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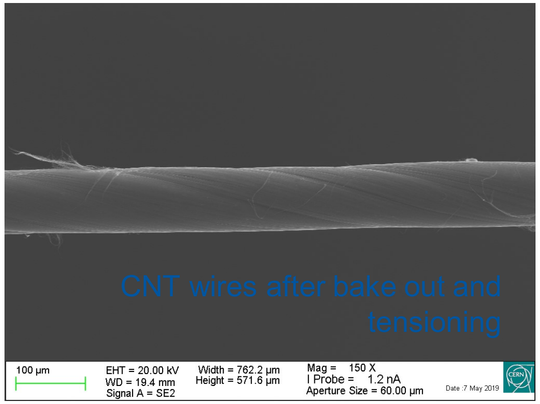
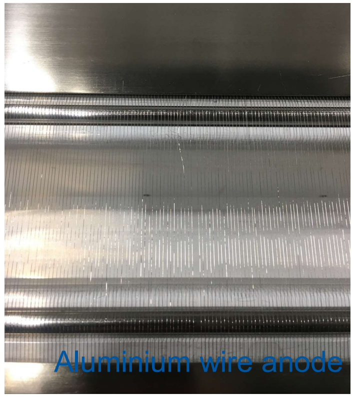


CNT wires after bake out and tensioning


Titanium wire, Ti cathode


Aluminium wire anode

Status of the electrode material R&D for electrostatic septa at CERN

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Anodise aluminium after severe conditioning


Polished titanium


Stainless steel after conditioning

Outline

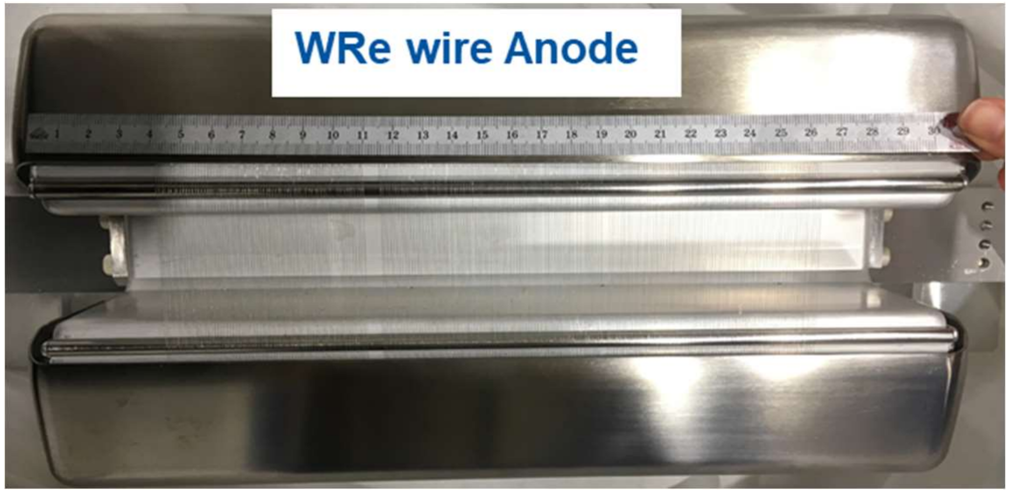
- Introduction
- HV test facility
- Anode material test results
- Cathode material test results
- Conclusion and outlook

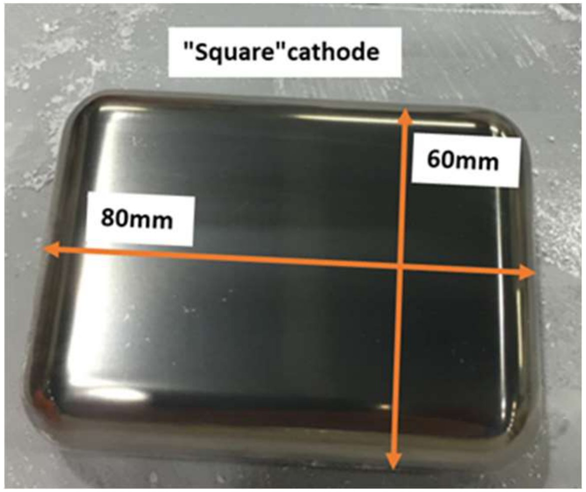
Introduction

- Equipment activation reduction using low density materials for septum wires and support is very promising [1].
- Anode wire options assessed.
- Cathode materials performance assessed.

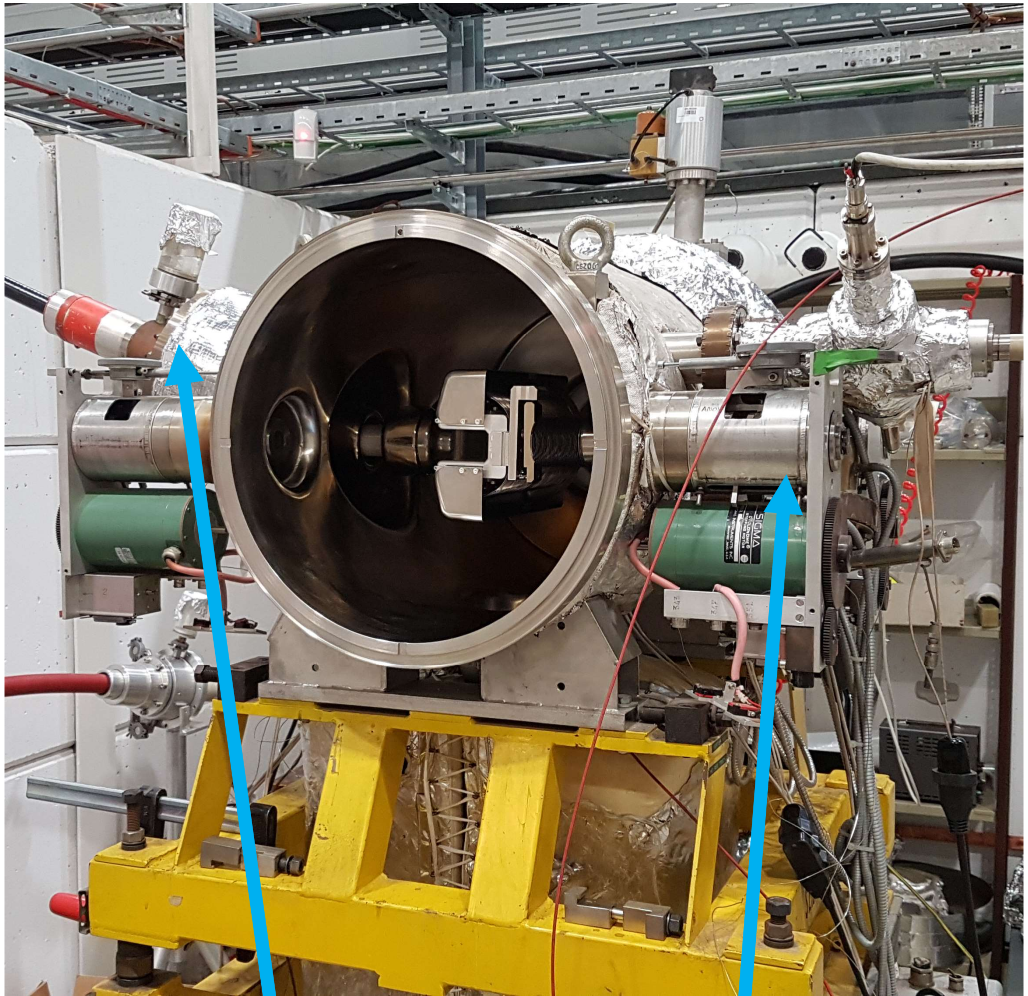
HV test facility 1/2

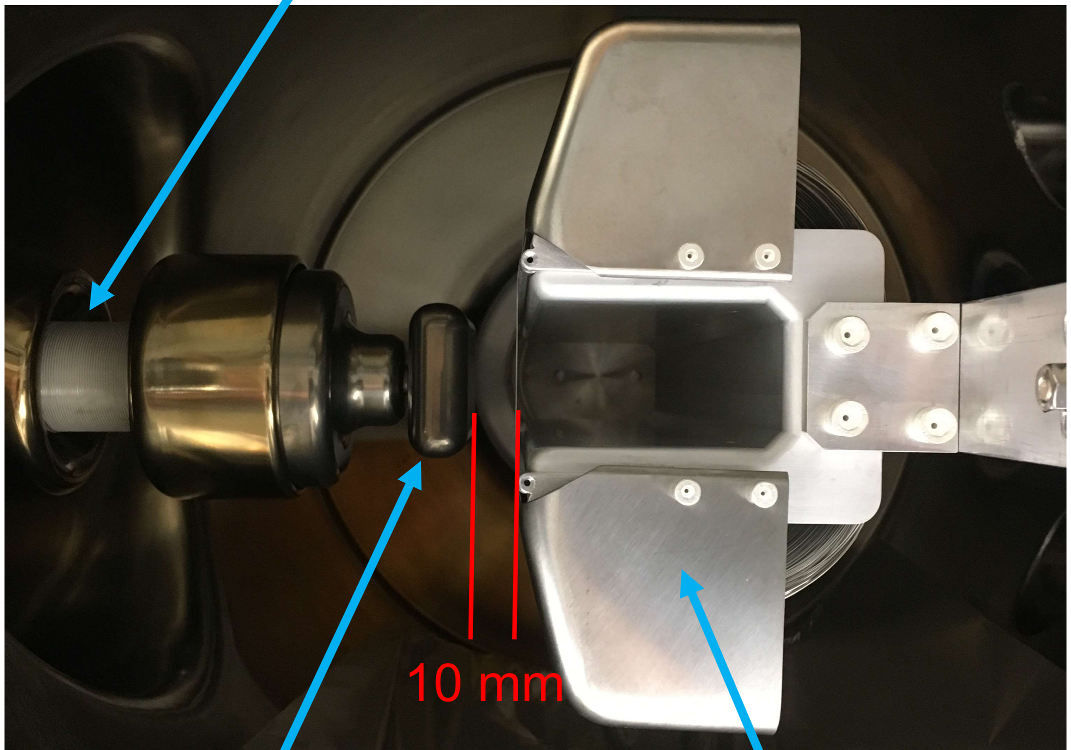
- Former LEAR septum is used as a test facility.
- Adjustable cathode gap (5 - 40 mm), nominal 10 mm.
- Septum anode wire 40 x 300 mm (V x H).
- Used existing test cathode.





HV test facility 2/2





Damping resistor

HV feedthrough

motorisation

Ti cathode

Anode wire support

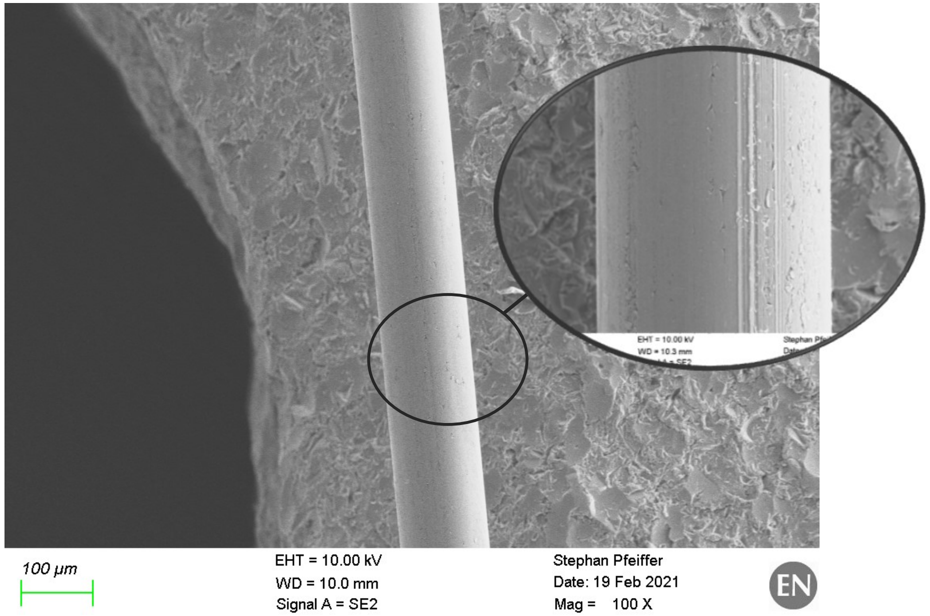
Anode wire materials

Wire material	Ø [μm]	Density [kg/l)	Alloy reference	state	Remarks
Tungsten	100	19.7	WRe (26%)	Annealed	Reference material
Stainless steel	100	7.9	316 L	Tempered hard	Not yet tested
Titanium	100	4.42	TA6V	Annealed	
Aluminium	125	2.7	AlMgSi (98/1/0.6 %)	As drawn	
Carbon Nano Tube	100	1.3	CNT wire made of 7μm CNT strands		Measured density ±0.2 kg/l

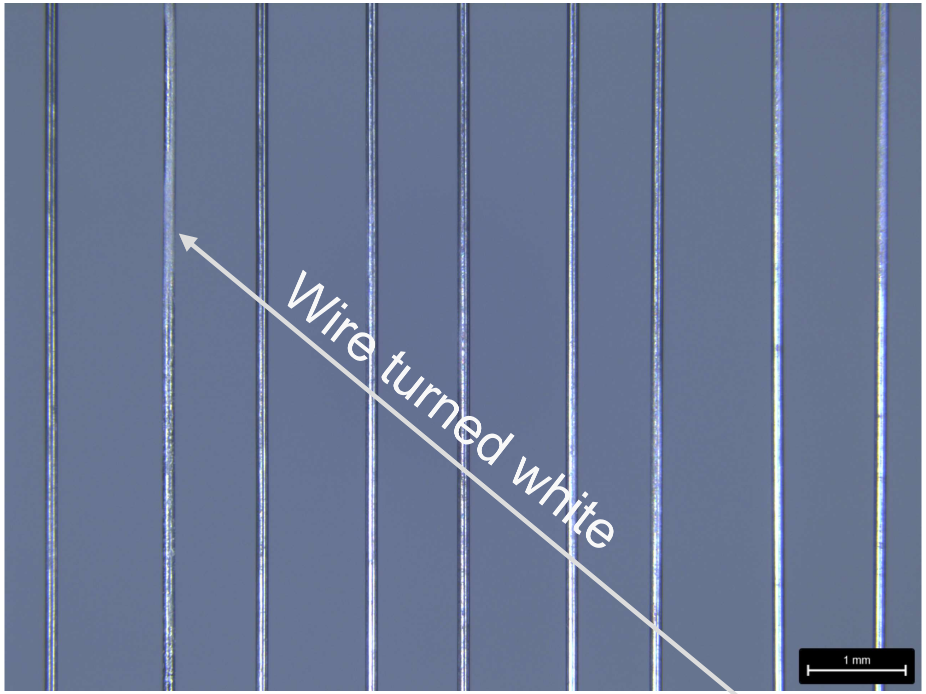
Aluminium wire

- In total 12 broken wires during conditioning, despite the initial tests with low current.
- Cathode seems to have suffered after conditioning, i.e. observed more surface irregularities then with other tests (Al deposits?, not yet determined).
- The surface of some wires that saw field are heavily deformed after conditioning.

Aluminium wires, after conditioning 1/2

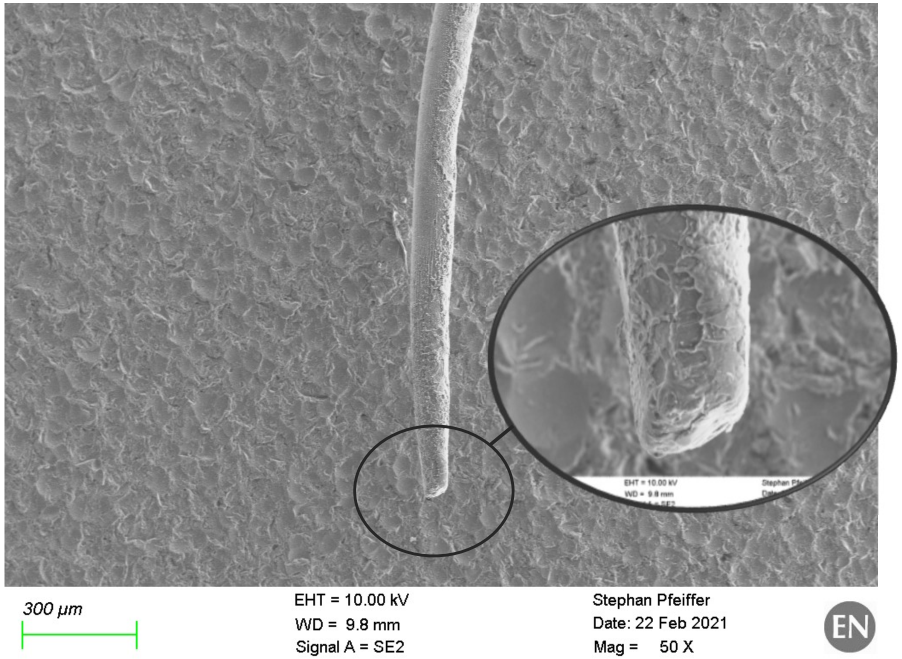


Wire surface of wire after exposure to high field; no surface damage observed.

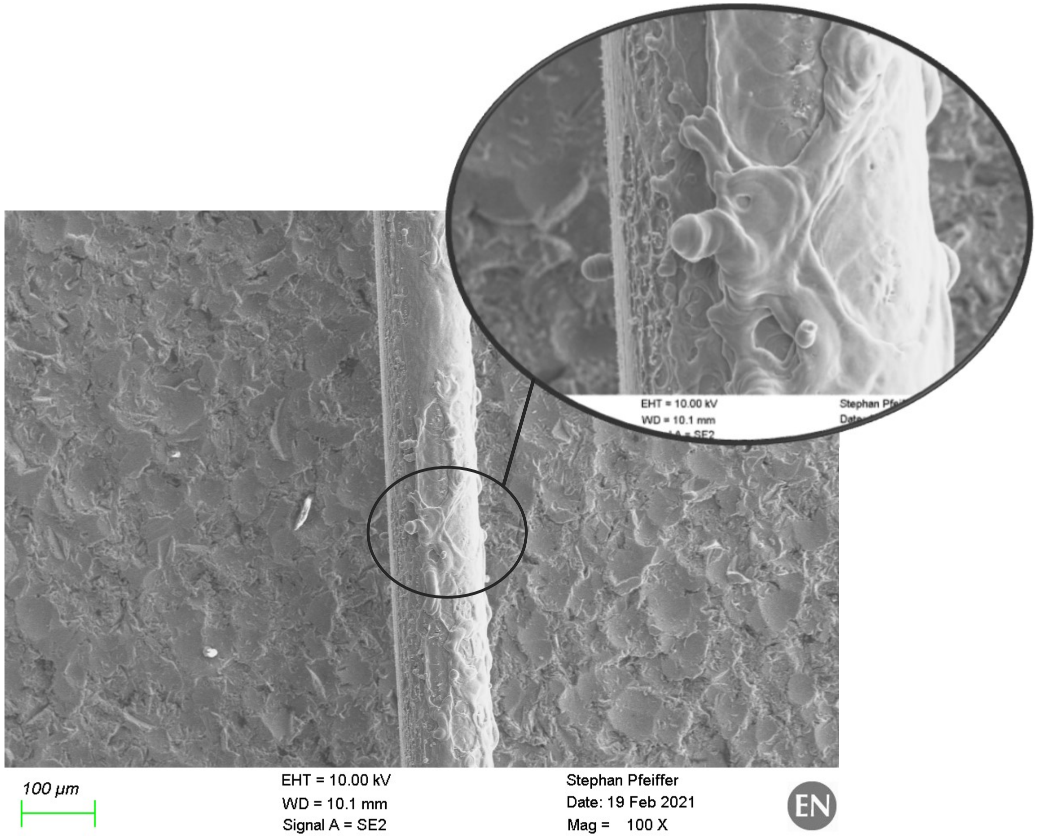


State of Al wires in the array after conditioning; some wires changed color.

Aluminium wires, after conditioning 2/2



Extremity of a wire broken during conditioning.



‘White’ wire after exposure to high field on the right side and low field on the left. Droplets created on surface. Conditioning damage?

Titanium wire

- The titanium revealed itself as a very springy wire: it was very hard to tension the wires straight (i.e. nicely parallel) on anode support.
- Only a few broken wires during conditioning. Mainly because higher currents were used to condition (up to 200 µA instead of several 10s of µA).
- When a **Ti wire broke (4) using a Ti cathode**, **welding of an end onto the cathode has occured**, shorting the system.
- Broken Ti wires (2) didn’t weld onto a stainless-steel cathode.

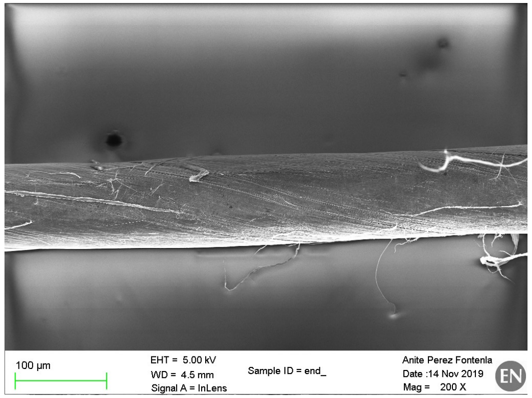
CNT wire

- Tested Stainless Steel and a Titanium cathode in combination with CNT wire anode.
- Similar behaviour appears independent of cathode material: 1 spark (at ~15kV) provokes an irreversible current, and voltage hold off decreases to 12kV.
- Could be recovered by N_2 conditioning at atm. pressure up to 15.9kV. Subsequently under vacuum 20 kV (E=2MV/m) could be achieved without current.

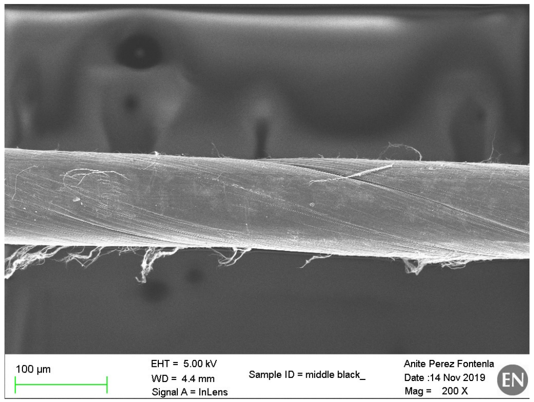
CNT wire investigation summary

- No broken wires during conditioning (sparking): mechanically very robust.
- Once a spark occurred, the cathode seems to become an electron emitter. The current could be increased 10-fold (or more) without increasing voltage or provoking a spark. Further conditioning became impossible.
- Same behaviour independent of the cathode material used (Ti and Stainless Steel).

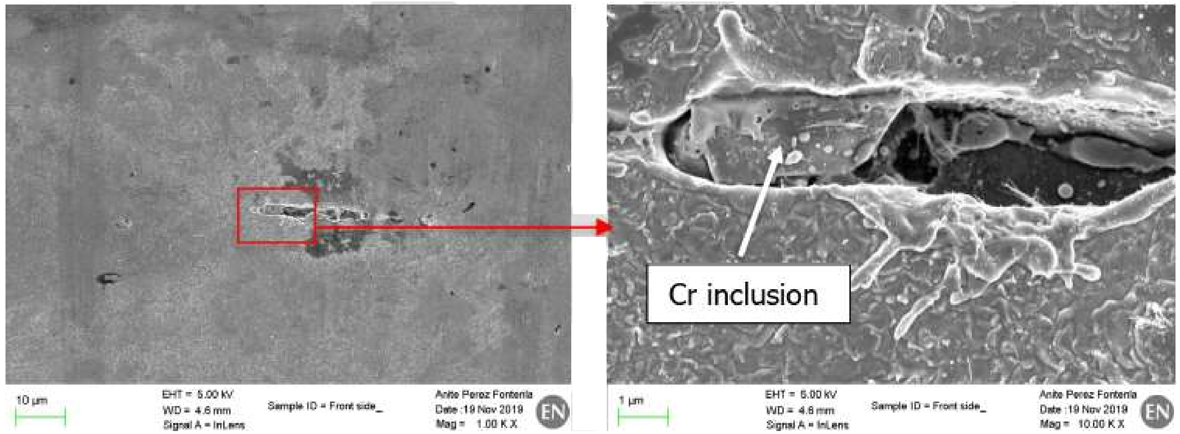
CNT wire and dust on cathode



Zoom of a wire in low field region after conditioning. Strand damage from installation only.



Zoom of wire in high field region after conditioning. Degradation of some strands was visible.



Cathode: surface aspect at 1k magnification and detail of the molten material at the inclusion edge at 10k magnification.

Inclusions were found on front (i.e. high field) face of the cathode, but none on the back side.

Hypothesis: the included CNT debris acts as electron emitter on cathode.

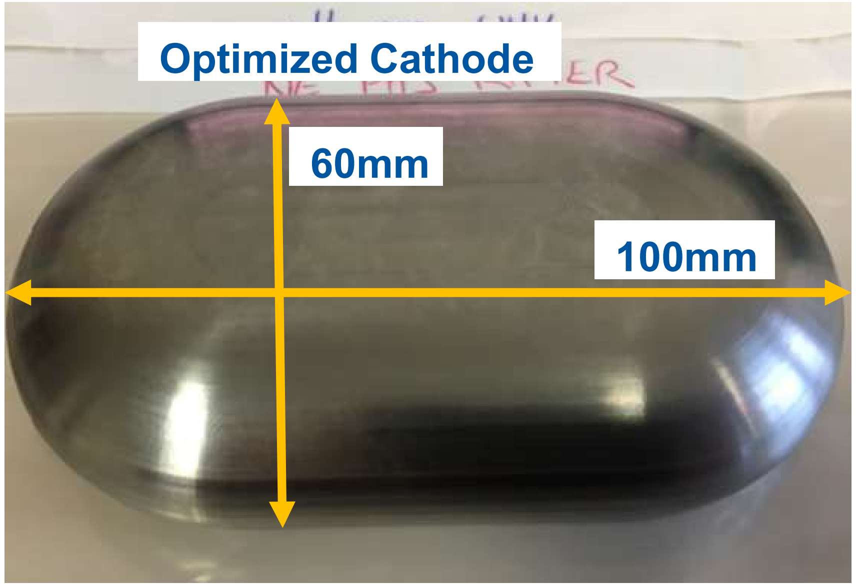
Test summary

Cathode Material	Anode Material	Gap width [mm]	Achieved voltage [kV]	Corresponding peak field [MV/m]	Test tank #/ cathode
St. steel.	WRe	10	70	7.7	23/v4
Ti	WRe	10	130	14.3	23/v4
St. steel.	CNT	10	30	*	11/sq
Ti	CNT	10	18	*	11/sq
St. Steel	Ti	10	100	11	11/v4
Ti	Ti	10	102	11.2	11/v4
Ti	Al	10	115	12.7	11/v4
St. Steel	Al	10	115	12.7	11/sq

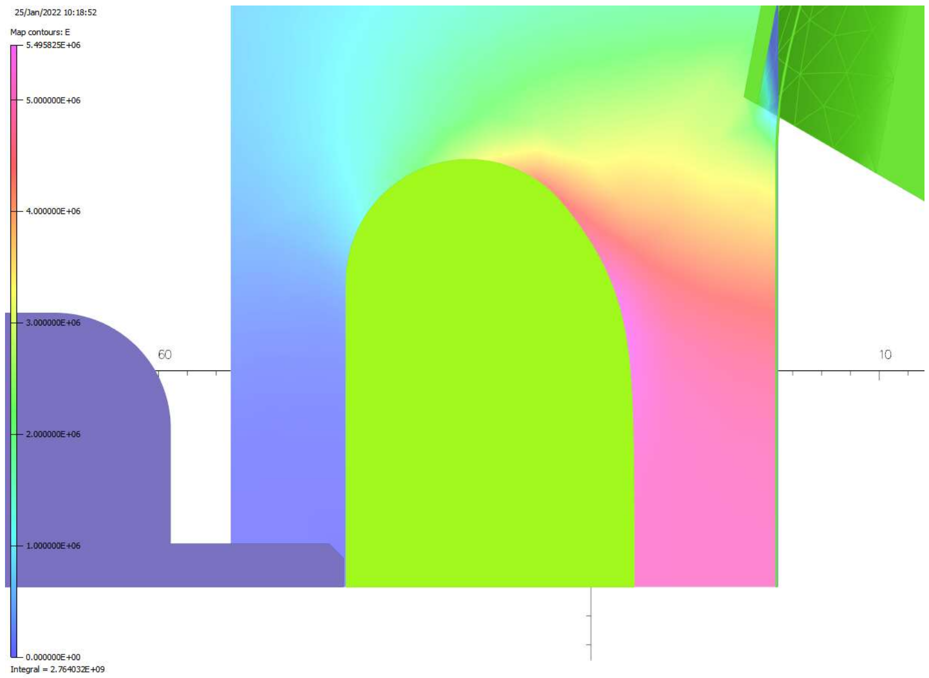
* Field amplification factor of square cathode not available.

Cathode material tests

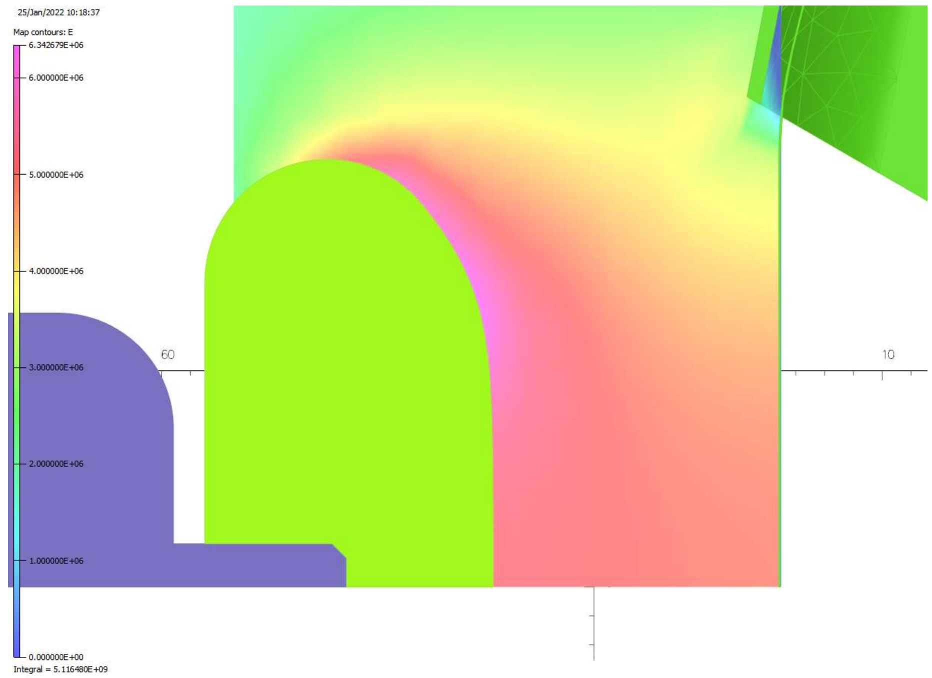
- A short cathode was designed, to minimize the field on the cathode surface.
- Manufactured from several materials to allow comparative testing.
- All tests done using a WRe wire anode.



Cathode profile



10 mm gap,
Cathode 50 kV
E_{gap} = 5 MV/m
E_{max}= 5.49 MV/m



20 mm gap,
Cathode 100 kV
E_{gap} = 5 MV/m
E_{max}= 6.34 MV/m

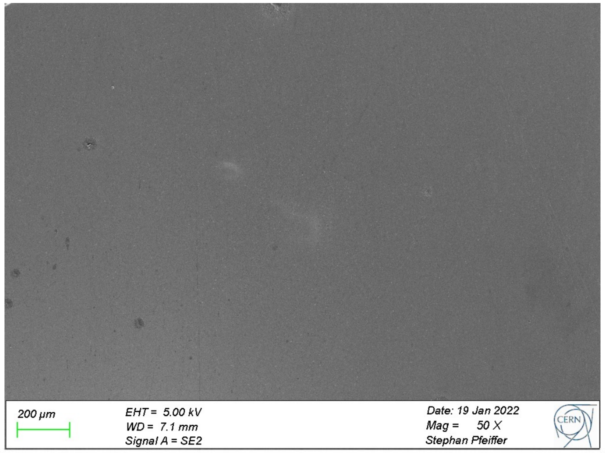
Aluminium cathodes

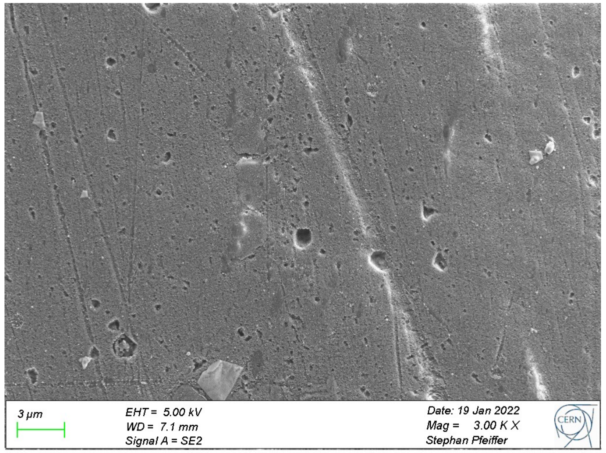
1) **Chromic Anodized** alloy used for small gaps ≤10 mm. Now prohibited.
2) **Sulfuric Anodized** Peraluman 300: used for larger gaps (used in operational CERN septa).
3) **Gold plated** aluminium alloy:
   - Used in the CSR ring (Max. Plack Institute, Heidelberg) to avoid Al_2O_3 layer to obtain better fields (charges cannot stick to surface, altering field distribution).
   - Achieved by successive coating with various metals, and a final gold layer.
   - Test cathode plated at CERN.

Bake-out compatibility 1/2

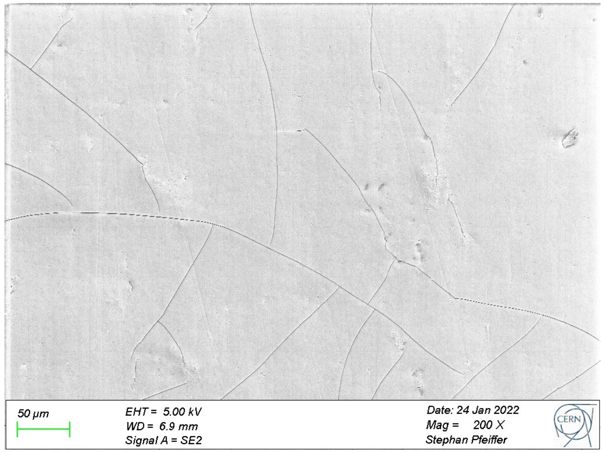
- Anodized Aluminium

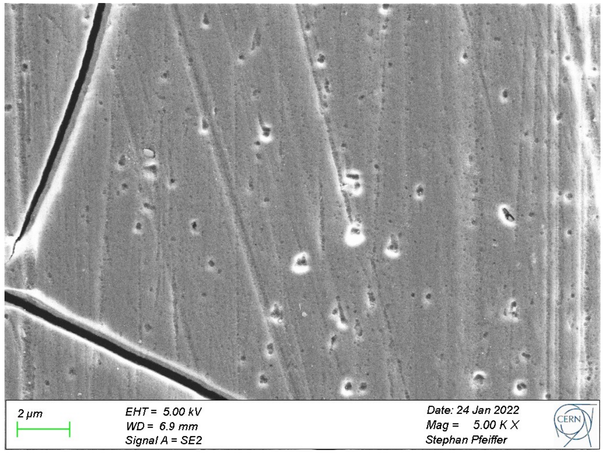
Before bake out
(50x and 3000x)





After bake out
(200x and 5000x)



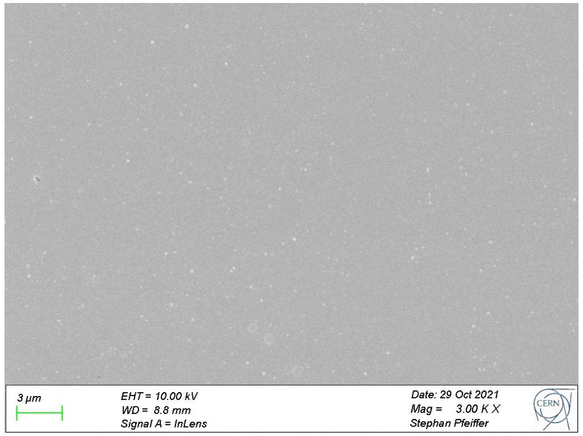


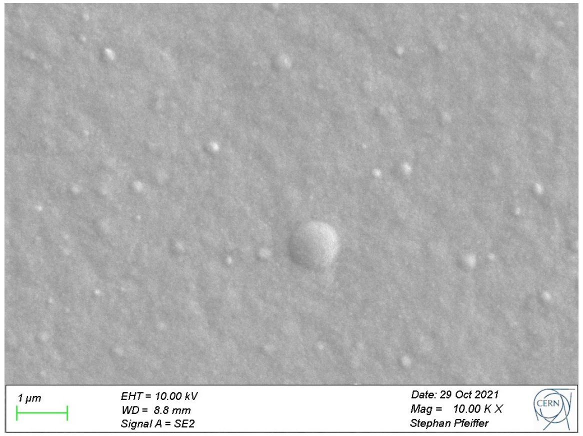
Conclusion:
Cracks visible, HV performance to be verified.

Bake-out compatibility 2/2

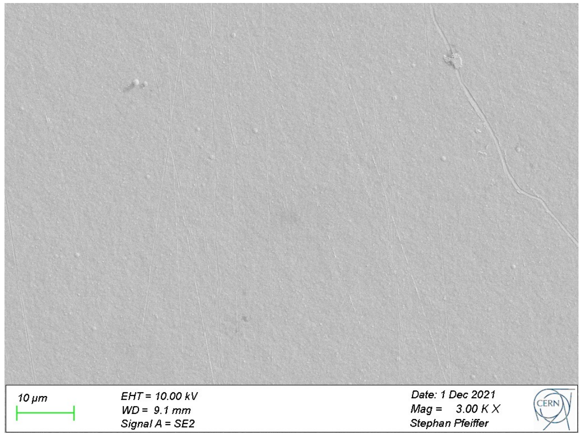
- Gold-plated Aluminium cathode

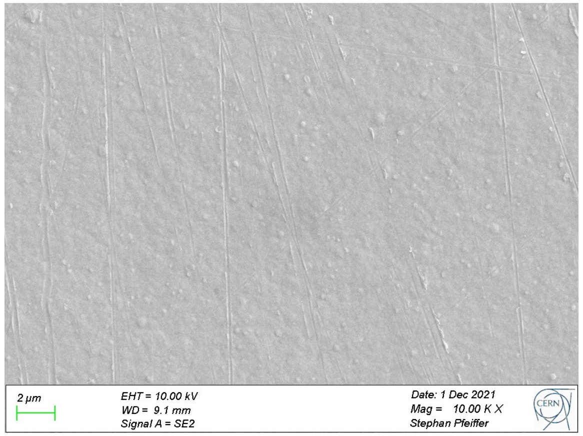
Before bake out
(3k x and 10k x)





After bake out at 200°C
(3k x and 10k x)





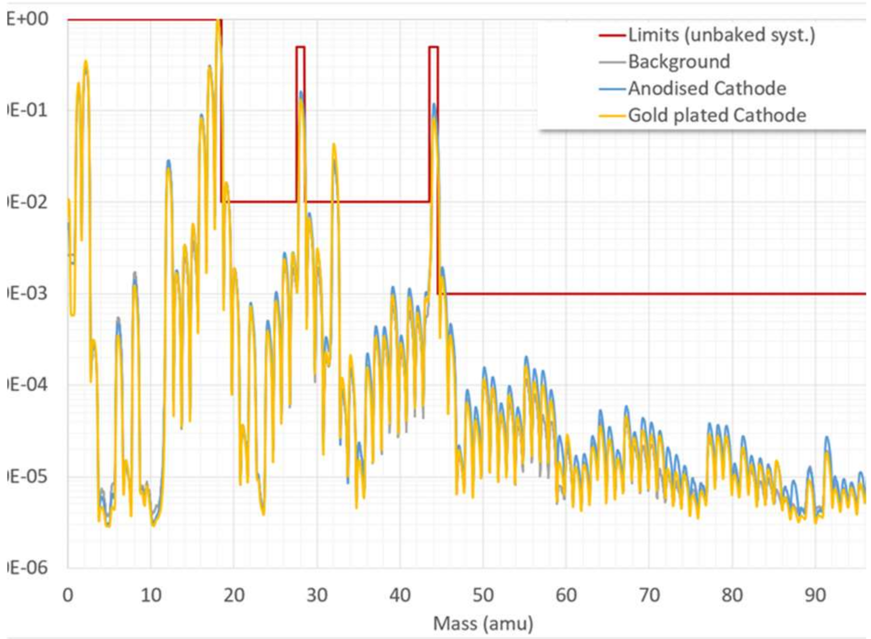
Conclusion:
no significant change of surface due to bake-out.

Vacuum performance

Cathode	**Outgassing rate [mbar.l/s]**	**remark**
Sulphuric anodized Al alloy	1.1e-5	After conditioning, no bake out
Gold-plated Al alloy	8.7e-8	After bake out, and conditioning
Stainless steel	3e-12	Typical value for reference [5]

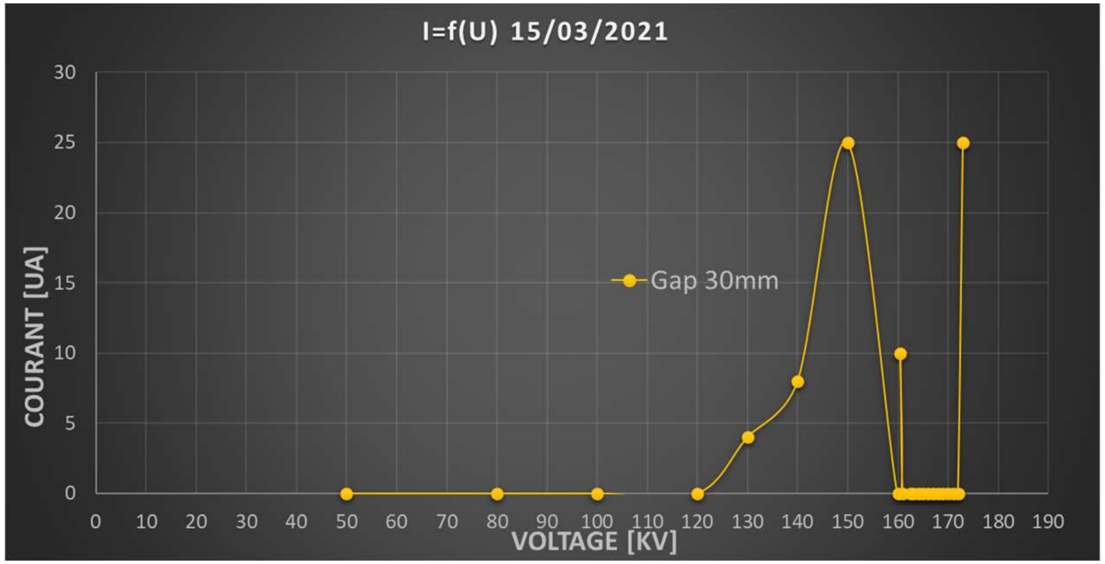
Outgassing of gold-plated Al alloy cathode much better than anodized variant.

Both cathodes residual gas analysis are compatible with CERN acceptance limits.

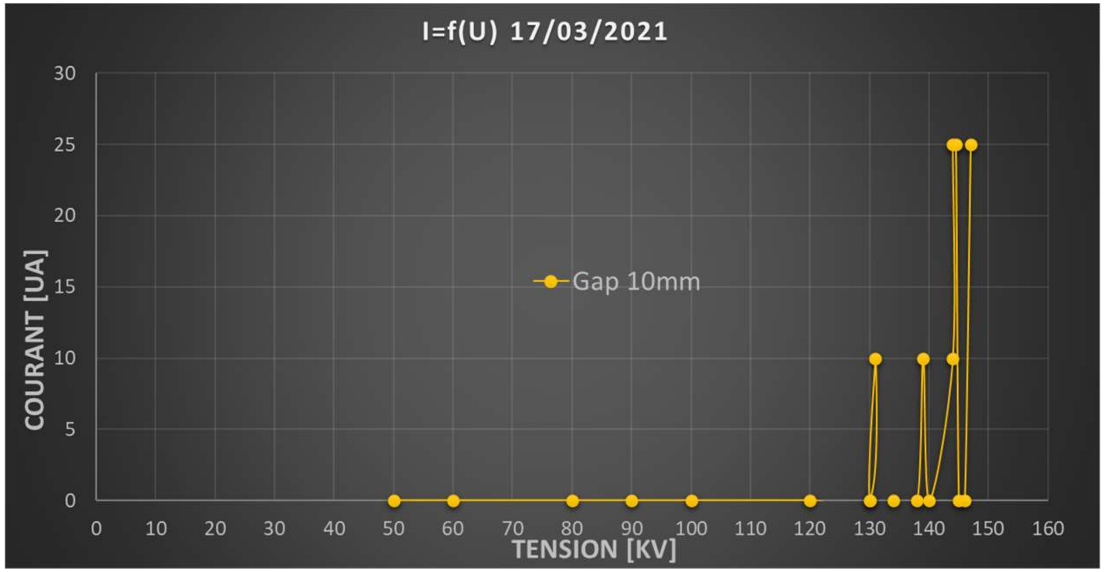


Conditioning

- Regulated current conditioning process.
- To validate set-up, first conditioned with a 30 mm gap.
- Sulphuric anodized Aluminium cathode with WRe anode array.



10 mm gap conditioning.



Conclusion:
Several sparks are needed to obtain stable performance.

Max. fields achieved

Cathode Material	Anode Material	Gap width [mm]	Best voltage without current (kV)	Corresponding peak field [MV/m]
Stainless steel.	WRe	10	70	7.7
Titanium	WRe	10	130	14.3
Anodised Aluminium	WRe	10	150-160	16.5-17.6
Anodised Aluminium after bake out	WRe	10		
Gold plated Aluminium	WRe	10	130	14.3
Gold plated Al after bake out 120°C	WRe	10	130	14.3
Gold plated Al after bake out 200°C	WRe	10	130	14.3

Conclusions and outlook

- Al and Ti anode wire materials remain of interest and warrant further study.
- Sparking with CNT anode wires led to cathode surfaces to be transformed in electron emitters.
- Gold plated aluminium cathodes permitted higher values than stainless steel and titanium, albeit still slightly less than anodised aluminium.
- Another topic of interest for operation is the spark rate. Source terms to explore:
  - temperature dependence
  - dependence of x-rays

References

1. D. Björkman et al., “Alternative material choices to reduce activation of extraction equipment”, IPAC 2019, Melbourne Australia
2. M. Meyer, “Characterization of (CNT) carbone nano-tube and tungsten wires”, EDMS report 2142296, CERN, Geneva, 2019.
3. J. Borburgh et al., ‘Experimental Results of Low-Z Materials as a High Voltage Septum Anode’, ISDEIV2021, Padova.
4. J. Borburgh et al., ‘Low-Z anode wires testing for particle accelerator electrostatic septa’, MevArc2021
5. I. Wevers, “Degassing of different steels for the Septum”, CERN EDMS 1725086