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Gaseous tracking at linear hadron collider: Pushing the limits

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Abstract. Gaseous detectors have been pushed to the limits when required to operate in the ferocious and aggressive rate environment of the new generation of HEP experiments. A great effort has resulted in the optimization and construction of large systems of gas detectors, some operational and some due for installation. In this paper some examples are presented along with the impediments that have been overcome; some open issues will be highlighted.

1. Introduction

Comparing a typical event from LEP [1] and a simulated one from LHC [2], one realizes the terrifying complexity demanded from gaseous detectors of this generation of experiments. At LEP, the environment was clean, gas detectors were ideal and have indeed performed with great success [3]. At an LHC bunch crossing of 25 ns, and luminosity of 1034 $cm^2 s^1$ *pp* collisions, about 23 overlapping minimum bias events, 1900 charged and 1600 neutral particles per bunch crossing [4]; see figures 1 for example. For this multitude of particles the ideal detector should provide a coverage of full solid angle with no cracks and possess fine segmentation. It has to track and identify all particles, measure their mass and charge and provide a measurement of momentum and energy. In addition it must be fast with a minimum dead time. A large HEP detector has a typical onion-like structure of detection layers in a magnetic field. No single detector can determine the identity and measure energies and momenta of all particles. Each subsequent layer tracks, identifies and measures or re-measures the energy of the particles unmeasured by the previous layer. The size of a detector at LHC is almost that of a 5 to 6 storey building; hence the surface area to be covered by the detectors is huge; see figure 2 for example. Given the practical limitations of space and budget, this is no easy task.

The very high rate of interaction implies that gas detector operation without prohibitively large currents is possible only beyond 50–80 cm or further from the beam [5].

Muon detection at LHC is fundamental in marking the discovery potential of all the experiments, fulfilling three basic tasks: identification, trigger and momentum measurement. The muon spectrometers of ATLAS, CMS, ALICE and LHCb experiments comprise large arrays of several thousand m^2 of active detector surface to cover a large rapidity interval. The challenge is the construction of sensitive detectors, operational in this hostile environment, and yet accurate and efficient. In this paper, for simplicity, only a few examples have been chosen from the multitude of gaseous detectors developed for LHC; the ATLAS

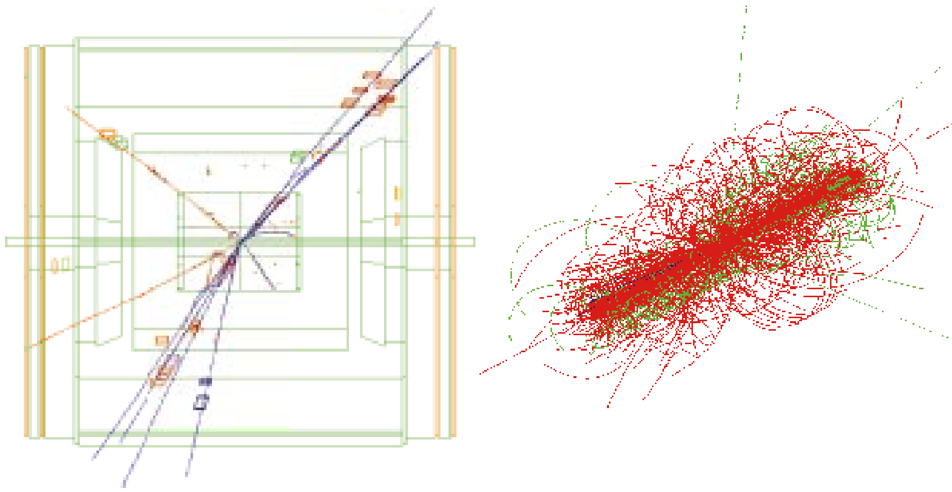

Figure 1. (**a**) A typical event at LEP. (**b**) A typical event at LHC.

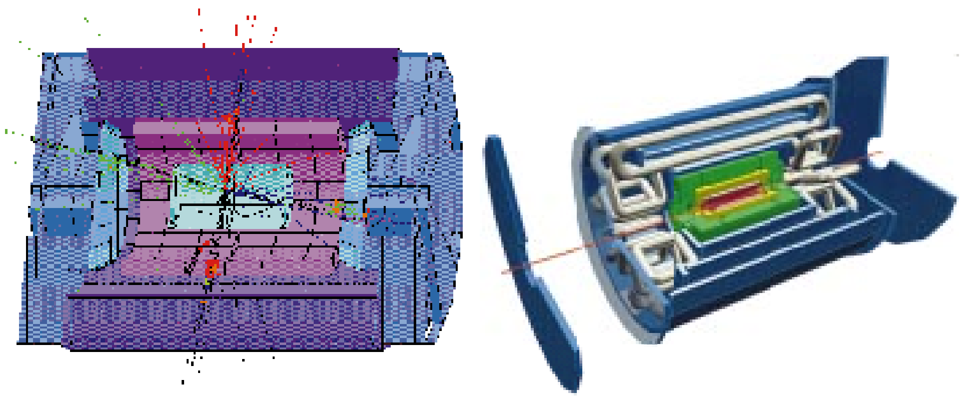

Figure 2. (**a**) Typical detector at LEP; length 10 m. (**b**) Typical detector at LHC, length 40 m.

'simple' muon drift tubes (MDTs) and the transition radiation tracker (TRT) will be described. They will then be compared to the CMS muon system, namely drift tubes (DTs) and cathode strip chambers (CSCs). Resistive plate chambers (RPCs) will be discussed and their open issues addressed. Finally, some comments will be made on the long term performance on aging of gaseous detectors.

2. ATLAS muon system

The ATLAS muon system (see figure 3) consists of specialized drift tubes (a schematic is shown in figure 4) operating in a magnetic field. Details may be found in ref. [6]. A muon ionizes the drift gas in the sensitive volume of the tube producing clusters of electrons

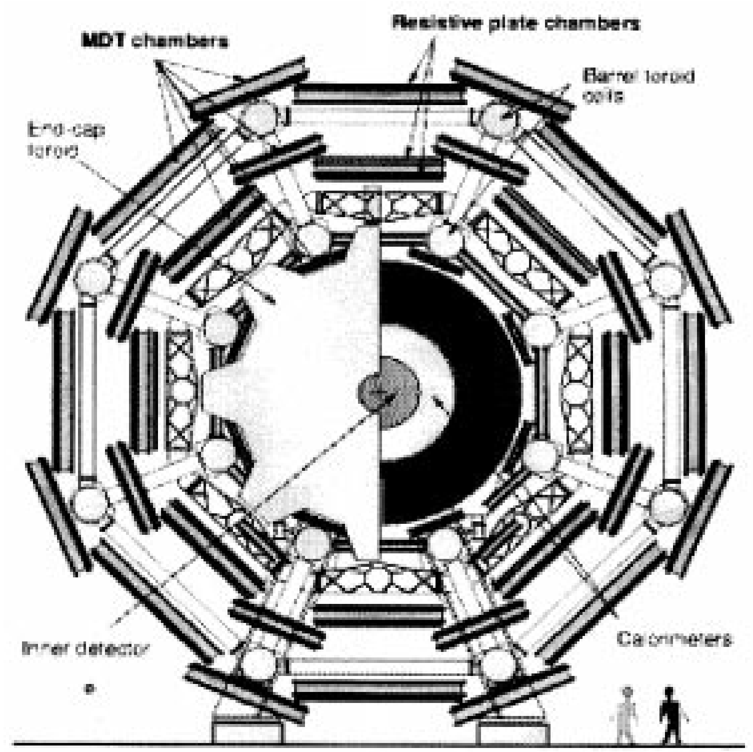

Figure 3. Muon stations in the ATLAS experiment. An MDT chamber is an arrangement of several layers of drift tubes.

and ions along its track. The electrons drift towards the wire approaching in an electric field increasing as $1/r$, r being the radius of the tube, and then produce an avalanche of electrons. The drifting positive ions produce the major component of the signal.

With a drift time measurement and a well-calibrated space-time relationship, these tubes have been tested to be perfectly conforming to the desired characteristics of spatial resolutions, track reconstruction efficiencies, as well as system stability. A fast and inorganic drift gas is used to avoid high occupancy and aging respectively.

The MDTs have been thoroughly studied and investigated both by simulations and experiment, effects limiting the resolution have been corroborated [7]. Figure 6 shows a finished MDT module at MPI, Germany.

3. The ATLAS TRT

The TRT detector for ATLAS provides continuous tracking over the full rapidity range inside the inner detector [8] providing electron identification from transition radiation (TR). It is a complex detector system with half a million straw proportional tubes arranged in the

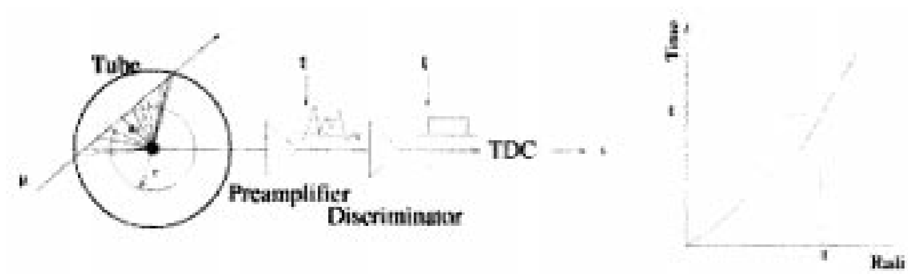

Figure 4. Principle of a proportional drift tube.

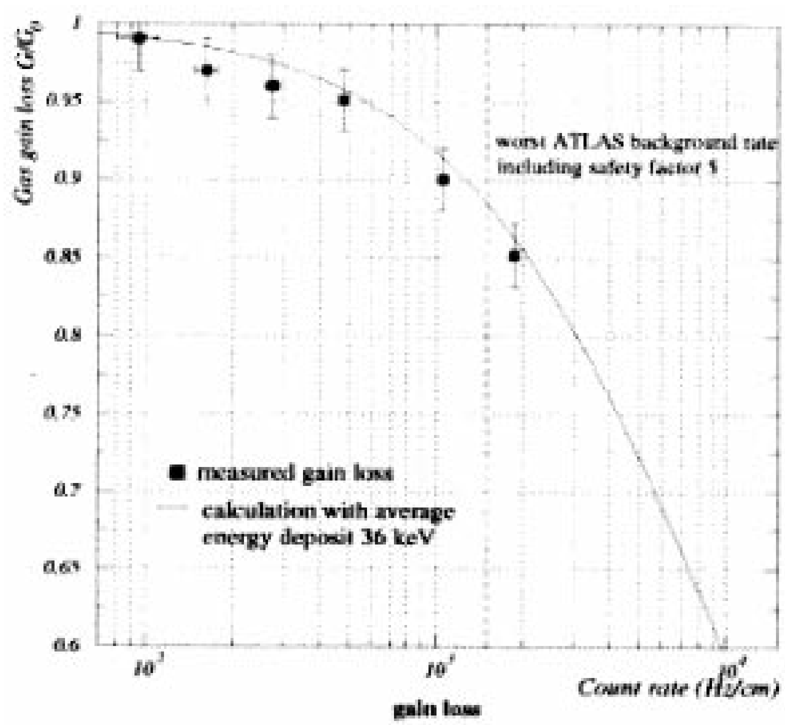

Figure 5. Space charge effects in an ATLAS MDT drift tube.

barrel and end cap as shown in figure 7. Despite being a 'simple' proportional detector the magnitude of the assembly is a big challenge. The straws need to be light so as not to absorb the TR photons; the global deformation of the structure should not deform the straws. The anode wire inside the straws should be placed very accurately. Again, an inorganic gas mixture of Xe, CO_2, CF_4 and gain 10^4 is used to ensure good efficiency and drift time measurement accuracy. The aging requirement translates in no gain degradation up to 1 C/cm of accumulated charge on the wire. Gain uniformity along the straw is also imperative and elaborate studies have been done to ensure this feature [9].

Figure 6. A finished MDT module at MPI, Germany.

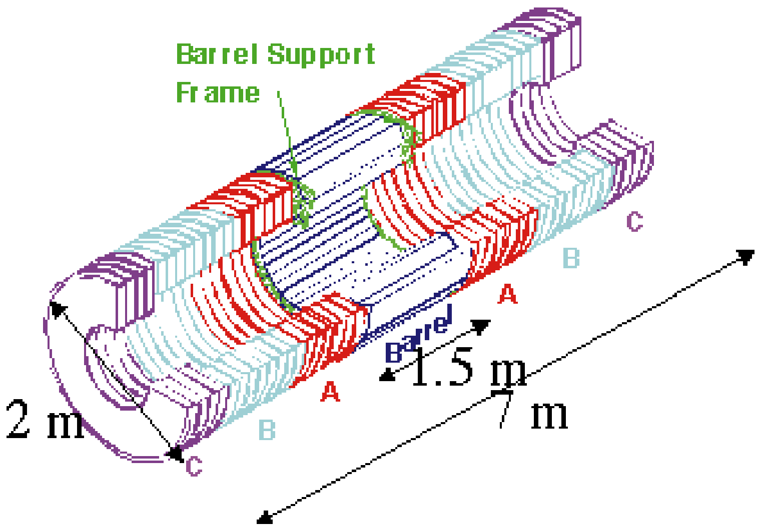

Figure 7. Schematic of the ATLAS TRT detector.

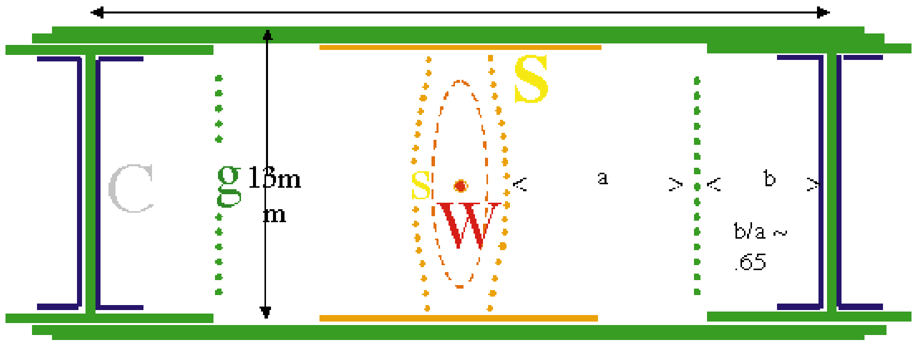

Figure 8. Schematic of the drift tubes of CMS. Continuous lines represent electrodes, dotted lines represent equipotential surfaces.

4. CMS muons

CMS employs different technologies to provide the requisite position resolution of 100 cm. In the CMS barrel a system of drift tubes (DTs) is used while in the end cap cathode strip chambers (CSCs) are used due to the excellent performance in a non-uniform magnetic field as will be seen in the next section. In both the barrel and the end cap, a system of resistive plate chambers (RPCs) will be operational due to the excellent timing and reasonable space resolution properties. In the following a brief summary of these chambers is given, the RPCs will be discussed in the following section on time of flight systems.

4.1 *Drift tubes*

Once again a simple detector with sense wire sandwiched between grounded plates. With the help of sophisticated simulation programs [10], the positions of equipotentials could be determined such that gain, saturated drift velocity, and space-time relationship are all pre-determined. Experiments have corroborated the simulation results. Figure 8 shows the drift cell and figure 9 shows the measurements of drift velocity and efficiency in a magnetic field [11]. Figure 10 shows the construction of a large module at Seattle [12].

4.2 *Cathode strip chambers (CSCs)*

In another concept of building large area with simple detectors, the CSCs employ wide gas gaps (1 cm) which relaxes the planarity requirements. Thick wires (50 m) at reduced voltages interspersed at 3.2 mm relax the wire placement tolerances. The planes are segmented to permit individual manipulations. The simple design is suitable for mass production (see figure 11). The caveat is that the spatial resolution is not uniform as shown in figure 12. Elaborate and long term aging tests [13] have been performed with the final chambers and all parameters have been demonstrated to be within specifications albeit the radiation rate for these tests was 100 times that of LHC. An accelerated test of this kind may not be the real benchmark since the aging rate is a function of the current density at the anode [14],

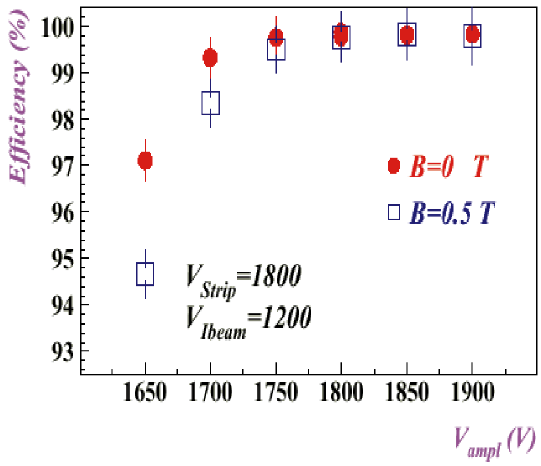

Figure 9. Chamber performance in magnetic field.

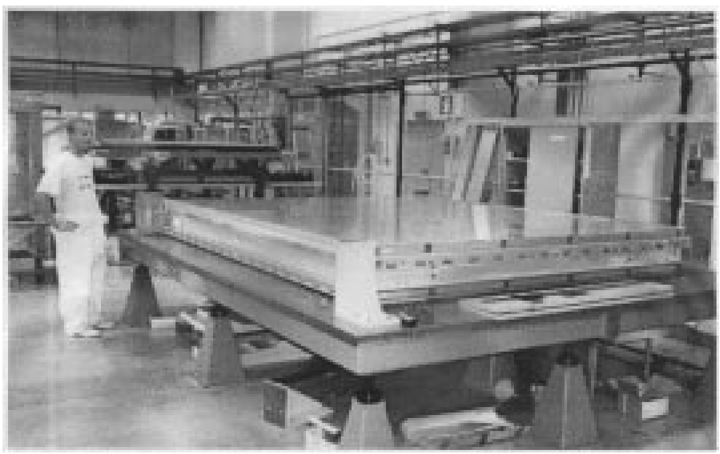

Figure 10. CSC production in Florida, USA.

the higher it is the more optimistic is the result. In figure 13 is shown the construction of a large CSC module [15] in Florida.

4.3 *Resistive plate chambers (RPCs)*

A resistive plate chamber (RPC) is an ideal detector for identifying particles with a time of flight (TOF) system which is imperative for identifying the huge number of particles produced, for example in heavy-ion collisions at high energy. The ALICE detector for LHC has an array of specialized RPCs for its TOF system. An RPC is a simple parallel

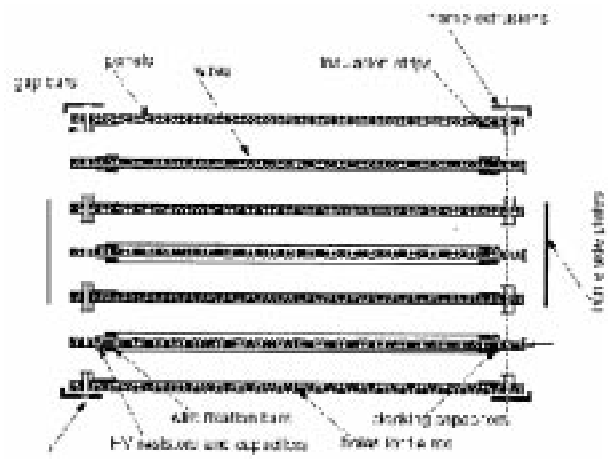

Figure 11. Cathode strip chambers.

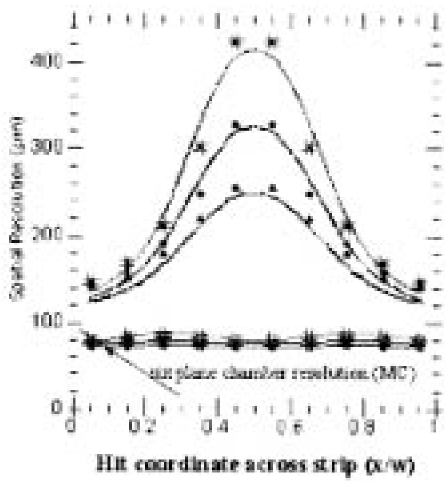

Figure 12. Resolution along readout strips for CSCs.

plate detector as shown in figure 14; delimiting the sensitive gas volume with two resistive plates. The outer surface of these plates is covered by a medium resistivity layer like graphite which is transparent to the induced signals; a high resistivity protection layer supports the readout strips (see figure 14). It can be used both in proportional or streamer mode, the latter can be suppressed by using small quantities of SF_6 in the gas mixture. The rate capability of these devices varies between a few 100 Hz/cm^2 to a few kHz/cm^2, in the streamer and avalanche mode of operation respectively. Specialized RPCs (microRPC) can attain high gains ($5{\cdot}10^4$) and high rates (MHz/cm^2) [16]. The time resolution of these devices depends on the gap and ranges from tens of ps for Pestov-type of RPCs [17] to a few ns typically, see for e.g. ref. [18]. Another device, the multigap RPC, developed at CERN has been demonstrated to have excellent space and time resolution [19]. The BaBar

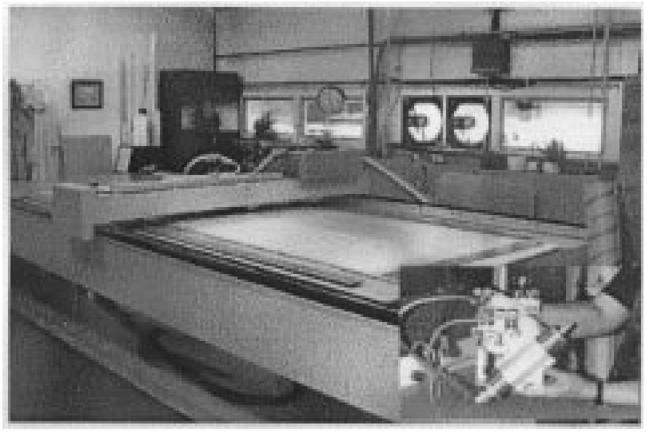

Figure 13. The construction of a large CSC module in Florida (see text for reference).

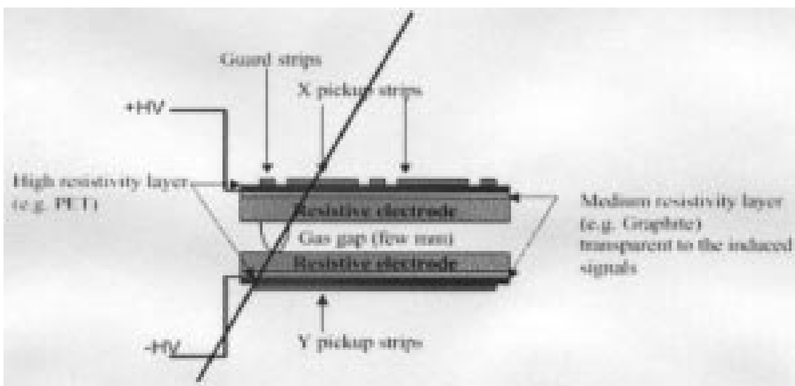

Figure 14. Schematic of a resistive plate chamber.

Figure 15. (**a**) Rough bakelite surface. (**b**) Bakelite surface with 30/70 linseed oil/pentane coating. (**c**) Bakelite surface with 70/30 linseed oil/pentane coating.

experiment at SLAC also employs a large surface of RPCs. Operating in streamer mode, these RPCs were essentially that of the L3 generation, with mechanical upgrades and a non-flammable gas mixture. It may be recalled that the bakelite RPC plates need a coating of linseed oil to smooth for the surface imperfections and get the desired resistivity (ω/cm) as evinced from figure 15. This treatment is not necessary for the BELLE RPC chambers as they are made of glass plates.

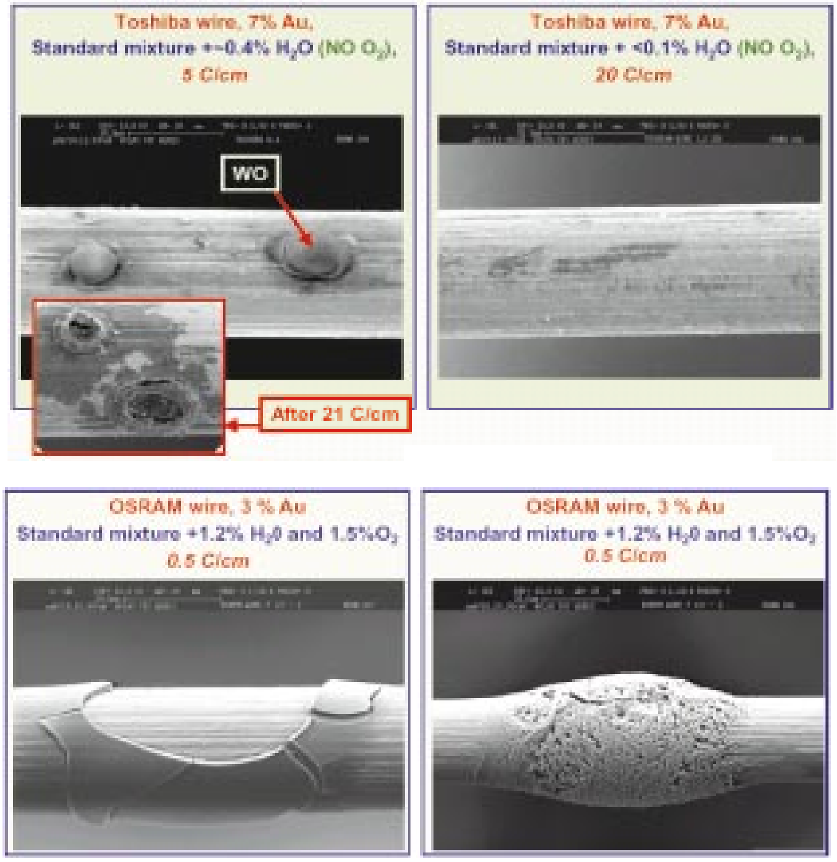

Figure 16. Examples of aged wires from the ATLAS TRT.

5. Aging

As discussed earlier, aging represents a serious concern for the forthcoming generation of collider experiments. Consequences of aging are worsening of the energy resolution, loss of gain, large currents, self-sustained discharges and eventually sparking and breakdown in the extreme case. A decrease of gas gain may be due to deposits on the anodes or subsequent degradation of the anode, as shown in figure 17 [20]. An attractive solution sought by several groups is the addition of CF_4 to the operational gas mixture. Very small quantities of CF_4 render very high electron drift velocity, low diffusion and higher primary ionization. On the negative side, it is known to be an etchant and is electronegative, thus resulting in lower resolution due to losses of electrons by attachment.

The muon chambers are also a concern for aging in the LHC era. RPCs at BaBar manifest high dark currents and reduction of detection efficiency possibly due to the formation of oil droplets under the influence of high temperature and high currents. New procedures for production are being developed with better bakelite surface quality and thinner coats of linseed oil as shown in figure 15.

6. Conclusions

In this paper some issues of tracking at high luminosity colliders with gaseous detectors have been reviewed. A large variety of chambers have evolved in the last decade to cope with the unprecedented rates and hostile environment expected at LHC. Huge progress has been made in understanding the long term operation of these devices and hold a promise for track detection with gaseous detectors at LHC.

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