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A Generator Level Study of top quark and anti-top quark production using Pythia 8 at LHC Energies

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Abstract: **The top quark have no substructure and it is point like, its mass is of the order of gold nucleus. Therefore it is believed to be closely related to the mechanism of mass generation with the Higgs bosons, the current study provides insight about the generation of top quarks i.e H->$t\bar{t}$, at center of mass energies 8TeV and 13TeV, the results represents invariant mass, transverse momentum, pseudorapidity, scattering azimuthal angle distribution of top quark and distribution of angular separation between top and anti-top quark.**

Purpose**: To study the angle between top and anti-top quark different angle will forms, means how it will be.**

Outcome Result**: When we detects quarks and anti-top quarks by use of Pythia 8 different angle will be shown and from that we will calculate the interaction between them.**

Keywords**: The standard model, Large Hadron Collider, Pythia8, top and anti-top quark.**

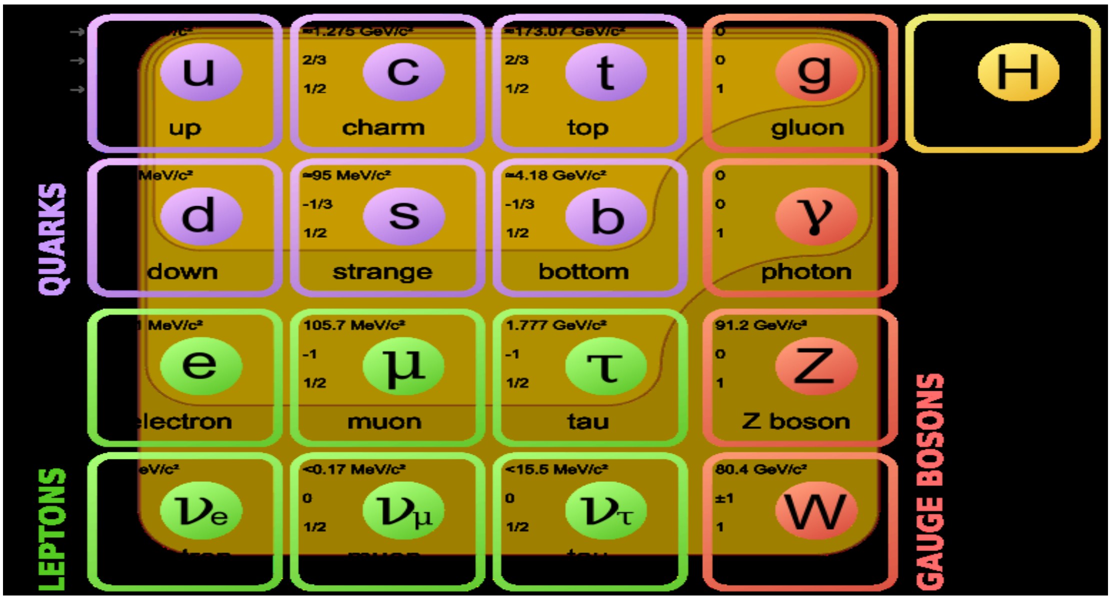
1. INTRODUCTION

Since the very beginning of civilization, curiosity has driven the human being to look for most fundamental objects around us. Matter has been the most influencing one and has driven many curiosities in human. ‘what is everything in the universe made of? or ‘what is the nature of the fundamental constituents of all matter? The answers of all questions were achieved from understanding the Particle Physics. Particle Physics investigates and describes the structure of the constituents of the matter as well as the forces acting among them. Particle Physics has been the best so far to explain the matter and its constituents through well-known theories like Standard Model of Particle Physics.

The elementary particle physics was born in 1897, with the discovery of electron by J.J Thomson's. The first experiment in this context is the one carried out by Ernest Rutherford in 1909, when he bombarded alpha particles on gold foils and concluded from the results that the atom has two sectors inside, namely a small positively charged nucleus where most of its mass is concentrated, and a planetary system of negatively charged electrons which accounts for most of the ‘volume’ of the atom. In 1932, Chadwick discovered that the nucleus, the core of the atom, consisted of protons and neutrons. The discovery of the neutron put the final touch on the classical period in elementary particle physics. The middle period in elementary particle physics was dominated by Yukawa’s meson, Dirac’s positron and Pauli’s neutrino. Dirac postulated in 1927 the existence of anti-matter as a consequence of his relativistic formulation of the Schrodinger equation in quantum mechanics.

The Standard Model

The Standard Model (SM) has been successfully tested at an impressive level of accuracy and provides at present ours best fundamental understanding of the phenomenology of particle physics. The particles involves in SM are characterized by their spin, mass and quantum numbers. It also explains the way by which 17 subatomic particles are bound together to create atoms by three of the four fundamental forces of nature: the strong force, the weak force and the electromagnetic force. It excludes the forth force, gravity which plays negligible role.These subatomic particles consists of 6 leptons and 6 quarks. Additionally there are 5 fundamental force carrier which acts as the exchange particles for the different fundamental interaction. Electro-magnetic interactions effect the particles carrying electric charge in them and are mediated by massless photon and they have infinite range. Weak interactions also known as contact interactions because of their extremely short range effects the particles carrying weak charge in them. These forces are mediated by massive particles namely W-, W+ and Z0 boson. The strong force effects the particles carrying color charges in them with gluons acting as the mediator. Leptons can be observed in isolated form but quarks always exists in the bounded form. Quarks can never be isolated because of the process of quark confinement.



2. LITERATURE REVIEW

The elementary particle physics started, with J. J. Thomson's discovery of the electron. John Dalton, in the 19th century, conclude that each element of the nature was composed of a single and different type of particle. After the discovery of the atom, early 20th century, scientists discovered that elements are not elementary at all: the atom is made of electrons and a nucleus, which contains proton and neutrons. The number of protons in the atom determines the type of element.

To cope with this problem, Dirac introduced the hypothesis, known as "hole theory", that the vacuum is the many-body quantum state in which all the negative-energy electron eigenstates are occupied. This description of the vacuum as a "sea" of electrons is called the Dirac sea. Since the Pauli exclusion-principle forbids electrons from occupying the same state, any additional electron would be forced to occupy a positive energy eigenstate, and positive-energy electrons would be forbidden from decaying into negative-energy eigenstates.

Energy eigenstates, the feature known as zitterbewegung, which arises from the interference of positive energy and negative-energy states, would have to be considered to be an unphysical prediction of time-dependent Dirac theory. This conclusion may be inferred from the explanation of hole theory given in the preceding paragraph. Recent results have been published in Nature [R. Gerritsma, et. al 463, 68- 71 (2010)] in which the Zitterbewegung feature was simulated in a trapped-ion experiment. This experiment impacts the hole interpretation if one infers that the physics-laboratory experiment is not merely a check on the mathematical correctness of a Dirac-equation solution but the measurement of a real effect whose delectability in electron physics is still beyond reach.

Dirac further reasoned that if the negative-energy eigenstates are incompletely filled, each unoccupied eigenstate – called a "hole" – would behave like a positively charged particle. The hole possesses a positive energy, since energy is required to create a particle–hole pair from the vacuum. As noted above, Dirac initially thought that the hole might be the proton, but Hermann Weyl pointed out that the hole should behave as if it had the same mass as an electron, whereas the proton is over 1800 times heavier. The hole was eventually identified as the positron, experimentally discovered by Carl Anderson in 1932.

The quarks must be bound together inside the proton by a specific interaction. The quanta of this interaction are called gluons. The strong force between protons and neutrons inside the nucleus is today believed to be a manifestation of the more fundamental interactions between quarks and gluons. Quarks have electrical charges which are multiples of 1/3 of the fundamental unit of charge, while gluons are electrically neutral. Quarks and gluons must also carry a charge, analogous to electrical charge, by which they interact strongly. This charge is called “color," and has no relation to ordinary optical color. There are three basic colors called red, green and blue, which are unrelated to the colors red, green and blue visible to the human eye. They are simply arbitrary labels. The rule that baryons are made from 3 quarks and the multiple of 1/3 fractional charges are related to the fact that there are three colors. The interactions between quarks and glions governed by color are described by a theory called quantum chromodynamics, or QCD. Processes based on QCD are called strong interactions.

Feynman Diagram:

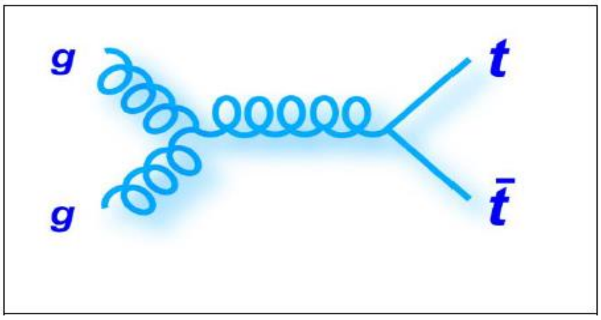
There are certain important parameters used in particle physics which define the fundamental interactions between particles. One of them is the scattering crosssections. Their calculation involves the description of incoming and outgoing particles along with an interaction Hamiltonian to describe how the particles deflect one another. This is achieved by the use of rather large complicated integrals over a large number of variables which include the position and momentum of every particle. To overcome this problem of complex calculations Richard Feynman gave the concept of Feynman diagrams. Feynman Diagrams provides a simple way to calculate the probability of collisions, annihilations, or decays of particles.

Key points of Feynman Diagram:

Annihilation Diagram: When matter and antimatter particles collide, they annihilate, leaving behind pure energy in the form of electromagnetic radiation (photons!).

Scattering Diagram: Here is the Feynman diagram for two electrons coming towards each other than repelling each other through the electromagnetic force (via *exchange* of a *virtual* photon).

In hadron collisions, the top quark is primarily produce via the strong interaction. The Large Hadron Collider collides proton on antiproton. In the current study, the process of our interest is the one in which two gluons goes to top $t$quark and an anti-top$\bar{t}$ quark as shown in Figure. The interaction takes place by the exchange of a force carrier which in this case is a gluon.

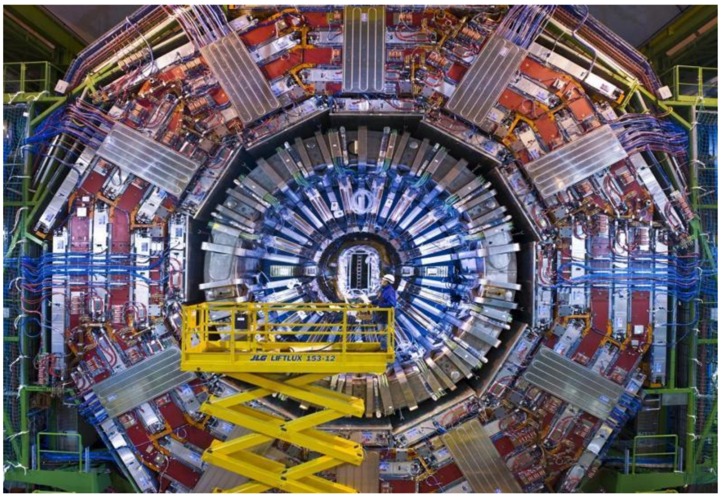


EXPERIMENTAL DETAILS (DETECTOR)

Large Hadron Collider

Large Hadron Collider (LHC) is the world’s largest and most powerful particle accelerator, colliding protons into each other at an energy of 14Tev (tera-electronvolts). LHC, starting up in 2007 at CERN, the European particle physics-laboratory on the Franco-Swiss border near Geneva. The LHC consists of a 27-kilometre ring of superconducting magnets with a number of accelerating structures to boost the energy of the particles along the way.

To direct the beams around the accelerator be use thousands of magnets of different varieties and sizes. These include 1232 dipole magnets 15 meters in length which bend the beams, and 392 quadrupole magnets, each 5–7 meters long, which focus the beams. Just prior to collision, another type of magnet is used to "squeeze" the particles closer together to increase the chances of collisions. The particles are so tiny that the task of making them collide is similar to firing two needles 10 kilometers apart with such precision that they meet halfway.

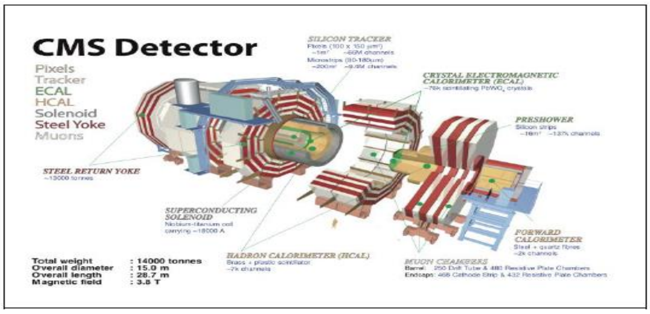


CMS Detector

Detectors are the eyes of High Energy Physicists which means all the observations are measured. The **Compact Muon Solenoid** (**CMS**) Collaboration is constructing a general-purpose proton-proton detector, which is designed to exploit the full discovery potential of LHC machine. The primary aim of the experiment is to discover the Higgs boson and to search for other new particles predicted in theories beyond the Standard Model.

CMS is 21.6 meters long, 15 meters in diameter, and weighs about 12,500 tonnes. Approximately 3,800 people, representing 182 scientific institutes and 42 countries, form the CMS collaboration who built and now operate the detector. It is located in an underground cavern at Cessy in France, just across the border from Geneva. In July 2012, along with ATLAS, CMS discovered a boson, which is very similar to the Standard Model Higgs Particle. Future research is required to decide if this boson is Higgs Particle or not. CMS is a general-purpose detector, designed for studying many aspects of proton collisions at 8 TeV, the center of mass energy of the LHC particle accelerator.

<u>There five layer on CMS detector</u>: Layer 1 – The tracker, Layer 2 – The Electromagnetic Calorimeter, Layer 3 – The Hadronic Calorimeter, Layer 4 – The magnet, Layer 5 – The muon detectors.



Software to be used

<u>ROOT</u>*: Root is a modular scientific software framework specifically designed for large scale data analysis. Root stores data in a very efficient way in a hierarchical objectoriented.*

<u>Pythia</u>: It is a computer simulation program for the generation of high energy collisions. It contains a library of hard processes and models for initial and final state parton showers, multiple parton-parton interactions, beams remnants, string fragmentation and particle decays. The objective of pythia is to provide as accurate as possible representation of event properties in a wide range of reactions, within and beyond the Standard Mode, with emphasis on those where strong interactions play a role, directly or indirectly, and therefore multihadronic final states are produced. The current release (Pythia 8) is focused towards LHC and Tevatron applications, i.e. high-energy pp and pp bar collisions. Also e+ e- and mu+ mu- annihilation processes may be simulated, but not e.g. e - p, γ - p or $\gamma - \gamma$ collisions (Pythia 6.4 contains this information). Another development in the recent times is that Pythia code (Pythia 8) is completely written in C++.

Importance of kinematic variables

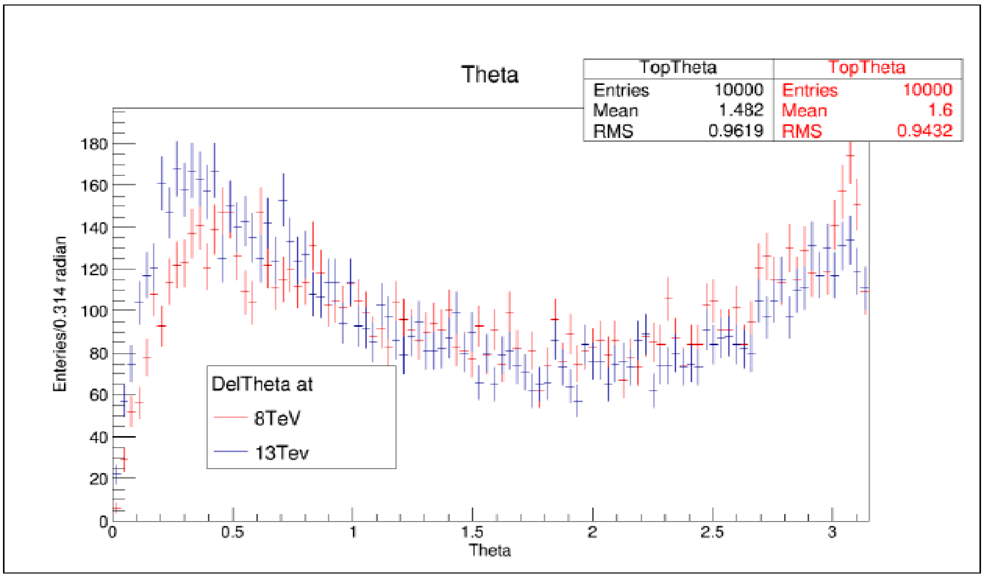
- Transverse momentum: The momentum of each particle produced in a collision can be divided into two components.
- Pseudorapidity: In experimental particle physics, η, **pseudorapidity**, is a commonly used spatial coordinate describing the angle of a particle relative to the beam axis.
- Azimuthal angle: The azimuthal is the angle formed between a reference direction (North) and a line from the observer to a point of interest projected on the same plane as the reference direction.
- Invariant Mass: The invariant mass, rest mass, intrinsic mass, proper mass or simply mass, is a characteristics of the total energy and momentum of an object or a system of objects that is the same in all frame of reference related by Lorentz transformations.

Analysis Strategy and Work Done

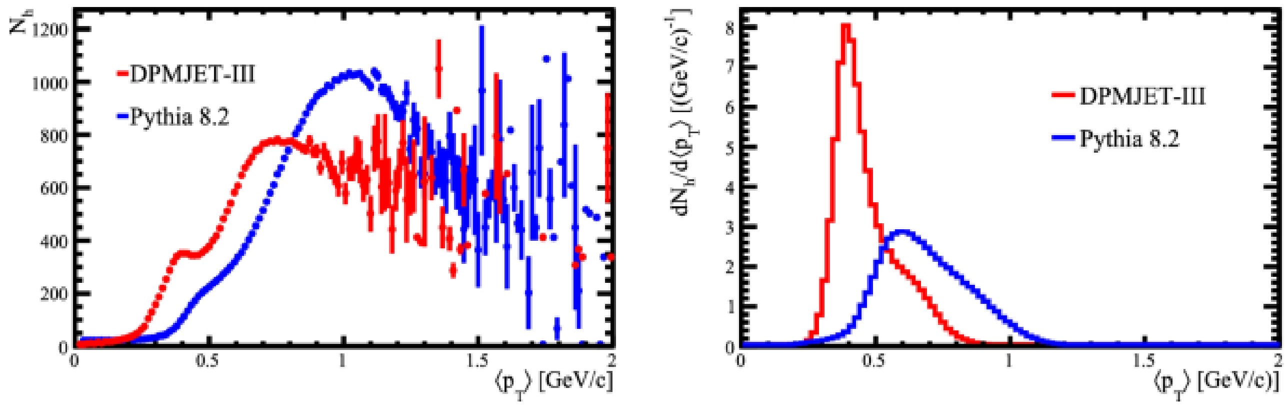
In experiments, an individual measurement may have a lots of variability; because it has to be made quickly, it is hard to determine the exact results. In order to get appropriate results, we need to have a large collection of same type of events, because measuring a single event more than once reduce error. The first step involves the initialization step where we try to generate gg -> $t\bar{t}$ 10,000 events and then we introduced some lines in code to obtain the location of final top and anti-top quark. These steps include the Pythia class to access all the important functions required for the initialization of events and their generation. The next steps involves to access the kinematic variables of final top quark, such as Invariant Mass, Pseudorapidity, Transverse momentum and azimuthal angle and then we include "Tfile.h" and "Histogram.h" directories to store informations about the distribution of these kinematic variables in terms of histograms. To find the angular separation between top and anti-top quark we include "TLorentzVector.h" directory. **TlorentzVector** is a four vector class means it has four arguments, which can we used for the description of position and time or momentum and energy associated with particle.

3. RESULT

A Pythia Event generates important kinetic variable information by using four momentum vector. The total number of events generated for each kinematic variable distribution are 10,000. Root is an object-oriented programming language is used to create histogram. For generating plots or histogram we apply generator level kinematic section cuts. These cuts are formulated from CMS geometry. The Histogram are created at two different center of mass energies, on which LHC operates.



At 8TeV and 13TeV energies in a logarithmic plot. It is clear from the distribution that the invariant mass peaks around 170.9 for majority of particles at both 8TeV and 13TeV energies. Which means, invariant mass or rest mass of a particle is a constant quantity and it does not depends upon the energy of two colliding proton and anti-proton.



When these effects are included the generator level information it may be similar to the experimental data. Therefore our next step should be to apply simulation and reconstruction based on the geometry of any general purpose detector like CMS, ATLAS etc. One can use GEANT 4 simulator for simulation and reconstruction which is another C++ program showing the geometry of general purpose detector.

REFERENCES

[1] Aad G et al. ATLAS Collaboration Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC. Phys.Lett. 2012; B716: 1–29.

[2] Aad G et al. ATLAS Collaboration, Search for direct production of charginos and neutralinos in events with three leptons and missing transverse momentum in √s = 7 TeV pp collisions with the ATLAS detector. JHEP04 2014; 169.

[3] Baak M, Goebel M, Haller J, Hoecker A, Kennedy D et al. The Electroweak Fit of the Standard Model after the Discovery of a New Boson at the LHC. Eur.Phys.J. 2012; C72: 2205.

[4] Belyaev A, Leroy C, Mehdiyev R, Pukhov A. Leptoquark single and pair production at LHC with CalcHEP/CompHEP in the complete model. JHEP 2005; 0509: 005.

[5] Branco G., Lavoura L., On the addition of vector like quarks to the standard model. Nucl. Phys. B. 1986; 278; 738.

[6] Chatrchayn S et al. CMS collaboration: the CMS experiment at the CERN Large Hadron collider. JINST 2008; 3: S08003.

[7] Chatrchyan S et al. CMS Collaboration Collaboration, Search for electroweak production of charginos and neutralinos using leptonic final states in pp collisions at √s = 7 TeV. JHEP 2012; 1211: 147.

[8] Chatrchyan S et. al. CMS Collaboration, Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC. Phys.Lett. 2012; B716: 30–61.

[9] Dobrescu BA and Poppitz E. Number of fermion generations derived from anomaly cancellation. Phys. Rev. Lett. 2001; 87: 031801.

[10] Gaillard M, Lee BW. Rare decay modes of the K-mesons in Gauge theories. Phys. Rev. D 1974; 10: 897.

[11] Glashow S L. Partial-symmetries of weak interactions. Nuclear Physics 1961; 22: 579–588.

[12] Glashow S, Iliopoulos J, Maiani L. Weak interactions with Lepton-Hadron symmetry. Phys.Rev. 1970; D2: 1285–1292.

[13] Glashow S. Partial symmetries of weak interactions. Nuclear Physics 22. 1961; 579–588.

[14] Glashow SL, Weinberg S. Natural conservation laws for neutral currents. Phys. Rev. E 1977; 15:1958.

[15] Griffiths. Introduction to Elementary Particles. John Wiley;1987 .

[16] Halzen F, Martin AD. Quarks and Leptons: An Introductory Course in Modern Particle Physics. Wiley; 1984.

[17] Lashkar Mohammad Kashif. Measurement of the Z boson cross-section in the dimuon channel in pp collisions at √s = 7 TeV; 2010.

[18] M. Carena, C. Grojean, M. Kad, V. Sharma. STATUS OF HIGGS BOSON PHYSICS; 2013.