ANWAR AHMAD BHATTI

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Employment

2002-Present	Associate Professor, Rockefeller University.
1995-2002	Assistant Professor, Rockefeller University.
1991-1995	Research Associate, Rockefeller University.
1984-1991	Research Assistant, University of Washington.
1982-1984	Teaching Assistant, University of Washington.
2003-	Adjunct Professor, National Center for Physics, Quaid-e-Azam University Islamabad, Pakistan.

Education

Ph.D.	1991	University of Washington, Seattle, WA, USA.
M.S.	1984	University of Washington, Seattle, WA, USA.
M.Sc.	1982	Quaid-i-Azam University, Islamabad, Pakistan.
B.Sc.	1978	Pakistan Air Force College, Sargodha, Pakistan.

Professional Affiliations

The Rockefeller University Group Leader at CMS experiment at LHC.
Member Collider Detector at Fermilab (CDF) Collaboration at Tevatron.
Co-Convener: Jet Studies sub-group at the DPF Snowmass Workshop, 1996.
Co-Convener: QCD group CDF Collaboration, Jan-1999–Dec-2000.
Co-Convener: Jet Energy Corrections group CDF Collaboration, June-2001–March 2005.
Member American Physical Society.
Member Division of Particles and Fields.
Member American Association for the Advancement of Science.

Honors

First Position, M.Sc., Quaid-i-Azam University, Islamabad, Pakistan (1982).
Bronze Medal, B.Sc., University of The Punjab, Pakistan (1978).
Silver Medal, F.Sc., Sargodha Intermediate Education Board, Pakistan (1976).

Personal Interests

Outside physics, I enjoy reading books and walking and hiking in wilderness.

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Physics Research

Currently, I am the leader of The Rockefeller University group working on the Compact Muon Solenoid (CMS) experiment at Large Hadron Collider (LHC) at CERN, Geneva, Switzerland. The Rockefeller CMS group includes myself, Prof. K. Goulianos and Prof. Luc Demortier, and three research associates. We are working on hadron calorimeter simulation, jet energy scale corrections, missing transverse energy corrections and statistical issues in High Energy Physics data analysis. Since July 2005, I have been working on the CMS experiment, dividing my time between CMS and CDF experiments. Below I described my activities and plans at CMS and CDF, followed by descriptions of the papers I worked on as one of the mains authors. Description of my teaching experience, detector development and software expertise and a list of referees are given at the end.

Compact Muon Solenoid (CMS) Experiment

Physics Interest: At CMS, I plan to work on search for Super-symmetry using the classic large missing transverse energy signature in multi-jet events. This is a natural application of my expertise in the jets. Our group is evaluating the Standard Model background from $Z \to \nu\bar{\nu}$ events to jet+missing transverse energy signal. In addition, I am collaborating with Robert Harris (Fermilab) and D. Mason (Fermilab) to measure the inclusive jet cross section and search for new particles which decay into hadronic jets. Inclusive jet cross section at $\sqrt{s} = 14$ TeV will validate the CMS detector calibration and software performance and provide another text book plot.
Jet Energy Scale Determination: I wrote the initial plan of jet energy scale determination for the CMS Physics Technical Design Report Vol II (2006). I am a member of the CMS jet energy scale task force. Following CDF procedure, the jet corrections at CMS will have a modular structure and will be applied in stages. I am contributing to

- determination of the rapidity-dependence of jet energy scale by balancing a jet at given rapidity against another jet of in the central region,
- determination of the jet scale in the central region by balancing a jet against a photon in photon-jet events,
- determination the jet scale using simulated data, tuned to test beam measurements (adapted from the successful CDF procedure),
- closure tests of the jet corrections.

These tasks are being performed in collaboration with Robert Harris, Jochen Cammin (Rochester) and K. Kousouris (Fermilab).

I have collaborated at LHC Physics Center (LPC) at Fermilab with many people on many different small projects:

- Evaluation of new jet cone clustering algorithm, SIScone, with Manoj Jha (Dehli University) and Marek Zielinski (University of Rochester) in CMS environment. This new algorithm is infrared safe and fast. Thus it is a major improvement over current algorithms and should be adopted by LHC experiments.

- Comparison of simulated pion response with test beam data with Huseyin Topakli (Cukurova University)

- Evaluation of calorimeter noise contribution to jets with Marek Zielinski(University of Rochester)

- Optimization of Outer Hadron calorimeter energy scale with Selda Esen (Cukurova University) and Shuichi Konuri (Maryland)

- Study of Outer Hadron calorimeter response with Seema Sharma (TATA Institute)

In addition, I wrote an analysis software package which is being used by many people to do studies of jet response, resolution and efficiency.

Collider Detector at Fermilab (CDF) Experiment

Physics Studies: I have worked on precision tests of QCD at the CDF experiment since 1992. These precision tests are important and interesting because, apart from testing the limits of our understanding, they provide essential information about the possible backgrounds which needs to be understood in future experiments when we look for the last missing piece of the Standard Model, the Higgs particle, or physics beyond the Standard Model. During CDF Run I, I worked on

- measurement of inclusive jet cross section at Run IA (1996), **302** citations,

- measurement of inclusive jet cross section at Run IB (2001), **93** citations,

- determination of strong coupling constant α_s showing the evolution up to $Q^2 =$ 62500 GeV (2001), **29** citations,

- tests of QCD scaling violations by comparing scaled inclusive jet cross section at $\sqrt{s} = 630$ and $\sqrt{s} = 1800$ GeV (A. Akopian's Thesis, 1999), unpublished,

- measurement of dijet production with central rapidity gaps (1998), **78** citations,

- measurement of diffractive dijet production (1997), **97** citations,

- ambient energy in minimum bias and hard interaction events (2004), **24** citations.

For CDF Run II, I collaborated on

- measurement of inclusive jet cross section (supervised Gene Flanagan from Michigan State University),

- search for new particles decaying into dijets with Dr. Kenichi Hatakeyama (Rockefeller University),

- search for W/Z boson decaying into jets with Andrea Bocci (Rockefeller University).

The initial inclusive jet paper from Run II data using $385pb^{-1}$ of data was published in 2006. The analysis was updated and extended to forward region up to $|\eta| = 2.1$ using $1.13fb^{-1}$ of data in collaboration with Craig Group, Kenichi Hatakeyama and Joey Huston. The analysis is approved and the draft paper is under preparation. The dijet resonance search analysis is near completion. The $W/Z \rightarrow jet-jet$ analysis is complete and the paper is under internal review at CDF.

The Rockefeller Group is measuring the diffractive structure function of the proton, diffractive W/Z production, double pomeron scattering. We are searching for exclusive di-jet production where final state contains only two jets and has no accompanying particles from interactions between remnants of the either protons or pomerons. Exclusive dijet production is of great interest to the LHC diffractive community as a bench mark process for various models used to predict exclusive Higgs production rates at $\sqrt{s} = 14$ TeV. Exclusive production is considered, by some people, as the golden mode to discover the Higgs boson at LHC. We meet every week to discuss these analyses. The exclusive dijet paper is under internal CDF review.

Jet Energy and Resolution Studies: In my opinion, at the CDF, the jet energy scale determination and the improvement of jet resolution along with b-tagging are the two most important ingredients to improve the top mass measurement and search for new particles such as Higgs boson in Run II. I have devoted most of my time in 2001-2005 toward determining the jet energy scale. As a convener of the jet energy correction and resolution group from June 2001 to March, 2005, I worked with many graduate students and postdoctoral research associates to

- understand the calorimeter energy scale in comparison with Run I energy scale,

- measure the calorimeter response from in-situ single track data,

- improve the calorimeter simulation,

- measure of jet fragmentation and track reconstruction efficiency inside a jet,

- determine the jet energy scale and validate the derived corrections.

Because of this work, the uncertainty on **top quark mass improved from 6.2 GeV (2004) to 2.9 GeV (2005), best single experiment measurement**, resulting in much stronger constraint on the Higgs mass allowed within the Standard Model.

Selected Papers

1. **Inclusive Jet Production at Large Transverse Energy:** The collider data from the 1992-93 data were analyzed to measure the inclusive jet production

cross section by me. This measurement probes the very small distance scales and hence may be a window to new physics. The observed rate was found to be significantly higher than the QCD predictions available at that time (1996) at the high transverse energy (E_T). Since then, many different explanations to the observed excess have been proposed. The most promising explanation is that the gluon content of the proton is higher than expected from fixed target photon-jet data. The photon-jet results have large theoretical uncertainties. Although the new gluon distribution is consistent with all other data, it cannot be shown to be correct or incorrect independent of the jet data. The CDF results are consistent with the results from DØ, another collider experiment at Fermilab. I also analyzed the CDF data taken during the 1994-95 running period and these data are consistent with the initial results. These results were published in a PRD in 2001.

2. **Measurement of the Strong Coupling Constant from Inclusive Jet production:** I, with Christina Mesropian, my graduate student from the Rockefeller University, determined the value of the strong coupling constant (α_s) using the jet data. The theory of strong interactions, QCD, predicts that the strength of coupling constant changes with the distance probed (Q^2). The collider jet data, because of high statistics and large energy range, is a unique place to test this prediction over a large Q^2 range. The results show a good agreement with QCD predictions up to $Q^2 = 62500$ GeV^2. The precision of this measurement is limited by theoretical uncertainties. The PRL on this analysis was published in 2001.

3. **Test of Scaling Violations in Jet Production:** In the naive quark-parton model the ratio of the scaled (dimensionless) jet cross section at two different center of mass energies is independent of $x_T = 2E_T/\sqrt{s}$ and equals unity. However, the QCD description of jet production depends on E_T through dependence of the QCD coupling constant and the parton distributions on Q^2 which is related to E_T. Thus the predicted ratio is not unity. Many of the uncertainties, both experimental and theoretical, cancel in measuring the ratio of two cross sections, making scaling violation a stringent test of QCD. This analysis was the thesis topic of Alexander Akopian. The scaled ratio, measured as a function of x_T, is found to be lower in magnitude and different in shape than NLO QCD prediction. This difference can not be explained within perturbative QCD. Non-perturbative effects, like power corrections, are invoked to explain the discrepancy. Our results are consistent with DØ results at $x_T > 0.15$. Below $x_T = 0.15$, the result is sensitive to underlying event energy corrections which are treated differently by the two experiments.

4. **Study of Ambient Energy in Jet Events:** To measure the jet cross section at $p\bar{p}$ colliders and compare with perturbative QCD predictions, the energy associated with the spectator interactions must be subtracted from the measured jet E_T. This is one of the largest systematic uncertainties on the inclusive jet cross section at low transverse energies. With Valeria Tano and Joey Huston

(Michigan State University), I measured the energy at 90° in azimuth to the leading jet in hard interaction events and compared it with minimum bias data and Herwig Monte Carlo predictions. The maximum of the two 90° cones increases with the lead jet E_T whereas the minimum is almost independent of lead jet E_T and is consistent with the energy observed in an active minimum bias event. The HERWIG Monte Carlo predictions show the same trend, though the magnitude is slightly lower. These results were used to improve the underlying event production in the HERWIG and the PYTHIA Monte Carlo generators. This paper was published in 2004.

5. **Jet Production with a Rapidity Gap between Jets:** In QCD, the dominant mode of jet production is the exchange of gluons or quarks. In such interactions, the entire rapidity space, apart from fluctuations, is filled with particles from radiation from color field connecting the hard scattering partons and the proton and antiproton remnants. In 1992, Bjorken predicted another class of events produced via colorless-exchange, in which no particles are generated in the rapidity space between jets. This process was first observed by Prof. Tom Devlin (Rutgers University) in 1988-89 CDF data by fitting the multiplicity distribution. I searched and observed the same process and studied properties of such events using the 1992-95 collider data. We developed a new model independent, data driven, technique where multiplicities in the central region in two classes of events were compared to extract the signal.

6. **Diffractive Jet Production:** A large fraction of hadron-hadron interactions (elastic scattering and single diffraction) are mediated by a pomeron, which, in QCD framework, is a combination of gluons and quarks having the same quantum numbers as vacuum. At present our knowledge of the structure of the pomeron is very limited. I studied jet production in diffractive events, where diffraction is tagged by the absence of particles in a forward rapidity space. The diffractive jet production rate was found to be about 0.75% of the total jet production rate with the same jet kinematics. The observation of high E_T jets suggests that the exchanged object (pomeron) consists of point-like particle i.e. partons. Coupled with diffractive W production, which is more sensitive to the quark component of the pomeron, this measurement was used to determine the quark and gluon fraction of the pomeron.

7. **Search for $W/Z \rightarrow jj$ resonance in photon+dijet events:** I am working with Andrea Bocci, a Rockefeller University graduate student, to search for hadronic decays of W/Z bosons in $\gamma + W/Z$ samples. For this analysis, a Neural Net based algorithm is used to separate the signal from large direct photon+two jets and three jets, where one jet is identified as a photon, backgrounds. Due to limited statistics, no signal was observed. However, techniques developed in this analysis can be used to search for other hadronic resonances such as Higgs, WW and ZZ production where, at least, one of weak bosons decays into jets.

8. **Search for resonances decaying into dijets:** I am collaborating with Kenichi Hatakeyama, a Rockefeller University Post Doctoral Fellow and Robert Harris (Fermilab) on a model independent di-jet resonance search. These results are used to put limits on various models e.g. Axigluons, excited quarks, Color Octet Technirhos, Randall-Sundrum Gravitons. This analysis is near completion.

9. **Ratio of the Neutron and the Proton Structure Function (F_2^n/F_2^p) in DIS Muon Scattering:** Understanding the parton momentum distribution functions (PDF) in hadron is essential to predict rates of various hadron interactions. The parton level cross sections can be calculated in perturbative QCD and the hadron level cross section is the convolution of the parton level cross section with the PDFs. I worked on measuring the ratio of the neutron to proton structure functions, F_2. The Gottfried sum rule, which predicts that $\int_0^1 \frac{dx}{x}(F_2^p - F_2^n)$ is 1/3, was found to be violated by the New Muon Collaboration at CERN. My measurement showed that the discrepancy cannot be resolved by going to small x_{BJ} accessible at E665 due to the higher muon beam energy. These were the first results which showed that the sea distribution of the up and down quarks in a proton are not equal, as was previously assumed.

In addition, I have served on many CDF internal physics analysis review committees.

Teaching Experience

Graduate Students

- Alexander Akopian
- Christina Mesropian

Mentoring

- Gene Flanagan (Michigan State University, Ph.D., CDF).
- Valeria Tano (Michigan State University, Ph. D.,CDF).
- Mehmet Vergili (Cukurova University, MS, LPC/CMS).
- Pelin Kurt (Cukurova University, Ph.D., LPC/CMS).
- Huseyin Topakli (Cukurova University, Ph.D, LPC/CMS).
- New York area high school summer students 1993, 1997-2002.

Mehmet worked on jet energy calibration using dijet balancing technique and finished his MS in December, 2006. Pelin has worked in jet fragmentation studies and is currently working on photon-jet balancing studies. Huseyin is working on validation of CMS calorimeter response and Z+jet studies.

In addition, as convener of CDF QCD and CDF Jet Energy Scale and Resolution groups, I interacted with many graduate students and post doctoral fellows on many different analyses.

I was a Teaching Assistant at the University of Washington from 1982-84.

Detector Research and Development

Tracking Chambers: In E665, I tested and maintained multi-wire proportional chambers (MWPC). This included setting up a test system using a radio-active source, writing the data acquisition software and analyzing the data and debugging/fixing the readout and trigger electronics.
Calorimeter and Shower Detectors: I also worked on research and development of pre-shower and shower-max detectors for the SDC experiment which was planned to be performed at Superconducting Super Collider. I was involved in testing the photo detectors (multi channel photo-tubes and avalanche photodiodes), the wavelength shifting fibers and the scintillator. I was in charge of trigger, data acquisition electronics, the tracking chambers for T-841, a SDC test-beam experiment at Fermilab. I wrote the reconstruction software for the tracking chambers and shower-max detectors and did the analysis for the shower-max detector. The second test (RD3) was done at CERN during 1992 and 1993 where I worked on installing, debugging the shower-max electronics. Although the proposed experiment was canceled, the experience and data collected during this project helped in the design of plug calorimeter at CDF which is based on the same technology.

Computing and Software Development

Both at CDF and E665, I have contributed to many projects involving software development and maintenance.

CDF Collaboration

- Simulation code for the central pre-shower detector and shower-maximum detector.
- Jet reconstruction code librarian
- QCD analysis code librarian.
- Simulation of the new CDF plug calorimeter.
- Simulation of the CDF calorimeter in Run II framework using C++.
- Minimum bias event generator in C++, based on Fortran version for run II.
- Development of new jet clustering algorithms.

- Determination of calorimeter/jet energy scale for Run II.

SDC Calorimeter Test beam

- Data acquisition software using CAMAC/FASTBUS/VAX-VMS system.
- Data analysis framework.
- Track reconstruction software.
- ShowerMax energy calibration and position reconstruction software.

E665 Collaboration

- Tracking chamber alignment software and alignment of the detector.
- Track reconstruction software.
- Vertex reconstruction software.
- Analysis framework software on VAX and AMDAHL.
- Data acquisition software using CAMAC/PDF-11.
- Testing/High voltage control using a dedicated PC running under MS-DOS..

At the Rockefeller University, I installed and maintain CDF reconstruction and analysis software and other utilities at the local computers. The local VMS cluster included 5 DEC-Alpha workstations. We had a local network of 4 SGI/O2 workstations and a local network of 5 Linux PC's. I managed these networks until August 2002, when I moved to Fermilab.

I have worked on the VMS (Digital), CMS (IBM main frame), MS-DOS/Windows (IBM PC) and UNIX/LINUX operating systems. I have mainly programmed in FORTRAN, and more recently in C++ and have some experience in Turbo-Pascal. I am familiar with and have used many of high energy software packages.

In short, I have extensive experience in managing, writing and working with large software packages on diverse platforms.

References

CMS:

- Dr. Dan Green
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  Fermi National Accelerator Laboratory
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CDF:

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