Search for the high mass Higgs with CMS

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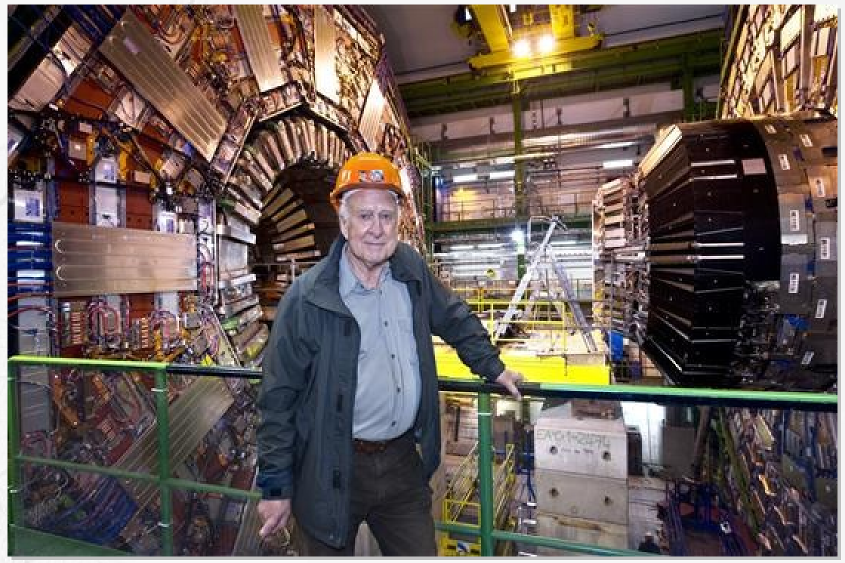
for CMS collaboration

With thanks to the collaboration for results of combined efforts presented here.
And to ASPEN'10 organizers for giving the opportunity to make the following presentation

- We kind of seen Higgs at CMS already:

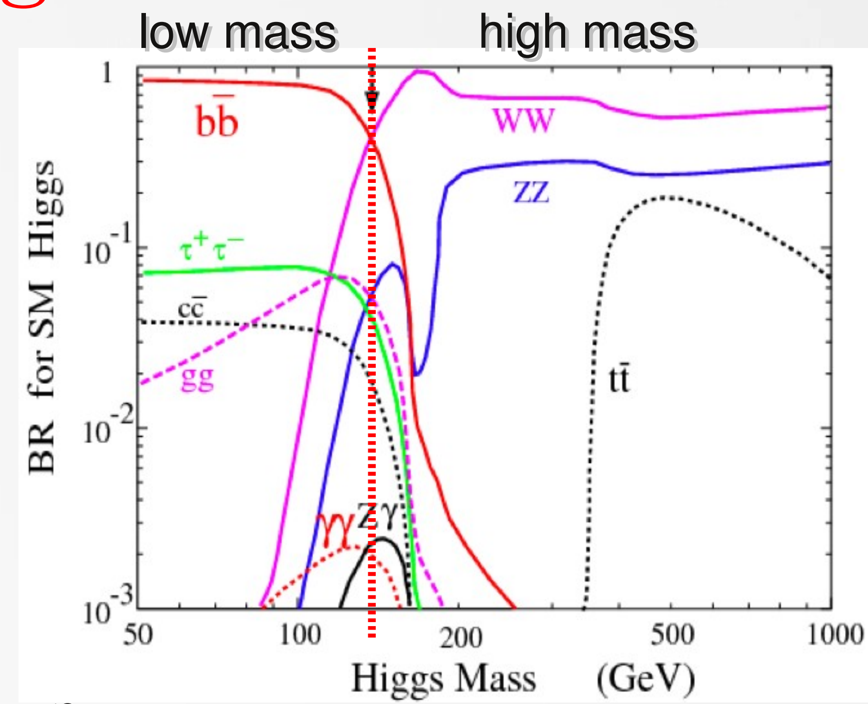


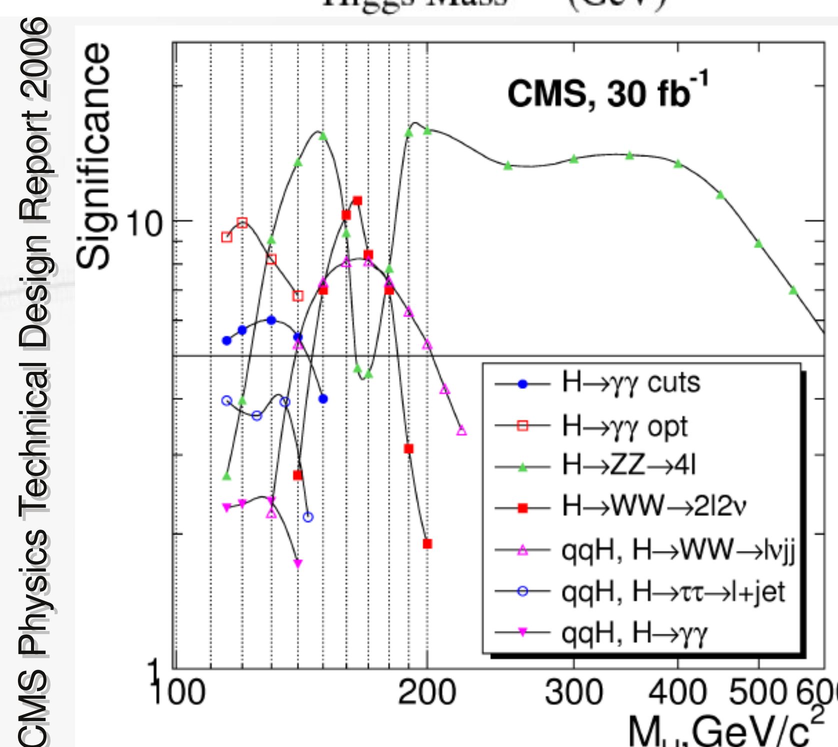
  - ...earlier we excluded the possibility that Higgs mass is less than 114
    - He himself says that with Tevatron's t-quark mass measurements, most likely Higgs mass is about 117
    - We will see about that...

Let's come back now to the Higgs boson, and scenarios where it has (relatively) high mass

High mass SM Higgs at CMS

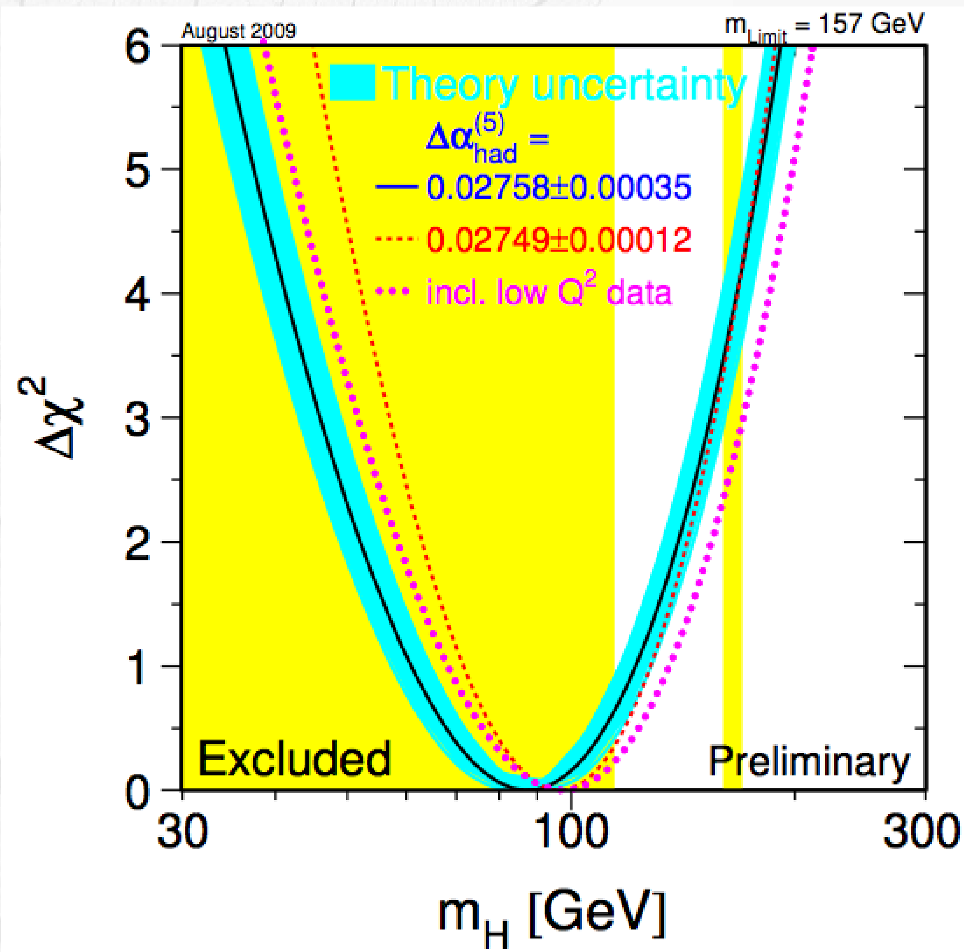
- By high mass Higgs we mean
  - H → WW, H → ZZ (m>130 GeV or so)
    - These are channels which take over from the low Higgs mass dominant channels like bb, 2gamma
- HZZ and HWW are dominant
  - Large branching ratio in wide mass range (**HWW**)
    - Enough expected events to set limits – WW is the leading one to set limits.
  - Signature is clean in **HZZ**
    - This one is 'golden" for discovery for the wide range of possible masses
  - Production:
    - inclusive
    - VBF (~20%) – include for several important reasons we outline below

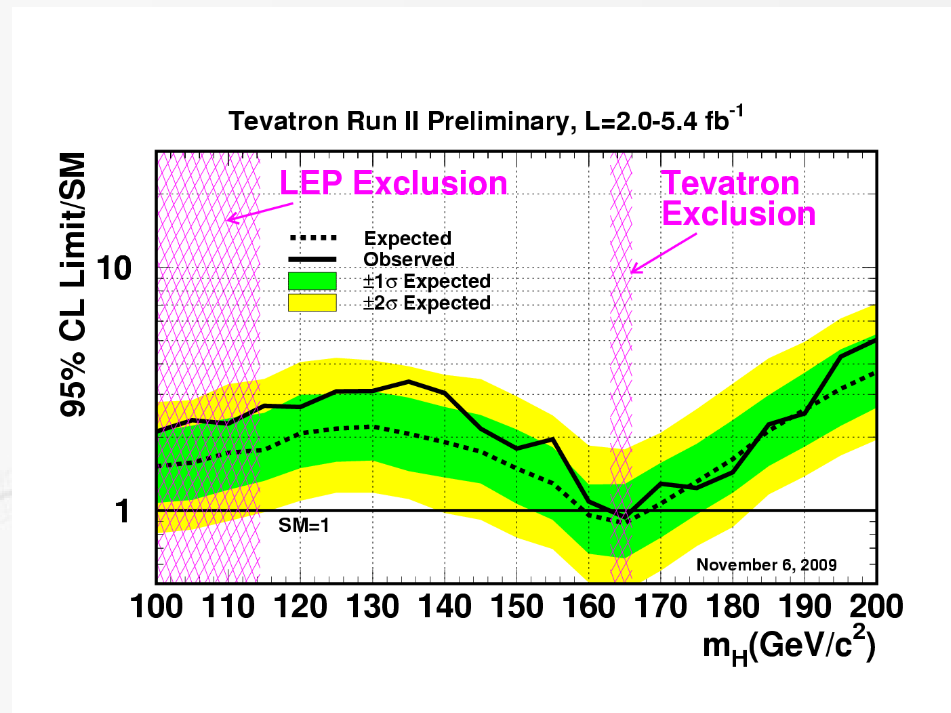




Context

- Theoretical constraints
- LEP limits
- EWK precision measurement constraints
- Tevatron limits: current and future (running experiments)

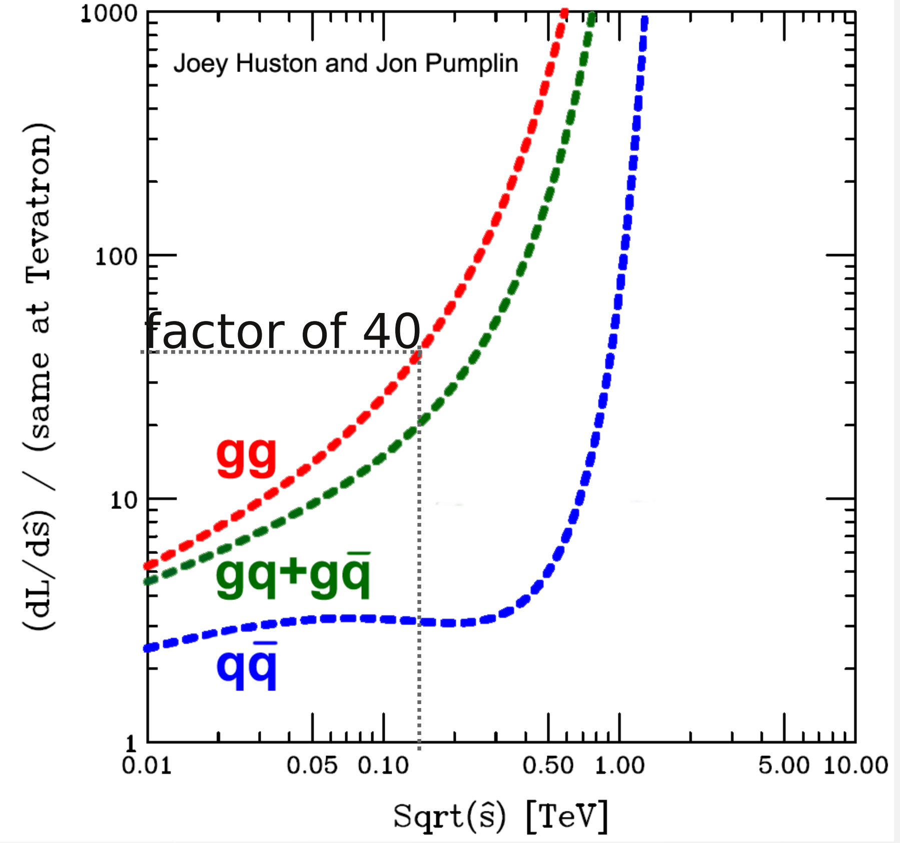




LHC potential with low luminosity

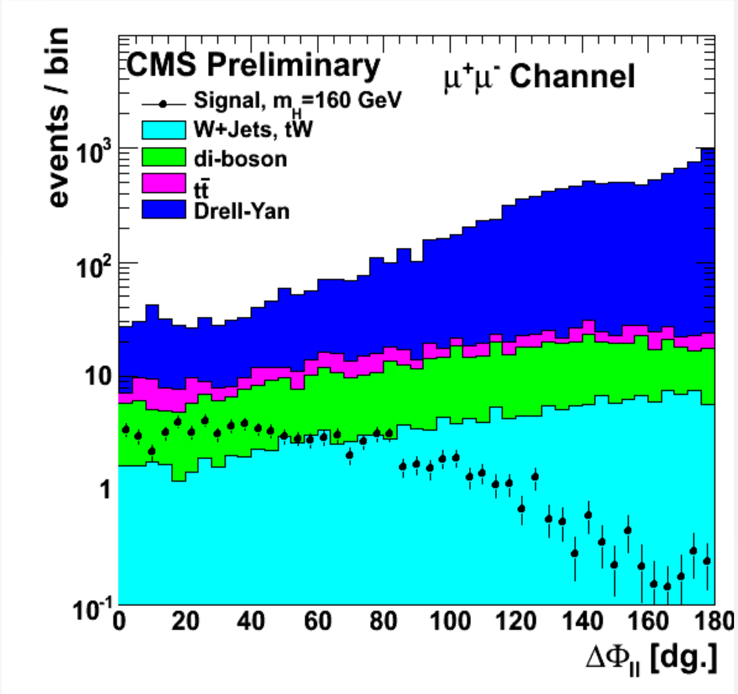
- Main question is – can we "compete" with Tevatron and/or contribute in a meaningful way?
  - Tevatron: ~8fb-1 per experiment, 2 TeV
  - LHC:
    - ~200 pb-1 per experiment, 10 TeV (Chamonix 2009)
    - ~500pb-1 per experiment, 7(?) TeV (current duscussions)
  - As one can see – we would need to gain a factor 40 to be compatible
    - Main factor is: larger cross sections
    - Roughly: we have factor 40 or more for m>150GeV
  - IMPORTANT NOTE:
    - For some channels (like HZZ and HWW) – signal is gg-dominated and main backgrounds are qq-dominated (ZZ and WW)
  - Acceptance, reconstruction efficiency and resolution are more or less similar

10 TeV LHC vs Tevatron



H → WW: analysis

- Production: H → WW → lνl'ν'
  - Final states considered are with l=e,mu. ll' = 2e, 2mu, e+mu
- Event selection
  - Event with two well reconstructed isolated leptons selected
    - PT>20,10
    - 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
  - Jet VETO: ET>30, |η|<2.5 → reject (tt)
  - Missing ET > 30 GeV (reject Z, QCD)
  - m(ll')>12 (to reject bb)

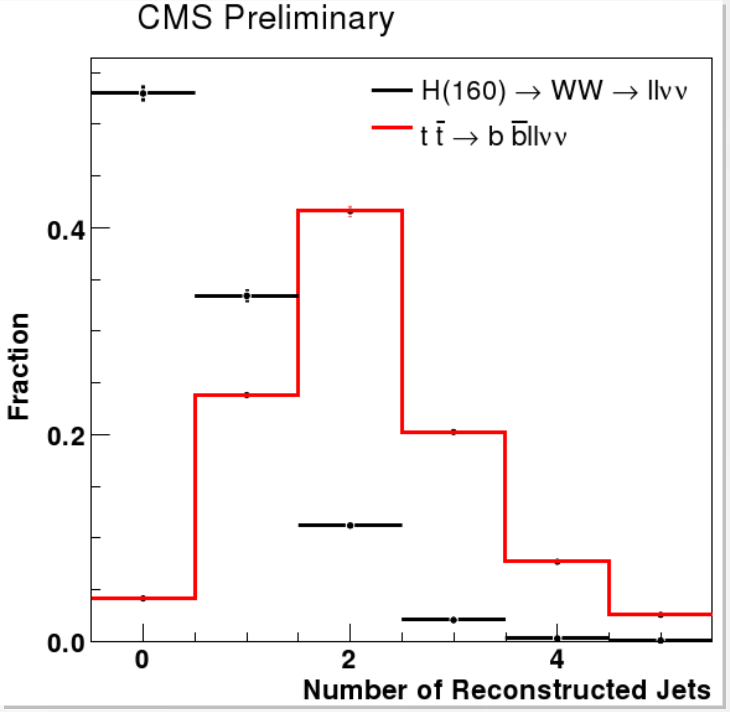


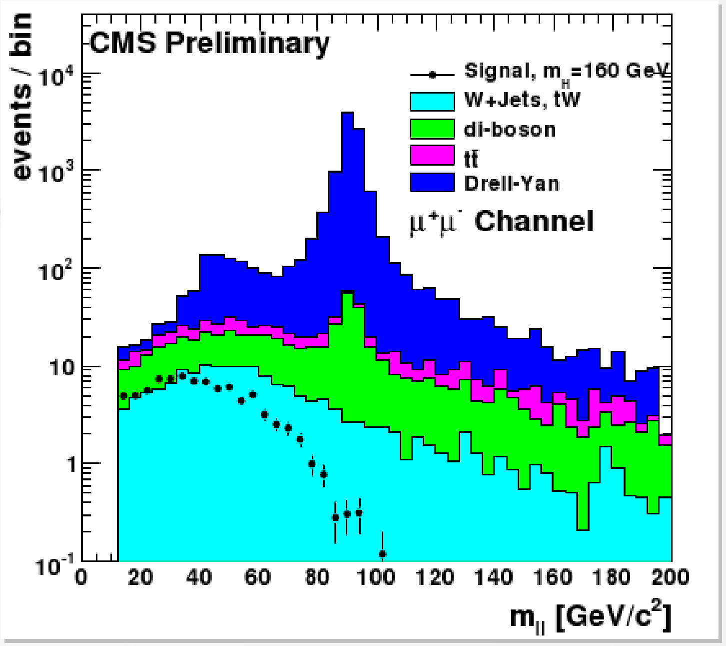
Used to dicriminate against WW (and DY)

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

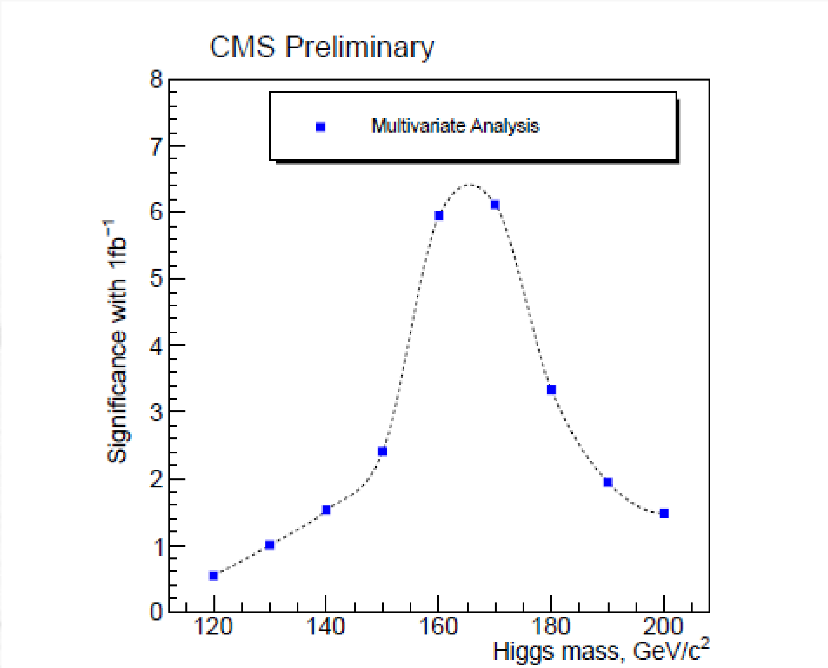
HWW: background control

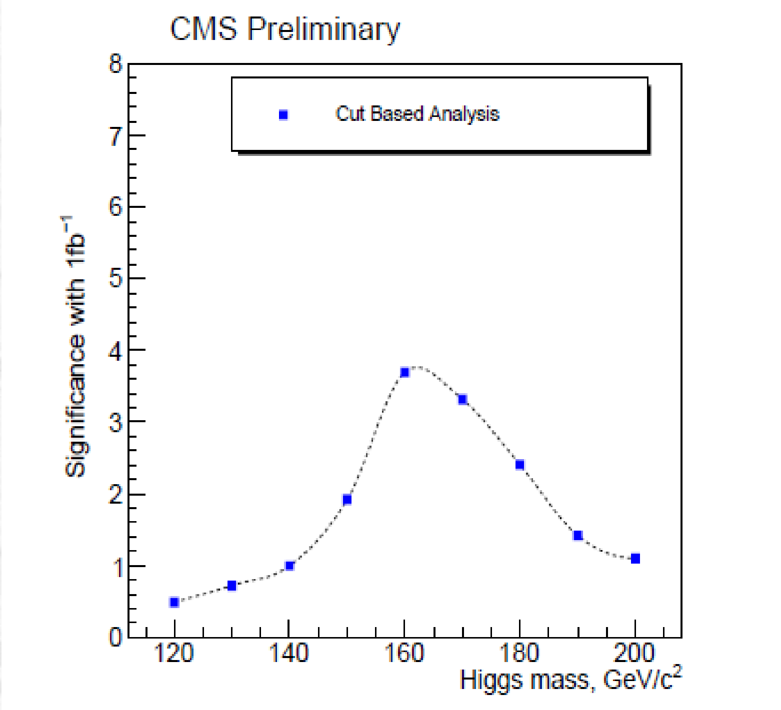
- Main backgrounds are WW, tt, W+jets, DY
  - This is for 0-jets channel (only public so far)
  - Pros for 1 or more jets in the final state
    - Factor of ~2 larger cross section w.r.t. LO
  - Cons:
    - Large tt contribution
- WW
  - Is controlled from small m(ll) region
- TT
  - Is controlled from n(Jets) >= 2
- IMPORTANT ISSUE:
    - We use NLO cross section and re-weighting PT of Higgs according to NLO spectrum. But signal yields/efficiencies we get are calculated for LO process, with no NLO, NNLO jets... So, factor ~2 we are "gaining" (w.r.t. LO) may be significantly smaller...



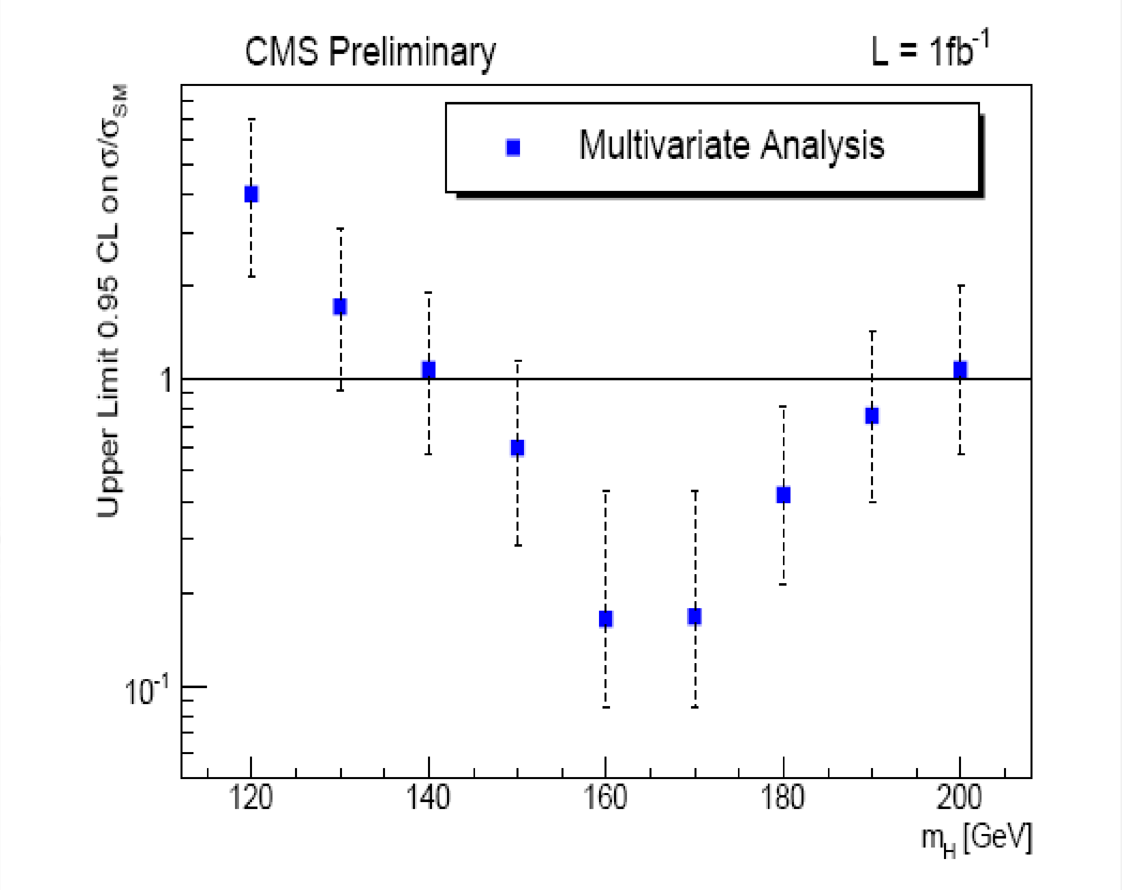


HWW: results





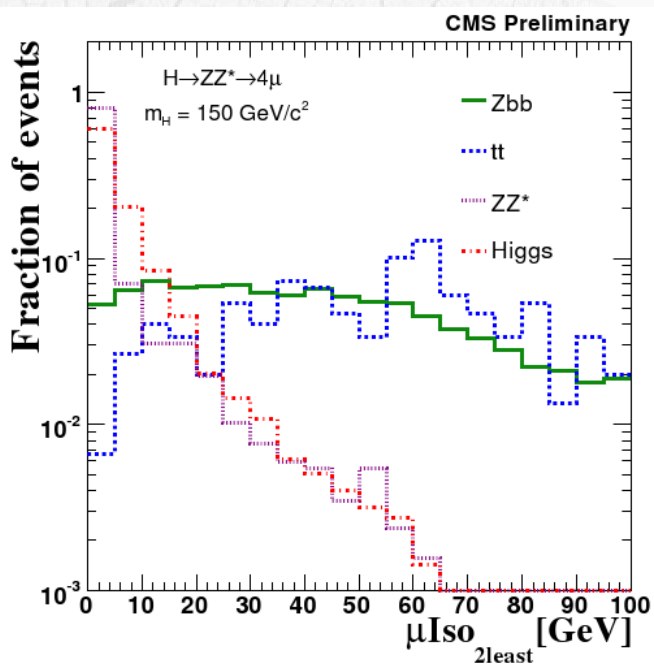
- Multivariate analysis performs way better than cut based
  - Results are for 1fb-1

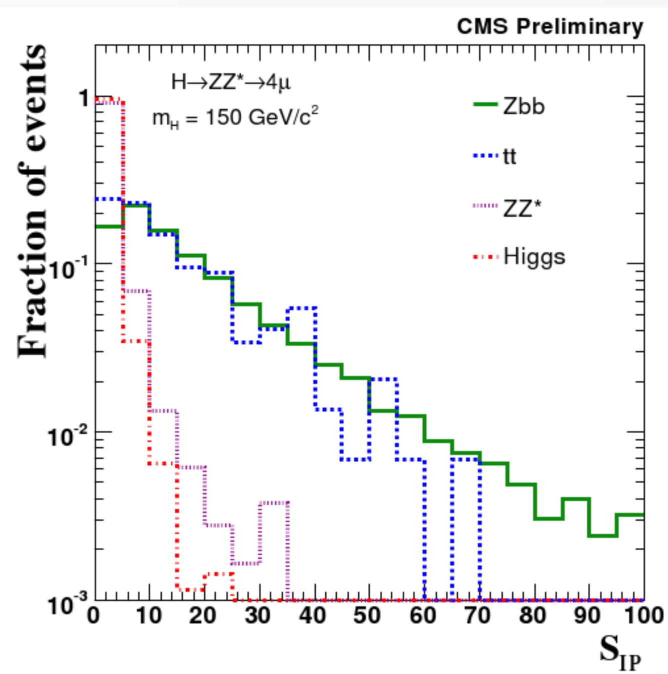


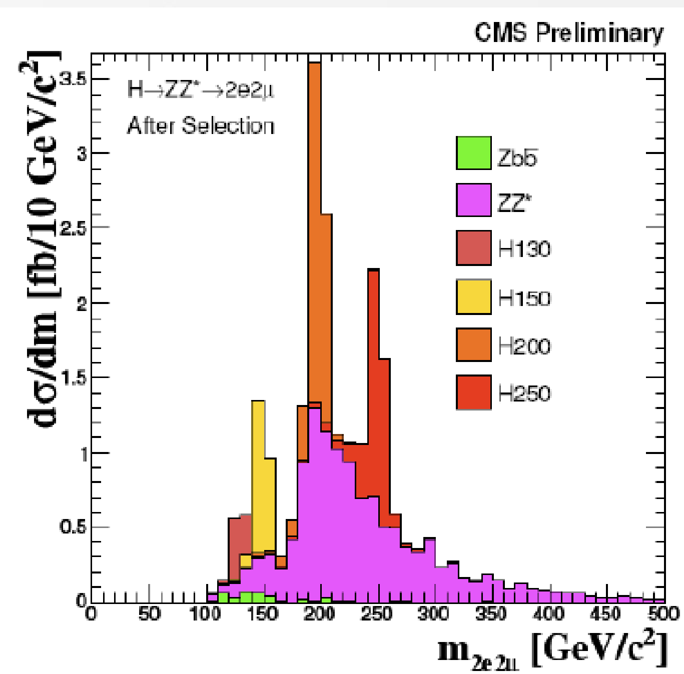
H → ZZ: analysis

- 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

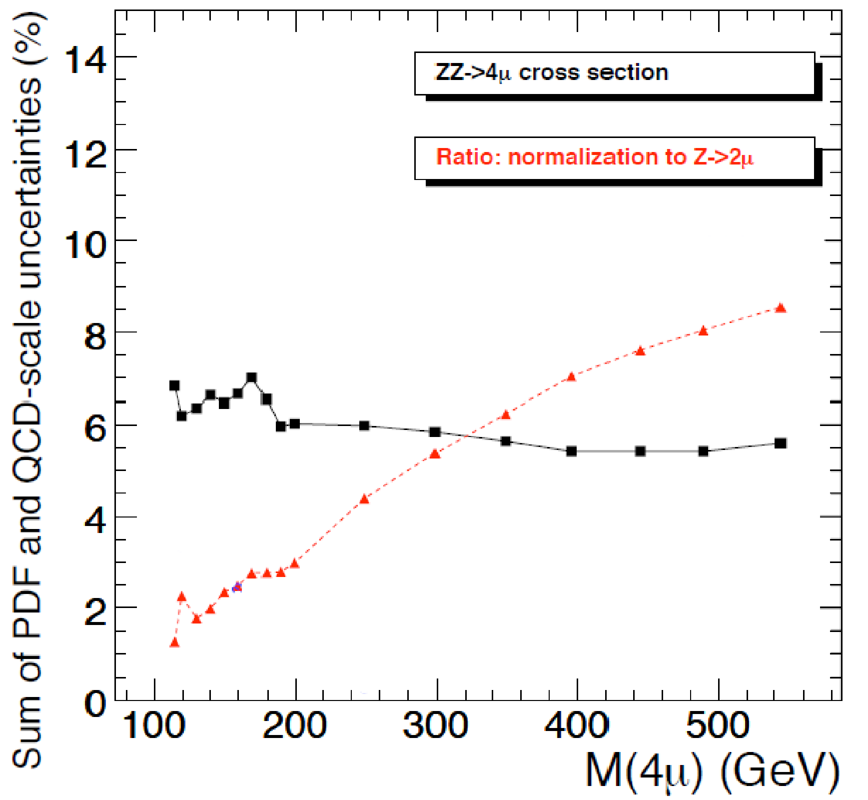






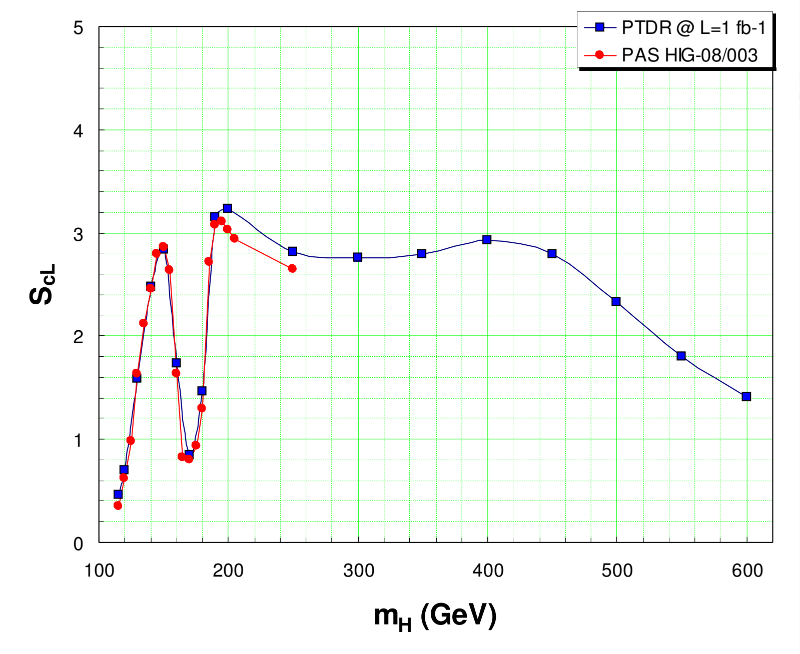
HZZ: background control

- ZZ → 4l – is the main background
  - Control it using ZZ/Z+jets ratio
    - The other method would be through side-bands – but that wouldn't work at the discovery times: too small statistics. On the left is plot from PTDR, for 30fb-1 when statistics was not an issue.
- gg → ZZ (box diagram)
  - Gives about 15% on top of ZZ @NLO
    - With large (~30%) uncertainty
- Zbb
  - Low statistics, hard to come up with data-driven method
    - But it is a minor background
- Other backgrounds:
  - Tt, W/Z+jets, WZ, QCD – should be even smaller



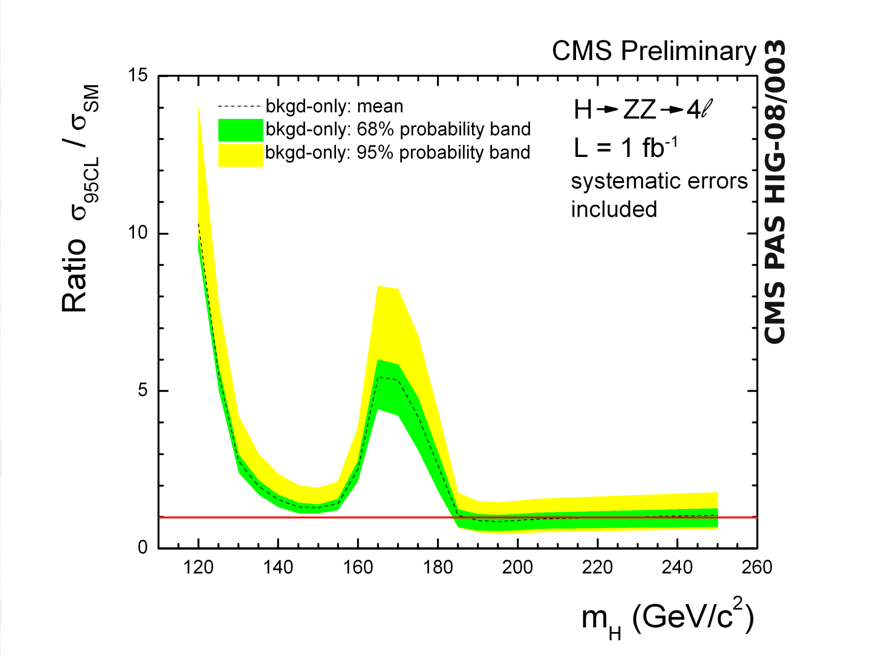
A simple minded estimation for side-bands:
200pb-1 → 3 ZZ events in total which would give approx. 70% uncertainty on prediction from side-bands...

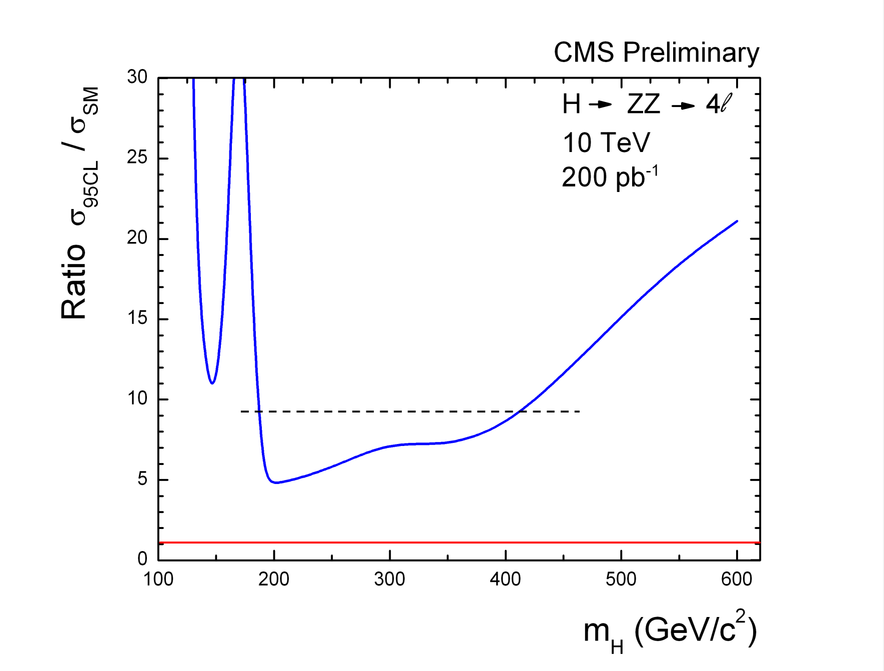
HZZ: results



CMS PTDR-2 scaled down to 1fb-1
CMS PAS HIG08/003 optimized
for mH=150GeV

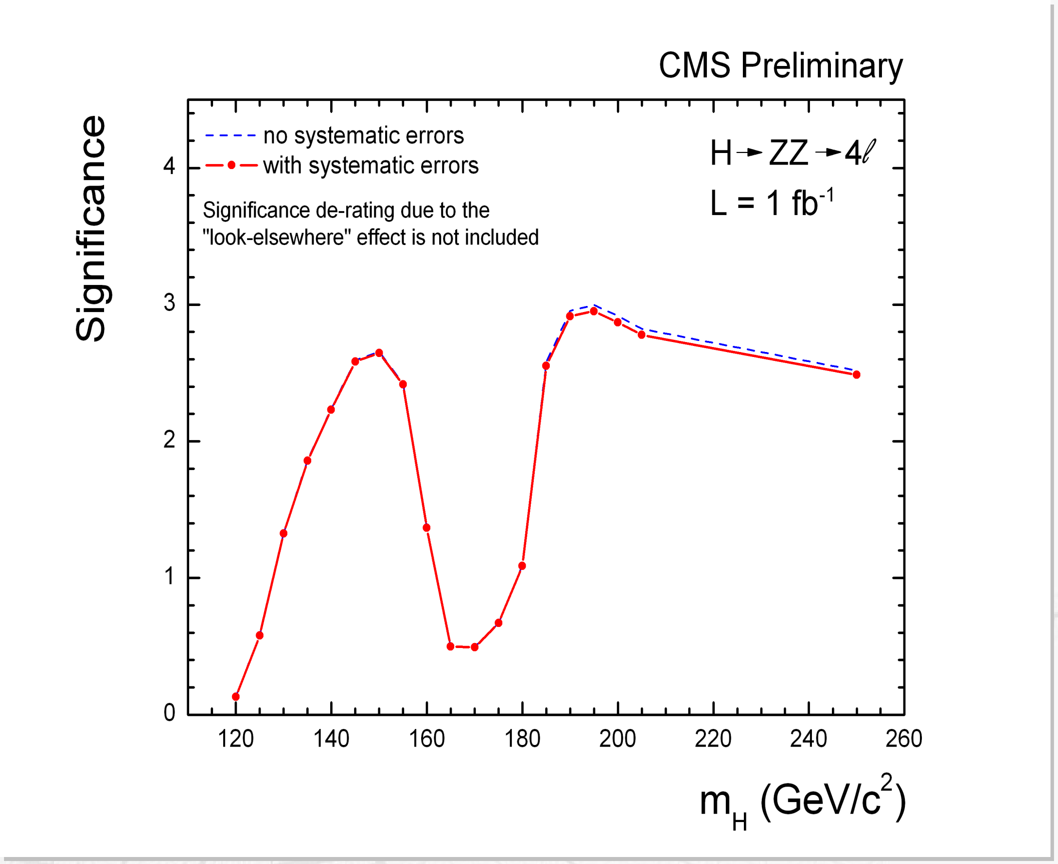
- Scale down PTDR signal and background events to 10 TeV and 200 pb-1:
  - ~3 bkgd events in the full spectrum
  - 0.7 signal events in the best m~200 GeV
- Unofficial projected exclusion limits
  - R<9 in the range 180-400
  - Meaningful in the context of 4 generations
  - High mass range is better than Tevatron

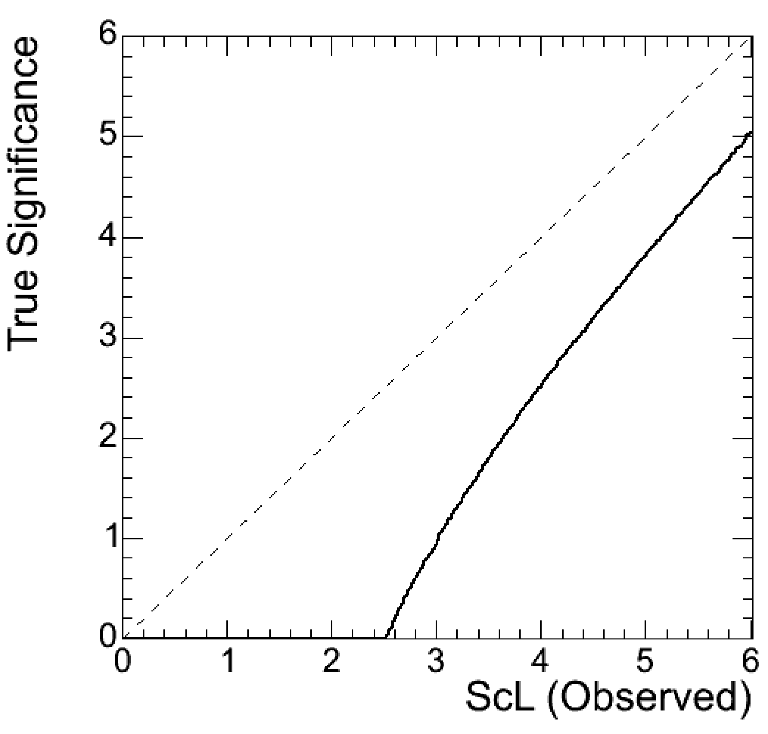




HZZ: results

– Plus: **Look Elsewhere Effect!**
  - Results for “evidence” reach of 2-3 sigma for ~1fb-1 decrease to the level of statistically insignificant bump...

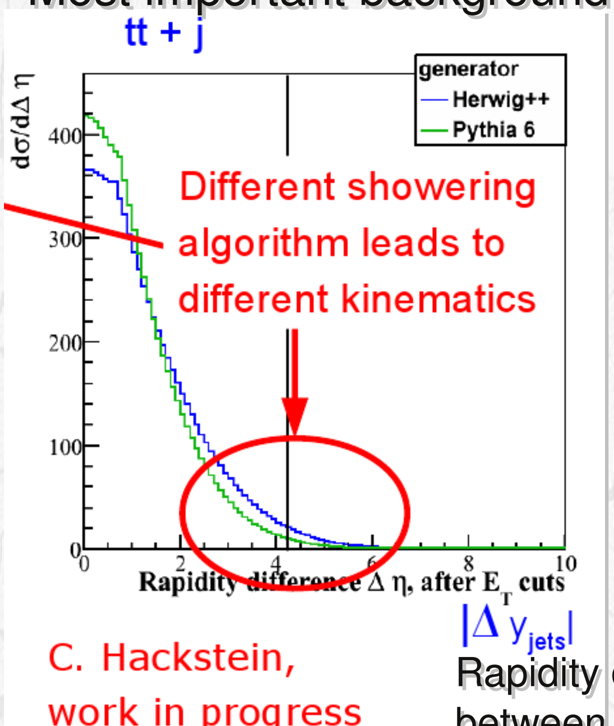




A few remarks on VBF

- It is not a forerunner channel, but it is important
  - Important for disentangling of Higgs couplings
  - Fermiophobic Higgs scenario: VBF becomes the most important mechanism
  - If we do discover SM Higgs: non-resonant VBF WW will confirm that the Higgs does what we expect it to do for WW → WW scattering. If EWK symmetry breaking would occur at ~1TeV scale, non resonant VBF WW may be the first sign of it
  - Problems: large uncertainties in signal and backgrounds → hard/impossible to make exclusions or discoveries...

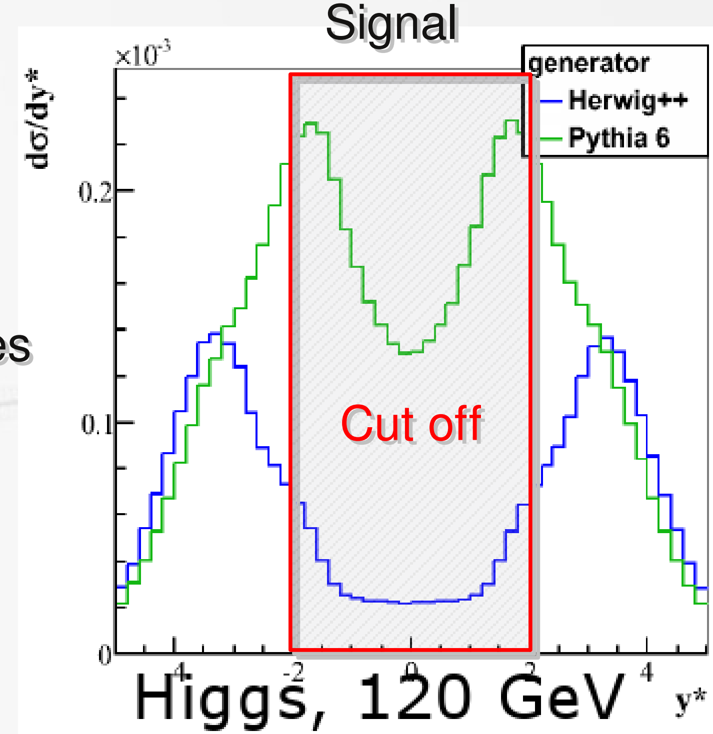
Most important background



$|\Delta y_{jets}|$ Rapidity distance between tag-jets

Additional hadronic activity in EW processes differs extremely for different generators...

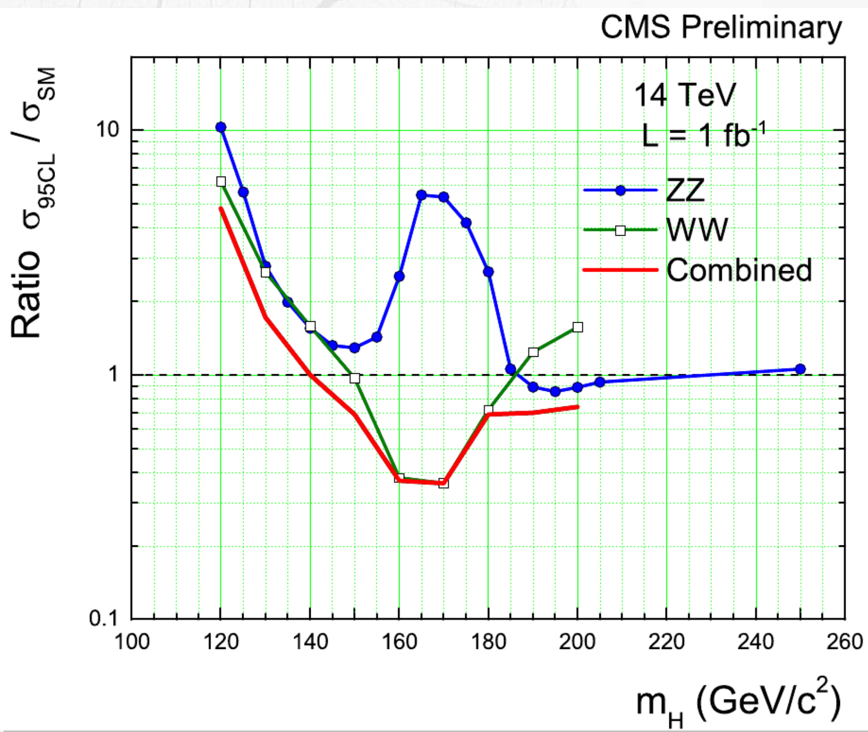
Signal

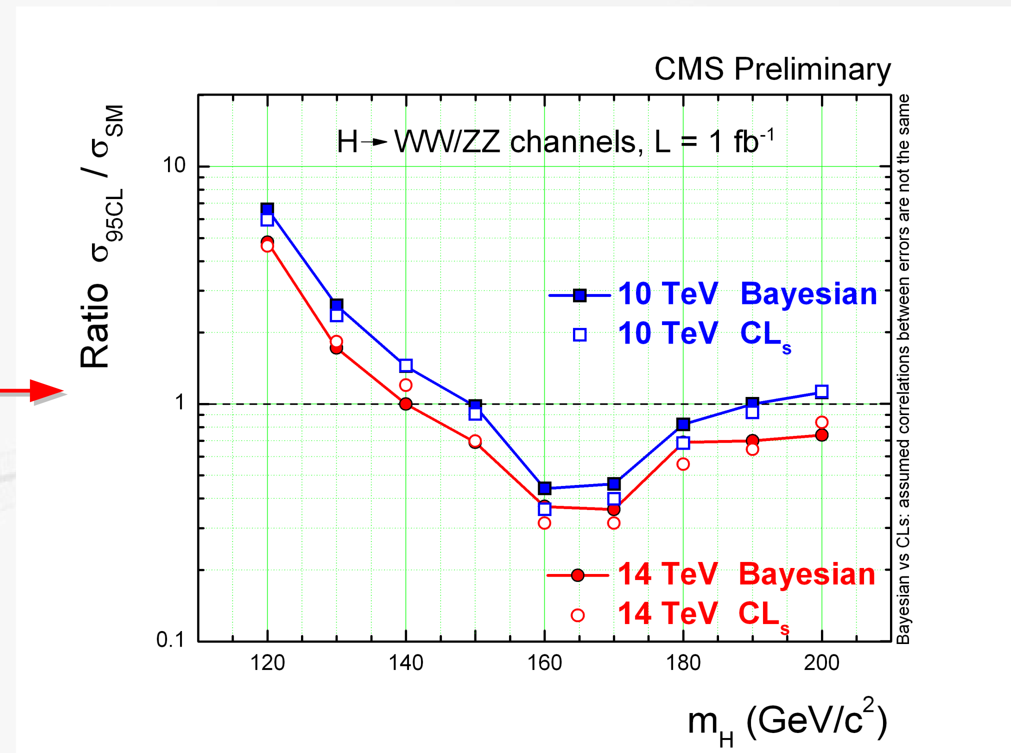


y*=yj-0.5(y1+y2) – this is a measure of how central any additional jet is...

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 example assuming 100% correlations between systematic uncertainties (for Bayesian), flat prior for Higgs, etc.



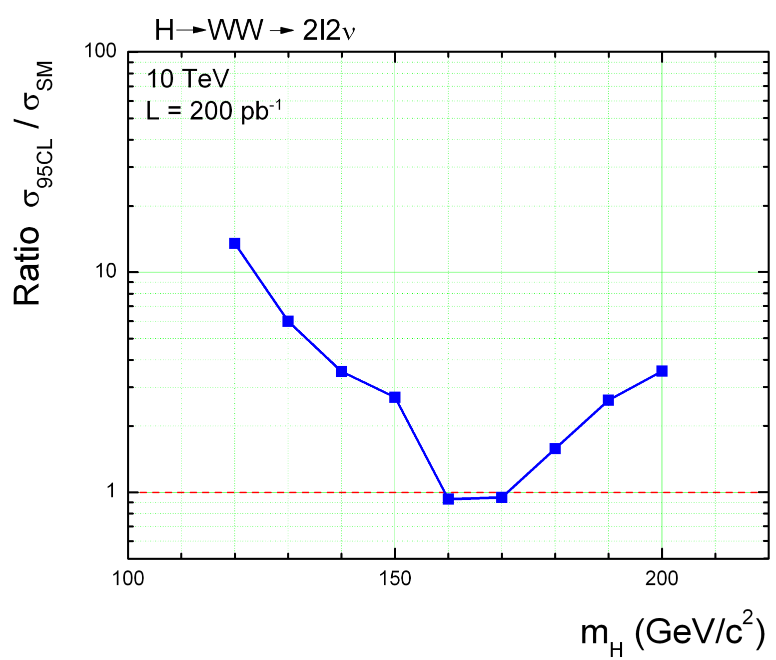


10 TeV, 200 pb-1

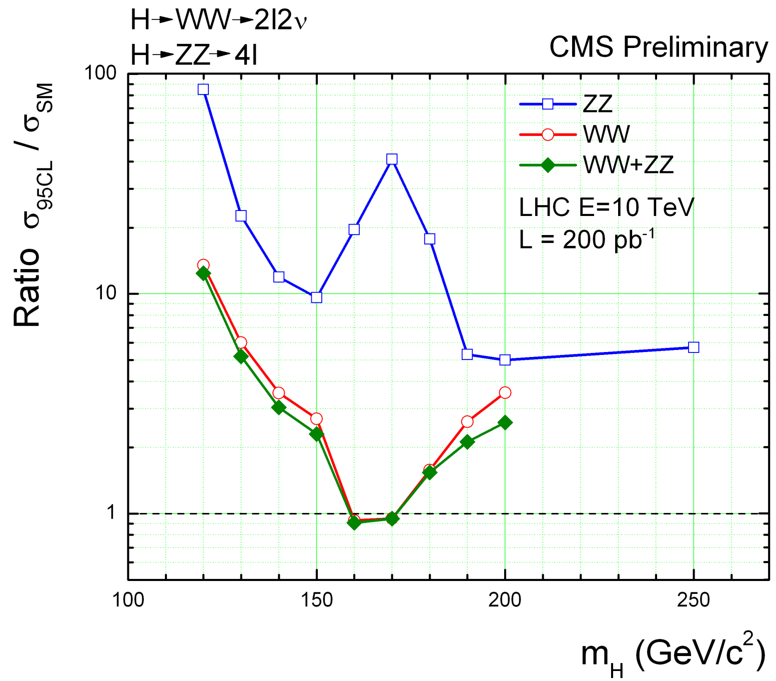
- ...one should scale even further to get to point relevant for 2010 LHC runs. HWW:

  scale PAS HIG-08/006
  signal and bkgd events down
  to 10 TeV and 200 pb-1
  - after a cut on the MVA output for mH=160 GeV
  - 4 bkgd events
  - 7.3 signal events

  Projected exclusion limits
  - r<1 in the range 160-170 GeV
  - r<9: ... - 200+ GeV (meaningful in the context of 4 generations)
  - comparable to or better than CDF/D0 above 150 GeV

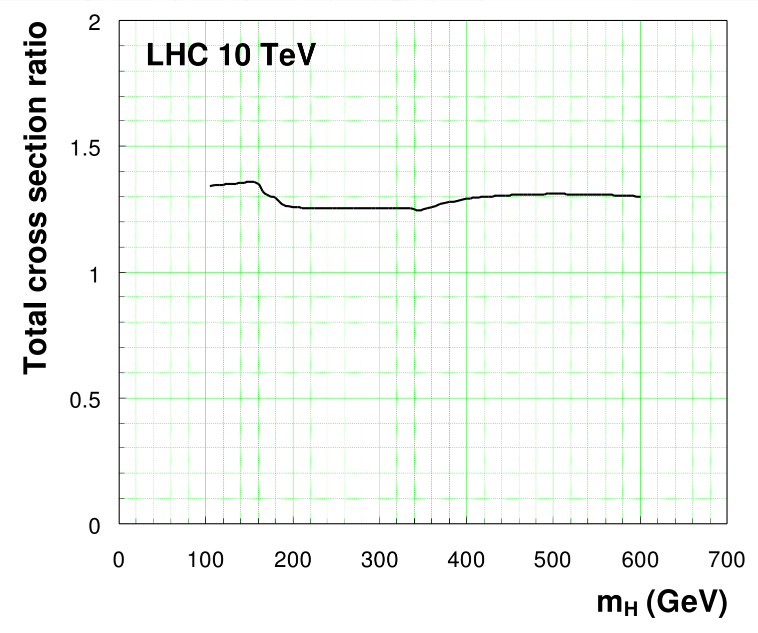


- And then combination: HWW+HZZ:
  - We end up with more or less current Tevatron exclusion interval



To end on a positive note…

- Tevatron experiment use NNLO, CMS – was not so far (for all the results above)
  - Recent calculations using HggTotal by Fabian Stoeckli
  - NNLO contribution to gluon-fusion: ~30% - “for free” :-)



$$ratio = \frac{gg(NNLO)+VBF(NLO)+VH(NLO)+ttH(LO)}{gg(NLO)+VBF(NLO)+VH(NLO)+ttH(LO)}$$

Conclusions

- 200pb-1 @ 10 TeV (500 pb-1 at 7 TeV) will put LHC experiments on a map of Higgs searches
  - We are looking forward to the challenge!