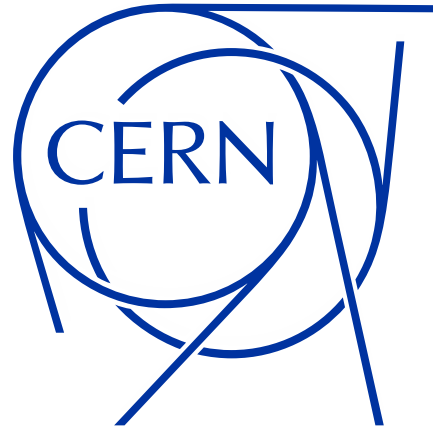




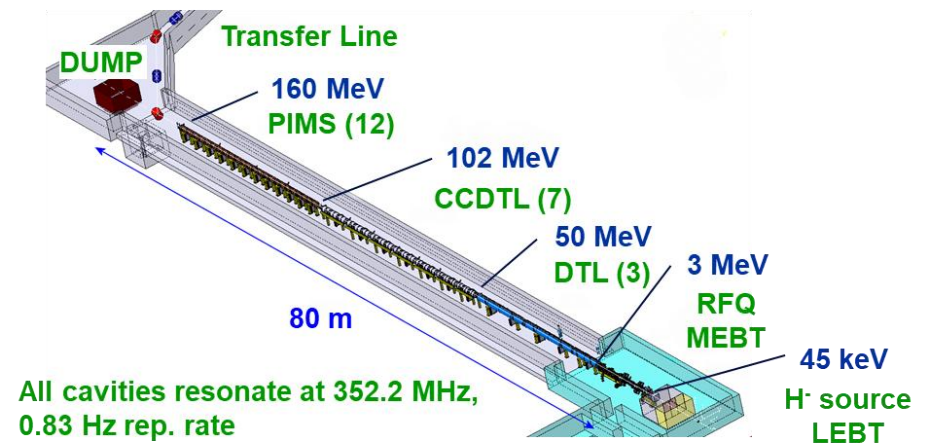
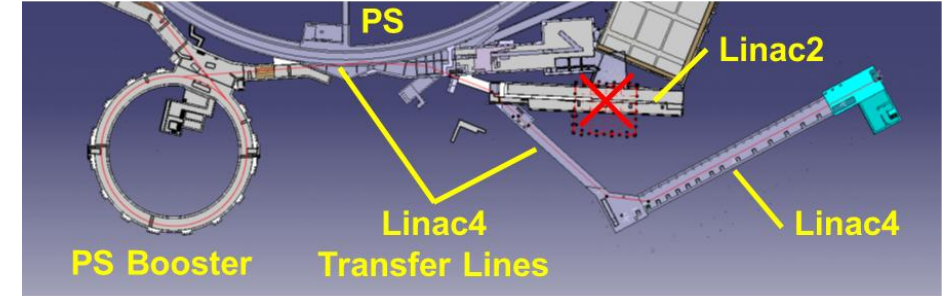
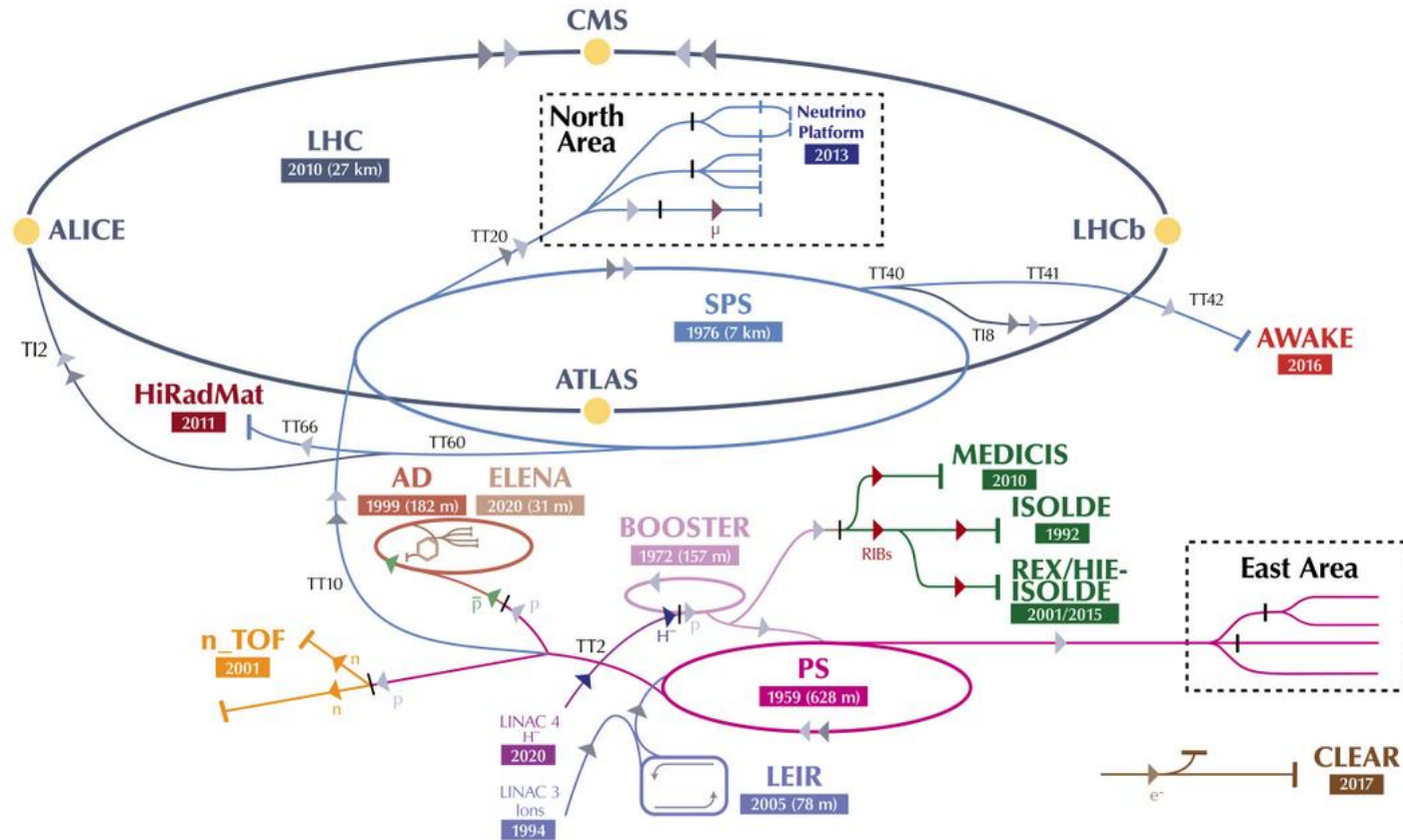
H^- source Developments and Operation at CERN

J.B. Lallement, G. Bellodi, S. Bertolo, F. Di Lorenzo, A. M. Lombardi, A. Mamaras, C. Mastrostefano, M. O'Neil,
E. Pasino, E. Sargsyan

21/09/2026



The source for the CERN proton complex



- Linac became the proton complex injector in 2021.
 - Source First to start – Last to stop.
 - **24/7 from early Feb. to Dec.**

Short Recap. Since 2008

- **2008-2010: RFQ input set from 95 keV to 45 keV**

- DESY (35 kV) adapted to 45 kV.

- **2010-2015**

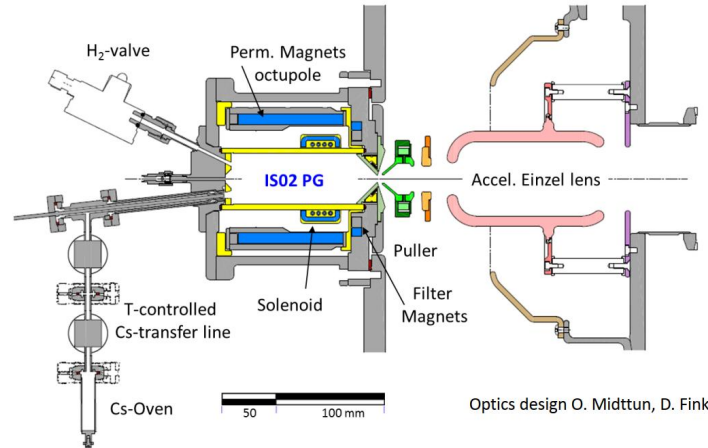
- IS02: Dumping at 10 keV.
- First cesiation late 2013.

- **2015-2022**

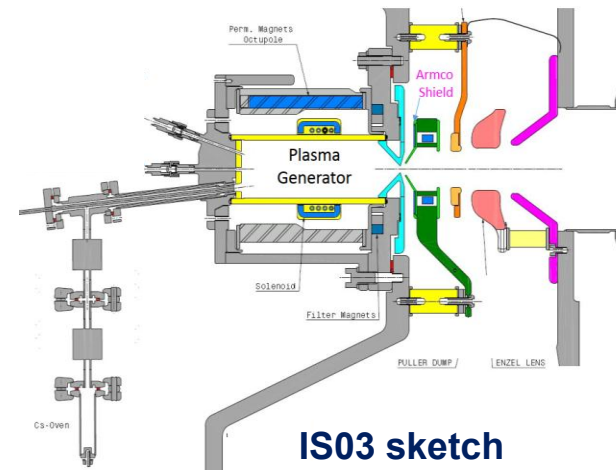
- IS03: Shorter einzel lens.

- **2023- present**

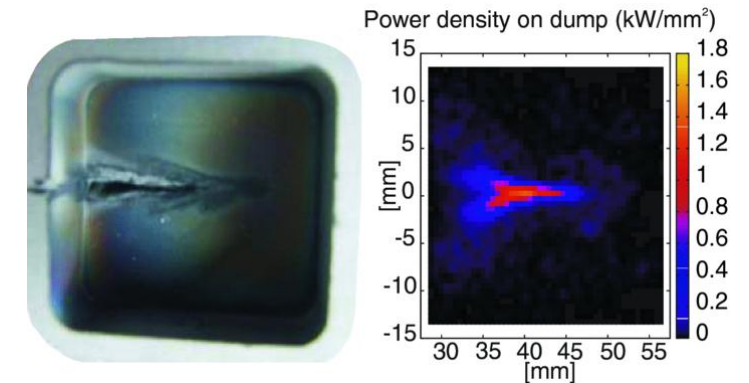
- IS04:



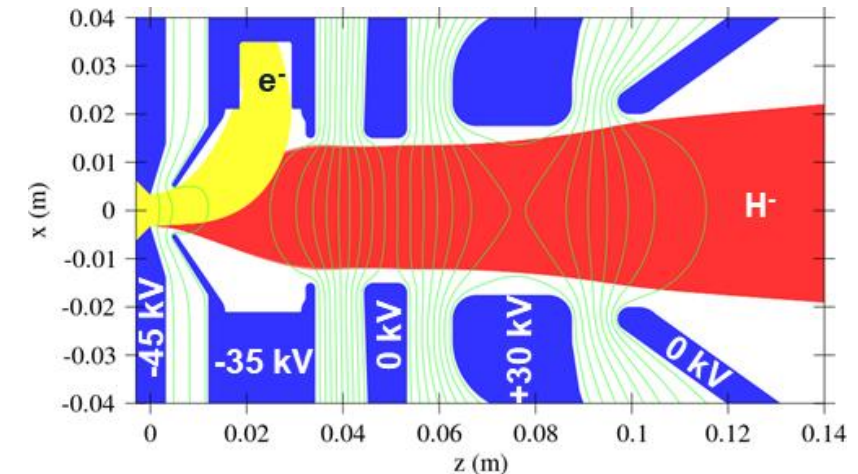
IS02 sketch



IS03 sketch



Damaged CERN/DESY source dump

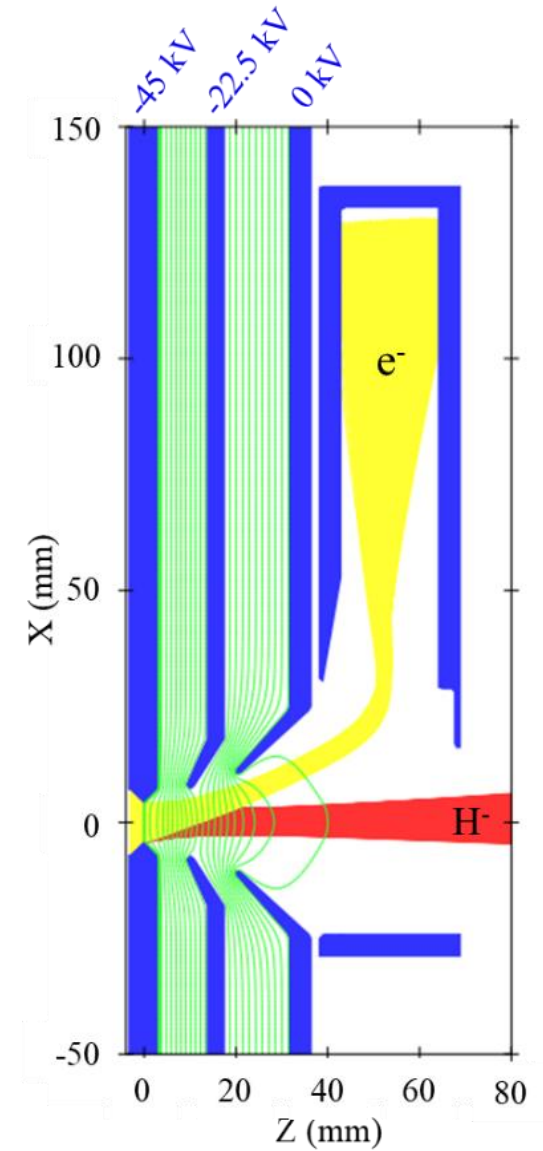
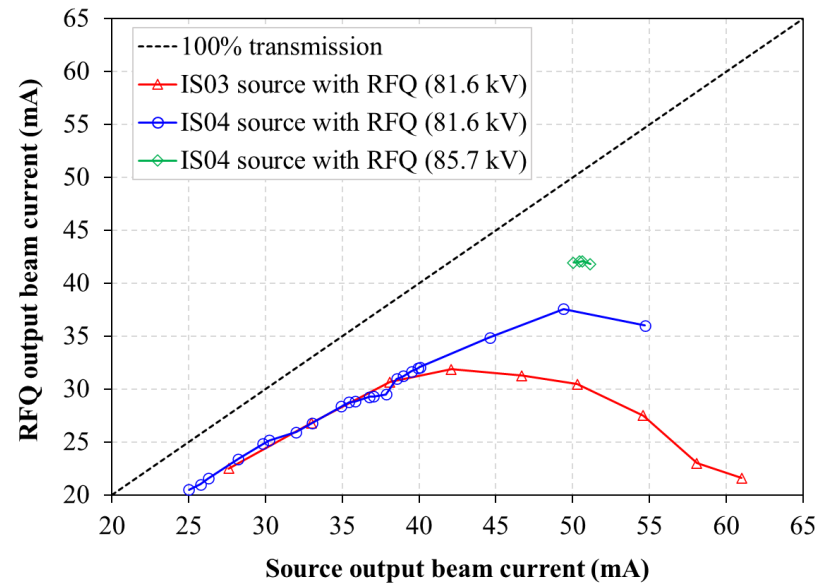
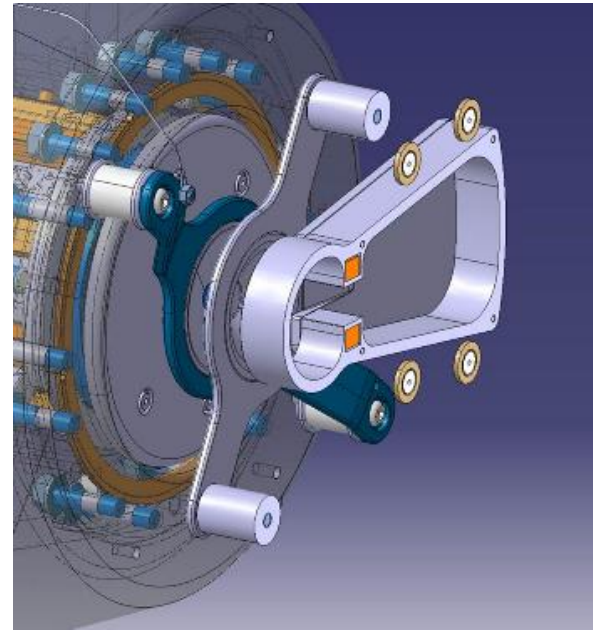
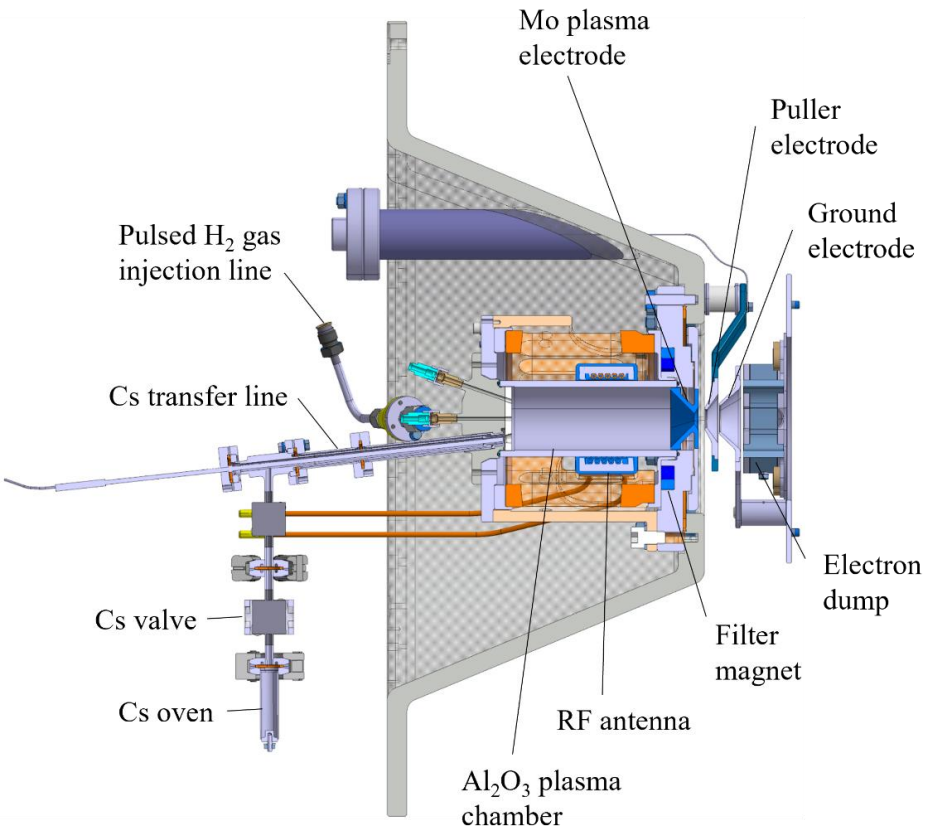


IS03 extraction and beam envelopes

Present Design: IS04

2023 – IS04:

- No einzel anymore.
- 2 electrodes: Puller and dump at 45 keV

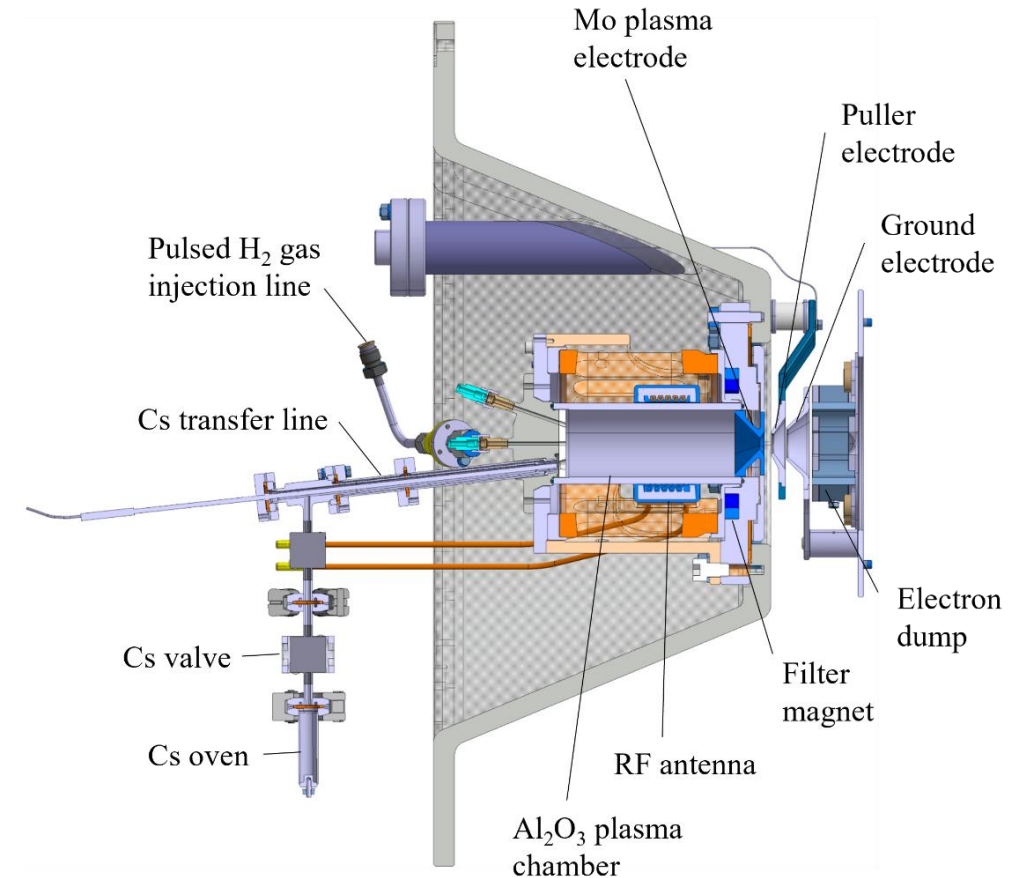


IS04 extraction and beam envelopes

Main Parameters

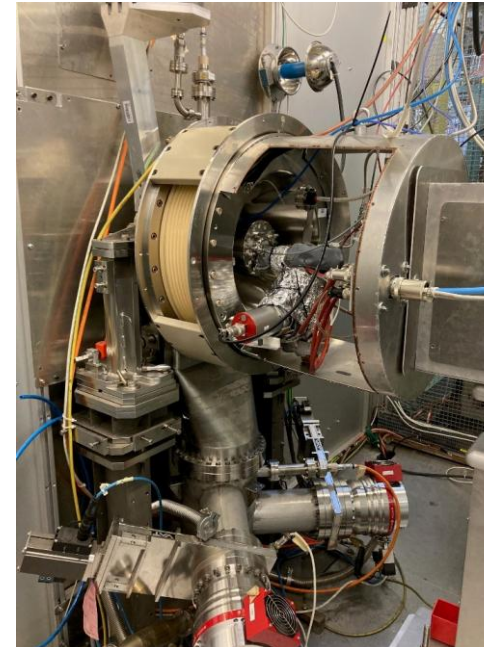
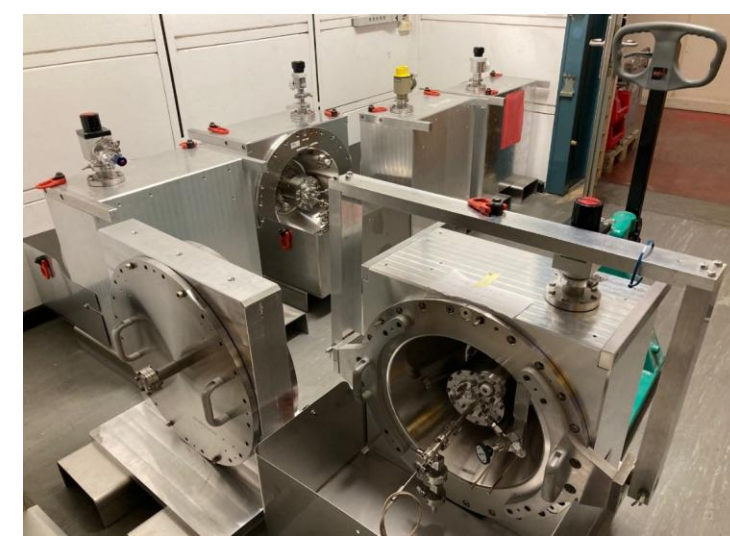
Linac4 Source IS04 parameters

Rep. rate	0.83 Hz
RF power	2 MHz - ~ 1 kW / mA
Continuous cesiation	Cs reservoir - 1 g - @ 60°C
Measured Cs consumption	80 – 100 mg / year
Gas injection	Pulsed
H- current	40 mA
H- current out of the RFQ	> 32 mA
Pulse length	850 μ s
e/H ratio	From 0.5 to 1
Lifetime	> 1 year
Pulse to pulse stability	< 1 % RMS
Availability	> 99%
Downtime / 10 months	~ 1 day total



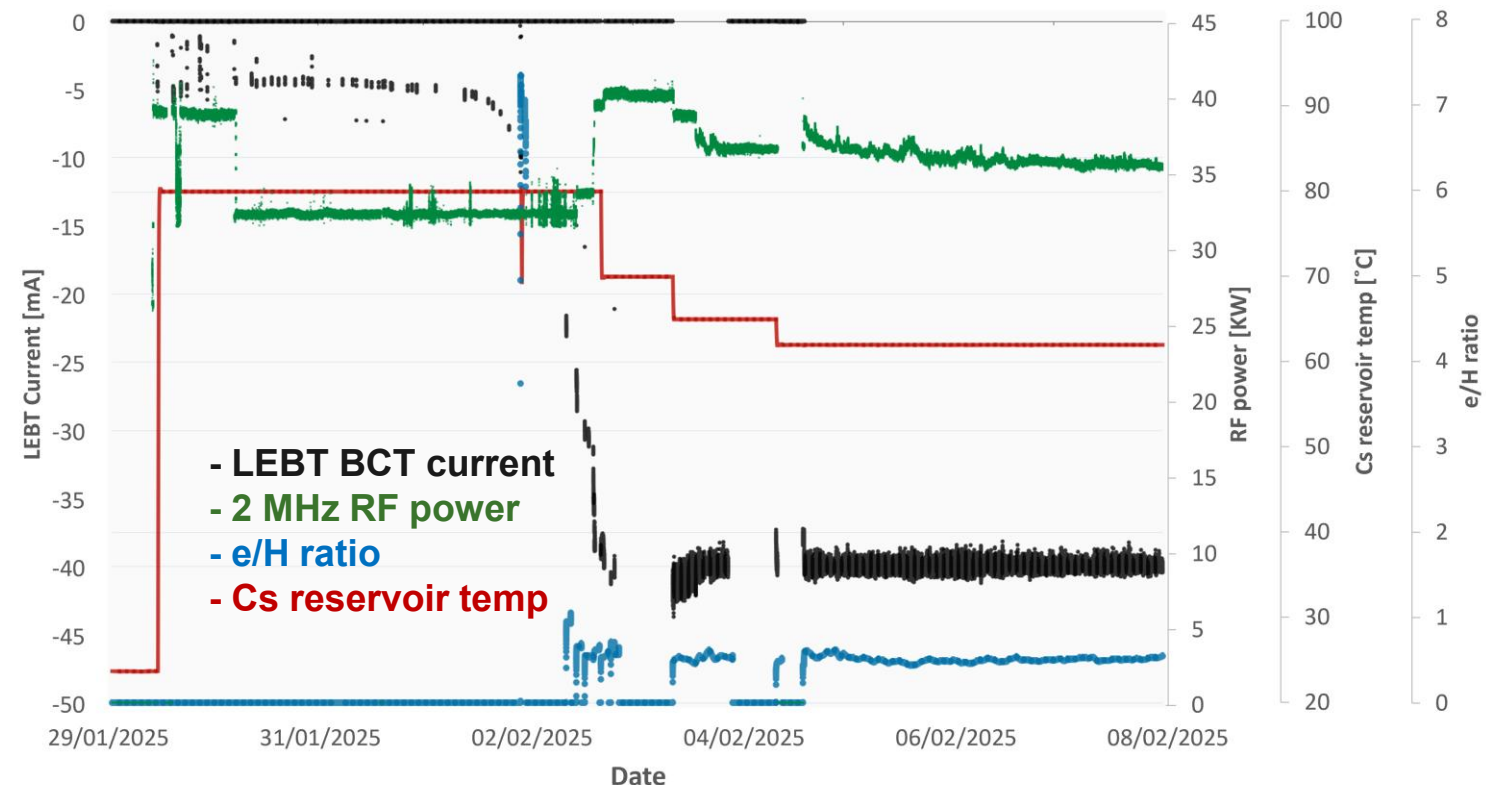
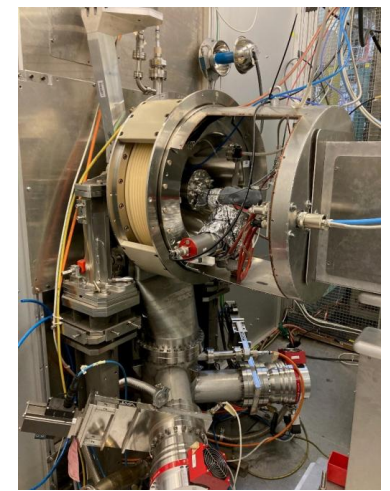
Source units management

- A new source unit is installed every year in January – early February.
 - We exceptionally ran the **same unit from Jan. 2025 to Sep. 2026**.
- The unit from the previous year is cleaned:
 - The plasma chamber is sand blasted / electrodes are cleaned.
 - A new Cs reservoir filled with 1 g of cesium is installed.
 - The gas injection valve is replaced.
 - The source is tested and qualified at the test stand and becomes an “official” spare.
- In total **4 x IS04** sources:
 - 1 operational unit: In the Linac4.
 - 2 spare units stored under N2.
 - 1 unit at the source test stand.
- 2 weeks booked in CERN schedule for source start-up:
 - Usually, < 1 week to reach nominal performances.
 - 1 week for contingency (leak, services, etc...).
 - More details on next slide.



Installation and Start-up

1. After at least one day under vacuum.
2. RF power and gas for plasma conditioning.
 - Cs reservoir set to 80°C (upper interlock limit).
 - Periodical checks of H⁻ and e⁻ currents switching on HV.
3. After few days (3-6):
 - e/H ratio < 1.
 - H⁻ current around 1 mA / kW.
4. Setting-up for operation
 - HV kept on...
 - Cs reservoir down to ~ 60°C.
 - Gas and RF phase fine tuned.
 - Feedback system turned on at 40 mA.



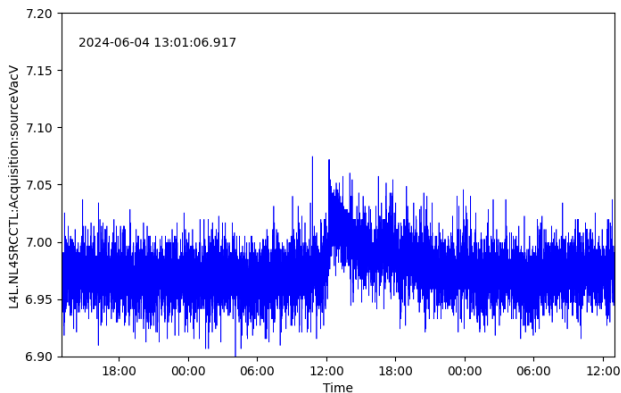
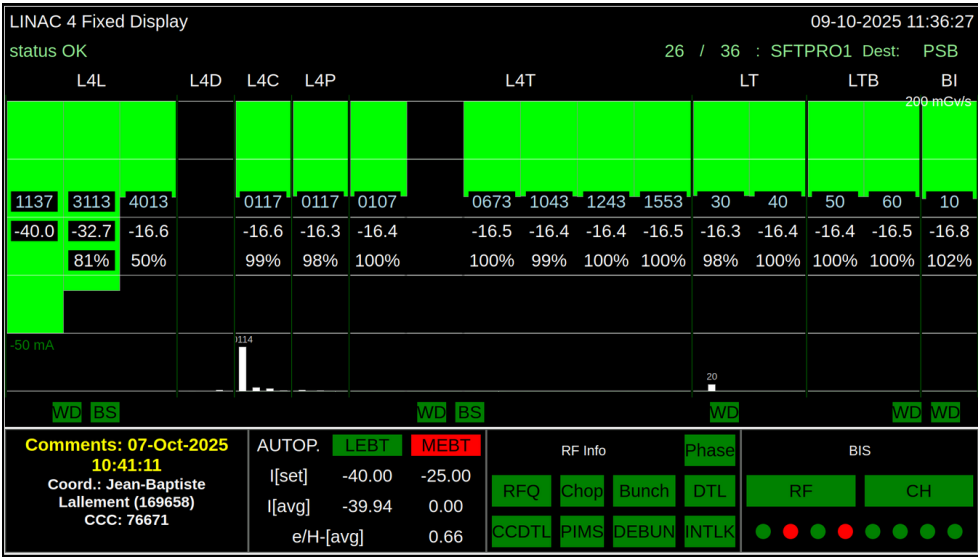
Source operation



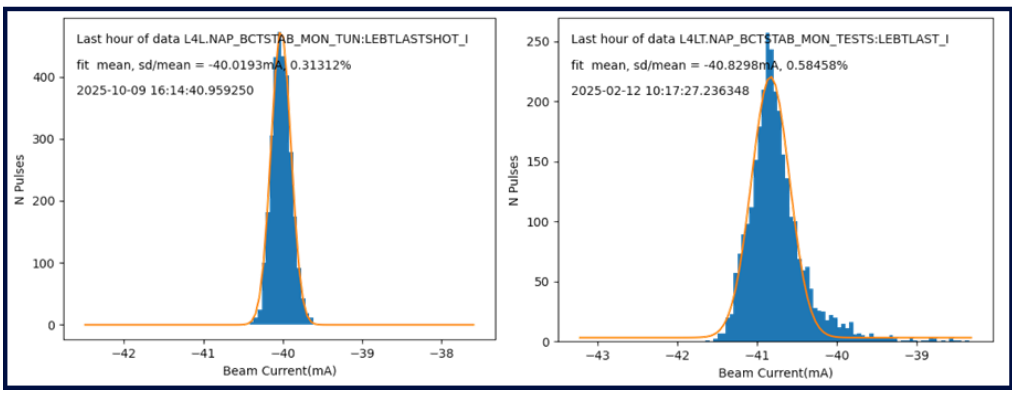
- The team: All in the Hadron Sources and Linac section - **HSL**
 - **5 “source specialists”** on-call rotating on a weekly basis.
 - Support from 4 technicians and technical engineers (mechanics, electronics, control).
 - **Team far from being 100% L4 source:** Linac3, Linac4, L4 test-stand, ELENA, Linac4, medical and societal activities...
- **Regulation - mainly 2 knobs:**
 - **Feedback** on the extracted source current, measured after the first LEBT solenoid – **Set to 40 mA – “Autopilot”**
 - **The amount of injected gas** – gas pulse width – is adjusted by the specialist:
 - Too much gas: higher e/H, impact on the RFQ transmission (pulse shape), risk of HV sparks.
 - Not enough: Plasma instabilities, large pulse to pulse current variation.
- **Main observables:**
 - Source current.
 - Pulse to pulse current stability.
 - Vacuum / Gas level and stability e/H ratio.
 - <https://linac-survey.web.cern.ch/linac4/linac4surv.html>

What to look at ?

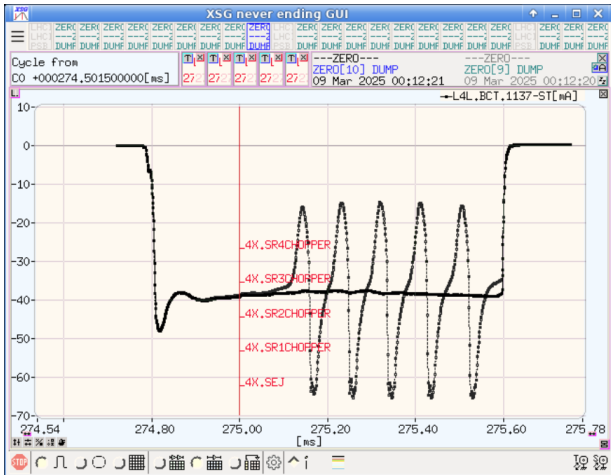
- Main observables:
 - Source current and pulse shape.
 - Pulse to pulse current stability.
 - Vacuum / Gas level and stability.
 - e/H ratio.
 - <https://linac-survey.web.cern.ch/linac4/linac4surv.html> [LS3 ;- (]



“Event” on the source pressure



Source output current distribution over 1 hour.
Left: everything is fine
Right: large distribution and tail

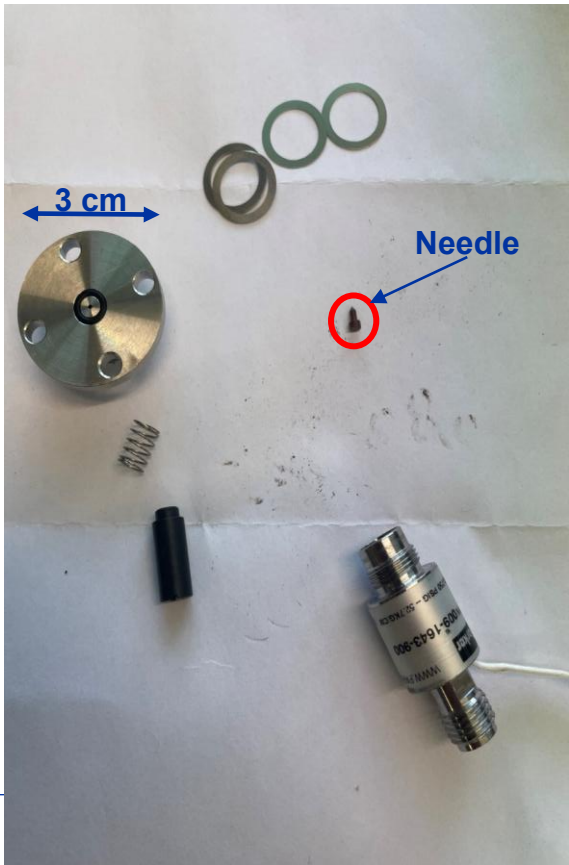
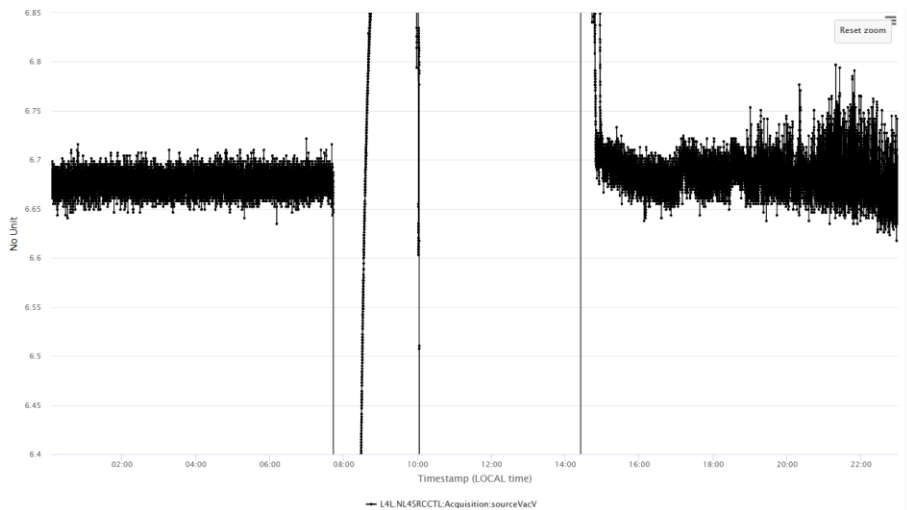


Overlap of two source beam pulses.
Stable and unstable plasma.

Reliability and Availability

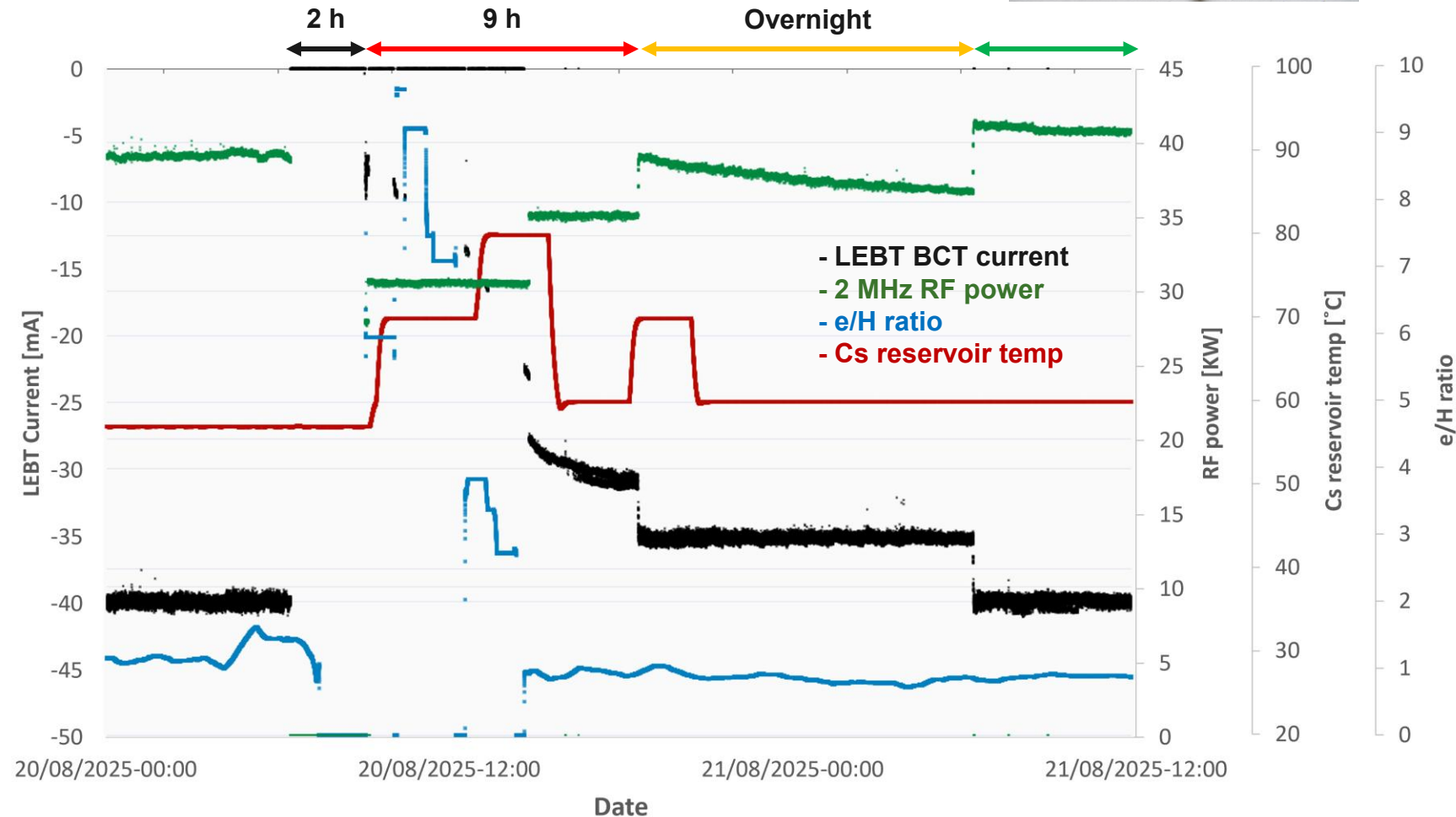
- **Over 9 to 10 months of 24/7 operation:**
 - 1-day technical stop when “almost” nothing done.
 - No HV spark since switched to IS04 design.
 - Most of the downtime / instabilities due to source gas injection.
 - Too much / too less gas.
 - Aging injection valve to be replaced – lifetime ~ 6 months (13 million pulses !).
 - A shut-off valve was installed in 2023.

Source yearly availability		Downtime
2022 (IS03)	97.5%	167 h
2023 (IS04)	99.9%	6 h
2024	99.6%	27 h
2025	99.7%	23 h
2026	99.99%	0.5 h

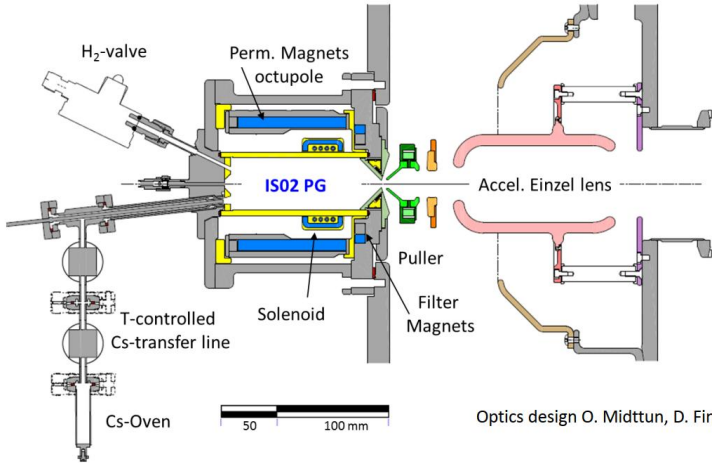


Injection Valve Replacement

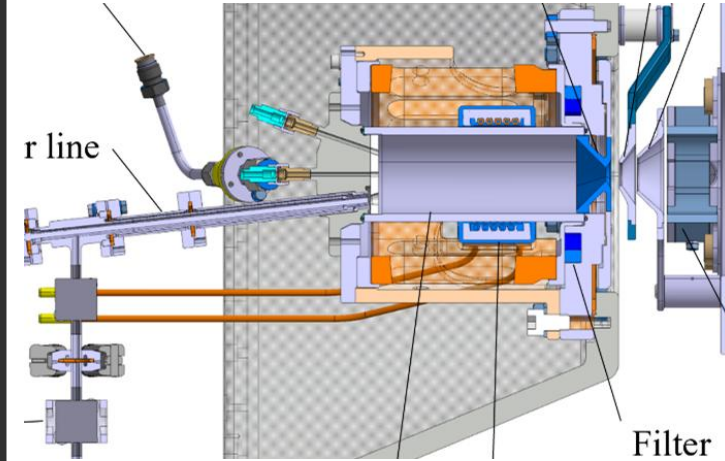
- Example: Last replacement during a run – August 2025.
 - Intervention – 2 hours.
 - Restart and cesiation – 9 hours.
 - 35 mA beam back to PSB



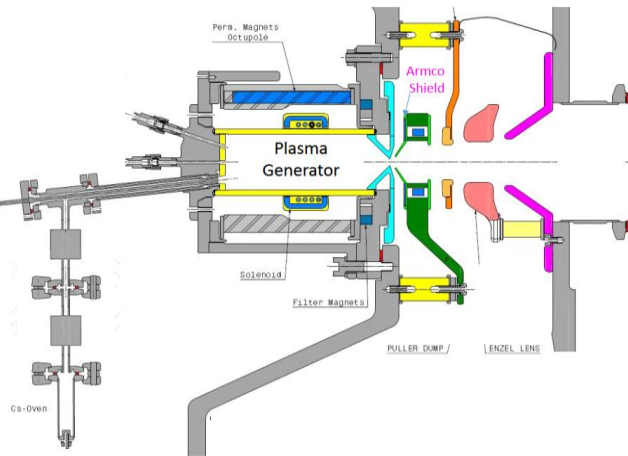
The Shorter the Extraction the Better ?



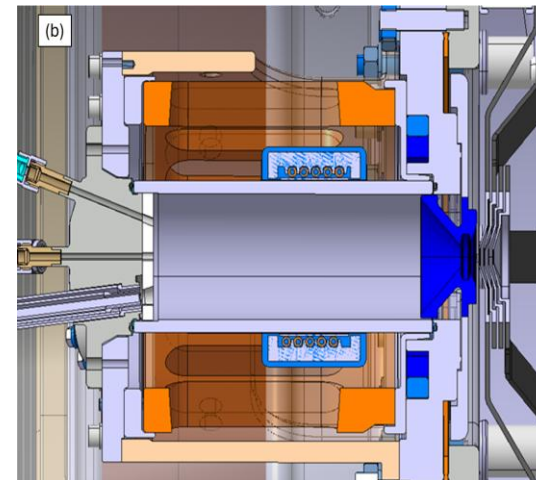
IS02
25 cm
10-20 mA @ 3 MeV



IS04
6 cm
32-42 mA @ 3 MeV

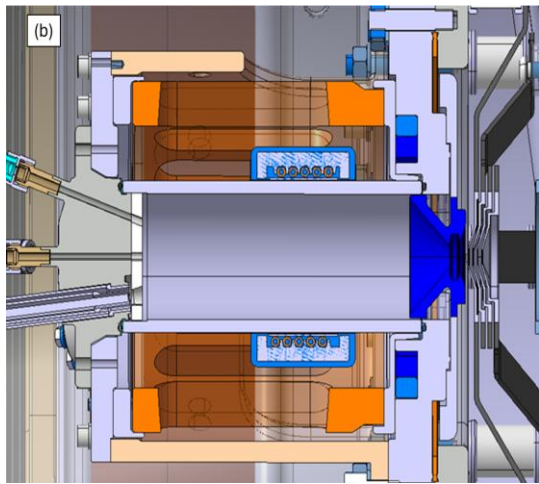


IS03
14 cm
24-30 mA @ 3 MeV

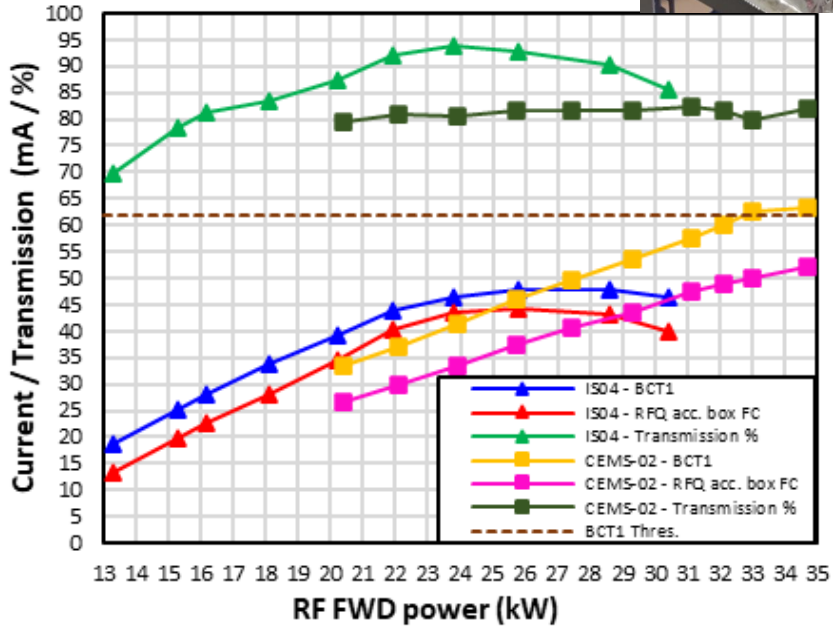
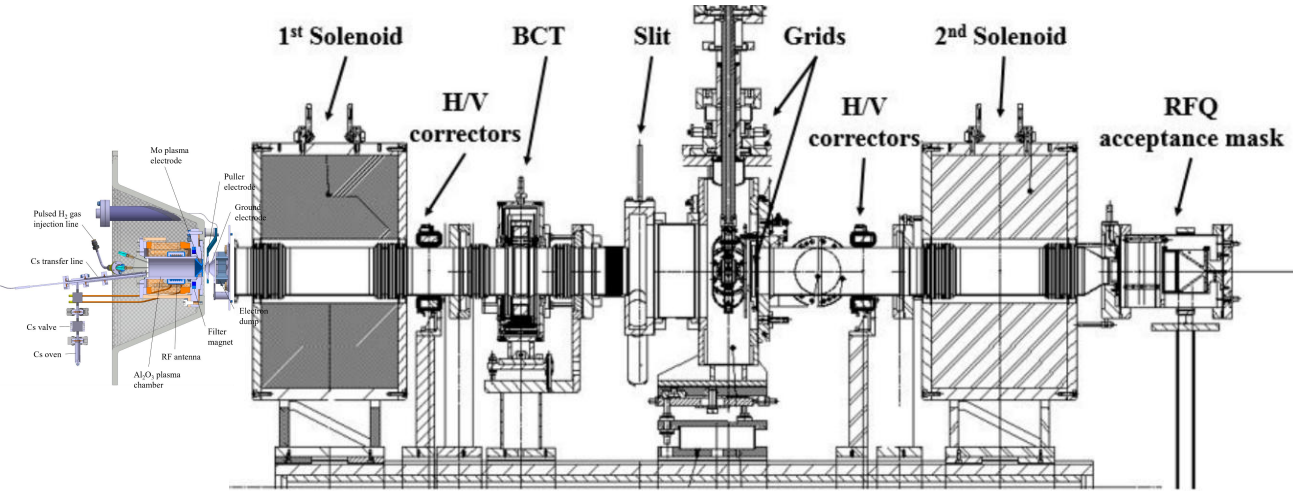
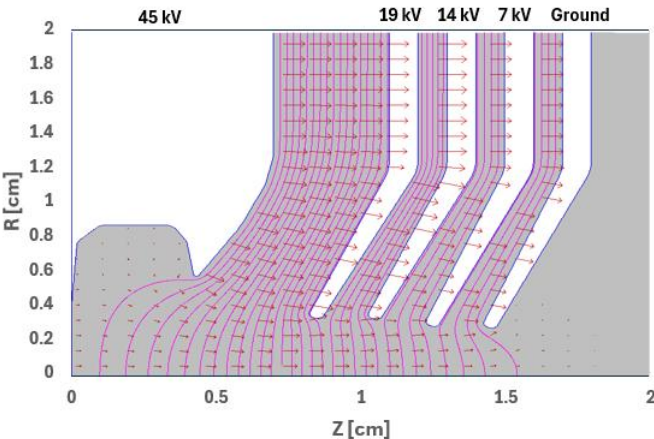


CEMS proton beam tests
2 cm
~ 50 mA expected @ 3 MeV

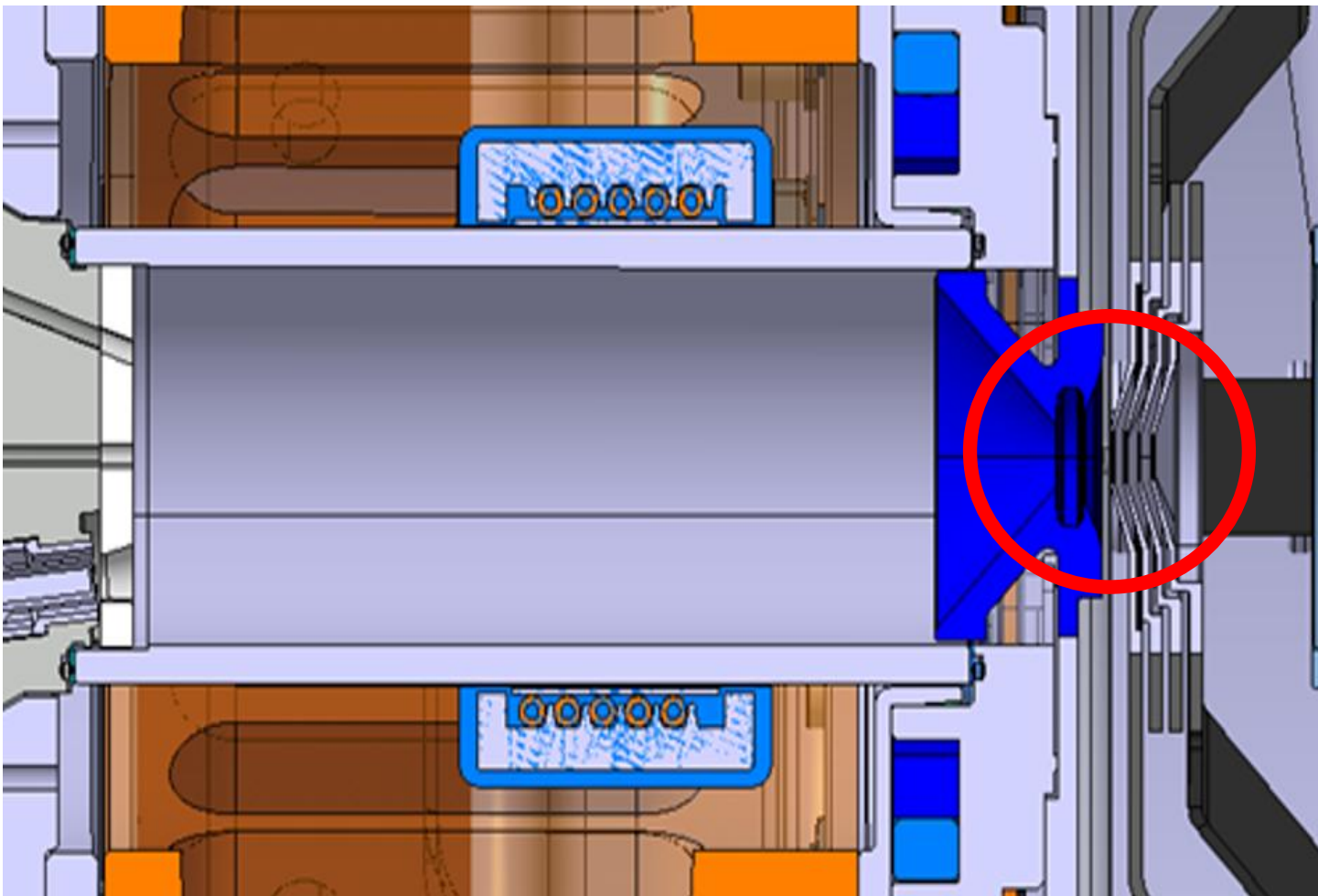
Toward IS05 ?



CEMS proton beam tests
2 cm
~ 50 mA expected @ 3 MeV



Toward IS05 ?



H⁻ source Developments and Operation at CERN

- Almost 20 years of development.
- 4 source generations.
- We learned a LOT.
- Now reached a level of maturity making our “clients” very happy.
- Still, would like to keep development going on !

Thank you !



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