The ATLAS hadronic tau trigger

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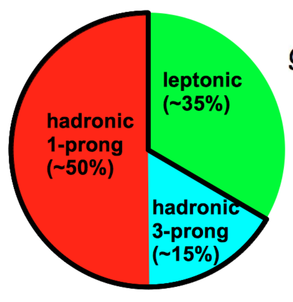
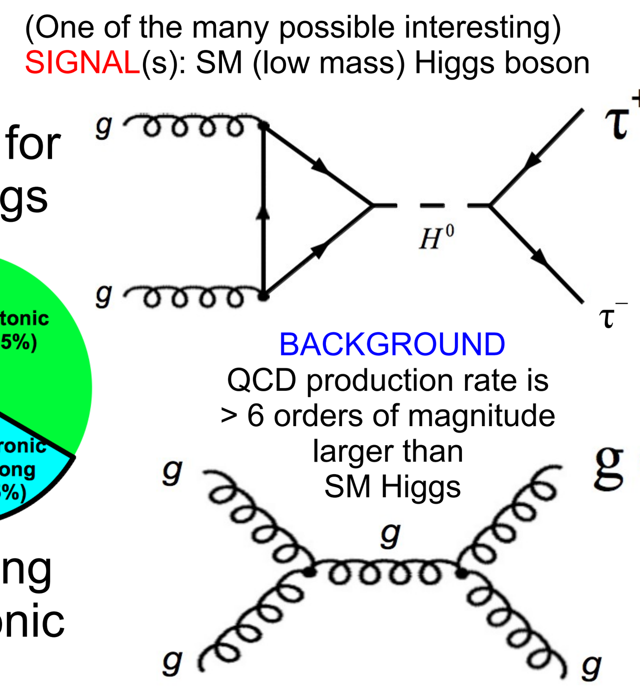
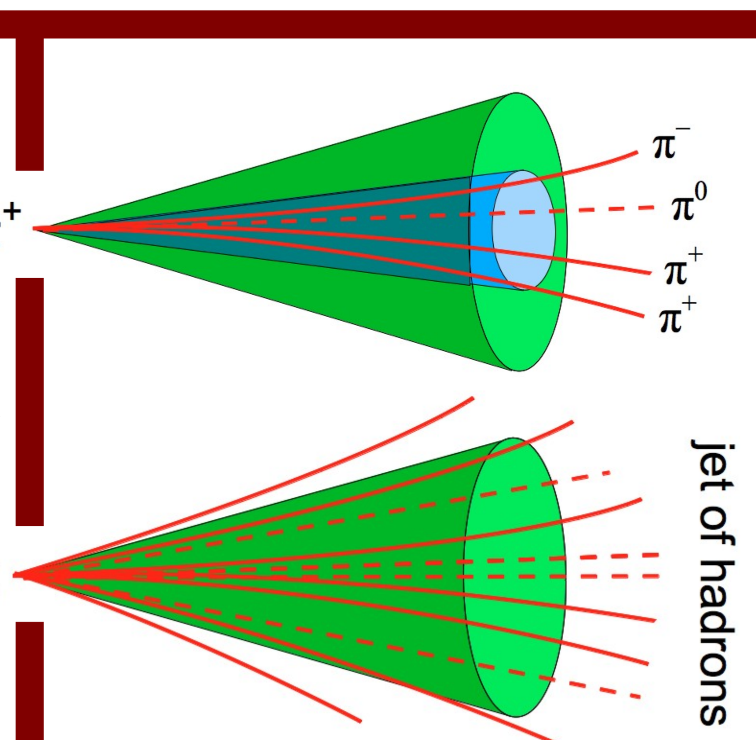
① Motivation

Tau leptons play an important role in many searches for new physics (NP) at the LHC, including the elusive Higgs boson. The Standard Model (SM) predicts a Higgs in the mass range of 100-125 GeV, which would decay in tau lepton pairs with branching fraction of 10%. Tau leptons decay to a large variety of modes, categorised as leptonic, 1-prong hadronic or 3-prong hadronic. Jets from QCD processes are an overwhelming background to hadronic taus. Thus, a dedicated hadronic tau trigger is imperative.







② Hadronic taus vs QCD jets

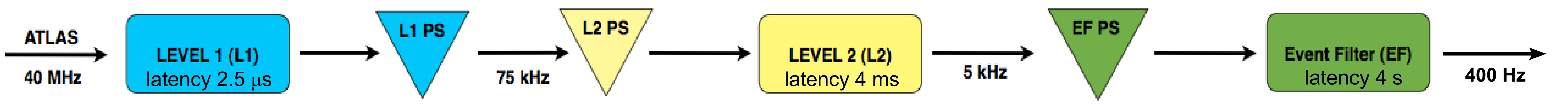
A typical hadronic tau decay contains 1 or 3 charged hadrons, neutral hadrons, and a tau-neutrino (that escapes detection).

Features that help to distinguish hadronic taus from QCD jets are:

- ► low track multiplicity;
- ► the particles from the tau decay form a narrow, well collimated jet;
- ► isolation: there is no activity around the narrow cone that contains the tau-candidate decay products.

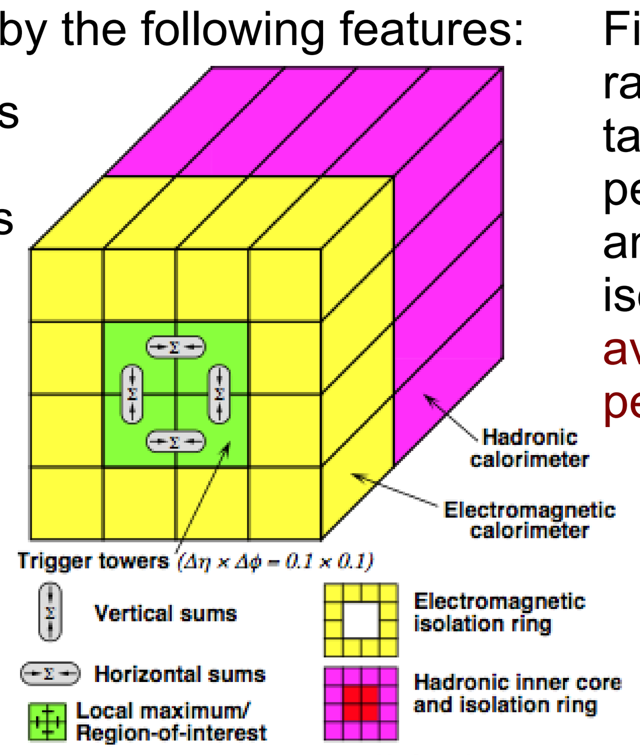
③ Tau trigger configuration

The ATLAS trigger identifies interesting events along three levels of increasing data-analysis complexity. The level 1 (L1) is hardware-based; it identifies geometrical Regions of Interest (RoI) using coarse granularity detector information. The software based level 2 (L2) analyses the RoIs using fast and specialized algorithms with partial event read-out. At the filter (EF) level, detailed reconstruction is performed with algorithms similar to those used offline.



The L1 tau trigger uses electromagnetic (EM) and hadronic (HAD) calorimeter trigger towers with granularity $\Delta\eta\times\Delta\varphi$ = 0.1×0.1. At L1, hadronic tau decay modes are identified by the following features:

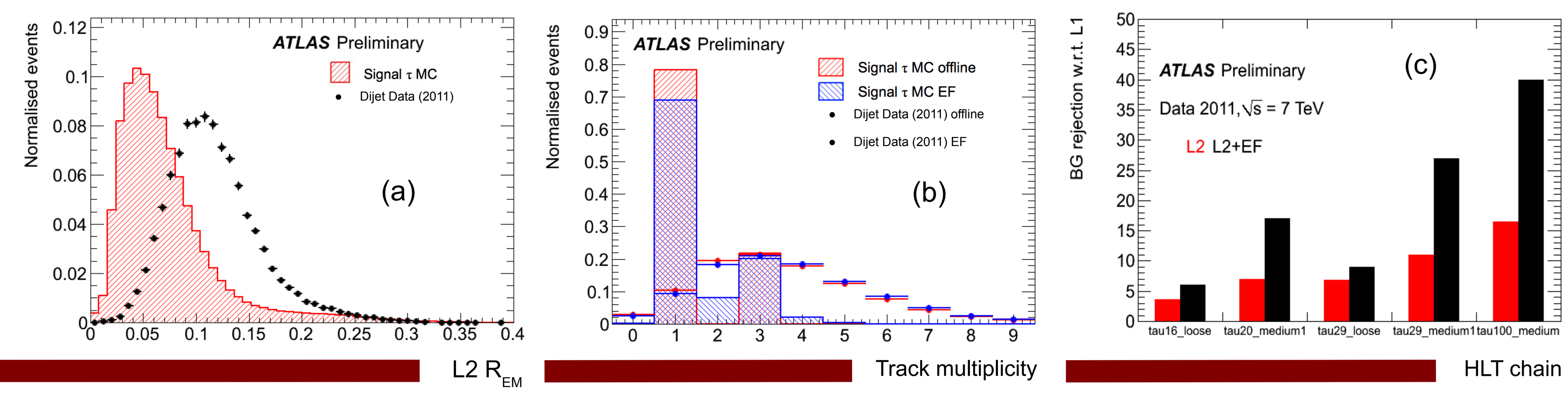
- ■ sum of energy in 2×1 pairs of EM towers;
- ■ energy in 2×2 HAD towers behind the EM cluster;
- ■ energy in a 4×4 isolation ring around the 2×2 core.



The L1 efficiency and rate can be tuned by adjusting the threshold on the transverse energy (E_T) of the 2×2 core, and the maximum allowed energy in the isolation ring.

The L2 calorimeter algorithm refines the position of the RoI and obtains the total E_T and shape variables using full detector granularity within a region $\Delta\eta\times\Delta\varphi$=0.8×0.8. Fig. (a) compares the EM-radius (L2 energy-weighted radius of the shower in the EM calorimeter) for signal taus and QCD jets. Track reconstruction is first performed at L2, with fast algorithms. Track counting and track-based isolation use tracks found in core and isolation regions of radii 0.1 and 0.3 respectively. To avoid efficiency loss due to large numbers of interactions per beam bunch crossing (pile-up) in 2012 (see ④), the size of the region used for the calculation of E_T and other shower shape variables was reduced to $\Delta\eta\times\Delta\varphi$ = 0.4×0.4, and only tracks with compatible impact parameters ($|\Delta z|$ < 2 mm) with the leading track are used.

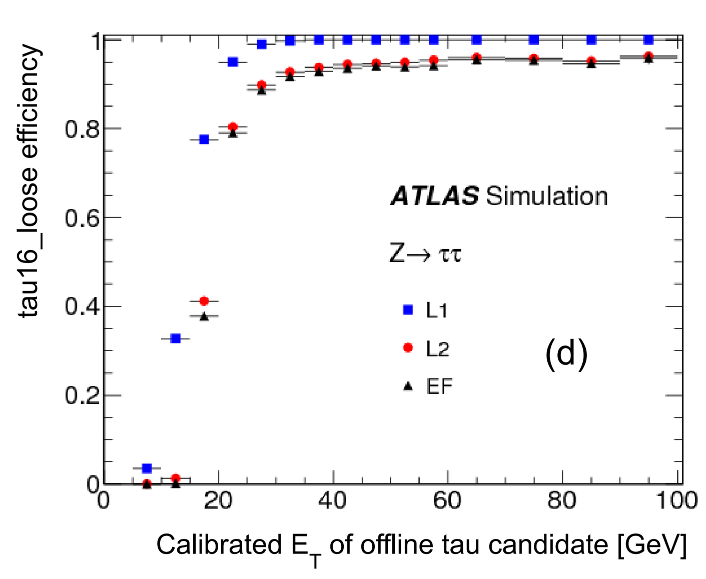
The EF trigger selects taus based on track multiplicity and shape variables calculated using offline tau track and calorimeter algorithms, with high discrimination power. Very good correlation with offline variables is achieved *e.g.* Fig. (b) for the track multiplicity. Fig. (c) shows the QCD jet rejection at L2 and L2+EF for trigger chains with *loose* or *medium(1)* identification (ID). For 2012, pile-up robust criteria *e.g.* track Δz, were also implemented at EF. Also new in 2012, multivariate (MV) techniques, similar to those used offline, were implemented to identify taus at the EF: Boosted Decision Trees (BDT), and Log-Likelihood (LLH).



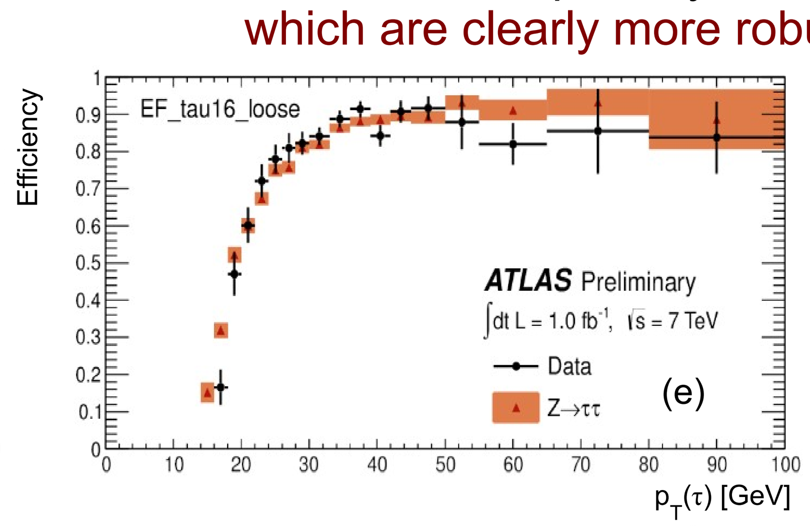
④ Tau trigger efficiencies

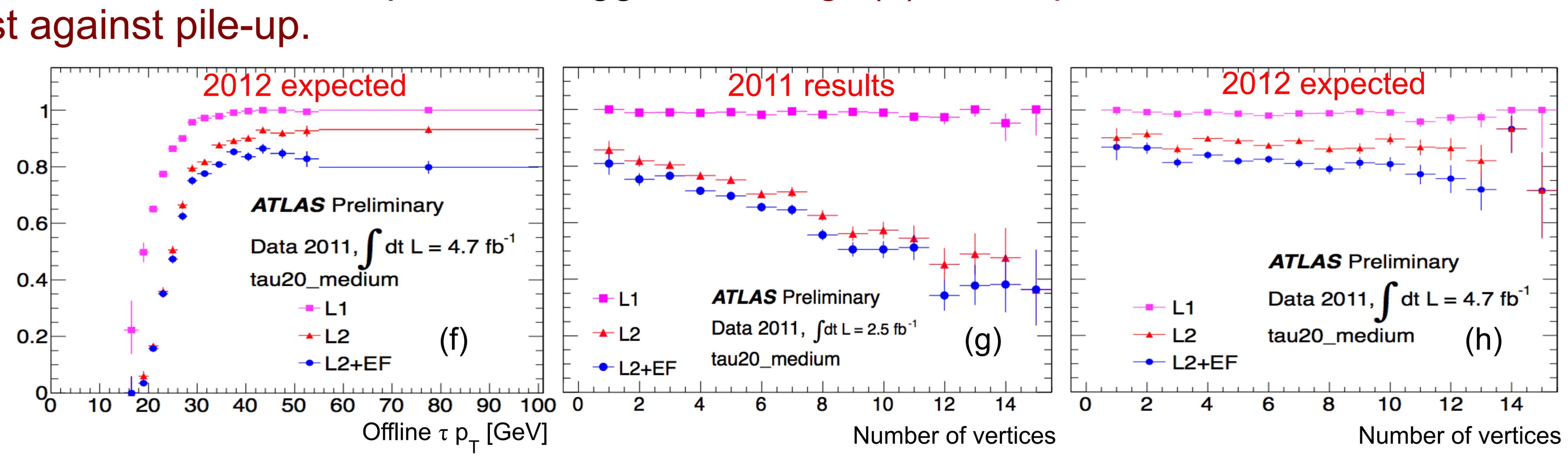
The tau trigger efficiency is measured with various methods, that use orthogonal triggers (electron, muon, etc.). The tau trigger efficiency is defined as the probability that an offline identified tau passes the corresponding trigger requirements.

Fig. (d) shows the trigger efficiency as determined with **MC** in $Z \to \tau\tau$ events for the EF tau trigger with 16 GeV E_T threshold and *loose* identification criteria. The L1 item that seeds this trigger has 6 GeV E_T threshold and no isolation requirement, so the L1 efficiency is 100% at the plateau. At L2 and EF there are ID criteria to reject QCD jets; the efficiency drops to ~95%.



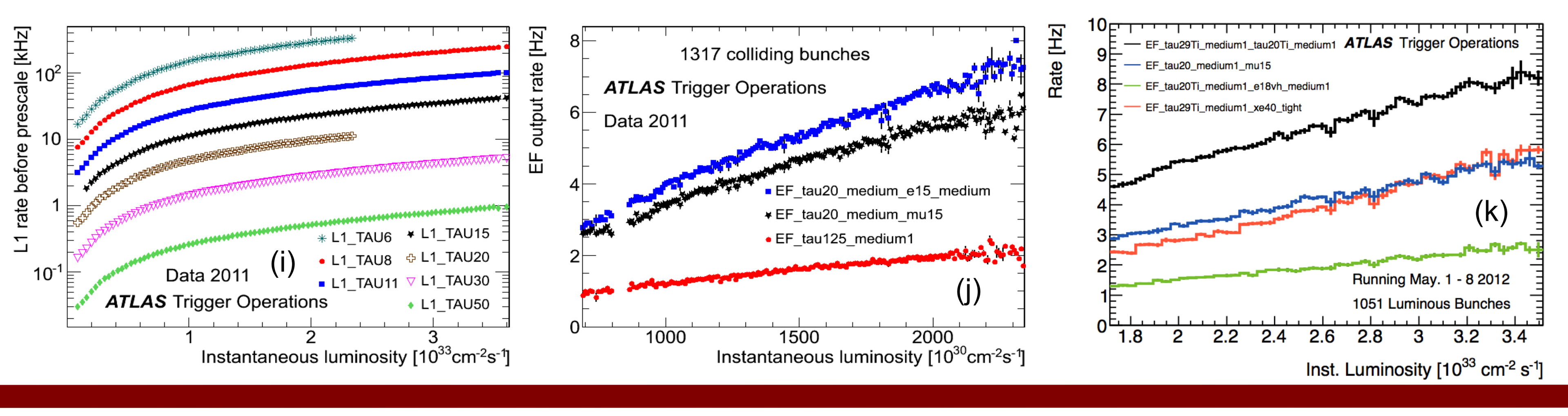
The tag-and-probe method is used in an unbiased sample of $\boldsymbol{Z \to \tau(\mu)\tau(had)}$ **data** events selected with a single muon trigger. Fig. (e) compares the measured efficiency in data and MC for the same EF trigger as in Fig. (d). Fig. (f) shows the expected efficiencies in 2012 w.r.t. offline taus identified by the BDT (with *medium* criterion), for the *tau20_medium* trigger (which in 2012 uses BDT at EF). Fig. (g) shows the efficiencies vs. the number of reconstructed primary vertices in 2011 for the equivalent trigger, and Fig. (h) the expected efficiencies in 2012 which are clearly more robust against pile-up.





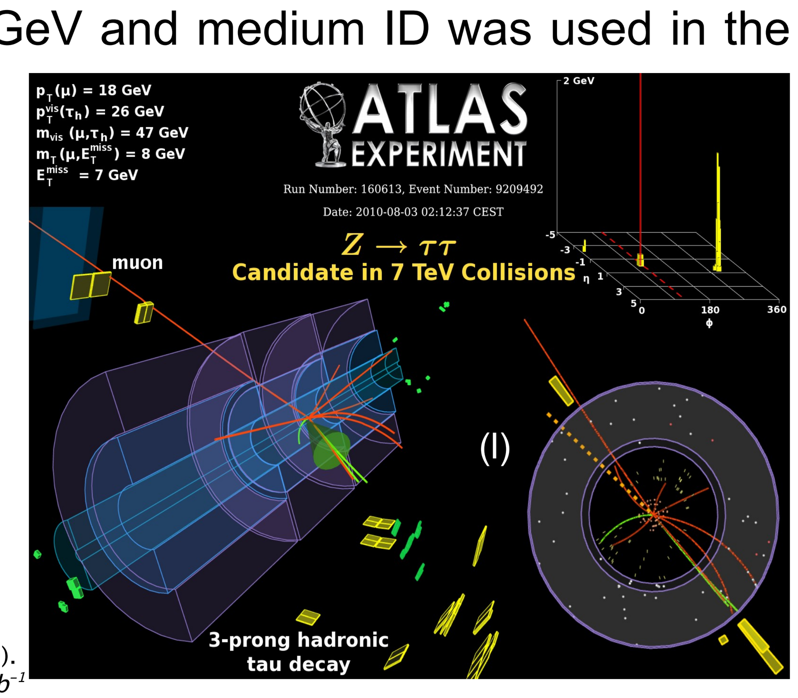
⑤ Tau trigger rates

The instantaneous luminosity of the LHC is constantly increasing, and with it the trigger rates follow. To keep the rates within bandwidth, different strategies can be applied: increase the E_T thresholds, include isolation, tighten the ID criteria. Fig. (i) shows the evolution of the L1 rates with the instantaneous luminosity for several tau trigger L1 items with different E_T thresholds. The rates scale linearly with the instantaneous luminosity. Similar behaviour is observed at EF (Fig. (j)) for combined triggers (⑥), where the rate has decreased to ~5 Hz thanks to the efficient L2 and EF identification algorithms. Early 2012 rates are shown in Fig. (k) for some of the combined triggers available for physics analyses with taus. All improvements previously mentioned for the 2012 run were included; resulting rates are within the rate restrictions for the full 2012 run.



⑥ Physics with taus

In order to reduce rates and improve the sensitivity of NP searches with hadronic taus, hadronic tau triggers are combined with other signature triggers (*e.g.* electron, muon, missing-E_T, a second hadronic tau) depending on the physics analysis. *E.g.*: *a)* a tau+missing-E_T trigger with 16 GeV tau E_T threshold and loose ID was used in the tau polarization measurement in $W \to \tau\nu$ decays [1]; *b)* a di-tau trigger with asymmetric E_T thresholds of 29 GeV and 20 GeV and medium ID was used in the search for the SM Higgs in the double hadronic tau decay channel [2]. Combined triggers also help to keep energy thresholds low, increasing the signal acceptance. Fig. (l) shows an event display of a $Z \to \tau(\mu)\tau$(had) decay candidate recorded by ATLAS in 2010. The hadronic tau candidate has three well identified tracks, and the muon and tau candidates have opposite sign reconstructed charges.



[1] "Measurement of τ Polarization in $W \to \tau\nu$ Decays with the ATLAS detector in pp Collisions at sqrt(s) = 7 TeV", The ATLAS Collaboration, CERN-PH-EP-2012-075, (arXiv:1204.6720).
[2] "Search for the Standard Model Higgs boson in the $H \to \tau^+\tau^-$ decay mode with 4.7 fb^{-1} of ATLAS data at sqrt(s) = 7 TeV", The ATLAS Collaboration, ATLAS-CONF-2012-014, March 2012.