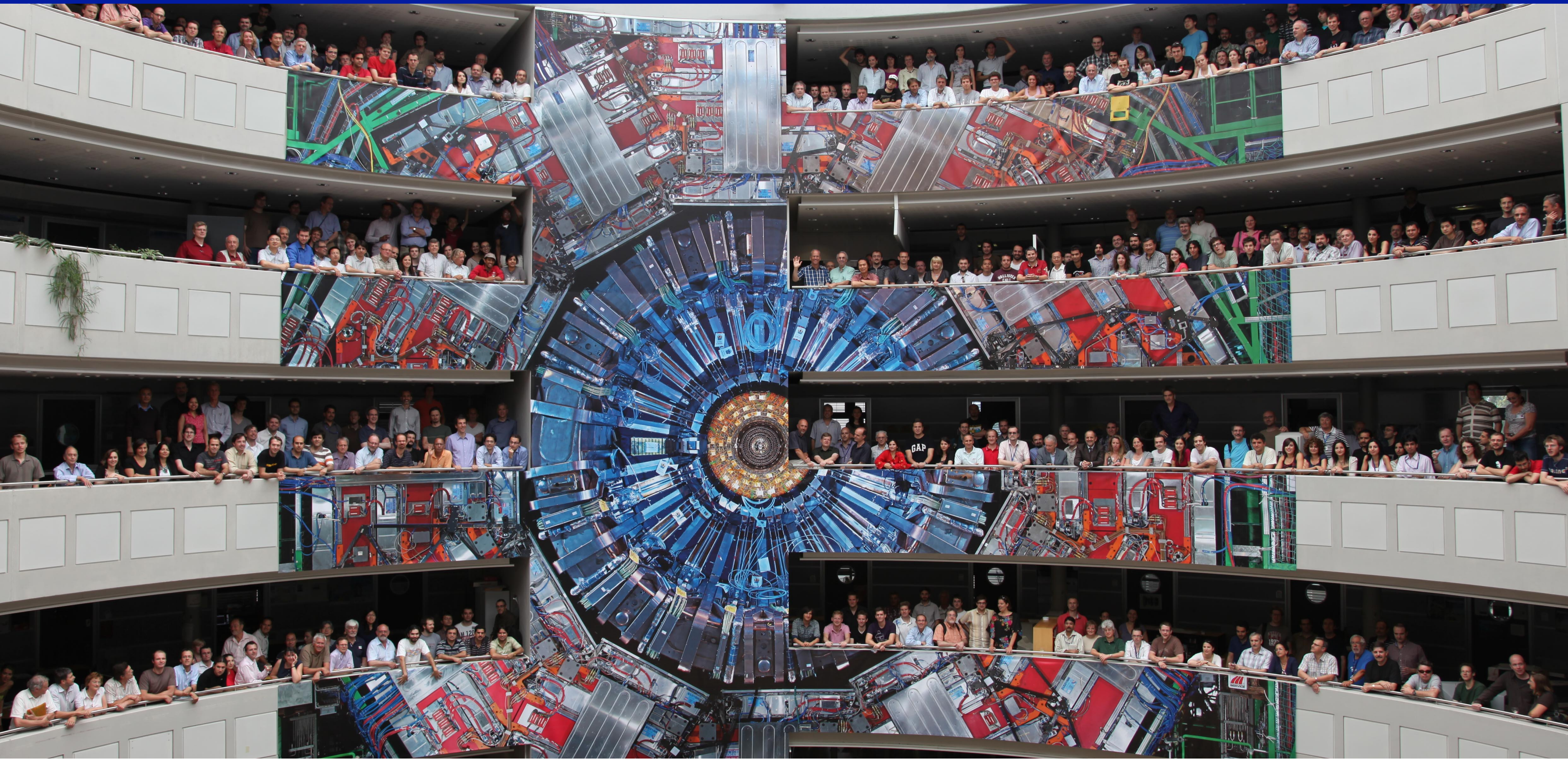
CMS X126 boson results

Andrey Korytov on behalf of the CMS Collaboration



The LHC Higgs Signal:

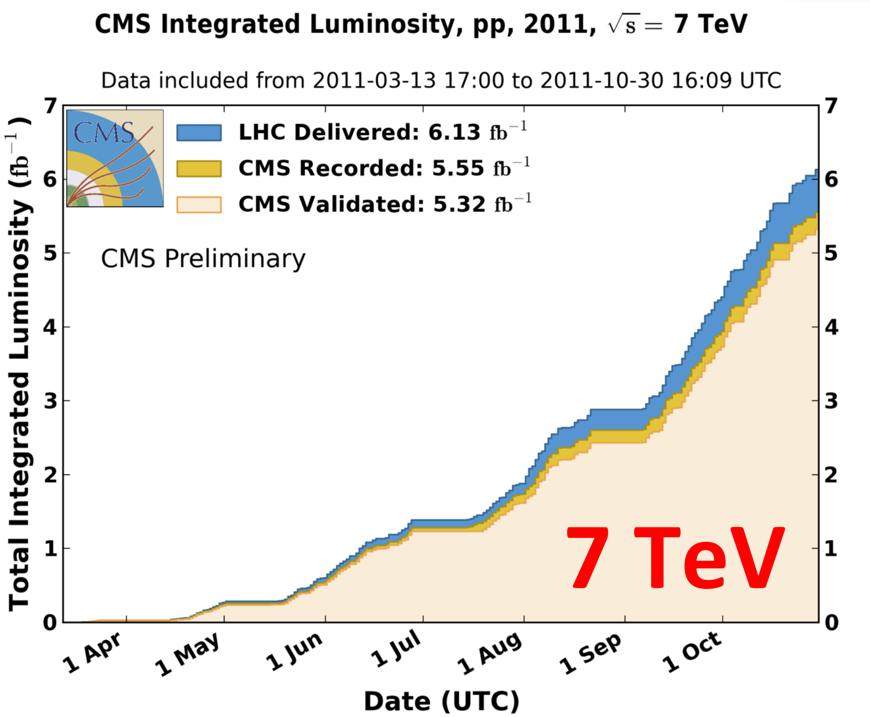
Characterization, Interpretation and BSM Model Implications

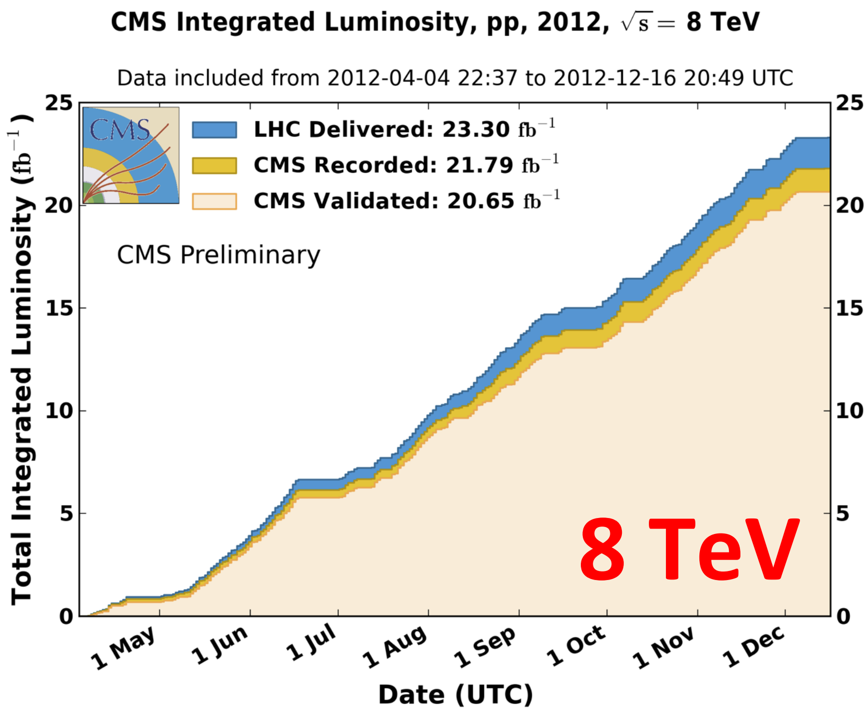
UC Davis, 22-26 April 2013

Outline

- CMS: a few highlights
- SM Higgs boson search symphony
  - individual search channels and grand combination
- Mass measurement
  - if X126 is the SM Higgs boson, its mass is the last SM parameter to measure
- Is X126 the SM Higgs boson?
  - What can we tell about the X126 width from the mass line shape (not available)
  - Compatibility of event yields with the SM Higgs boson
  - Recast the event yields into "measurements" of couplings
  - Spin-parity properties
  - Is X126 one particle?

CMS: operation





Stats for the 8 TeV run:

– **recorded**: 94% of delivered

– **validated for physics**: 95% of recorded

– **sub-detector operational status**: 96% - 99%

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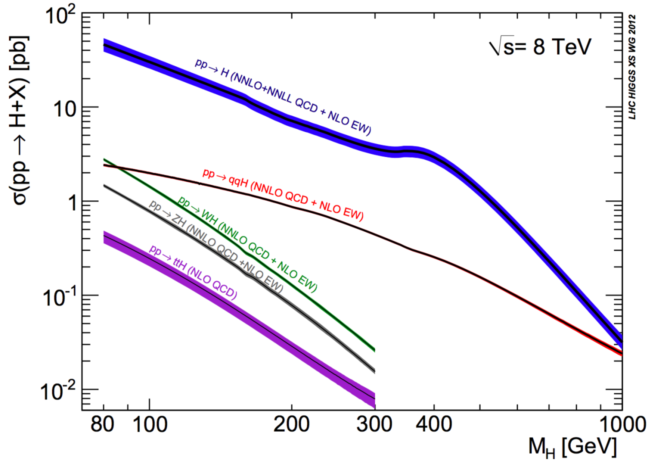
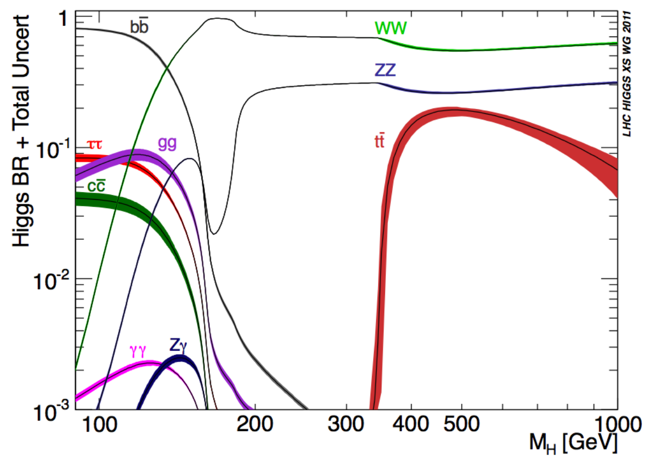
Search channels at low mass

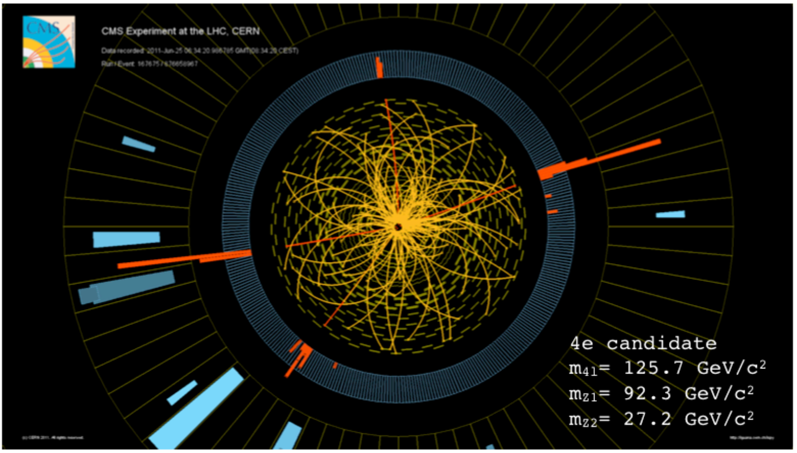


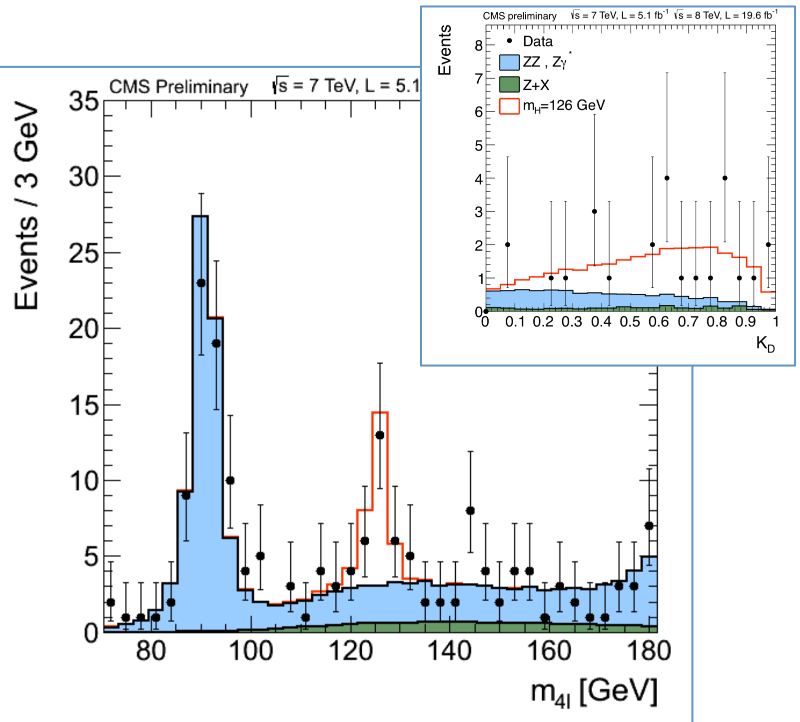


	untagged	VBF-tag	VH-tag	ttH-tag
WW	5 + 20	5 + 12	5 + 20	
ZZ	5 + 20	5 + 20		
bb			5 + 12	5 + 5
ττ	5 + 20	5 + 20	5 + 20	
γγ	5 + 20	5 + 20	5 + 20	
Zγ	5 + 20			

- Quoted X + Y numbers: X fb^{-1} @7 TeV + Y fb^{-1} @ 8 TeV (numbers are rounded)
- **BEWARE: Tags are never pure**; e.g. VBF-tags have 20%-80% of ggF, depending on analysis
- Zγ is not in combination

H → ZZ → 4l





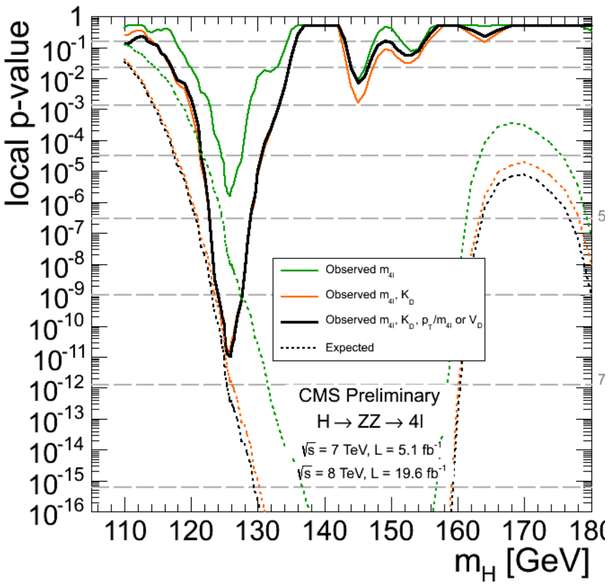
Analysis strategy:

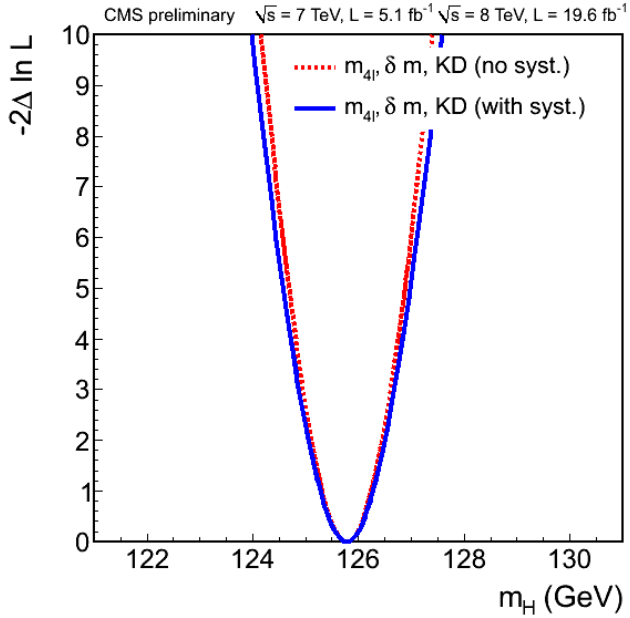
- four prompt leptons (low p_T is important!)
- **four-lepton mass** is the key observable
- split events into 4e, 4μ, 2e2μ channels:
  - different mass resolutions
  - different S/B rates (for reducible bkgd with "fake" leptons)
- add **ME-based discriminant K_D** (2^{nd} observable)
- split events further into exclusive categories:
  - untagged (add a 3^{rd} observable: **four-lepton p_T/m**)
  - di-jet tagged (add a 3^{rd} observable: **$V_D(m_{jj}, \Delta\eta_{jj})$**)
- Backgrounds:
  - ZZ (dominant) from MC
  - reducible (with "fake" leptons): from control region

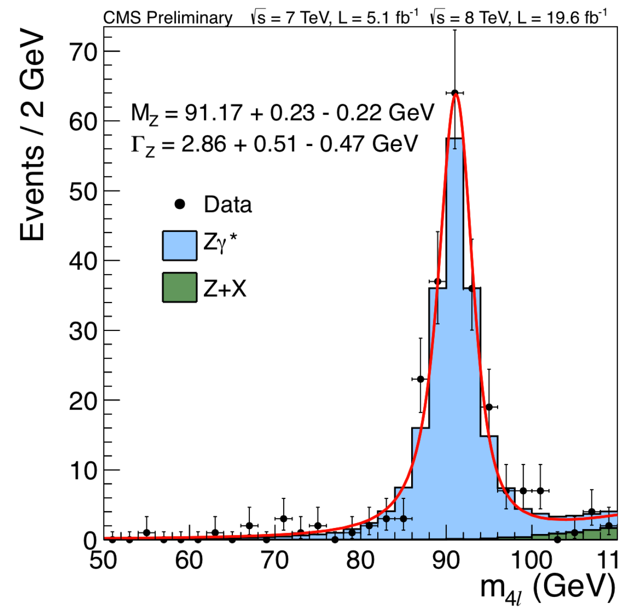
Analysis features to note:

- high S/B-ratio, but small event yield
- 4l mass resolution = 1-2%

H → ZZ → 4l: results







Z_{obs} = 6.7 σ
Z_{exp} = 7.2 σ

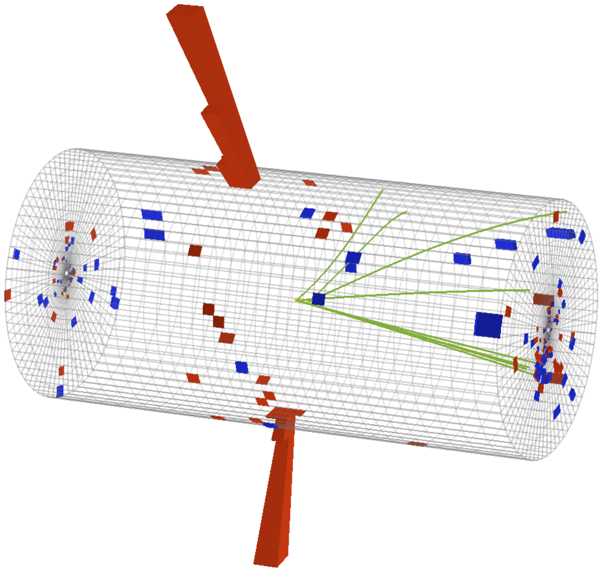
m_X = 125.8 ± 0.5 GeV
$\mu = 0.91^{+0.30}_{-0.24}$

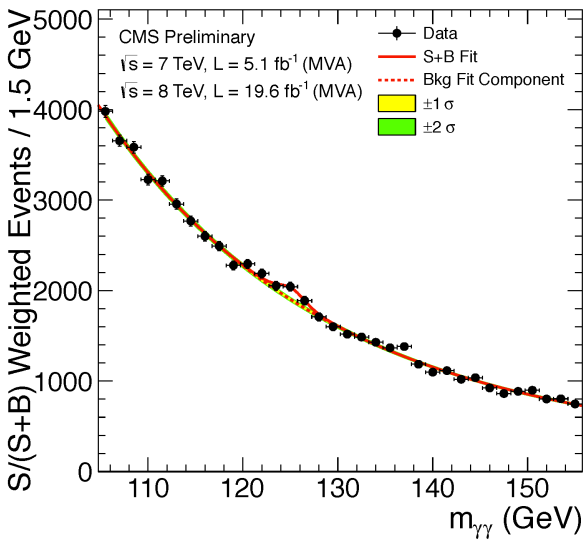
Z→4l standard candle
m_Z = 91.2 ± 0.2 GeV
Γ_Z = 2.9 ± 0.5 GeV

Points to note:

- **>5σ in one decay mode**
- di-jet tag does not help much in sensitivity (too few expected events), but is needed to assess the relative contributions of ggF and VBF production (will be shown later)
- ZZ→4l channel provides the **most accurate mass measurement** (event-by-event mass uncertainties improve the measurement by about 8%)
- signal strength is about equal to the expected
- Z→4l standard candle allows one to validate the mass (and future width) measurements (and eventually will allow one to measure σ_H/σ_Z with small experimental errors)

H → γγ





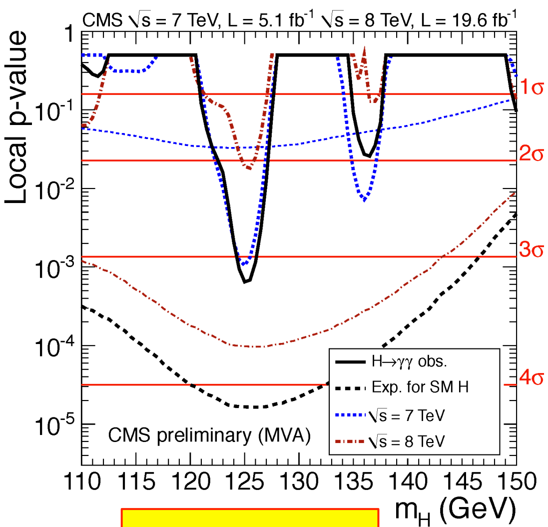
- Analysis strategy:
  - two isolated high-p_T photons
  - vertex from recoiling charged particles
  - **di-photon mass** is the key observable
  - split events into exclusive categories:
    - untagged, and further divided into 4 classes based on
      - expected mass resolution
      - expected S/B-ratio
    - di-jet tagged, and further divided into 2 classes based on
      - expected S/B-ratio
    - MET-tagged
    - electron-tagged
    - muon-tagged
  - background: from $m_{\gamma\gamma}$-distribution sidebands

→ $m_{\gamma\gamma}$

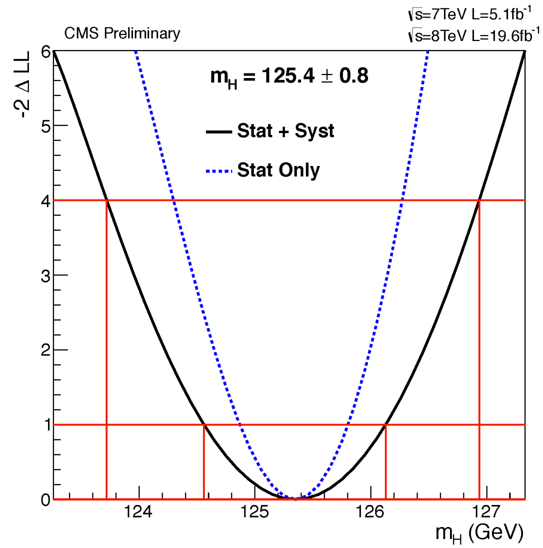
- Two versions of analysis:
  - MVA for photon-ID and event classification
  - Cuts for photon-ID and event classification

- Analysis features to note:
  - bad S/B-ratio, but high event yield (cf. ZZ->4l)
  - di-photon mass resolution = 1-2%

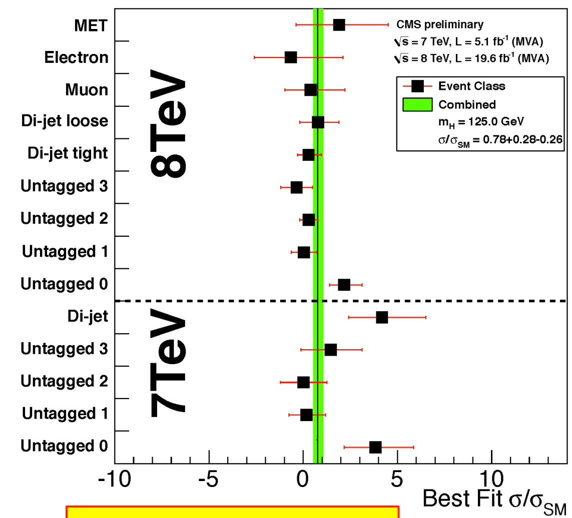
H → γγ: results



Z_{obs} = 3.2 σ
Z_{exp} = 4.2 σ



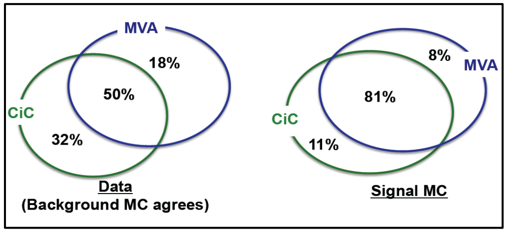
m_X = 125.4 ± 0.8 GeV



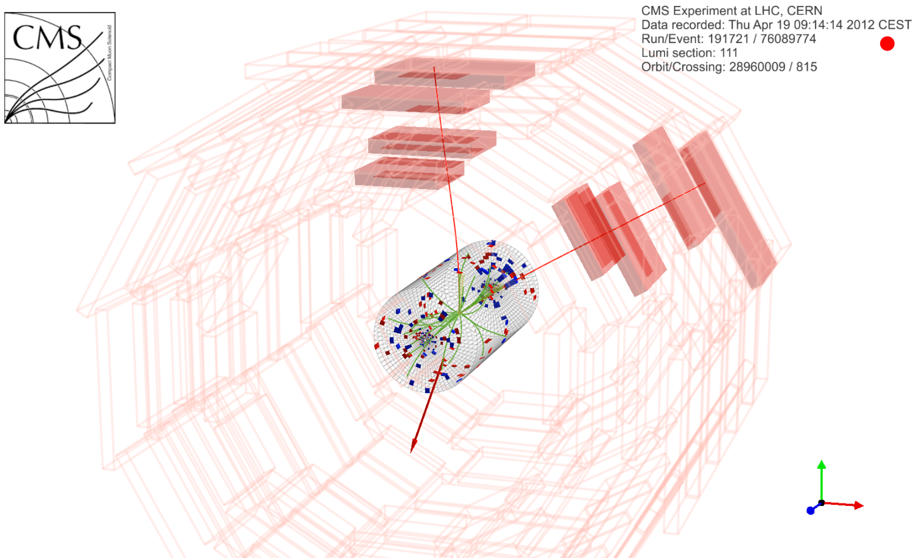
μ = 0.78 ± 0.27
(at m_H=125 GeV)

Points to note:

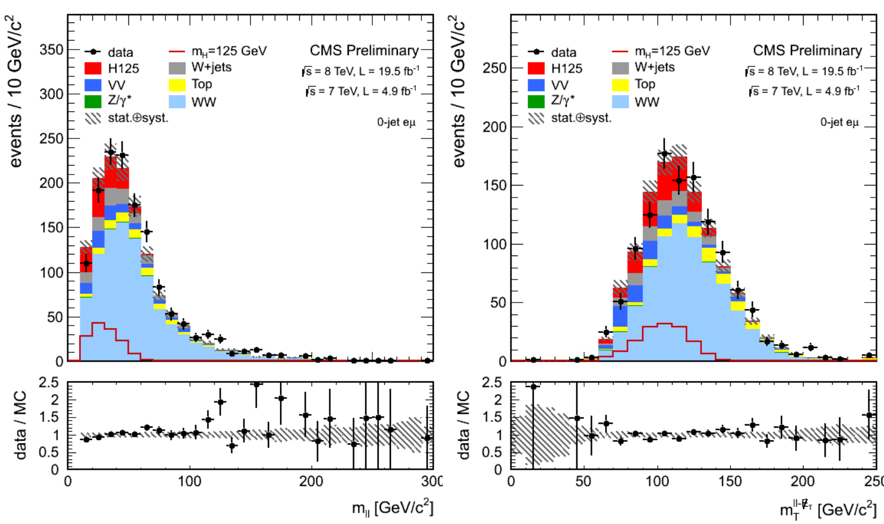
- alternative analysis results: Z=3.9 (exp. 3.5) and μ = 1.11 ± 0.31
  - statistical correlation between two analyses is found to be 0.75
  - taking this into account, **stat significance of the difference in results is 1.5 σ**
- significance is reduced compared to ICHEP:
  - ICHEP (10 fb^{-1}): **observed = 4.1**, expected = 2.7 (±1)
  - ICHEP (25 fb^{-1}): **observed = 3.2**, expected = 4.2 (±1)
  - New data show fewer than expected signal-like events (“Unlucky”? Or is it a “pay-back” for being too lucky before?)
  - The expected sensitivity evolves as sqrt(L)
- Is the past intrigue of a seemingly enhanced γγ-signal washing out?
- mass measurement becomes limited by systematic uncertainties



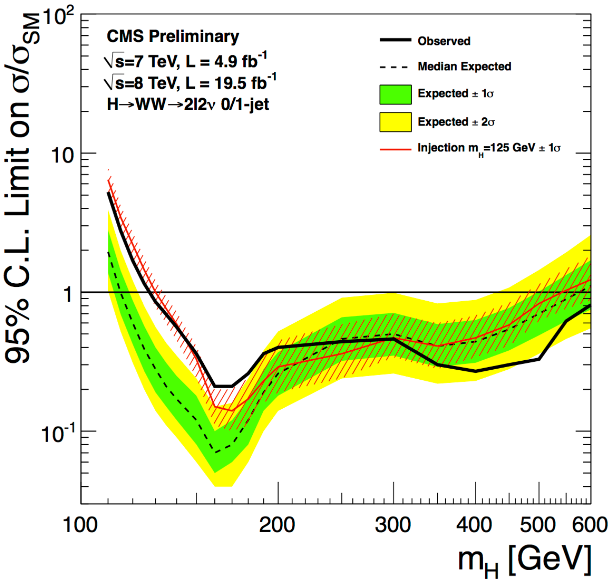
H → WW → lνlν

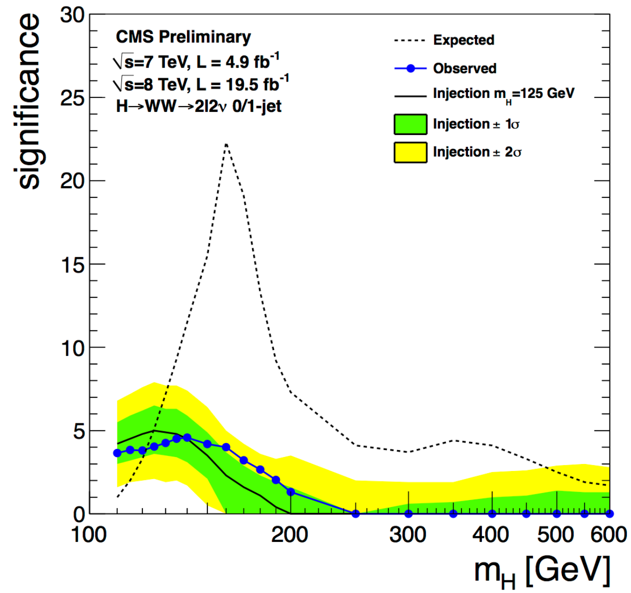


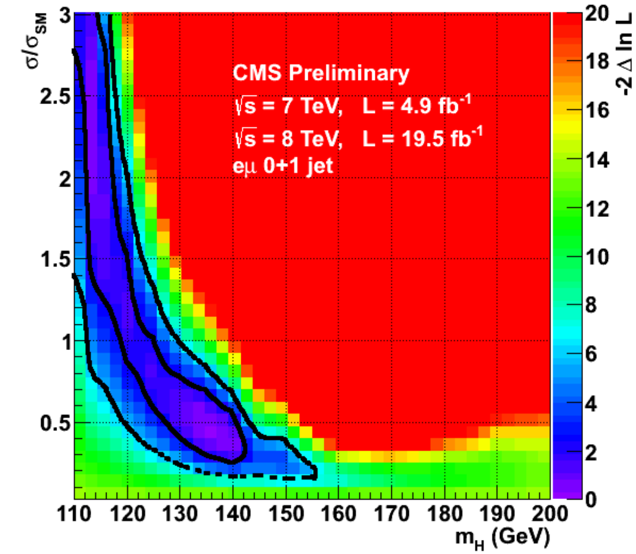
- Analysis strategy:
  - two prompt high-p_T leptons
  - MET
  - split events into ee, μμ, eμ channels:
    - different S/B rates: Drell-Yan in ee/μμ !
  - split events further into 0/1-jet:
    - different S/B rates: ttbar in 1-jet !
  - Same-flavor dileptons: **cut-based analysis**
  - Different-flavor: **2D distribution $N(m_{ll},m_T)$**
  - Backgrounds (for low mass Higgs):
    - WW, tt, W+jets, DY+jets, Wγ: from control regions
    - ZW, ZZ: from MC (very small contribution)
- Analysis features to note (mH=125):
  - OK S/B-ratio, fair signal event yield
  - poor mass resolution ≈20%



H → WW → lνlν: results







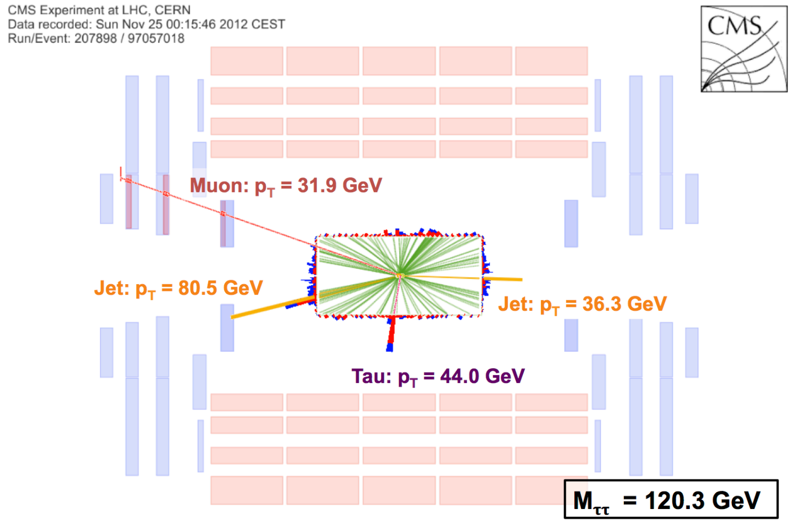
Z_{obs} = 4.0 σ
Z_{exp} = 5.0 σ (m = 125)

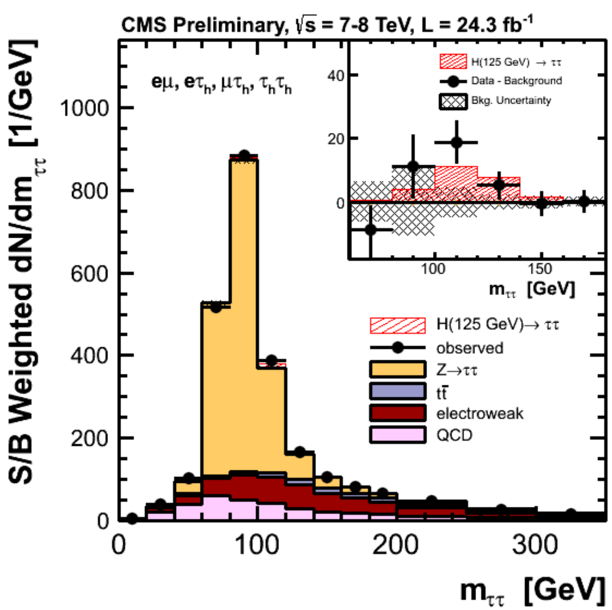
μ = 0.76 ± 0.21
(m = 125 GeV)

Points to note:

- very broad access, consistent with **SM Higgs rate** and the instrumental **mass resolution** (see injected signal)
- poor mass resolution does not allow to pin down the mass and hence signal strength
- the excess is consistent with m_H=125 GeV (μ=0.76 ± 0.21)
- significant updates should be expected:
  - di-jet tag channel results are not yet available
  - cut-based (same-flavor) and 2D-shape based (different-flavor)

H → ττ

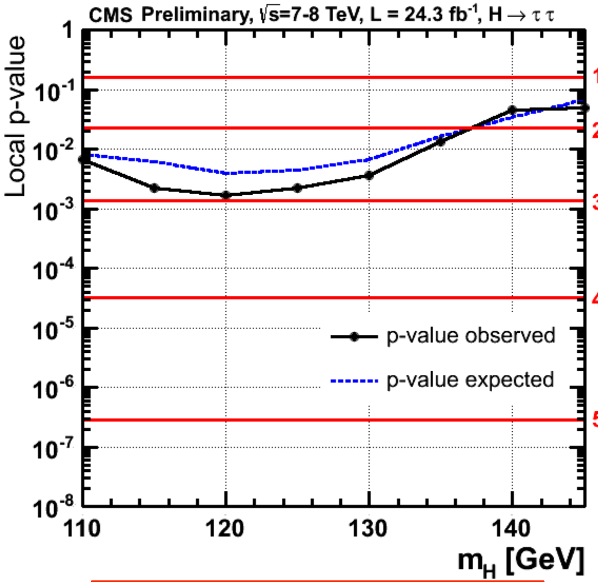




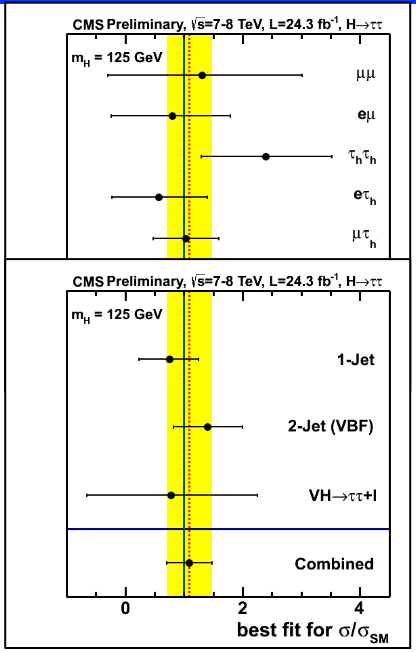
- **Analysis strategy:**
  - di-tau candidates: $e\tau_h$, $\mu\tau_h$, $e\mu$, $\mu\mu$, $\tau_h\tau_h$
  - MET
  - **DiTau mass (including MET)**: key distribution
  - split events into jet categories:
    - **2-jets (VBF-tag)**: best S/B-ratio
    - **1-jet (ggF, VH)**: acceptable S/B-ratio
    - untagged: control region (S/B≅0)
  - split 1-jet events further high/low p_T tau
    - different S/B rates
  - Backgrounds:
    - Z→ττ: Z→μμ (data) with a simulated μ-τ swap
    - Z→ee, W+jets, ttbar: MC for shapes, data for normalization
    - QCD: from control regions

- **Analysis features to note (m_H=125):**
  - poor S/B-ratio, poor signal event yield
  - Higgs is on falling slope of Z-decays
  - poor mass resolution ≈15%

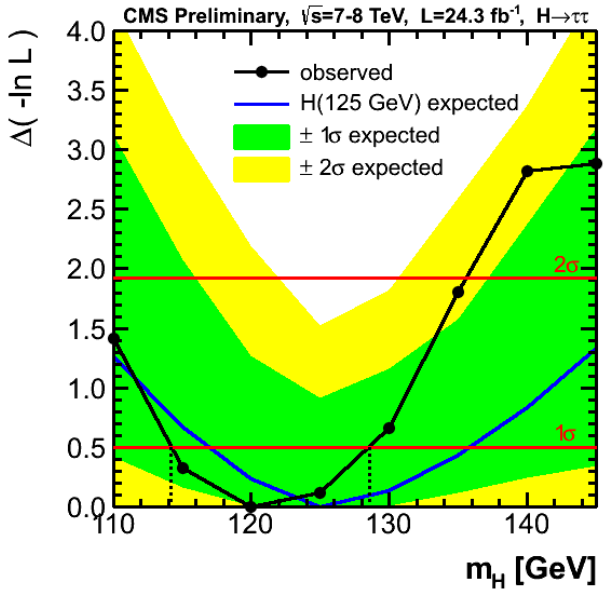
H → ττ: results



Z_{obs} = 2.9 σ
Z_{exp} = 2.6 σ (m = 125)



μ = 1.1 ± 0.4
(m = 125 GeV)

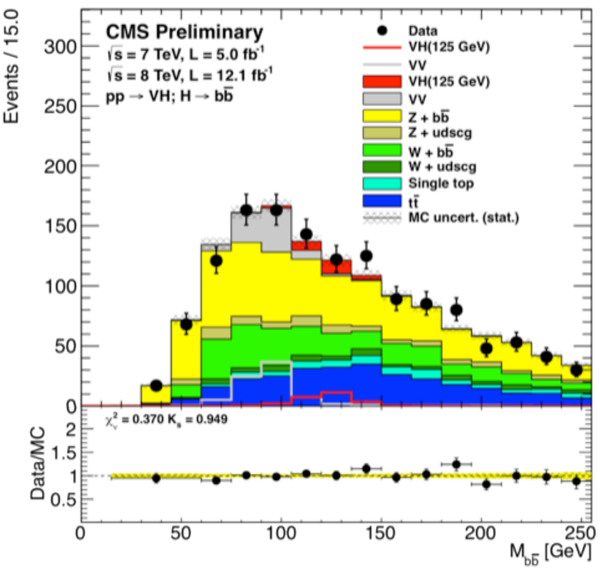


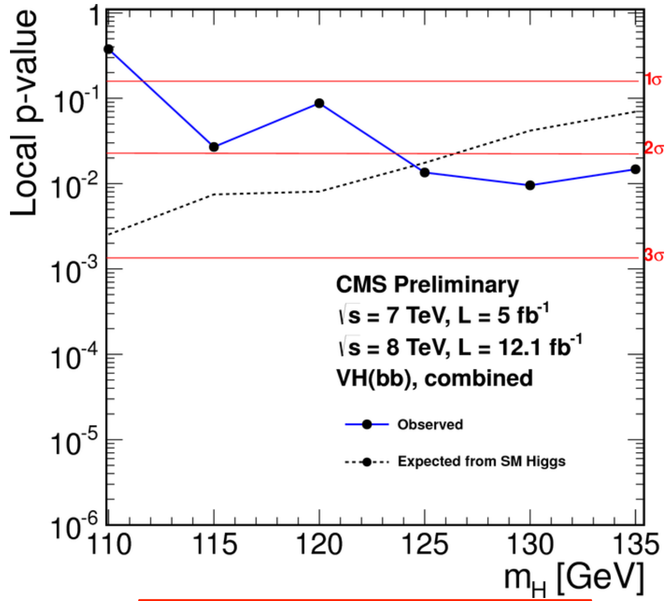
$m_X = 120^{+9}_{-7}$ GeV

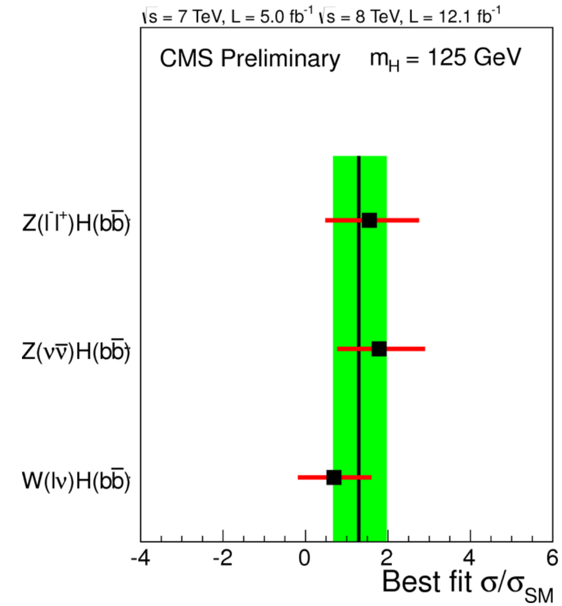
Points to note:

- broad access (poor mass resolution), consistent with **SM Higgs rate**
- close to reaching a 3σ-sensitivity: **fair sensitivity for measurements**
- 1-jet channel has a respectable weight in the search (cf. ±δμ for 1-jet and 2-jet channels)
- **VH(ττ) analysis is updated too**; its sensitivity can be seen in the μ-compatibility plot
- despite poor mass resolution, the TauTau channel is **not completely mass-blind** !

VH, H → bb: no updates since HCP (yet)







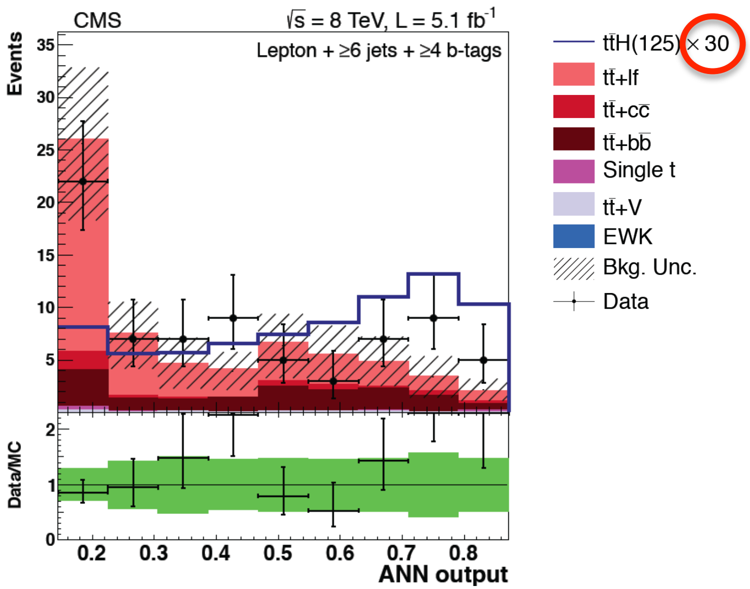
Z_{obs} = 2.2 σ
Z_{exp} = 2.1 σ (m = 125)

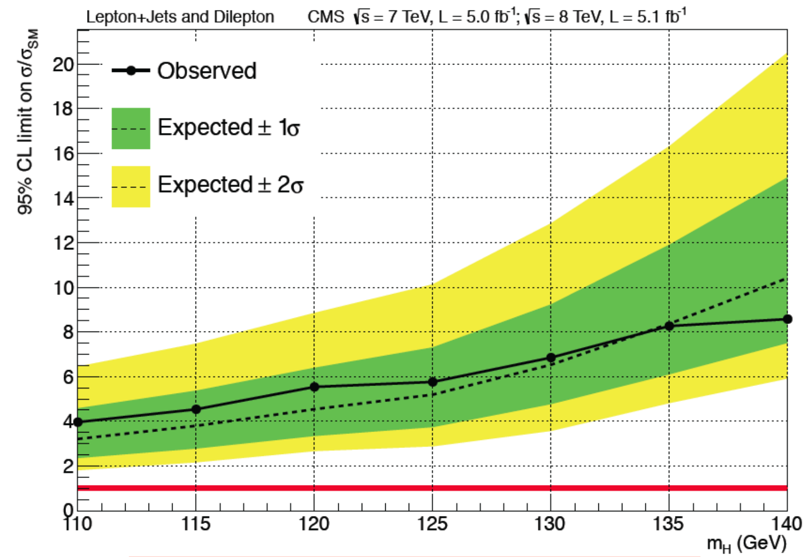
μ = 1.3 ± 0.7
(m = 125 GeV)

Brief summary:

- publicly available: **5 + 12 fb^{-1}**; update with the full lumi is expected shortly
- Event classification: 2 b-jets + (eν, μν, ee, μμ, νν); V has low/high-pT; events with high-pT: tight/loose b-tag
- MVA-shape analysis gives 2σ-sensitivity: **fair sensitivity for measurements**
- **2σ-excess** with a signal strength consistent with the SM Higgs boson: **μ = 1.3 ± 0.7**
- mass resolution **≈10%**

ttH, H → bb: updated, but 5+5 fb^{-1} only



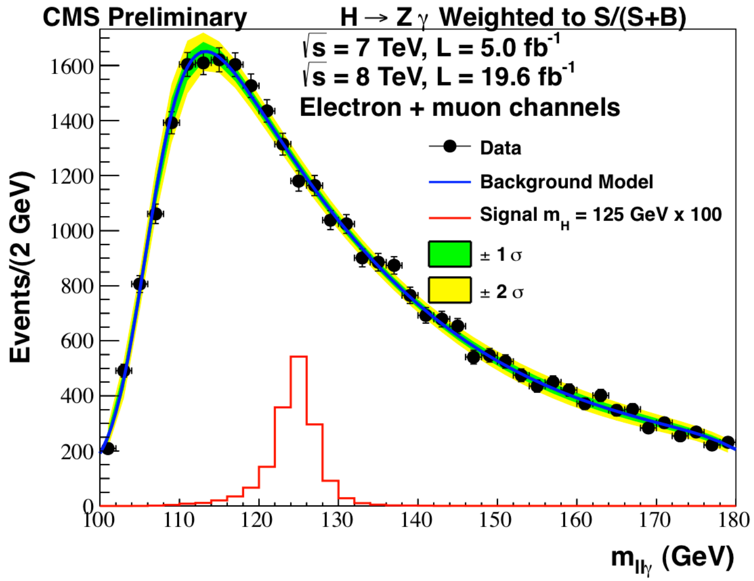


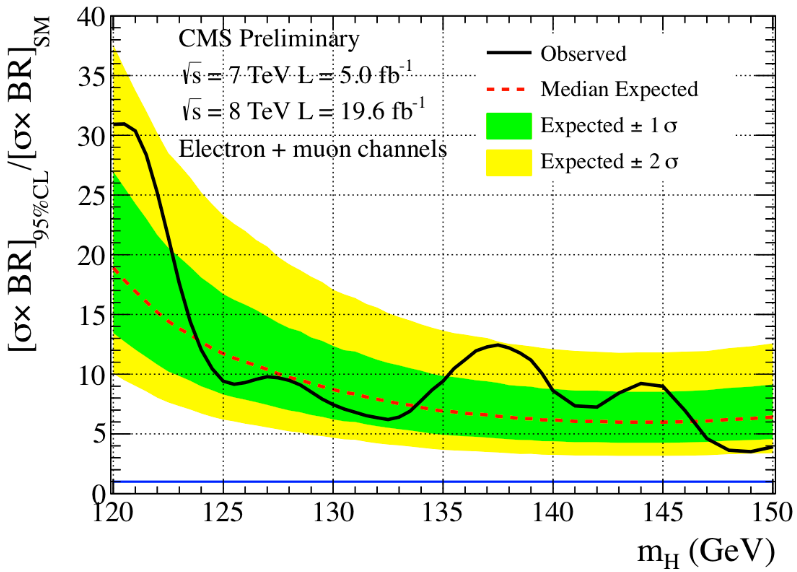
μ > 5.8 excluded at 95% CL
(m = 125 GeV)

Brief summary:

- publicly available: **5 + 5 fb^{-1}**; update with the full lumi is expected shortly
- Event classification: bb+(lνjjbb); bb+(lνlνbb); events are categorized based on # of jets and # of b-tags
- very small event rate; fair S/B-ratio
- MVA-shape analysis: exclude μ>5.8 at 95% CL
- To reach 2σ-sensitivity, **we need 30^{x} data**

H → Zγ





Analysis strategy:

- two prompt leptons: Z→ee, Z→μμ
- isolated photon
- **dilepton-photon mass** is the key observable
- split events further into 4 classes, based on "geography" of leptons/photon and photon cluster quality
  - different mass resolutions
  - different S/B-ratios
- Background: fit using sidebands

Analysis features to note:

- very poor S/B-ratio, very small event yield
- 4l mass resolution = 1-2%

Results: **m_H=125: μ>10 is excluded at 95% CL**

Points to note:

- **need 100^x data** to reach 2σ-sensitivity

Excess near 125 GeV: summary

Decay mode	Expected (σ)	Observed (σ)
ZZ	7.1	6.7
$\gamma\gamma$	3.9	3.2
WW	5.3	3.9
bb	2.2	2.0
$\tau\tau$	2.6	2.8

Good mass resolution channels:

- **ZZ(4l):** **6.7 σ**
- **γγ:** **3.2 σ**

Poor mass resolution channels:

- **WW:** **3.9 σ**
- **ττ:** **2.8 σ**
- **bb:** **2.0 σ** VH(5+12 fb^{-1}); ttH(5+5 fb^{-1}); updates come soon
- **ττ+bb:** **3.4 σ** evidence for fermionic decays

Higgs-like signal is certainly there beyond any reasonable and unreasonable doubt

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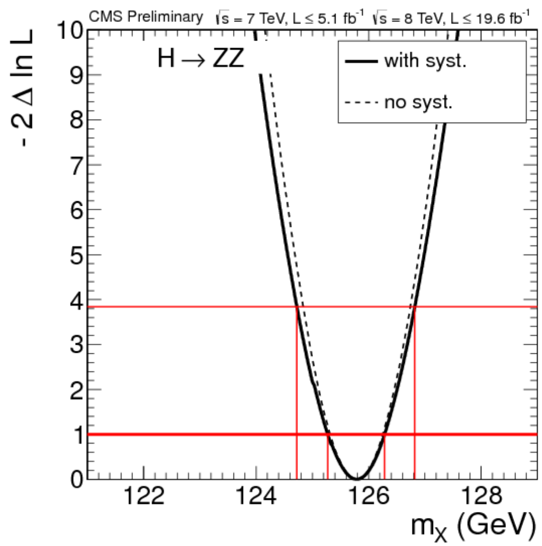
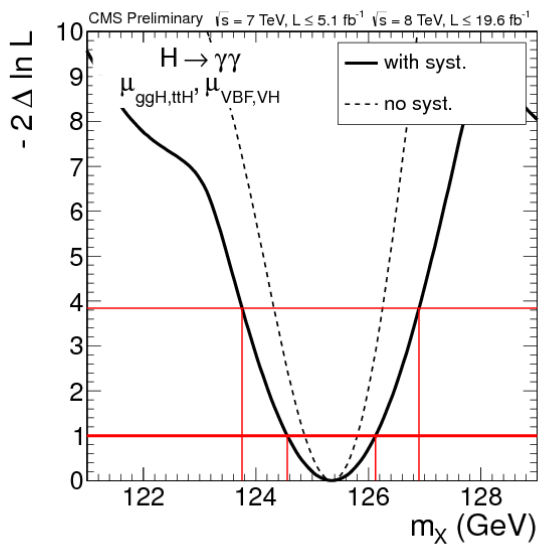
Mass measurement





- **A narrow resonance is seen with high significance in the two good mass resolution channels, ZZ(4l) and γγ**

ZZ(4l): m_X = 125.8 ± 0.5 (stat) ±0.2 (syst) GeV

main sources of systematic uncertainties:

- electron energy scale: 0.3%
- muon energy scale: 0.1%

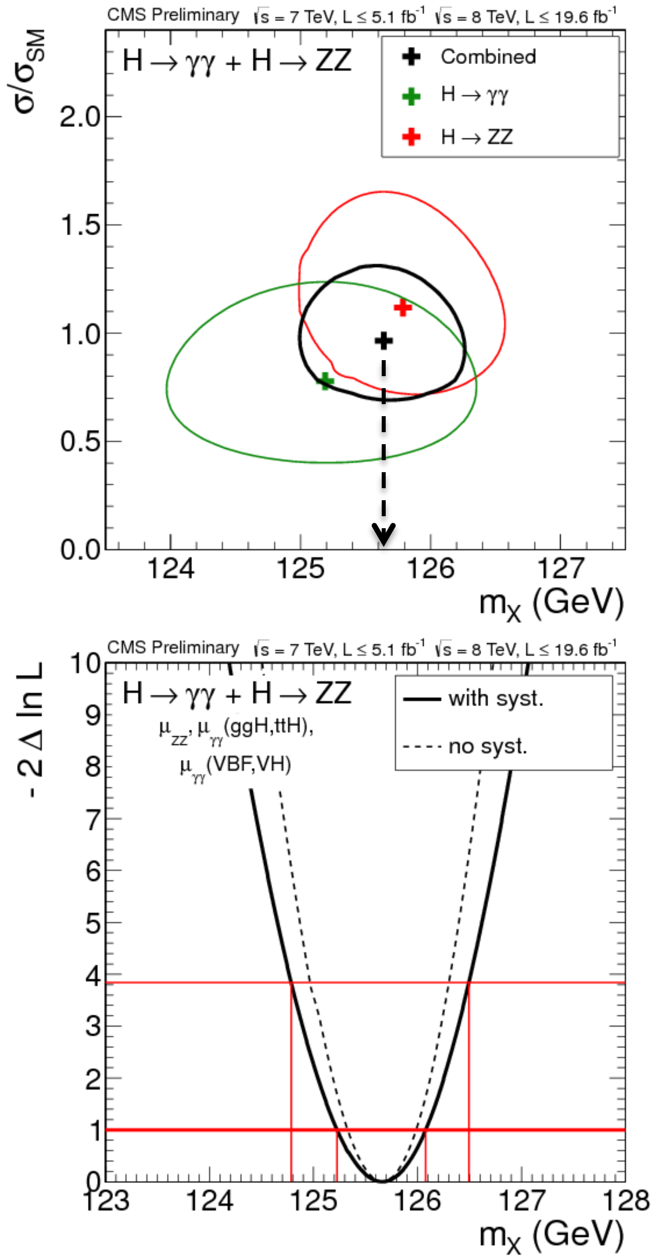
γγ: m_X = 125.4 ± 0.5 (stat) ± 0.6 (syst) GeV

– main sources of systematic uncertainties:

- electron-photon extrapolation
- p_T scale extrapolation from $m_Z/2$ to $m_H/2$

- **Results are consistent with one particle X**
  → proceed with a combined mass measurement

Mass measurement



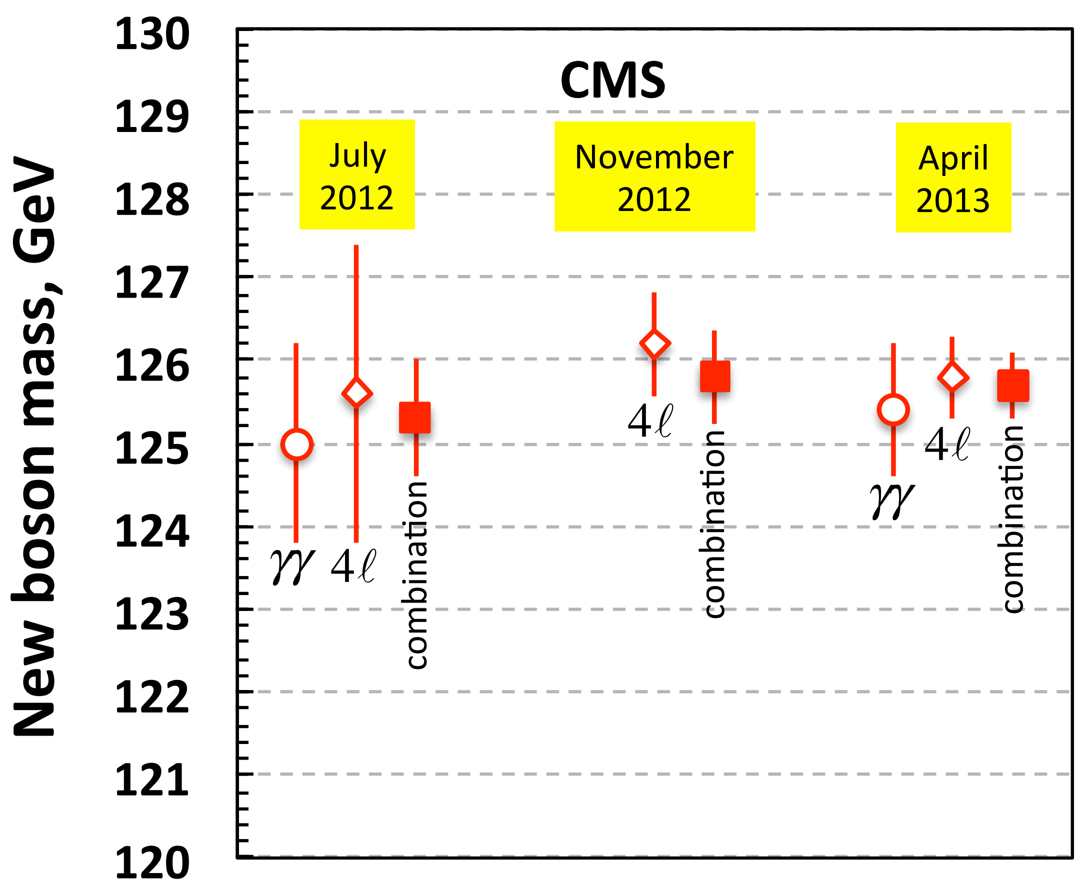
Assuming we indeed see one particle X, one can combine the two results

- either assuming the SM Higgs-like relationship for relative production rates (top plot)
- or letting relative event yields float free in the almost-model-independent fit (bottom plot):

m_X = 125.7 ± 0.4 (0.3%) GeV

= 125.7 ± 0.3 (stat) ± 0.3 (syst) GeV

Evolution of m_X with time



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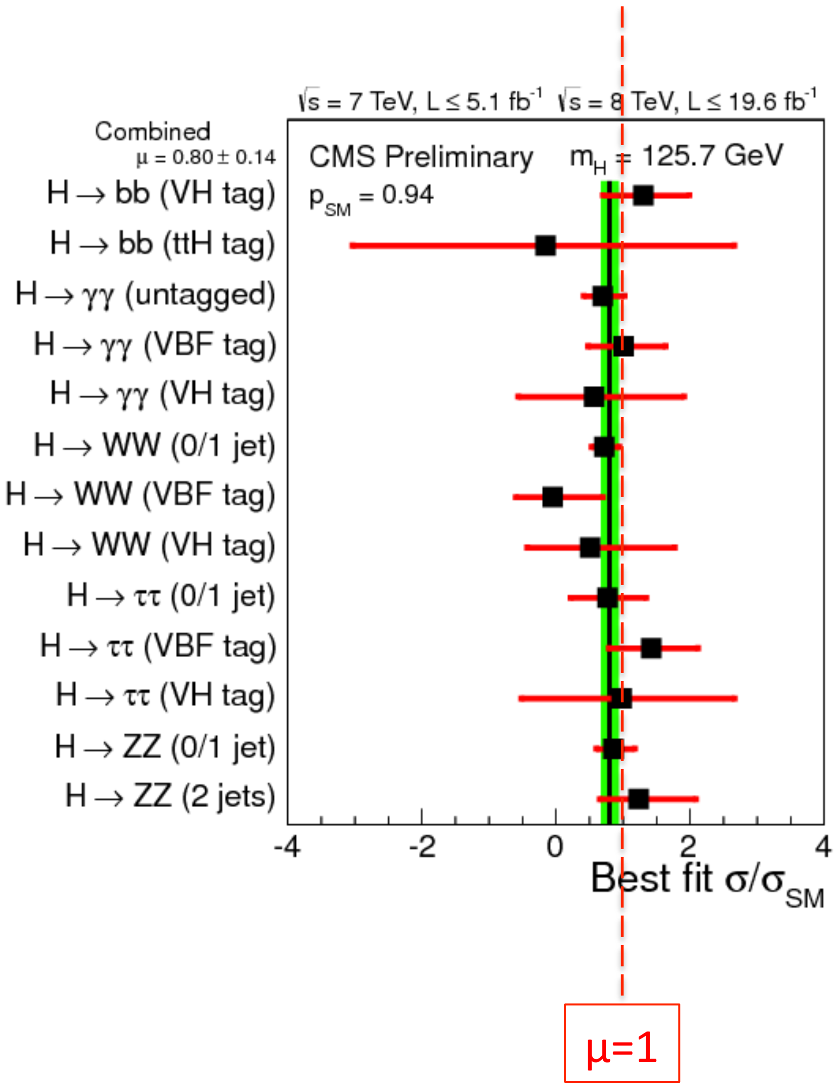
Consistency of event yields (1)



Overall best-fit signal strength

$\mu = 0.80 \pm 0.14$

Sub-combinations grouped by (production tag) × (decay mode)

Consistency with the **SM Higgs**:

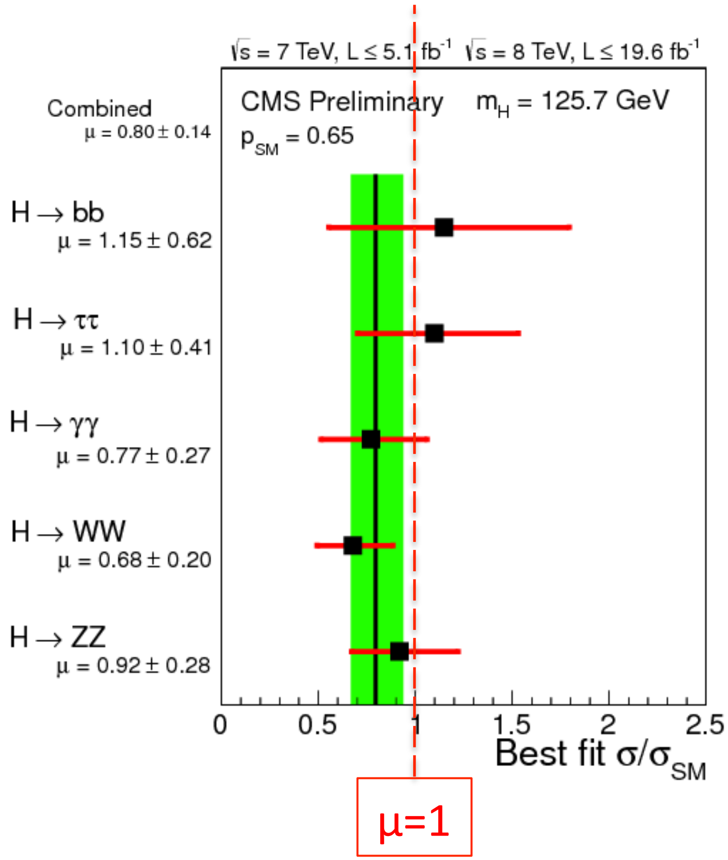
χ^2 / ndf = 6.2 / 13

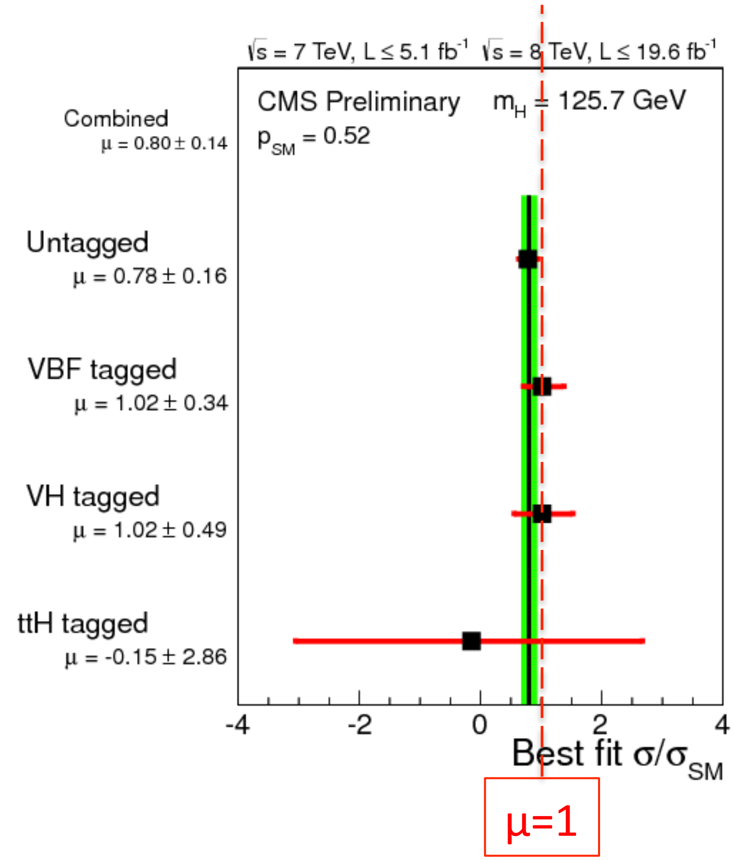
asymptotic $P(\chi^2>6.2|ndf=13) = 0.94$

pseudo-experiments: P = 0.87

NB: VBF-tagged channels have large gg->H contributions

Consistency of event yields (2)





χ^2 / ndf = 3.3 / 5

asymptotic $P(\chi^2 > 3.3 | ndf=5) = 0.65$

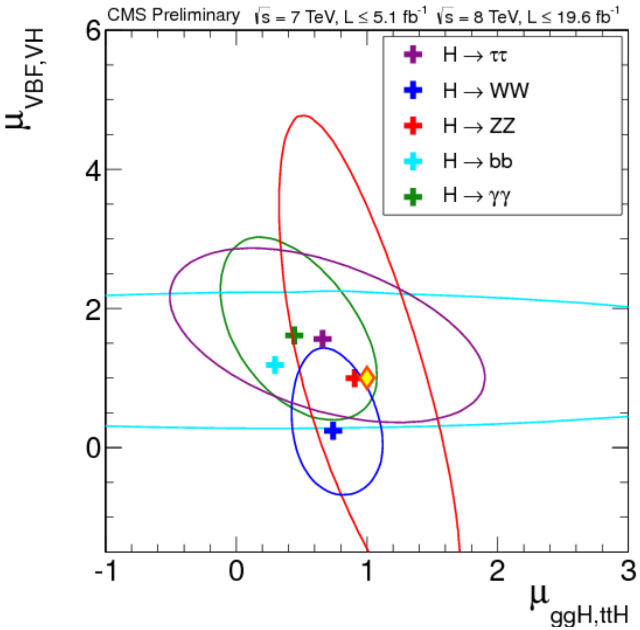
pseudo-experiments: P = 0.50

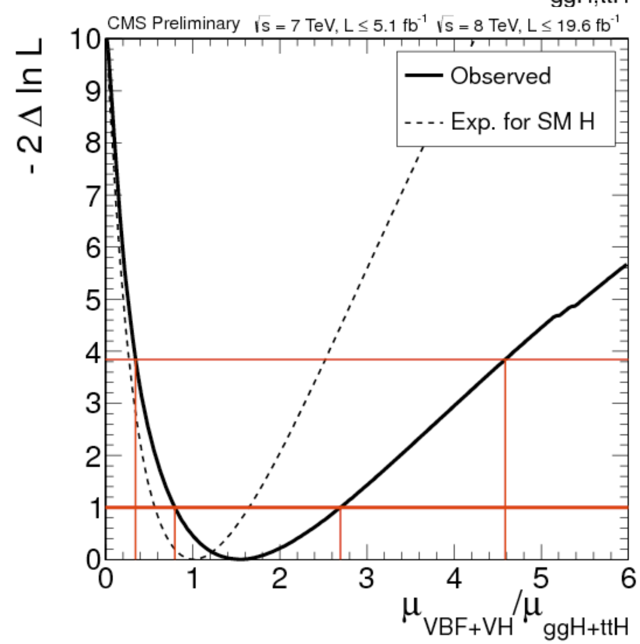
χ^2 / ndf = 1.3 / 4

asymptotic $P(\chi^2 > 3.2 | ndf=4) = 0.52$

pseudo-experiments: P = 0.37

Consistency of event yields (3)





- Introduce two signal strengths **(μ_F, μ_V)** in each of the 5 decay channels:
  - μ_F scales the **fermion-coupling** induced production mechanisms (gg-fusion, ttH)
  - μ_V scales the **W/Z-coupling** induced production mechanisms (VBF, VH)
- **All channels give results consistent with the SM Higgs boson: (1,1)**
- These 2D-results obtained for individual decay channels cannot be combined: they are decoupled by independent BRs.
- But the ratios μ_V/μ_F can be combined as BRs cancel out in such ratios
- The need W/Z-coupling induced production mechanisms is established with >3σ significance

Production × Decay parameterization

8 independent parameters to describe all currently relevant decays and production mechanisms:

- Γ_{WW}
- Γ_{ZZ}
- Γ_{bb}
- $\Gamma_{\tau\tau}$
- $\Gamma_{\gamma\gamma}$ (loop induced)
- Γ_{gg} (loop induced)
- Γ_{tt}
- Γ_{TOT} (including H → "invisible")
- $\Gamma_{Z\gamma}$ (loop induced) not used in the present combination

$$\sigma(xx \to H) \cdot BR(H \to yy) \;\propto\; \frac{\Gamma_{xx} \cdot \Gamma_{yy}}{\Gamma_{\mathrm{TOT}}}$$

	untagged	VBF-tag	VH-tag	ttH-tag
WW	✔	✔	✔	
ZZ	✔	✔		
bb			✔	✔
ττ	✔	✔	✔	
γγ	✔	✔	✔	
Zγ	✔			

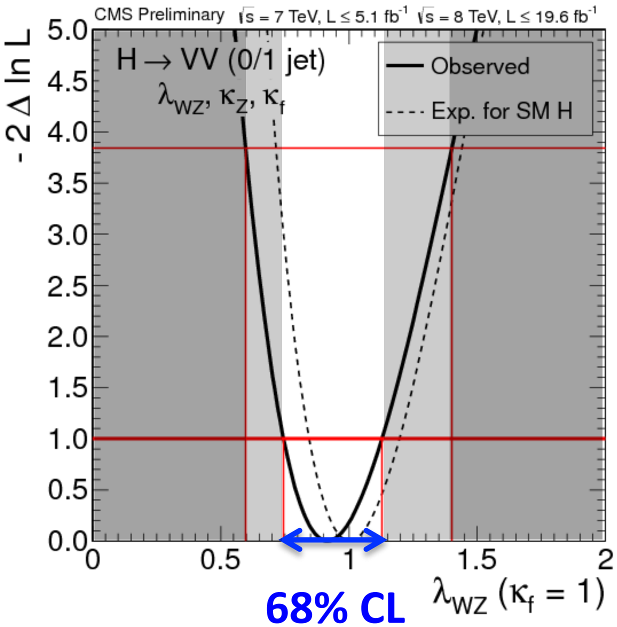
Couplings compatibility tests

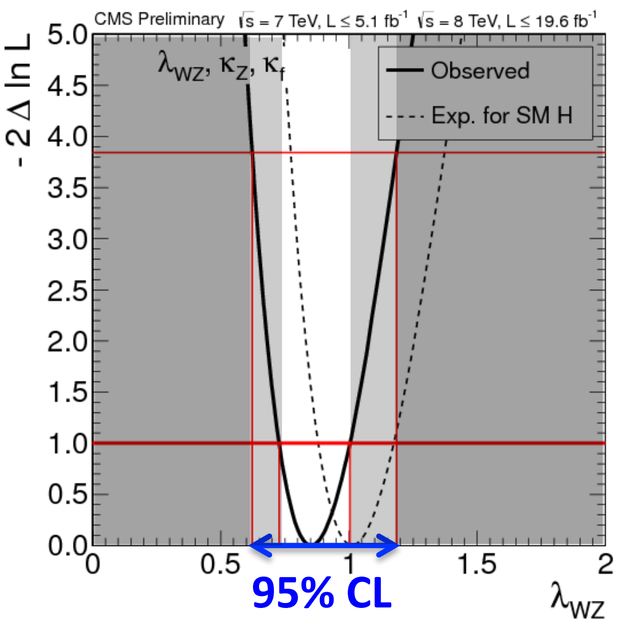
- Extraction of all 8 parameters is too early with the current data

- Instead, we go after coupling compatibility tests:
  - assume SM Higgs couplings
  - introduce **a limited number of scaling factor** for:
    - couplings (κ): $g_a = \kappa_a \cdot g_a^{\mathrm{SM}}$
    - or ratios of couplings (λ): $\left(g_a / g_b\right) = \lambda_{ab}\left(g_a^{\mathrm{SM}} / g_b^{\mathrm{SM}}\right); \quad \lambda_{ab} = \kappa_a / \kappa_b$
  - also can add and probe BR(H->BSM): $\Gamma_{\mathrm{TOT}} = \Gamma_{\mathrm{SM}} + \Gamma_{\mathrm{BSM}} = \dfrac{\Gamma_{\mathrm{SM}}}{1 - BR_{\mathrm{BSM}}}$

- **These are <u>compatibility tests</u>, not measurements of couplings:**
  - In SM, couplings are not free parameters
  - Any significant deviation of scaling factors from 1 would
    - imply new physics beyond SM
    - require a re-fit of event yields in the framework of particular BSM models

Custodial symmetry: λ_{WZ} and κ_Z (κ_F)





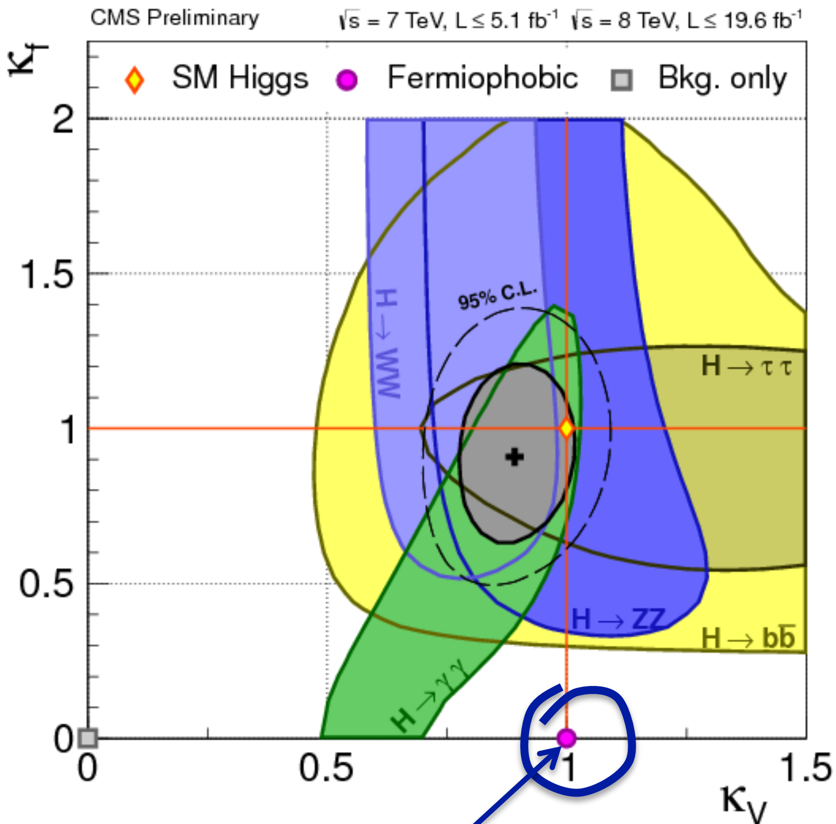
- **Custodial symmetry:** in SM, the ratio of couplings to W and Z bosons is almost not affected by loop corrections

- **Compatibility test No.1 (top plot):**
  - use **un-tagged WW and ZZ** channels
  - the ratio of signal event yields: $\sim g_W^2 / g_Z^2 = \lambda_{WZ}^2$
  - Assume SM coupling to fermions (κ_F=1); dependence on this assumption is weak
  - Fit for: λ_{WZ} and κ_Z
- **Compatibility test No.2 (bottom plot):**
  - use **all** channels
  - Assume a common scaling factor κ_F for all fermionic couplings
  - Fit for: λ_{WZ} and κ_Z, κ_F

Data are consistent with the custodial symmetry

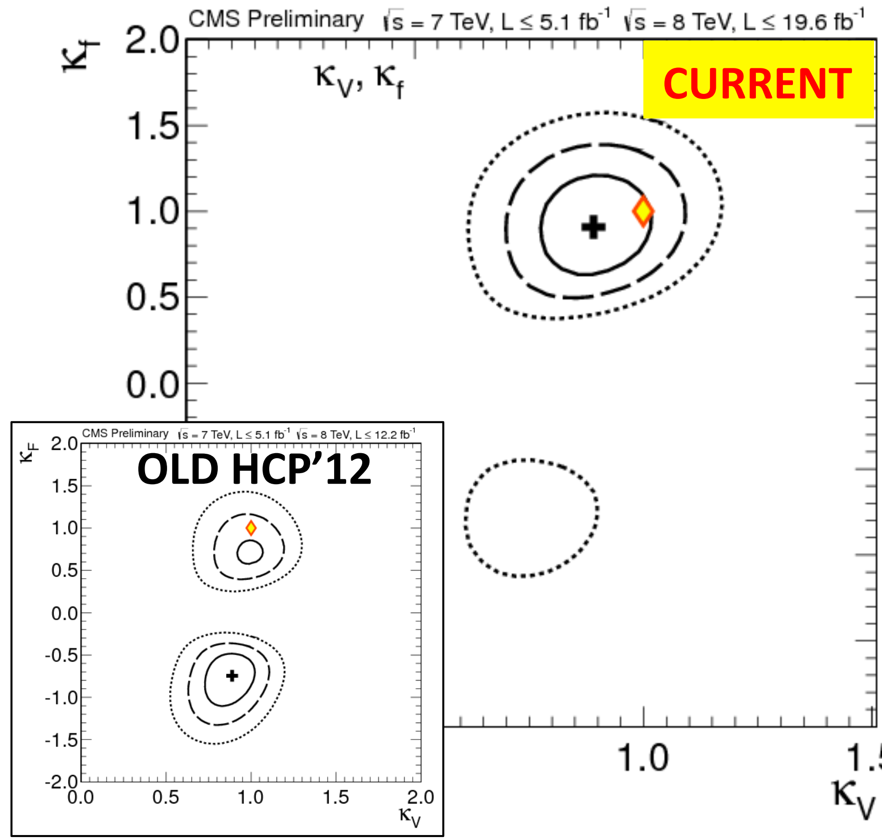
- **Further, we always use $\kappa_W = \kappa_Z$ (κ_V)**

Two parameters: κ_V and κ_F



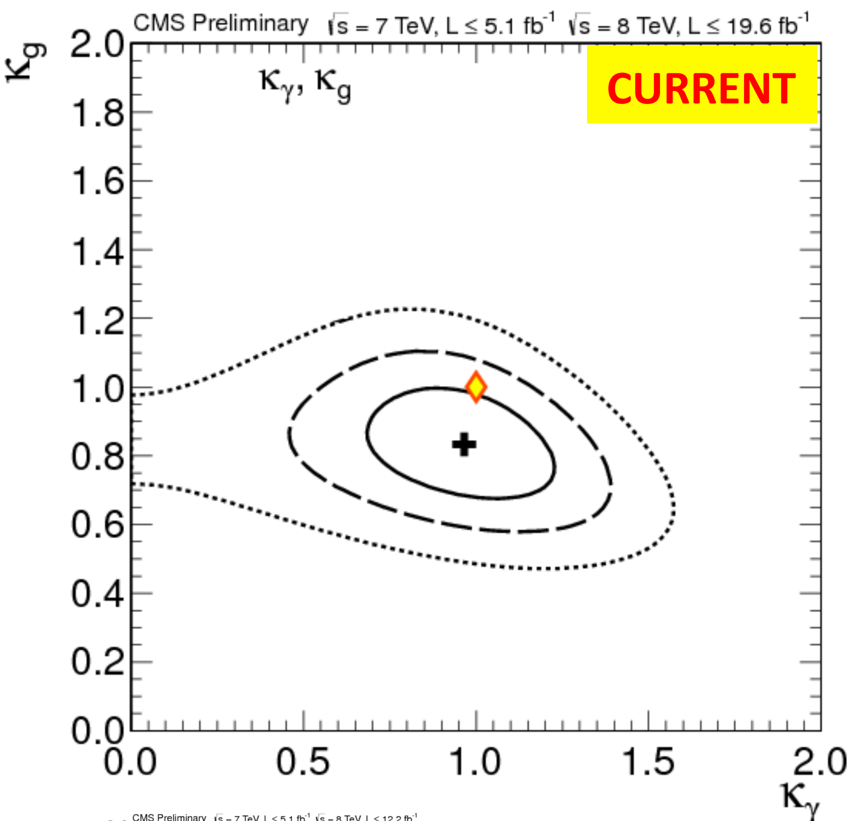
Fermiophobic scenario is reliably excluded

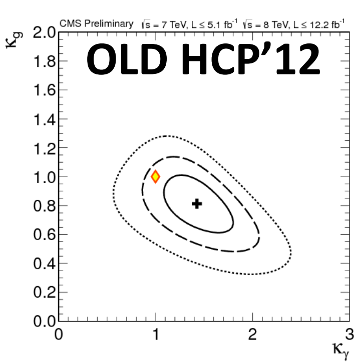
Data are consistent with (κ_V; κ_F)=(1; 1)



The previously seen global minimum of the likelihood in the (+; –) quadrant is gone, since the γγ-channel is no more enhanced

Look for new physics in loops: κ_g and κ_γ





Two-parameter fit

– use all channels

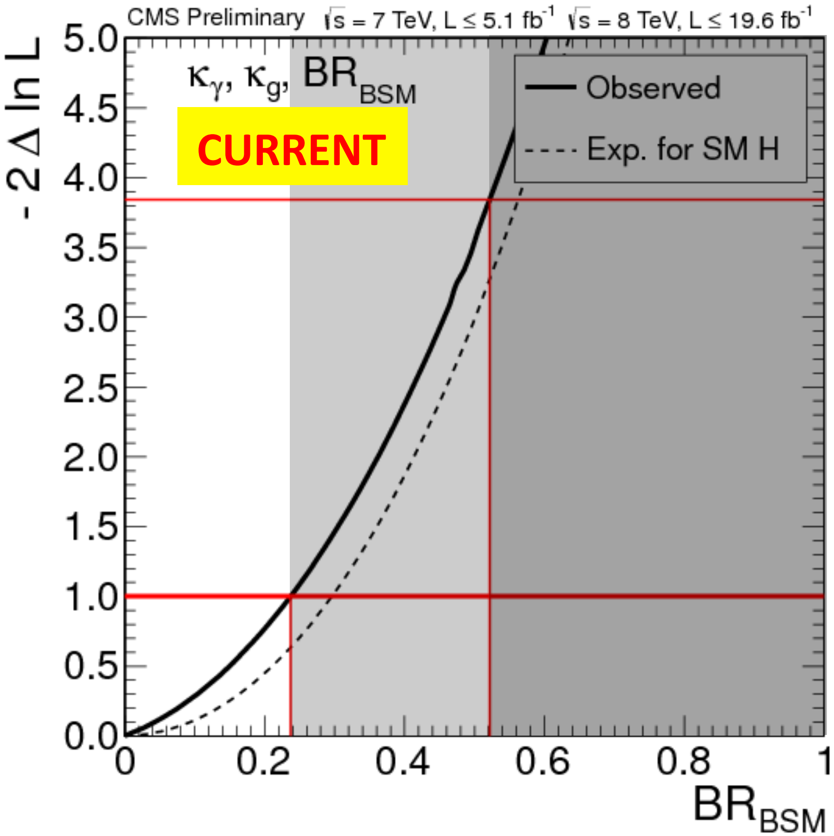
– assume tree-level couplings = SM

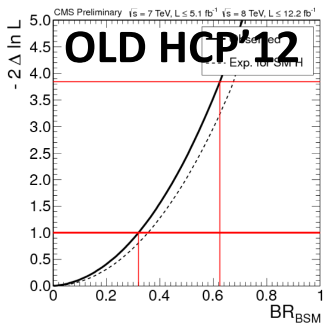
– assume BR(BSM)=0

– **Fit for:** κ_γ , κ_g

Data are consistent with (κ_γ; κ_g)=(1; 1)

Look for new physics: BR(BSM), κ_g , κ_γ





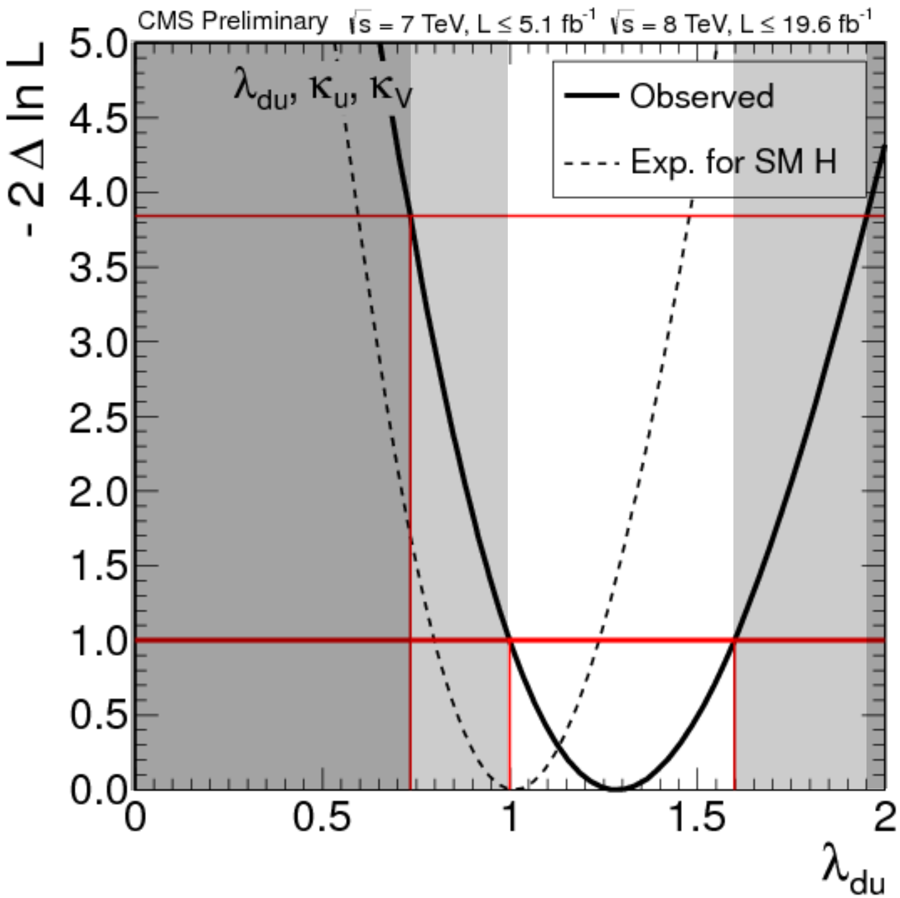
Three-parameter fit

- use all channels
- assume tree-level couplings = SM
- allow for BR(BSM) ≠ 0
- **Fit for: BR("invisible"), κ_γ , κ_g**

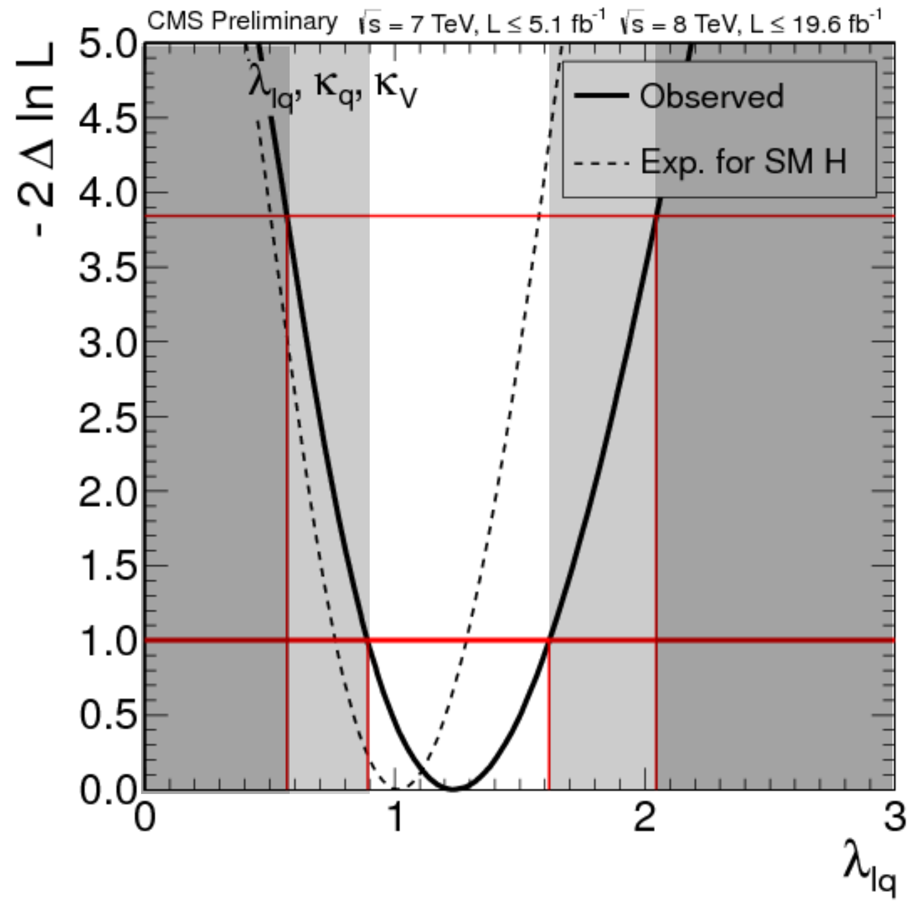
BR(BSM) < 0.52 at 95% CL

Asymmetry of couplings to fermions

Ratio of coupling between down- and up-fermions



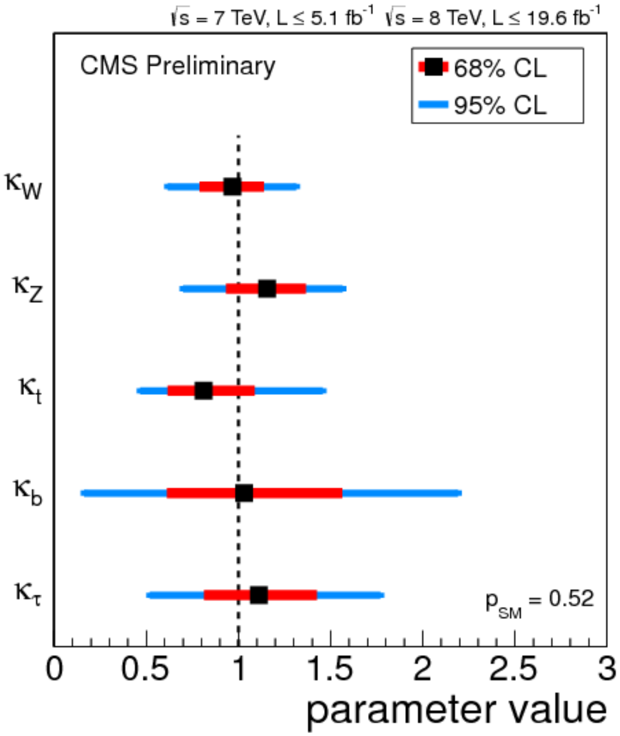
Ratio of coupling between leptons and quarks



C5 model (almost a measurement)

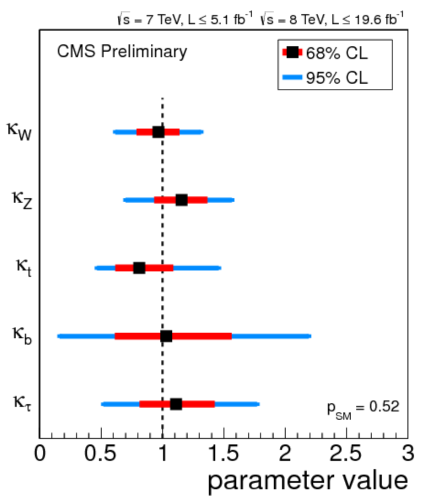
8 independent parameters to describe all currently relevant decays and production mechanisms:

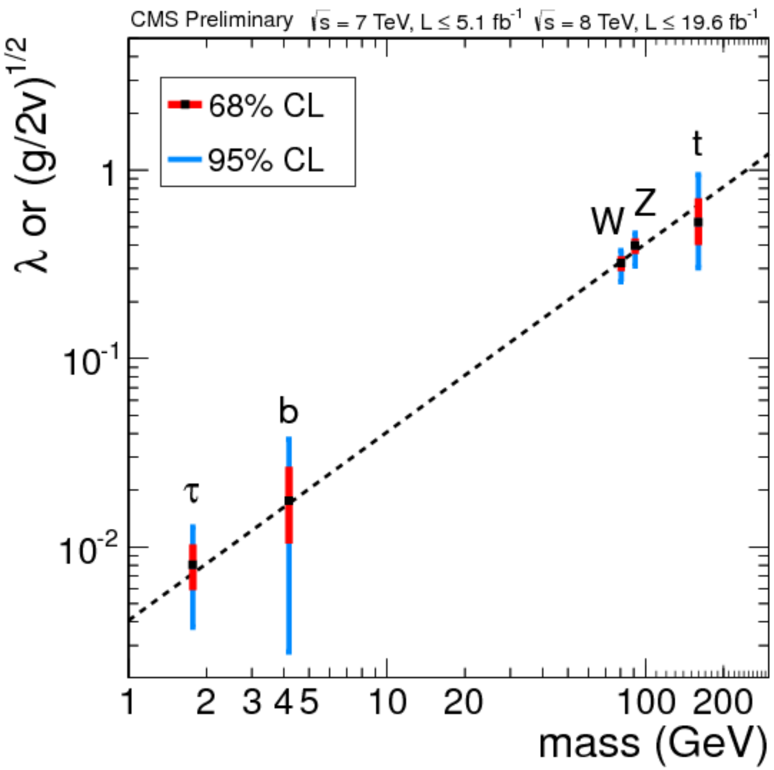
- Γ_{WW} → κ_W
- Γ_{ZZ} → κ_Z
- Γ_{tt} → κ_t
- Γ_{bb} → κ_b
- $\Gamma_{\tau\tau}$ → κ_τ
- $\Gamma_{\gamma\gamma}$ (loop is resolved) → κ_W, κ_t
- Γ_{gg} (loop is resolved) → κ_t, κ_b
- assume **BR(BSM)=0**
- Assume couplings to the 1st, 2nd, 3rd generations are modified the same way



C5 model (almost a measurement)

- Scale SM couplings by measured scale factors and plot modified couplings vs particle masses:
  - λ_f(Yukawa coupling) ~ m_f
  - $(g_V/2vev)^{0.5}$ ~ m_V



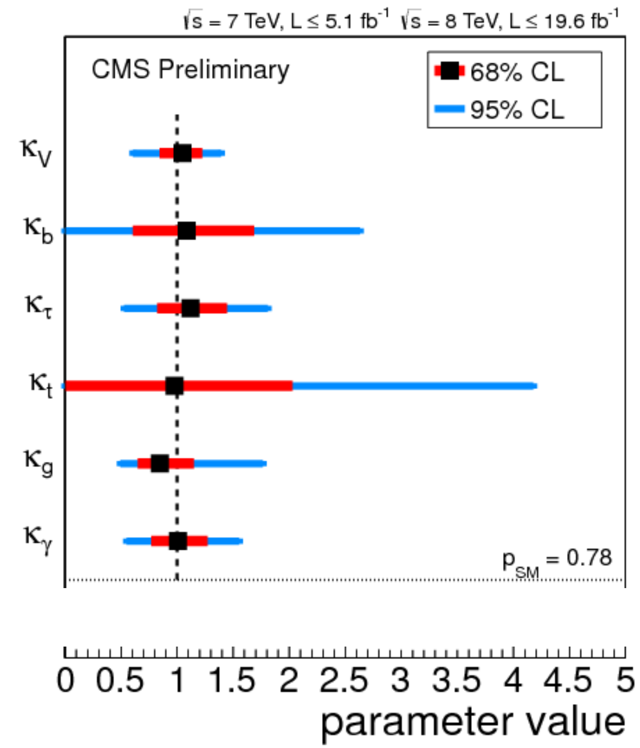


Note: the magnitude of couplings we try to assess range by a factor of 100!
A test with 20+% accuracy is actually a very respectable test.

C6 model (almost a measurement)

8 independent parameters to describe all currently relevant decays and production mechanisms:

- Γ_{ZZ} → κ_V
- Γ_{WW}
- $\Gamma_{\tau\tau}$ → κ_τ
- Γ_{bb} → κ_b
- $\Gamma_{\gamma\gamma}$ (loop induced) → κ_γ
- Γ_{gg} (loop induced) → κ_g
- Γ_{tt} → κ_t
- assume **BR(BSM)=0**
- Assume couplings to the 1st, 2nd, 3rd generations are modified the same way



Spin-parity (J^{CP})

CMS has performed the following tests:

- ZZ4L:
  - 0^-, 0^+_h, $qq \rightarrow 1^-$, $qq \rightarrow 1^+$, $gg \rightarrow 2^+_m$, $qq \rightarrow 2^+_m$
- WW:
  - $gg \rightarrow 2^+_m$
- ZZ+WW:
  - $gg \rightarrow 2^+_m$
- γγ:
  - not spin-1 (Landau-Yang theorem)
  - spin-2 (not yet available)

ZZ->4L J^{CP} analysis: discriminants

- Analysis considers alternative signal+background hypotheses, where signal *X* can be either gg→H or *xx* → J^{CP}

  - Construct two ME-based discriminating observables:

    where ME are complete LO matrix elements, and $m_X = m_{4\ell}$

$$KD(\mathrm{H;ZZ}) = \frac{|ME_{\mathrm{H}}(gg \to H \to 4\ell)|^2}{|ME_{ZZ}(q\bar{q} \to 4\ell)|^2}$$

$$KD(J^{CP};\mathrm{ZZ}) = \frac{|ME_{J^{CP}}(xx \to J^{CP} \to 4\ell)|^2}{|ME_{ZZ}(q\bar{q} \to 4\ell)|^2}$$

  - Extend KDs to include discriminating information from four-lepton mass:

$$D(H;ZZ) = \frac{|ME_X(xx \to H \to 4\ell)|^2 \cdot pdf(m_{4\ell} \mid m_H)}{|ME_{ZZ}(q\bar{q} \to 4\ell)|^2 \cdot pdf(m_{4\ell} \mid ZZ)}$$

$$D(J^{CP};\mathrm{ZZ}) = \frac{|ME_{J^{CP}}(xx \to J^{CP} \to 4\ell)|^2 \cdot pdf(m_{4\ell} \mid m_{J^{CP}})}{|ME_{ZZ}(q\bar{q} \to 4\ell)|^2 \cdot pdf(m_{4\ell} \mid ZZ)}$$

  - Without any loss of information, one can change “variables”:

$$D(\mathrm{H;ZZ})$$

$$D(J^{CP};\mathrm{H}) = \frac{D(\mathrm{J^{CP};ZZ})}{D(\mathrm{H;ZZ})} = \frac{|ME_{J^{CP}}(xx \to \mathrm{J^{CP}} \to 4\ell)|^2}{|ME_{\mathrm{H}}(gg \to \mathrm{H} \to 4\ell)|^2}$$

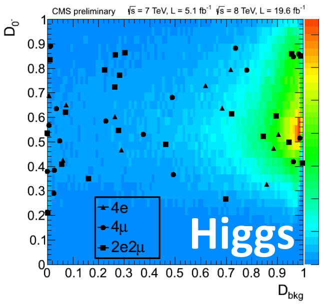
  - And again without any loss of information, compress discriminants to be between 0 and 1

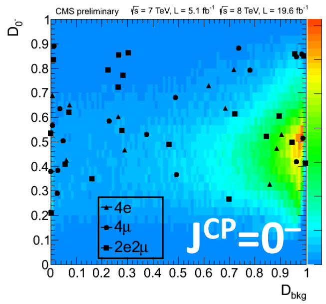
$$D_{bkg} = \frac{1}{1 + const \cdot D(\mathrm{H;ZZ})}$$

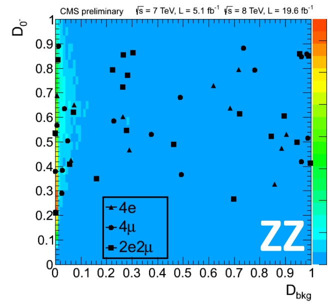
$$D_{J^{CP}} = \frac{1}{1 + const \cdot D(J^{CP};\mathrm{H})}$$

ZZ->4L J^{CP} analysis: statistical analysis

- Build 2D-pdf's (templates) for different processes:





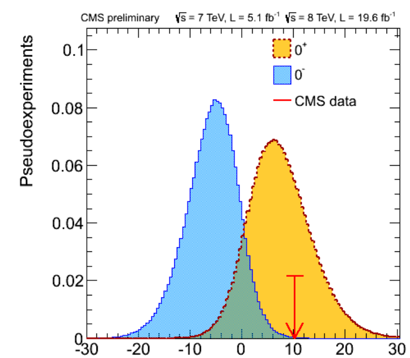


$$pdf\left(D_{bkg}, D_{J^{CP}} \mid \mathrm{H}\right) \leftarrow \text{from MC}$$
$$pdf\left(D_{bkg}, D_{J^{CP}} \mid \mathrm{J^{CP}}\right) \leftarrow \text{from MC}$$
$$pdf\left(D_{bkg}, D_{J^{CP}} \mid ZZ\right) \leftarrow \text{from MC}$$
$$pdf\left(D_{bkg}, D_{J^{CP}} \mid reducible\ \text{bkg}\right) \leftarrow \text{from control region}$$

- Weigh templates by event rates to construct expected 2D-distributions for alternative signal+background hypotheses:
  - ZZ event rate: from MC
  - reducible background event rate: from control region
  - H and J^{CP} signal event rate: from two fits to data

$$\frac{\partial^2 N}{\partial D_{bkg} \partial D_{J^{CP}}}$$

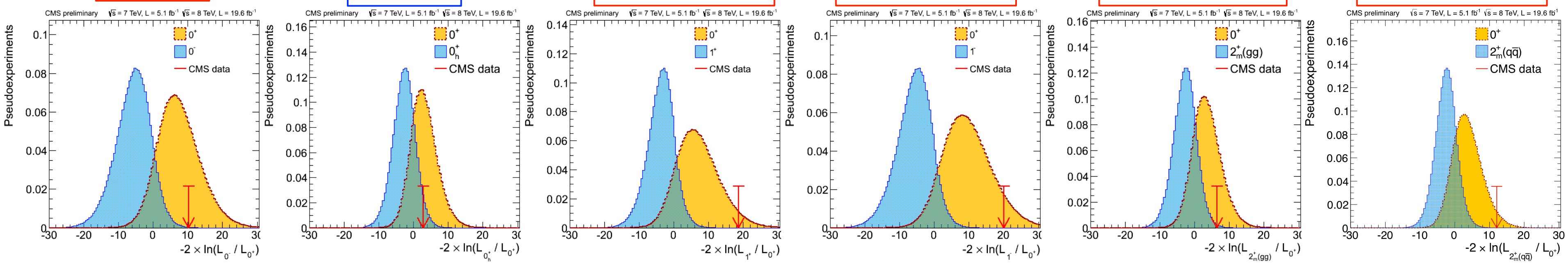
- Using 2D event distributions for alternative hypotheses, construct the usual log-likelihood-ratio test statistic and perform statistical analyses by generating pseudo-observations



$$q = -2\ln\frac{L\left(\text{observation} \mid J^{CP} + bkg\right)}{L\left(\text{observation} \mid H + bkg\right)}$$

ZZ->4L J^{CP} analysis: results

0^- vs H	0^+_h vs H	$q\bar{q} \to 1^-$ vs H	$q\bar{q} \to 1^+$ vs H	$gg \to 2^+_m$ vs H	$q\bar{q} \to 2^+_m$ vs H

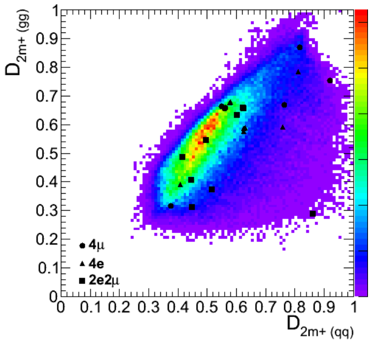


$CL_s = 0.0016$ excluded	$CL_s = 0.081$ not yet	$CL_s < 0.001$ excluded	$CL_s < 0.001$ excluded	$CL_s = 0.015$ excluded	$CL_s < 0.001$ excluded

$$CL_S = \frac{P\left(q \geq q^{obs} \mid J^{CP} + bkg\right)}{P\left(q \geq q^{obs} \mid H + bkg\right)}$$

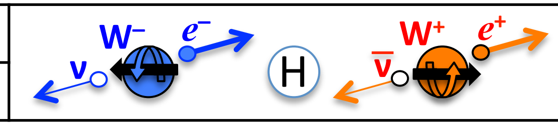
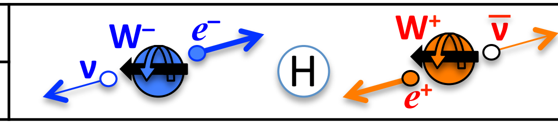
The observed test statistic value is

- consistent with the SM Higgs boson in all J^{CP} tests
- off the "SM Higgs median" in the same direction for all tests:
  - manifestation of correlations between kinematic properties of alternative J^{CP} bosons
  - CMS data "statistically lucky": observed limits are a bit stronger than expected



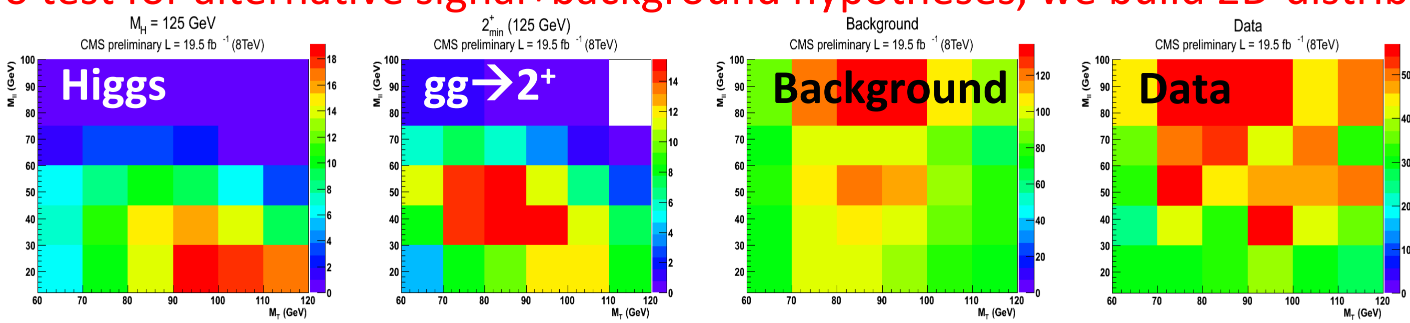
WW->2l2ν J^{CP} analysis

- Full event reconstruction is not possible, but:

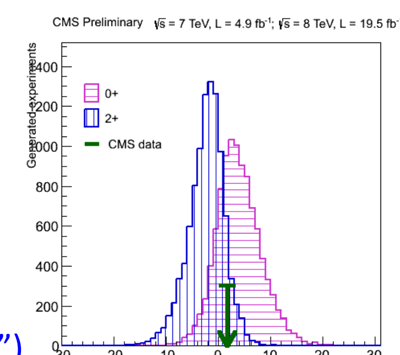
spin-0	leptons tend to go in one direction: **small m_{ll}** neutrinos – in the other direction: **large MET**	
spin-2	leptons tend to go in opposite directions: **larger m_{ll}** neutrinos also go in opposite directions: **smaller MET**	

- To test for alternative signal+background hypotheses, we build 2D-distributions

$$\frac{\partial^2 N}{\partial m_{\ell\ell}\partial E_T^{mis}}$$



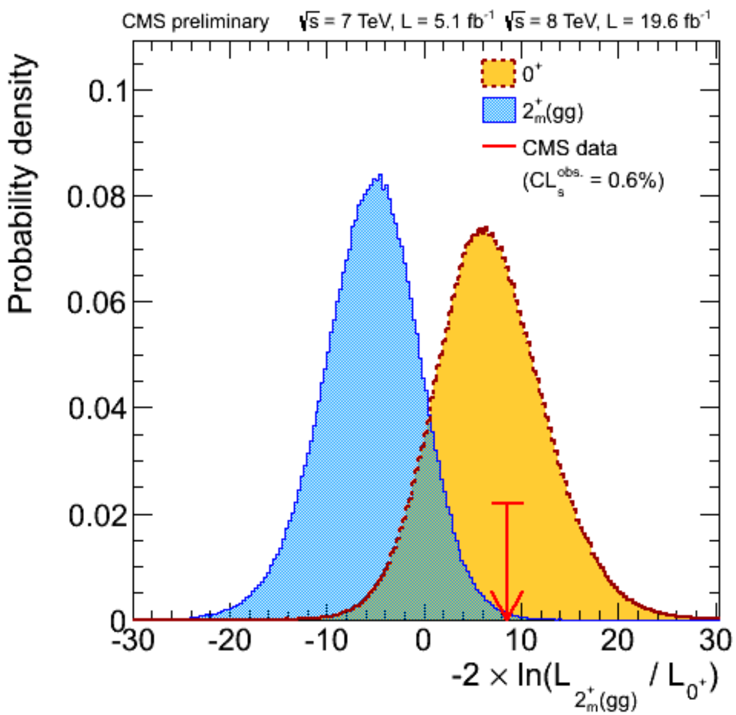
- Using 2D event distributions for alternative hypotheses, construct the usual log-likelihood-ratio test statistic and perform statistical analyses by generating pseudo-observations
  - **Observed CL_s=0.14** (data disfavor 2^+, but exclusion at 95% CL cannot be claimed)
  - Observed test statistic is **consistent with the SM Higgs boson**
  - Observed test statistic is off "SM H median expected" to the left ("unlucky fluctuation")



$$q = -2\ln\frac{L(\text{observation} \mid 2^+ + bkg)}{L(\text{observation} \mid H + bkg)}$$

ZZ+WW $gg \to 2^{+}_{m}$ combination

	Expected $1\text{-}CL_s$	Observed $1\text{-}CL_s$
ZZ	93.1%	98.6%
WW	91.9%	86.0%
Combination	**98.8%**	**99.4%**

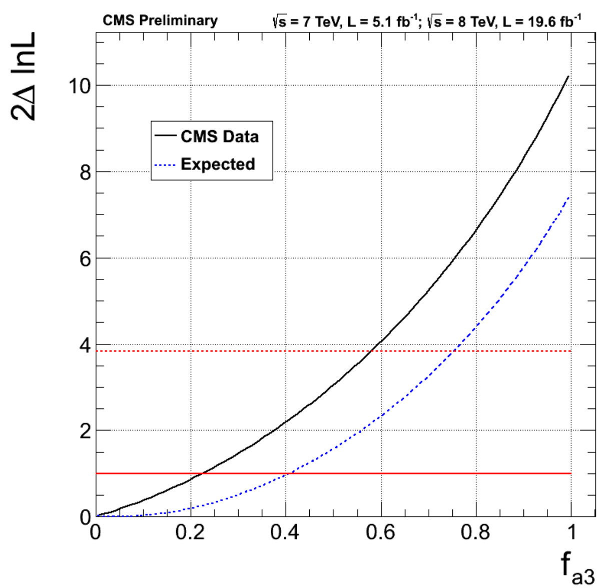


- ZZ and WW have similar sensitivities, $1\text{-}CL_s$ = 92%-93%
- **In combination, $gg \to 2^{+}_{m}$ is excluded at 99% CL**

Is X126 one particle?

What if X126 is two bosons with near degenerate masses?

- What can we infer from the mass line shape?
  - **no public results yet**
- What can we infer from kinematics of decays?
  - CP-odd contribution (within detector acceptance): ***f*(0⁻) < 0.58 at 95% CL**



Summary

- In a **combined search** for the SM Higgs boson, **a significant excess of events near m_H=126 GeV** persists beyond any doubt and now has been established in **individual decay channels**:
  ZZ (6.7σ), WW (3.9σ), γγ (3.2σ), bb+ττ combined (3.4σ)

- **New boson's mass: m_X = 125.7 ± 0.4 GeV** (from ZZ+γγ channels)

- **Is X126 the SM Higgs boson?**
  - **event yields in all individual channels are consistent with the SM Higgs boson;**
  - **couplings agree with the SM Higgs boson** with the current statistical accuracy: **20% (W & Z), 25% (t), 30% (τ), 60% (b);**
  - **100% pure $J^{CP} = 0^{-}$, $1^{\pm}$, 2^{+}_{m} states are excluded at >99% CL;**
  - **CP-odd contribution** (within detector acceptance)**: *f*(0⁻) < 0.58 at 95% CL**

Conclusions

- **X126 looks very much like the SM Higgs boson… STILL?**
- **No signs for extra Higgs-like bosons… YET?**