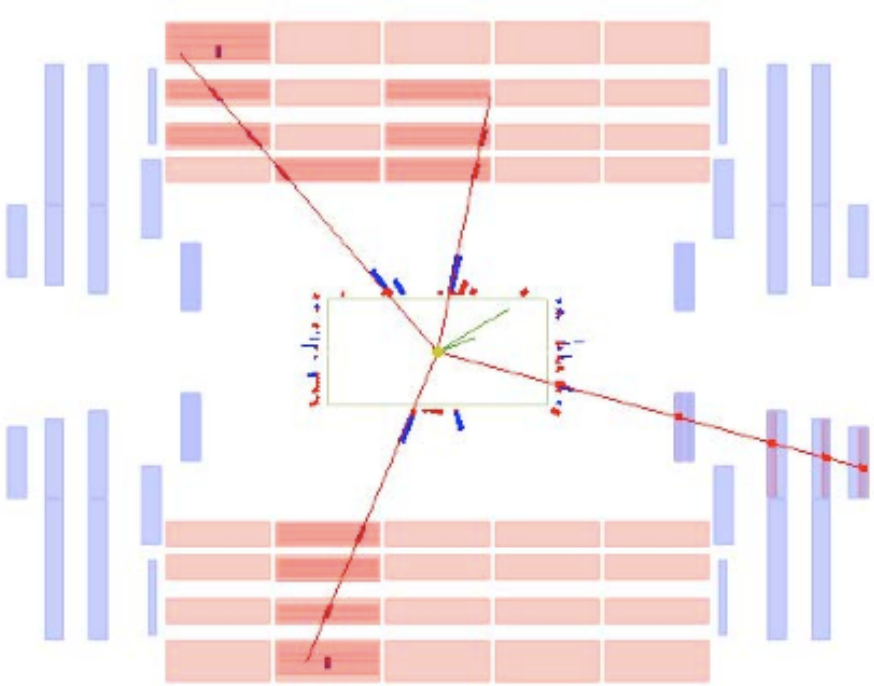
New Modes for Higgs Search At CMS

Adish Vartak [University of California San Diego]

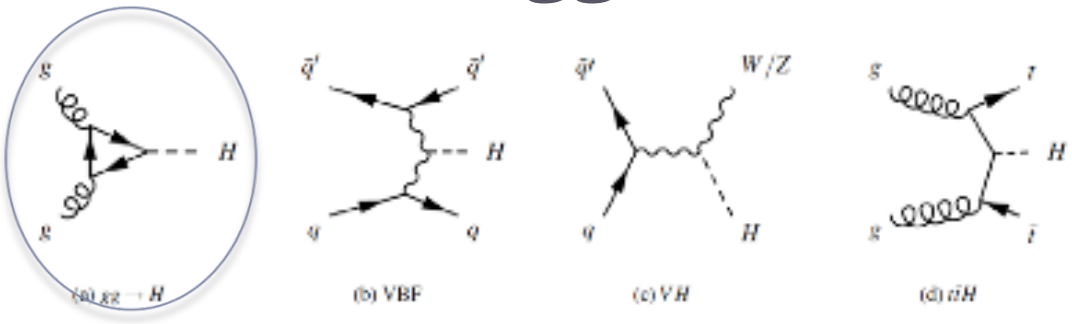
LHC and the Higgs

- In 2010 LHC has become the world's premiere particle collider
- CMS – One of two general purpose experiments at LHC will drive the search for new physics in the coming years
- Higgs – A flagship search for CMS will take center-stage next year
- We have already taken some strides in that direction

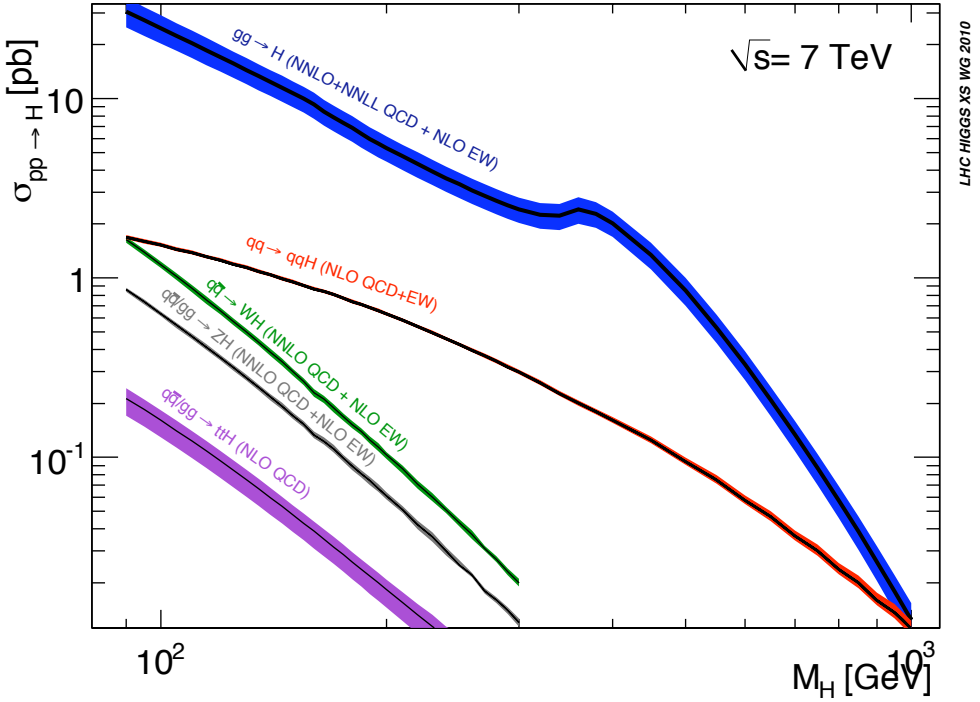


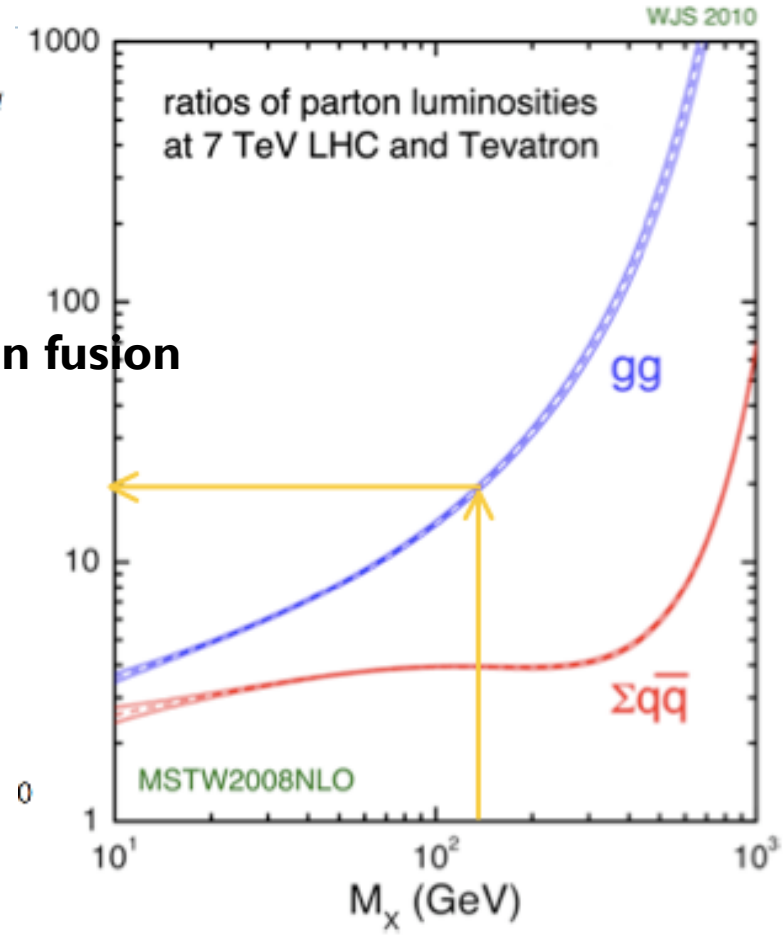
A 4-muon event observed in CMS

Higgs Production @ LHC



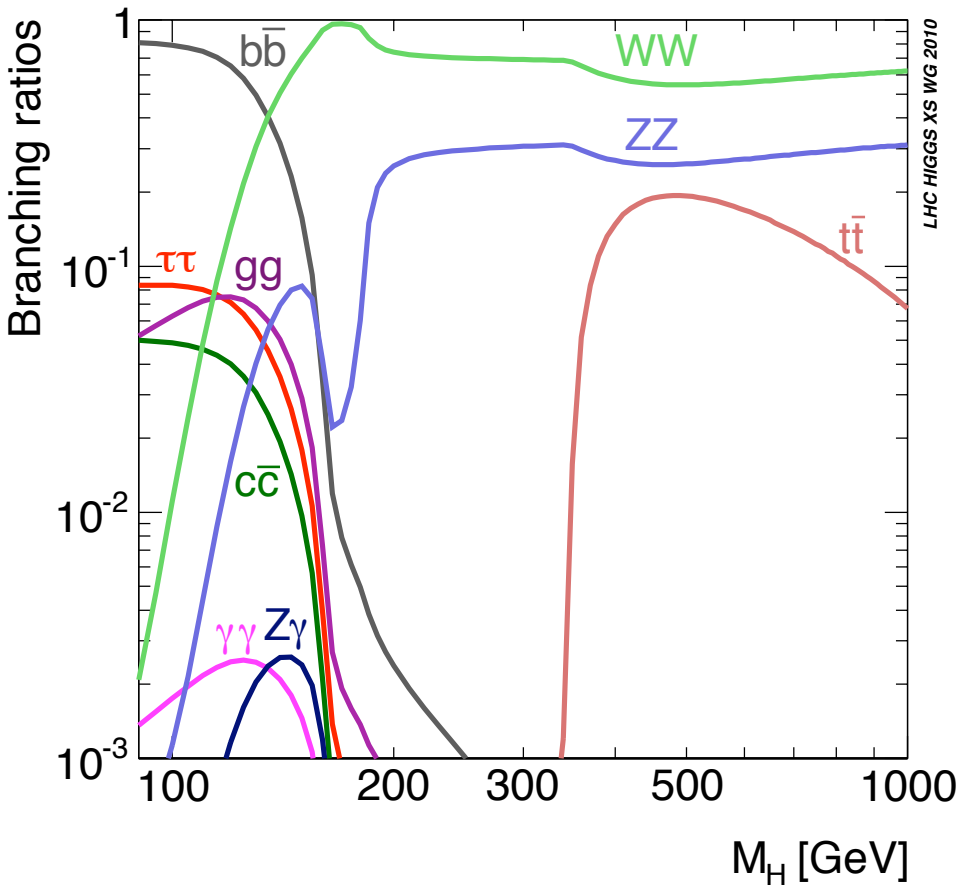
At 7 TeV Higgs production dominated by gluon fusion





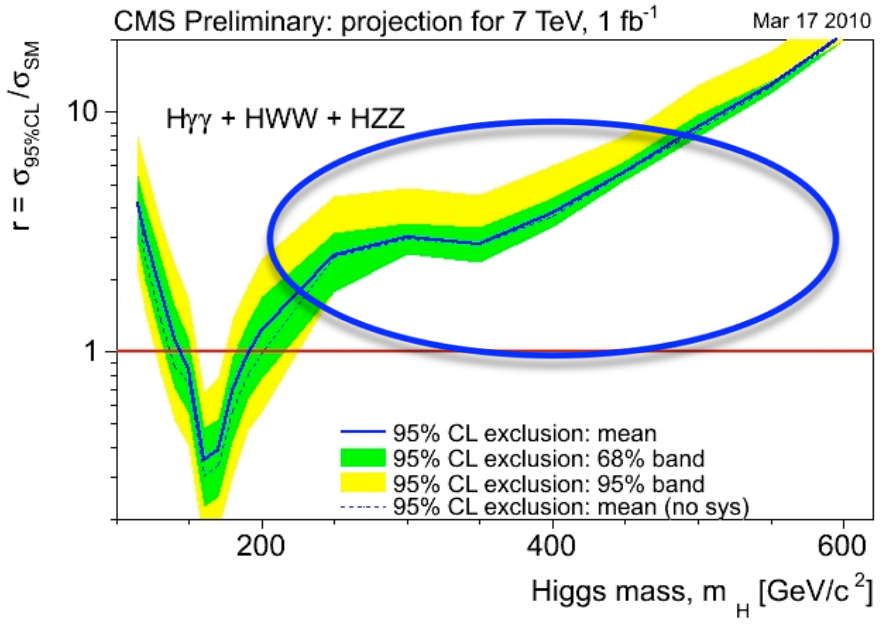
Decay Modes for Higgs Hunting

- Searches broadly divided into 3 groups based on Higgs branching ratios
- Low mass : m(H) < 150 GeV
  - H->ϒϒ, W/Z H(bb)
- Medium mass (WW sweet spot) : 150 < m(H) < 200 GeV
  - H->WW
- High mass : m(H) > 200 GeV
  - H->ZZ



Higgs Sensitivity (Conservative) for 1 fb^{-1} @ 7 TeV

- CMS Higgs effort has largely focused on the 'discovery' modes – H->WW->2l2ν , H->ZZ->4l, H->$\gamma\gamma$
- Projections combining these modes do not exclude Higgs beyond 200 GeV
  - H->ZZ->4leptons runs out of steam at 1 fb^{-1}
  - H->WW not very sensitive at high masses with loss of angular correlation between leptons
- The only way to improve sensitivity is to add new modes



Is this the best that can be done with 1 fb-1 of data?

Are we covering the full ground?

Add More Drops in the Higgs Bucket

- The clean leptonic final states are prime candidates for Higgs discovery
- The downside – much smaller σ x BR
- ZZ->4l has a branching ratio of just 0.4%
  - For 400 GeV Higgs only 2 events expected in the 4 leptons channel at 1 fb^{-1} (ignoring detector acceptance!)
- What are we missing out ?

Mode	*Br.Ratio*	*Total*
$H \to ZZ \to [\ell^+\ell^-][\ell^+\ell^-]$	$[2\times 3\%]\times[2\times 3\%]$	0.4%
$H \to ZZ \to [\ell^+\ell^-][\nu\bar{\nu}]$	$[2\times 3\%]\times 20\%\times 2$	2.4%
$H \to ZZ \to [\ell^+\ell^-][b\bar{b}]$	$[2\times 3\%]\times 15\%\times 2$	1.8%
$H \to ZZ \to [\ell^+\ell^-][jj]$	$[2\times 3\%]\times 70\%\times 2$	8.4%
$H \to ZZ \to [\nu\bar{\nu}][b\bar{b}]$	$20\%\times 15\%\times 2$	6%

Detecting the New Higgs Modes

- Clearly a lot of Higgs fuel available to boost sensitivity
- Can we 'see' all these new modes?
- **Trigger**
  - To detect a final state it is imperative to trigger on the event topology
  - Easy to trigger on final states with leptons
  - H->ZZ->2 ν 2b much harder to trigger on
- **Backgrounds**
  - All the new HZZ modes are faced with huge backgrounds
  - Z+Jets, TTbar backgrounds common to all modes
  - Typically 4-5 orders of magnitude larger cross-section than the signal
  - We are literally looking for a needle in a hay stack

$$H \to ZZ \to [\ell^+\ell^-][\nu\bar{\nu}]$$

A bit about H->ZZ->2l2 ν

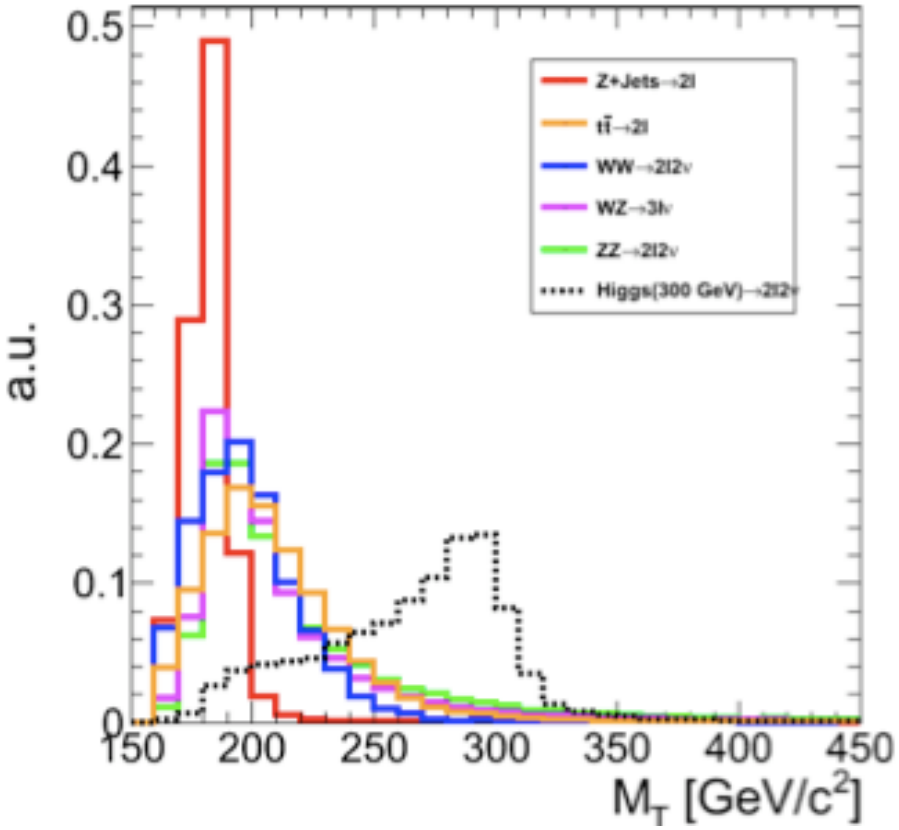
- Final state comprising of two high P_T, isolated leptons and large missing transverse energy from neutrinos
- Higgs cannot be fully reconstructed

$$M_T^2 = (\sqrt{P_{TZ}^2 + M_Z^2} + \sqrt{ME_T^2 + M_Z^2})^2 - (\vec{P}_{TZ} + M\vec{E}_T)^2$$

- One can define a transverse mass variable M_T similar to the W->l ν analysis

Major backgrounds to this process :

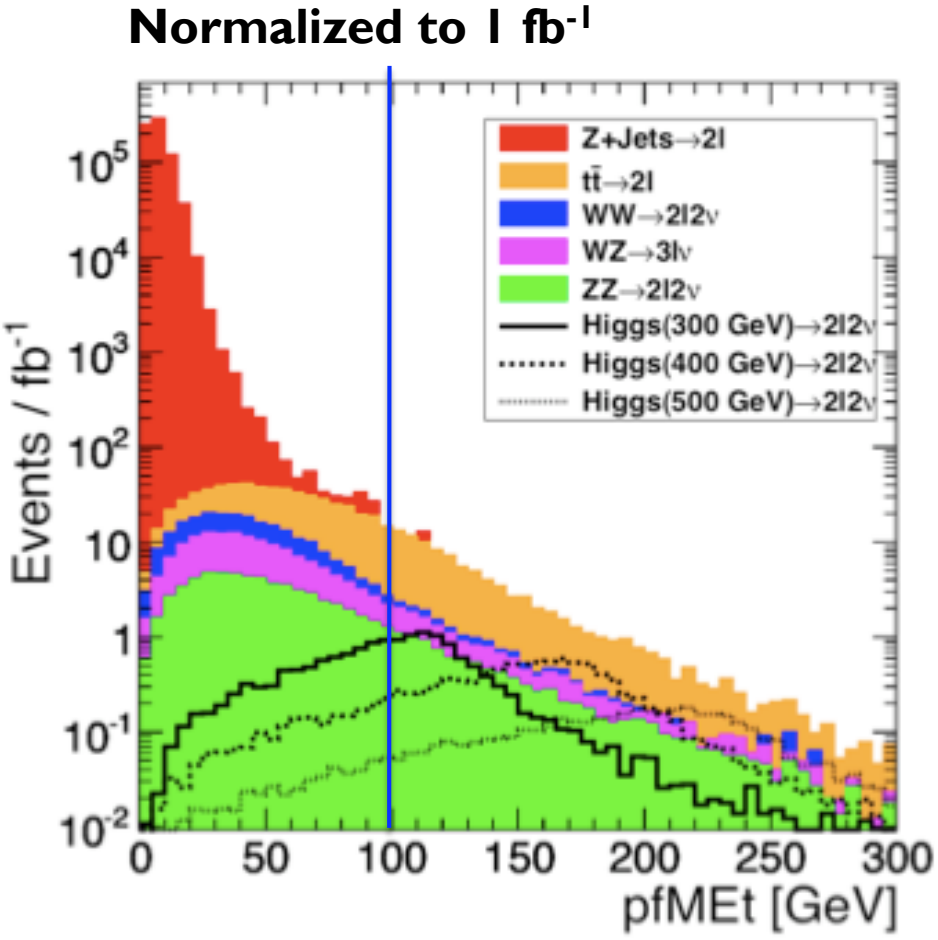
- Z+Jets – Jets faking MET signature
- TTbar – Fully leptonic decay, real MET from neutrinos
- ZZ – Irreducible background
- WZ to 3l+ ν – Closely mimics signal if the lepton from W decay goes undetected



All distributions normalized to unity

H->ZZ->2l2ν : Missing Energy Signature

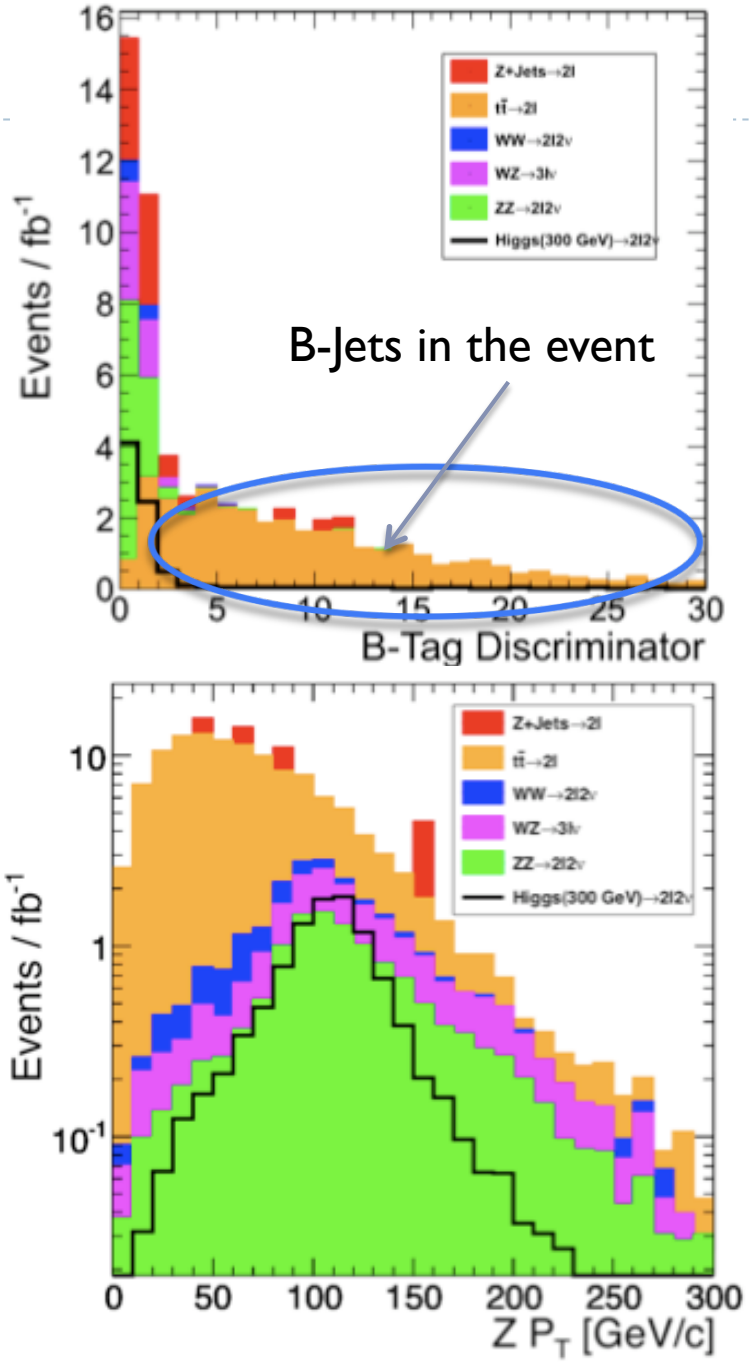
- 2l2ν signature :
  - Well reconstructed Z Candidate
  - Large missing transverse energy (MET) in the detector
- MET is the key handle to suppress the large Z+Jets background
- MET in Z+Jets events comes from detector resolution and mismeasured jets
- MET in signal is essentially the P_T of the Z coming from the Higgs
- Larger the Higgs mass, greater the Z boost and hence larger is the observed MET



MET > 100 GeV typically expected for 300 GeV and heavier Higgs decays

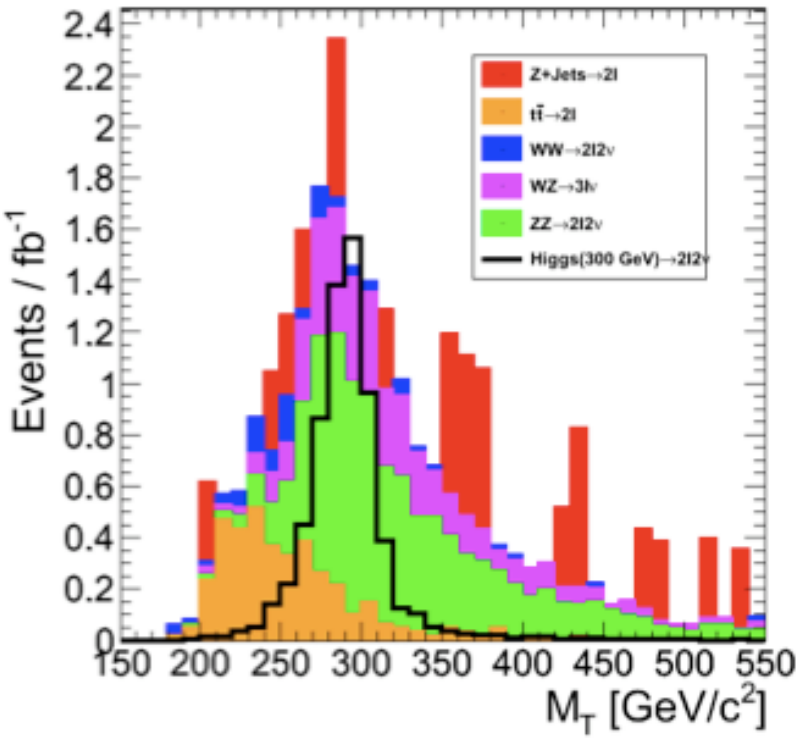
H->ZZ->2l2ν : Other Discriminants

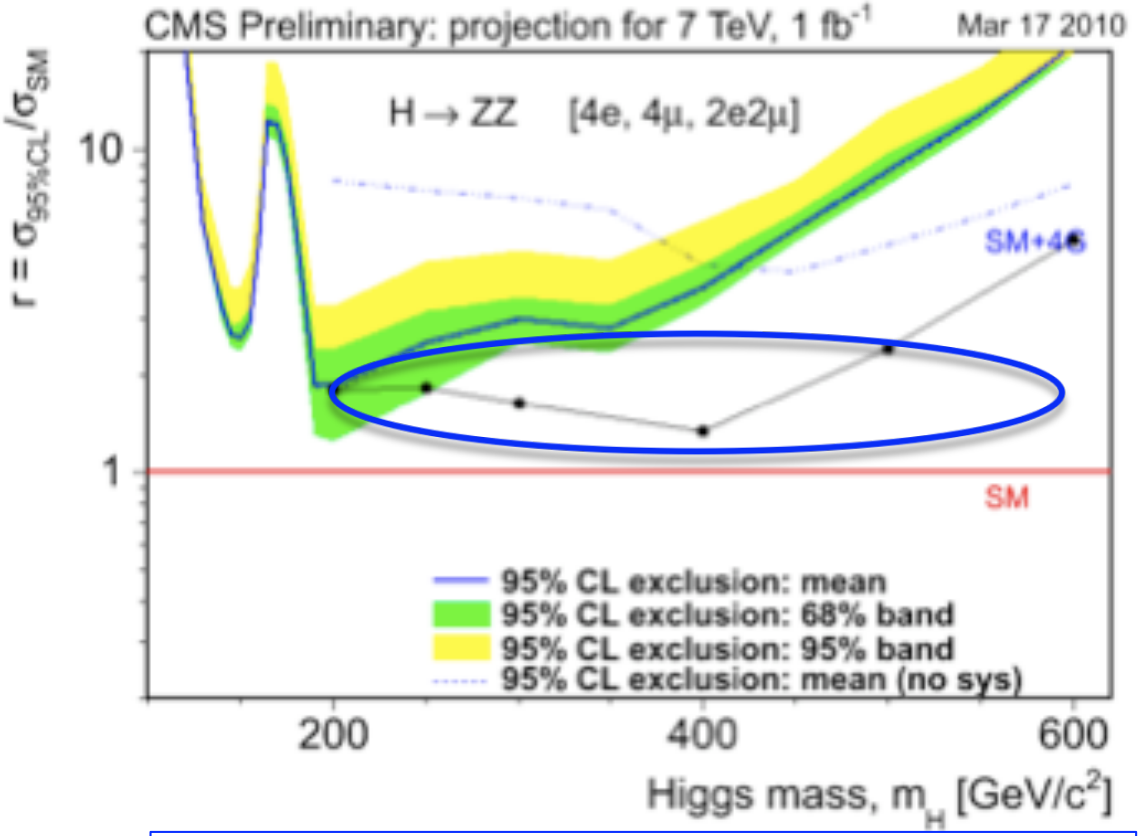
- After MET cut, background dominated by TTbar, ZZ and WZevents
- TTbar can be controlled by vetoing events with b-tagged jets
- P_T of the reconstructed Z candidate also has discriminating power – heavy Higgs decays produce boosted Zs



Plots shown after applying 100 GeV MET cut
Normalized to 1 fb^{-1}

H->ZZ->2l2ν : Final Results





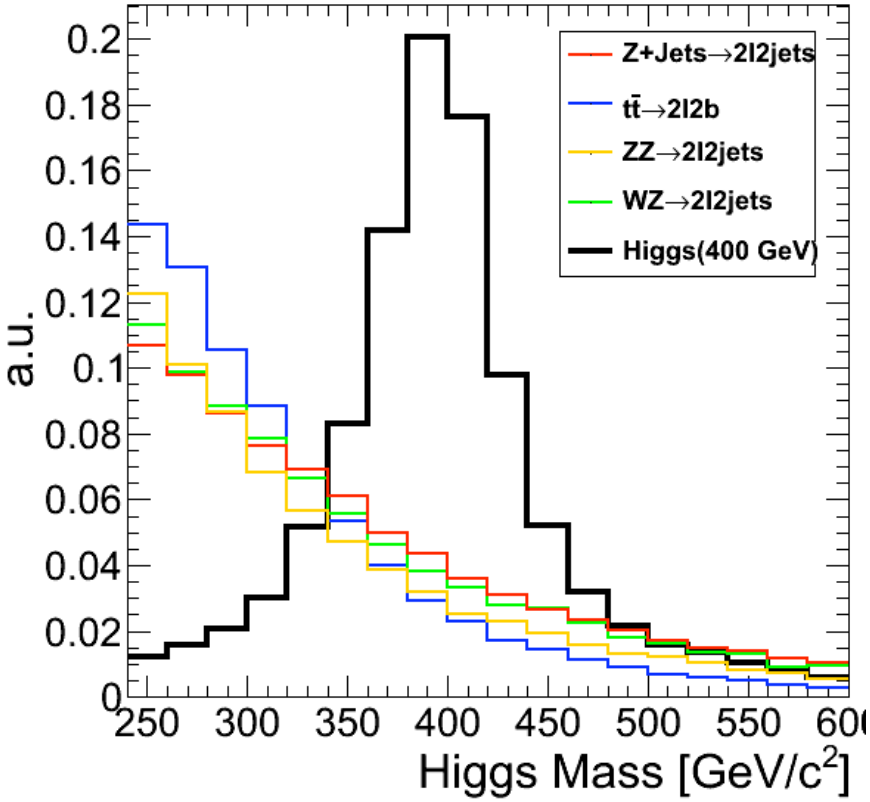
Finally **5 signal** and **7 bkg** events expected for 300 GeV Higgs at 1 fb^{-1}

Significant improvement in sensitivity on adding the 2l2ν mode
Exclusion curve more or less flat over a broad mass range

$$H \rightarrow ZZ \rightarrow [\ell^+\ell^-][b\bar{b}]$$

About H->ZZ->2l2b

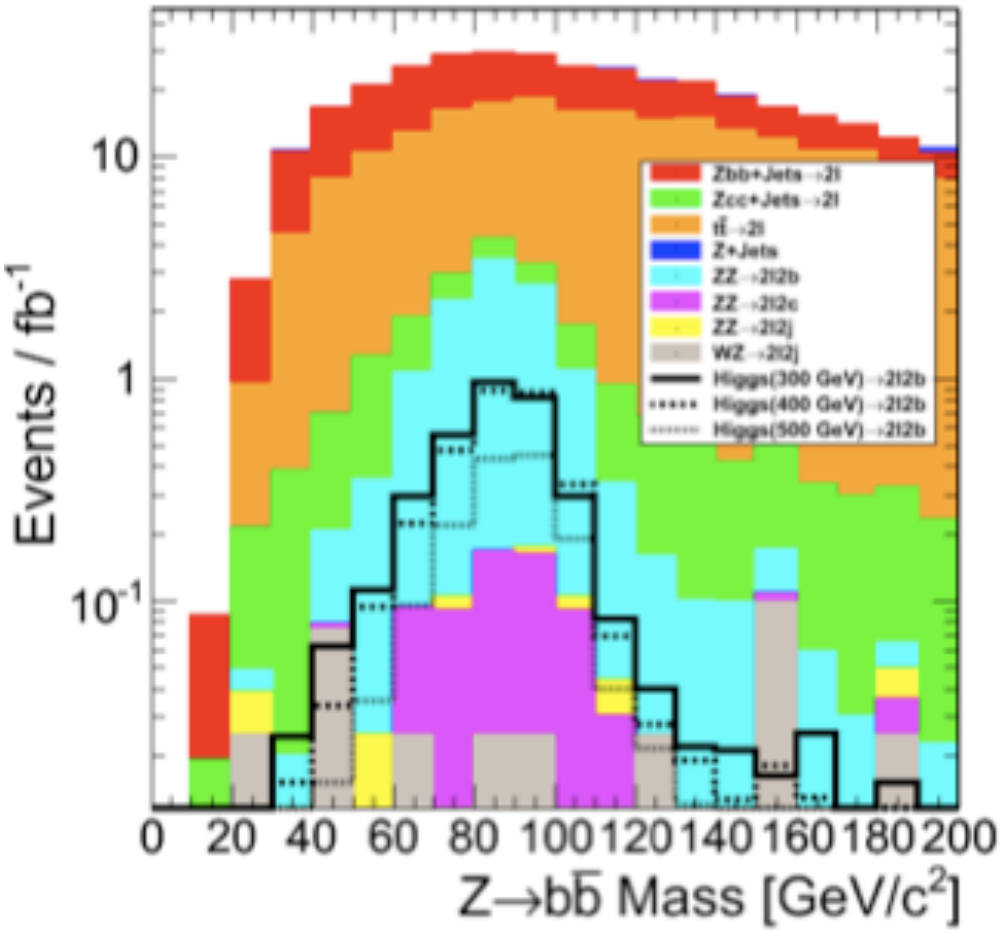
- Fully reconstructed Higgs mass from 2 leptons and 2 jets in the final state
- Z+Jets and TTbar are major backgrounds
- B-tagging is a powerful tool to kill the large Z+Jets background
- MET is a useful handle on TTbar
- Zs from Higgs boosted as in 2l2 ν



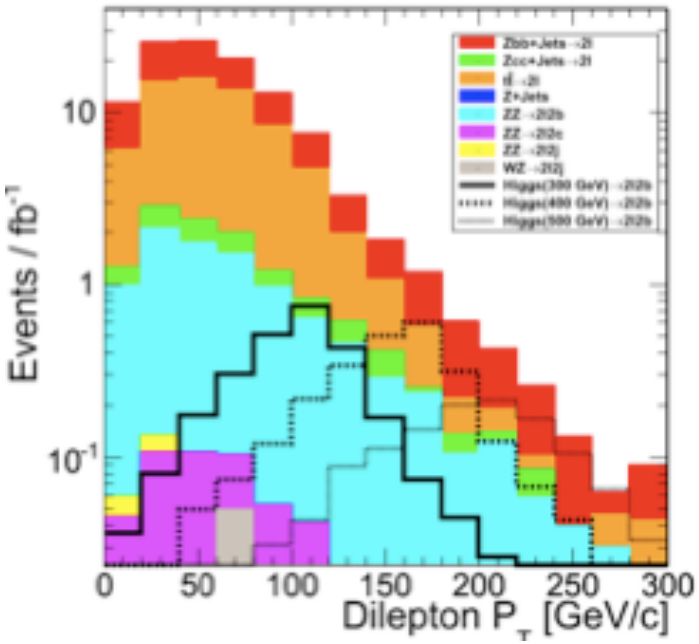
Signal and backgrounds normalized to unity

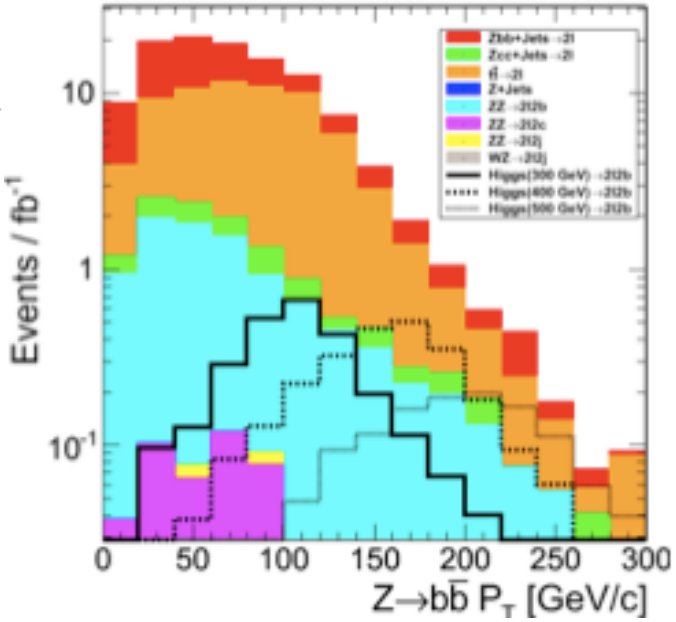
H->ZZ->2l2b : Event Signature

- Final state signature :
  - Z candidate from two prompt isolated leptons
  - Two b-tagged jets with dijet mass in the Z window
- Background dominated by Z+Heavy Flavor Jets (Z+bb, Z+cc)

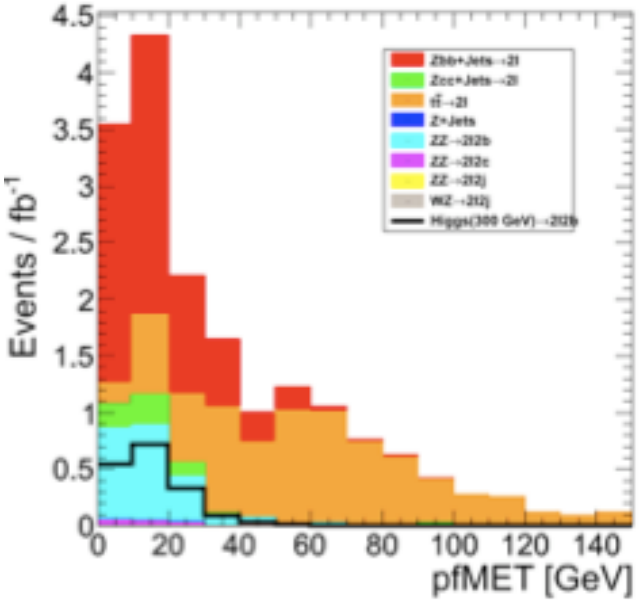


H->ZZ->2l2b : Discriminating Variables

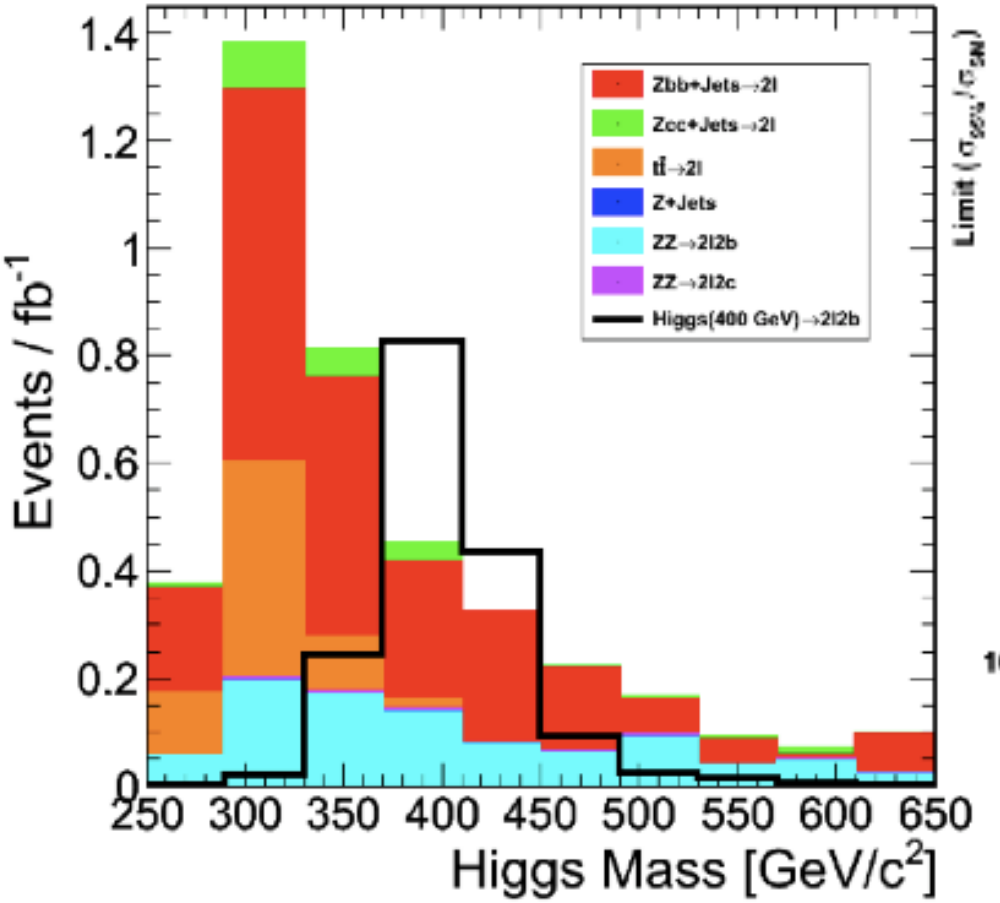




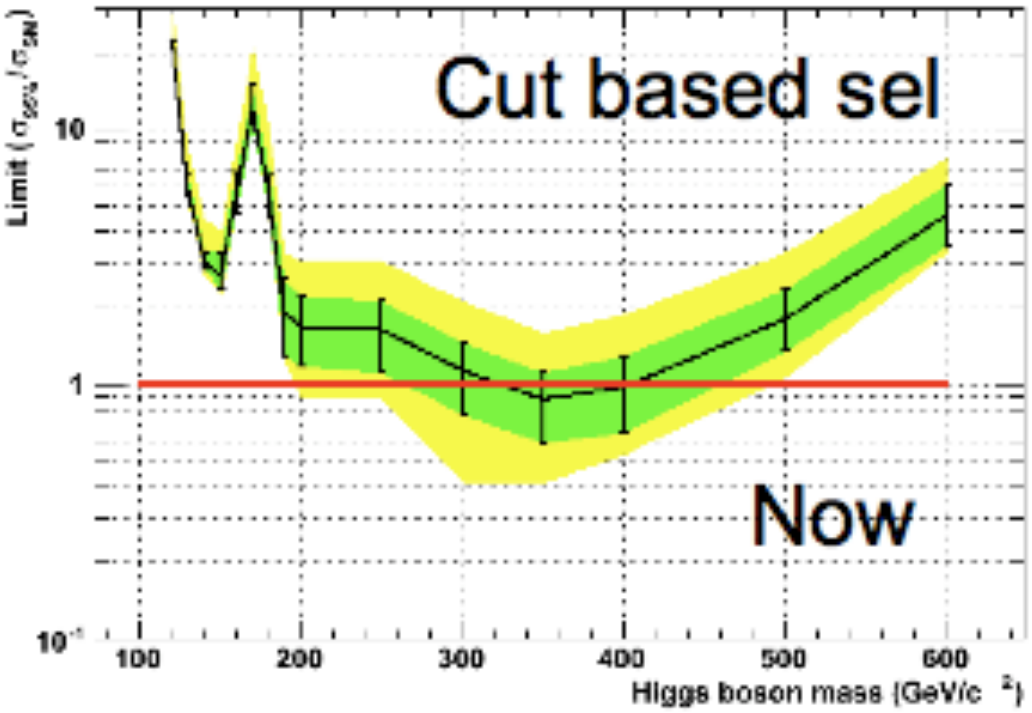
- **P_T of the two Z candidates provides good discrimination between signal and background**
- **Remaining TTbar events can be killed with a MET cut**



What we Finally End Up With



Finally we can expect upto 2 signal events at 1 fb^{-1} (400 GeV Higgs)



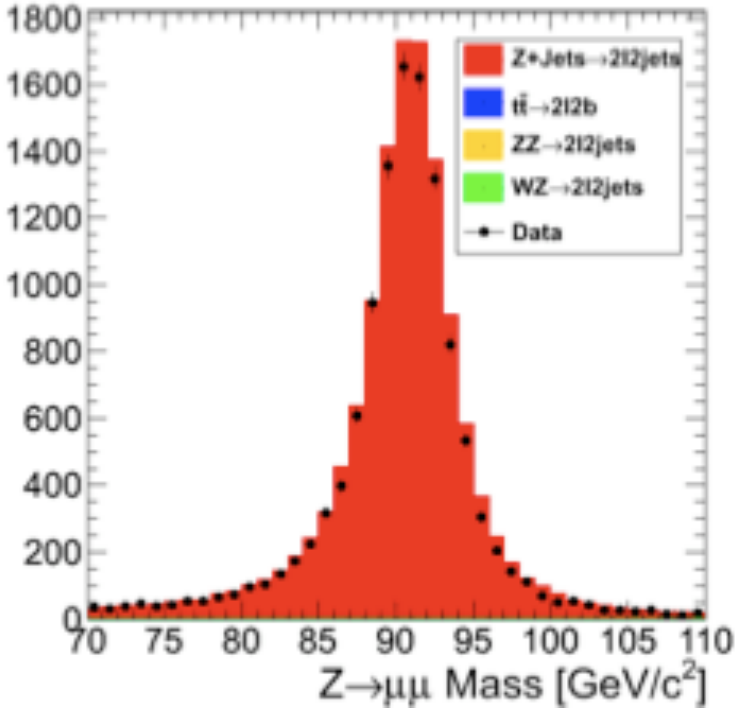
$$H \rightarrow ZZ \rightarrow 4\ell + 2\ell 2\nu + 2\ell 2b$$

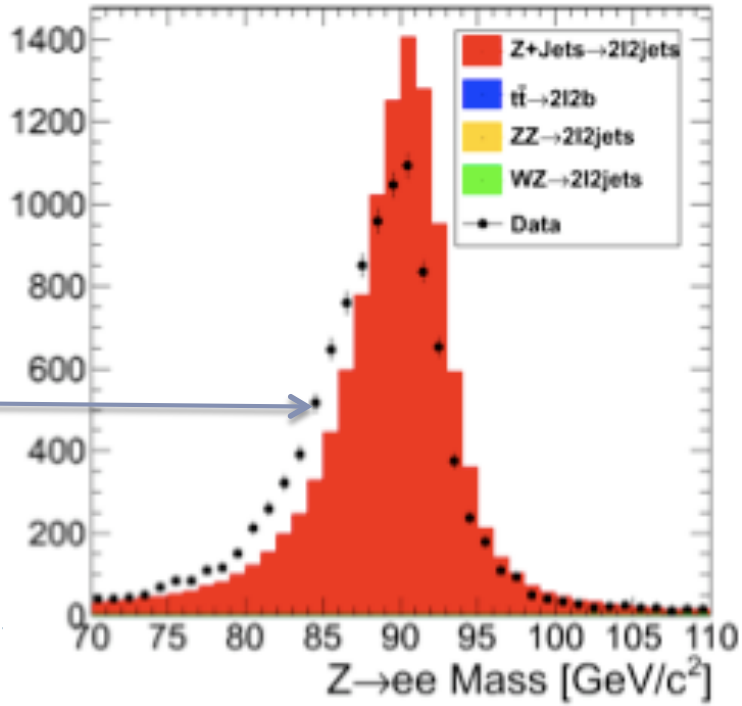
Combining the 2l2 ν and 2l2b modes we can exclude Higgs in the 400 GeV neighbourhood

And this only with a simple cut-based analysis

First Look at Data (35 pb^{-1}) Z Candle

- With 35 pb^{-1} of data we got our first glimpse into high PT physics at 7 TeV
- Good opportunity to study key physics objects directly from data
- Z candidates in data serve as standard candles for leptons

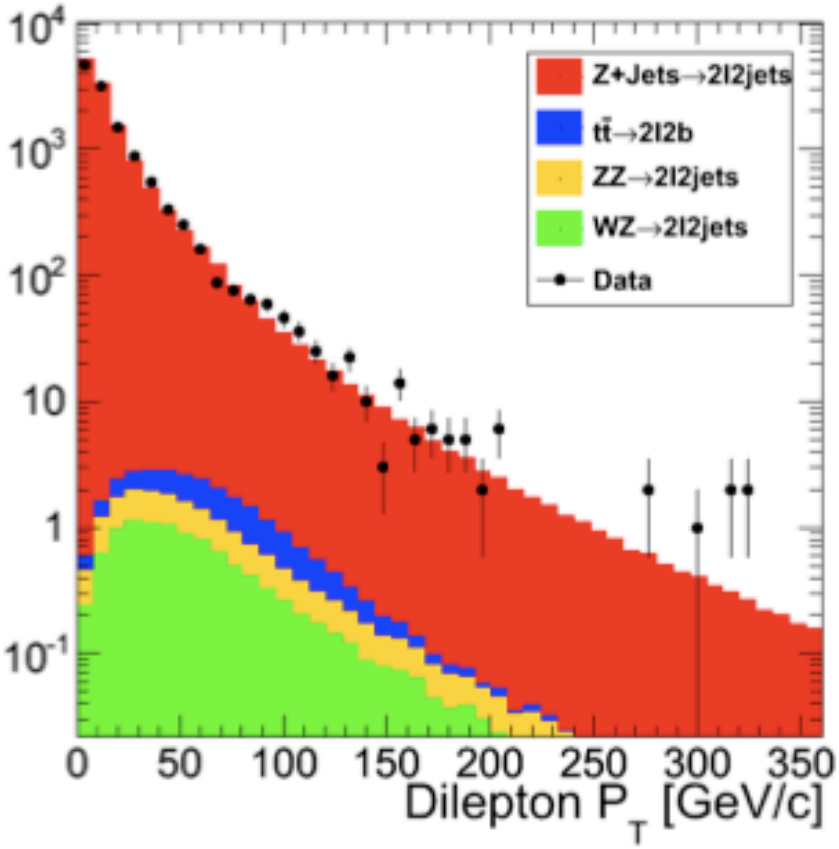




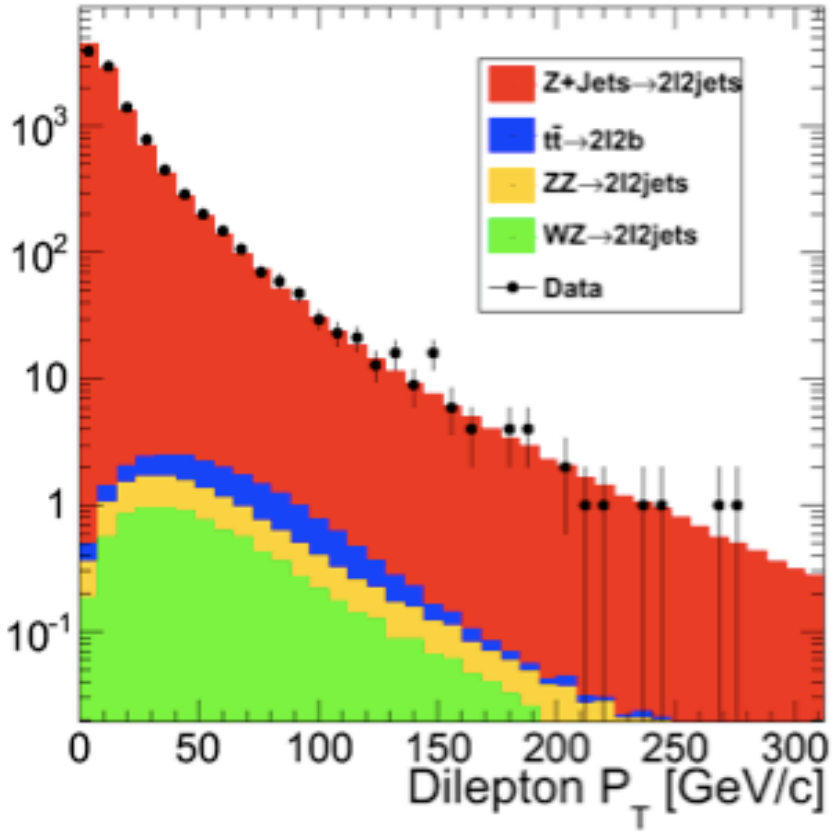
Discrepancy in the Z->ee mass peak to be fixed with improved ECAL calibration

PT Distribution of Z Candidates

Muon Channel



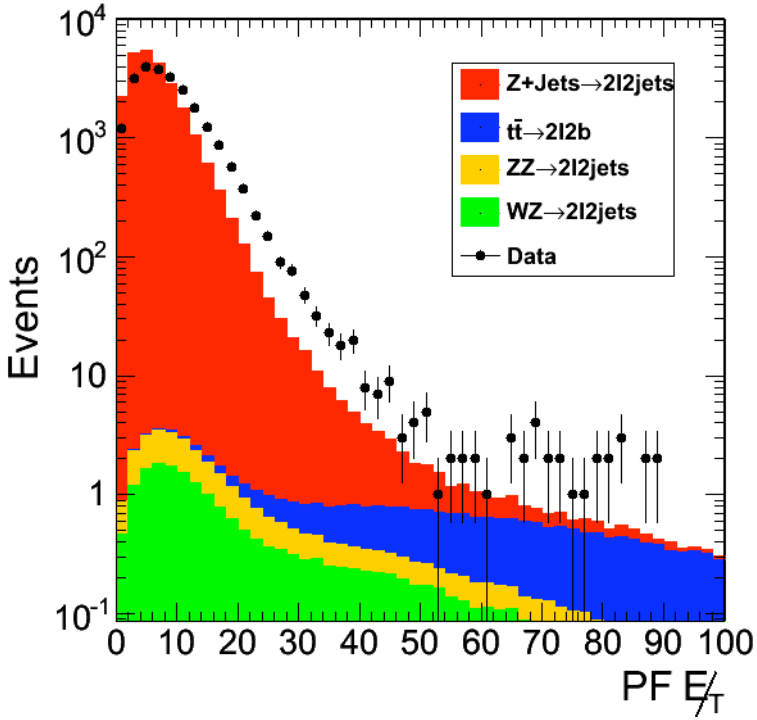
Electron Channel



Z PT is a crucial discriminating variables in the 2l2 ν and 2l2b analyses
Good agreement seen between data and MC

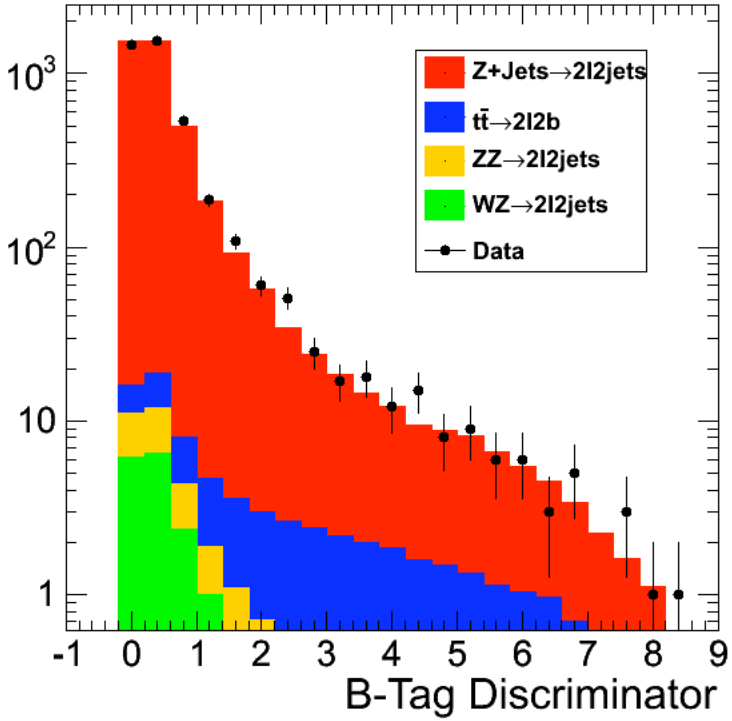
Missing Energy and B-Tagging

MET Distribution in Z events



Large discrepancy between data and MC
Discrepancy due to pileup in data
Effect of pileup on MET will require close monitoring next year

B-Tagger (Jet B Probability)



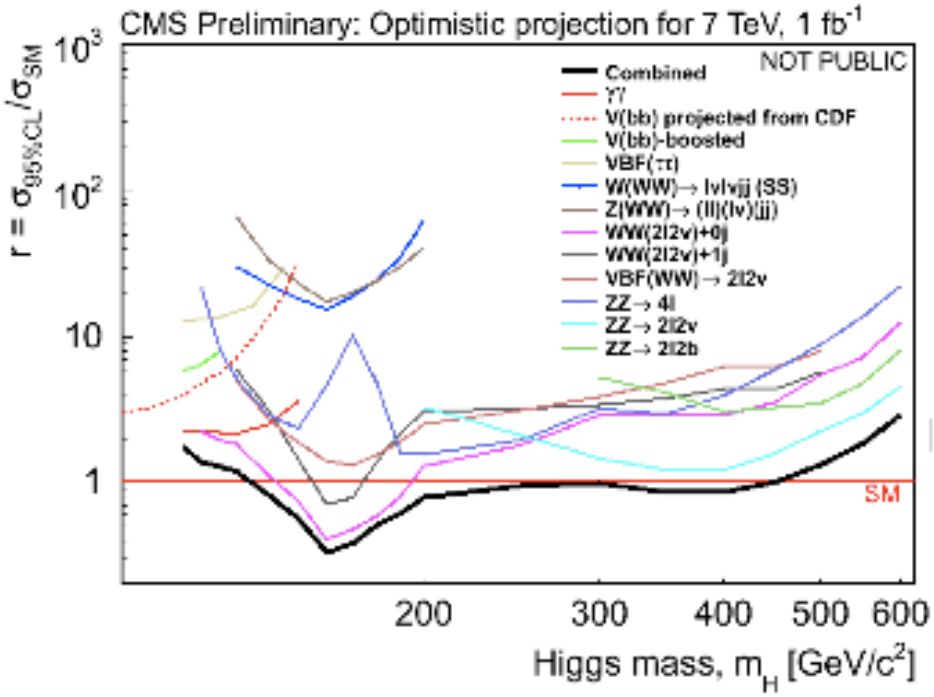
Good agreement between data and MC
Estimating tagging efficiency and mistag rate is critical for the 2l2b analysis

2l2ν & 2l2b : Next Steps

- 2l2ν and 2l2b studies are still at a nascent stage
- Need lots of work to mature into full blown analyses
- First priority – Develop robust techniques for estimating backgrounds from data
- Close monitoring of physics objects – MET, b-tagging, etc. absolutely essential
- With 150 pb-1 of data the 2l2ν mode an start excluding the SM Higgs in the 4th generation scenario
- This means we need to be ready with a complete analysis by March

What's In Store For 2011

- 2011 will be a crucial year for Higgs physics
- Quite a few new modes being actively pursued to improve Higgs sensitivity
- New modes show great promise but also require a lot of work to turn into full blown analyses
- Next year will see a flood of data
- A lot will depend on how quickly we can analyze this data



CMS has the potential to exclude Higgs from 130 GeV to 480 GeV all by itself with 1 fb-1 of data

Thank You !