Ageing tests for the MEG II drift chamber

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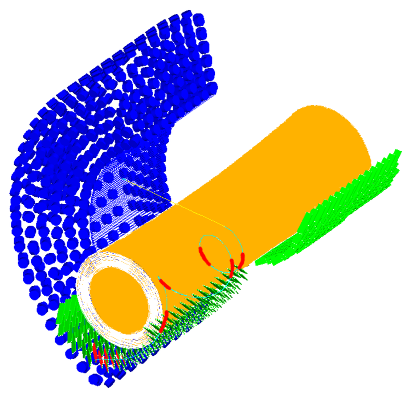
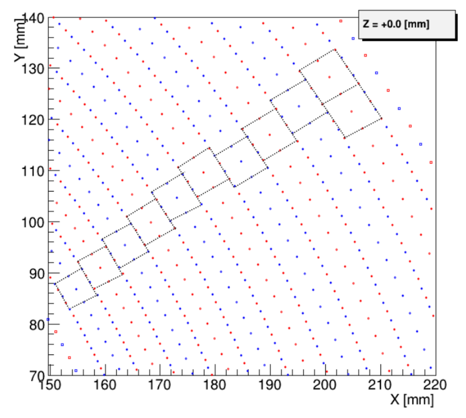
The MEG II Drift Chamber

The MEG II experiment will search for the **$\mu^+ \to e^+\gamma$** decay at the Paul Scherrer Institut (PSI) with an expected sensitivity of **~5x10^{-14}**. Positrons from μ^+ decays will be tracked by a magnetic spectrometer composed of a **cylindrical drift chamber** and two matrices of plastic scintillator tiles for timing.
The single volume drift chamber (see [1]) is composed of 10 layers with alternating stereo angles ±7°÷8°. Drift cells have an approximately squared shape 7x7 mm^2. As a trade-off between transparency and ionisation statistics an **ultra-low mass gas mixture** with helium and isobutane 85:15 has been chosen. With an expected single-hit resolution of ~110 μm (see [2]), the chamber will track positrons with a resolution of ~130 keV on momentum and ~5 mrad on the emission angles.

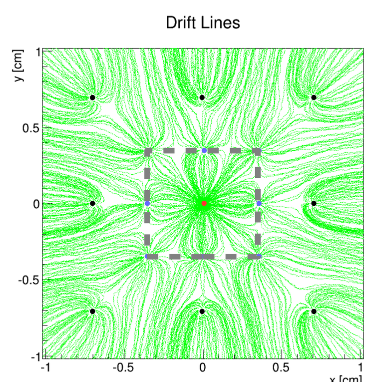


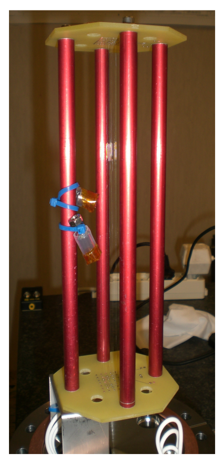


Single-cell prototypes

For ageing test purpose we built **small size** (20 cm long) single cell prototypes. Field and guard wires are set to negative high voltage, while the sense wire is grounded with a Keithley Sourcemeter 2635A, measuring the **current** flowing through it. The working point of the prototype is chosen according to Garfield++ simulations [5]. Two ^{241}Am sources are placed on one of the rods for monitoring the operation of the chamber with α-particle signals.

	Prototype I	Prototype II
Cell parameters:		
Anode	25 μm W (Au)	20 μm W (Au)
Cathodes	80 μm W (Au)	80 μ m Al (Ag)
Gas mixture	90:10 - 85:15	85:15
Gas flow rate	40 sccm - 5 sccm	15 sccm
Cell gain	$\sim 1 \times 10^4$	$\sim 3 \times 10^4$
Irradiation spot	2.5 cm - 1.8 cm	3 cm
Accelerating factor	×17 - ×26	×10 - ×20



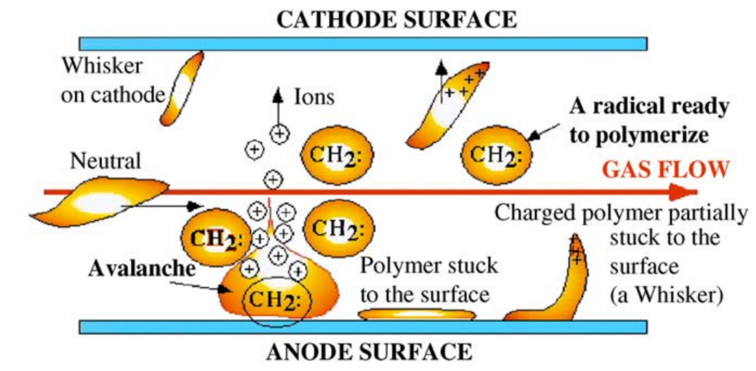


The Issue

The detector will undergo an intense rate of **Michel positrons**. In the hottest portion of the innermost wire the occupancy will be ~30 kHz/cm^2, corresponding to a maximum anodic current of 10 nA/cm which yields a collected charge of about **0.5 C/cm** in the full data taking period. At such amounts of collected charges ageing issues my occur [3,4].

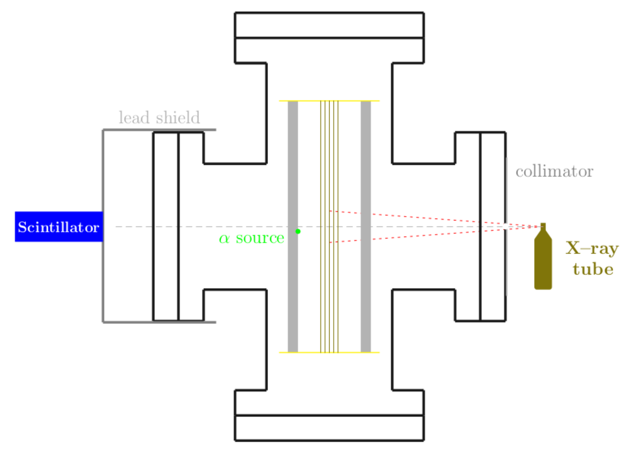
Ageing causes
- Gas molecules fragmentation
- **Free radicals** formation.
- Polymer **deposits** on wire surfaces.

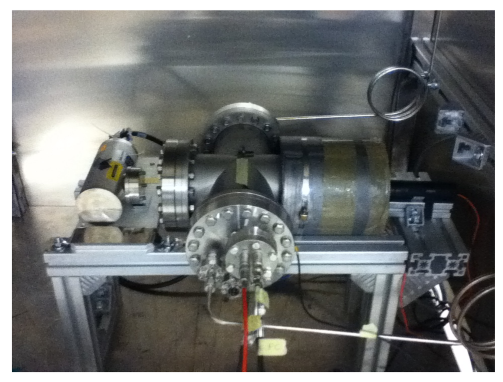
Ageing effects
- **Gain loss.**
- Loss of response uniformity.
- **Electrical instability** and dark currents.

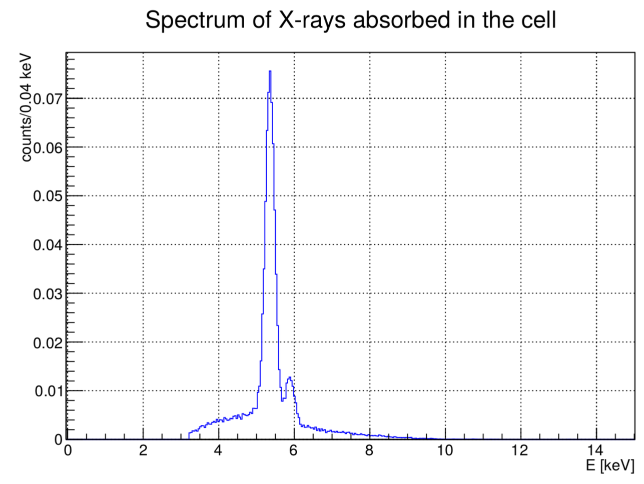


Pisa Irradiation Facility

For the test of drift chamber robustness at high amounts of collected charge an irradiation facility was built from scratch. A CF-100 cross containing a single-cell prototype is placed between an **X-ray source** and a **scintillator**, used to **monitor** the X-ray rate. Radiation enters and exits the test chamber through two 150 μm **Mylar windows**. The irradiation area is set by a collimator placed on the X-ray source. The radiation exiting the cross is damped by a lead cylinder with a thickness of 2 mm, with a 0.6 mm collimator to prevent the scintillator from being overirradiated. For safety reasons, the whole apparatus is placed in a 1x1x1 m³ box with 2 mm lead walls. As irradiating sources two different X-ray tubes were used: a Moxtek Magnum X-ray gun with tungsten anode and an Oxford Apogee XTF5011 with chromium anode.





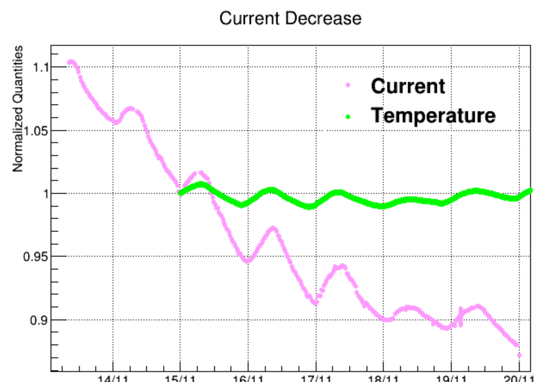


Test procedure

As an indicator of the ageing of the chamber, we measured the **relative gais loss** as a function of the collected charge. Gain loss evaluation is obtained by measuring the anode current variations under constant irradiation. For reducing the operation time from about 600 days to about a month a factor 20 of accelerated irradiation should be set in order to reach the same charge collection. Two major effects arise with this test methodology [6].

$$\mathcal{R} = -\frac{1}{G_0}\frac{\mathrm{d}G}{\mathrm{d}Q}\left(\frac{\%}{\mathrm{C/cm}}\right)$$

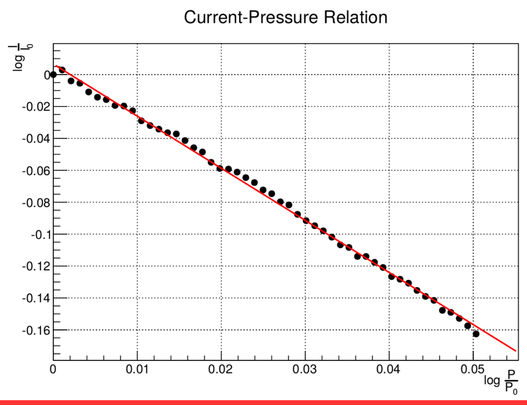
Environmental changes



Since the gas system keeps the absolute pressure of the chamber fixed, the gas status was monitored by measuring temperature through a Pt100 sensor. **Current oscillations induced by temperature variations** were removed offline. Since gas gain has a power dependence on temperature and pressure with opposite power indices

$$\left(\frac{G'}{G}\right) = \left(\frac{T'}{T}\right)^{\alpha}_{P} = \left(\frac{P'}{P}\right)^{-\alpha}_{T}$$

we measured the behaviour of current as a function of the gas pressure, and obtained the power index by fitting the curve.



Saturation

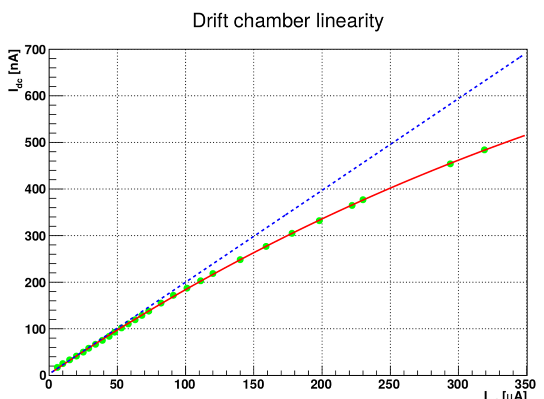
Saturation represents an intrinsic limit on gain loss evaluation in accelerated test. The dependence of drift chamber current from the rate of incoming radiation shows clear deviation from linearity. For describing the curve we adopted a phenomenological expression

$$I = I^{\mathrm{NS}} \exp\left(-kI^{\mathrm{NS}}\right)$$

where $I^{\mathrm{NS}} = \varepsilon I_{\mathrm{xrt}}$ is the **non-saturated current**, proportional by definition to the X-ray tube current. For small deviations from linearity, we can calculate the non-saturated current as

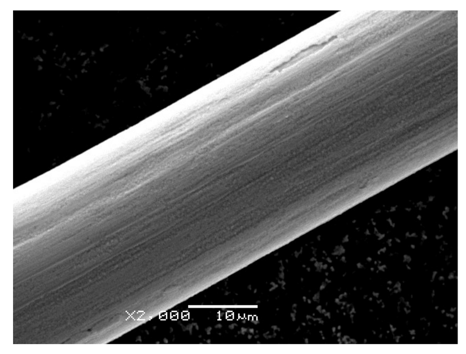
$$I^{\mathrm{NS}} = I \exp\left(kI\right)$$

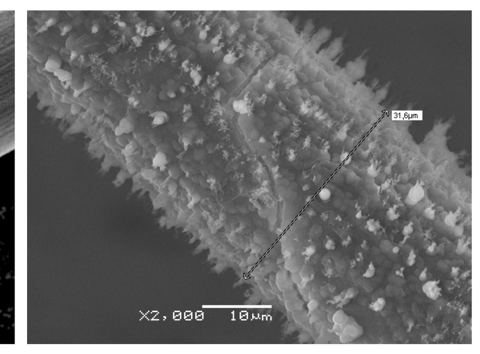
with the parameter *k* obtained from the fit in the figure below. Since the non-saturated current is proportional to the gain, it can be used for calculating $\mathcal{R}$.

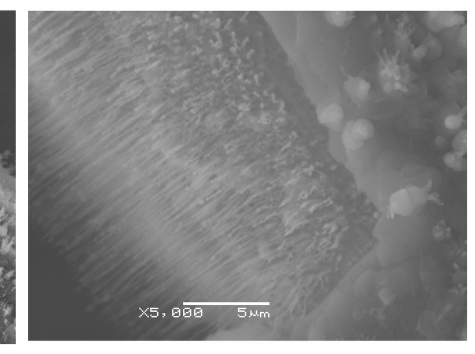


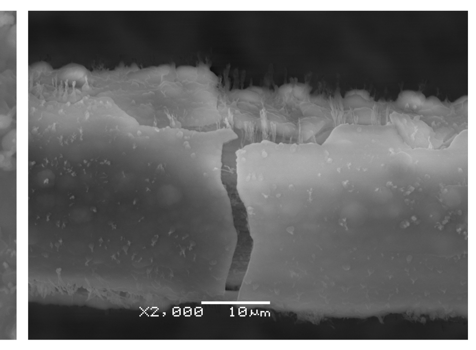
Inspection

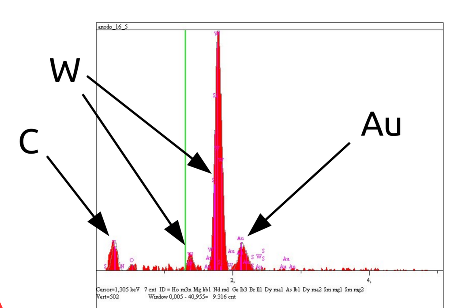
Selected portions of wires were analysed with **Scanning Electron Microscopy** (SEM) and **Energy Dispersive X-ray** (EDX) analysis at the SEM facilities of INFN in Lecce and Pisa, with the aim of looking for modifications of the wires that can induce gain loss. Cathodes do not present visible modifications, but EDX analysis shows contaminations of **carbon**, **nitrogen**, **oxygen** and **silicon**, that increase approaching the centre of the irradiated portion of the wire. On the other hand, a uniform coating covers the anode surface. The mean wire diameter is about 30 μm, with extrusions making the peak-to-peak wire size up to about 40 μm (in spite of the original 25 μm). In the proximity of the centre of the wire, in an area extending for about 2 cm, **bubbles** and **whiskers** emerge from the coating.

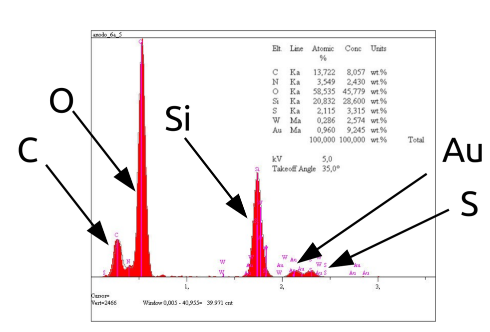


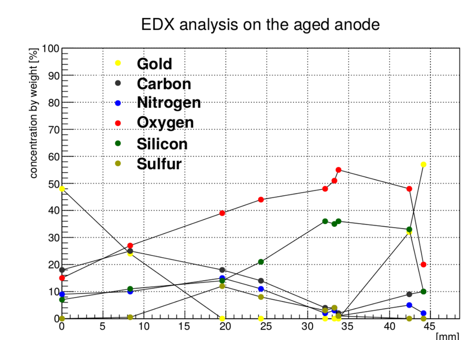






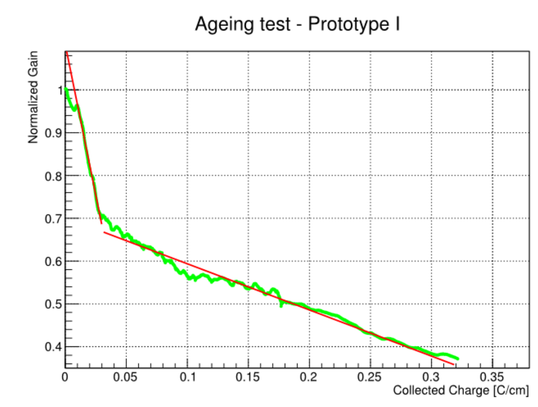




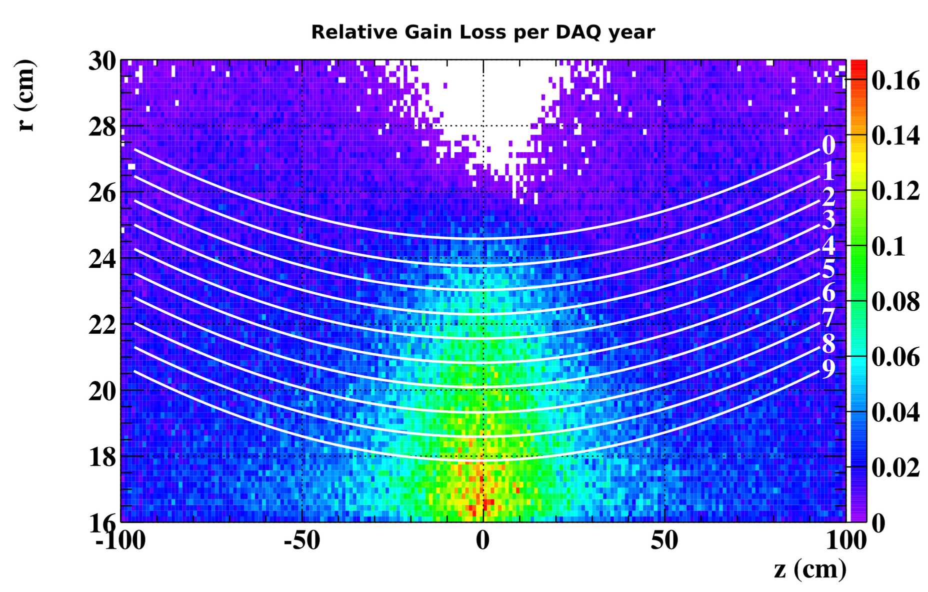


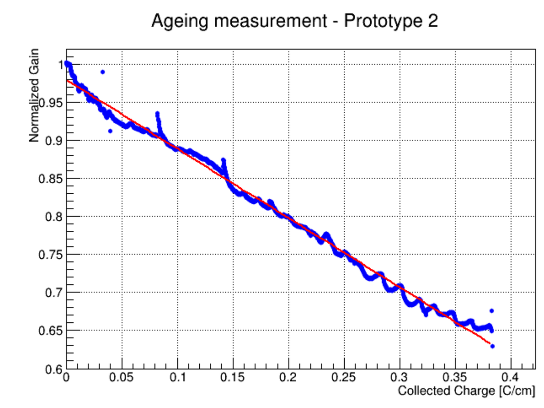
Results and Conclusions

The ageing rate of the chamber was measured in two distinct tests at several working points (reported in detail in the table on the left). No significant slope change corresponds to modification of the chamber working conditions. However a slope change is visible in the normalized gain as a function of the collected charge with Prototype I. The ageing rates measured in the two tests are compatible within 20%.



$$\mathcal{R}_1 = 108 \pm 1\,\%/\,(\mathrm{C/cm})$$
$$\mathcal{R}_2 = 90.9 \pm 0.3\%/(\mathrm{C/cm})$$





In the central region of the hottest wire the gain loss is about **16 %/year**, while in most wires the gain loss is below 10%/year. This can be easily recovered with a small increase in the high voltage of the wires.

Bibliography

[1] M. Grassi et al., Poster at this conference.
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[6] M. Venturini, Master Thesis, University of Pisa, 2013

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