THE ALICE TIME PROJECTION CHAMBER

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The ALICE TPC is a conventional TPC based on experience with previous TPCs used in heavy ion beams. However, the unpreceeded high particle multiplicities at LHC Pb+Pb collision has led in detail to many innovations in its design and construction.

1 Introduction

It seems that roughly every 5 years, forced by the augmented energy of heavy ions beams, a major Time Projection Chamber (TPC), setting new standards, comes into operation. This is documented in Table 1, which contains a comparison of design parameters of the NA49 [2] TPC at the SPS ($\sqrt{s} = 17$ GeV) , the STAR [3] TPC at RHIC ($\sqrt{s} = 200$ GeV) and the projected ALICE [1] TPC at LHC ($\sqrt{s} = 5500$ GeV) . From this table it can be seen that the ALICE TPC exceeds its predecessors in basically all aspects. This is forced by the expected high charged particles multiplicities of up to 8000 per unit rapidity, which is a factor of 5-10 higher than at RHIC. These unpreceeded high multiplicities are a major challenge both to the construction and the operation of the ALICE TPC. In this contribution we will show how the design of the ALICE TPC readout chambers, being basically conservative and based on the NA49 and STAR TPC's, are optimized to be able to handle the high particle load.

2 TPC Layout

The overall acceptance of the TPC is $0.9 < \eta < 0.9$. To cover this acceptance the TPC is of cylindrical design with an inner radius of about 80 cm, an outer radius of about 250 cm, and an overall length in the beam direction of 500 cm schematic layout of the ALICE TPC is shown in Fig. 1

The TPC field cage provides a highly uniform electrostatic field in a cylindrical high-purity gas volume to transport primary charges over long distances (2.5 m) towards the readout end-plates. The field configurations is defined by a high-voltage (up to 100 kV) electrode located at the axial centre of the cylinder. As drift gas a mixture of $NeCO_2$, as is currently used in the NA49

Table 1. Comparison of the NA49, the Star and the planned ALICE TPC

parameter	NA49 SPS fixed target 1995	STAR RHIC collider 2000	ALICE LHC collider 2005
No. of channels	182k	140k	570k
gas	$NeCO_2$ (90-10) (vertex) $ArCH_4CO_2$ (90-5-5) (main)	$ArCH_4$ (90-10)	$NeCO_2$ (90-10)
gas gain	2×10^4 (vertex) 5×10^3 (main)	3.6×10^3 (inner) 1.3×10^3 (outer)	2×10^4
field cage	$W = 390\,cm$ $L = 390\,cm$ $H = 180\,cm$ (main) $V = 27\,m^3$	$L = 420\,cm$ $R = 210\,cm$ $V = 50\,m^3$	$L = 500\,cm$ $R = 250\,cm$ $V = 88\,m^3$
drift voltage	13.4/19.5 kV 200/175 V/cm	31 kV 150 V/cm	100 kV 400 V/cm
minimal pad size	$3.5 \times 16\,mm^2 = 56.0\,mm^2$	$3.5 \times 11.5\,mm^2 = 32.8\,mm^2$	$4 \times 7.5\,mm^2 = 30.0\,mm^2$
Luminosity [$cm^{-2}\ s^{-1}$]	$\approx 10^{25}$	2×10^{25}	$0.5 - 1 \times 10^{27}$

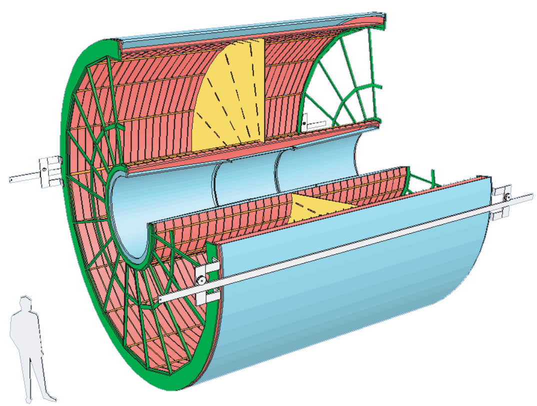

Figure 1. The ALICE TPC showing the central electrode, the field cage,and the end plates

(90%/10%) and CERES (80%/20%) experiments at the SPS, is chosen.

The readout chambers are basically conventional multiwire proportional chambers with cathode pad readout as used in many TPCs before. In detail, their construction, however, requires to overcome significant technical challenges as discussed below. The overall area to be instrumented is 32.5 m^2. The azimuthal segmentation of the readout plane follows that of the subsequent ALICE detectors, leading to 18 trapezoidal sectors, each covering 20 degrees in azimuth. The radial decrease of the track density leads to changing the requirements for the readout chamber design as a function of radius. Consequently, there will be two different types of readout chambers, the inner and outer chambers. Each outer chamber is further subdivided into two sections with different pad sizes, leading to a triple radial segmentation of the readout plane, with 557568 readout pads in total.

3 TPC challenges

The most obvious negative consequence of a high track density is the corresponding high occupancy of the readout channels. In the following we show that a simple increase in the readout granularity would be of limited help if not accompanied by a number of other measures.

3.1 Pad Size

A sufficient number of pads per charge cluster in terms of position resolution is 2-3. Thus an increase in the number of pads is sensible only if the induced charge from the (point-like) avalanche spread over no more the 2-3 pads. This can be achieved by reducing the distance between anode wire and pad plane. However, at a certain point the distance HV-GND gets critical. There are also other reasons why it makes little sense to decrease the pad size beyond a certain limit: the width of the charge cloud after 250 cm of drift is of the order of mm depending on the choice of the drift gas and voltage. I.e., any reduction of the pad beyond a certain size result in an oversampling of the track without any gain of information.

3.2 Time direction

The situation in time direction is similar: one could think of increasing the frequency of the time sampling, however, as diffusion occurs also in longitudinal direction this would result as well in an oversampling of the pulse. The choice of a shorter shaping time is limited by the fact that below 150-200 ns shaping time the signal/noise ratio becomes critical.

3.3 Optimization

From of the above considerations one is left with the following measures to optimize for best performance in a high density environment:

1) minimization of the diffusion, i.e. choice of a "cold" gas ($NeCO_2$, 90-10) and a high drift field (400 V/cm).
2) choice of a minimal pad area ($A = 30\,mm^2$) which still gives a reasonable signal; this implies
   a) the proper choice of the anode-pad distance (2 mm) to have the desired pad response function (PRF) and
   b) a high gain, because the faint signal from the small pad needs high amplification. This can be done both by gas and electronic amplification, however, to optimize the signal/noise ratio (S/N¿20) a high gas gain (2×10^4) and low electronic gain (8 mV/fC) is preferable. This choice should lead to a number of equivalent noise electrons below 1000.
3) For a given pad area the proper choice of the aspect ratio ($4 \times 7.5\,mm^2$) will further decrease the number pads occupied by a cluster. The principal reason for this is that the tracks are oriented in a preferred direction, i.e., radially.

4 Long Term Stability

In principle, the long term behavior of gaseous detectors is not testable, as the only halfways realistic test would require an exposure of the chambers at rates and durations comparable to the experimental conditions. For an expected running time of several years this is not possible for obvious reasons. One resorts therefore to short time tests with high intensity exposure to accumulate at least as much charge per unit length anode wire (where the amplification takes place) as in the experiment. In our case we exposed an anode area of about $1\,cm^2$ with a strong ^{55}Fe source for about 2000 hrs. The resulting anode current of 25 nA was monitored and found to be stable for the whole measurement period. The corresponding charge/unit length of the anode wire is calculated to be 60 mC. This has to be compared with an estimated accumulated charge of 1.1 mC per cm wire and ALICE year (1 ALICE year $= 10^6$ s).

5 Space Charge

There are two distinct sources of space charge in the TPC drift volume:

a) positive ions from primary ionization by a charged particle, and

b) positive ion leaking back from the amplification zone into the drift space.

Owing to the much smaller mobility of the ions as compared to the electrons a quasi-stationary positive charge will distort the drift field significantly. While a) is unavoidable and leads to distortions of the tracks of up to 0.5 mm for $NeCO_2$ as drift gas, b) could cause much larger distortions if the ion feedback is not sufficiently blocked by the gate. This is particularly dangerous at the high amplification of 2×10^4 in the present ROC's. First tests on prototype chambers showed indeed that ions leak back into the drift space even with gate closed. Two-dimensional calculations of the field configuration revealed the ion-leaks were located at the radial borders of the chamber, i.e., at the discontinuities of the otherwise regular gating grid structure. To circumvent the problem electrostatic "shims" were introduced to optimize the field geometry. The gating inefficiency was assessed by measuring the drift electrode current as a function of the gating offset voltage. At high gating offset voltage the measurement was limited by the sensitivity of the ammeter of ≈ 10 pA. An upper limit of 0.5×10^{-4} for the gating inefficiency was deduced. This, together with an amplification of 2×10^4 results in less than 20 ions/cm track coming from the amplification and is of the same order of magnitude as the ions from primary ionization.

6 High Rate

So far, previous TPC's have not yet been operated both at high gain and at high track density. It is thus questionable whether under those conditions the chamber can be operated stably at all. A first test was performed at GSI employing a TPC readout chamber formerly used in the NA35 experiment. The chamber was irradiated with secondaries from a ^{12}C beam hitting a thick target. By varying the target thickness and/or the beam intensity track densities from overlapping events similar LHC Pb+Pb collisions could be reached. It turned out that the chamber could sustain several tens of μA anode current without signs of instability.

7 Simulation Results

Even after the optimization steps described above one is left with an occupancy exceeding 50% at the innermost radius for an assumed multiplicity of dN/dy = 8300 plus background ($\approx$ 30%). Previous experience from the NA49 experiment demonstrated that the tracking efficiency is reduced dramatically for occupancies above 20%. The situation, however, is different for a fixed target experiment as NA49 and an experiment in collider geometry where the track density decreases quadratically with the radius. The ALICE tracking group has adopted novel tracking algorithms which are based on local methods, i.e., the tracking starts at the outer parts of the TPC and proceeds to smaller radii. No global track model is needed in this case. Employing Kalman filtering leads to an acceptable efficiency, i.e., of 88% of all recognizable track are found with only 2% fake tracks. At present, the momentum resolution is evaluated for the TPC only, i.e., the connection to the other tracking detectors - ITS at small radii and TRD at large radii - is not included in the tracking algorithms. The momentum resolution Δp/p at $1Gev/c$ is found to be 2.4%, which is close to the expectation of the Technical Design Report [1]. For high momentum tracks with $p > 5GeV/c$ the resolution is at present $> 14\%$, clearly not good enough for high pt physics. However, with the additional information from the other tracking detectors is it expected that the resolution for high momentum track is well below 5% [4]. The simulations yield a dE/dx resolution of 8-9% in the high track environment, while the resolution of a single, isolated track is $\approx 5\%$, which is close to the optimum. Thus the particle identification properties of the TPC are as good as they can possibly be under the given circumstances.

8 Summary

We have shown that the measures taken to optimize the TPC readout chambers will allow to operate the ALICE TPC even under the highest anticipated particle load. The simulated performance indicates that momentum and dE/dx will be sufficient the reach the physics goals as formulated in [1].

References

1. ALICE Collaboration, Technical Design Report, CERN/LHCC 2000-001
2. S. Afanasev et al., *The NA49 Large Acceptance Hadron Detector*, Nucl.Instrum.Meth. A430:210-244, 1999
3. H. Wieman, *Recent Developments in TPC Technology and the STAR TPC at RHIC*, this conference
4. ALICE Collaboration, Technical Design Report, CERN/LHCC 2001-021, p. 156