Research Proposal

Anwar A Bhatti

The current theory of fundamental constituents of matter and their interactions, standard model (SM), is successful in describing all but a few observations so far. The first exception is the existence of invisible (dark) matter, which is inferred from the measured rotational speed of galaxies and by observing the bending of light by invisible cluster of matter (gravitational lensing). The second one is the observation of the deficit of electron neutrinos coming from the sun compared to the rate predicted by standard solar model, suggesting that the electron neutrinos can oscillate into some other type of neutrinos. This oscillation between different flavors of neutrinos has been confirmed in many other experiments. It implies that neutrinos have mass whereas the SM can accommodate only massless neutrinos. Despite its phenomenal success in explaining most of the observations, SM is not an intellectually satisfying theory as it leaves many questions open and has many free parameters which must be determined experimentally. Thus we must go beyond the SM. Theories proposed beyond the SM postulate new symmetries, new spacial dimensions, and invariably new particles. I am particularly interested in finding out the nature of dark matter, whether there are any new symmetries in nature and if the space has more than three spatial dimensions.

It is expected that the signatures of this new theory will be observable in the TeV scale interactions and thus at the Large Hadron Collider (LHC), a proton-proton collider at the European Laboratory for Nuclear Physics, CERN, Geneva, Switzerland. The LHC program has been very successful. The LHC accelerator, though at an energy which is lower than the designed 14 TeV, has performed exceptionally well. All the detectors are also very efficient in recording, have novel calibration techniques, and have unprecedented resolution in measuring all the physics object, jets, leptons, photons and missing transverse energy. With these data, we have been able to explore the SM in a new energy regime and search for deviations from the SM expectation. In about 1 fb^{-1} of pp collisions data at 7 TeV, the SM has performed exceptionally well and no significant deviation from the SM expectations has been observed. Expected manifold increase in data during 2012, possibly at a higher center of mass energy, will allow us to further explore new physics signatures even with a small production rate. The LHC is the largest and most sophisticated scientific machine built ever. I believe the data collected by LHC data will change the landscape of particle physics, hopefully by discovering evidence of physics beyond the standard model. However, it seems that this journey may be long and challenging. It will be very gratifying to find out nature of the dark matter, discover new symmetries of the nature (if present) or determine whether the quark and leptons are composite particles and if the space structure is more exotic than the three dimensions we know well. Over the last six years at CMS, I have contributed significantly to this endeavor and I wish to continue this active participation in the coming revolution.

At CMS, I have worked on many different projects including 2006 test beam data analysis, hadron calorimeter calibration, jet energy scale determination, jet reconstruction algorithms studies, design of hadronic SUSY triggers, the QCD measurements, and searches for dijet resonances, super-symmetry and extra dimensions. Currently I am working on three physics analyses, (a) search for super-symmetry in fully hadronic channel, (b) search for large extra dimensions in monojet events and (c) measurement of internal structure of jets. These analyses are briefly described on the next page. I plan to continue the searches for SUSY in the hadronic channel and the search for new physics in the mono-jet data. Increased integrated luminosity will open up many new avenues to pursue. Current hadronic SUSY analysis can be augmented by adding two jet events, by analyzing the data set in exclusive jet multiplicity bins, and by employing new variable like effective mass of the system to discriminate between SM and the new physics. I also think, in light of results from 2011 LHC data, the event selection cuts should also be revisited. Topology of the events used for the extra dimension search is simple. However, there are many new models which also predict the same signature and I plan to interpret the experimental results in terms of these models. In addition, I would like to use the shape of kinematic distributions to discriminate between new physics and SM backgrounds. Shape comparisons will greatly increase the discovery potential of these searches.

In addition to the aforementioned two searches, I am interested in measuring the mass of single jets. Decay products of the highly boosted particles are very collimated and thus may be appear as a single jet in the detector. Such jets can be separated from QCD jets which originate from a quark or a gluon by measuring their internal structure. I plan to measure the mass of a single jet and other jetshapes and their dependence on the jet transverse momentum. These measurements are a good test of perturbarive QCD calculations and parton showering algorithms used by the Monte Carlo event generators. This work is also an extension of my measurement of the classical jetshapes. I would also like to explore the techniques to differentiate between quark and gluon jets. Such techniques can be used to enhance the discovery potential of new physics where the jets in the final states are exclusively from the quarks or from the gluons. I am also interested in measuring the ratio of the Z+jet and the photon+jet p_T spectra. This measurement is a good test of recent NNLO perturbative QCD calculations and will also reduce the systematic uncertainties in many searches where $Z(\nu\nu)$ production is a significant background.

Given my experience in different physics analyses ranging from precision QCD measurements to complex searches such as hadronic SUSY search where all the backgrounds are measured directly from the data, I can collaborate in any physics studies at CMS. I have detailed knowledge of triggers, calorimeters, jets, missing transverse energy, lepton and photon identification and all other aspects of a physics analysis.

In addition to physics analyses, I have extensive experience in building and testing wire chambers, tracker alignment, calibration and simulation of calorimeters, data acquisition systems and online software, detector simulation software and reconstruction software. I am very interested in instrumentation and detector research and development. I immensely enjoyed setting up the apparatus, writing data acquisition software, collecting data, analyzing it for the shower-max and preshower detectors for SDC experiment at Fermilb T841 and CERN RD3 experiments. Such projects are very important for future experiments and interesting in their own right. The technologies developed can have wider application. They are also very educational for both graduate and summer students. I enjoy working on such projects. I plan to make an extra effort to contribute to CMS detector upgrade. I have worked on CMS hadron calorimeter calorimeter test beam, calibration and noise studies but my interests are not limited to hadron calorimeter upgrade.

Here are some details of the physics analyses I am working on at the CMS experiment.

- **Search for SuperSummetry using Large Transverse Momentum in Multijet Events:** I am working on search for Super-symmetry using missing transverse energy signature in multi-jet events (RA2). We study the event yield at the large missing momentum in event with three or more jets. All the backgrounds, namely $Z(\nu\nu)$, top quark pairs, W+jet and QCD multijets events are the major backgrounds and are measured directly from the data. This is one of the flagship analyses of the CMS collaboration. As convener of CMS hadronic SUSY group during 2008, I along with Dr. Oliver Buchmuller, Prof. Jeff Richmann, and Dr. Alex Tapper laid the foundations of the current CMS hadronic SUSY group efforts. I, with Prof. Teruki Kamon, also established the missing energy+jets topology group at the LHC Physics Center (LPC) at Fermilab which has transformed into current LPC RA2 working group. It includes members from the Rockefeller University, Fermilab, Baylor University, University of Iowa, University of Illinois at Chicago, and Florida International University. I work closely with every member of this group. Our group is closely integrated with other CMS groups working on RA2 namely University of Hamburg, University of California Santa Barbra, and University of California Riverside. We have already published journal article using 36 pb^{-1} of data taken in 2010. For that analysis, I was one of the three editors of the Physics Analysis Summary note and the final journal article. We contributed to analysis cut flow, trigger design, and measurement of $Z(\nu\nu)$ boson background using Z and W boson charged leptonic decays. We also contributed to the measurement of the jet resolution and the measurement of the heavy quark component of the jets, both of these are essential component of the QCD background estimation technique. In addition we contributed to the interpretation of the experimental results by calculating the exclusion regions in SUSY parameters in cMSSM framework and determining the maximum allowable cross section limits for production of a few simple event topologies. New cMSSM results show a significant improvements on the limits from the Tevatron. We meet formally once a week and informally as many times as needed. For 2011 data analysis, the LPC RA2 group took even more responsibilities and is also working on the measurement of the the $Z(\nu\nu)$ background using photon+jets data and the measurement of hadronic τ background. In addition, we are exploring new techniques to measure the QCD multijet background. The results using 1.1 fb^{-1} of data from 2011 were approved during summer, 2011. Currently, we are working on the journal article using full data from 2011 run.

- **Search for Large Extra Dimensions and Unparticles using large transverse energy in jet events:** Another extension of SM, large extra dimension theory (LED), proposes existence of more than three spatial dimensions to solve the SM hierarchy problem i.e. the large disparity between the strengths of gravity (Planck mass) and other fundamental forces (Electroweak symmetry breaking scale). I am analyzing monojet events to search for large extra dimensions. The same signature is also used to search for unparticles. This search is being performed in collaboration with Sarah Malik (a Rockefeller University post doctoral fellow), Mehemt Vergili (LPC student), Latife Nukhet Vergili (LPC Student), Shuichi Konuri (Fermilab), Steve Worm (RAL) and Leonardo Benucci (Universiteit Antwerpen). There was a lot of synergy between monojet analysis and susy analysis. The clean-up cuts used in RA2 were adopted for monojet search. The most important background for both analyses is $Z(\nu\nu)$ boson events and we used same machinery and techniques to measure that background. The paper based on 36 pb^{-1} has been accepted by Phys. Rev. Lett. The analyis using first 1.1 fb^{-1} of data was approved during summer 2011 and currently we are working on the journal articles using complete dataset from 2011.

- **Measurement of Jet Shapes** Using 2010 data, we measured jetshapes i.e. energy flow around the jet axis. This was the thesis topic of Pelin Kurt, an LPC student from Cukorova University Turkey, under my supervision. This is a precision measurement and the results will be used to tune the parton showering algorithms and the underlying event models in QCD-inspired event generators. Initial analysis which used calorimeter towers and tracks from 1 nb^{-1} of data was approved for ICHEP 2010. We moved to using particles reconstructed by the Particle-Flow algorithm using information from the tracker, electromagnetic calorimeter, hadron calorimeter and muon system. The jetshape results have been approved by the collaboration. We are implementing comments from the collaboration review of the journal paper draft. We expect to submit the paper for publication in a couple of weeks. This analysis can be easily extended to include other jetshapes like planer-flow and single jet mass. Such variables are proposed for search for new physics where high momentum particles decay into quarks which fragment into a single jet [] and understanding mass of QCD jets is essential for the design the discriminating variable to separate the jets produced by decay of the massive particles from the QCD jets.