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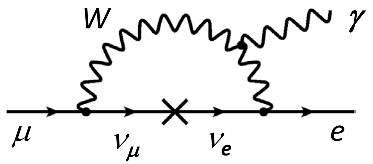
Hajime Nishiguchi, KEK, and Malte Hildebrandt, PSI
on behalf of the MEG Collaboration

HV stability and aging phenomena observed in the drift chamber system of the MEG experiment

3rd International Conference on Detector Stability and Aging Phenomena in Gaseous Detectors
CERN, 07.11.2023

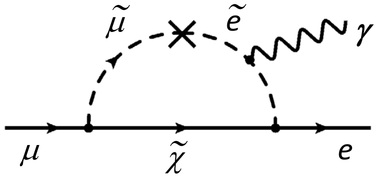
Charged Lepton Flavour Violation

- charged lepton flavour violating (cLFV) decay $\mu^+ \rightarrow e^+ \gamma$ not yet observed
- Standard Model (SM): forbidden decay
- Standard Model with ν masses and oscillations: strongly supressed due to small ν masses



BR ($\mu^+ \rightarrow e^+ \gamma$) ≈ 10^{-54}

- Beyond Standard Model (BSM) theories: enhanced probability due to mixing of new particles



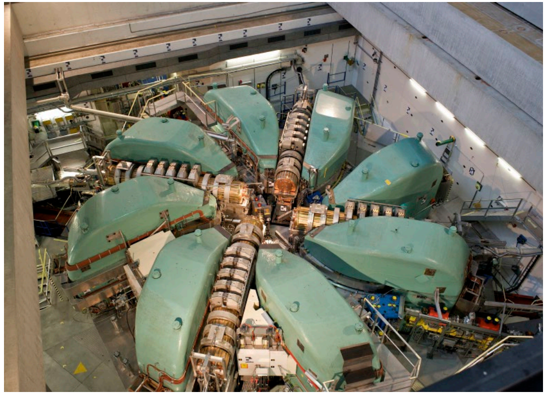
BR ($\mu^+ \rightarrow e^+ \gamma$) >> 10^{-54} (10^{-11} - 10^{-14})

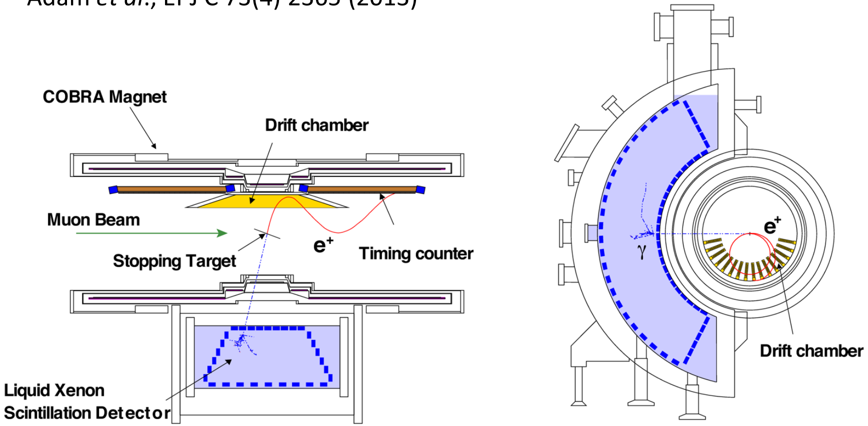
→ experimental observation of $\mu^+ \rightarrow e^+ \gamma$ is clear signature of "New Physics" beyond the SM

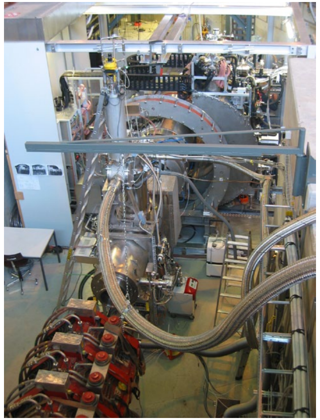
MEG Experiment

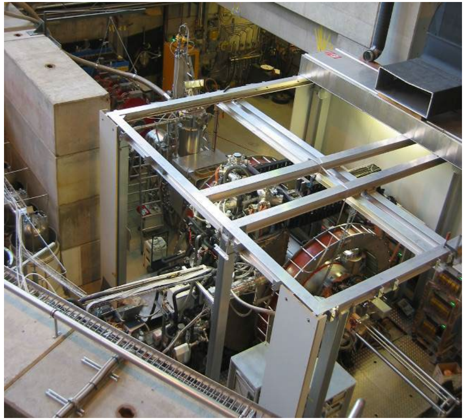
- search for cLFV decay $\mu \rightarrow e + \gamma$
- located at CHRISP facility @ Paul Scherrer Institut (PSI)
  - p-cyclotron: 590 MeV, 2.4 mA (→1.4 MW)
  - πE5: most intense DC low momentum (28 MeV/c) muon beam in the world: intensity $O(10^8\ \mu/s)$
- dedicated detector design to measure the observables characterising the $\mu^+ \rightarrow e^+ \gamma$ event: E_γ, E_e, $t_{e\gamma}$, $\vartheta_{e\gamma}$, $\varphi_{e\gamma}$

Adam *et al.*, EPJ C 73(4) 2365 (2013)









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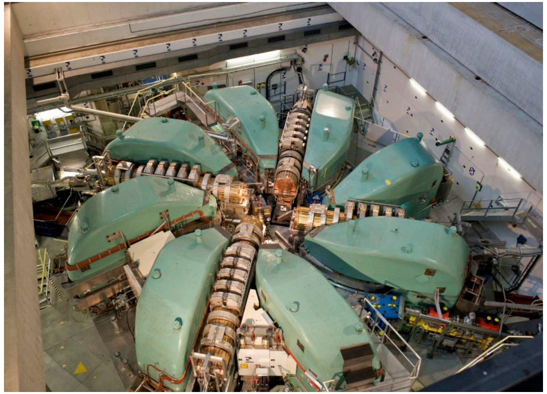


- MEG: ▫ analysis of full data sample 2009-2013

  BR $(\mu^+ \rightarrow e^+ \gamma) < 4.2 \cdot 10^{-13}$ (90% CL)

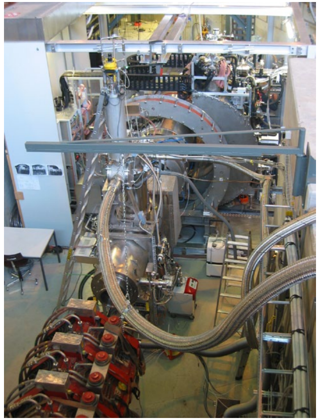
  Baldini *et al.*, EPJ C 76((), 434 (2016)

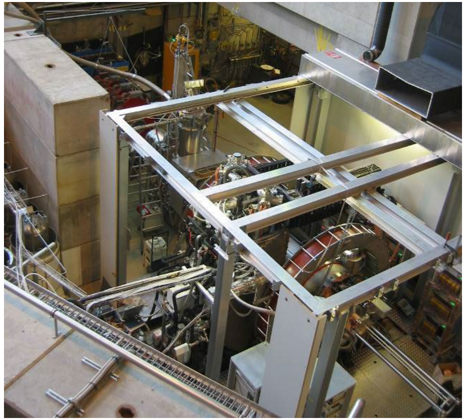
- MEG II: ▫ analysis of data sample 2021 & MEG

  BR $(\mu^+ \rightarrow e^+ \gamma) < 3.1 \cdot 10^{-13}$ (90% CL)

  arXiv:2310.12614 [hep-ex]

  ▫ goal: final sensitivity 10^{-14} level

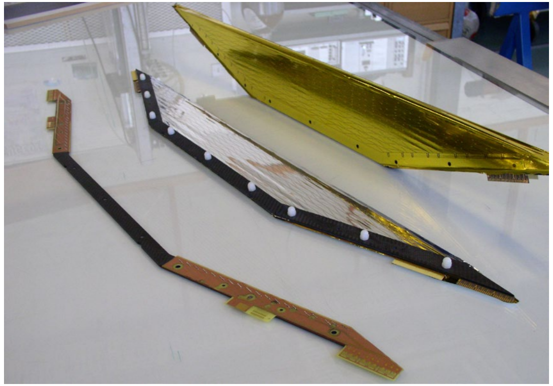


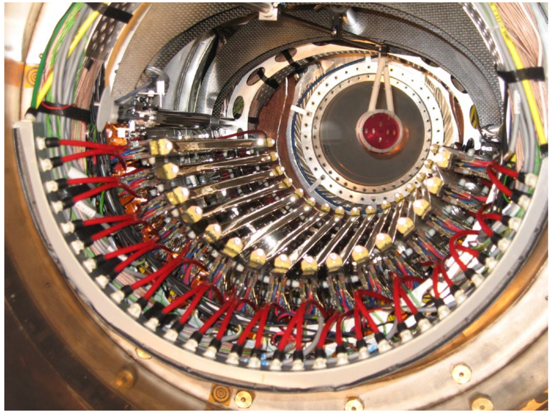


Drift Chamber System @ MEG

- designed to measure 52.8 MeV e^+ (achieved $\sigma_E \approx 330$ keV)
  - 16 individual drift chamber modules
  - aligned radially in half circle, 10.5° intervals
  - low multiple scattering contribution
    - $2.6 \cdot 10^{-4}$ X_0 per module
    - $2.0 \cdot 10^{-3}$ X_0 along e^+ track
  - filling gas He/C_2H_6 (50/50)
  - operated in Helium atmosphere
  - operated in B-field, 0.5 - 1.26 T

- mechanics
  - 1m long, V-shaped / open trapezoidal geometry
  - carbon fibre frames
  - two (staggered) detector planes per module to resolve ambiguities
  - carbon fibre support structure (DC modules, HV/LV cables, gas tubes, etc.)

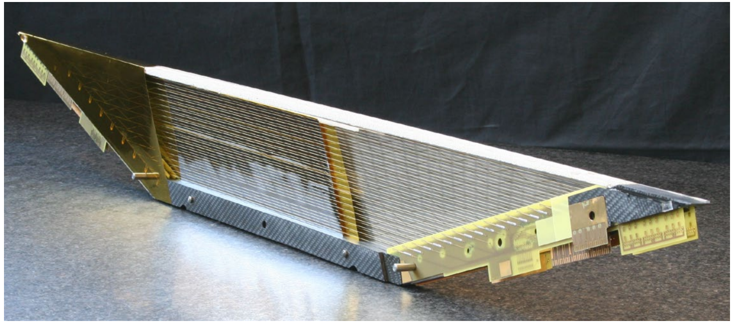


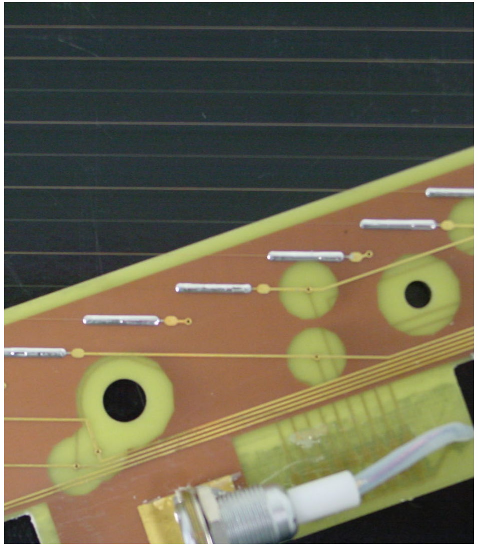


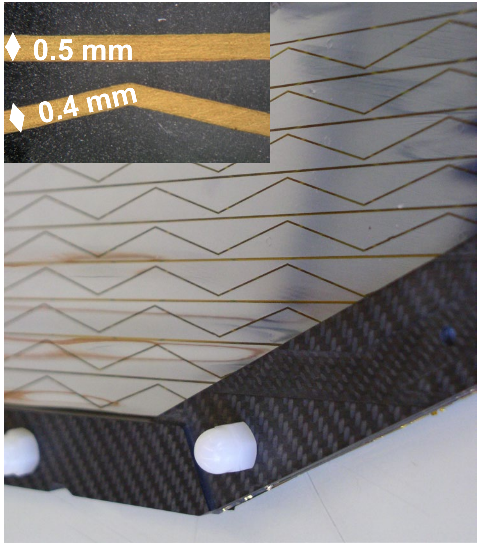
Hildebrandt, NIM A623, 111 (2010)
Adam *et al.*, EPJ C 73(4) 2365 (2013)

Drift Chamber System @ MEG

- wiring
  - 25 μm Ni80/Cr20 wires (2.2 kΩ/m)
  - 50 μm Cu98/Be2 wires
- soldering
  - low-temperature tin (w/o rosin)
  - common flux
- cathode
  - 12.5 μm polyamide foil
  - ~250 nm sputtered aluminium coating
  - Vernier pattern (λ = 5 cm, 47.5 Ω/m)
  - wet etching process
- gluing and sealing
  - Araldite AY 103-1, HY 991
  - ThreeBond 1533D (Silyl-based polymer)







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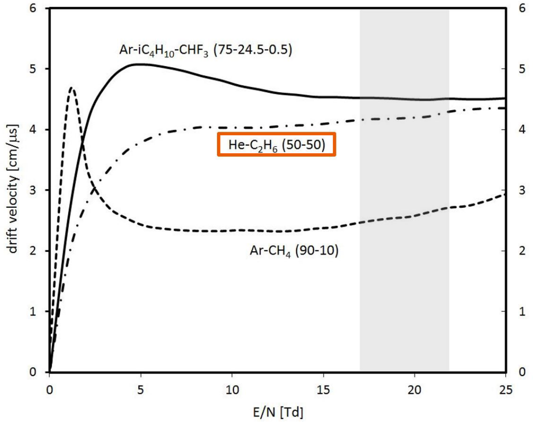
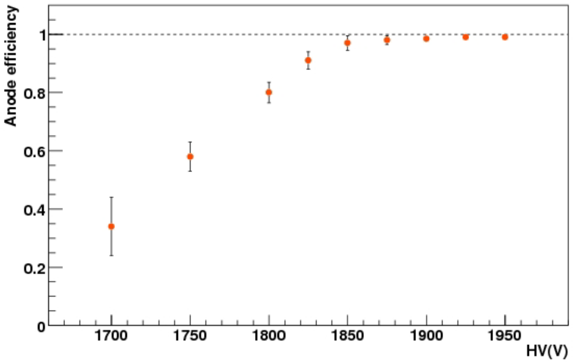
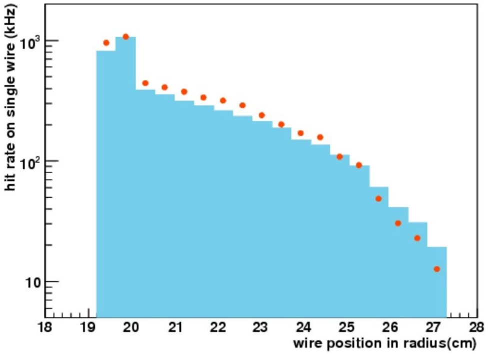
Filling Gas and Operation Parameters

- filling gas
  - He/C_2H_6 (50/50)
  - high, saturated v_d ~4 cm/μs, small $\alpha_{Lorentz} < 8°$
  - He: X_0/ρ = 64 000 cm, but: low breakdown voltage
  - C_2H_6: good quenching properties, but: risk of polymerisation
- gas system
  - stainless steel, Swagelok fittings, polyurethane
- electron amplification
  - E ≈ 5.2 kV/cm ≈ 20 Td
  - electron amplification: ~$5 \cdot 10^5$
- particle rate
  - up to 30 kHz/cm
- accumulated charge
  - up to 1 C/cm/8months







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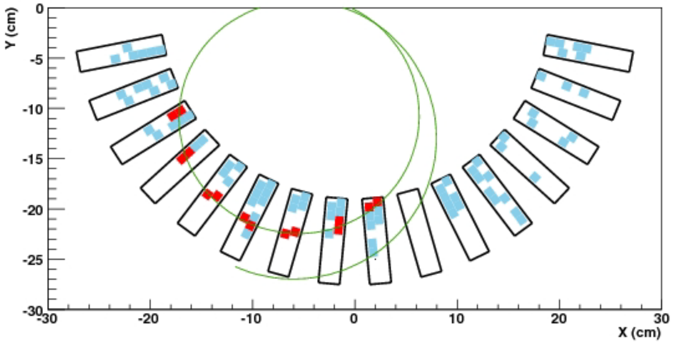
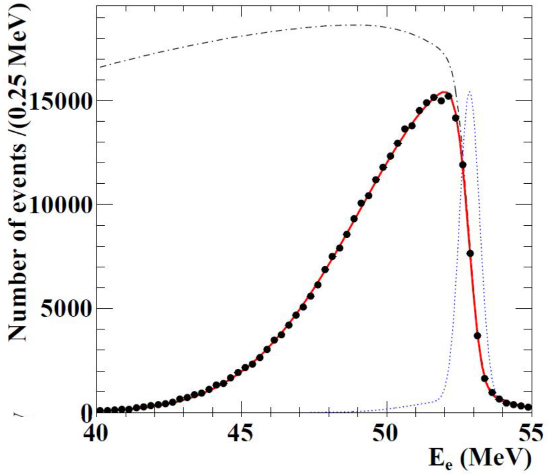
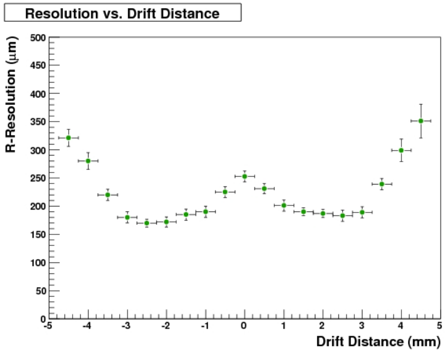
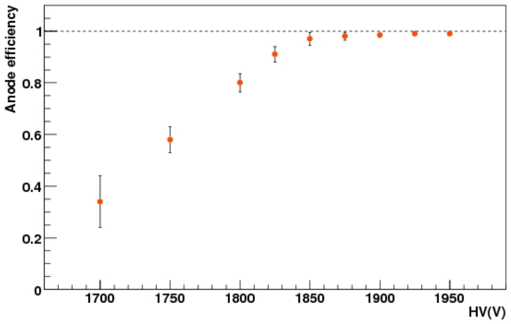
Drift Chamber System @ MEG

- operation
  - initial problems (2007/08) with HV stability due to
    - sealing of HV connections in outer Helium atmosphere and
    - «helium pocket»
  - anode and cathode aging phenomena
- performance (resolution σ)
  - energy ~330 keV (@52.8 MeV)
  - angular ~8.5 mrad in θ, ~7.7 mrad in ϕ



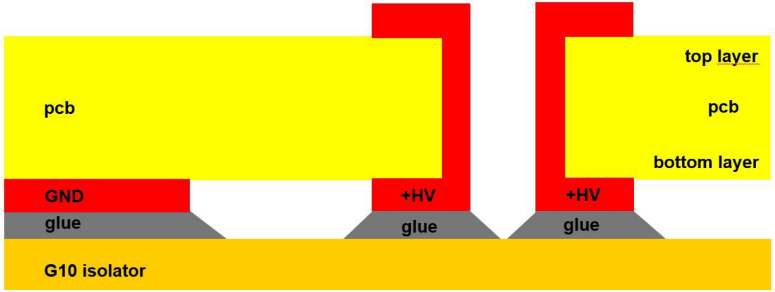


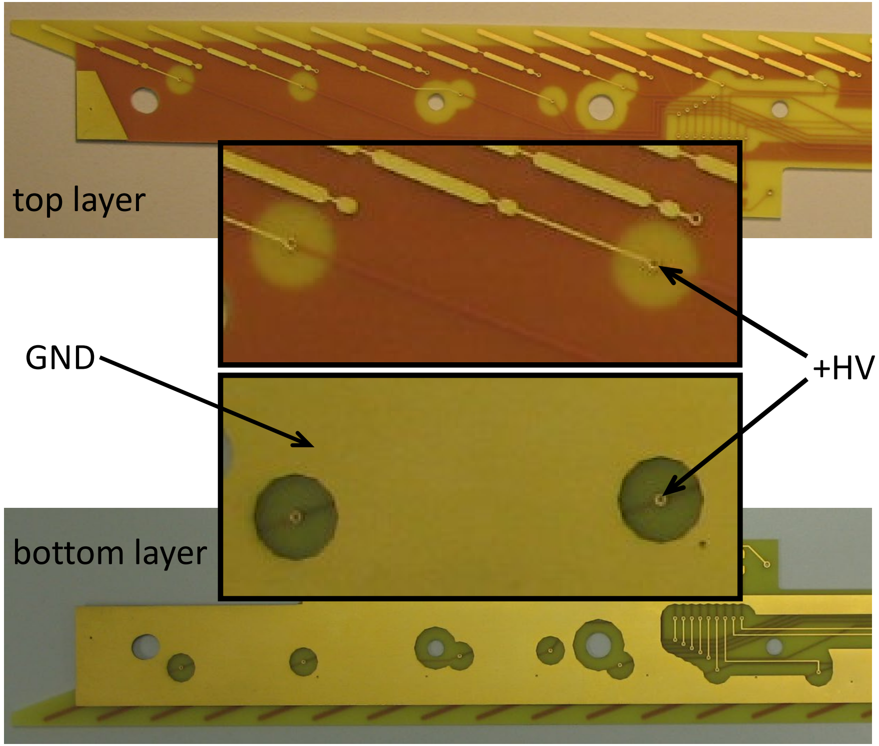




«Helium Pocket»

- degradation of drift chamber performance
  - occurred within first weeks of operation
  - frequent HV trips
  - operation voltage continuously decreasing
  - individual timescale for different dc modules
- “helium pocket”
  - gas volume enclosed by HV and GND
  - He from filling gas penetrated in this gas volume
  - increasing He concentration led to decreasing breakdown voltage

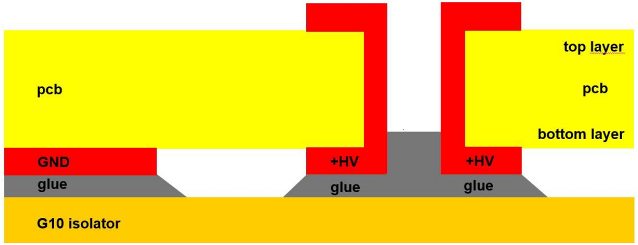


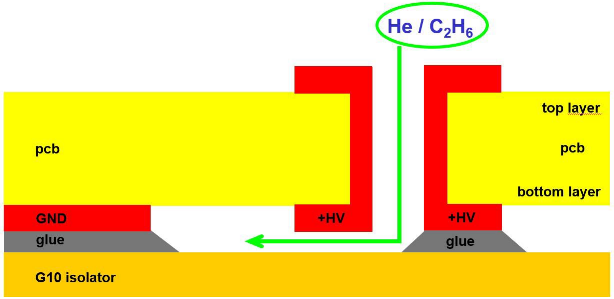


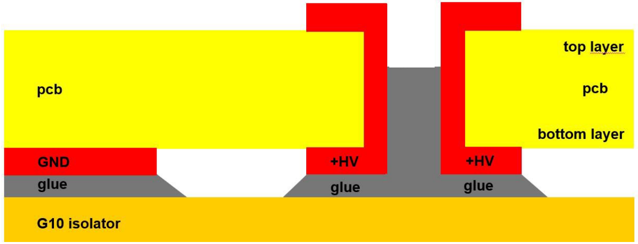
«Helium Pocket»

- individual timescales of performance degradation
  - within few weeks
  - within few months
  - never

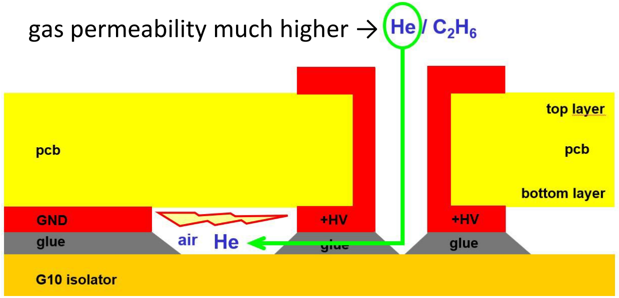
→ depending on thickness of glue that needs to be penetrated by Helium (within few weeks / within few months)

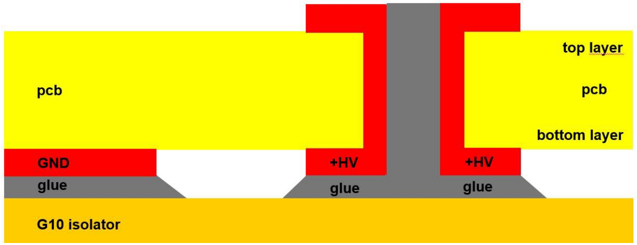






gas permeability much higher →



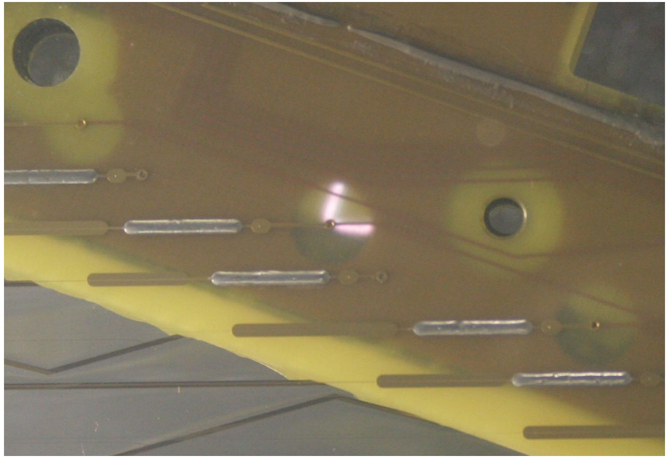


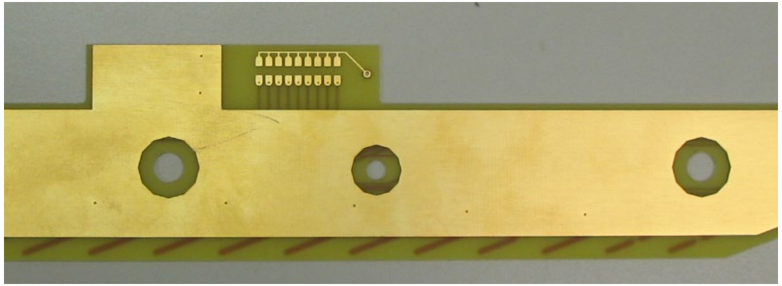
«Helium Pocket»

- confirmation of hypothesis
  - drift chamber module without outer cathode hood
  - operated in He and He/C_2H_6 atmosphere
  - after 65 days of operation: observation of discharge

- solution
  - new layout of wire pcb
  - no HV traces on bottom layer
  - individual layers for HV and GND
  - “tapped blind vias” to connect only appropriate layers

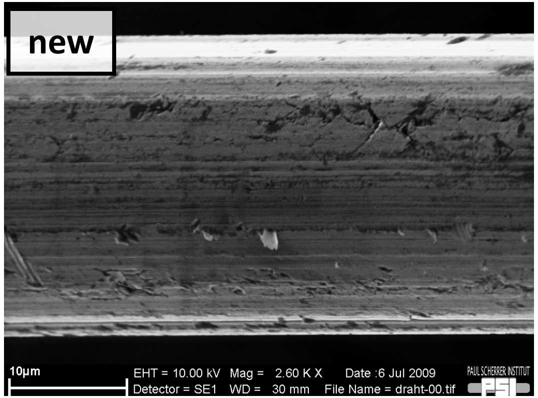
- newly build drift chamber modules worked in long-term operation
  → occurrence of long-term aging phenomena

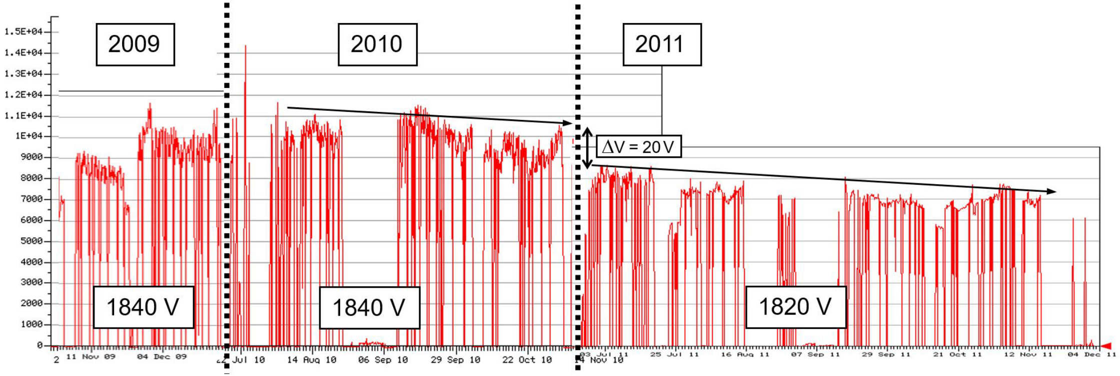




Anode Wire

- Ni/Cr (80/20) 25μm
- data sheet
  - Ni balance
  - Cr 18 - 20 %
  - Si 1.5 %
  - Al 1000 ppm
  - Fe 2000 ppm
  - Mn 2000 ppm
- scanning electron microscope (SEM)
  (S. Ritter, PSI)





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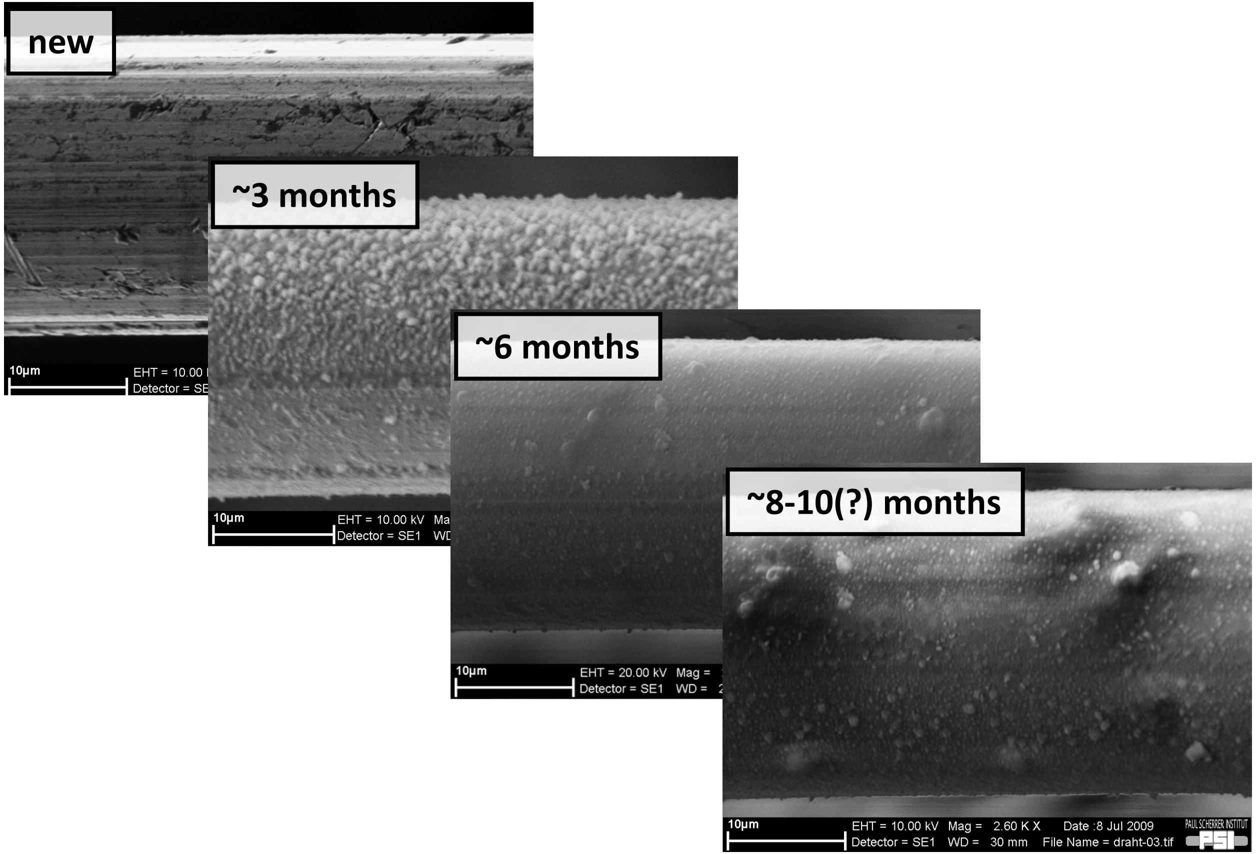

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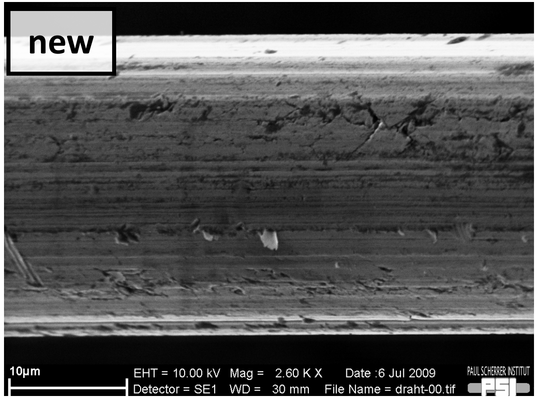

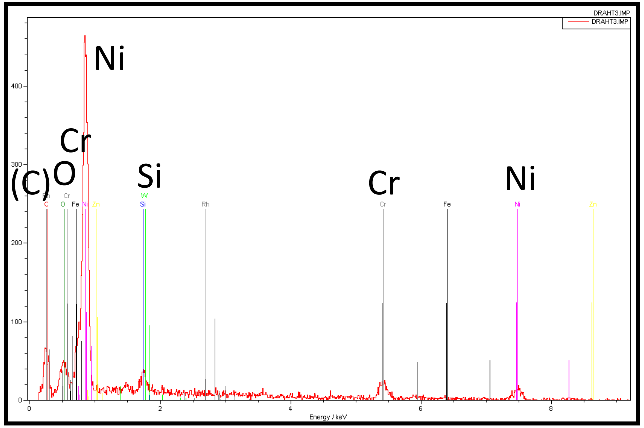

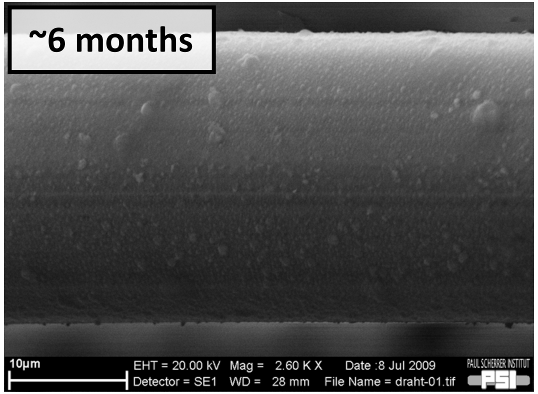

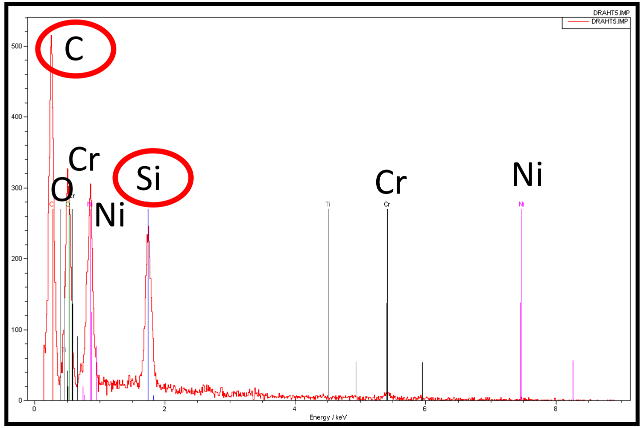

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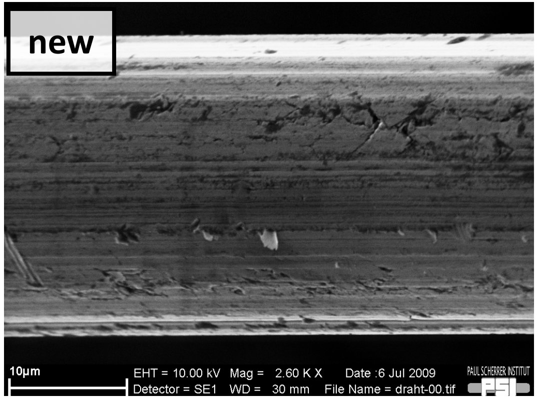
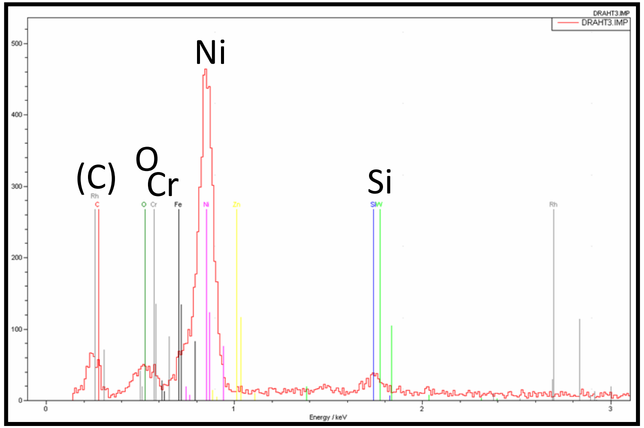
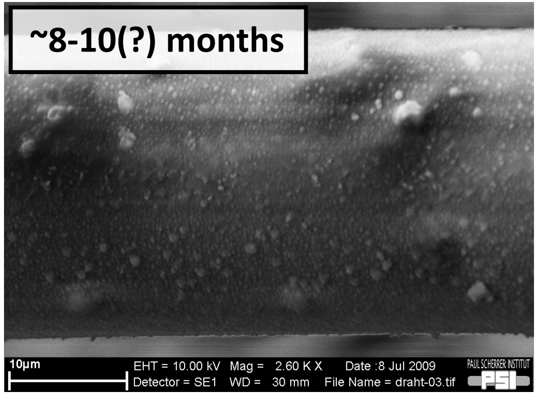
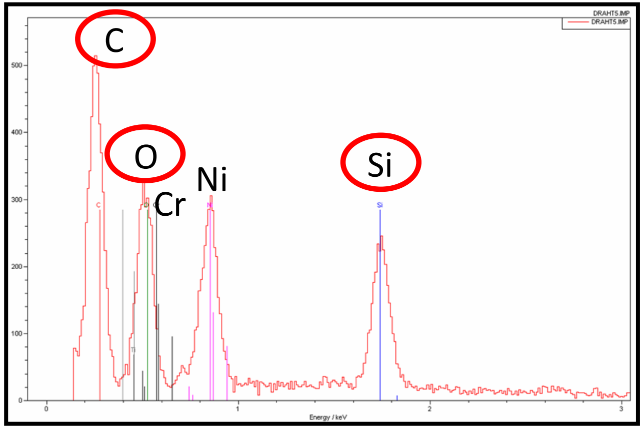


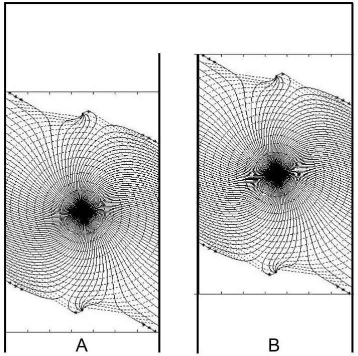


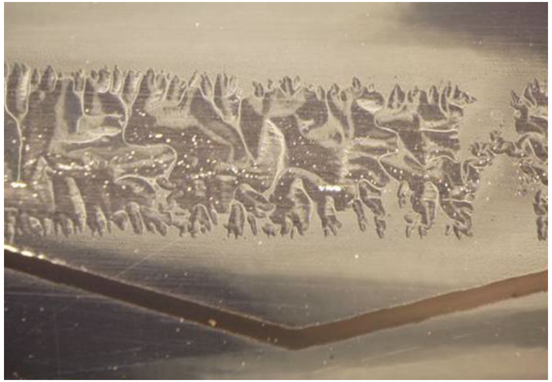


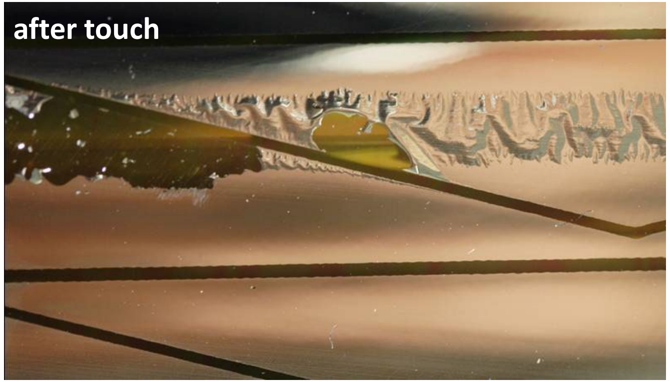


Cathode

- aluminium peeling off
  - effected region with sharp edges
  - not symmetric to anode wire, shifted due to 'rotation' of E-field in E×B configuration?
  - feedback manufacturer: maybe due to missing chromium underlayer

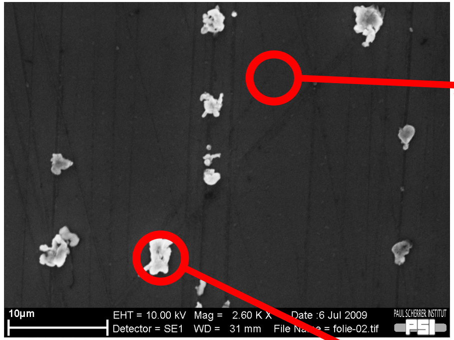


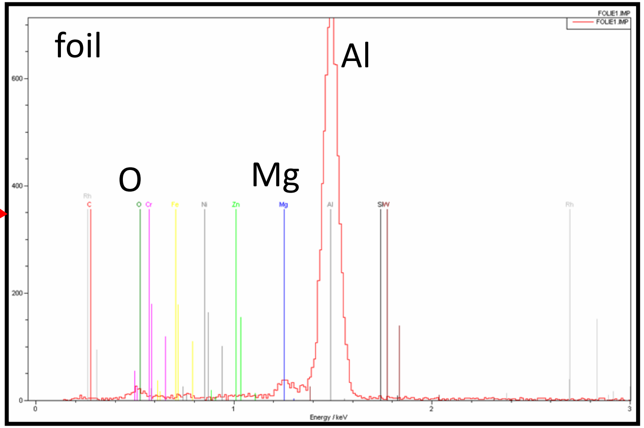


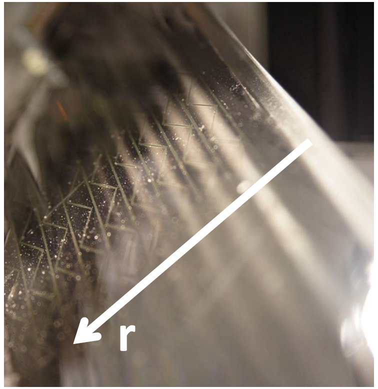


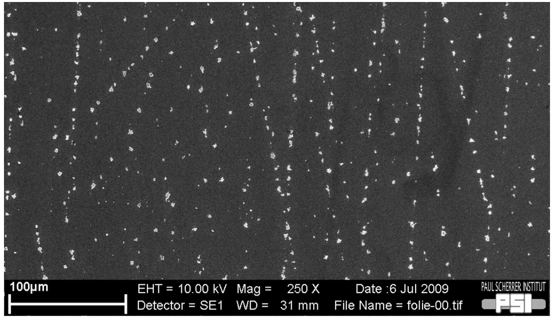
Cathode

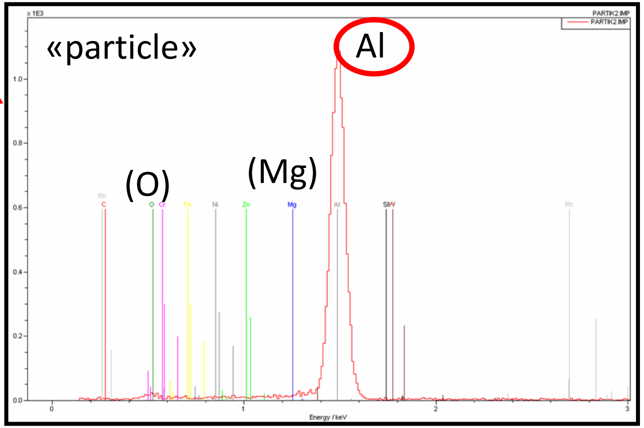
- white “shadow”
  - intensity decreasing with increasing r
  - not continuous in r, but separated stripes
  - not symmetric to anode wire
  - with magnification: “particles” perfectly aligned in lines
  - assumption: scratches seed for material coming up to the surface





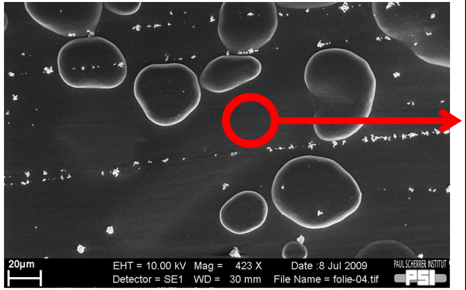


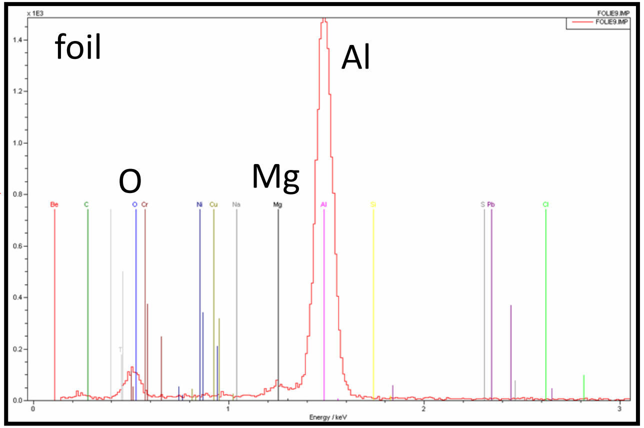


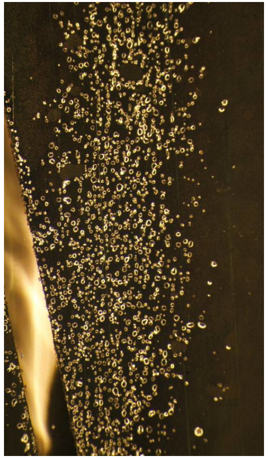


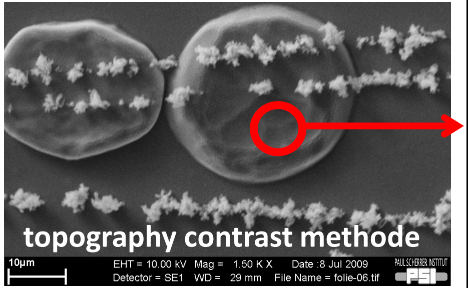
Cathode

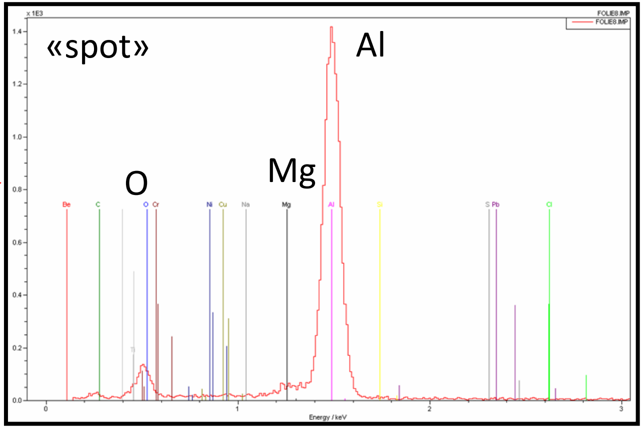
- “spots”, “peaks”
  - effected region with sharp edges
  - slightly extended at etched gaps
  - not symmetric to anode wire
  - with magnification: “bubbles”(?)
  - precursor for peeling off?







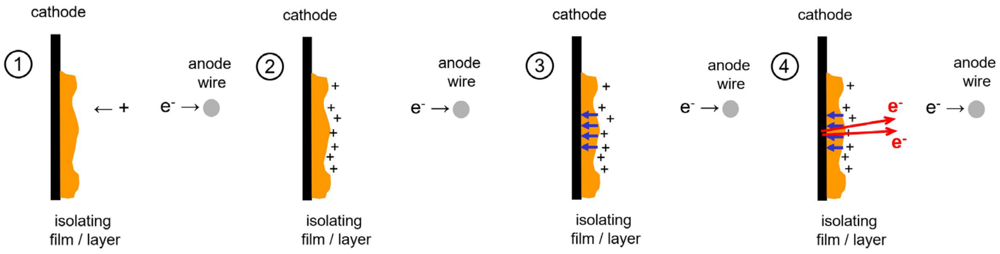


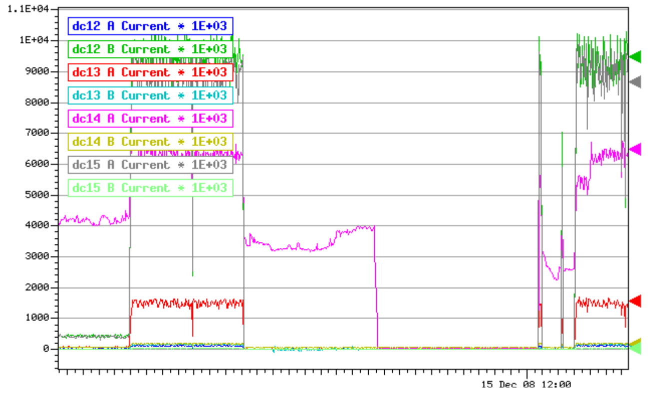


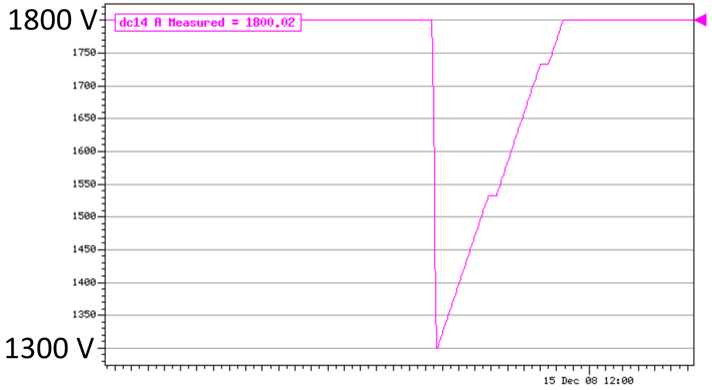
Malter Effect

- remaining current
  - current starts only during high-rate irradiation (not a surface current)
  - remaining current stays, even external irradiation finished
  - only when HV is reduced to 1300 V ($\alpha_{Townsend} = 0$) remaining current dies away

- Malter effect ("thin film field emission")
  - Louis Malter, Phys.Rev. 50 (1936) 48-58

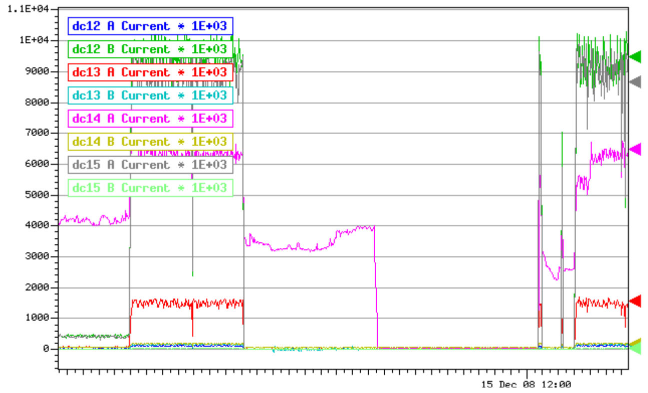






Malter Effect

- remaining current
  - current starts only during high-rate irradiation (not a surface current)
  - remaining current stays, even external irradiation finished
  - only when HV is reduced to 1300 V ($\alpha_{Townsend} = 0$) remaining current dies away



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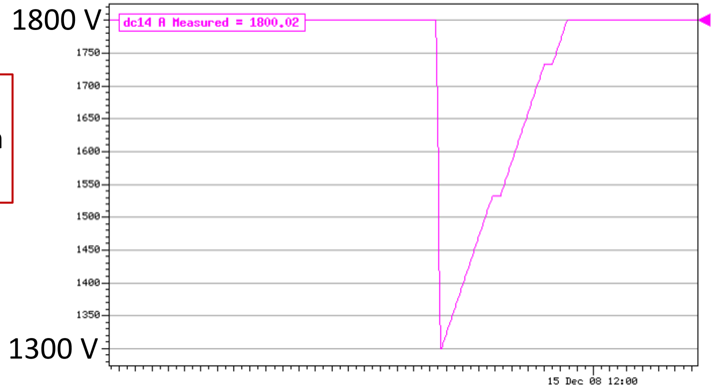

- potential insulating thin film on cathode
  - remaining photoresist
  - traces of glue
  - fingerprints

→ improved cleaning procedure by manufacturer improved operation of newly build dc modules

  - avalanche-produces polymers from filling gas (C_2H_6)
  - gas pollutants
  - insulating deposits left from sparks

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Wir schaffen Wissen – heute für morgen

Summary

- The drift chamber system of the MEG experiment faced quite some challenges: He, C_2H_6, aluminium, high gain, high rate

- Initial HV instabilities due to “helium pocket” fixed with new design of wire pcb.

- Long-term operation showed ‘classical’ and ‘textbook-like’ anode wire and cathode aging.