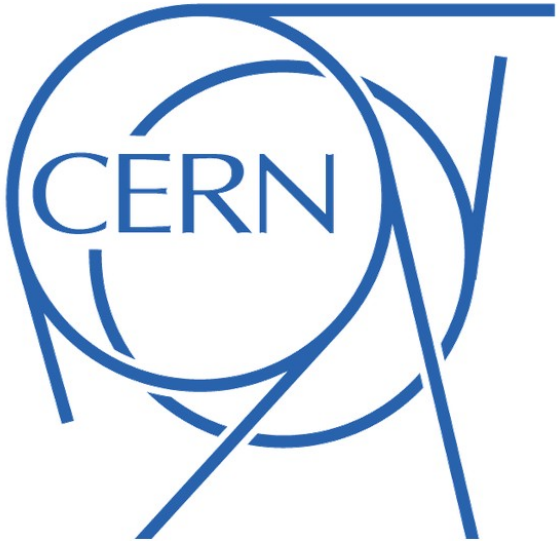
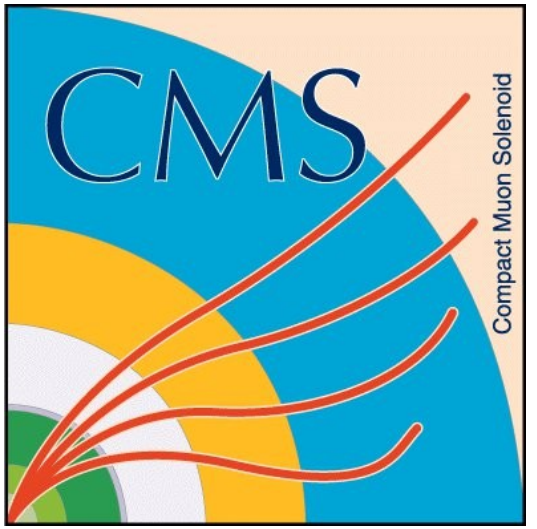




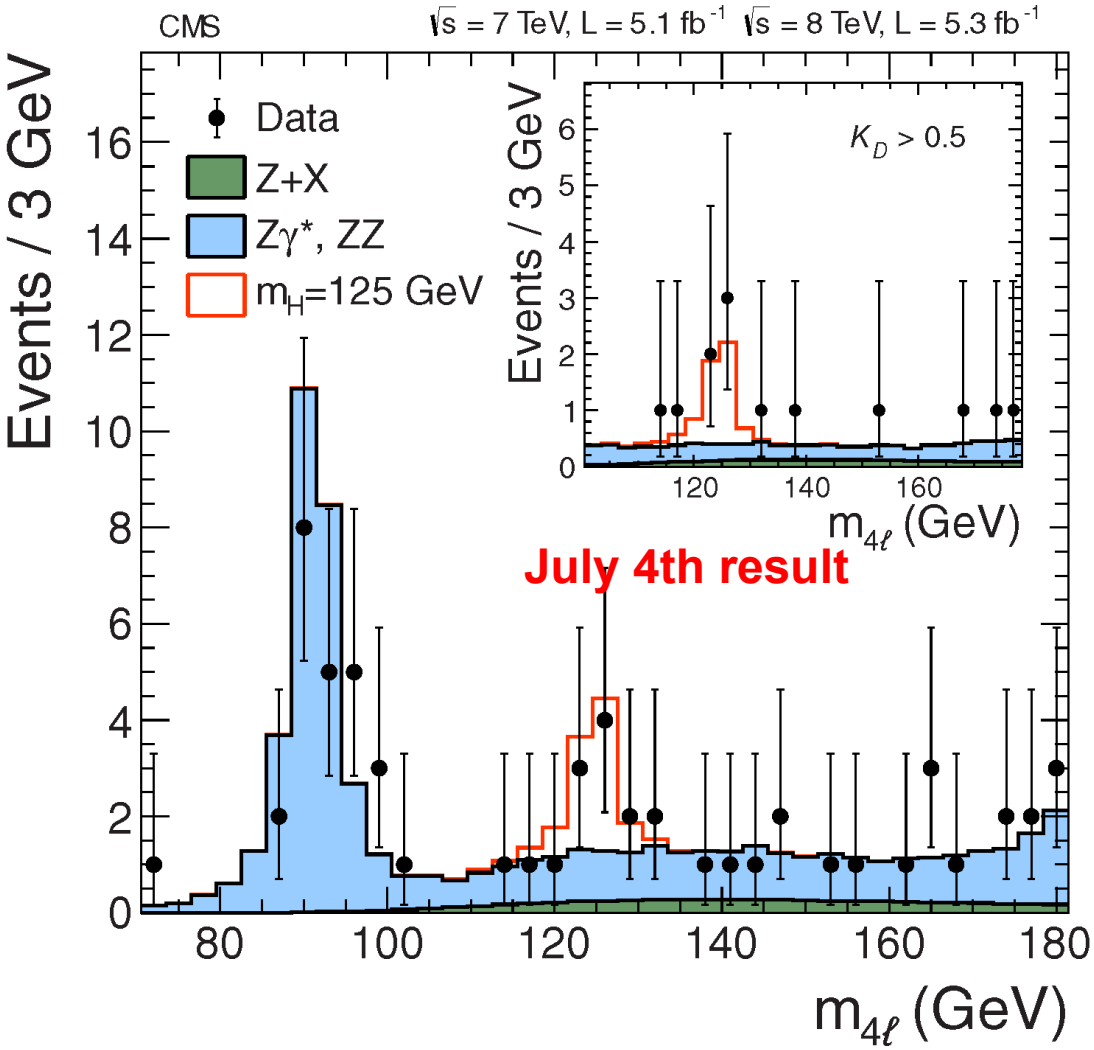
Update of the CMS $H \rightarrow ZZ \rightarrow 4\ell$ results

M. Bachtis

KITP Higgs Identification Workshop

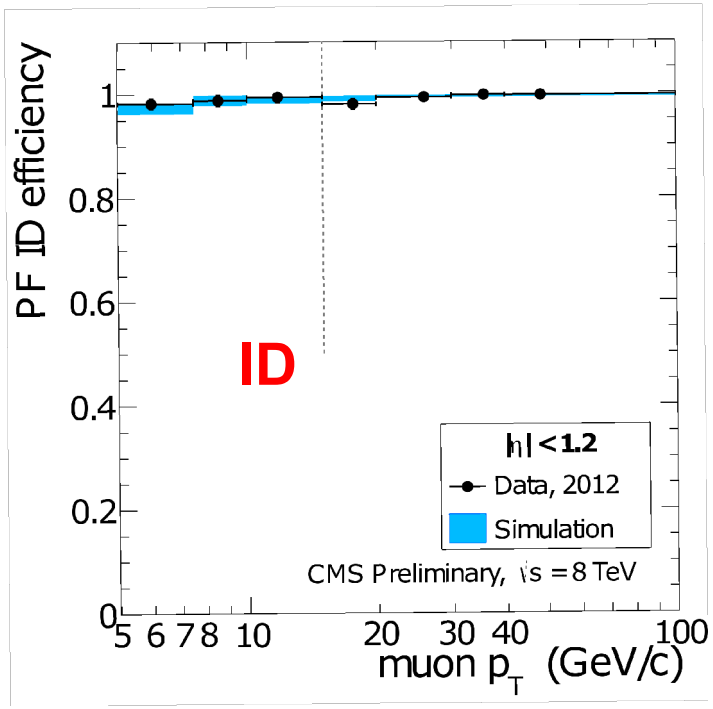
Introduction

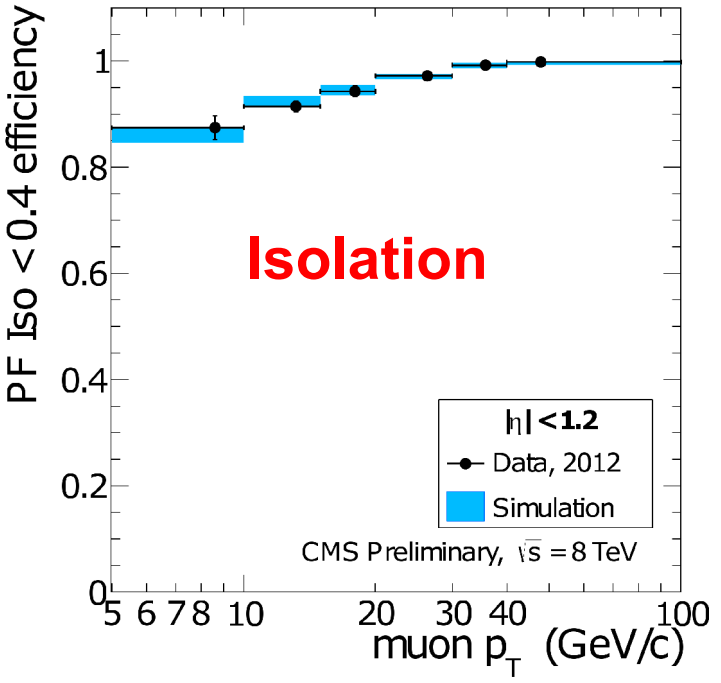
- The golden channel
  - Search for a bump in a very small and flat background
  - Expected signal yield very small
    - Introduces additional challenges
- Requirements
  - High detector coverage
  - Excellent lepton reconstruction efficiency
  - Excellent knowledge of lepton scale and resolution
- Will also briefly cover the new $H \rightarrow Z\gamma$ results



Muons

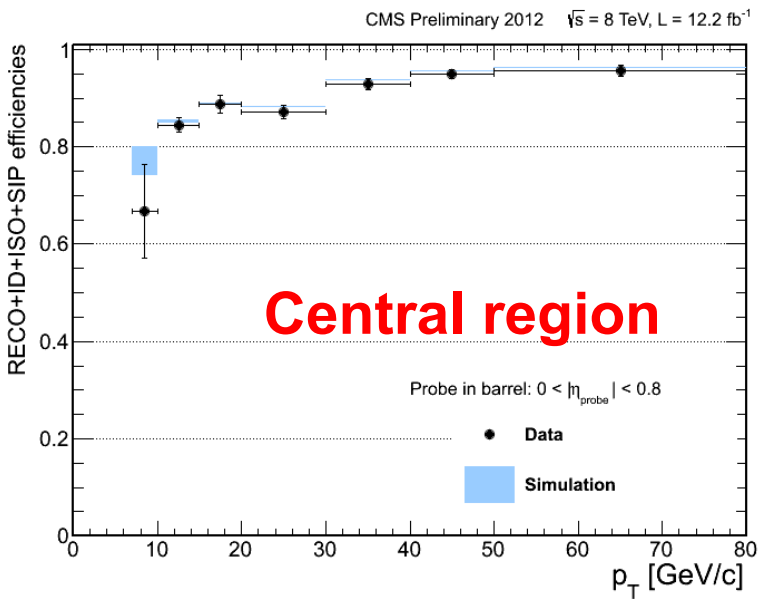
- Pt > 5 GeV , |η|<2.4
- Particle Flow identification
  - Using all CMS subdetectors
- Isolation and impact parameter requirements
  - To reject fakes and muons in jets
  - Isolation /Pt <0.4
  - Impact parameter significance<4
- Efficiency measured using Z and J/ψ events

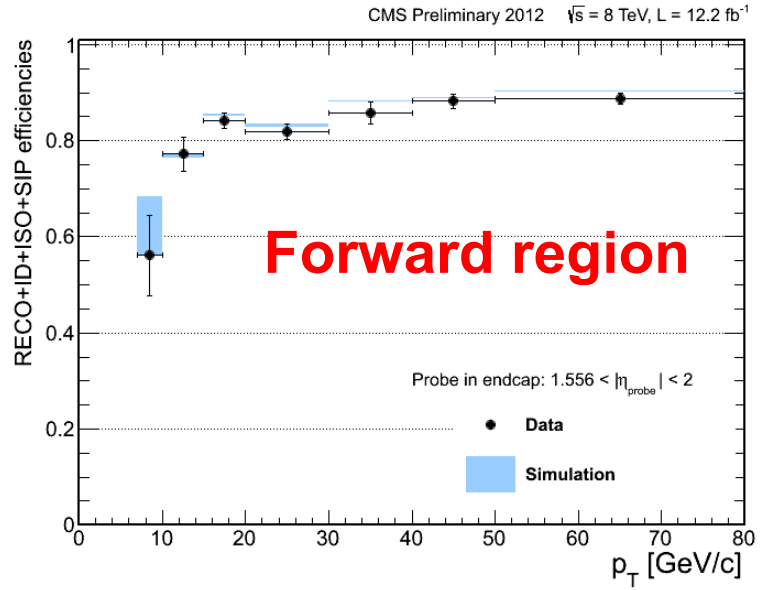




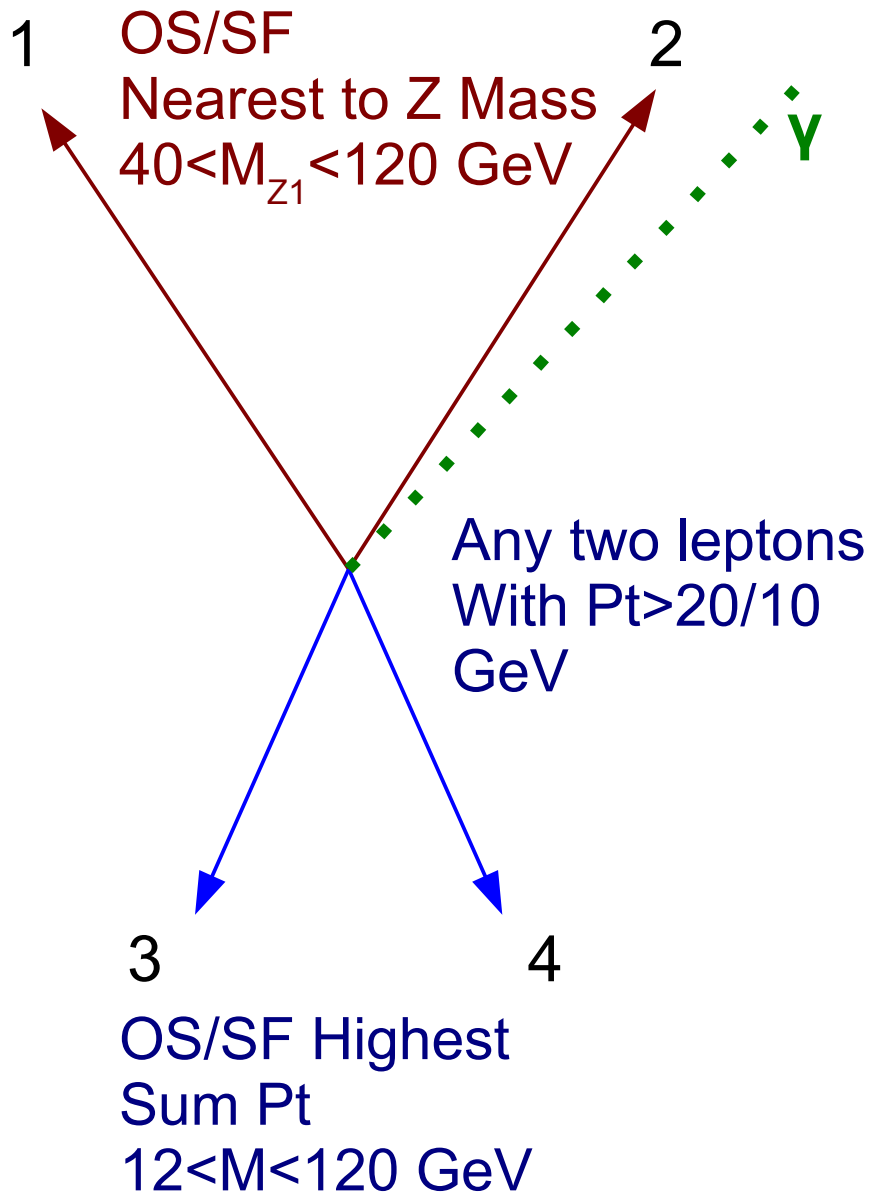
Electrons

- Pt > 7 GeV, |η|<2.5
- Multivariate electron ID
  - exploiting shower shapes and track variables
- Isolation and impact parameter requirements
  - Isolation /Pt <0.4
  - Impact parameter significance < 4
- Efficiency measured using Z events

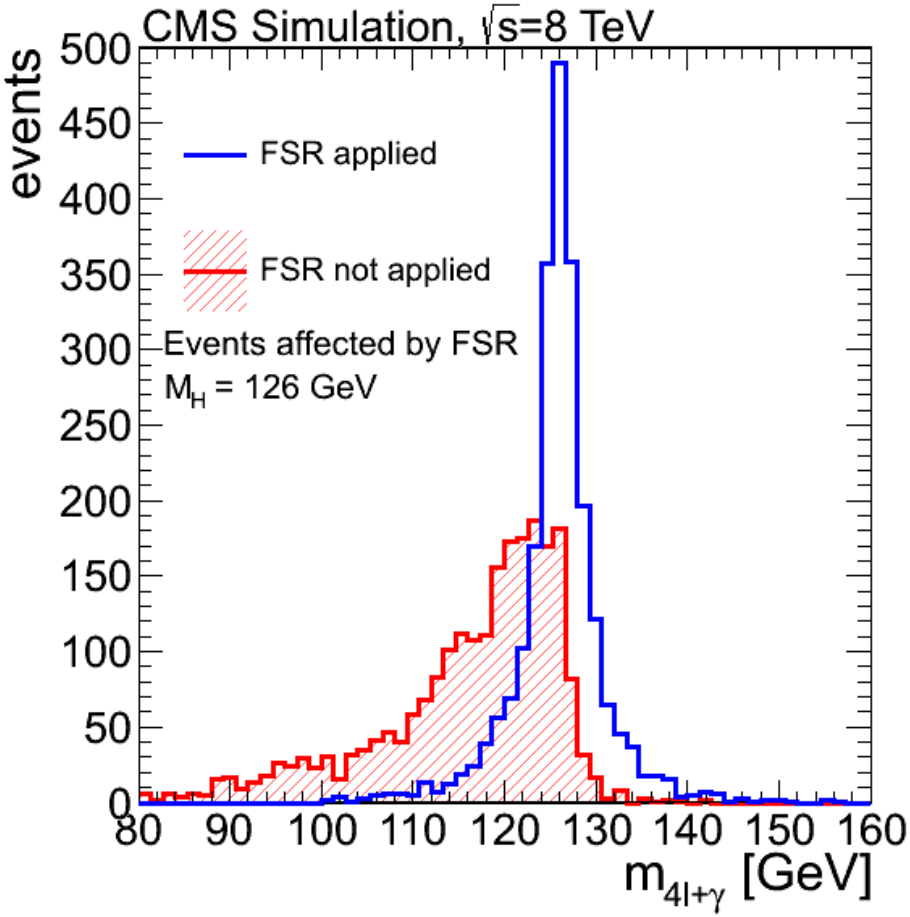




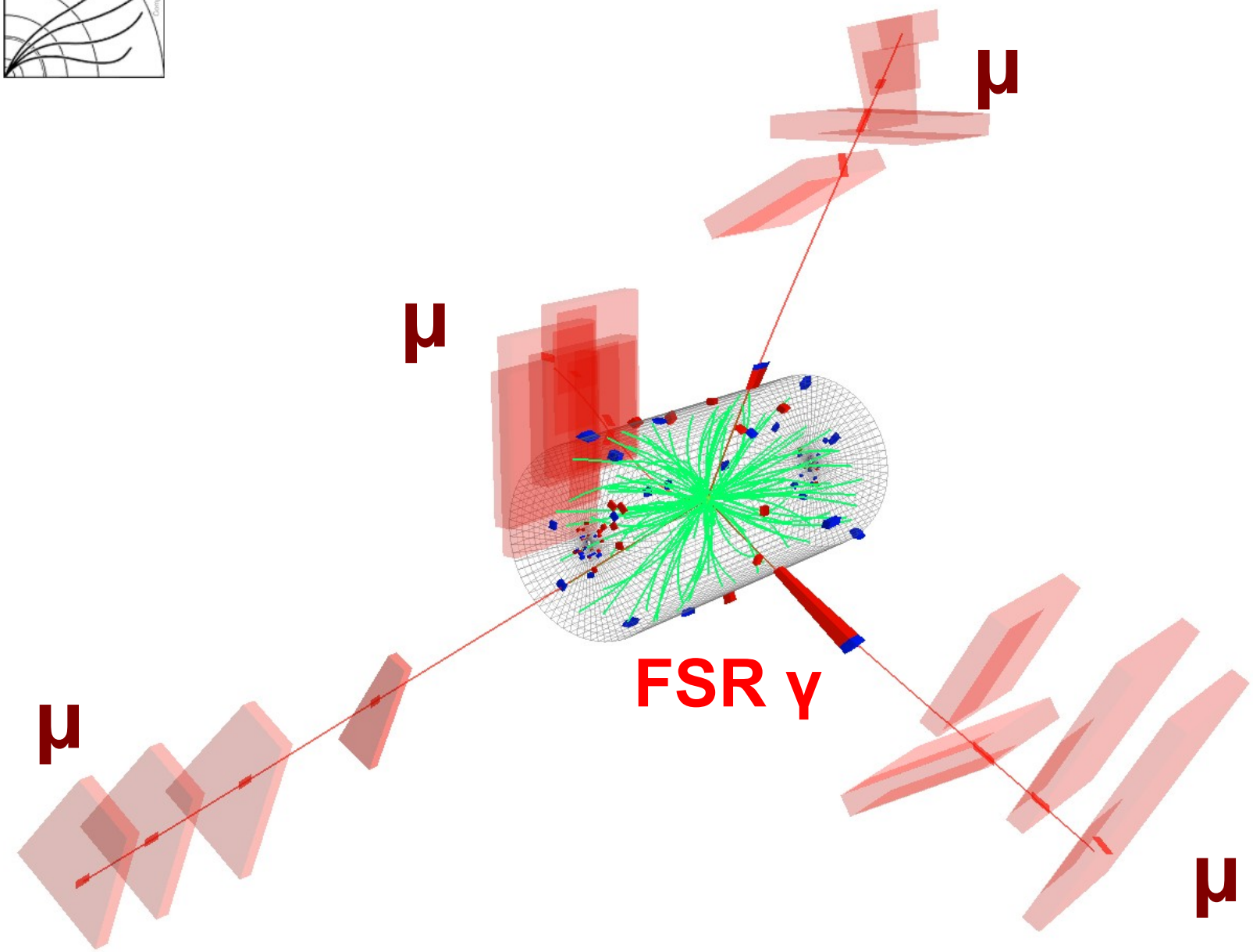
Building 4ℓ candidates



- Any OS/SF lepton pair must have M_{ll}>4 GeV
  - To suppress QCD
- FSR recovery
  - Photons added to the Z candidates before cuts

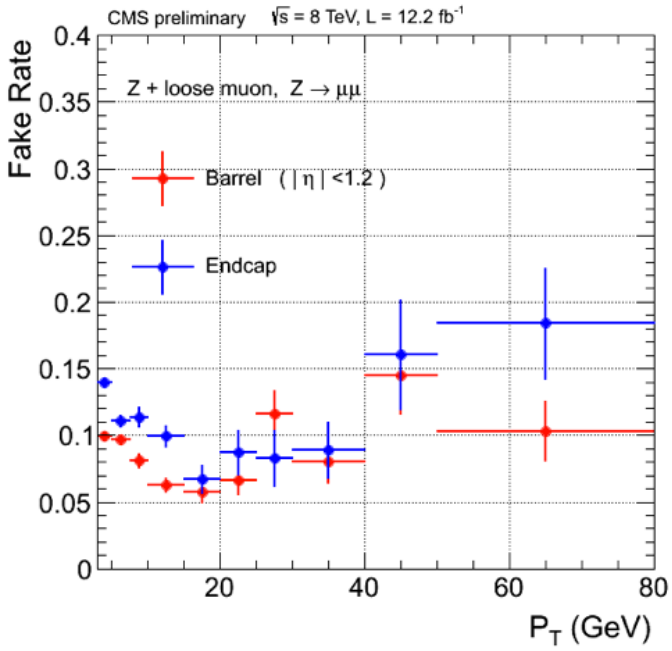


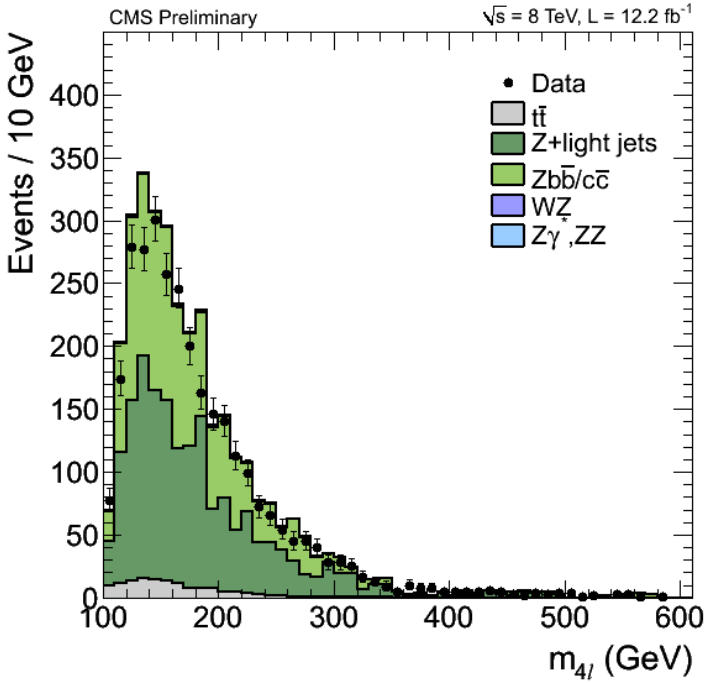
Four lepton candidate event



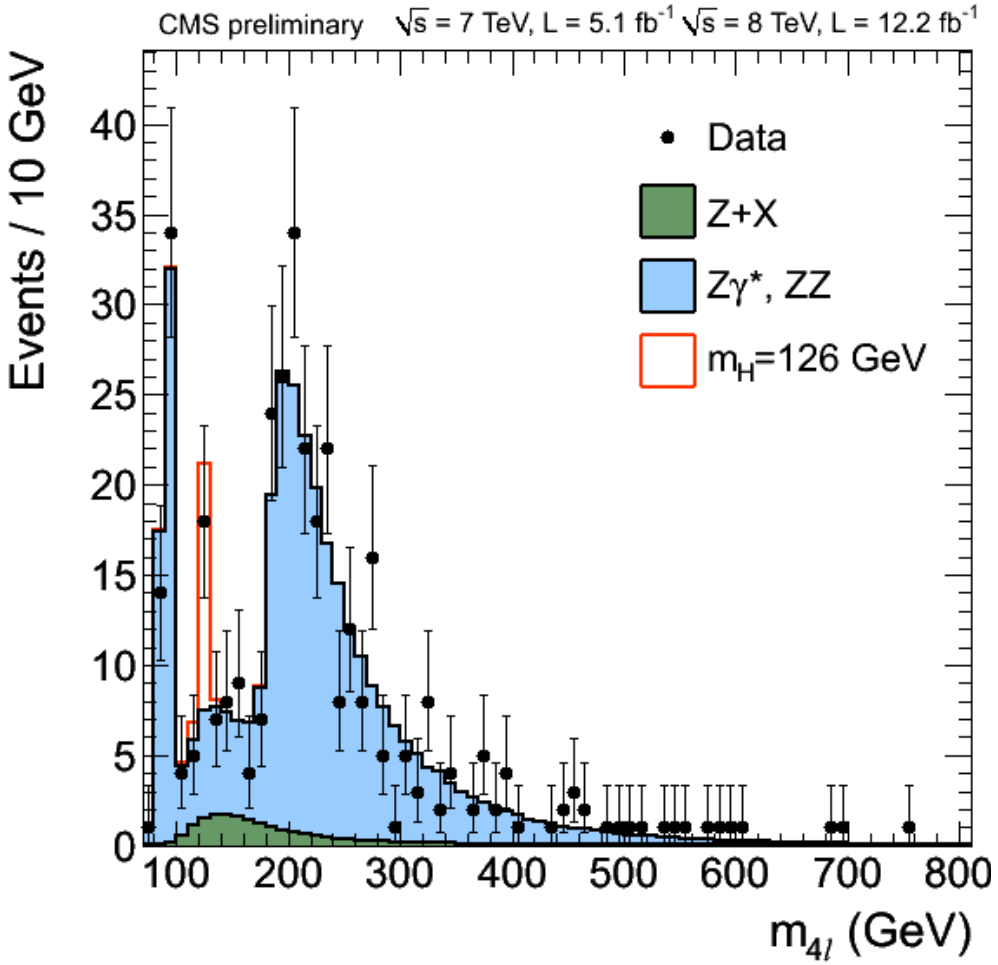
Background estimation

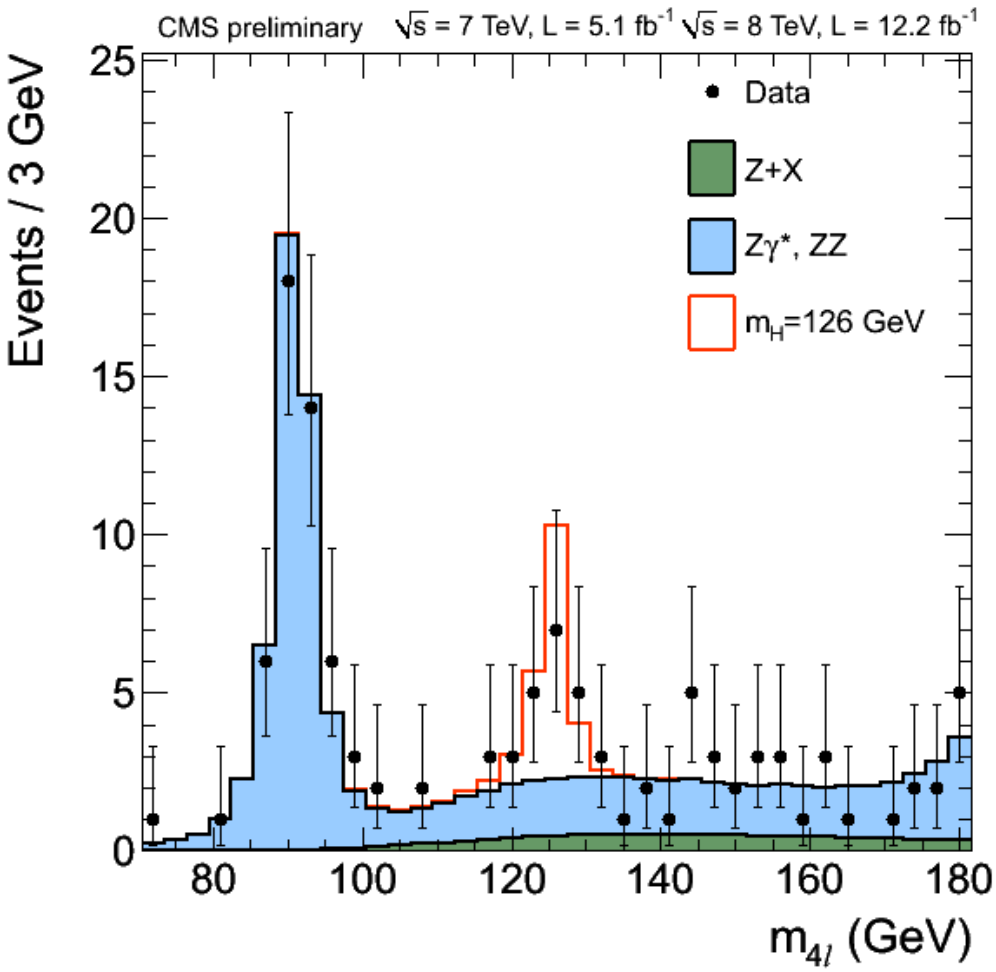
- Irreducible ZZ background
  - qq → ZZ modeled by POWHEG
    - PDF uncertainty (5%), scale 2-6%
  - gg → ZZ modeled by GG2ZZ
    - PDF uncertainty (10%), scale(24-44%)
- Reducible background
  - Using data extrapolated from control regions





4ℓ invariant mass after all selections

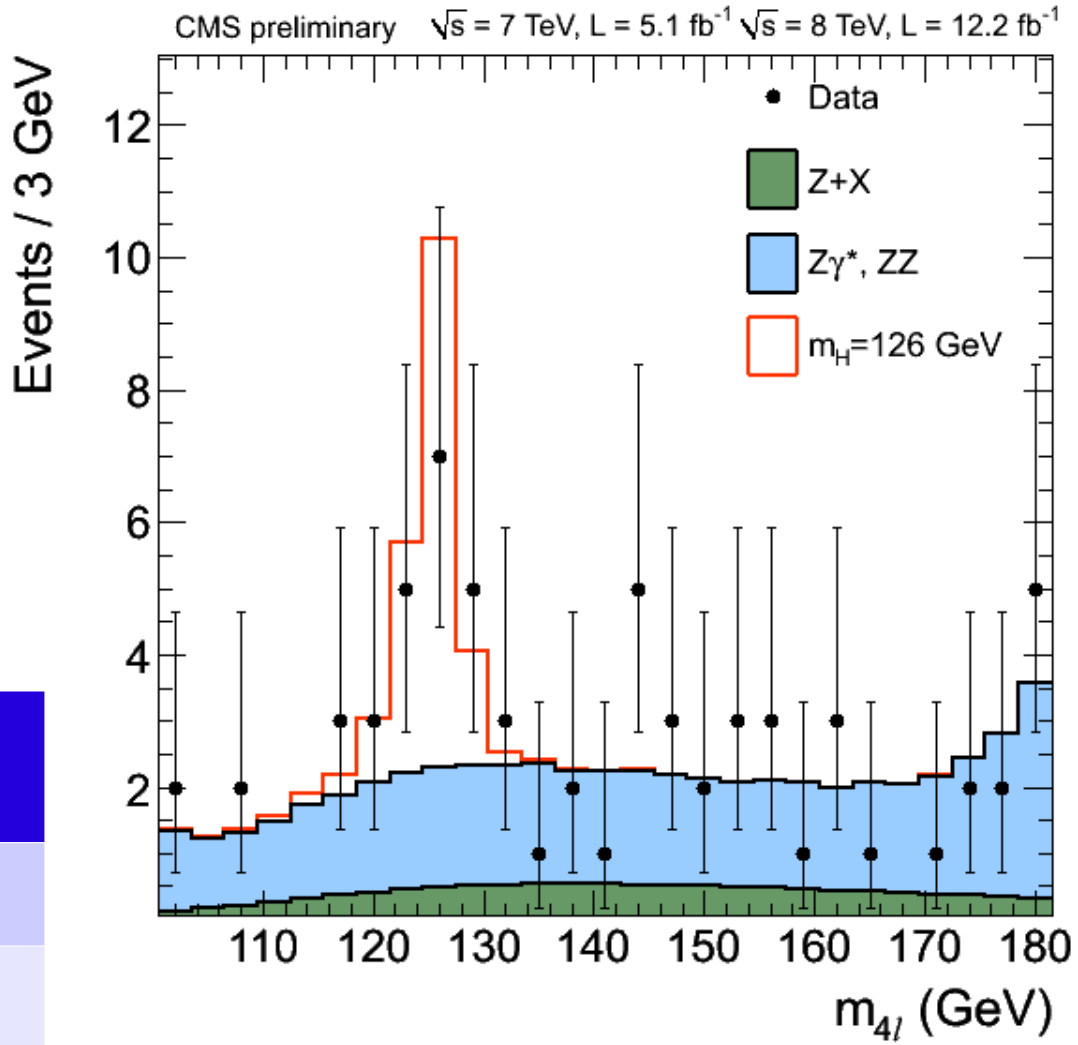




- Good modeling of the ZZ continuum and the resonant $Z \rightarrow 4\ell$ peak
- Enhanced peak for the h_{126} boson
  - Clean peak , yield consistent with SM Higgs

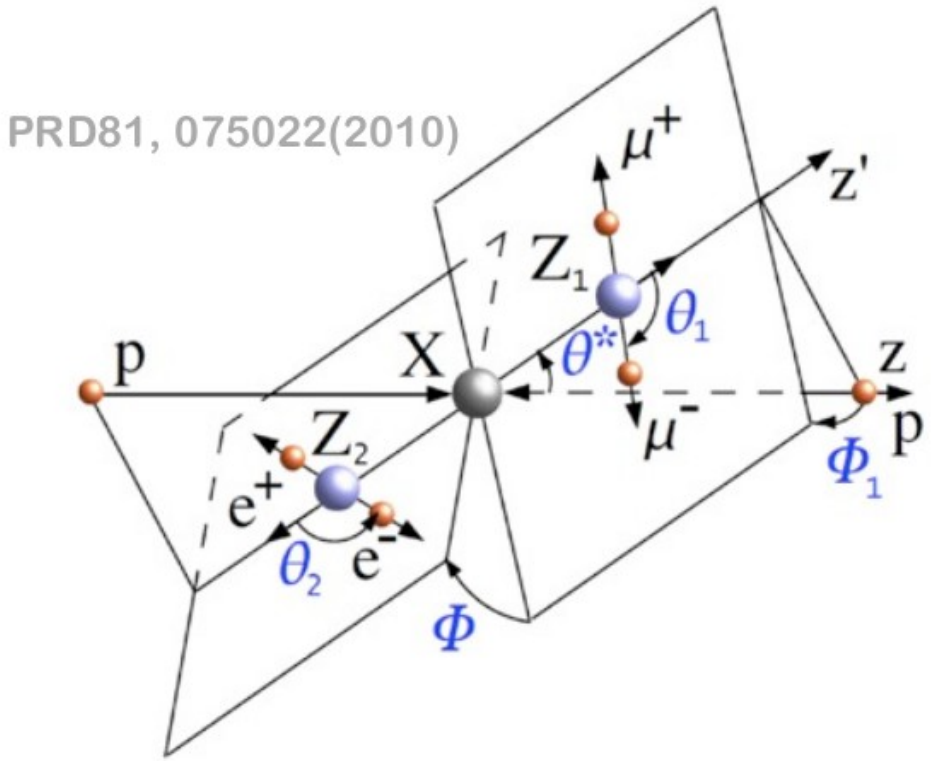
Zoom into the bump

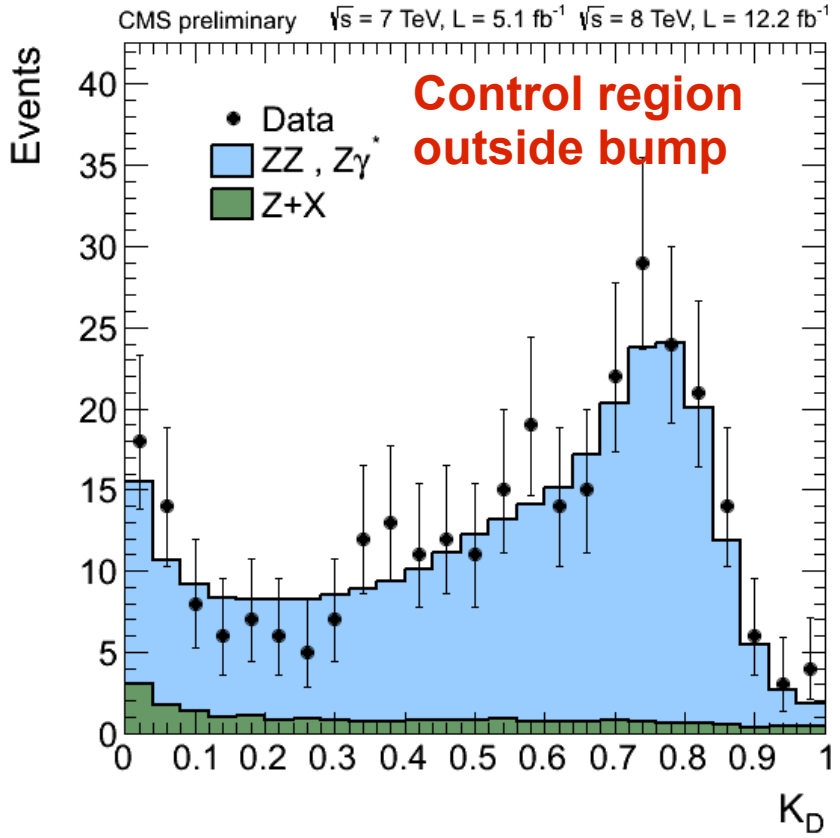
- Expecting ~ 19 S+B events in the range of 121.5-130.5 GeV
  - For m_H = 126 GeV
- Observed 17 events



	Exp. Bkg	m_H = 126	Obs
4e	1.25	2.20	3
4μ	2.09	4.26	6
2e2μ	3.14	5.97	8
Total	6.48	12.43	17

Matrix Element approach

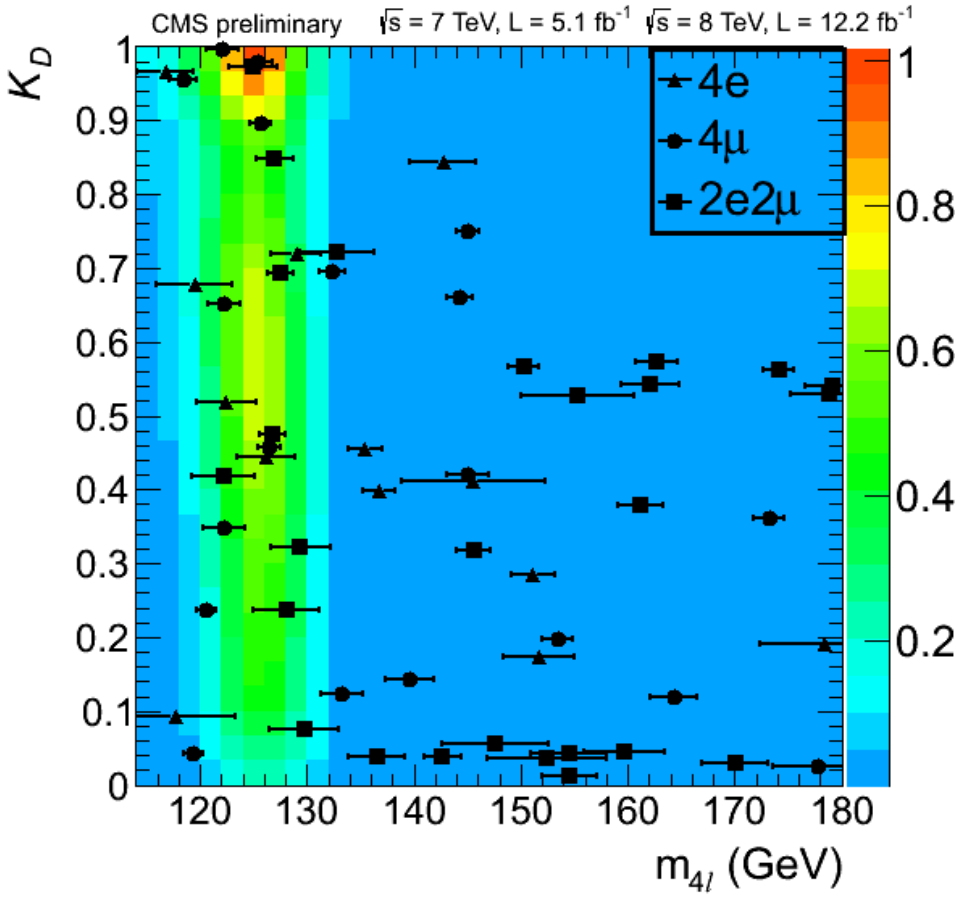


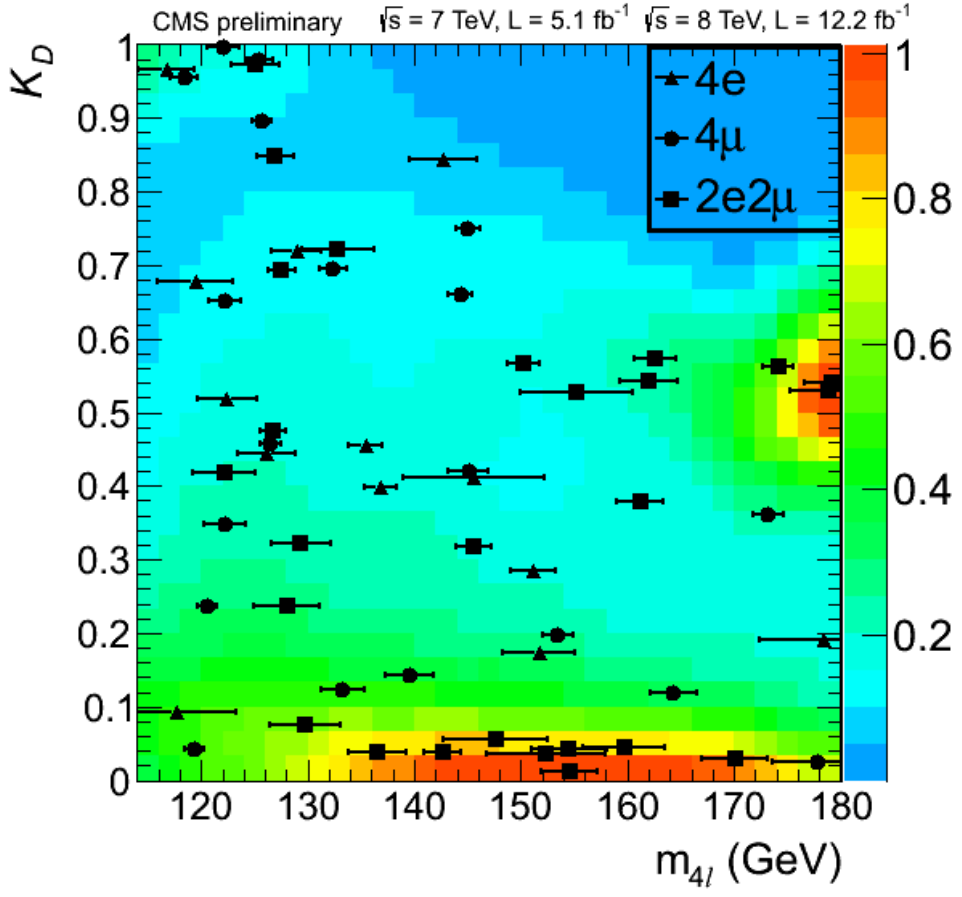


- Form kinematic discriminant exploiting 2 masses and five angles
- Discriminant can be defined wrt background or alternative models
- MELA analytical approach cross checked with Madgraph/MCFM

$$\mathrm{KD} = \frac{\mathcal{P}_{\mathrm{sig}}}{\mathcal{P}_{\mathrm{sig}} + \mathcal{P}_{\mathrm{bkg}}} = \left[1 + \frac{\mathcal{P}_{\mathrm{bkg}}(m_1, m_2, \vec{\Omega}|m_{4\ell})}{\mathcal{P}_{\mathrm{sig}}(m_1, m_2, \vec{\Omega}|m_{4\ell})}\right]^{-1}$$

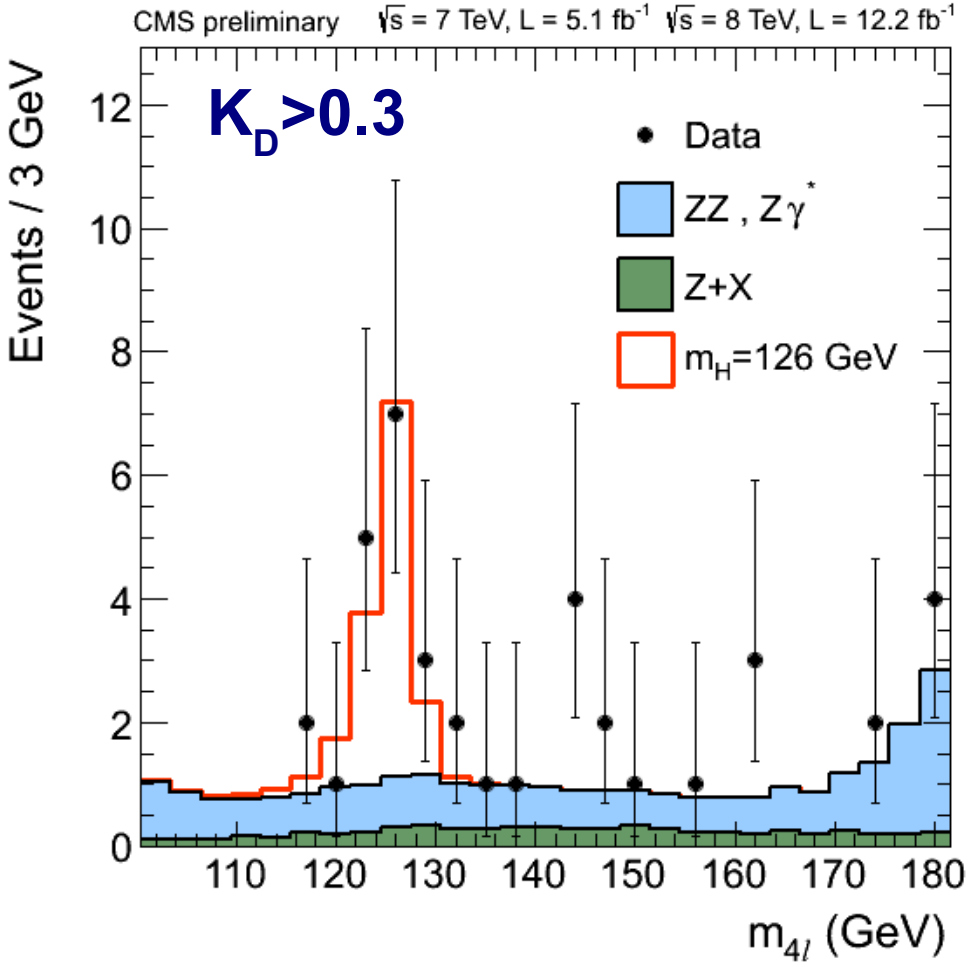
K_D vs $m_{4\ell}$

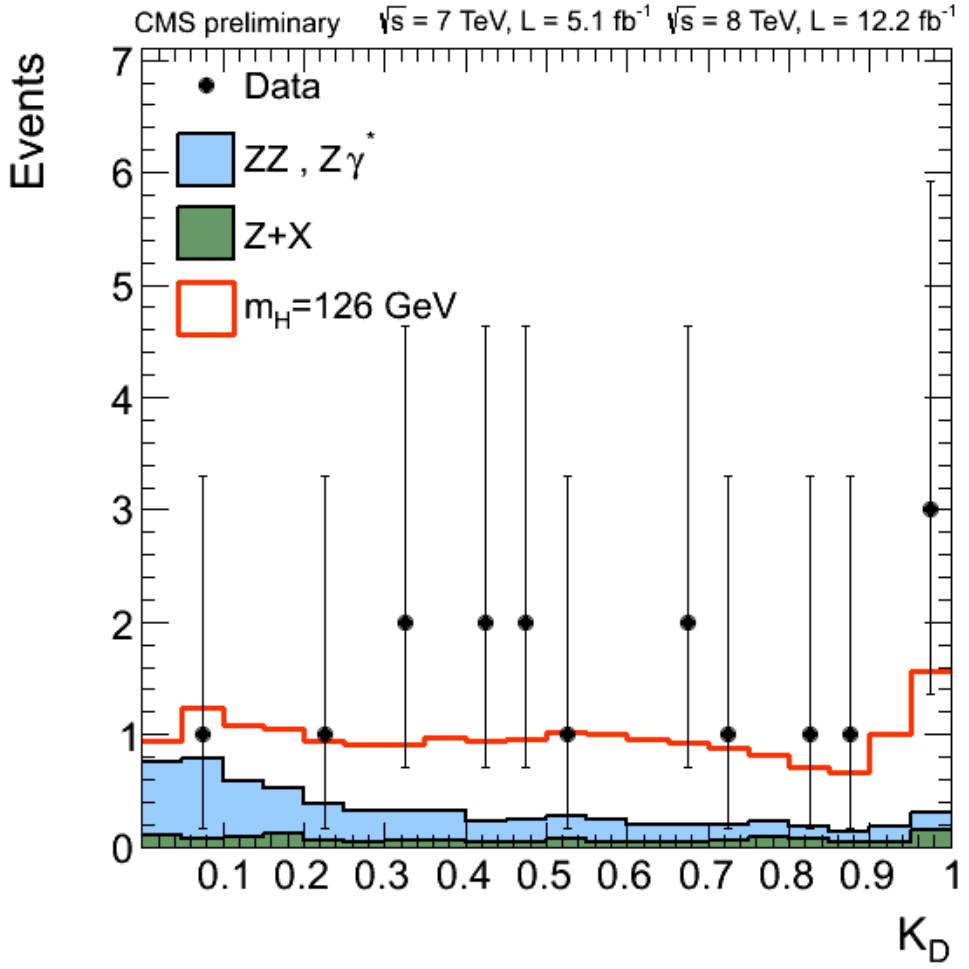




- Most of the events at ~126 GeV produced with signal like KD score
- Sidebands well consistent with background only hypothesis

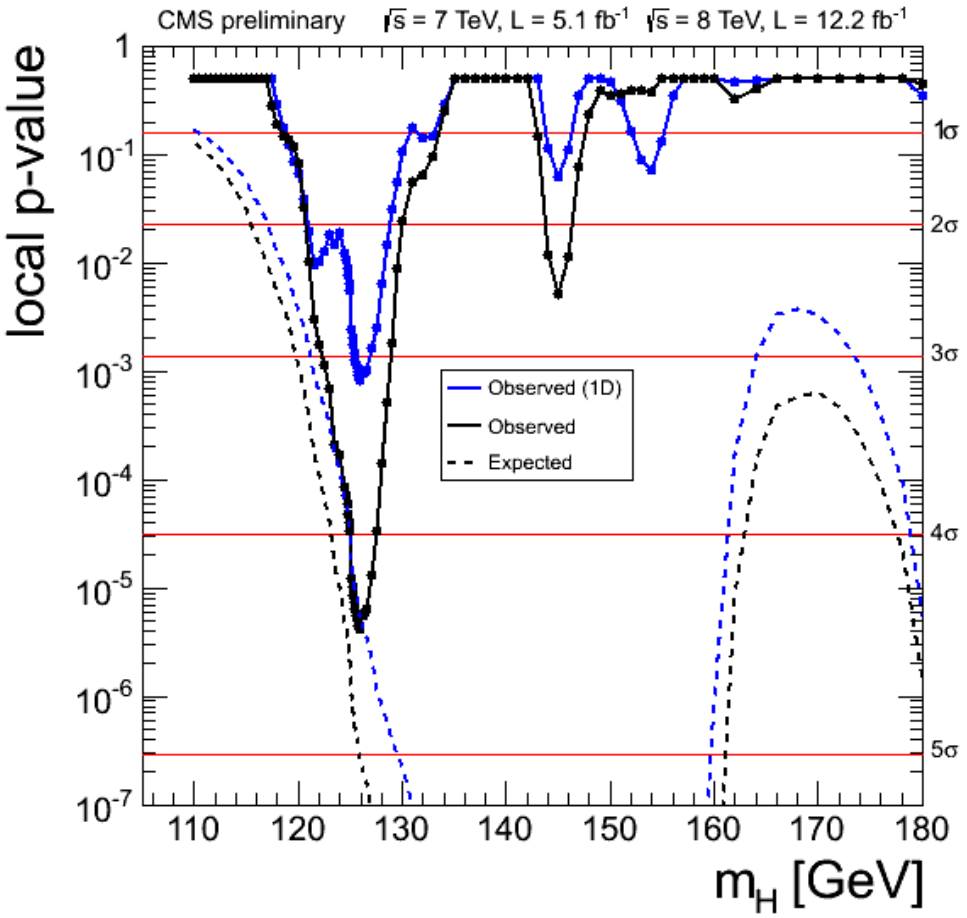
Mass after K_D cut/K_D on the bump

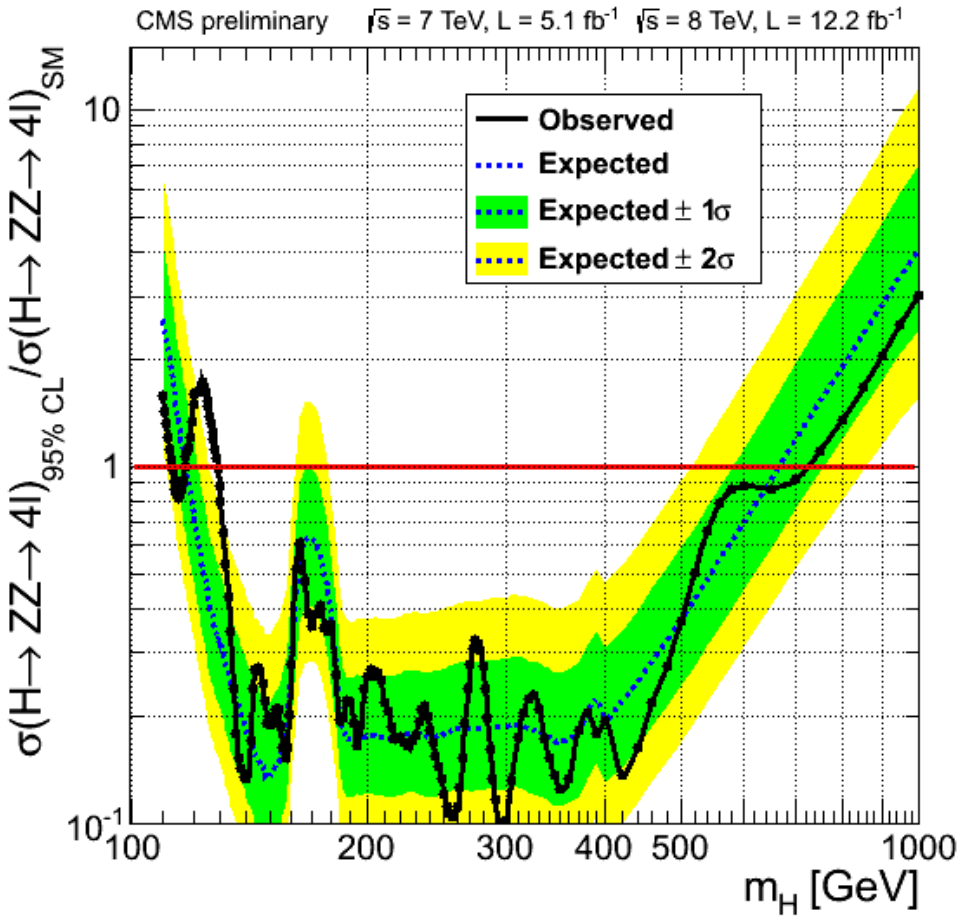




- Mass after K_D cut enhances S/B
- Signal like distribution of K_D in the bump

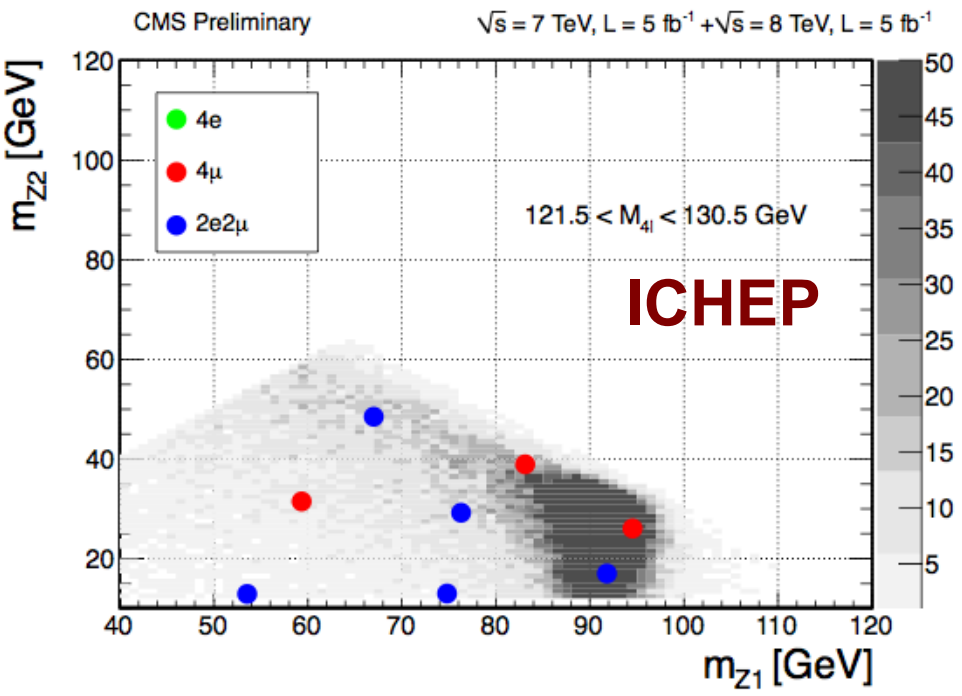
Significance of the excess

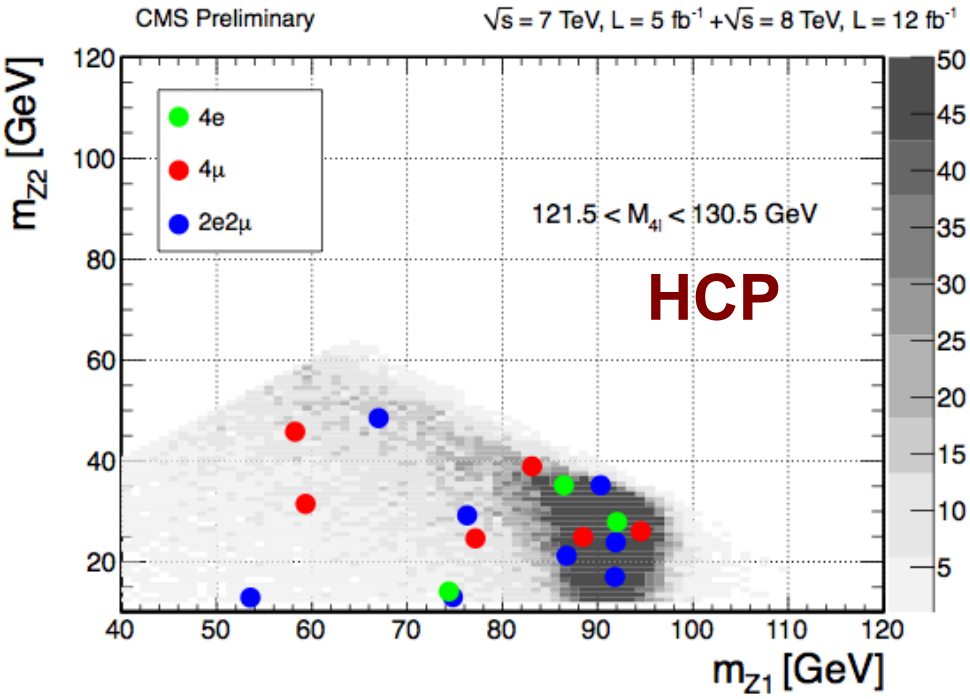




- Using a 2D model of mass and kinematic discriminant
  - Significance of the excess : 4.5 σ, Expected 5.0σ
  - Signal strength $\mu = 0.80^{+0.35}_{-0.28}$
- 1D (no KD) and 2D models consistent
- No significant additional excesses observed at high mass

M_{Z1} vs M_{Z2} business

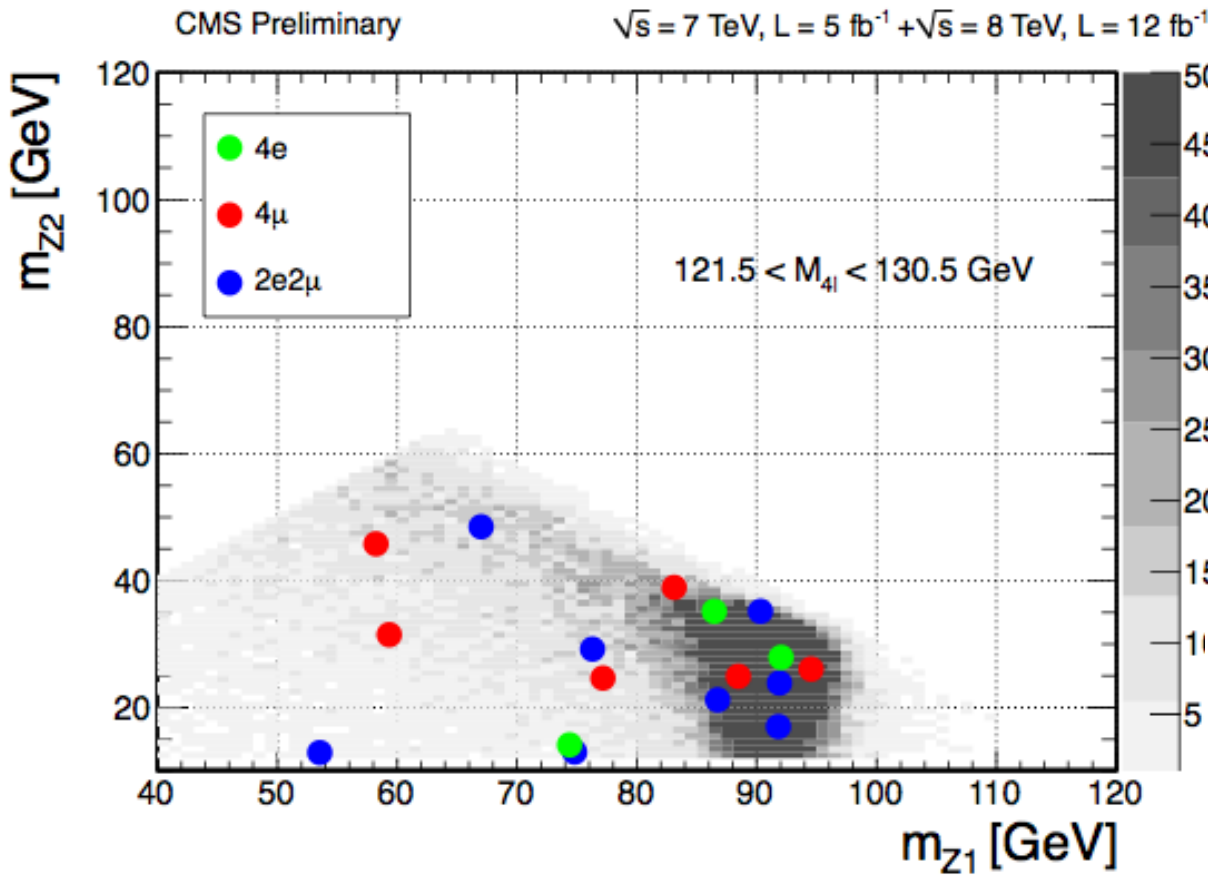


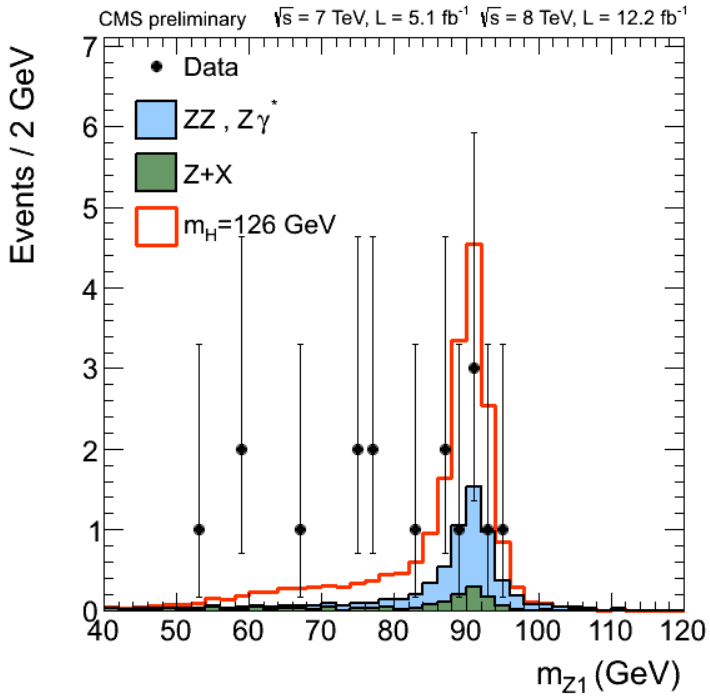


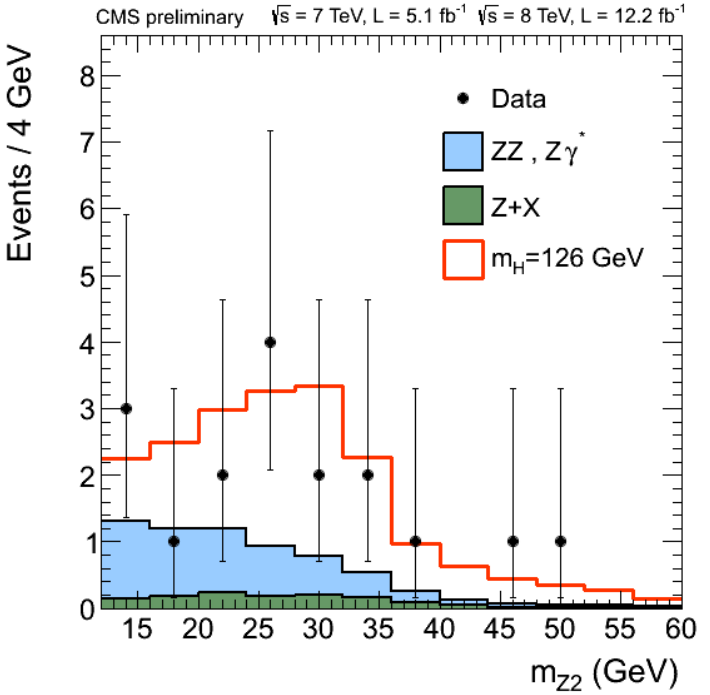
- Distribution was exciting at ICHEP
  - Most events were off shell for Z1
- Most events collected after ICHEP at the right spot
  - Giving consistent picture for the full dataset

M_{Z1} vs M_{Z2} in the full sample

$121.5 < m_{4l} < 130.5$ GeV





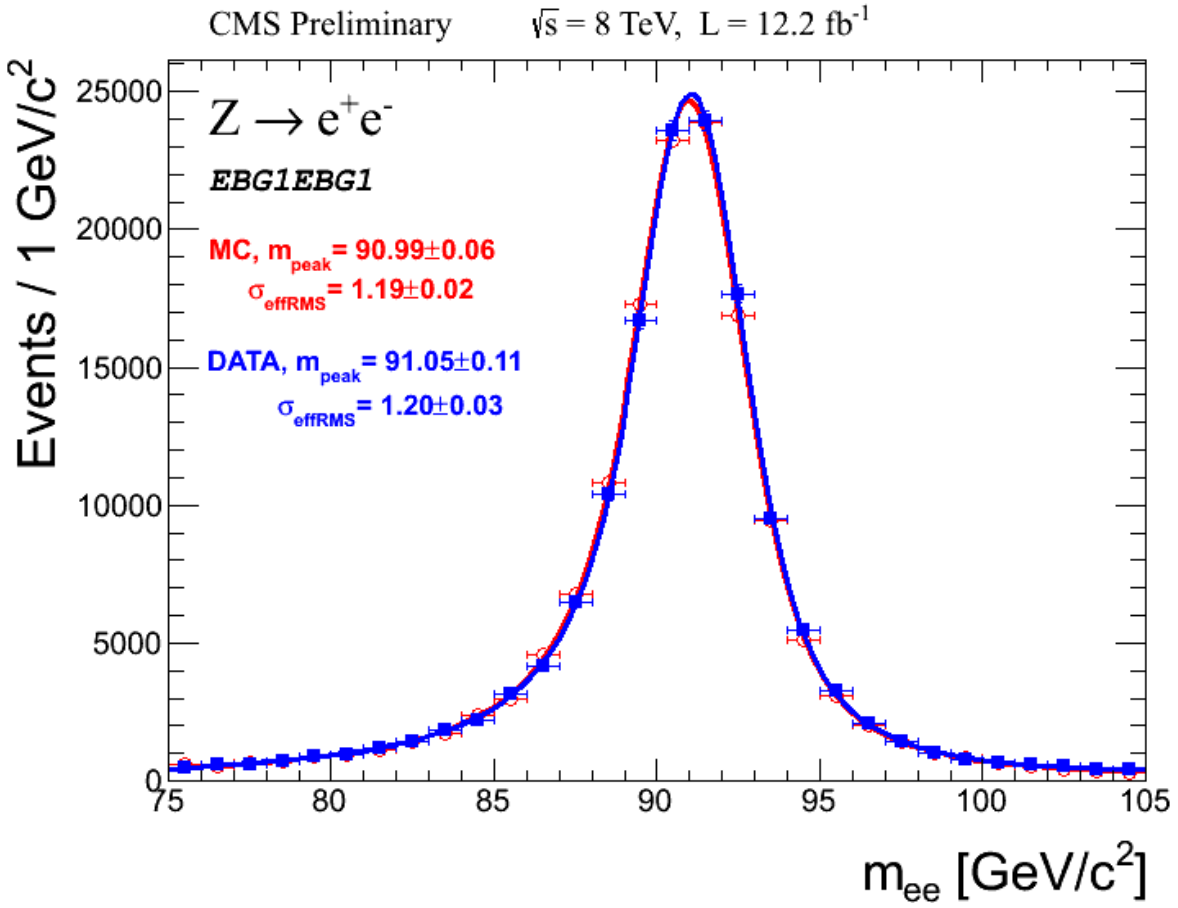


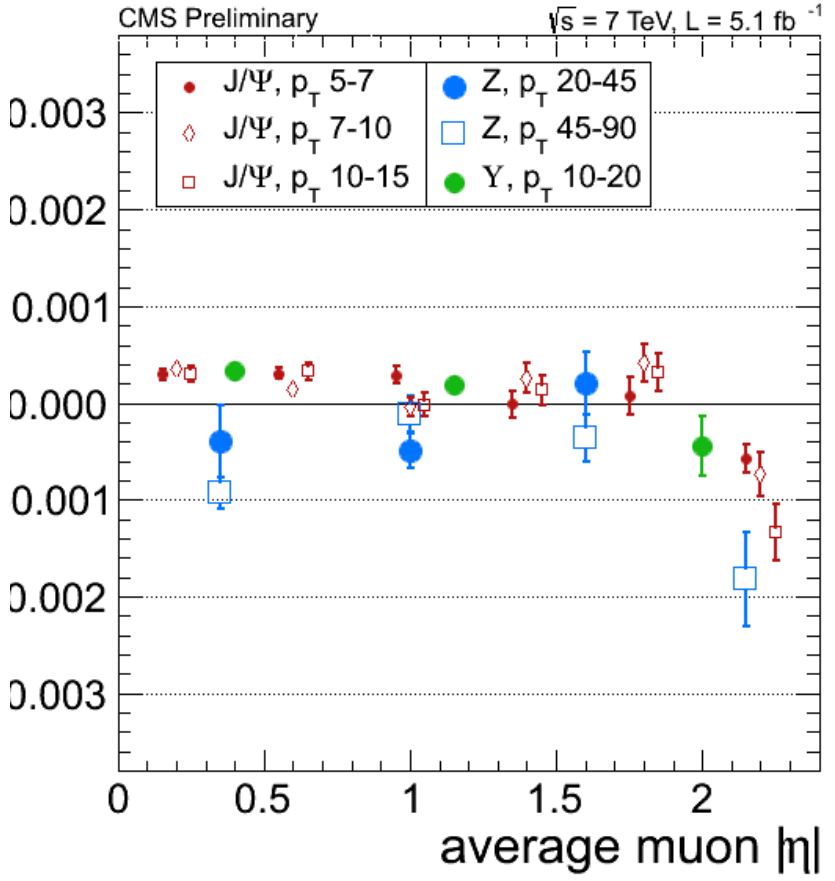
- New picture consistent with the SM expectation

Measurement of the mass

- Precise mass measurement requires
  - Excellent calibration and knowledge of the momentum scale of the leptons
  - Precise resolution model
- Utilizing event-by-event errors
  - Each event has its own resolution based on the detector and calibration uncertainties
- To perform the mass fit we introduce a 3^{d} dimension to the fit ($m_{4\ell}$,KD,$\delta m_{4\ell}$)

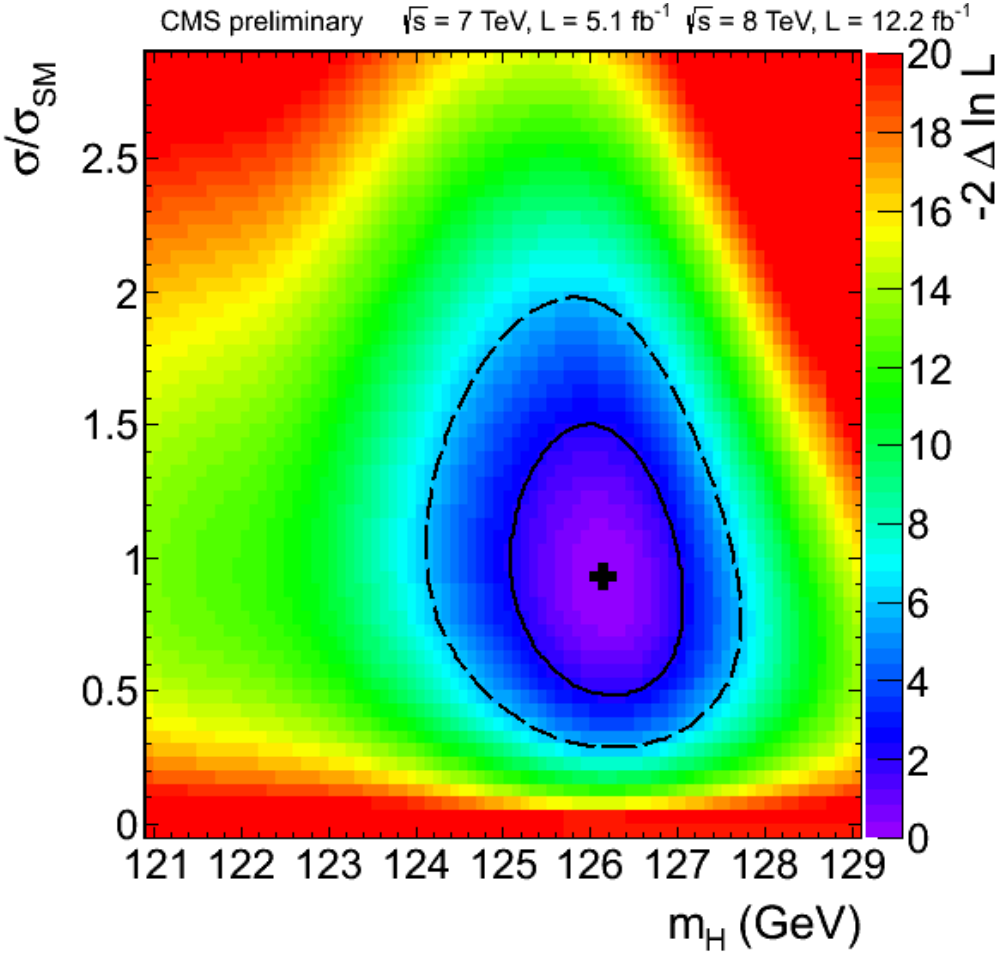
Key point : Precise Calibration!

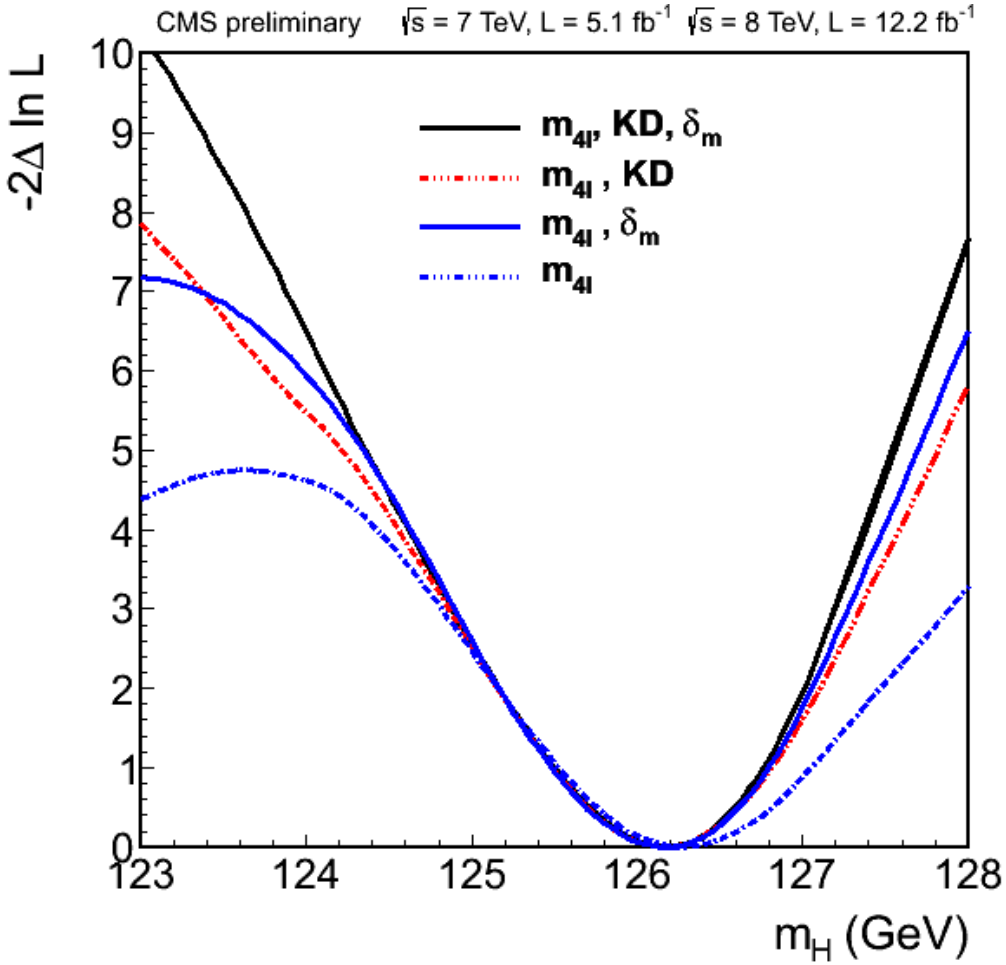




- Lepton scale and resolution measured with high precision on Z , J/ψ and Υ events
- 0.1%(0.2%) scale uncertainty for muons(electrons)
- 20% uncertainty of the resolution

Mass result

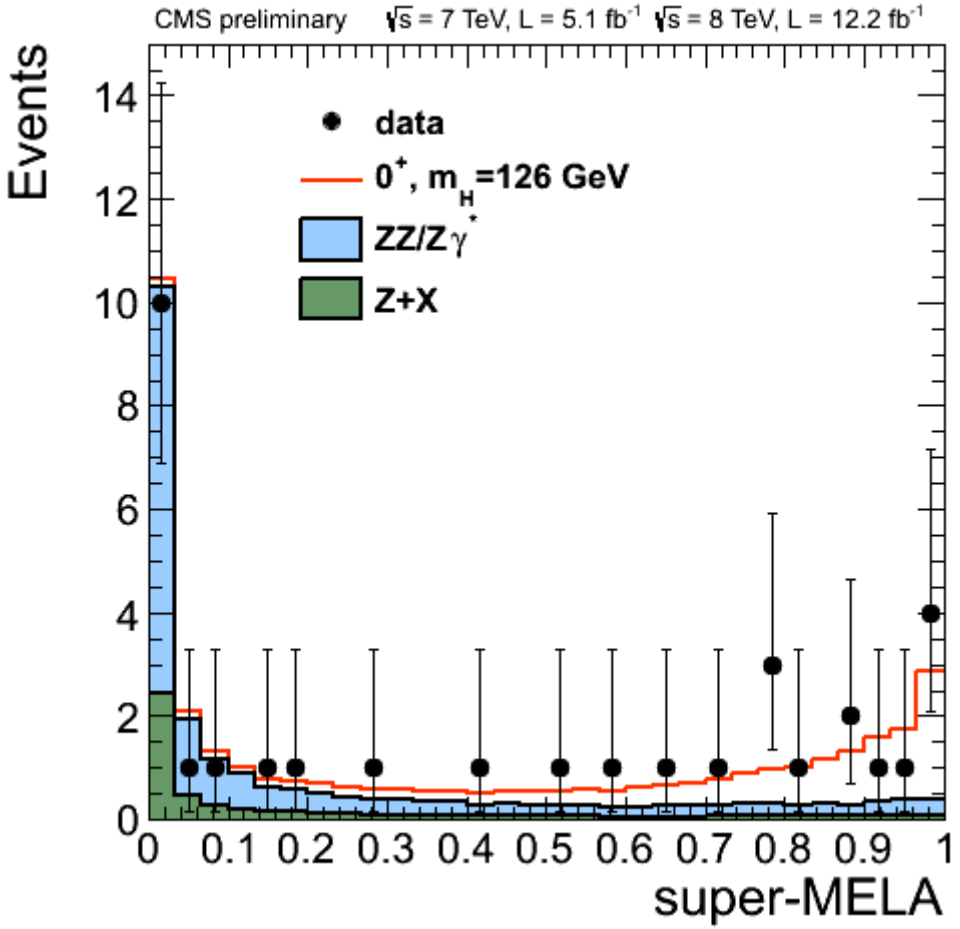




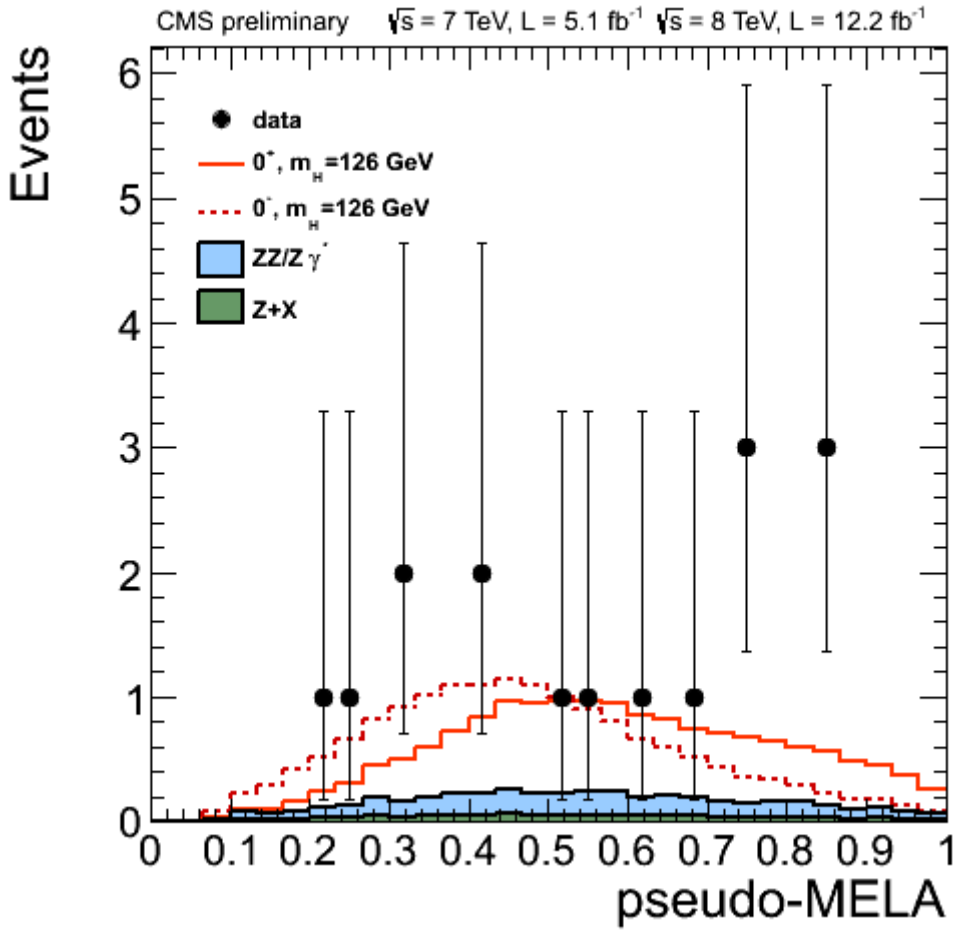
- Measured mass = 126.2 ± 0.6 (stat) ± 0.2 (syst) GeV (3D model)
- Consistency between different statistical models and H → γγ final state

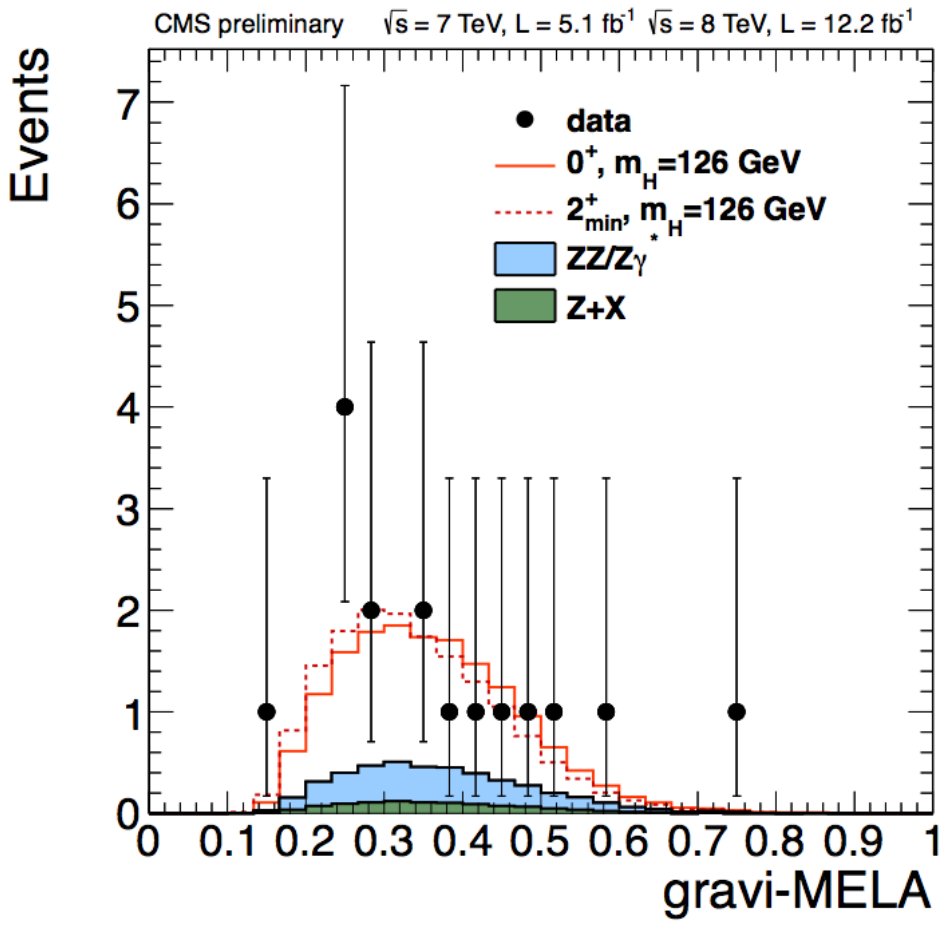
Spin – parity measurements

- Define new kinematic discriminants to discriminate between models:
  - PseudoMELA
    - discriminates between scalar and pseudoscalar hypotheses
  - GraviMELA
    - discriminates between SM and graviton with minimal couplings
- To reduce the number of dimensions in the fit:
  - combine mass and kinematic discriminant against background into one variable: SuperMELA
- Perform 2D fit of the SuperMELA and the alternative model discriminants



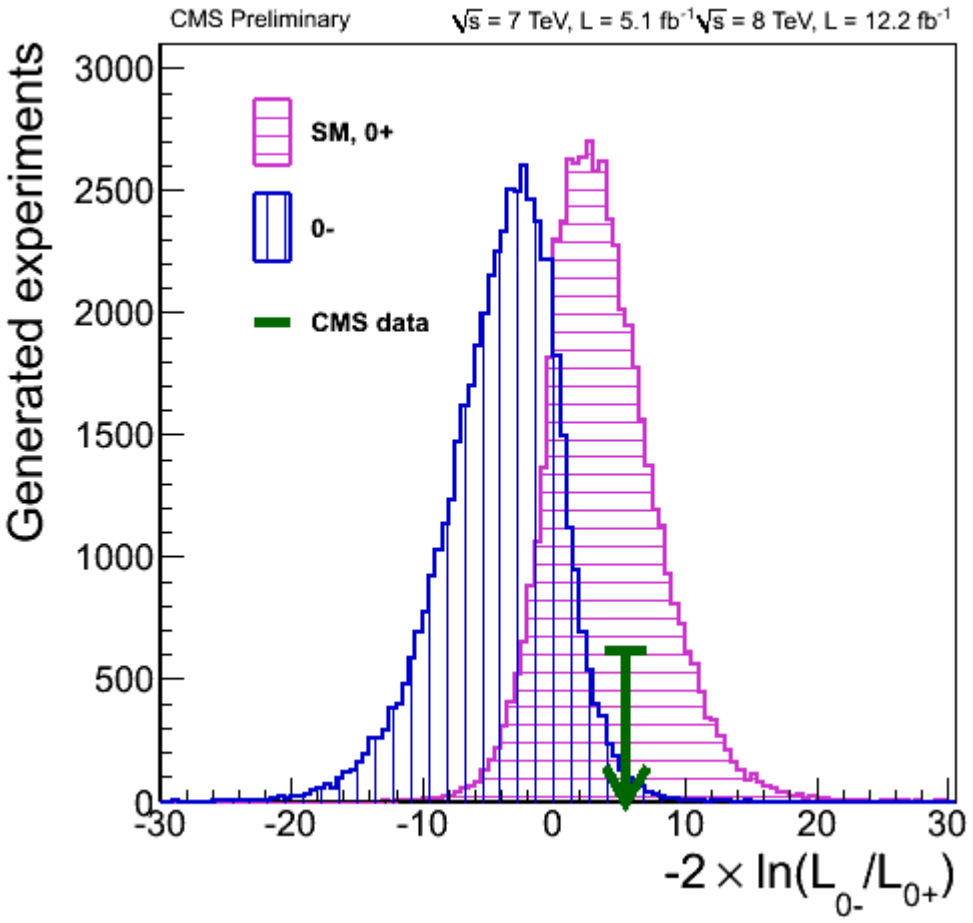
Spin/Parity discriminants

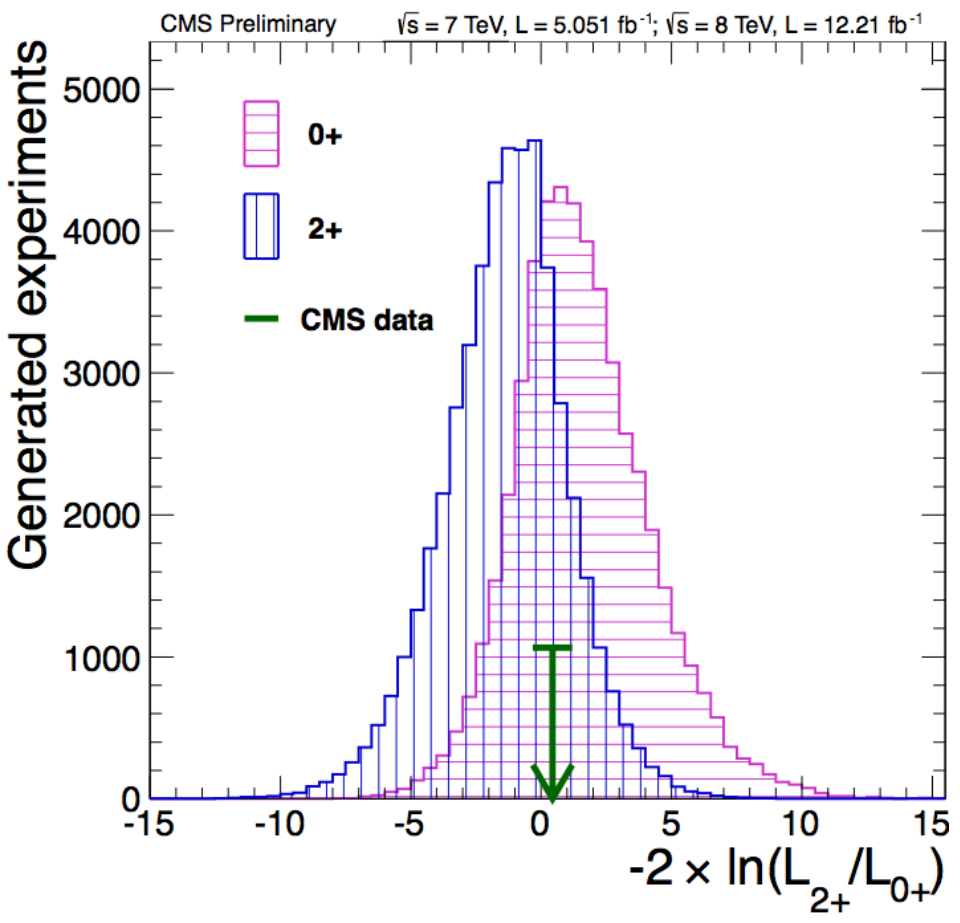




- Parity discriminant tends towards SM hypothesis
- Low discrimination power for 2^+ discriminant
  - Need ~ 4x more data to get similar discrimination power as in the parity case

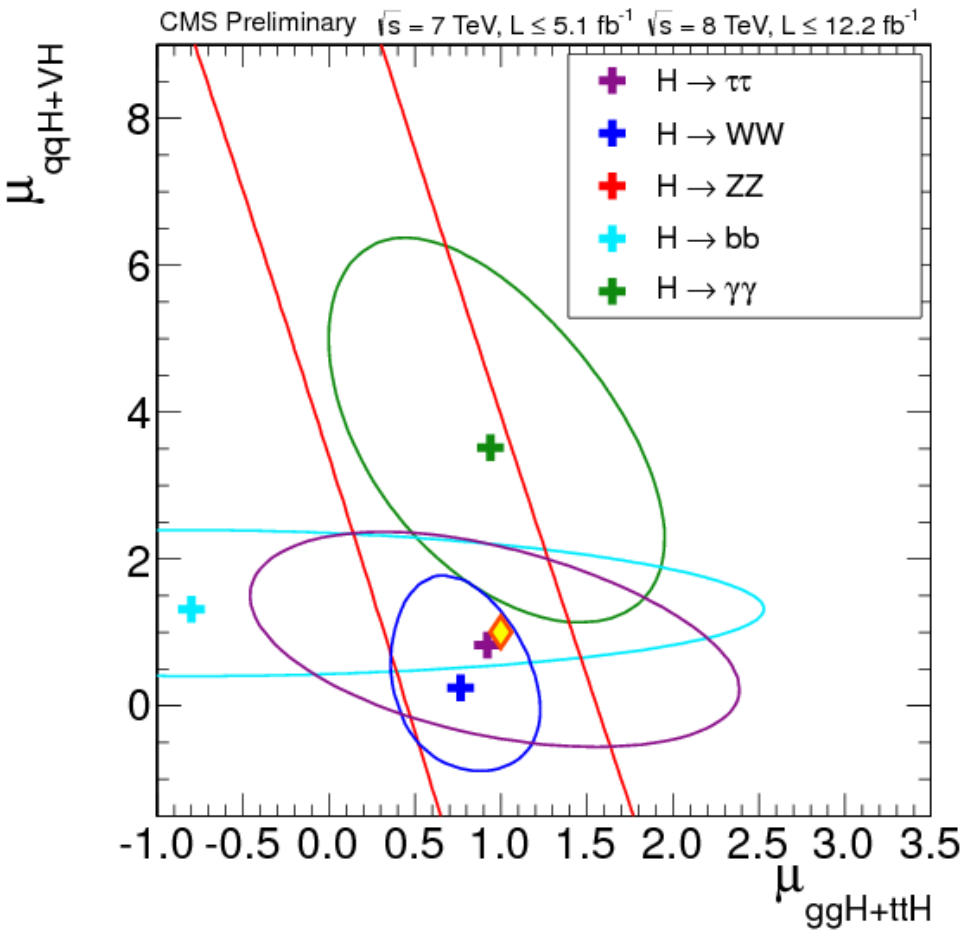
Spin/CP Results

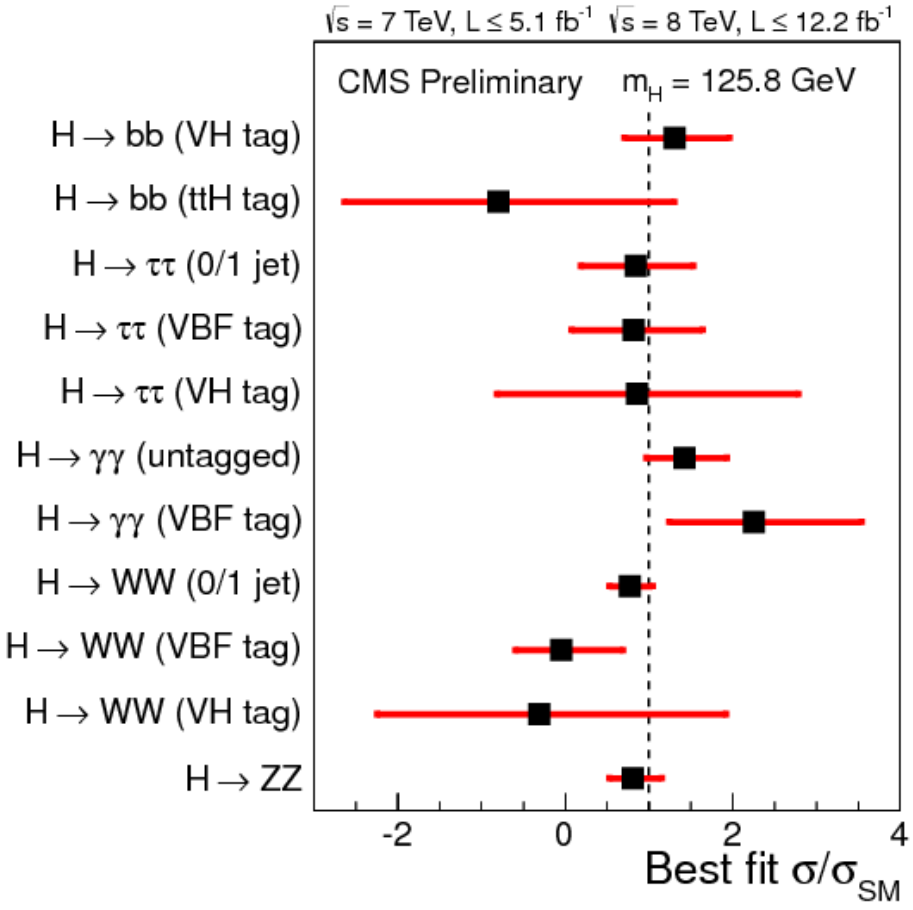




- Parity: Data consistent with SM
  - Pseudoscalar hypothesis disfavored at 2.4σ
  - Mean of the expected 0+ distribution 1.9 σ in the tail of 0-
- 2+ : Very low discrimination power. Need more data

Putting it together with the others





- Cross section in good agreement with SM and other channels
- Due to model independent search low power in disentangling production mechanisms
  - Need to add VBF/VH discrimination capabilities

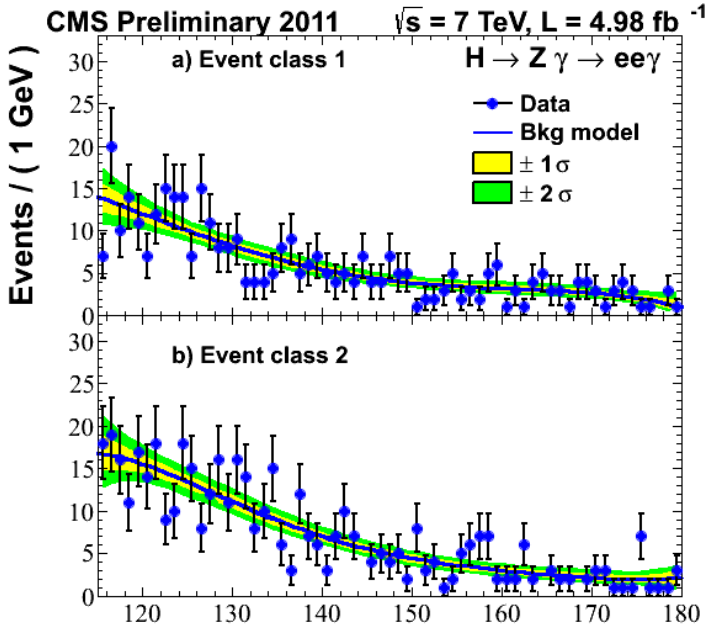
H → Zγ analysis

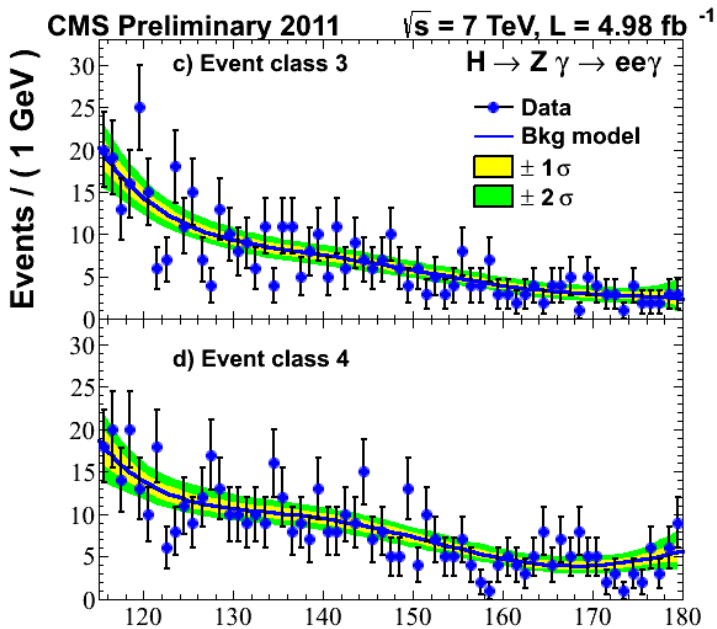
- Branching ratio = 70% of H → γγ @ 126 GeV
  - Huge event loss due to the Z → μμ/ee BR
  - For each H → γγ event we expect 0.04 Zγ events
- Main backgrounds
  - SM production of Z+ISR photon
  - Drell Yan production + fake photon
- Event selection
  - Leptons > 20 (10) GeV , Photons > 15 GeV
  - $M_{\ell\ell}$ >50 GeV (to have exclusive sample wrt γγ + converted photon)
  - $M_{\ell\ell\gamma}$ in [110 ,180] GeV window
- Events classified in 4 categories based on expected resolution

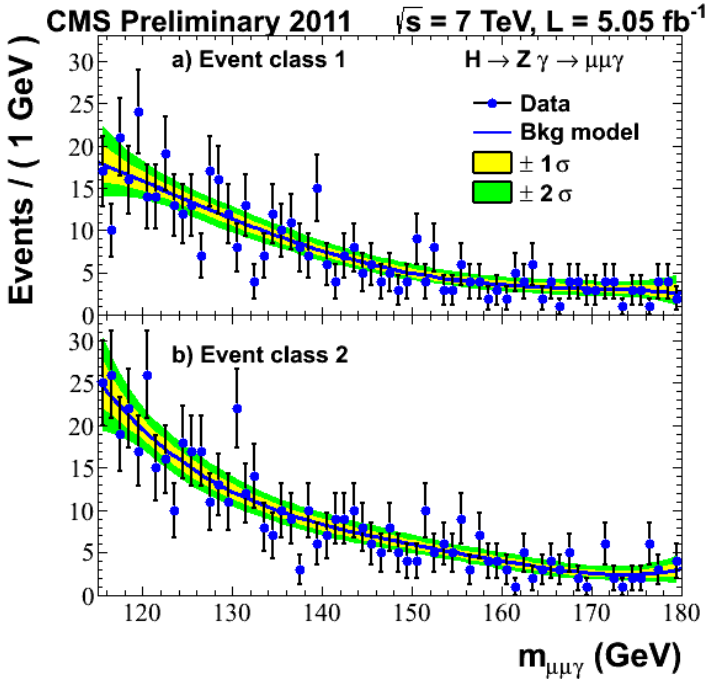
Mass spectra @ 7 TeV

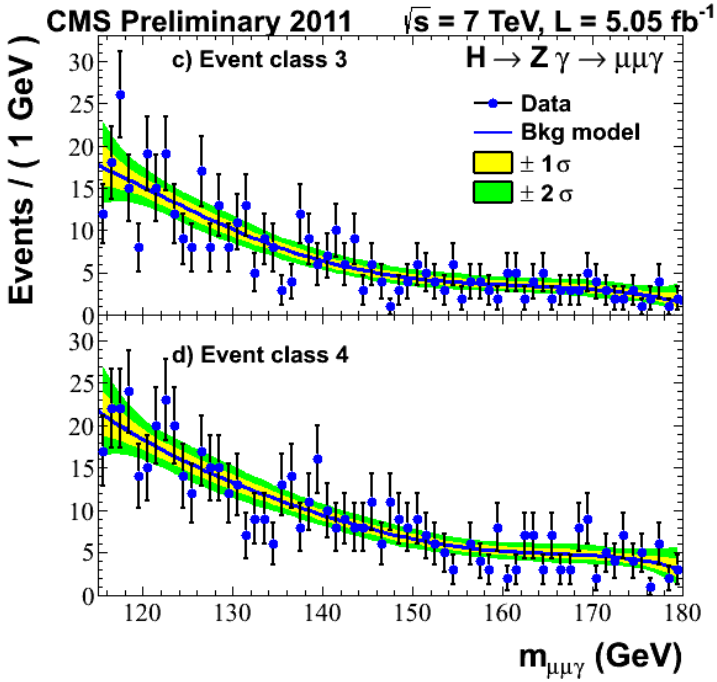
Electrons

Muons



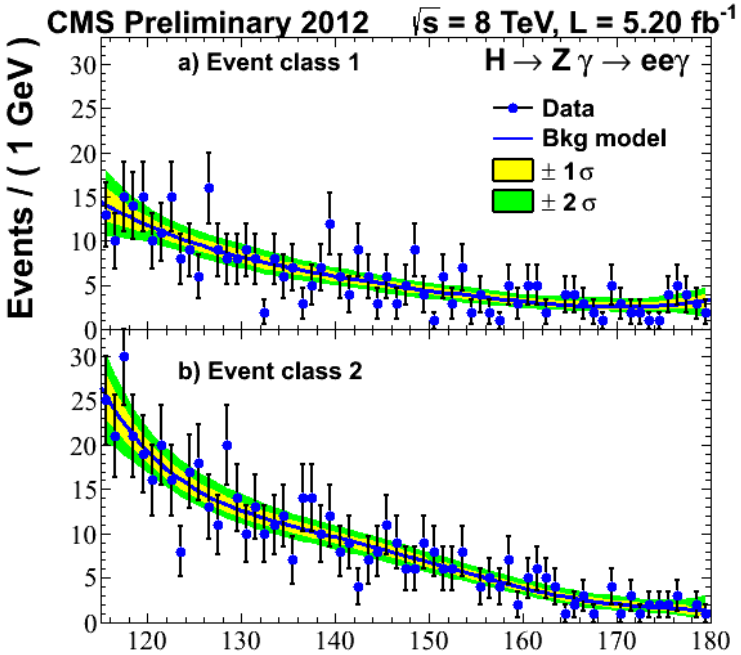


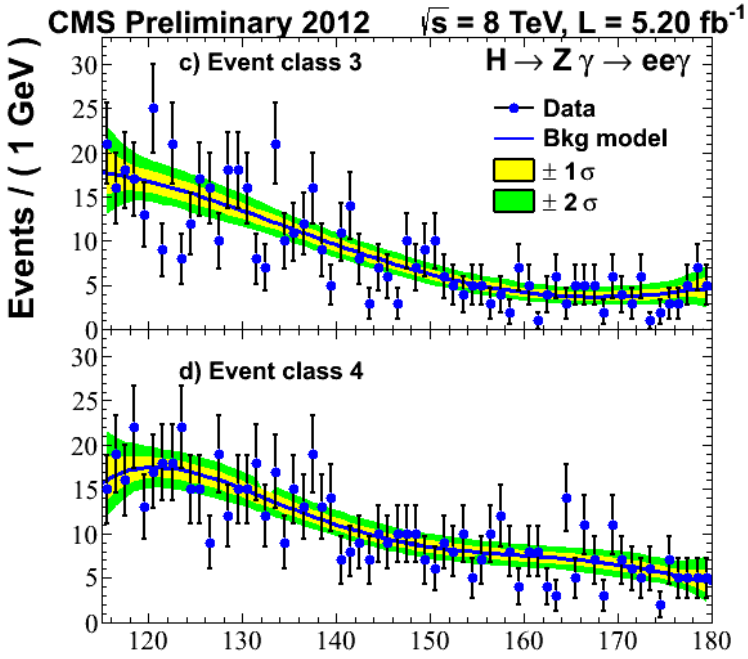




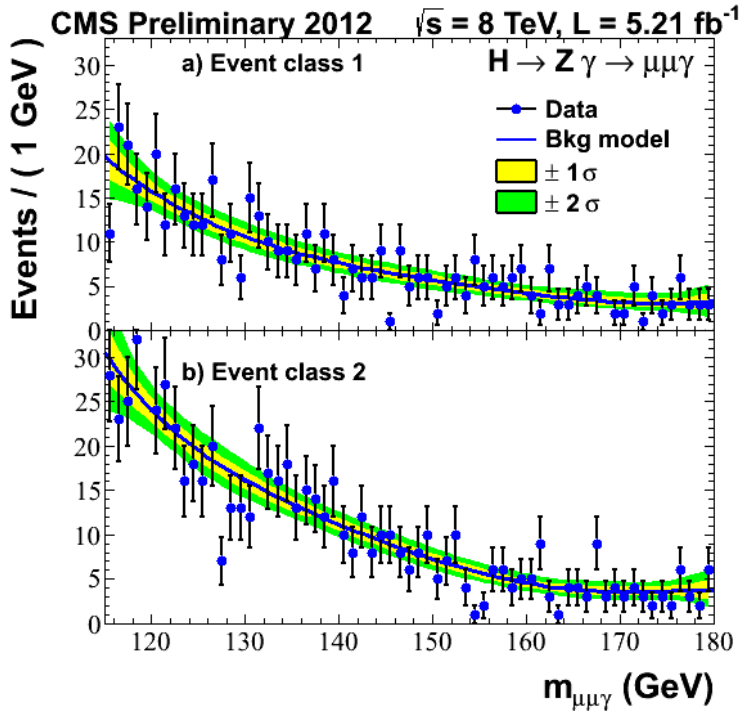
Mass spectra @ 8 TeV

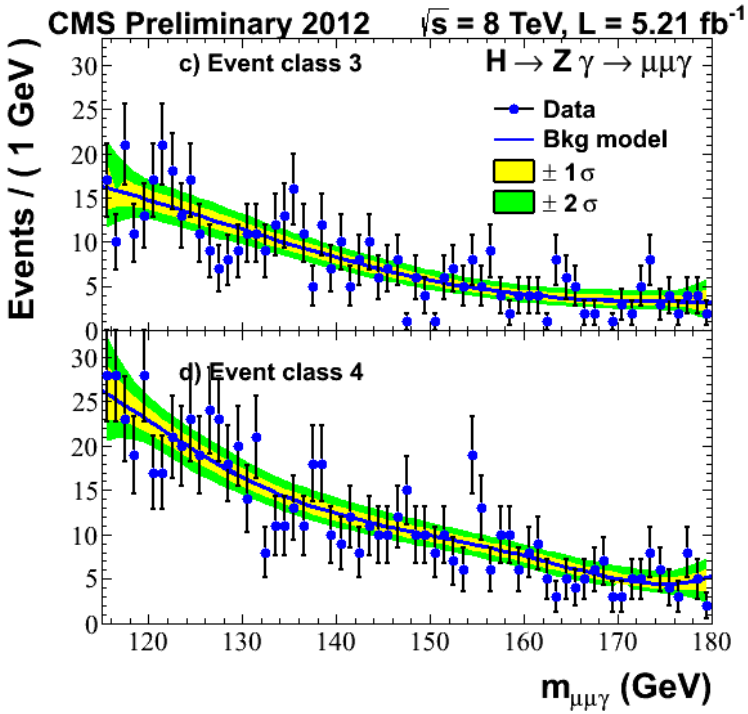
Electrons



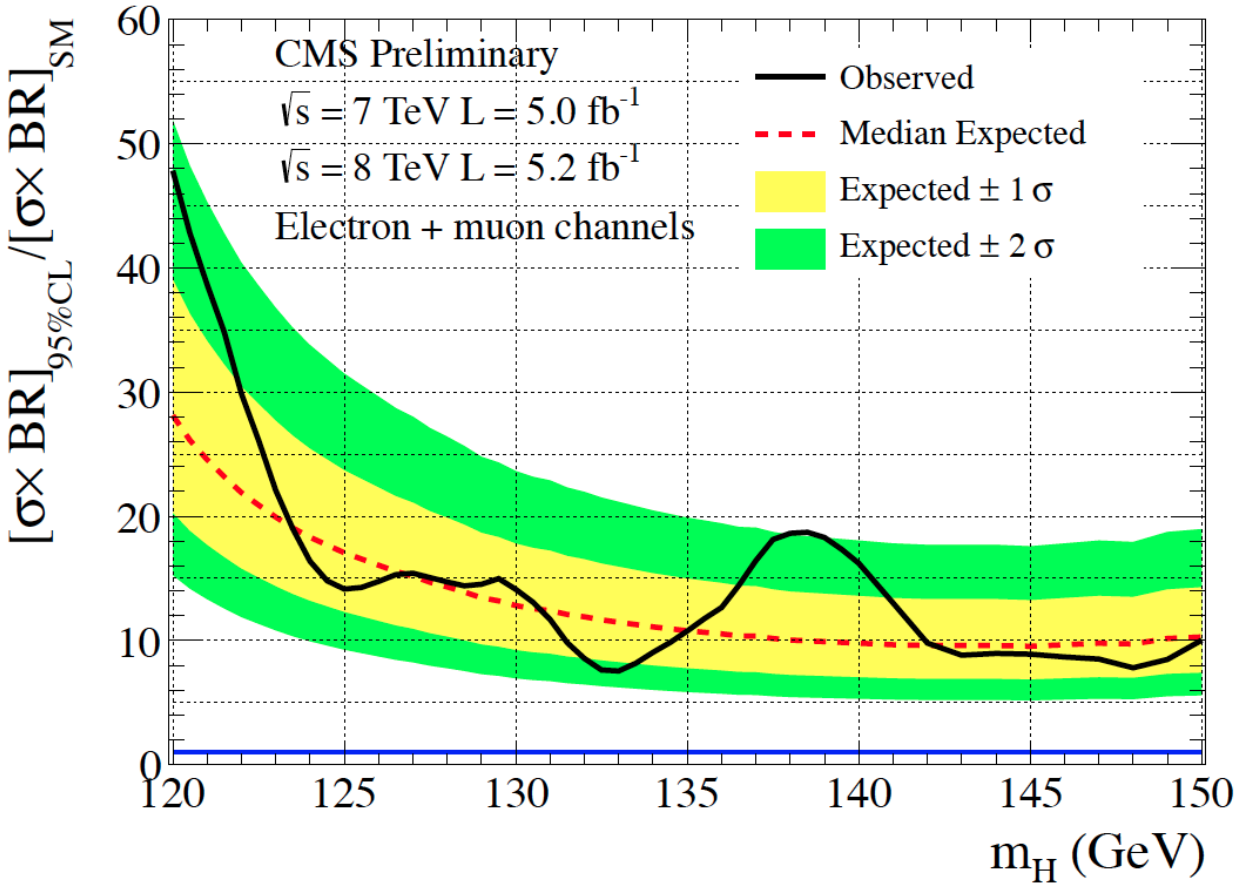


Muons





Results



- Low sensitivity for a SM Higgs boson
  - ~ 16x SM @ 125 GeV
  - Final state expected to be relevant at much higher luminosities
- No significant deviations from the background hypothesis

Conclusions

- Updated results with 12+5 fb-1 for HCP for $H \rightarrow ZZ \rightarrow 4\ell$ analysis
  - The observed boson is still there!
  - Cross section and parity consistent with the SM expectation
  - Mass of 126 ± 0.6 (stat) ± 0.2 (syst) GeV
- First $H \rightarrow Z\gamma$ results public with 5+5 fb-1
  - Low sensitivity for a SM Higgs
  - No deviations compatible with BSM signal at low mass
  - Analysis could benefit from improvements