LHC FORWARD PHYSICS

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This report describes the Forward Physics plans of the LHC experiments. The physics topics include a measurement of the total pp cross section (and luminosity) with a 1% precision, elastic pp scattering in the momentum transfer squared range $10^{-3} < |t| < 10$ GeV^2, and both soft and hard diffractive phenomena including inclusive and exclusive Double Pomeron Exchange and leading particle and energy flow in the forward direction.

1. Introduction

1.1. *Kinematic Considerations*

The many activities involving forward physics at the CERN Large Hadron Collider (LHC) include plans by ALICE, ATLAS, CMS, FP420 (an R&D project), LHCf and TOTEM. In fact, of the approved experiments, only LHCb is not studying the possibility of forward physics at the present time.

The general philosophy is to place additional detectors about the Interaction Point (IP). The goal of the Roman Pot (RP) proton detector is to measure small scattering angles (~ a few mrad) $\theta^{*}_{min} = K\sqrt{(\varepsilon/\beta^{*})}$, with a beam divergence $\sigma(\theta^*) = \sqrt{(\varepsilon/\beta^{*})}$. Hence one needs large values of β^*. However, the luminosity L α $1/\beta^*$ means small β^* is preferred. As a result, there will be a range of β^* values (0.5-1540 m). The RPs will be located 140-420 m from the IP. At 220 m, the proton momentum loss, $\xi = \Delta p/p$, is reconstructed with $0.02 < \xi < 0.2$, while for smaller values $0.002 < \xi < 0.02$, detectors in the "cold region" around 420 m are needed.

1.2. *Experimental Apparatus*

The TOTEM + CMS detectors are shown in Figure 1. The TOTEM T1 telescope consists of Cathode Strip Chambers covering the rapidity range 3.1 <

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$\eta < 4.7$. T1 consists of 5 planes with measurements of 3 coordinates per plane, with 3° of rotation and an overlap between adjacent planes. TOTEM's T2 GEM telescope ($5.3 < \eta < 6.5$) has digital readout pads and analog readout circular strips. The RP unit consists of vertical and horizontal pots mounted as close as possible to each other. Leading protons can be detected down to distances of $10\sigma_{beam}$ +d (with $\sigma_{beam} \approx 80$ μm), requiring "edgeless" detectors that are efficient up to the physical edge to minimize "d". Currently there are two techniques being pursued that provide 5-10 μm and 40-50 μm dead regions. CMS's CASTOR is a very forward calorimeter covering the region $5.25 < \eta < 6.5$.

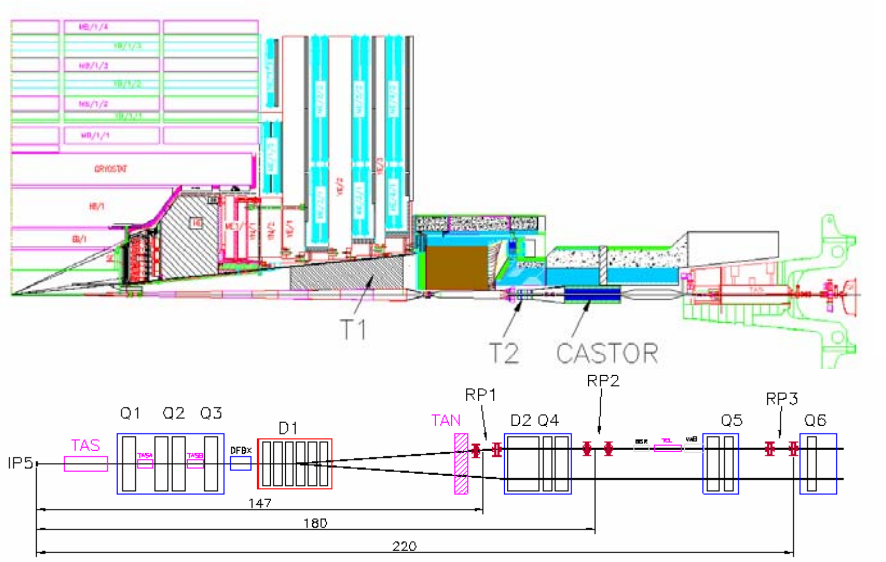

Figure 1. Schematic plan view of the CMS and TOTEM detectors at IP5.

ATLAS has similar plans with RPs at 240 m, LUCID, a Cerenkov counter acting as a luminosity monitor, for $5.4 < \eta < 6.1$ and a calorimeter at zero degrees.

2. *Forward Physics at the LHC*

There is a wide range of Forward Physics that can be studied at the LHC. This includes the pp total and elastic scattering cross sections, both soft and hard diffractive phenomena, inclusive and exclusive Double Pomeron Exchange (DPE) and leading particle measurements to provide a connection and constraint on Cosmic Ray phenomena. (pA, AA, $\gamma\gamma$ and γp processes will not be discussed here.) Different β* run scenarios provide access to different kinematic regions of phase space. Table 1 shows the possible scenarios, as currently being discussed by TOTEM, and the different physics that can be reached with each scenario.

Table 1. Possible Running Scenarios for Diffractive Physics for TOTEM.

Scenario =	1 Low |t| elastic, σ_{tot}, min bias Soft diffraction	2 Diffraction	3 Large |t| elastic	4 Hard diffraction Large |t| elastic (still under study)
β* [m]	1540	1540	18	90
N of bunches	43	156	2808	156
N part./bunch (x10^{11})	0.3	0.6 – 1.15	1.15	1.15
Half cross. angle [μrad]	0	0	160	0
Peak Luminosity [cm^{-2} s^{-1}]	1.6x10^{28}	2.4x10^{29}	3.6x10^{32}	2x10^{30}

2.1. *Total cross section and Luminosity monitor*

The experiments plan to measure the pp total cross section with the luminosity-independent method using the Optical Theorem, see Eq. (1). TOTEM expects to measure the total rate (N_{el} +N_{inel}) with a precision of 0.8% (with σ_{diff} ~18 mb and minimum bias ~65mb). Extrapolation of the pp elastic cross section to t=0 will be dominated by systematics with a precision of 0.5% (the statistical error is 0.07% after 1 day of running). Using the COMPETE [1] estimate for ρ = Re f(0)/Im f(0) yields a precision of 0.2% and an overall precision on σ_{tot} of 1%.

$$\left.\frac{d\sigma_{el}}{dt}\right|_{t=o} = \frac{1}{L}\left.\frac{dN_{el}}{dt}\right|_{t=o} = \left(1+\rho^2\right)\frac{\sigma_{tot}^2}{16\pi} \qquad \sigma_{tot} = \frac{16\pi}{1+\rho^2}\frac{\left.\left(dN_{el}/dt\right)\right|_{t=0}}{N_{el}+N_{inel}}$$

$$\sigma_{tot} = \frac{\left(N_{el}+N_{inel}\right)}{L} \qquad L = \frac{1+\rho^2}{16\pi}\frac{\left(N_{el}+N_{inel}\right)^2}{\left.\left(dN_{el}/dt\right)\right|_{t=0}} \qquad (1)$$

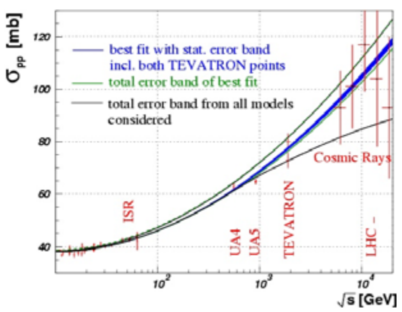

Figure 2. Total pp cross section as a function of pp Center of Mass energy.

Figure 2 shows the current situation for the pp total cross section. The COMPETE prediction [1] at the LHC is 111.5±1.2+4.1-2.1 mb.

ATLAS has submitted a Letter of Intent to complement their experiment with a set of forward detectors for a luminosity measurement (to 2-3%) and monitoring by installing RPs at 240 m to probe elastic scattering in the

Coulomb interference region and installing their dedicated detector for luminosity monitoring (LUCID). On a longer time scale, ATLAS plans to study opportunities for diffractive physics with additional detectors.

The absolute luminosity measurement is important for precision comparisons with theory; eg, deviations of measured cross sections (σ_{bb}, σ_{tt}, $\sigma_{W/Z}$, etc) from those predicted by the SM could be a signal for new physics.

2.2. *Elastic pp scattering*

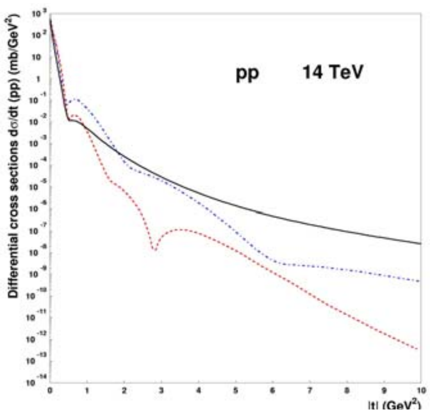

Figure 3 compares three predictions [2-4] for the pp elastic differential cross section as a function of |t|. The following features are expected: the forward cross section increases (with σ_{el}/σ_{tot} ~30%?), the diffractive peak shrinks, and the interference dip moves to smaller |t| as $\sqrt{s}$ increases. For $|t| > 1$ GeV^2, $d\sigma/dt \sim 1/t^8$ (due to 3-gluon exchange) although there is a wide variation in these three predictions.

Figure 3. Elastic pp differential cross section as a function of momentum transferred squared. At $|t|$~10 GeV^2, the upper curve is from Islam et al [2], the middle curve from Bourrely et al [3] and the lower curve is from Desgrolard et al [4].

2.3. *Diffractive Physics*

Figure 4 shows two diffractive processes: single diffraction and Double Pomeron Exchange (DPE). To measure these processes over a wide range of kinematics requires a large acceptance detector. CMS/TOTEM will be the largest acceptance detector ever built at a hadron collider: covering ±7.5 in η and 90% (65%) of all diffractive protons detected for β* = 1540 (90) m and, for β* = 1540 m, 10^7 minimum bias events, including all

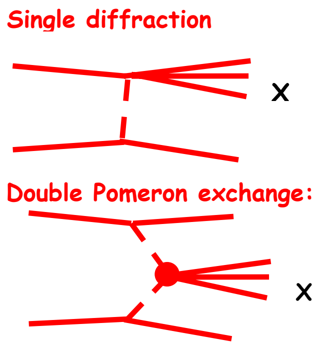

Figure 4. (up) The pp → pX single diffractive process; (down) the pp → pXp Double Pomeron Exchange process.

diffractive processes, can be collected in one day.

ALICE is studying the possibility of implementing a trigger requiring a rapidity gap on both sides of a central region of 1.5 units of rapidity.

For the inclusive DPE process, TOTEM+CMS can reach masses of the X system up to $M_X = \sqrt{(\xi_1 \xi_2 s)} \leq 1.4$ TeV when both protons are detected.

For the exclusive process, in which X is a single state, many studies have been made estimating cross sections for X = Higgs [5]. A important feature of this process is that the selection rules for 2 gluons mean that the central region is (to a good approximation) 0^{++} and for the H → b-bbar decay they imply that the QCD b-bbar background is suppressed. Tagging with two protons provides excellent mass resolution (~GeV), irrespective of the decay products. Hence, proton tagging may be the discovery channel in certain regions of the MSSM [5]. The FP420 R&D project has the study of this process as a high priority [6].

2.4. *Forward Physics: the connection to Cosmic Rays*

As is well known, there are several issues in Ultra High Energy Cosmic Rays. The spectrum is shown in Fig. 5 [7]. The issue here is whether or not there is a cutoff (known as the GZK cutoff) above $10^{19.5}$ eV. Another UHECR issue relates to the composition of the primary CRs, ie are they protons or heavier elements?

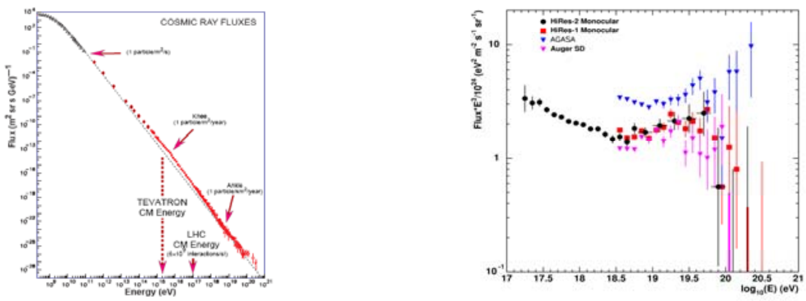

Figure 5. (Left) UHECR spectrum; (right) the highest energy part of the spectrum multiplied by E^3.

Interpreting CR data often depends on our hadronic simulation programs. However, the very forward region is poorly known so that models differ by factors of two or more. Measurements of the very forward energy flux (including diffraction) and of the total cross section are therefore essential for the full understanding of CR events. For this reason, forward measurements are needed at LHC energies. Note that at the LHC pp energy, there are 10^4 Cosmic

Ray events per km^2 per year, while there will be 10^7 events at the LHC in one day.

In addition to the TOTEM/CMS measurements in the forward direction, LHCf plans to measure photons and neutral pions in the very forward region of the LHC. In this forward region, the highest energy measurements of the π^0 cross sections were made by UA7 (E = 10^{14} eV). The direct measurement of the π production cross sections as a function of P_T is essential to correctly estimate the energy of the primary CRs. The vacuum tube at IP1 contains two counter-rotating beams. The beams transition from one beam in each tube to two beams in the same tube. In the space between beams, 140 m from IP1, LHCf will install two detectors: scintillating fibers downstream and silicon μstrips upstream.

3. *Summary*

There are plans at the LHC for a wide range of Forward and Diffractive measurements that can be achieved at different luminosities. The total pp cross section can be determined with a precision of 1%; elastic scattering can be measured in the range $10^{-3} < |t| < 8$ GeV^2; there will be studies of soft and hard diffractive physics and inclusive and exclusive Double Pomeron Exchange; very forward particle production will be studied to connect with UHE Cosmic Ray phenomena and to look for exotic phenomena such as centauros and Disoriented Chiral Condensates (DCC) in the forward region.

3.1. *Acknowledgments*

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