Summary of aging tests of straw tube detectors for the PANDA Forward Tracker

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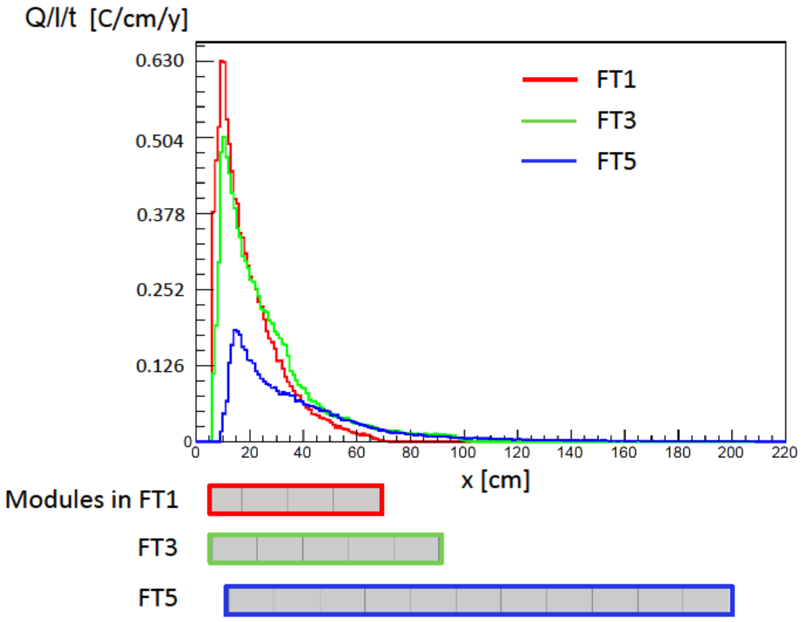
- Accumulated charges expected in PANDA FT
- Test setup
- Measurements of gain drop
- Deposits on anode wires and cathodes
- Conclusions

Aging of gas detectors

Aging - degradation of performance under irradiation:

- loss of gas gain
- worsening of gain uniformity along wires
- dark currents
- self-sustained currents
- …

Expected accumulated charges in FT



Estimation of particle fluxes

- p_b= 15 GeV/c
- *pbar-p* interaction rate 2x10^7 s^{-1}
- 25 kHz cm^{-2} in the vicinity of beam pipe

Accumulated charge

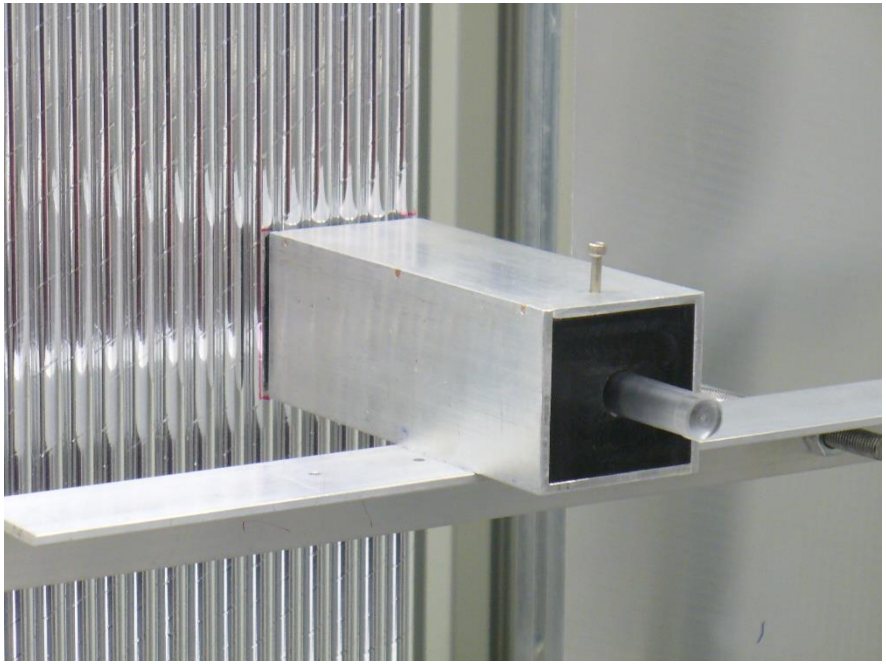
- gas gain 5x10^4
- primary ionization due to MIPs: 200 electrons
- 6 months of data taking per year
- in 10 years of PANDA lifetime, accumulated charge Q/l < 0.75 C/cm for distances from beam axis x > 40 cm, but for smaller distances Q/l reaches 6 C/cm in FT1

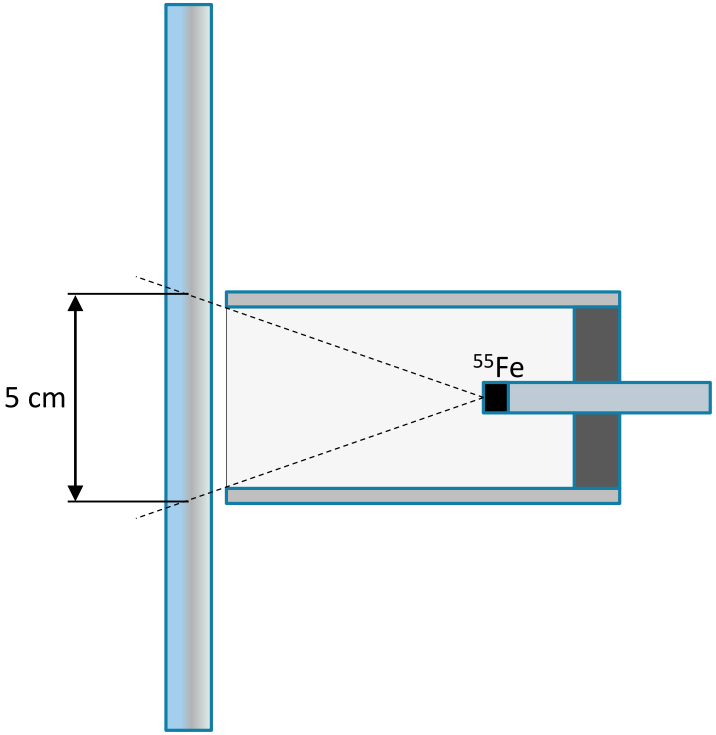
Aging tests performed so far

Test	Period	Max. charge [C/cm]	Tested
1	18.03-5.05.2019	0.36	Straws glued with **UHU** Endfest 300
2	26.02-3.06.2020	0.73	Two component epoxies: **UHU** Endfest 300 vs. **Araldit** AY103+hardener 991
3	25.08-20.10.2020	0.36	Gas pipes: copper, PTFE (teflon), PVC
4	12.11.2020- 2.02.2021	0.53	as above but with gas mixture Ar:CO2 (80:20)
5	16.09.2021- 16.02.2022	1.2	Two-component epoxies: **Ablestic** 2115, **Stycast** 1266, UHU **Endfest** 300, **Araldit** AY103+hardener 991

Test setup

- Collimated ^{55}Fe source
- 4 straws irradiated, each on a length of 5 cm
- 1st test, spring 2019: irradiation period 44 days, accumulated charge 0.36 C/cm





Operating conditions and monitored parameters (1st test)

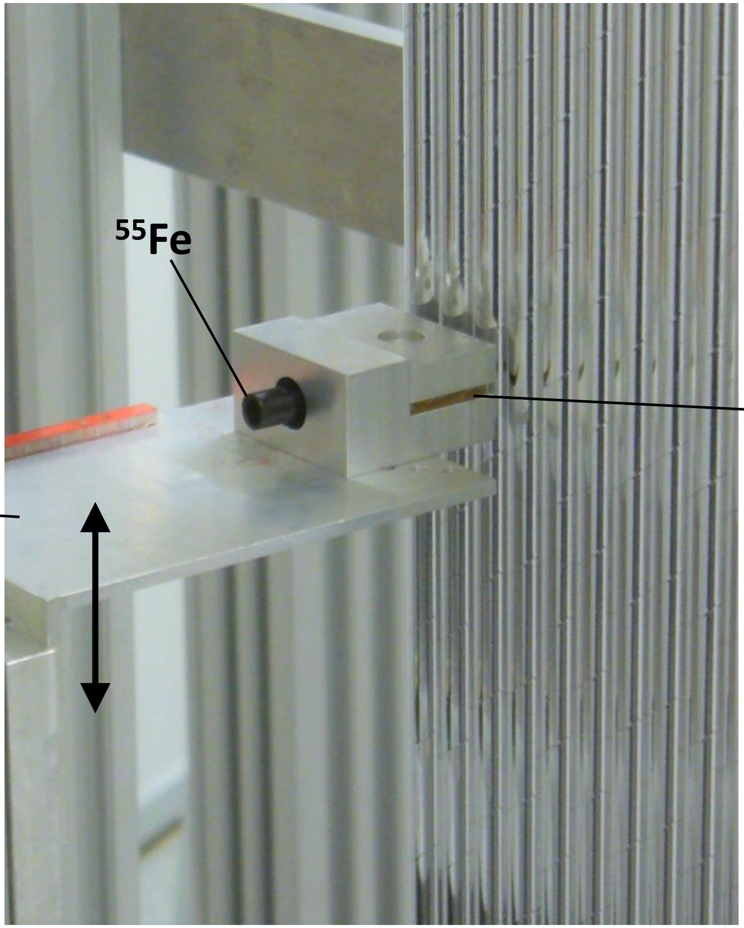
Operating conditions:

- Gas mixture: Ar+CO_2 (90:10) at 2 bar
- Gas flow: 1 volume exchange/hour
- HV: 1850 V,   gas gain: $\sim 5 \times 10^4$

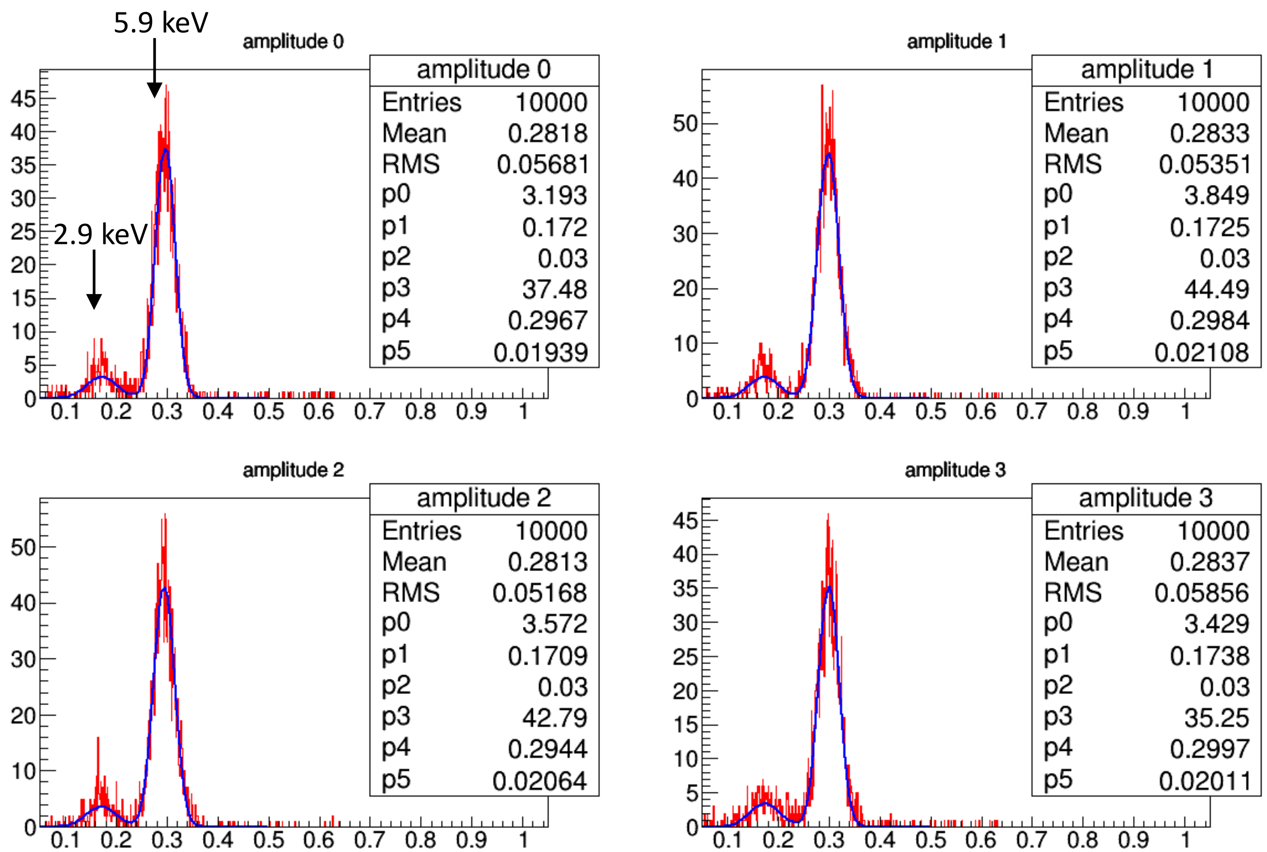
Monitored:

- Rate: ~ 300 kHz/straw (~ 60 kHz/cm) registered with the TRB
- Current: ~ 500 nA/straw
- Amplitude of pulses: measurement with a scope
- Amplitude of pulses as a function the position along the straw was measured for accumulated charges: 0.0, 0.085, 0.194 and 0.36 C/cm

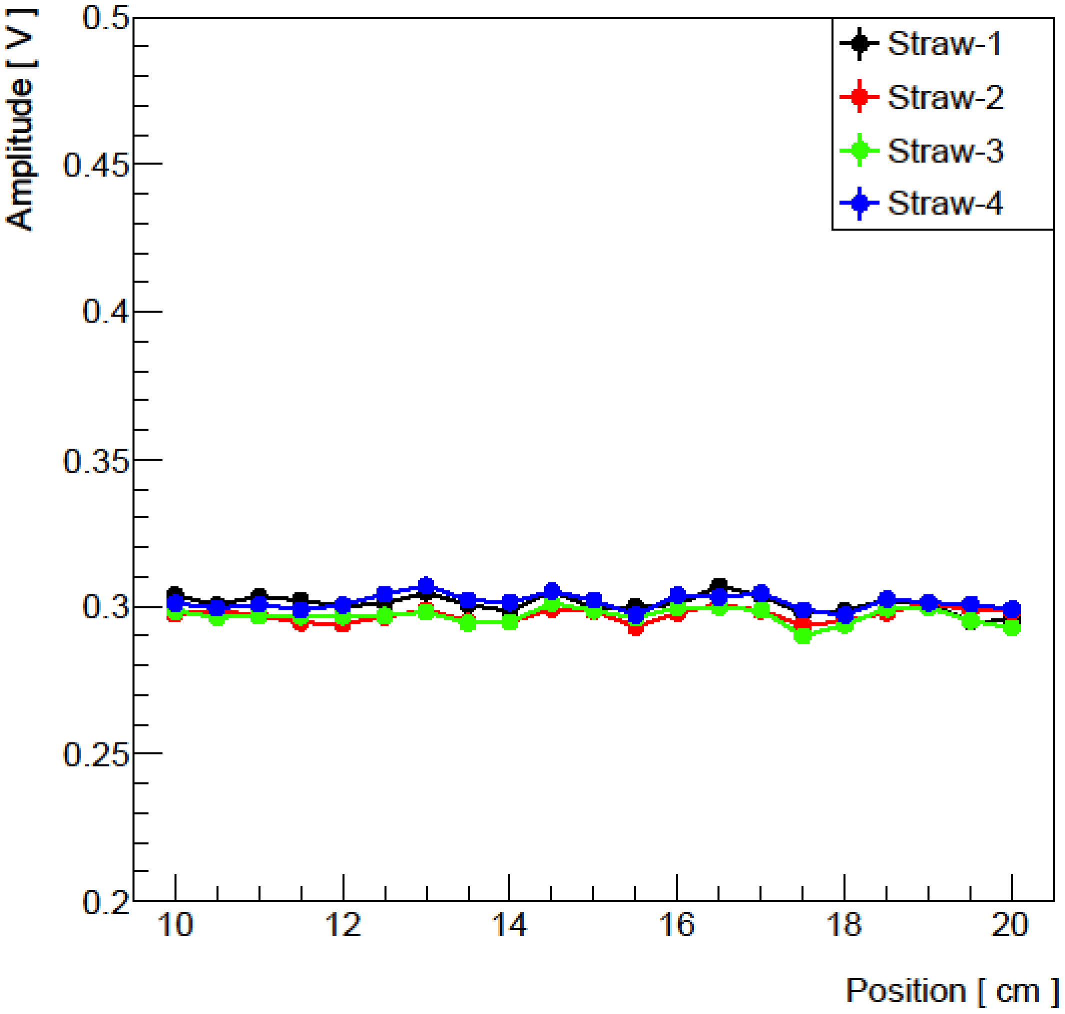
Measuring gas gain along straw



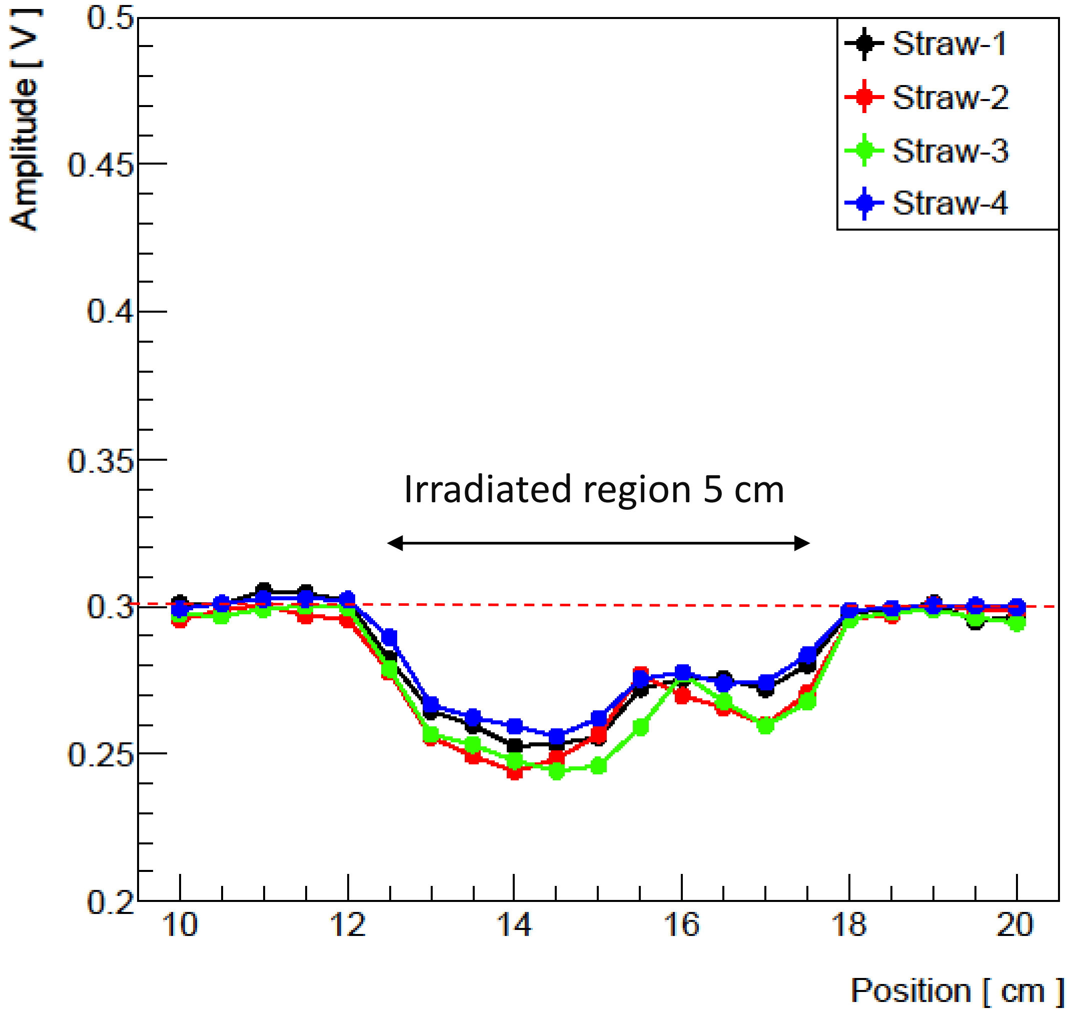
Gaussian fitting of the amplitude spectra



Amplitude of the 5.9 keV peak, 15.03.2019, Q/l = 0 C/cm



Amplitude of the 5.9 keV peak, 7.05.2019, Q/l = 0.36 C/cm

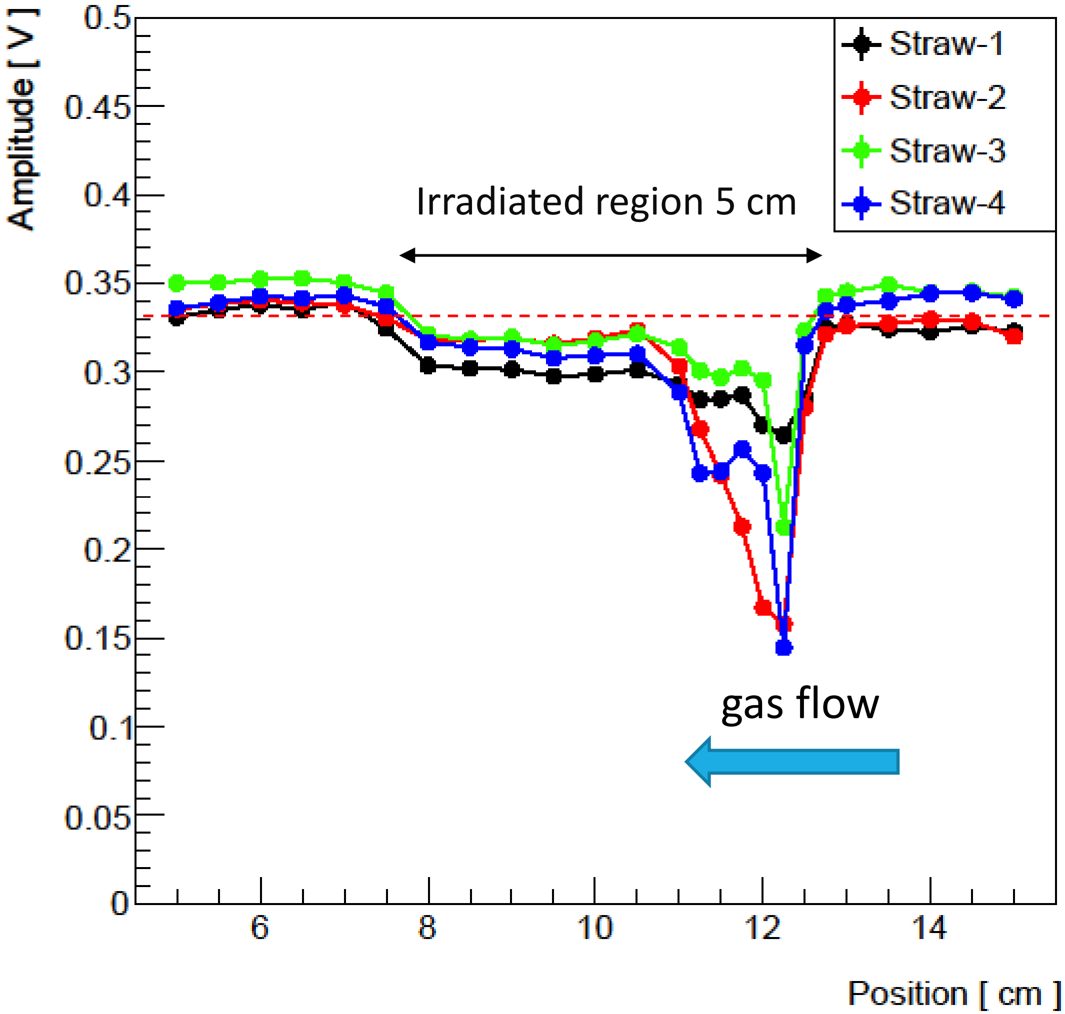


- gain drop ~10 - 20%

2nd aging test, Febr.-June, 2020, Q/l= 0.73 C/cm

- 4 straws irradiated with ^{55}Fe:
  - 2 straws (#1 and #2) glued with **UHU Endfest 300**
    and another 2 (#3 and #4) with **Araldit AY103 + hardener 991**
  - straw #1 and #3 – **long plastic pipe (22 cm)** at gas inlet (lower gas flow);
    straw #2 and #4 – **short plastic pipe (10 cm)** at gas inlet

amplitude vs. position
for Q/l= 0.63 C/cm (19.05.2020)



UHU, long pipe

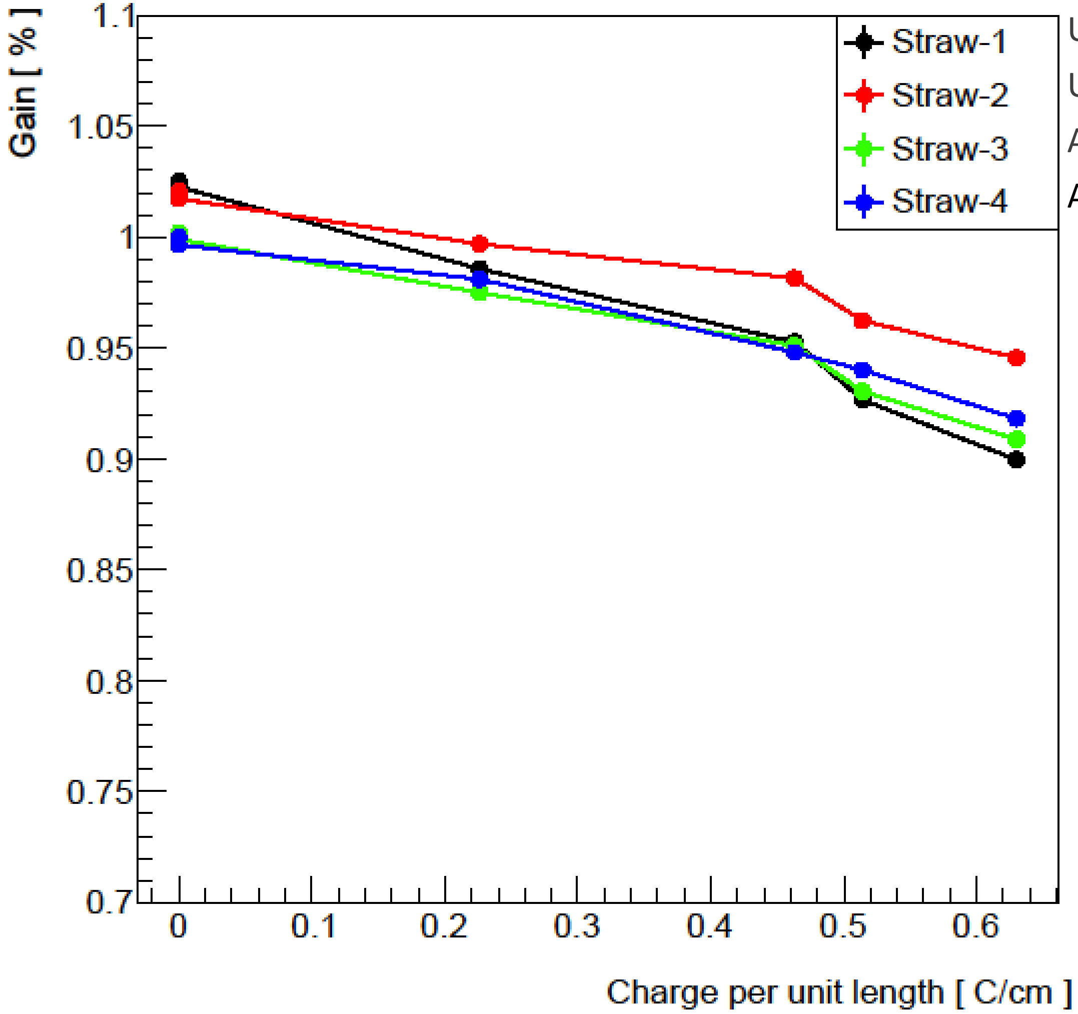
UHU, short pipe

Araldite, long pipe

Araldite, short pipe

- Lower gas flow (straw #1, #3) – smaller gain drop at gas inlet and higher further downstream compared to higher gas flow (straw #2, #4)
- No big differences between gain drop for straws glued with UHU and Araldit
- Gain drop in straws glued with UHU smaller than in the 1st test presumably due to longer gas flushing before test

Gain drop in the region (8 cm, 10 cm)



UHU, long pipe

UHU, short pipe

Araldite, long pipe

Araldite, short pipe

- For accumulated charge 0.63 C/cm, observed gain drop is ~8 % in irradiated region downstream gas flow (8cm, 10cm)

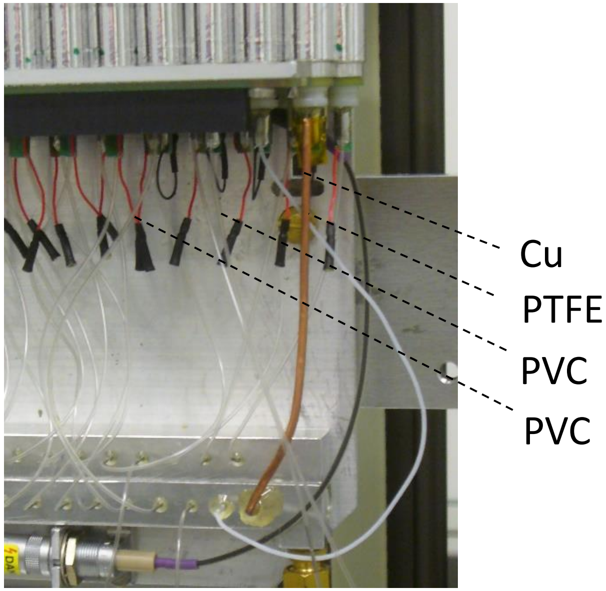
Measurement of self sustained current for irradiated straws

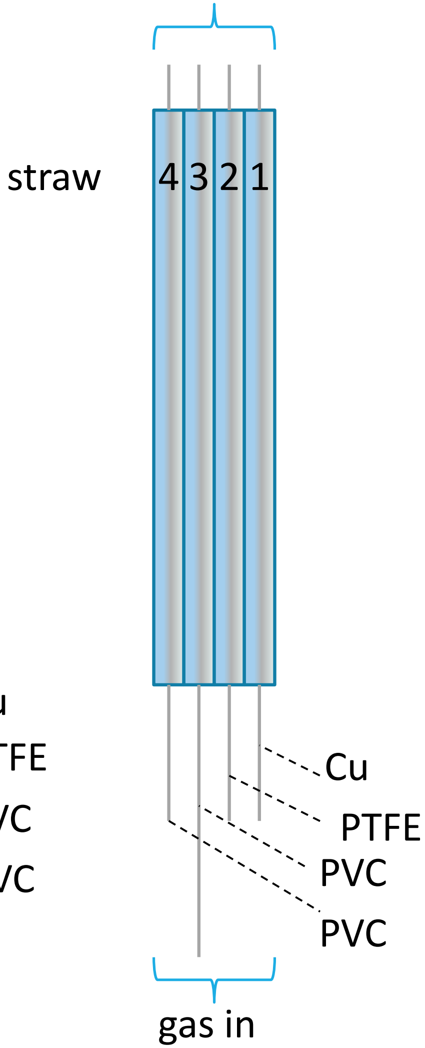
- At HV = 1800 V, current with source = 1007 nA drops to 2 nA within approx. 1 second after removing the source
- Rate drops from 240 kHz to ~1 Hz
- Scope: clean pulses, no after-pulses observed

3rd aging test, August- Oct. 2020, Q/l= 0.36 C/cm

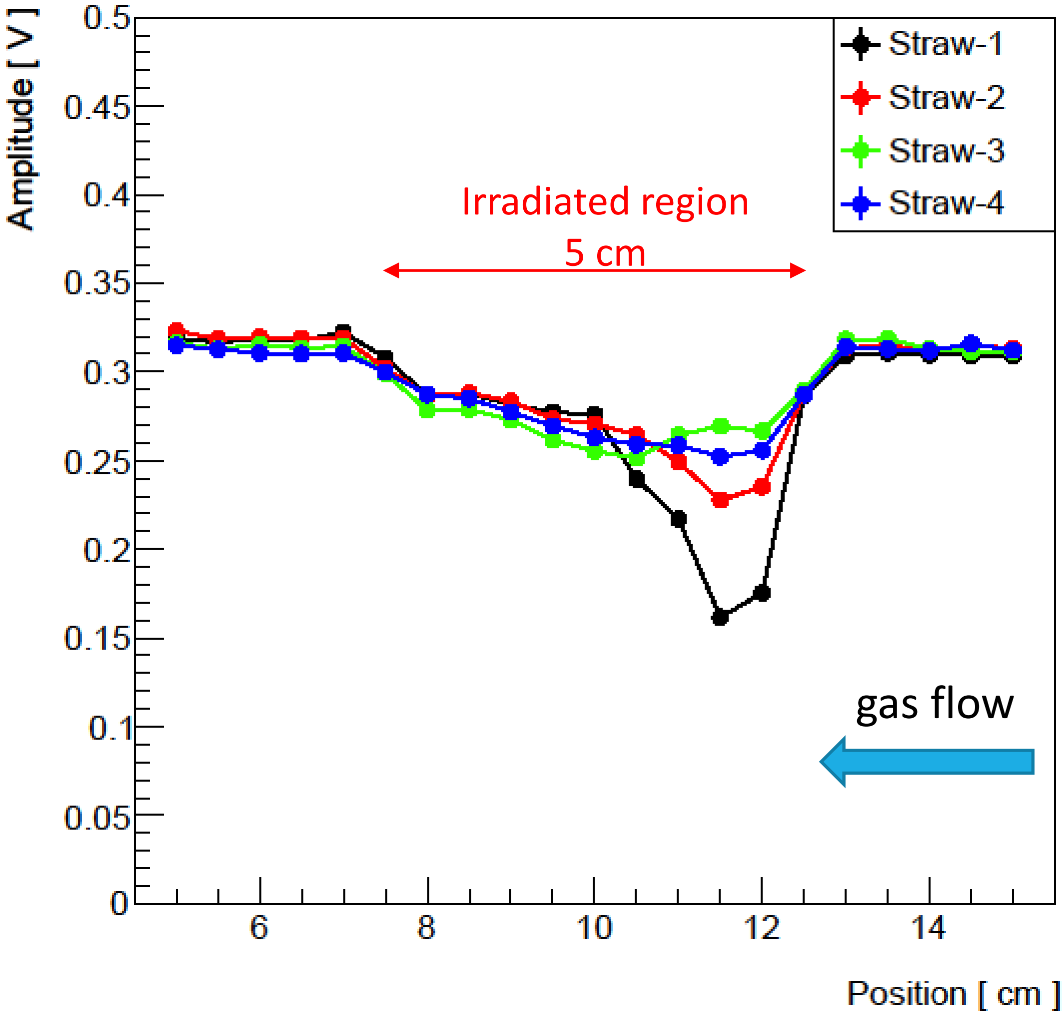
- straws glued with **Araldit AY103-1 + hardener 991**
- gas pipes used at the inlet to the straw:
  - Straw 1 - **copper capillary tube (Øin = 0.6 mm)**
  - Straw 2 **– PTFE (Teflon) tube (Øin = 0.56 mm)**
  - Straw 3 – **PVC tube (Øin = 0.5 mm) l = 24 cm**
  - Straw 4 – **PVC tube (Øin = 0.5 mm) l = 12 cm**

> the same gas flow





Amplitude vs. position for Q/l= 0.36 C/cm



gas pipe

Cu
PTFE
PVC
PVC

- No significant difference between PTFE and PVC pipes -> **PVC pipes do not contribute to the aging**
- Amplitude drop larger for Cu pipe (due to higher gas flow or higher contamination by outgassing from Araldite?)
- The same gain drop for straw #3 and #4 (same gas flow but 2x longer PVC pipe at input of #3) -> **PVC pipes do not contribute to the aging**

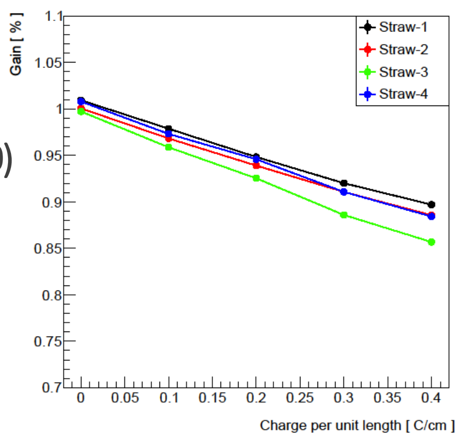
4th aging test, Nov. 2020- Feb. 2021, Q/l= 0.53 C/cm

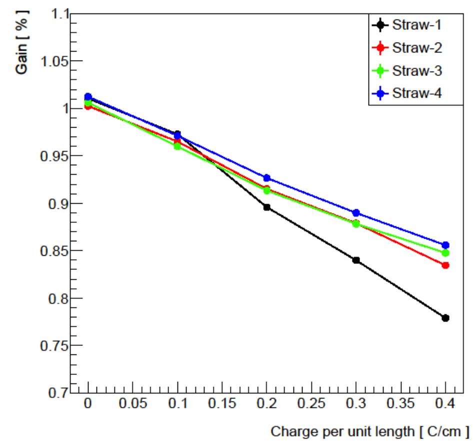
Setup as in test 3 but gas mixture Ar:CO2 (80:20)

region (8 cm, 10 cm) (8 cm, 12 cm)

Test 3:

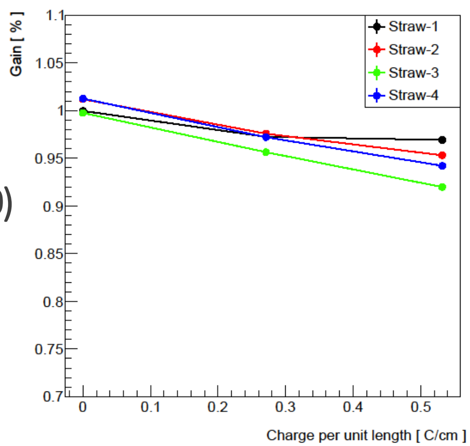
Ar:CO2 (90:10)

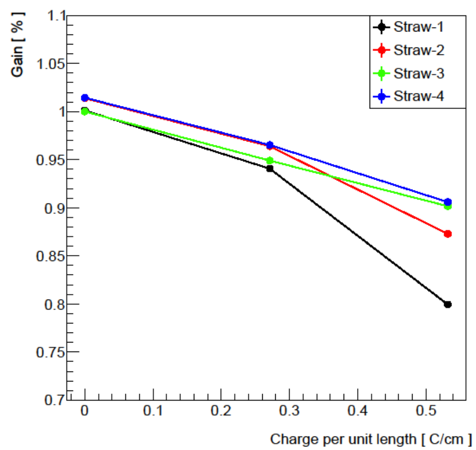




Test 4:

Ar:CO2 (80:20)

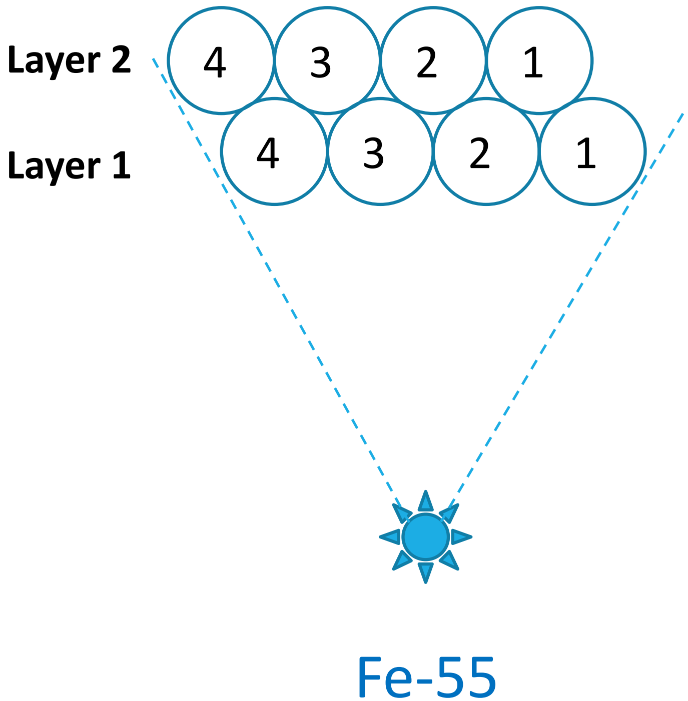




- Gain drop in test 4 smaller than in test 3 (Ar:CO_2 90/10).

It may result from higher CO_2 content or longer gas flushing.

5th aging test, Sept. 2021-Febr. 2022, Q/l up to 1.2 C/cm

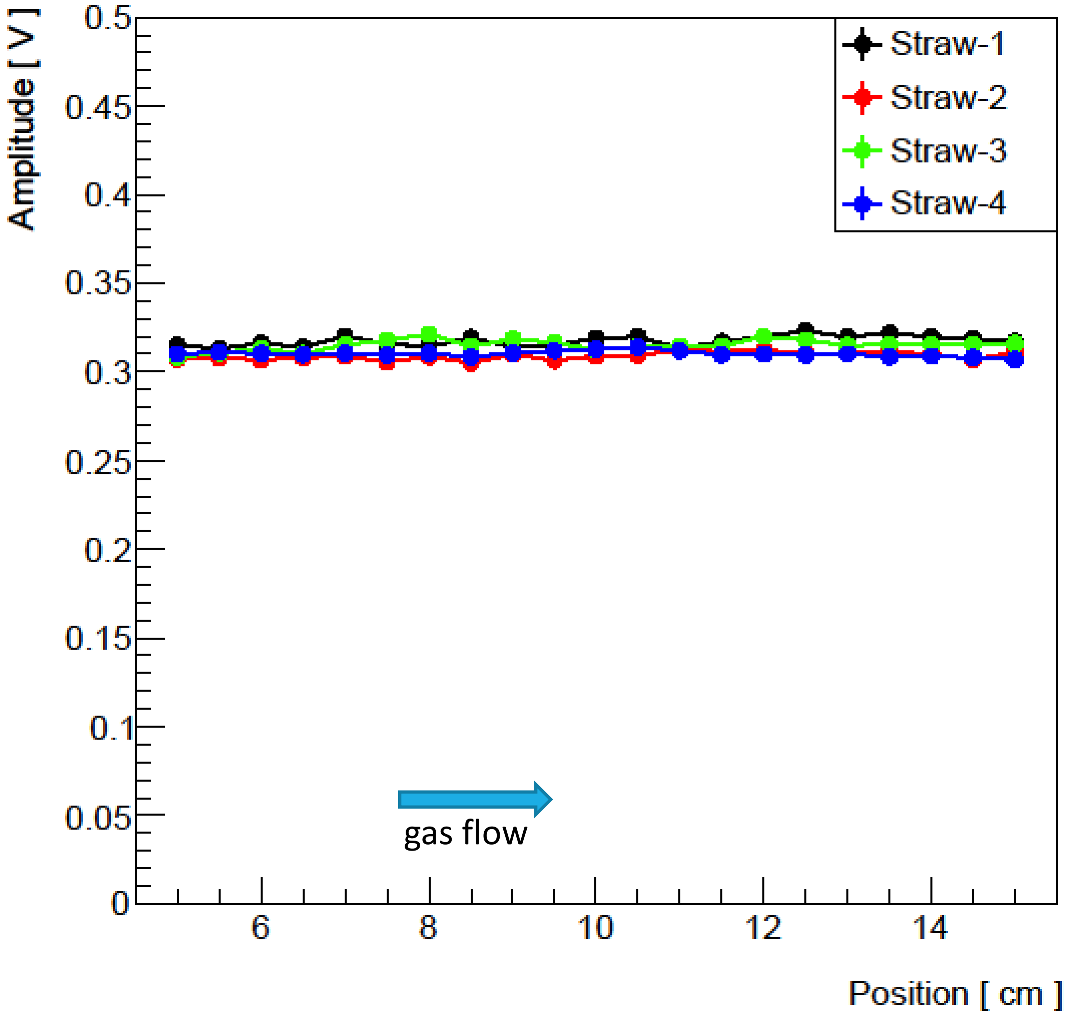


Layer 2:
- Straw 1 - Ablestic 2115
- Straw 2 - Stycast 1266
- Straw 3 – UHU Endfest 300
- Straw 4 – Araldit AY103+ hardener 991

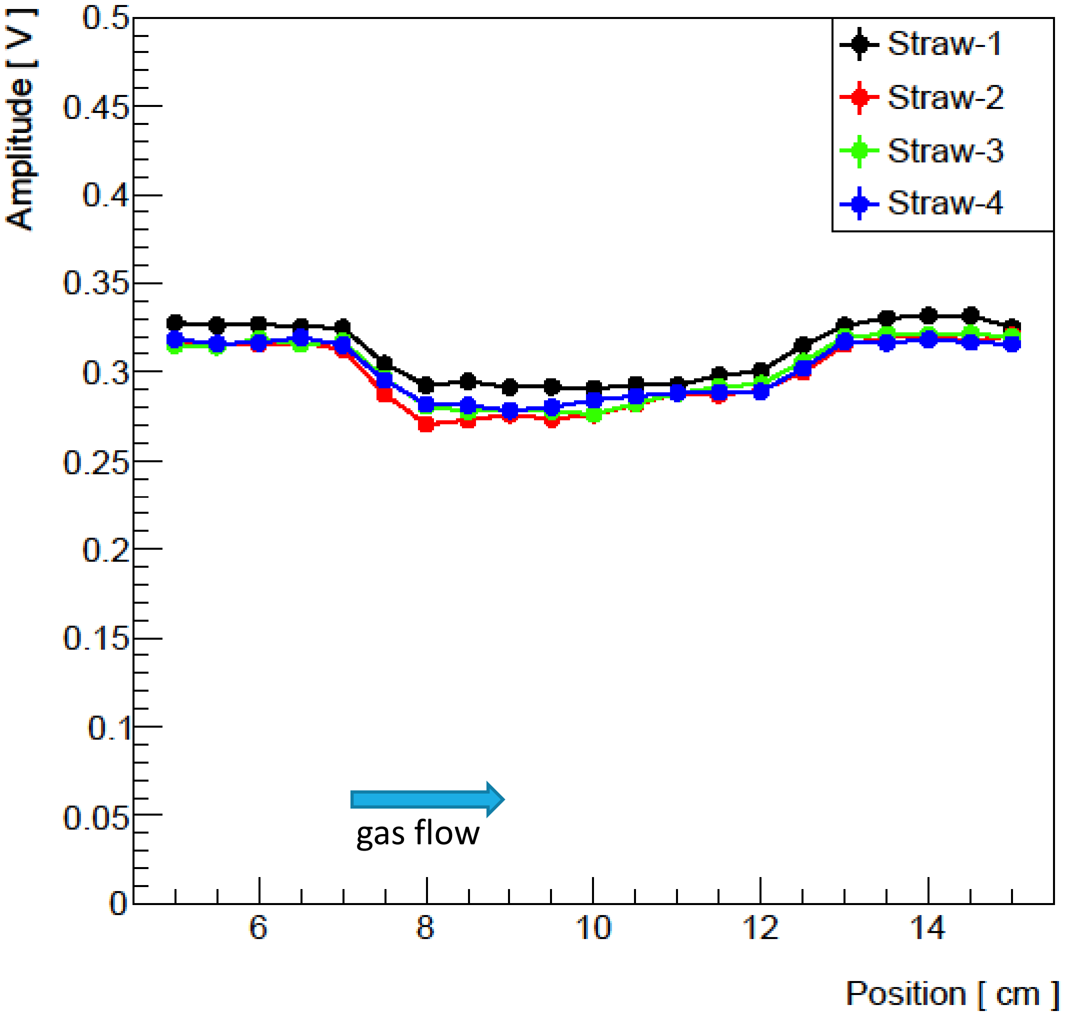
Layer 1:
- Straw 1 - Ablestic 2115
- Straw 2 - Stycast 1266
- Straw 3 - Stycast 1266
- Straw 4 – Araldit AY103+ hardener 991

Gas mixture from the gas system flows first through the straws in the first layer and then through the second layer

amplitude vs. position, 1st layer for Q/l= 0.0 C/cm (15.09.2021)



amplitude vs. position, 1st layer for Q/l= 0.27 C/cm (19.10.2021)



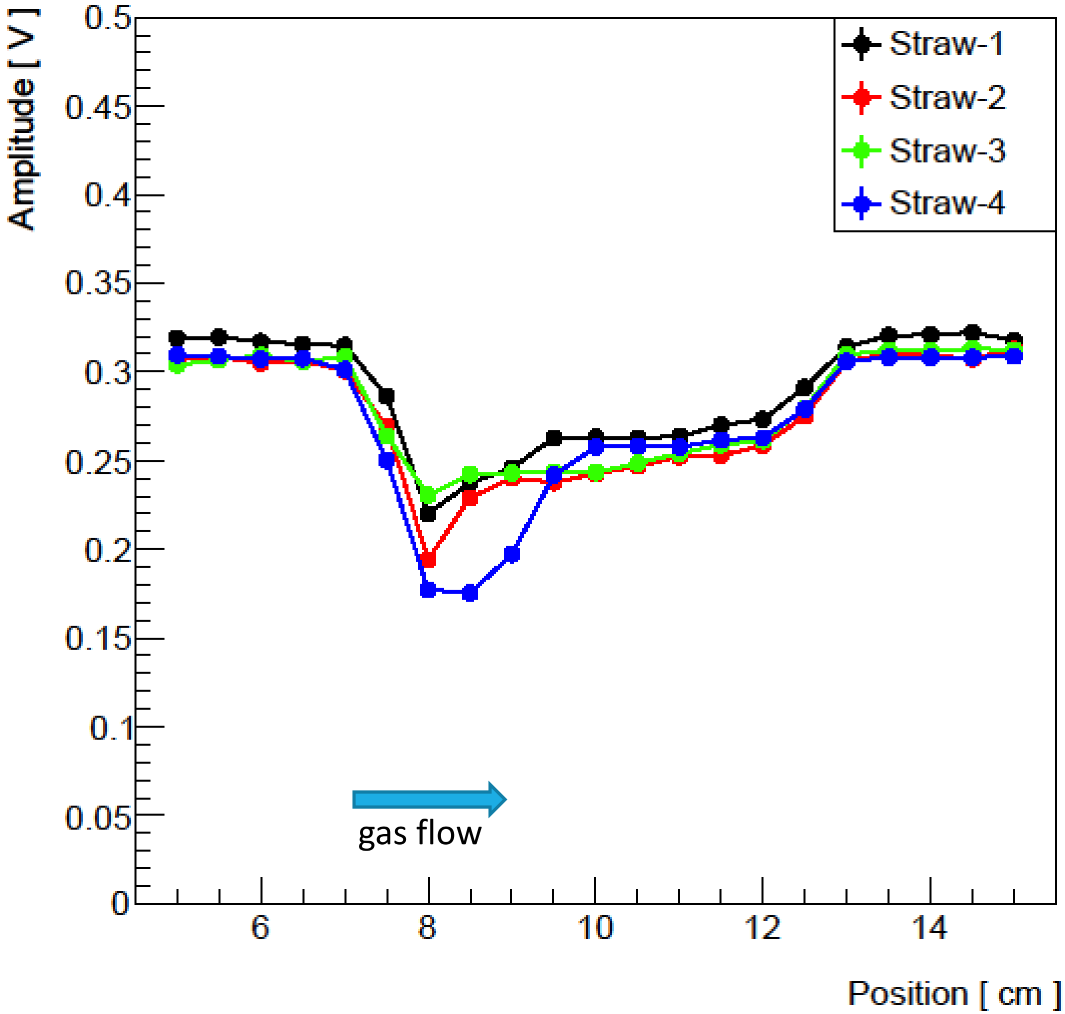
1 - Ablestic 2115

2 - Stycast 1266

3 - Stycast 1266

4 – Araldit AY103

amplitude vs. position, 1st layer for Q/l= 0.65 C/cm (3.12.2021)



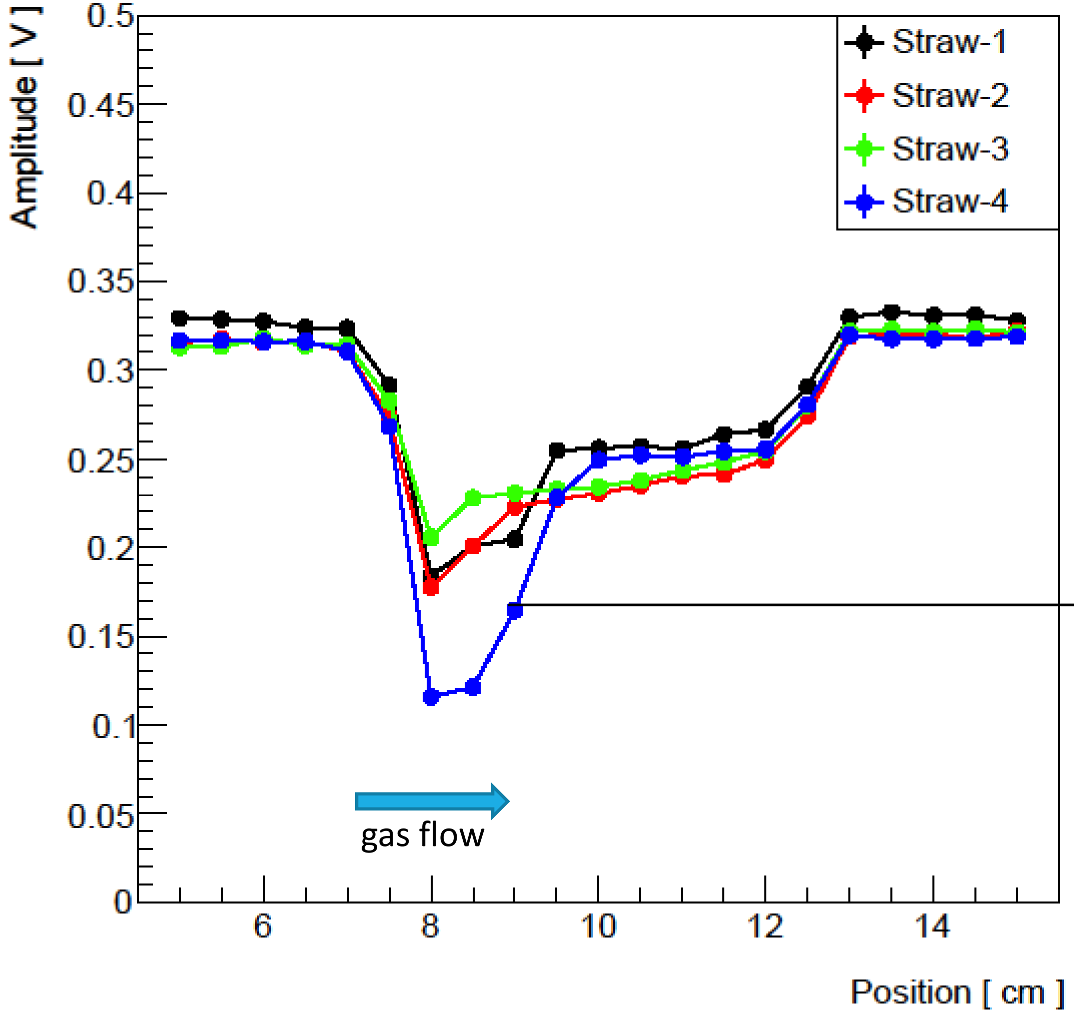
1 - Ablestic 2115

2 - Stycast 1266

3 - Stycast 1266

4 – Araldit AY103

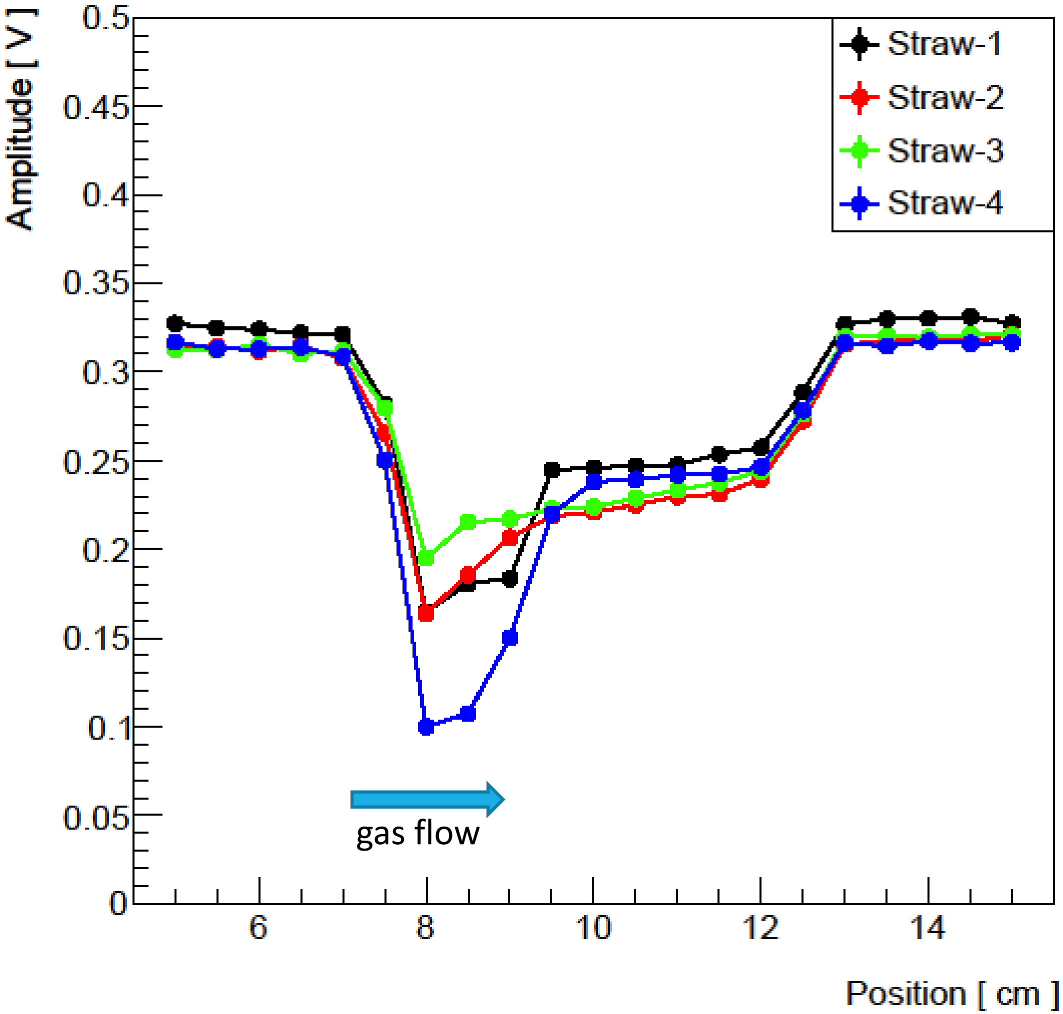
amplitude vs. position, 1st layer
for Q/l= 1.0 C/cm (21.01.2022)



1 - Ablestic 2115
2 - Stycast 1266
3 - Stycast 1266
4 – Araldit AY103

Higher outgassing (Araldit)

amplitude vs. position, 1st layer for Q/l= 1.2 C/cm (16.02.2022)



1 - Ablestic 2115

2 - Stycast 1266

3 - Stycast 1266

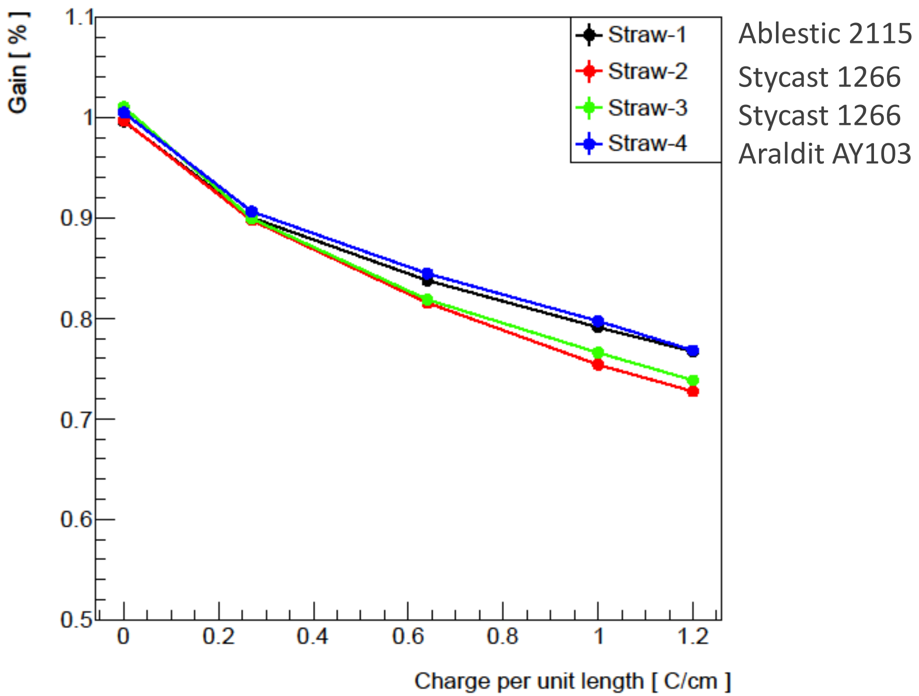
4 – Araldit AY103

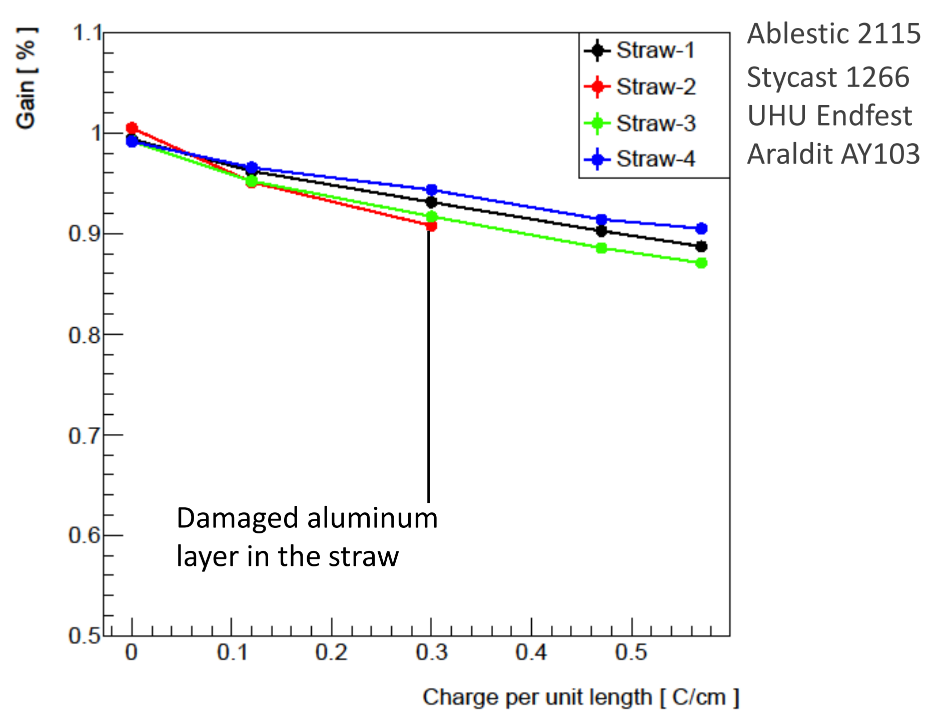
- Araldite causes a higher gain drop at the gas inlet (higher outgassing), but otherwise there are no major differences between the adhesives.

Gain drop downstream gas flow

Layer 1, region (10 cm, 12 cm)

Layer 2, region (8 cm, 10 cm)

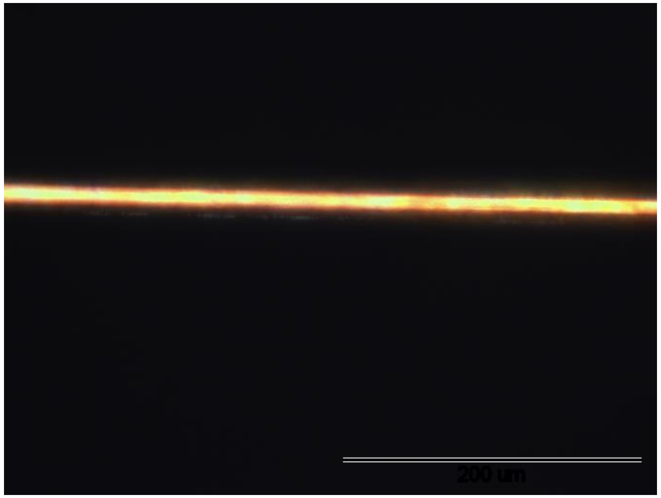




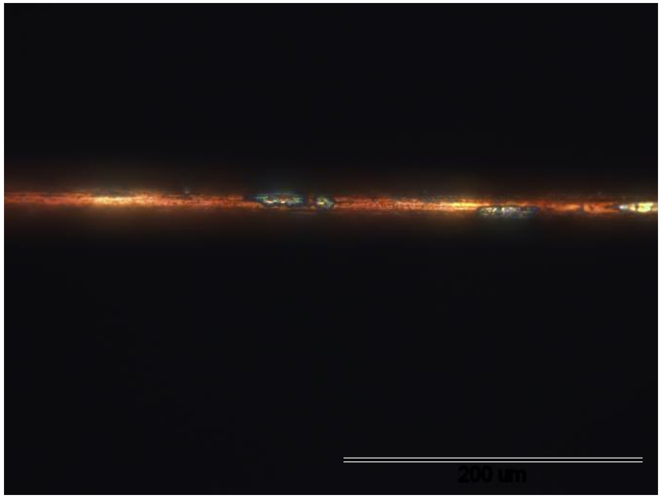
- In the second layer, the aging for Araldite is smaller than for UHU
- Gain drop in the second layer is smaller than in the first layer; gas is cleaned in the first layer or higher ozone content (?)

Deposits on anode wires (gold-plated W/Re, 20 μm)

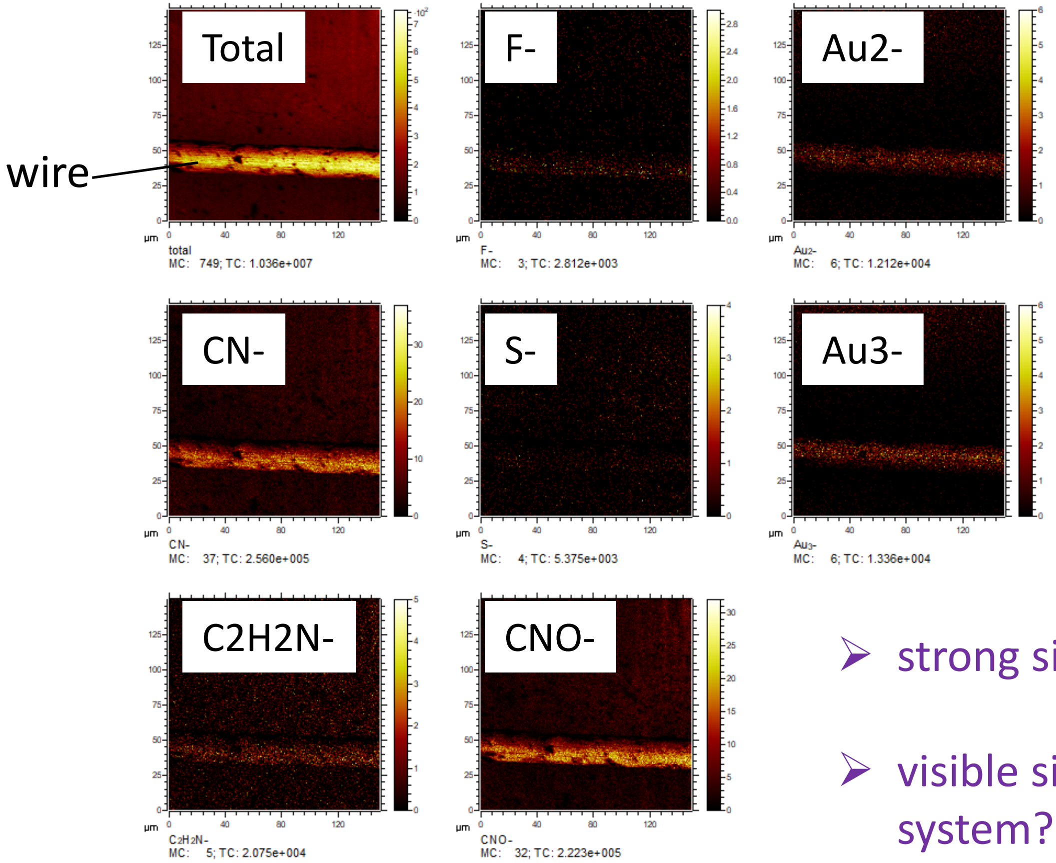
Pristine



Exposed (1st test)



Analysis of deposits by TOF-SIMS (Time Of Flight - Secondary Ion Mass Spectrometry).



- strong signal from organic molecules, e.g. CNO
- visible signal from fluoride (gaskets in the gas system?)

Measurements with Scanning Electron Miscroscope (SEM)

Definitions

SE – Secondary Electrons (surface topography)

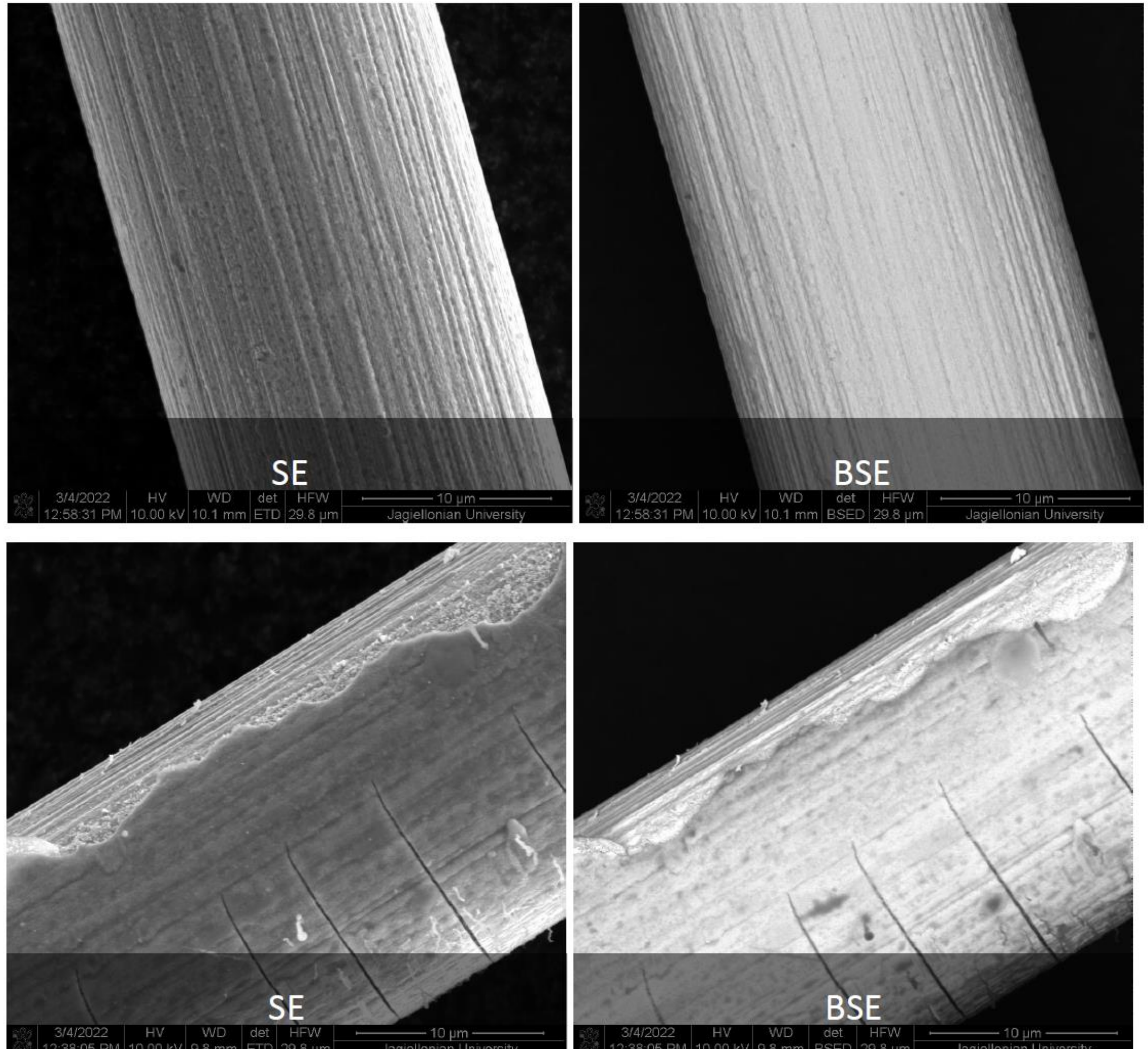
BSE – Backscattered Electrons (composition – atomic number)

EDX – Energy-dispersive X-ray spectroscopy

SEM SE/BSE (Tungsten wire)

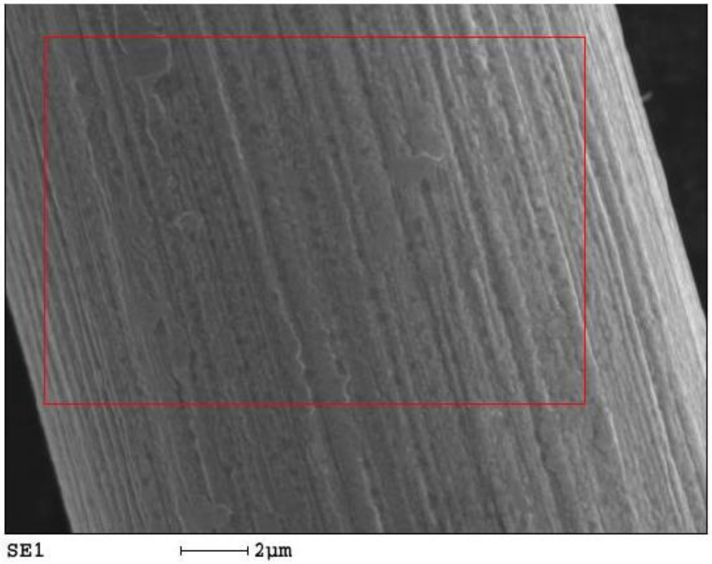
Pristine

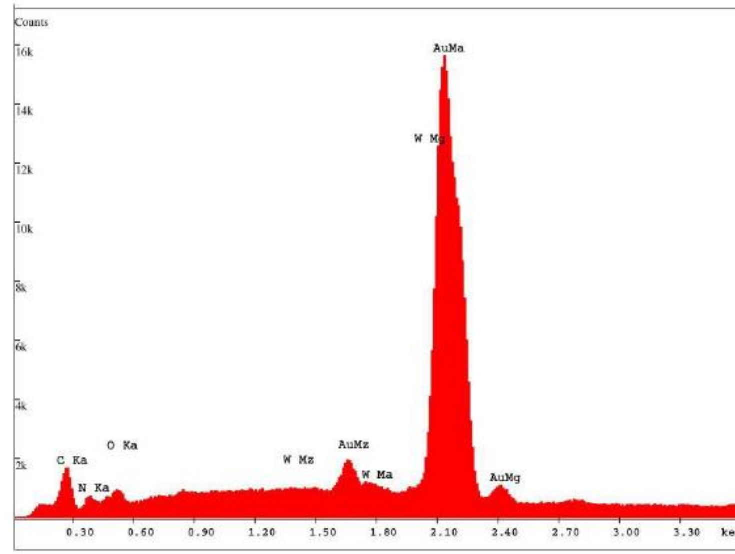
Exposed



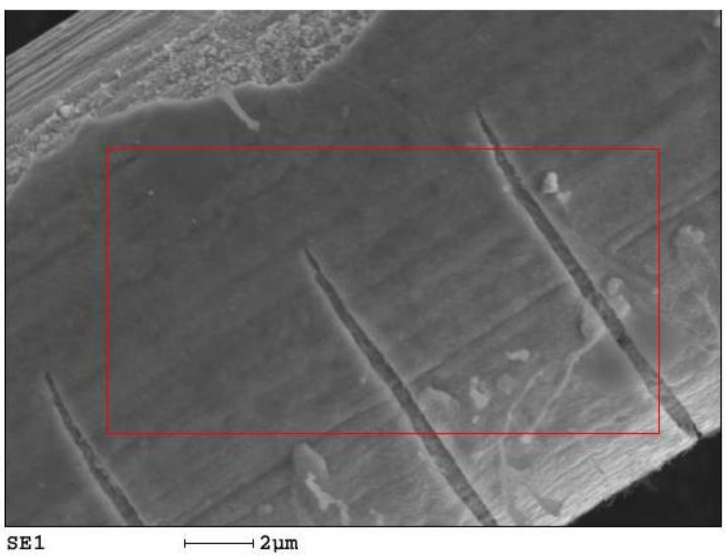
SEM EDX (Tungsten wire)

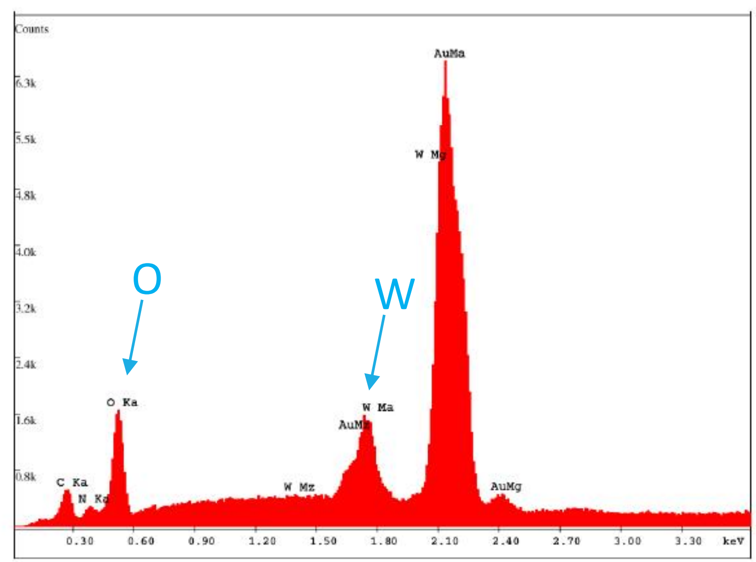
Pristine





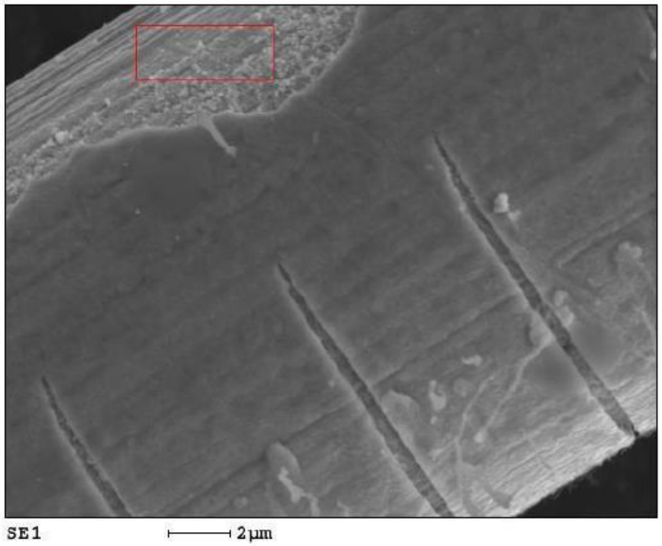
Exposed

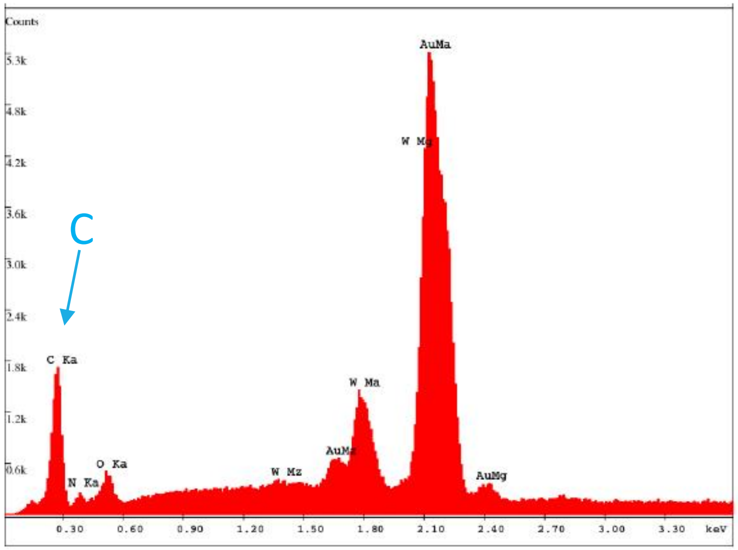




SEM EDX (Tungsten wire)

Exposed



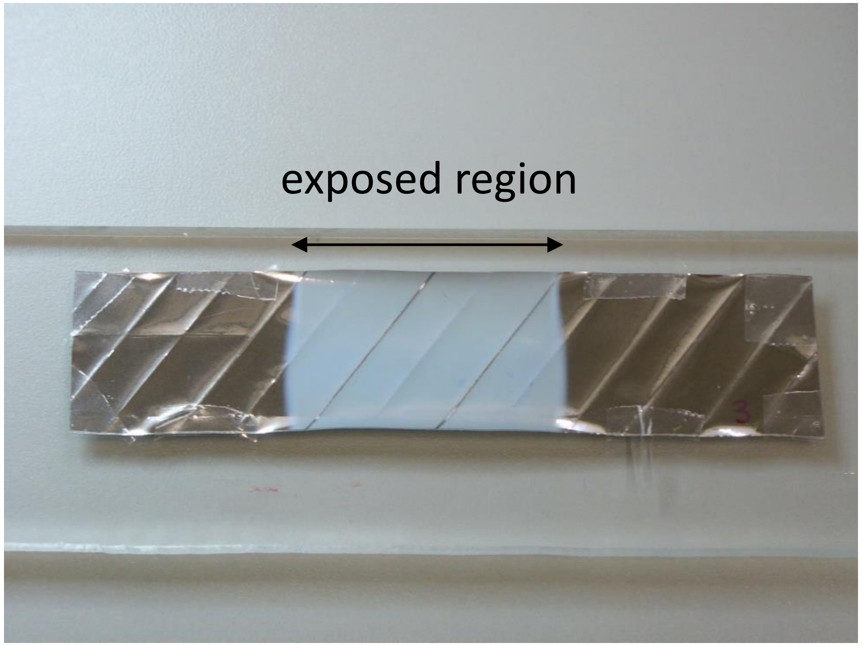


➢ SEM EDX of exposed wire shows the presence of carbon, oxygen and tungsten (damaged gold coating)

Degradation of cathode foil

Straw foil: 27μm Mylar + 1000 Å aluminum coating

straw foil after 1st test



Resistance of cathode foil before and after irradiation (test 3+4)

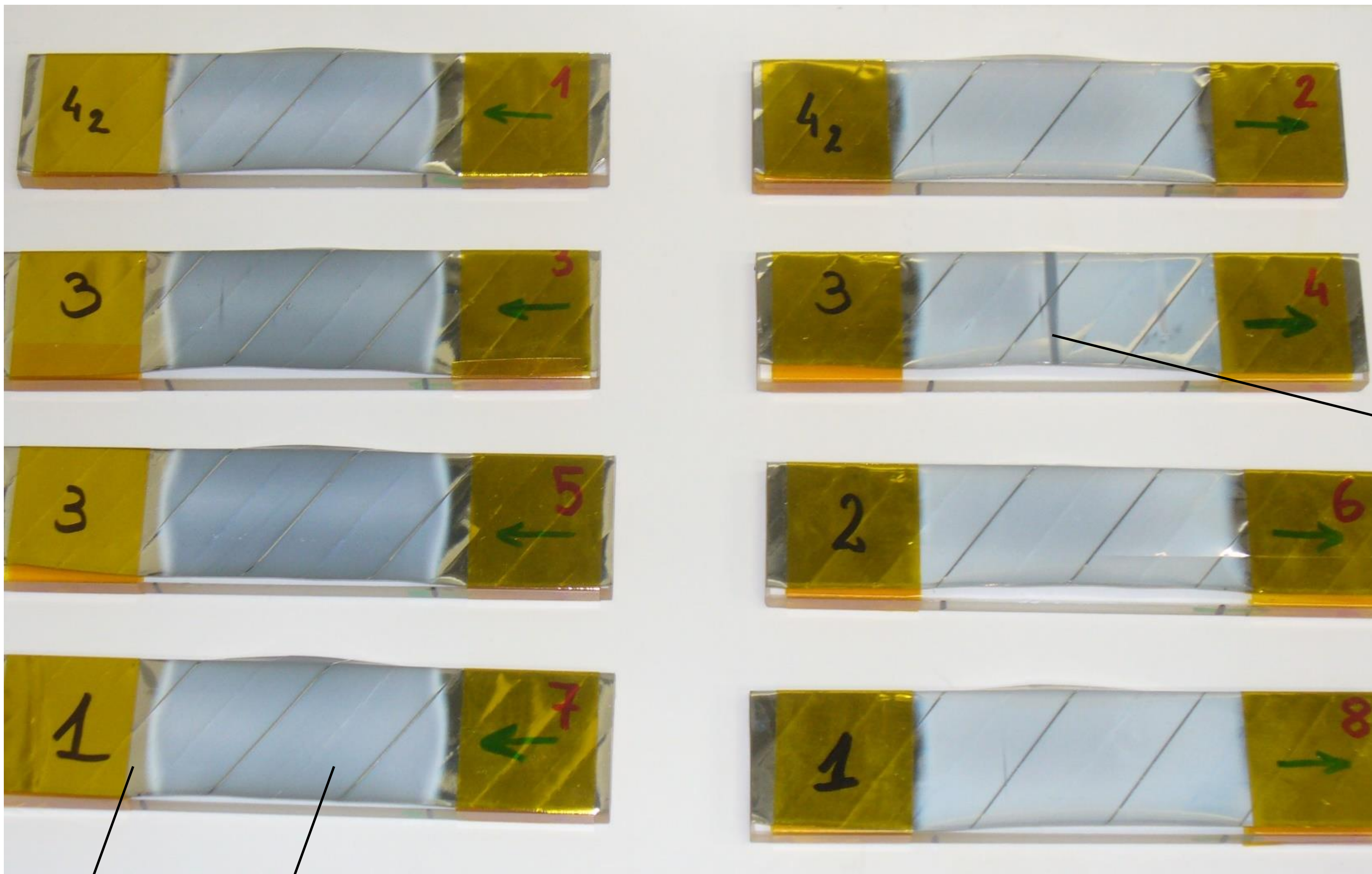
Resistance *R* measured between ends of 60 cm long straw

For 4 straws not irradiated $R \sim 19\ \Omega$

For 4 straws irradiated in test 3 and 4 along L = 2x5 cm =10 cm $R \sim 24\ \Omega$

- resistance of 5 cm long segment of straw increases from 1.6 Ω to 2.5 Ω after irradiation ~ 0.4-0.5 C/cm

Degradation of cathode foil (5th test)



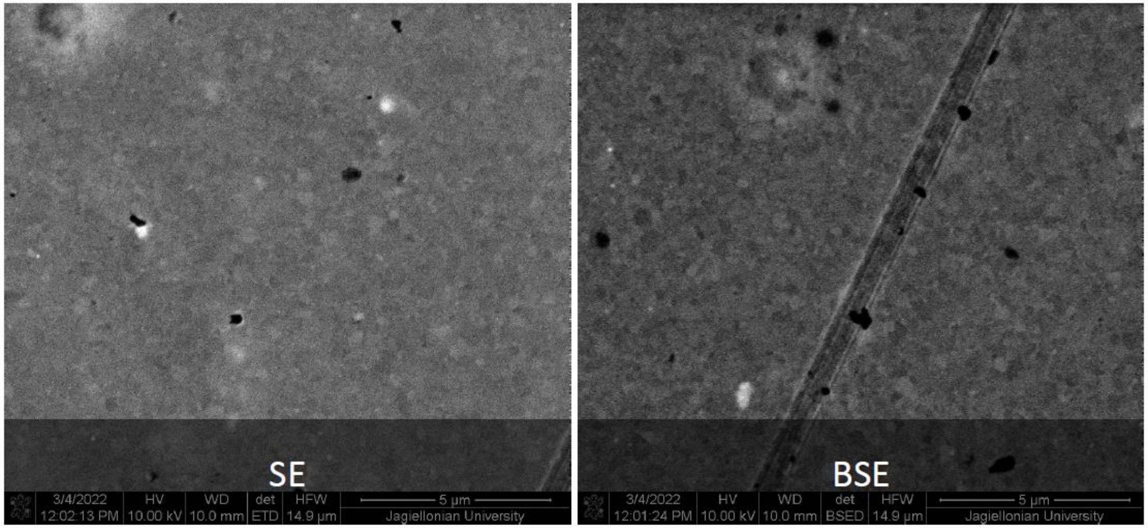
break in aluminum layer (due to discharge ?)

pristine

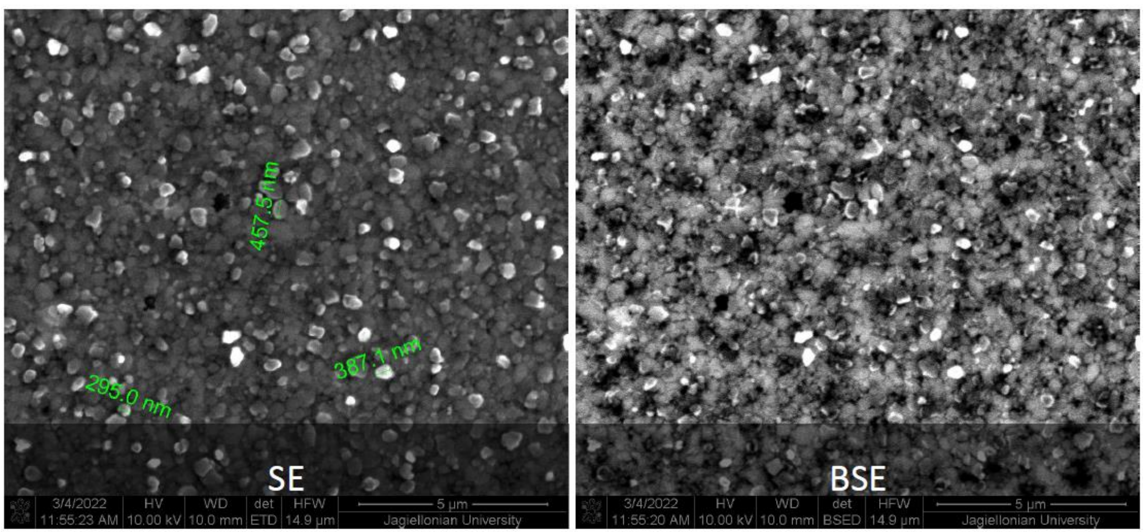
exposed

SEM SE/BSE (Mylar/Al.)

Pristine



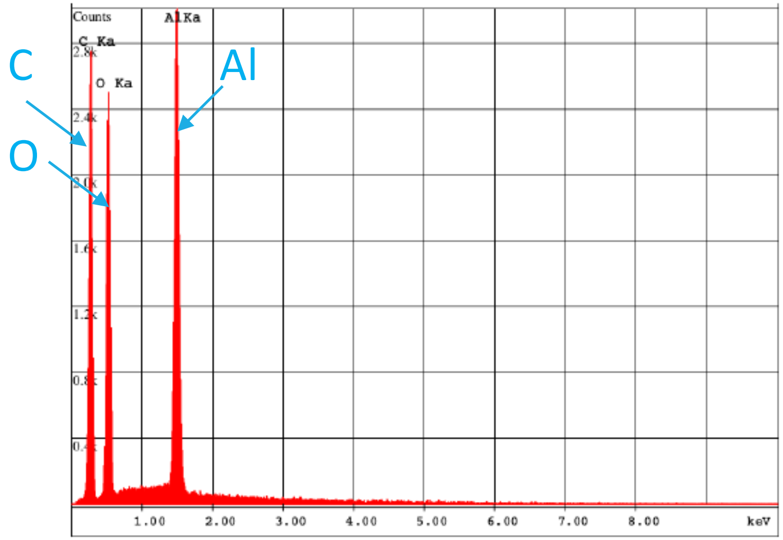
Exposed



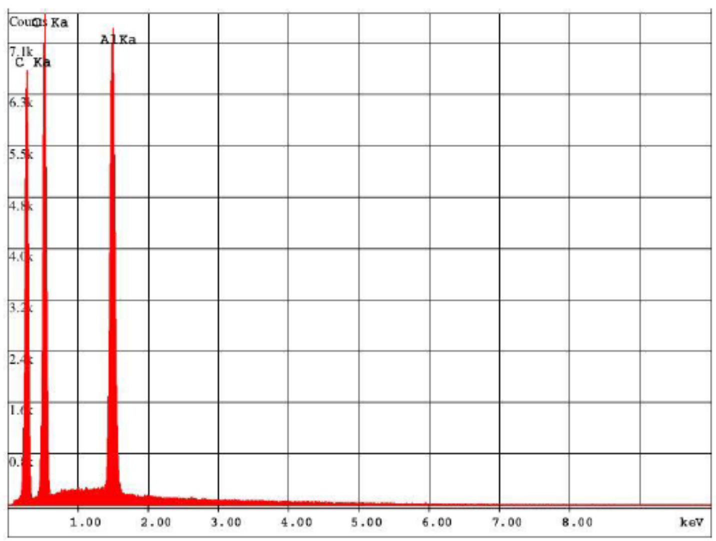
- SEM SE of exposed aluminized mylar shows degradation of the surface flatness

SEM EDX (Mylar/Al.)

Pristine



Exposed

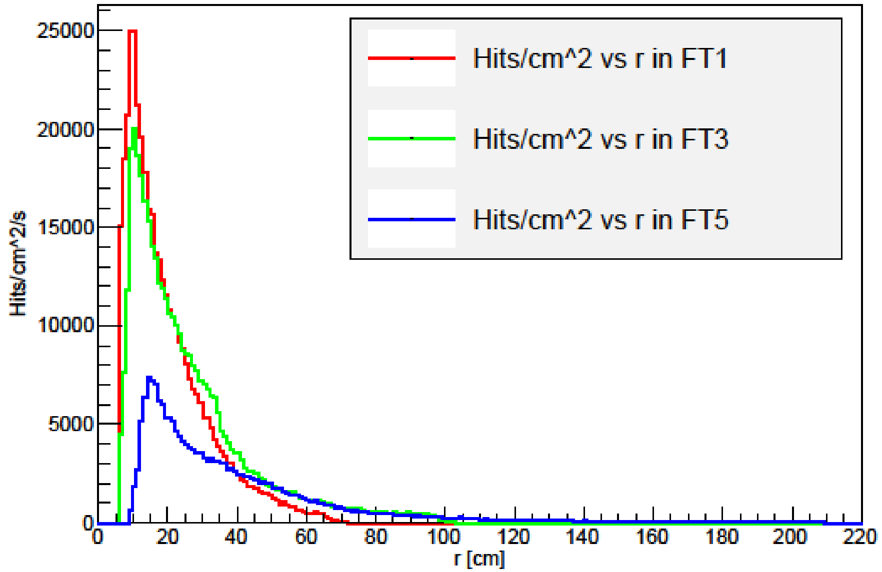


Summary of the aging tests performed so far

- Aging of FT straws studied for accumulated charges up to 1.2 C/cm
- Observed effects:
  - Drop of gas gain
  - Deposits on anode wires
  - Deterioration of aluminium straw surface
- The cause of aging has not been identified, but:
  - Outgassing of PVC pipes rather excluded
  - The use of various types of epoxies is not decisive for observed aging
  - Long-term flushing of the detector (several months) prior to testing helps reduce aging
- Planned further tests:
  - with new, clean gas system
  - adding ~1% oxygen to gas mixture to increase ozone content

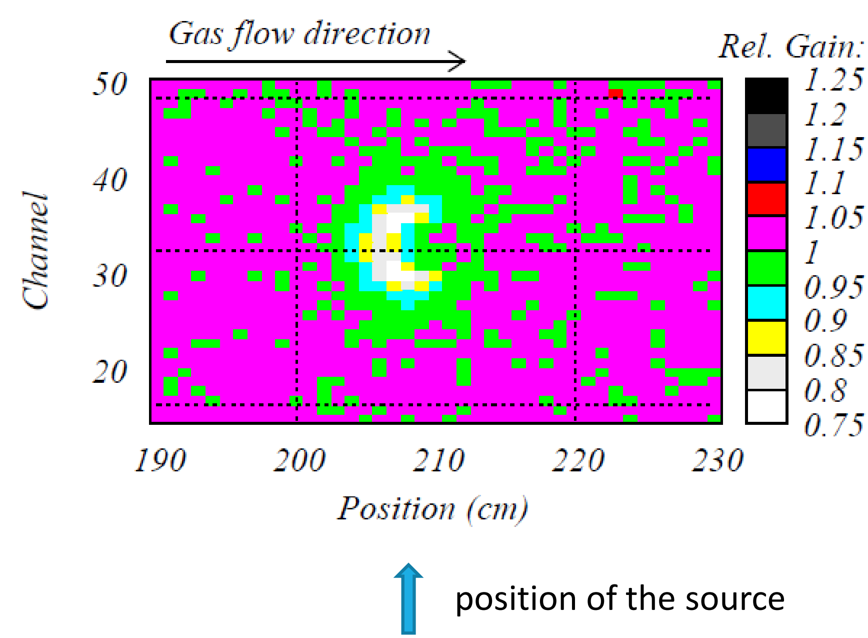
Backup slides

Expected particle rates in FT



Aging of the LHCb straw tubes

- Straw tubes: Ø 4.9 mm, 25 μm W/Au wire, Ar-CO2 (70%-30%)
- Gluing and sealing of the straws with Araldite AY103-1 +hardener HY991
- Detected aging at moderate intensities in laboratory tests (after straw mass production was completed)
- The gain loss up to 25% for integrated dose of 0.1 mC/cm at intensity of 2 nA/cm
- Aging upstream the source
- Lower gas flow- lower aging
- Wire inspection: deposits of carbon



For more details see:
S. Bachman et al., NIM A617 (2010) 202,
N. Tuning et al., NIM A 656 (2011) 45

Cause of the aging in LHCb straws

- No aging observed for straws sealed with o-ring instead of the Araldite
- Also no aging for Araldite replaced by Tra-Bond 2115
- Outgassing of the araldite AY103-1 identified as the cause of observed aging (probably outgassing of plastifier: di-isopropyl-naphthalene contained in AY103-1).
- Negative correlation observed between the aging rate and the production of ozone.

LHCb OT aging remedies

- Adding ~1 % O_2 to Ar-CO_2 (increasing ozone concentration)
- Lowering gas flow (ozone is transported away more slowly)
- Longterm flushing the modules
- Heating the modules
- HV training