Limits on neutral Higgs boson production in the forward region in pp collisions at $\sqrt{s} = 7$ TeV

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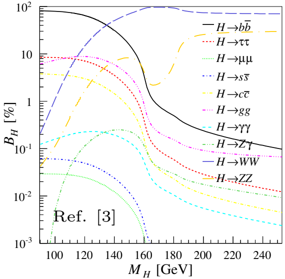
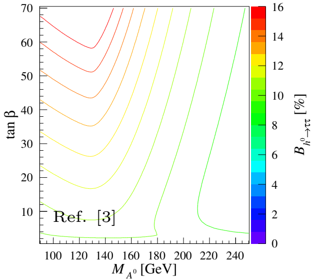
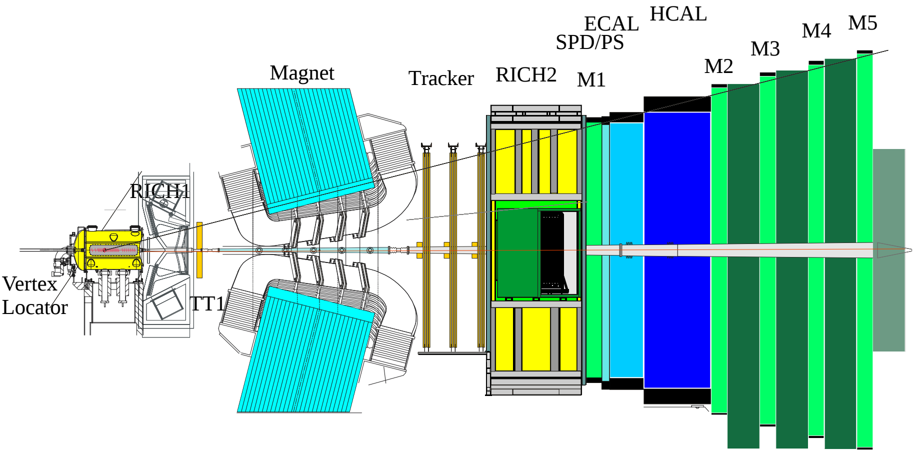
Introduction

- presentation of results from arXiv:1304.2591 [1]
- set Higgs limits using $\Phi^0 \rightarrow \tau\tau$ final states
  - determine model independent $\sigma_{\Phi^0} \times \mathcal{B}_{\Phi^0 \rightarrow \tau\tau}$ Higgs upper limits
  - determine MSSM Higgs limits on $\tan\beta$ as a function of M_{A^0}
- data from LHCb $Z \rightarrow \tau\tau$ cross-section analysis
  - JHEP **01** (2013) 111 [2]
- full 2011 dataset
  - $\mathscr{L} = 1\ \text{fb}^{-1}$

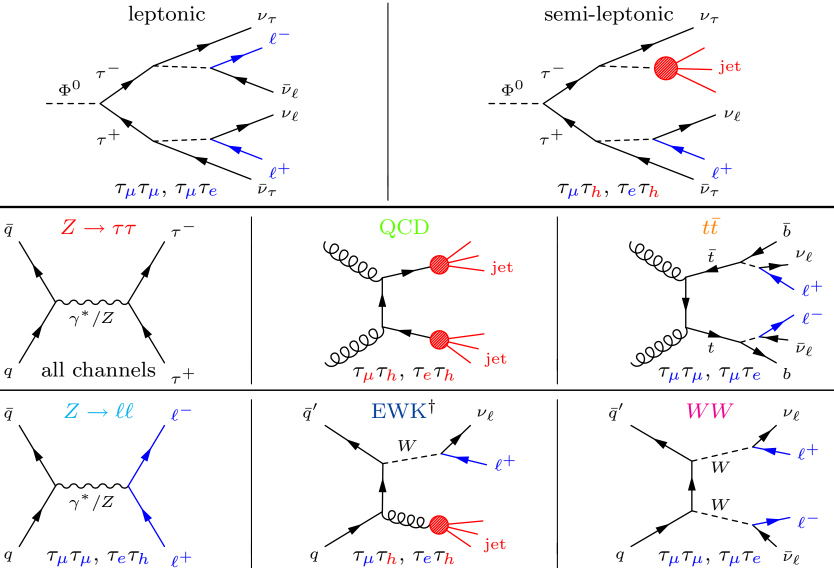




Detector


ECAL
HCAL
SPD/PS
M4
M5
M3
M2
Magnet
Tracker
RICH2
M1
RICH1
Vertex
Locator
TT1

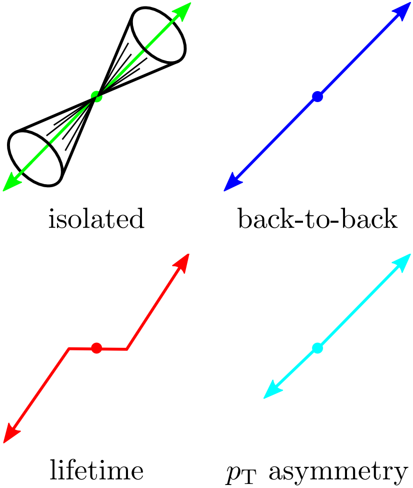
Signals and Backgrounds



† EWK is a single hard lepton from an EWK boson and does not include $Z \to \tau\tau$, $Z \to \ell\ell$, $t\bar{t}$, WW

Reconstruction and Selection

- triggers
  - muon ($p_T > 10$ GeV)
  - electron ($p_T > 15$ GeV)
- muon
  - muon track
- electron
  - large E_{ECAL}/p
  - small E_{HCAL}/p
- hadron (single-pronged)
  - small E_{ECAL}/p
  - large E_{HCAL}/p



Signal and Background Estimation

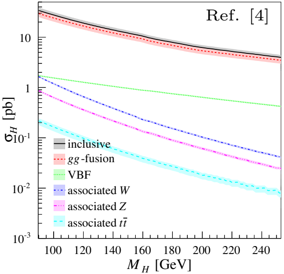
- $\Phi^0 \to \tau\tau$, $Z \to \tau\tau$, $t\bar{t}$, and WW

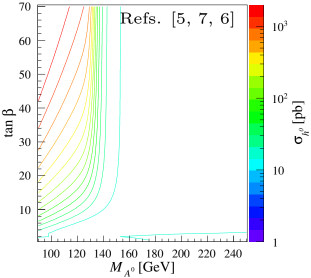
$$N = \mathscr{L} \cdot \sigma \cdot \mathcal{B} \cdot \mathcal{A} \cdot \varepsilon$$

  - luminosity ($\mathscr{L}$) from Van de Meer scan and beam-gas imaging
  - cross-sections (σ), branching fractions ($\mathcal{B}$), and acceptances ($\mathcal{A}$) from theory
  - efficiencies (ε) from data using tag-and-probe methods
  - simulated shape corrected for efficiencies and detector resolution
- QCD and EWK
  - fractions from same-sign template fit of Δp_{T} distribution
  - shape from isolated sideband (QCD) and simulation (EWK)
- $Z \to \ell\ell$
  - shape from sidebands, normalization from peak or mis-id rates

Theory Calculations

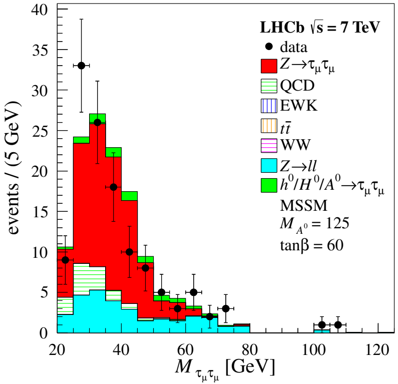
- $Z \to \tau\tau$ cross-section with DYNNLO
- SM cross sections at $\sqrt{s} = 7$ TeV with DFG [4]
    - NNLL QCD contributions, NLO electroweak contributions
- MSSM cross sections using $m_{h^0}^{\max}$ scenario at $\sqrt{s} = 7$ TeV
    - gg-fusion at NLO/NNLO with HIGLU [5] and GGH@NNLO [6]
    - associated $b\bar{b}$ at NNLO in QCD with BBH@NNLO [7]
- branching fractions with FEYNHIGGS 2.7.4 [3]





Observed $\tau_\mu\tau_\mu$

[arXiv:1304.2591]

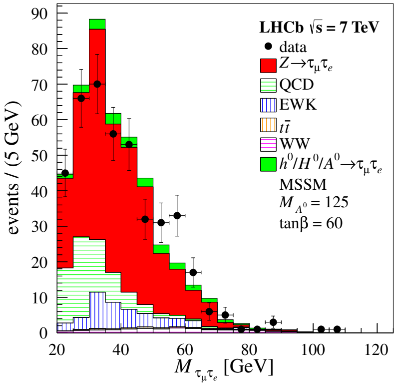


$Z \to \tau\tau$	79.8 ± 5.6
QCD	11.7 ± 3.4
EWK	0.0 ± 3.5
$t\bar{t}$	$< 0.1 \pm 0.1$
WW	$< 0.1 \pm 0.1$
$Z \to \ell\ell$	29.8 ± 7.0
Total	121.4 ± 10.2
Observed	124
SM $\times$ 100	3.9 ± 0.5

- secondary background: $Z \to \mu\mu$
- primary systematic: (5.8%) $Z \to \mu\mu$ *background estimation*

Observed $\tau_\mu \tau_e$

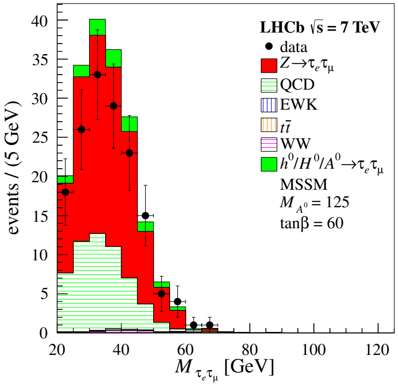
[arXiv:1304.2591]



$Z \to \tau\tau$	288.2 ± 26.2
QCD	72.4 ± 2.2
EWK	40.3 ± 4.3
$t\bar{t}$	3.6 ± 0.4
WW	13.3 ± 1.2
$Z \to \ell\ell$	—
Total	417.9 ± 26.7
Observed	421
SM $\times$ 100	11.9 ± 1.6

- secondary background: EWK
- primary systematic: (3.9%) *electron efficiency*

Observed $\tau_e \tau_\mu$ [arXiv:1304.2591]

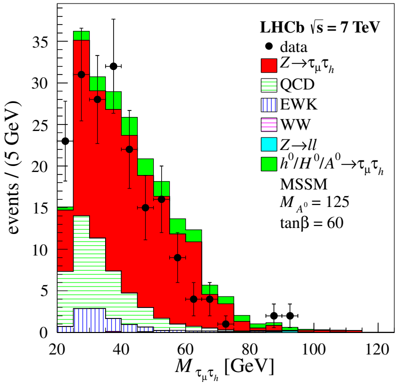


$Z \to \tau\tau$	115.8 ± 12.7
QCD	54.0 ± 3.0
EWK	0.0 ± 1.3
$t\bar{t}$	1.0 ± 0.1
WW	1.6 ± 0.2
$Z \to \ell\ell$	–
Total	172.4 ± 13.1
Observed	155
SM × 100	3.8 ± 0.5

- secondary background: QCD
- primary systematic: (3.6%) *electron efficiency*

Observed $\tau_\mu \tau_h$

[arXiv:1304.2591]

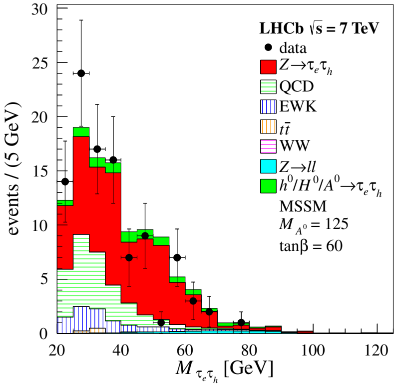


$Z \to \tau\tau$	146.1 ± 9.7
QCD	41.9 ± 0.5
EWK	10.8 ± 0.5
$t\bar{t}$	$< 0.1 \pm 0.1$
WW	0.2 ± 0.1
$Z \to \ell\ell$	0.4 ± 0.1
Total	199.3 ± 9.7
Observed	189
SM $\times$ 100	9.7 ± 1.3

- secondary background: QCD
- primary systematic: (3.5%) *luminosity*

Observed $\tau_e\tau_h$

[arXiv:1304.2591]

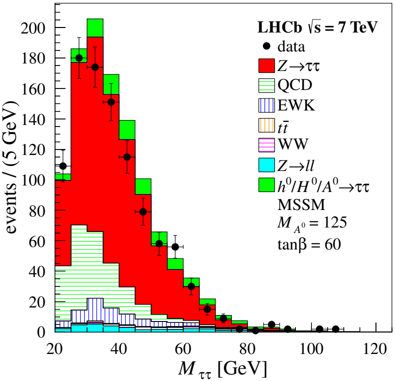


$Z \to \tau\tau$	62.1 ± 8.0
QCD	24.5 ± 0.6
EWK	9.3 ± 0.5
$t\bar{t}$	0.7 ± 0.4
WW	$< 0.1 \pm 0.1$
$Z \to \ell\ell$	2.0 ± 0.2
Total	98.7 ± 8.0
Observed	101
SM $\times$ 100	4.2 ± 0.6

- secondary background: QCD
- primary systematic: (3.5%) *electron efficiency*

Observed Combined

[arXiv:1304.2591]



Statistics

- extended likelihood using mass shape

$$L_{\text{extended}}(\vec{x}|\mu,\vec{\theta}) = e^{-(N_{\text{b}}+\mu N_{\text{s}})} \prod_{i=1}^{N_{\text{obs}}} F\left(\vec{x}_i|\mu,\vec{\theta}\right) \prod_{j=1}^{N_\theta} \phi(\theta_j)$$

$\vec{x} \equiv$ observables (mass) $\quad \mu \equiv$ signal strength

$\vec{\theta} \equiv$ nuisance parameters $\quad F \equiv$ expected mass distribution

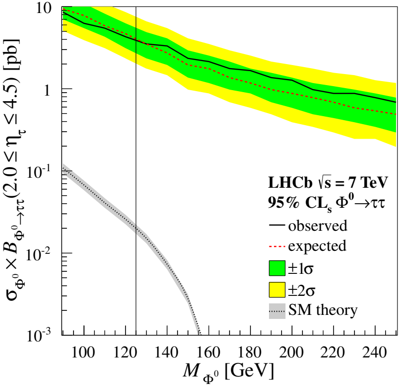
- systematics as absolute scale nuisance parameters
- mass resolution as shape morphing nuisance parameters
- profile likelihood ratio with asymptotic limit

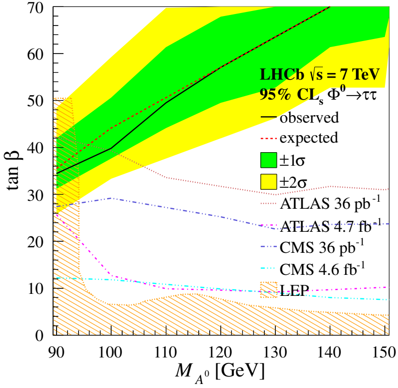
$$q_\mu = \begin{cases} -2\left[LL\left(\vec{x}|\mu,\hat{\hat{\vec{\theta}}}\right) - LL\left(\vec{x}|\hat{\mu},\hat{\vec{\theta}}\right)\right] & \hat{\mu} \leq \mu \\ 0 & \hat{\mu} > \mu \end{cases}$$

- upper limits calculated at $\text{CL}_{\text{s}} = 95\%$

Limits

[arXiv:1304.2591]





Conclusion

- full analysis of neutral model independent Higgs and MSSM Higgs
- $\sigma_{\Phi^0} \times \mathcal{B}_{\Phi^0 \to \tau\tau}$ exclusion in the forward region, $2.0 \leq \eta_\tau \leq 4.5$
  - 8.6 pb at $M_{\Phi^0} = 90$ GeV
  - 0.7 pb at $M_{\Phi^0} = 250$ GeV
  - nearly two orders of magnitude above SM expectation
- MSSM $m_{h^0}^{\max}$ exclusion
  - $\tan\beta = 34$ GeV at $M_{A^0} = 90$ GeV
  - $\tan\beta = 70$ at $M_{A^0} = 140$ GeV
- LHCb has the capability to detect Higgs like particles in the forward region
- important for investigating models with forward production

Bibliography

[1] LHCb collaboration, *Limits on neutral Higgs boson production in the forward region in pp collisions at* $\sqrt{s} = 7$ *TeV*, arXiv:1304.2591.

[2] LHCb collaboration, *A study of the Z production cross-section in pp collisions at* $\sqrt{s} = 7$ *TeV using tau final states*, JHEP **01** (2013) 111, arXiv:1210.6289.

[3] S. Heinemeyer, W. Hollik, and G. Weiglein, *FeynHiggs: a program for the calculation of the masses of the neutral CP even Higgs bosons in the MSSM*, Comput. Phys. Commun. **124** (2000) 76, arXiv:hep-ph/9812320.

[4] D. de Florian and M. Grazzini, *Higgs production through gluon fusion: updated cross sections at the Tevatron and the LHC*, Phys. Lett. **B674** (2009) 291, arXiv:0901.2427.

[5] M. Spira, *HIGLU: a program for the calculation of the total Higgs production cross-section at hadron colliders via gluon fusion including QCD corrections*, arXiv:hep-ph/9510347.

[6] R. V. Harlander and W. B. Kilgore, *Production of a pseudoscalar Higgs boson at hadron colliders at next-to-next-to leading order*, JHEP **10** (2002) 017, arXiv:hep-ph/0208096.

[7] R. V. Harlander and W. B. Kilgore, *Higgs boson production in bottom quark fusion at next-to-next-to leading order*, Phys. Rev. **D68** (2003) 013001, arXiv:hep-ph/0304035.

Cross-Section [JHEP **01** (2013) 111]