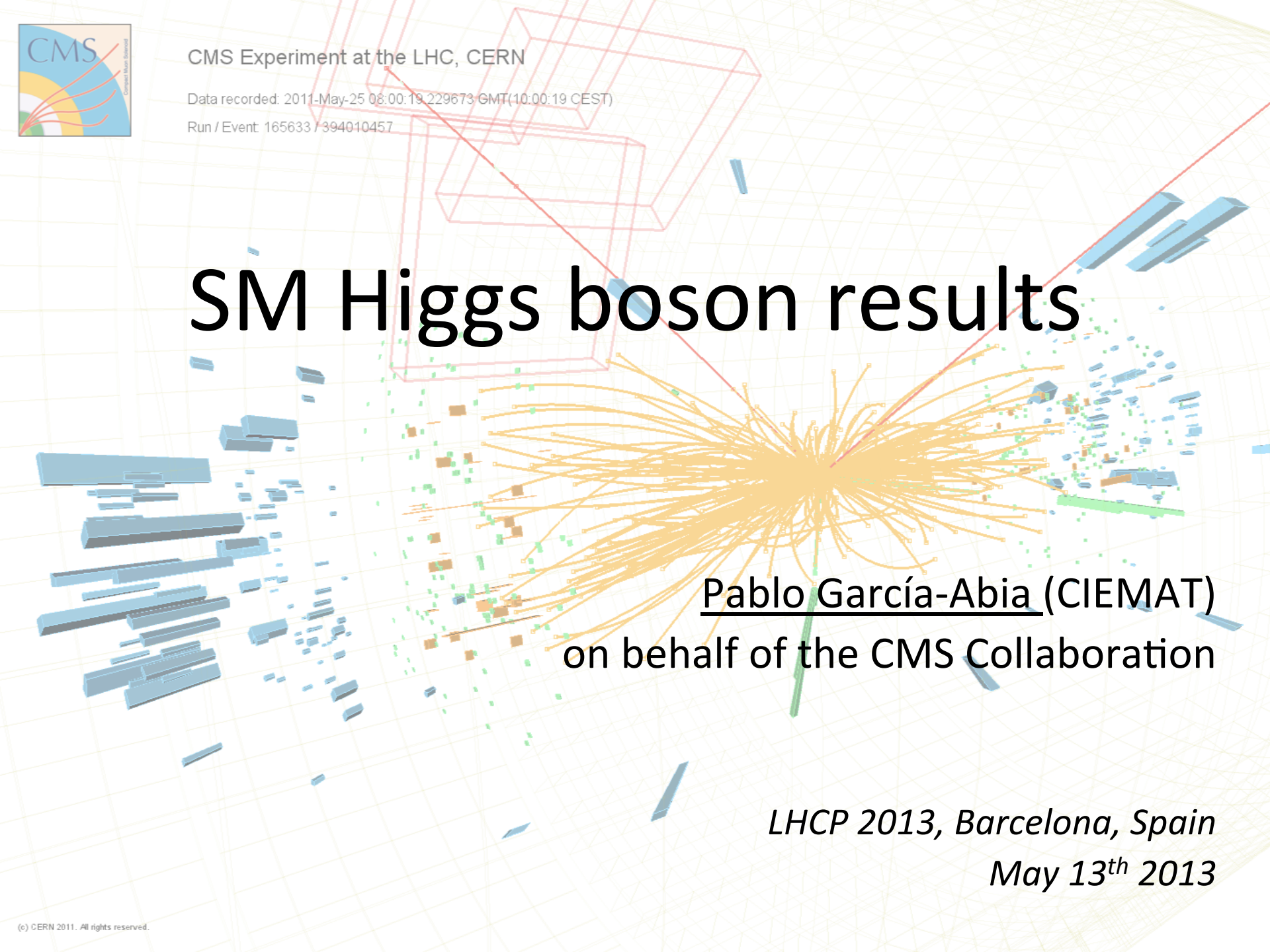


SM Higgs boson results

Pablo García-Abia (CIEMAT)

on behalf of the CMS Collaboration

LHCP 2013, Barcelona, Spain

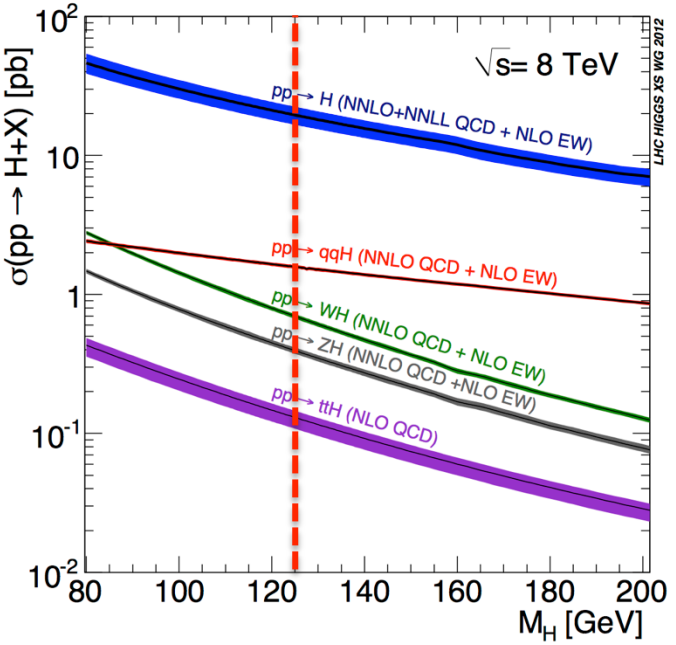
May 13th 2013

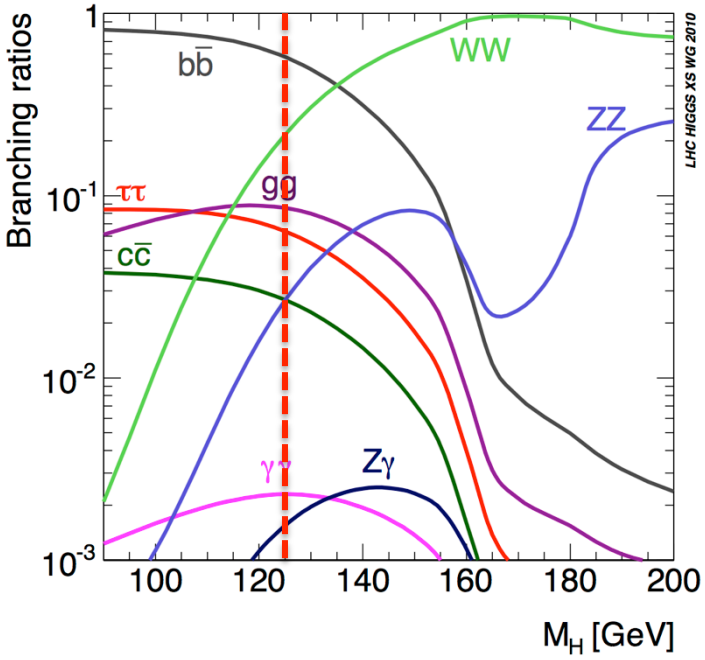
A new boson

SM-like Higgs boson observed by ATLAS and CMS (2012), mass around 125 GeV.

Essential to observe the decay modes and to measure with high precision the mass, couplings to bosons and fermions, and spin-parity, of the new state to establish its nature.

To have access to the Higgs couplings to fermions and bosons, the analyses are split in exclusive categories sensitive to the production mechanisms.





CMS results - public documents

$H \to \gamma\gamma$	CMS-PAS-HIG-13-001	
$t\bar{t}H, H \to \gamma\gamma$	CMS-PAS-HIG-13-015	NEW
$H \to ZZ \to 4\ell$	CMS-PAS-HIG-13-002	
$H \to ZZ \to 2\ell\, 2\nu$	CMS-PAS-HIG-13-014	NEW
$H \to WW \to 2\ell\, 2\nu$	CMS-PAS-HIG-13-003	
$WH \to WWW \to 3\ell\, 3\nu$	CMS-PAS-HIG-13-009	
$t\bar{t}H, H \to b\bar{b}$	arXiv:1303.0763, JHEP accepted	NEW
$VH\ H \to b\bar{b}$	CMS-PAS-HIG-13-012	NEW
$VBF\ H \to b\bar{b}$	CMS-PAS-HIG-13-011	NEW
$WH/ZH, H \to \tau\tau$	CMS-PAS-HIG-12-053	
$H \to \tau\tau$ (+VBF)	CMS-PAS-HIG-13-004	
Properties	CMS-PAS-HIG-13-005	

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIG

CMS Higgs talks (and posters)

More details on the individual analyses will be given in specific CMS talks:

- Bosonic decays: P. Musella - Higgs 1, Mon. 13 at 14:45
- Fermionic decays: N. Mohr - Higgs 1, Mon. 13 at 16:00
- Properties: A. D. Benaglia - Higgs 2, Tue. 14 at 12:00
- Exotic decays: F. Primavera - Higgs 3, Thu. 16 at 11:45

Posters:

- C. Böser: WH → ℓν bb
- P. Eller: ZH → 2ℓ bb
- C. Vernieri: ZZ/WZ signal in ZH/WH → (2ℓ, 2ν)/ℓν bb
- S. Donato: ZH → 2ν bb
- F. Micheli: ttH, H → γγ
- H. L. Brun: H → WW → 2ℓ 2ν
- D. A. Belknap: H → ZZ → 4ℓ

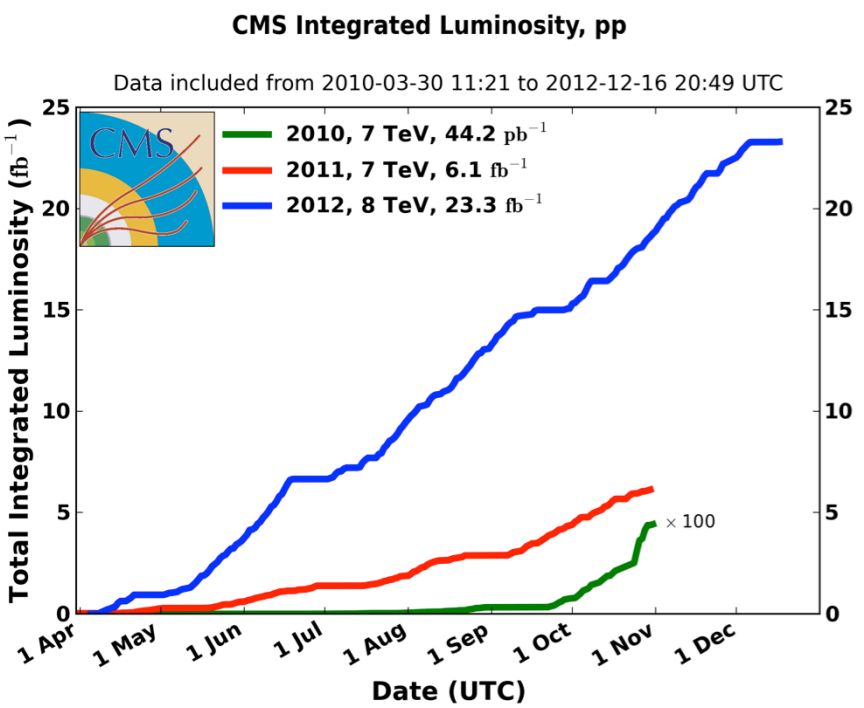
LHC

Provides pp collisions at high luminosity, significantly increasing since startup:

2011, 6.1 fb^{-1} at 7 TeV,

2012, 23.3 fb^{-1} at 8 TeV.

Congratulations to the LHC team for the excellent performance !!



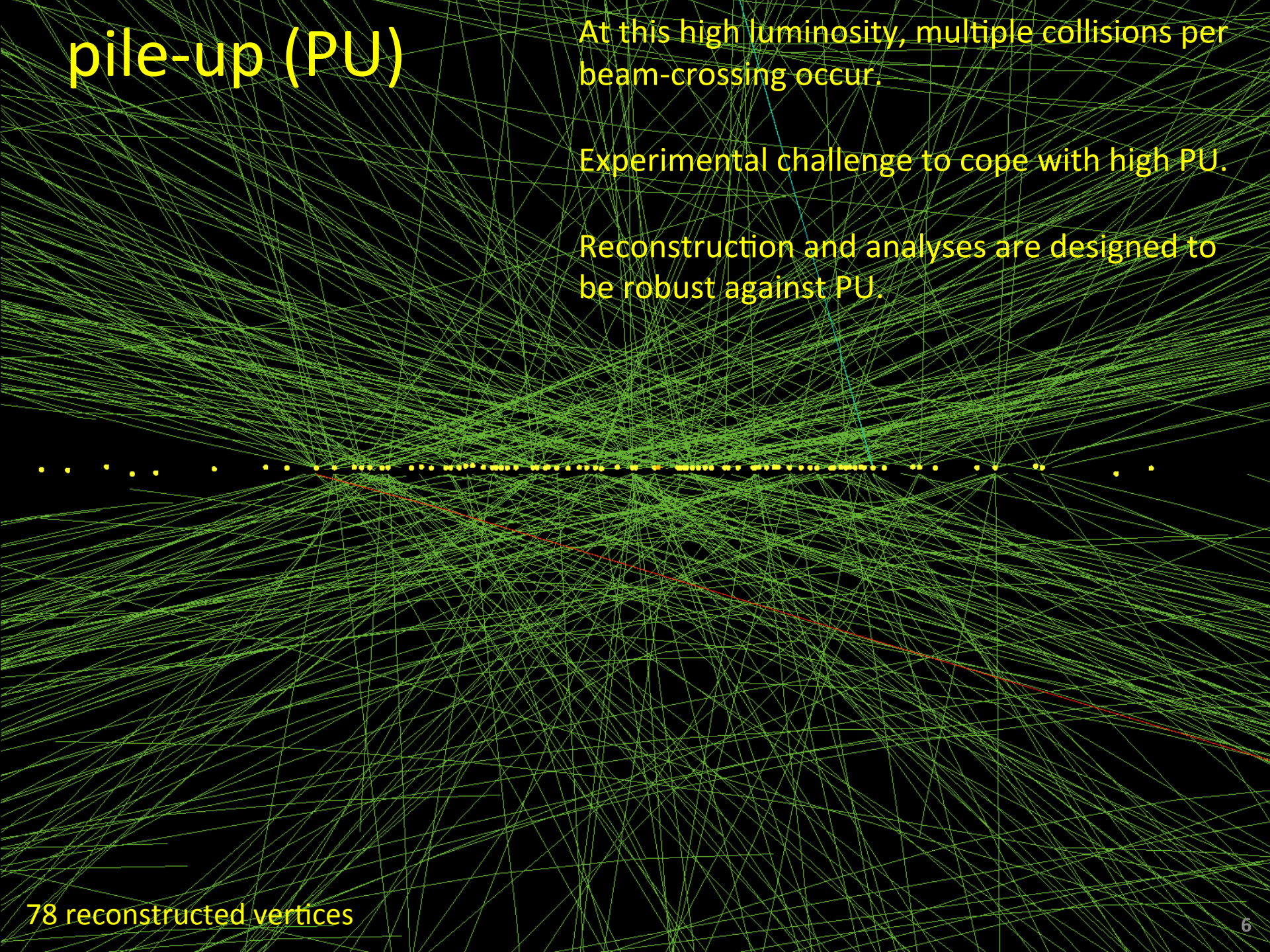
Peak instantaneous luminosity
7.7×10^{33} cm^{-2} s^{-1}

pile-up (PU)

At this high luminosity, multiple collisions per beam-crossing occur.

Experimental challenge to cope with high PU.

Reconstruction and analyses are designed to be robust against PU.



78 reconstructed vertices

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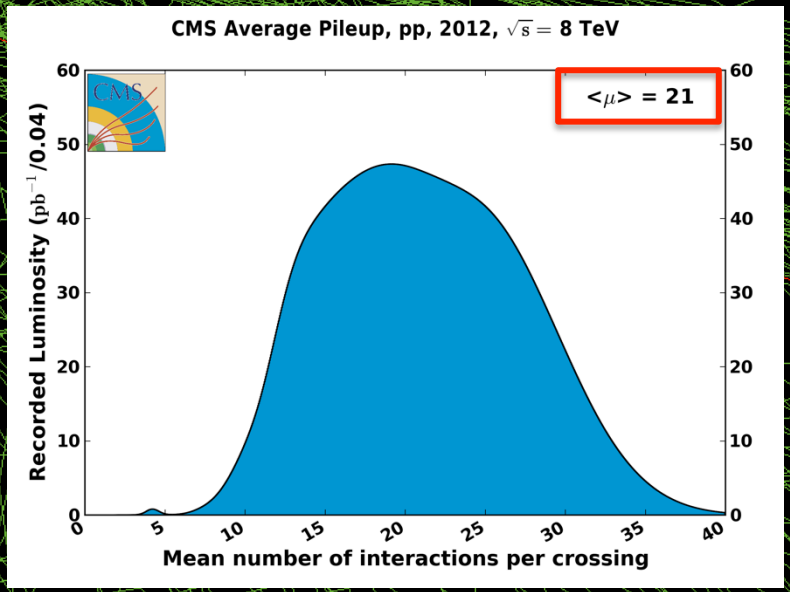
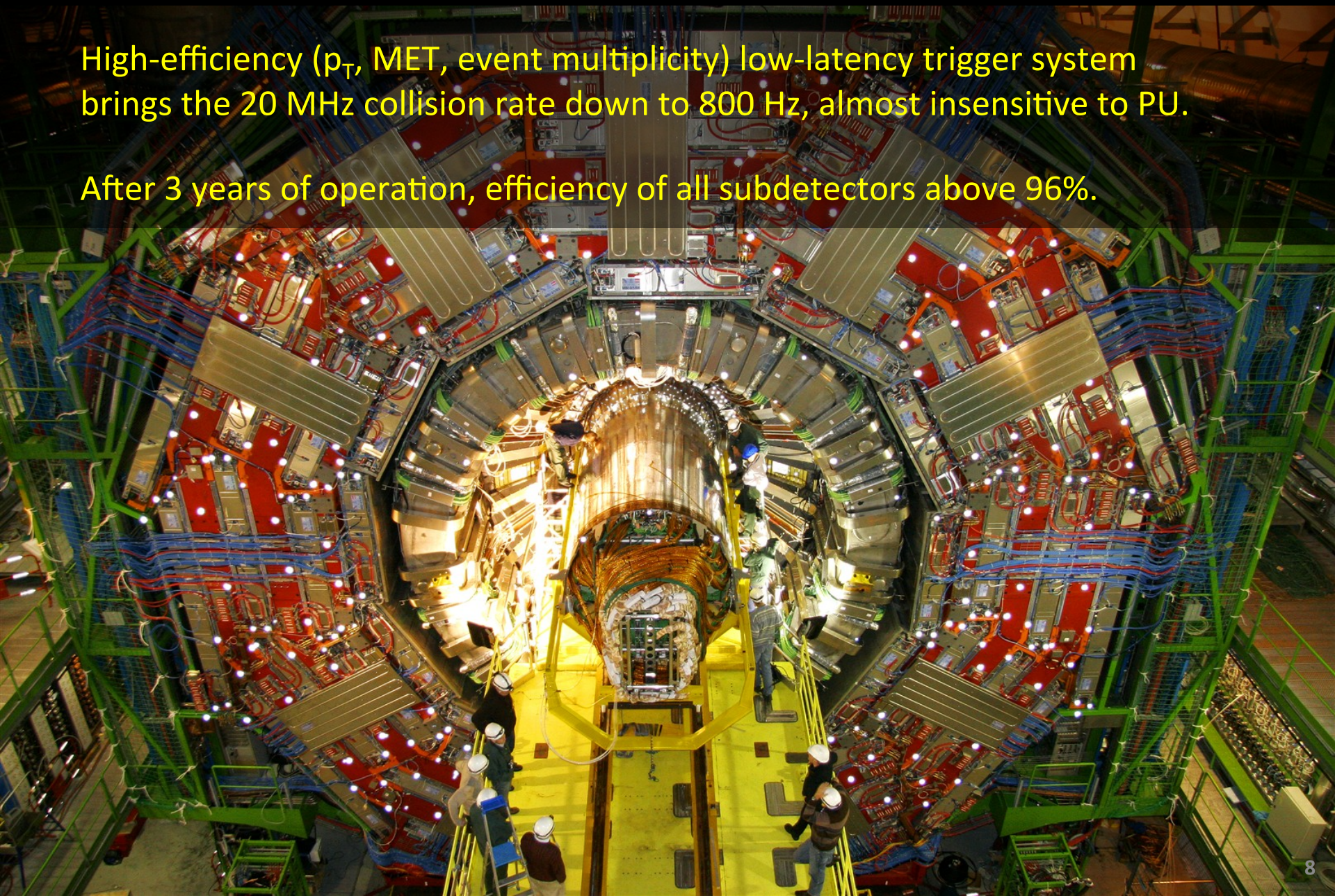


78 reconstructed vertices

CMS is a large compact fast-electronics detector (80 M channels, 40 MHz), embedded in a 4 T magnetic field, precise 3D event reconstruction.

High-efficiency (p_T, MET, event multiplicity) low-latency trigger system brings the 20 MHz collision rate down to 800 Hz, almost insensitive to PU.

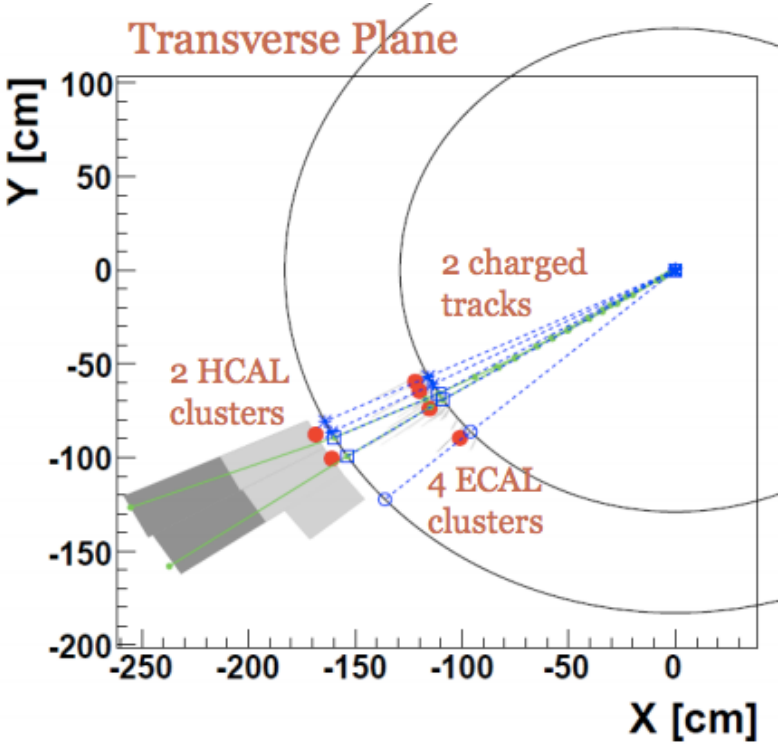
After 3 years of operation, efficiency of all subdetectors above 96%.



Object reconstruction

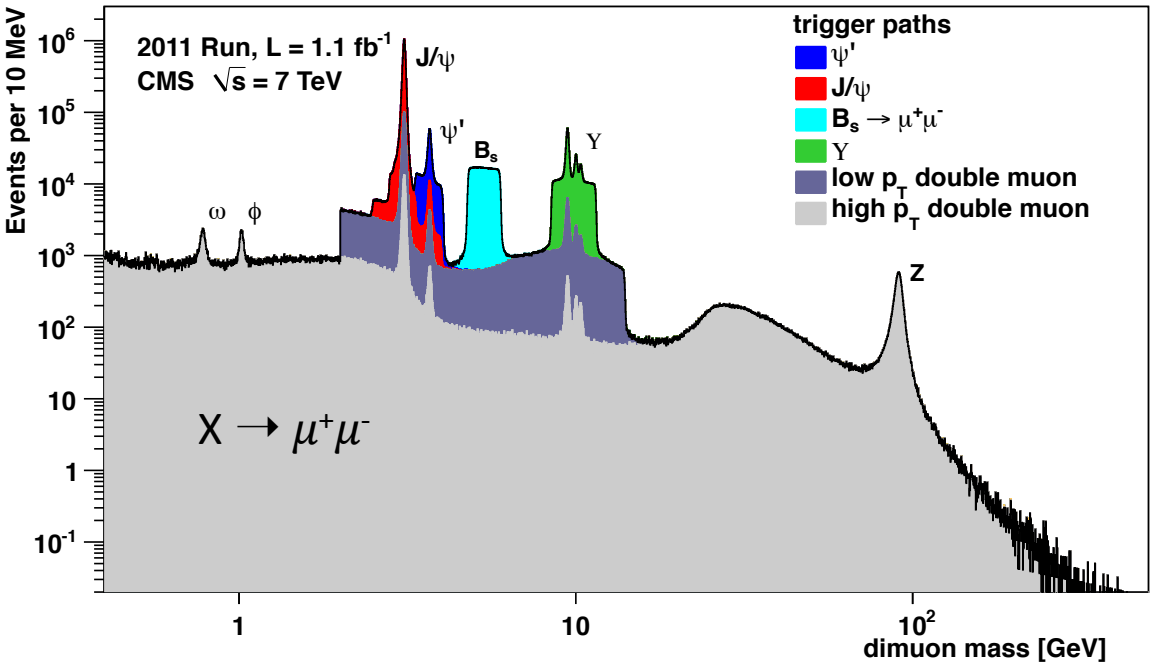
Particle flow algorithm attempts to reconstruct all the individual particles in the event: photons, charged and neutral hadrons, electrons, muons.

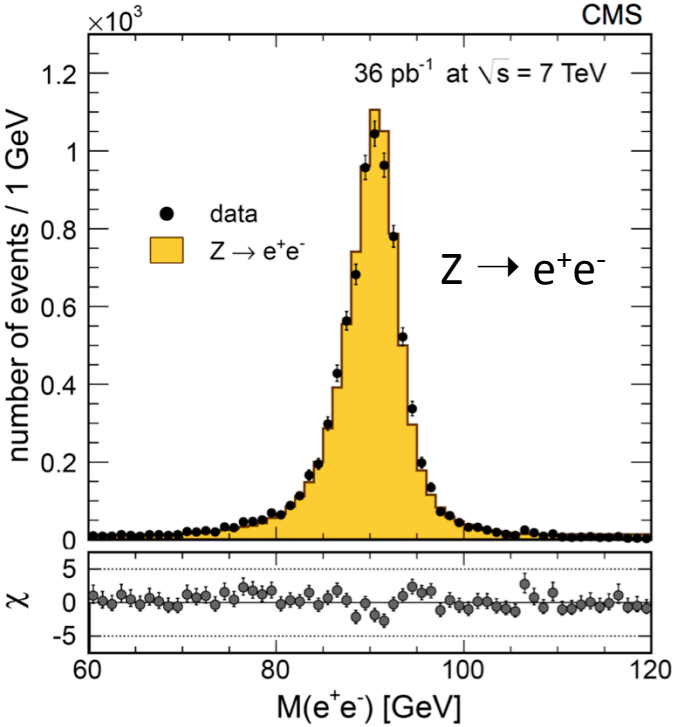
- high efficiency identification of leptons (e, μ, τ) and photons,
- very good momentum, energy, and angular resolution, of isolated particles and jets,
- efficient tagging of b-jets,
- good missing-energy (MET) resolution,
- robust against PU.

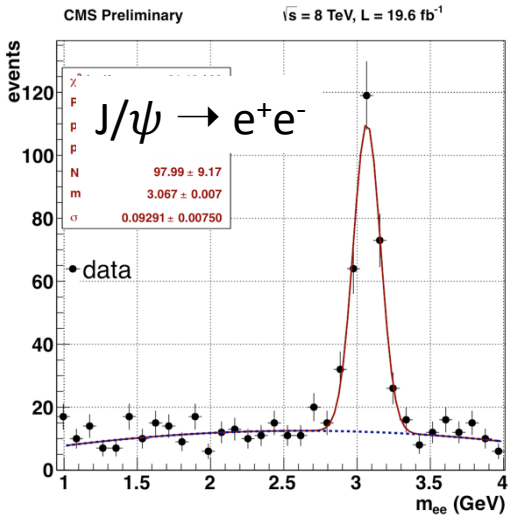


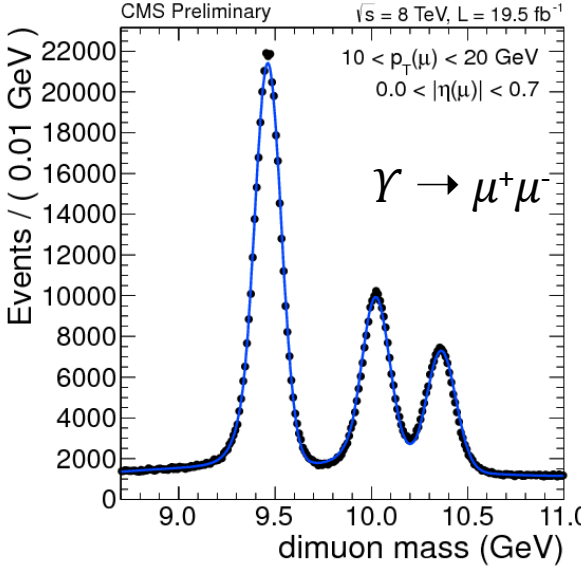
Efficiencies and resolutions determined from control data samples.

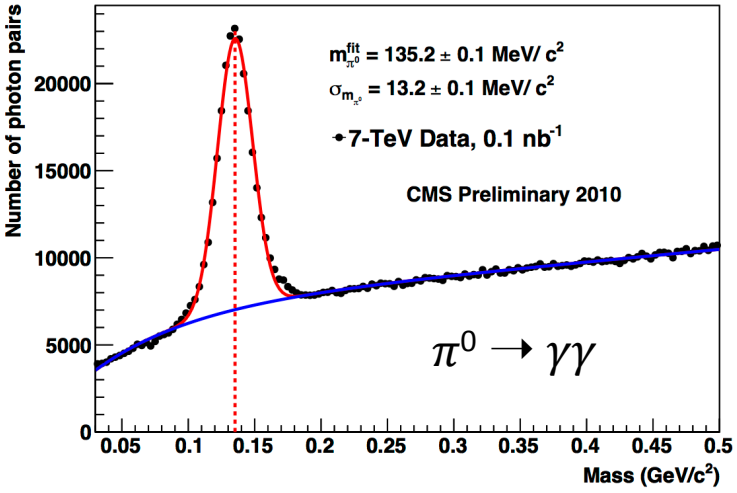
Some examples







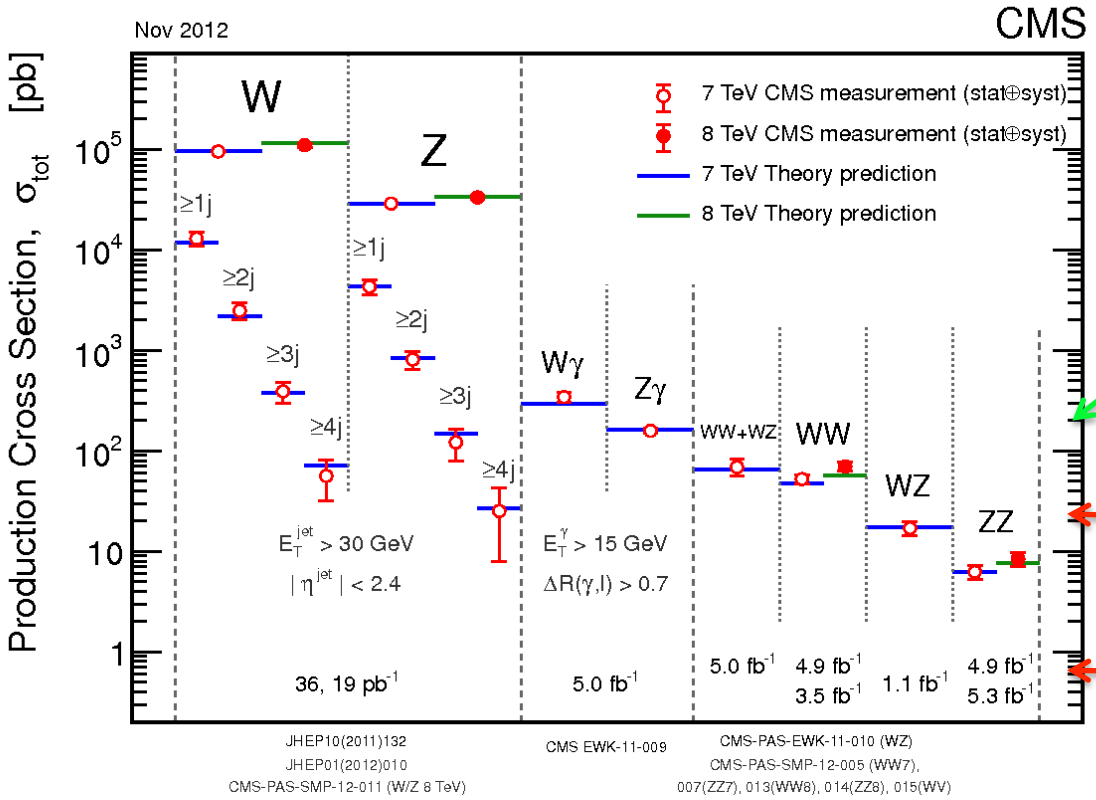




di-electron mass

Precise SM measurements, the key to discovery

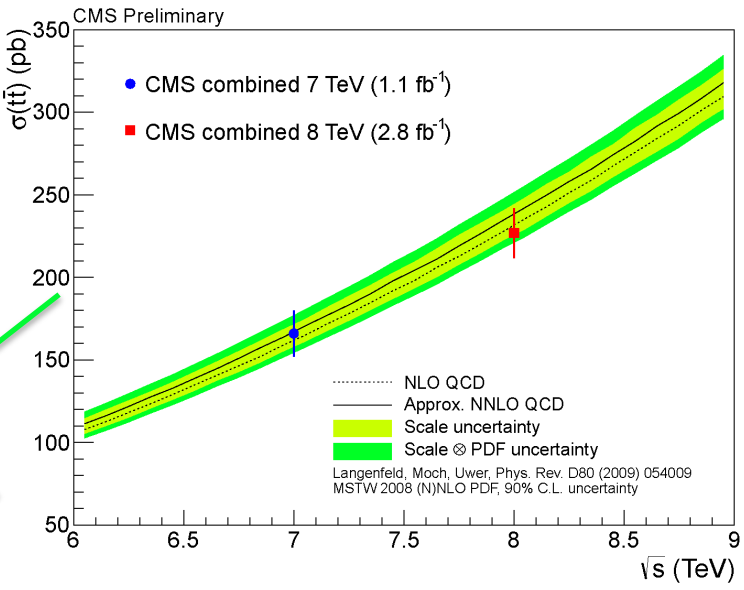
bosons (+ jets), dibosons



H

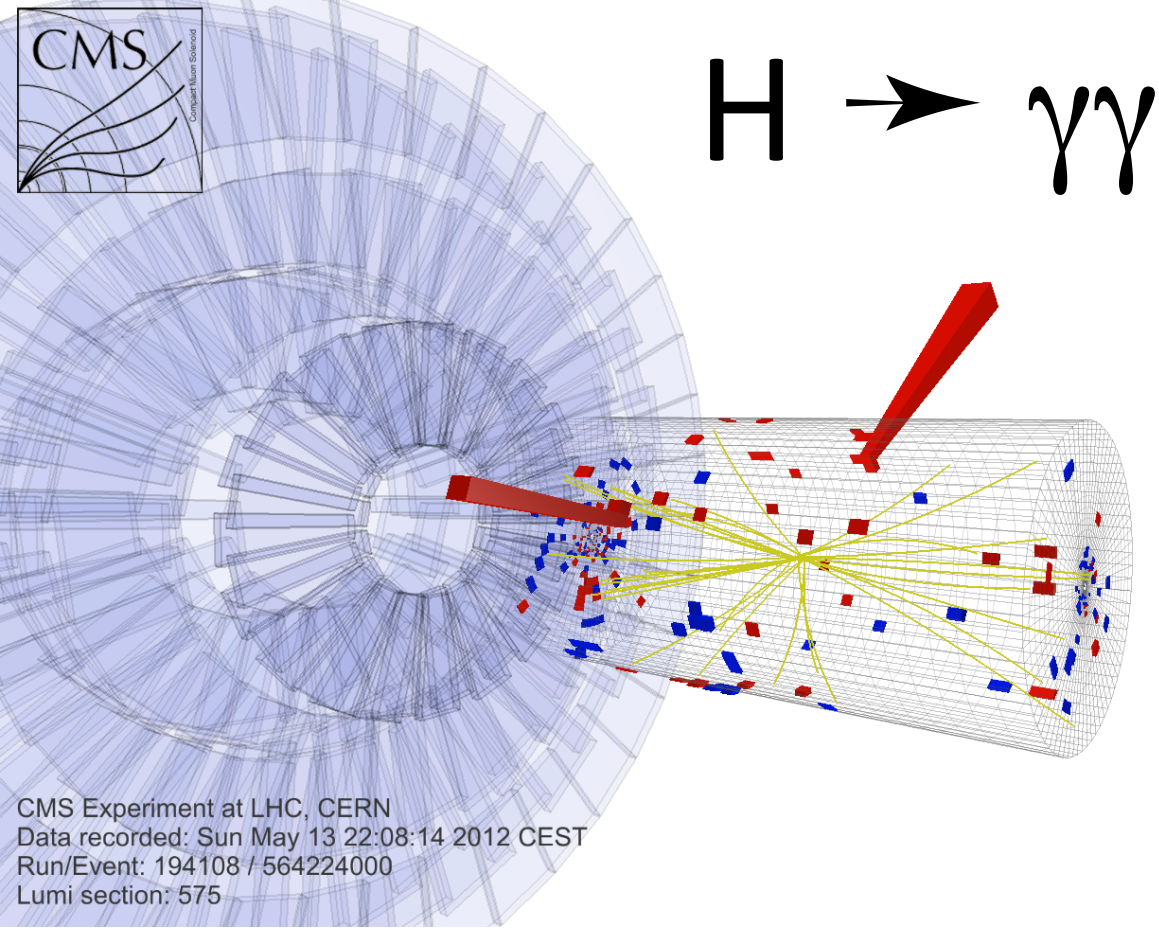
H→ZZ

t $\bar{t}$

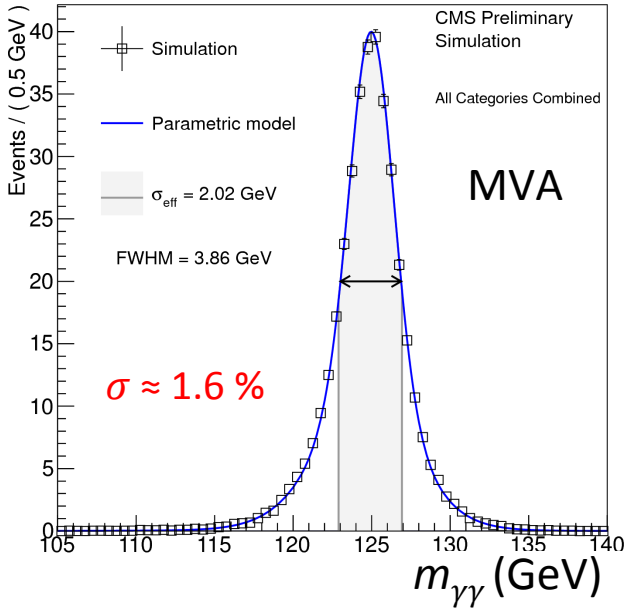


These measurements require good understanding of the detector, and of the SM predictions (backgrounds to the H signal).

$H \rightarrow \gamma\gamma$



signal model



Two high-p_T isolated photons with a narrow mass distribution, $m_{\gamma\gamma}$, steeply falling for the background.

MVA techniques to perform γ identification, and vertex determination.

Background evaluated from a fit to the data, no reference to the simulation.

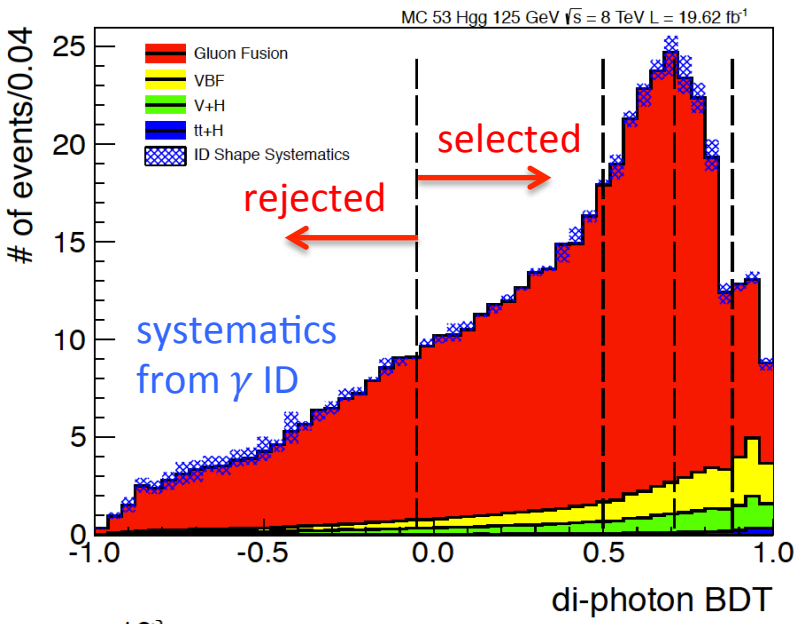
Two Inclusive analyses:

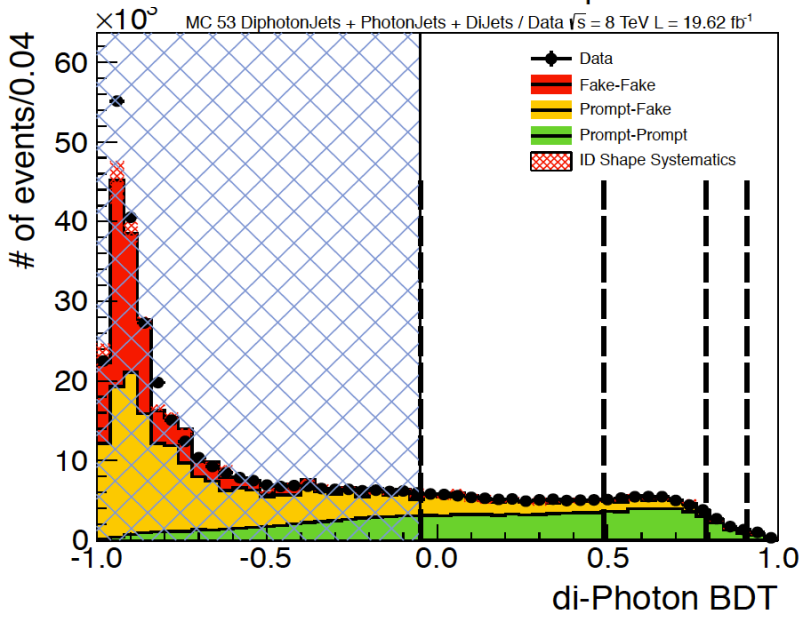
- MVA-based selection: MVA from γ shower shape and isolation (γ ID MVA), kinematics, and $m_{\gamma\gamma}$ resolution.
- Cut-based selection (cross-check): cuts on η_γ (ECAL η region), γ conversion.
- 4 categories with different S/B and $m_{\gamma\gamma}$ resolution.

Exclusive analyses:

- 3 VH channels: e, μ, MET tag
- VBF: 2 dijet categories

125 GeV H signal



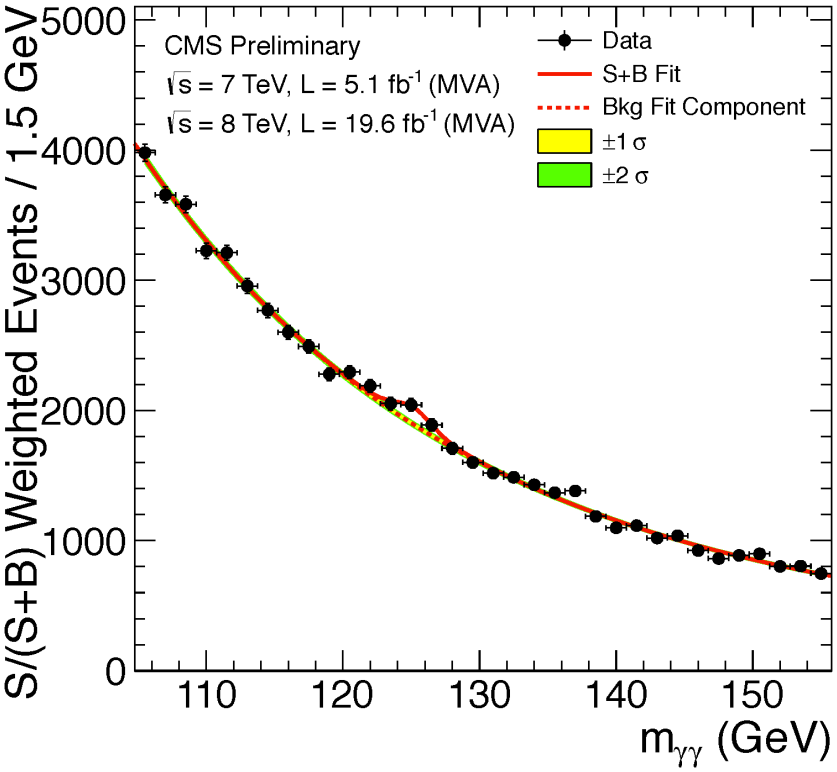


Simulated background and data

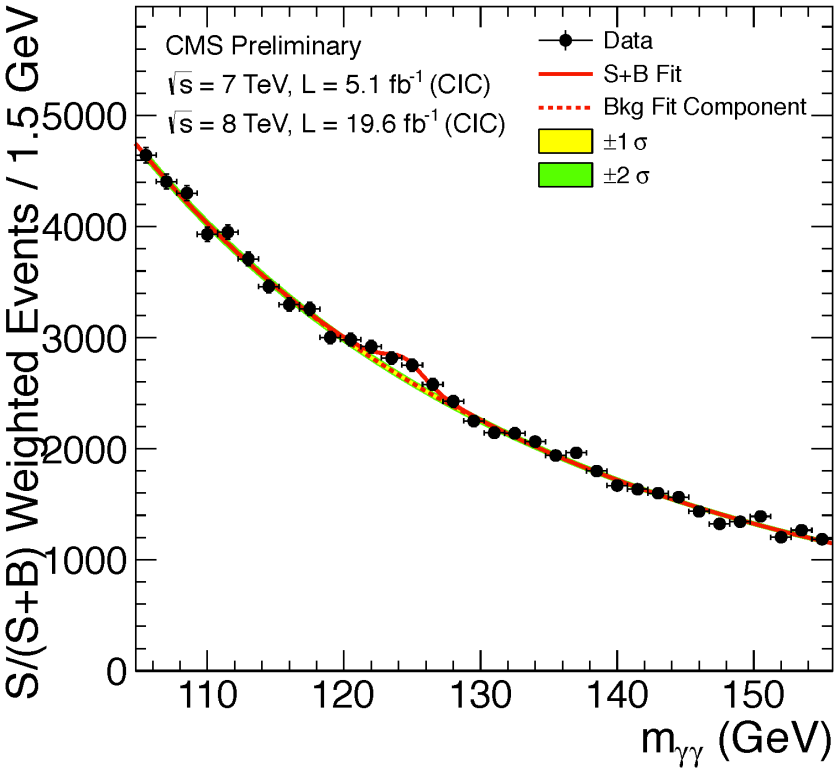
weighted mass distributions

$m_{\gamma\gamma}$ distribution with each event weighted by the S/(S+B) value of its category (for visualization only).

MVA analysis



Cut-based analysis



m_H = 125.4 ± 0.5 (*stat.*) ± 0.6 (*sys.*) GeV

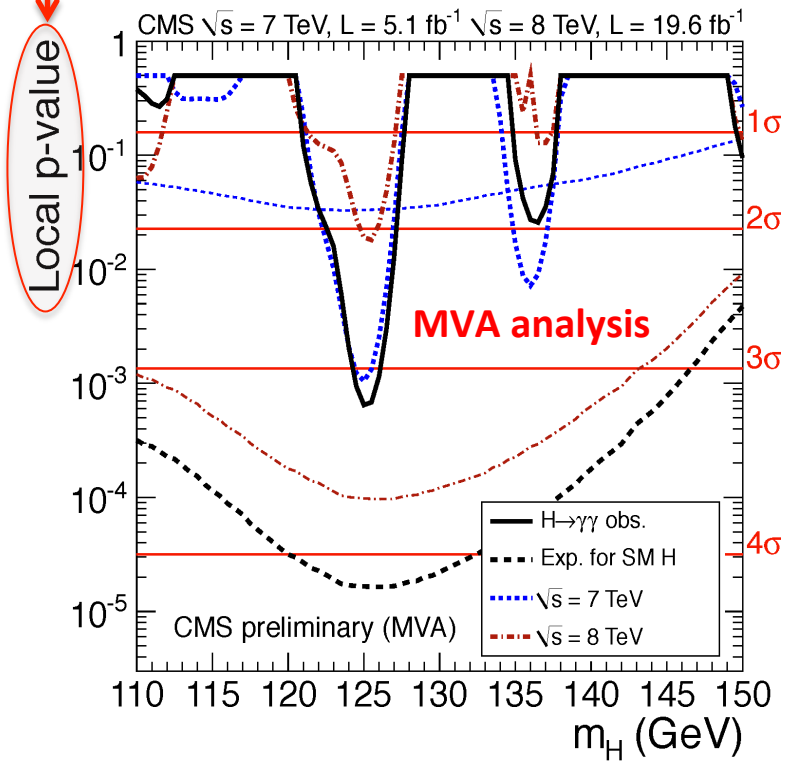
Signal strength for MVA analysis

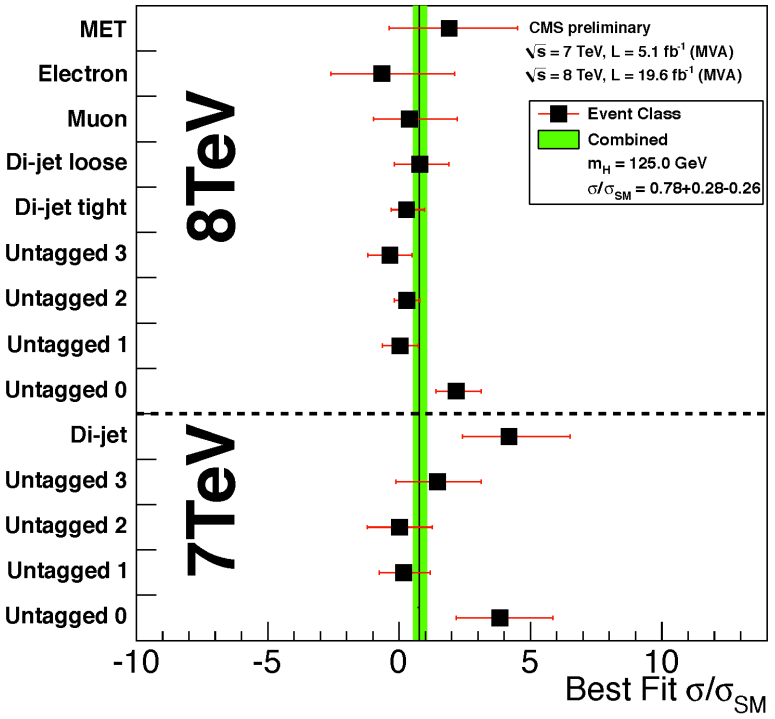
Ratio of the production cross section times the relevant branching fractions over the SM expectation: σ/σ_{SM} = 0.78 ± 0.27 (m_H = 125 GeV)

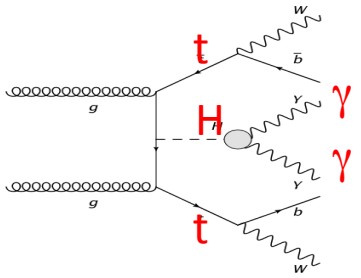
profile likelihood ratio

Significances (σ) for m_H = 125 GeV:

- MVA: observed 3.2, expected 4.2
- Cut-based: observed 3.9, expected 3.5







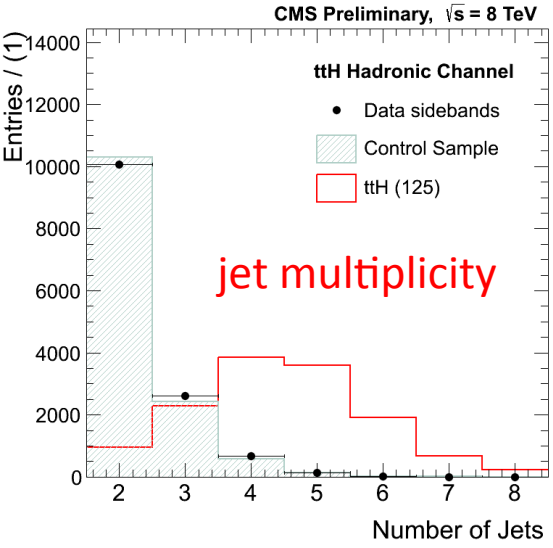
ttH, H → γγ

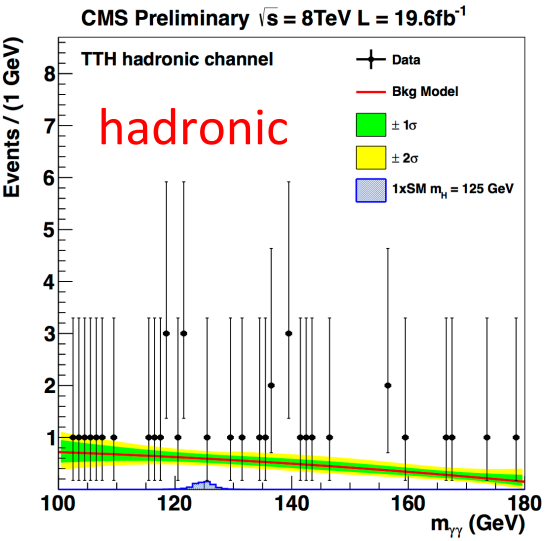
NEW

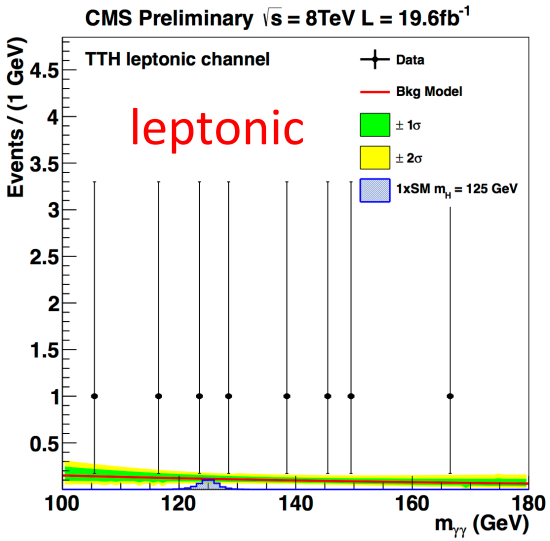
Small signal expected.

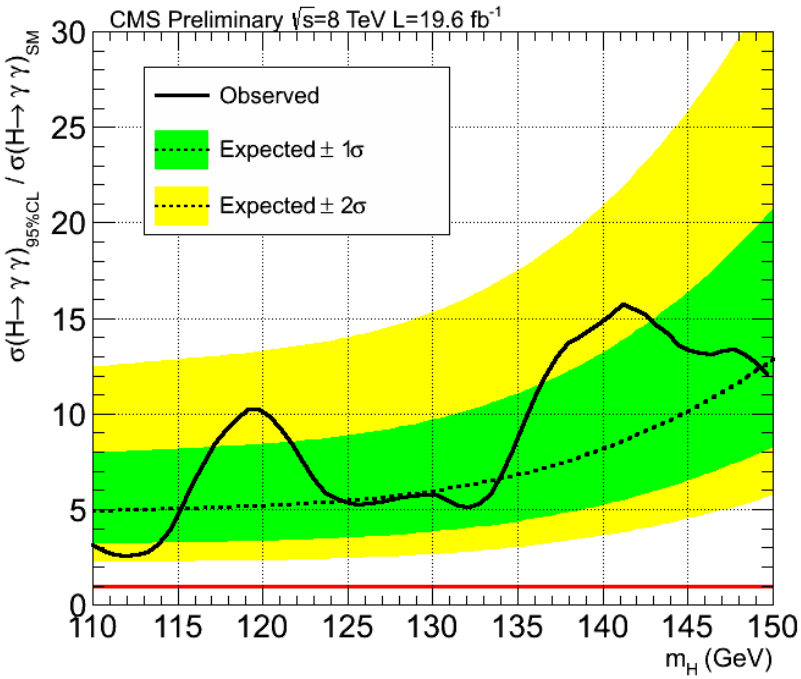
Preform two analyses to maximize sensitivity, optimized for leptonic and hadronic tt decays.

Not a significant excess observed, 95% CL upper limit on $\sigma(ttH) \times BR(H \rightarrow \gamma\gamma) = 5.4 \times SM$, 5.3 expected, at $m_H = 125$ GeV.

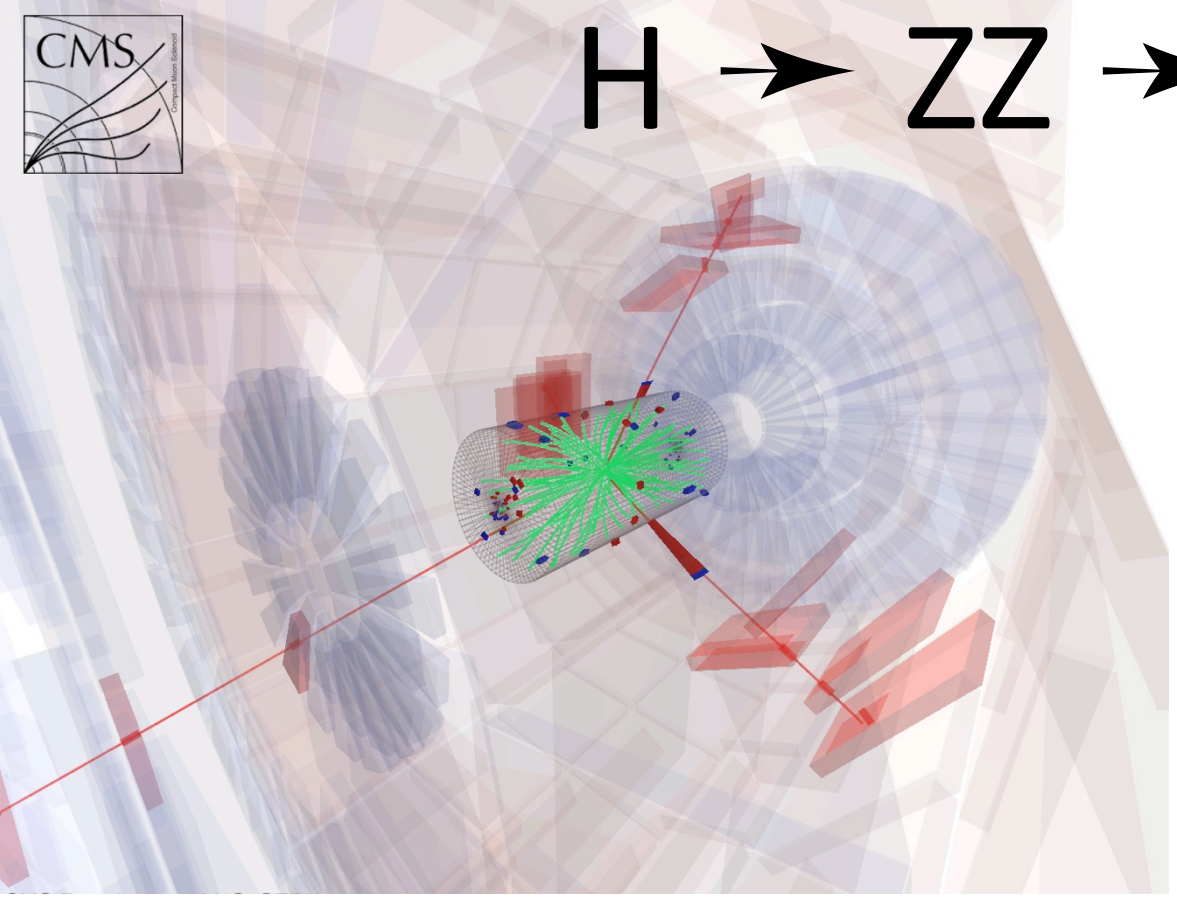




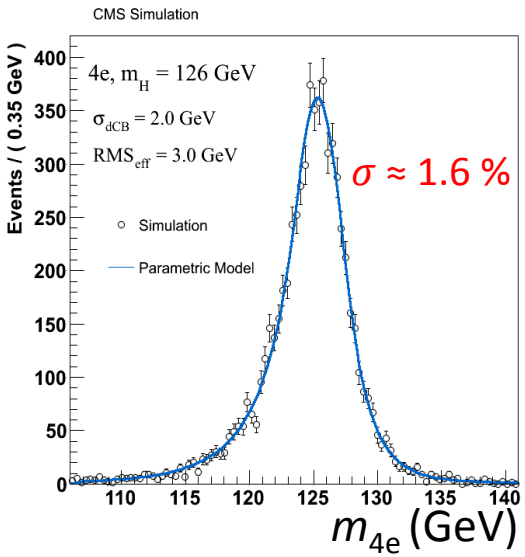


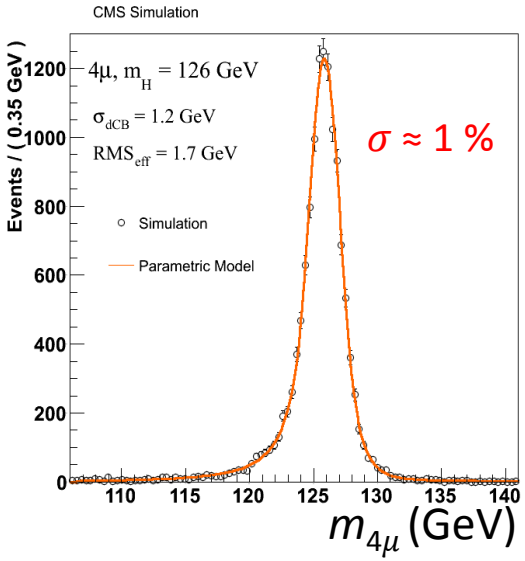


H → ZZ → 4ℓ



signal model





Four high-p_T isolated leptons from the primary vertex.

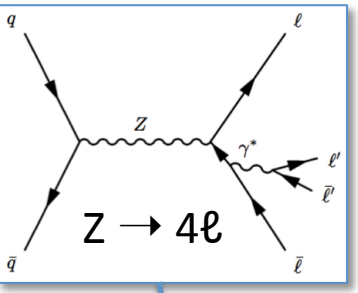
Narrow 4-lepton mass distribution, keep resolution and momentum scale under control.

Clean 4e, 4μ and 2e2μ events, but low branching ratio.

Important to keep efficiency as high as possible.

Two jet categories: untagged (0/1) and dijet tagged (≥ 2).

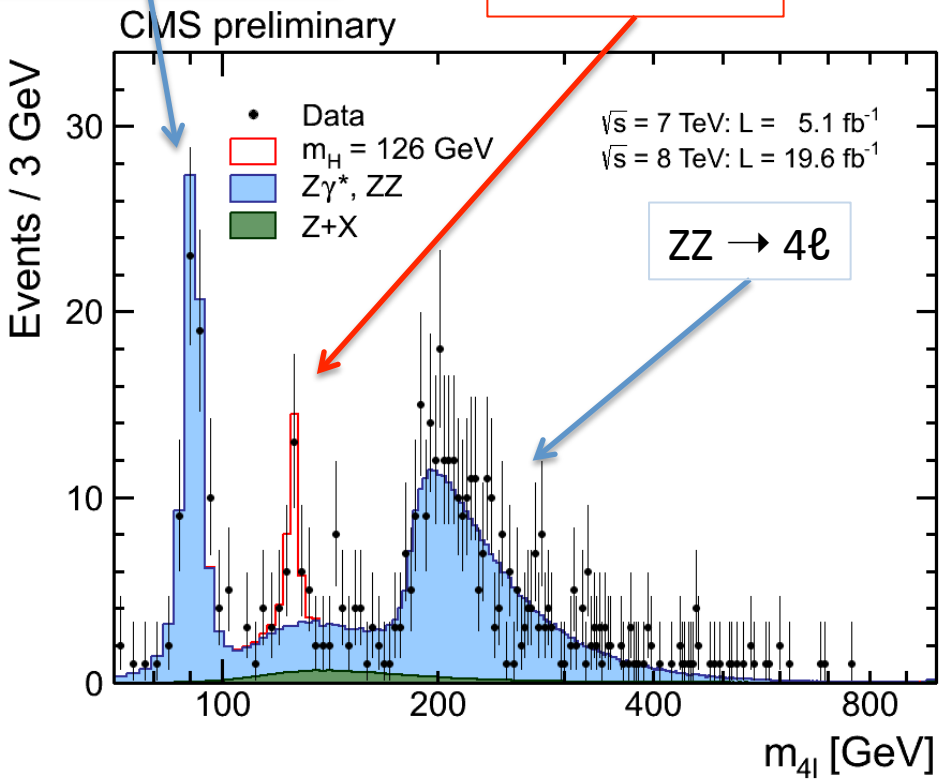
4ℓ mass distribution

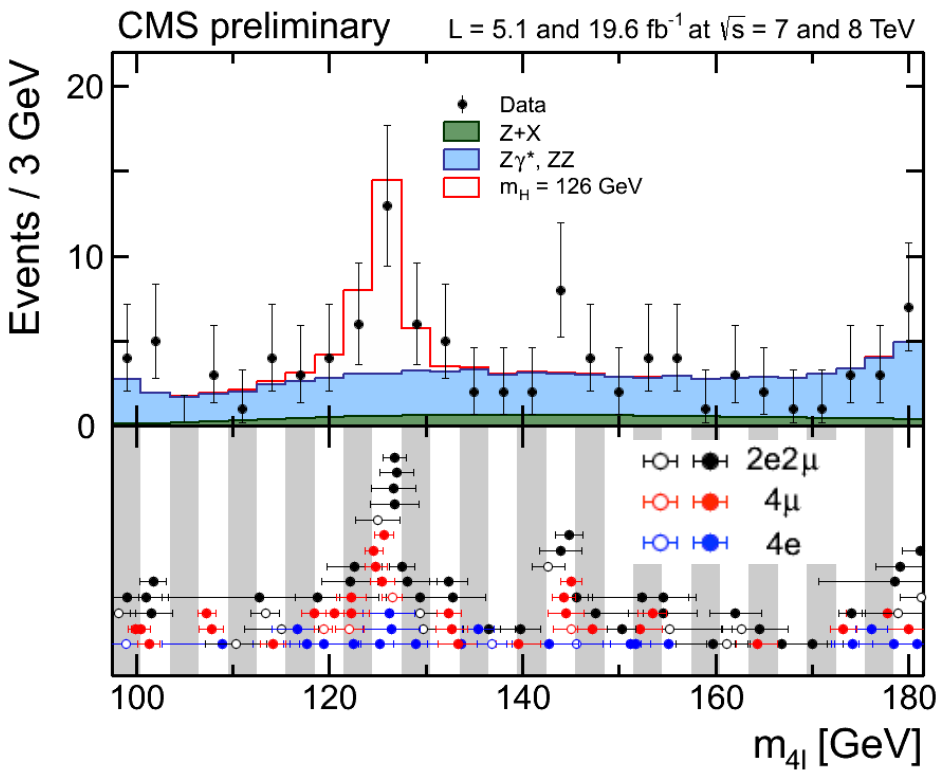


X → ZZ → 4ℓ

ZZ → 4ℓ

mass of the candidates



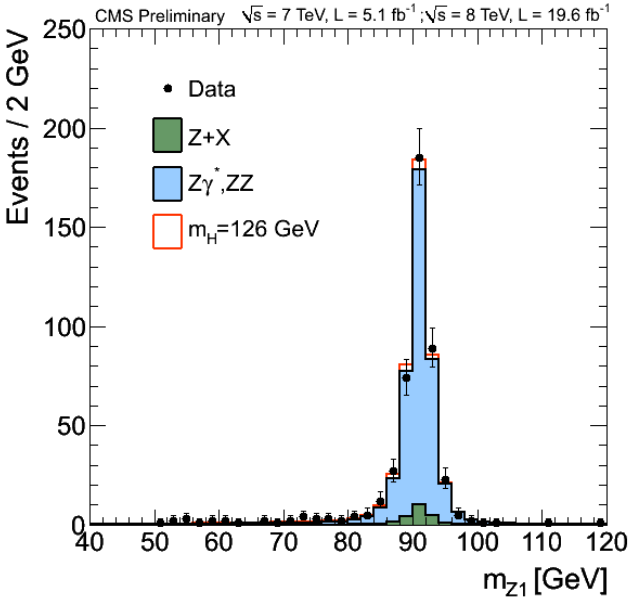


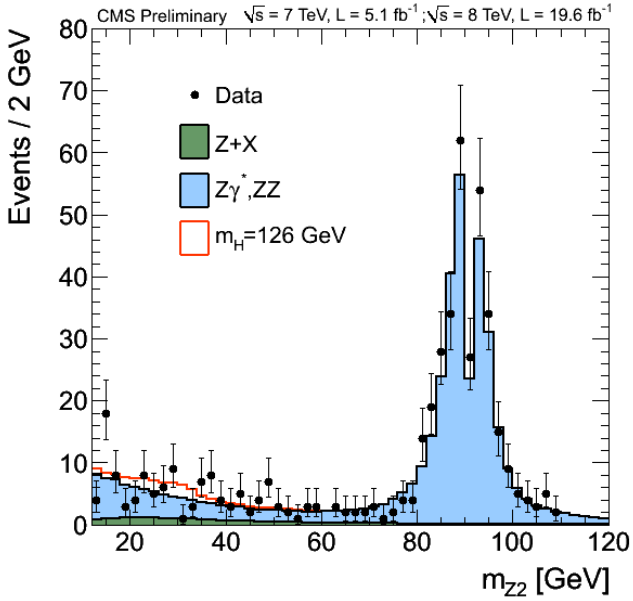
Four-lepton reconstructed mass for the sum of the 4e, 4μ, and 2e2μ channels.

Mass resolution measured from data. ZZ background well under control.

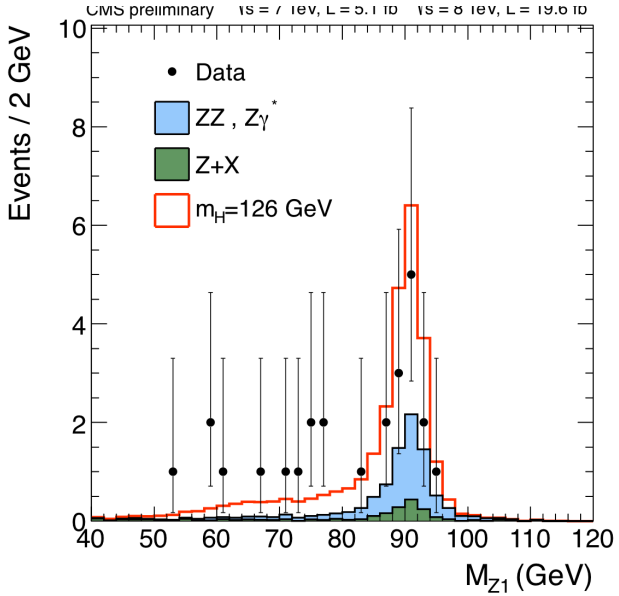
mass of the two Z's ($m_{\ell\ell}$)

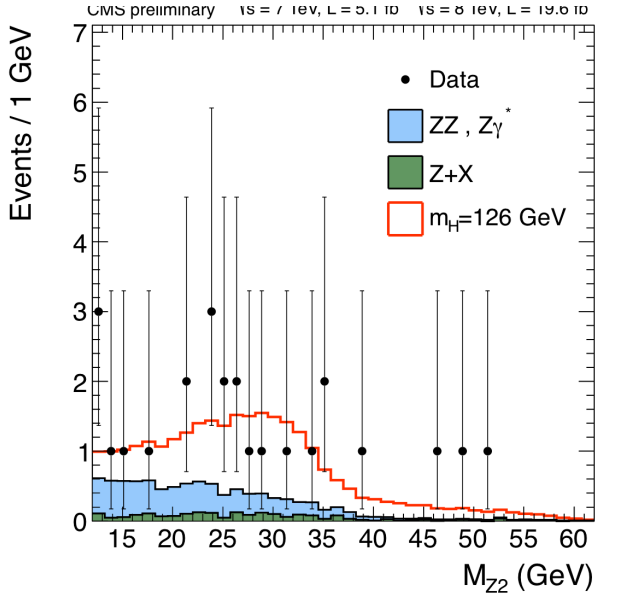
Distributions for events with $m_{4\ell} > 100$ GeV





Events in the $m_{4\ell}$ range [121.5-130.5] GeV



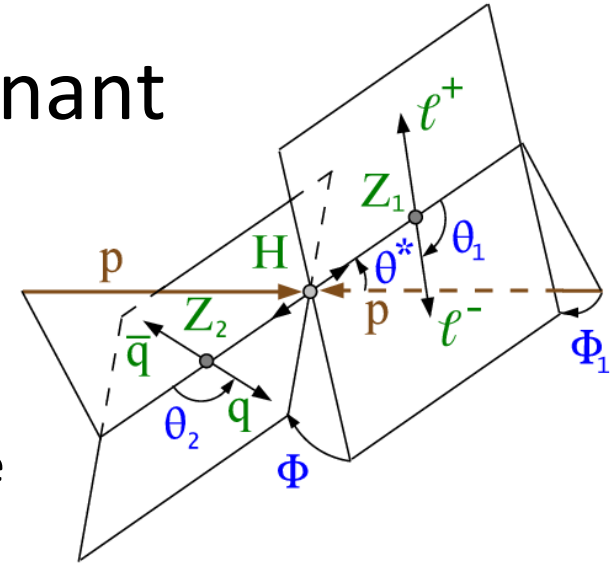


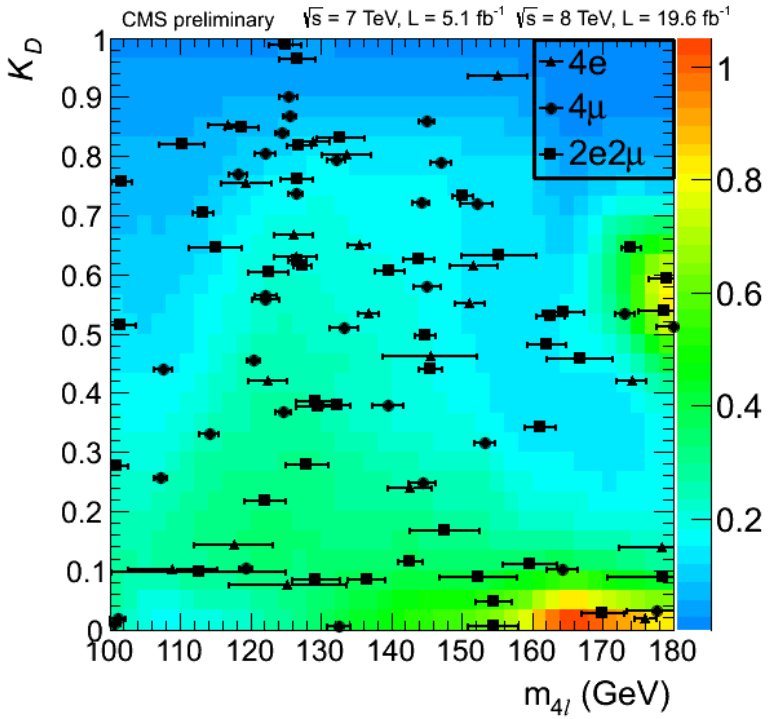
J^P-dependent Kinematic Discriminant

$K_D = P_S / (P_S + P_B)$

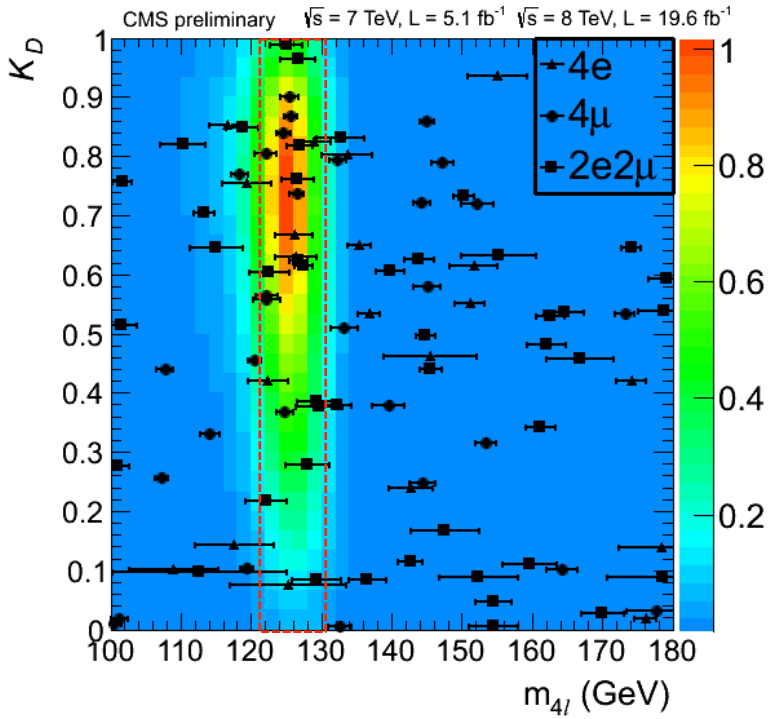
where $P_{S,B} = f(m_1, m_2, \theta_1, \theta_2, \Phi_1, \theta^*, \Phi^* | m_{4\ell})$

calculated from production and decay kinematics in the Z's and H rest frames.





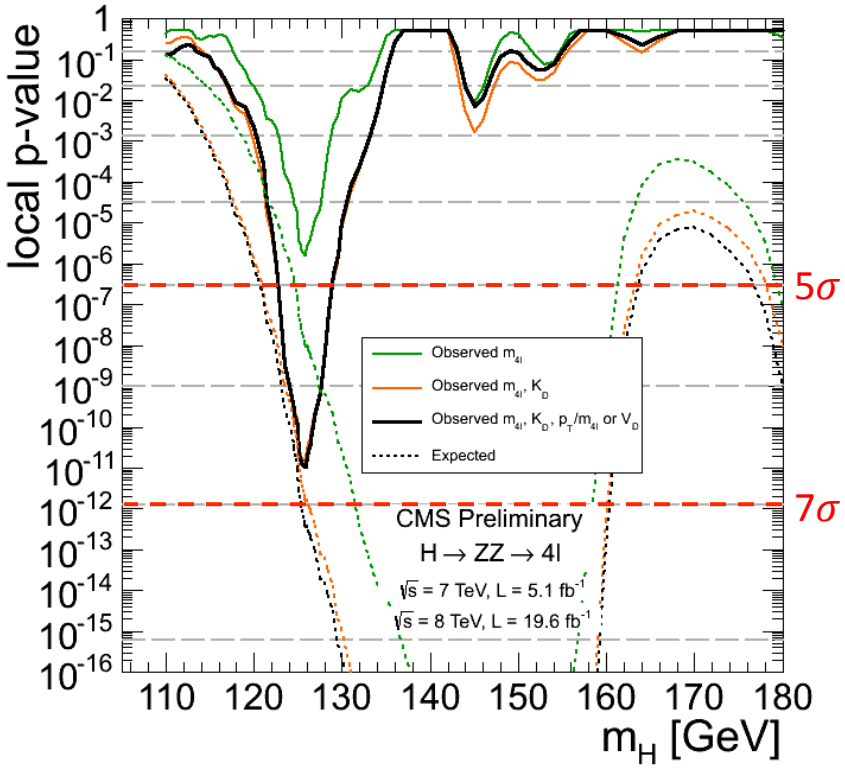
background expectation



m_H = 126 GeV signal

Significance of the local excess

3D fit to $m_{4\ell}$, K_D and (for jet categories) $p_T(4\ell)/m_{4\ell}$ or linear discriminant (VBF).



Significance (σ) for m_H = 125.8 GeV:

observed 6.7, expected 7.2

$\sigma/\sigma_{SM} = 0.91^{+0.30}_{-0.24}$

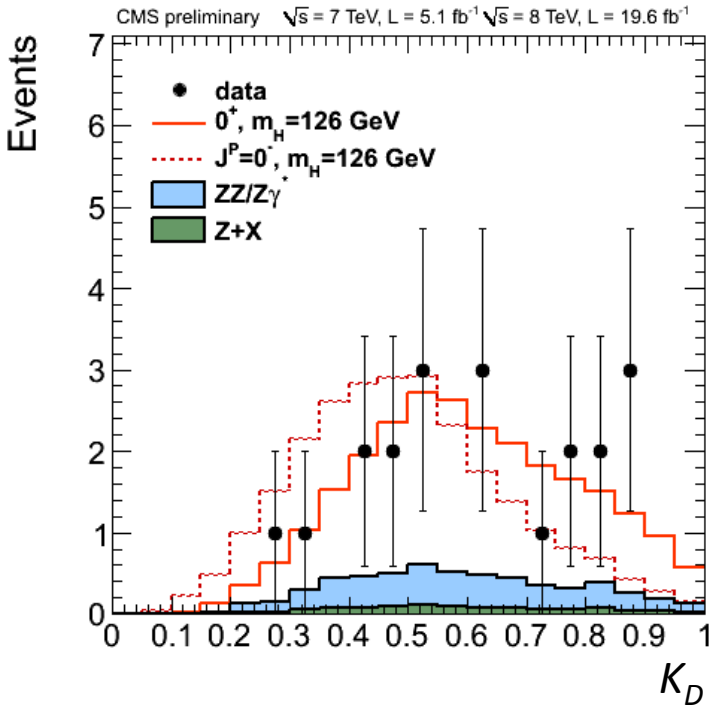
$m_H = 125.8 \pm 0.5\ (stat.) \pm 0.2\ (sys.)$ GeV

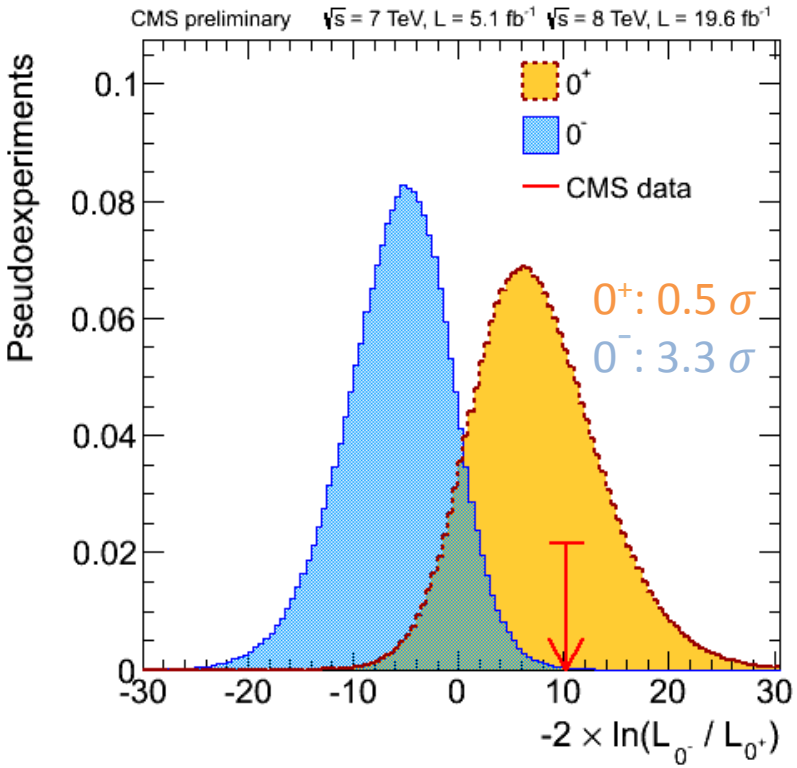
spin-parity

K_D constructed for different J^P Higgs-like states, having different kinematics.

several J^P hypotheses tested

J^P	obs. 0^+	obs. J^P	CL_s
0^-	0.5σ	3.3σ	0.16%
0^+_h	0.0σ	1.7σ	8.1%
2^+_{mgg}	0.8σ	2.7σ	1.5%
$2^+_{mq\bar{q}}$	1.8σ	4.0σ	<0.1%
1^-	1.4σ	$>4.0\sigma$	<0.1%
1^+	1.7σ	$>4.0\sigma$	<0.1%



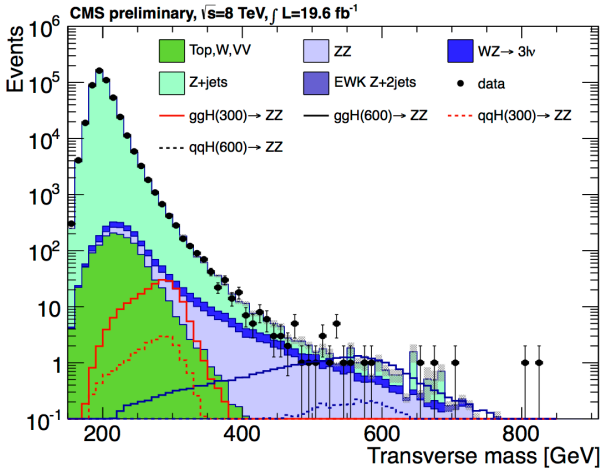


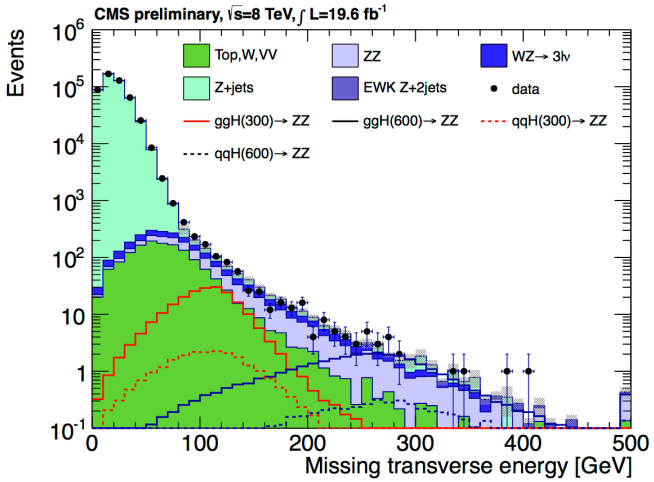
$H \rightarrow ZZ \rightarrow 2\ell\, 2\nu$

NEW

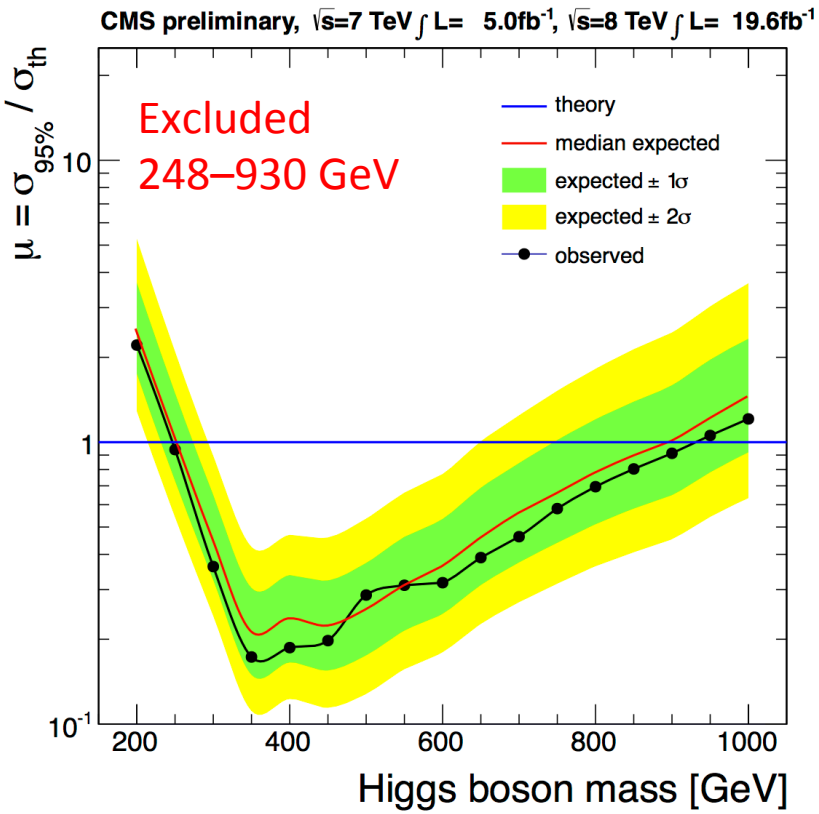
SM-like heavy Higgs boson search, mass > 200 GeV.

Two leptons (e, μ) from the Z and large missing energy (2ν). Mass not reconstructed.





Cut-in-categories and shape analyses based on transverse mass and missing energy. Jet categories optimized separately for VBF and ggH.



BSM interpretation of the results: search for an EW singlet scalar mixing with the new boson, excluded for various widths and branching ratios to new particles.

CMS-PAS-HIG-13-014

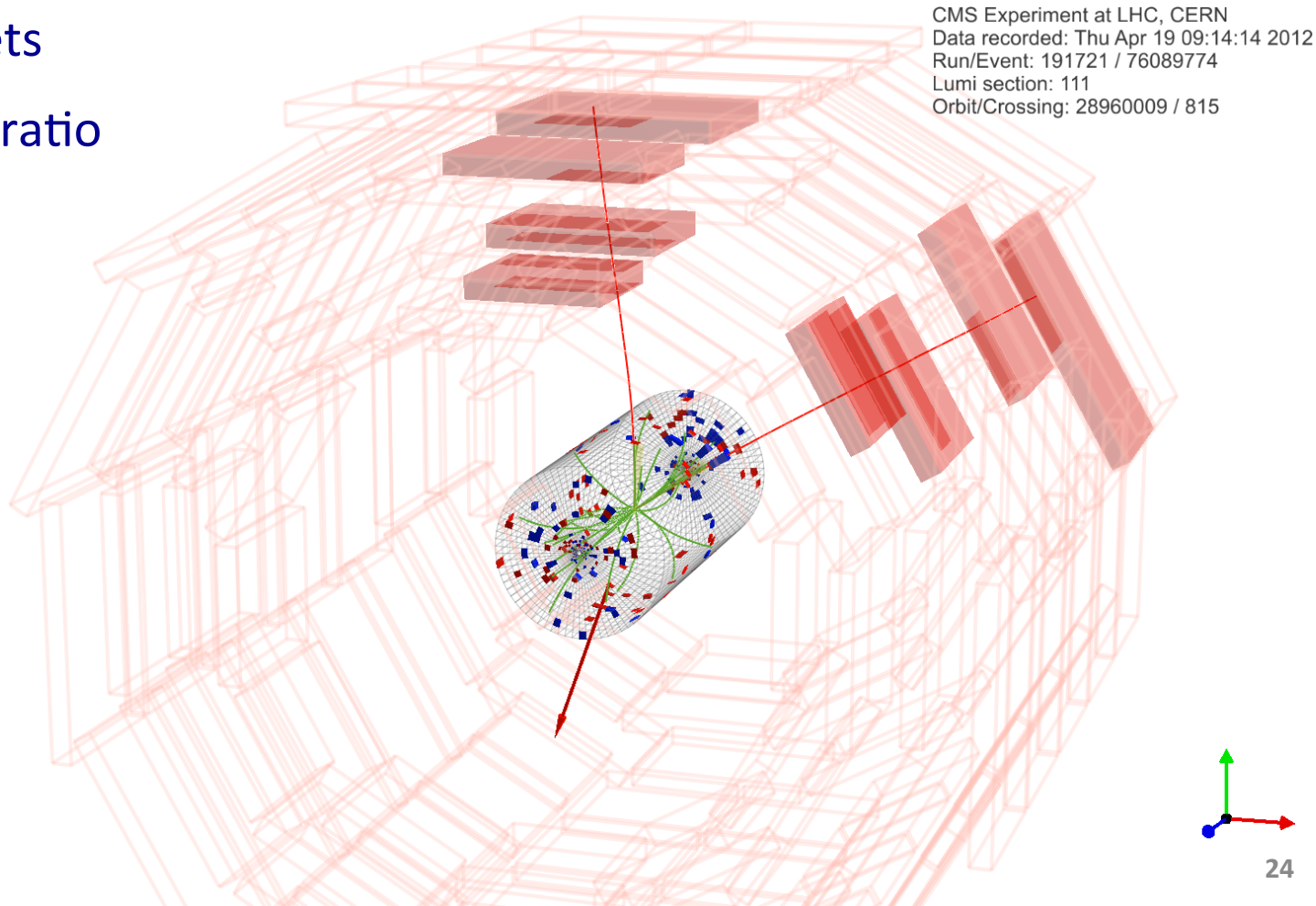
H ➔ WW ➔ 2ℓ 2ν

2 high-p_T isolated leptons, low opening angle (sensitivity to spin)

large MET (ν's), mass not reconstructed (transverse mass, M_T)

veto b-tagged jets

large branching ratio

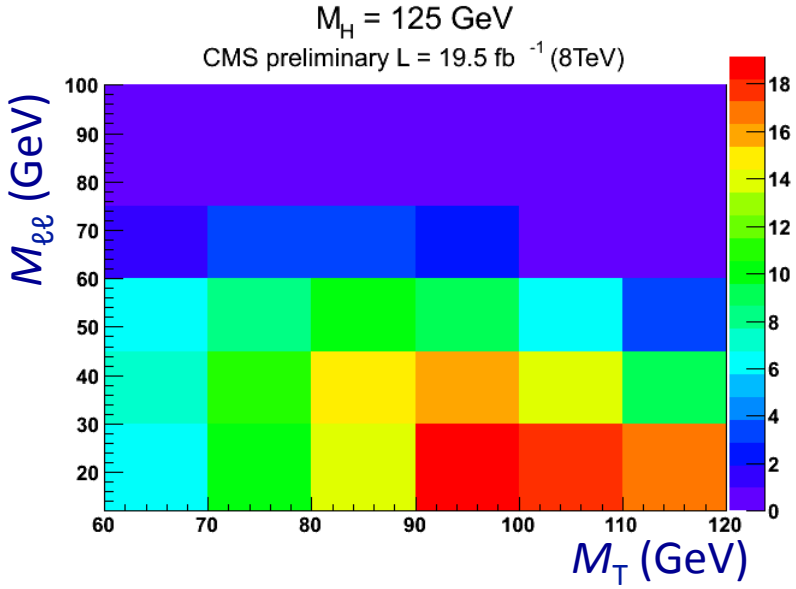


analysis

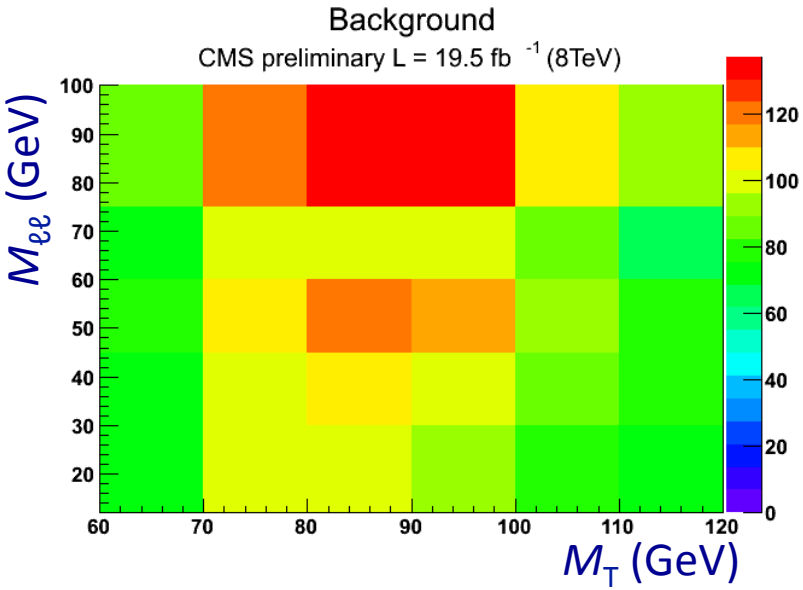
Jet categories: 0 jet, 1 jet, 2 jet (VBF)

Two analyses in the 0 and 1 jet categories:

- SF: same lepton flavor → cut-based
- DF: different lepton flavor → 2D shape analysis M_T and $M_{\ell\ell}$



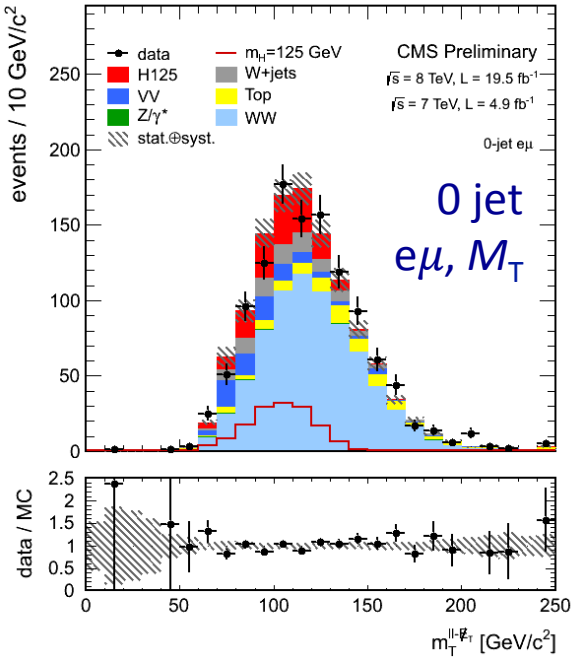
signal

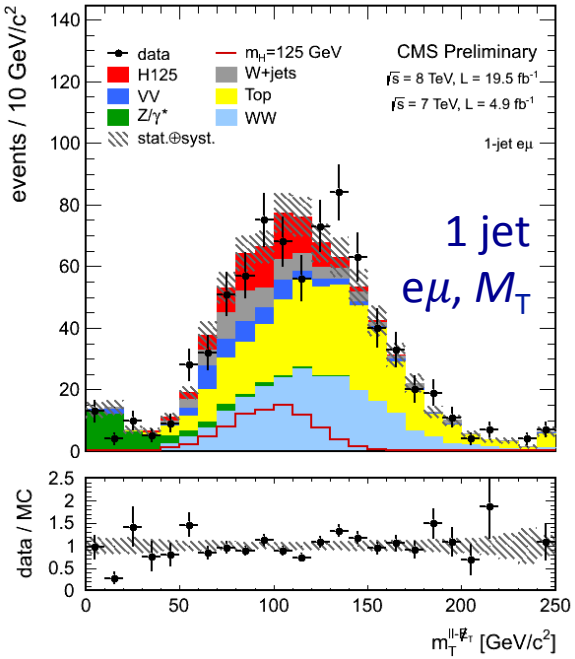


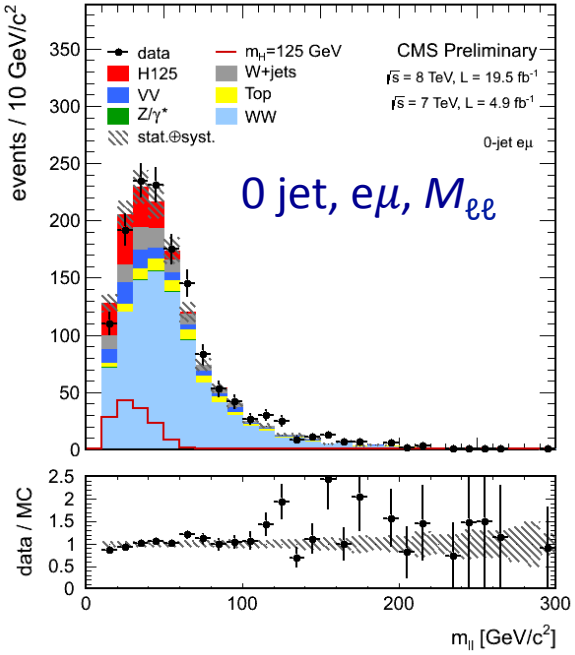
background

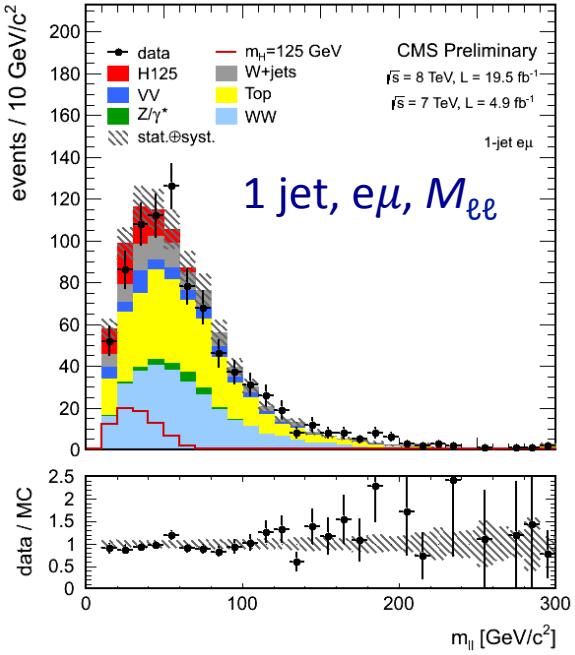
Background from Drell-Yan, WW, top, W+jets, estimated from control regions in data.

125 GeV Higgs signal.









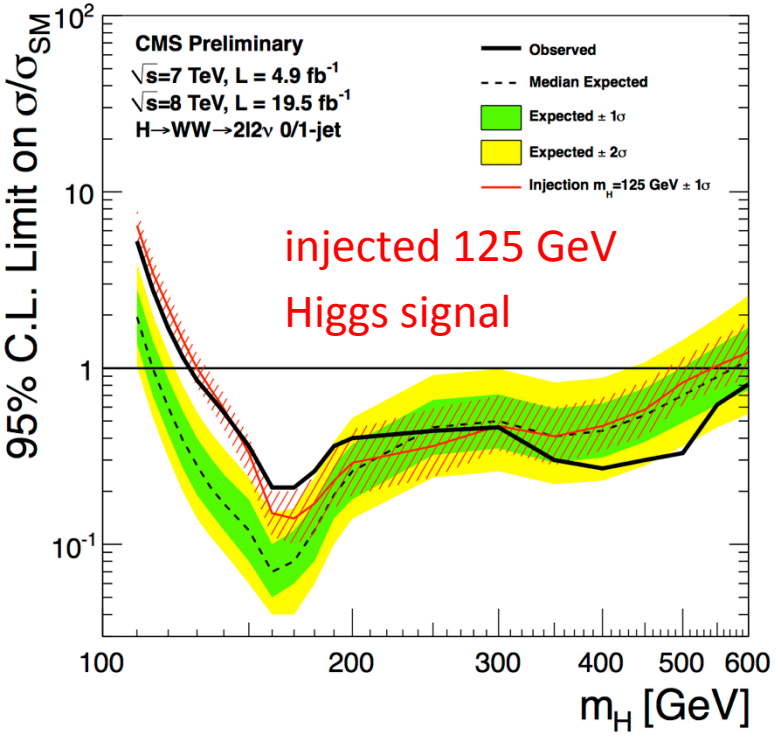
Broad excess compatible with a Higgs signal at low mass.

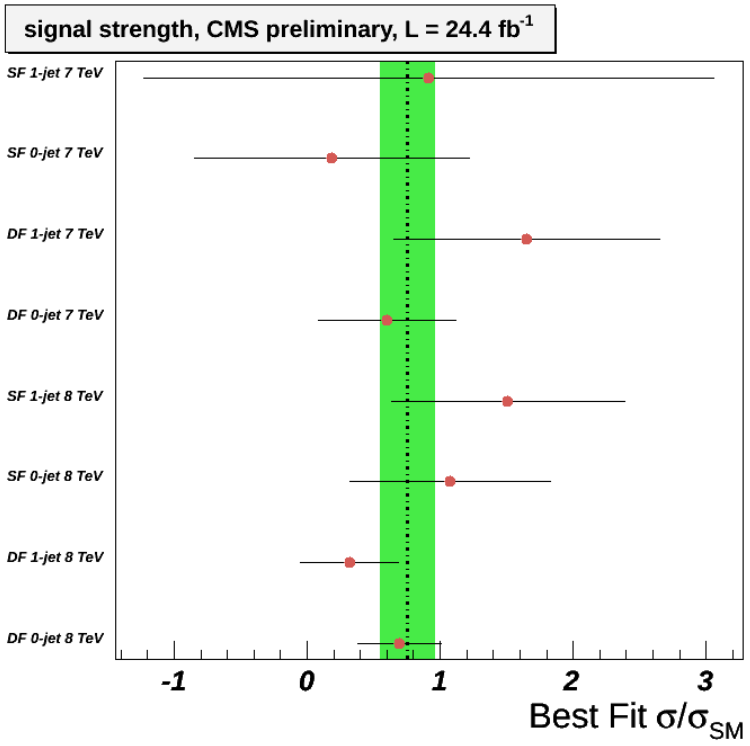
Significance (σ) for m_H = 125 GeV:

observed 4, expected 5.1

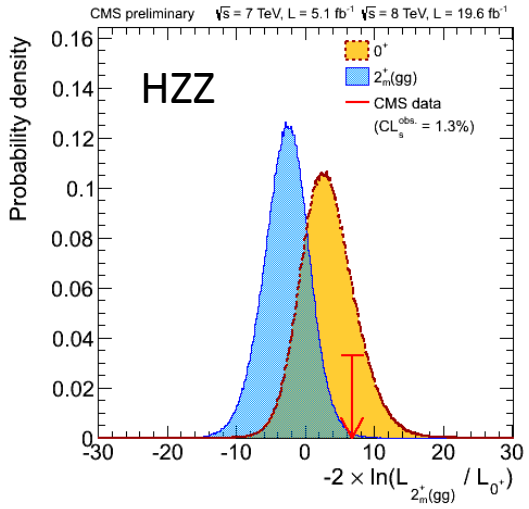
σ/σ_{SM} = 0.76 ± 0.21

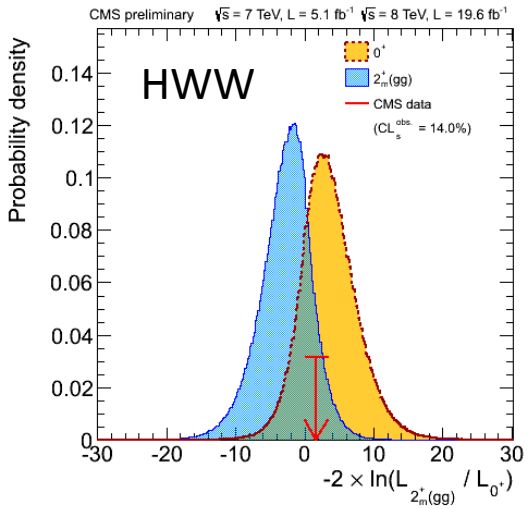
Consistency among analyses.



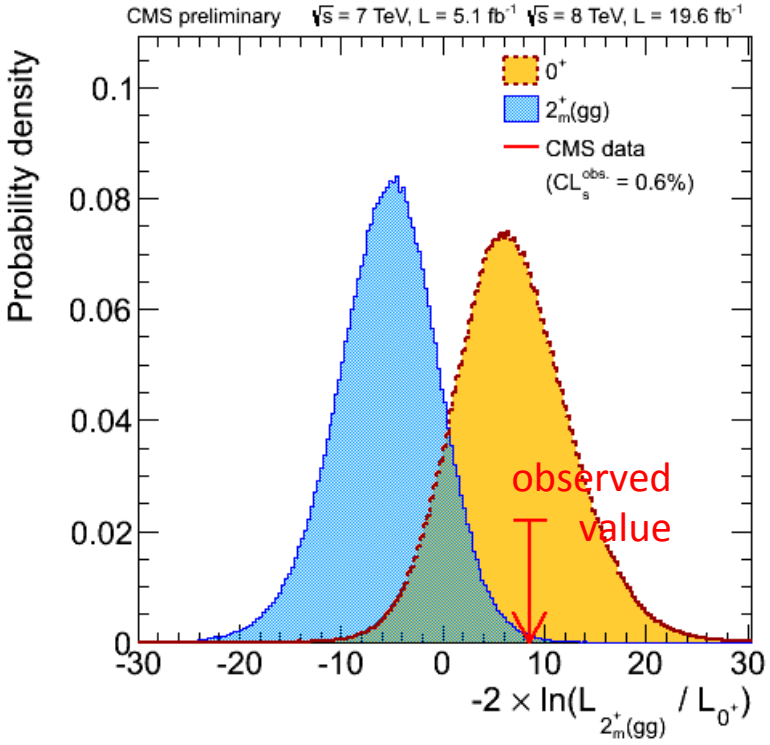


Combined WW+ZZ results for spin 2





Test statistic comparing the signal J^P hypotheses **0^+** and **$2^+_m(gg)$** in the best fit to the data.



Graviton-like boson with minimal couplings to gg disfavored by data

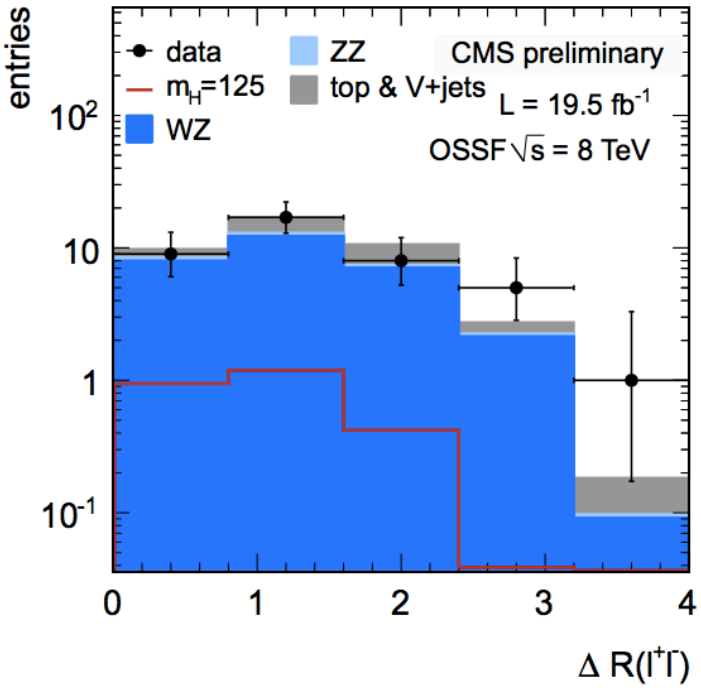
Post-fit model (μ_i profiled)	$ZZ \to 4\ell$	$WW \to \ell\nu\ell\nu$	Combined
$P(q \le q^{\text{obs.}} \mid 0^+)$	-0.90σ	0.44σ	-0.34σ
$P(q \ge q^{\text{obs.}} \mid 2^+_m(gg))$	2.81σ	1.32σ	2.84σ
$1 - \text{CL}_s^{\text{obs.}}$	98.6%	86.0%	99.4%

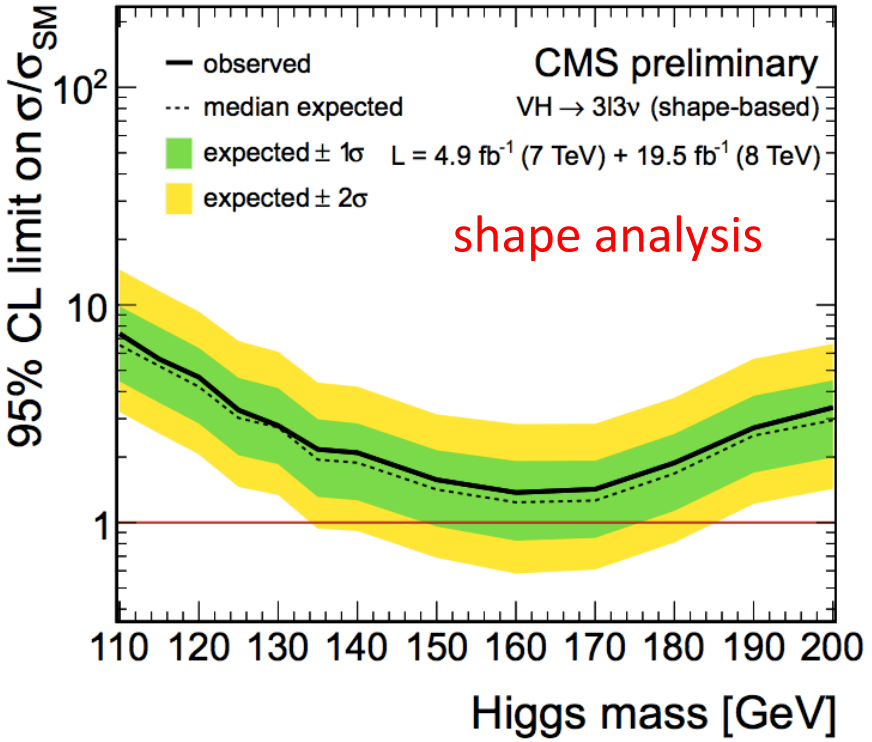
WH ➔ WWW ➔ 3ℓ 3ν

Events with 3 high-p_T isolated leptons (e, μ), large missing energy, low hadronic activity.

Z veto and anti b-tagging to reject WZ and top events.

Cut- and shape-based analyses based on the smallest distance between opposite-charge leptons: $\Delta R_{\ell^+\ell^-}$





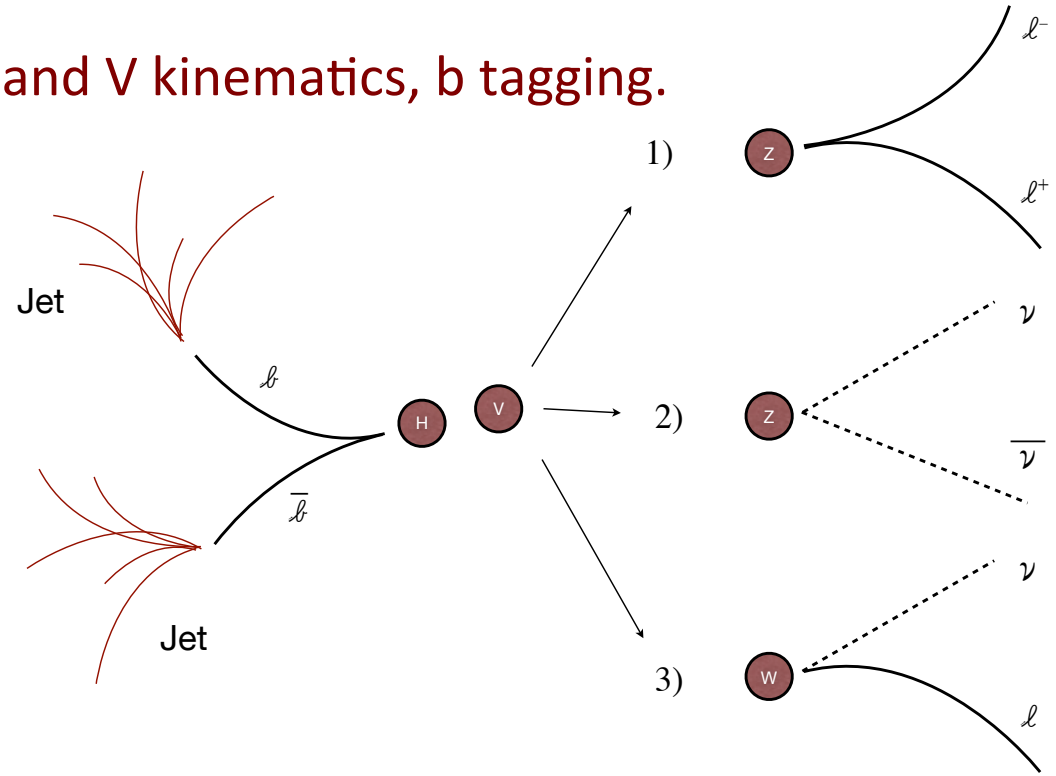
No significant excess of events. Observed (expected) upper limits on $\sigma(WH)/\sigma_{SM}$ at the 95% CL: 3.3 (3.0) for m_H = 125 GeV.

VH → bb + X

2 central b jets plus V (W, Z) decaying into leptons and/or neutrinos.

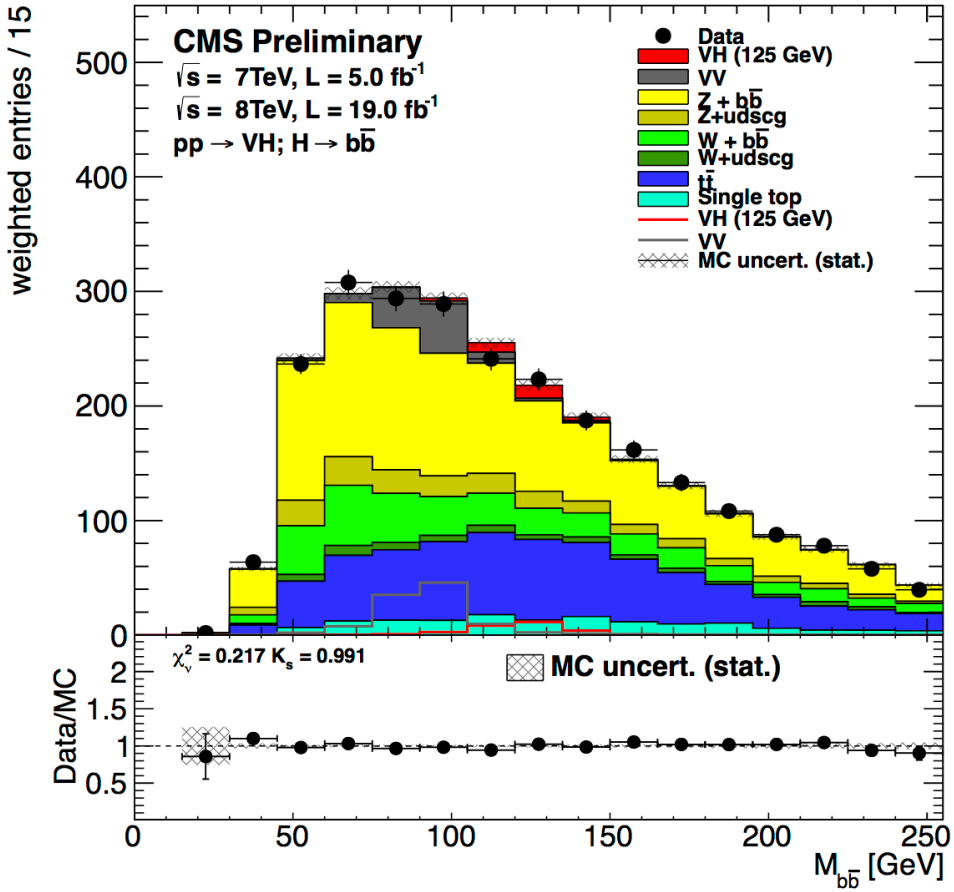
Background from V+jets, VV, top+X.

<u>BDT shape analysis</u>: jets and V kinematics, b tagging.

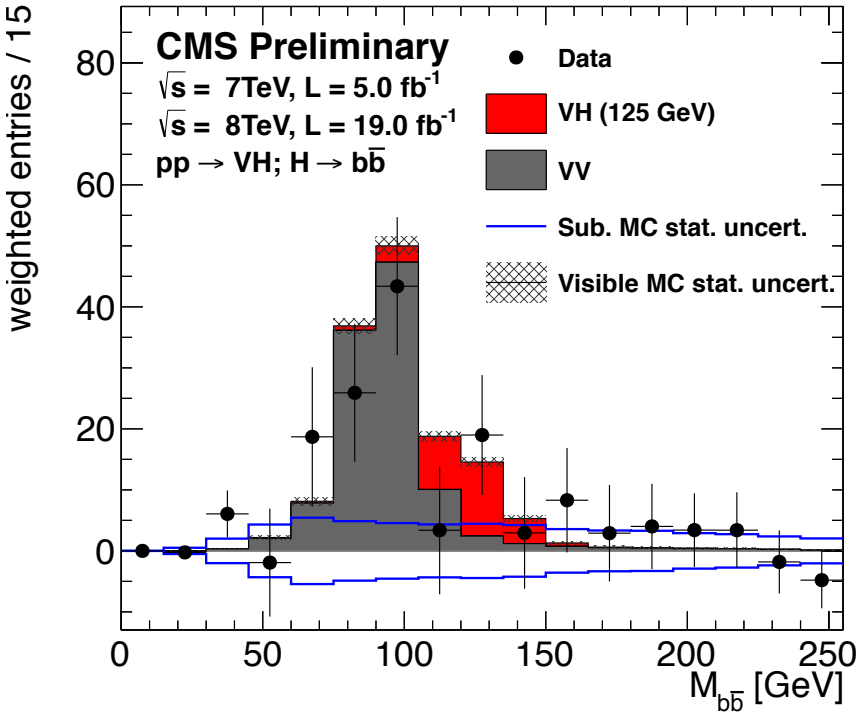


di-jet mass distributions

all channels combined



Backgrounds (except VV) subtracted mass distribution.

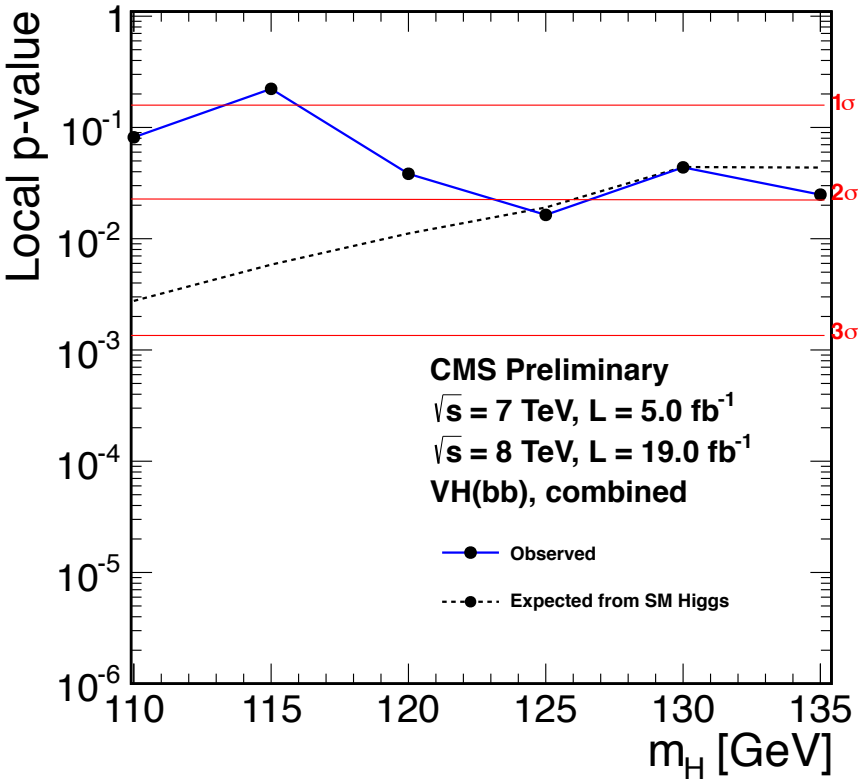


Broad excess (jet resolution) compatible with a Higgs signal at low mass.

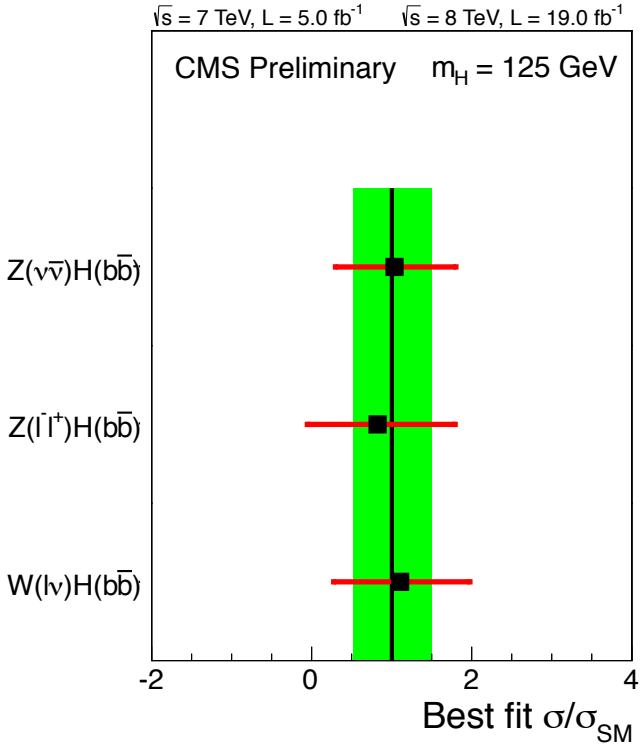
Significance (σ) for m_H = 125 GeV:

observed 2.1, expected 2.1

σ/σ_{SM} = 1.0 ± 0.5



Consistent among analyses.



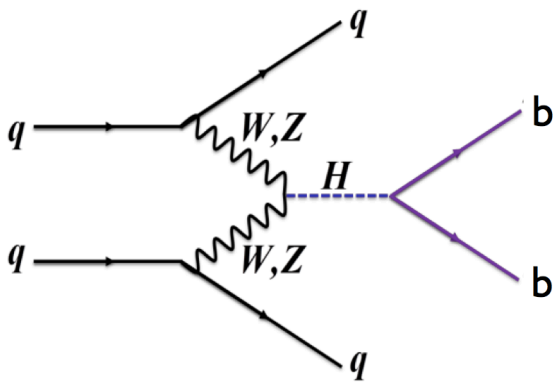
NEW

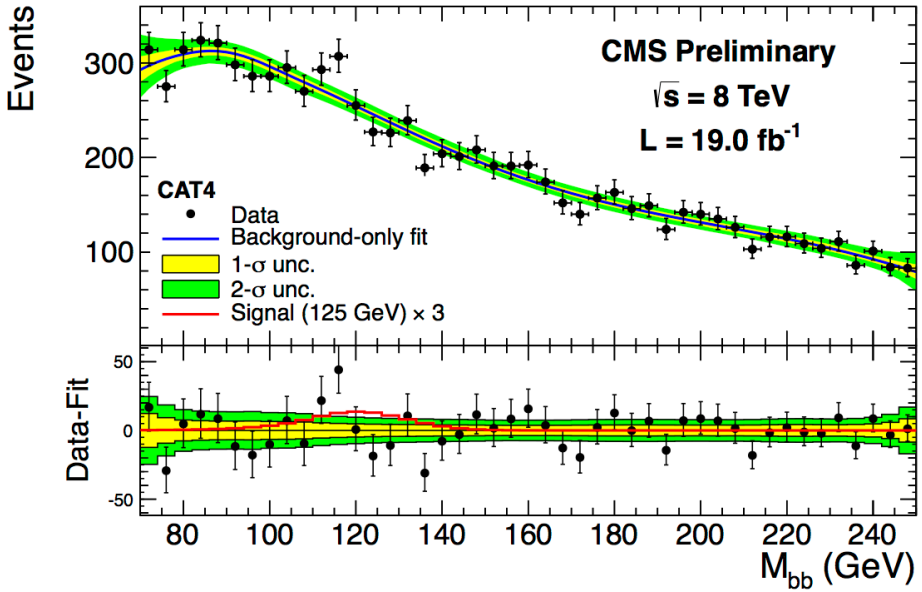
VBF H → bb

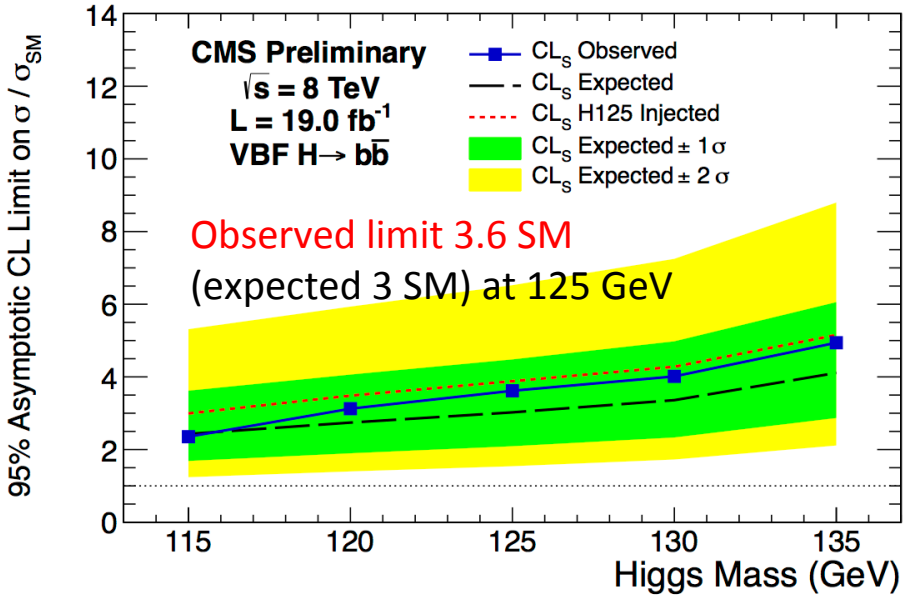
Fully hadronic final state (b jets), dominated by QCD background.

Increase signal sensitivity splitting the sample in 4 categories (NN).

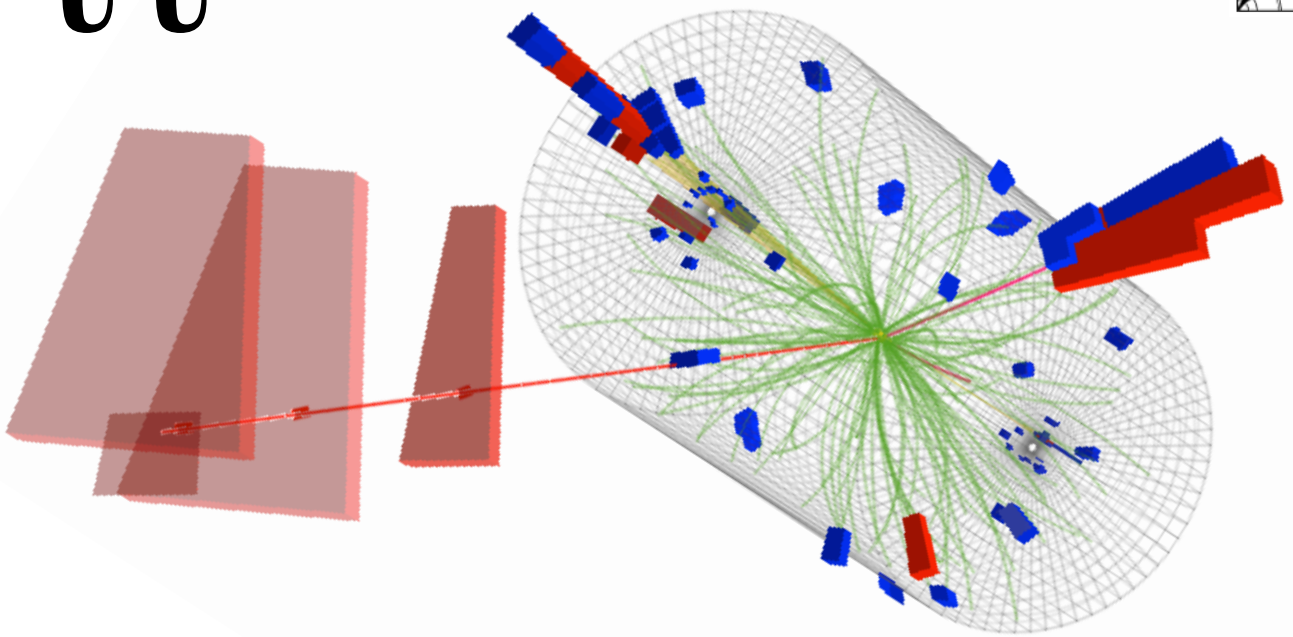
Use m_{bb} distribution to discriminate signal from background.







$H \rightarrow \tau\tau$



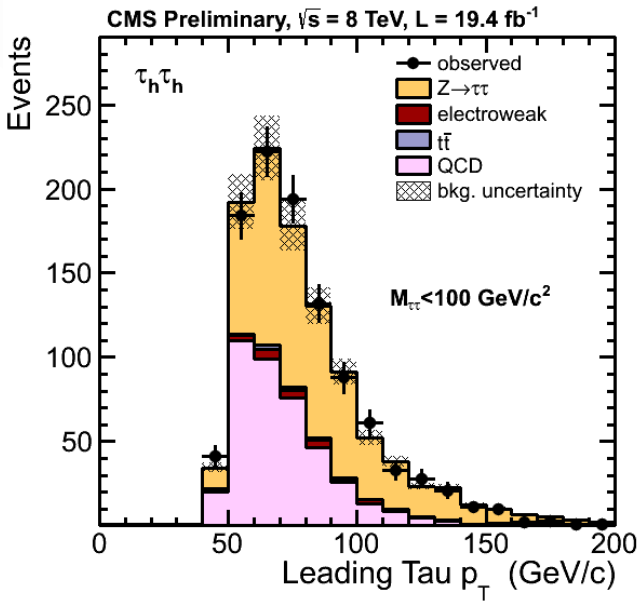
Isolated leptons, τ_h, using MVA algorithm.

Final states: $\mu\tau_h$, $e\tau_h$, $e\mu$, $\tau_h\tau_h$, $\mu\mu$ and VH ($\tau\tau$).

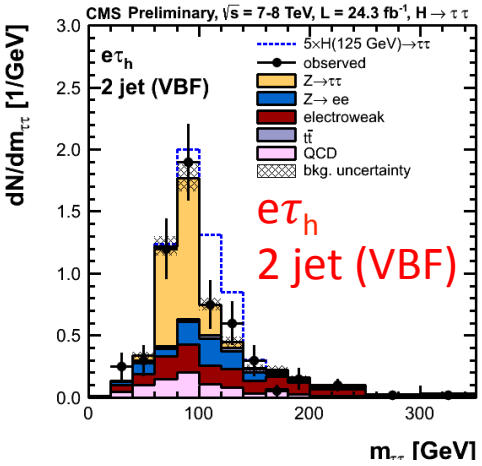
Background from QCD, Z($\tau\tau$)+jets, W+jets.

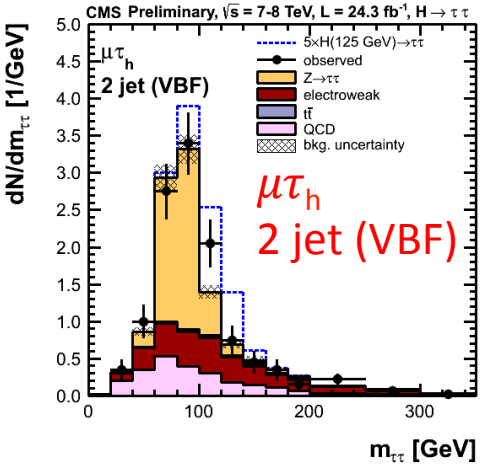
Categories: 0/1 jet (background), 2 jets (VBF).

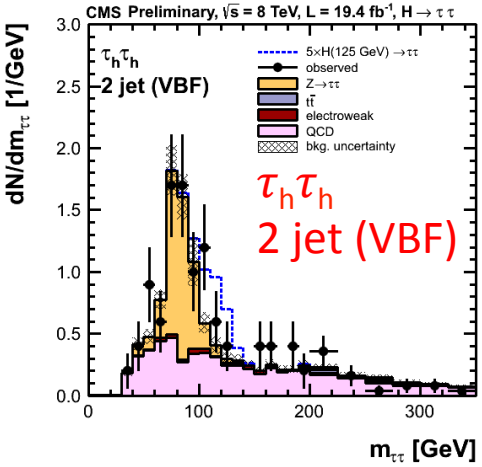
$m_{\tau\tau}$ from template fit.



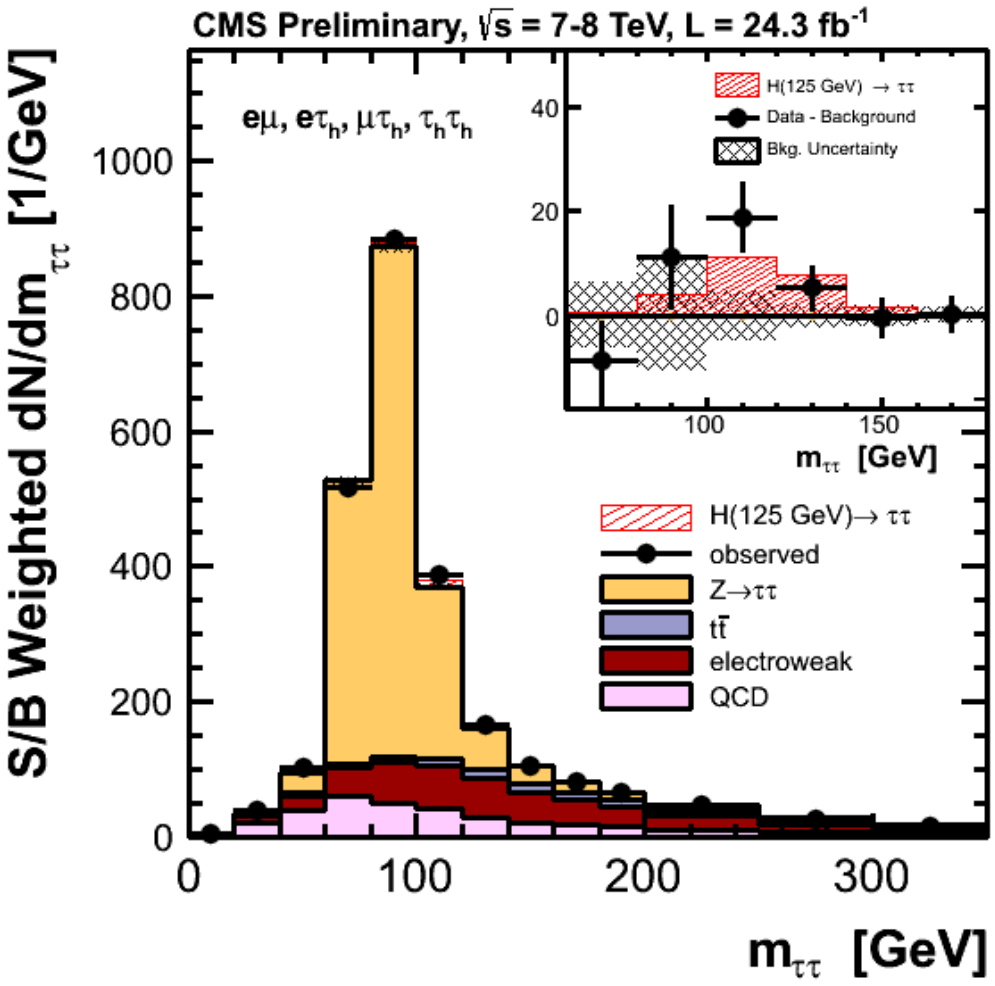
$m_{\tau\tau}$ distributions







Channels combined weighted with S/B.

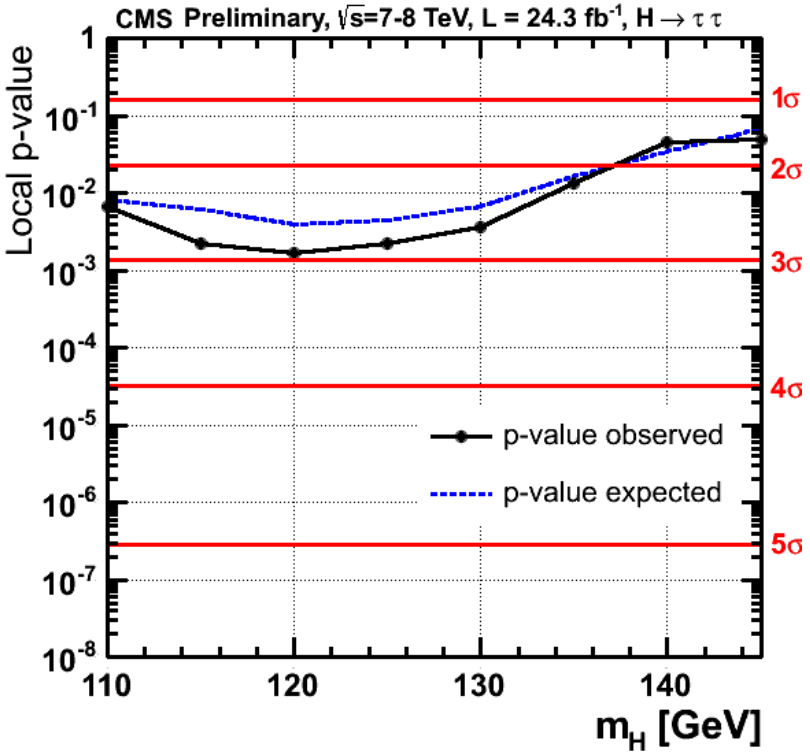


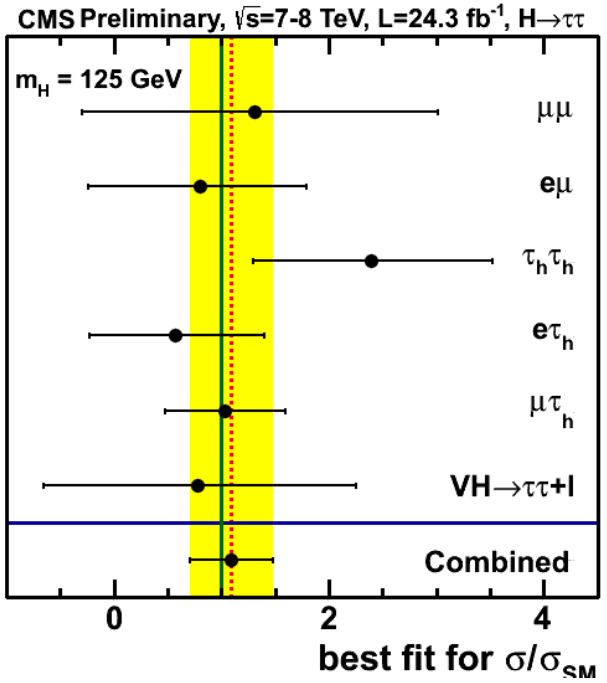
Broad low mass excess compatible with a 125 GeV Higgs signal.

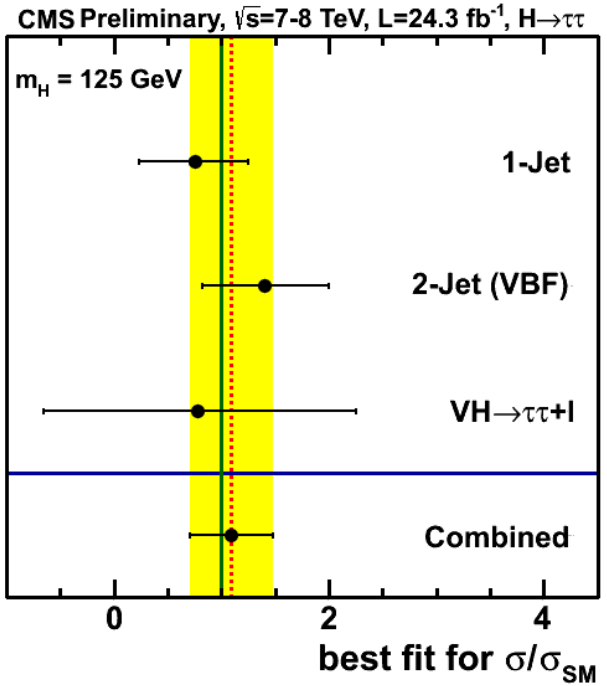
Significance (σ) for m_H = 125 GeV:

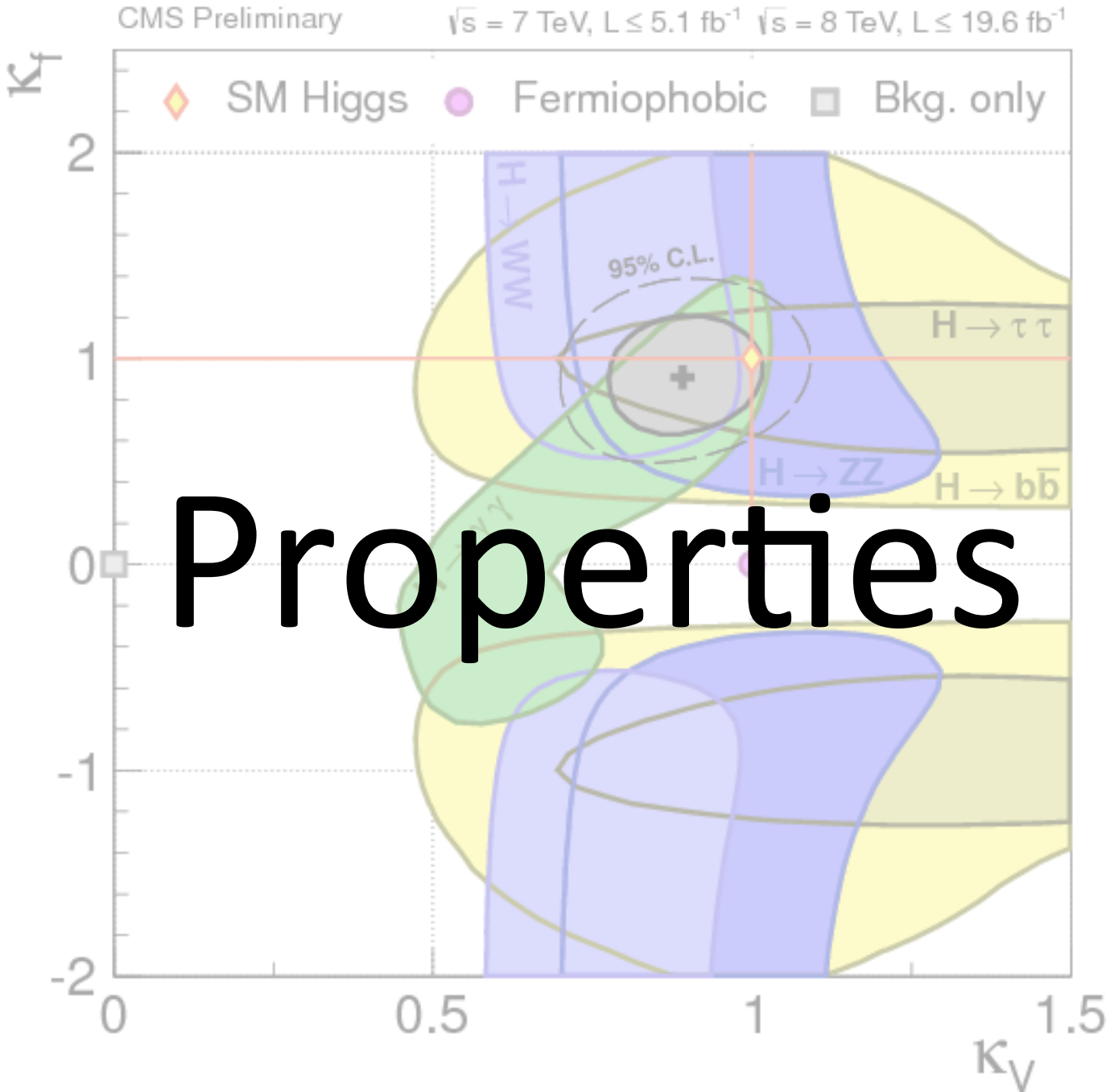
observed 2.9, expected 2.6

σ/σ_{SM} = 1.1 ± 0.4





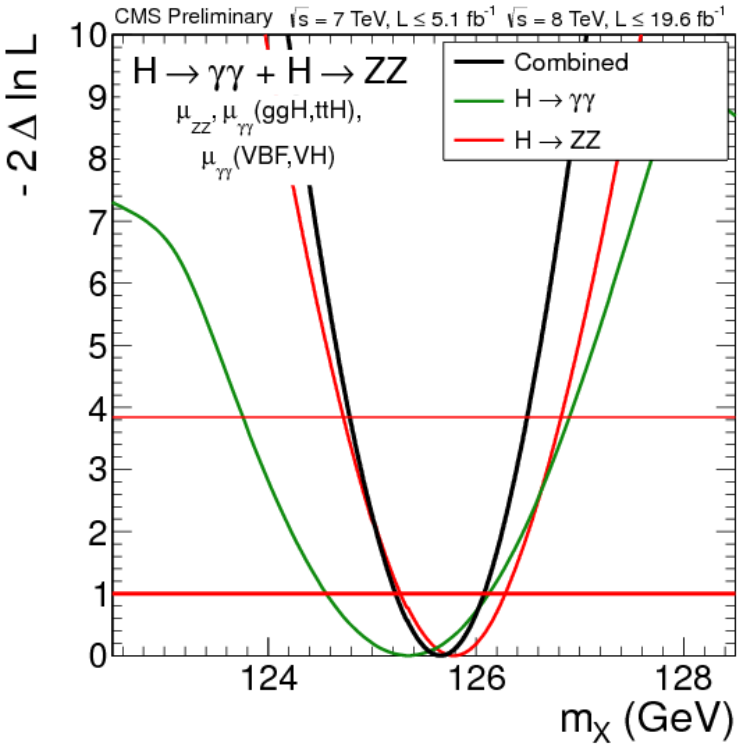


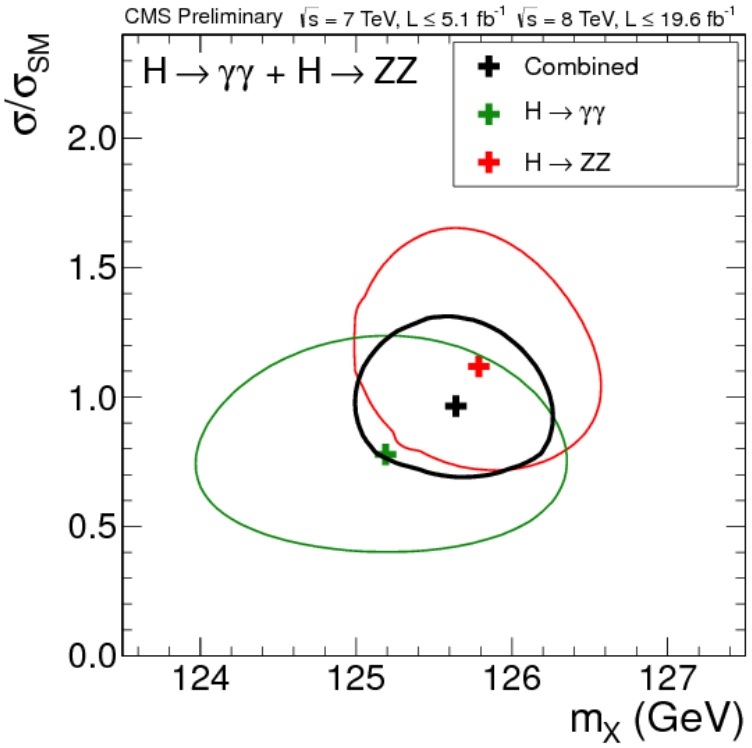

CMS Preliminary
√s = 7 TeV, L ≤ 5.1 fb-1 √s = 8 TeV, L ≤ 19.6 fb-1
SM Higgs
Fermiophobic
Bkg. only
95% C.L.
H → WW
H → ττ
H → ZZ
H → bb̄
H → γγ
κf
κV
2
1
0
-1
-2
0
0.5
1
1.5

Properties

Mass of the observed state

m_X = 125.7 ± 0.3 (*stat.*) ± 0.3 (*sys.*) GeV
= 125.7 ± 0.4 GeV





Couplings to fermions and bosons

$$(\sigma \cdot \mathrm{BR})\,(x \to \mathrm{H} \to ff) = \frac{\sigma_x \cdot \Gamma_{ff}}{\Gamma_{\mathrm{tot}}}$$

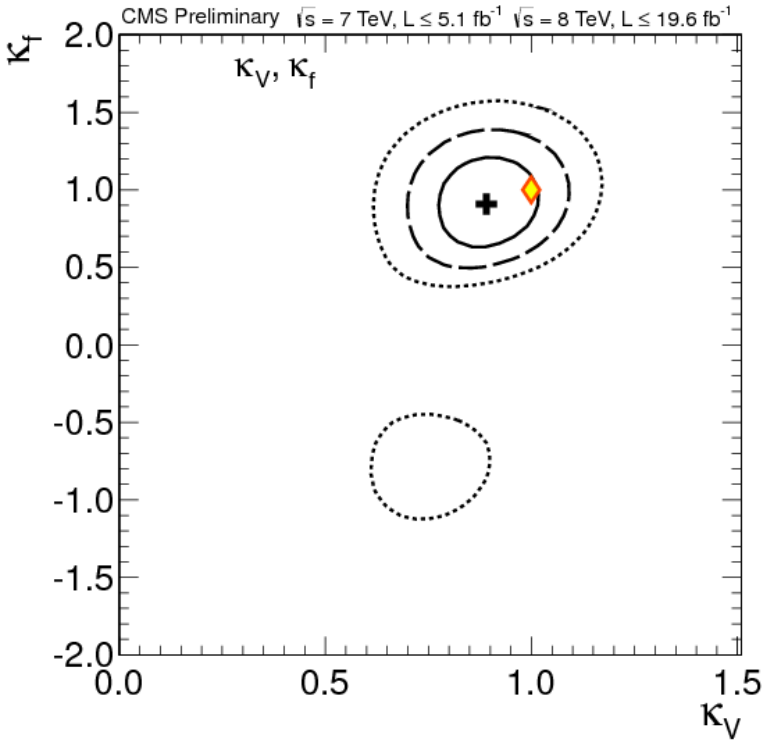
x is ggH, VBF, WH and ZH, and ttH

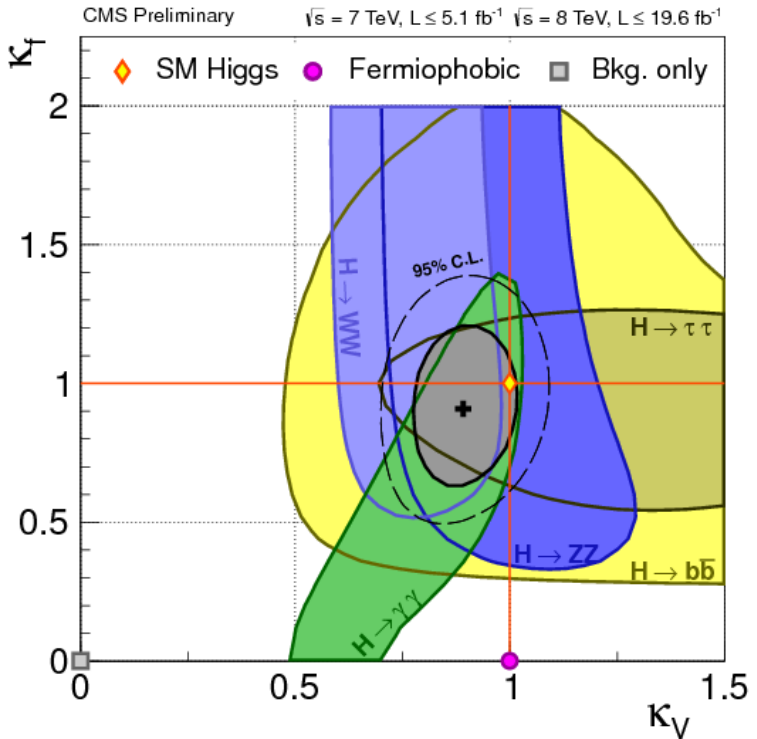
Γ_{ff} partial decay width, ff = W, Z, b, t, γ, Zγ;

Γ_{tot} total width of the H.

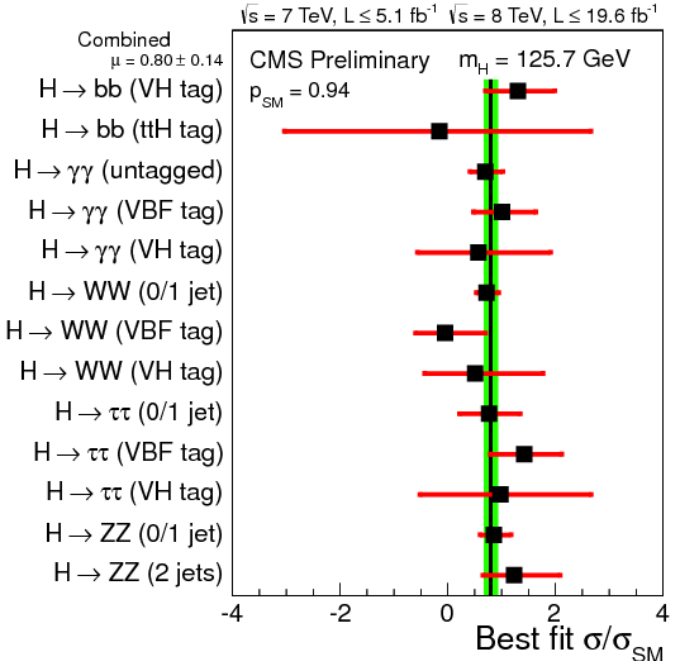
Γ_{ff} proportional to effective H couplings (g_i) → scale factors: $\kappa_i = g_i / g_i^{SM}$

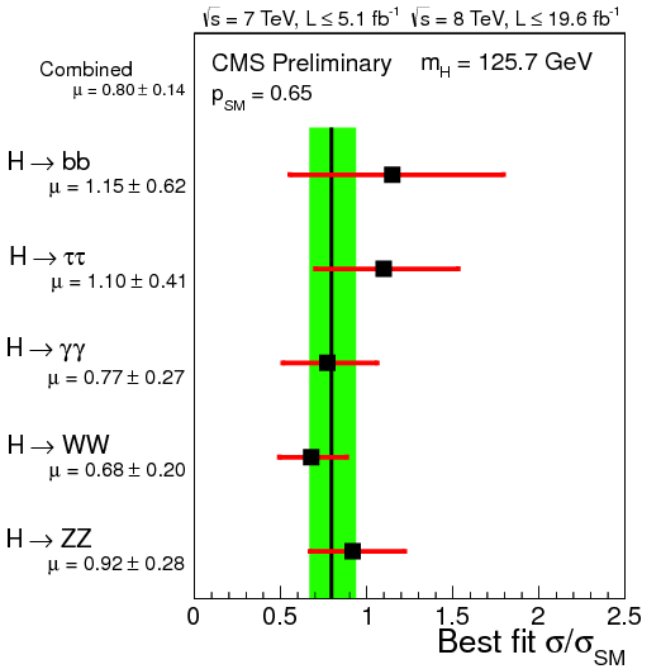
Mass fixed to the measured value, 125.7 GeV



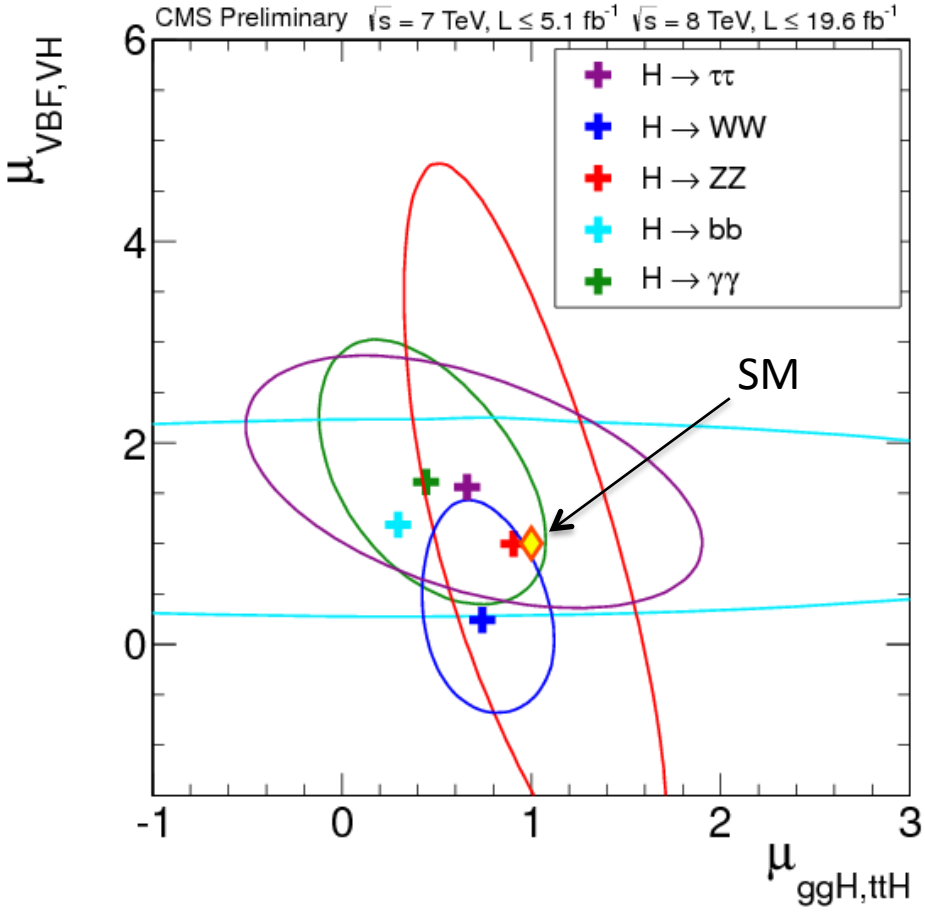


test production modes





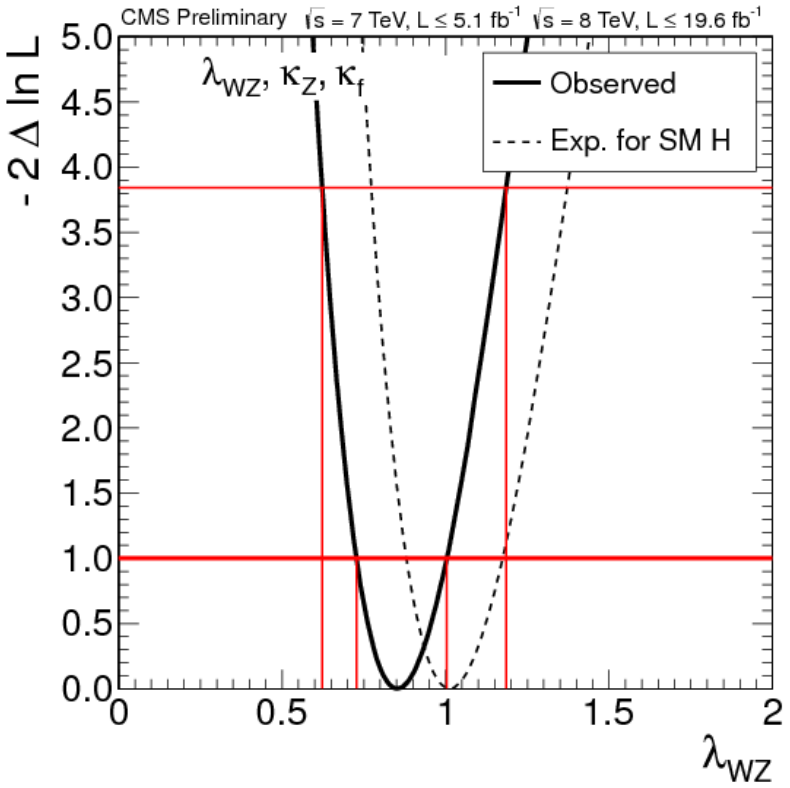
Best σ/σ_{SM} = 0.80 ± 0.14



Test of custodial symmetry

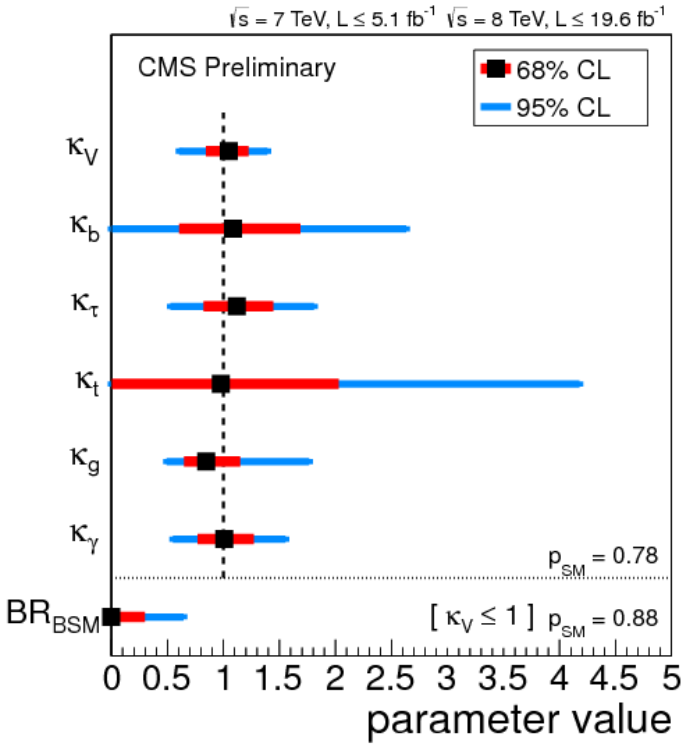
Modify the SM Higgs boson couplings to the W and Z bosons introducing two scaling factors k_W and k_Z and perform two combinations to assess that

$$\lambda_{WZ} = k_W / k_Z = 1$$

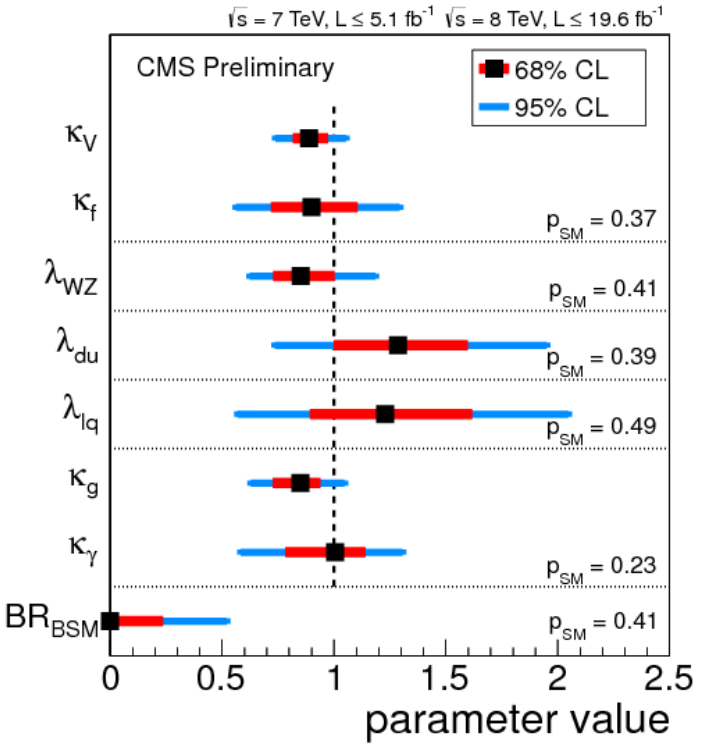


95% CL interval for λ_{WZ}: [0.62,1.19]

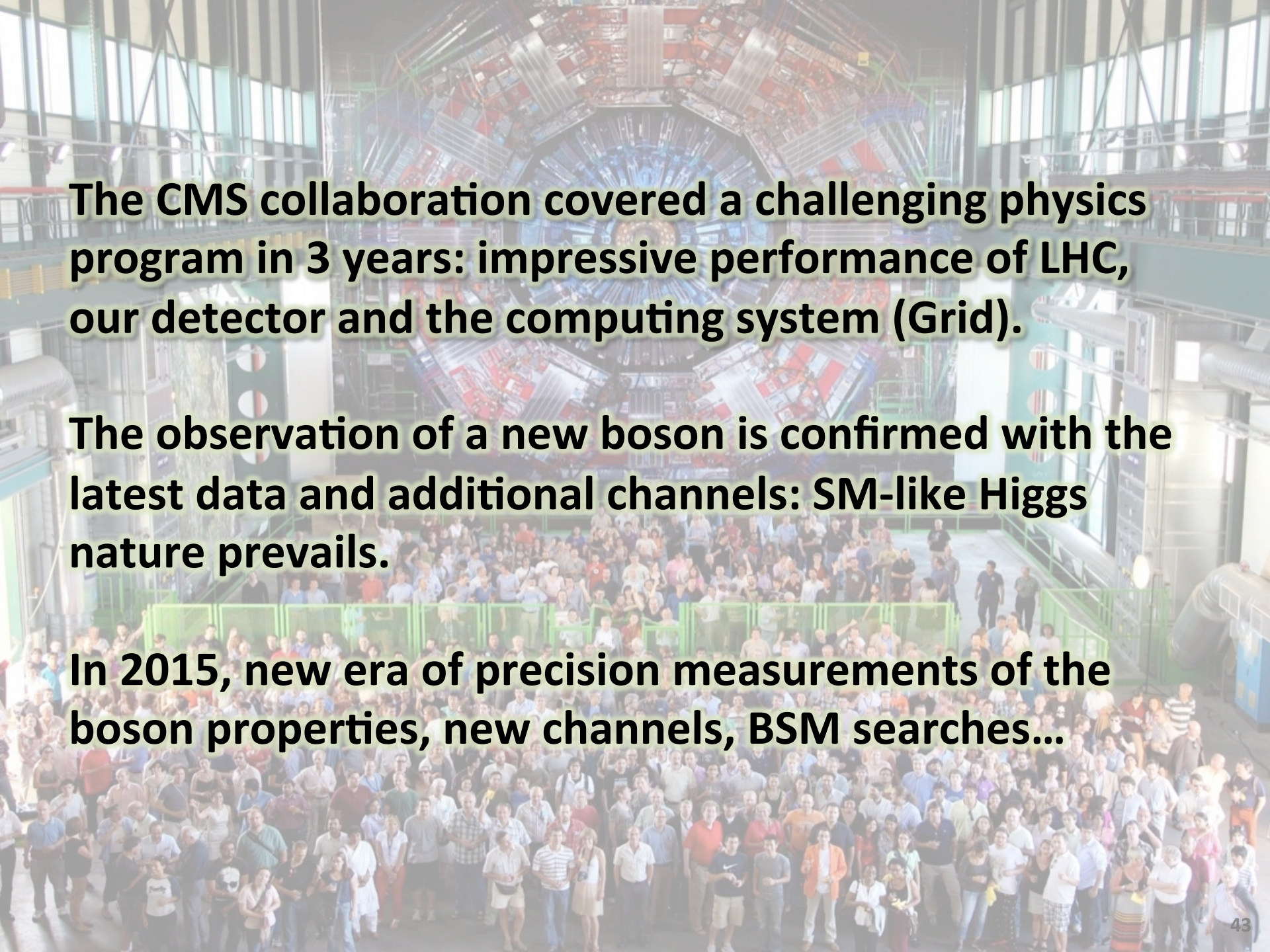
Summary of deviations in the couplings for various models



Generic six-parameter model



LHC XS WG benchmark models (arXiv:1209.0040)



The CMS collaboration covered a challenging physics program in 3 years: impressive performance of LHC, our detector and the computing system (Grid).

The observation of a new boson is confirmed with the latest data and additional channels: SM-like Higgs nature prevails.

In 2015, new era of precision measurements of the boson properties, new channels, BSM searches…


small fraction of the CMS collaboration