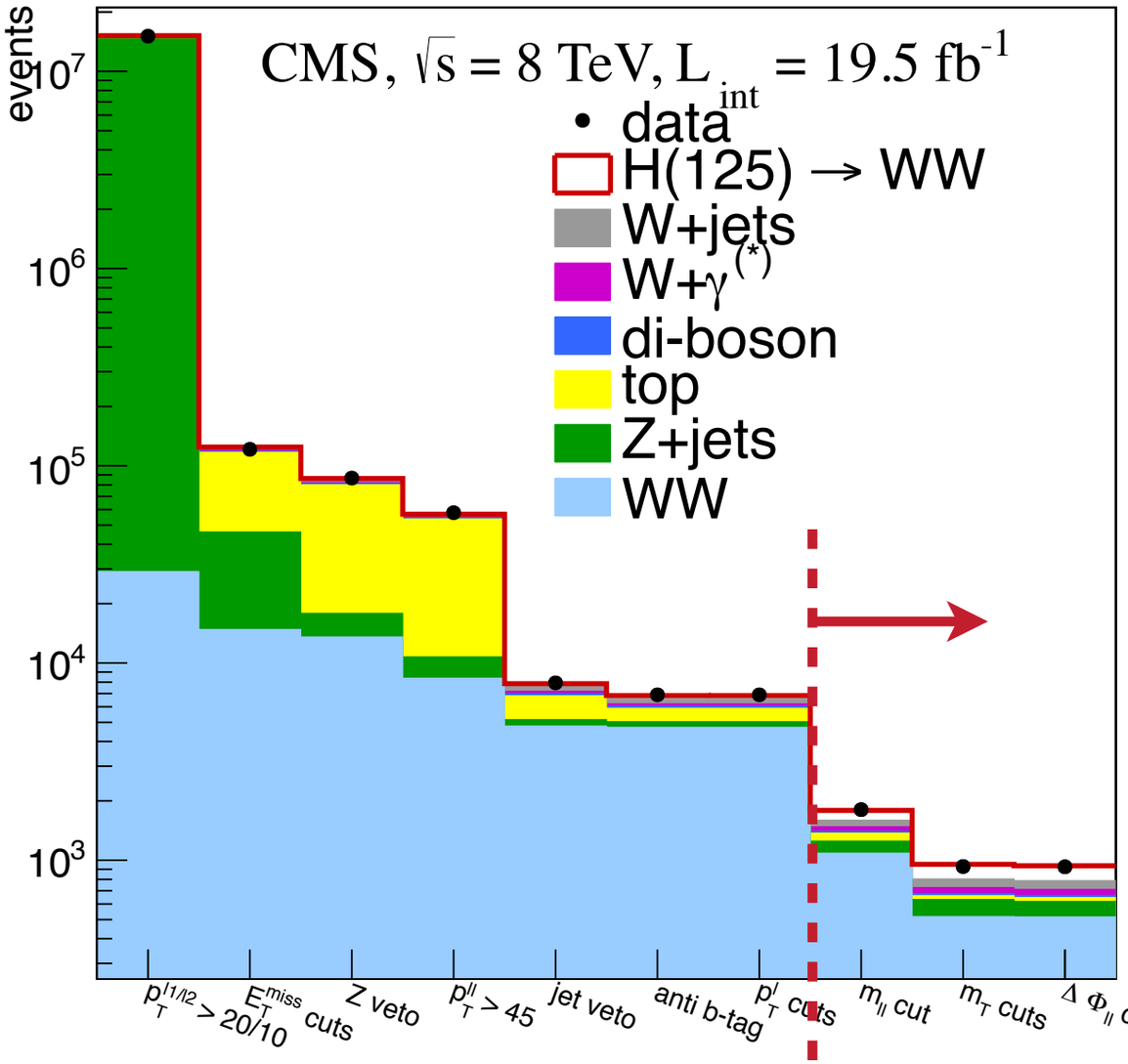


Signal extraction

- Template fit to kinematic distributions (eμ channel)
- Cut and count (ee/μμ channel)
  → systematics limited

Background Rejection

Cut evolution



preselection

optimised for each m_H

Z/γ*:
exclude region near m_Z in ee/μμ
missing E_T based discriminant

tt, tW:
veto on b-jet (IP, soft muon)

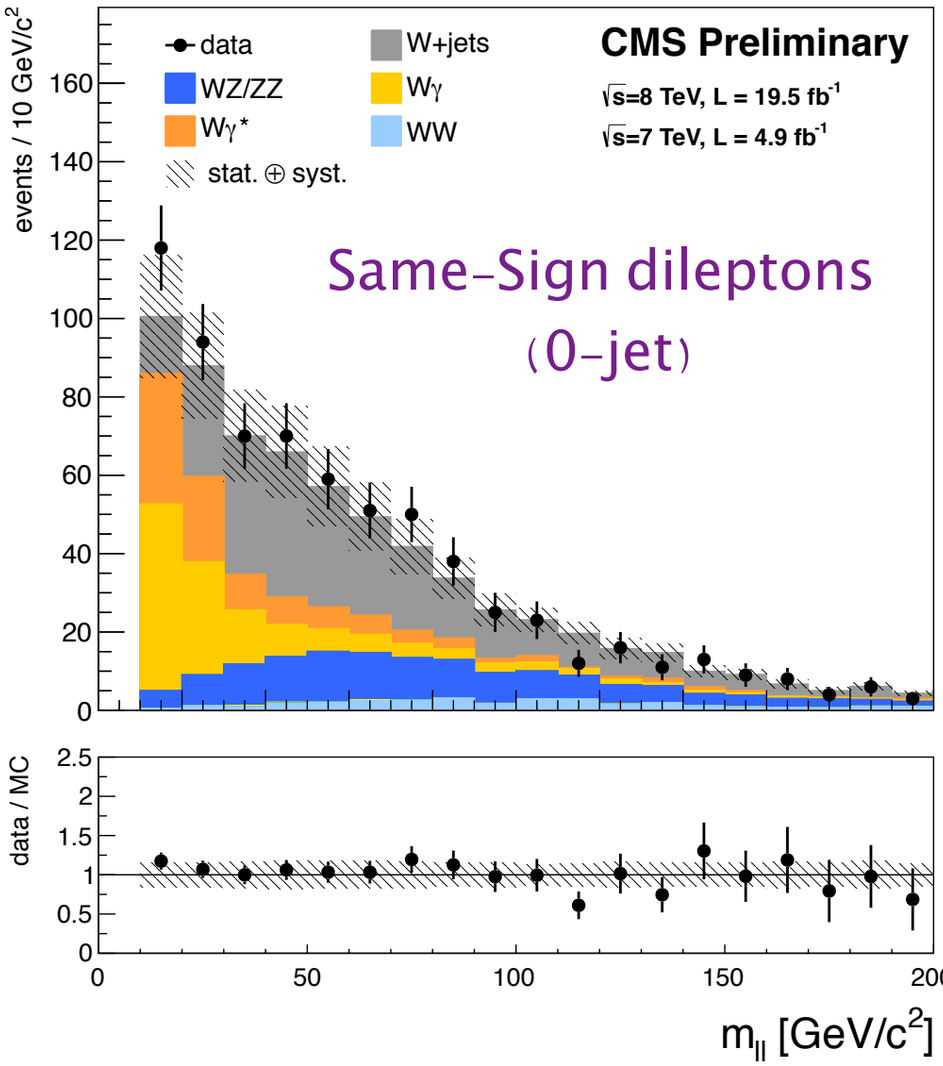
W+jets:
tight quality lepton selection

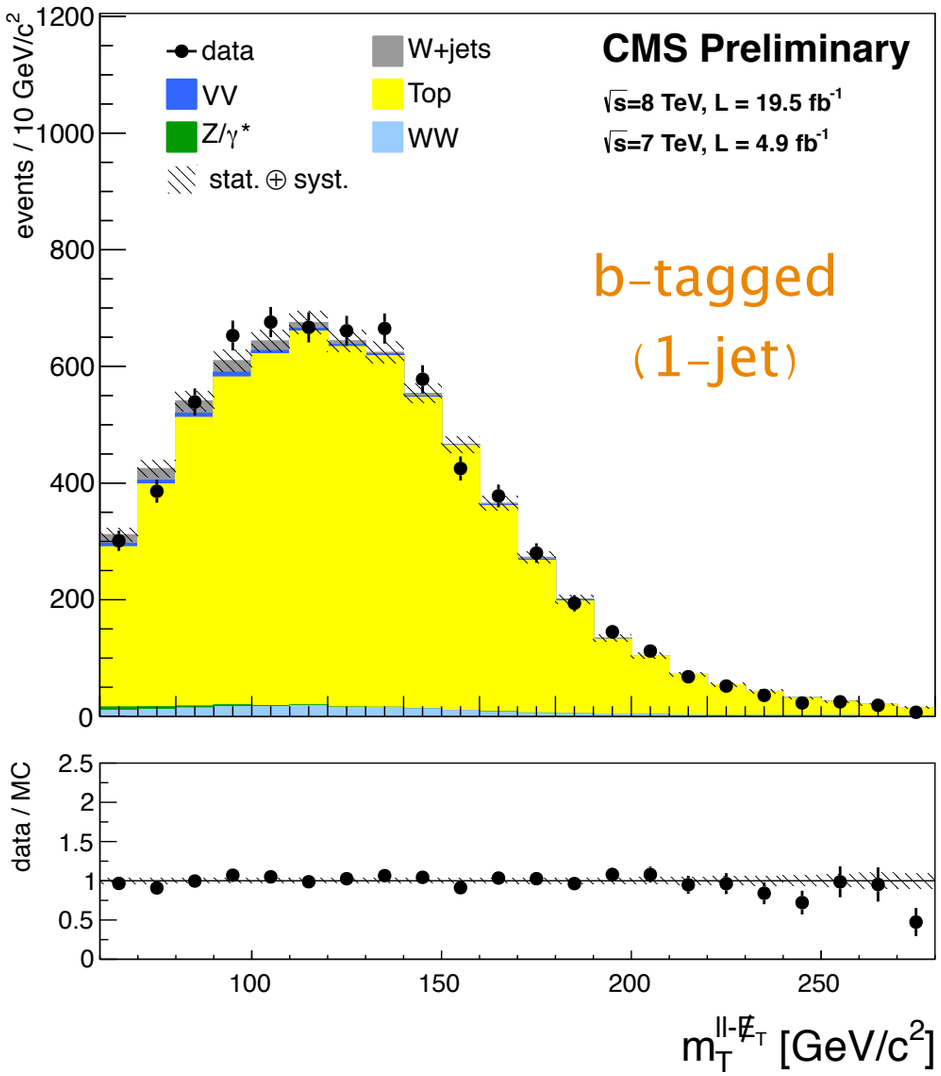
Wγ, Wγ*:
conversion rejection, isolation

WZ, ZZ:
no extra lepton, Z veto

WW:
kinematic selection

Background Control

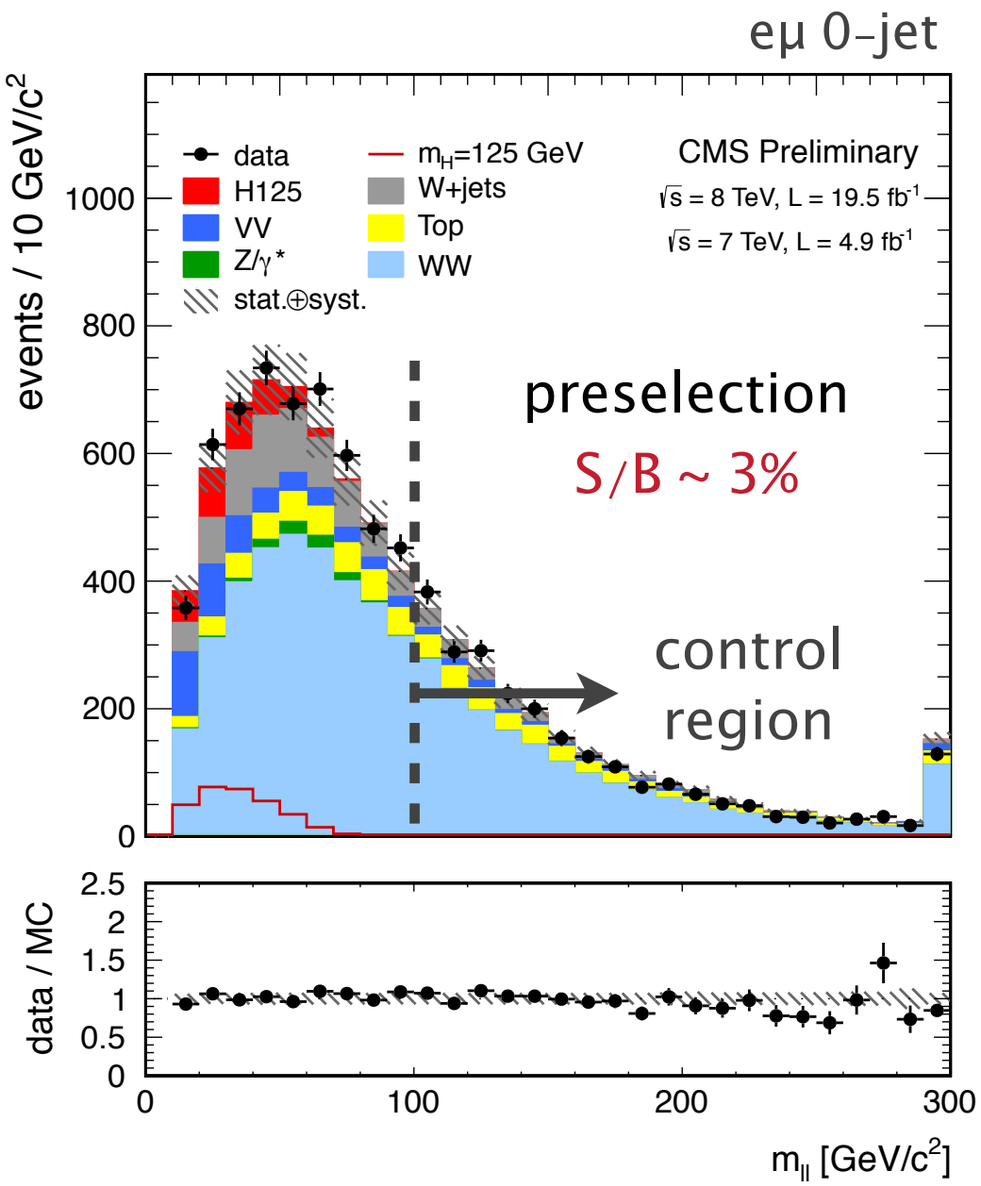


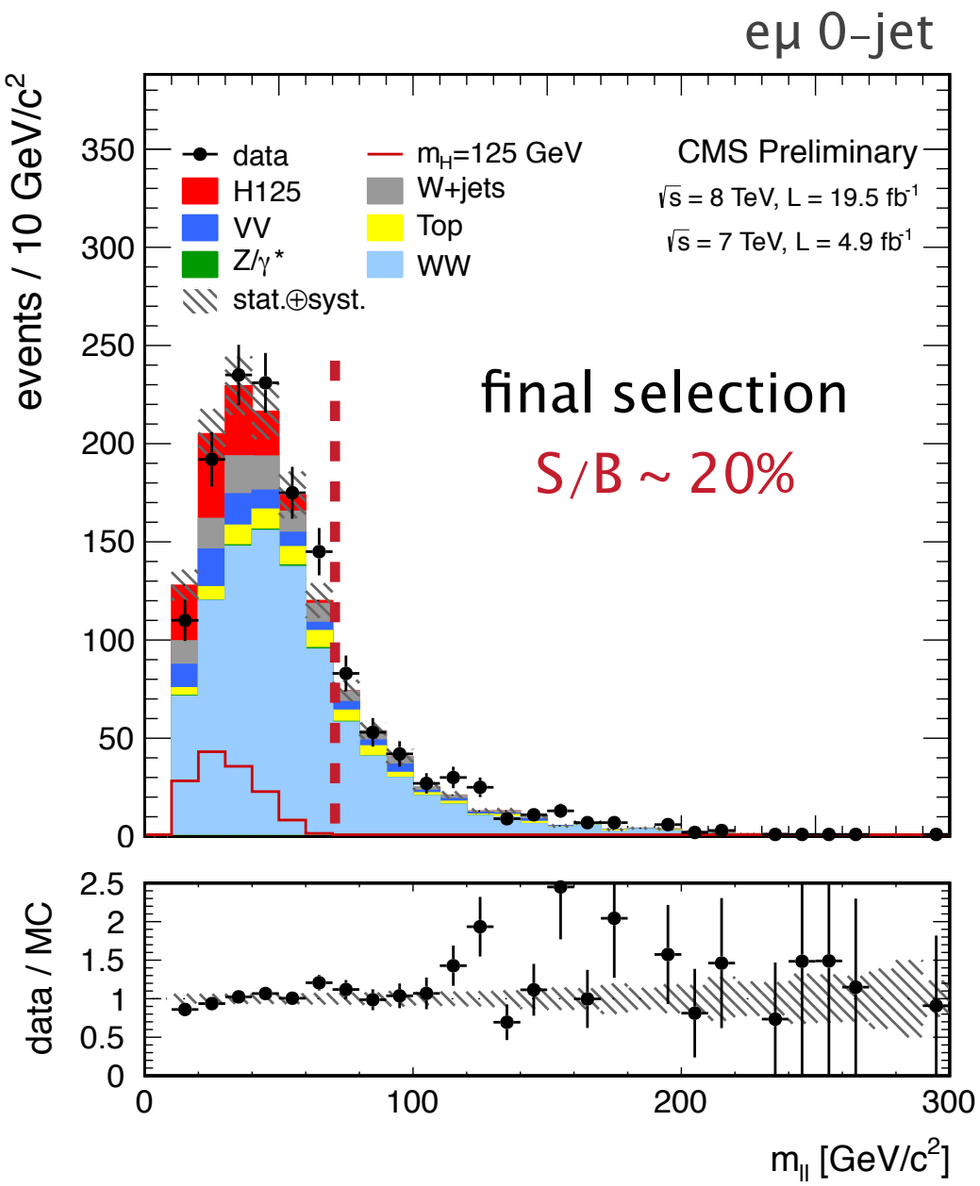


Backgrounds are estimated using data-driven methods (WZ/ZZ and Wγ from MC)

Normalisation and shape modelling are cross checked in control regions

Cut-Based Signal Extraction

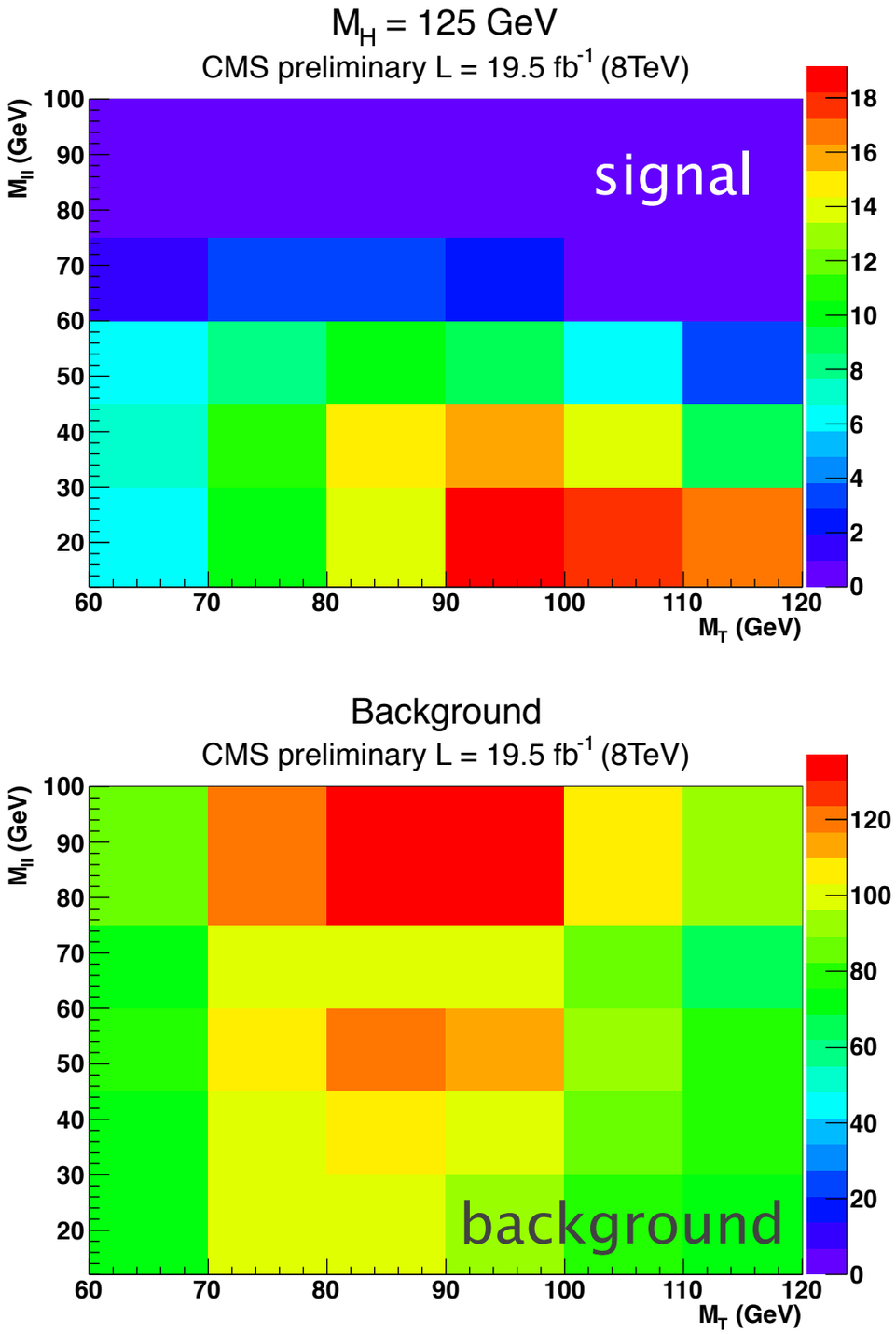




m_H dependent selection using $\Delta\varphi(\ell\ell)$, $m(\ell\ell)$, $mT(\ell\ell, m.E_T)$ + lepton p_T's for high m_H

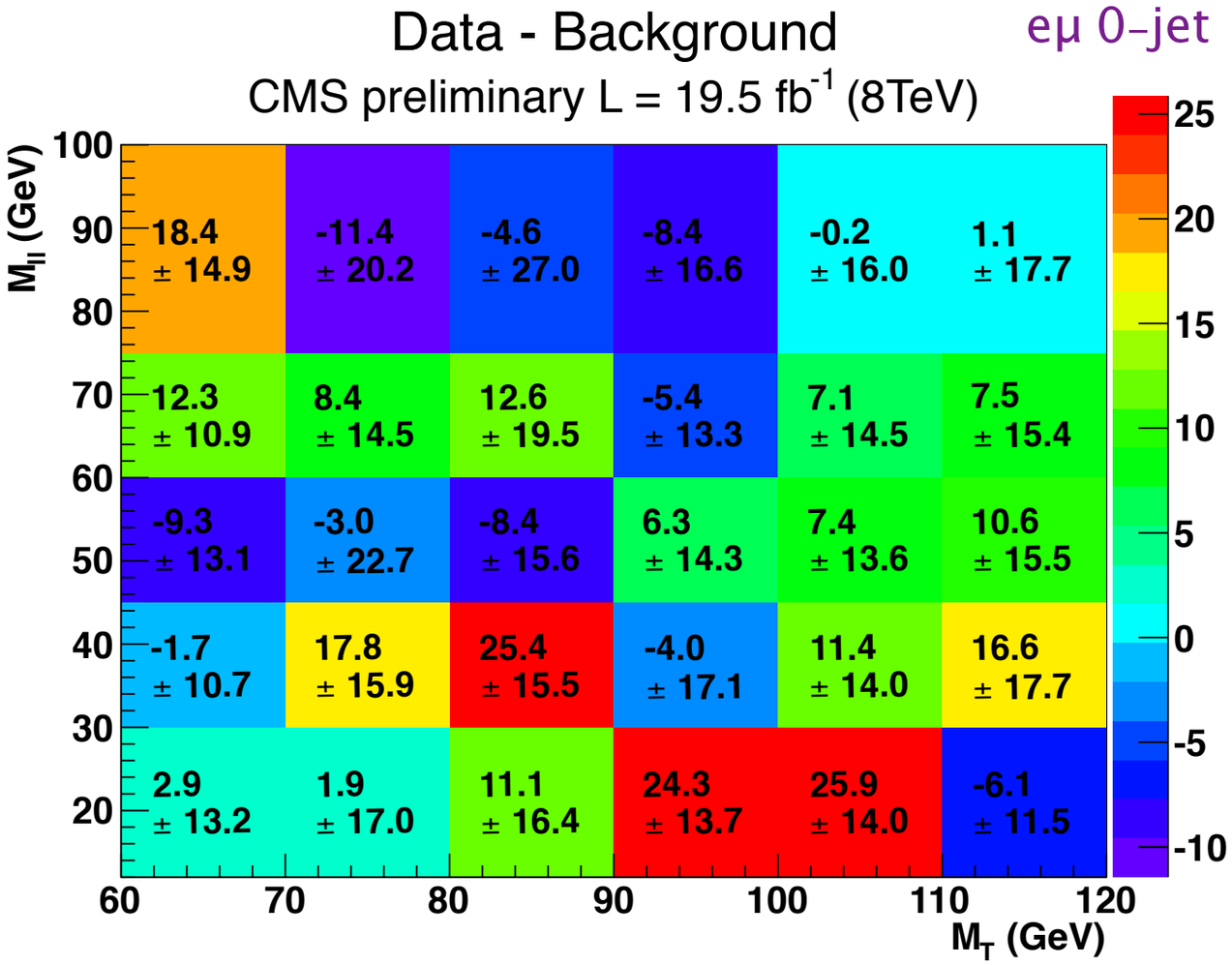
WW background normalised to data in $m(\ell\ell) < 100$ GeV before final selection

2D Template Fit



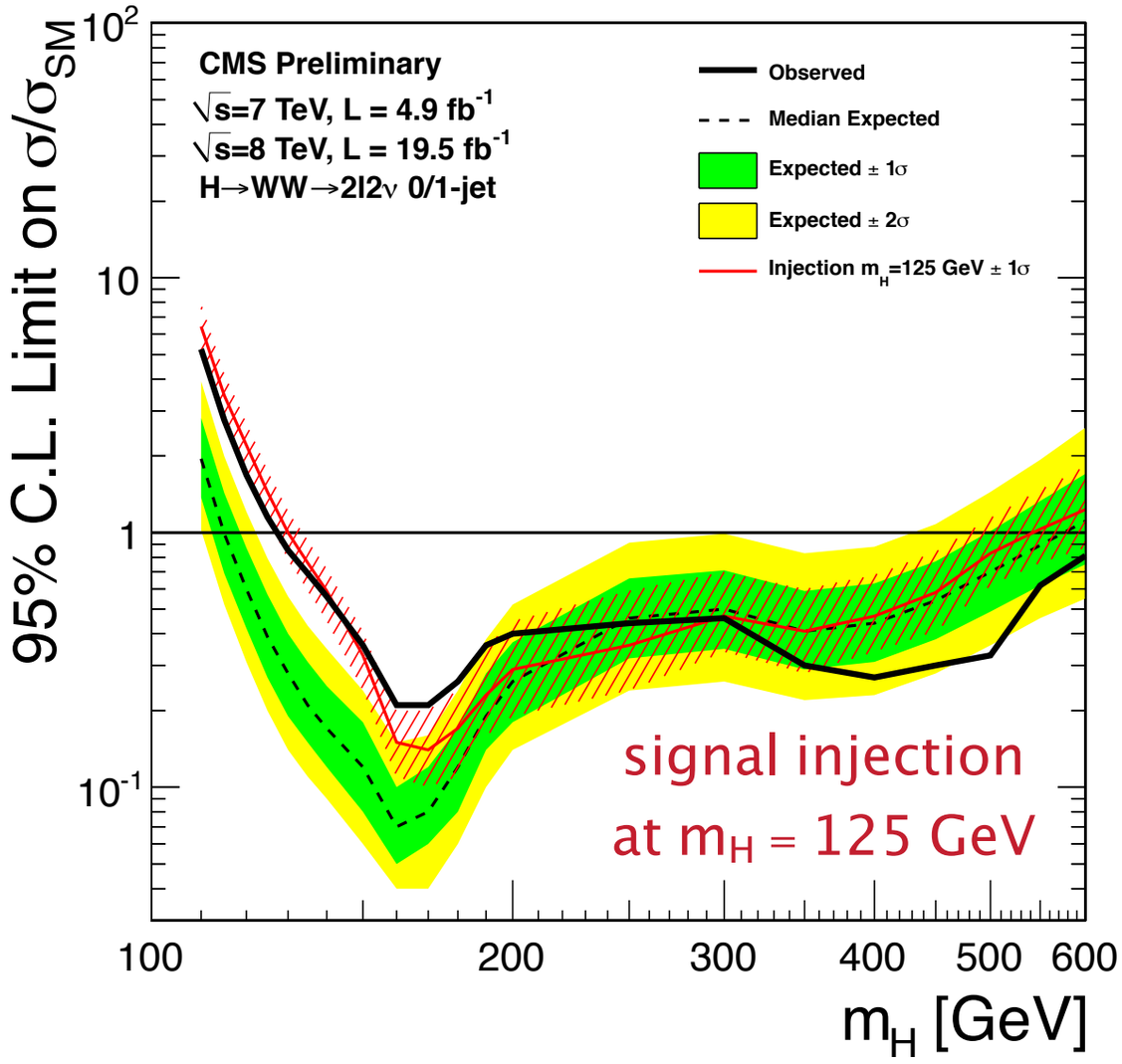
2D fit to extract signal & backgrounds

- $m(\ell\ell) < 200$ GeV, $m_T(\ell\ell, m.E_T) < 280$ GeV
- Use most sensitive eμ channel in 0/1-jet
- WW normalisation left floating

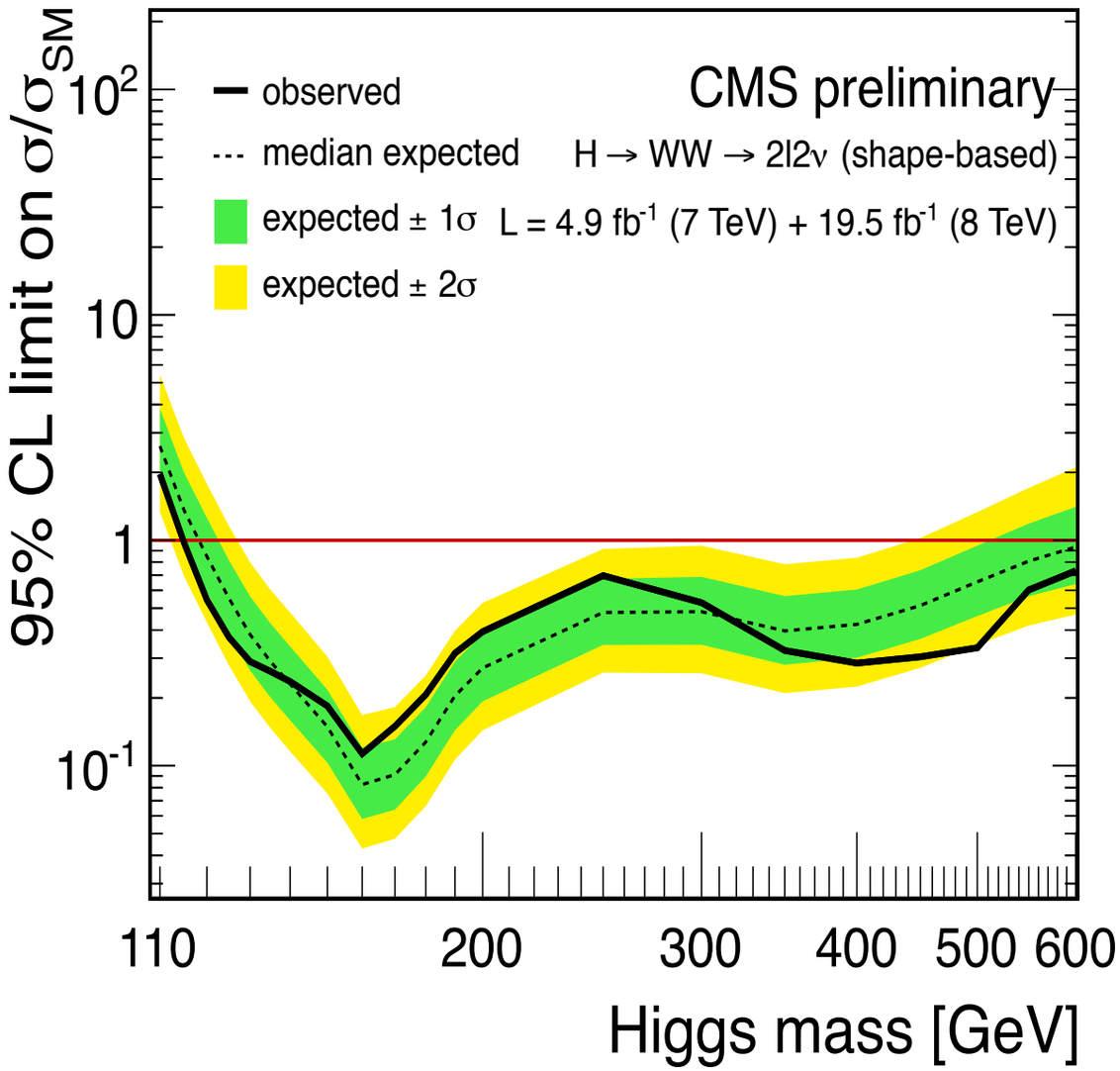


Upper Limits on σ

Observed in 2011+2012 data



SM m_H = 125 GeV as a background



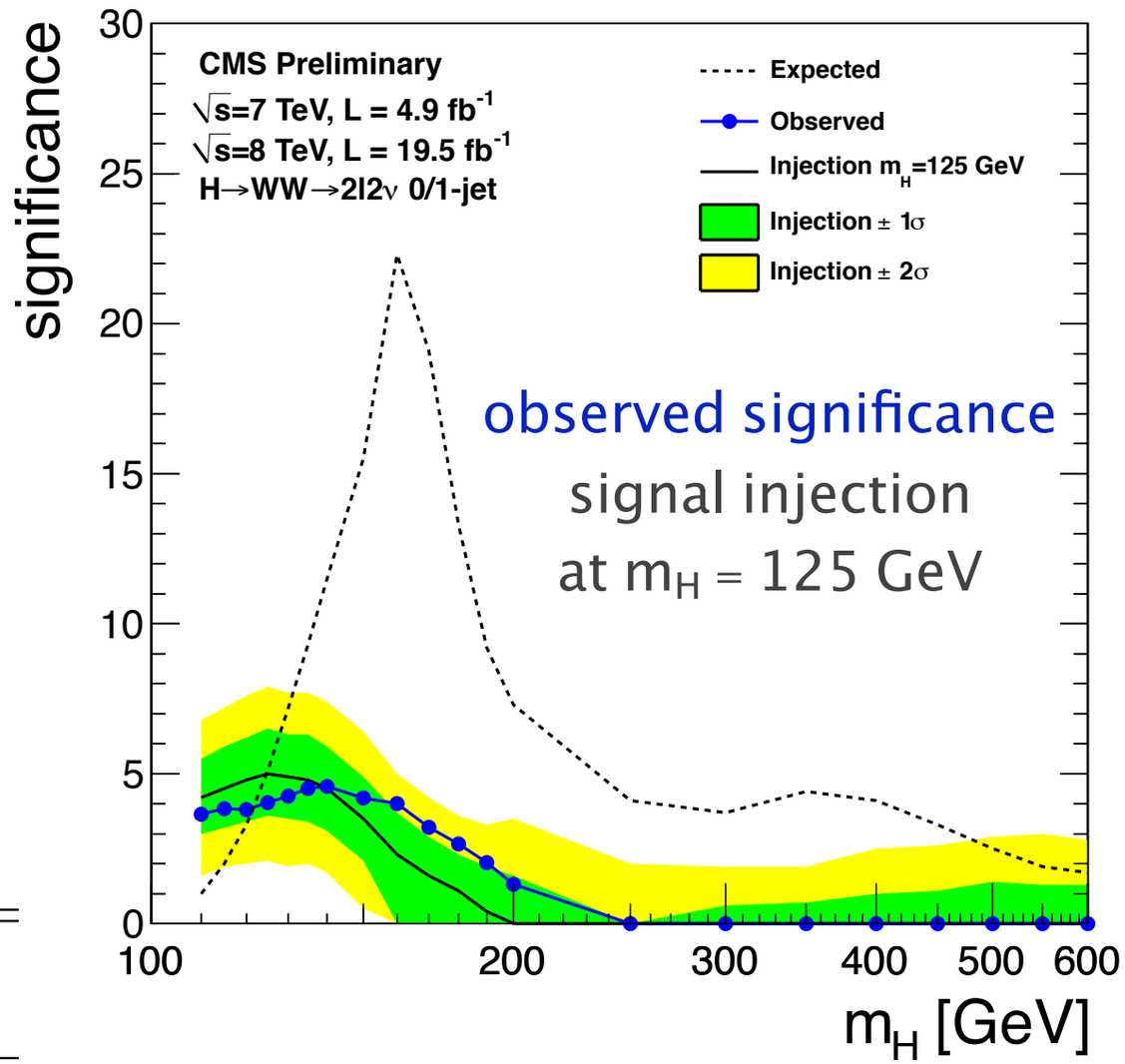
Exclusion for SM Higgs in 128–600 GeV at 95% C.L.

Signal Significance

Significance at m_H = 125 GeV

expected (cut-based): 5.1 (2.7) σ
observed (cut-based): 4.0 (2.0) σ

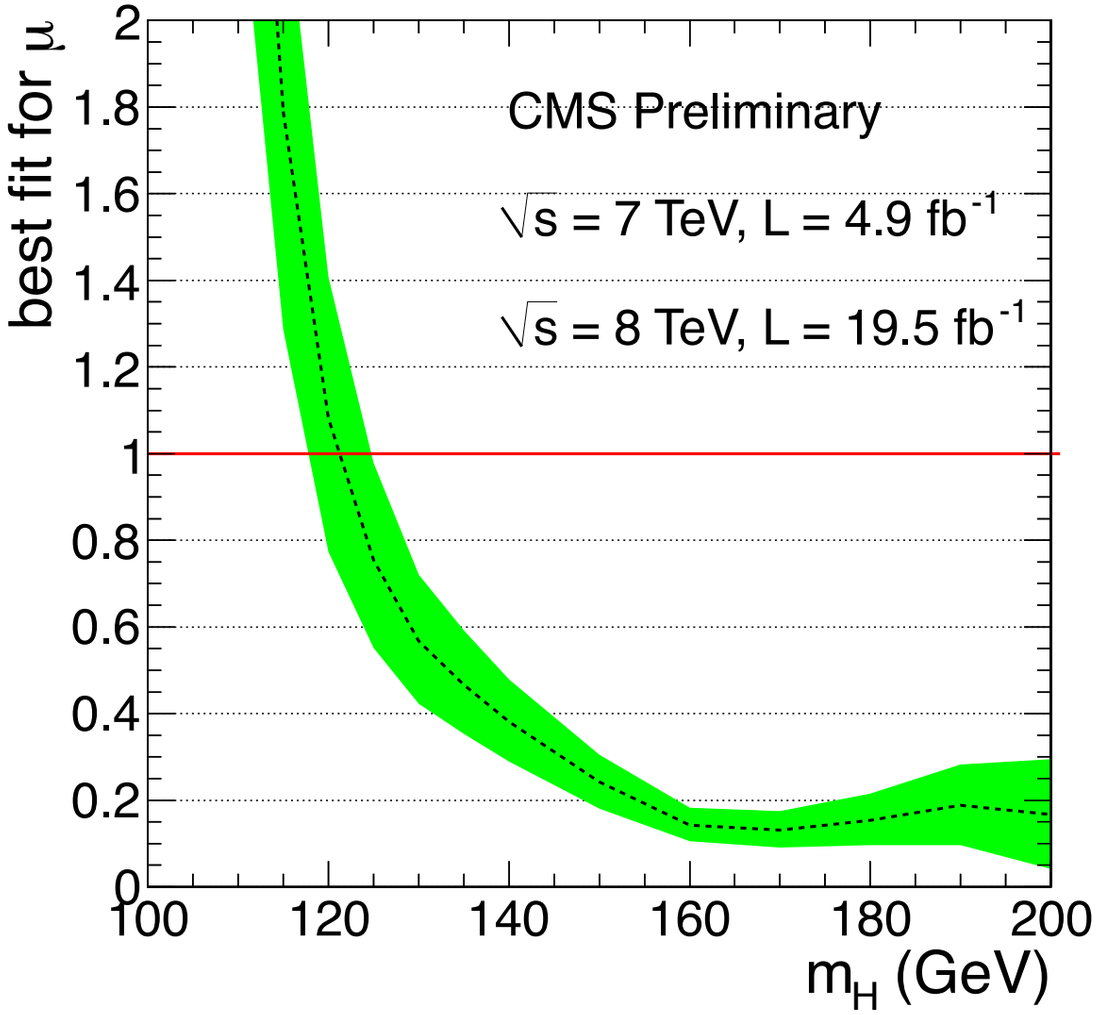
- Constraints on backgrounds from fit
- Broad excess due to mass resolution



Yields at cut-based final selection for m_H = 125 GeV

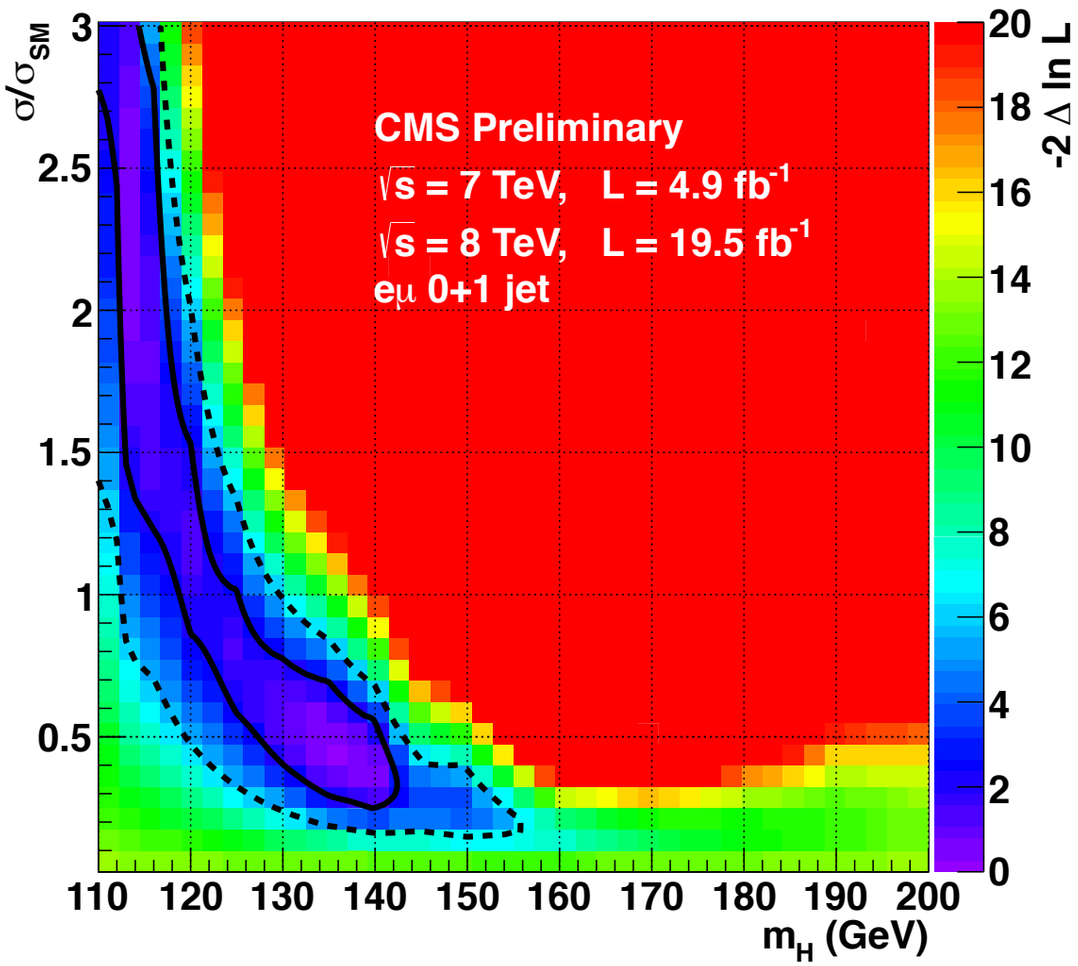
		H→WW	backgrounds	data
0-jet	$\ell\ell'$	89.9 ± 19.3	429.4 ± 34.2	505
	$\ell\ell$	56.3 ± 12.2	359.8 ± 37.6	421
1-jet	$\ell\ell'$	42.1 ± 12.2	208.5 ± 14.1	228
	$\ell\ell$	18.0 ± 5.2	111.3 ± 8.6	140

Signal Strength



Best fit μ at mH = 125 GeV

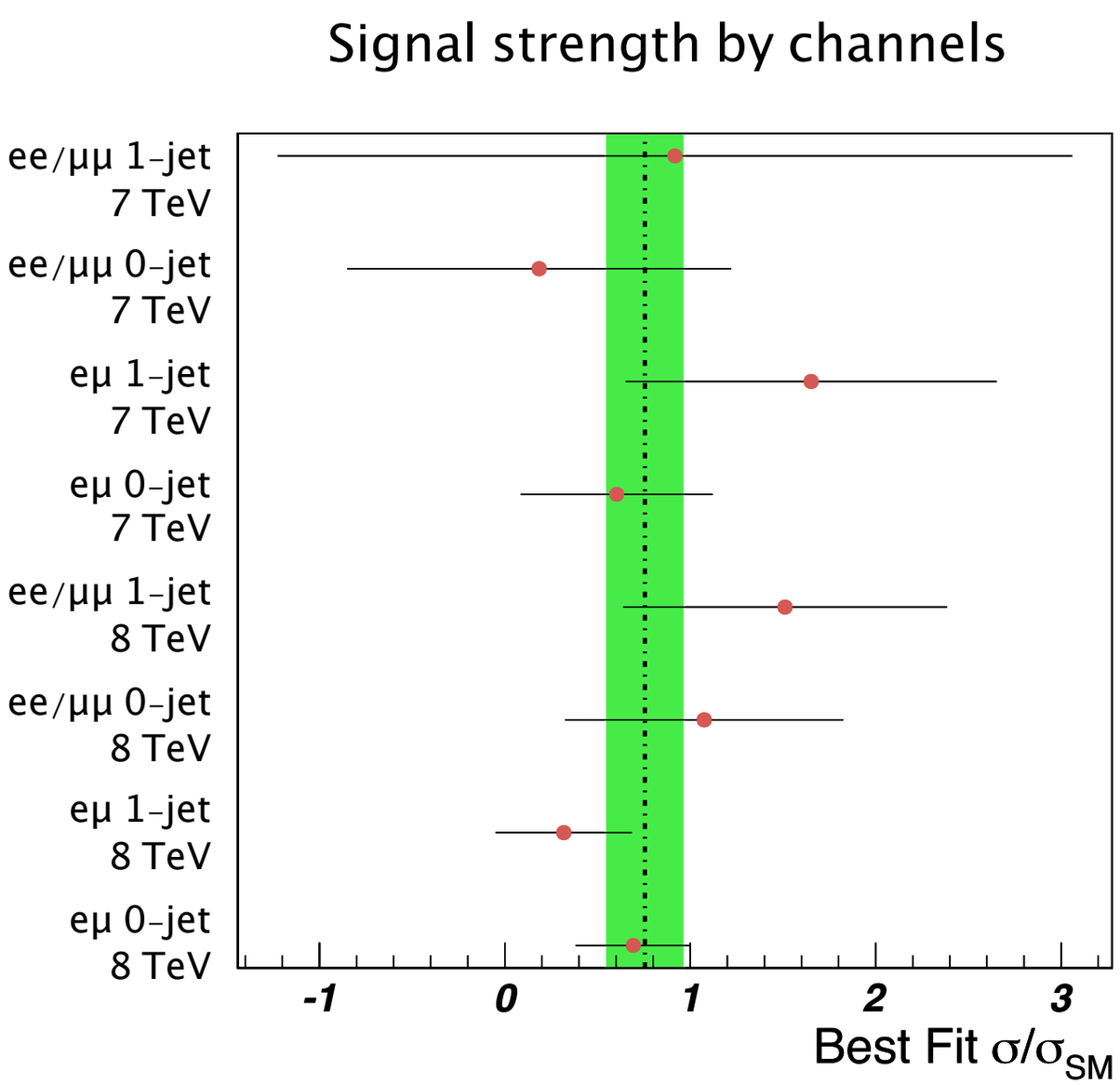
$\sigma / \sigma_{SM} = 0.76 \pm 0.21$



Likelihood scan in μ over m_H show wide spread of flat minimum

(m_H independent 2D fit)

Consistency of Results



Results are consistent in different categories and data taking periods

best fit μ (σ/σ_{SM})		
	cut-based	2D shape
7 TeV	0.46 ± 0.57	0.91 ± 0.44
8 TeV	0.79 ± 0.38	0.71 ± 0.22
combined	0.71 ± 0.37	0.76 ± 0.21

signal significance (exp/obs)		
	cut-based	2D shape
7 TeV	1.7/0.8	2.5/2.2
8 TeV	2.6/2.1	4.7/3.5
combined	2.7/2.0	5.1/4.0

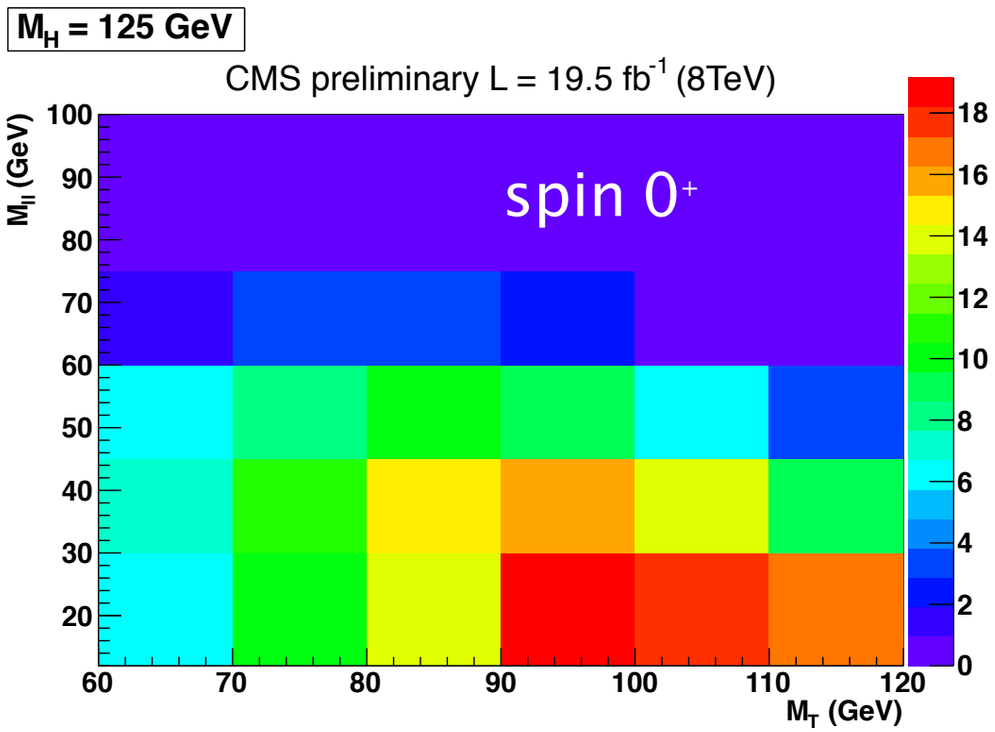
Spin Separation

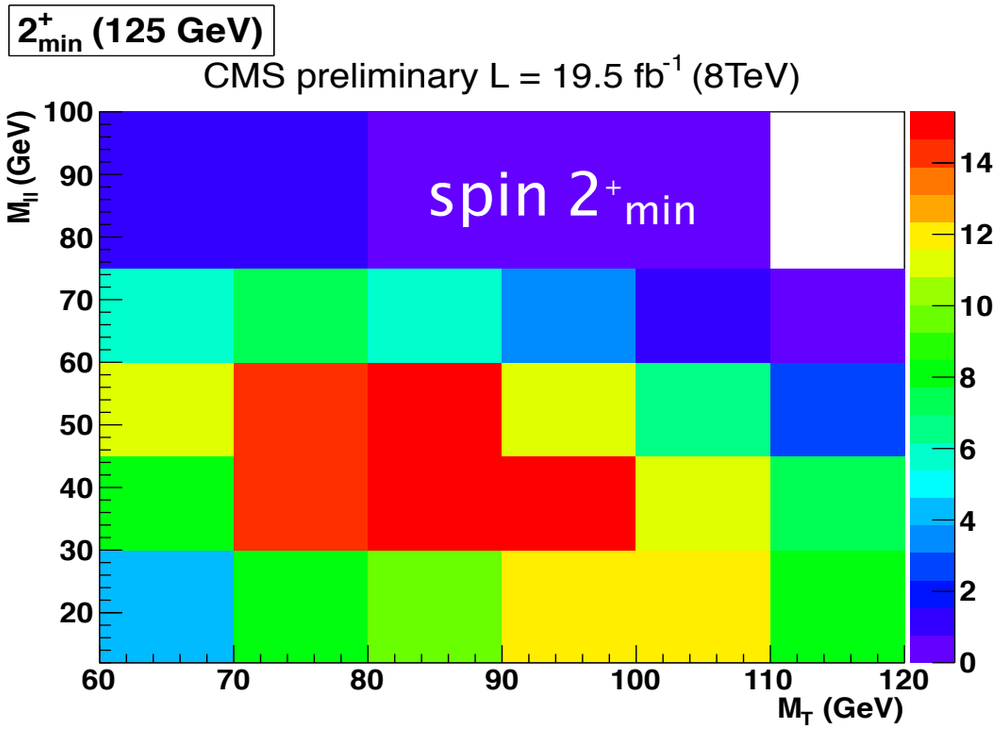
Spin 0^+ and 2^+_{min} hypotheses

- Spin 2 signal with minimum coupling modelled by JHU generator
- SM spin 0 signal using POWHEG (same as the standard analysis)

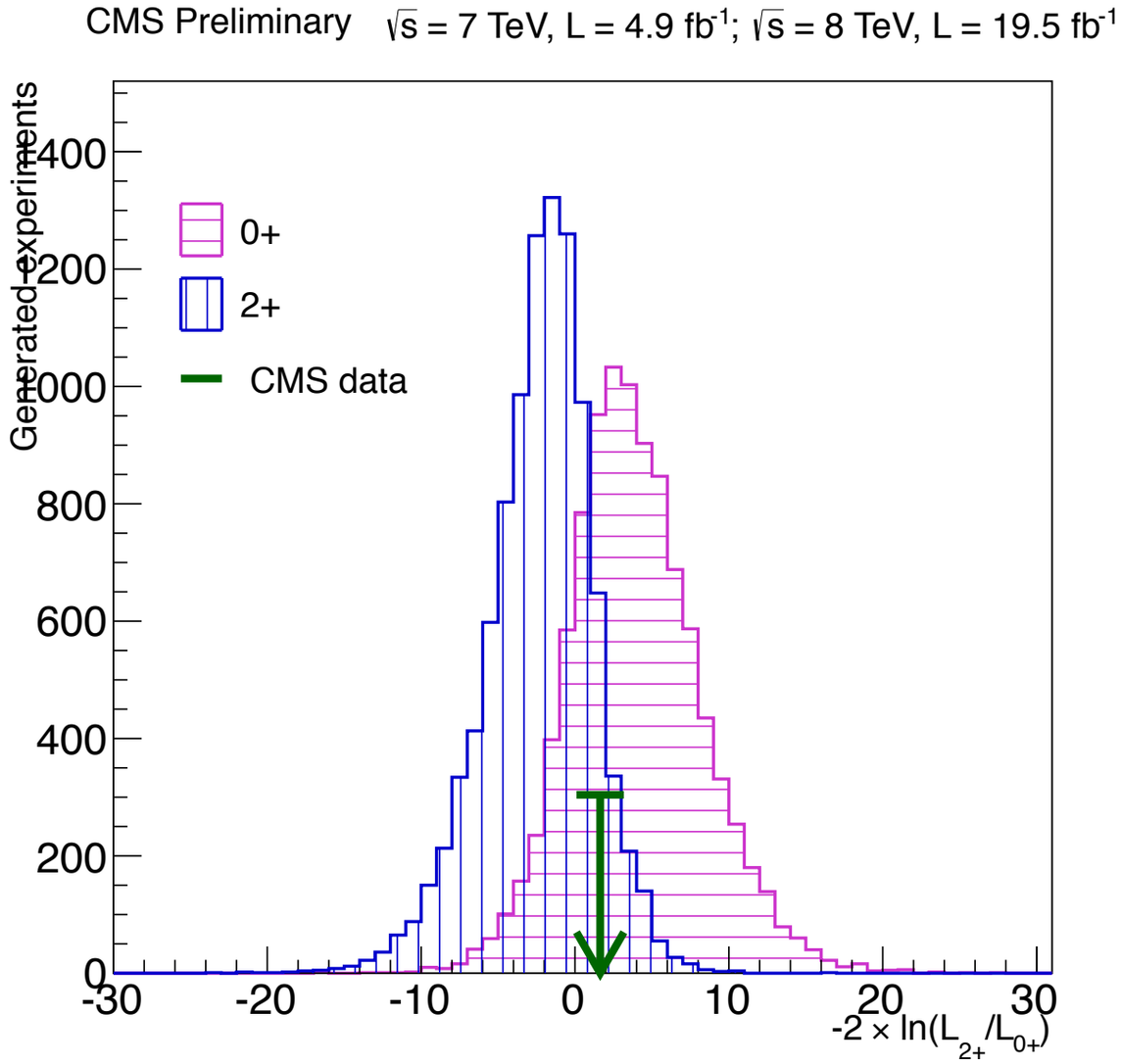
2D template fit in $m(\ell\ell)$ and $m_T(\ell\ell, m.E_T)$

- Same background description and templates as the standard 2D analysis





Spin Separation



	expected	observed
$P(q > q_{0^+})$	1.5	0.5
$P(q < q_{2^+_{min}})$	1.8	1.3

Maximum likelihood (L) fit

- Perform toy experiments to construct expected distribution

$$q = -2 \ln (L_{2^+}/L_{0^+})$$

- Evaluate probabilities of a given (observed) q being 0^+ or 2^+_{min}

Fit to data for each hypotheses

- Measured signal strengths

$\sigma_{0^+} / \sigma_{SM} = 0.76$

$\sigma_{2^+min} / \sigma_{SM} = 0.83$

- Expected separation using full luminosity in 2011 + 2012 (eμ only) is 1.5–1.8 σ

Tri-Lepton Final State

WH, H → WW/ττ

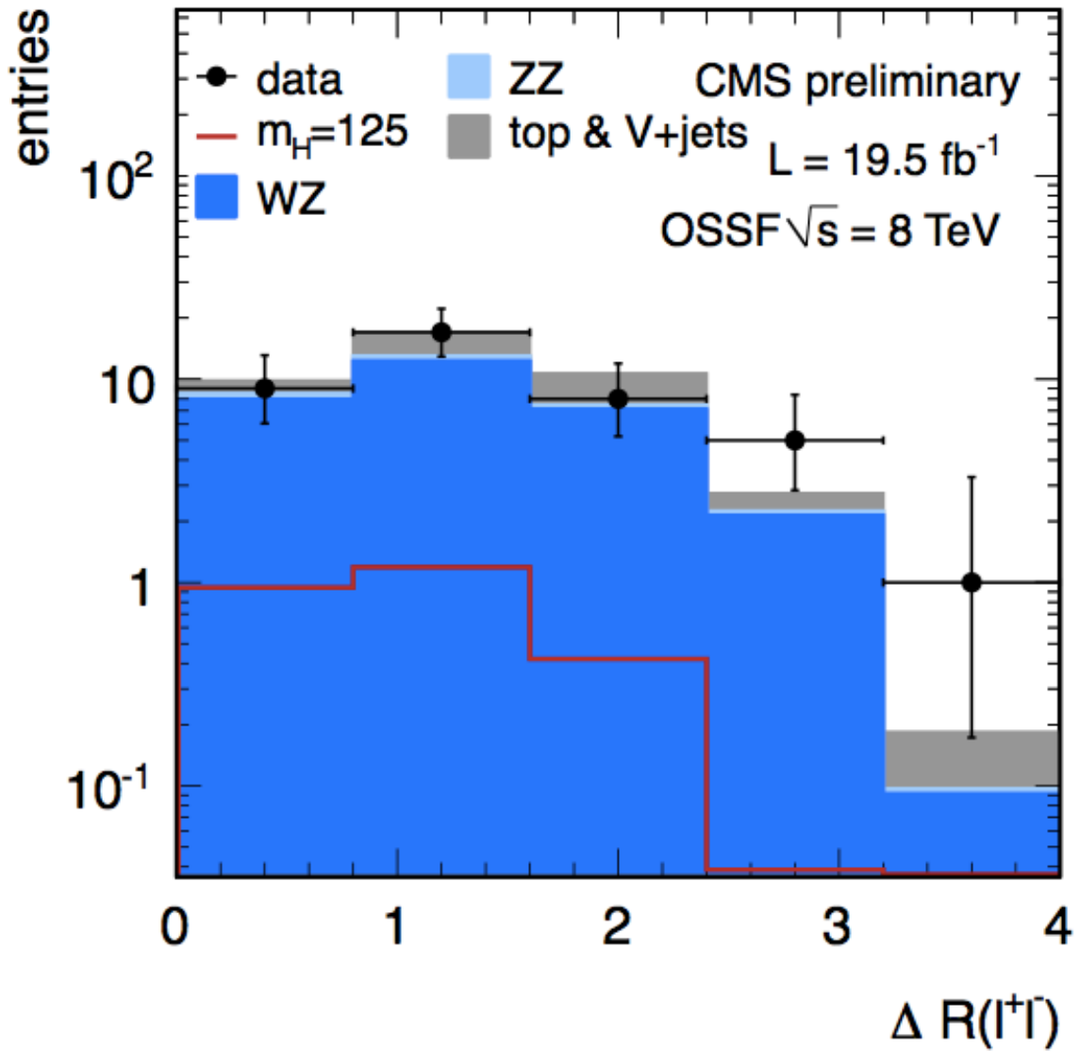
- 3 leptons (p_T > 20/10/10 GeV)
- Tighter missing E_T and Z mass veto, and relaxed jet veto
- ~30% from H→ττ

Backgrounds

- WZ normalised within Z resonance
- fake leptons in Z+jet and top

Signal extraction using shape of $\Delta R(\ell^+\ell^-)$

~3 x SM sensitivity at m_H = 125 GeV using full dataset in 2011+2012



WW + 2 jets

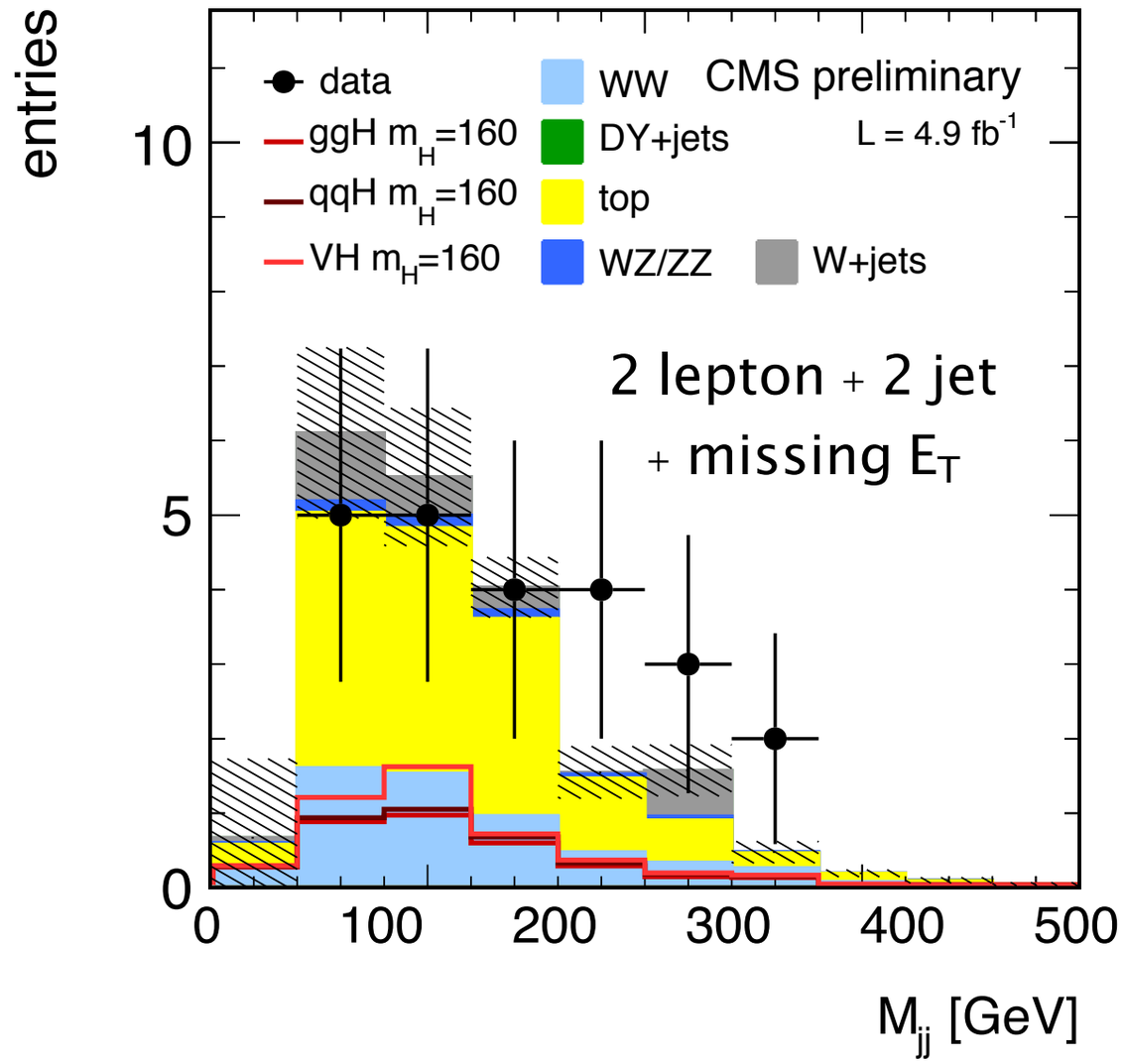
VH → qq WW

- Two jets (p_T > 30 GeV) from W/Z decay + WW → lνlν
- Selection based on dilepton and jet kinematics + window in $m_T(\ell\ell, m.E_T)$ for different m_H
- ~50% gg →H contribution

Last update using 2011 data

- ~12 x SM at m_H = 125 GeV

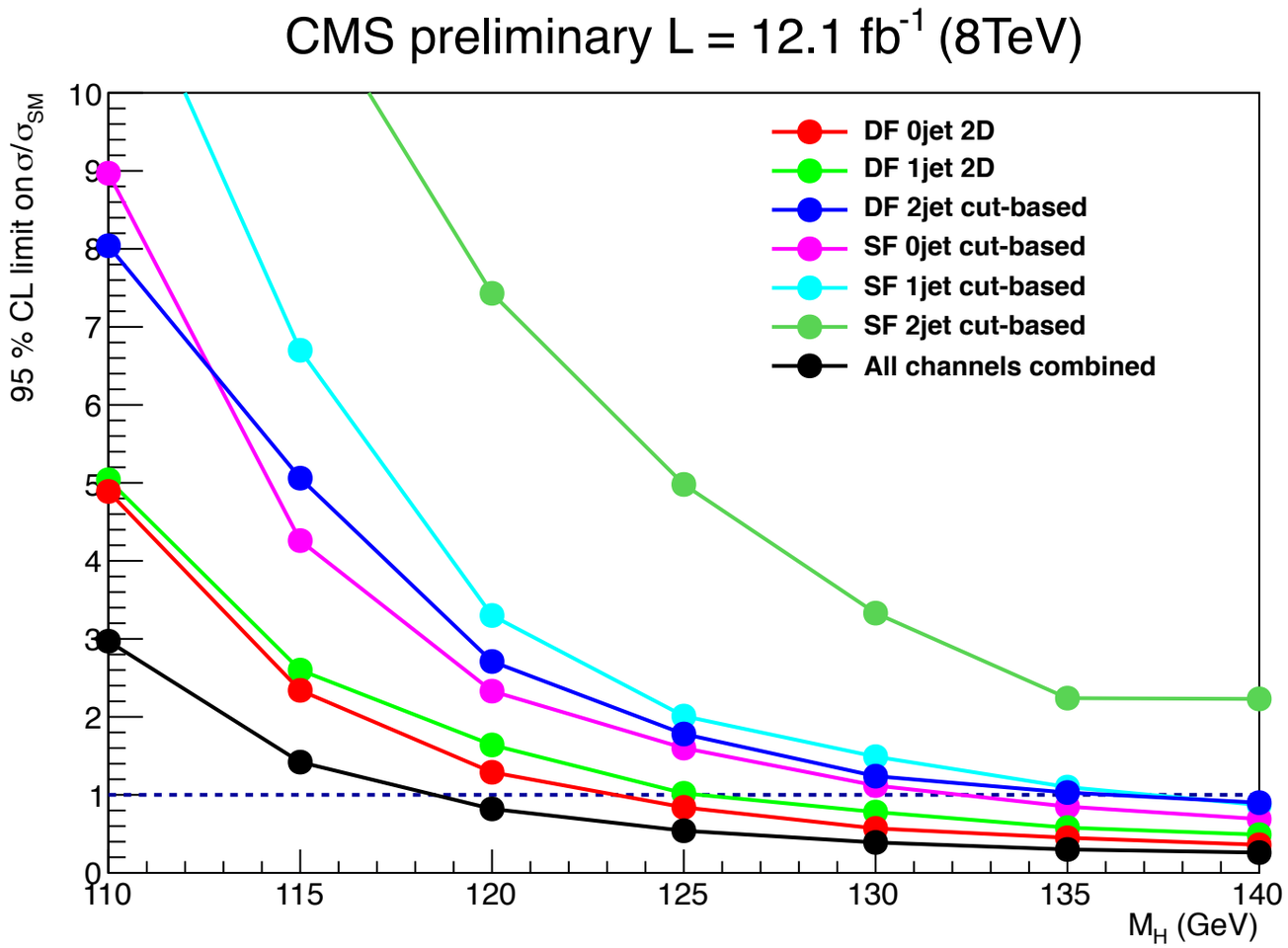
8 TeV analysis in progress



WW + 2 jets in VBF

qqH → qq WW

- VBF selection based di-jet kinematics: $\Delta\eta(jj)$, $m(jj)$
- Low statistics but high purity: $S/B \sim 1$ around $m_H = 200$ GeV

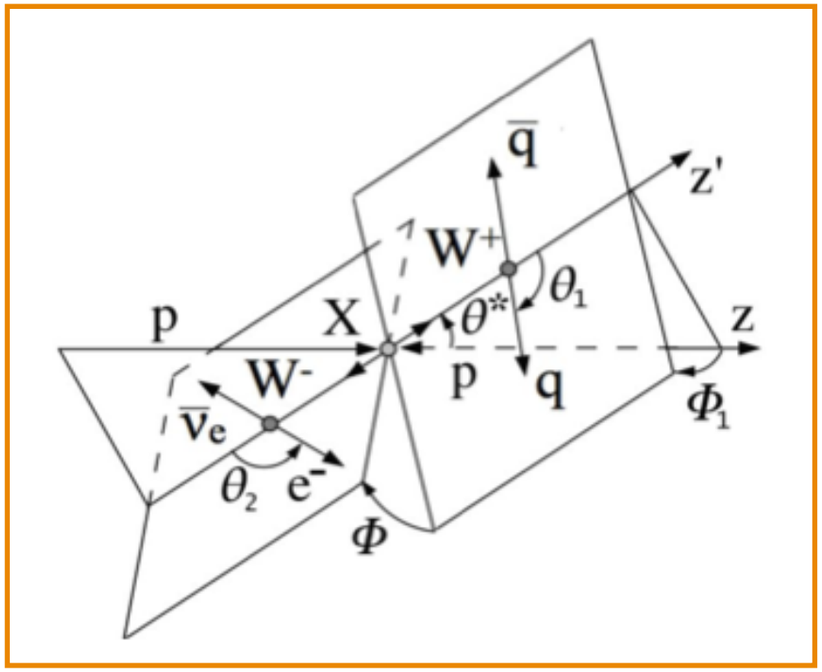


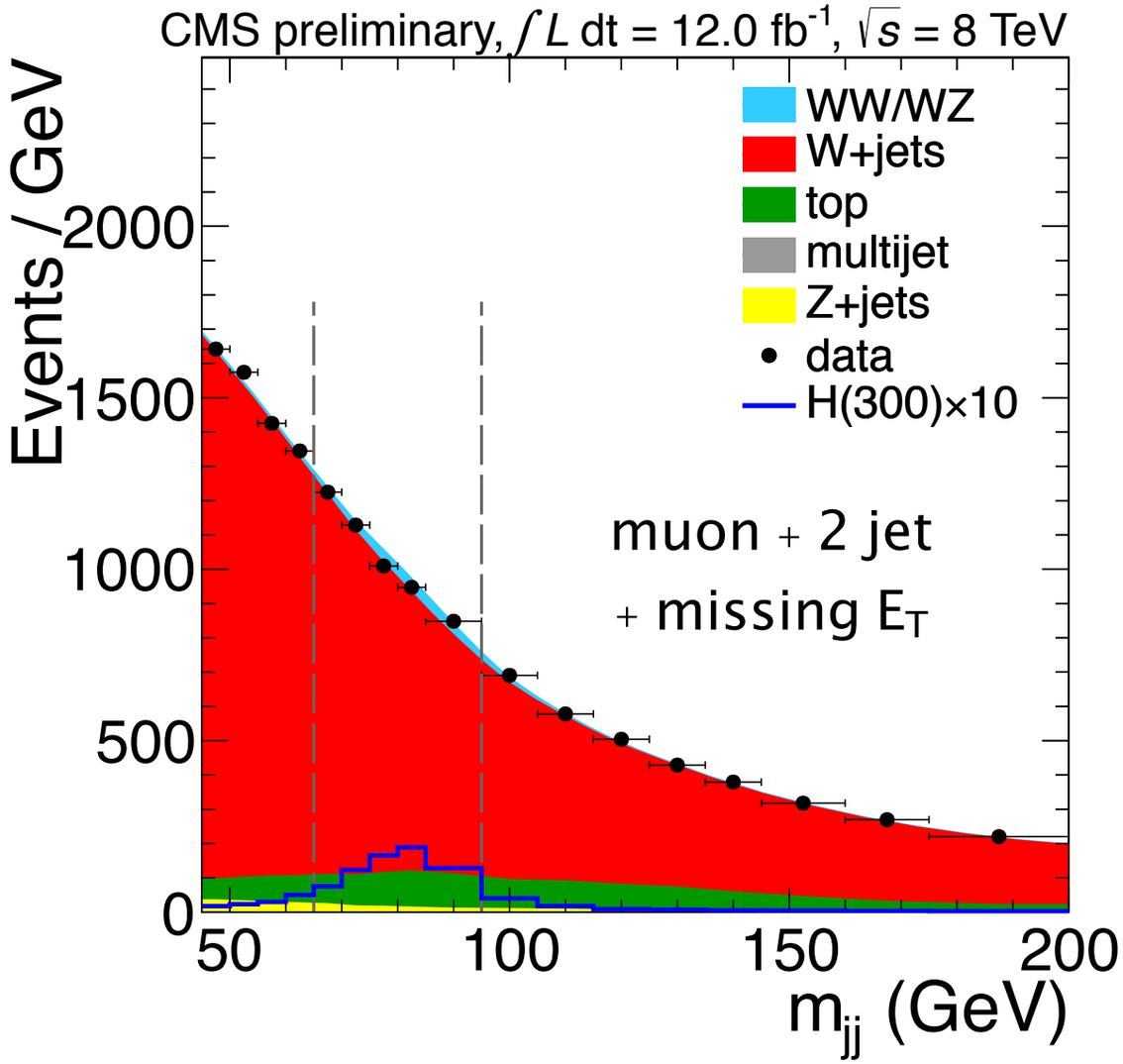
Last update using 12.1 fb^{-1}

- Exclude SM Higgs in intermediate mass range
- ~2 x SM at $m_H = 125$ GeV

Update using full luminosity in progress

H → WW → ℓν qq



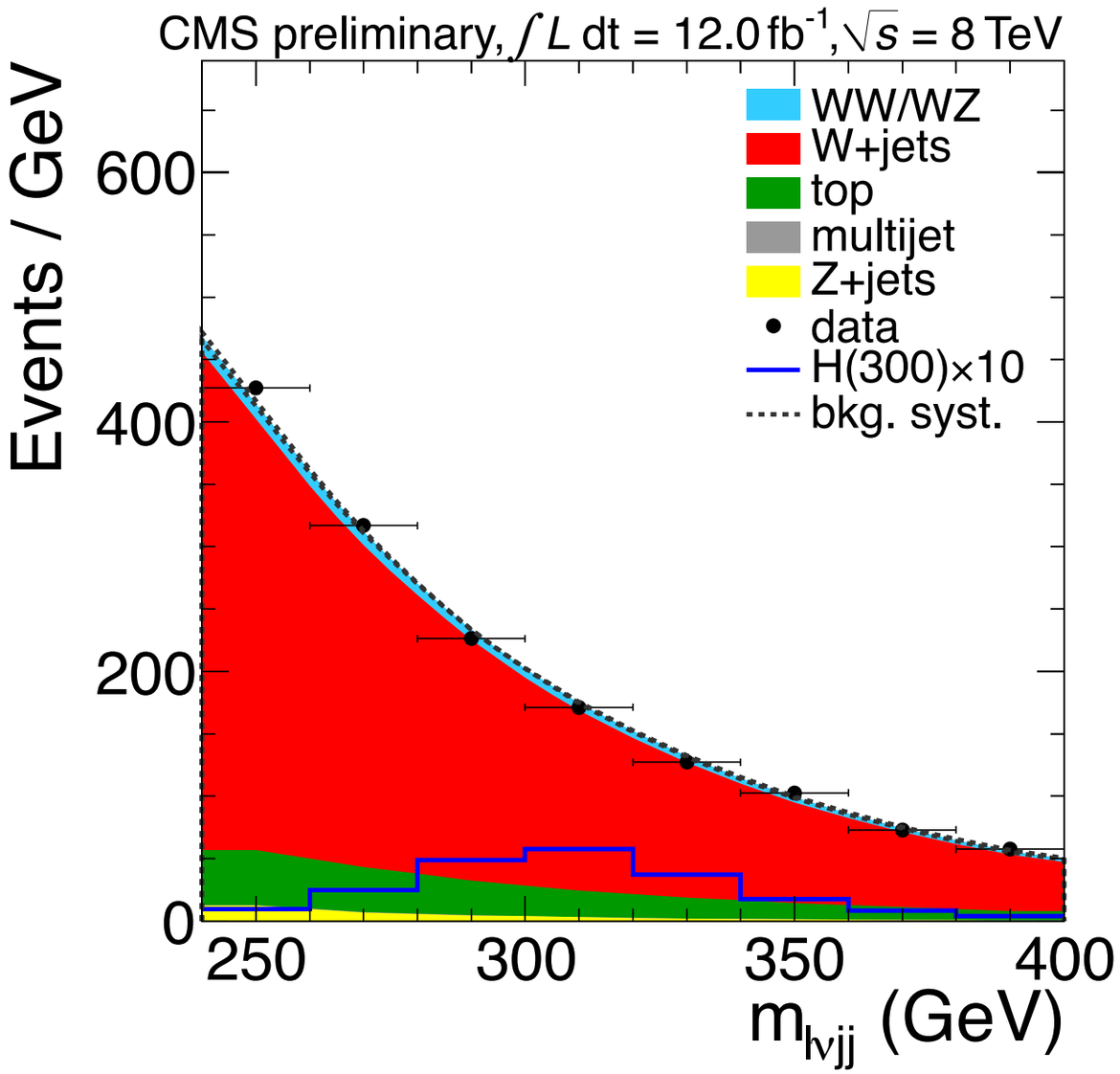


WW → ℓνqq

- High p_T lepton (25/35 GeV for μ/e) + 2/3 jets (p_T > 30 GeV) + missing E_T
- m_H-dependent likelihood discriminant (decay angles, WW p_T and rapidity)

Side-band fit to m(jj) to obtain W+jets normalisation and shape

H → WW → ℓν qq



Final fit to 4-body mass, m(ℓνjj)

- m(ℓν) and m(jj) are individually constrained to m_W from kinematic fit

Exclusion range for SM Higgs

(5 fb^{-1} @ 7 TeV + 12 fb^{-1} at 8 TeV)

- expected: 220-560 GeV
- observed: 225-485, 550-600 GeV

Analysis is preparing for a search in higher m_H

Summary

Analysis in H → WW decay mode at CMS

Inclusive WW → $\ell\nu\ell\nu$ and WH in trilepton final state updated using full luminosity of 4.9 fb^{-1} (7 TeV in 2011) + 19.5 fb^{-1} (8 TeV in 2012)

H → WW → $\ell\nu\ell\nu$

- Observation compatible with SM around m_H = 125 GeV

  significance = 4.0σ obs, 5.1σ exp

  best fit signal, $\sigma / \sigma_{SM} = 0.76 \pm 0.21$

- No significant additional excess up to m_H = 600 GeV
- Sensitivity to spin 0 vs spin 2 hypotheses at 1.5–1.8σ

Expect full updates of all channels and additional improvements towards summer

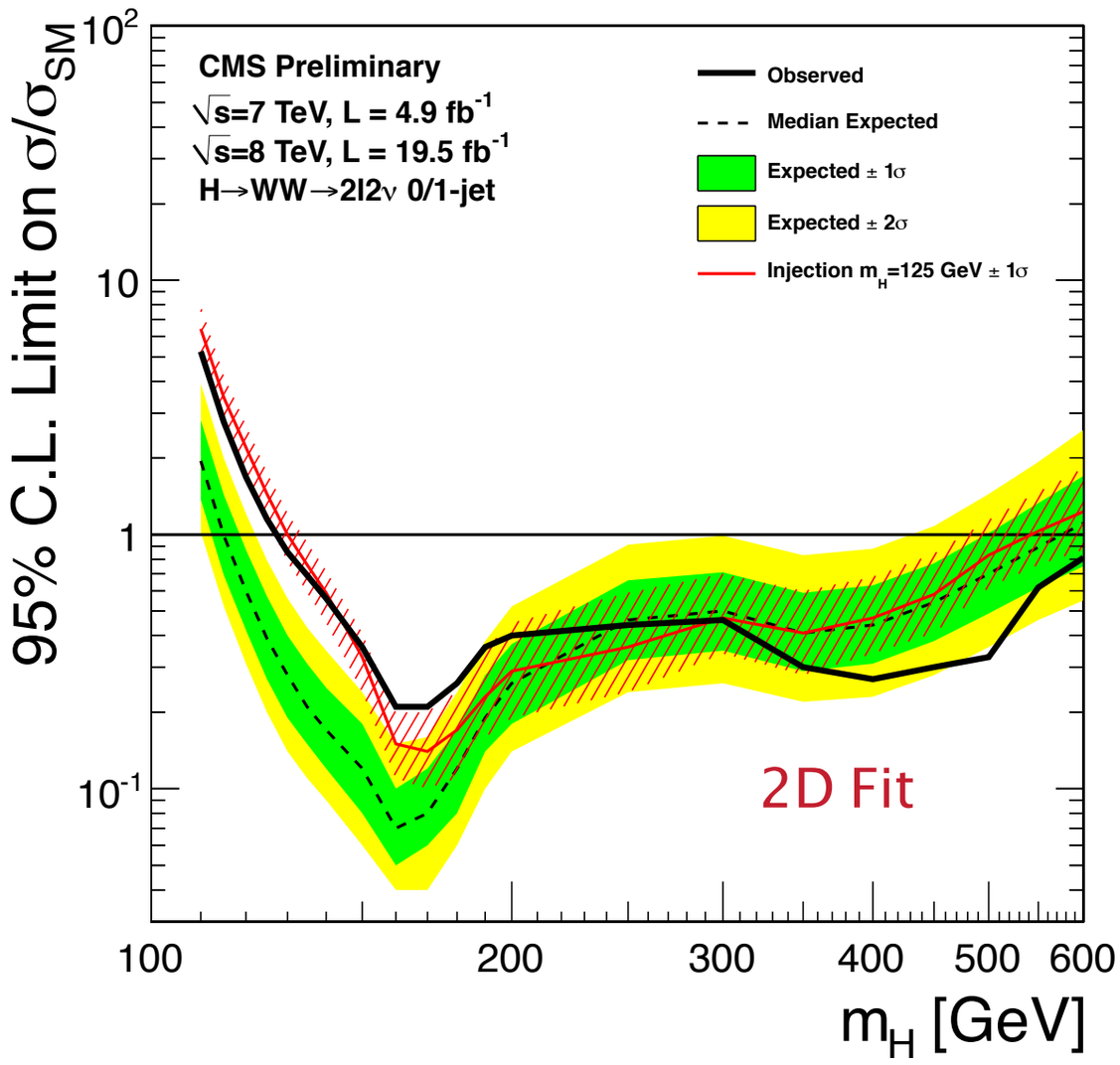
Back Up

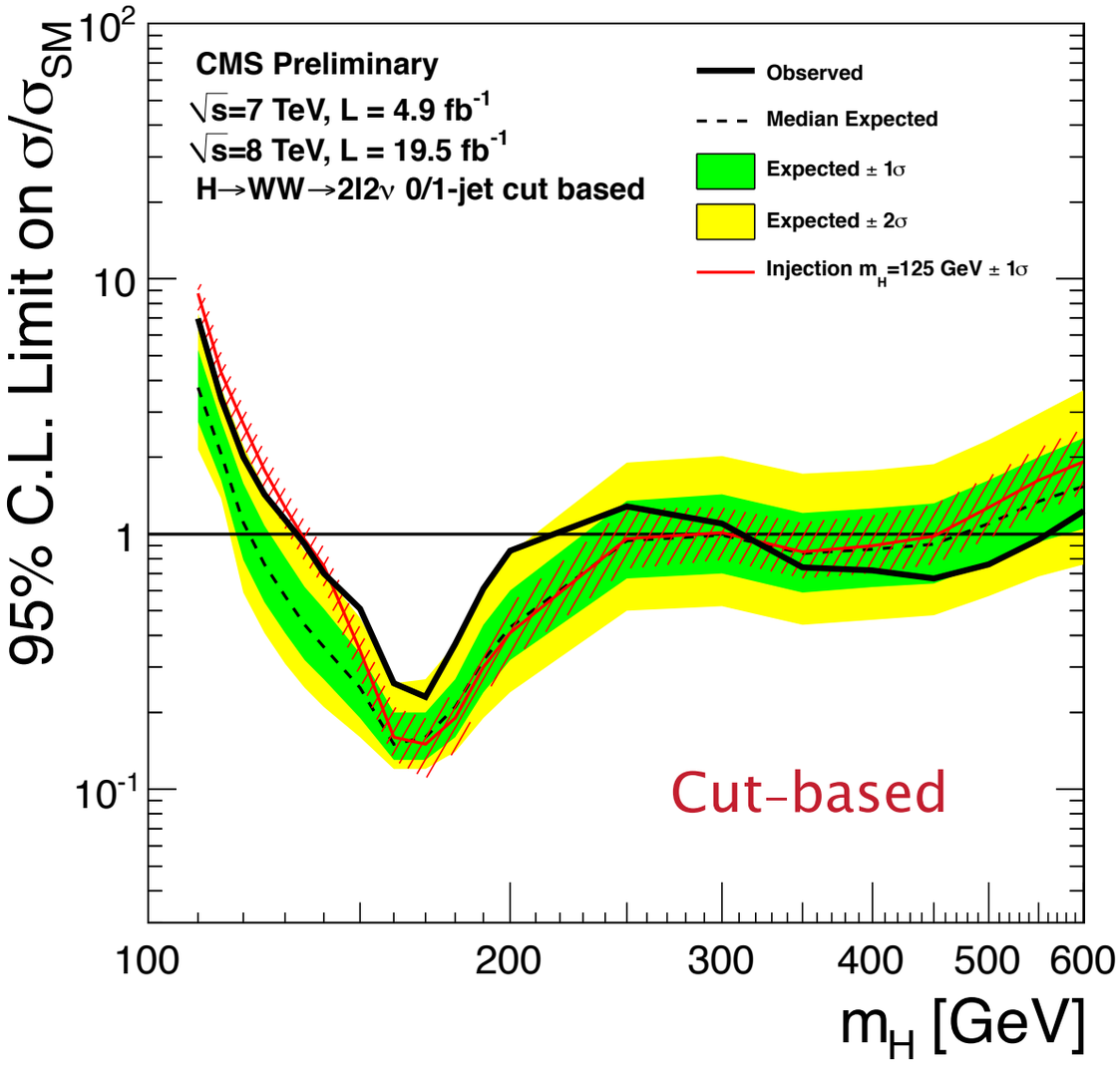
References

Public documents and material for the most recent results

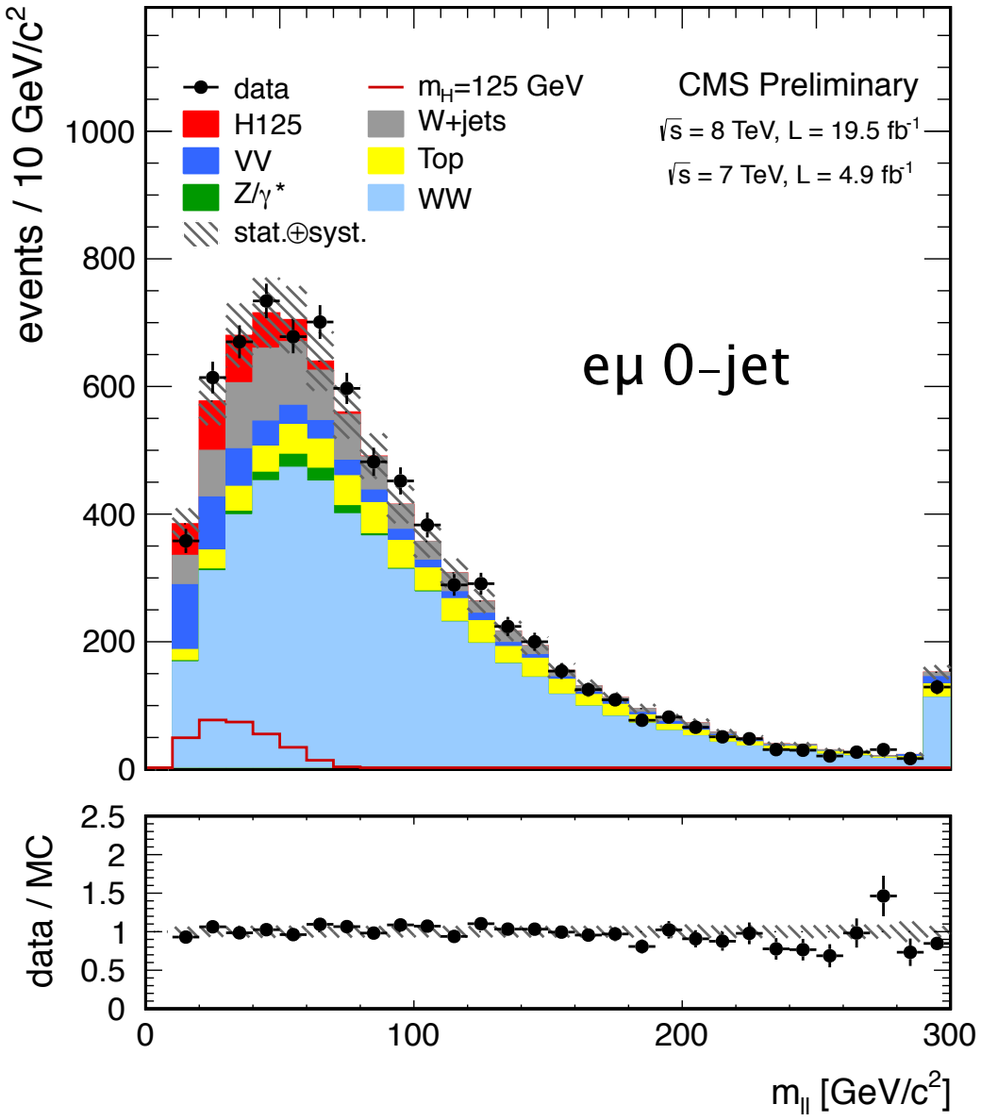
- WW → lνlν: CMS-PAS-HIG-13-003, web
- WW → lνqq: CMS-PAS-HIG-12-046 , web
- WH in trilepton: CMS-PAS-HIG-13-009, web
- VH → qq WW: CMS-PAS-HIG-12-014 , web
- VBF: CMS-PAS-HIG-12-042 , web

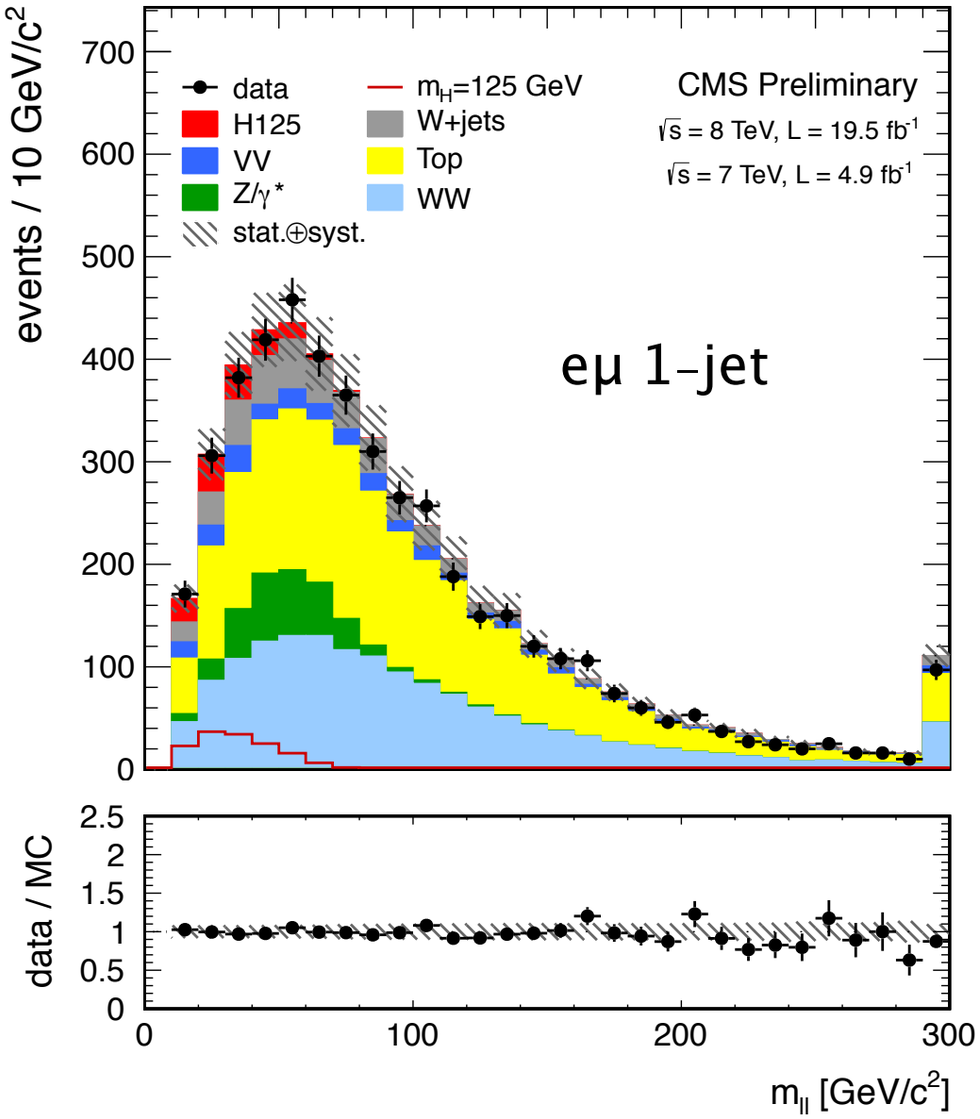
Upper Limits on σ





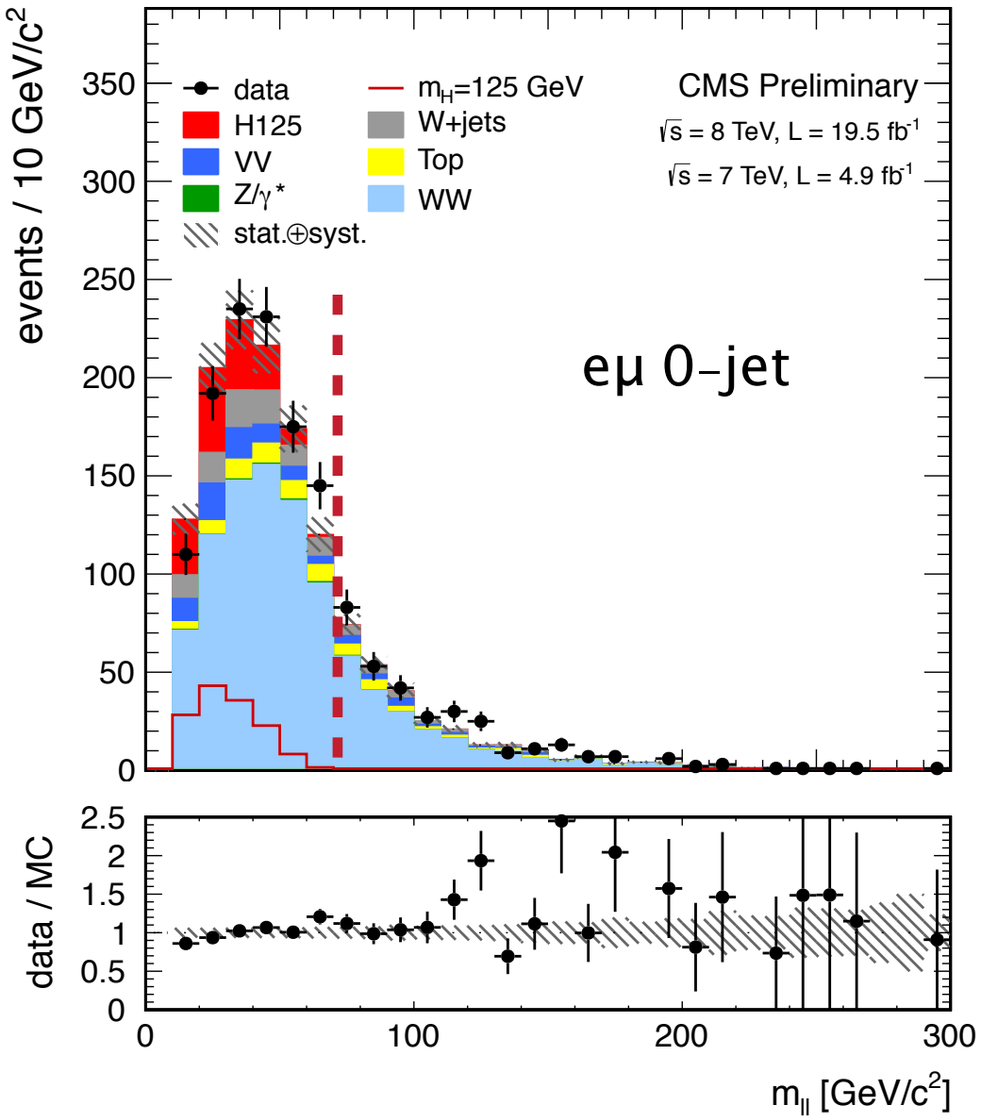
Events at Preselection

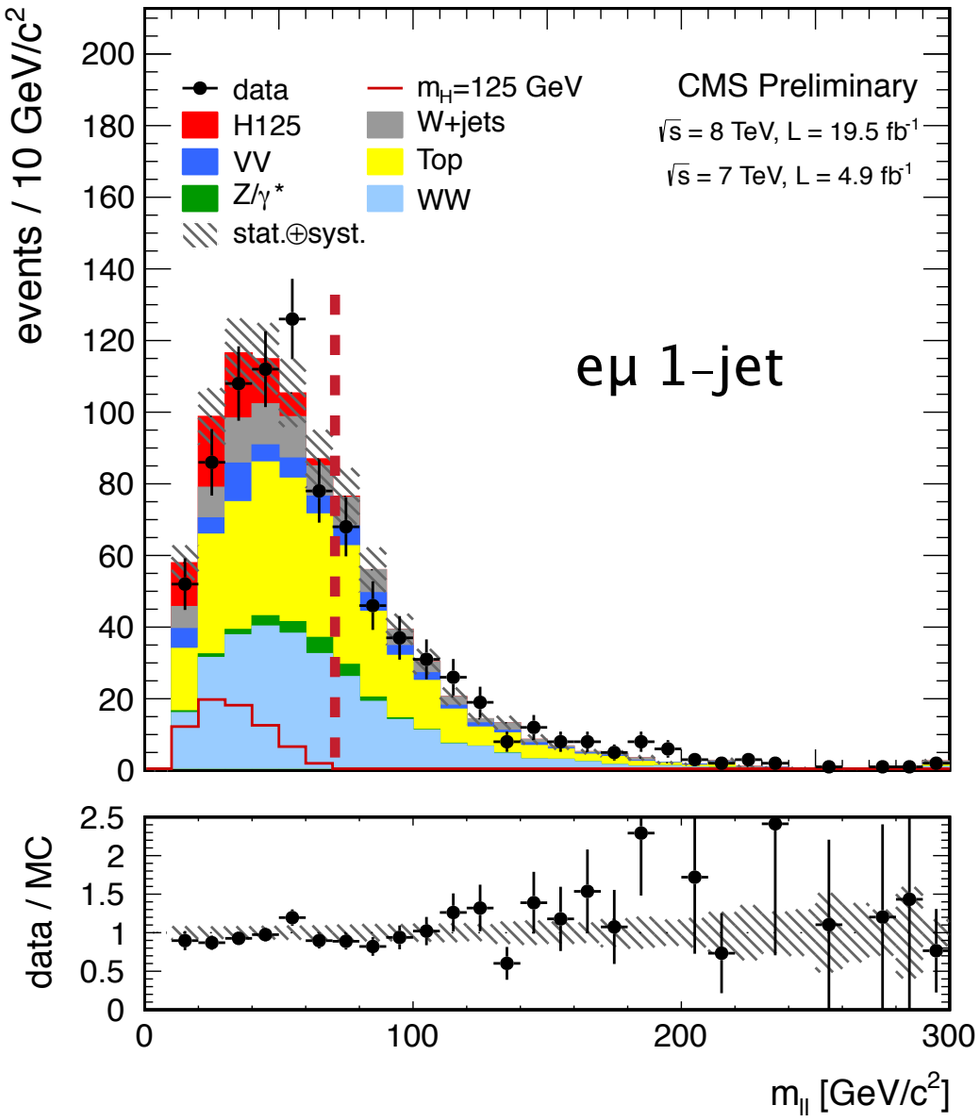




Distribution of dilepton invariant mass

Events at Cut-Based Final Selection





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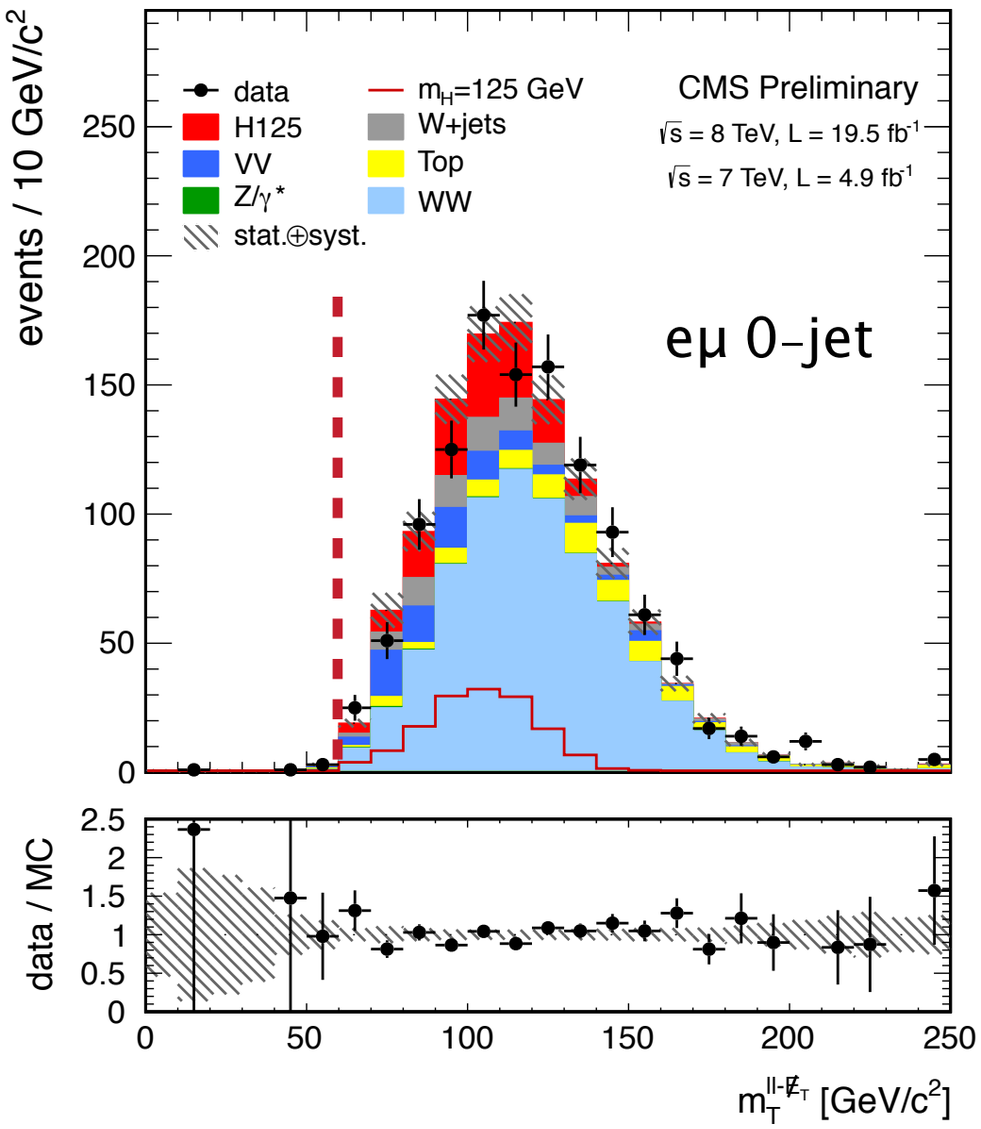
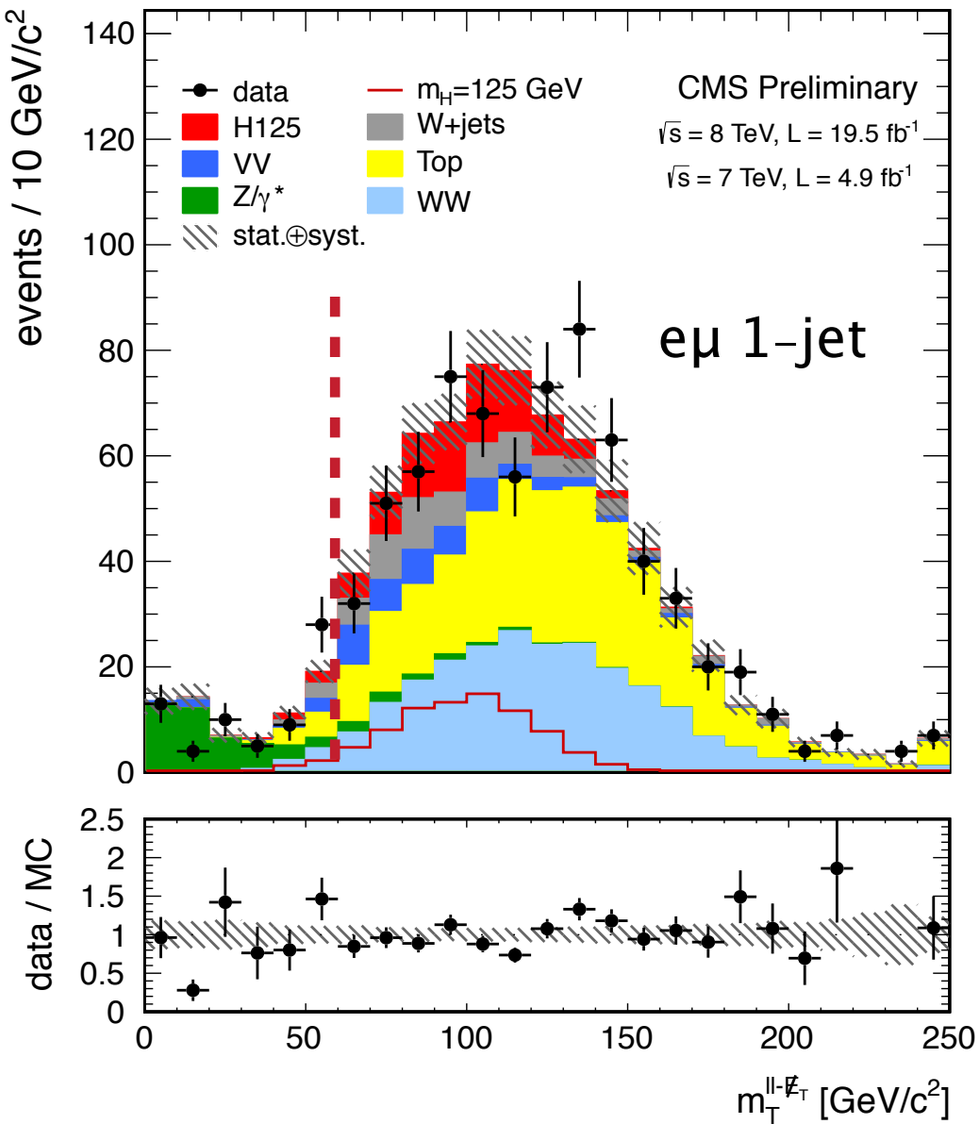


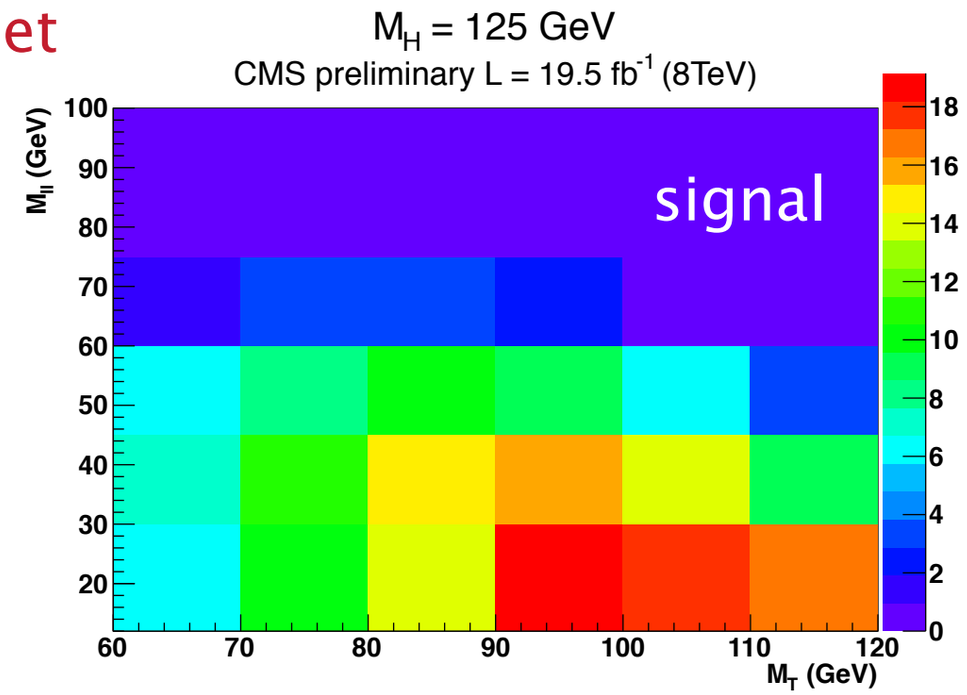


Distribution of transverse mass

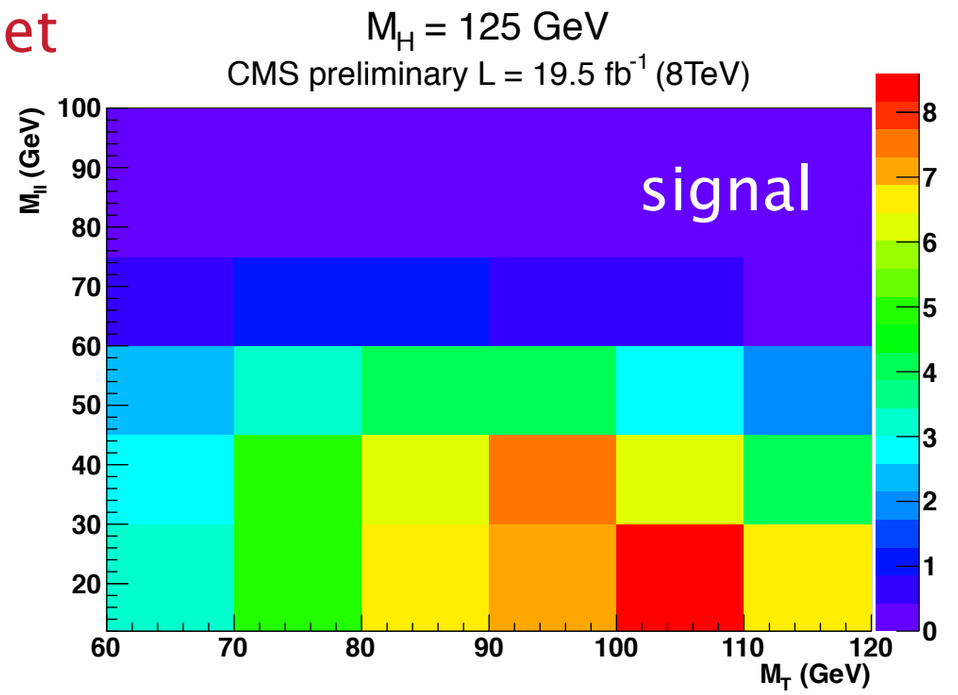
$$m_{\mathrm{T}}(\ell\ell,\mathrm{E}_{\mathrm{T}}^{\mathrm{miss}}) = [\ 2\ \mathrm{p}_{\mathrm{T}}^{\ell\ell}\ \mathrm{E}_{\mathrm{T}}^{\mathrm{miss}} \cos(\Delta\phi_{\ell\ell,E_{\mathrm{T}}^{\mathrm{miss}}})\ ]^{1/2}$$

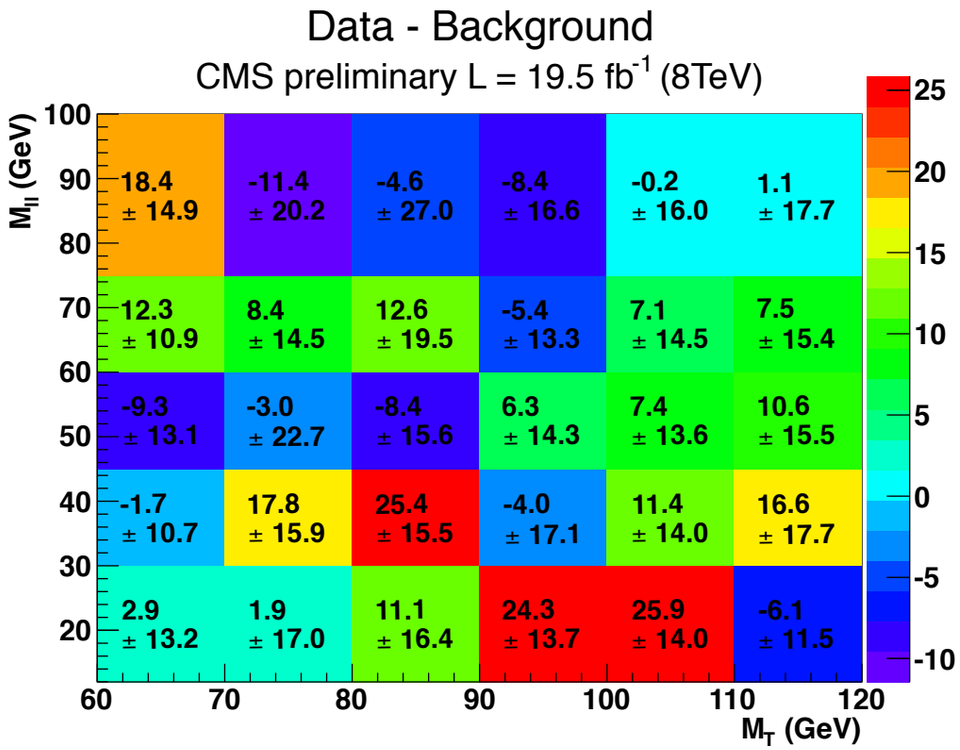
2D Template Fit

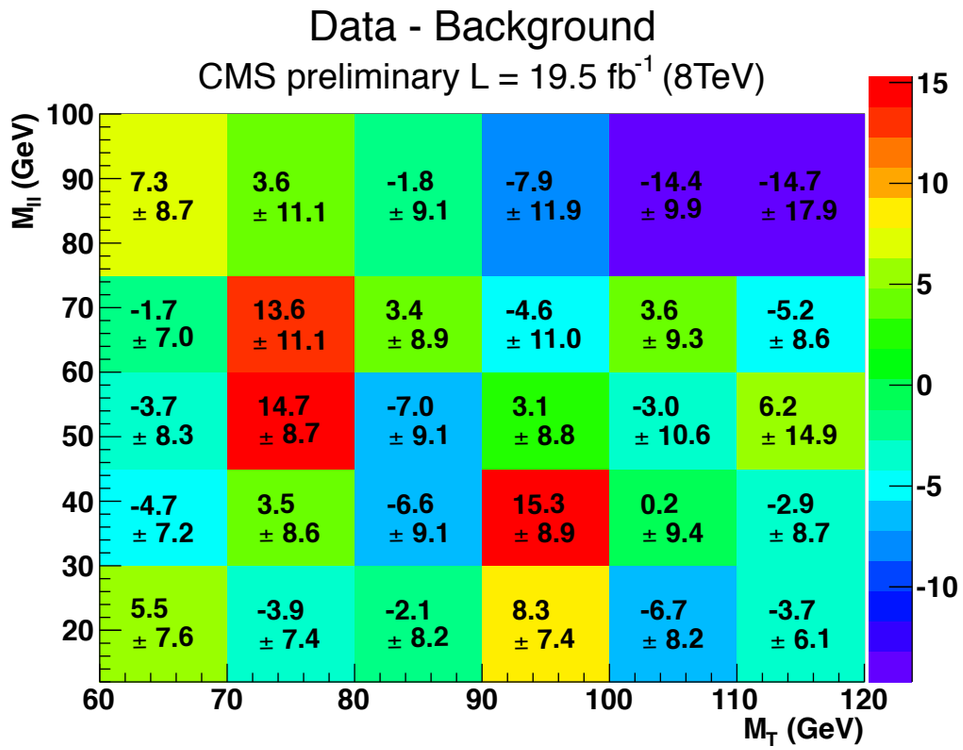
0-jet



1-jet







WW Template

Signal significance and best fit σ/σ_{SM} obtained using different generators for the WW background template

7+8 TeV data sample expected/observed significance		
MC@NLO	POWHEG	MADGRAPH
5.3/4.2	5.1/3.9	5.1/4.0

best fit value		
MC@NLO	POWHEG	MADGRAPH
0.82 ± 0.24	0.74 ± 0.21	0.76 ± 0.21

Shape uncertainties on WW template

- Renormalisation and factorisation scales
- PDF
- Generator (nominal = Madgraph, alternative = MC@NLO)