New Forward and Diffractive Physics at CMS

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Abstract. Forward and Diffractive Physics (FWP) in LHC is a new open window to understand this type of strong interactions. We will present a didactic description of the topics being developed at CMS. As we know there still is no new results to present for FWP. We are accumulating data to have soon new results. We will show a number of topics and the detectors properties to do the observation of several topologies. We expect to give an optimistic view of the area.

1. Introduction

High Energy Physics (HEP) is the science of the Fundamental Interactions of Nature and of its most elementary particles. HEP, as a frontier science, is permanently changing its facilities with new Instrumentation, new computing, new analysis methodology and so on. One region of the spectrum of the phase space available for interactions is the Diffraction situated on the Forward direction of the scattering. Diffraction is perhaps one of the oldest subjects of physics. Just for curiosity, the Diffraction in Optics was first observed by Leonardo Da Vinci [1] (1452-1519). Historical information can be found in the references [2, 3].

The Large Hadron Collider (LHC) is the last new machine which represent one of the most important challenge scientific and technologically. We never did an experiment at 14 TeV. It is the great opportunity to make advancements in Science. We are working on the limits of the present technology. In particular, the Compact Muon Solenoid (CMS) is one of the 4 main detectors of LHC. (There are three other experiments, ALICE, LHCb and ATLAS (figs.1, 2). Each one of these experiments is dedicated to one main subject. ALICE for heavy Ions interactions; LHCb for b-Physics, and ATLAS, like CMS are the exceptions, they are general purpose experiments.

The main parameters of LHC are:

- It is a proton x proton collider;
- it has 27 km of circumference;

1 An interesting reference: “Leonardo Da Vinci - An Artabras Book” - Reynal and Company in Association with William Marrow and Company N.Y. Chapter: Leonardo’s Optics, Domenico Argentieri p. 405, says the following: “I did a great discovery founding the transcription of Gian Battista Venturini which was in the Reggio Emilia Library. The text shown clearly that Leonardo observed the diffraction phenomena but made a wrong interpretation".
Figure 1. The LHC and the Interaction Points for each Experiment/Detector

- It is at 100 m under surface;
- The beam Energy of each is 7 TeV;
- Energy at SCM (Center of Mass) is 14 TeV;
- It has 1800 Superconductor Magnets;
- It has 7000 km of Superconductor wires;
- It has 120 Tones of Liquid Helium (700 K litters);
- The temperature of the supercondutor is 1,9 Kelvin;
- It is built to work with 2808 bunches per Beam;
- And $1.15 \times 10^{11}$ Particles per Bunch.

Figure 2. This is part of the 27 km of the tunel of the LHC.

The present status of LHC is working in a very good performance. Only for curiosity, after to start in 20/09/2008 an unexpected accident heppened on the tunel. A small device of the cryogen system stopped to work causing problem on the process of the Superconducting Magnets. 53 Dipoles and 14 Quadripoles was removed and repaired. In November of 2009 LHC started to work again up till now. We had a very rich run period and stop to prepare the Heavy Ions run. However the figure 3 show a plot of Luminosity which represent the sucess of the LHC. That allow us to expect for the near future good results and even discoveries.

Figure 3. The Luminosity between March and November 2010
The CMS Detector as we show in figure 4 is all parts of the Central Detector: Pixels Detector, Tracker Detector, the Electromagnetic and Hadronic Calorimeters, the Solenoid, the Muons Detector and the steel Yokes. These are the main parts constituting the main CMS Detector. To complete the view of CMS Detectors we show in figure 5 the set of detectors of Forward Physics. These detectors open a new window for CMS. Finally we would like to warn the reader that we will not show results from LHC since they are still in a very preliminar studies but we expect soon to have new results to present.

![Figure 4. CMS Detectors and its main parts](image)

![Figure 5. The Forward Detectors of CMS](image)

2. Forward Physics and Diffraction

In general CMS Detector will study a large number of subjects like: Higgs (the most popular subject), Dark Matter, Matter and Antimatter, Heavy Ions Physics, Supersymmetry, Extra Dimensions, Leptoquarks, Jets and Multijets, New Physics or Beyond the Standard Model topics, Centaurus and Strange Objects and Forward and Diffractive Physics. But in this talk we are interested mainly on Diffractive Physics.

![Figure 6. A slice of the Detector showing the particles detected by each part of the spectrometer](image)

In figure 6 we show the particles that can be detected by the Central Detector. There are 5 particles ($\gamma$, $e^-$, Neutral Particles (e.g. neutron), Charged Particles (e.g. pions), muons) and its path crossing the sub-detectors. The neutral particles deposit the energy mainly in the Electromagnetic Calorimeter and the charged particles go to the Hadronic Calorimeters. Muons
cross all sub-detectors leaving their signatures on the Muon detectors. Photons and electrons go to the Electromagnetic Calorimeter (EM). All charged particles suffer deviation with the magnetic field.

Many topologies of Forward Physics and Diffraction, as shown in fig. 7, need to have the two proton scattered triggered with the event in the Central Detector well defined. But in the present we have to work with the rapidity gap. We still do not have triggered events. There are many subtopics in Forward and Diffractive Physics: Elastic Scattering and Total cross section after the installation of Roman Pots of the TOTEM detectors; Single and Double Hard Diffraction; Hard Double Pomeron exchange, Higgs production, Glueballs, Diffractive W and Z production and so on.

Figure 7. Diffraction topologies and the Gap on $\varphi$ versus $\eta$

The plots and distributions are always presented with the Kinematics Variables appropriated. They are the:

- $t = (p_f - p_i)^2 \rightarrow$ Transfer momentum
- $x_P = p_f/p_{\text{Beam}} \rightarrow$ Scattered Proton Momentum Fraction
- $\zeta = 1 - x_P \rightarrow$ Momentum Fraction
- $M_X = \sqrt{s\zeta} \rightarrow$ Diffractive Mass
- $\eta = -\ln(\tan(\theta/2)) \rightarrow$ Pseudorapidity
2.1. Elastic Scattering and Soft Diffraction

The Elastic Scattering is an important diffraction component. It is with the TOTEM Detectors, the Roman Pots, that will be possible to do measurement of Elastic Scattering and Total Cross Section for proton-proton at 14 TeV. These future results has an important aspect for the asymptotic Theorems [4]. Soft component of Diffraction is very well described by Regge Theory [5]. The main characteristic of Diffraction is the exchange of the vacuum quantum number ($J^{PC} = 1^{++}; I^{G} = 0^{+}; Q = B = S = 0$) and a good experimental signature is the rapidity gap found when we do the 3-dimensional plot of the energy deposit on forward hadron calorimeter cells.

2.2. Diffraction Topologies and Associated Gap Expected

As we know, 1/3 of the Inelastic cross section at the LHC is diffractive. This give us a good optimistic view for the next years. The gaps and the topologies of the diffraction scattering are show in figure 7.

At the partonic interaction level, Diffraction is a good way for probing proton and measure the Diffractive Parton Distribution which give us information about the structure of the proton and also give us the probability of the event type being studied as we can see in the figure 8.

On the left side we see the Single Hard Diffraction with a Pomeron exchanged. The X represent the jets produced by the diffractive interaction between the Pomeron and the Proton. At Partonic level of the right side is represented by the Jets produced by the interaction.

**Figure 8.** This is the representation of the partonic interaction or the Pomeron probing the proton.

When we face the partonic approach for diffraction scattering using QCD to calculate the cross section it appear a number of difficulties and some of them are not definitely solved. The first one is the Factorization theorem. The calculation of the differential cross-section of Diffractive (DIS) Deep Inelastic Scattering is Structure Function dependent as

$$F_2^{D(4)}(\beta, x_P, t; Q^2) = \sum_i \int_{\beta}^1 \frac{dz}{z} C_i \left(\frac{z}{\beta}\right) f^D_i(\beta, x_P, t; Q^2)$$

where, $f^D_i(\beta, x_P, t; Q^2)$ is the universal Diffractive Parton Distribution Function (DPDF). Using the Data from HERA, for DIS the structure function can be obtained,

$$\sigma^D(\gamma^* p \rightarrow X p) = \sum_i \bar{\sigma} \otimes \int_{x_{Pom}}^{x_{Pom}} (x_{Pom}, t, z, Q^2)$$

This is the QCD factorization theorem proven by J. Collins [10, 11].

While the Factorization theorem works for HERA [12] for $p \bar{p}$ the factorization theorem breakdown. The single diffraction rates of W and Z [13, 14], Dijet [15, 16], b-quark [17], $J/\psi$ show a factor 10 lower than this one expected using DPDFs from HERA. This is a strong disagreement for hard diffraction. A possible explanation is based on the difference between the initial states. $p\bar{p}$ has an important number of partons then the gap could be filled by the multiple interactions and the diffractive events not appear properly. The way to have a quantitative measurement of this is calculate the survive probability.
It is very important to test again on the LHC, this time on proton proton scattering. Another difficulty for Particle Diffraction it will be the pile up produced for high luminosity. We have to pay attention to this physical effect consequence of high energy and high luminosity. Then it is very important for the future of the Diffraction to have all Forward detectors installed at CMS. These detectors, as we said above are:

- The spectrometer TOTEM with its Telescopes and Roman Potes [7]
- The CASTOR, a Forward Calorimeter [20]
- The ZDC, a Zero Degree Calorimeter [8]
- The FP420/HPS, a fundamental detector to get scattered protons [9]

2.3. Forward Detectors

CMS is by far the most complete experiment for Forward Physics, since there is an important number of Forward Detectors dedicated to Forward Physics. It is important to know that it is the first experiment to consider a so significative number of subdetectors which will open the number of possibilities for CMS. One very interesting example is this one of the possible diffractive observation of Higgs with the Central Production Topology. Let us see a bit about each one of the most important but not exhaustive list of detectors.

2.3.1. TOTEM - TOTEM is a set of sub-detectors to measure the Elastic and Total Cross-Section [7]. The spectrometer is constituted by Roman Pots at 147 m and 220 m near to the beam. The rapidity gap range fill the space between 3.1 and 6.5. This experiment is important for studies of elastic scattering and it is also important to get a new number for total cross-section in view of the values found by the E811 and CDF at Tevatron/Fermilab [19]. We need to compare to the predictions of the asymptotic extrapolation of the two know measures.

2.3.2. CASTOR - Centauro And STrange Objects Research - Castor is a Forward Calorimeter with two components, one Electromagnetic and another Hadronic. This was designed to attend the request for an eventual Centauro event. The Electromagnetic sector has 16 segments in \( \phi \) and 12 for hadronic part. The active part is made of Tungsten sandwiched with plates of Quartz. A air-core lightguides transmit the Cerenkov light to the PMTs. These PMTs have special treatment for radiation resistance. Its position is at the end of the HF-Hadronic Calorimeter. The range of pseudo-rapidity \( \eta \) is: \( 5.2 < \eta < 6.6 \). Centauros are the phenomena observed in Cosmic Ray Physics [20]. The main characteristic of Centauros are the large multiplicity of hadrons with a low activity electromagnetic or almost no \( \gamma \) no \( \pi^0 \) production. In Cosmic Ray Physics, as is shown in the references given above, there are different level of mass for Centauros: 200 to 300 \( GeV/c^2 \) those called Centauros, for mini-centauros they can have 20 - 30 \( GeV/c^2 \), for Chiron 200 \( GeV/c^2 \) and for Geminion 15 - 30 \( GeV/c^2 \). These value have to be a guide/hint to our experiment at LHC/CMS.

2.3.3. ZDC-Zero Degree Calorimeter - The (ZDC) is a subdetector located 140 m down the tunnel on each side of the central detector CMS interaction point. This Calorimeter is part of the complex of calorimeters like Castor, with five electromagnetic channels and four hadronic, as a sub-system of the CMS Forward HCAL hadron Calorimeters. The physics associated to this calorimeter are the luminosity, then the LHC itself, the heavy ion physics, cosmic ray physics and diffraction [8].
2.3.4. FP420/HPS - The FP420 is a project [9] for a new Forward sub-detector for CMS. It was conceived to be a silicon detector and having the possibility to detect scattered protons at high precision. It will be on both sides of the tunnel of LHC at 420 m from the interaction point of CMS. The physics associated to this sub-detector include several important topics connected to the diffractive central exclusive production of the interaction of $pp \rightarrow p + \phi + p$ where both outgoing protons remain intact $\phi$ can be a Higgs boson decay in the $b\bar{b}$ or any other heavy flavor. The reader will find many interesting details on the reference above.

3. Conclusion
Forward Physics and Diffraction are very important to complete the understanding of Strong Interactions. Many comparisons between Theory/Models and Experiment data does not consider the diffractive component. Then it is interesting to know how much the diffractive part of the cross section contribute. This is being studying calculating the rate of the diffractive and no diffractive or diffractive and all production. This can give us a better understand of the mechanisms of production and eventually make the eventual corrections on the calculations. On the other hand these detectors for measurement of diffraction, helps in different ways other topics like the calculation of the luminosity. There are many topics under investigation on the Forward Physics Group of CMS. The rate of diffractive/non diffractive of Heavy Flavor, the topology Jet Gap Jet in which we can have some light about the production of a number of states: Single Diffraction Z and W production, Dijets and multijets in diffraction, Centauros, and so on. We expect for next years by the introduction of new detectors like FP420 we could continue to do this physics even with the high rate of pile-up. We could not extend each subtopic of this talk due to limitation of space. Then we did a very short overview of the physics of Diffraction on CMS.

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