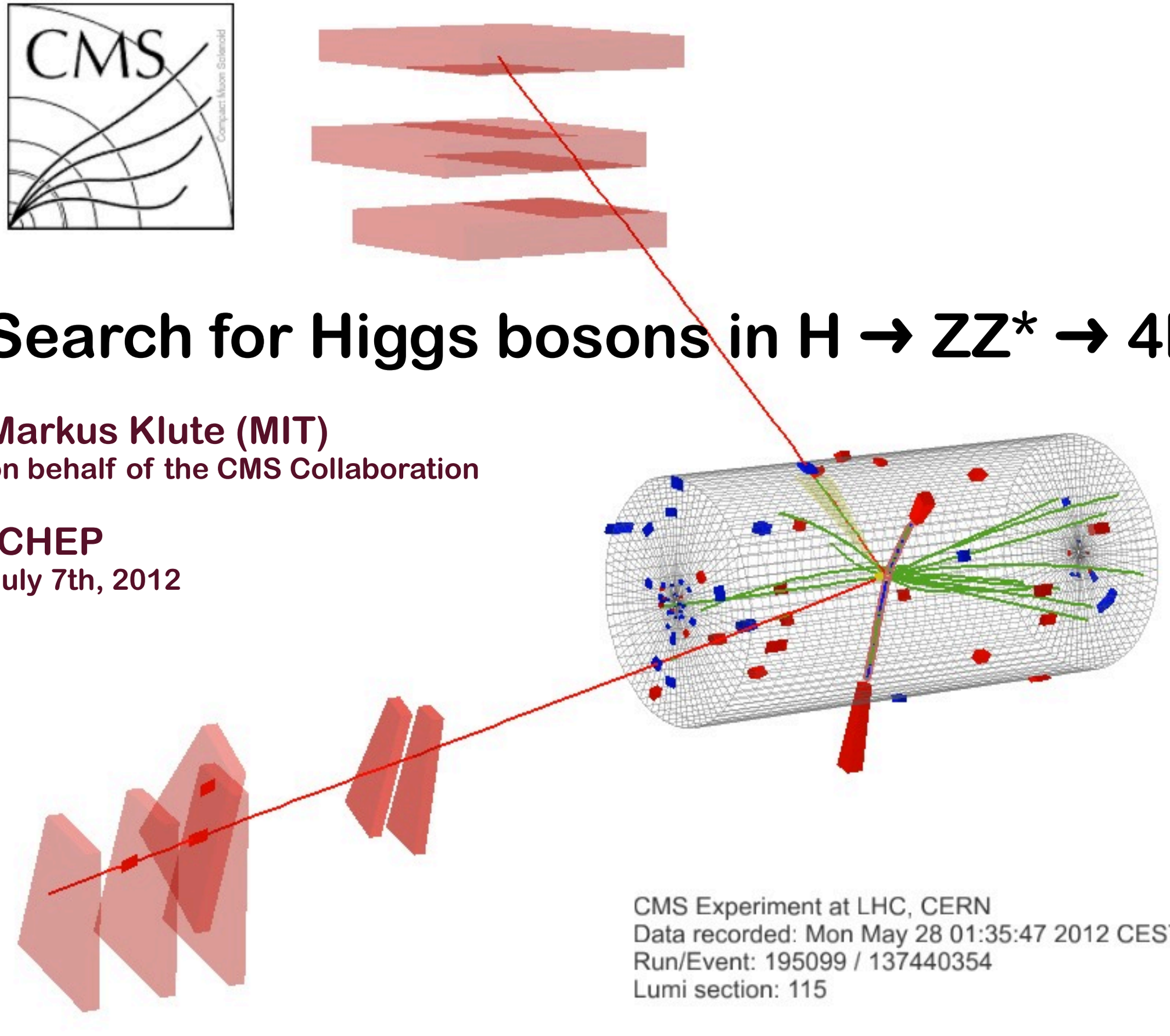


Search for Higgs bosons in H → ZZ* → 4l

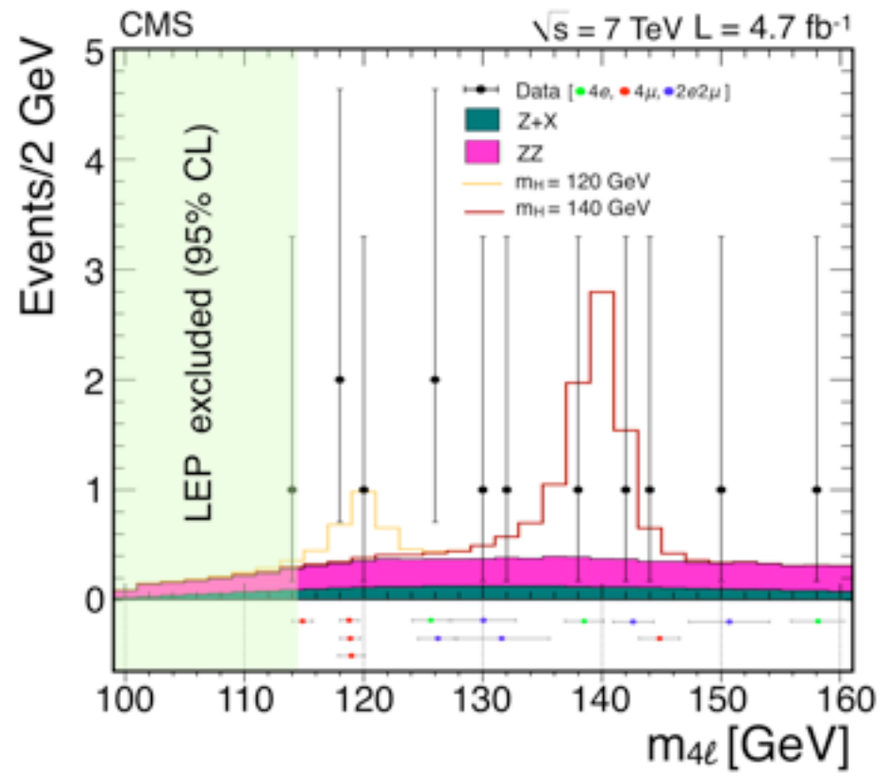
Markus Klute (MIT)
on behalf of the CMS Collaboration

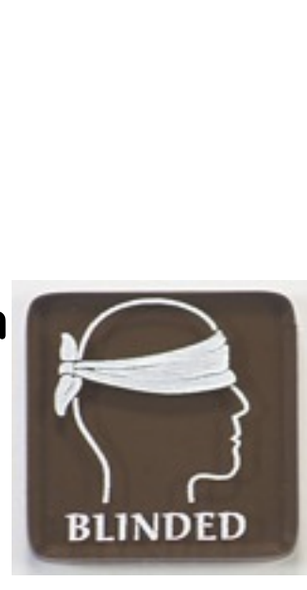
ICHEP
July 7th, 2012

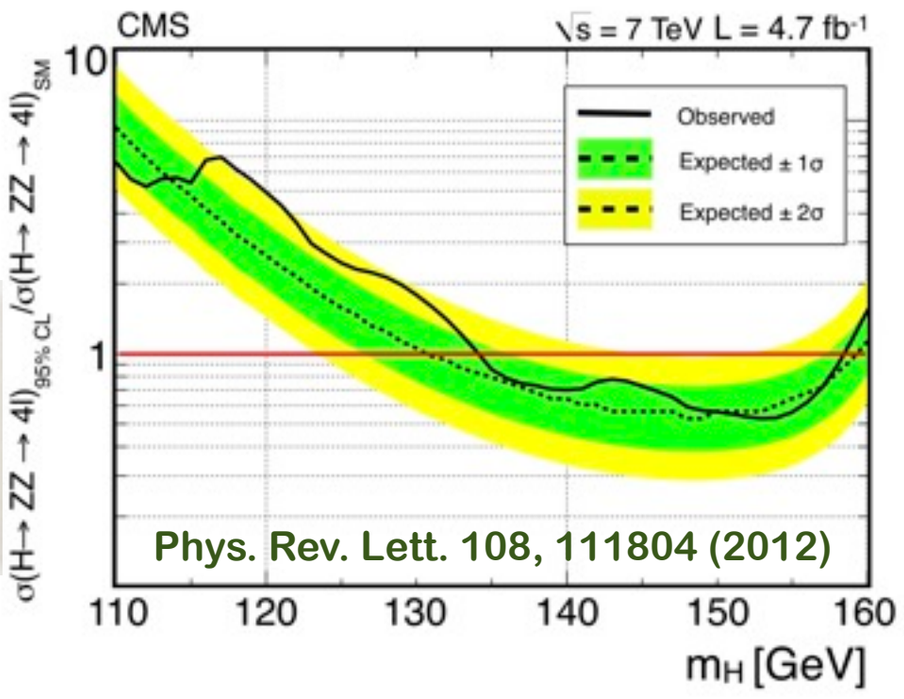
CMS Experiment at LHC, CERN
Data recorded: Mon May 28 01:35:47 2012 CEST
Run/Event: 195099 / 137440354
Lumi section: 115

Introduction

- **Golden channel**
  - Clean experimental signature, four isolated leptons
  - Benefits from excellent electron and muon resolution
  - Narrow resonance in four lepton mass spectrum
- **Background**
  - Irreducible: ZZ*
  - Reducible: Z+jets/ttbar/WZ
- **Sensitivity**
  - 115 < mH < 600 GeV
- **Substantial changes to the analysis**
  - New lepton identification and isolation
  - Final state radiation (FSR) recovery
  - 2D analysis: use of mass and angular information

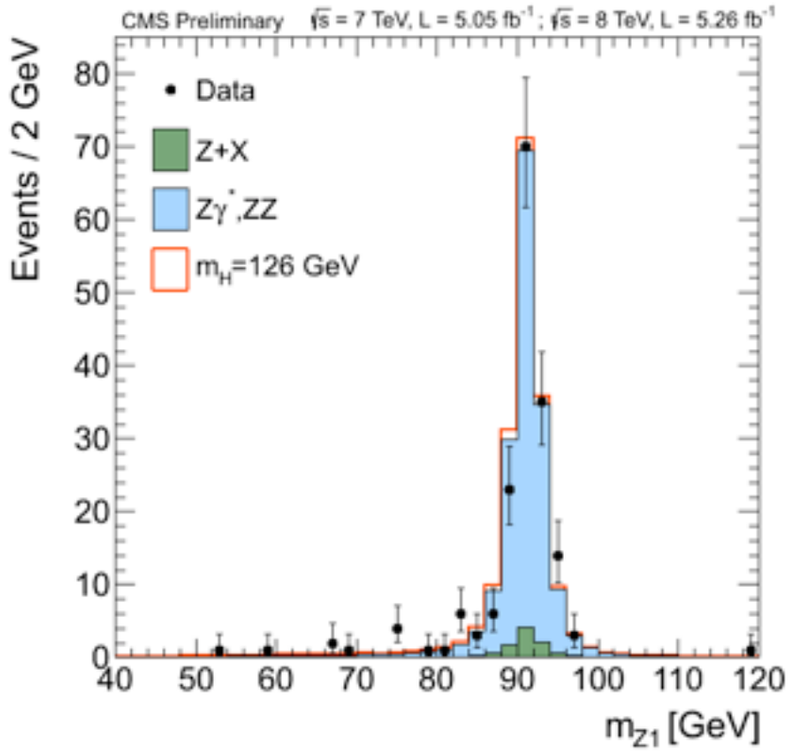


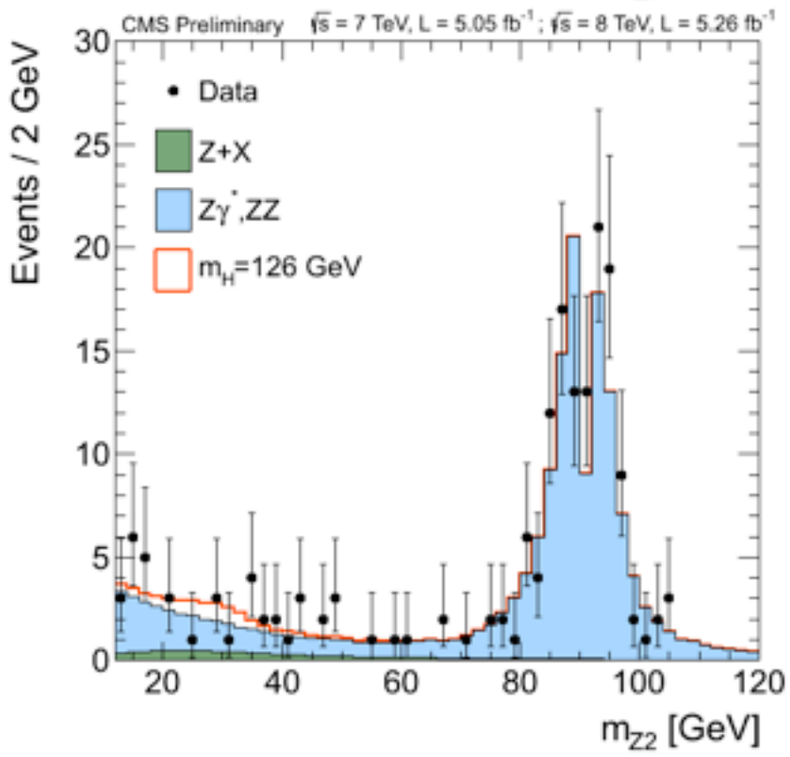




Event Selection

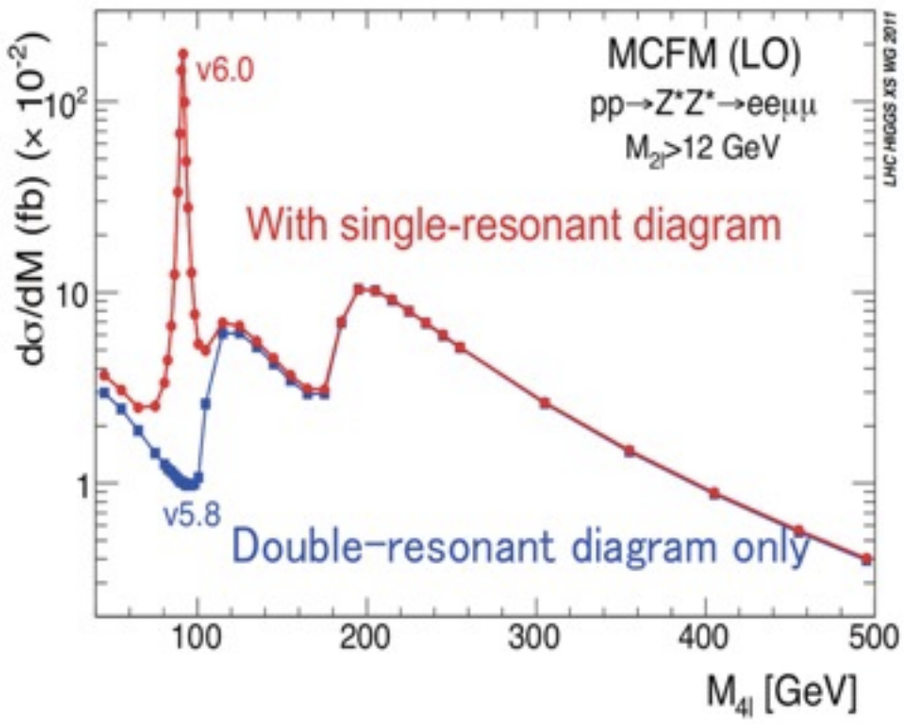
- Trigger: di-lepton signatures (ee, eμ or μμ)
- Leptons
  - muons: pT > 5 GeV, |η| < 2.4, isolated, compatible with PV
  - electrons: pT > 7 GeV, |η| < 2.5, isolated, compatible with PV
- Lepton selection
  - at least one lepton with pT > 20 GeV
  - at least two leptons with pT > 10 GeV
- First Z candidate (Z1)
  - chosen as di-lepton pair with m(ll) closest to mZ
  - apply: 40 < m(ll) < 120 GeV
- Second Z candidate (Z2)
  - build from remaining highest pT leptons
  - apply: 4 < m(ll) < 120 GeV
- mll > 4 GeV of opposite-sign and same flavor pairs
- Kinematics
  - Higgs: m(4l) > 100 & mZ2 > 12 GeV

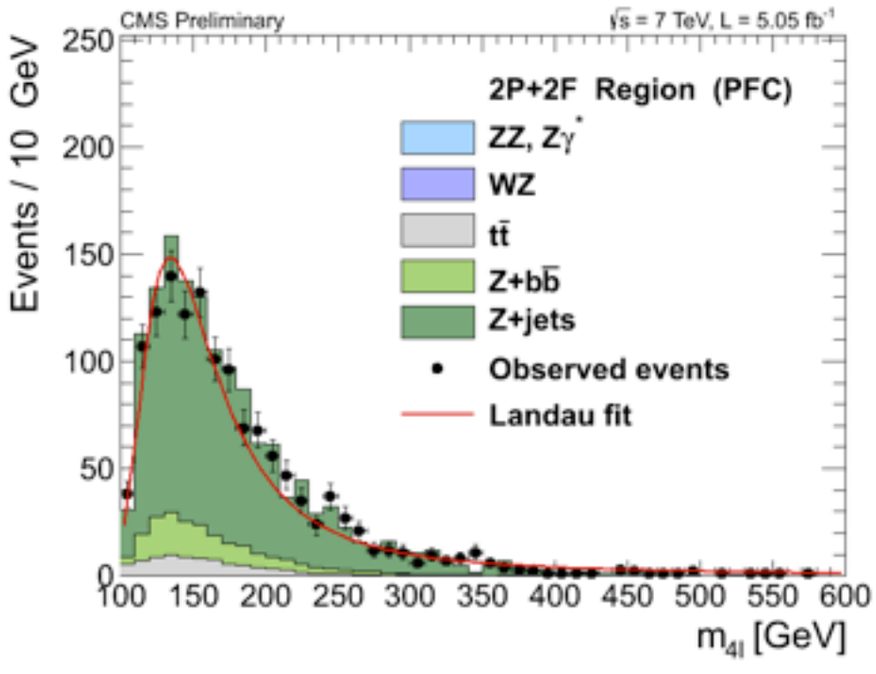


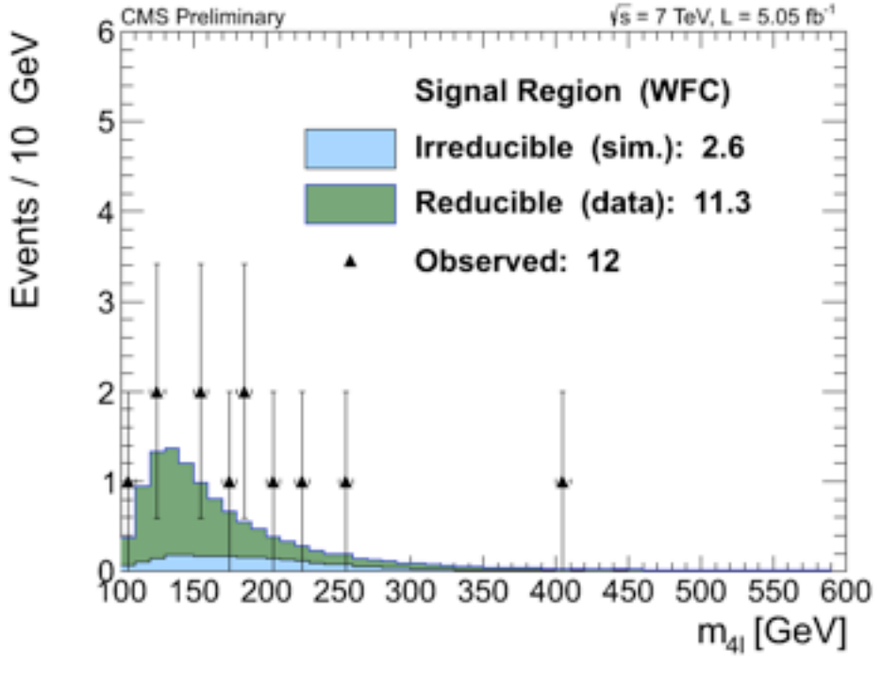


Backgrounds

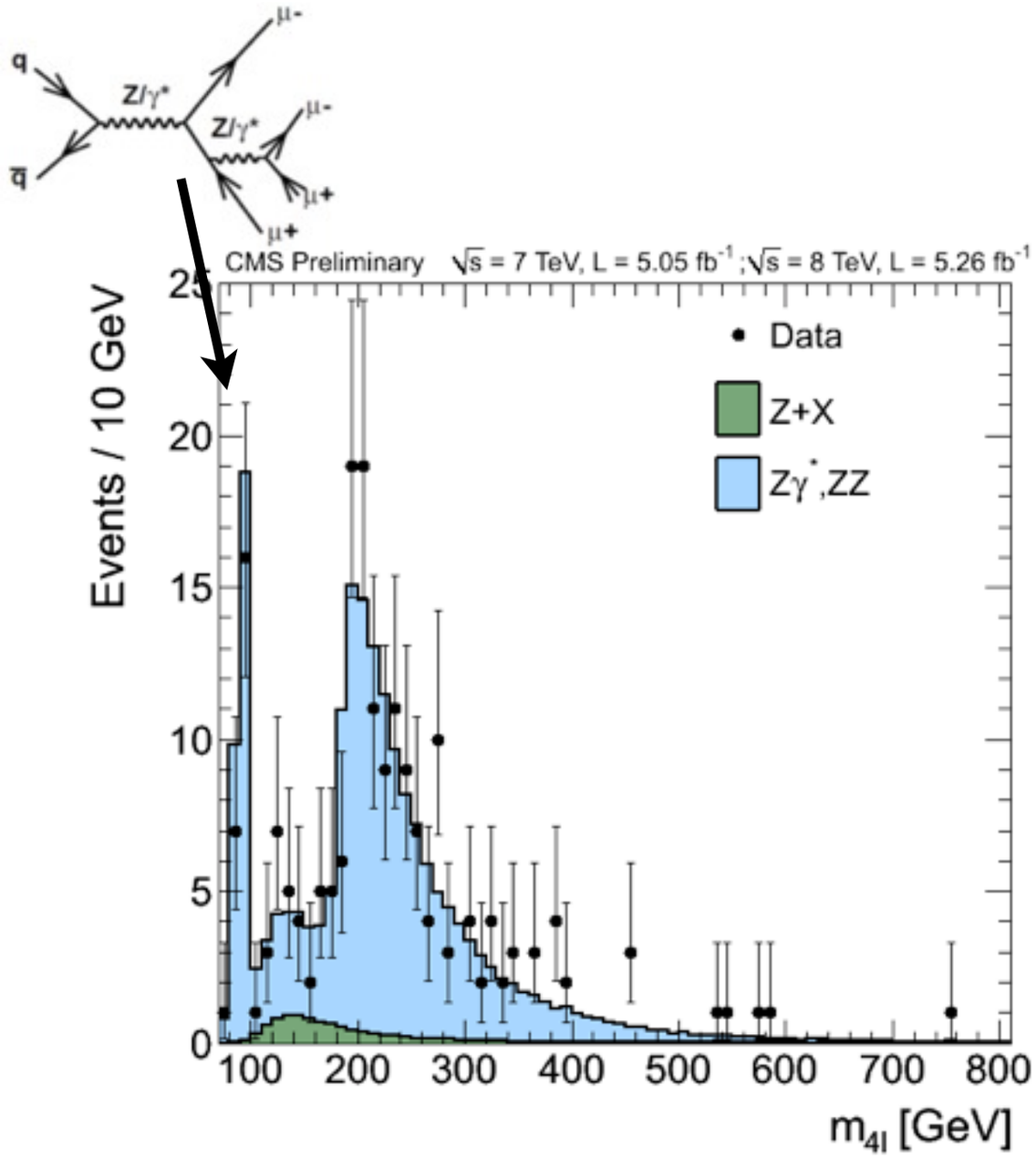
- Irreducible ZZ*
  - normalized to theoretical cross section
    - considered qq and gg production mode
  - acceptance taken from Monte Carlo; corrected for data/MC differences
  - phenomenological model for shape
- Reducible backgrounds
  - "fake rate" measured wrt loose leptons
  - inclusive approach to measure Z+jets, ttbar, WZ+jets







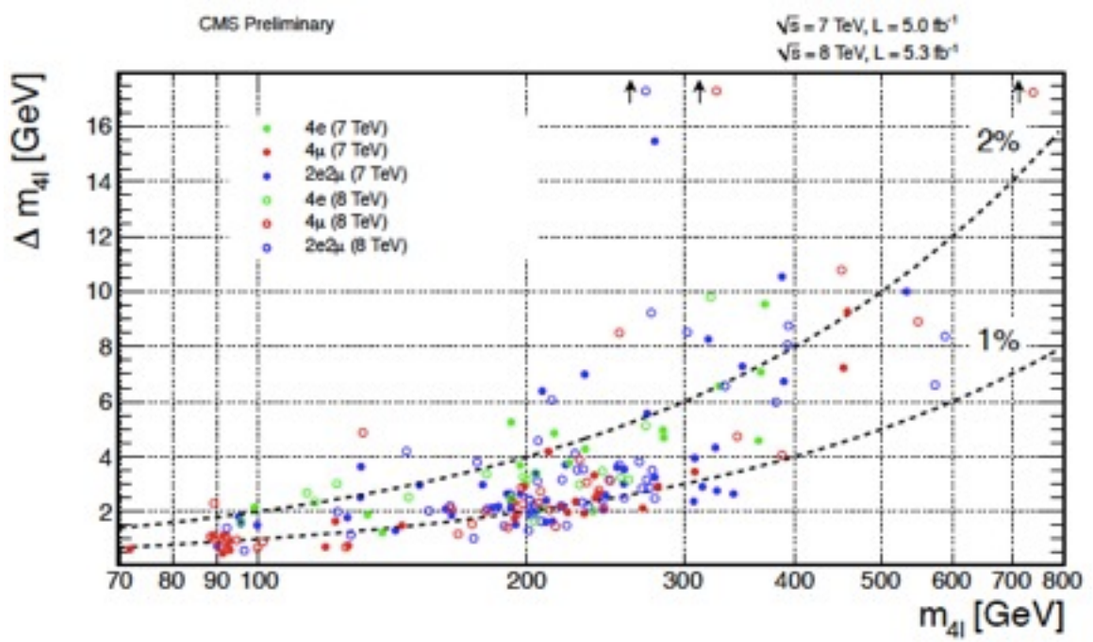
4-Lepton Mass Spectrum



Channel	4e	4μ	2e2μ	4ℓ
ZZ background	29.3 ± 3.4	49.0 ± 5.1	75.5 ± 8.0	153.7 ± 10.1
Z+X	$3.0^{+2.7}_{-1.9}$	$2.2^{+1.6}_{-1.3}$	$5.0^{+4.0}_{-3.0}$	$10.2^{+5.0}_{-3.8}$
All backgrounds	$32.3^{+4.4}_{-3.9}$	$51.2^{+5.3}_{-5.3}$	$80.5^{+9.0}_{-8.6}$	$163.9^{+11.3}_{-10.8}$
$m_H = 200$ GeV	8.3 ± 2.0	13.3 ± 2.7	21.6 ± 4.5	43.2 ± 5.6
$m_H = 350$ GeV	4.8 ± 1.2	7.5 ± 1.6	12.7 ± 2.9	24.9 ± 3.5
$m_H = 500$ GeV	1.7 ± 0.8	2.6 ± 1.2	4.4 ± 2.0	8.7 ± 2.4
Observed	32	47	93	172

164 events expected in 100-800 GeV

172 events observed in 100-800 GeV



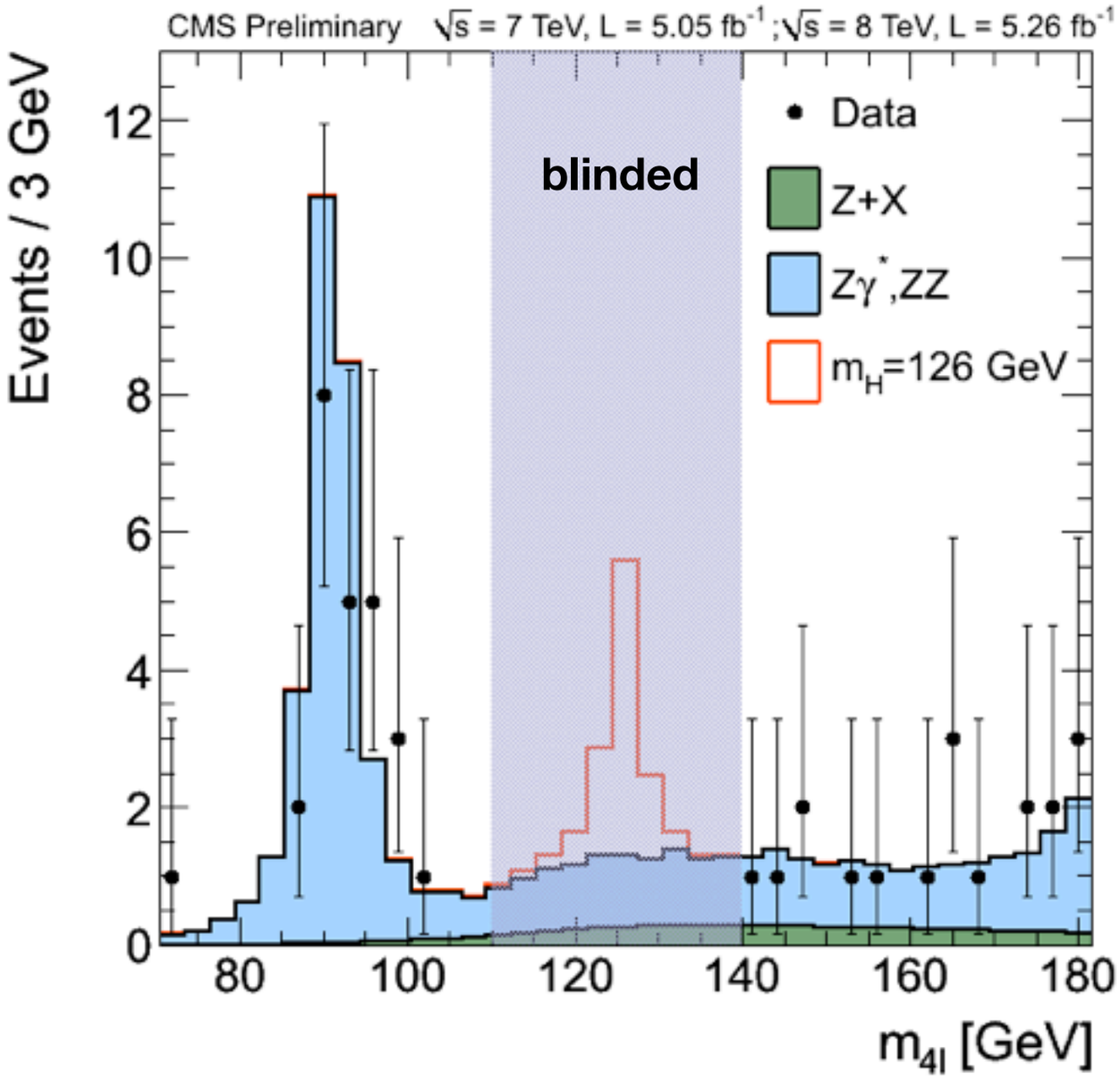
4-lepton mass resolution 1-2%

σ (pp → ZZ+X) = 8.4 ± 1.0(stat) ± 0.7(sys) ± 0.4(lumi) pb

σ (pp → ZZ+X) = 7.7 ± 0.4 pb predicted

Markus Klute

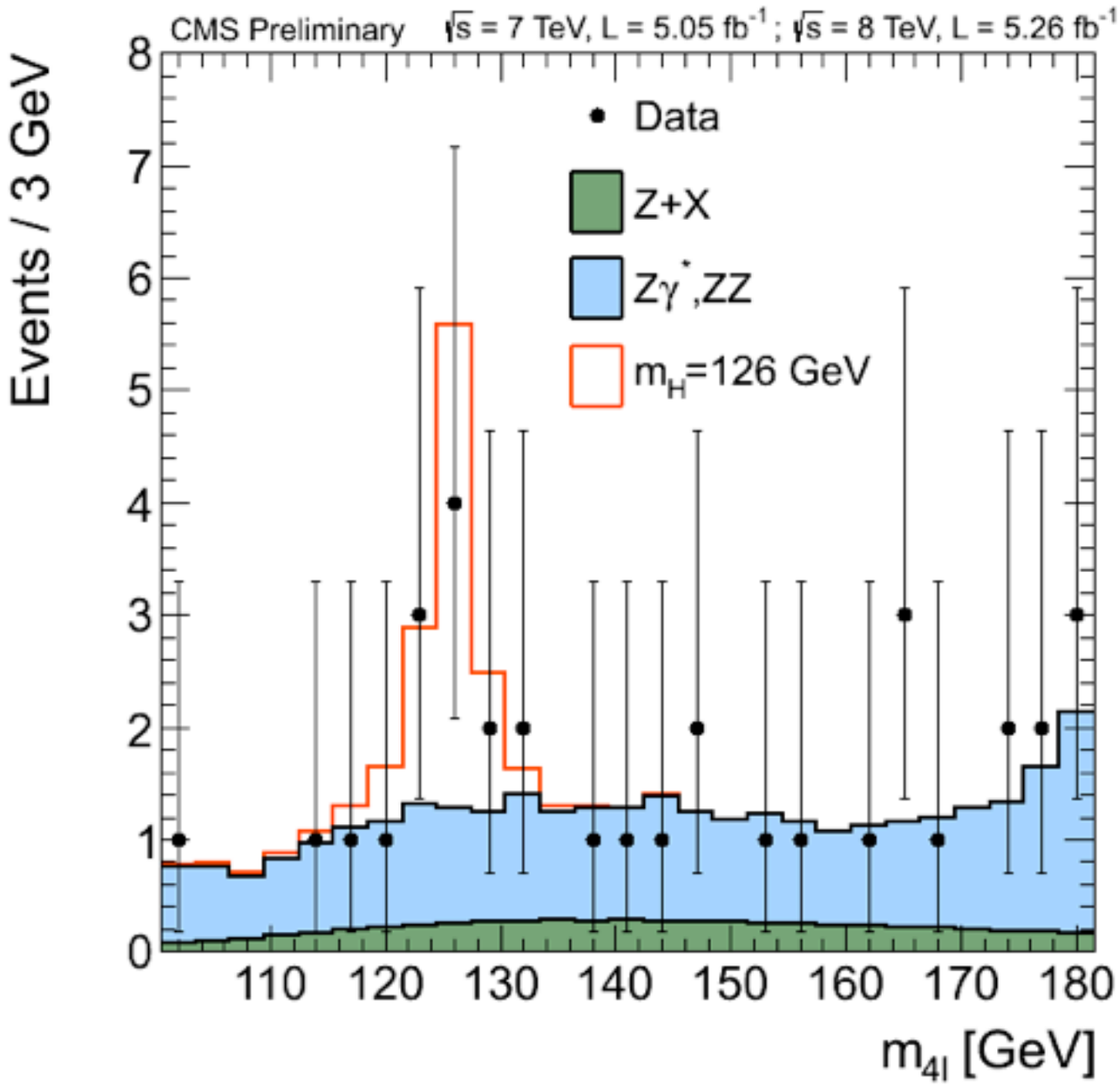
4-Lepton Mass Spectrum (zoom)



event yields in 110-160 GeV

Channel	4e	4μ	2e2μ	4ℓ
ZZ background	2.7 ± 0.3	5.7 ± 0.6	7.2 ± 0.8	15.5 ± 1.0
Z+X	$1.2^{+1.1}_{-0.8}$	$0.9^{+0.7}_{-0.6}$	$2.3^{+1.8}_{-1.4}$	$4.4^{+2.2}_{-1.7}$
All backgrounds	$3.9^{+1.1}_{-0.8}$	$6.6^{+0.9}_{-0.8}$	$9.5^{+2.0}_{-1.6}$	$19.9^{+2.4}_{-2.0}$
$m_H = 120$ GeV	0.8 ± 0.2	1.6 ± 0.3	1.9 ± 0.5	4.4 ± 0.6
$m_H = 126$ GeV	1.5 ± 0.5	3.0 ± 0.6	3.8 ± 0.9	8.3 ± 1.2
$m_H = 130$ GeV	2.1 ± 0.7	4.1 ± 0.8	5.4 ± 1.3	11.6 ± 1.6
Observed	6	6	9	21

4-Lepton Mass Spectrum (zoom)



event yields in 110-160 GeV

Channel	4e	4μ	2e2μ	4ℓ
ZZ background	2.7 ± 0.3	5.7 ± 0.6	7.2 ± 0.8	15.5 ± 1.0
Z+X	$1.2^{+1.1}_{-0.8}$	$0.9^{+0.7}_{-0.6}$	$2.3^{+1.8}_{-1.4}$	$4.4^{+2.2}_{-1.7}$
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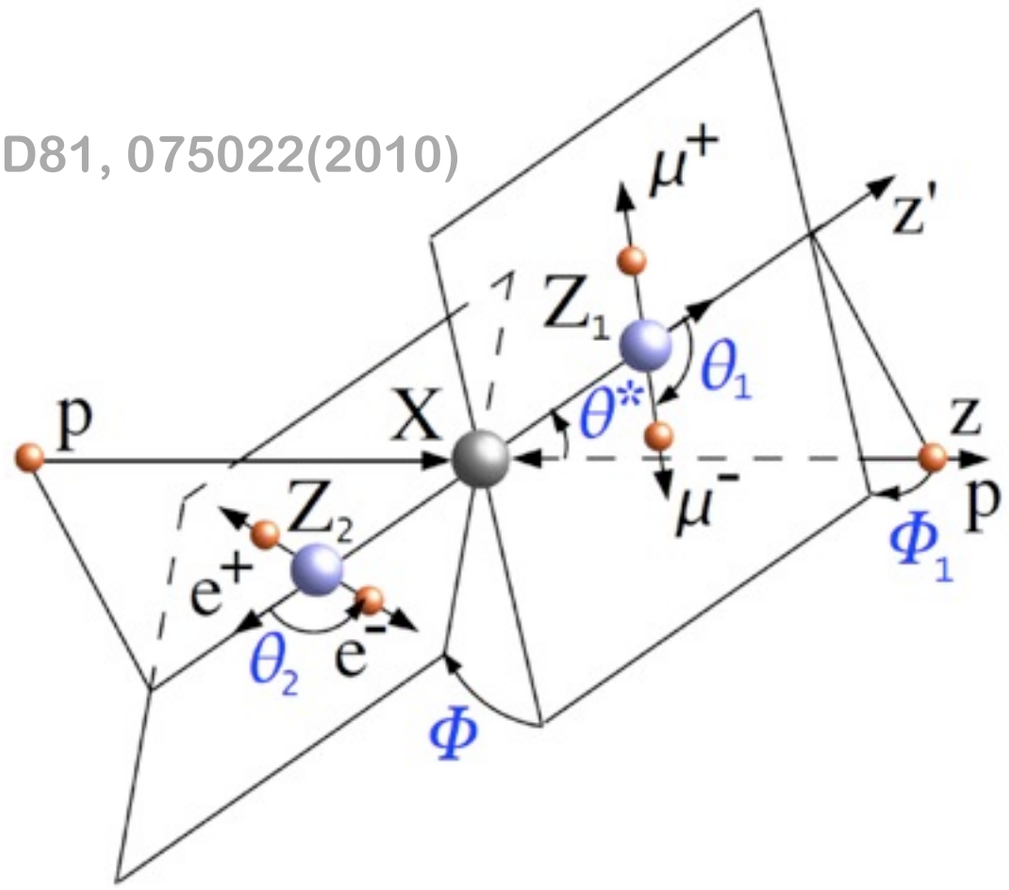
Observed	6	6	9	21

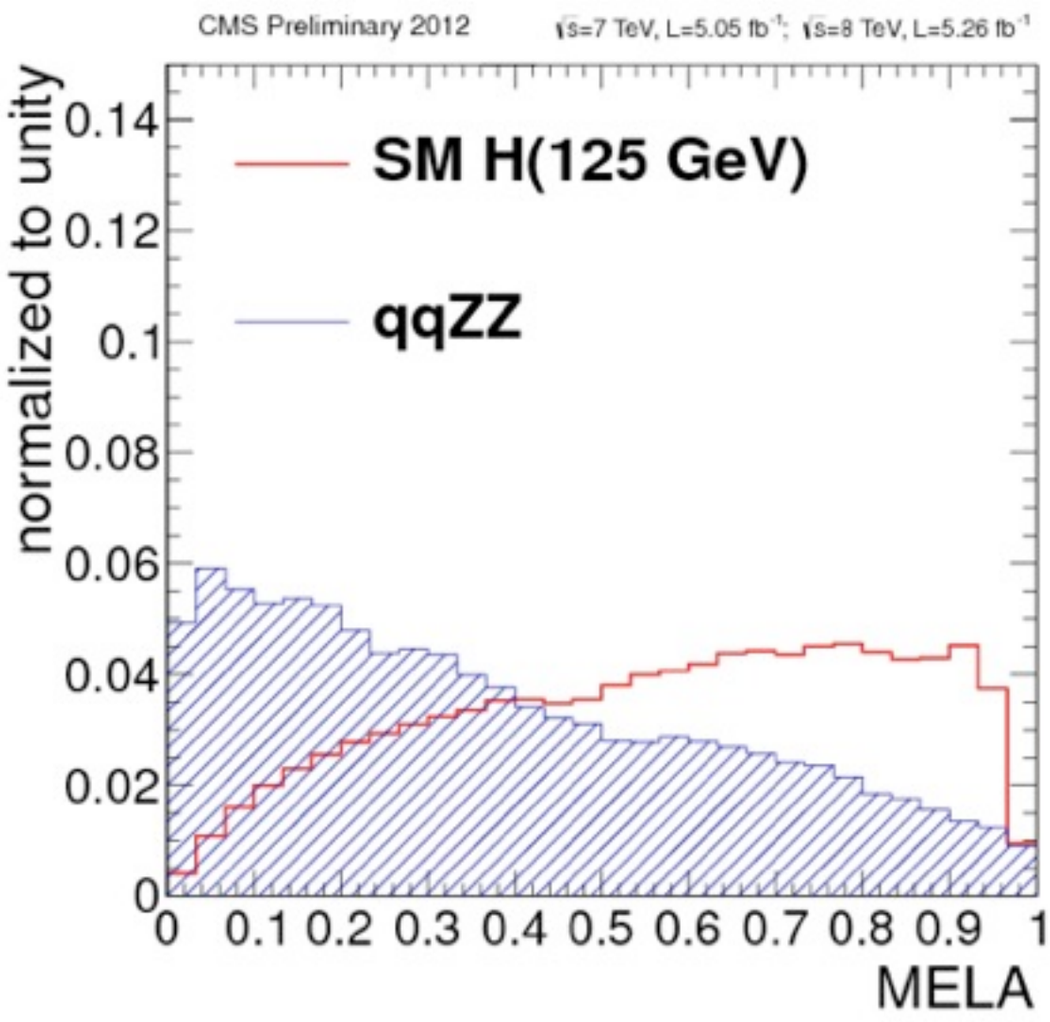
Angular analysis

- **Decay kinematic fully described by 5 angles and 2 masses**
  - **discriminates spin 0 particle from background**
  - **analogous of $\Delta\phi$ in H → WW analysis**
  - **MELA: matrix element likelihood analysis**

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

PRD81, 075022(2010)

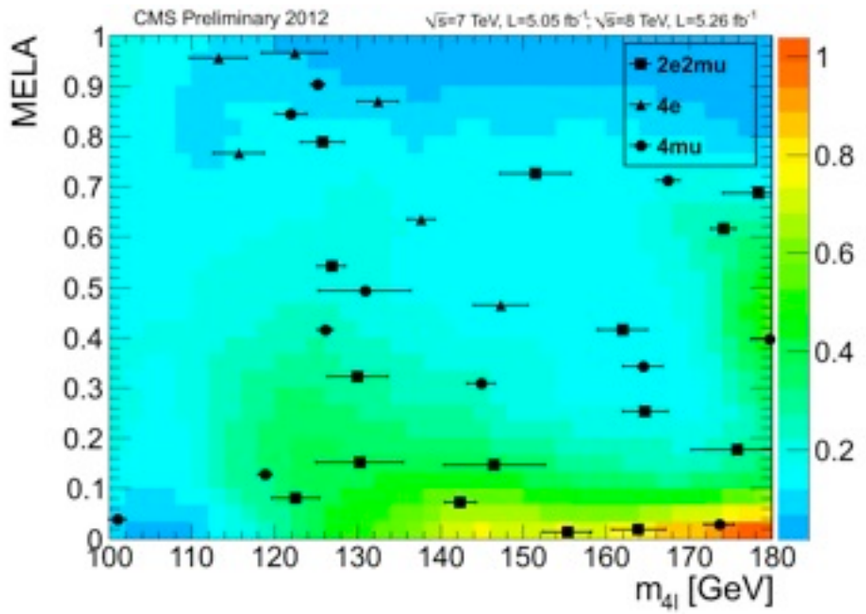


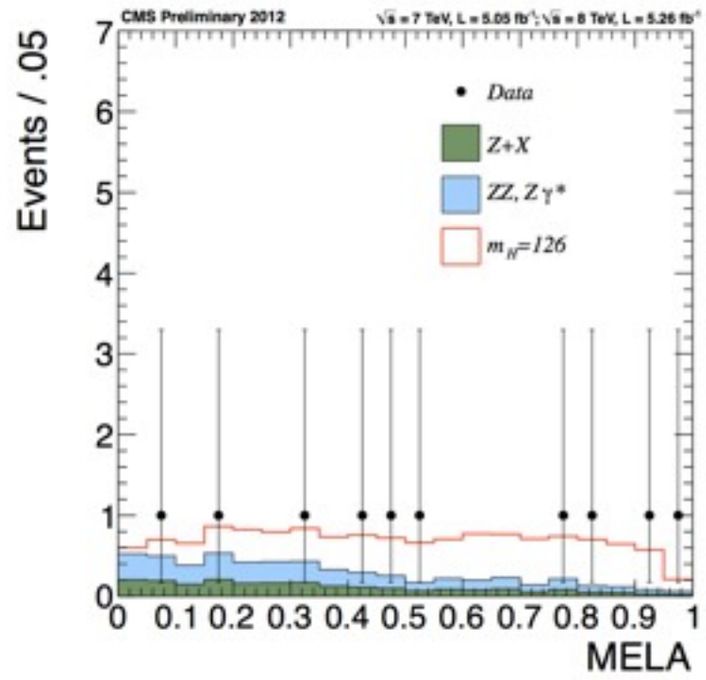


Statistical analysis

- **Analysis performed using a 2D fit of likelihood discriminant and 4-lepton mass**

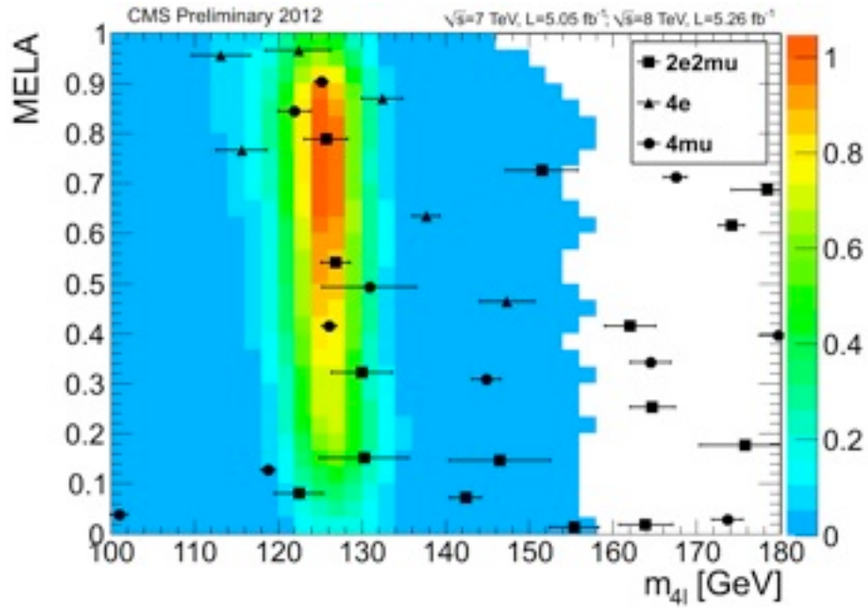
data wrt background expectation

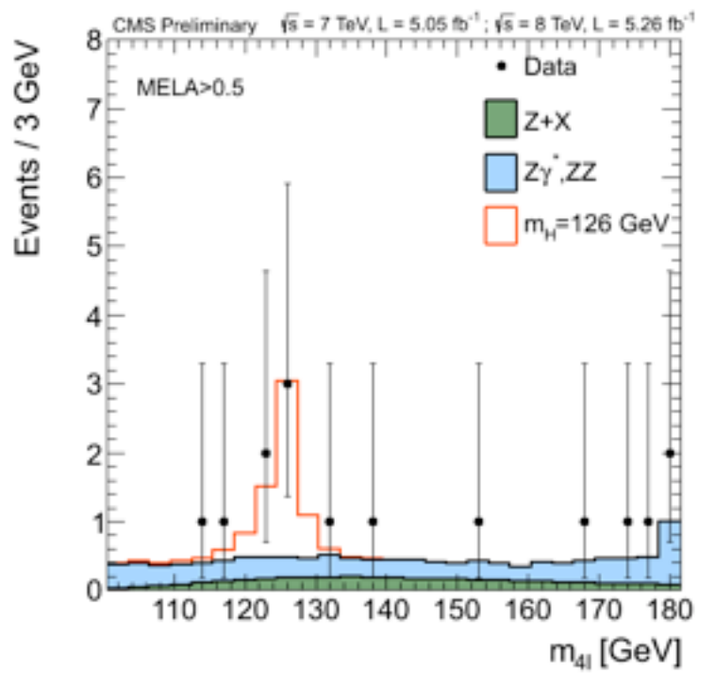




for illustration: MELA projection in m(4l) 121-131 GeV

data wrt signal (mH = 126 GeV) exp.

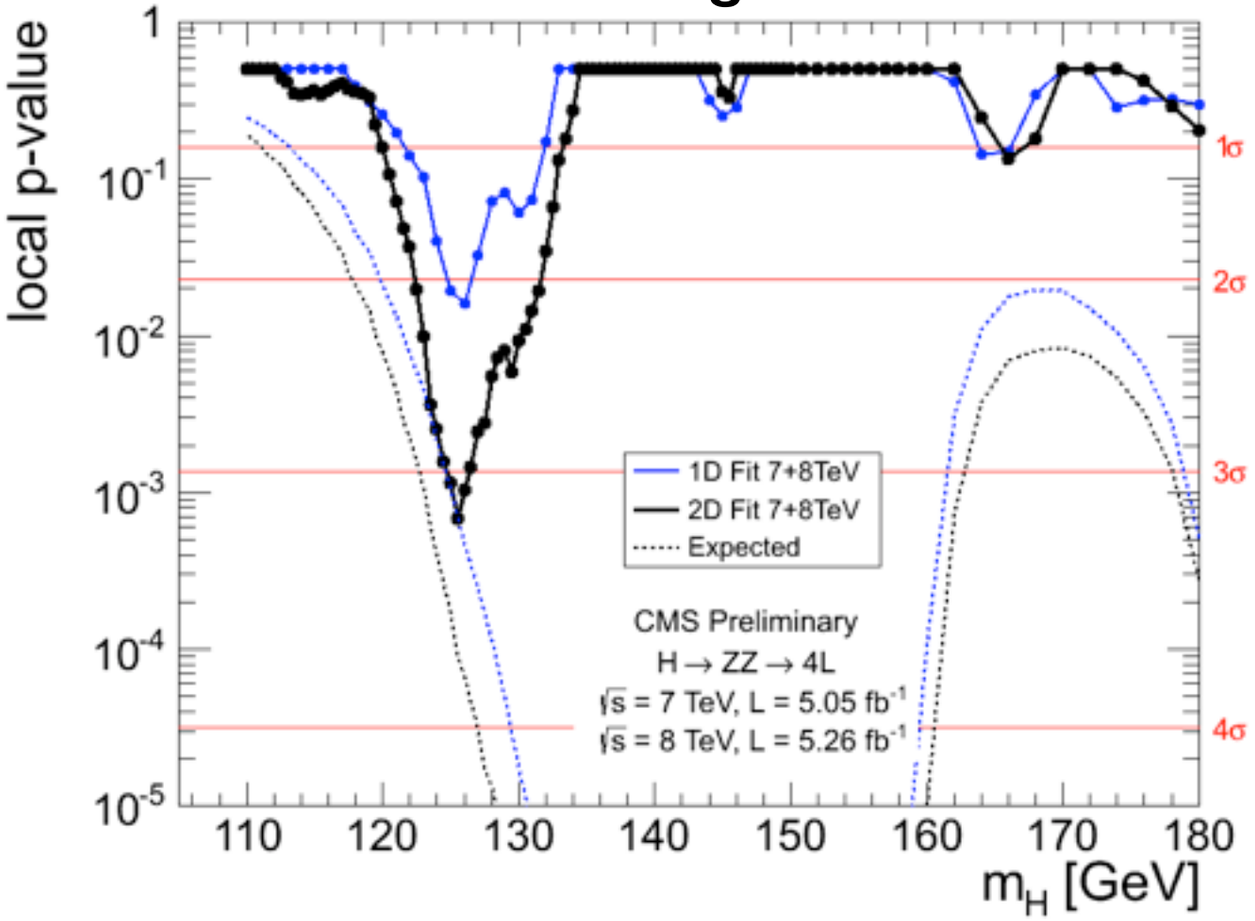




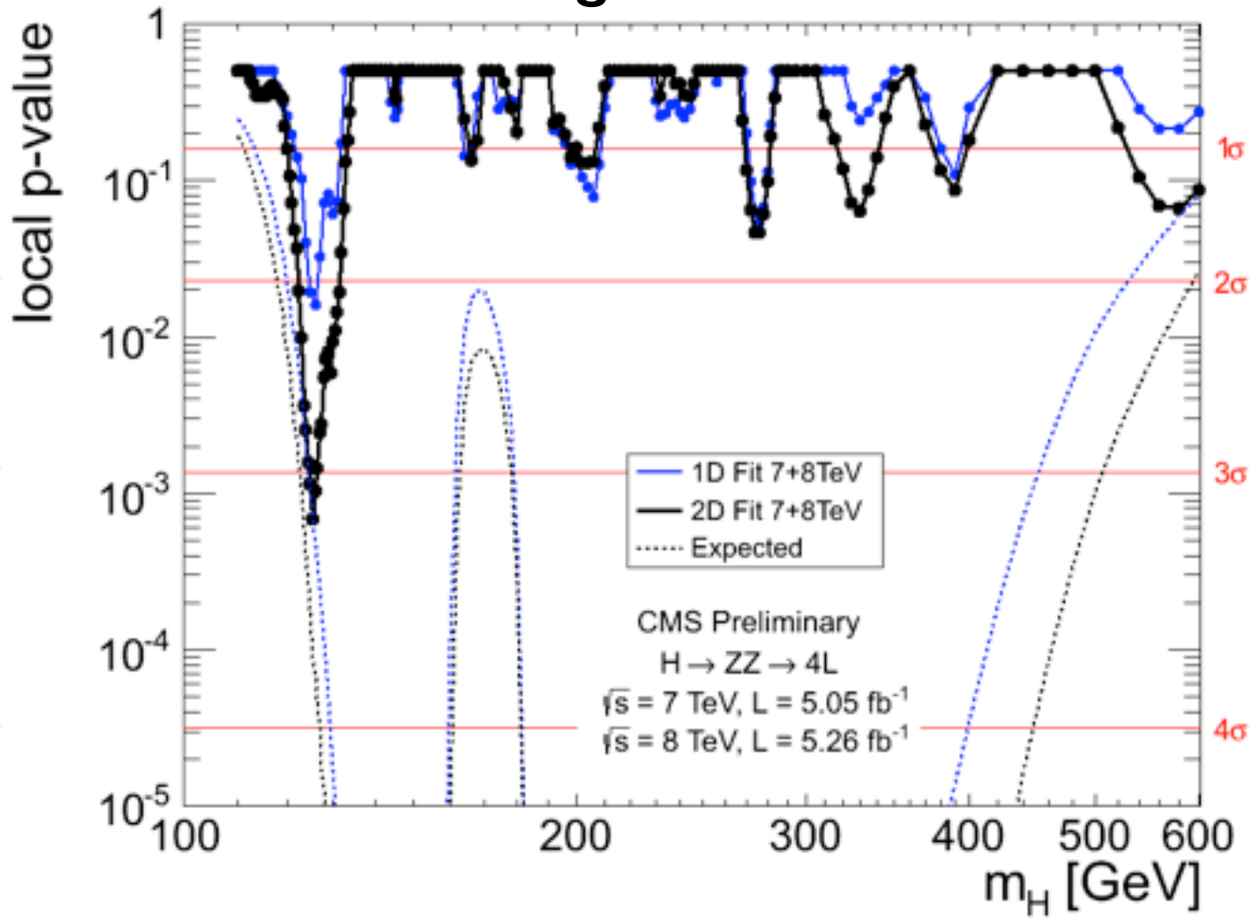
for illustration: m(4l) with cut MELA > 0.5

Local P-values

Zoomed mass range



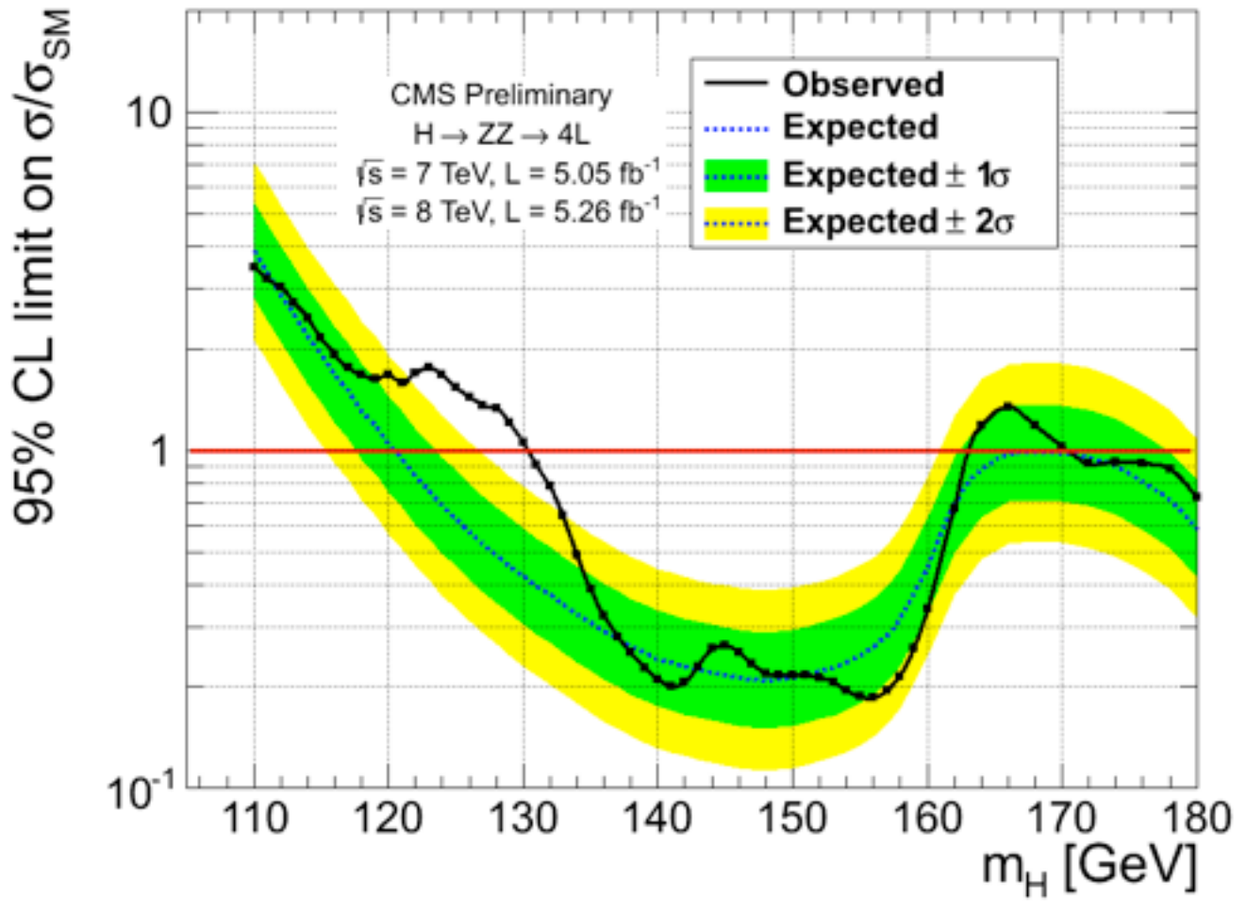
Full mass range



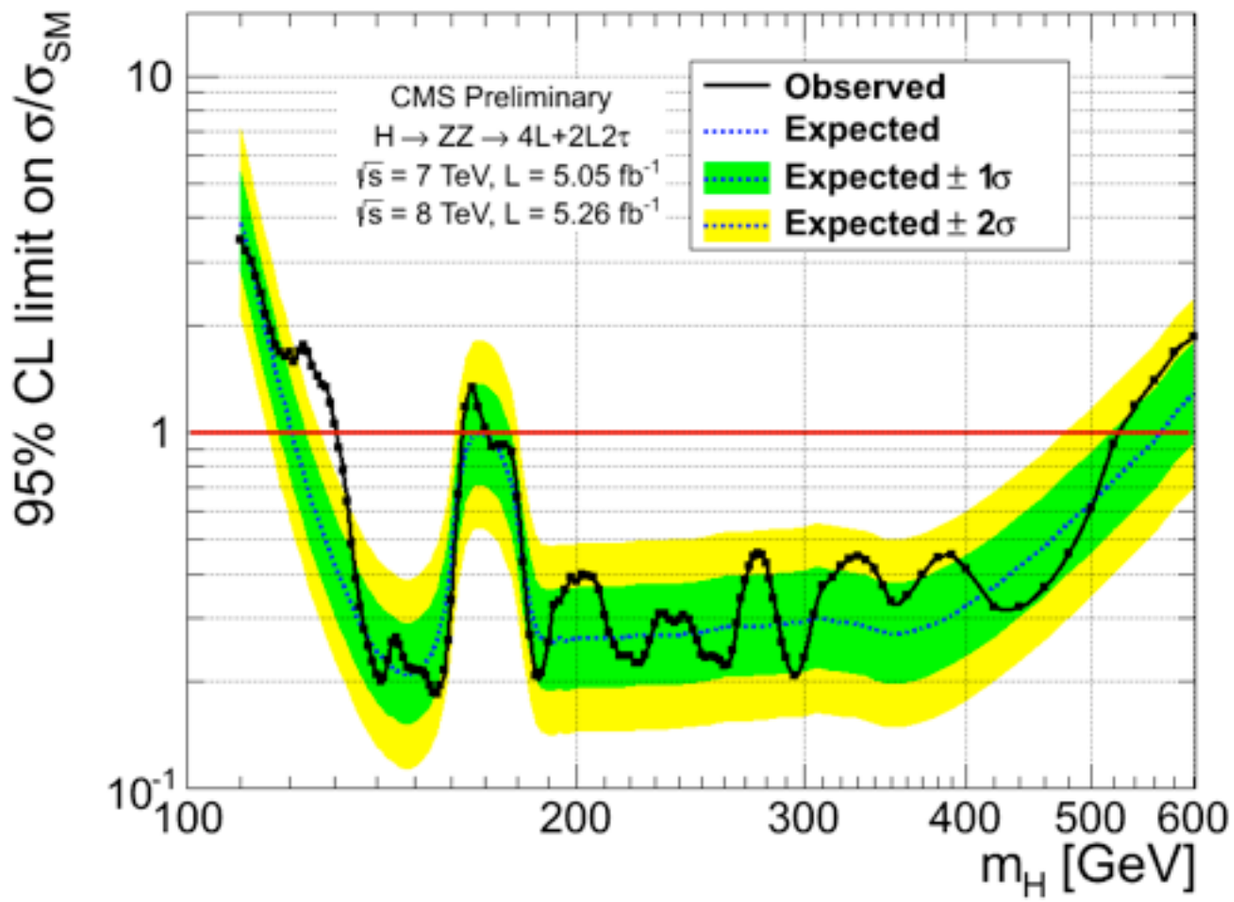
Expected local significance at 125.5 GeV: 3.8σ
Observed local significance at 125.5 GeV: 3.2σ

95% Confidence Limits

Zoomed mass range



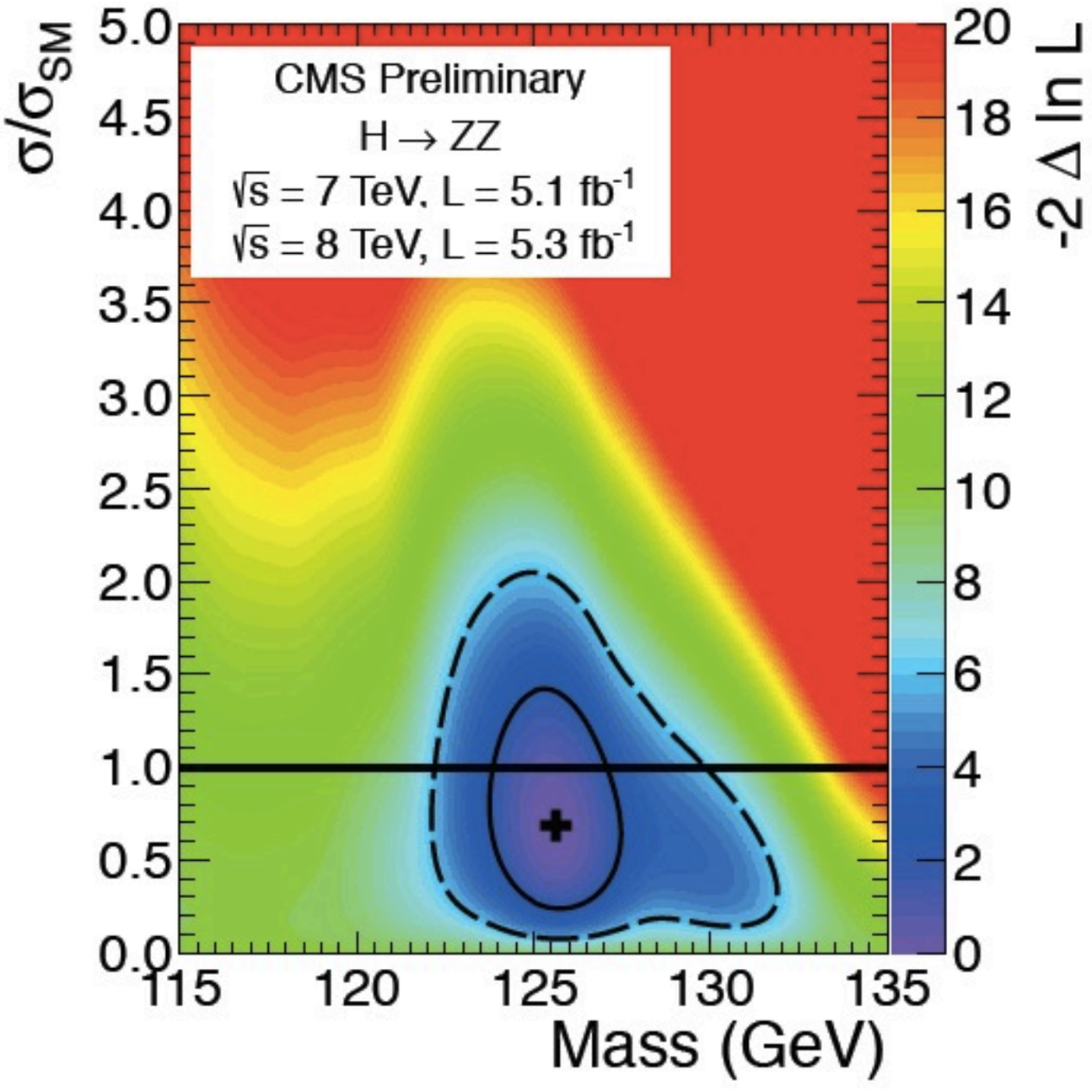
Full mass range



Expected exclusion at 95% CL: 121-550 GeV
Observed exclusion at 95% CL: 131-162 and 172-530 GeV

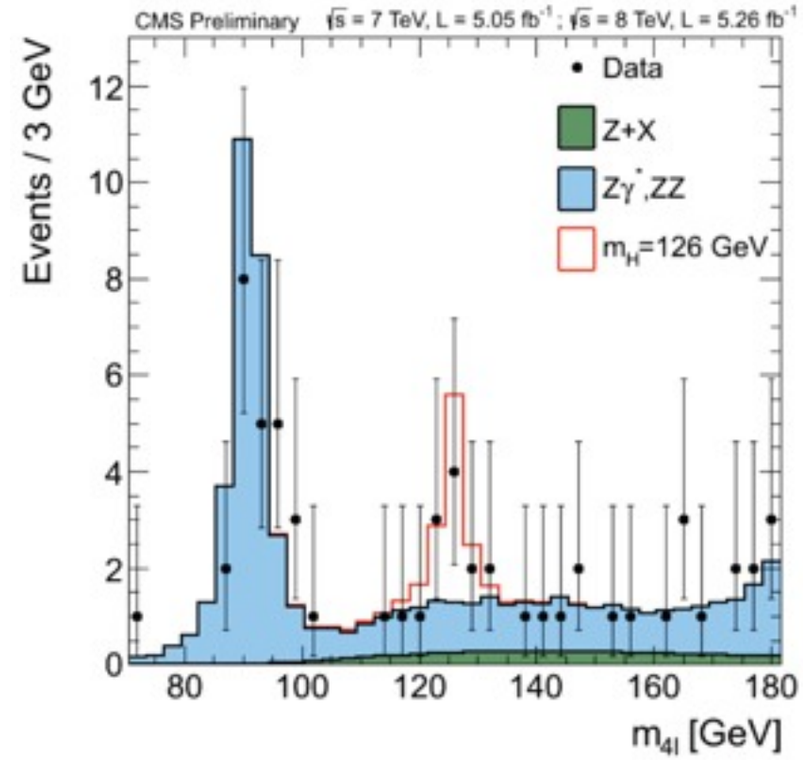
Mass and signal strength

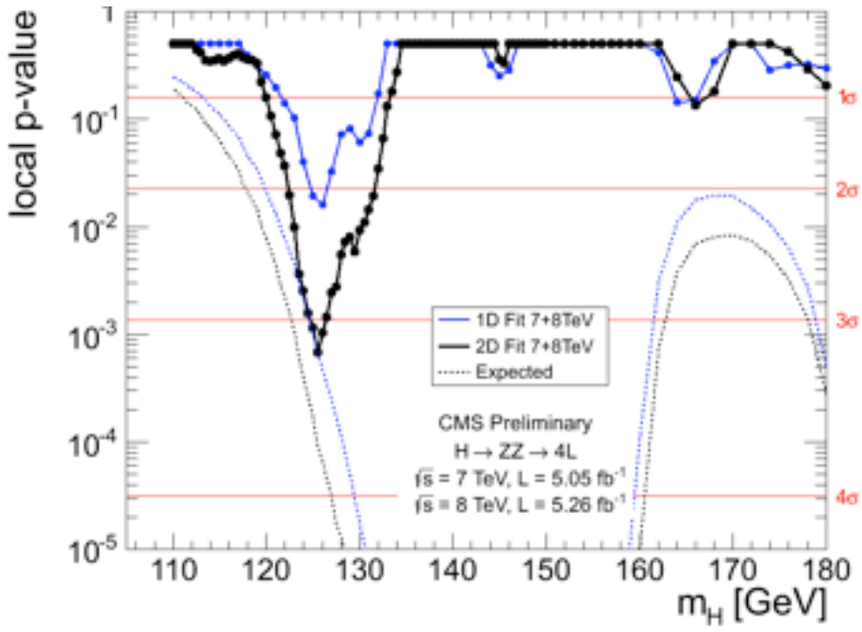
- Likelihood scan performed on full dataset
- Global minimum of likelihood
  - m(4l) = 125.6 ± 1.2 GeV
  - μ = 0.7 ± 0.4 (signal strength)
- Ellipses indicate 68% and 95% CL contours



Conclusion

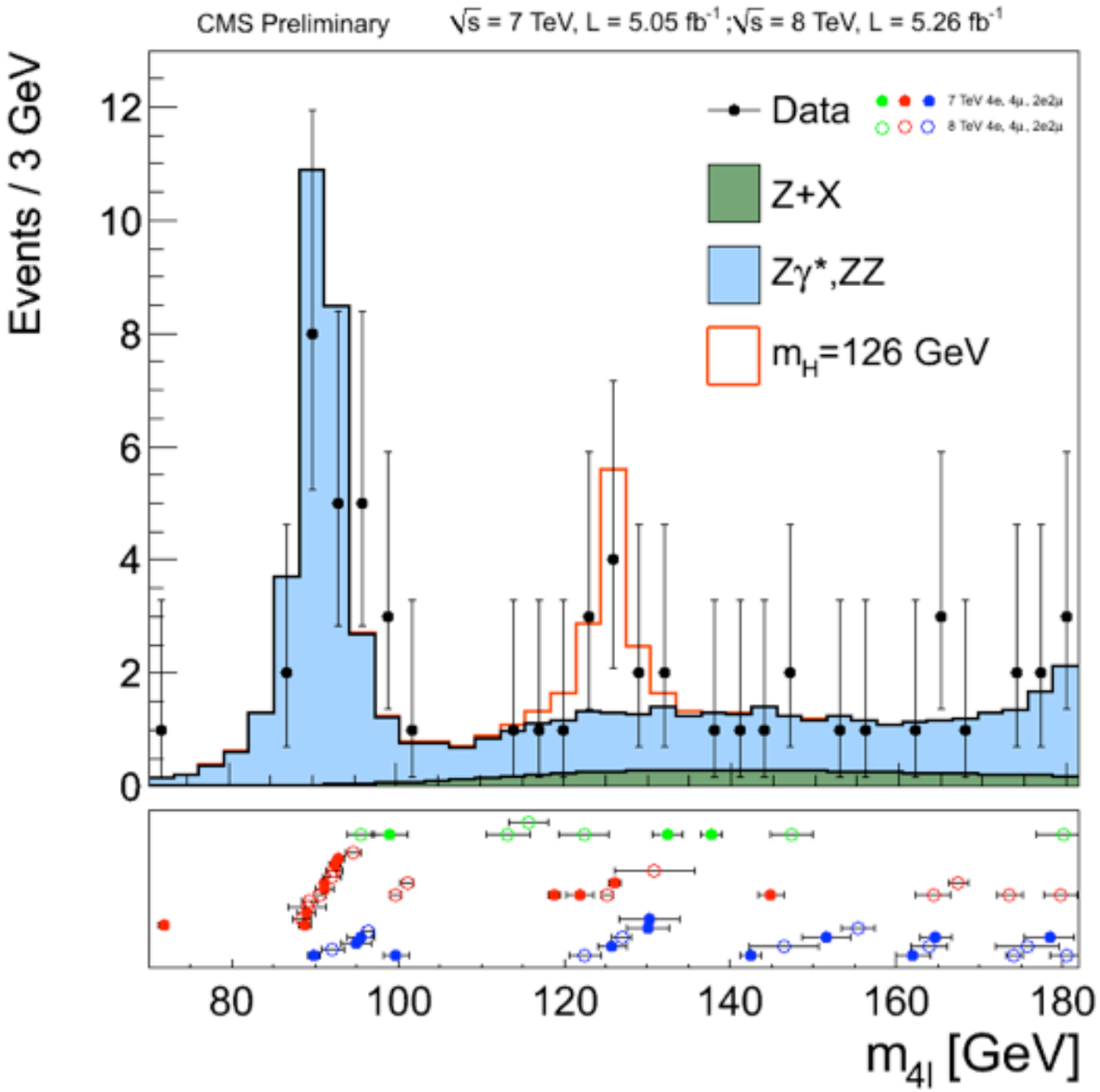
- **Presented search for H → ZZ → 4L**
  - re-analyzed 7 TeV data (5.1/fb)
  - added 8 TeV data (5.3/fb)
  - CMS-PAS-HIG-12-016 and 020
  - significant improvements in analysis
- **Cross section consistent with SM prediction (incl. taus)**
  - σ (pp → ZZ+X) = 8.4 ± 1.0(stat) ± 0.7(sys) ± 0.4(lumi) pb
  - σ (pp → ZZ+X) = 7.7 ± 0.4 pb predicted
- **Anatomy of the data**
  - largest excess is observed local significance of 3.2σ
    - evidence for 4L resonance
  - exclusion at 95% CL: 131-162 and 172-530 GeV
  - best mass m(4l) = 125.6 ± 1.2 GeV
  - best signal strength μ = 0.7 ± 0.4





Backup Material

4-Lepton Mass Spectrum (zoom)



event yields in 110-160 GeV

Channel	4e	4μ	$2e2\mu$	4ℓ
ZZ background	2.7 ± 0.3	5.7 ± 0.6	7.2 ± 0.8	15.5 ± 1.0
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All backgrounds	$3.9^{+1.1}_{-0.8}$	$6.6^{+0.9}_{-0.8}$	$9.5^{+2.0}_{-1.6}$	$19.9^{+2.4}_{-2.0}$
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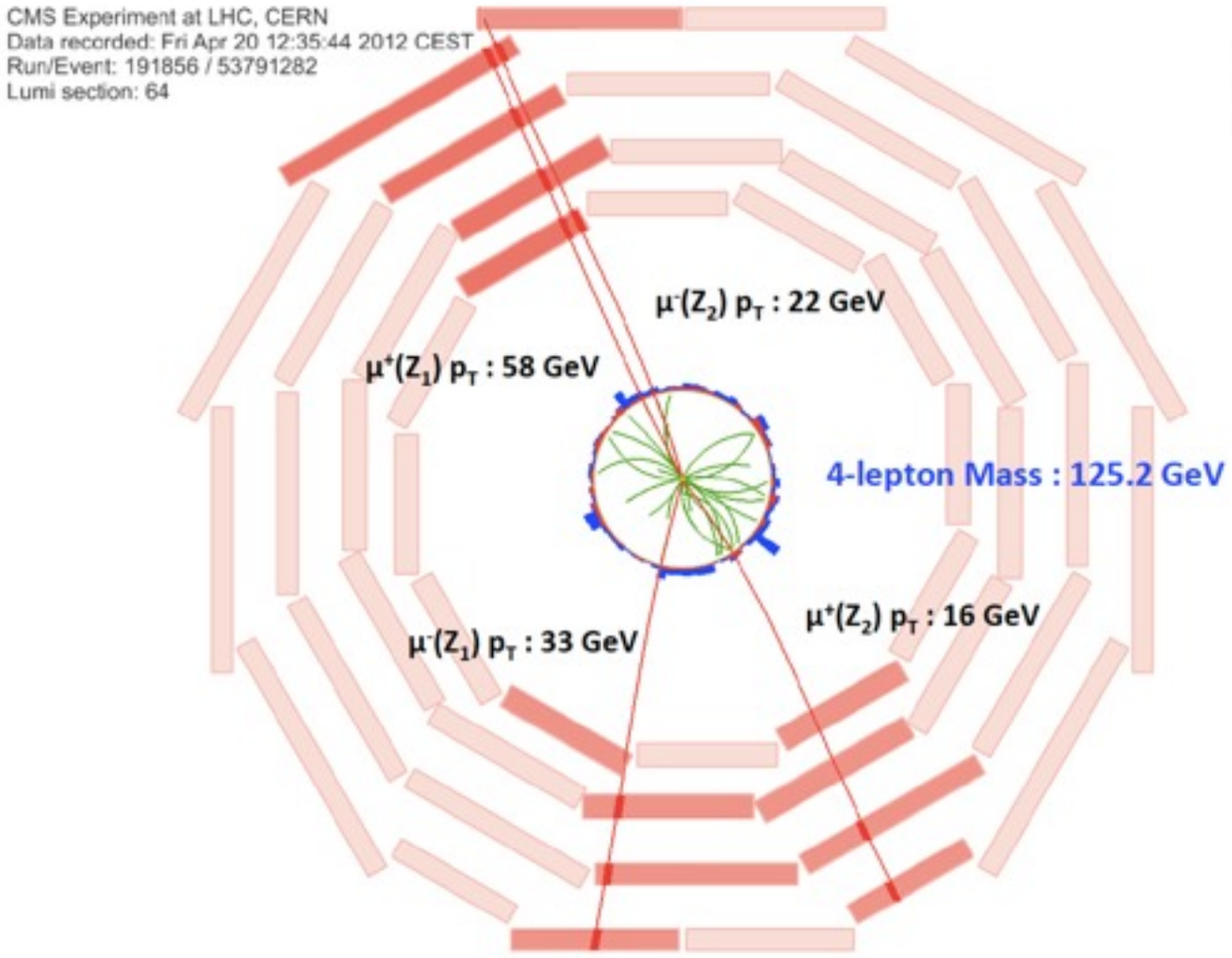
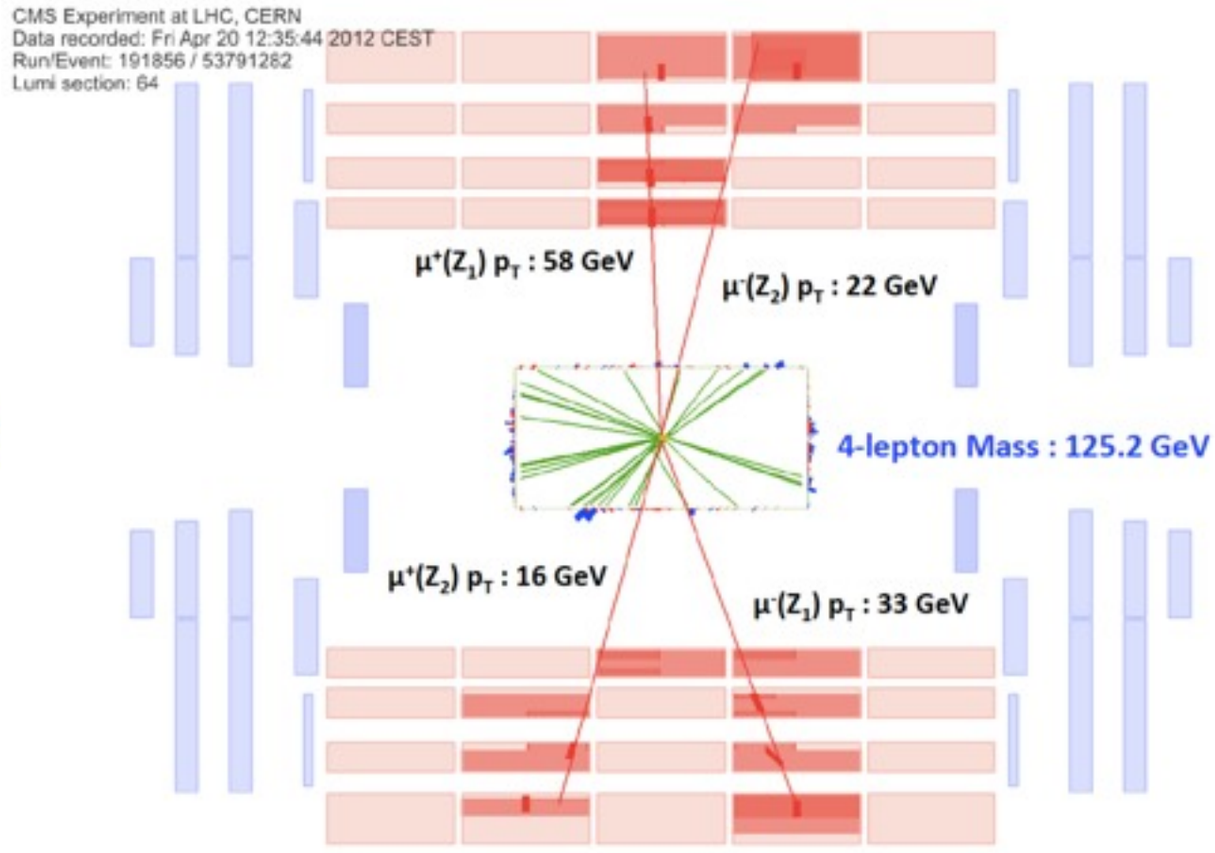
$m_H = 126$ GeV	1.5 ± 0.5	3.0 ± 0.6	3.8 ± 0.9	8.3 ± 1.2
$m_H = 130$ GeV	2.1 ± 0.7	4.1 ± 0.8	5.4 ± 1.3	11.6 ± 1.6
Observed	6	6	9	21

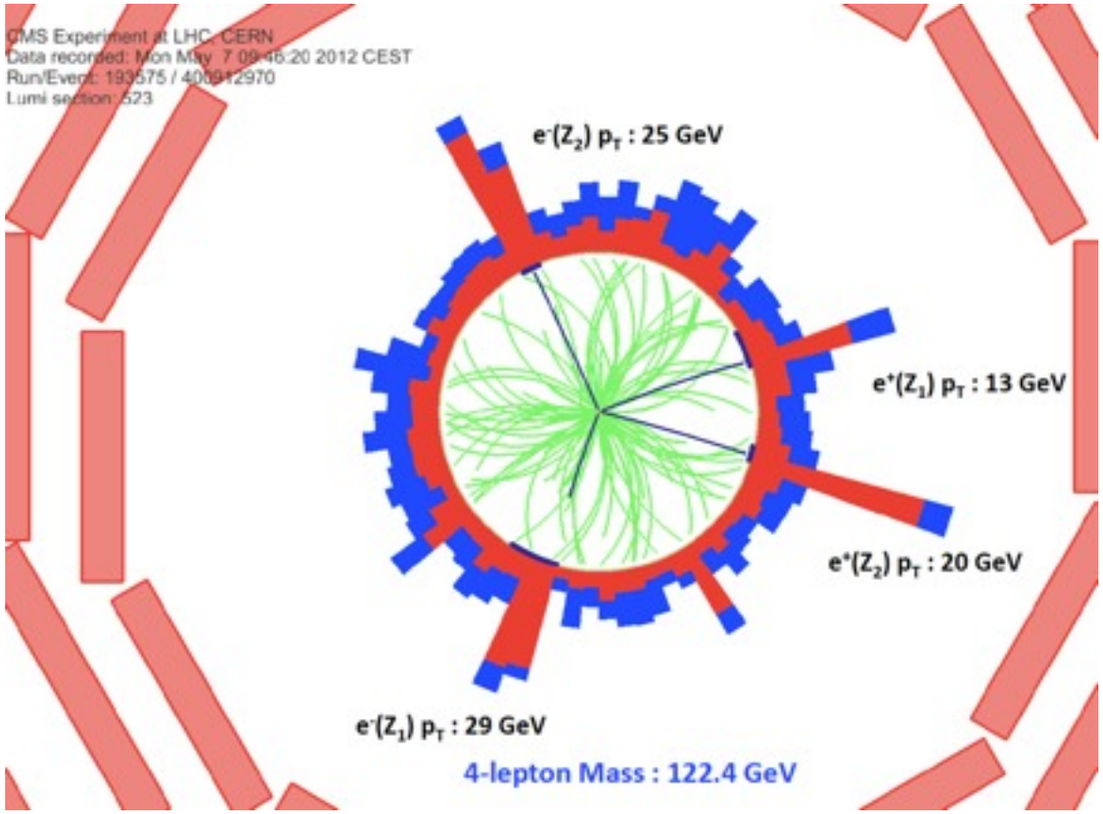
per event mass uncertainty

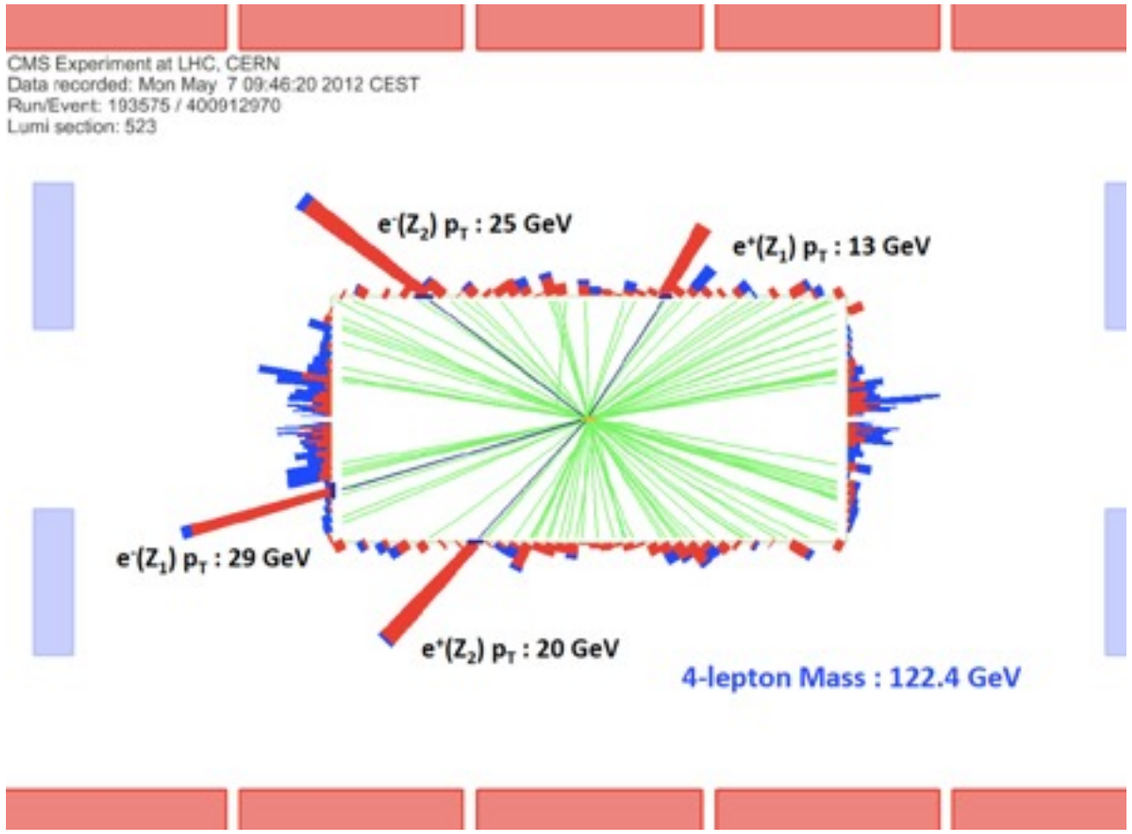
Event Display



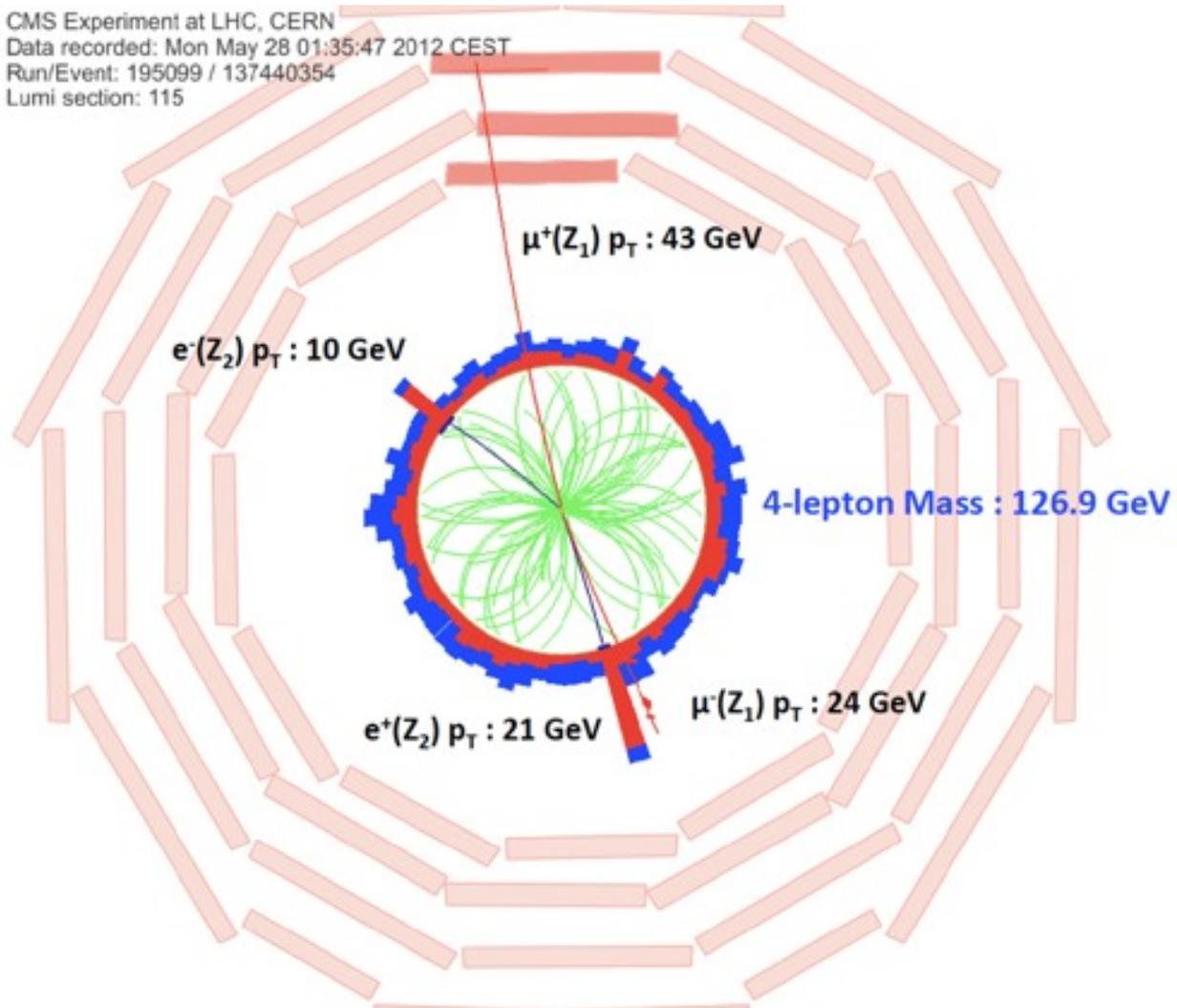


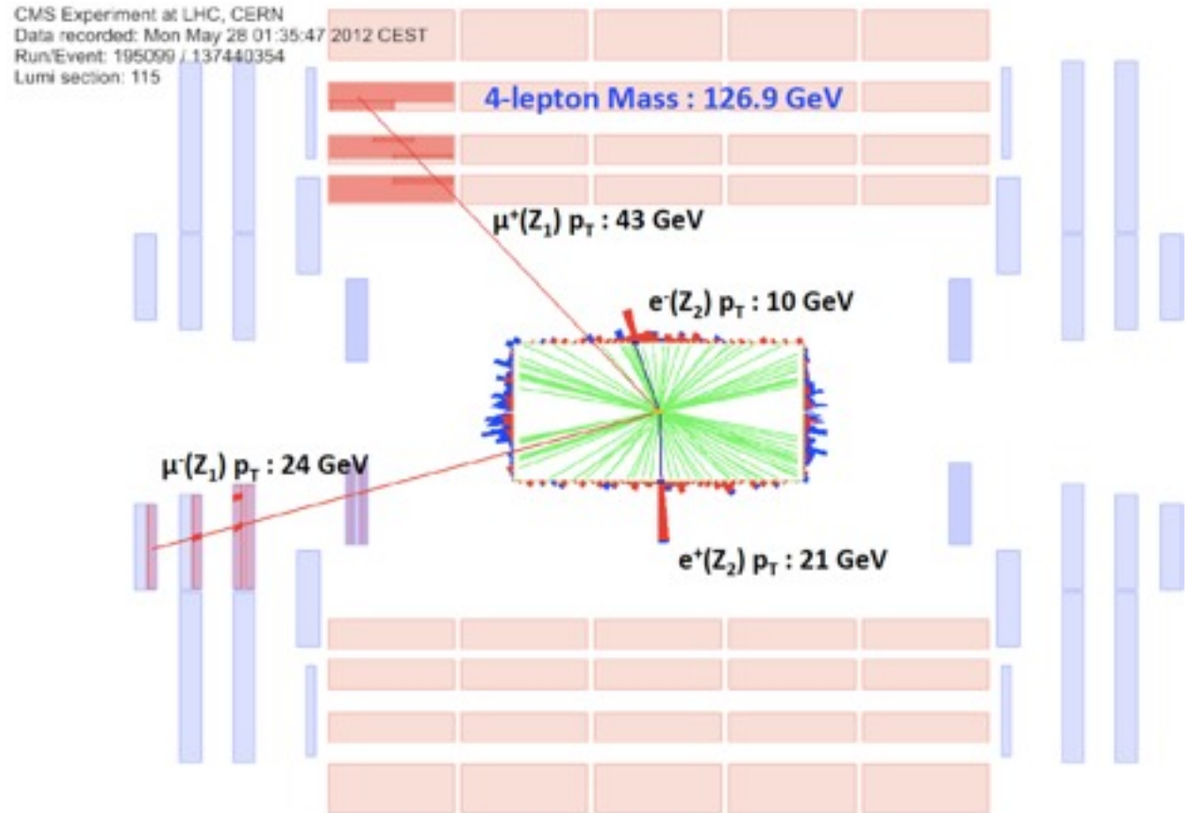
Event Display



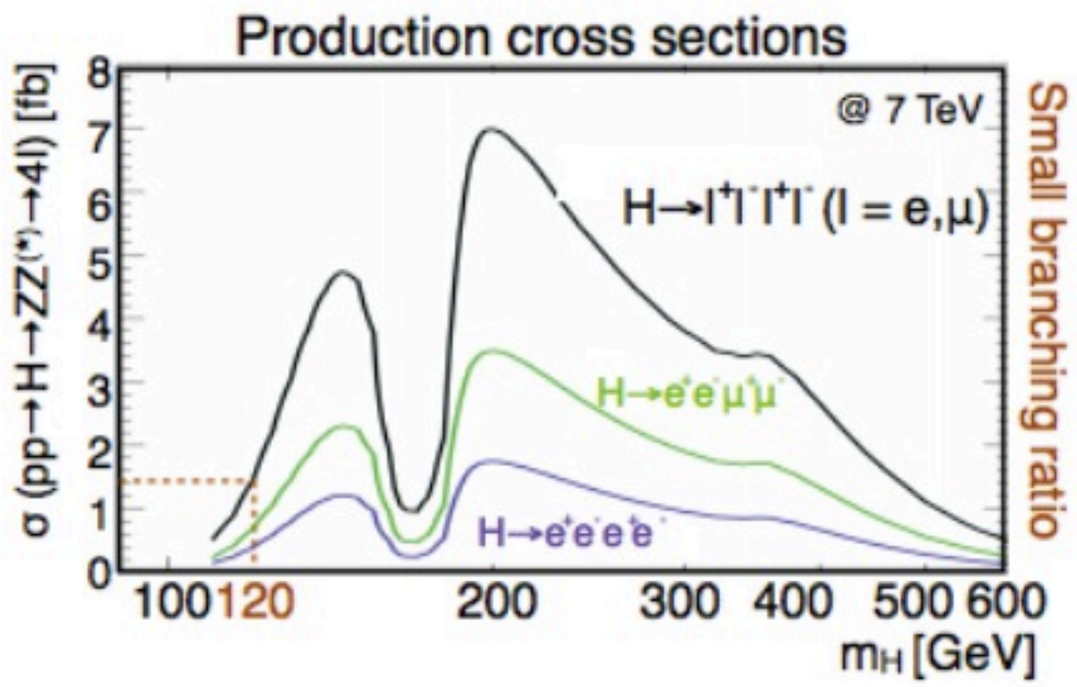


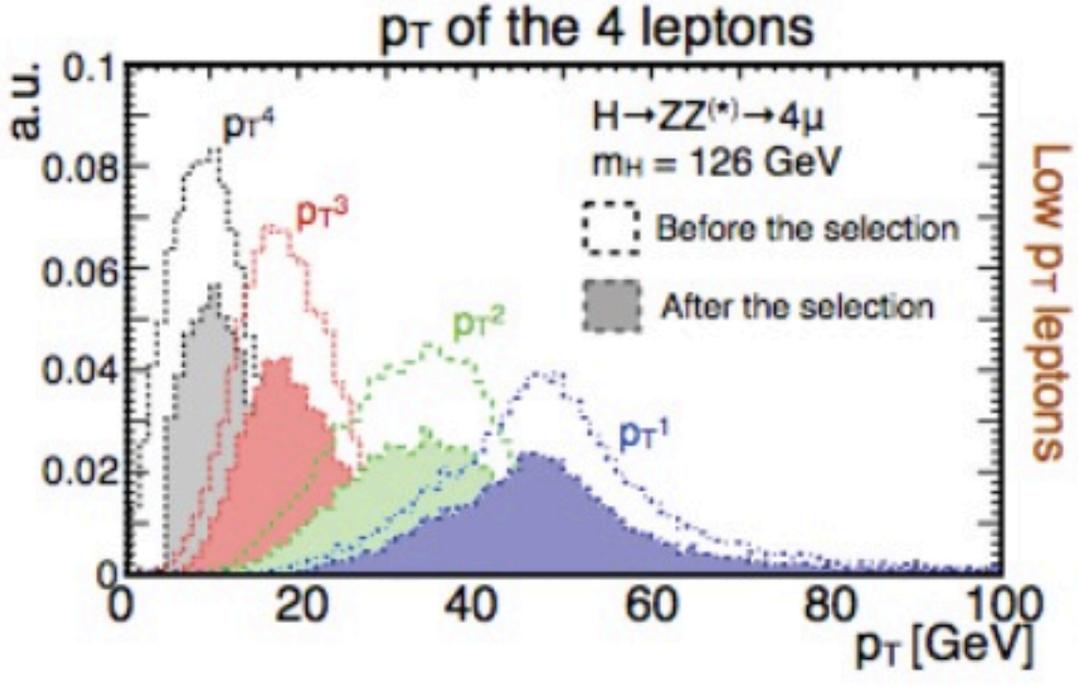
Event Display



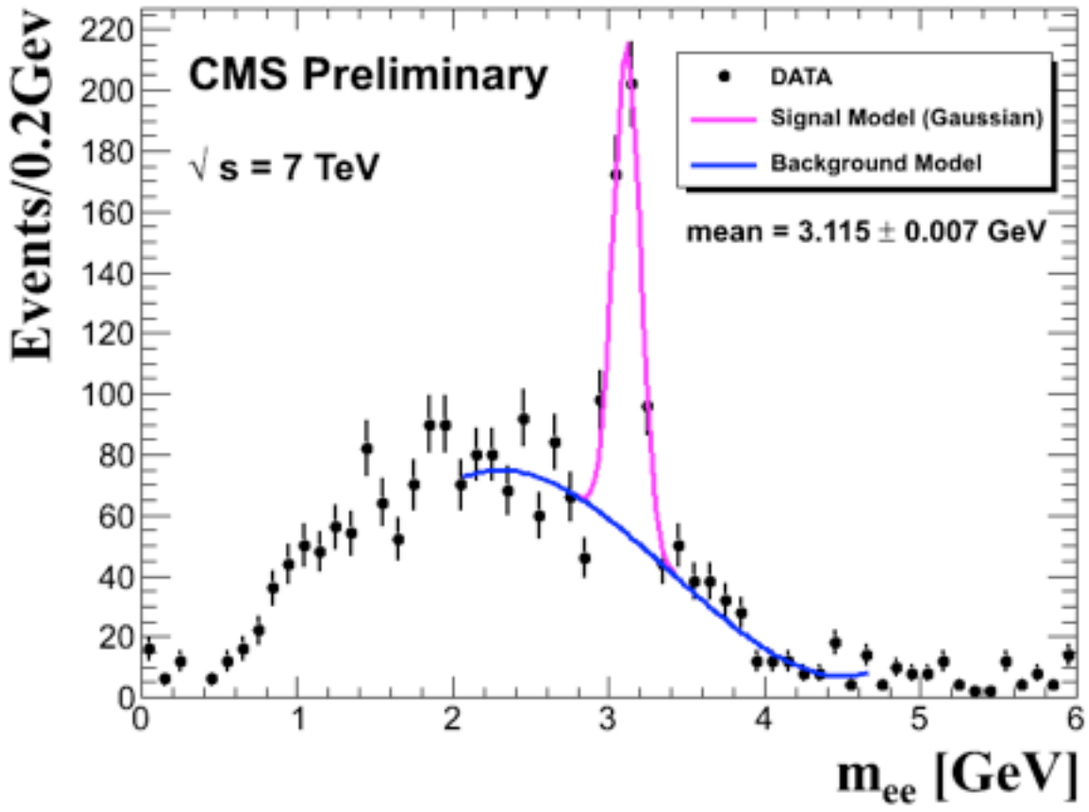


Experimental Challenge



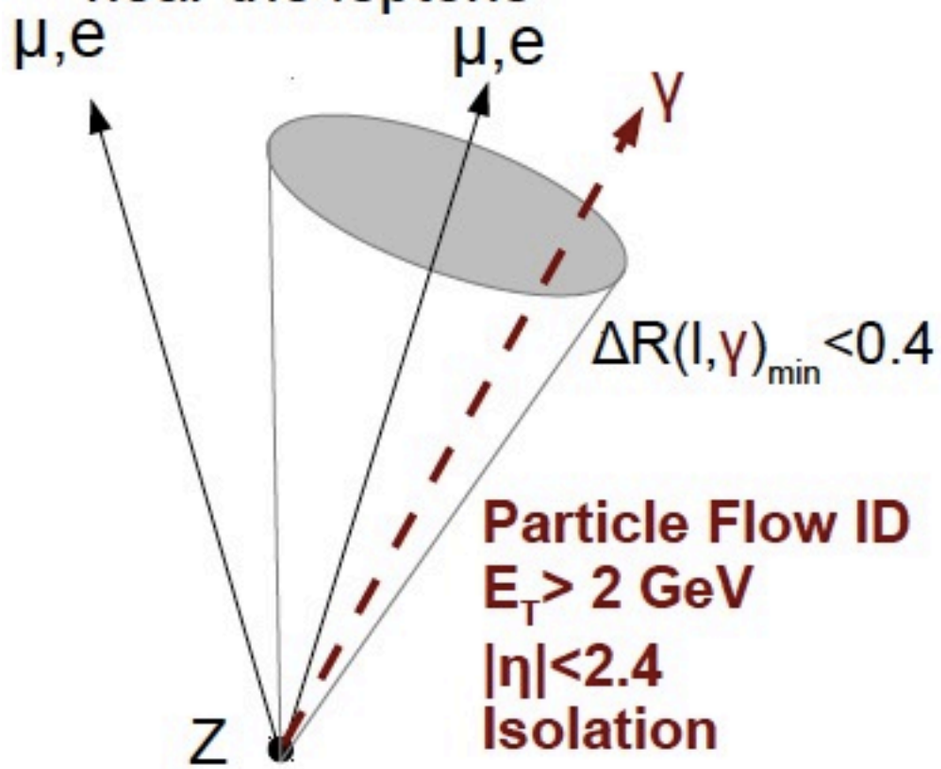


Lepton Performance



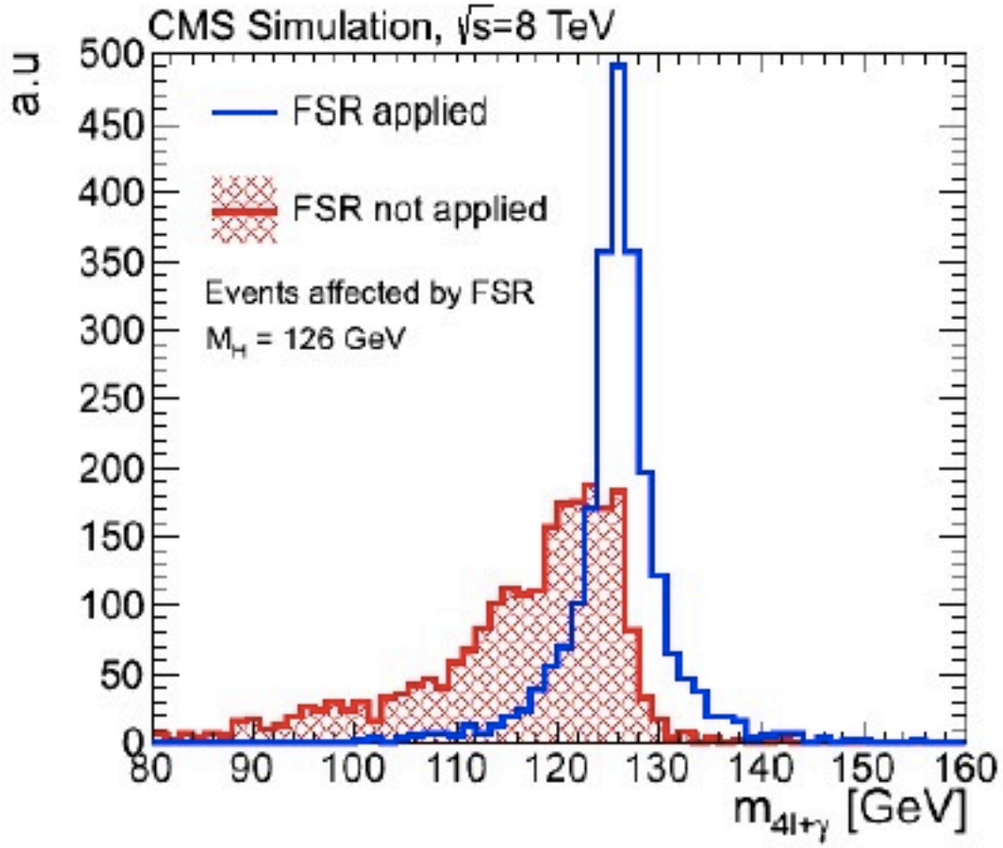
Final State Radiation Recovery

- Applied on each Z for photons near the leptons

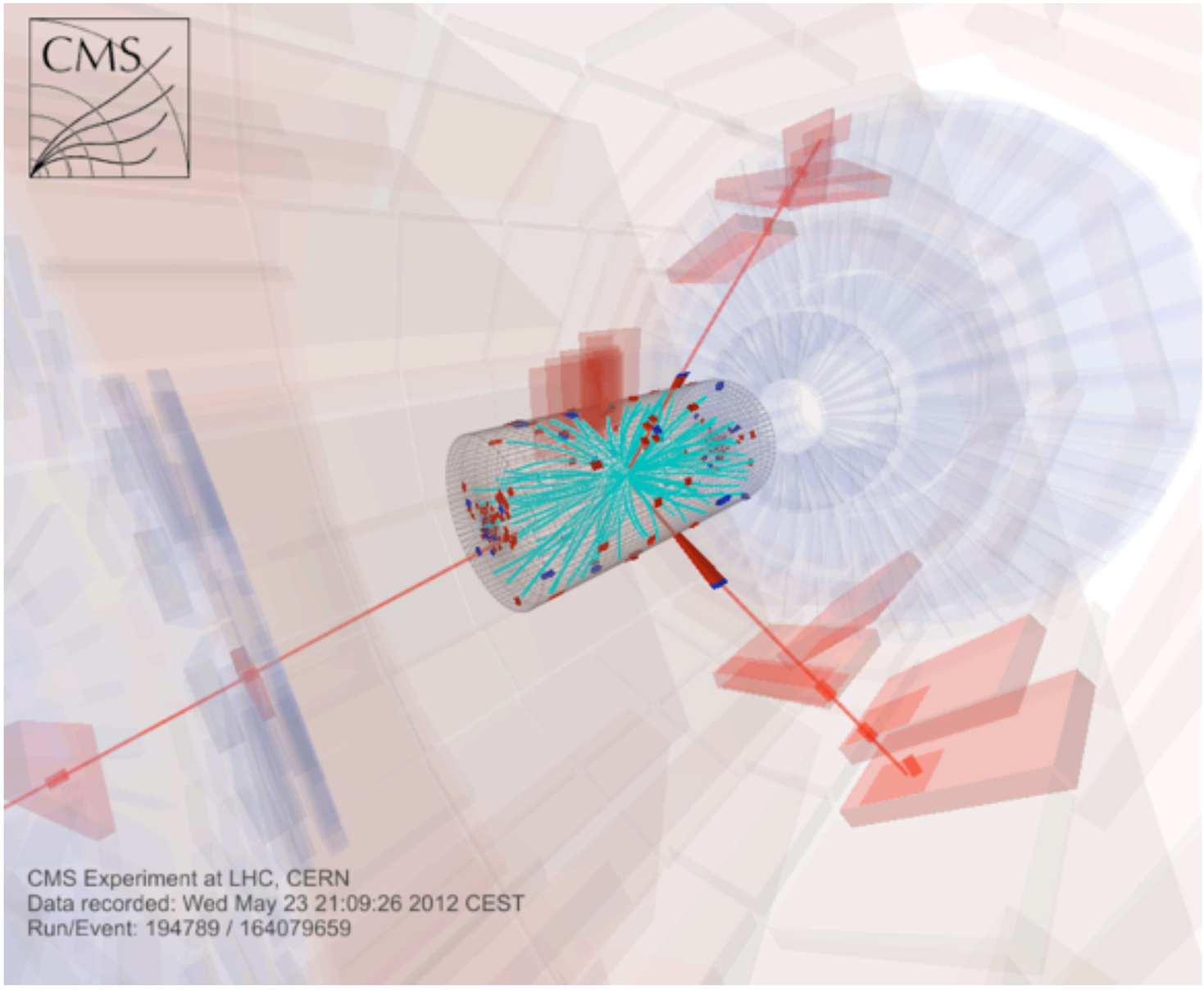


- Associates the photon with Z if:
  - M(ll+γ)< 95 GeV
  - $|M(ll+\gamma)-M_Z|<|M(ll)-M_Z|$
- Removes associated photons from lepton isolation calculation

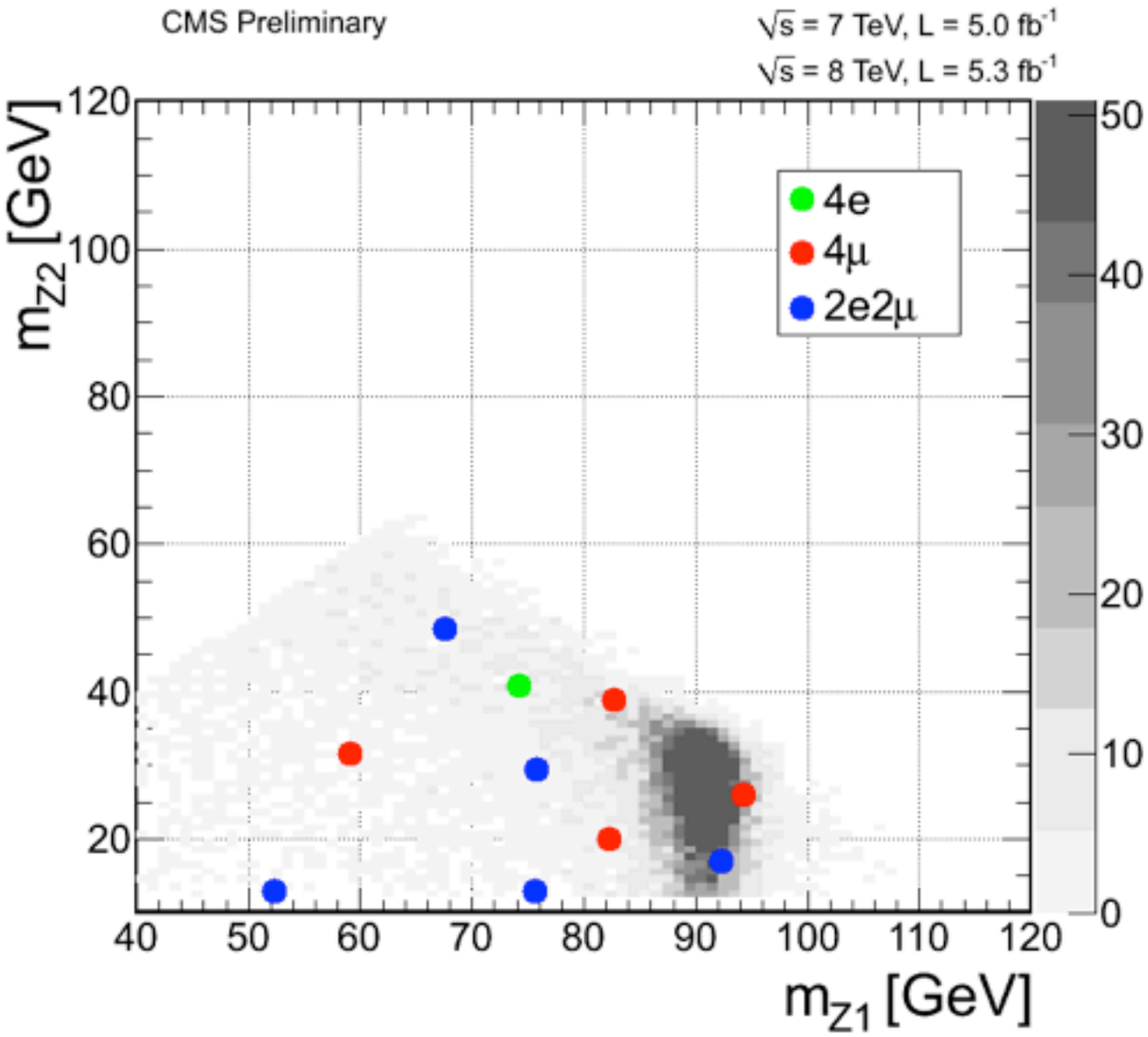
- Expected Performance
  - 6% of the events affected
  - 4.8% of the events: mass improved
  - 1.2% of the events: mass degraded
  - 2% more events added into sample after FSR recovery

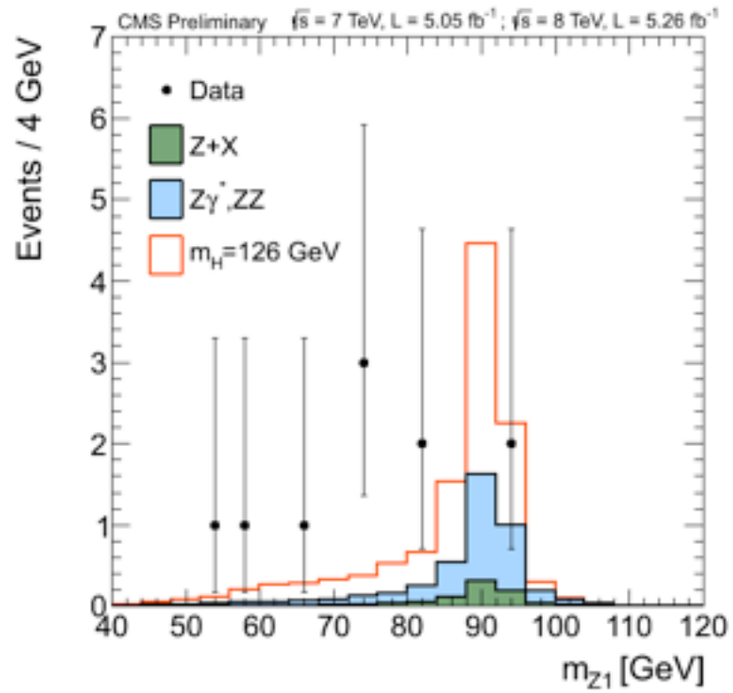


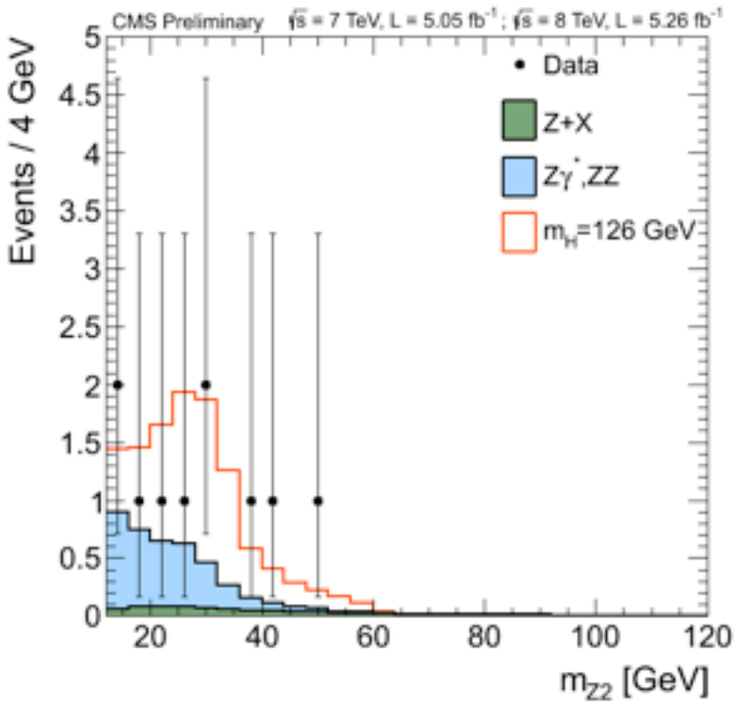
Final State Radiation Recovery



Di-lepton Mass







Scalar or Pseudoscalar

- separation with 10 and 35/fb