



Gun and Collector Development on the Electron Cooler Test Stand (ECTS)

G. Khatri, J. Cenede, A. Frassier, A. Rossi, G. Tranquille | CERN

29 Oct 2025,

Outline

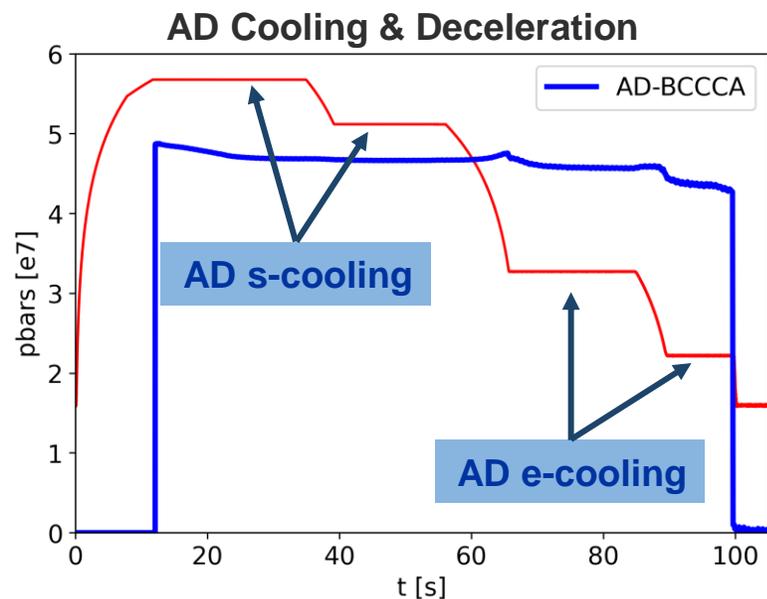
- **Introduction**
- **AD e-cooler (old & new)**
- **ECTS test stand**
- **Collector development & test results**
- **Gun development & test results**
- **Future tests**
- **Summary & Conclusion**

Introduction

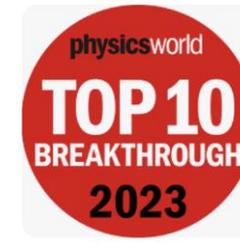
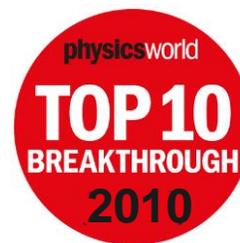
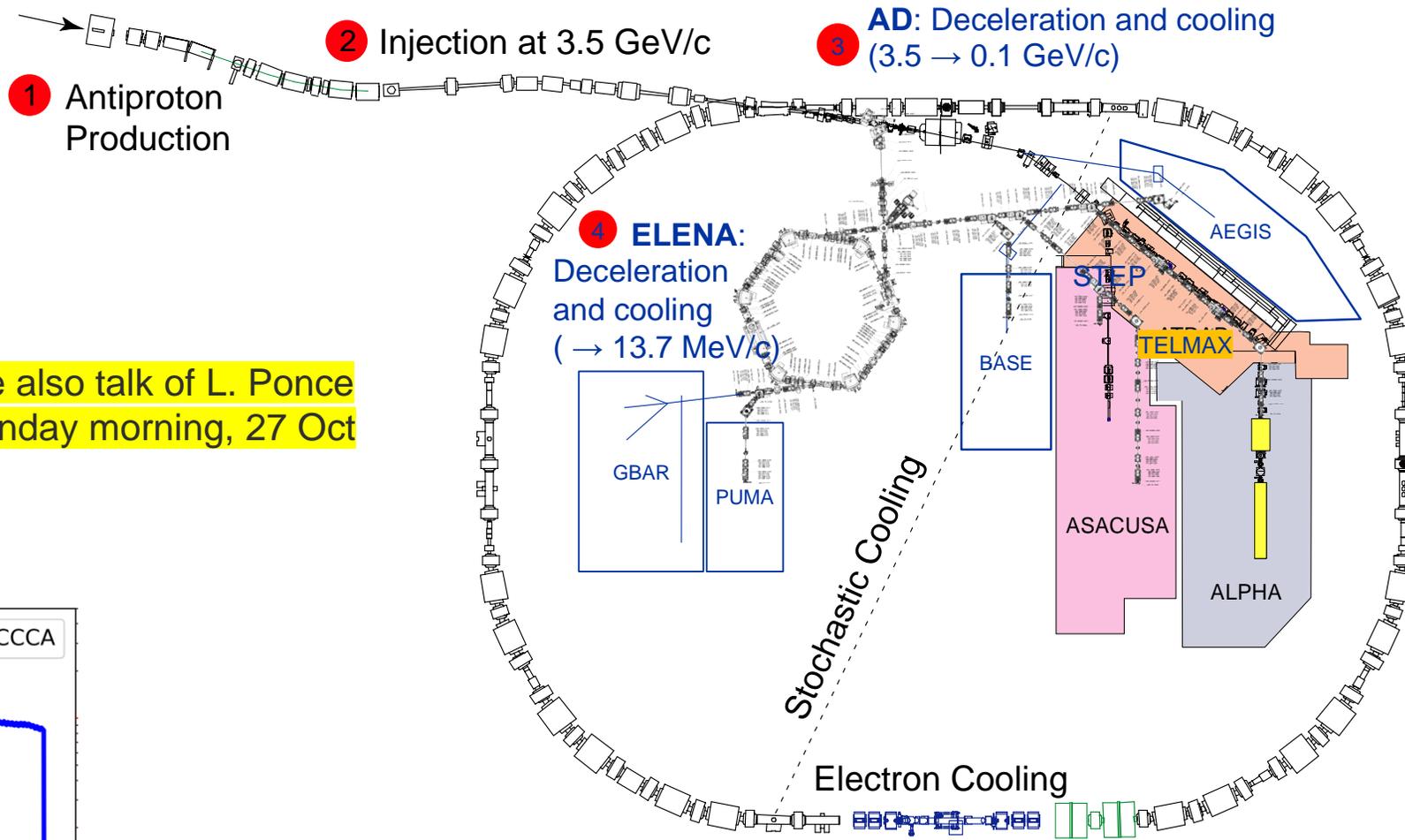
Antiproton Decelerator (AD):

- Operational since ~2000
- Decelerates $\sim 6.25 \times 10^7$ antiprotons every ~ 100 s
- Injection @ 3.5 GeV/c
- Extraction @ 5 MeV/c
- Ring circumference 182m
- S-cooling (3.57 GeV/c & 2 GeV/c)
- E-cooling (300 MeV/c & 100 MeV/c)

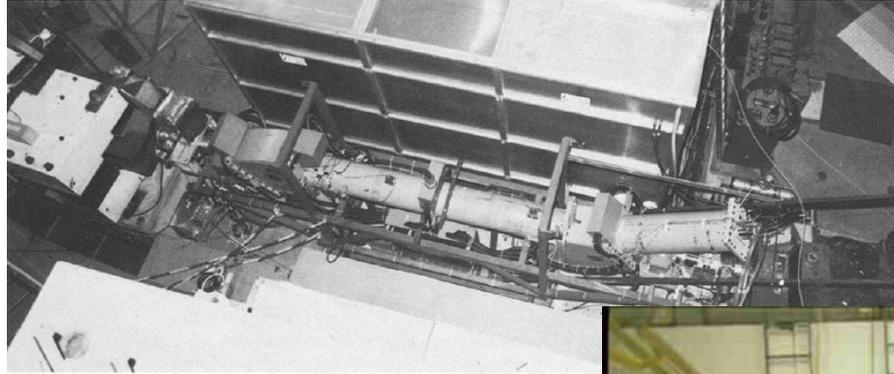
see also talk of L. Ponce
Monday morning, 27 Oct



Sketch of the AD + ELENA & Experiments (courtesy: AD OP team)



Present (old) AD electron cooler



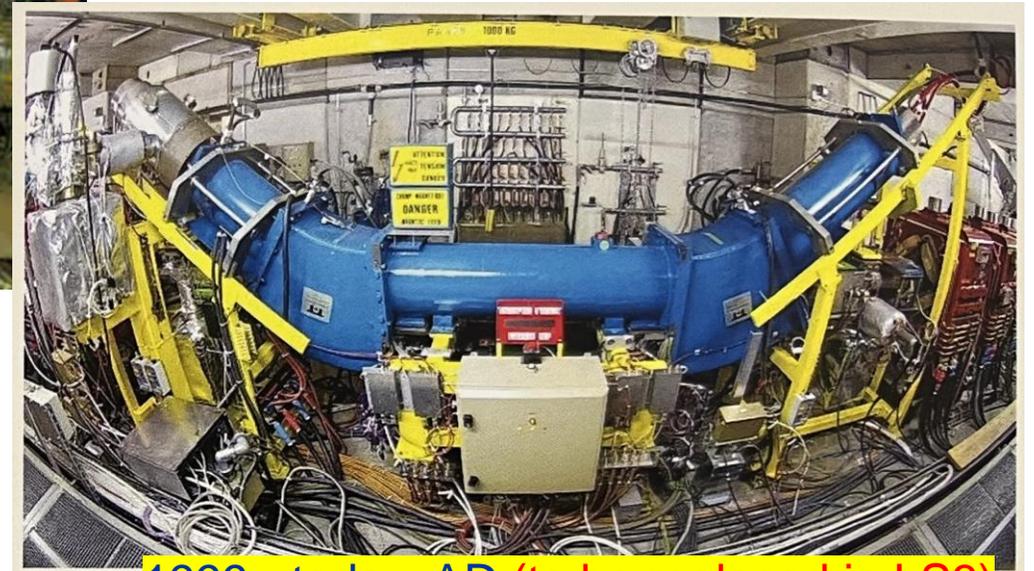
1977-1980: ICE



1982-1997: LEAR

Motivation for consolidation

- 40+ years old hardware
- lack of critical spares
- reliability & maintainability



1999 - today: AD (to be replaced in LS3)

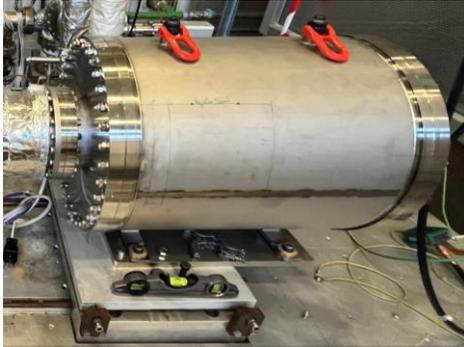
References:

1. [F. Krienen, "Initial Cooling Experiments \(ICE\) at CERN", 1980](#)
2. [Bossler et al., "The new collector for the electron cooling device at LEAR", 1992](#)
3. [I. N. Meshkov et al., "The variable current gun: the parameter tests and the results of the first electron cooling experiments at LEAR", 1995](#)

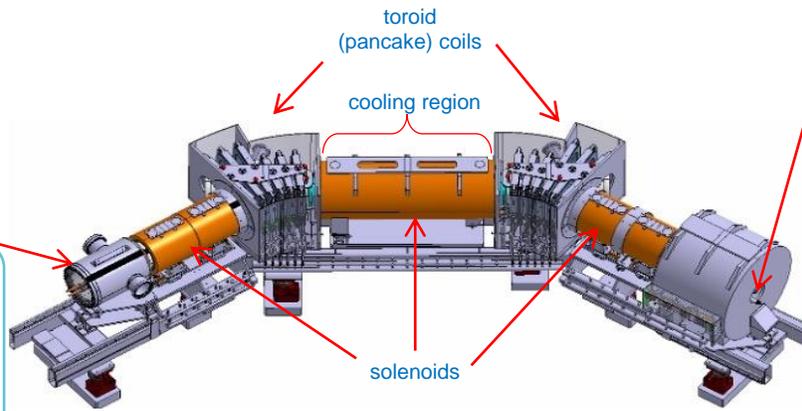
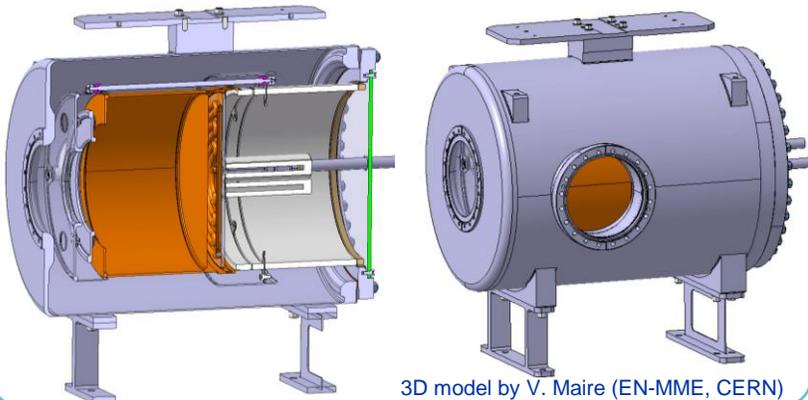
New AD electron cooler

collector

- Proto (improved) collector for present AD cooler fully tested and ready for OP



- Final collector for new cooler under production, delivery in Nov 2025

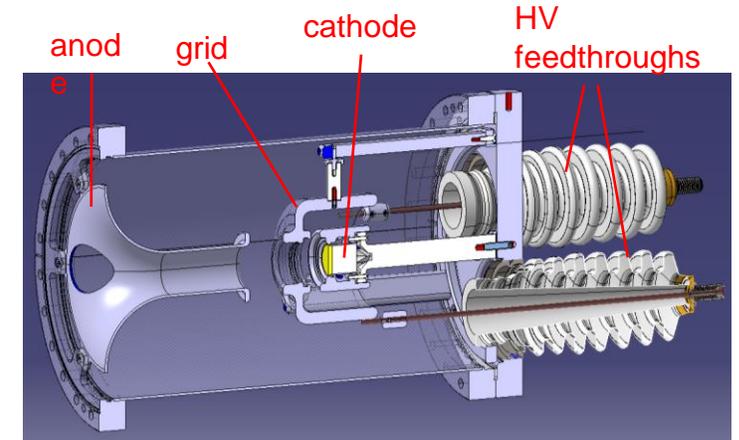


Reference:

[Specifications and Status of the New Electron Cooler for the CERN Antiproton Decelerator \(AD\), A. Rossi et al., 2024](#)

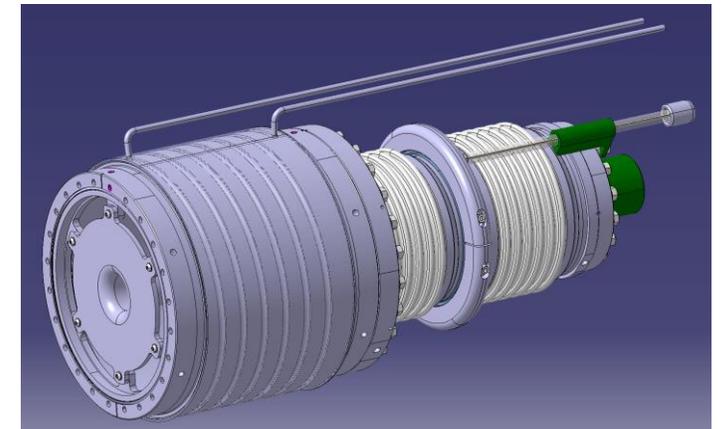
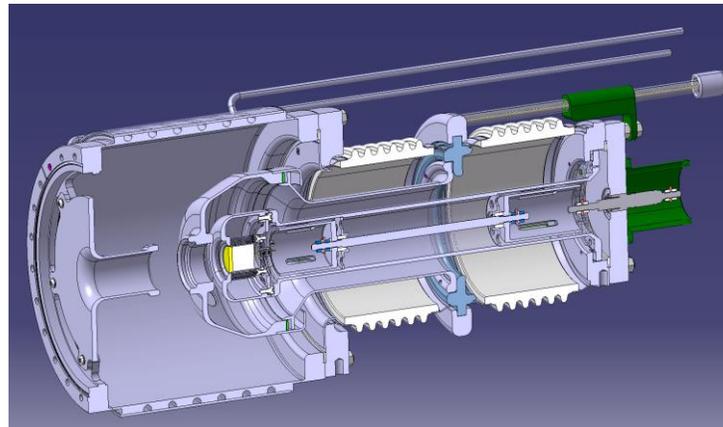
gun (inside expansion solenoid)

- 1st proto tested – lessons learned !



3D model by J. Cenede

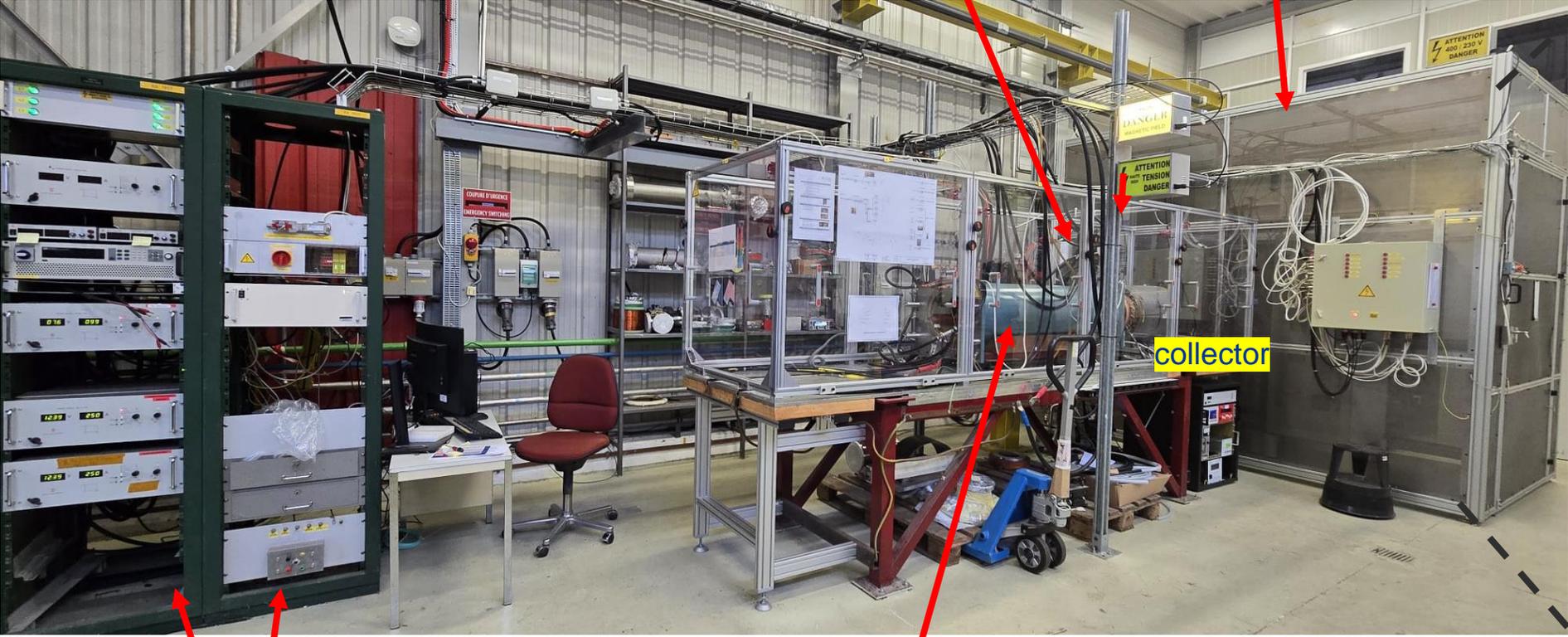
- Final gun: revised, robust design based on 1st proto and current Russian gun
- Cooling water for high ceramic resistance, wavy modulation better HV insulation
- Production for test by June 2026



3D model by V. Maire (EN-MME, CERN)

Electron Cooler Test Stand (ECTS) facility

For details on ECTS, see our COOL23 paper:
DOI: [10.18429/JACoW-COOL2023-THPOSRP06](https://doi.org/10.18429/JACoW-COOL2023-THPOSRP06)



vacuum pumps

faraday cage + HV platform

cross relay

HV divider

racks on HV platform + power supplies

collector

solenoid (1.5 m, 600 Gauss)

racks on ground potential for magnet supplies

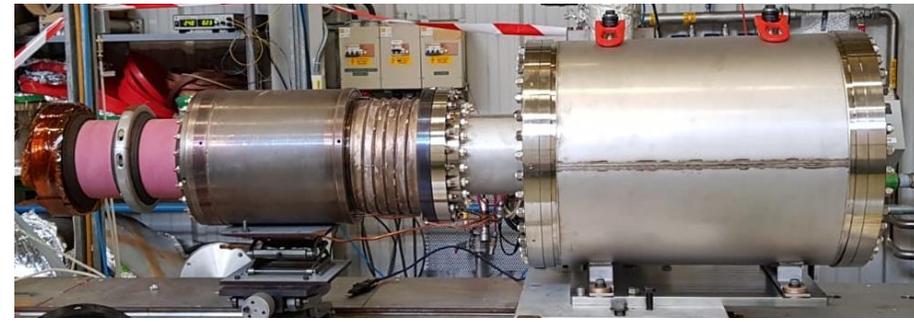
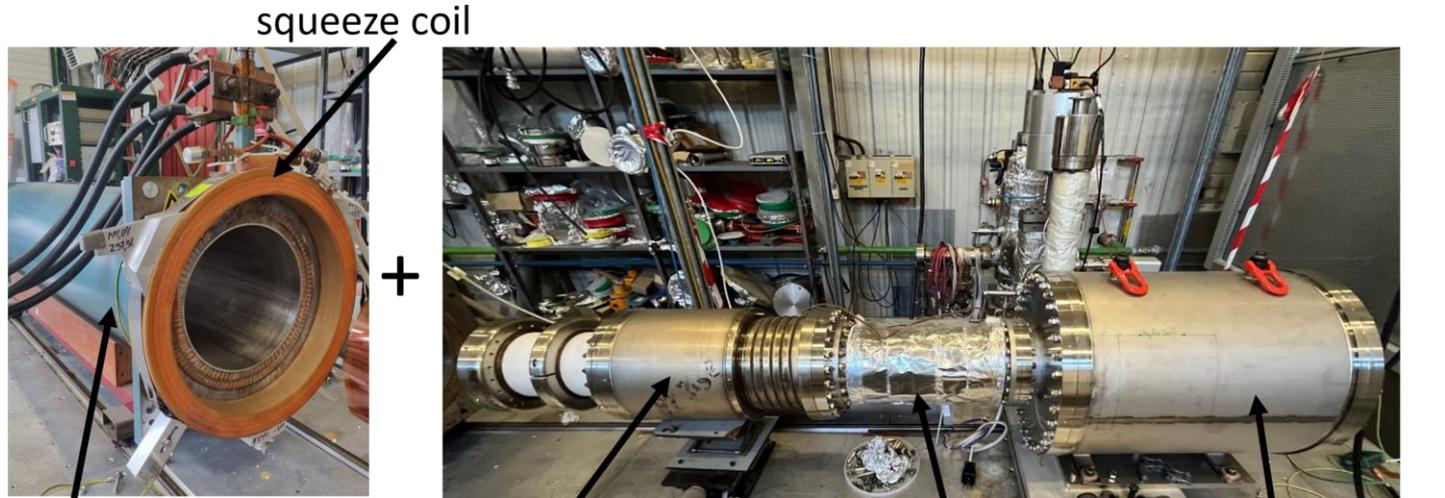
Courtesy: A. Frassier, J. Cenede



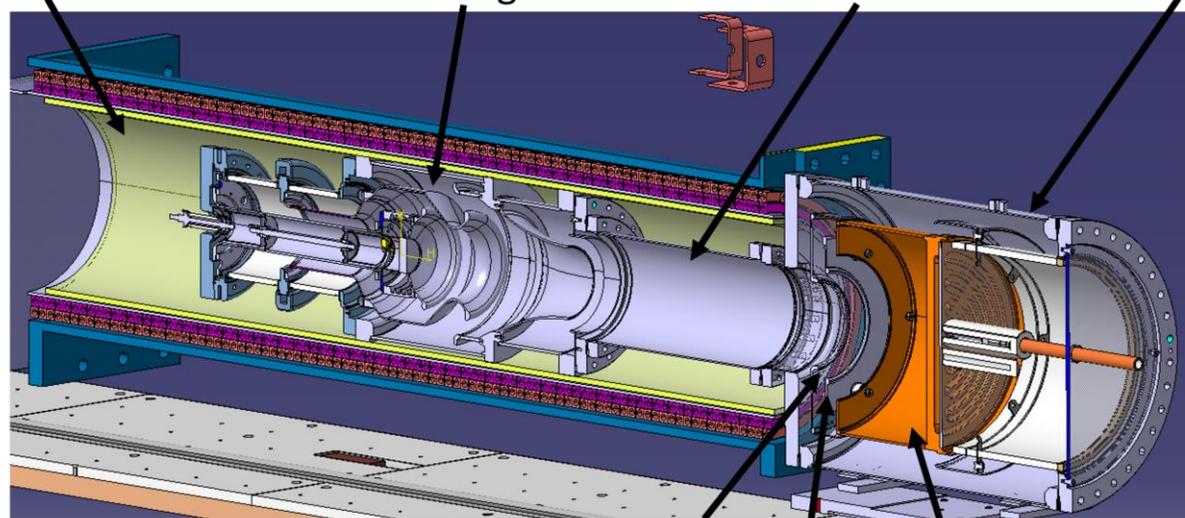
3-phase isolation transformer (80 kV, 50 kW)



Electron Cooler Test Stand (ECTS)



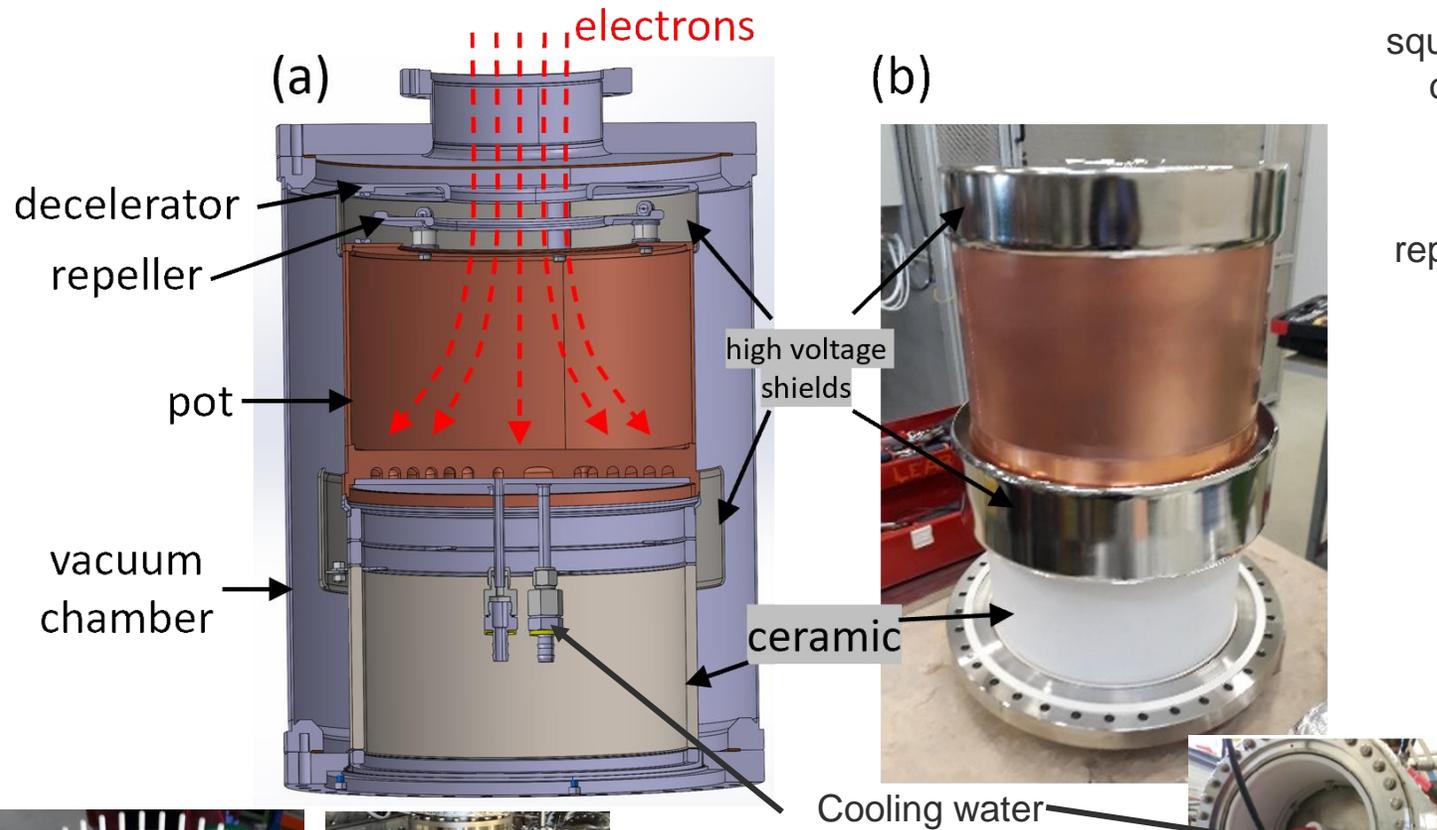
1.5 m drift solenoid old AD gun drift tube new collector



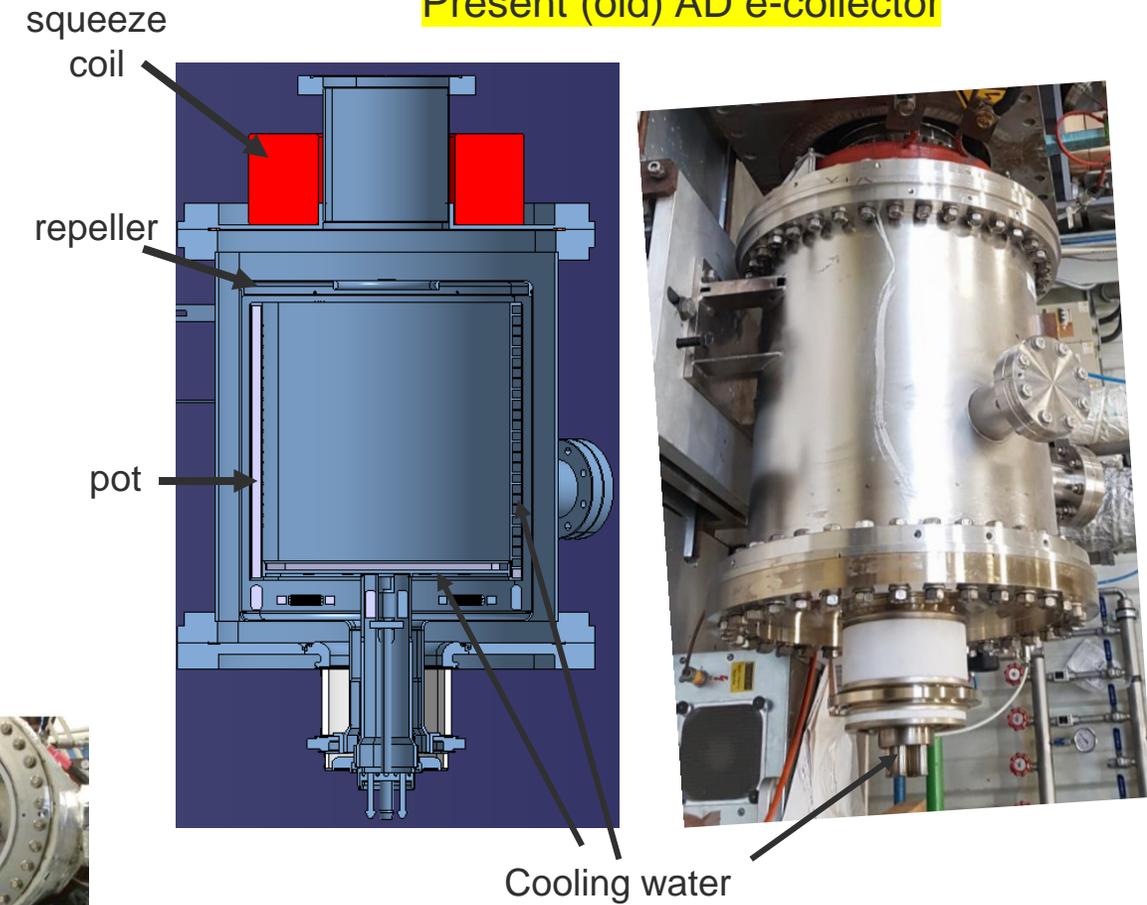
decelerator repeller collector pot

- Raspberry Pi, Python, Labview based controls
- Remote control to HV platform via OF + Wifi
- Shunt resistors to monitor current/voltages
- Dummy load test: 70 kV (25 kW) for 2 h
- Safety and interlock integrated
- Dedicated cooling water circuit for the collector with purifiers and resin filters to keep water conductivity low
- Old AD gun (2.2 A / 27 keV) used for testing the new collector

Electron collector



Present (old) AD e-collector



Key features

- Cooling water de-coupled from vacuum
- Copper pot – better heat conduction
- 3rd electrode at the beam entrance

History

- Served in LEAR since 1995, then in AD since 2000
- 2018 leak between vacuum and cooling water

Key results – collector tests & validation

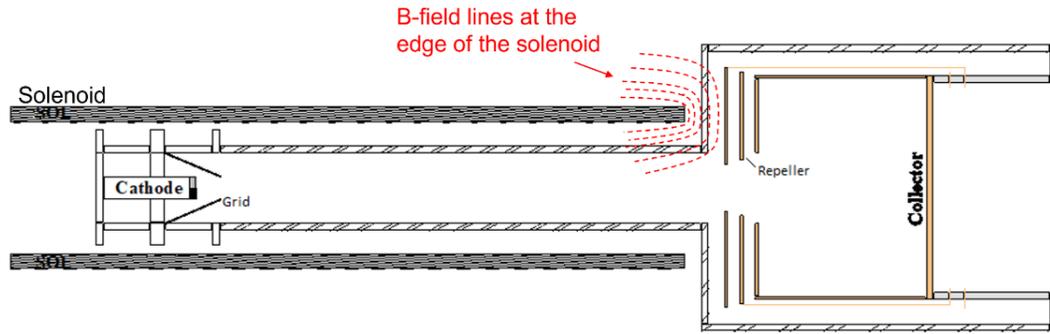
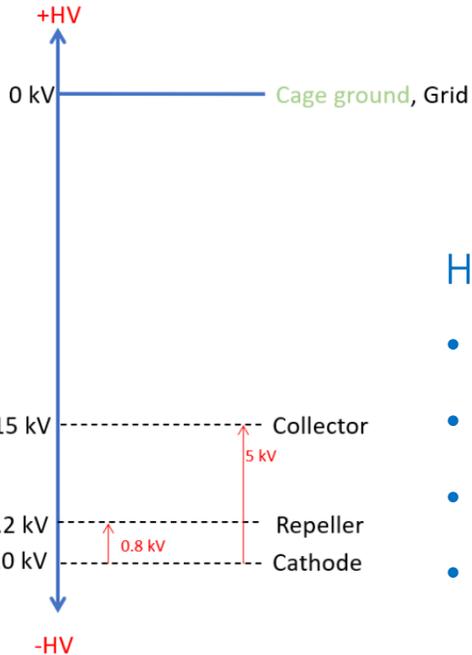
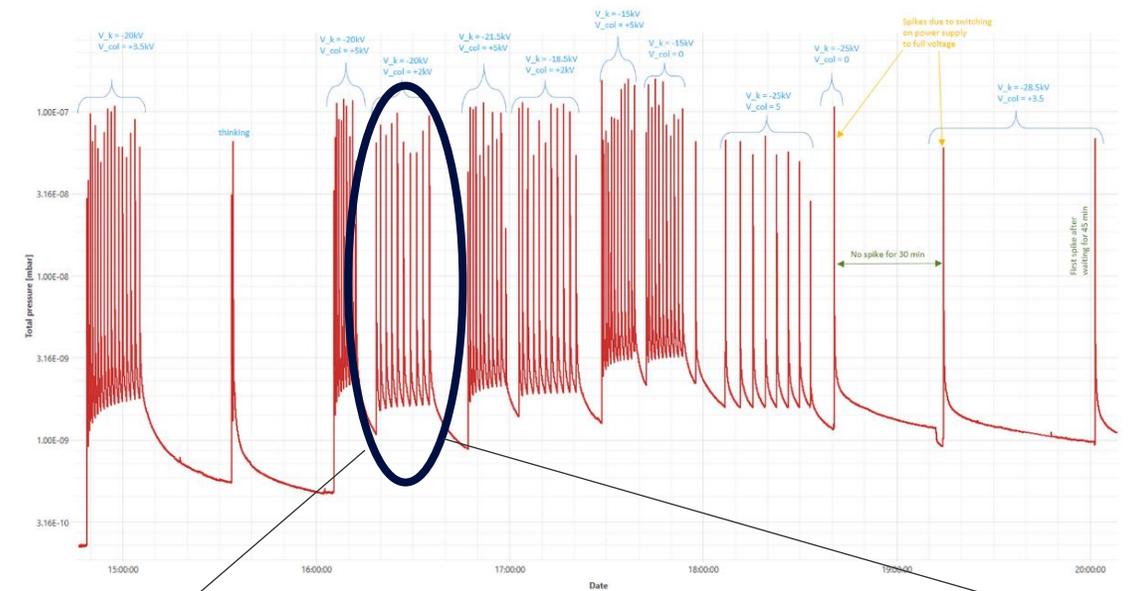
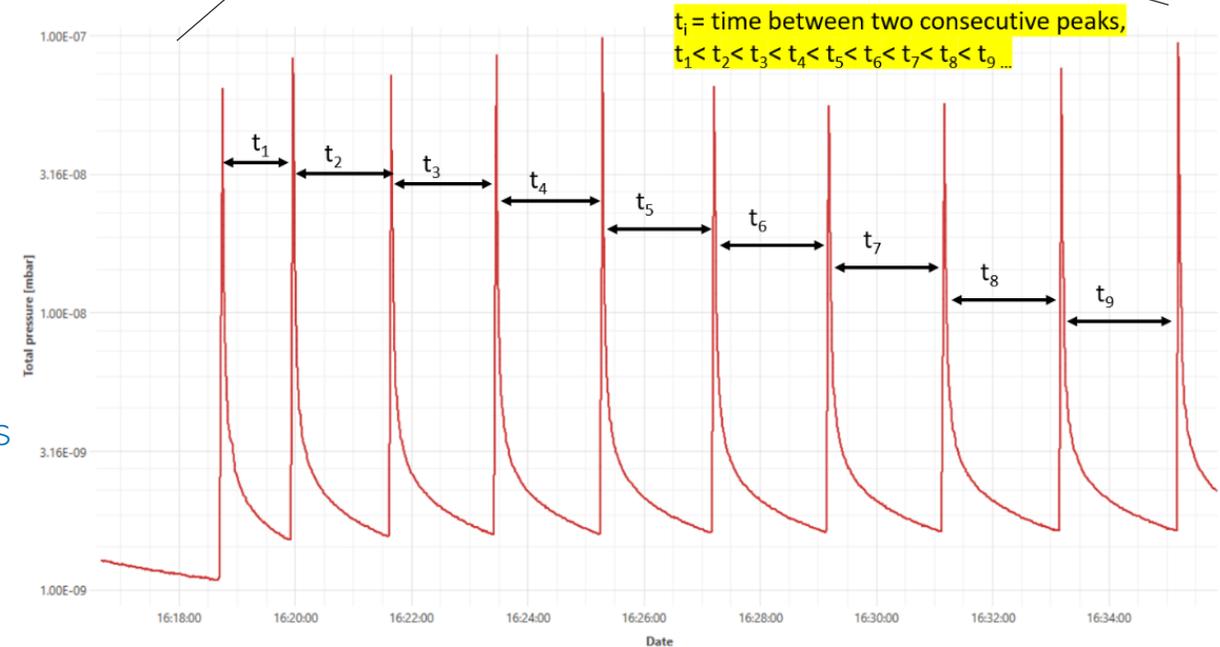


Figure 1: Schematic view of the setup is shown. The gun (cathode and grid) is in the uniform B-field. The gun and collector are fixed on a vacuum chamber but they can move freely inside the solenoid bore.

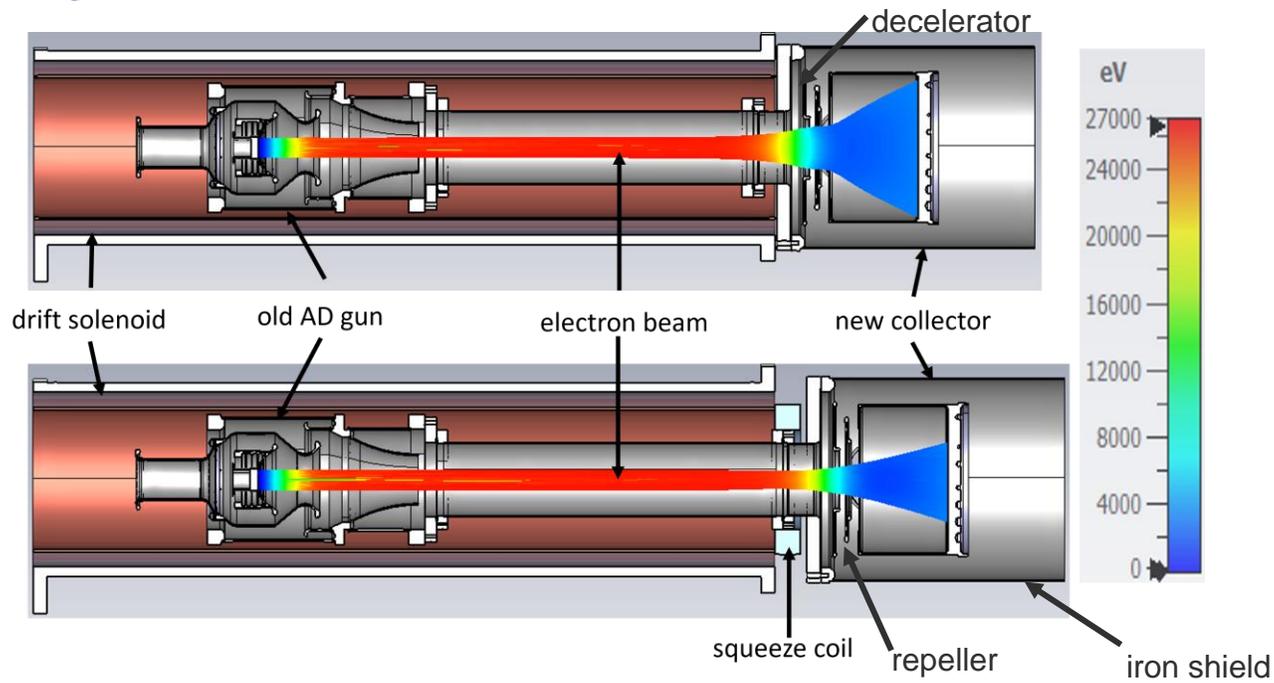


High voltage discharges when $B \neq 0$

- Applying HV, vacuum stable
- Then switching on magnet => vacuum spikes
- Identified as ExB discharges
- Resolved by improving vacuum

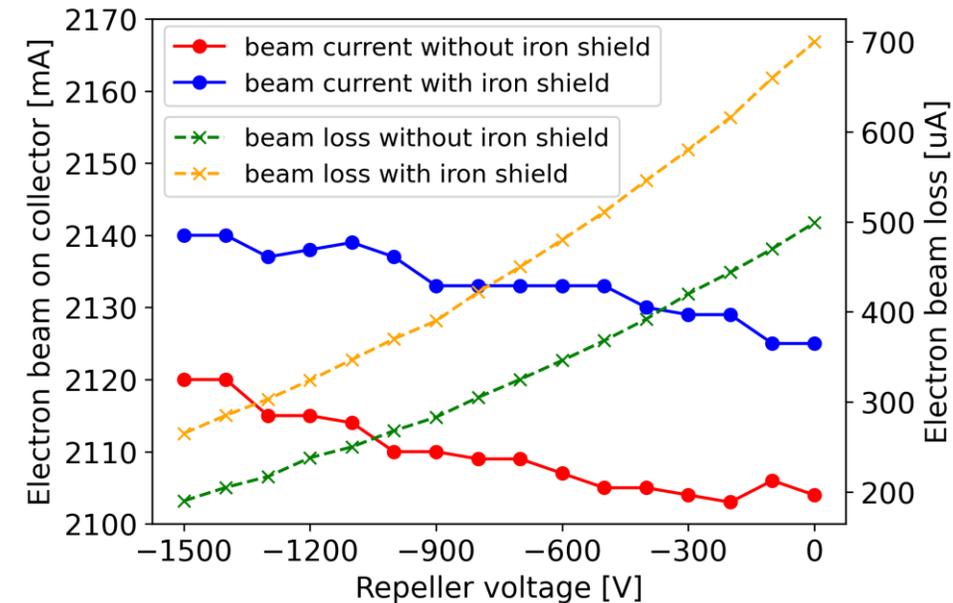
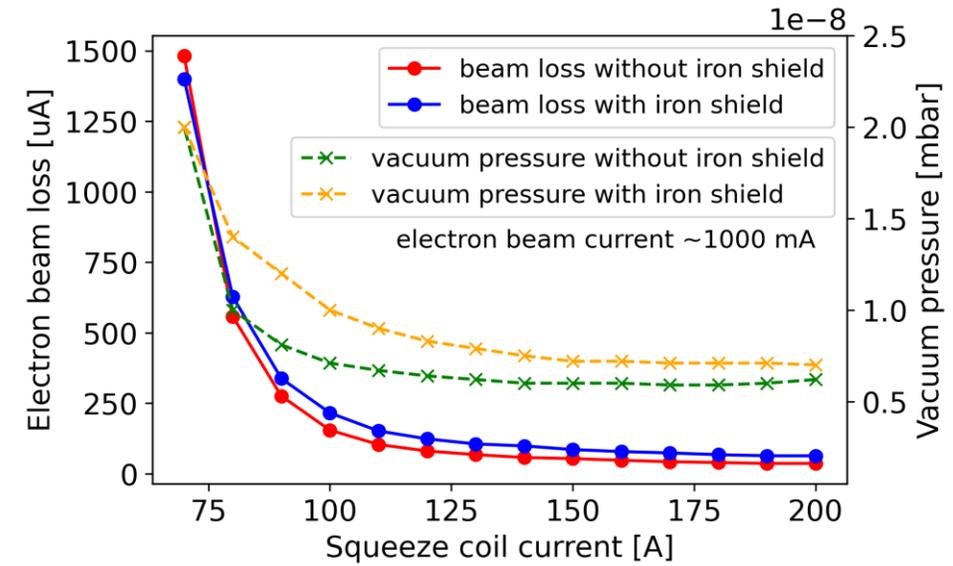


Key results – collector tests & validation



Switching on electron beam (2.2 A @ 27 keV, dia = 50mm)

- The setup optimized to reduce the electron losses
- Squeeze coil @ entrance & mag.shield @ on chamber
- Repeller biased negatively w.r.t. cathode
- Total losses < 300 uA (gun + collector + cooling water + e-loss)
- NB: loss in water + ceramic estimated to be few ~10s of uA
- Secondary & back reflected electrons (suppression + mag. bottle)



Key results – collector tests & validation

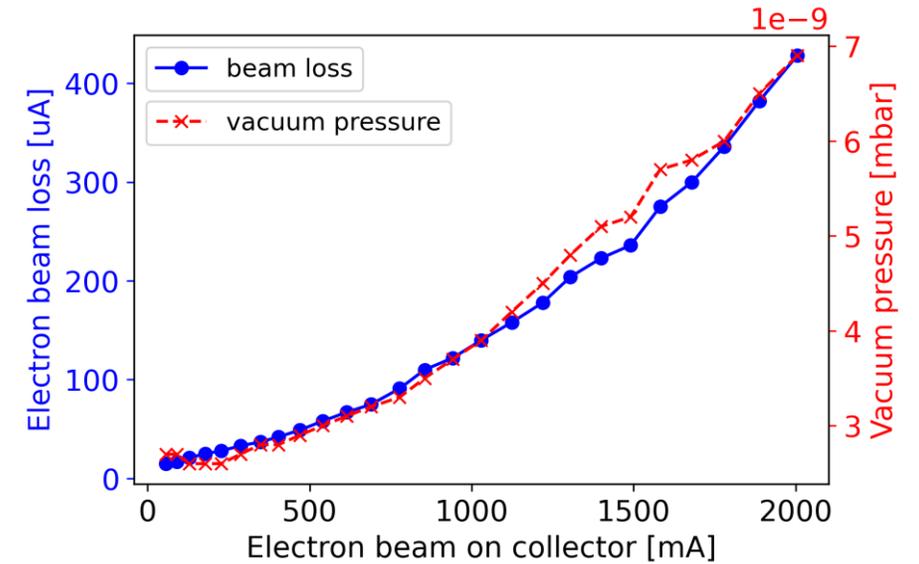
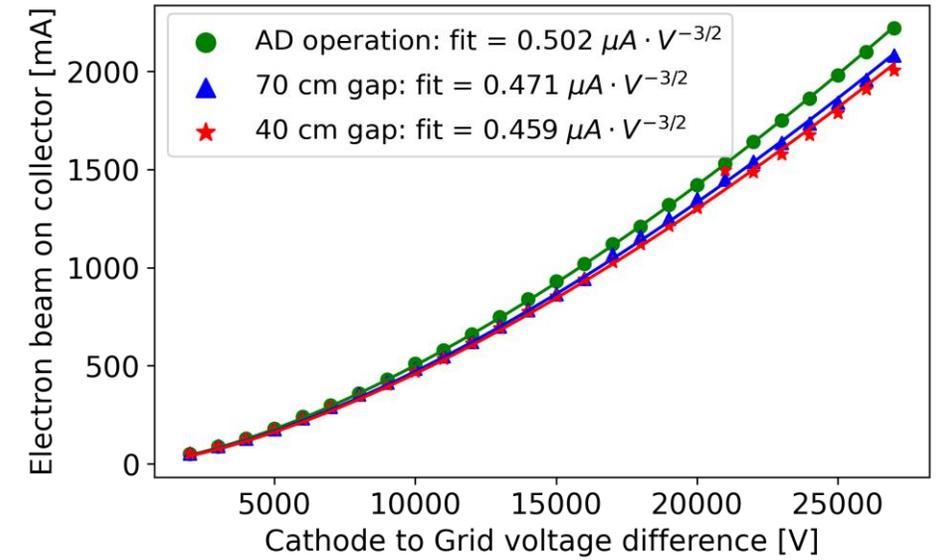
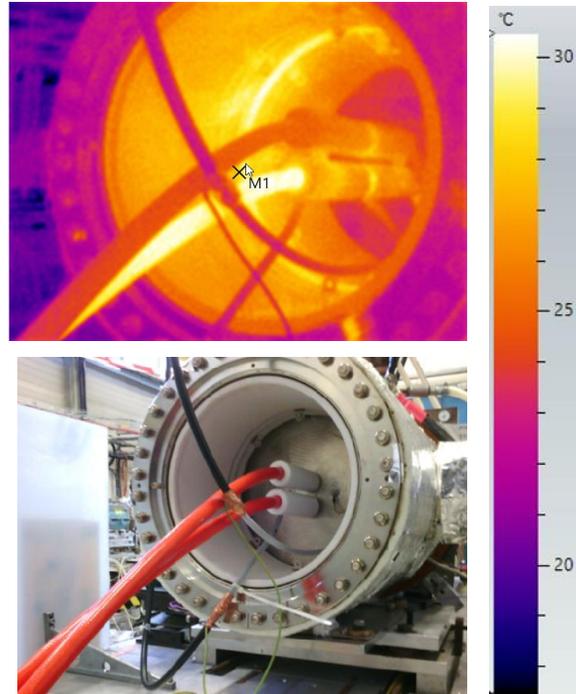
Stability/reliability test results

- Handled 2.4 A DC e-beam, 10 kW power for > 24 hours
- NB: Operation full power 16 s every 2 min (15% duty cycle)
- Weeks of of operation for Mon-Fri, roughly 4-8 hours (vacuum scrubbing)
- No visible damage however sign of setup misalignments (magnets ?)
- Collector demonstrated 99.99% collection efficiency
- At full DC power, cooling water $\Delta T = 20^\circ\text{C}$, collector body $\Delta T = 40^\circ\text{C}$

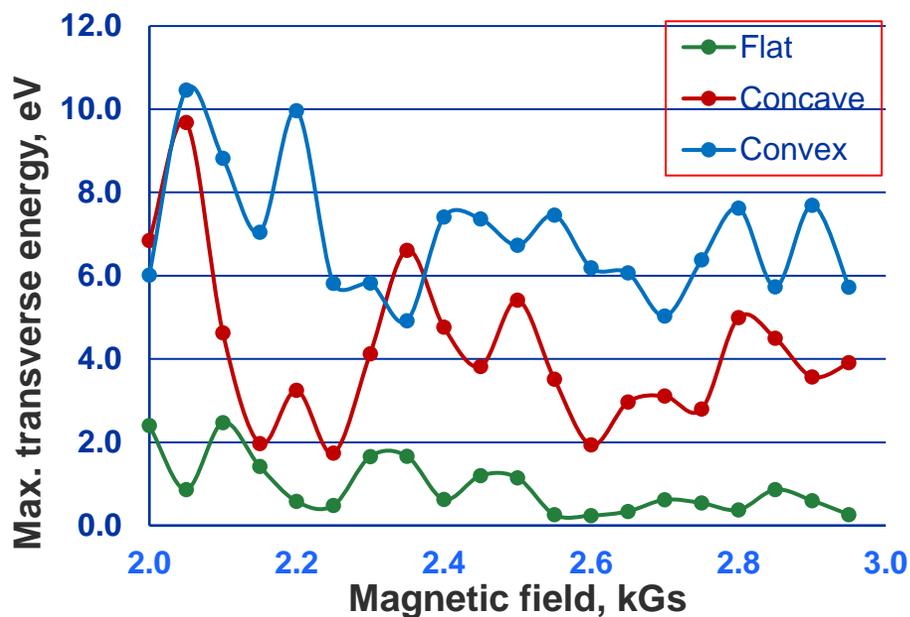
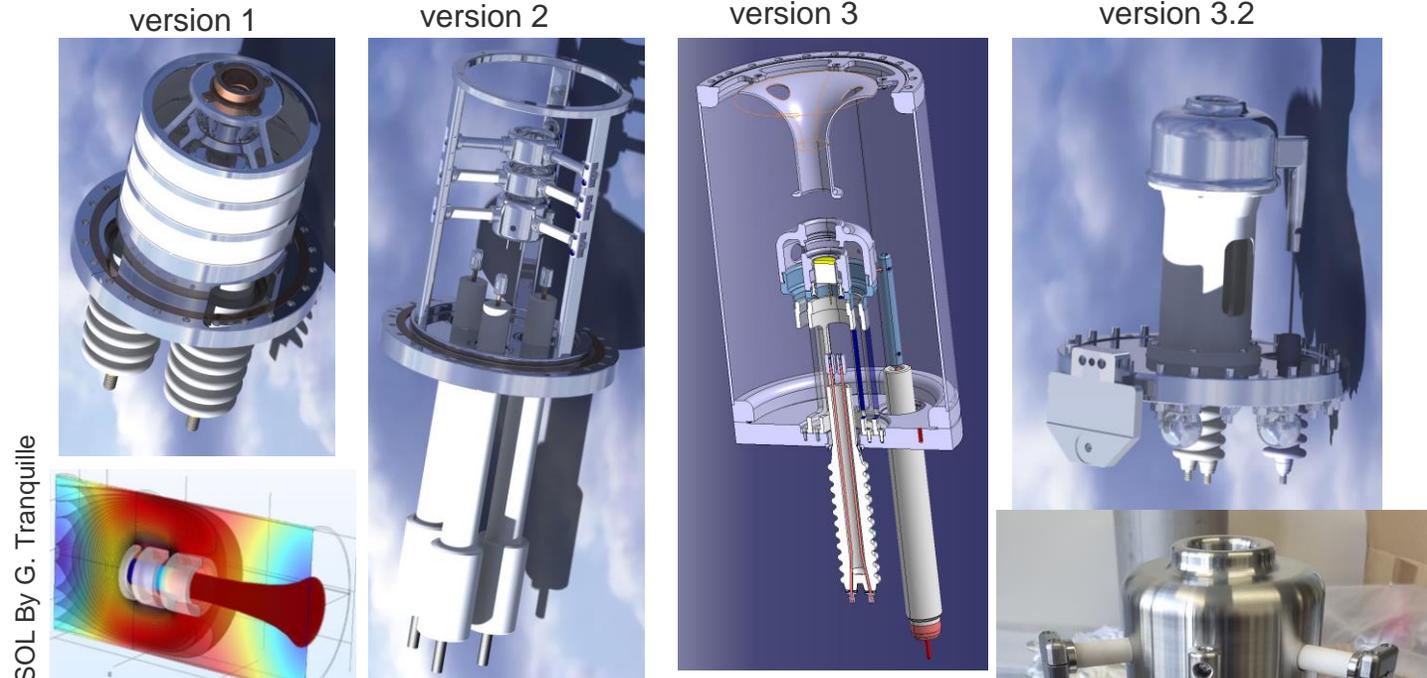
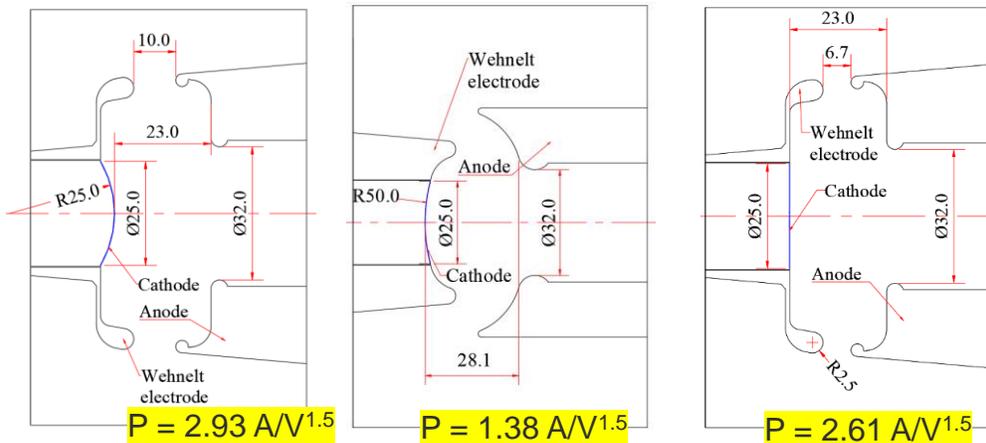
$$\eta = \frac{I_{\text{collector}}}{I_{\text{beam}}} \times 100\%$$

$$\eta = \frac{2.1998 \text{ A}}{2.2 \text{ A}} \times 100\%$$

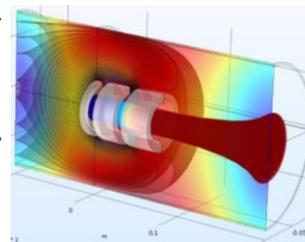
$$\eta \approx 0.999909 \times 100\% \approx 99.99\%$$



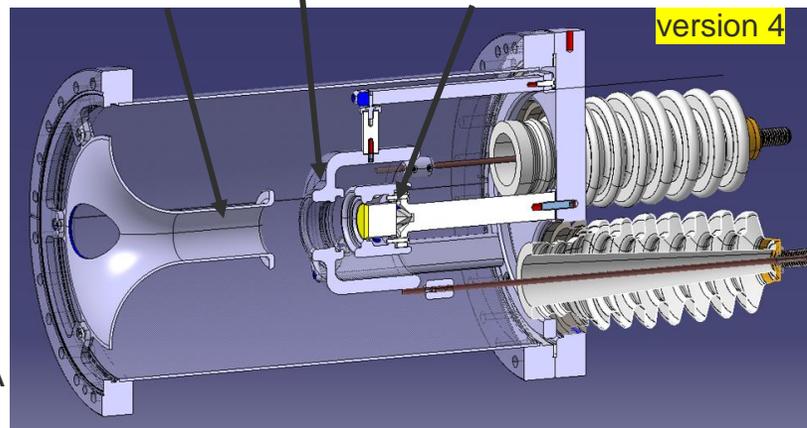
Electron gun – simulation to conceptual (prototype) design



COMSOL By G. Tranquille



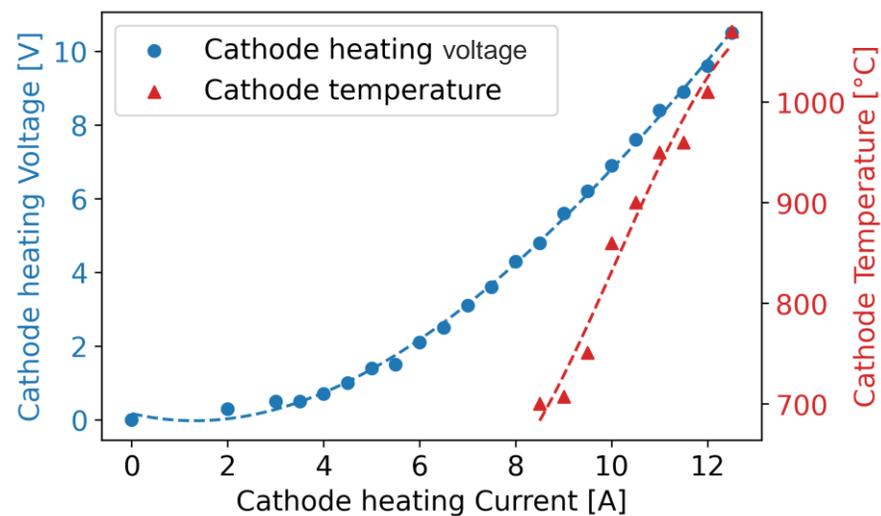
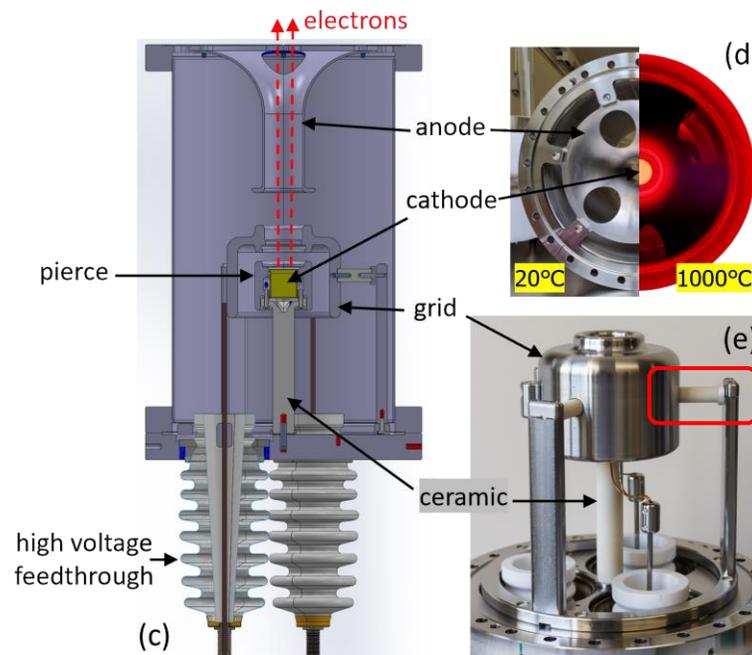
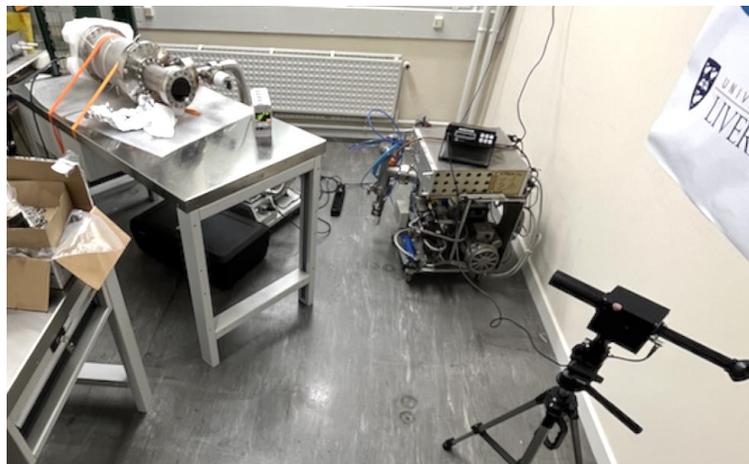
Anode - Grid - Cathode



prototype from version 4

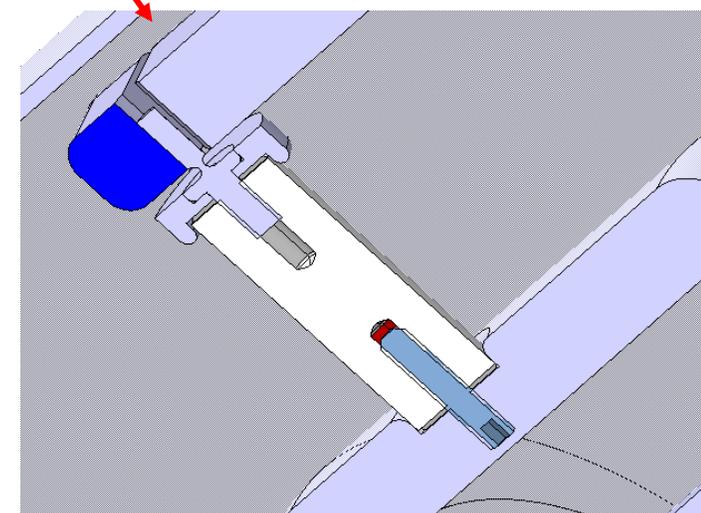
- Transverse energy for 3 cathode shapes, dia = 25 mm, I = 3.5 A
- Simulated in TRAK (Field Precision) by A. Pikin

Key results – gun tests & validation



High Voltage insulation & cathode heating up

- Holds 30 kV @ 20 °C
- Cathode temperature measured with pyrometer
- I-V-T curve agree w (SPECTRAMAT data sheet)
- Thermo-mech. simulation => break ceramic
- Clever design => no damage when opened
- Ceramics: Macor & Alumina

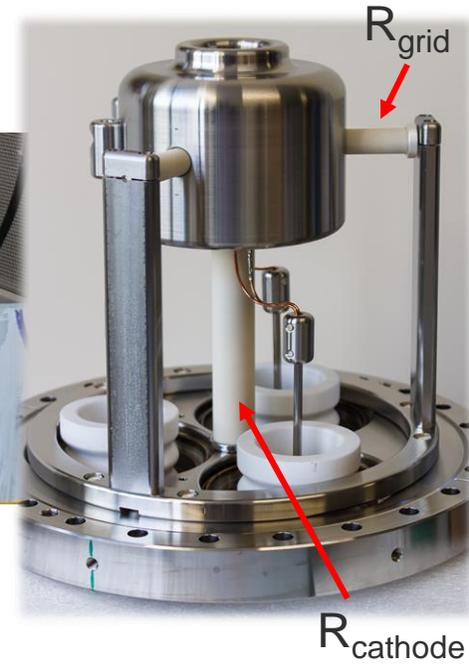
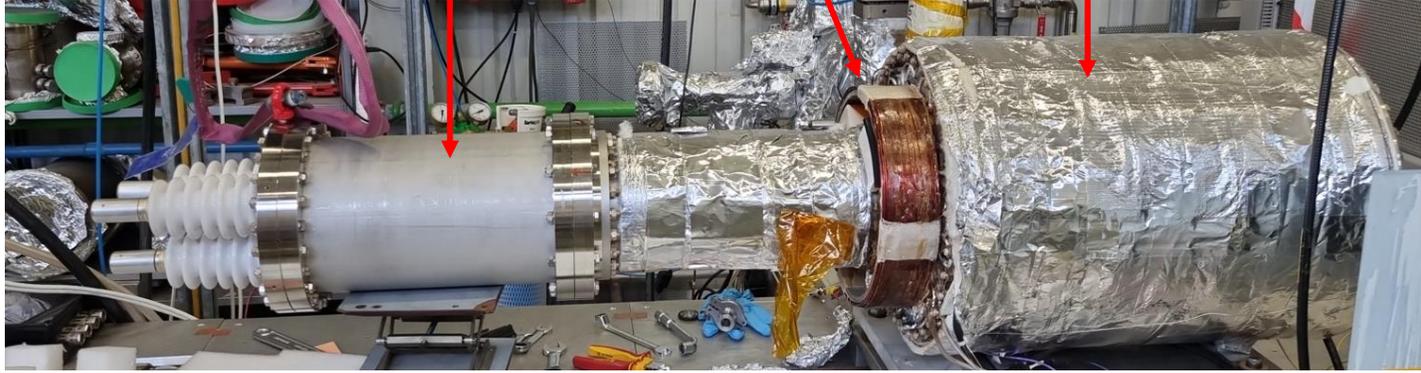


Key results – gun tests & validation

prototype gun

squeeze coil

new collector



26.Oct.23

filament 13A (P=191W)

lbcc_leir = 390 A

Isol = 600 A

lbcc_canada = 5 A

Vool = 3kV

Vrep/ = 0.8kV

Vacuum (pfeiffer full range) = 1.2E-7 mbar

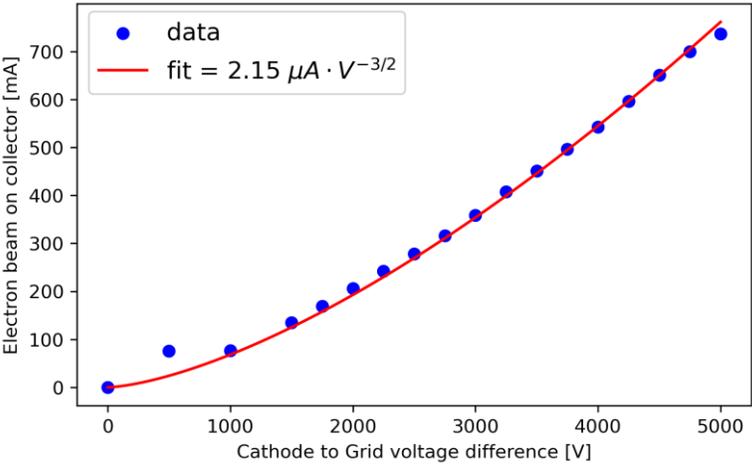
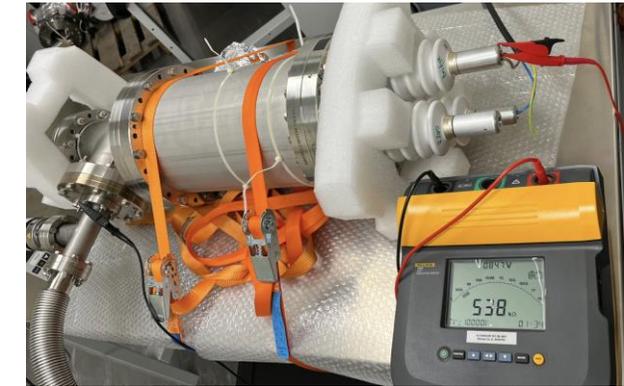
Sector Valve open

Vgrid = 0V DVM between grid and ground (Ie_grid)

Vk(kV)	Ie_dvm(A)	Ie_grid(uA)	Iloss(uA)	VAC (mB)
0	0.075	2.7	3	1.2E-7
0.5	0.076	2.7	3.5	1.2E-7
1.0	0.077	2.7	3.5	1.2E-7
1.5	0.135	5.6	17	1.3E-7
1.75	0.169	9	39	1.4E-7
2.0	0.206	15	77	1.5E-7
2.25	0.242	21	115	1.4E-7
2.5	0.278	34	163	1.5E-7
2.75	0.316	55	234	1.7E-7
3.0	0.359	89	341	2.1E-7
3.25	0.408	105	465	2.2E-7
3.5	0.451	153	599	2.7E-7
3.75	0.496	194	712	2.7E-7
4.0	0.543	221	830	2.7E-7
---wait to let vacuum recover ~10 min---				
4.0	0.543	206	800	2.5E-7
4.25	0.596	191	873	2.3E-7
4.5	0.651	234	1037	2.4E-7
4.75	0.700	300	1220	2.7E-7
5.0	0.737	462	1515	3.5E-7

Electron beam extracted

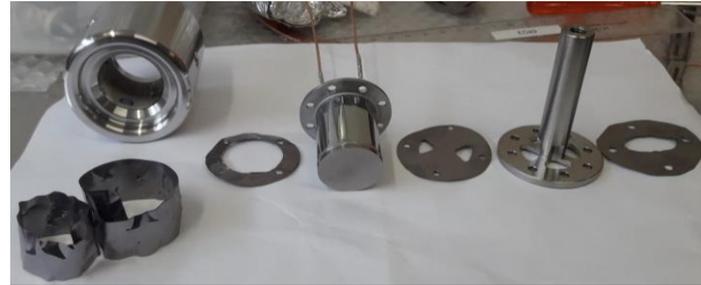
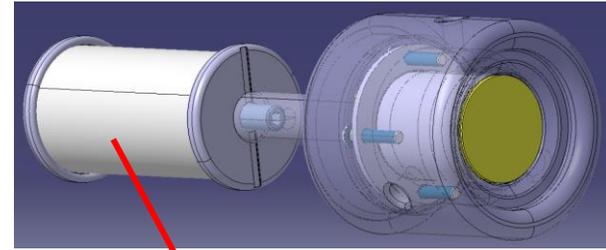
- Perveance close to simulated value (up to 5 keV, 700 mA)
- High current loss + leakage ~ 2 mA (need < 300 uA)
- Poor vacuum at collector 3.5 E-7 mbar (@ cathode ~1E-6 mbar)
- B = 900 Gauss (need 2400 Gauss to avoid beam scalloping)
- Cathode heated to 1100 °C ($I_{fill} = 13 A$)
- Hot ceramic => low electrical resistance => high leakage current
- $R_{cathode} = 540 k\Omega$, $R_{grid} = 10.4 M\Omega$
- Solution: keep ceramic COOL



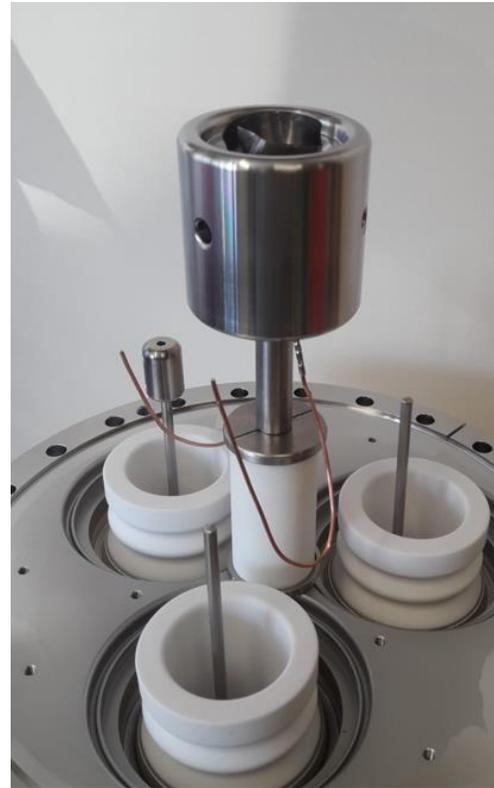
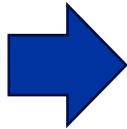
Key results – gun tests & validation

From the lessons learned + old gun inspiration: keep the ceramic temperature low by

1. increase distance from cathode (12 cm => 6 cm)
2. add tantalum shield around cathode

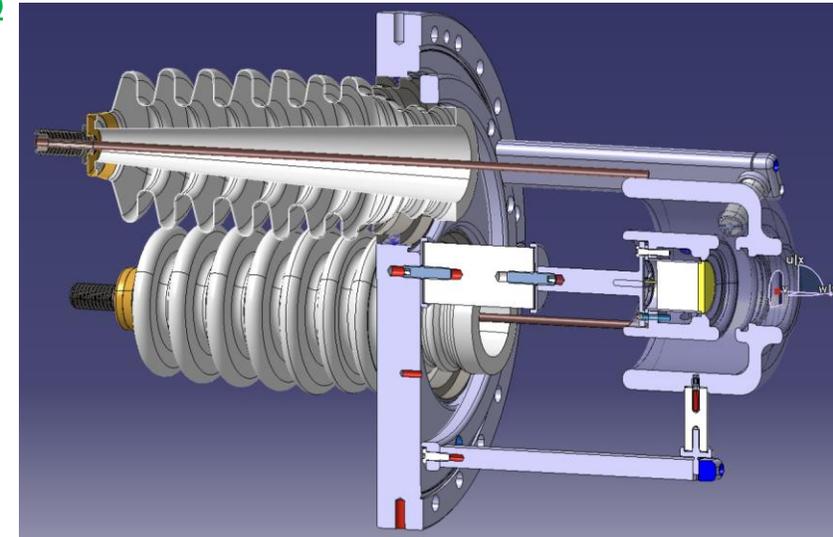


@500 °C	El. Res. (Ω.cm)	Th. Con. (W/m/K)
Macor	$10^9 - 10^{10}$	1 - 2
Shapal	$10^9 - 10^{10}$	55
Alumina	$10^9 - 10^{10}$	8 - 10

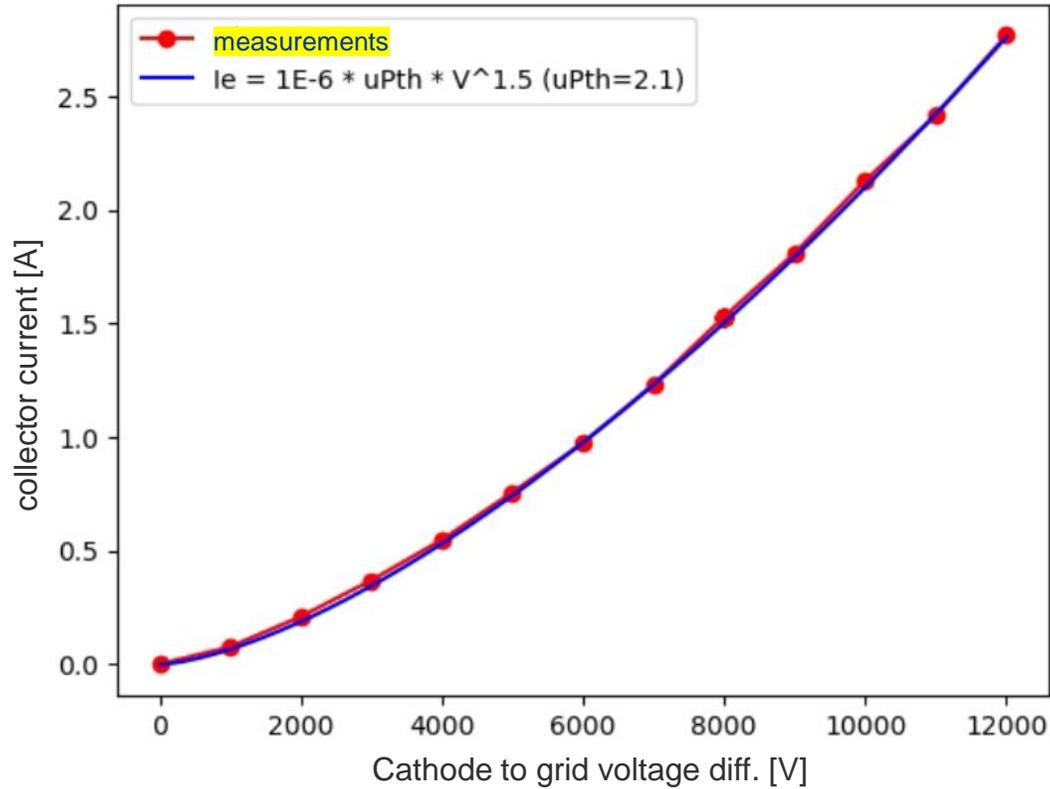


New ceramic resistances @ hot cathode

- $R_{\text{cathode}} = 540 \text{ k}\Omega \Rightarrow 30 \text{ G}\Omega$
- $R_{\text{grid}} = 10.4 \text{ M}\Omega \Rightarrow 7 \text{ G}\Omega$



Key results – gun tests & validation



by A. Frassier

```

: 13-08-2025 11:10:22
Test with Beam

Ibbc = 100A
Isol = 500A
Ifil = 12A

Vk = -27kV

Vgrid(kV) | Vrep(kV) | Vcol(kV) | IBeam (mA) | ILoss(uA) | Igrid (uA) | Pcol(kW) | VAC(mBar) |
-----|-----|-----|-----|-----|-----|-----|-----|
+10.5 | -0.7 | +3.0 | 2297 | 4351 | 519 | 6.9 | 1.3E-7 |
+10.5 | -0.7 | +3.0 | 2262 | 4461 | 528 | 6.9 | 1.9E-7 | +10 min
    
```

Gun version	27 keV	2.4 A	e-loss <300 uA	24h tested in DC	cathode @ 1000 C	B = 2400 Gauss	Perveance >2.1
Long Alumina	-	-	-	-	yes	-	yes
Macor	yes	yes	-	-	-	-	-
Shapal	-	-	-	-	-	-	-
Alumina	yes	yes	-	-	yes	-	yes

Proto gun results summary:

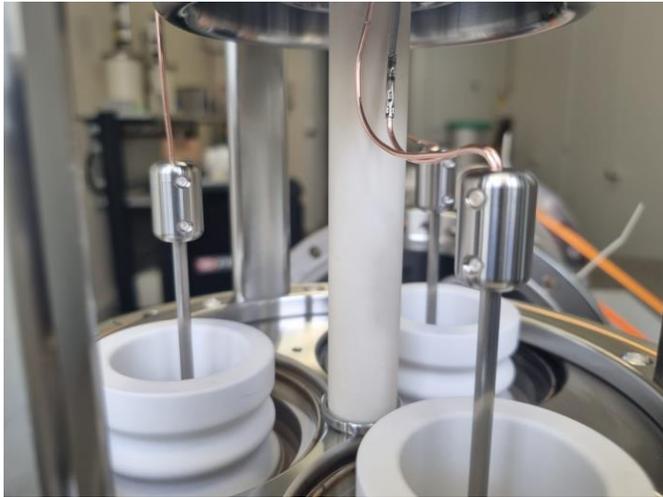
- demonstrated energy (27 keV), intensity (2.4 A) and perveance (2.15 uP) for ~10 min
- the electron losses still needs to be understood in detail (total loss ~4.3 mA)
- vacuum quality needs to be improved (2E-7 mbar at collector, 2E-6 mbar at gun)

Note:

$$I_{LOSS (total)} = I_{ceramic} + I_{water} + I_{beam}$$

Key results – gun tests & validation

Clean gun assembly before use.



Risk of contamination of ceramic when exposed directly to the ion path (sputtering)

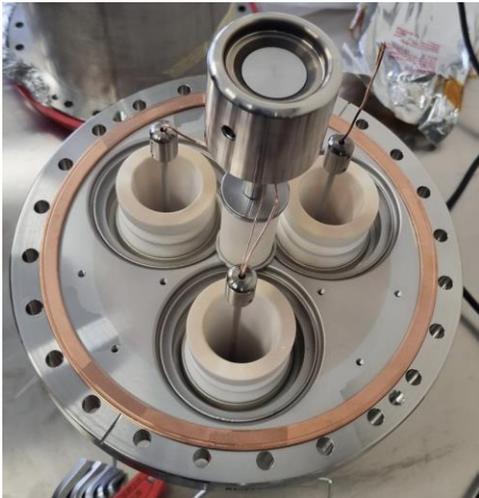
Mechanical alignment not guaranteed in this design (EN-MME)



Overheating of cathode caused Molybdenum evaporation (14 A instead of 12 A)

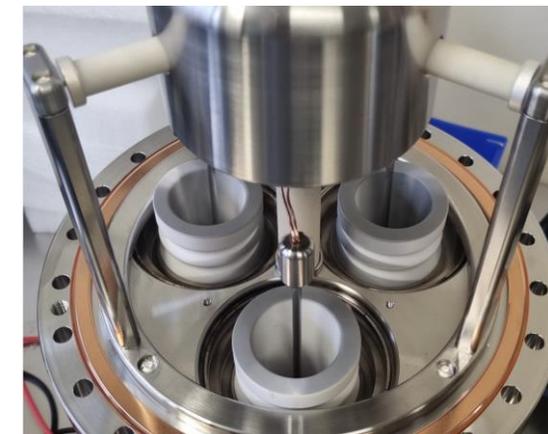
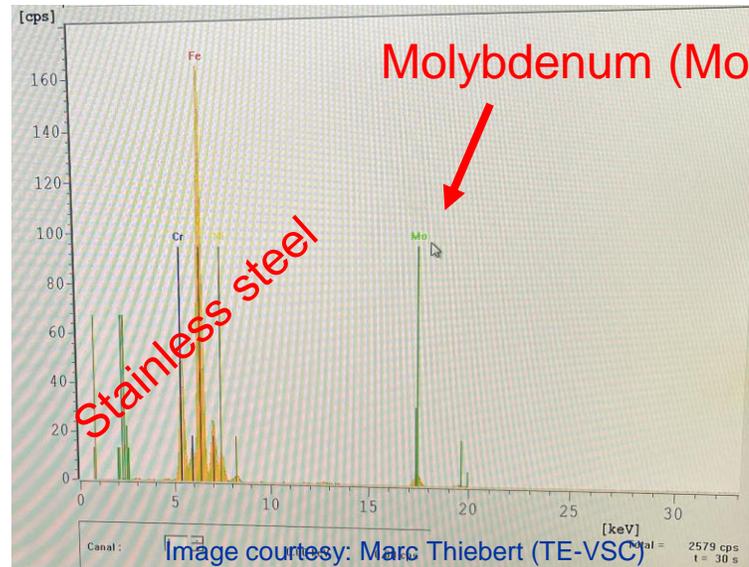


Pink residue possibly due to copper wire evaporation



Resistance at room temperature reduced from Tohm to 200 Gohm.

Never recovered even after cleaning !



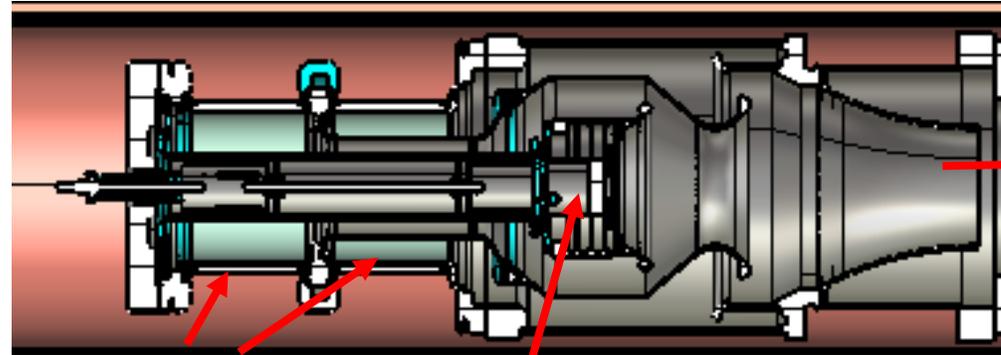
Postmortem of Russian gun design

J. Cenede

Russians had thought through about the thermal management very carefully !



Tantalum foils for radiative heat shield inside hollow pierce electrode



ceramic cathode

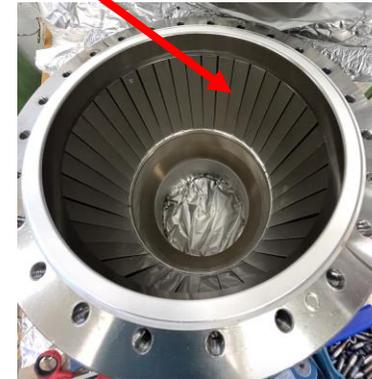


Silver coated anode (thermal emissivity is about 10 times lower than that of ss)



Cooling water on the outside of anode chamber

Cathode is far from ceramic, large ceramic tube air side,

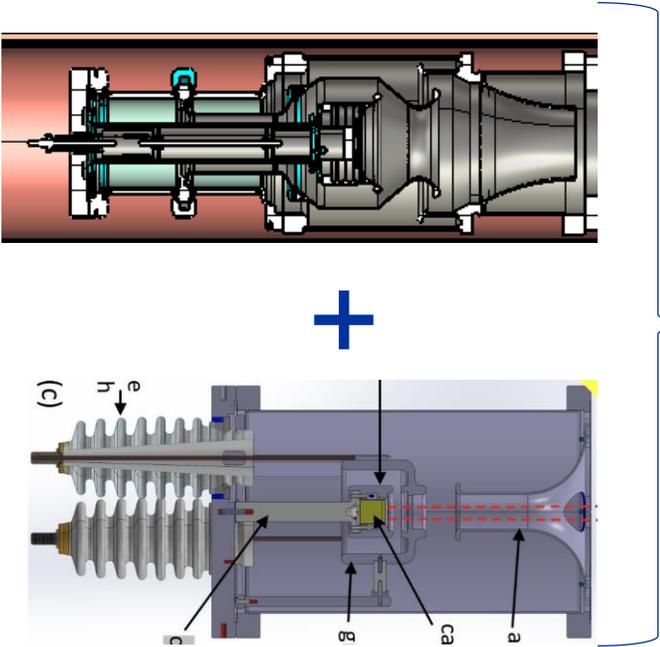


cathode inside chamber that has metal strips for thermal shield, cooling water behind

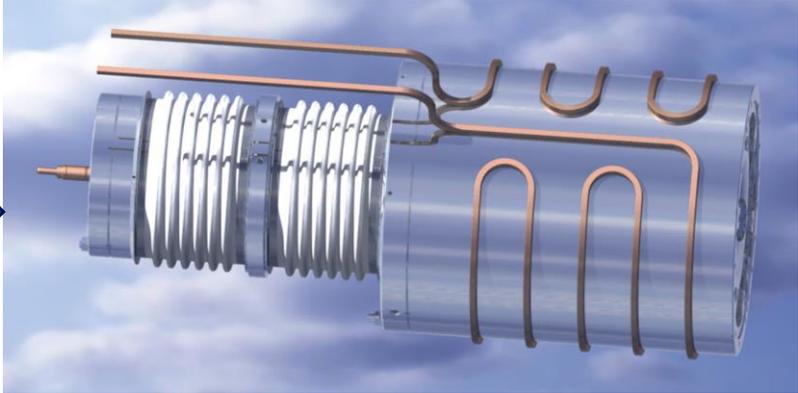
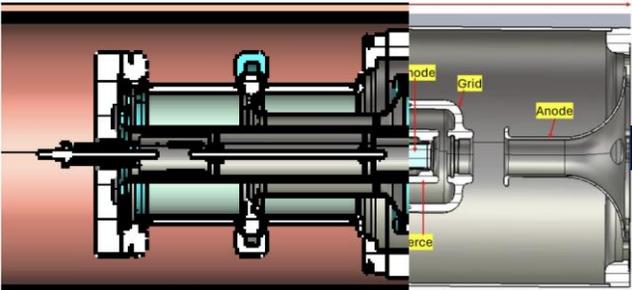
[old AD e-cooler gun, NIM A, 1995, I. N. Meshkov](#)

Russian gun + proto gun = Final gun design

Ceramic resistance tested



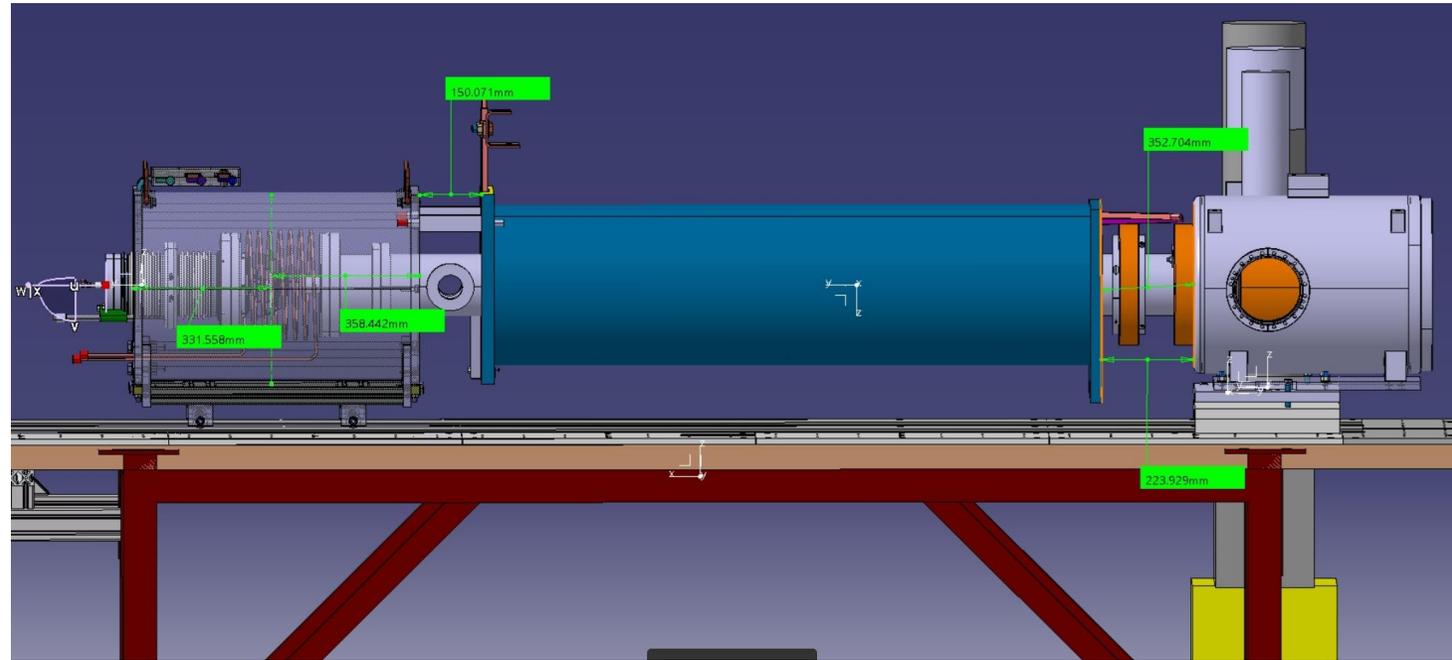
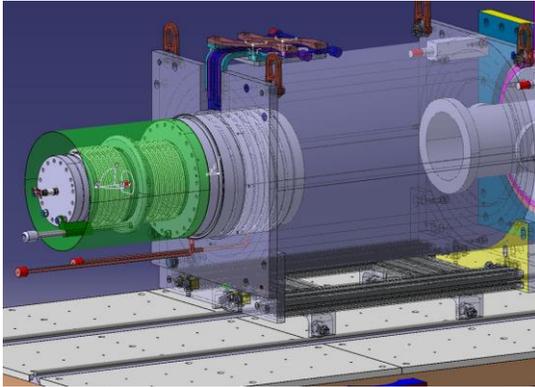
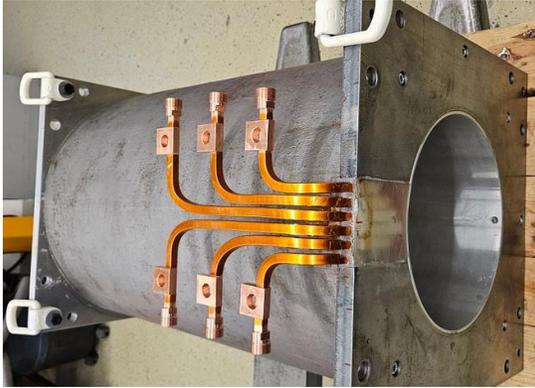
Electrode shape (perveance) tested



Final gun based on known working solutions (high confidence) but of course, needs to be tested

Future tests

courtesy: J. Cenede



What is next:

- Test new collector (Q1 2026)
- Add expansion solenoid (2400 Gauss)
- Test new gun (Q2-Q3 2026)
- NB: improved safety of the ECTS

Summary and conclusion

- Being a new design, R&D was needed for both the gun and collector
- A working collector has been demonstrated, copy with larger chamber expected in Q1 2026
- The proto gun is not (yet) ready for installation but can work if proved reliable
- Proposed final gun has high confidence of working in new AD E-Cooler
- Timeline is tight but a working gun deliverable for LS3 installation (Q4 2025)

Thank you

*AD CONS E-cooler collab: A. Rossi, C. Accettura, W. Andreatza, **J. Cenede**, N. Chritin, Y. Coutron, **A. Frassier**, D. Gamba, L. Joergens , M. Karppinen, M. Lazzaroni, C. Machado, O. Marquversen, A. Newborough, L. Ponce, M. Sameed, J. Ferreira Somoza, Y. Thurel, T. Todorcevic, G. Tranquille, L. Von Freeden, M. Wendt, E. Rigutto, T. Hernandez, T. Coiffet, T. Lefevre, J. Storey, W. Devauchelle, V. Maire, V. Sibue, T. Demaziere*

F. Wenander, A. Pikin (ABP gang)



EXTRA slides

Thank you for your attention !

Thermal results with MACOR/Alumina

N: macor_Radiation_nonlinear_symmetry_VESSELL_withcathode_2_enclosure

Temperature

Type: Temperature

Unit: °C

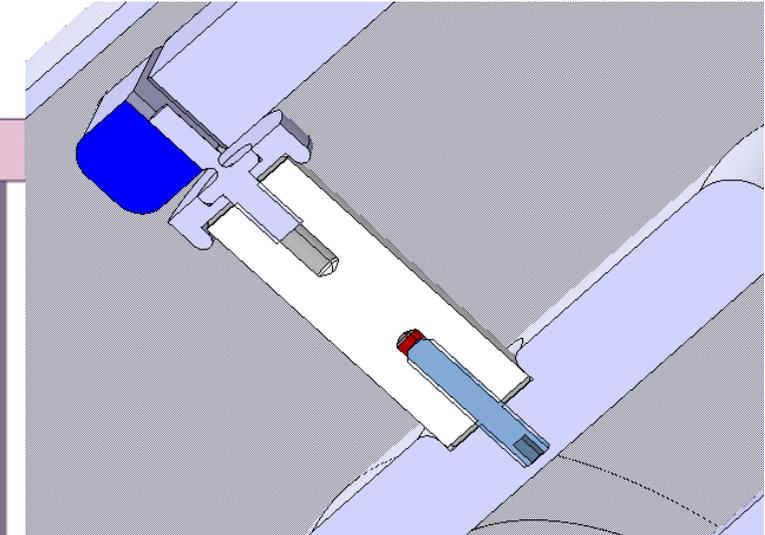
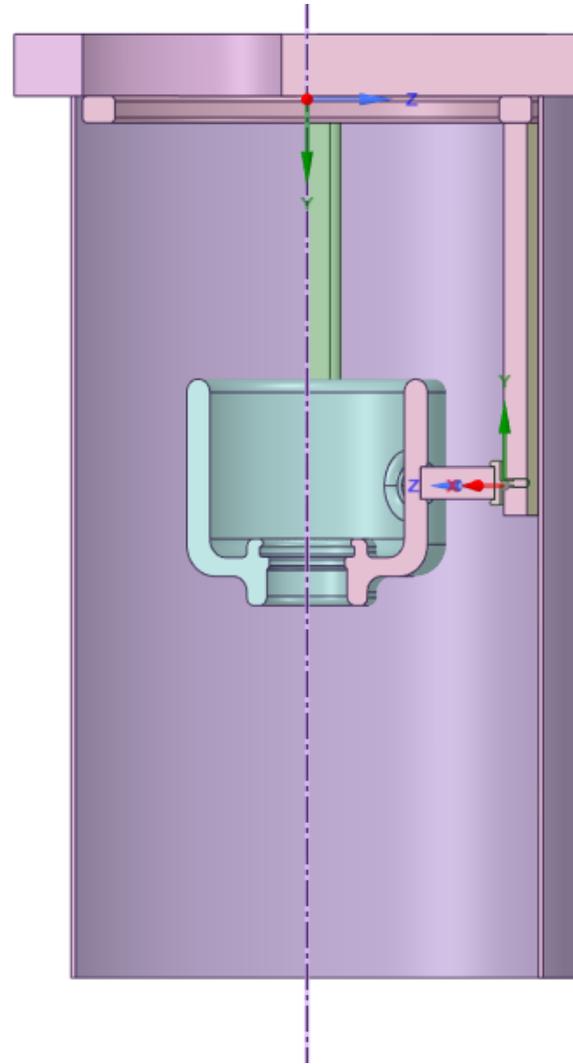
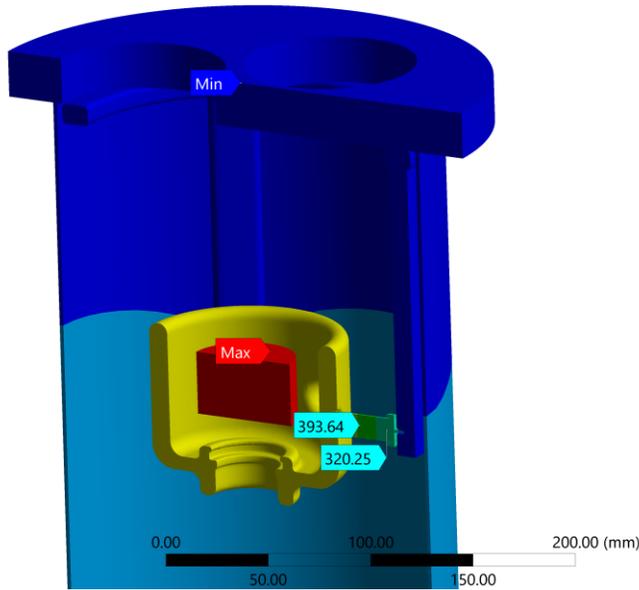
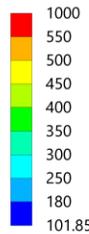
Time: 1

Custom

Max: 1000

Min: 101.85

03/11/2022 08:59



N: macor_Radiation_nonlinear_symmetry_VESSELL_withcathode_2_enclosure

Temperature 5

Type: Temperature

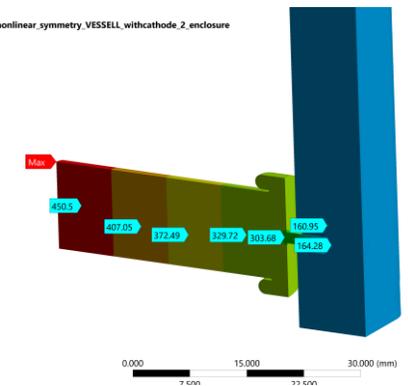
Unit: °C

Time: 1

Max: 468.33

Min: 106.61

03/11/2022 08:53



- Average Temperature MACOR= 390°C (thermal conductivity=1.6 W/mK) → Higher DeltaT on the ceramic

Courtesy: C. Accettura (EN-MME group at CERN)

SEE – secondary electron emission in CST (Furman)

work in progress, not fully optimized the CST parameters for setup, used default in CST settings!

