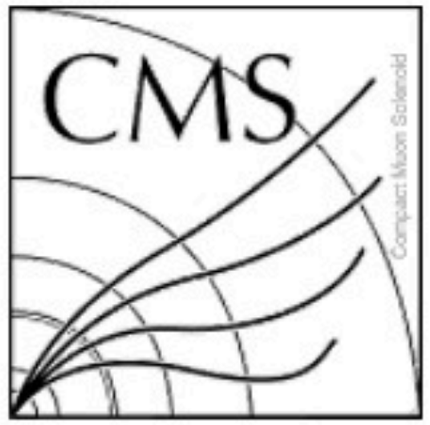
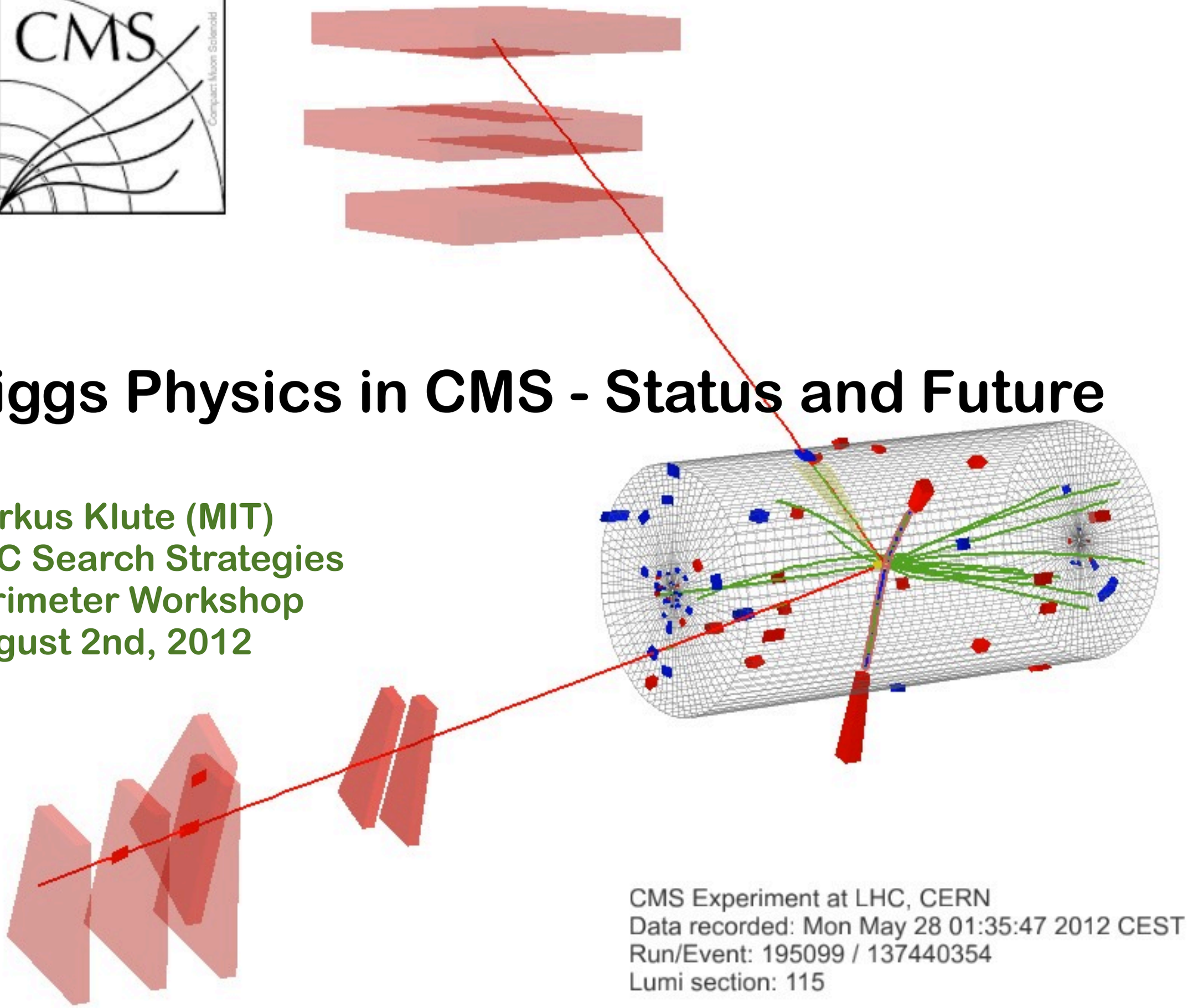


Higgs Physics in CMS - Status and Future

Markus Klute (MIT)

LHC Search Strategies
Perimeter Workshop
August 2nd, 2012



We have it! Do we?

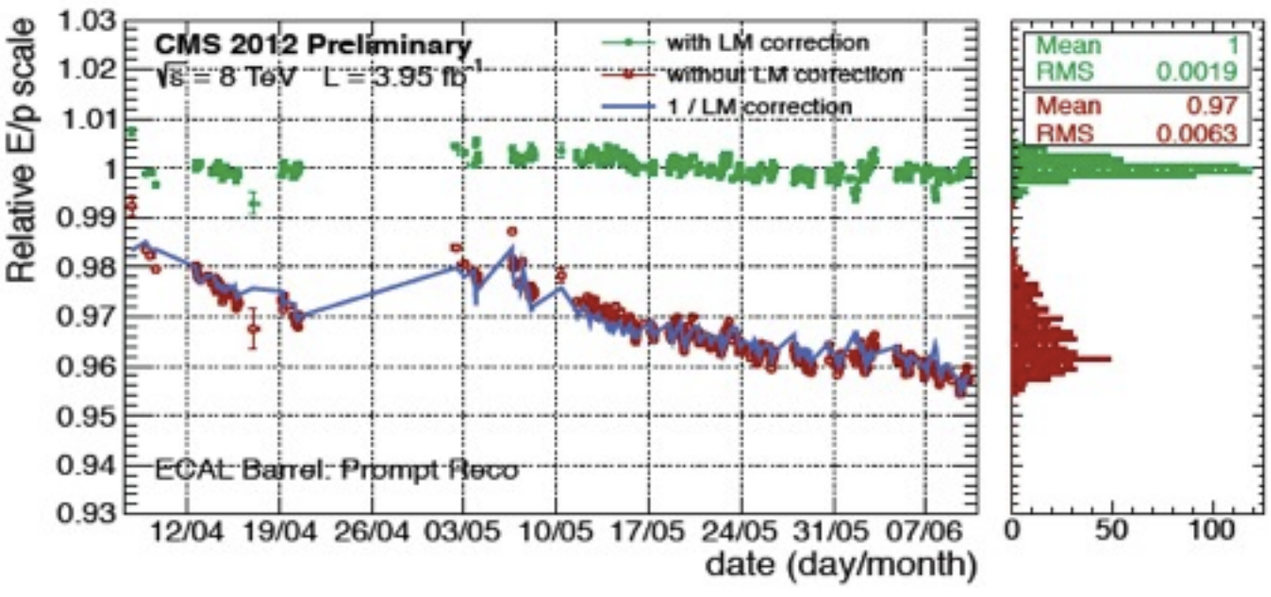
- We have something to celebrate!
- 5σ excess observed, 5.8σ expected
- New state with mass of 125.3 ± 0.6 GeV
- Consistent with SM prediction
  - more data and more studies are needed to draw conclusions
- HIG-12-028, arXiv:1207.735 submitted to Phys. Lett. B
- Going forward with two prong approach
  - characterize new state
  - continue search for BSM physics in the Higgs sector

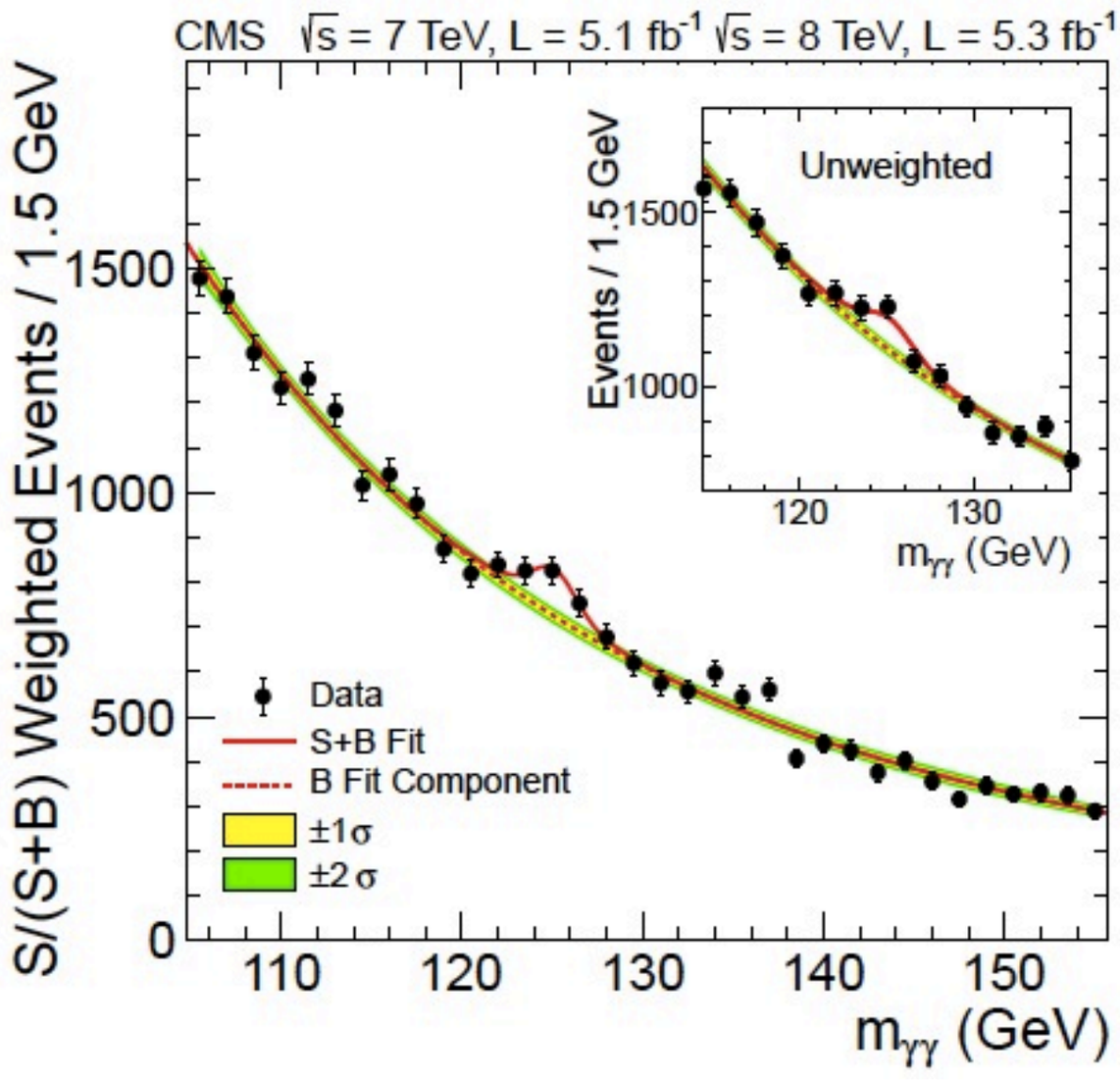
Master table of SM Higgs searches

Channel	Mass range [GeV]	Lumi'11 [1/fb]	Lumi'12 [1/fb]	Topologies	gF	VBF	VH	ttH
H → γγ	110-150	5.1	5.3	incl. + VBF	☺	☺	-	-
H → ττ	110-145	4.9	5.0	0/1 jet + VBF + WH + ZH	☺	☺	☺	-
H → bb	110-135	5.0	5.0	WH + ZH + ttH	-	-	☺	☺
H → ZZ → 4l	110-600	5.1	5.3	inclusive	☺	-	-	-
H → WW → 2l2v	110-600	4.9	5.3	0/1 jet + VBF + WH + ZH	☺	☺	☺	-
H → ZZ → 2l2v	200-600	5.0	5.0	0/1 jet + VBF	☺	☺	-	-
H → ZZ → 2l2q	130-600	4.9	-	0/1/2 b-tags	☺	-	-	-
H → WW → lvqq	240-600	4.9	5.1	inclusive	☺	-	-	-

Discovery channel: H → γγ

- Search for narrow resonance in di-photon mass spectrum
- Events categorized by mass resolution, event kinematics and primary vertex probability
- Multivariate analysis techniques deployed
- Di-jet categories to target VBF production
- Reprocessed 2011 data with improved calibration
- 2012 reconstructed using prompt calibration loop (laser monitoring)

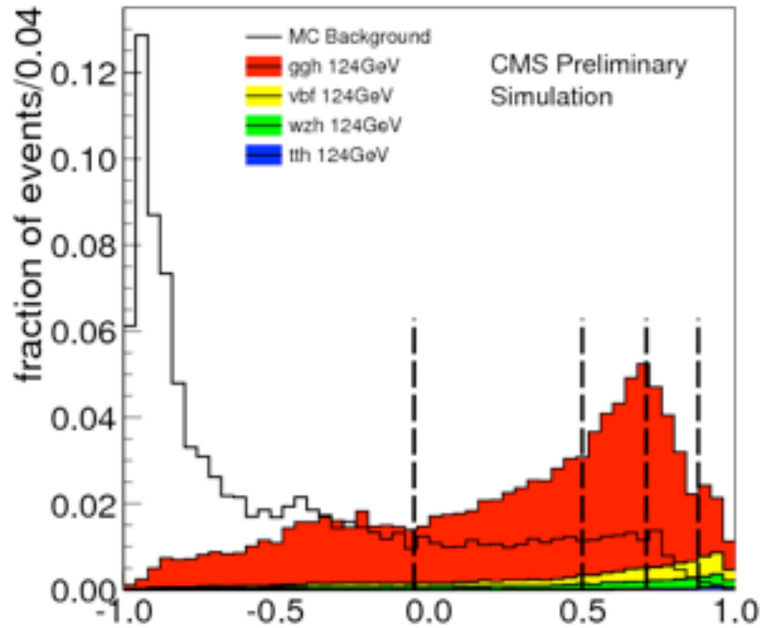




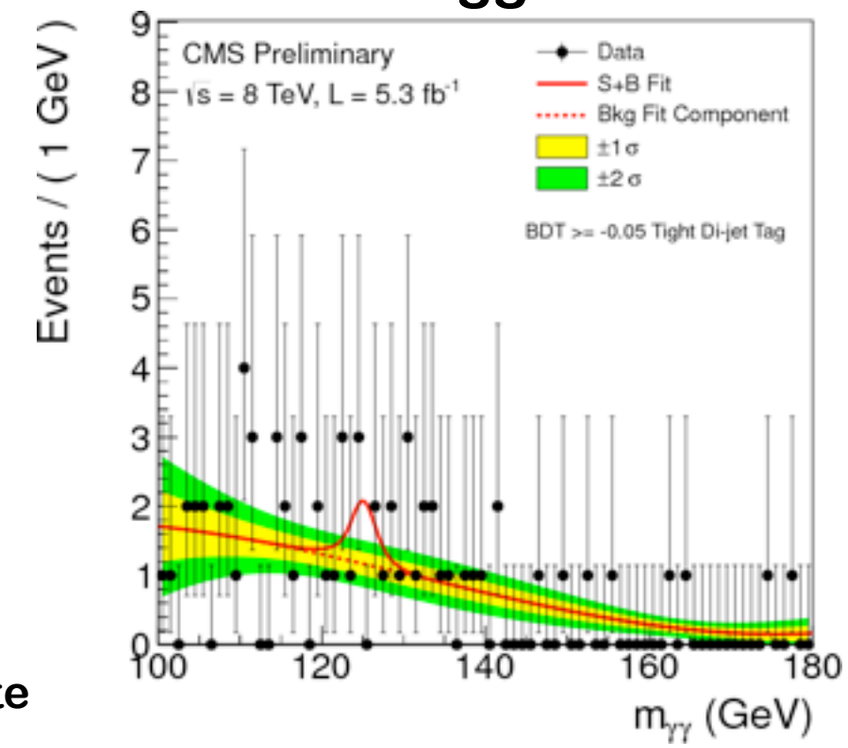
Discovery channel: H → γγ

Expected signal and estimated background

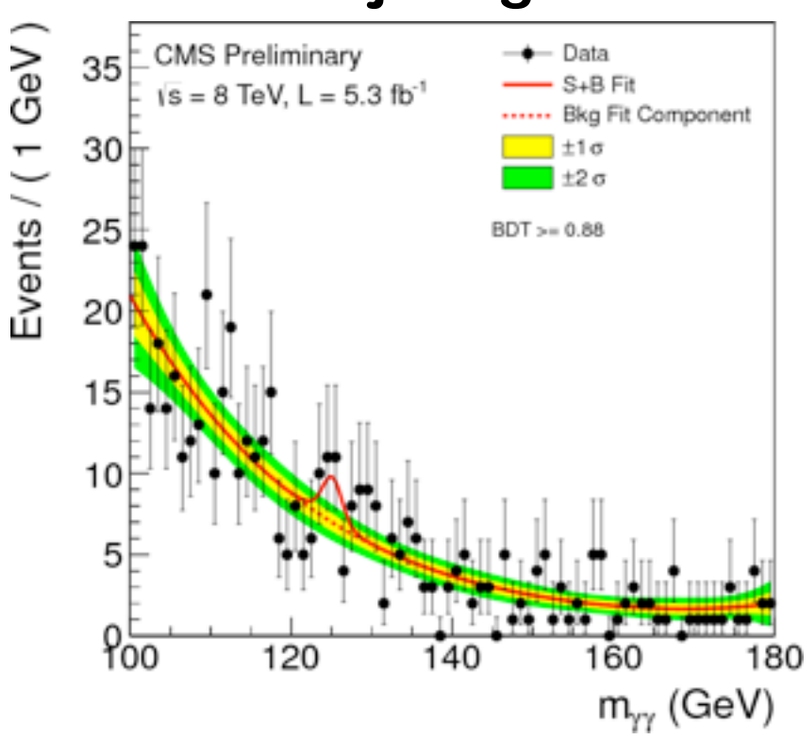
Event classes		SM Higgs boson expected signal (m_H=125 GeV) Total	ggH	VBF	VH	ttH	σ_{eff} (GeV)	FWHM/2.35 (GeV)	Background $m_{\gamma\gamma}$ = 125 GeV (ev./GeV)
7 TeV 5.1 fb^{-1}	Untagged 0	3.2	61%	17%	19%	3%	1.21	1.14	3.3 ± 0.4
	Untagged 1	16.3	88%	6%	6%	1%	1.26	1.08	37.5 ± 1.3
	Untagged 2	21.5	91%	4%	4%	–	1.59	1.32	74.8 ± 1.9
	Untagged 3	32.8	91%	4%	4%	–	2.47	2.07	193.6 ± 3.0
	Dijet tag	2.9	27%	73%	1%	–	1.73	1.37	1.7 ± 0.2
8 TeV 5.3 fb^{-1}	Untagged 0	6.1	68%	12%	16%	4%	1.38	1.23	7.4 ± 0.6
	Untagged 1	21.0	88%	6%	6%	1%	1.53	1.31	54.7 ± 1.5
	Untagged 2	30.2	92%	4%	3%	–	1.94	1.55	115.2 ± 2.3
	Untagged 3	40.0	92%	4%	4%	–	2.86	2.35	256.5 ± 3.4
	Dijet tight	2.6	23%	77%	–	–	2.06	1.57	1.3 ± 0.2
	Dijet loose	3.0	53%	45%	2%	–	1.95	1.48	3.7 ± 0.4



Untagged 0

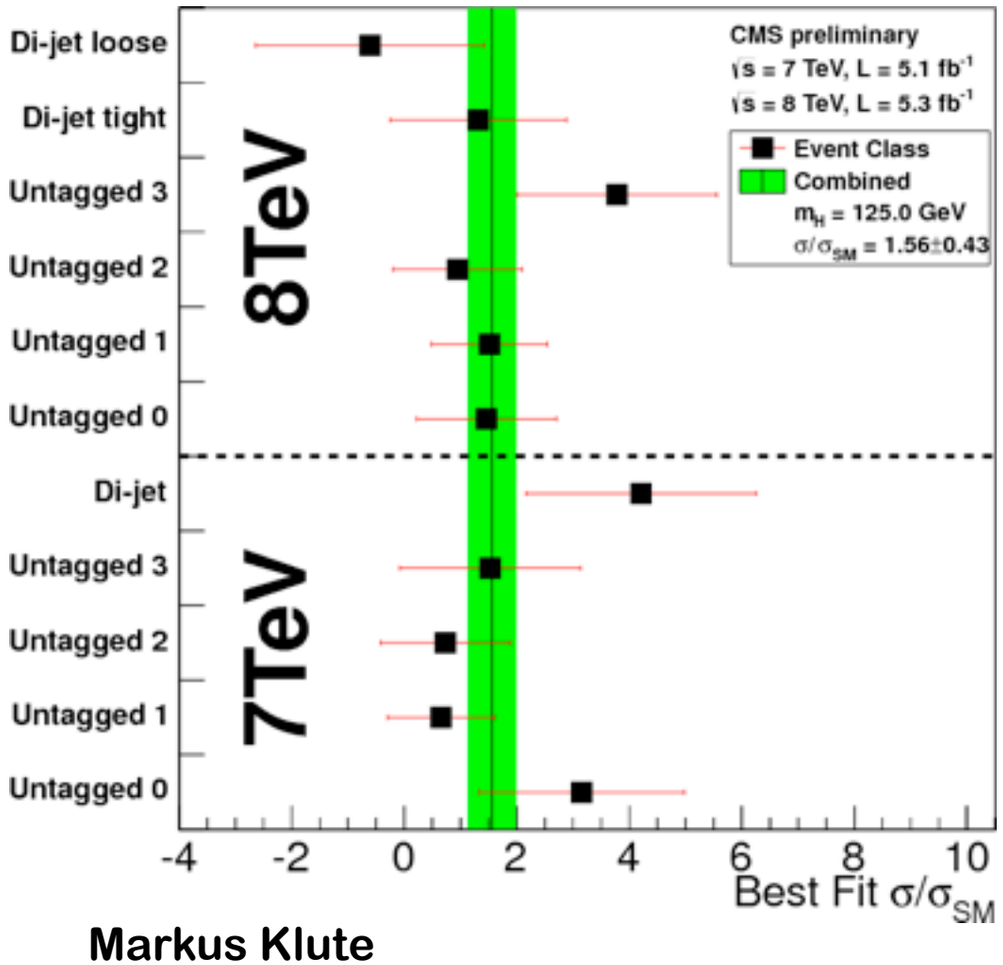


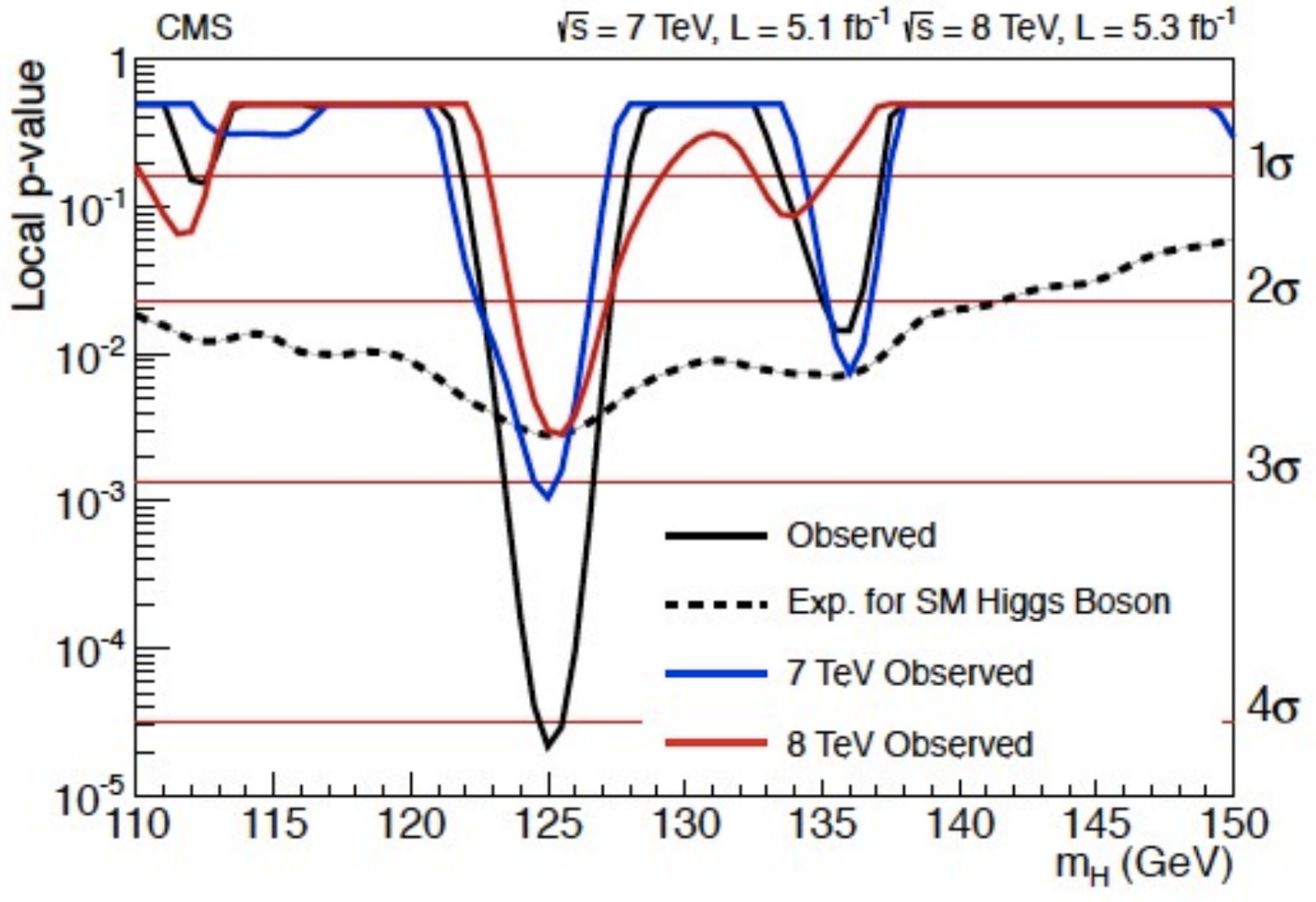
Dijet tight



Discovery channel: H → γγ

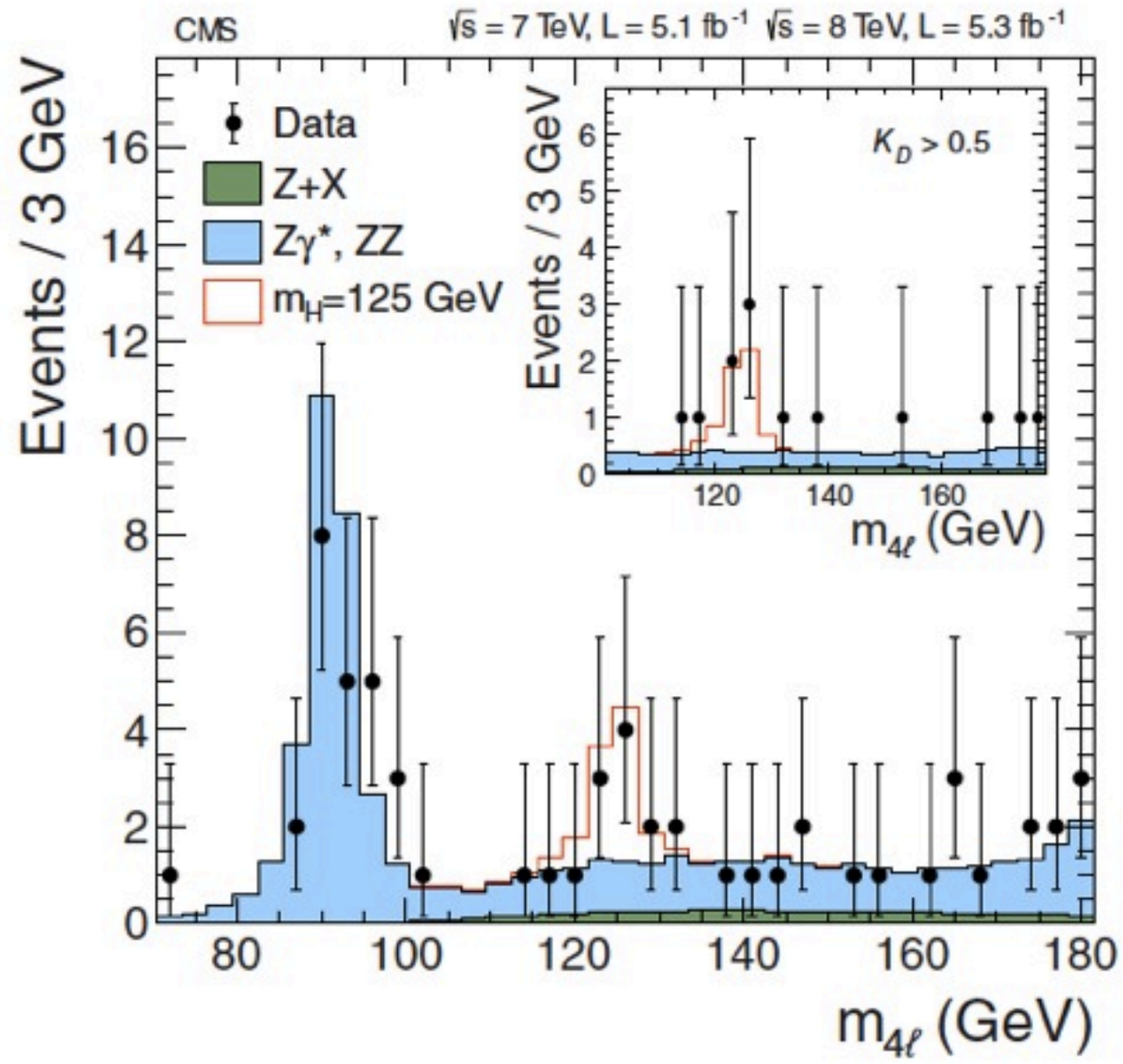
- Significant excess observed at 125 GeV
- Consistent between categories
- Consistent in 7 and 8 TeV data
- Local significance 4.1
- Signal strength 1.6 ± 0.4





Discovery channel: H → ZZ → 4l

- **Lepton selection**
  - muons: pT > 5 GeV, |η| < 2.4, isolated
  - electrons: pT > 7 GeV, |η| < 2.5, isolated
  - at least one (two) lepton with pT > 20 (10) GeV
- **Z candidates**
  - di-lepton pair with m(ll) closest to mZ
  - apply: 40 < m(ll) < 120 GeV
  - build from remaining highest pT leptons
  - apply: 12 < m(ll) < 120 GeV
- **Backgrounds**
  - Irreducible: ZZ*
  - Reducible: Z+jets/ttbar/WZ
- **Substantial changes to the analysis**
  - New lepton identification and isolation
  - Final state radiation (FSR) recovery
  - 2D analysis: use of mass and angular information



Discovery channel: H → ZZ → 4l

- **Decay kinematic fully described by 5 angles and 2 masses**
  - **discriminates spin 0 particle from background**
  - **analogous of $\Delta\phi$ in H → WW analysis**
  - **MELA: matrix element likelihood analysis**

$$\mathrm{MELA} = \left[1 + \frac{\mathcal{P}_{\mathrm{bkg}}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}{\mathcal{P}_{\mathrm{sig}}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}\right]^{-1}$$

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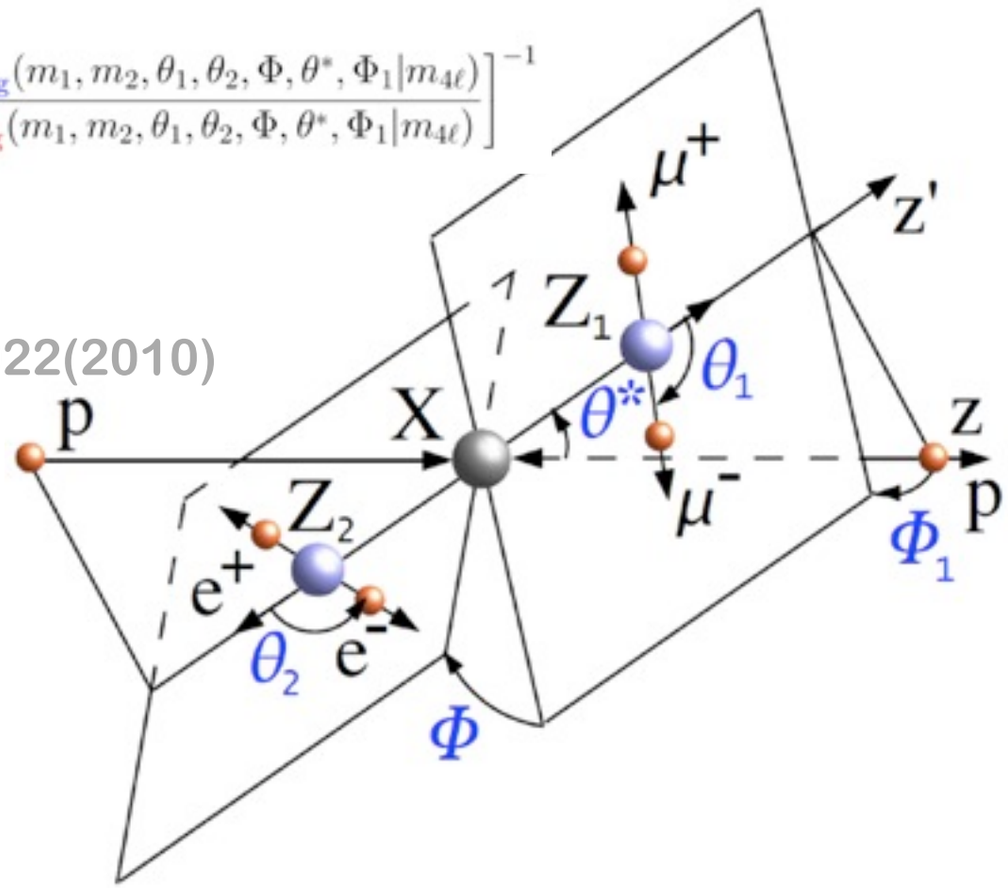
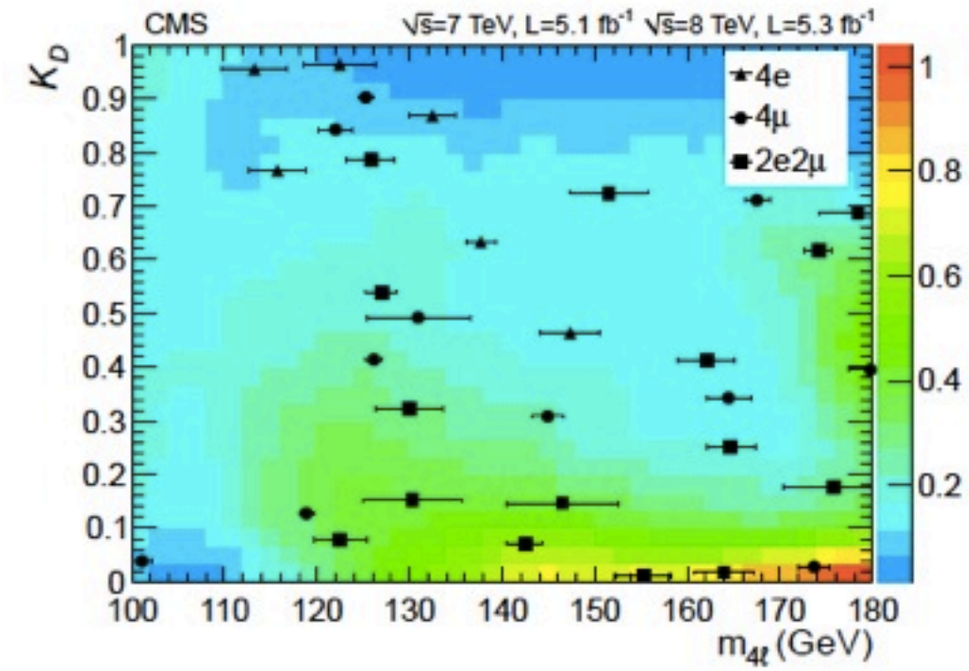
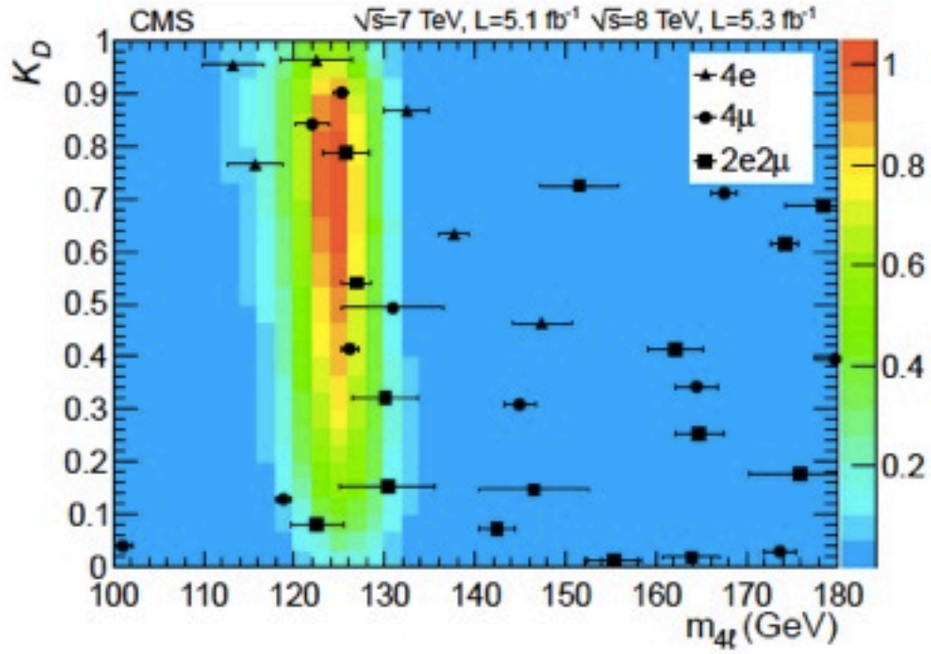


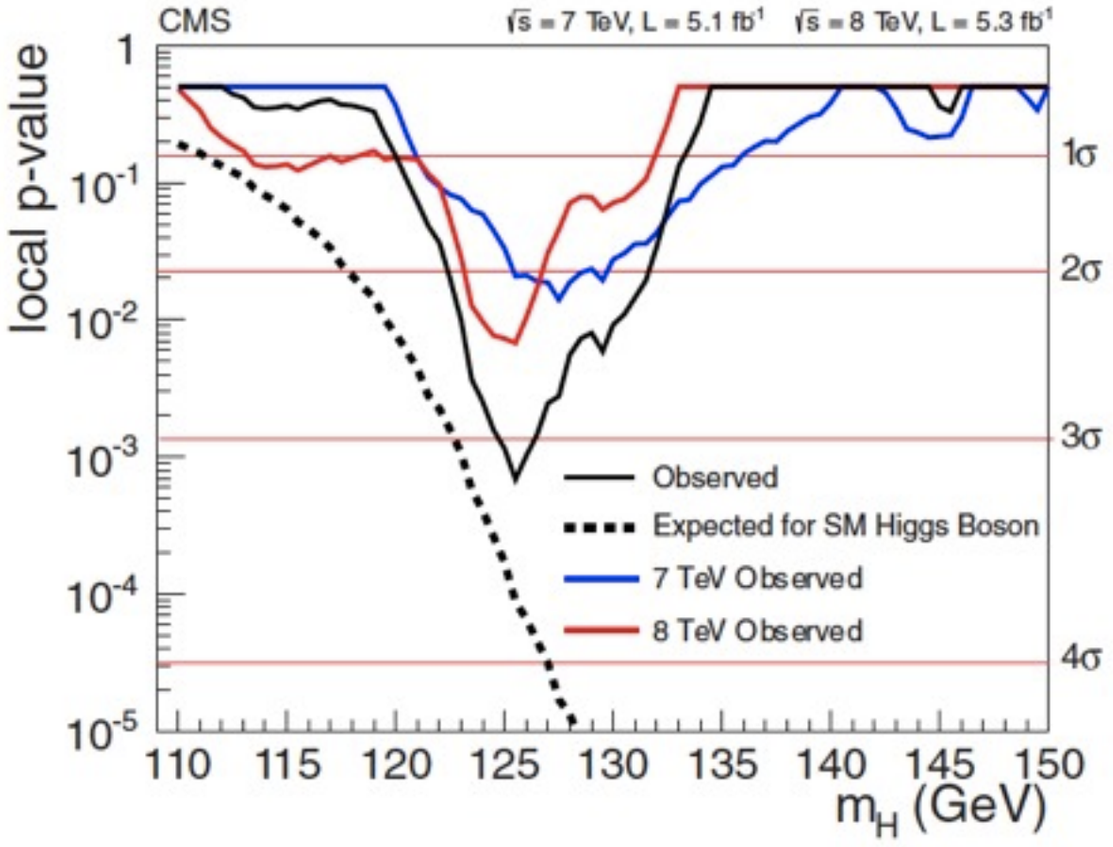


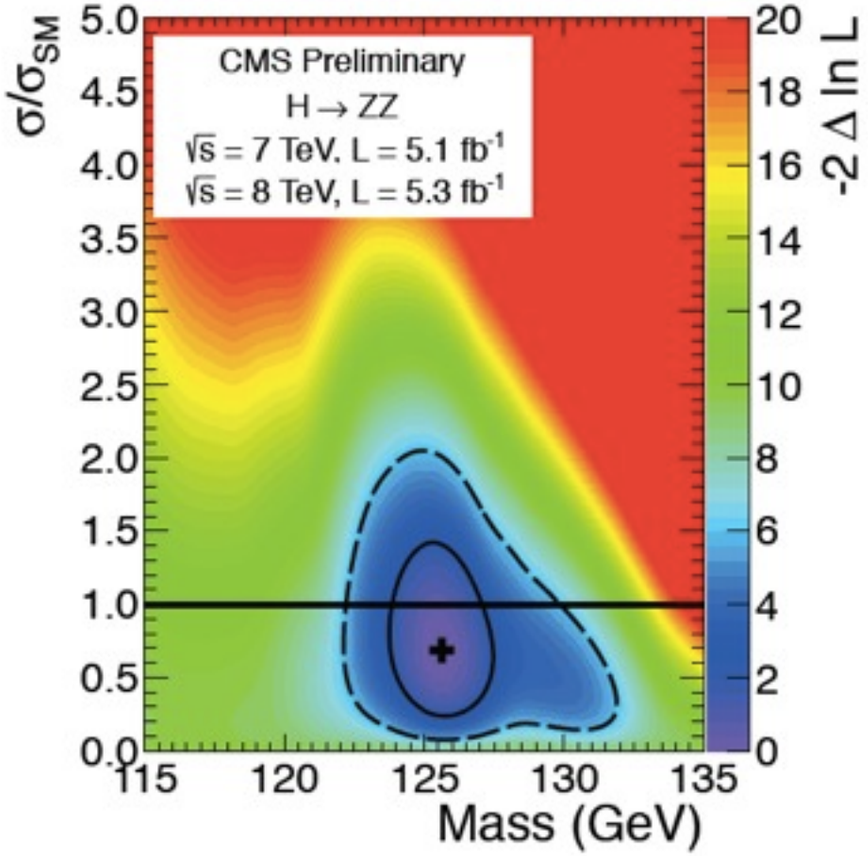


Discovery channel: H → ZZ → 4l

- Excess with local significance of 3.2σ, expected 3.8σ
- Likelihood scan performed on full dataset
- Global minimum of likelihood
  - m(4l) = 125.6 ± 1.2 GeV
  - μ = 0.7 ± 0.4 (signal strength)
- Ellipses indicate 68% and 95% CL contours

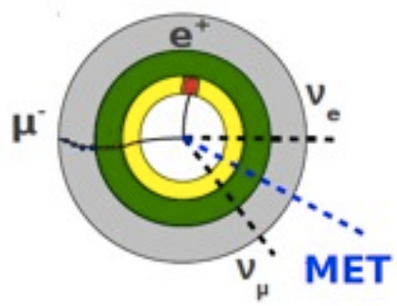
Channel	4e	4μ	2e2μ	4ℓ
ZZ background	2.7 ± 0.3	5.7 ± 0.6	7.2 ± 0.8	15.6 ± 1.4
$Z + X$	$1.2^{+1.1}_{-0.8}$	$0.9^{+0.7}_{-0.6}$	$2.3^{+1.8}_{-1.4}$	$4.4^{+2.2}_{-1.7}$
All backgrounds ($110 < m_{4\ell} < 160$ GeV)	4.0 ± 1.0	6.6 ± 0.9	9.7 ± 1.8	20 ± 3
Observed ($110 < m_{4\ell} < 160$ GeV)	6	6	9	21
Signal ($m_H = 125$ GeV)	1.36 ± 0.22	2.74 ± 0.32	3.44 ± 0.44	7.54 ± 0.78
All backgrounds (signal region)	0.7 ± 0.2	1.3 ± 0.1	1.9 ± 0.3	3.8 ± 0.5
Observed (signal region)	1	3	5	9

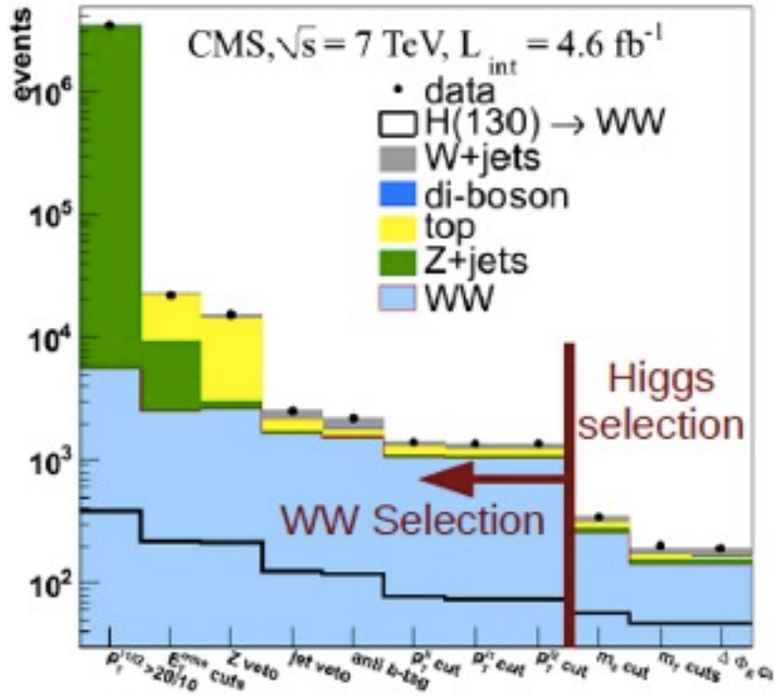


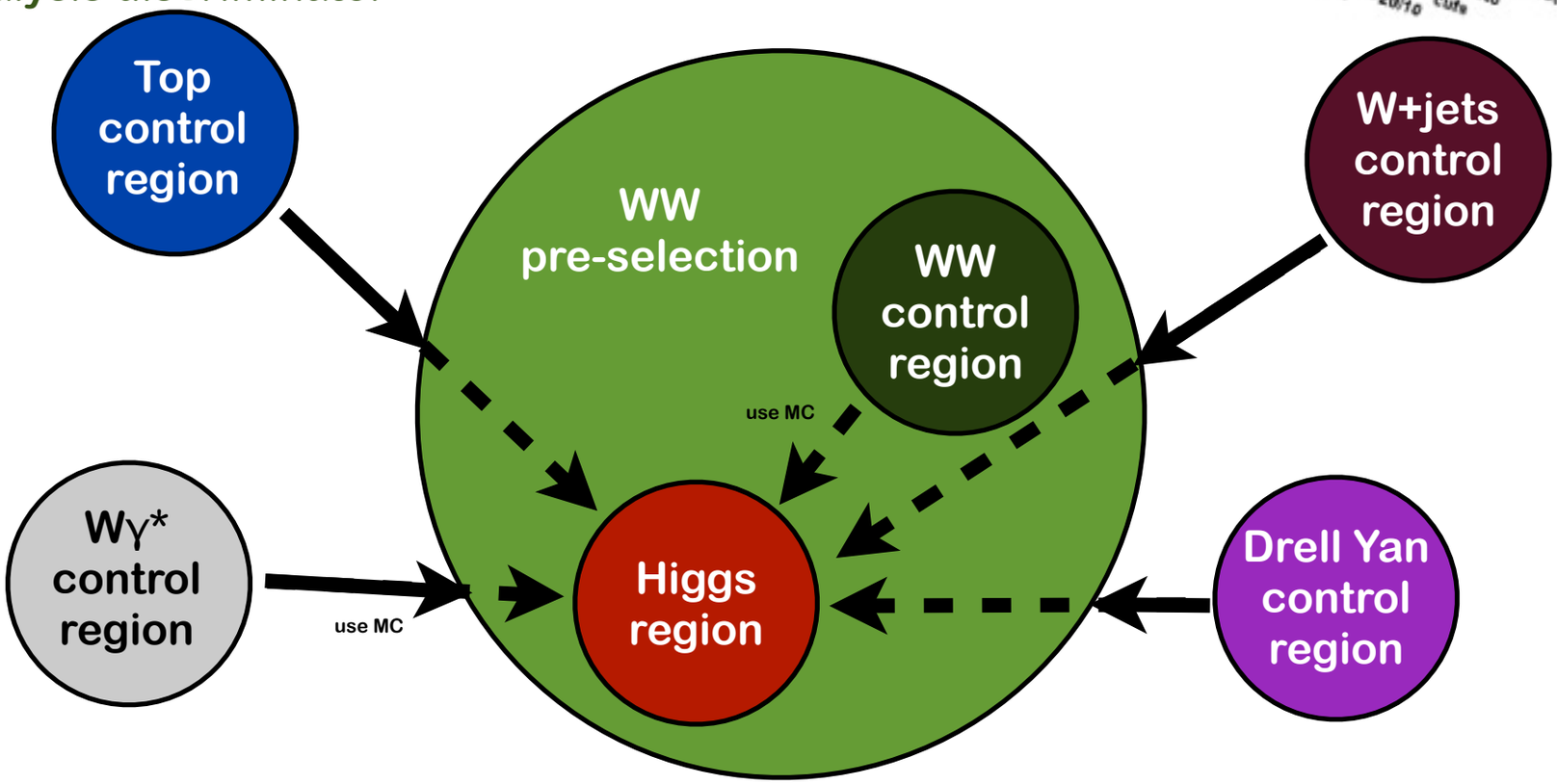


Search channel: H → WW → 2l2ν

- Analysis strategy
  - WW pre-selection
    - establish WW signature
    - data driven estimates of main backgrounds
  - Higgs selection
    - discriminate Higgs against WW background
    - cut-based selection or multivariate analysis discriminator

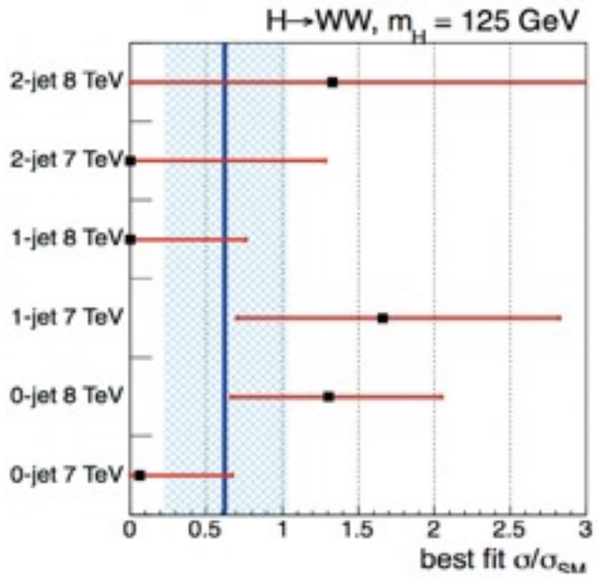


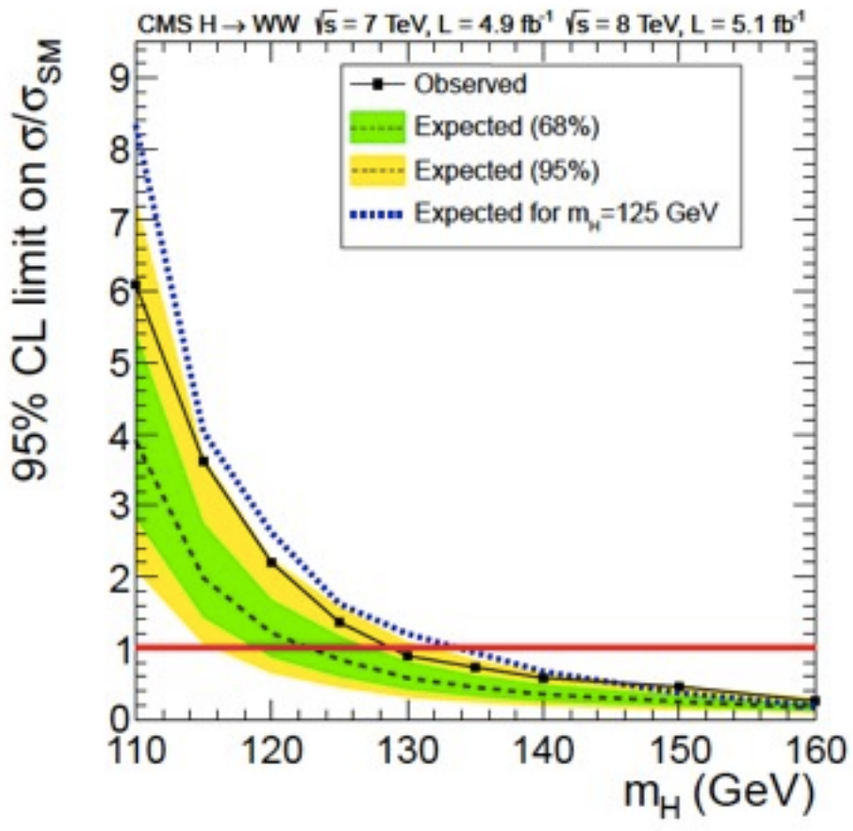


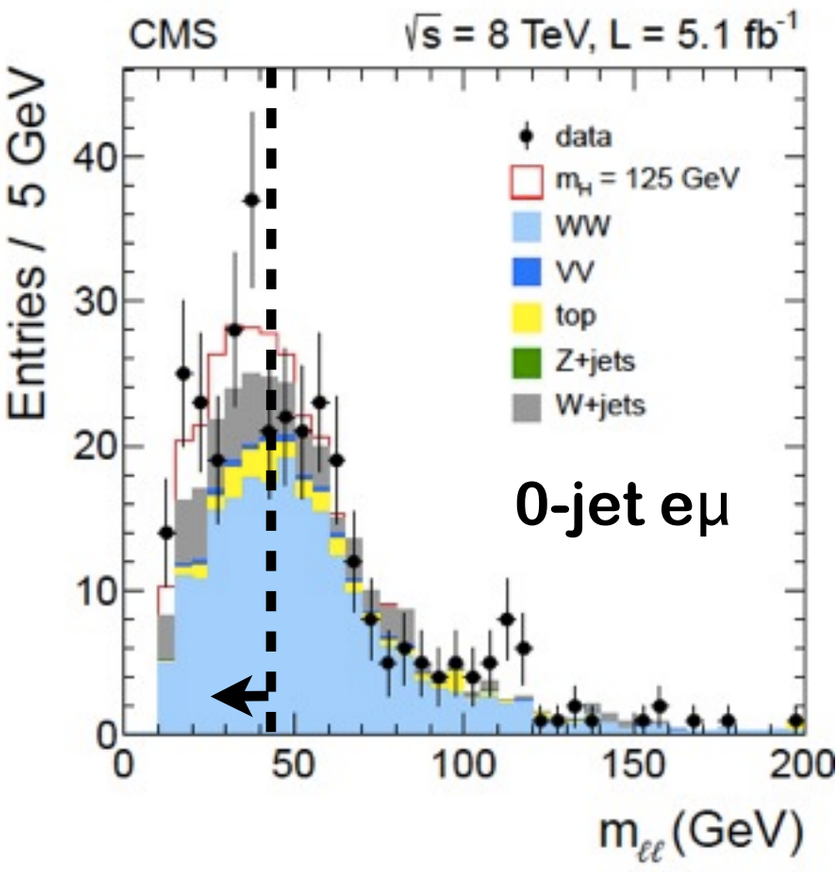


Search channel: H → WW → 2l2ν

- **Broad excess of about 1.6σ, expected 2.4σ**





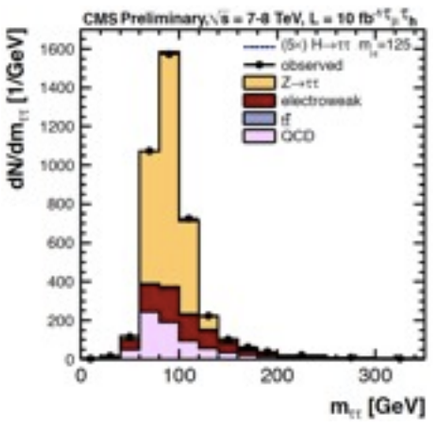


Category:	0-jet eμ	0-jet $\ell\ell$	1-jet eμ	1-jet $\ell\ell$	2-jet eμ	2-jet $\ell\ell$
WW	87.6 ± 9.5	60.4 ± 6.7	19.5 ± 3.7	9.7 ± 1.9	0.4 ± 0.1	0.3 ± 0.1
$WZ + ZZ + Z\gamma$	2.2 ± 0.2	37.7 ± 12.5	2.4 ± 0.3	8.7 ± 4.9	0.1 ± 0.0	3.1 ± 1.8
Top	9.3 ± 2.7	1.9 ± 0.5	22.3 ± 2.0	9.5 ± 1.1	3.4 ± 1.9	2.0 ± 1.2
W + jets	19.1 ± 7.2	10.8 ± 4.3	11.7 ± 4.6	3.9 ± 1.7	0.3 ± 0.3	0.0 ± 0.0
$W\gamma^{(*)}$	6.0 ± 2.3	4.6 ± 2.5	5.9 ± 3.2	1.3 ± 1.2	0.0 ± 0.0	0.0 ± 0.0
All backgrounds	124.2 ± 12.4	115.5 ± 15.0	61.7 ± 7.0	33.1 ± 5.7	4.1 ± 1.9	5.4 ± 2.2
Signal ($m_H = 125$ GeV)	23.9 ± 5.2	14.9 ± 3.3	10.3 ± 3.0	4.4 ± 1.3	1.5 ± 0.2	0.8 ± 0.1
Data	158	123	54	43	6	7

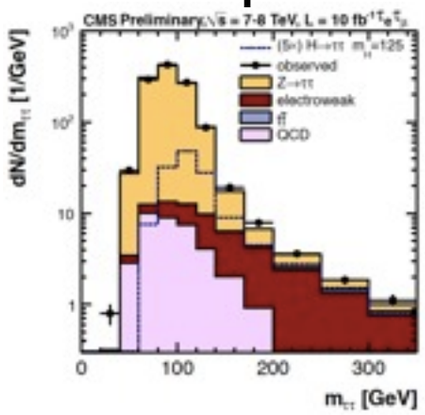
Search channel: H → ττ

- e-τ_{had}+X, μ-τ_{had}+X, e-μ+X, μ-μ+X channels
- di-τ mass reconstruction
- jet and τ pT categories

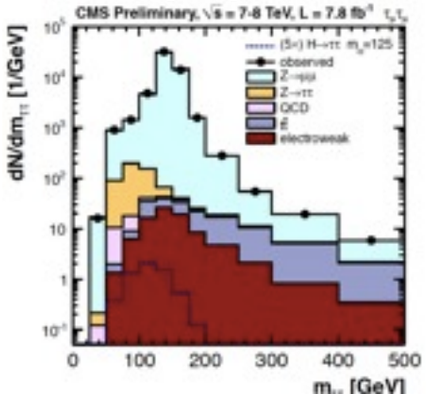
μ-τ_{had}+X



e-μ+X

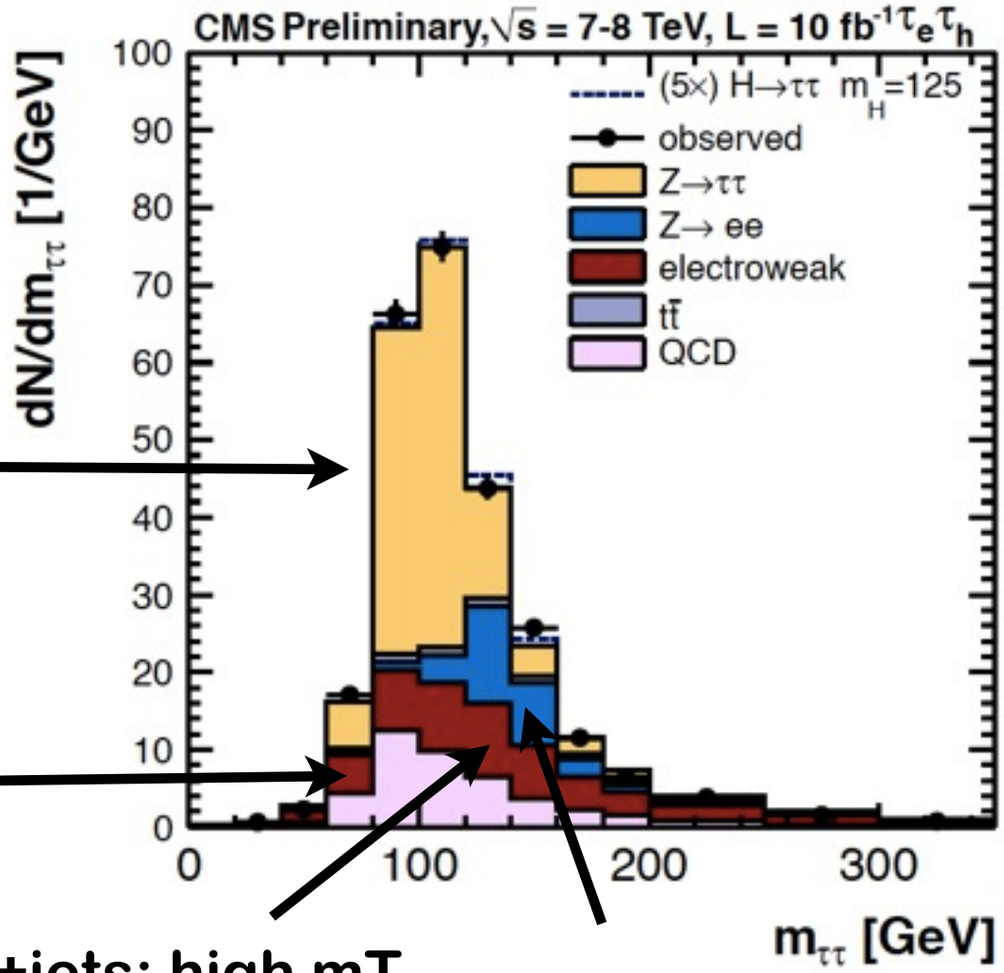


μ-μ+X



DY→ττ: mass shape and efficiencies measured from embedded sample

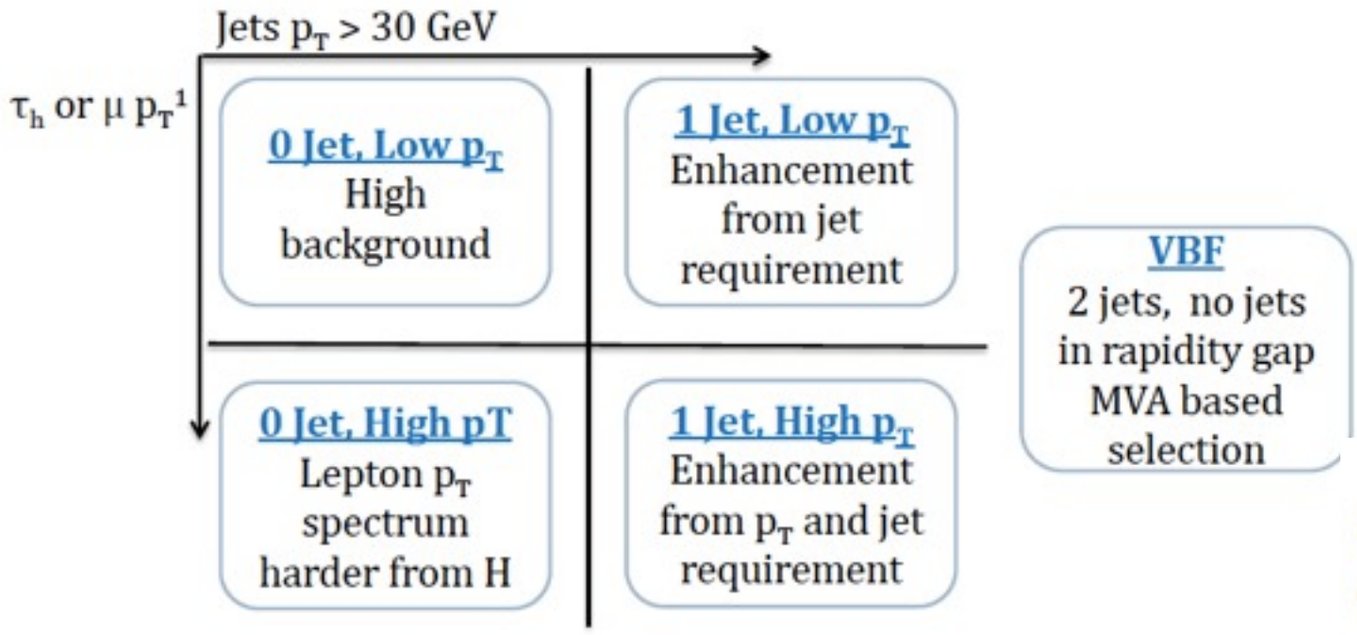
QCD: estimated form same-sign events



W+jets: high mT sideband

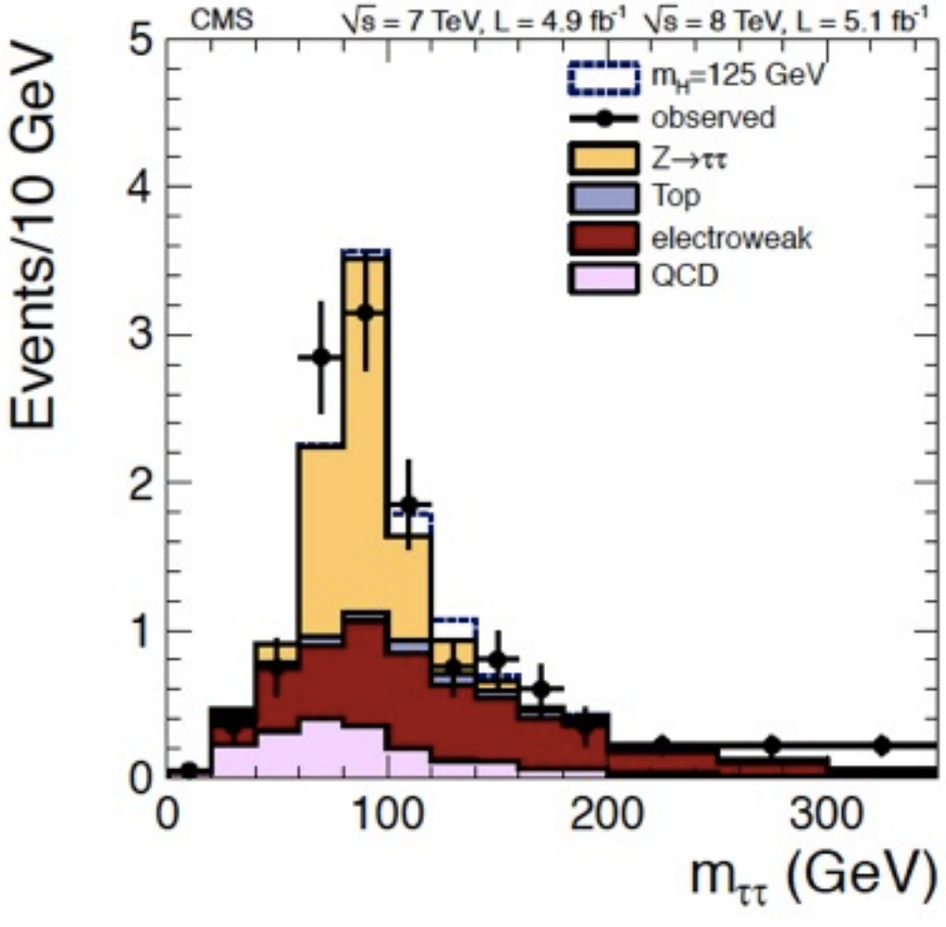
DY→ll: fake rate method

Search channel: H → ττ



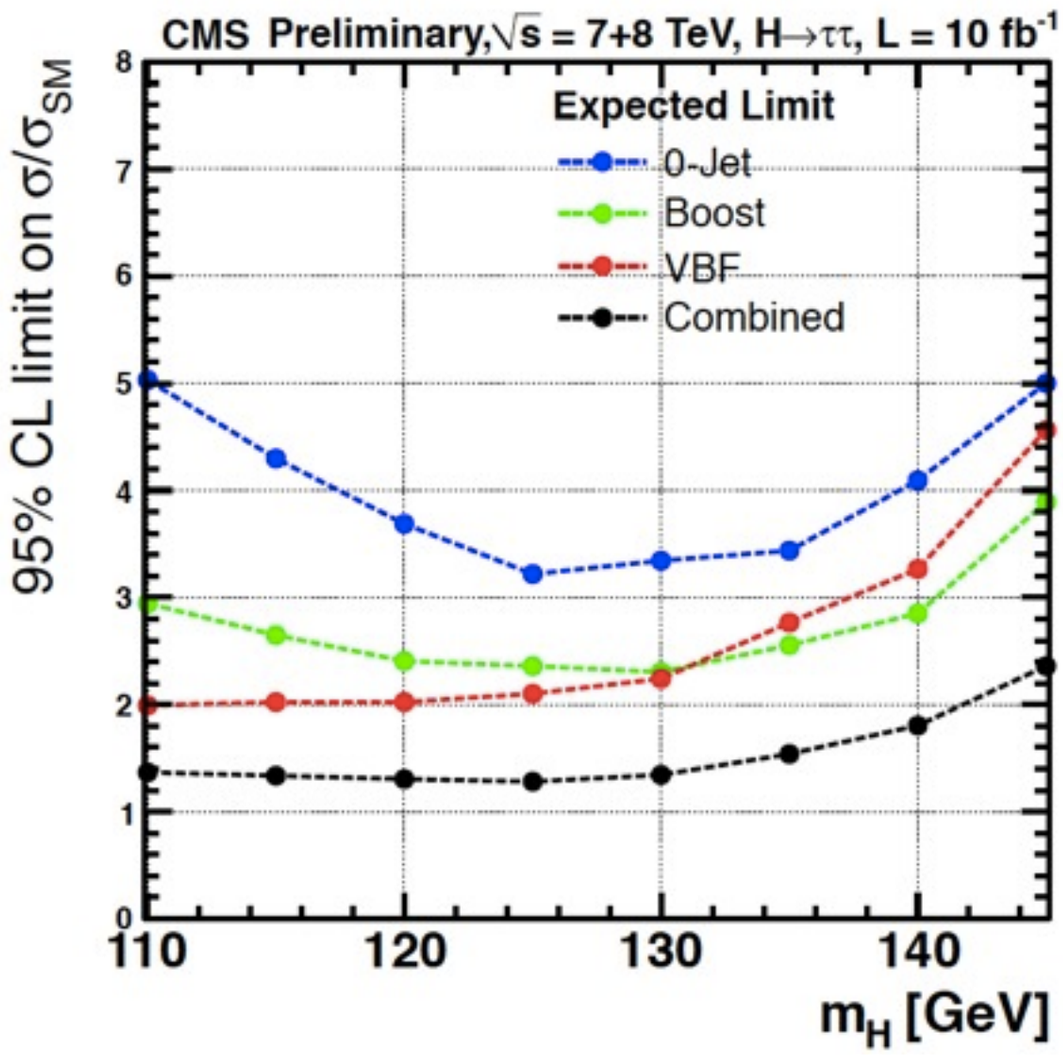
Event yield in VBF category

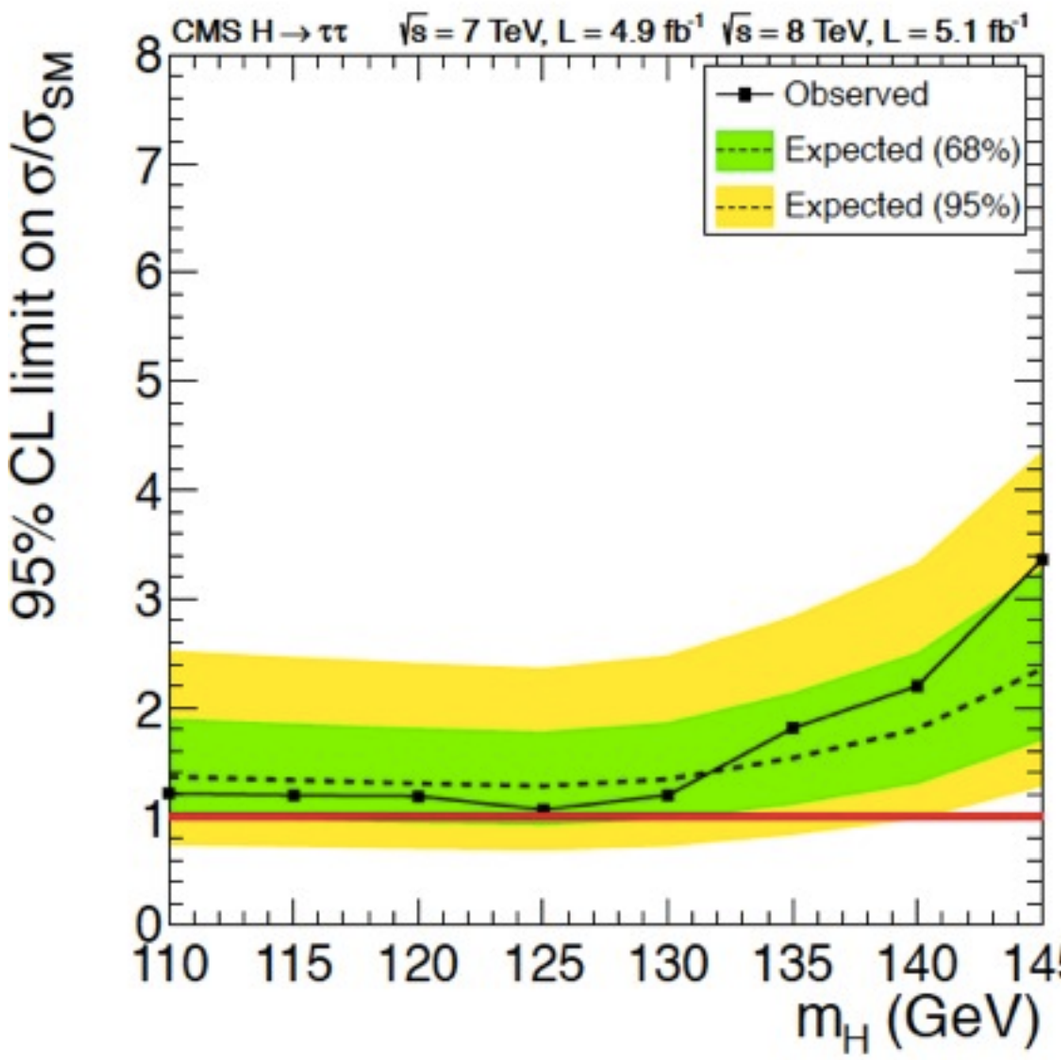
Subchannel	$e\tau_h$	$\mu\tau_h$	$e\mu$	$\mu\mu$
$Z \to \tau\tau$	53 ± 5	100 ± 9	56 ± 12	5.3 ± 0.4
QCD	35 ± 7	41 ± 9	7.4 ± 1.4	–
W+jets	46 ± 10	72 ± 15	–	–
Z+jets	13 ± 2	2.5 ± 0.6	–	–
$Z \to \mu\mu$	–	–	–	70 ± 8
$t\bar{t}$	7.0 ± 1.7	14 ± 3	24 ± 2	6.7 ± 1.5
Dibosons	1.2 ± 0.9	2.9 ± 2.1	11 ± 2	2.4 ± 0.9
All backgrounds	156 ± 13	233 ± 20	99 ± 13	85 ± 9
Signal ($m_H = 125$ GeV)	4.3 ± 0.6	7.7 ± 1.1	3.5 ± 0.4	0.8 ± 0.1
Data	142	263	110	83



Search channel: H → ττ

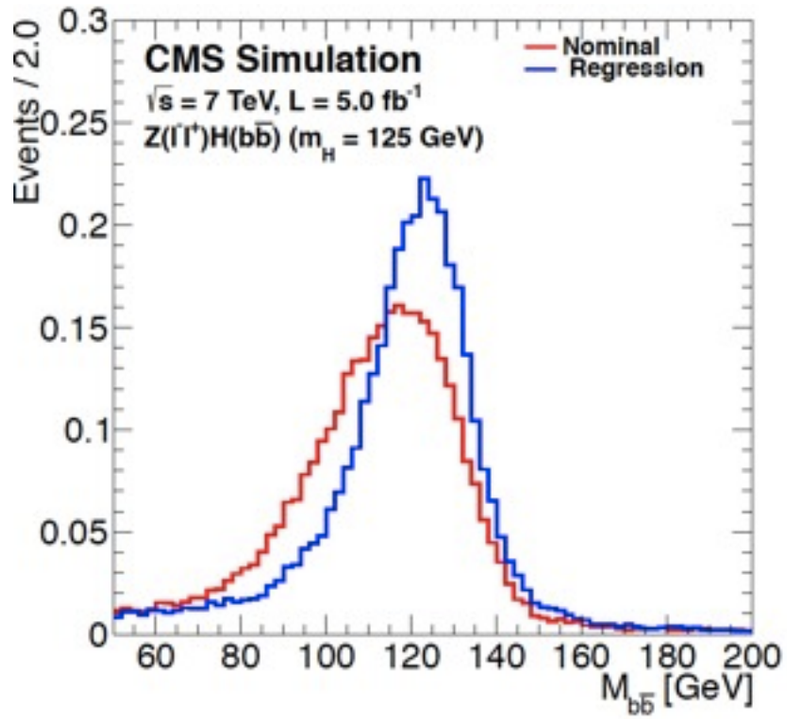
- No excess observed
- Channel compatible with background or signal
- Sensitivity close to SM cross section

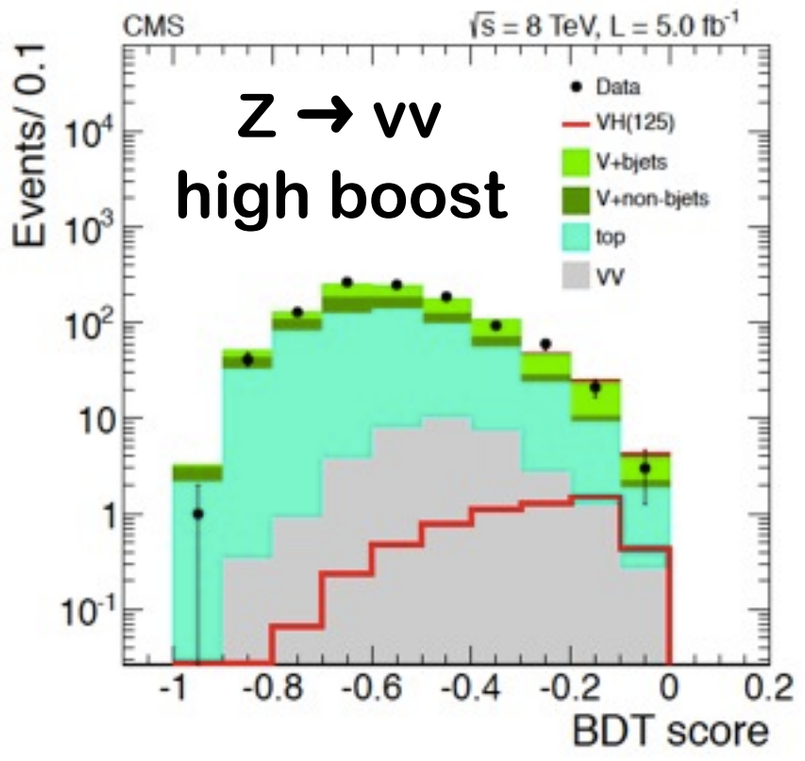




Search channel: H → bb

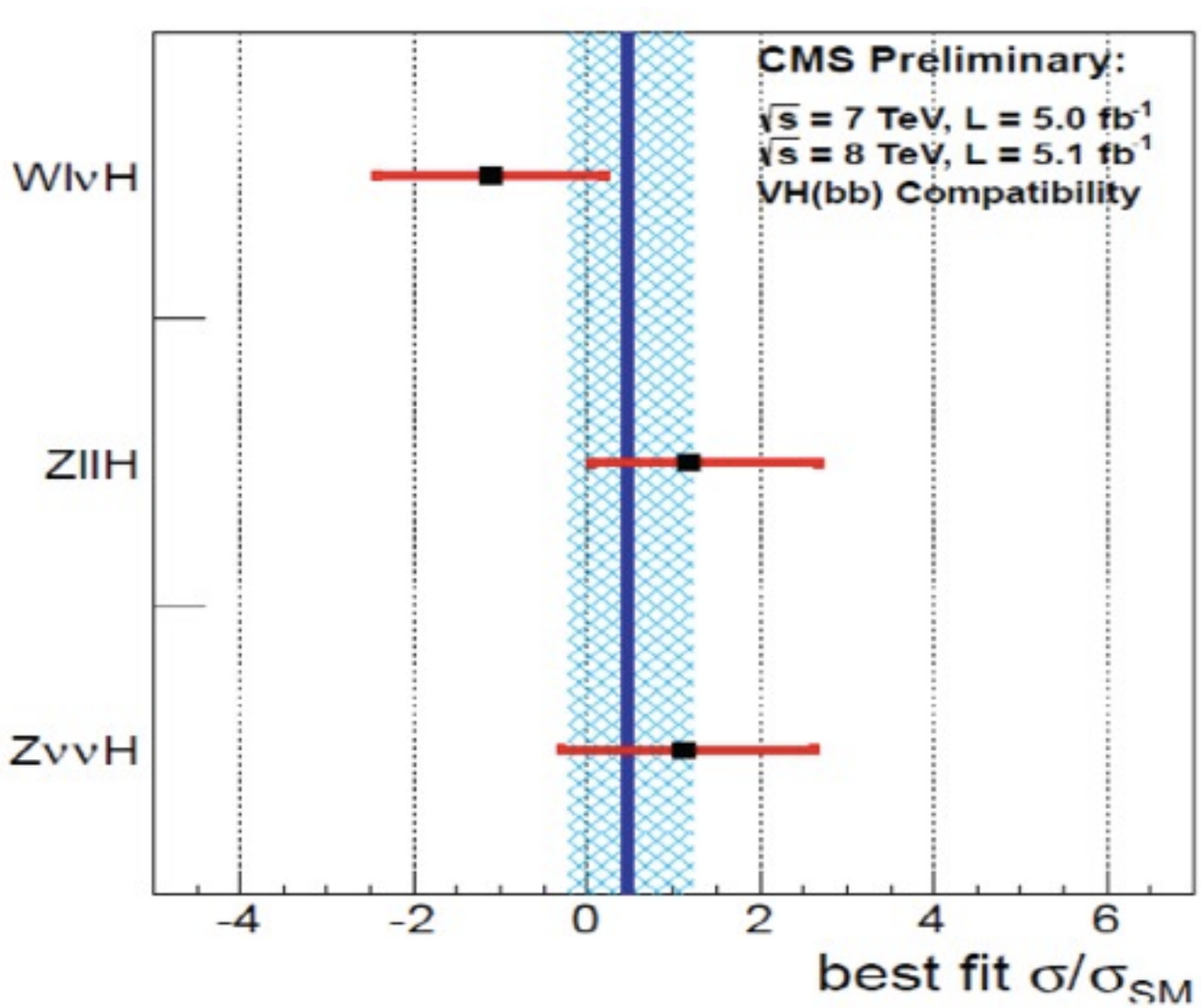
- W/Z+H, H → bb
  - W → eν, μν
  - Z → ee, , μμ, νν
- Improvements w.r.t 2011 analysis
  - jet energy measurement using BDT regression
  - categorized events in medium and high boost
  - full shape analysis of final BDT discriminator
  - Gain is sensitivity ~50%

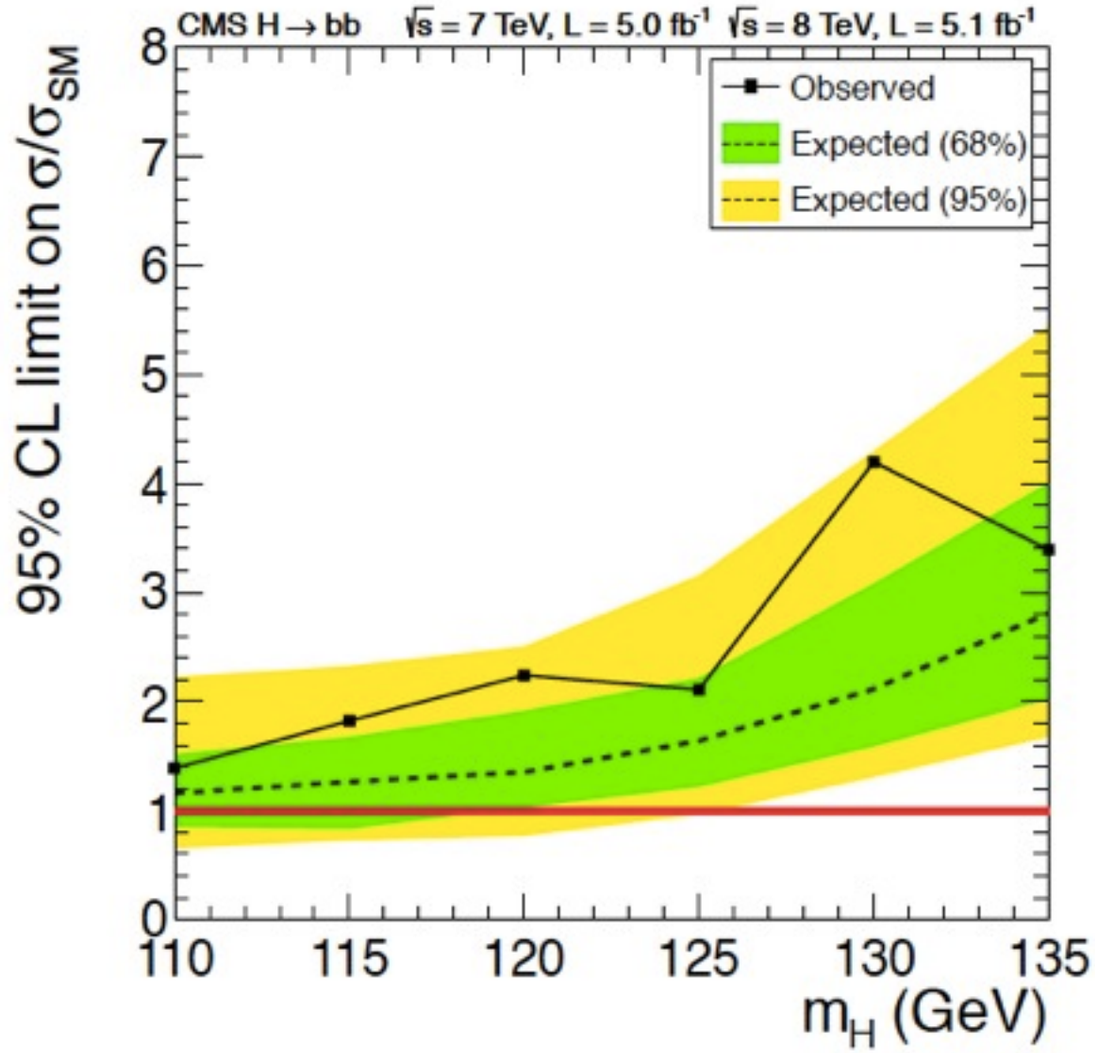




Search channel: H → bb

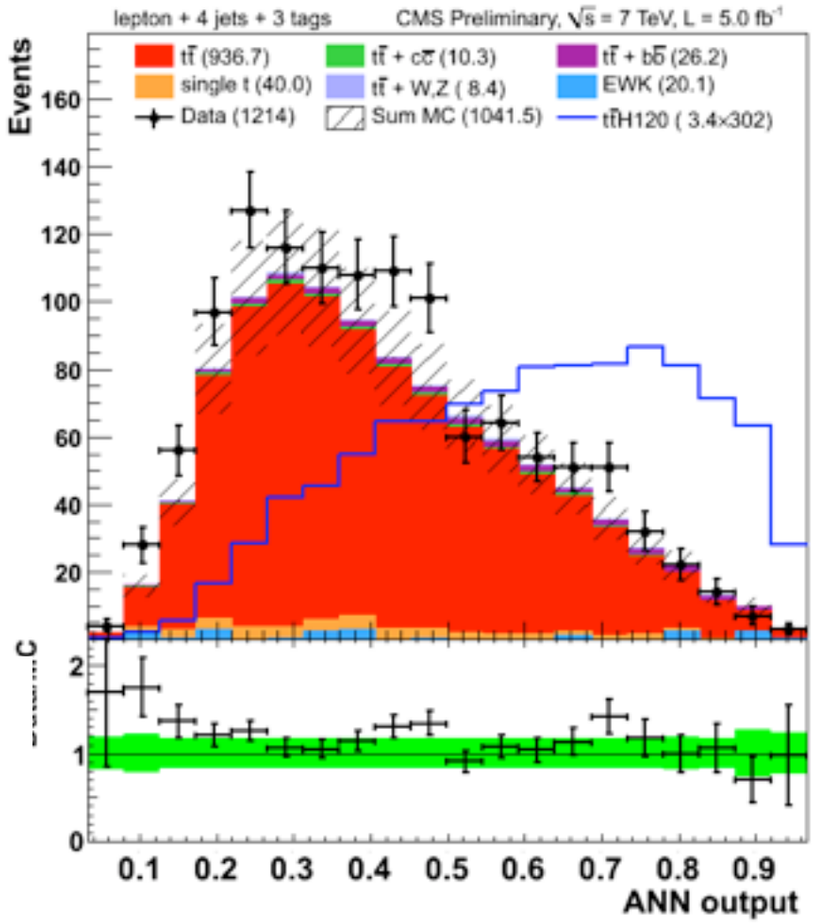
- Observed small excess (~1σ)
- Channel compatible with background or signal

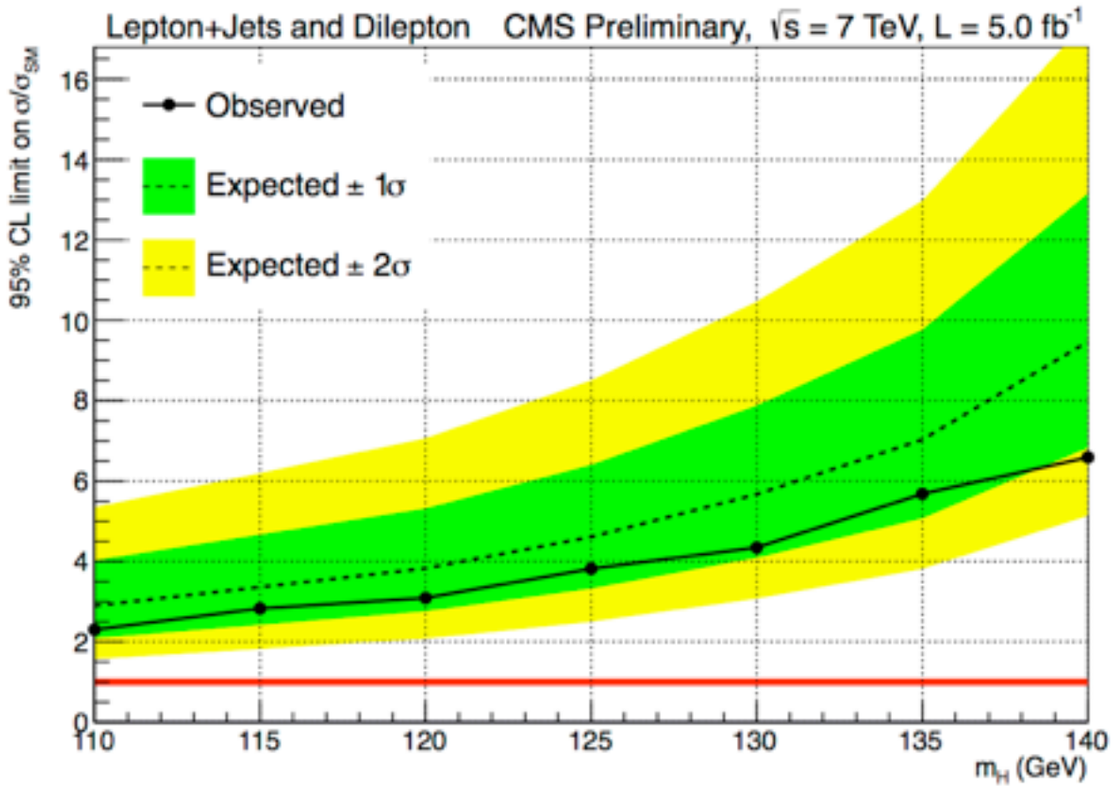




Search channel: H → bb

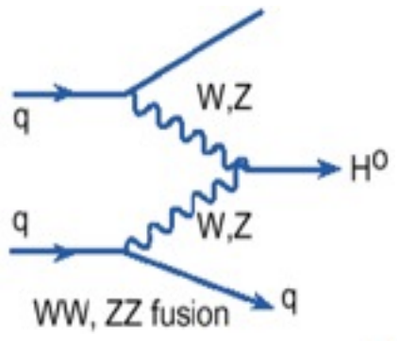
- ttH, H → b (new)
- categorize events by top decay mode (di-lep, l+jets) and jet multiplicity and b-tags
- MVA shape analysis in each category
- Low S/B regions constrain backgrounds
- Analyzed 2011 data. 2012 analysis is work in progress
- No excess observed

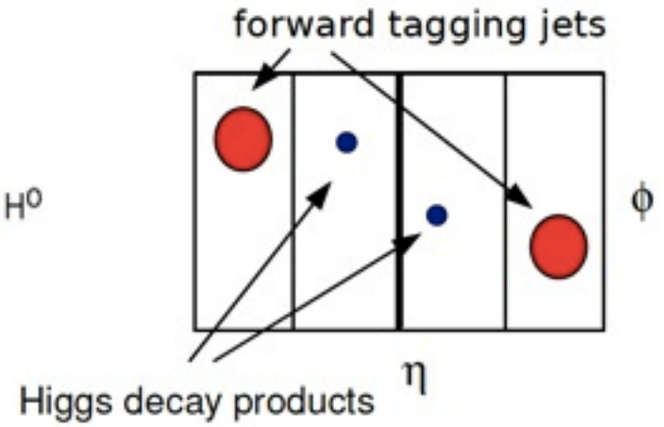




Vector boson fusion

- VBF signature
  - γγ, ττ, WW channels deploy VBF signature
  - ZZ(4l) has very low signal yield
  - bb is challenging and work in progress





- increases sensitivity and allows coupling measurement
- three analysis deploy quite different strategies

Channel	Technique	Variable	Jet kinematic	Pile-up	gluon fusion cont. at 125 GeV
H → γγ	cuts, 2 categories	m(jj), Δη(jj), Δϕ(H,jj), Zep.	pT > 20 (30) GeV, |η| < 4.7	cut jet ID	53%, 23%
H → ττ	MVA	m(jj), Δη(jj), Δη(H,j), Δϕ(jj), pT(ττ), pT(jj)	pT > 30 GeV, |η| < 5.0	MVA jet ID	20%
H → WW	cuts	m(jj), Δη(jj)	pT > 30 GeV, |η| < 4.7	MVA jet ID	15%

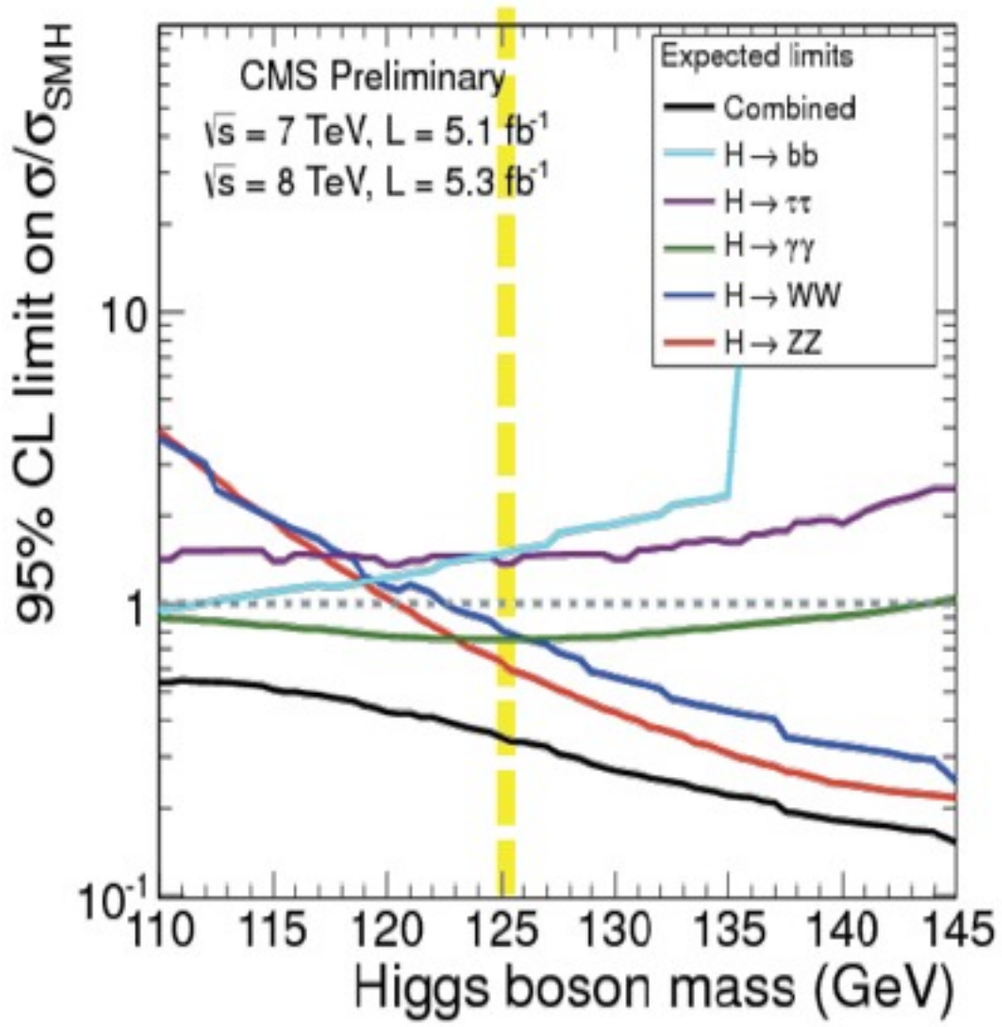
- diversity result of independent development and optimization, but needs investigation!

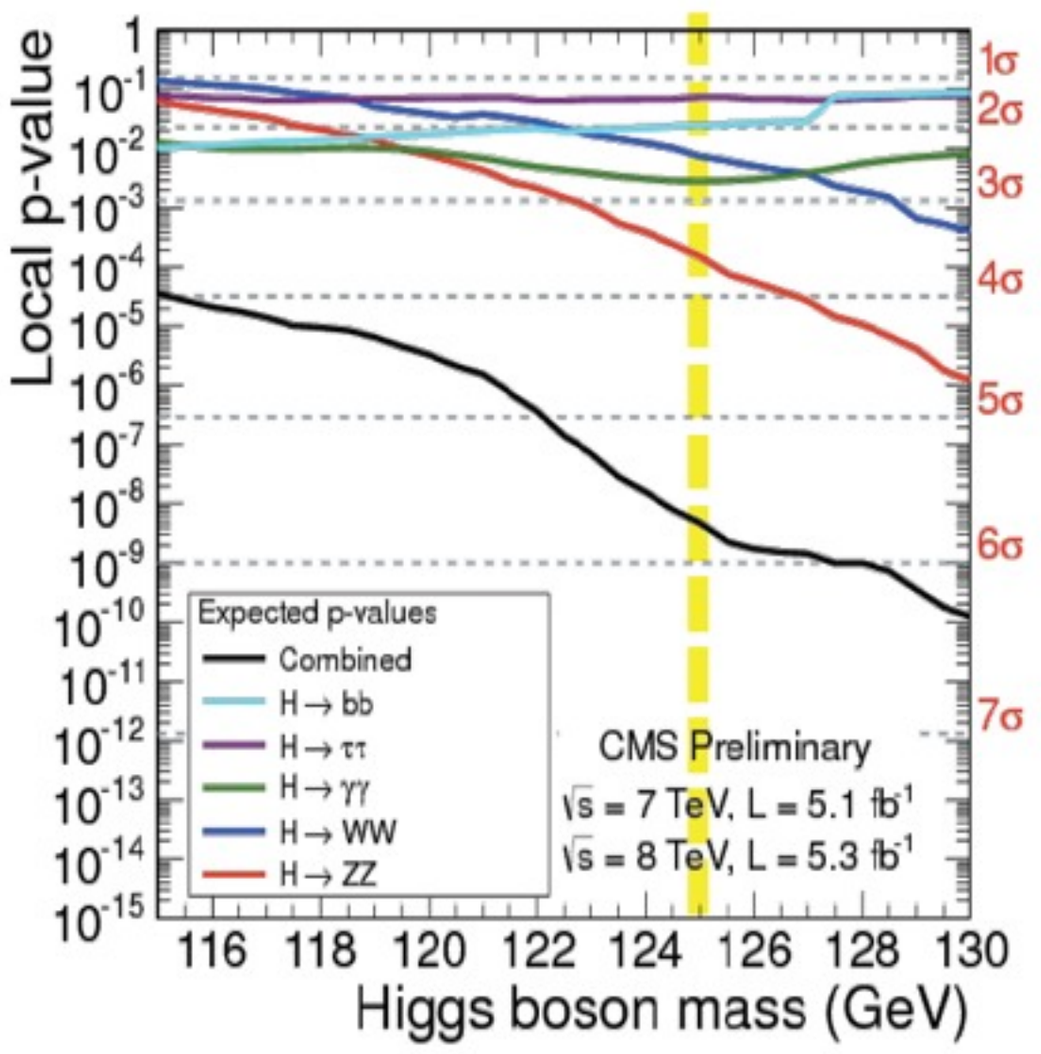
SM-like Higgs search strategies

- Analyses optimized categorizing events based on purity and mass resolution
- Specific categories targeting production modes
- Strategy improves sensitivity for discovery
- Can also be used to increase performance of properties measurements, e.g gluon fusion vs VBF separation

Combination

- **ICHEP combination with 95 individual channels at 125 GeV**

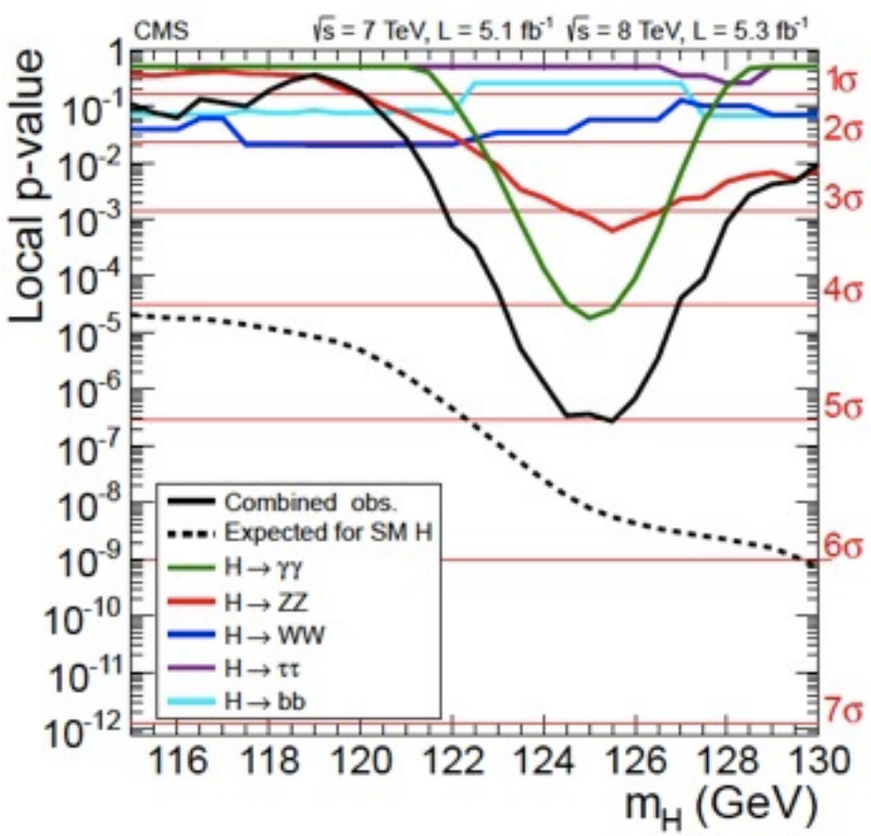


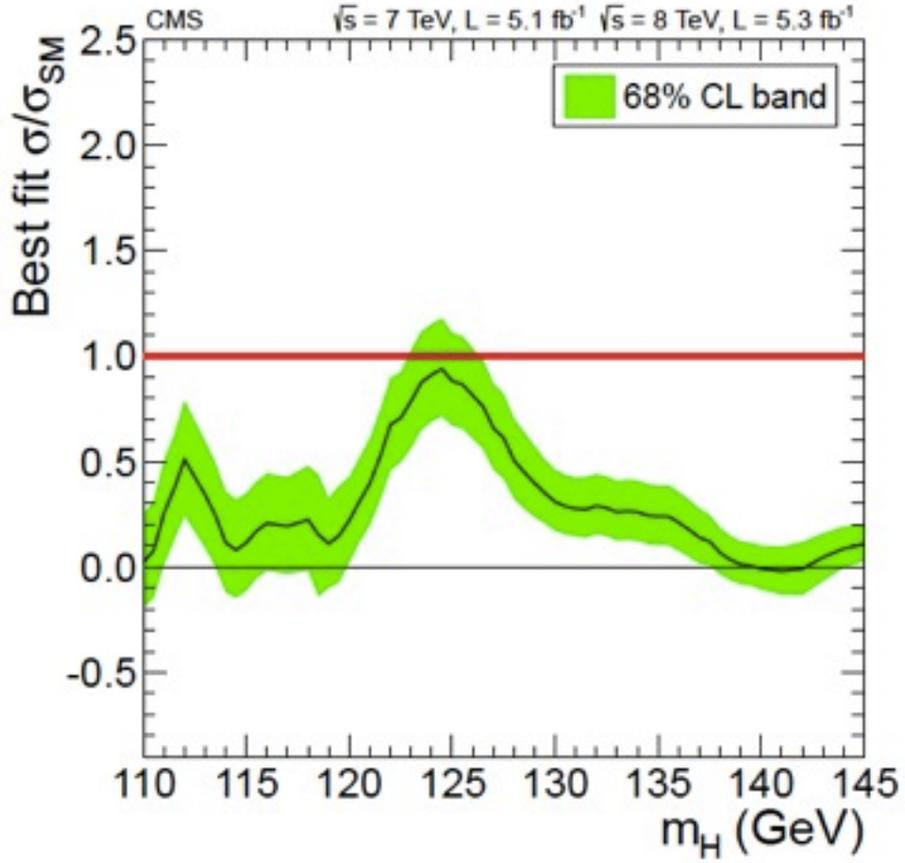


Combination

- Local significance: 5.0σ
- Expected significance: 5.8σ
- Global significance > 4σ
- Best fit result: 0.87 ± 0.23

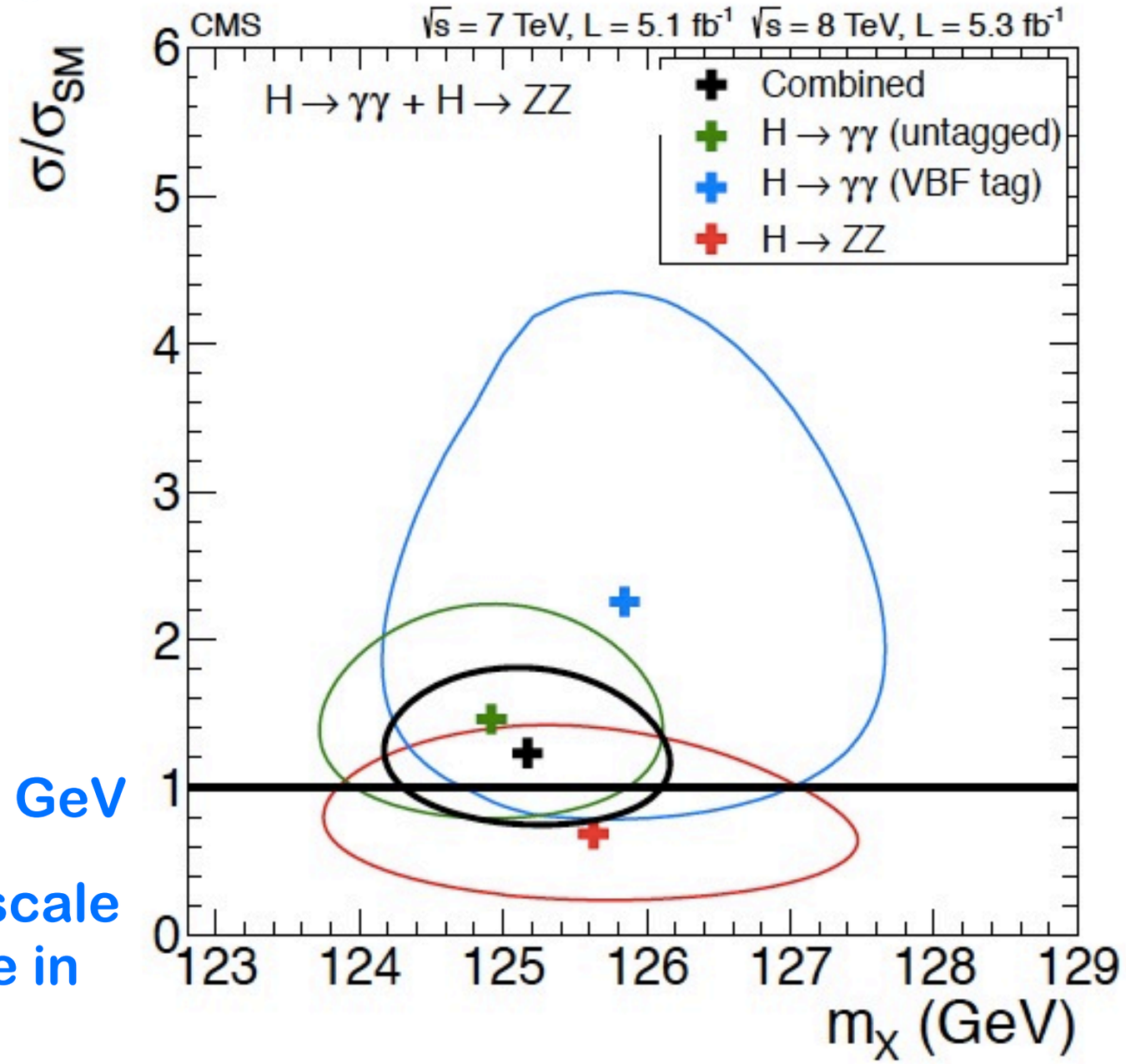
Decay mode/combination	Expected (σ)	Observed (σ)
$\gamma\gamma$	2.8	4.1
ZZ	3.6	3.1
$\tau\tau$ + bb	2.4	0.4
$\gamma\gamma$ + ZZ	4.7	5.0
$\gamma\gamma$ + ZZ + WW	5.2	5.1
$\gamma\gamma$ + ZZ + WW + $\tau\tau$ + bb	5.8	5.0





Mass measurement

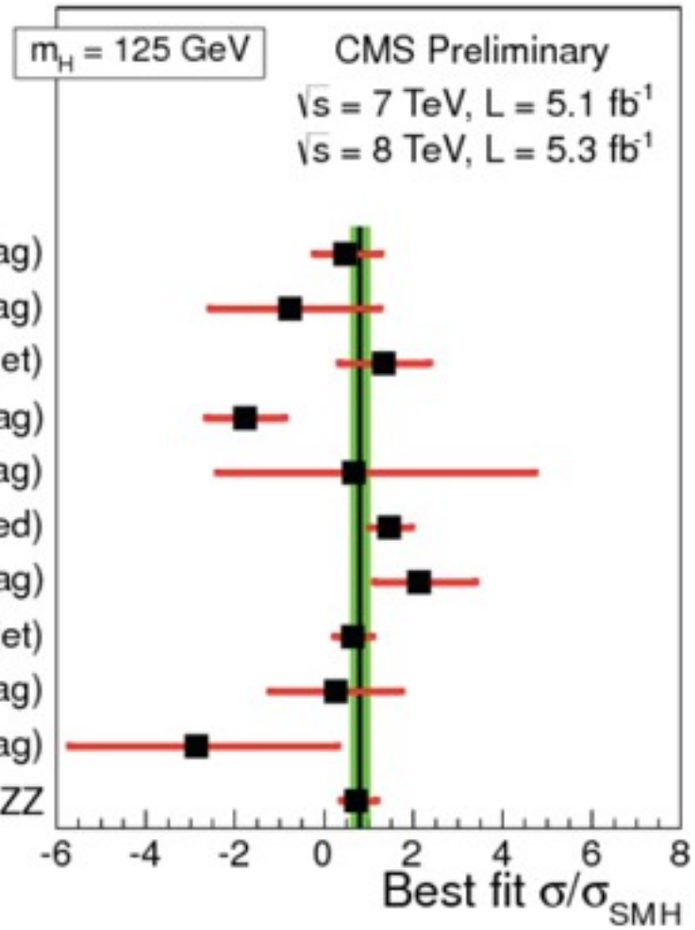
- Likelihood scan for mass and signal strength
- Three high mass resolution channels included
  - ZZ → 4l
  - γγ untagged
  - γγ with di-jet tag
- Results are compatible within uncertainties
- Fit of the mass: M = 125.3 ± 0.6 GeV
- Systematics driven by energy scale uncertainty ~0.5%. Will improve in the future.



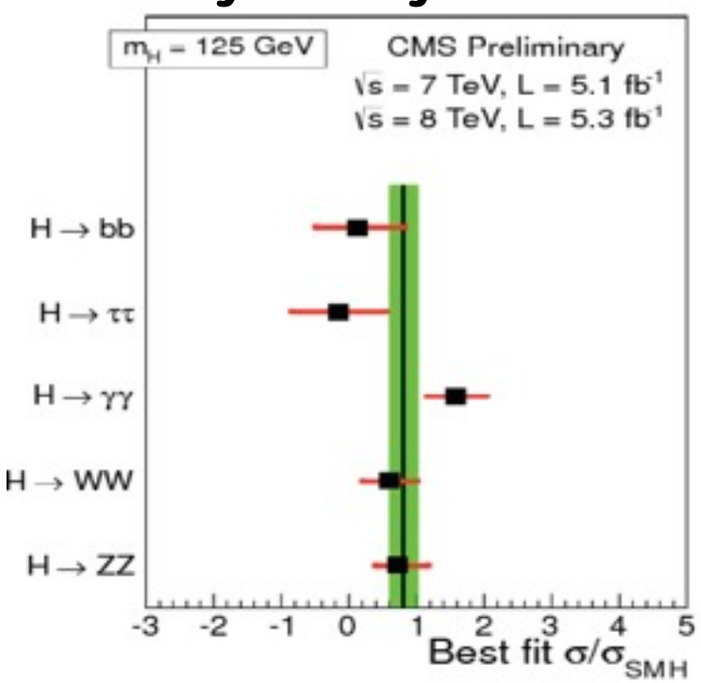
Compatibility with SM Higgs

- Study signal strength per decay and production mode
- Compatible with SM Higgs within uncertainties
- Pictures nicely summarize the key feature of SM Higgs search results

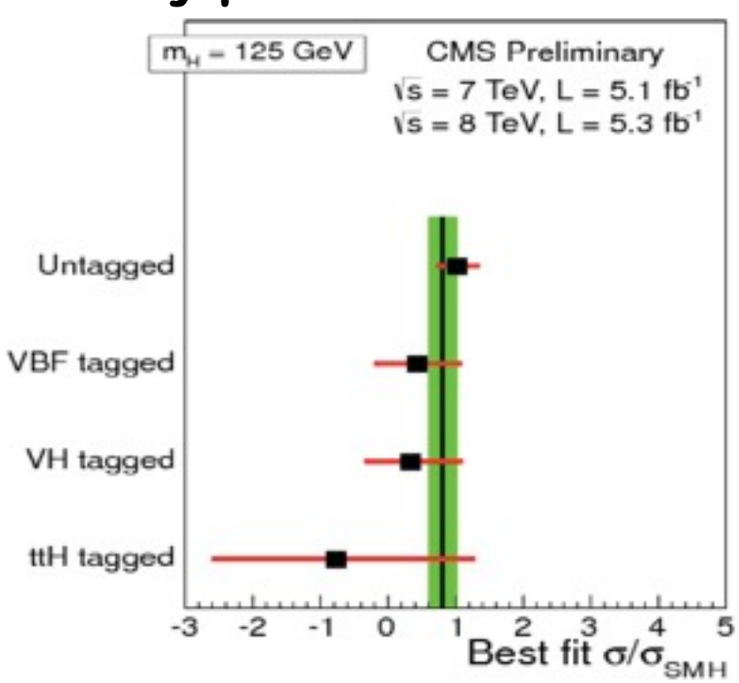
all combination of decay and production modes



by decay mode

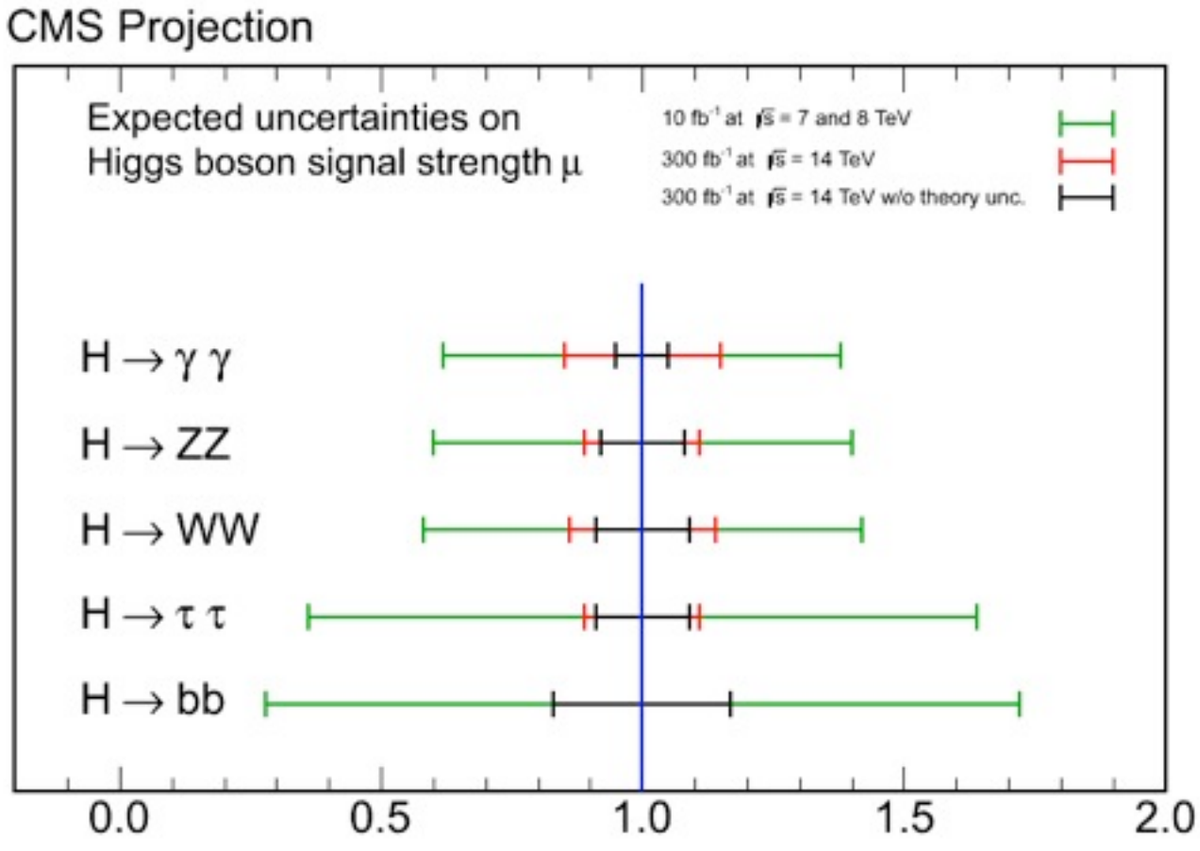


by production modes

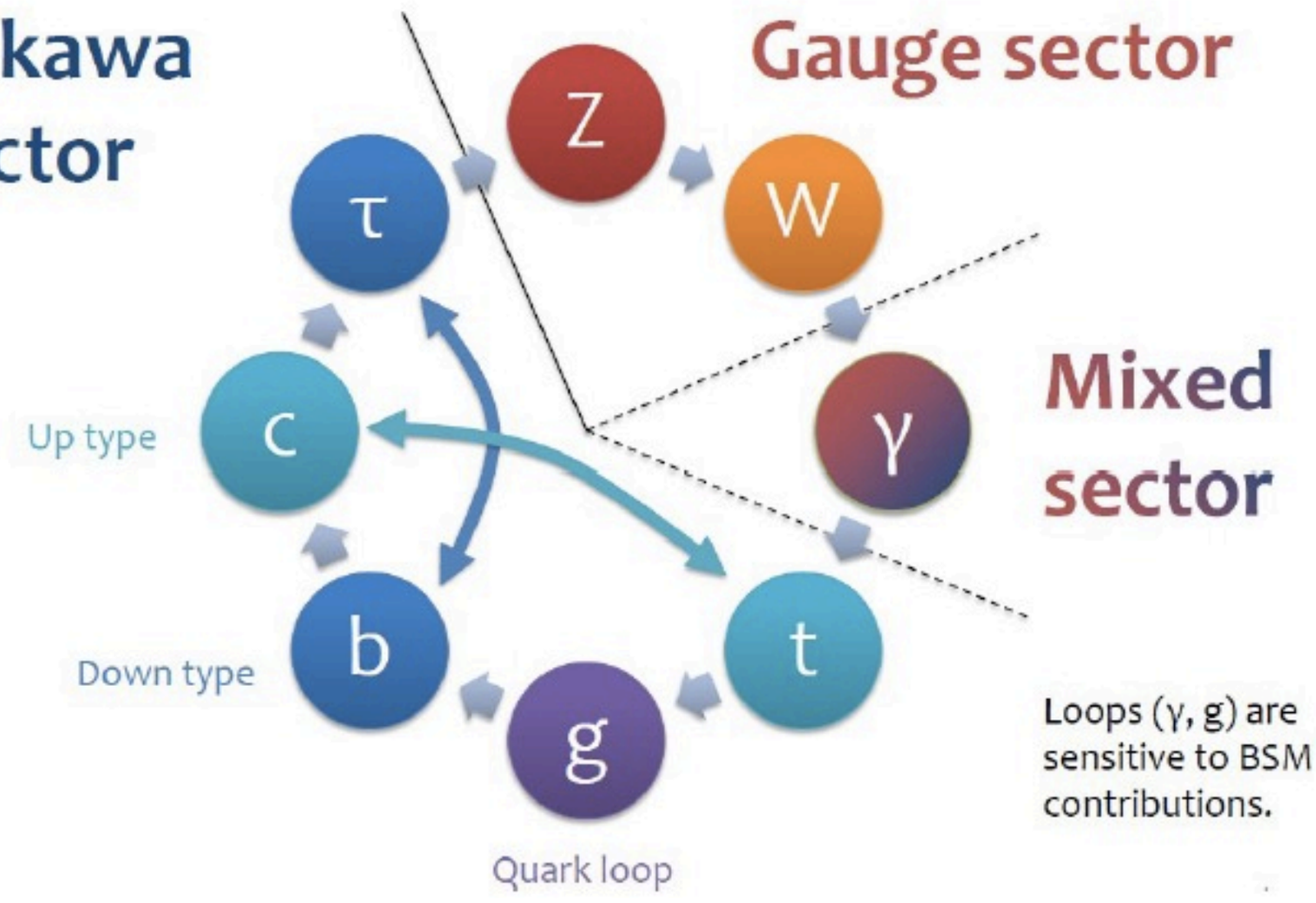


Compatibility with SM Higgs

- Projecting signal strength per decay mode
- Showing 10/fb at 7/8 TeV and 300/fb at 14 TeV
  - scale signal and background cross section
  - systematic uncertainties unchanged or w/o theory uncertainties
  - analysis strategies are not optimized
- 5-15% uncertainties with 300/fb



Compatibility with SM Higgs



Proposed implementation

- Start from best knowledge of SM Higgs cross section and branching fractions
- Make minimal set of assumptions (next slide)
- Derive scale factors

Production modes

$$\frac{\sigma_{ggH}}{\sigma^{SM}_{ggH}} = \begin{cases} C_g^2(C_b, C_t, m_H) \\ C_g^2 \end{cases}$$

$$\frac{\sigma_{\mathrm{VBF}}}{\sigma^{SM}_{\mathrm{VBF}}} = C^2_{\mathrm{VBF}}(C_W, C_Z, m_H)$$

$$\frac{\sigma_{WH}}{\sigma^{SM}_{WH}} = \frac{\Gamma_{WW}}{\Gamma^{SM}_{WW}} = C_W^2$$

$$\frac{\sigma_{ZH}}{\sigma^{SM}_{ZH}} = \frac{\Gamma_{ZZ}}{\Gamma^{SM}_{ZZ}} = C_Z^2$$

$$\frac{\sigma_{t\bar{t}H}}{\sigma^{SM}_{t\bar{t}}} = C_t^2$$

Detectable decay modes

$$\frac{\Gamma_{WW}}{\Gamma^{SM}_{WW}} = C_W^2$$

$$\frac{\Gamma_{ZZ}}{\Gamma^{SM}_{ZZ}} = C_Z^2$$

$$\frac{\Gamma_{b\bar{b}}}{\Gamma^{SM}_{b\bar{b}}} = C_b^2$$

$$\frac{\Gamma_{\tau\tau}}{\Gamma^{SM}_{\tau\tau}} = C_\tau^2$$

$$\frac{\Gamma_{\gamma\gamma}}{\Gamma^{SM}_{\gamma\gamma}} = \begin{cases} C_\gamma^2(C_b, C_t, C_W, \\ C_\gamma^2 \end{cases}$$

$$\frac{\Gamma_{Z\gamma}}{\Gamma^{SM}_{Z\gamma}} \sim C_W^2$$

Undetectable decay modes

$$\frac{\Gamma_{t\bar{t}}}{\Gamma^{SM}_{t\bar{t}}} = \frac{\sigma_{t\bar{t}H}}{\sigma^{SM}_{t\bar{t}}} = C_t^2$$

$$\frac{\Gamma_{gg}}{\Gamma^{SM}_{gg}} = \frac{\sigma_{ggH}}{\sigma^{SM}_{ggH}}$$

$$\frac{\Gamma_{c\bar{c}}}{\Gamma^{SM}_{c\bar{c}}} = C_t^2$$

$$\frac{\Gamma_{s\bar{s}}}{\Gamma^{SM}_{s\bar{s}}} = C_b^2$$

$$\frac{\Gamma_{\mu\mu}}{\Gamma^{SM}_{\mu\mu}} = C_\tau^2$$

Total width

$$\frac{\Gamma_H}{\Gamma^{SM}_H} = \begin{cases} C_H^2(C_i, m_H) \\ C_H^2 \end{cases}$$

- Analyze scale factors in benchmarks

Assumptions and limitations

- Observations originate from a single particle
- Use zero-width approximation
- Consider only modifications to couplings strength. No modification to tensor structure, i.e. assume CP-even scalar state
- Additional assumptions necessary to measure Ci and not just ratios of couplings, e.g. no new Higgs decay modes

$$C_H^2(C_i, m_H) = \sum_{\substack{k = WW, ZZ, b\bar{b}, \tau\tau, \gamma\gamma, \\ Z\gamma, gg, t\bar{t}, c\bar{c}, s\bar{s}, \mu\mu}} \frac{\Gamma_k(C_i, m_H)}{\Gamma_H^{SM}(m_H)}$$

- Interference effects are not considered beyond SM

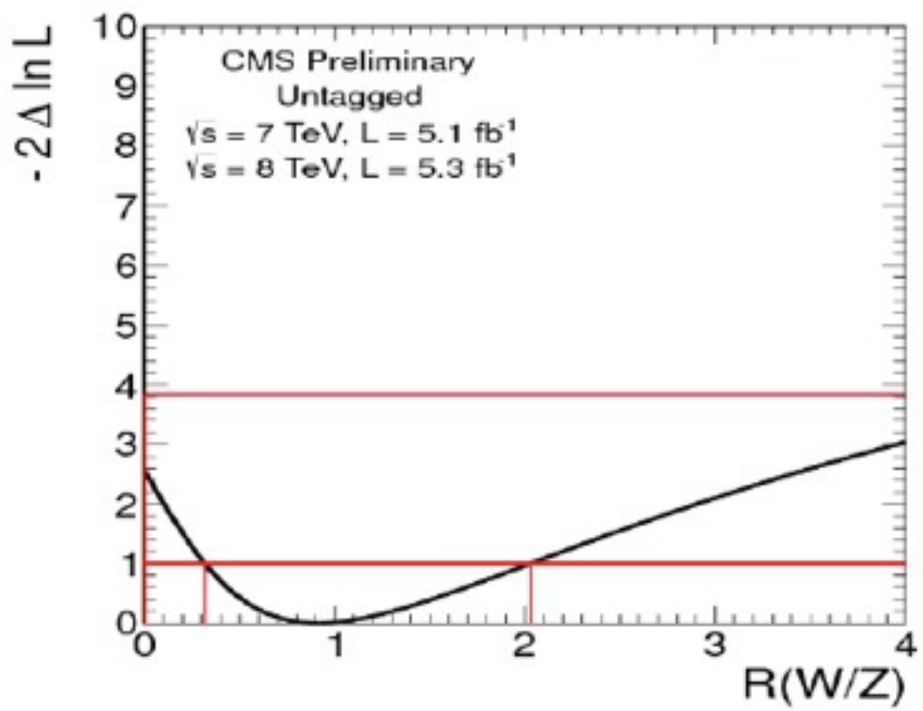
Test custodial symmetry

- Compare WW and ZZ signal strength
- Fit WW (0/1 jet) and ZZ data assuming

$$\sigma \times BR_{H\to ZZ} = \mu_{ZZ} \times [\sigma \times BR_{H\to ZZ}]_{SM\ Higgs}$$
$$\sigma \times BR_{H\to WW} = R_{W/Z} \times \mu_{ZZ} \times [\sigma \times BR_{H\to WW}]_{SM\ Higgs}$$

- Result compatible with SM (large uncertainties)

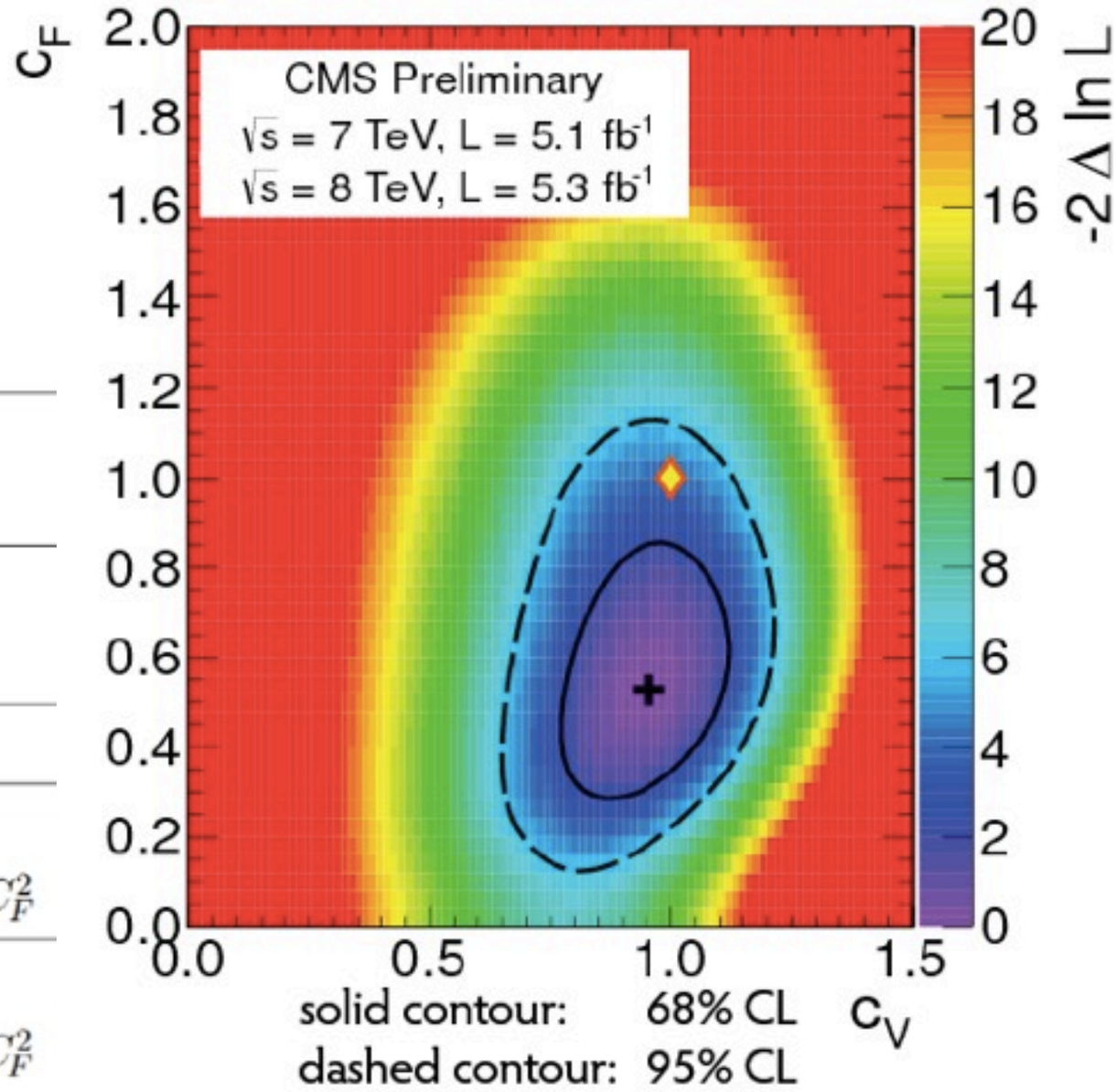
$$R_{W/Z} = 0.9^{+1.1}_{-0.6}$$



Test C_V-C_F

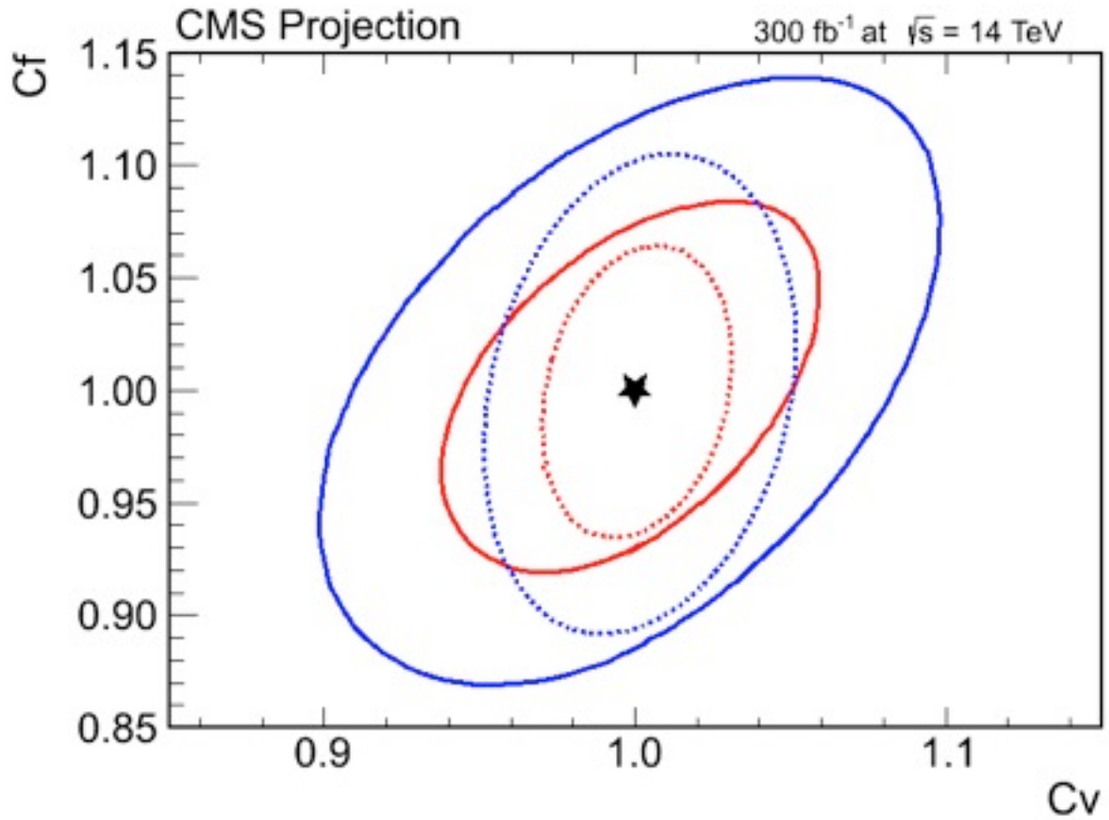
- Test compatibility by introducing two parameter (C_V, C_F)
- C_V and C_F modify expected signal yields in each mode through simple LO expressions

Production	Decay	LO SM	
VH	$H \to bb$	$\sim \frac{C_V^2 \times C_F^2}{C_F^2}$	$\sim C_V^2$
ttH	$H \to bb$	$\sim \frac{C_F^2 \times C_F^2}{C_F^2}$	$\sim C_F^2$
VBF	$H \to \tau\tau$	$\sim \frac{C_V^2 \times C_F^2}{C_F^2}$	$\sim C_V^2$
ggH	$H \to \tau\tau$	$\sim \frac{C_F^2 \times C_F^2}{C_F^2}$	$\sim C_F^2$
ggH	$H \to ZZ$	$\sim \frac{C_F^2 \times C_V^2}{C_F^2}$	$\sim C_V^2$
ggH	$H \to WW$	$\sim \frac{C_F^2 \times C_V^2}{C_F^2}$	$\sim C_V^2$
VBF	$H \to WW$	$\sim \frac{C_V^2 \times C_V^2}{C_F^2}$	$\sim C_V^4/C_F^2$
ggH	$H \to \gamma\gamma$	$\sim \frac{C_F^2 \times (8.6C_V - 1.8C_F)^2}{C_F^2}$	$\sim C_V^2$
VBF	$H \to \gamma\gamma$	$\sim \frac{C_V^2 \times (8.6C_V - 1.8C_F)^2}{C_F^2}$	$\sim C_V^4/C_F^2$



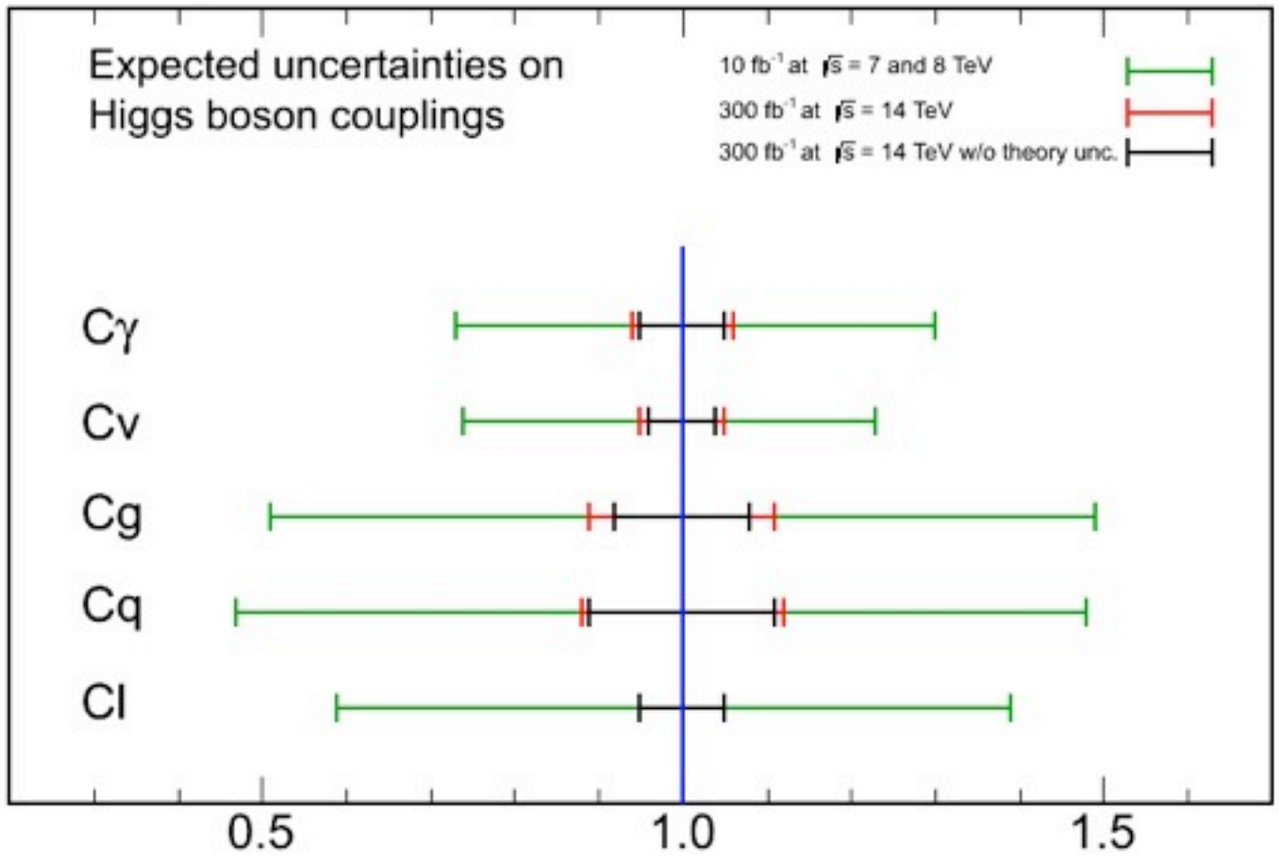
Test C_V-C_F

- Test compatibility by introducing two parameter (C_V, C_F)
- C_V and C_F modify expected signal yields in each mode through simple LO expressions
- Projecting to 30/fb at 8 TeV and 300/fb at 14 TeV
  - scale signal and background cross section
  - systematic uncertainties unchanged (dashed lines: no theory unc.)



Test multiple Ci

CMS Projection



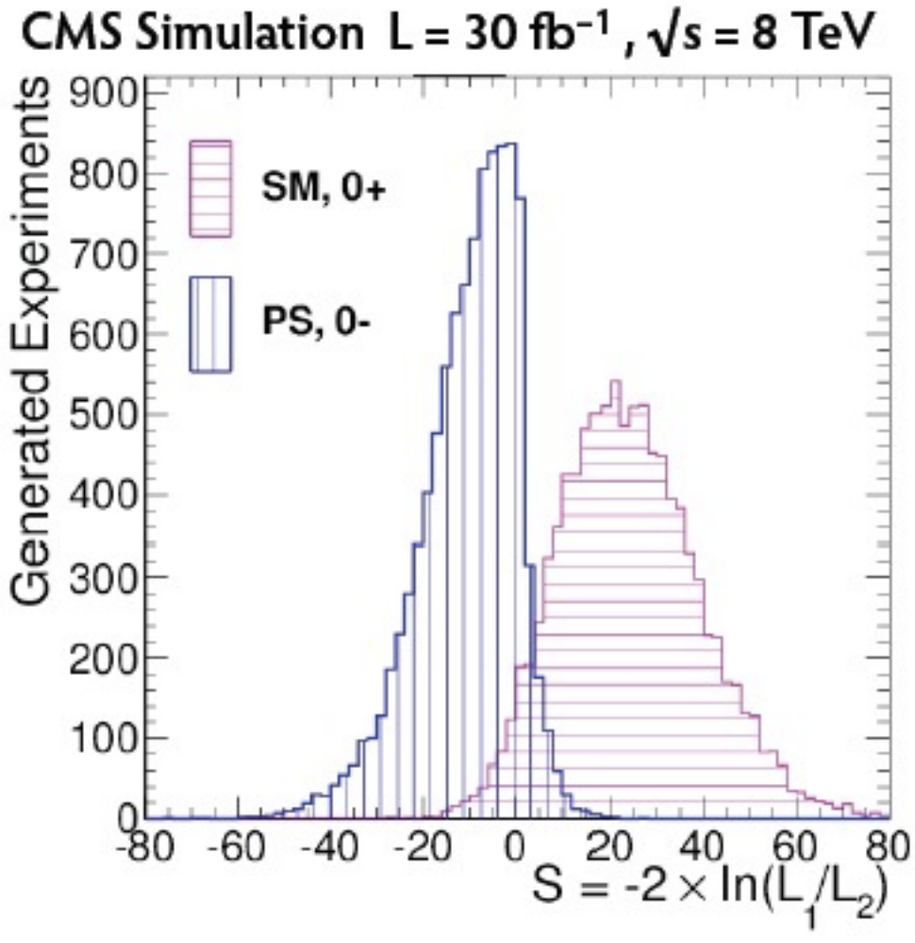
mH = 125	10/fb 7&8 TeV	300/fb 14 TeV
Cγ	0.27	0.05
Cv	0.26	0.05
Cg	0.49	0.11
Cq	0.53	0.12
Cl	0.41	0.05

Not applied to data yet

Note: while the procedure to estimate couplings is well defined, there are uncertainties on the SM value.

J^{PC} measurement

- ZZ→4l: expect 3σ scalar vs pseudo-scalar separation with 30/fb using MELA approach
- WW→2l2ν: feasibility studies look promising for spin-0 vs spin-2 separation
- Furthermore
  - VBF signature has sensitivity
  - Spin-0 vs spin-2 separation using γγ final state
  - Fermion final states



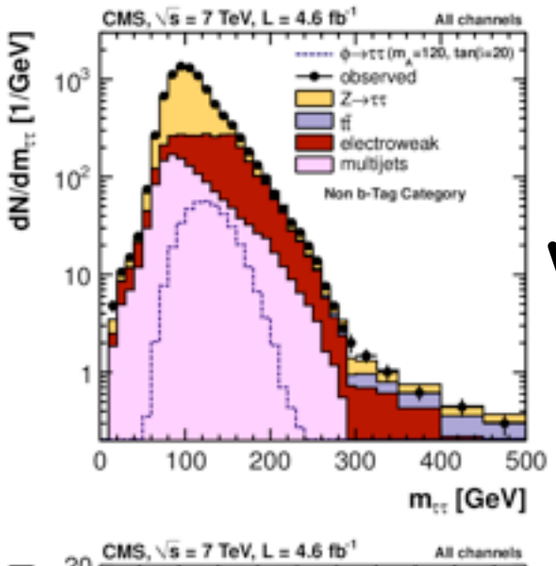
Beyond the SM-like Higgs searches

Model	Type	Final State	Mass Range [GeV]	Documentation
MSSM	h, H, A	ττ	90-600	HIG-12-018 pub. in PLB
MSSM	h, H, A	bb	90-350	HIG-12-026 & 27
MSSM	h, H, A	μμ	115-300	HIG-12-011
MSSM	H^+	τ+jets, τ+e/μ, e+μ	80-160	HIG-11-019 sub. to JHEP
nMSSM	a	μμ	5.5-9 & 11.5-14	HIG-12-004
minimal type-II See-Saw model	H^{++}	l^+l^-, l = e, μ or τ	140-500	HIG-12-005

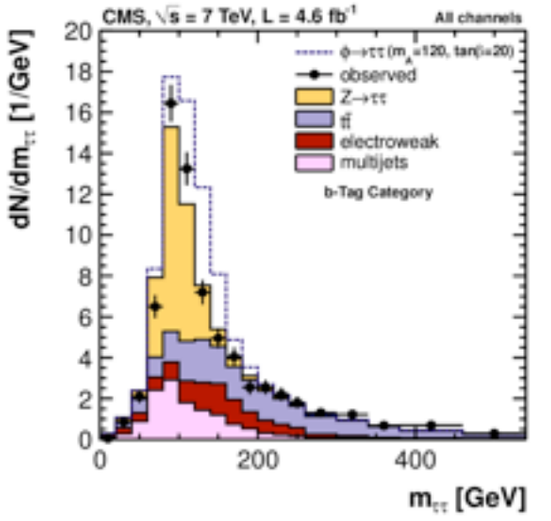
MSSM Higgs search channel: H → ττ

- Analysis strategy similar to SM H → ττ search
  - Replace VBF category with b-tag category
- Not updated with 8 TeV dataset yet

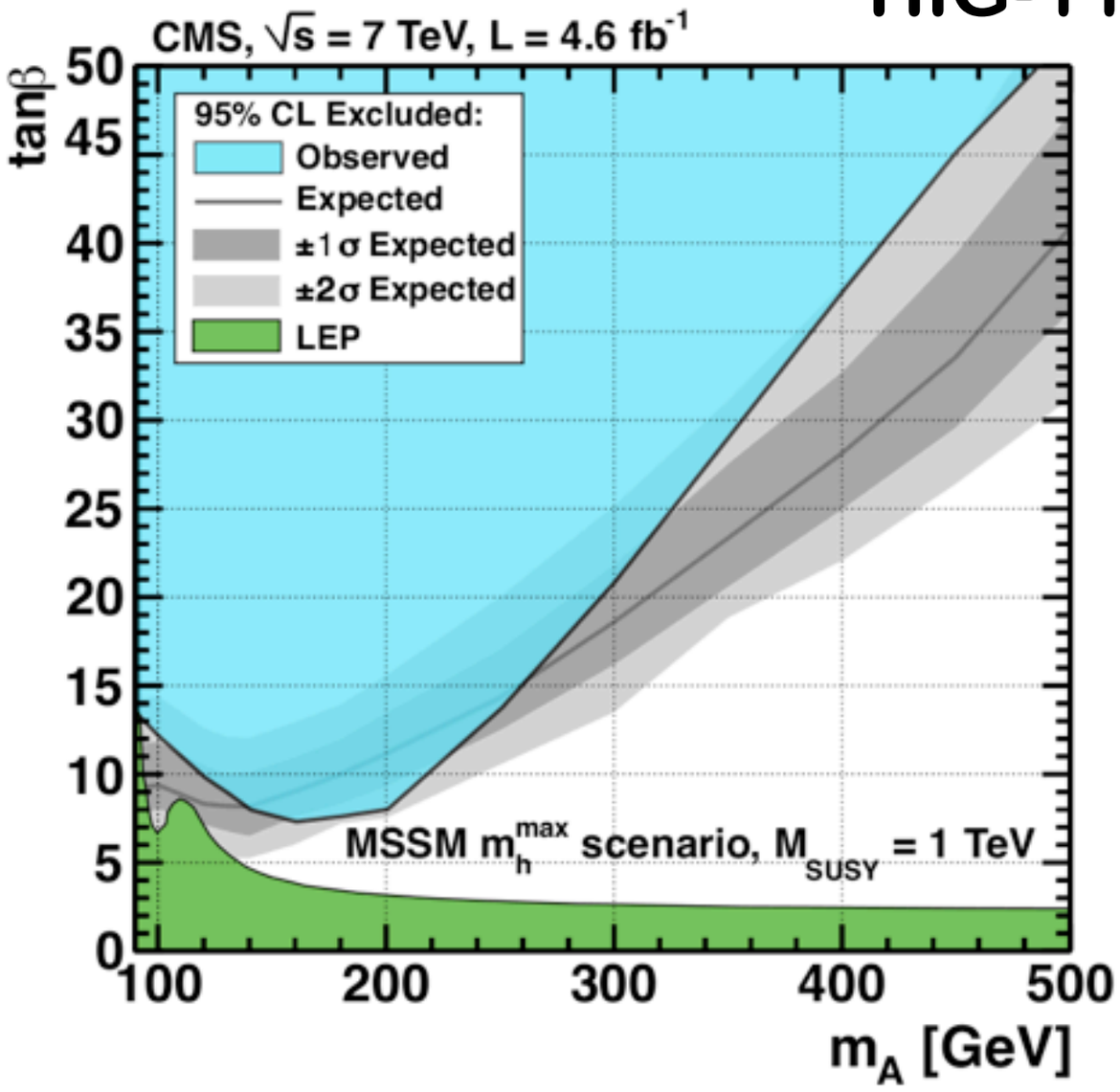
HIG-11-029



w/o b-tag



w/ b-tag



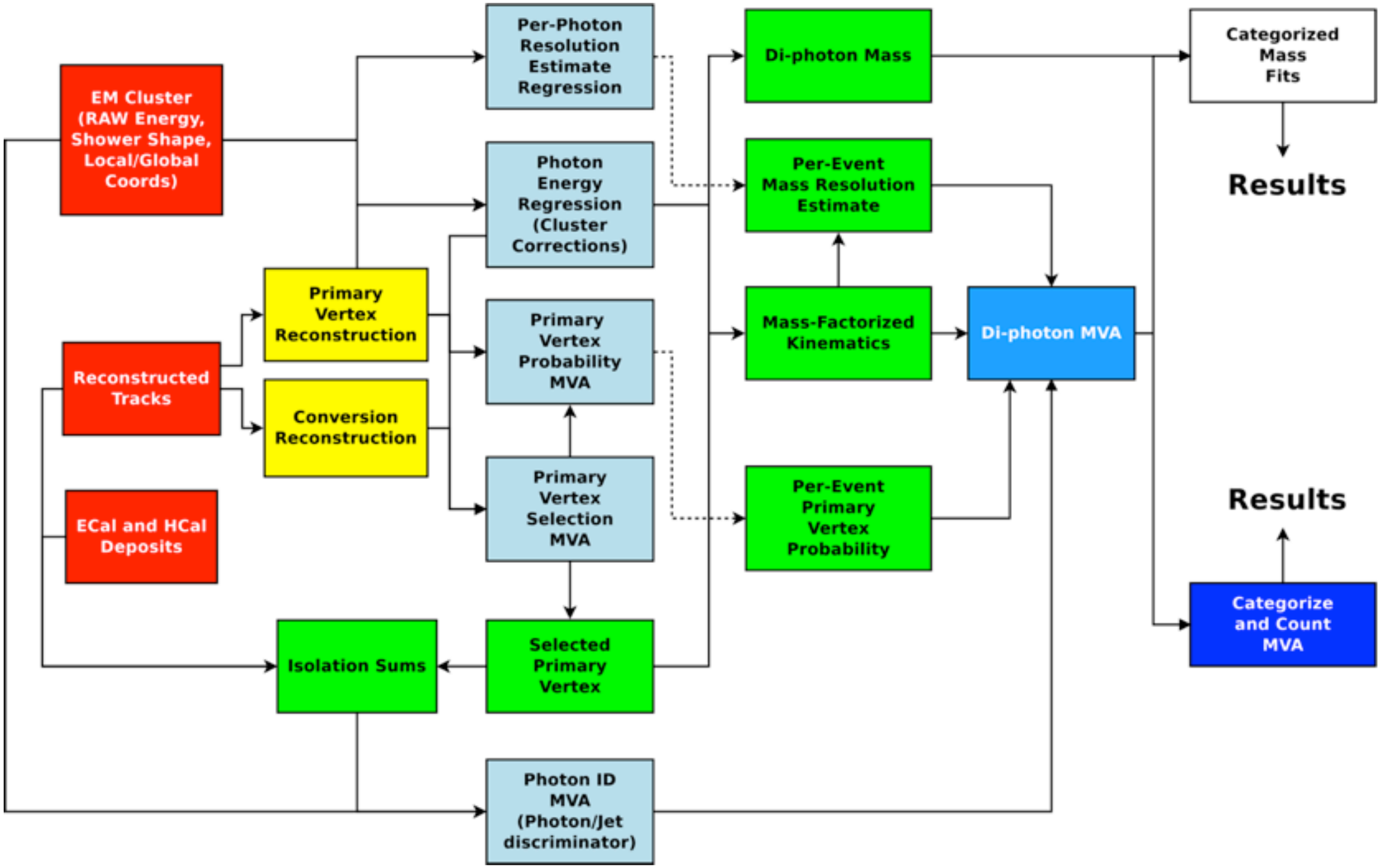
Conclusion: We have it! Do we?

- We have something to celebrate!
- 5σ excess observed, 5.8σ expected
- New state with mass of 125.3 ± 0.6 GeV
- Consistent with SM prediction
  - more data and more studies are needed to draw conclusions
- HIG-12-028, arXiv:1207.735 submitted to Phys. Lett. B

Conclusion: what's next

- More data, hope for 30/fb this year
- Characterize new state
  - mass, J^{CP}, couplings
- Increase diversity of SM searches
  - explore all possible production and decay modes
  - extended mass ranges (high and low)
- Non-SM-like Higgs searches
  - continue BSM program
  - explore new channels / states

Discovery channel: H → γγ



Coupling measurements

- **Production scale factors**

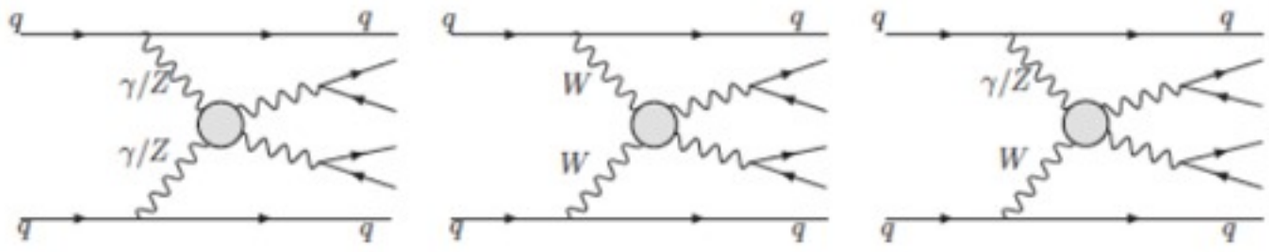
$$C^2_{\mathrm{VBF}}(C_W, C_Z, m_H) = C^2_W \cdot \frac{\sigma^{SM}_{WF}(m_H)}{\sigma^{SM}_{VBF}(m_H)} + C^2_Z \cdot \frac{\sigma^{SM}_{ZF}(m_H)}{\sigma^{SM}_{VBF}(m_H)}$$

$$= \frac{C^2_W + C^2_Z \cdot \frac{\sigma^{SM}_{ZF}(m_H)}{\sigma^{SM}_{WF}(m_H)}}{1 + \frac{\sigma^{SM}_{ZF}(m_H)}{\sigma^{SM}_{WF}(m_H)}}$$

$$C^2_g(C_b, C_t, m_H) = \frac{C^2_t \cdot \sigma_{tt}(m_H) + C^2_b \cdot \sigma_{bb}(m_H) - C_t C_b \cdot |\sigma_{tb}(m_H)|}{\sigma_{tt}(m_H) + \sigma_{bb}(m_H) - |\sigma_{tb}(m_H)|}$$

VV scattering studies

- VV scattering scenario
  - ~~no Higgs scenario (mH = infinity)~~
  - low mass scenario (mH = 125 GeV)
  - high mass Higgs scenario (mH = 1 TeV)
  - ~~BSM unitarization model~~
- Closure test for SM Higgs
  - orthogonal approach
- Final state
  - lv + 4j (qqWW, qqWZ)
  - ll +4j (qqZZ, qqWZ)
  - 2j vvll (same sign, qqWW)
  - 2j vvll (opposite sign, qqWW and qqZZ)
  - 2j llll (qqZZ)



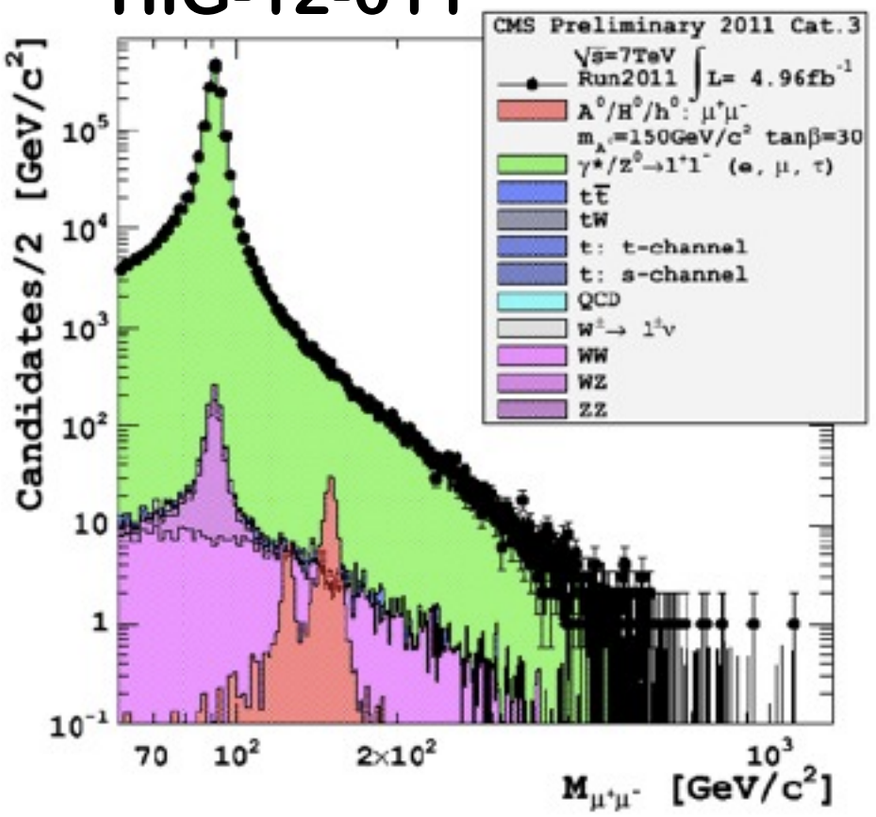
Future master table of SM Higgs searches

Channel	Mass range [GeV]	Lumi'11 [1/fb]	Lumi'12 [1/fb]	Lumi'?? [1/fb]	Topologies	gF	VBF	VH	ttH
H → γγ	110-150	5.1	5.3		incl. + VBF	☺	☺	☺	☺
H → ττ	110-145	4.9	5.0		0/1 jet + VBF + WH + ZH	☺	☺	☺	☺
H → bb	110-135	5.0	5.0		WH + ZH + ttH	-	☺	☺	☺
H → ZZ → 4l	110-600	5.1	5.3		inclusive	☺	☺	☺	☺
H → WW → 2l2v	110-600	4.9	5.3		0/1 jet + VBF + WH + ZH	☺	☺	☺	☺
H → Zγ	125	5	30			☺	☺	☺	☺
H → μμ	125	5	30	3000	0/1 jet + VBF	☺	☺	-	-
H → HH	125	5	30	3000	inclusive	☺	-	-	-

Rare decays

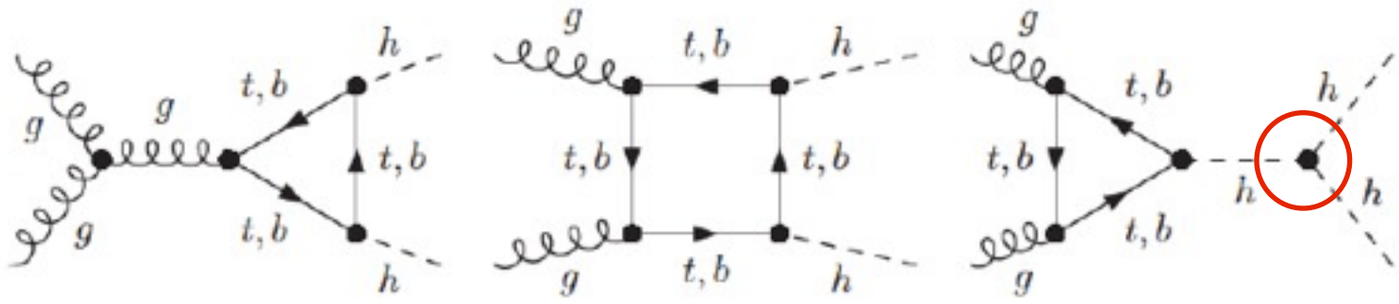
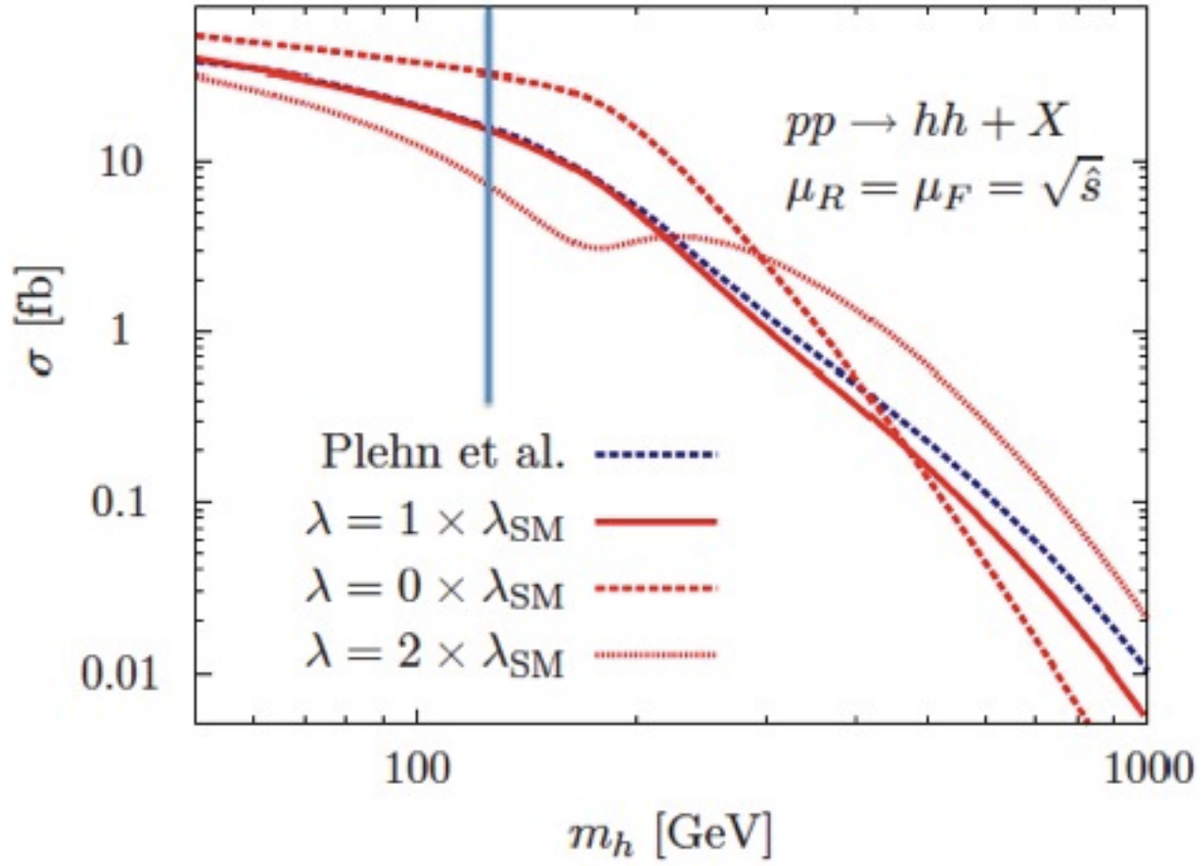
- Can CMS measure H →μμ?
  - very difficult for LC experiments
  - CLIC: 7% unc. on coupling with 2/ab @ 3TeV
- Three results from CMS
  - HEP-ph arXiv:0204087
    - pre-collision data
  - CMS has MSSM search (HIG-12-011)
    - not optimized for SM
  - Feasibility study
    - exclusive signal selection (VBF)
- Results show 5 sigma excess possible in 3000/fb at 14 TeV
  - allows hμμ coupling measurement with 10% uncert.

HIG-12-011



Higgs self couplings

- Higgs self couplings
  - hep-ph arXiv:0310056
  - hep-ph arXiv:0211224
  - hep-ph arXiv:0204087
  - hep-ph arXiv:1206.5001
- Study of Higgs pair production
  - larger interference effects
- Cross sections
  - 14 (33) TeV 34 (206) fb for SM
- Final states



hh →		BR	Comment
bbγγ	ok	0.26%	Possible
bbμμ	?	0.025%	Maybe possible
bbττ	?	3.7%	More studies needed
bb2l2v	no		Top background
bb4l	?	0.014%	Low rate
γγγγ	no	0.00052%	Very low rate
…	?