ATLAS実験における
終状態に4つのbクォークを含む
ヒッグス粒子対生成事象を通じた新粒子探索

Search for new particles via Higgs boson pair production in the 4b final state with the ATLAS experiment

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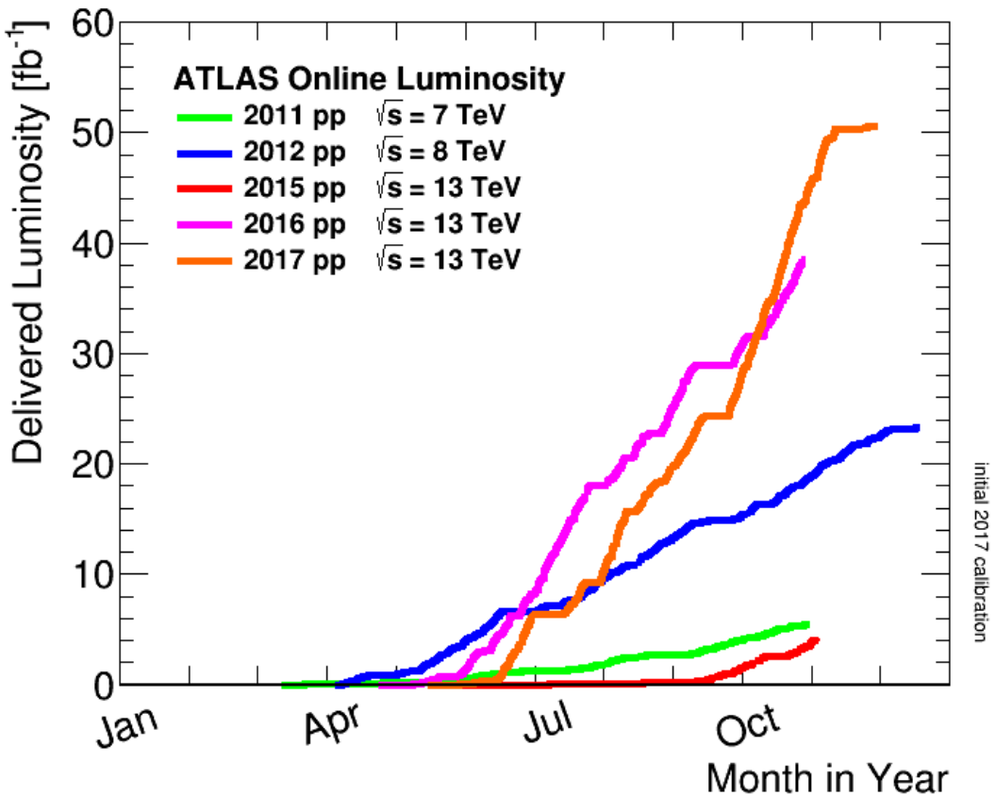
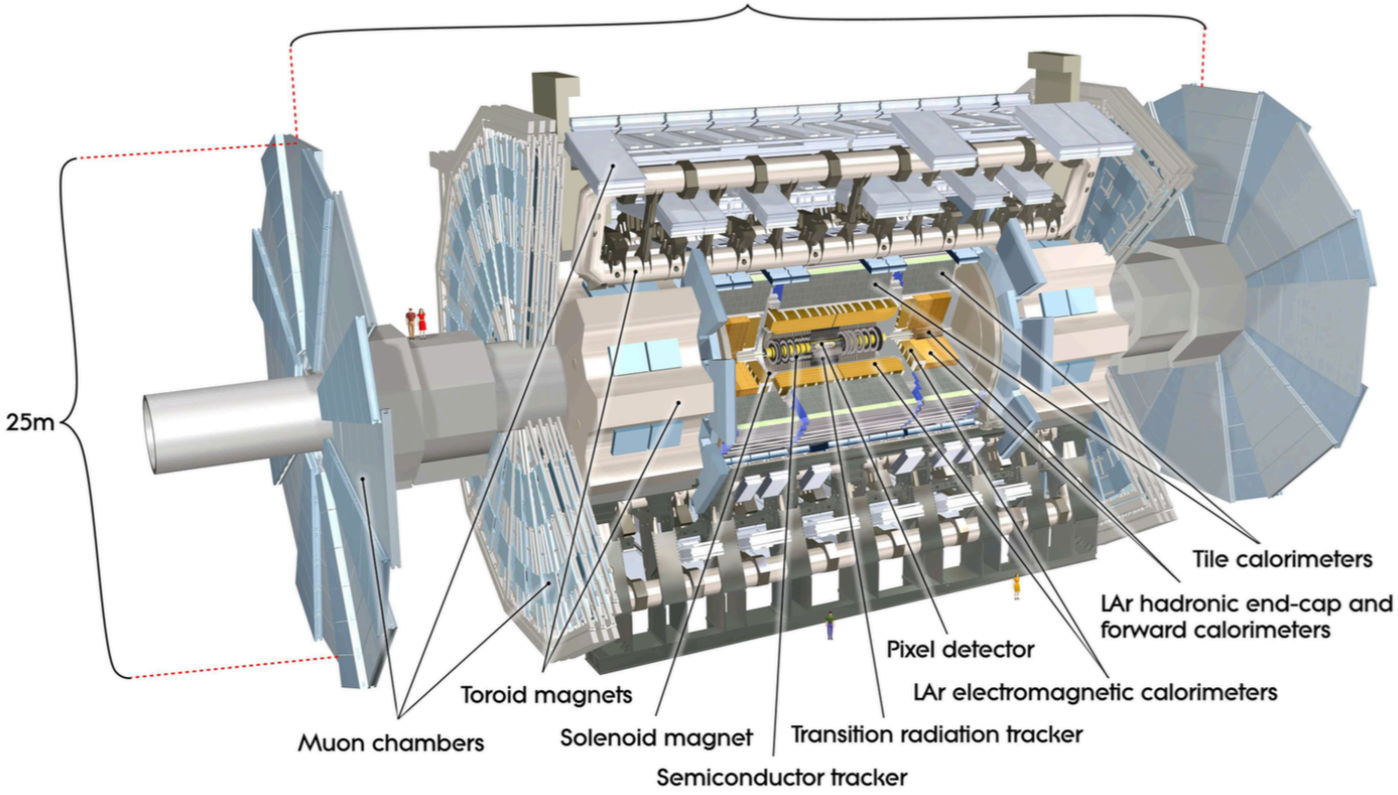
LHC-ATLAS Experiment

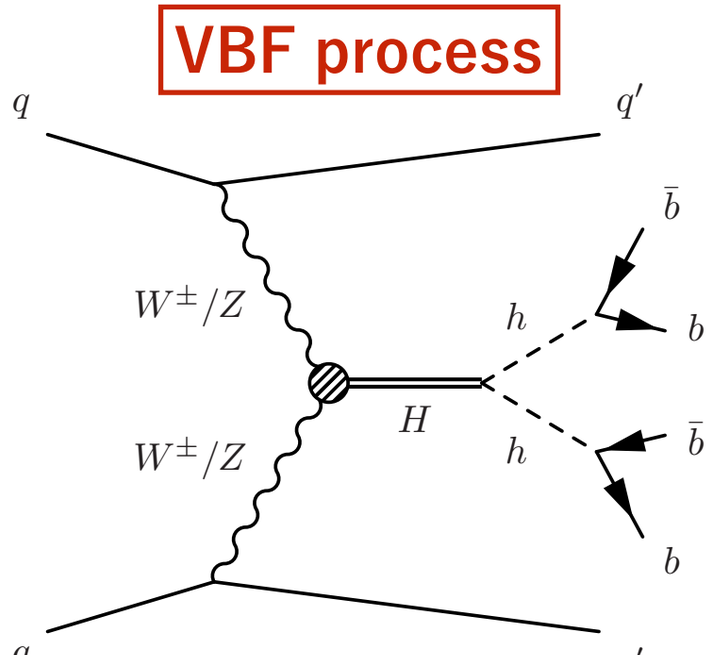
- ATLAS experiment
  - Goal：Search for new physics, Precise measurement of Higgs boson
  - Using Large Hadron Collider (CM energy = 13TeV)
    - Unique experiment which can observe Higgs as well as CMS
- Run-2 is running from 2015

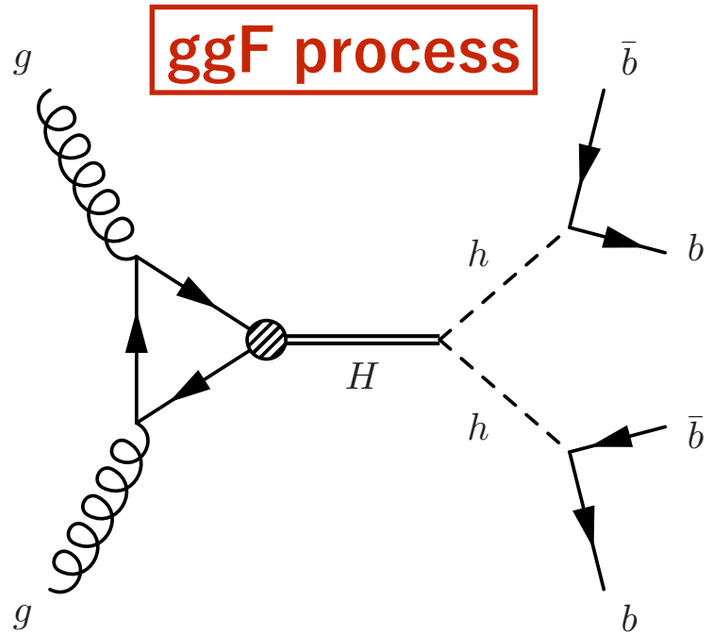




Target

- Search for Higgs pair production events
  - Vector boson fusion (VBF)
  - Gluon gluon fusion (ggF)
  - Theory
    - 2 Higgs Doublet Model
      - Heavy higgs (H_0)
    - Randall-Sundrum model
      - Graviton (G_{RS})
- Discrepancy from SM
  - hhVV 4-point coupling
  - Higgs self-couplings
- Dimension-6 operator

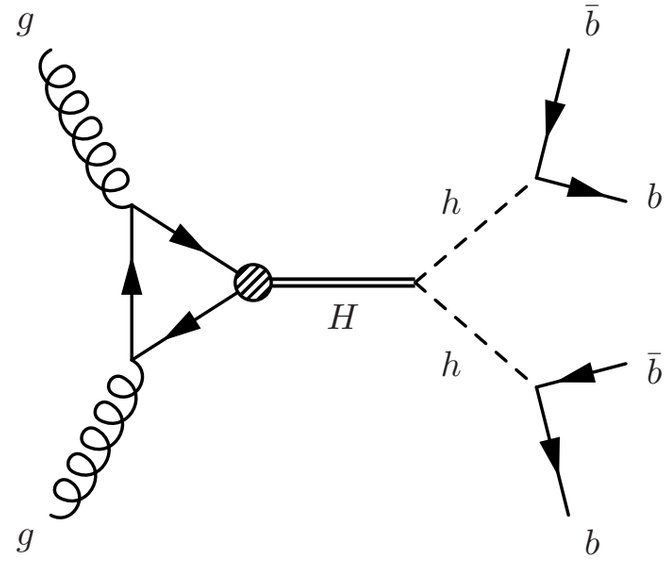




hh → 4b (VBF) analysis

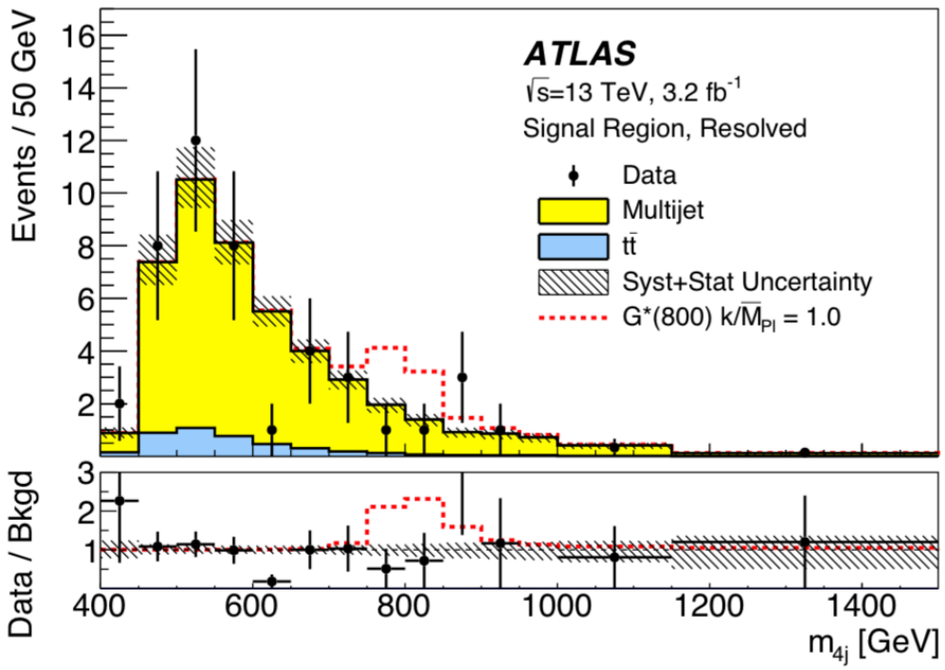
Strategy

- Dataset
  - Signal : 2HDM MC samples
    + Background : 2016 data



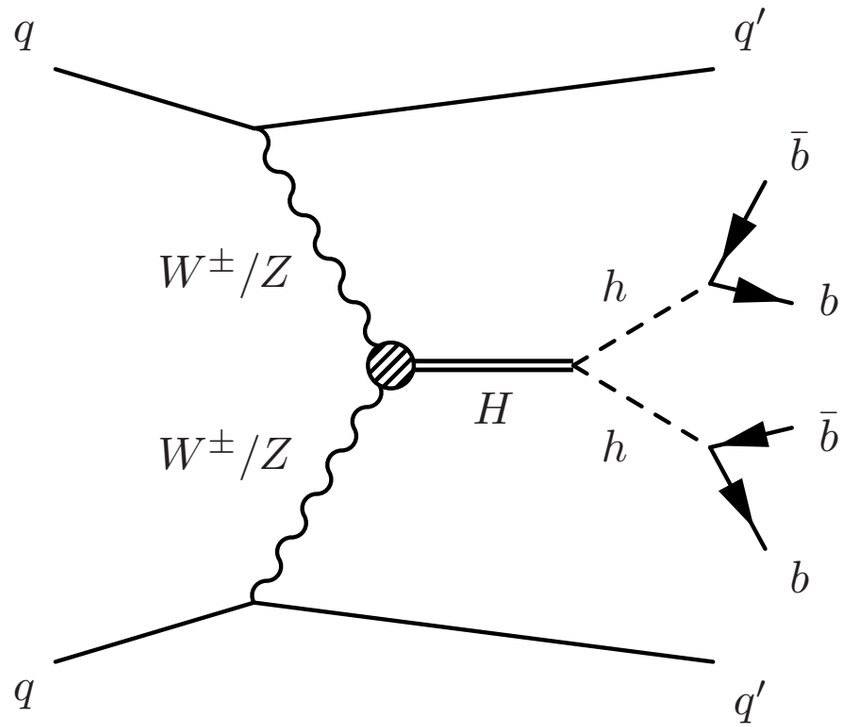
- Searches for di-Higgs events via gluon gluon Fusion(ggF) process
  - Results of ATLAS Run1, 2(~2015) analysis are published
- Optimize and introduce new method to current ggF analysis for this VBF analysis

hh→4b search using 2015 Data
Phys. Rev. D94 (2016) 052002

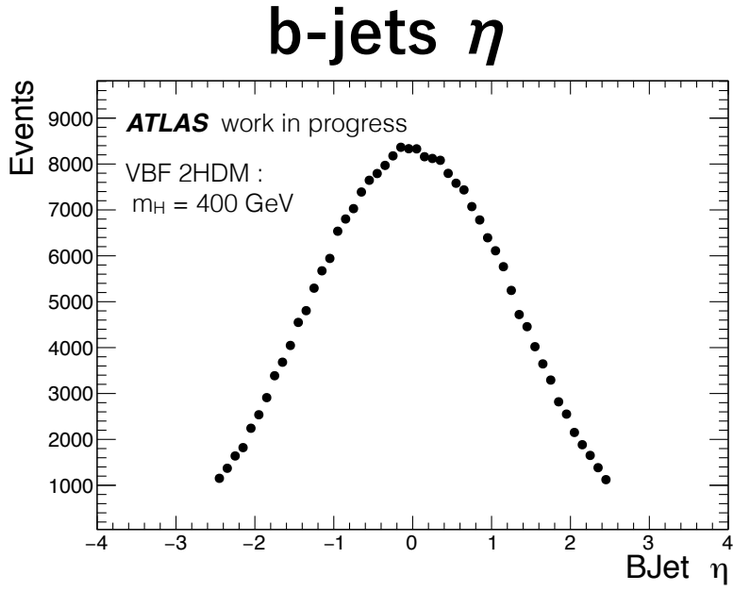


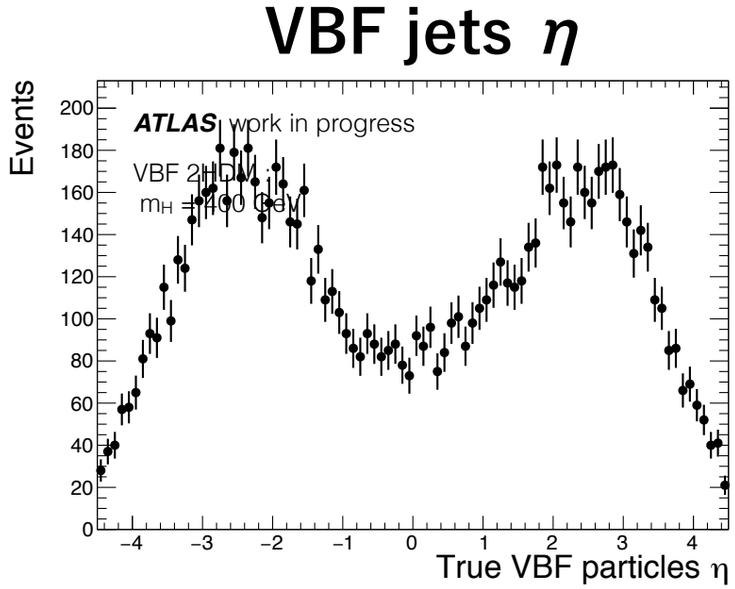
Characteristic signal

- di-Higgs
  - 4 b-jets in the final state
  - Correlation between distance of 2 b-jets and Higgs momentum



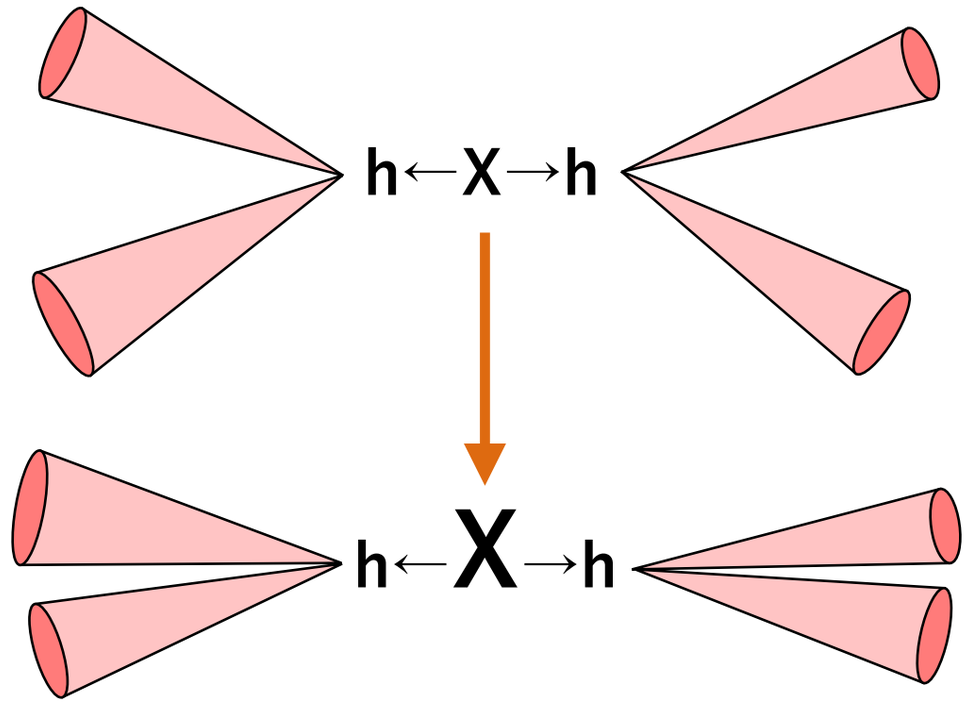
- VBF
  - 2 forward jets
    - Large m_{jj}
    - Large $\Delta\,\eta$



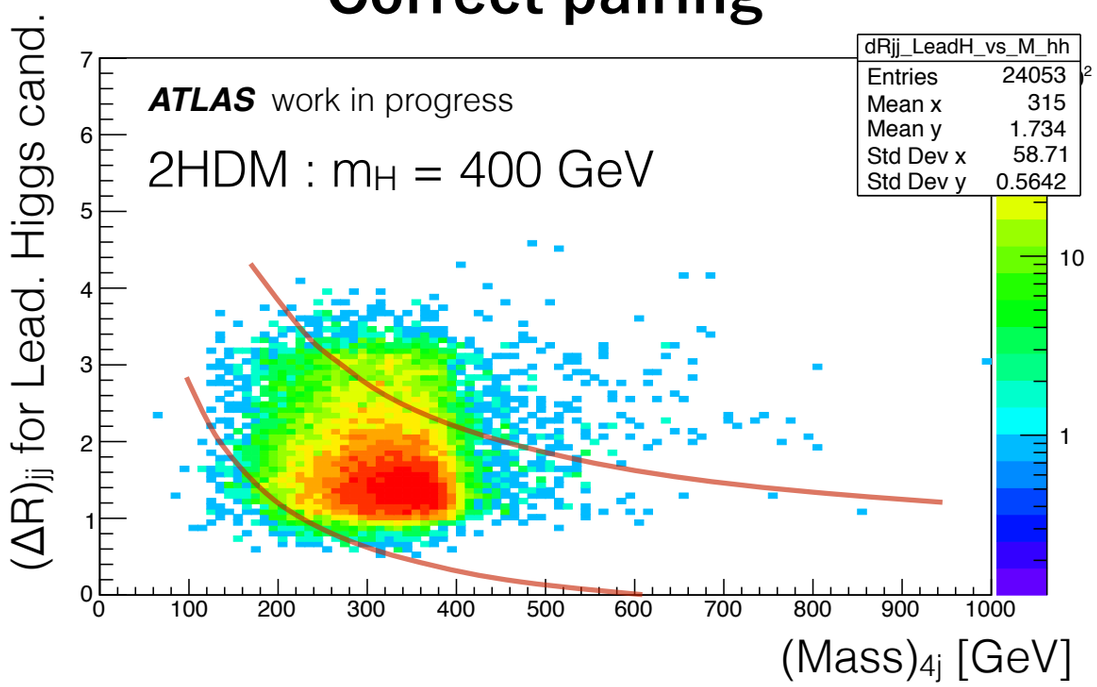


Reconstruction of Higgs

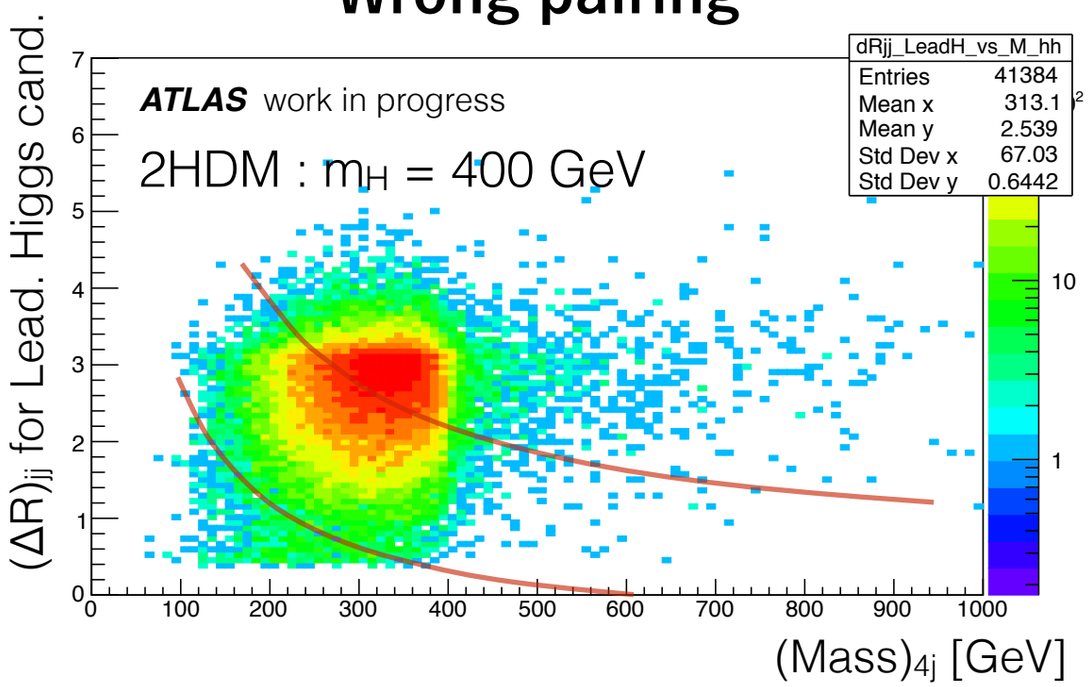
- At least 4 b-tagged jets
- b-jet pair from Higgs decay
  - → ΔR_{jj} is highly correlating to M_{4j}
- Apply cuts
  avoiding biasing toward M_{4j} distribution



Correct pairing



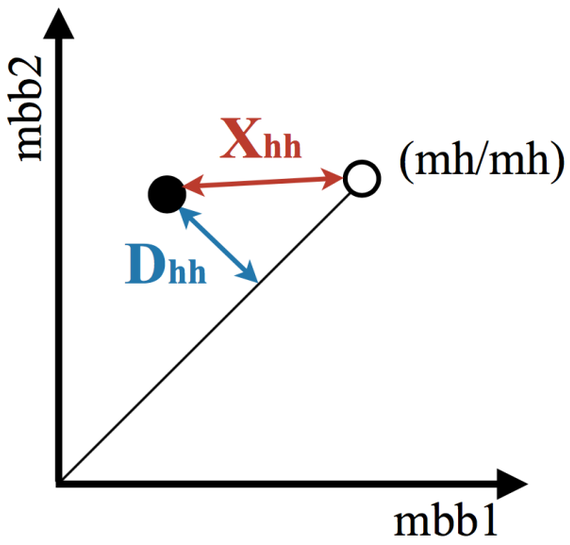
Wrong pairing

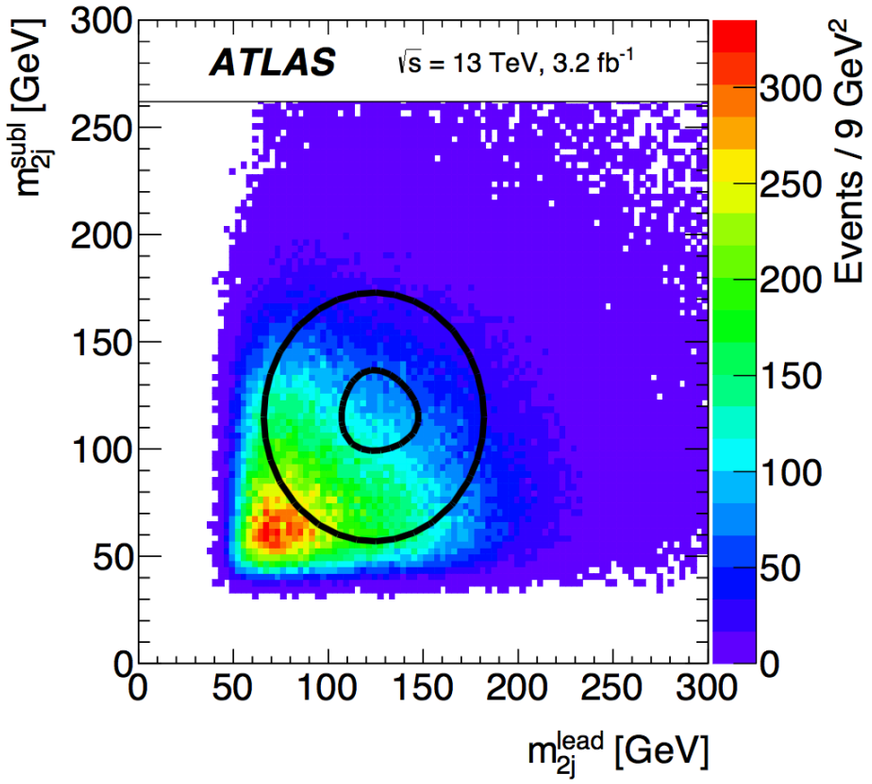


Event selection for ggF

- 0. Pre-selection : #jets $>$ 4 & #b-jet $>$ 1 with ($p_T > 25$ GeV & $|\eta| < 2.5$)
- 1. At least 4 b-jets with ($p_T > 40$ GeV & $|\eta| < 2.5$)
  - 4 b-jets with the highest b-tagging score are used for pairing
- 2. ΔR_{jj} cut :
  - If multiple pairings pass this cut, choose the pairing with minimum D_{hh}
- 3. p_T - m_{4j} cut
- 4. $|\Delta \eta_{hh}| < 1.5$
  - → Depends on m_{4j}
- 5. Xhh cut :
  - → Signal region

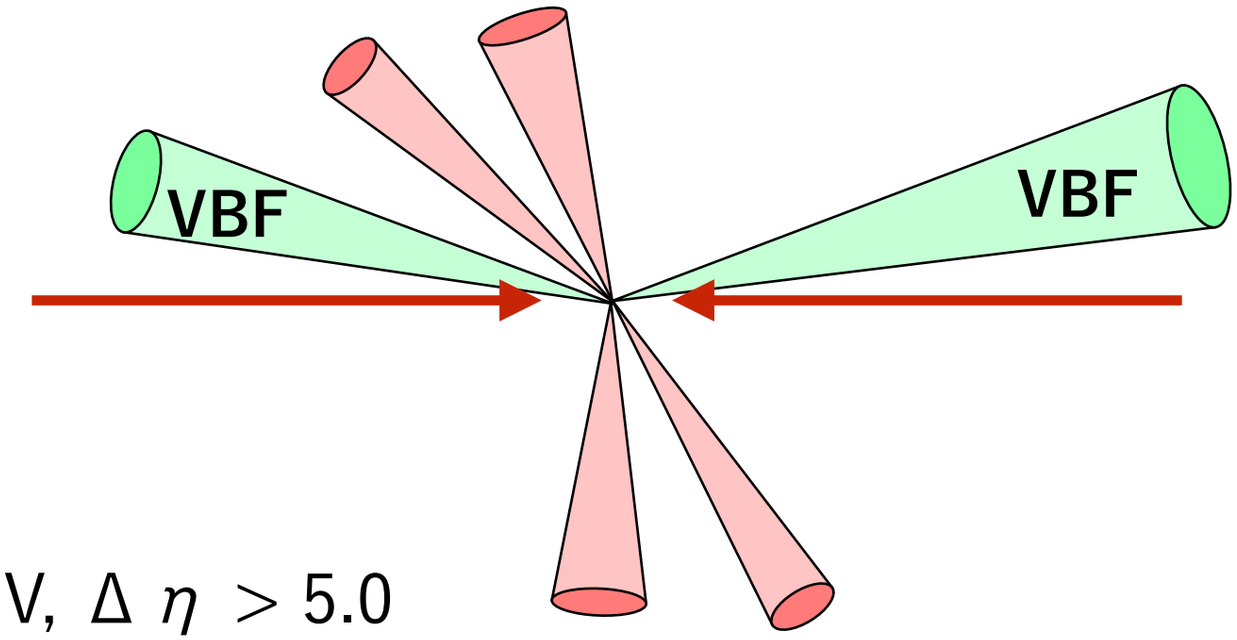
From 2015 analysis
Phys. Rev. D94 (2016) 052002



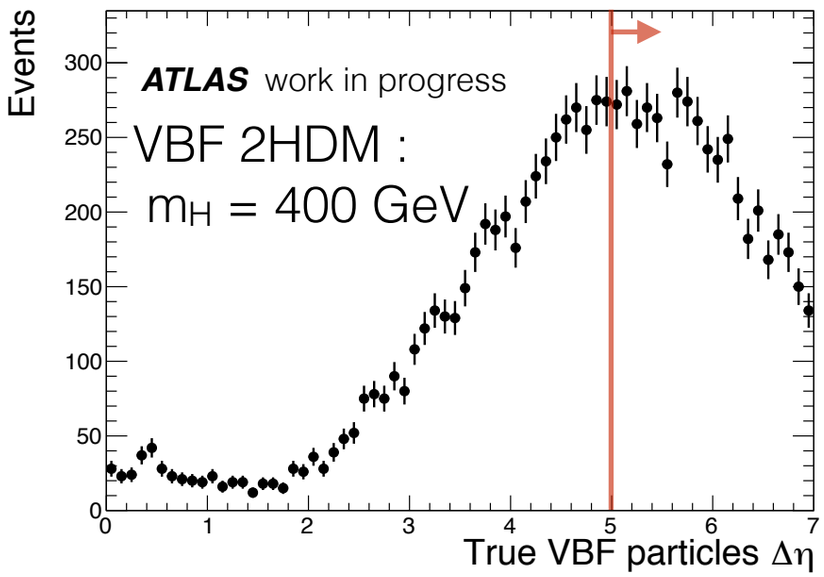


New selection for VBF process

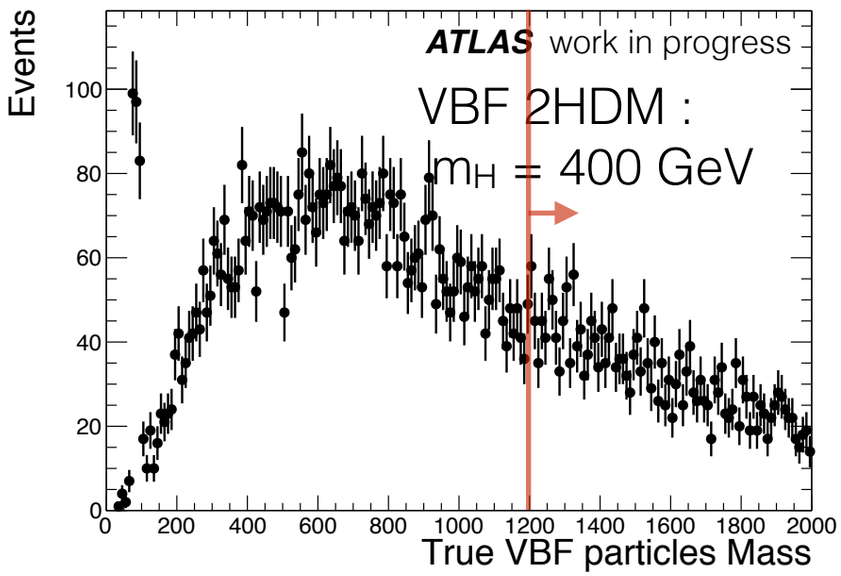
- Unique kinematic features for VBF process
  - Forward jets
  - Large invariant mass
- Add selections below
  - For non b-tagged jets
- Jet pairs requiring mjj > 1200GeV, $\Delta\eta > 5.0$



$\Delta\eta$ between 2 VBF jets

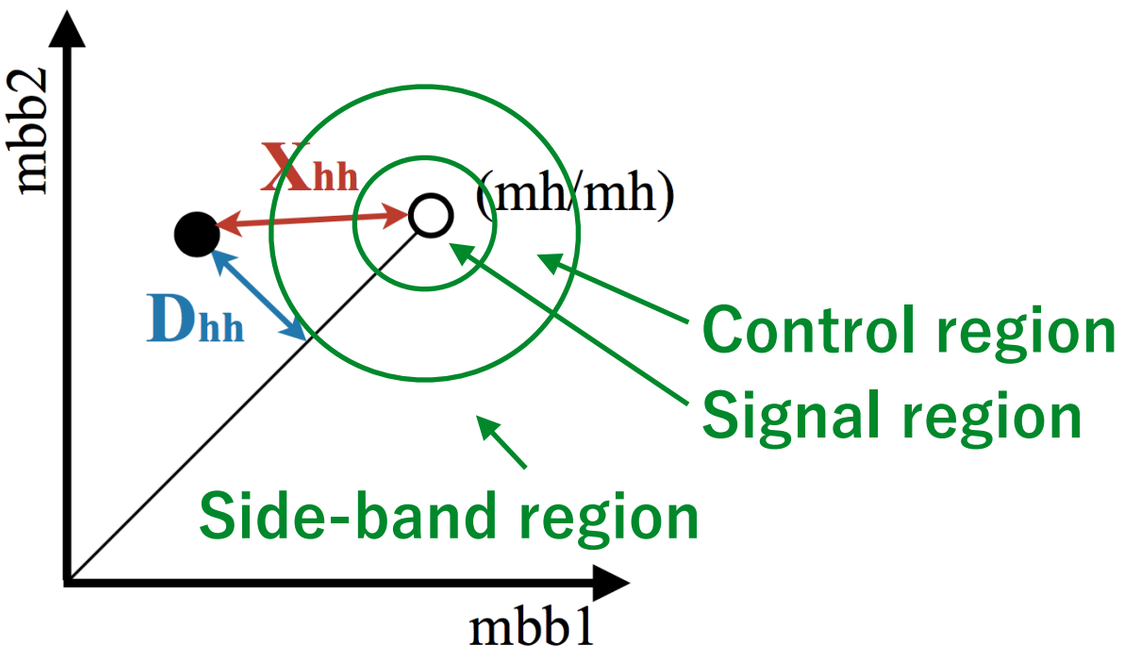


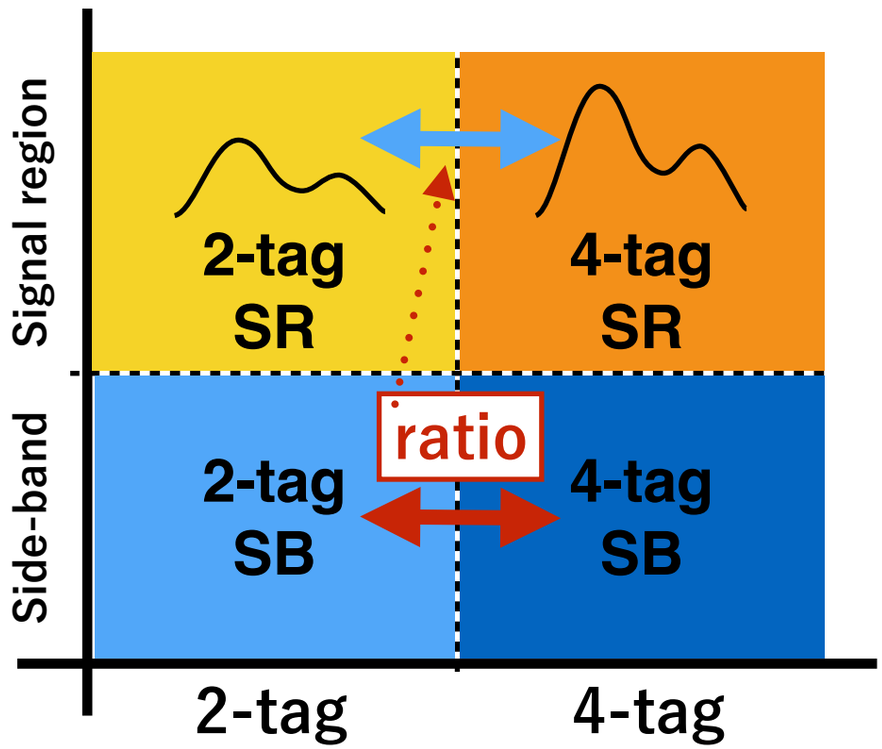
Invariant mass of VBF jets



Background Estimation

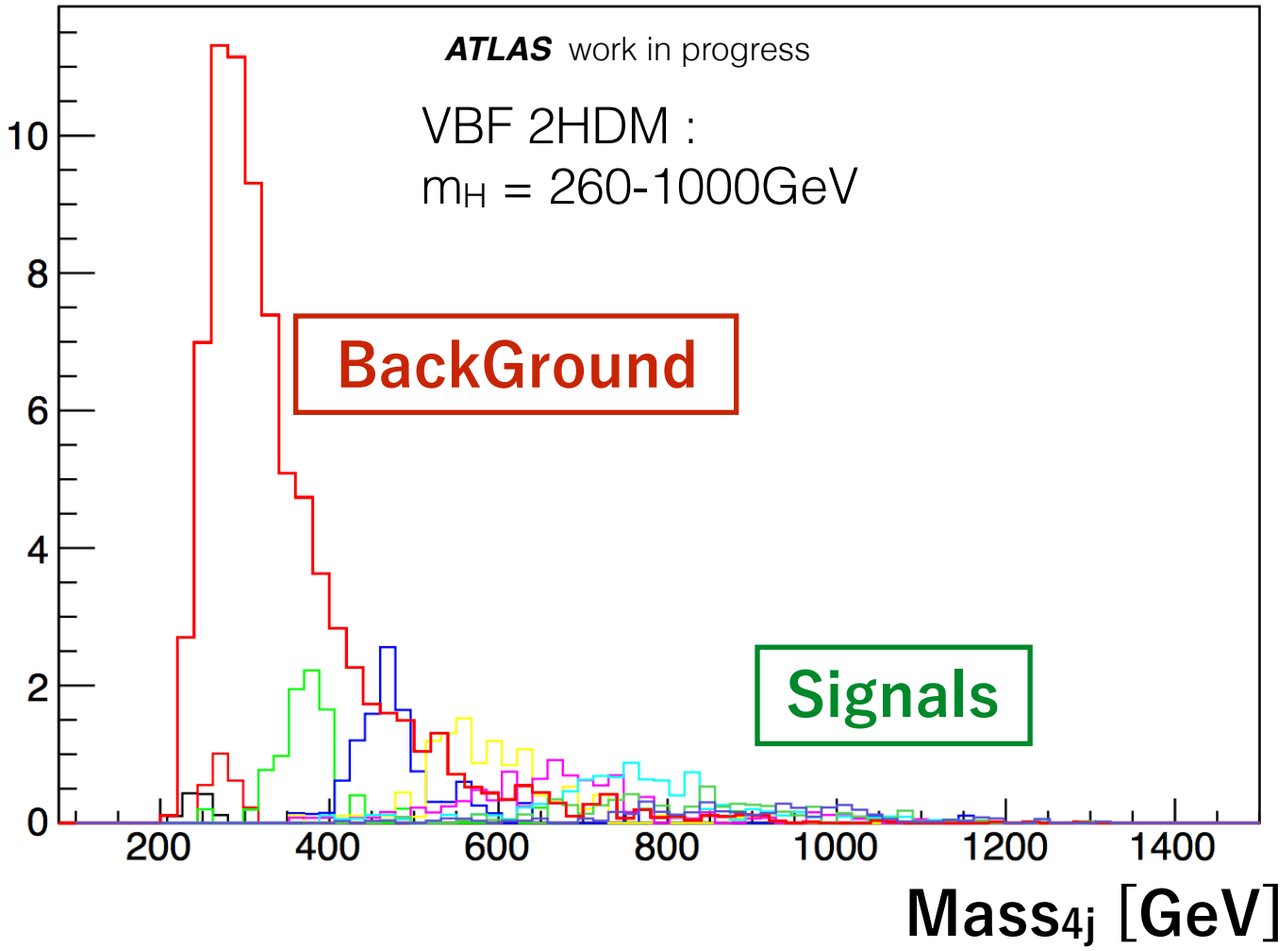
- Backgrounds
  - QCD multi jet、ttbar+jets, VBF WW, WZ, ZZ …
- Estimate the number of QCD background from the data
  - Shape : 2-tag category
  - Scale : (2-tag)/(4-tag) ratio in side-band region





Sensitivity Estimation

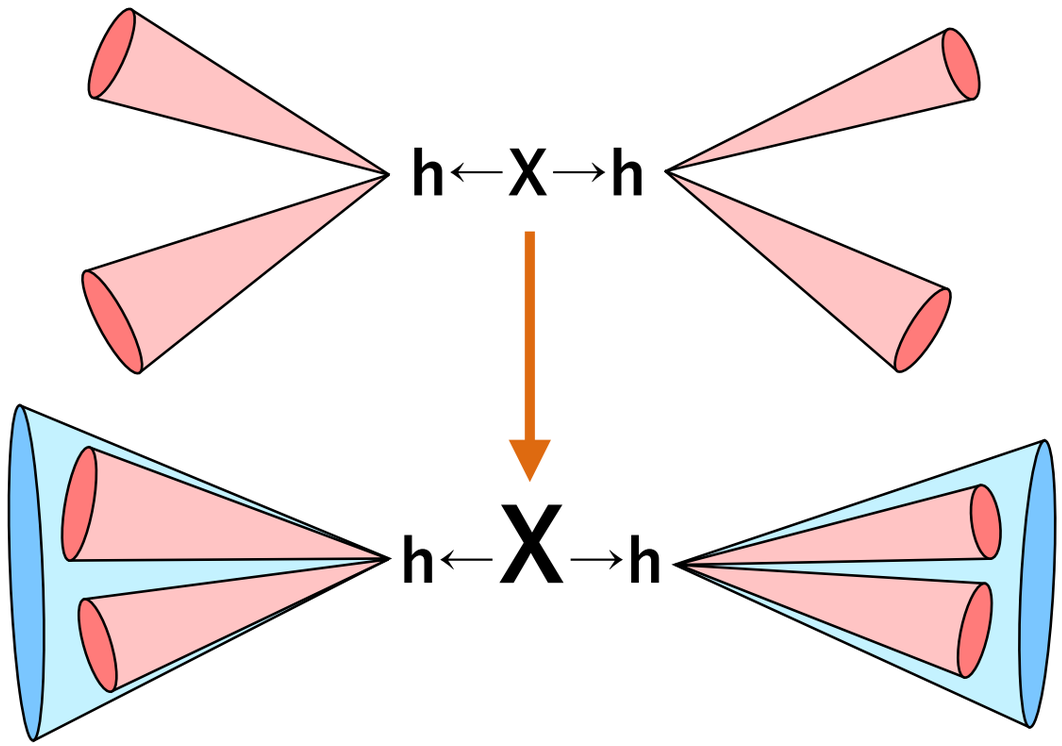
- Calculate sensitivity to new particle based on Signal/BG ratio
  - Assuming 2HDM Type-II model ($\tan\beta = 2.0$, $\sin(\beta - \alpha) = 0.6$) and $\int L\,dt = 80fb^{-1}$
- 0.20 (mH=260GeV) - 3.24 σ (800GeV)



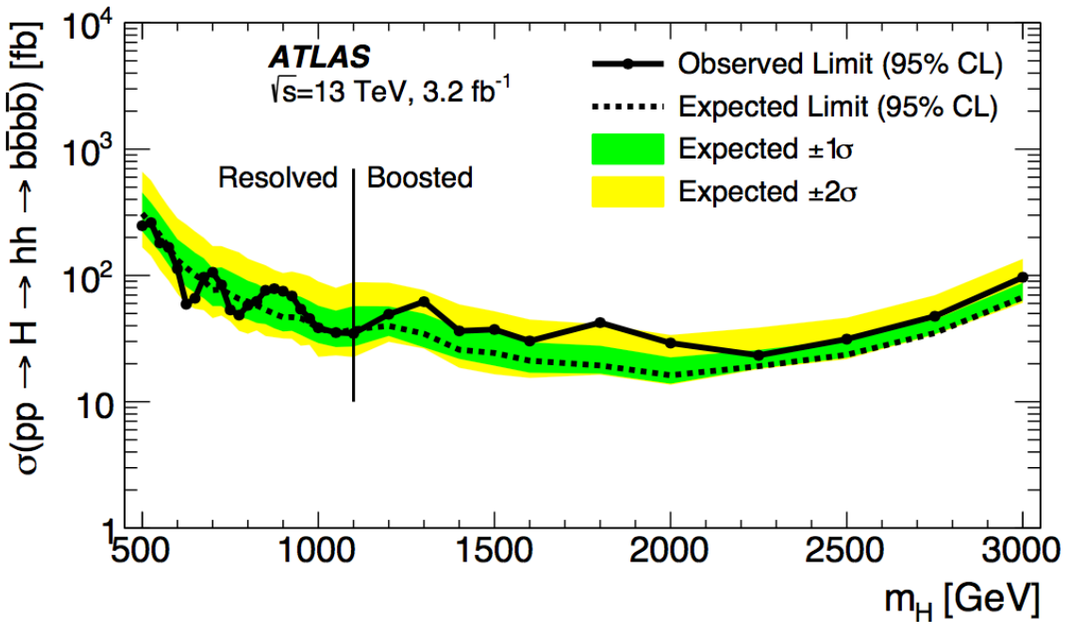
Plan for hh → 4b (ggF) analysis

ggF analysis

- Resolved
  - Pair of b-jets separates
  - Reconstucted by Anti k_T (R=0.4)
  - Target
    → Lighter new particle(< 1TeV)

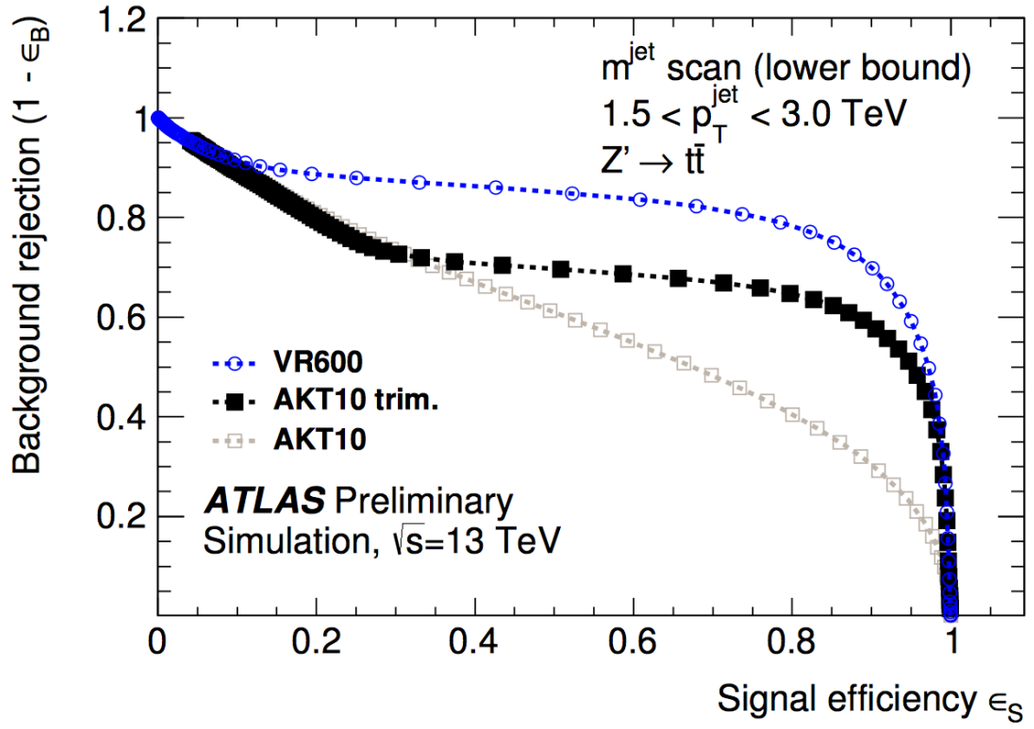


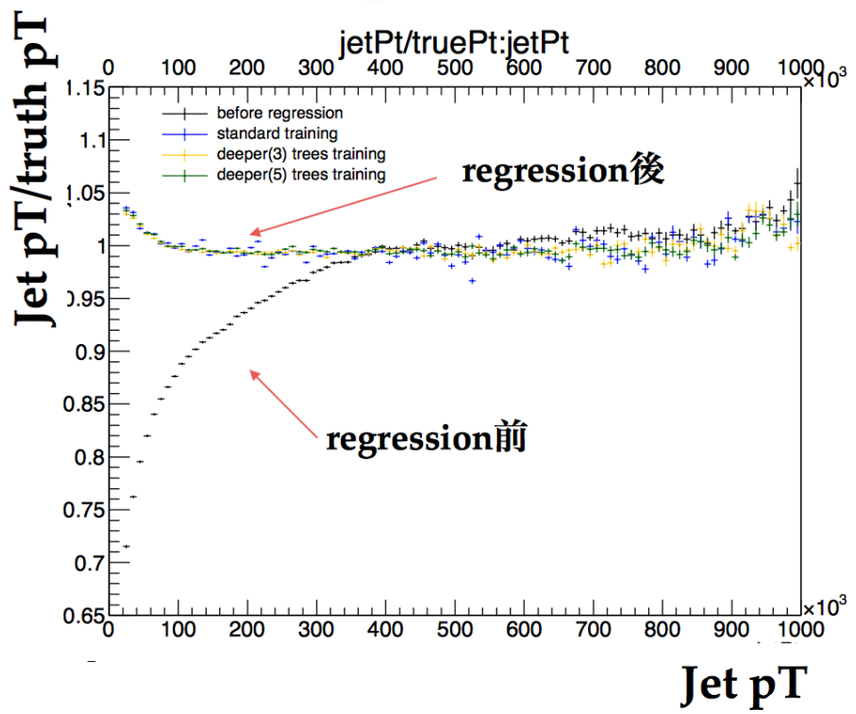
- Boosted
  - Pair of b-jets is merged
  - Anti k_T (R=1.0) → Large-R jets
  - Target
    → Heavier new particle(> 1TeV)



Ideas

- Variable-R jet reconstruction
  - ΔR_{bb} depends on Higgs p_T
    - But now, “R” is fixed value on reconstruction phase
    - → make it float
- MVA for jet energy reconstruction
  - Introduce Multi Variables Analysis(MVA) to jet energy reconstruction
  - Use information of tracks, leptons in jets, ..etc.
  - Already discussed in VH analysis





Conclusion

- Aiming to discover new particles via Higgs boson pair production in the 4b final state with the ATLAS experiment

- Discussed about possibility of discovering Higgs pair production events via VBF process for the first time
  - Optimized and introduced new method to the current ggF analysis for this VBF analysis → Improve

- Developing new analysis techniques for searching hh→4b events via ggF process

Additional slides

Event selections for ggF di-Higgs Resolved

- 0. Pre-selection : #jets > 4 & #b-jet > 1 with (p_T > 25 GeV & $|\eta| < 2.5$)
- 1. At least 4 b-jets with (p_T > 40 GeV & $|\eta| < 2.5$)
  - 4 b-jets with the highest b-tagging score are used for pairing
- 2. ΔR_{jj} cut : Formula 1.
  - If multiple pairings pass this cut, choose the pairing with minimum D_{hh} (Formula 2.)
- 3. p_T cut : Formula 3.
- 4. $|\Delta \eta_{hh}| < 1.5$
  - → Depends on m_{4j}
- 5. Xhh cut : Formula 4.
  - → Signal region

1.

$$\left.\begin{aligned} \frac{360}{m_{4j}} - 0.5 < \Delta R_{jj,\mathrm{lead}} < \frac{653}{m_{4j}} + 0.475 \\ \frac{235}{m_{4j}} < \Delta R_{jj,\mathrm{subl}} < \frac{875}{m_{4j}} + 0.35 \end{aligned}\right\} \text{if } m_{4j} < 1250\,\mathrm{GeV}$$

$$\left.\begin{aligned} 0 < \Delta R_{jj,\mathrm{lead}} < 1 \\ 0 < \Delta R_{jj,\mathrm{subl}} < 1 \end{aligned}\right\} \text{if } m_{4j} > 1250\,\mathrm{GeV}$$

2.

$$D_{hh} = \sqrt{\left(m_{2j}^{\mathrm{lead}}\right)^2 + \left(m_{2j}^{\mathrm{subl}}\right)^2}\left|\sin\left(\tan^{-1}\left(\frac{m_{2j}^{\mathrm{subl}}}{m_{2j}^{\mathrm{lead}}}\right) - \tan^{-1}\left(\frac{110}{120}\right)\right)\right|$$

3.

$$p_T^{\mathrm{lead}} > 0.5 m_{4j} - 90\,\mathrm{GeV}$$
$$p_T^{\mathrm{subl}} > 0.33 m_{4j} - 70\,\mathrm{GeV}$$

4.

$$X_{hh} = \sqrt{\left(\frac{m_{2j}^{\mathrm{lead}} - 120\,\mathrm{GeV}}{0.1 m_{2j}^{\mathrm{lead}}}\right)^2 + \left(\frac{m_{2j}^{\mathrm{subl}} - 110\,\mathrm{GeV}}{0.1 m_{2j}^{\mathrm{subl}}}\right)^2} < 1.6$$