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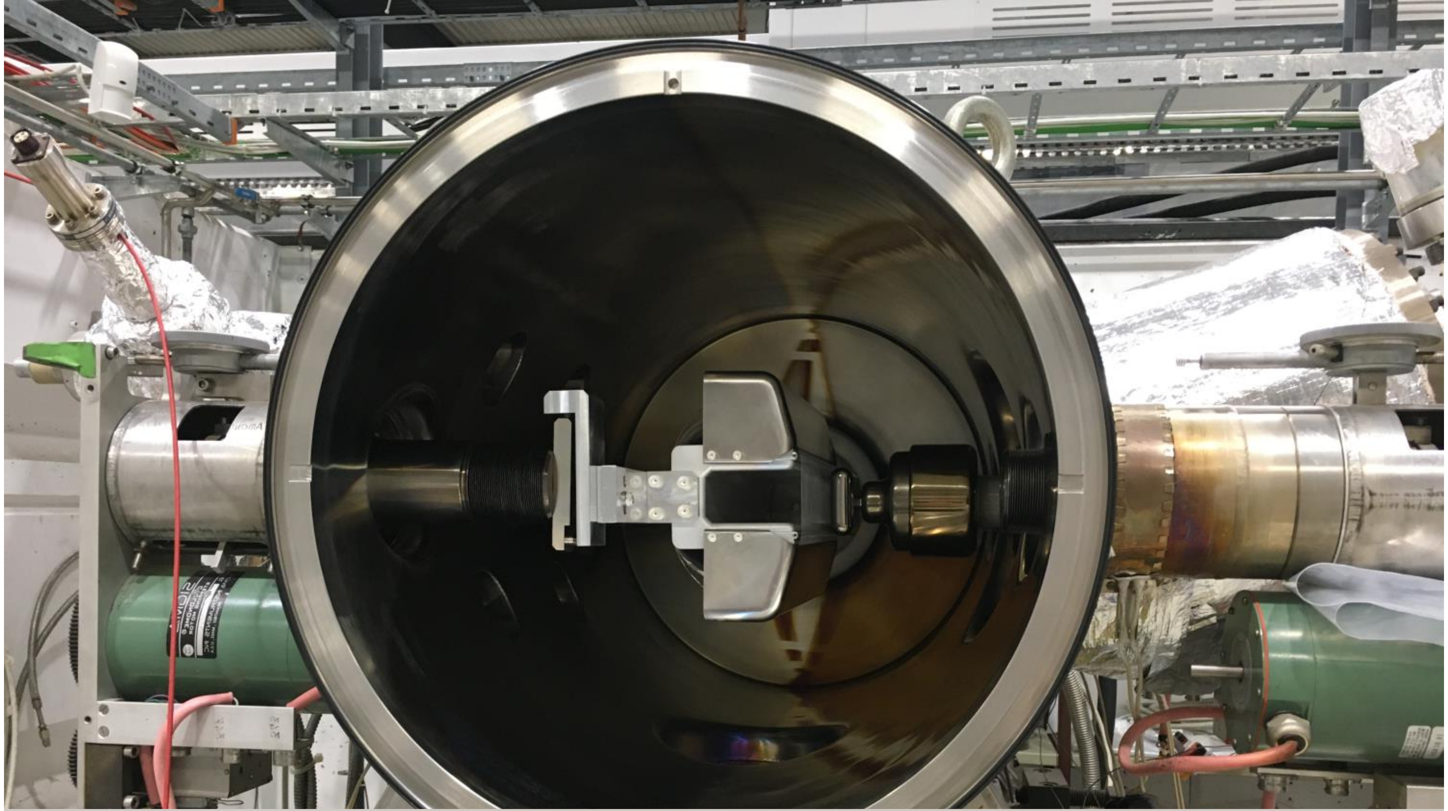

Low-Z anode wires testing for particle accelerator electrostatic septa

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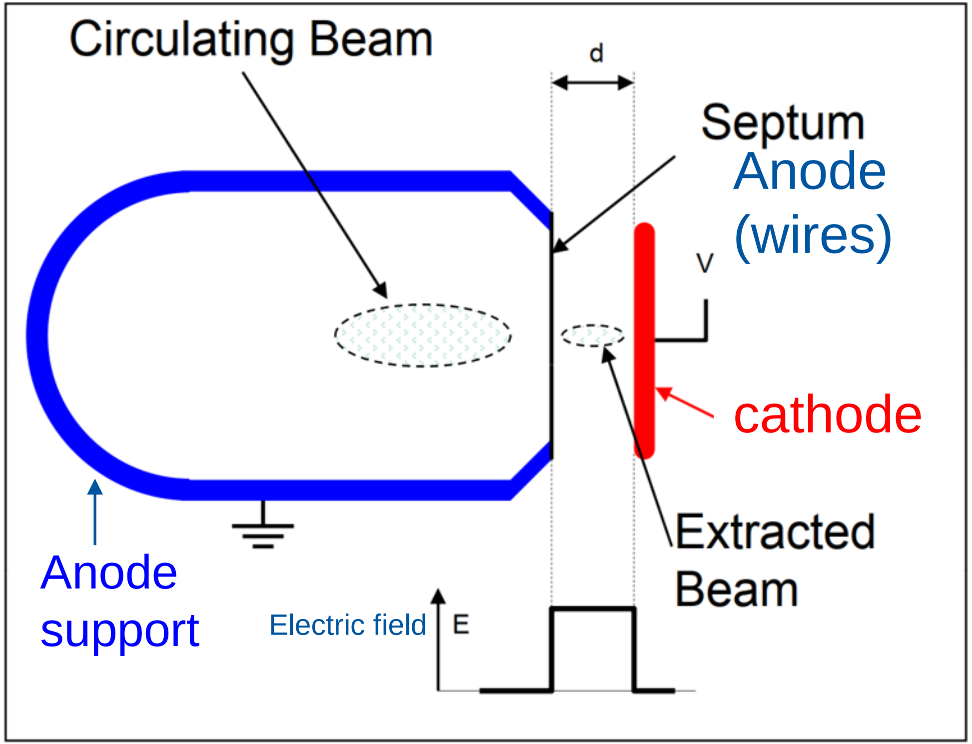
Purpose

To reduce extraction losses in slow extraction electrostatic septa, it is beneficial to use a low-Z septum instead of an array of WRe (26%Re) wires as used up to now.

A laboratory test set-up was built, allowing the high voltage (HV) testing of anodes using wires made of different materials.

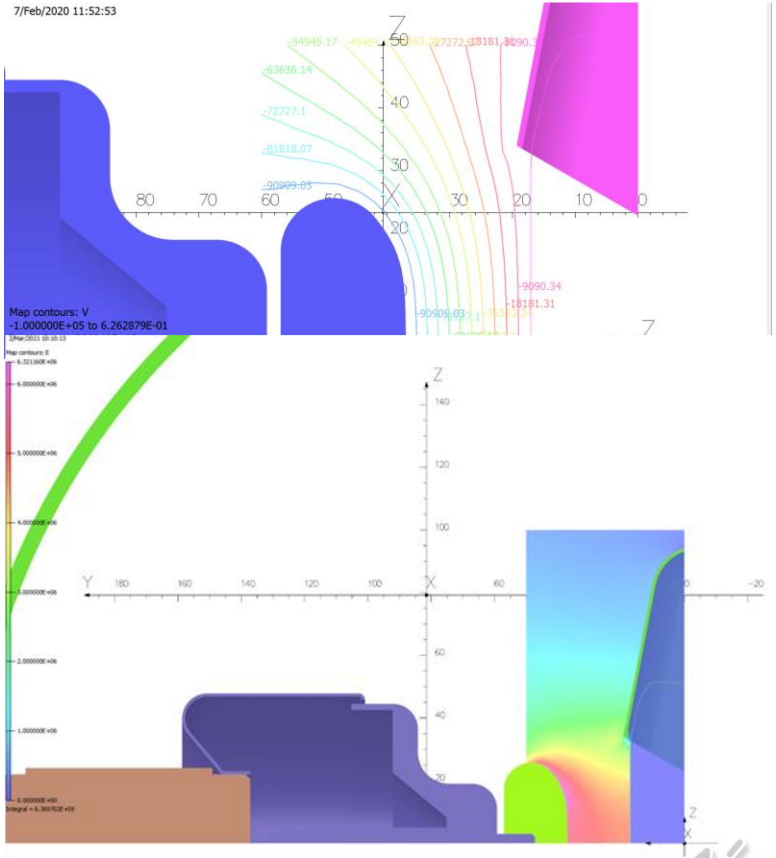


Cathode design

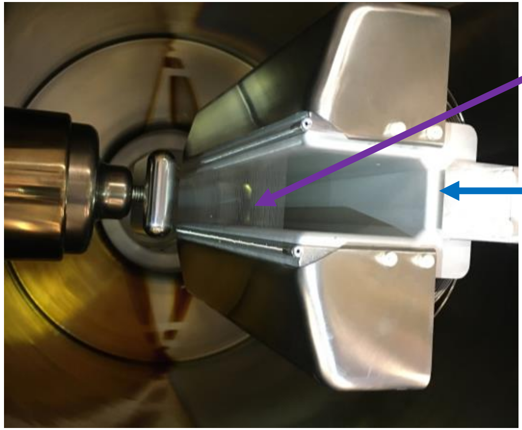
Cathode (60 x 80 mm) was designed to limit field amplification when place opposite the existing anode.
Several cathodes with the same profile were made, using stainless steel (304L) and titanium (grade 2).

Of note: the E field mentioned in the following slides, is the average field between cathode and anode wires, i.e.

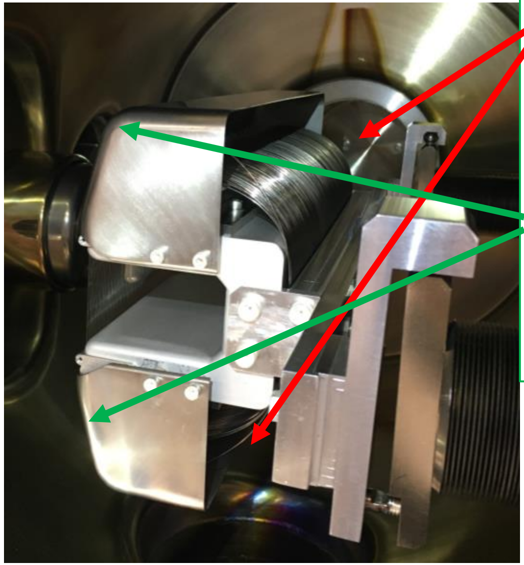
$$E = \frac{U_{cathode}}{d_{cathode-anode}}$$



(Existing) Anode layout



Anode wire array, strung on the hollow (C-shaped) anode support.



Springs, to allow retraction of any broken wires behind the stainless steel HV deflectors

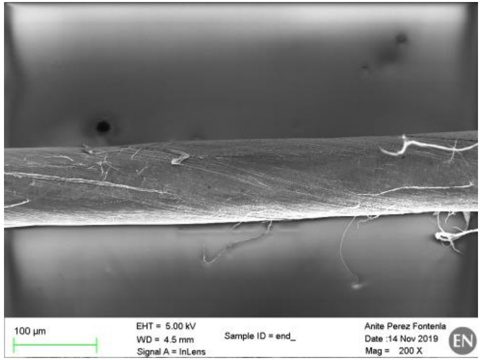
Tested anode wire materials

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

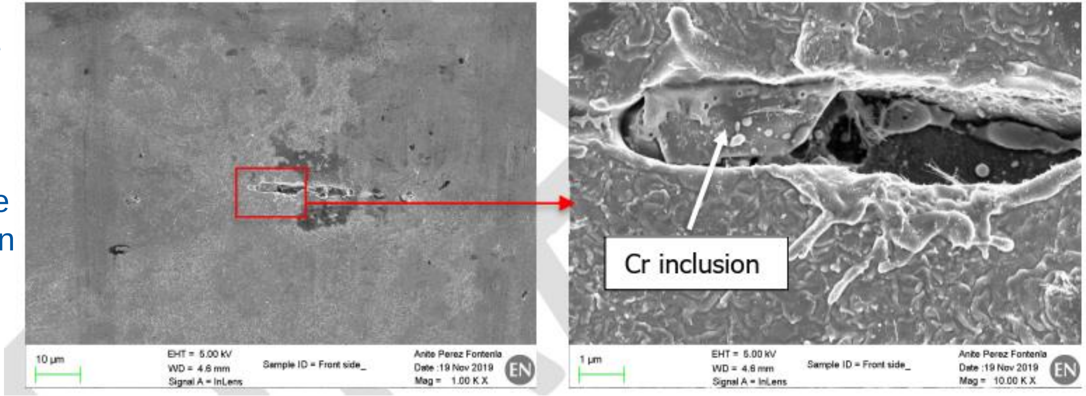
CNT wire investigation

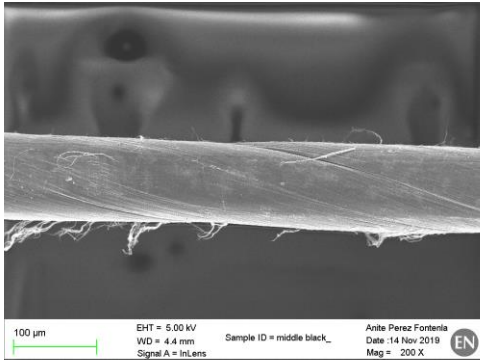
- No broken wires. Very robust mechanically.
- Once a spark occurred, the cathode seems to become an electron emitter. The current could be increased 10-fold (or more) without increasing voltage or provoking a spark. Further conditioning became impossible.
- After conditioning, Carbon deposit was observed on the cathode using an electron microscope.

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.

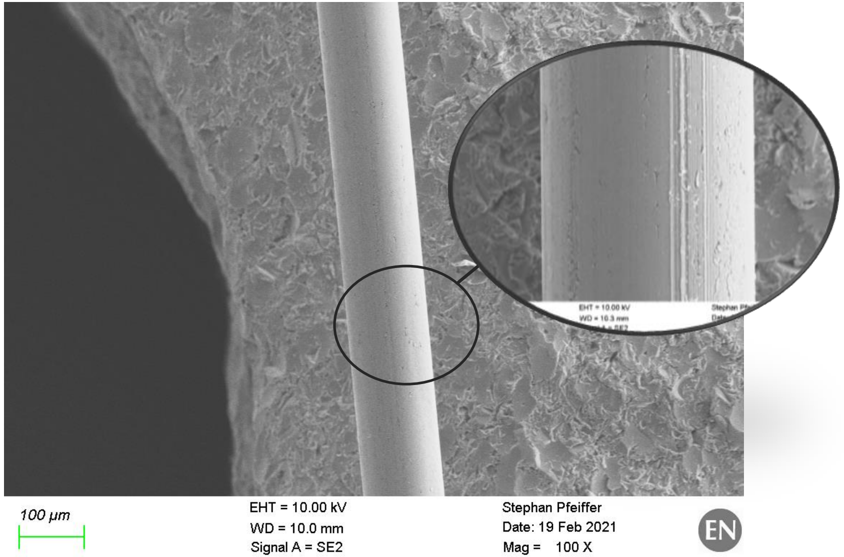
Inclusions were found on front (i.e. high field) face of the cathode, but none on the back side.

Hypothesis: the included CNT debris acts as electron emitter.

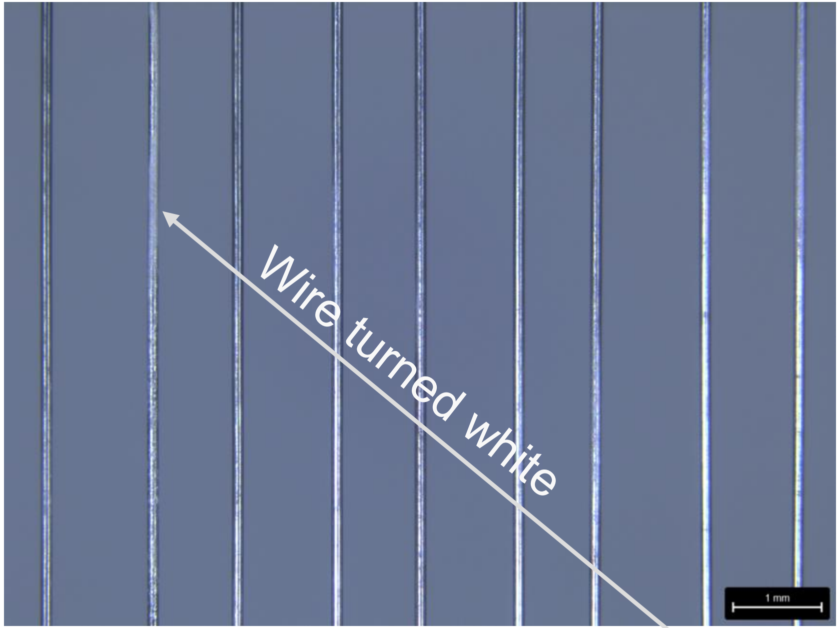
Aluminium wire

- In total more broken wires (12) during conditioning, although the initial tests with low current (showed less wires broken w.r.t. what was expected due to its low melting temperature.
- The fields achieved are definitely the highest achieved compared to CNT or titanium.
- 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

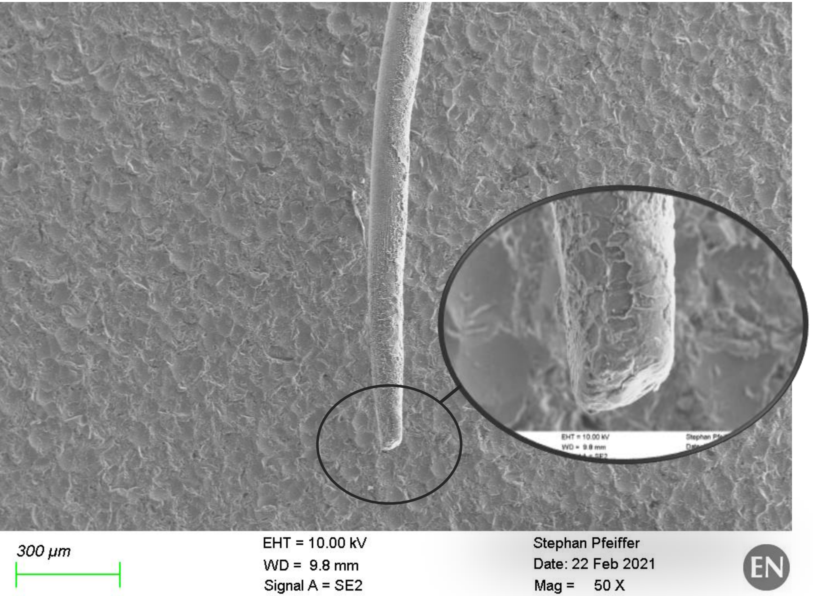


Wire surface of wire after exposure to high field; no surface damage observed.

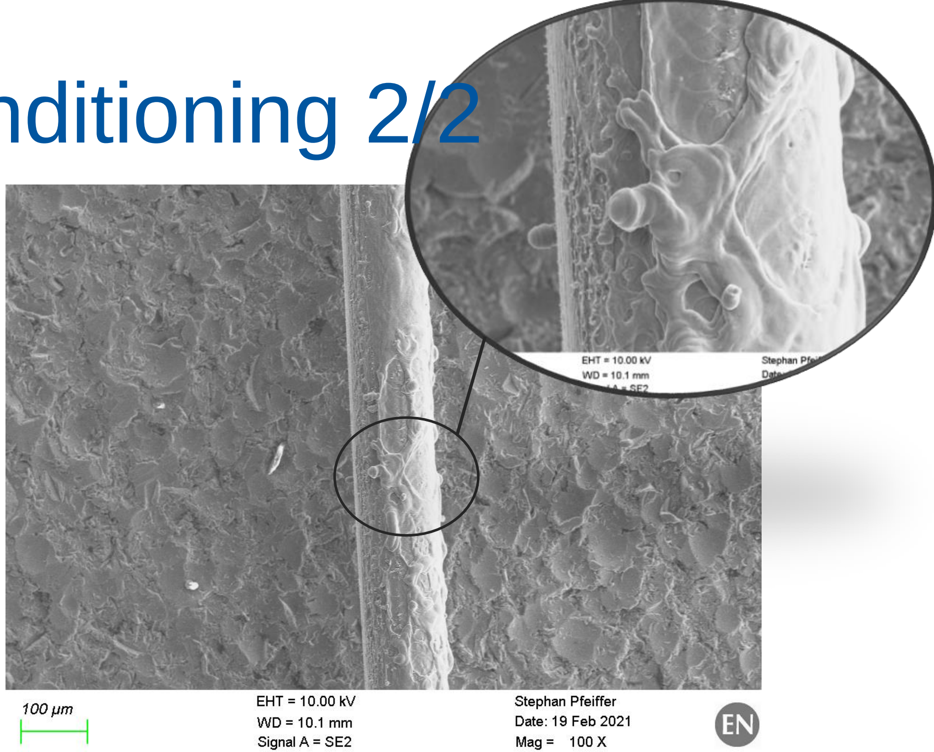


State of Al wires in the array after conditioning; some wires changed colour.

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

- 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.
- 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.

Achieved E fields

Cathode Material	Anode Material	Gap width [mm]	Achieved voltage [kV]	Average gap field [MV/m]	
St. steel.	WRe	10	25	2.5	Reference set-up
St. steel.	WRe	30	50	1.7	
Ti	WRe	10	130	13	
St. steel.	CNT	10	30	3.0	Fields achieved too low for application
Ti	CNT	10	18	1.8	
Ti	CNT	30	33	1.1	
St. Steel	Ti	10	120	12	Useable field
St. Steel	Ti	20	140	7	Feedthrough limited?
Ti	Ti	10	100	10	Useable field
Ti	Al	20	115	5.8	Feedthrough limited?
Ti	Al	10	110	11	Useable range of fields
Ti	Al	5	55	11	
St. Steel	Al	10	105	10.5	
St. Steel	Al	5	53	10.6	

Summary

- The test set-up seems more adapted to small gap tests.
- CNT doesn’t seem to be a valid alternative, since after sparking, carbon debris is deposited on the cathode, preventing further conditioning.
- Aluminium wires broke, but less than what was expected based on their low melting temperature. However, significant surface damage was observed after conditioning.
- With titanium wires in combination with a Ti cathode, it was observed several times that a broken wire extremity welded onto the cathode, unlike the same wires opposite a stainless-steel cathode.
- For future use in slow extraction septa, other criteria play a role as well. Beam interaction will provoke wire heating for example and loss of mechanical properties, which may lead to wire break down as well.

Outlook

- Initial testing of titanium wires didn’t reveal any showstoppers. Now, we are looking for a more ductile titanium alloy, to allow stringing of the wires sufficiently straight on the anode support.

- Another alternative that we would like to study is graphene. Clamping the graphene foils will need a new fixation to be designed.

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