# The ATLAS Hadronic Tau Trigger

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## Abstract

During the 2012 run, the Large Hadron Collider (LHC) reached instantaneous luminosities of nearly $10^{34}$ cm$^{-2}$s$^{-1}$, with bunch crossings occurring every 50 ns. In this difficult environment of several overlapping interactions per bunch crossing (pile-up), the trigger system of the ATLAS detector has the task of reducing the event rate from 40 MHz to a few hundred Hz while keeping the most interesting physics events.

Being the heaviest of all leptons, the tau lepton plays an important role in many physics processes. The ability to trigger on events containing hadronically decaying taus is therefore of special interest. In this poster the hadronic tau trigger is described and its performance during 2012 is shown.

## Motivation

The tau lepton plays not only an important role in the measurements of the Standard Model (SM) but also in searches for physics beyond the Standard Model (BSM).

At the moment it is fundamental for the measurement of Higgs properties to find out if the fermionic Higgs couplings agree with the predictions of the SM. Otherwise this would be a first hint of new physics.

## Introduction

With a mass of 1.777 GeV/c$^2$ the tau lepton is the heaviest of the leptons in the SM. It has a short lifetime of $2.9 \cdot 10^{-13}$ s and a decay length of 87 μm. Therefore it decays already within the beam pipe and has to be identified via its decay products. In 65% of the cases the tau lepton decays hadronically (mainly into pions). The hadronic tau trigger aims to trigger these events while the leptonically decaying taus are covered by the electron & muon triggers.



Tau decay modes
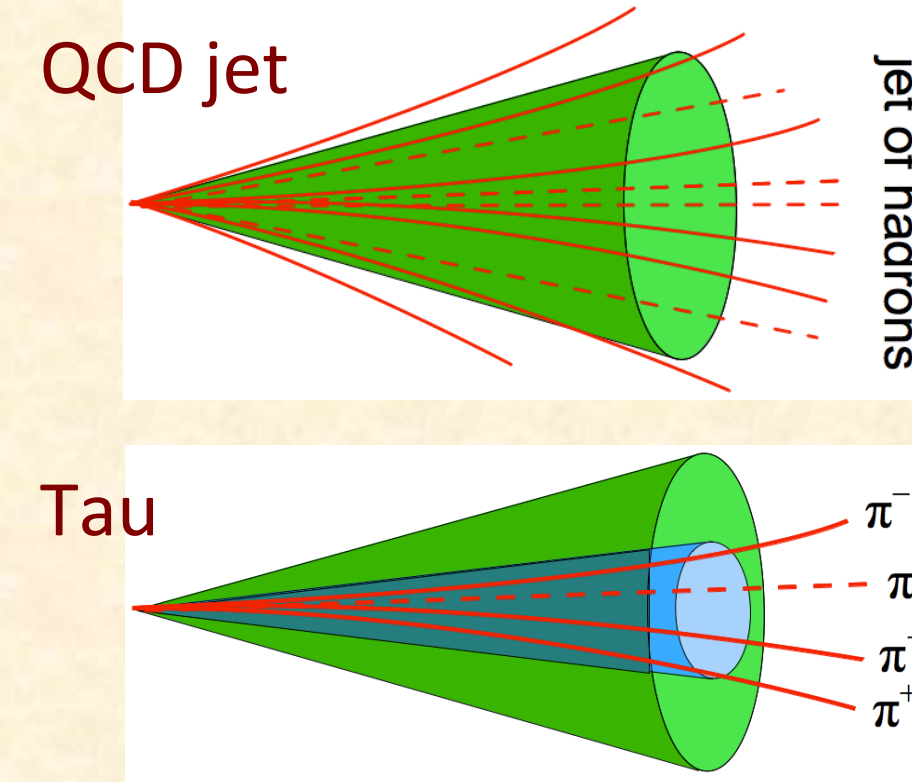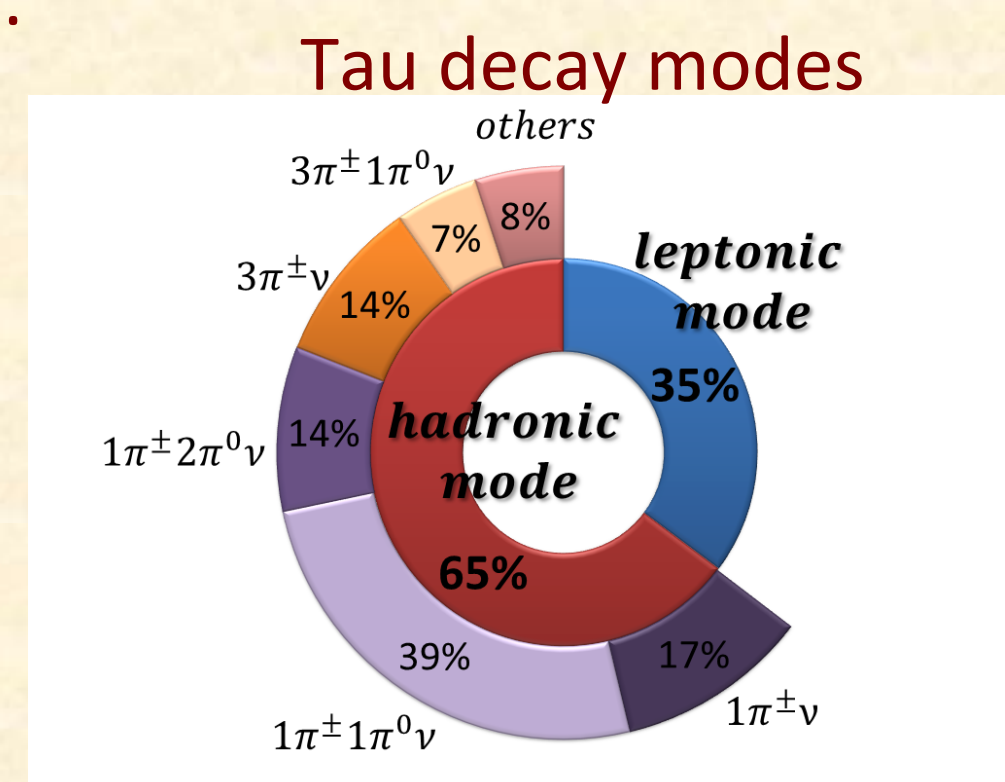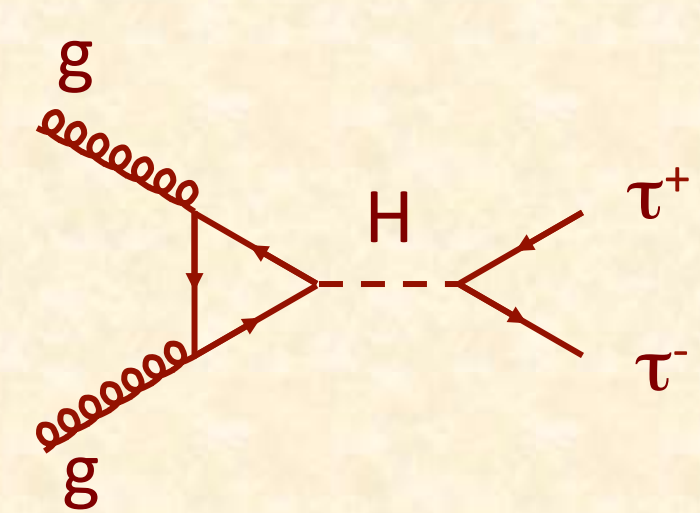
## Properties

Quark or gluon jets (QCD) and hadronically decaying taus both produce particle showers in the electromagnetic and hadronic calorimeter. To differentiate between these signatures the inner structure has to be studied. While QCD jets contain a larger number of tracks coming from charged hadrons, the tau lepton decays mainly into one or three charged pions, some neutral pions and neutrinos.

The typical signature consists therefore of:
- 1 or 3 tracks
- a narrow collimated jet
- an isolation ring (which contains no tracks) around the inner cone

## ATLAS tau trigger

To reduce the initial bunch crossing rate to a feasible rate for disk storage while keeping the most interesting physics events, a three level trigger system is used.

ATLAS — 40 MHz → Level 1 (L1) — ~ 75 kHz → Level 2 (L2) — ~ 5 kHz → Event Filter (EF) — ~ 400 Hz →

The **L1 trigger** is hardware based and uses the information about the energy deposits in the electromagnetic (EM) and hadronic (HAD) calorimeter towers ($\Delta\eta \times \Delta\phi$ = 0.1 x 0.1):
- Sum of energy in 2 x 1 pairs of EM towers
- Sum of energy in 2 x 2 HAD towers behind the EM layers
- Sum of energy in isolation region (4 x 4 ring around the core region of 2 x 2 towers)

Depending on the specific L1 item, thresholds on the energy and the isolation are set. The position of the energy deposit is called region of interest (RoI) and is given to the next trigger level.

The **L2 trigger** is software based and uses the full detector granularity within the RoI's given by the L1 trigger. In addition to the calorimeter the inner detector is used as input. To distinguish between QCD jets and taus, discriminating variables such as the track multiplicity, the narrowness of the decay products and the shape of the particle showers are used.

In 2012 an additional threshold on $\Delta z_0$, the distance along the beam direction between a track and the track with the highest $p_T$, is introduced to reduce the number of tracks coming from pile-up events.

The **EF** is the final software based trigger level and uses the full detector information. The algorithms are very similar to the offline reconstruction algorithms to achieve a good background rejection.

Since 2012 multivariate algorithms (MV) such as Log-Likelihood (LLH) and Boosted Decision Trees (BDT) are used instead of threshold based selections. They take several pile-up robust variables as input and lead to a great performance as shown in the efficiency plots.
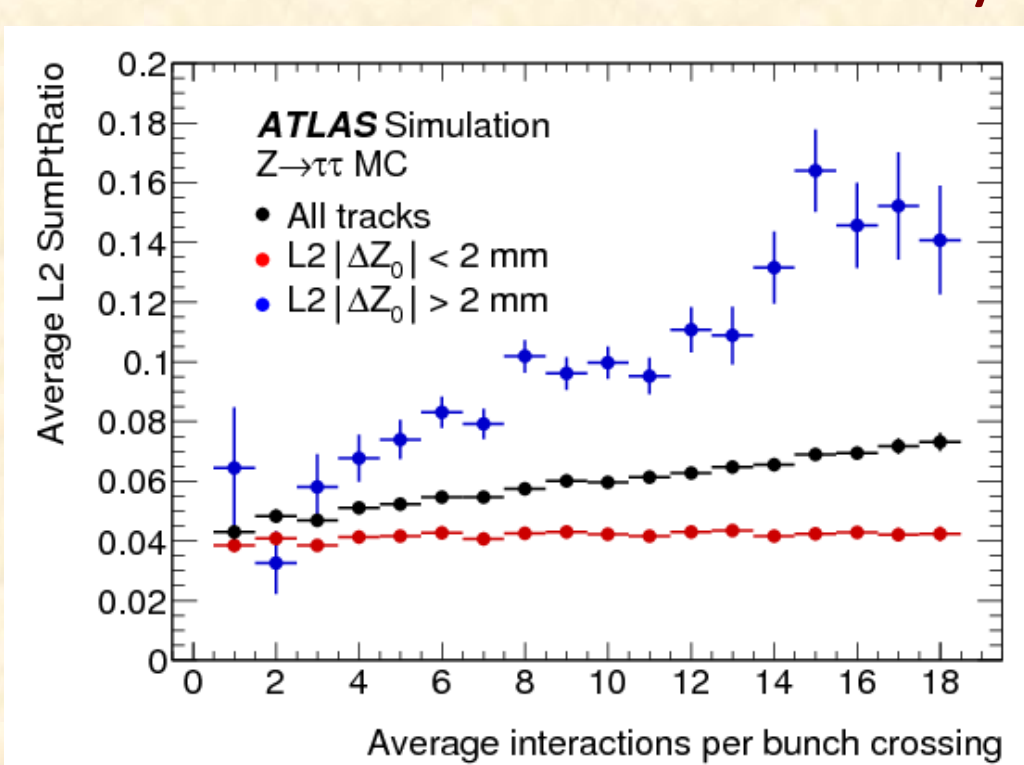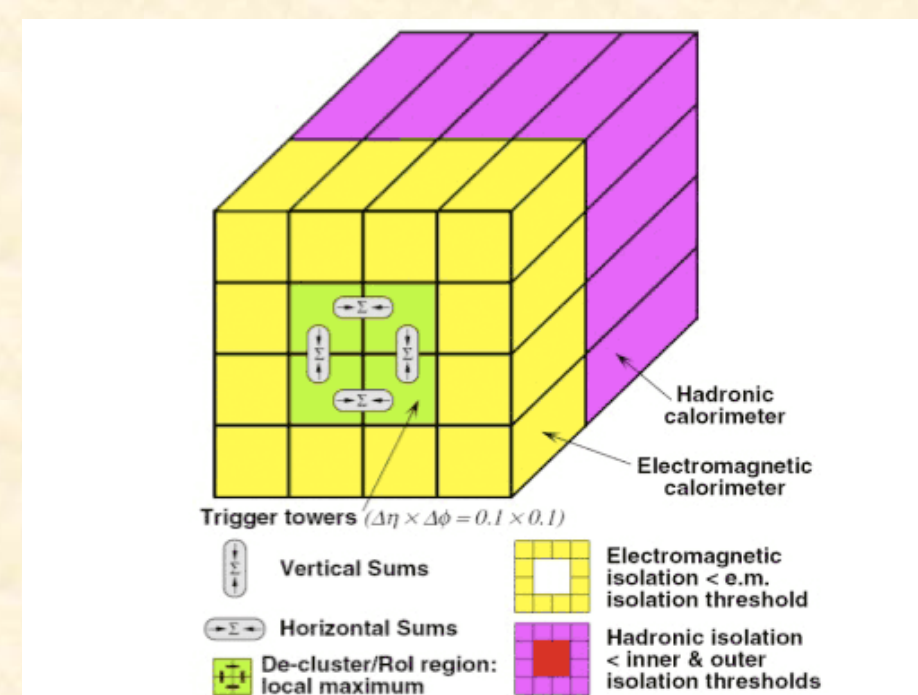


One of the discriminating L2 variables plotted against the number of interactions per bunch crossing with and without $\Delta z_0$ cut.

## Tau trigger efficiency

If physics analyses want to use a tau trigger it is necessary to know the efficiency of this trigger. The efficiency is defined as the probability of a reconstructed and identified offline tau to pass the trigger.

To measure this efficiency on data a $Z \rightarrow \tau\tau \rightarrow \mu\nu_\tau\bar{\nu}_\mu \tau_{had}$ **tag-and-probe method** can be used. In this decay the isolated muon is used to tag the process while the hadronically decaying tau can be used to probe the tau trigger performance. To reject the main backgrounds, W+jets and QCD, requirements on the transverse mass m$_T$ ($m_T = \sqrt{2p_T^l \cdot E_T^{miss}(1-\cos\Delta\phi(l, E_T^{miss}))}$), the angle between the objects, the visible mass and further values are set.

The two plots show the dependency of the trigger efficiency on the $p_T$ of the offline tau and the number of primary vertices (pile-up). Due to the changes in 2012 no significant loss of efficiency in high pile-up events is observed.

The trigger used in these plots has a $p_T$ threshold of 20 GeV (11 GeV at L1), a requirement on the calorimeter isolation and three or less tracks. On EF level and for the offline selection a BDT algorithm was used.
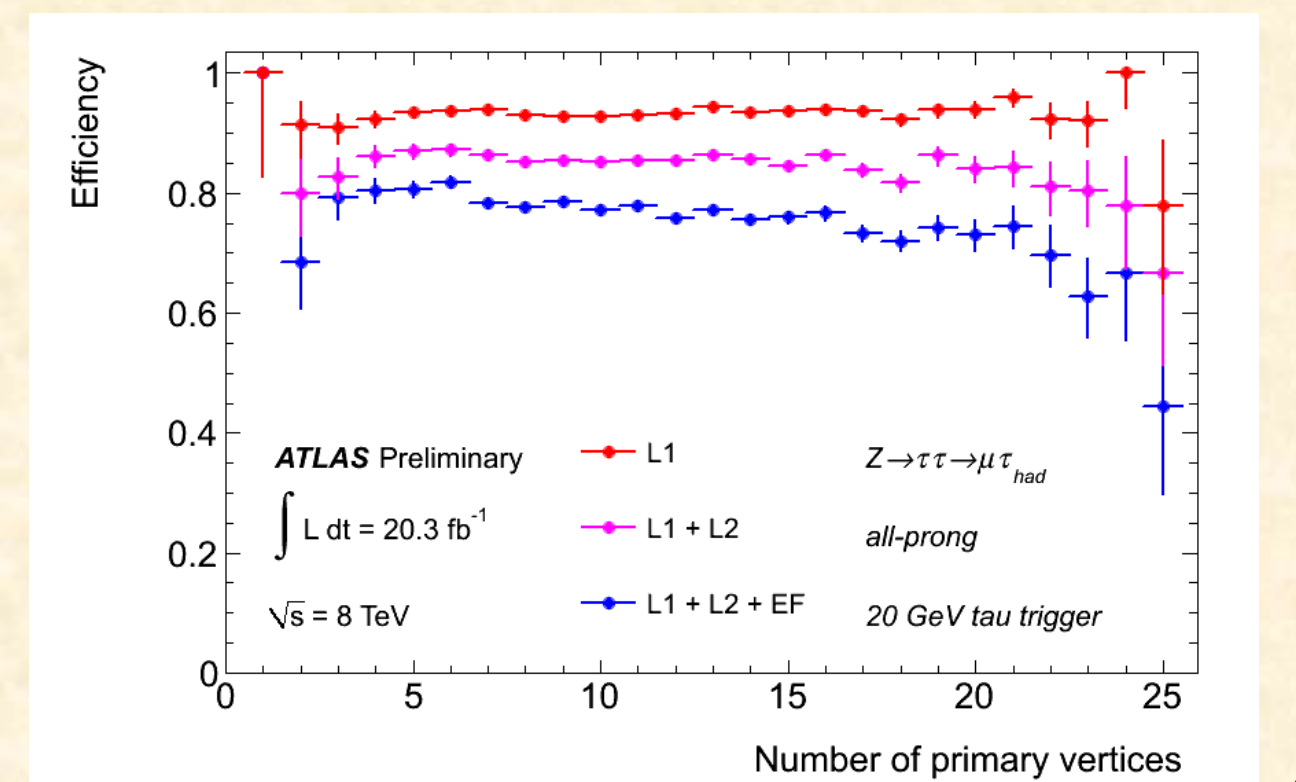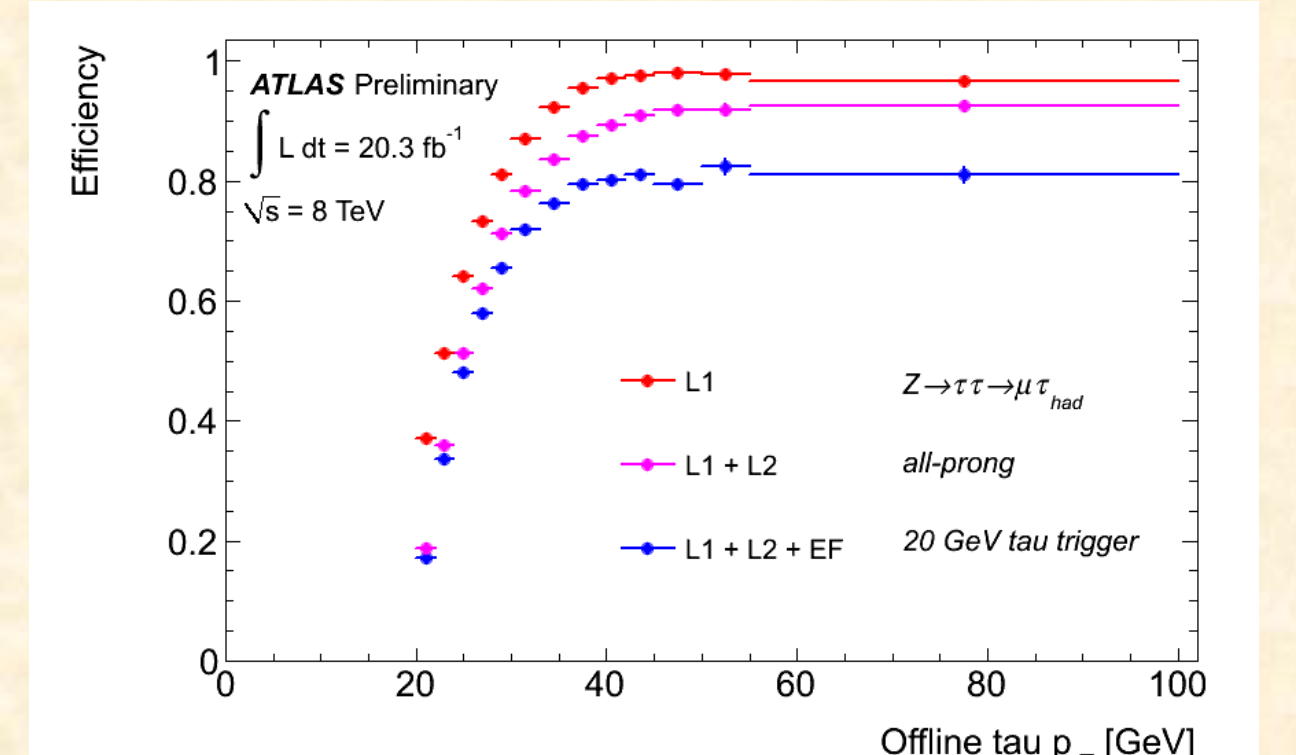




## Tau trigger menu & rates 2012

To keep interesting events with taus of low energy, it is necessary to add additional requirements due to the high rates.

Therefore different combinations of triggers (di-tau, taus with muons, electrons and missing energy) were used in the 2012 menu (only the triggers which ran the whole year are shown):

| | Chain |
|---|---|
| single τ | tau 125 GeV |
| di − τ | isolated tau 29 GeV + isolated tau 20 GeV |
| | tau 38 GeV + tau 38 GeV |
| τ + μ | tau 20 GeV + muon 15 GeV |
| τ + e | isolated tau 20 GeV + electron 18 GeV |
| | tau 38 GeV + electron 18 GeV |
| τ + MET | isolated tau 29 GeV + missing transverse energy 55 GeV |

The trigger rates, for single and combined tau triggers, at EF as a function of the instantaneous luminosity are shown.
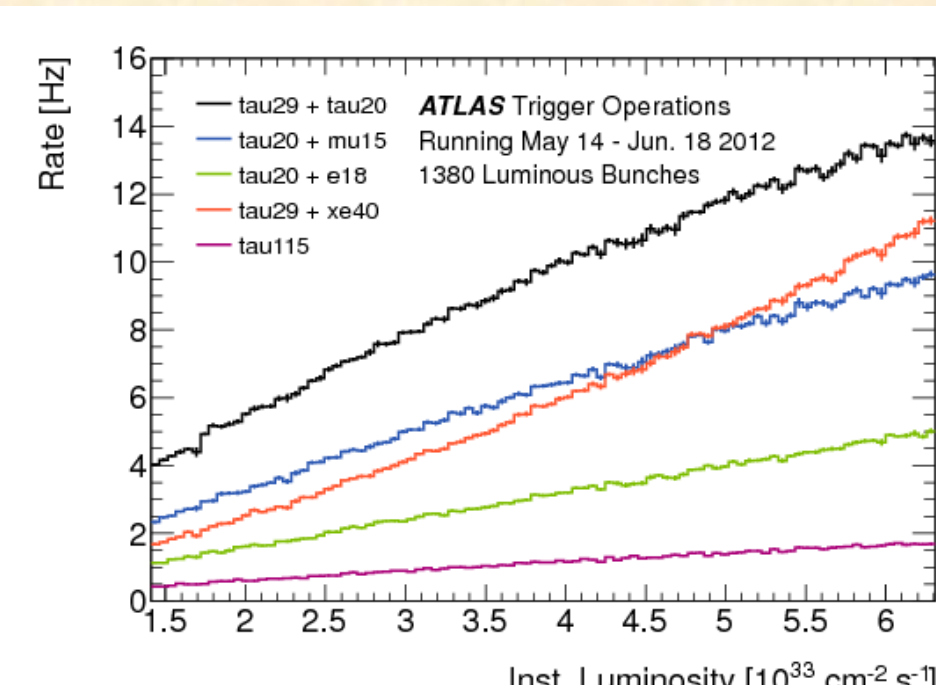


## Taus in Higgs searches & outlook

As an example for physics analyses using a tau trigger, the di-tau trigger is chosen which is especially interesting for the H-> ττ search. This ATLAS event display shows an event candidate for a H-> ττ decay. It contains two hadronically decaying taus, MET and an additional jet.



### Outlook

After the first long shutdown of the LHC, the bunch crossing rate will be increased by a factor of two. Having such a high rate combined with a high instantaneous luminosity, it will be challenging to keep the tau trigger rates low without increasing the thresholds significantly. Therefore new techniques are studied:
- Adding requirements on the event topology for multi-object triggers at L1
- Using topological energy clustering at an earlier stage to improve the energy resolution
- Implementing the Fast Tracker (FTK) which will provide a global track reconstruction before L2