Experimental summary

Halina Abramowicz
DESY and Tel Aviv University

Abstract

A summary of the experimental results presented at this conference is discussed together with an attempt to point out the links between the various areas of research, affected by the understanding of elastic and diffractive scattering.

1 Introduction

As demonstrated at this conference, elastic and diffractive scattering affect many areas of research in high energy physics. While the definition of elastic scattering in hadron-hadron collisions is unique, both theoretically and experimentally, the definition of diffractive scattering is less precise. In elastic scattering, the interacting particles preserve their identity in the final state and carry out of the scattering all the available energy. In single diffraction, one of the incoming particles remains unscathed and is expected to carry out most of its initial momentum. Typical of diffractive scattering at high energy is a large rapidity gap separating the diffracted system from the 'unscathed' particle. In double diffractive scattering, both incoming particles loose their identity, however the respective final states, again well separated in rapidity, preserve the quantum numbers of the colliding particles.

In soft hadron-hadron interactions, elastic and diffractive scattering are described by Regge theory and understood as due to the exchange of the Pomeron trajectory [1,2]. The appearance of diffractive scattering with associated large transverse momentum jets in $p\bar{p}$ collisions observed by the UA8 experiment [3], have prompted Ingelman and Schlein [4] to propose the concept of a partonic structure of the Pomeron. Today, more than a decade after the discovery of diffractive interactions in deep inelastic ep scattering (DIS) at HERA [5, 6], it is clear that the Pomeron is predominantly a gluonic object [7]. This is consistent with expectations of perturbative QCD where, in leading order, diffractive scattering is mediated by two-gluon exchange [8, 9]. The appearance of diffraction is therefore closely related to the structure function of the proton and its large gluon component at low x, where x is the fraction of the proton momentum carried by a parton.

At high energy, elastic and diffractive scattering constitute a large fraction of the total scattering cross section. However, in spite of a large theoretical effort vested in understanding the dynamics of diffractive scattering (see summary by K. Golec-Biernat in these proceedings), there is as yet no consistent theoretical framework able to describe all the aspects of experimental observations. Various theoretical frameworks, based on different degrees of freedom (partons, color dipoles, color glass condensates, Regge trajectories), achieve different level of success, weakening therefore their predictive power and making the present and future experimental program that much more interesting and important.

The various aspects of diffractive scattering (large gluon density at low x, leading particle effect, factorization breaking) correlate many research programs, at HERA, at FNAL, at RHIC, at LHC and even in cosmic ray physics with extensive air showers (EAS). Some of it will be pointed out in this summary.

2 Inclusive diffraction and rescattering

In DIS at HERA, the diffractive structure function of the proton, F_2^D, can be parameterised in terms of diffractive parton distributions (dPDF) which can then be used to test the diffractive QCD factorisation theorem, expected to hold at large Q^2 [10]. Factorisation in diffractive scattering has been successfully tested in dijet [11, 12] and in charm [13, 14] production in DIS , as well as in diffractive charm photoproduction [14, 15].

As expected, factorisation fails in $p\bar{p}$ interactions [18], where typically rates for diffractive production in the presence of a hard scale are a factor 10 lower than expected from the HERA dPDF. This rate reduction may be explained as the result of multiple interactions, whereby the remnant partons of the diffracted proton rescatter off the leading proton and the products of the rescatter destroy the large rapidity gap (gap survival probability) [19]. A similar effect, albeit at a lower rate because of the size of the photon, is expected in dijet production in γp interactions [20], in the regime in which the photon interacts with the proton through its partonic component. A factor two suppression of dijet photoproduction has been observed by the H1 experiment [16] independent of whether the reaction proceeds through the resolved or direct photon component (see Fig. 1), though for the latter one expects factorisation to hold. A much weaker suppression,

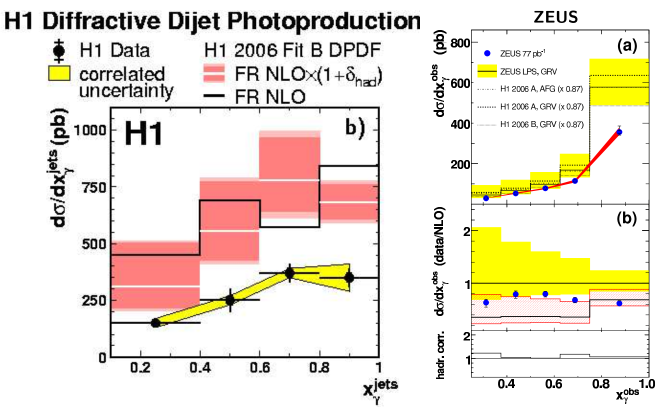

Fig. 1: The differential cross section for diffractive dijet production in γp scattering as a function of the fraction of the photon momentum involved in the interaction, x_γ^{jets} or x_γ^{obs}, as measured by H1 (left) and by ZEUS (right).

if at all, has been reported by the ZEUS experiment [17] (see Fig. 1). This apparent discrepancy requires further studies. What might be significant is that the transverse momenta of jets probed by ZEUS are higher than those of H1, possibly squeezing the photon into a smaller transverse configuration, in which case a smaller suppression would be expected. Gap survival and its dependence on the projectile size may turn out to be important in understanding and modeling multiple interactions.

3 Exclusive reactions in hard diffraction

The sensitivity of diffractive scattering to the size of interacting objects may be directly probed in exclusive reactions, such as vector meson production or deeply virtual Compton scattering (DVCS), in ep interactions at HERA. The size of the interacting photon may be controlled either by its virtuality Q^2, or the mass of the vector meson (J/ψ, Υ), or the momentum transferred squared at the proton vertex. Indeed, as discussed by A. Levy at this conference, when the photon is squeezed into a small size $q\bar{q}$ fluctuation, a bare proton emerges from the interaction and the measurements are consistent with a picture in which the exclusive processes proceed via the exchange of a two-gluon ladder.

In a larger picture, exclusive processes in ep scattering become a source of knowledge of generalized parton distribution (GPD) functions [21] from which one can extract not only the standard one-dimensional, longitudinal, parton distributions in the proton, but also the transversal distributions and various correlations.

3.1 DVCS and GPDs

The various GPDs, which contribute to DVCS, $H,\ E,\ \tilde{H},\ \tilde{E}$, may be extracted from exclusive photon production, $ep \to ep\gamma$, from the interference terms between the DVCS (QCD) and the Bethe-Heitler amplitude. The interference terms distort the distribution of the azimuthal angle, ϕ, and lead to beam-charge, beam-spin, longitudinal target-spin asymmetries. The measurements reported by the HERMES experiment at this conference clearly demonstrate the presence of these asymmetries (see talk by R. Fabbri). These data will be invaluable in constraining GPDs, for which the QCD evolution is known.

An attempt to extract GPDs in NLO and the ensuing three dimensional view of the proton structure has been presented at this conference (see talk by K. Passek-Kumericki). As x decreases, the number of partons increases as expected, and the radial coverage in the transverse plane increases (see Fig. 2). This is an important correlation which will affect the probability of

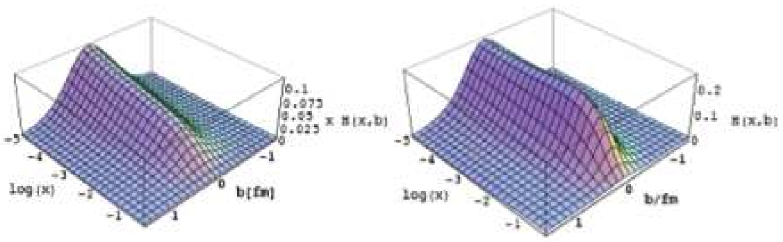

Fig. 2: Three dimensional extraction of the quark (left) and gluon (right) GPD (H).

multiple interactions in pp collisions as a function of x and the scale of the interaction [22].

3.2 Exclusive diffraction in $p\bar{p}$

An analogue of the two-gluon exchange reaction in $p\bar{p}$ (pp) is shown in Fig. 3(left). The same

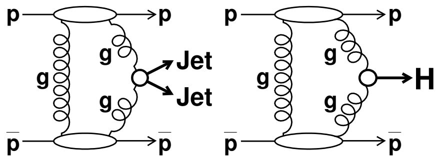

Fig. 3: Exclusive dijet (left) or Higgs (right) production in $p\bar{p}$ interactions.

diagram, as shown in Fig. 3(right,) may lead to exclusive Higgs production, which may yet turn out to be the cleanest way to measure the Higgs properties at the LHC [23], as massless quark production in $gg \rightarrow q\bar{q}$ is suppressed in leading order QCD by the $J_z = 0$ selection rule (for a discussion see contribution by A. De Roeck in this proceedings).

CDF has searched for diffractive exclusive dijets production in their RunII data. A significant excess of events in which the invariant mass of the two jets, M_{jj} saturates the total diffractive mass measured, M_X, is observed over MC expectations for diffractive, inclusive dijet production. As shown by K. Goulianos at this conference, the excess, in shape and rate, agrees well with the expectations of the model by Khoze et al. [23]. Moreover, as expected by the $J_z = 0$ selection rule, the fraction of dijets containing either charm or beauty decreases for large values of M_{jj}/M_X.

This is certainly good news for the LHC forward physics program as indeed diffractive Higgs production may be observed, although the expected rates are not very encouraging. In the best case scenario of the SM, about 100 events are expected (acceptance included) for an integrated luminosity of 30 fb^{-1} (see talk by J. Forshaw). The rates could turn out to be much larger in some scenarios of the MSSM, where the channel $h, H \rightarrow b\bar{b}$ is enhanced.

4 Forward physics at LHC

Both the ATLAS and the CMS experiments have instrumented forward regions to study the energy flow of particles in the very forward region, and to tag elastic and diffractive scattering (see contributions by M. Tasevsky, M. Deile, A. Hamilton, A. De Roeck, L. Fano, C. Sbarra) . The ATLAS forward detectors include LUCID, ALFA and ZDC. The first two, located at $\pm$17 m and $\pm$220 m from the interaction point (IP), were originally designed for precise luminosity measurement, while ZDC, located at $\pm$140 m is sensitive to neutral particles emitted at $0°$. In addition, the LHCf experiment has its calorimeters and trackers located at 140 m from the IP of ATLAS. As an example, the pseudo-rapidity coverage provided by these detectors is shown in Fig. 4. The CMS forward detectors include HF, CASTOR, and CMS-ZDC. The HF calorimeters, for forward jet tagging is located $\pm$11 m from the IP. The CASTOR calorimeters are located at $\pm$14 m from the IP. As in the case of ATLAS, the ZDC in CMS is located at $\pm$140 m from the IP. In addition, the TOTEM experiment has its two tracking telescopes (at about $\pm$10 and $\pm$14.5 m from the IP) and its Roman-pot stations (at $\pm$147 and $\pm$220 m from the IP) included in the read-out of CMS, making the pseudo-rapidity coverage of CMS the largest ever achieved at colliders.

For precise measurements of the Higgs mass from exclusive diffraction, the detectors lo-

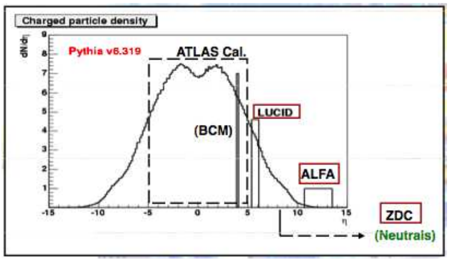

Fig. 4: The η coverage in the ATLAS experiment.

cated at 220 m from IP will have to be complemented by detectors at 420 m.

The forward coverage may provide a substantial extension of the low x range probed at large scales, as to be sensitive to the expected saturation (unitarity) effects in QCD. In any event, measurements of the very forward energy flow, be it in a restricted phase space, will provide invaluable information for tuning MC programs which model the development of EAS and which at present may differ by as much as factor two (see talk by A. Hamilton).

5 Underlying event and MPIs

Hard collisions in hadron-hadron interactions are accompanied by the so-called underlying event, which is the result of fragmentation of hadron remnants after their color coherence is broken by the hard parton-parton scattering. This part of the underlying event is usually assumed to have the characteristics typical of soft interactions (cylindrical phase space). In addition, because parton-parton scattering has an unphysically large cross section for low transverse momenta jets, multiple hard scatters are expected. The added activity in the event obscures the properties of hard physics, to be confronted with theory, and it is essential to model the underlying event properly.

The pp and $p\bar{p}$ data indicate that the presence of one subcollision enhances the probability of another one (for a review and discussion see contribution by G. Gustafson in these proceedings) . Moreover the harder the collision, the larger the probability of another collision. Multiple interactions are also needed to describe jet production in ep collisions at HERA at moderate Q^2, which is interpreted as due to the presence of resolved virtual photons (see presentation by T. Namsoo). This adds yet another dimension to the multiparton interactions, which may well depend on the size of interacting objects.

An extensive study of the underlying event has been made by R. Field at the Tevatron (see for example [24]) and he managed to tune the underlying event model of Sjoestrand and van Zijl [25] in PYTHIA to essentially describe all the data. However the correlation between the transverse energy and hadron multiplicity is not properly reproduced. An important ingredient of the model is the non-uniform distribution of partons inside the proton and the dependence of the cross section on the impact parameter. The studies of GPDs may help in modeling this aspect of multiple interactions.

The experiments at the LHC, where the analysis will be complicated by the added presence of multiple collisions between two protons, are gearing themselves towards the direct measurement of the properties of the underlying events. For that purpose both the forward and central detectors will be used with special triggers, in particular for minimum bias events, as discussed by L. Fano at this conference. It will be very interesting to observe what happens when at the LHC the high density of gluons will be probed. Surprises may be expected, as diffraction is not part of the modeling of multiple interactions.

6 Forward physics in heavy ion collisions

The complexity of the physics of forward particle production is exemplified by the results from RHIC (see talk by D. Roehrich). Forward produced particles, with high transverse momenta, originate from interactions of low x partons, predominantly from gq and gg interactions as derived from NLO QCD calculations, which provide a reasonable description of the data. Therefore, sensitivity to effects due to gluon saturation is expected on nuclear targets, where the gluon density is enhanced by the presence of many nucleons, and in particular in central collisions.The pattern of particle production and suppression (see Fig. 5) strongly suggest that collisions in-

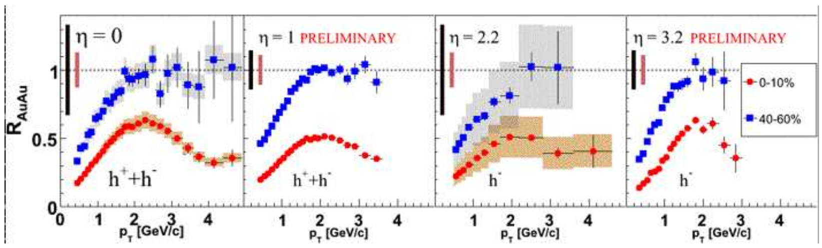

Fig. 5: Nuclear modification factor R_{AuAu} as a function of transverse momentum p_T for different values of pseudo rapidity η, for central (dots) and peripheral (squares) $AuAu$ collisions.

volving nuclear targets at RHIC probe a novel regime of QCD governed by coherent non-linear phenomena and gluon saturation - the color glass condensate. These effects are expected to be amplified in heavy ion collisions at LHC.

7 Total cross section measurements and luminosity at the LHC

The energy dependence of the total pp cross section as well as the t dependence of elastic cross cross section constitute a reference for the properties of soft interactions at high energy. Both measurements are notoriously difficult at colliders. At present, the model dependent extrapolation of the total cross section to be expected at the LHC is anywhere between 90 and 130 mb [26].

The LHC community has set a goal to measure both the total cross section and the t dependence of the elastic cross section to high precision. The TOTEM experiment (see talk by M. Deile), with the $3.1 < |\eta| < 6.5$ region of phase space instrumented with trackers and Roman pots, close to the CMS IP, aims at measuring the total pp cross section to a precision of 4% in the early stages of LHC running, to be improved to a 1% level at a later stage. This will be achieved by determining the $d\sigma_{el}/dt$ at $t = 0$ and by measuring the elastic and inelastic rates. The detector acceptance for inelastic events is close to 95%, where most of the loss is due to low mass diffraction. A byproduct of these measurements is luminosity. Dedicated beam conditions will be needed to achieve these goals.

The results of TOTEM will be used by the ATLAS experiment to calibrate its luminosity monitor (LUCID) and later will be cross checked when the very forward ALPHA detectors will be installed (see talk by C. Sbarra).

8 Cosmic rays

Cosmic ray energy spectrum extends far beyond 10^{17} eV, the LHC energy reach. Cosmic rays are therefore a unique source of high energy particles and could be important in providing information on total cross section behavior beyond accelerator energies. The interaction length is extracted from properties of EAS, such as the shower maximum, and the total number of muons and electrons at the observation depth, as explained by R. Ulrich in this conference. The translation of these properties into cross section requires simulations of shower development in air, which are based on extrapolating our understanding of particle production to very high energies. These simulations are particularly sensitive to the inelastic cross section and to particle production spectra, which as shown in Fig. 6, vary substantially from model to model (see talks by G. G. Trinchero and A. Tricomi). New constraints on these models are expected from the LHCf

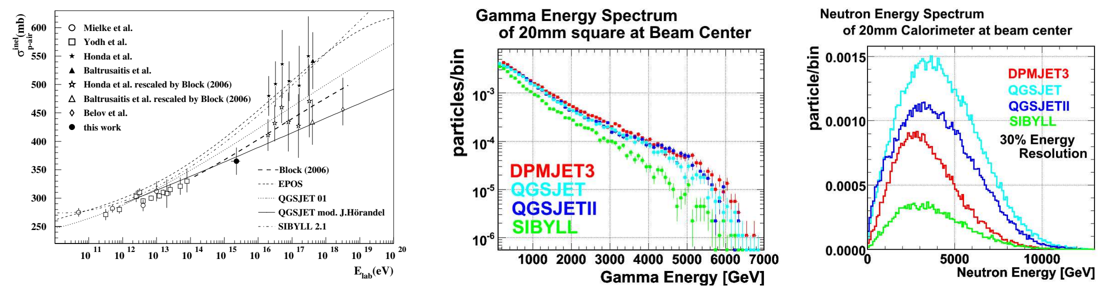

Fig. 6: Comparison of various shower development models: for inelastic p-air cross sections as a function of energy (left), for expected γ spectrum (middle) and neutron spectrum (right).

detector whose purpose is to measure the forward spectra of neutral particles, π^0 and neutrons, at the LHC (see talk by A. Tricomi).

9 Conclusions

The area of high energy physics, which encompasses total, elastic and diffractive cross sections, is far from being understood from first principles, yet it impacts many other aspects of high energy physics. There is a steady influx of new experimental results to guide the theoretical concepts. New results are expected at the LHC, though the experimental environment is very difficult and requires great ingenuity of experimentalists.

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