Study of Standard Model $H \rightarrow b\bar{b}$ production via Weak Boson Fusion at CMS

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Outline of the talk

1) Introduction to Higgs Boson Production and Decay modes

2) Motivation for Weak Boson Fusion Channel

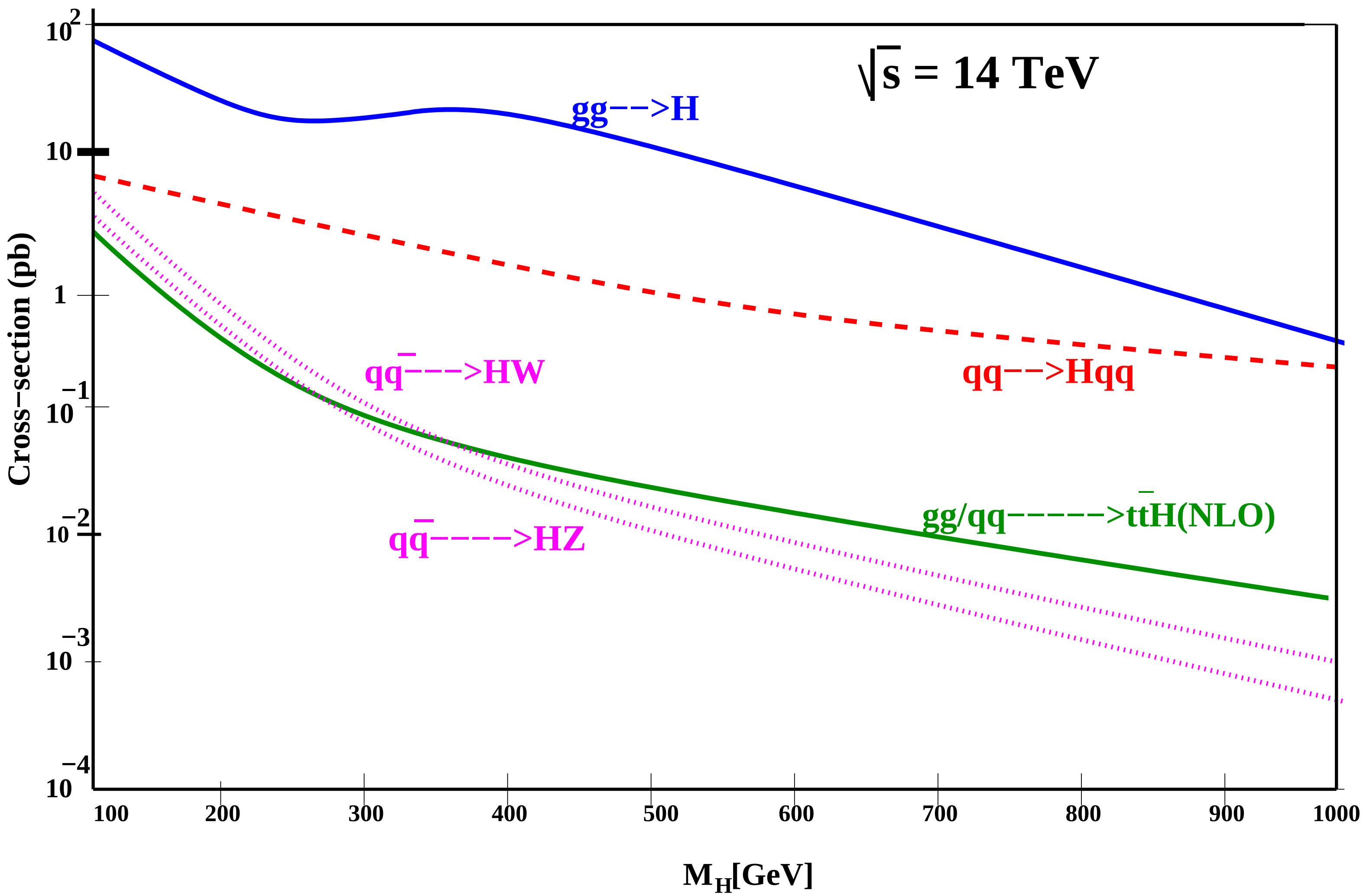
3) Higgs Channel $qq \to qqH \to qqb\bar{b}$

4) Backgrounds considered for the Channel $qq \to qqH \to qqb\bar{b}$

5) Procedure

6) Analysis

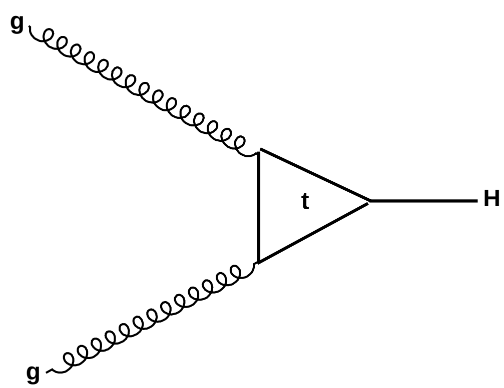
Higgs Production Cross-section



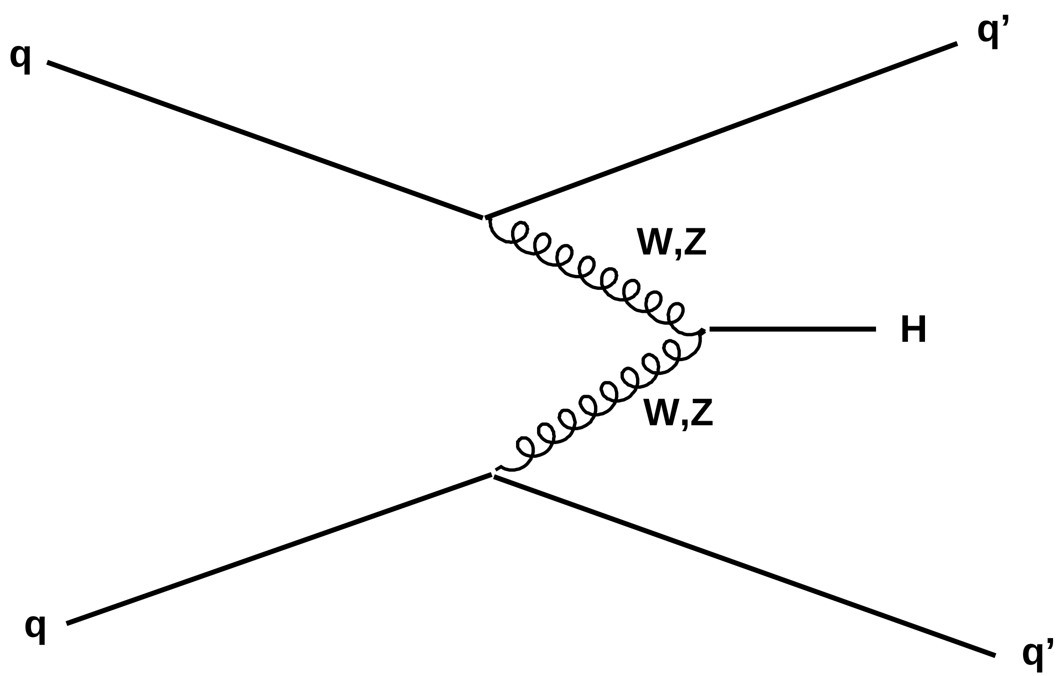
Higgs production modes at LHC

In proton proton collision at 14 TeV and for $M_H > 114.4$ GeV, Higgs is produced mostly via

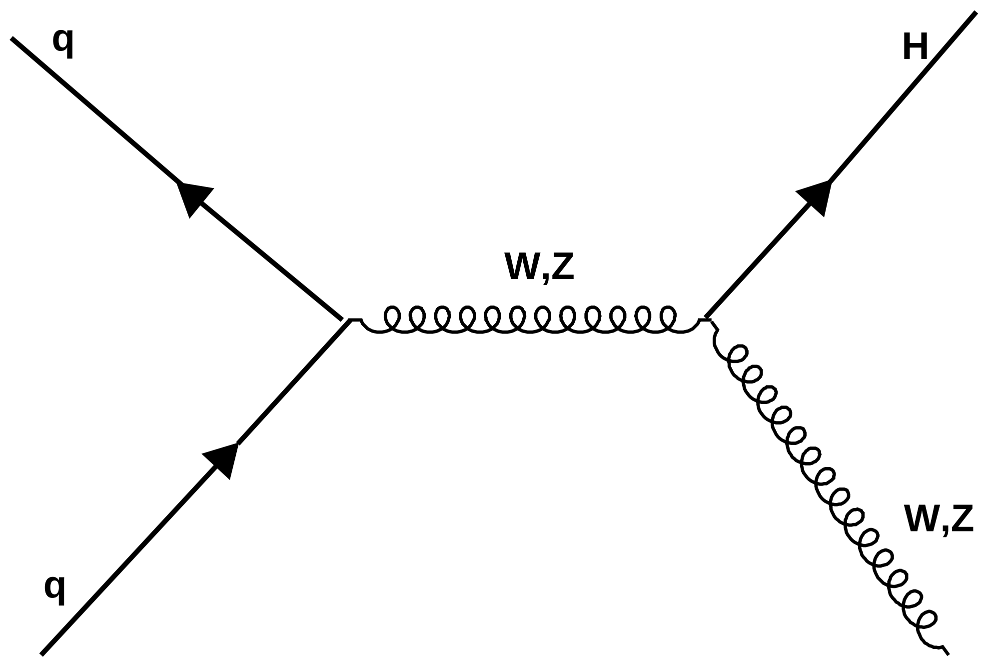
1. **Gluon fusion**
   - Dominant for all M_H
   - Rate is proportional to top yukawa coupling y_t



2. **Weak Boson Fusion (WBF)**
   - Second largest rate
   - Proportional to Vector Boson coupling VVH

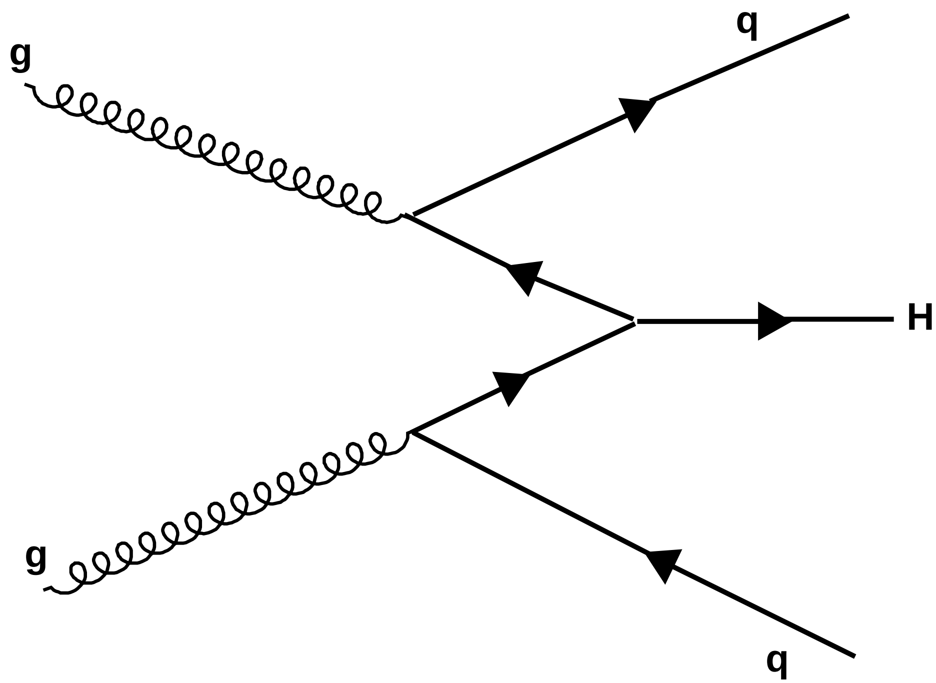


3. **Higgs-strahlung**
   - Third largest rate
   - Same coupling as WBF

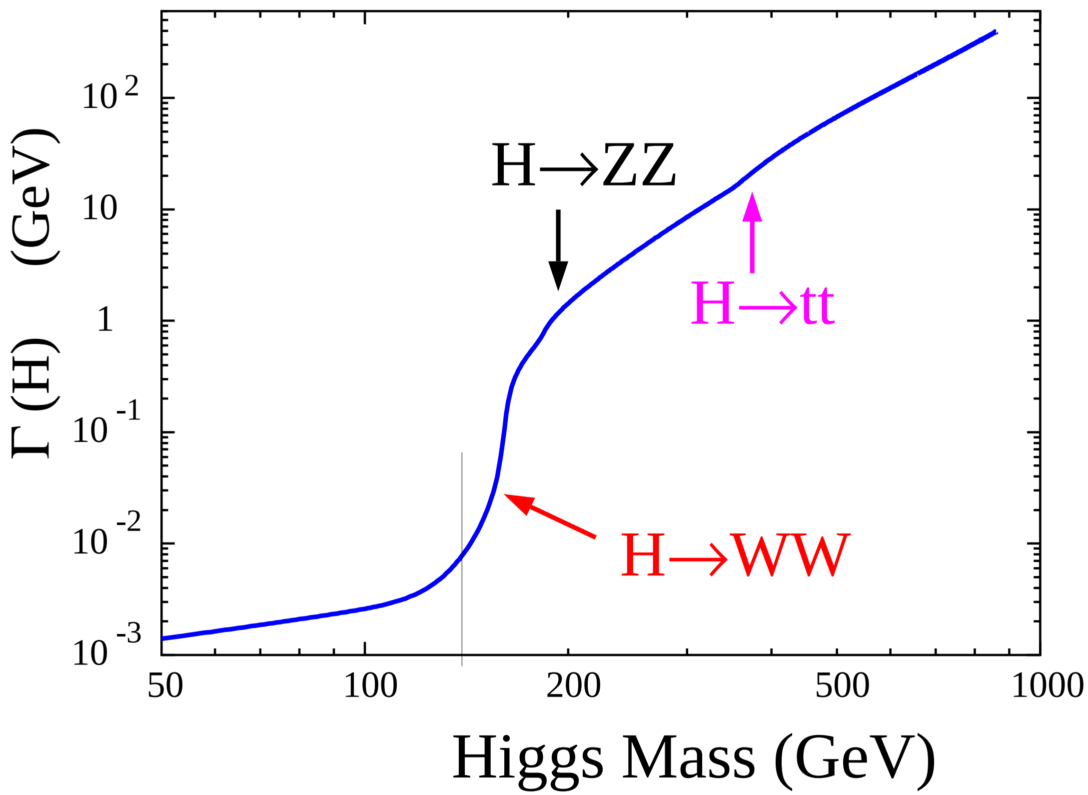


4. **Associated production**

- Same initial state as in gg fusion, but higher x range
- Proportional to heavy quark yukawa coupling Y_Q

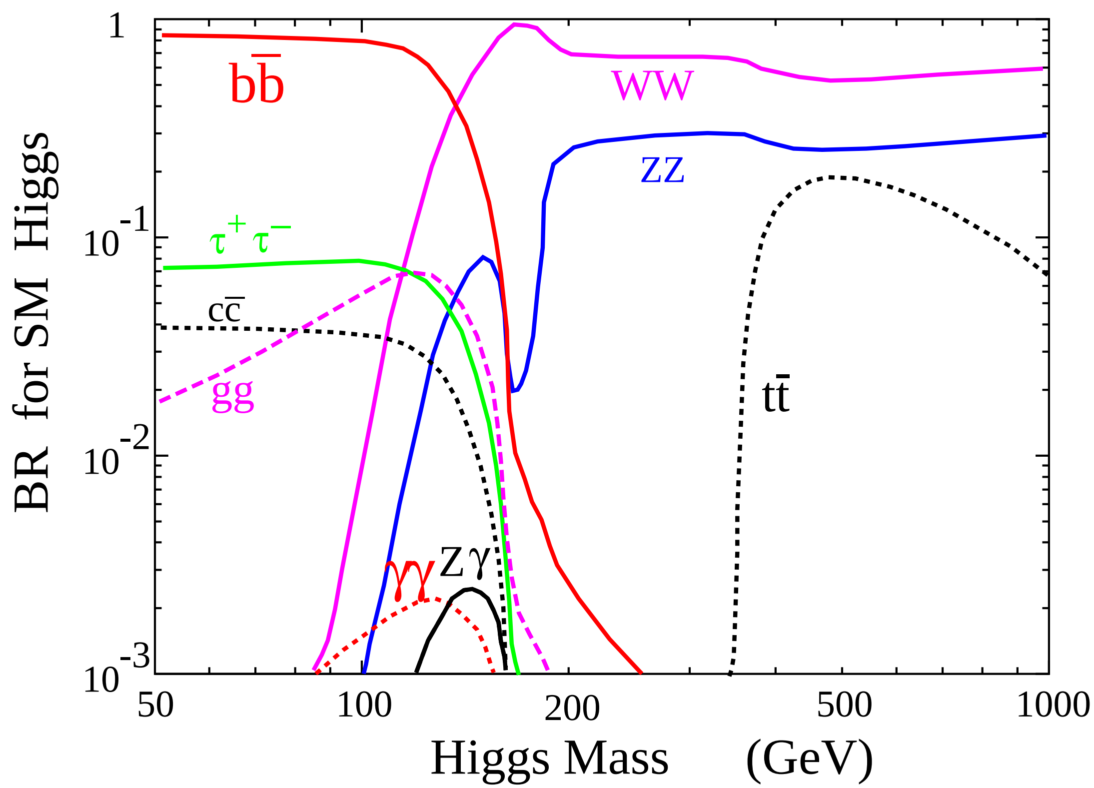


Higgs Decay Width



Higgs Decay width becomes extremely narrow at low Higgs masses, few MeV at $m_H \sim$ 100 GeV and 1 GeV at $m_H \sim$ 200 GeV. At higher masses, it becomes broad, $\Gamma > 100$ GeV above $m_H = 600$ GeV.

Higgs Branching Ratio

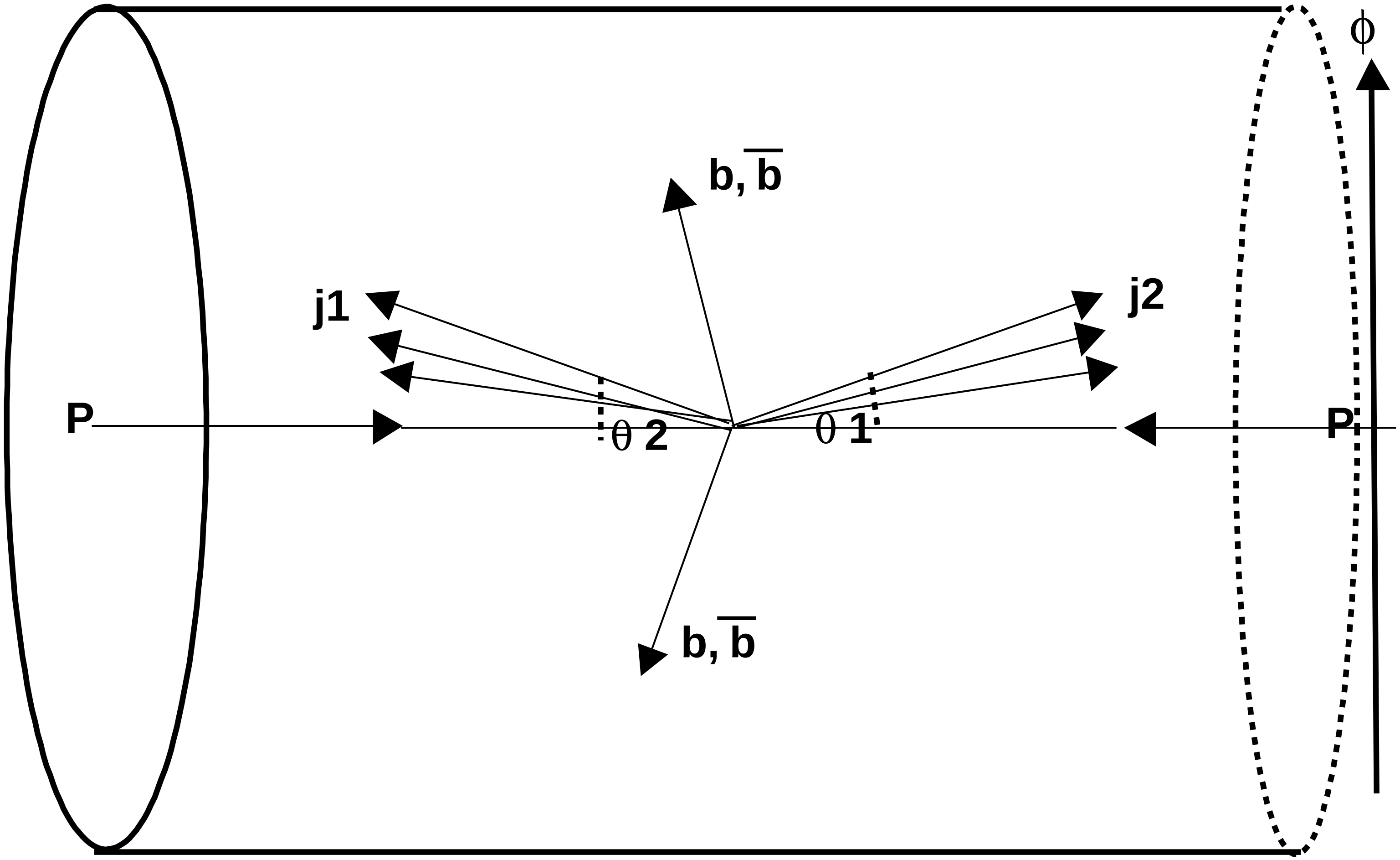


The rapid variation of branching ratio with Higgs mass making it necessary to have different strategies for the Higgs identification depending on its mass

Motivation for Weak Boson Fusion

- WBF events contain additional information in the observable quark jets. Techniques like forward jet tagging can be exploited to reduce the backgrounds
- Most important feature of WBF signal is lack of color exchange between initial state quarks. Color coherence between initial and final state gluon bremsstrahlung leads to suppressed hadron production in the central region between two tagging jet candidates of the signal. One can use this feature to isolate signal from the backgrounds
- Depending upon mass of the Higgs, WBF channel requires low integrated luminosity for Higgs discovery as compared to other production channels.

Channel:- WBF H$\rightarrow b\bar{b}$ in CMS detector



Background Considered

1. **QCD production of $b\bar{b}jj$ final states.**
   - Here two b quarks alongwith two final state light jets are produced with $p_T^b > 30$ GeV and $p_T^j > 60$ GeV.
2. **QCD production of $jjjj$ final states.**
   - These processes has the largest production cross-section because it is a strong interaction process and the gluons are the dominant partons in the proton at low x values
3. **Associated production of $Z^*/\gamma^* \to b\bar{b}$ and light jets**
4. **$t\bar{t}$ production**
   - Top decaying hadronically and final states we get is $bbjjjj$. We can loose two jets either because they are too forward or because they are soft/collinear.

Procedure

1. **Events Generation**

   - Higgs is produced with two back to back jets in the forward and backward rapidity region using ALPGEN generator
   - ALPGEN donot include any form of Hadronisation. Thus, the unweighted events from the ALPGEN are interfaced with Showering and Hadronisation Algorithm, PYTHIA.
   - CMKIN-4.3.1 is used to interface ALPGEN events with PYTHIA

2. **Detector Simulation**

   - The generated ntuples are passed to OSCAR-3.6.5 for detector simulation
   - Here the effect of detector material to the generated events are studied.

- The output of OSCAR is SimHits

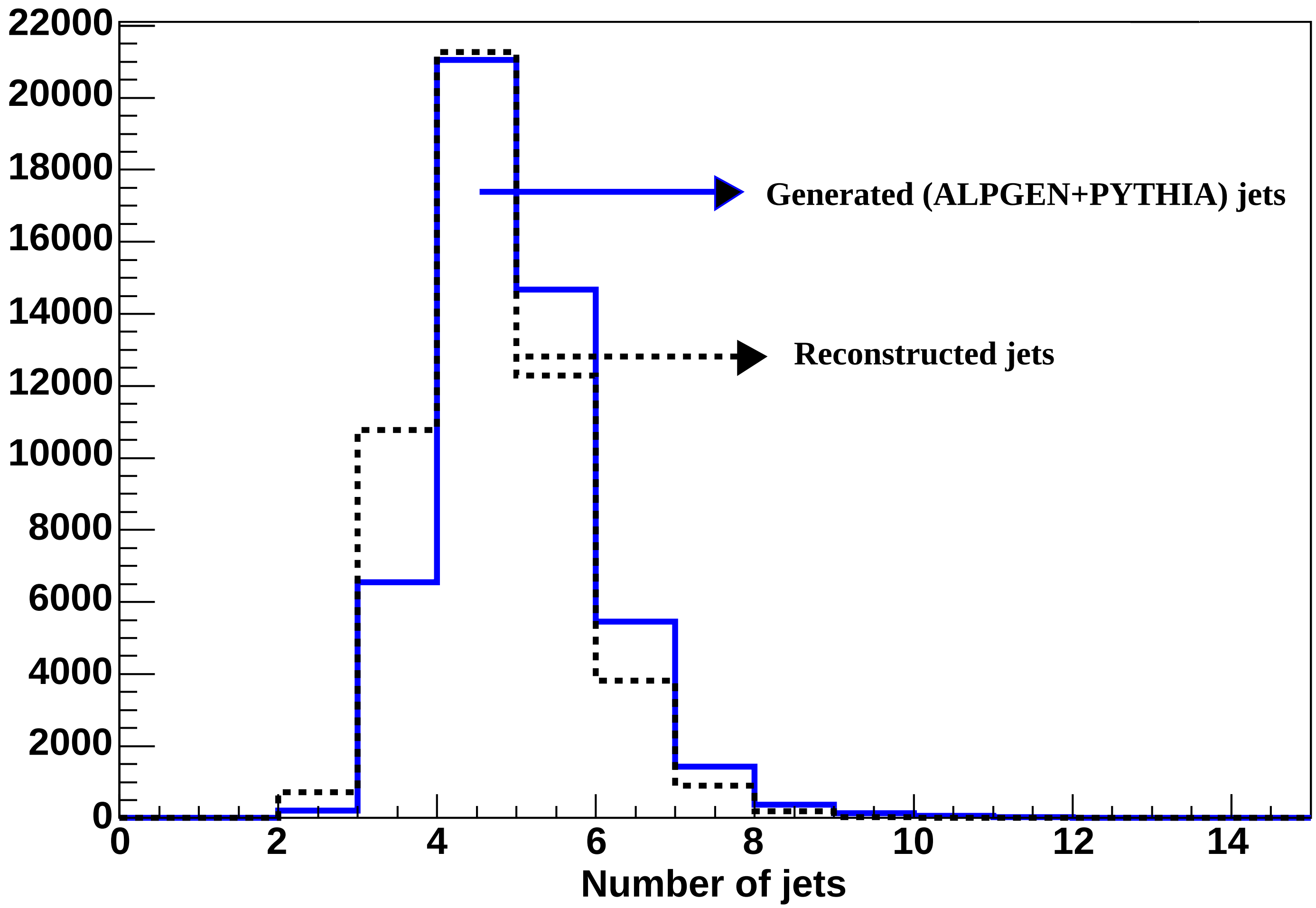
3. **Digitisation**

- The SimHits from the detector simulation requires some algorithm for readout.
- ORCA-8.7.1 is used for digitisation process
- The Output after this step is Digis

4. **Reconstruction**

- The ORCA-8.7.4 reconstruction package used is JetMetAnalysis.
- This step includes gathering information from the Monte Carlo and detector reconstruction.
- Jets are made using Persistent Jet Finder, algorithm used is Iterative Cone Algorithm with $p_T > 30$ GeV and the correction used in jets is MC jet correction

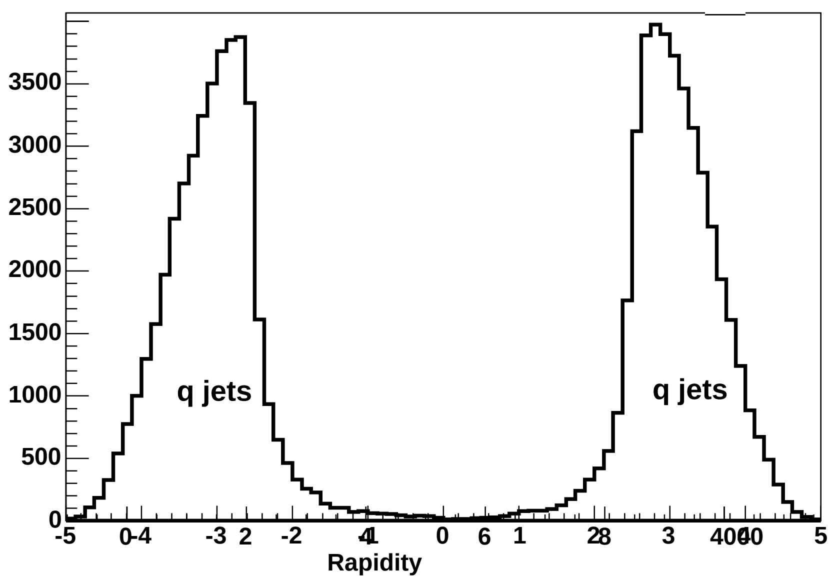
Jet Multiplicity



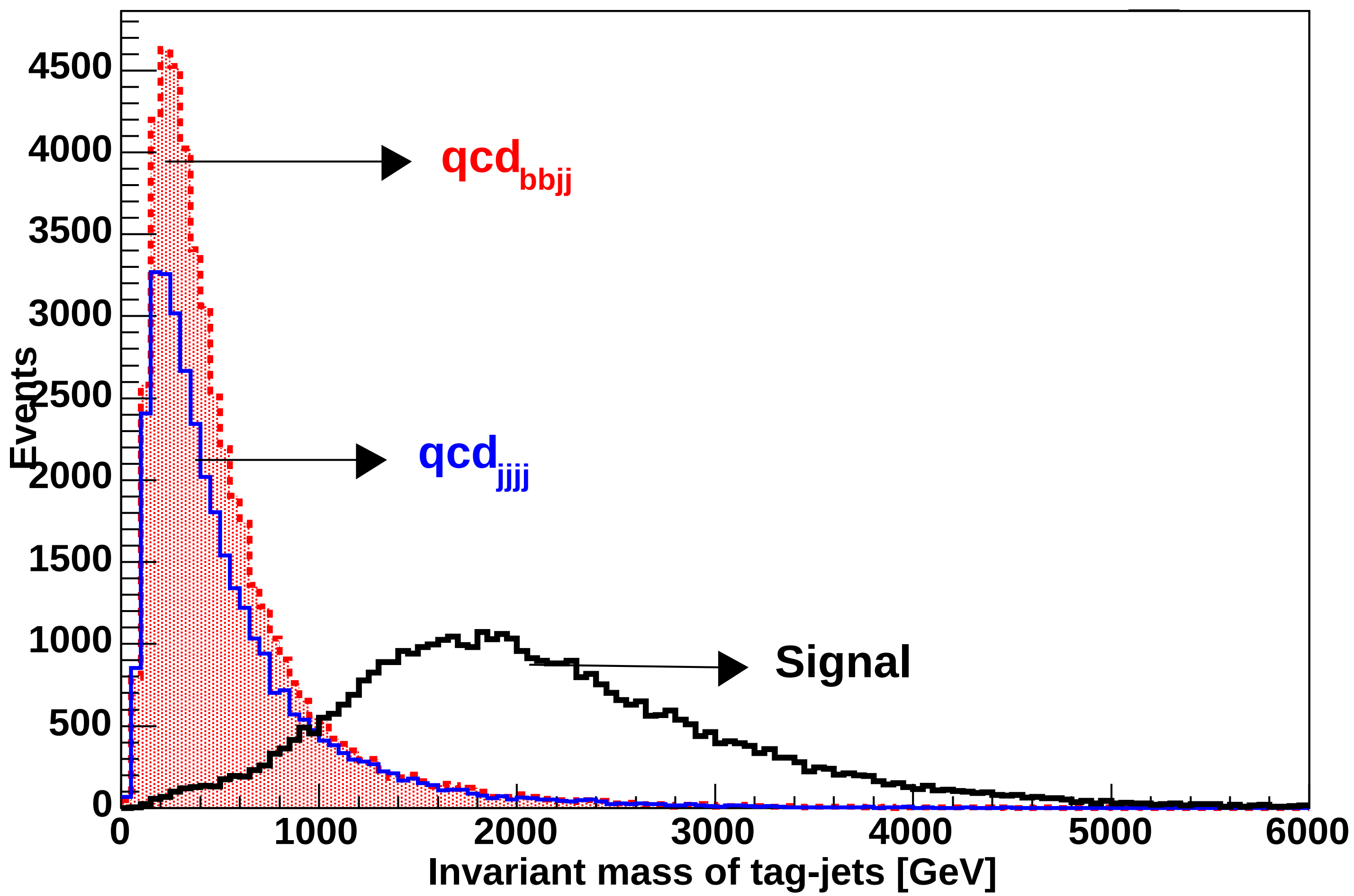
Analysis

- The four highest transverse energy (E_T) jets are selected and sorted according to their rapidity (η). The jet with least and the highest η are treated as tag jets and jets with η in between two tag jets as b-jets.

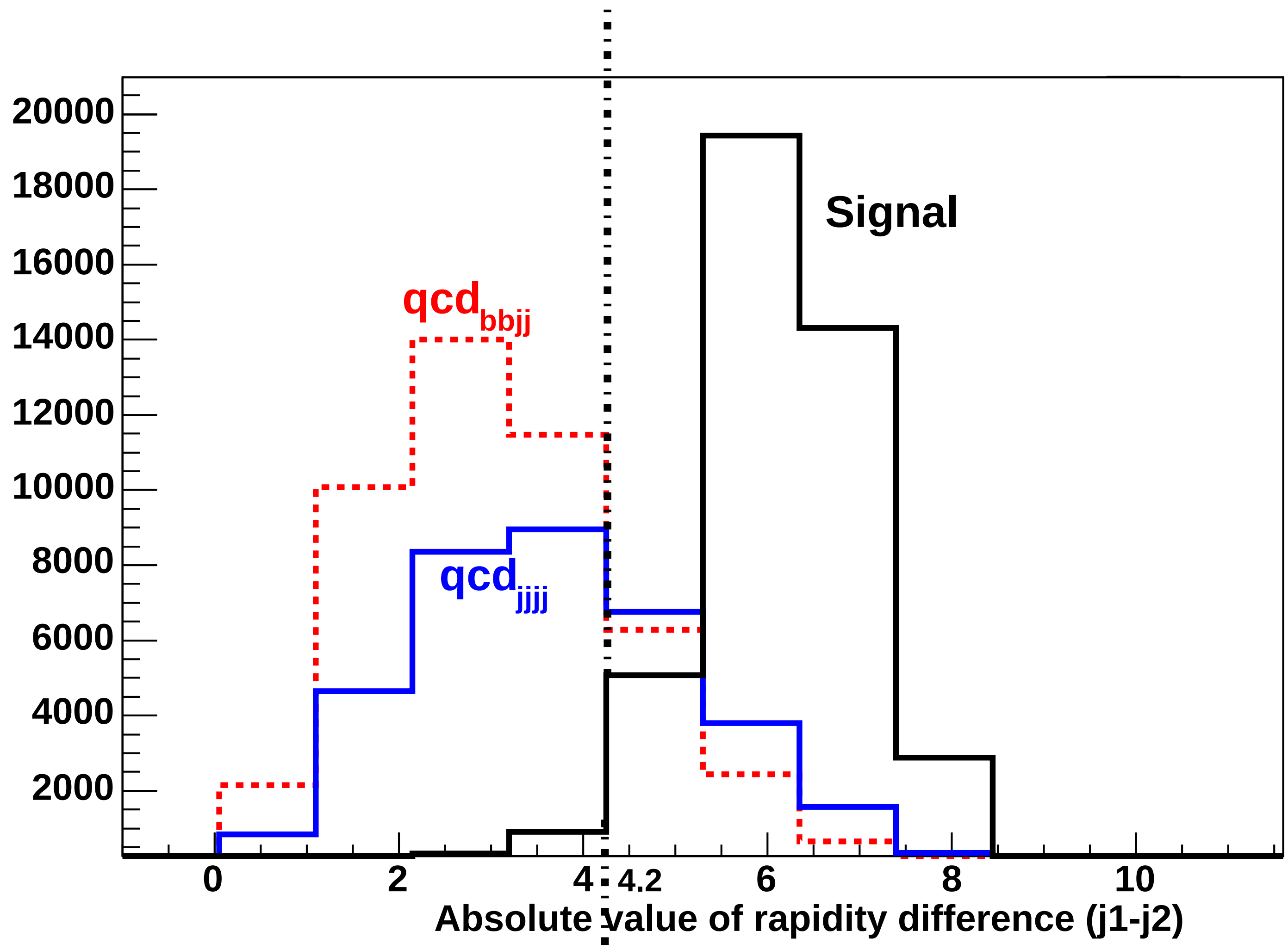
Rapidity of forward tagging jets



Invariant mass of tag jets



Rapidity difference of forward tagging jets



Set of Initial cuts becomes

for b-jets

$p_T^b >$30 GeV, $\Delta R_{bb} >$0.5, $|\eta_b| <$2.5

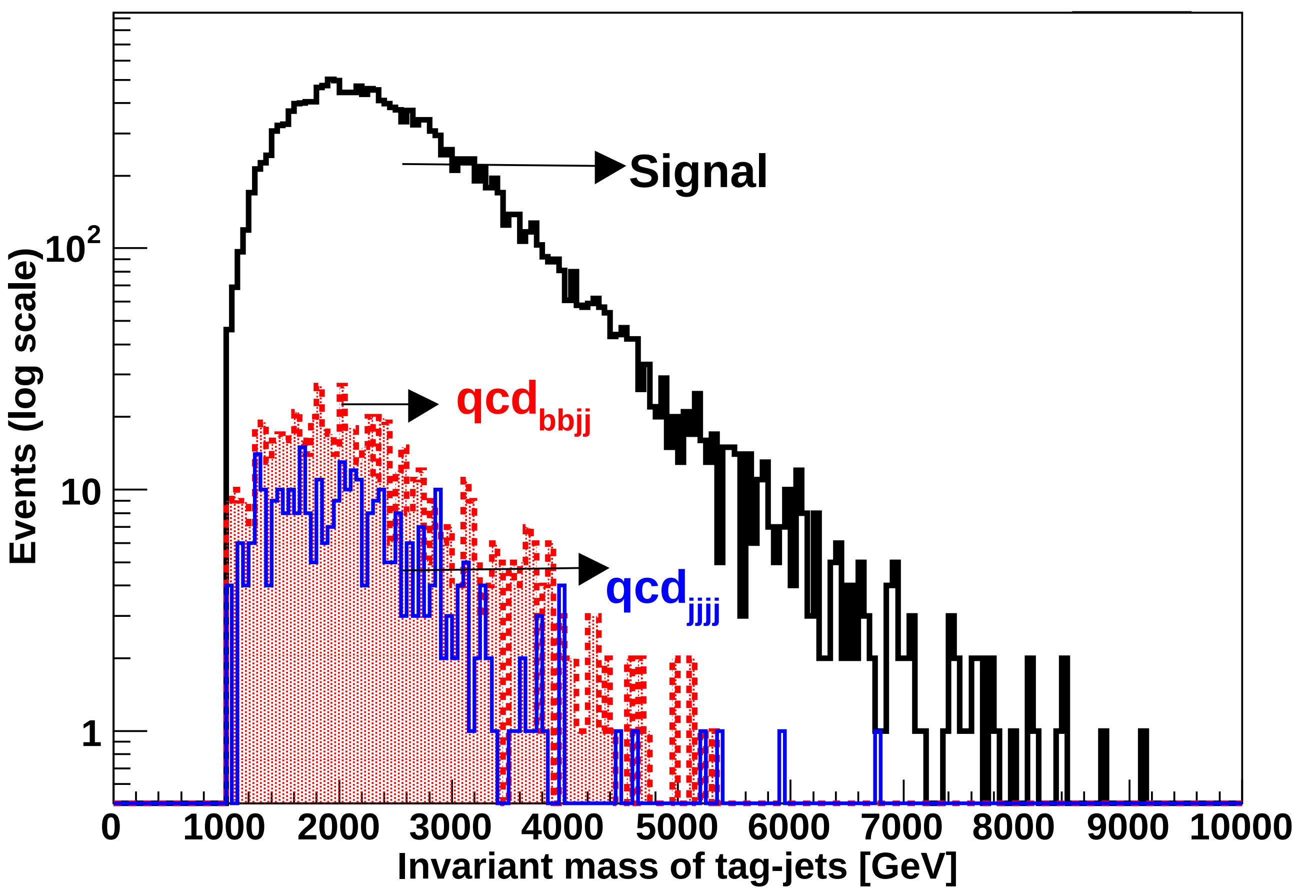
for tag-jets

$p_T^j >$60 GeV, $2.5 < |\eta_j| < 5$ $\eta j1.\eta j2 <$0, $\Delta R_{jj}>$0.5

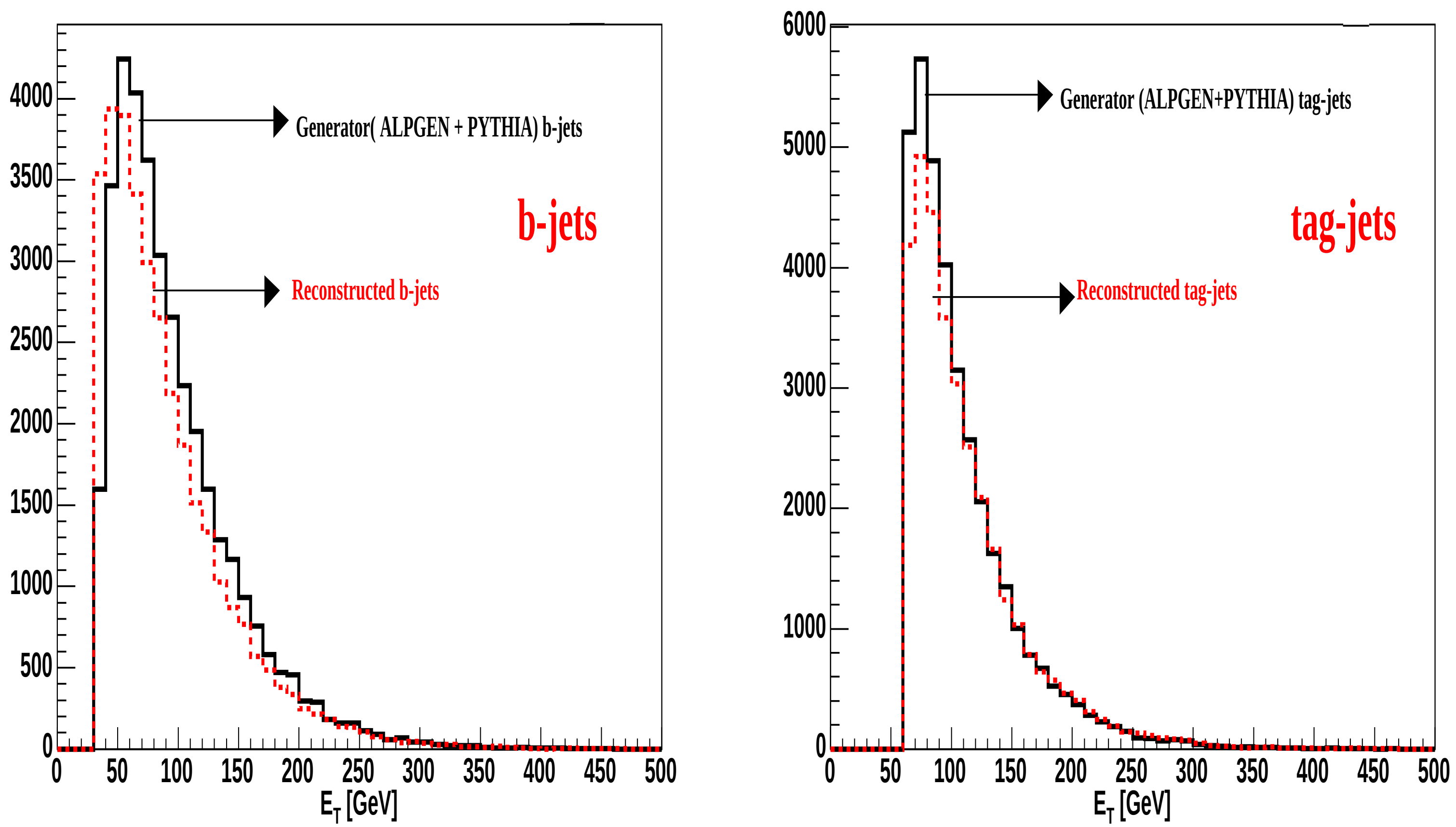
To reduce particularly QCD backgrounds

$|\eta_{j1} - \eta_{j2}| >$4.2 $M_{jj} >$ 1000 GeV

Invariant Mass of forward tagging jets after applying selection cuts



E_T of b-jets and tag-jets with initial cuts



Energy Resolution of Calorimeter

By looking into E_T plot of b-jets, it is noticed that there are more events at the lower E_T cutoff for reconstructed level than for generator level showing thereby that some fake jets are reconstructed. To get rid of these fake jets we revise cuts by taking into account the σ_{E_T} as given by

$$(\frac{\sigma_{E_T}}{E_T})^2 = (\frac{120}{\sqrt{E_T}})^2 + (5)^2\%$$

Calculating 2σ for the E_T of b-jets and tag-jets, we get

for $E_T = 60$ GeV, we get $2\sigma \sim 20$ GeV for quark jets

&

for $E_T = 30$ GeV, we get $2\sigma \sim 15$ GeV for b-jets.

Set of Revised cuts becomes

for b-jets

p_T^b >45 GeV, ΔR_{bb} >0.5, $|\eta_b|$ <2.5

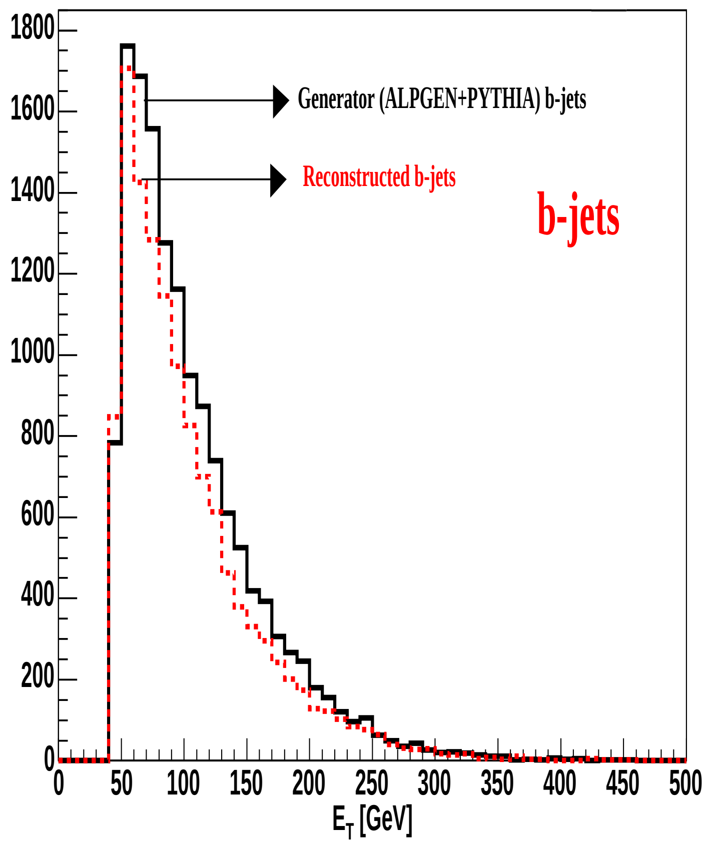
for tag-jets

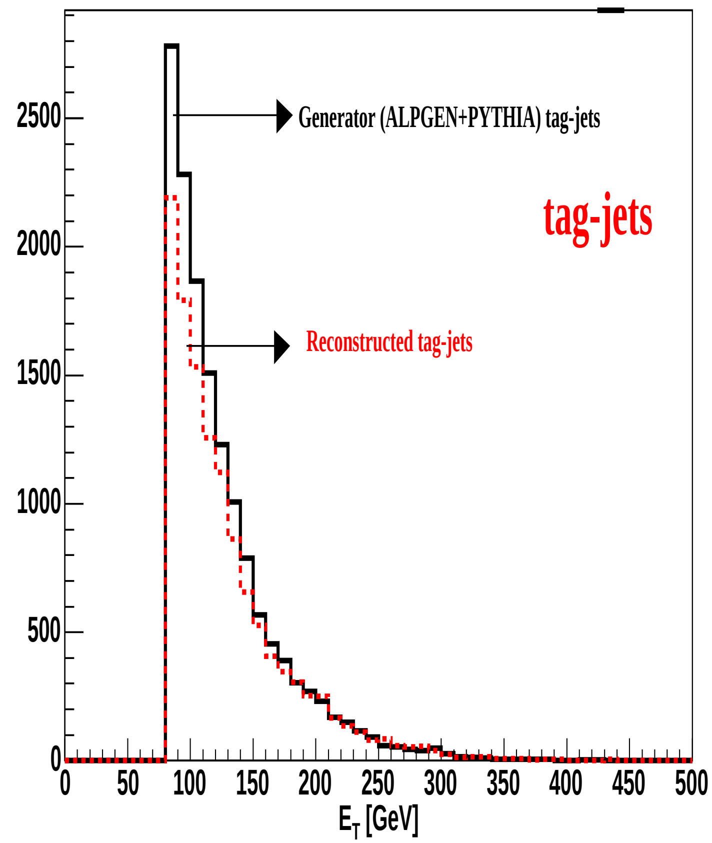
p_T^j >80 GeV, $2.5 < |\eta_j| < 5$ $\eta j1.\eta j2$ <0, ΔR_{jj}>0.5

To reduce particularly QCD backgrounds

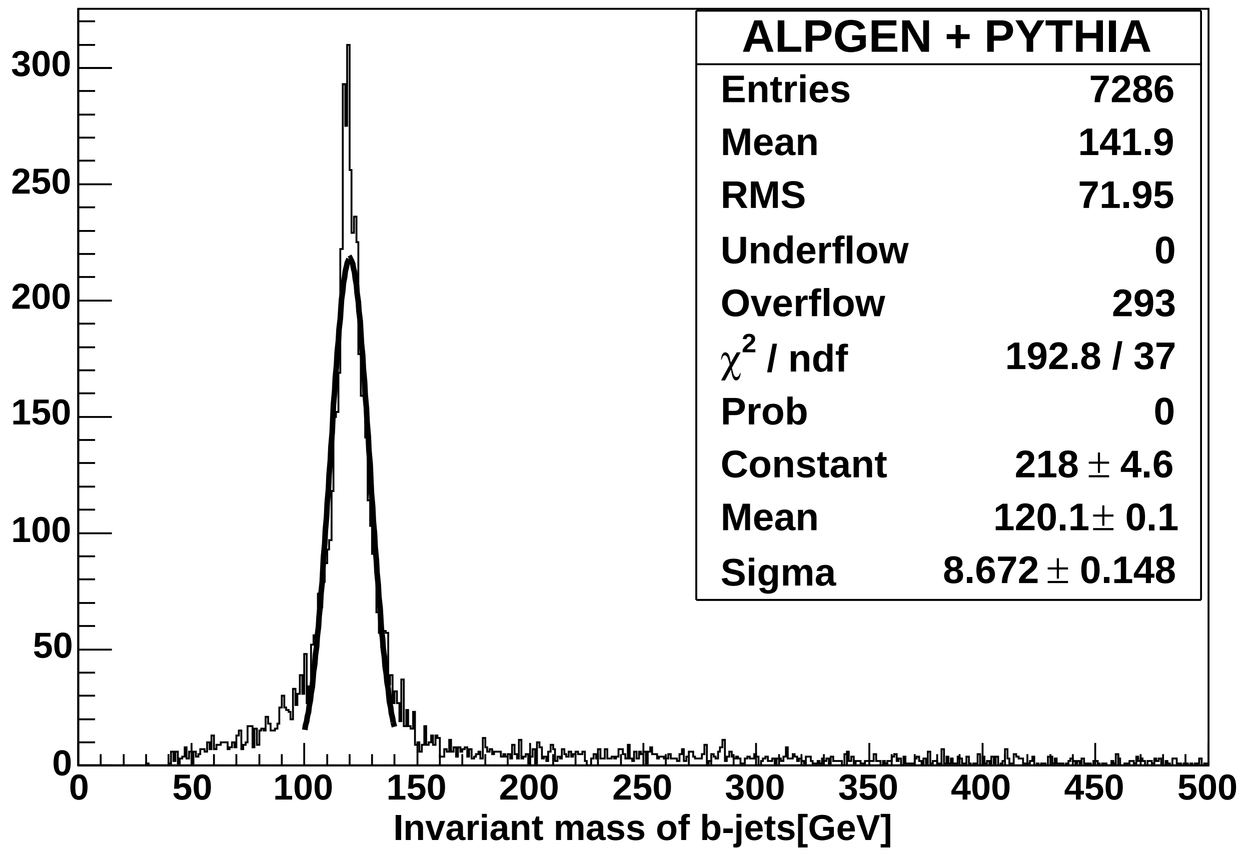
$|\eta_{j1} - \eta_{j2}|$ >4.2 $M_{jj} >$ 1000 GeV

E_T of b-jets and tag-jets with Revised cuts

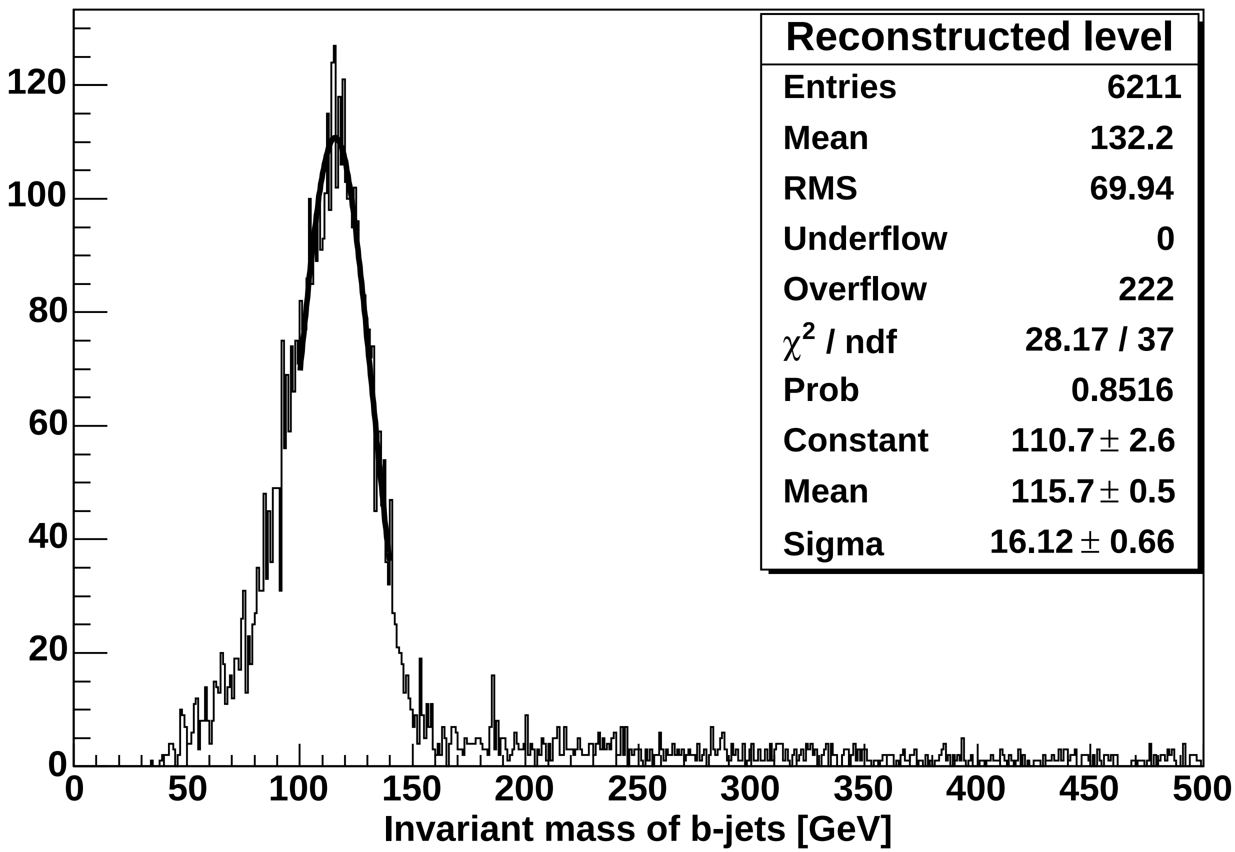




Invariant Mass of b-jets at ALPGEN + PYTHIA level



Invariant Mass at Reconstructed level



Cross-section

Events	Cross-section(pb)	
	Generator level	Reconstructed level
signal	3.444×10^{-3}	2.473×10^{-3}
qcd_{bbjj}	4.3161	2.0311
qcd_{jjjj}	4.3006×10^{-2}	3.8705×10^{-2}
$t\bar{t}$	1.336×10^{-2}	$6.68\ \times10^{-3}$
zjj	2.8222×10^{-3}	1.9171×10^{-3}

The numbers are corrected for the b-tagging efficiency to be 60% (0.6) in case of the signal events and b-mistagging efficiency of 1% (0.01) in case of QCD jjjj background.

Expected Number of events with 60 fb^{-1} integrated luminosity.

Events	**Generator level**	**Reconstructed level**
$signal$	1.40×10^2	1.002×10^2
qcd_{bbjj}	2.589×10^5	1.218×10^5
qcd_{jjjj}	2.58×10^3	2.32×10^3
$t\bar{t}$	8.016×10^2	4.008×10^2
zjj	1.69×10^2	1.15×10^2

Signal to Background Ratio

Level	$(S/\sqrt{B})$
Generator level	0.27327
Reconstructed level	0.283822

Signal to background ratio $(S/\sqrt{B})$ significantly depends on the b-quark tagging algorithm efficiency since major background comes from the process QCD $bbjj$ & QCD $jjjj$. We have not yet incorporated b-quark tagging in this analysis

Status & Future plans

- Analysis is submitted as CMS Internal Note
- We are in process of generating large samples $\sim$ 100k events for signal & all backgrounds and use them for further analysis using b-tagging.