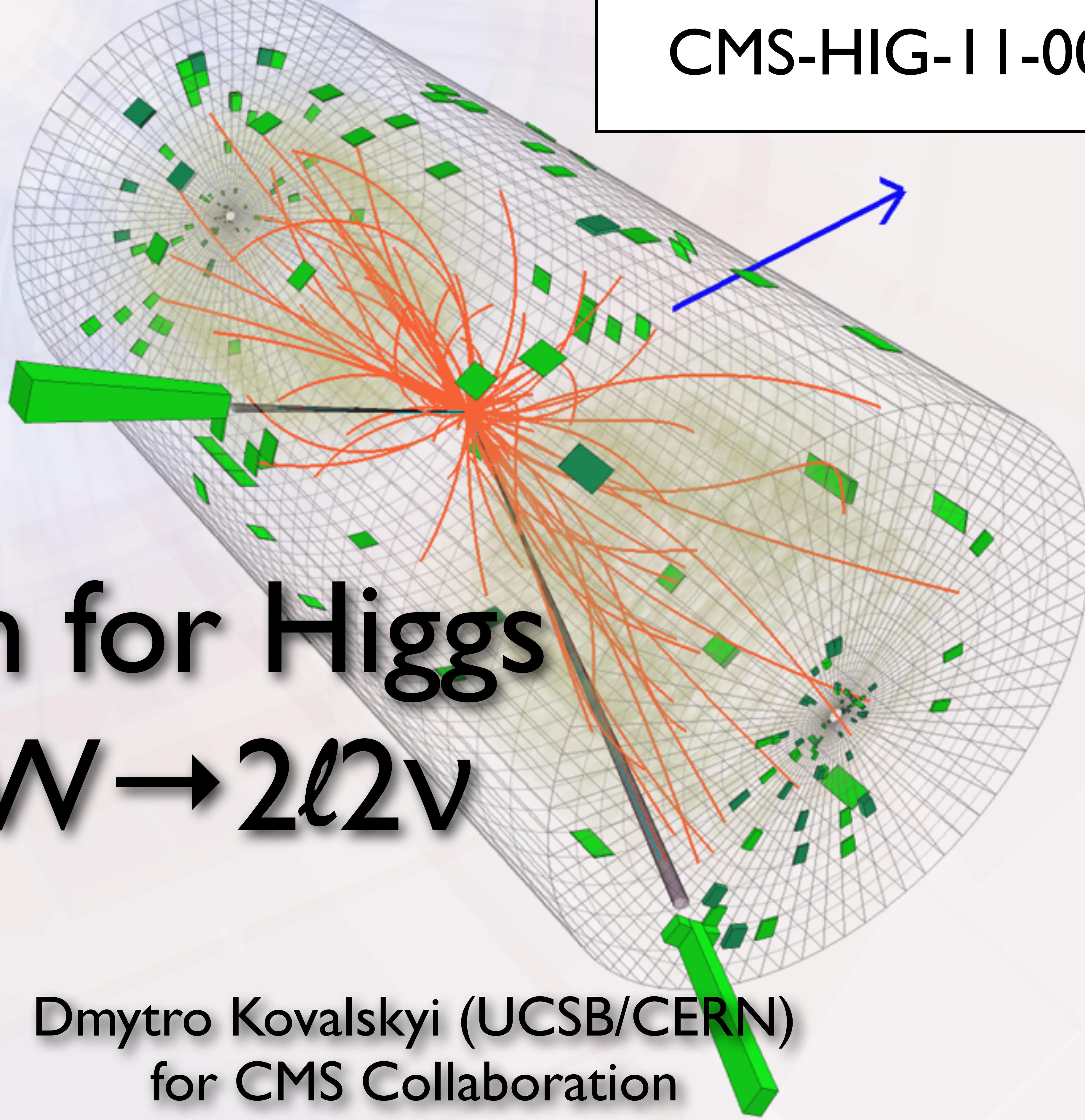
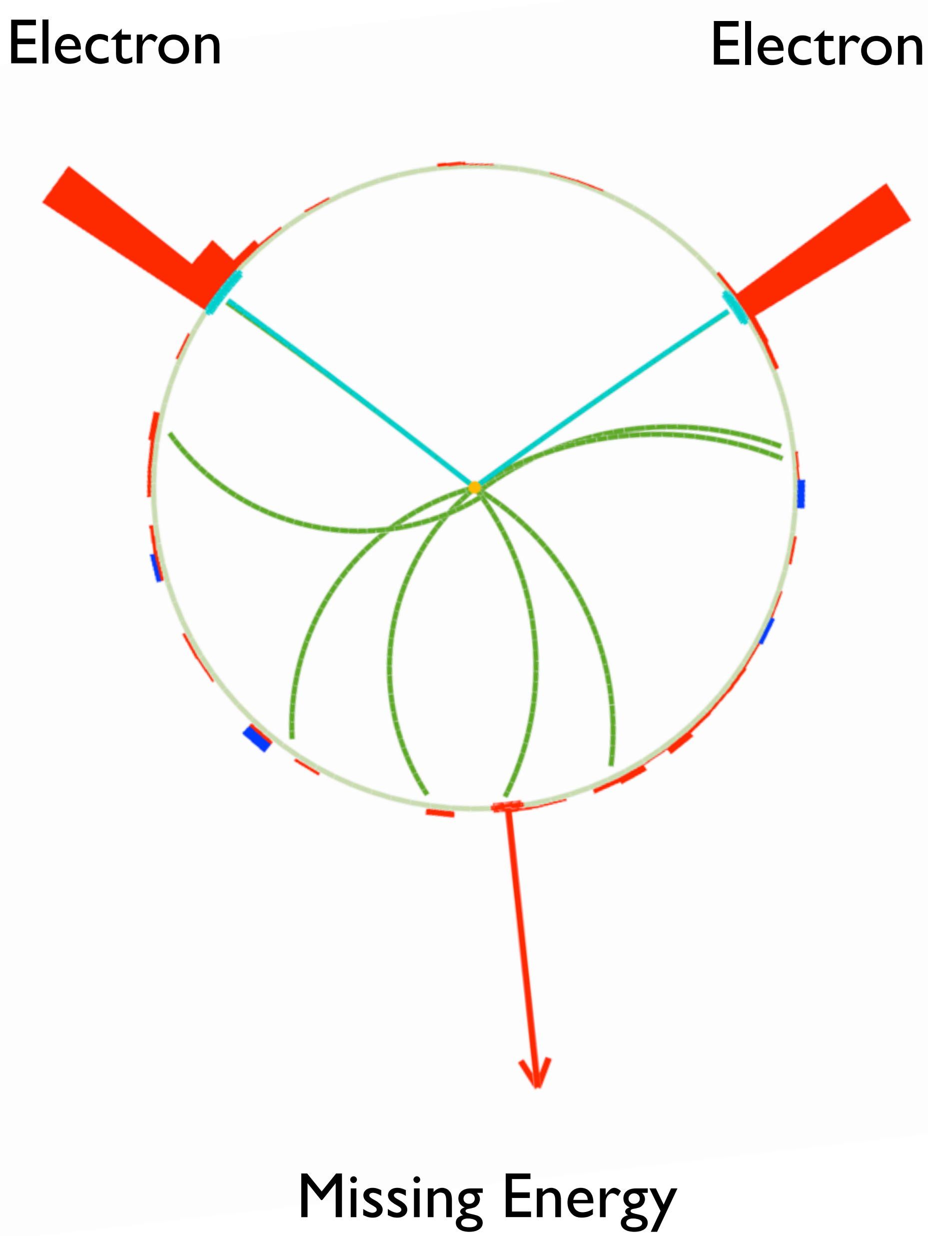
CMS-HIG-11-003



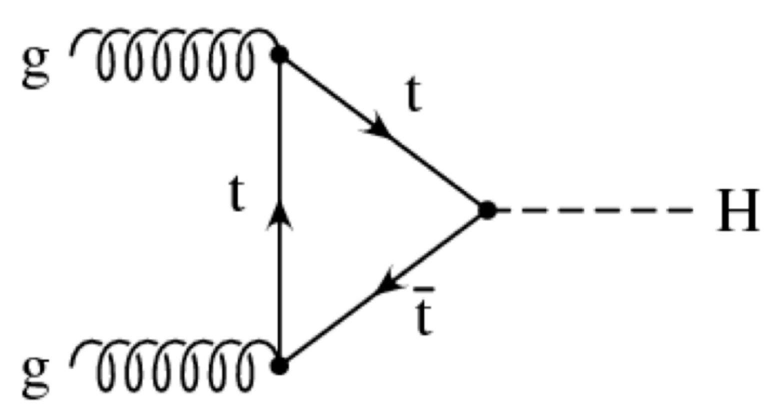
Search for Higgs in WW → 2ℓ2ν

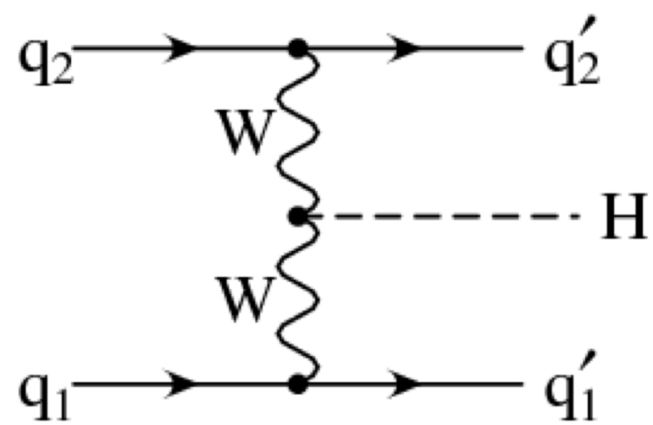
Dmytro Kovalskyi (UCSB/CERN)
for CMS Collaboration

Higgs $\rightarrow$ WW $\rightarrow$ 2l2ν

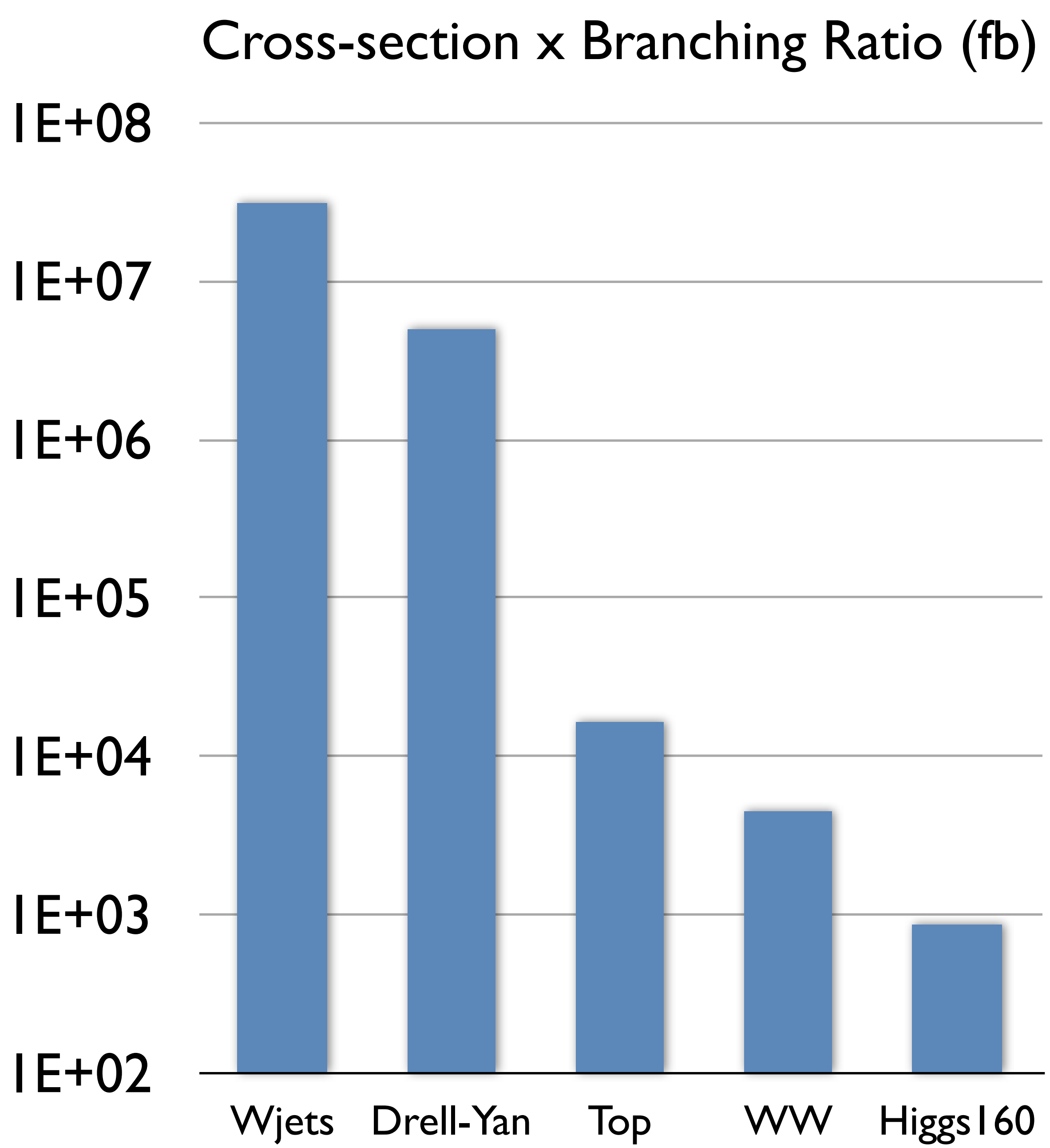


- **Higgs Signature**:
  - 2 isolated leptons (electron or muon)
  - large missing energy
- **Three categories of events**:
  - 0, 1 and 2 jets



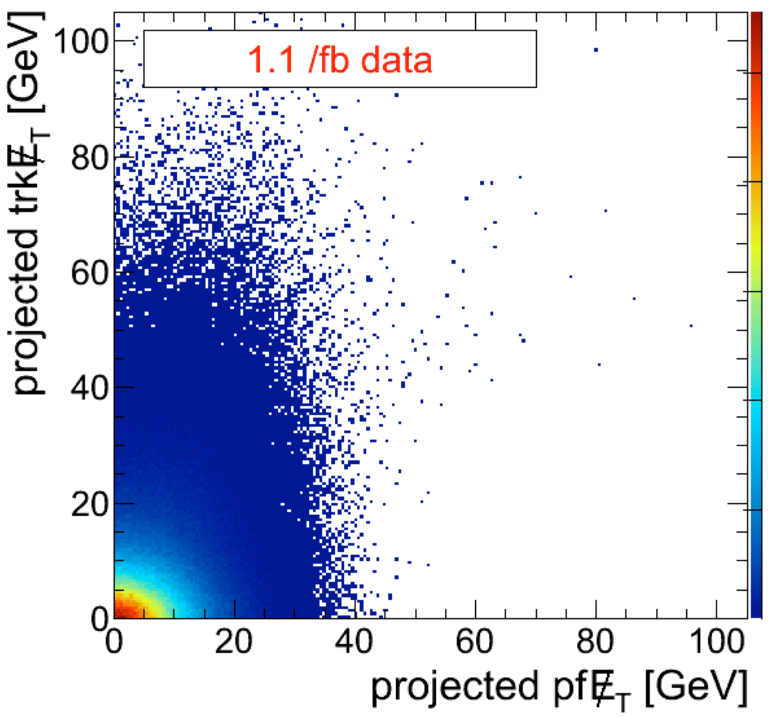


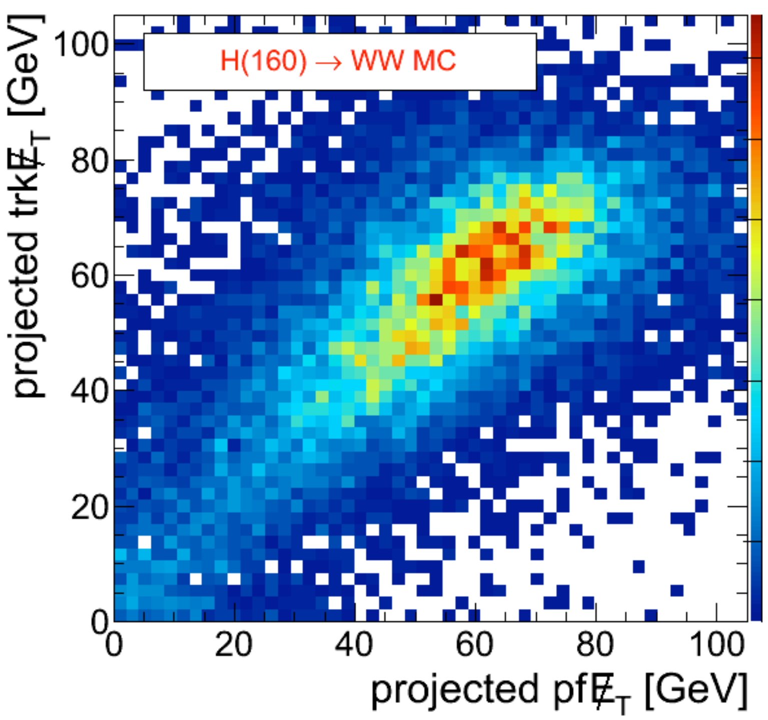
Analysis Challenges



- No mass is reconstructed - essentially a **counting experiment**
- Key selection requirements:
    - lepton pt>10 GeV with tight identification and isolation - **QCD, Wjets**
    - large missing transverse energy (MET) and Z veto - **Drell-Yan**
    - number of jet classification (Pt>30GeV) and b-quark veto - **Top**
    - kinematics (m_{ll}, dφ) - **WW**
- Final step selection requirements are optimized for different Higgs mass hypotheses

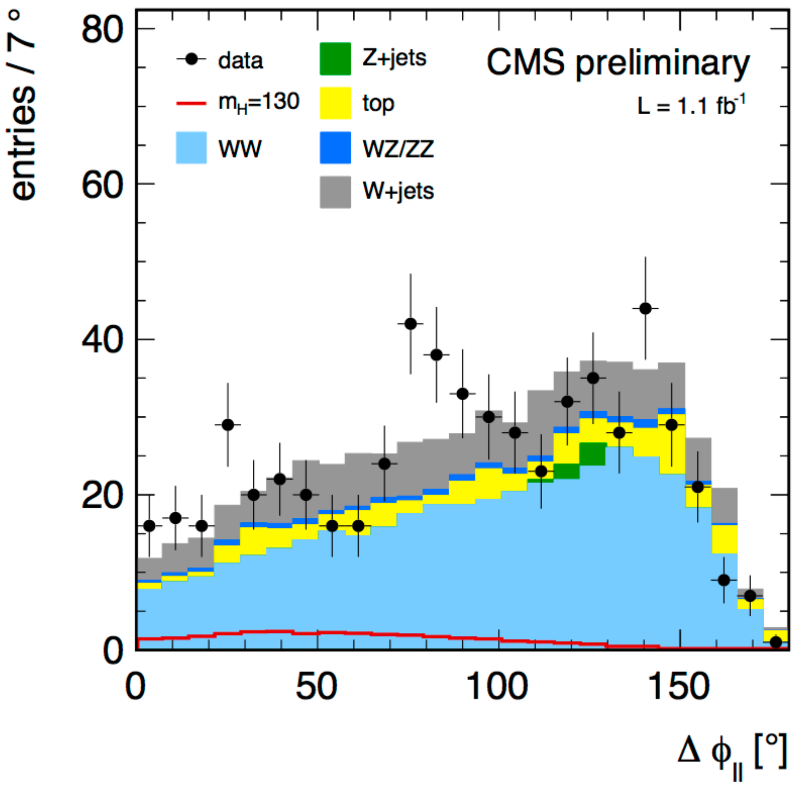
Missing Energy with PileUp

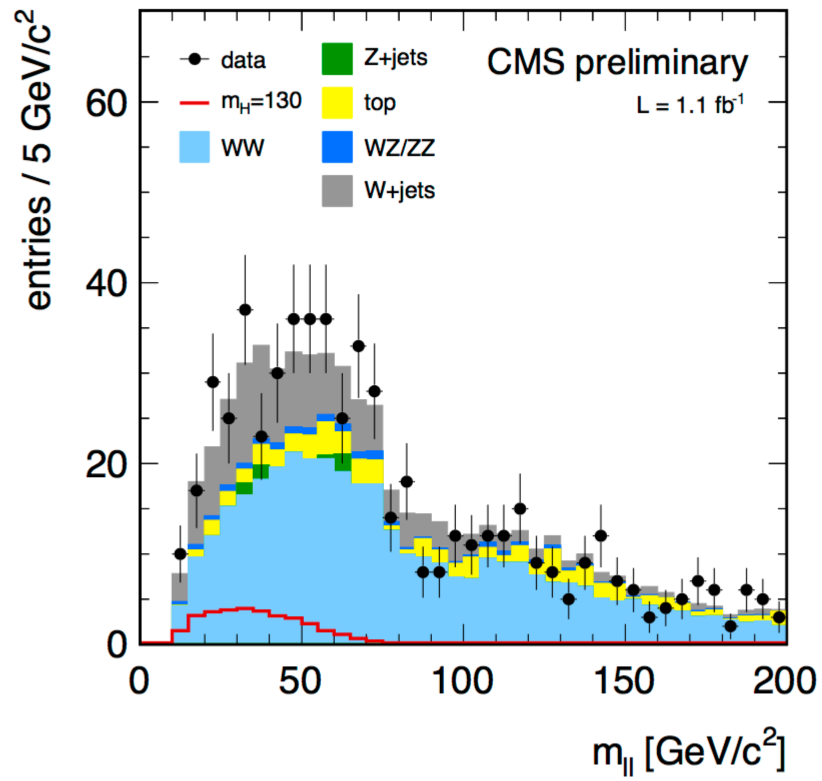


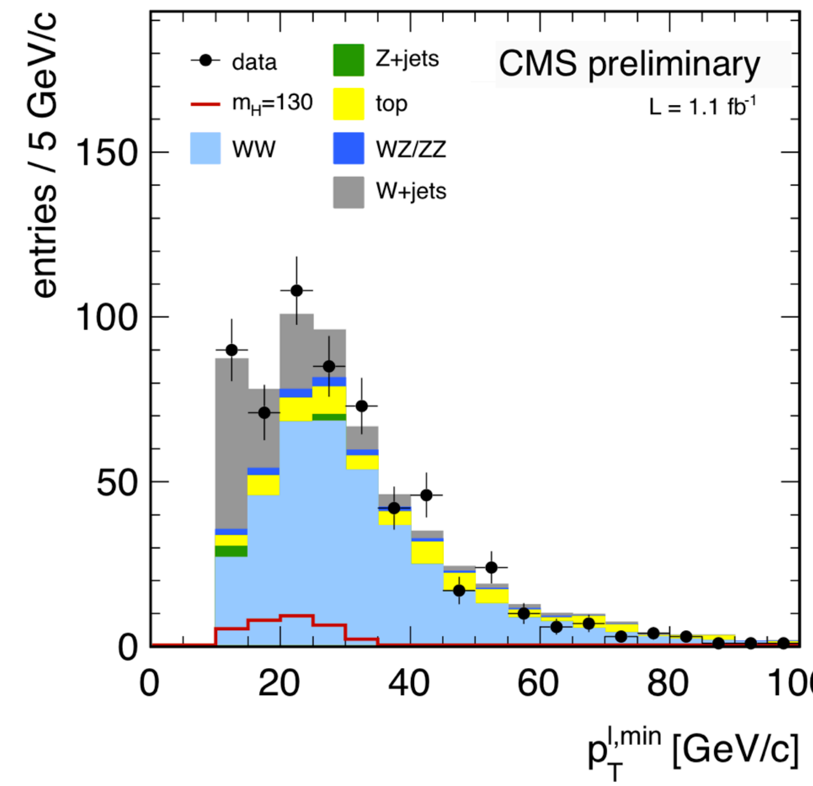


- **2011 data differs from 2010**:
  - ~8 interactions per bunch crossing
  - larger tails in the missing energy distribution
- **Two different MET variables**:
  - nominal - calorimeter and tracker
  - only tracker based MET
    - not affected by pile up
- **pfMET and trkMET are weakly correlated for backgrounds**
  - use the smaller one for each event
  - minMet>40 (same flavor)
  - minMet>20 (opposite flavor)

WW Background

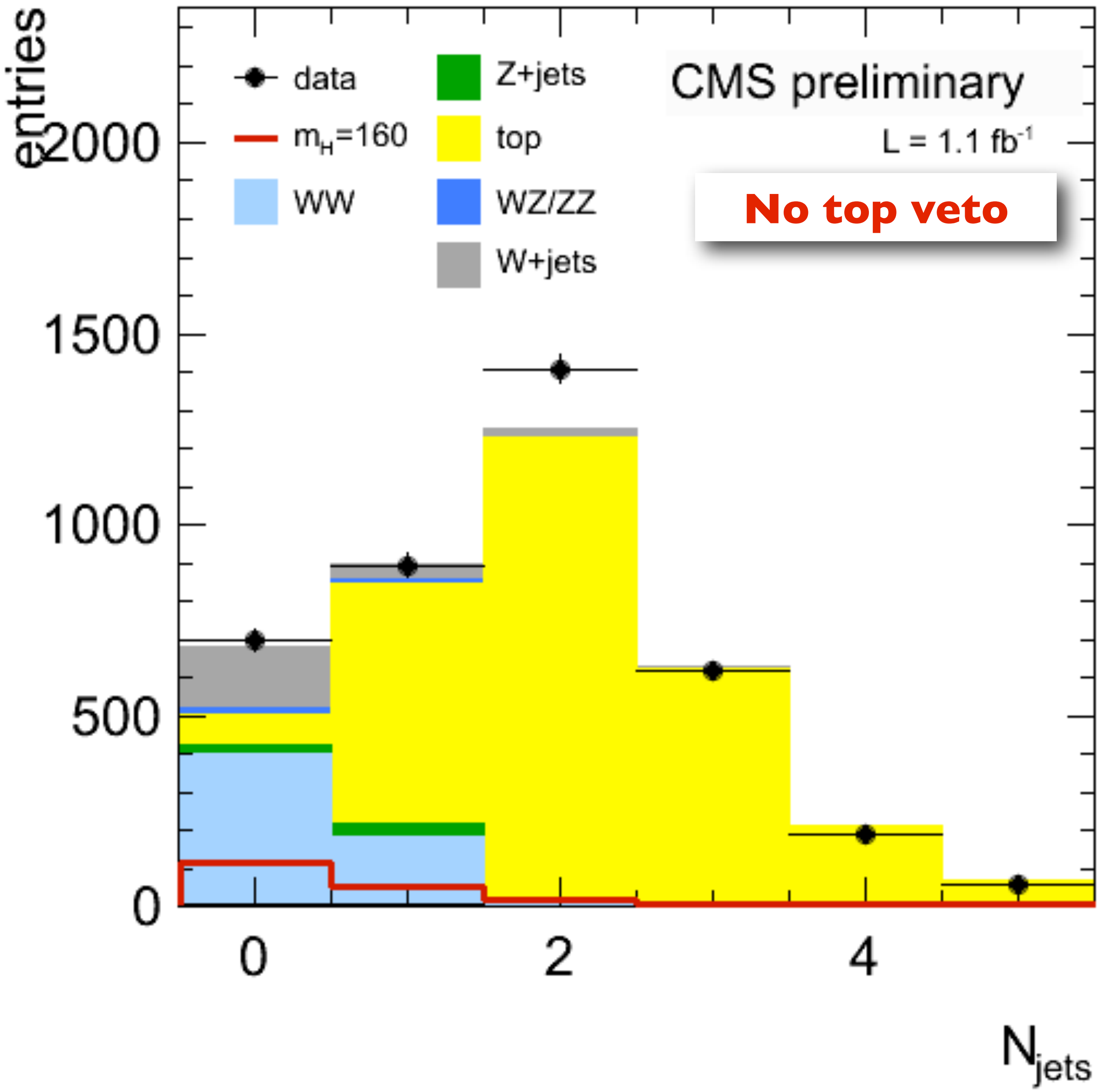






- **WW is an irreducible background** - one order of magnitude larger SM Higgs
- **Kinematics is the main discriminator**:
  - low mass - dPhi, Mll
    - for mH≤130 need to lower lepton pt → larger Wjets background
  - above 200GeV - WW and Higgs harder to distinguish
- **Use signal free events to calibrate WW yield**

Other Backgrounds



- **Top background - top veto**:
  - soft muons
  - b-jet tagging (including low pt)
- **WZ/ZZ - no extra leptons**
- **Conversions (Wjets, Wγ)**:
  - no missing hits in pixel detector
  - conversion pair veto

Event Yield at WW Selection

	data	all bkg.	$qq \to W^+W^-$	$gg \to W^+W^-$	$t\bar{t} + tW$	$W + \gamma$
0-jet	626	568.6 ± 52.2	349.7 ± 30.3	17.2 ± 1.6	63.8 ± 15.9	8.7 ± 1.7
1-jet	334	316.0 ± 24.7	101.4 ± 9.3	5.9 ± 0.5	141.1 ± 14.1	2.4 ± 0.8
2-jet	175	164.6 ± 18.0	22.1 ± 2.0	1.1 ± 0.1	99.3 ± 9.9	1.1 ± 0.5

	WZ/ZZ not in $Z/\gamma^* \to \ell^+\ell^-$	$Z/\gamma^* \to \ell^+\ell^- + WZ + ZZ$	$Z/\gamma^* \to \tau^+\tau^-$	$W + \text{jets}$
0-jet	8.5 ± 0.9	12.2 ± 5.3	1.6 ± 0.4	106.9 ± 38.9
1-jet	7.2 ± 0.8	10.5 ± 11.5	10.6 ± 1.2	36.9 ± 13.8
2-jet	1.5 ± 0.2	19.2 ± 13.5	3.9 ± 0.7	16.4 ± 6.4

- **Dominant contributions at WW selection level**:
  - 0-jet: WW, Wjets, Top
  - 1-jet: WW, Top
  - 2-jet: Top
- **WW cross-section**:
  - 55.3 ± 3.3 (stat.) ± 6.9 (syst.) ± 3.3 (lumi.) pb
  - Standard Model prediction is 43 ± 2 pb

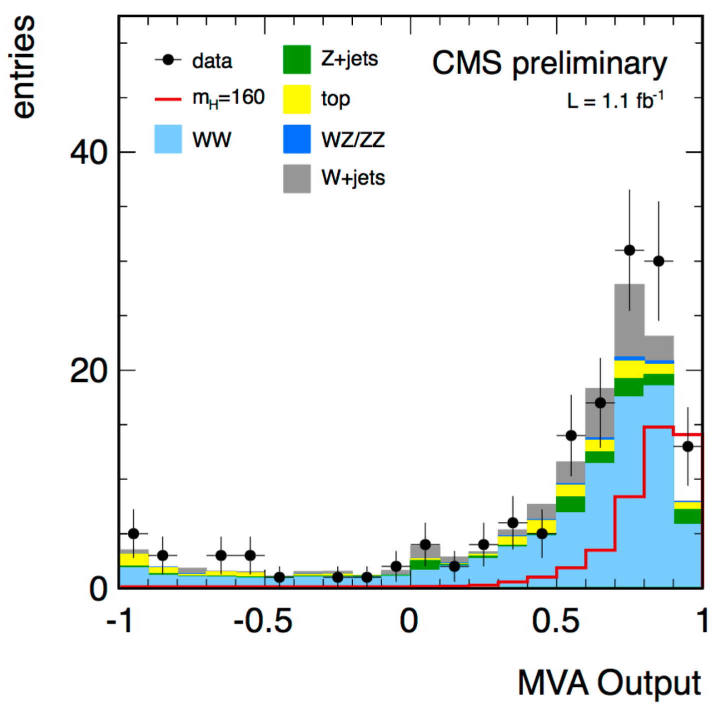
Cut Based Analysis

m_H[GeV]	$p_T^{\ell,\max}$ [GeV/c]	$p_T^{\ell,\min}$ [GeV/c]	$m_{\ell\ell}$ [GeV/c^2]	$\Delta\phi_{\ell\ell}$ [dg.]	$m_T^{\ell\ell E_T^{miss}}$ [GeV/c^2]
	>	>	<	<	[,]
130	25	10	45	90	[75,125]
150	27	25	50	90	[80,150]
160	30	25	50	60	[90,160]
180	36	25	60	70	[120,180]
200	40	25	90	100	[120,200]
300	70	25	200	175	[120,300]

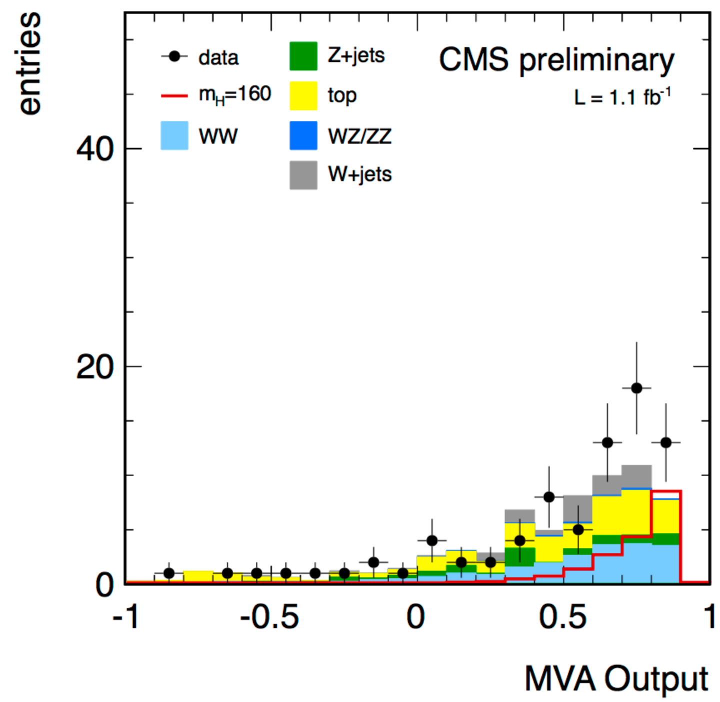
- **Discriminating variables**:
  - di-lepton mass
  - angle between two leptons
  - lepton pt
  - transverse mass (dilepton + MET)
  - For 2-jets: $|\Delta\eta|>3.5$, mjj>450Gev
- **Background estimation**:
  - from data at Higgs selection level: Wjets, Drell-Yan, WW
  - from data at WW selection level: Top
  - from Monte Carlo: WZ, ZZ, Wγ, Drell-Yan→ττ

Multivariate Analysis

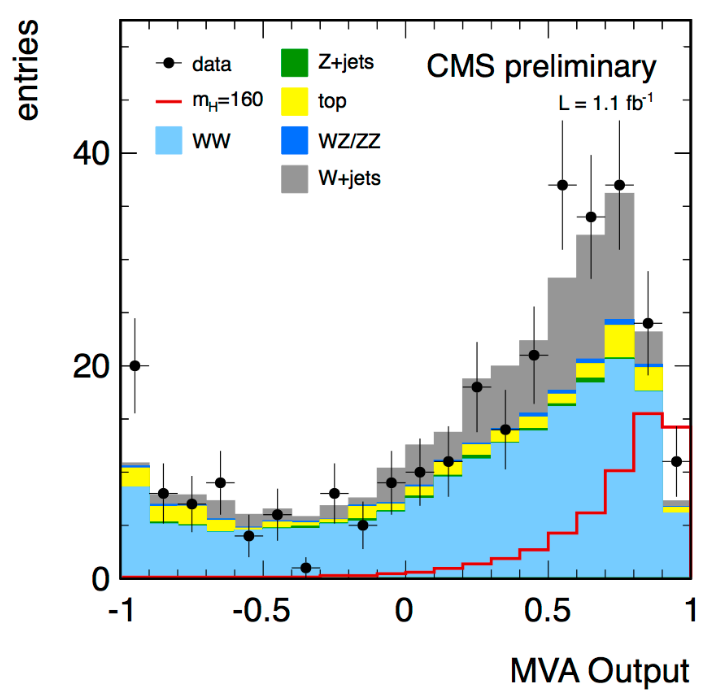
0-jet same flavor



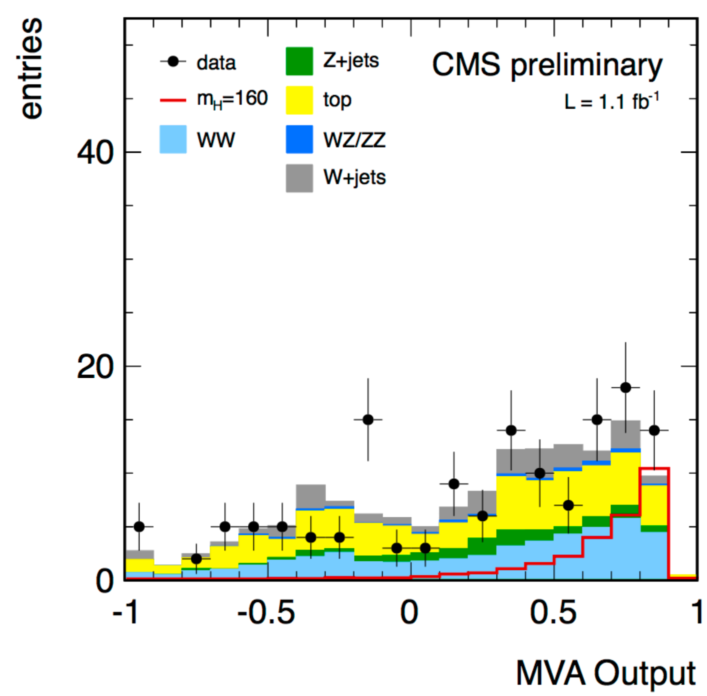
1-jet same flavor



0-jet opposite flavor



1-jet opposite flavor



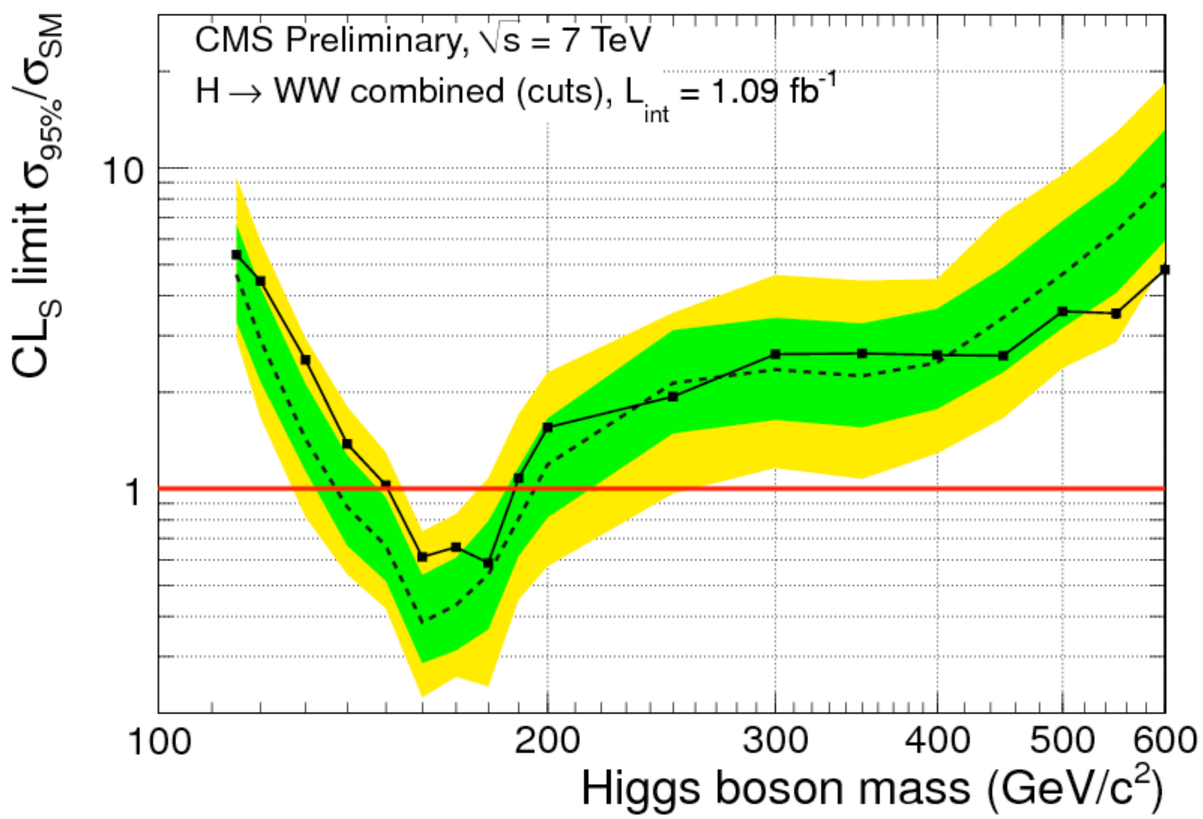
- **MVA** - Boosted Decision Tree
- Same inputs as cut based plus a few more
- **Use binned MVA output** to look for signal - more optimal use of information
- **The expected exclusion range with 1.1/fb of data**:
  - Cut based: [140,195] GeV
  - MVA based: [130,200] GeV

Systematics

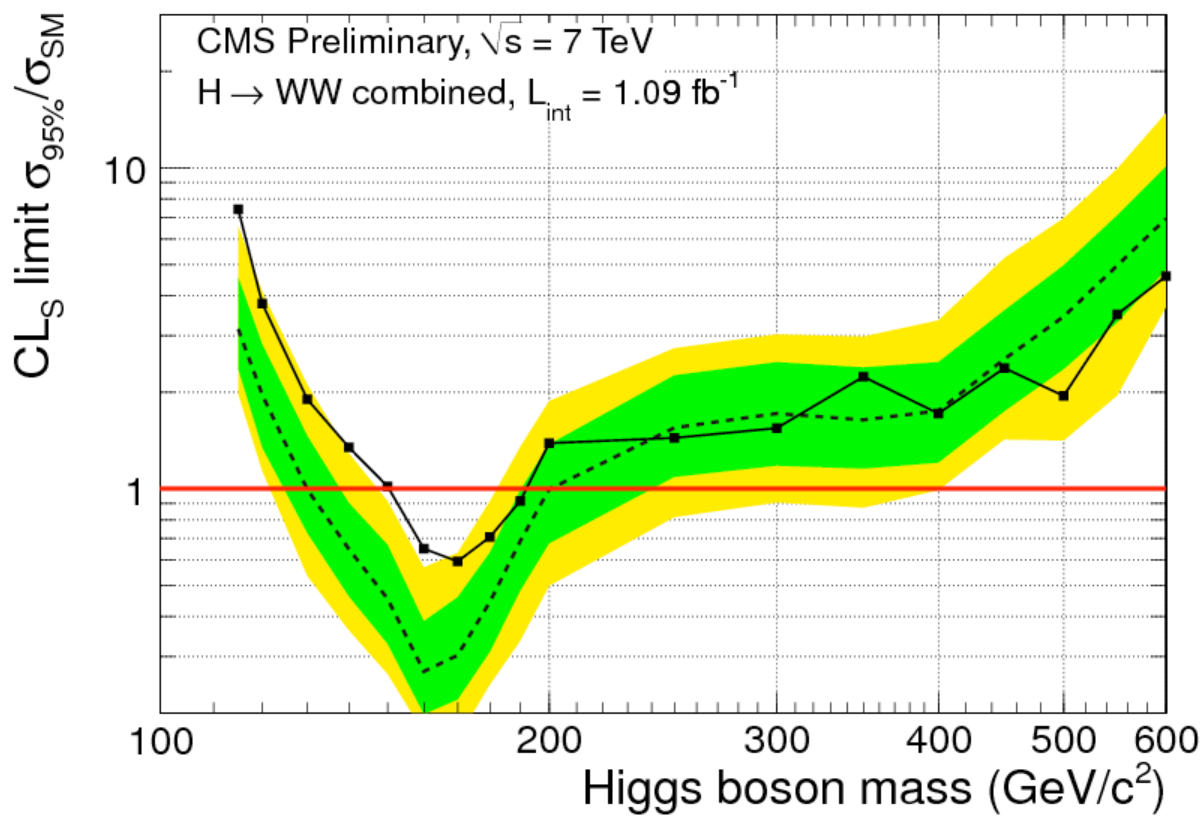
- The dominant systematic effects are associated with the dominant background estimation:
  - **Wjets**: 36%
  - **Drell-Yan**: 60%
  - **Top**: 25%
  - **WW**: 15%-30%
- Most of these uncertainties are statistical in nature and will get smaller with more data
- Theoretical uncertainties very in large range, but they are not dominant at the moment

Results

Cut based analysis



MVA based analysis



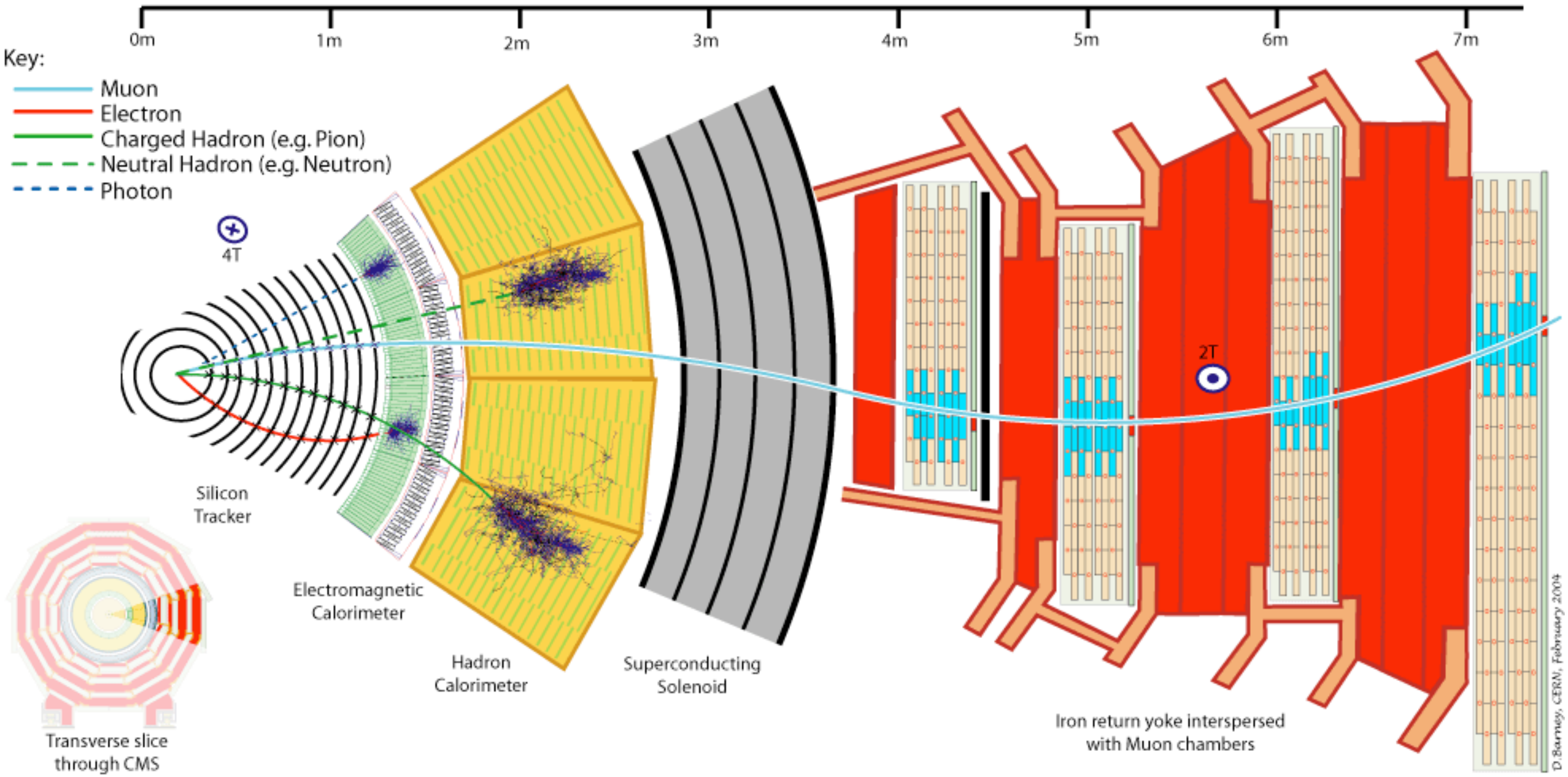
- The exclusion limits are extracted following CLs-LHC procedure
- Green/Yellow - 68%/95% local probability for background to fluctuate
    - no "look elsewhere" effect corrections
    - Mass resolution is poor: ~30GeV
- Observed exclusion region: [150,193]

Summary

- CMS searched for the Standard Model Higgs in WW fully leptonic final state with 1.1/fb of data collected in 2011
- Backgrounds is a challenging issue for Higgs search in WW final state. Lots of work was done to get the best result.
- The observed upper limit is found to be [150,193] GeV at 95% C.L.
- LHC delivers data fast, new results can be expected as soon as in a month from now in time for Lepton-Photon conference

Backup Slides

CMS Detector



Missing Energy and Drell Yan

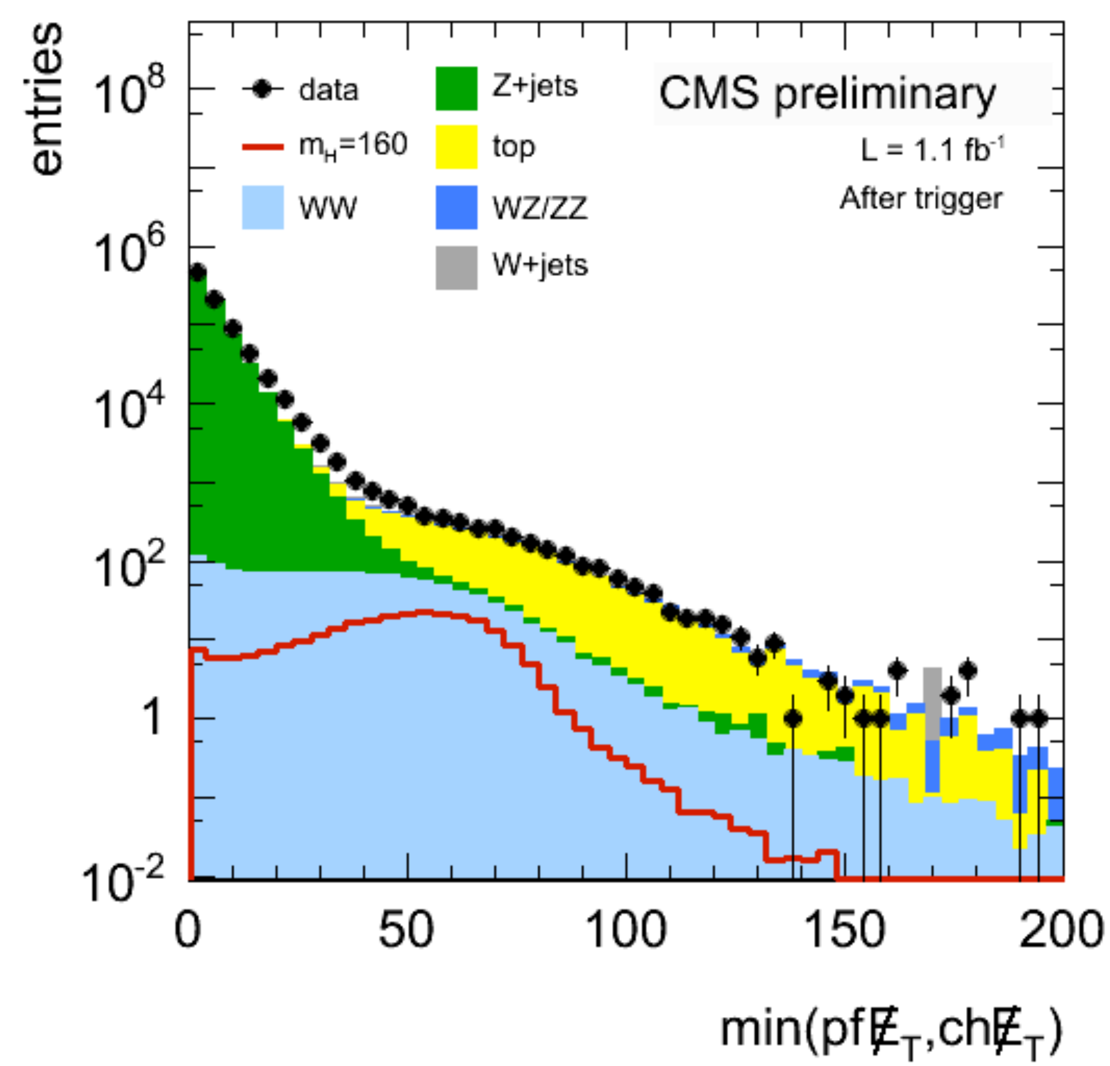
- MET is computed as a negative vector sum of calorimeter energy depositions (E_T), corrected for muons and tracks.
  - The track correction substitutes the expected energy deposition for each tracks with the Pt measured by the tracker
- Drell-Yan has 4-order of magnitude higher cross-section than Higgs(160) and the main discriminating power comes from requiring large missing energy
- Projected MET helps to reject Drell-Yan to tau-tau decays that tend to have MET aligned with one of the leptons:

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

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

Drell-Yan Background Estimation

- Drell-Yan differs from other backgrounds since it mostly consists of same flavor events
- Drell-Yan background can be estimated by subtracting the opposite flavor (emu) events from the total yield.
- In order to decrease the uncertainty of the estimate we look at events in the Z peak window and estimate the remaining Drell-Yan background outside the Z peak window using a factor called Rout/in
- Rout/in is measure both in simulation and in data



opposite flavor events measured in Z-peak

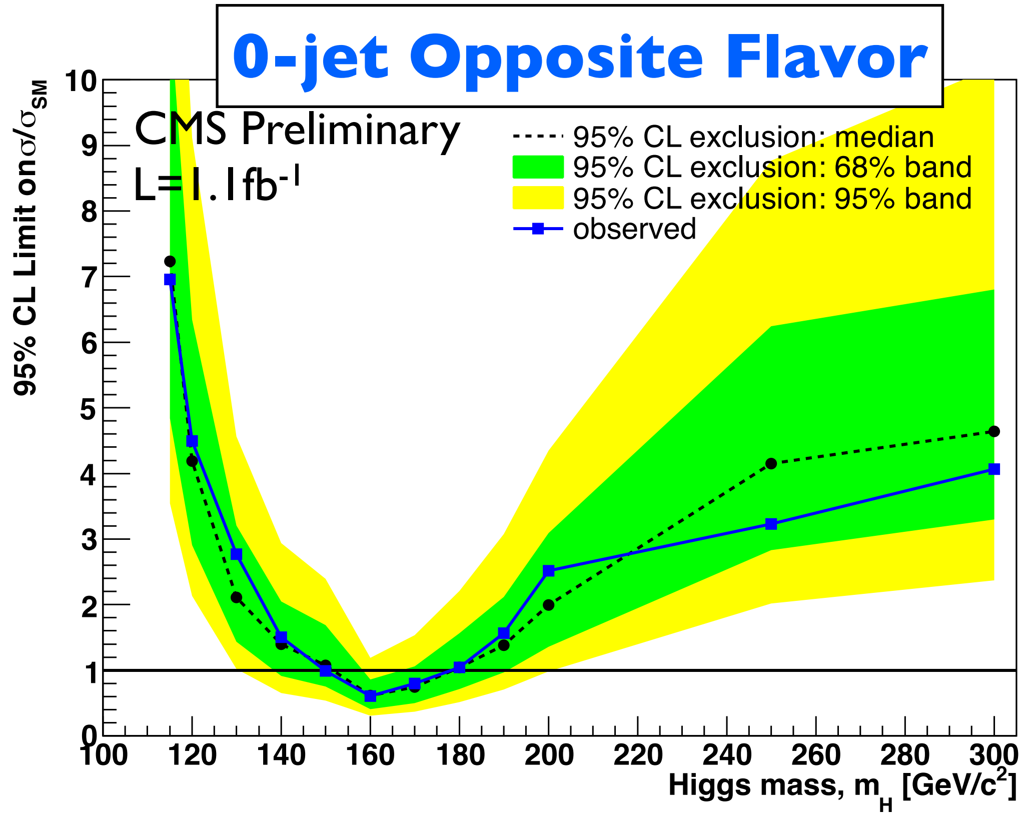
expected VZ contribution from MC

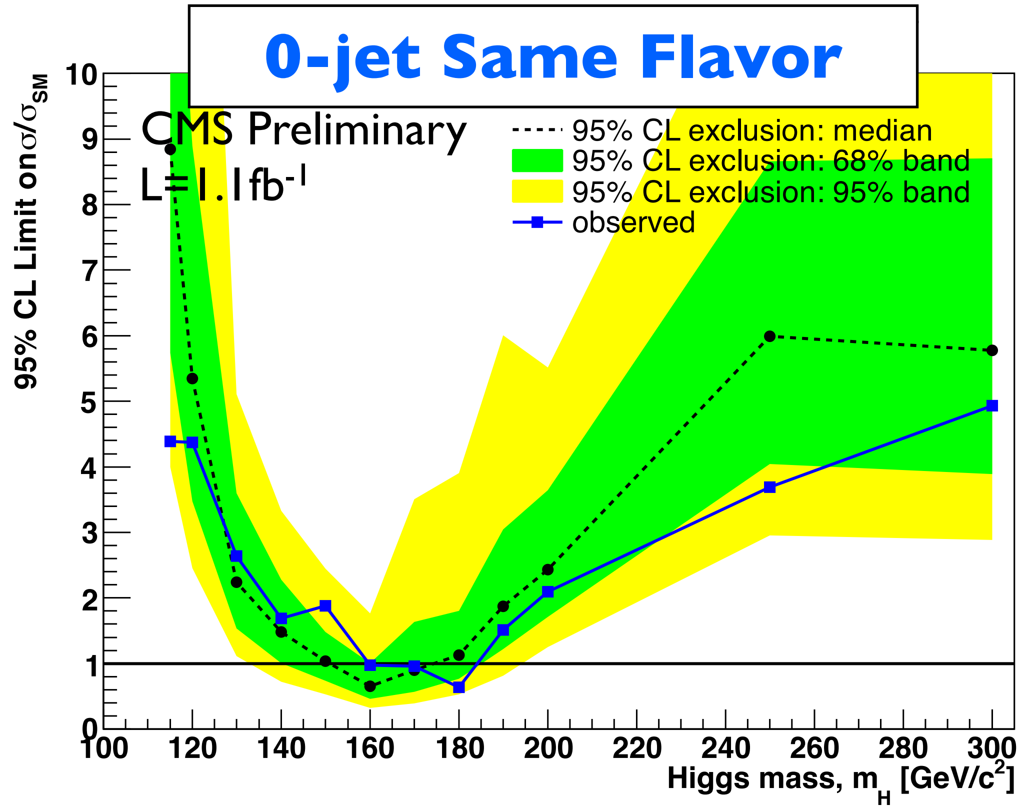
$$N^{ll,exp}_{out} = R^{ll,loose}_{out/in}(N^{ll}_{in} - 0.5N^{e\mu}_{in}k_{ll} - N^{\text{ZV, sim.}}_{\text{control}})$$

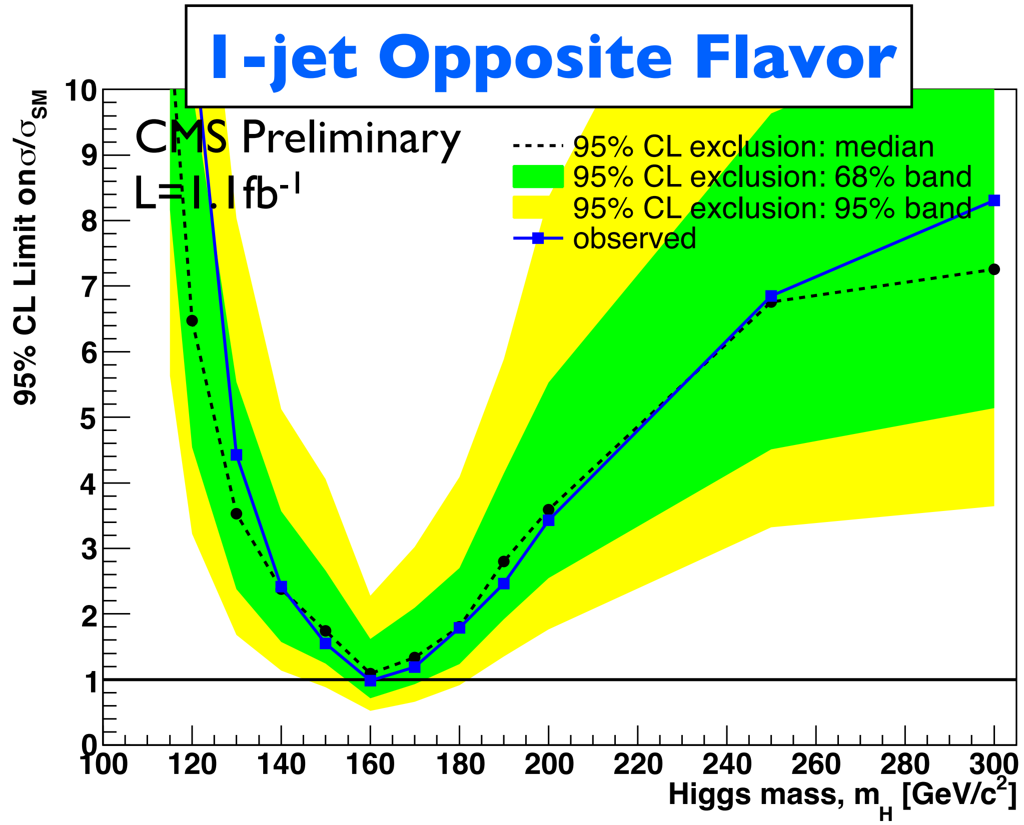
same flavor events measured in Z-peak

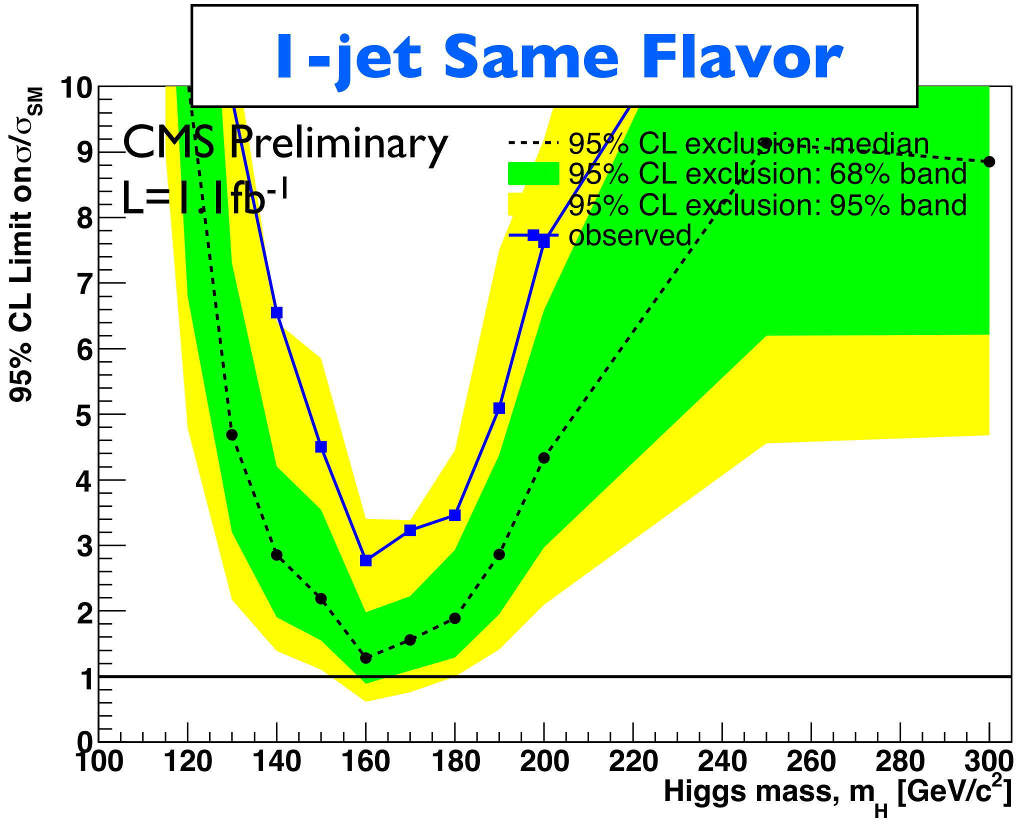
correction for differences in lepton efficiency

Limits by Channels (Cut based)



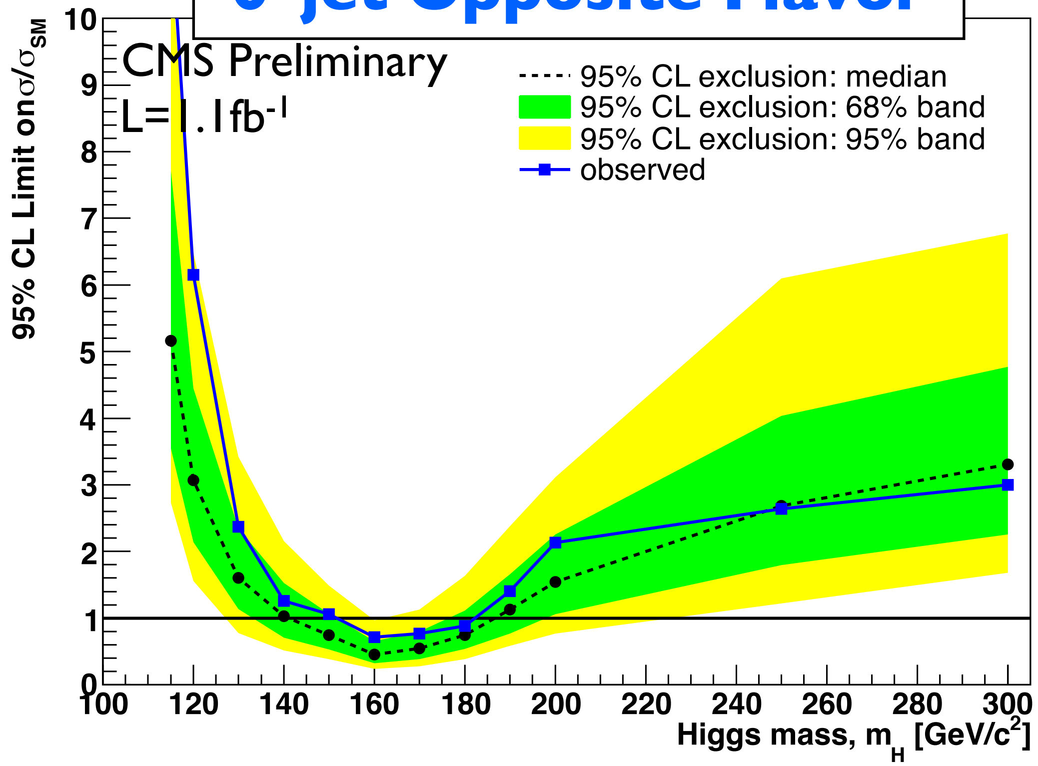




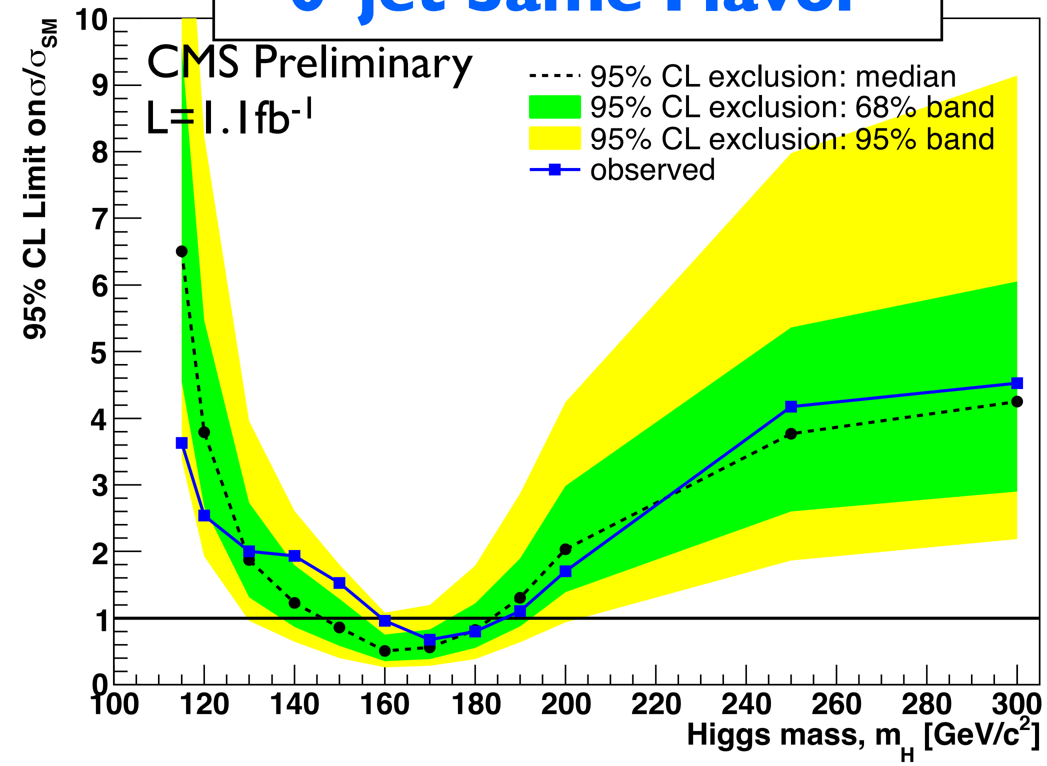


Limits by Channels (MVA based)

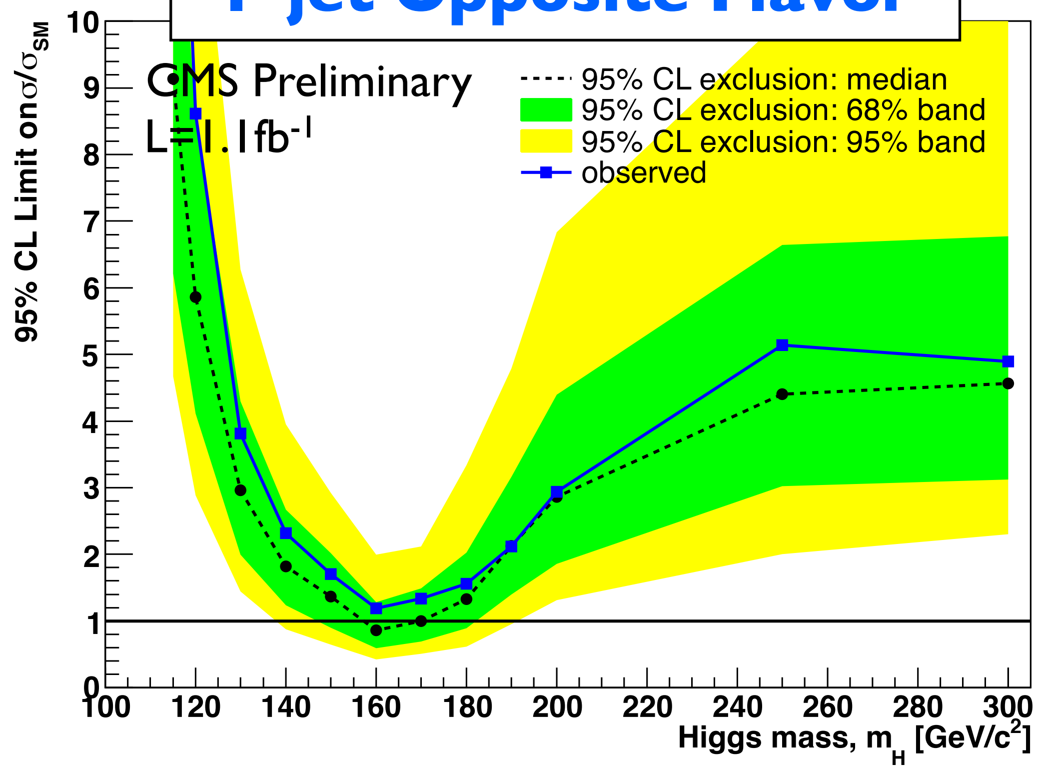
0-jet Opposite Flavor



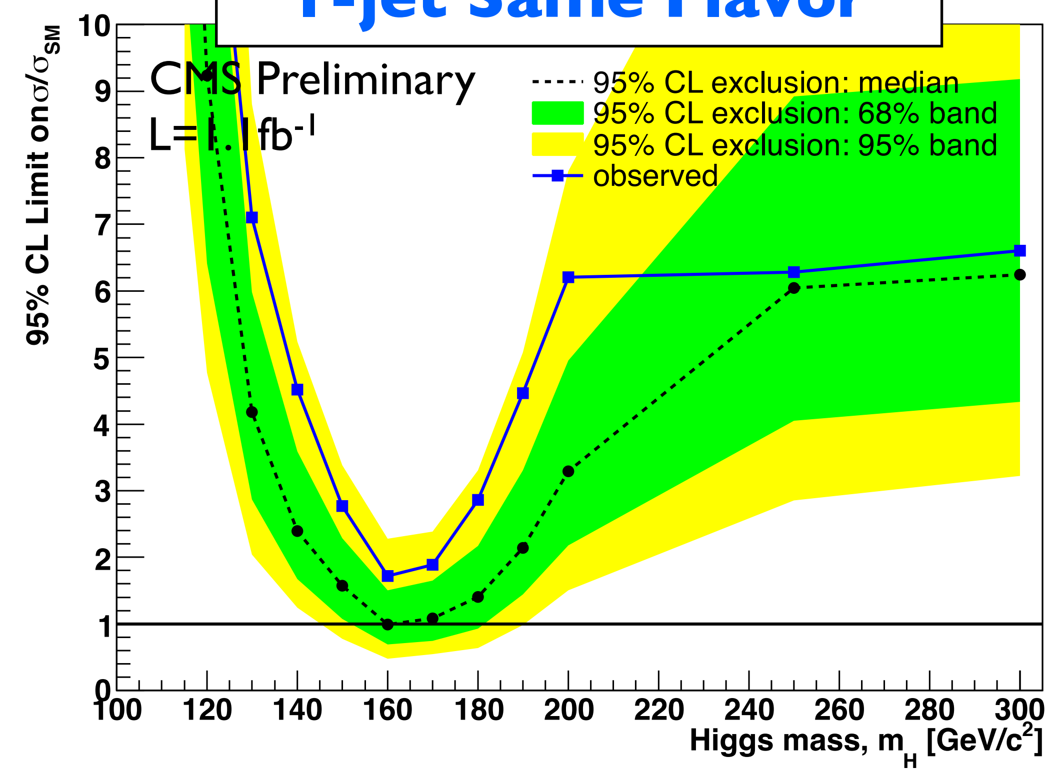
0-jet Same Flavor



1-jet Opposite Flavor



1-jet Same Flavor



Limits by NJet Category