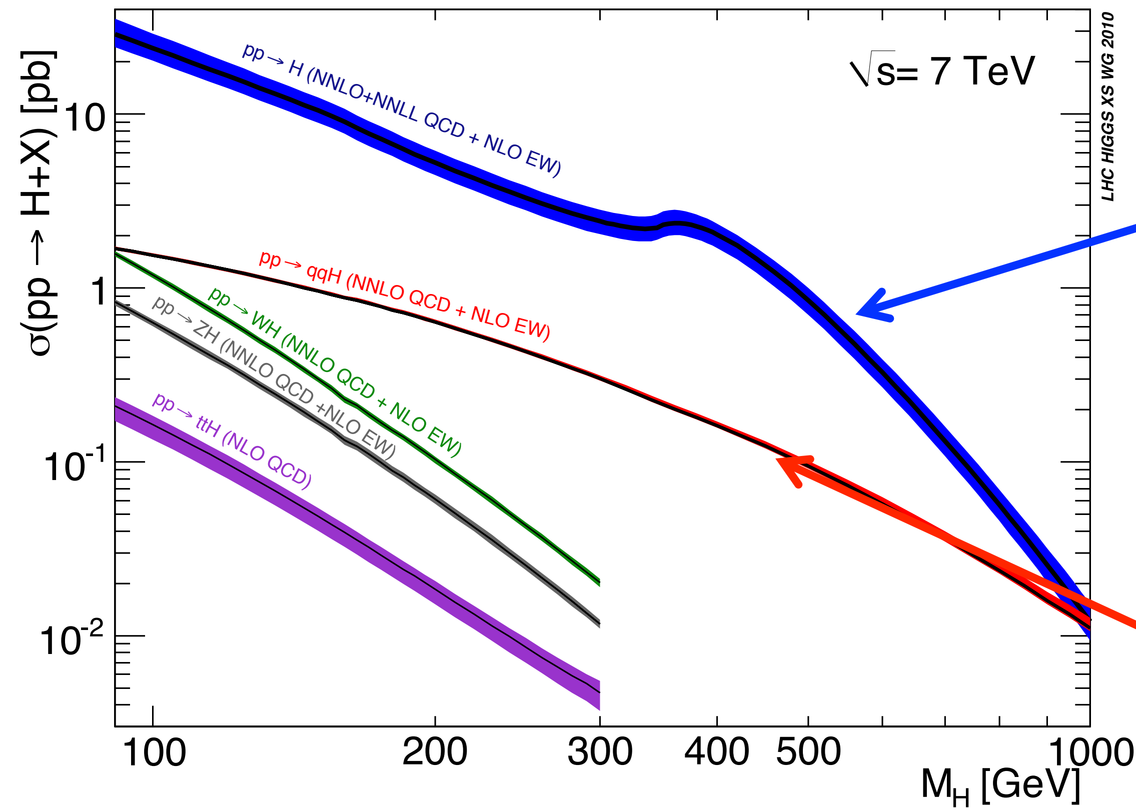
Search for Higgs in the dilepton dineutrino final state with CMS

Frank Würthwein
UCSD

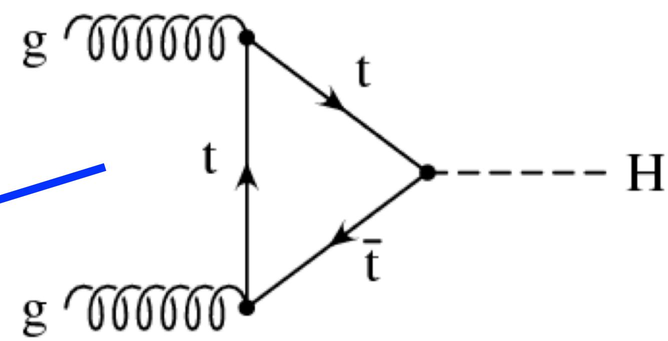
Outline

- Introduction
- H to WW to lv lv
  - Background Suppression & Estimation
  - Results
- H to ZZ to ll vv
  - Background Suppression & Estimation
  - Results
- Outlook

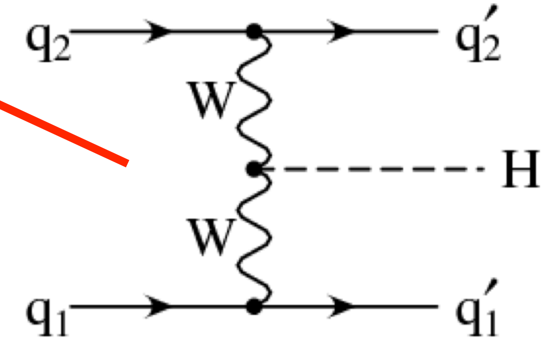
Higgs Production



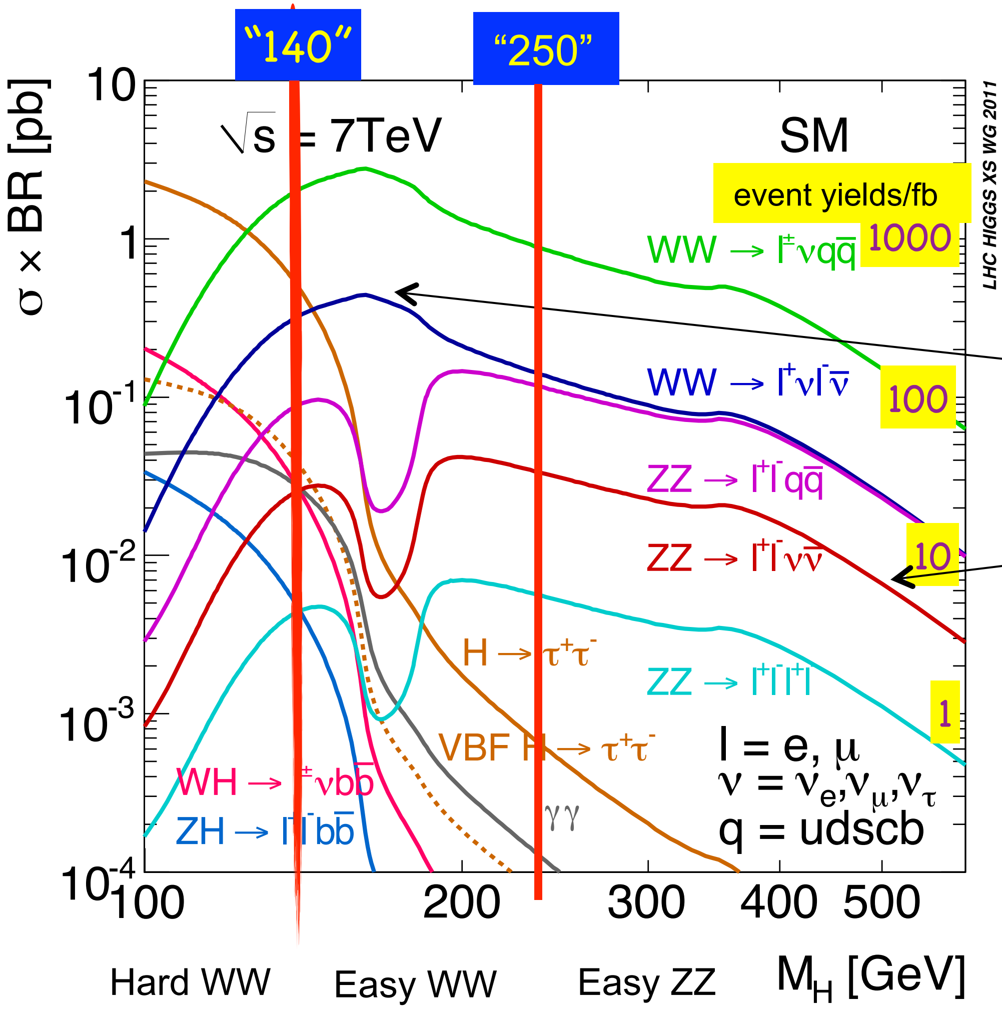
Dominant Process



Subdominant Process



Higgs Production x Decay



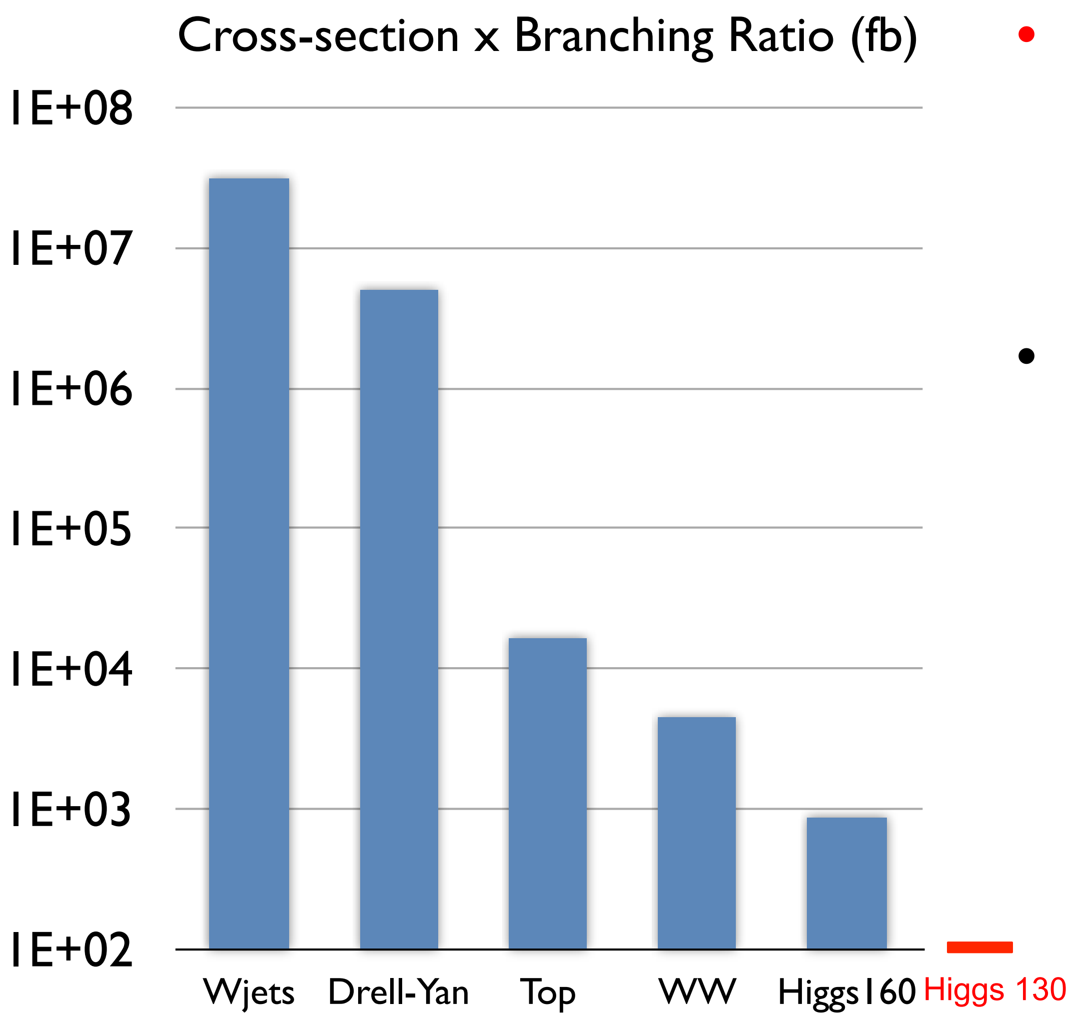
In this talk, I will focus on dilepton + MET .

WW -> lv lv

ZZ -> ll vv

There are crudely speaking 3 experimental regimes.

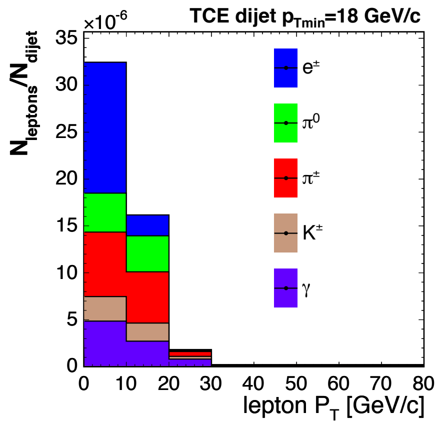
SM backgrounds

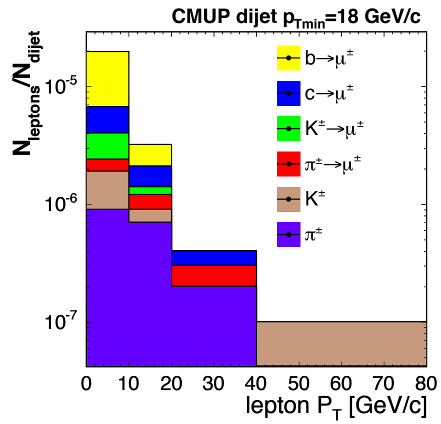


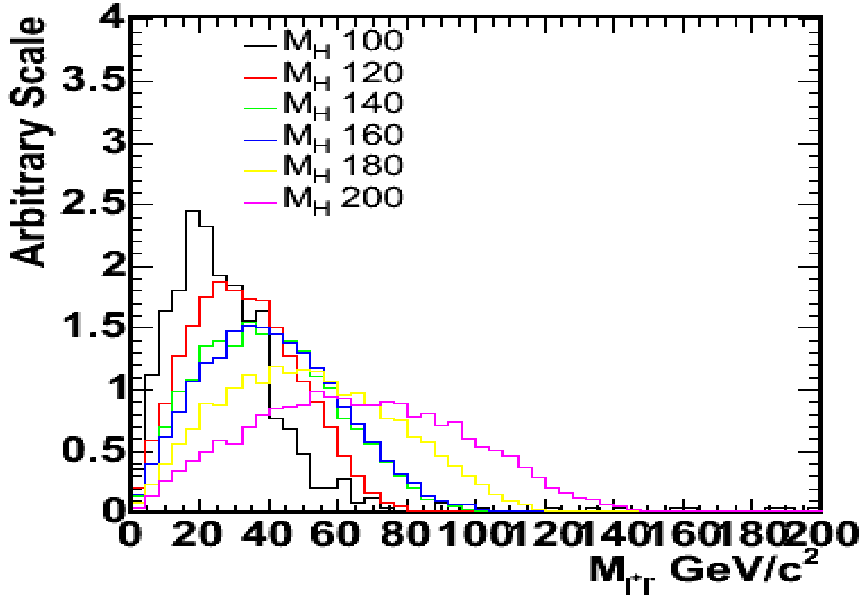
In addition: WZ,ZZ,W$\gamma^{(*)}$

- No striking signature to distinguish higgs from bkg's.
  - Counts & multi-dim. shapes
- Key selections:
  - Lepton pT > 20/10GeV with tight Id & Isolation
    - **Wjets, QCD**
  - Large MET, MT, and Z veto
    - **Drell-Yan**
  - # of jet classification (pT>30GeV) and top veto
    - **Top**
  - Kinematics (m_{ll}, $\Delta\Phi$)
    - **WW**

H -> WW for low vs medium mass







Plots from CDF out of S.-C. Hsu thesis

Bkg from Wjets grows as lepton pT decreases.

Lepton pT decreases as W* becomes more virtual.

Bkg from DY grows for very small dilepton mass.

Dilepton mass is small for low higgs mass.

WW vs ZZ for high mass

- As higgs mass increases the boost of the Z in higgs to ZZ leads to significant MET and significant transverse mass of the ll+MET system.
- This makes H -> ZZ -> ll + MET an interesting channel in the mH ~ 300 – 500 GeV range already this year.

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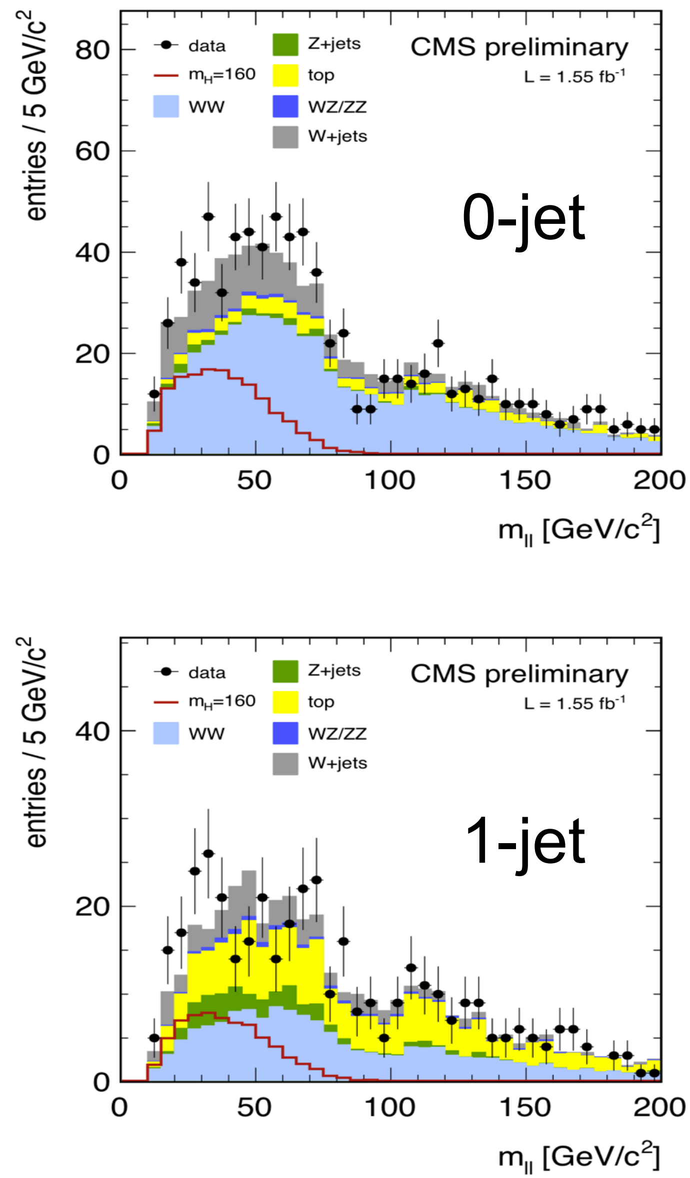
Summary of bkg estimation

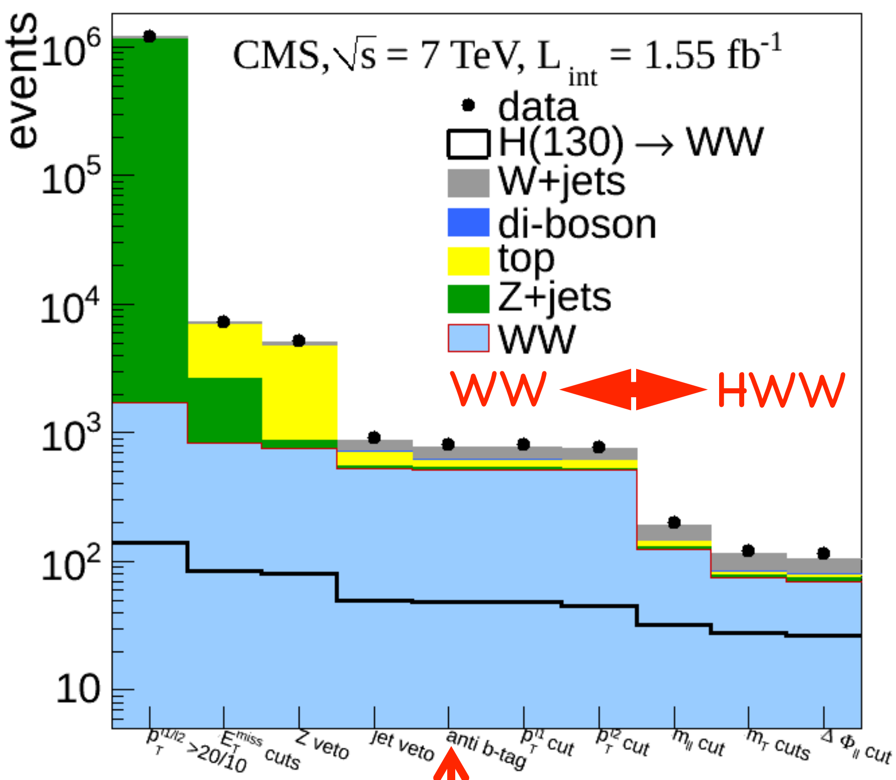
- Bkg estimated from data
  - Evaluated at HWW selection
    - WW (for mH < 200GeV)
    - Wjets
    - Drell-Yan
  - Evaluated at WW level
    - Top
      - rely on MC to extrapolate to HWW
- Bkg estimated from MC
  - Dibosons (WZ,ZZ,Wγ)
  - Z to ττ

WW selection – m_H=160



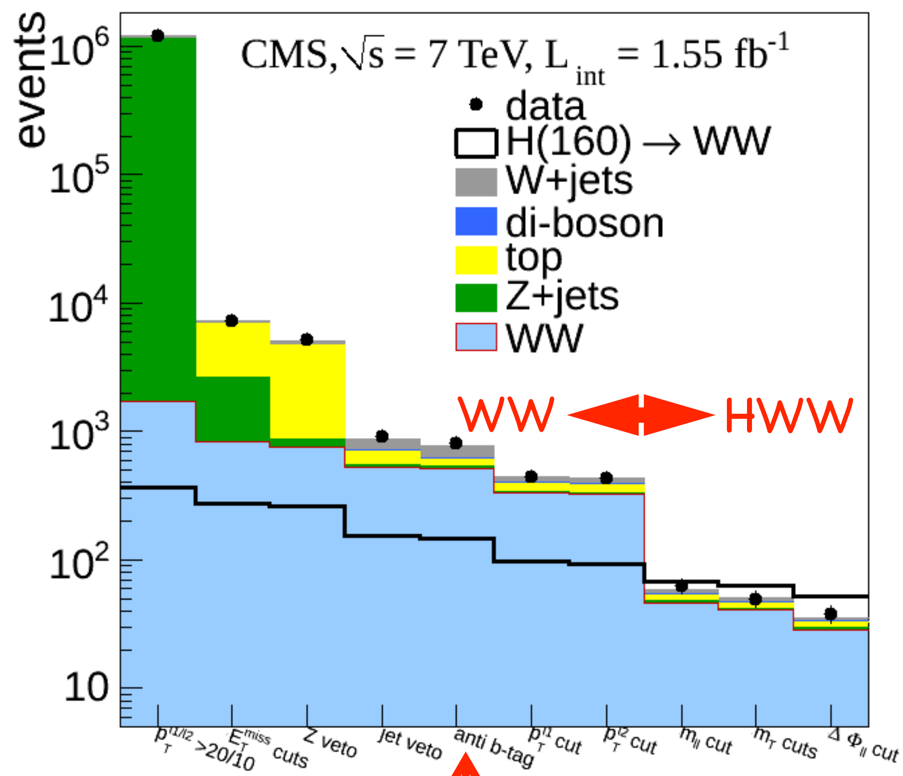
Cut based analysis

H130



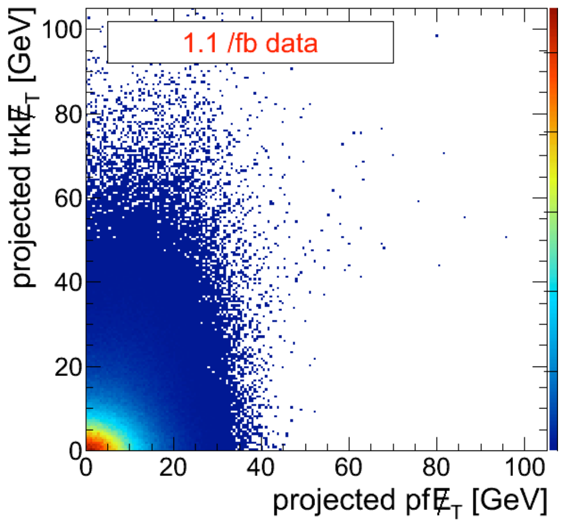
WW selection

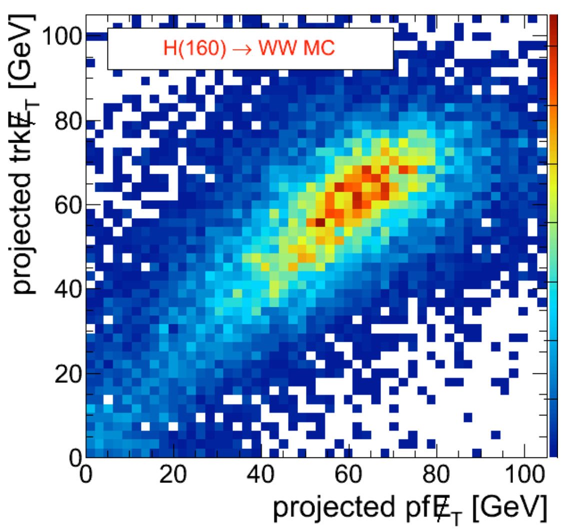
H160



WW selection

Missing Energy and pile-up

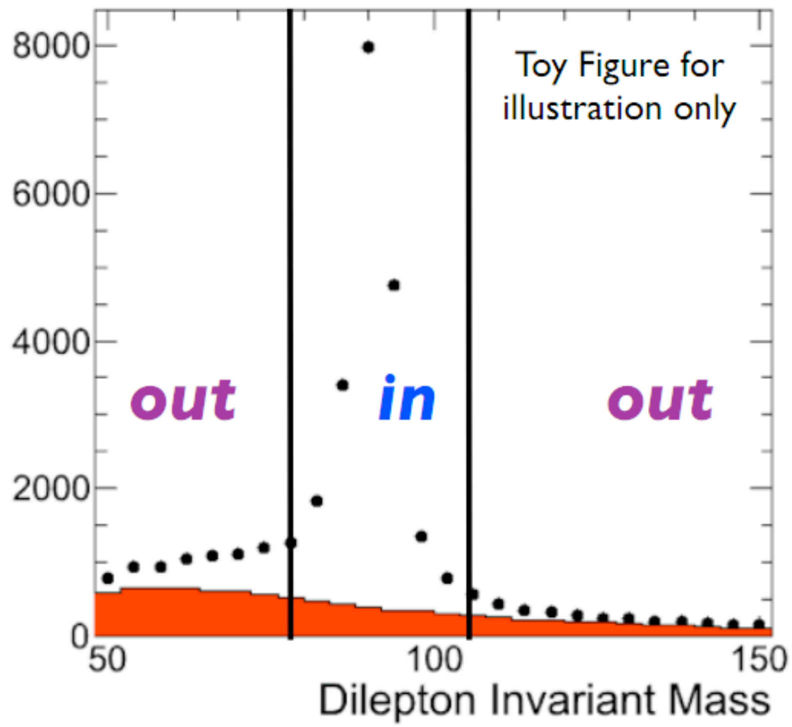




- **2011 data differs from 2010**:
  - ~8 interactions per bunch crossing
  - larger tails in the missing energy distribution
- **Two different MET variables**:
  - nominal - calorimeter and tracker
  - only tracker based MET
    - not affected by pile up
- **pfMET and trkMET are weakly correlated for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

Drell-Yan Estimation

- DY (mostly) in ee,μμ
  - Fake MET due to tails of detector resolution => difficult to simulate
- Predict "out" from "in"
  - Measure same flavor "in"
  - Subtract non-res contribution via eμ
  - Subtract VZ based on MC
  - Multiply result by R
    - Measured in MC and at higher MET in data.



opposite flavor events measured in Z-peak

expected VZ contribution from MC

$$N_{out}^{ll,exp} = R_{out/in}^{ll,loose}\left(N_{in}^{ll} - 0.5 N_{in}^{e\mu} k_{ll} - N_{\mathrm{control}}^{\mathrm{ZV,\,sim.}}\right)$$

same flavor events measured in Z-peak

correction for differences in lepton efficiency

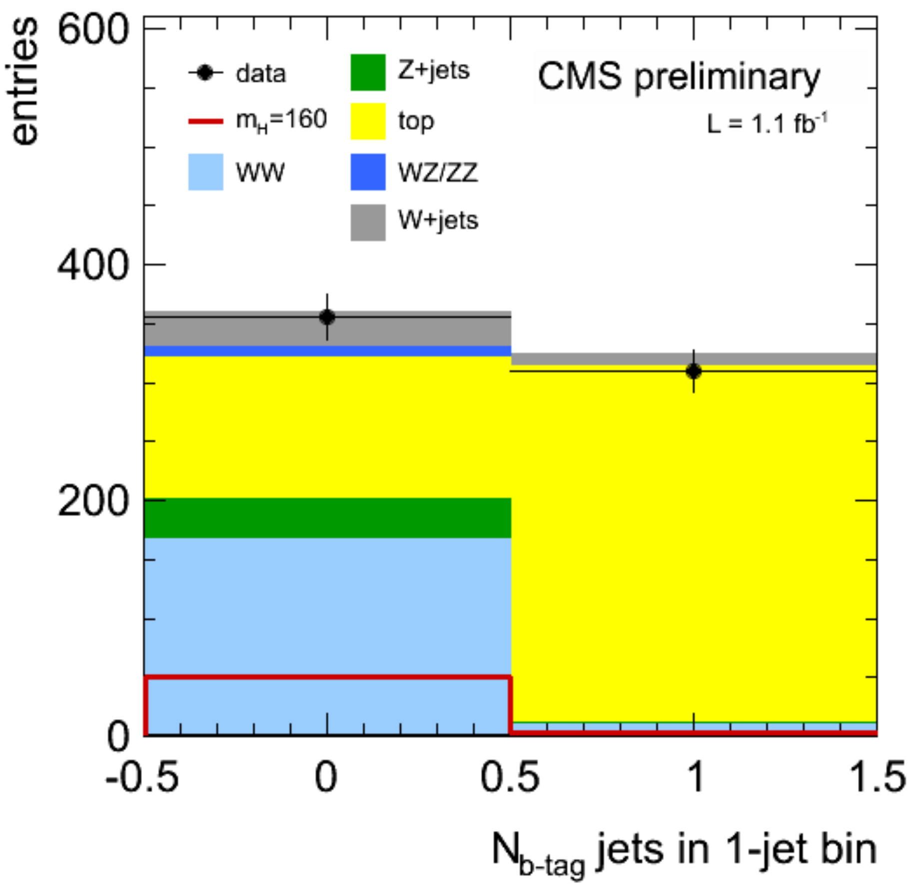
Wjets Estimation

- Measure “FR” with QCD events
  - FR = prob. for “fake” lepton that passes loose selection to also pass tight lepton selection.
  - FR = function of (pT,η)
- Extrapolate Wjets applying FR onto 1 loose 1 tight after higgs selection

Validation of Method in same sign at WW selection:

Type	Yield
Estimated events from fake rate method	$68.4 \pm 3.8^{+15.6}_{-10.6}$
Observed same-sign events in Data	92
Monte Carlo estimate of non-fake contribution (WZ & Wγ)	28.0 ± 1.9
Fake background observed	64.0 ± 9.7

Top background



- Jet veto kills top
- Remaining top can be tagged
  - Soft b-jets
  - Soft muons
- Top tagging eff. ~50% in 0-jet
- Residual top estimated via:

$$N_{top} = N_{tag} \frac{\varepsilon}{1-\varepsilon}$$

- Measure ε in 1 b-jet events
  - There must be another b-quark
- Systematics ~20-30%

Yields at WW selection

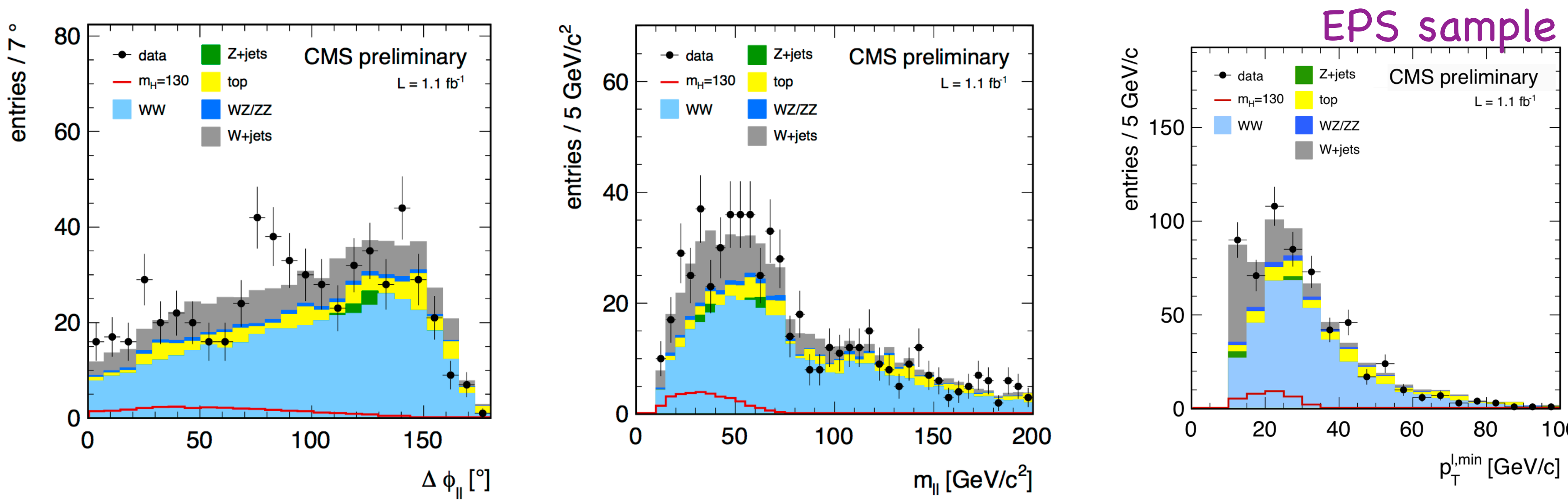
Summary of yields for 1.6/fb in the 0-, 1-, 2-jet bins.

	data	all bkg.	$qq \to W^+W^-$	$gg \to W^+W^-$	$t\bar{t} + tW$	$W + \gamma$
0-jet	811	771.2 ± 52.2	494.8 ± 2.5	23.8 ± 0.3	72.6 ± 17.4	12.3 ± 1.9
1-jet	435	427.6 ± 24.7	152.1 ± 1.4	8.2 ± 0.1	156.3 ± 15.6	3.4 ± 1.0
2-jet	252	235.4 ± 18.0	33.2 ± 0.7	1.5 ± 0.1	131.7 ± 13.2	1.6 ± 0.7

	WZ/ZZ not in $Z/\gamma^* \to \ell^+\ell^-$	$Z/\gamma^* \to \ell^+\ell^- + WZ + ZZ$	$Z/\gamma^* \to \tau^+\tau^-$	W + jets
0-jet	12.0 ± 0.4	15.2 ± 7.6	1.9 ± 0.5	138.5 ± 49.8
1-jet	10.1 ± 0.4	16.3 ± 8.2	14.9 ± 1.7	56.3 ± 20.3
2-jet	2.2 ± 0.2	28.3 ± 14.2	4.3 ± 0.8	22.6 ± 8.1

Yields agree with expectations.
Measure WW cross section as a crosscheck

WW background



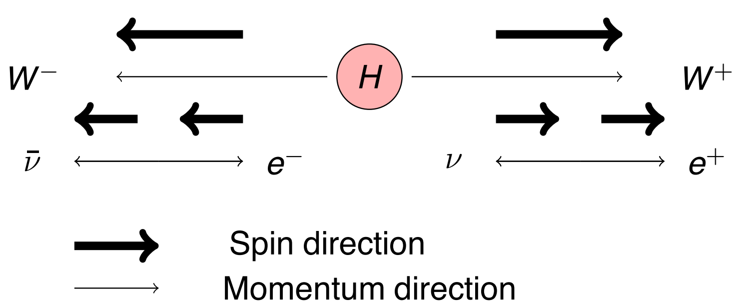
Example: mH=130 GeV

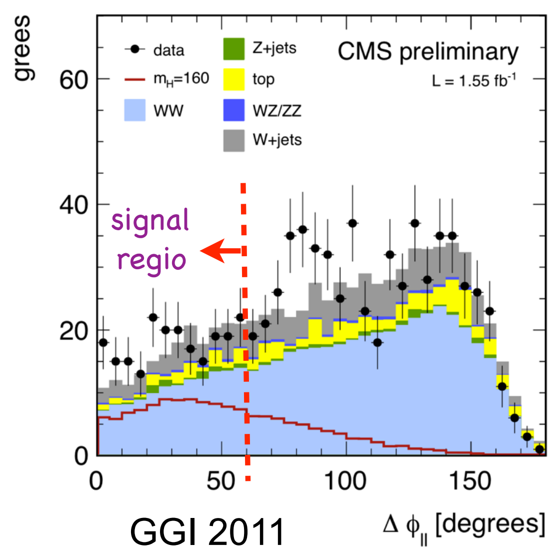
- Irreducible background with no single striking discriminator
- Kinematic shapes in multidimensional space
  – low mass, $\Delta\Phi_{ll}$, lepton momenta, transverse mass of higgs

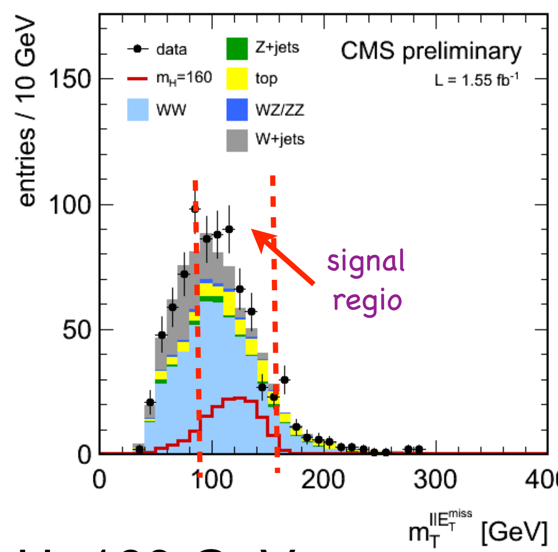
Cut based Higgs selection

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.]	$m_T^{\ell\ell E_T^{\text{miss}}}$ [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]

Spin-0 physics

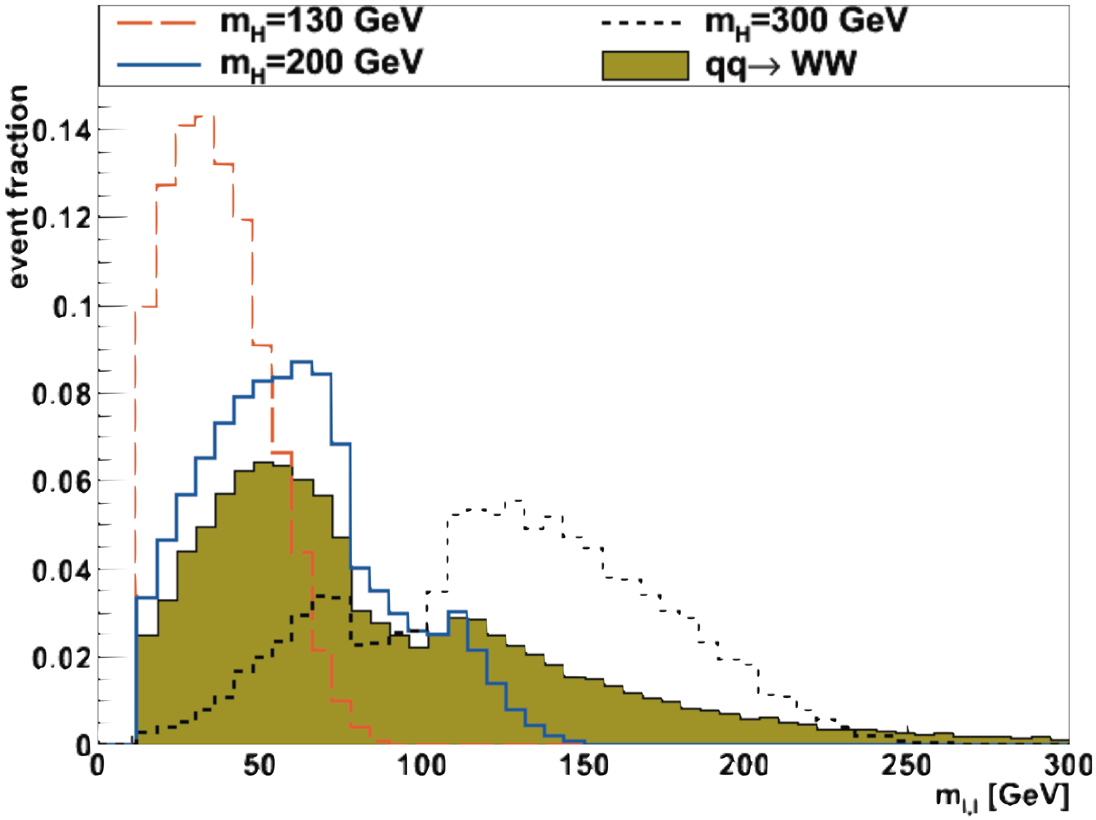






Example: mH=160 GeV

WW bkg estimate from data



- For mH < 200GeV there is very little higgs contribution above 100GeV in dilepton mass.
- We thus can use that region to determine the normalization of WW bkg, and extrapolate into the higgs selection region using MC.

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Yields after Higgs selection

Example: mH=140GeV

Process	0-j OF	0-j SF	1-j OF	1-j SF	2-j
qqWW	31.5 ± 5.5	29.1 ± 5.1	8.3 ± 3.1	5.8 ± 2.2	0.6 ± 0.2
ggWW	1.5 ± 0.8	1.3 ± 0.7	0.5 ± 0.3	0.3 ± 0.2	0.1 ± 0.1
VV	0.8 ± 0.1	0.5 ± 0.1	0.5 ± 0.1	0.3 ± 0.1	0.0 ± 0.0
Top	3.1 ± 1.1	1.4 ± 0.5	5.6 ± 1.2	3.2 ± 0.8	2.6 ± 1.5
Zjets	0.1 ± 0.0	3.1 ± 4.2	0.2 ± 0.1	1.2 ± 2.7	0.8 ± 0.6
Wjets	5.6 ± 2.3	5.3 ± 2.2	2.4 ± 1.1	1.5 ± 0.9	1.0 ± 0.6
$W\gamma$	1.5 ± 0.7	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.2	0.0 ± 0.0
$Z\tau\tau$	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.2	0.0 ± 0.0	0.2 ± 0.2
Tot. Bkg.	44.0 ± 6.2	40.6 ± 7.0	17.8 ± 3.5	12.6 ± 3.7	5.3 ± 1.7
Higgs	19.1 ± 4.3	16.1 ± 3.6	7.7 ± 2.6	5.3 ± 1.8	2.5 ± 0.3
Data	46	41	23	23	7

Good agreement between observed and expected

No sign of Higgs

Yields after Higgs selection

Example: mH=140GeV

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qqWW	31.5 ± 5.5	29.1 ± 5.1	8.3 ± 3.1	5.8 ± 2.2	0.6 ± 0.2
ggWW	1.5 ± 0.8	1.3 ± 0.7	0.5 ± 0.3	0.3 ± 0.2	0.1 ± 0.1
VV	0.8 ± 0.1	0.5 ± 0.1	0.5 ± 0.1	0.3 ± 0.1	0.0 ± 0.0
Top	3.1 ± 1.1	1.4 ± 0.5	5.6 ± 1.2	3.2 ± 0.8	2.6 ± 1.5
Zjets	0.1 ± 0.0	3.1 ± 4.2	[illegible]	[illegible]	[illegible]
Wjets	5.6 ± 2.3	5.3 ± 2.2	2.4 ± 1.1	1.5 ± 0.9	1.0 ± 0.6
$W\gamma$	1.5 ± 0.7	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.2	0.0 ± 0.0
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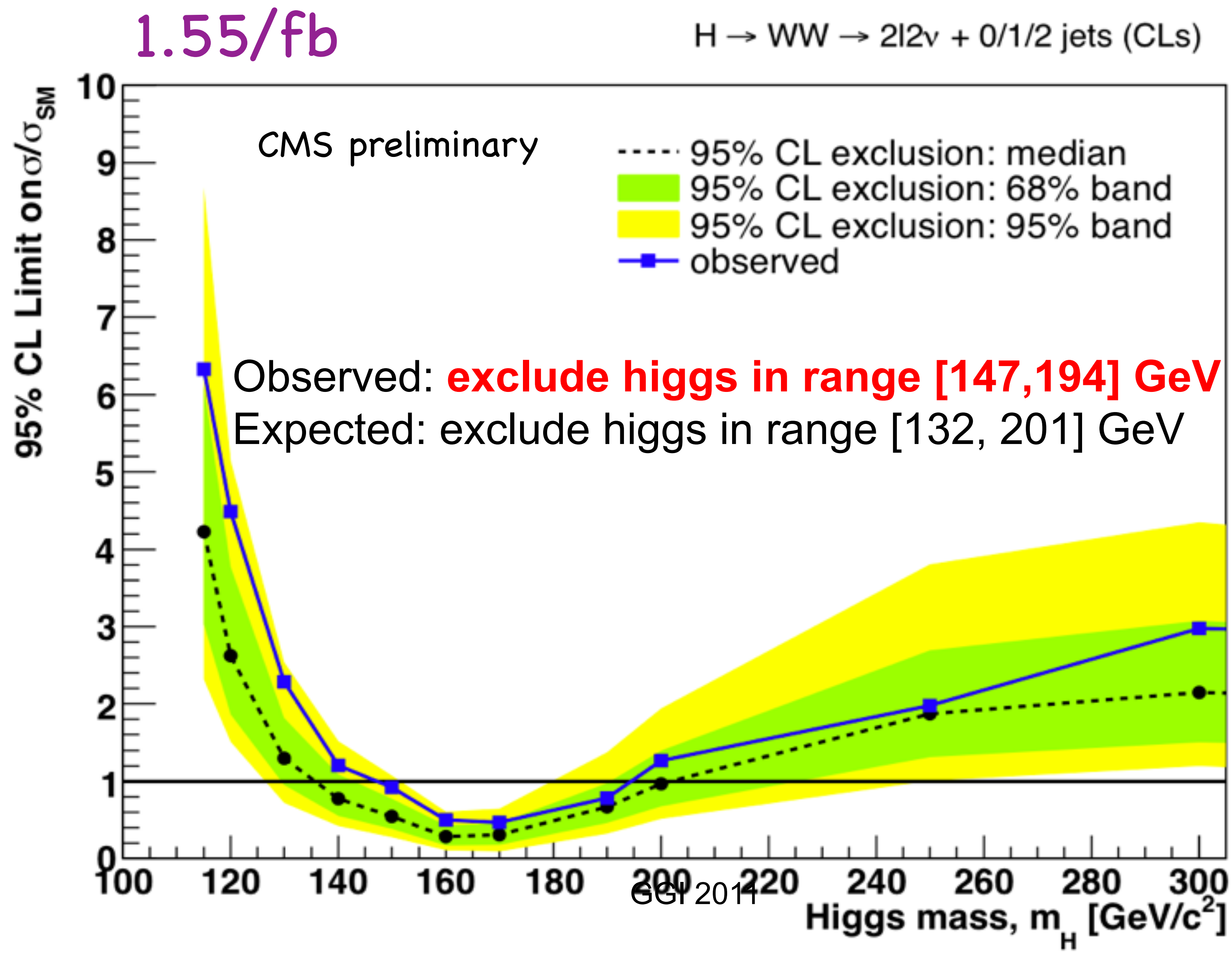
Data	46	41	23	23	7

0-jet has most of the sensitivity

Good agreement between observed and expected

No sign of Higgs

Limits for cut based analysis



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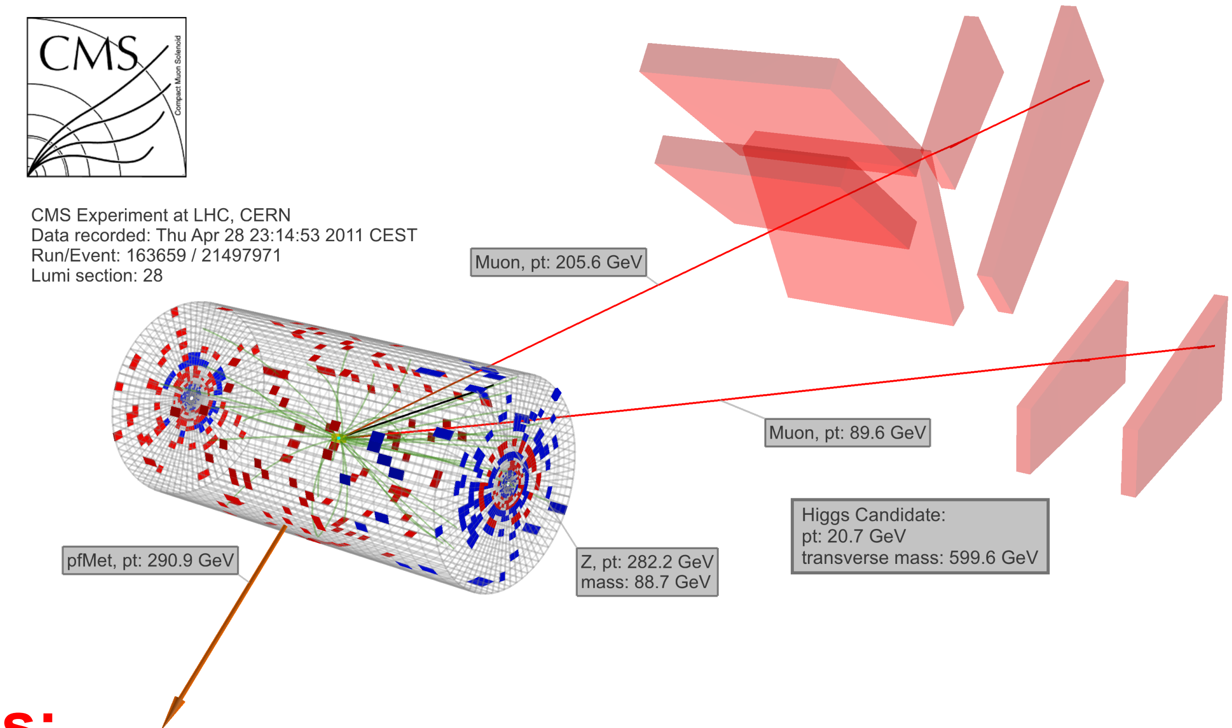
H to ZZ to ll νν



Key Issues:

- MET resolution and its non-gaussian tails – Zjets
- Estimating WW & top via eμ
- MC used to estimate WZ/ZZ bkg

Analysis Strategy

- Two high pT isolated same flavor leptons (ee, μμ).
- Tight dilepton mass window (+- 15GeV) around Z mass.
- Large MET to suppress Zjets
- Veto events with:
  - small $\Delta\phi$ between MET and nearest jet
    - Suppress Zjets with MET from large undermeasurements of jets
  - b-tagged jets => suppress top
  - third lepton => suppress WZ/ZZ

Selections

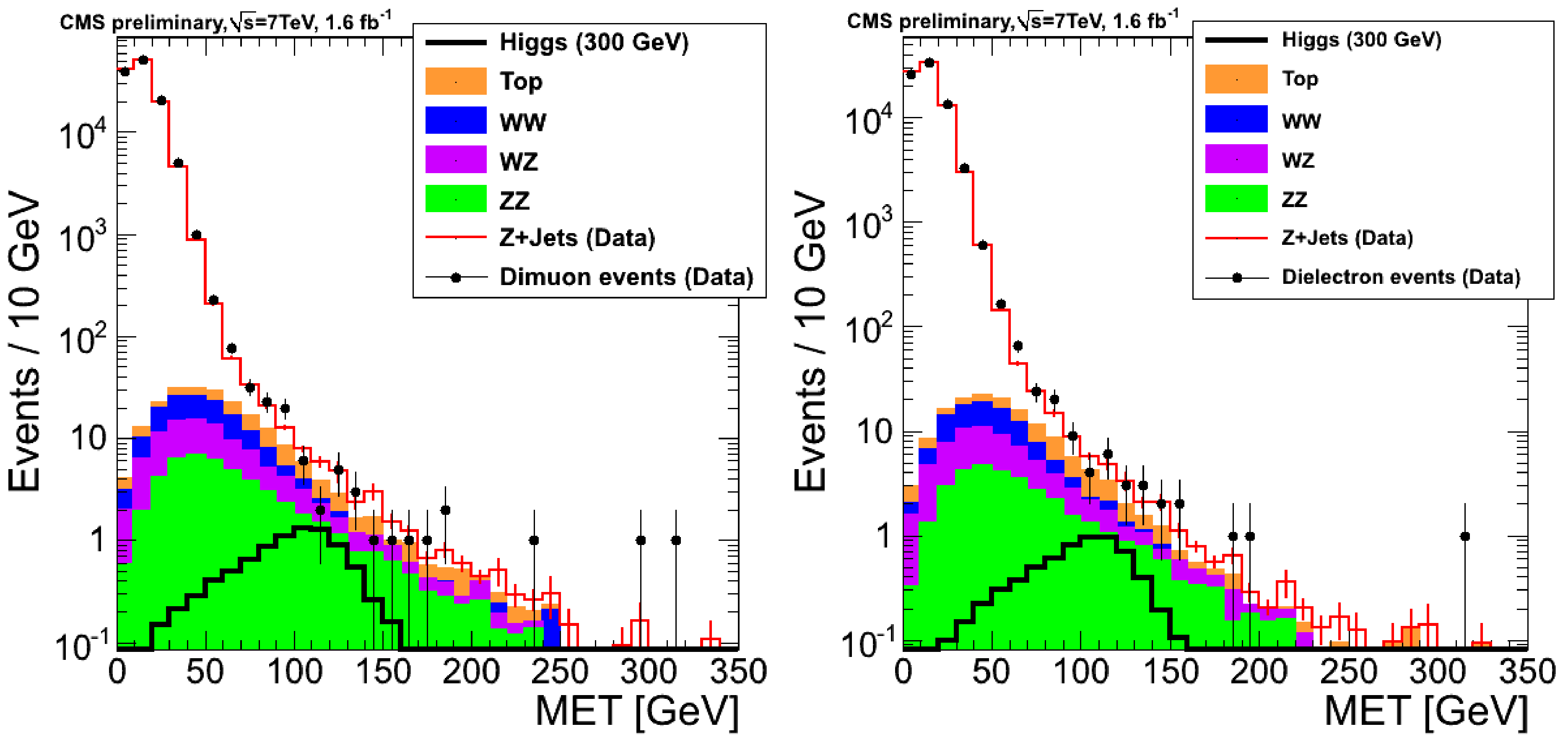
Cut	Cut Value
Lepton transverse momenta	$p_T > 20$ GeV/c
Z mass window	$\|m_{ll} - 91.1876\| \leq 15$ GeV/c^2
Z transverse momentum	Z $p_T > 25$ GeV/c
Transverse momentum of vetoed 3rd lepton	$p_T > 10$ GeV/c
Reject events with a soft muon ($p_T > 3$ GeV/c)	-
b-tag veto (jet $p_T > 30$ GeV/c)	TCHE discriminator < 2

Higgs mass (GeV/c^2)	$\Delta\phi$(MET, jet)	MET (GeV)	M_T (GeV/c^2)
250	> 0.62	> 69	> 216 AND < 272
300	> 0.28	> 83	> 242 AND < 320
350	> 0.14	> 97	> 267 AND < 386
400	–	> 112	> 292 AND < 471
450	–	> 126	> 315 AND < 540
500	–	> 141	> 336 AND < 600
550	–	> 155	> 357 AND < 660
600	–	> 170	> 377 AND < 720

Bkg Estimation

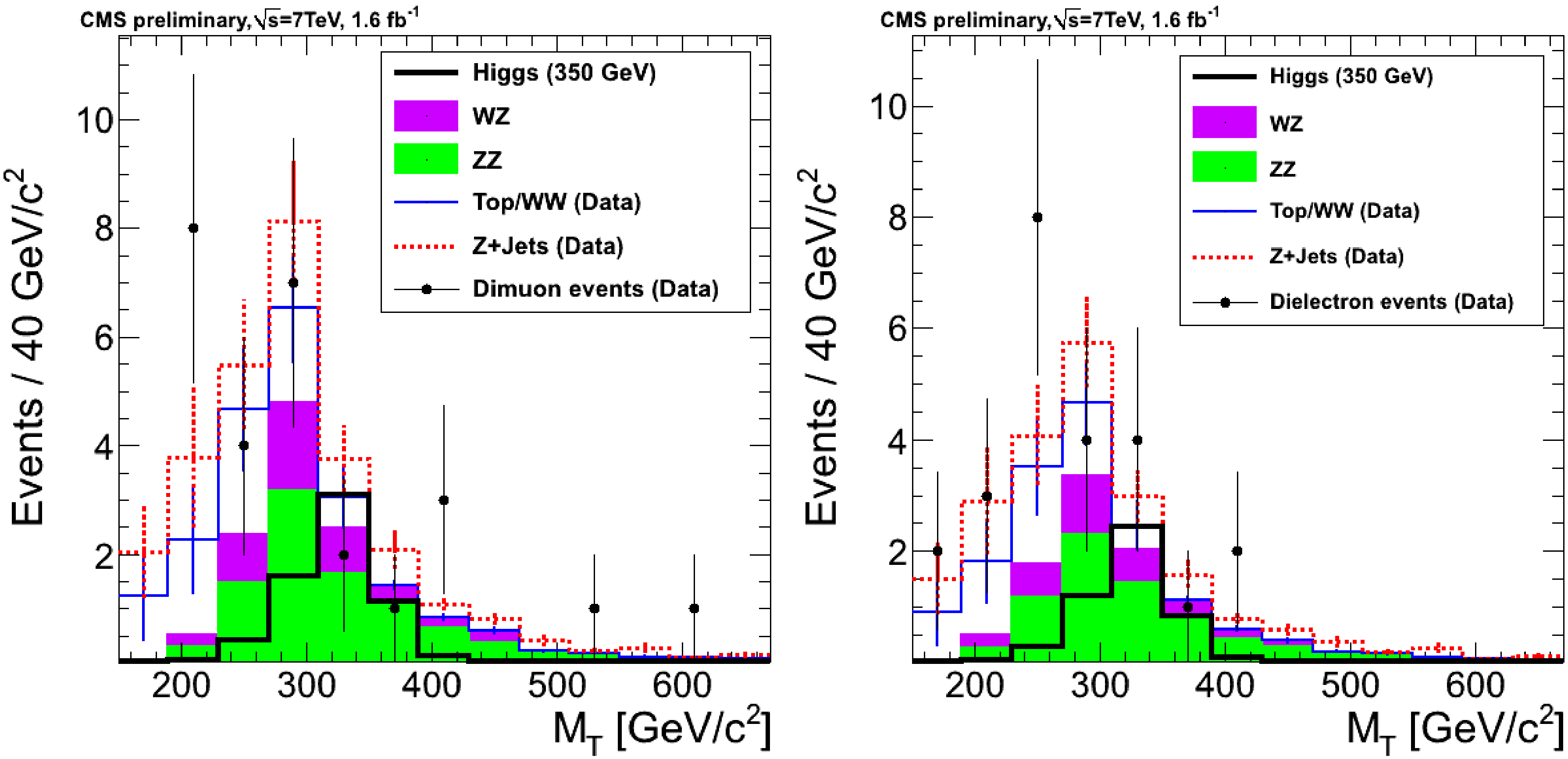
- Data Driven:
  - MET tails measured in γ+jets to estimate Zjets.
  - Top, WW using eμ events
- From MC:
  - WZ, ZZ

MET from γ+jets reweighting



μμ ee

Higgs transverse mass



Transverse mass of Higgs larger than all backgrounds only for very large higgs masses.

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Final Yields

Channel	ZZ	WZ	Top/WW/W+Jets	Z+Jets	Total	mH(250)	Data
$\mu\mu$	$9.2 \pm 0.18 \pm 0.9$	$6.1 \pm 0.25 \pm 0.71$	$16 \pm 1.9 \pm 3.1$	$7.4 \pm 1.4 \pm 1.5$	39 ± 4.3	5.5 ± 0.73	35
ee	$6.6 \pm 0.16 \pm 0.7$	$4.7 \pm 0.23 \pm 0.58$	$12 \pm 2.1 \pm 2.3$	$5 \pm 0.86 \pm 0.96$	29 ± 3.5	4.2 ± 0.59	32
Channel	ZZ	WZ	Top/WW/W+Jets	Z+Jets	Total	mH(300)	Data
$\mu\mu$	$7.3 \pm 0.16 \pm 0.71$	$4.1 \pm 0.21 \pm 0.48$	$5.3 \pm 0.61 \pm 1.8$	$4.4 \pm 0.64 \pm 1.1$	21 ± 2.4	5.4 ± 0.72	18
ee	$5.4 \pm 0.15 \pm 0.58$	$2.8 \pm 0.18 \pm 0.35$	$4 \pm 0.66 \pm 1.3$	$3 \pm 0.42 \pm 0.74$	15 ± 1.9	4.2 ± 0.59	22
Channel	ZZ	WZ	Top/WW/W+Jets	Z+Jets	Total	mH(350)	Data
$\mu\mu$	$5.8 \pm 0.15 \pm 0.57$	$2.8 \pm 0.17 \pm 0.32$	$2.3 \pm 0.27 \pm 1.2$	$2.8 \pm 0.47 \pm 0.85$	14 ± 1.7	5.6 ± 0.85	10
ee	$4.6 \pm 0.14 \pm 0.49$	$2 \pm 0.15 \pm 0.25$	$1.8 \pm 0.3 \pm 0.88$	$1.9 \pm 0.31 \pm 0.58$	10 ± 1.3	4.4 ± 0.7	9
Channel	ZZ	WZ	Top/WW/W+Jets	Z+Jets	Total	mH(400)	Data
$\mu\mu$	$4.6 \pm 0.14 \pm 0.45$	$1.8 \pm 0.14 \pm 0.21$	$0.58 \pm 0.067 \pm 0.58$	$2.3 \pm 0.48 \pm 0.85$	9.3 ± 1.3	4.5 ± 0.6	7
ee	$3.7 \pm 0.13 \pm 0.4$	$1.5 \pm 0.13 \pm 0.19$	$0.44 \pm 0.074 \pm 0.44$	$1.7 \pm 0.33 \pm 0.6$	7.4 ± 0.95	3.6 ± 0.5	9
Channel	ZZ	WZ	Top/WW/W+Jets	Z+Jets	Total	mH(500)	Data
$\mu\mu$	$2.7 \pm 0.11 \pm 0.26$	$0.92 \pm 0.1 \pm 0.11$	0	$1.7 \pm 0.41 \pm 0.8$	5.3 ± 0.95	2 ± 0.28	6
ee	$2.1 \pm 0.097 \pm 0.22$	$0.77 \pm 0.093 \pm 0.095$	0	$1.3 \pm 0.31 \pm 0.62$	4.2 ± 0.74	1.6 ± 0.24	3
Channel	ZZ	WZ	Top/WW/W+Jets	Z+Jets	Total	mH(600)	Data
$\mu\mu$	$1.6 \pm 0.085 \pm 0.15$	$0.51 \pm 0.075 \pm 0.06$	0	$0.91 \pm 0.22 \pm 0.53$	3 ± 0.61	0.8 ± 0.12	5
ee	$1.3 \pm 0.077 \pm 0.14$	$0.37 \pm 0.064 \pm 0.046$	0	$0.78 \pm 0.19 \pm 0.45$	2.4 ± 0.51	0.66 ± 0.1	2

Observed and predicted agree well.

No sign of higgs.

Final Yields

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ee	$4.6 \pm 0.14 \pm 0.49$	$2 \pm 0.15 \pm 0.25$	$1.8 \pm 0.3 \pm 0.88$	$1.9 \pm 0.31 \pm 0.58$	10 ± 1.3	4.4 ± 0.7	9
Channel	ZZ	WZ	Top/WW/W+Jets	Z+Jets	Total	mH(400)	Data
$\mu\mu$	$4.6 \pm 0.14 \pm 0.45$	$1.8 \pm 0.14 \pm 0.21$	$0.58 \pm 0.067 \pm 0.58$	$2.3 \pm 0.48 \pm 0.85$	9.3 ± 1.3	4.5 ± 0.6	7
ee	$3.7 \pm 0.13 \pm 0.4$	$1.5 \pm 0.13 \pm 0.19$	$0.44 \pm 0.074 \pm 0.44$	$1.7 \pm 0.33 \pm 0.6$	7.4 ± 0.95	3.6 ± 0.5	9
Channel	ZZ	WZ	Top/WW/W+Jets	Z+Jets	Total	mH(500)	Data
$\mu\mu$	$2.7 \pm 0.11 \pm 0.26$	$0.92 \pm 0.1 \pm 0.11$	0	$1.7 \pm 0.41 \pm 0.8$	5.3 ± 0.95	2 ± 0.28	6
ee	$2.1 \pm 0.097 \pm 0.22$	$0.77 \pm 0.093 \pm 0.095$	0	$1.3 \pm 0.31 \pm 0.62$	4.2 ± 0.74	1.6 ± 0.24	3
Channel	ZZ	WZ	Top/WW/W+Jets	Z+Jets	Total	mH(600)	Data
$\mu\mu$	$1.6 \pm 0.085 \pm 0.15$	$0.51 \pm 0.075 \pm 0.06$	0	$0.91 \pm 0.22 \pm 0.53$	3 ± 0.61	0.8 ± 0.12	5
ee	$1.3 \pm 0.077 \pm 0.14$	$0.37 \pm 0.064 \pm 0.046$	0	$0.78 \pm 0.19 \pm 0.45$	2.4 ± 0.51	0.66 ± 0.1	2

Bkg decreases tenfold from low to high mass.

Sensitivity to higgs largely a matter of luminosity.

Final Yields

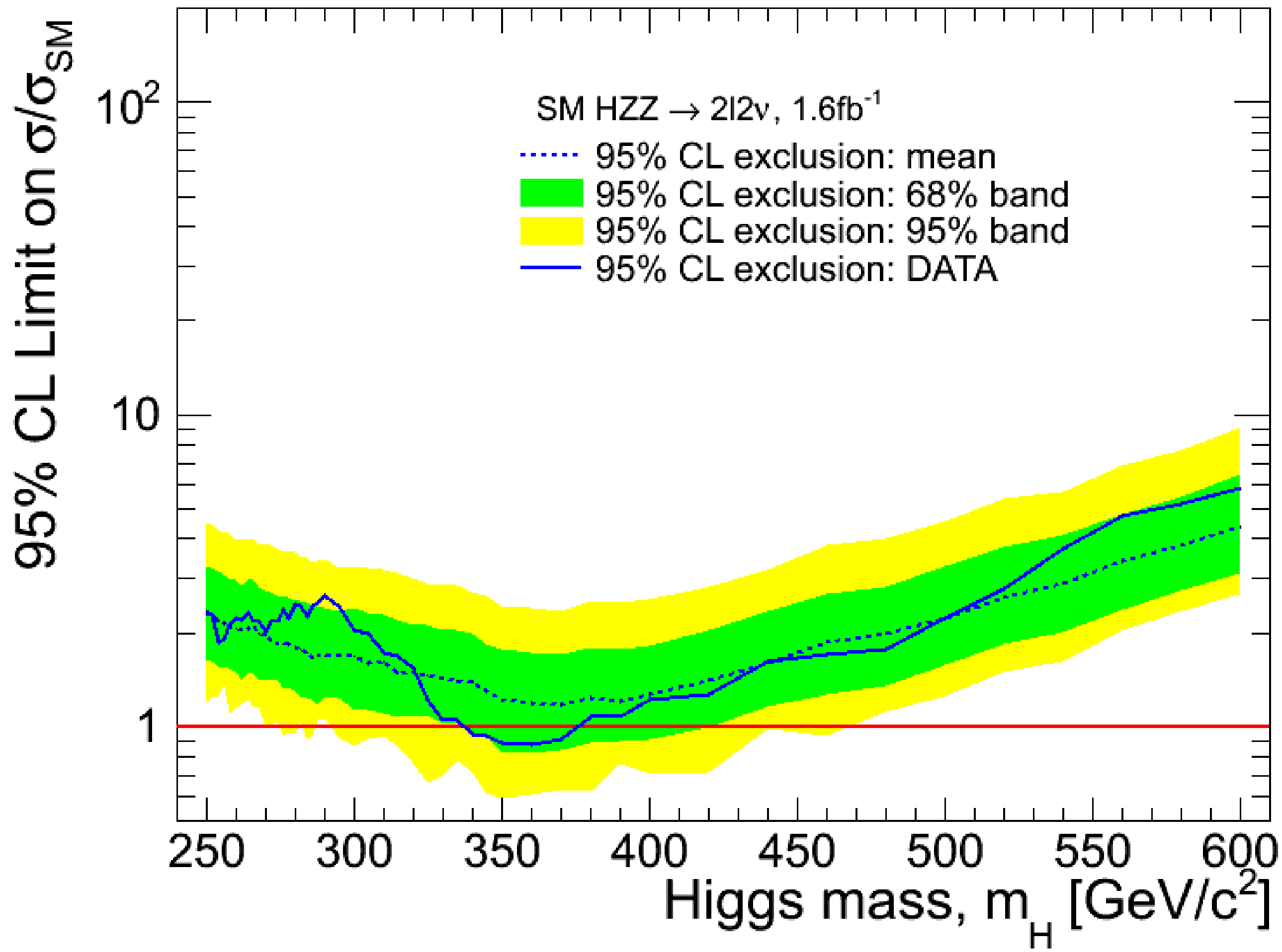
Channel	ZZ	WZ	Top/WW/W+Jets	Z+Jets	Total	mH(250)	Data
$\mu\mu$	$9.2 \pm 0.18 \pm 0.9$	$6.1 \pm 0.25 \pm 0.71$	$16 \pm 1.9 \pm 3.1$	$7.4 \pm 1.4 \pm 1.5$	39 ± 4.3	5.5 ± 0.73	35
ee	$6.6 \pm 0.16 \pm 0.7$	$4.7 \pm 0.23 \pm 0.58$	$12 \pm 2.1 \pm 2.3$	$5 \pm 0.86 \pm 0.96$	29 ± 3.5	4.2 ± 0.59	32
Channel	ZZ	WZ	Top/WW/W+Jets	Z+Jets	Total	mH(300)	Data
$\mu\mu$	$7.3 \pm 0.16 \pm 0.71$	$4.1 \pm 0.21 \pm 0.48$	$5.3 \pm 0.61 \pm 1.8$	$4.4 \pm 0.64 \pm 1.1$	21 ± 2.4	5.4 ± 0.72	18
ee	$5.4 \pm 0.15 \pm 0.58$	$2.8 \pm 0.18 \pm 0.35$	$4 \pm 0.66 \pm 1.3$	$3 \pm 0.42 \pm 0.74$	15 ± 1.9	4.2 ± 0.59	22
Channel	ZZ	WZ	Top/WW/W+Jets	Z+Jets	Total	mH(350)	Data
$\mu\mu$	$5.8 \pm 0.15 \pm 0.57$	$2.8 \pm 0.17 \pm 0.32$	$2.3 \pm 0.27 \pm 1.2$	$2.8 \pm 0.47 \pm 0.85$	14 ± 1.7	5.6 ± 0.85	10
ee	$4.6 \pm 0.14 \pm 0.49$	$2 \pm 0.15 \pm 0.25$	$1.8 \pm 0.3 \pm 0.88$	$1.9 \pm 0.31 \pm 0.58$	10 ± 1.3	4.4 ± 0.7	9
Channel	ZZ	WZ	Top/WW/W+Jets	Z+Jets	Total	mH(400)	Data
$\mu\mu$	$4.6 \pm 0.14 \pm 0.45$	$1.8 \pm 0.14 \pm 0.21$	$0.58 \pm 0.067 \pm 0.58$	$2.3 \pm 0.48 \pm 0.85$	9.3 ± 1.3	4.5 ± 0.6	7
ee	$3.7 \pm 0.13 \pm 0.4$	$1.5 \pm 0.13 \pm 0.19$	$0.44 \pm 0.074 \pm 0.44$	$1.7 \pm 0.33 \pm 0.6$	7.4 ± 0.95	3.6 ± 0.5	9
Channel	ZZ	WZ	Top/WW/W+Jets	Z+Jets	Total	mH(500)	Data
$\mu\mu$	$2.7 \pm 0.11 \pm 0.26$	$0.92 \pm 0.1 \pm 0.11$	0	$1.7 \pm 0.41 \pm 0.8$	5.3 ± 0.95	2 ± 0.28	6
ee	$2.1 \pm 0.097 \pm 0.22$	$0.77 \pm 0.093 \pm 0.095$	0	$1.3 \pm 0.31 \pm 0.62$	4.2 ± 0.74	1.6 ± 0.24	3
Channel	ZZ	WZ	Top/WW/W+Jets	Z+Jets	Total	mH(600)	Data
$\mu\mu$	$1.6 \pm 0.085 \pm 0.15$	$0.51 \pm 0.075 \pm 0.06$	0	$0.91 \pm 0.22 \pm 0.53$	3 ± 0.61	0.8 ± 0.12	5
ee	$1.3 \pm 0.077 \pm 0.14$	$0.37 \pm 0.064 \pm 0.046$	0	$0.78 \pm 0.19 \pm 0.45$	2.4 ± 0.51	0.66 ± 0.1	2

ZZ dominates except for low mass.

Zjets remains second largest bkg even at high mass.

WZ bkg with lost 3rd lepton significant at all masses.

Limits on H to ZZ to ll νν



Higgs excluded in range 340-375 GeV

Outline

- Introduction
- H to WW to lv lv
  - Background Suppression & Estimation
  - Results
- H to ZZ to ll vv
  - Background Suppression & Estimation
  - Results
- Outlook

Necessary Improvements

Yields table of H->WW for a few mass points:

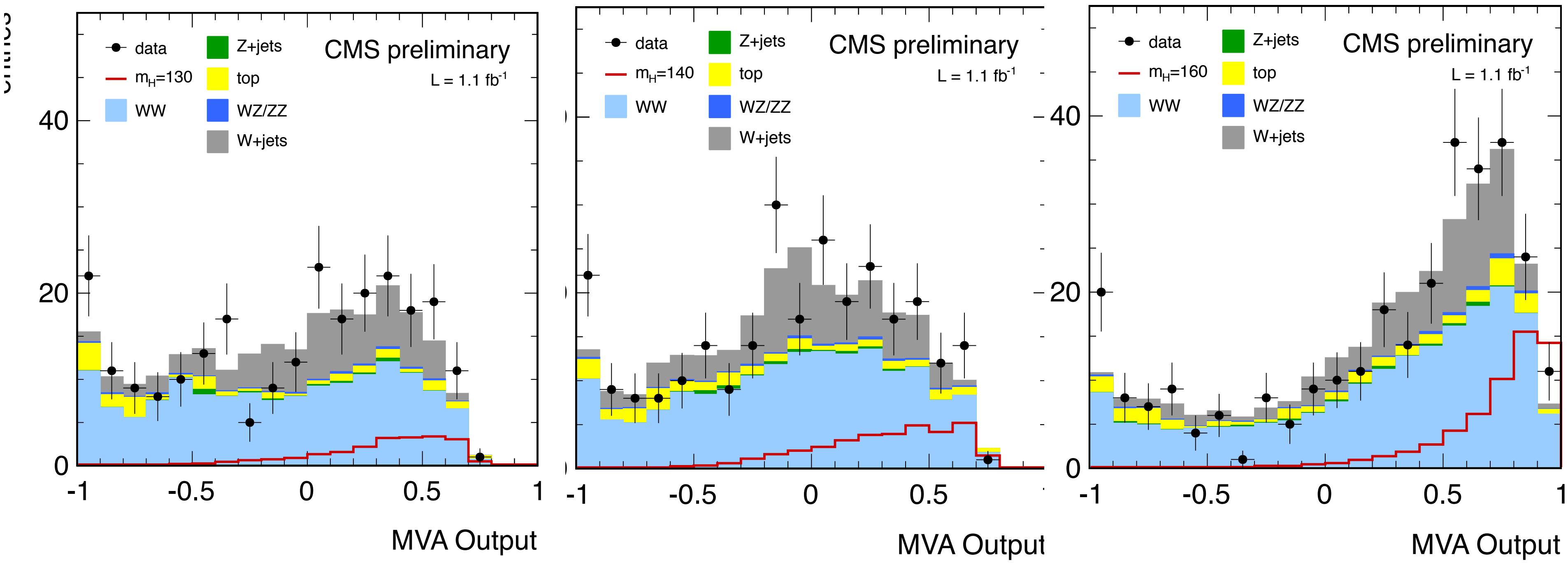
mH	ggH	qqWW	ggWW	VV	Top	Zjets	Wjets	Wgam	Ztt	∑Bkg	Data
120	7.6±1.7	33.7±5.9	1.3±0.7	0.8±0.1	3.0±1.1	0.1±0.0	19.4±7.3	3.9±1.2	0.0±0.0	62.3±9.5	67
140	18.8±4.2	31.5±5.5	1.5±0.8	0.8±0.1	3.1±1.1	0.1±0.0	5.6±2.3	1.5±0.7	0.0±0.0	44.0±6.2	46
160	26.6±6.1	13.5±2.4	1.3±0.7	0.3±0.1	1.9±0.9	0.0±0.0	2.0±1.1	0.0±0.0	0.0±0.0	19.0±2.9	18

For higgs mass of 120 GeV the systematic error on Wjets is roughly the same as the expected higgs signal.

Progress requires innovation in addition to luminosity !!!

Desirable Improvement

MVA output for eμ 0-jet and 130,140,160GeV higgs



- There is information left inside the cuts
- There is information in correlations of the kinematic variables that is not fully exploited by square cuts.

Conclusions

- No higgs found
  - H to WW to lv lv excludes mH from 147 – 194 GeV
  - H to ZZ to ll vv excludes mH from 340 – 375 GeV
- Pushing the sensitivity towards lower mass higgs requires innovation and luminosity.
- Pushing the sensitivity towards higher mass higgs requires mostly luminosity.