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ALICE

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Abstract. ALICE, the dedicated heavy-ion experiment at LHC, will be presented in this paper. The physics goals of the experiment will be briefly discussed, with emphasys on those items which are new or more relevant with respect to RHIC and SPS energies. The general features and the performance of the ALICE detector will be outlined, together with the planned data taking program.

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1 Introduction

Ultra-relativistic heavy-ion experiments are performed to produce and study the Quark-Gluon Plasma (QGP). According to lattice-QCD calculations, this new state of matter is expected to exist at high temperatures and/or high baryon densities. This prediction has triggered an extensive experimental activity, which has been carried out at different accelerators, able to deliver higher and higher bombarding energies. The extremely interesting results obtained by the SPS heavy-ion experiments [1], corroborated by the first RHIC data [2], represent a strong experimental motivation to set up a heavy-ion programme at the forthcoming CERN Large Hadron Collider (LHC). In this frame, the leading role will be played by ALICE [3],[4],[5], the LHC experiment fully devoted to (and specifically designed for) the study of heavy-ion collisions. While at previous accelerator facilities (AGS, SPS and RHIC) different Physics observables relevant for QGP studies were addressed by different experiments, ALICE is conceived as a general–purpose detector and will address most of the phenomena related to the QGP formation at LHC energies. If, on one hand, this all-in-one approach makes the experimental task very challenging, on the other it is also clear that the LHC energy regime will offer unprecedented conditions for the formation and the study of the Quark-Gluon Plasma.

The paper is organized as follows. The main Physics issues which are new or more relevant at LHC energies with respect to the SPS and RHIC will be outlined in Sect. 2. A description of the ALICE detector will be given in Sect. 3 and its performance will be outlined in Sect. 4. Finally, the data taking scenario will be overviewed in Sect. 5.

2 Heavy-ion physics at LHC

The advent of the LHC will bring heavy-ion Physics into a completely new energy region, previously accessible only in the interactions of the highest energy cosmic rays. In fact, the LHC will deliver Pb-ions at a center of mass energy of 5.5 TeV per nucleon pair, which represents a jump of more than one order (two orders) of magnitude with respect to the RHIC (SPS) energy. The higher colliding energy will lead to ideal conditions for the formation and the study of the QGP. First of all, the higher energy will improve by large factors all parameters (such as energy density, size and lifetime of the system) relevant to QGP formation. Secondly, the initial temperature will largely exceed the calculated critical temperature for QGP formation, therefore allowing the study of the QGP in its asymptotic ideal gas form. Finally, the net baryon density in the central region will essentially vanish: this will make the experimental conditions close to the ones of latice QCD calculations as well as to those of the early universe.

Another relevant point is that the increase of the energy opens the possibility to exploit a wider set of observables as compared to the previous accelerators, leading to a better and more comprehensive understanding of the properties of the system. In this respect, an outstanding example is represented by the hard probes, which are sensitive to the nature of the medium in its early stages. In fact, since high-p_t partons are expected to lose a significant fraction of their energy when crossing a deconfined medium [6], a suppression of the hadronic activity at high transverse momenta (the so-called jet quenching) should be observed in case of QGP formation [7]. This powerful QGP signature can be extensively studied with high statistics at LHC since, at this energy, the cross section will be dominated by semi-hard and hard processes: about 30 (3×10^{-3}) partons with transverse energy larger than 10 GeV (100 GeV) are in fact expected per central Pb-Pb collision [8].

The LHC heavy-ion program will allow to probe a novel range of Bjorken-x values, down to about 10^{-5} [8].

This region looks extremely interesting, since at small x the gluon density is expected to be close to saturation (gluon shadowing), leading to modifications of the particle production rates.

The traditional study of heavy quarkonia production and suppression will be improved with respect to previous accelerators as well. At LHC energies, in fact, the whole spectrum of heavy quarkonia (J/ψ and Υ families) will be measured and, for the first time, energy densities high enough to melt the Υ (1S) could be reached. Together with heavy quarkonia, also open heavy flavours will be abundantly produced (about 100 c-$\bar{c}$ and few b-$\bar{b}$ pairs per central Pb-Pb collision), making a detailed study of D and B meson production feasible [9].

The temperature of the system should be high enough to allow the detection of thermal photons and dileptons.

This kind of measurement would provide direct information on the temperature of the system.

The very high multiplicity (of the order of 2500 to 6000 charged particles per unit of rapidity, according to extrapolations based on RHIC data) will allow the measurement of several observables on a event-by-event basis. The single event analysis of multiplicity, particle composition and spectra and HBT parameter of the system will be used to identify non-statistical fluctuation related to critical phenomena.

3 Overview of the ALICE detector

ALICE is conceived as a general-purpose detector, in which the most part of hadrons, leptons and photons produced in the interaction can be measured and identified. The design of the detector was driven by two main considerations. The first one is the need to cope with the high multiplicities expected in Pb-Pb collisions: ALICE is designed to operate at multiplicities up to 8000 charged particles per unit of rapidity, i.e. a number which represents a reasonable safety margin with respect to the current expectations, previously quoted in Sect. 2. The second one is that, because of ion losses due to electromagnetic processes, the maximum luminosity with Pb-beams will be limited to 10^{27} cm^{-2}s^{-1}. Given this luminosity and an inelastic cross section of 8 b, the maximum event rate for Pb-Pb collisions will $\sim$ 8000 minimum bias collisions per second. Such a low interaction rate, coupled to the high multiplicity, has led to the choice of slow but high granularity detectors, like the time projection chamber (TPC) and the silicon drift detectors (SDD).

The layout of the ALICE experiment is shown in Fig. 1. The main component of the ALICE detector is the central barrel, where hadrons, photons and electrons are measured in the central rapidity region ($-0.9 \leq \eta \leq 0.9$). It consists of a complex system relying on high-granularity, yet relatively slow drift detectors, on a weak solenoidal magnetic field (B$\leq$ 0.5 T) and on detectors devoted to particle identification. The detection of muons is performed by a dedicated forward spectrometer ($2.5 \leq \eta \leq 4$), based on a large warm dipole equipped with tracking and trigger chambers. The set-up is completed by a set of small detectors, located at large rapidities, devoted to event characterization. The main features of these three components are briefly summarized in the following.

3.1 The central barrel

The primary purpose of the central detectors is to provide safe and robust track finding. The main tracking detectors are the Time Projection Chamber (TPC) and the Inner Tracking System (ITS). As it will be discussed below and in Sect. 4.1, the tracking performance is further improved when the information from these two detectors is combined with the one from the Transition Radiation Detector.

The ALICE TPC [10] (88 m^3 in volume) is the largest TPC ever built. Together with track finding and momentum measurement, it is design to provide particle identification via dE/dx. It has a cylindrical shape, with an inner radius of 90 cm (given by the maximum acceptable hit density of 0.1 cm^{-2}) and an outer radius of 250 cm. The latter is determined by the track length needed to achieve a dE/dx resolution better than 10%. To optimize the double-track resolution, the detector is operated with a 90/10 Ne/CO$_2$ gas mixture. The total number of channels is 570,000.

The role of the Inner Tracking System [11] is to provide secondary vertex reconstruction for hyperon and charmed meson decays, tracking and identification of low-p_t particles and to improve the momentum resolution for high momentum particles crossing the TPC. It consists of six cylindrical layers, located at radii ranging from 4 cm to 44 cm. Because of the particle density and to achieve an impact parameter resolution better than 100 μm, silicon pixel detectors have been chosen for the two innermost layers and silicon drift for the following two. The two outer layers consist of double-sided micro-strip silicon detectors. Four layers will have analog read-out to perform particle identification via dE/dx measurement in the $1/\beta^2$ region, in such a way to allow the use of the ITS as a standalone spectrometer for low-p_t particles.

Particle identification in the ITS and in the TPC is performed via dE/dx measurements and is therefore restricted to relatively low transverse momenta. PID is extended to higher transverse momenta thanks to dedicated detectors, specially developed for this purpose. These are the Time Of Flight detector (TOF), the Transition Radiation Detector (TRD) and the ring imaging Cherenkov detector for High-Momentum PID (HMPID).

The TOF system [12] is based on Multigap Resistive Plate Chambers (MRCP): a new-concept detector with excellent time resolution, much better than 100 ps. The multigap RPC consists of a stack of resistive plates which are kept few hundred microns apart each other in such a way to obtain a series of gas gaps. The voltage between the two external plates is fixed, while the intermediate plates take the correct voltage due to electrostatics. The high resistivity of the plates makes them "transparent" for the avalanche signals, so that the signal induced on the

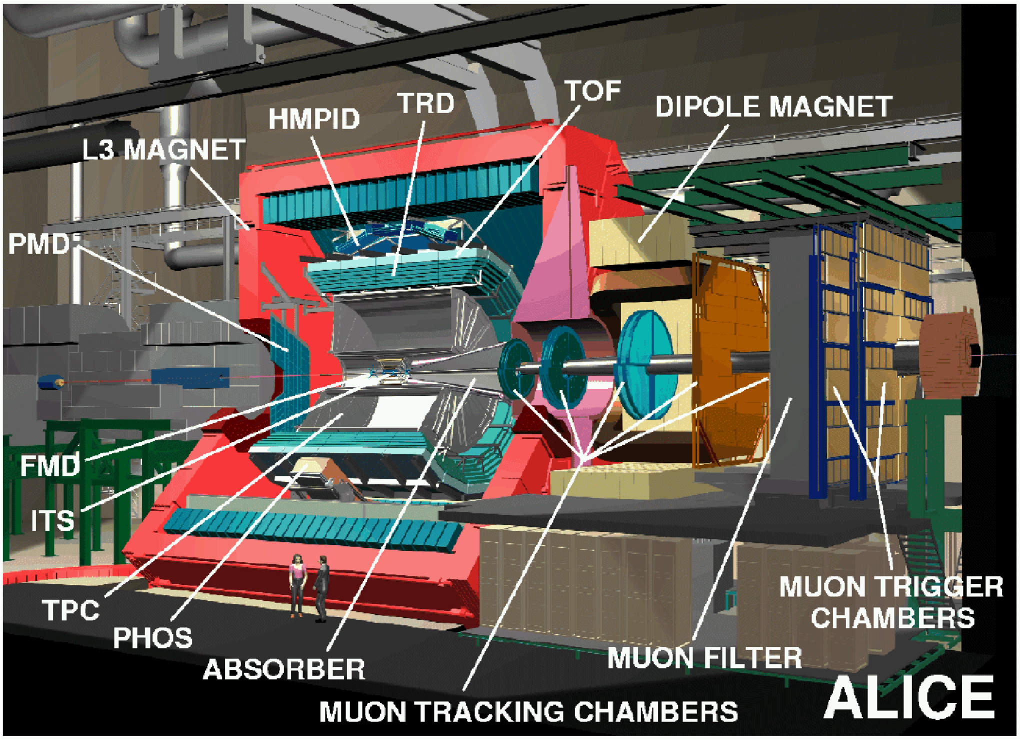

Fig. 1. ALICE layout

external plates (which is read-out by means of strips or pads) corresponds to the "analog sum" of the avalanches in all the gaps. The ALICE MRPC design consists of a double stack of 2×5 gaps and the plate material is low-cost glass. Several tests have shown that resolutions of the order of 50-60 ps are achieved by this detector. The ALICE TOF system will consist of a MRPC cylindrical layer with radius equal to 3.7 m and a total surface of 140 m^2; the total number of channels is 160,000.

The identification of particles with higher momentum will be provided (in a restricted area) by the HMPID [13], a proximity-focus RICH detector placed at a distance of about 4.5 m from the beam axis. The HMPID consists of seven modules, each 1.5×1.5 m^2, for a total of over 160,000 readout channels.

The Transition Radiation Detector (TRD) [14] will play the main role in providing electron identification. It consists of six layers of radiator followed by Time Expansion Chambers filled with Xenon/CO_2. This detector provides electron identification for $p_t \geq 1$ GeV/c (the e/π rejection power is about 100 at $p_t \geq 3$ GeV/c) and electron trigger for $p_t \geq 3$ GeV/c. The TRD is operated in conjuction with the ITS and the TPC for precise momentum measurements. In this way it is possible to achieve the invariant mass resolutions (similar to those of the forward muon spectrometer, see Sect. 3.2) needed for the identification of heavy vector mesons in the e^+e^- decay channel. There is indeed another synergy between the TRD and the main tracking detectors (ITS and TPC). Although the TRD chief goal is electron identification, its excellent localizing properties (about 500 μm in rϕ) can be exploited to increase the tracking lever arm, hence obtaining a significant improvement in momentum resolution, in particular at high momenta. In addition, thanks to its fast tracking capabilities, it can be used to trigger on high p_t electrons and hadrons. The latter option is essential for selecting jet leading partiles. The detector covers the whole ALICE central barrel; its radial position is about 3 m, the total surface is 800 m^2 and the total number of electronics channels is about one million.

Prompt photons, π^0's and η's are measured in the PHOS [15], a single-arm, high-resolution electromagnetic calorimeter. The accuracy of the single inclusive photon spectra will be determined by the systematic errors on photon-reconstruction efficiency and by the knowledge of the decay background. An acceptable systematic error can be obtained only at low channel occupancy and therefore requires a calorimeter with small Molière radius, R_M, at a large distance (≈ 5 m) from the vertex. The acceptance has been defined such as to keep the statistical errors below the expected systematic ones. The PHOS is located 5 m vertically beneath the interaction region and is built from $PbWO_4$, a crystal with small Molière radius and high light output.

3.2 The muon spectrometer

The complete spectrum of heavy quark vector mesons (as well as the invariant mass continuum) will be measured in the $\mu^+\mu^-$ channel by the ALICE Forward Muon Spectrometer [16]. The choice of the forward geometry allows the detection of low p_t J/ψ's. In fact, muon identification is only feasible for muon momenta above 4 GeV/c due to the amount of material (absorber) required to reduce the flux of hadrons. Hence, detection of low p_t charmonia is possible only at small angles, where the muons are Lorentz-boosted. The spectrometer is designed to detect muons in the angular interval between 2 and 9 degrees, which corresponds to the pseudorapidity interval $2.5 \leq \eta \leq 4.0$. The spectrometer consists of a front absorber ($\sim 10\ \lambda_{INT}$), to absorb hadrons and photons from the interaction vertex, a large dipole magnet (nominal field 0.7 T, field integral of 3 T·m) a high-granularity tracking system (10 detection planes) and a trigger system (4 detection planes) placed behind a passive muon filter wall ($\sim 10\ \lambda_{INT}$). The tracking and trigger detectors are protected from particles and secondaries produced at large rapidity by a high-density shield placed around the beam pipe all along the spectrometer. The tracking system is based on low-thickness (about $0.03X_0$) cathode pad chambers. These are arranged in five stations (each one made of two chambers): two of them are placed before, one inside and two after the dipole. To keep the occupancy at the 5% level, a high segmentation of the readout pads is needed, leading to a total number of channels of about one million. Thanks to the high space resolution (better than 100 μm in the bending plane) and to the bending power of the magnet, an invariant mass resolution as good as 70 MeV/c^2 (100 MeV/c^2) is achieved in J/ψ (Υ) region, allowing to resolve all the heavy quark vector mesons. The aim of the trigger system is to select events containing a pair of high-p_t muons of opposite sign emitted in heavy quarkonia decays. The p_t selection is made by two trigger stations, each one consisting of two planes of Resistive Plate Chambers (RPCs) operated in streamer mode and equipped with a new-concept dual-threshold front-end chip which allows to reach time resolutions of the order of 1 ns. The trigger electronics (based on programmable circuits working in pipeline) performs the comparison of the coordinates measured in the first and second station and selects the muon p_t in a time of about 700 ns.

3.3 Large rapidity detectors

The ALICE setup is completed by several small detector systems (ZDC, PMD, FMD, T0 and V0) located at small angle (i.e. at large rapidities, both forward and backward). The purpose of these detectors is to measure global event characteristics and to provide trigger signals which enable the first level of event selection.

The impact parameter is measured by a set of Zero Degree Calorimeters (ZDCs) [17], placed at about 116 m from the Interaction Point. At this distance from IP, spectator protons are spatially separated from neutrons by the magnetic elements of the LHC beam line and therefore are detected in two different calorimeters. These are quartz-fiber calorimeters: the shower generated by incident particles in a dense absorber (passive material) produces Cerenkov light when crossing the quartz fibers (active material) interspersed in the absorber.

The Photon Multiplicity Detector (PMD) [18] measures the ratio of photons to charged particles and is also used for determining the reaction plane. It consists of a few m^2 pre-shower gaseous detector which covers the pseudorapidity region $-3.5 \geq \eta \geq -2.5$.

The Forward Multiplicity detector (FMD) measures the pseudorapidity distribution of charged particles over a large pseudorapidity interval ($-5.1 \geq \eta \geq -1.7$ and $1.7 \geq \eta \geq 3.4$) almost complementary to the one covered by the ITS. It consists of a mosaic of silicon pads detector arranged in 5 discs surrounding the beam pipe.

The task of the T0 Cerenkov counter array is to determine the event time with a precisione better than 50 ns, while the one of the V0 scintillator array is to provide a fast measurement of the event multiplicity (to be used in the main interaction trigger) and to locate the interaction vertex.

4 ALICE performance

The performance of the ALICE detector is discussed in this section, with emphasys on the relevant sectors of tracking, particle identification, lepton (both electrons and muons) and jet measurements.

4.1 Tracking

A detailed simulation of the ALICE tracking system has been carried out taking into account the details of the detectors involved. Vertex finding is the first step of the tracking procedure: it is performed by means of the first two layers of the ITS (silicon pixels). This method allows to identify the interaction vertex with a precision of 5 μm in z (i.e. along the beam axis) and of 15 μm in the transverse plane for Pb-Pb collisions (averaged over the centrality). At design multiplicity the tracking efficiency of the TPC is better than 90%, almost independent of p_t down to about 100 MeV/c. At lower multiplicities, the efficiency increases, reaching a value of about 97% below 4000 charged particles per unit of rapidity. When the ALICE tracking detectors (i.e. ITS and TPC) are used in conjunction with the TRD, a momentum resolution better than 1.5% is reached for momenta between 0.2 and 2 GeV/c and it still remains of the order of 12% at 100 GeV/c. Such a good resolution at very high momenta is relevant for jet physics, allowing a detailed study of the fragmentation functions. If the relevance of a good tracking performance at high momenta has been widely discussed in this paper, it is also important to underline here the capabilities of the ALICE tracking system at low momenta, below 100 MeV/c. In this region, the tracking is accomplished by the ITS used as a standalone spectrometer. This feature is relevant to reconstruct the low-p_t particles emitted in hyperon decays. Another relevant role played by the ITS is the identification of the secondary vertex. In this respect, the crucial parameter is the impact parameter resolution: it improves when increasing p_t, reaching a value of 60 μm at 1 GeV/c. This value is adequate for the detection of short-lived B and D mesons ($c\tau$ of the order of 100 to 300 μm).

4.2 Particle identification

Protons, pions and kaons are identified over the whole acceptance of the ALICE barrel by combining the $\mathrm{d}E/\mathrm{d}x$ measurements in the ITS and in the TPC with the precise measurement of the time-of-flight performed by the TOF system. This allows π/K (K/p) discrimination from ~ 100 MeV/c up to $\sim$2.5 GeV/c ($\sim$4 GeV/c), leading to a number of identified particles, for each Pb-Pb event, high enough to perform event-by-event studies. In addition, hadron identification is improved by the HMPID up to higher momenta (K/π to 3 GeV/c and p/K to 5 GeV/c) on a limited area corresponding to about 15% of the acceptance of the ALICE barrel. Thanks also to the good momentum and angular resolution, the decay $\phi \to KK$ can be measured with great precision, with an invariant mass resolution of 2 MeV/c. In addition, the excellent vertexing capability of the ALICE tracking system allow the detection of hyperons (including the rare Ω) and of the hadronic decays of charmed mesons. Besides its relevance from the point of view of Physics (already underline in Sect. 2), the latter represents an oustanding example of the combined power of the PID, tracking and vertexing capabilities of the ALICE detector system. The result is a measurement of neutral D mesons via $K\pi$ decay with a significance of about 37, which allows a direct study of the p_t dependence of charmed meson production down to transverse momenta of the order of 1 GeV/c (significance $\sim$ 12).

4.3 Leptons

Both electrons and muons are measured in ALICE: the former in the central barrel (electron identification is provided by the TRD) and the latter in the forward muon spectrometer. This will allow the detection of the whole spectrum of heavy quark vector mesons (charmonium and bottomonium states) both in the $\mathrm{e}^+\mathrm{e}^-$ and $\mu^+\mu^-$ decay channels.

Although the global performance and the expected statistics (few thousands Υ's and few hundred thousands J/ψ's detected in one month of Pb-Pb data taking), are similar, the two experimental methods are indeed complementary under different points of view: first of all, the rapidity windows covered (midrapidity in the central barrel, forward region in the muon spectrometer). A second complementarity is represented by the different transverse momentum regions in which the detection of charmonium states is performed. Such a difference is due to the different p_t cuts on single leptons applied at the trigger level (3 GeV/c for the TRD, 1 GeV/c for the muon arm). The small value of the p_t cut on muons allow the detection of charmonium states down to $p_t \sim 0$ in the muon channel, while the higher p_t cut on electrons prevents charmonium detection below $p_t \sim 5$ GeV/c in the electron one (we note explicitely that, due to their high mass, bottomonium states are detected down to zero transverse momentum both in the TRD and in the muon arm). Furthermore, while vertexing is not performed in the forward rapidity region where the muons are detected, the vertexing capabilities of the ITS can be coupled to the TRD. In this way, in the electron channel it will be possible to distinguish between primary and secondary J/ψ. While the identification of the former is relevant for QGP studies, the identification of the latter allows a direct measurement of the B meson production cross section. In addition, vertexing can be also used to perform a direct measurement of the D and B meson production via their semileptonic decay, while for the muon channel the yields of these particles can be inferred only by the analysis of inclusive spectra. Finally, $c\bar{c}$ and $b\bar{b}$ cross sections can be measured in ALICE via electron-muon coincidence - the only leptonic channel that gives direct access to correlated $c\bar{c}$ and $b\bar{b}$ pairs. For this measurement, the TRD and the muon spectrometer are operated in conjunction, the electron being identified in the central barrel and the muon in the forward spectrometer. This methods allows the study of open charm and beauty in the rapidity window $1\leq y \leq 3$, therefore bridging the acceptances of the central part and of the muon spectrometer. By combining all the different methods outlined above ALICE can measure charm and beauty production in the interval $-1\leq y \leq 4$.

4.4 Jets

Jets are measured in ALICE by reconstructing charged particles in a cone around a "seed" particle of high p_T. The TRD triggering capability provides the possiblity to record $\approx 10^6$ events per month of Pb-Pb data-taking with jet energy above 100 GeV (10^4 above 200 GeV). Therefore ALICE will collect sufficient statistics to exploit its excellent tracking and PID capability for the study of detailed jet fragmentation functions, which is a very sensitive tool for the study of jet quenching. Using the photon measured in the PHOS as a tag, ALICE can study photon-jet back-to-back pairs. In this way, the average jet energy is defined by the photon measurement, and the fast parton energy loss is directly accessible. The range of jet energies accessible with such a measurement would be greatly enhanced by the proposed large acceptance electromagnetic calorimeter. If available, the EMCal would also significantly improve the measurement of the jet energy, by complementing the measurement of the charged particles performed by the tracking system, and provide an improved jet trigger.

5 Perspectives

The LHC is at present scheduled to start operation in 2007. The acceleration of nuclear beams is a part of the initial program and a pilot run with heavy ion is foreseen in the first LHC year. The LHC will operate according to the scheme already adopted at the SPS, with 4-6 weeks (corresponding to about 10^6 s of useful beam time) dedicated to heavy ions each year. The experimental program with heavy ions at present foresees Pb-beams for two or three years, for one year a run with proton-nucleus collisions and finally a run with lighter ions (probably Ar-Ar) to vary the energy density. The plan for the the following years will be decided on the basis of the results of the initial program. It is important to underline that ALICE also plans to partecipate to the standard p-p runs. In fact, proton-proton data, together with p-A, represent the baseline necessary for understanding the data collected with heavy-ions. As already mentioned, the maximum luminosity with Pb-beams will be limited to 10^{27} cm^{-2}s^{-1}, a value which in any case allows to carry out the Pb-Pb part of the ALICE program. The p-p run (in parallel with the other LHC experiments) will be carried out at full beam intensity but at reduced luminosity, below $3\cdot 10^{30}$ cm^{-2}s^{-1}.

In order to be ready for data taking at the start of the beam, the ALICE experiment has entered the construction phase: mass production already started or will start before the end of year 2003 for the most part of the ALICE subsystems.

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