Diffractive and ultraperipheral physics with ALICE

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The ALICE experiment consists of a central barrel, a muon spectrometer, zero degree calorimeters and additional detectors for trigger and event classification purposes. Such a geometry allows the implementation of a double gap trigger. A diffractive physics program of ALICE is outlined and a few specific reaction channels are discussed in order to illustrate the interest in such a diffractive physics program.

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1. The ALICE Experiment

The ALICE experiment is designed to take data in the high multiplicity environment of lead-lead collisions[1]. The central barrel of ALICE and the forward muon spectrometer cover the pseudorapidity range $-0.9 < \eta < 0.9$ and $-4.0 < \eta < -2.4$, respectively. Additional detectors for event classification and trigger purposes are located in the range $-4.0 < \eta < 5.0$.

2. The ALICE Central Barrel

The detectors in the ALICE central barrel track and identify hadrons, electrons and photons in the pseudorapidity range $-0.9 < \eta < 0.9$. The magnetic field strength of 0.5 T allows the measurement of tracks from very low transverse momenta of about 100 MeV/c to fairly high values of about 100 GeV/c. The tracking detectors are designed to reconstruct secondary vertices resulting from decays of hyperons, D and B mesons. The main detector systems for these tasks are the Inner Tracking System (ITS), the Time Projection Chamber (TPC), the Transition Radiation Detector (TRD) and the Time of Flight array (TOF). These systems cover the full azimuthal angle within the pseudorapidity range $-0.9 < \eta < 0.9$. The Pixel Detector of the Inner Tracking System has an extended coverage of $-2.0 < \eta < 2.0$. Additional detectors with partial coverage of the central barrel are a PHOton Spectrometer (PHOS), an electromagnetic calorimeter (EMCAL) and a High-Momentum Particle Identification Detector (HMPID).

3. The ALICE Zero Degree Neutron Calorimeter

The Zero Degree Neutron Calorimeters (ZDC) are placed on both sides of the interaction point at a distance of 116 m[2]. The ZDC information can be used to select different diffractive topologies. Events of the types $pp \rightarrow ppX, pN^*X, N^*N^*X$ will have no signal, signal in one or in both of the ZDC calorimeters, respectively. Here, X denotes a centrally produced diffractive state from which the diffractive L0 trigger is derived.

4. The ALICE diffractive gap trigger

Additional detectors for event classification and trigger purposes are located on both sides of the ALICE central barrel. First, an array of scintillator detectors (V0) is placed on both sides of the central barrel covering two units in pseudorapidity. Second, a Forward Multiplicity Detector (FMD) is located on both sides of the central barrel. The pseudorapidity coverage of this detector is $-3.4 < \eta < -1.7$ and $1.7 < \eta < 5.1$, respectively. The geometry of the central barrel in conjunction with the additional detectors V0 and FMD is well suited for the definition of a rapidity gap trigger. Such a gap trigger can be defined by the requirement of signals coming from the central barrel detectors while V0 and FMD not showing any activity. This scheme requires a trigger signal from within the central barrel for L0 decision. The pixel detector of the ITS or the TOF array can deliver such a signal[3]. The integration of the TRD pretrigger system into the ALICE diffractive trigger scheme requires special considerations[4].

5. ALICE diffractive physics

The low luminosity of ALICE as compared to the other LHC experiments restricts the ALICE physics program to reactions with cross section of a few nb per unit of rapidity. Due to this low luminosity, the probability for multiple interactions within one bunch crossing is negligible. The tracking capabilities at very low transverse momenta together with the excellent particle identification make ALICE an unique facility to pursue a long term physics program of diffractive physics.
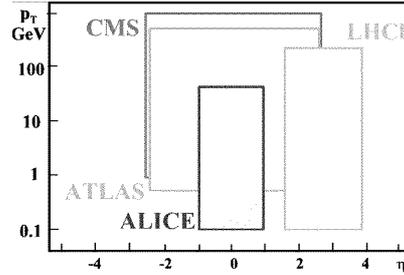
Figure 1: Rapidity and transverse momentum acceptance of the LHC experiments

Fig.1 shows the transverse momentum acceptance of the four main LHC experiments. Not shown in this figure is the TOTEM experiment. The acceptance of the TOTEM telescopes is in the range of $3.1 < |\eta| < 4.7$ and $5.3 < |\eta| < 6.5$. The CMS transverse momentum acceptance of about 1 GeV/c shown in Fig.1 represents a nominal value. The CMS analysis framework foresees the reconstruction of a few selected data samples to values as low as 0.2 GeV/c[5].

The ALICE gap trigger selects reactions which produce a rapidity interval void of particles. Such a signature can result from photon, W-boson or gluonic color singlet exchange. Two photon interactions are being discussed in the quest for new physics signals at the LHC[6]. The gluonic color singlet exchange has a C-even and C-odd part represented by the Pomeron and the Odderon.

Double pomeron exclusive reactions containing proton-antiproton as well as pion and kaon pairs have been studied at the Intersecting Storage Ring (ISR) at CERN. These events showed structures in the invariant pion pair mass which might be related to glueballs[7, 8]. At the SPS energy, data were taken in the central region and the azimuthal dependence of meson production was analyzed[9]. The ALICE gap trigger enables the continuation of such pomeron studies at the much higher energy of the LHC with correspondingly larger pomeron fluxes. The ALICE diffractive physics program includes the study of mesonic states such as glueballs, heavy quarkonia χ_c, χ_b and the search for Odderon signatures in diffractive production of J/Ψ[10]. Glueball signatures can, for example, be searched for in the analysis of $\phi\phi$ events. The study of baryonic final states includes the analysis of $p\bar{p}$ pairs as discussed below as well as the search for hyperon pairs like $\Lambda\bar{\Lambda}$ and $\Sigma\bar{\Sigma}$.

6. Central diffractive processes

The formalism for central exclusive production of a system X folds the unintegrated gluon distribution with the elementary cross section gg $\rightarrow$ X. Higher order QCD corrections to ensure no additional gluon radiation in the hard process are taken into account by the Sudakov suppression

factor. The probability that the rapidity gap is not destroyed by additional soft particles from the rescattering of the protons is represented by the gap survival factor S^2. Central exclusive production is thought to be a clean environment for identifying the Higgs boson at the LHC[11]. The calculated Higgs cross section is, however, small with large associated uncertainties due to the different ingredients as explained above. The cross section for exclusive production of photon-photon, jet-jet and χ_c, χ_b events can be calculated within the same formalism. In particular, the resulting cross section for χ_c and dijets is orders of magnitude higher than the Higgs cross section. A measurement of centrally produced χ_c and dijets is of interest in its own but also of importance for a systematic study of the uncertainties inherent in the formalism of central exclusive production.

7. χ_c production

A study of centrally produced χ_{c0} in pp collisions at LHC energy $\sqrt{s}$ = 14 TeV was carried out in Regge formalism and perturbative QCD approach. This study finds cross section values of $\frac{d\sigma}{dy}|_{y=0}$ = 340 nb and 30 nb for exclusive and inclusive production, respectively[12]. Here, the exclusive cross section is larger as compared to the inclusive one due to the low mass of the χ_{c0}.

At the ALICE pp-luminosity $\mathscr{L} = 5 \cdot 10^{30}$ cm^{-2}s^{-1}, $3.4 \cdot 10^6$ χ_{c0}'s are produced in 10^6 seconds.

decay mode	BR	signal
$\chi_{c0} \to \pi\pi$	$7 \cdot 10^{-3}$	$2.4 \cdot 10^4$
$\chi_{c0} \to K^+ K^-$	$6 \cdot 10^{-3}$	$2.1 \cdot 10^4$
$\chi_{c0} \to J/\Psi\, \gamma$	$1 \cdot 10^{-2}$	$3.5 \cdot 10^4$
$\chi_{c0} \to p\bar{p}$	$2 \cdot 10^{-4}$	700

Table 1: Branching ratios and signal sample of χ_{c0} decays

Table 1 shows the branching ratio for different χ_{c0} decay channels together with the signal sample resulting from $3.4 \cdot 10^6$ decays. The signal sample has to be folded with the detector acceptance and analysis efficiency for getting the number of reconstructed χ_{c0}'s. A simulation study of the decay $\chi_{c1,2} \to J/\Psi\, \gamma$ finds an acceptance of 10% and a reconstruction efficiency of 0.9% for identifying the J/Ψ by its e^+e^- decay and the photon by the conversion method[13]. These values in conjunction with the χ_{c0} cross section shown above results, however, in a data sample of very low statistics. Much better statistics can be achieved in the $\pi\pi$, KK and $p\bar{p}$ decay channels. Of particular interest is the $p\bar{p}$ channel with a statistical uncertainty of a few percent while the background is thought to be much reduced as compared to the $\pi\pi$ and KK channels.

8. Exclusive vector meson production in lead-lead collisions

The electromagnetic interaction between two nuclei can be studied in ultra-peripheral collisions where the impact parameter is larger than the sum of the two radii[14]. The photons of the electromagnetic field of the beams can interact in a variety of ways. First, two photon interactions will result in copious production of π^0, η and η'. Second, the photon of one beam can interact hadronically with a nucleus of the other beam resulting in photonuclear interactions. Inelastic and

elastic photonuclear reactions are characterized by breakup and no-breakup of the nucleus, respectively. The elastic photonuclear cross section is dominated by exclusive vector meson production.
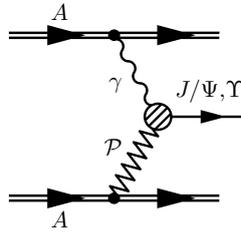
Figure 2: Exclusive vector meson production in AA collision

A photon can fluctuate into virtual vector meson states and subsequently get on-shell by diffractively scattering off a nucleus as depicted in Fig.2. The cross section for production of ρ^0, J/Ψ and Υ(1S) in lead-lead interactions at LHC energies is found to be 5.2 b, 32 mb and 280 μb, respectively[15]. The detection of the ρ by its $\pi^+\pi^-$ and of the J/Ψ, Υ by its e$^+$e$^-$ decay results in data samples in one month of data taking of $2 \cdot 10^8$, $1 \cdot 10^5$ and 400, respectively.

9. Conclusions

A rapidity gap trigger in the ALICE experiment enables the measurement of many diffractive and electromagnetic reaction channels. These measurements open the way for a diverse diffractive physics program both in proton-proton and heavy-ion induced reactions.

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