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The LHC Ring as a Photon-Photon Search Machine

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Abstract
The LHC Collider Ring can be turned into a photon-photon search machine based on Central Exclusive Process (CEP): $pp \rightarrow p + X + p$. The present extensive Beam Loss Monitoring (BLM) system of the LHC precisely registers the exit points of the final state CEP protons according to their longitudinal momentum losses. The BLM system is being continuously extended, and equipped with fast timing and data acquisition systems, will enable efficient new physics event tagging together with the LHC experiments. The LHC Ring can be used to facilitate an on-line automatic search machine for the physics of tomorrow.

Keywords
LHC ring detector, photon-photon collisions, central exclusive production

1 Introduction

In the following, the LHC Ring is described as a new photon-photon physics search facility based on existing instrumentation of the LHC ring and the LHC experiments. The approach presented here is novel, and uses the LHC Beam Loss Monitoring (BLM) and other LHC beam instrumentation devices for tagging the new physics event candidates in a model-independent way. The physics potential of the proposed facility is huge, and highly complementary to the present experimental installations at the LHC (ALICE, ATLAS/ALPHA, CMS/TOTEM, LHCb/MoEDAL experiments).

A few selected Central Exclusive Production (CEP) processes are discussed together with high mass Single Diffractive (SD) scattering. The CEP processes provide an ideal test ground for the proposed approach - here a pair of coincident final state protons, exiting the LHC beam vacuum chamber, are used to tag the event candidates. The fractional momenta of the final state protons are directly related to the invariant mass of the centrally produced system. The proposed approach [1, 2] is independent of the particular decay modes of a centrally produced system, and substantially enhances the potential of observing new heavy particle states at the LHC. Performance of the customary Roman Pot technology is limited by the location of the pots, and the allowed transverse access to the beam.

The collaborators represent the key areas of this proposal: in accelerator physics and LHC instrumentation (S. Redaelli et al., CERN Beams Division), accelerator theory (Werner Herr, CERN Beams Division), theoretical high energy physics (Lucian Harland-Lang, University College, London, K. Huitu, Division of Particle Physics and Astrophysics, University of Helsinki; Valery Khoze, University of Durham University; M.G. Ryskin Petersburg Nuclear Physics Institute, Gatchina, St. Petersburg; V. Vento, University of Valencia and CSIC) and experimental high energy physics (A. De Roeck, CERN EP; M. Kalliokoski, CERN Beams Division; Beomkyu Kim, University of Jyväskylä; Jerry W. Lämsä, Iowa State University, Ames; C. Mesropian, Rockefeller University; Mikael Mieskolainen, University of Helsinki; Toni Mäkelä, Aalto University, Espoo; Risto Orava, University of Helsinki, Helsinki Institute of Physics and CERN; J. Pinfold, FRSC, Centre for Particle Physics Research, Physics Department, University of Alberta; Sampo Saarinen, University of Helsinki; M. Tasevsky, Institute of Physics of Academy of Sciences, Czech Republic.

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The project has break-through potential in a number of physics processes beyond the examples discussed here. The basic infrastructure, the LHC Ring with its beam instrumentation and experiments, already exists, and only minor extensions are proposed for relatively inexpensive additional detectors and for facilitating triggering and automatic event selection. Preliminary analyses of the BLM signals validate the basic approach adopted by the authors, and include exiting candidate events in different physics categories listed below.

2 Scanning for new physics

The Central Exclusive Production (CEP) of particle state, X, is described by the following three processes:

$$pp \to p + (\gamma\gamma \to X) + p, \tag{1}$$
$$pp \to p + (\gamma + gg \to X) + p, \tag{2}$$
$$pp \to p + (gg \to X) + p, \tag{3}$$

where the $+$ signs indicate rapidity gaps. The CEP sub-processes are facilitated by the photons (photon-photon interaction) (1), photons and gluons ("photo-production" or "photon-pomeron" interaction) (2), and gluons ("diffractive" or "double pomeron exchange") (3). In Figure 2, the corresponding Feynman diagrams for the processes (1-3) are shown.

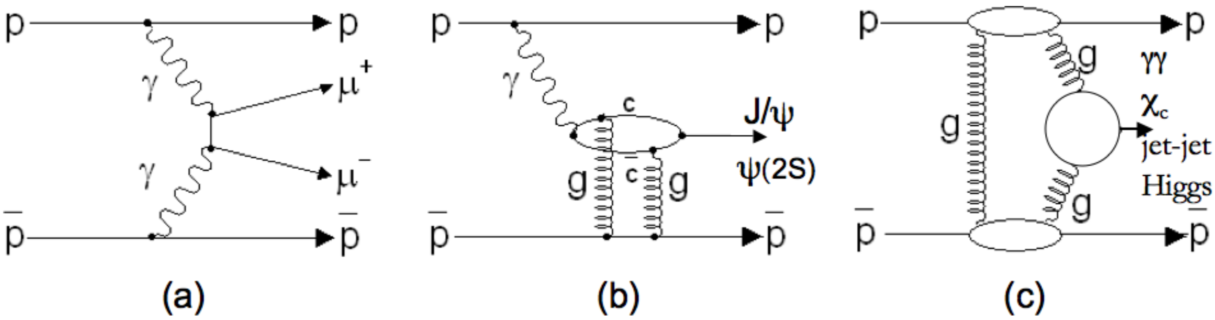

Fig. 1: The Central Exclusive Production (CEP) processes facilitated by: (a) photon-photon sub interaction $pp(\gamma\gamma) \to p + (l^+l^-, W^+W^-) + p$, (b) photon-gluon sub-interaction $pp(\gamma + gg) \to p + (J/\psi, \psi(2S)) + p$, and (c) gluon-gluon sub-interaction $pp(gg) \to p$ + (χ_c, jet-jet, Higgs) + p.

The respective cross sections for the processes ((1-3)) are calculated as the convolutions of the effective luminosities $L(\gamma\gamma)$, $L(\gamma + gg)$, or $L(gg)$ (Figure 2) and the square of the matrix element of the corresponding sub-process [3]. In the Central Exclusive Production (CEP), a number of advantageous properties exist compared to inclusive (or semi-inclusive) production: The mass and width of the centrally produced state, X, is correlated with the fractional (longitudinal) momentum losses, $\xi_i = 1 - p'_{z_i}/p_z$, of the final state protons p'_z and the initial beam proton p_z, as:

$$M^2 \simeq \xi_1 \xi_2 s \tag{4}$$

where s is the centre-of-mass energy squared. A measurement of the invariant mass of the decay products would be required to match the missing mass condition available by the measurement of the pair of final state proton fractional momentum losses. At higher central masses, $M_X \gtrsim 200$ GeV, the photon-photon process (1) dominates.

The following example processes are considered: Magnetic monopolium: Numerous experimental searches for magnetic monopoles have been carried out but all have met with failure. These experiments have led to a lower mass limit in the range from 350 . . . 500 GeV. A way out of this impasse is the above old idea of Dirac [4], namely, monopoles are not seen freely because they are confined by their strong

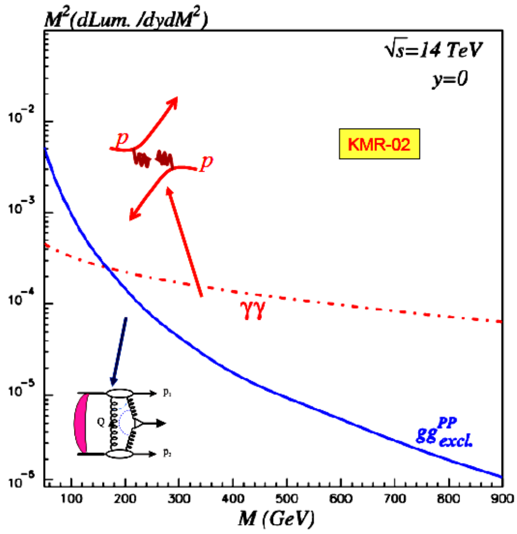

Fig. 2: Gluon (solid curve) and photon (dotted-dashed curve) luminosities as a function of the central mass in Central Exclusive Production (CEP) [3].

magnetic forces forming a bound state called monopolium [5]. Here the CEP produced monopolium states [6] are searched for by registering the pair of final state protons exiting the beam vacuum chamber at the distance of some $\sim$ 230 meters from IP8 (MoEDAL/LHCb experiment); W^+W^- pairs and anomalous couplings: Central exclusive production (CEP) of W^+W^- (Z^0Z^0) pairs can be used both as a luminosity monitoring process [7] and as a process for studying basic physics questions beyond the Standard Model, such as anomalous vector boson couplings.

In a recent publication the contribution of the W^+W^- (Z^0Z^0) mechanism is compared to the gluon induced CEP process $gg \rightarrow W^+W^-$ [8]. The phase space integrated gluon induced CEP cross section is found to be considerably smaller (less than 1 fb), while the photon induced CEP is calculated to have a cross section of 115 fb. The photo-production process dominates at small four-momentum transfers for a wide range of W^+W^- (Z^0Z^0) invariant masses, and allows efficient analyses of anomalous triple-boson (WW/ZZ) and quartic-boson (WW/ZZ) couplings together with tests of the models beyond the Standard Model. The $\gamma\gamma \rightarrow W^+W^-$ cross section peaks at $M_X \simeq 200$ GeV yielding (in a symmetric case) a pair of protons exiting the beam vacuum chamber at $\sim$ 330 meters from the interaction point.

All four LHC experiments have sufficient luminosity for studying the processes; The Standard Model (SM) and BSM Higgs bosons: The Higgs boson observations at the LHC are almost exclusively based on the $\gamma\gamma$ and $ZZ \rightarrow 4l$ decay mode [9]. Measurement of the Higgs boson production in Central Exclusive Process (CEP) was first analysed by some of the authors, and the process $pp \rightarrow p + (gg \rightarrow h^0) + p$ provides important complementary information concerning the spin-parity state of Higgs since $J^{PC} = 0^{++}$ state is strongly favoured in CEP. By tagging the Higgs event candidates independently of the Higgs decay products enables detailed analysis of the production mechanism and Higgs couplings. A measurement of the azimuthal angle between the final state protons can be used to discriminate between different Higgs production scenarios [10]. The Standard Model Higgs boson, when produced in the CEP process (3), has a proton pair exiting the LHC beam vacuum chamber at a distance of ~ 427 meters from the IP. ATLAS, CMS and LHCb experiments are here relevant counterparts due to their sufficiently high integrated luminosities; Single Diffractive (SD), where the exiting proton at the longest distance from a given LHC Interaction Point, combined with a hadron shower at the experiment, efficiently identifies high mass SD event candidates.

3 CEP protons exiting the LHC ring

By tracing CEP protons of different z-values through the LHC accelerator lattice, a relation between the CEP proton exit points and the ξ-values of the final state protons is established. For the background studies of this proposal, both ξ and the transverse momentum p_T of the final state protons are considered in mapping out the exit points around the LHC ring.

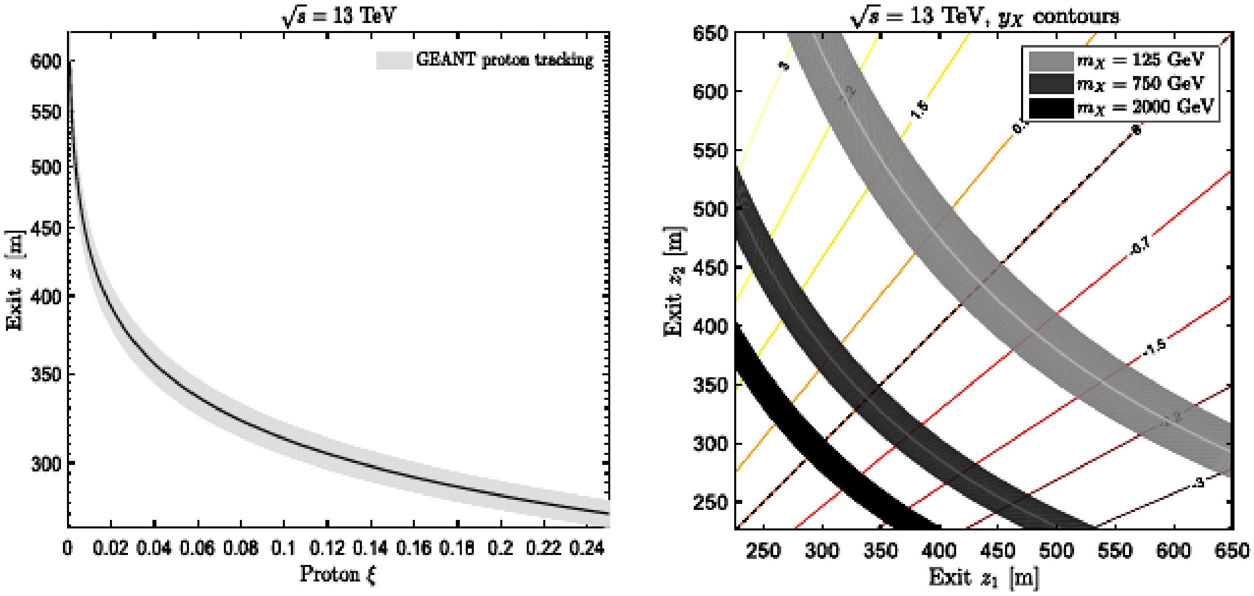

Fig. 3: Left: Proton exit point, z, in CEP: $pp \to p+X+p$, as a function of the fractional momentum loss, ξ (solid line). The exit points of the leading protons out from the beam vacuum chamber are given in meters from IP5, the shaded band reflects smearing in proton transverse momentum. Right: The proton exit point combinations in CEP: $pp \to p+X+p$, as a function of central mass M_X (grey bands). The exit points of the leading protons out from the beam vacuum chamber are given in meters from the Interaction Point 5 (IP5), the symmetric cases ($\xi_1 \simeq \xi_2$) have $z_1 \simeq z_2$ (dashed diagonal line). Rapidity of the centrally produced state is given as $y_X = 0.5\ln(\xi_1/\xi_2)$ [1].

In Figure 3 (left panel), the proton exit points, shown as a function of their fractional momentum loss, ξ_i, are produced by the proton tracing codes. Through Equation 4, the measured proton exit locations can then be used for an M_X mass scan of the centrally produced systems (Figure 3, right panel). The band widths reflect smearing in proton transverse momentum, p_T. The following steps are taken in tagging the CEP event candidates for each IP (IP1/ATLAS, IP2/ALICE, IP5/CMS, and IP8/LHCb): (i) The candidate CEP events are scanned by locating pairs of coincident proton exits on the opposite sides of the interaction point (IP) in question (Figure 3, right panel), (ii) The tagged events are correlated with the LHC Beam Cross Overs (BCOs) within the time window for the chosen IP, (iii) The tagged LHC BCOs are analysed as candidates for the CEP events with central masses, M_X, corresponding to a registered pair of exit points (Figure 3, right panel).

In Figure 4, the registered proton exit points are plotted together with the reconstructed ones obtained by fits. In Figure 5, the reconstructed diffractive masses in high mass SD scattering are shown for $M_X = 500, 1000$ and 1500 GeV. A resolution of $\Delta M_X/M_X \sim 10\%$ is obtained.

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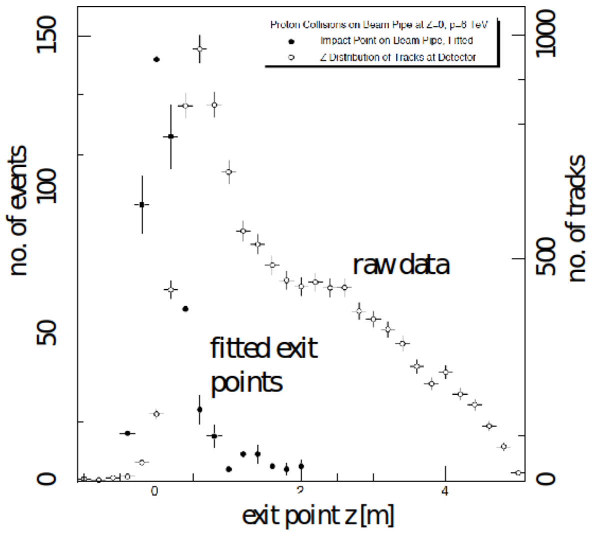

Fig. 4: The registered proton exit points, z, for raw data (open circles) and after reconstruction based on the detected hits in scintillators installed around the gaps of LHC magnets.

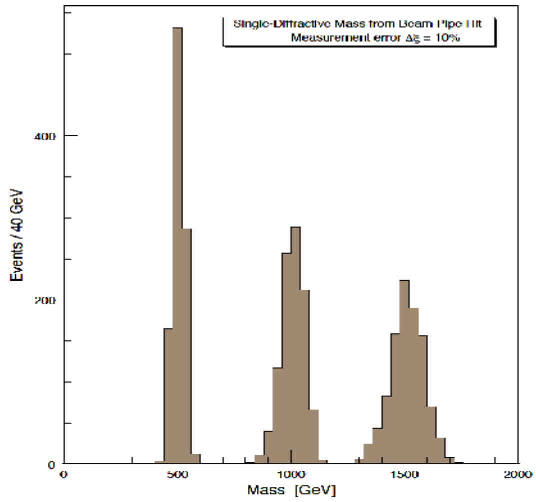

Fig. 5: The reconstructed central masses, M_X, in Single Diffractive process (SD): $pp \to p + X$, for $M_X = 500, 1000$ and 1500 GeV (Phojet simulation by J.W.Lämsä). The proton showers detected by scintillators assembled around the gaps between the LHC dipole magnets.

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