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First Results of Z to tau tau studies in CMS

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Abstract

Studies of Z bosons decaying to taus constitute a test of the Standard Model in the new energy regime as well as a benchmark process for Higgs searches. This paper describes the first results of Z to tau tau studies performed with 1.7 pb^{-1} of data collected with CMS detector up to end of Summer 2010.

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First observation of $Z \rightarrow \tau^+\tau^-$ production in pp collisions with CMS at $\sqrt{s} = 7$ TeV

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Studies of Z bosons decaying to τ leptons constitute a test of the Standard Model(SM) in the new energy regime as well as a benchmark process $H \rightarrow \tau^+\tau^-$ searches. This paper describes the first results of $Z \rightarrow \tau^+\tau^-$ studies performed with 1.7 pb^{-1} of data collected with CMS detector up to end of Summer 2010.

1. Introduction

Measurement of $Z \rightarrow \tau^+\tau^-$ production cross section is an important part of the CMS [1] electroweak physics programme. Comparison to the electron and muon channels constitutes a test of lepton universality in the new energy regime probed by the LHC. Since Higgs boson couples to mass and tau is the heaviest lepton, excess of events in the tau final state could result in the evidence of Higgs bosons decaying to taus. Therefore, $Z \rightarrow \tau^+\tau^-$ is a dominant background and also an important benchmark point for future $H \rightarrow \tau^+\tau^-$ searches as well.

This analysis uses final states where one tau decays to hadrons and a neutrino and the other one to a muon and two neutrinos. This final state corresponds to 22.6% of the di-tau branching ratio. The study is performed with data collected up to the end of August 2010 corresponding to an integrated luminosity of 1.7 pb^{-1} .

2. Particle Flow reconstruction and tau identification

Particle Flow(PF) [2] reconstruction is designed to provide a unique event description by combining data from all sub-detectors. The PF algorithm combines tracks and calorimeter clusters to form particle candidates that can be used for building composite objects such as taus, jets and E_T^{miss} . In addition, particle flow candidates

can be used for lepton isolation by using the combined particle deposits around the leptons.

The majority of the tau identification algorithms uses particle flow reconstruction to build the hadronic tau objects [3]. Hadronic taus decay dominantly to single charged hadrons (π , K), to $\pi^+\pi^0$ via the $\rho(770)$ resonance and to three charged pions via the a_1 resonance. The aim of the hadronic tau ID is to reconstruct those meson final states.

Figure 1. HPS Tau ID fake rates as measured in data and comparison to PYTHIA 6 simulation.

Figure 2. Muon and tau transverse momenta after preselection. Good agreement is observed between data and simulation.

In this analysis, the Hadrons Plus Strips (HPS) algorithm is used. HPS accounts for the material effects by describing the neutral pions as strips of electromagnetic energy to account for bremsstrahlung and bending of electrons coming from photon conversions. After strips are created, the algorithm combines strips and PF charged hadrons to create the tau objects. Three combinations are allowed:

- Single hadron (π, K)
- Hadron plus strip ($\rho(770)$)
- Three hadrons (a_1)

After reconstructing the intermediate mesons, a narrowness criterion is applied. Hadronic taus are expected to be very narrow due to the boost of the decay products in the lab frame. The narrowness criterion requires:

$$\text{cone}(\Delta R) \leq \frac{2.8}{p_T}, \quad (1)$$

where $\text{cone}(\Delta R)$ is the opening ΔR cone of the decay products and p_T is the hadronic tau transverse momentum (in GeV/c). The cone is not allowed to exceed 0.1 or be smaller than 0.07.

The final step of the HPS Tau ID is isolation. Isolation is applied in a solid cone of $\Delta R = 0.5$ around the reconstructed tau axis after removing the tau constituents. Three isolation working points are provided that achieve a jet fake rate of 1% (loose), 0.3% (medium) and 0.15% (tight). Figure 1 shows the fake rates as measured in data for the three HPS working points and comparison to PYTHIA 6 [4] simulation. There is an average 30% underestimation of the fake rate by the simulation for the current MC tune. This study used the loose isolation working point.

3. Event selection

Events are required to pass a single muon trigger with a transverse momentum threshold of 9 GeV/c in the high level trigger (HLT). This trigger path utilizes full muon reconstruction in the tracker and the muon system starting from a L1 muon trigger requirement with $p_T > 7 \text{ GeV}/c$. Offline, the muon is required to have $p_T > 10 \text{ GeV}/c$ and to be within $|\eta| < 2.1$. The HPS PF Tau is required to have a transverse momentum above 15 GeV/c and to be within $|\eta| < 2.4$. Before applying tight selection requirements, data vs simulation agreement is examined. Figure 2

shows the transverse momenta of muons and taus before applying isolation. As expected the sample is dominated by jets. In this case a muon is faked by a heavy flavour decay or a π, K decay in flight and the tau is faked by a jet. Good agreement is observed between data and simulation regarding the kinematics. The second dominant background in this analysis comes from W + jets. In the W + jets case there is an isolated energetic muon produced from the W decay and a jet that fakes the tau. The characteristic of those events is the high missing E_T and the compatibility of the muon and the missing E_T with the W . To dis-

Figure 3. Transverse mass of muon and E_T^{miss} . Agreement between data and simulation observed for the W enriched (high M_T) region.

criminate against W + jets, the transverse mass of the muon and E_T^{miss} is formed:

$$M_T = \sqrt{2 \cdot p_T^\mu E_T^{miss} (1 - \cos \phi)}, \quad (2)$$

where p_T^μ is the muon transverse momentum, E_T^{miss} is the missing transverse energy and ϕ is the acoplanarity angle between the muon and the E_T^{miss} transverse momentum vectors. Figure 3 shows the M_T distribution for the preselected

sample. The high M_T region is dominated by W and a good agreement with simulation is observed. For W + jets suppression, a selection requirement of $M_T < 40 \text{ GeV}/c^2$ is applied.

Figure 4. Comparison of the particle-based and sub-detector based isolation for prompt muons coming from tau decays and non prompt muons from decays in flight and heavy quark decays.

4. Muon isolation

Isolation is the most efficient discriminator against QCD background. Energetic muons from tau decays are expected to be isolated in the detector while muons produced from decays in flight or heavy flavour cascades are expected to be inside jets. Muon isolation was performed using a combination of tracks and calorimeter deposits. For this study a new particle based approach [5] was proposed. To compute muon isolation all particles that are reconstructed by Particle Flow are used. Particle transverse energies are summed for charged and neutral particles in a cone of $\Delta R = 0.4$ around the muon. Relative combined isolation is defined as the sum of the particle deposits divided by the transverse momentum of the

muon

$$I_{rel}^{PF} = \sum \left(p_T^{charged} + E_T^\gamma + E_T^{neutral} \right) / p_T^\mu, \quad (3)$$

The particle based approach is expected to provide better discrimination power due to the fact that the calorimeter deposits of the tracks are not double-counted. The PF algorithm associates the calorimetric deposits to the charged hadrons and only deposits non compatible with the tracks, result in neutral particles.

Figure 3 shows a comparison of particle based and sub-detector based isolation for prompt muons coming from tau decays and non prompt muons from decays in flight and heavy quark decays using MC simulation. Deploying particle based isolation results in background reduction by a factor of 1.5 to 2 for the same signal efficiency. For the $Z \rightarrow \tau^+\tau^-$ analysis a selection requirement of $I_{rel}^{PF} < 0.1$ is applied.

Figure 5. Visible mass of muon and hadronic tau after all selection requirements.

5. $Z \rightarrow \tau^+\tau^-$ reconstruction

For the final event selection muon and tau isolation are applied and the thresholds of the leptons

are raised to $P_T^\mu > 15$ GeV/c and $P_T^\tau > 20$ GeV/c for muons and hadronic taus respectively. The final result is depicted in Figure 4. A clean $Z \rightarrow \tau^+\tau^-$ peak is observed in the visible mass spectrum that consists of 22 data events. For the processed integrated luminosity of 1.7 pb $^{-1}$, 22 events are expected (signal and background) with expected purity of 75%.

6. QCD background estimation from SS data

Due to the existence of three neutrinos in the final state the visible mass peak extends in the range 30-100 GeV/c 2 , therefore all background contributions peak under the signal.

Figure 6. Comparison of OS and SS data for the QCD enriched region.

For a precise extraction of the signal yield efficient background estimation techniques are essential. The low accumulated statistics of this initial sample did not allow for data-driven estimation of all background contributions however a first cross check is performed on estimation of QCD from the same sign data (SS). The yield of the SS

events in data, for the QCD background, is expected to agree with that of the OS events. This agreement is verified in a QCD enriched control region which is selected by dropping the isolation requirement. Figure 6 shows the visible mass distribution of OS and SS data for the QCD enriched region. The visible mass shapes are in agreement and small excess is observed for the OS case. The OS/SS ratio is measured to be:

$$f^{os/ss} = 1.03 \pm 0.01(stat) \quad (4)$$

which agrees with the expected value from the simulation (1.036 ± 0.002).

7. Conclusions

A first convincing $Z \rightarrow \tau^+\tau^-$ signal has been established using 1.7 pb^{-1} of data collected with CMS up to end of August 2010. This early observation constitutes a proof of excellent performance of the CMS detector, particle flow reconstruction and tau identification in real data and a first step towards the measurement of the $Z \rightarrow \tau^+\tau^-$ cross-section and searches of new particles decaying to taus.

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