



## Geometrical Models and Hadronic Radii

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**Abstract:** With the new results from TOTEM at LHC, we hope to have a glimpse of the total cross section at cosmic ray energies. We explore the behaviour of total and diffractive scattering at ultrahigh energies in the light of Geometrical models. A consistent picture of the hadronic matter is offered. A comparison is also made with other results.

**Keywords:** total cross section, Geometrical models

### 1. Introduction

Advancements in accelerator technology have helped in bringing a revolution. Large hadron Collider (LHC) facility is just one example, besides several others taking up physics agenda at a sub-atomic level. The machine, now operational, is set to explore ‘new physics’ at a TeV scale. Measurements at LHC will provide us a better understanding of QCD, B-physics, Heavy ions, Supersymmetry, Black Holes, Extra dimensions and much more. During the past sixty years we have enhanced understanding of sub-atomic physics with a lasting change in our understanding of the physical concepts [1- 17]. A huge resource of literature is available which describes these developments and many of these are available on CERN archives.

Our work encompasses theory (Geometrical models) as confronted to TOTEM measurements at LHC [1]. These measurements will cover total and elastic scattering and consequently throw light on the shape and size of proton. In our work, we will review various scenarios based on predictions for the total cross section and infer a picture of hadronic size.

### 2. TOTEM Measurements

As reported in a recent CERN bulletin in its November 2010 issue [2], “TOTEM is the LHC experiment (currently) dedicated to the measurement of the proton total cross-section. This first proton run produced a wealth of

data that is allowing the collaboration to probe the proton as never before”.

According to TOTEM spokesperson [2], Karsten Eggert, “We are there to measure the total cross-section of the proton, which describes the likelihood that some kind of interaction will occur between the protons”. He further explained that “In order to do so, we have to understand all the individual processes and separately measure the different cross-sections”. He further explained that “During this first run we collected hundreds of thousands of elastic scattering events and were able to confirm that the diffractive pattern observed by previous experiments at much lower energies persists at high energies”. In a scattering collision, we can “look inside the proton without breaking it apart” [2]. “With this technique we can infer what the distribution of quarks and gluons might be inside the proton”, continues Karsten Eggert. “There are several theoretical models that predict how the proton behaves internally and our spectra will allow us to compare the different models with real data by the end of this year”.

According to the approved plan, TOTEM [2] is an experiment “dedicated to the measurement of total cross section, elastic scattering and diffractive processes at LHC”. Measurements are planned from 7 to 14 TeV for  $pp$  total and elastic scattering. LHC running at reduced c.m. energy of 1.8 TeV, will provide an opportunity to compare the results with FERMILAB. “Total cross section will be measured using the luminosity independent method which is based on the simultaneous detection of elastic scattering at low momentum transfer and of the inelastic

interactions. This method also provides an absolute calibration of the machine luminosity” [1,2].

### 3. Geometrical models

Geometrical (or Eikonal) picture [3-12] has firm roots in electromagnetic scattering of light, nuclear physics etc. In high energy physics, it has had remarkable success in explaining a wide variety of data. As reported in our earlier work [4], the partial wave amplitude  $T(s,b)$  in an Eikonal model has the form

$$T(s,b) = 2k^2 [\exp(2i\delta(s,b)) - 1] / 2i$$

The quantity  $2\delta(s,b)$  is usually denoted by  $-i\Omega(s,b)$  where  $\Omega$  is called the Eikonal phase or the "Eikonal". For elastic scattering, it represents the phase shift at a given impact parameter. In terms of the Eikonal, scattering amplitude  $T(s,t)$  is written as

$$T(s,t) = -i \int b db J_0(b\sqrt{-t}) [1 - \exp(-\Omega(s,b))]$$

Expression for  $\Omega$  and the corresponding justification varies from author to author but the general philosophy remains the same.

Chou and Yang [3] first applied geometrical picture to pp elastic scattering. Since then the model has undergone several changes and is now significantly developed. Scores of papers [3-12] have been published using the central theme employed by Chou and Yang. In view of space constraint, we will restrict to representative data. Salient features of these models are:

1. Saleem and Fazal-e-Aleem generalized the model by using multiple diffraction theory [4]. The model assumes that for large  $-t$ , "central partons dominate the process". Multiple scattering therefore occurs, i.e., the central parton constituting a colliding particle suffers successive collisions with two or more partons of the other particle before leaving the scattering region. Since then, it has been applied to a variety of collisions involving strong interactions [4].
2. Hüfner and Povh [5] gave an analysis of  $p(p)p$  elastic scattering. They relied on two experimental observations: "relation between the shape of the differential cross section and hadronic form factors" and "a relation between total cross sections and slope". Using a suitable parameterization, including "both relations", they generalized it incorporating the requirements of analyticity. In their physical picture, hadronic radius is not viewed as "a static distribution of quarks and gluons in the hadrons but as an interaction radius, which increases with energy because more inelastic channels open up and new degree of freedom of the colliding hadrons contribute".

3. Efforts were made to incorporate ideas of QCD. These models incorporate "semi-hard scattering of quarks and gluons or partons in the nucleus". Models differ mostly in their treatment of QCD and also whether or not they respect the constraints imposed by unitarity [4].
4. Block et al [6] assumed that increase of cross sections is "a consequence of the increasing number of soft partons populating the colliding particles". They argue that at asymptotic energies, "hadrons evolve into black disks of partons". Gluon-gluon interactions explain the increase in total cross section.
5. Lam [7] explained data by "looking at QCD phase shift". Rise of the total cross section was explained while ensuring that Froissart bound is fulfilled. They computed the quark-quark scattering phase shift in two-loop order, in the leading *log* approximation.
6. Kopliovich et al [8] gave a "dynamical description of small angle elastic scattering of light hadrons" and calculated "cross section of gluon radiation in high energy hadronic interactions". They point to a possible existence of small gluonic clouds surrounding the valance quarks in light hadrons. It was pointed out "the effective Pomeron trajectory is a steeply rising function of the impact parameter".
7. Several other authors [9-12] published their work, which fit the current data in the GeV region using Dispersion relations, Regge theory and Geometrical models [4]. However, these results differ at the TeV scale.

An overview of theoretical models show that 'existing data in GeV region' is fitted nicely. However, these models do not give similar results at the TeV energies and beyond. Accurate measurements at TOTEM will throw more light on the validity of these models.

### 4. Hadronic radii

Having discussed geometrical models including those incorporating QCD, and their predictions, we will give a brief outline of the hadronic picture. This will also include the one based on our work [13] which, encompasses the behaviour of hadronic radii and the associated physical picture.

Both macroscopic and microscopic studies exist for studying *nuclear* radii. Among the macroscopic models, the liquid drop model has been the most successful in describing radii of stable nuclei. Besides, unstable nuclei were also taken up. For halo nuclei, liquid drop model fails to explain sudden increase of nuclear *rms* radii near the drip line. A simple empirical formula was proposed to represent the halo nuclear radii [13-17].

Geometrical models have been successful in studying hadronic/nuclear properties including radii [4,13]. In our recent work [13], *rms* radii for several hadrons were computed using Generalized Chou-Yang model.

Theoretically [4,13], the mean square charge radius of a hadron/nucleus can be obtained either by finding the minima of respective form factor or from the behavior of form factor under the limit  $t^2 \rightarrow 0$ . Computations were made with electromagnetic form factors of hadrons as used in the Generalized Chou Yang model. Predicted radii were found to be consistent with those from scattering experiments and other models [13]. It was observed that radii vary with the quark content of the hadron. This aspect was highlighted and probed for both mesons and baryons separately.

## 5. Conclusions

It has been observed [4] that at LHC, different models predict significantly different values of the total cross section. "We observe that the value of total cross section for different models varies from about 95 to about 145 mb. Although cosmic ray data due to large error bars accommodate these values, accurate measurements at LHC will be very important". "What actually is the energy dependence of the total cross section? As yet it is an open question without a definite answer. Data at ISR, SPS and Tevatron can be fitted with both  $\log s$  and  $\log^2 s$  behavior. In geometrical models, rise of  $\sigma_T$  is related to the shape of the colliding particles. In QCD inspired models, origin of this quantity is accounted for by the increase in the number of gluons [4].

The computed *rms* radii using GCYM indicate that the size of hadron decreases, separately for baryons and mesons, with increasing quark content of the hadrons. Thus, as argued in earlier work, [13], we can say that size of hadrons (separately for baryons and mesons) decreases with increase in the magnitude of strangeness for almost all hadrons.

**Note:** In view of the vastness of the subject, many details have not been given and are available in excellent review articles/conference proceedings/web archives. We apologize to all those whose scholarly work has either been cited partially or could not be included due to representative selection of the literature. Details will be published elsewhere.

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