Long-term Operation of the Multi-Wire-Proportional-Chambers

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based on the paper: **F. P. Albicocco** *et al* 2019 *JINST* **14** P11031

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Outlines

- General description of Muon LHCb infrastructure;
- Structure of MWPC;
- Operational and trip intro (What is the trip? Malter-like currents);
- The number of malfunctioned chambers during the Runs;
- A process of chamber curing/restoring;
- Result;

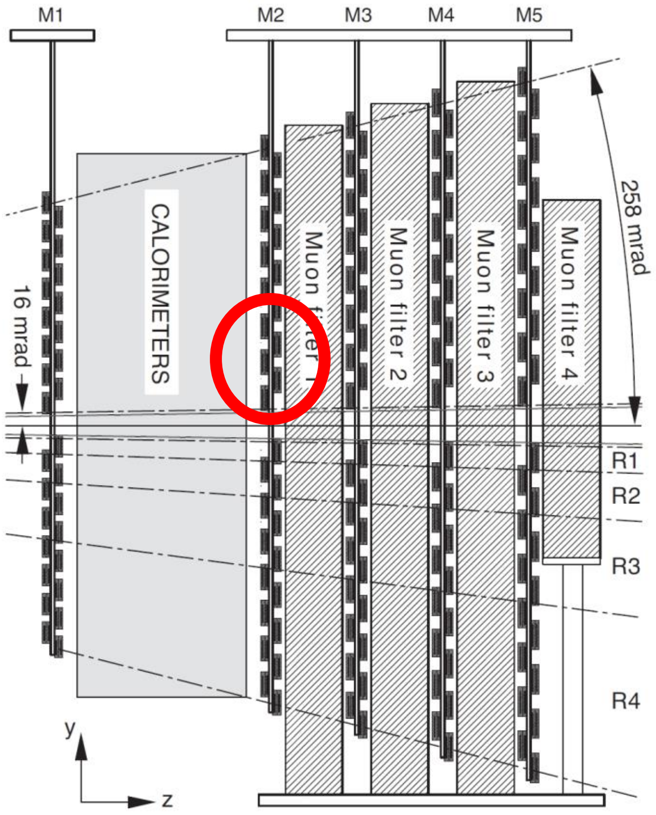
LHCb Muon System

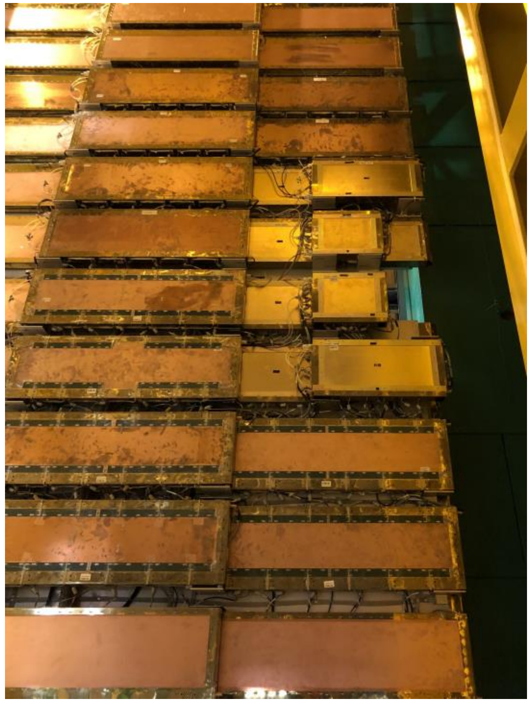
LHCb Muon System:

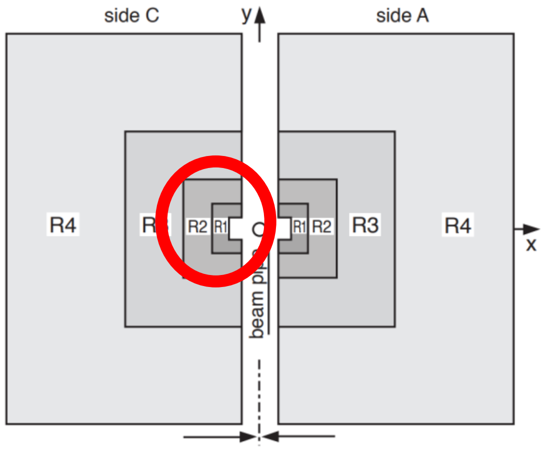
- 5 stations M1-M5 (Run 1) reduced to 4 M2-M5 in Run 2 and Run 3;
- 4 regions R1-R4;
- 20 chamber types;
- 1368 MWPCs cover 435 m^2.

Operational information:

- $L_{instantaniously} = 4 * 10^{32} \, cm^{-2} * s^{-1}$
- Operational efficiency >99%;
- More than 13 years of sustained work.



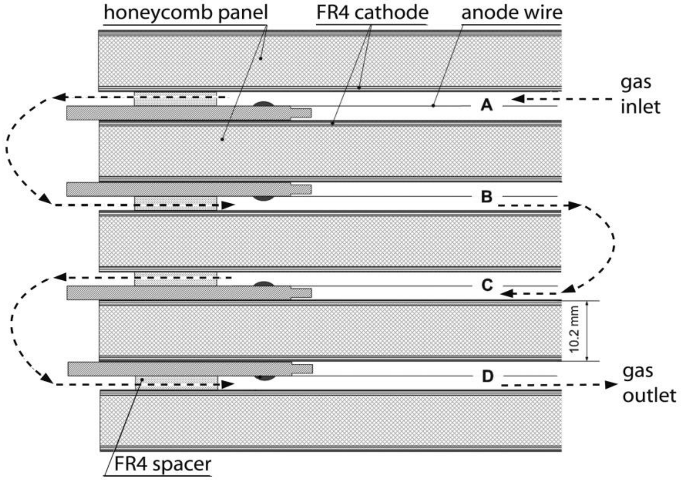




LHCb Collaboration, LHCb muon system: Technical Design Report, Geneva : CERN, 2001. - 89 p.

Design of MWPC (M2-M5)

- 4 High Voltage independent gaps (A-D) per chamber;
- **Cathod**: fiber-glass plates (FR4) + 35 µm copper coating;
- **Anode:** 30 µm tungsten wires;
- Gap-structures divided by **honeycomb** planes;
- **OR**-ed readout;
- 40% ***Ar*** + 55% ***CO2*** + 5% ***CF4*** gas mixture;

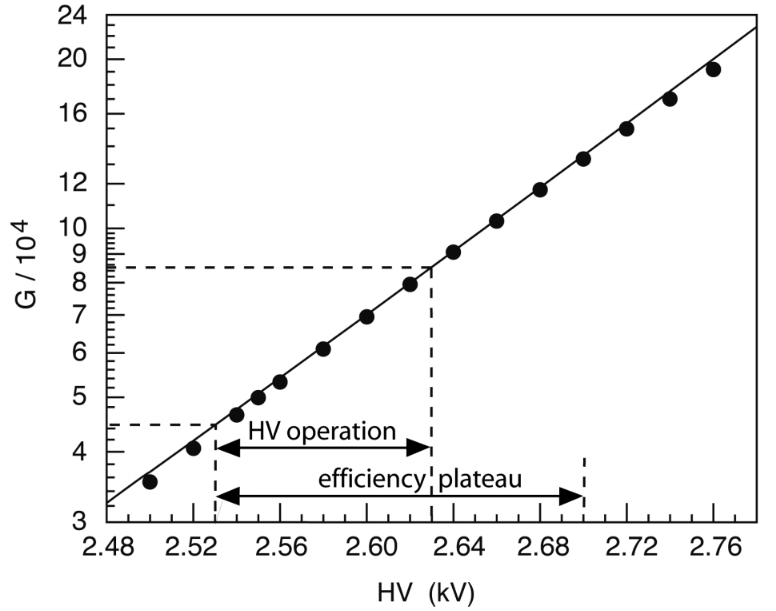


Internal structure of MWPC

LHCb Collaboration, LHCb muon system: Technical Design Report, Geneva : CERN, 2001. - 89 p.

LHCb Muon Gas System

- 40% ***Ar*** + 55% ***CO2*** + 5% ***CF4*** gas mixture[1];
- ***CF4***:
  - prevents the formation of Si-deposits during MWPC operation;
  - provides to suppress an effect of Malter-like currents;
- Operations on Efficiency plateau: **2.53-2.63 kV**;
- Gas Gain coefficient on Efficiency plateau: **$4.4*10^4$ - $8.6*10^4$;**



Gas gain as a function of Voltage in the LHCb Muon MWPCs[2]

1. **Werner Riegler,** *Detector physics and performance: simulations of the MWPCs for the LHCb muon system*, LHCb-2000-060.
2. **E. Dané, G. Penso, Davide Pinci, A. Sarti**, *Detailed study of the gain of the MWPCs for the LHCb muon system*, NIM A, Volume 572, Issue 2, 11 March 2007, Pages 682-688.

MWPC Initial conditions

- **General training procedure** – … increasing of voltage to the nominal one step by step and controlling the value of currents on gaps under training;
- V_{pos}(max) = 2.85 kV, Imax < 0.010 uA;
- V_{neg}(max) = 2.30 kV, Imax < 0.150 uA;

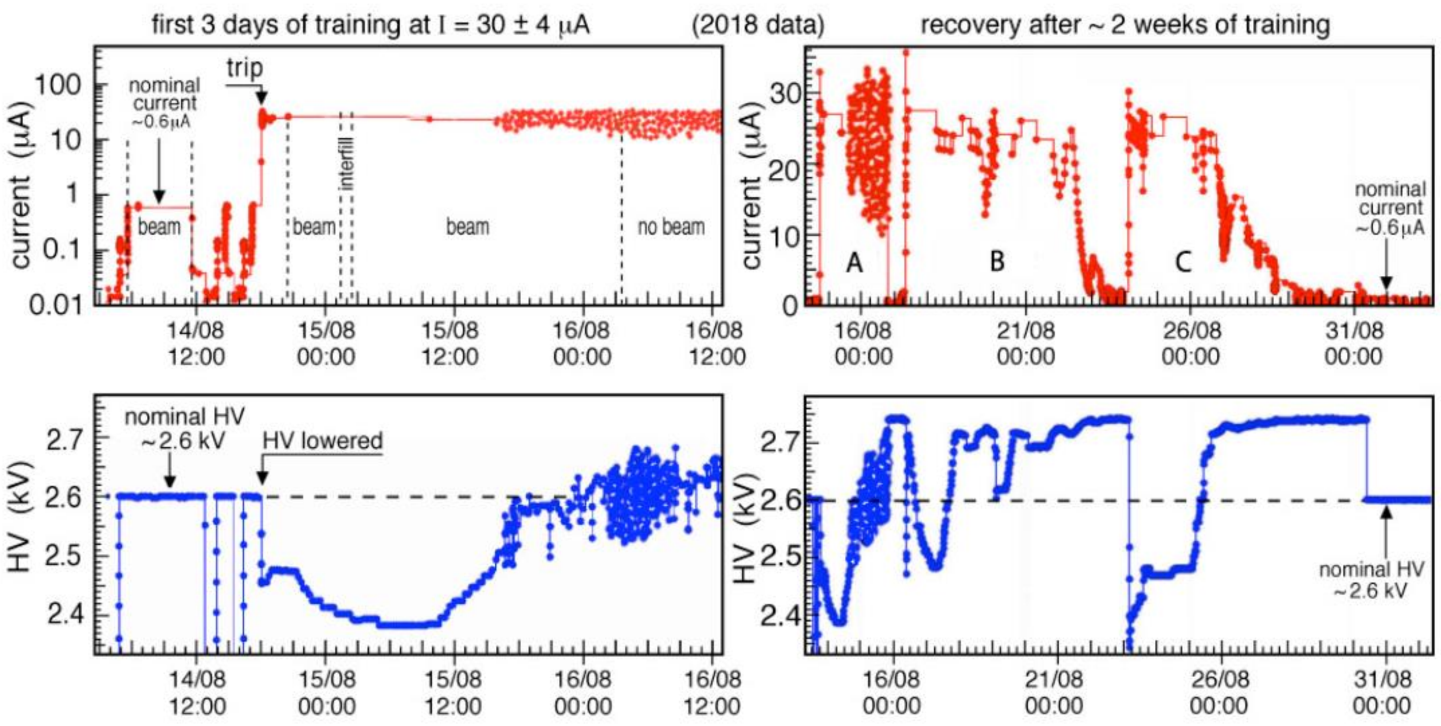
- **Additional training procedure** for R1/R2 chambers on Gamma Irradiation Facility*;
- V_{pos}(max) = 2.75 kV
- $t_{irr.}$ = 48 hours;
- $q_{deposited}$ = 1 mC/cm.

1. **V. Souvorov et al.**, First results of an aging test of a full scale MWPC prototype for the LHCb muon system, Nucl. Instrum. Meth. A 515 (2003) 220.
2. **S. Agosteo et al**., A facility for the test of large-area muon chambers at high-rates, Nucl. Instrum. Meth. A 452 (2000) 94.
3. **J.-S. Graulich et al.**, Conditioning of MWPCs for the LHCb Muon System, NSS/MIC IEEE 2005Conference Record.

Effectiveness of training procedure

Status of malfunctioned MWPCs:

- Reduces of gas gain have not been observed;
- The effect of high **self-substained currents** has been detected in ~100 MWPCs gaps per each year;
- **A higher current increases the concentration of fluorine radicals, produced by CF4, which react with deposits (silicone, polymers), leading to surface etching by means of the creation of volatile products in the plasma;**
- The procedure of training provides to restore the functionality of MWPC gap affected by Malter-like currents.



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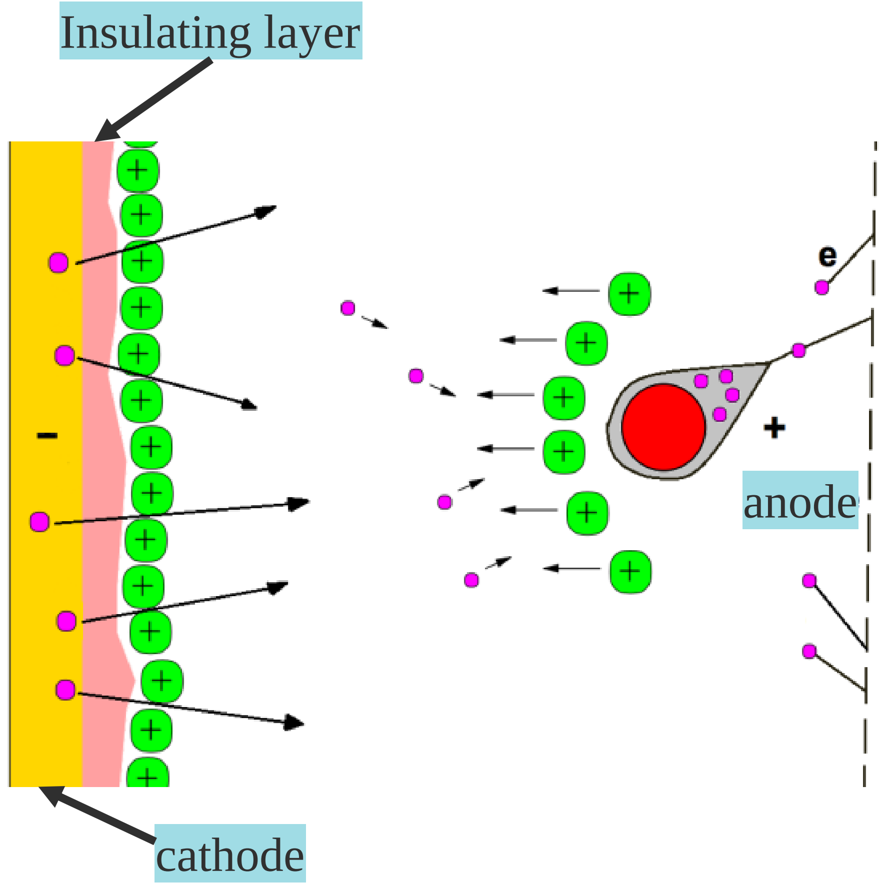
Malter Effect

Malter Current Effect is secondary electron emission which appears when:

1. an insulating layer exists on the cathode;
2. the rate of ion build-up is higher than its removal from the insulating layer;
3. some ignition mechanism take place .

Manifestation of Malter Current Effect:

1. self-sustained discharge ignited by high intensity irradiation and micro sparks;
2. sustained uA current independent from external irradiation.



J. Va’vra, DESY workshop, October 2, 2001

Curing Malter-like effects in MWPC in presence of CF4

- Polyurethane foam is injected between two mold planes forming the cathode surface on the stage of MWPC production;
- A mold release agent (ACMOIL36-4600) contains 5-10% silicone;
- This product is suspected to create patches of insulating film on the cathode surface[1,2];
- Dissociation process of CF_4 provides to cure the ME. Free radicals of CF_4 dissociation are produced around anode wires at the electric field 20 –200 kV/cm;
- The radicals CF_3, $\bullet CF_2$, $F\bullet$ react with different silicon formations.
- Formed molecules of CO_2, O_2 and SiF_4 are removed from the detector volume by the gas flow;
- **The formation process is ongoing around anode wires. The concentration of free radicals is low around the cathod!**

$$e^- + CF_4 \rightarrow CF_3^+ + F\bullet + 2e^-$$

$$e^- + CF_4 \rightarrow \bullet CF_3 + F\bullet + e^-$$

$$e^- + CF_4 \rightarrow \bullet CF_2 + 2F\bullet + e^-$$

$$4F\bullet + Si \rightarrow SiF_4\uparrow$$

$$4F\bullet + SiO_2 \rightarrow SiF_4\uparrow + O_2\uparrow$$

$$Si + \bullet CF_3 + F\bullet + 2O \rightarrow SiF_4\uparrow + CO_2\uparrow$$

The training process requires a lot of time

1. **M. Capeans**, Aging and materials: lessons for detectors and gas systems, Nucl. Instrum. Meth. A 515 (2003) 73.
2. **S. Belostotski et al.**, Extension of the operational lifetime of the proportional chambers in the HERMES spectrometer, Nucl. Instrum. Meth. A 591 (2008) 353.
3. **F.P. Albicocco** ***et al*** 2019 *JINST* **14** P11031

Training procedure

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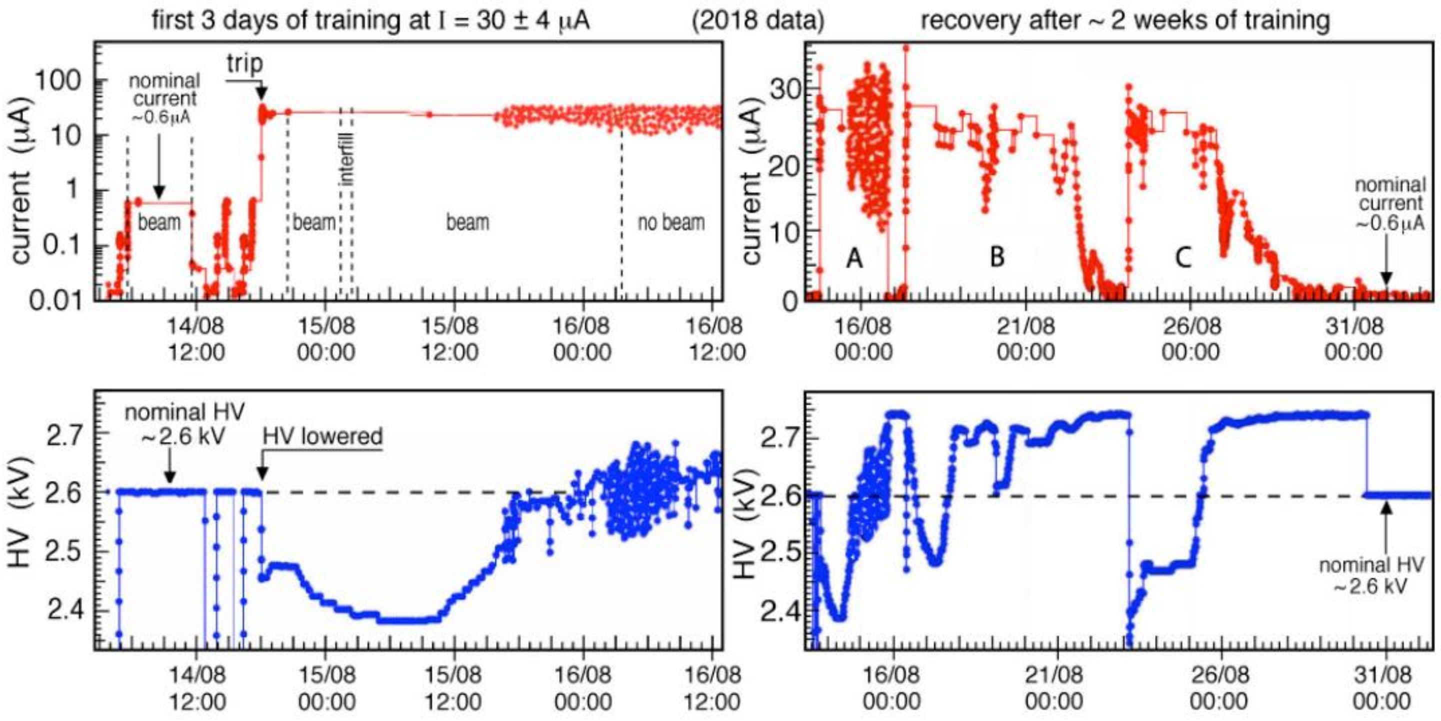
- MWPC Type: M5R3
- **Operation conditions:**
  - Beam: V = 2.6 kV, I ≤ 0.6 uA;
  - No beam: I ~ 0 uA;
- **Affected conditions:** V = 2.6 kV, I > 30 uA;
- Training procedure:
  - Decreasing the voltage to safe limit: I_{lim}=30 uA with ΔI = 4 uA;
  - **Ramping voltage up/down step by step to hold the current is around limit I_{lim};**
  - Training process required ~2 weeks;
  - Restored the current values close to the nominal ones.
  - Nominal values turned back to operational conditions



Phases of training:

A. ~3 days. Slightly decreasing of Malter-like current, appearing of the current at the end of period;

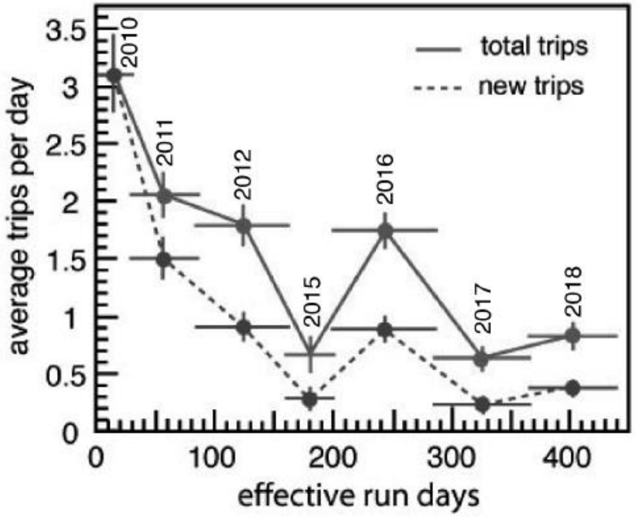
B. ~7 days. Decreasing of current value during two weeks and it appearing at the end of period;

C. ~7 days. Fully recovered after one (last) week of training.

Training procedure: statistics

- Average duration of training is around two months (in some cases the procedure required four months);
- 25-30 gaps go through the training procedure at the same time (Efficiency loss is less than 1%);
- 375/ 4944 gaps were affected by Malter-effect and have been treated;
- 27/375 haven't been restored;
- Most of self-substained currents appeared during the luminosity ramping-up phase;
- No correlation with particle flux and integrated luminosity.

Year	2010	2011	2012	2015	2016	2017	2018	Total
Effective run days	29	56	76	39	86	80	72	438
L_{int} (pb^{-1})	40	1220	2210	370	1910	1990	2460	10200
L_{peak} (10^{32} cm^{-2} s^{-1})	1.7	3.8	4.0	3.5	3.7	3.5	4.4	–
New trips	90	84	69	11	76	18	27	375
Recurrent trips	0	31	67	15	74	32	32	251



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Oxygen recovering: Gas compositon for accelerated recovery from Malter effect

- Etching rate in a CF4/O2 mixture is significantly higher in comparison to the one in a pure CF4 plasma;
- Oxygen radicals provide to produce the •COFx
- •COFx quickly dissociates with electrons and atoms and indirectly increases the number of fluorine radicals in the gas discharge plasma;
- Both oxygen molecules O• • and *O2 are chemically aggressive and may be used for the etching processes;
- **O2 content in MWPC working gas mixture must be optimized** due to reducing of the electron density in discharge plasma;
- The optimization of O2 content in LHCb Muon MWPCs was based on a GARFIELD simulation in range of O2 percentage 0-20%;
- At 1- 4 % O2 content the electron attachment coefficient increases only in the drift region (around the cathode surface). While the oxygen content is more than 10%, the electron attachment occurs at the all drift and avalanche regions;
- The optimized value ~2 %.

$$O\bullet + \bullet CF_3 \rightarrow \bullet COF_2 + F\bullet$$

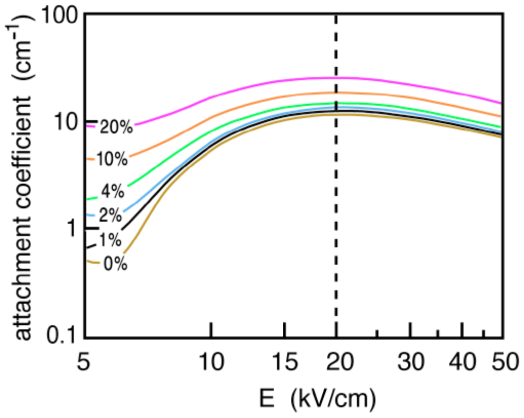
$$O\bullet + \bullet CF_2 \rightarrow \bullet COF + F\bullet$$

$$e^- + COF_2 \rightarrow \bullet COF + F\bullet + e^-$$

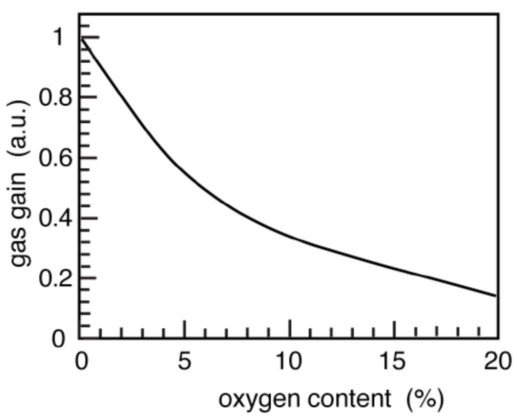
$$O\bullet + \bullet COF \rightarrow CO_2\uparrow + F\bullet$$

$$e^- + O_2 \rightarrow O^- + O^{\bullet\bullet}$$

$$e^- + O_2 \rightarrow {}^*O_2 + e^-$$



Electron attachment coefficient as a function of an electric field



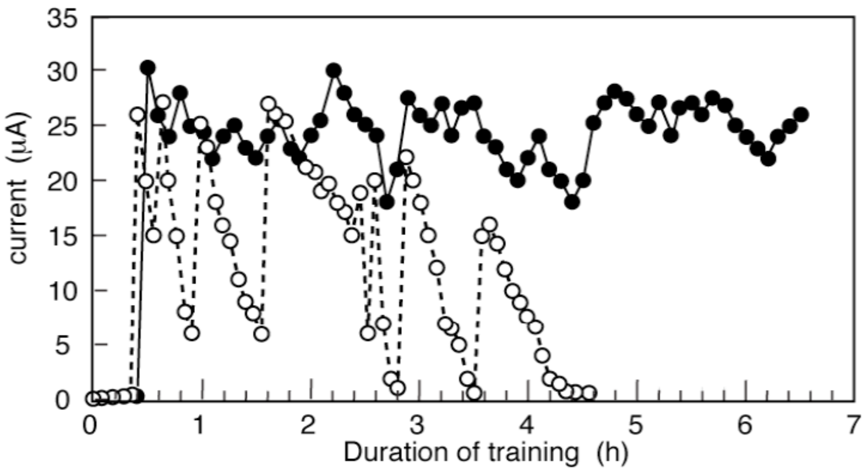
Relative gas gain coefficient as a function of Oxygen content

1. **Yu.N. Grigoryev, A.G. Gorobchuk,** Numerical Simulation of plasma-chemical reactors, Comput. Technol. 2003. Vol. 8. Special Issue. Pt. 2. P. 53–73.
2. **J. Mogab, A. C. Adams, and D. L. Flamm**, Plasma etching of Si and SiO2 - The effect of oxygen additions to CF4 plasmas, J. Appl. Phys. 49 (1978) 3796.
3. **F.P. Albicocco *et al*** 2019 *JINST* **14** P11031

Oxygen recovering: Accelerated recovery of MWPCs

Chamber Type	Number of detected ME zones	ME ignition voltage (kV)	Time for recovery (h)
M2R4	2 (gap A)	2.75	3
		2.8	1
M4R4	1 (gap D)	2.7	5
M5R4	1 (gap A)	2.6	4
	1 (gap B)	2.7	3
	1 (gap D)	2.8	2

- Test the Oxygen recovering on LHCb Muon MWPCs unmounted from the cavern due to the high currents during LHC Long Shutdown 1;
- HV+ and HV- trainings was not provided the succesfully recovering;
- Several ***“problematic” zones*** have been found during MWPCs irradiation by Sr^{90} source;
- ~7 hours of training procedure use ***nominal gas mixture*** + ***Sr^{90} irradiation***
- ~5 hours of training procedure use ***oxygen + nominal mixture + Sr^{90} irradiation***;
- All MWPCs gaps have been recovered and mounted back to detector;
- **Successfully LHCb Muon operations with recovered chambers during Run 2.**



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Conclusion

- ✓ LHCb muon detectors did not show a gain reduction or any other apparent deterioration in performance
- ✓ 19% out of 1368 chambers were affected by self-substained currents;
- ✓ Less than 1% MWPCs have been replaced in 9 years operation;
- ✓ Non-invasive method has been applied to restore the detector efficiency;
- ✓ Tested additional technique of fast restoring by adding an oxygen into gas mixture;
- ✓ The high efficiency of both techniques have been demonstrated.

Many thanks for your attention!

Backup slides

Long-term Operation of the Multi-Wire-Proportional-Chambers of the LHCb Muon System

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https://arxiv.org/abs/1908.02178