Mass Determination Methods At Large Hadron Collider

A THESIS

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by

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UDAIPUR

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To

My Parents and Teachers

DECLARATION

I, **Mr. Abhaya Kumar Swain**, *S/o Mr. Alekha Swain, resident of Room No. J115, PRL Navarangapura Hostel, Navarangapura, Ahmedabad, Gujarat 380009, hereby declare that the research work incorporated in the present thesis entitled,* **"Mass Determination Methods At Large Hadron Collider"** *is my own work and is original. This work (in part or in full) has not been submitted to any University for the award of a Degree or a Diploma. I have properly acknowledged the material collected from secondary sources wherever required. I solely own the responsibility for the originality of the entire content.*

Date:

(Abhaya Kumar Swain)

CERTIFICATE

I feel great pleasure in certifying that the thesis entitled, **"Mass Determination Methods At Large Hadron Collider"** embodies a record of the results of investigations carried out by Mr. Abhaya Kumar Swain under my guidance. He has completed the following requirements as per Ph.D regulations of the University.

(a) Course work as per the university rules.

(b) Residential requirements of the university.

(c) Regularly submitted six monthly progress reports.

(d) Presented his work in the departmental committee.

(e) Published minimum of one research papers in a refereed research journal.

I am satisfied with the analysis, interpretation of results and conclusions drawn. I recommend the submission of thesis.

Date:

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Head of the Department

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ABSTRACT

The remarkable discovery of the Higgs boson at the Large Hadron Collider filled the last missing bit of the Standard Model and marked the beginning of a new era of searching for physics beyond the SM. TeV scale new physics, if it exists, should show up at the Large Hadron Collider. Among all new physics models, dark matter motivated theories are of particular interest. The dark matter signals in the Large Hadron Collider are challenging in respect of discovering them as well as determination of properties like mass, spin *etc.* associated with the new particles in the discovery signal. Study of mass sensitive observables in this regard can not only provide mass and spin information but can also be used as a discovery tool.

In this thesis, we demonstrate how the already available constraint(s) can further sharpen the mass bound variables considering both inclusive and exclusive observables. We have studied the mass bound variables $\sqrt{\hat{S}_{min}}$ and its variants by minimizing the parton level center of mass energy that is consistent with all inclusive measurements. They were proposed to have the ability to measure mass scale of new physics in a fully model independent way. Here we relax the criteria by assuming the availability of partial information of new physics events and thus constrain this mass variable even further. Starting with two different classes of production topology, *i.e.,* antler and non-antler, we demonstrate the usefulness of these variables to constrain the unknown masses. This discussion is illustrated with different examples, from the standard model Higgs production and beyond standard model resonance productions leading to semi-invisible production. We also utilize these constraints to reconstruct semi-invisible events and thus improving the measurements to reveal the properties of new physics.

We further moved to mass-constraining variable M_2, a $(1 + 3)$-dimensional natural successor of the extremely popular M_{T2}. M_2 possesses an array of rich features having the ability to use on-shell mass constraints in semi-invisible production at a hadron collider. We investigate the consequence of applying a heavy resonance mass-shell constraint in the context of a semi-invisible antler

decay topology produced at the LHC. Our proposed variable, under additional constraint, develops a new kink solution at the true masses. This enables one to determine the invisible particle mass simultaneously with the parent particle mass from these events. We analyze a way to measure this kink optimally, exploring the origin and the properties of such interesting characteristics. We also study the event reconstruction capability inferred from this new variable and find that the resulting momenta are unique and well correlated with the true invisible particle momenta. This proposal of reconstruction is demonstrated with a potentially interesting scenario, when the Higgs boson decays into a pair of τ leptons. The LHC has already started exploring this pair production to investigate the properties of Higgs in the leptonic sector. Dominant signatures through hadronic decay of tau, associated with invisible neutrinos compound the difficulty in the reconstruction of such events. Exploiting the already existing Higgs mass bound, this new method provides a unique event reconstruction, together with a significant enhancement in terms of efficiency over the existing methods.

Keywords : Beyond Standard Model, Standard Model, Hadronic Colliders, Particle and resonance production, Higgs, Tau lepton, Event reconstruction.

LIST OF PUBLICATIONS

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List of Abbreviations

SM	Standard Model
BSM	Beyond Standard Model
SUSY	Supersymmetry
MSSM	Minimal Supersymmetric Standard Model
RH	Right-Handed
LH	Left-Handed
VEV	Vacuum Expectation Value
EW	Electroweak
EWSB	Electroweak Symmetry Breaking
SSB	Spontaneous Symmetry Breaking
LHC	Large Hadron Collider
DM	Dark Matter
HS	Hard Scattering
UTM	Upstream Transverse Momentum
ISR	Initial State Radiation
FSR	Final State Radiation
MAOS	M_{T2} assisted on-shell

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