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SUPPLEMENTS

Design of a large area fast RICH detector with CsI photocathode for particle identification at ALICE-LHC

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ALICE, A Large Ion Collider Experiment, at the LHC collider operated with heavy-ion beams, envisages a Ring Imaging Cherenkov detector (RICH) system to identify particles in the momentum range: .7 GeV/c ÷ 2.5 GeV/c, as an alternative to a time of flight (TOF).

In 1992 an extensive R&D programm was started to design and optimize a fast RICH detector based on proximity focusing of the Cherenkov radiation on a wire chamber with a Cesium Iodide solid photocathode.

The implementation of an analog pad read-out scheme provides two dimensional information and efficient discrimination between ionizing particle and Cherenkov photoelectron impact points.

After a discussion on the requirements, a description of the first large area prototype follows. Results of a beam test and detector performances are finally reported together with future developments and engineering issues.

1. INTRODUCTION

The Large Hadron Collider (LHC), planned at CERN in the coming years, operating with lead beams of 3 TeV/c per nucleon will represent an extraordinary facility to study heavy ions collisions.

The ALICE Collaboration proposes to build a dedicated, general purpose detector which will be operational at the LHC start-up . The aim is to study the physics of the nuclear matter at high densities and temperatures through the systematic study of a number of specific signals, together with a global survey of the events.

In the proposed experimental lay-out a fundamental role is played by the particle identification (PID) system.

The expected hadronic particle ratios range from $K/\pi=10\%$ (low pt) at $K/p=1$ (high pt). Therefore a separation power greater than 3 σ is required on a track-by-track basis to keep the contamination below a 10% level in presence of a huge bulk of hadrons at low momentum, moreover a reliable pattern recognition is mandatory due to the high track density.

Several techniques are under study for the PID

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system based on time-of flight (TOF) measurements and a proximity focusing ring imaging Cherenkov device (RICH) with liquid radiator.
In this paper we describe the approach and initial tests for the RICH system definition. In particular we present an innovative photon detection based on CsI used as a solid photoconverter. Preliminary R&D results and engineering studies are reported as well as pattern recognition issues.

2. ALICE EXPERIMENTAL LAY-OUT

The ALICE detector has been proposed to fully cover two units of rapidity at mid-rapidity.
The experiment is being designed to cope with the highest particle multiplicities, i. e. $2000 \div 8000$ particles per unit of rapidity for central Pb-Pb collisions.
An artist view of the lay-out is shown in fig. 1.

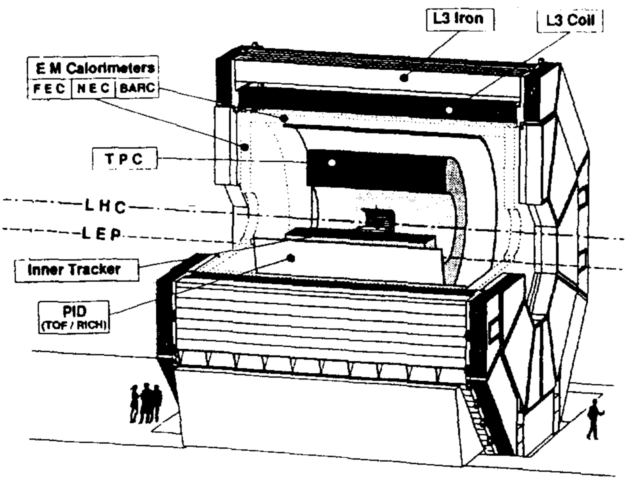

Figure 1. Schematic view of the ALICE lay-out.

Four main detector systems are embedded in a weak solenoidal field provided by a huge L3-like magnet: an inner tracking system (ITS) with five layers of high resolution silicon detectors, a cylindrical large volume time projection chamber (TPC), a particle identification array and an outer electromagnetic calorimetric complex.
The entire system is designed to track and identify hadrons, di-leptons and photons in the momentum range from 120 MeV/c to 3000 MeV/c.
A detailed description of ALICE can be found in ref.[1]; here we give more information on the PID and its requirements only.
An array of specific detectors is necessary to complement the particle identification in the momentum region not covered by the ITS and the TPC where the particle discrimination cannot be made via energy loss measurements. In that region the particle identification must be accomplished using the momentum of the particle measured by the ITS and TPC as complementary information.
Depending on the performance achieved by the most suitable technology, the PID system will be placed at radii between 3 and 4.5 m.
Since LHC operated with lead beams will likely reach the luminosity of $2 \cdot 10^{27}$ $cm^{-2}s^{-1}$, an interaction rate of about 10^4 Hz is expected, fortunately a small fraction, approximately $2 \div 3\%$, corresponds to the most interesting central collisions with maximum particle production.
It follows that the requirements on the PID front-end electronics are much less stringent than those in LHC-pp experiments, but as already pointed out the high multiplicity represents in this case a very demanding task when it combines with the large rapidity range to be covered. Moreover the realization of such ambitious detector complex must be based on a cost effective production of the system elements with standard techniques, with reliability and durability as key factors.

2.1. The RICH array

A proximity focusing RICH system based on CsI as photoconverter seems the best suited to assist in particle identification at high spatial and angular particle densities when a true bidimensional pad readout is implemented [2].
A complete and exhaustive description of this technique can be found in ref [3].
The radiating medium is a 1 cm thick layer of liquid C_6F_{14} with an index of refraction of $n=1.2834$ at $\lambda=175$ nm.
The generated photons are detected via the

pad readout cathode of a MWPC: each pad is equipped with an analog front-end electronics, allowing thus distinction between the ionization and the avalanche induced by the single photoelectrons kicked off from the CsI layer deposited on the cathode.

The implementation of a solid converter as a thin layer of CsI gives clear advantages, if compared to most traditional detectors operated with gas mixtures containing TMAE [4]. Above all advantages, one has to stress that the photoconversion is achieved in a single layer, thus eliminating an important source of parallax error present in detectors where a photosensitive gas is used instead of a solid photocathode.

Here is a list of specific features of the CsI-RICH:
1) detector operation at room temperature;
2) simplified structure due to the suppression of the photon detector window;
3) cost-saving and reduced total radiation length;
4) thin sensitive volume and therefore a reduced background due to ionizing particles.

In 1992, a large detector development effort was started in view of the very ambitious technological aspects to be fulfilled. A specific R&D was approved by the DRDC at CERN under the name RD26 [5].

The RICH design for ALICE has largely benefited from activities carried on in RD26 and the on-going researches will very likely still contribute in assessing the final performances.

An updated RD26 status report has been recently published [6], some of the outcomes are really fundamental to a succesful realization of a well performing CsI-RICH for ALICE. For istance, the technology of evaporating large photocathodes has been successfully implemented and tested with photocathodes up to 50×50 cm^2. The method is inexpensive and works without the use of time-consuming masking techniques. We are confident that the same technique may be applied for larger sizes.

3. EXPERIMENTAL RESULTS FROM THE TEST-RUN

A large size prototype (50×50 cm^2) with 3600 readout channels has been tested in november 1993 at the CERN-PS T11 test beam at the CERN-PS.

Three GeV/c positive hadrons are available in this beam line, with a negligible kaon content due to the long distance between the production target and the test area.

A scintillator based TOF system tags protons and pions.

The schematic of the prototype is shown in fig 2.

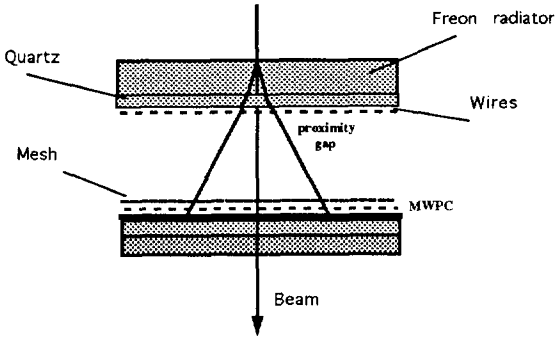

Figure 2. Schematic of the RICH prototype used for the test run.

An electrode made of 100 μm diameter wires with a pitch of 4 mm and a stainless steel cross wire mesh having 50μm wire diameter and 500 μm pitch define the 70 mm thick "proximity gap". The photodetector is a classical MWPC with an active volume 4 mm thick.

Twenty micron diameter sense wire are made of gold plated tungsten and have a pitch of 4 mm.

Cherenkov photon conversion points are measured on the pad cathode, this allows the determination of two coordinates of the hit.

The conversion of UV photons into electrons is achieved using a solid photocathode consisting of a 500 μm thick layer of CsI evaporated onto a plane segmented into pads of 8×8 mm^2.

Special care was taken on the CsI deposition process by standard techniques [7].

The size of the pads related to the chamber gap is chosen to allow sufficient coupling of the anode to the cathode, and to achieve a single-electron detection efficiency of about 85 $\div$ 90%, with a satisfactory spatial resolution.

The photodetector is operated with pure methane at a charge gain $\simeq 10^5$.

The front-end electronics based on the 16 channels AMPLEX [8] chips is fully integrated on the back side of the cathode plane.

The total material thickness of the MWPC including the readout electronics is 0.03 X_0.

Measurements were made at two different incident angles: 0^o and 10^o with respect to the radiator plane normal and with a 13 mm thick C_6F_{14} radiator.

Fig. 3 shows the raw data obtained at the two different incidence angles: one may observe the widening of the Cherenkov ring when the particle impinges the radiator plane at 10^o with respect to the normal. The beam spots are clearly visible.

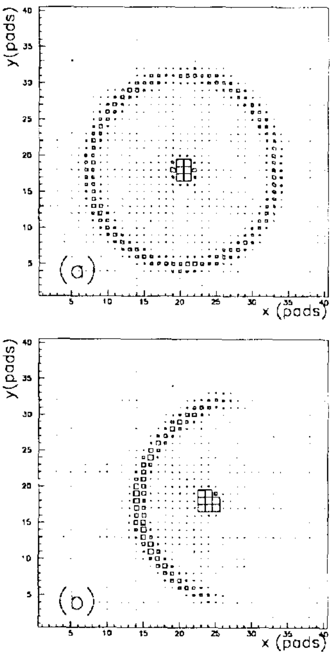

Figure 3. Superimposed images for π's tracks at normal incidence (a) and at 10^o (b).

The UV photons impact points have been reconstructed calculating the analog center of gravity of clusters formed by adjacent side by side hit pads [9].

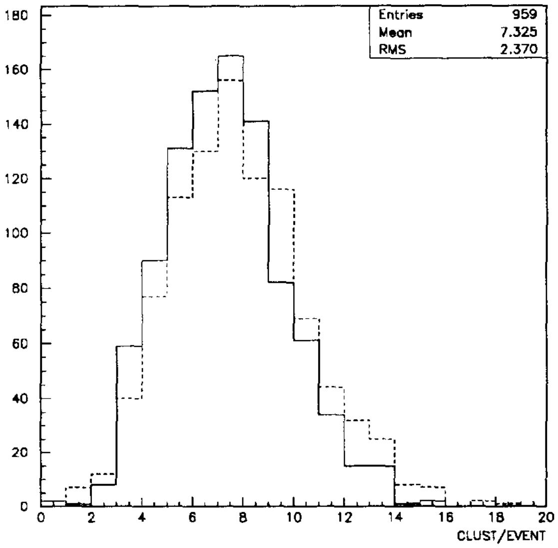

Figure 4. Number of reconstructed photons per event for π's tracks at normal incidence. A Poissonian distribution with the same mean is also shown (- - -).

In fig. 4, the number of reconstructed photons per event is shown. The average number of detected photons per ring is N=7.3

Comparison with a Poissonian distribution with the same mean shows that the measured distribution is slightly narrower at large number of clusters. This effect could be explained because at large N, photoelectrons induced charge distribution can easily overlap and be counted as one cluster.

The mean cluster size for the ionizing particle is four pads while the mean cluster size for photon clusters is 1.5 pads. The larger size of particle clusters allows a good spatial precision on the particle impact point on the radiator, which is of paramount importance for the tracking precision as well as for the pattern reconstruction. The precision on the photon centroid position is less demanding as long as it is lower than errors due to chromatic aberration and geometrical effects (proximity gap and radiator thickness).

The calculated spatial resolution for the centroids

of the particle impact is better than 500 μm.
The two-track resolution has been determined by simulations to be better than 2 mm [10].
The reconstructed single photon Cherenkov angle distributions for pions are shown in fig 5.

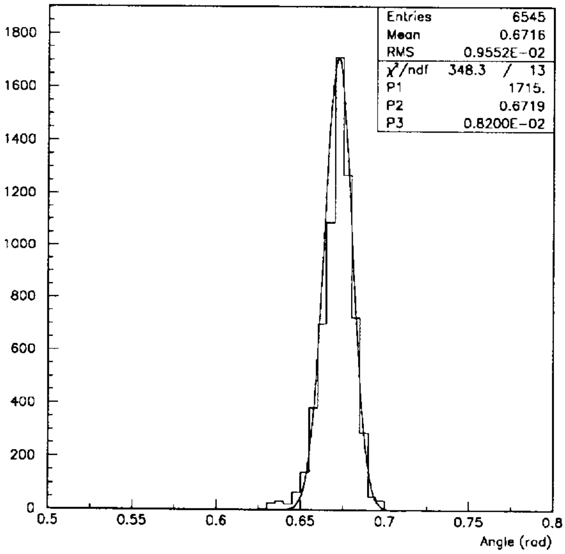

Figure 5. Reconstructed single-photon Cherenkov angle distribution for pions at normal incidence.

The most probable Cherenkov angle is $< \theta_c >=$ 671.9 mrad for pions and $< \theta_c >=$ 606.9 mrad for protons. The resolution is $\sigma = 8.2$ mrad and 10.8 for pions at 0° and 10°, respectively; while for protons $\sigma = 10.7$ and 12.2 at 0° and 10°, respectively.
The data obtained demonstrate the good particle identification potential (see § 5). Operation of the prototype over several months has been very successful and the experimental results show that detector performances did not degrade with time.

4. ENGINEERING ISSUE

Presently, the RICH system for ALICE represents the largest scale application of such a technique.
The layout is governed by the need to optimize the detector performances in terms of angle resolution and efficient pattern recognition. In fact the best localization accuracy is achieved along the sense wire so that the detector wires must be positioned perpendicular to the beam direction. Moreover, since the best angle resolution is achieved for particles with normal incidence to the radiator, it is necessary to shape the detector in a way to minimize the angular dispersion of incoming particles.
An efficient way to fulfill the above requirements is to design the RICH barrel based on modular construction with elements of the largest technically feasible area, in order to reduce the total number needed to cover the acceptance region. The RICH array is conceived as a barrel of 3.6 m radius and 7.2 m length, composed of 60 modules on a supporting structure that allows the tilting of each module independently.
The detector is placed inside the magnetic field with a segmentation of 12 modules in azimuth and 5 along the beam axis. The polar angle coverage is about 90°.
Emphasis must be put on the precise relative alignment of modules. The barrel can be moved sideways independently to give free access for installation and survey of major detector components. Fig. 6 shows details of the detector arrangement.

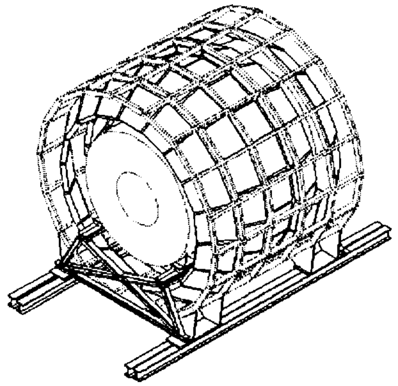

Figure 6. Perspective view of the ALICE RICH barrel with the polygonal modular structure.

The C_6F_{14} radiator vessel represents the most critical part in the detector design. The rather high freon and silica glass densities, 1.68 g/cm^3 and 2.1 g/cm^3 respectively, and the need to avoid pollution from the material in contact with the liquid radiator that would affect the transparency in the $160 \div 220$ nm band, require a careful investigation and optimization.

The liquid radiator container, which is currently under study, consists of a tray made of composite material closed by $7 \div 8$ mm thick UV transparent quartz window.

An aramide-fibre/epoxy honeycomb material has been chosen for its high mechanical strength and low thermal expansion. Fig. 7 shows a cut through the freon vessel structure.

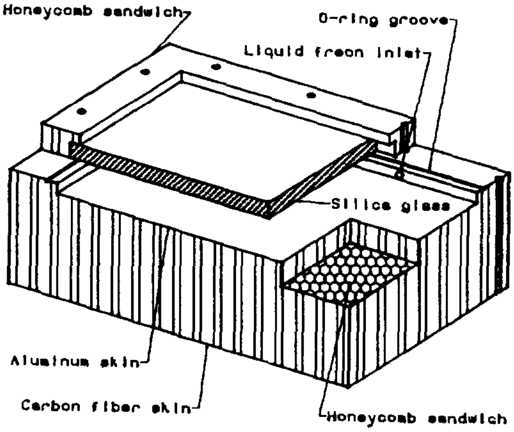

Figure 7. Cut-away view of the freon vessel structure.

Aramide honeycomb (NOMEX) has been chosen as inner layer because its thermal expansion coefficient is very small and its very low density (40 kg/m^3) makes it almost transparent to the incoming particles.

A 100 μm carbon fiber layer is used for the skin surfaces because of its high modulus of elasticity. The inner surface of the vessel is covered with 50 μm thick aluminum foil to prevent the liquid C_6F_{14} to come into contact with the carbon fiber tissue. All the elements are glued with Araldite AW106.

The liquid radiator inlet and outlet are preformed in the honeycomb volume inserting two teflon pipes that run lengthwise along the container wall on opposite vessel corners, the outlet always being at the highest location.

Given the quantum efficiency achieved so far, the radiator thickness is chosen 10 mm for an optimal Cherenkov angle resolution. The vessel exit windows consist of UV-grade fused silica plates whose thickness and size must be carefully optimized investigating the best compromise between the detector total radiation length and the freon hydrostatic pressure.

A possible solution is to segment each module in four or six independent sections with reinforcement ribs of composite material.

A reduced scale prototype is being realized to gain useful information on its mechanical and chemical stability.

5. FUTURE PLANS

A program has been developed for the simulation of the MWPC response based on experimental data acquired with the same detector using minimum ionizing particles and single photoelectrons.

The identification possibilities of the proposed RICH detector in ALICE varying the particle densities have been analyzed.

The results indicate that a satisfactory PID may be achieved for densities up to 50 particles/m^2 at the quantum efficiencies presently obtained on large photocathodes: 3 σ π/K separation at 2.1 GeV/c [11].

More precise simulation, using the full GEANT simulation of events at the position of the RICH and taking into account the secondary particles produced in the RICH itself is necessary to fully assess the pattern recognition capabilities. Nevertheless only real test of prototypes in heavy ion beams will finally demonstrate the feasibility of such approach for PID. On the side of the detector development we plan to investigate the photocathodes long term stability and to design a dedicated electronics to better exploit the poten-

tialities of this technique with the cost effectiveness of the electronic chain in mind, due to the high number of channels ($\simeq$ 16000 per m^2).
The architecture of a VLSI chip allowing fast readout amplitude analysis on the board and sparse readout capability is being developed [6]. The chip has 16 channels, with locally multiplexed digitization, via an 8 bit ADC (11 bit sensitivity) achieving full conversion in less than 4 μs. This scheme allows the detector operation at higher luminosities expected with Ca beams.

6. CONCLUSIONS

ALICE is a 4π detector with emphasis on particle identification, two dimensional information, high granularity and precise impact point localization. Due to the high track density expected, an approach based on the RICH technique with photodetectors having a true bi-dimensional readout as PID system has been proposed and investigated.
The proposed modular design should allow a simple and cost effective scheme, consisting of a classical MWPC operated at normal temperature and pressure and a liquid radiator (C_6F_{14}) in a sealed box of dimensions 1600 × 1600 × 10 mm^3.
Pattern recognition can be successfully implemented on high density events (50 tracks per m^2), since an analog pad read-out scheme provides efficient discrimination between ionizing particle and Cherenkov photoelectron impact points.
In this report we have described the construction of the prototypes and their performances during the first test with hadron beams.
Results have shown that the prototype works satisfactorily.
All components function reliably, however more studies are needed to prove that this technique is well-suited for the future implementation in ALICE.

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