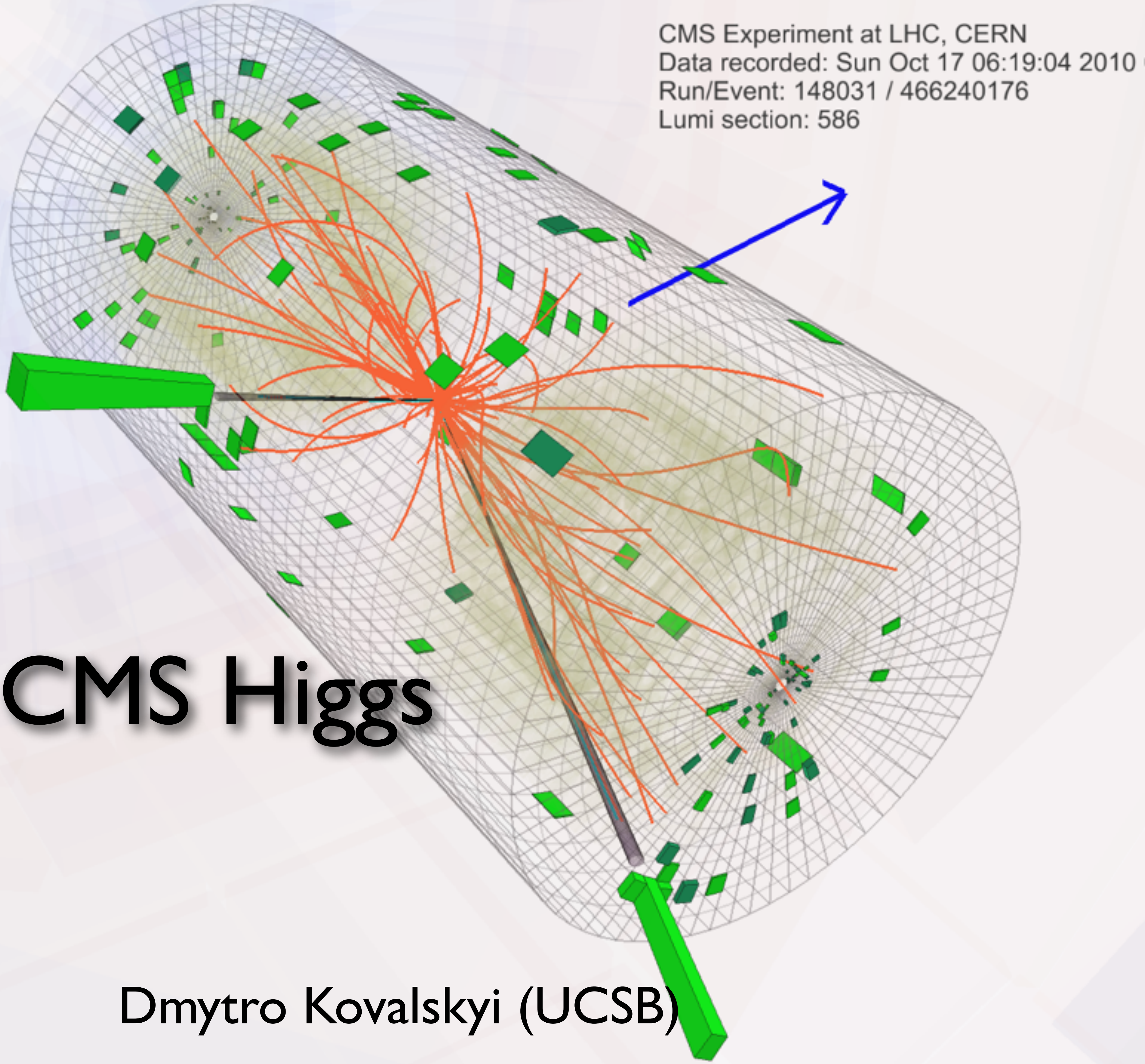
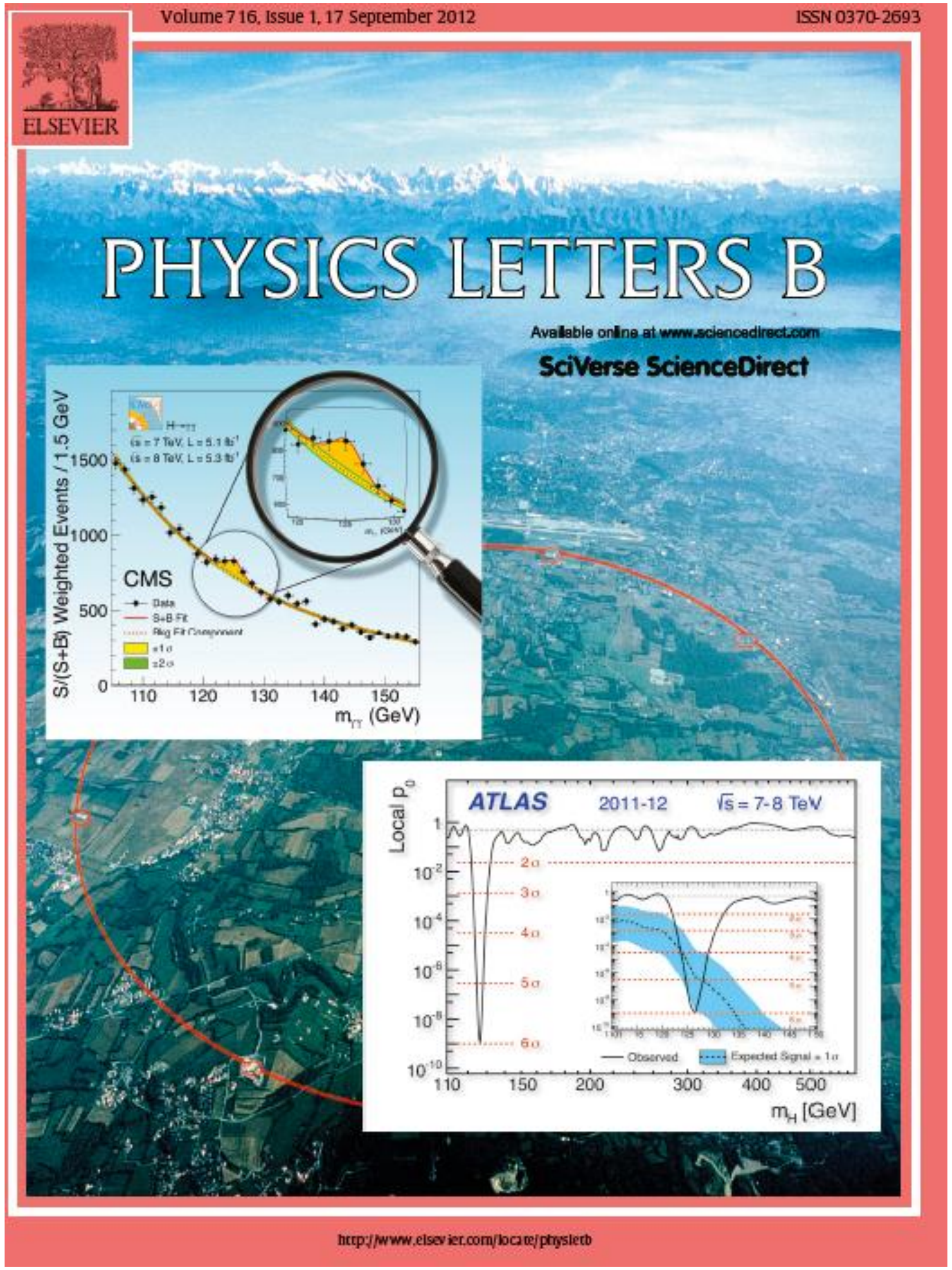
Latest CMS Higgs



Dmytro Kovalskyi (UCSB)

Discovery



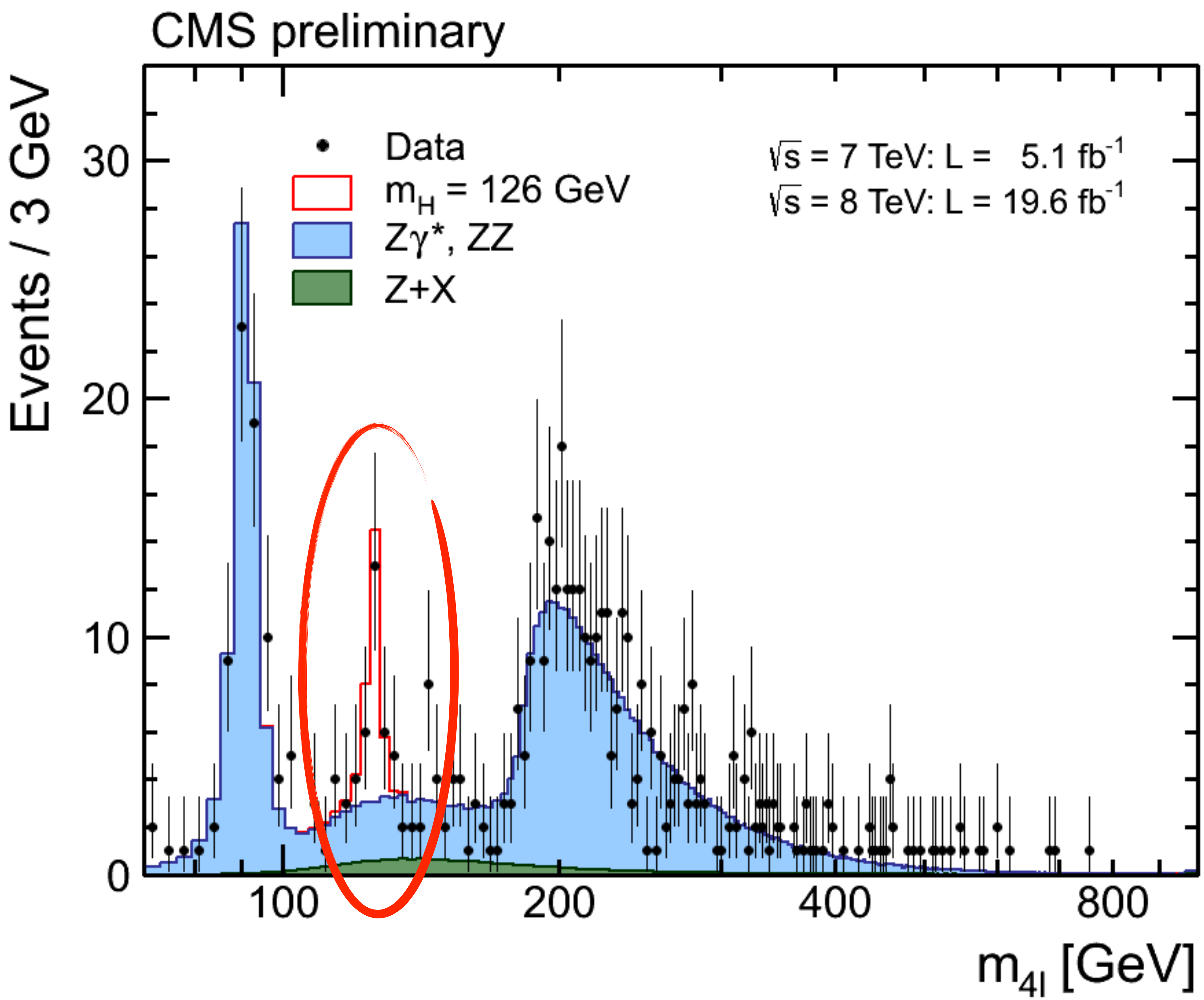
- New particle with ~125 GeV mass
- 5σ discovery claim from both ATLAS and CMS
- Tevatron: 2.9σ excess for Higgs from 115 to 130 GeV

$H \to ZZ \to 4\ell$

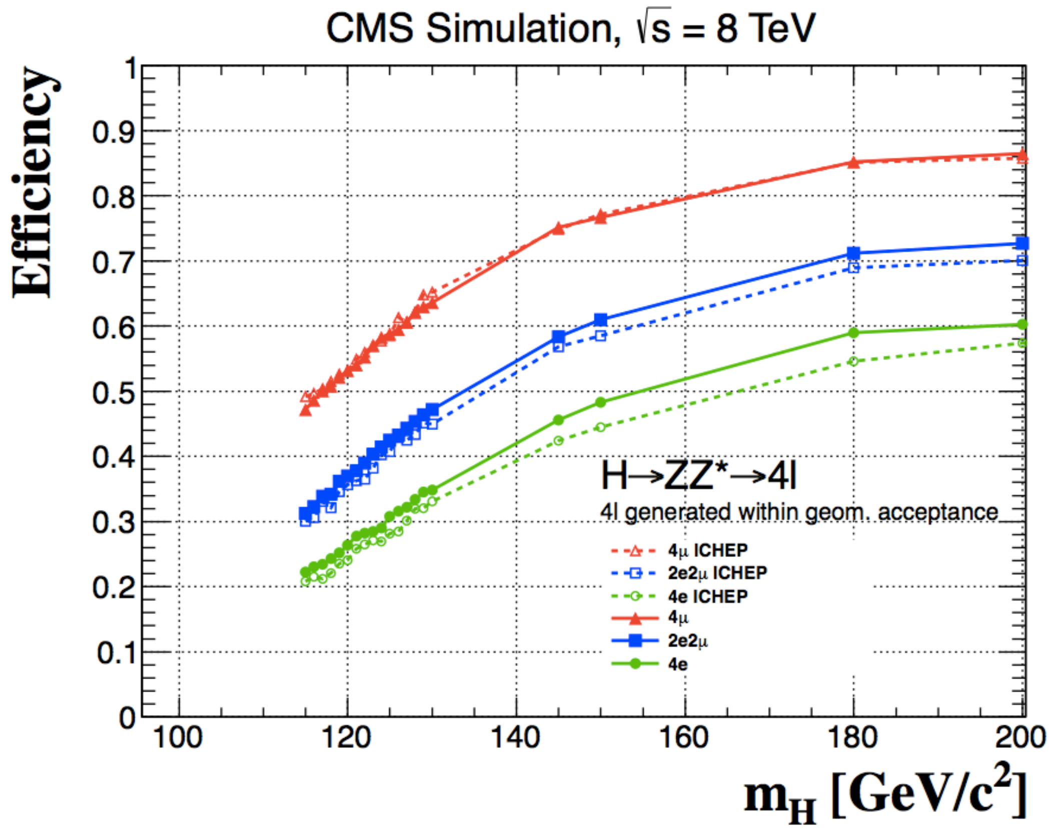
PAS (HIG-13-002): http://cdsweb.cern.ch/record/1523767

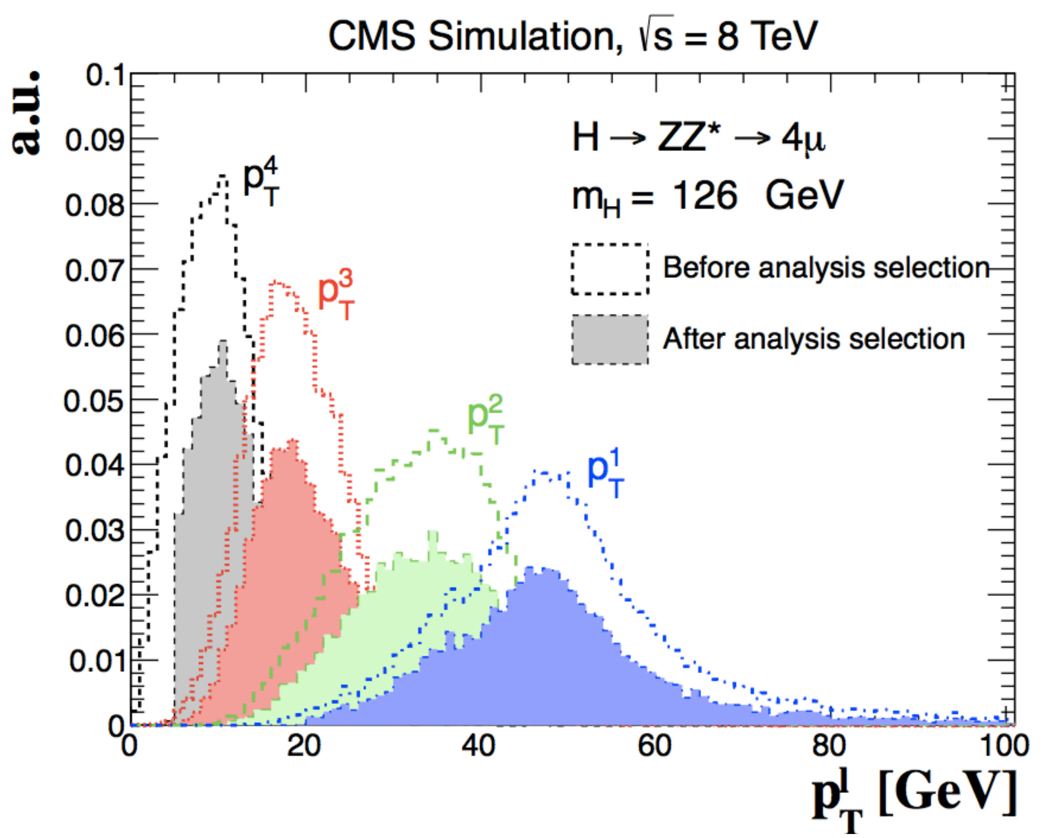
TWiki: https://twiki.cern.ch/twiki/bin/view/CMSPublic/Hig13002TWiki

Golden Channel - Signal is Strong



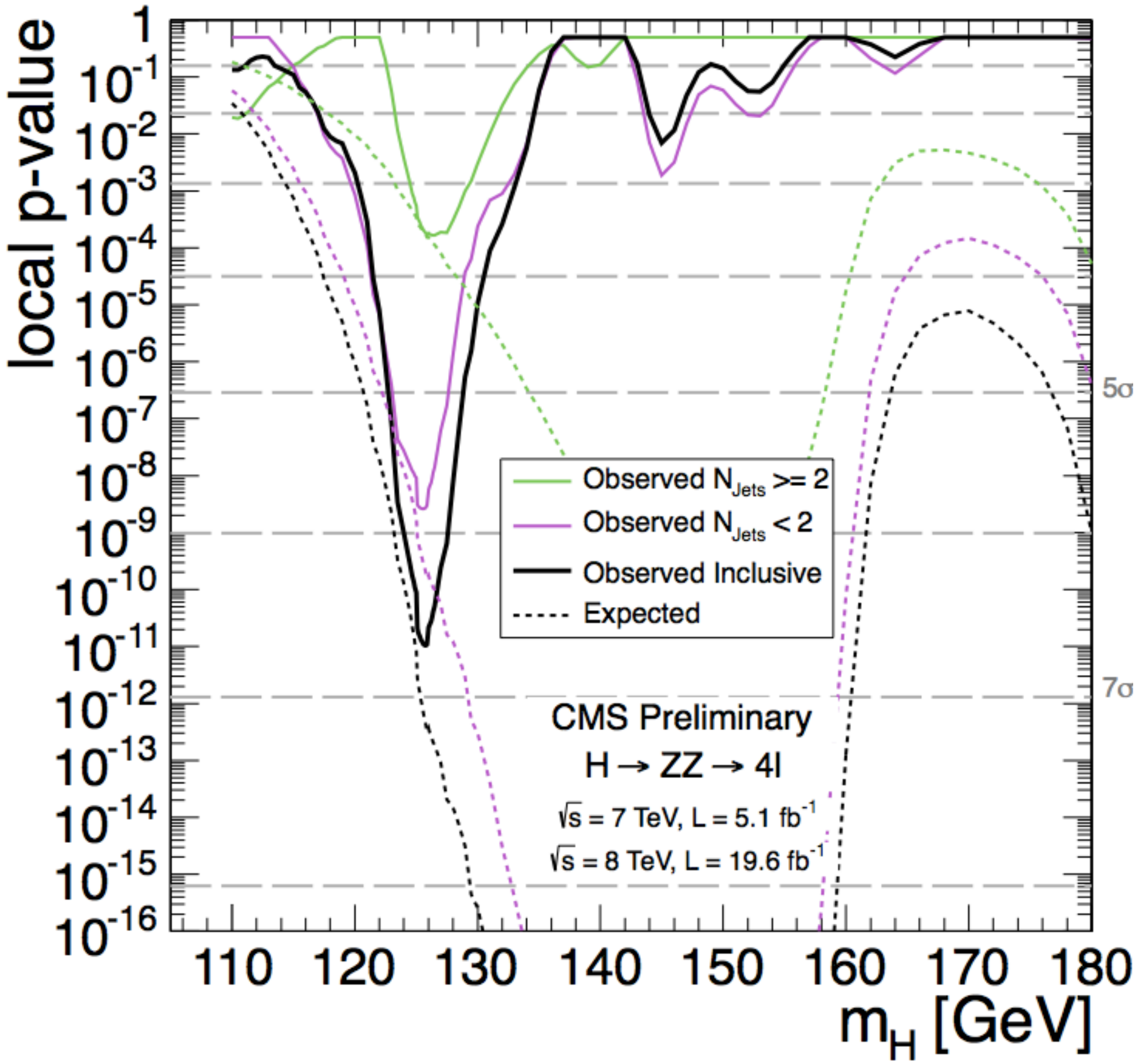
HZZ Analysis Details

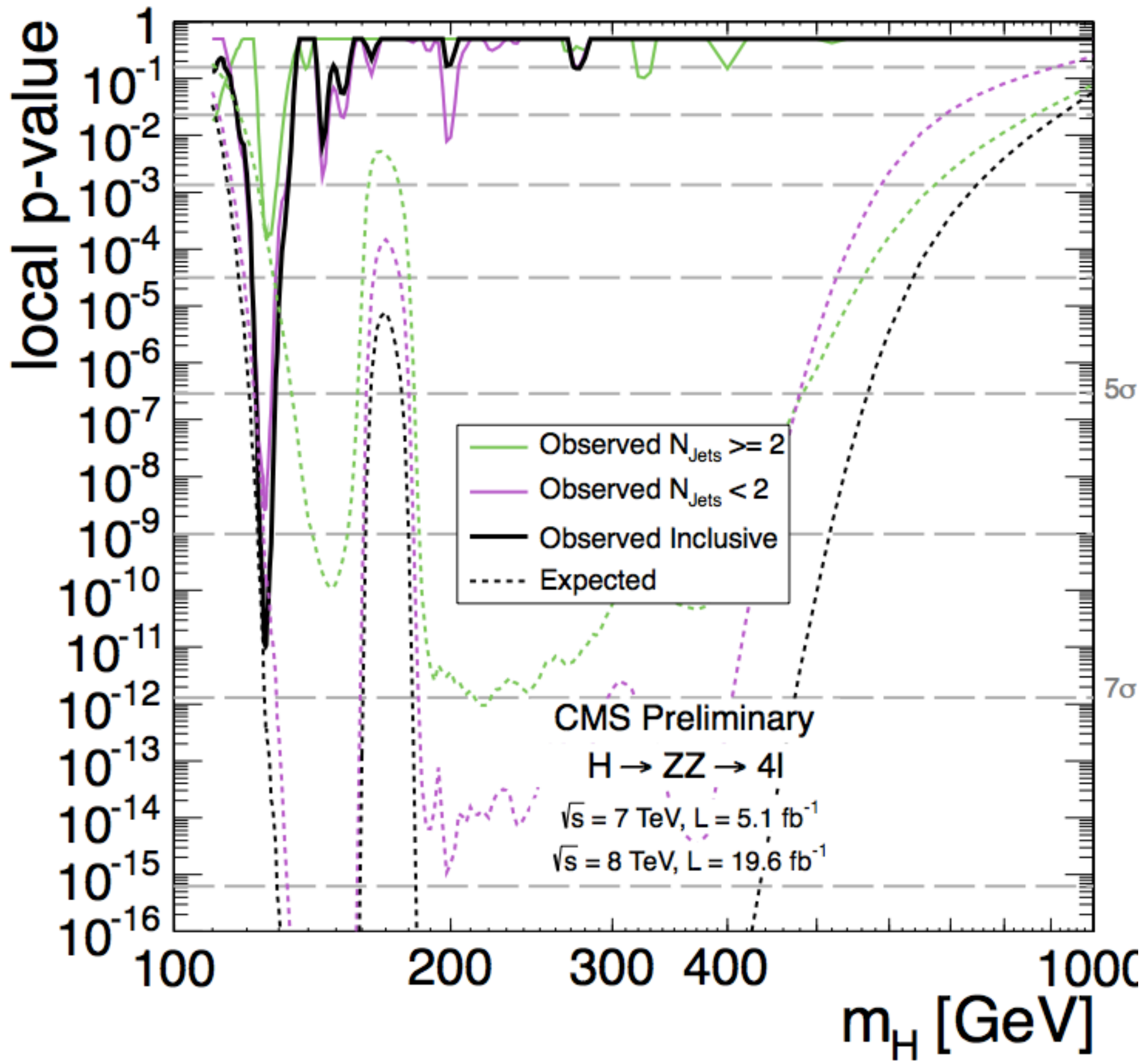




- New with respect to November 2012
  - event categorization based on jet multiplicity
    - probe qqH, VH and ttH production mechanisms
  - improved background estimation methods
- Selection requirements
  - Muon/electron min Pt: 5/7 GeV
  - mZ1∈[40,120] GeV; mZ2∈[12,120] GeV
  - Loose ID and isolation requirements
  - 3D impact parameter significance < 4
- Background estimations
  - ZZ, Zγ* - irreducible (from Monte Carlo)
    - POWHEG, Madgraph (alternative)
  - Z+fakes - reducible (data-driven methods)

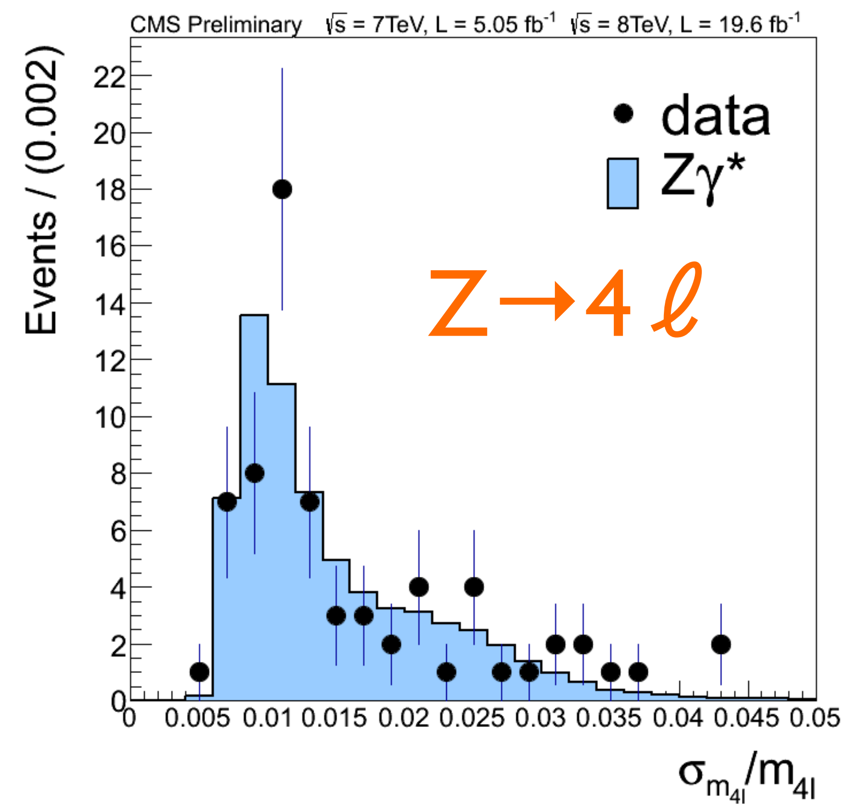
Signal Strength

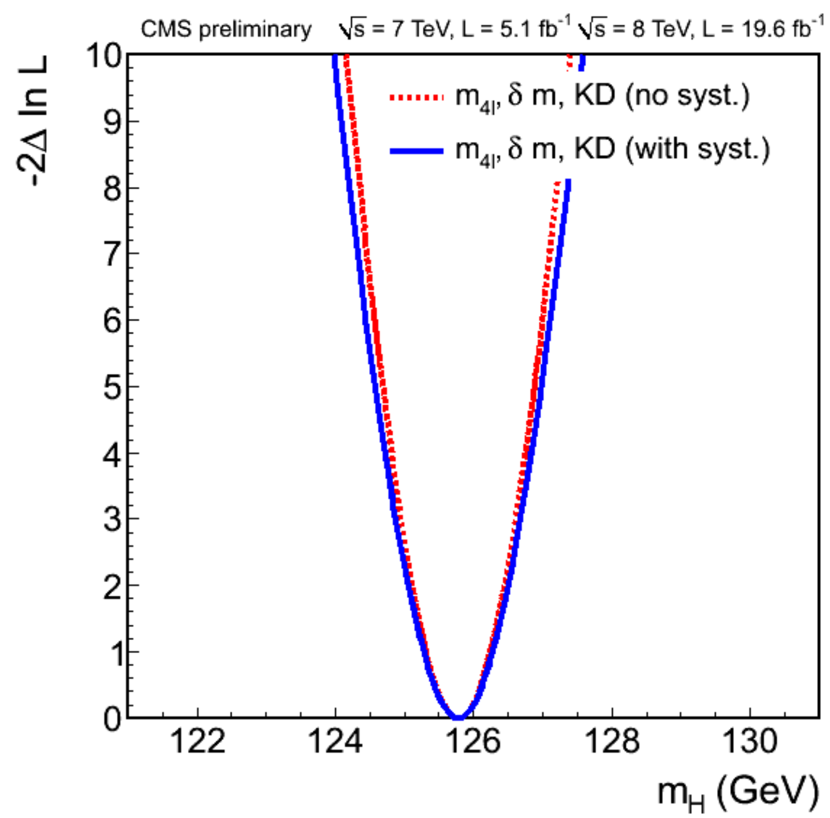


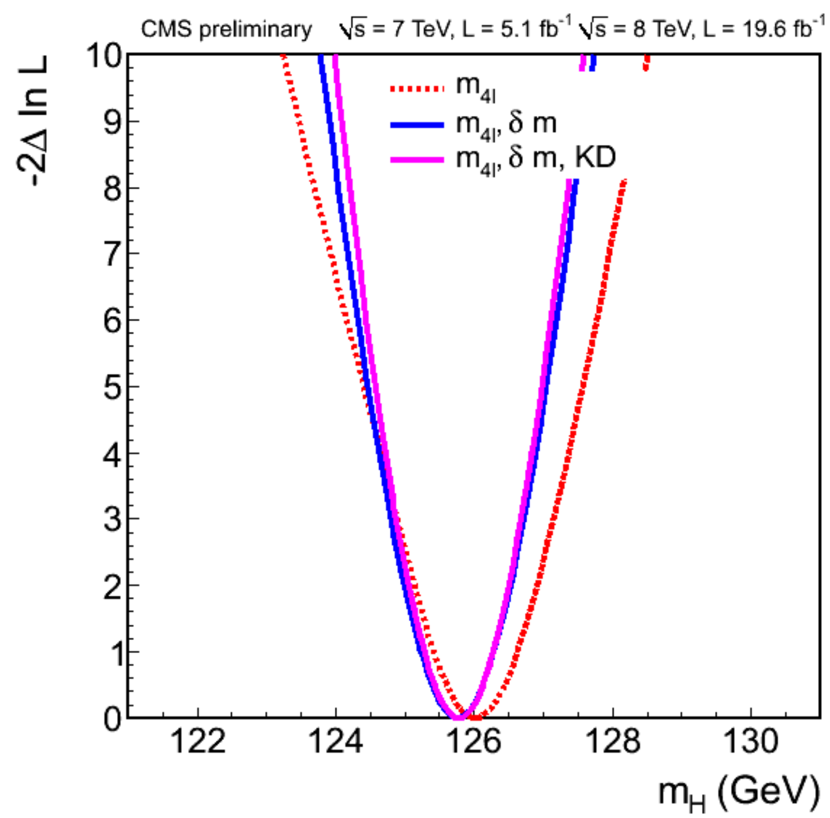


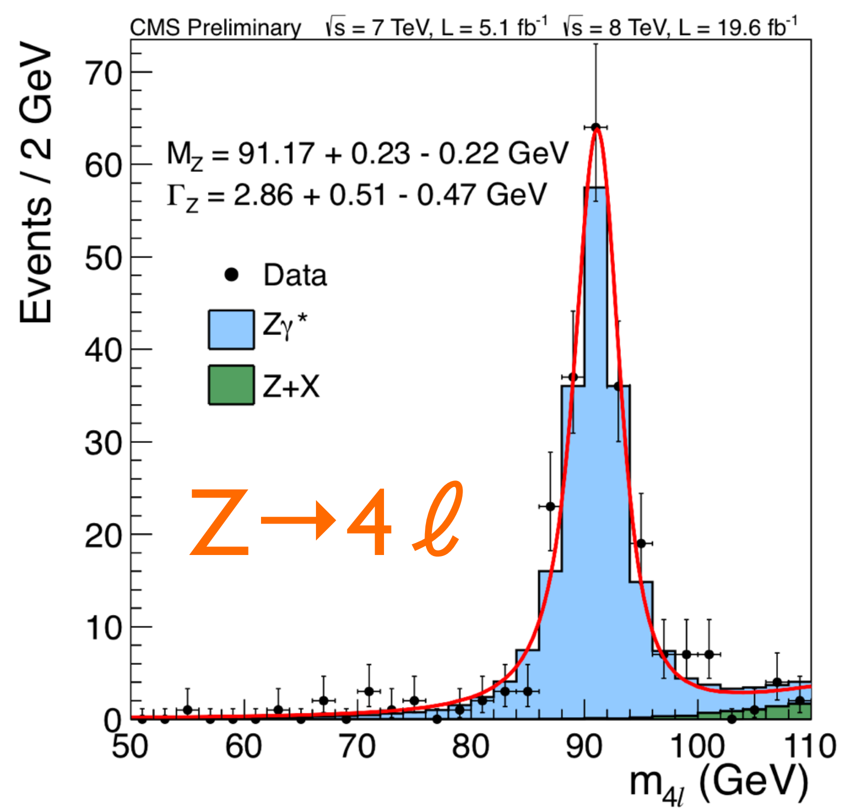
- Observed/expected signal significance: 6.7σ / 7.2σ
- Cross-section with respect to SM: σ/σ_{SM} = 0.91+0.30-0.24

Mass



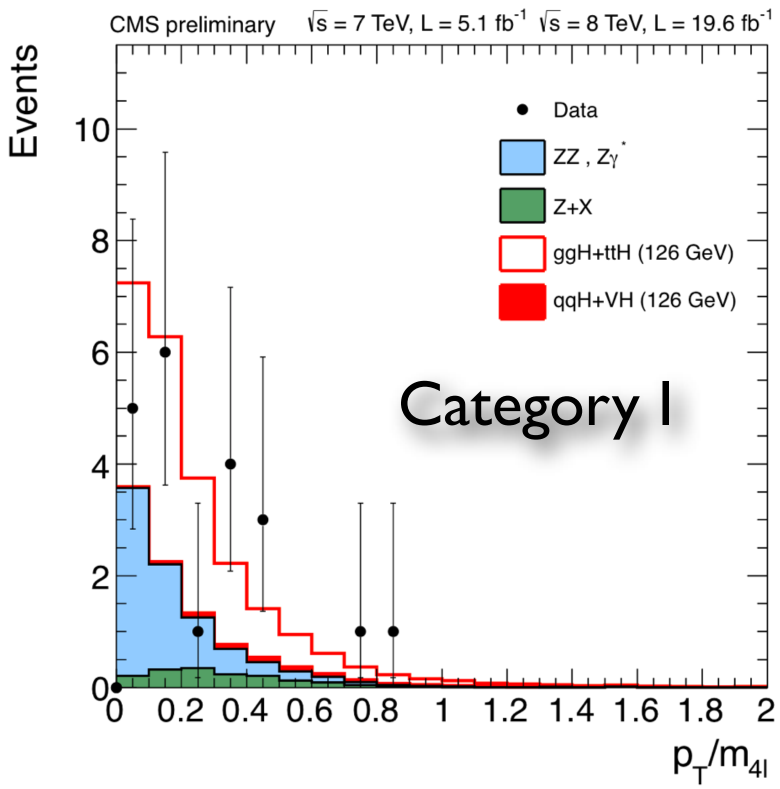


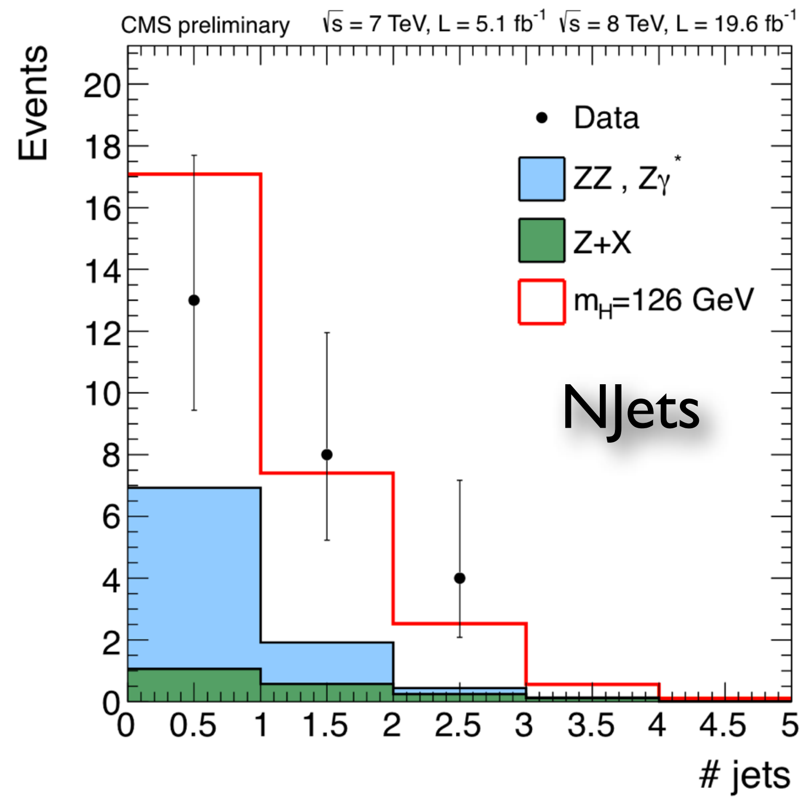


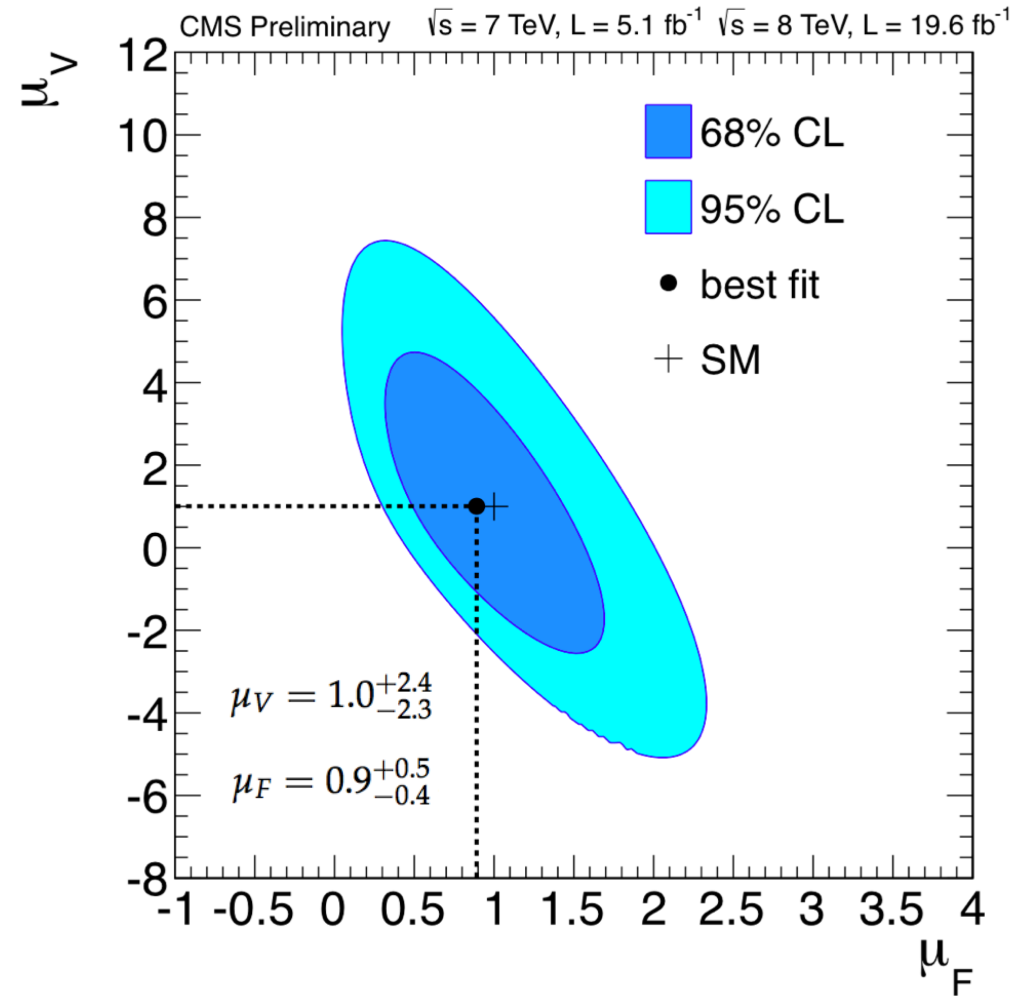


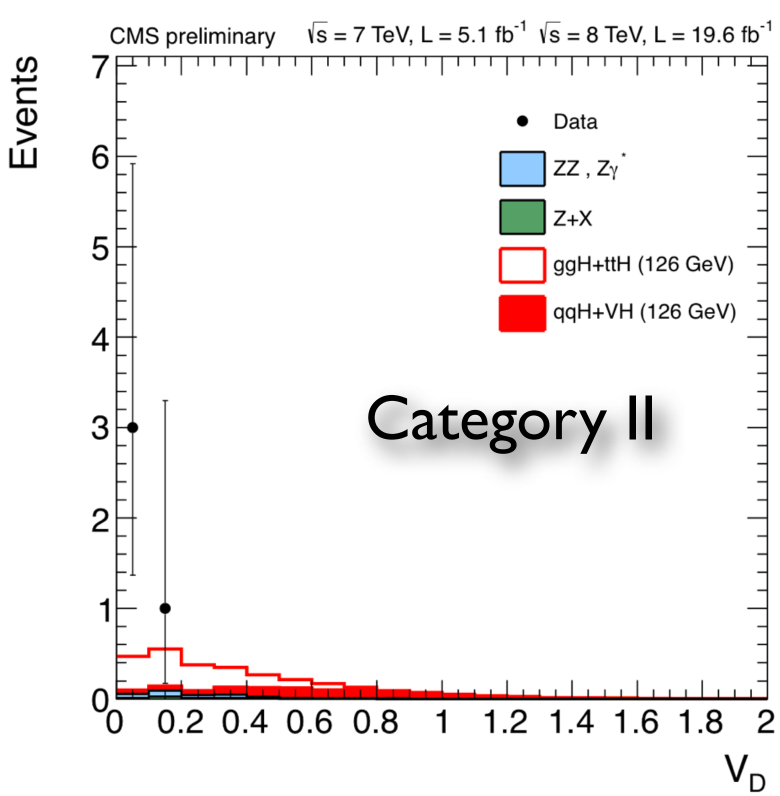
- Mass measurement inputs:
  - per-event $m_{4\ell}$
  - per-event mass error
  - kinematic discriminant
- m = 125.8 ± 0.5 (stat.) ±0.2 (syst.)

Higgs Production









- Higgs enriched distributions
  - m_{4l} in [121.5, 131.5] GeV, signal purity ~ 3:1
- Category I: Events with fewer than two jets
  - VBF contribution is 5%
- Category II: Events with at least two jets.
  - VBF contribution is 20%

Hypothesis Testing

Table 3: List of models used in analysis of spin-parity hypotheses corresponding to the pure states of the type noted. The expected separation is quoted for two scenarios, when the signal strength for each hypothesis is pre-determined from the fit to data and when events are generated with SM expectation for the signal yield (μ=1). The observed separation quotes consistency of the observation with the 0^+ model or J^P model, and corresponds to the scenario when the signal strength is pre-determined from the fit to data. The last column quotes CL_s criterion for the J^P model.

J^P	production	comment	expect (μ=1)	obs. 0^+	obs. J^P	CL_s
0^-	$gg \to X$	pseudoscalar	2.6σ (2.8σ)	0.5σ	3.3σ	0.16%
0_h^+	$gg \to X$	higher dim operators	1.7σ (1.8σ)	0.0σ	1.7σ	8.1%
2_{mgg}^+	$gg \to X$	minimal couplings	1.8σ (1.9σ)	0.8σ	2.7σ	1.5%
$2_{mq\bar{q}}^+$	$q\bar{q} \to X$	minimal couplings	1.7σ (1.9σ)	1.8σ	4.0σ	$<0.1\%$
1^-	$q\bar{q} \to X$	exotic vector	2.8σ (3.1σ)	1.4σ	$>4.0\sigma$	$<0.1\%$
1^+	$q\bar{q} \to X$	exotic pseudovector	2.3σ (2.6σ)	1.7σ	$>4.0\sigma$	$<0.1\%$

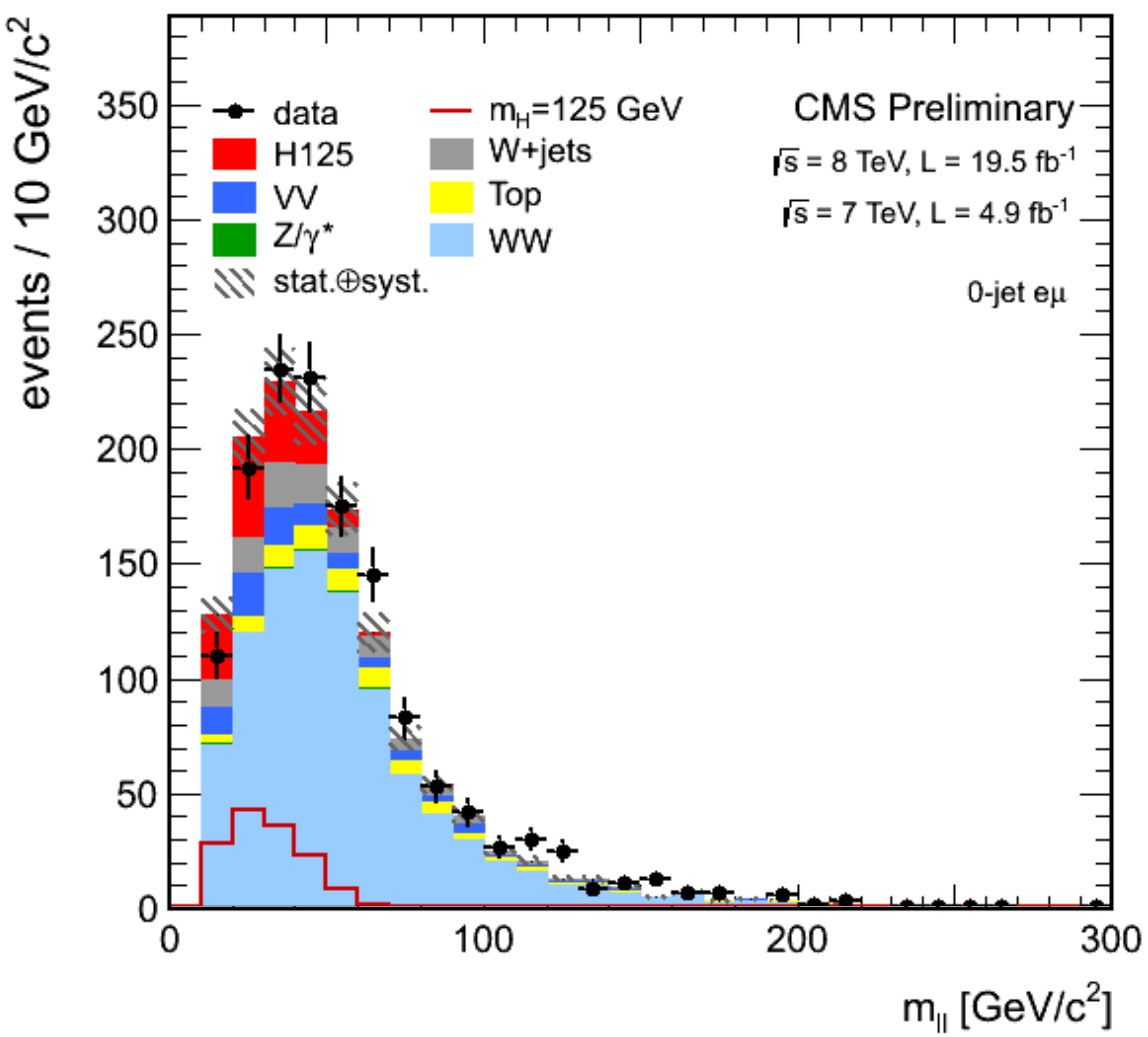
All results are consistent with SM

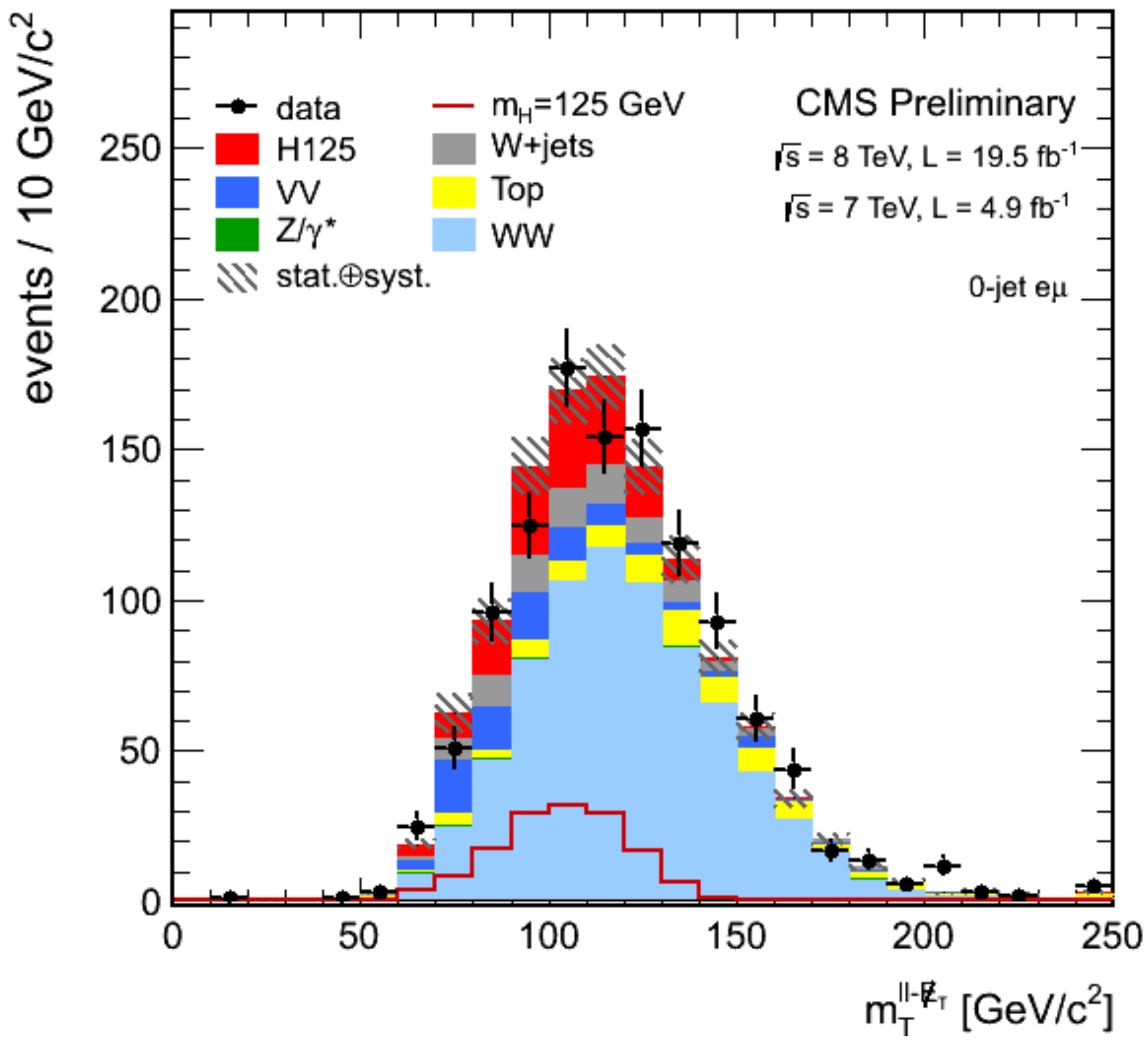
$H \rightarrow WW \rightarrow 2\ell 2\nu$

PAS (HIG-13-003): http://cdsweb.cern.ch/record/1523673

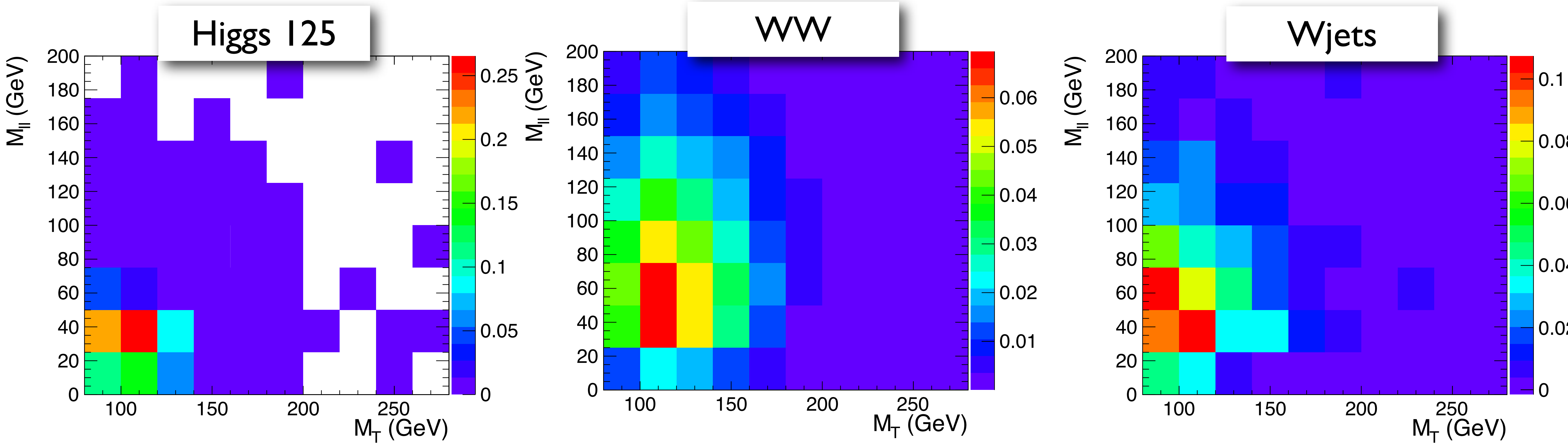
TWiki: https://twiki.cern.ch/twiki/bin/view/CMSPublic/Hig13003TWiki

Higgs→WW→2 ℓ 2ν



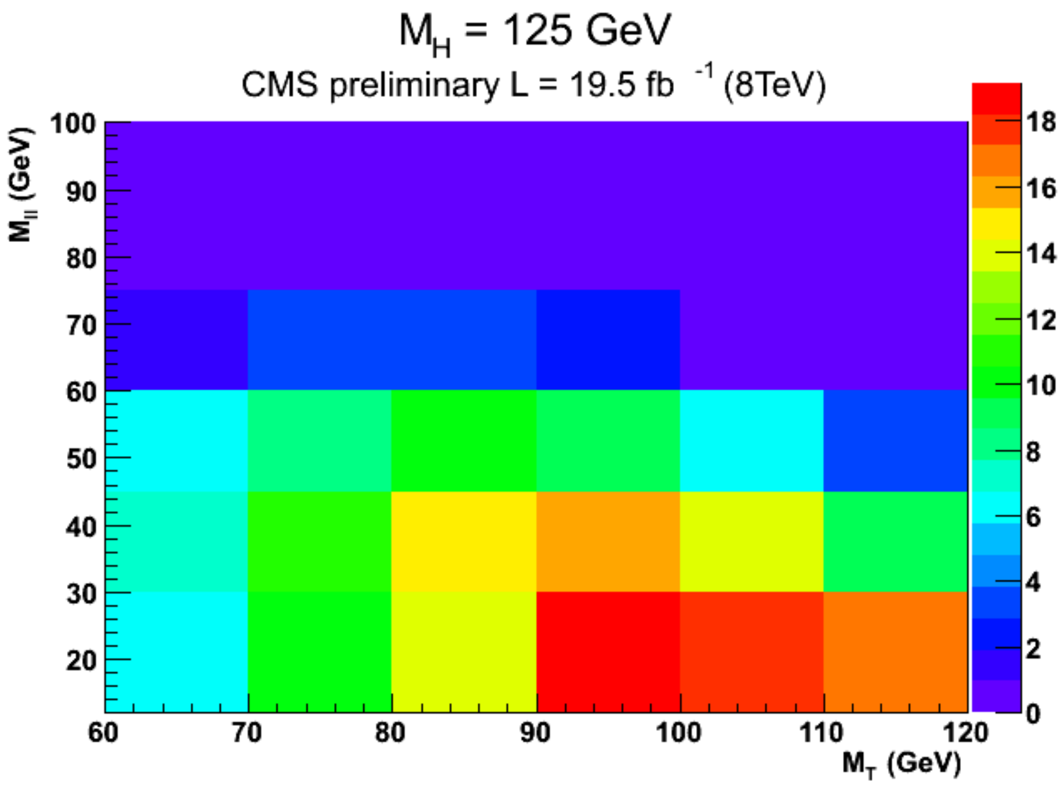


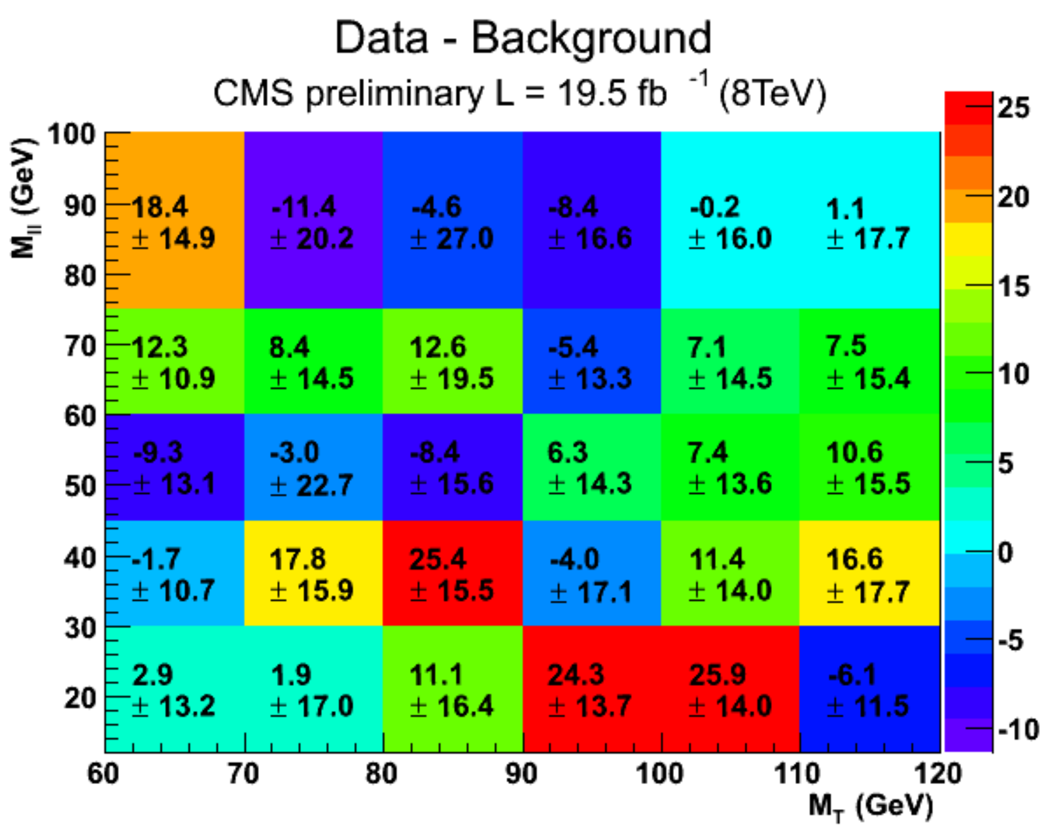
- No mass peak due to undetected neutrinos (effectively a counting experiment)
- Proper estimation of backgrounds is vital (data driven for more reliable results)
- Dominant backgrounds: WW, top, W+jets and Z+jets
- Events are categorized by number of jets and lepton final states (ee + μμ, eμ)

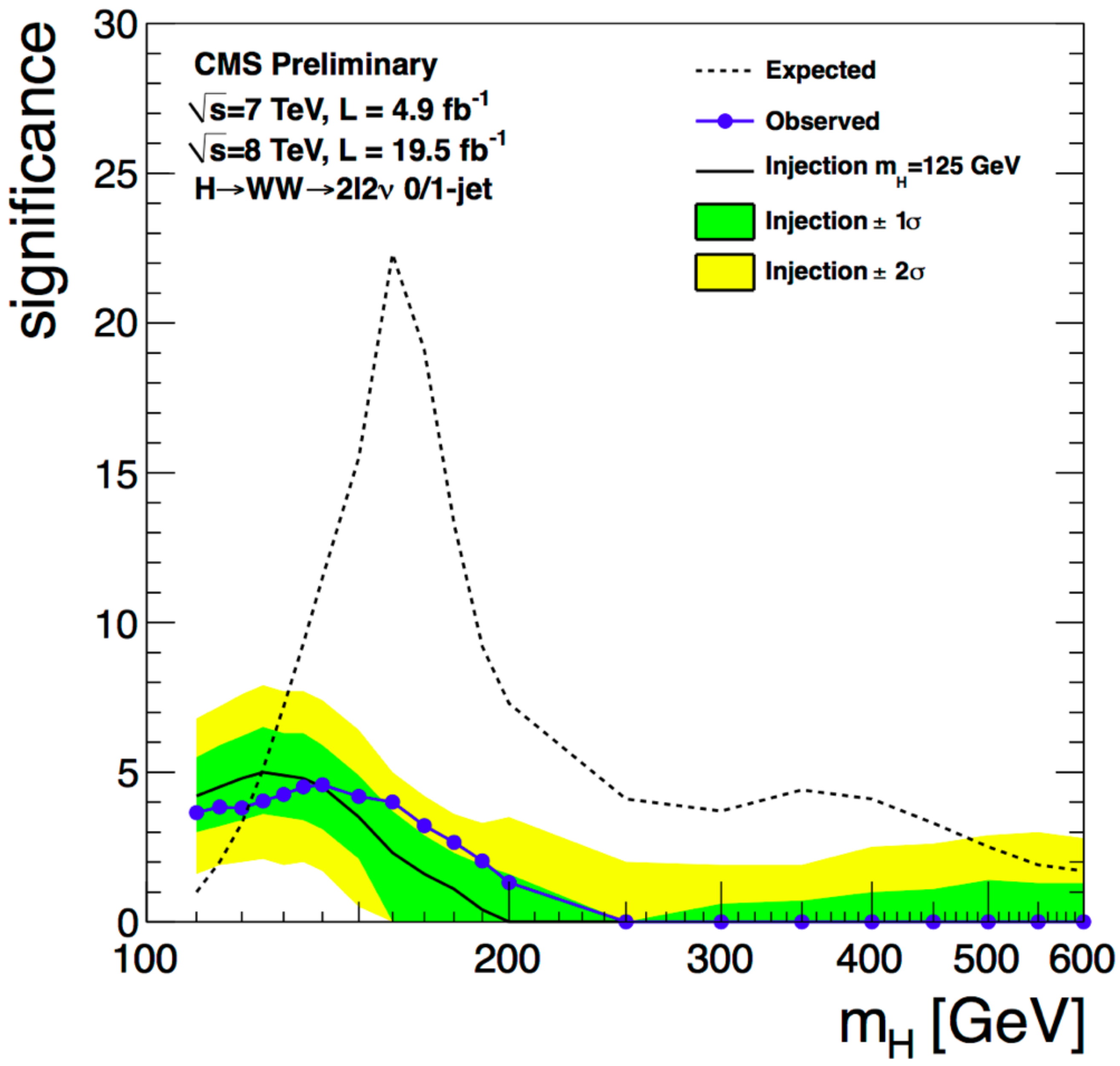


- Selection
  - Leading/trailing lepton Pt: 20/10 GeV
  - Stringent lepton identification
  - min(projected MET, projected track MET) > 20 GeV for eμ
  - DY MVA for ee/μμ
- 2D shape analysis (mll vs mT)
  - optimal sensitivity for low mass Higgs
  - straight-forward interpretation of data
- Nothing fundamentally new with respect to November 2012 update

Signal Strength

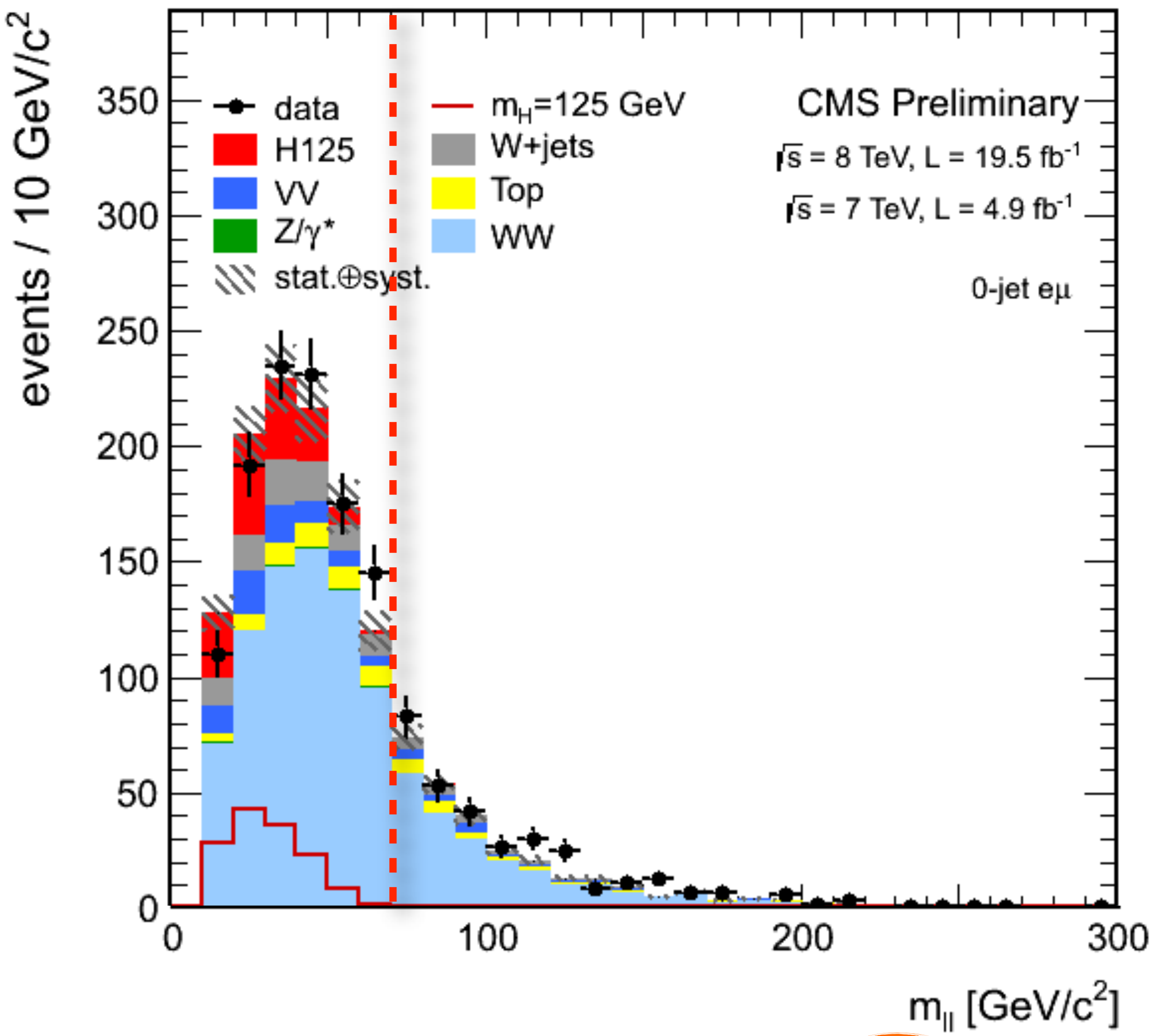






- $\mu(125) = 0.76 \pm 0.13$ (stat.) ± 0.16 (syst.)
- Signal Significance (exp/obs): 5.1σ / 4.0σ

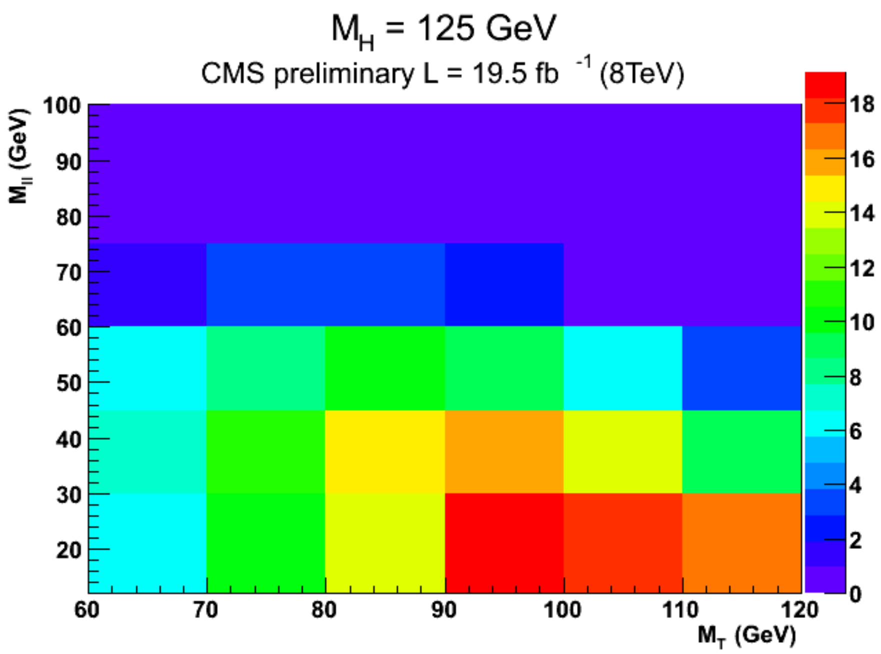
WW Background

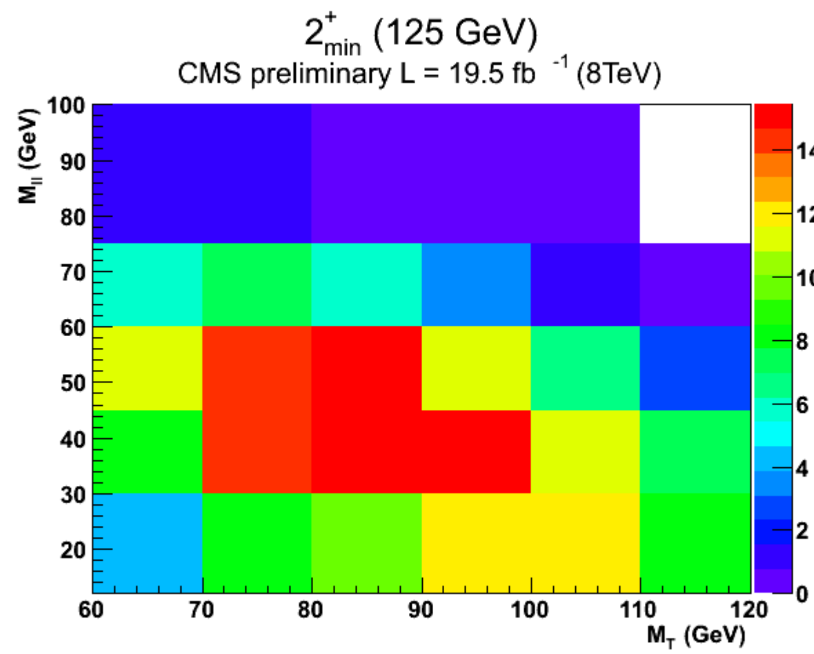


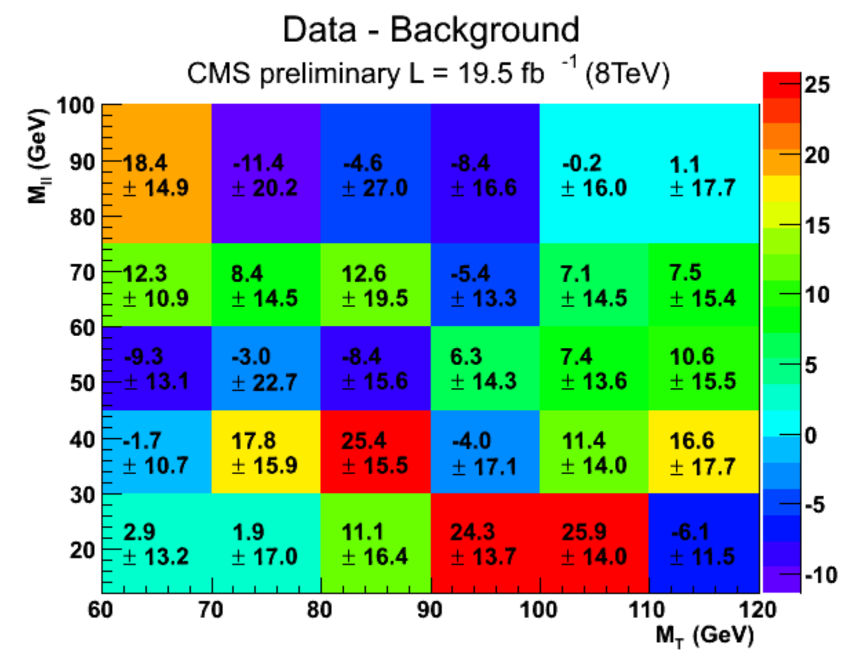
7+8 TeV data sample expected/observed significance		
MC@NLO	POWHEG	MADGRAPH
5.3/4.2	5.1/3.9	5.1/4.0
best fit value		
MC@NLO	POWHEG	MADGRAPH
0.82 ± 0.24	0.74 ± 0.21	0.76 ± 0.21

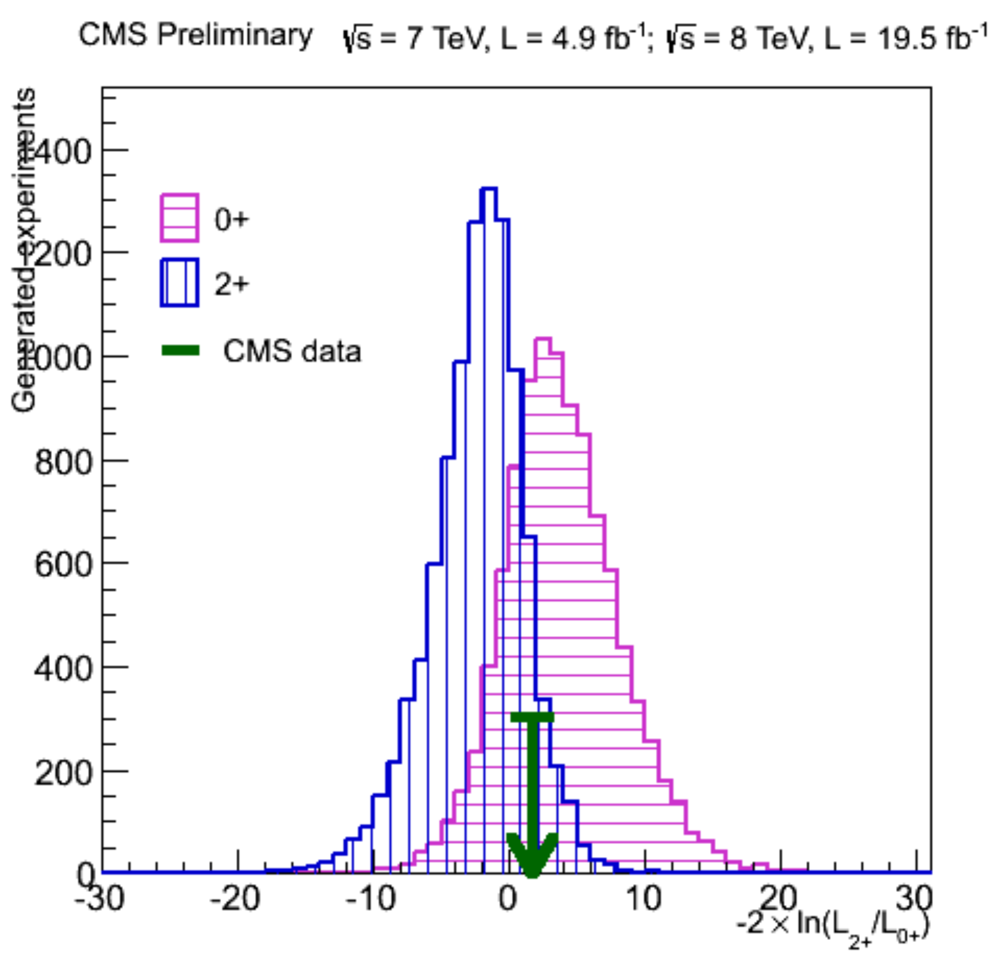
- WW background estimation is critical
  - Rely on Monte Carlo to reproduce m_{ll}
- CMS cut-based and ATLAS default analyses use high m_{ll} region to predict WW in signal region
  - The ratio N_{low}/N_{high} has theory uncertainty ~10%
    - Dominant systematics limiting sensitivity
  - B. Holdom (arXiv:1211.2729) points our significant difference in the ratio of m_{ll} in [10-50] over m_{ll} in [80,290]:
    - MCFM: 0.555, MC@NLO-Herwig6: 0.55, POWHEG-Pythia6: 0.60, Herwig++@NLO: 0.625
- CMS shape analysis relies on the shape
  - Fit can vary the shape within the uncertainty bounds
  - Data allows to constrain the shape in regions where WW dominates
    - Less extrapolation is needed→small systematics
- Cross-check - compare results using different shapes
  - The results are very stable (well within systematic uncertainties)

Spin Analysis



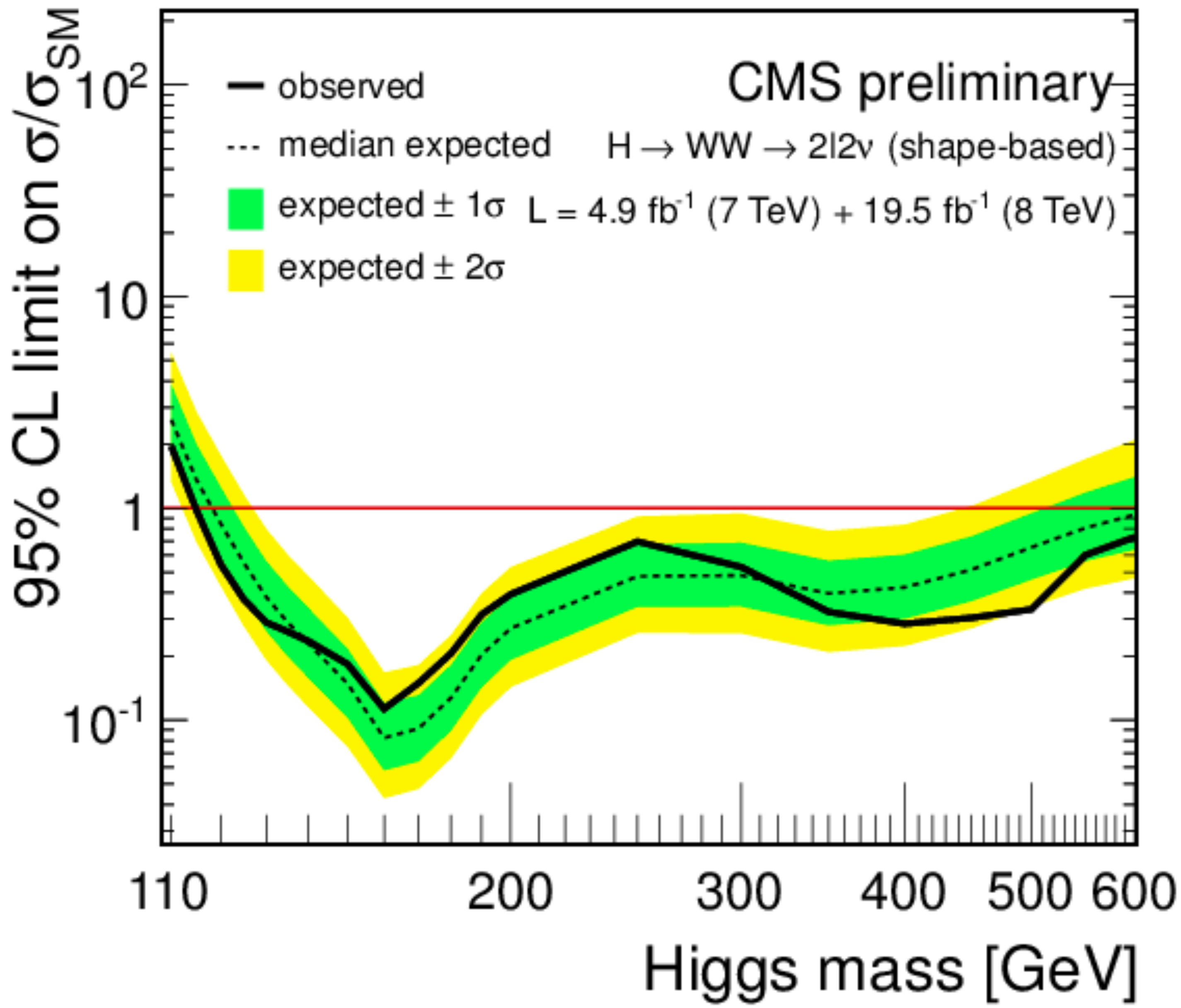






- HWW analysis is designed in a way to easily accommodate spin2 hypothesis testing
  - The analysis is sensitive only to minimal couplings spin2
- Expected separation for μ=1 - 2.4σ
- For observed signal strength
  - Expected separation of Spin2 from SM: 1.8σ
  - Observed separation of Spin2 from SM: 1.3σ
- Result is consistent with HZZ results

Search for extra Higgs like particles



- Search for second SM Higgs like particle
- Treat the observed boson as a SM background
- No evidence for new particle is found

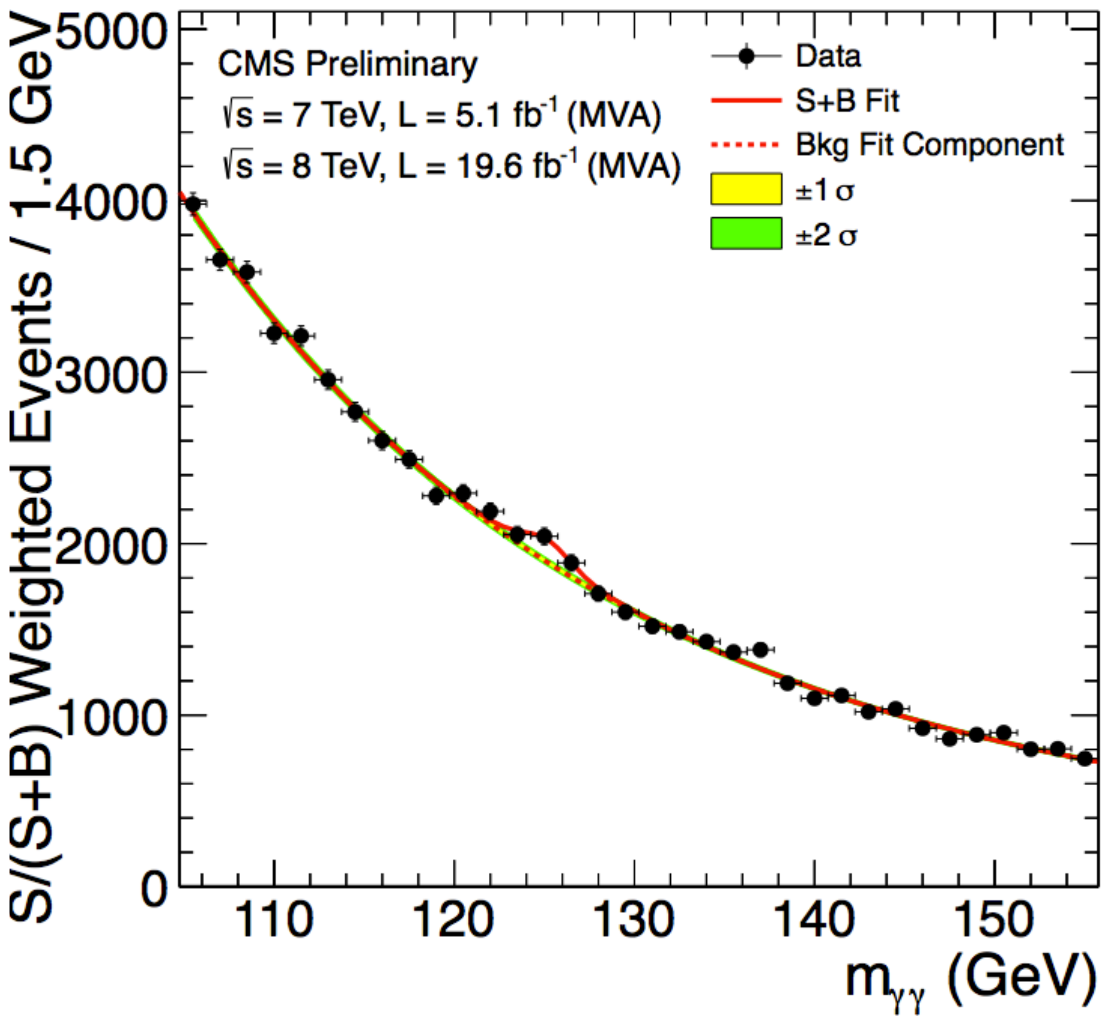
$H \rightarrow \gamma\gamma$

No public documentation yet

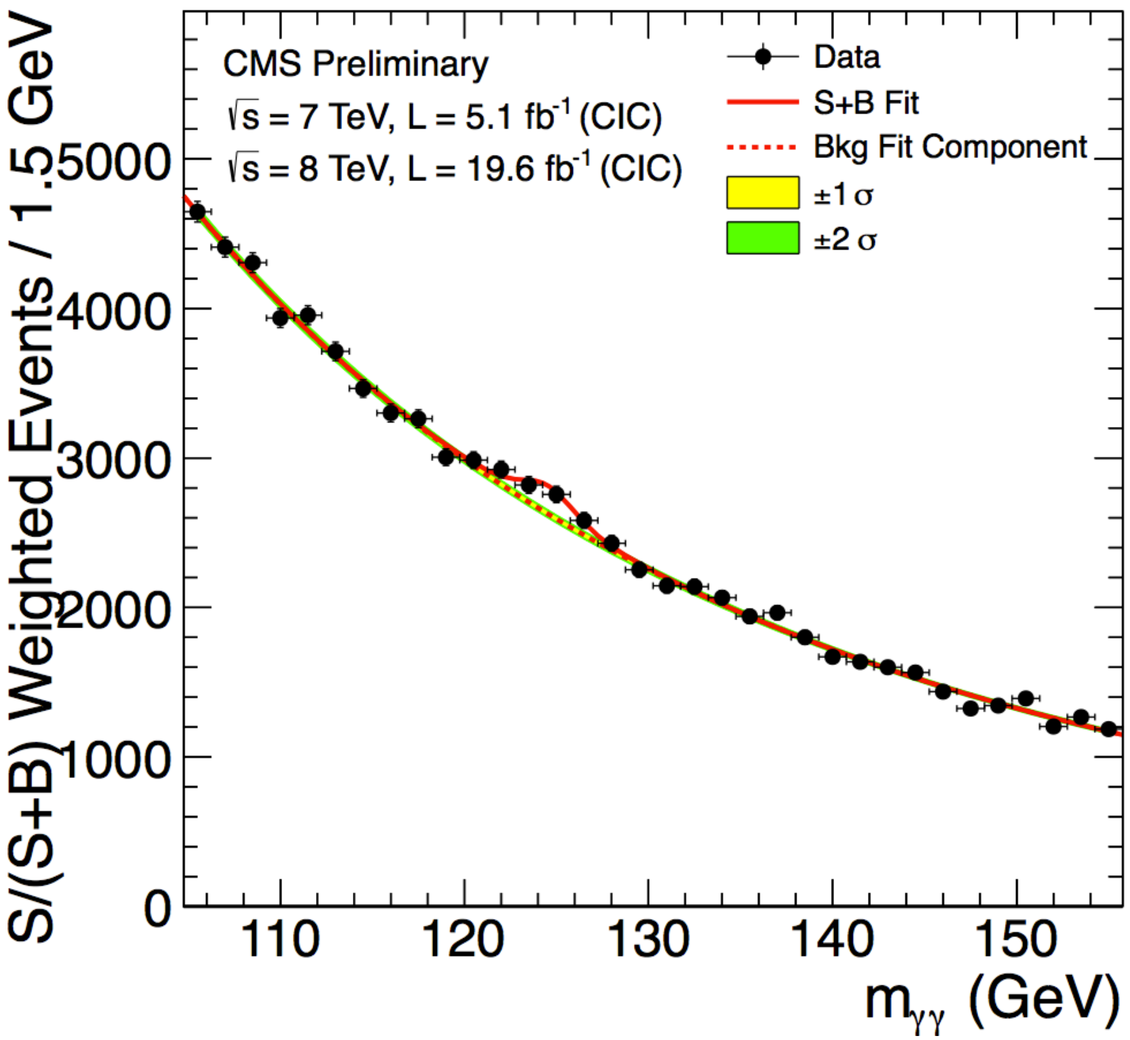
Morion Talk: http://moriond.in2p3.fr/QCD/2013/ThursdayMorning/Ochando.pptx

Higgs to γγ

MVA analysis
(default)



Cut-based analysis
(cross-check)



- Signature: two isolated energetic photons
- Photon Pt: $m_{\gamma\gamma}/3$ / $m_{\gamma\gamma}/4$ GeV
  - for $m_{\gamma\gamma}$=120: 40/30 GeV

$H\gamma\gamma$ Analysis Details

- Signal extraction:
  - Split events in categories
    - First tag events with large contributions from VBF and associated productions
    - Categorized untagged events by signal purity
  - Fit for a peak in $m_{\gamma\gamma}$ distributions in each category

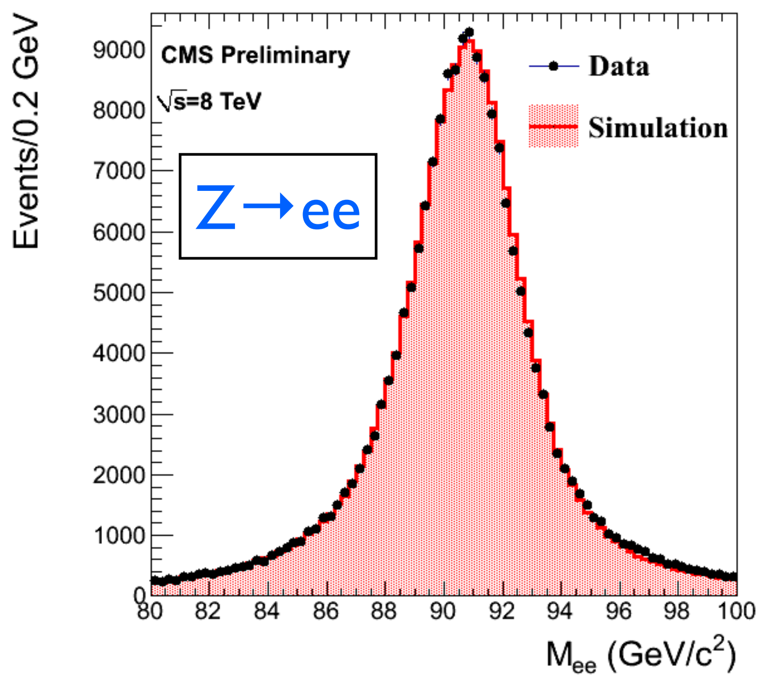
MVA analysis

- MVA discriminant (BDT) constructed using
  - photon kinematics
    - relative transverse momenta of both photons ($p_T/m_{\gamma\gamma}$)
    - pseudo-rapidities of both photons
    - $\cos(\varphi_1 - \varphi_2)$
  - photon ID MVA score (shower shape, isolation)
  - di-photon mass resolution
    - depends on probability to pick correct primary vertex
- 4 untagged categories with different S/B

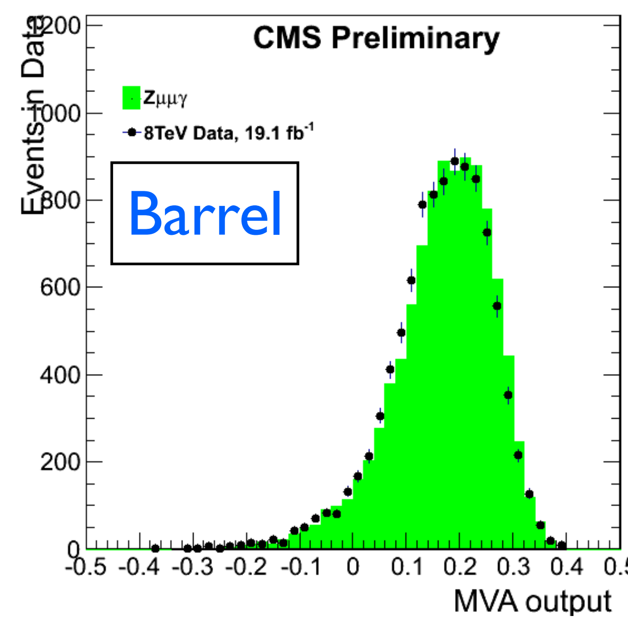
Cut-based analysis

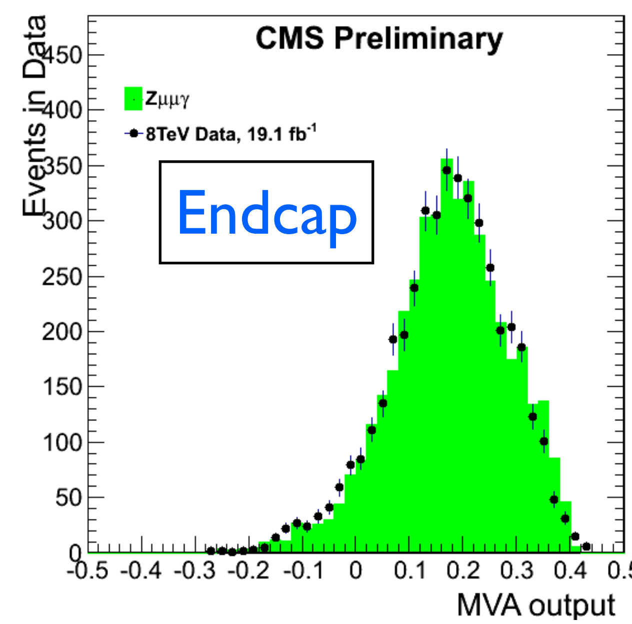
- 4 untagged categories:
  - Barrel / endcap and converted/ unconverted from shower shape R9
  - Different mass resolution and S/B among the 4 categories
- 4 MVA analysis has ~15% better sensitivity

Detector Calibration

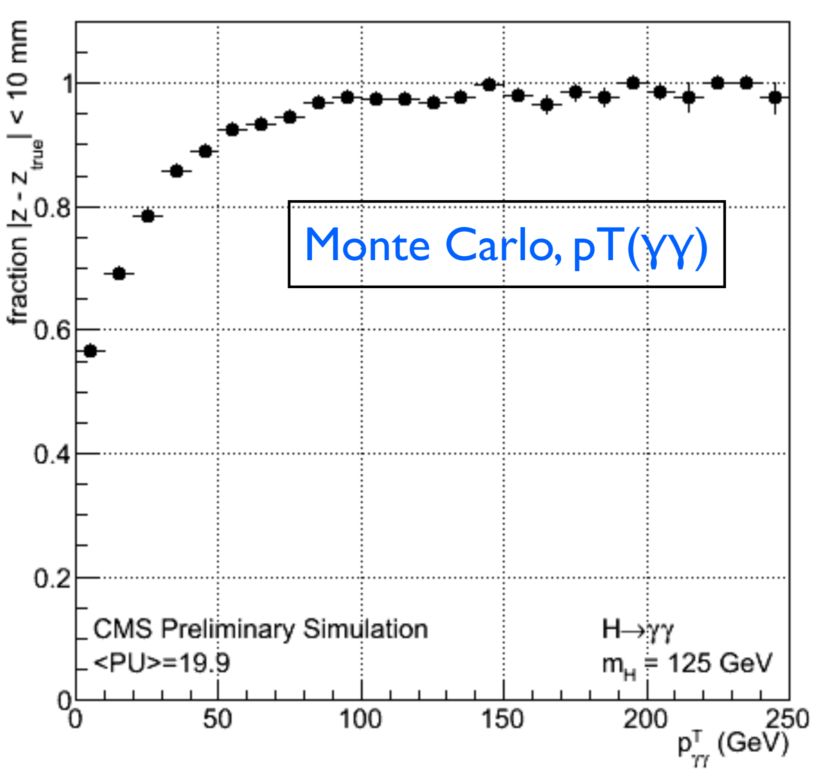


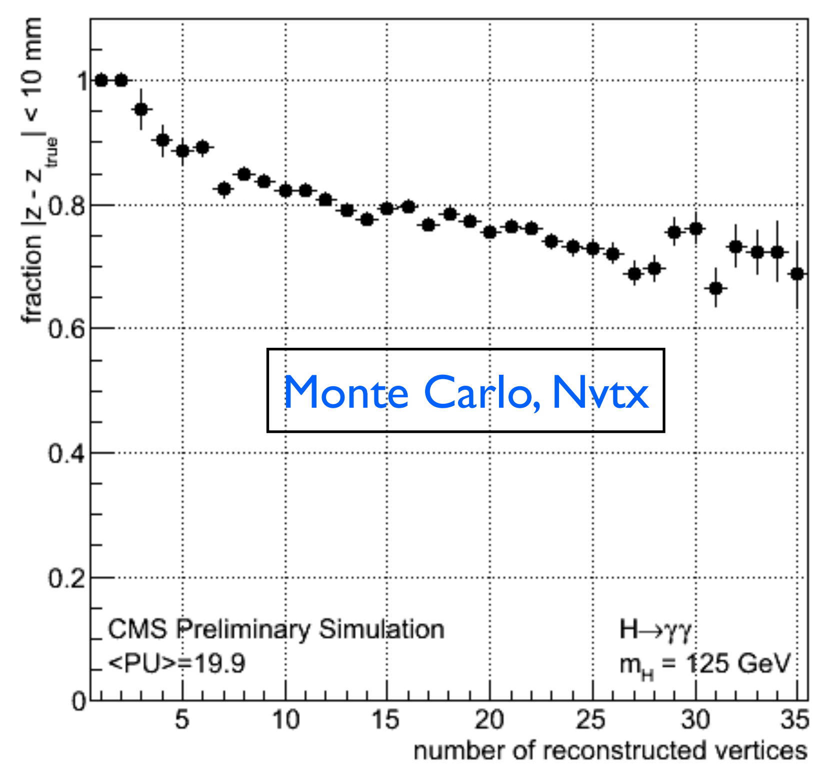
Photon ID MVA validation on Z→μμγ

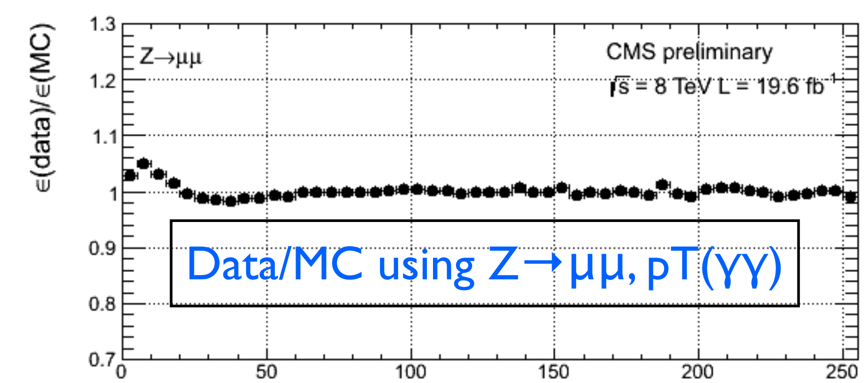


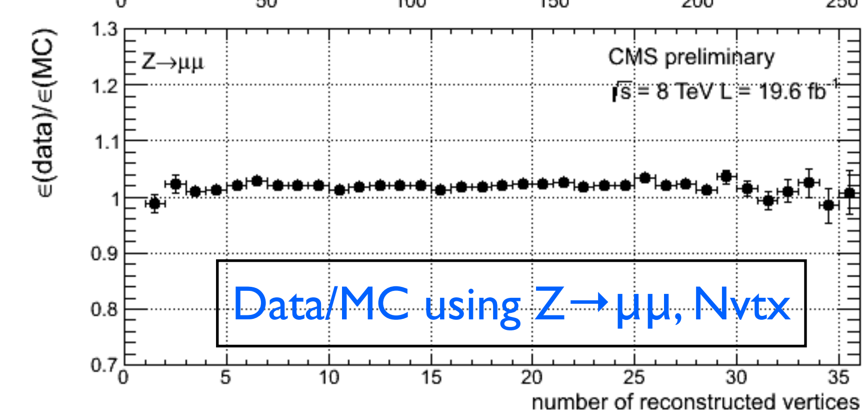


Probability to select correct vertex

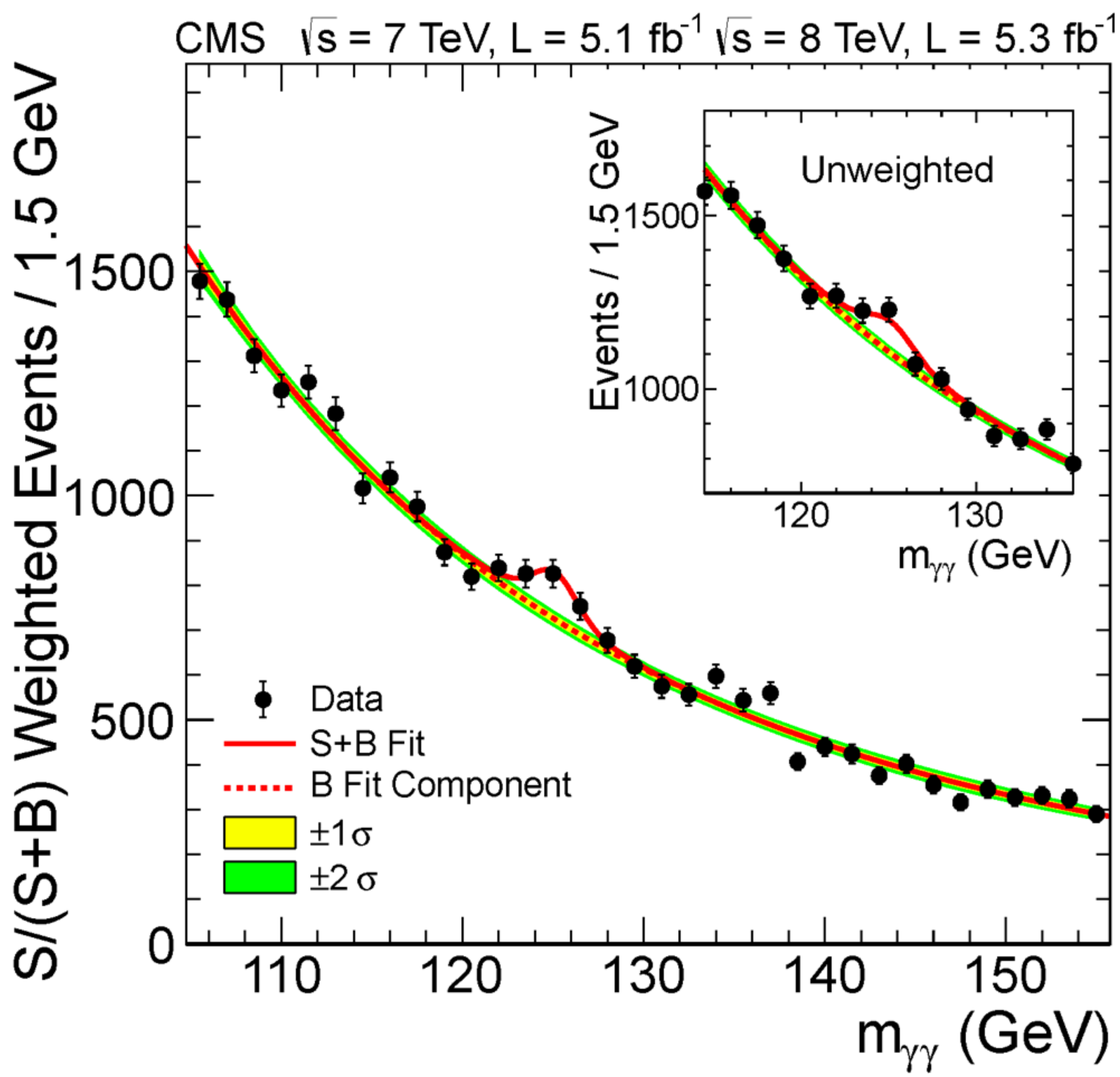


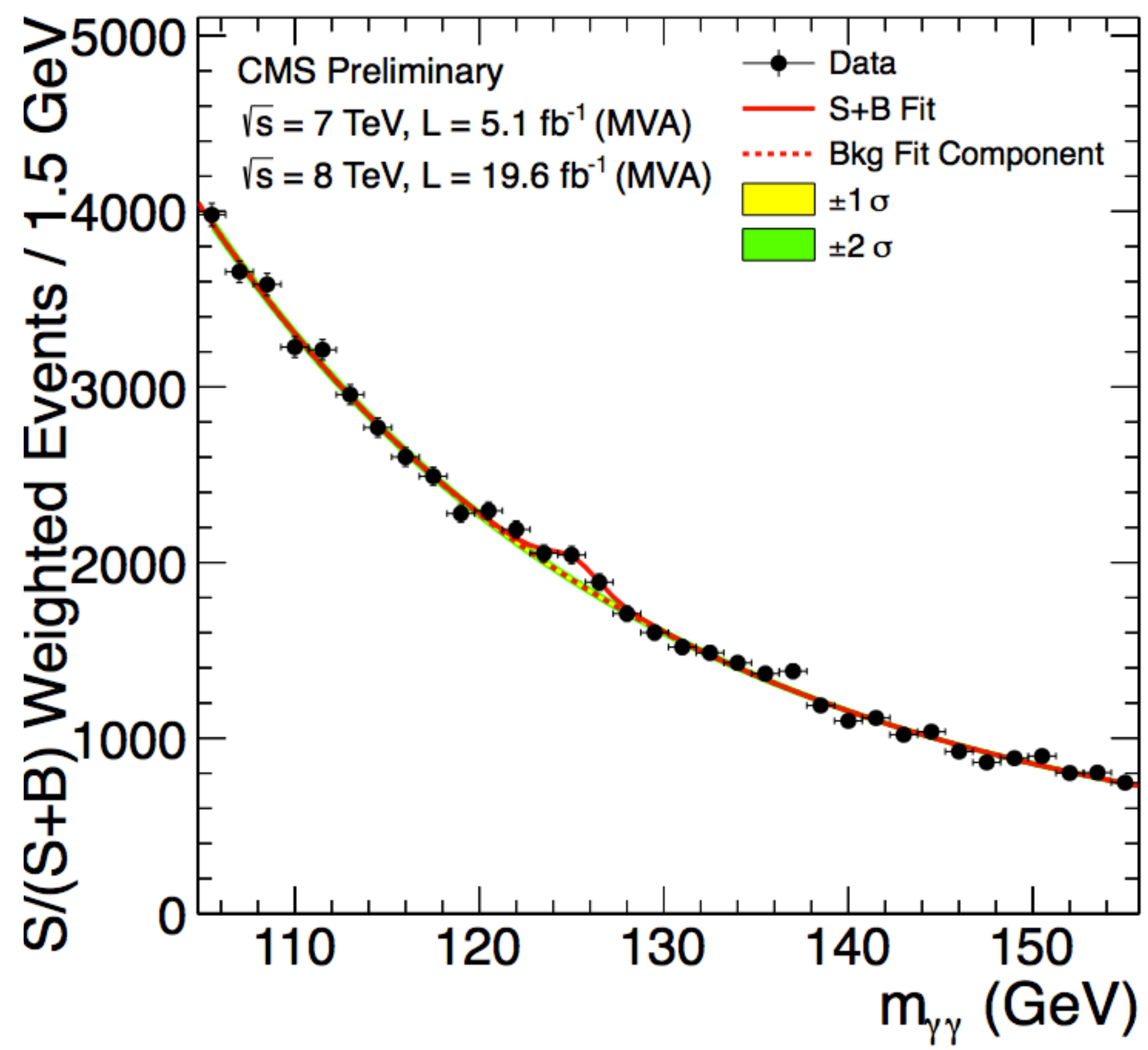






ICHEP 2012 vs Moriond 2013



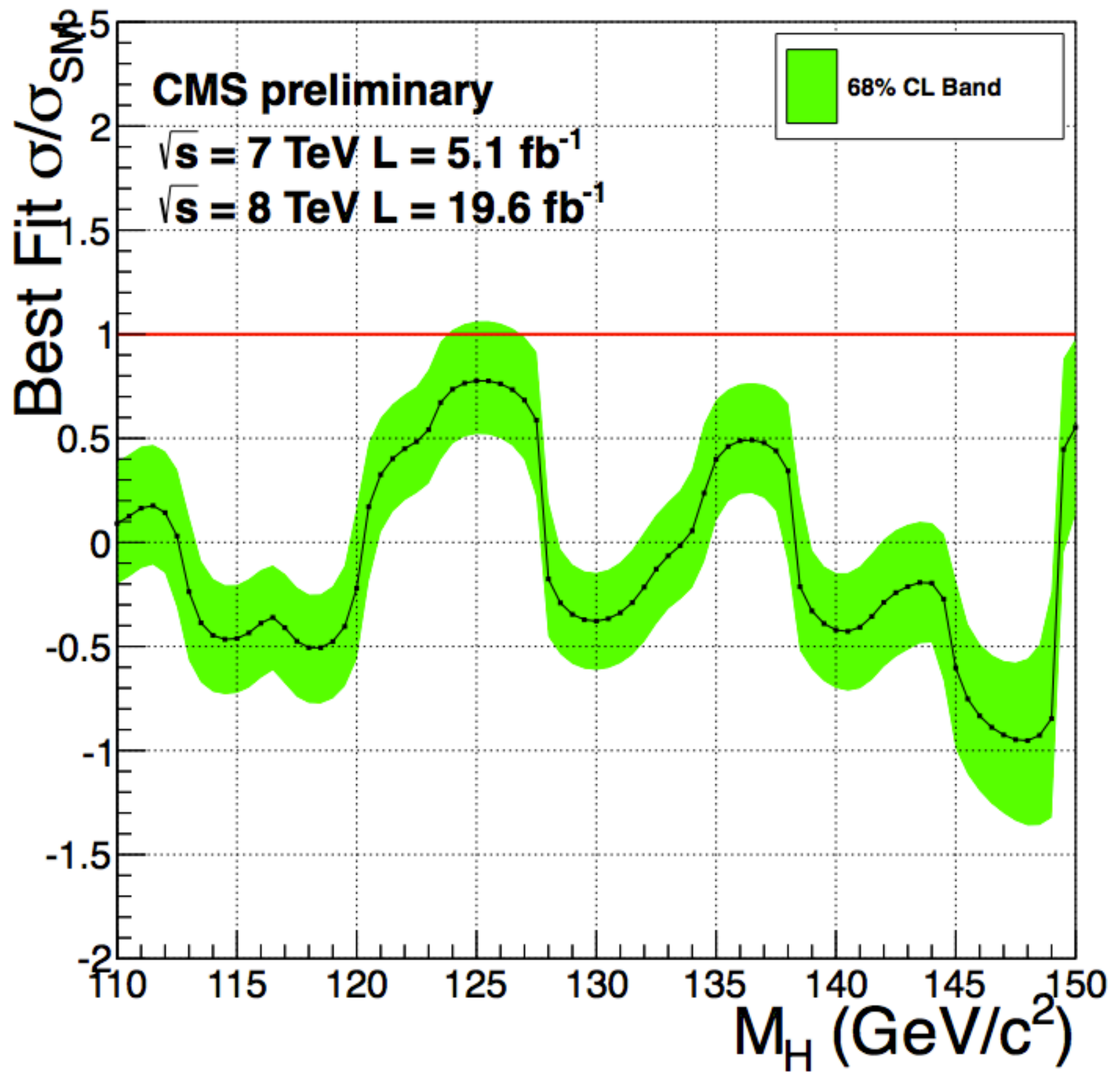


- Cross-section: $\sigma/\sigma_{SM} = 1.6 \pm 0.4$
- Significance (exp/obs): 2.8σ / 4.1σ

- Cross-section: $\sigma/\sigma_{SM} = 1.6 \pm 0.4$
- Significance (exp/obs): 4.2σ / 3.2σ

Comparing Two Analyses

MVA analysis

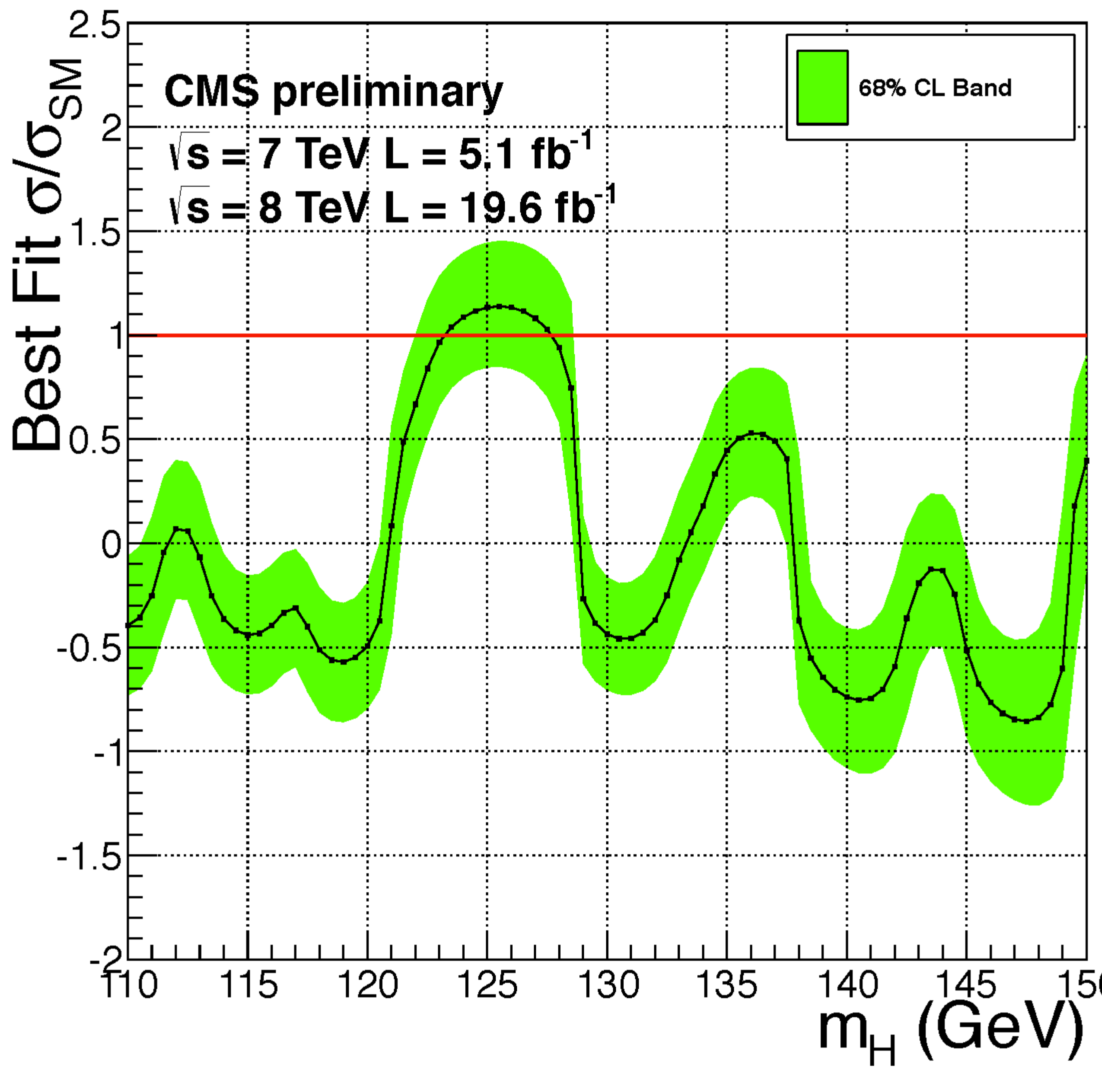


7+8 TeV: σ/σ_{SM} @ 125.0 GeV = $0.78^{+0.28}_{-0.26}$

7 TeV: σ/σ_{SM} @ 125.0 GeV = $1.69^{+0.65}_{-0.59}$

8 TeV: σ/σ_{SM} @ 125.0 GeV = $0.55^{+0.29}_{-0.27}$

Cut-based analysis



7+8 TeV: σ/σ_{SM} @ 124.5 GeV = $1.11^{+0.32}_{-0.30}$

7 TeV: σ/σ_{SM} @ 124.5 GeV = $2.27^{+0.80}_{-0.74}$

8 TeV: σ/σ_{SM} @ 124.5 GeV = $0.93^{+0.34}_{-0.32}$

What all does it mean?

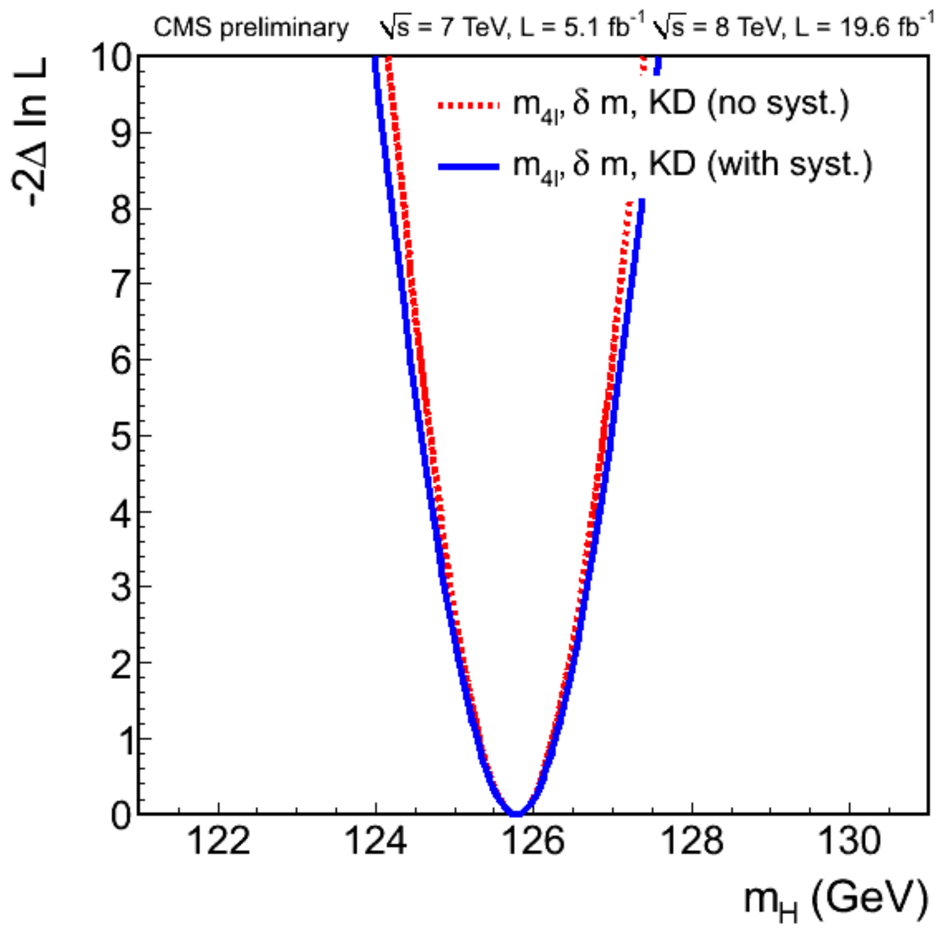
- Low signal to background ratio a fundamental feature of this channel
  - Uncertainty on signal strength driven by statistical fluctuations of the background
  - Analysis changes can lead to statistical changes due to fluctuations in selected events and their mass
- Correlation between MVA and cut-based measurements is 0.76
  - Estimated using jackknife techniques
- Observed changes in results are all statistically compatible at less than 2σ
- Delay in making results public was caused by additional checks that were requested by CMS Collaboration
  - We found no reasons to believe that either analysis is wrong
  - Results are considered to be solid enough to be made public

Test	Signal strength compatibility
MVA vs CiC 7+8 TeV	1.5 σ
MVA vs CiC 8 TeV only	1.8 σ
Updated MVA vs published (5.3/fb 8TeV)	1.6 σ
Updated CiC vs published (5.3/fb 8TeV)	0.5 σ

Mass Measurement

H→ZZ→ 4l

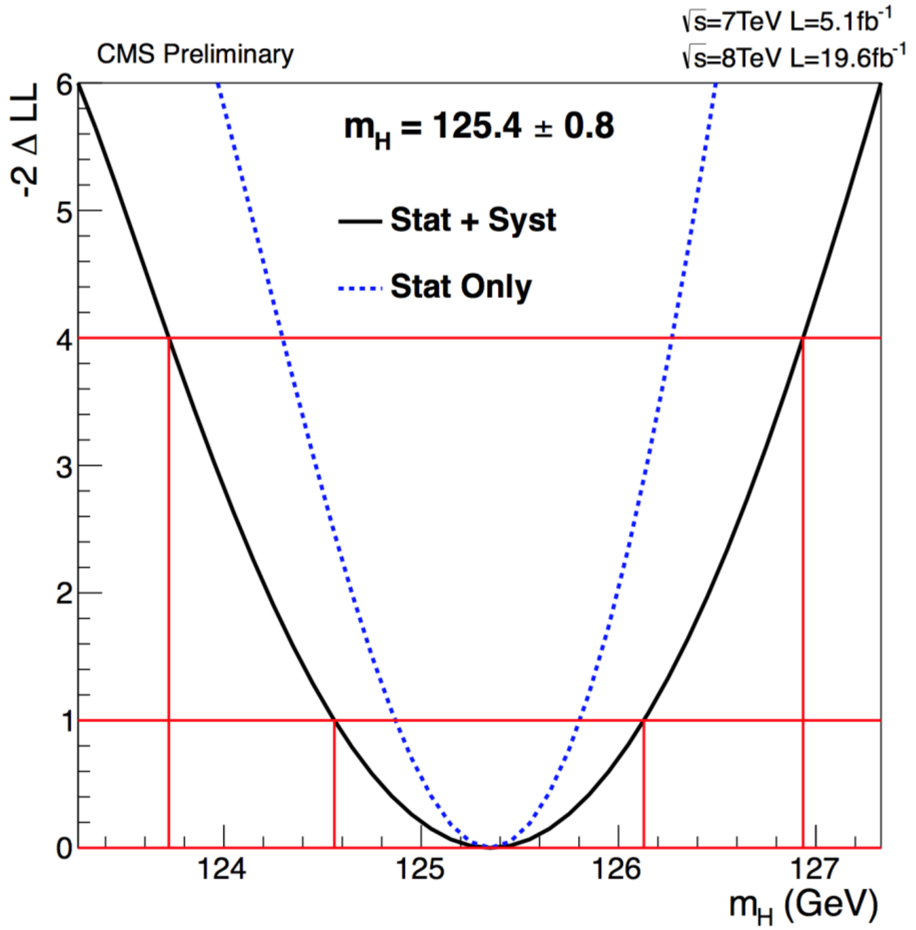
- Lepton momentum scale & resolution validated with Z, J/ψ, and ϒ→ll samples.
- m4l uncertainties due to lepton scale: 0.1% (4μ), 0.3% (4e)



m_H = 125.8 ± 0.5 (stat.) ± 0.2 (syst.)

H→γγ

- Systematic errors dominated by overall photon energy scale: 0.47% (mostly coming from extrapolation from Z→H and e→γ)



m_H = 125.4 ± 0.5 (stat.) ± 0.6 (syst.)

Measurements in the two channels are well compatible.

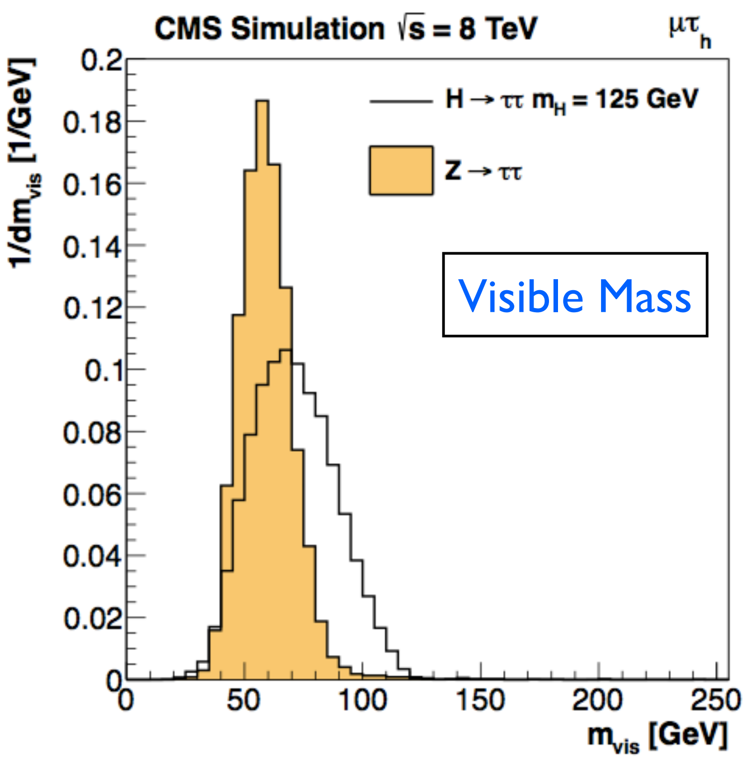
H→ττ

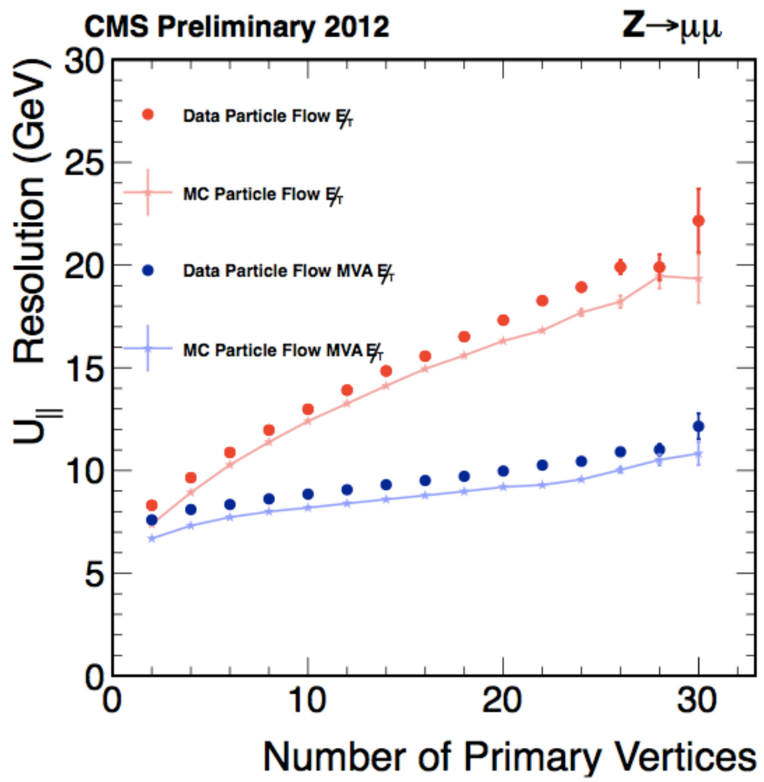
No public documentation yet, only talks:

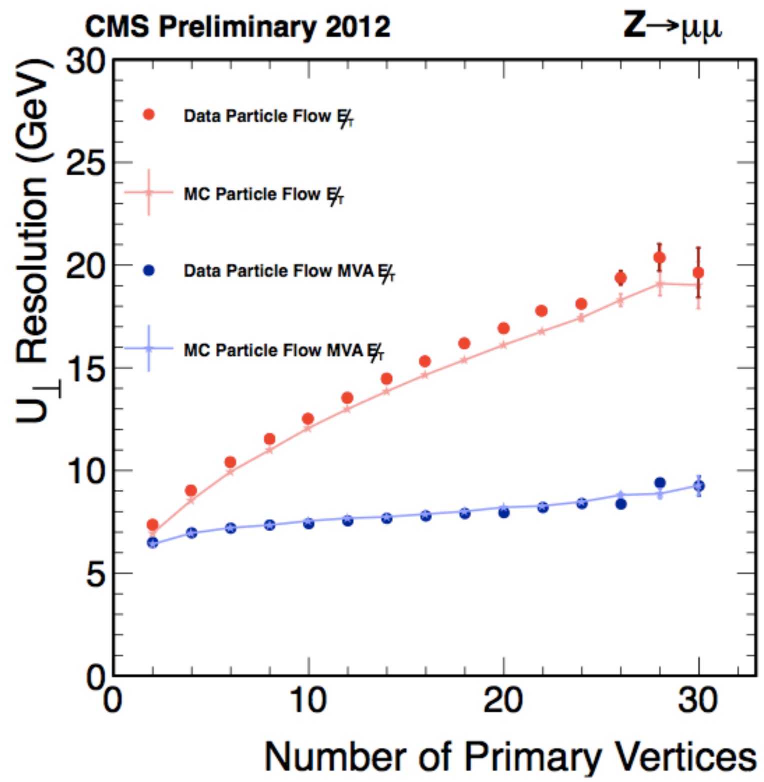
https://indico.in2p3.fr/getFile.py/access?contribId=57&sessionId=6&resId=0&materialId=slides&confId=7411

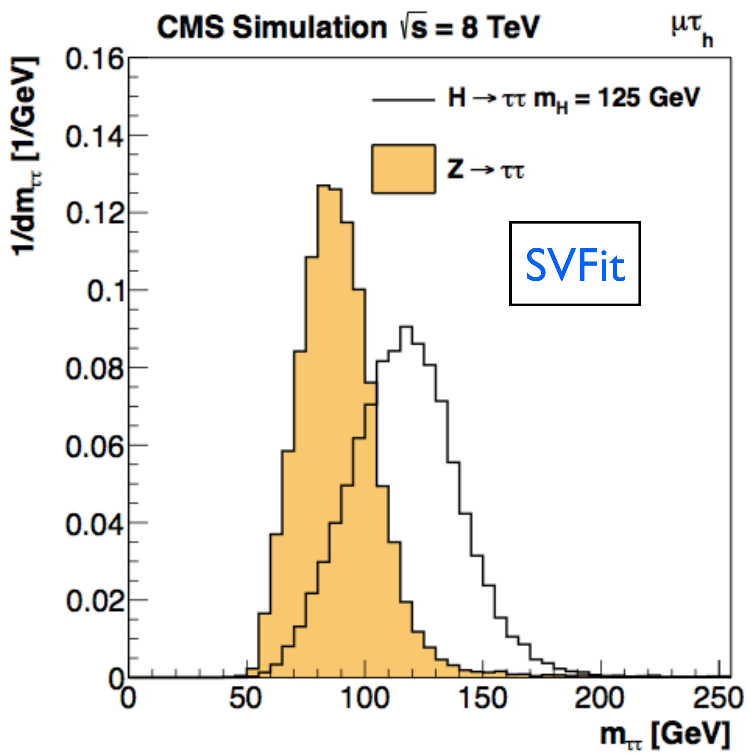
http://moriond.in2p3.fr/QCD/2013/ThursdayMorning/Puigh.pdf

Analysis Strategy





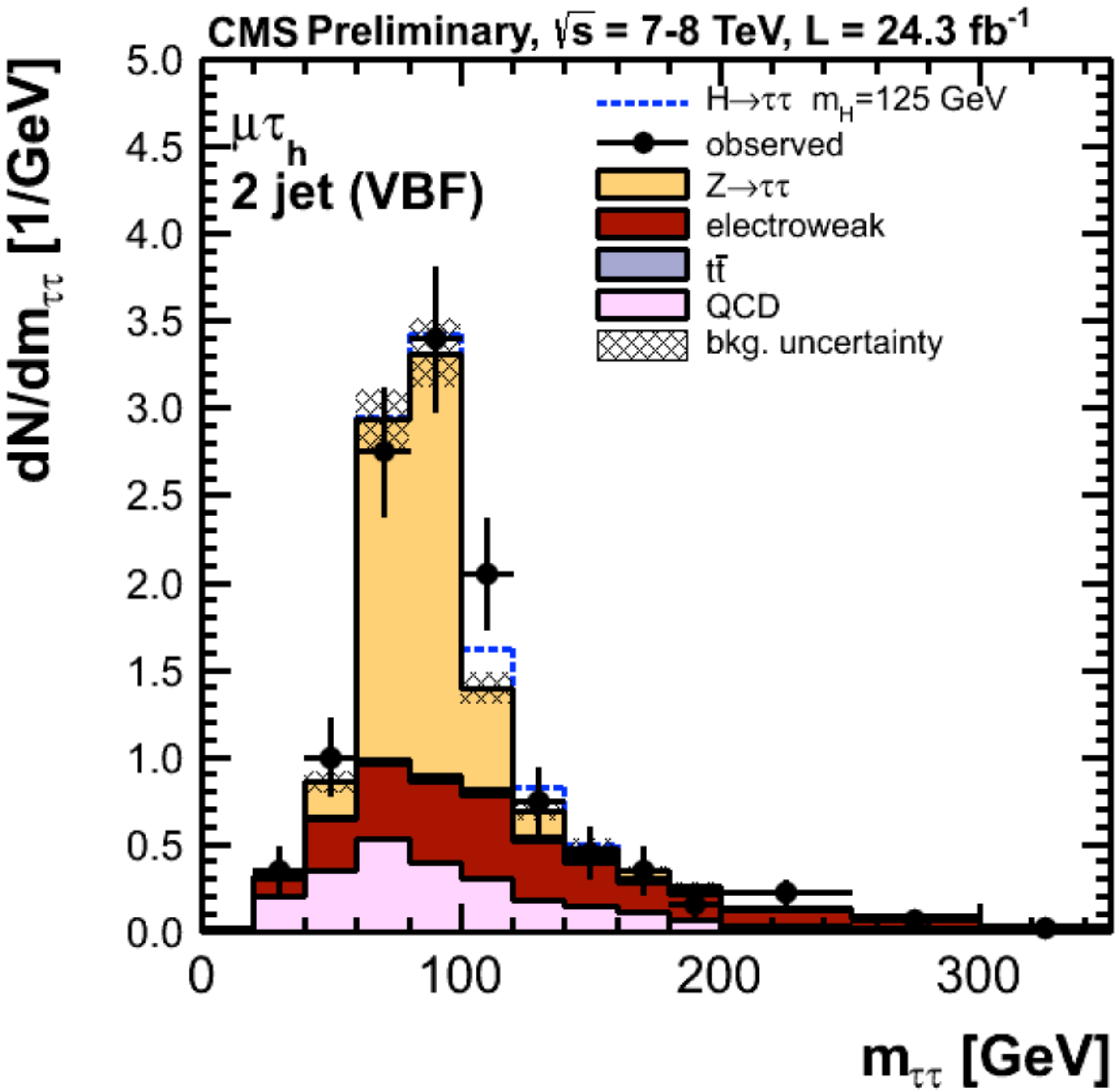




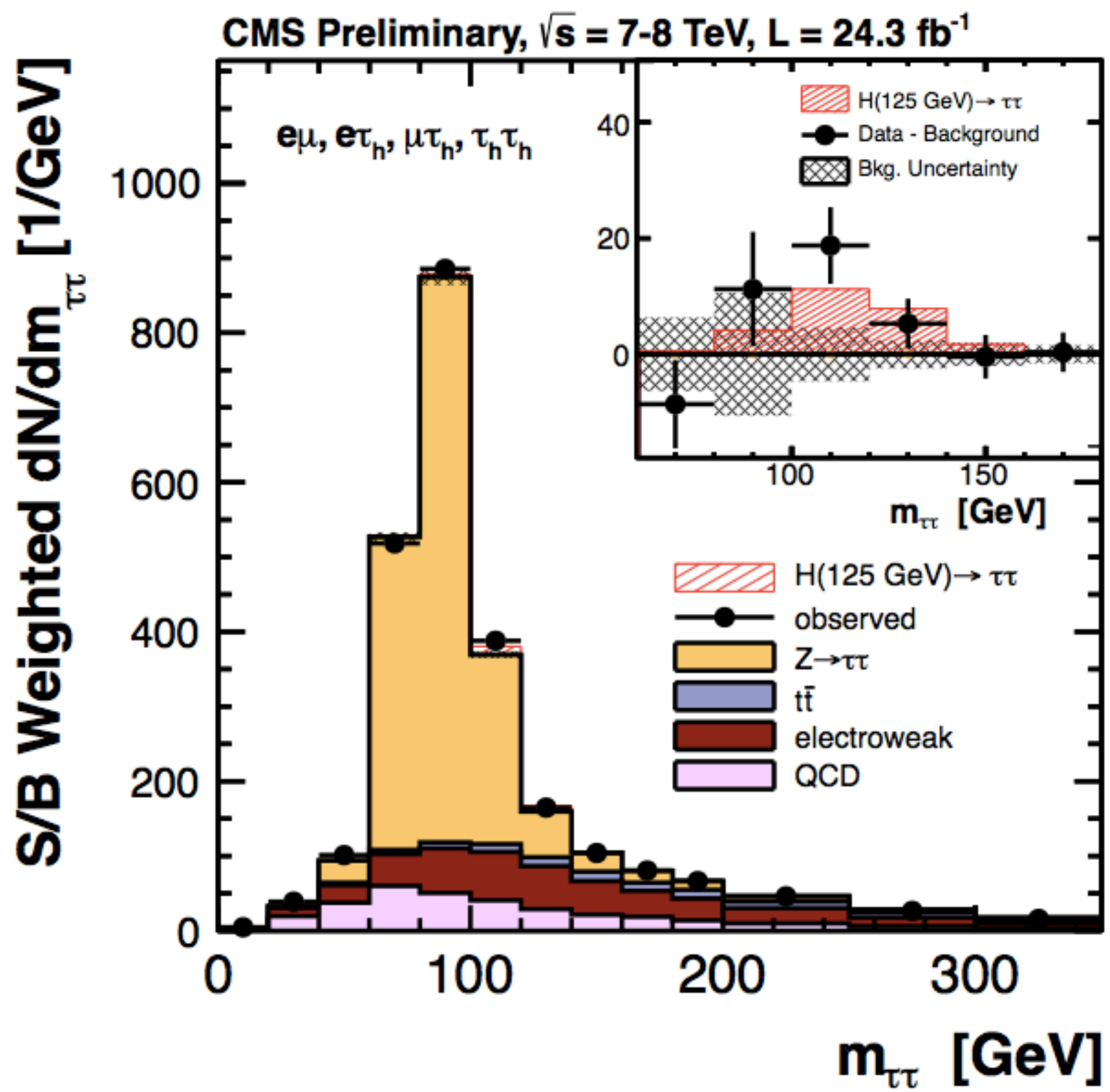
- Final states: $\mu\tau_h$, $e\tau_h$, $e\mu$, $\tau_h\tau_h$, $\mu\mu$
- Mass reconstruction - SVFit
  - under-constrained ML fit using a matrix element to compute likelihood of the leptonic tau decays
- Use multivariate regression to avoid PU related resolution degradation
- Event Classification
  - by number of jets and Higgs Pt

Mass Distributions

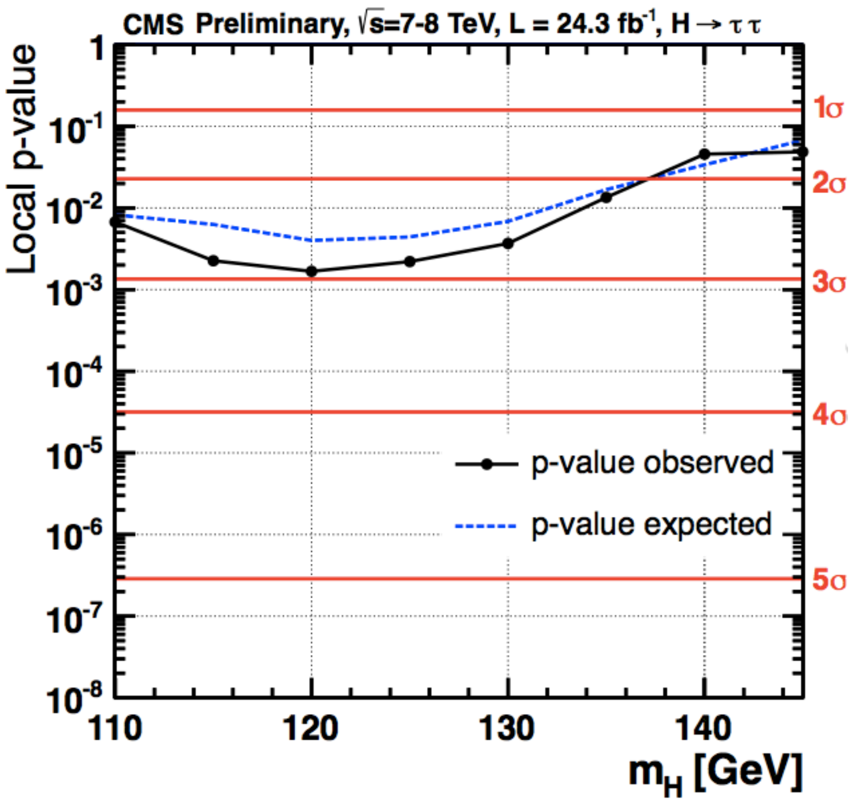
μτh (VBF) - one of most sensitive channels

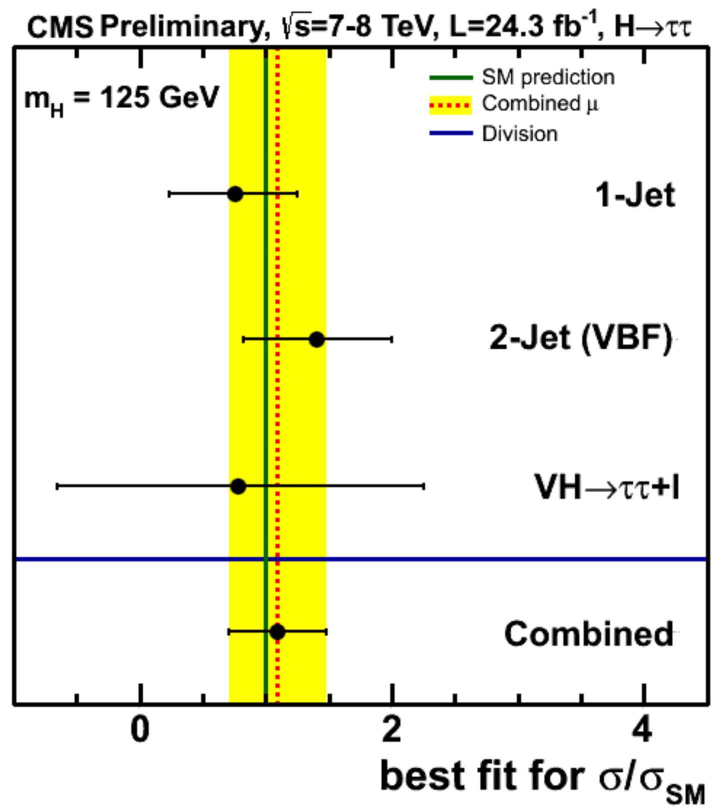


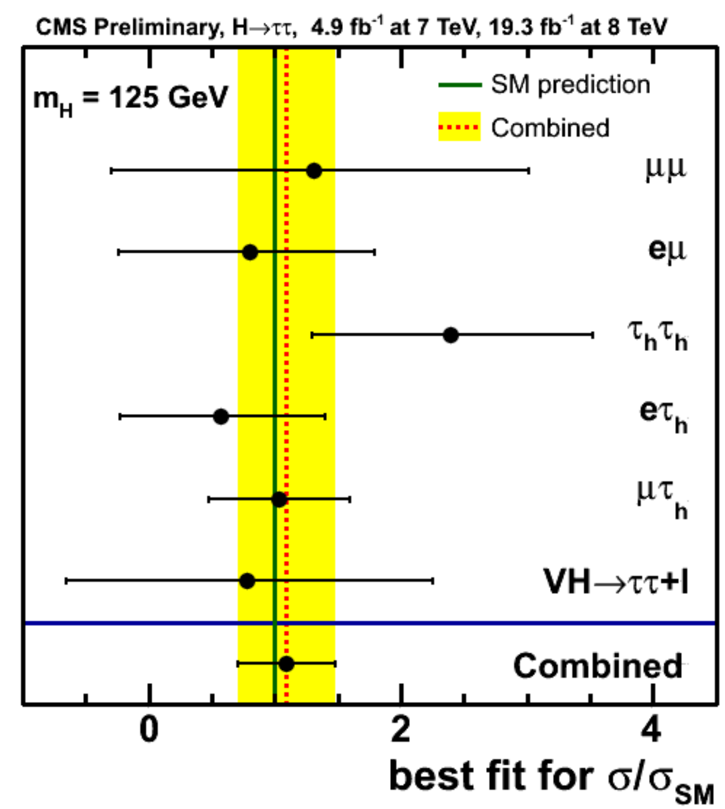
Weighted multi-channel distribution

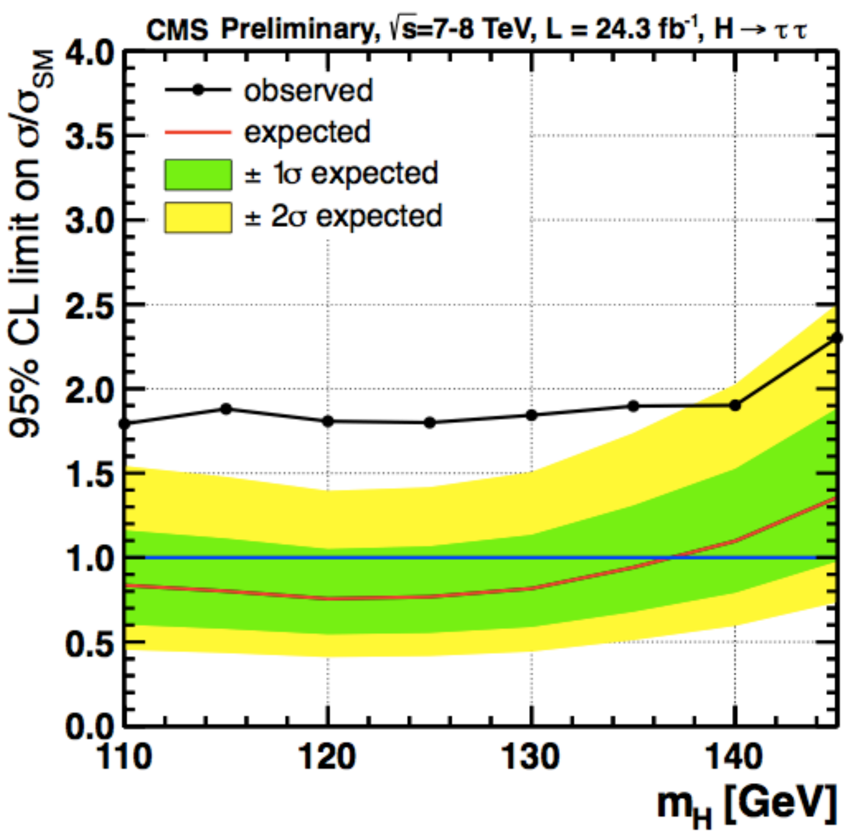


Results



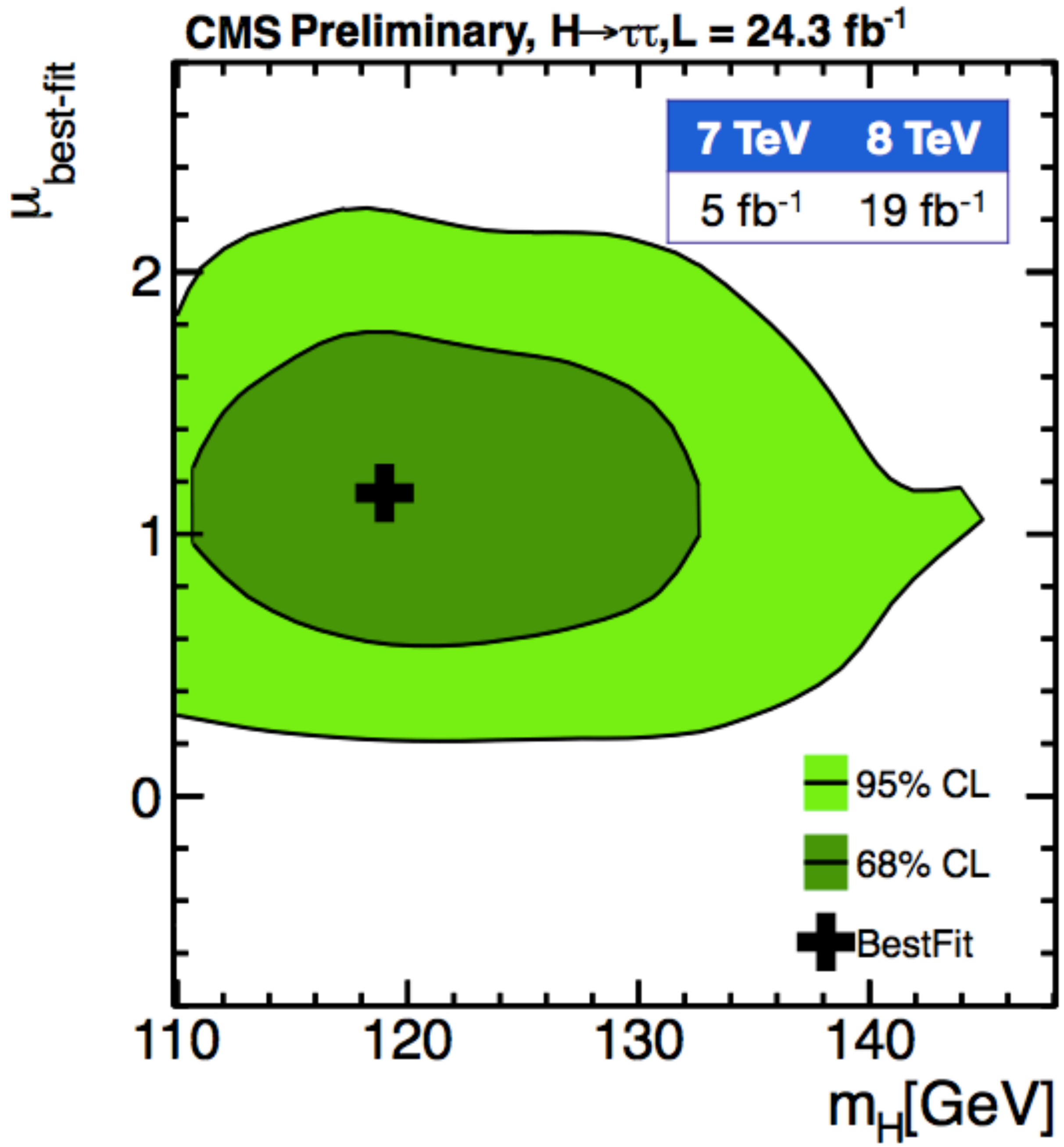


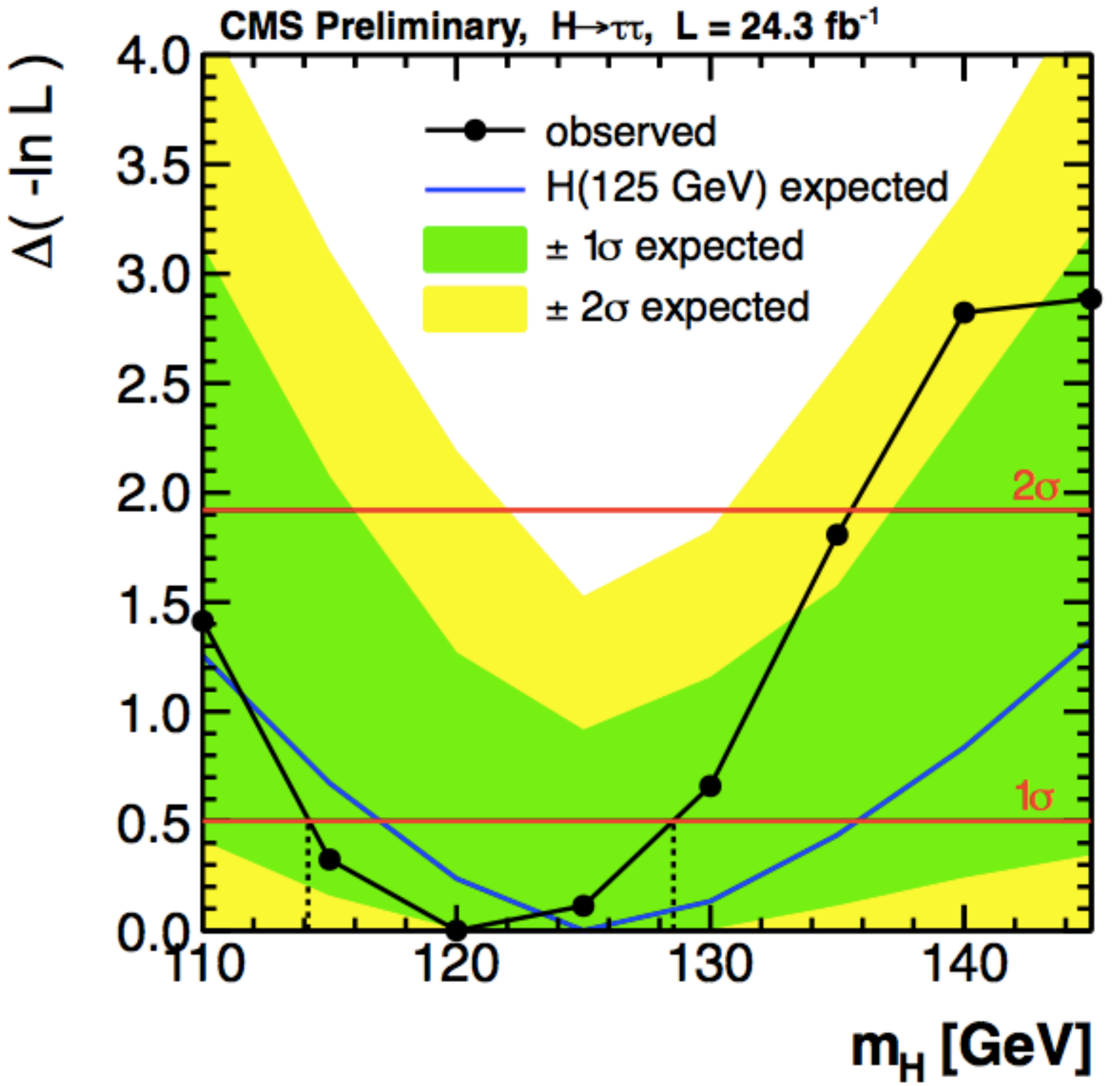




- Signal significance: 2.9σ
- $\sigma/\sigma_{SM} = 1.1 \pm 0.4$

Mass Measurement





$m_H = 120 + 9 - 7$ GeV

$H \to bb$

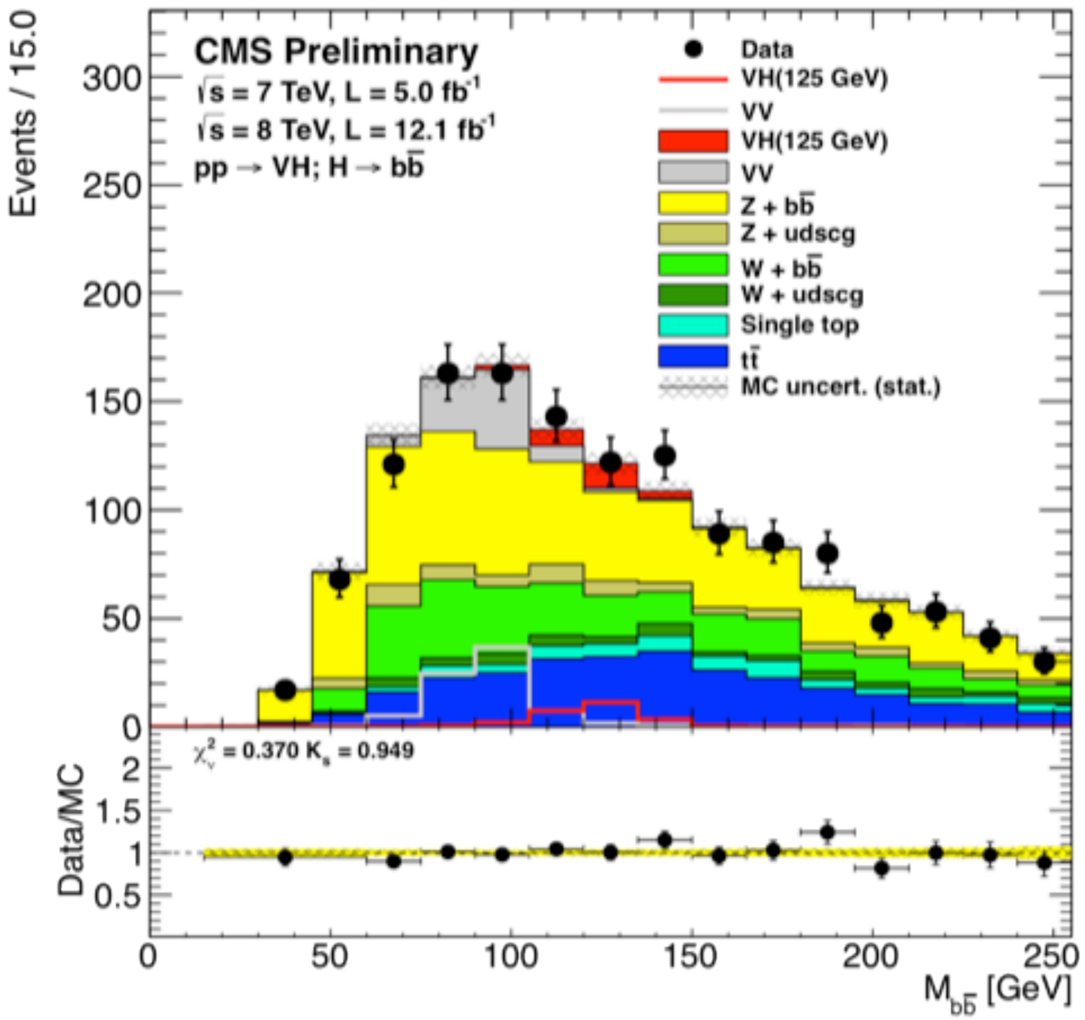
Last update November 2012

PAS (HIG-12-044): http://cdsweb.cern.ch/record/1493618

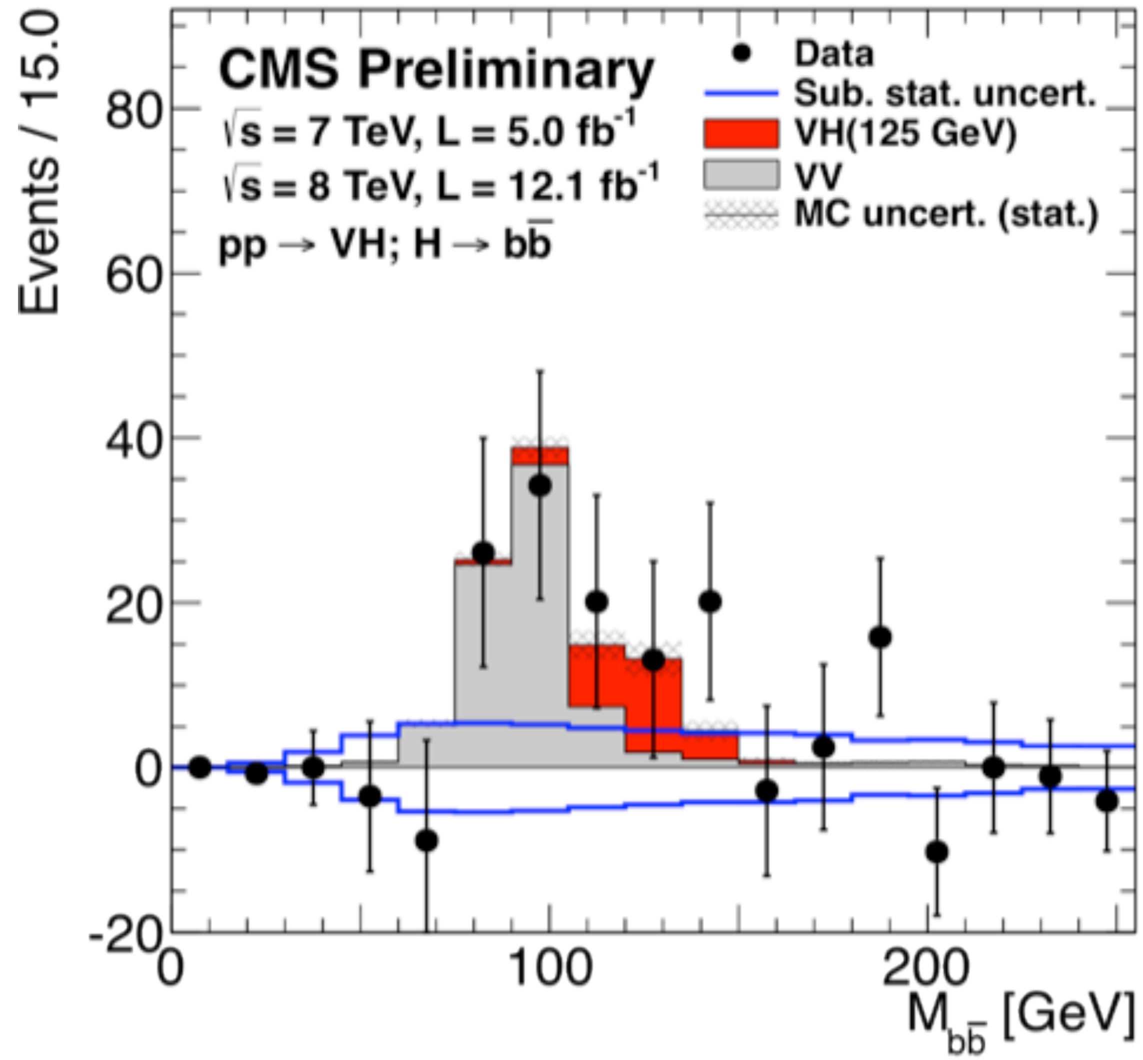
TWiki: https://twiki.cern.ch/twiki/bin/view/CMSPublic/Hig12044TWiki

Analysis Overview

All Channels

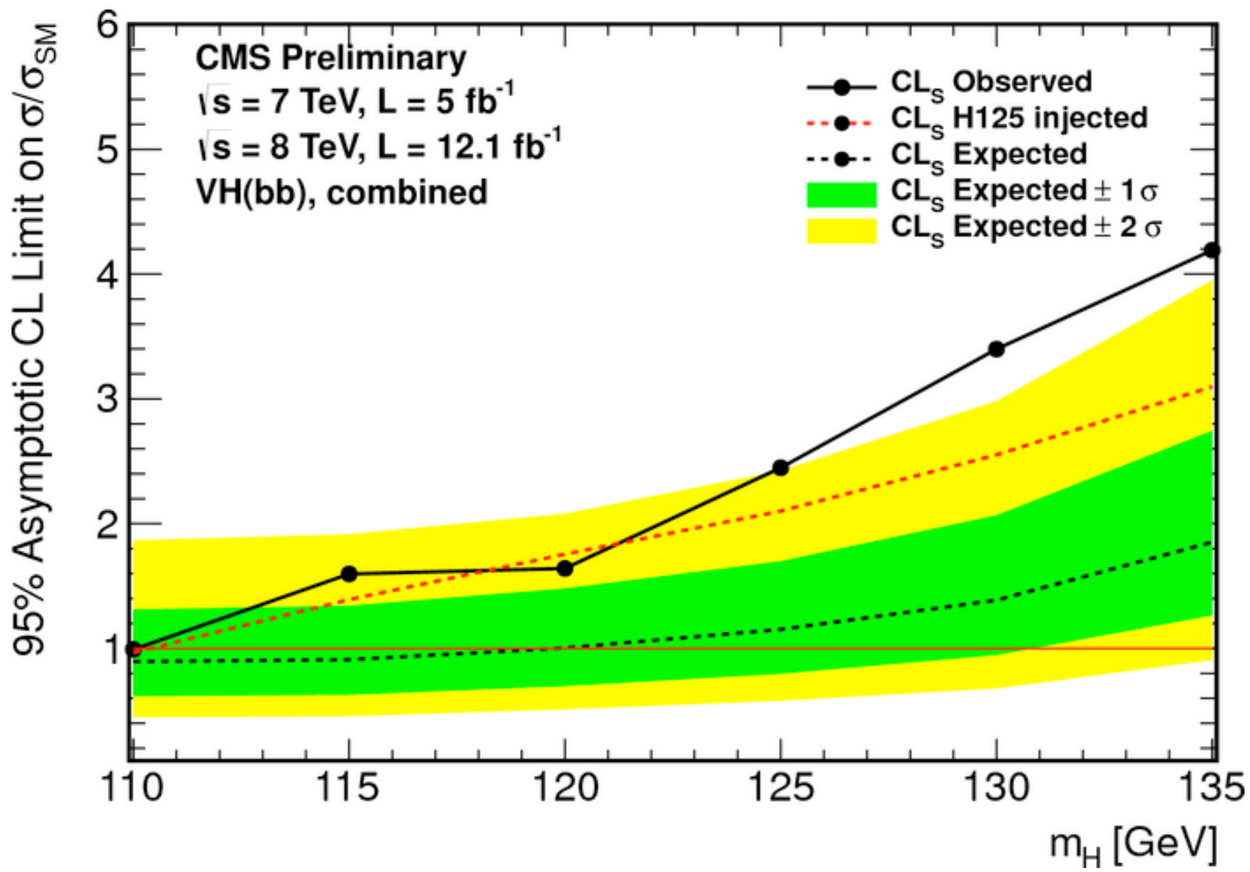


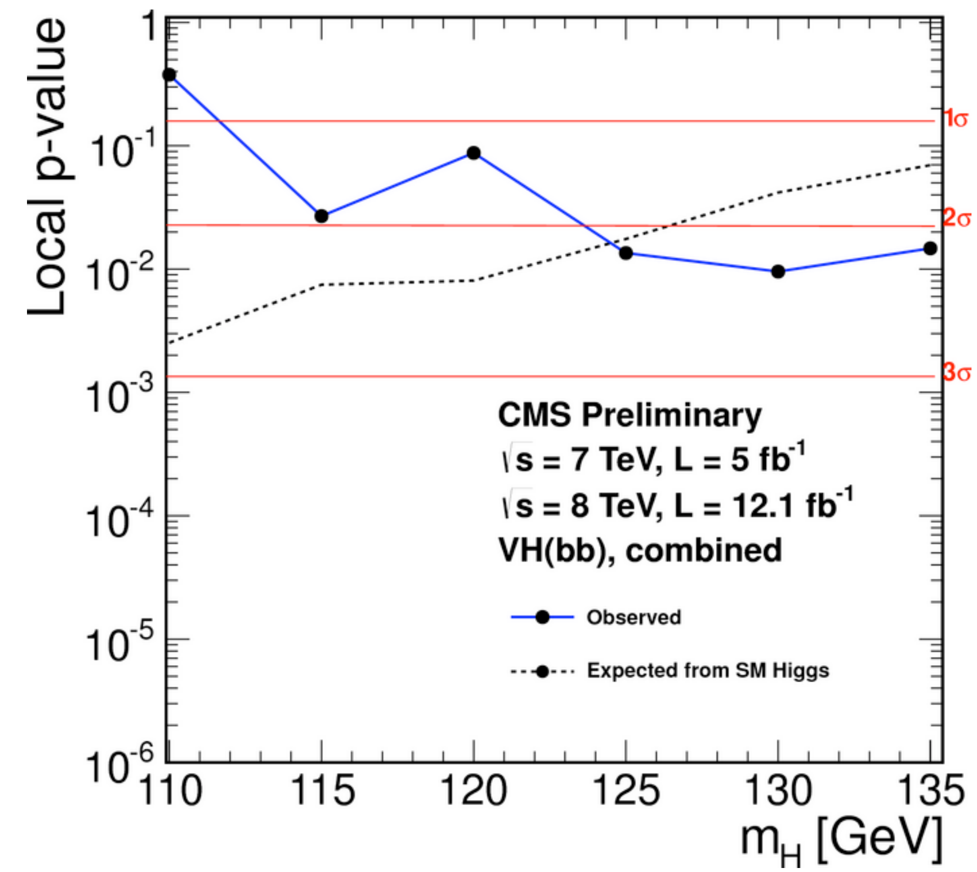
VV + VH (background subtracted)

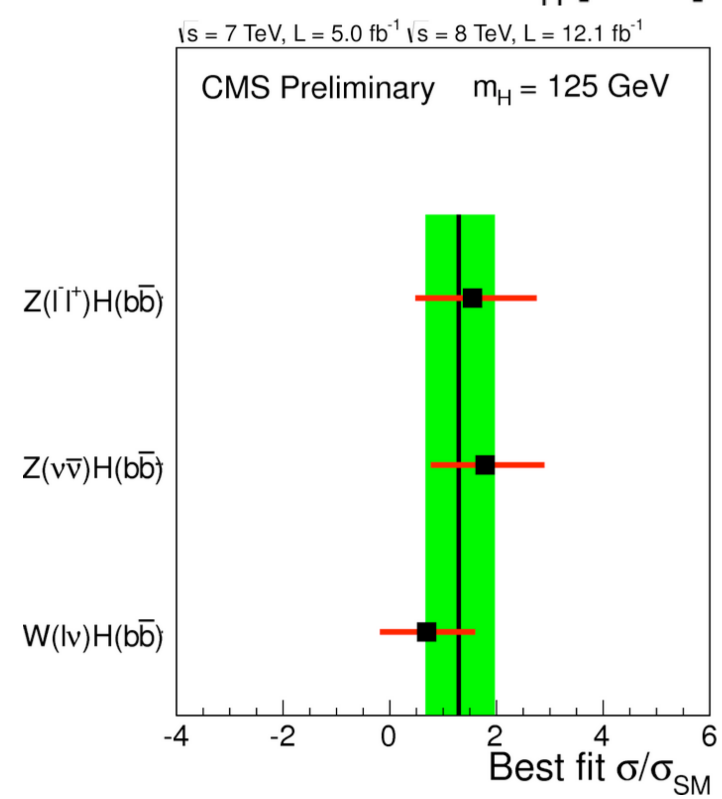


- Hbb events reconstructed only in association with W and Z decaying leptonically
  - Dominant backgrounds: Wjets, Zjets, Top
- Analysis Strategy - use MVA to get best Signal/Background separation
  - rely on boosted W/Z and Higgs
  - b-jet energy regression helps improve resolution

Results

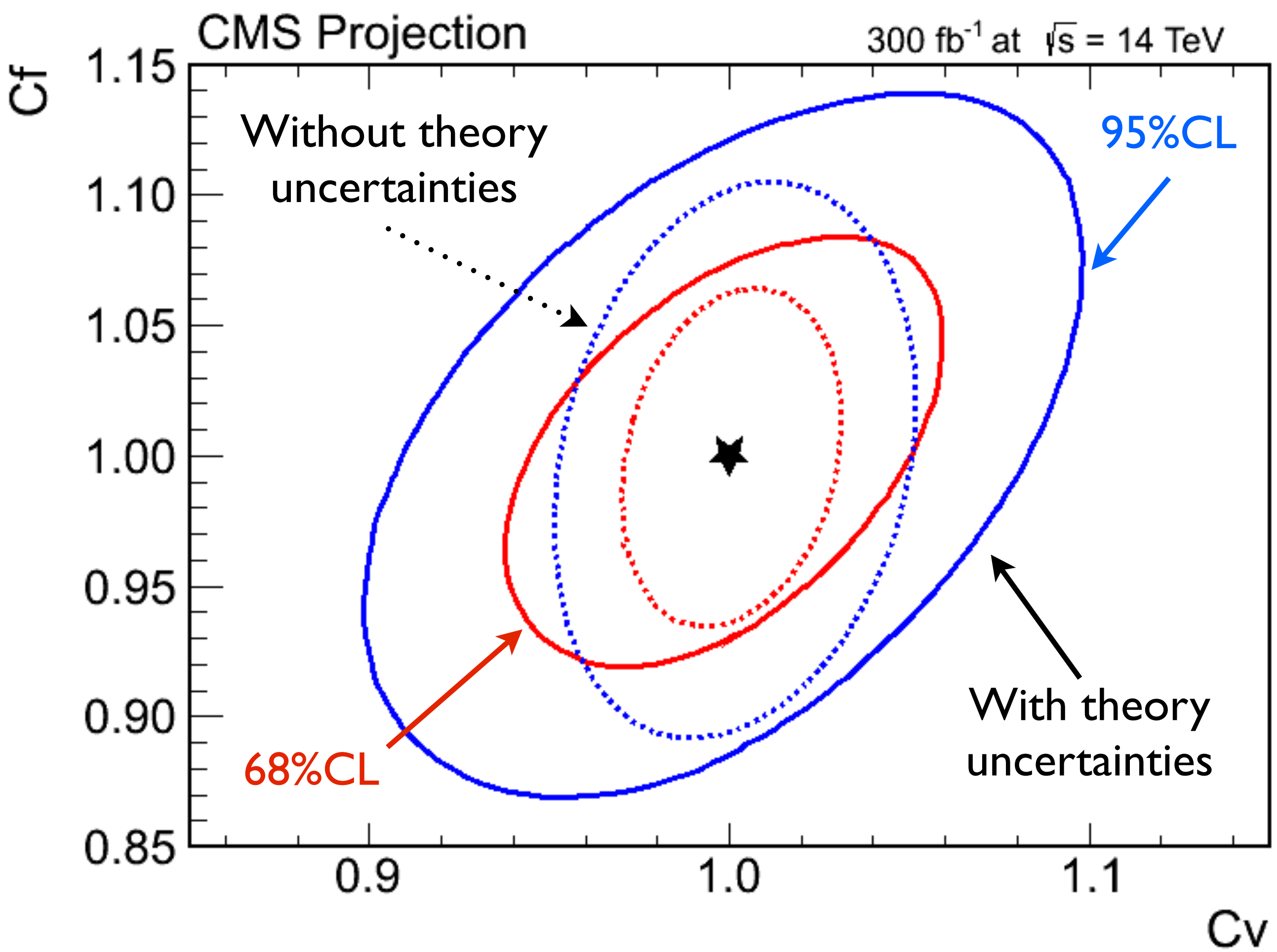


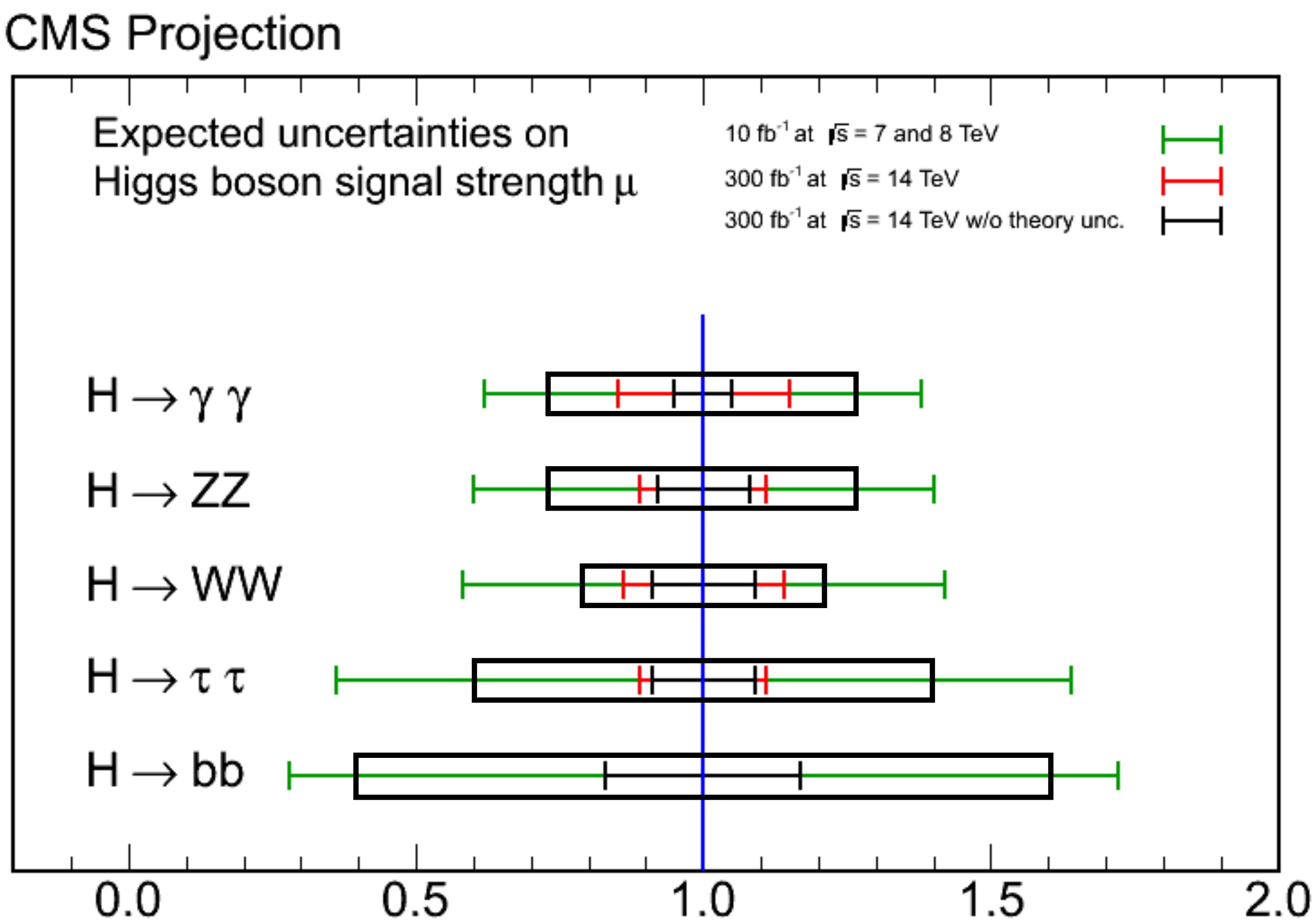




- Observed (expected) limit of 2.5 (1.2) x SM at 125 GeV
- Observed (expected) local significance of 2.2σ (2.1σ) for mH = 125 GeV
- Combined best-fit $\mu = 1.3^{+0.7}_{-0.6}$

Expected Sensitivity with 300/fb





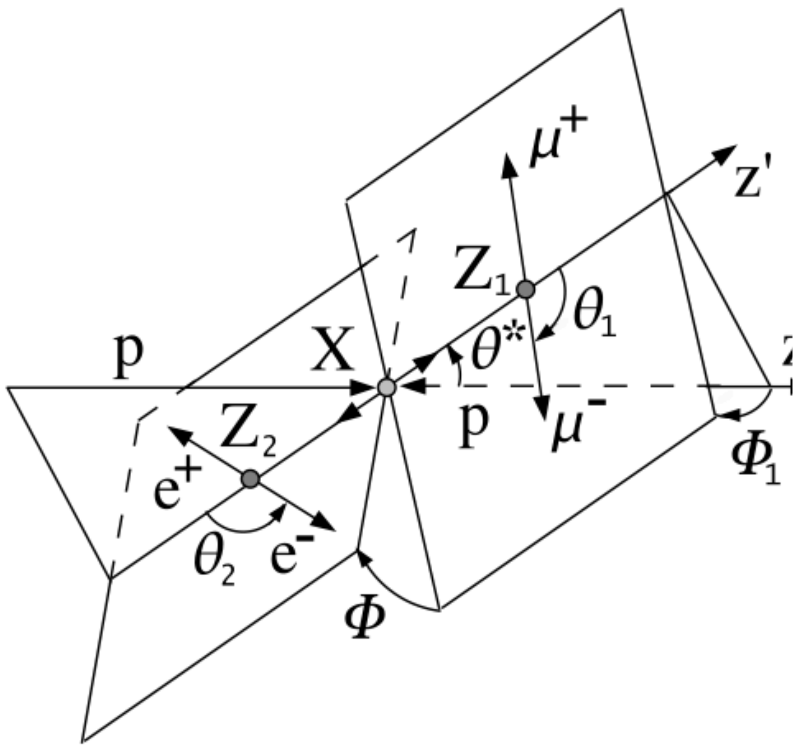
Boxes show current results

Summary

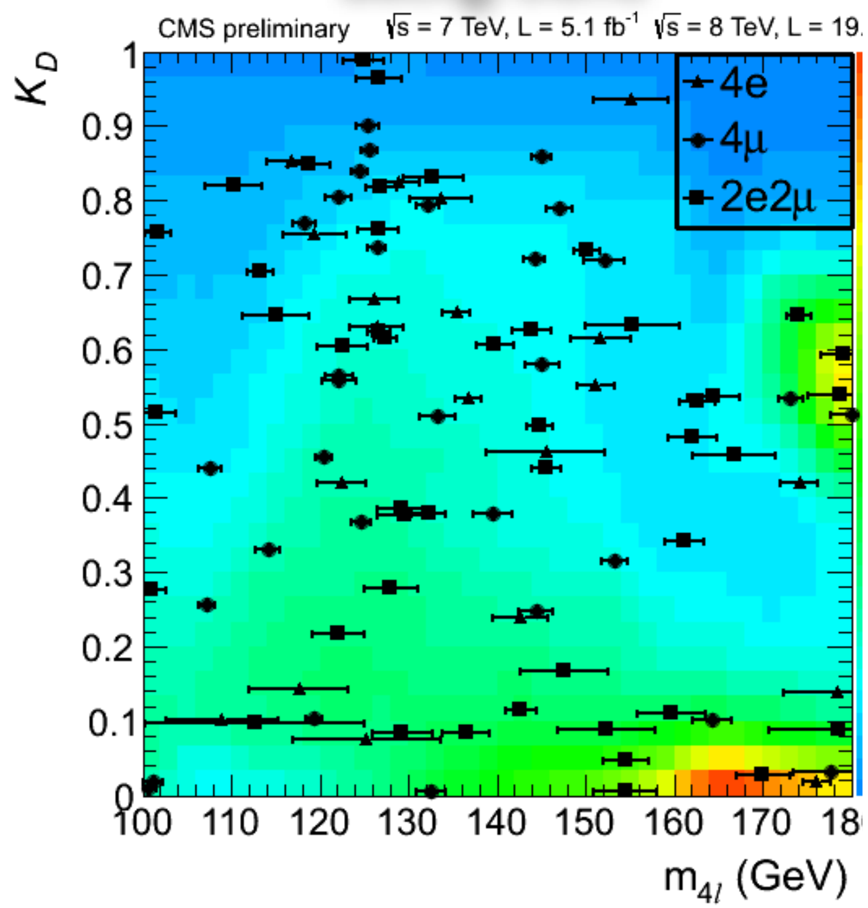
- LHC delivered good quality data
  - ~25/fb of data at 7-8 TeV
  - Higgs results look extremely good
- Signal Strength (σ/σ_{SM}):
  - $H \rightarrow ZZ \rightarrow 4l$: $0.91^{+0.30}_{-0.24}$
  - $H \rightarrow WW \rightarrow 2l2\nu$: 0.76 ± 0.21
  - $H \rightarrow \gamma\gamma$: $0.78^{+0.28}_{-0.26}$
  - $H \rightarrow \tau\tau$: 1.1 ± 0.4
  - $H \rightarrow bb$: $1.3^{+0.7}_{-0.6}$
- Looks like the new boson is the Standard Model Higgs

Backup Slides

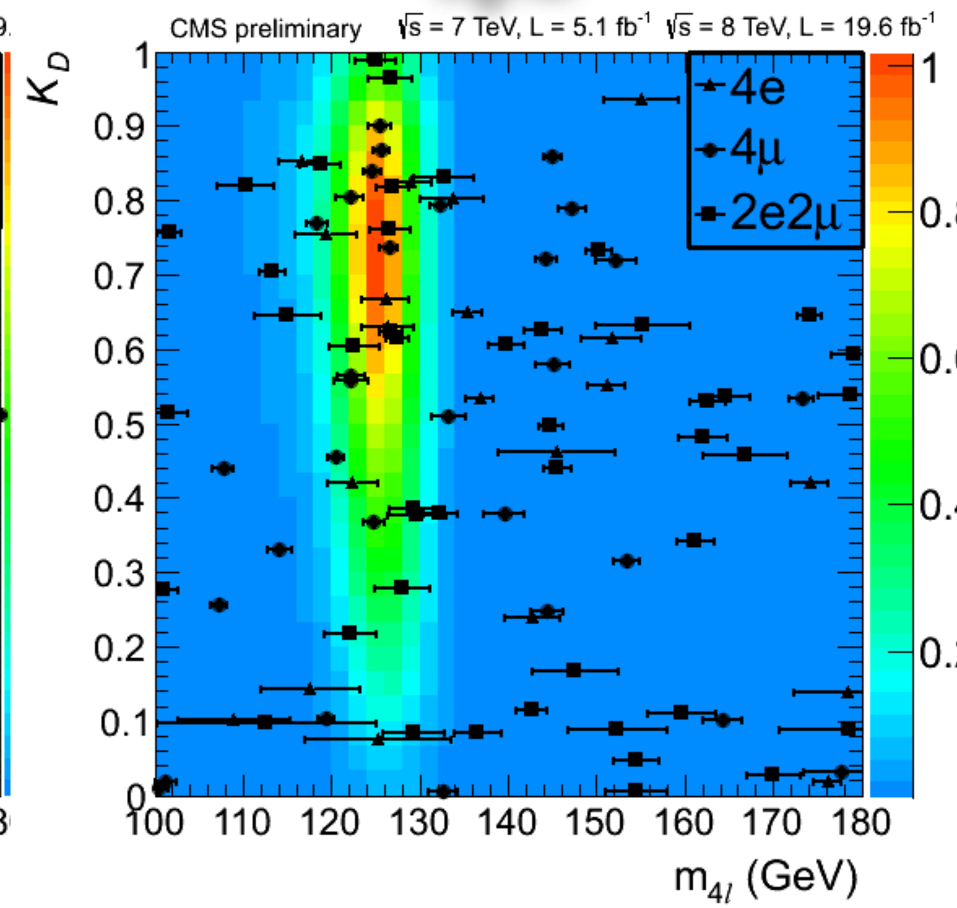
H_{ZZ} Kinematic Discriminant



Background



Signal



- Matrix Element
  - 5 angles, M_{Z1}, M_{Z2}
  - transverse momentum of the four-lepton system

HZZ Hypothesis Testing 2

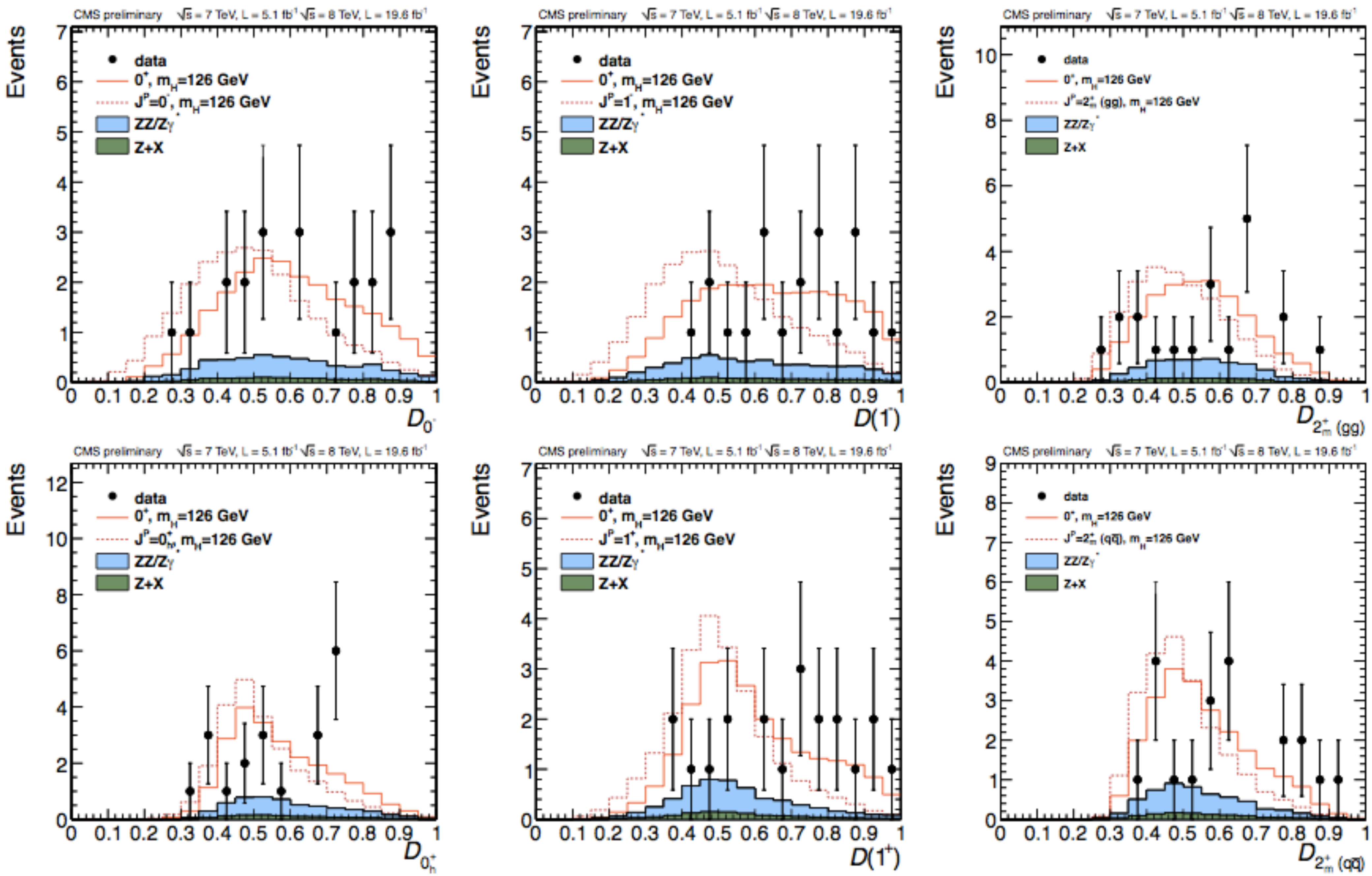


Figure 13: Distributions of $\mathcal{D}_{J^P}$ with a requirement $\mathcal{D}_{\rm bkg} > 0.5$. Distributions in data (points with error bars) and expectations for background and signal are shown. Six alternative hypotheses are tested from top to bottom and left to right: $J^P = 0^-, 0^+_h, 1^-, 1^+, 2^+_m(gg), 2^+_m(q\bar{q})$.

Hzz Hypothesis Testing 3

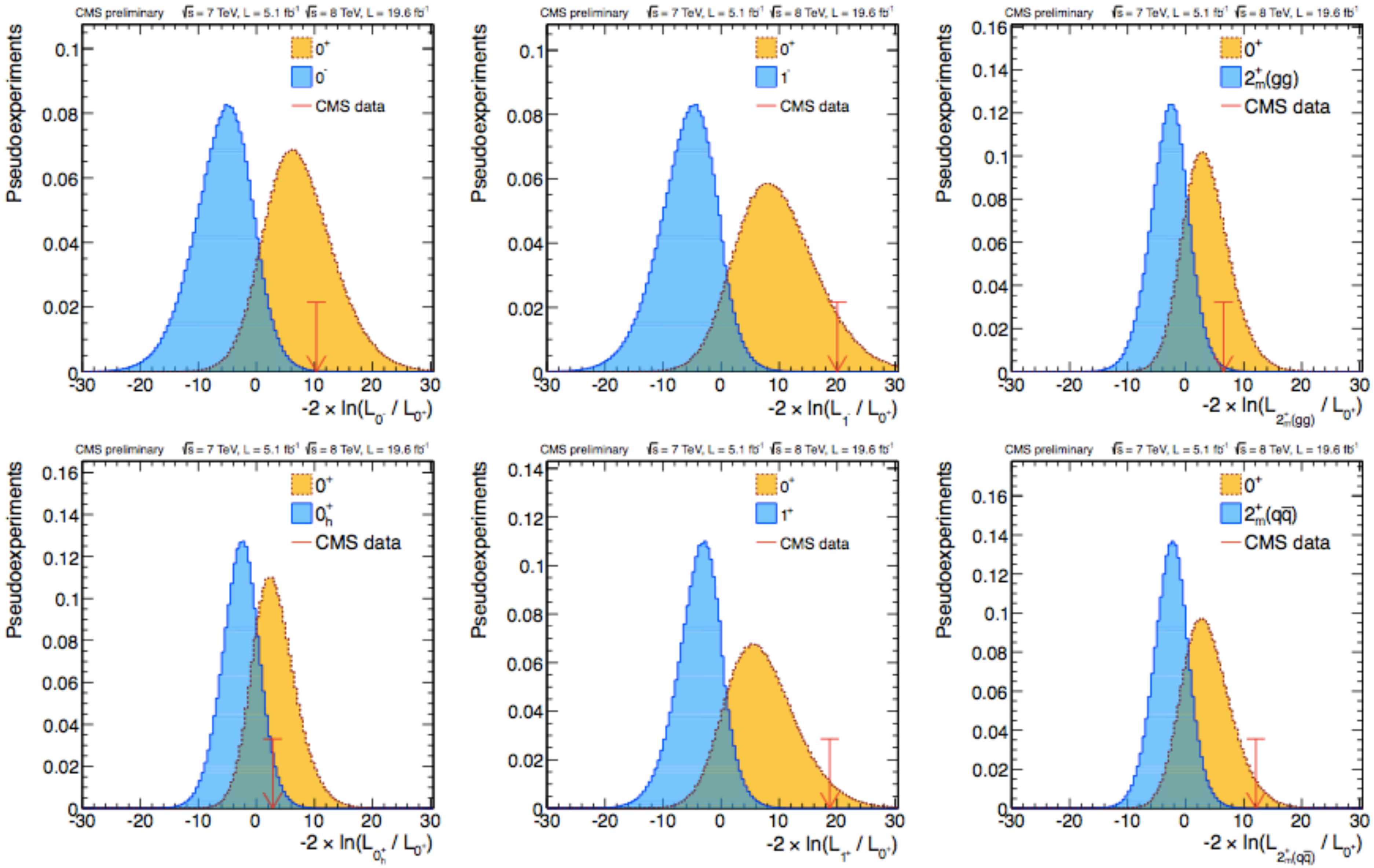
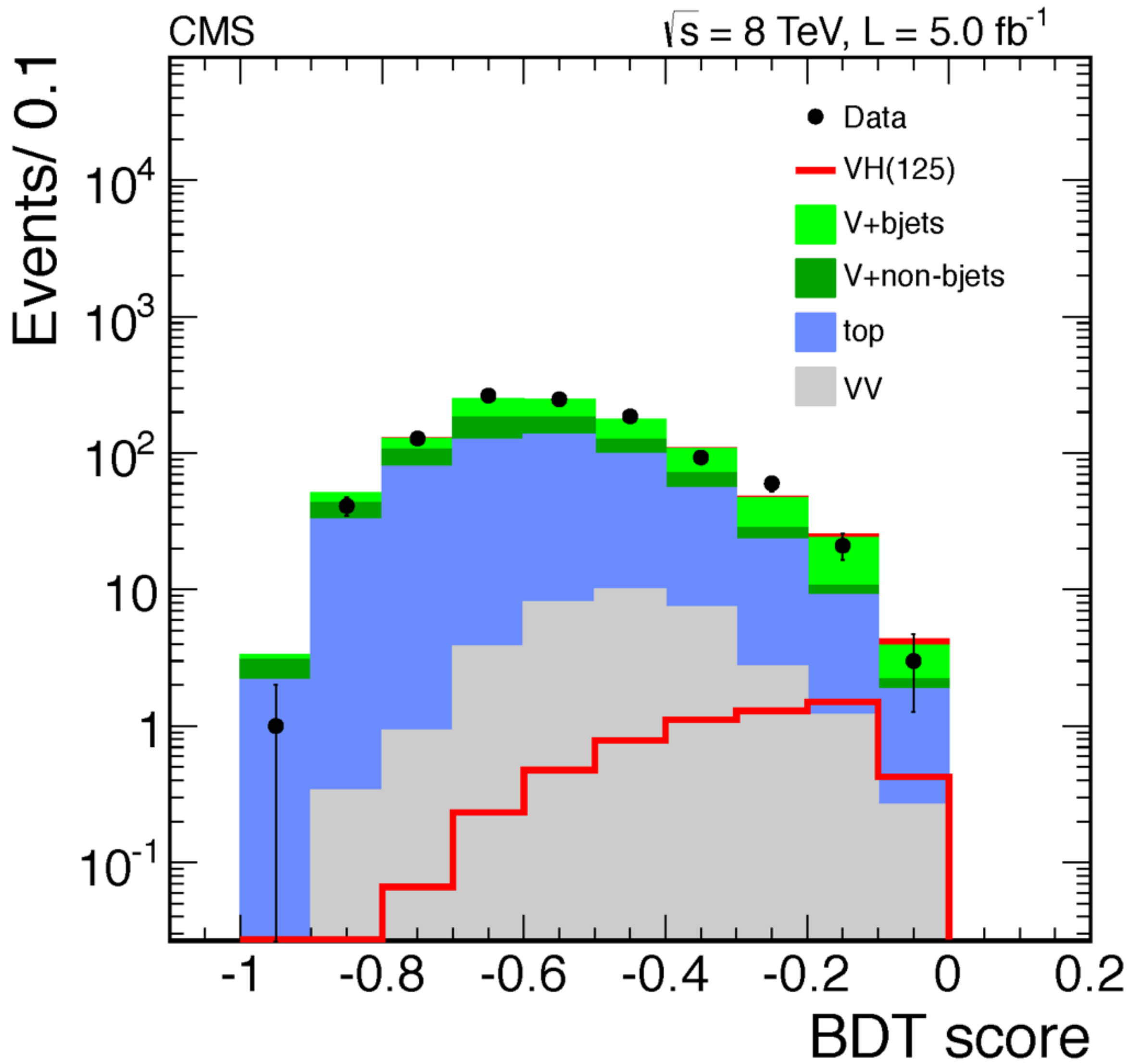
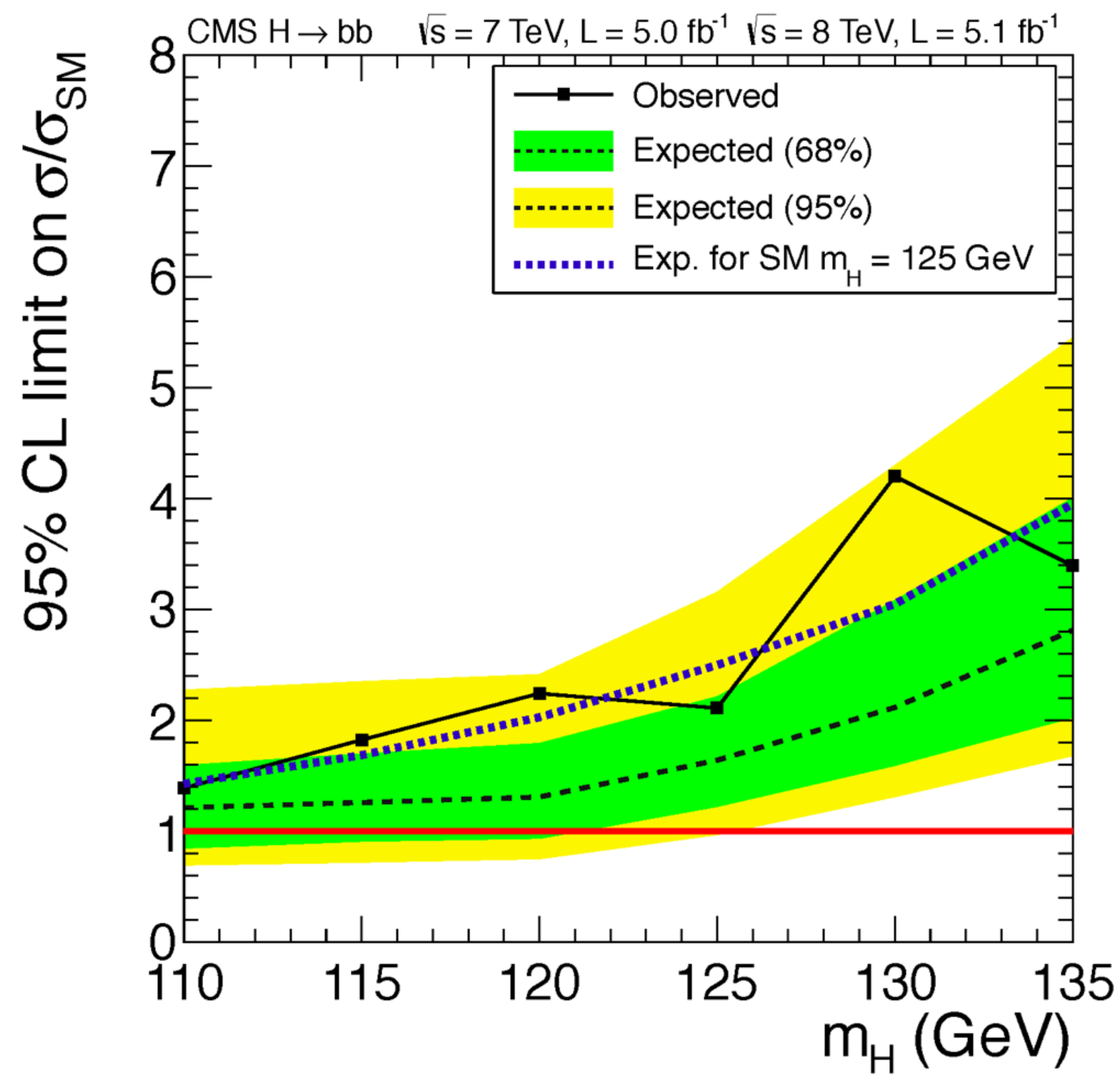


Figure 14: Distribution of $q = -2\ln(\mathcal{L}_{J^P}/\mathcal{L}_{\mathrm{SM}})$ for two signal types (0^+ represented by the yellow histogram and alternative J^P hypothesis by the blue histogram) for $m_H = 126$ GeV shown with a large number of generated experiments. The arrow indicates the observed value. Six alternative hypotheses are tested from top to bottom and left to right: $J^P = 0^-, 0^+_h, 1^-, 1^+, 2^+_{mgg}, 2^+_{mq\bar{q}}$.

Higgs to bb





- Most challenging channel
  - Higgs is searched in associated production WH, ZH to control QCD bb background
- Events are categorized by W/Z pt and its decay channel, i.e. $\ell\ \ell$, νν, ℓ ν
- Dominant backgrounds: V+bjets, Top

Exploring Couplings

- Effective Lagrangian approach: SM + "anomalous couplings"
  - Kinematic distributions are likely to be modified
  - In the simplest model one can looks for deviations only in coupling strength

$$(\sigma \cdot \mathrm{BR})(gg \to H \to \gamma\gamma) = \sigma_{SM}(gg \to H) \cdot \mathrm{BR}_{SM}(H \to \gamma\gamma) \cdot \frac{\kappa_g^2 \cdot \kappa_\gamma^2}{\kappa_H^2}$$

For Standard Model κ = 1

Production modes

$$\frac{\sigma_{ggH}}{\sigma_{ggH}^{SM}} = \begin{cases} \kappa_g^2(\kappa_b, \kappa_t, m_H) \\ \kappa_g^2 \end{cases} \quad (3)$$

$$\frac{\sigma_{VBF}}{\sigma_{VBF}^{SM}} = \kappa_{VBF}^2(\kappa_W, \kappa_Z, m_H) \quad (4)$$

$$\frac{\sigma_{WH}}{\sigma_{WH}^{SM}} = \kappa_W^2 \quad (5)$$

$$\frac{\sigma_{ZH}}{\sigma_{ZH}^{SM}} = \kappa_Z^2 \quad (6)$$

$$\frac{\sigma_{t\bar{t}H}}{\sigma_{t\bar{t}H}^{SM}} = \kappa_t^2 \quad (7)$$

Detectable decay modes

$$\frac{\Gamma_{WW^{(*)}}}{\Gamma_{WW^{(*)}}^{SM}} = \kappa_W^2 \quad (8)$$

$$\frac{\Gamma_{ZZ^{(*)}}}{\Gamma_{ZZ^{(*)}}^{SM}} = \kappa_Z^2 \quad (9)$$

$$\frac{\Gamma_{b\bar{b}}}{\Gamma_{b\bar{b}}^{SM}} = \kappa_b^2 \quad (10)$$

$$\frac{\Gamma_{\tau^-\tau^+}}{\Gamma_{\tau^-\tau^+}^{SM}} = \kappa_\tau^2 \quad (11)$$

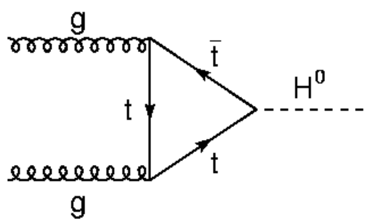
$$\frac{\Gamma_{\gamma\gamma}}{\Gamma_{\gamma\gamma}^{SM}} = \begin{cases} \kappa_\gamma^2(\kappa_b, \kappa_t, \kappa_\tau, \kappa_W, m_H) \\ \kappa_\gamma^2 \end{cases} \quad (12)$$

$$\frac{\Gamma_{Z\gamma}}{\Gamma_{Z\gamma}^{SM}} = \begin{cases} \kappa_{(Z\gamma)}^2(\kappa_b, \kappa_t, \kappa_\tau, \kappa_W, m_H) \\ \kappa_{(Z\gamma)}^2 \end{cases} \quad (13)$$

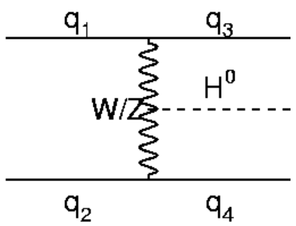
Benchmark Parametrization

- A number of parameterizations can be derived with different assumptions
  - LHC HXSWG interim recommendations to explore the coupling structure of a Higgs-like particle (arXiv:1209.0040)
- Simplest model - common scale factor: $\kappa = \kappa_t = \kappa_b = \kappa_\tau = \kappa_W = \kappa_Z$
  - ATLAS: $\kappa = 1.4 \pm 0.3$
  - CMS: $\kappa = 0.87 \pm 0.23$
- Scaling of vector boson and fermion couplings
  - Higgs can play a different role in vector boson and fermion sectors

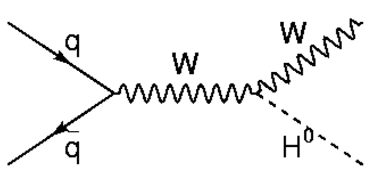
ggH



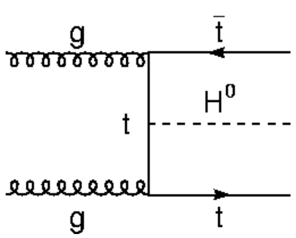
VBF



WH



ttH



Boson and fermion scaling assuming no invisible or undetectable widths

Free parameters: $\kappa_V (= \kappa_W = \kappa_Z)$, $\kappa_f (= \kappa_t = \kappa_b = \kappa_\tau)$.

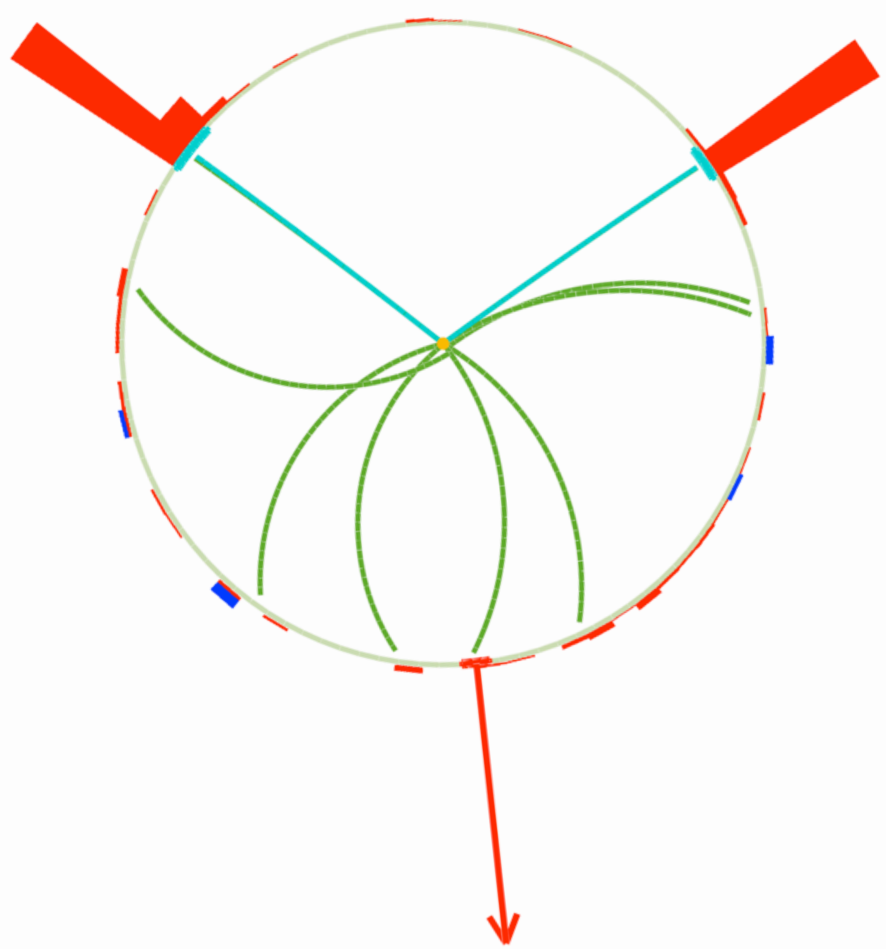
	$H \to \gamma\gamma$	$H \to ZZ^{(*)}$	$H \to WW^{(*)}$	$H \to b\bar{b}$	$H \to \tau^-\tau^+$
ggH $t\bar{t}H$	$\frac{\kappa_f^2 \cdot \kappa_\gamma^2(\kappa_f,\kappa_f,\kappa_f,\kappa_V)}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_f^2 \cdot \kappa_V^2}{\kappa_H^2(\kappa_i)}$		$\frac{\kappa_f^2 \cdot \kappa_f^2}{\kappa_H^2(\kappa_i)}$	
VBF WH ZH	$\frac{\kappa_V^2 \cdot \kappa_\gamma^2(\kappa_f,\kappa_f,\kappa_f,\kappa_V)}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_V^2 \cdot \kappa_V^2}{\kappa_H^2(\kappa_i)}$		$\frac{\kappa_V^2 \cdot \kappa_f^2}{\kappa_H^2(\kappa_i)}$	

Spin Study Hypotheses

TABLE I: List of scenarios chosen for the analysis of the production and decay of an exotic X particle with quantum numbers J^P. The subscripts m (minimal couplings) and h (couplings with higher-dimension operators) distinguish different scenarios, as discussed in the last column. The spin-zero and spin-one X production parameters do not affect the angular and mass distributions, and therefore are not specified.

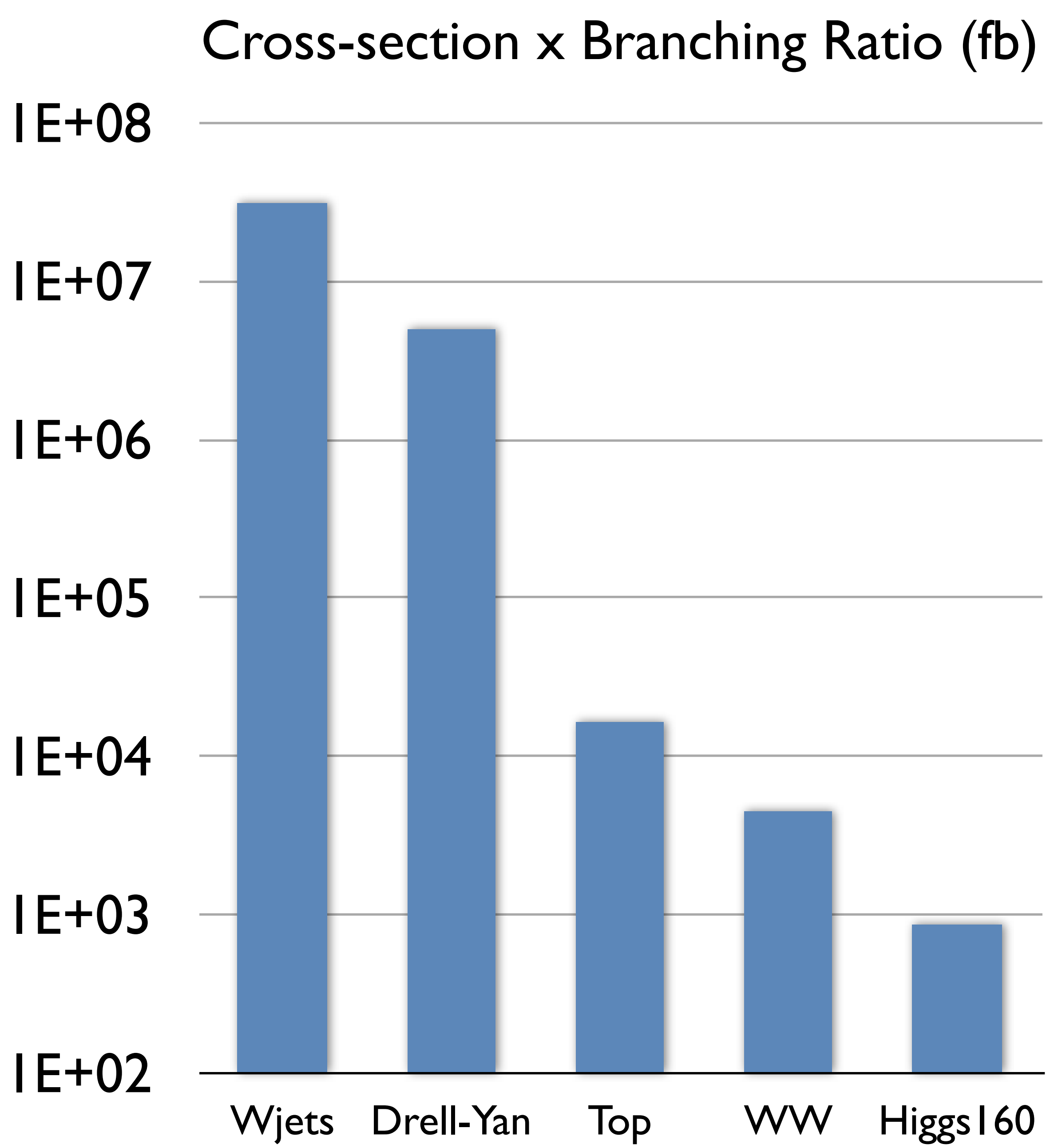
scenario	X production	$X \to VV$ decay	comments
0^+_m	$gg \to X$	$g_1^{(0)} \neq 0$ in Eq. (9)	SM Higgs boson scalar
0^+_h	$gg \to X$	$g_2^{(0)} \neq 0$ in Eq. (9)	scalar with higher-dimension operators
0^-	$gg \to X$	$g_4^{(0)} \neq 0$ in Eq. (9)	pseudo-scalar
1^+	$q\bar{q} \to X$	$b_2 \neq 0$ in Eq. (16)	exotic pseudo-vector
1^-	$q\bar{q} \to X$	$b_1 \neq 0$ in Eq. (16)	exotic vector
2^+_m	$g_1^{(2)} \neq 0$ in Eq. (18)	$g_1^{(2)} = g_5^{(2)} \neq 0$ in Eq. (18)	graviton-like tensor with minimal couplings
2^+_h	$g_4^{(2)} \neq 0$ in Eq. (18)	$g_4^{(2)} \neq 0$ in Eq. (18)	tensor with higher-dimension operators
2^-_h	$g_8^{(2)} \neq 0$ in Eq. (18)	$g_8^{(2)} \neq 0$ in Eq. (18)	"pseudo-tensor"

Higgs → WW → 2l2ν



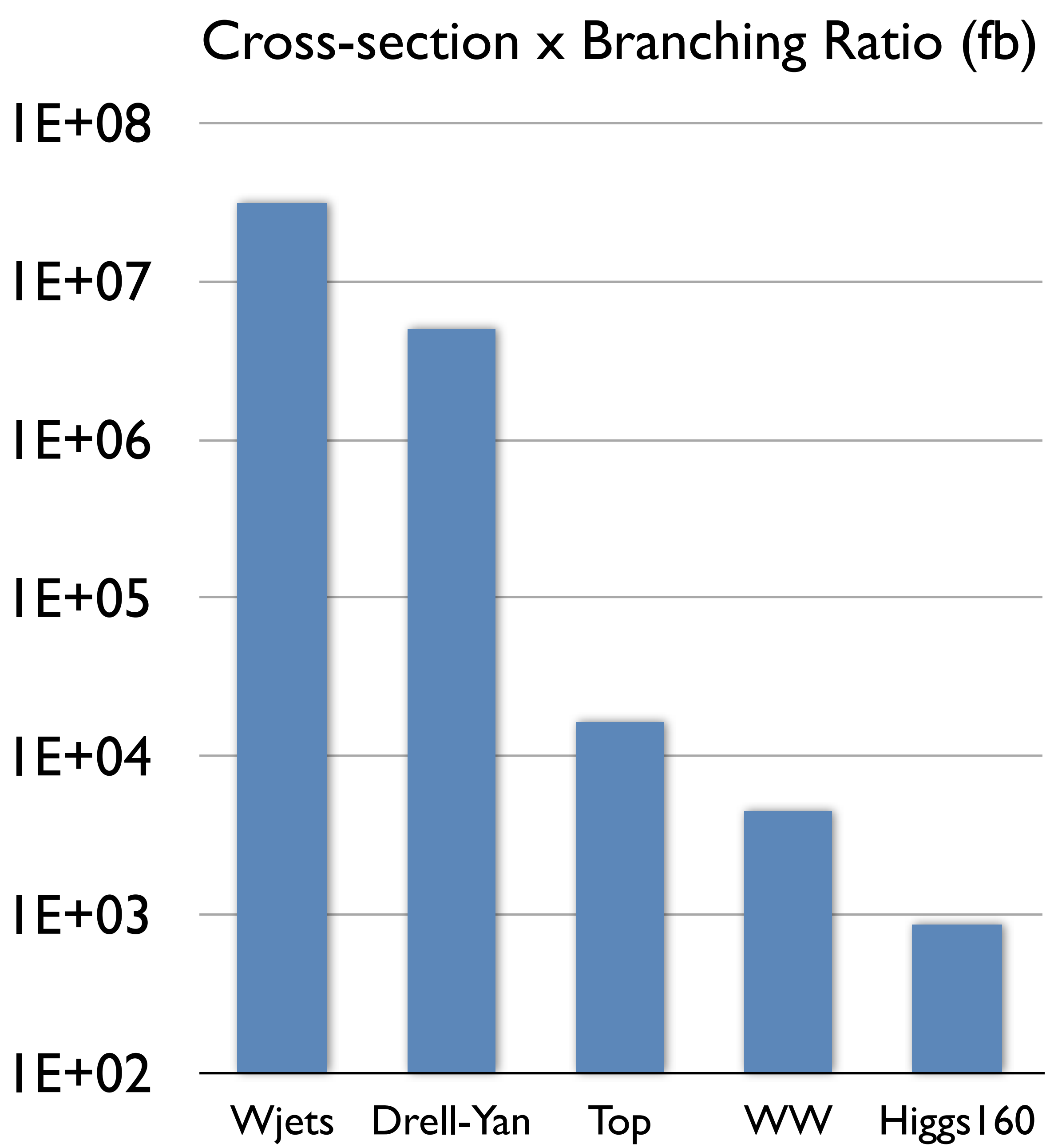
- **Higgs Signature**:
  - 2 isolated leptons (electron or muon)
  - large missing energy
- **Sensitivity**: low and high mass
- Highest rate with manageable background
- Counting experiment, no mass peak

Analysis Challenges



- No mass is reconstructed - essentially a **counting experiment**
- Key selection requirements:
  - lepton pt>10 GeV with tight identification and isolation - **QCD, Wjets**
  - large missing transverse energy (MET) and Z veto - **Drell-Yan**
  - number of jet classification (Pt>30GeV) and b-quark veto - **Top**
  - kinematics (m_{ll}, dφ) - **WW**
- Final step selection requirements are optimized for different Higgs mass hypotheses

Analysis Challenges



- No mass is reconstructed - essentially a **counting experiment**
- **Underestimation of any background can lead to a signal like excess!**
  - **Background estimation is the most important part of the analysis**

Wjets

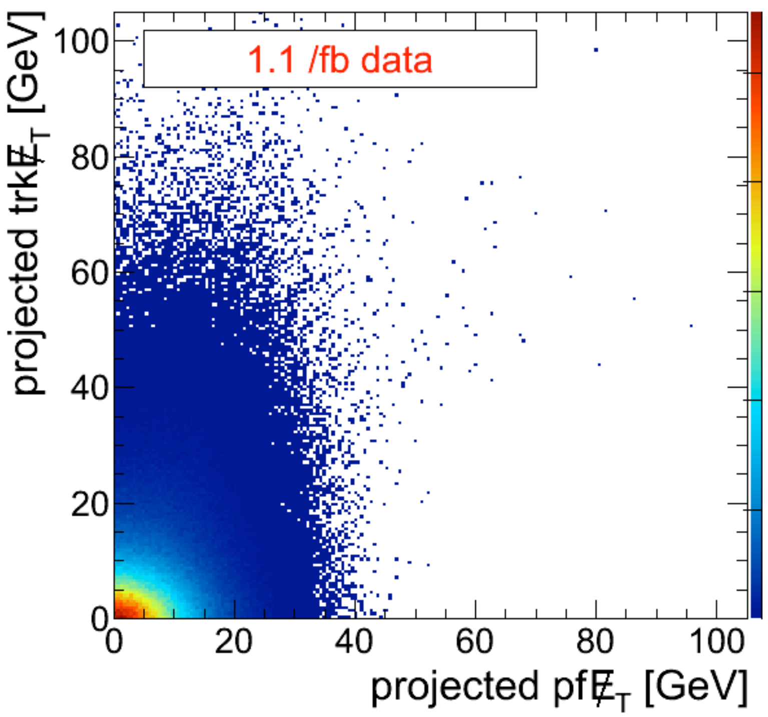
A Loose !Tight **QCD**	B Tight **QCD**
C Loose !Tight **Data**	D Tight **Data**

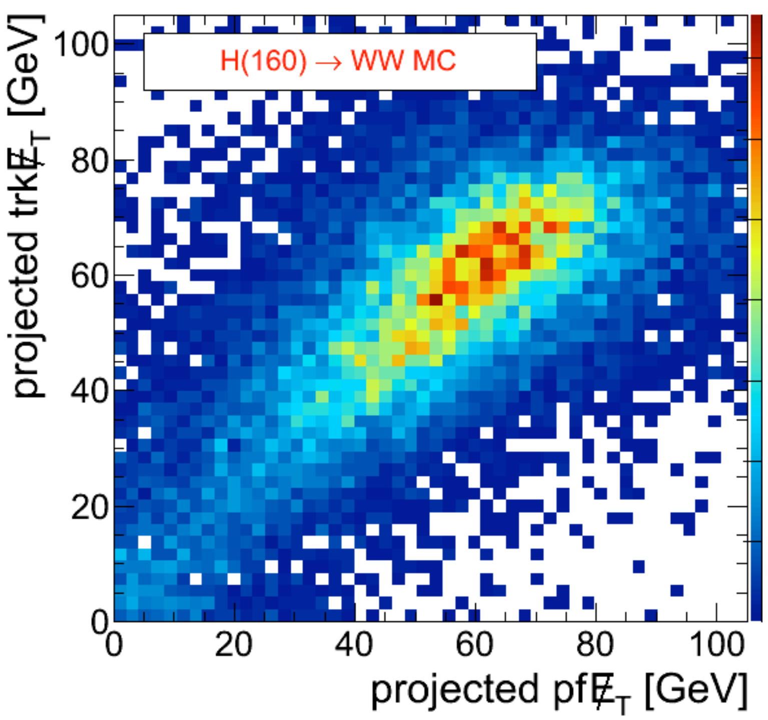
- Jets - main source of fakes
- Requirements: pt, isolation, impact parameter, quality
- Tight →Loose: 10-100 time more fake leptons
- Use QCD sample to measure fake rate: $\varepsilon = N_B/N_A$
- Background estimation:

$$N_D = N_C \frac{\varepsilon}{1-\varepsilon}$$

Systematic uncertainty of the method: ~35%

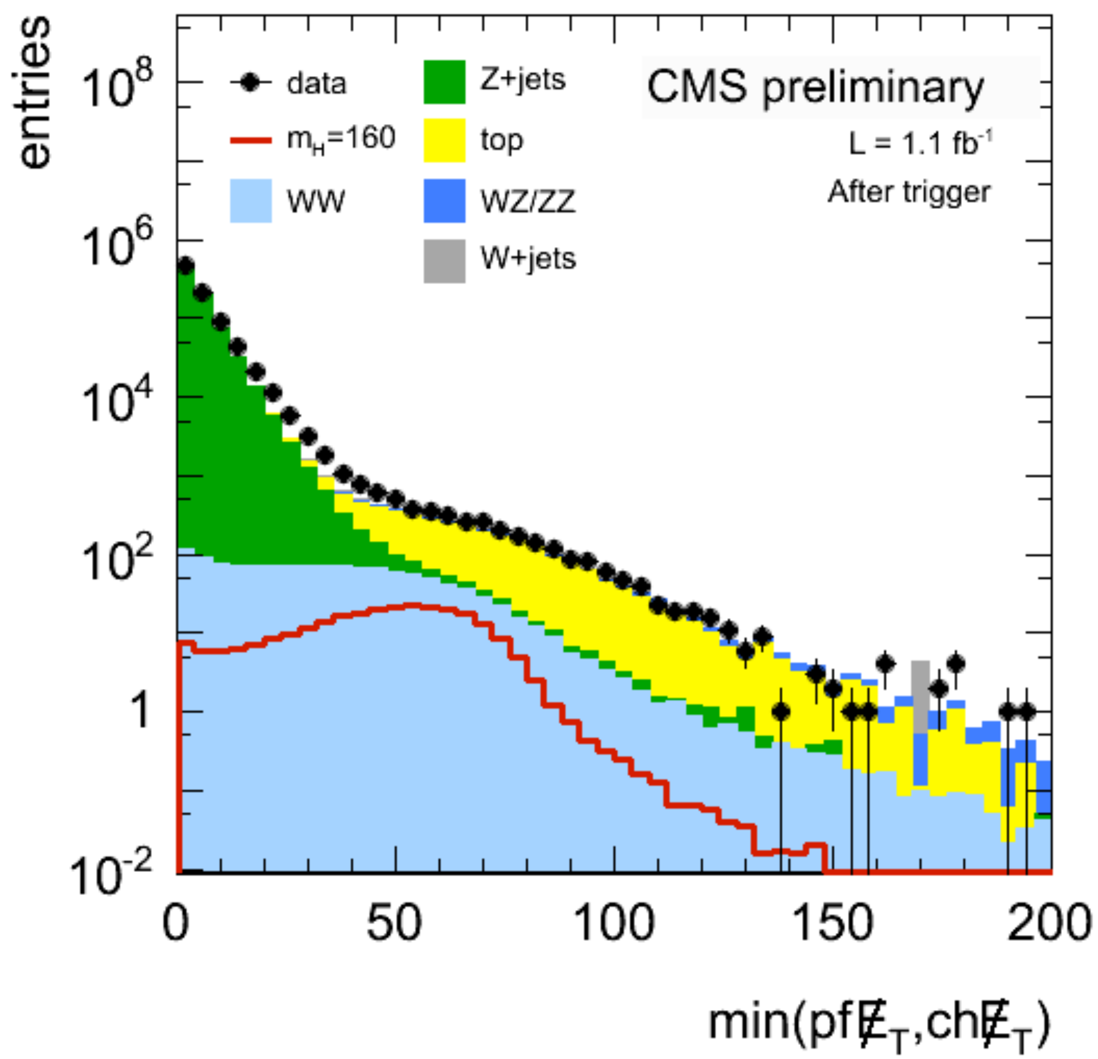
Missing Energy with PileUp





- **2011 data differs from 2010**:
  - ~8 interactions per bunch crossing
  - larger tails in the missing energy distribution
- **Two different MET variables**:
  - nominal - calorimeter and tracker
  - only tracker based MET
    - not affected by pile up
- **pfMET and trkMET are weakly correlated for backgrounds**
  - use the smaller one for each event
  - minMet>40 (same flavor)
  - minMet>20 (opposite flavor)

Drell-Yan Estimation

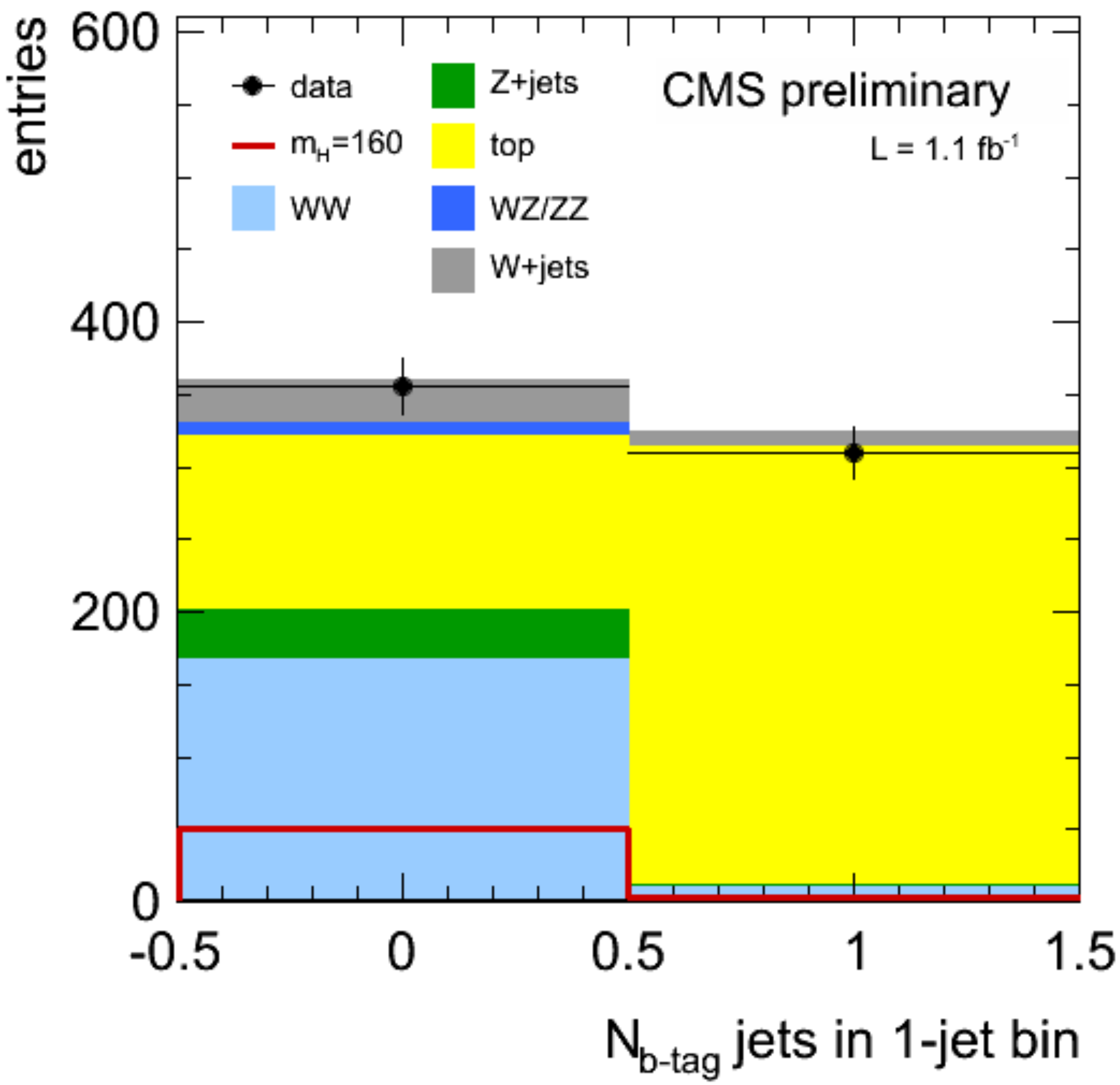


- Drell-Yan: ee/μμ, but not eμ
- Use eμ events to subtract backgrounds
- Narrow Z-peak - little background
- Rout/in is measure both in simulation and in data
- Systematic uncertainties can be as large as 100%

$$N_{out}^{ll,exp} = R_{out/in}^{ll,loose}(N_{in}^{ll} - 0.5N_{in}^{e\mu}k_{ll} - N_{\text{control}}^{\text{ZV, sim.}})$$

- N_{in}^{ll}: same flavor events measured in Z-peak
- $N_{in}^{e\mu}$: opposite flavor events measured in Z-peak
- k_{ll}: correction for differences in lepton efficiency
- $N_{\text{control}}^{\text{ZV, sim.}}$: expected VZ contribution from MC

Top Background

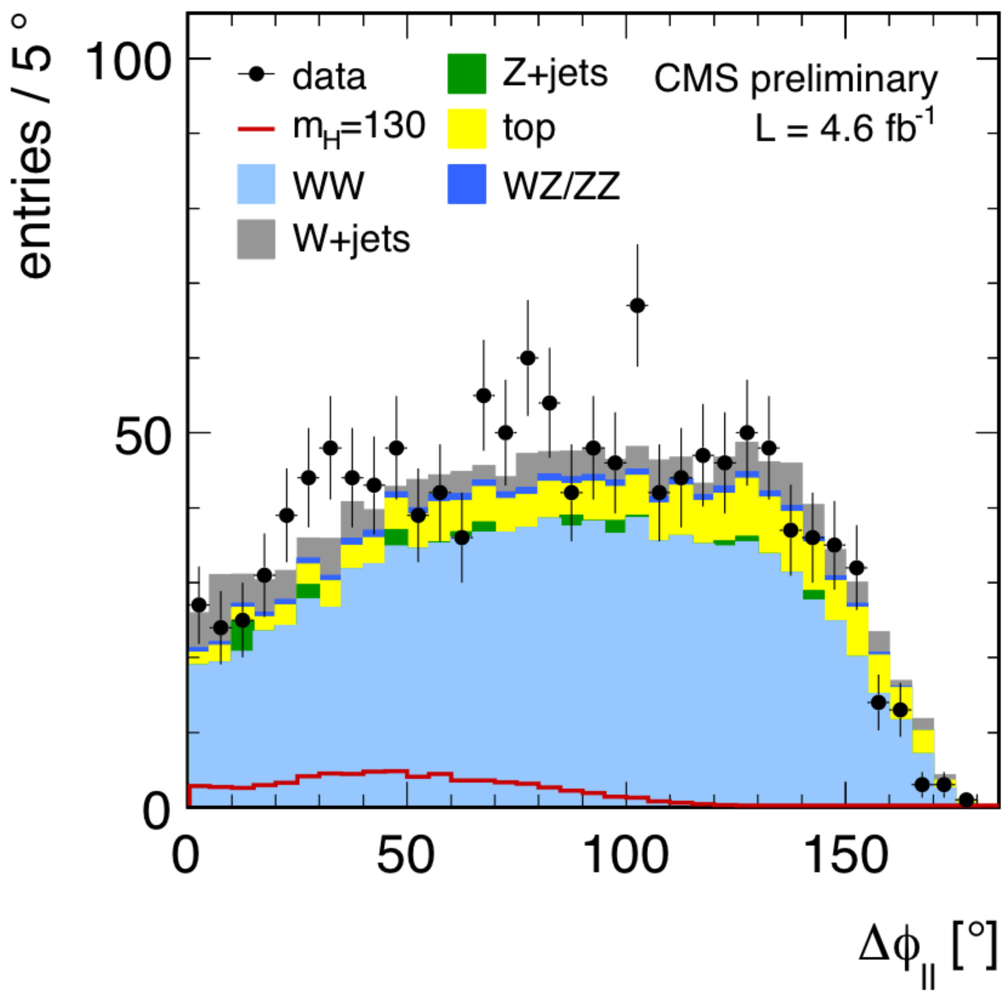


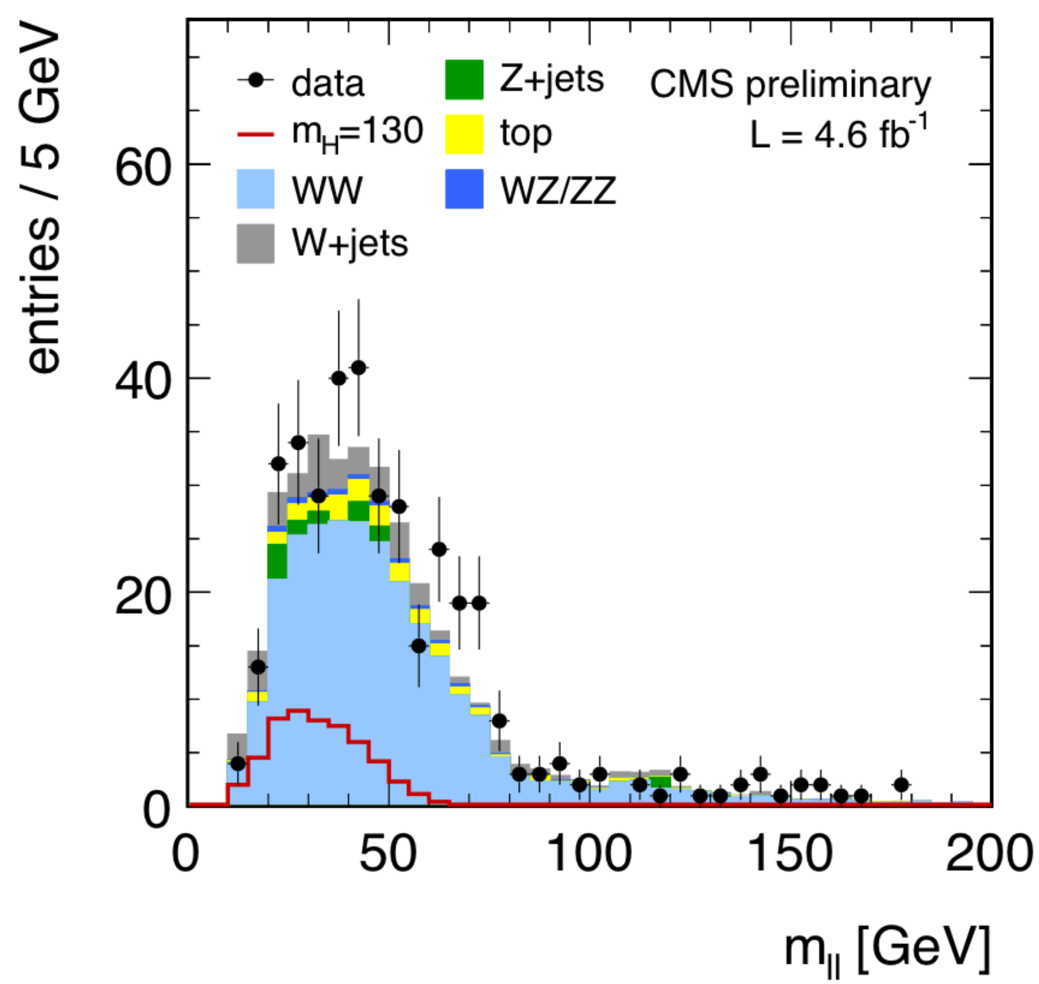
- Jet veto kills top
- Remaining top can be tagged:
  - soft b-jets
  - soft muons
- Top tagging eff is ~50% for 0-jet
- Estimate residual top:

$$N_{top} = N_{tag} \frac{\varepsilon}{1 - \varepsilon}$$

- Measure ε in 1-bjet events
  - There mast be another b-quark
- Systematics ~ 20-30%

WW Background





- **WW is an irreducible background** - one order of magnitude larger SM Higgs
- **Kinematics is the main discriminator**:
  - low mass - dPhi, Mll
    - for mH≤130 need to lower lepton pt → larger Wjets background
  - above 200GeV - WW and Higgs harder to distinguish
- **Use signal free events to calibrate WW yield**