Diffractive physics in ALICE at the LHC

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Abstract. Diffractive and photon induced physics is a research area with a remarkable discovery potential at the LHC. ALICE has started a program to exploit its unique capabilities to study the subject in both proton-proton and heavy ion collisions. We discuss some aspects of a new sub-detector for the ALICE experiment at the LHC. This detector would enhance the performance of ALICE to address some relevant topics on this matter. It consists of four stations of scintillator pads that would tag the diffractive gap more efficiently.

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INTRODUCTION

The ALICE experiment has been designed to study heavy ion collisions at the Large Hadron Collider (LHC) [1]. A physics research program on proton-proton interactions is on-going with the double purpose of providing a reference for the heavy ion measurements and to address several topics.

Diffractive processes are of particular interest at the energies of the LHC. ATLAS and CMS are proposing forward detectors for diffractive studies [2]. These experiments, however, are not suited to access a very low transverse momentum of centrally produced tracks. ALICE has excellent particle identification capabilities and can resolve low transverse momentum tracks, i.e. ALICE has unique tools to study soft and hard diffractive events at the LHC.

In addition, the high flux of photons associated with Coulomb fields of lead ions will produce high luminosity in $\gamma\gamma$ collisions. The physics of photon-photon interactions includes a number of QED and QCD processes like lepton pair and jet pair production.

The potential of ALICE to tag the rapidity gap extending the rapidity coverage of the experiment is under study. We show that adding detectors around the interaction point would significantly improve the efficiency to tag diffractive events. The detector system under study consists of four stations of scintillator counters.

In order to cover the spectra of small diffractive masses, as well as to enhance the sensitivity of the detector to tag diffractive events, a pseudo-rapidity coverage extending beyond $\eta = 5$ is needed.

DIFFRACTIVE PROCESSES

Diffractive reactions can be defined in terms of rapidity gaps [3]. The inelastic proton-proton reaction rate is in principle the sum of rates of non diffractive, single diffractive and double diffractive processes. Particles emitted in diffractive reactions are mainly found at rapidities close to that of the parent proton. It is possible to differentiate between single, double or central diffraction processes depending on the actual location of the rapidity gaps.

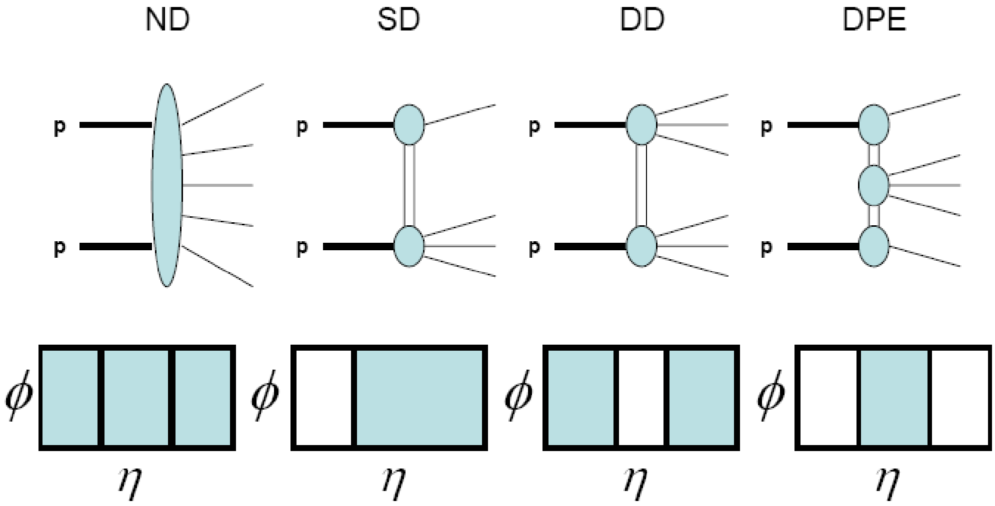

FIGURE 1. Proton-proton collisions and the azimuthal (ϕ) and pseudo-rapidity (η) distributions of the tracks produced in the interaction for ND: No Diffractive, SD: Single Diffractive, DD: Double Diffractive, DPE : Double Pomeron Exchange.

Figure 1 shows diagrams of possible processes in proton-proton interactions. Those diagrams in which a strongly interacting color singlet is exchanged, result in the scattering of a proton or the two colliding protons. The ϕ-η plot shows the distribution of particles. The diagram for single diffractive scattering is similar to elastic scattering except that the proton breaks up populating a limited region of rapidity.

Soft diffractive processes are dominated by non-perturbative dynamics. They may account approximately 20% of the total inelastic cross section.

THE ALICE EXPERIMENT AT THE LHC

The ALICE detector is shown in Fig. 2. It is formed by 16 subsystems. It has tracking system over a wide range of transverse momentum which goes from 100 MeV/c to 100 GeV/c as well as particle identification able to separate pions, kaons, protons, electrons, muons and photons. A detailed description of the detector can be found in [4]. The central part of the detector is inside of a solenoid that provides a magnetic field of 0.5 T.

Electrons and photons are measured in a high resolution calorimeter (PHOS) located 5 m below the interaction point. PHOS is built from $PBWO_4$ crystals which have a high light output.

An electromagnetic calorimeter which covers the central barrel is now in construction. Two modules have been operating already. EMCAL is made of almost 13,000 towers of plastic scintillator and lead plates in a sandwich array which is read out with wavelength shifting optical fibers. Avalanche photodiode sensors are used to convert light into an electronic signal.

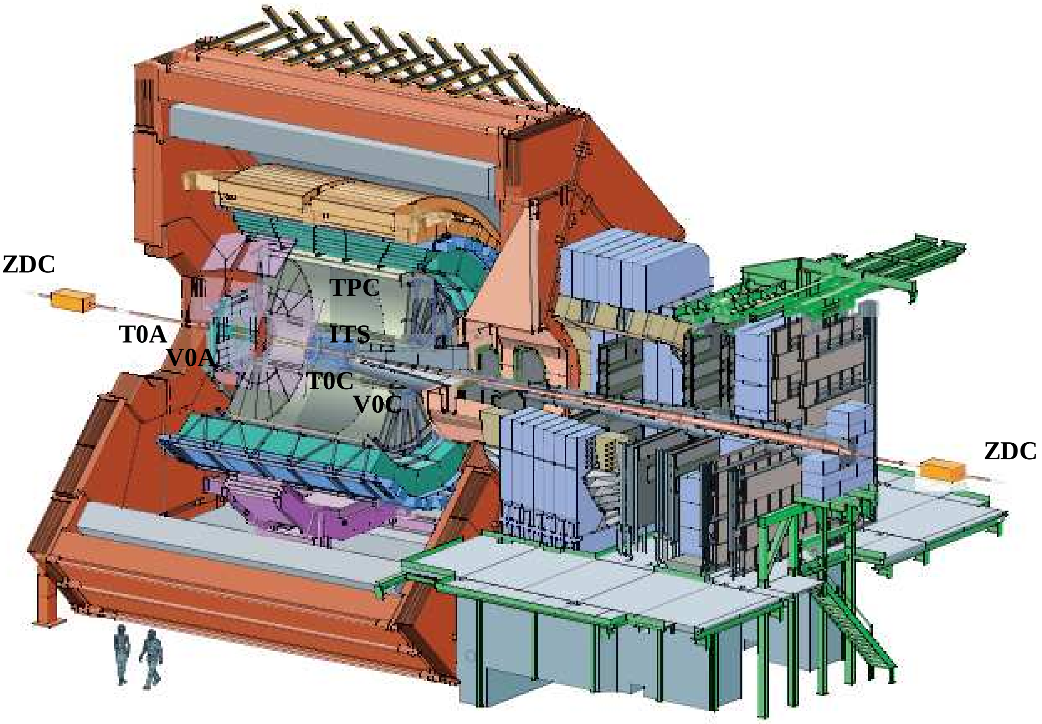

FIGURE 2. The rapidity coverage of several components of ALICE suited for the study of diffractive physics. In the forward direction: V0A $2.8<\eta<5.1$; V0C $-1.7<\eta<-3.7$; T0A $4.5<\eta<5.0$; T0C $-2.9<\eta<-3.3$; ZDC: $-8.4<\eta<8.4$; FMD: $1.7<\eta<5.0$; $-3.4<\eta<-1.7$. In the barrel: ITS: $-1.4<\eta<1.4$, $-2.0<\eta<2.0$, TPC: $-0.9<\eta<0.9$

The track measurement is performed with a set of six barrels of silicon detectors (ITS: Inner Tracking System) and a large Time Projection Chamber (TPC). The TPC has an effective volume of $88\,m^3$. It is the largest TPC ever built. In addition a Transition Radiation Detector (TRD) and a Time of Flight (TOF) system provides electron and hadron identification at intermediate momentum. The TOF uses Multi-gap Resistive Plate Chambers. A Ring Imaging Cherenkov extends the particle identification to higher momentum particles (HMPID). It covers 15% of the acceptance in the central area and separate pions from kaons with momentum up to 3 GeV/c and kaons from protons with momentum up to 5 GeV/c.

The setup of ALICE for forward physics is shown in Fig. 2. Some sub-detectors are used to extend the measurement of charged particles. The Forward Multiplicity Detector (FMD) made of silicon detectors and the Photon Multiplicity Detector (PMD) at moderately large forward rapidity as well as the Zero Degree Calorimeter (ZDC) which can be used to tag the leading neutron from the nuclear break-up are some of the devices that can be used. In addition ALICE has a forward muon spectrometer at a rapidity region not covered by CMS or ATLAS. The muon arm give us the possibility to study J/ψ, ϒ as well as $W^{\pm}$ and Z^{0} production in single diffractive events. It covers a pseudo-rapidity $-4< \eta<-2.5$.

The inclusion of electromagnetic calorimeters for photon detection is expanding the possibilities to address a number of research topics in both diffractive and photon induced physics.

DIFFRACTIVE PHYSICS IN ALICE

ALICE has started a research program with the existing data to study light states in diffractive processes. It will also measure the production of J/ψ mesons as well as vector meson photo-production.

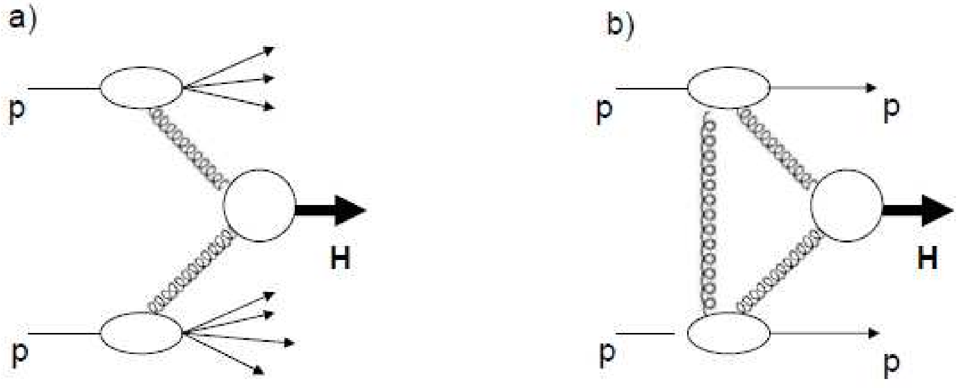

FIGURE 3. a) Shows the typical Higgs production mechanism in proton-proton via gluon-gluon fusion. b) An extra screening gluon conserves color and the proton remains intact.

As for high transverse momentum physics, there are some topics of interest. The case for Diffractive Physics in ATLAS and CMS is the production of Higgs via gluon fusion [5] as it is shown in Fig. 3.

Exclusive processes like $pp \to pAp$ have been observed at the Tevatron [6]. In particular, the process $pp \to p\chi_c p$ is driven by the same production mechanism as that for exclusive Higgs production. The production of χ_c however, would have a much larger cross section. It is therefore considered a "standard candle" for Higgs production in diffractive processes. ALICE is well equipped to observe χ_c production.

Other high transverse momentum research topics are shown in Fig. 4. The production of jets would be of interest to study the structure of diffractive exchange.

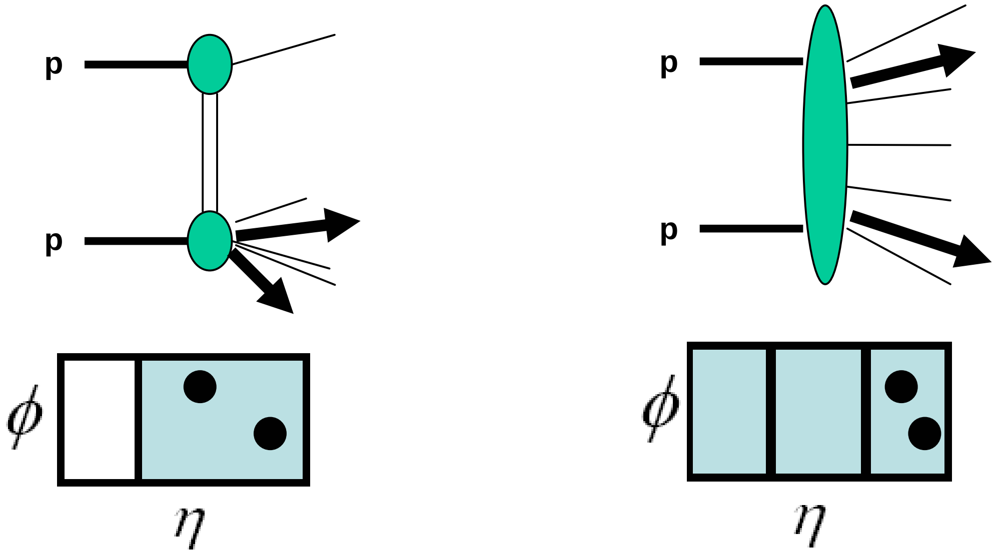

FIGURE 4. a) Single Diffractive b) Non Diffractive production of jets. Azimuthal (ϕ) and pseudo-rapidity (η) distribution of tracks produced in the reaction.

The observation of jets in diffractive events would probe the partonic nature of the exchanged object, whether it is the pomeron or something else. The first experimental results on this, were published by the UA8 Collaboration at CERN [7]. Fig. 4 shows the diagram for single diffraction producing two jets, a scattered proton and a rapidity gap and the similar process for proton-proton non diffractive scattering in which the rapidity gap is not present.

The study of hard diffractive processes has been very intensive in recent years. The observation of diffractive jet and W boson production are some of the topics of interest in high-pT physics.

A whole array of four stations with four pads each, i.e. 16 channels, would improve the capabilities of ALICE considerably [8].

Figure 5 shows the ALICE detector in the cavern at point 2 of the LHC ring. The arrows signal the places where the stations could be placed. The first stations on both sides of the interaction point would be located inside the cavern. The other two would be installed in the LHC tunnel.

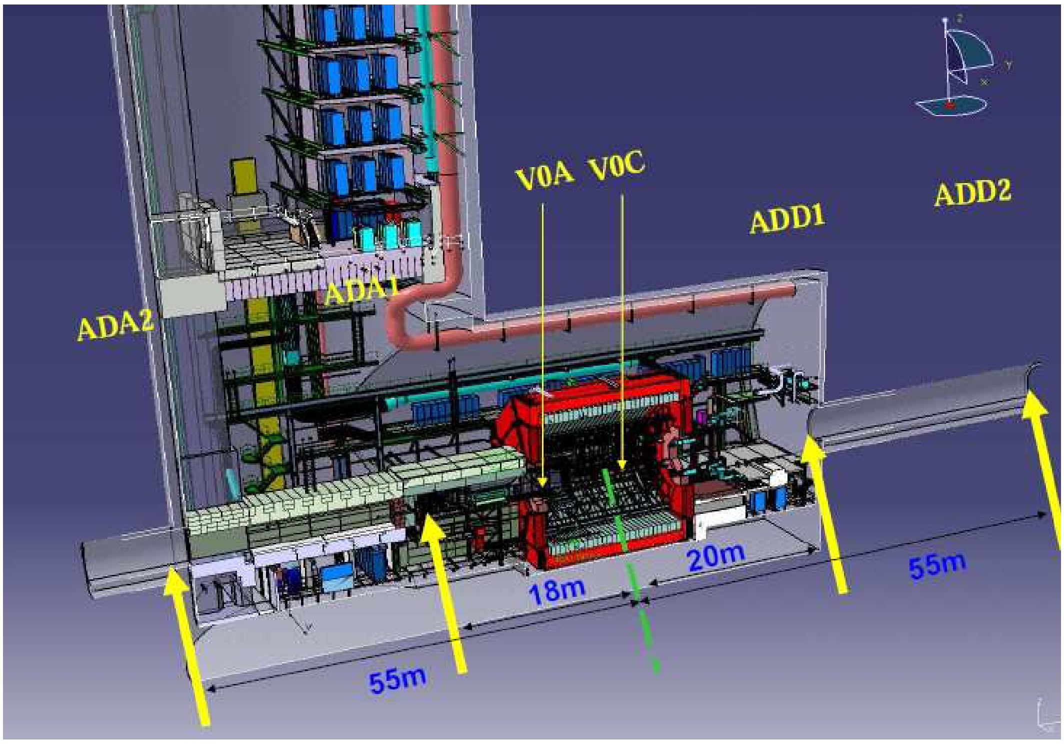

FIGURE 5. Proposal to install four stations: ADA1 ADA2 on one side of the interaction point and ADD1 and ADD2 on the other. The detectors V0A and V0C are the existing trigger detectors of ALICE.

Table 1 gives the distance and size of each station as well as the pseudo-rapidity coverage. Figure 6 shows the shape of the pads proposed. The scintillator shape does focus the light towards the guide which brings the photons to a PMT.

An estimate of the efficiency improvements to collect diffractive events can be done considering the present minimum bias trigger of ALICE, the so called MB1. This trigger takes an OR of hits in V0A, V0C and Silicon Pixel Detector (SPD). Monte Carlo simulations using PYTHIA for proton proton collisions at 7 TeV shows that the efficiency for single diffractive events of MB1 is 70%. Taking an OR with one station of the new array would increase the efficiency to almost 90 % for single diffractive events in the direction of the detector.

TABLE 1. Distance from the interaction point and size of the disc of scintillator for the proposed array of four stations.

A side	distance - outer, inner - η radius	C side	distance - outer, inner η radius
ADA1	17m 14 cm 5cm 5.5/6.5	ADD1	20m 16cm 6cm - 5.5 /- 6.5
ADA2	55m 16 cm 6cm 6.5/7.5	ADD2	55m 16cm 6cm - 6.5 /- 7.5

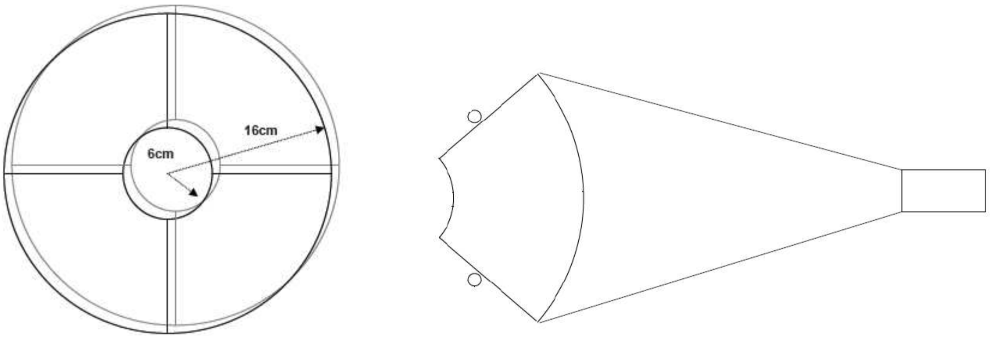

FIGURE 6. The proposed detector geometry is shown. The shape of the scintillator pad favors the collection of light.

Similarly, the contamination in selecting central diffractive events is reduced considerably when using ADA and ADD information. A Monte Carlo simulation with PHOJET for proton-proton interactions at 7 TeV shows that the MB1 trigger would select 70% of central diffractive processes when assuming 100% intrinsic efficiency in the detectors. This means 30% contamination from non diffractive, single diffractive and double diffractive events. By taking the information from ADA and ADD into account the selection of Central Diffractive events increases to 95 % [8] reducing the contamination to 5%.

Figure 7 shows the pseudo-rapidity coverage of the Forward Multiplicity Detector (FMD), the Zero Degree Calorimeter (ZDC), the V0 detector and the proposed ADA and ADD stations.

Moreover, the efficiency improves for low multiplicities in both single and double diffractive events. This favors the reconstruction of low diffractive invariant masses.

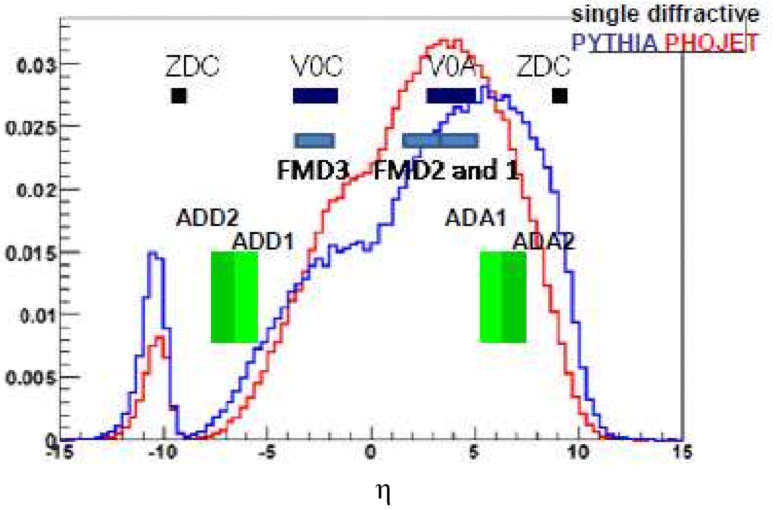

FIGURE 7. Pseudo rapidity coverage of the proposed array of detectors. The histogram shows the normalized tracks rapidity distribution of single diffractive events obtained with PYTHIA and PHOJET Monte Carlo generators.

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