SM Higgs searches in CMS

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- Introduction to SM Higgs
- First results using 2010 statistics
- Projections for the SM Higgs searches with increased statistics
- Conclusion

Higgs in CMS

- CMS and ATLAS are optimized for Higgs detection
  - Higgs – major reference process in design of both detectors
  - All signatures "detectable" : $e/\mu/\tau$, γ, jets, E_t^{miss}
- Higgs searches are of highest priority. Projections of future sensitivity are based on available simulations, they are reevaluated on a regular basis

  - results presented in this talk are based on 2010 statistics, much more is expected very soon (for summer conferences)

  - Only the SM Higgs searches are discussed since there is a talk in this conference on the CMS BSM Higgs searches

SM Higgs: what we know from theory

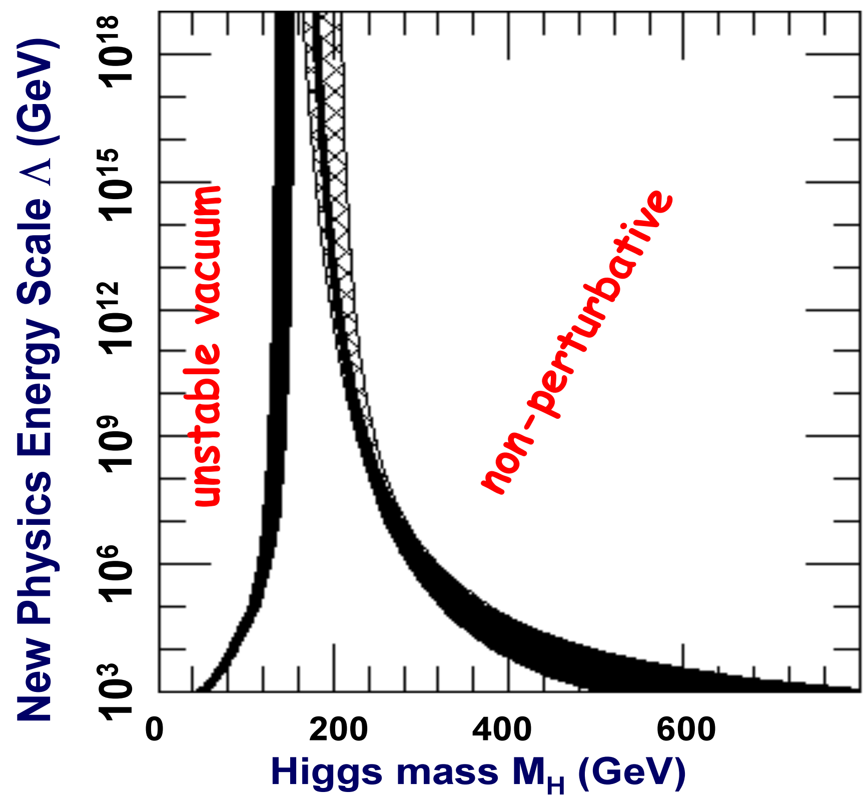
One pseudo-scalar doublet Φ (4 degrees of freedom)

Potential $V = \lambda|\Phi|^4 - \mu^2|\Phi|^2$

After spontaneous symmetry breaking:
- **$W^{\pm}$ and Z acquire masses (3 degrees of freedom)**
- **the last remaining degree of freedom (4-3=1): scalar CP-even Higgs of unknown mass**

λ runs with Q:
- **small m_H at 1-TeV scale**
  at some Q, $\lambda(Q) < 0$
  V has no minimum (vacuum breaks loose)
- **large m_H at 1-TeV scale**
  at some Q, $\lambda(Q) = \infty$
  theory is non-perturbative (theorists do not like it)
- **chimney**
  $\lambda(Q)$ ~ const due to cancellation of +/- terms (fine tuning)

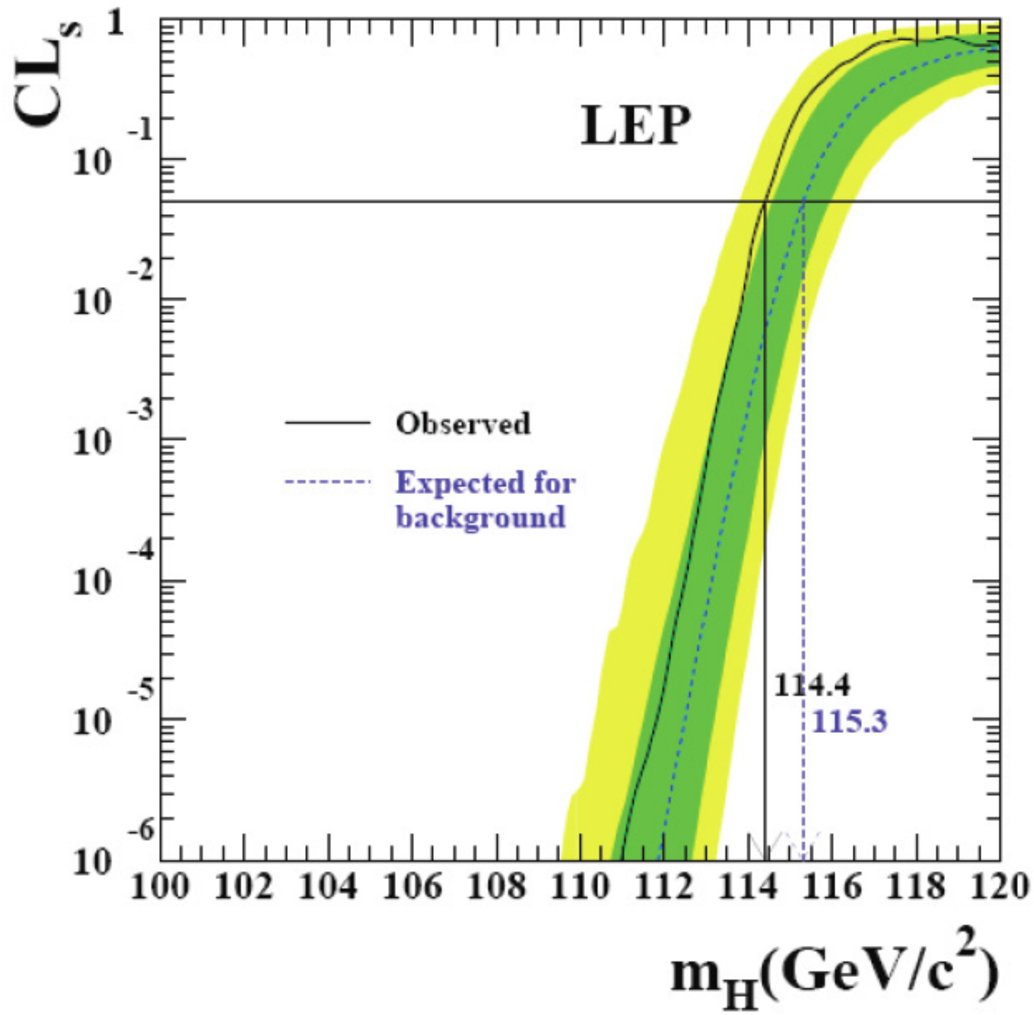
mass must be within 50-600 TeV range



What we know experimentally: LEP

Direct search at LEP:

m_H>114.4 GeV @ 95%CL



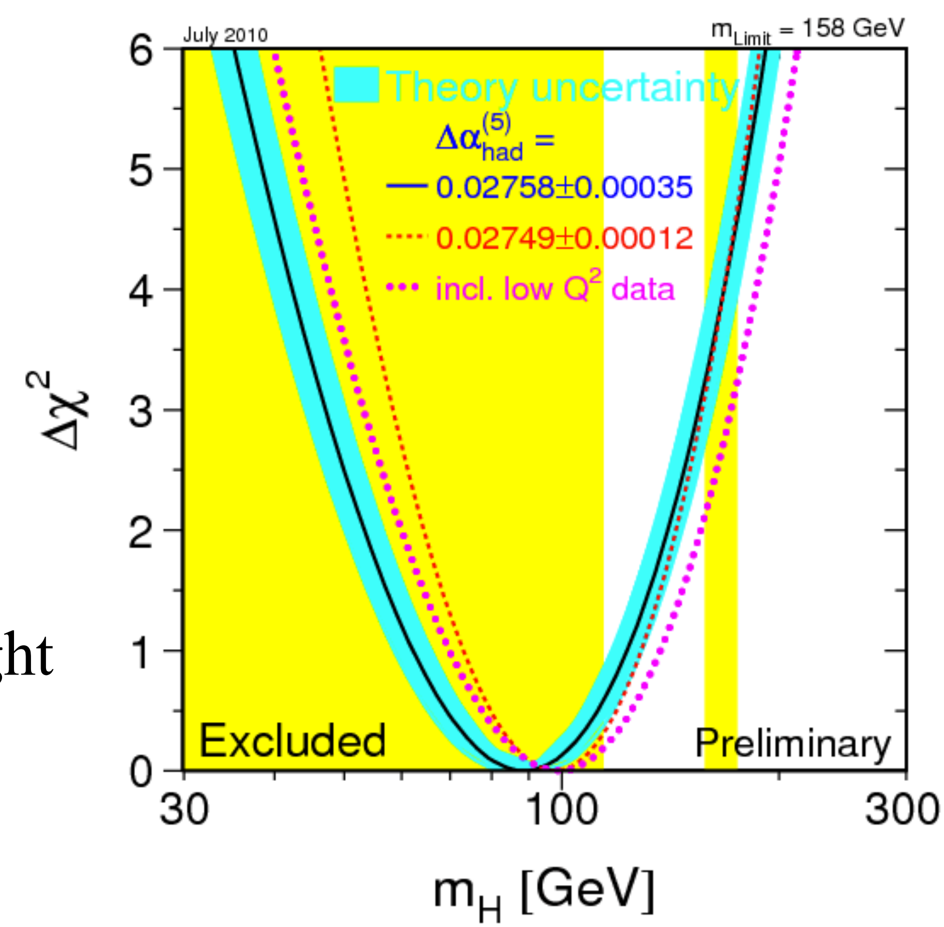
What we know experimentally: direct searches at LEP and Tevatron. EWK fits

Experimental searches for a Standard Model Higgs boson:

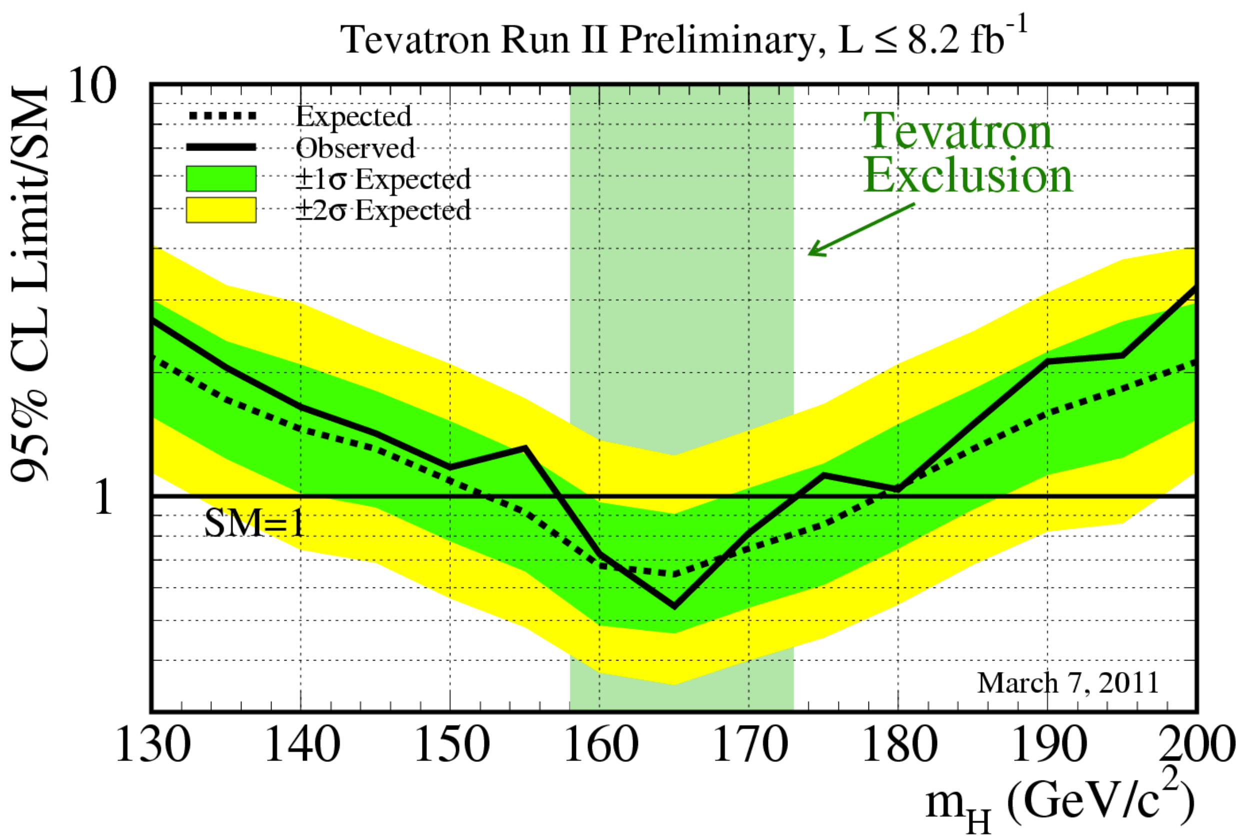
-LEP direct result: MH > 114.4 GeV at 95% C.L.

-Tevatron 2011 direct result excludes at 95% C.L. the mass range: 158 < MH < 173 GeV

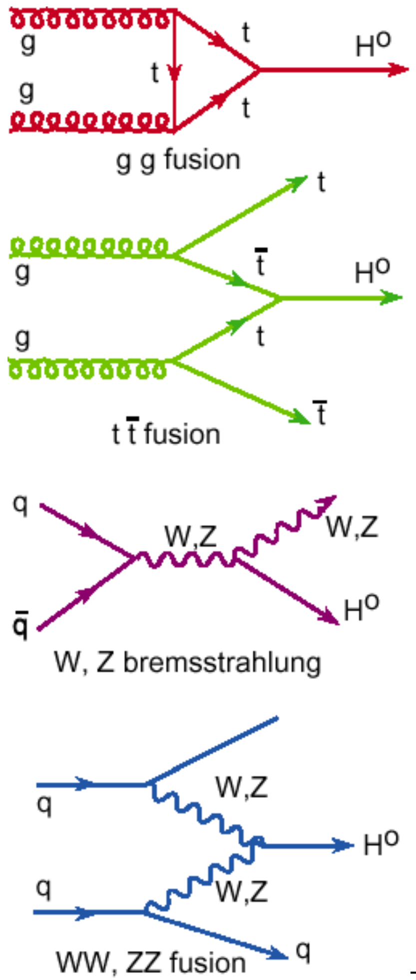
-Indirect SM constraints and global data EWK fits prefer a light Higgs boson:
MH < 158 GeV at 95% C.L.

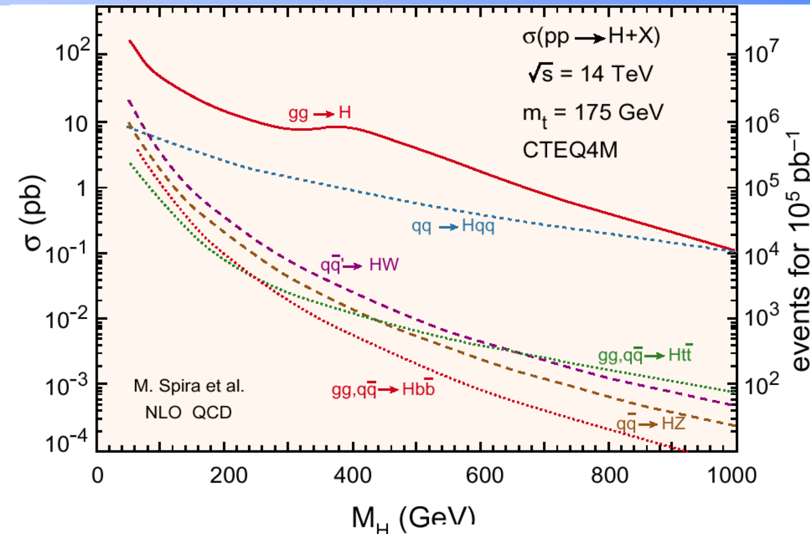


Results from Tevatron (also see Higgs at Tevatron talk)



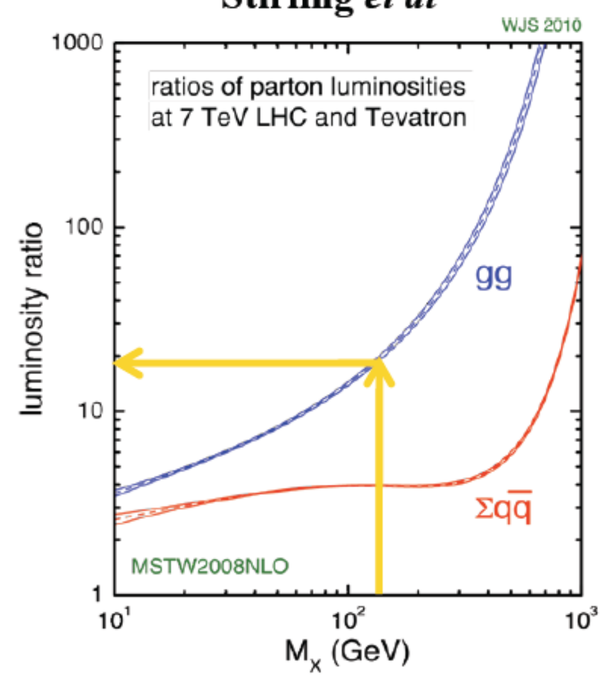
SM Higgs: production



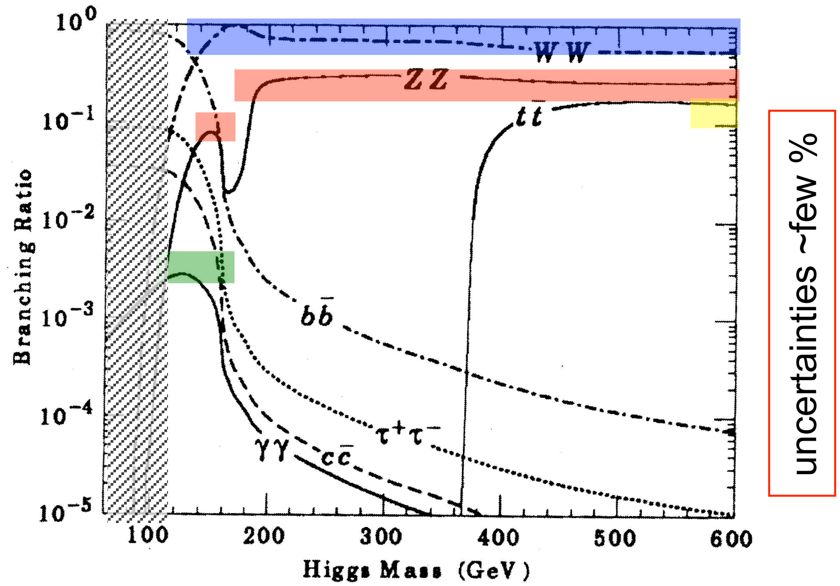


gg-fusion is dominant, particularly at LHC

Stirling *et al*



SM Higgs at LHC: best channels for detection (based on simulations)



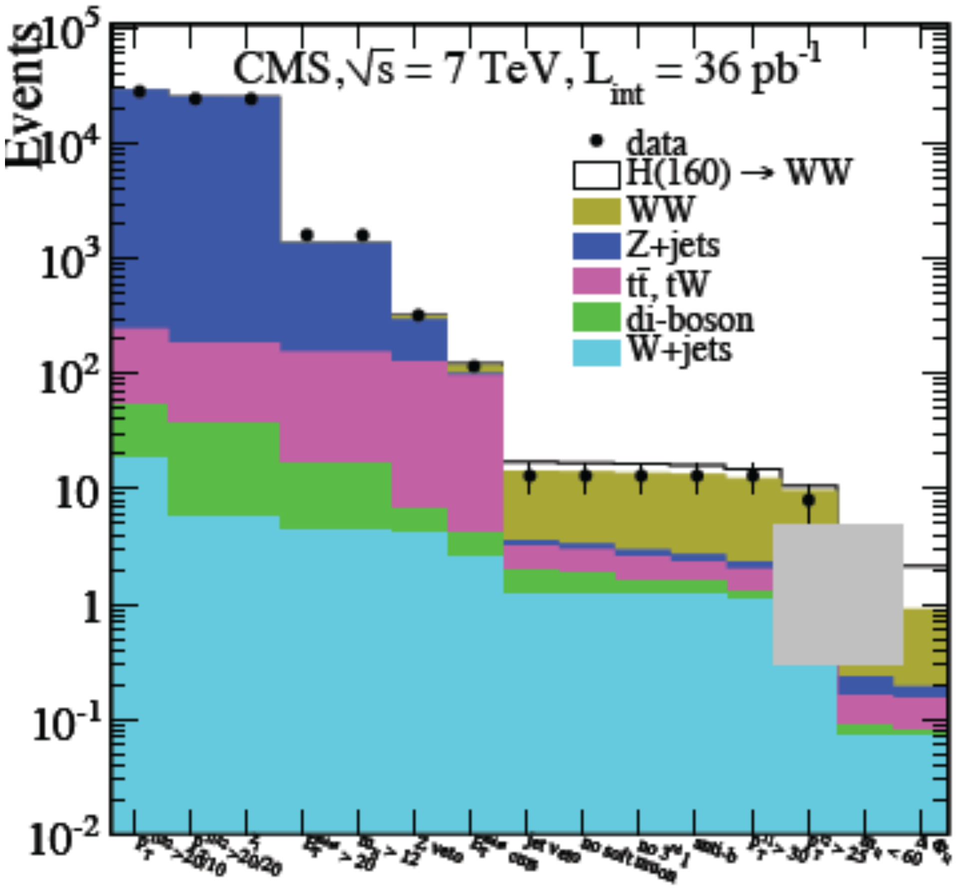
	H→bb	H→ττ	H→γγ	H→WW	H→ZZ
inclusive			YES	YES	YES
VBF (qqH)		maybe		YES	YES
W/Z+H					
ttH					

- YES = { discovery in the appropriate range of masses at L<30 fb^{-1} }

Next few transparencies are on the CMS Higgs→ WW search (2010 data)

- Selection of events
- WW – cross section measurement
- Background Estimation
- Higgs Signal Extraction
- Results

Event Selection



- two energetic isolated leptons (electron or muon), pt>20GeV - **QCD, Wjets**
- large missing transverse energy (MET) and Z veto - **Drell-Yan**
- jet veto (no jets above 25GeV Pt) - **Top**
- kinematics (m*ll, dφ) – **WW** (requirements are optimized for different Higgs masses)

Missing Transverse Energy (MET)

- MET is computed as a negative vector sum of calorimeter energy depositions (ET), corrected for muons and tracks with the Tracker measurement

- Projected MET rejects Drell-Yan to tau-tau decays that usually have MET aligned with a lepton:

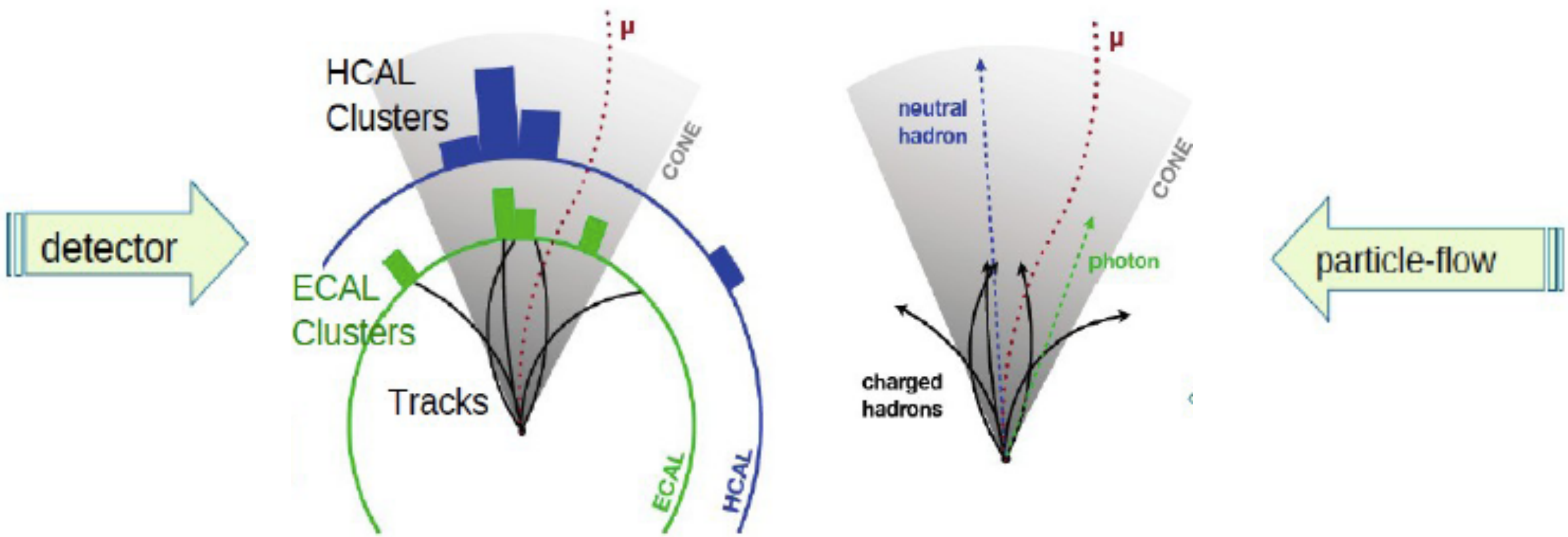
$$\Delta\phi_{min} = min(\Delta\phi(\ell_1, E_{\mathrm{T}}^{\mathrm{miss}}), \Delta\phi(\ell_2, E_{\mathrm{T}}^{\mathrm{miss}}))$$

$$\text{projected } E_{\mathrm{T}}^{\mathrm{miss}} = \begin{cases} E_{\mathrm{T}}^{\mathrm{miss}} & \text{if } \Delta\phi_{min} > \frac{\pi}{2}, \\ E_{\mathrm{T}}^{\mathrm{miss}} \sin(\Delta\phi_{min}) & \text{if } \Delta\phi_{min} < \frac{\pi}{2} \end{cases}$$

- For ee/μμ: projected MET > 35 GeV
- For eμ: projected MET > 20 GeV

Jet Veto

- For jet veto we use corrected jets reconstructed with the particle flow algorithm



•To measure the signal efficiency of the jet veto we measure the jet veto efficiency for Z events and rely on Monte Carlo to correct for the difference between Z and WW jet activity.

W+jets background

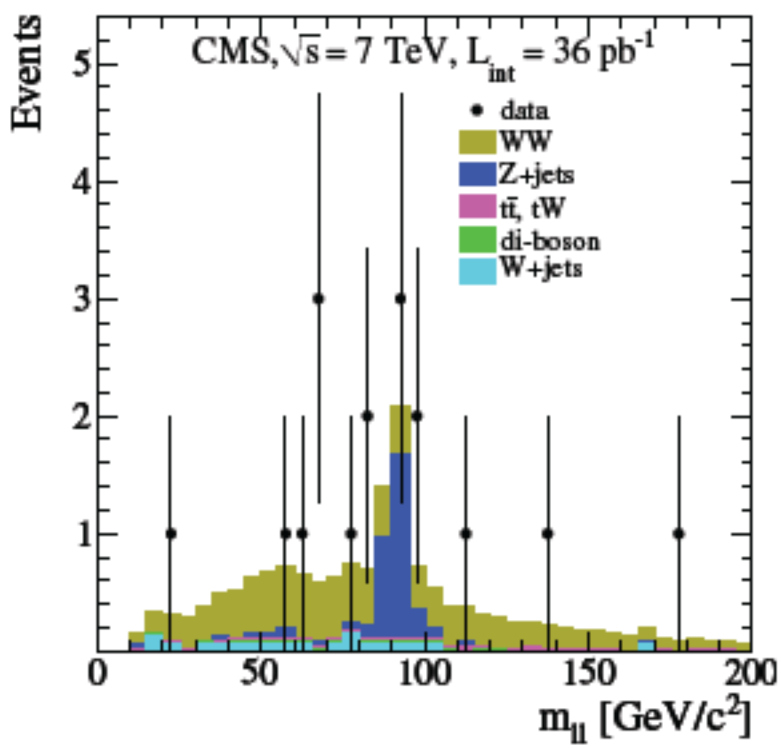
- W+jets is one of the dominant backgrounds where one lepton is originating from a W decay and the other is a fake lepton.

- W+jets has 5 orders of magnitude larger cross-section than Higgs(160).

- With tight identification and isolation requirements W+jets background contribution can be suppressed.

- Remaining background can be estimated by extrapolating to the signal region the number of events in the sideband: area with looser identification and isolation requirements.

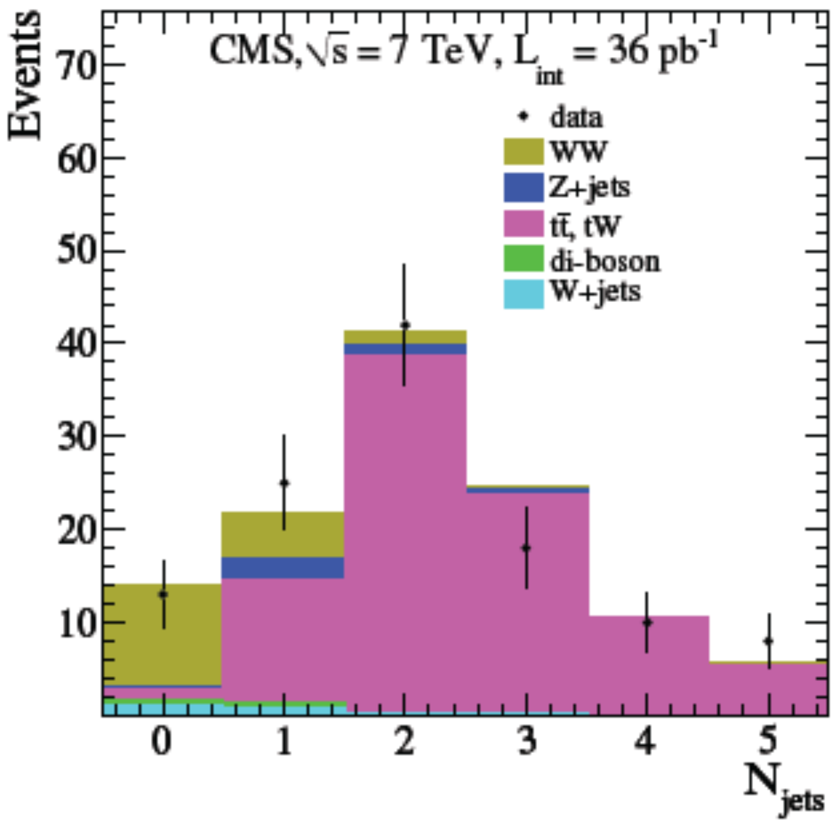
Drell-Yan background



• Drell-Yan has 4-order of magnitude higher cross-section than Higgs(160) and the main discriminating power comes from requiring large missing energy

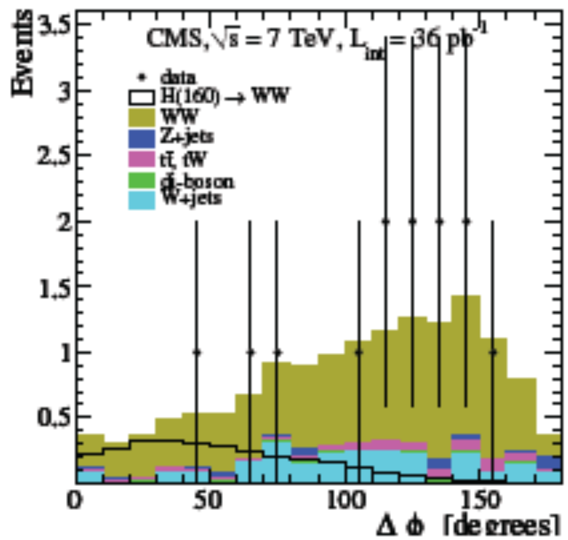
• In addition events around the Z-mass peak are vetoed and used to estimate how much background remains taking the ratio of In-to-Out of peak yield from simulations

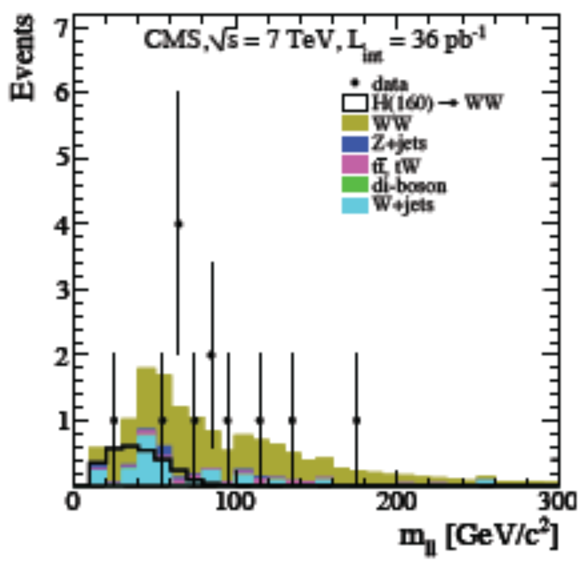
Top background



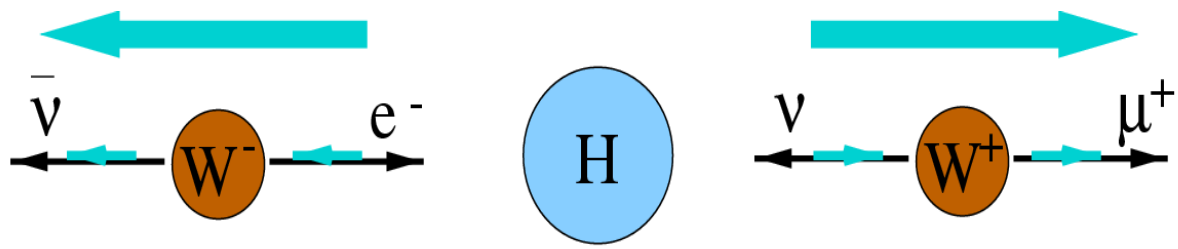
- Top background (TTbar and TW) has the cross-section a factor of 20 larger than Higgs(160)
- Top events differ from WW by presence of extra b-jets
- Top background suppression is based on vetoing events with jets above a threshold of 25GeV and using top tagging techniques that identify b-quarks
- The remaining background can be estimated by observing how many events are rejected by top tagging veto after cuts including the jet-veto

WW -background





- Electro-weak WW production is an irreducible background for Higgs to WW, it has a factor of 5 larger cross-section than Higgs(160).
- Difference in kinematic distributions can help
- At low mass Higgs the angular correlation of the leptons helps to extract signal



- Contribution of WW-background into signal region can be estimated using high dilepton mass region, which is dominated by WW background

WW -Cross-Section measurement

- With 36/pb of 2010 data with WW selection requirements, 13 events have been observed
- Background contributions estimated using data driven methods and Monte Carlo simulations is in the table below:

Process	Events
W+jets + QCD	$1.70 \pm 0.40 \pm 0.70$
$\mathrm{t\bar{t}} + \mathrm{tW}$	$0.77 \pm 0.05 \pm 0.77$
$W\gamma$	$0.31 \pm 0.04 \pm 0.05$
$\mathrm{Z} + WZ + ZZ \to \mathrm{e^+e^-}/\mu^+\mu^-$	$0.20 \pm 0.20 \pm 0.30$
WZ + ZZ, leptons not from the same boson	$0.22 \pm 0.01 \pm 0.04$
$Z/\gamma^* \to \tau^+\tau^-$	$0.09 \pm 0.05 \pm 0.09$
Total	$3.29 \pm 0.45 \pm 1.09$

$$\sigma_{\mathrm{W^+W^-}} = 41.1 \pm 15.3\,(\mathrm{stat}) \pm 5.8\,(\mathrm{syst}) \pm 4.5\,(\mathrm{lumi})\ \mathrm{pb}$$

The Standard Model Prediction for WW-cross-section is 43pb, excellent agreement

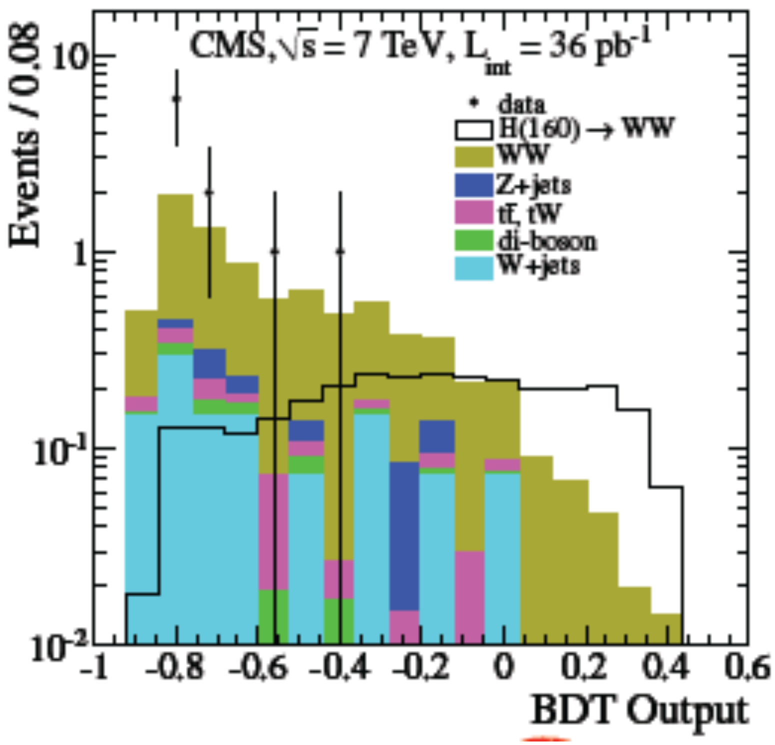
Higgs signal: 1) cut based analysis

Cut based analysis uses optimized cuts on the following variables :
1) di-lepton mass, 2) angle between two leptons, 3) momenta of leptons to distinguish Higgs signal and WW -background:

m_H (GeV/c^2)	$p_T^{\ell,max}$ (GeV/c) >	$p_T^{\ell,min}$ (GeV/c) >	$m_{\ell\ell}$ (GeV/c^2) <	$\Delta\phi_{\ell\ell}$ (degree) <
130	25	20	45	60
160	30	25	50	60
200	40	25	90	100
210	44	25	110	110
400	90	25	300	175

Background reduction factors are estimated from simulations, WW background yield is estimated from di-lepton mass sideband in data

Higgs signal: 2) Multivariate Analysis (Boosted Decision Tree or BDT)



• Multivariate analysis approach is using Boosted Decision Tree algorithm to combine multiple discriminating variables: m*ll*, $\Delta\varphi ll$ $\Delta\eta$, angles between MET and leptons, projected MET, transverse mass of each lepton & MET and final state flavor (ee, eμ, μμ)

• MVA gives roughly ~20% better Sensitivity than cut based analysis

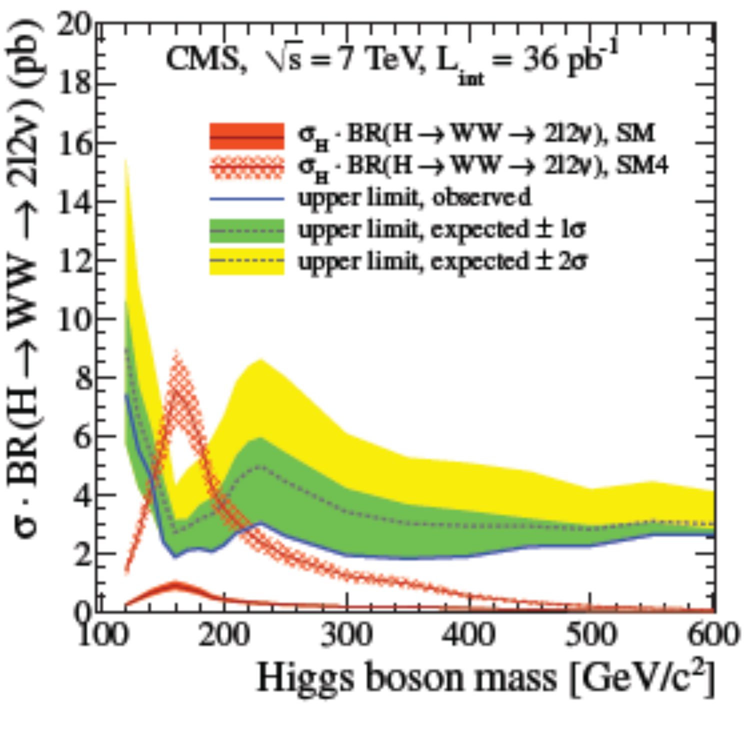
Systematics evaluation

• With 2010 data we found that systematic uncertainties on major Backgrounds sre around 50% or more. With more data it will be possible to improve understanding of backgrounds

• The jet veto efficiency is a single most important systematics which is found to be is of the order of 5-6%.

• For the published results luminosity uncertainty was estimated to be 11%. Recently we improved our understanding of related uncertainties, so in future this uncertainty will be smaller

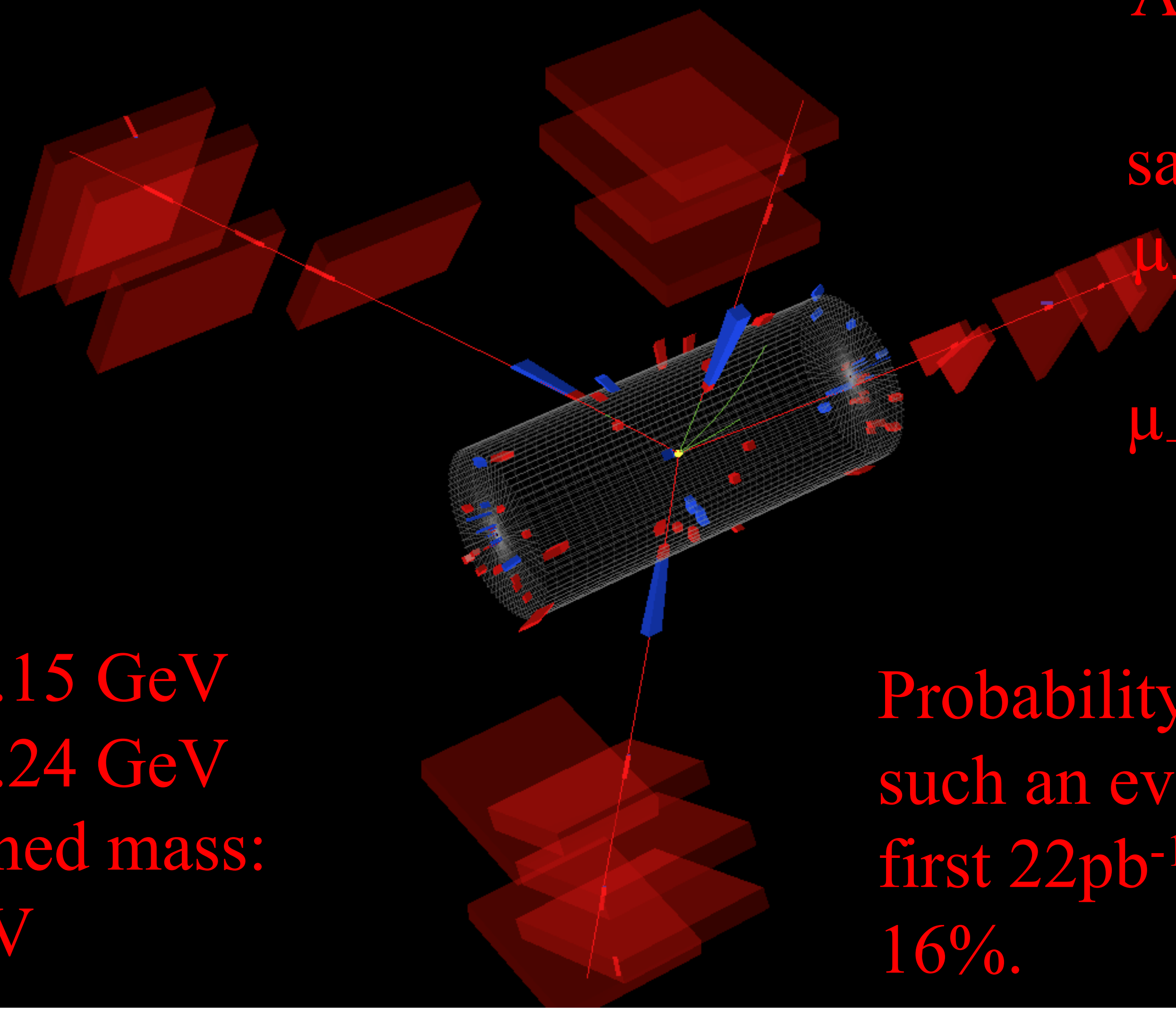
Higgs→ WW searches results



- 95% C.L. upper limit is a factor of 2 bigger than the Standard Model cross-section for H(160)→WW

- An extension with 4 fermion generations predicts roughly a factor of 9 enhancement in the cross-section. For this model we exclude Higgs in mass range from 144GeV to 207GeV

ZZ→4μ event, found in first 22/pb

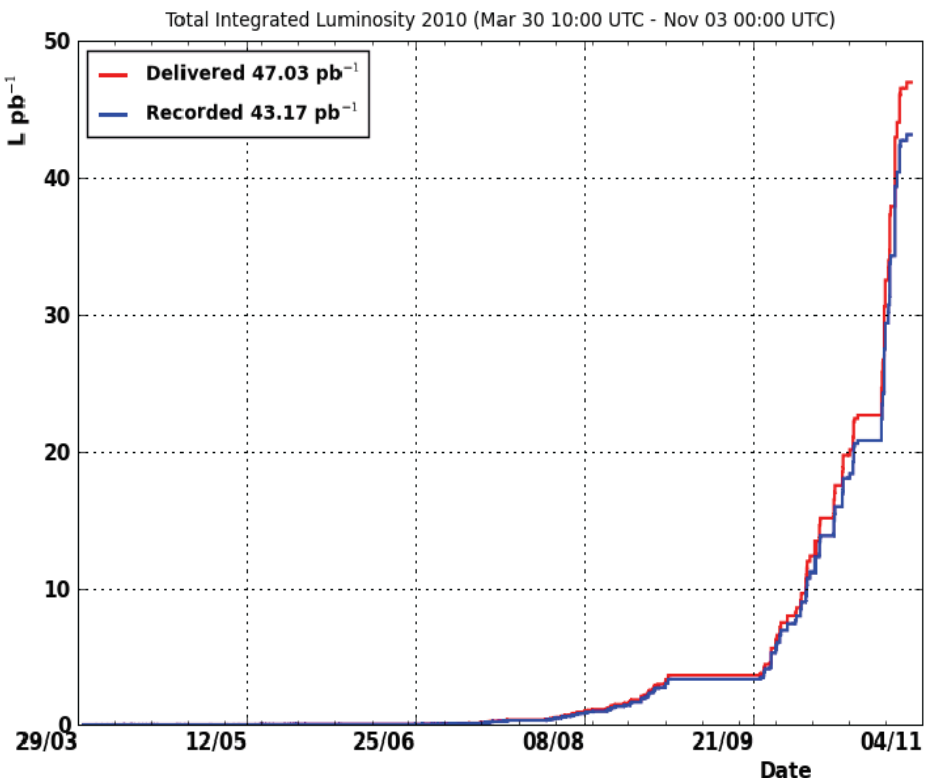


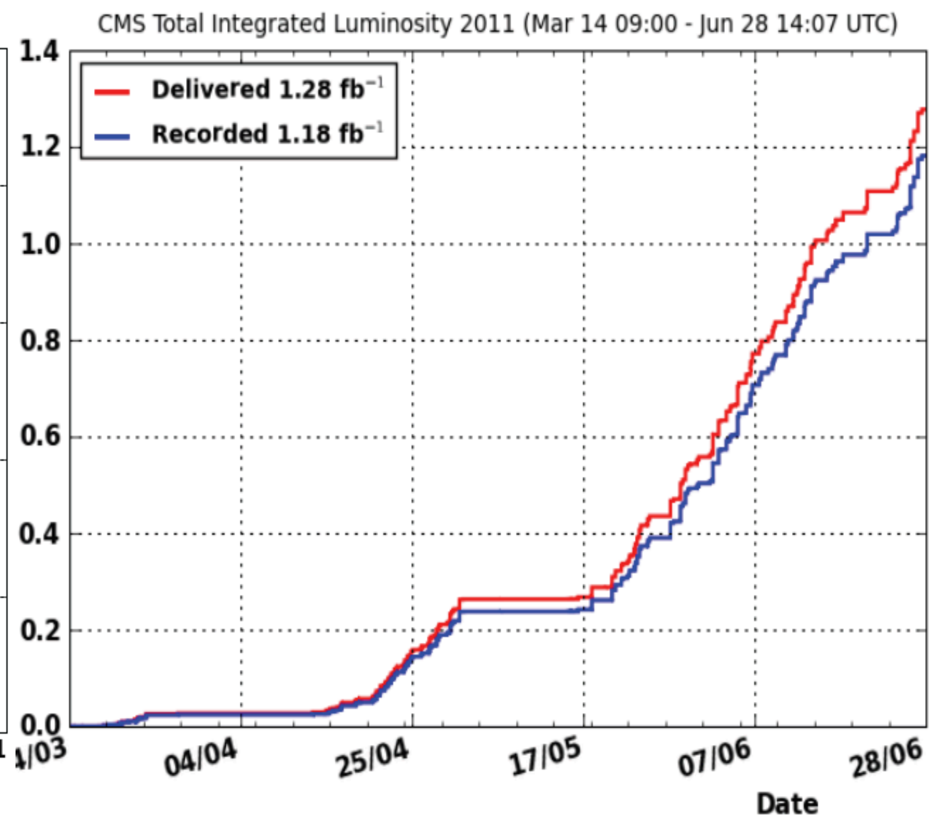
All 4 muons from the same vertex:
μ_{-1} 48.1; μ_{+2} 43.4 GeV
μ_{+3} 25.9; μ_{-4} 19.6 GeV

Z_1= 92.15 GeV
Z_2= 92.24 GeV
Combined mass: 201GeV

Probability to find such an event in the first $22pb^{-1}$ of data: 16%.

CMS integrated luminosity in 2010 and 2011 (so far)



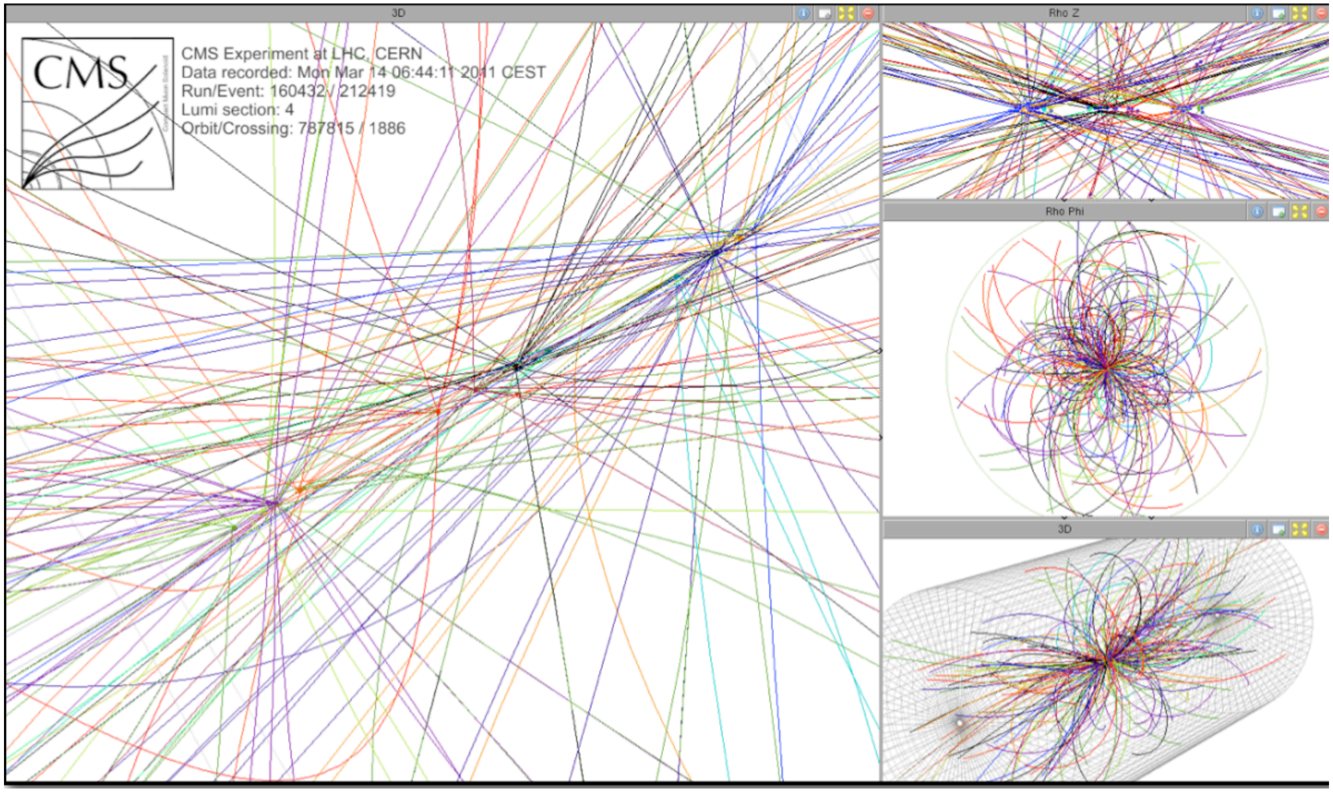


LHC luminosity exceeds all expectations!

My naive unofficial projection:

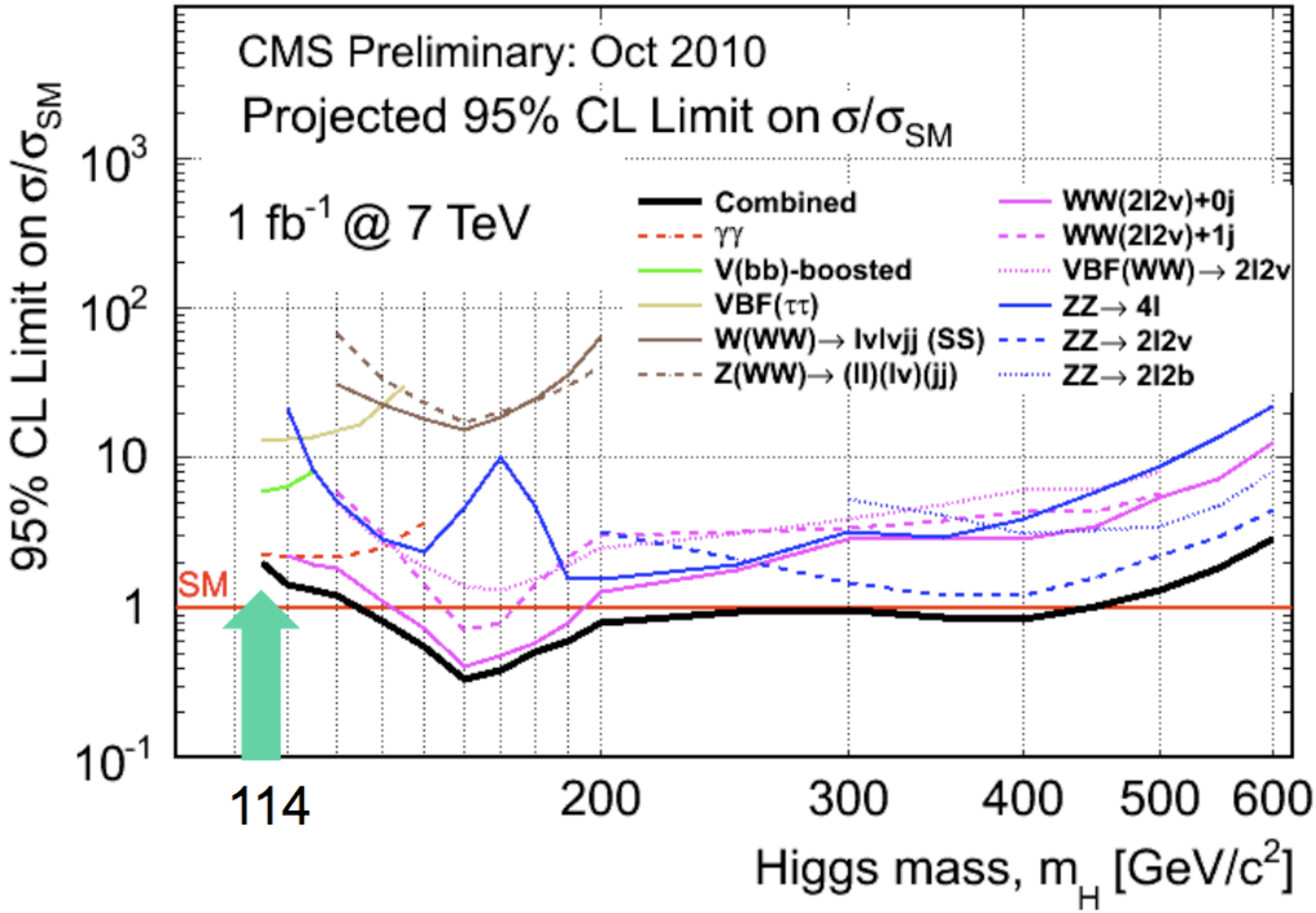
~ 5 fb^{-1} by the end of 2011, >10 fb^{-1} by the end of 2012

High Luminosity at LHC: Trigger selectivity, Pile-up, CPU, etc.

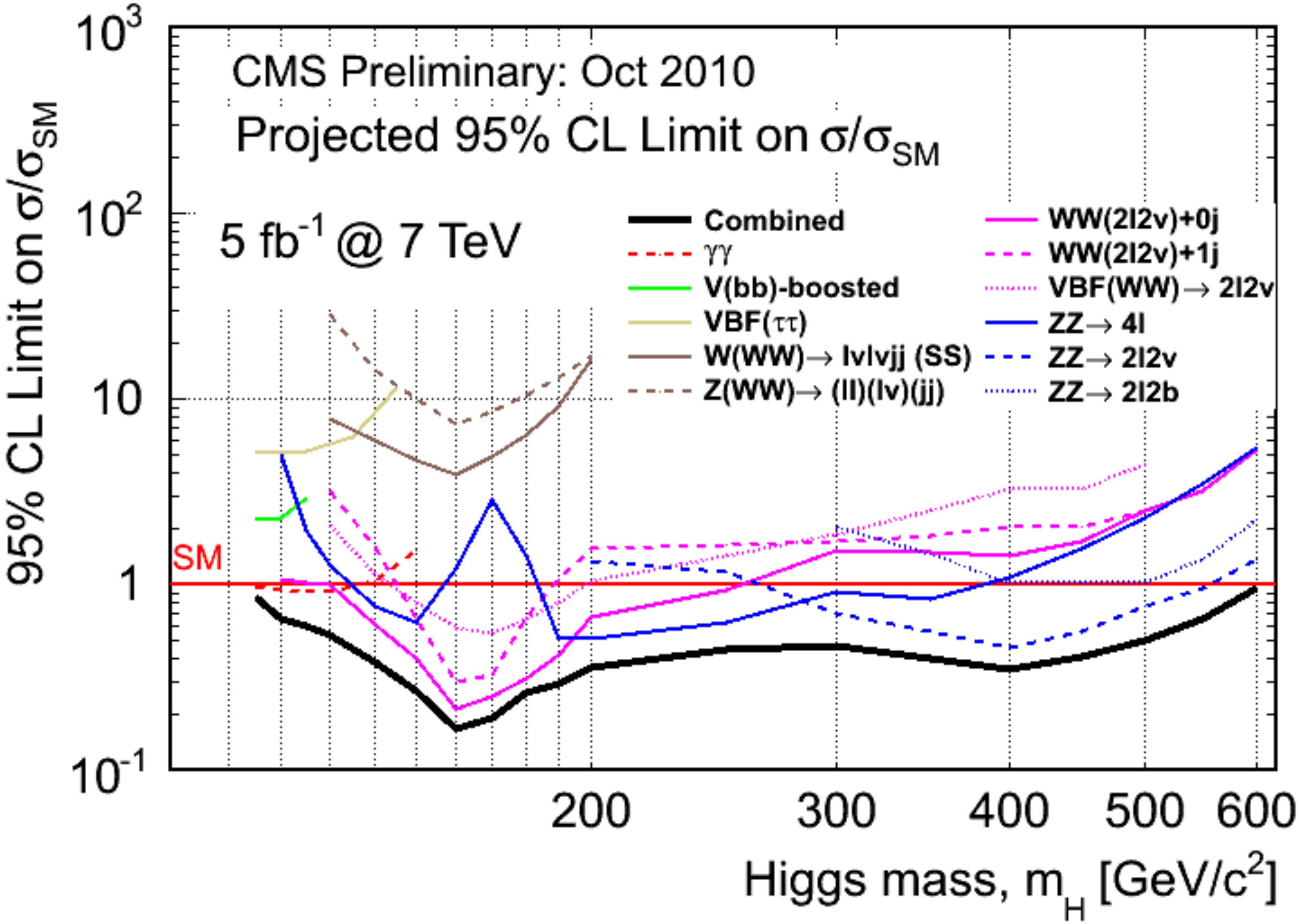


Operating at ~ 1.5x10^{33} (or more!) with 50ns bunch structure presents many challenges

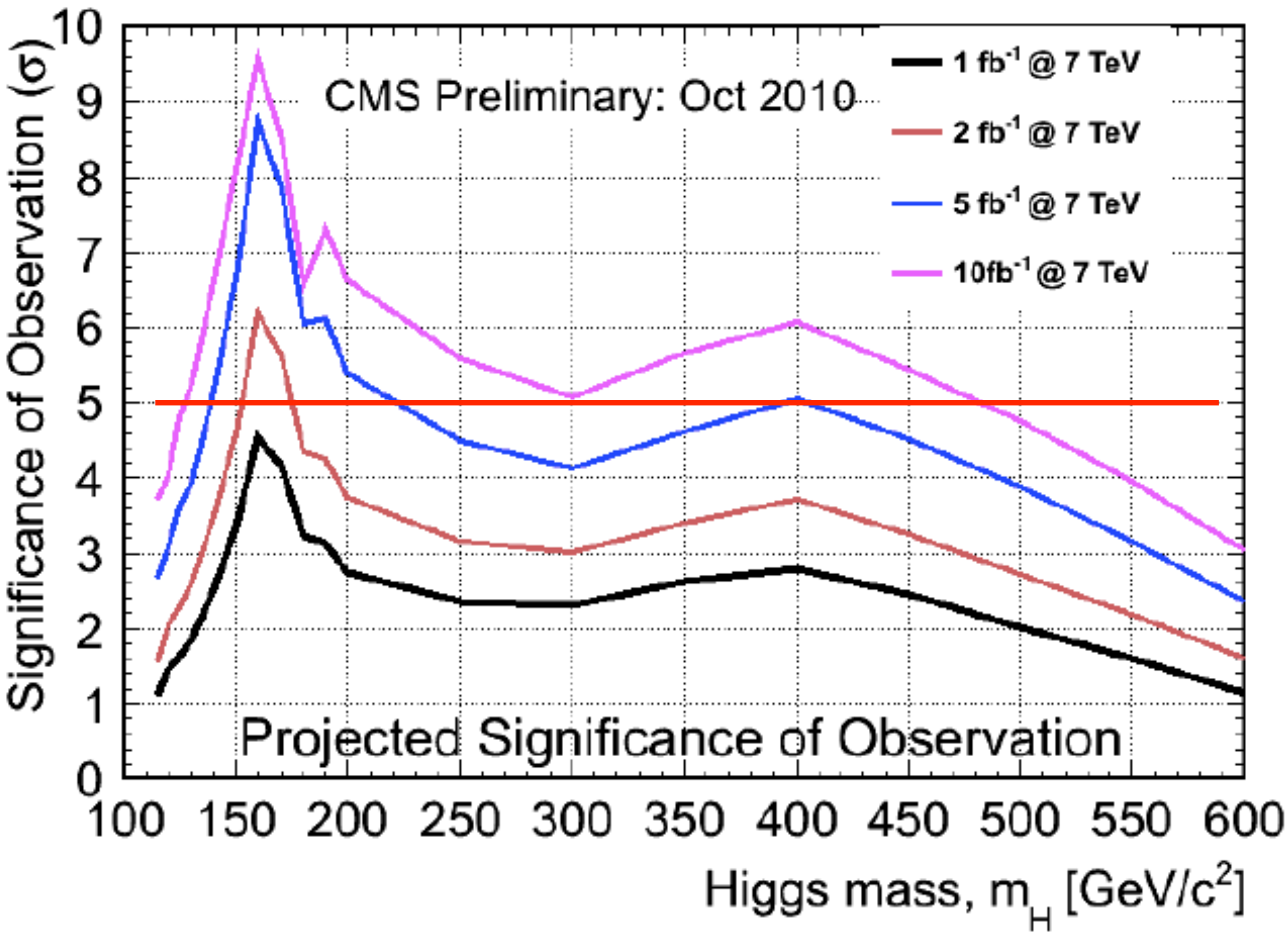
CMS sensitivity for exclusion: $1 fb^{-1}$ (~now)



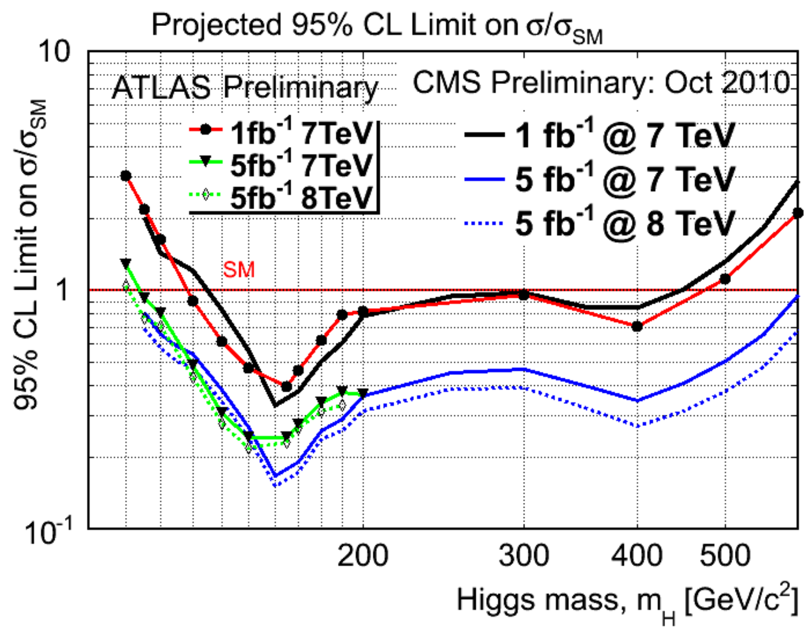
CMS Sensitivity for exclusion: 5fb^{-1} (all SM Higgs mass range by end of 2011?)



CMS Higgs Discovery Prospects with 1 - 10fb^{-1}



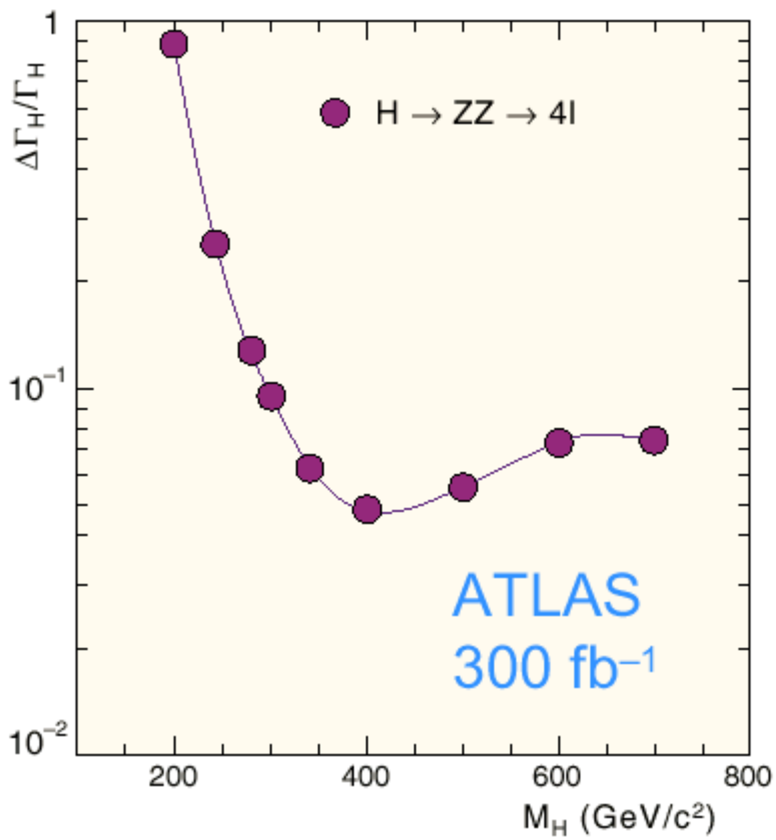
CMS+ATLAS Projections

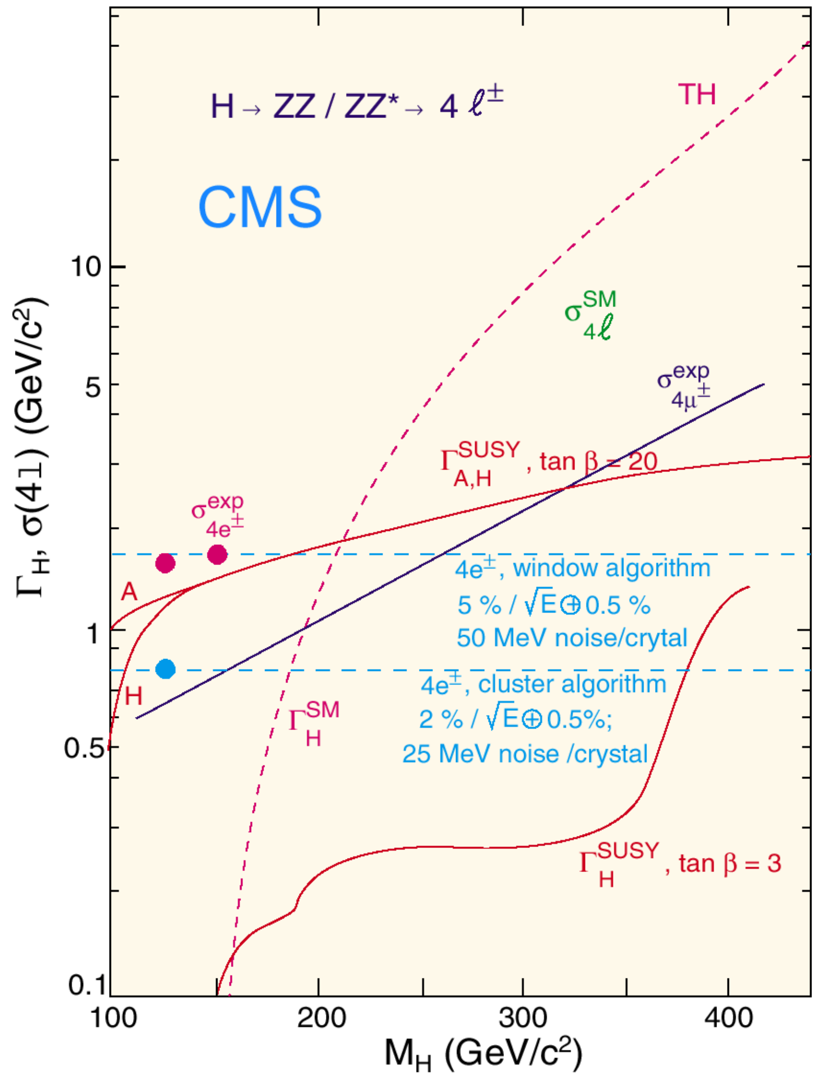


ATLAS + CMS ≈ 2 x CMS	95% CL exclusion	3σ sensitivity	5σ sensitivity
1 fb^{-1}	120 - 530	135 - 475	152 - 175
2 fb^{-1}	114 - 585	120 - 545	140 - 200
5 fb^{-1}	114 - 600	114 - 600	128 - 482
10 fb^{-1}	114 - 600	114 - 600	117 - 535

Long term perspective: SM Higgs properties: width (if M_H>200 Gev)

- **Width (assume CMS ~ ATLAS):**
  - **Direct measurement if M_H>200 using golden mode (4ℓ)**





Long term perspective: SM Higgs properties: width determination (low M_H, indirect)

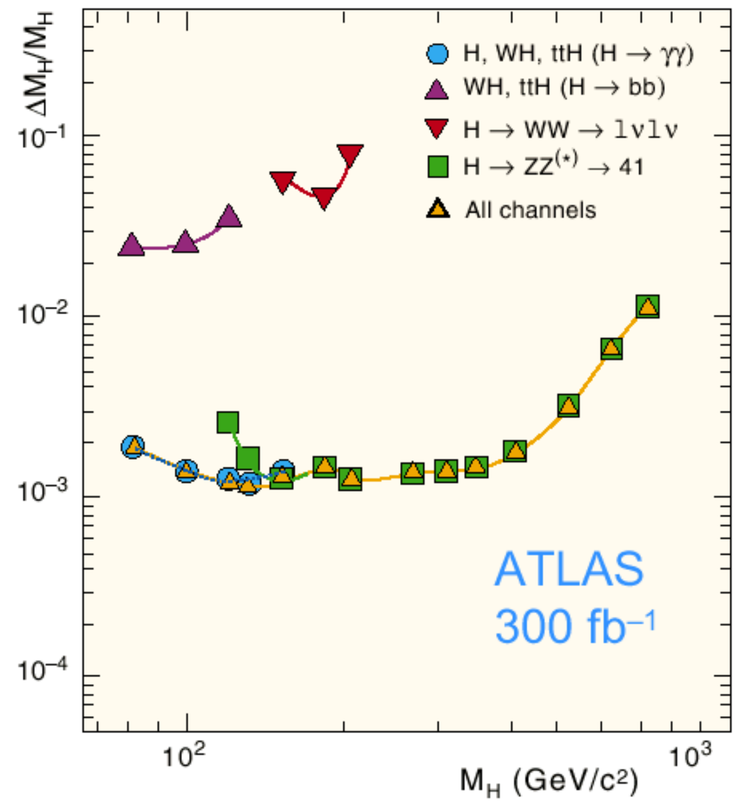
- **Combine measurements of several Higgs channels in VBF and gg production: $qq \to qqH$, $gg \to H$**
  - Can measure the following: $X_i = \Gamma_W \Gamma_i / \Gamma$ from $qq \to qqH \to qqii$
    - Here: $i = \gamma, \tau, W(W^*)$; precision~10-30%
  - Measure also $Y_i = \Gamma_g \Gamma_i / \Gamma$ from $gg \to H \to ii$
    - Here: $i = \gamma, W(W^*), Z(Z^*)$; precision~10-30%
  - Ratios of X_i and Y_i (~10-20%) → couplings

  - Γ and Γ_W can be estimated from:

    - $(1-\varepsilon)\Gamma_W = X_\tau(1+y) + X_W(1+z) + X_\gamma + Y_W$
    - $\varepsilon = (1-(B_b+B_\tau+B_W+B_Z+B_g+B_\gamma)) = B_C \ll 1$
    - From SM: $z = \Gamma_W/\Gamma_Z$; $y = \Gamma_b/\Gamma_\tau = 3\eta_{QCD}(m_b/m_\tau)^2$
    - $X_W = (\Gamma_W)^2/\Gamma$ - observable

Long term perspective: SM Higgs properties: mass measurement

- **Accuracy of mass measurement depends on SM Higgs mass**
  - Limited by absolute energy scale, assume
    - leptons & photons: 0.1% (with Z calibration)
    - Jets: 1%
  - Resolutions: assume numbers
    - For $\gamma\gamma$ & $4\ell \approx 1$ GeV/c^2
    - For bb ≈ 15 GeV/c^2
  - If Higgs mass is large, decreasing precision due to large Γ_H



Even longer term studies (if SM Higgs is found, need A LOT of statistics)

– **Higgs spin e.g. using angular correlations in 4l decays (if Higgs is SM and mass is high enough)**
– **Higgs self couplings (experiments may wait for SLHC or LC):**

Summary (unofficial projections for near future: next 1.5 years)

- With ∫L ~ 40 pb-1 at $\sqrt{s}$ = 7 TeV CMS experiment have started exploring SM Higgs Physics in Higgs→WW channel. With ∫L>1 fb^{-1} (available now!) CMS is expected to surpass Tevatron sensitivity for high mass Higgs searches
- With integrated luminosity ~ 5 fb^{-1} (end of 2011?) , CMS will have sensitivity to exclude SM Higgs in all possible range of masses up to 600 GeV.
- By the end of 2012 run CMS+ATLAS are likely to achieve sensitivity for 5 σ discovery of SM Higgs in all possible mass range

EXITING TIMES AHEAD OF US!