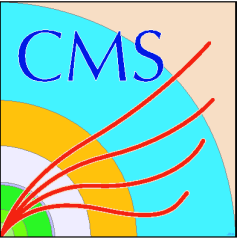
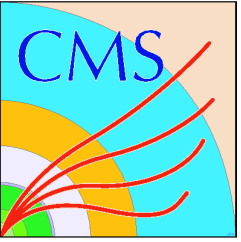


Higgs searches in CMS

July 23, 2012

Irakli Svintradze KSU

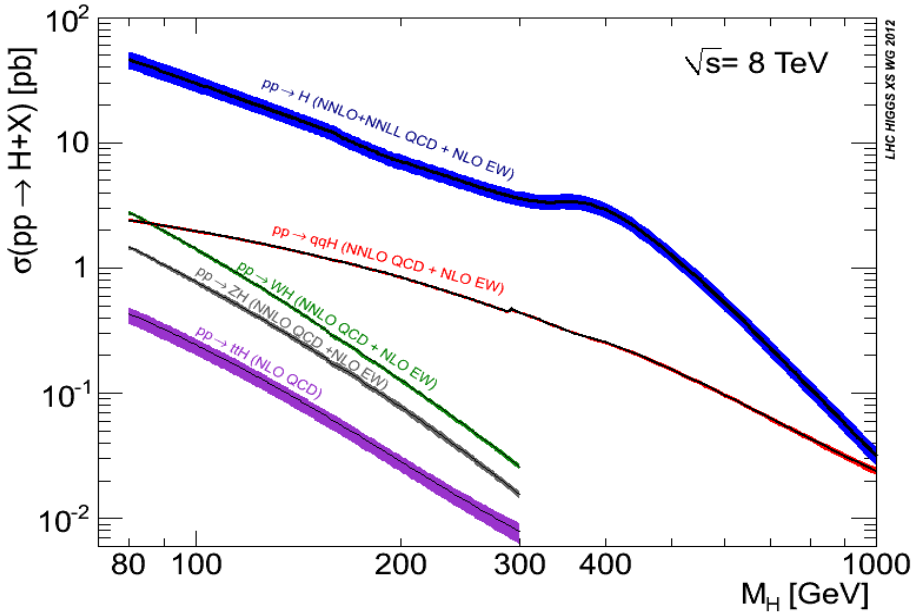
On a behalf of CMS collaboration

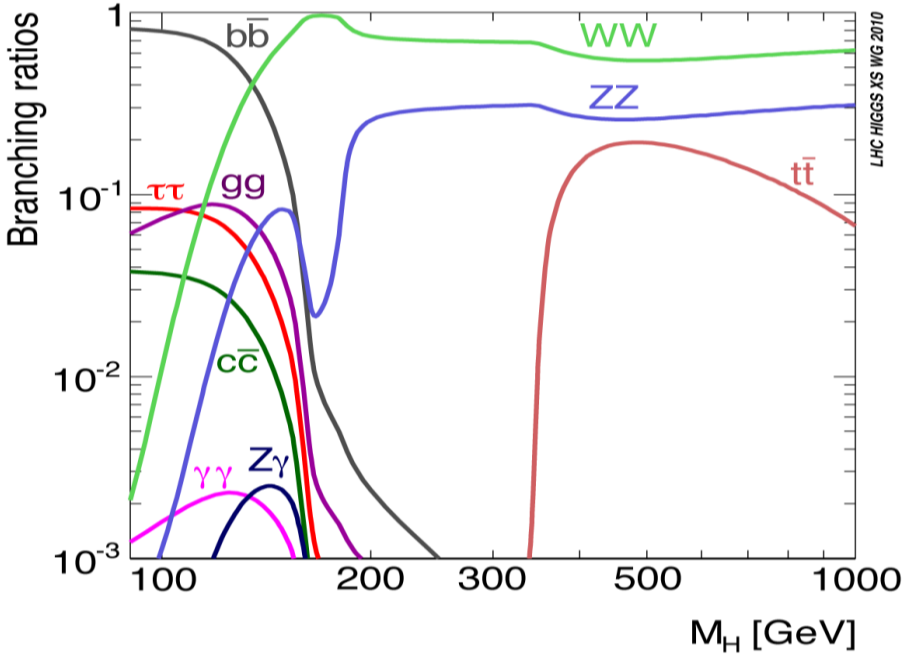


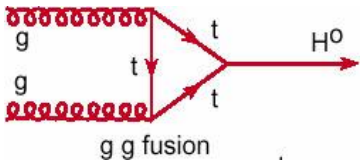
Introduction

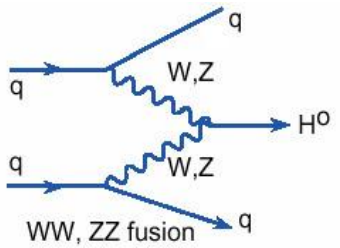
- One of the major goals of LHC experiments is to uncover mechanism responsible for electroweak symmetry breaking
- On 4th of July both ATLAS and CMS announced evidence of new particle that seems to be likely the evidence of Higgs boson
- This talk summarizes all important analysis public most up-to-date results done with CMS collaboration

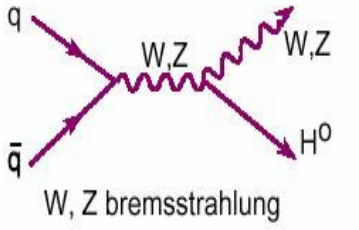
SM Higgs production rate and decay modes

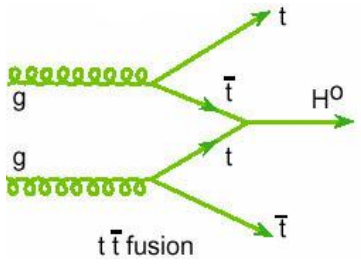






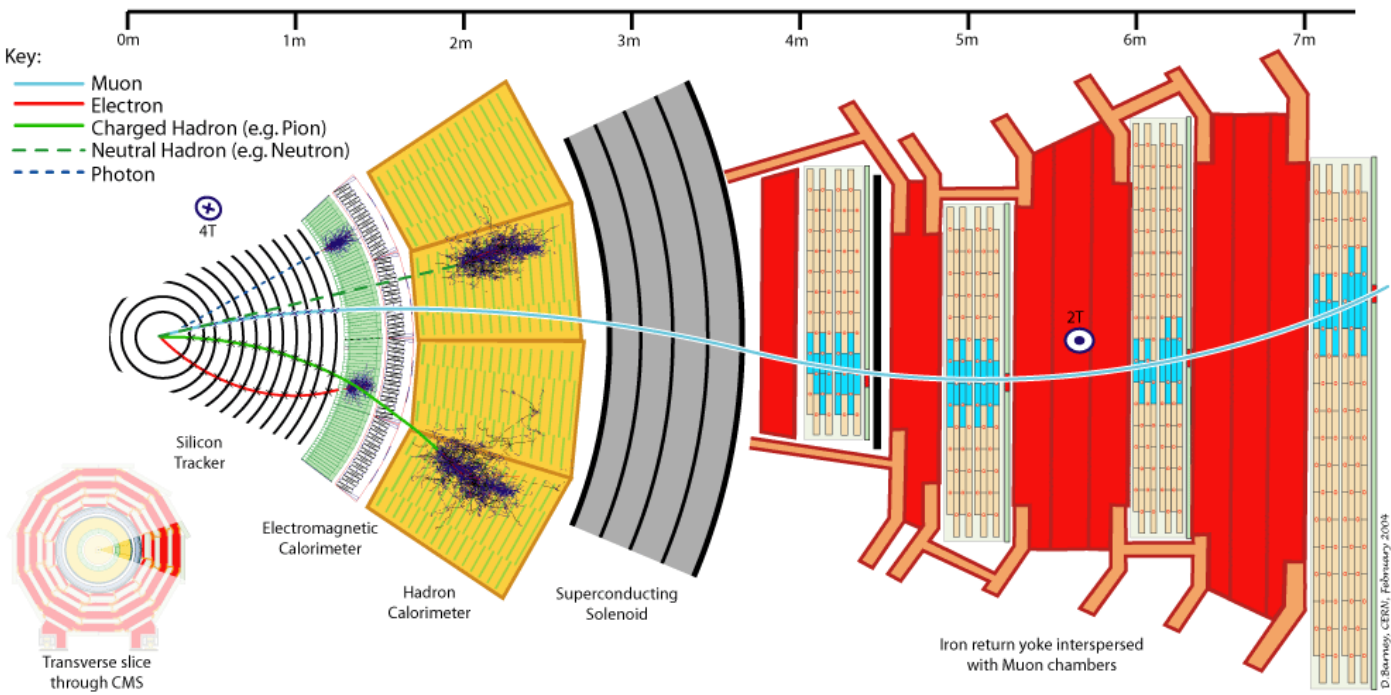






CMS detector

Total weight **14000 t**
Overall diameter **15 m**
Overall length **28.7 m**



Silicium pixel and strips
$|\eta|<2.4$

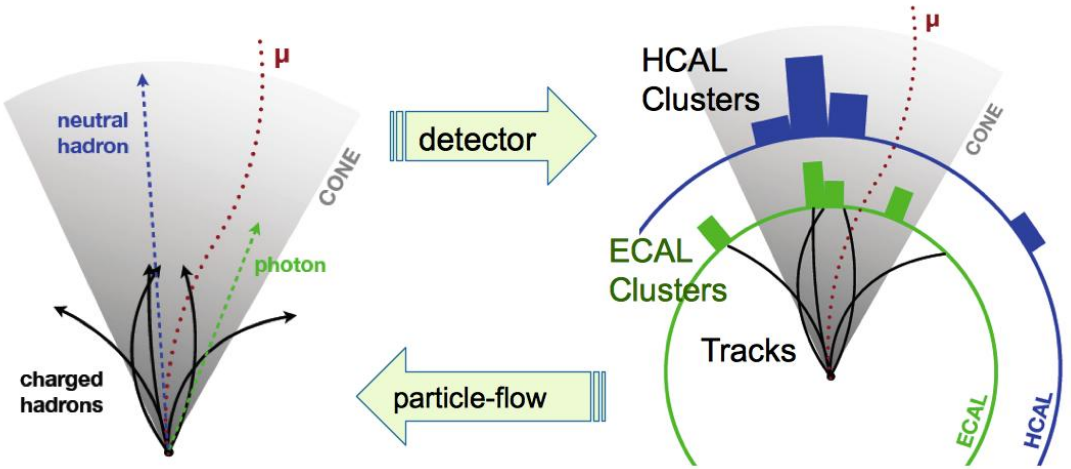
EM calorimeter:
76K $PbW0_4$ crystals
$|\eta|<3$

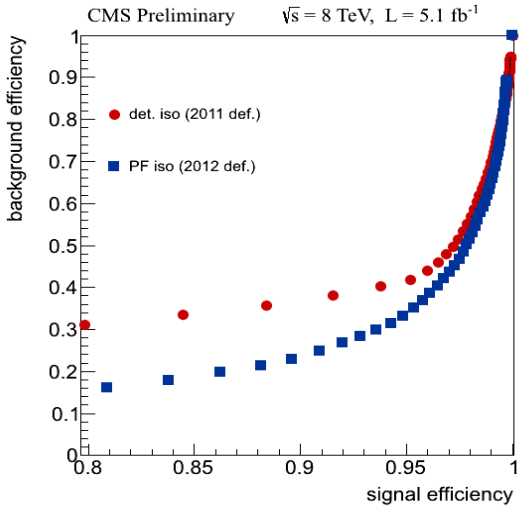
HCAL:
Scintillator/brass
Interleaved ~7k ch
$|\eta|<5$

Muon DT+ RPC
$|\eta|<2.4$

Particle Flow reconstruction

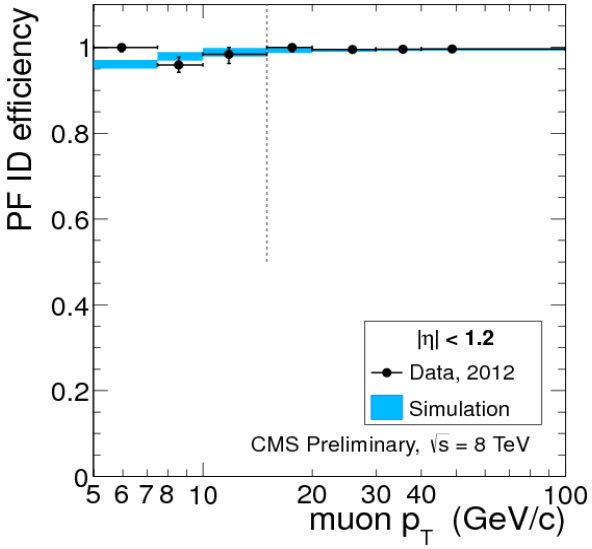
- High granularity and magnetic field makes new algorithms possible
  - Full information from all sub-detectors used
  - Reconstructs all particles in the event
  - Enables charged particle tagging from pile up
  - Improves lepton and photon isolations and missing E_T resolution

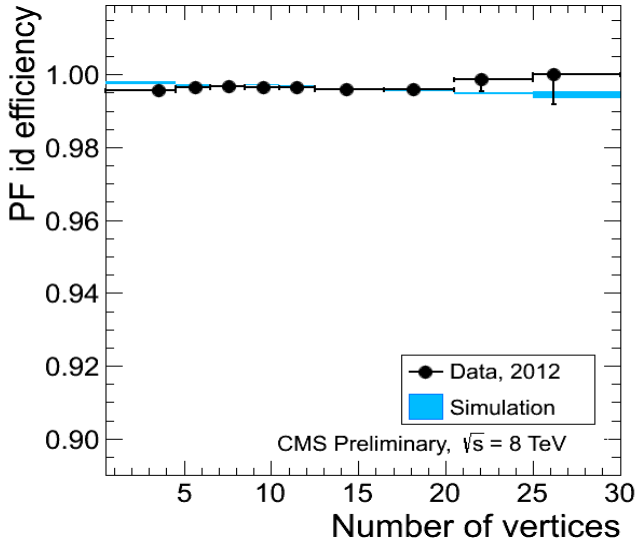


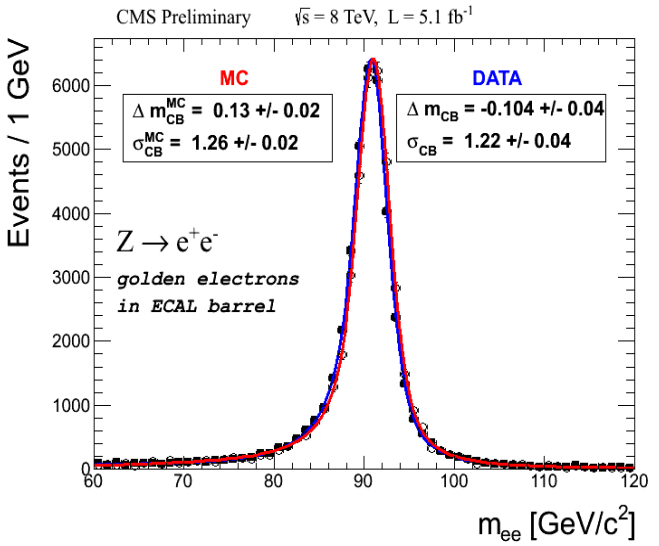


Calibration and modeling

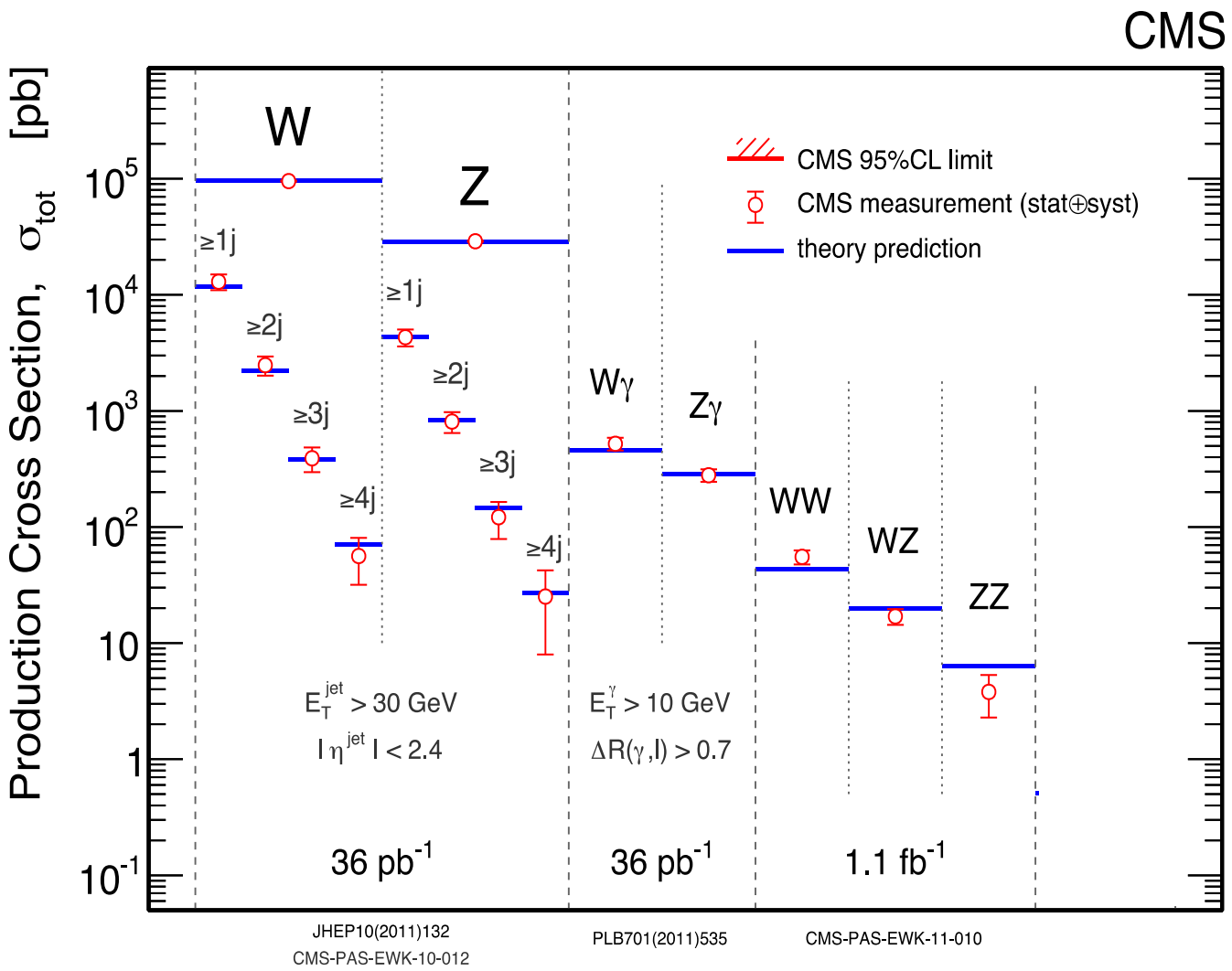
- Z and J/ψ to leptons extensively used
  - Lepton efficiency using tag-and-probe method
  - Energy scale and resolution well understood







Standard Model at 7 TeV 2010-2011

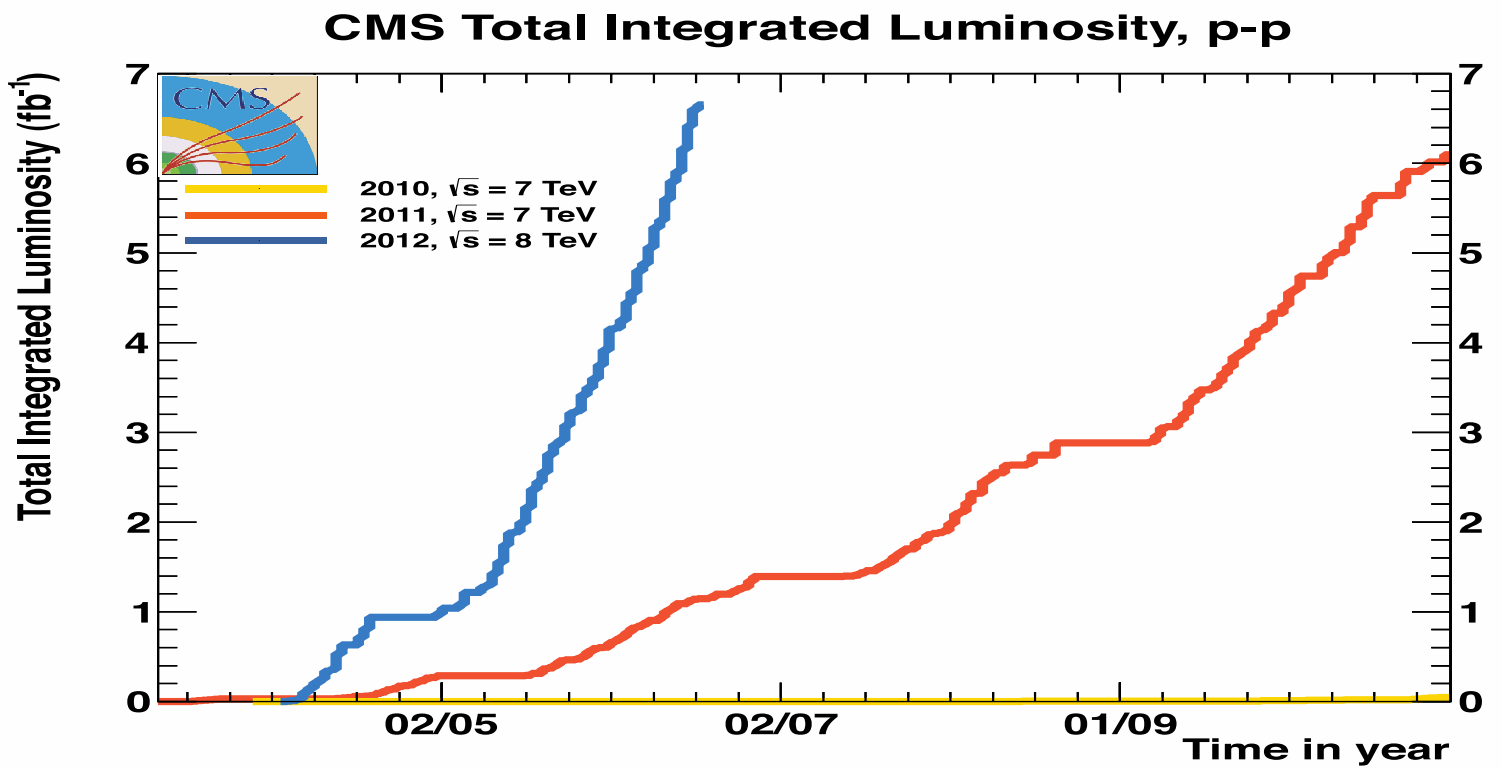


Standard model predictions well measured

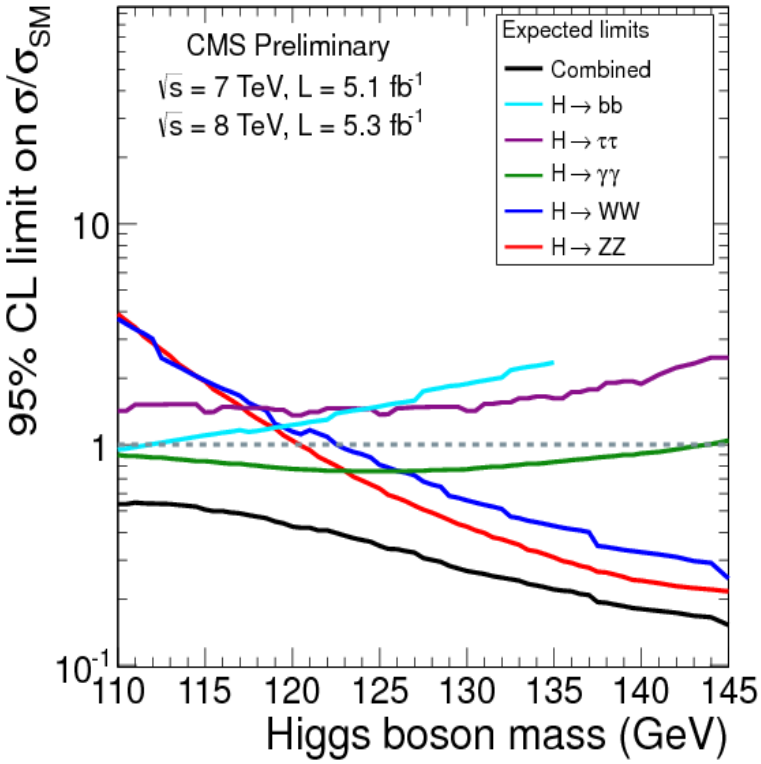
7

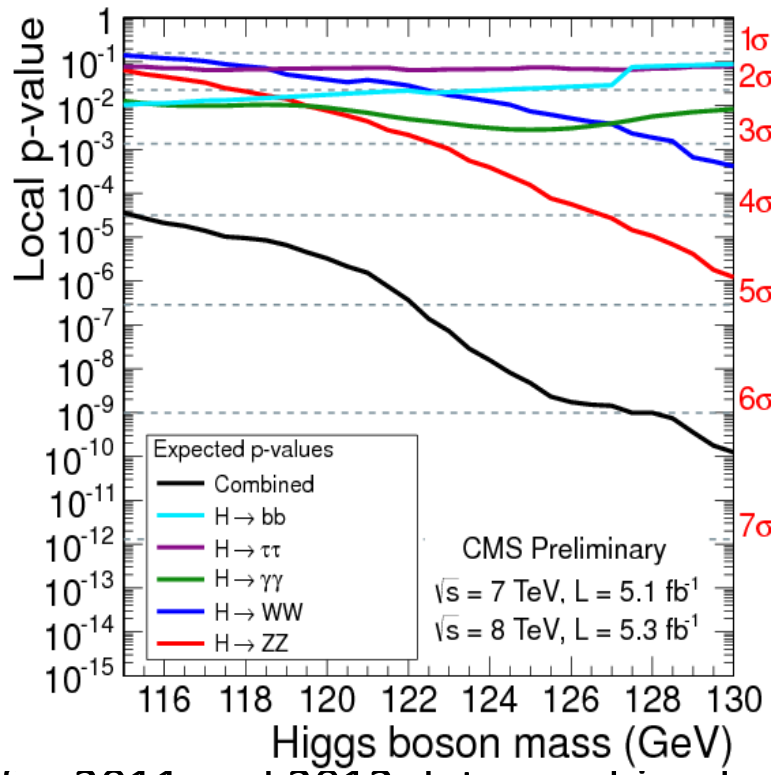
Data gathered at LHC

- Instantaneous luminosity challenged 7×10^{33}
  - 20-30 pile-up interactions per bunch crossing
  - 7 TeV and 8 TeV data 5 fb^{-1} each run

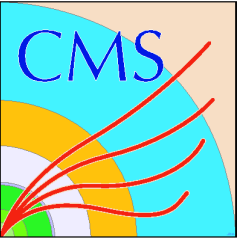


Exclusion or discovery





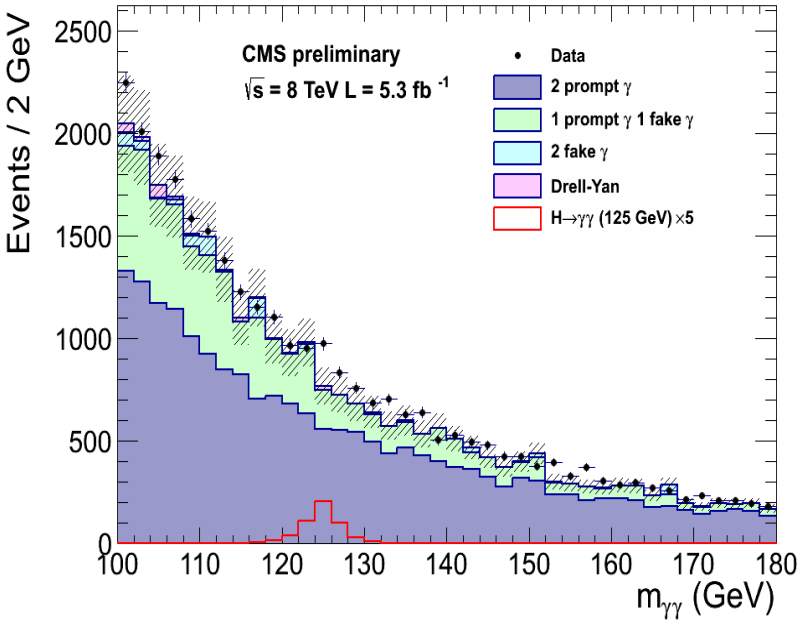
- Hard work presenting combined results for 2011 and 2012 data combined for all channels
  - Most sensitive to low-mass Higgs search: $\gamma\gamma$, *ZZ*
  - Very important, but less mass resolution: *bb*, *WW*, $\tau\tau$
- this talk you will concentrate on two former ones and will summarize the latter three



$$H \rightarrow \gamma\gamma$$

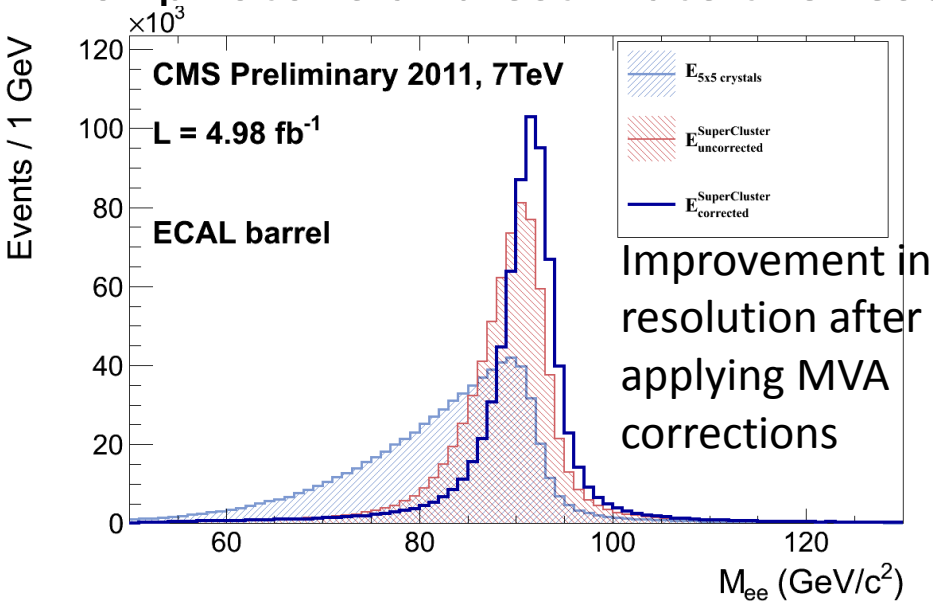
Overview

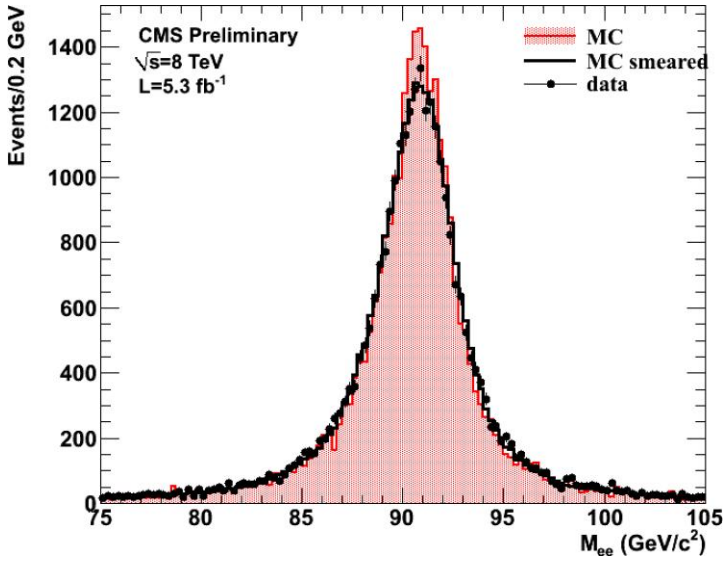
- Narrow mass peak
- Sensitivity improvement
  - Energy scale and resolution
  - MVA based photon ID
  - Di-photon mass MVA
  - Event categorization by jet multiplicity
  - Vertex identification
- Results cross checked with cut bases analysis



Photon Energy Scale and Resolution

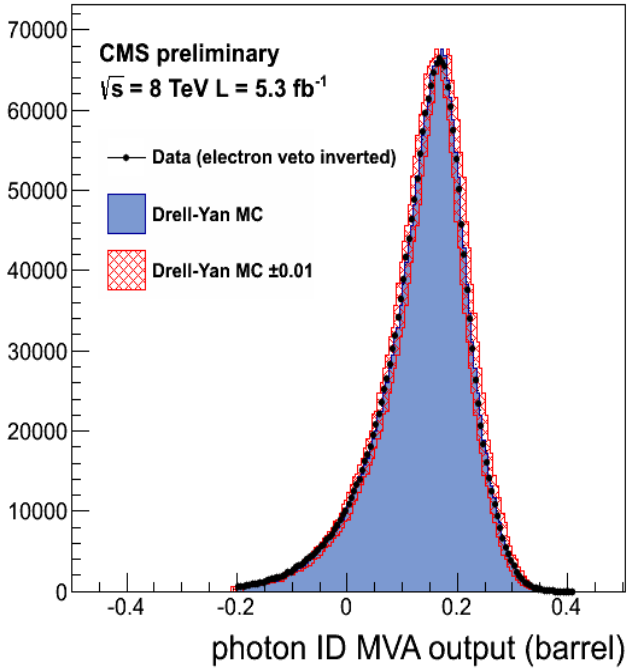
- MC trained multivariate regression to correct energy depositions in ECAL
  - Improves resolution
  - Flat response of energy scale as a function of pileup
- Use Z→ee data and electron/photon MC to infer energy scale for photons and estimate the resolution

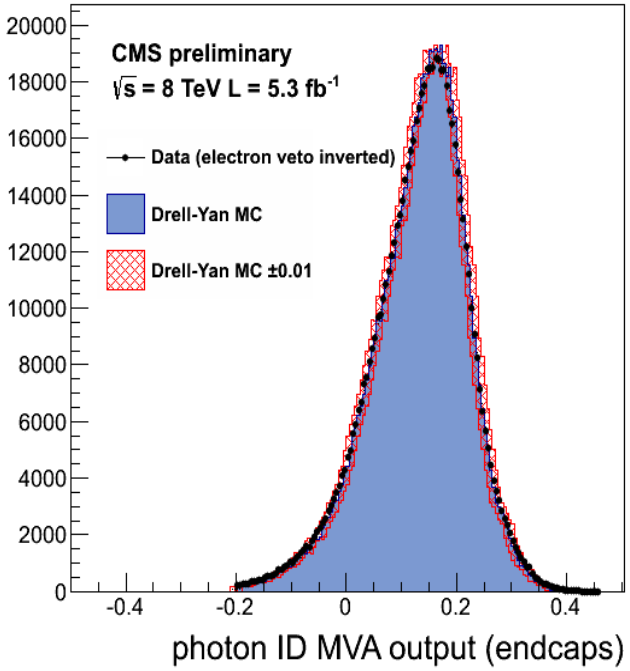




Photon identification

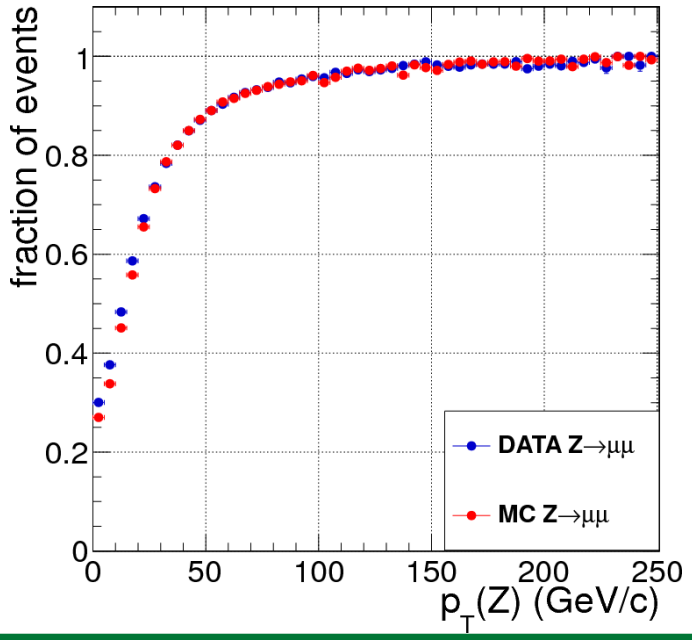
- **Uses PF isolation**
- **MVA output discriminates true photons from fakes:**
  - Inputs: isolation, shower shape, per event energy density, pseudo-rapidity
  - Efficiency measured using tag and probe with Z→ee

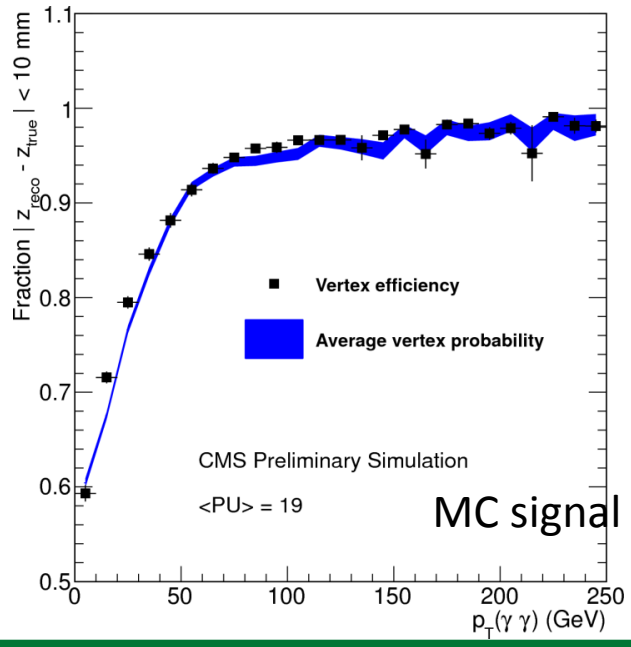




Vertex identification

- Finer the correct position of the primary vertex – the better di-photon mass resolution
- Using Boosted Decision Tree (BDT)
  - Input variables: Σp_t^2, Σp_t projected onto the γγ transverse direction, p_t asymmetry and conversions
  - Correct identification for 80% of PU events

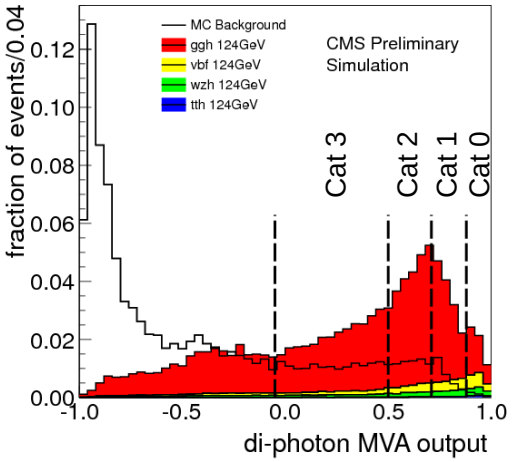


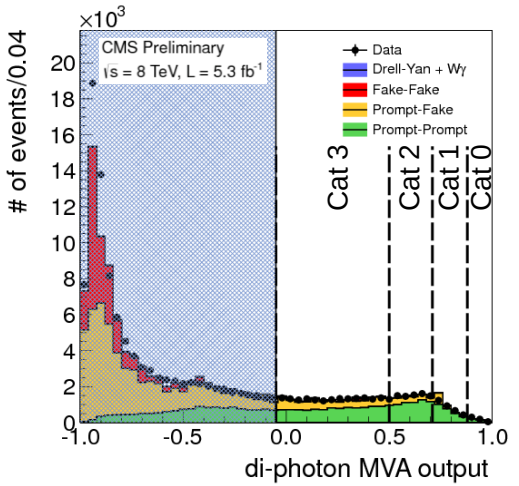


MC signal (120)

Di-photon MVA

- Encode all information into single di-photon MVA and trained on signal and background MC with input variables largely independent of $m_{\gamma\gamma}$
  - Kinematics: p_T and η of each photon, and $\cos\Delta\phi$ between the 2 photons
  - Photon ID MVA output for each photon
  - Vertex probability
- Only discrepancy in background region excluded from analysis (shaded)

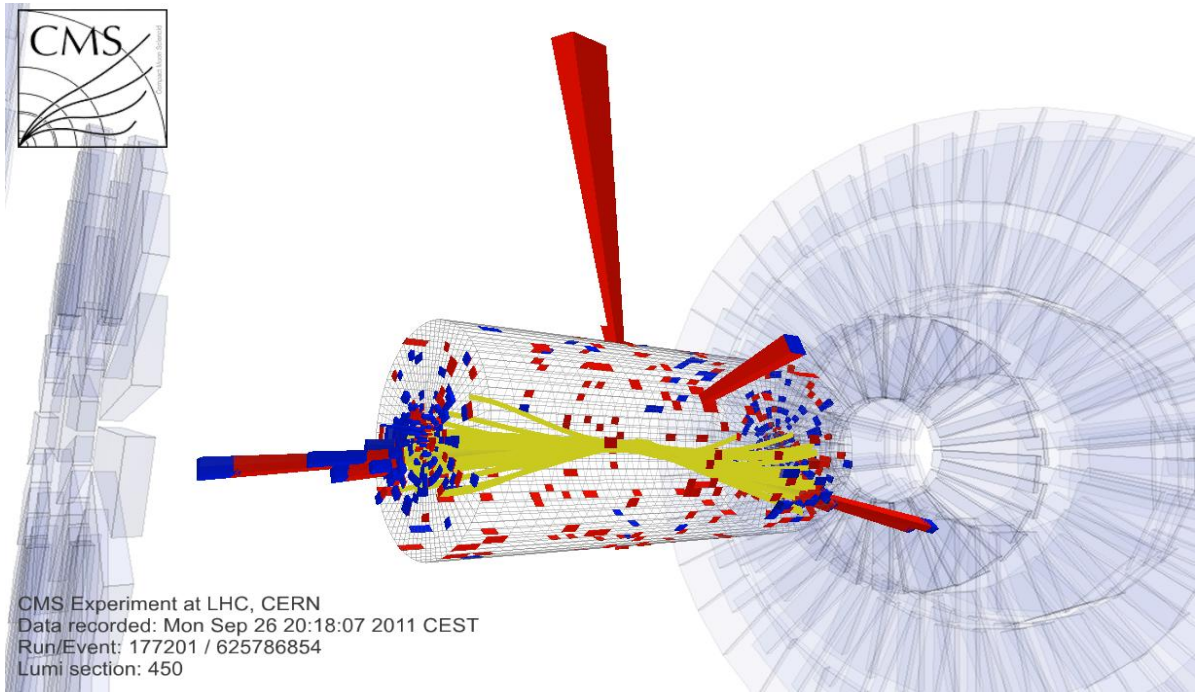




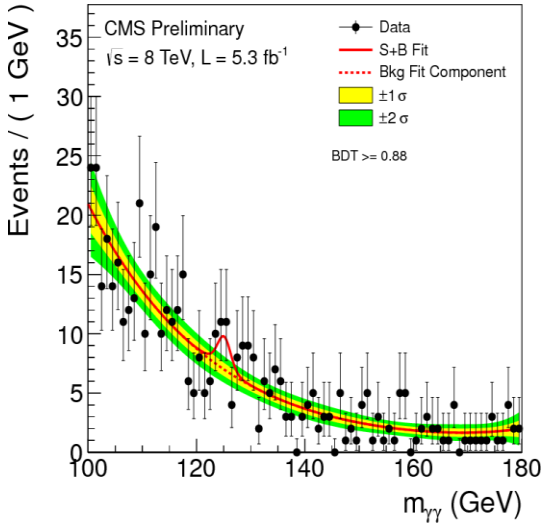
Di-jet Tagging

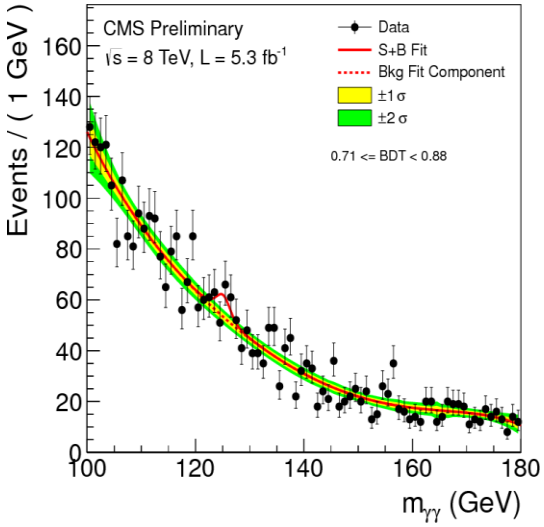
- VBF like topology
  - Two forward high p_T jets with large invariant mass
- High S/B
  - 10% improvement to sensitivity

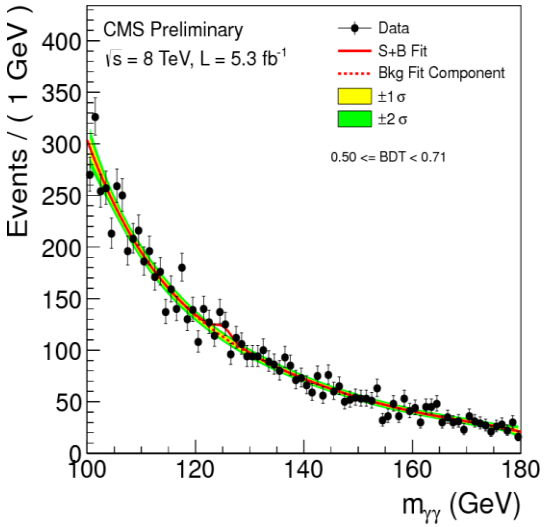
Di-jet event with:
- diphoton mass 121.9 GeV
- dijet mass 1460 GeV
- jet p_T: 288.8 and 189.1 GeV
- jet η: -2.022 and 1.860

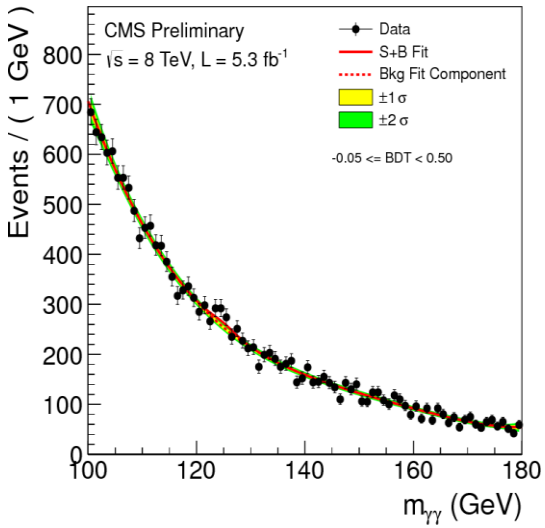


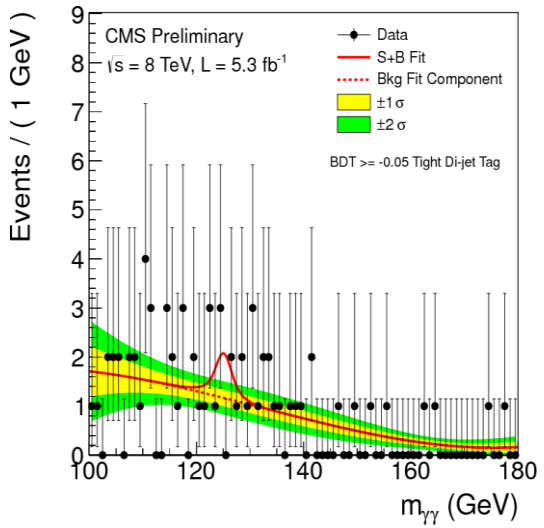
Mass Distribution in Categories

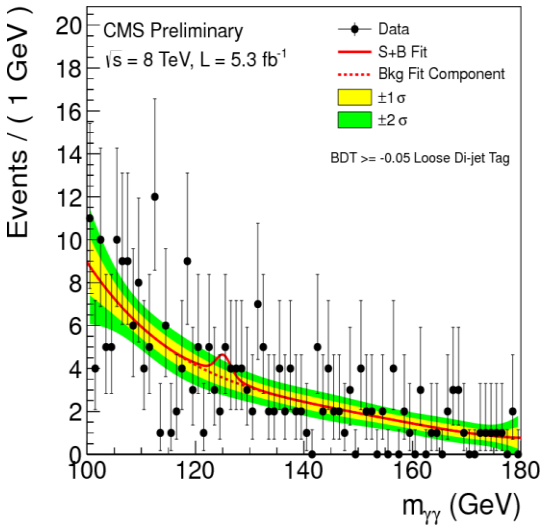






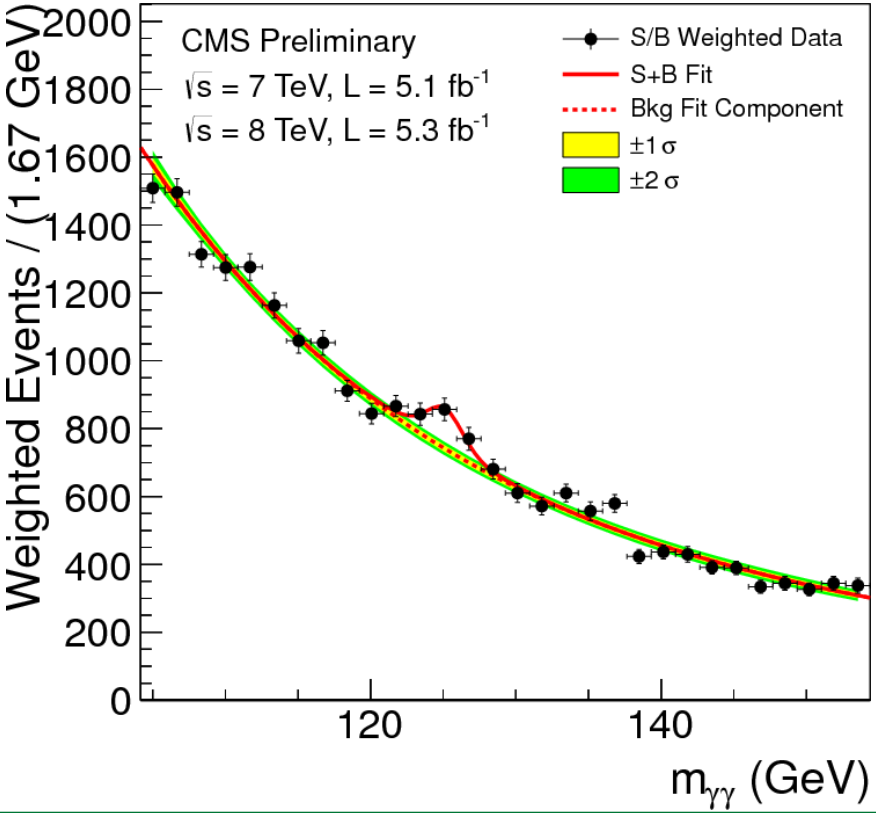


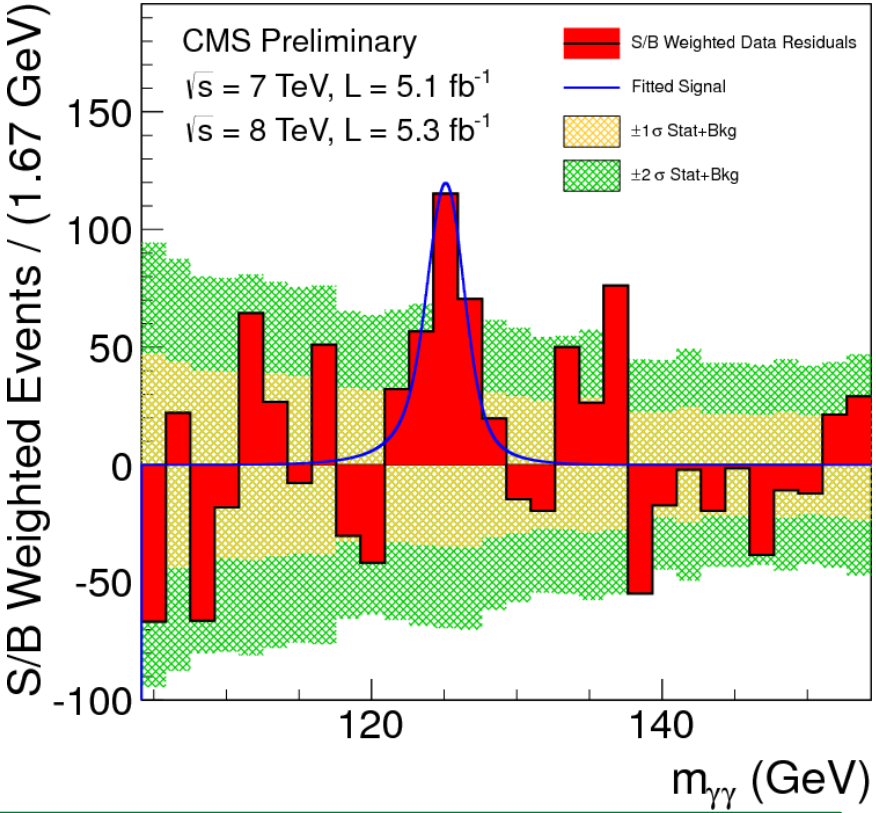




S/B Weighted Mass Distribution

- Sum of mass distributions for all event classes weighted by *S/B*
  - B is integral of background model over a constant signal fraction interval

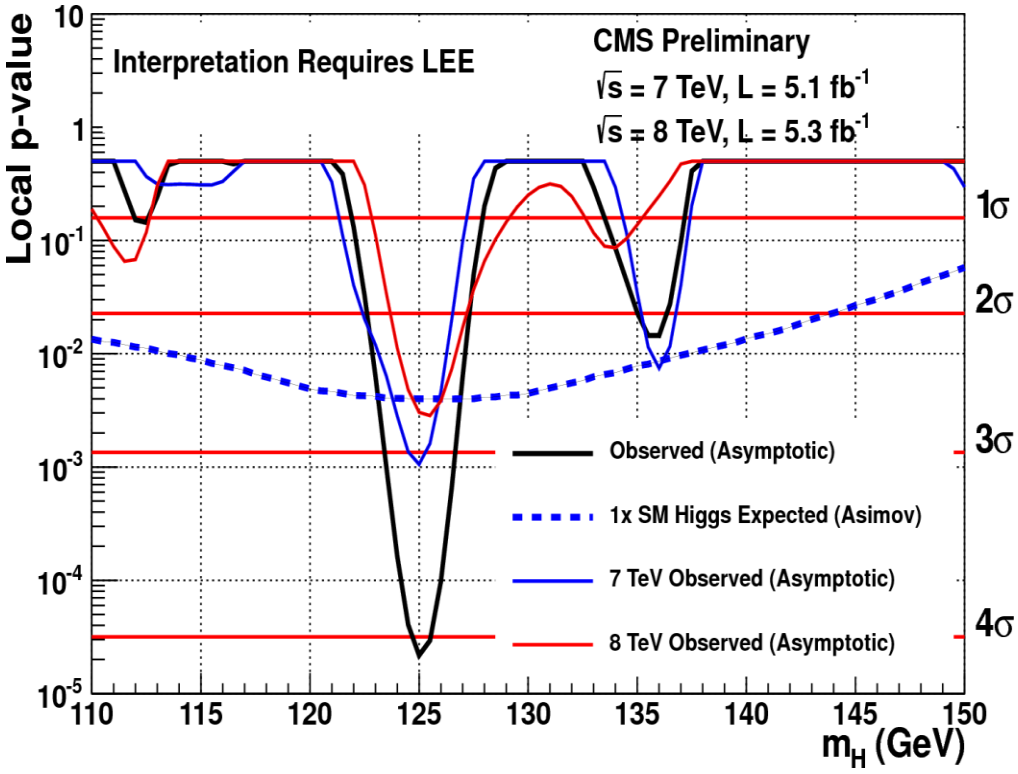


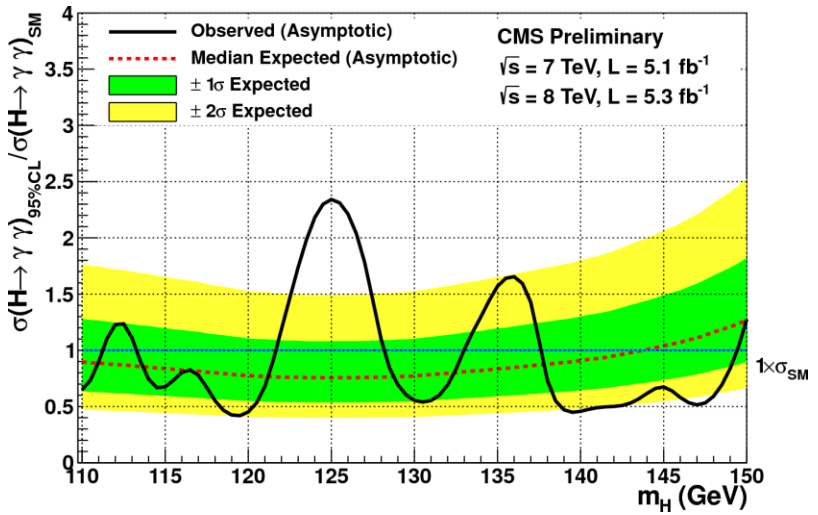


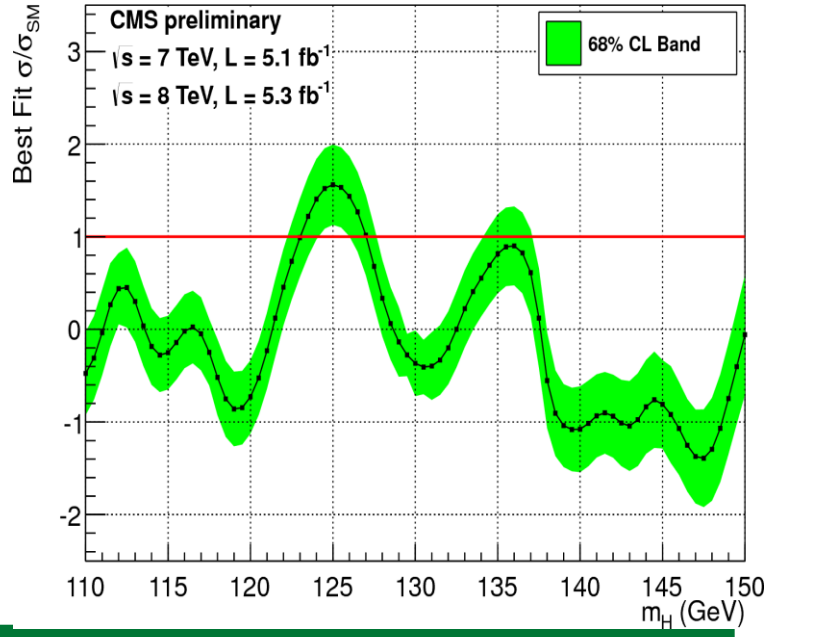
Results

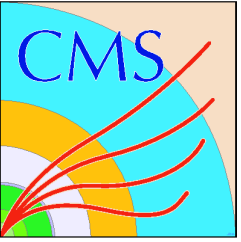
Local significance 4.1σ.

Signal strength 1.6 ± 0.4 × σ_{SMH}





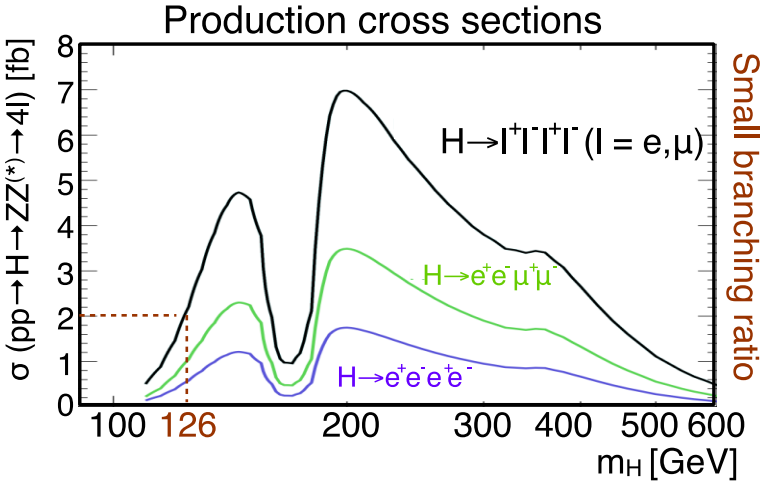


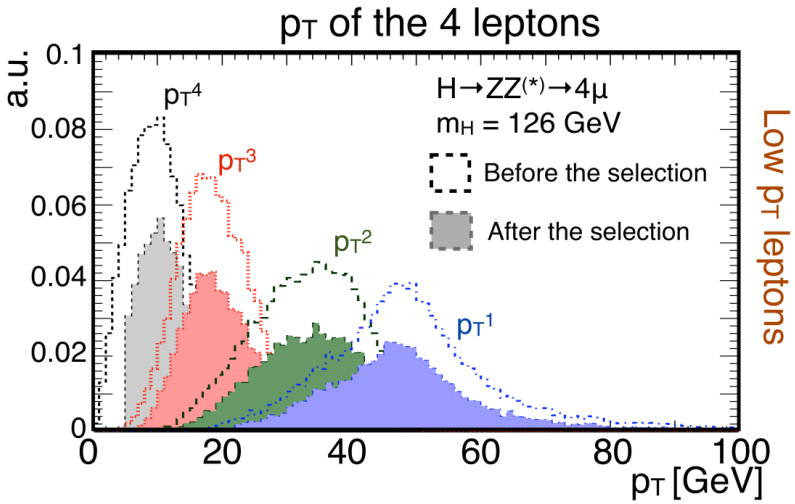


$H \rightarrow ZZ$

Overview

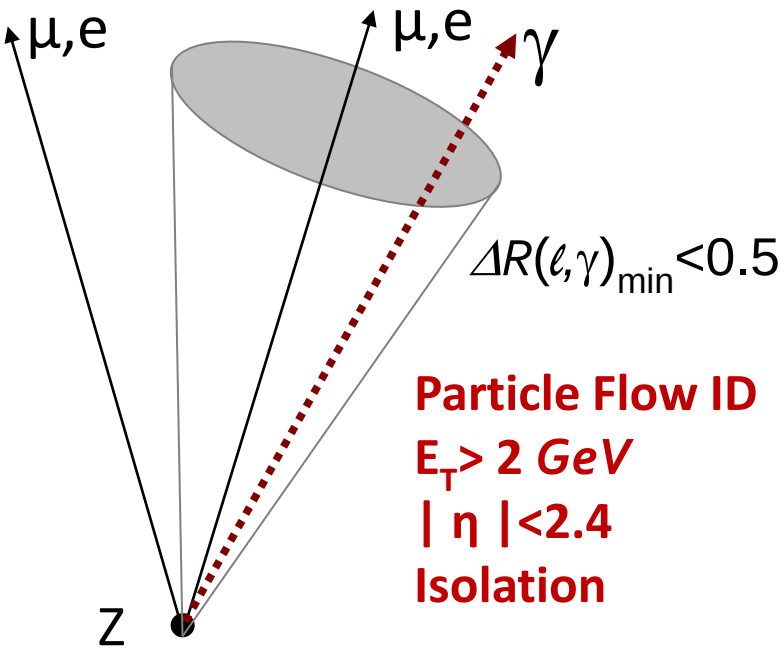
- Clean signature
  - High S/B and narrow peak
- Sensitive to selection efficiency
  - PF lepton ID and isolation
  - MVA
  - Final State Radiation (FSR) recovery
  - Angular information used to discriminate signal from irreducible ZZ background
    - 2D analysis: m4l + Kinematic Discriminant
  - Sensitivity gain 20% compared to 2011



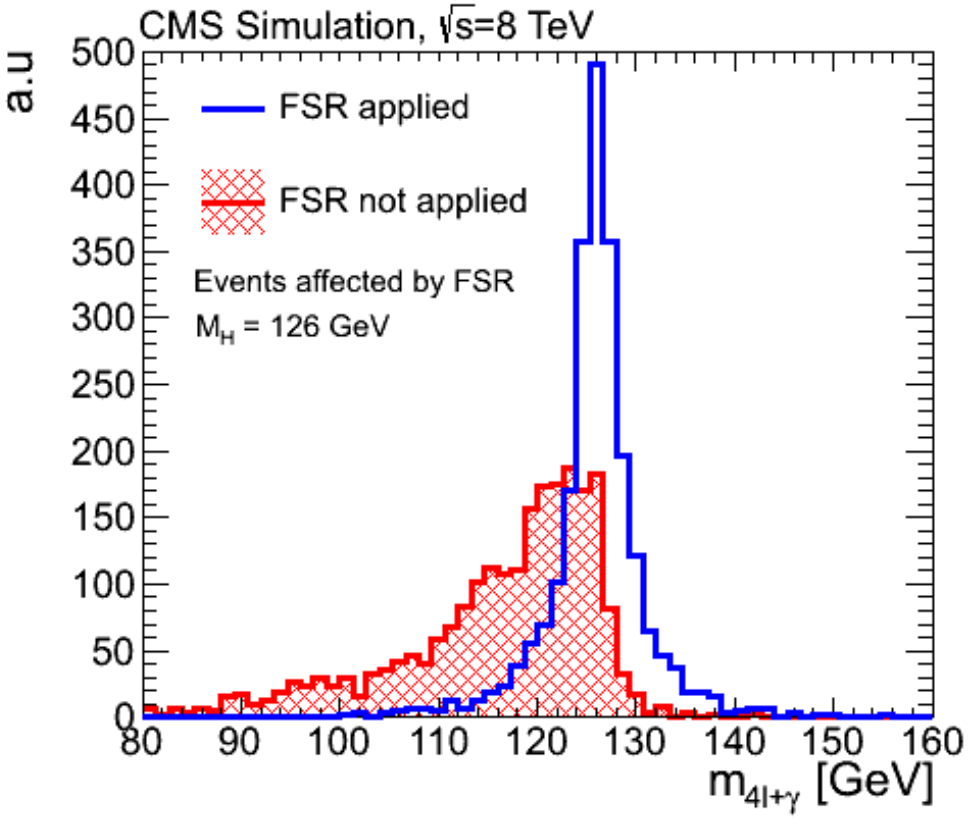


Final State Radiation recovery algorithm

- Applied on each *Z* for photons near the leptons

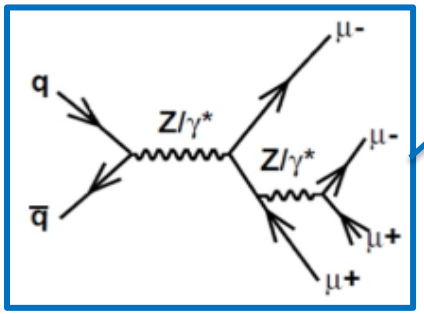


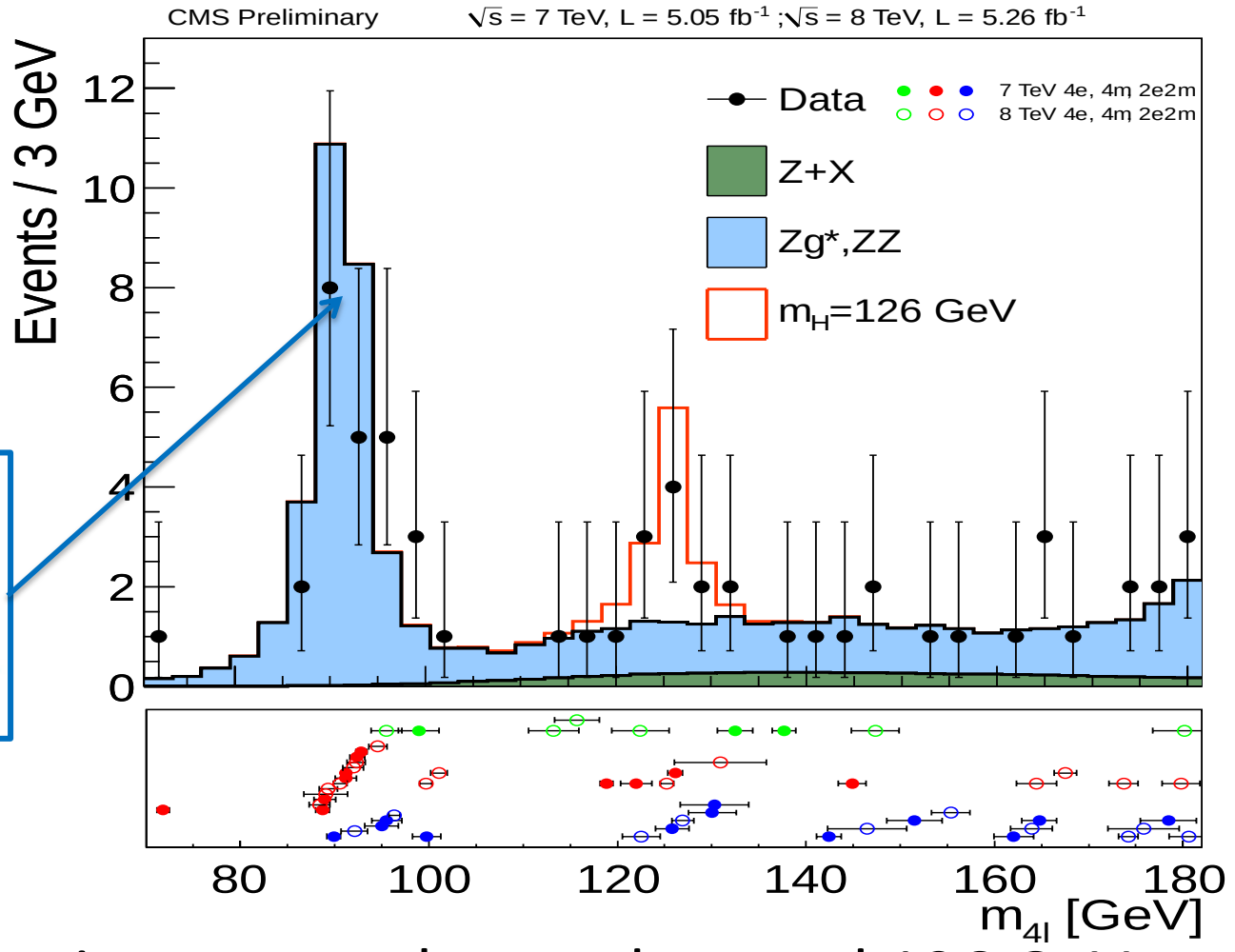
Particle Flow ID
E_T> 2 *GeV*
| η |<2.4
Isolation



- Associates photon with *Z* if:
  - $M(\ell\ell+\gamma)$< 100 *GeV*
  - $|M(\ell\ell+\gamma)-M_Z|<|M(\ell\ell)-M_Z|$
- Associated photon is removed from lepton isolation calculation

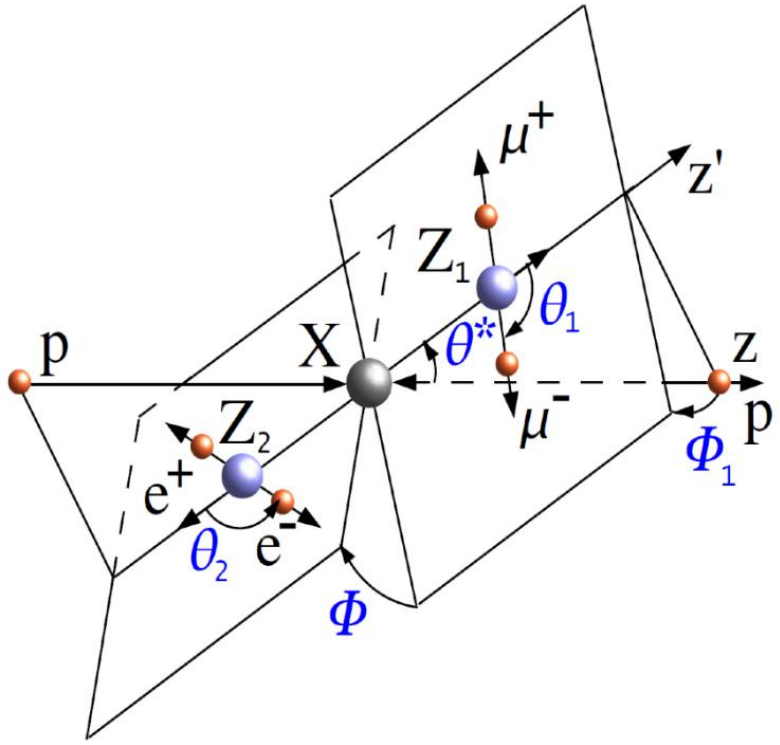
ZZ mass spectrum





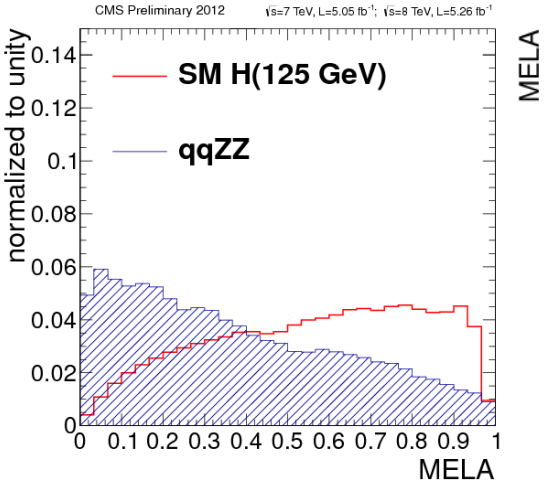
Excessive events observed around 126 GeV

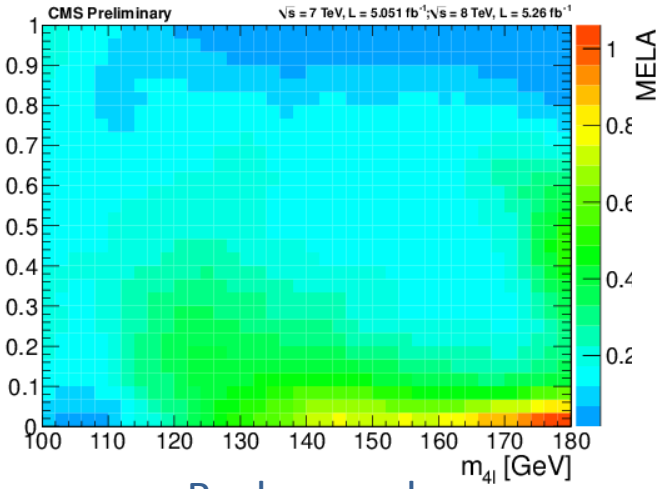
MELA



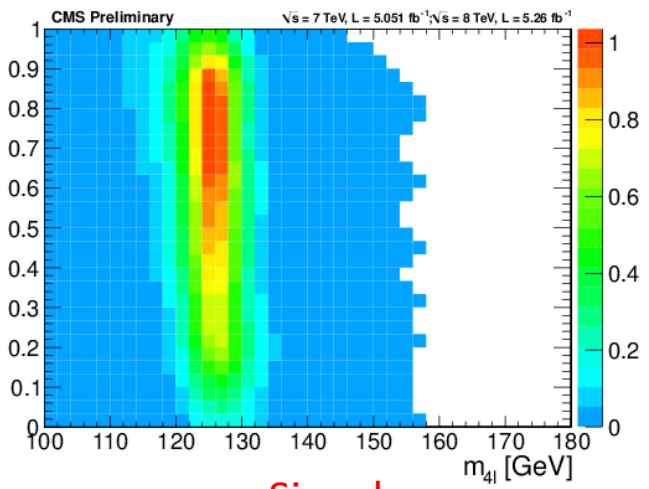
Matrix Element Likelihood Analysis:
uses kinematic inputs for
signal to background discrimination
$\{m_1, m_2, \theta_1, \theta_2, \theta^*, \Phi, \Phi_1\}$

$$\mathrm{MELA} = \left[1 + \frac{\mathcal{P}_{\mathrm{bkg}}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}{\mathcal{P}_{\mathrm{sig}}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}\right]^{-1}$$



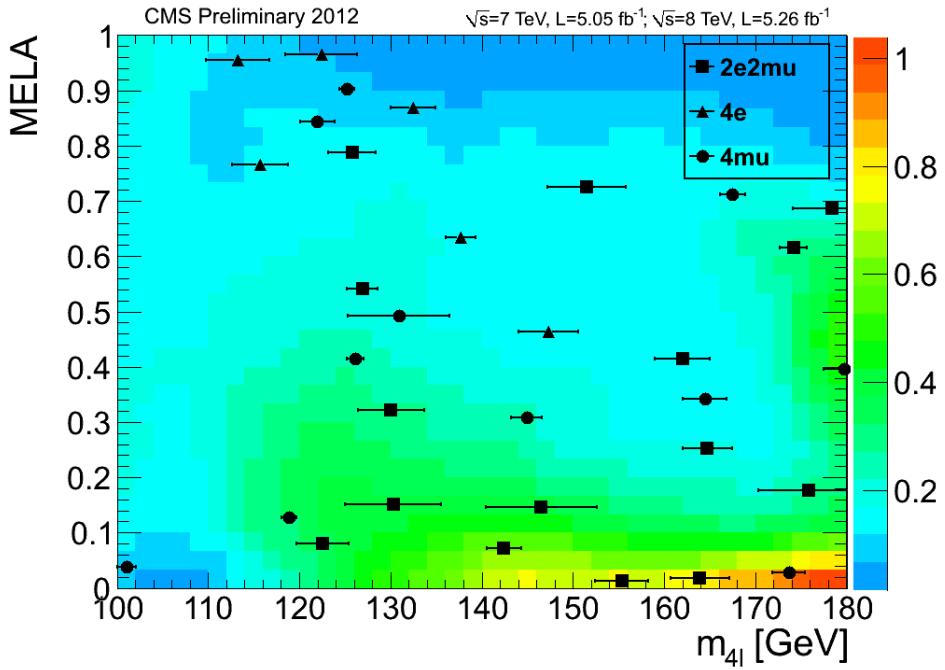


Background



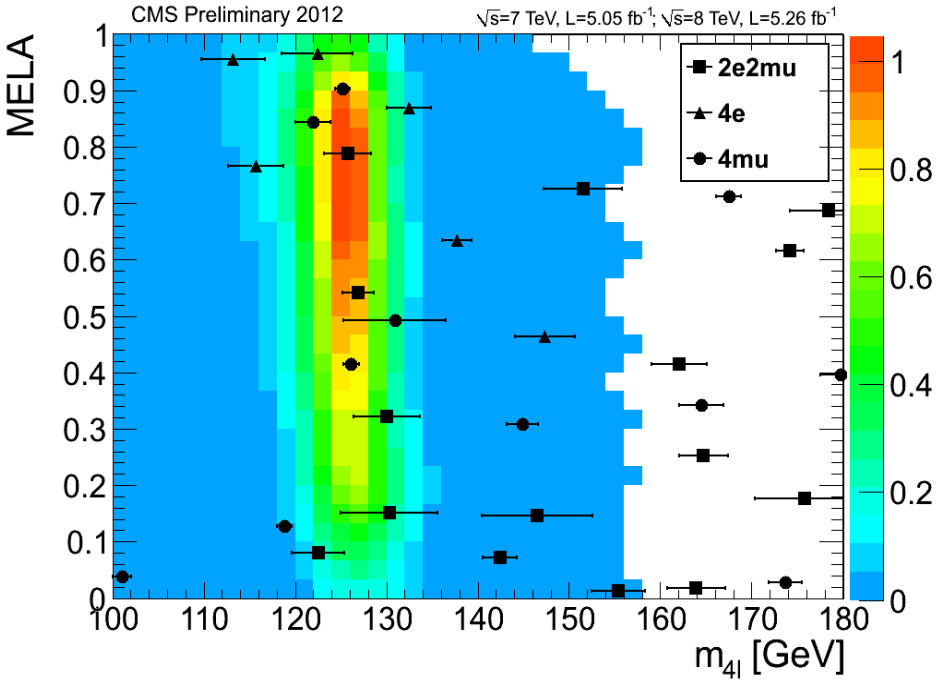
Signal

2D fit with MELA

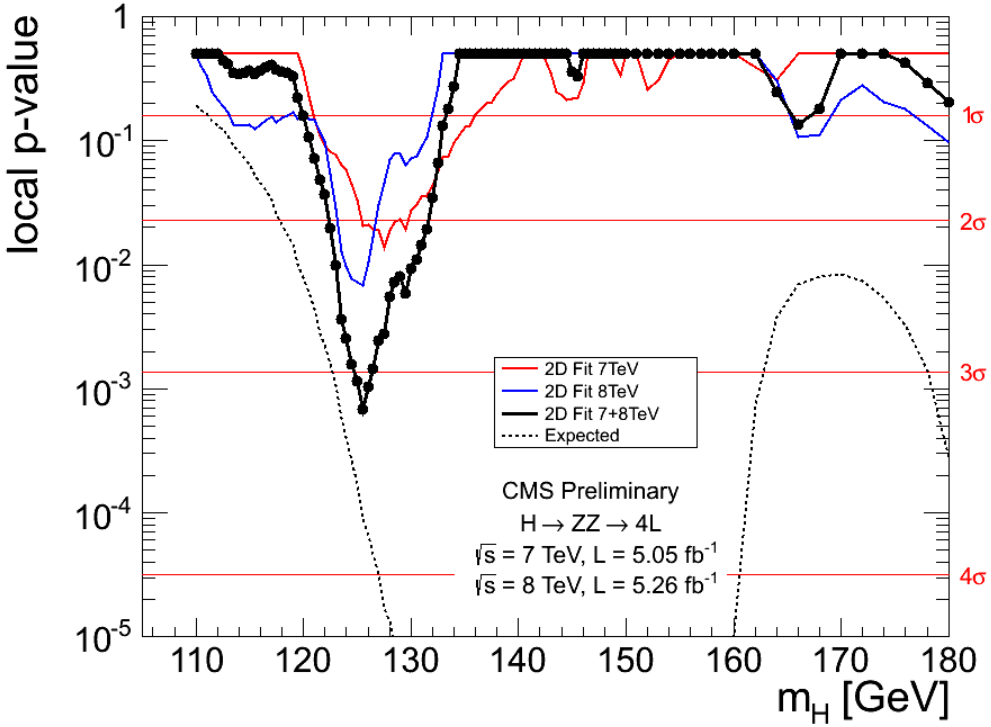


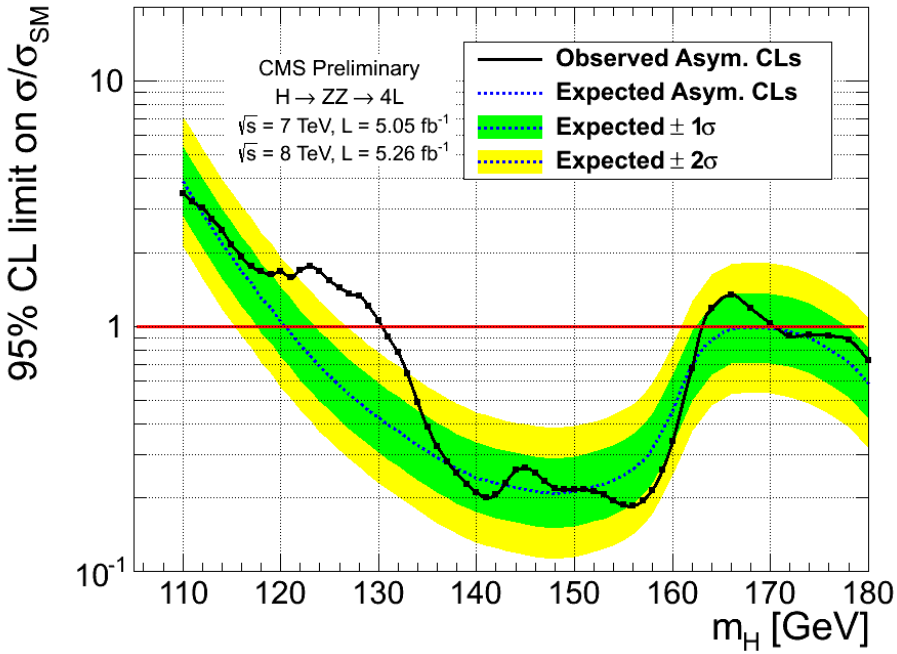
Data overlaid with background

Data overlaid with signal



Results



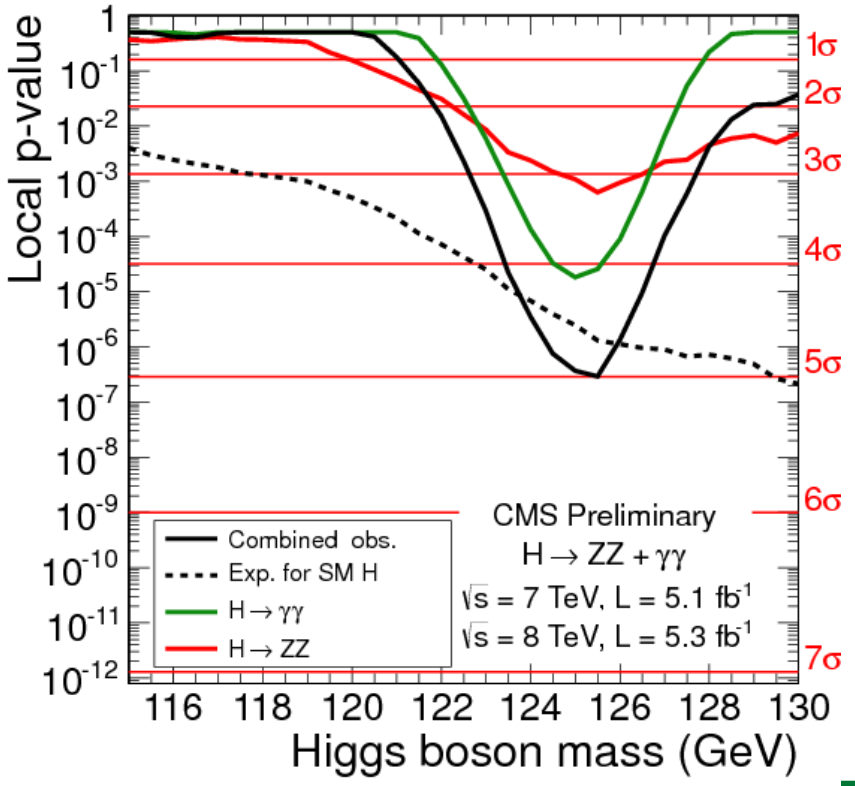


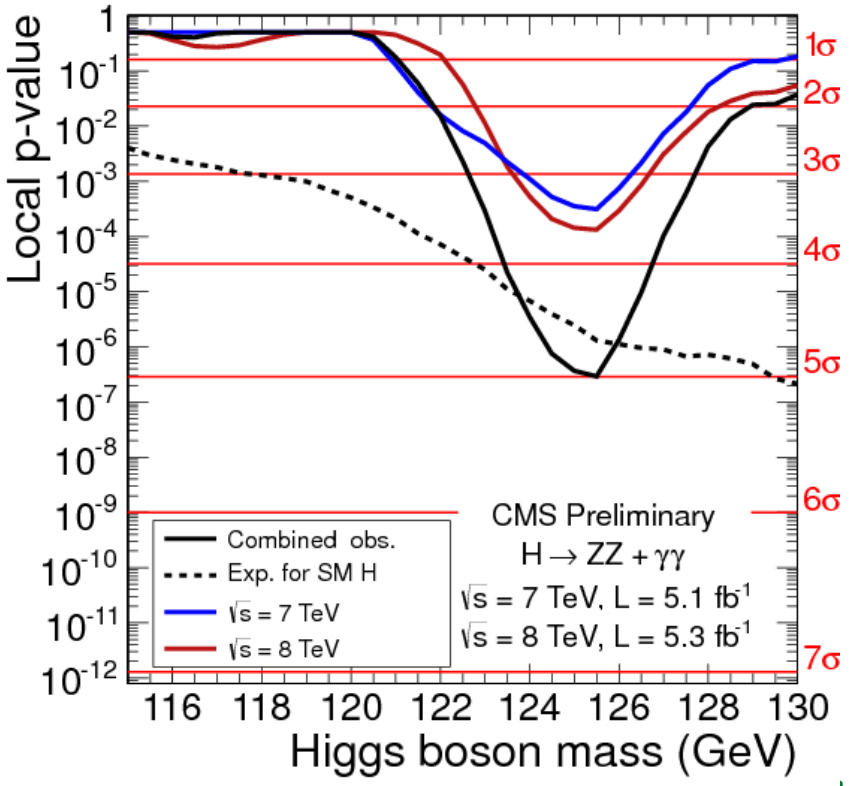
Local significance 3.2σ
expected from SM H: 3.8σ

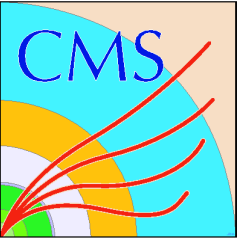
Combined ZZ and $\gamma\gamma$ Results

Local significance 5.0σ

Expected from SM H: 4.7σ







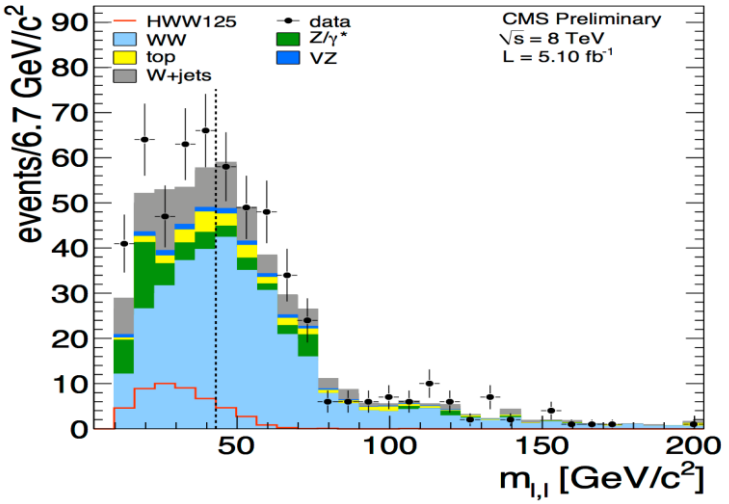
$H \rightarrow WW$

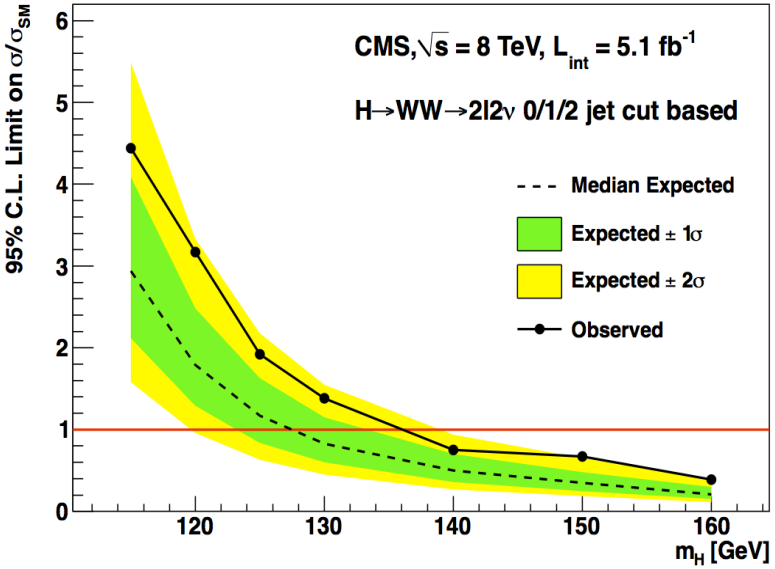
$H \rightarrow bb$

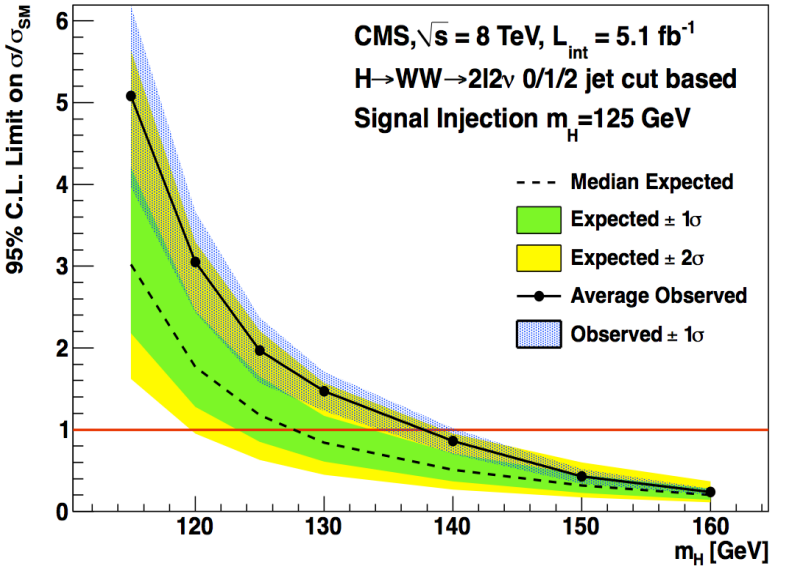
$H \rightarrow \tau\tau$

$H \rightarrow WW \rightarrow \ell\nu\ell\nu$

- Two leptons and large missing transverse energy
- Categorized in exclusive jet multiplicity
- A cut and count analysis
- **1.5σ excess compatible with SM Higgs expectation givem poor resolution**

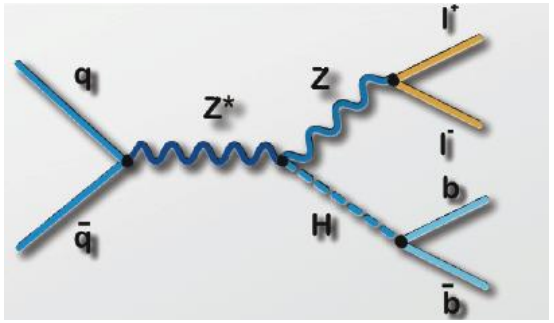


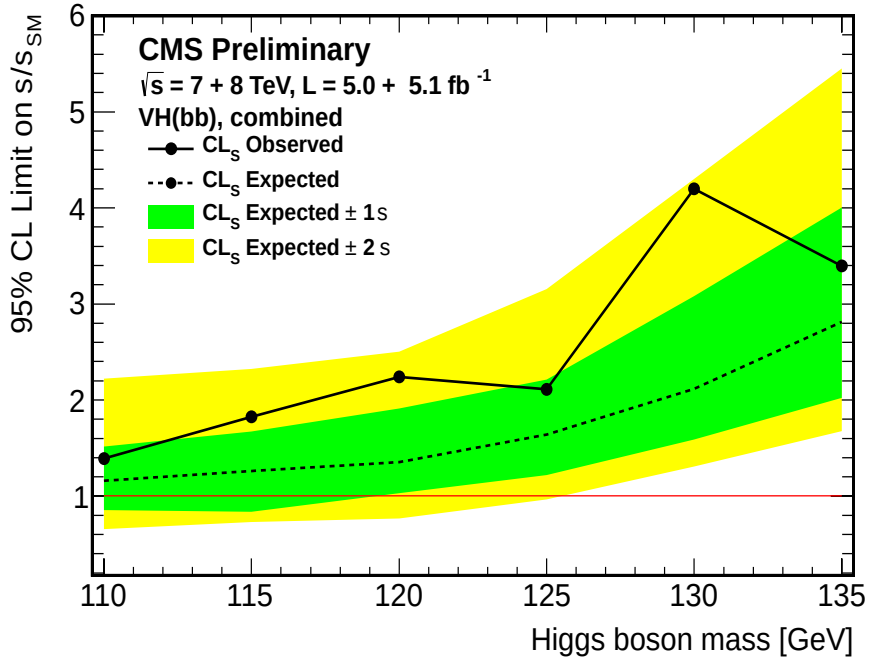




$VH \rightarrow Vbb$, $V \rightarrow \ell\nu, \ell\ell, \nu\nu$

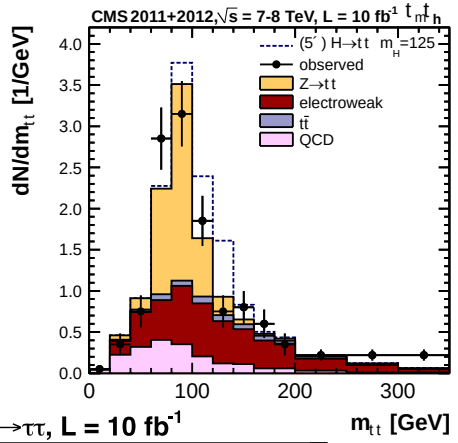
- Largest Br for light Higgs model, but also has huge background
- Associated Production
- final states with leptons, MET and b-jets
  - 5 channel
    - Z(ll)H(bb), Z(νν)H(bb), W(lν)H(bb)
- Backgrounds
  - QCD, ttbar, W/Z+ light jets
  - V+bb, ZZ(bb), WZ(bb)
- **Compatible with either background or signal from 125 GeV Higgs**

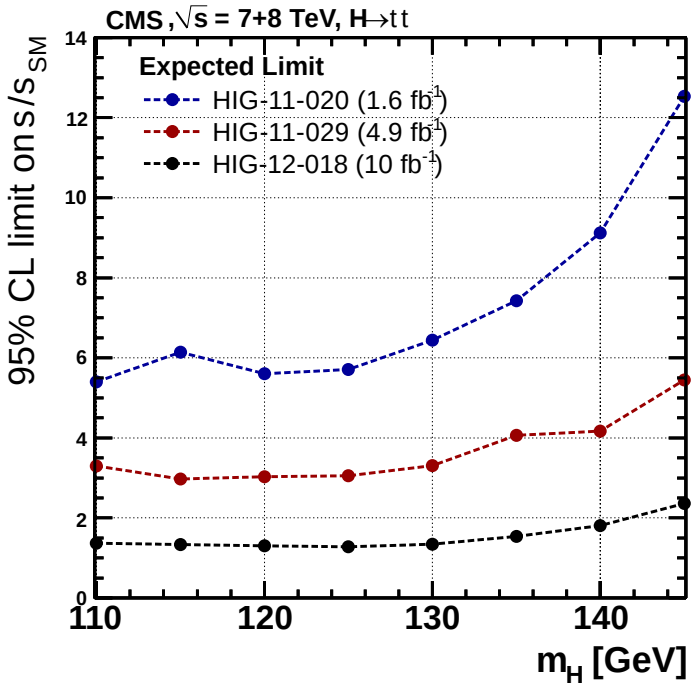


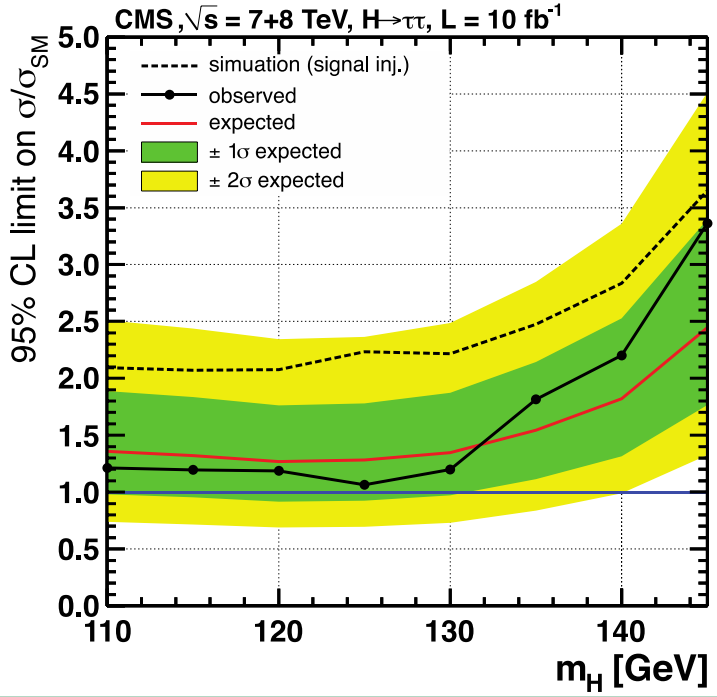


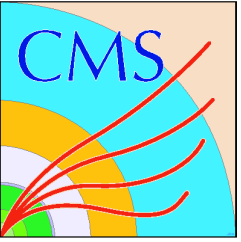
$H \rightarrow \tau\tau \rightarrow \mu\tau_h$, $e\tau_h$, $e\mu$, $\mu\mu$

- Sensitive to all production modes
- Probes coupling to leptons
- Very challenging large backgrounds
- **No excess could indicate non-SM Higgs…**



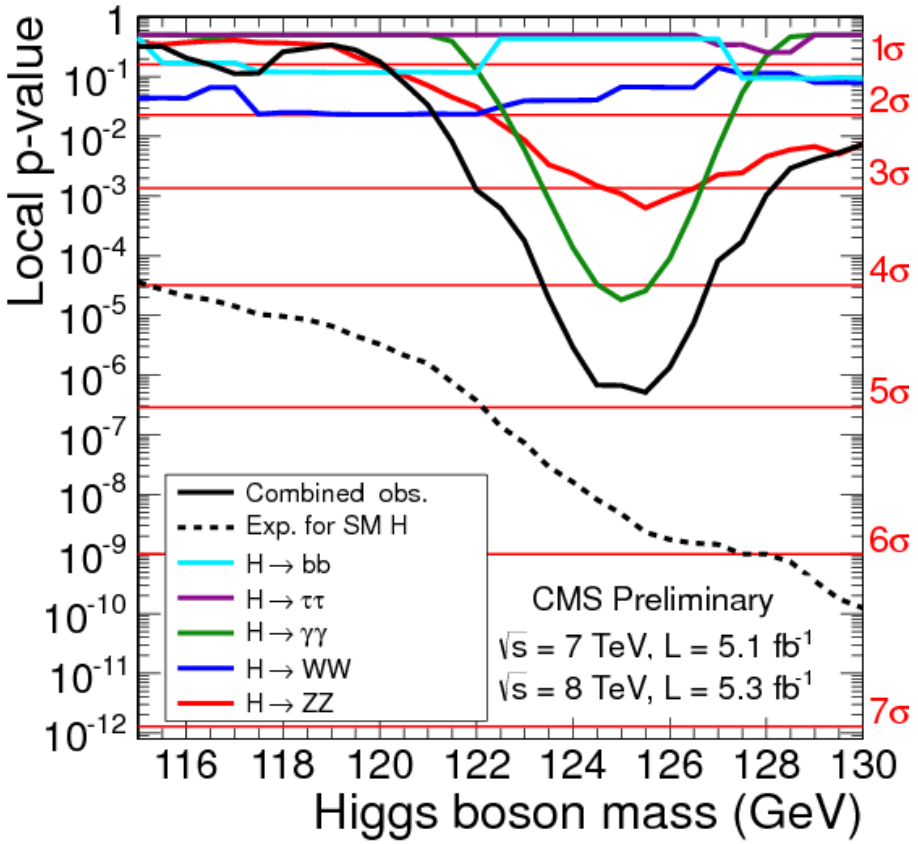


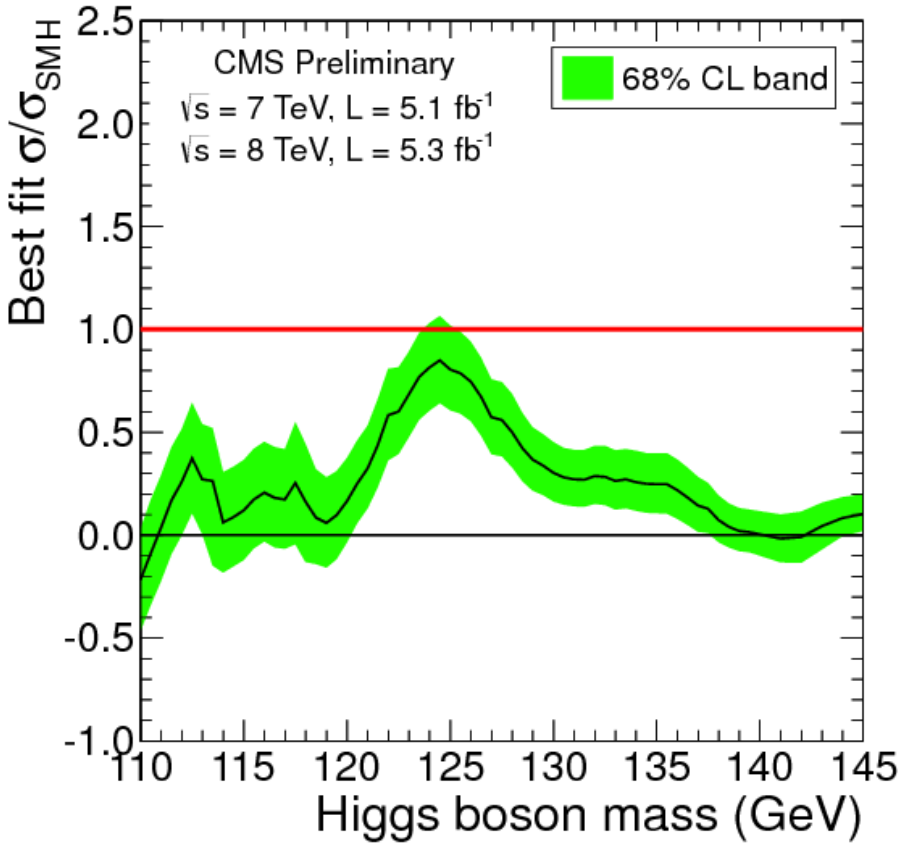




Full combination

Combined results: all channels

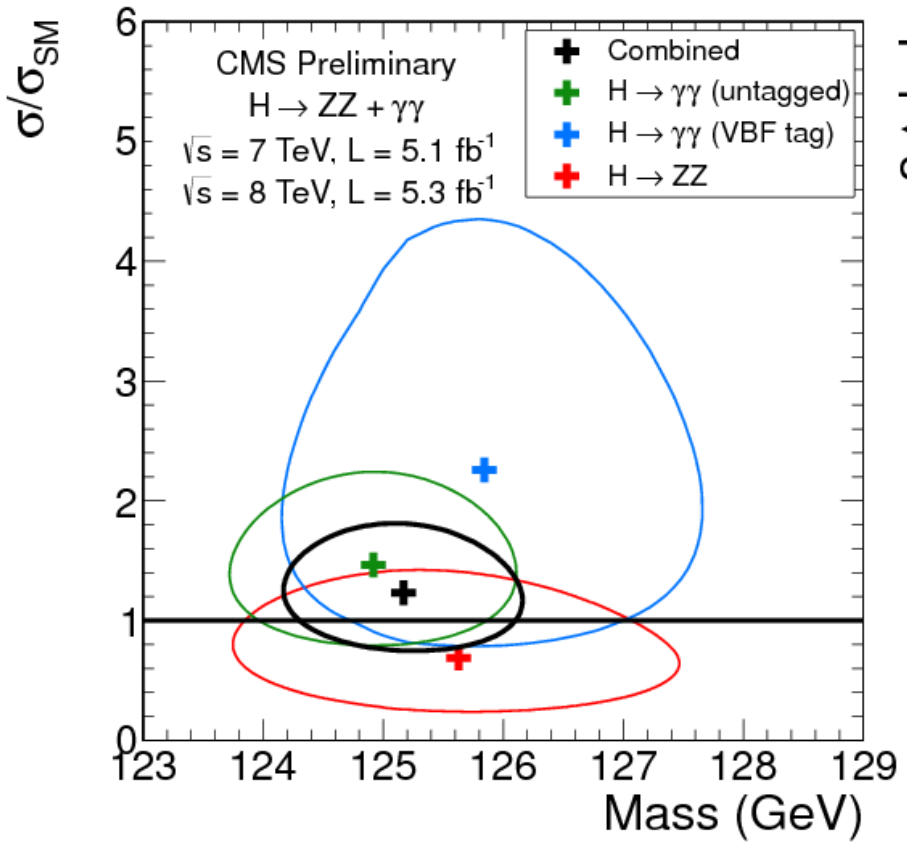


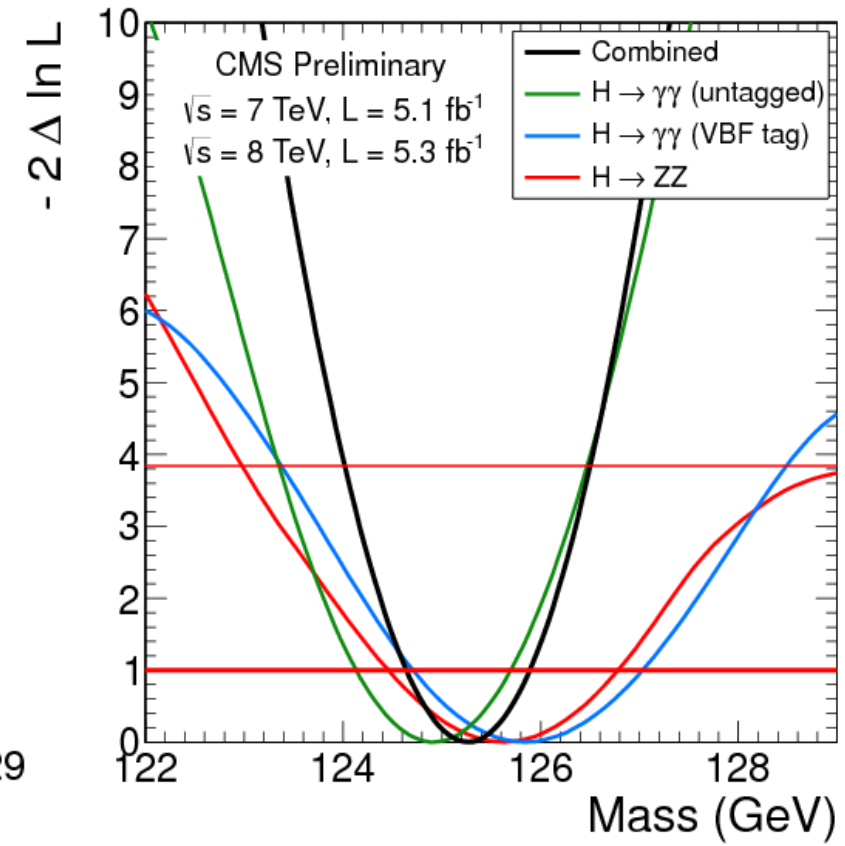


Local significance 4.9 σ, SMH expected 5.9σ

The best fit signal strength at mass 125 GeV: $(0.80 \pm 0.22) \times \sigma_{SMH}$

Characterization

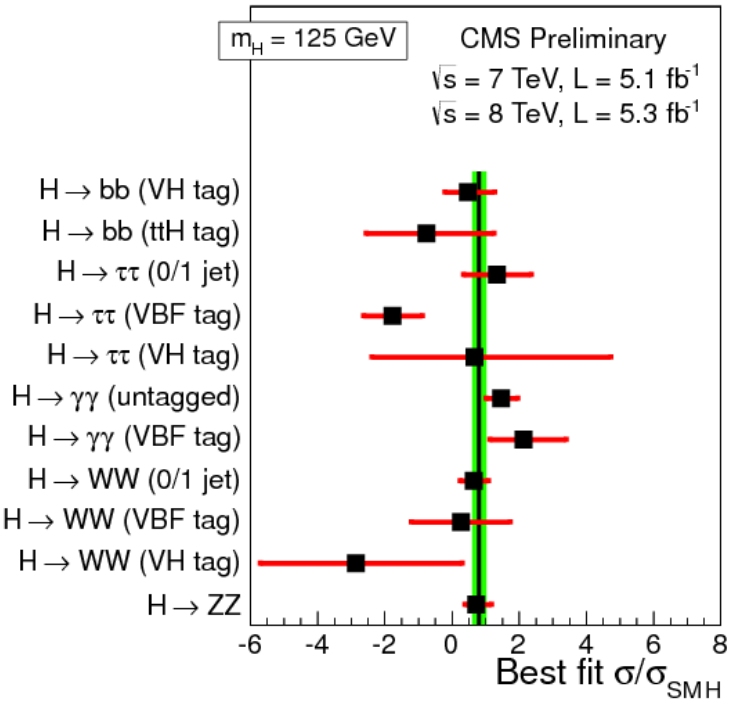


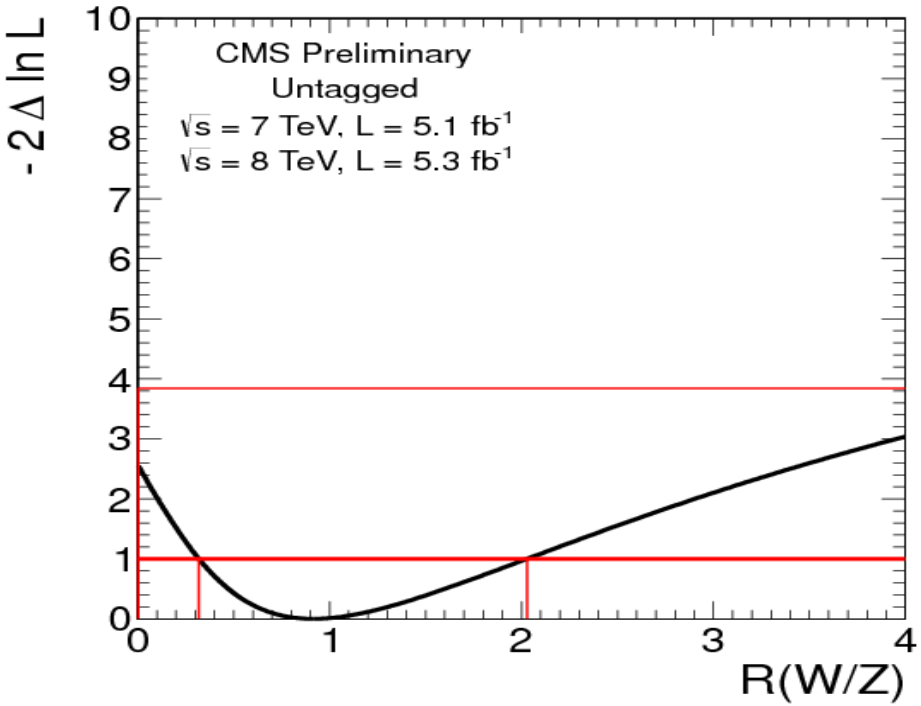


Results are compatible within the uncertainties

Let signal strength float and perform a fit of the mass of three final state – reduces model dependence $\mathbf{m_X = 125.3 \pm 0.6\ GeV}$

Compatibility with SM Higgs boson





Overall signal stength compatible with a SM Higgs

Some modes haven't reached sensitivity

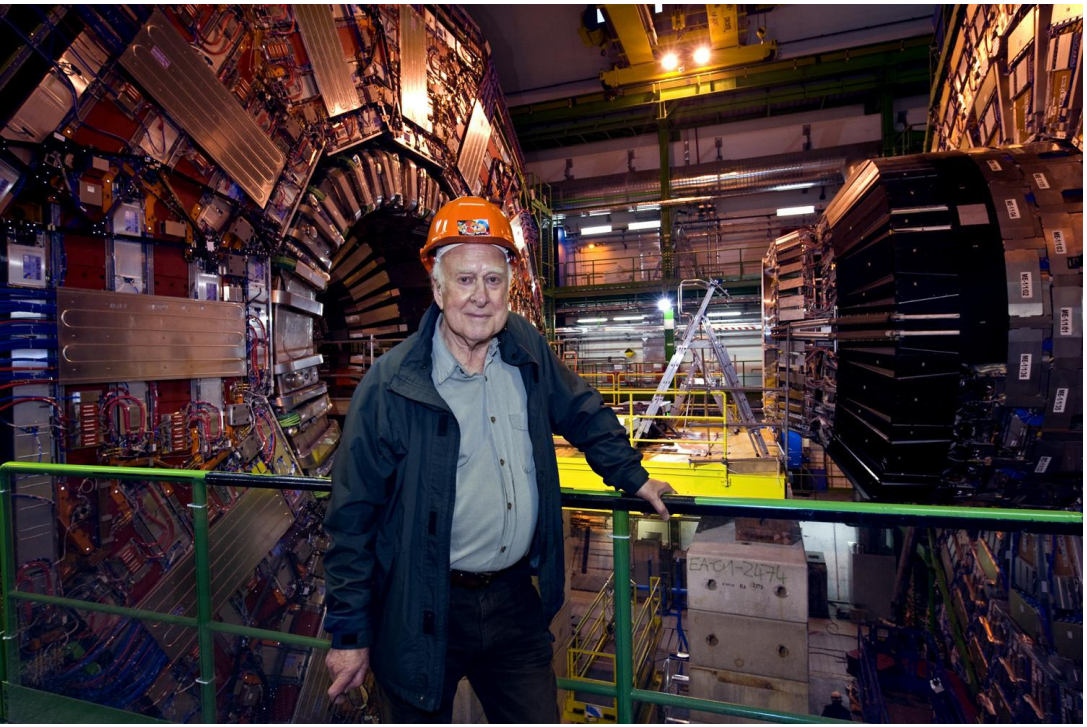
Signal strength ratio of WW and ZZ modes in VBF:

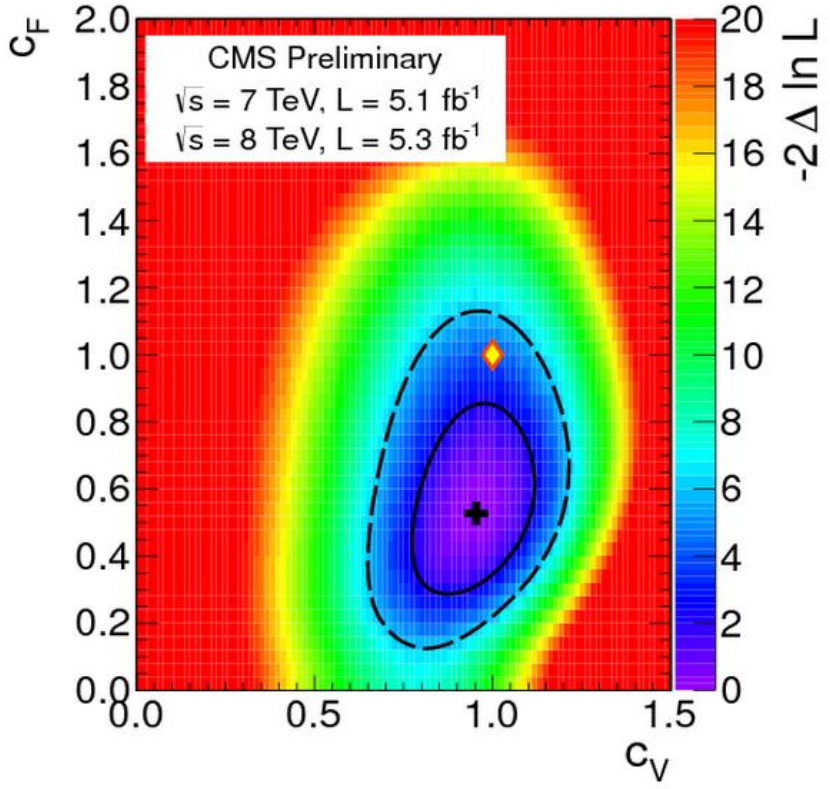
driven by the ratio of the Higgs couplings to WW and ZZ

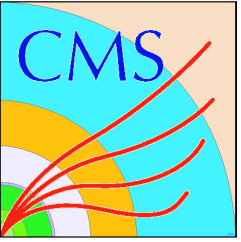
Compatable with SM $R_{W/Z} = 0.9\ ^{+1.1}_{-0.6}$

Summary

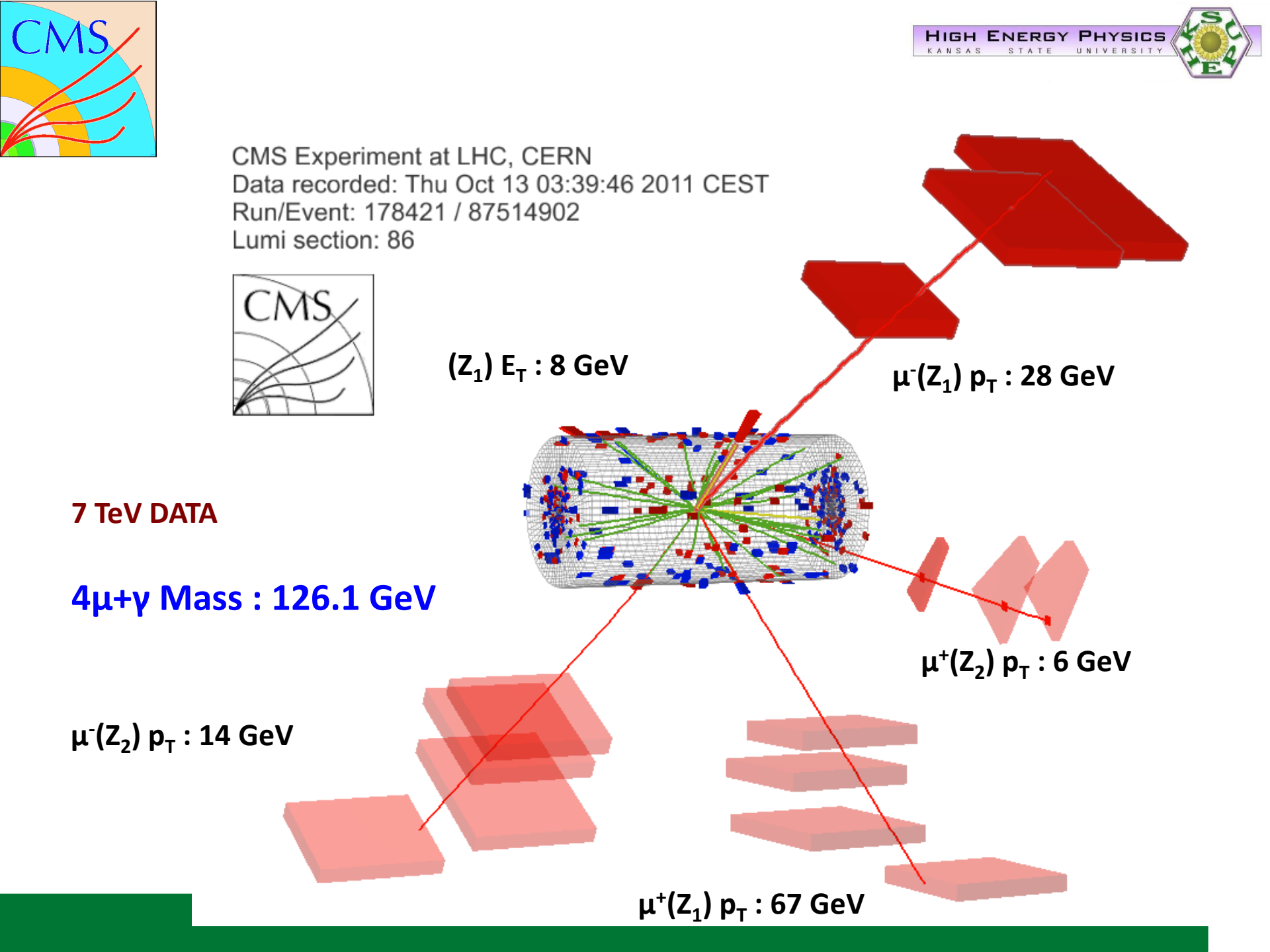
- **We have observed a new boson particle with a mass of 125.3 ± 0.6 *GeV* at 4.9σ**
- **Observation is in compatible with the SM Higgs boson prediction at 125 *GeV* within the 95% confidence range!**
- **More data is needed to conclude if new particle is really a Higgs boson**

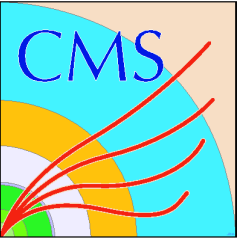


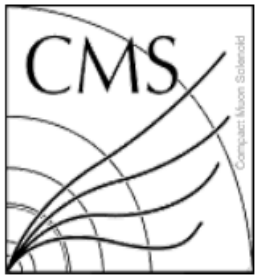


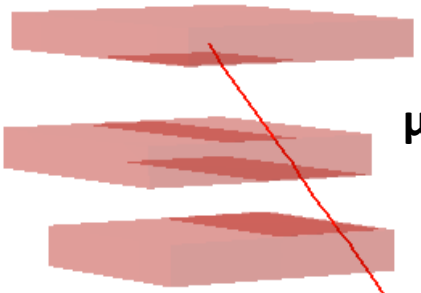


BACKUP SLIDES


CMS Experiment at LHC, CERN
Data recorded: Thu Oct 13 03:39:46 2011 CEST
Run/Event: 178421 / 87514902
Lumi section: 86
CMS
(Z1) ET : 8 GeV
μ-(Z1) pT : 28 GeV
7 TeV DATA
4μ+γ Mass : 126.1 GeV
μ+(Z2) pT : 6 GeV
μ-(Z2) pT : 14 GeV
μ+(Z1) pT : 67 GeV







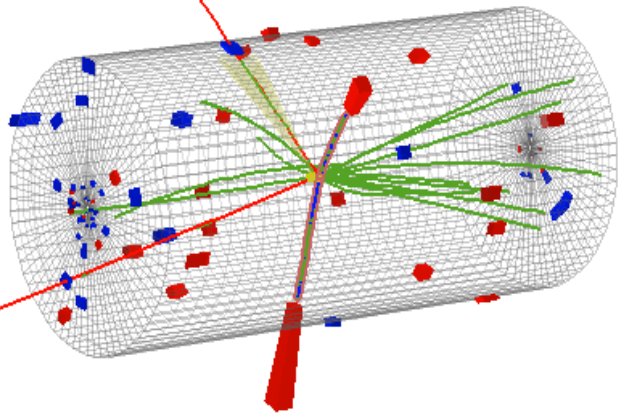
$\mu^+(Z_1)\ p_T$: 43 GeV

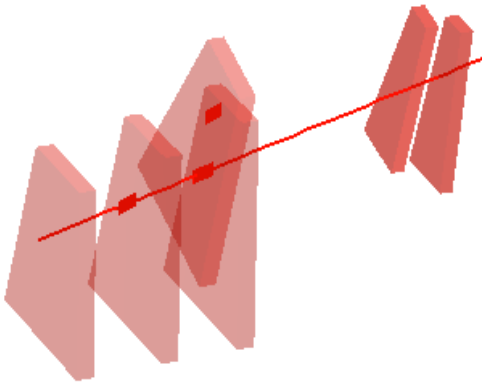
$e^-(Z_2)\ p_T$: 10 GeV

8 TeV DATA

4-lepton Mass : 126.9 GeV

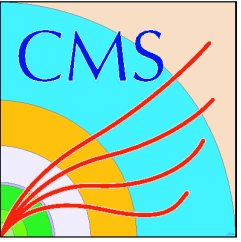
$\mu^-(Z_1)\ p_T$: 24 GeV





$e^+(Z_2)\ p_T$: 21 GeV

CMS Experiment at LHC, CERN
Data recorded: Mon May 28 01:35:47 2012 CEST
Run/Event: 195099 / 137440354
Lumi section: 115



CMS Experiment at LHC, CERN
Data recorded: Tue Oct 4 00:10:13 2011 CEST
Run/Event: 177782 / 72158025
Lumi section: 99

7 TeV DATA

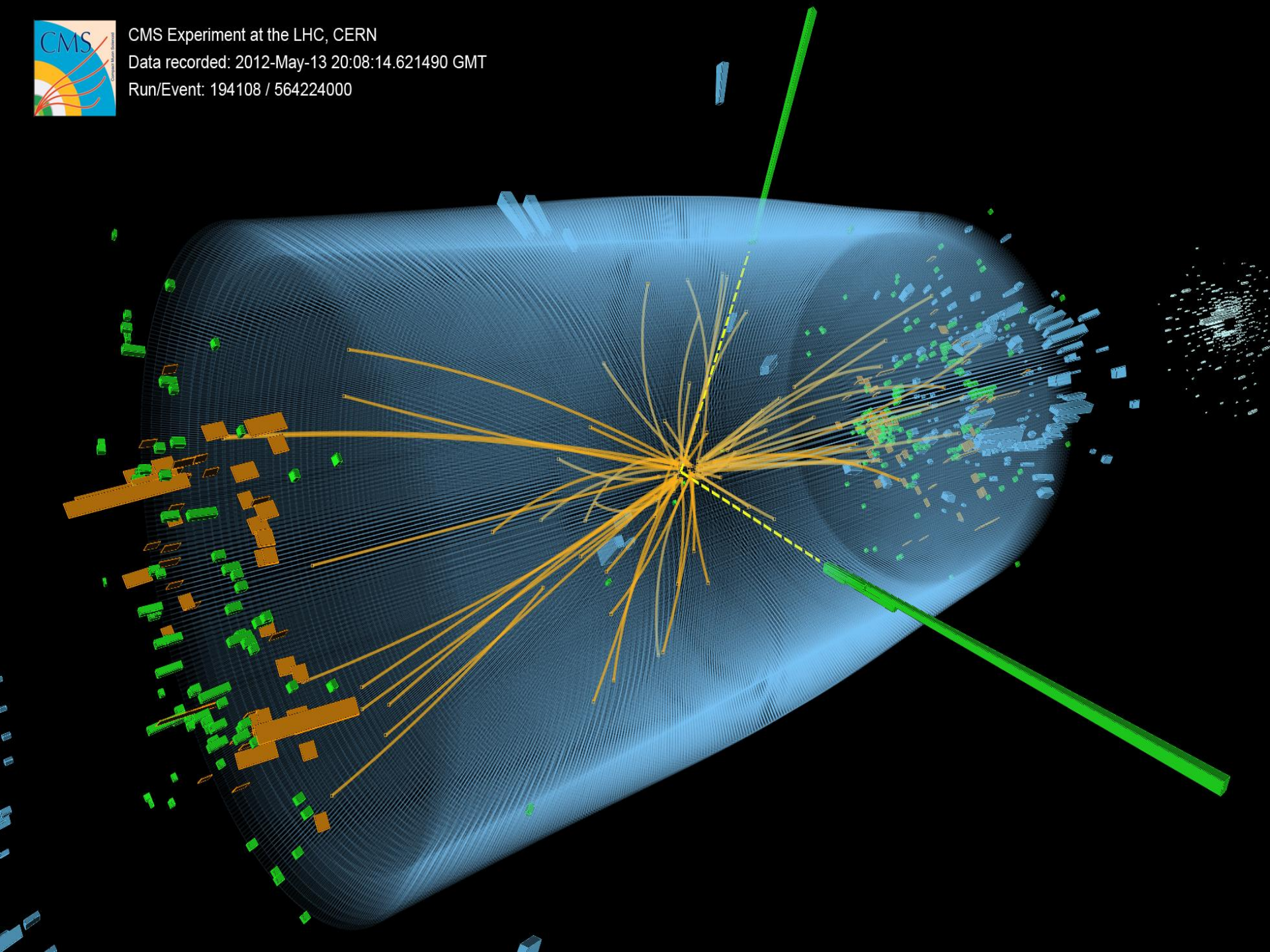
4-lepton Mass : 125.8 GeV

$\mu^-(Z_2)$ p_T : 15 GeV

$e^+(Z_1)$ p_T : 28 GeV

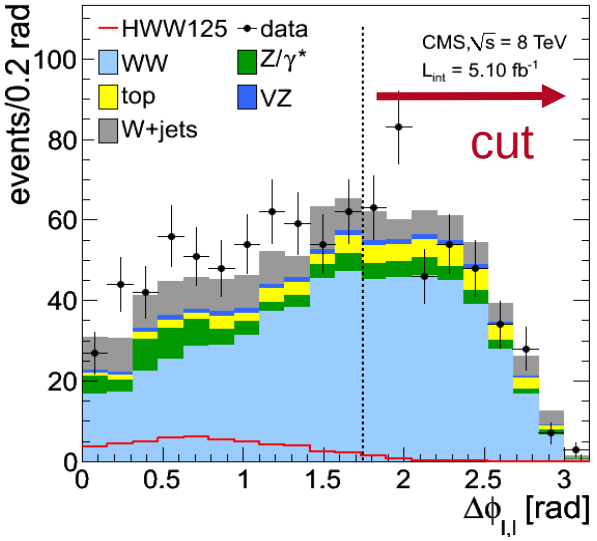
$\mu^+(Z_2)$ p_T : 12 GeV

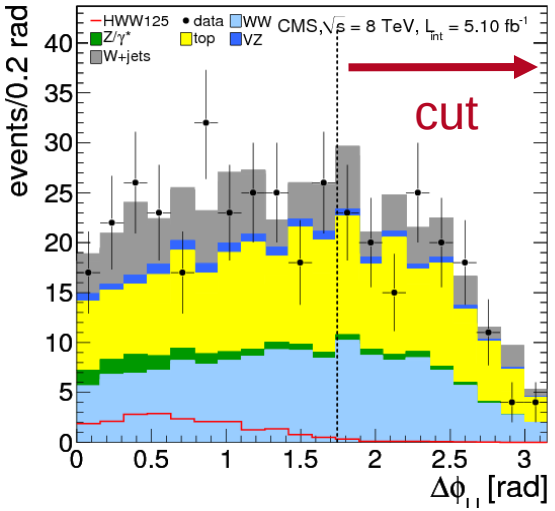
$e^-(Z_1)$ p_T : 14 GeV


CMS Experiment at the LHC, CERN
Data recorded: 2012-May-13 20:08:14.621490 GMT
Run/Event: 194108 / 564224000

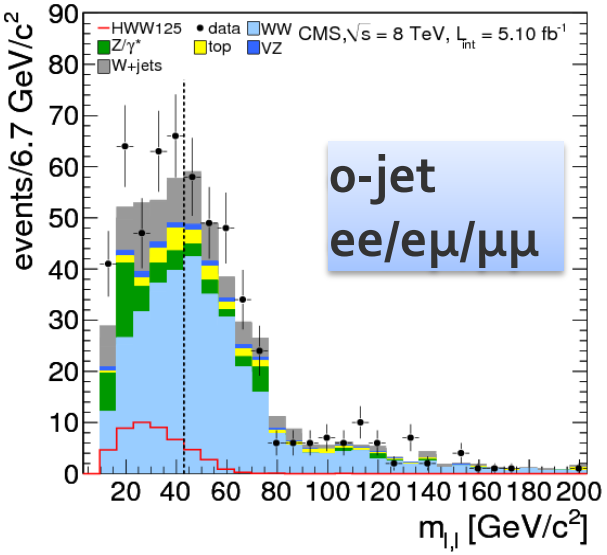
Kinematics at Final Selection

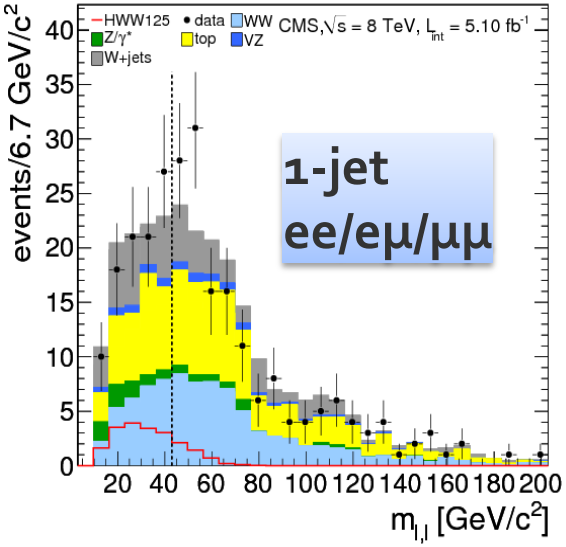
One step before the final selection
(no cuts on Δϕ(ll) and m(ll))





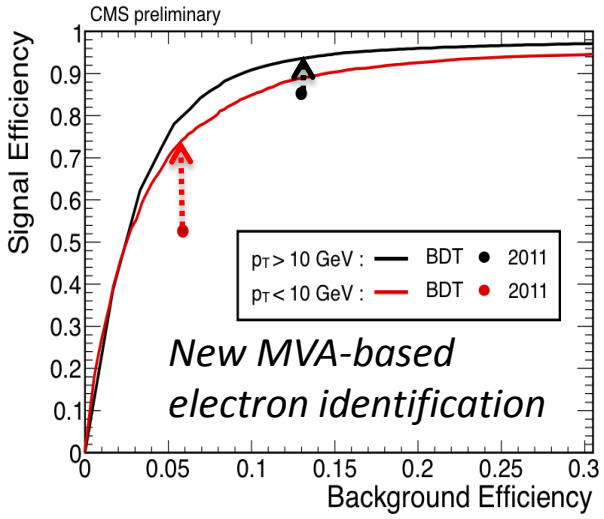
Final selection on m(ll)
(all other selection applied)

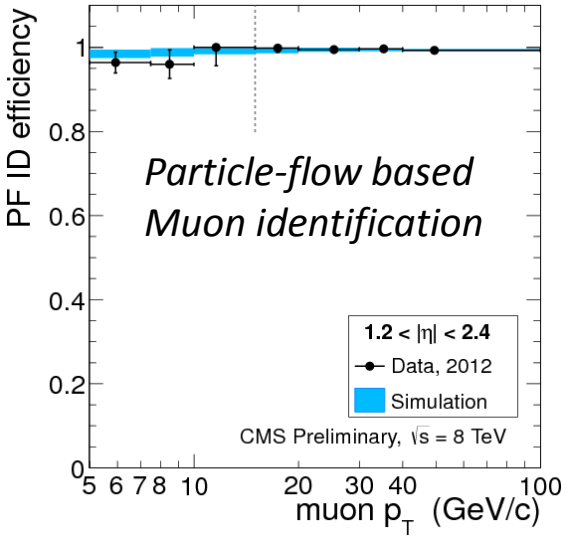


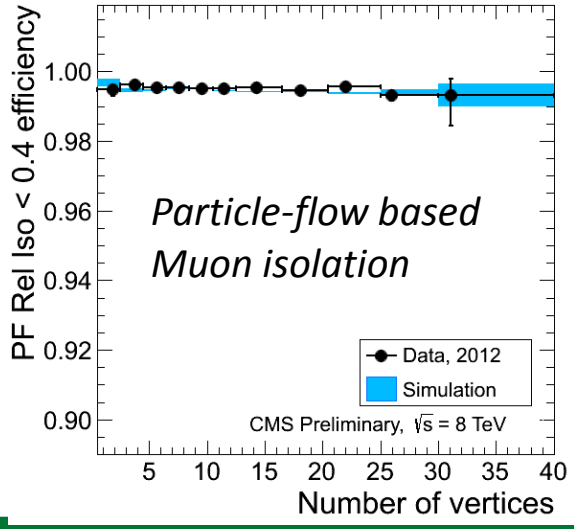


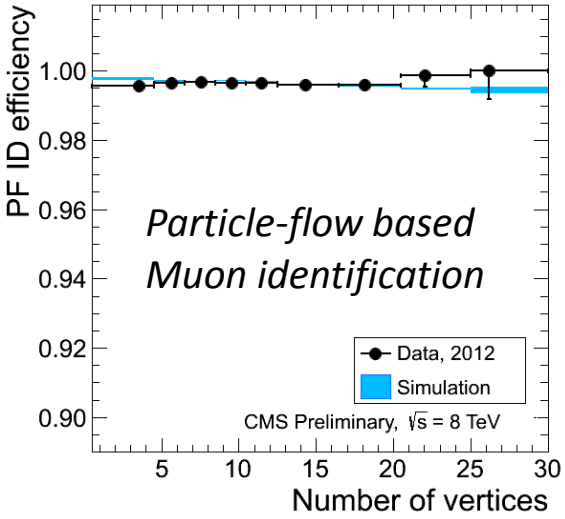
Improving lepton selection

New algorithms: higher efficiency for same background









stable performance in high pile-up environment (important for higher lumi runs in the future!)

2012: the luminosity challenge

Instantaneous luminosity up to ~$7 \cdot 10^{33}$

20-30 pile-up interactions per bunch crossing