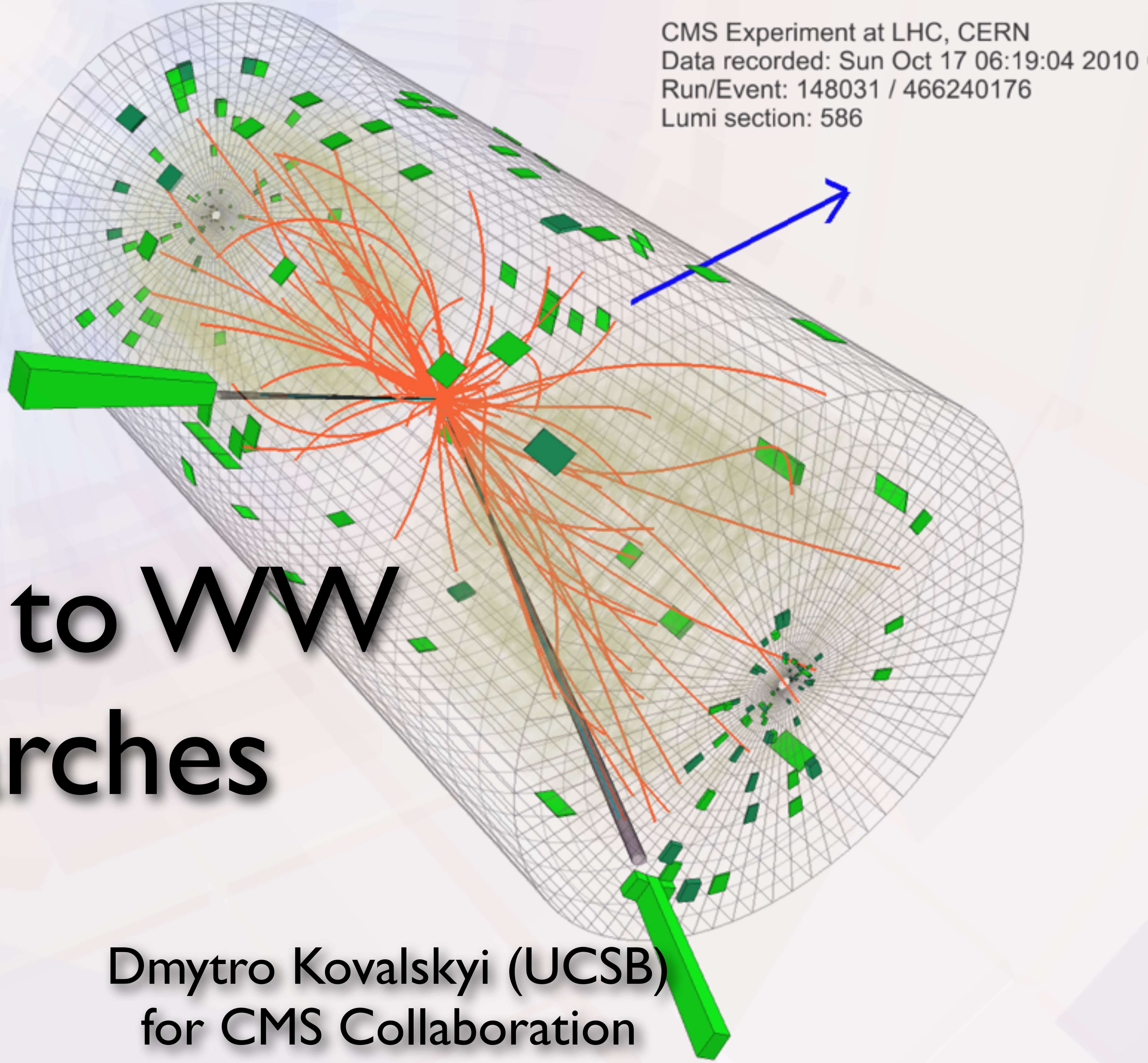
Higgs to WW Searches

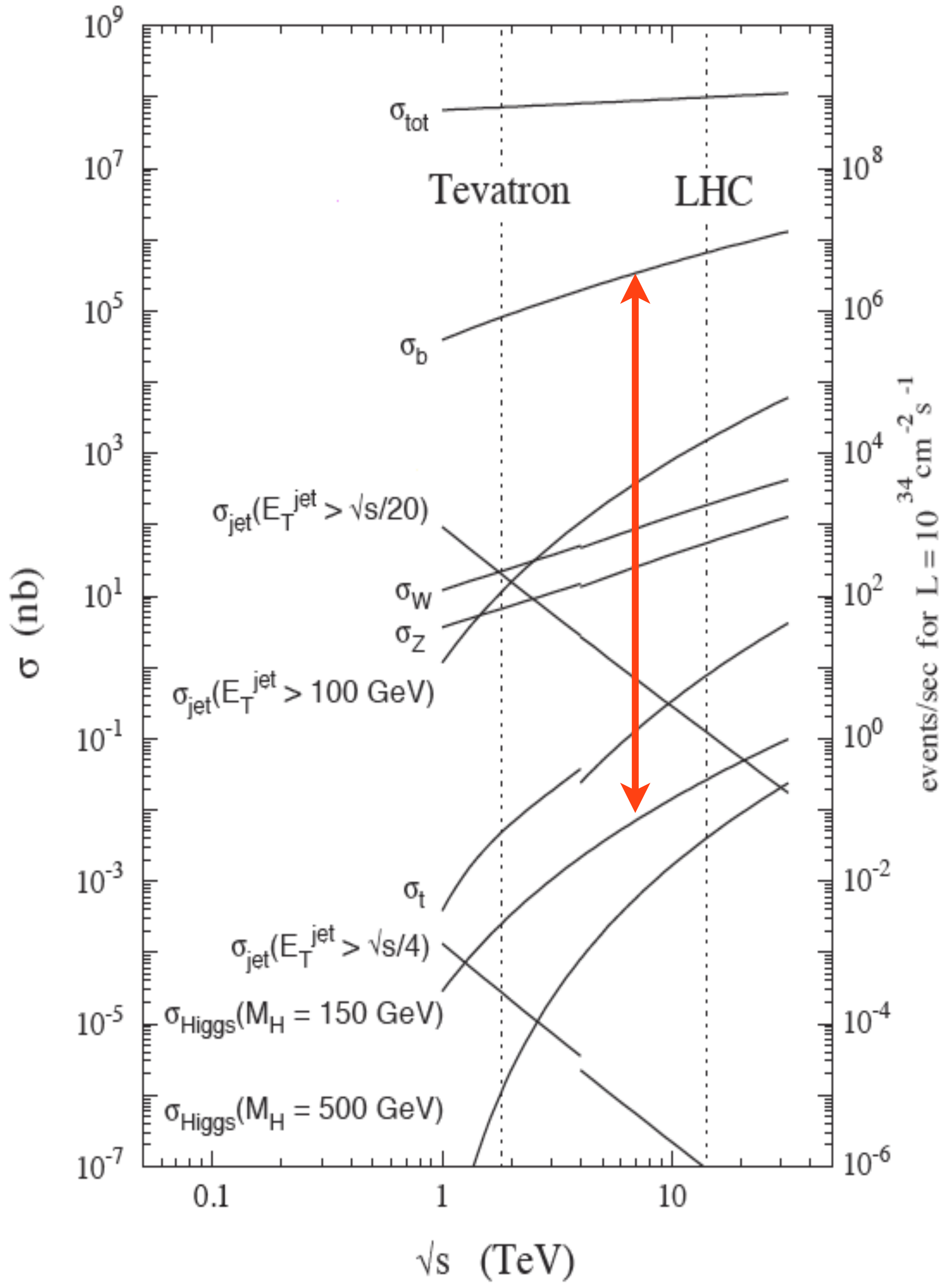


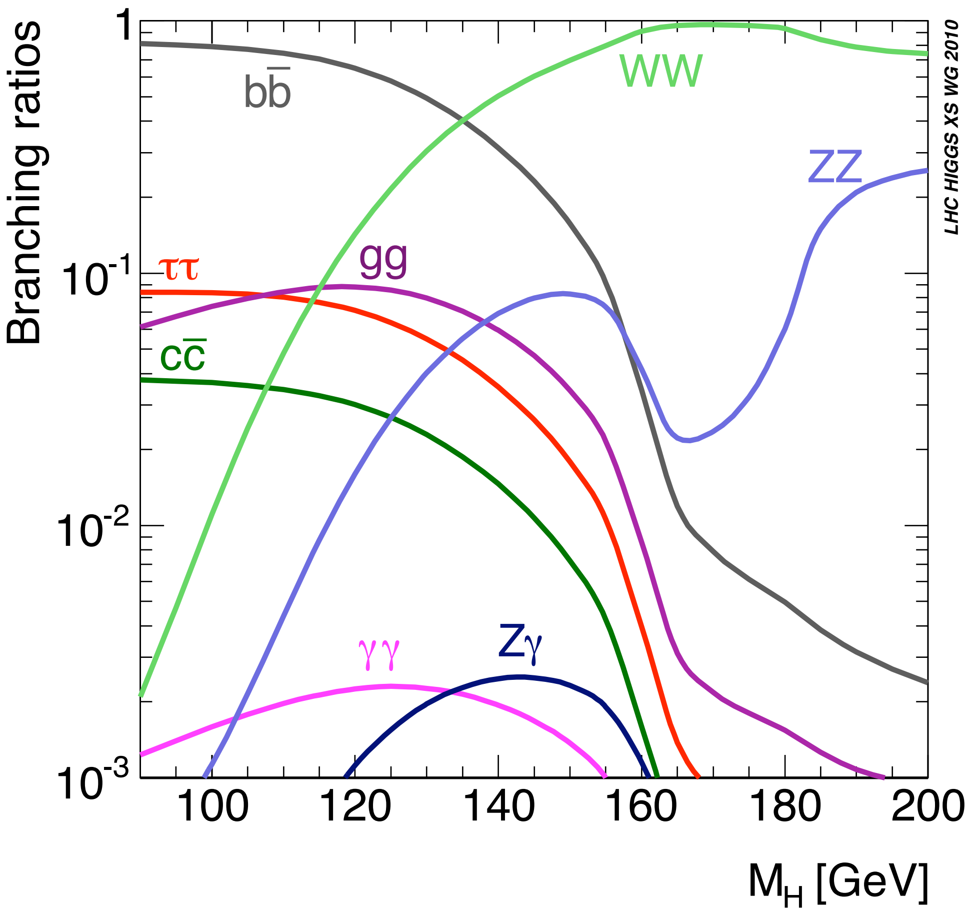
Dmytro Kovalskyi (UCSB)
for CMS Collaboration

Outline

- Introduction
- Event Selection
- Background Estimation
- Higgs Signal Extraction
- Results

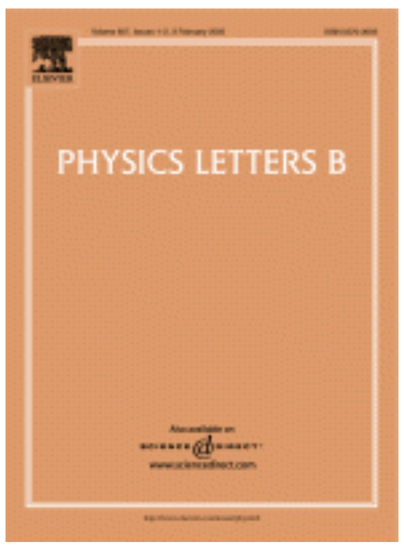
Introduction





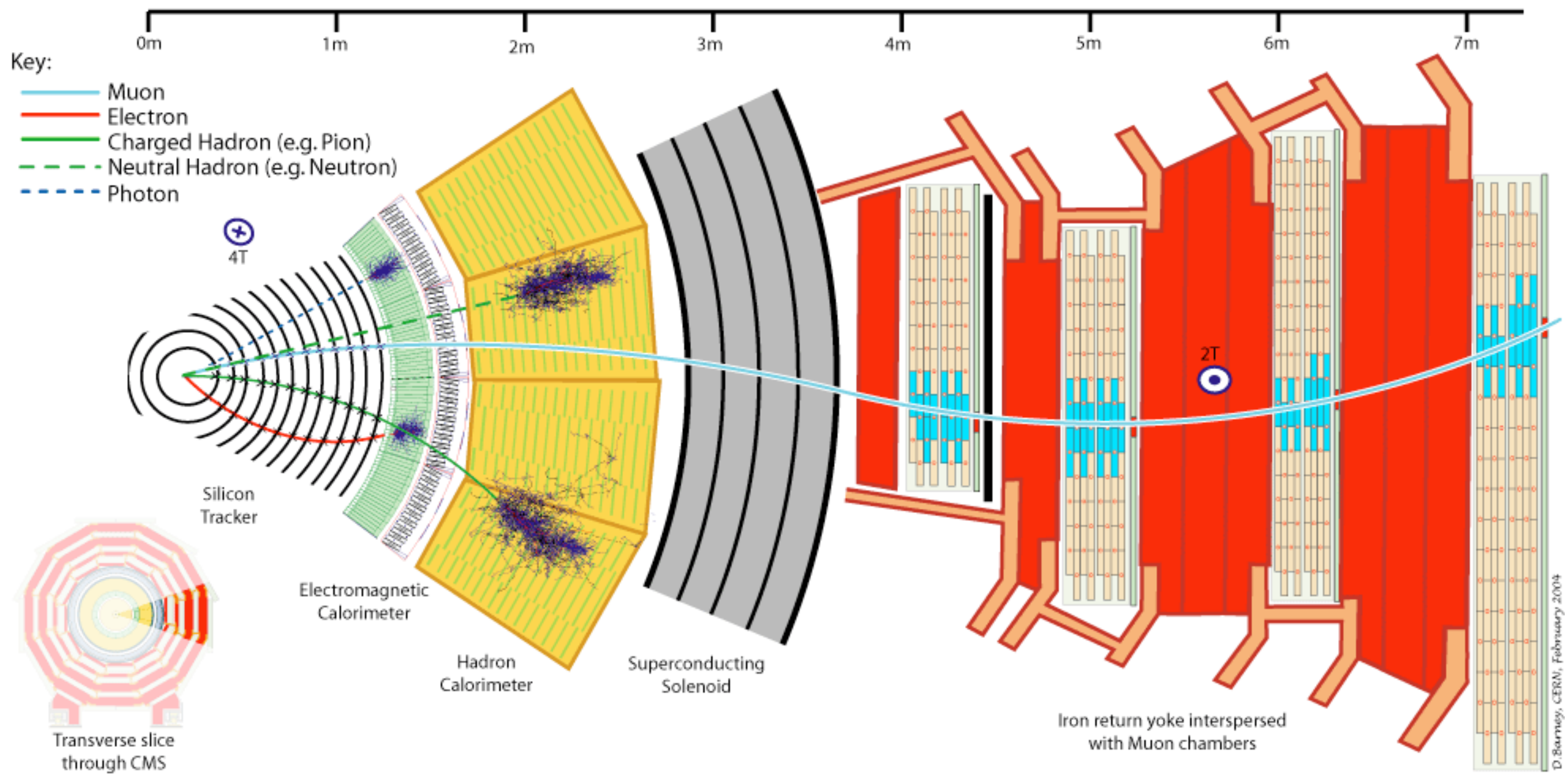
Higgs to WW is the most sensitive channel for Higgs searches in a wide range of Higgs masses

CMS SM Higgs Results

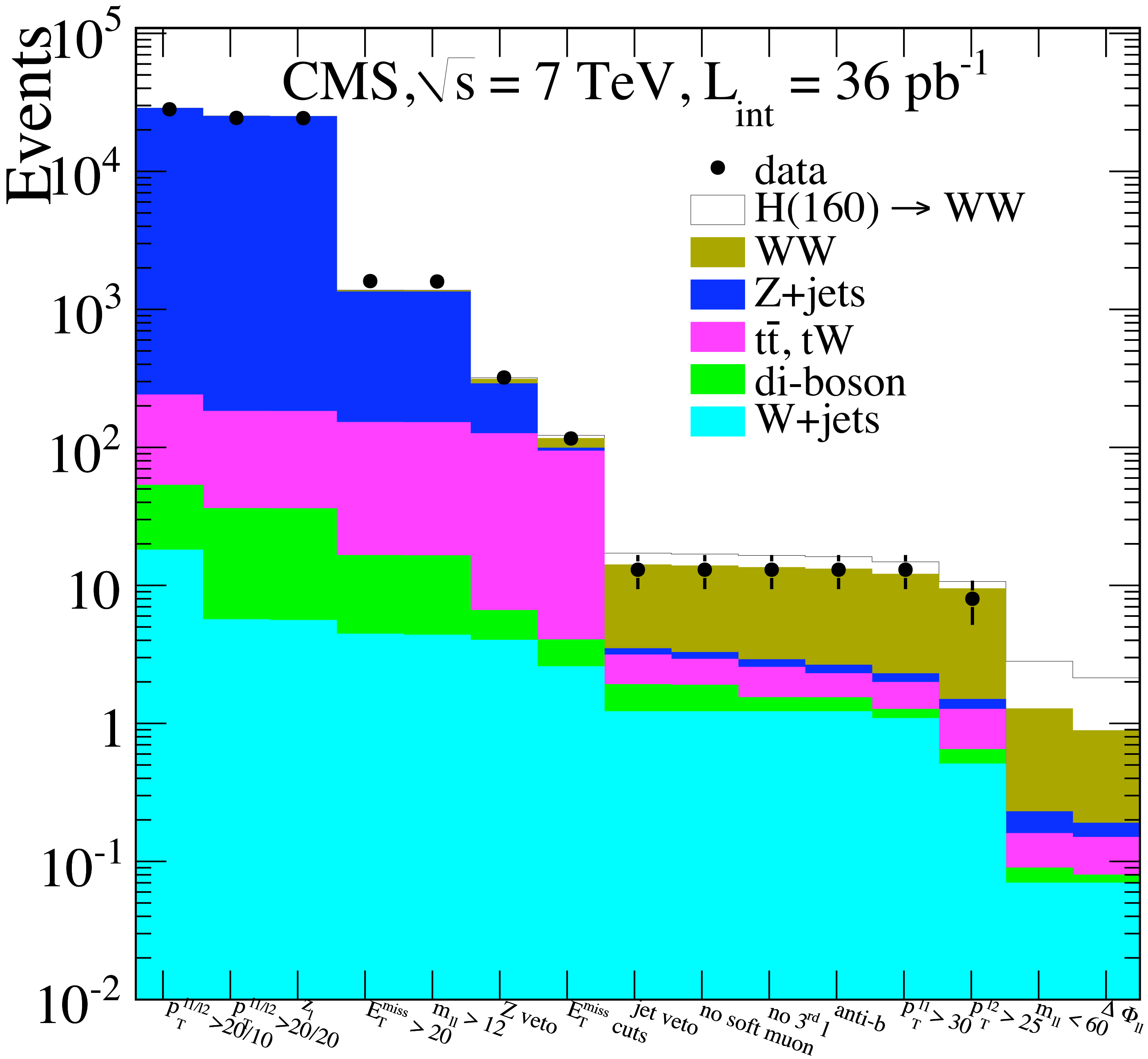


- Among various channels for the Standard Model Higgs searches, CMS only published Higgs to WW in dilepton final state.
  - arXiv:1102.5429, accepted by PLB for publication
- Other channels don't have enough sensitivity with 36/pb of data at 7 TeV
- In this talk only Higgs to WW searches are presented

CMS Detector



Event Selection



- Key selection requirements:
  - 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**
- Final step selection requirements are optimized for different Higgs mass hypotheses

MET

- MET is computed as a negative vector sum of calorimeter energy depositions (E_T), corrected for muons and tracks.
  - The track correction substitutes the expected energy deposition for each tracks with the Pt measured by the tracker
- Projected MET helps to reject Drell-Yan to tau-tau decays that tend to have MET aligned with one of the leptons:

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

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

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

Jet Veto

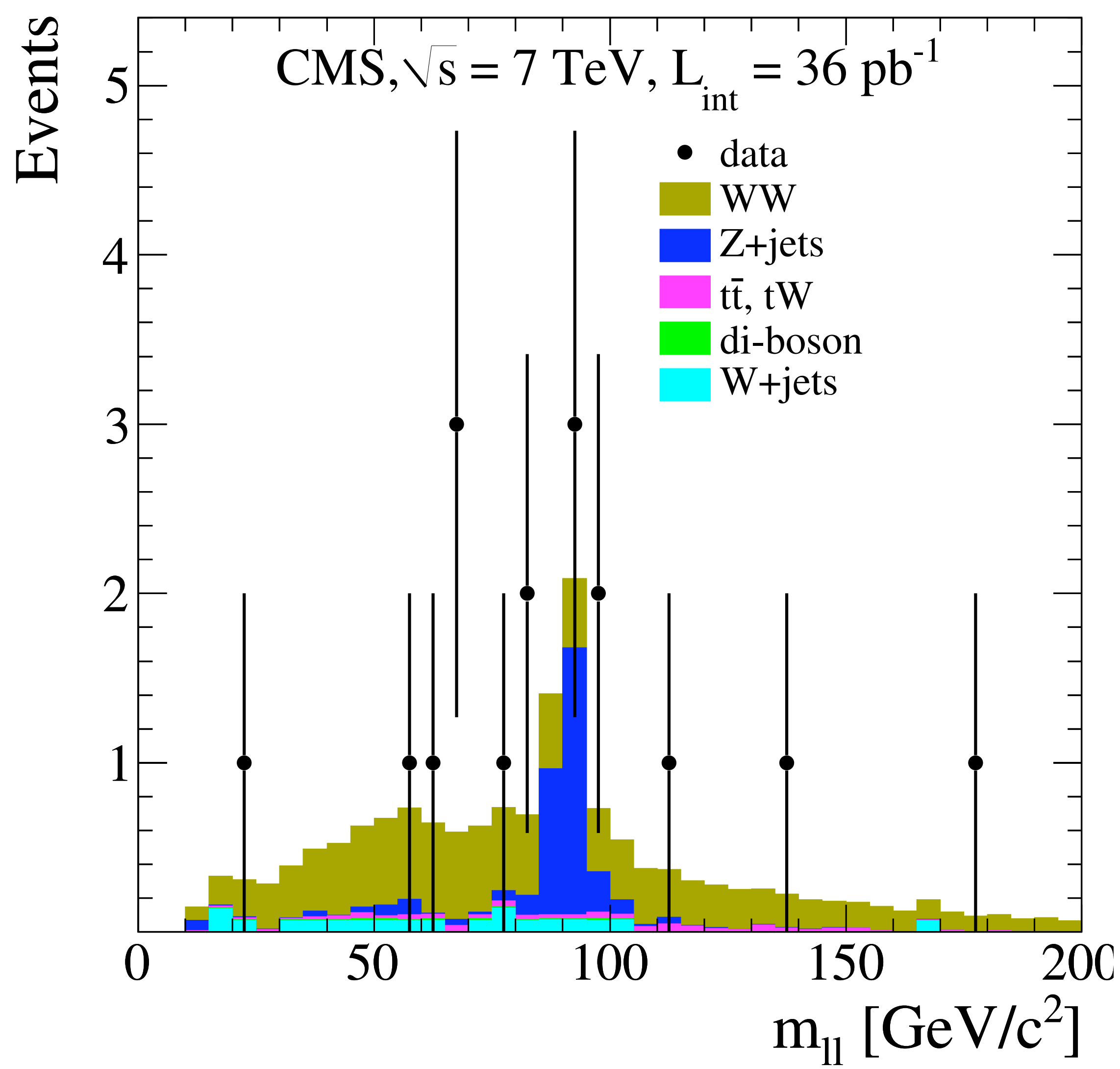
- For jet veto we use corrected jets reconstructed with the particle flow algorithm.
- To improve Top background rejection the jet veto uses jets with pseudo-rapidity up to 5.
- To measure the signal efficiency of the jet veto we measure the jet veto efficiency for Z events and rely on Monte Carlo to correct for the difference between Z and WW jet activity.
  - For Z events jet veto efficiency matches well for data and Monte Carlo after taking into account pile up effects
- In order to estimate theoretical uncertainty due higher order corrections we vary the factorization and renormalization scales (independently)

Background Estimation

Wjets background

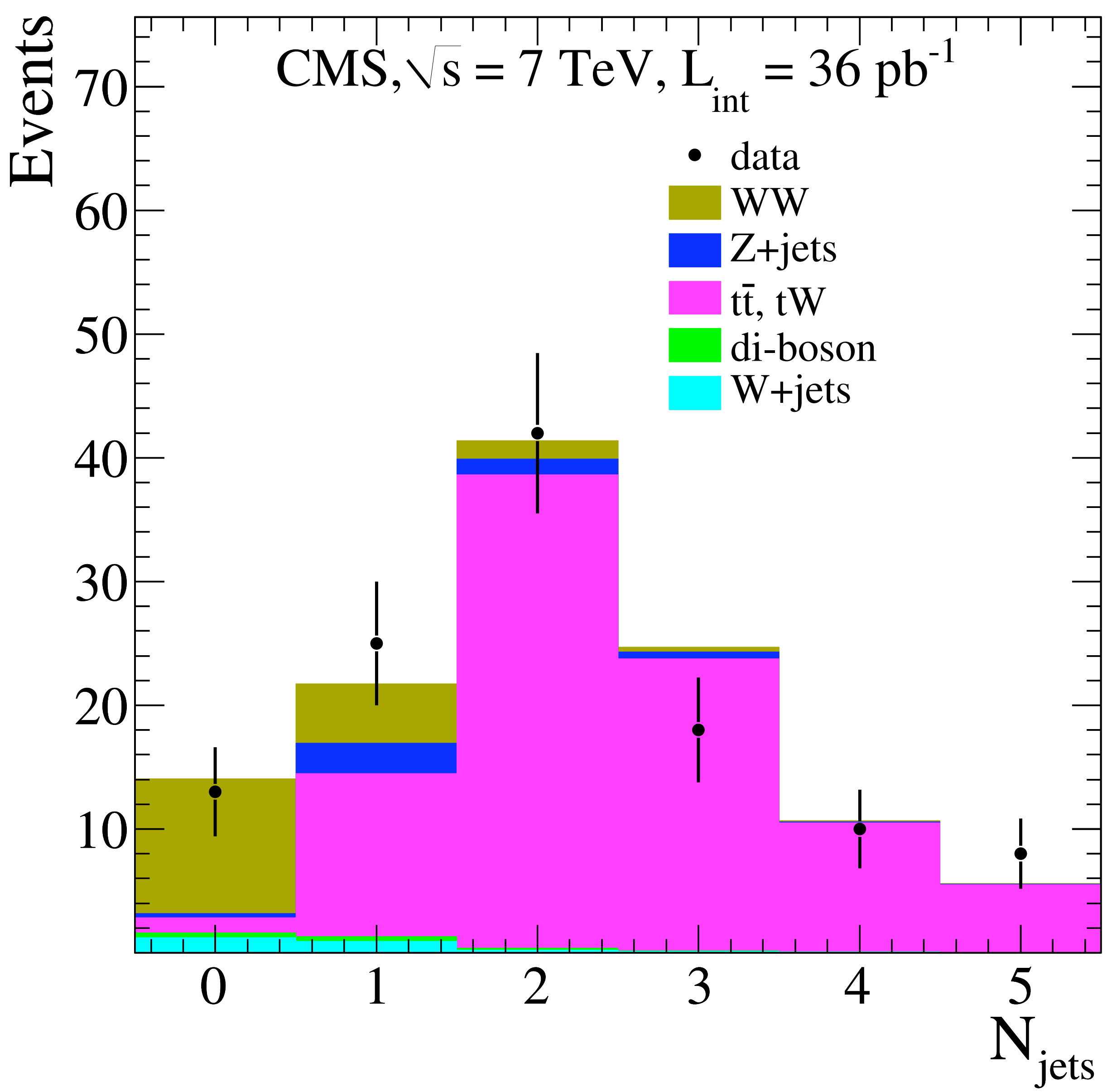
- W+jets is one of the dominant backgrounds where one lepton is originating from a W decay and the other is a fake lepton.
- Even though CMS has quite good electron and muon identification, the fact that Wjets has 5 order of magnitude larger cross-section than Higgs(160) makes it important especially for low mass Higgs searches.
- With tight identification and isolation requirements Wjets background contribution can be effectively suppressed.
- The main technique to estimate the remaining background is to look at the signal sideband, i.e. events with looser identification and isolation requirements. The event yield in the sideband region can be used to estimate the background yield in the signal region.

Drell-Yan background



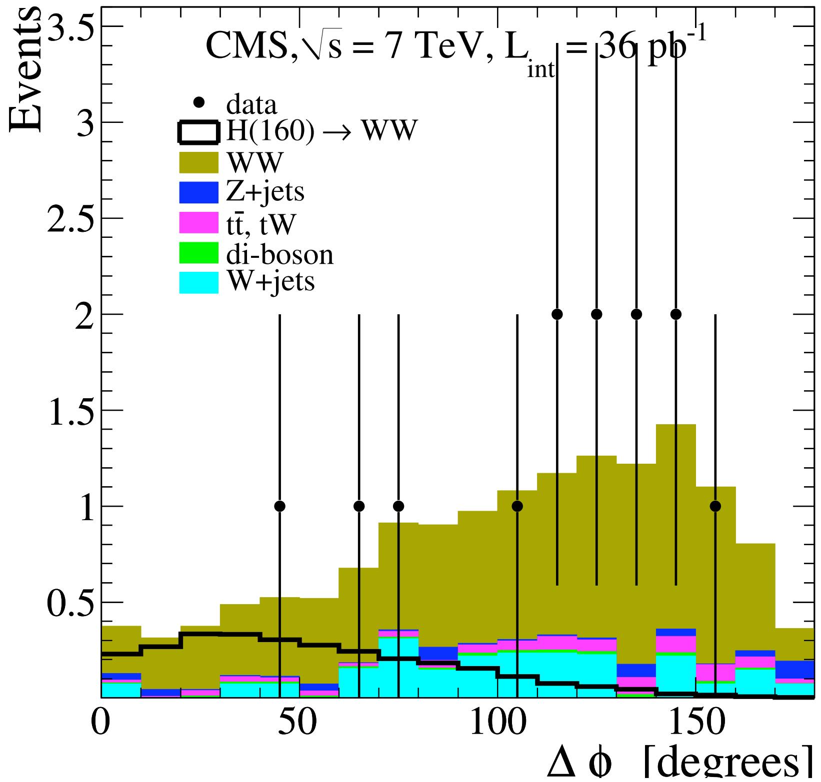
- Drell-Yan has 4-order of magnitude higher cross-section than Higgs(160) and the main discriminating power comes from requiring large missing energy
- Since MET is one of the most complicated observables we put a lot of effort in tuning its performance.
- Poor detector performance, noise, pile up can lead to degradation of MET performance and may make ee and μμ channels unusable
- We veto events around the Z-mass peak and use them to estimate how much off-peak background remains taking the ratio of In-to-Out of peak yield from simulations

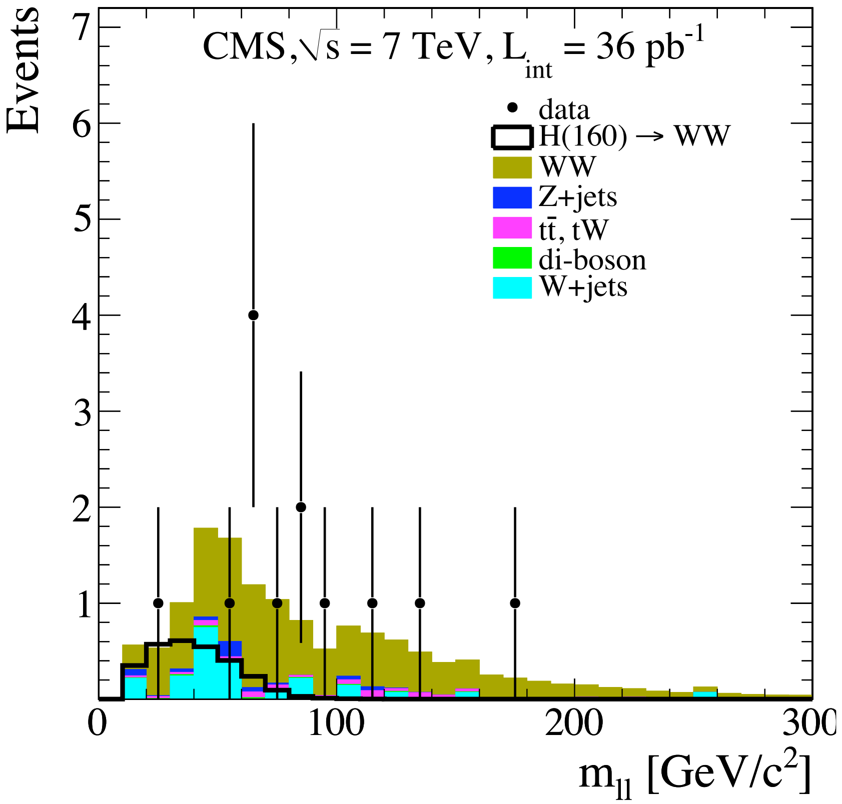
Top background



- Top background (TTbar and TW) is the next dominant background for WW final state with the cross-section a factor of 20 larger than Higgs(160)
- Top events differ from WW by presence of 1 or 2 extra b-jets
- The strategy of the background suppression is based on vetoing events with jets above certain threshold (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 all other cuts including the jet-veto

WW background





- Electro-weak WW production is an irreducible background for Higgs to WW, which has a factor of 5 larger cross-section than Higgs(160).
- Kinematic distributions is the primary source of discriminating power.
  - At low mass Higgs the angular correlation of the leptons helps to extract signal
  - WW and Higgs to WW get very similar kinematic distributions for 200-250GeV Higgs mass range. That is a region with worst sensitivity
  - Below 160GeV one of the W boson is off-shell leading to significant drop of the cross-section. Experimentally it becomes challenging since the minimum lepton pt threshold need to be lowered to ~10 GeV and Wjets background increases
- Background estimation strategy is to use high dilepton mass region dominated by WW to estimate the amount of background in the signal region.

WW Cross-Section

- Using 36/pb of data with WW selection requirements, we observe 13 events total.
- Background estimation using data driven methods and Monte Carlo simulations:

Process	Events
W+jets + QCD	$1.70 \pm 0.40 \pm 0.70$
$t\bar{t}$ + tW	$0.77 \pm 0.05 \pm 0.77$
$W\gamma$	$0.31 \pm 0.04 \pm 0.05$
$Z + WZ + ZZ \to e^+e^- / \mu^+\mu^-$	$0.20 \pm 0.20 \pm 0.30$
$WZ + ZZ$, 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	$3.29 \pm 0.45 \pm 1.09$

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

- The observed WW cross-section is consistent with the standard model prediction of 43pb. That gives us additional confidence that we simulate WW events properly.

Signal Extraction

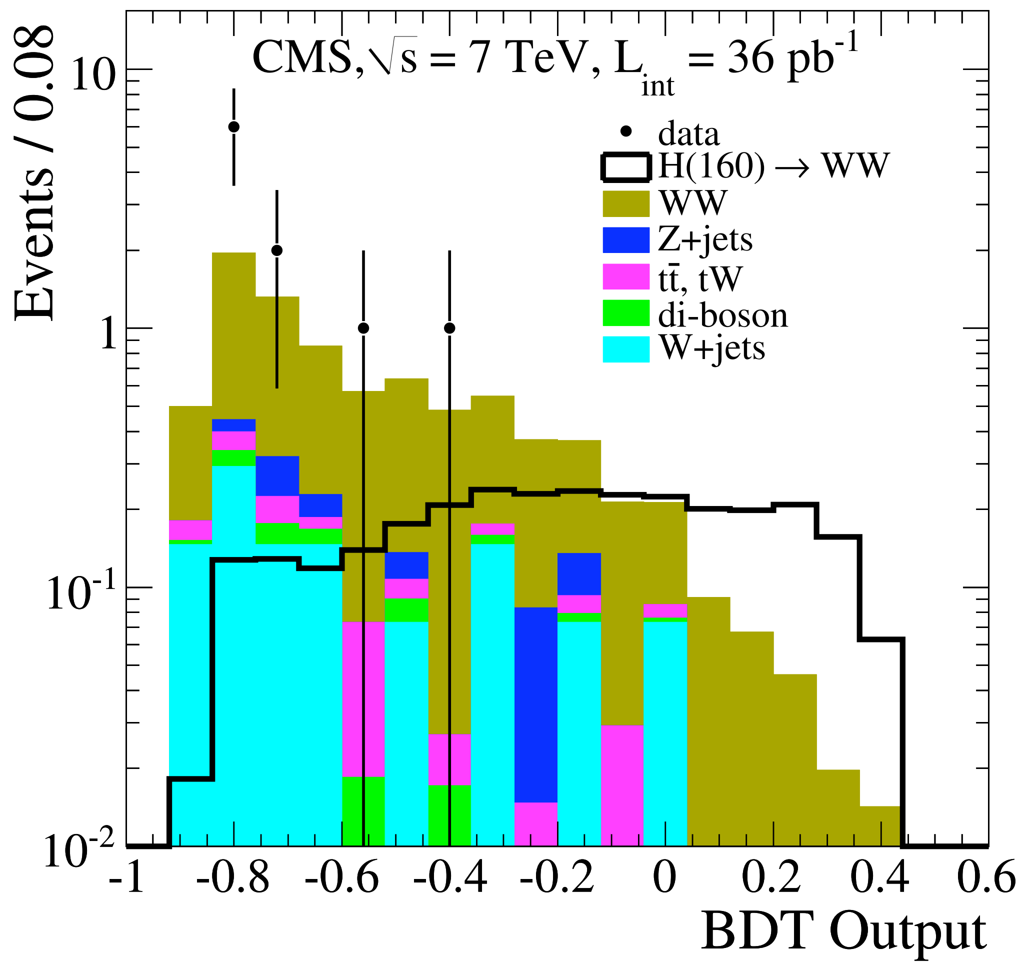
Cut Based Analysis

- Cut base analysis is using di-lepton mass, angle between two leptons and their momenta to distinguish Higgs 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, while WW background yield is estimated from di-lepton mass sideband in data

m_H (GeV/c^2)	data	SM $H \to W^+W^-$	SM with 4th gen. $H \to W^+W^-$	all bkg.	$qq \to W^+W^-$	$gg \to W^+W^-$	all non-W^+W^-
cut-based approach							
130	1	0.30 ± 0.01	1.73 ± 0.04	1.67 ± 0.10	1.12 ± 0.01	0.10 ± 0.01	0.45 ± 0.10
160	0	1.23 ± 0.02	10.35 ± 0.16	0.91 ± 0.05	0.63 ± 0.01	0.07 ± 0.01	0.21 ± 0.05
200	0	0.47 ± 0.01	3.94 ± 0.07	1.47 ± 0.09	1.13 ± 0.01	0.12 ± 0.01	0.23 ± 0.09
210	0	0.34 ± 0.01	2.81 ± 0.07	1.49 ± 0.05	1.09 ± 0.01	0.10 ± 0.01	0.30 ± 0.05
400	0	0.19 ± 0.01	0.84 ± 0.01	1.06 ± 0.03	0.79 ± 0.01	0.04 ± 0.01	0.23 ± 0.03



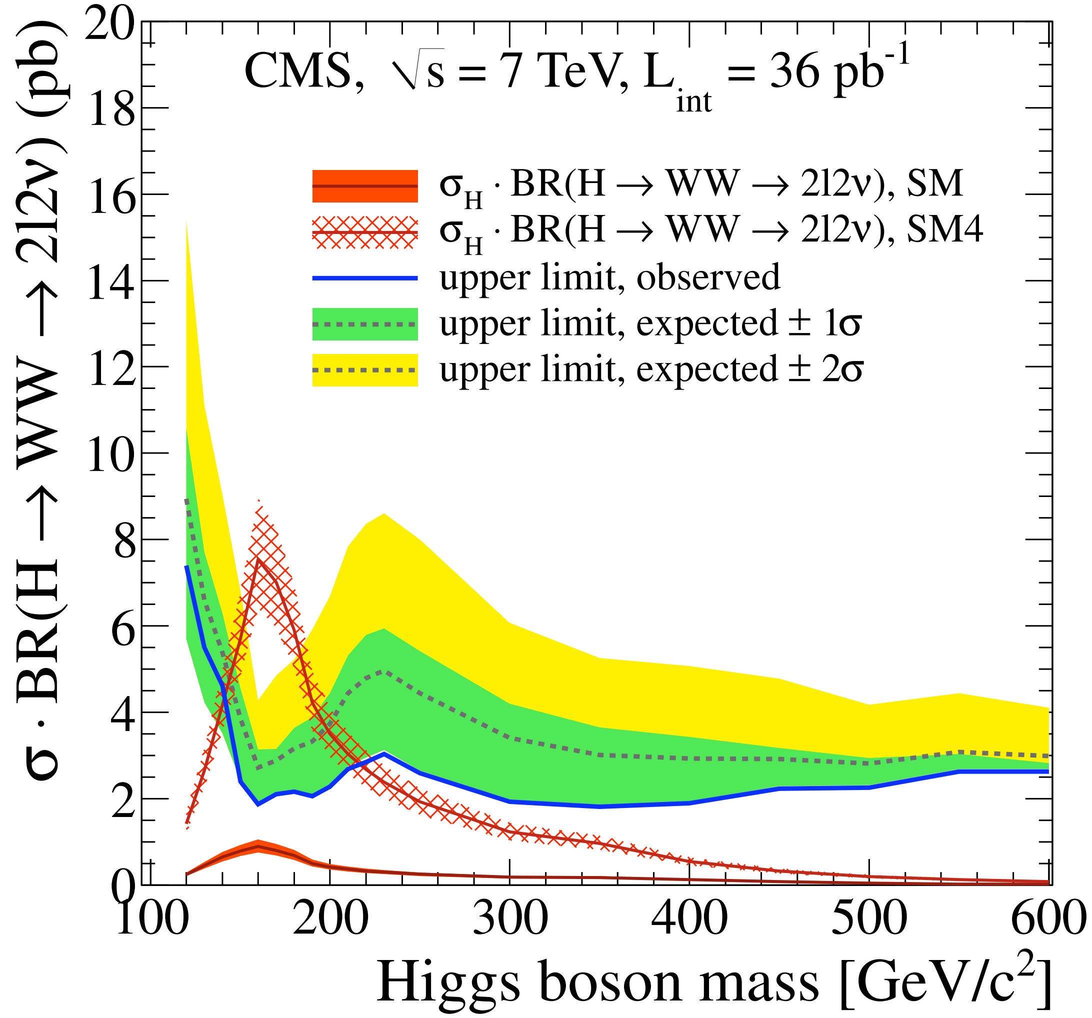
- Multivariate analysis approach is using Boosted Decision Tree algorithm to combine multiple discriminating variables: m_{ll}, $\Delta\varphi_{ll}$ $\Delta\eta$, angles between MET and leptons, projected MET, transverse mass of each lepton & MET and final state flavor (ee, eμ, μμ)
- MVA gives roughly ~20% better sensitivity

m_H (GeV/c^2)	data	SM $H \to W^+W^-$	SM with 4th gen. $H \to W^+W^-$	all bkg.	$qq \to W^+W^-$	$gg \to W^+W^-$	all non-W^+W^-
multivariate approach							
130	1	0.34 ± 0.01	1.98 ± 0.04	1.32 ± 0.18	0.75 ± 0.01	0.04 ± 0.00	0.53 ± 0.18
160	0	1.47 ± 0.02	12.31 ± 0.17	0.92 ± 0.10	0.63 ± 0.01	0.06 ± 0.00	0.22 ± 0.10
200	0	0.57 ± 0.01	4.76 ± 0.07	1.47 ± 0.07	1.07 ± 0.01	0.13 ± 0.00	0.27 ± 0.07
210	0	0.42 ± 0.01	3.47 ± 0.07	1.44 ± 0.07	1.03 ± 0.01	0.12 ± 0.00	0.29 ± 0.07
400	0	0.20 ± 0.01	0.90 ± 0.01	1.09 ± 0.07	0.75 ± 0.01	0.04 ± 0.00	0.30 ± 0.07

Systematics

- Background estimation
  - Uncertainty on the background estimation is the most important and challenging issue of the analysis.
  - With 2010 data we found that systematic uncertainties on major backgrounds is around 50% or more.
  - With more data we should be able to improve our understanding of backgrounds and get better sensitivity to Higgs
  - $gg \rightarrow WW$ is a challenging background with significant theoretical uncertainty
- Signal efficiency
  - The jet veto efficiency is a single most important systematics that we have, which is of the order of 5-6%.
- Luminosity
  - 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 of the order of 4%

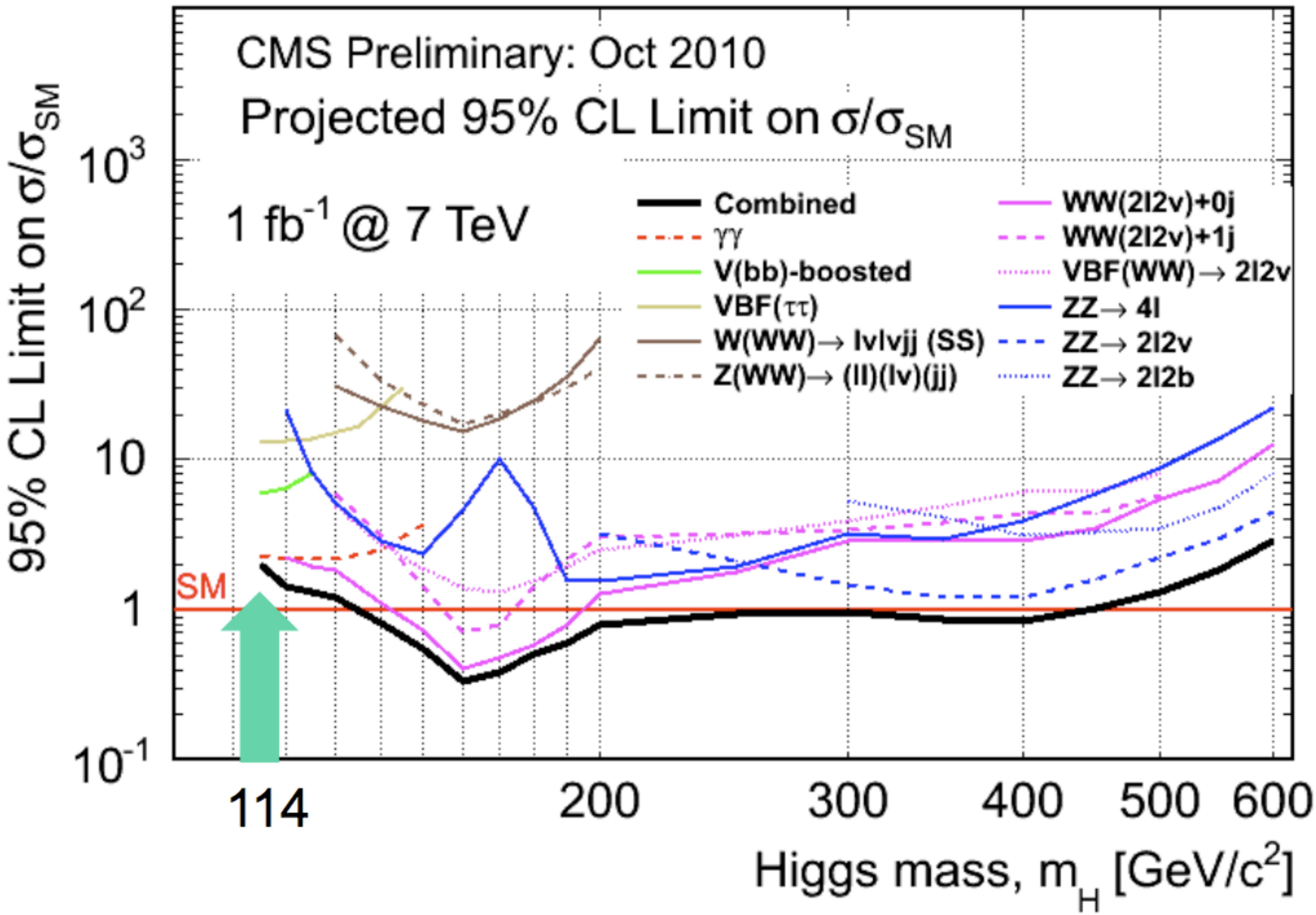
Results



- 95% C.L. upper limit is a factor of 2 bigger than the Standard Model x-section for HWW160
- A Standard Model 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

m_H (GeV/c^2)	$\sigma \cdot BR$ SM	BR(H→WW) SM	$\sigma \cdot BR$ 4th gen.	BR(H→WW) 4th gen.	lim. obs. cut-based	lim. exp. cut-based	lim. obs. BDT-based	lim. exp. BDT-based
130	0.45	0.30	2.57	0.19	6.30	8.07	5.66	6.57
160	0.87	0.91	7.25	0.85	2.29	3.22	1.93	2.72
200	0.41	0.74	3.39	0.73	2.80	4.59	2.32	3.72
210	0.36	0.72	2.94	0.72	3.41	5.53	2.76	4.43
400	0.12	0.58	0.55	0.58	2.08	3.12	1.94	2.93

Projections for 1/fb

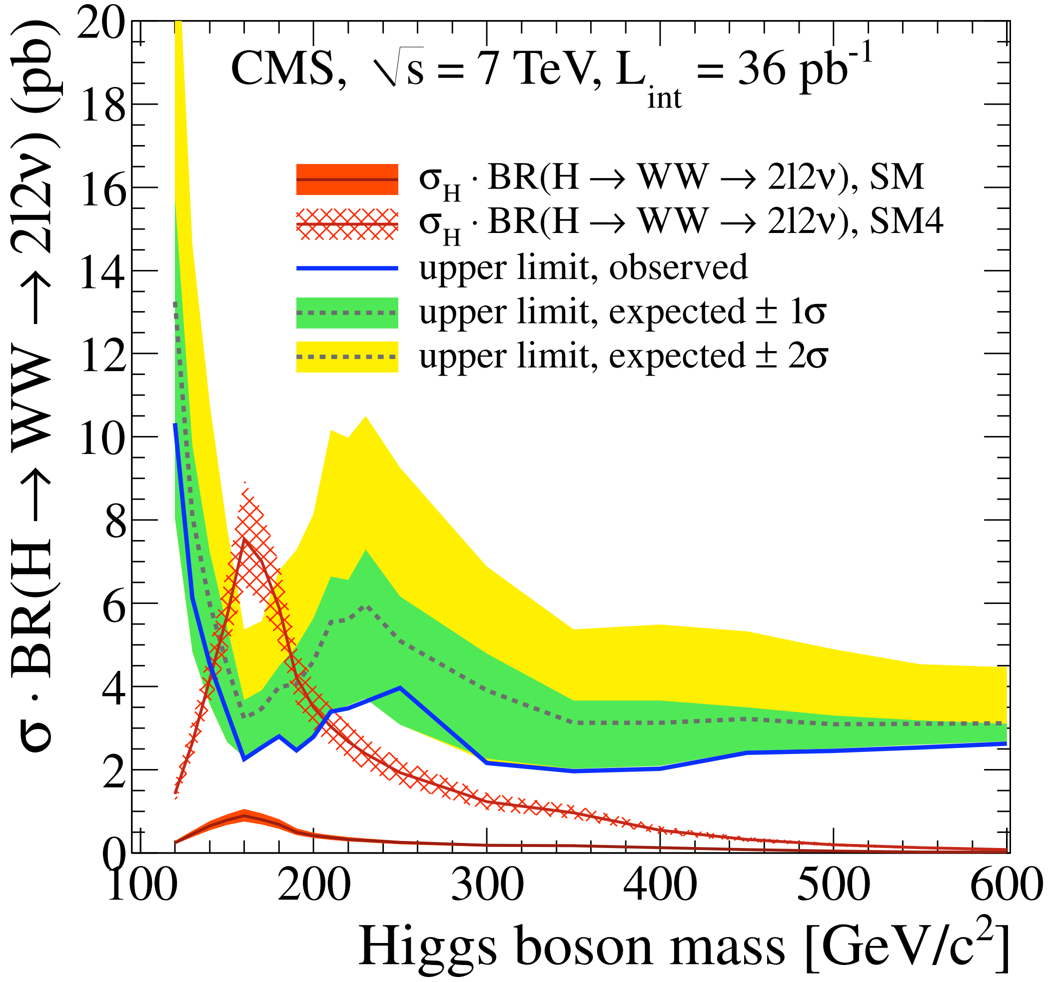


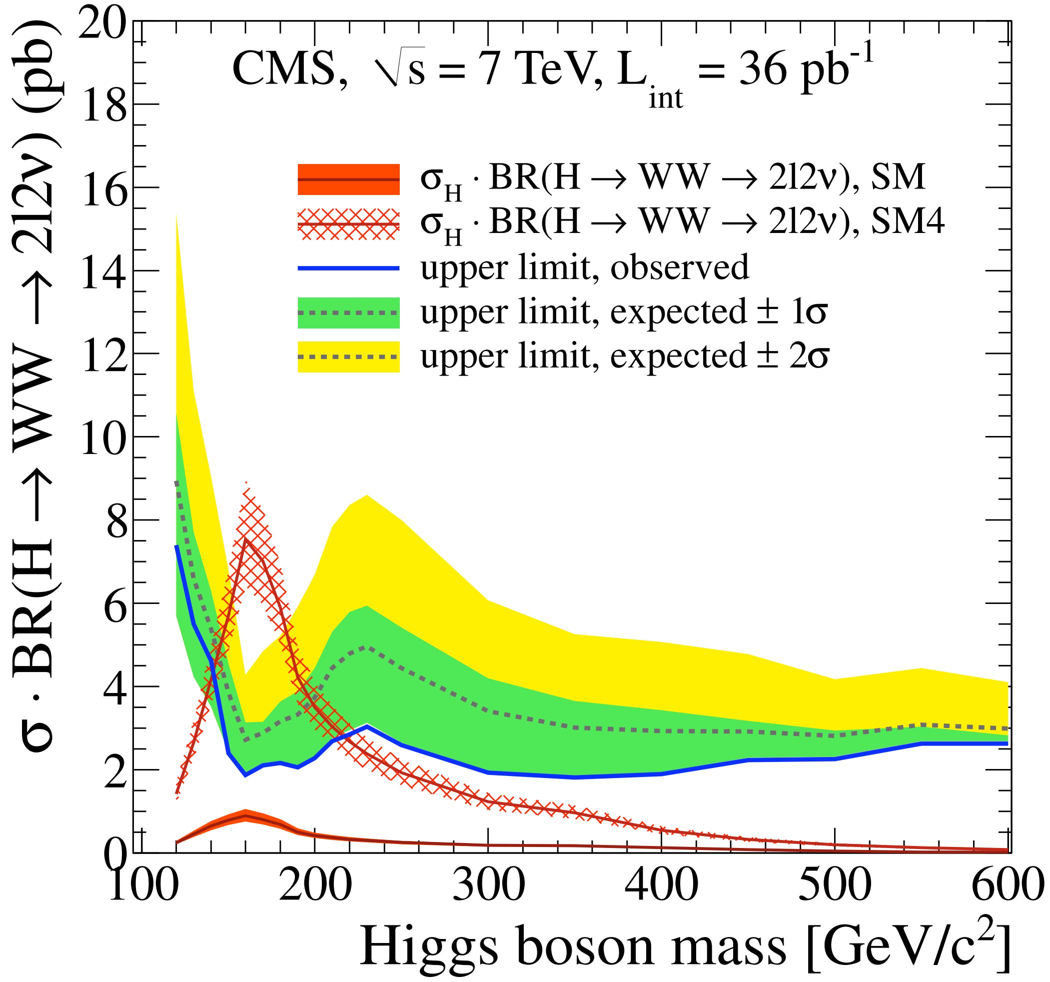
Summary

- CMS published its first paper on the Standard Model Higgs searches using 36/pb of data collected in 2010
- Our observed upper limits for Higgs cross-section are a factor of two bigger than the Standard Model Higgs at 160GeV mass point
- We have enough sensitivity to exclude Higgs boson with mass in 144-207GeV range in an extension of the Standard Model with 4-fermion generations.
- With 1/fb of data we should have enough sensitivity to exclude Higgs in WW channel for a mass range of 140-190GeV

Backup Slides

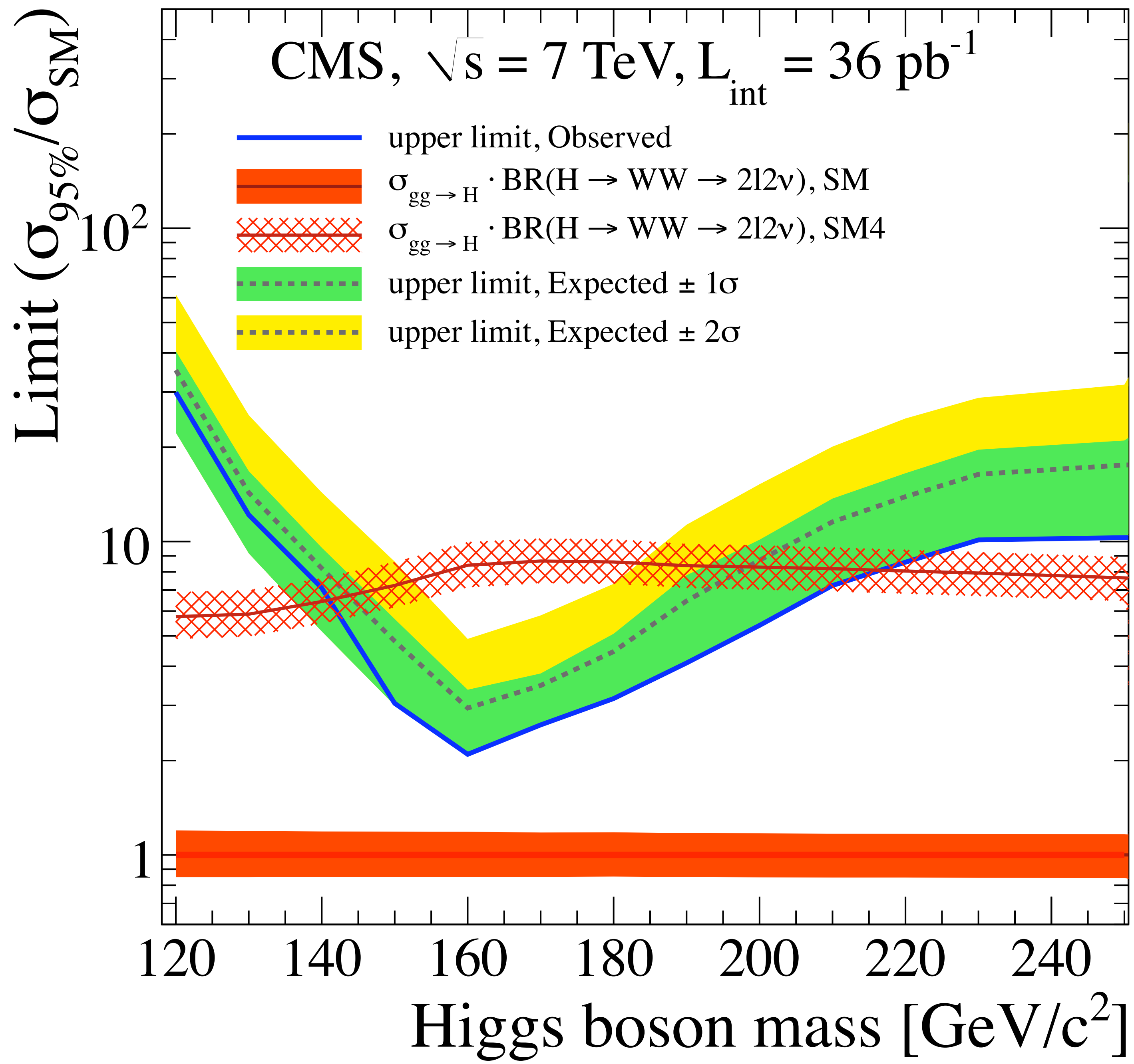
Cut Based vs MVA



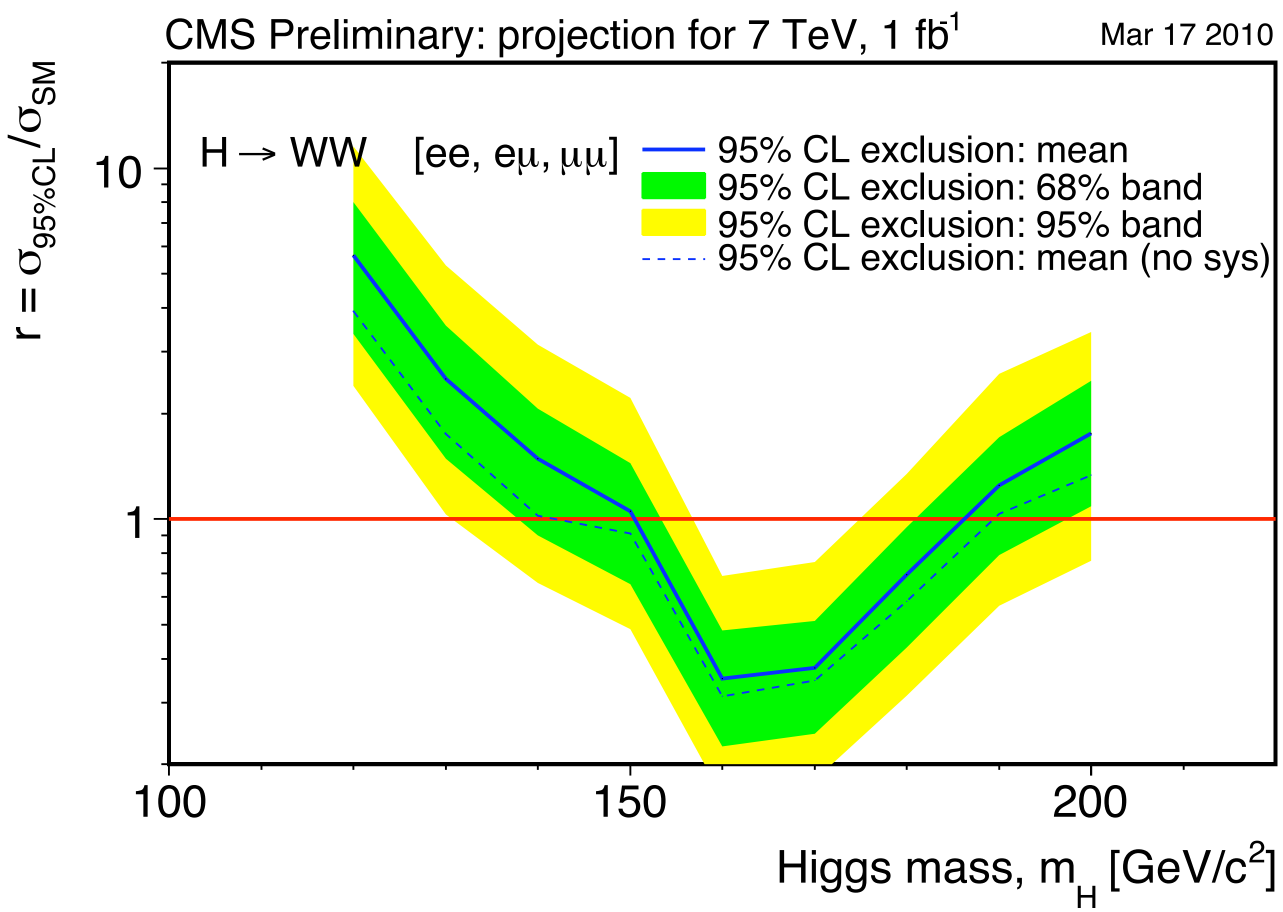


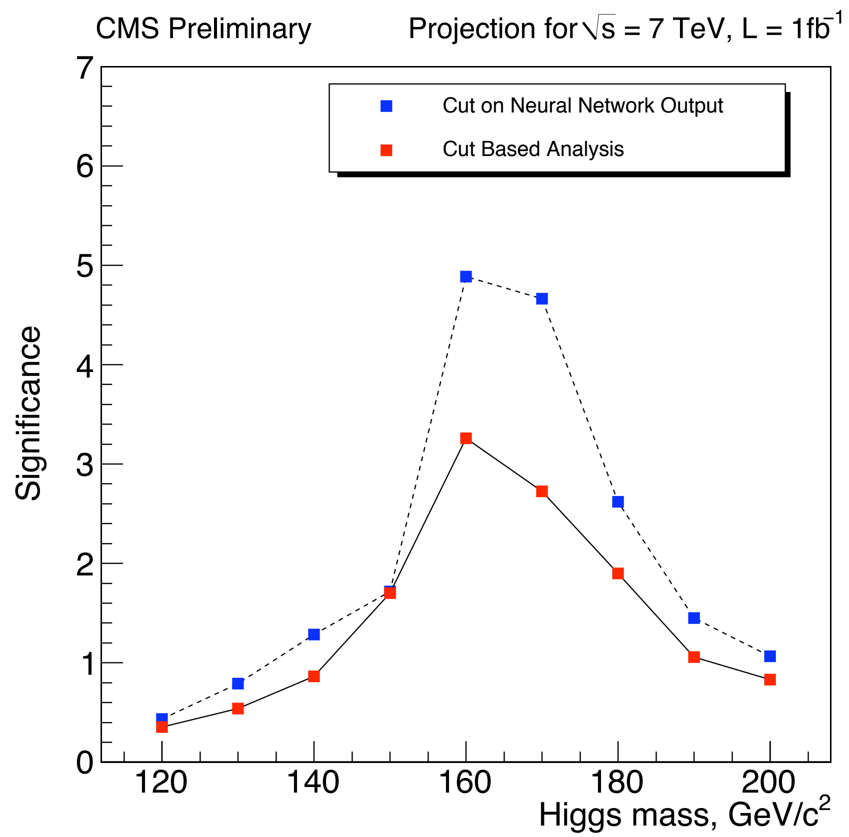
m_H (GeV/c^2)	$\sigma \cdot BR$ SM	BR(H→WW) SM	$\sigma \cdot BR$ 4th gen.	BR(H→WW) 4th gen.	lim. obs. cut-based	lim. exp. cut-based	lim. obs. BDT-based	lim. exp. BDT-based
130	0.45	0.30	2.57	0.19	6.30	8.07	5.66	6.57
160	0.87	0.91	7.25	0.85	2.29	3.22	1.93	2.72
200	0.41	0.74	3.39	0.73	2.80	4.59	2.32	3.72
210	0.36	0.72	2.94	0.72	3.41	5.53	2.76	4.43
400	0.12	0.58	0.55	0.58	2.08	3.12	1.94	2.93

Upper Limit on Cross-Section Ratio



Projected Sensitivity HWW





Last year projections are consistent with what we see in data in 2010

Summary of Selections

- Two isolated well identified leptons with pt>20GeV
    - Sum(Ecal,Hcal,Trk)/pt < 0.1 (0.15) for electrons (muons)
- No jets with corrected Pt>25GeV within |eta|<5.0
- Conversion rejection for electrons
- Projected MET > 20 (35) GeV in eμ (ee/μμ) final states
- Z veto - reject events within 15GeV of the Z peak in ee/μμ
- No extra isolated leptons in the event to suppress ZZ and WZ
- Top tagging veto (displaced track counting and soft muon tagging)

Analysis Perspectives

- This year we will try to lower the minimum lepton pt requirements to improve our sensitivity at low mass Higgs
  - Triggers become a tough issue especially due to high rate of QCD and Wjets events that pass the online selection
- Higher instantaneous luminosity brings a new challenge - large number of multiple interactions per crossing. Missing energy and jet veto are the most sensitive components of the analysis.
- We are working on extending the analysis by including
  - WW+1 jet final state
  - VBF Higgs