Panel Discussion EDS'09 – What can we learn / expect from the LHC Experiments?

Chaired by Karsten Eggert[6]
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1 Introduction

Author: Karsten Eggert

The panel discussion between experimentalists (most of the LHC experiments were represented) and theorists focussed on the following subjects:

What are the most important topics on forward and diffractive physics to be addressed at the start of the LHC? How much can we learn from the experience gained during the forward detector operation at FNAL (K. Goulianos) and HERA (H. Jung) and from their latest physics results? What kind of collaborations between the LHC experiments can be envisaged to maximise synergy effects, including common trigger and run strategies, beam analysis, Monte Carlos and combination of data?

The LHC experiments benefit from their large acceptance overlaps of the very forward detectors up to the Roman Pot detectors several hundred meters upstream. As an example, the multiplicity distributions for different pseudorapidity intervals have to be corrected with the individual experimental and trigger acceptances to be able to obtain cross-sections for diffractive processes (K. Safarik). The different systematics of the experiments will help disentangle the various cross-sections.

The measurement of the elastic scattering cross-section over a large transverse momentum range t ($10^{-3} < t < 10\,\mathrm{GeV}^2$) is also quite challenging, and benefits from different systematics of the two set-ups (ATLAS and TOTEM) and the way the collaborations will extract the total cross-section (Per Grafström).

New ideas about the measurements of protons with low relative momentum losses (typically 10^{-3}) using the large dispersion of the LHC at some selected places around the LHC ring have been presented for future upgrades (A. De Roeck and H. Niewiadomski).

On the theoretical side, M. Strikman presented his ideas about probing parton correlations by studying multiparton interactions in diffractive processes, and C.-I Tan suggested the duality of diffractive scattering and Pomeron physics.

It was generally felt that the LHC will address exciting physics in diffraction and forward physics with probably some new insights, but also that close collaborations between the experiments are mandatory to fully explore the LHC potential.

2 Experimental Synergy – From the ATLAS Point of View

Author: Per Grafström

In the context of the discussion of "What can we learn /expect form the LHC experiments?" I was asked to give some examples of possible synergy between the ATLAS forward detectors and other forward detectors at the LHC.

The obvious example is the benefit that both ATLAS and TOTEM can gain from a close collaboration. Comparing the acceptance of the TOTEM Roman Pot detectors with those of ATLAS it is evident that there is a large overlap in the measured t-ranges between the two experiments. In addition, the overlap is in the regions which are associated with large theoretical uncertainties. Sharing experimental information of what is happening at very small angles will certainly help us to better understand this region. To reach the very small $|t|$-values will for sure be a challenge, and the possible success will to a large extent depend on detailed knowledge of the LHC halo, machine background and detailed knowledge of the optics parameters. Here clearly ATLAS and TOTEM can mutually profit from each other as the problems are close to identical. We will need to work together with the specialists from the LHC to better understand the beam conditions and share all the relevant knowledge in an efficient way.

There are also evident cross-checks of the luminosity calculation for ATLAS that can profit from early TOTEM results. ATLAS will calculate the absolute luminosity in many different ways. However one option is to also use TOTEM results on the total cross-section. The total cross-section will most likely be measured by TOTEM with higher precision than by ATLAS, and probably it will also be measured somewhat earlier. In this case, ATLAS could use the TOTEM measurement together with the Optical Theorem and data from elastic scattering in ATLAS at some moderate small $|t|$-values to estimate the luminosity for ATLAS.

There is also a case of synergy between the calorimeters of LHCf and the Zero Degree Calorimeter (ZDC) of ATLAS. Those calorimeters are installed 140 metres away from the ATLAS Interaction Point in an absorber of neutral particles (TAN), whose main function is to protect the downstream magnets from quenching. The space inside the absorber is limited, and during early data taking LHCf will occupy the space in front of the Zero Degree Calorimeter (ZDC) of ATLAS. Actually LHCf will use the space where later the electromagnetic part of the ZDC of ATLAS will be installed. During this transition phase, the ATLAS ZDC will only be equipped with the hadronic modules. Throughout this initial phase one could think of sharing energy sums between the two experiments. One could think of doing this both for the trigger and also for the actual data. Both experiments would obviously profit from such a sharing.

In a more general context, the forward detectors will contribute to the understanding of minimum bias events which in turn will be important for the understanding of the underlying event which is sort of the pedestal to the high p_T events. Here again a collaboration across all forward detectors will be important. Each one covers different η regions and has its own characteristics, and combining data will help in getting a better understanding of the global picture.

Let me just finish with what one could hope one day would be the outcome of the small angle elastic measurements at the LHC. Measurements of ρ – the ratio of real to imaginary

part of the forward elastic amplitude – at the ISR in the middle of the seventies were used to predict the total cross-section at energies much higher than the ISR energies. Using dispersion relations the total cross-section was correctly predicted in the energy range of the S$\bar{\text{p}}$pS collider. In the same way the results from measurements of ρ at the S$\bar{\text{p}}$pS and the Tevatron have been used to predict the total cross-section at the LHC. If we succeed in measuring ρ at the LHC, we could use the same method to predict the total cross section at energies well above the LHC energy. There might be many difficulties before such a programme can be realised. It may well be that the LHC halo will make it very difficult to go as close to the beam as needed to precisely measure ρ. In addition there might be theoretical difficulties to extract ρ from the data. Maybe we will be confronted with a new regime of saturation effects and strong t-dependence of ρ that requires extremely accurate measurements of the differential cross section in order to be able to extract the relevant parameters. Hopefully we will know in a couple of years from now.

3 The Alice Experiment

Author: Karel Safarik

The ALICE experiment at LHC was designed as the dedicated heavy-ion experiment. However, it has some unique capabilities which contribute to the interest in using the ALICE detector also for genuine pp studies, in addition to the obvious reference pp data taking. The relatively low magnetic field, 0.5 T, used in central tracking, results in a very low transverse-momentum cutoff; particles with transverse momenta down to 100 MeV/c are reconstructed with a reasonable efficiency. The particle identification system in central barrel, which uses practically all known particle identification techniques (ionisation energy loss measurements in silicon detectors and TPC, time-of-flight detector, transition-radiation detection, ring-imagining Cerenkov detector), gives the possibility to identify charged-hadron species in a wide momentum range.

At the start of the LHC, ALICE will measure the charged-particle pseudorapidity density. In order to properly normalise this distribution for a given class of events (inelastic, non-single-diffractive), relative yields of non-diffractive, single-diffractive and double-diffractive processes have to be determined either by combination of measurements or by Monte-Carlo. These estimates are, however, quite model dependent, and we came to the conclusion that, taking into account the current spread of model predictions, this normalisation will be the main source of systematic uncertainty of such measurements. Therefore, we are trying to assess what we can do experimentally to constrain the relative yields of diffractive processes. For this, various detectors with different pseudorapidity coverage are used: silicon-pixel detector in central region ($-1.4 < \eta < 1.4$), two scintillating-tile arrays on two sides ($-3.7 < \eta < -1.7$ and $2.8 < \eta < 5.1$) and two sets of zero-degree calorimeters ($\eta < -6.5$ and $\eta > 6.5$). This way we cover five distinct pseudorapidity intervals and we record for each event whether or not in these intervals at least one charged particle was produced. Then we divide the event sample into $32 (= 2^5)$ sets according the combination of pseudorapidity intervals which were hit. It is essential that the pseudorapidity intervals do not overlap, in order to avoid correlations between event numbers in different sets. Using a model for soft hadron-hadron collisions (usually a Monte Carlo event generator) we calculate for the three event types (non-diffractive, single-diffractive and double-diffractive events) the 32 probabilities to end-up in one of the 32 sets. We then use these probabilities to fit the relative event yields constrained to the measured event populations in the 32 sets.

In this approach the model dependence is mainly reduced to the kinematics of diffractive

processes, and we are not sensitive to the relative cross sections of diffraction in the models. To study systematic uncertainties due to the diffraction kinematics we are using different event generators. At the LHC start-up we plan to record the events on bunch-bunch crossing signal (sometimes called zero-bias trigger) and the above-described procedure is perfectly adequate for selecting (offline trigger) the non-empty events from the recorded event sample. It is worth mentioning that a 'collision event' has to be defined by some selection criteria, that unavoidably introduce some bias and model dependency.

As a result of recent discussion we aim to add to the ALICE set-up another scintillating counter at higher negative pseudorapidities to enhance the rapidity-gap selection capabilities (currently covered only up to $\eta = -3.7$). Other studies under consideration concern the central diffraction production of light mesons and of charmonium states: J/ψ (sensitive to odderon exchange) and χ_c (possible separation of different χ_c states is also under investigation). For central-diffractive charmonium production a selective trigger would be needed.

4 Beyond Inclusive Cross-Sections

Author: Hannes Jung

The measurement of the total proton-proton cross-section is important in its own right. This total cross-section is mainly driven by soft processes, however with hard perturbative contributions. The calculation of inclusive processes is "relatively" simple since all the final states are integrated out.

At HERA the measurement of the total deep inelastic cross-section has provided a lot of new information on the parton densities which can be used for calculating any final state process also in pp. However, even at HERA, a satisfactory description of dedicated final states, like the forward jet cross-section is lacking [1]. This is because the hadronic final state is sensitive to very different phenomena: higher order QCD radiation, multiparton interactions, diffraction, saturation and hadronisation. Especially at high energies or small x it is expected that fixed order calculations and the DGLAP parton shower approaches are not sufficient. This has been shown with the forward jet measurements.

Approaches which go beyond the collinear factorisation and try to better describe multi-parton radiation, are available and look promising [2, 3], but are still not able to fully describe the measurements. The investigations at HERA allow to determine precisely the mechanism of multi-parton radiation and to test models on initial and final state parton showers. These tests are essential when aiming to describe final states in pp, since there the contribution from multi-parton scattering complicates the situation.

At high energies or at small x the parton densities will become very large, and parton recombination and saturation might occur. It is essential to separate soft contributions to the taming of the parton densities from perturbative contributions. The $\Delta\phi$ dependence of the dijet cross-sections at large E_t can be used to study possible saturation effects [4] in the truly perturbative region: at $\Delta\phi \sim 180^\circ$ (back-to-back jets) the transverse momentum of the incoming partons to the hard scattering is small, and is sensitive to possible saturation effects. The cross-section in the back-to-back region should be smaller than expected from standard calculations (even including resummation effects).

A still unsolved problem is the connection of the total elastic pp cross-section with diffractive dissociation and multiparton interaction. If there is a significant hard diffractive component, then a hard perturbative component must be also visible in multiparton interactions. Multi-

parton interactions and underlying events are studied by measuring the transverse momentum spectrum and multiplicities of charged particles in jet events transverse to the jet direction [5]. However, the charged particles are sensitive to soft processes. A similar measurement using "mini-jets" with $E_t > 5(20)$ GeV could be performed, which then shows the sensitivity to a perturbative contribution.

It is important to measure not only single differential distributions, but also correlations, because they could show details on the underlying physics process, as shown in [6].

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5 Probing Correlations of Partons Near Nucleon Edge

Author: Mark Strikman

Studies of the exclusive hard processes at HERA and at fixed target energies allowed to determine the transverse spread of gluons in nucleons as a function of x. Using this information one can calculate the rate of the production of four-jet events originating from $4 \to 4$ hard collisions. If the transverse correlations between the partons are neglected one finds a rate which is a factor of two smaller than in experiment; for summary and references see [1]. Hence a realistic description of the pp collisions at the LHC should account for such correlations.

It is important to understand how such correlations depend on the transverse distance, ρ of the parton from the nucleon centre. The inclusive multijet production is dominated by impact parameters $b \leq 0.7\,\text{fm}$. Hence it is predominantly sensitive to the correlations at $\rho \leq 0.5\,\text{fm}$. At the same time, the presence of significant correlations at large ρ may help to solve the problem with S-channel unitarity [2].

It is possible to obtain information on the correlations of partons at large ρ from the study of the multiparton interactions in diffractive processes.

One could consider both cases of single and double diffraction with production of two and four jets:

$$\text{pp} \to \text{p} + \text{X}\ (2\ \text{jets} + \text{Y},\ 4\ \text{jets} + \text{Y}) \tag{5.1}$$

$$\text{pp} \to \text{pp} + \text{X}\ (2\ \text{jets} + \text{Y},\ 4\ \text{jets} + \text{Y}). \tag{5.2}$$

In the case of single diffraction with production of four jets, depicted in Fig. 5.1, one can study

- the rate of such events – the smaller the transverse size of the Pomeron exchange, the larger is the cross-section;

- factorization of the (x_1, x_2)-dependence to the product of single parton distributions as measured in the single diffraction with production of two jets;
- dependence of the $x_1 + x_2$ spectrum on t – the larger $-t$, the closer is the interaction to the perturbative regime, and hence the harder is the spectrum. In particular, for large $-t$, one could look for a peak near $x_1 + x_2 = x_{I\!P}$.

It is important to study also the dependence of the cross-section on x_3, x_4 in production of both two and four jets. Large x_3 correspond to partons which are likely to be closer to the centre of the nucleon than small x partons, leading to decrease of the probability of the gap survival with increase of x_3, x_4. Correlations between the partons should also enhance the cross-section of the exclusive channel of four jet production in the double diffraction when the light-cone fraction carried by two of the interacting partons of both nucleons are close to maximal: $(x_1 + x_2)/x_{I\!P} \sim 1$. Such a contribution should be enhanced if $-t_1, -t_2$ are large enough (few GeV^2) to squeeze the transverse sizes of the exchanged ladders (see Fig. 5.2) [2].

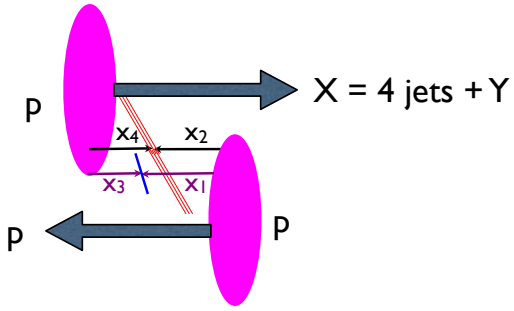

Figure 5.1: Single diffraction process with production of four jets.

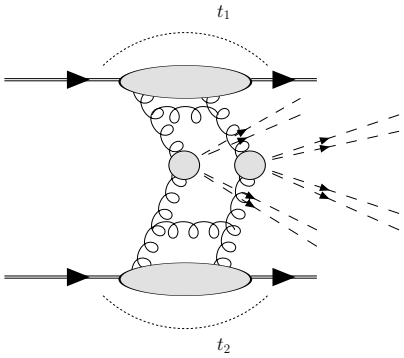

Figure 5.2: Double Pomeron process with production of two pairs of dijets.

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6 What can we learn / expect *on elastic and diffractive scattering* from the LHC experiments ?

Author: Konstantin Goulianos

6.1 Introduction

Diffraction is the last frontier in the effort to harness the standard model under a computational framework that includes non-perturbative quantum electrodynamics (npQCD). Despite the success of lattice calculations in predicting the hadron mass spectrum, predictions for diffraction are still based on phenomenological models. The transition from phenomenology to theory will benefit from the larger rapidity and transverse momentum that will become available at the Large Hadron Collider (LHC). The aim should be twofold: unveil the QCD basis of diffraction, and use diffraction as a tool to discover new physics either within (dark energy?) or beyond the standard model (supersymmetry?).

The goal of conducting studies of elastic and diffractive scattering at hadron colliders should be twofold: unveil the QCD nature of the diffractive exchange, which historically is referred to as the *Pomeron*, and use diffraction as a tool in searching for new physics [1].

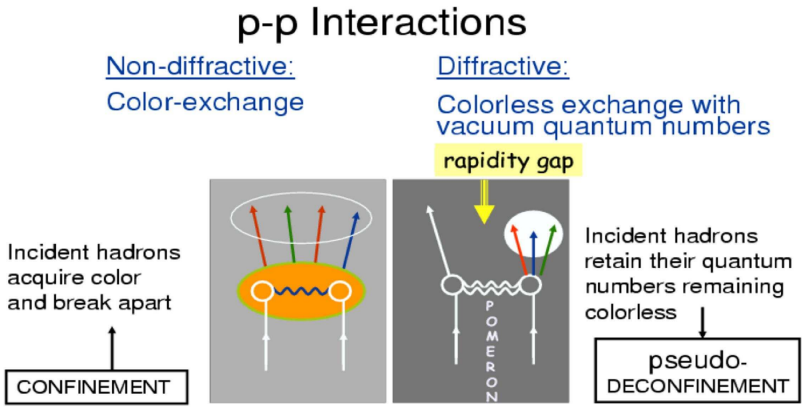

Figure 6.1: Non-diffractive and diffractive pp interactions.

Figure 6.1 illustrates the final-state event topologies of non-diffractive (ND) and single-diffractive (SD) pp interactions. A general QCD process involves a colour transfer by gluons and/or quarks. Due to colour-confinement, this is a short-range interaction. In diffraction, the exchange is a colour-singlet combination of gluons and/or quarks carrying the quantum numbers of the vacuum. As no colour is transferred, the process can be viewed as *pseudo-deconfinement*, where the prefix *pseudo* is used because the exchange has an imaginary mass and the process can proceed only if there is enough energy transferred to produce a pion. This is not unlike photon emission, in which a photon can only *deconfine* itself from the proton by interacting with an electromagnetic field, as for example in passing through matter. However,

the difference is that the photon is massless, while the quantum of the strong force, the pion, has mass.

An interesting question arises: what happens if the emitted Pomeron has such low energy that it cannot produce a pion upon absorption by a nearby proton? Will it keep going in search of another hadron, or more precisely in search of a quark and be trapped in the Universe as a large wave length energy bundle in the process of being exchanged? Such an energy bundle will correspond to an imaginary mass, which brings up the next question: what are the gravitational consequences of this imaginary energy trapped in the Universe?

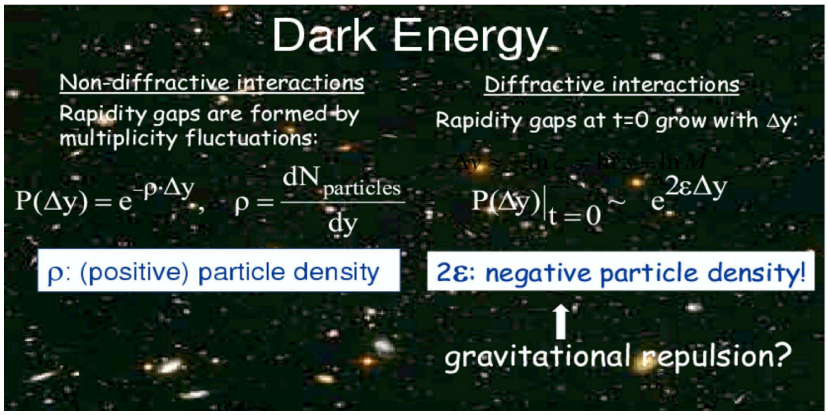

Figure 6.2: (left) In non-diffractive interactions the probability $P(\Delta y)$ for forming a gap Δy is exponentially suppressed as $\exp[-\rho \cdot \Delta y]$, where ρ is the final state particle density per unit rapidity; (right) in diffractive interactions, $P(\Delta y)$ at $|t| = 0$ increases with Δy, which corresponds to a *negative* particle density $\rho' = -2\epsilon$. Does this lead to gravitational repulsion?

The dependence of the diffractive cross-section on the size of the rapidity gap may be a clue that provides the answer. As displayed in Fig. 6.2, in writing the differential diffractive cross section in terms of the rapidity gap Δy instead of the forward momentum loss fraction ξ using $\Delta y = -\ln \xi$, the term 2ϵ, where ϵ is the excess above unity of the intercept of the Pomeron trajectory, appears formally as a negative particle density. Does this signify a gravitational repulsion caused by this unrealized energy permeating the Universe? If yes, can one relate the value of ϵ with the rate of gravitational expansion?

6.2 What to do at the LHC

Goal	· understand the QCD basis of diffraction and discover new physics
Exploit	· large $\sqrt{s} \Rightarrow$ large σ, $\Delta\eta$, E_T
TEV2LHC	· from Tevatron to LHC: confirm, extend, discover...
	$\Rightarrow$ confirm Tevatron results and extend them into the new kinematic domain
Specifics	· elastic, diffractive, total cross-sections, and ρ-value
	$\Rightarrow$ diffractive structure function: dijets vs. W-boson, ...
	$\Rightarrow$ multi-gap configurations
	$\Rightarrow$ jet·gap·jet: $d\sigma/d\Delta\eta$ vs. $E_T^{\rm jet} \Rightarrow$ BFKL, Mueller-Navelet jets

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7 String Theory and the Pomeron

Author: Chung-I Tan

The application of the so-called Anti-de-Sitter / Conformal-Field-Theory (AdS/CFT) correspondence between strongly coupled QCD and weakly coupled gravity has recently been successfully applied to the computation of various observables in high-energy heavy-ion physics. The application of this duality to diffractive scattering and the Pomeron physics represents another area where a connection with the string-theory-based techniques can be made. Furthermore, it is now possible to extend this treatment to central diffractive production of Higgs at LHC.

The connection with the stringy aspects in a five-dimensional description is indeed very direct. In gauge theories with string-theoretical dual descriptions, the Pomeron emerges unambiguously. The Pomeron in QCD can be associated with a Reggeized Graviton, where both the IR (soft) Pomeron and the UV (BFKL) Pomeron are dealt with in a unified single step. Indeed, the Pomeron is directly related to the graviton and its higher spin partners on the leading (five-dimensional) Regge trajectory.

In AdS/CFT, confinement is associated with a deformed AdS_5 geometry having an effective horizon, e.g., that for a black hole. The solution to this is unknown and represents the major theoretical challenge in model-building. Each model leads to a certain unique signature. LHC data can provide guidance and direction in this endeavor.

The traditional description of high-energy small-angle scattering in QCD has two components – a soft Pomeron Regge pole associated with exchanging tensor glueballs, and a hard BFKL Pomeron at weak coupling. On the basis of gauge/string duality, a coherent treatment of the Pomeron can be achieved (BPST)[1], thus providing a firm theoretical foundation for the Pomeron in QCD. It is now possible to identify a *dual Pomeron* as a well-defined feature of the curved-space string theory. In the large 't Hooft coupling, the Pomeron can be considered as a *Reggeized Massive Graviton*, propagating in a 5-dimensional curved space, the so-called AdS_5.

The fact that a 5-dimensional description enters in high energy collisions can be understood as follows. In addition to the usual LC momenta, $p_\pm = p^0 \pm p^z$ (2d), and transverse impact variables, $\vec{b}$ (2d), there is one more "dimension": a "resolution" scale specified by a probe, e.g., $1/Q^2$ of the virtual photon in DIS, (see Fig. 7.1a.) Because of conformal symmetry, these 5 coordinates transform into each others, leaving the system invariant. In the strong coupling limit, conformal symmetry is realized as the $SL(2,C)$ isometries of Euclidean AdS_3 subspace of AdS_5, where the AdS radius r^2 can be identified with Q^2.

The *dual Pomeron* has been identified as a well-defined feature of the curved-space string theory (BPST). In the strong coupling limit, conformal symmetry requires that the leading $C = +1$ Regge singularity is a fixed J-plane cut. For ultraviolet-conformal theories with

[1] R. Brower, J. Polchinski, M. Strassler, and C-I Tan.

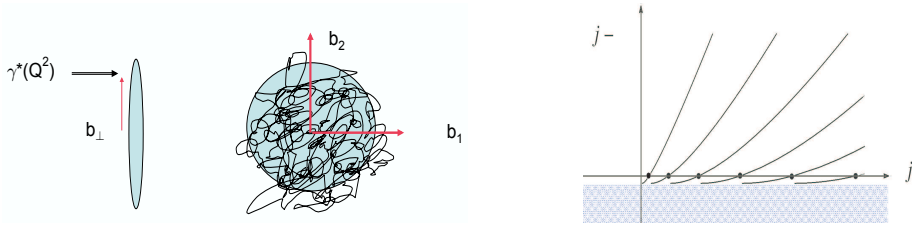

Figure 7.1: Left: Intuitive picture for AdS_5 kinematics. Right: Schematic representation of J-plane singularity structure.

confinement deformation, the spectrum exhibits a set of Regge trajectories at positive t, and a leading J-plane cut for negative t, the cross-over point being model-dependent (see Fig. 7.1b). For theories with logarithmically running couplings, one instead finds a discrete spectrum of poles at all t, with a set of slowly-varying and closely-spaced poles at negative t.

This strong-coupling formalism can also be extended to diffractive central production of Higgs in forward proton-proton scattering at LHC, e.g. the double-diffractive process, $pp \to pHp$. The theoretical estimates generally involve the assumption of perturbative contribution of gluon fusion in the central rapidity region, (e.g., the Durham group.) In these estimates the Pomeron is effectively replaced by two-gluon exchange referred to in the early literature as the Low-Nussinov Pomeron. In spite of the plausibility of this approach, there are considerable uncontrolled uncertainties. The Regge description for diffractive production is well known to be intrinsically non-perturbative. An analysis in strong coupling based on the AdS/CFT correspondence and conformal strong coupling BPST Pomeron can now be carried out. While this also will have its uncertainties, a careful comparison between weak and strong coupling Pomeron should give better bounds on these uncertainties. Ultimately, the strong coupling approach calibrated by comparison with experimental numbers for double diffraction heavy quark production, can provide increasingly reliable estimates for Higgs production.

8 The FP420 Project

Author: Albert De Roeck

The physics potential of forward proton tagging at the LHC has attracted much attention in the last years. The focus of interest is the central exclusive production (CEP) process $pp \to p + \phi + p$ in which the protons remain intact and the central system is separated from the outgoing protons by a large rapidity gap. A very interesting case is the CEP process of a Higgs particle. A picture of the basic process is shown in Fig. 8.1 (left).

There are several advantages of CEP [1, 2]:

- The selection rules for CEP are such that the central system is – to a good approximation – a 0^{++} state. Observing CEP thus gives access to the quantum numbers of the state ϕ.

- The three particle final state is a very constrained system. As a consequence the azimuthal correlation between the outgoing protons is directly sensitive to CP quantum numbers and is a possible way to study CP violating Higgs scenarios in detail.

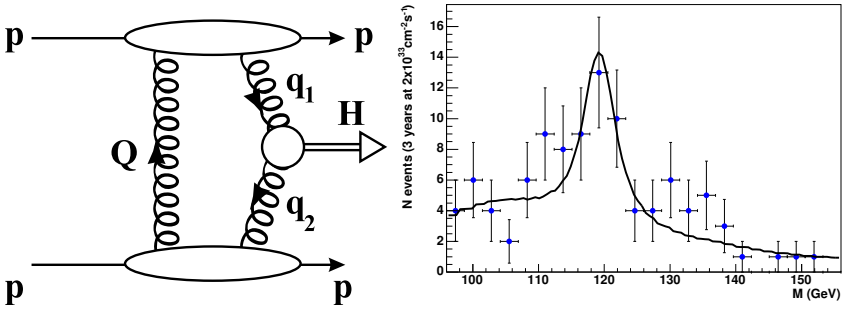

Figure 8.1: (Left) Diagram for the CEP process; (Right) A typical mass fit for 3 years of data taking at 2×10^{33} cm^{-2} s^{-1} (60 fb^{-1}), using only events with both protons tagged at 420 m.

- The tagging of the proton allows for the measurement of the mass of the system ϕ with a precision of the order of 1-2 GeV, via the missing mass w.r.t. the incoming proton beams $M_{miss} = (p_1 + p_2 - p_1' - p_2')^2$ with p_1, p_2 the incoming and p_1', p_2' the outgoing protons. This measurement is independent of the way the central system ϕ decays.
- The QCD backgrounds such as $gg \to qq$ are strongly suppressed in LO.
- CEP can be a discovery channel in certain regions of the MSSM parameter space.
- CEP gives a unique access to a host of interesting QCD phenomena.

The main physics topics studied by FP420 are the Central Exclusive Production, including Higgs production and searches for new physics, QCD and diffractive studies with tagged protons and photon induced processes with tagged protons. These topics are reported in [3]. Fig. 8.1 shows an example of signal plus background estimates [4]. The cross-section can be a factor 10 or more larger than the SM model one. This has recently been explored in a systematic way in [5]. There are still some issues and concerns on the CEP soft survival probability at the LHC and the uncertainties in the PDFs. This question will be settled with the first data at the LHC.

New detectors are needed to complement the CMS and ATLAS experiments to detect these protons [6]. FP420 is an R&D collaboration that studies the feasibility to detect the protons of CEP with detectors at a distance of 420 m away from the interaction point [7]. Such detectors allow to accept protons with a fractional momentum loss (or ξ) of 0.1% to 1%. With these detectors the protons of CEP Higgs production in the mass range of $70 < M_\phi < 150\,\mathrm{GeV}/c^2$ can be detected.

The FP420 project is schematically presented in Fig. 8.2. The aims of the R&D study are:

- Redesign the area of the machine around 420 m. Right now this area contains a connecting cryostat, but no magnet elements.
- Study the mechanics, stability, services for detectors at 420 m
- Design and test tracking detectors to operate close to the beam
- Design fast timing detectors (with O(10) ps resolution)

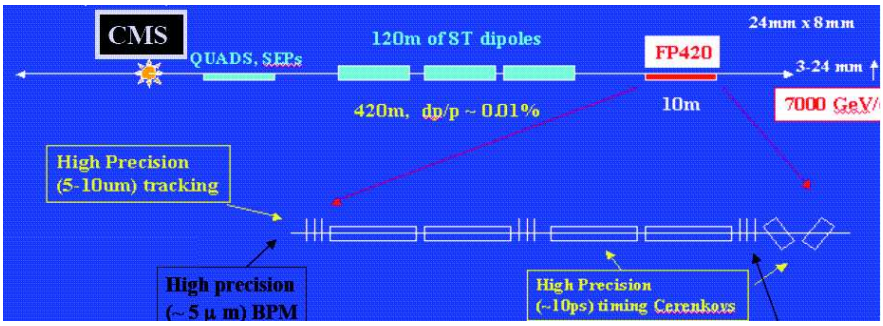

Figure 8.2: Schematic layout of the FP420 detectors.

- Study RF pickup, integration, precision alignment, radiation and resolution issues
- Study trigger, event selection, and pile-up issues.
- Study the operation of FP420 detectors at the highest LHC luminosity.

The FP420 collaboration has members from ATLAS, CMS, and 'independent' physicists, and has excellent contacts with the LHC machine group. In the emerging design the principle of FP420 is based on moving "pockets" which contain tracking and timing detectors. The tracking detectors that are developed are 3D silicon pixel detectors, which are radiation hard and can detect particles close to the edge. Timing detectors include both gas and crystal radiators. The test beam results of all these detector types have been excellent and e.g. show that the 10 ps timing can be achieved. A full pocket beam-test was performed in October 2007. A full account of the R&D results achieved so far has been published in 2008 [3] and forms the basis for the discussions on FP420 with the ATLAS and CMS experiments. Both experiments are now in the process of a review procedure.

Synergy has been a cornerstone of FP420 from the start, through the common efforts of ATLAS and CMS and externals on this project. Clearly when established to the end, this technology could also be used at other interaction points. Furthermore the exciting physics opportunities offered by FP420 have no doubt triggered the vigilant efforts at the Tevatron making measurements to check the theoretical predictions of several of the associated exclusive processes, as reported at this workshop. Recent developments include extending the FP420 techniques in the region around 220 m. For ATLAS it is already foreseen to have a common 220/420 project proposal. In the case of CMS, the TOTEM experiment is located at 220 m around IP5. So there are in principle two paths possible: either have an upgrade of the 220 m detectors with e.g. detector extensions for timing – which is absolutely essentially to control the pile-up at high luminosity – and have common readout with TOTEM/CMS, or use the 240 m area which is still free. The common readout was originally planned from the start but seemingly will not be a priority at start-up. On the other hand, the operational experience of TOTEM as the first experiment with near beam detectors will be extremely valuable and calls for a common study from all proponents interested in such type of measurements from the very beginning.

CMS and ATLAS will start their diffractive/rapidity gap programme making measurements with events which have regions void of energy and particles, at low luminosities when pile-up

is absent. This will allow to measure some of the key phenomena, such as the gap survival probability, necessary to gauge the theoretical predictions for CEP processes.

In short, now that the technology is getting established for FP420-like stations, it is of interest to see where else (e.g 220 m) they could be deployed, and to use the imminent startup of the LHC in order to gain as much operation experience on near beam detectors as possible, within a collaboration across the experiments.

References

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9 Proton Detection at IR3

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9.1 Introduction

As motivated in the previous chapter (A. De Roeck), TOTEM also investigated in which locations the machine dispersion is large and the beam size small, in order to optimise the proton acceptance at small momentum losses. The momentum cleaning region IR3 (Figure 9.1, left) seems to be optimal. Its optics has been optimised to absorb the protons with relative momentum deviations $\xi = \Delta p/p$ exceeding $\pm 1 \times 10^{-3}$. Such protons can be detected by near-beam insertions located in the warm region of IR3 before being intercepted by the momentum cleaning collimators. The technical aspects of the proposed RP insertions are presented in [1].

This would highly extend the diffractive mass acceptance of the TOTEM experiment. In case of the Double Pomeron Exchange process, a continuous mass acceptance from 30 GeV to 2.5 TeV would be accessible, allowing for a promising diffractive physics programme. In addition, within a certain ξ range, the diffractive protons from all LHC interaction points are detected, thus making online inter-experimental luminosity calibrations possible.

9.2 Beam Optics and Insertion Location

By design, the IR3 region is optimised such that off-momentum protons can be intercepted by the collimators. This is achieved by maximising the ratio D_x/σ_x, i.e. exactly the beam optics property needed for a momentum measurement down to low values of ξ with good resolution. The closest safe approach of a detector to the beam is given by a certain multiple – typically 10 to 15 – of the beam size σ_x, which limits the lowest detectable ξ-values. As a result of the large value of D_x, the diffractive protons are deflected further away from the beam centre and can be measured in the near-beam detectors.

Figure 9.1 (right) shows the dispersion and beam width in the IR3 region for both beams and both transverse projections, x and y, for the nominal LHC optics configuration with $\beta^* = 0.5$ m

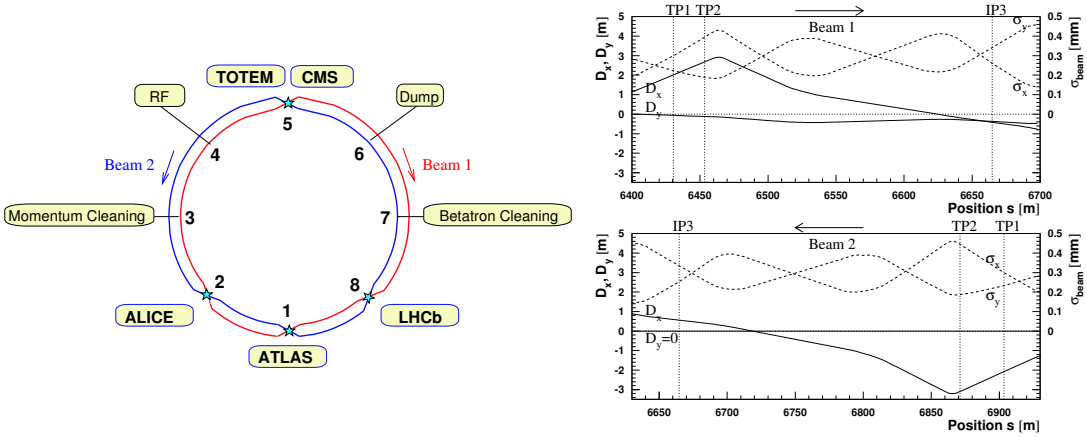

Figure 9.1: Left: Schematic drawing of the LHC with its eight "interaction" points, showing the location of the momentum cleaning insertion IR3. Right: Dispersion (left-hand axes) and beam width (right-hand axes) in x and y for both beams in the IR3 region. The dispersion shown is valid for protons with $\xi = 0$ and produced in IP5. The position axis s follows beam 1 and has its origin in IP1. TP1 and TP2 are the two proposed tracking detector planes located in a warm region of the machine.

and $\sqrt{s} = 14\,\text{TeV}$. The horizontal dispersion D_x at the two potential tracking detector positions, TP1 and TP2, has a magnitude in the range of 2–3 m, as compared to 8 cm at the TOTEM Roman Pot station RP220. The high ratio $D_x/\sigma_x \approx 6.7 \times 10^3$ (as compared to $\approx 1.1 \times 10^3$ at RP220) results in an acceptance down to $\xi = 1.6 \times 10^{-3}$.

In addition to promising perspectives for diffractive physics, the placement of detectors in front of the momentum cleaning collimators has advantages for machine diagnostics and protection. It enables the study of beam losses at the collimators. Furthermore, all showers possibly created by the detector insertion are absorbed immediately downstream by the collimators. Finally, the insertions are proposed in a warm region and therefore their installation should not be technically too complicated.

9.3 Proton Acceptance and Reconstruction in IR3

The proton acceptances for both beams are shown in Figure 9.2 (left). The protons are characterised by ξ, integrated over all their other kinematic parametres. The IR3 acceptance for beam 1 protons originating from diffractive scattering in IP5 is reduced since these protons have to pass through the aperture limiting betatron cleaning insertion IR7. Beam 2 protons on the other hand have an almost continuous acceptance from $\xi = 1.6 \times 10^{-3}$ to 0.19 (50% acceptance limits) with only a gap between 0.01 and 0.018. This momentum acceptance gives access to diffractive masses ranging from 30 GeV to 2.5 TeV in the case of Double Pomeron Exchange events. A detailed reconstruction study, discussed in detail in [2], led to the ξ-resolution shown

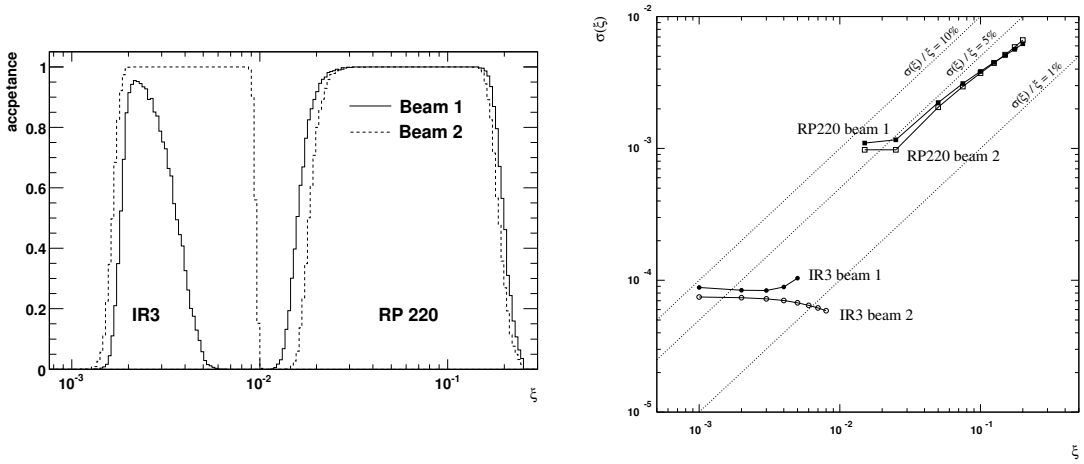

Figure 9.2: Left: Acceptance in ξ at the TOTEM Roman Pots RP220 and in IR3 for both LHC beams. Right: Resolution in the reconstructed ξ at the TOTEM Roman Pots RP220 and 206 m upstream of IP3 for both LHC beams. Nominal LHC optics $\beta^* = 0.5\,\mathrm{m}$ and $\sqrt{s} = 14\,\mathrm{TeV}$ was applied.

in Figure 9.2 (right). Note that the resolutions $\sigma(\xi) \sim 10^{-4}$ achieved for measurements in IR3 reach the limit imposed by the energy uncertainty of the LHC. In all cases, the relative resolution $\sigma(\xi)/\xi$ is better than 10%.

References

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