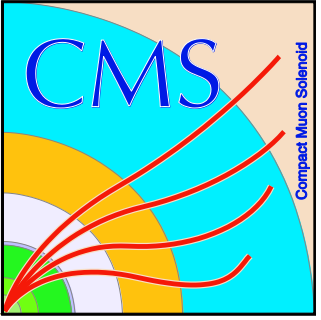


Higgs search prospects at LHC

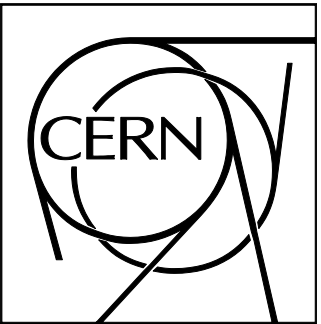
Rebeca González Suárez
IFCA

On behalf of the **ATLAS** and **CMS** Collaborations

26 June 2010

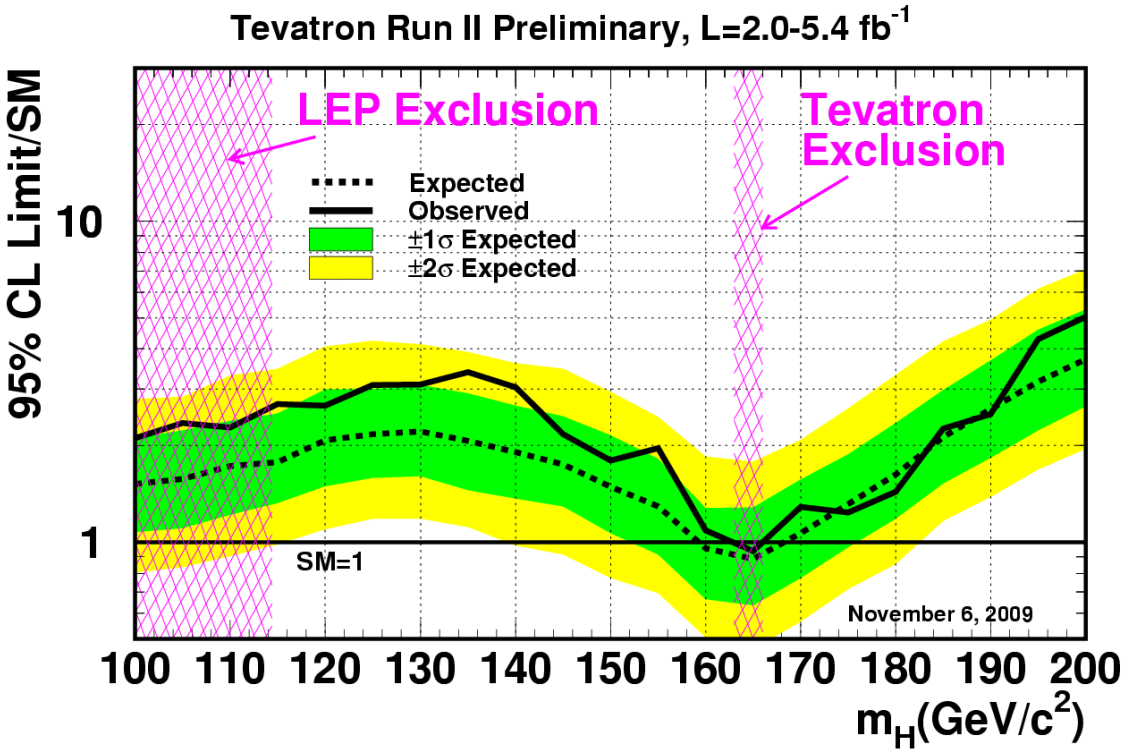
BEACH 2010 - IX International Conference on Hyperons, Charm and Beauty Hadrons

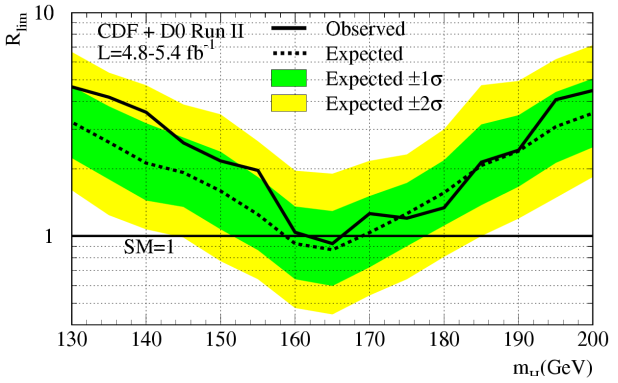
University of Perugia, Italy

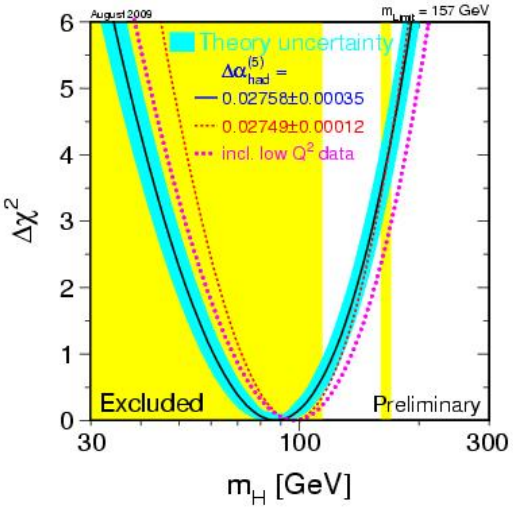


Current Status of the Higgs Searches

Direct Searches: $m_H > 114.4$ GeV and outside the [162, 166] interval
Indirect (precision fit): $m_H < 157$ GeV; including LEP2 $m_H < 186$ GeV



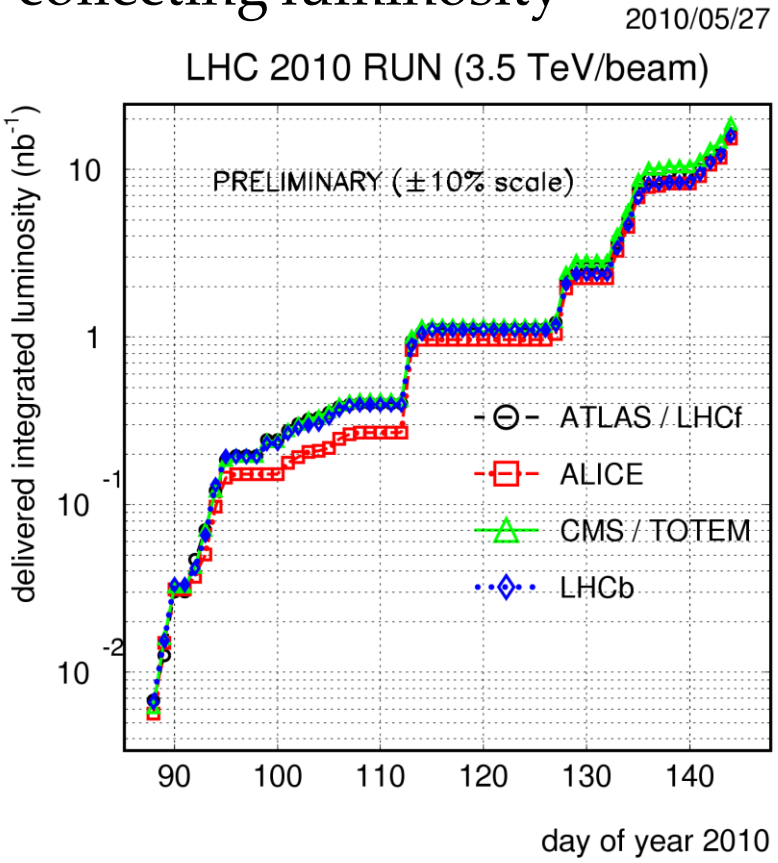




LEP Higgs Working Group
Tevatron New Phenomena & Higgs Working Group

The LHC is running!

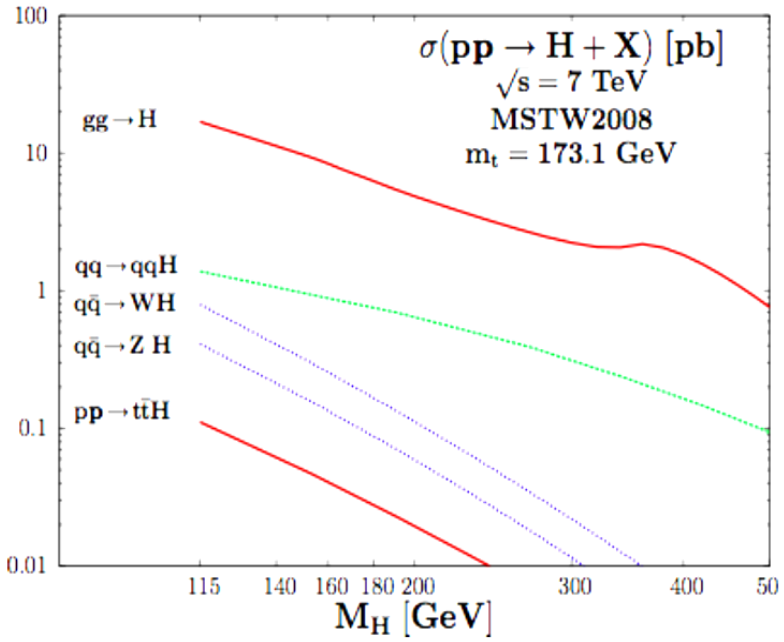
- Running at **7 TeV** since March 30th 2010
- Continuously collecting luminosity



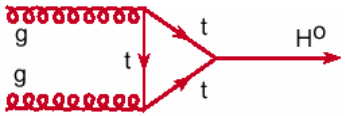
LHC status report
(11 June 2010)
Jorg Wenninger

Projected Luminosity deliver before the shut down to go to higher energies:
100 pb^{-1} by Nov 2010 → **1 fb^{-1}** by end of 2011

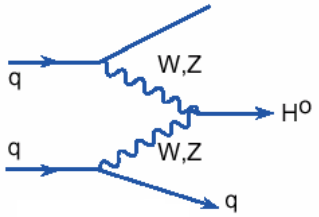
Higgs production at the LHC



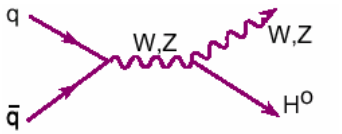
Gluon-gluon fusion (**ggH**):
Dominant production mode

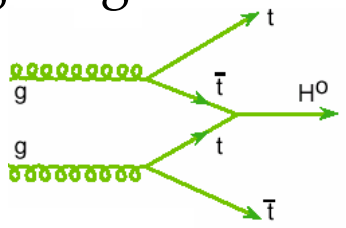


Vector Boson Fusion, VBF (**qqH**):
Characteristic signature with two forward jets and rapidity gap, increasingly important for high masses

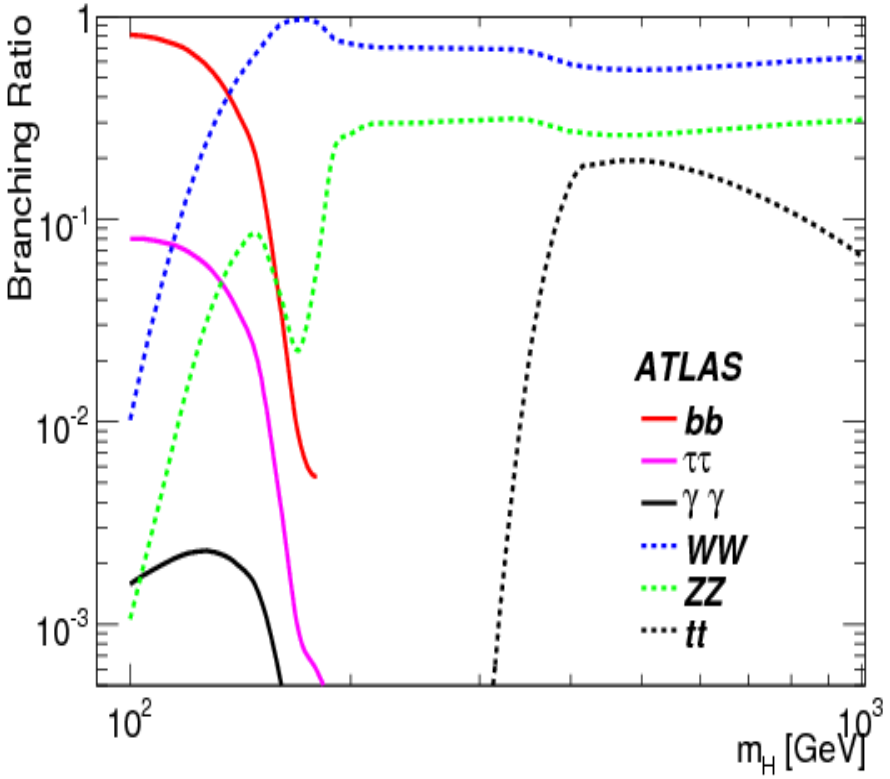


Associated production (**WH, ZH**, **ttH**):
Relevant in the low mass region, brings an 'easy' triggering





Higgs decay modes



Low mass ($m_H < 2m_Z$)

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

H→ττ: Important for low masses. Collinear approx.→mass reco. Accesible through VBF

H→γγ: Important for low masses. Mass-peak with good resolution, decays through top and W loops

High mass ($m_H > 2m_Z$)

H→tt: Difficult selection

H→WW: **Earliest sensitivity**

H→ZZ: Very clean experimental signature (4 leptons). Mass peak.

LHC Vs. Tevatron

- Higgs searches in **ATLAS** and **CMS** at the LHC will go in paralell with the Tevatron experiments **CDF** and **DØ**

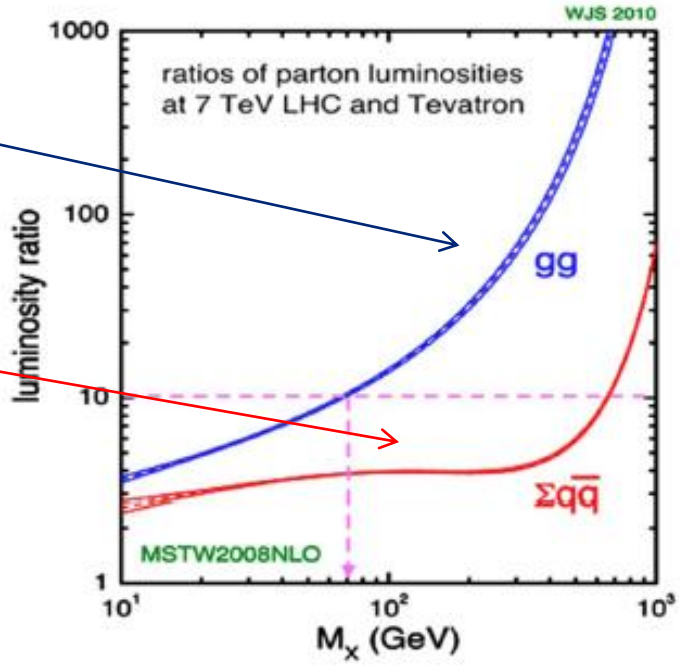
Tevatron 2011: 2 TeV, 10 fb^{-1}
LHC 2011: 7 TeV, 1 fb^{-1}

LHC

Higher cross-sections:
More than a factor 10 for gg processes (Higgs)

Better S to B:
The effect in σ is less pronounced for qq (Backgrounds)

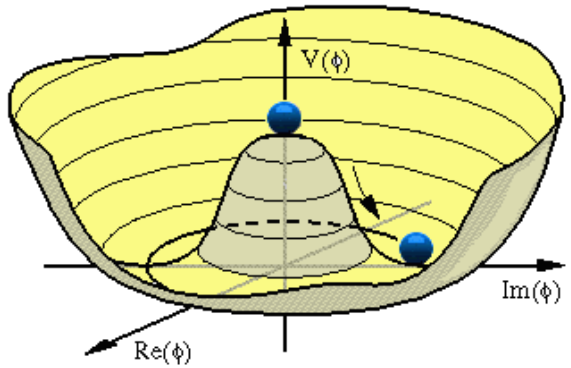
Detectors optimized for Higgs searches



Prospective Higgs Searches ATLAS/CMS

Both experiments work in a wide range of Higgs decay channels (see backup)

Public results available at different √s: CMS ATLAS



CMS : 7 TeV Projections for the main search channels

About the projections

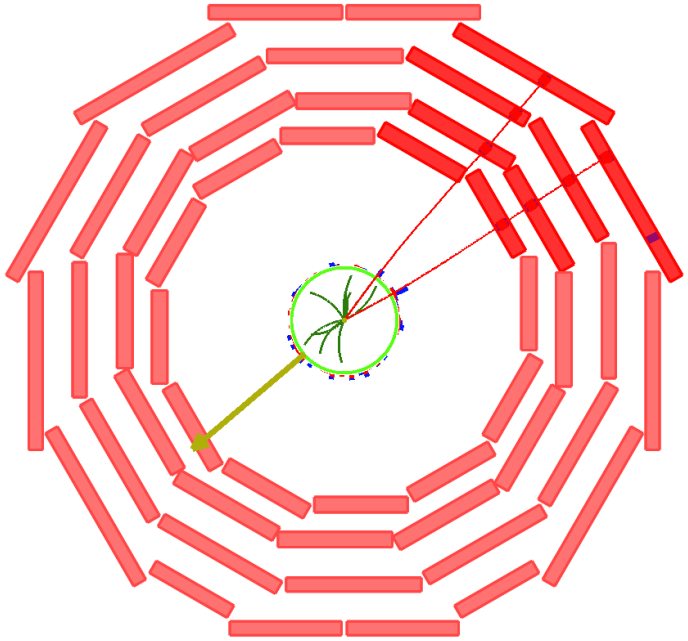
The 7 TeV projections are **not** new analyses done with 7 TeV MC samples and new detector simulation/reconstruction software.

Start from public results at **14 TeV** ($\int L$ **~1-30 fb^{-1}**)
Re-scale signal and background event counts by the ratio of **7 TeV / 14 TeV** cross sections
Project for $\int L$ **1 = fb^{-1}**

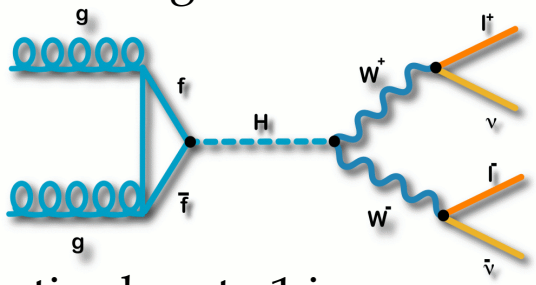
No corrections for higher acceptance at smaller √s, up to ~20%
No corrections for improvements in reconstruction (efficiencies, resolution)

(*ATLAS projections at 7 TeV will be public by ICHEP)

SM H → WW* → 2l2ν



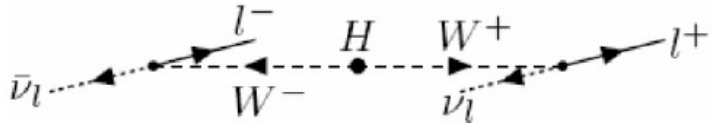
- The **discovery channel** for a SM Higgs boson in a wide mass range in the LHC



- 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

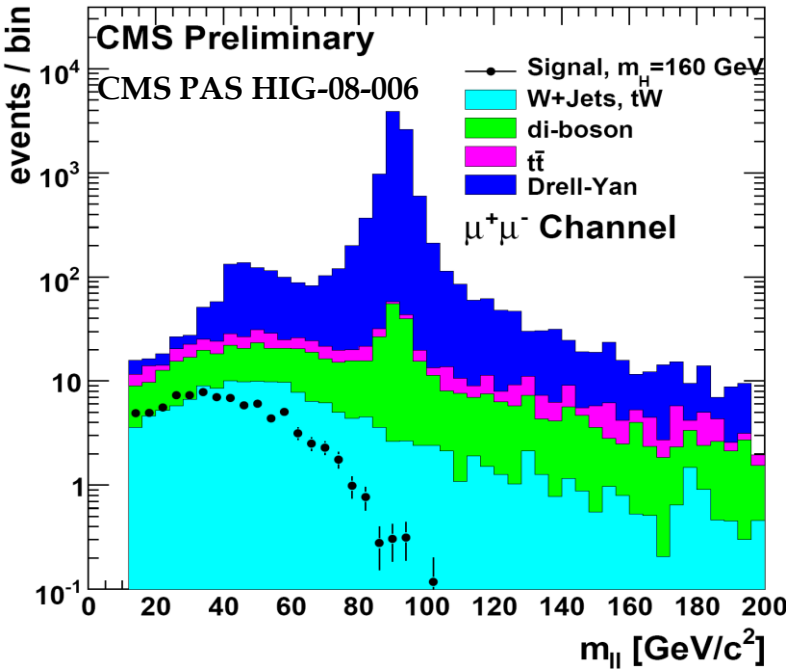


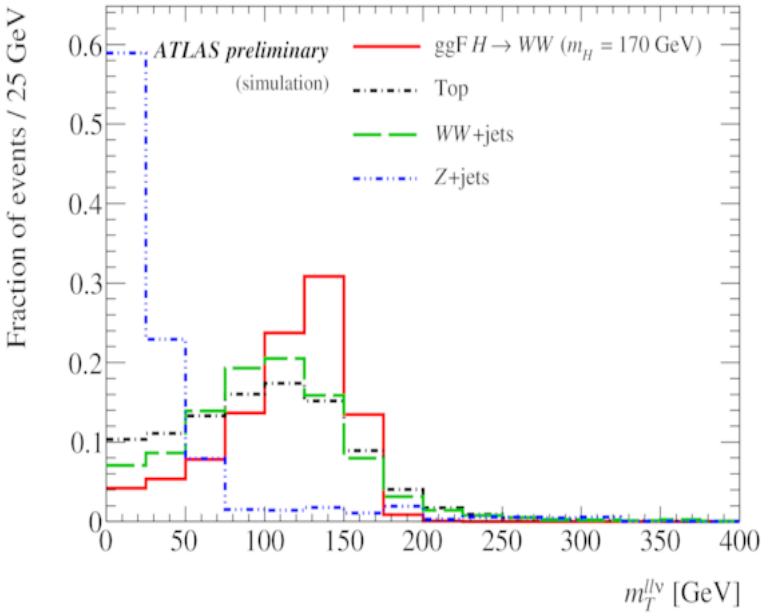
  - Missing ET
  - No jets (GF) or two forward jets with rapidity gap (VBF)

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

SM H → WW* → 2l2ν

ee, μμ, eμ final states
No mass peak
Good **knowledge of backgrounds** mandatory (control regions & data-driven methods)
Systematic uncertainties
Multivariate approach

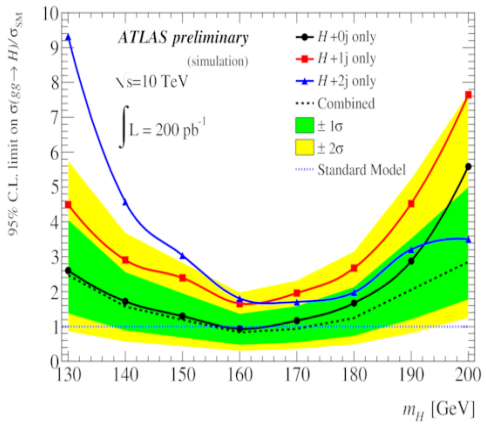




ATLAS
Three events selections:
H+0 j;H+1 j and H+2 j analyses
Use of the transverse mass

CMS
H+0j (+ independent VBF analysis)
Sequential cut-based analysis: 3 final states
Multivariate analysis: all together

SM H → WW* → 2l2ν



ATLAS

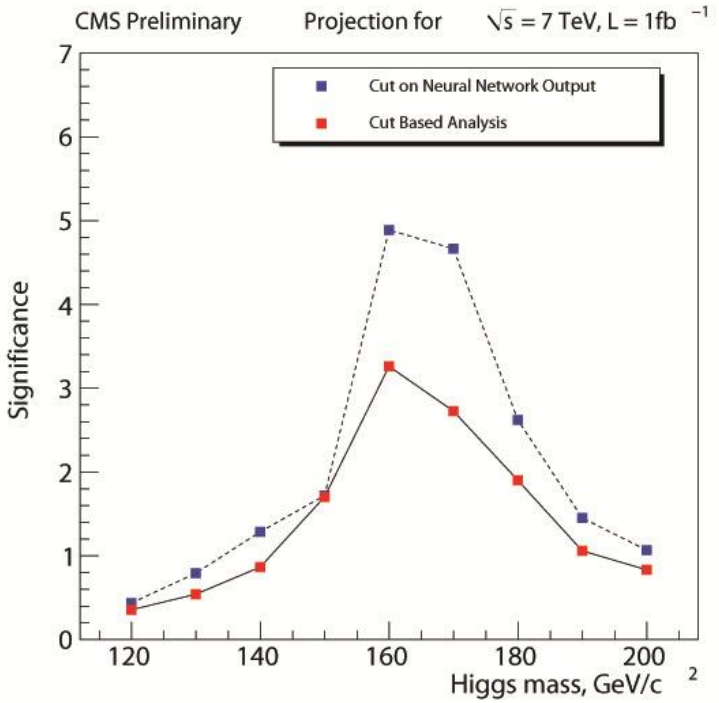
10 TeV, ∫Ldt = **200pb^{-1}** exclusion: ***160-170 GeV*** 95%CL

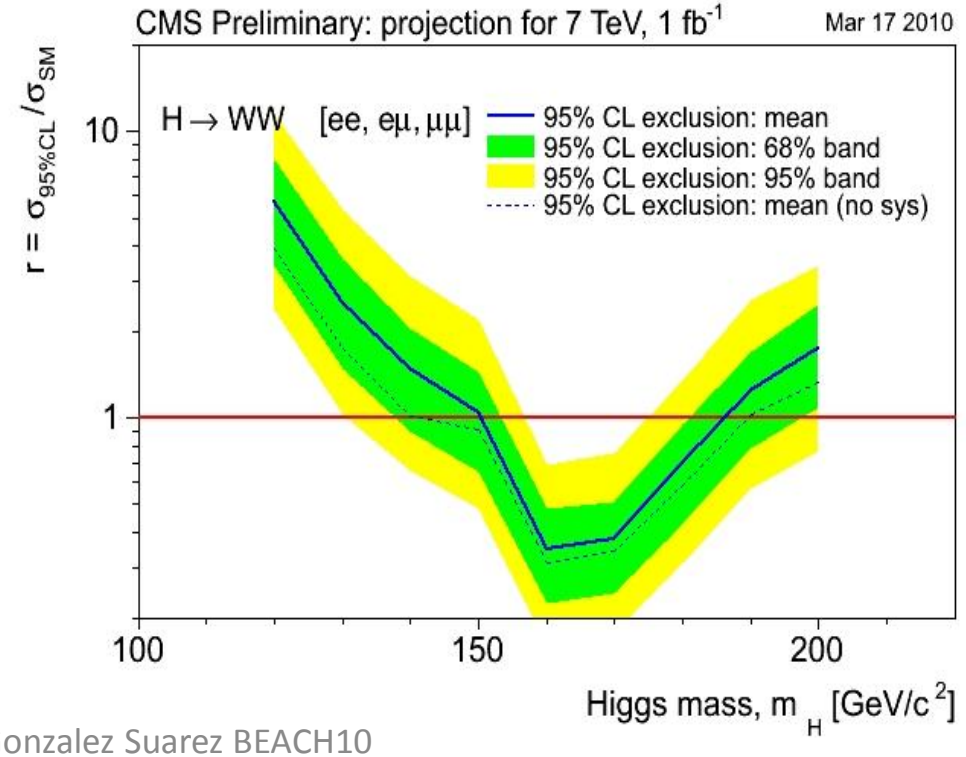
CMS

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

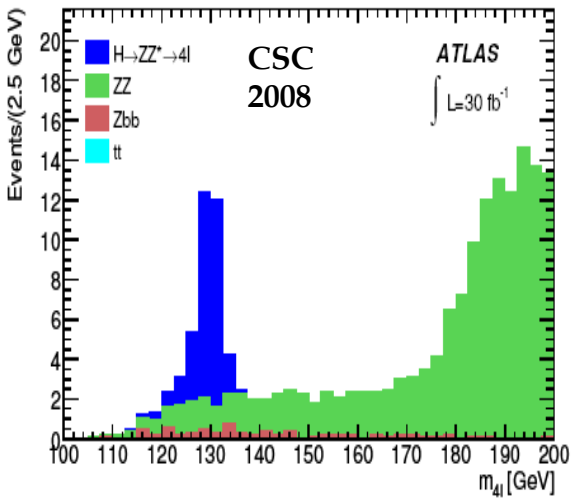
Exclusion 95%CL: **150<m_H<185 GeV**

Discovery level sensitivity (~5σ) : **160<m_H<170 GeV**





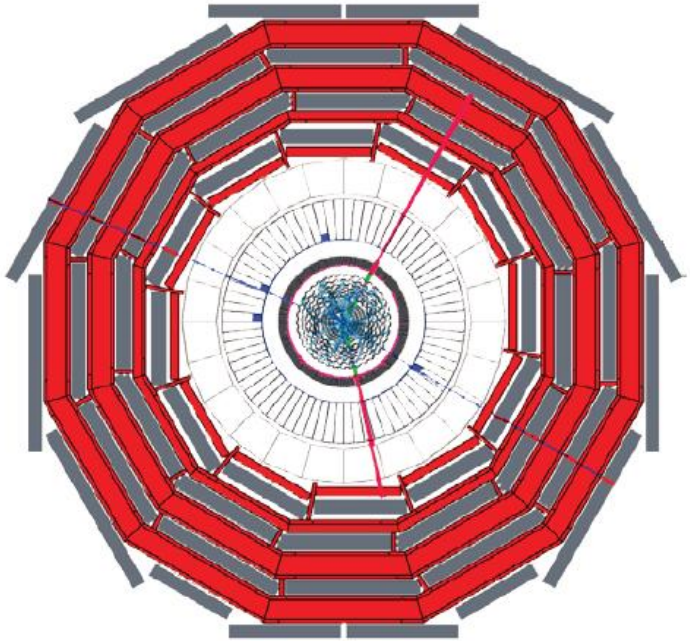
SM H → ZZ*→ 4l



'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**

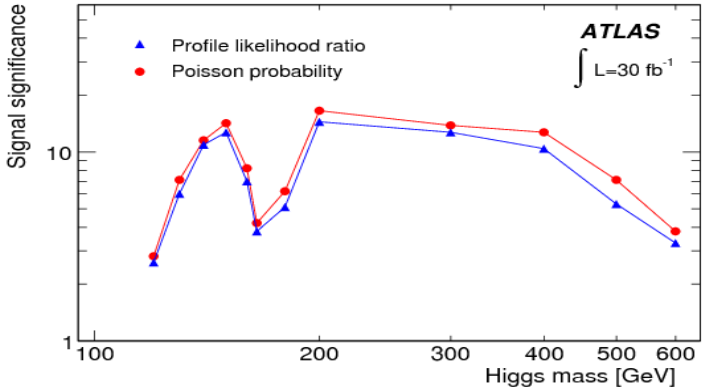
SM H → ZZ*→ 4l

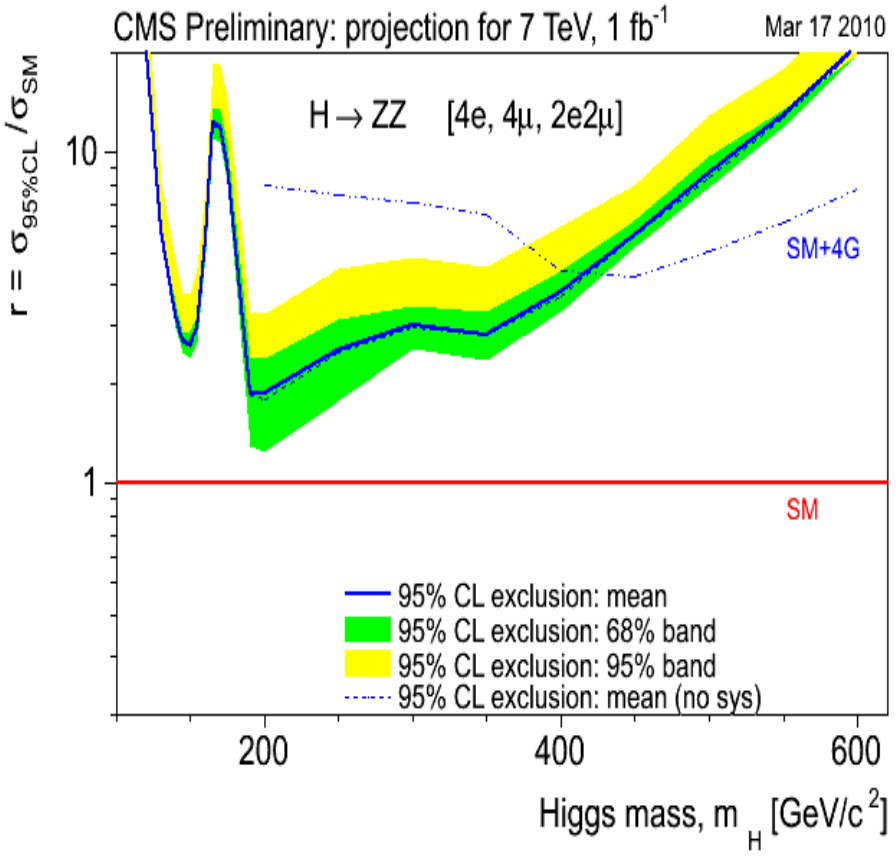
ATLAS

14 TeV, ∫Ldt = **30fb^{-1}**

Highly sensitive in the high mass region

(**200 GeV/c^2 < m$_H$ < 400 GeV/c^2**)





CMS

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

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

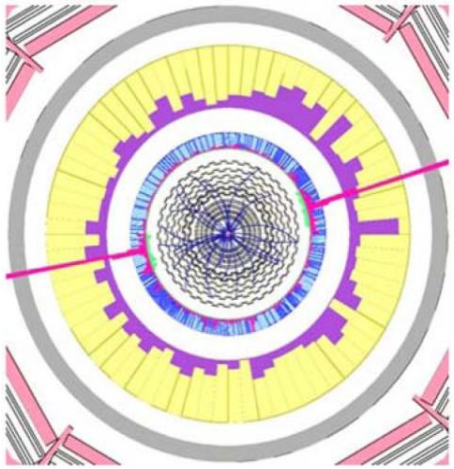
In the 4th generation model* the Higgs boson with a mass:

m$_H$<400 GeV

would be excluded

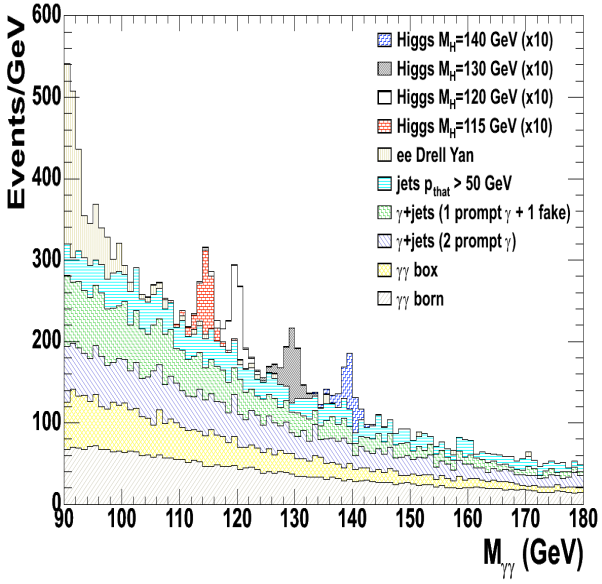
* An extra doublet of quarks would make the gg→H production rate ~9 times larger, regardless of how massive the the two extra quarks might be.

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



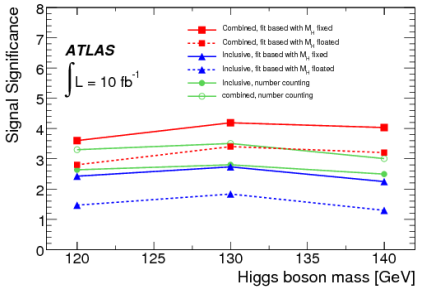
Background assessed from data sidebands

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

CMS
Cut-based analysis
Event-by-event kinematical Likelihood Ratio

ATLAS
Search for **H → γγ** and **H → γγ + jets**
Unbinned maximum-likelihood fit

SM H → γγ



ATLAS

14 TeV, ∫Ldt = **10fb^{-1}**

Event Counting : σ= **2.6**

Fixed (floating) mass fit [0j,1j,2j]: σ = **3.6** (2.8)

CMS

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

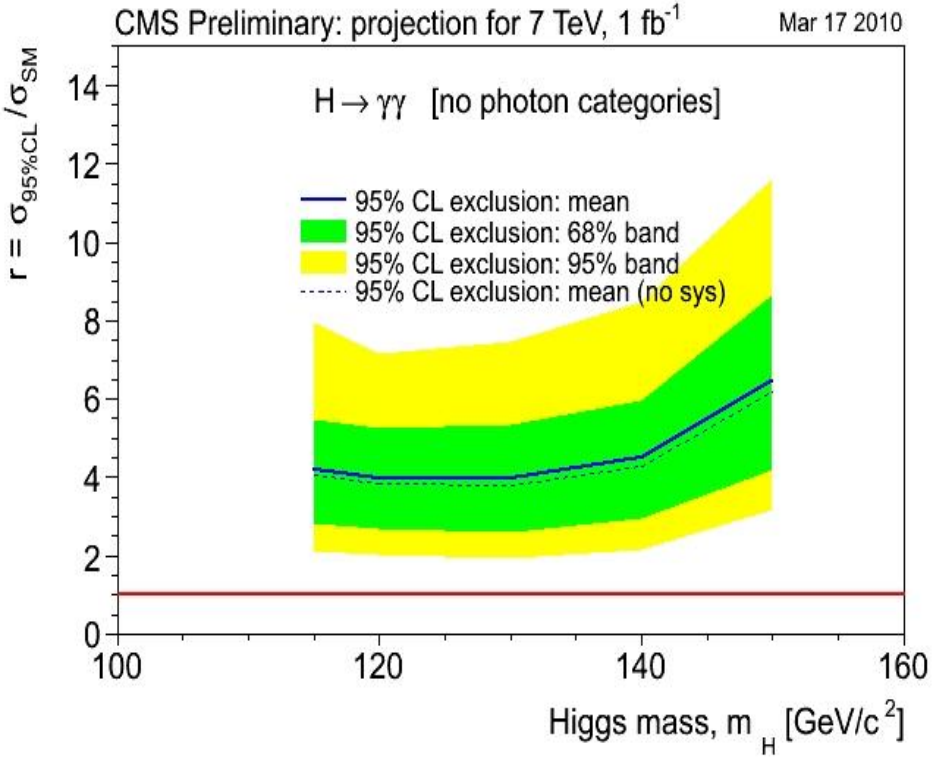
The SM Higgs boson cannot be excluded anywhere in the mass range.

A fermio-phobic Higgs* with:

m_h<110 GeV

would be excluded, as for this mass range, the yield

$\sigma(pp \rightarrow h_{fph}) \times BR(h_{fph} \rightarrow \gamma\gamma)$ is ~4



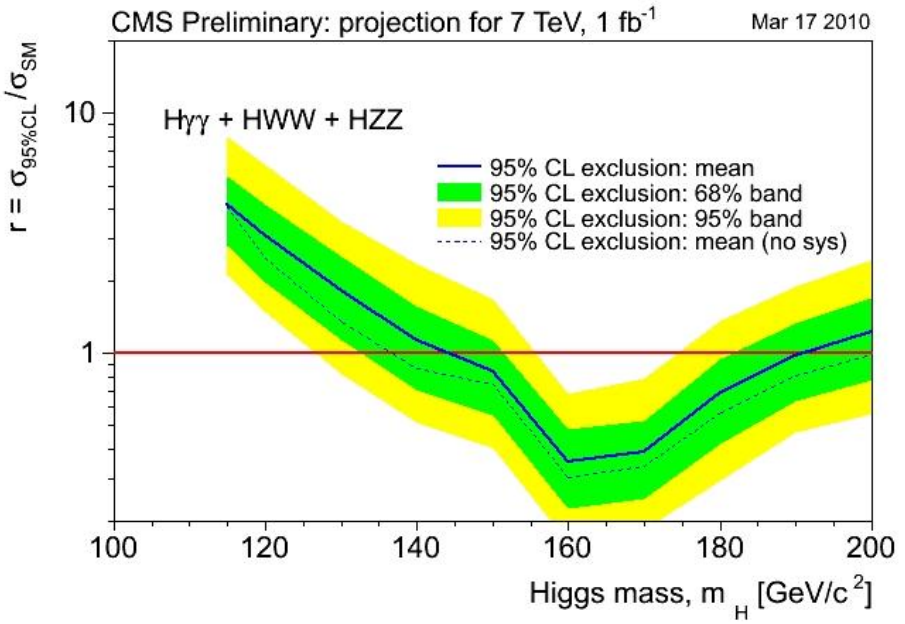
*The limit on the anomalous production is expected to be about 4 times $\sigma(pp \rightarrow H_{SM}) \times BR(H_{SM} \rightarrow \gamma\gamma)$.

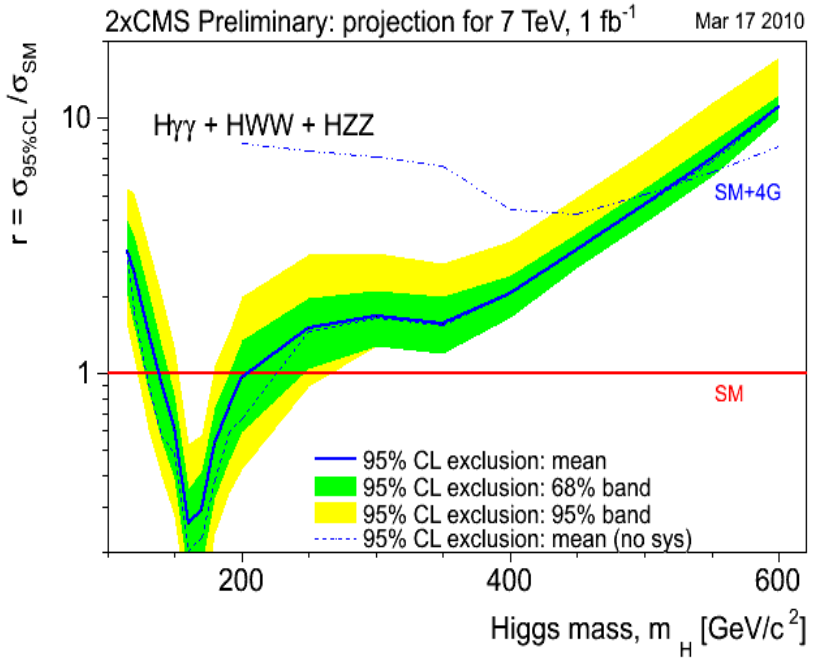
SM Higgs Combination at 7 TeV

CMS

Projected exclusion limits combining
$H \to WW \to 2l2\nu$, $H \to ZZ \to 4l$, $H \to \gamma\gamma$
Expected exclusion 95%CL:

$145 < m_H < 190$ GeV





2xCMS :

Projected exclusion limits assuming twice amount of data to *indicate* **ATLAS + CMS**.

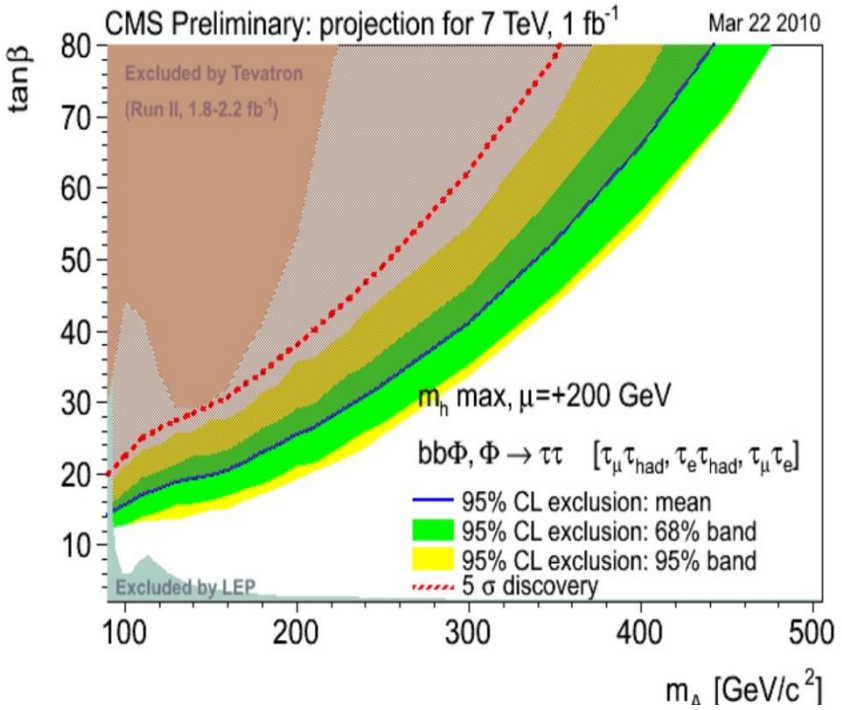
SM Higgs:
$140 < m_H < 200$ GeV
SM Higgs +4th fermion generation:
$m_H < 500$ GeV

MSSM Higgs bbΦ

Heavy neutral MSSM Higgs bosons at the LHC
→ b quark associated production with subsequent **decay to τ leptons**

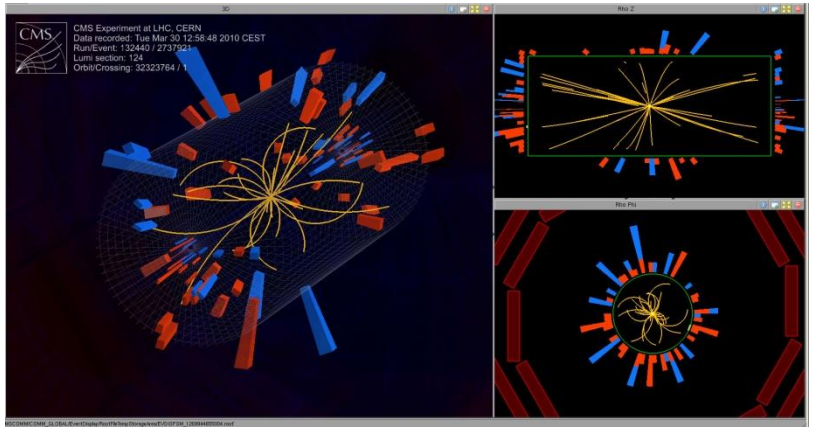
Final states with:
Isolated pairs of $(\tau_{had}\tau_{\mu})$ $(\tau_{had}\tau_{e})$ $(\tau_{e}\tau_{\mu})$
MET
one b-tagged jet, veto extra jets
counting events in ττ−mass window (collinear approximation)

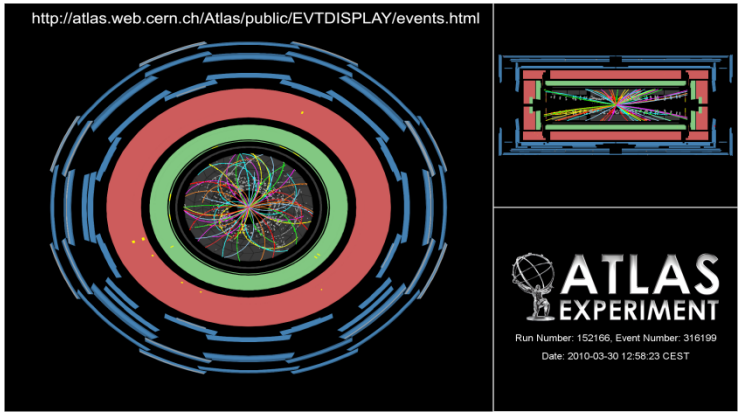
Backgrounds:
Z+bb/cc/jets
tt



CMS
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





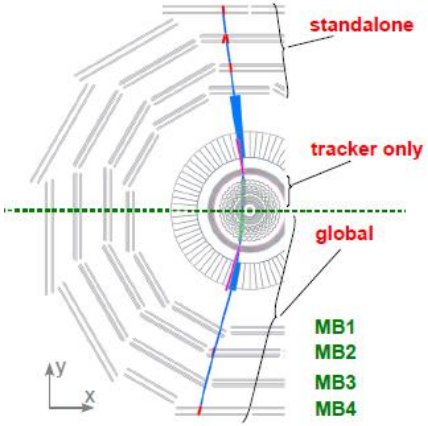
Currently…

It is a bit too early for Higgs physics at the LHC, but

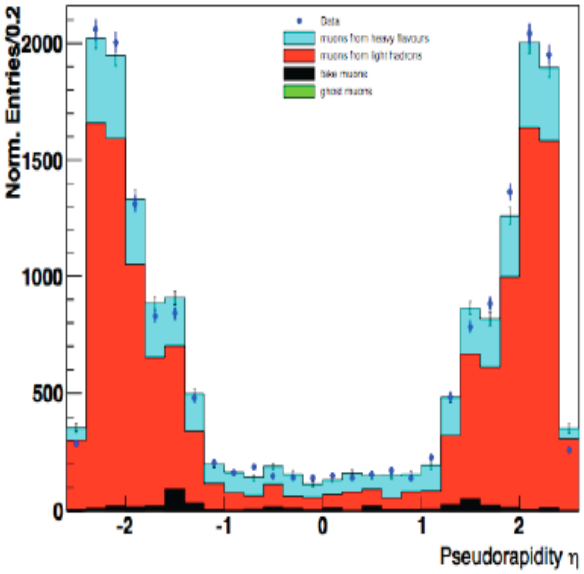
we can already look at the main ingredients with the **first data at 7 TeV**

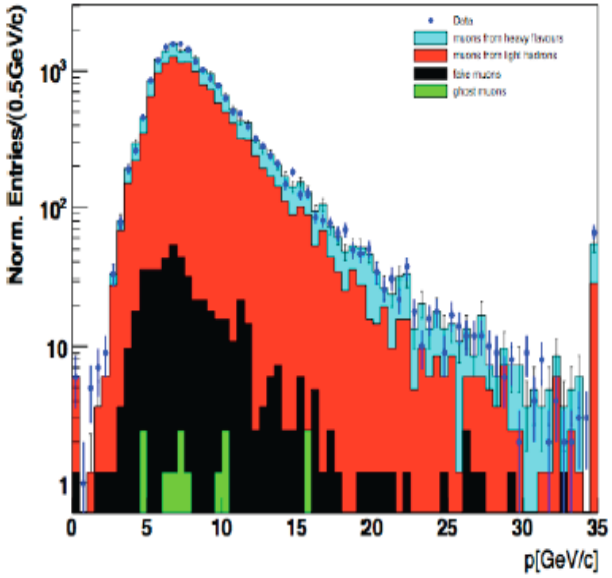
Muons

- Several Cosmic ray data campaigns → Muons well understood before collisions
- Good performance in collisions



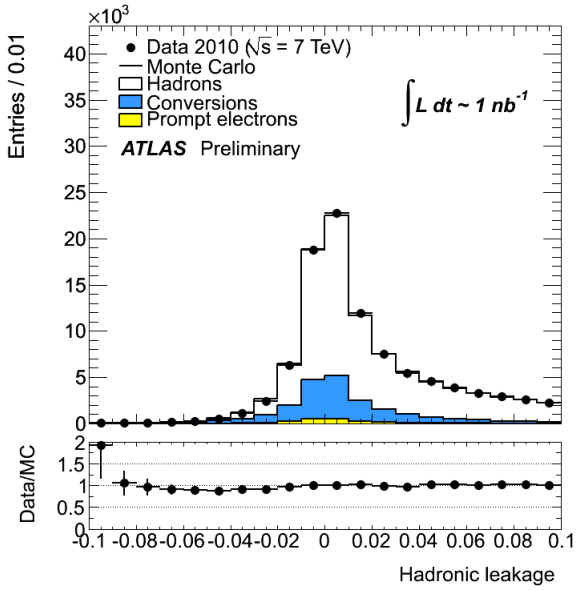
CMS

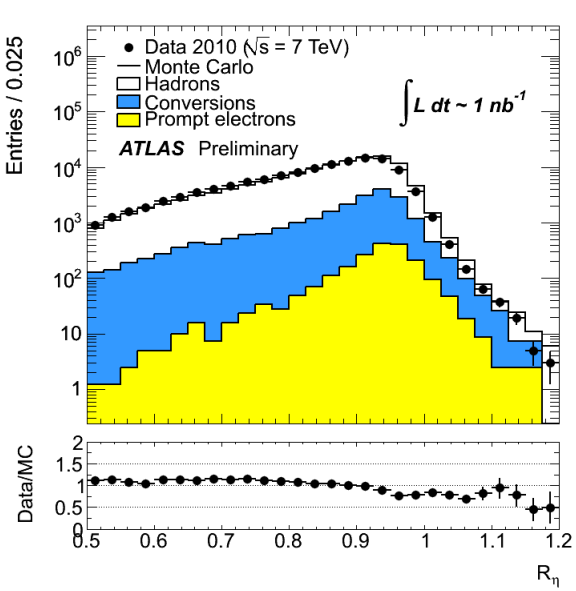


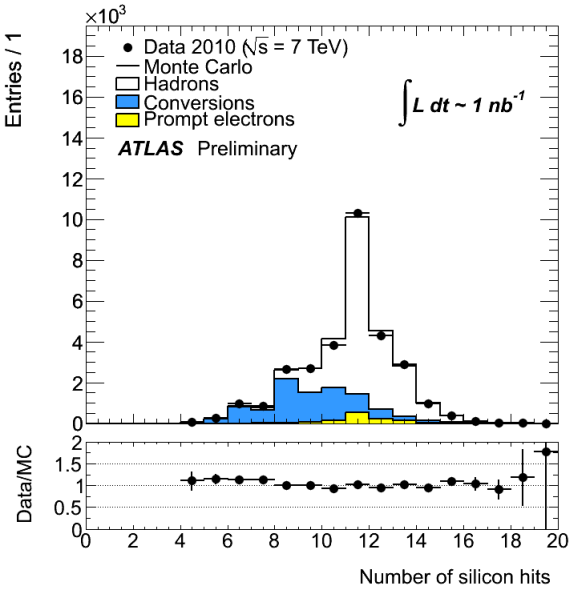


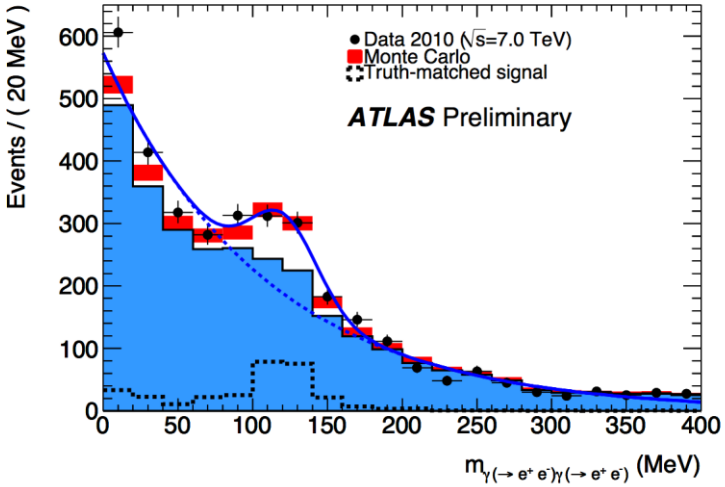
η and P_T distributions dominated by light hadron decay muons (red), good agreement with MC prediction including heavy flavor decays (blue), punch-through (black) and fakes (green).

Electrons / Photons









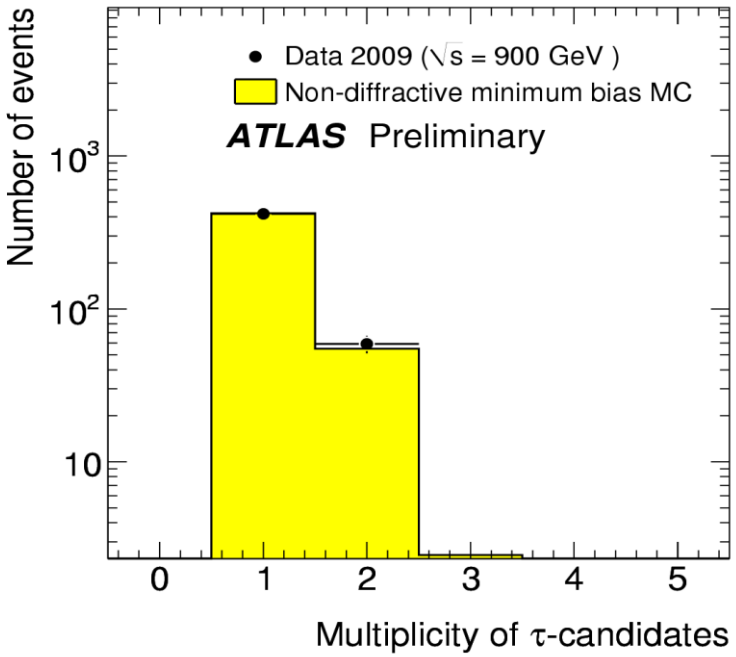
Hadronic leakage, R_eta and Silicon hits for electrons.

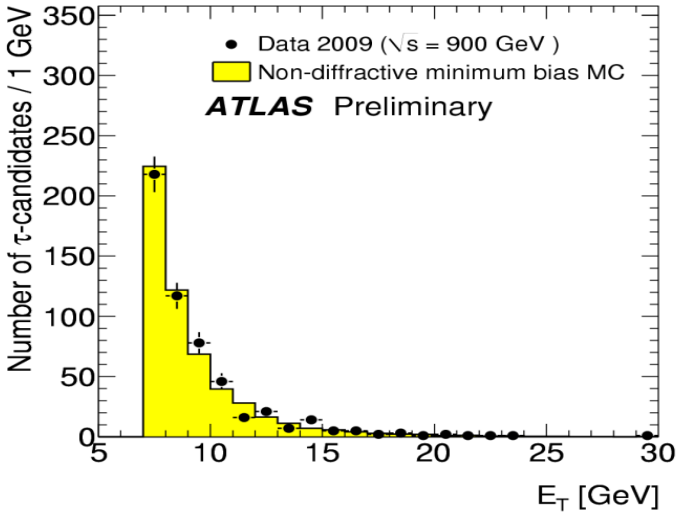
ATLAS

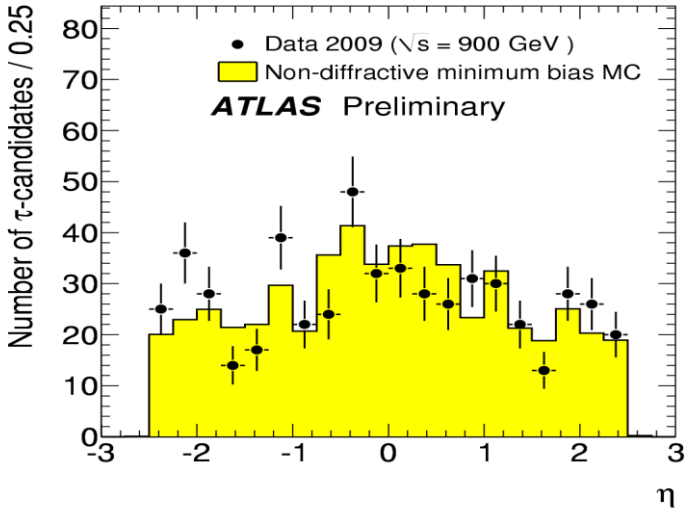
Reconstructed pi0->gamma gamma where both photons have converted.

Taus

ATLAS



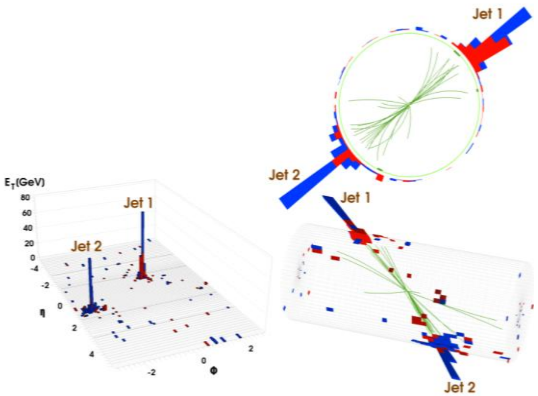




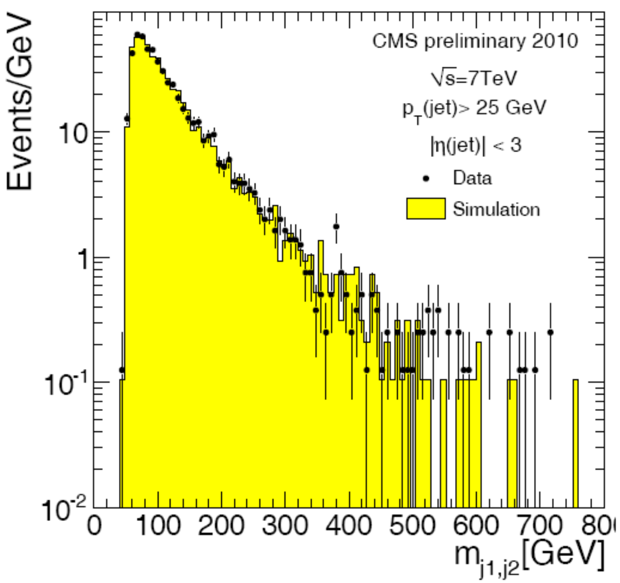
Number of reconstructed tau candidates, uncalibrated transverse energy and pseudorapidity of reconstructed tau candidates for the inclusive sample.

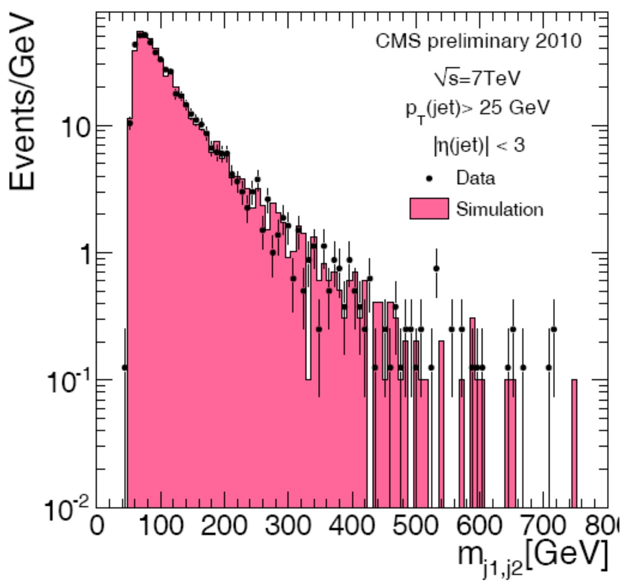
Jets

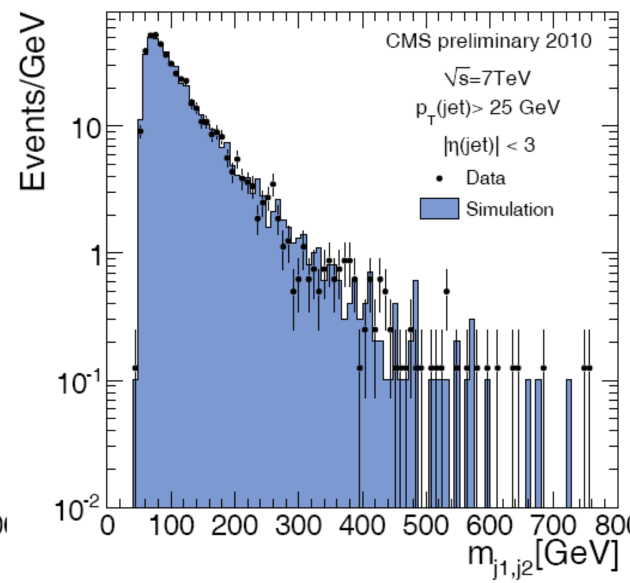
CMS



m_{j1j2} in di-jet events
Jets reconstructed with the anti-k_T 0.5 algorithm
Dijet selection :
Jet E_T > 25 GeV, $\Delta\Phi$ > 2.1, $|\eta| < 3$

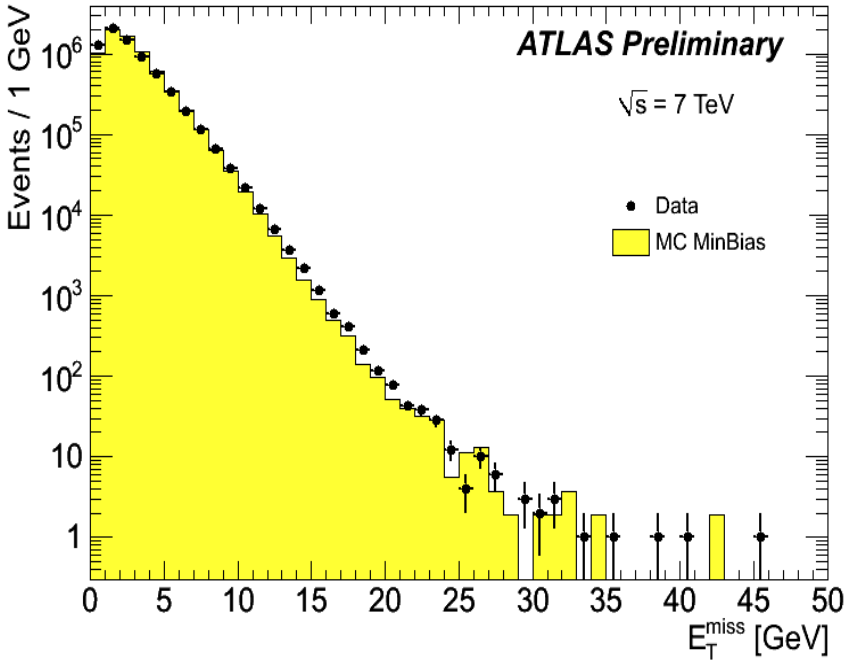


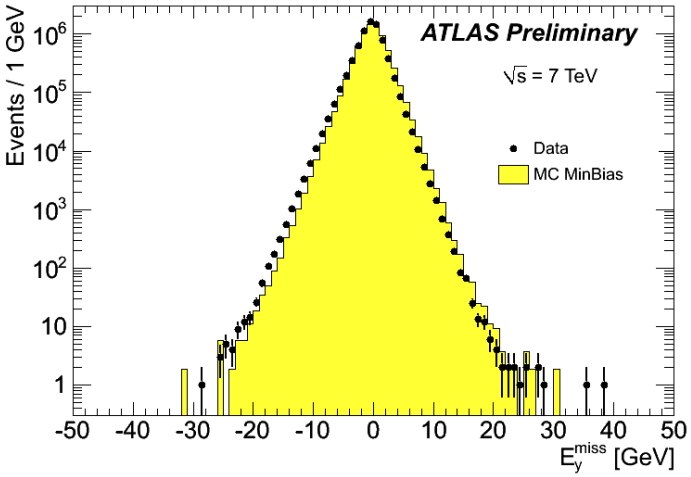


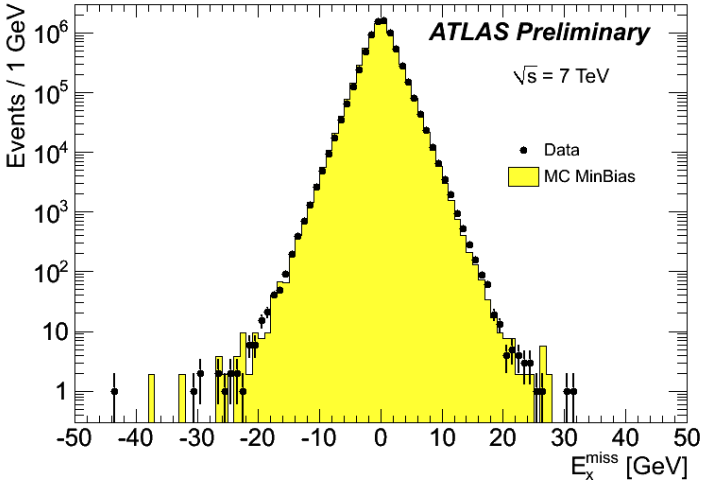


Three different approaches:
Pure **Calorimetric**, **Track corrected** calo and **Particle flow**

Missing ET





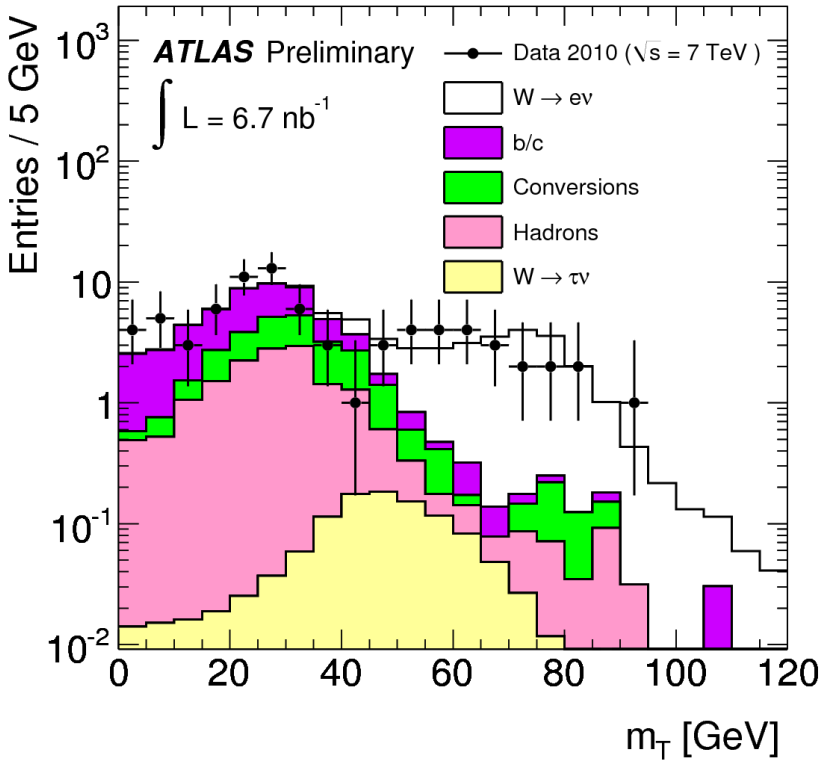


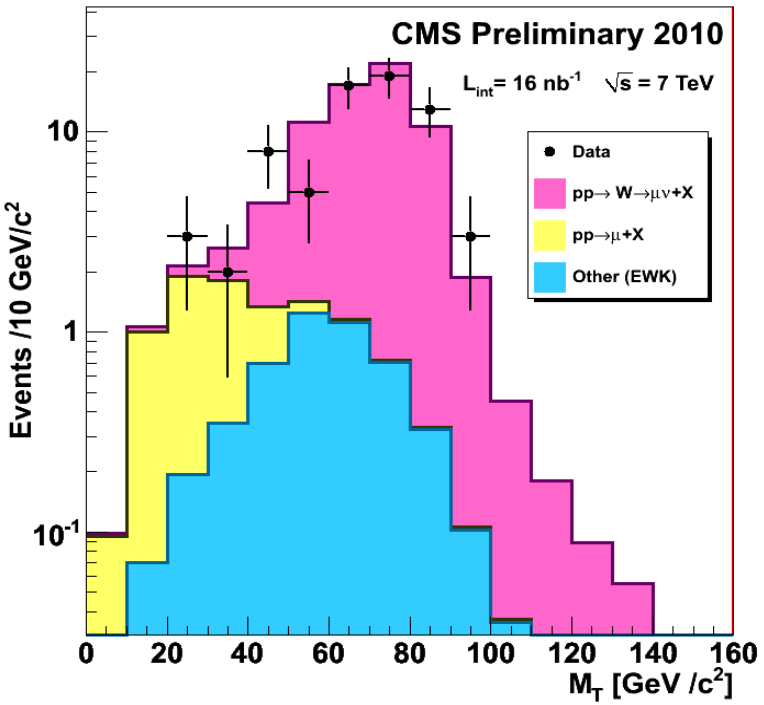
ATLAS

Only topological cluster cells used, with energies calibrated at the electromagnetic scale.

First SM Backgrounds: W

- $W \rightarrow \mu\gamma$ and $W \rightarrow e\gamma$ observed in CMS and ATLAS

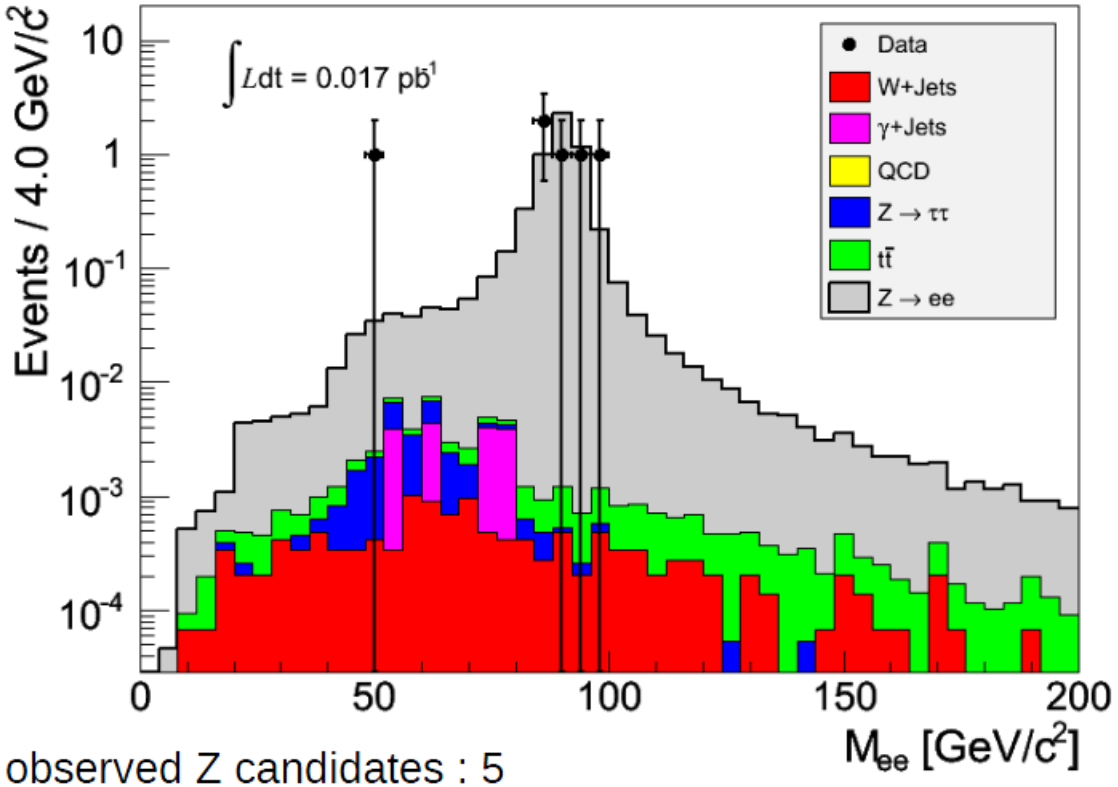




First SM Backgrounds: Z

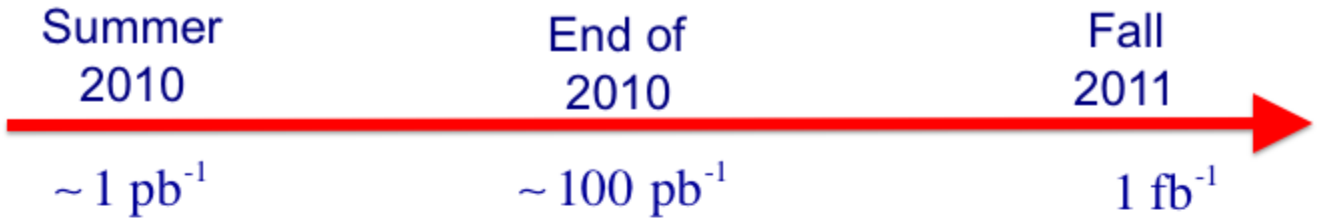
- $Z \rightarrow \mu\mu$ and $Z \rightarrow ee$ also observed in CMS and ATLAS

CMS



- Number of observed Z candidates : 5

The road ahead at the LHC



- QCD, b measurements
- W, Z cross sections
- Electroweak program
- Early ttbar observation
- Early searches, mainly Exotica

- + top physics program
- + broad search program: Mainly Exotica, SUSY

- + Higgs program

Summary

- The performance of ATLAS and CMS in collision data has been very good since the start of the data taking
- The main physics objects used in the Higgs analyses are performing well
- Low luminosity, tens of nb^{-1}: enough already to start exploring Standard Model processes (W and Z, soon top!)
- At 7 Tev with enough luminosity (1 fb^{-1}), ATLAS and CMS will begin to explore a sizable range of Higgs mass:

  – **SM Higgs discovery sensitivity** : **[160-170]** GeV
  – **SM Higgs exclusion range** : **[140-200]** GeV
  (Low mass SM Higgs searches require high $\sqrt{s}$ and $\int L$)

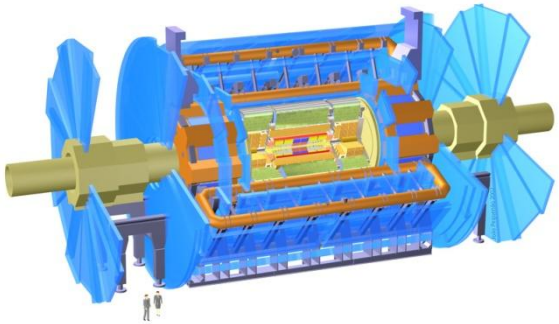
  – **MSSM Neutral Higgs discovery range**: **tanβ ~20** for small mA
  – **MSSM Neutral Higgs exclusion range** :down to **tanβ ~15** for small mA

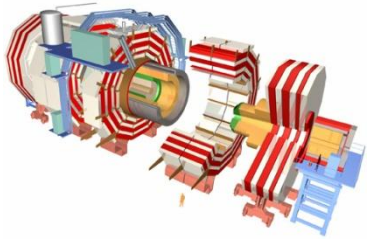
With $\int L \sim 1fb^{-1}$ at $\sqrt{s} = 7$ TeV
We will do Higgs physics at the LHC !

Backup

ATLAS Vs. CMS

	ATLAS (A Toroidal LHC ApparatuS)	CMS (Compact Muon Solenoid)
Dimensions	Width: 44m Diameter: 22 m Weight: 7.000 t	Width: 22 m Diameter: 15 m Weight: 14.500 t
Magnetic Field	2T solenoid + 3 toroid (0.5T barrel, 1T endcaps)	4T solenoid + return yoke
Tracker	Si pixels, strips + TRT	Si pixels, strips
ECAL	Pb + LAr (Liquid Argon Calorimeter) (Optimized towards background rejection)	PbWO4 crystals (Crystal calorimeter) (optimized towards precise measurements)
HCAL	Fe + scint. / Cu + LAr (10λ)	Cu + scintillator (5.8λ + catcher)
Muon System	Air core spectrometer	Iron core spectrometer
Trigger	3 – Level (region-of-interest 2-Level)	2 - Level





Similar concepts, different execution, detector technologies, design emphasis…

Prospective Higgs Searches ATLAS/CMS

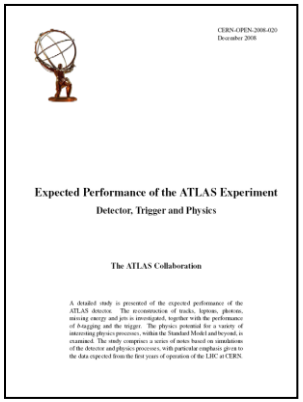
ATLAS:

H → γγ
H → ZZ
H → WW
VBF H → ττ
ttH (H → bb)
ttH, H → WW*
WH, H → WW*
MSSM h/A/H → ττ
MSSM h/A/H →μμ
Invisible Higgs
Charged Higgs
…

CMS:

H → γγ
H → ZZ
H → WW
VBF H → WW/ZZ/invisible
H → ττ
Light charged Higgs
Heavy charged Higgs
Doubly charged Higgs
…

Public Results
CMS ATLAS


CERN-OPEN-2008-020
December 2008

Expected Performance of the ATLAS Experiment
Detector, Trigger and Physics

The ATLAS Collaboration

A detailed study is presented of the expected performance of the ATLAS detector. The reconstruction of tracks, leptons, photons, missing energy and jets is investigated, together with the performance of b-tagging and the trigger. The physics potential for a variety of interesting physics processes, within the Standard Model and beyond, is examined. The study comprises a series of notes based on simulations of the detector and physics processes, with particular emphasis given to the data expected from the first years of operation of the LHC at CERN.


CMS Physics Technical Design Report,
Volume II: Physics Performance

The CMS Collaboration

ATLAS: CERN OPEN 2008-020
(+ some 10 TeV updates)

CMS: CERN / LHCC2006-021
(+ Updates!!)

SM VBF H →ττ

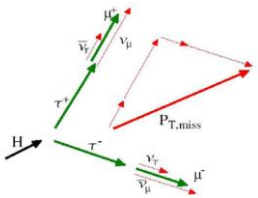
Backgrounds:
Z+jets, tt, W+jets, QCD

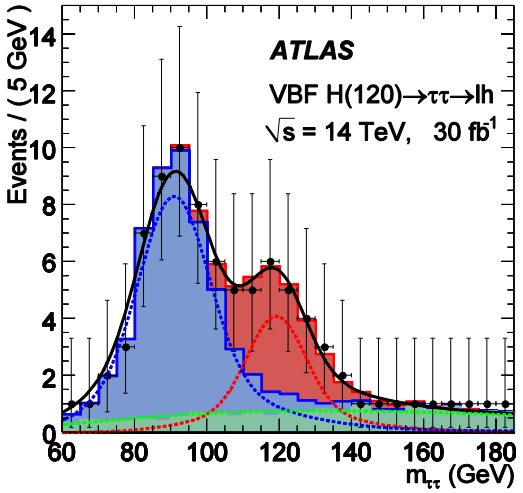
- Three channels investigated:

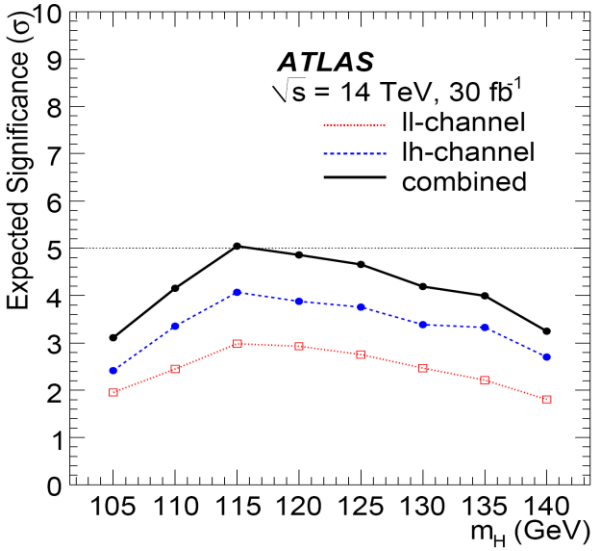
  $H \to \tau_l\tau_l$, $H \to \tau_l\tau_h$, $H \to \tau_h\tau_h$

- Hadronically decayed taus reconstructed as **tau-jets**
- VBF signature:

  two forward jets with large rapidity gap
- Mass reconstruction:
  - **Collinear approximation**

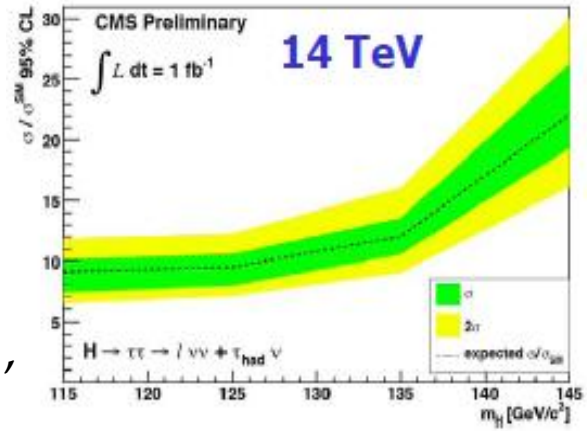






ATLAS
14 TeV, ∫Ldt = **30fb-1**
5σ for 115-120 GeV

CMS
14 TeV, ∫Ldt = **1fb-1**
exclusion limit r~12
At 7 TeV signal drops by 50%, r will get worse



SM H→bb

Modes considered: ***ttH, H→bb & VH, H→bb***

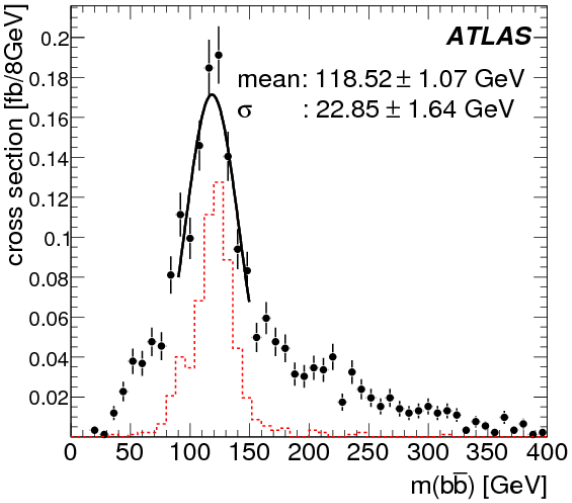
ttH: Experimentally very challenging

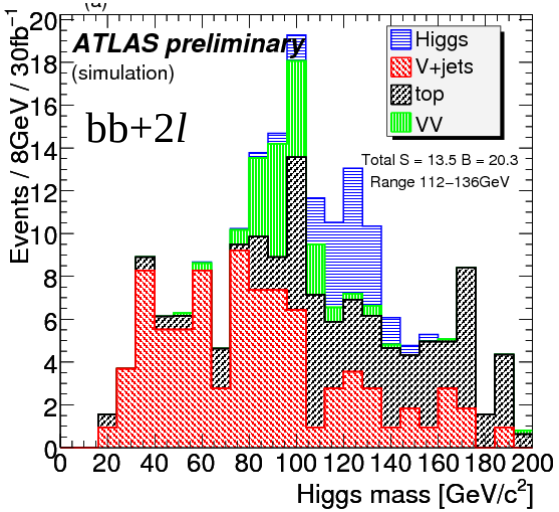
- Full reconstruction of the final state demanding
- Combinatorics of jet assignement to W, t, H

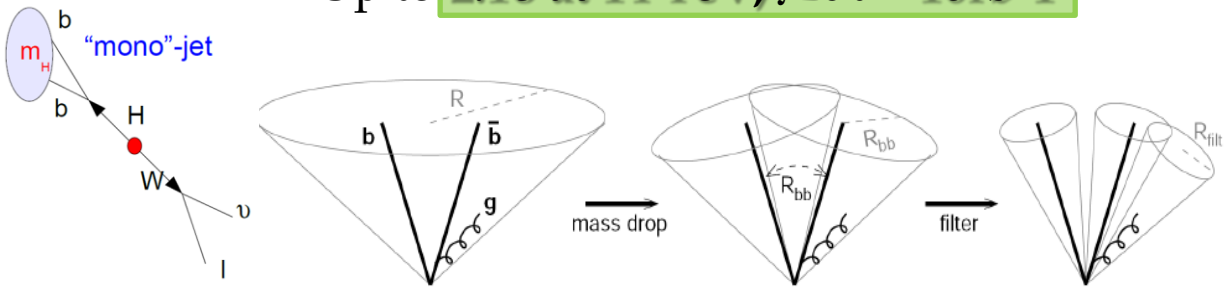
Good control of backgrounds needed to contribute to sensitivity

VH: Three channels: ***bb+1l, bb+2l, bb+(missing ET)***

- More robust against systematics than ttH
- Substantially improves sensitivity for H→bb
  - Up to **2.1σ at 14 TeV, ∫Ldt = 10fb-1**







b-quarks in the fat mono-jet → Need to analyse jet sub-structure

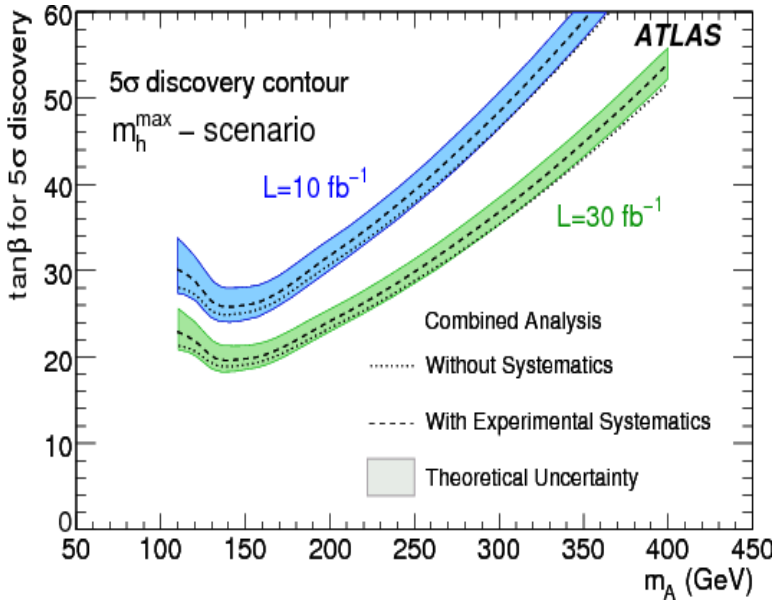
MSSM Higgs

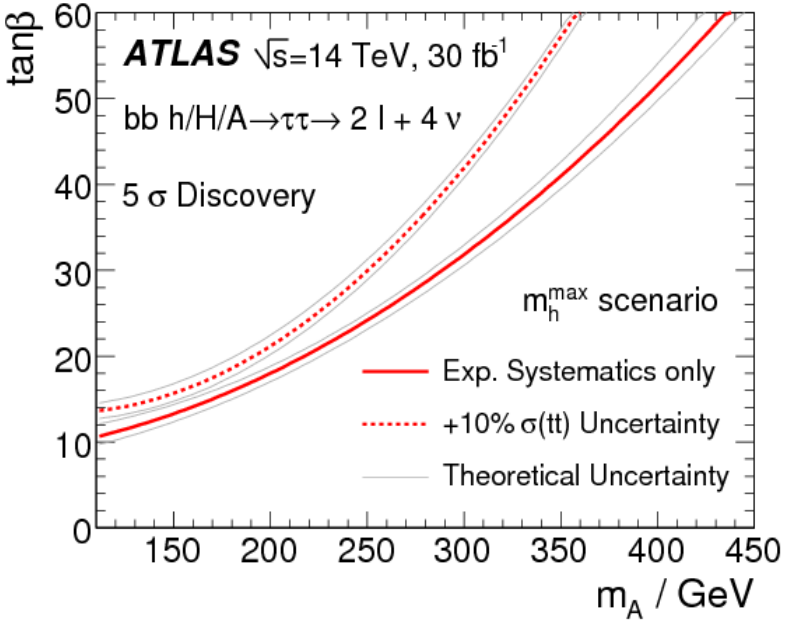
h/H/A→μμ

- Two analyses:
  0b-tag (gluon fusion) & ≥*1b-tag* (bbH production)
- Backgrounds:
  Zb, Z+jets, ZZ, WW, tt
  - Estimate with side-bands & control samples

h/H/A→ττ→*ll*+4ν

- Only ≥*1b-tag* (bbH production)
- Main backgrounds:
  Z→ττ (low m_H), ***tt*** (high m_H)
  - Estimation in similar way as SM VBF channel





Charged Higgs

- Five channels investigated
  - 3 channels for $m_{H^+} < m_t$:

    $tt \rightarrow bWbH^+$, $H^+ \rightarrow \tau\nu$ with $\tau \rightarrow had$ or $l\nu\nu$

    $W \rightarrow qq$ *or* $l\nu$
  - 2 channels for $m_{H^+} > m_t$:

    $gg/gb \rightarrow [b]tH^+$, $H^+ \rightarrow \tau\nu$ or $H^+ \rightarrow tb$
- Need good τ- and b-tagging, E_T^{miss} and lepton reconstruction
- Most important backgrounds: *tt*, QCD
  - Produce control samples using embedding technique