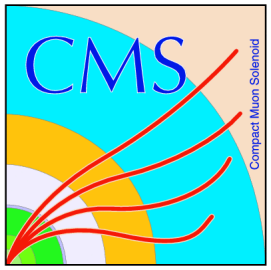



Vrije Universiteit Brussel

# Higgs and SUSY searches in CMS

**Rebeca González Suárez**

**for the CMS collaboration**

29 November 2010

**II CPAN days, Valencia**


IFCA

Instituto de Física de Cantabria

# Introduction

**The Standard Model** (SM) of Particle Physics is in very good agreement with the experimental data, but there are still some uncovered aspects, open questions that the LHC will try to answer

Reveal the physical mechanism responsible for **the breaking of electroweak symmetry**, responsible for the masses of the particles

A simple mechanism (among many others) that can be incorporated to the SM to solve this is the **Higgs Mechanism**, that leaves the SM mostly untouched and:

- adds one additional scalar boson that has to be detected, **the Higgs boson**

**Supersymmetry** gives a solution for the **hierarchy problem** (protect $m_H$ from divergence) and the **unification of all the forces** including gravity, also provides an important candidate for Dark Matter

This talk reviews some of the **searches oriented to find a SM Higgs boson** and introduces **Minimal Supersymmetric (MSSM) and Supersymmetric (SUSY) searches in CMS**, with prospects for the early running of the LHC

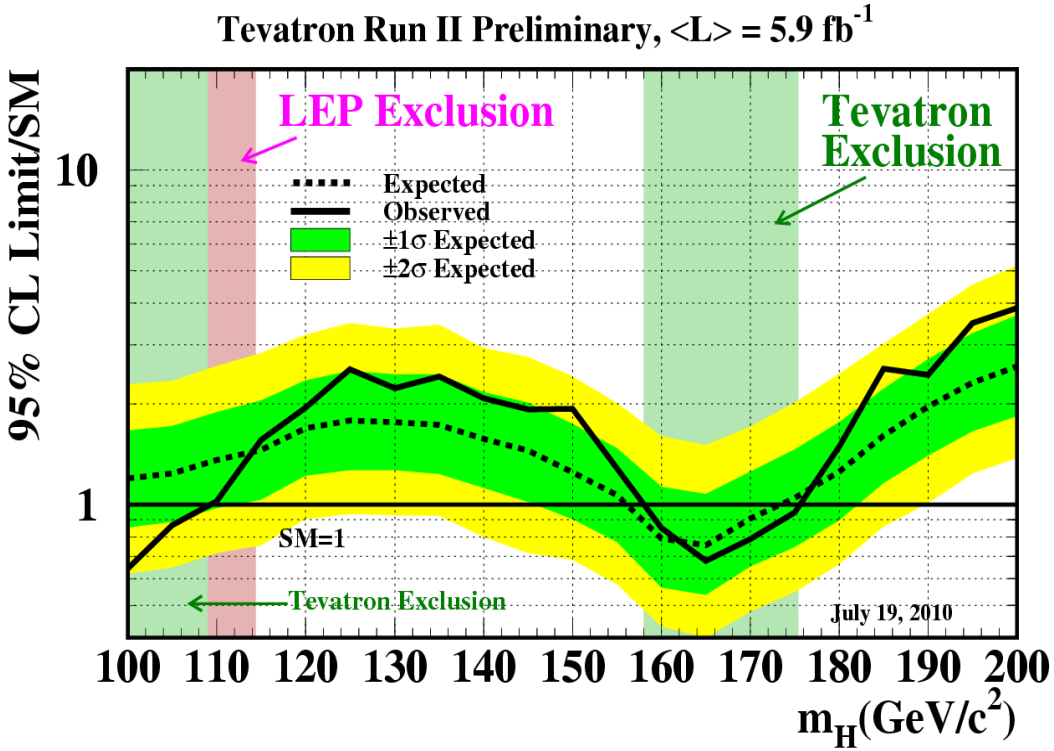
# Previous and Current Higgs Searches

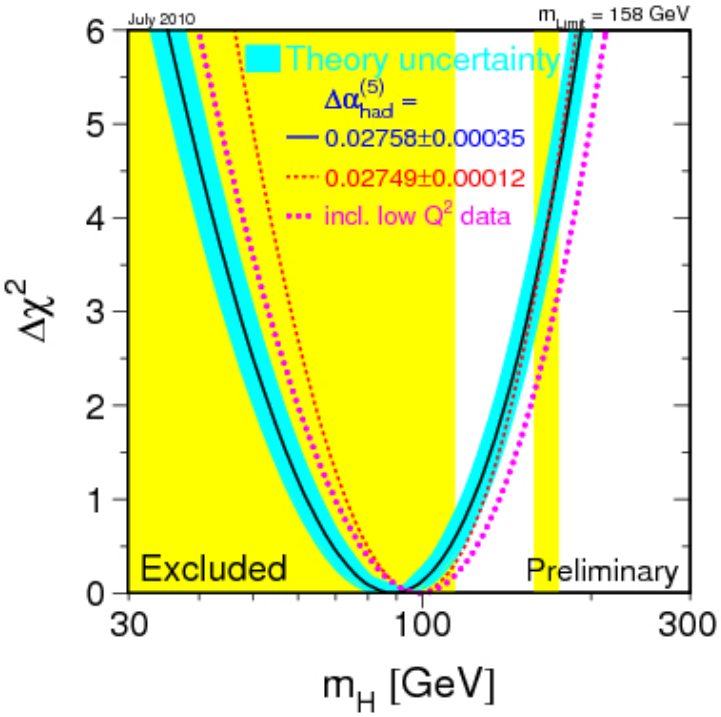
Current search scenario defined by **direct and indirect measures**:

**LEP** set a 95% CL limit of $m_H \geq 114.4$ GeV/$c^2$

**Precision electroweak measurements** tell that, for a Standard-Model Higgs boson:

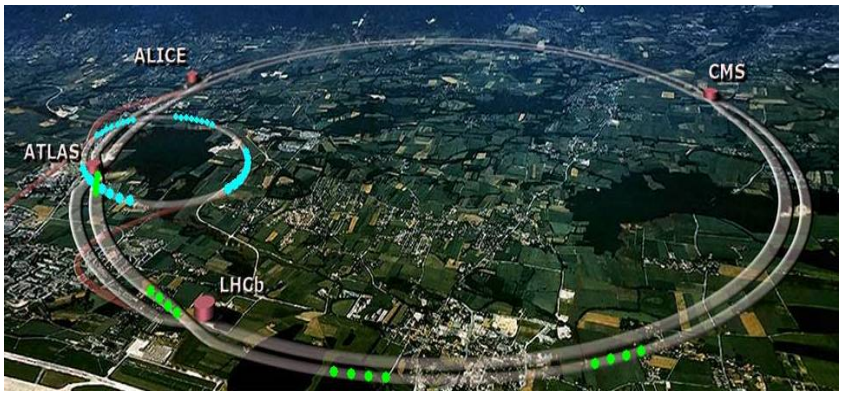
$m_H <$ ~158 (185 GeV/$c^2$ with LEP-2 data)




The **most recent** combined result from the Tevatron experiments **CDF** and **DØ**, **excludes the mass range between 158 and 175 GeV/$c^2$, and between 100 and 109 GeV/$c^2$ at 95% CL**

# The Large Hadron Collider




The **Large Hadron Collider** (LHC) the largest and highest-energy particle accelerator of the world, located at CERN (Geneva, Switzerland)

It has 4 big experiments (**ALICE, ATLAS, CMS, LHCb**), two of them (**CMS** and **ATLAS**) intended for general purposes

It operated at a **proton-proton** collision energy of **7 TeV** since March 30$^{th}$ 2010
Continuously collecting luminosity in pp collisions until heavy ions run (November 7) delivering ~ 47pb$^{-1}$

**Plans for next year:**

- Beam back at the end of February
- End of run – 12$^{th}$ December
- **~200 days proton physics**
- (+ 4 weeks ion run)

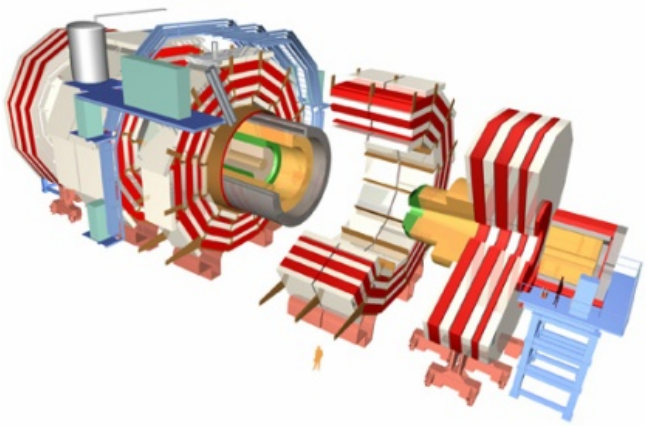
**Collision energy: 8 TeV**
(to be decided in Chamonix)

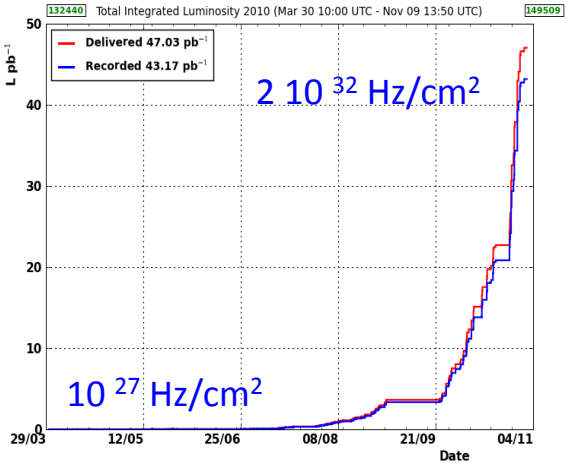
| | "Reasonable numbers" | "Ultimate reach" |
|---|---|---|
| Peak luminosity | 6.4 x $10^{32}$ | 2.2 x $10^{33}$ |
| Integrated per day | 11 pb$^{-1}$ | 38 pb$^{-1}$ |
| 200 days | **2.2 fb$^{-1}$** | **7.6 fb$^{-1}$** |
| Stored energy | 72 MJ | 134 MJ |

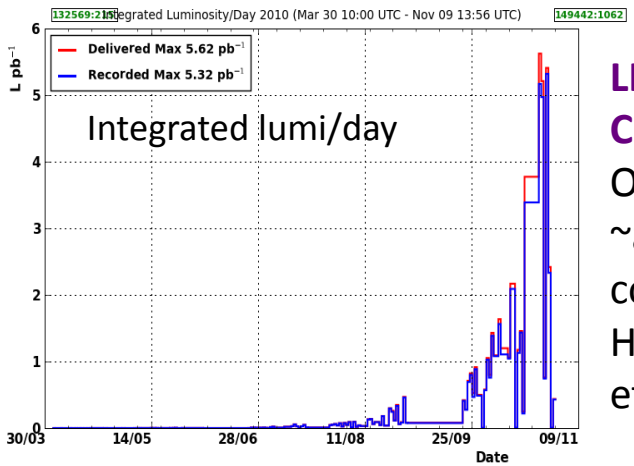
# The Compact Muon Solenoid

**CMS** is, with ATLAS one of the two main general purpose LHC experiments
CMS stands for **Compact Muon Solenoid**

**Compact**
"Small" in size when compared to ATLAS, but two times heavier
**Muon**
Optimized for Muon detection
**Solenoid**
Magnetic field produced by a superconducting solenoid





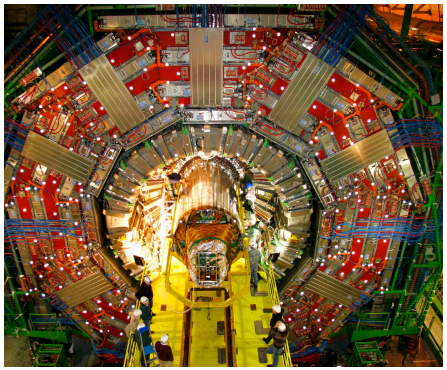



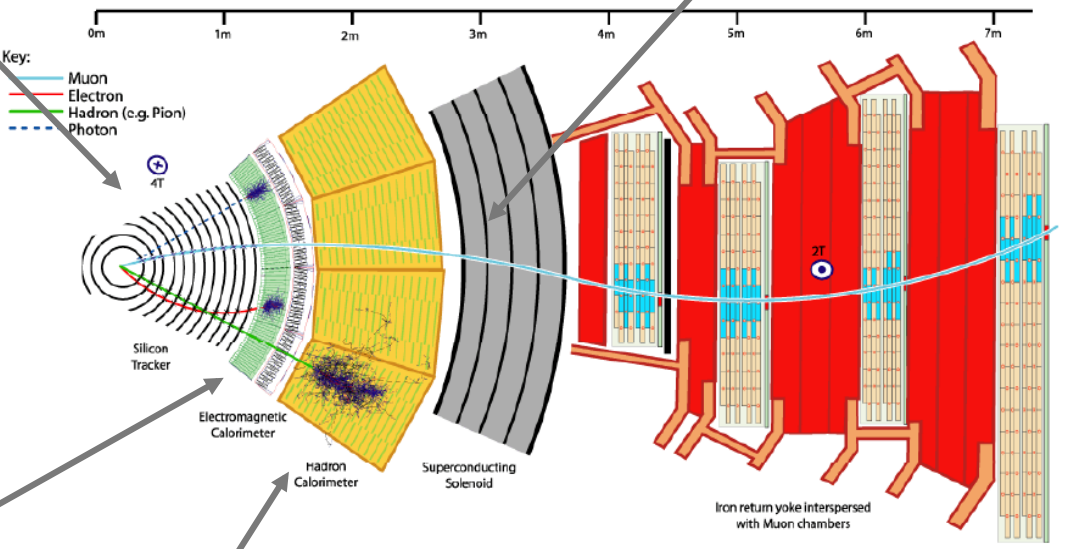

**LHC Delivered 47 pb$^{-1}$**
**CMS recorded 43 pb$^{-1}$**
Overall data taking efficiency 92%
~85% with all sub-detectors in perfect conditions
Heavy Ions: delivered ~ 1.96 $\mu$b$^{-1}$, efficiency > 95%

# The CMS detectors

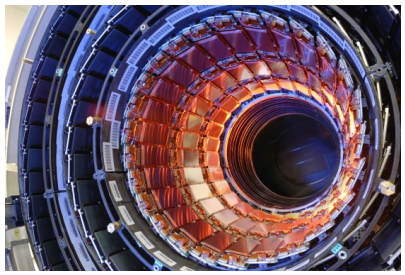
Tracker
Charged Particles

Superconducting solenoid






Electromagnetic Calorimeter (ECAL)
Electrons and photons



Hadronic Calorimeter (HCAL)
Hadrons
Protons, neutrons, pions, kaons…
Jet/MET measurements

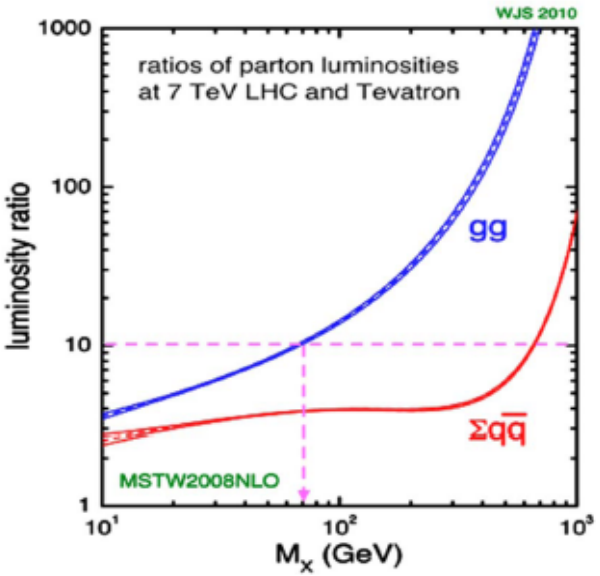
Muon System
Identify muons
Measure Pt
Trigger

Drift tubes (DT)
Cathode Strip Chambers (CSC)
Resistive Plate Chambers (RPCs)

# LHC Vs. Tevatron

- The Higgs searches at the first period of the LHC will go in paralell with the Tevatron experiments
- Expectations 2011

| | | Energy (TeV) | L ($fb^{-1}$) |
|---|---|---|---|
| TeVatron | (p+ p-) | 2 | 2 |
| LHC | (p p) | 7-8 | 2-7 |




**The LHC benefits from:**

**Higher cross-sections**

More than a factor 10 for gg processes at certain masses

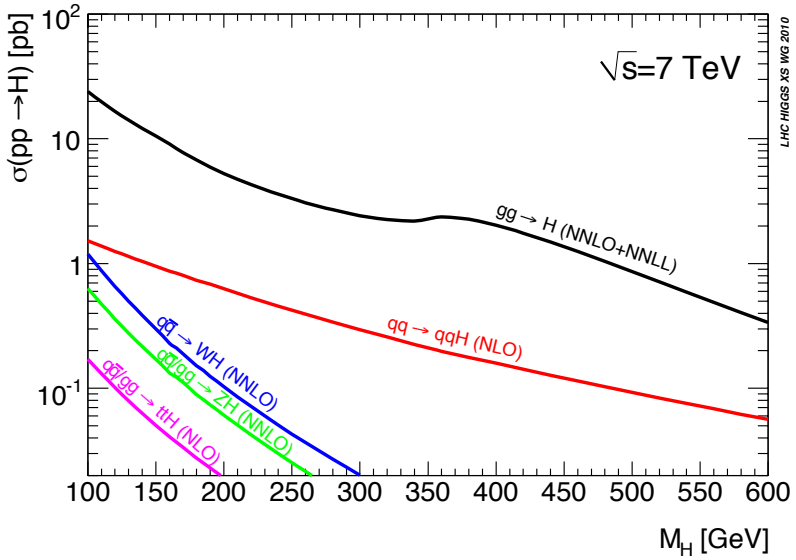
**Better S to B**

The effect in the cross-section less pronounced for qq-induced processes, especially at high masses

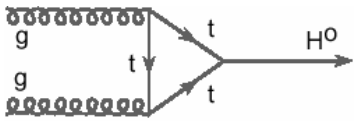
**Detectors optimized for Higgs searches**

# Higgs production at the LHC

The Search Strategy for a particular Higgs mass hypothesis → determined by the **production mode** and **decay channel**

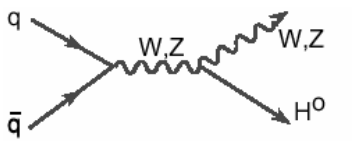


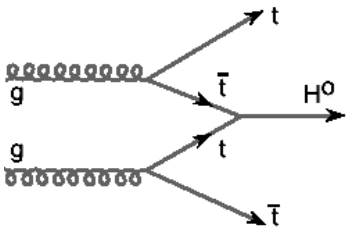

**Gluon-gluon fusion** (**ggH**):
Dominant production mode

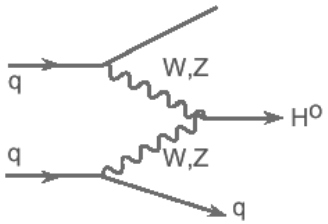



**Vector Boson Fusion, VBF** (**qqH**):
Characteristic signature with two forward jets and rapidity gap, increasingly important for high masses

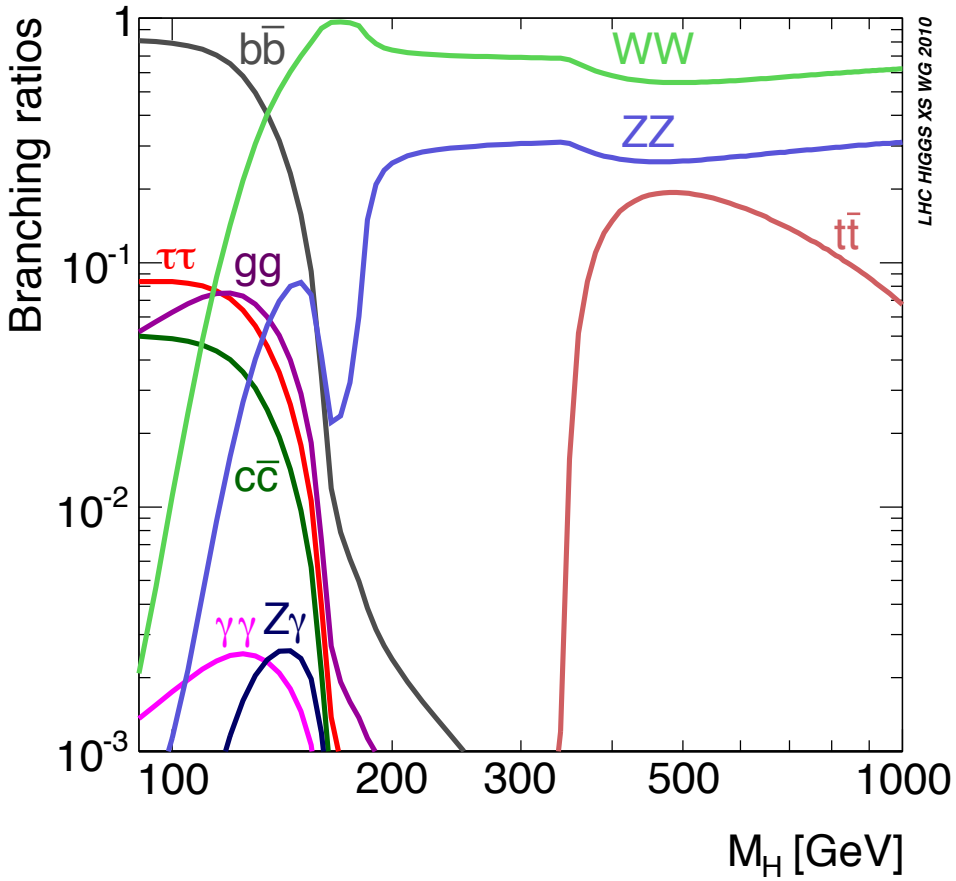
**Associated production** (**WH**, **ZH**, **ttH**): Relevant in the low mass region, allows for'easy' triggering



# Higgs decay modes




**Low mass ($m_H < 2m_Z$)**

**H→bb**: Highest BR for low masses. Challenging experimentally, huge QCD background

**H→ττ**: Collinear approx.→mass reco. Accesible through VBF

**H→γγ**: Mass-peak with good resolution

**High mass ($m_H > 2m_Z$)**

**H→tt**: Difficult selection

**H→WW**: **Earliest sensitivity**

**H→ZZ:** Very clean experimental signature with 4 leptons.

# Higgs Searches in CMS

**CMS works in a wide range of Higgs decay channels**, and will be producing results very soon

**gluon-gluon fusion Higgs decaying to → $\gamma\gamma$, ZZ, WW**

VBF Higgs → WW/ZZ/invisible/$\tau\tau$

MSSM Higgs → $\tau\tau$, Light/heavy/double charged Higgs

+ more to come!

**Public results with Monte Carlo** for different center of mass energies (14-10)

Projections for the **current √s 7 and 8 TeV scenarios**: **Bayesian Exclusion Limits (95%CL)** and **Significance**

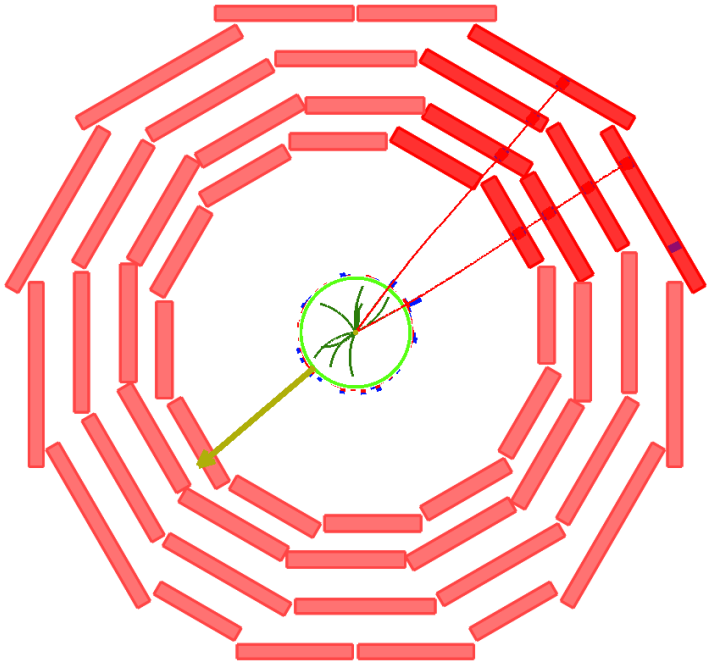
**About the projections**

Using public results at 14 TeV and more recent (not public) studies at 7 and 10 TeV.
Re-scale signal and background event counts to **7-8 TeV** cross sections and integrated luminosities of **1-10 fb$^{-1}$**

- No corrections for acceptance at different √s or improvements in reconstruction (efficiencies, resolution)

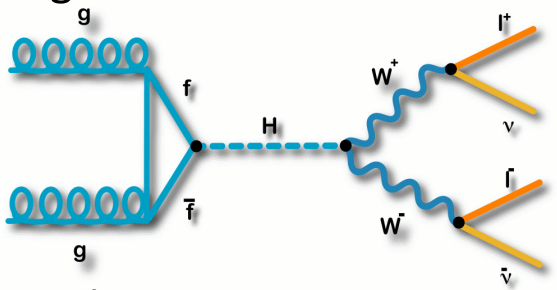
-Systematic errors included (scaled with energy/luminosity)

# SM H → WW* → 2l2ν



**Backgrounds:**
Real or fake multi-lepton final states + missing ET:
*'irreducible'* **WW (WZ, ZZ),**
**ttbar (tW),**
**Drell-yan, W+jets…**

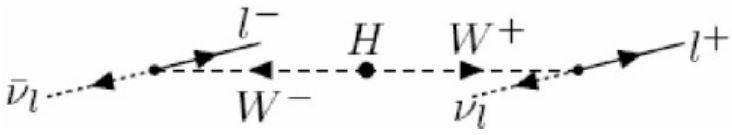
- The **discovery channel** for a SM Higgs boson in a wide mass range in the LHC




- Branching ratio close to 1 in

$$2m_W < m_H < 2m_Z$$

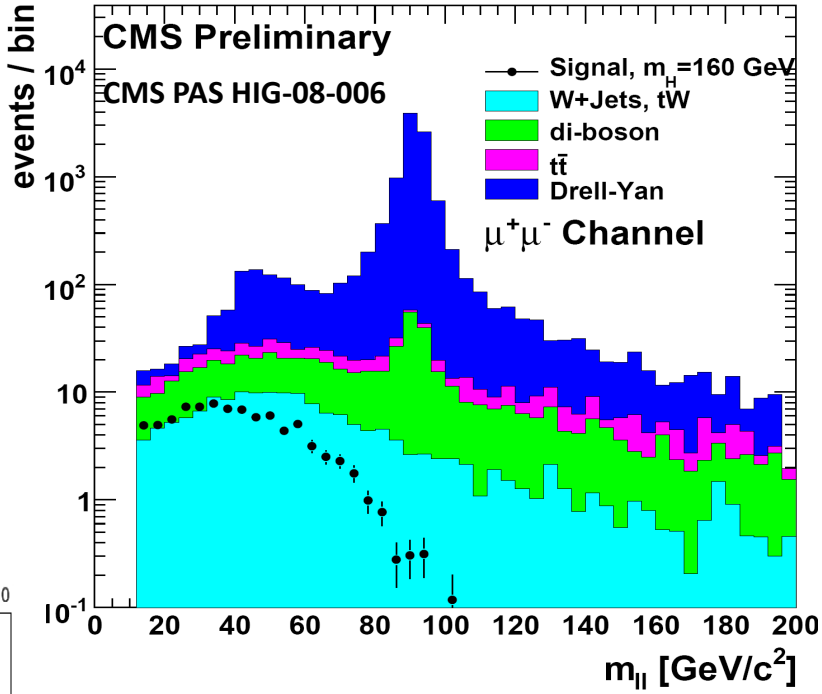
- Clear **experimental signature**:
  - 2 high PT leptons with opposite charge and a **small transverse opening angle** (spin correlations)

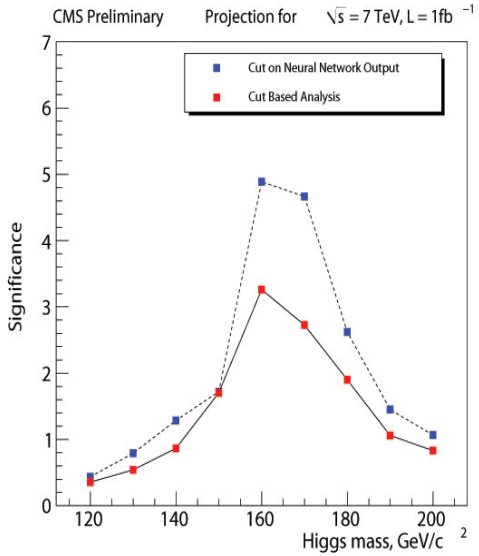



  - Missing ET
  - No jets (GF) or two forward jets with rapidity gap (VBF)

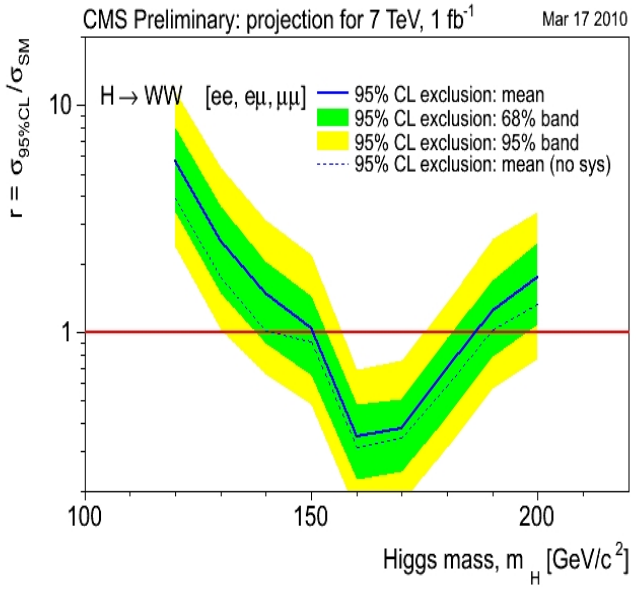
# SM H → WW* → 2l2ν

**ee, μμ, eμ final states**
**No mass peak**
Good **knowledge of backgrounds** mandatory
(control regions & data-driven methods)
Sequential cuts
Multivariate approach
*H+0j* (+ independent VBF analysis)



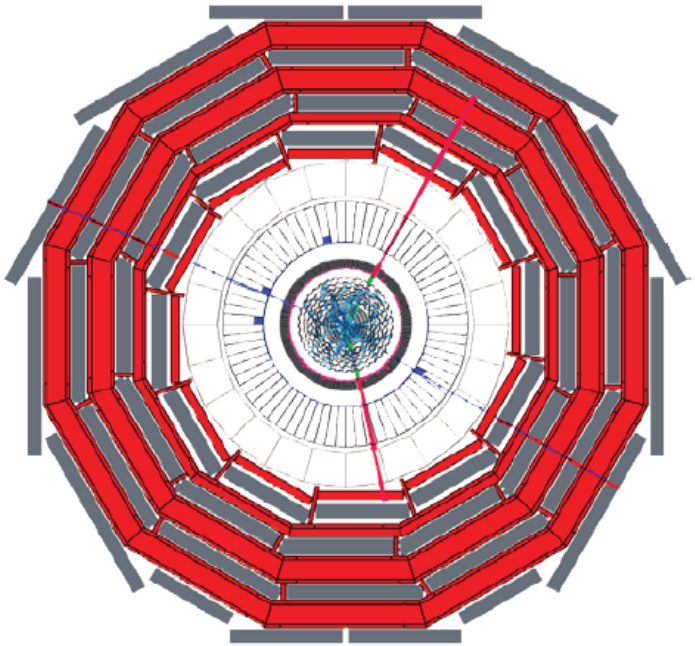




**CMS AN 2010/008**




**7 TeV,** ∫Ldt = **1fb$^{-1}$ (projection)**
Exclusion 95%CL: **150<$m_H$<185 GeV**
**Discovery level sensitivity** (~5σ) :
**160<$m_H$<170 GeV**

# SM H → ZZ*→ 4l



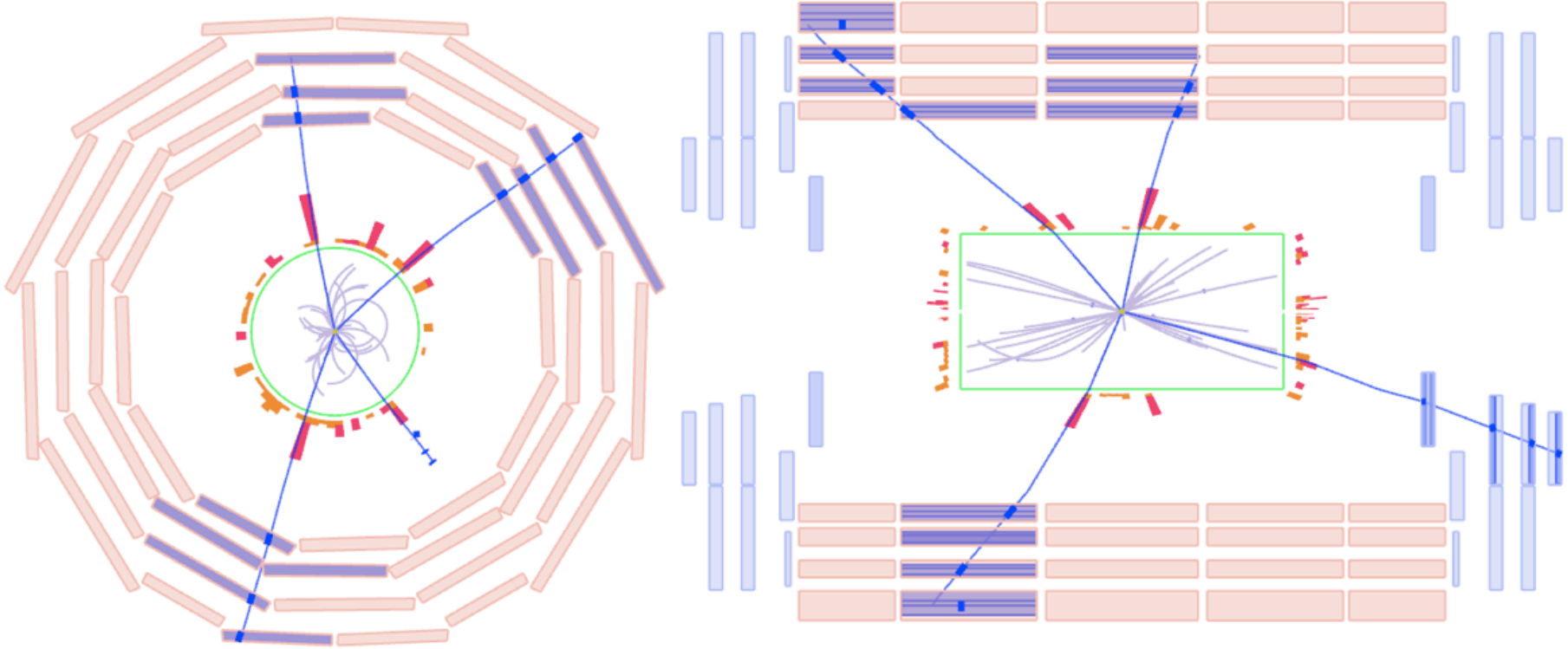
**'Golden' Higgs decay**:
experimentally cleanest signature for discovery
**Narrow 4-lepton invariant mass peak** on top of a smooth background
Wide mass range

Challenge: $m_H$ between 120 and 150
**(one of the Z's off-shell)**

2 pairs of same flavour, opposite-sign leptons
(**4e, 4μ, 2e2μ**)
H mass reconstruction
Lepton isolation & impact parameter cuts
Background estimation by fit on sidebands

**Backgrounds:**
Irreducible: **ZZ*** dominant
Reducible: **Zbb, tt, ZW, Z + X**

# First ZZ candidate



**First ZZ → μμμμ candidate**
**Recorded by CMS**

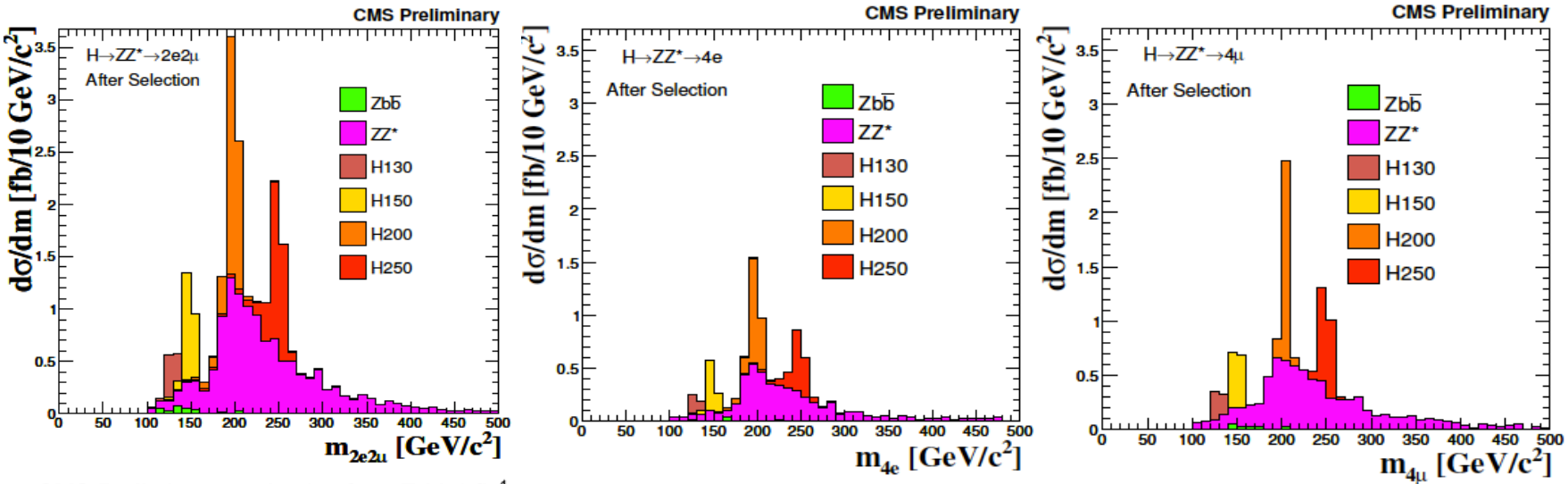
**Invariant Masses**

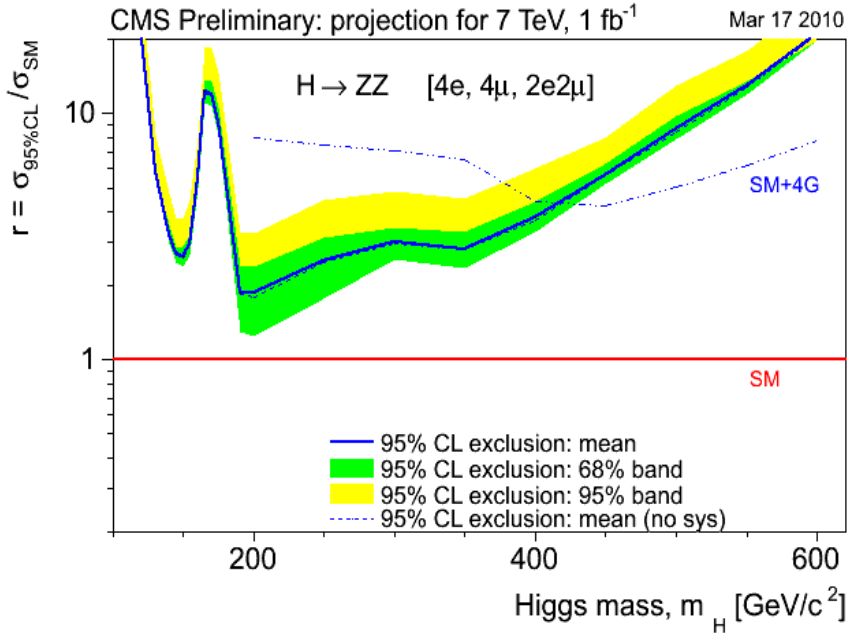
$\mu_0 + \mu_1$: 92.15 GeV (total($Z$) $p_T$ 26.5 GeV, $\phi$ -3.03),
$\mu_2 + \mu_3$: 92.24 GeV (total($Z$) $p_T$ 29.4 GeV, $\phi$ +.06),
$\mu_0 + \mu_2$: 70.12 GeV (total $p_T$ 27 GeV),
$\mu_3 + \mu_1$: 83.1 GeV (total $p_T$ 26.1 GeV).

**Invariant Mass of 4μ: 201 GeV**

# SM H → ZZ*→ 4l

**CMS PAS HIG-08-003**




**7 TeV,** ∫Ldt = **1fb$^{-1}$ (projection)**

The SM Higgs boson cannot be excluded anywhere in the entire mass range.

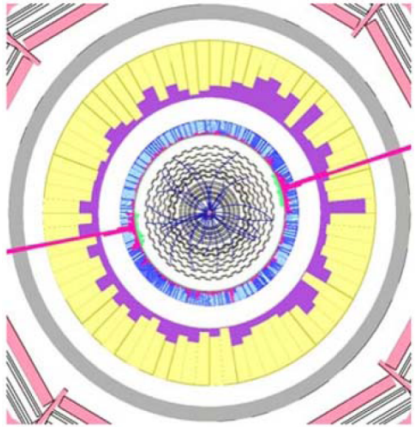
In the 4$^{th}$ generation model* the Higgs boson with a mass:

**$m_H$<400 GeV**

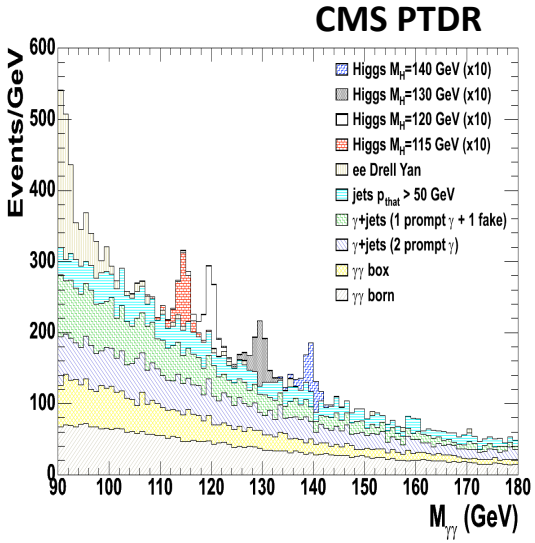
would be excluded

** An extra doublet of quarks would make the gg→H production rate ~9 times larger, regardless of how massive the the two extra quarks might be.*

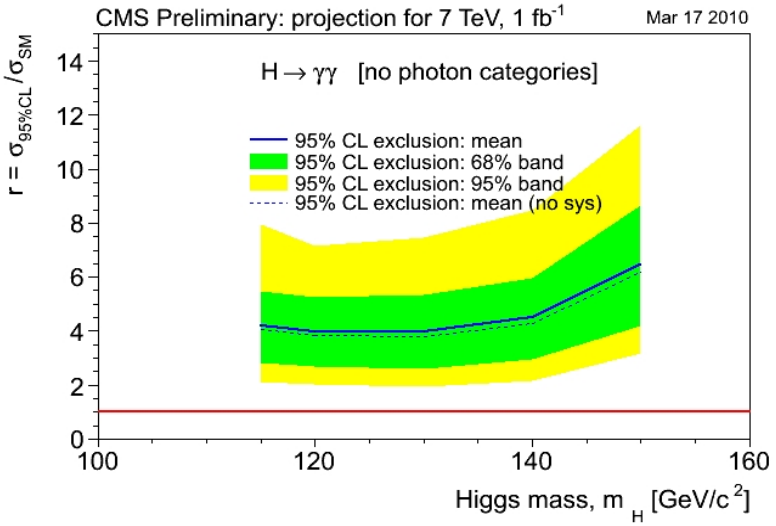
# SM H → γγ



Promising channel in the **low mass range**
**(110 < $m_H$ < 140 GeV)**
**Clear signature:**
-2 High $E_T$ isolated photons
-**Mass peak**
Small Branching ratio,
**High Luminosity analysis**




**Backgrounds:**
γγ, γγ+jets (irreducible)
γ+jets, jets, DY




Background assessed from data sidebands
Cut-based analysis & Event-by-event kinematical Likelihood Ratio

**7 TeV,** ∫Ldt = **1fb$^{-1}$ (projection)**
The SM Higgs boson cannot be excluded anywhere in the mass range.
A fermio-phobic Higgs* with **$m_h$<110 GeV** would be excluded

**The limit on the anomalous production is expected to be about 4 times σ ($pp \rightarrow H_{SM}$)xBR($H_{SM} \rightarrow \gamma\gamma$).*

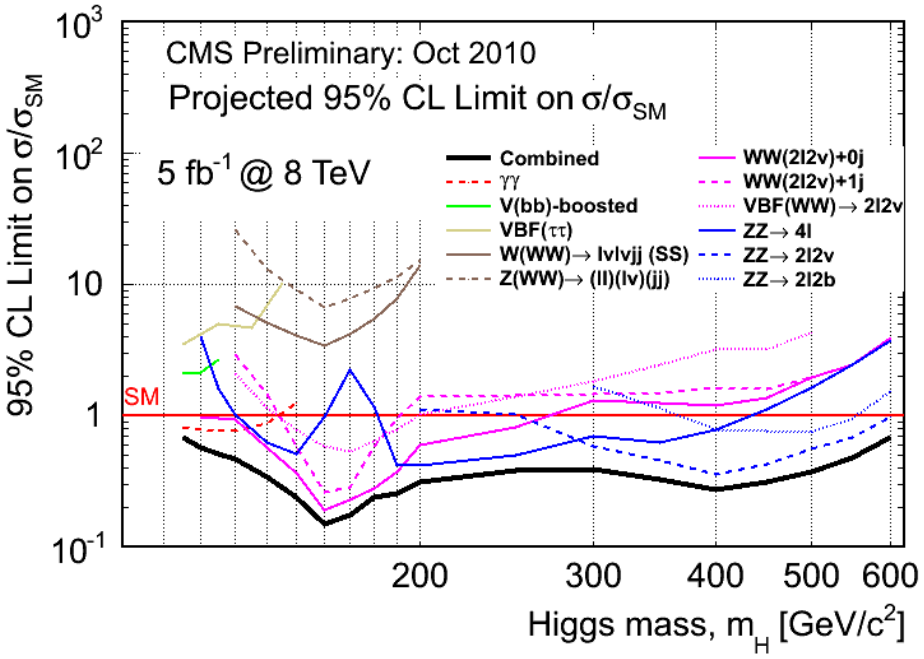
# SM Higgs combination

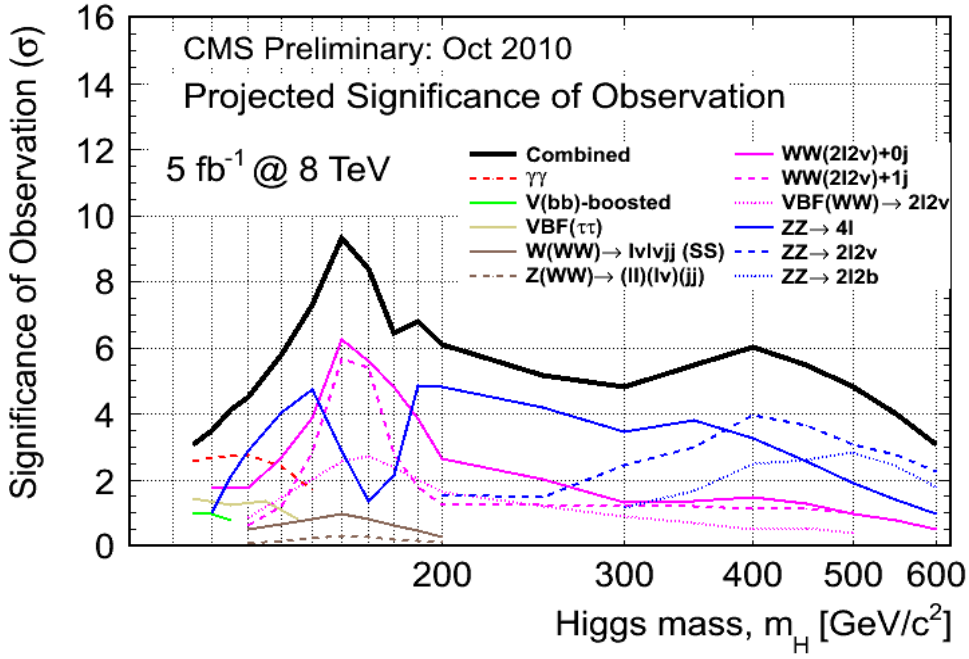
Considering the **expected 2011 scenario**
Projections are obtained using an **expanded list of SM Higgs signatures** that are already under study or will be studied as soon as possible in CMS
Considering 7 and **8 TeV** as collision energy
Several integrated luminosities: **1-5 $fb^{-1}$**

| Channels included | Higgs mass range used in analyses (GeV) |
|---|---|
| H→γγ | 115-150 |
| VBF H→ττ | 115-145 |
| VH, H→bb (highly boosted) | 115-125 |
| VH, H→WW→lνjj | 130-200 |
| H→WW→2l2ν + 0/1 jets | 120-600 |
| VBF H→WW→2l2ν | 130-500 |
| H→ZZ→4l | 120-600 |
| H→ZZ→2l2ν | 200-600 |
| H→ZZ→2l2b | 300-600 |

# Limits and Significance

Projected exclusion limits and expected observation significance for a SM Higgs search at **√S = 8 TeV with L = 5 fb$^{-1}$**



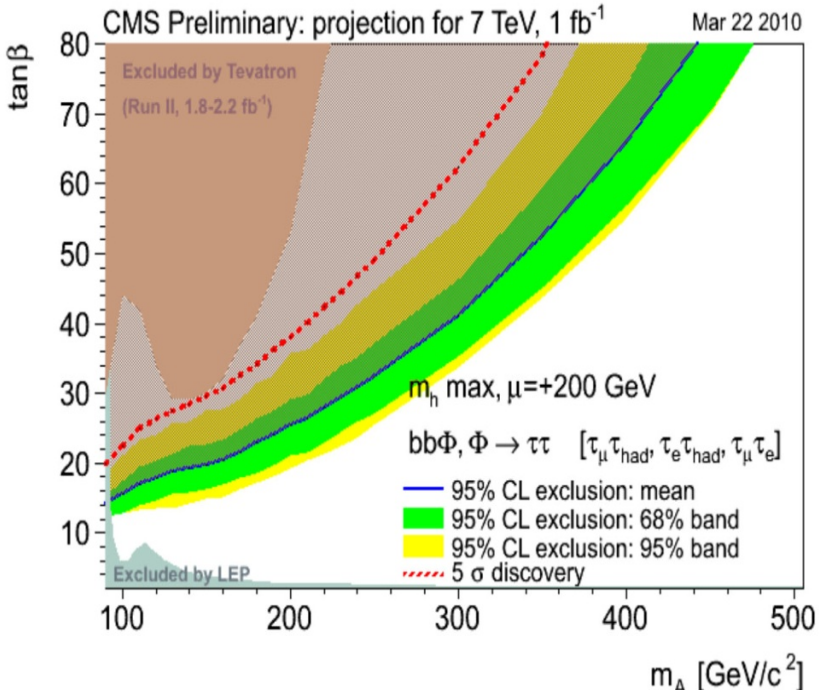

CMS is expected to reach an **exclusion sensitivity in the mass range from the LEP limits (114 GeV) to 600 GeV** and the **observation sensitivity in the same mass range of 114-600 GeV is expected to be 3σ or higher**, depending on the Higgs mass

# MSSM Higgs

Heavy neutral MSSM Higgs bosons in CMS, bbΦ
→ b quark associated production with subsequent **decay to $\tau$ leptons**

Final states with:
Isolated pairs of ($\tau_{had}\tau_{\mu}$) ($\tau_{had}\tau_{e}$) ($\tau_{e}\tau_{\mu}$)
**MET**
**one b-tagged jet, veto extra jets**
**counting events in ττ–mass window (collinear approximation)**

**Backgrounds:**
**Z+bb/cc/jets**
**tt**




**7 TeV,** ∫Ldt = **1fb$^{-1}$ (projection)**
pp→bbΦ→bbττ channel.

At low $m_A$~90 GeV, discovery could be possible for
**tanβ>20**
Exclusion could be achieved for
**tanβ~15**

# SUSY searches in CMS

- Search for **Supersymmetric (SUSY) particles** in many different final states
  - jets, leptons, photons, missing transverse momentum
- Backgrounds from **Data-driven methods** whenever possible as the analysis look at tails of distributions (dominated by detector resolution and fake rate effects)
- Key final states (very striking non-SM signatures): **all hadronic** and **like-sign dilepton**
- Limitations on the sensitivity: Many SUSY models and lack of knowledge of the backgrounds
- Sensitivity expressed for **mSUGRA (minimal Super GRAvity)**, that reduces the 127 parameters of general SUSY models to 5 parameters:

**$m_0$, $m_{1/2}$:** common scalar and gaugino mass at GUT scale

**A:** common gaugino coupling at GUT scale

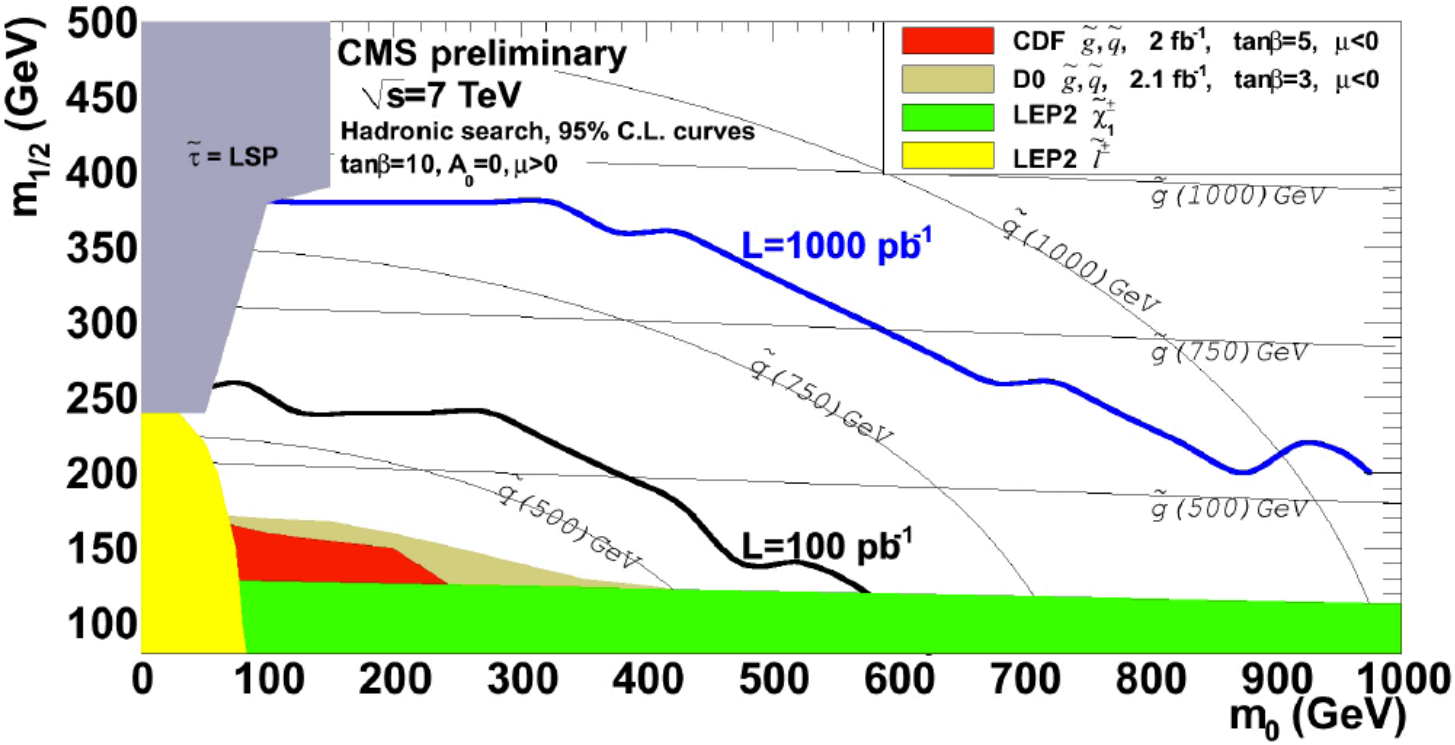
**tanβ:** ratio of vev of Hu and Hd

**sign(μ):** μ being the Higgs mixing parameter

# All-Hadronic Final States

- Events with no isolated electrons or muons ($P_T$ > 15, 10)
- At least 3 jets ($P_T$ > 50), the missing $P_T$ vector pointing away from the leading jets

**Backgrounds:**
QCD multijet events, Z+jets, W+jets, tt…
Irreducible **Z+jets: Z → νν**

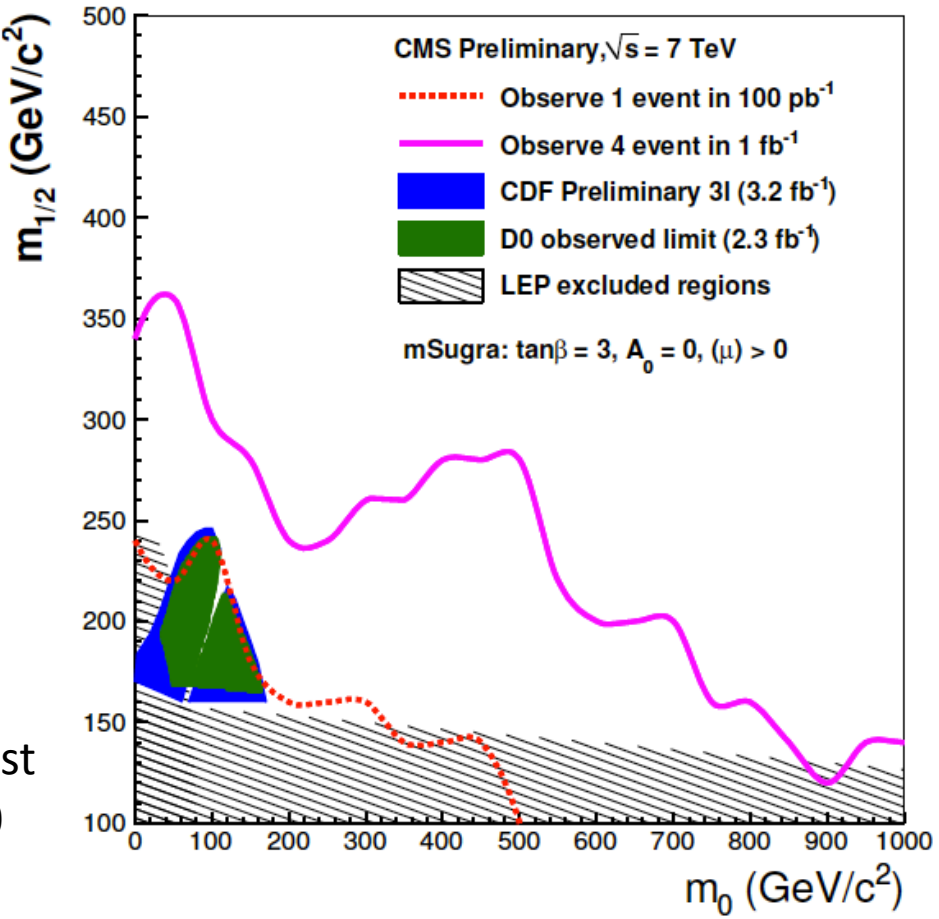



**Sensitivity to SUSY parameter space beyond current Tevatron limits** with < 100 $pb^{-1}$

# Like-sign Lepton Final States

- **Very rare event topology** but **highly suppressed background** (~ 1 event / 100pb$^{-1}$)
- At least three jets ($P_T$ > 30), the scalar sum of the transverse momentum $H_T$ > 200
- Same sign pair of isolated leptons ($P_T$ > 10, 20) in three channels: **ee, eμ, μμ**
  Missing $P_T$ > 80

**Backgrounds:**
Main contribution: tt




**Expected 95% CL upper limit**
contours combining the three channels (7 TeV), as well as the latest exclusion region from CDF and D0

# Summary

- The performance of CMS in collision data has been very good since the start of the data taking.

- At 7-8 Tev with enough luminosity (5 $fb^{-1}$), CMS will explore the complete range of Higgs mass up to 600 GeV:
  - **SM Higgs 3σdiscovery sensitivity** : **[114-600]** GeV
  - **SM Higgs exclusion range** : **[114-600]** GeV

- Before the first $fb^{-1}$ of data is collected, many SUSY searches will be fully performed, and a sizable region of the paremeter space will be explored, reaching **sensitivity to regions of SUSY (mSUGRA) parameter space beyond the current Tevatron limits**

- **During next year, a wide catalogue of Higgs, MSSM and SUSY searches will be performed by CMS at the LHC, with potential to exclude and discover new physics in regions never before reached**