Separating Diffractive and Non-Diffractive events in High energy Collisions at LHC energies.

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The charged particle multiplicity distribution in high energy hadronic and nuclear collisions receive contribution from both diffractive and non-diffractive processes. It is experimentally challenging to segregate diffractive events from non-diffractive events. The present work aims to separate and extract the charged particle multiplicity distribution of diffractive and non-diffractive events in hadronic collisions at LHC energies. A data driven model using the topic modelling statistical tool, DEMIX, has been used to demonstrate the proof of concept for p−p collisions at \( \sqrt{s} = 7 \) TeV generated by Pythia 8 event generator. The study suggests that DEMIX technique can be used to extract the underlying base distributions and fractions for experimental observables pertaining to diffractive and non-diffractive events at LHC energies and can therefore be used as a step forward for an experimental determination of precise inelastic cross-sections in p−p collisions.

I. INTRODUCTION

The estimation of total inelastic proton−proton (p−p) cross-section is an important observable to characterize the global properties of interactions. The inelastic cross-section receives a significant contribution (≈ 26 - 29%) from diffractive process and the precision estimation of p−p cross-section as the diffractive cross-section cannot be calculated in the pQCD framework and they depend on predictions made by models based on Regge theory [4]. The precise estimation of p−p inelastic cross-section and improving the theoretical description of diffractive processes is quintessential as it serves as an important input for modelling hadronic interactions in various theoretical models and is required for the calculation of the number of binary collisions in heavy ion physics.

The diffractive processes are characterized as dissociative processes with absence of net color flow between the initial state protons while non-diffractive ones have color flow between them. Generally, the diffractive events are characterized by exchange of pomerons which are color-singlet particles carrying the vacuum quantum numbers. The current work is based on the DEMIX statistical tool which has been successfully used recently to separate quark and gluon jets in p−p collisions [5, 6]. Additionally the investigation has been extended to study differences in quark and gluon jet modifications in heavy ion collisions [7].

The DEMIX method is commonly used to isolate mixture of two different probability distributions to their base distributions [8–10]. In this work, the method has been explained in terms of distributions functions related to diffractive and non-diffractive events. Generally the method works for any two distinct classes of events. Let \( p_1(x) \) and \( p_2(x) \) be the probability distributions of charged particle multiplicity in sample \( S_1 \) and \( S_2 \) respectively. They can be expressed as distinct sum of the underlying probability distributions of diffractive and non-diffractive events, \( p_D(x) \) and \( p_{ND}(x) \), respectively. These underlying pure distributions are known as the base distributions. Therefore, \( p_i(x) \) can be expressed as

\[
p_i(x) = c_i p_D(x) + (1 - c_i)p_{ND}(x) \quad (1)
\]

where \( c_i \)s (0 < \( c_i \) < 1) are fractions and one can have infinite ways of obtaining \( p_i(x) \) depending on the values of \( c_i \)s. A further constraint required for the tool to work is that one of the samples, \( S_1 \) should be enriched in diffractive events while the other sample, \( S_2 \) in non-diffractive events. This requirement enables one to use the maximum likelihood ratio, \( L_{S_1/S_2} \), as a classifier to distinguish between \( S_1 \) and \( S_2 \). The likelihood ratio can be written as:

\[
L_{S_1/S_2}(x) \equiv \frac{p_1(x)}{p_2(x)} = \frac{c_1 L_{D/ND}(x)}{c_2 L_{D/ND}(x)} + (1 - c_1)
\]

(2)

where \( L_{D/ND}(x) = \frac{p_D(x)}{p_{ND}(x)} \) is the likelihood ratio of diffractive and non-diffractive events in charged collisions.

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particle multiplicity space. As \( L_{S_i/S_2}(x) \) is a monotonic function of \( L_{D/ND}(x) \), one can find the diffractive enriched regions in \( x \) where \( L_{D/ND}(x) \) is maximum. If one can find regions in \( x \) observable where the diffractive and non-diffractive distributions are pure, then \( L_{ND/D}(x_D) = 0 \) or \( L_{ND/ND}(x_{ND}) = 0 \). One can then define the reducibility factor, \( \kappa(D, ND) \) as

\[
\kappa(D, ND) = \min_x \frac{p_D(x)}{p_{ND}(x)}
\]

If mutually irreducible in \( x \), \( \kappa(p_D, p_{ND}) = \kappa(p_D, p_{ND})=0 \). Thus, \( p_1(x) \) and \( p_2(x) \) can be expressed in form of mutually irreducible distributions, \( t_D(x) \) and \( t_{ND}(x) \) for which \( \kappa(t_D, t_{ND}) = 0 \). These distributions are referred as topics. The \( \kappa \)s are related to the fractions \( c_i \)'s. Therefore, the operational definition of diffractive and non-diffractive events can be considered as the topic distributions and are expressed as

\[
t_D(x) = \frac{p_1(x) - \kappa(D, ND)}{1 - \kappa(D, ND)} \frac{p_2(x)}{1 - \kappa(D, ND)}
\]

\[
t_{ND}(x) = \frac{p_2(x) - \kappa(ND, D)}{1 - \kappa(ND, D)} \frac{p_1(x)}{1 - \kappa(ND, D)}
\]

The details of the method are given in [6]. The method was tested through a toy model where two different probability distributions are generated assuming Poisson (mean = 30) and Binomial (mean= 60, variance = 55) distribution, respectively. The two mixed samples were constructed by mixing the distributions such as the fraction of Poisson function in one distribution (sample-1) is 85% and in the second sample (sample-2) is 18%. The DEMIX procedure was then applied to obtain the topic distribution and was compared to the generated base distribution. This is shown in Figure 1 and one can observe that the base distributions are in excellent agreement with the extracted topics. The extracted fraction of Poisson function in sample-1 after applying DEMIX is 0.85 while it is 0.18 in sample-2.

It is quite challenging to differentiate between the diffractive and non-diffractive events at the event level in high energy hadronic \((p−p)\) collisions. This study is basically a proof-of-concept which demonstrates that DEMIX method can be used to separate the diffractive and non-diffractive components of charged particle multiplicity distribution. The method present in this work is similar to that employed in [7] to separate quark and gluon jets. The diffractive and non-diffractive events were generated using the Pythia 8 event generator for \( p−p \) collisions at \( \sqrt{s} = 7 \) TeV. Pythia 8 event generator has been extensively used to study both diffractive and non-diffractive physics at LHC energies [13]. The diffractive events were comprised of single diffractive, double diffractive and central diffractive events [11] [12]. The two mixed samples of charged particle multiplicity distribution, one enriched in diffractive events and other in non-diffractive events were obtained by mixing different fractions of the generated non-diffractive and diffractive events. The diffractive enriched sample (DIFF) has 80 % diffractive events and 20% non-diffractive events while non-diffractive enriched events (NON-DIFF) has 80% non-diffractive events. The charged particles were required to have \(|η| < 2.5\). Figure 2 shows the diffractive and non-diffractive topic distribution extracted from the DEMIX method. The extracted topics are compared to the base distributions of charged particle multiplicity for diffractive and non-diffractive events. One can observe that the extracted topics are in good agreement with the base distributions obtained by Pythia 8.2. The obtained \( c_2 = 0.22 \) which is close to the input fraction of 0.20 used for generating the mixed sample.

However, in realistic experimental scenario, one does not have prior information about the enriched
samples at event level and one has to depend on various kinematic cuts dictated by the diffractive physics like presence of large rapidity gap, diffractive mass etc at event level to segregate the diffractive events. The recent estimation of inelastic cross-section in p−p collisions at √s = 7 TeV by ATLAS experiment used the DL model [14] with Pythia 8 fragmentation for calculating diffractive cross-sections and uncertainties[3]. Therefore, the present study can provide a model independent estimation of the cross-sections in real data. The study has been extended to minimum bias sample obtained with Pythia 8 to differentiate between diffractive and non-diffractive charged particle distributions. The default minimum bias Pythia 8 events has ~ 29% diffractive events and ~ 71% non-diffractive events and is quite similar to the real experimental data. The sample-1 was taken to be the DIFF enriched while the minimum bias sample was used as sample-2 for this study. The charged particles were required to have |η| < 2.5 and pT > 0.05 . Figure 3 shows the charged particle multiplicity distributions of the enriched samples, the topics extracted and their comparison to the base distributions in the accepted region. It can be observed that the distribution of topics extracted from the two distributions are in good agreement with the base distributions in the selected kinematic range. The fraction of diffractive events in min-bias was obtained to be 29.1% which is in agreement with the default fraction of 0.29 present in the minimum bias Pythia sample. This shows that one can use this technique in high energy hadronic collisions to obtain diffractive cross-section for precise measurements of inelastic cross-section.

II. SUMMARY

The charged particle multiplicity distributions in high energy hadronic and nuclear collisions receive contribution from both diffractive and non-diffractive processes and it is imperative to distinguish them to obtain precise inelastic cross-sections. A data driven model using the statistical tool DEMIX was used to extract the fraction of diffractive component in the charged particle multiplicity distribution of p−p collisions at LHC energies. The application of tool suggests that DEMIX technique can be used to extract the underlying base distributions and fractions for experimental observables pertaining to diffractive and non-diffractive physics at LHC energies and there-
fore can be used for a model independent experimental determination of inelastic cross sections to a better precision.

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