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Status and performances of physics objects at $\sqrt{s}$ = 13 TeV for CMS

Tae Jeong Kim on behalf of the CMS collaboration*
Hanyang University
E-mail: taekim@hanyang.ac.kr

The Large Hadron Collider (LHC) at CERN started the data taking at the center of mass energy 13 TeV in June 2015. After the higgs discovery, the phase of searching for higgs boson have been moved to searching for the possible new physics which might explain what the standard model can not explain such as dark matter. A top quark is believed to have a hint in this journey. To accomplish this goal using a top quark, we need to understand our detector beforehand at the new center of mass energy with the physics objects. The decay products from a top quark contain most of all physics objects we identify in our detector. We present the status and performance of physics objects with data corresponding to an integrated luminosity of 42 pb^{-1} collected at $\sqrt{s}$ = 13 TeV by the CMS experiment during the summer in 2015.

8th International Workshop on Top Quark Physics, TOP2015
14-18 September, 2015
Ischia, Italy

*Speaker.

PoS(TOP2015)004

1. Introduction

The Compact Muon Solenoid (CMS) experiment [1] at the Large Hadron Collider (LHC) has collected the proton-proton collision data corresponding to an integrated luminosity of around 42 pb^{-1} (after data qualification and with magnetic on condition) with 50 ns crossing time at the center of mass energy 13 TeV during the summer in 2015. After the higgs discovery, the phase of searching for higgs boson have been moved to searching for the possible new physics which might explain what the standard model can not explain such as dark matter. A top quark is believed to have a hint in this journey. To accomplish this goal using a top quark, we need to understand our detector beforehand at the new center of mass energy with the physics objects. The decay products from a top quark contain most of all physics objects we identify in our detector. We present the performances of all physics objects from the top decay.

2. Event Reconstruction

The particle-flow event algorithm [2] reconstructs and identifies each individual particle with an optimized combination of information from the various elements of the CMS detector. The energy of photons is directly obtained from the ECAL measurement, corrected for zero-suppression effects. The energy of electrons is determined from a combination of the electron momentum at the primary interaction vertex as determined by the tracker, the energy of the corresponding ECAL cluster, and the energy sum of all bremsstrahlung photons spatially compatible with originating from the electron track. The energy of muons is obtained from the curvature of the corresponding track. The energy of charged hadrons is determined from a combination of their momentum measured in the tracker and the matching ECAL and HCAL energy deposits, corrected for zero-suppression effects and for the response function of the calorimeters to hadronic showers. Finally, the energy of neutral hadrons is obtained from the corresponding corrected ECAL and HCAL energy.

3. Jets/MET

Jet momentum is determined as the vectorial sum of all particle described in Section 2 momenta in the jet, and is found from simulation to be within 5% to 10% of the true momentum over the whole p_{T} spectrum and detector acceptance. The resolution can be worsen due to pileup events. For Run 2 data taking period, a typical event is expected to contain 40 additional pileup events on average while it contains 20 pileup events for run 1 period. To mitigate this pileup effect, there are multiple techniques available for Run 2 such as constituent subtraction, jet cleansing and pileup per particle identification (PUPPI) [3]. Among them, PUPPI is the one of the promising methods which can be used for Run 2 analyses. The method is based on the vertex information to distinguish pileup-like radiation. Based on the fact that pileup events have uncorrelated particles from the vertex while the particles from a hard physics process are likely to be near each other, the shape α is defined. Based on α, a weight is assigned to each particle and is used to rescale their four-momentum of the particle before clustering as a jet.

In the standard model measurements, jets are clustered from objects reconstructed with parameter r = 0.4 for Run 2 while for the boosted region, the parameter of r = 0.8 is used. For the

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jets in boosted region, the PUPPI algorithm is compared with two other pileup mitigation methods: Charged Hadron Subtraction (CHS) removing charged particles associated with pileup vertices and Soft Killer (SK) [4]. Figure 1 (left) shows that PUPPI has a good stability as a function of pileup vertices [5].

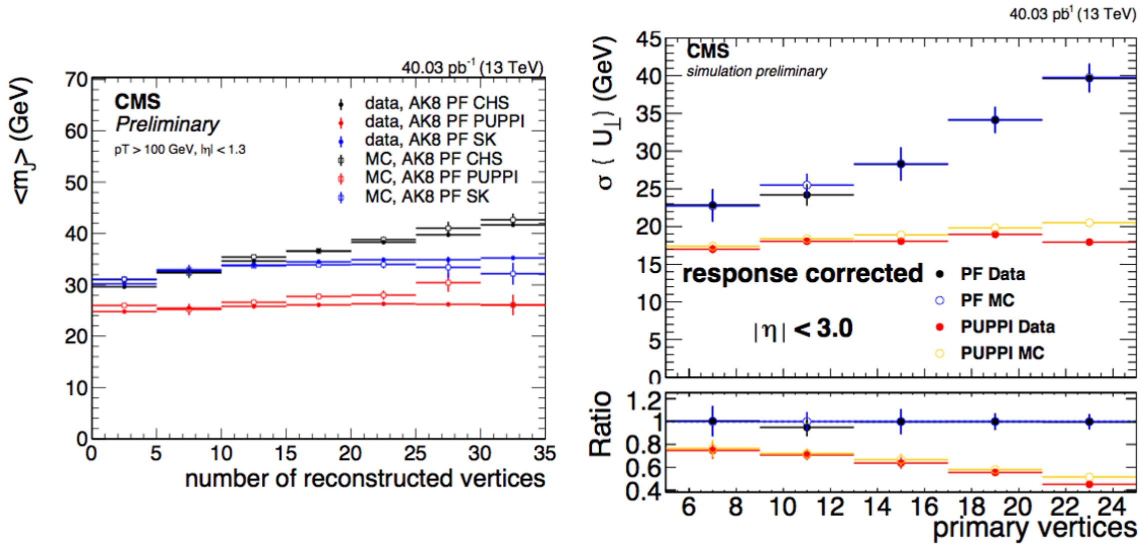

Figure 1: The resolution of AK8 ungroomed jet mass (left) and the recoiling transverse energy (right) s a function of number of pileup events comparing CHS, SK and PUPPI.

The default missing transverse energy in the transverse plane (MET) is reconstructed by the vector sum of all particle-flow particles in the opposite direction. Determination of the MET using multivariate analysis (MVA) technique plane was developed during run 1 period to suppress pileup contributions by making use of additional knowledge about the event. MVA technique is applied to Run 2 data and compared with the default PF MET. The resolution of the recoiling transverse energy treating the Z boson as MET for the default and PUPPI algorithm is shown Fig 1 (right). The plot shows that the PUPPI works well and have a good modeling with Run 2 data.

4. b-tagging

Details about b-tagging in CMS collaboration can be found in Refs. [7, 8]. The improved Combined Secondary Vertex algorithm (CSVv2) uses a multivariate analysis technique to combine variables based on track and secondary vertex information. The CSVv2 algorithm is the best performing b-tagging algorithm in the CMS collaboration, as can be seen from the left panel in Fig 2. The scale factor of data over the simulated b-tagging efficiency is obtained from Run 2 data events. An uncertainty of 5 to 9% on this scale factor is obtained for jets with a transverse momentum between 30 and 300 GeV for the medium working point, which is a requirement on the minimum CSVv2 value that corresponds to a probability of 1% to misidentify a non-b jet [9]. For searches beyond the SM at a high mass scale, physics objects are produced with a momentum considerably higher, resulting in its decay products to be collimated into a single reconstructed *fat* jet. A new double b-tagging algorithm was developed that exploits the presence of two B hadrons within a fat jet. This algorithm uses a Boosted Decision Tree (BDT) and is trained using as signal events simulated radion events decaying to 2 Higgs bosons each decaying to a pair of b quarks. For the background events, simulated QCD multijet events were used. The input variables combined in the BDT are based on tracks, secondary vertices and soft leptons present in the fat jet. The double b-tagging algorithm performs better on boosted topologies with two b quarks reconstructed as a single fat jet than subjet or fat jets b-tagging with the CSVv2 algorithm [10].

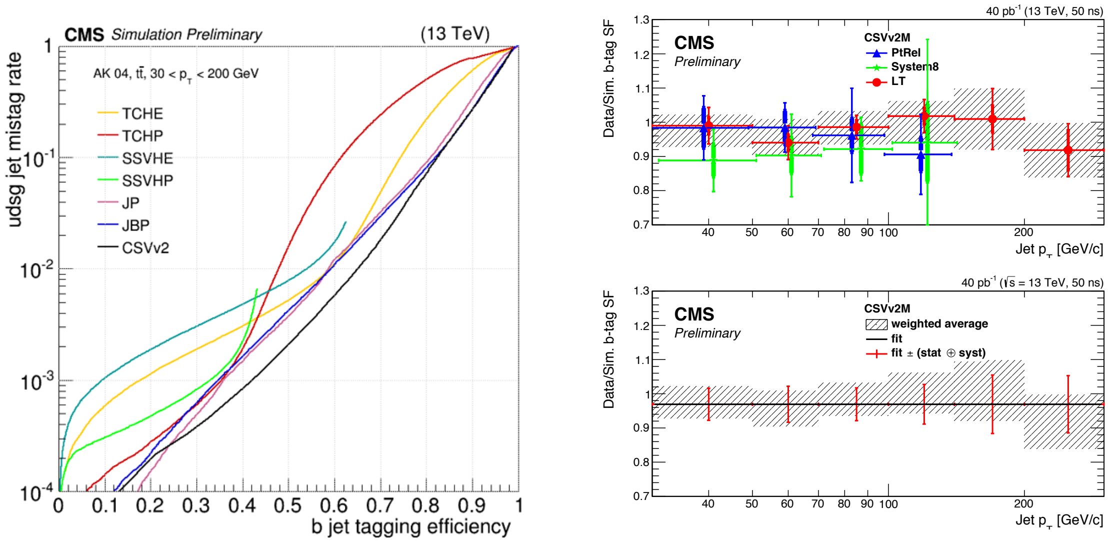

Figure 2: Comparison of the performance of different b-tagging algorithms available in the CMS collaboration. Signal efficiency and mistagging efficiency for light jets are evaluated in $t\bar{t}$ events (left). Scale factor to correct the simulated b-tagging efficiency is obtained for three different methods (upper right). The combined scale factor is also shown (lower right).

5. Muons

The Run 2 reconstruction improves the average tight identification [11] efficiency by $1-2\%$, in particular, in high pileup events thanks to the improved track reconstruction algorithm [12]. The muon selections are at least one pair of two opposite-signed muons with loose identification criteria [11]. The muon should pass $p_T > 20$ (10) GeV for the first (second) leading muon and $|\eta| < 2.4$. To remove the QCD contribution, the isolation criteria of the sum of the transverse momentum of charged hadrons, neutral hadrons and photons within $\Delta R < 0.4$ with respect to the direction of the pivotal muon object divided by muon p_T is used and should be less than 0.2 after removing the pileup contribution. Figure 3 (left) shows a good agreement between data and MC in dimuon invariant mass spectrum [12]. The pileup mitigation in the isolation using the particle flow candidate weighted by the PUPPI algorithm was compared with the $\delta\beta$ correction to subtract pileup neutral contribution rescaling from tracks associated to pileup vertices (while CHS for charged hadrons from pileup). PUPPI isolation with three configurations: a default implementation with muons which tends to make the weight higher value, excluding muons based on the assumption that the muons are prompt muon and combination simply taking the average [3] are compared with $\delta\beta$ correction in Fig. 3 (right). The combination shows the best performance as seen in Fig.3 (right).

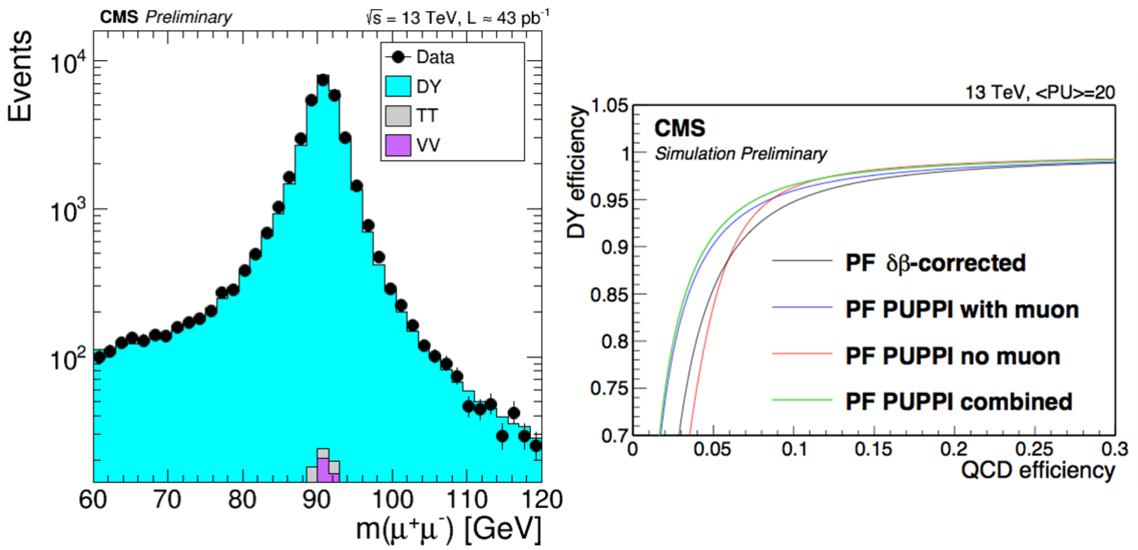

Figure 3: Dimuon invariant mass distribution (left). Isolation performance with different configurations (see the text for details).

6. Electrons/Photons

Thanks to excellent ECAL, we reconstruct electromagnetic energy deposits with very good resolution down to low p_{T}. With the completely overhauled reconstruction algorithm in the preparation for Run 2, all possible electron and photon candidates are reconstructed simultaneously using the similar characteristics of the ECAL clusters from electrons and photons. New reconstruction is completely integrated with particle flow and provides additional flexibility at analysis level. Using a tag and probe techniques within the invariant mass of $60 < M_Z < 120$ GeV, the scale factors are found close to 1 for various η regions and working points as seen in Figs 4. The efficiency for loose, medium and tight working point is 90%, 80% and 70%, respectively. Other kinematics distributions of electrons are also compared between data and MC simulation and shows a good agreement (see Ref. [14]).

7. Taus

Tau object in the hadronic decay mode is reconstructed using Hadron Plus Strip (HPS) algorithm to take into account the broadening in ϕ of calorimeter signature from early showering photons from π^0. The improvement came from the reconstruction of the four momentum of tau. As a result, the invariant mass of Z boson decaying to taus is fully reconstructed and shows better resolution (see Ref. [14]).

8. Conclusion

The object performance study is the key for the future precision measurements and also searches beyond the SM. Advanced pileup mitigation techniques are already available to use against larger pileup event for Run 2 period. With all remarkable physics object agreements shown with

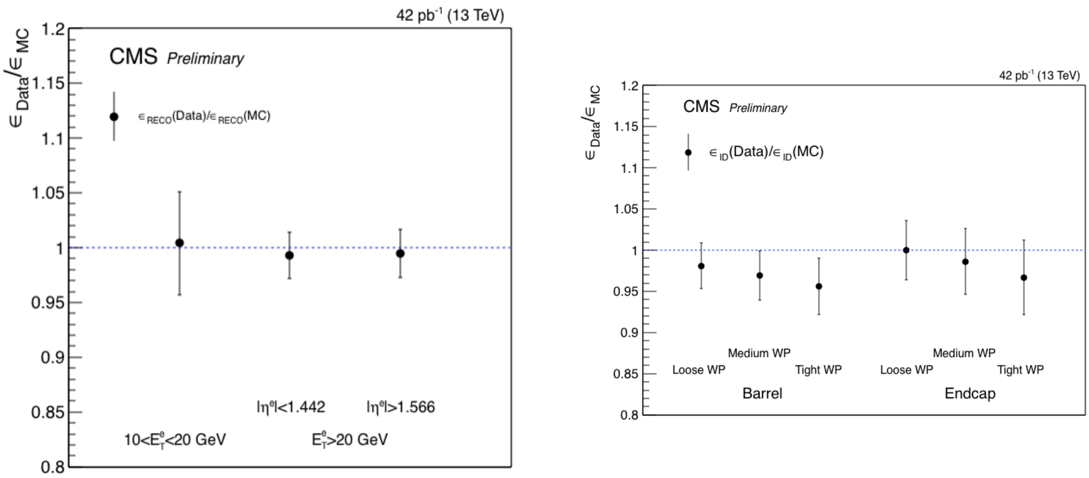

Figure 4: Scale factor for electron identification efficiency for the different η regions and working points using a tag and probe data driven technique.

early data at $\sqrt{s}$ = 13 TeV, our journey towards discovering nature using top quark events from Run 2 data is ready.

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