Acceptance Tests and Criteria of the ATLAS Transition Radiation Tracker

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***Abstract*—The Transition Radiation Tracker (TRT) sits at the outermost part of the ATLAS Inner Detector, encasing the Pixel Detector and the Semi-Conductor Tracker (SCT). The TRT combines charged particle track reconstruction with electron identification capability. This is achieved by layers of xenonfilled straw tubes with periodic radiator foils or fibers providing TR photon emission. The design and choice of materials have been optimized to cope with the harsh operating conditions at the LHC, which are expected to lead to an accumulated radiation dose of 10 Mrad and a neutron fluence of up to $2 \cdot 10^{14}$ n/cm^2 after ten years of operation. The TRT comprises a barrel containing 52 000 axial straws and two end-cap parts with 320 000 radial straws. The total of 420 000 electronic channels (two channels per barrel straw) allows continuous tracking with many projective measurements (more than 30 straw hits per track). The assembly of the barrel modules in the US has recently been completed, while the end-cap wheel construction in Russia has reached the 50% mark. After testing at the production sites and shipment to CERN, all modules and wheels undergo a series of quality and conformity measurements. These acceptance tests survey dimensions, wire tension, gas-tightness, high-voltage stability and gas-gain uniformity along each individual straw. This paper gives details on the acceptance criteria and measurement methods. An overview of the most important results obtained to-date is also given.**

***Index Terms*—Acceptance criteria, gas detectors, quality control, straw tubes, tracking, transition radiation.**

I. Introduction

THE TRT, which combines tracking and particle identification, is a large-scale gaseous detector which will be operated within the ATLAS experiment as part of the Inner Detector [1]. It will have to cope with the harsh radiation environment of the LHC. A total of 96 barrel modules and 112 end-cap wheels, containing a total of ~370 000 straws have to pass a series of stringent acceptance tests before the integration with the front-end electronics. They have been designed to guarantee reliable operation over 10 years at the LHC. The TRT functional units have to adhere to strict quality assurance specifications, based on which acceptance tests have been defined and conducted. While strict envelopes are required for smooth assembly and integration, local acceptance criteria such as wire eccentricity have considerable influence on the operational behavior of each single straw. This behavior has to be monitored closely since it might affect the functionality of the neighbor straws, connected e.g., to the same high-voltage component or front-end chip.

The majority of the acceptance tests are conducted using the commonly used and easily available Ar-CO_2 70/30 gas mixture. It has been demonstrated that it represents a valid alternative to the costly Xe-based operating gas (Xe-CO_2-O_2 70/27/3), to perform all tests relevant to the TRT performance. Sufficient safety margins are guaranteed through the rather stringent acceptance criteria, in order to compensate for the differences between the test and future operating mixture.

Tests are conducted at the assembly sites, followed by a full set of tests at CERN, before wheels and modules enter the stage of final assembly equipped with the front-end electronics. Test results are recorded in databases and permanently fed back to the institutes engaged in the production.

It is clear that a complete and detailed description of all tests would go beyond the scope of this paper, hence only a rather concise and abstract description is given here. Acceptance tests and criteria for the TRT barrel modules and end-cap wheels are described in [2] and [3].

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II. Acceptance Tests and Criteria

A. Dimensional Checks

Considering the tight geometrical tolerances for the TRT, which is placed in between the SCT and Liquid Argon

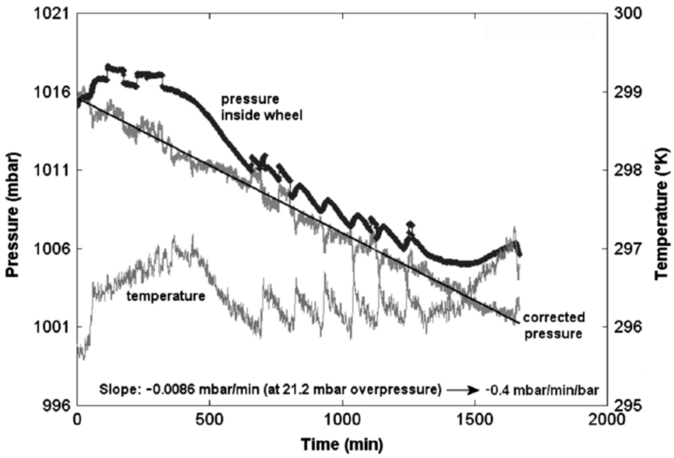

Fig. 1. Evaluation of the leak rate by measuring the pressure drop at approximately 20 mbar overpressure (example for an end-cap wheel).

calorimeter, it is extremely important to comply with the given dimensional envelopes. The required precision for production and assembly of the TRT (∅2.2 m, 6.8 m length) is of the order of 0.1 mm. All critical dimensions of the end-cap wheels and barrel modules are checked and compared to the drawings' specifications. They include, for the end-cap wheels, inner and outer radii and thickness, and, for the barrel modules, length, flatness and torsion.

B. Active Gas Leak Test

In the active gas leak test, assembled barrel modules as well as 4-plane or 8-plane end-cap wheels are filled with 20 mbar over-pressured argon. The leak rate is evaluated by measuring the pressure drop in the closed detector gas volume over a sufficiently long period (12–16 h). The maximum acceptable leak rate of 1 mbar/min/bar is motivated by the high price of xenon gas. However a leak rate of order 0.1 mbar/min/bar remains the aim and is in the majority of cases achieved (see Fig. 1 for one example of such a measurement).

C. High-Voltage Tests

High-voltage stability tests are carried out already at the production sites to detect leakage currents or shorts, mainly through the outer barrel and wheel structures, since high-voltage is applied to the straw tubes. The crucial tests at CERN are, for both barrel and end-cap wheels, long-term high-voltage tests in active gas at a higher voltage (1550 V) than the nominal one (corresponding to 2–4 times the nominal gas gain). Currents and numbers of trips are recorded over two and four weeks for end-cap wheels and barrel modules respectively. Channels with trips over the last ten days (barrel: three weeks) are subject to review and possible disconnection. The requirements for the barrel wires are more stringent because they have been handled before stringing for assembly of a glass wire joint at the middle of the wire, and hence the stringing process has induced more problems for the barrel modules than for the end-cap wheels.

Straw tubes are checked for dark anode currents, generally caused by dust particles on the wire ("hot wires"). The acceptable leakage current should be below 1 nA/wire. Experience has shown that high-voltage trips most often disappear after an initial test period, indicating some kind of "cleaning process" in the straw tubes. In more persistent cases, a reverse voltage treatment showed some measure of success. It should be mentioned that elevated levels of humidity in the laboratory sometimes cause high shell-to-ground leakage currents, which will be absent in the controlled dry environment of the running experiment.

D. Wire-Tension Measurements

An enhancement of the electric field in the straw significantly reduces the margin to the breakdown point. Therefore control of wire tension is necessary to avoid instabilities from wires suffering gravitational and electrostatic sag. Special attention is paid to it since all wires in the TRT are pinned (barrel) or crimped (end-cap), clean and technically feasible options. Practically, tension is derived from the change of capacitance that an oscillating wire causes in a straw tube under voltage, when excited (mechanically or acoustically) with its eigenfrequency. An upper limit on the wire tension assures sufficient distance from the point of rupture. Whereas the design of the barrel modules allows wire restringing, the end-cap wheels lack this option, a fact that demands more stringent limits during production (55–80 g). Large changes in tension are of concern, posing a threat to a full high-voltage group (eight straws in case of the end-cap wheels), if a single wire is slipping into the instability regime. Barrel straws are accepted, if their wire tension is measured to be within 47–100 g, and furthermore exhibit no subsequent loss of tension bigger than 8 g. For the end-cap wheels, all straws with less than 40 g of tension or a tension loss greater than 15 g (barrel: 5 g) must be disconnected. For the barrel straws with the electrically split wires held together by a glass wire joint, an additional acceptance criterion is set, requiring a back-to-front tension difference of 8 g at most.

While material fatigue (creep) of the tungsten wires can be excluded, incompletely inserted crimp pins could lead to significant tension loss after relaxation (0.3 mm relaxation correspond to a loss of 15 g). Fig. 2 shows the results of the wire-tension measurement in the case of a barrel module. Specific long-term studies of the evolution of wire tension with time have shown no tendency toward global loss of tension in any module or wheel. Cases of large change of tension are extremely rare ($<10^{-4}$) for $\sim$120 000 wires measured to-date.

E. Gas-Gain Uniformity Along Straws

Uniform gas gain along the straw tube is important for safety reasons and optimal performance. The foreseen working point lies at a gas gain of 25 000 with an upper limit of 40 000, before space-charge effects and streamers (of self-quenching nature) deteriorate performance and eventually jeopardize operation. Eccentric wires (technically, these correspond to bent straw tubes) distort the radial symmetry of the electric field in the straw, which results in an overall increase in gain and amplitude variations. The safety margin to the point of high-voltage breakdown is significantly decreased (Fig. 3), such that straws with wire offsets larger than 400 μm have to be disconnected from high-voltage. The technical difficulty to directly determine wire positions in 370 000 straws demands an indirect way to assess eccentricity or other geometric deformations of the straw that

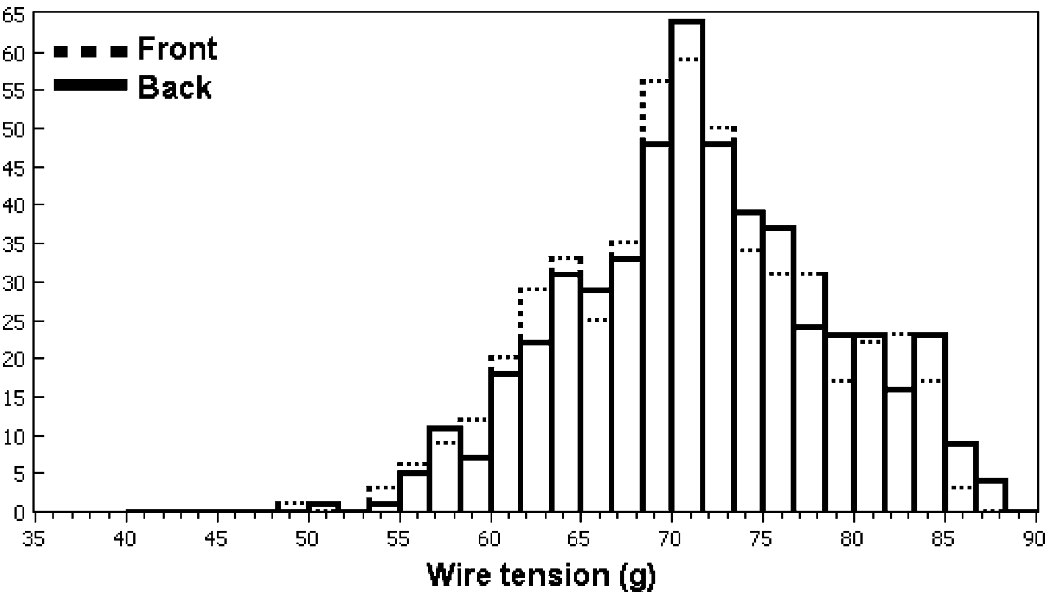

Fig. 2. Tension distribution in a barrel module.

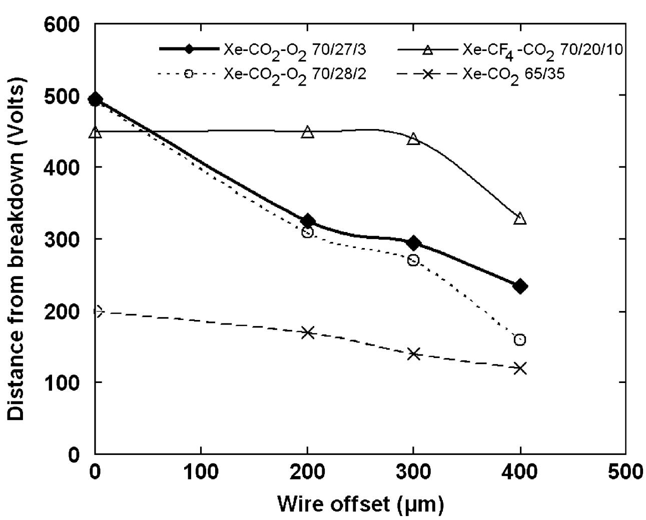

Fig. 3. Safety margin to the point of high-voltage breakdown in straws with different wire offsets and for various gas mixtures.

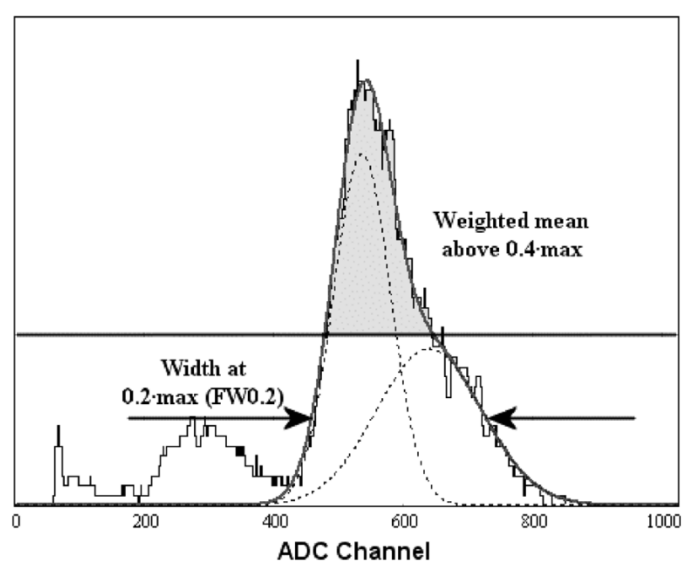

Fig. 4. Fit of a distorted ^{55}Fe spectrum. Description parameters (mean, width) are illustrated.

compromise operation. This is done by recording X-ray spectra at different positions (barrel: 2×25 points; end-cap: six points) along the wire and examining their behavior in terms of amplitude and width. The barrel gain mapping is done with 12 keV X-rays from bromine X-ray fluorescence (XRF) in order to penetrate the carbon fiber shell and efficiently reach the innermost straws. For the end-cap 4-plane wheels, it is sufficient to use 5.9 keV X-rays from ^{55}Fe. With the help of calibration curves, relating wire eccentricity to both change in gas gain and deterioration of peak width, one can extract straws with nonconforming behavior. In the offline analysis all conspicuous straws are flagged automatically for visual review and are then manually fit with a Gaussian (end-cap: double-Gaussian) function to obtain peak position and resolution. For improved sensitivity, the peak position in the end-cap straws is defined as the weighted mean of the histogram bins above 40% peak height while the resolution is taken as the full width at 20% peak height ($FW_{0.2}$) as illustrated in Fig. 4. In a similar fashion, the bromine peak resolution is defined as the partial width S on the right side of the peak mean A at 20% peak height for the barrel modules.

The calibration curves for these measurements have been determined in experiments where a controlled deformation is applied to reference straw tubes in order to understand the response to ^{55}Fe X-rays and the correlation of gas gain (Fig. 5) and energy resolution (Fig. 6) with wire eccentricity.

Additionally, the shape of the gas gain and the resolution profile provide an indication of the nature of various anomalies, which have been observed. Various examples of such profiles along the straw are shown in Fig. 7.

After applying safety factors accounting for measurement uncertainties, it was decided that straws with amplitude variations greater than 9% in the end-cap straws and 8% in the barrel straws are subject to critical review and possibly disconnection.

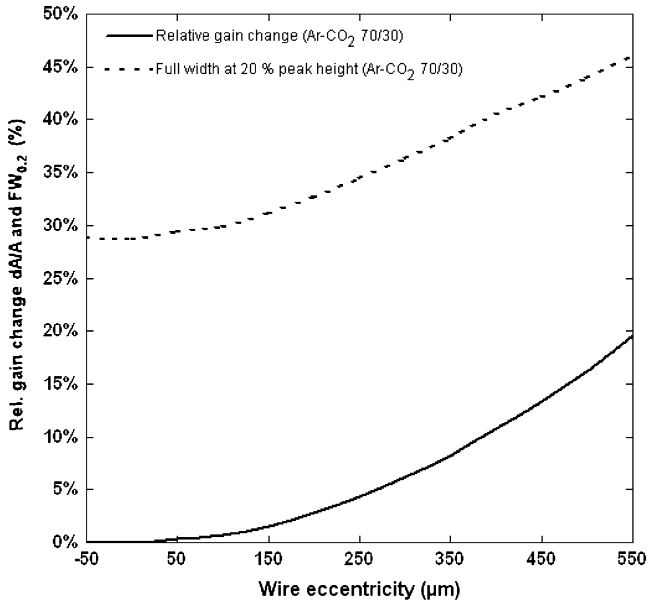

Fig. 5. Gain change versus wire eccentricity in Ar-CO_2 $70/30$. The graph shows the calibration curve from straw bending experiment.

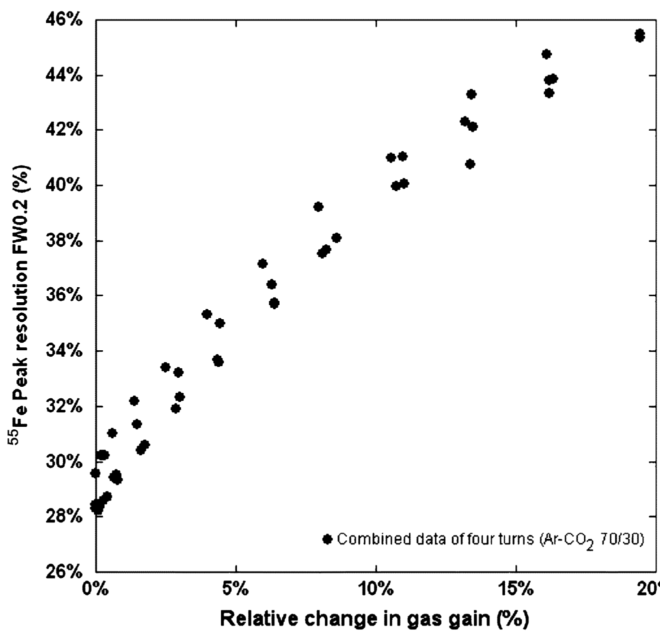

Fig. 6. ^{55}Fe spectrum resolution (width at 20% peak height) versus relative change in gas gain in Ar-CO_2 $70/30$. Results from straw bending experiment.

The gas-gain variation is defined by the difference between the largest and smallest gain point normalized to the smallest. An additional acceptance criterion is the peak resolution, required to have $FW_{0.2} > 35\%$ for the end-cap straws and $S/A > 23\%$ for the barrel straws.

Fig. 8 (barrel) and Fig. 9 (end-cap) show the statistics measured to-date for the gas gain uniformity of $\sim$50 000 barrel straws and $\sim$75 000 end-cap straws. The total number of disconnected channels because of too large wire eccentricity is $\sim$100 (0.2%) for the barrel and $\sim$35 (0.05%) for the end-cap (see also Table I).

III. Summary

The results of all acceptance tests are stored in production databases and summarized in so-called electronic barrel and end-cap wheel passports. Measured distributions of wire tension and wire eccentricity represent an important quality indicator, similarly to the overall fraction of straws that are lost in the TRT. In addition, careful testing and analysis have sometimes helped to detect problems at the assembly stage. The overall goal is to achieve a detector with initially less than 1% of dead channels (3% dead channels were simulated for various Technical Design Reports, hopefully providing a conservative estimate of the performance after ten years of operation).

At the end of November 2004, all barrel modules had passed acceptance with a total of 1.5% of channels lost. End-cap straw losses for the first 20 tested wheels are below 0.2%. The somewhat worse result in the barrel is due to the more complex and delicate design of wire preparation, fixation and location. Nevertheless 936 wires (1.78%), identified as faulty during the various tests, had been replaced successfully.

The end-cap wheel testing is well under way with an expected completion by fall 2005. The integration process of both barrel modules and end-cap wheels is in full swing and expected to be complete toward the end of 2005. Before final installation in the ATLAS cavern in spring 2006, the TRT barrel and end-caps will be integrated and tested with their respective SCT counterparts.

Acknowledgment

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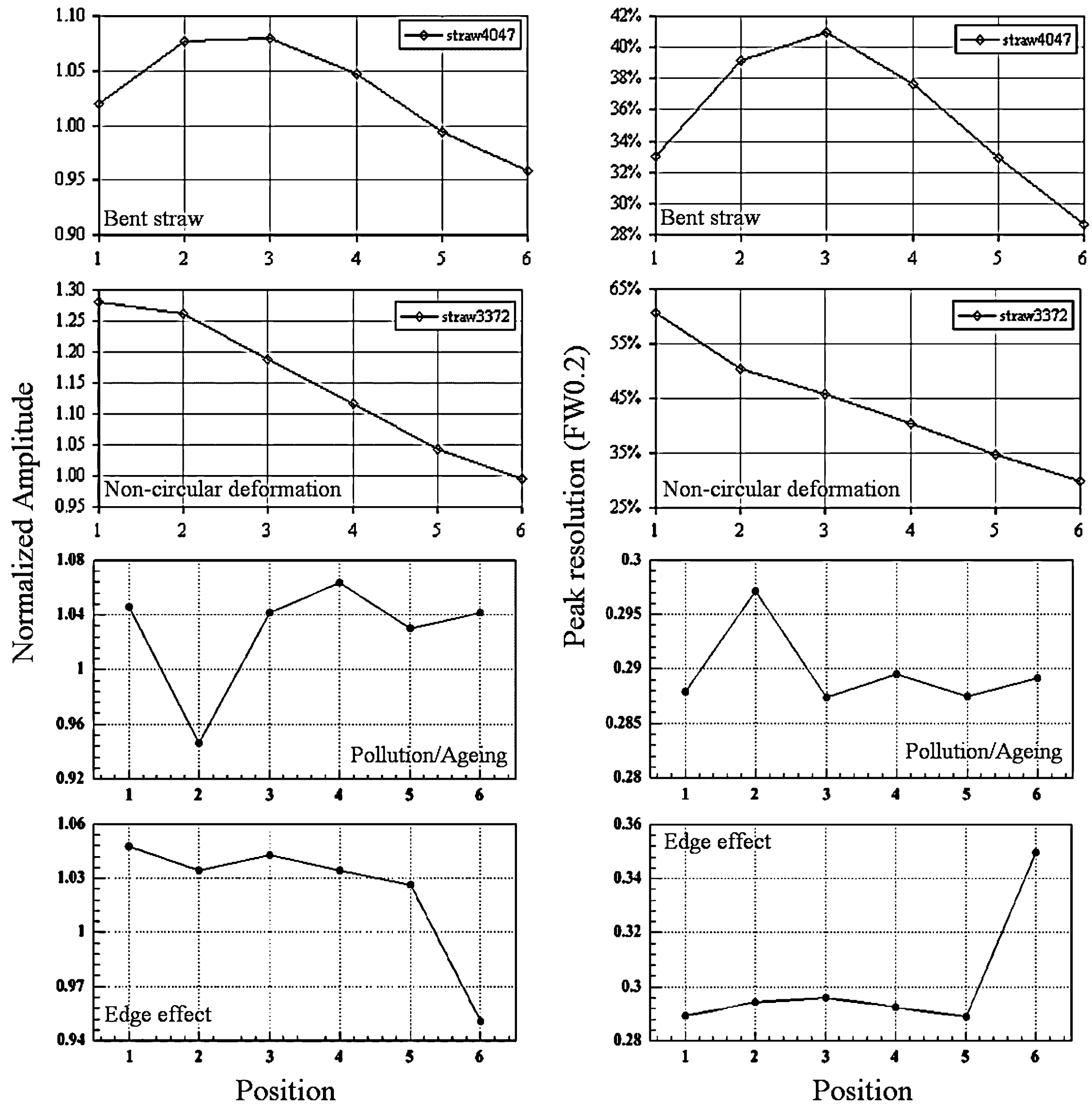

Fig. 7. Amplitude and resolution profiles of various anomalous straws. The following examples show from top to bottom: a classical bent straw tube, a straw with a noncircular ("quasielliptic") deformation at the end ("squeezed"), a straw with pollution or deposit on the wire, a straw where the spectrum at the edge is deteriorated due to field distortions (probably too close to the crimping pin). The ^{55}Fe peak resolution ($FW_{0.2}$) in a normal TRT straw lies around 28–29%. The measurement positions 1–6 along the straw are spaced by approximately 7 cm.

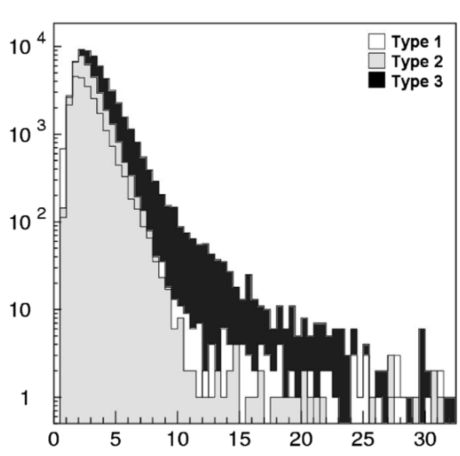

Fig. 8. Distribution of gas-gain variations of all barrel modules, shown separately for the different module types (type three biggest in size).

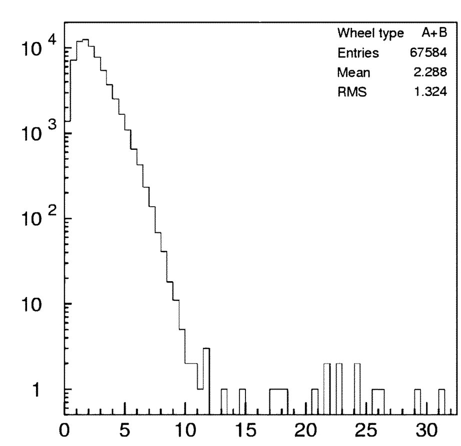

Fig. 9. Distribution of gas-gain variations of 22 end-cap wheels.

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