Conditioning of MWPCs for the LHCb Muon System

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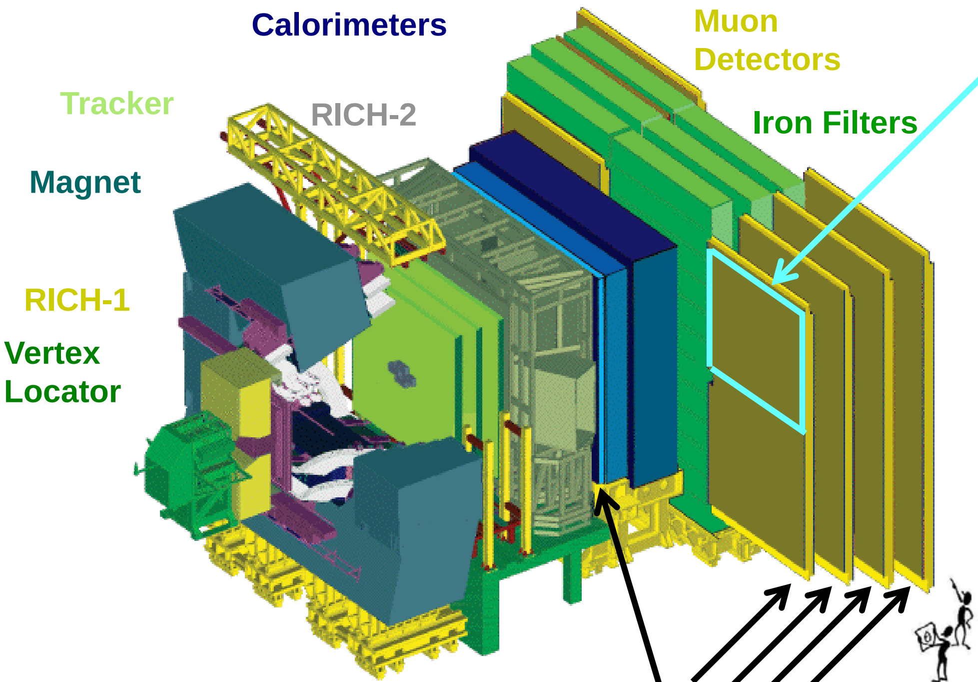
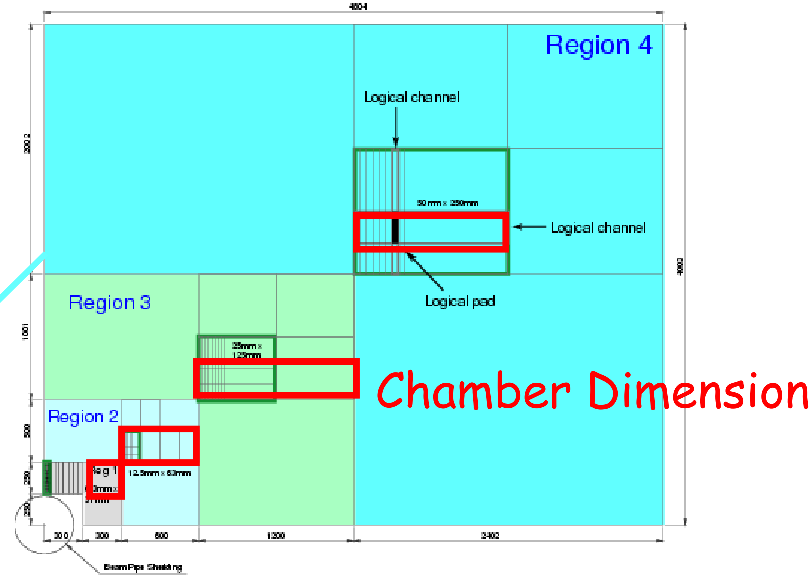
Contents:

MWPCs in the LHCb Muon System

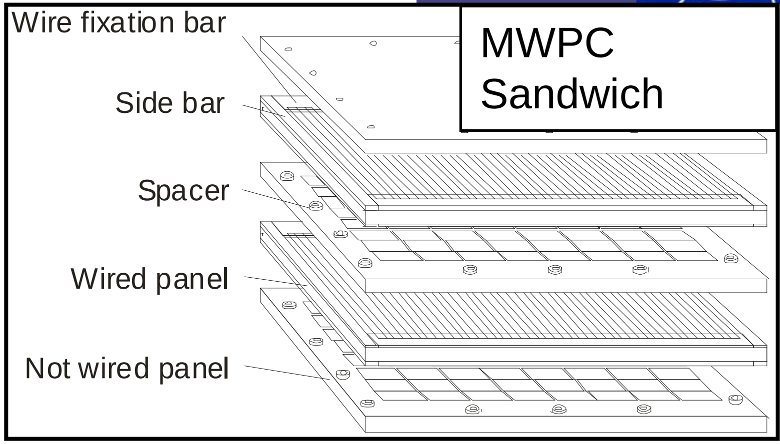


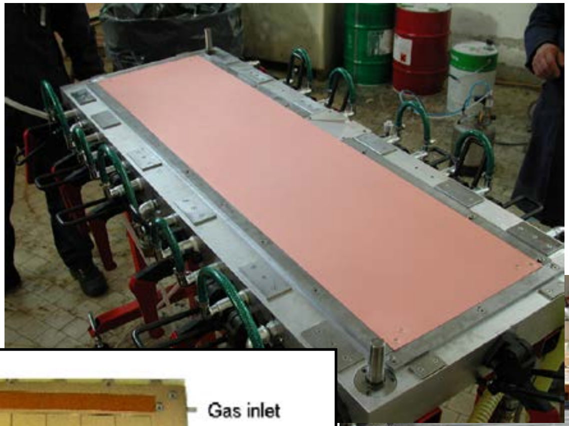


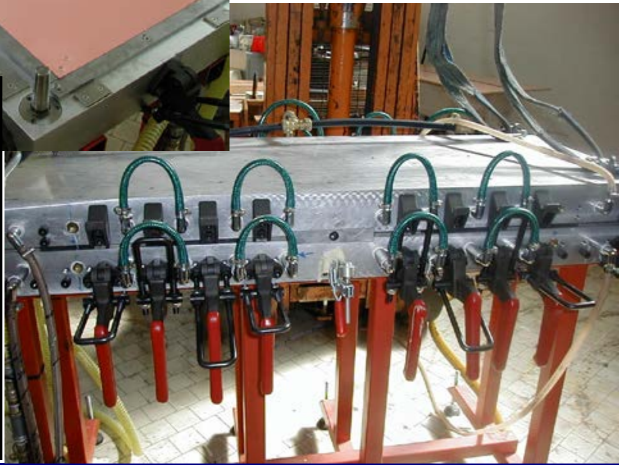
- Multi Wire Proportional Chambers (MWPCs):
  - Fast muon triggering
  - Muon identification
- 5 Muon Stations, 4 Regions / Station
  - 20 different chamber sizes
  - 1368 chambers

MWPC Design

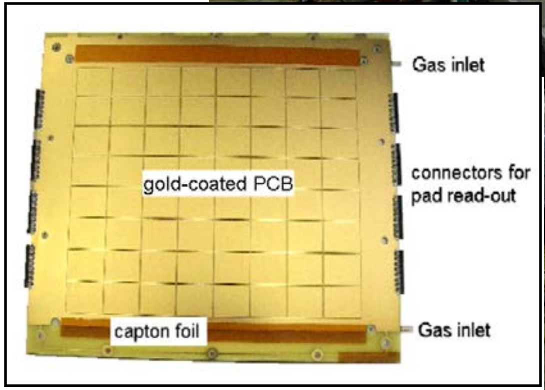
- 4-gap MWPC
- gap size: 5 mm (wire plane centered)
- gas mixture: $Ar/CO_2/CF_4$ (40:55:5)
- wire: Gold-plated Tungsten, 30 µm Ø, 250 to 310 mm wire length
- wire spacing: 2 mm, mechanical tension: 65 gr
- HV = 2.650 kV
- field on wires: 262 kV/cm
- field on cathodes 6.2 kV/cm
- gas gain: G ≈ 50 000
- gain uniformity: ≤ 30%





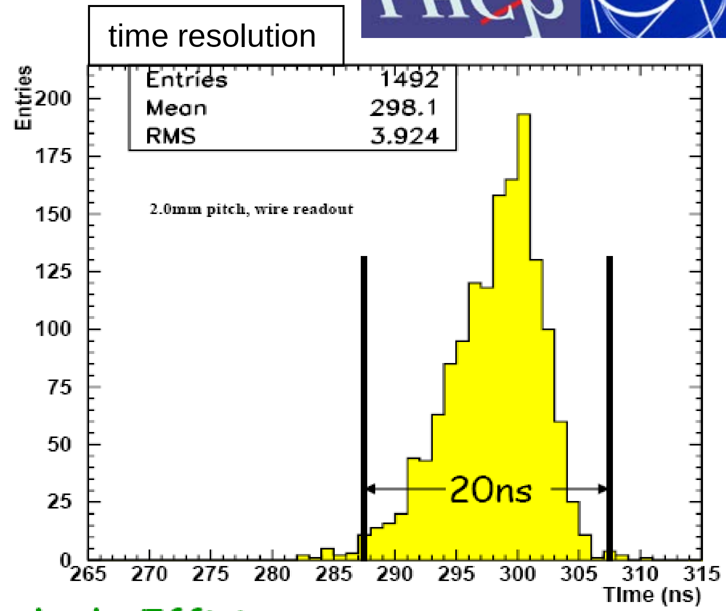


- panel production:
  - PCB coated by 35 µm copper, 5 µm nickel, 0.2 µm gold
  - foam injected between 2 PCBs in mould

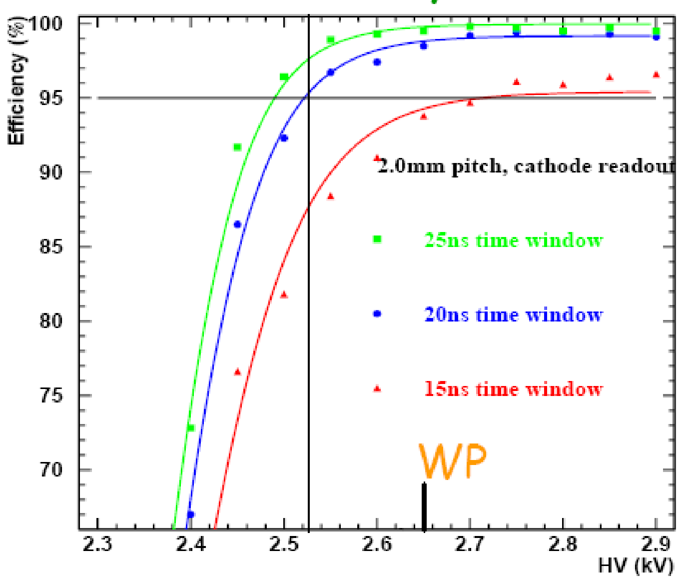


MWPC Requirements

- fully efficient and robust level-0 high p_t muon trigger:
  - 5-fold coincidence of at least 1 hit within 20ns in each station
- high efficiency and time resolution:
  - high efficiency (>99%) per station requires a time resolution of ~4ns
  - achieved by use of 2-fold OR (double-gaps)
- **high rate capability:**
  - up to 0.2 MHz/cm^2 for inner chambers at a luminosity of L = 5 x 10^{32} cm^{-1} s
- **ageing resistance** over 10 years:
  - the accumulated charge < 1C/cm
- spatial resolution:
  - we require a p_t resolution < 20%, therefore we need a spatial resolution in the order of 1 cm in bending plane (6-30 mm)



Cathode Efficiency:

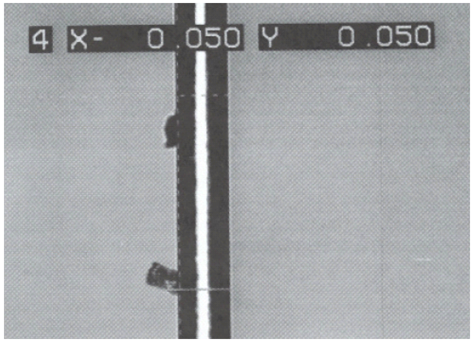


Chamber Conditioning

- Motivation for Conditioning:
  - by stepwise applying positive HV on anode wire for the first time, we have difficulties to reach operating point within safe current region < 50 nA
  - we assume impurities on the anode wire and on the flat cathode surface responsible for self-sustaining discharge under positive HV
- Conditioning Procedure:
  - Step 1: Inversed HV-Conditioning: negative HV up to -2300 V at anode wire
  - Step 2: Normal HV-Conditioning: positive HV up to +2900 V at anode wire

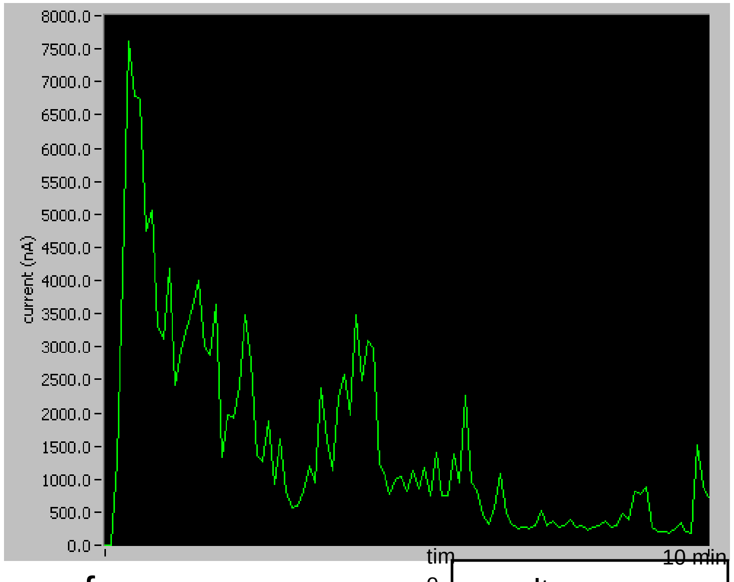
General rule: In order not to damage any surfaces (wire and cathode) high currents must be avoided ! (nominal dark current: ~ 3 nA)

- Cleaning Effects due to:
  - positive ion bombardment on cathode
  - negative ion and electron bombardment on anode
- Results:
  - surfaces smoothened
  - current reduction



impurities on wire

Step 1:
Negative HV Conditioning



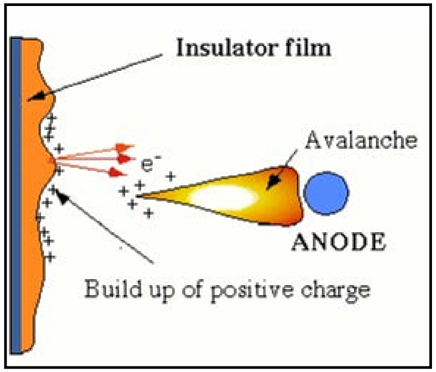
result: current reduction

- Procedure:
  - applying negative HV to wire
  - stepwise increasing HV up to -2300 V
- Effect:
  - possibly electron emission from metallic tips on wire surface
  - positive ion bombardment on wire surface

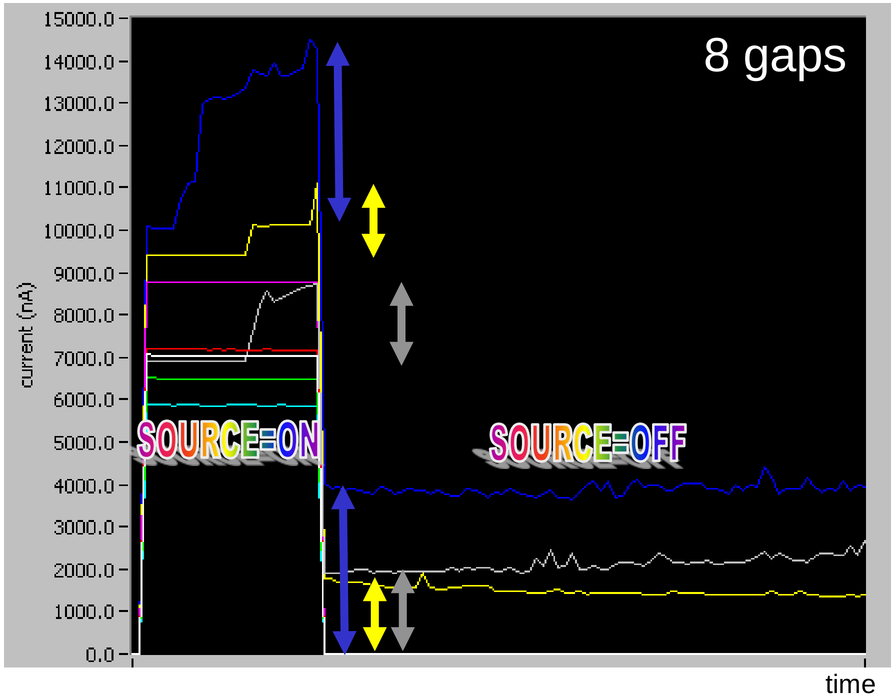
  → E-field reduction due to wire surface smoothening
- Advantage:
  - safe procedure: weak avalanche effect at this HV range (at -2300 V: gas gain ~100)
- Results:
  - at each HV step: fast current reduction (10 μA->100 nA) within 10 minutes
  - mean conditioning time at -2300 V: 45 hours
  - after this: positive HV = 2900 V is quickly reached (within 15 minutes) with a dark current level of 3 nA

Step2: Positive HV Conditioning

- Motivation: High Rate Capability of chambers is tested at GIF
  - all chambers of inner regions (highest particle flux up to 0.2 MHz/cm^2) are exposed to high gamma radiation at the Gamma Irradiation Facility (GIF) at CERN for testing.
  - ^{137}Cs source (photons 660 keV) similar to LHC background radiation
- Outcome:
  - in ~ 20% of all tested gaps Malter-like emission detected
- Malter effect: Thin Film Field Emission
  (L. Malter, Phys. Rev. 50, 1936)
  - thin insulator film on cathode surfaces charged up by GIF irradiation
  - high electric field starts e$^-$-emission

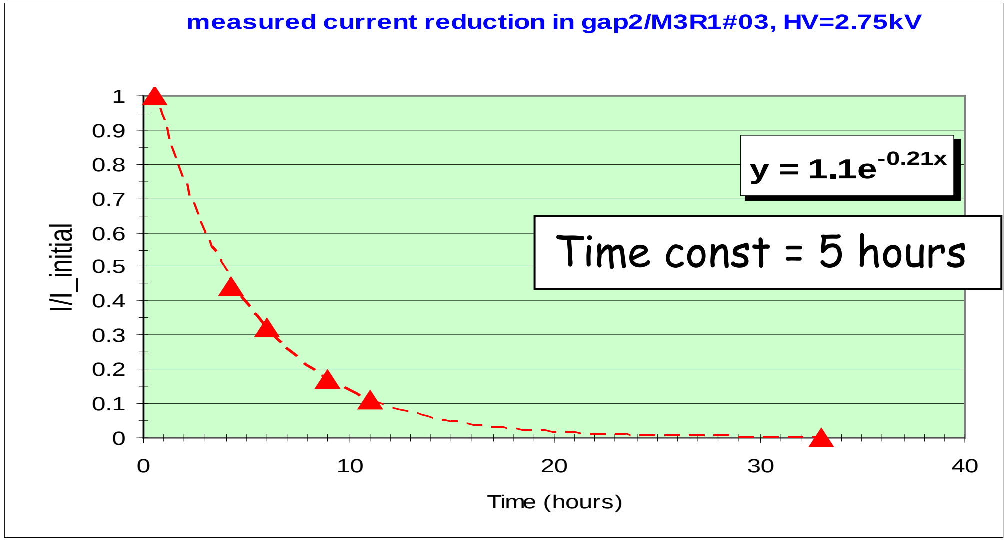


(from: J. Va'vra, NIM A367, 1995)



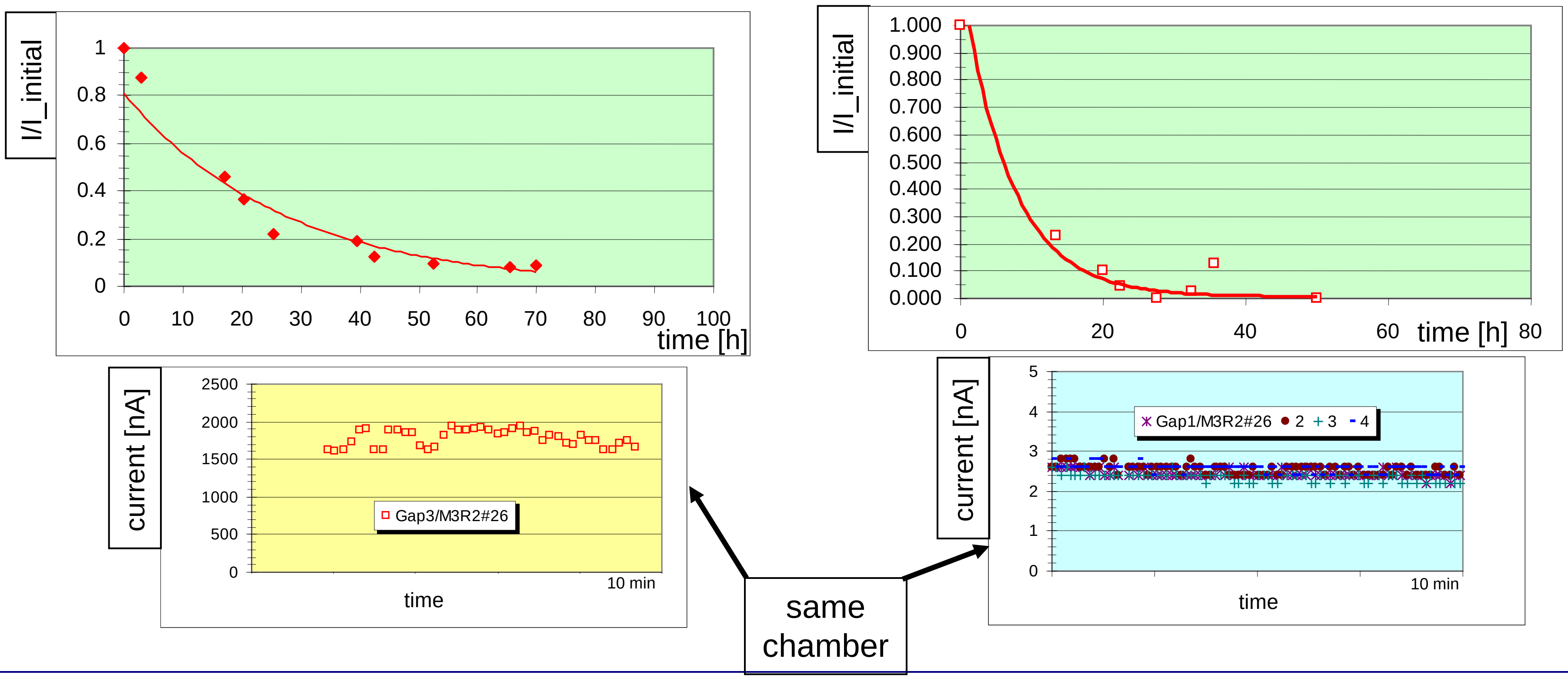
- **Chemistry:**
  - cathode panel production: mould release agent ACMOIL36-4600 contains long C-chains (Isoalcine C9-C12) with silicone (5-10%) → indication for a remaining insulating film on surface
  - panels are cleaned by hand (Isopropyl alcohol, 4-Methyl-Pentanol, n-Hexane, demineralized water), problematic region for dirt: between cathode pads
- Treatment at GIF:
  - positive HV applied in steps of 50-100 V for the range of 2.2 kV – 2.75 kV
  - high gamma ray irradiation leads to charge up of insulator spots → e^--emission → positive ions
  - F-radicals are created due to 5% CF_4 in gas mixture
  - remove Si by creating SiF_4 molecules, that are volatile and will be removed by gas flux
- Results:
  - exponential current reduction
  - conditioning time: 0.5 – 70 hours
- Draw Back:
  - molecular bonds may recover when irradiation or HV removed

  → currents return, but decay is faster



- Test without CF_4:
  - gas mixture: Ar/CO_2(40:60); HV=2.75 kV
  - current reduction slow
  - remaining current level still too high [μA]
  - HV trips observed

- Test with 5% CF_4:
  - gas mixture: Ar/CO_2/CF_4(40:55:5); HV=2.75 kV
  - current reduction faster
  - remaining current level excellent [~2 nA]
  - no HV trips



- **Emission Physics:**
  - first attempts to combine Malter-effect with field emission (Fowler-Nordheim) can be found in literature (A. Boyarski, NIM A535, 2004)

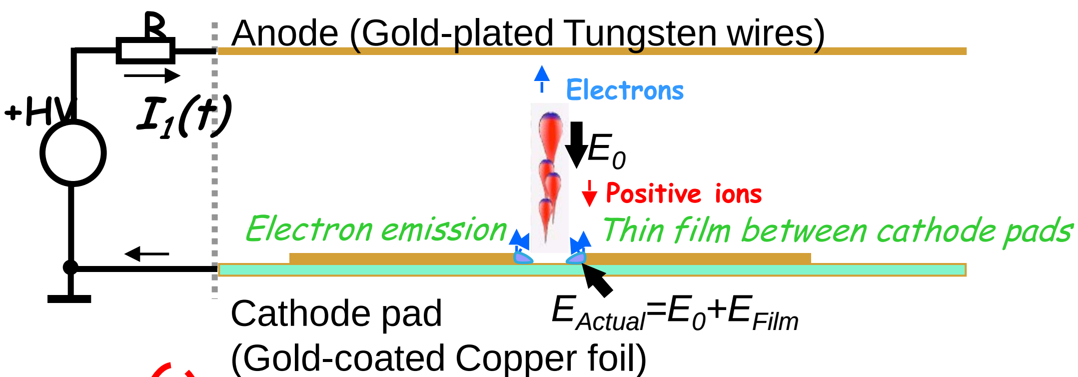
$$J \cong 5.4\times10^{-5}(\beta E)^2 \exp\left(-\frac{5.43\times10^{10}}{\beta E}\right)[A/m^2]$$

ß… field enhancement factor
E… electric field in [V/m]
for a gold-coated wire

- For our MWPCs: high currents most probably due to 2 effects:
  - electron emission from metallic tips on surfaces
  - thin film field emission → most likely from area between cathode pads
- For our measurements:
  - measure I, V
  - include gas gain G(V) depending on V

$$I = \alpha \cdot J \cdot G(V)$$

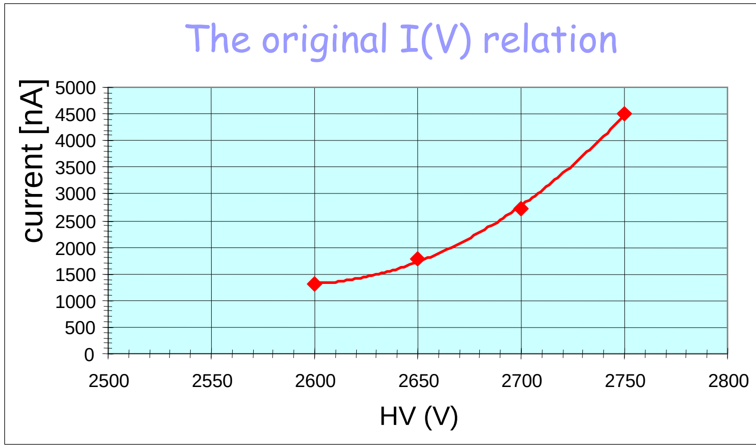
  - approximation:



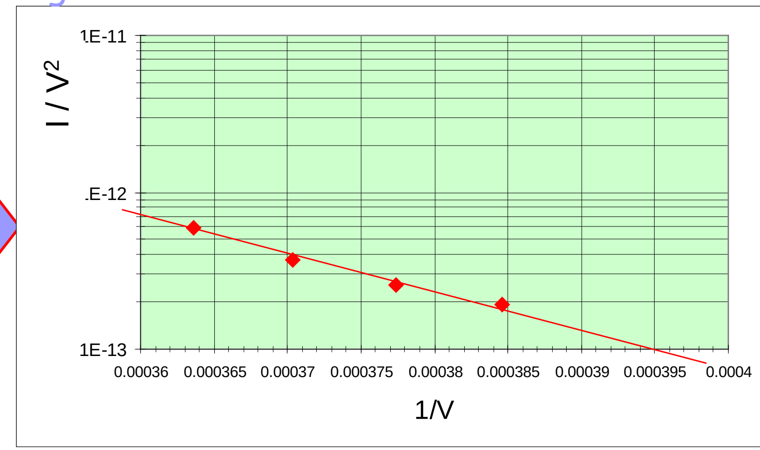
$$y=\log\left(\frac{I}{V^2}\right) = \log\left[\alpha\frac{a\beta^{*2}}{1.1\varphi}\cdot G(V)\right] - \frac{b\phi^{3/2}}{\beta^*}\frac{1}{V}=x$$

→ field factor ß* estimated from the slope

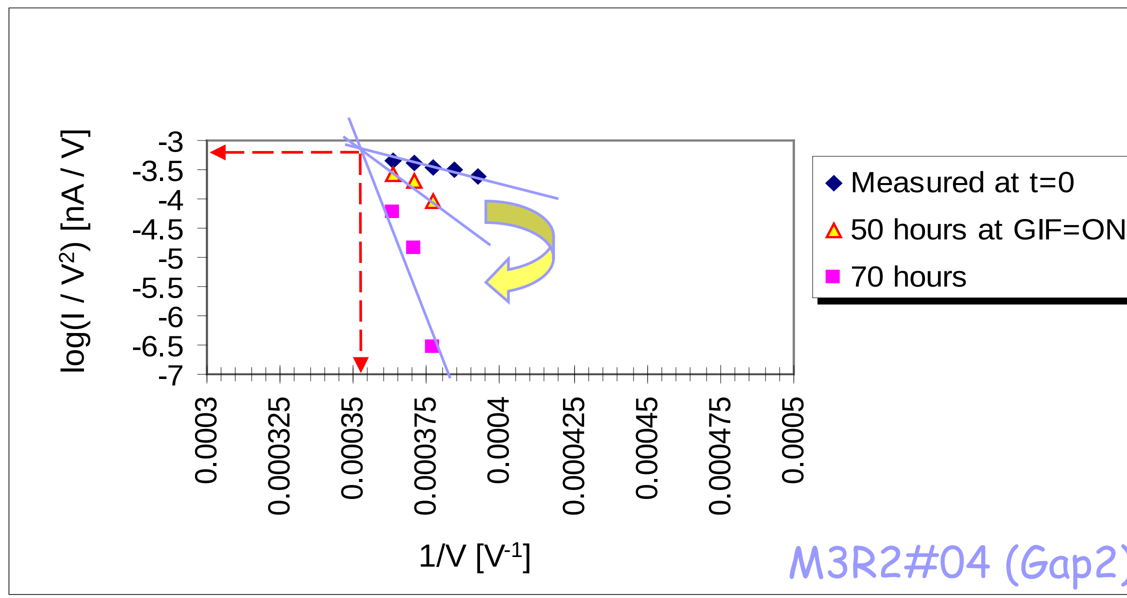
- Measurments:



logarithmic scale:



  - repeated measurements on the same chamber show rotation of straight lines with increasing slopes



- Result:
  - E-field decreasing

    → surface cleaned
  - conditioning time: up to 500 hours (20 days)

Summary

- MWPC Conditioning in 2 steps:

- Step1: negative HV on wire
  - apply negative HV up to 2300 V
  - check current at positive HV=2900 V:
    - If I < 3 nA → Step 2
    - If I > 3 nA → repeat Step1
- Step 2: positive HV on wire under High Gamma Ray Irradiation
  - stepwise increase positive HV on wire for the range of 2.2 kV – 2.75 kV
  - at each step of 50-100 V switch source off to check current:
    - If I < 10 μA → increase HV
    - If I > 10 μA → repeat irradiation at same HV

Conclusion

- Achieved excellent conditioning result by applying 2 steps:
  - Inversed HV Conditioning
  - Normal HV Conditioning under High Gamma Ray Irradiation
- Effects are:
  - successful wire cleaning
  - successful cathode cleaning

→ **We can assume that the observed anomalous currents are self-suppressed during MWPC operation (high background radiation)**

→ **Therefore we are optimistic, that these currents will not be a problem for the long term operation of the LHCb Muon System**