Aging Phenomena in the LHCb Outer Tracker

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on behalf of the LHCb Outer Tracker Group

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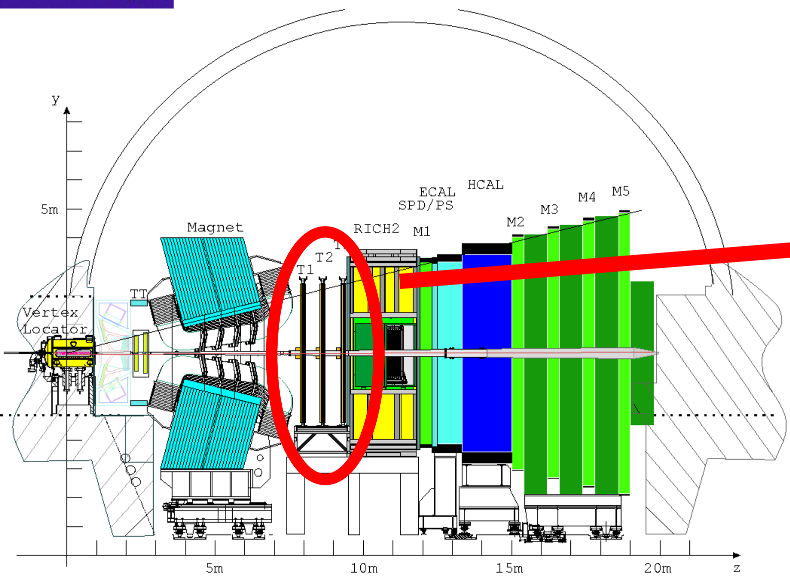
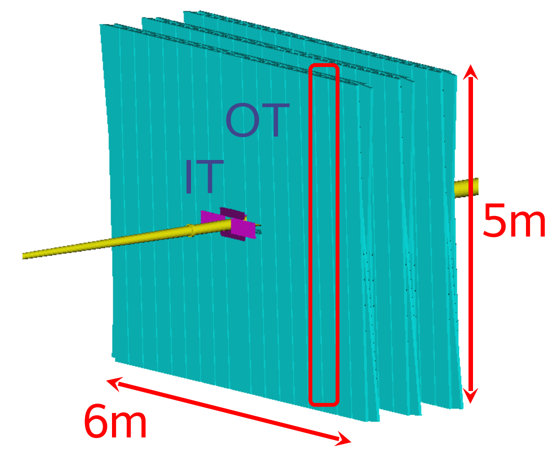
The Outer Tracker within LHCb



The LHCb forward spectrometer



The Outer Tracker stations:

- Modular design
- Drift tube technology
- Straw tubes, diameter: 5 mm

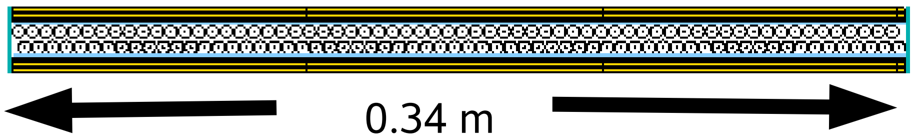
Operation parameters:

- Gas: Ar/CO_2 (70% / 30%)
- Gain ≈ 40 000
- Expected accumulated charge:
  ≈ 1C/cm at the hottest region
  in 10 y LHCb
  at L = $2*10^{32}$ /(cm*s^2)

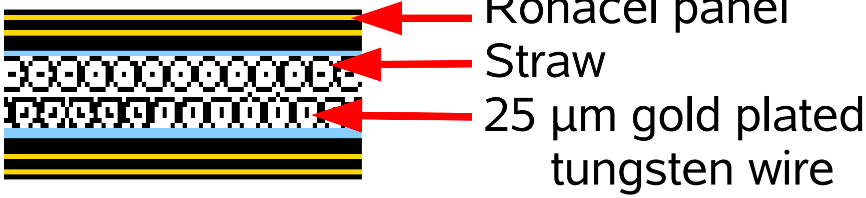
The Outer Tracker modules

The Outer Tracker:
- 264 modules
- 2 layers of straws per module
- 53760 straws

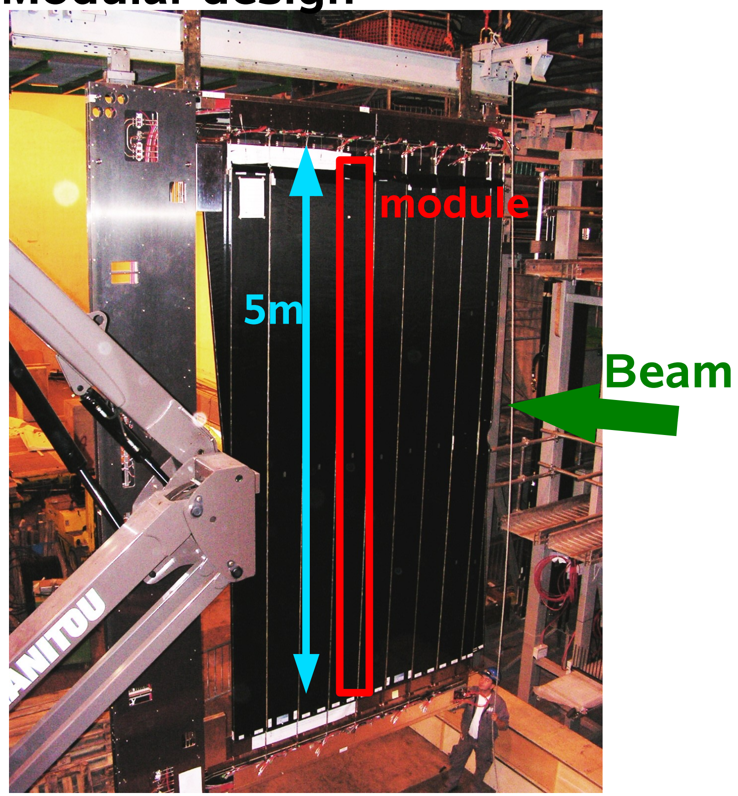
Drift tube technology
profile of a module



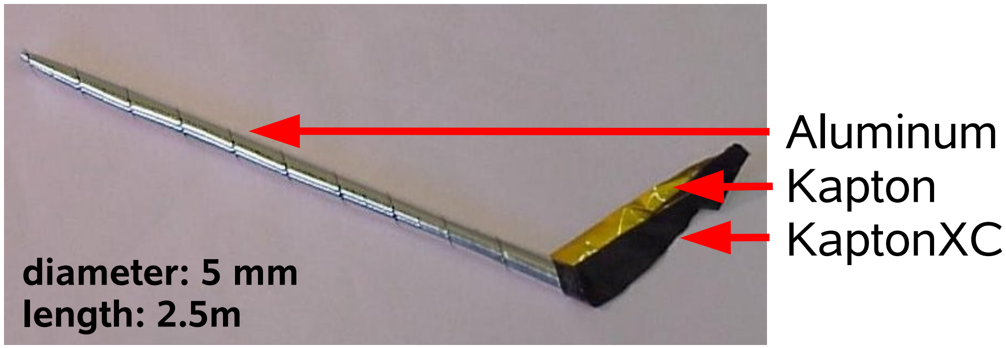
Zoom



Modular design



Straw tubes

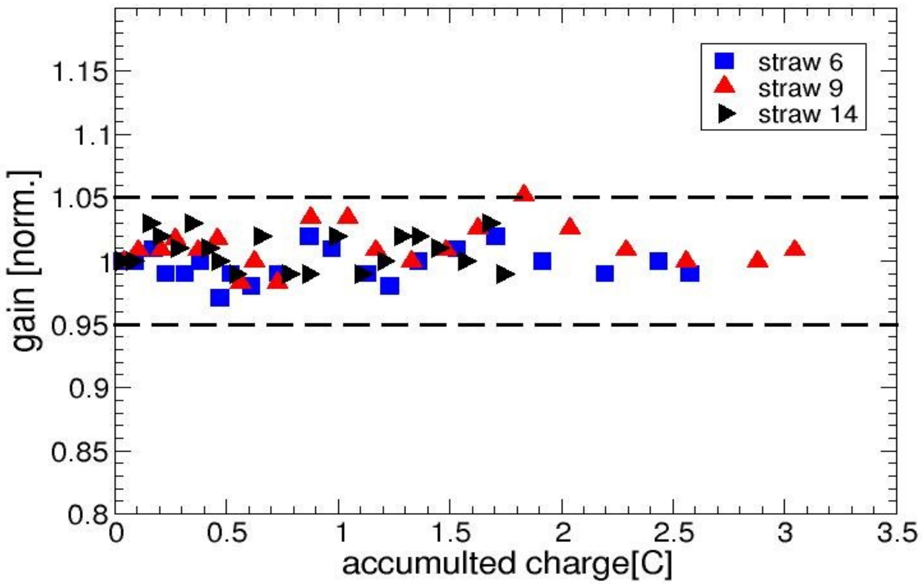


High rate aging tests during R&D-phase

Intensive test program:

1) Proton irradiations (highly ionizing particles)
2) Irradiations in X-ray facility (9 keV) with 1m - test modules (materials out of production)
→ Studies on long term effect with high irradiation dose (0.5 – 3 C/cm)

Acceleration factor: 8 – 30
Irradiation time: 2 weeks – 4 month / test

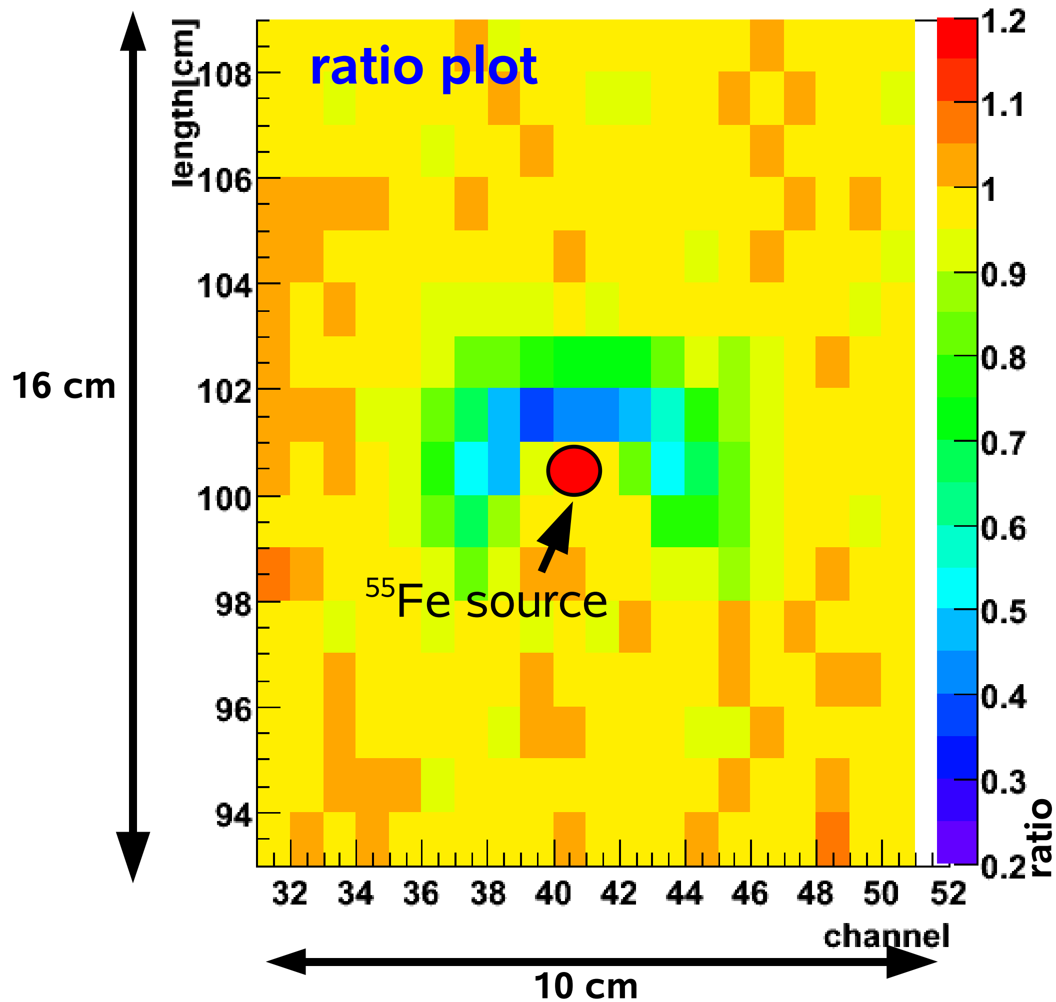


Longtime measurement over 120 days

High rate, high irradiation dose:
No aging detected

Low rate aging of production modules

gas flow direction

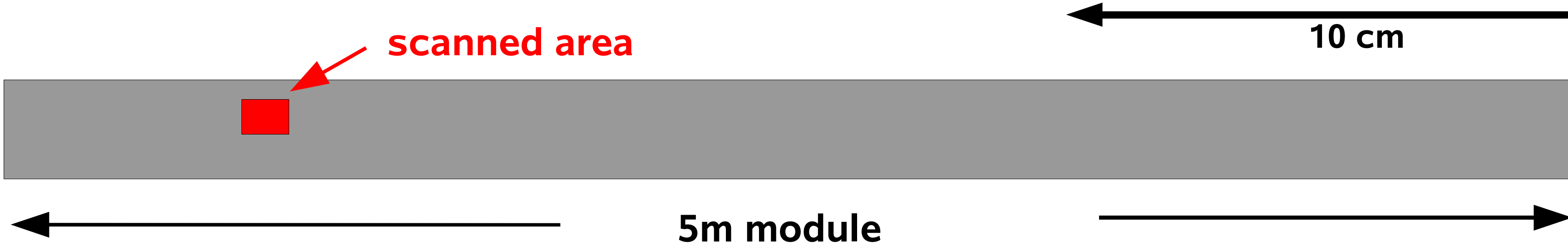


Irradiation with weak laboratory source: ^{55}Fe

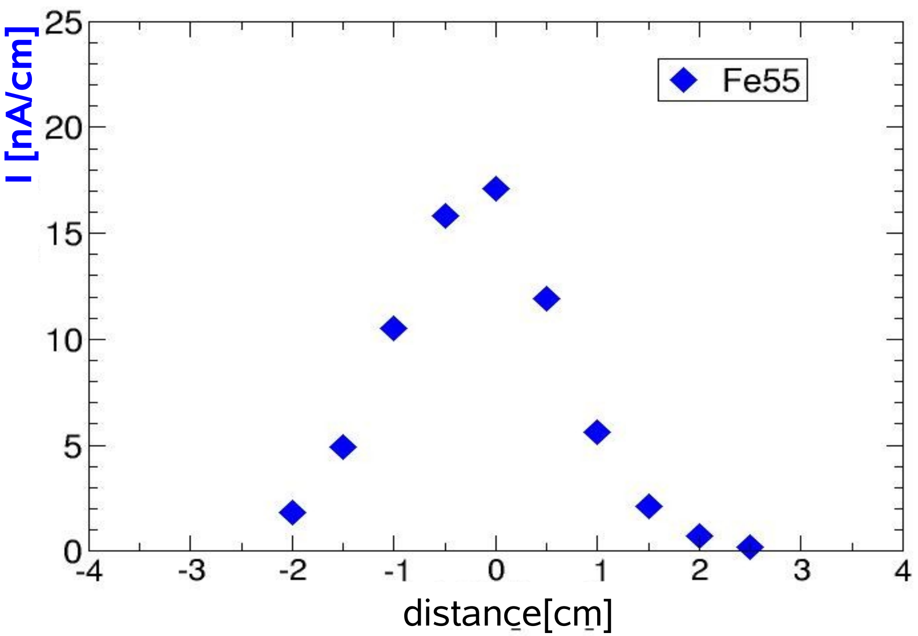
- Irradiation time: **144 h**

$$\text{ratio} = \frac{\text{signal height (after irradiation)}}{\text{signal height (before irradiation)}}$$

- Half moon shape
- Sensitive to gas flow direction
- No gain drop beneath the source
- Sensitive to radiation strength
- Similar results with ^{90}Sr (β source)

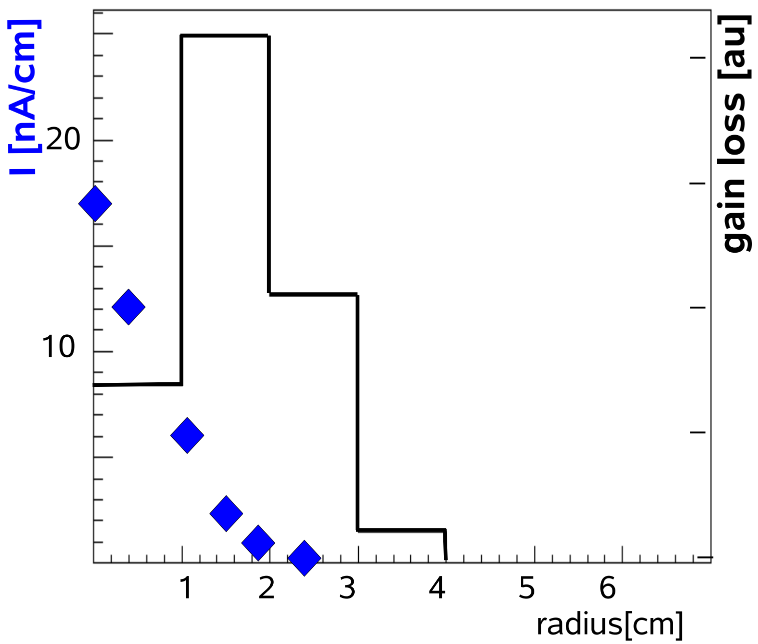


Dependence on current



Intensity profile of ^{55}Fe source

- Strongest damage at 2 – 5 nA/cm

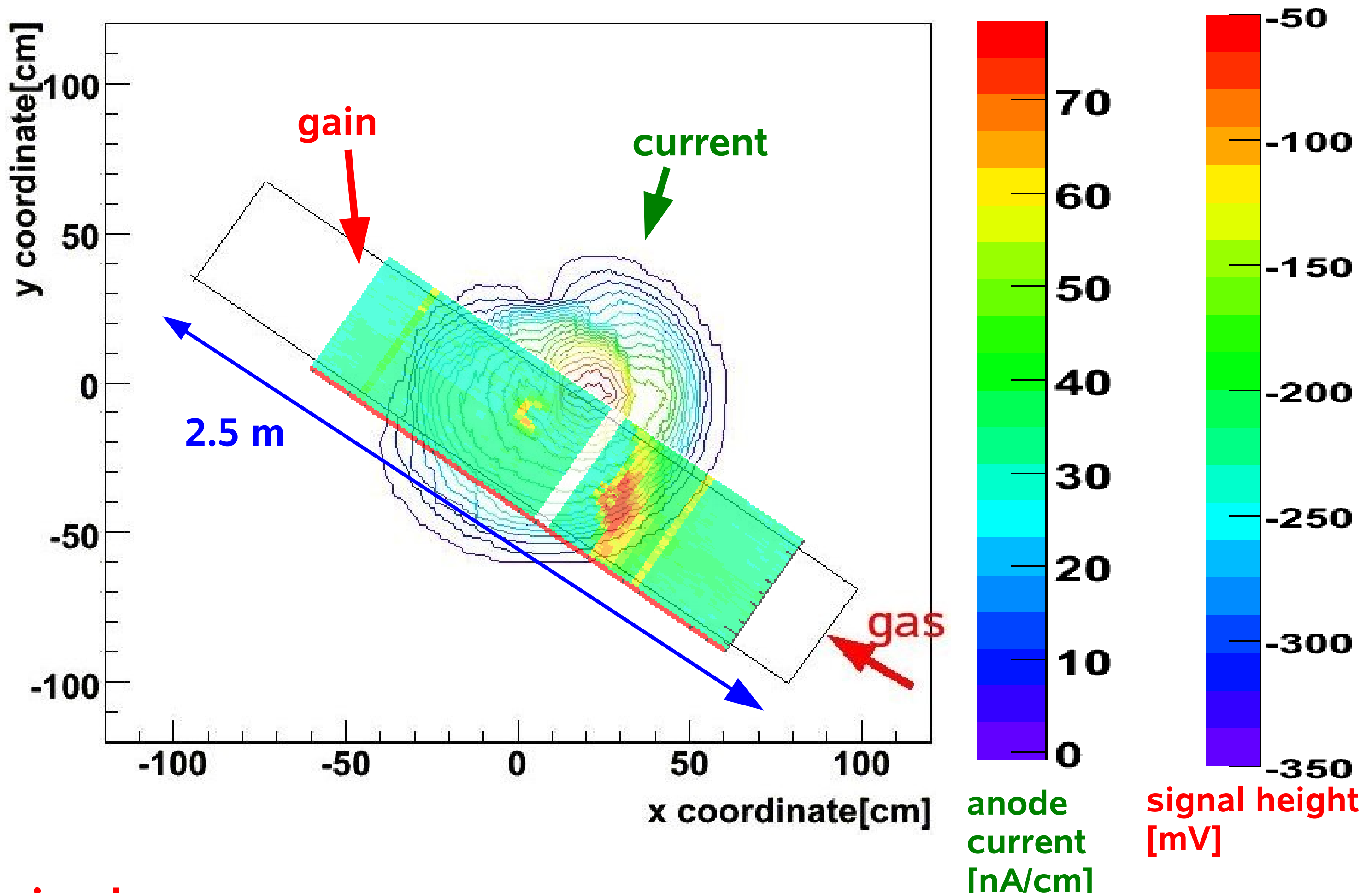


Beam profile compared to damage of the spot

Irradiation of a large area

Irradiation at X-ray facility

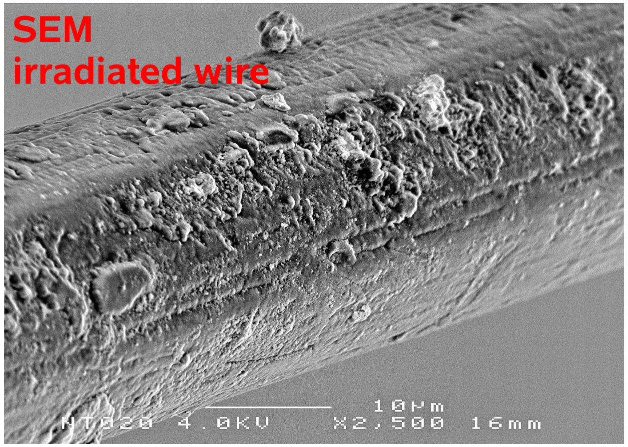
- 2.5 m mass production module
- 9 keV photons
- Irradiated area >3000 cm^2 (typical: 30-80cm^2)
- Irradiation time: 160h

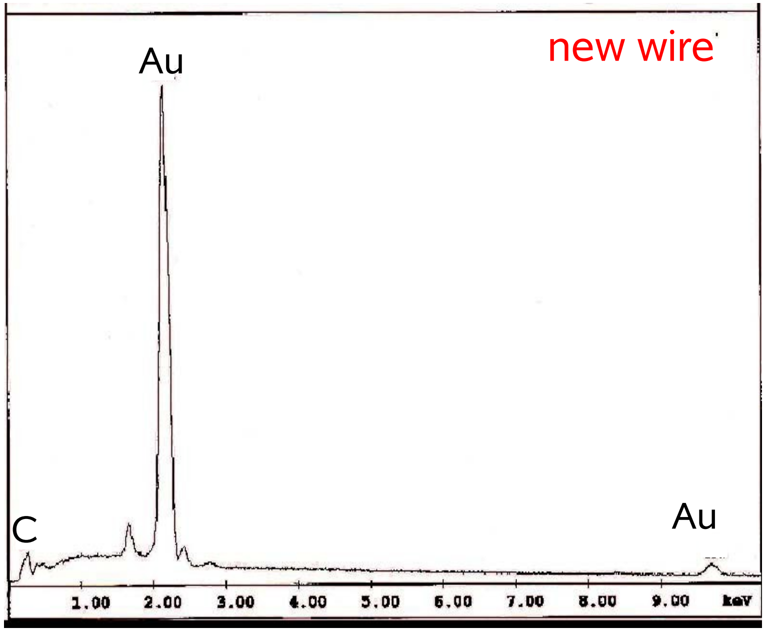


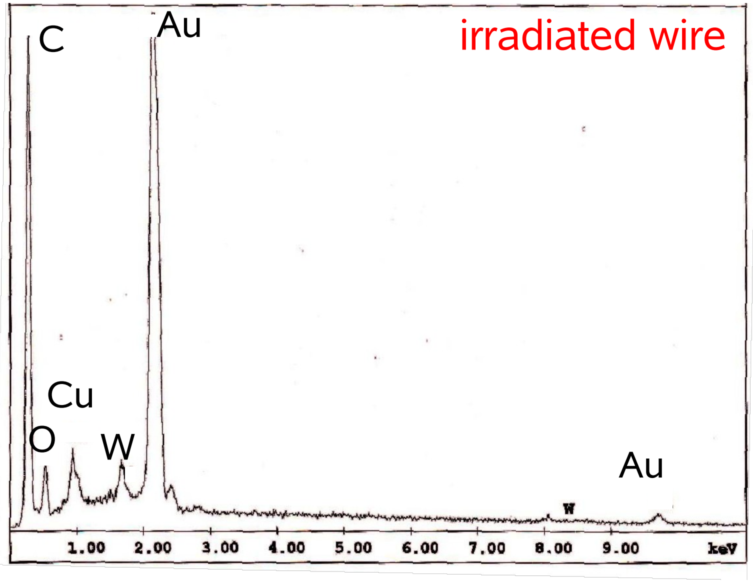
Results consistent with aging by radioactive sources

Inspection of the wire

X-ray spectroscopy







Analysis of irradiated wire

- **Optical microscope**
- **SEM** (Scanning electron microscope)
- **EDS** (Energy dispersive X-ray spectroscopy)
- **WDS** (Wavelength dispersion)

→ thin layer of deposits (few 100 nm),
deposits insulating (SEM)
mainly Carbon
(probably Hydrogen, but not detectable)

No silicon found

Components of chamber modules

Material	Literature	tested by us
Straws: Aluminum	✓	
Kapton, KaptonXC	✓[1]	✓
End pieces, wire locater: Noryl N110	✓[1]	✓
Aluminum coated rohacel panel		✓
Glue: Araldit AY103 + Hardener HY 991 + silica gel	✓[2]	✓ ✓
Aluminum end pieces, solder points, PCB		✓

No obvious source of outgassing

1) J. A. Kadyk, Nucl. Instr. and Meth. A 300 (1991) 436-479.

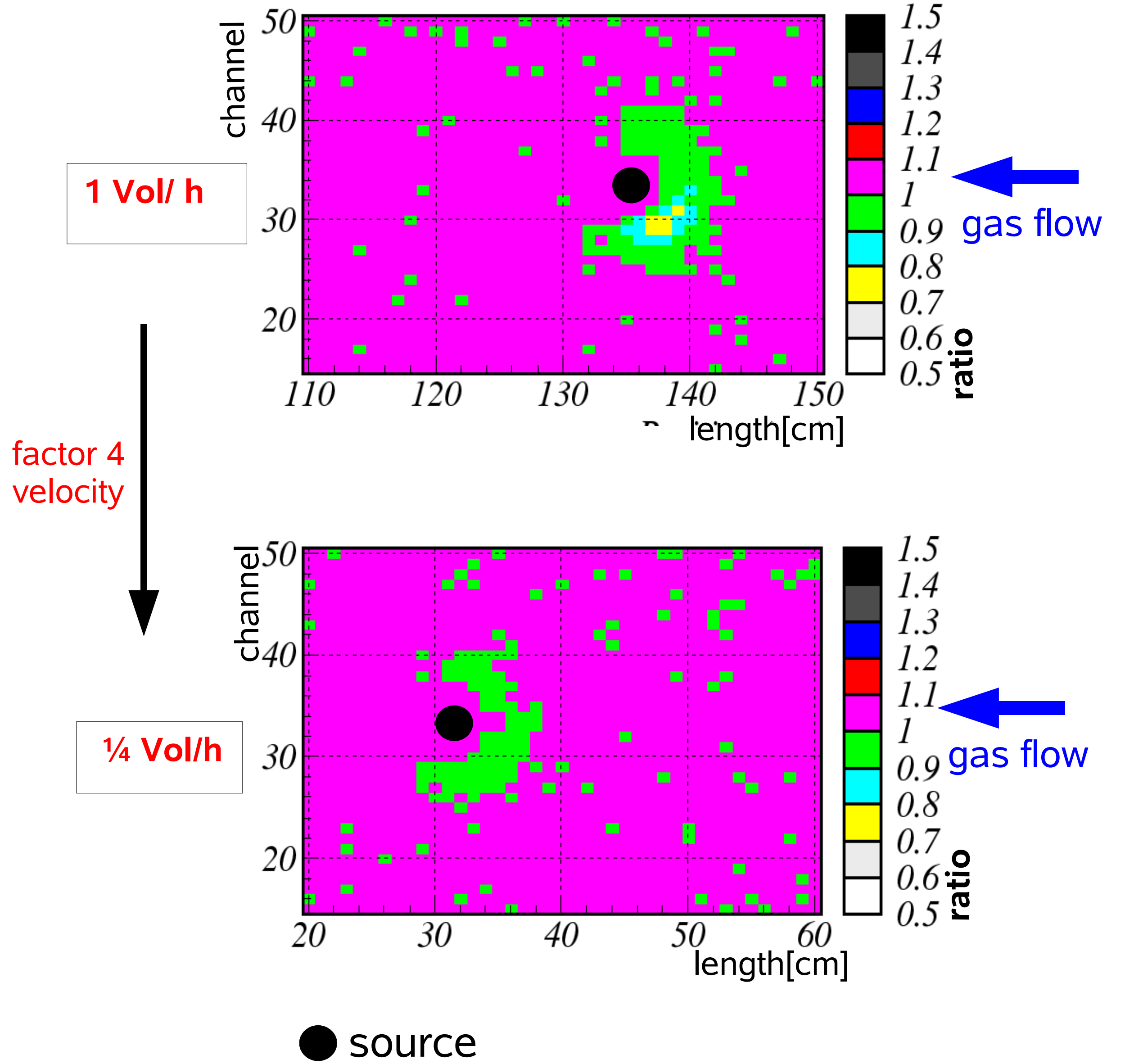
2) M. Capeans, Aging of Gaseous Detectors: assembly materials and procedures

Gas flow dependence

Systematic studies:

- Dependence on flow direction
  Aging only upstream of the source

- Change of gas flow velocity
  from 1 Vol/h to ¼ Vol/h:
  aging reduced significantly



Other systematic studies:

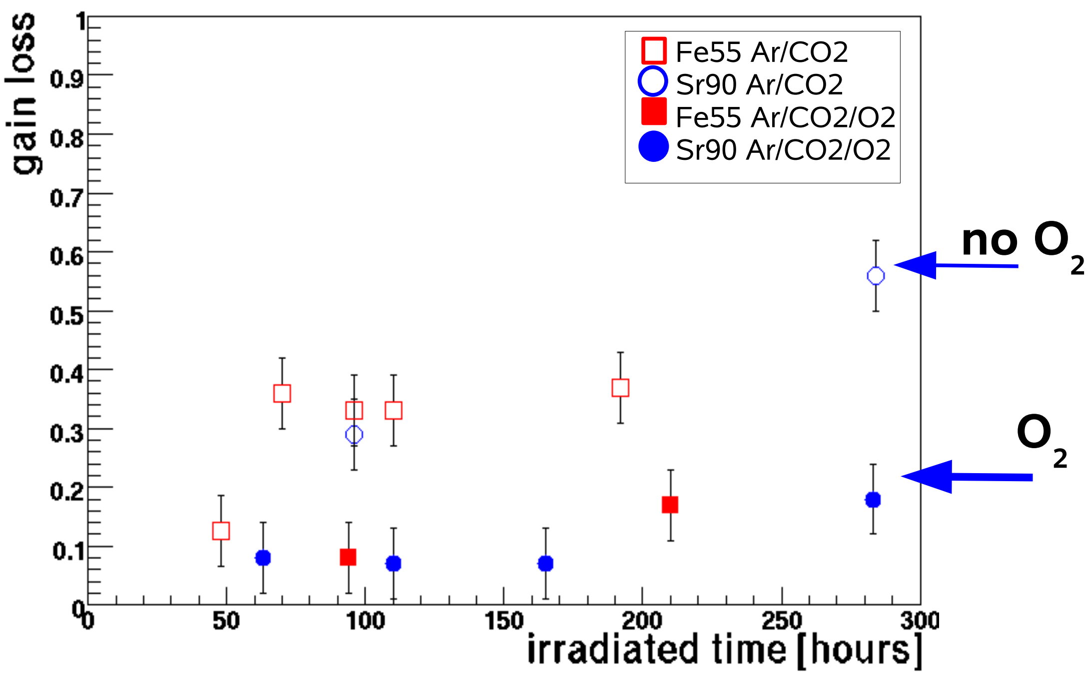
- Time
- Straw position
- High voltage
- Intensity
- Source
- Gas mixture

Dependence on gas mixture

Addition of **CF_4** No effect on aging

Variation of **Water content** No effect on aging

Addition of **O_2:**



Addition of Oxygen to gas mixture:
$Ar/CO_2/O_2$ (70%:27.5%:2.5%):
aging reduced significantly

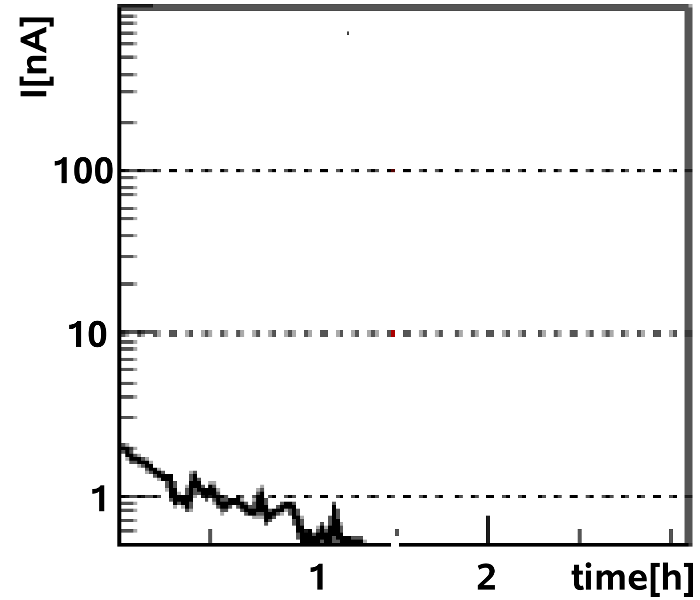
only small effect on HV plateau, gain and shape of the ^{55}Fe spectrum measured

Module conditioning

Deposit could be already on the wires before irradiation

High currents (> 50 nA/cm) could remove deposits

- Irradiation with strong source
- Inverse high voltage
  (-1300 V – -1400 V)
- High Voltage (+1800 V – +1900 V)

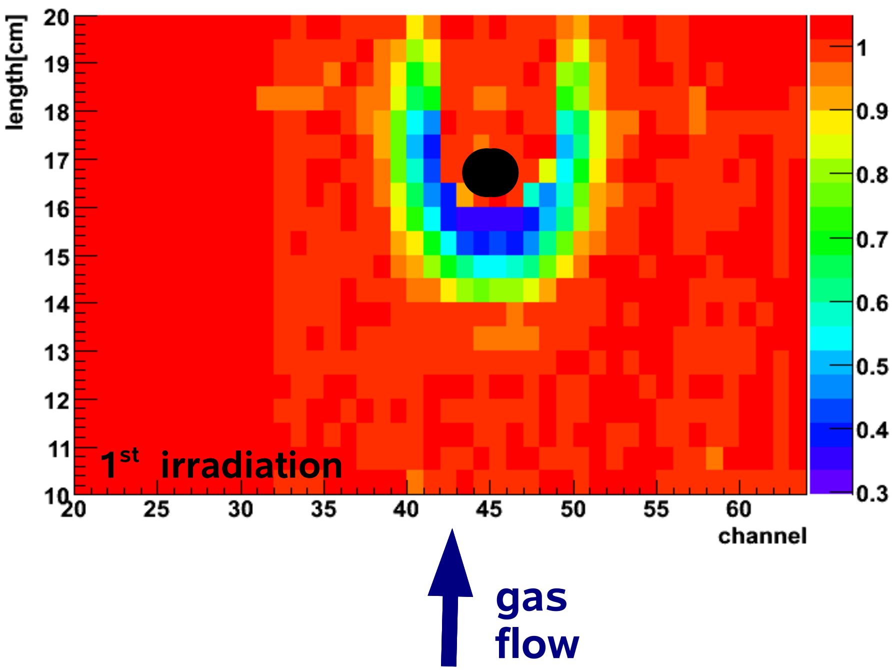


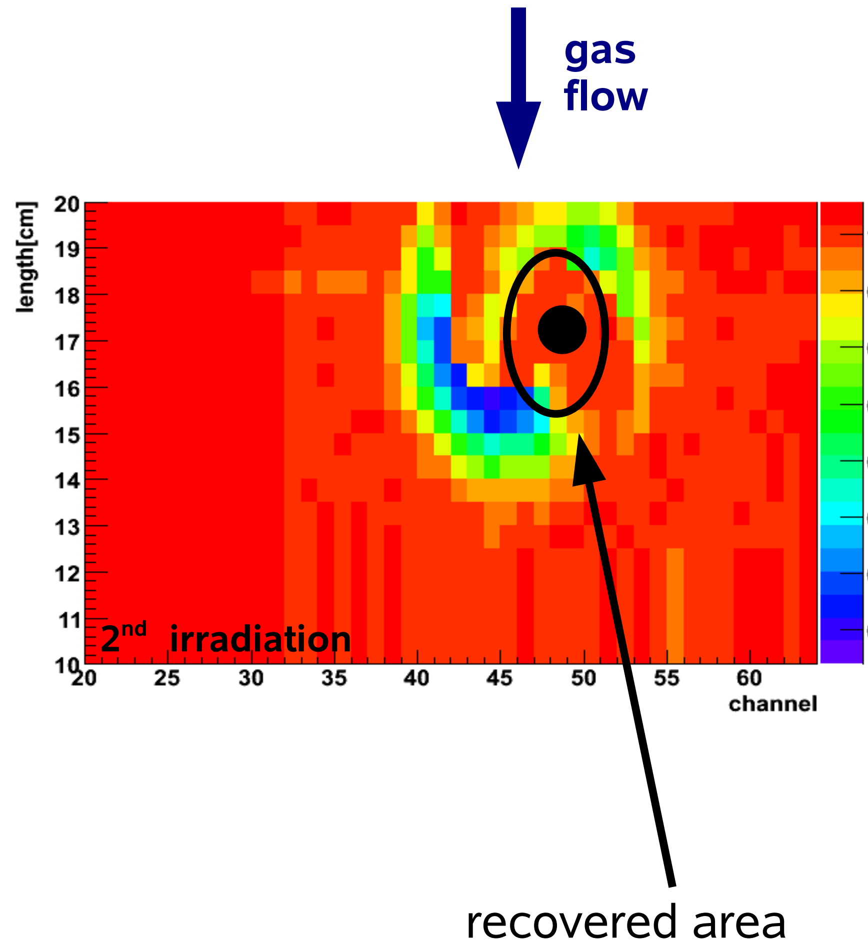
Typical dark current for one wire after 1.5 h training at 1600 V

→ current per wire < 1nA
→ current/cm < 0.004 nA/cm

Irradiation of aged spots

Irradiation with ^{55}Fe source

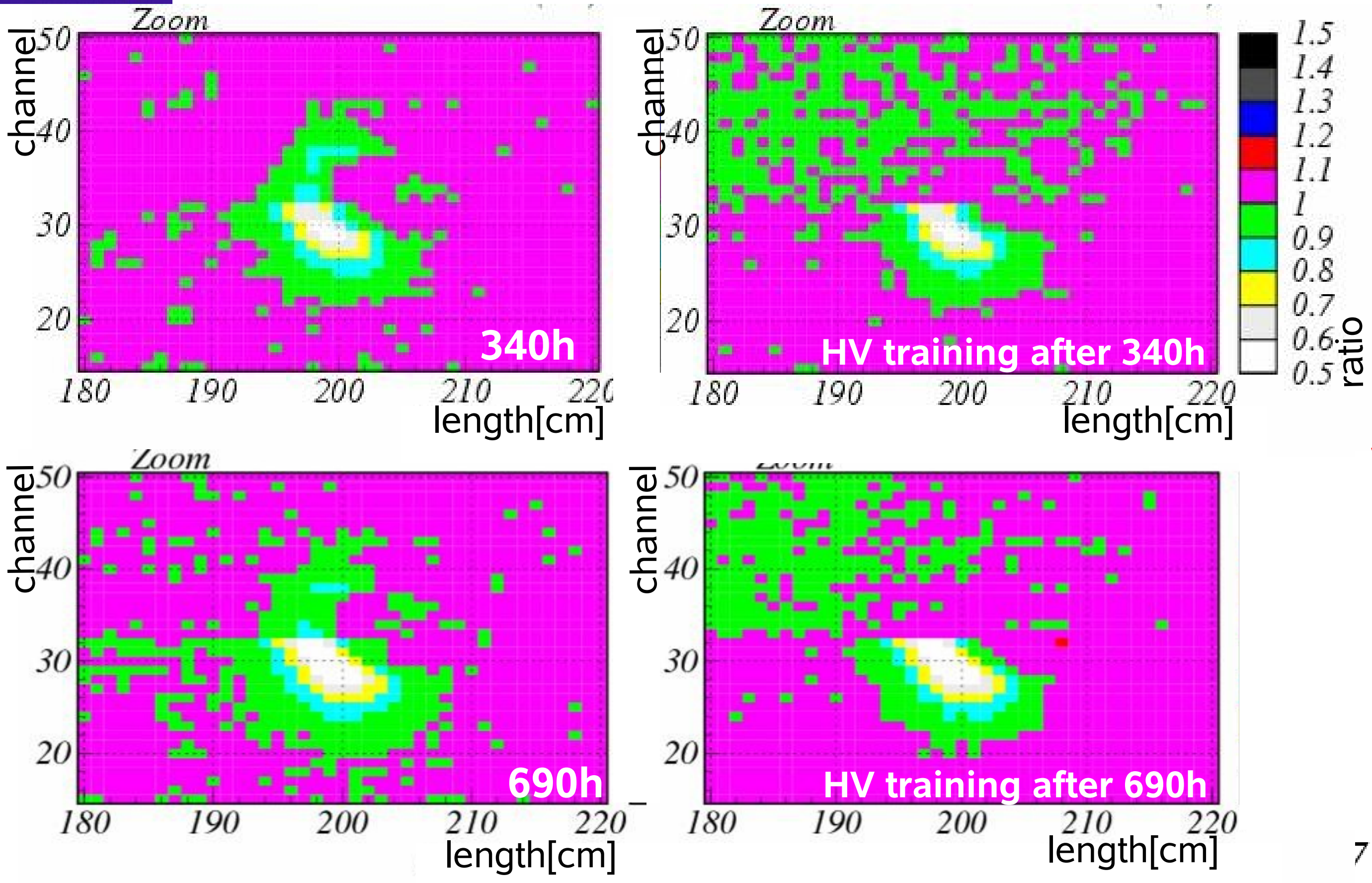


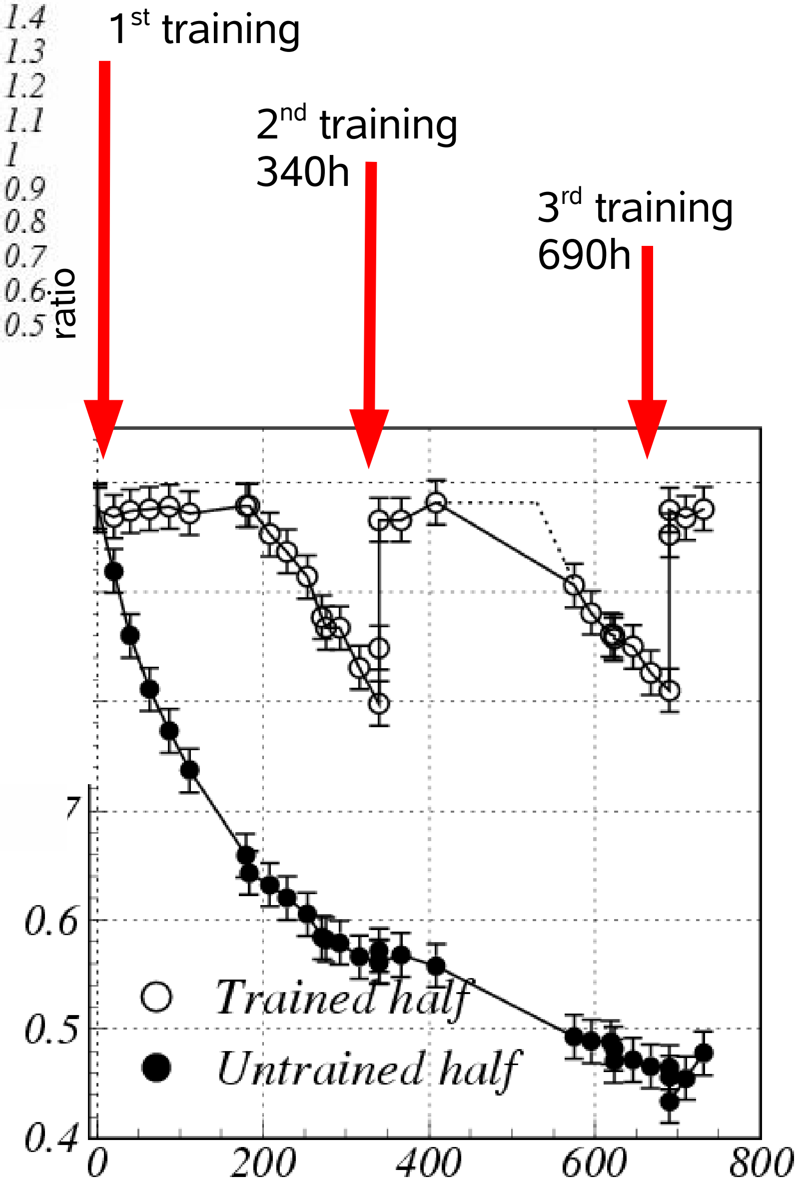


- No prevention of aging by conditioning with currents
- Deposits removed by higher currents (≈100 nA/cm)

● source

Training with positive voltage

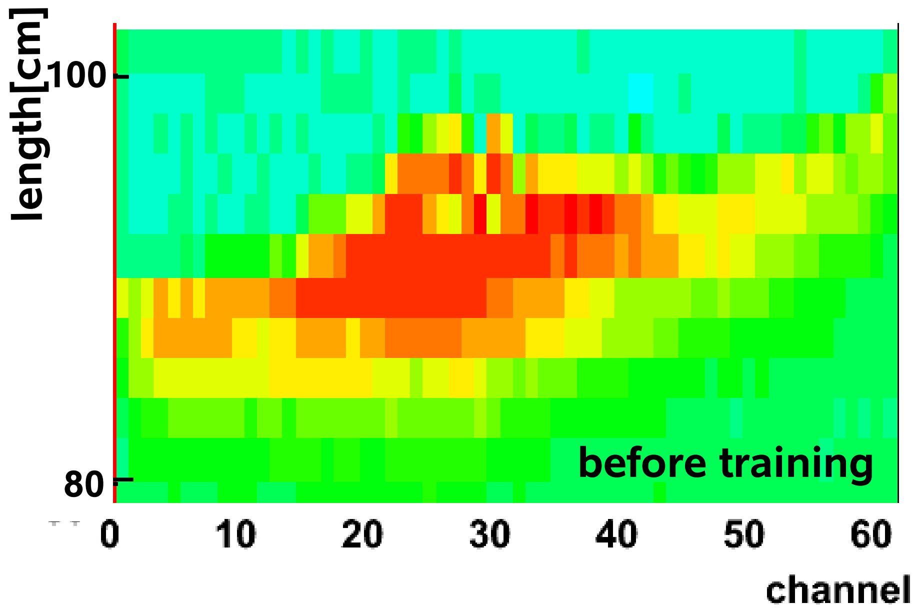


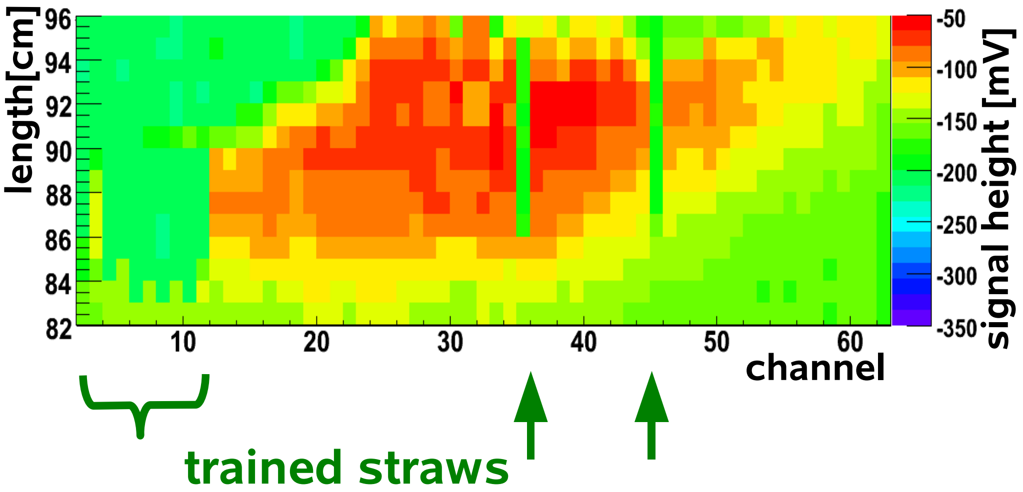


- No permanent prevention of aging
- Training repairs the damage previously inflicted by irradiation
- HV training repeatable

  but inspection of the wire necessary

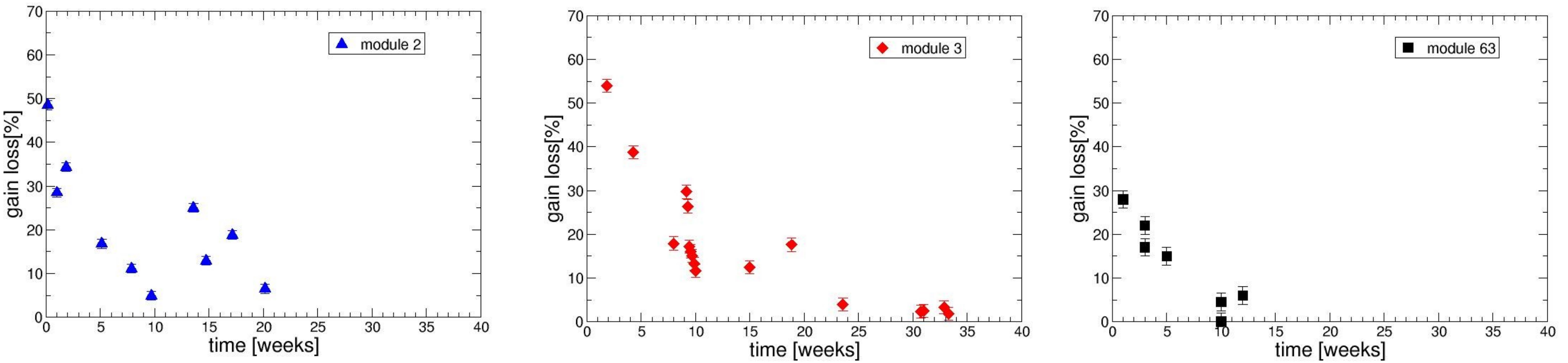
Training with negative voltage





Negative training repairs the damage previously inflicted by irradiation

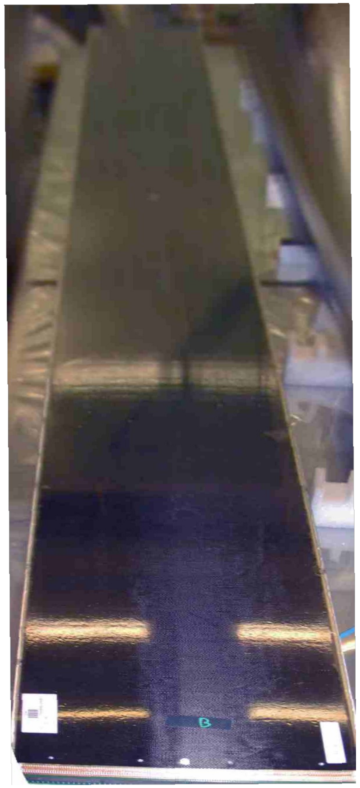
Long-term flushing



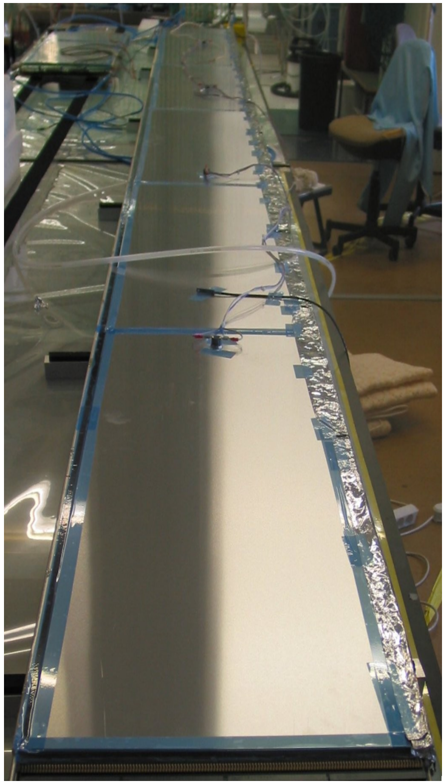
gain loss: after a fixed irradiation time

Flushing for several month improves the behavior of the modules
→ Improvement due to flushing is an indication for outgassing

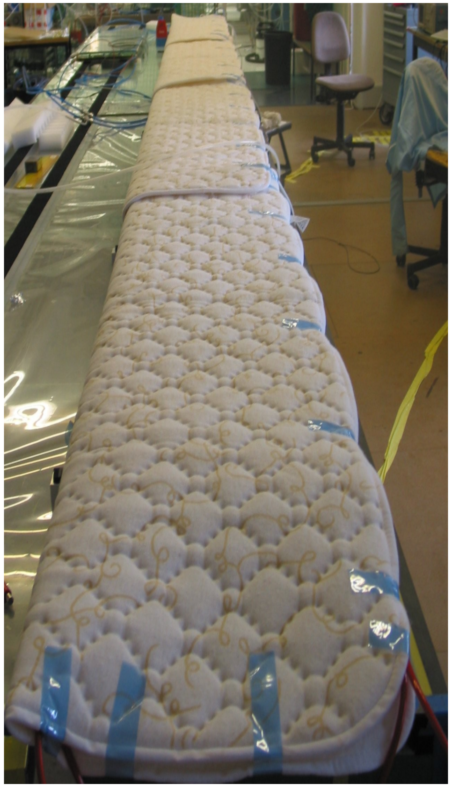
Warming up a module



new 5 m module



cover the module with thin aluminum plates



wrap the module in electric blankets

add insulation

Flushing at higher temperatures

Heat the modules:

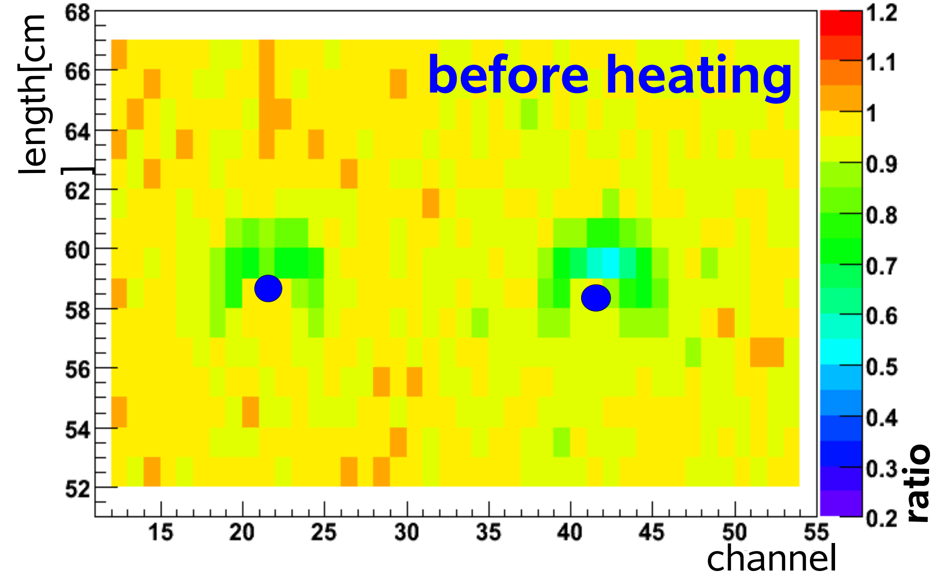
- Temperature: 40 – 45 °C
- 10 – 12 days of heating
- Constant gas flow

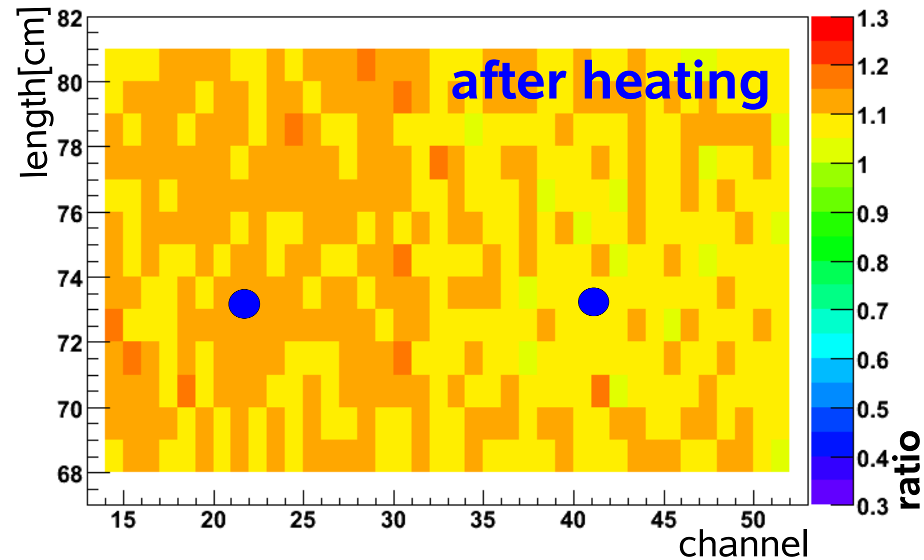
Improvement of the module behavior – can't be explained by flushing only

Another indication of outgassing?

Test successfully repeated with three modules,
but discrepancies with other setups

→ Results are not yet fully conclusive





after 75 h of irradiation

source ●

Conclusion

- Intensive aging test with prototype modules up to 3 C/cm showed no effect
- Mass production modules show gain drop at modest irradiation rate (2 – 5 nA/cm)
- Effect depends on
  - Gas flow direction
  - Gas flow velocity
  - Gas composition (Oxygen)
  - ...
- Despite the huge amount of tests, the origin of the aging phenomenon is still not understood, although the strong effect of flushing (+heating) hints to outgassing.

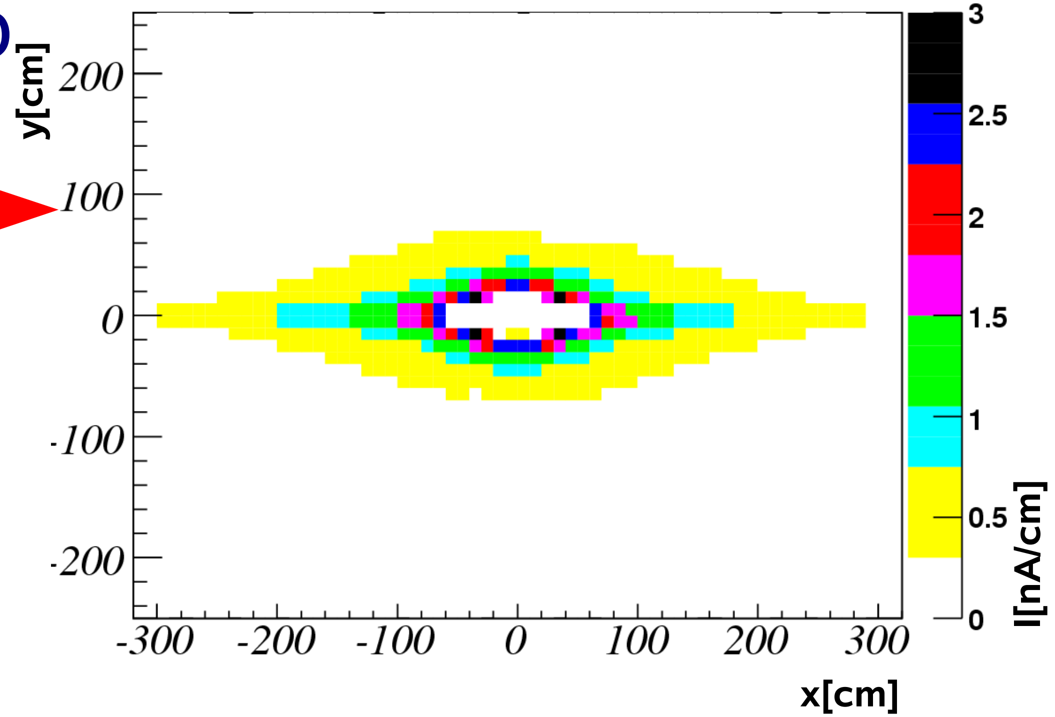
.

Flushing (+Heating) improves modules very significantly.
Therefore, we are confident, that long-term flushing (+heating) up to LHC start-up will provide a detector capable of standing several years of operation at LHC.

Back up

Expectations for LHCb

Expected current profile for running at 2×10³² /cm² s¹ (OT chamber plane)

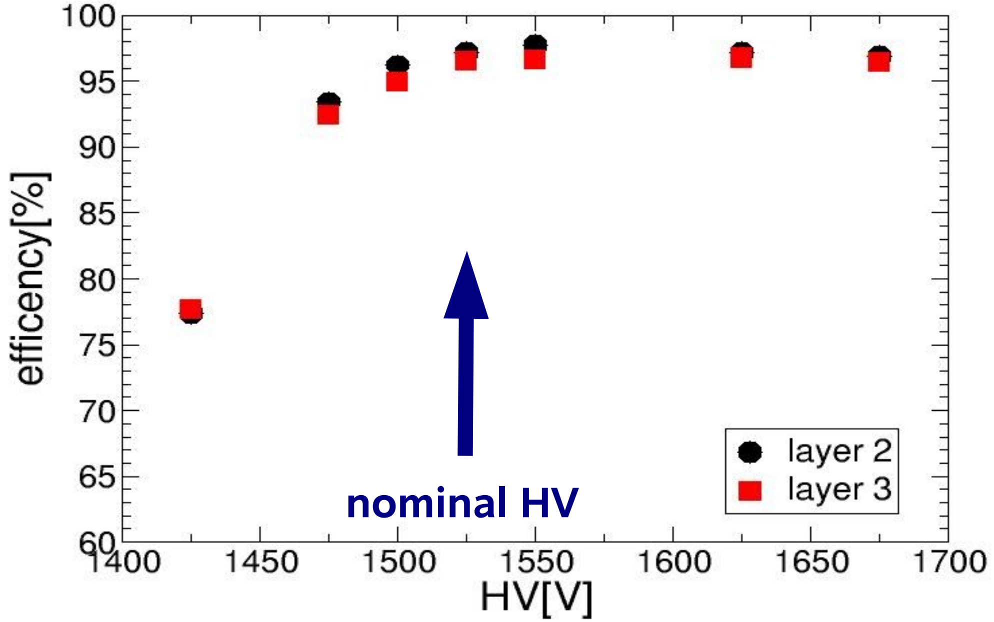


Assume max. damage in the region of 2 – 5 nA/cm.

Estimated **gain drop** in the most damaged area for 3 years ($3x10^7$ s) of LHCb running at $2x10^{32}$ /cm²s¹ :

~ 10% if the positive results from heating is used for the extrapolation

~ 50% if a conservative extrapolation is used,



Gain drop of 50% results in ~15% lower drift-cell efficiency (marginal effect on tracking)

Can be compensated by an high-voltage increase of ~70V

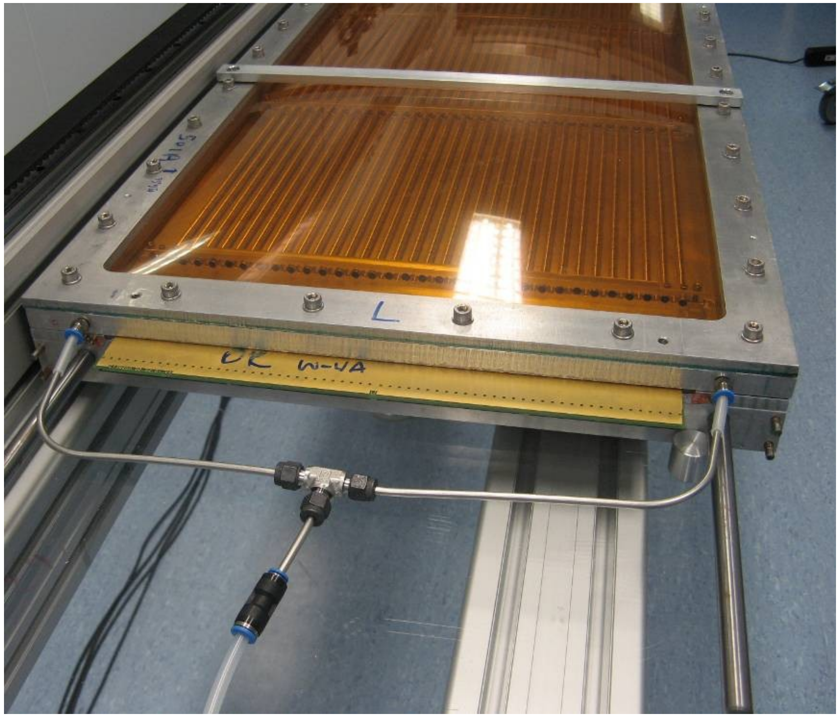
Test of the components

Module build without glue and rohacel panels

1) Irradiation of the module without any additions
2) Addition of glue
   → Irradiation
3) Addition of rohacel panel
   → Irradiation

Until a gain drop will be measured

→ Identify outgassing component

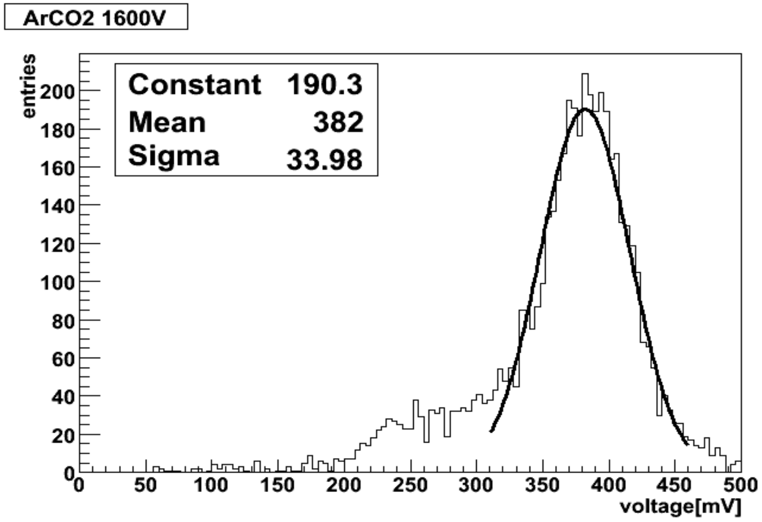


Other possible sources of outgassing

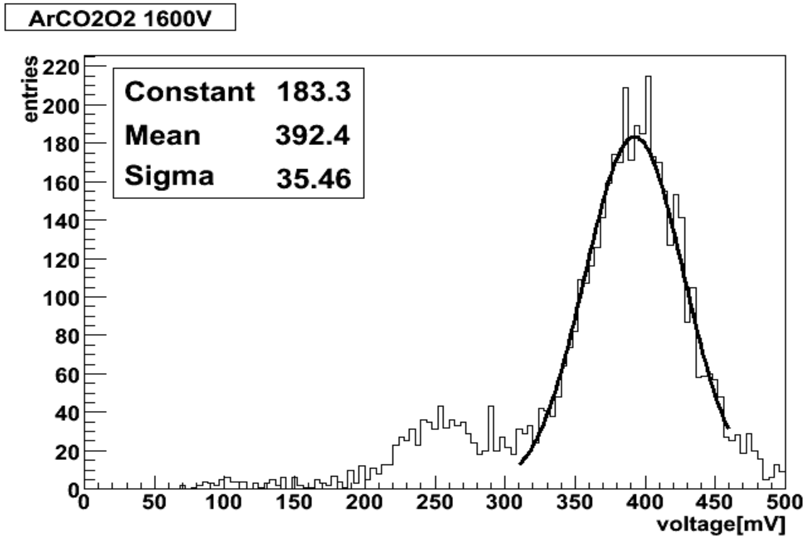
Material contaminated	material delivered in several batches during mass production, but all modules are affected
Pollution during production	modules from all three production sites are affected
Polluted gas system	several gas systems, some completely from stainless steel, were used, aging was seen with each setup
Gas mixture	gas was delivered from different companies

Admixture of O_2

Comparison of ^{55}Fe spectra at 1600V:



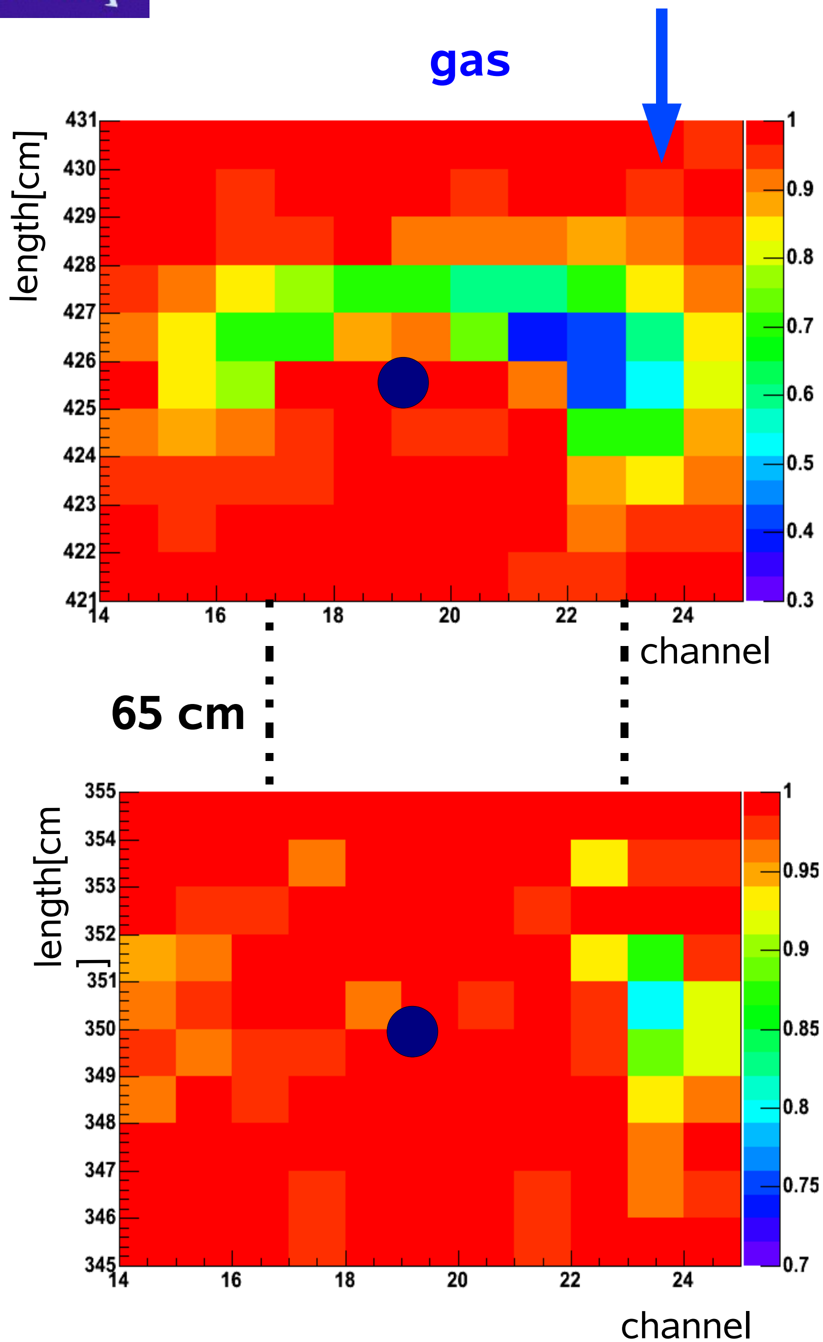
Ar/CO_2 (70%/ 30%)



Ar/CO_2/O_2 (70%/27.5%/2.5%)

Gain at 1600 V: ≈ 88000 ≈ 82000

Transport phenomenon



Setup:

- Two irradiations at the same time
  - Same straws, but different positions along the wire
  - Distance between the sources: 75 cm

→

- Typical gas flow dependence for the upstream source
- Downstream source: no aging at channels with higher irradiation upstream

source