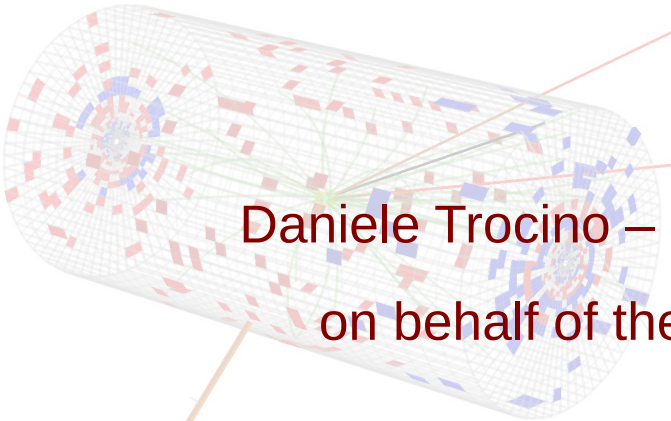
A Search For The Higgs Boson In $H \rightarrow ZZ \rightarrow 2\ell 2\nu$ Mode



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on behalf of the CMS Collaboration

Meeting of the Division of Particles and Fields of the American Physical Society

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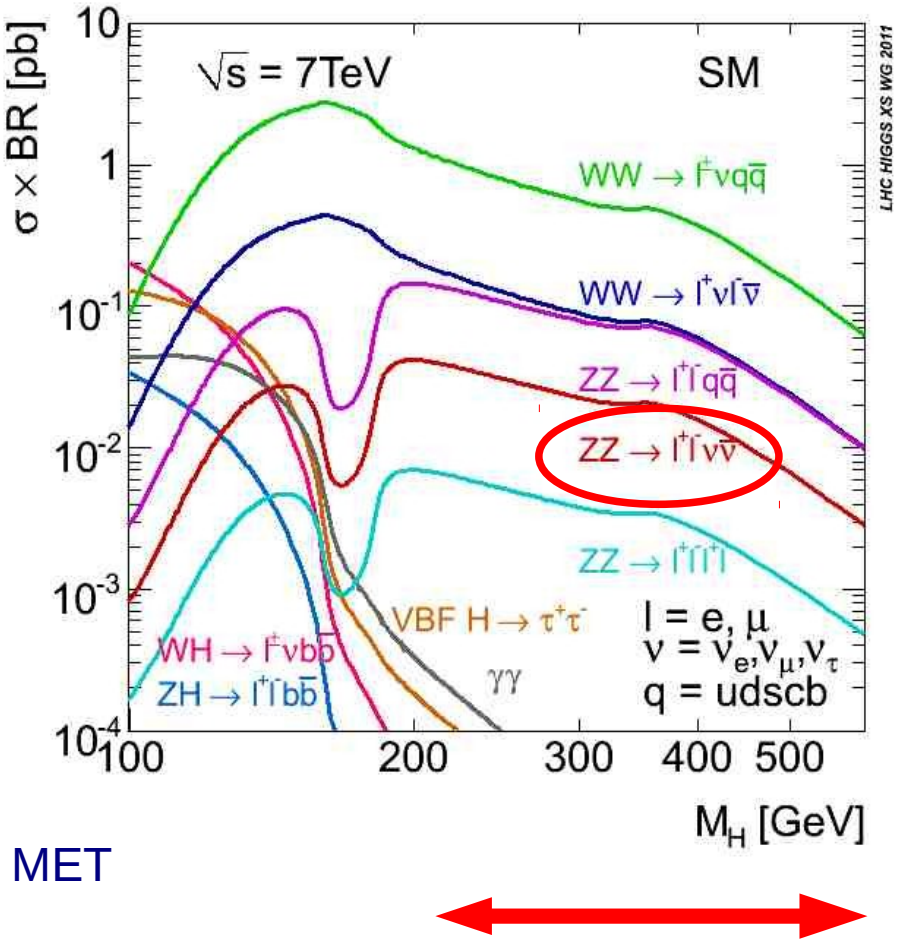
Why $H \to ZZ \to \ell\ell\nu\nu$?

$BR(H \to 2\ell 2\nu) \approx 6 \times BR(H \to 4\ell)$

Main features

- No Higgs mass peak
- Large Drell-Yan background
  (~5 orders of magnitude larger than signal)
- Good for exclusion in the high Higgs mass region (M_H ~ 250-600 GeV/c^2)
- Signature: boosted Z's



➔ $\ell^+\ell^-$ pair in the Z mass window + high MET

- Cut-based analysis, ~ 1.1 fb^{-1}

Signal

- Signal MC sample (POWHEG) includes
  - $H \to ZZ \to 2\ell 2\nu$
  - $H \to WW \to 2\ell 2\nu$

  } *gg, VBF*

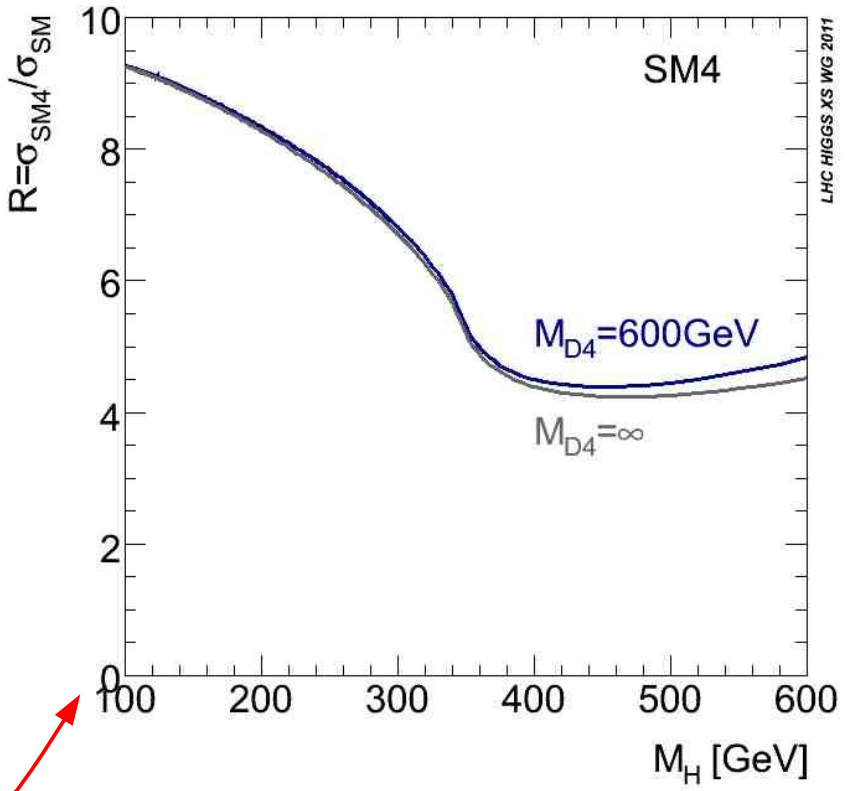
- Re-weighting to match the NNLO + NNLL Higgs p_T spectrum

- Cross sections for exclusion are obtained for on-shell Higgs in the narrow-width approximation
  - Not accurate for high mass (400-600 GeV/c^2)
  - For the time being, 10-30% uncertainty added to the theoretical cross section

- SM + 4th fermion generation model (SM4) also explored

  M(4th ferm.) = 600 GeV/c^2

  ➔ $gg \to H$ cross section enhanced, different branching ratios

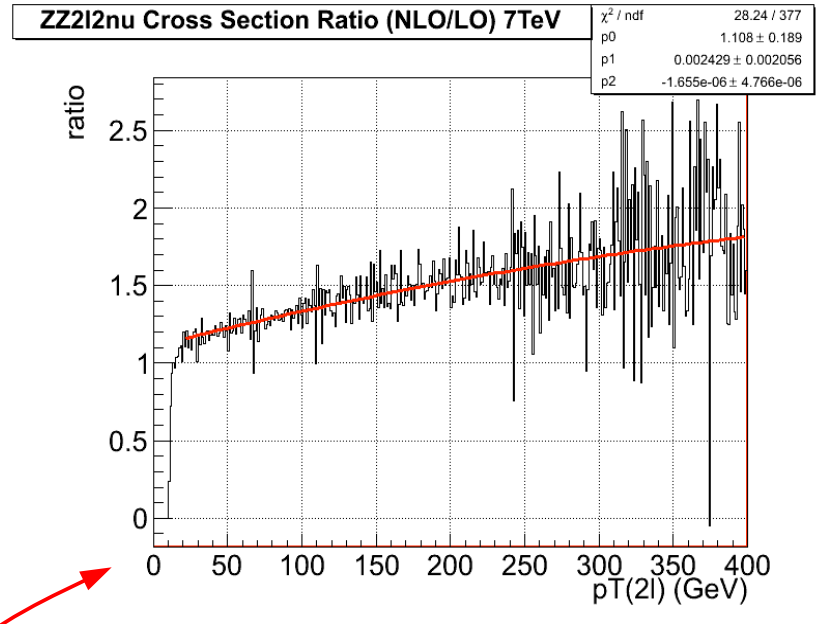


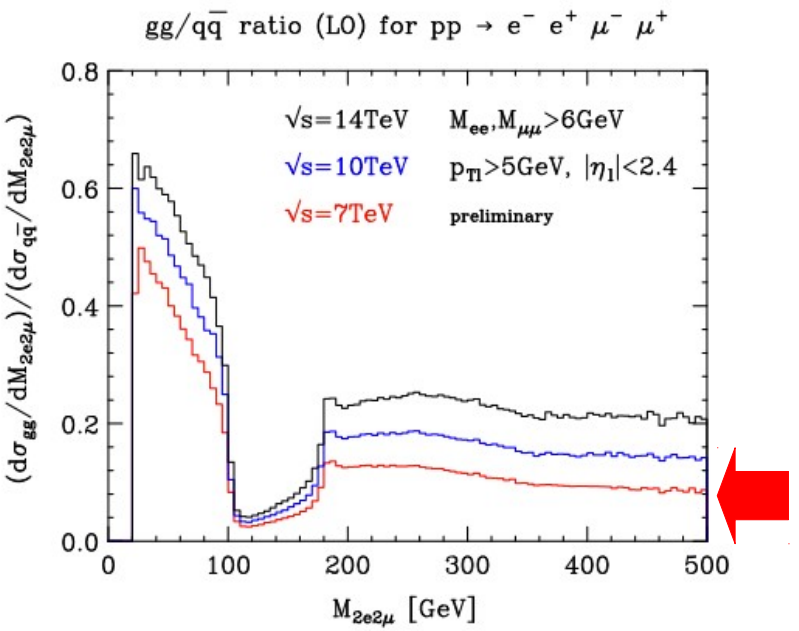
Cross sections, branching ratios from the "LHC Higgs Cross Section Working Group"

arXiv:1101.0593 [hep-ph]

Backgrounds

- Z + jets, with fake MET due to mis-measured jets, leptons, and to detector effects
  - ~ 5 orders of magnitude larger than signal
  - Need to be measured from data
- Non-resonant (i.e. no Z peak): *tt*, single *t*, WW, W+jets
  - Measured from data
- Irreducible ZZ, WZ
  - Modeled from simulation
  - LO ZZ cross section re-weighted with Z p_T-dependent NLO *k*-factor (from MCFM) + 12% for gg → ZZ contribution





Signal Selection: Dilepton and Lepton Veto

Dilepton selection

- Two leptons (muons, electrons) with same flavor, opposite charge
- p_T > 20 GeV/c, $\left|M(\ell\ell) - 91.1876\ \text{GeV}/c^2\right| < 15\ \text{GeV}/c^2$, $|\eta| < 2.4$ (μ) or 2.5 (e)
- Transverse + longitudinal impact parameters w.r.t. the primary vertex
- Isolation: tracks' p_T + calorimeter energy around the lepton ($\Delta R < 0.3$)
  - correction to reduce sensitivity to pile-up interactions
- Muons: tight ID, track quality requirements
- Electrons: tight ID, photon conversion veto

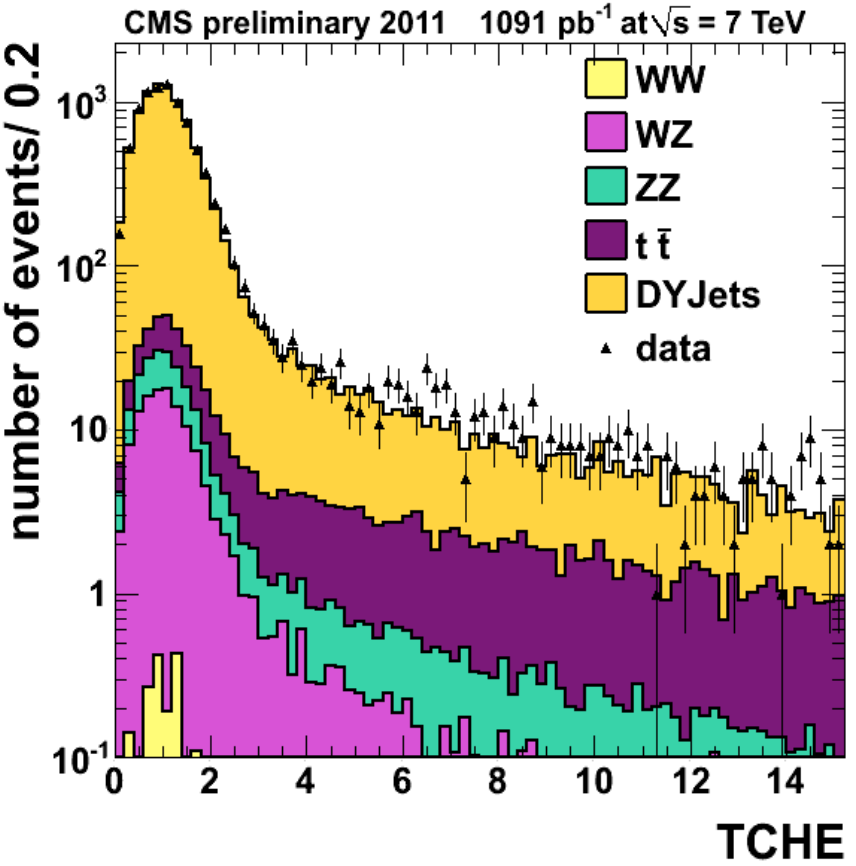
Additional Lepton veto

- Events with an additional lepton (selection above, p_T > 10 GeV/c) are vetoed

➔ Against WZ (W decaying leptonically) and also ZZ (both Z's decaying into leptons)

Signal Selection: B-Jet Veto

- To suppress *tt* and single *t* backgrounds, events with a *b*-tagged jet are vetoed
- Particle Flow jets considered
  - anti-k_T algorithm, $\Delta R < 0.5$
  - $p_T > 30$ GeV/c, $|\eta| < 2.4$
- Track Counting High Efficiency (TCHE) discriminator
  - Based on number of displaced tracks in a jet



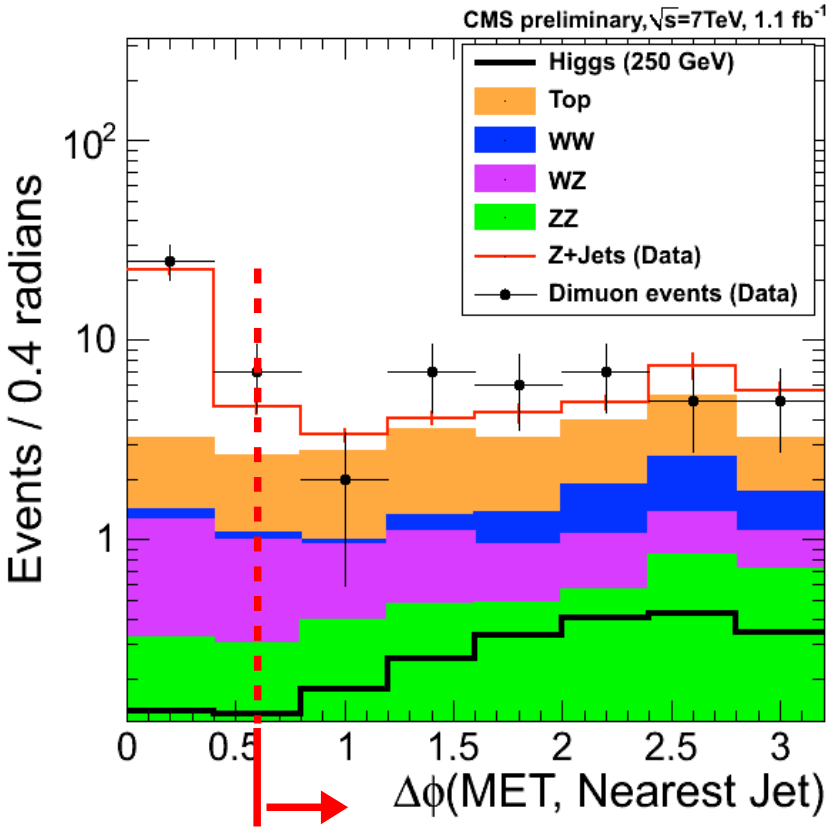
Signal Selection: Missing Transverse Energy

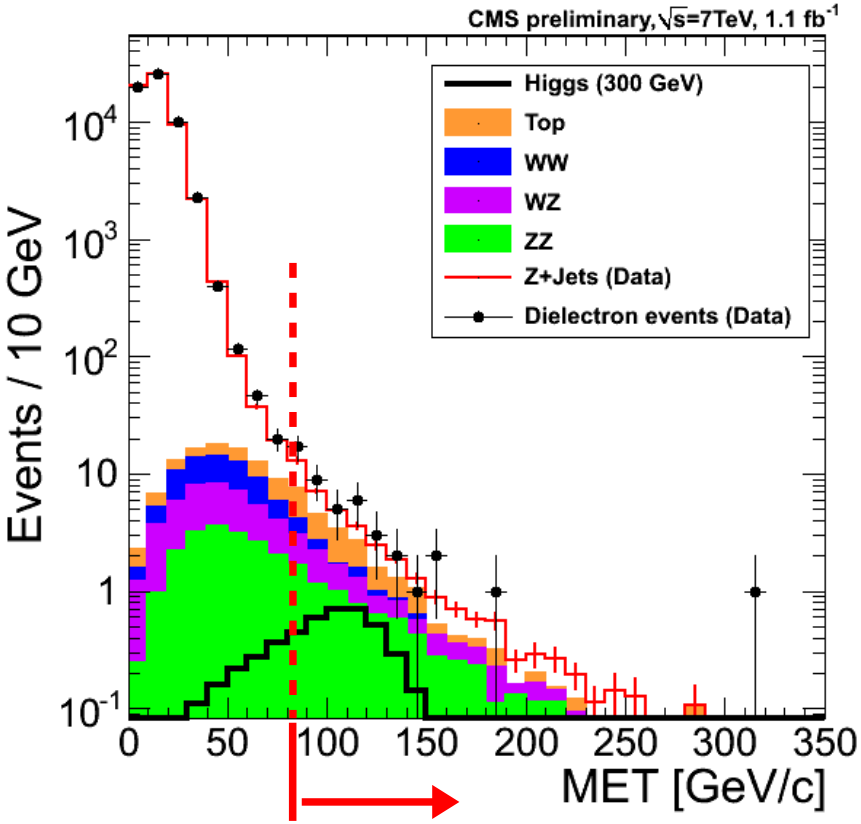
- MET is crucial to suppress the Z + jets background

  ➔ cut on Particle Flow MET

- Events with significant fake MET due to mis-measured jets can pass the MET cut

  ➔ cut on Δφ between MET and the closest jet





MET and Δφ cuts are M_H-dependent. E.g.:

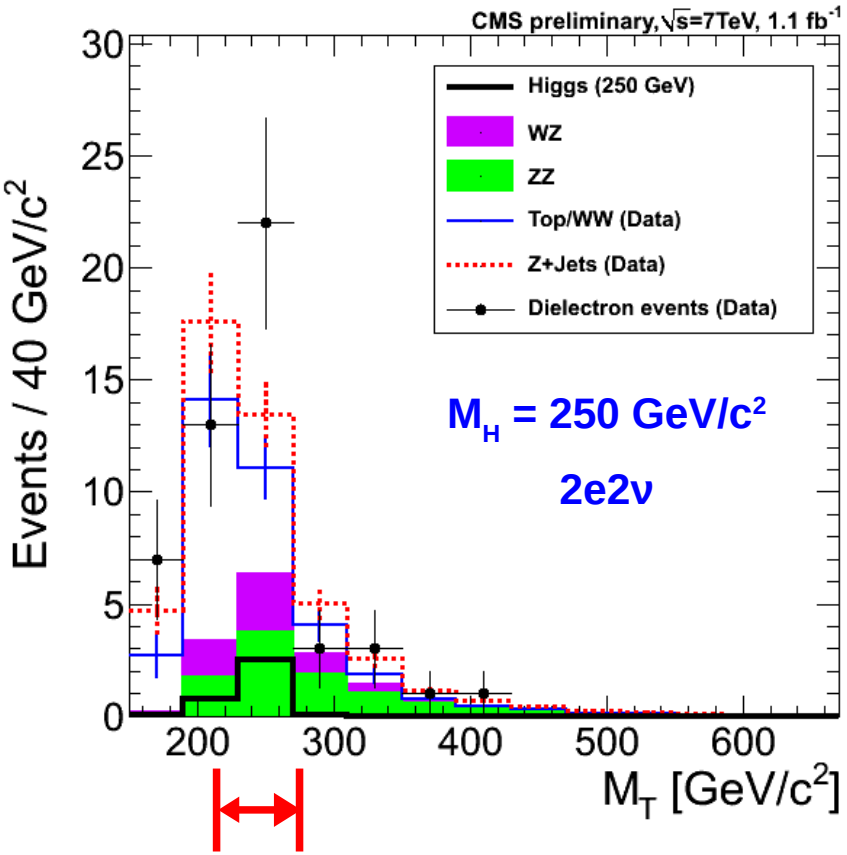
Higgs mass [GeV/c²]	MET [GeV]	Δφ(MET, jet)
250	> 69	> 0.62
350	> 97	> 0.14

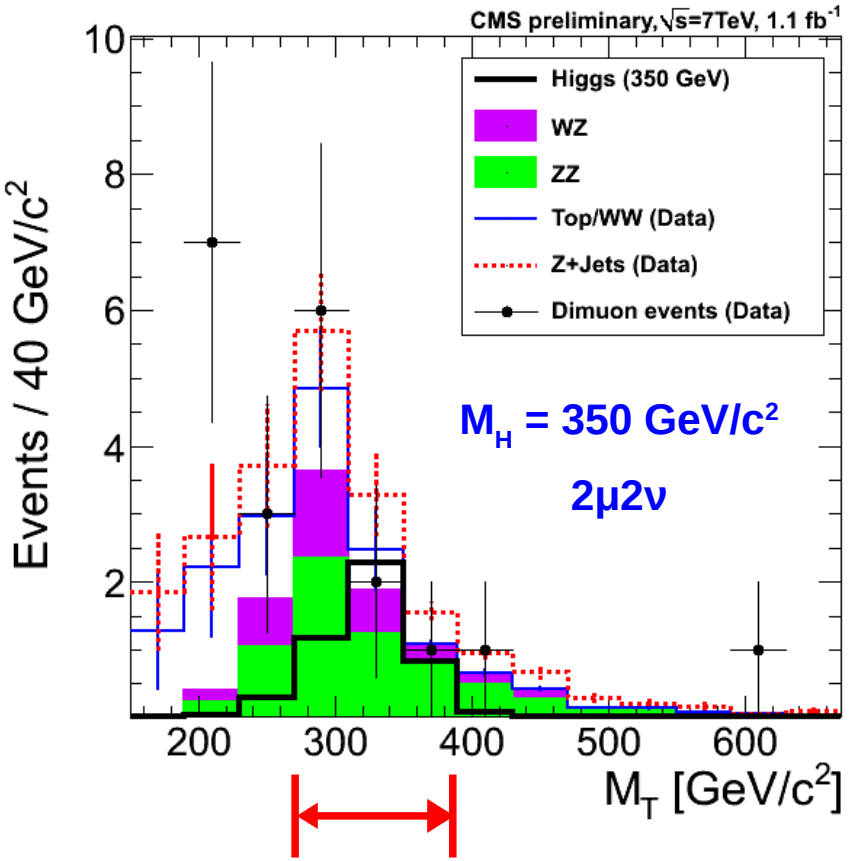
Signal Selection: ZZ Transverse Mass

- Final discriminating variable M_T

$$M_T^2 = \left(\sqrt{P_{T,Z}^2 + M_Z^2} + \sqrt{MET^2 + M_Z^2}\right)^2 - \left|\vec{P}_T + \vec{MET}\right|^2$$

- Signal is selected in a M_H-dependent M_T window





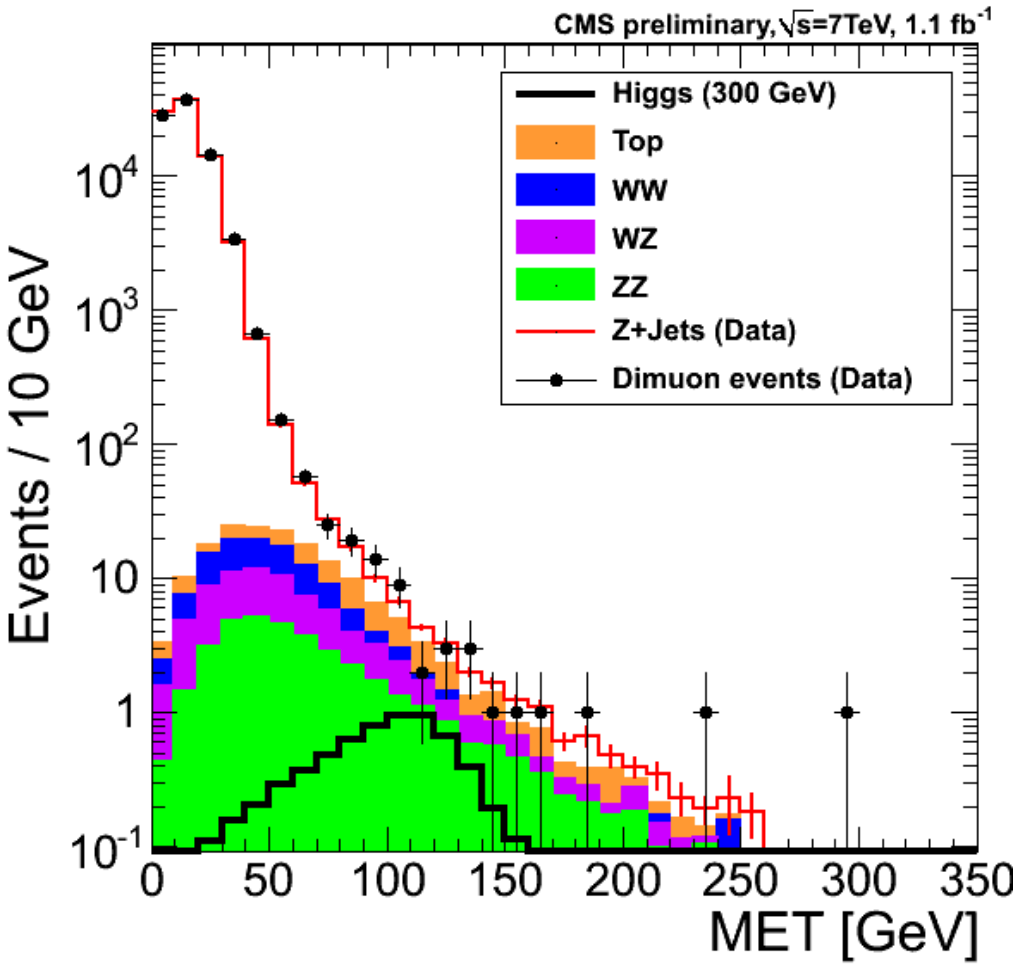
Background Estimation: Drell-Yan From γ + Jets

Z + jets background is modeled using γ + jets events

- Z + jets and γ + jets have similar MET response
- γ + jets events are re-weighted according to
  - Z p_T shape
  - number of jets
- Each photon is assigned a random "mass" by sampling from the Z line-shape in data
- γ + jets yield is normalized to the observed Z + jets yield

✔ Good agreement between **dilepton** spectrum in data and **Z + jets** model

✔ Re-weighted γ + jets distribution used to measure the remaining Z + jets events in the signal region

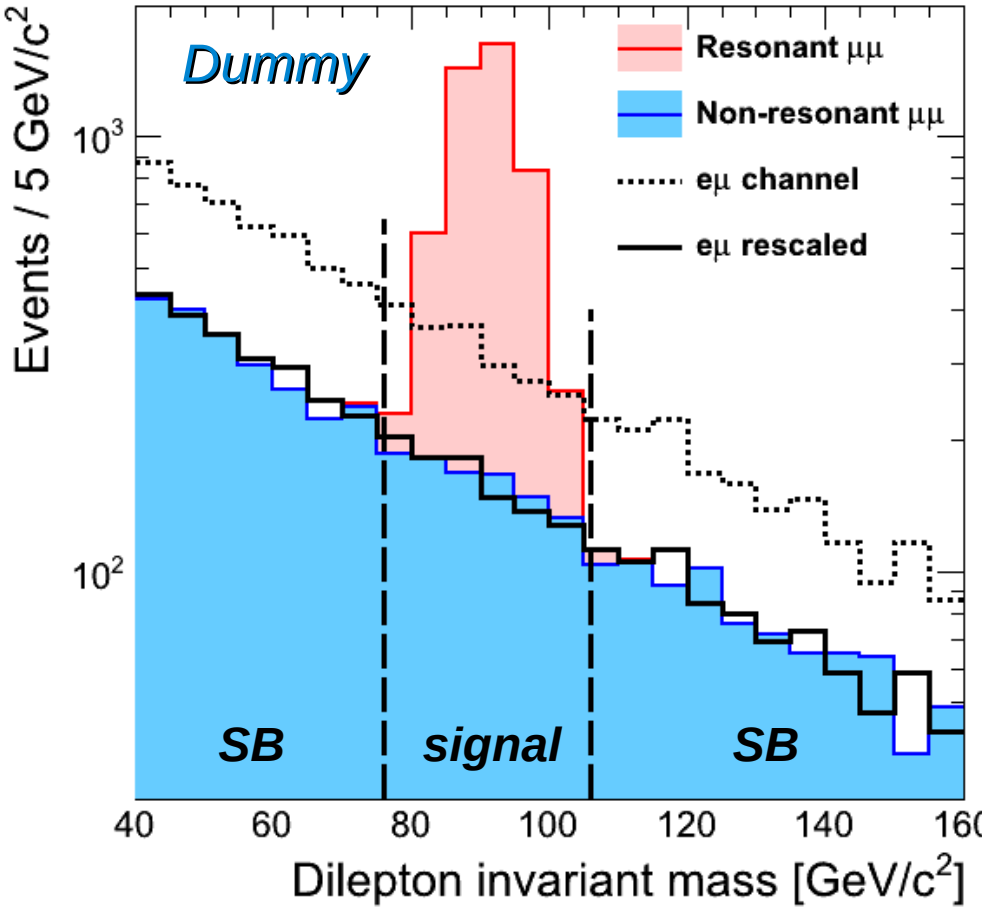


Background Estimation: Non-Resonant Backgrounds

- *tt*, single *t*, WW, W + jets – no Z peak
- Estimated collectively by using events in the eμ final state
- Scaling factors between eμ and ee/μμ final states are obtained from the *side-bands* of the Z peak

$$N_{ee}^{sign} = \alpha_{ee} \cdot N_{e\mu}^{sign}, \quad \alpha_{ee} = N_{ee}^{SB} / N_{e\mu}^{SB}$$

$$N_{\mu\mu}^{sign} = \alpha_{\mu\mu} \cdot N_{e\mu}^{sign}, \quad \alpha_{\mu\mu} = N_{\mu\mu}^{SB} / N_{e\mu}^{SB}$$



- Cannot distinguish between non-resonant backgrounds and signal events in the H→WW→2ℓ2ν channel

➔ H→WW treated as a background

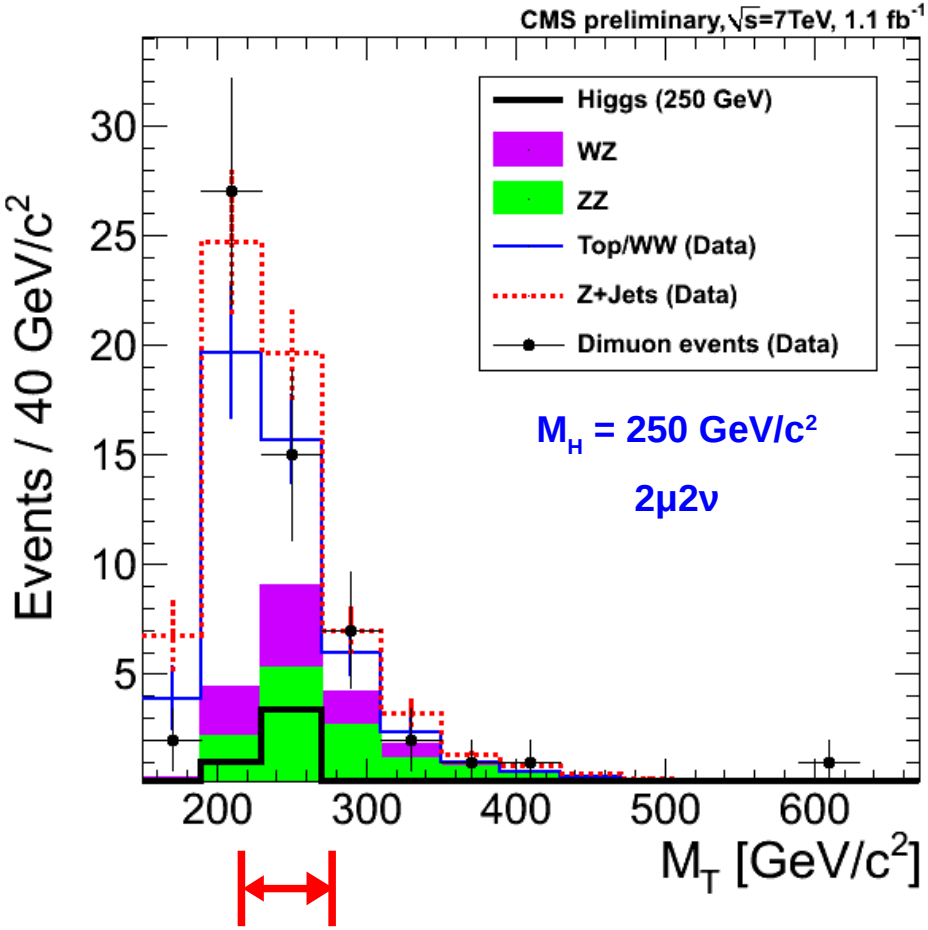
➔ H→WW contributes by 7% / 3% for M_H = 250 / 350 GeV/c² (52% / 8% in SM4)

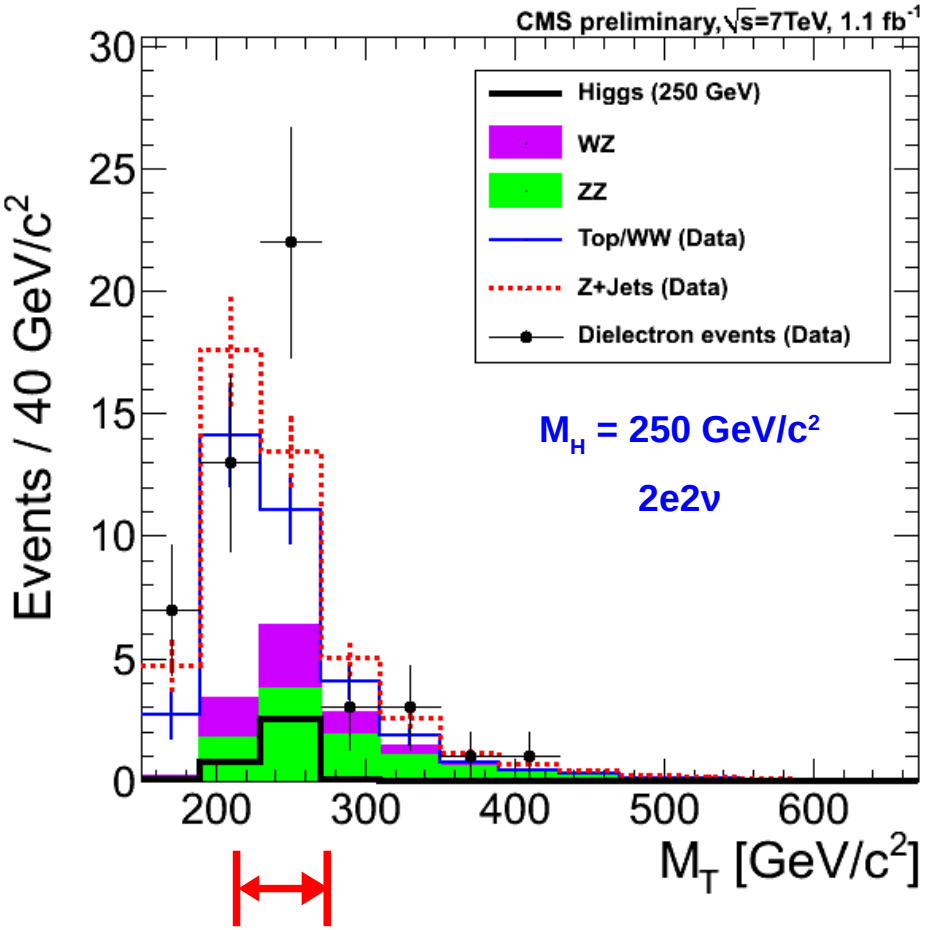
Systematic Uncertainties

	Source of uncertainty		Uncertainty [%]
Theory	Signal cross section (PDF ⊕ QCD scale)		~ 20
	Background cross section (PDF ⊕ QCD scale)	ZZ	~ 8
		WZ	~ 9
Experimental	Luminosity		6
	Pile-up		1-3
	Trigger efficiency	Muons	2
		Electrons	1
	Lepton ID & Isolation efficiency	Muons	1
		Electrons	1
	Lepton momentum scale	Muons	2
		Electrons	5
	Jet energy scale		1.5
	B-jet veto		1
	Background measurement	Non-resonant	15-100
		Drell-Yan	~ 50

Results (m_H = 250 GeV/c^2)

Signal yields



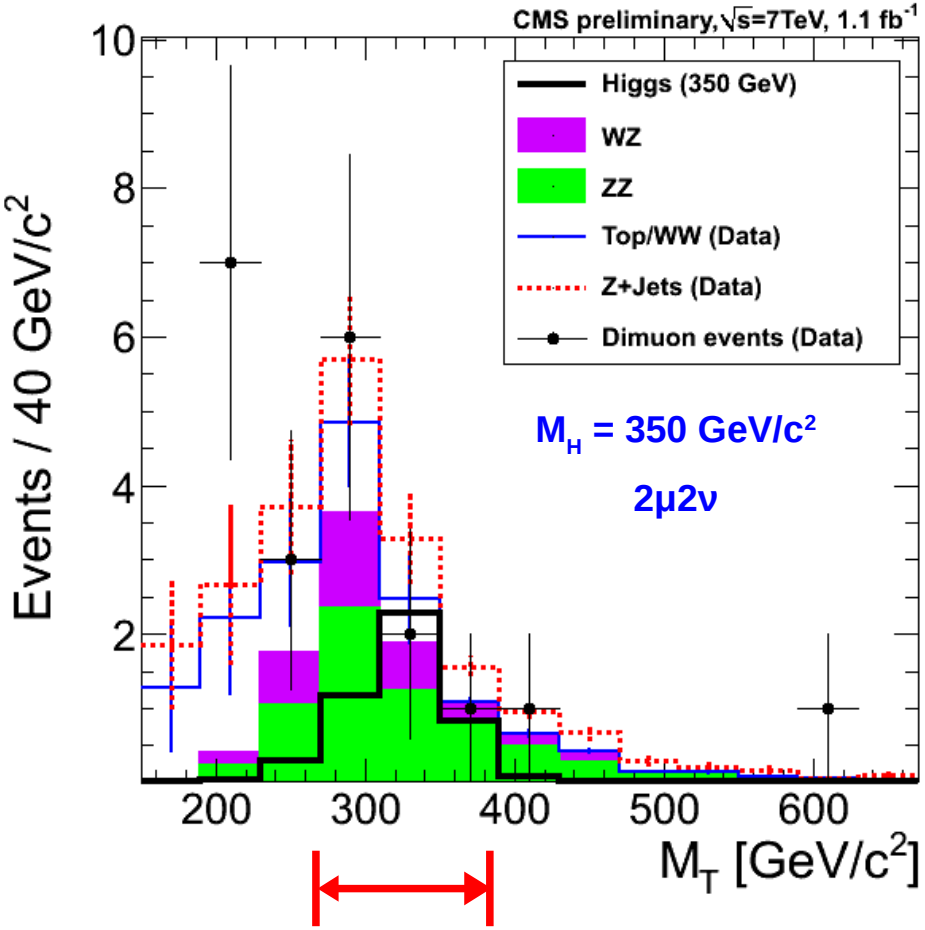


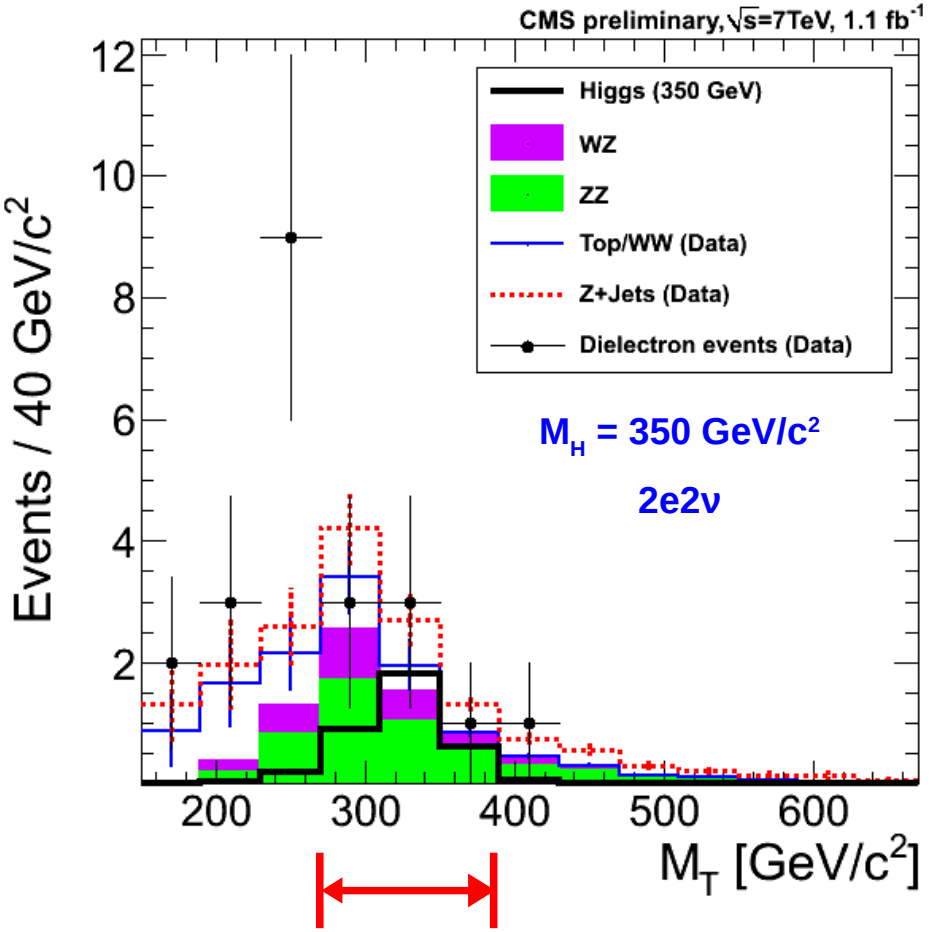
Background	Higgs	Observed
30 ± 5	3.9 ± 0.5	28

Background	Higgs	Observed
22 ± 5	3.1 ± 0.4	29

Results (m_H = 350 GeV/c^2)

Signal yields

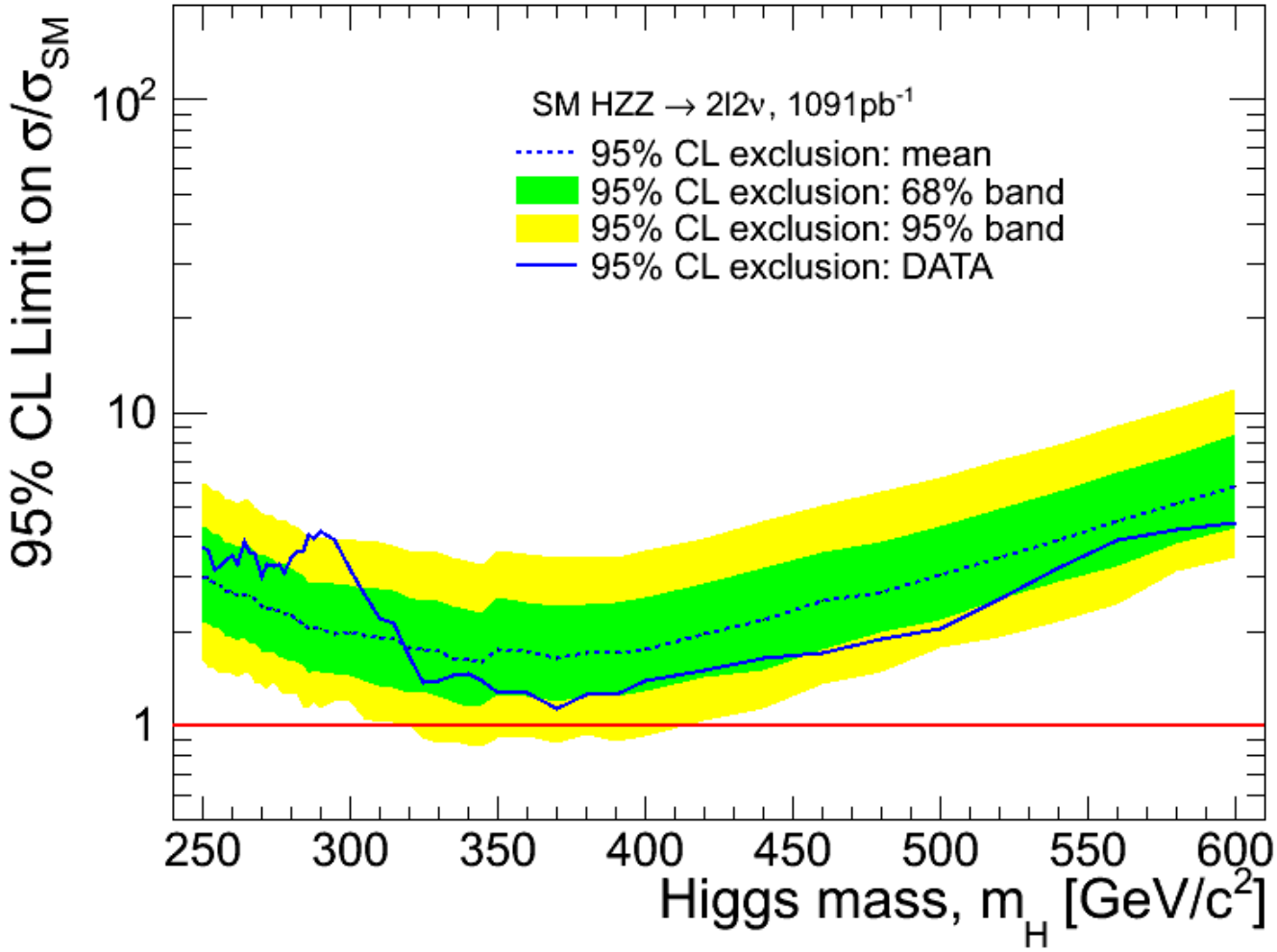




Background	Higgs	Observed
13 ± 2	3.9 ± 0.6	11

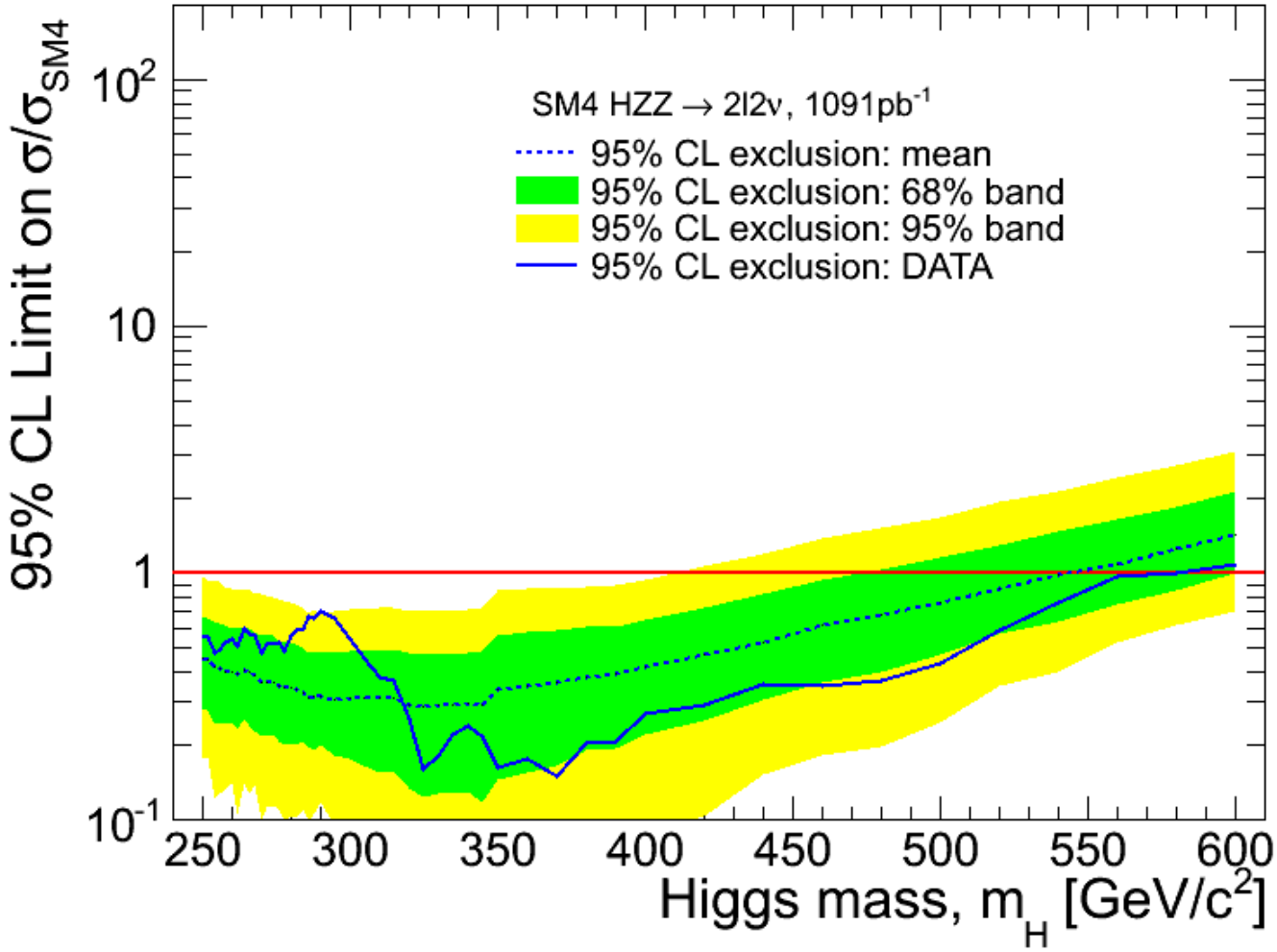
Background	Higgs	Observed
11 ± 3	3.2 ± 0.5	8

Results: Excluded Cross Sections



- With ~1.1 fb^{-1}, no evidence of Higgs boson production
- All fluctuations within ~2σ
- Not enough statistics for exclusion in this decay mode alone, need to combine with other channels

Results: Excluded Cross Sections in SM4



- In a Standard Model scenario with a 4th generation of high-mass fermions (600 GeV/c^2), production cross sections are enhanced
- The Higgs boson in SM4 is *excluded* at 95% C.L. in the mass range 250-550 GeV/c^2

Summary

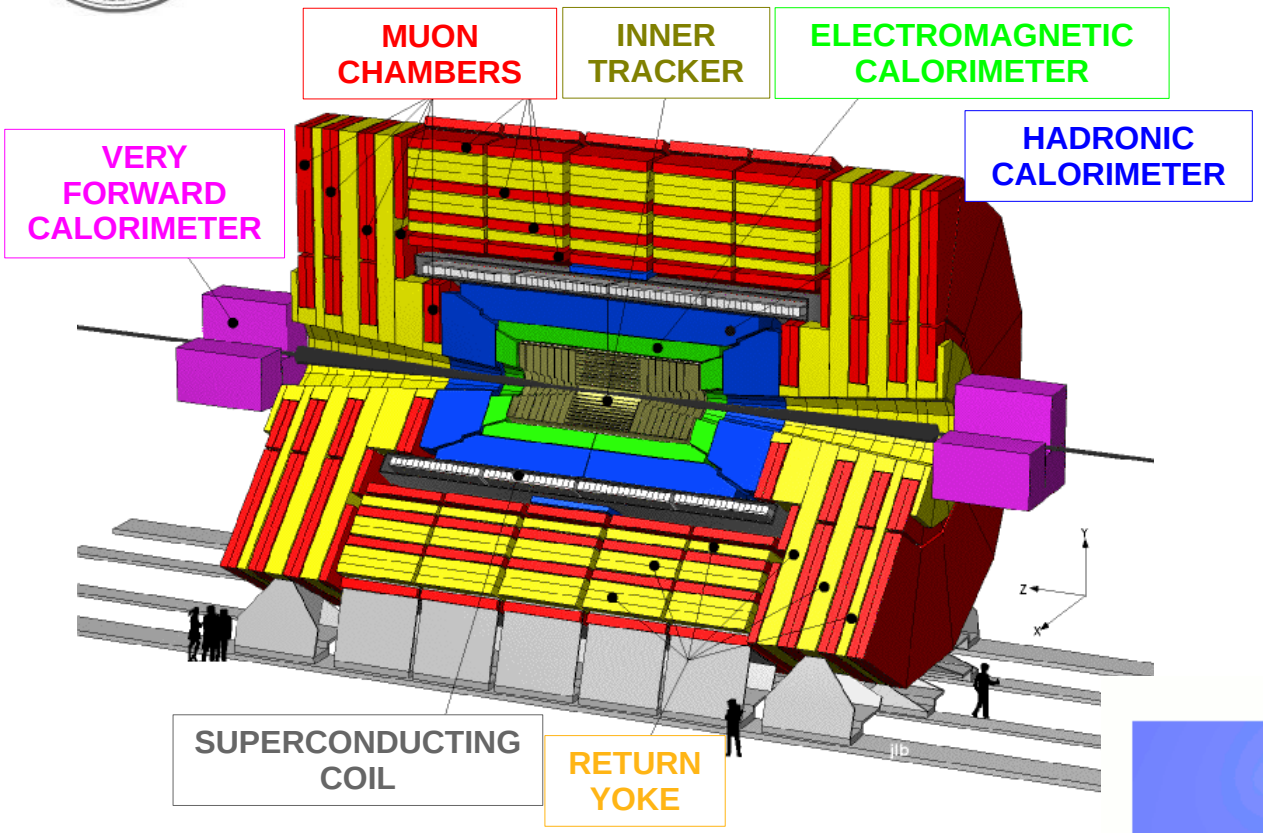
- A full analysis for the $H \rightarrow ZZ \rightarrow \ell\ell\nu\nu$ channel has been presented
- No excess observed in the transverse mass spectrum with 1.1 fb^{-1} data
- Exclusion limits on the Higgs cross-section for a mass range 250-600 GeV/c^2 are reported in the Standard Model and Standard Model + 4th fermion generation scenarios
  - ➔ In SM, no exclusions; $\sigma_{95\%} / \sigma_{SM}$ close to 1 around 370 GeV/c^2
  - ➔ In SM4, the Higgs is excluded at 95% C.L. in the mass range 250-550 GeV/c^2

Reference:

CMS Collaboration, "Search for the Higgs boson in the $H \rightarrow ZZ \rightarrow 2l2\nu$ channel in pp collisions at $\sqrt{s}$ = 7 TeV", CMS PAS HIG-11-005

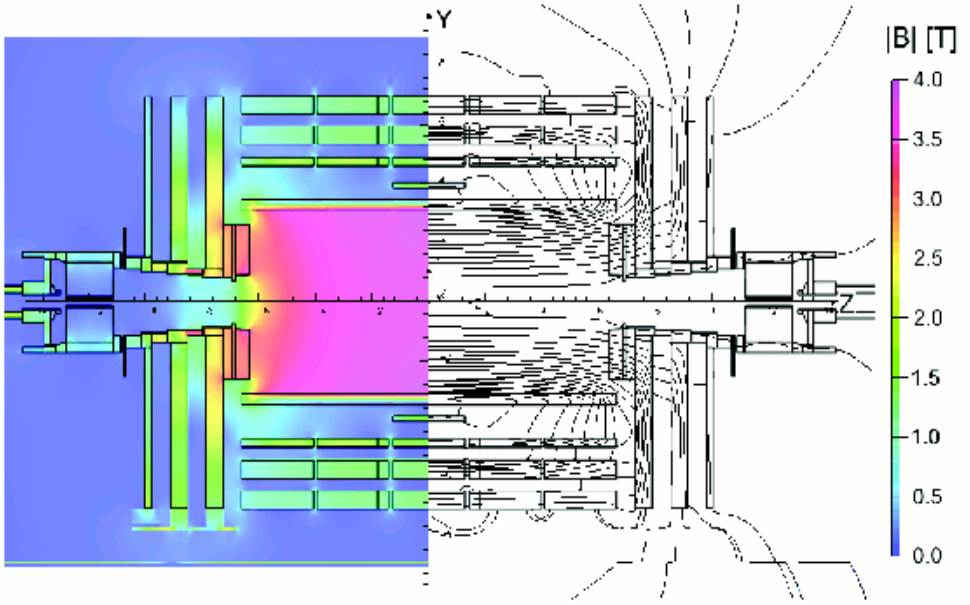
Backup Slides

The CMS Detector



Inside the Solenoid

- 3.8 T magnetic field
- longitudinal, ~homogeneous
- tracker, ECAL, HCAL

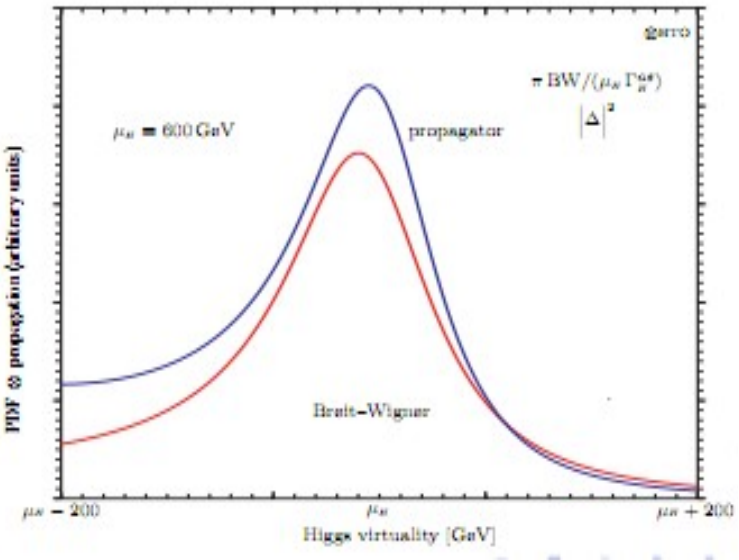


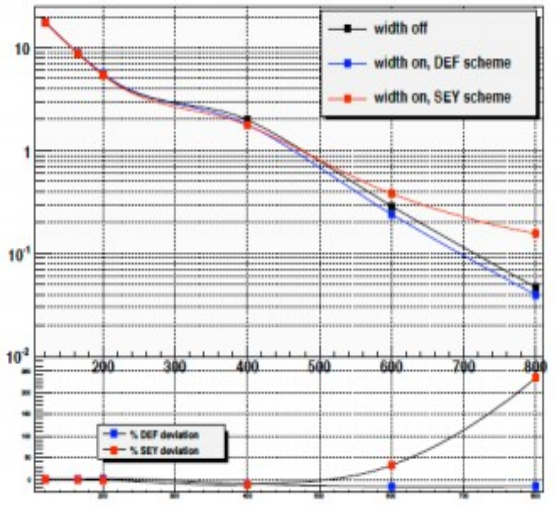
Outside the Solenoid

- ~1.8 T return field, mostly in the Iron Yoke
- muon spectrometer

Cross Section and Width at High Mass

- For high-mass Higgs (m_H > 300 GeV/c^2), the narrow-width approximation and the description of the Higgs boson propagator with *ad hoc* Breit-Wigner distributions are not accurate
- Large discrepancies w.r.t. to the correct QFT-propagator, allowing also for
  - off-shellness of the Higgs boson
  - dynamical QCD scales
  - interference effects between Higgs signal and backgrounds





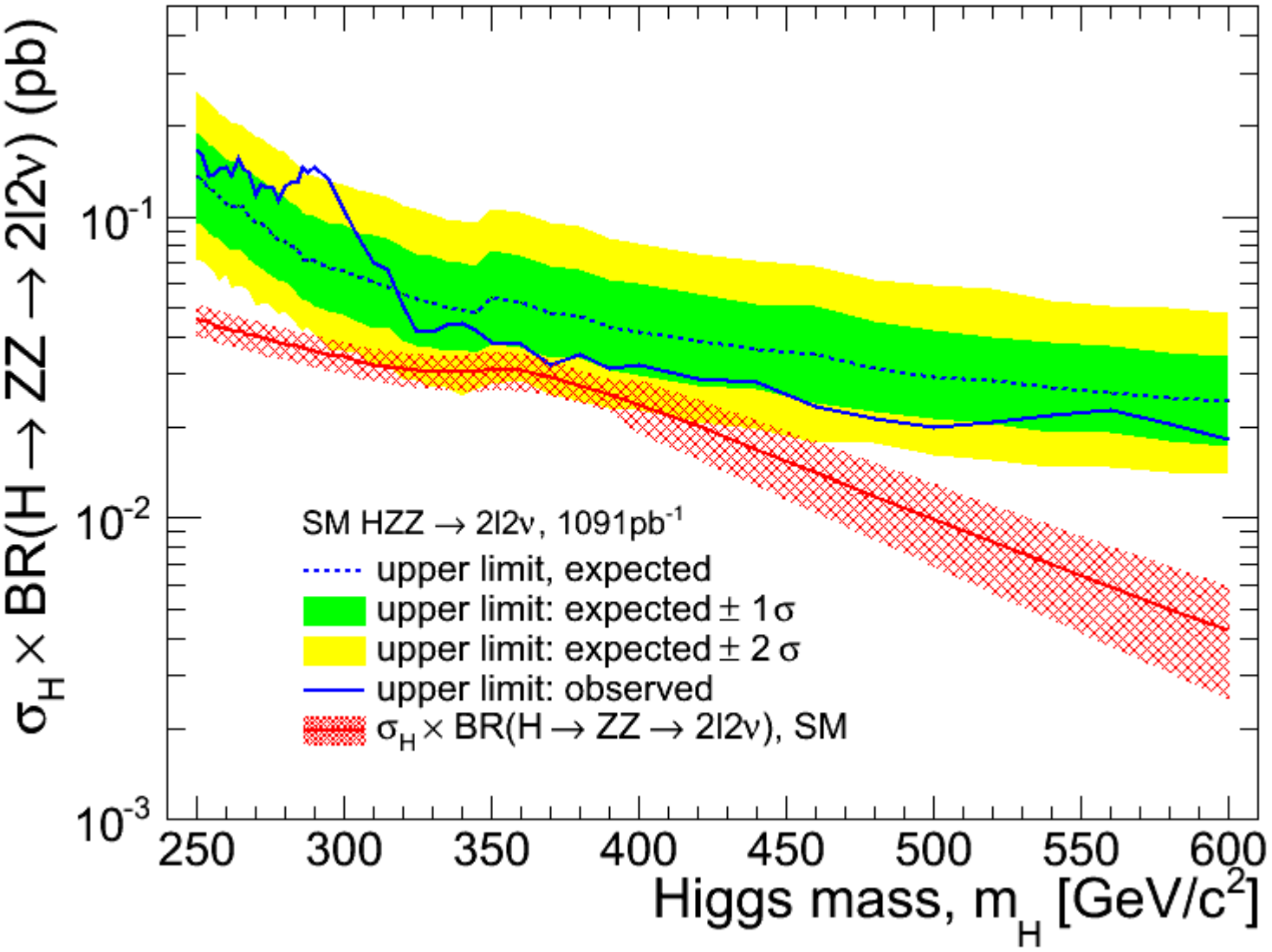
Official prescription from the LHC Higgs XS WG

$$\text{uncertainty}\,[\%] = 150 \times M_H^3$$

(M_H in TeV/c^2)

M_H [GeV/c^2]	Uncertainty
200	1%
400	10%
600	32%
800	77%

Results: Excluded Cross Sections



Results: Excluded Cross Sections in SM4