Higgs searches with CMS

Lara Lloret Iglesias
(Universidad de Oviedo – Spain)
On behalf of the CMS collaboration

PHENO2011 – Madison, 10th May 2011

CMS Compact Muon Solenoid

Universidad de Oviedo

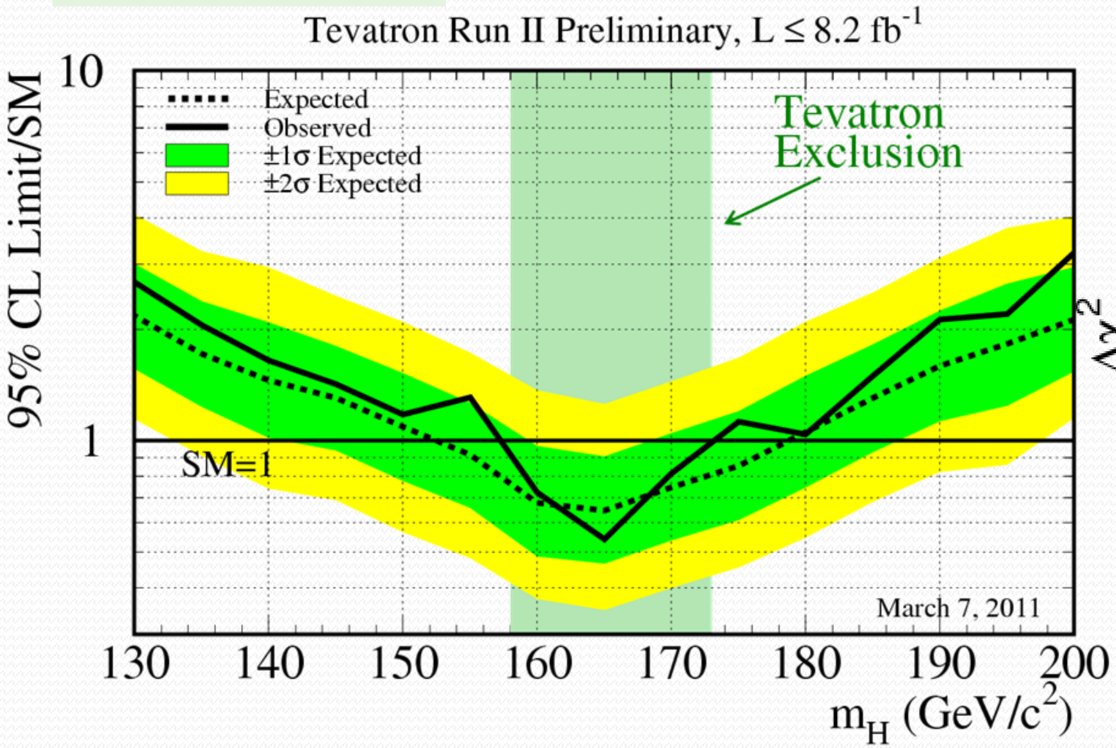
Outline

- **Higgs search status**
- **Higgs production and decay modes at LHC**
- **Public Higgs searches results at CMS:**
  - **$H \to WW \to 2l2\nu$**
  - **MSSM Higgs $\to \tau\tau$**
  - **Charged Higgs**
  - **Doubly charged Higgs**
  - **$H \to ZZ$**
- **Projections**
- **Conclusions**

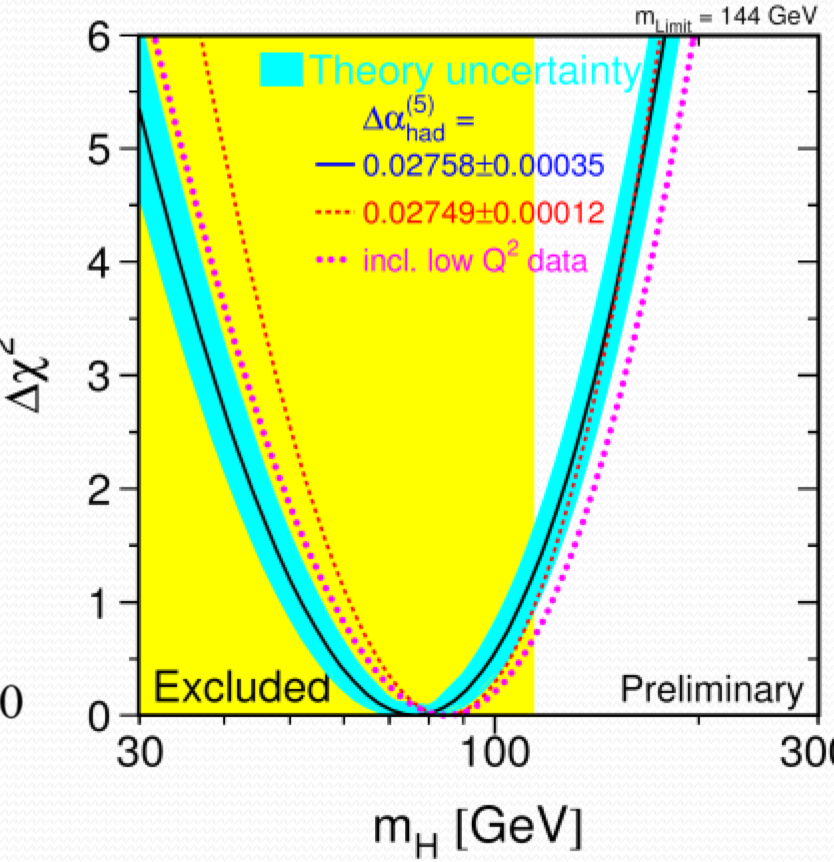
Higgs search status

TEVATRON: 95% CL → 158 < M_H < 175; 100 < M_H < 109 GeV/c^2
LEP: 95% CL → M_H > 114 GeV/c^2

Direct searches



Indirect searches



Higgs production and decay modes at the LHC

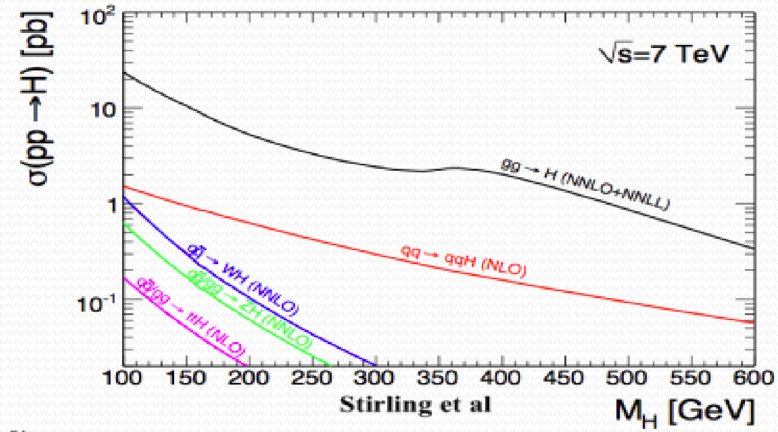
- Dominant production mechanism:

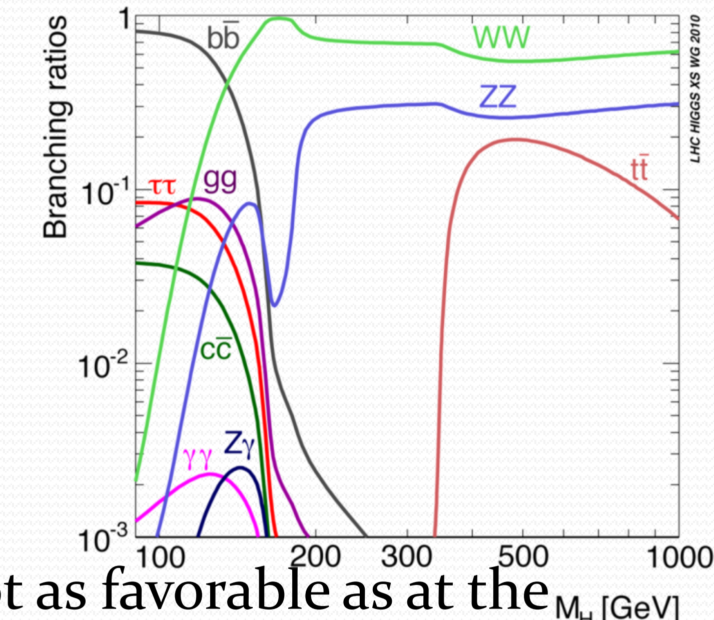
gg → H

- **For M_H > 140 GeV/c²**

- **Dominant decay mode H-> WW,ZZ**

The gg luminosity is **15 times higher** than at Tevatron while dominant backgrounds are produced mainly through qqbar.





- **For M_H < 140 GeV/c²**

Dominant decay modes (ordered by BR)

- H→ bb, ττ, γγ
- Higgs-strahlung (qq→VH) at the LHC is not as favorable as at the Tevatron with main backgrounds coming from ttbar, W/Z+bbar (gg-fusion processes)

CMS

- **Several studies and analysis performed in CMS with 2010 data.**
- **Four of them already published:**

$\bullet H \rightarrow W^+W^-$

$\bullet H^+ \rightarrow \tau^+\nu$

$\bullet H \rightarrow \tau^+\tau^-$

$\bullet H^{++} \rightarrow l^+l^+$

Not enough sensitivity with 36pb^{-1}
but also working on other main channels

$\bullet H \rightarrow ZZ$

$\bullet H \rightarrow \gamma\gamma$

+ Studies of

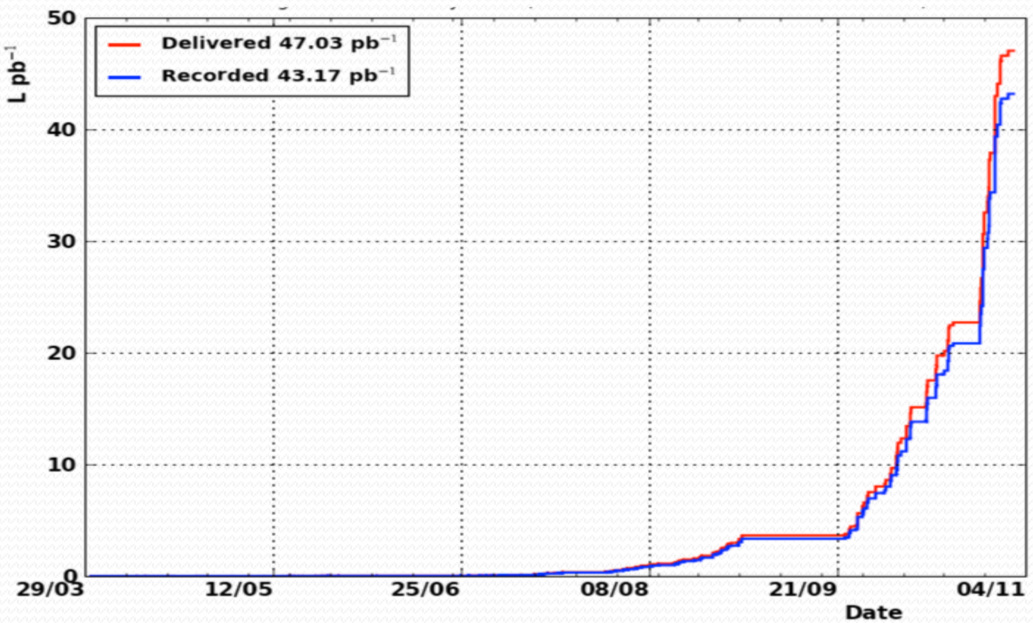
(Irreducible) backgrounds in Higgs searches

$*$ $pp \rightarrow WW$ cross section

$*$ $pp \rightarrow Z \rightarrow \tau^+\tau^-$ cross section

$*$ $pp \rightarrow \gamma\gamma$ rate vs $M_{\gamma\gamma}$

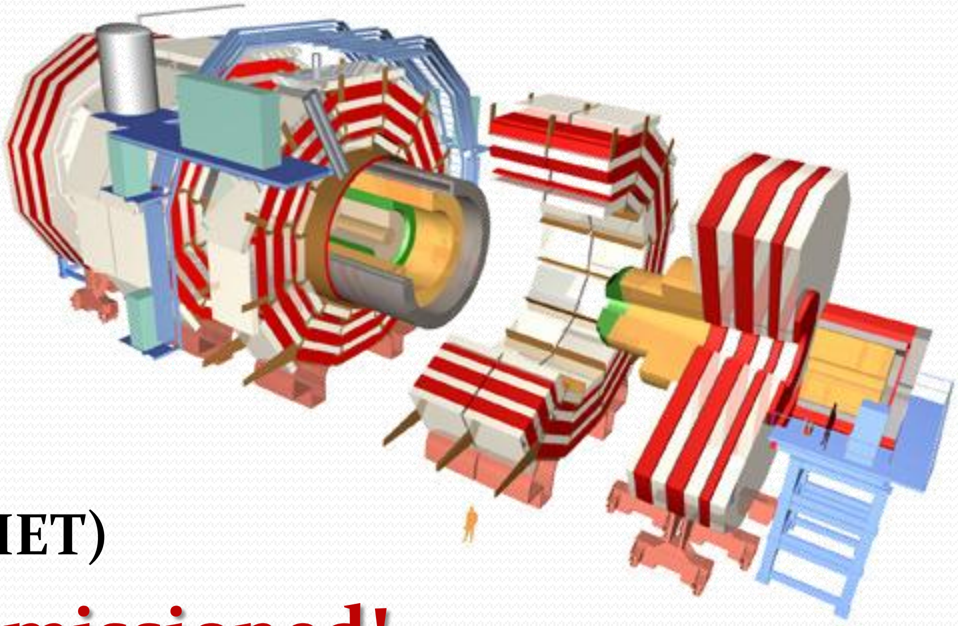
$*$ Discriminating variables in H^+ search



Luminosity uncertainty already < 4% !!
→ Good understanding of the machine

Basic Pillars of Higgs Searches

- **An efficient Higgs search requires excellent performance from the entire detector and several reconstructed objects**
- **Key objects:**
  - **Photon**
  - **Electron and Muon**
  - **Tau**
  - **b quark tagging**
  - **Jets**
  - **Missing transverse energy (MET)**



All tools for searches commissioned!

2010 data has demonstrated the excellent performance of CMS in reconstruction and identification of these basic objects

Performance in data closely matches expectations based on simulations (MC)

H→WW→2l2ν : Main channel for $120 < M_H < 200$

Pros: Large signal production rate.
Cons: No mass peak. Systematic control crucial.

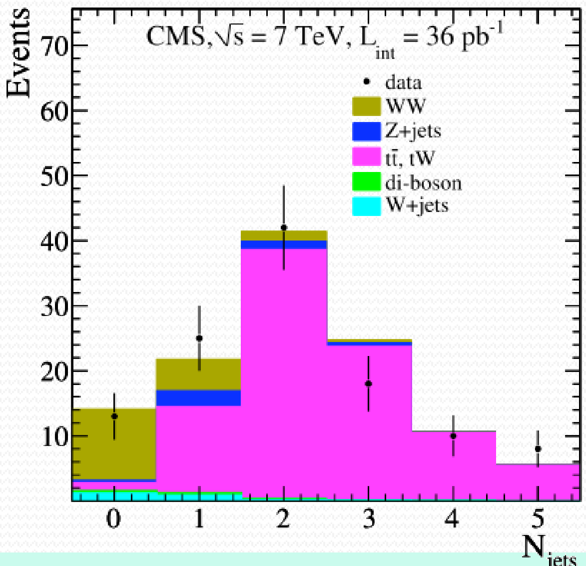
http://arxiv.org/abs/1102.5429
(Together with pp→WW cross section estimation)

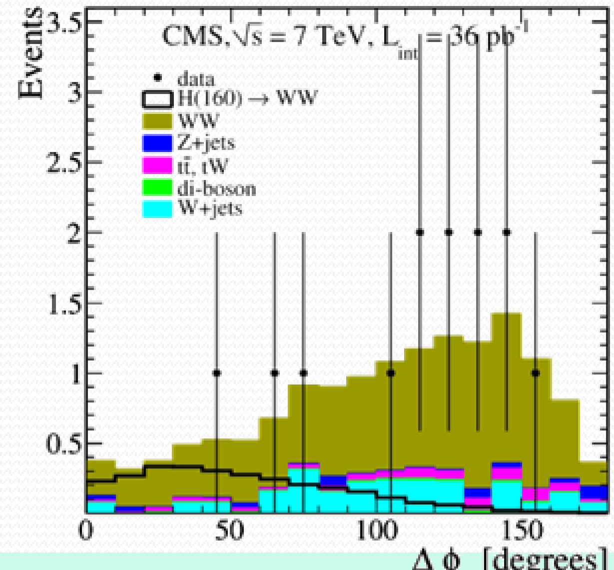
- **Signal:**

2 isolated leptons, small Δφ + MET + 0 (1, 2) jets

- **Reduction and estimation of major backgrounds:**

WW: Irreducible background. Can be decreased using Δϕ between the leptons and m_{ll}. **The WW background estimation** strategy is to select a region with low signal rate and simulation is used to extrapolate this background into the signal region.



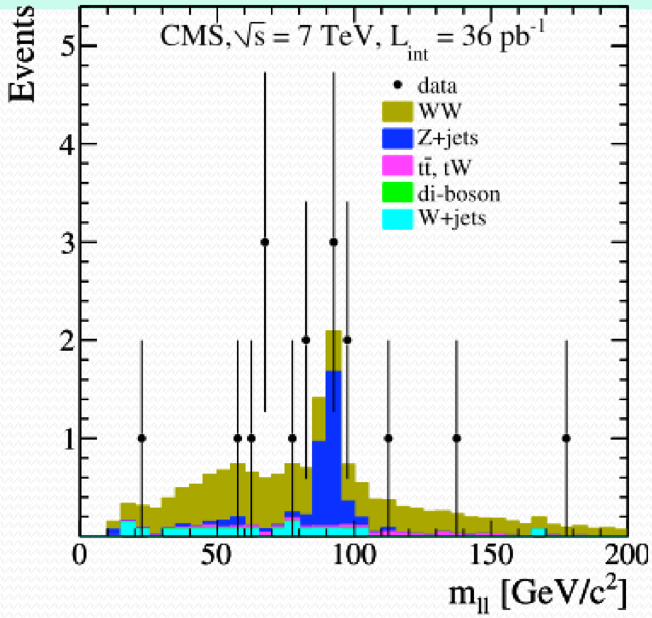


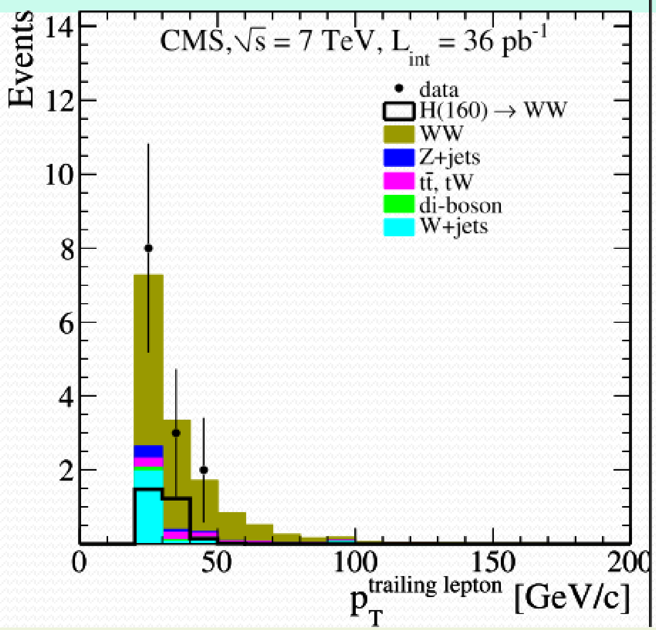
ttbar: Reduced by vetoing events with jets above certain threshold and using top tagging techniques that identify b-quarks.
The remaining ttbar background can be estimated by observing how many events are rejected by top tagging veto after all other cuts including the jet-veto

H→WW→2l2ν search

DY: Main discriminant is to require a **large MET**. **The DY background estimation is** done vetoing events around the Z-mass peak and using them to estimate how much off-peak background remains **taking the ratio of In-to-Out of peak yield from simulations.**

$$N_{\text{out}}^{\ell\ell,\text{exp}} = R_{\text{out/in}}^{\ell\ell}\left(N_{\text{in}}^{\ell\ell} - N_{\text{in}}^{\text{non-Z}}\right), \quad \text{with } R_{\text{out/in}}^{\ell\ell} = N_{\text{out}}^{\ell\ell,\text{MC}} / N_{\text{in}}^{\ell\ell,\text{MC}}$$





W+jets: Main source of fakes. With tight identification and isolation requirements W+jets background contribution can be effectively suppressed. **Background estimation** by looking at **events with looser identification and isolation requirements**.

→Misidentification probability (as a function of η and p_T) is **calculated** in a set of loosely selected lepton-like objects dominated by dijet production and **applied** to a sample with 1 lepton fulfilling all the tight criteria and the other just the looser ones.

H→WW→2l2ν search

2 counting methods used:
- Cut on kinematic observables
- Cut on a BDT output & count

• **Cut based analysis**

→The cut values are tuned for different Higgs mass hypothesis.

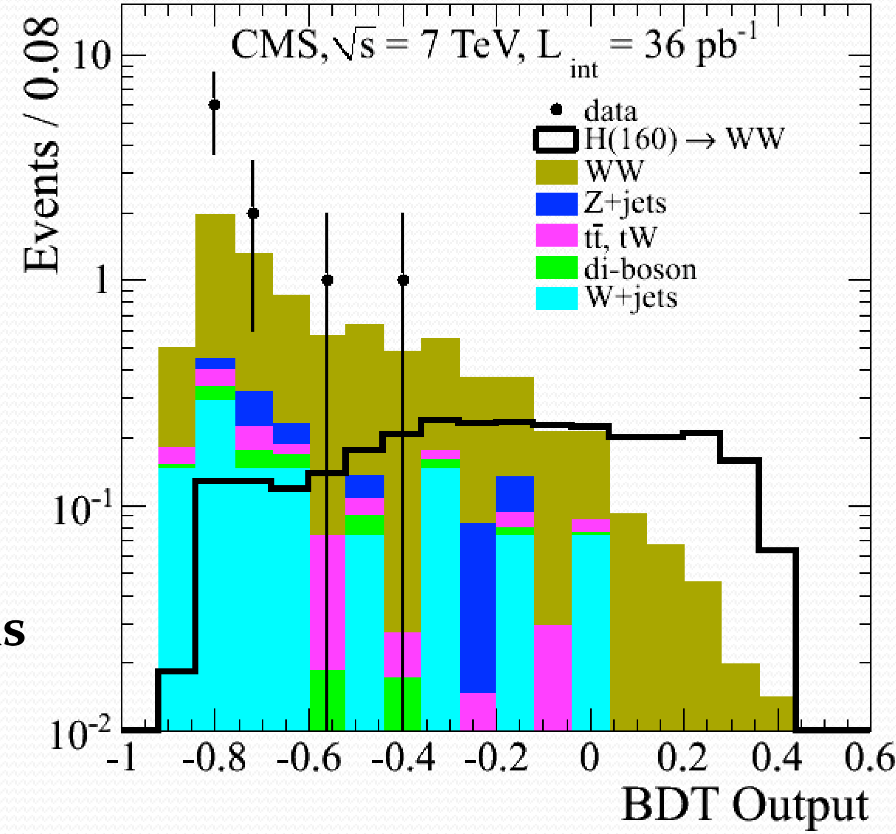
→final state (ee, e μ, μμ)

• **Multivariate analysis** approach uses a Boosted Decision Tree algorithm to combine multiple discriminating variables, such as

→ Angular distributions between leptons and missing energy

→ Dilepton mass, tranverse mass

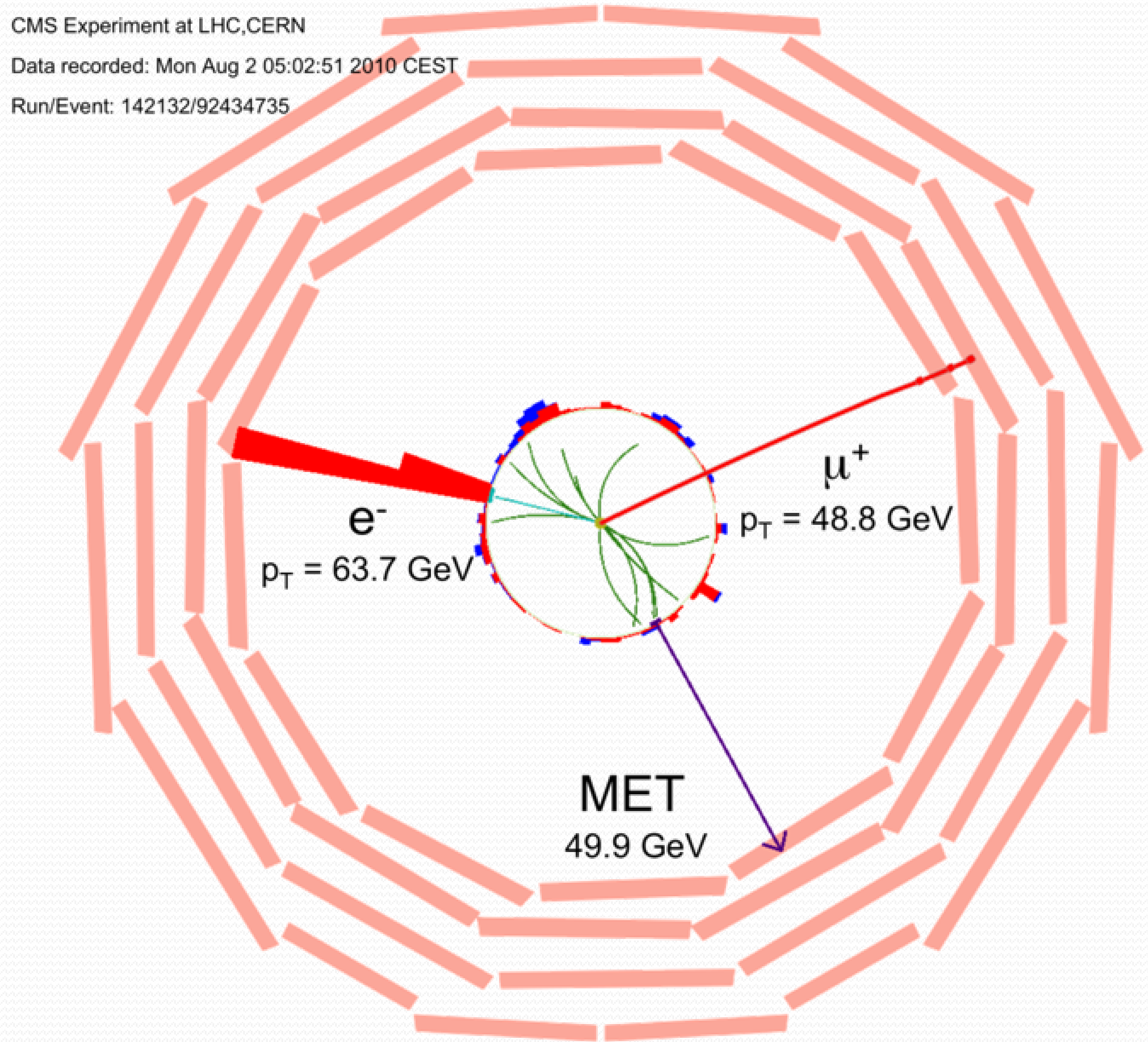
→final state (ee, e μ, μμ)



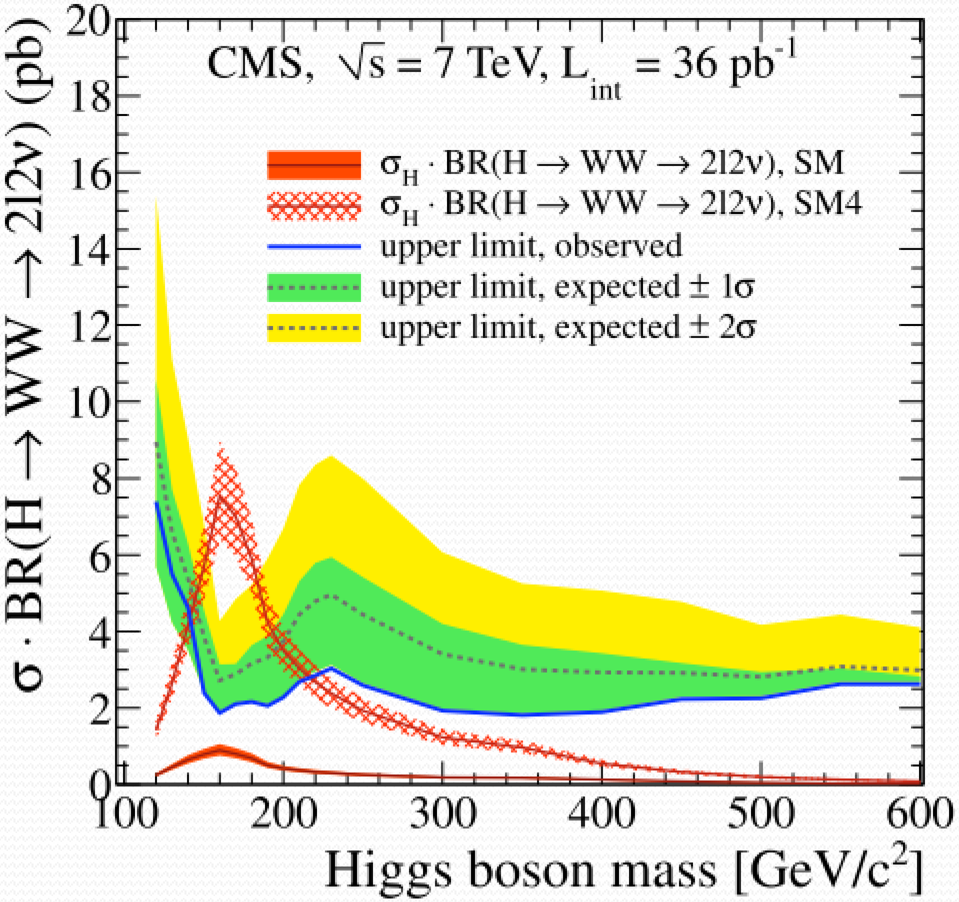
• **MVA gives roughly ~20% better sensitivity**

http://arxiv.org/abs/1102.5429

H→WW→2l2ν search



H→WW→2l2ν : RESULTS



•Upper limit (95% C.L) set is a factor of 3 bigger than the Standard Model x-section for HWW160

• A Standard Model extension with 4th fermion generations that predicts roughly a factor of 9 enhancement in the cross-section.

→ For this model we exclude Higgs in a mass range from 144GeV to 207GeV

In 2011 CMS is going to improve the analysis to increase sensitivity to the Higgs boson signal.

MSSM Higgs → ττ

CMS-PAS-HIG-10-002

Search is similar to those performed at the Tevatron and complementary to the MSSM Higgs search at LEP2

Final states studied:

-Identified e or μ + 1 jet

-Two leptonic tau decays

Main sources of background:

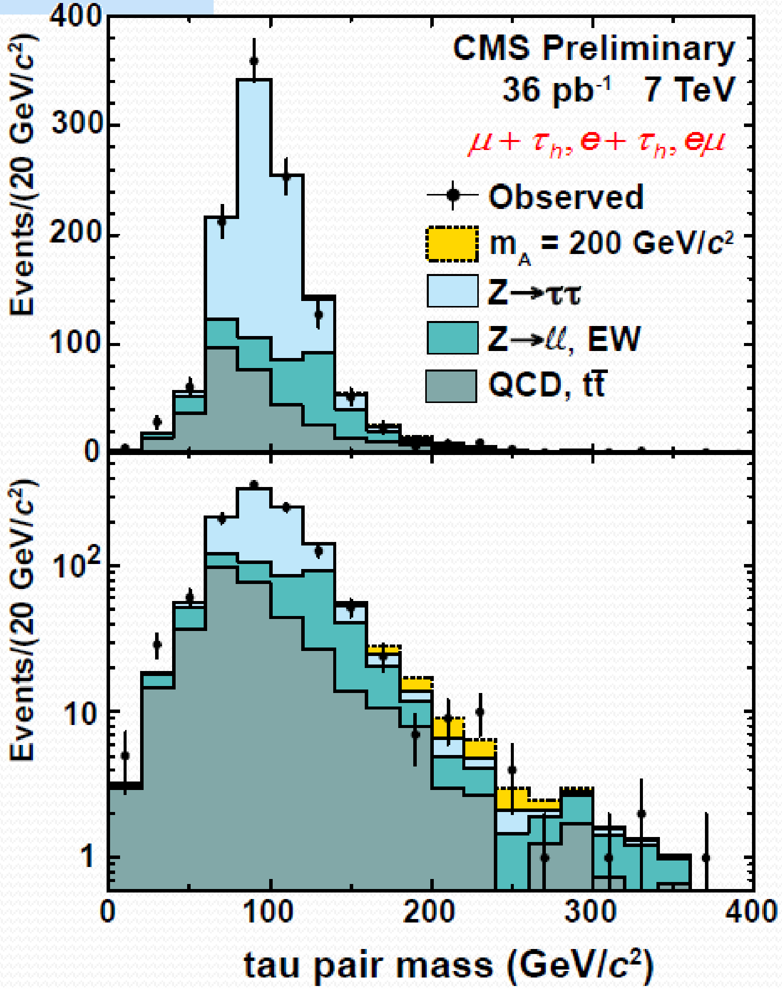
-Z→ττ

-QCD processes: Where a jet is missidentified as an hadronic τ and there is a real or fake high p_T e or μ.

-W+jets: Where a jet is misidentified as an hadronic τ.

Other background sources:

-ttbar, Z→ee/μμ

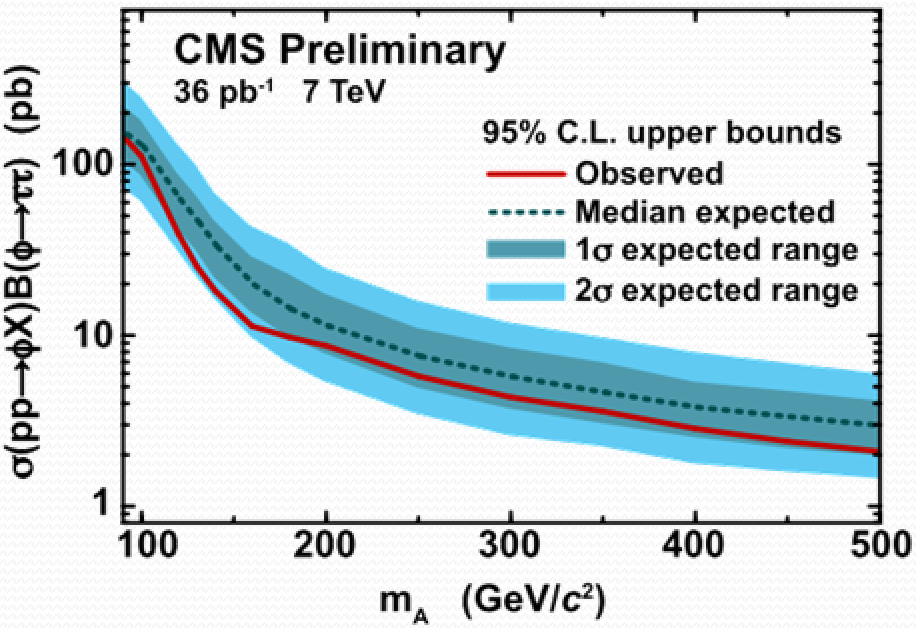


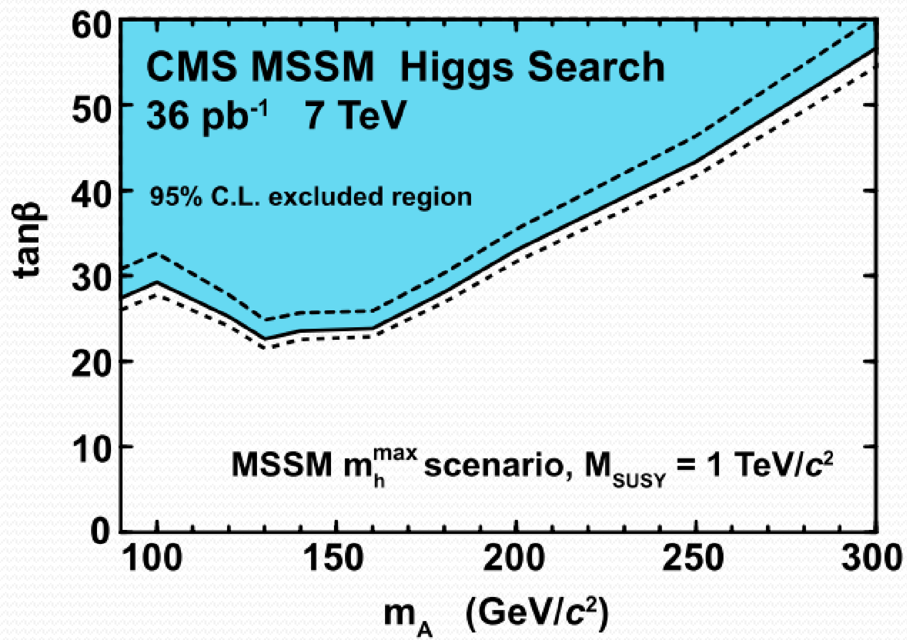
To distinguish the higgs boson signal from the background the tau pair mass is reconstructed using a likelihood technique.

MSSM Higgs → ττ : Results

No signal excess observed

- Set upper limits on σ(pp → ΦX) x BR(Φ → ττ), assuming tanβ = 30
- Can also be interpreted in MSSM parameter space of tanβ vs m_A, choosing a benchmark scenario
  - **Significantly extends previous limits**





CMS-PAS-HIG-10-002

Charged Higgs boson

Charged Higgs bosons may contribute to ttbar decays

• Same selection as for ttbar cross section measurement [CMS PAS-TOP-10-002]

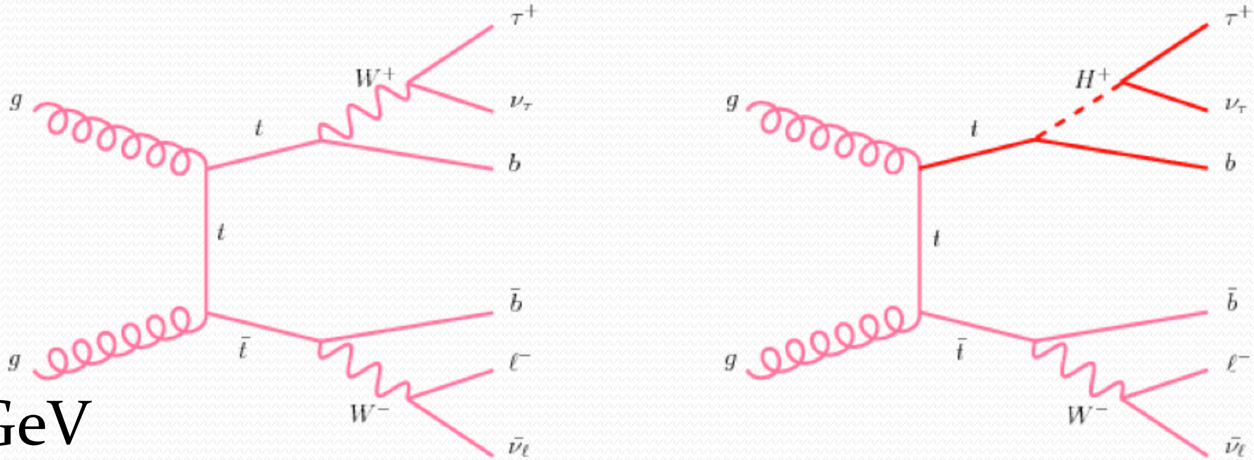
CMS-HIG-11-002

→One electron (muon) with p_T > 30 (20) GeV

→At least two jets

→MET > 40 GeV

→Hadronic τ p_T > 20 GeV



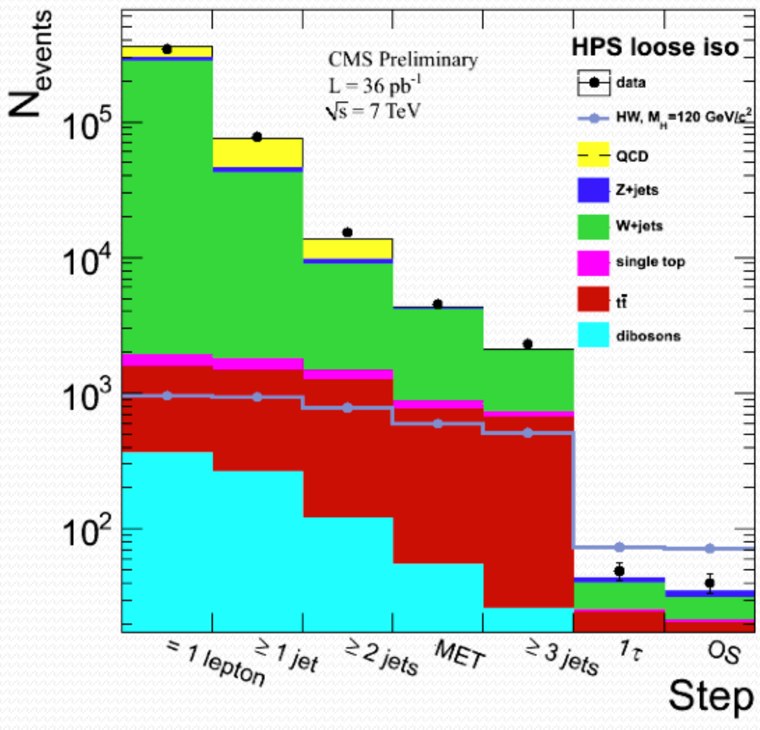
Substitute $H^\pm$ for $W^\pm$ in ttbar decays to τ

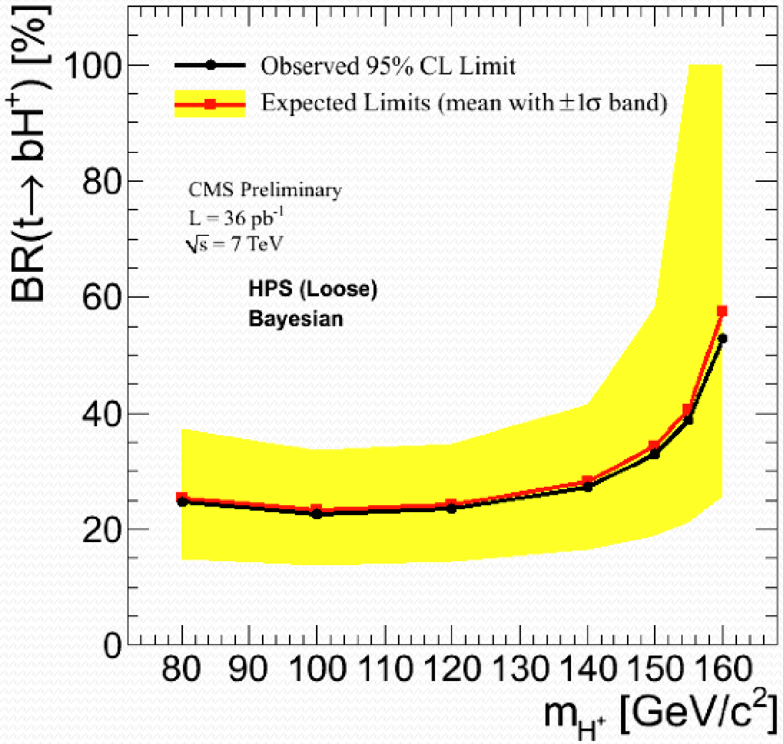
•Backgrounds in two categories:

→ Fake hadronic τ: use fake rate method to estimate from data
→ Real hadronic τ: use simulation to estimate background

Charged Higgs

CMS-HIG-11-002





No signal observed

- Assuming BR($H^+ \rightarrow \tau^+ \nu$)=1 limits has been set (95% C.L) on BR ($t \rightarrow bH^+$)
- Limit ~0.25-0.30 for 80 GeV < mH^+ < 140 GeV
- Limits are already comparable with Tevatron

Doubly charged Higgs

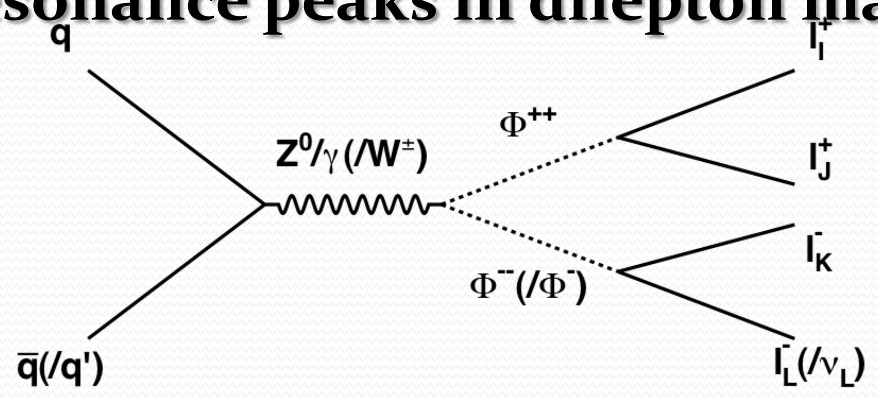
Possible to extend Standard Model adding scalar triplet: $\Phi^{\pm\pm}$, $\Phi^{\pm}$ and Φ^{0}

→**Triplet responsible for neutrino masses**

CMS-HIG-11-001

- Look for events with **3 or 4 isolated leptons**
- Decay to $W^{+}W^{+}$ kinematically forbidden
- Consider model where $\Phi^{\pm\pm} \rightarrow l^{\pm}l'^{\pm}=1$

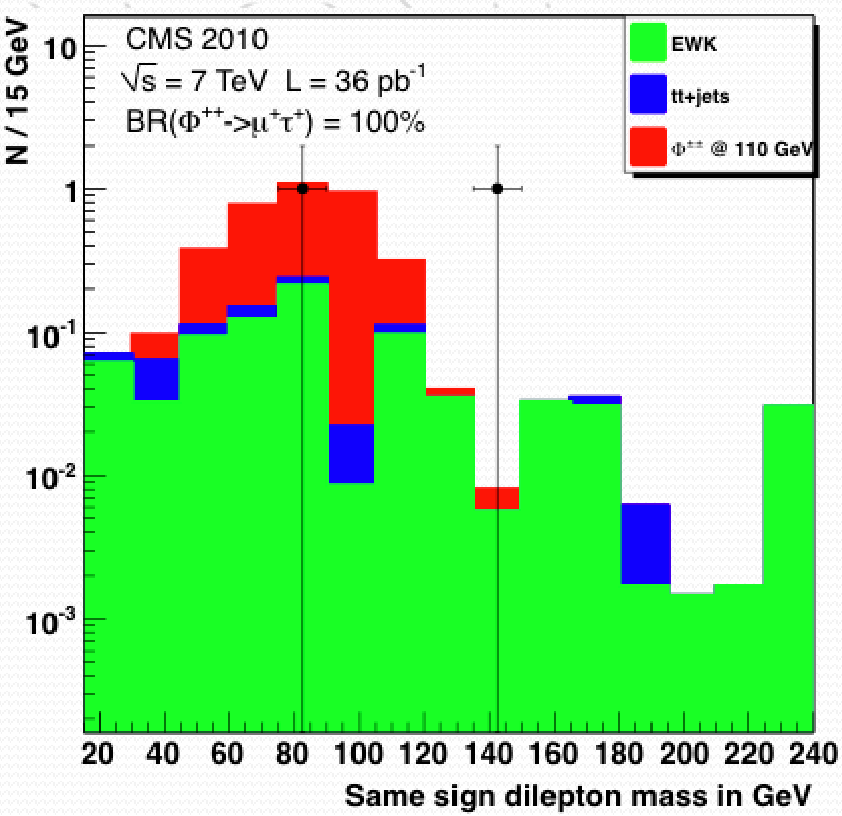
→Strategy: **Look for resonance peaks in dilepton mass distributions**



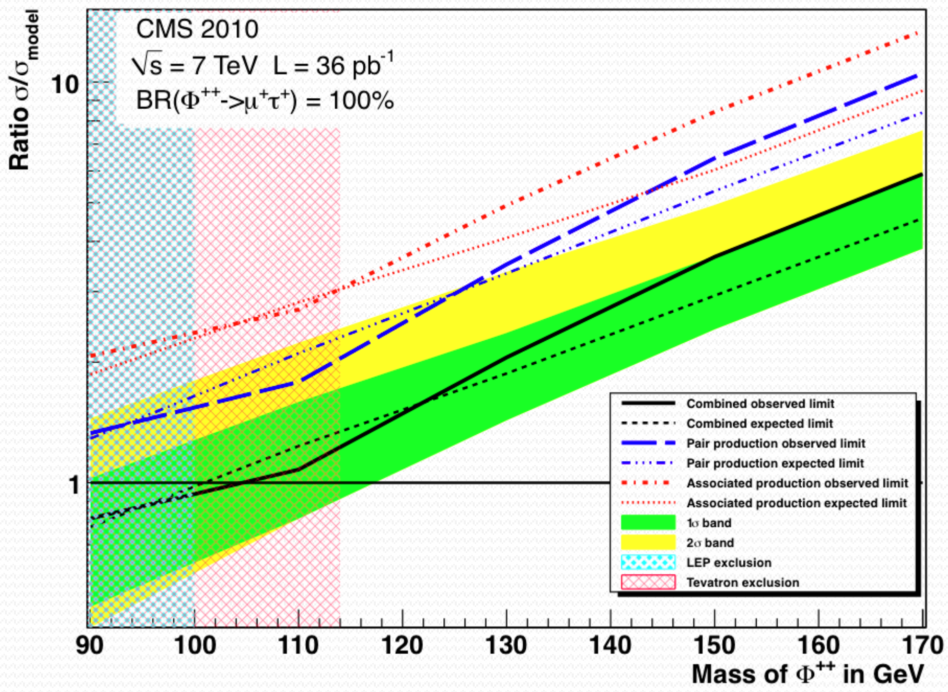
Doubly charged Higgs

CMS-HIG-11-001

→ Example for $\mu^+\tau^+$ final state (one of many considered)



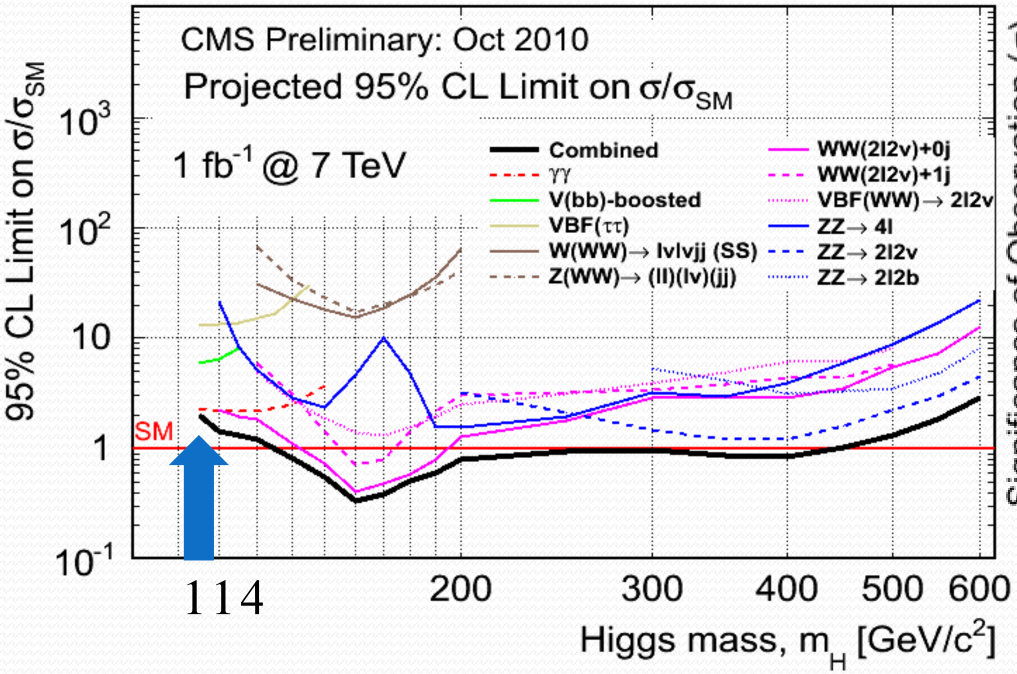
Exclusion limit (95% confidence level)



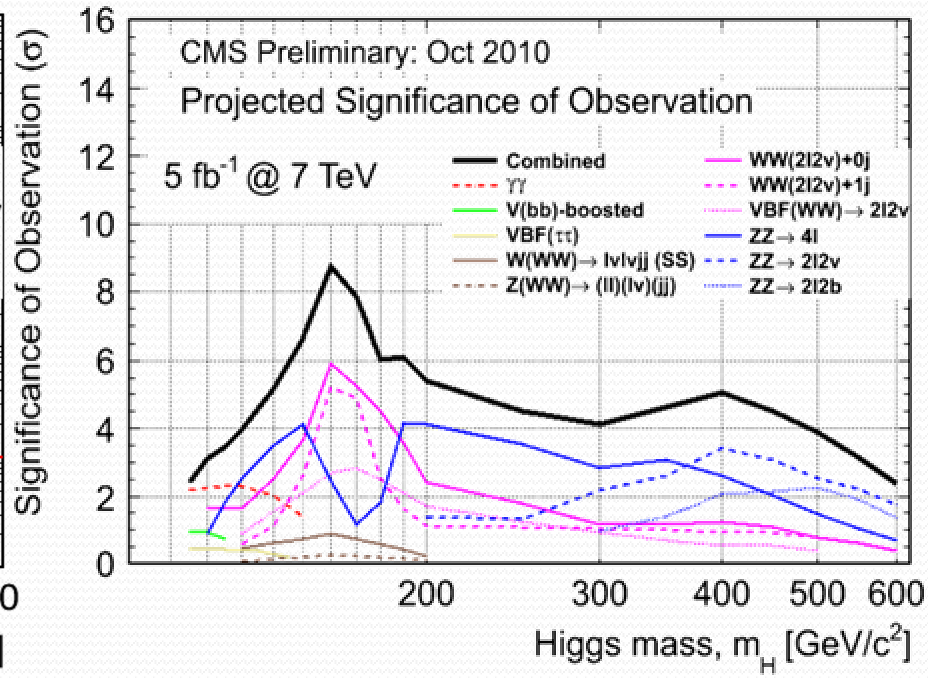
No signal observed. Set limit on cross-section: extending reach of previous experiments

SM Higgs: CMS projections

Projected exclusion with 1 fb^{-1}



Projected significance with 5 fb^{-1}



Conclusions

- First Higgs searches from CMS shown
- Unfortunately no observations yet ➔ set limits
- Commissioned all the tools for searches
- Wide range of searches underway, with novel techniques!
- Ready to make discoveries in 2011/12!

Backup slides

H→ZZ→4l : Golden channel

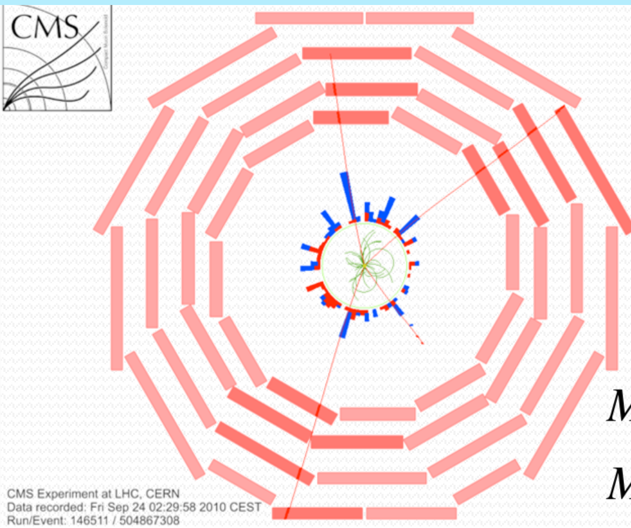
Pros: Mass peak for the signal.
Cons: Low signal rate. Need to push lepton ID for highest possible efficiency and excellent energy and momentum resolution

No public results yet

Signal:
Clear and narrow mass peak

Main background:
- **ZZ → irreducible background**
- ttbar & Z+bb →removed by lepton isolation and impact parameter requirements

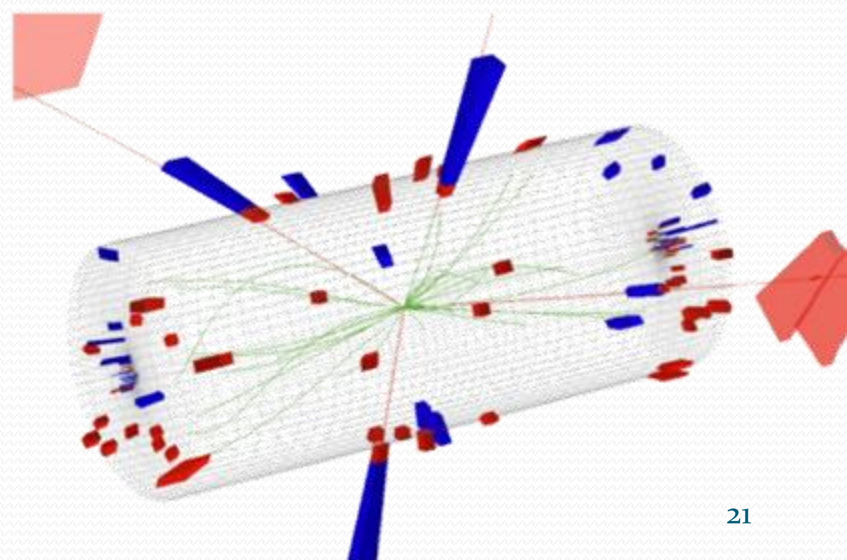
Event selection:
- Four lepton (4e, 2e2μ, 2μ)
- Looking for at least one on shell candidate.



$P_t^{\mu 1} = 48.1$ GeV
$P_t^{\mu 2} = 43.4$ GeV
$P_t^{\mu 3} = 25.9$ GeV
$P_t^{\mu 4} = 19.6$ GeV

$M_{\mu 1 \mu 2} = 92.15$ GeV
$M_{\mu 3 \mu 4} = 92.24$ GeV
$M_{4\mu} = 201$ GeV

Prob. of observing a pp→ ZZ →4μ event in 36 pb^{-1} is ~ 20%



All muons coming from the same vertex.

Projections

Higgs production/decay channels and mass range used for the projections in previous slides

Channels included	Higgs mass range used in analyses (GeV)
$H \rightarrow \gamma\gamma$	115-150
VBF $H \rightarrow \tau\tau$	115-145
VH, $H \rightarrow bb$ (highly boosted)	115-125
VH, $H \rightarrow WW \rightarrow l\nu jj$	130-200
$H \rightarrow WW \rightarrow 2l2\nu$ + 0/1 jets	120-600
VBF $H \rightarrow WW \rightarrow 2l2\nu$	130-500
$H \rightarrow ZZ \rightarrow 4l$	120-600
$H \rightarrow ZZ \rightarrow 2l2\nu$	200-600
$H \rightarrow ZZ \rightarrow 2l2b$	300-600

Some simulated events