Higgs → WW and ZZ
and projected exclusion limits on the SM Higgs boson cross sections

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for CMS collaboration

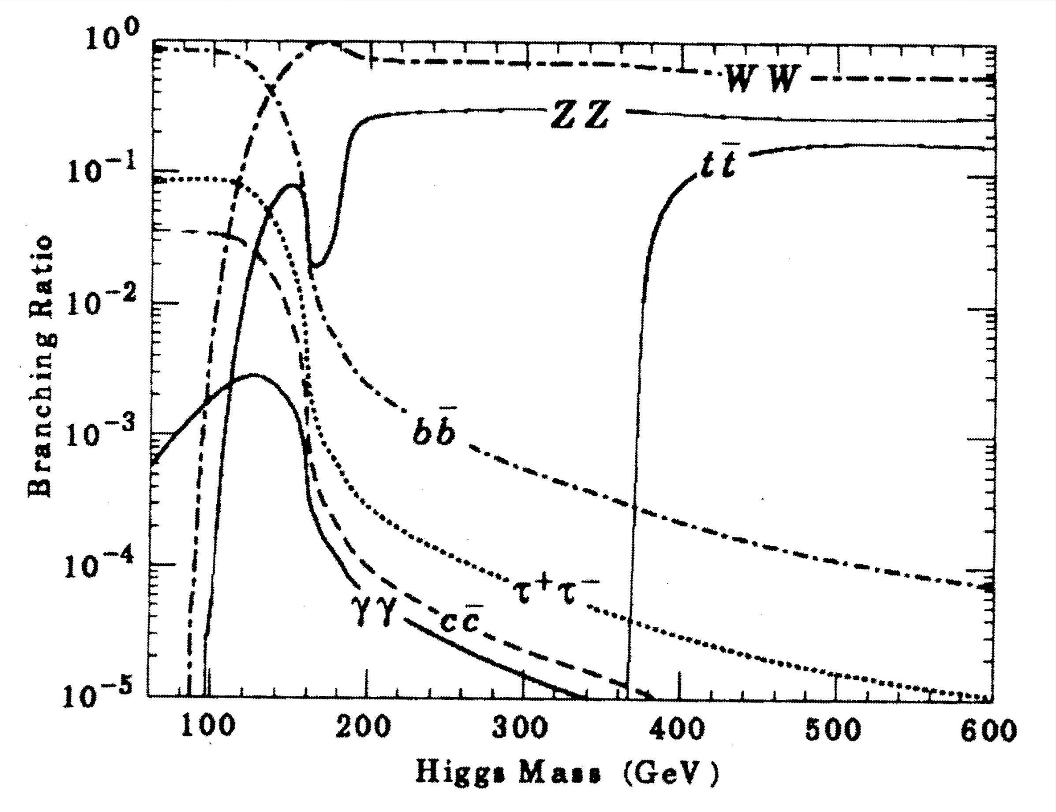
With thanks to the collaboration for results of combined efforts presented here, and to DPF'09 organizers for giving the opportunity to make the following presentation

Talk summary

- Most recent results from CMS cover analyses with 1fb-1 of integrated luminosity with 14TeV in the center of mass energy. Plus projection for 10TeV and ~200pb-1 of integrated luminosity
  - $H \rightarrow WW$: CMS PAS HIG 08/006
  - $H \rightarrow ZZ$: CMS PAS HIG 08/003
  - VBF $H \rightarrow \tau\tau$: also updated, contributing (CMS PAS HIG 08/001,008)
  - $H \rightarrow \gamma\gamma$: contributing for low Higgs mass searches
    - Latest public update: **CMS PTDR v.2**
- $H \rightarrow WW$ and $H \rightarrow ZZ$ are **leading analyses** covering most of the possible SM Higgs mass-range for 95% CL exclusion
  - **95% CL with 1fb^{-1} for 140-230 GeV** m(Higgs) at CMS
  - Mass interval shrinks to about **150-190GeV for 10 TeV**
  - Just starting to get into exclusions with 200pb-1 per experiment at 10TeV – latest official "promise" from the LHC side

Why H → WW and H → ZZ?

- Large branching ratio in wide mass range
  - Enough expected events to set limits
- Signature is clean (ZZ) or relatively clean (WW)
  - Easier to deal with backgrounds
- **WW is the best** to set limits



Why WW is so good?

- To set limits – we need events. Event counts for 1fb-1, 14 TeV:

H→WW , BR(WW→lvlv) = 0.1 x 0.1 x4

M(H)	σ_{gg}	BR(H→WW)	σ_{gg}xBR	N_{evts} (L=1 fb^{-1})	N_{gg}+VBF
130	31.7	0.28	0.355	355	395
160	21.9	0.90	0.788	788	898
200	14.8	0.73	0.432	432	502
500	3.8	0.54	0.082	82	94

H→ZZ , BR(ZZ→llll) = 0.004

M(H)	σ_{gg}	BR(H→ZZ)	σ_{gg}xBR	N_{evts} (L=1 fb^{-1})	N_{gg}+VBF
130	31.7	0.039	0.0055	5.5	6
160	21.9	0.043	0.004	4	4.5
200	14.8	0.26	0.0154	15	16
500	3.8	0.26	0.004	4	4.5

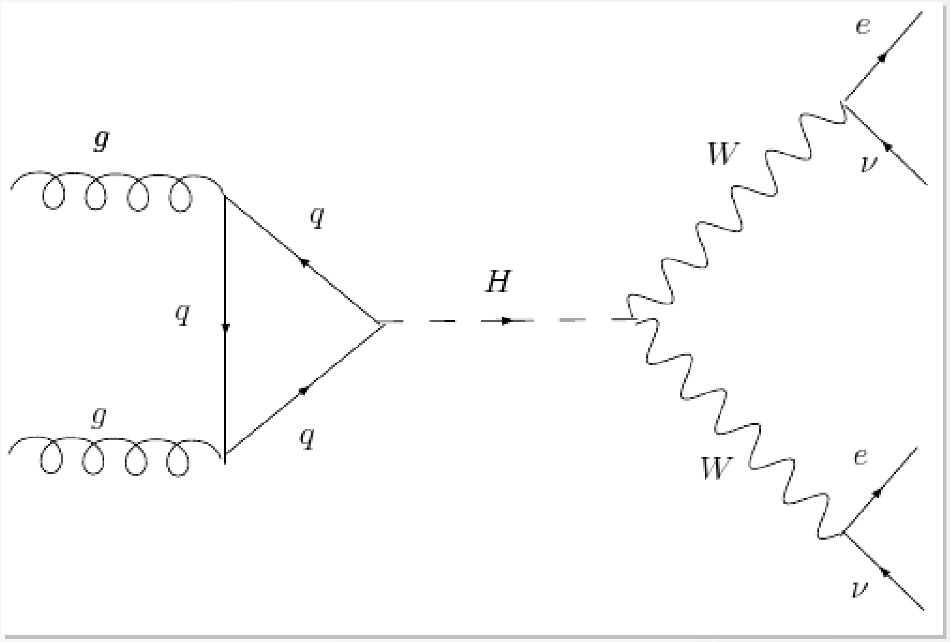
H→$\gamma\gamma$

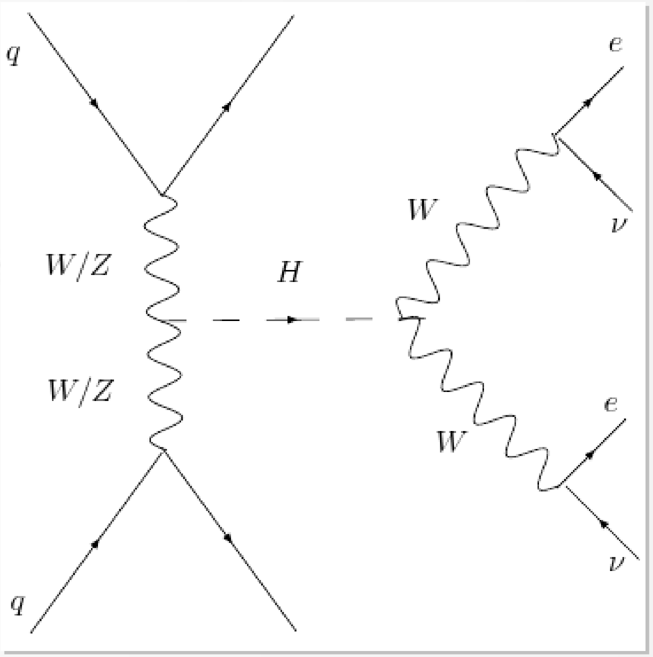
M(H)	σ_{gg}	BR(H→$\gamma\gamma$)	σ_{gg}xBR	N_{evts} (L=1 fb^{-1})
130	31.7	0.22	0.070	70
150	21.9	0.14	0.034	34
160	14.8	0.05	0.011	11

- H → WW covers relatively small interval in terms of discovery potential
  - H → ZZ is “cleaner”, has a narrow peak, and systematic uncertainties which have next to negligible effect
  - Similarly for H → γγ for small masses
- ...but H → WW is leading in setting limits and combined with VBF and final states with W → jets is even more powerful

H → WW

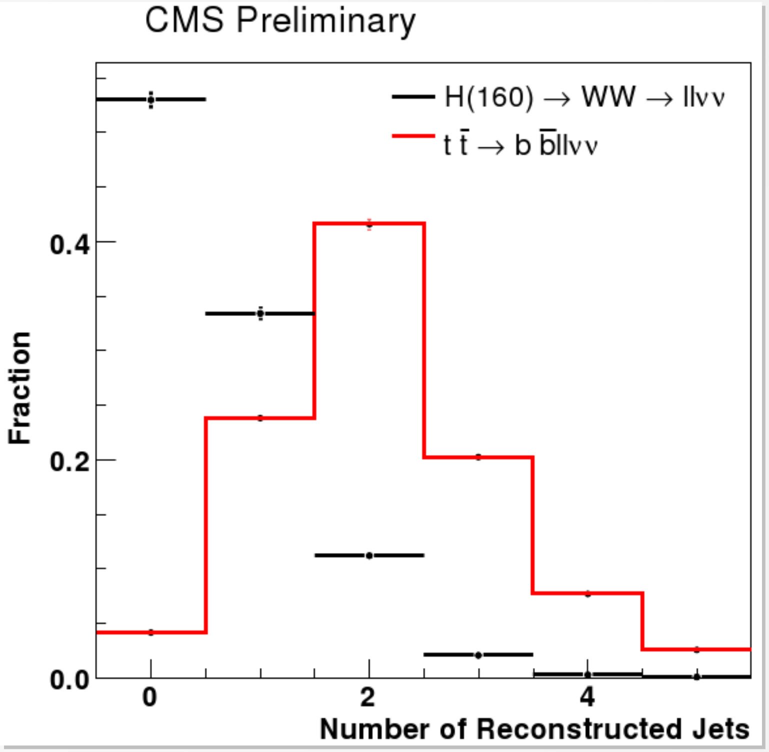
- Production: H → WW → lνl'ν'
  - Final states considered are with l=e,mu. ll' = 2e, 2mu, e+mu
- Signature:
  - 2 isolated high PT leptons
  - With small opening angle
  - Significant missing ET
  - With no hard jets in the central part of the CMS detector
- Dominant SM backgrounds
  - Continuum WW and tt production
  - Many other backgrounds were also considered





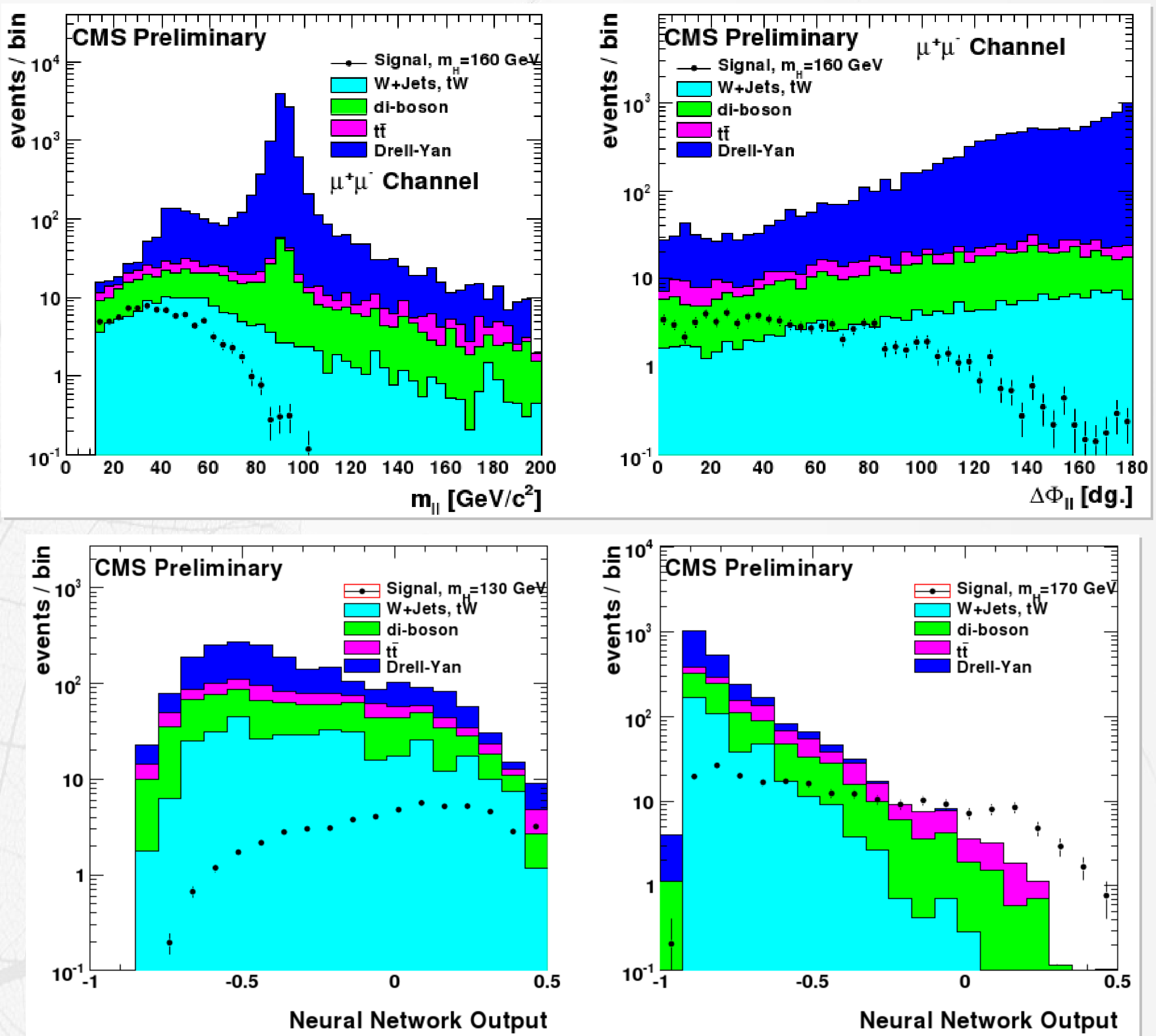
H → WW: selection

- Event selection
  - Event with two well reconstructed isolated leptons selected
    - PT>20,10
    - Also adding impact parameter constraint
    - If more than two such leptons → rejecting (against WZ, ZZ)
  - Electron-ID cuts applied to reduce W+jets contamination
  - Single lepton triggers used (~90%)
    - Only marginal gain from double lepton triggers
  - If jet, ET>15, |η|<2.5 → reject (tt)
  - Missing ET > 30 GeV
  - m(ll')>12 – to reject bb



- PLUS (for optimization):
- Opening angle (small for leptons from WW from scalar H): against WW continuum
- Upper cut on m(l+l-): against Z
- MET (upper and lower bound)
- PT of both leptons
- Even more cuts used for NN input

H → WW: distributions



H → WW: tt and WW backgrounds control

- Tt
  - Control sample: same selection of events only 2 jets in the central region required. Final uncertainty ~ 18%

Final state	$t\bar{t}$	WW	Other background
$\mu\mu$	1090	14	82
ee	680	10	50
$e\mu$	2270	40	125

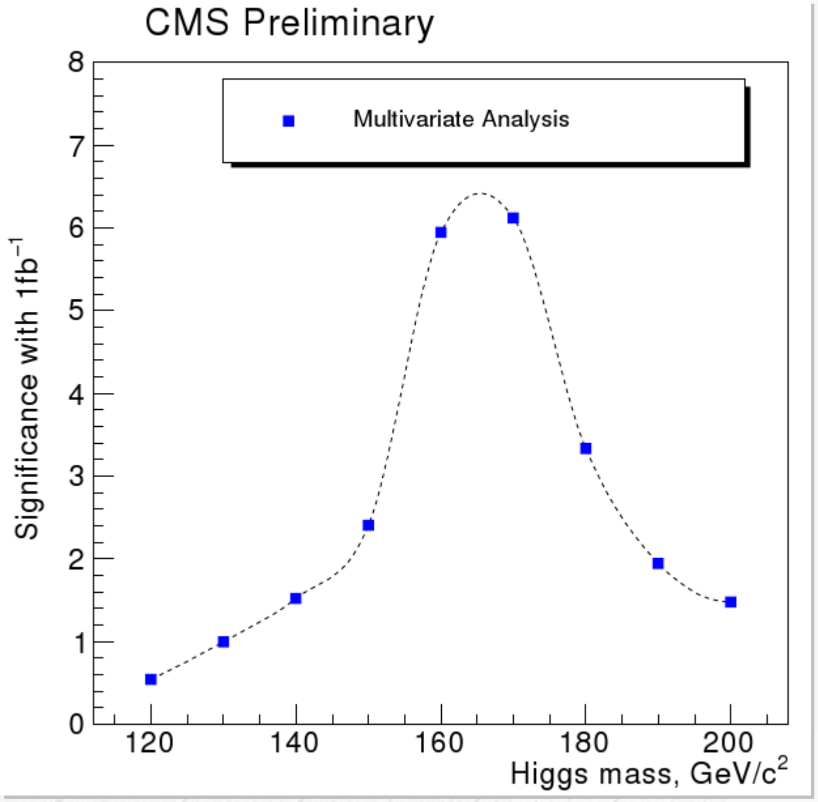
- WW
  - Control sample: same selection plus m(ll') > 115 GeV (to avoid signal contamination). Other backgrounds contribute much too, largest by far is tt. Assuming overall backgrounds uncertainty in the region 15% → one will have ~22% uncertainty on WW estimation.
- Special care taken to control fake leptons rate from data (against W+jets)
  - Measuring jet probability to be mis-identified as lepton
  - Multi-jet events (QCD) are plentiful and allow to make the measurement
- Uncertainties also used for DY (5%) and for di-boson (10%)

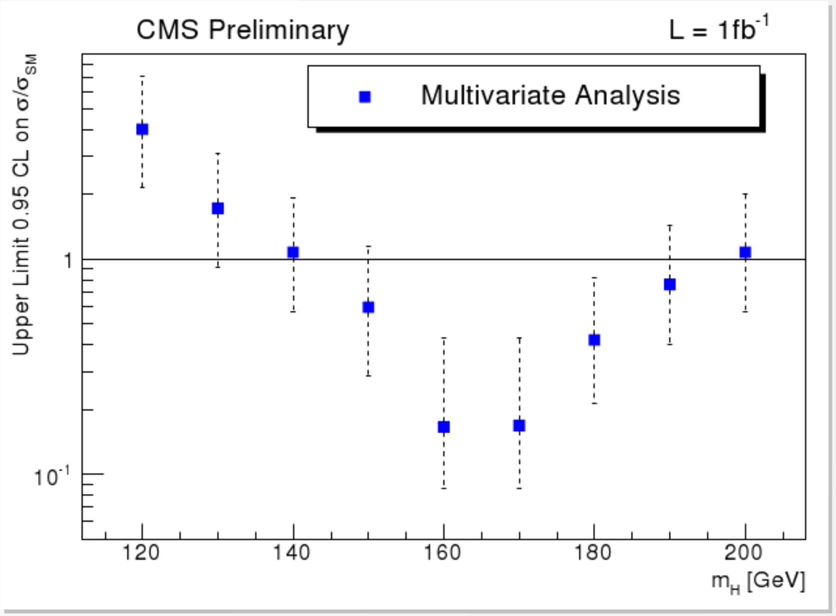
H → WW: systematics

- Luminosity:
  - ~20% (LHC input), ~5% from CMS luminosity monitors for 1fb-1
- Lepton ID and trigger efficiencies:
  - ~ few % - using tag-and-probe, Z events.
- Missing ET:
  - ~5%, effect of MET uncertainty on analysis is relatively small
- Jet reco-efficiency and JES:
  - ~10% overall
- Monte Carlo statistics:
  - 5% for signal, 10% for background
- Also considered:
  - PDF uncertainties and NLO corrections
  - Mis-alignment and mis-calibration scenarios

Source	Signal (%)	Background (%)
Luminosity	5	5
Lepton & trigger efficiencies	4	4
Muon miscalibration and misalignment	2	2
Electron miscalibration and misalignment	4	4
E_T^{miss} modeling	1	2
Jet reconstruction	3	8
PDF uncertainties	5	5
$t\bar{t}$ cross-section	—	18
WW cross-section	—	22
WZ/ZZ/Wt cross-sections	—	10
DY cross-section	—	5
W+jets cross-sections (fakes)	—	100
MC statistics	5	10

H → WW: results

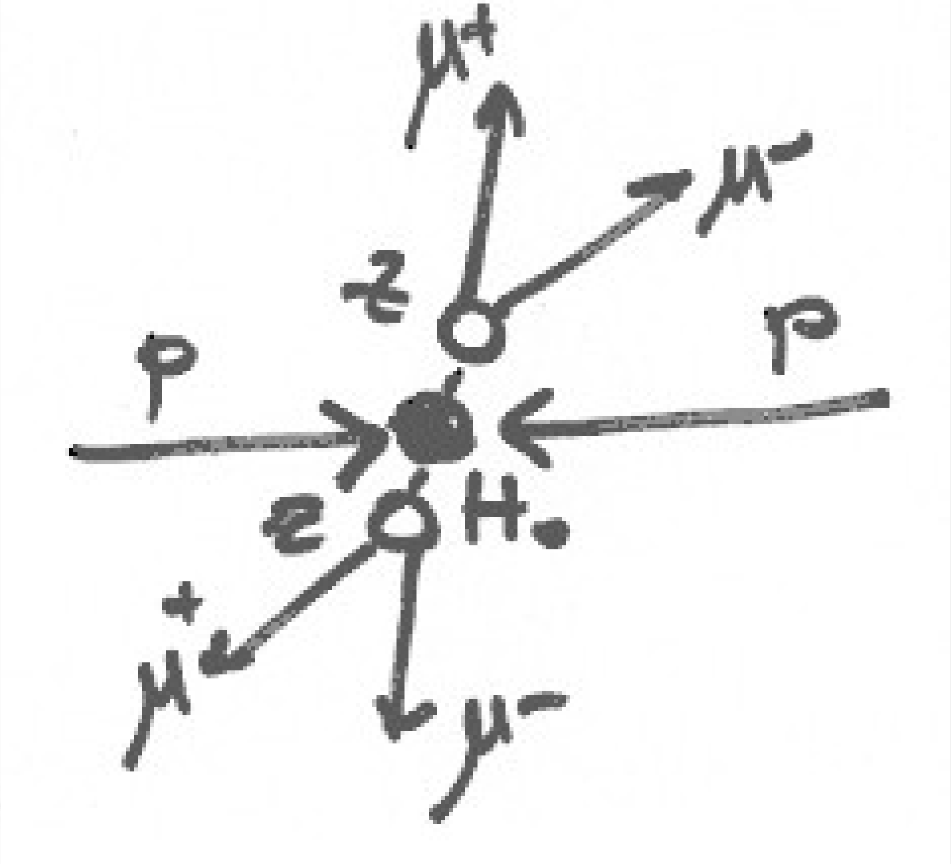




- NN analysis results: discovery potential
  - 1fb-1
  - 14 TeV
- Ditto: 95% CL
  - 1fb-1
  - 14 TeV

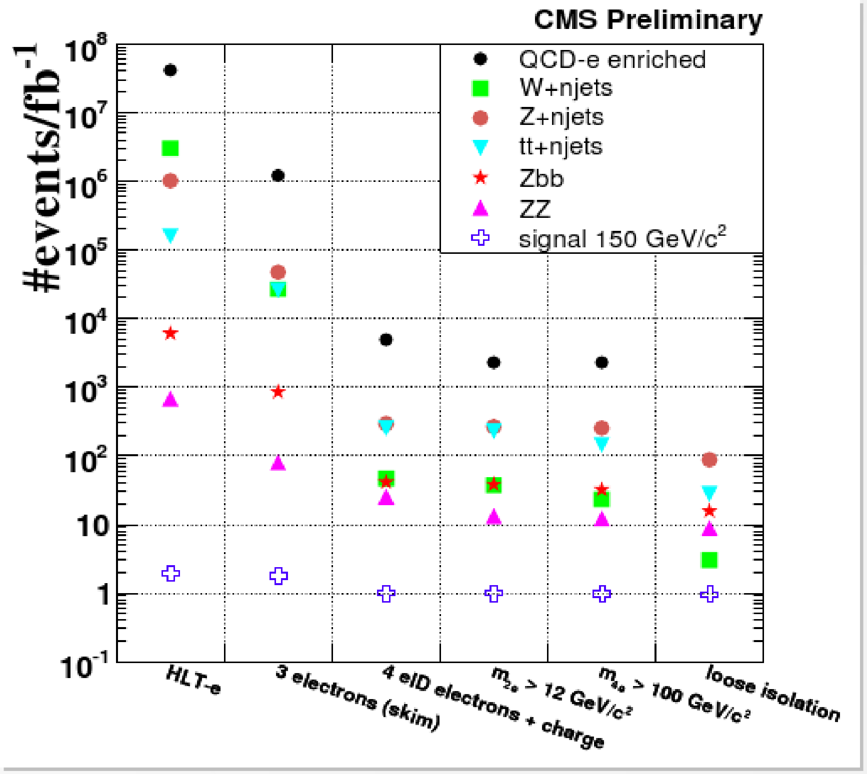
H → ZZ

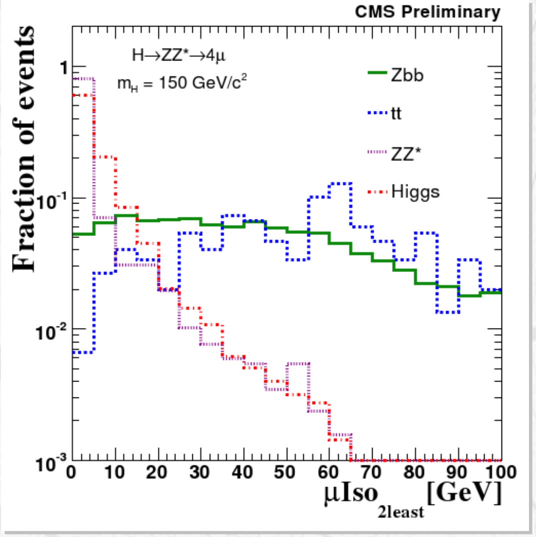
- Production:
  - H → ZZ → 4l, l=e,mu
  - Final states: 4e, 2e2mu, 4mu
    - Other channels (Z->neutrinos, jets) are under consideration too
- Signature:
  - 4 high PT isolated leptons
  - ...from the same vertex
  - Narrow m(4l) peak
- Dominant SM backgrounds:
  - ZZ (irreducible)
  - Tt, Zbb
- Emphasis of most recent analysis
  - Robust, mass independent analysis for early data
    - See also PTDR for more sophisticated approaches
  - Calibration & control of variables/backgrounds from data

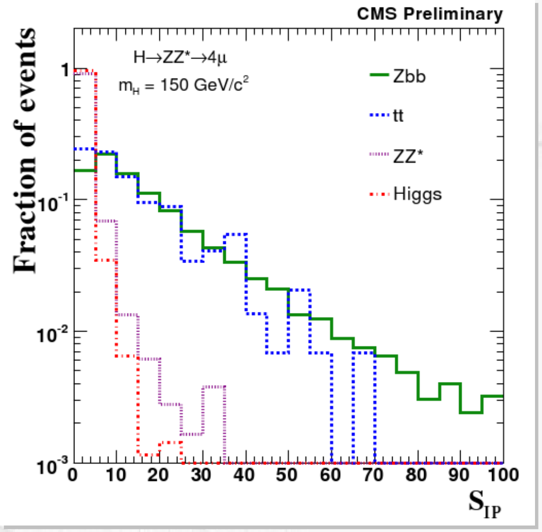


H → ZZ: selection

- Event selection
  - PT>10,5,5 (skim: against QCD)
  - Single/di-lepton triggers used (100%)
  - Event with two pairs of well reconstructed isolated leptons selected
  - Two m(l+l-)>12GeV to fight multi-jet events (QCD, W/Z+jets, tt, Zbb)
  - m(4l) > 100 GeV (not excluded region)
  - Loose track-based isolation (~99% signal)

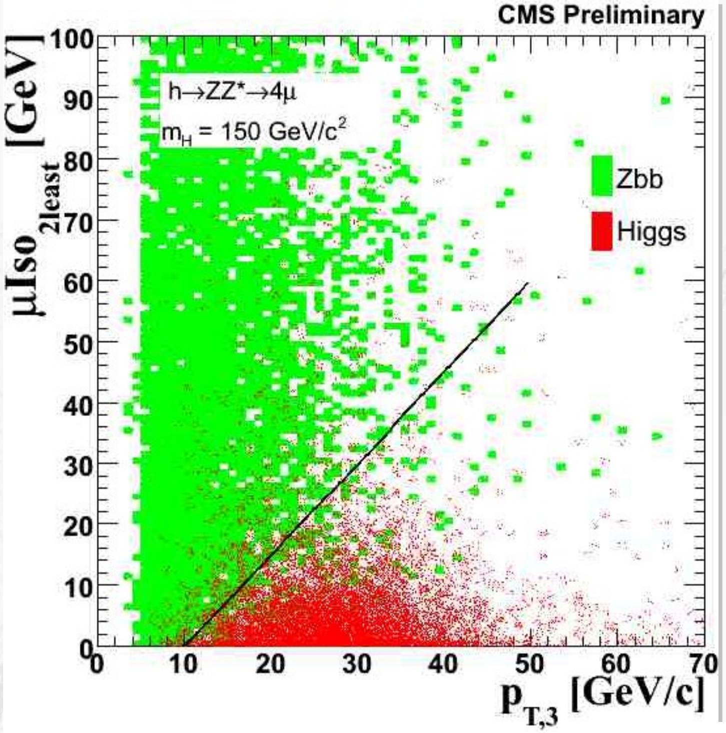






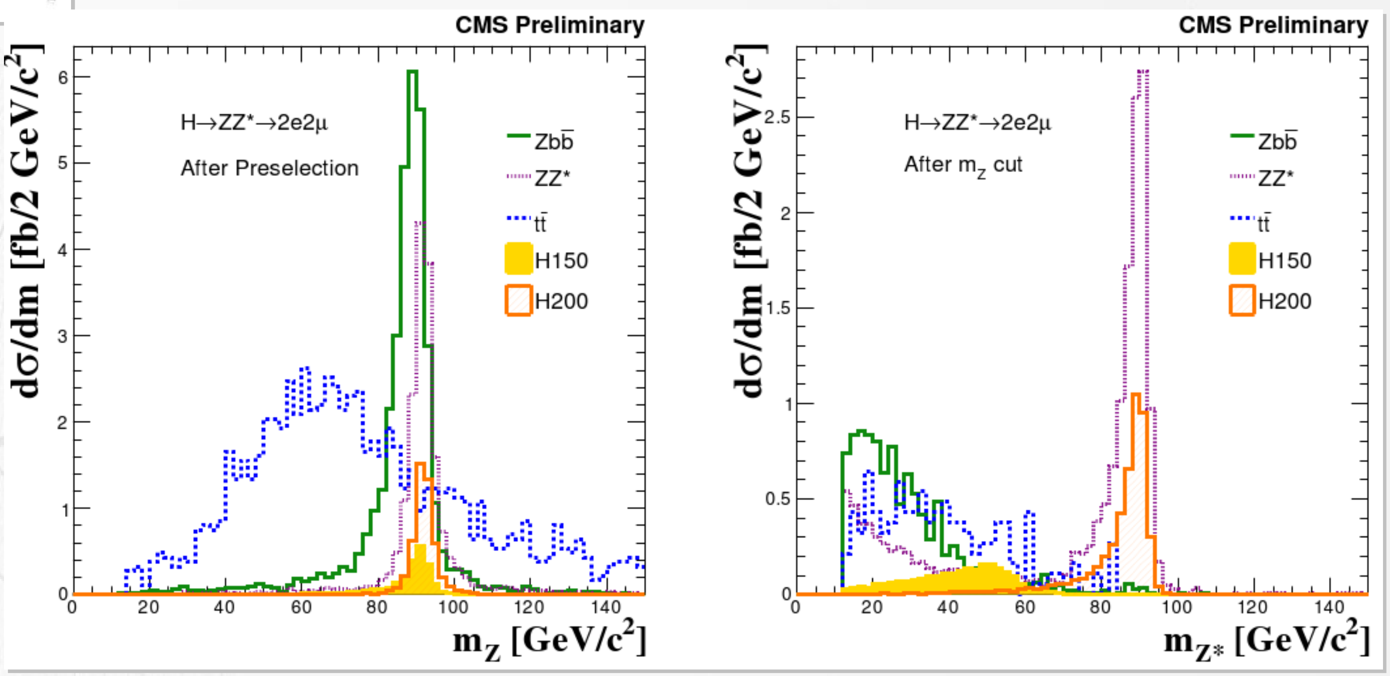
- PLUS (for optimization):
- Isolation for all 4 leptons
- Impact parameter
- m(4l), m(l+l-), m(l'+l'-)
- PT of leptons

H → ZZ: distributions



2D: isolation vs. PT of the next to smallest PT lepton → profit from differences between softer, non-isolated leptons of Zbb (& tt) vs. Higgs ones

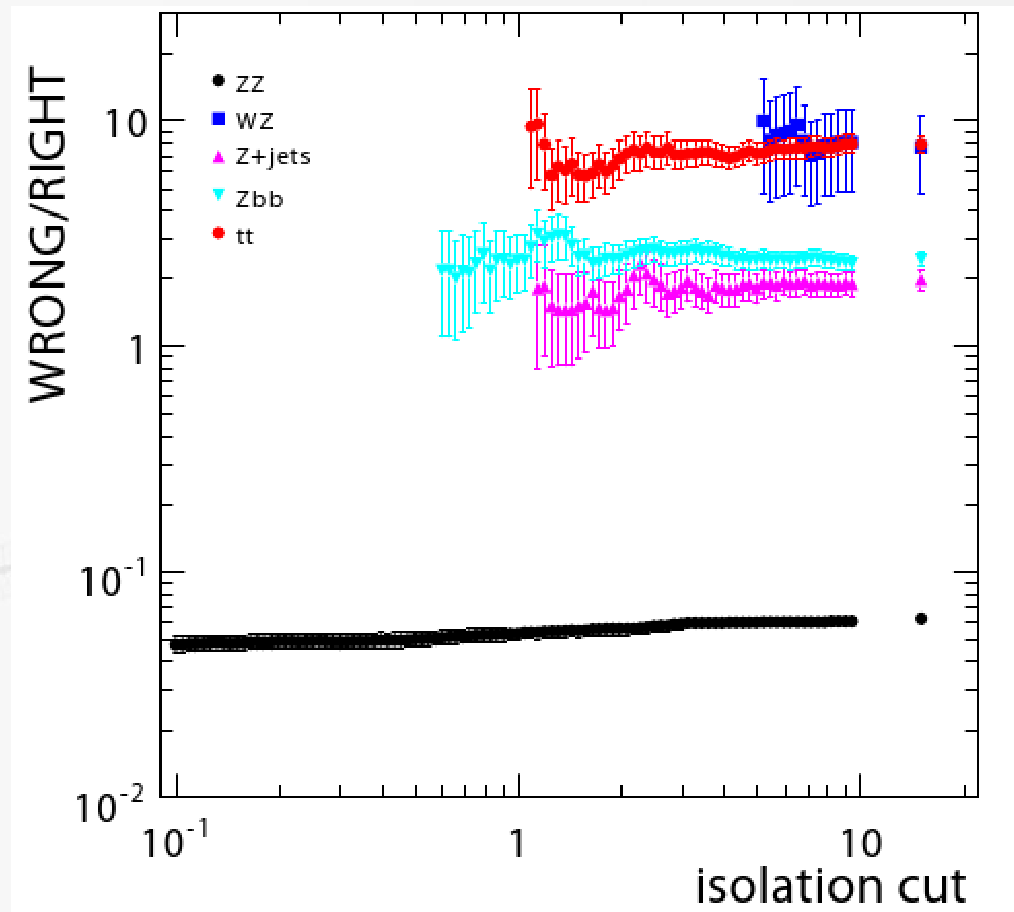
m(l+l-) cuts, both pairs:
- mZ: all but ZZ, Zbb
- mZ*: against all, but ZZ



H → ZZ: backgrounds control

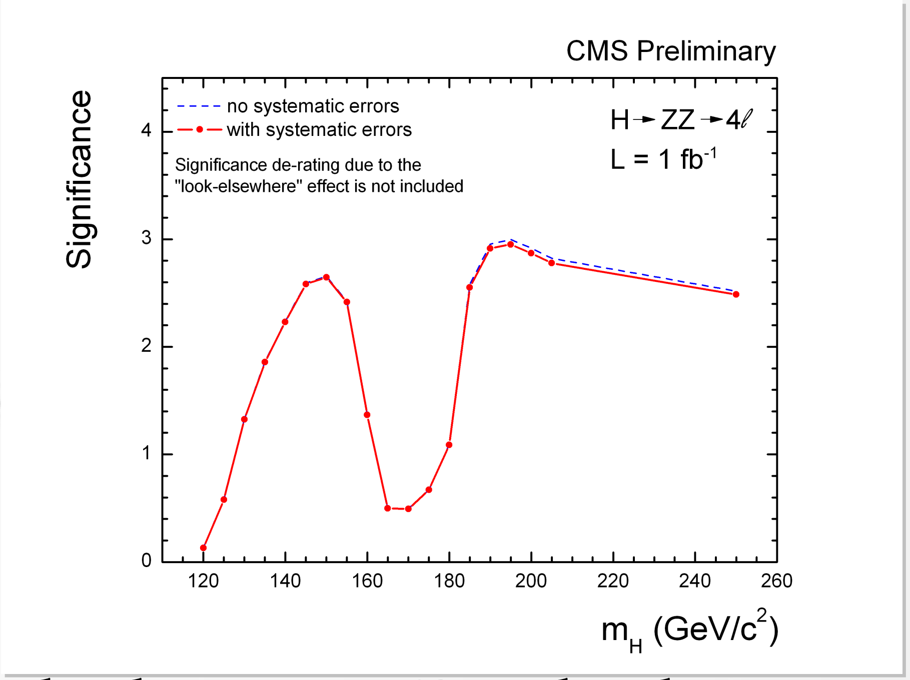
- Zbb: using Zbb-dominated control sample (2D plot, previous slide)
- ZZ: side bands AND/OR calibration vs. Z+jets
  - Dedicated effort to take into account s-channel & box diagram
  - Correct for dynamic kNLO vs. m(4l)
- Zbb, tt, Z/W+jets, QCD and other backgrounds: using number of WRONG/RIGHT combinations method

	m+ m+	m+ m-	m+ e+	m+ e-	m- m+	m- m-	m- e+	m- e-	e+ m+	e+ m-	e+ e+	e+ e-	e- m+	e- m-	e- e+	e- e-
m+ m+	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
m+ m-	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
m+ e+	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
m+ e-	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
m- m+	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
m- m-	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
m- e+	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
m- e-	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
e+ m+	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
e+ m-	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
e+ e+	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
e+ e-	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
e- m+	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
e- m-	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
e- e+	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
e- e-	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1



H → ZZ: systematics

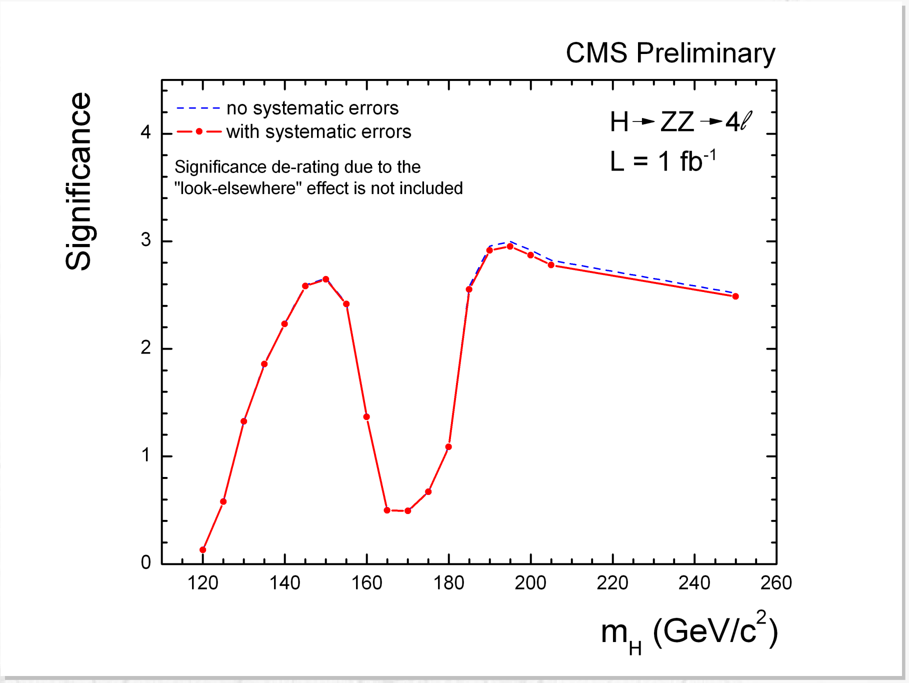
- Lepton trigger, reconstruction and identification efficiency:
  - ~6%
- Lepton isolation:
  - ~2%, dedicated effort: random cone, tag-and-probe techniques
- Mis-calibration. Mis-alignment:
  - ~2% - small effect: stability of m(4l) resolution
- Projecting of ZZ from Z+jets:
  - ~3% from PDF uncertainties
- Zbb normalization
  - ~15%
- Luminosity
  - ~5%



- Total: 21% for low masses and ~8% for high masses. Results dominated by statistical uncertainty.

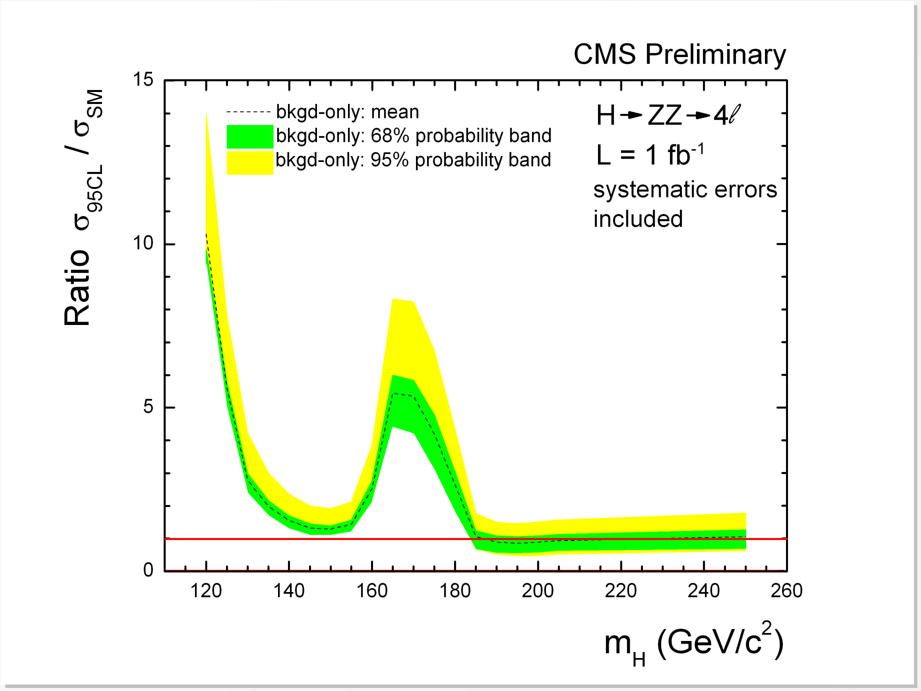
H → ZZ: results

- Doesn't depend on systematics



- NOTE: Look elsewhere effect is not taken into account in the above plot. Including LEE basically eliminates any possibility for Higgs discovery in H → ZZ with ~1fb-1

- Uncertainty is statistical



- NOTE: this channel alone is barely enough to touch 95% CL line for masses ~200GeV and that is with 1fb-1 and 14TeV

VBF $H \rightarrow \tau\tau$

- The analysis was recently updated at CMS
  - With dedicated analysis on tau-identification
  - See detailed talk during today's Higgs III session

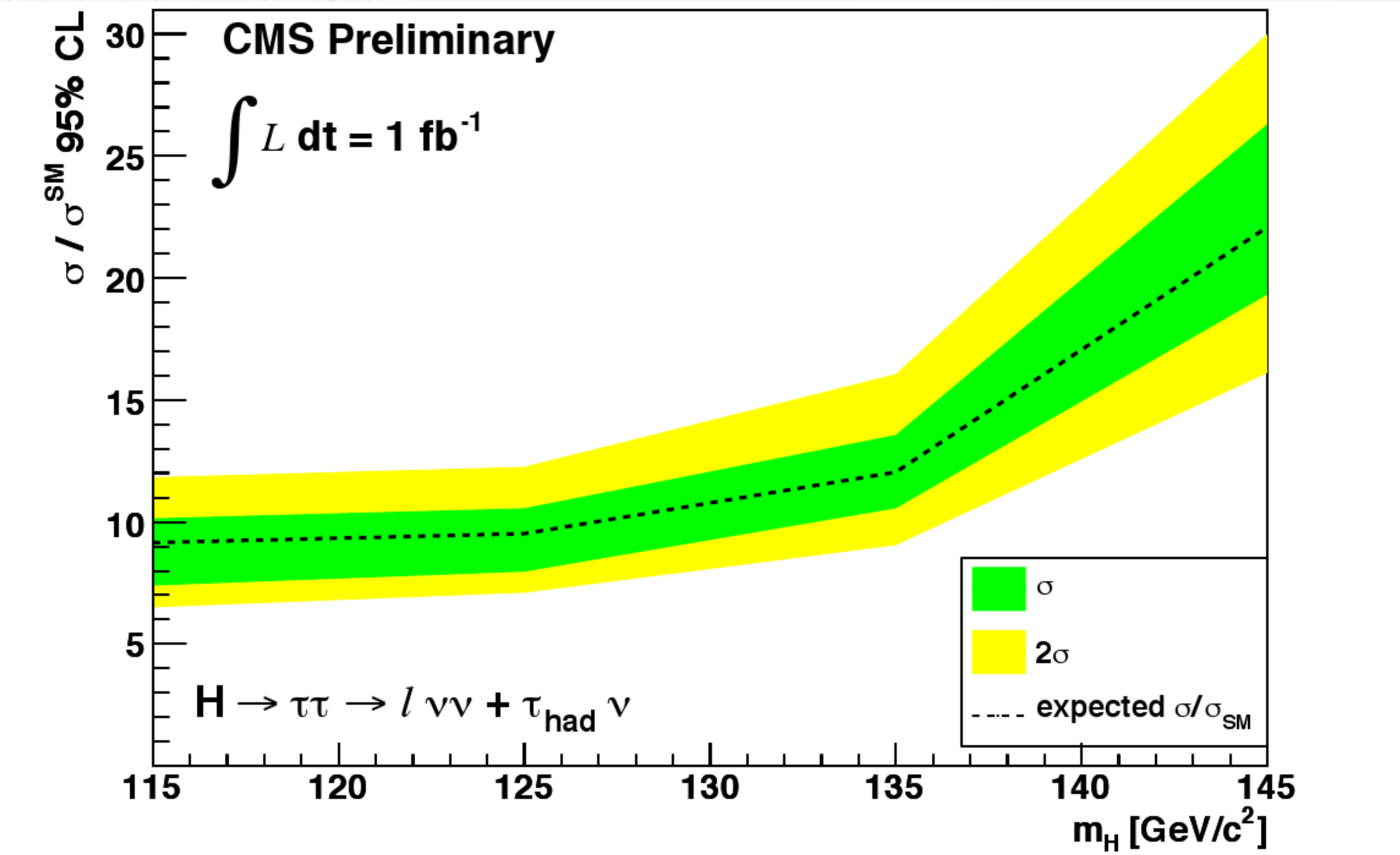
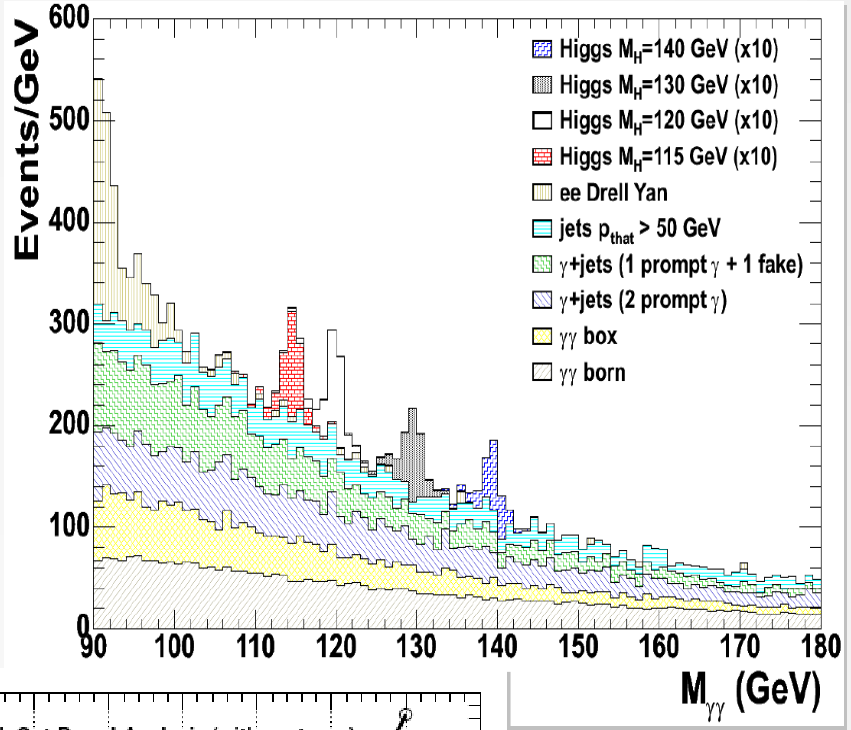
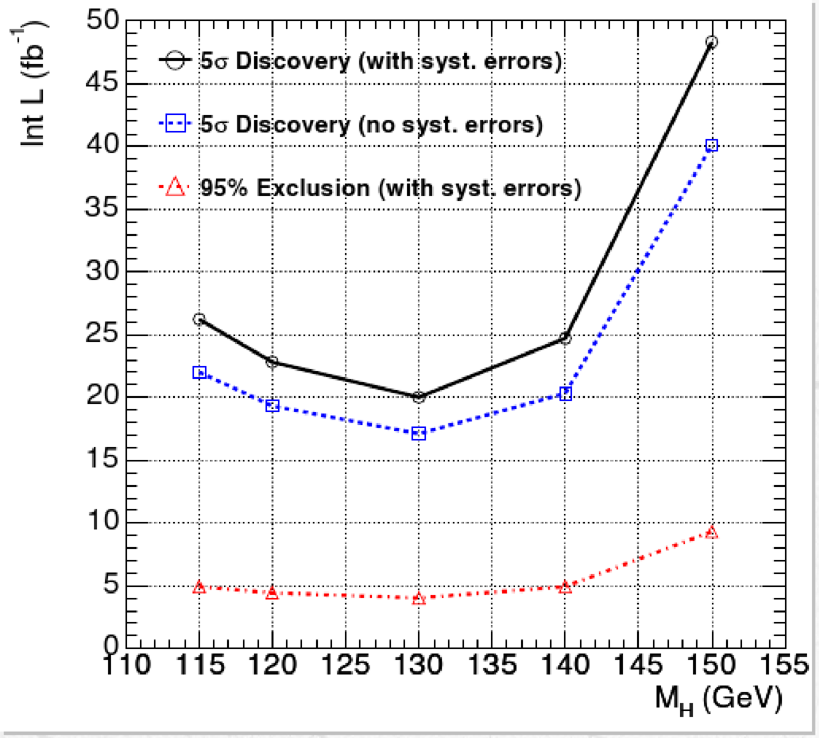


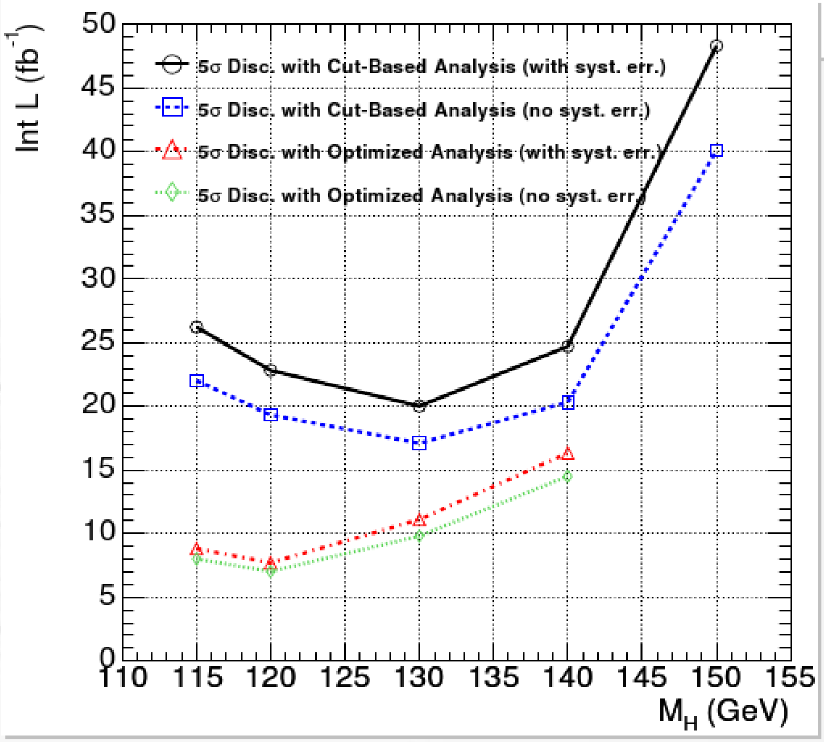
Figure 4: The 95% CL limit on the cross section times the branching ratio expected for 1 fb^{-1} as a function of the Higgs boson mass with systematics taken into account. The 1 σ and 2 σ bands originated from the statistical fluctuation of the number of background events are also shown.

$H \to \gamma\gamma$

- Latest public results available are from CMS PTDR v.2 and produced for 30 fb-1
  - Since it's a large statistics channel – a simple-minded 1/sqrt(30) to get an estimation for 1fb-1 would work reasonably well
  - We want to mention it as it's complementary-to-leading for low masses

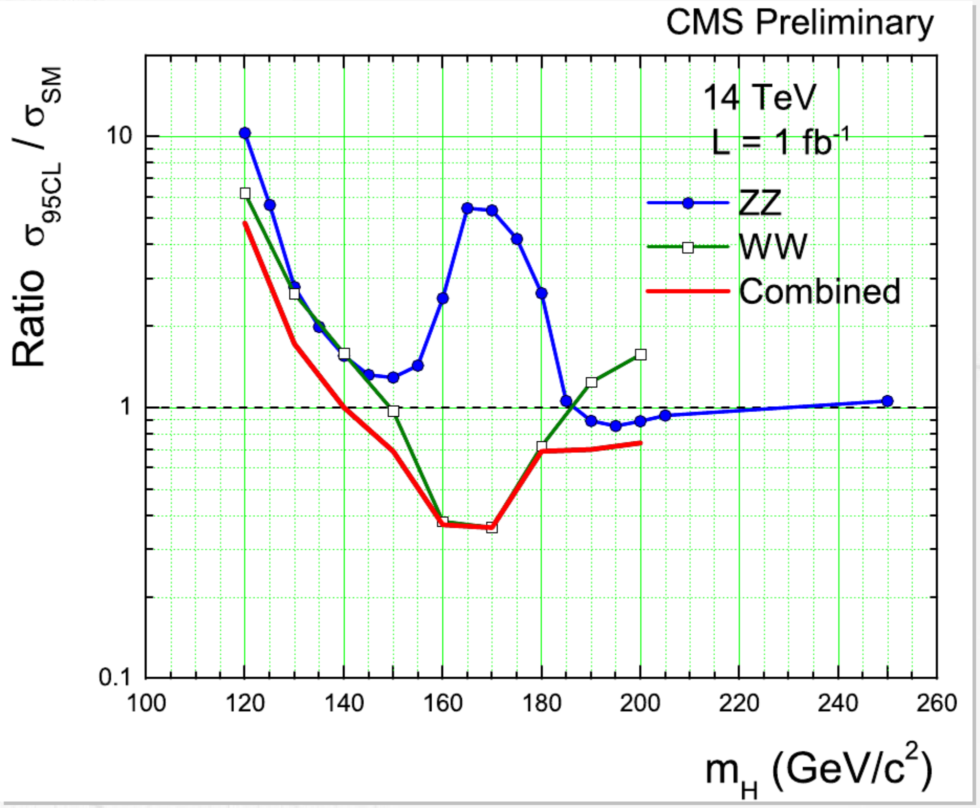






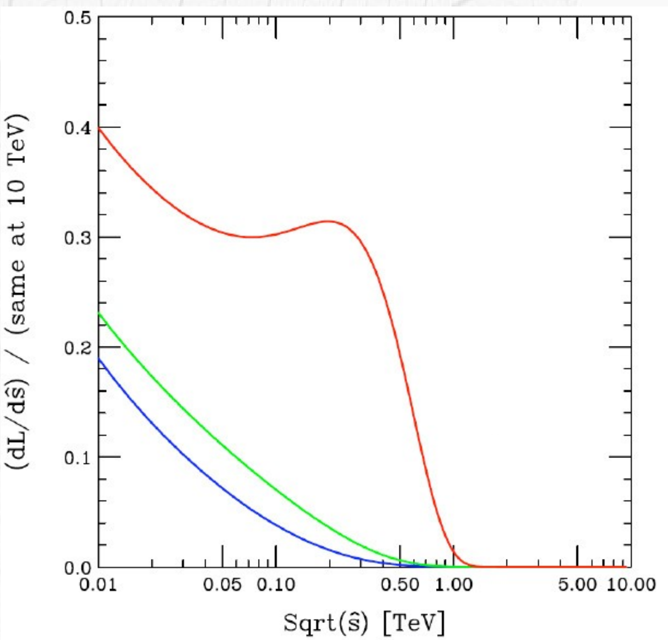
HZZ and HWW combination

- 14 TeV, 1fb-1
- Statistical tools
  - We use Bayesian and modified frequentist (CLs) approaches
  - In both cases we use approximations to do a quick estimation for now
    - For example assuming 100% correlations between systematic uncertainties (for Bayesian), flat prior for Higgs, etc.

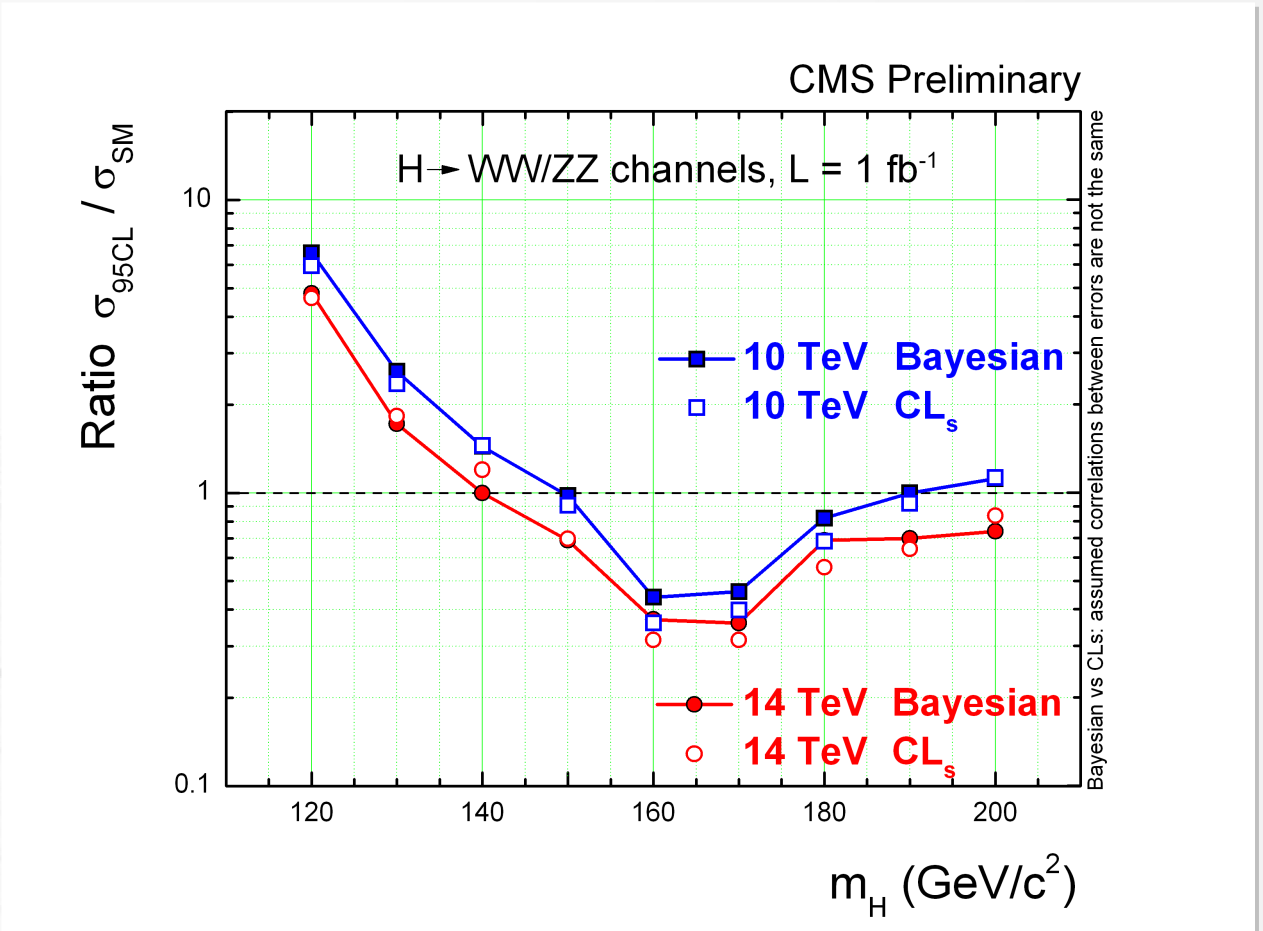


10TeV?

- At Chamonix'09 workshop on LHC it was decided to start with 10TeV
  - Cross sections go down with decreased energy. And for signal they go down faster (gluon fusion) then for backgrounds (qq in initial state).



From Joey Huston's talk (for CTEQ collaboration) at CMS Higgs PAG meeting from March 27



Summary

- Combination of only leading channels (HWW + HZZ) should allow CMS to exclude with 95% CL Higgs in the region of masses 140..230 GeV
  - For 1fb-1, for 14 TeV
- We also show that going from 14 TeV to 10 TeV would shrink the region of exclusion to 150..190 GeV for 1fb-1
  - Performance goes down with decreasing c.o.m. energy very fast
    - According to decisions of the Chamonix Feb'09 workshop (on LHC) we may expect 200pb-1 per experiment, which would allows us only to start to "scratch" the exclusion limit interval (around recently excluded by Tevatron experiments masses
- The whole story changes of course if Higgs production is more "exotic" than the SM proposes
  - Fermiofobic, SUSY, etc.
- Whatever the energy, luminosity, timing – we are eager to start with real data – there is a lot of work to do with "standard candles" anyway...