24th Rencontres de Blois

Results on SM Higgs boson searches at low mass from CMS

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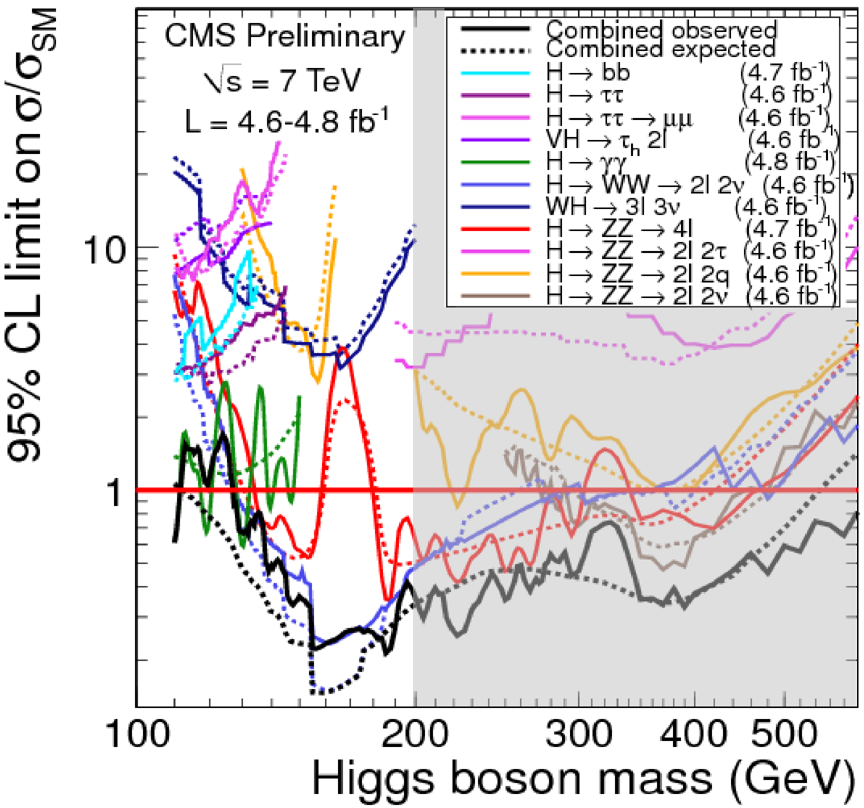
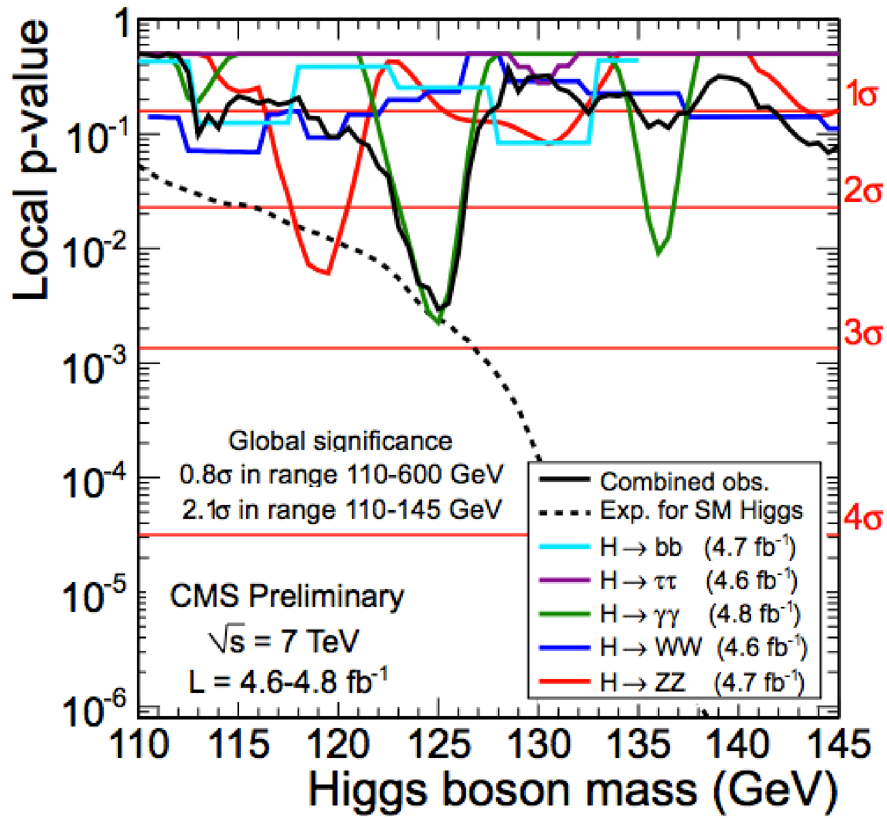
On behalf of the CMS Collaboration

Highlights from Monday's CMS Talk…

(C. Mariotti)





- 9 analyses contribute to low mass
- Hottest channels below 200 GeV:

$H \to \gamma\gamma$, $H \to ZZ \to 4\ell$, $H \to WW \to \ell\nu\ell\nu$

SM Higgs Searches at CMS

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIG

Channel	Mass range	Subch.	Res.	Ref.
$H \to \gamma\gamma$	**110-150**	2	**1-2%**	arXiv:1202.1487, HIG-12-001
$H \to \tau\tau \to \ell\tau_h/e\mu$	**110-145**	9	20%	arXiv.1202.4083
$H \to \tau\tau \to \mu\mu$ (VBF)	**110-140**	3	20%	HIG 12-007
$WH \to \ell\nu\tau\tau$	**100-140**	2	20%	HIG 12-006
$H \to bb$ (VH)	**110-135**	5	10%	arXiv:1202.4195
$H \to WW \to \ell\nu\ell\nu$	**110-**600	5	20%	arXiv:1202.1489
$WH \to W(WW) \to 3\ell 3\nu$	**170-**600	3	20%	HIG 11-034
$H \to ZZ \to 4\ell$	**110-**600	3	**1-2%**	arXiv:1202.1997
$H \to ZZ \to 2\ell 2q$	**130-164** 200-600	6	3%	arXiv:1202.1416
$H \to WW \to \ell\nu qq$	170-600			HIG 12-003
$H \to ZZ \to 2\ell 2\nu$	200-600	2	7%	arXiv:1202.3478
$H \to ZZ \to 2\ell 2\tau$	190-600	8	10-15%	arXiv:1202.3617

High mass channels & VBF: see talks by Y. Gao and B. Jäger!

$H \rightarrow \gamma\gamma$

- Search for narrow peak over large, smoothly falling background
  - Background from $m_{\gamma\gamma}$ distribution in data; resolution is critical

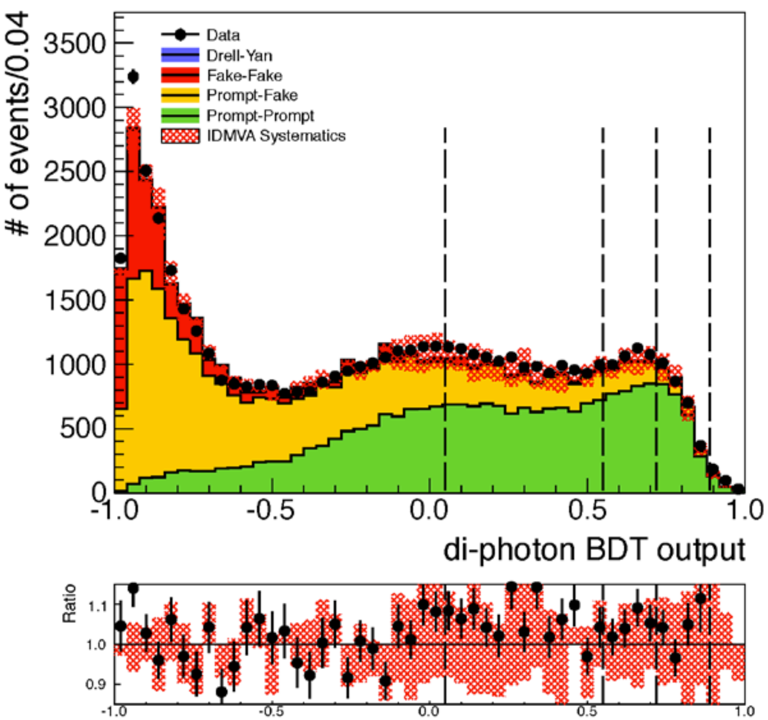
Multivariate analysis (HIG-12-001):

- Primary vertex selection
  - MVA combining information on track recoil against di-photon system with conversion pointing (when available)
  - Additional per-event vertex probability MVA estimate
  - Data/MC studied with $Z \rightarrow \mu\mu$ events (removing μs) and γ+jets (w/conversion)
- Select two photons with $p_T > m_{\gamma\gamma}/3(4)$
  - Loose preselection on shower shape and isolation; electron veto
  - Photon ID MVA to give per-object γ/π^0 discriminator with shower topology, isolation variables, N_{vtx}, η of supercluster
  - Efficiency measured on $Z \rightarrow ee$, and $Z \rightarrow \mu\mu\gamma$ for electron veto
- Multivariate energy correction for electromagnetic cluster containment; with resolution estimate
- Energy scale and MC resolution corrections from $Z \rightarrow ee$
- Classification with di-photon MVA

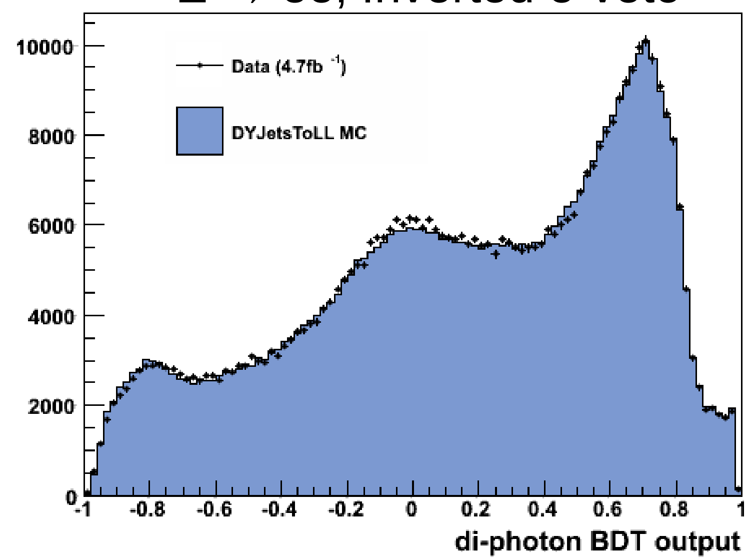
Di-photon MVA

- Encode all sig/bg discriminaton (except $m_{\gamma\gamma}$) in a single variable
  - Inputs: $m_{\gamma\gamma}$-independent kinematics, per-event resolution and vertex probability, and photon ID
  - Di-photon MVA output for signal-like events validated with $Z \rightarrow ee$ events by inverting electron veto in the pre-selection
- Use this to categorize events

Full selection

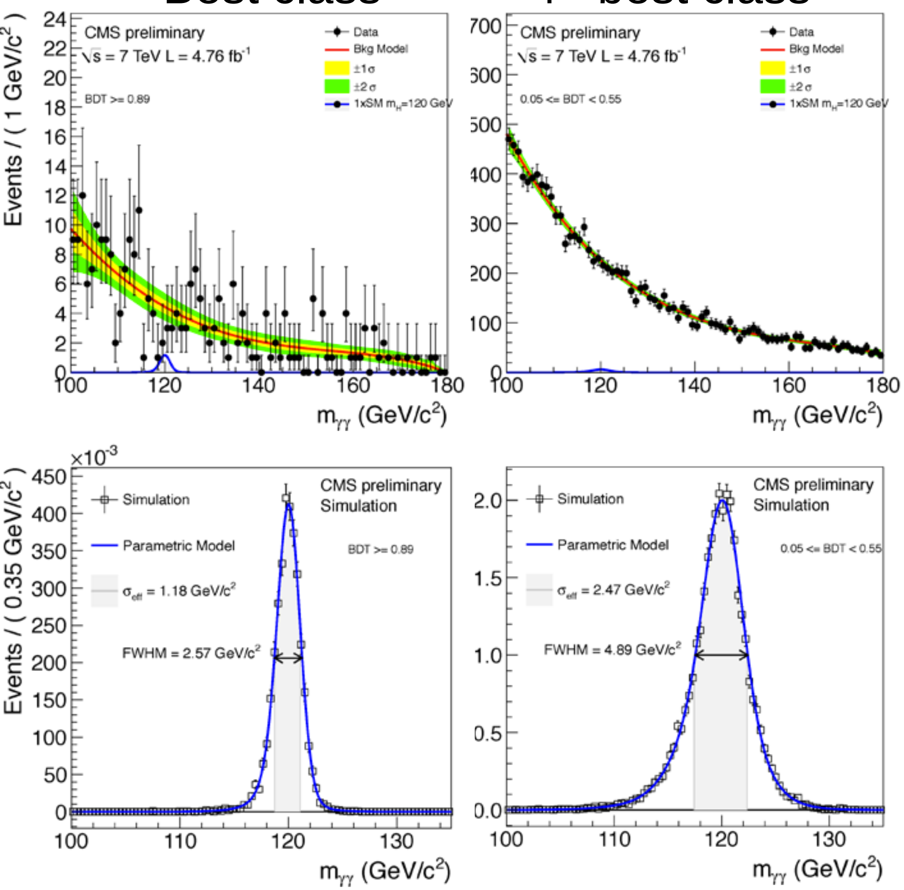


$Z \rightarrow ee$, Inverted e-veto

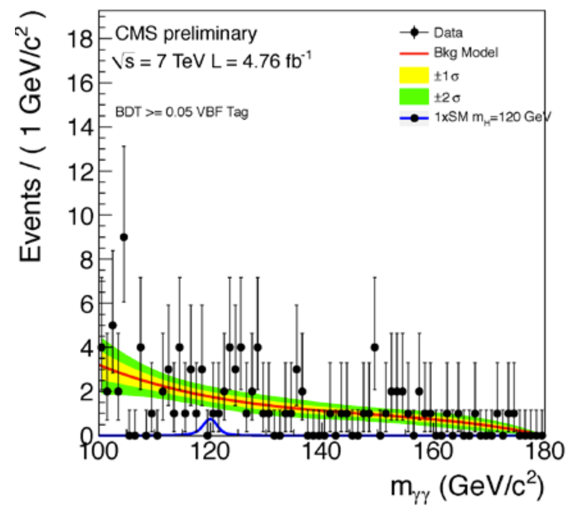


$H \to \gamma\gamma$: Event Classification

Best class | 4th best class



- Define 4 classes of events according to di-photon MVA output
  - Mass resolution and S/B vary signicantly as a function of event class
- 5th class for events with di-jet tag (VBF topology): s/b ~1/3



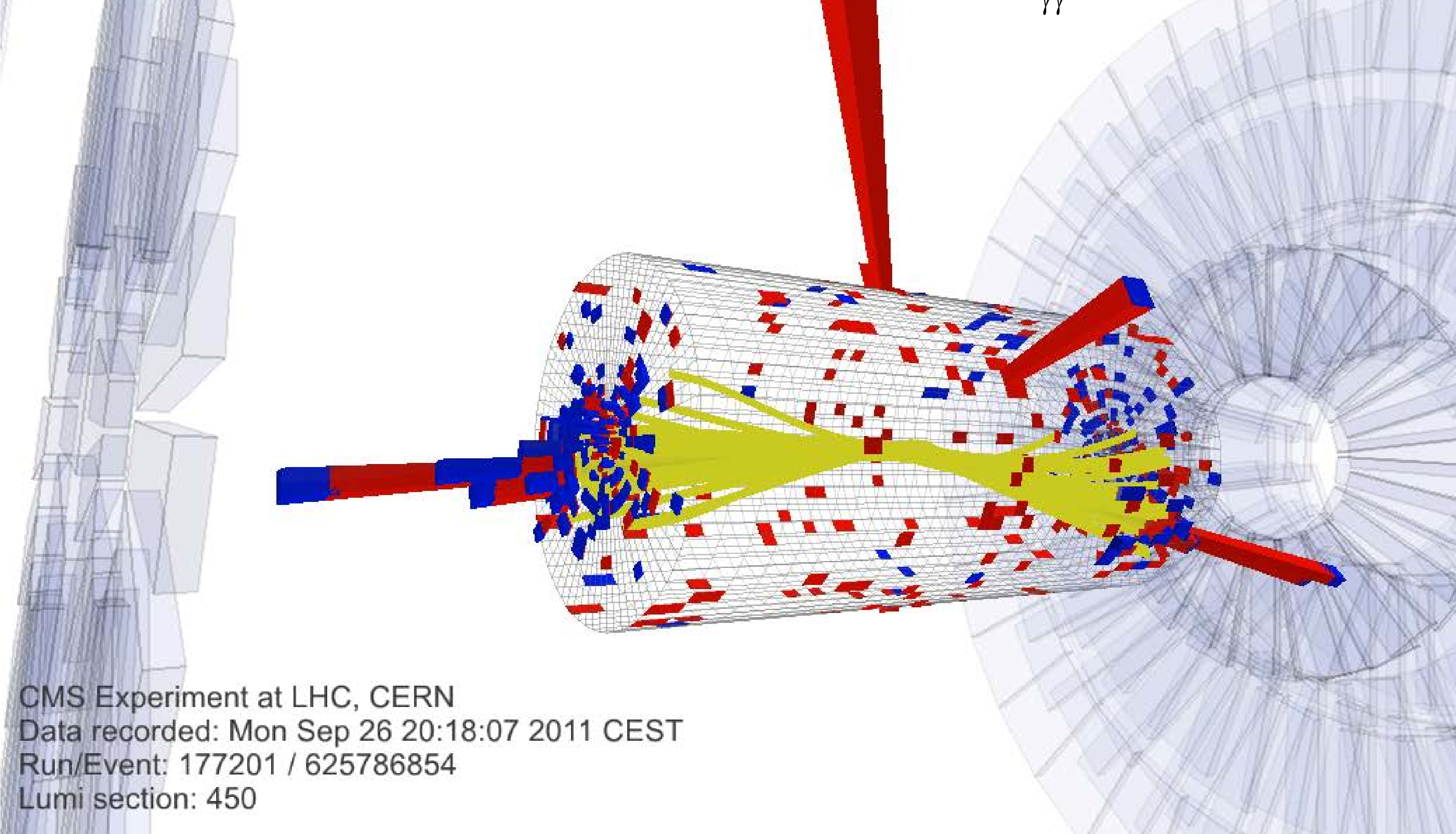
- Background modelling from fit to data
  - Sufficient polynomial order chosen with toy studies category by category
  - Alternative using mass-sideband model
- Signal modelling from Monte Carlo with smearing and scale factors applied

$\gamma\gamma$ candidate with di-jet tag

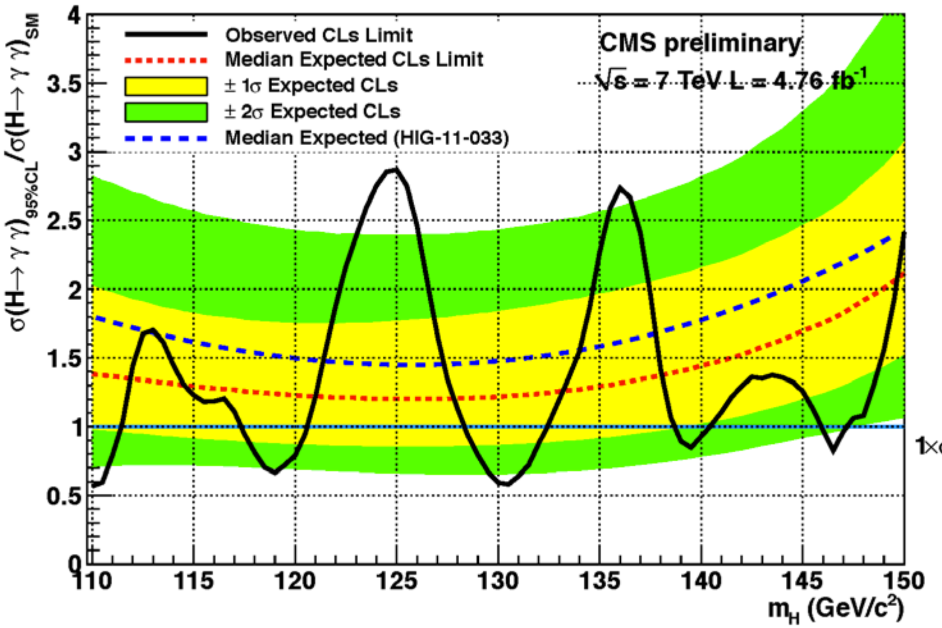
$p_T^1 = 193.9\ GeV/c^2$

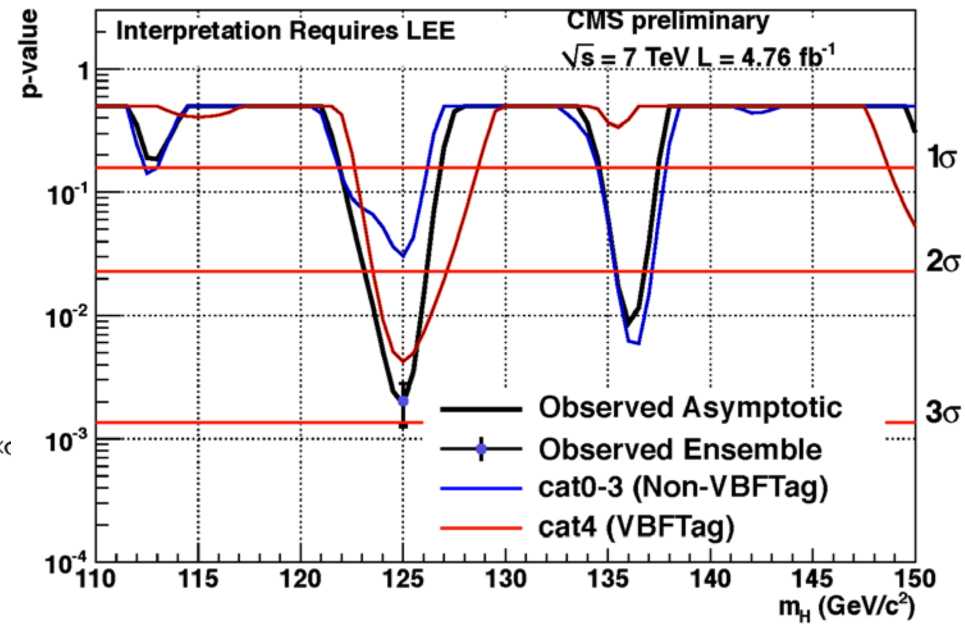
$p_T^2 = \ 78.0\ GeV/c^2$

$m_{\gamma\gamma} = 121.9\ GeV/c^2$



$H \to \gamma\gamma$: Results



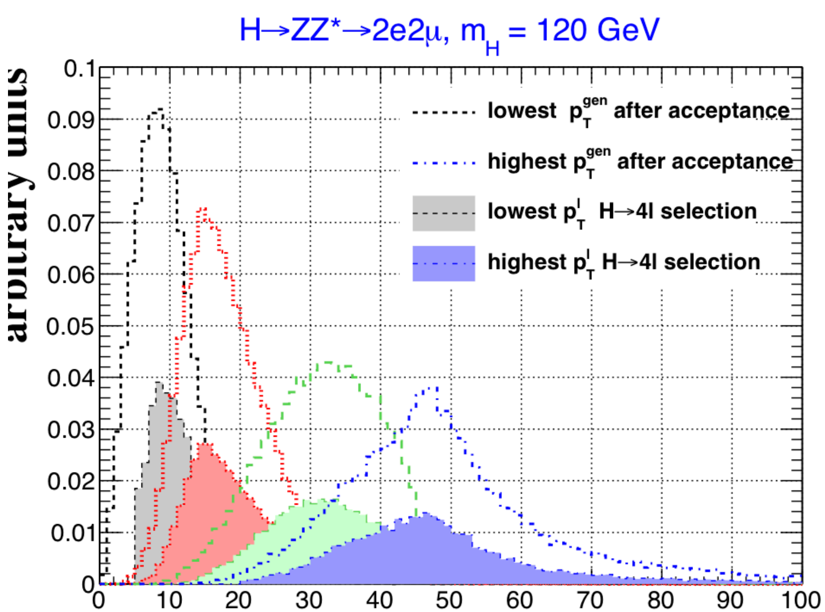


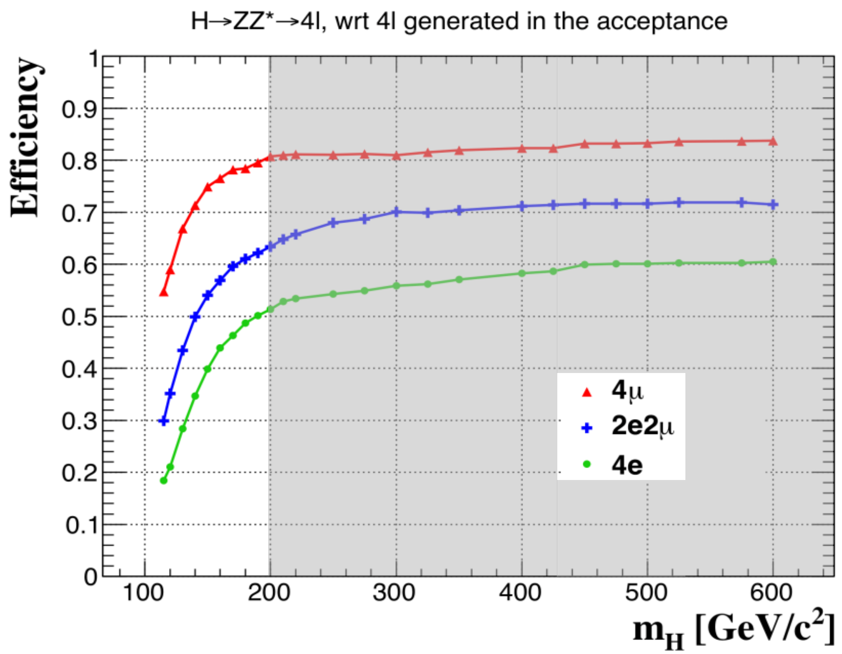
Global significance:1.5σ in range 110–145 GeV

- Use $m_{\gamma\gamma}$ shape for final results
  - 95% C.L. exclusion for 110.0-111.0, 117.5-120.5, 128.5-132.0,139.0-140.0, 146.0-147.0 GeV.
- Two regions of excess: 125 GeV and 136 GeV
  - At 125 GeV, both di-jet tagged and not-di-jet-tagged categories contribute

$H \to ZZ \to 4\ell$

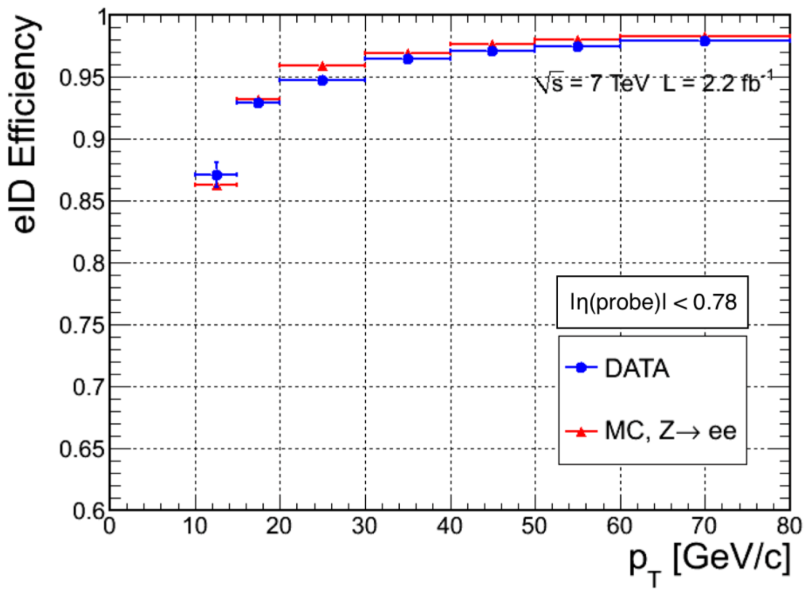
- High purity, excellent resolution (1-2%), robust against pile-up
  - Narrow peak over a locally flat background continuum
- Small signal : Need to preserve highest efficiencies for ID, isolation, kinematics
- Select 4 isolated leptons with small impact parameter to PV
  - $|\eta|<2.5$ (m), 2.4 (e);
  - p_T 1,2 > 20, 10 GeV, p_T 3,4 > 5 (μ) or 7 (e) GeV
  - $50 < m_{Z1} < 120$ GeV, $12 < m_{Z2} < 120$ GeV

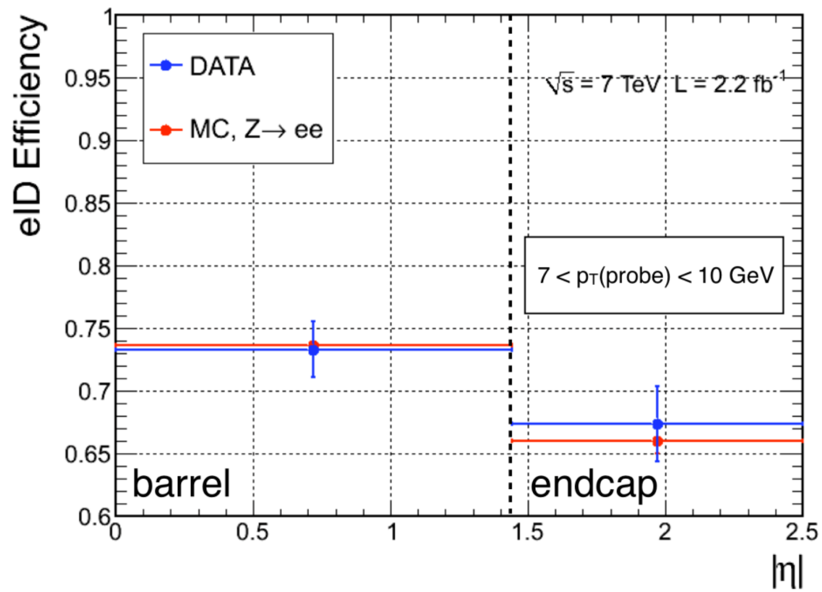




$H \to ZZ \to 4\ell$

- Control lepton efficiencies from data with tag-and-probe on Z (for e,μ) and J/Ψ (for low p_T μ)





- Irreducible $ZZ \to 4\ell$ continuum background estimated from MC
- Reducible Z+j, Z+bb and tt backgrounds estimated from Z + $\ell\ell$ (same-sign) sample, with fake rates from Z + ℓ sample

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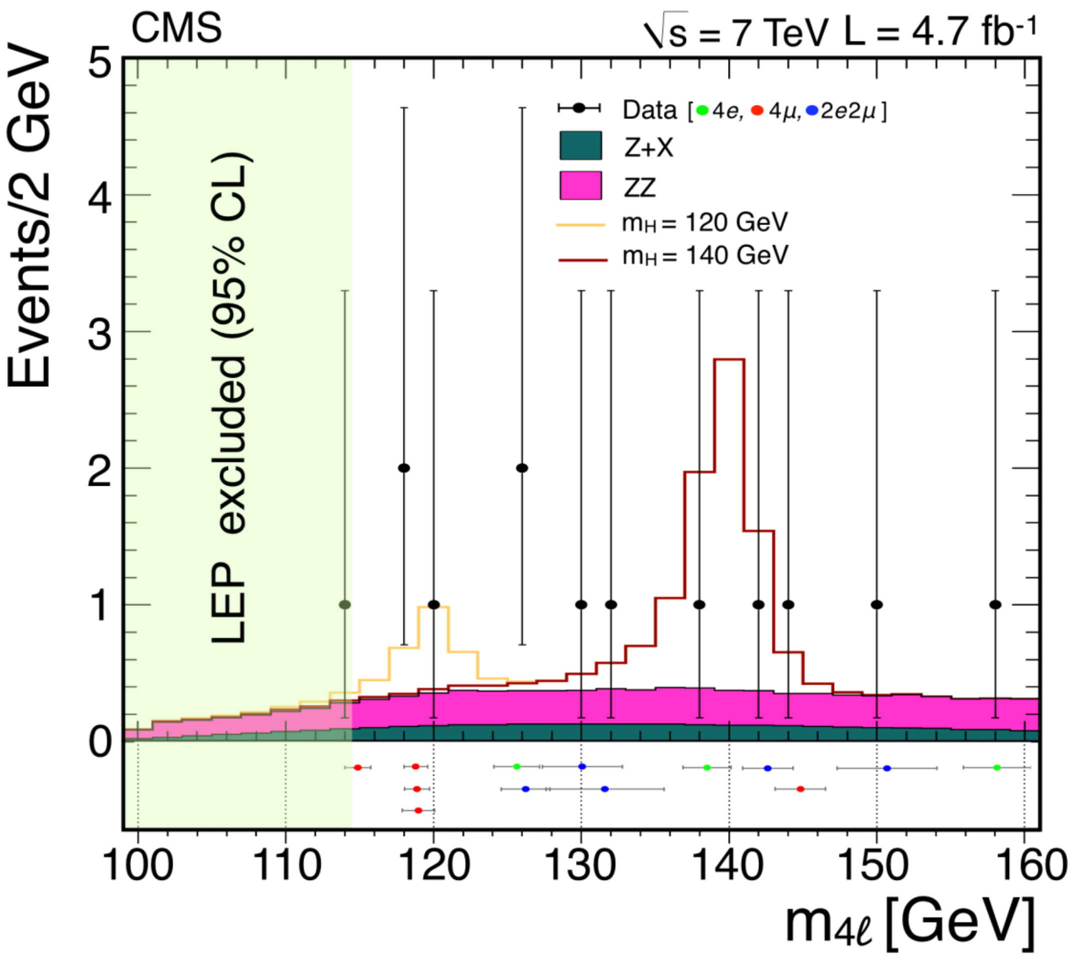
$H \to ZZ \to 4\ell$: observed events

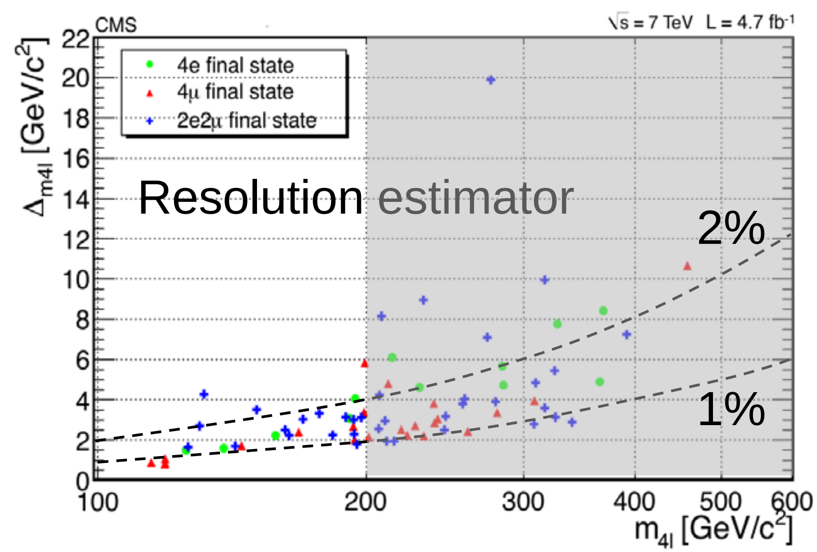


In the region 100 – 160 GeV:

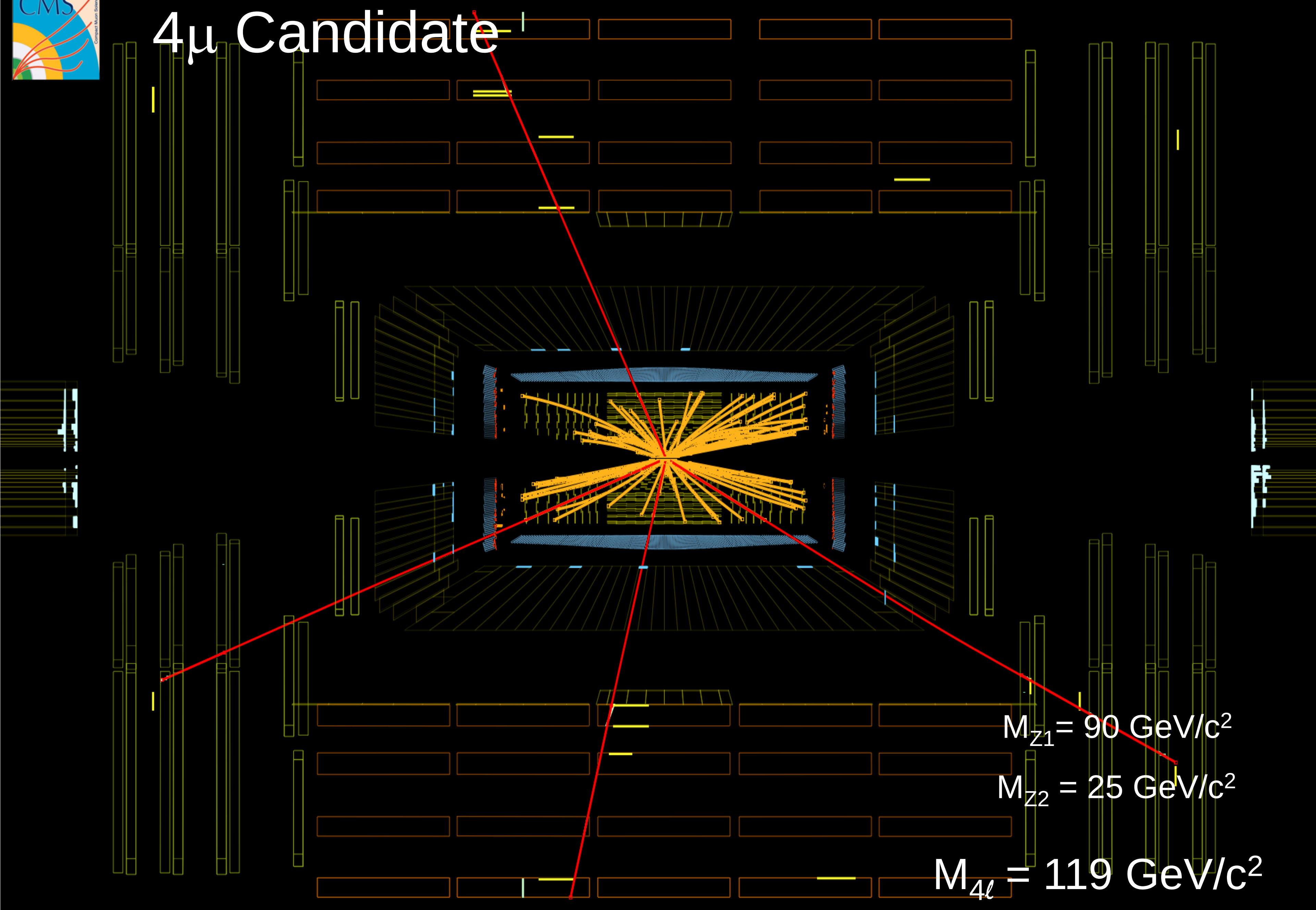
- 13 events observed
- 9.5 ± 1.3 expected

Final state:	4e	4μ	2e2μ
Obs. events:	3	5	5
Exp. events:	1.7	3.3	4.5

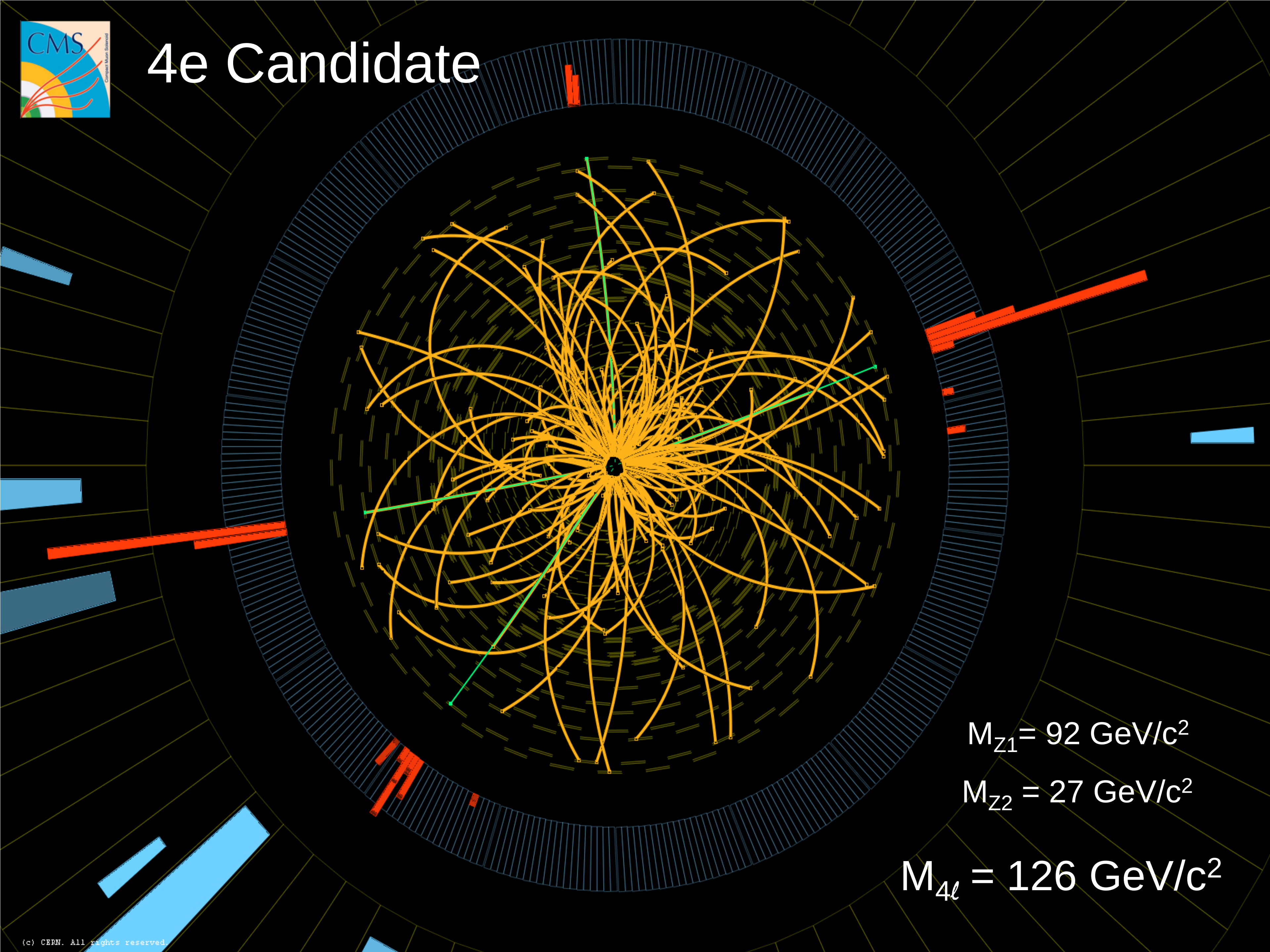
Some clustering in 4μ near 119 GeV



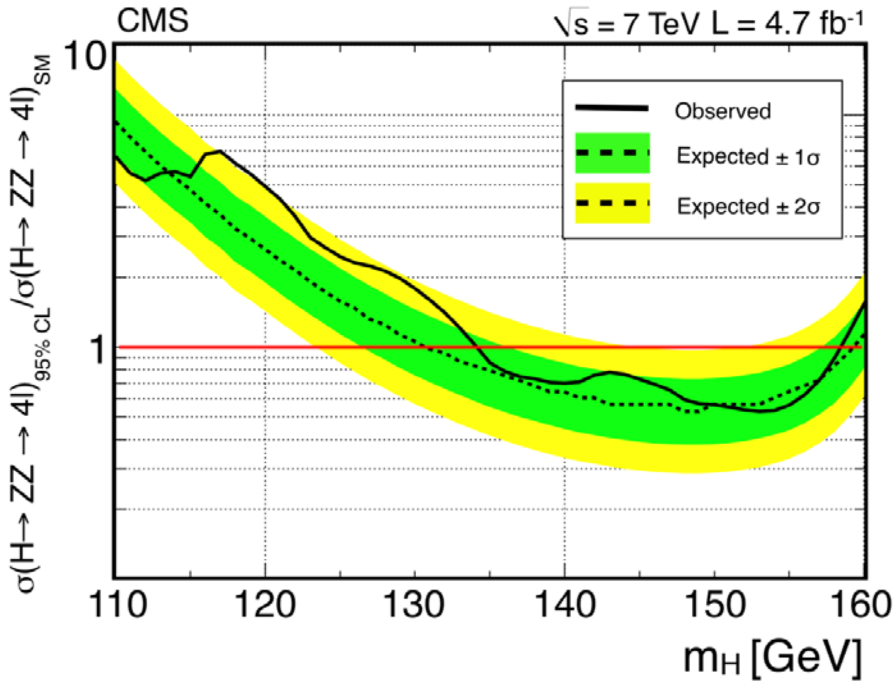
4μ Candidate

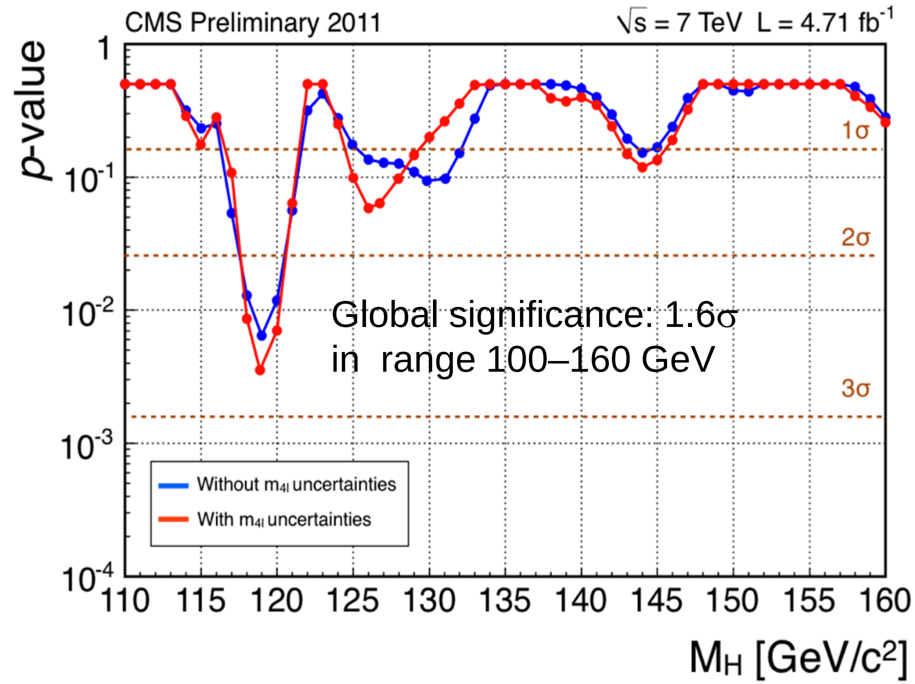


4e Candidate



$H \to ZZ \to 4\ell$: Results



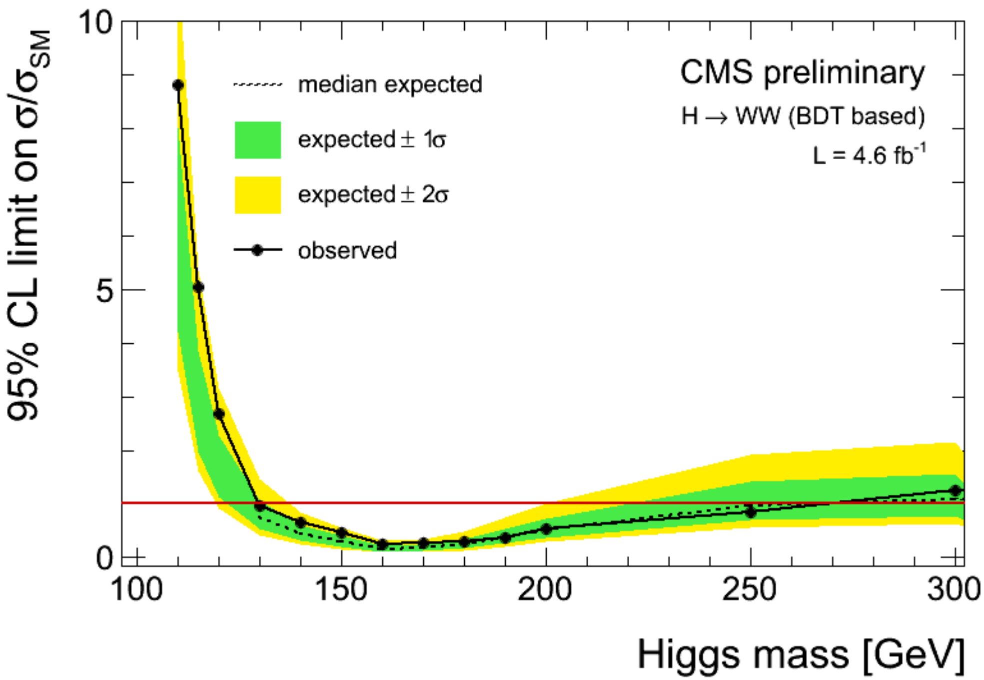


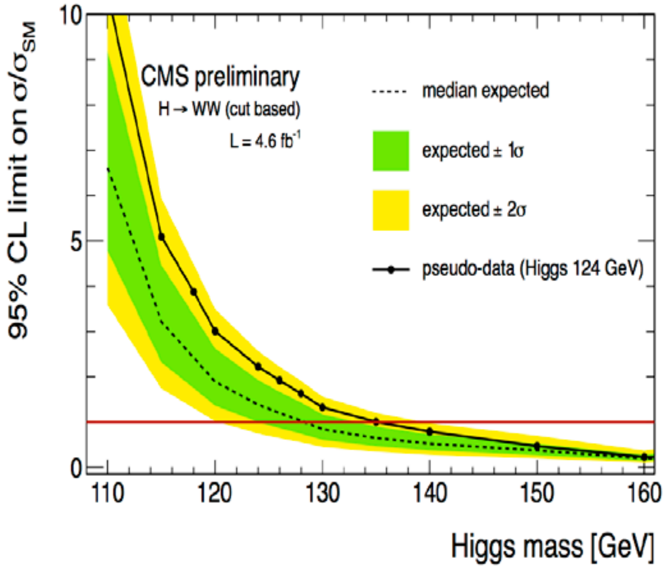
- m_{4l} shape used to extract final results
- 95% C.L. exclusion for134-158, 180-305, 340-465 GeV
- “observed excess makes limit weaker than expected”

HIG-11-024 (arXiv.1202.1489)

$H \to WW \to 2\ell 2\nu$

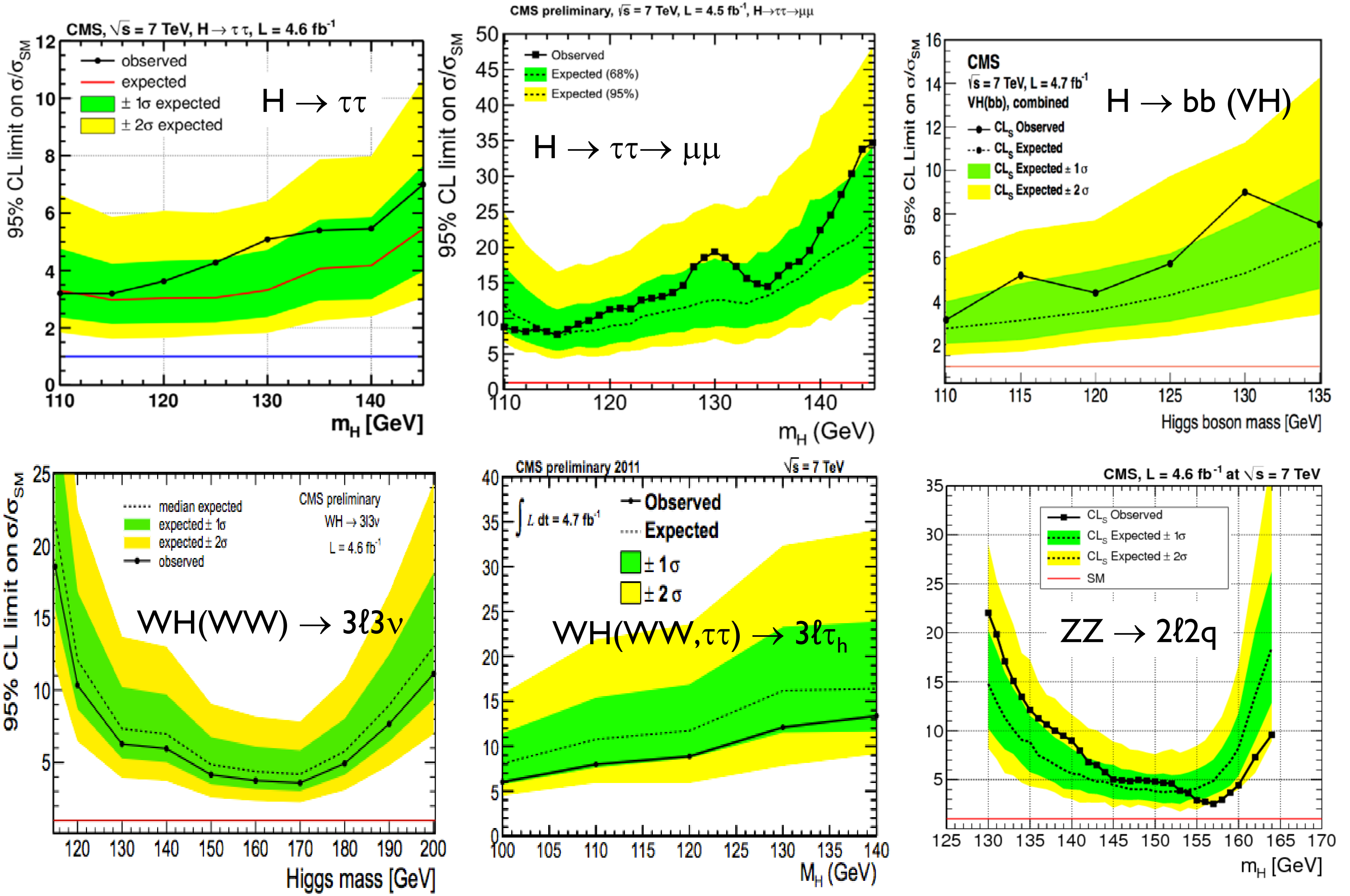
- Analysis discussed in next talk!
  - Results from MVA shape analysis 5 categories: 0/1 jet (SF/OF), 2jets (VBF)
- Results (95% CLS)
  - Exp exclusion: 127-270 GeV
  - Obs exclusion: 129-270 GeV



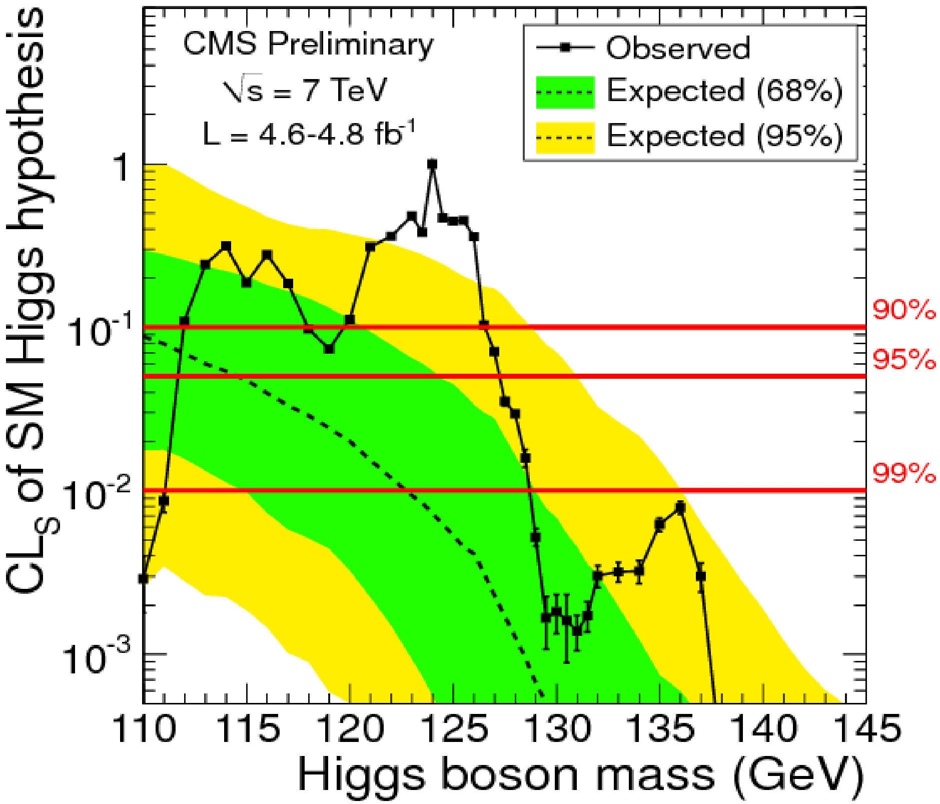


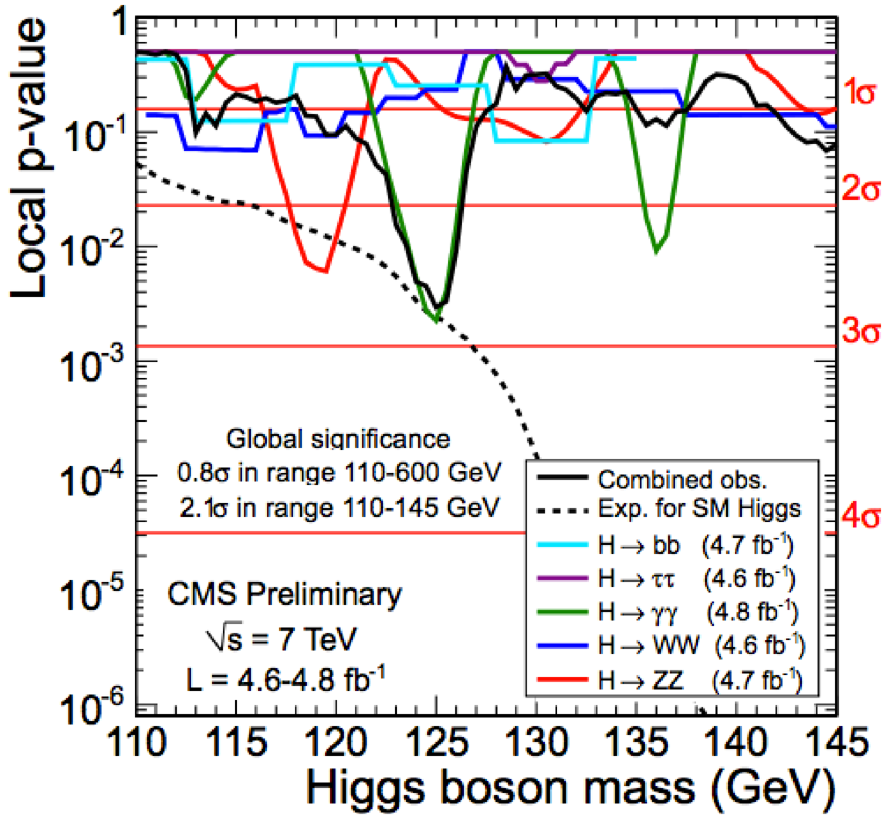
- Broad "excess" below exclusion
  - But poor mass resolution (no peak)
  - How would a signal look like in this plot?
    - run pseudo- experiments with pseudo-data @ 124 GeV

Other Low Mass channels…

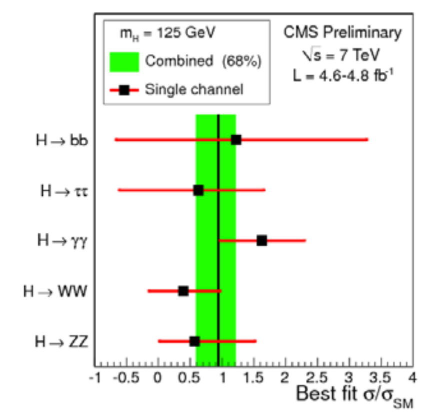


Combination





- 95% C.L. Expected exclusion: 114.5 – 543 GeV
- 95% C.L. Observed exclusion: 127.5 – 600 GeV



Summary

- 9 analyses presently contribute to low mass H results
  - full 2011 dataset analyzed
- SM Higgs excluded at 95% C.L. above 127.5 GeV
- Modest excess does not allow to exclude the range between 114.4 and 127 GeV, leaving a window open for the Higgs

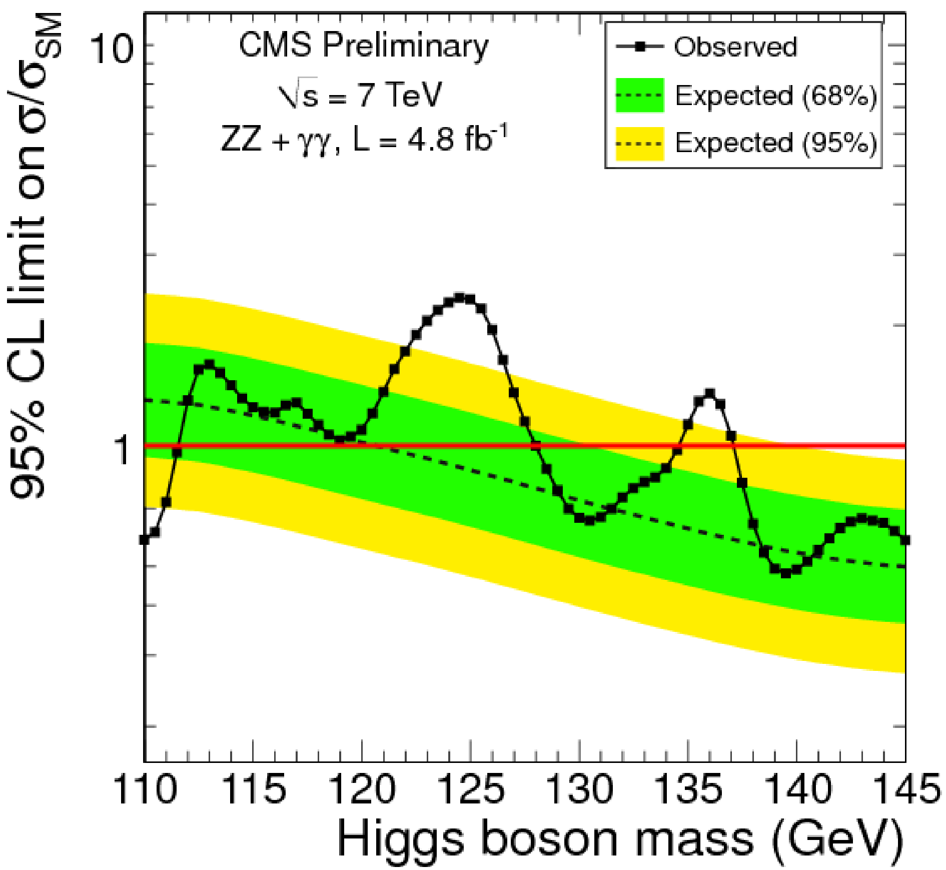
"More data are required to ascertain the origin of the observed excess" - *HIG-12-008*

The data is coming!!

Backups

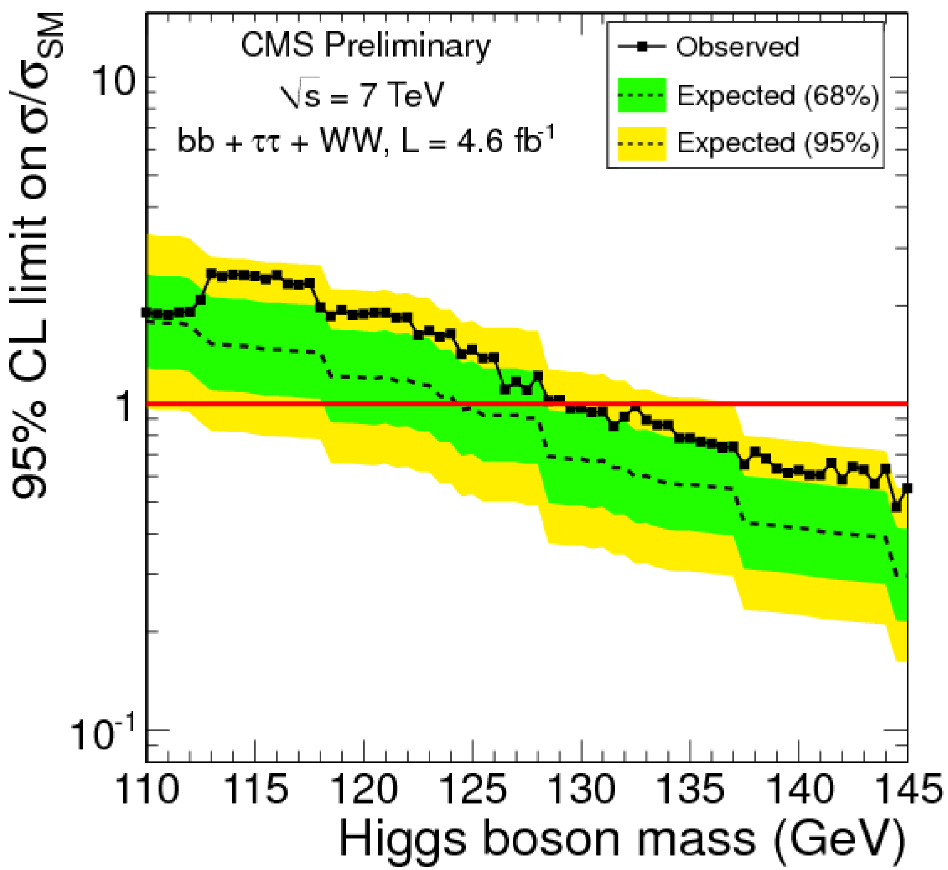
$\gamma\gamma$ + ZZ vs. bb + $\tau\tau$ + WW

1-2% mass resolution



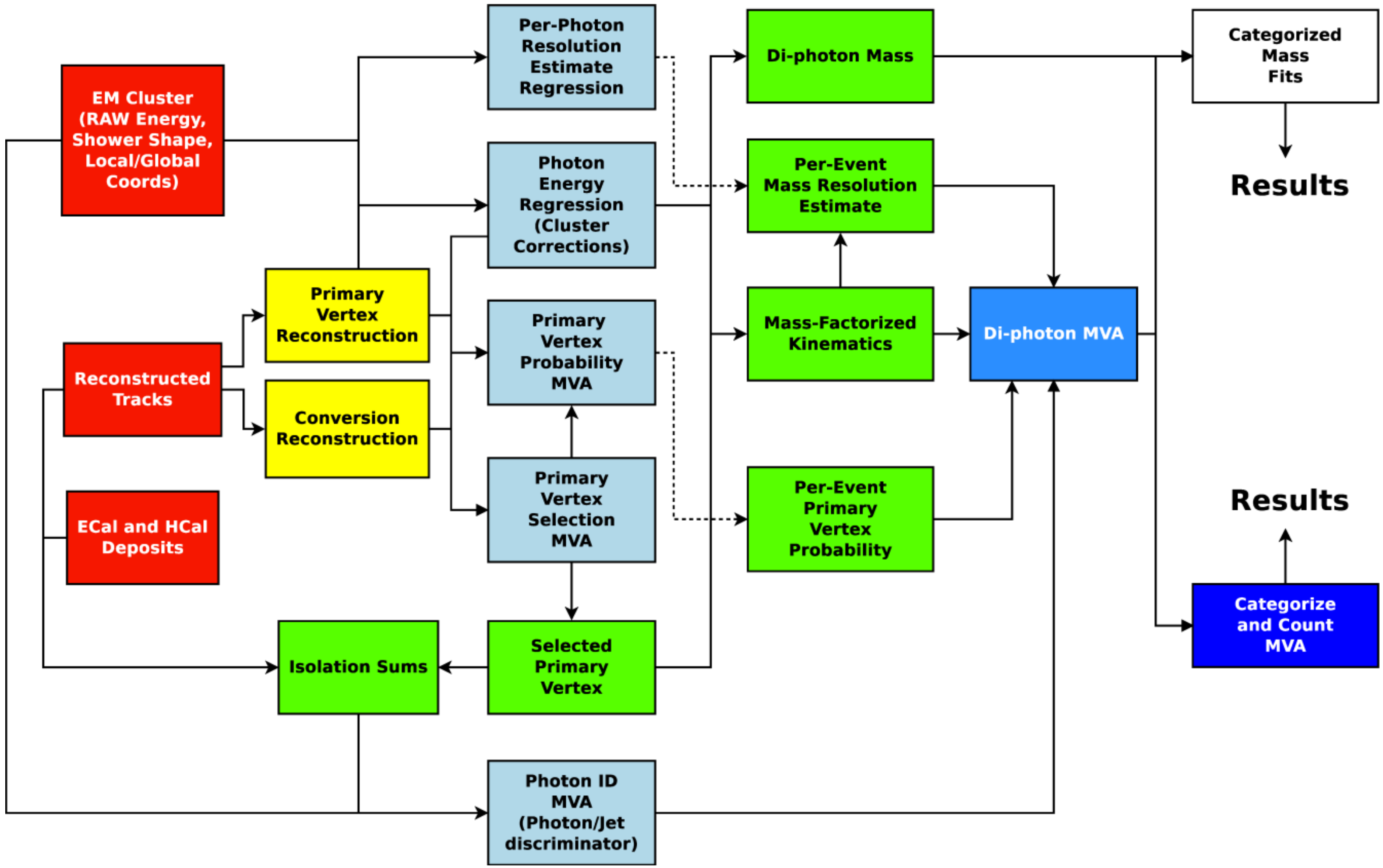
ZZ does not remove excesses

10-20% mass resolution



Broad 1σ excess 112 – 145 GeV

$H \to \gamma\gamma$: Analysis flow



Strategy: Process available information into quantities with straightforward physical interpretations in order to combine per-event knowledge of expected mass resolution and S/B into a single Di-photon MVA" variable

$H \rightarrow ZZ \rightarrow 4\ell$: Background Estimation

Rely on Data:

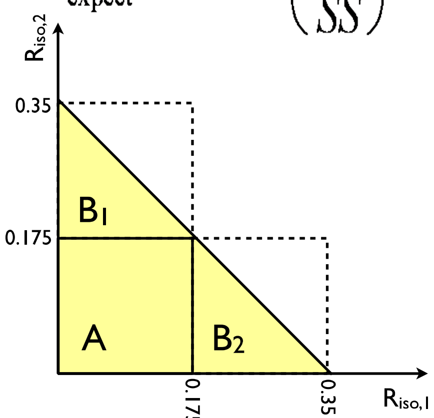
Start with Z1 + $\ell^{reco}\ell^{reco}$

Which contains would-be signal-like Z+jets, Zbb and tt

"Fake Rate Method"

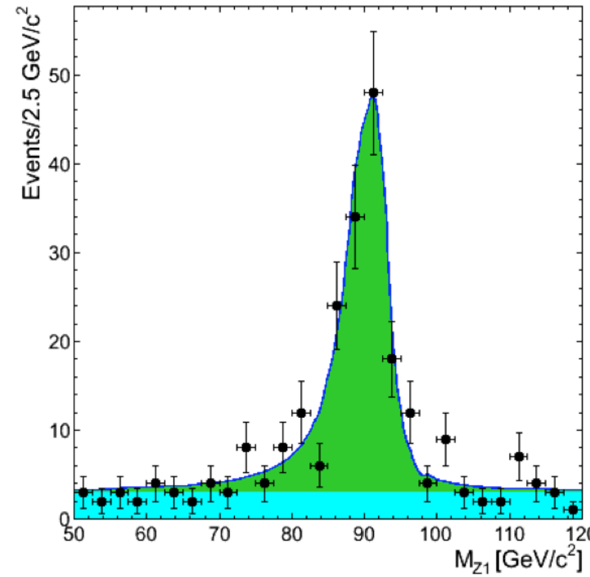
Define a sample of SS-SF
i.e. Z1 + $e^{\pm}e^{\pm}$, μ μ

$$N^{Z+X}_{\text{expect}} = N^{\text{Data}} x \left(\frac{OS}{SS}\right)^{MC} x \left(\sum \varepsilon_1(p_T,\eta)_{Riso<k} x \varepsilon_2(p_T,\eta)_{Riso<k}\right)$$



$\varepsilon_i(p_T,\eta)_{Riso<k}$
= fake rate obtained from independent sample Z1 + exactly one ℓ^{reco}

Cross-check HF component:
Define a sample with leptons at large impact $|SIP_{3D}| > 5$

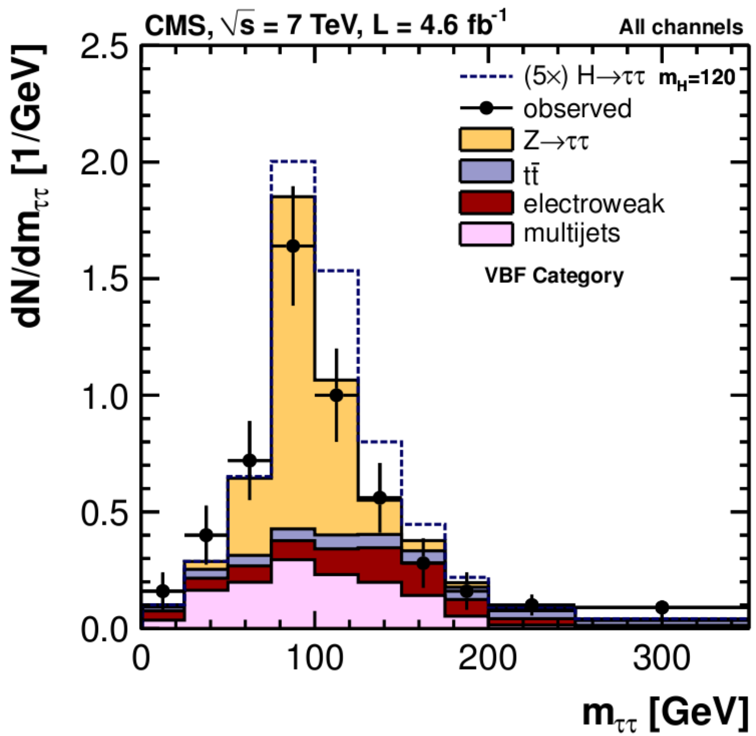


Extrapolate to signal region using SIP_{3D} shapes

$\Rightarrow$ tt contribution proven negligible in signal region
$\Rightarrow$ Zbb/tt proven negligible for $60 < M_{Z1,2} < 120$ GeV

$H \to \tau\tau$

- Analysis method:
  - Use $e\mu$, $e\tau_h$, and $\mu\tau_h$ final states
  - $\mu\mu$ mode added recently [HIG-12-007]
- mass reconstructed using kinematic fit of visible products and missing E_T with likelihood constraints on decay kinematics
- $Z \to \tau\tau$ background estimated from $Z \to \mu\mu$ events in data with replaced by simulated τ
- W + jets and multijet background estimated from high transverse mass and same-sign control region
- Binned ML fit to $m_{\tau\tau}$ in 3 categories for each final state
  - di-jet VBF tagged, boosted (leading jet pT > 150 GeV), remaining 0/1 jet events
- Also: $WH(\tau\tau)$ [HIG-12-006]
  - Use $te^+\mu^+\tau_h^-$, $\mu^+\mu^+\tau_h^-$ and c.c.



VH → bb

- V kills QCD; provides trigger
  - p_T spectrum of V+jets is softer
    - boosting V and H increases S/B
  - 3 topologies (5 channels):
    - $Z \to \ell\ell$, $Z \to \nu\nu$, $W \to \ell\nu$ [ℓ = e, μ]
- Main backgrounds
  - V+bb, ttbar, single top, VV
- Mass-dependent MVA analysis
  - Trained on simulated signal/bk
  - Rates for W/Z+jets and tt from data
  - Diboson, single t from MC
  - Cut&count on MVA output
- b-tagging
  - Fake rate ~2% for ε = 70%; pT dependence calibrated on data with tt events