Higgs Boson search at CMS

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(for the CMS collaboration)

Plenary Talk :
International Conference on New Frontiers in Physics
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Outline

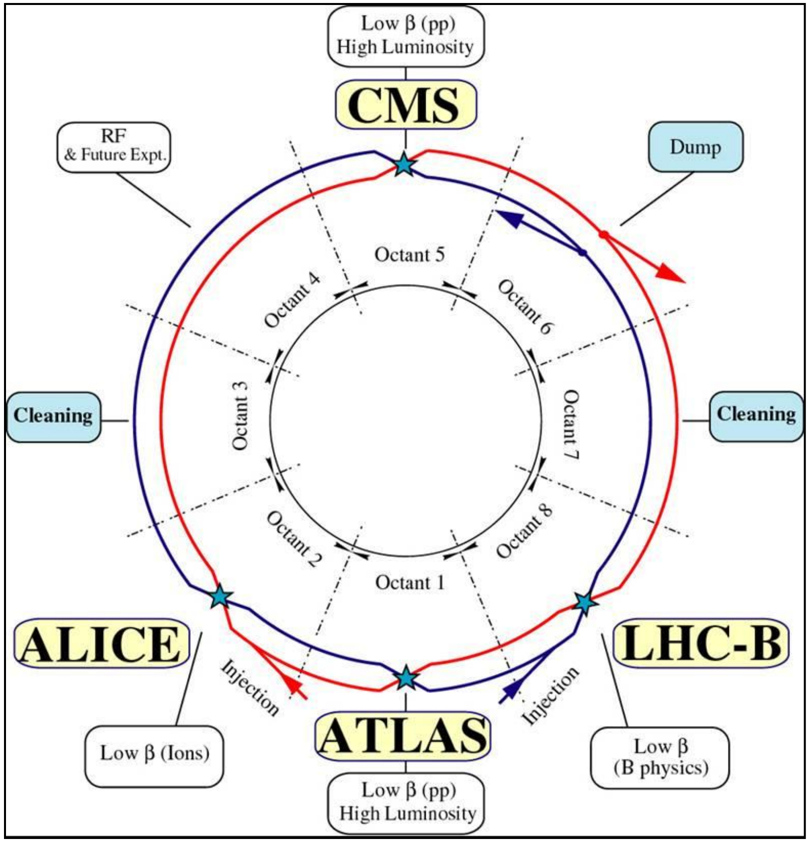
LHC & the CMS detector

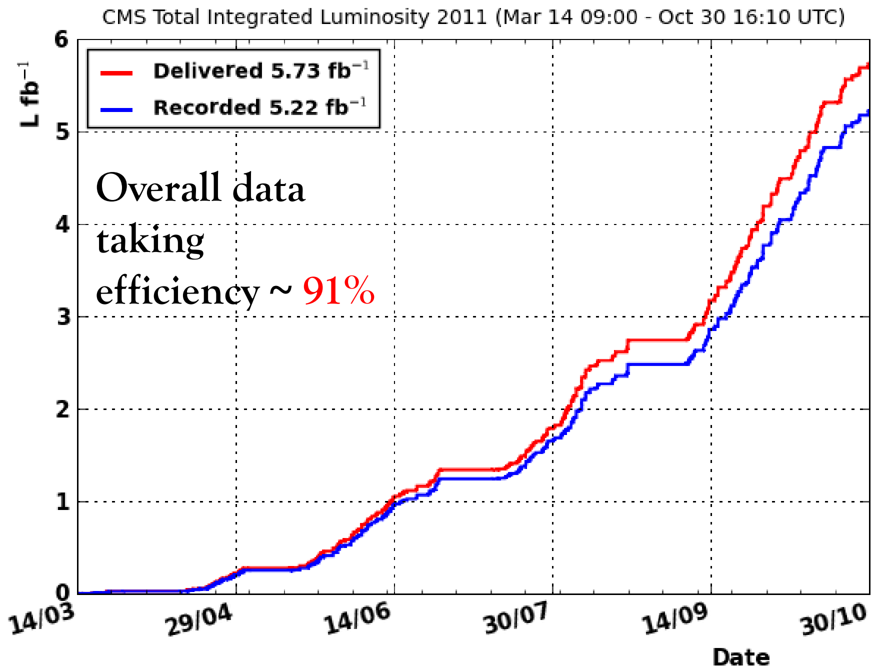
Physics Objects

SM Higgs Boson Search

Beyond SM Higgs Search

Summary & Outlook





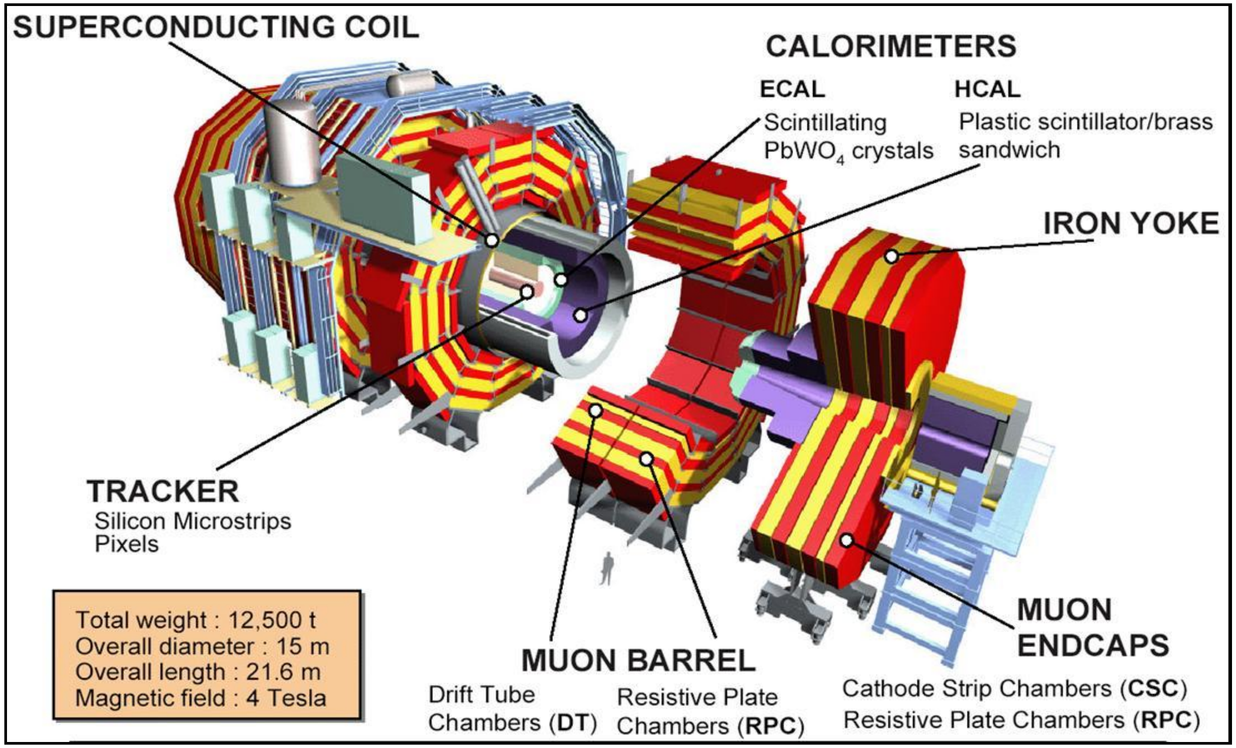
LHC 7 TeV pp run for 2011 reached successful conclusion on 30 October 2011

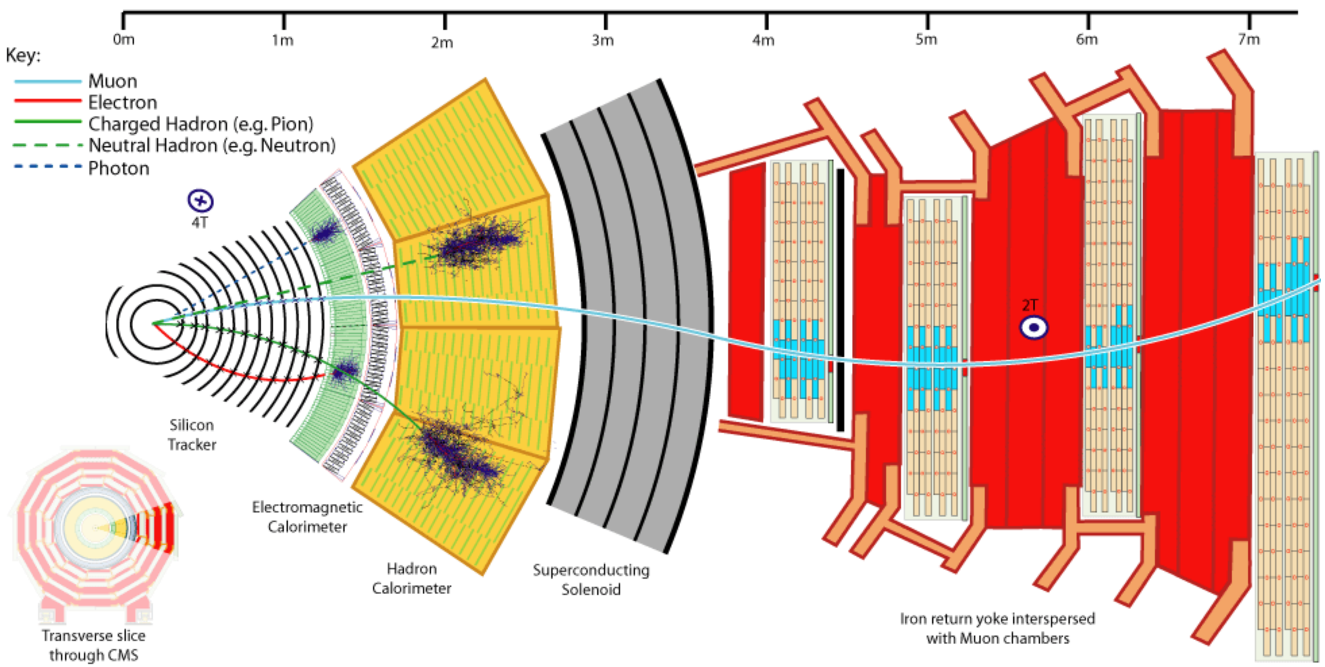
Delivering over 5 fb^{-1} integrated lumi
Max instantaneous lumi 3.54 x $10^{-33}cm^{-2}s^{-1}$

Machine performance better than expected

3.8 T superconducting solenoid envelop:

- Inner Tracker (silicon pixel and strip detectors) $|\eta| < 2.5$
- ECAL ($PbWO_4$ crystals)
  Barrel $|\eta| < 1.48$
  Endcap $1.48 < |\eta| < 3.0$
- HCAL (brass/scintillator samplers)
- Muon Chambers – gas ionization detectors embedded in steel return yoke outside the solenoid, $|\eta| < 2.4$
  Drift Tubes, Cathode Strips and Resistive Plate Chambers





Particle – Flow technique at CMS

Basic physics objects :

Muon: Matching tracks in inner tracker and muon chambers

Electron: EM cluster with an associated track

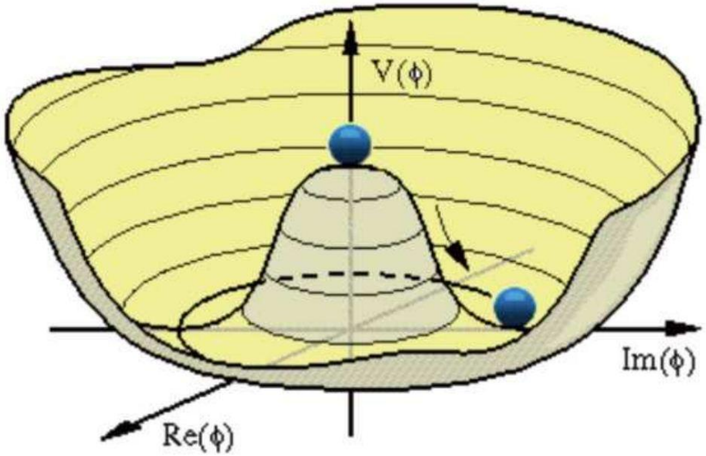
Photon: EM cluster without a matching track

Jet: Cluster in EM and hadronic calorimeters (and inner tracker)

Tau lepton : Narrow jet with matching track(s)

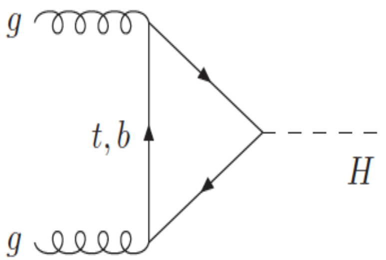
MET: p_T required to balance all of these

Part 1: SM Higgs Boson

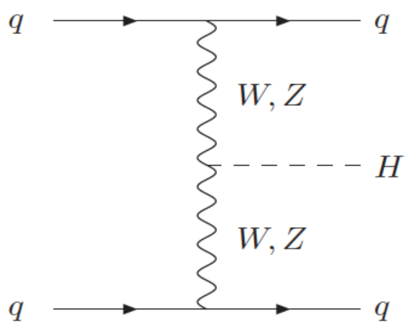


SM Higgs: Production and Decay

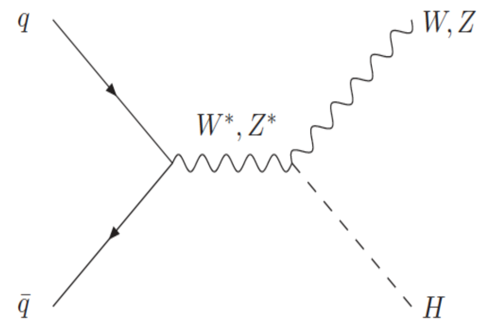
gluon-fusion



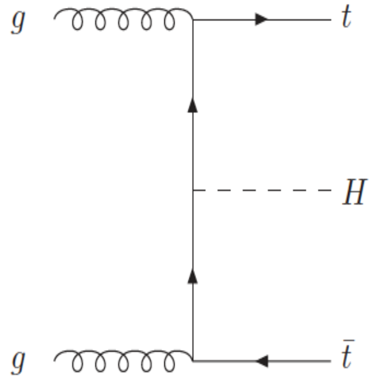
VBF



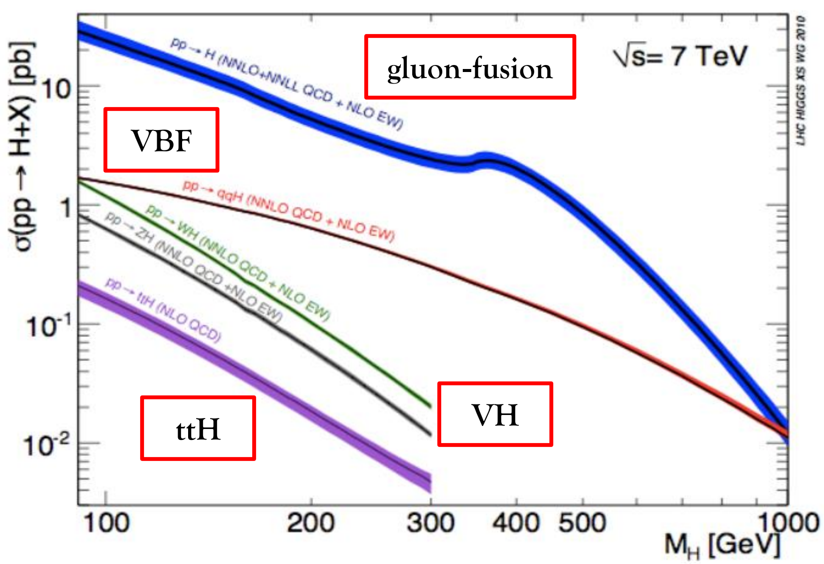
VH



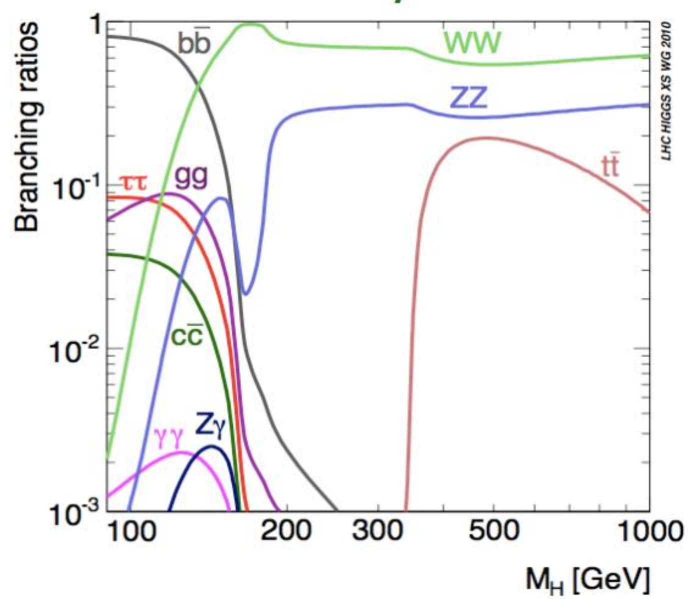
ttH



Production



Decay



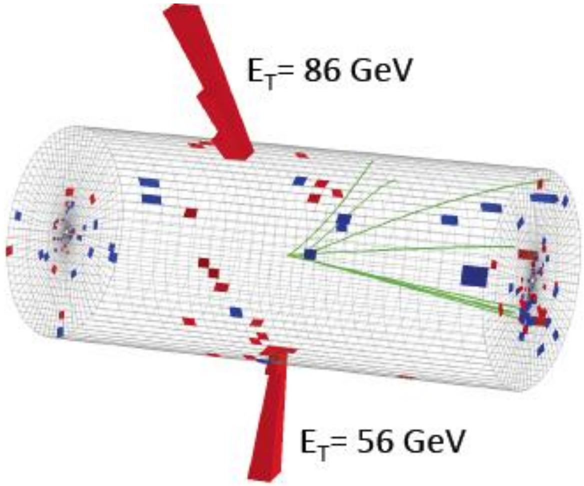
CMS search channels

- 11 independent channels cover the mass range between 110 - 600 GeV
- gluon fusion, vector boson fusion and associated production mechanisms exploited

Low Mass

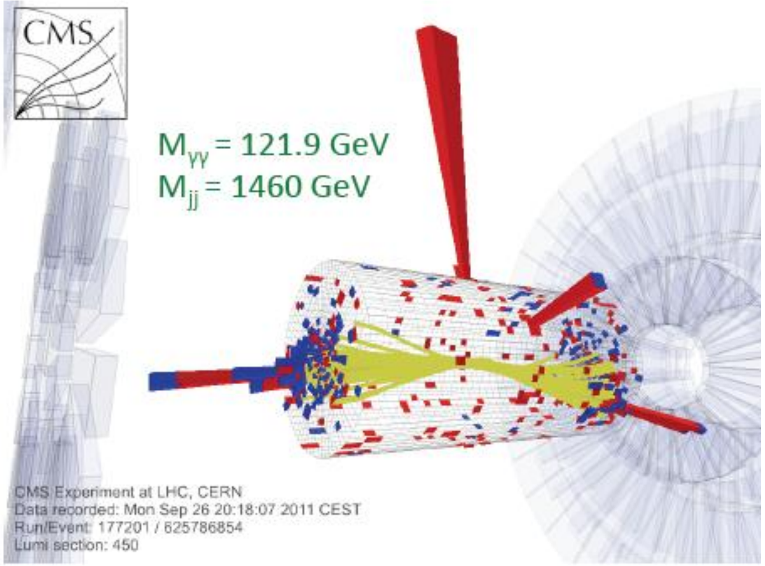
channel	mass range (GeV)
$H \rightarrow \gamma\gamma$	110 - 150
$H \rightarrow \tau\tau \rightarrow e\tau_h/\mu\tau_h/e\mu + X$	110 - 145
$H \rightarrow \tau\tau \rightarrow \mu\mu + X$	110 - 140
$WH \rightarrow e\mu\tau_h/\mu\mu\tau_h + \nu$	110 - 140
$(W/Z)H \rightarrow bb$	110 - 135
$H \rightarrow WW \rightarrow \ell\nu\ell\nu$	110 - 600
$WH \rightarrow W(WW^*) \rightarrow 3\ell3\nu$	110 - 200
$H \rightarrow ZZ \rightarrow 4\ell$	110 - 600
$H \rightarrow ZZ \rightarrow 2\ell2q$	(130 - 164) + (200 - 600)
$H \rightarrow ZZ \rightarrow 2\ell2\tau$	190 - 600
$H \rightarrow ZZ \rightarrow 2\ell2\nu$	250 - 600

High mass



Event sample classified into: Inclusive and VBF: γγ with 2 forward jets
Cut-based analysis and Multivariate (MVA) analysis (recent!)
MVA Inclusive Category => sub-divided on BDT output values

Signature: Narrow γγ mass peak
very good mass resolution 1 - 2%
Two isolated high E_T photons over large smoothly decreasing background
Small Branching Ratio: ~ 2×10^{-3}
Irreducible: 2 photon QCD production
Reducible: γ + jet with one fake γ
DY with electrons faking photons



Multivariate analysis techniques improve
$H \rightarrow \gamma\gamma$ search sensitivity
provides more optimal event classification

subdivided according to output value of a di-photon BDT

=► signal-like kinematic characteristics with a high score

=► good $\gamma\gamma$ mass resolution events with a high score

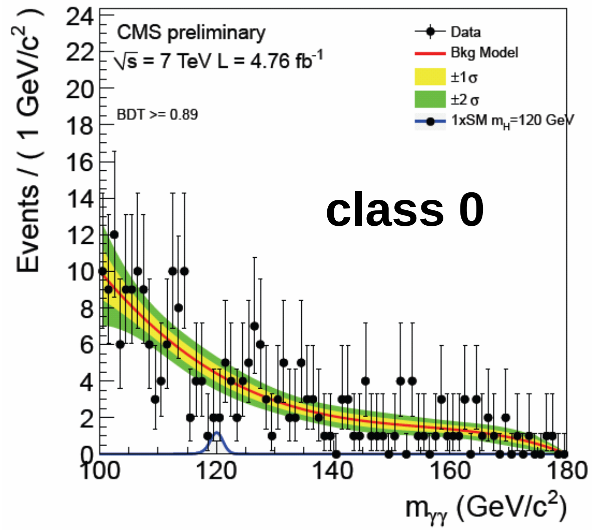
=► high score from γ identification BDT with a high score

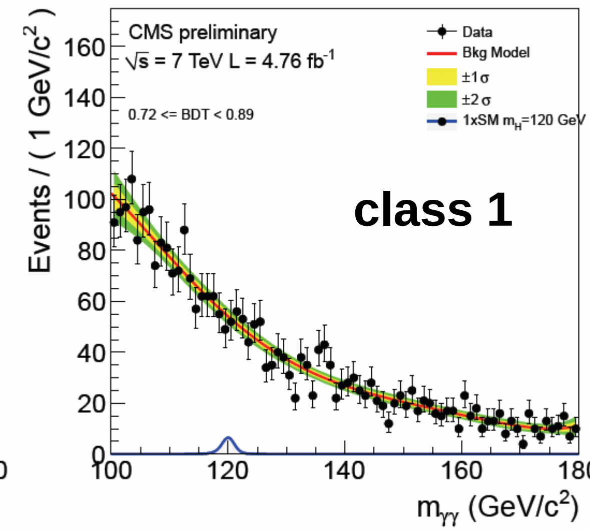
=► it should be $\gamma\gamma$ mass independent

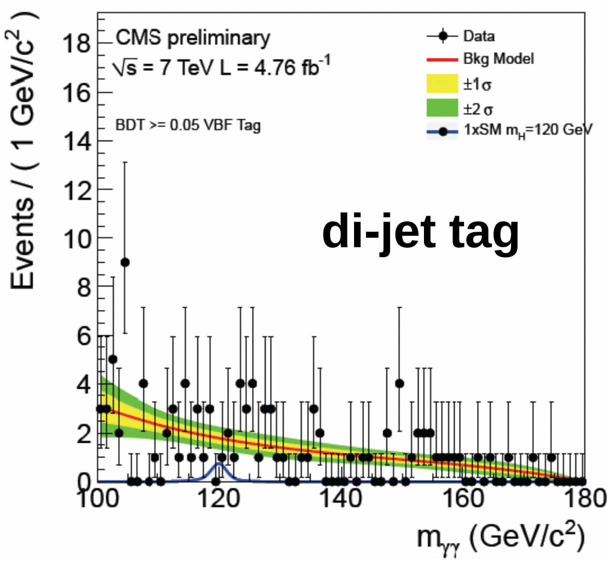
- Di-photon MVA trained to distinguish $H \rightarrow \gamma\gamma$ events from background and to identify good resolution signal events
- Uses BDT method on MC background and Higgs boson signal events
- Training variables include photon ID, kinematics, right vertex probability and estimate mass resolution
- good resolution as desired feature weighting signal events by 1/estimate mass resolution
- MVA output used to make 5 categories with different S/B
  Inclusive & Separate di-jet tagged category to select VBF Higgs production
- MVA combines event level information into a classification variable categorizing in S/B and mass resolution

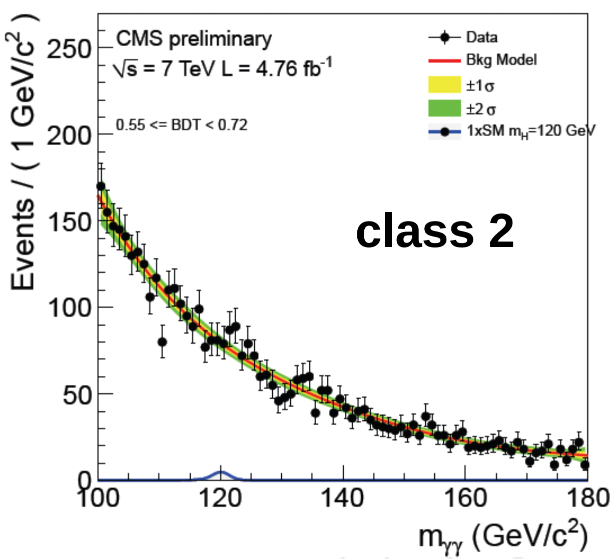
H → γγ

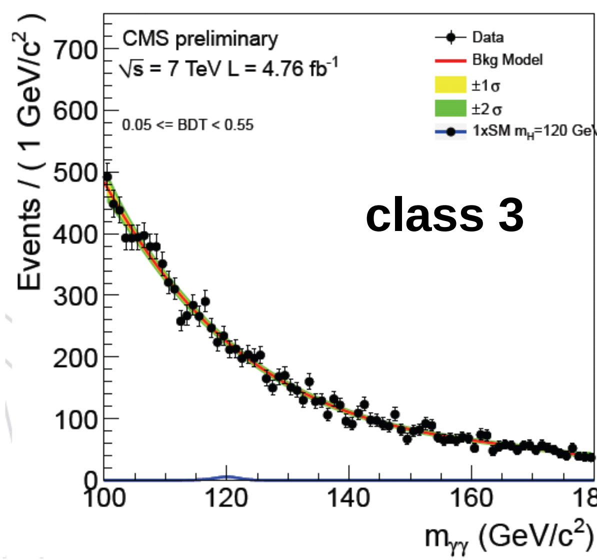
- Higgs mass modeled using MC with energy scale and resolution correction from Z → ee
- Background mass spectrum modeled by polynomial fit
- Polynomial order between 3 and 5 depend on event category statistics



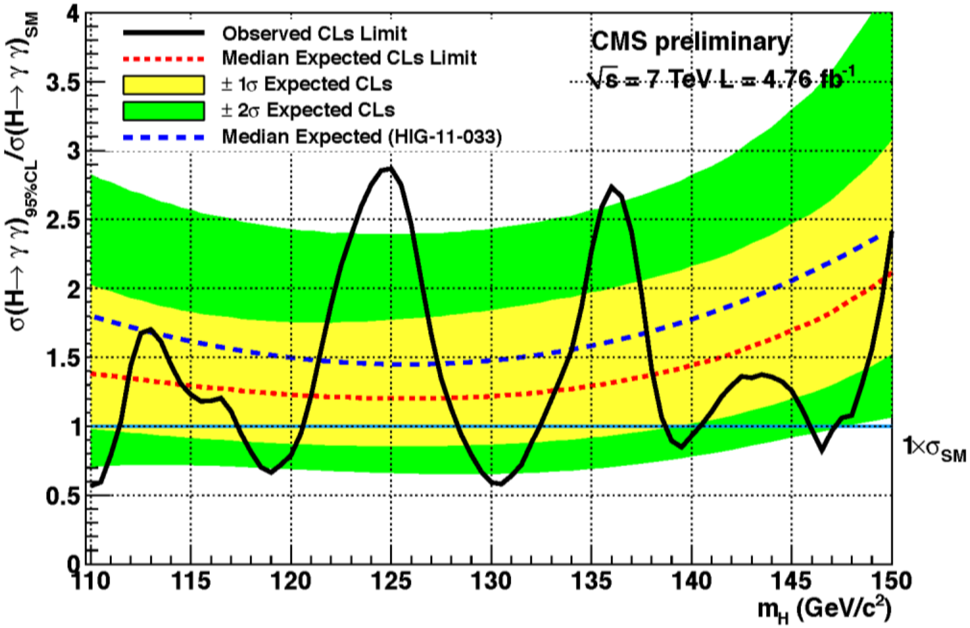


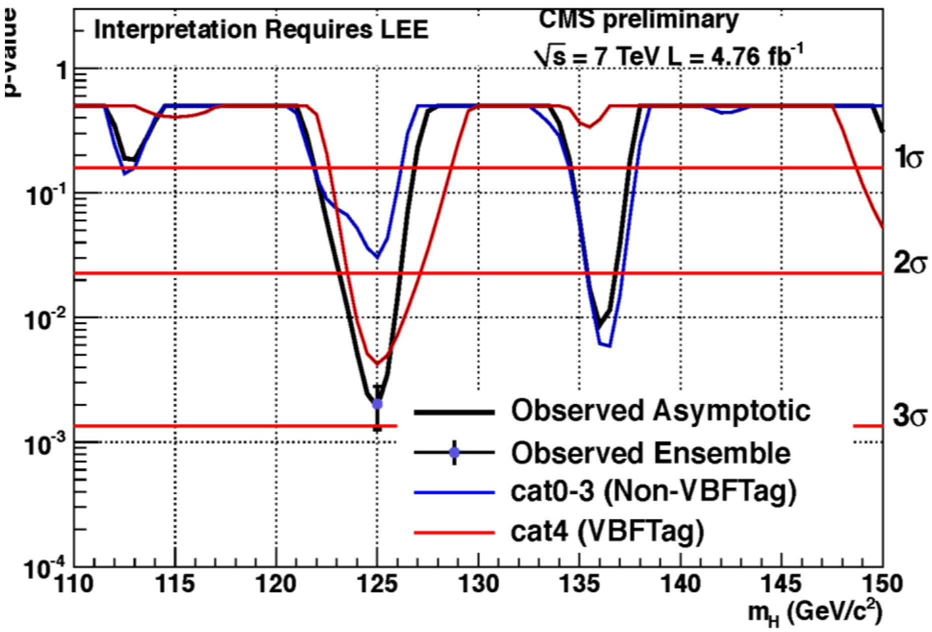






$H \rightarrow \gamma\gamma$





Expected 95% CL exclusion limit:
1.2 – 2 x SM cross section

High resolution channel sensitive to fluctuations of the background, accounted for by the "look elsewhere effect" (LEE)

Probability for same excess everywhere in the considered mass range

p — value : probability that a background only fluctuation is at least as large as the observation

⇒ Largest excess observed at 125 GeV with 2.9 σ local significance

Excess at 125 GeV for both Inclusive and VBF

⇒ Global significance 1.6 σ [110 - 150] GeV

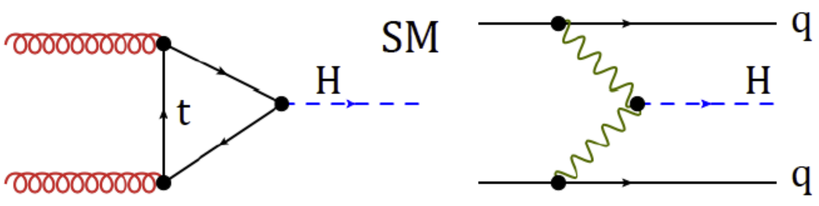
3 different channels with 3 states $e\tau$, $\mu\tau$ and $e\mu$

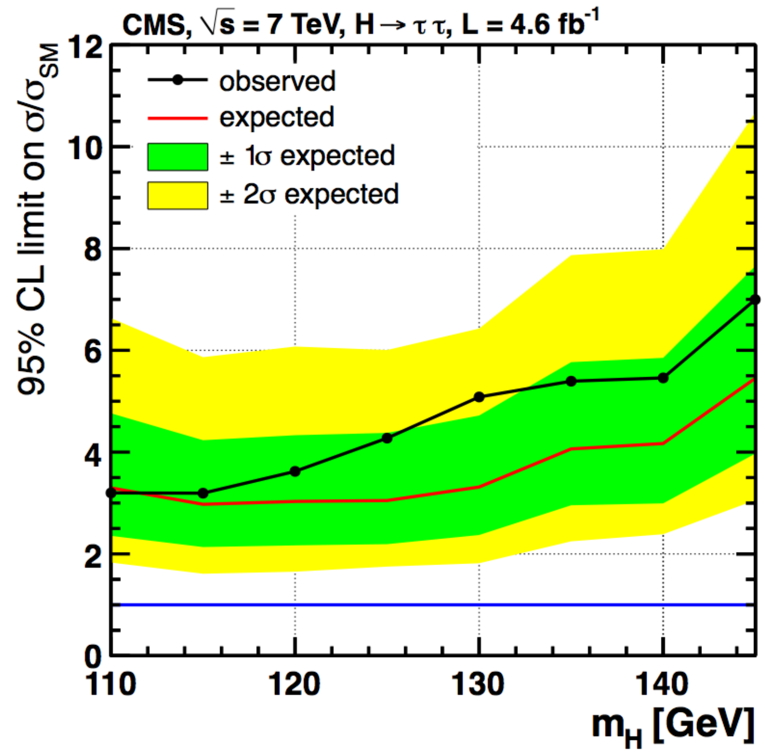
- gluon-gluon fusion with at most 1 jet
- VBF: two additional forward jets

2 jets with large rapidity gap - better sensitivity due to the greatly reduced background from $Z \rightarrow \tau\tau$

- Boosted Higgs: one jet with $p_T > 150$ GeV

reduces background $Z \rightarrow \tau\tau$ and improves resolution of tau-pair invariant mass



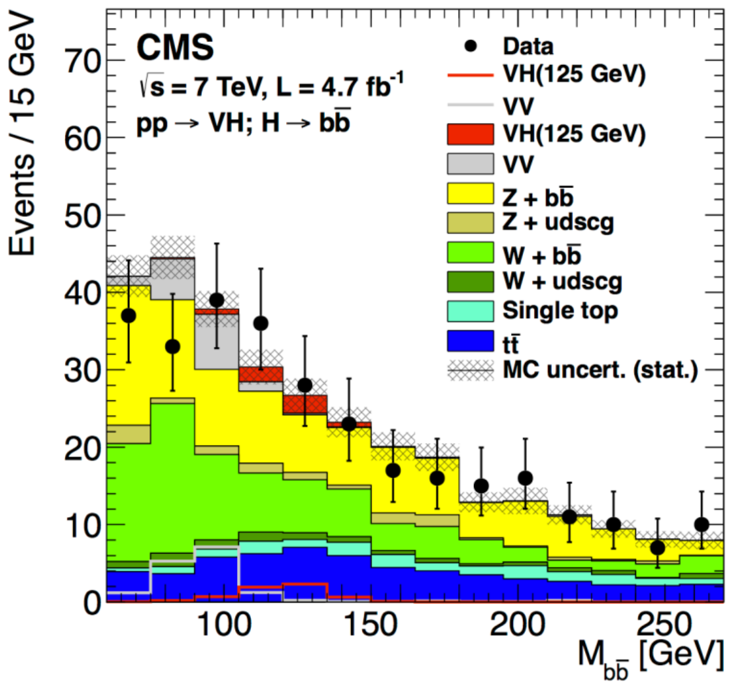


- $\tau\tau$ mass reconstructed using kinematic fit of visible products and MET with likelihood constraints on decay kinematics
- $Z \rightarrow \tau\tau$ background from $Z \rightarrow \mu\mu$ in data with μ replaced by simulated τ
- W + jets and multi-jet background from large transverse mass and same-sign control regions, respectively

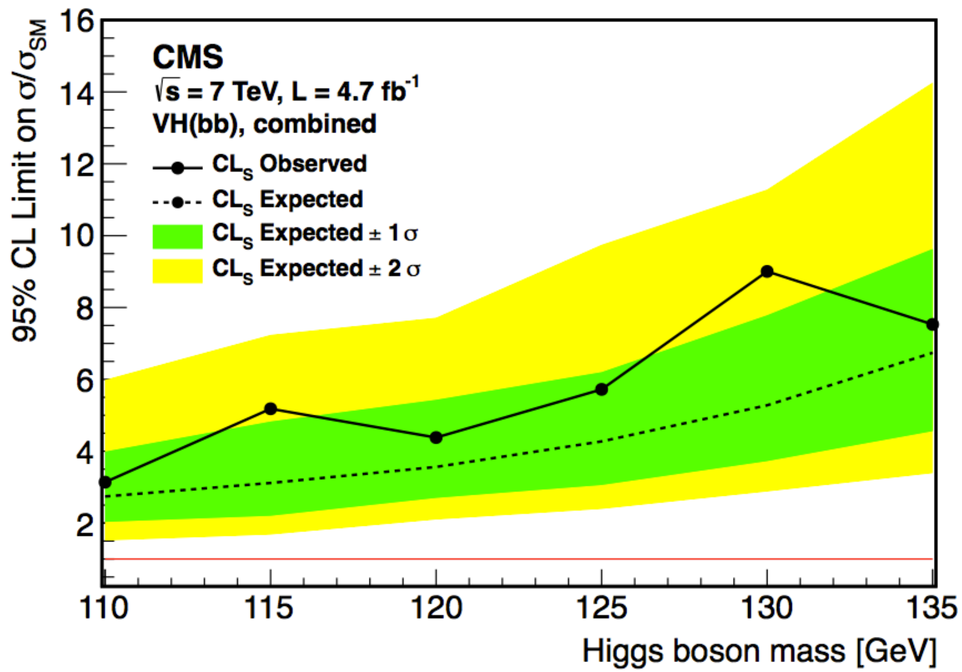
Mass resolution ~ 20%

- high branching ratios but huge QCD backgrounds
- select W /Z + H, V → (ℓν) (ℓℓ) (νν) events with significant W/Z boost
- Require two central b-tagged jets (p_T threshold dependent on final state)

- Cut and Count analysis on BDT output (dijet and W/Z kinematics)
- Background yields scaled to data in control regions from inverted b-tagging (W/Z + light flavour), tighter b-tagging plus extra jets (tt), low $p_T^{W/Z}$ (W/Z + bb)



Mass resolution for bb channel ~ 10%

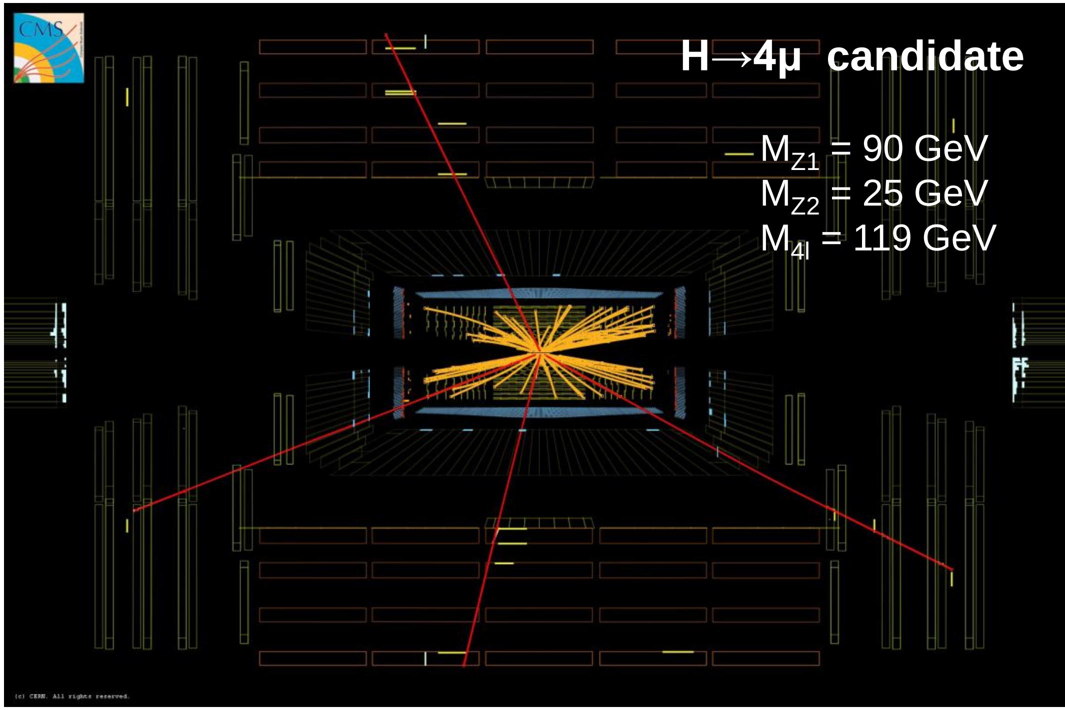


exclusion at 95% CL for 3-9 σ_{SM}

Excellent mass resolution
and small background, S/B>1

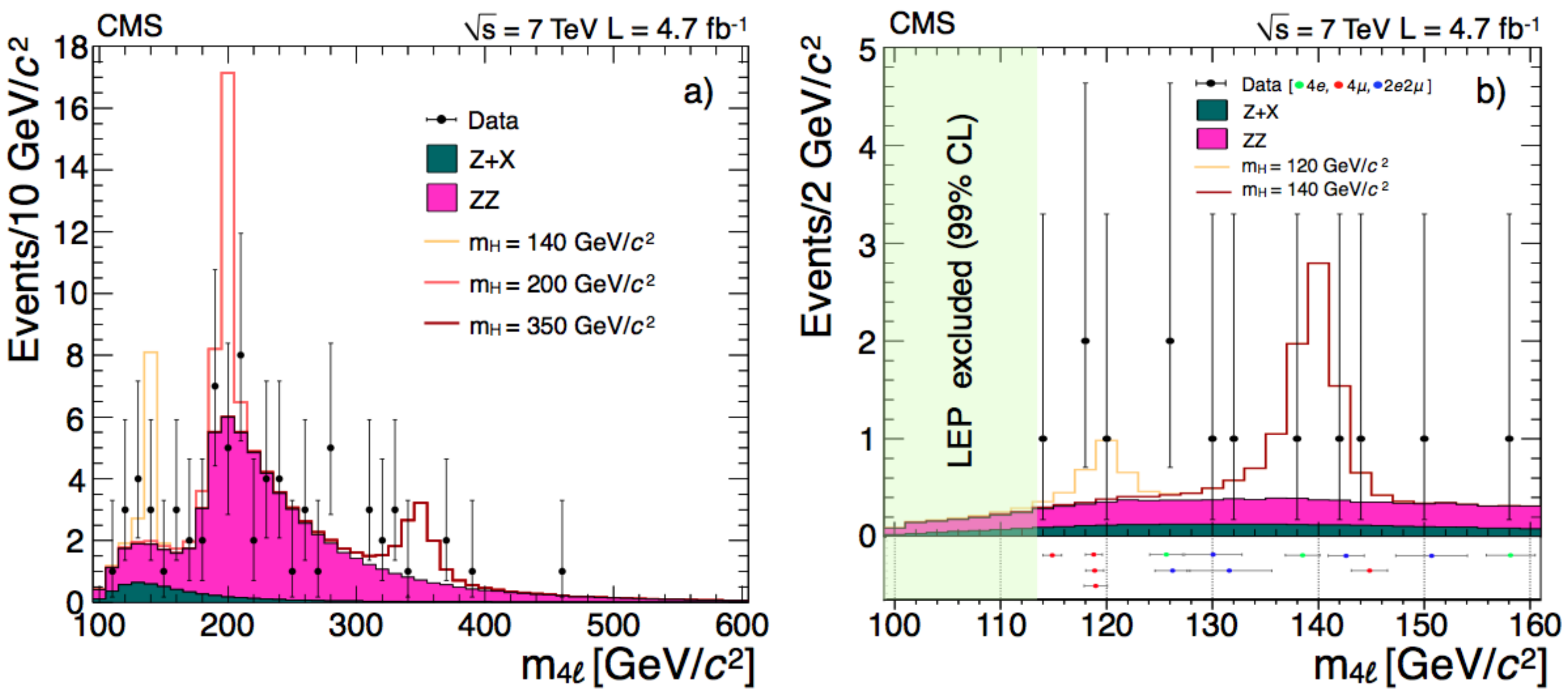
Select 2 lepton pairs with opposite charge and same flavour,
$50 < m_{Z1} < 120$ GeV,
$12 < m_{Z2} < 120$ GeV

Electron acceptance :
$|\eta| < 2.5$, $p_T > 7$ GeV
Muon acceptance :
$|\eta| < 2.1$, $p_T > 5$ GeV

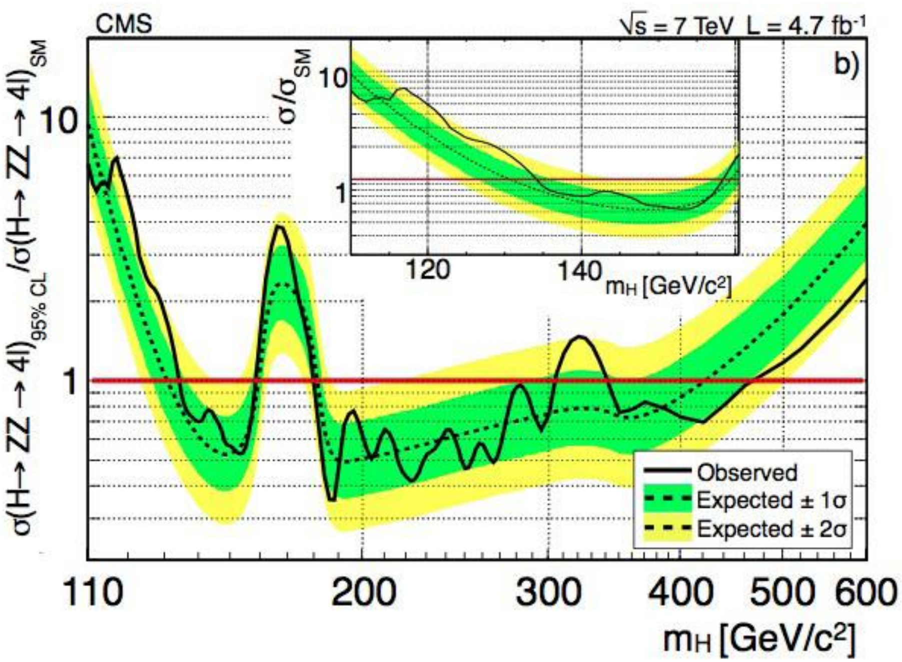


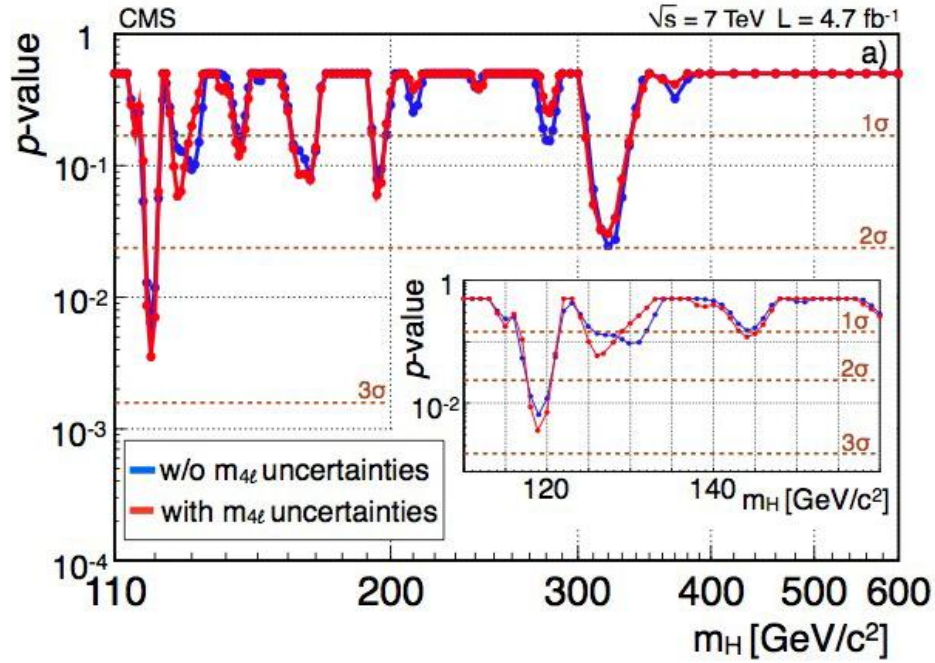
Irreducible ZZ→4l continuum background estimated from MC normalized to Z + jets on data

Irreducible Z + bb and tt backgrounds estimated from Z + same-sign dilepton sample, with fakes rate from Z + loose lepton sample



Expected background 67±6 events, observed 72 events over the full mass range, 9.5±1.3 expected and 13 observed in [100 - 160] GeV





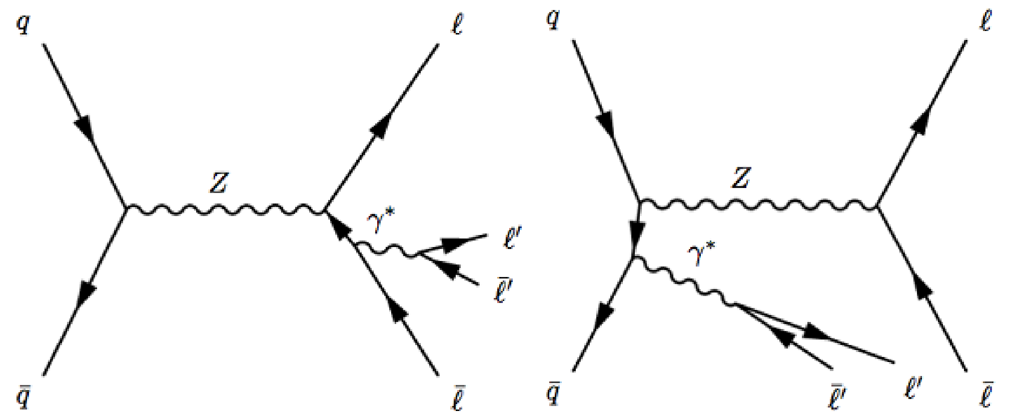
Largest excess observed 119.5 GeV : Global significance 1.6 **σ** (2.5 **σ** local)

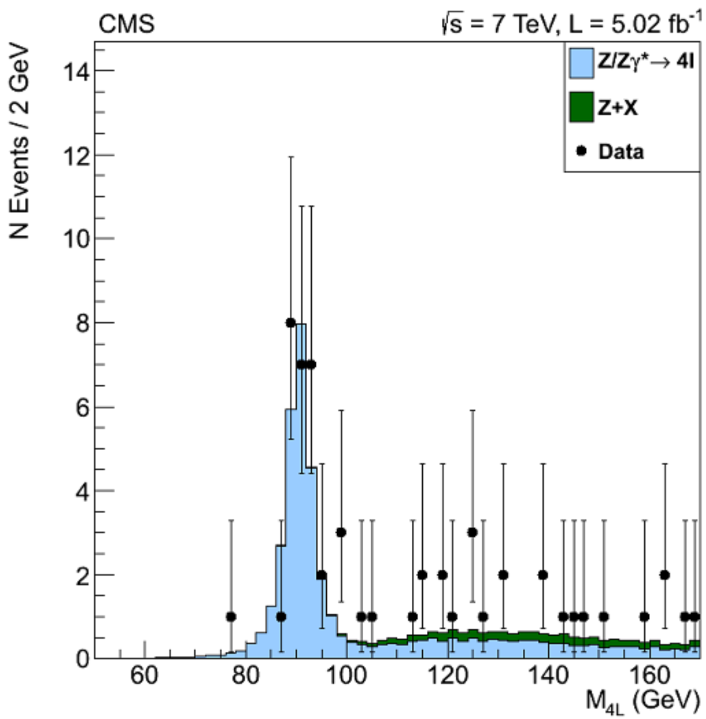
320 GeV : Global significance 1.0 **σ** (2.0 **σ** local)

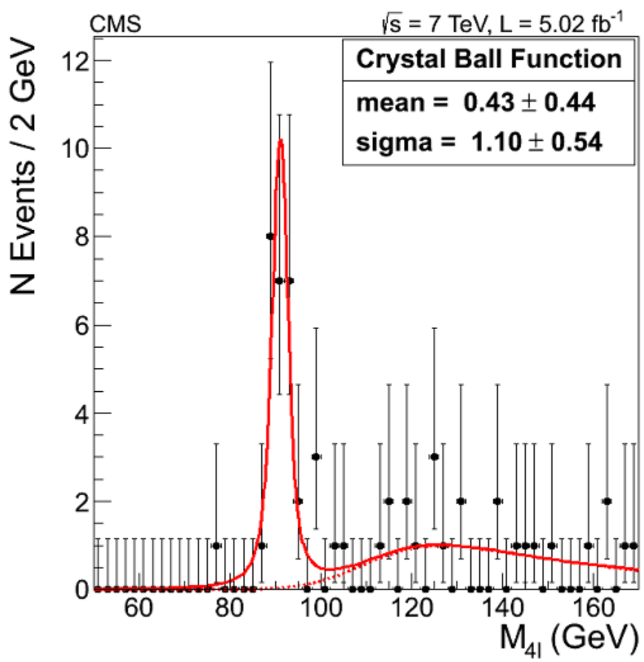
Exclusion limit at 95% CL for M_H [134 - 158] , [180 - 305] and [340 - 465] GeV

$H \to ZZ \to 4l$

$Z \to 4l$ decays as a standard candle in the $H \to ZZ \to 4l$ search mode





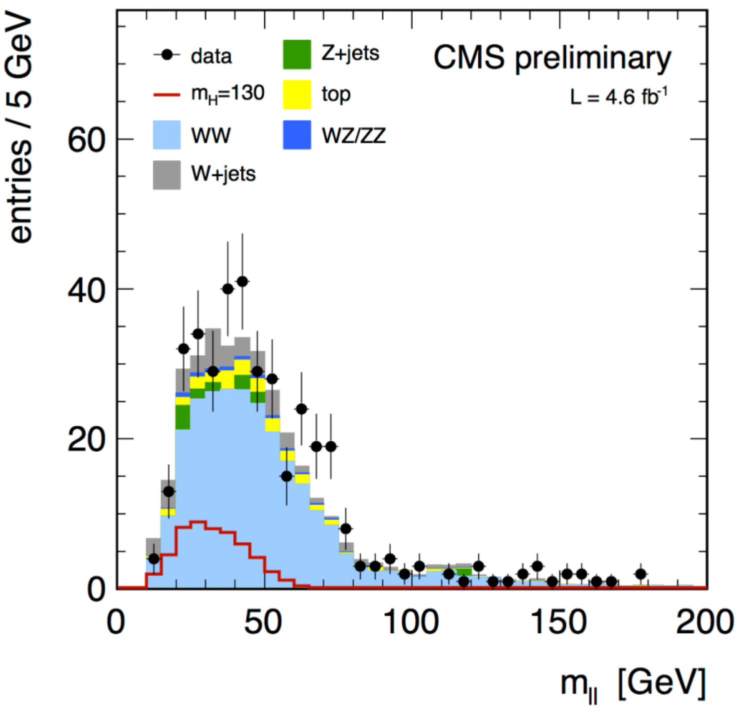


$Z \to 4l$ decay clean resonant peak in 4 lepton invariant mass distribution

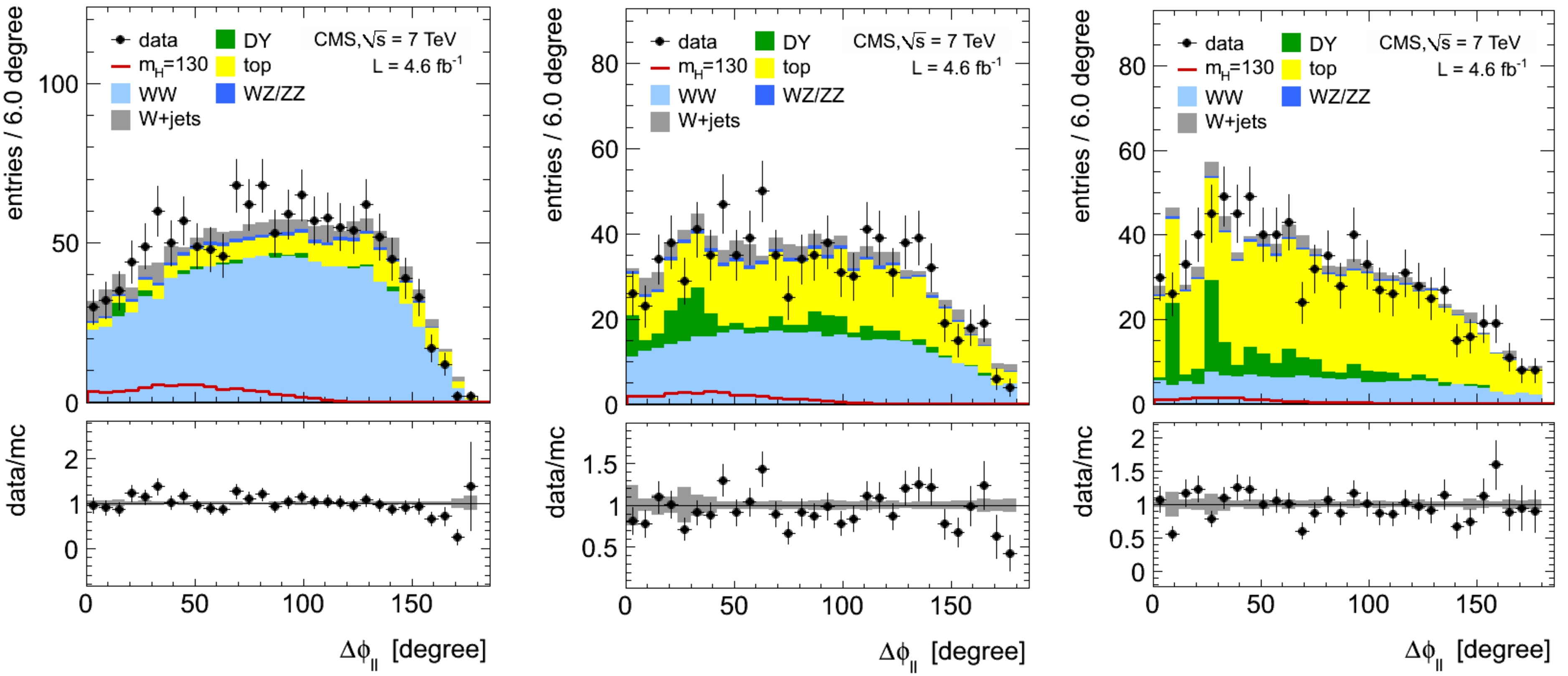
statistical significance 9.7 σ

obs. 28 events
exp. 29.4 events
in 80 - 100 GeV mass window

- Two opposite charge isolated leptons with 20/10 (15) GeV p_T threshold for opposite-flavour (same flavour) events + MET (not compatible with a Z decay)
- Exclusive jet multiplicities (0, 1, VBF bins) and flavour (ee, **μμ**, e**μ)**
- Main backgrounds: WW (irreducible), tt, Z+jets, W+jets, WZ, ZZ
- BDT-based shape analysis in 0,1 jet bins, cut and count in VBF
- BDT Input variables: p_T of leptons, $M_{\ell\ell}$, $\Delta\varphi_{\ell\ell}$, $\Delta R_{\ell\ell}$, M_T (for di-lepton system and each lepton)



di-lepton invariant mass in the 0-jet bin at Higgs selection level

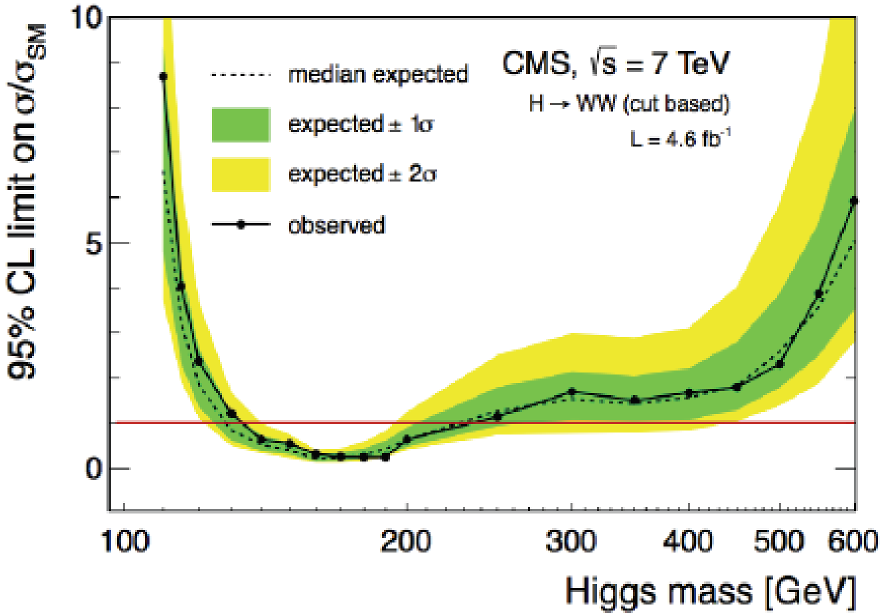


$\Delta\varphi_{ll}$ in the 0-jet / 1-jet / 2-jet bin at the Higgs selection level – dominance of different background contributions

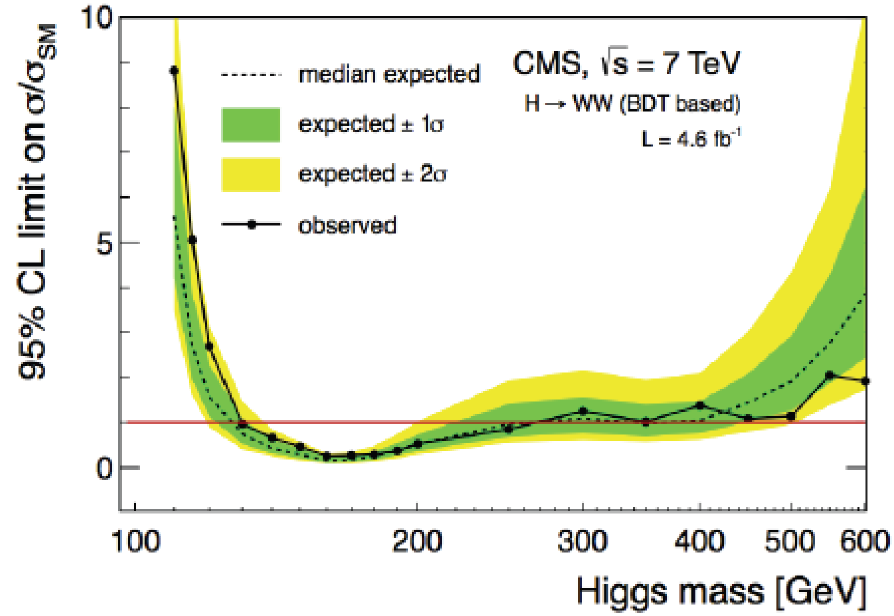
$H \rightarrow WW \rightarrow 2l2\nu$

No significant excess in the full mass range

Cut based



MVA based

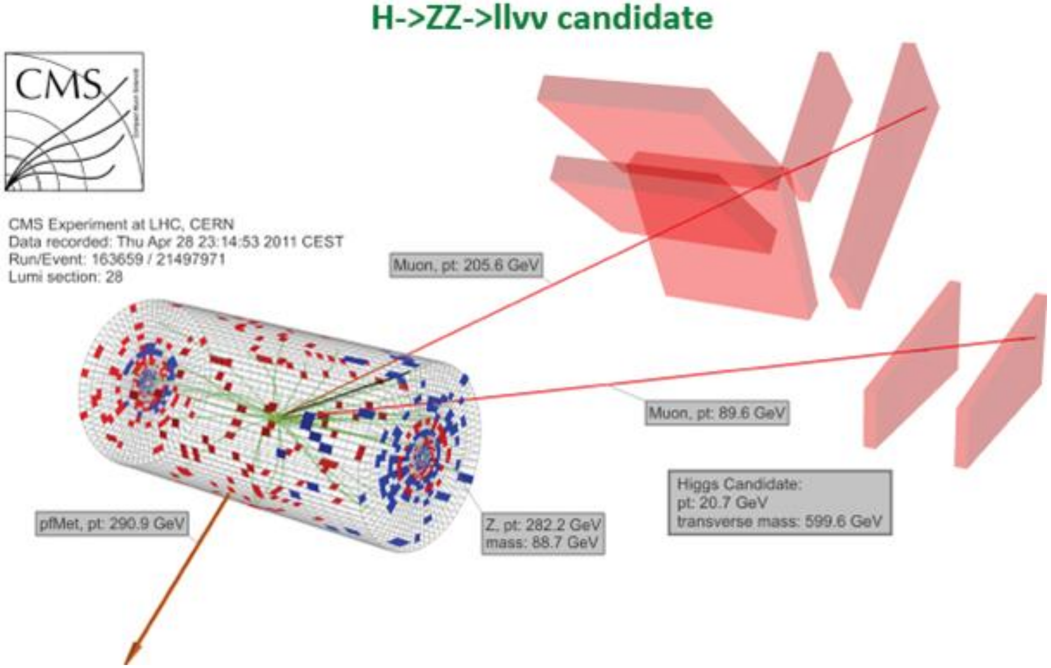


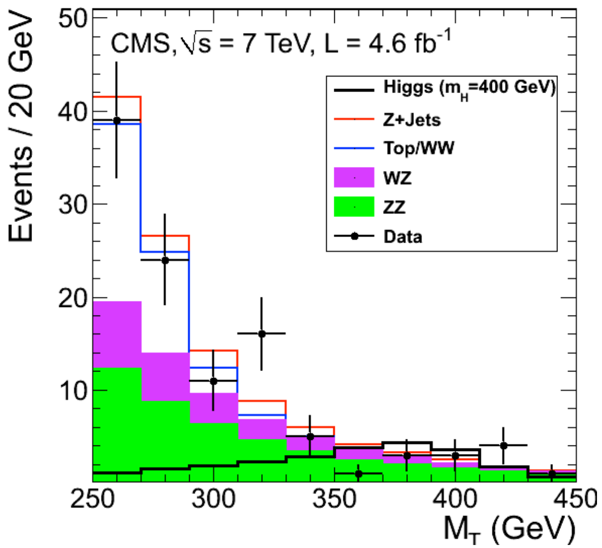
Multivariate analysis more sensitive ➡ our baseline result

Slight excess seen at low mass

- 95% CL expected exclusion for M_H 127 – 270 GeV
- 95% CL observed exclusion for M_H 129 – 270 GeV

$H \rightarrow ZZ \rightarrow 2l2\nu$



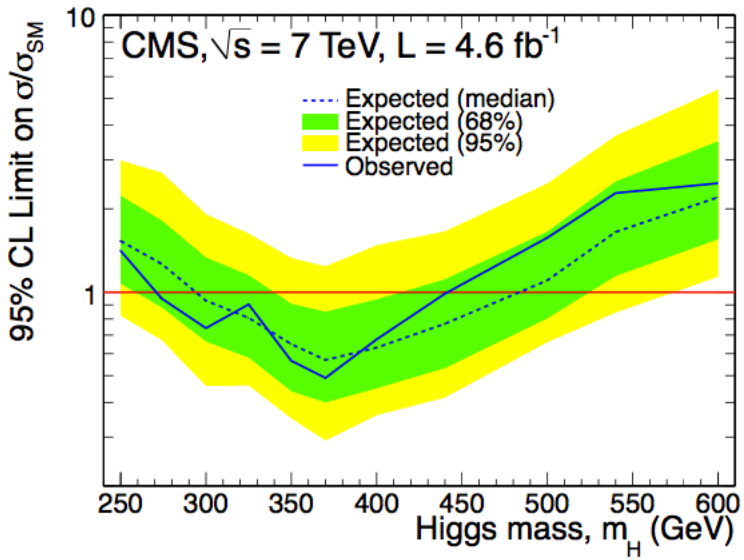


Two analysis : Cut & count and mass shape

Discriminating variable for shape analysis : transverse mass

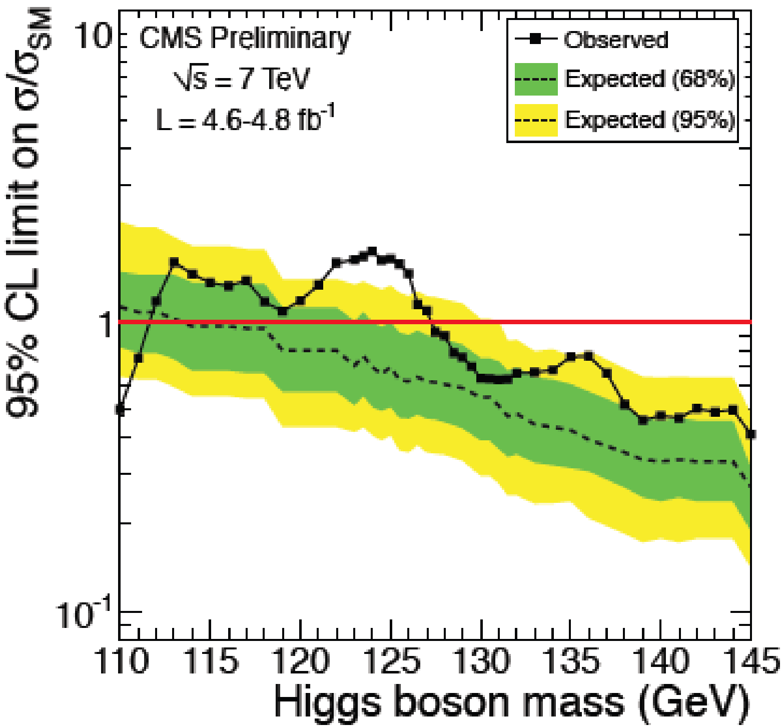
Background estimate :

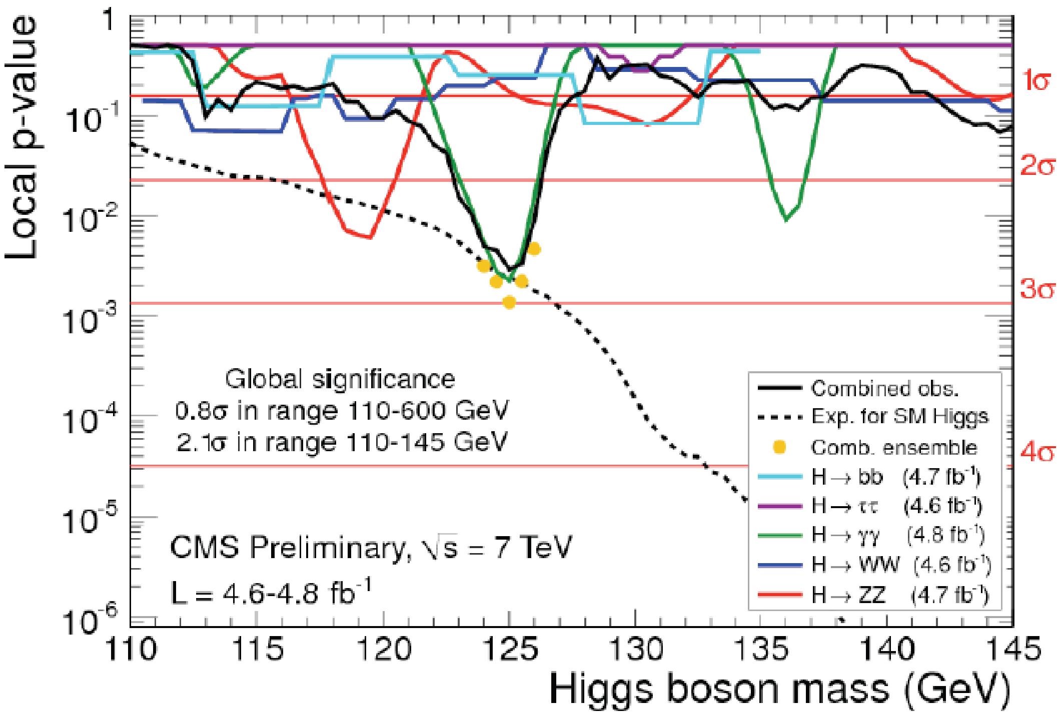
- Z + jets estimated using γ-jet to model MET distribution
- Non-resonant background normalization from eμ events
- ZZ and WZ from MC



Exclusion limits : Expected 95% CL for M_H in [290-480] GeV observed 95% CL for M_H in [270-440] GeV

Combination of all channels



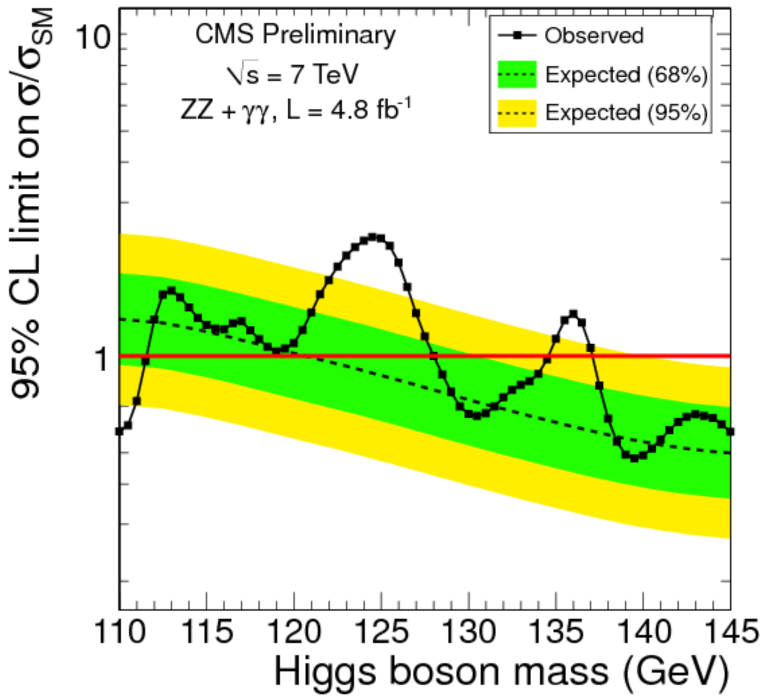


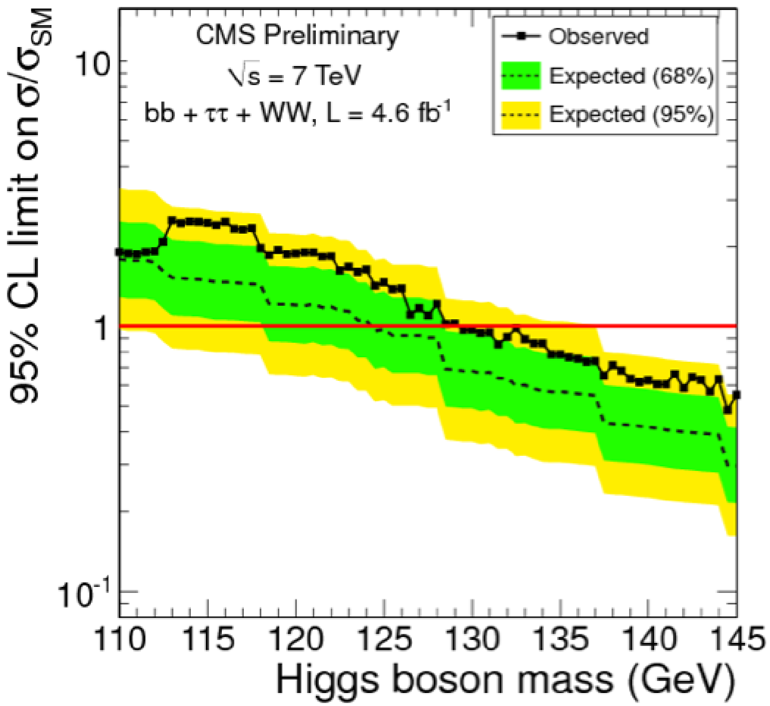
Minimum p-value observed at 125 GeV

Global significance 2.1 σ [110-145] GeV (0.8 σ [110-600] GeV)

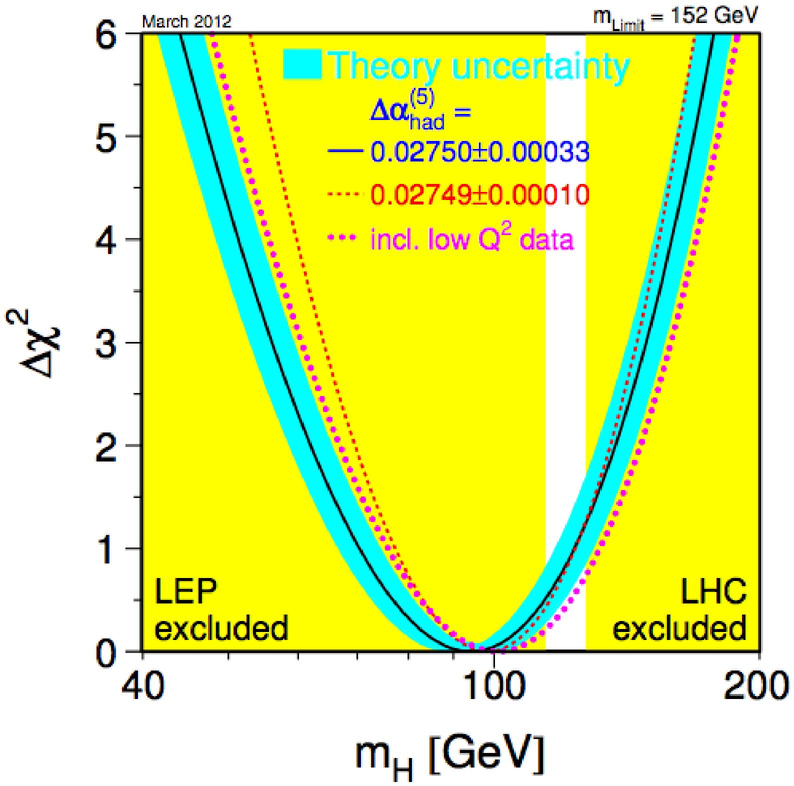
95% CL allowed mass range : [114.5 - 127.5] GeV

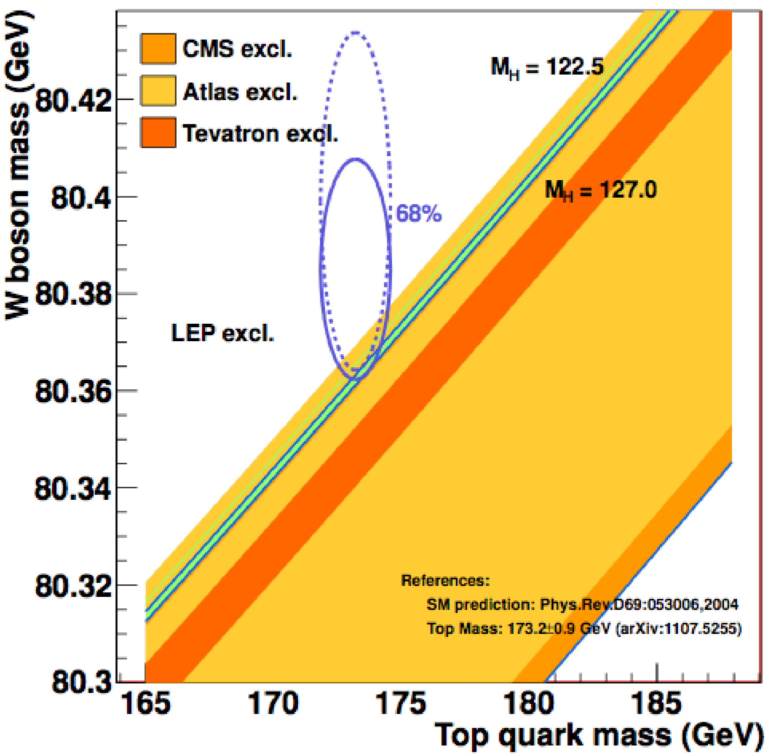
Limits shown for two groups of channels



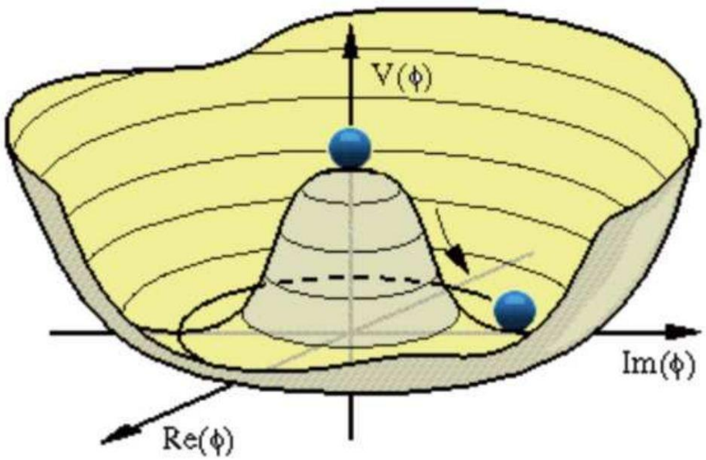


Higgs search and the electroweak fits





Part 2: BSM Higgs Boson



Minimal Super- Symmetric Model (MSSM)

Two isospin Higgs doublets

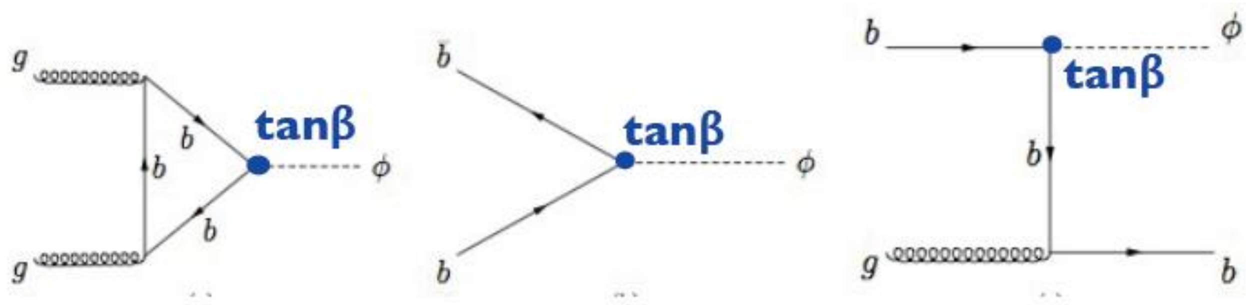
$$H_1 = \begin{pmatrix} H_1^0 \\ H_1^- \end{pmatrix} \text{ and } H_2 = \begin{pmatrix} H_2^+ \\ H_2^0 \end{pmatrix}$$

2 Higgs doublets each with 4 degrees of freedom

EW symmetry breaking: 5 physical Higgs bosons

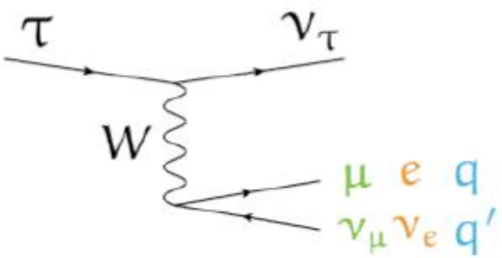
- h, H (scalar, CP-even)
- A (pseudo-scalar, CP-odd)
- $H^{\pm}$ (charged)

Production rate enhanced × $\tan^2\beta$
coupling bbA ~ $\tan\beta$ at LO
gg fusion with top/stop loops, bottom/sbottom + associated b quark production



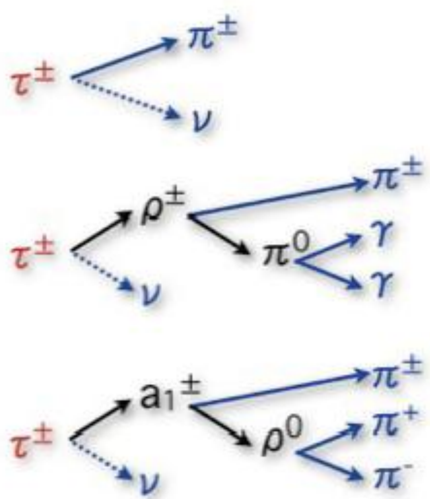
Decays to b-quark (~ 90%) and τ (~ 10%) pairs enhanced at all masses

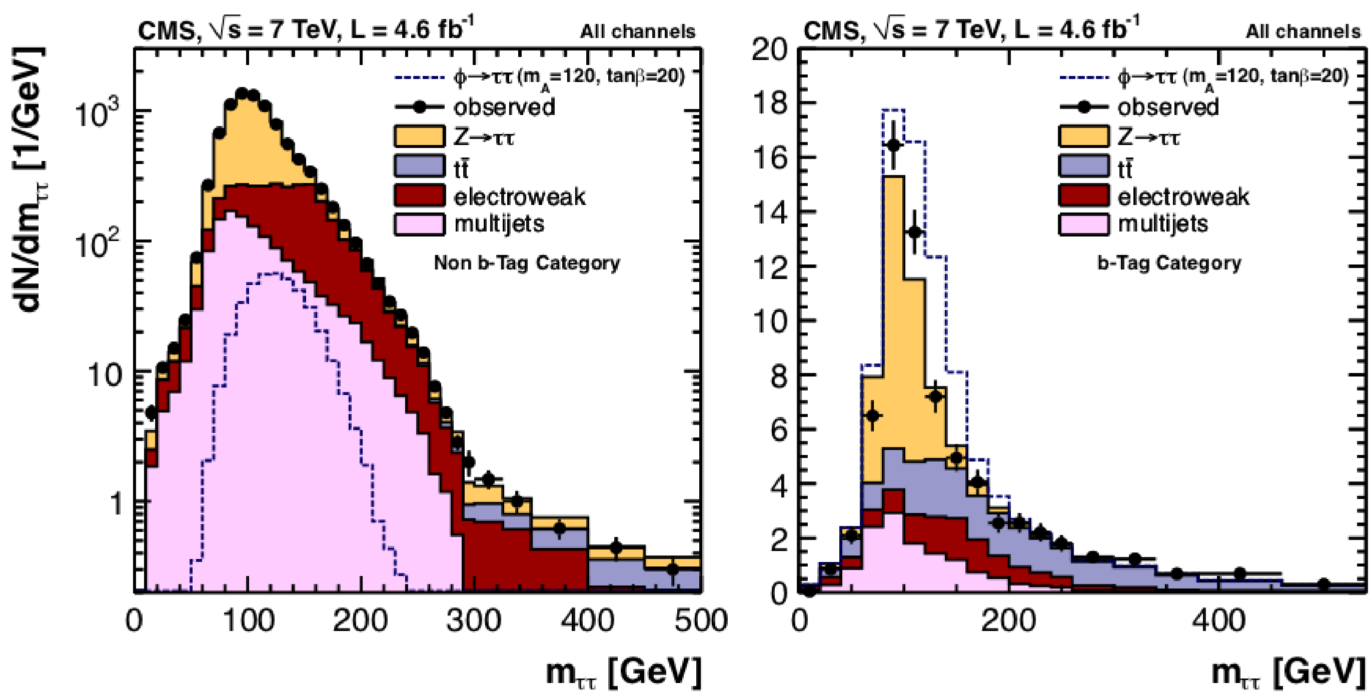
2 parameters (M_A, $\tan\beta$ – ratio of the two doublets)
study done in maximal mixing scenario

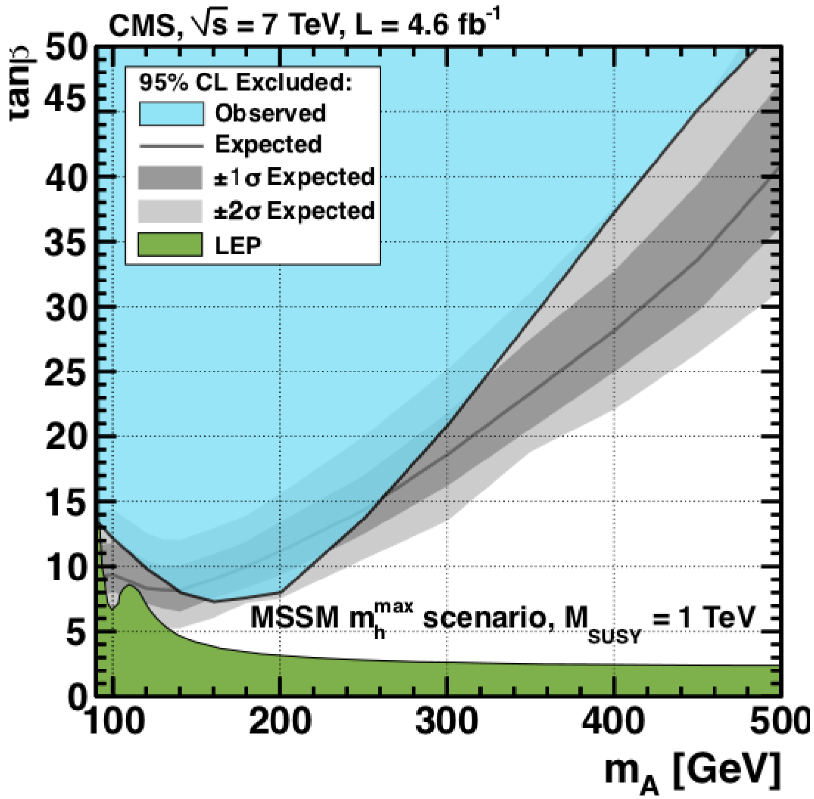


Tau pairs reconstructed in decays leptons (e/**μ**)+ hadrons (1 or 3 prong) or e**μ**

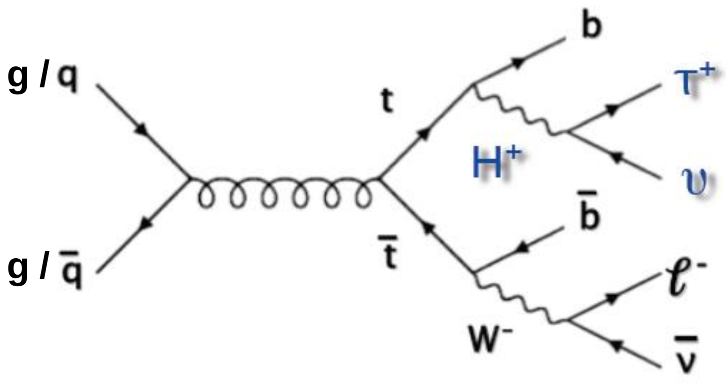
Two categories : non-b-tagged and b-tagged (to enhance bb**Φ** coupling)



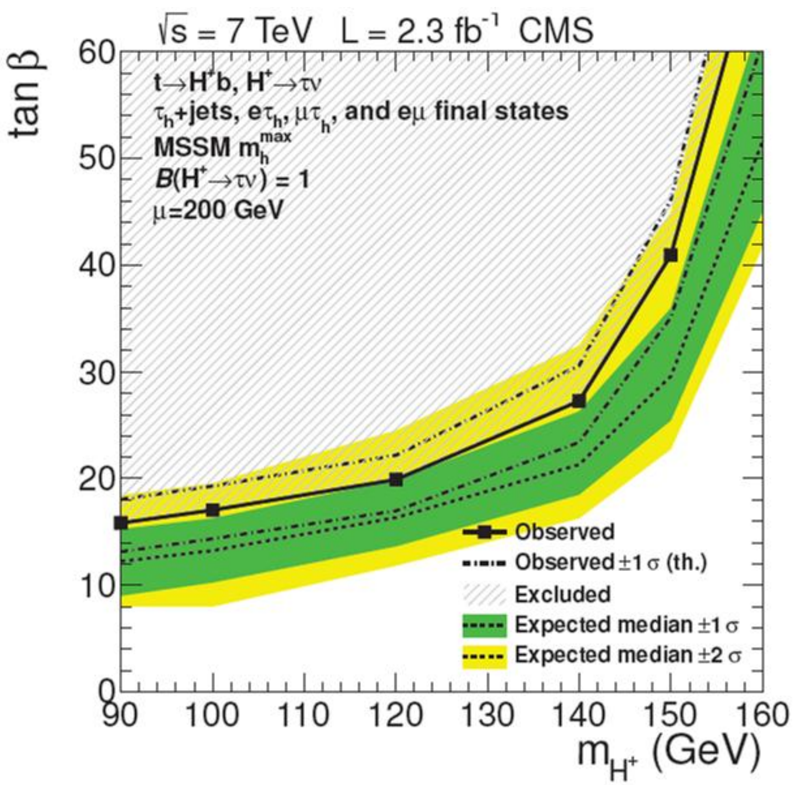




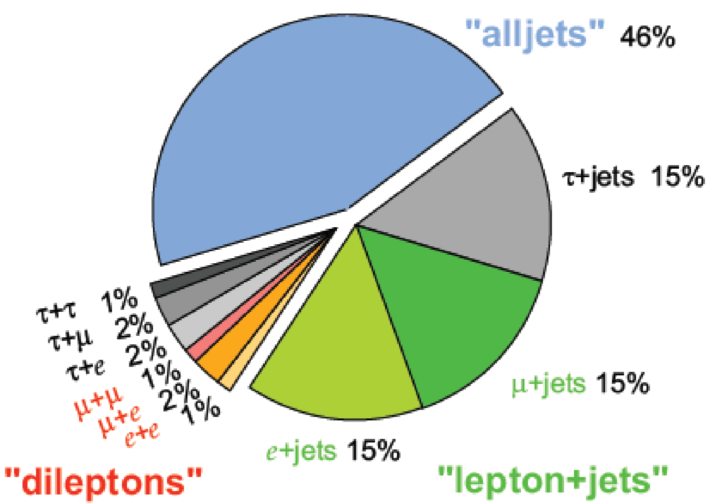
This excludes previously unexplored region:
reaching as low as tan β = 7.1 at m_A = 160 GeV



Event with (τ + MET) from $H^{\pm}$, 2 b-jets , 2 jets or (e/μ + MET) from W

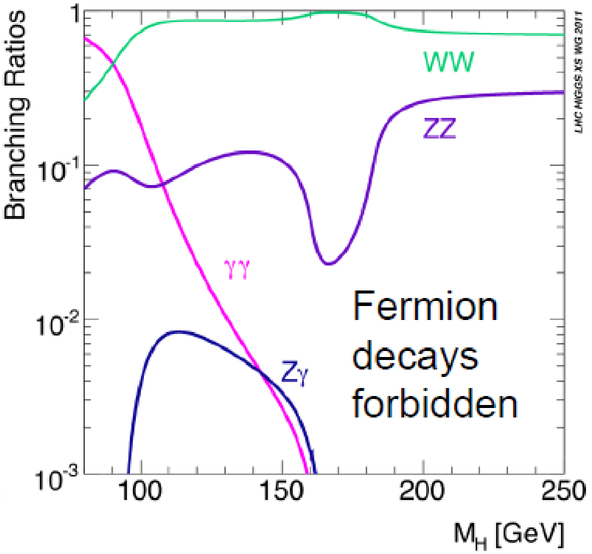


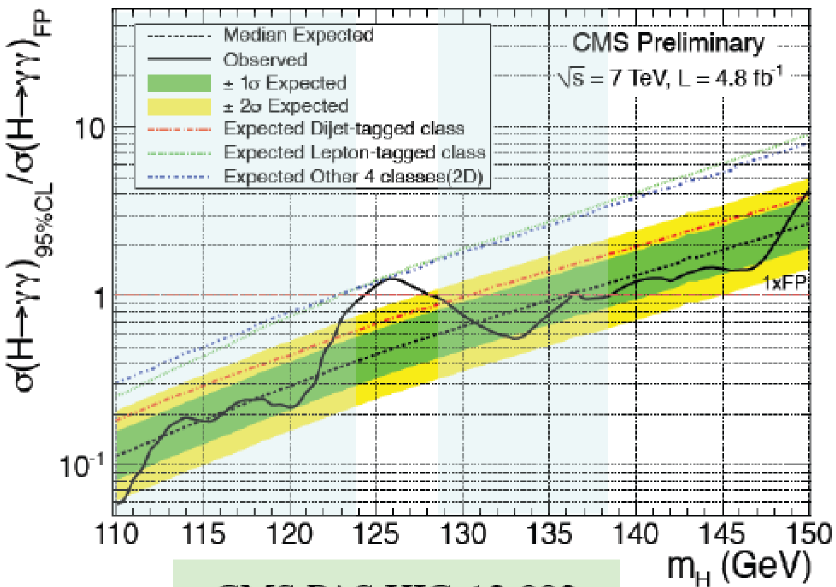
Top Branching Fractions in SM



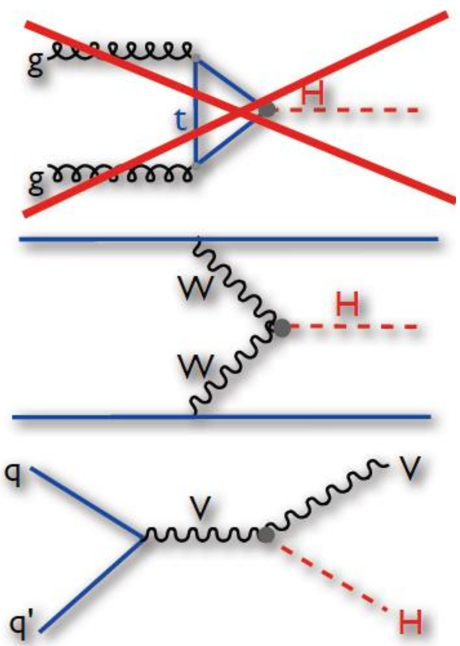
Significant constraint on BR ($t \rightarrow H^{+}b$) < 2 - 3%
Excludes a large region in $m(H^{+})$ – tan **β** plane

ggH forbidden, VBF or VH associated production only: exploit presence of 2 tag jets in forward region or associate W and Z (lepton-tag)





CMS PAS HIG-12-002



$H \rightarrow \gamma\gamma$ enhanced by an order of magnitude wrt SM
$\gamma\gamma$ only expected exclusion M_H<135 GeV
Small excess observed at 126 GeV
2.7σ local significance, 1.2σ global significance (LEE)

Combination VBF and VH with $H \rightarrow WW$, ZZ dilutes excess to <1σ

Summary

- SM Higgs boson search in 11 independent channels combined in CMS
  - Expected 95% exclusion for M_H 114.5-543 GeV
  - Observed 95% exclusion for M_H 127.5-600 GeV
- SM Higgs boson, if it exists, is limited at 95% CL to 114.5-127.5 GeV
- Excess observed around 125 GeV with local significance 2.8 σ and global significance 0.8σ (full search range) and 2.1 σ (110-145 GeV)
- The excess is both consistent with a background fluctuation, or with the 'birth' of a signal for a Higgs Boson around 125 GeV

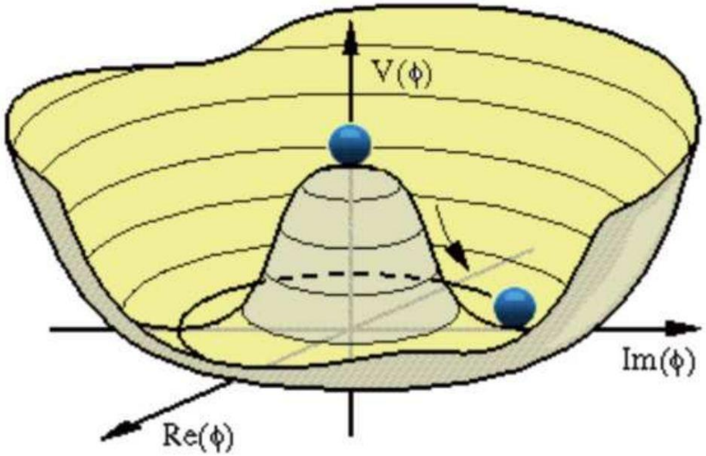
- Broad program of BSM Higgs searches with the CMS detector
- MSSM Higgs parameters constrained with $H \rightarrow \tau\tau$
- Small excess for the $\gamma\gamma$ channel in the fermiophobic model
- No evidence for new BSM Physics in the Higgs sector so far

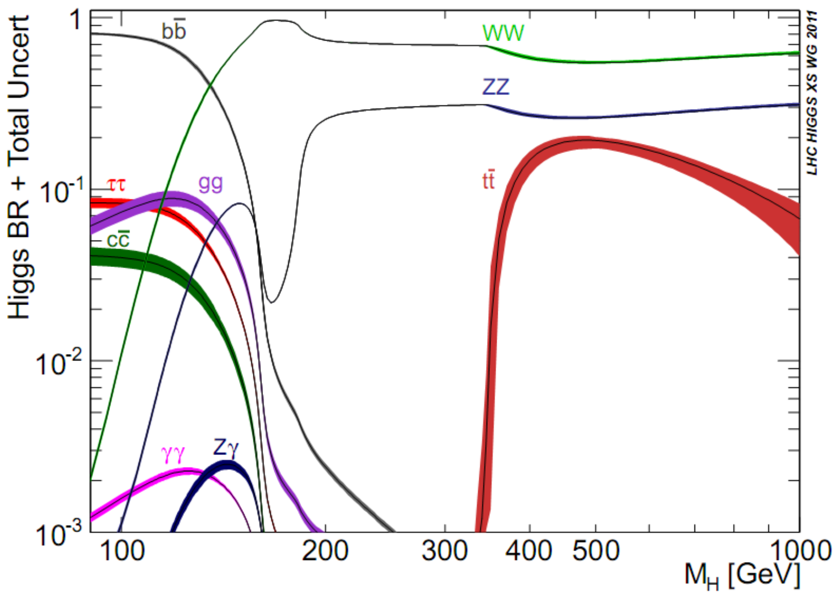
Outlook

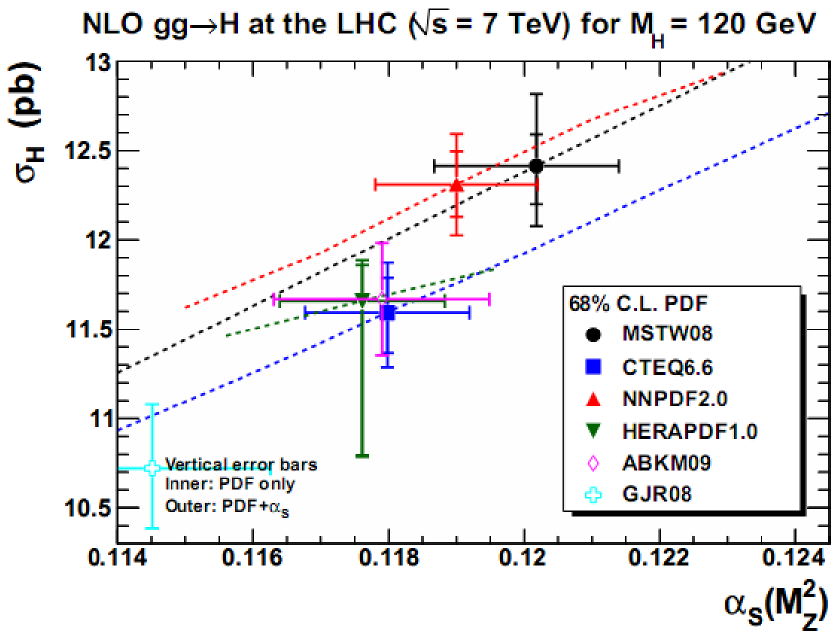
- No conclusive statement drawn on SM Higgs from 2011 data.
- 2012 data would have major impact! Analysis of 2012 data underway
- CMS has recorded over 4 fb^{-1} of integrated luminosity at 8 TeV so far
- 2012 data will either discover the Higgs or exclude it completely in 114.5 – 127.5 GeV
- New techniques to further improve the analysis and results ongoing
- Expecting something sensational! Exciting time ahead of us!

- 2012 data @ 8 TeV with 15 fb^{-1} expected to shed light on BSM Higgs
- Further scan of MSSM Higgs parameter space
- Fermiophobic, Doubly Charged Higgs, NMSSM scenarios
- Possibility of non-SUSY scenario investigation

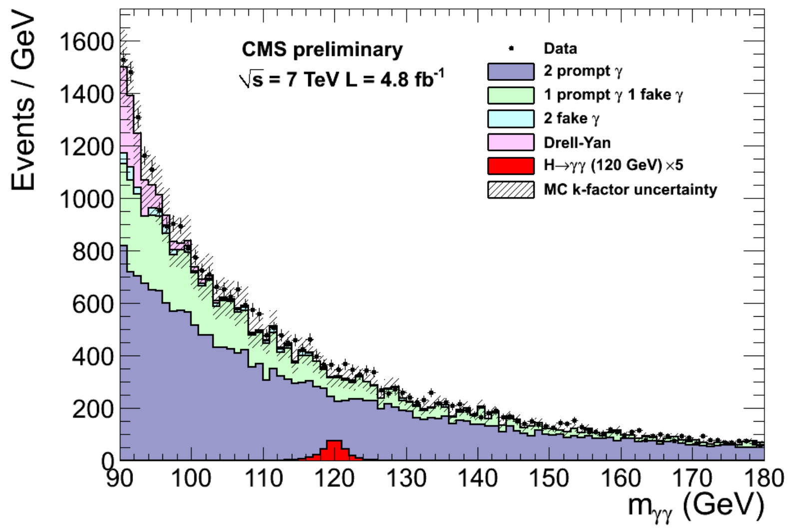
Back-up Slides

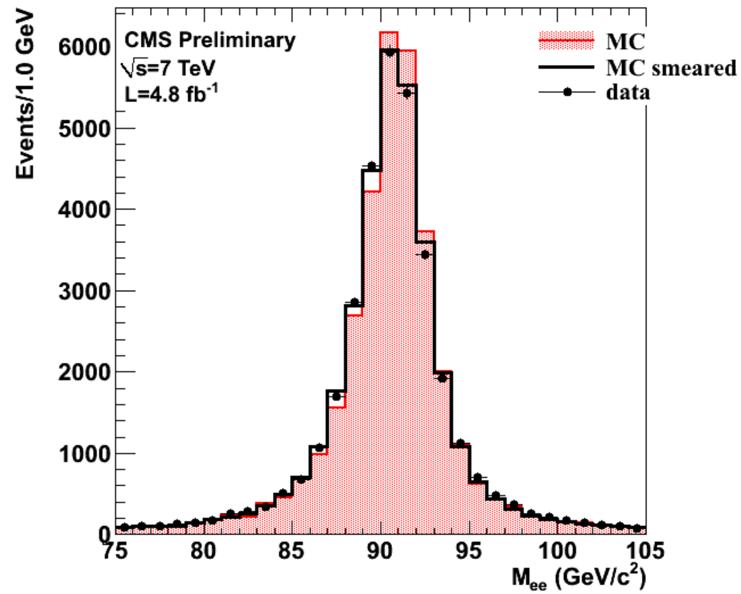


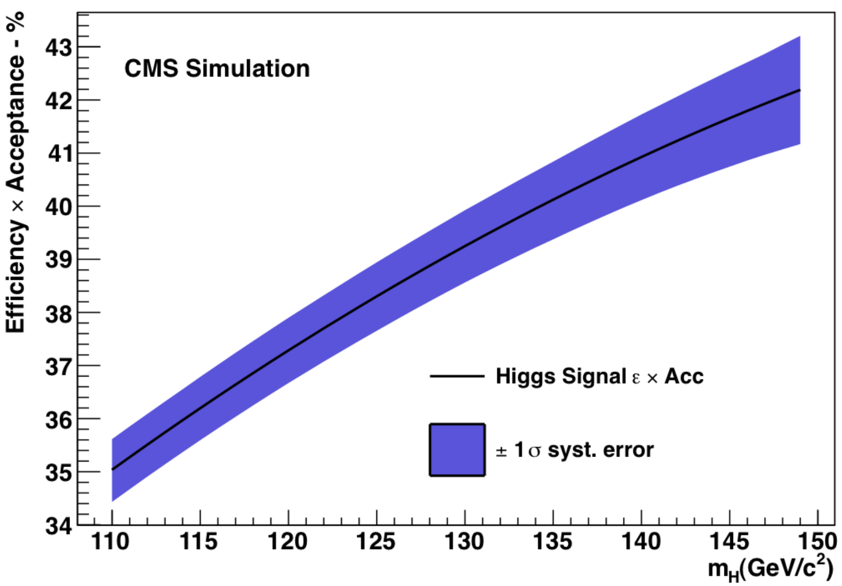

Higgs BR + Total Uncert
bb̄
WW
ZZ
tt̄
ττ
gg
cc̄
γγ
Zγ
LHC HIGGS XS WG 2011
1
10^{-1}
10^{-2}
10^{-3}
100
200
300
400
500
1000
M_H [GeV]


NLO gg→H at the LHC (√s = 7 TeV) for M_H = 120 GeV
σ_H (pb)
13
12.5
12
11.5
11
10.5
0.114
0.116
0.118
0.12
0.122
0.124
$\alpha_S(M_Z^2)$
68% C.L. PDF
MSTW08
CTEQ6.6
NNPDF2.0
HERAPDF1.0
ABKM09
GJR08
Vertical error bars
Inner: PDF only
Outer: PDF+α_S

$H \rightarrow \gamma\gamma$







Energy resolution in different regions of the detector

⇒ smearing energies of electrons in MC simulated $Z \rightarrow ee$

⇒ comparing the resulting Z mass distribution with data.

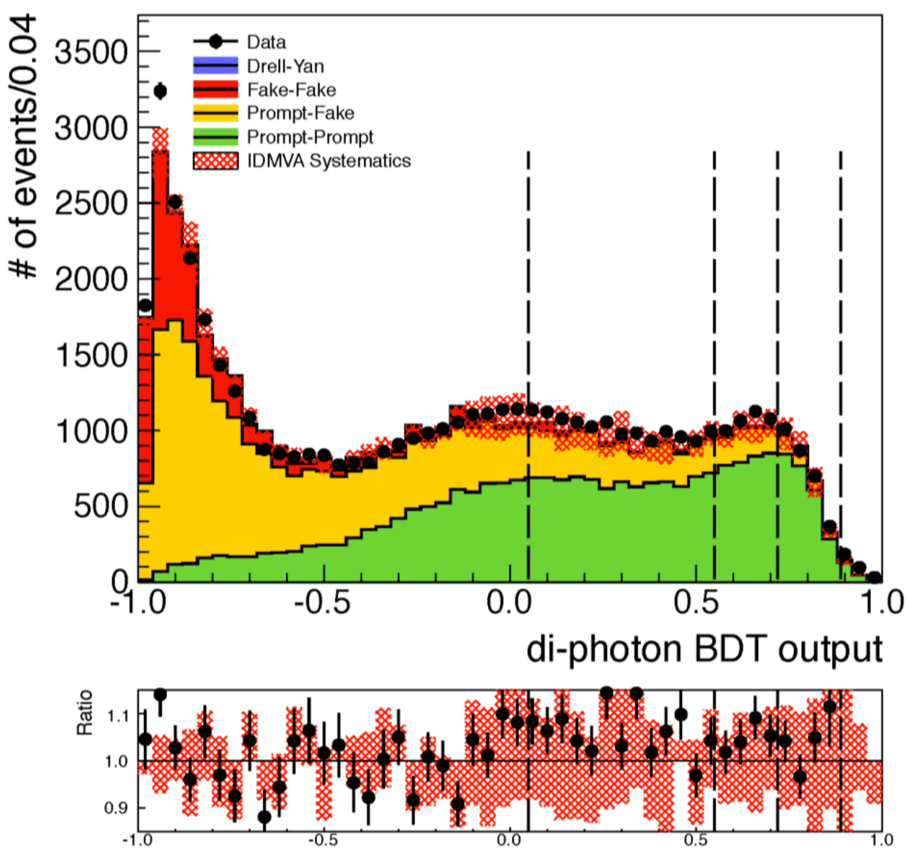
$H \rightarrow \gamma\gamma$

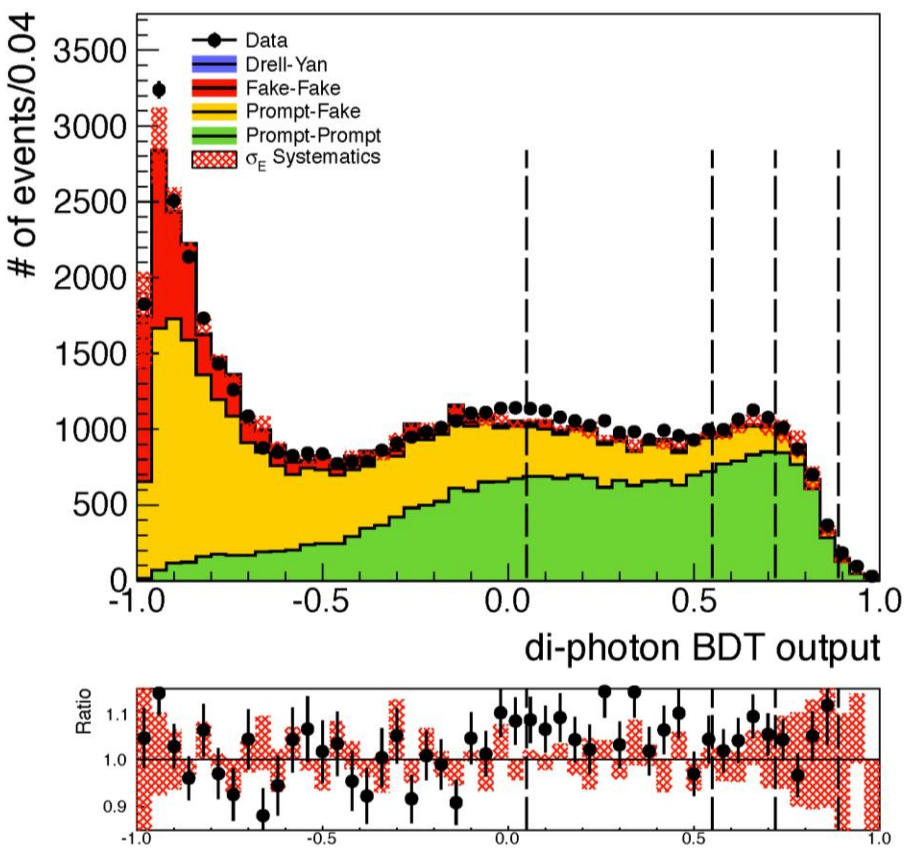
Photon identification efficiencies: using a tag and probe applied to $Z \rightarrow ee$ events (for all requirements except the electron veto).
Both statistical and systematic errors for the data measurement combined quadratically to calculate error on ratio eff(data)/eff(MC).

Category	ϵ_{data} (%)	ϵ_{MC} (%)	$\epsilon_{data}/\epsilon_{MC}$
Barrel, $R_9 > 0.94$	89.26±0.06±0.04	90.61±0.05	0.985±0.001
Barrel, $R_9 < 0.94$	68.31±0.06±0.55	68.16±0.05	1.002±0.008
Endcap, $R_9 > 0.94$	73.65±0.14±0.39	73.45±0.12	1.002±0.006
Endcap, $R_9 < 0.94$	51.25±0.11±1.25	48.70±0.08	1.052±0.026

Number of selected events in different event classes, for a SM Higgs boson signal (m_H = 120 GeV) and mass resolution, and for data at 120 GeV

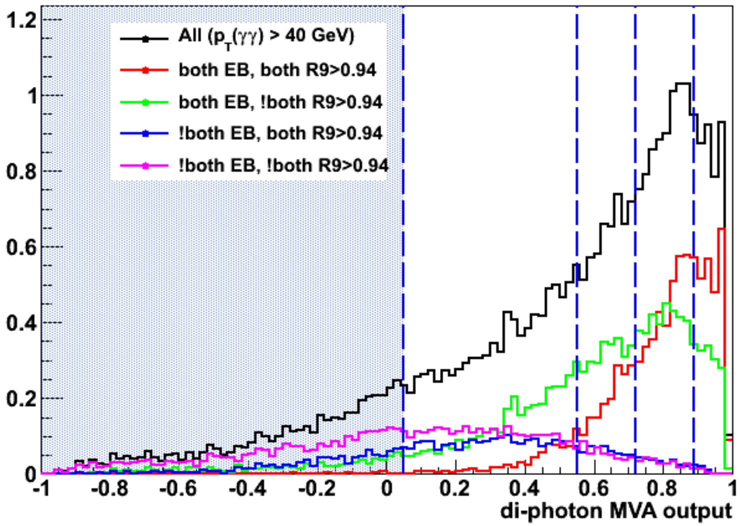
	Both photons in barrel		One or both in endcap		Dijet
	R_9^{min} >0.94	R_9^{min} <0.94	R_9^{min} >0.94	R_9^{min} <0.94	tag
SM signal expected	25.2 (33.5%)	26.6 (35.3%)	9.5 (12.6%)	11.4 (14.9%)	2.8 (3.7%)
Data (events/GeV)	97.5 (22.8%)	143.4 (33.6%)	76.7 (17.9%)	107.4 (25.1%)	2.3 (0.5%)
σ_{eff} (GeV)	1.39	1.84	2.76	3.19	1.71
FWHM/2.35 (GeV)	1.19	1.53	2.81	3.18	1.37

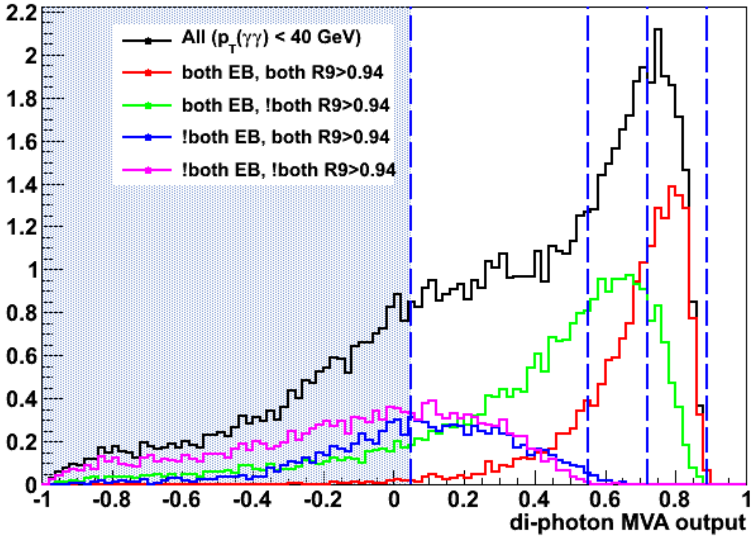


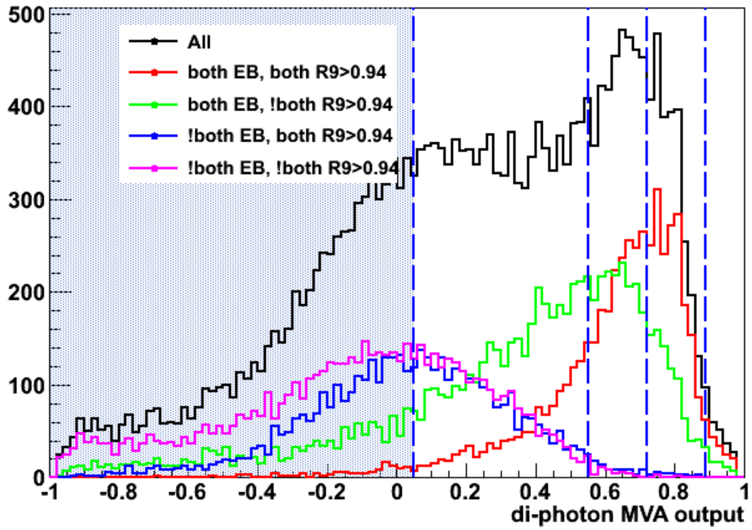


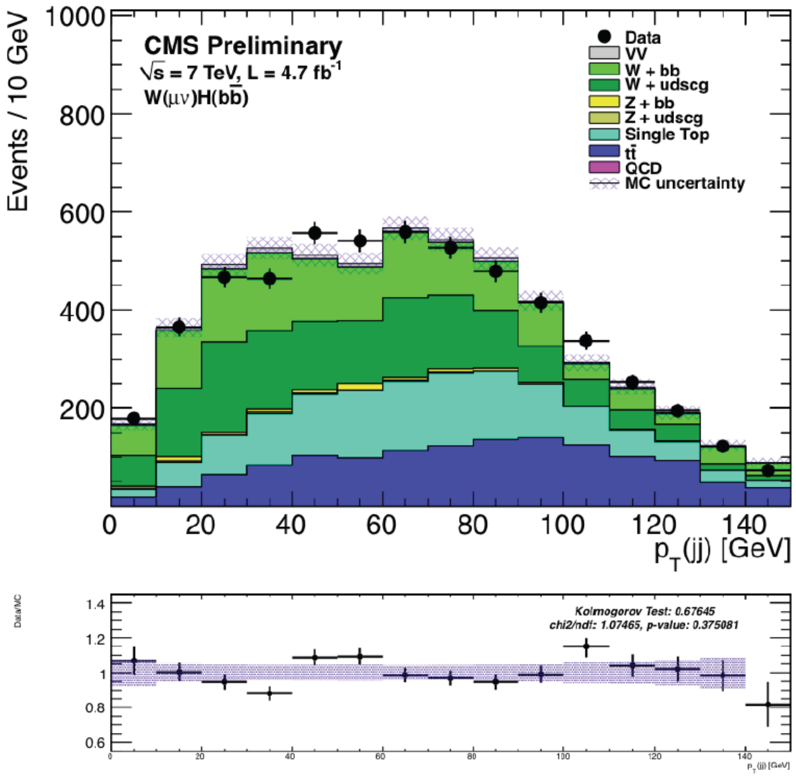
effect of systematic uncertainty assigned to the γ ID BDT output on γγ BDT output, for background MC (100 < mgg < 180 GeV), and for data

effect of systematic uncertainty assigned to the γ energy resolution BDT output on γγ BDT output, for background MC (100 < mgg < 180 GeV), and for data

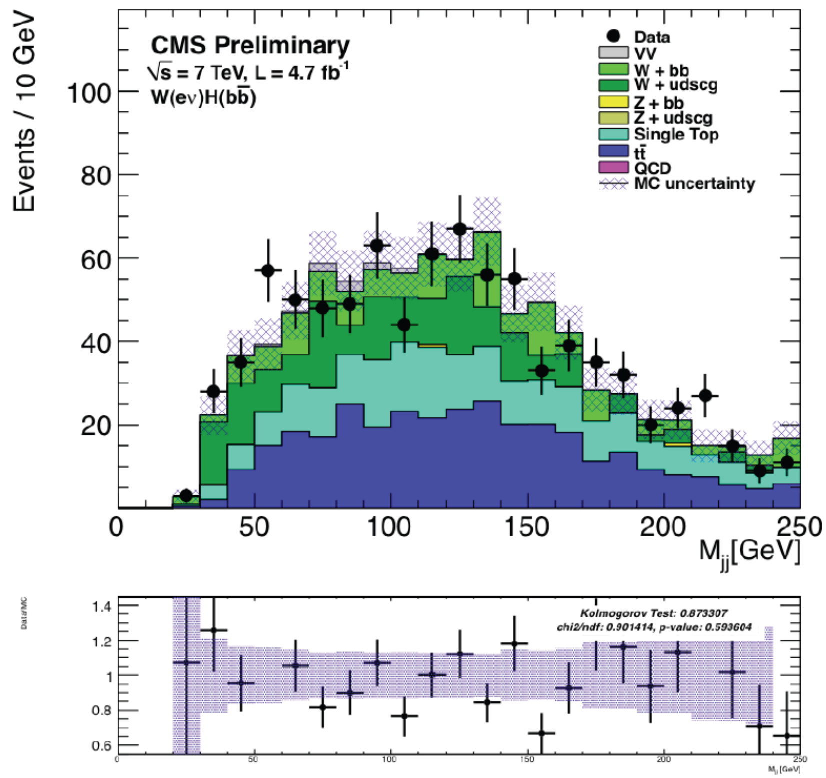

All (p_T(γγ) > 40 GeV)
both EB, both R9>0.94
both EB, !both R9>0.94
!both EB, both R9>0.94
!both EB, !both R9>0.94
di-photon MVA output


All (p_T(γγ) < 40 GeV)
both EB, both R9>0.94
both EB, !both R9>0.94
!both EB, both R9>0.94
!both EB, !both R9>0.94
di-photon MVA output


All
both EB, both R9>0.94
both EB, !both R9>0.94
!both EB, both R9>0.94
!both EB, !both R9>0.94
di-photon MVA output

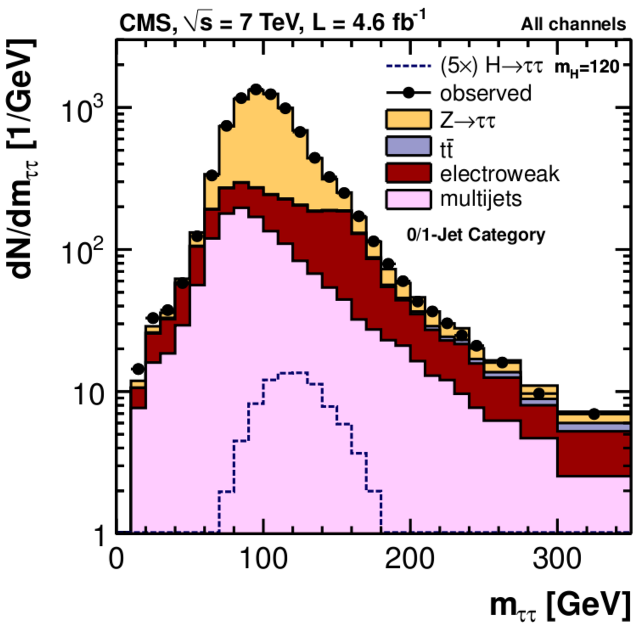


Di-jet p_T in the W + bb control region for W(**μν**)H(bb)

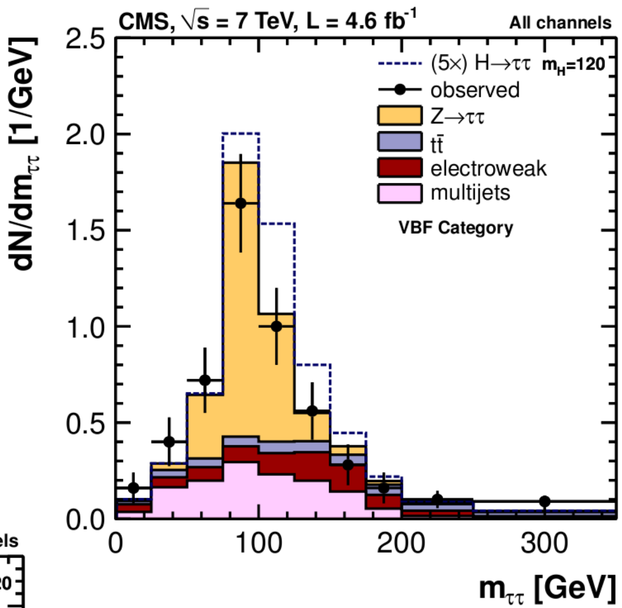


Di-jet invariant mass in the W + bb control region for W(e**ν**)H(bb)

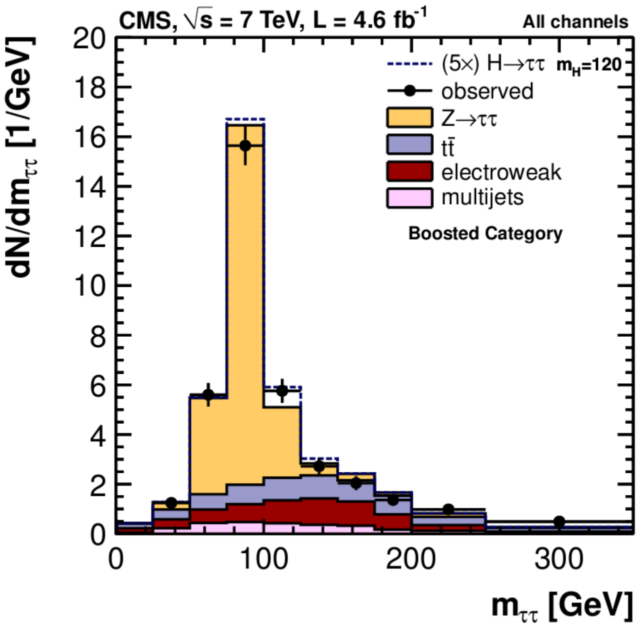
H → ττ



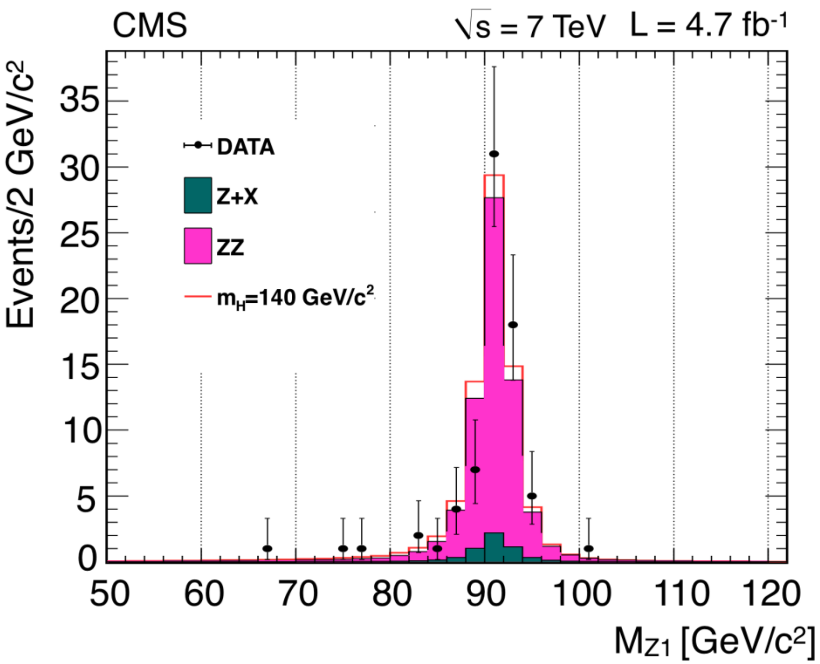
CMS, √s = 7 TeV, L = 4.6 fb-1
All channels
(5×) H→ττ mH=120
observed
Z→ττ
tt̄
electroweak
multijets
0/1-Jet Category
dN/dmττ [1/GeV]
mττ [GeV]

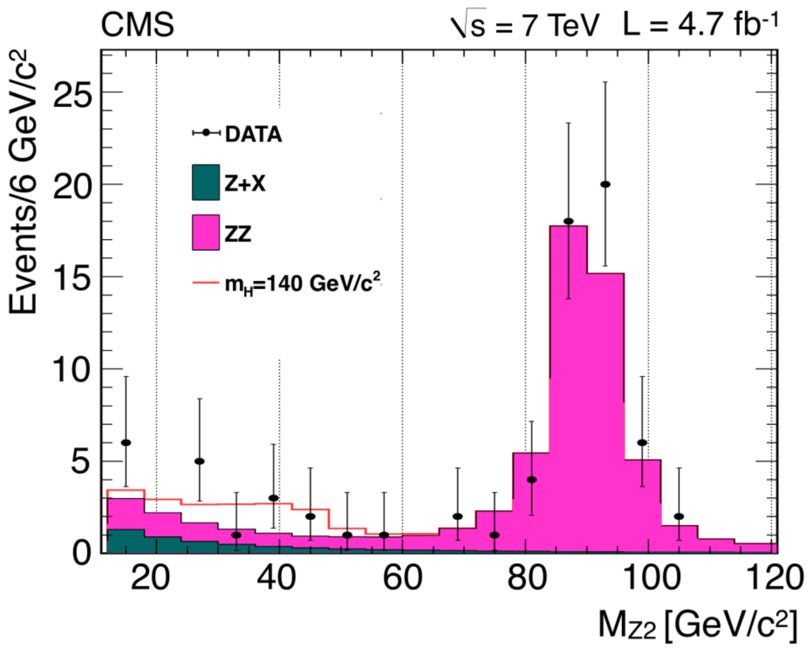


CMS, √s = 7 TeV, L = 4.6 fb-1
All channels
(5×) H→ττ mH=120
observed
Z→ττ
tt̄
electroweak
multijets
VBF Category
dN/dmττ [1/GeV]
mττ [GeV]

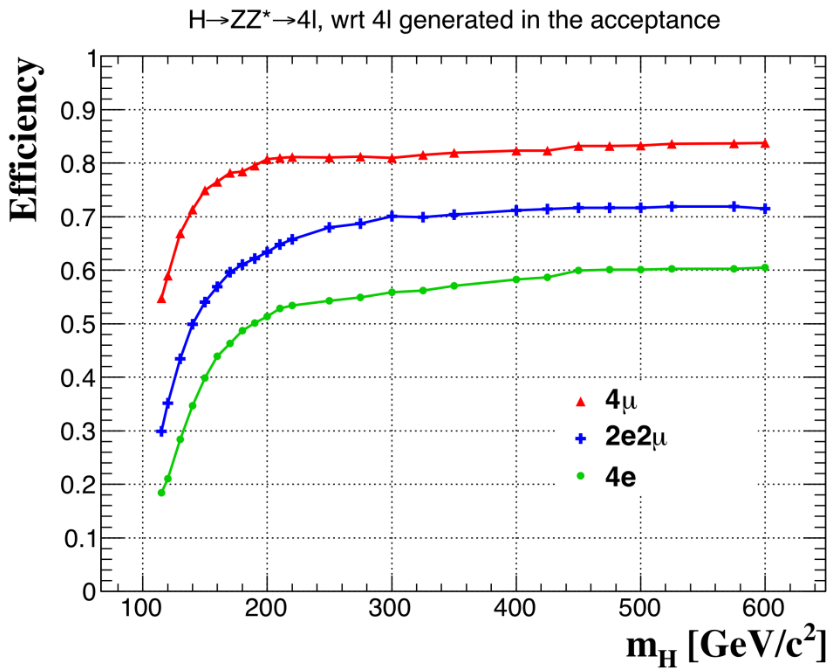


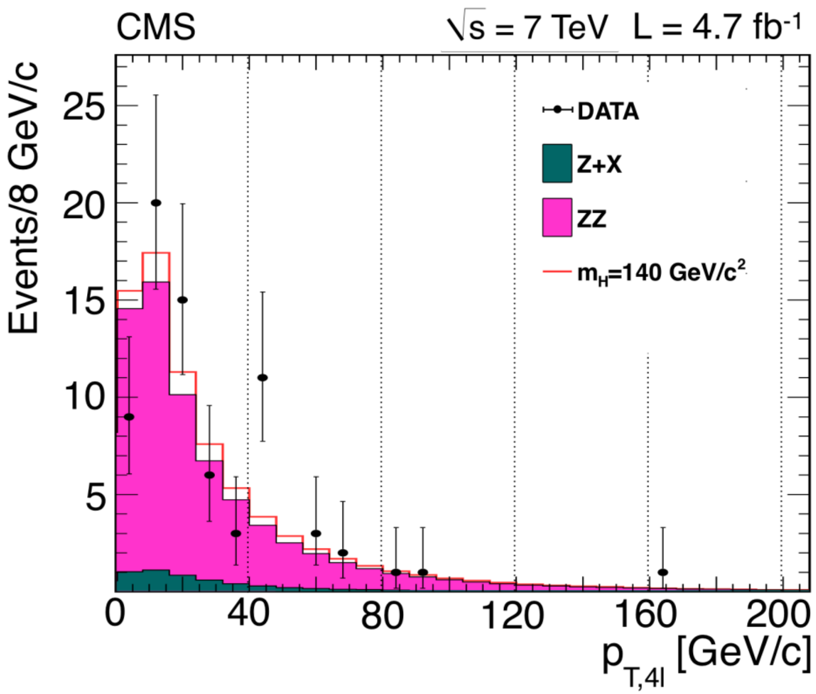
CMS, √s = 7 TeV, L = 4.6 fb-1
All channels
(5×) H→ττ mH=120
observed
Z→ττ
tt̄
electroweak
multijets
Boosted Category
dN/dmττ [1/GeV]
mττ [GeV]



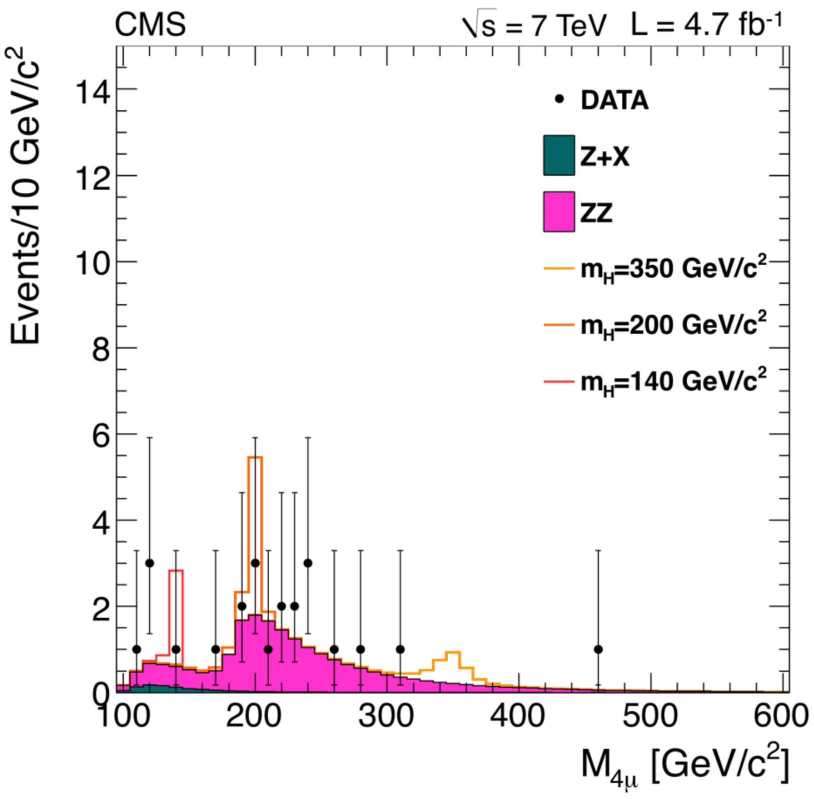


Baseline	$4e$	4μ	$2e2\mu$
ZZ	12.27 ± 1.16	19.11 ± 1.75	30.25 ± 2.78
Z+X	1.67 ± 0.55	1.13 ± 0.55	2.71 ± 0.96
All background	13.94 ± 1.28	20.24 ± 1.83	32.96 ± 2.94
$m_H = 120\,\mathrm{GeV}/c^2$	0.25	0.62	0.68
$m_H = 140\,\mathrm{GeV}/c^2$	1.32	2.48	3.37
$m_H = 350\,\mathrm{GeV}/c^2$	1.95	2.61	4.64
Observed	12	23	37

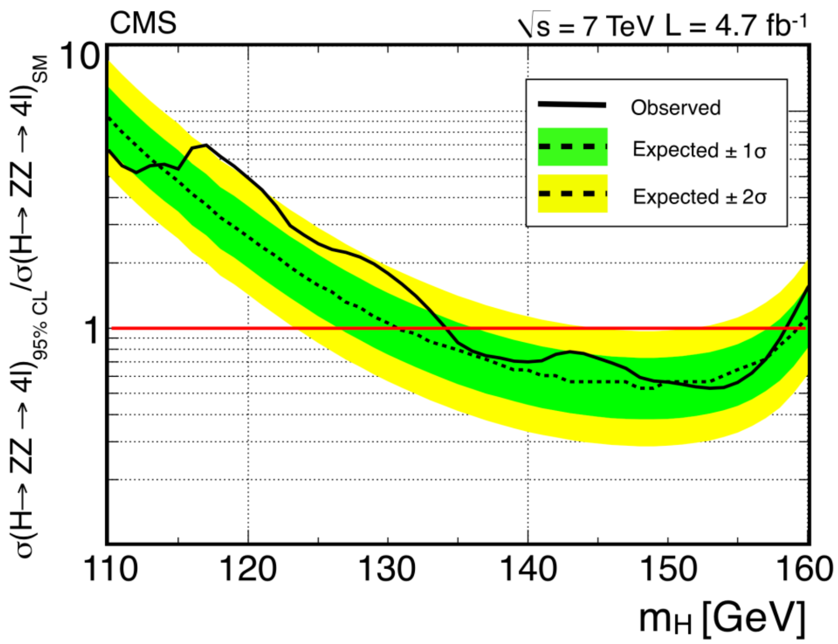

H→ZZ*→4l, wrt 4l generated in the acceptance
Efficiency
4μ
2e2μ
4e
m_H [GeV/c^2]


CMS
√s = 7 TeV L = 4.7 fb-1
Events/8 GeV/c
DATA
Z+X
ZZ
m_H=140 GeV/c^2
p_T,4l [GeV/c]

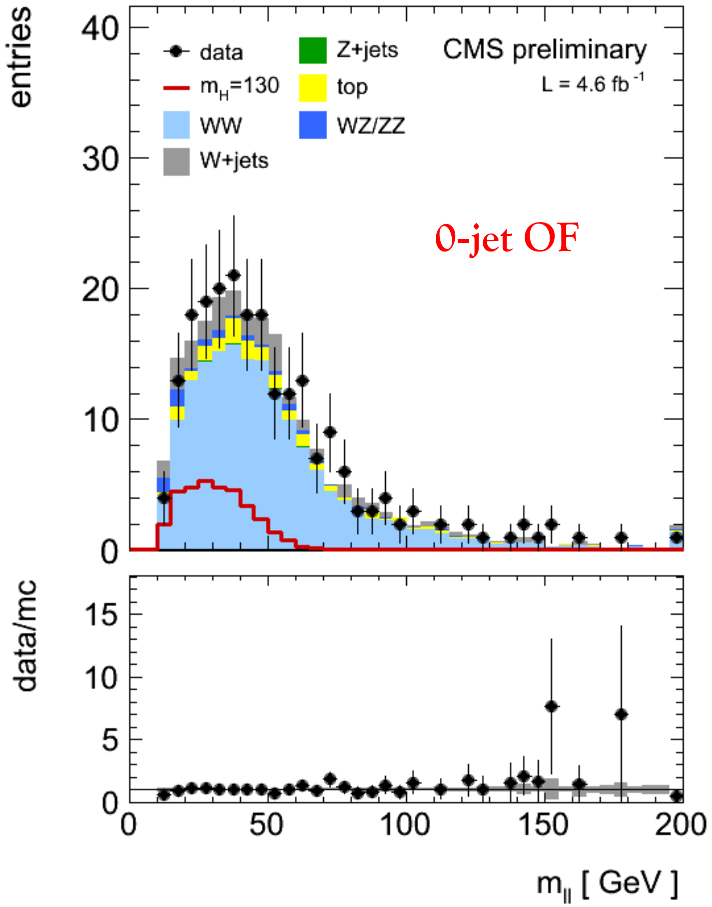
H → ZZ → 4l

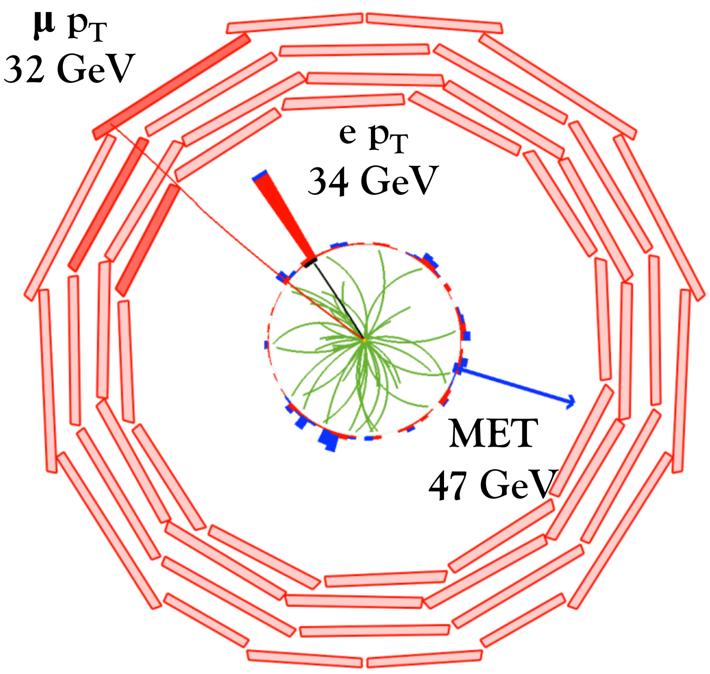


CMS
√s = 7 TeV L = 4.7 fb-1
DATA
Z+X
ZZ
mH=350 GeV/c2
mH=200 GeV/c2
mH=140 GeV/c2
Events/10 GeV/c2
M4μ [GeV/c2]



CMS
√s = 7 TeV L = 4.7 fb-1
Observed
Expected ± 1σ
Expected ± 2σ
σ(H→ ZZ → 4l)95% CL/σ(H→ ZZ → 4l)SM
mH [GeV]


entries
data
m_H=130
WW
W+jets
Z+jets
top
WZ/ZZ
CMS preliminary
L = 4.6 fb^-1
0-jet OF
data/mc
m_ll [GeV]


μ p_T
32 GeV
e p_T
34 GeV
MET
47 GeV

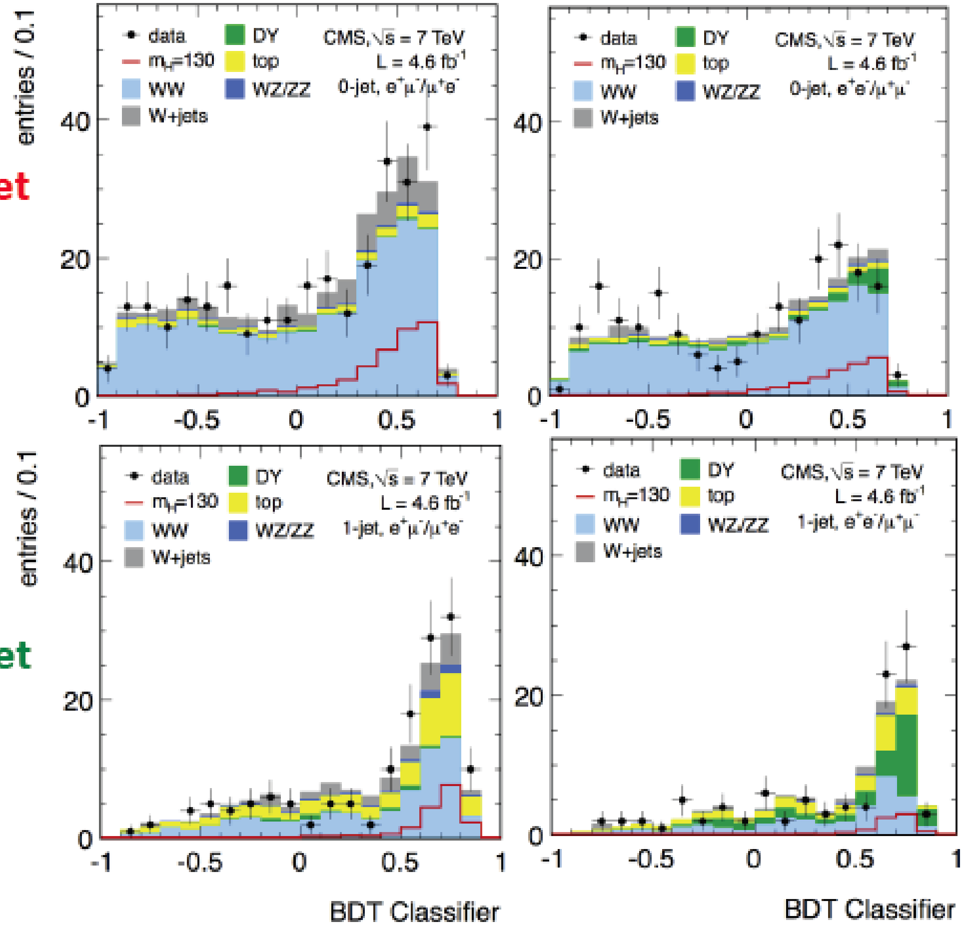
M_H=130 GeV

0-jet eμ

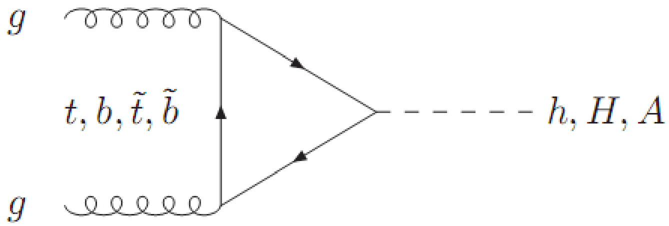
0-jet ee, μμ

1-jet eμ

1-jet ee, μμ



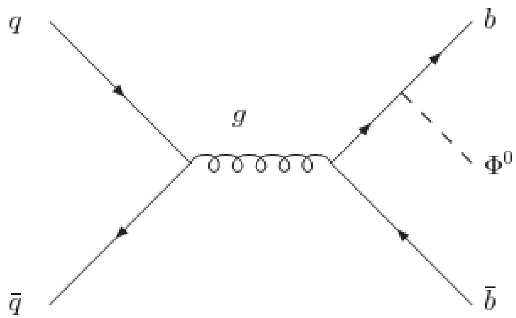
Most sensitive channel is eμ in 0-jet bin
higher s/b and smaller systematic errors

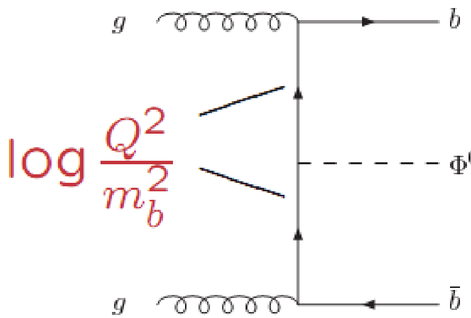


$$\sigma^{MSSM}(gg \to \phi) = \left(\frac{g_t^{MSSM}}{g_t^{SM}}\right)^2 \sigma_{tt}(gg \to \phi) + \left(\frac{g_b^{MSSM}}{g_b^{SM}}\right)^2 \sigma_{bb}(gg \to \phi) + \frac{g_t^{MSSM}}{g_t^{SM}} \frac{g_b^{MSSM}}{g_b^{SM}} \sigma_{tb}(gg \to \phi)$$

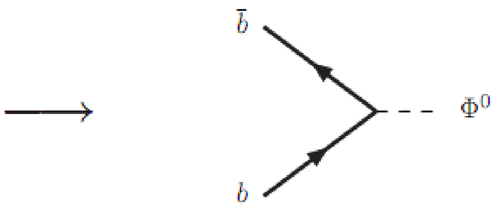
$$\Delta\sigma_{tt}^{NNLO}(gg \to \phi) = \Delta K_{NNLO}\ \sigma_{tt}^{LO}(gg \to \phi)$$

$$\Delta K_{NNLO} = \frac{\sigma^0_{NNLO} - \sigma^0_{NLO}}{\sigma^0_{LO}}$$

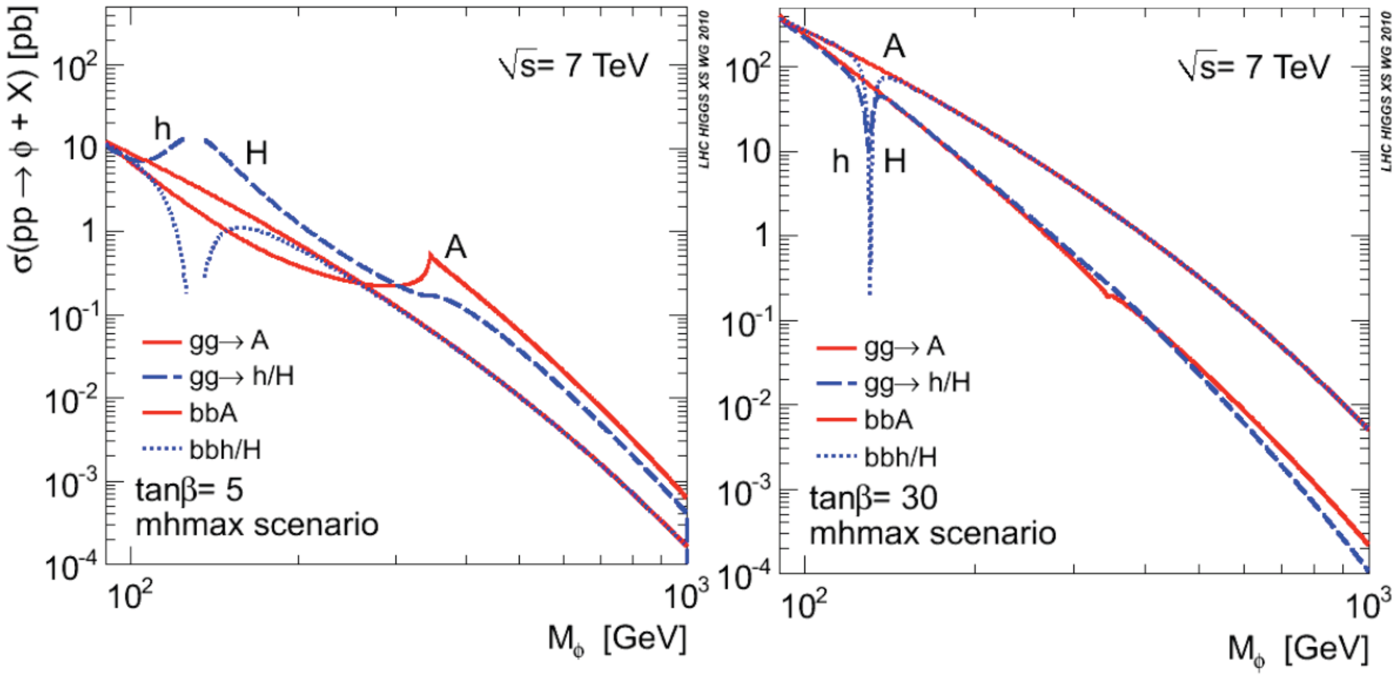


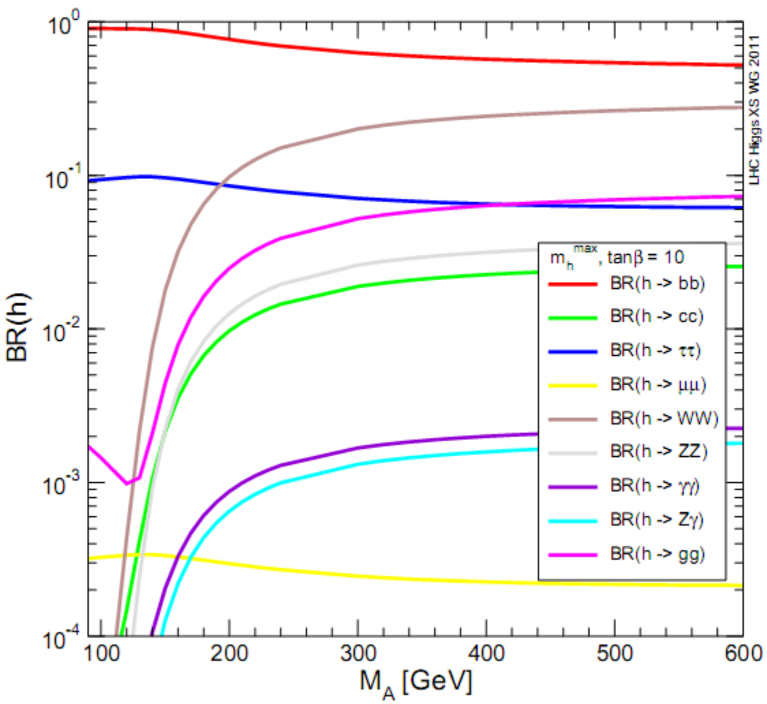


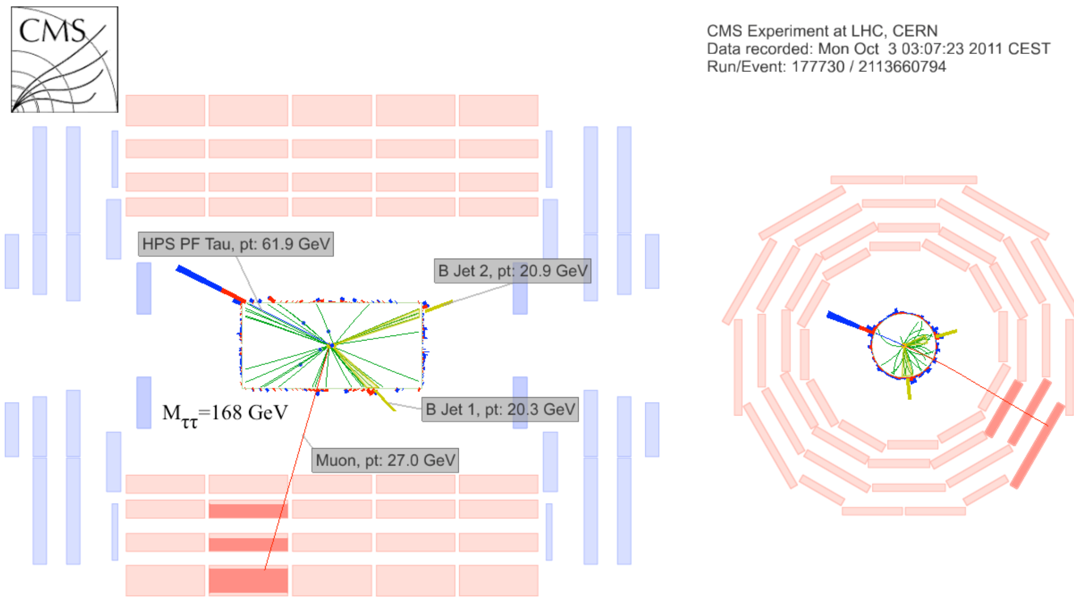
dominant



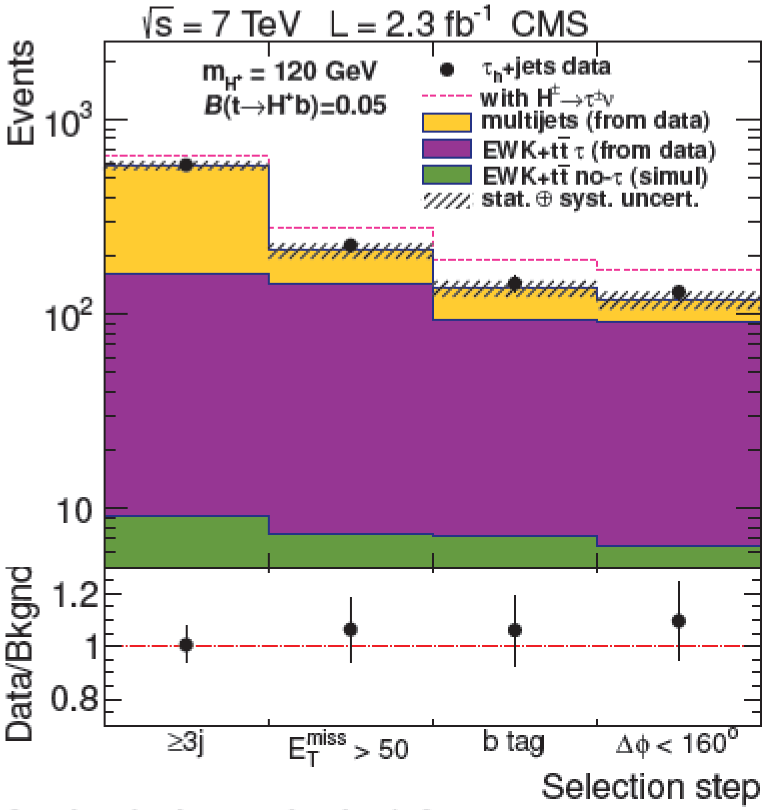
Large logs from phase space integration → bottom PDF resummation ≡ DGLAP evolution


σ(pp → φ + X) [pb]
√s= 7 TeV
LHC HIGGS XS WG 2010
h
H
A
gg→ A
gg→ h/H
bbA
bbh/H
tanβ= 5
mhmax scenario
tanβ= 30
mhmax scenario
M_φ [GeV]

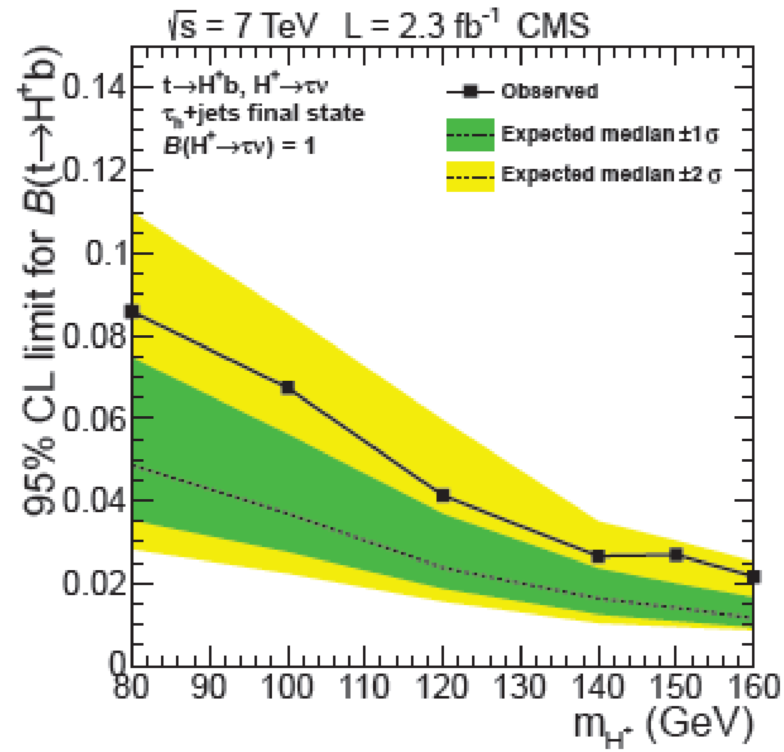

m_h^{max}, tanβ = 10
BR(h -> bb)
BR(h -> cc)
BR(h -> ττ)
BR(h -> μμ)
BR(h -> WW)
BR(h -> ZZ)
BR(h -> γγ)
BR(h -> Zγ)
BR(h -> gg)
LHC HiggsXS WG 2011
BR(h)
M_A [GeV]


CMS
CMS Experiment at LHC, CERN
Data recorded: Mon Oct 3 03:07:23 2011 CEST
Run/Event: 177730 / 2113660794
HPS PF Tau, pt: 61.9 GeV
B Jet 2, pt: 20.9 GeV
B Jet 1, pt: 20.3 GeV
Muon, pt: 27.0 GeV
$M_{\tau\tau}$=168 GeV

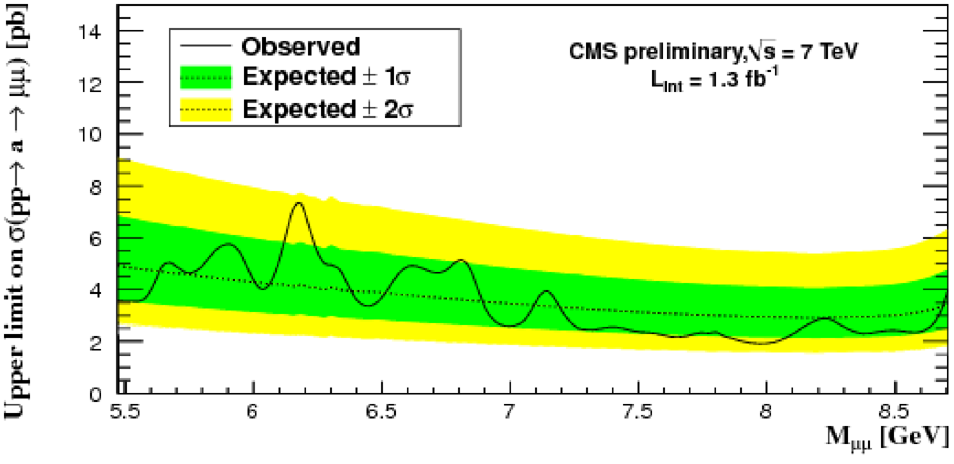
MSSM Higgs: Charged



The event yield after each selection step for the τ_h+jets analysis

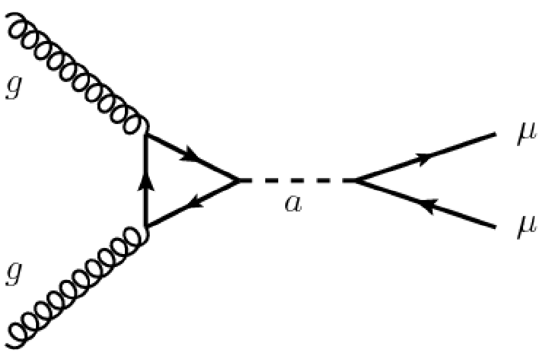


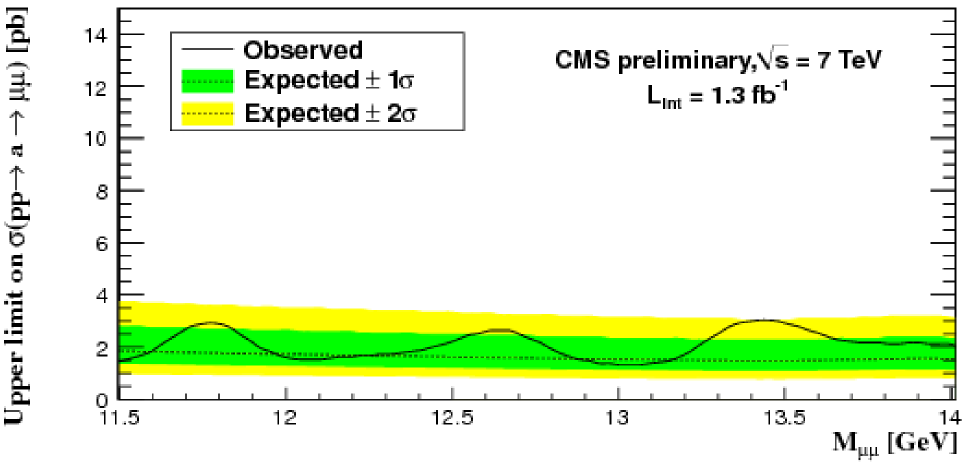
Upper limit on B(t → H⁺b) as a function of m_{H+} for the fully hadronic



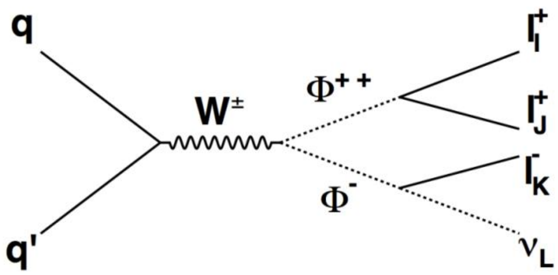
Next-to-Minimal Supersymmetric Standard Model (NMSSM):
Adds singlet scalar field, thereby expanding the Higgs sector to three CP-even (h_1, $h_2$and h_3), two CP-odd (a_1, a_2) and two charged scalars

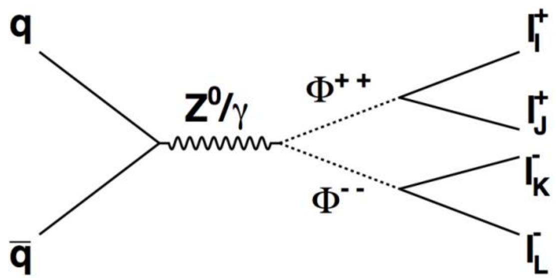
light (~10 GeV) boson produced: Search for a_1 in its decays to opposite sign di-muon pairs

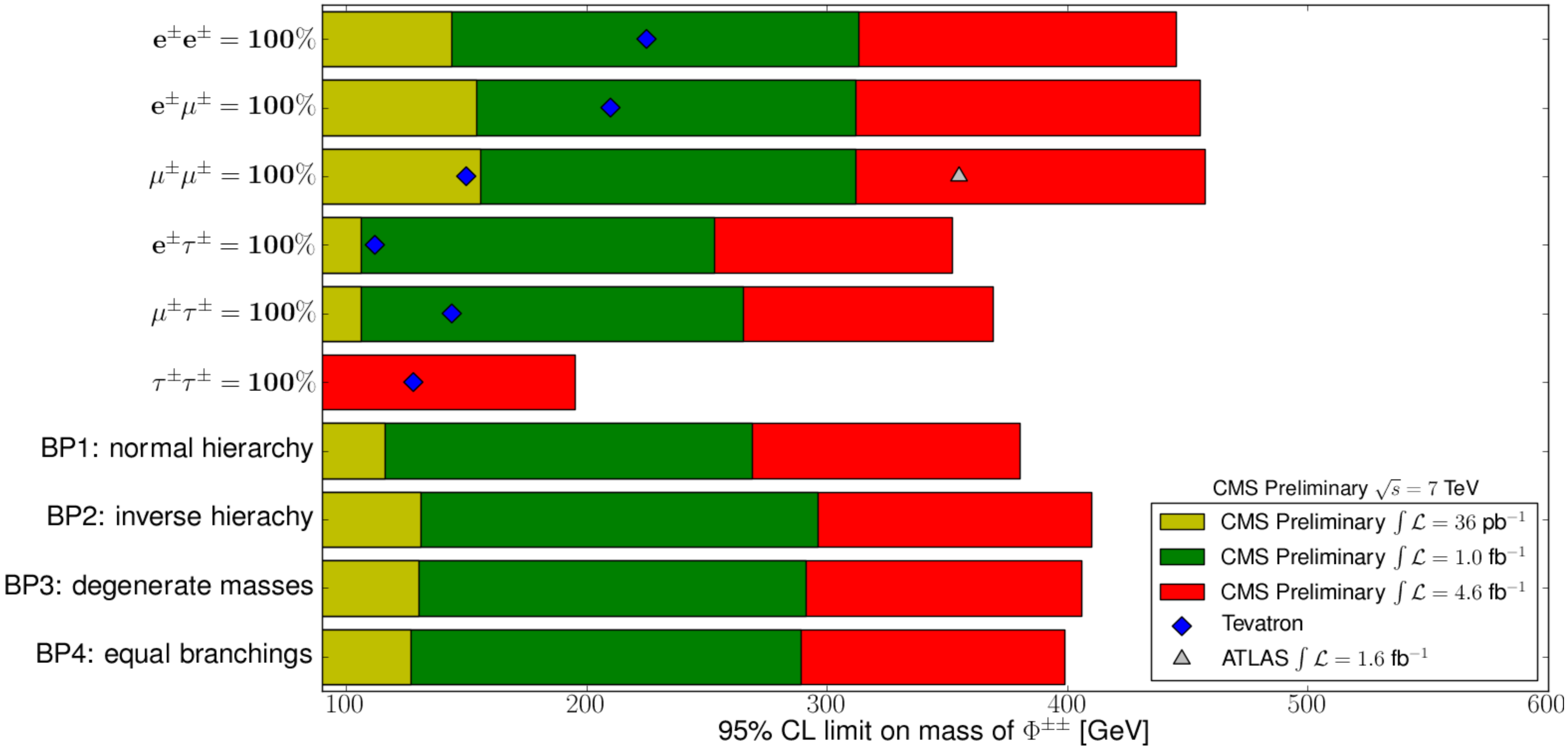




Doubly-Charged Higgs







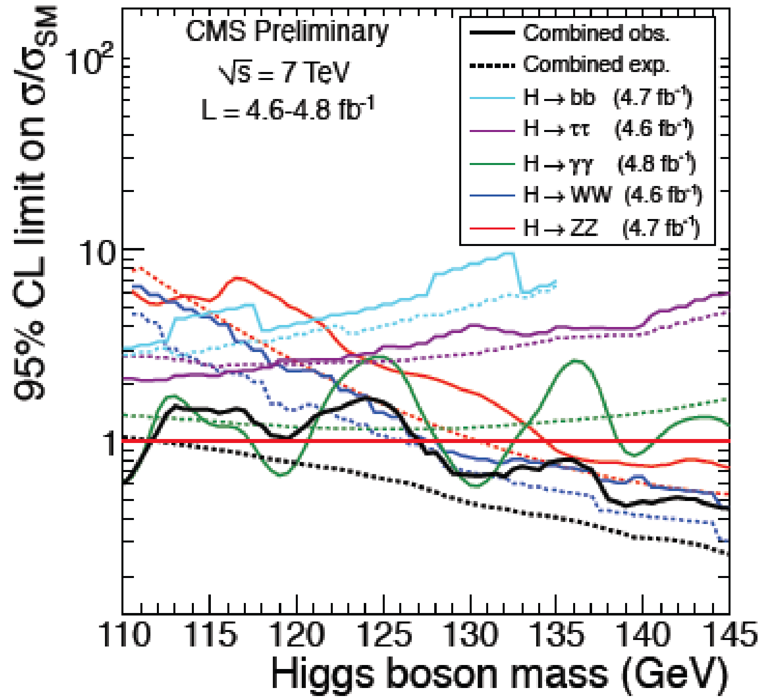
find the values of the nuisance parameter that best fit the experimental data for the background-only and signal+background hypothesis

use these values to generate toy MC pseudo-data for background-only and signal+background to construct test statistic p.d.f. for a signal with strength **μ** and background only hypothesis:

$$f(\tilde{q}_\mu|\mu, \hat{\theta}_\mu^{\rm obs}) \qquad f(\tilde{q}_\mu|0, \hat{\theta}_0^{\rm obs})$$

from the p.d.f.s the p-values for background-only and signal+background hypothesis are found and the CL_S as the ratio of the two p-values

$$CL_s(\mu) = \frac{P\left(q_\mu \geq q_\mu^{obs} \,|\, \mu s(\hat{\theta}_\mu^{obs}) + b(\hat{\theta}_\mu^{obs})\right)}{P\left(q_\mu \geq q_\mu^{obs} \,|\, b(\hat{\theta}_0^{obs})\right)}$$

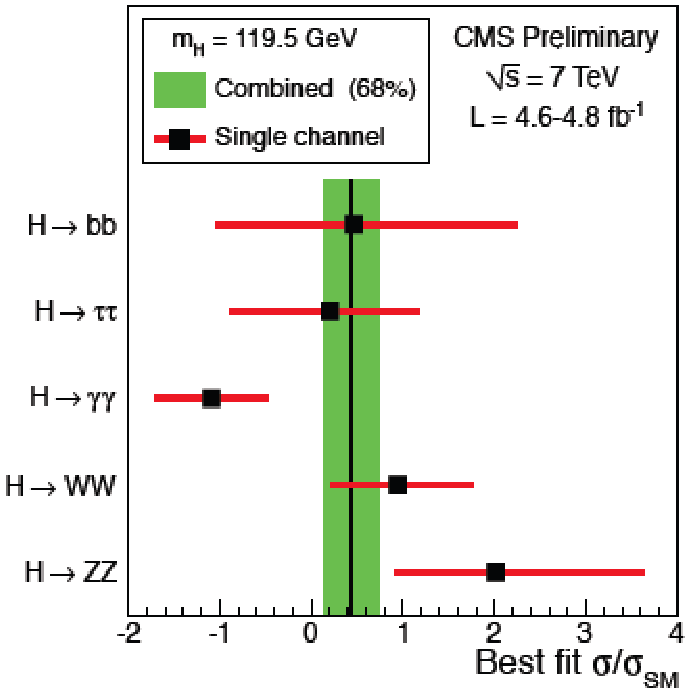


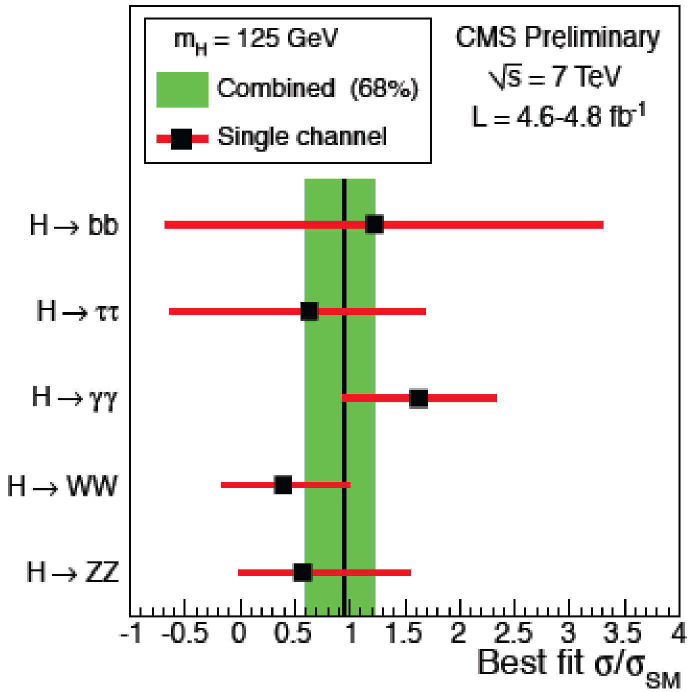
To set exclusion limits on a Higgs boson hypothesis:

$$q_\mu = -2\ln\frac{\mathcal{L}(\text{data}\,|\,\mu\cdot s(\hat{\theta}_\mu)+b(\hat{\theta}_\mu)\,)}{\mathcal{L}(\text{data}\,|\,\hat{\mu}\cdot s(\hat{\theta})+b(\hat{\theta})\,)} \qquad 0 \leq \hat{\mu} < \mu$$

To quantify the statistical significance of an excess over the background-only expectation:

$$q_0 = -2\ln\frac{\mathcal{L}(\text{data}\,|\,b(\hat{\theta}_0)\,)}{\mathcal{L}(\text{data}\,|\,\hat{\mu}\cdot s(\hat{\theta})+b(\hat{\theta})\,)} \qquad \hat{\mu} \geq 0$$


m_H = 119.5 GeV
Combined (68%)
Single channel
CMS Preliminary
$\sqrt{s}$ = 7 TeV
L = 4.6-4.8 fb^{-1}
H → bb
H → ττ
H → γγ
H → WW
H → ZZ
-2 -1 0 1 2 3 4
Best fit σ/σ_{SM}


m_H = 125 GeV
Combined (68%)
Single channel
CMS Preliminary
$\sqrt{s}$ = 7 TeV
L = 4.6-4.8 fb^{-1}
H → bb
H → ττ
H → γγ
H → WW
H → ZZ
-1 -0.5 0 0.5 1 1.5 2 2.5 3 3.5 4
Best fit σ/σ_{SM}