Search for Higgs boson pair production at the LHC using the $hh \to \tau\tau bb$ channel

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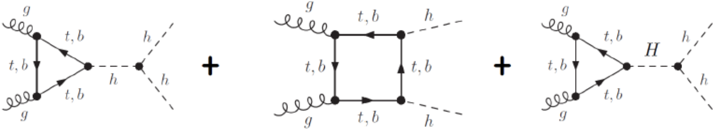
US-LUA annual meeting
14th of November 2014

Overview

Production of Di-Higgs: Motivation

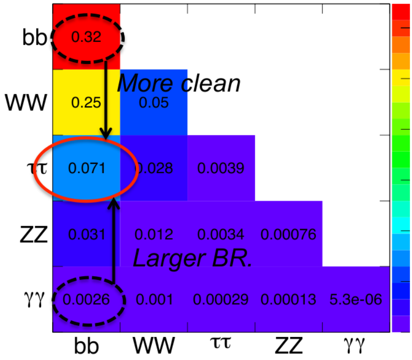
- To investigate the possibility of BSM di-Higgs production.
- In SM, di-Higgs production is a non-resonant process. $\sigma(pp \to hh) = 33.86$ fb at $\sqrt{s} = 14$ TeV, $m_h = 125$ GeV, too small for it to be observable at the LHC within next decade



- TeV-scale (BSM) resonances can decay to di-Higgs: $H \to hh$ in 2HDM, RS kk Graviton$\to hh$
- Enhancement through (BSM) non-resonant di-Higgs production

Di-Higgs decay modes

- $hh \to \tau\tau bb$ channel contains leptons in the final state so will be easier to trigger on and it also has high branching ratio
- If one of the two h's decays into pair of τ's and the other into a pair of b's then the signature is item-wise identical to in $t\bar{t}$ production where $t \to H^+ b$
  $t \to bW$ and $H^+ \to \tau\nu$
  $W \to l\nu$



8 TeV analysis of $h \to \tau\tau$ channel: τ identification

- τ identification:
  - Leptonic decay(τ_{lep}): (BR:35.3 %)

$$\tau^+ \to \mu^+ \nu\nu \quad (1)$$

$$\tau^+ \to e^+ \nu\nu \quad (2)$$

  - Hardonic decay(τ_{had}):
    - One prong decay: (BR:49.5 %)

$$\tau^+ \to \pi^+ \nu (BR : 10.9\%) \quad (3)$$

$$\tau^+ \to \pi^0 \pi^+ \nu (BR : 25.5\%) \quad (4)$$

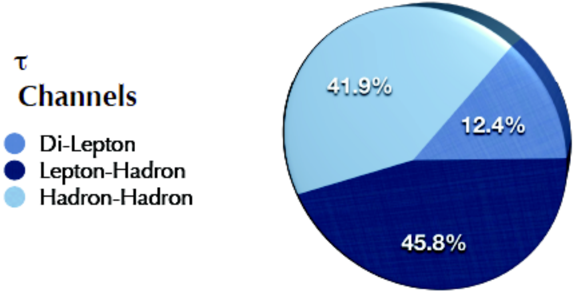
$$\tau^+ \to \pi^+ \pi^0 \pi^0 \nu (BR : 9.5\%) \quad (5)$$

    - Three prong decay: (BR:15.2 %)

$$\tau^+ \to \pi^+ \pi^+ \pi^- \nu (BR : 9.3\%) \quad (6)$$

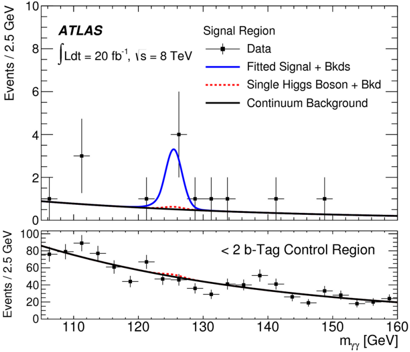
$$\tau^+ \to \pi^+ \pi^+ \pi^- \pi^0 \nu (BR : 4.6\%) \quad (7)$$

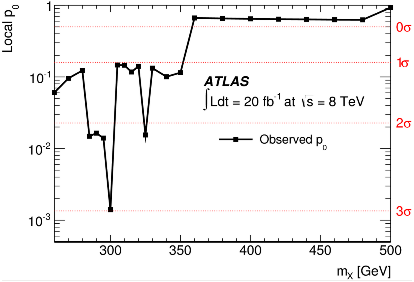
8 TeV analysis of $h \to \tau\tau$ channel: τ channels and Backgrounds



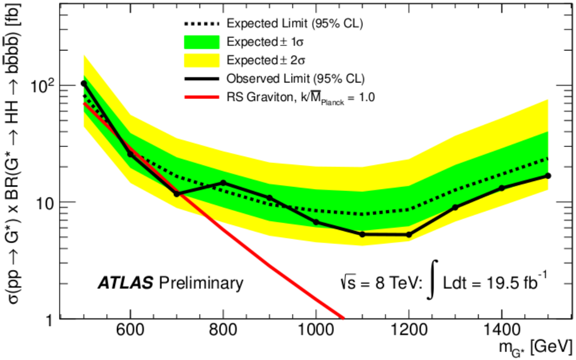
- $h \to \tau\tau$:Background:
  - $Z \to \tau\tau$
  - For $\tau_{lep}\tau_{lep}$ channel: multijet, $Z \to ee$, $Z \to \mu\mu$, W+jets , $t\bar{t}(l\nu bl\nu b)$, $W^+W^-, ZZ, W^{\pm}Z$, $h \to WW \to l\nu l\nu$
  - For $\tau_{lep}\tau_{had}$ channel:$Z \to ee$, $Z \to \mu\mu$, $t\bar{t}(l\nu bqqb)$, W+jets
- For $hh \to \tau\tau bb$ we would not consider the $\tau_{lep}\tau_{lep}$ channel for low branching ratio

8TeV analysis of $hh \to bb\gamma\gamma$ arXiv:1406.5053





8TeV analysis of $hh \to bbbb$
http://cds.cern.ch/record/1666518



- The observed upper limit on $\sigma(pp \to G^*) \times BR(G^* \to HH \to bbbb)$ at the 95 % CL range from 100 fb at 500 GeV to 7 fb at 1 TeV.

Prospects of $hh \to \tau\tau bb$ analysis in Run 2: Backgrounds for $hh \to \tau\tau bb$

- The dominant background will be top pair production and decaying into $tt \to bb\tau\tau$ channel
- Next dominant background may be Z associated production of Higgs where $Z \to \tau\tau$ and $h \to bb$ or $Z \to bb$ and $h \to \tau\tau$
- Other possible background contribution can come from single Higgs production associated with bb , where $h \to \tau\tau$
- QCD jets and Z+jets

Prospects of $hh \to \tau\tau bb$ analysis in Run 2: Background cross sections from 8 TeV to 13 TeV

- Dominant background is top pair production:

$$\sigma(8\ \mathrm{TeV}) = 255\ \mathrm{pb} \tag{8}$$

$$\sigma(13\ \mathrm{TeV}) = 853\ \mathrm{pb} \tag{9}$$

- *ZH* production cross section (at Higgs mass 125 GeV) :

$$\sigma(8\ \mathrm{TeV}) = 0.42\ \mathrm{pb} \tag{10}$$

$$\sigma(13\ \mathrm{TeV}) = 0.87\ \mathrm{pb} \tag{11}$$

Prospects of $hh \to \tau\tau bb$ analysis in Run 2: Background modeling

- Top background: data-based estimate from Run2.
- Multi-jet events: matrix method
- Events with true τ: embedding
  In data sample of $Z \to \mu\mu$ muon tracks and associated calorimeter cells are replaced by τ leptons from simulated $Z \to \tau\tau$ sample with the same kinematics.
- Events with e/$\mu \to \tau$fakes: simulation
- QCD jets $\to \tau$fakes: data (fake factor method)

Prospects of $hh \to \tau\tau bb$ analysis in Run 2: Trigger

- Trigger on $h \to \tau\tau$ from Run 1 (http://cds.cern.ch/record/1954724):
  - $h \to \tau_{had}\tau_{lep}$:
    Exactly one electron with $E_T > 24$GeV or one muon with $p_T > 24$GeV and one oppositely charged τ_{had} with $p_T > 20$ GeV
  - $h \to \tau_{had}\tau_{had}$:
    Two identified oppositely charged τ_{had} candidates $p_T > 20$GeV and $p_T > 29$ GeV are required
- Run 2:
  - FTK will aid τ trigger chains
    (note: Fast TracKer (FTK) is an electronics system that rapidly finds and fits tracks in ATLAS inner detector silicon layer (pixel and SCT) for every event that passes the Level-1 trigger)

Prospects of $hh \to \tau\tau bb$ analysis in Run 2: General issues

- For high mass resonances, Higgs decay products start to merge, problems for objects ID and reconstruction
- In highly boosted regime τ pair and b pair can merge. Below $\triangle R = 0.4$ τ reconstruction algorithm will have to be revised
- Dedicated tau-findings for high mass-resonances will be essential
- At high CM energy and high instantaneous luminosity, pile up will be worse and more fake τs: need dedicated trigger for boosted pair
- Significant improvement in tau ID will keep the fake tau background same

References

- Search for Higgs Boson Pair Production in the $\gamma\gamma b\bar{b}$ Final State using pp Collision Data at $\sqrt{s} = 8$ TeV from the ATLAS Detector
  arxiv.org/pdf/1406.5053v2.pdf
- A search for resonant Higgs-pair production in the $b\bar{b}b\bar{b}$ final state in pp collision at $\sqrt(s) = 8$ TeV
  http://cds.cern.ch/record/1666518
- Evidence for Higgs boson Yukawa coupling in the $H \to \tau\tau$ decay mode with the ALTAS detector
  http://cds.cern.ch/record/1954724