H^- Ion Source Development at RAL

Dan Faircloth

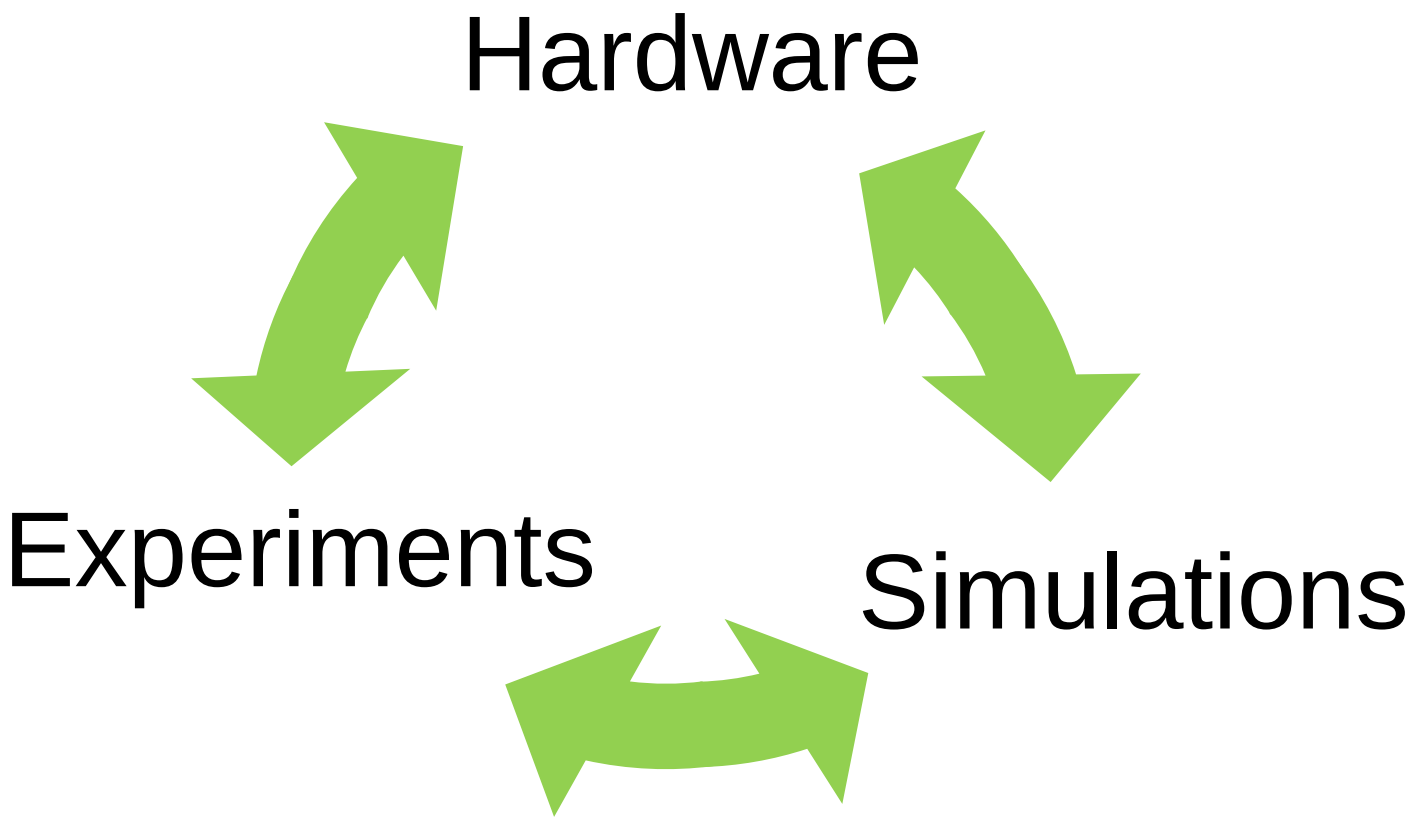
12-14 January 2012 Fermilab

Development Achievements

×2 increase in current: 35 mA to 70 mA

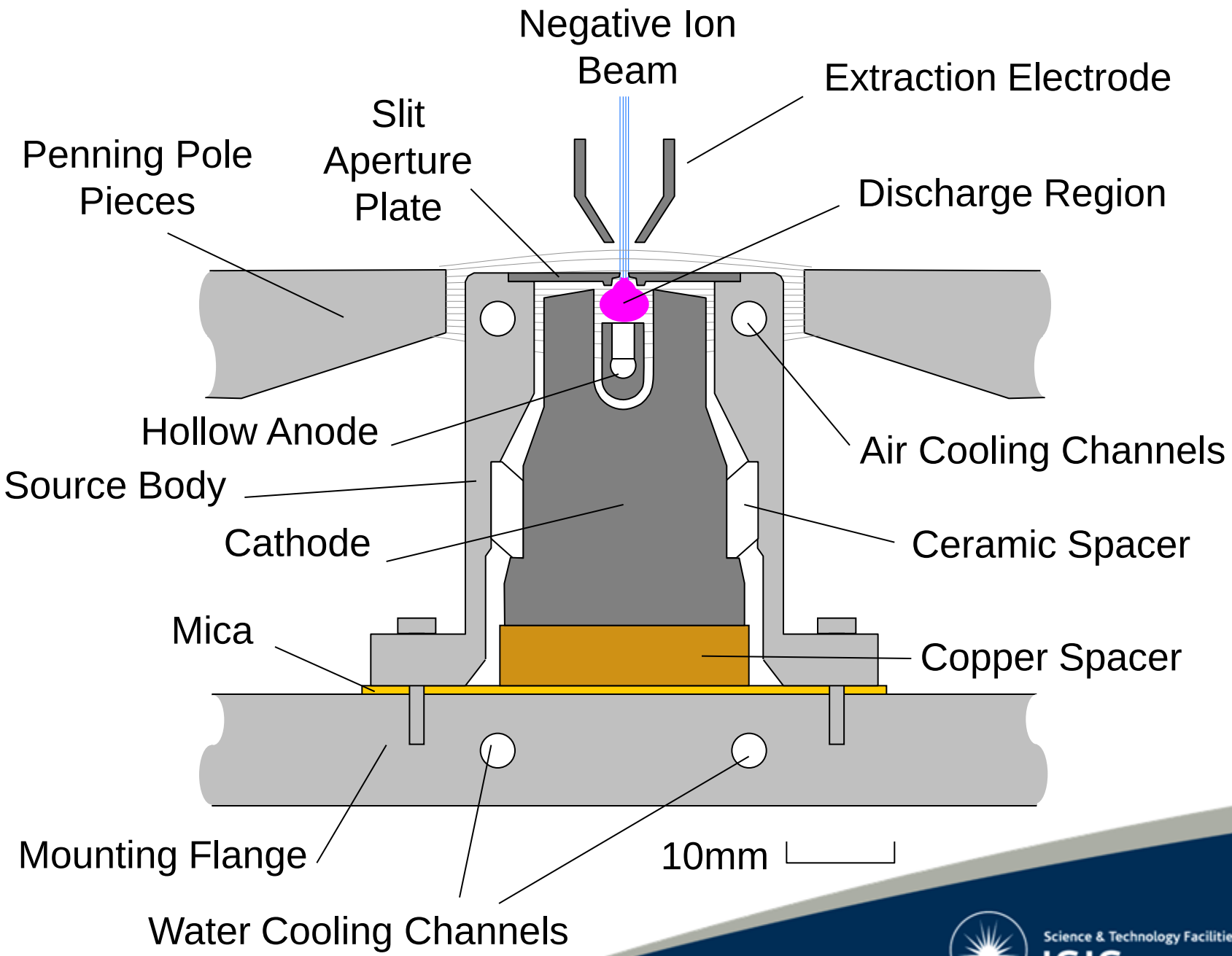
×8 increase in pulse length: 250 μs to 2 ms

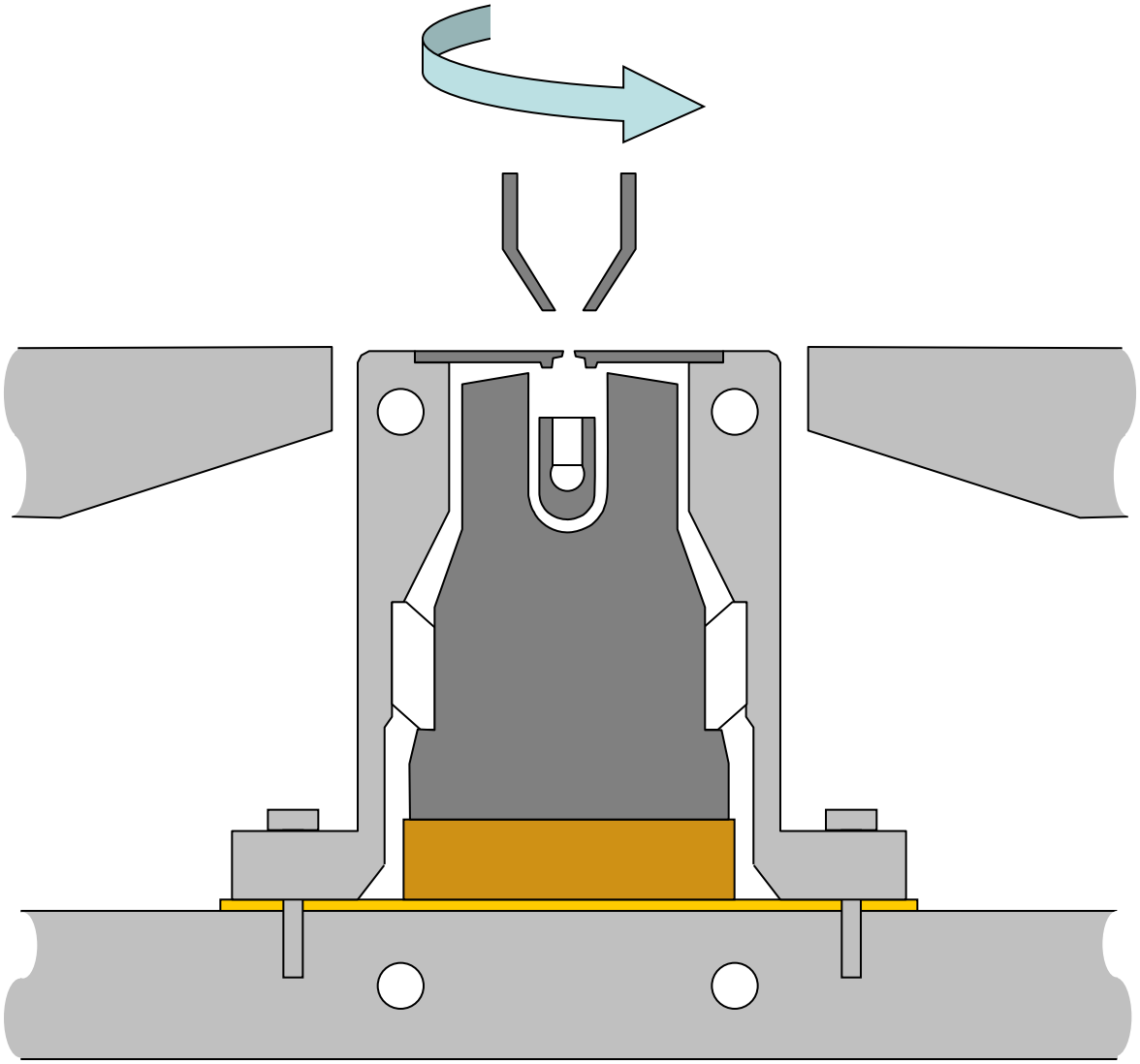
The Development Cycle

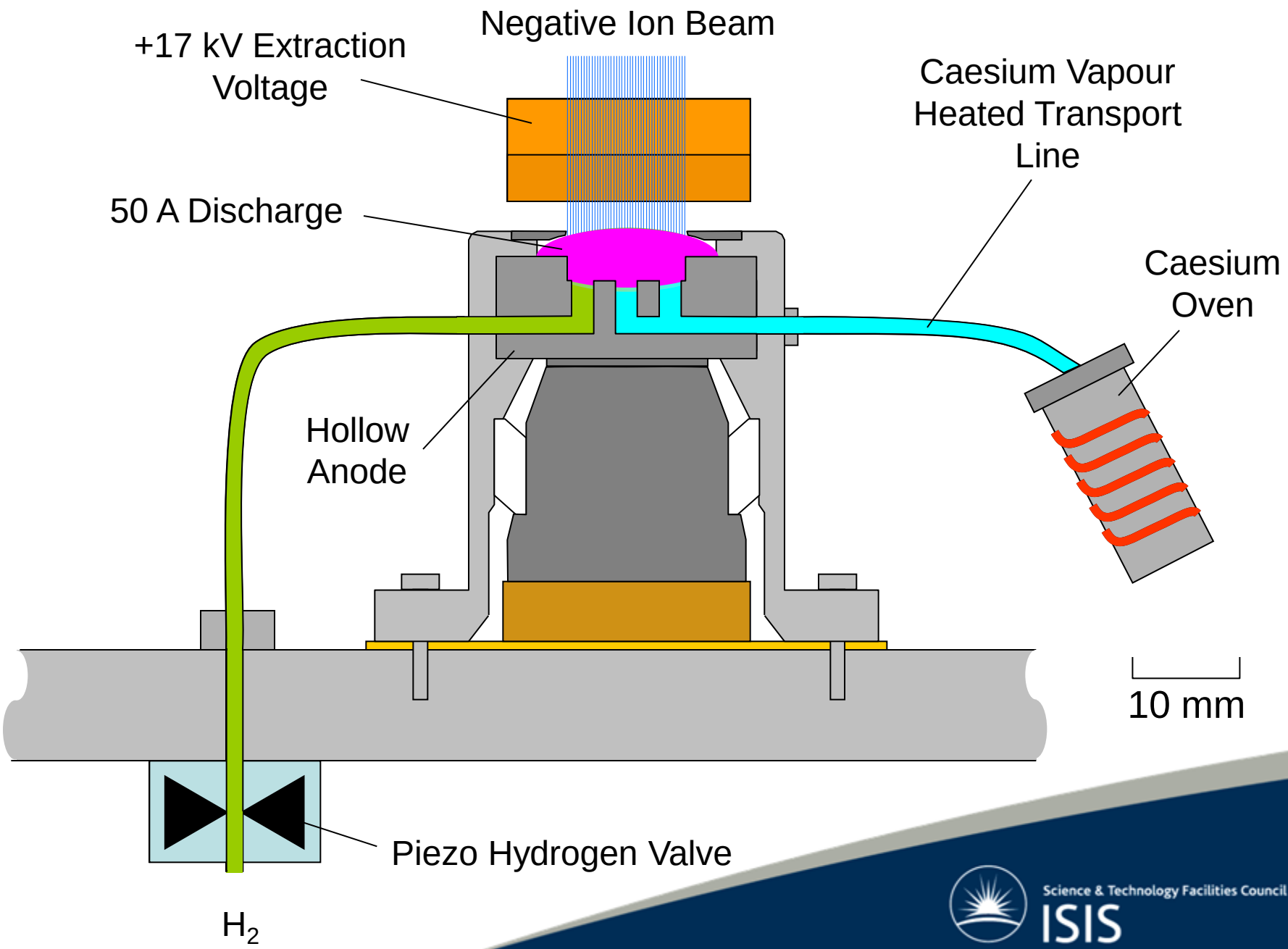


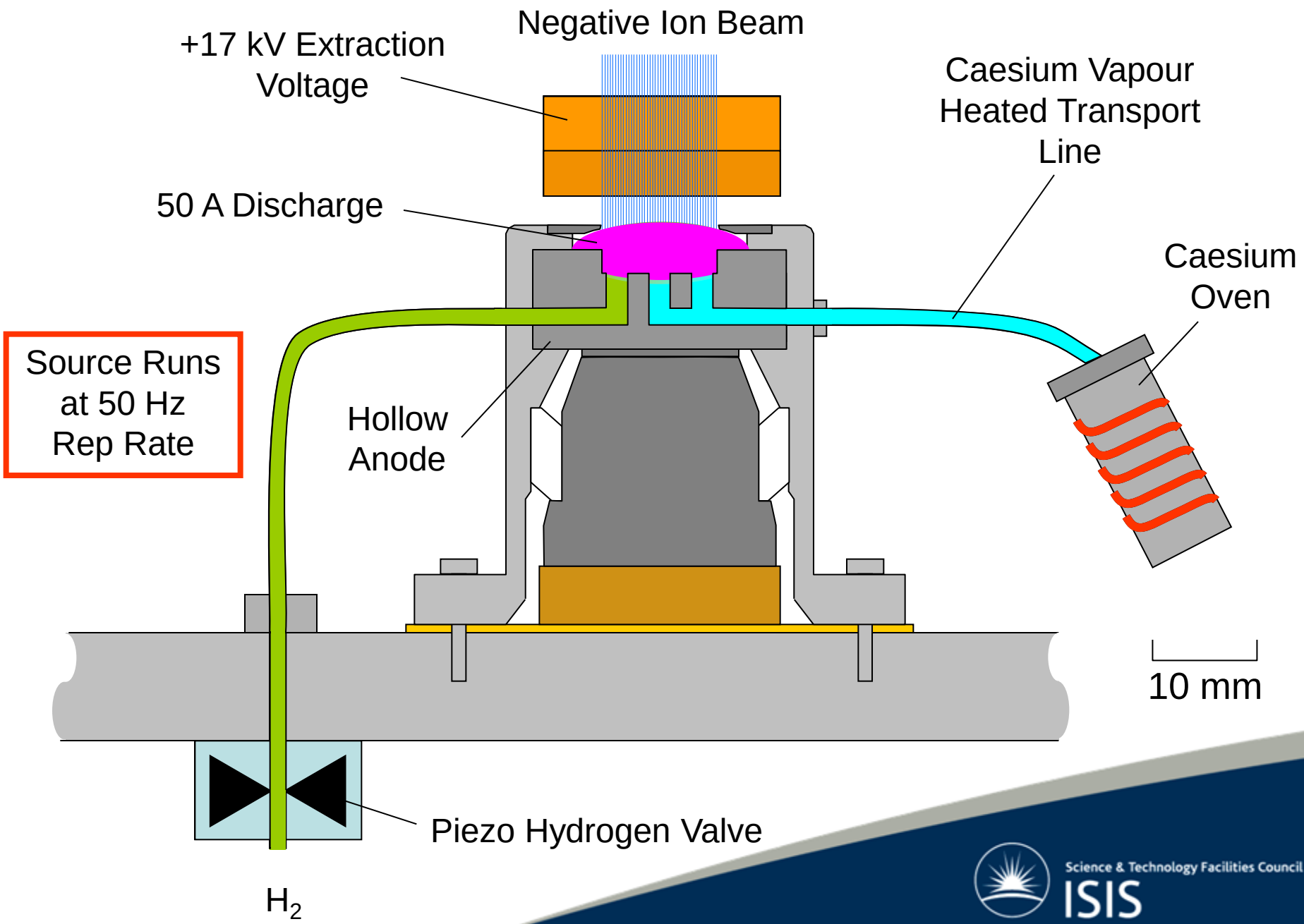
The ISIS H^- Ion Source

- Penning H^- ion source
- Surface plasma source (SPS)
- Dudnikov type
- 15 ml/min H_2
- 3 g/month Cs
- 20 day average lifetime

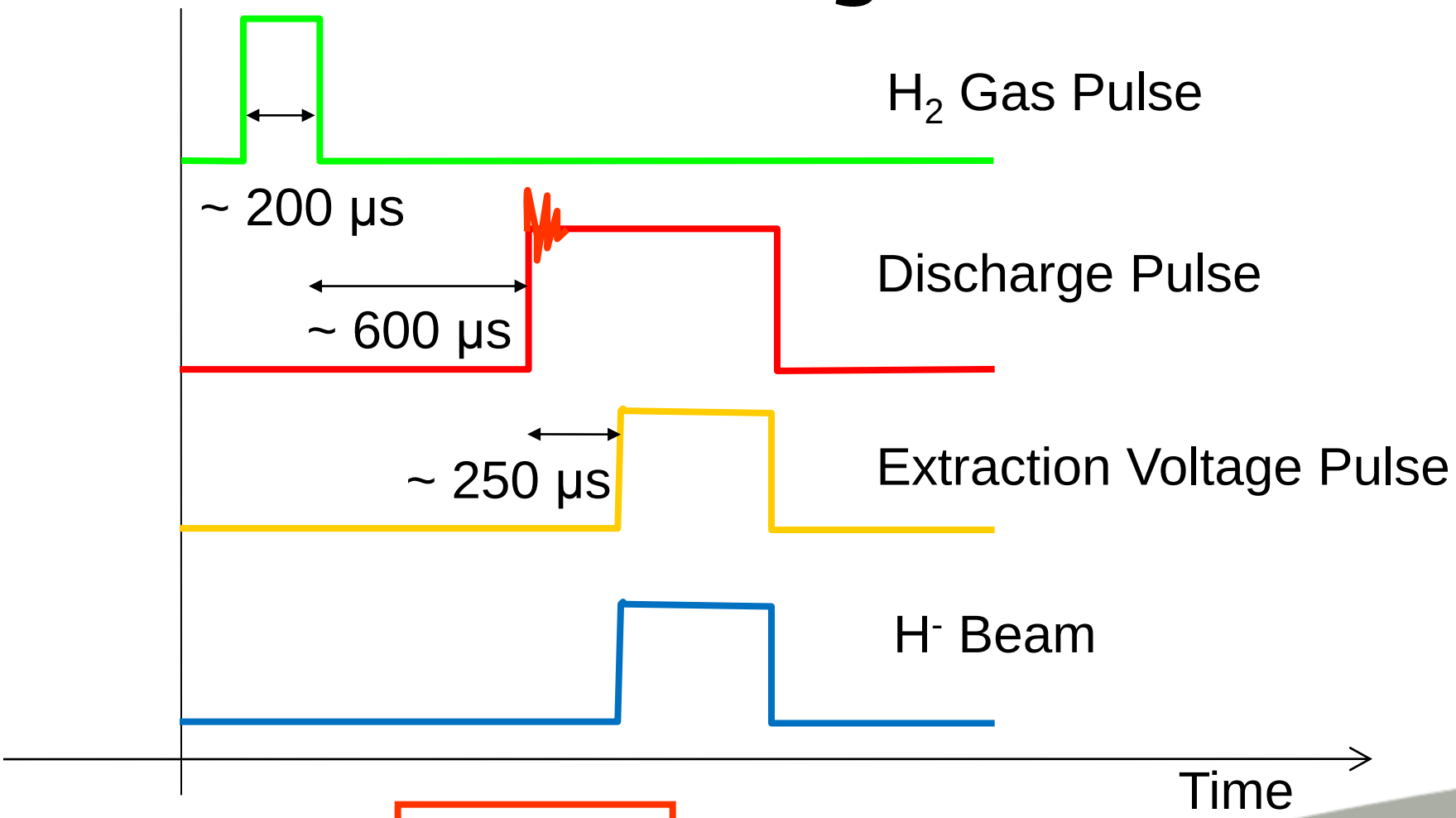

Negative Ion Beam
Extraction Electrode
Slit Aperture Plate
Penning Pole Pieces
Discharge Region
Hollow Anode
Air Cooling Channels
Source Body
Cathode
Ceramic Spacer
Mica
Copper Spacer
Mounting Flange
10mm
Water Cooling Channels



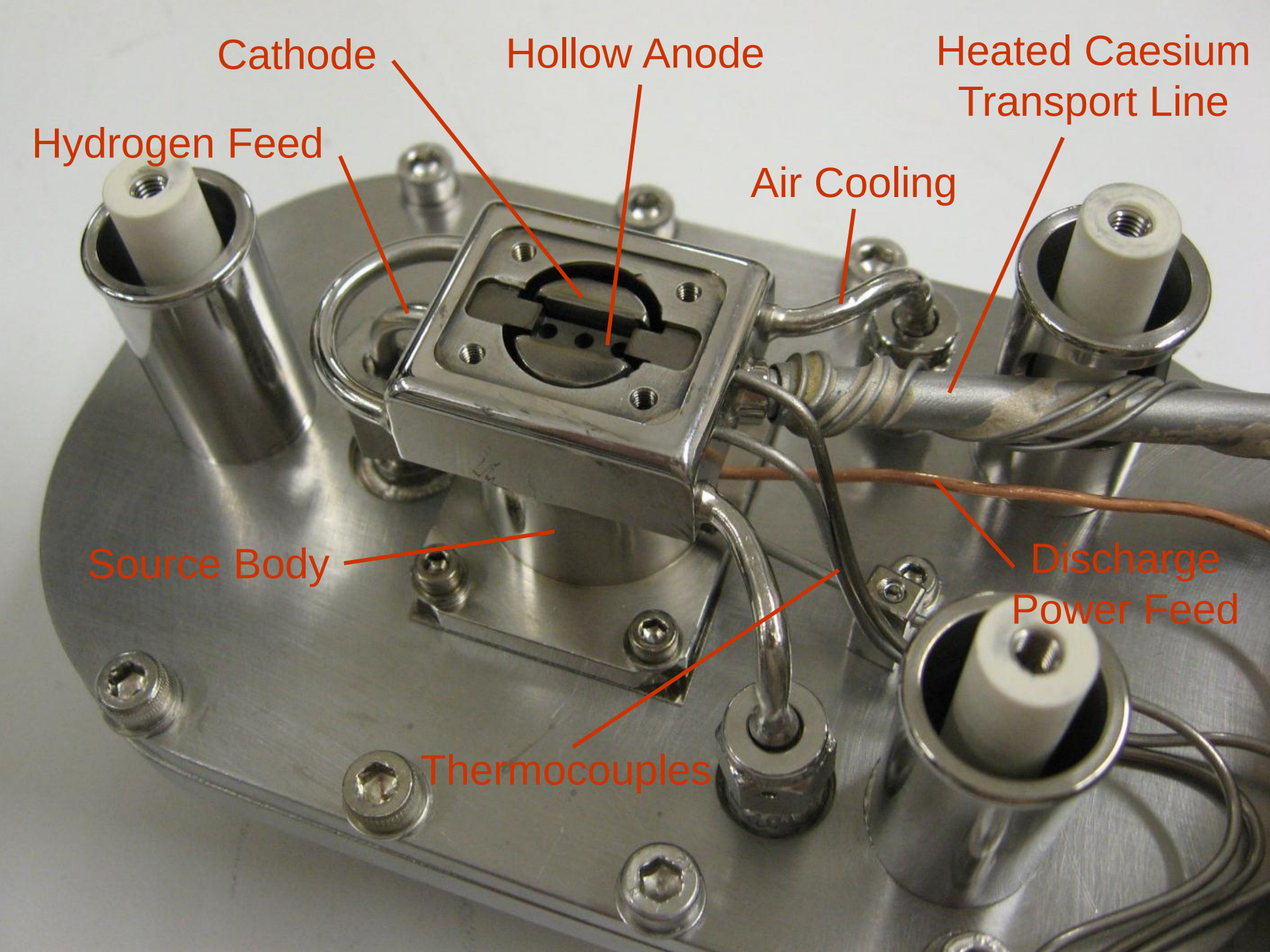

Negative Ion Beam
+17 kV Extraction Voltage
Caesium Vapour Heated Transport Line
50 A Discharge
Caesium Oven
Hollow Anode
10 mm
Piezo Hydrogen Valve
H_2

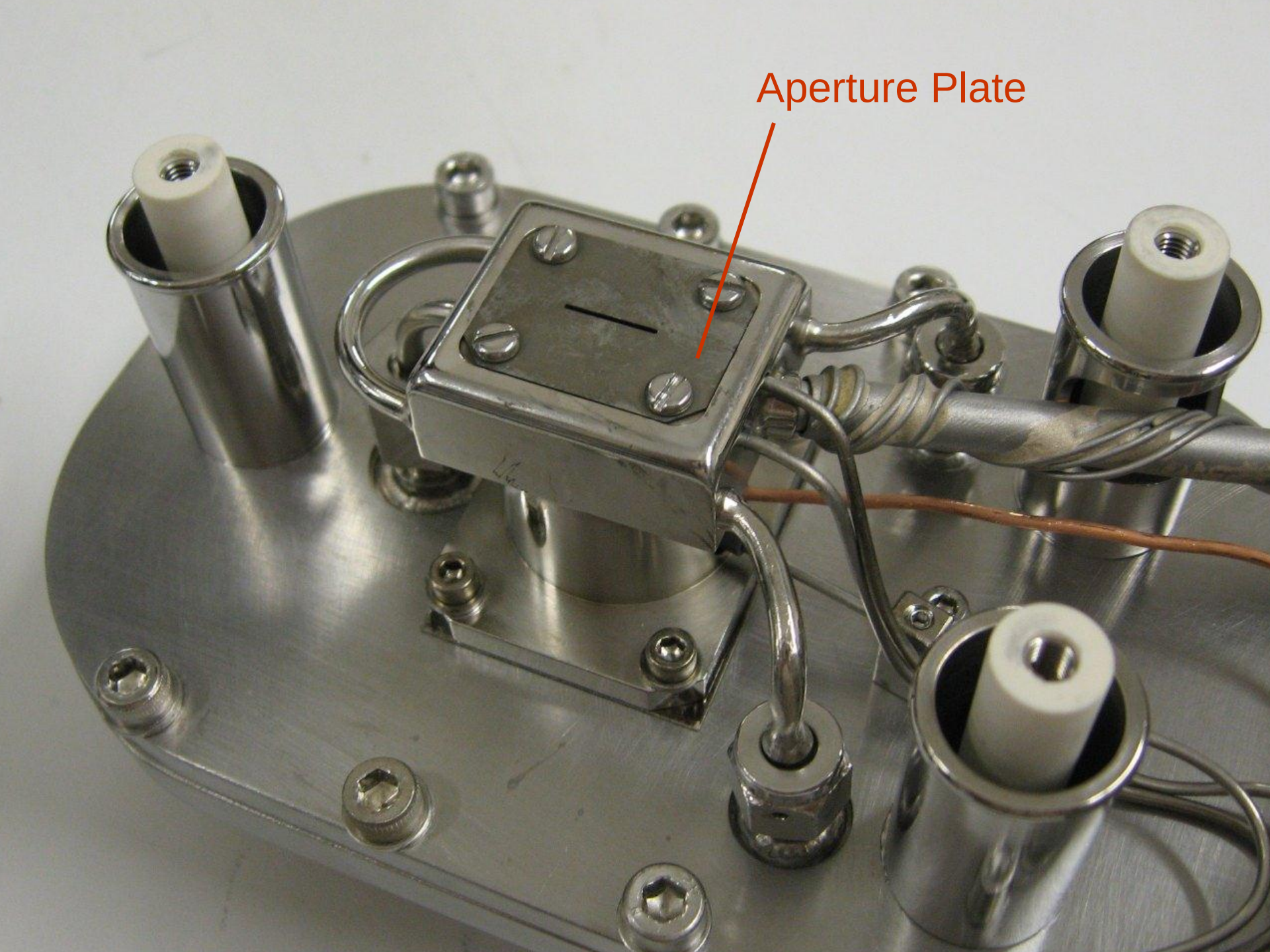

Negative Ion Beam
+17 kV Extraction Voltage
Caesium Vapour Heated Transport Line
50 A Discharge
Caesium Oven
Source Runs at 50 Hz Rep Rate
Hollow Anode
10 mm
Piezo Hydrogen Valve
H_2

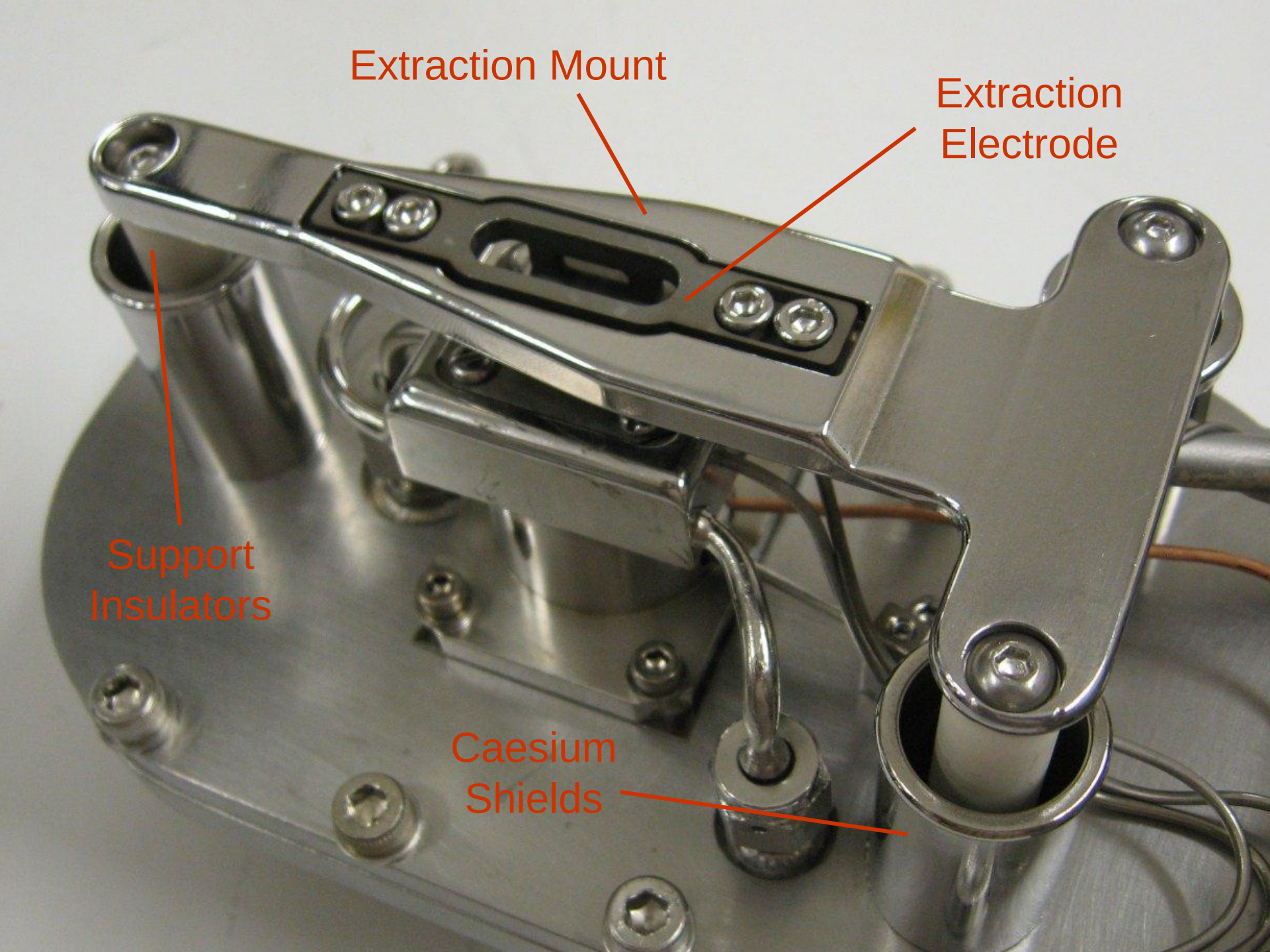
Timing



Source Runs
at 50 Hz
Rep Rate


Cathode
Hollow Anode
Heated Caesium
Transport Line
Hydrogen Feed
Air Cooling
Source Body
Discharge
Power Feed
Thermocouples


Aperture Plate


Extraction Mount
Extraction Electrode
Support Insulators
Caesium Shields

3 Sources at ISIS

Operational Source

24 x 7 operation
20 day average lifetime
200-300 μs pulse length
50 Hz
35 keV
35 mA @ RFQ

Ion Source Development Rig

Pre-test operational sources

Problem solving

FETS Source

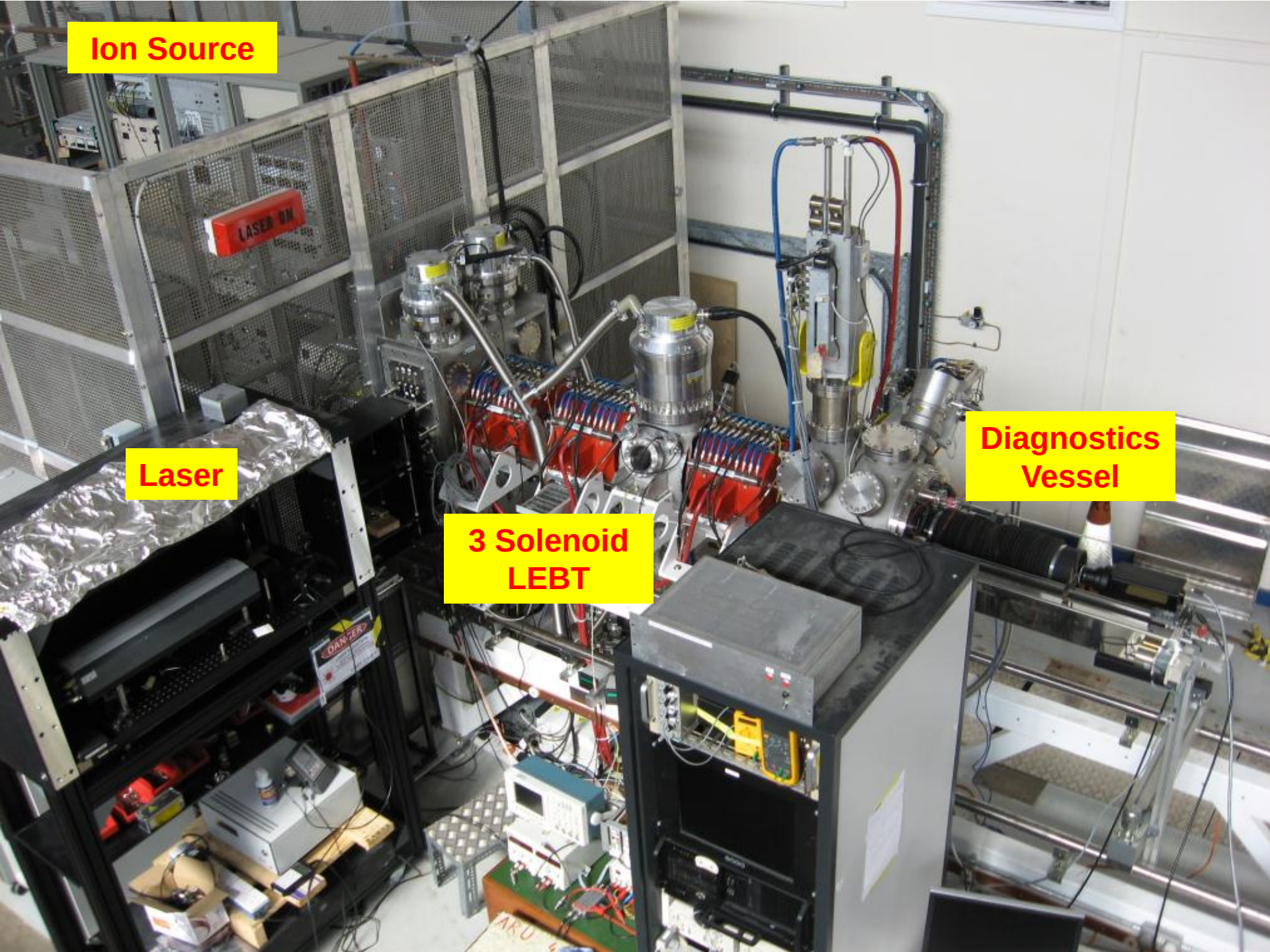
Experimental sources

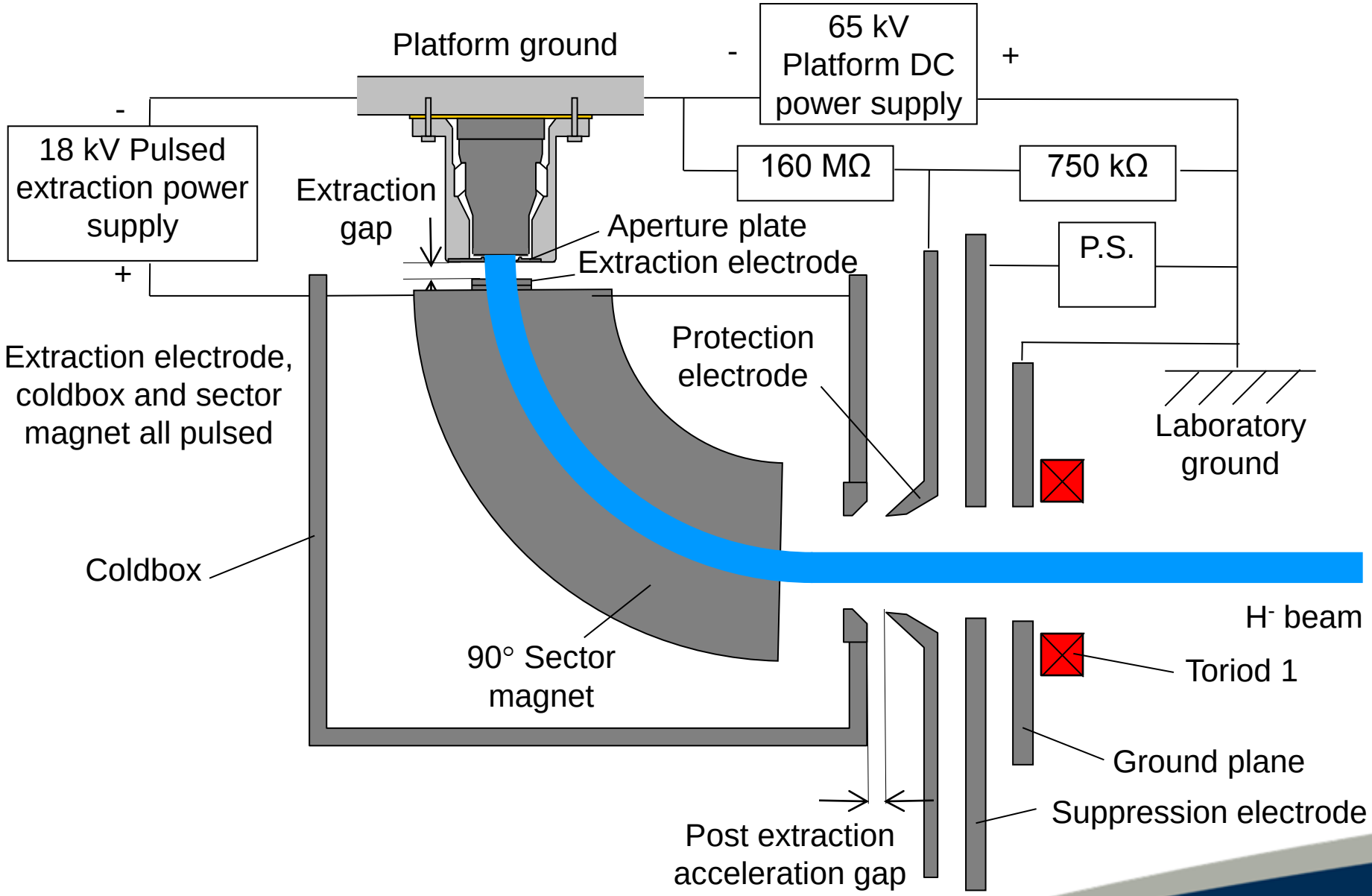
High current

Long pulse

65 keV

FETS
65 kV high voltage platform


Ion Source
LASER ON
Laser
3 Solenoid
LEBT
Diagnostics
Vessel



FETS Source Schematic

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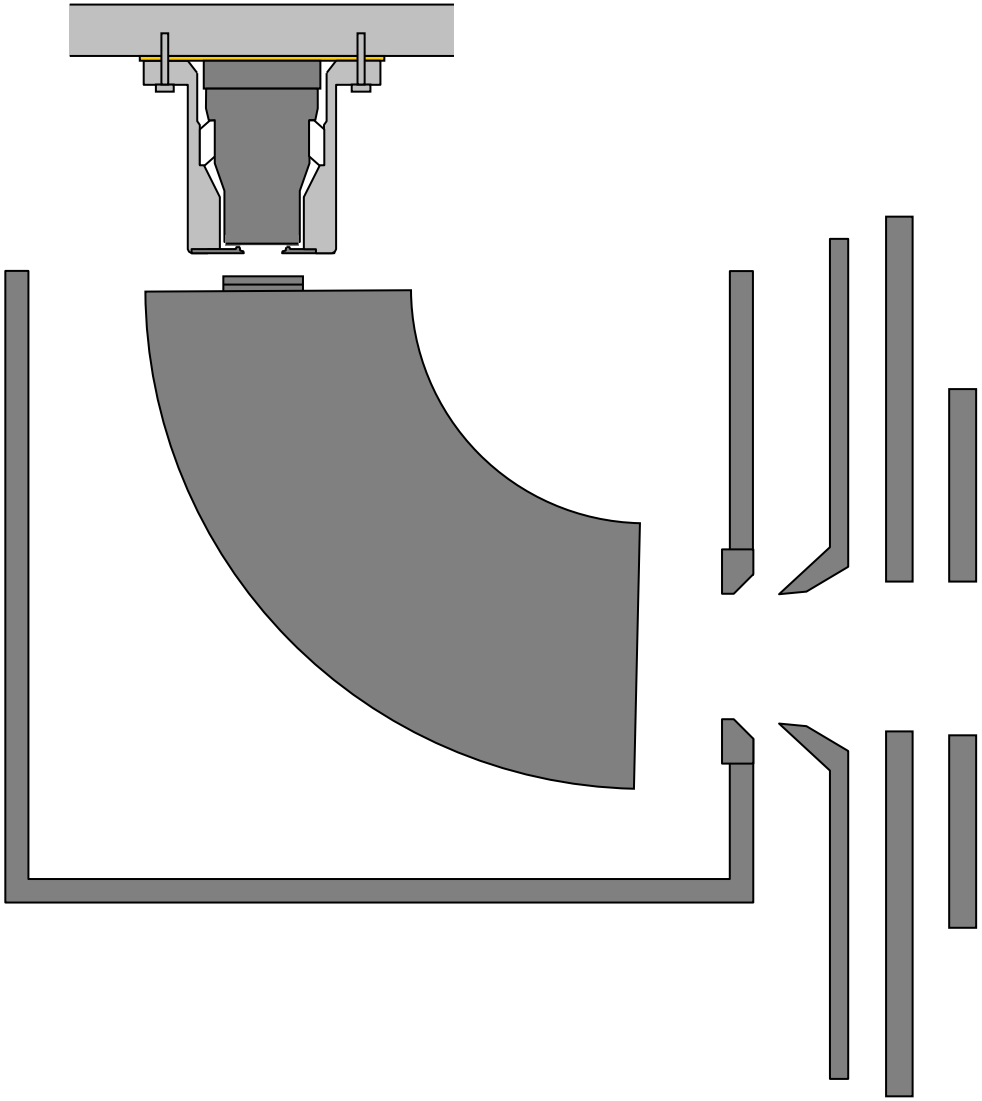

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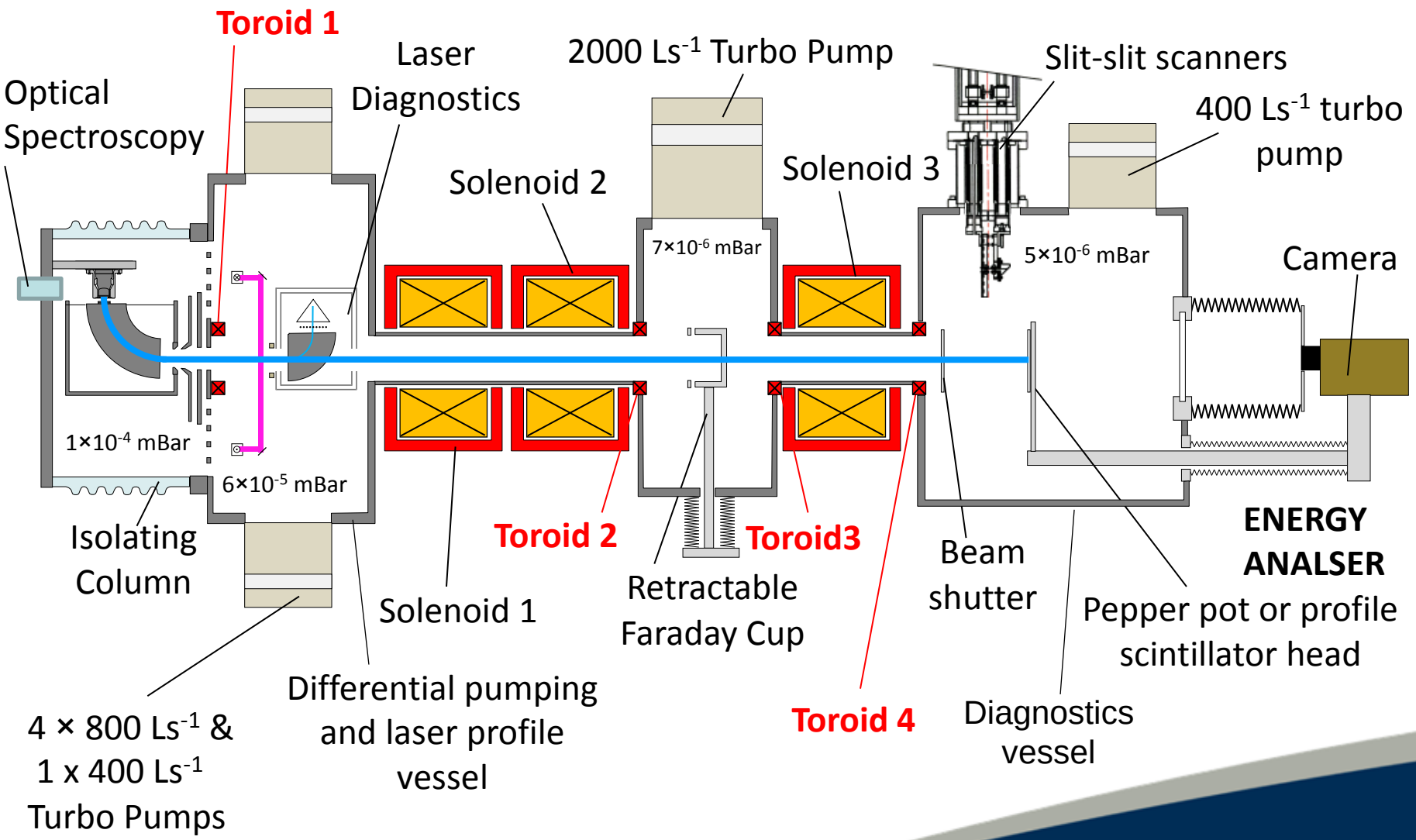
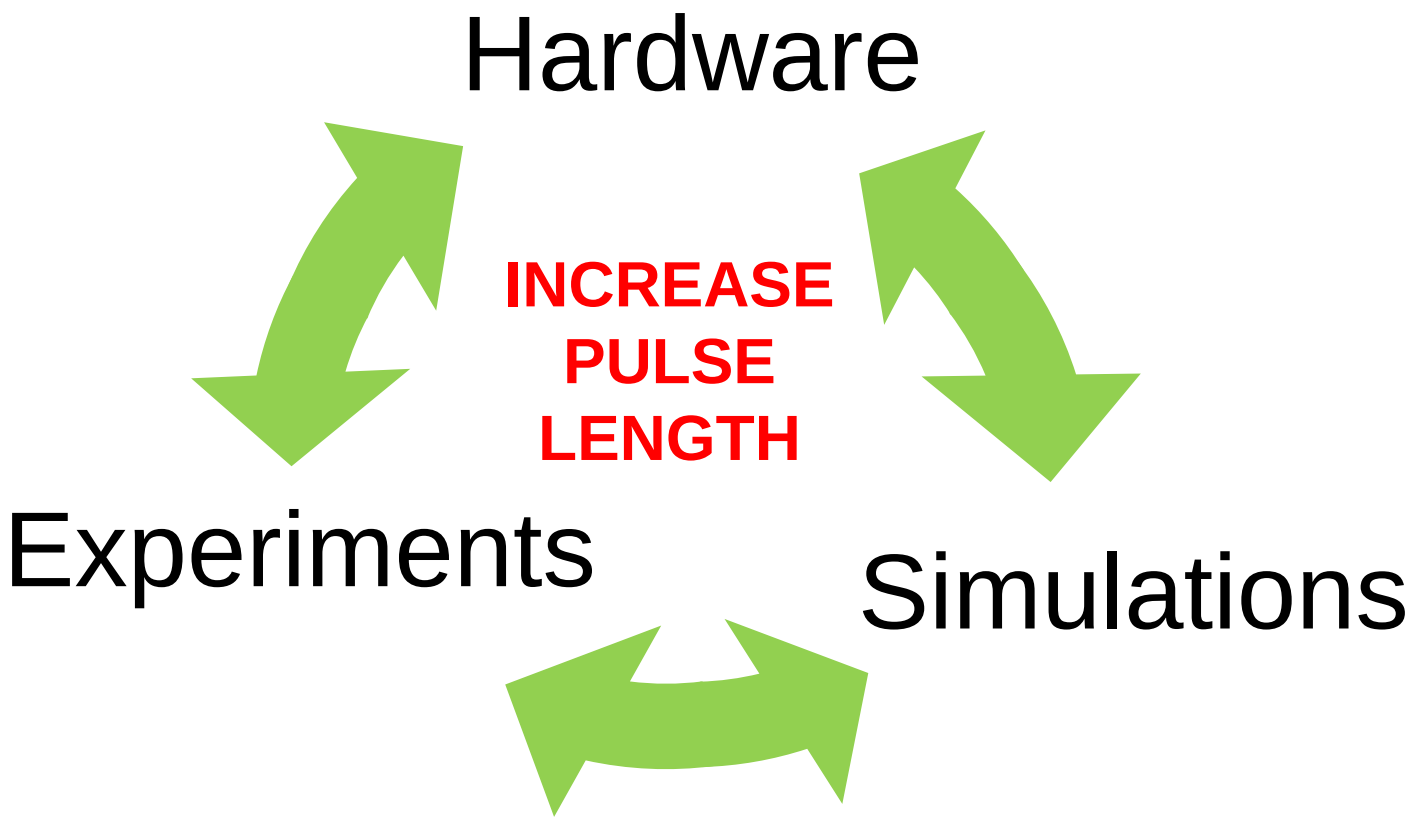
Diagnostics and a LEBT are critical to Ion Source Development

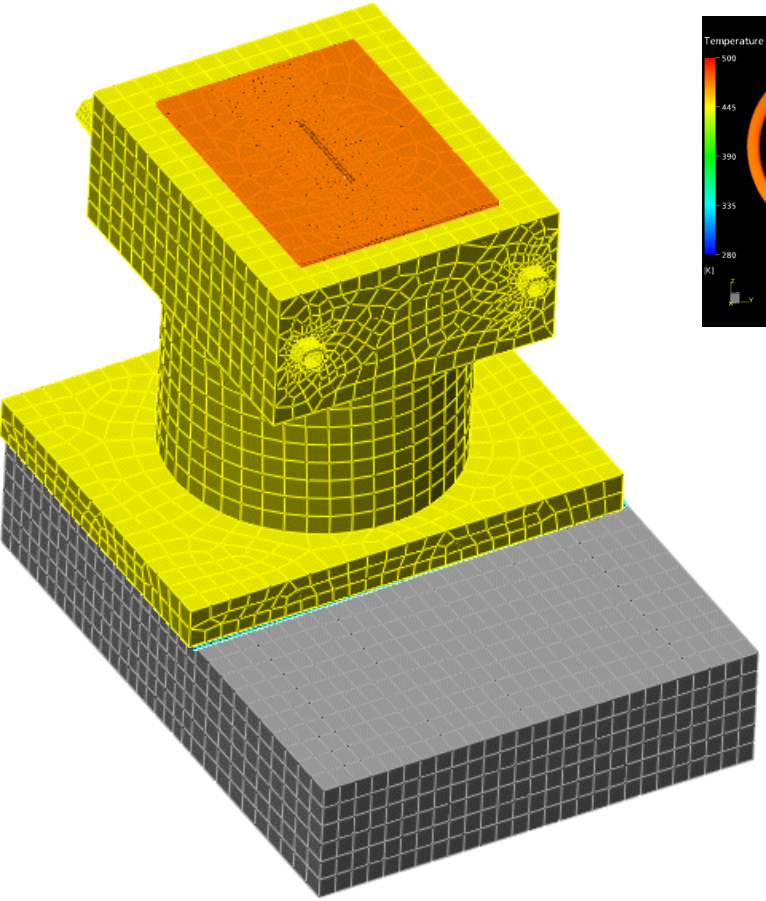


The Development Cycle

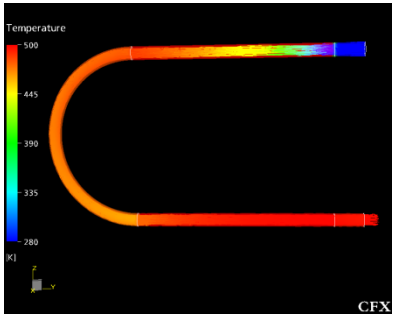


Thermal Modelling

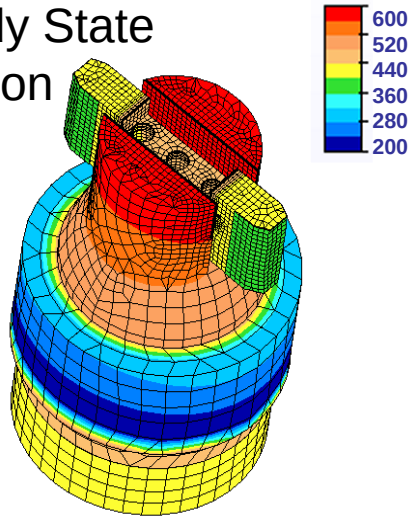
3D Finite Element Model of the Ion Source using ALGOR.



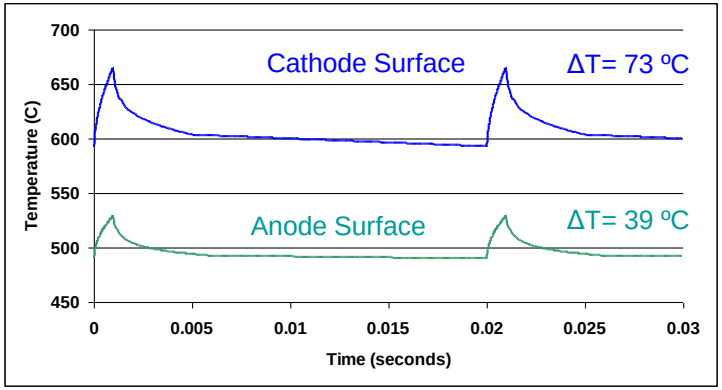
Computational Fluid Dynamic Cooling Calculation

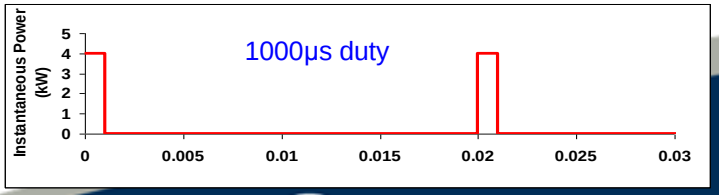


Steady State Solution



Transient Solution





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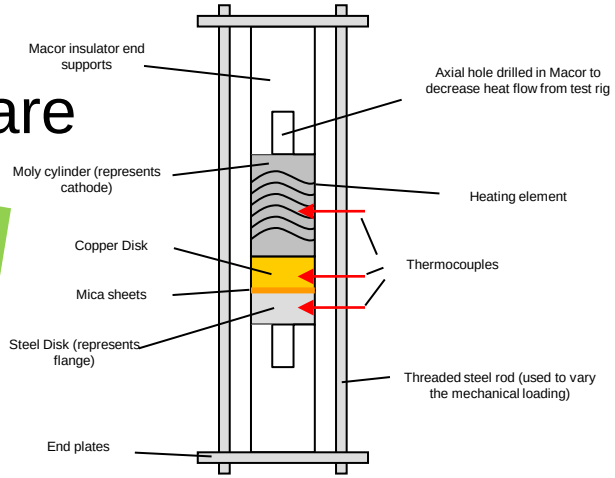
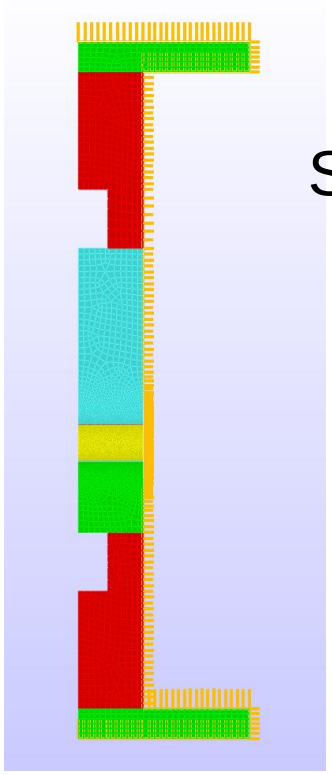
Thermal Test Rig– To Find Model Parameters

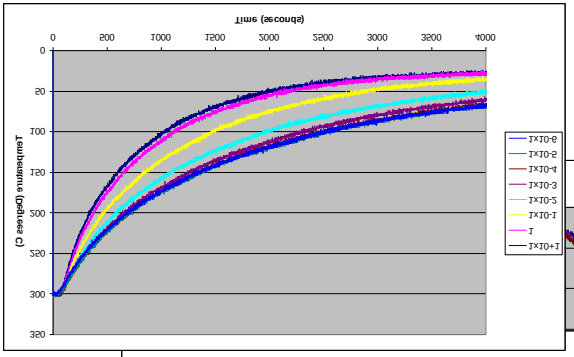
Hardware

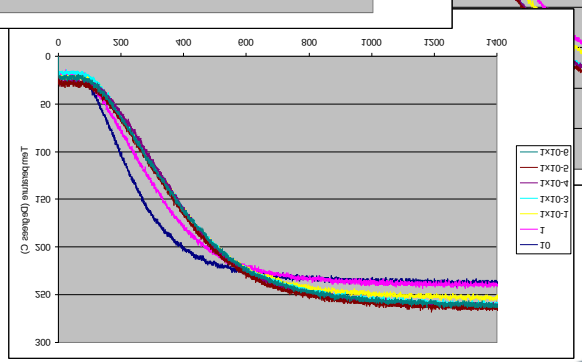


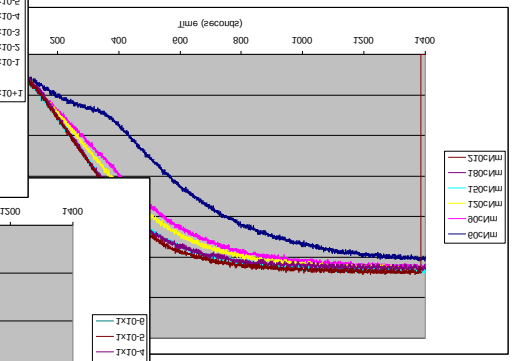
Simulations



Experiments







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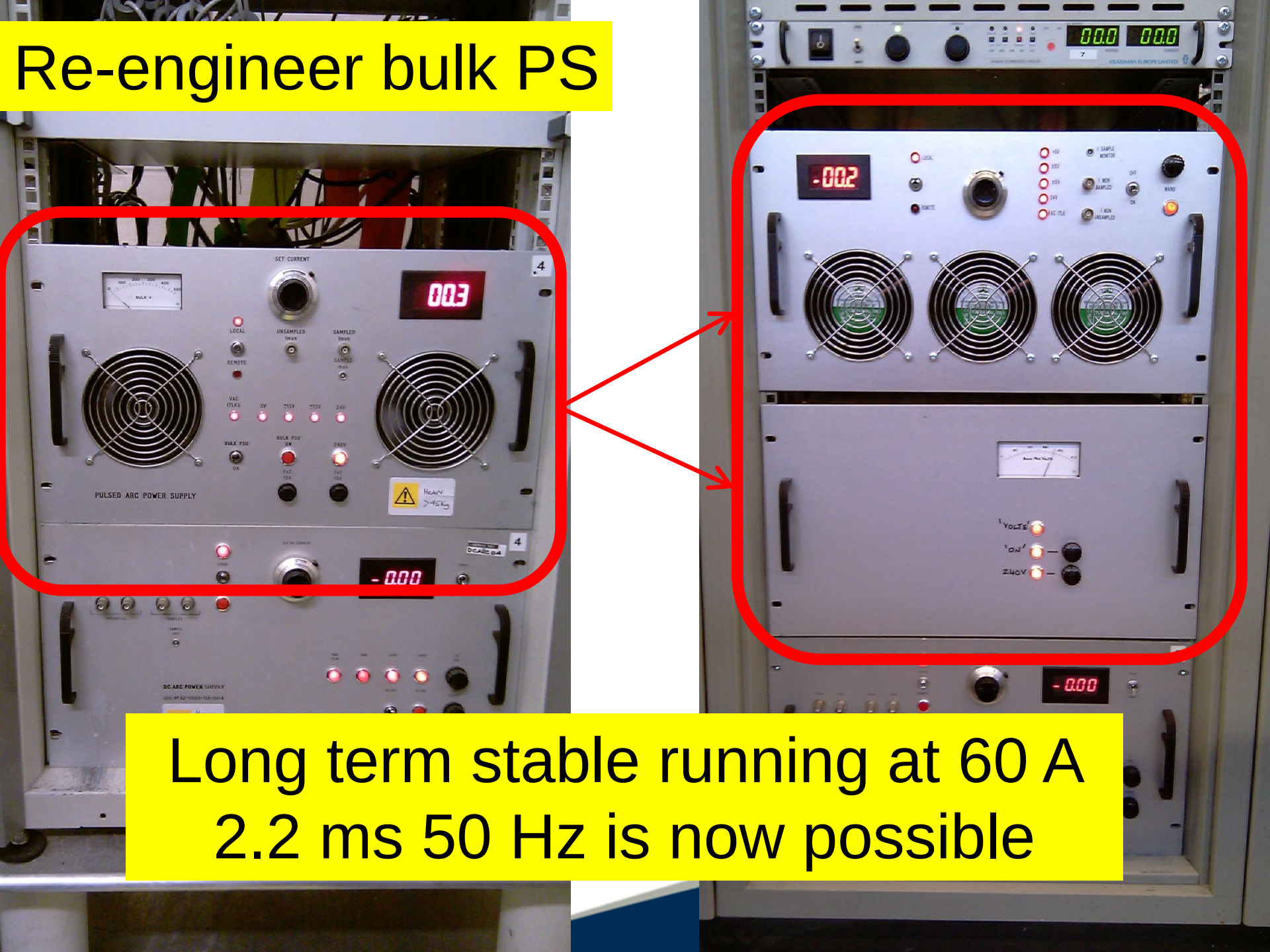
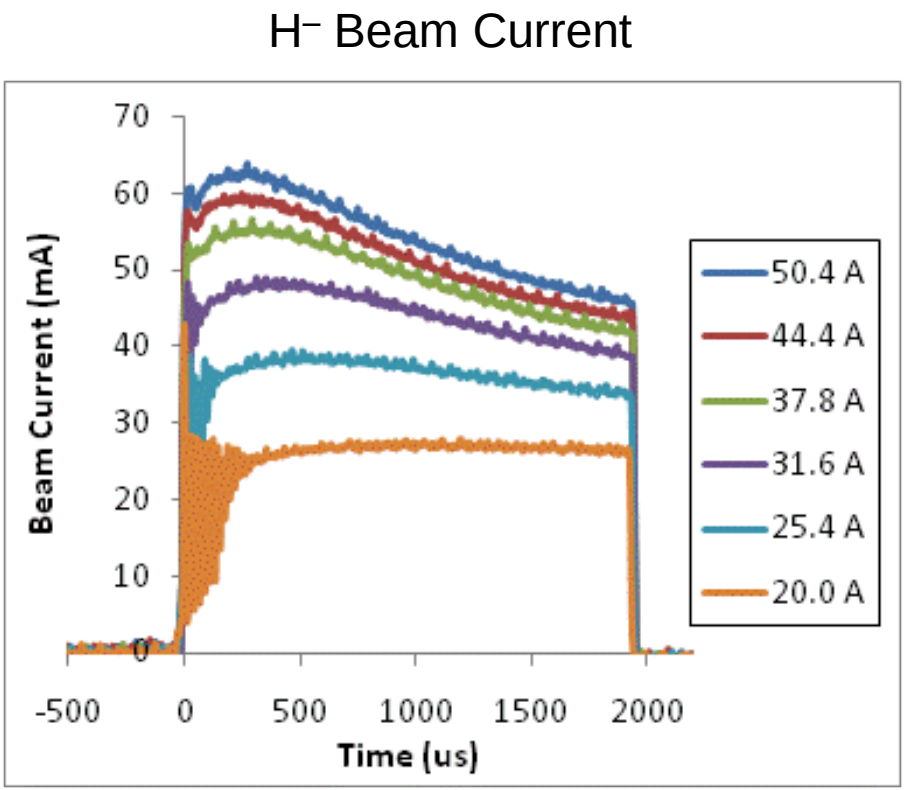
Re-engineer bulk PS



Long term stable running at 60 A
2.2 ms 50 Hz is now possible

Droop is unavoidable at 50 Hz 2 ms



- Hydrogen timing has been fully investigated including double pulses
- Neither caesium or hydrogen settings can mitigate this droop

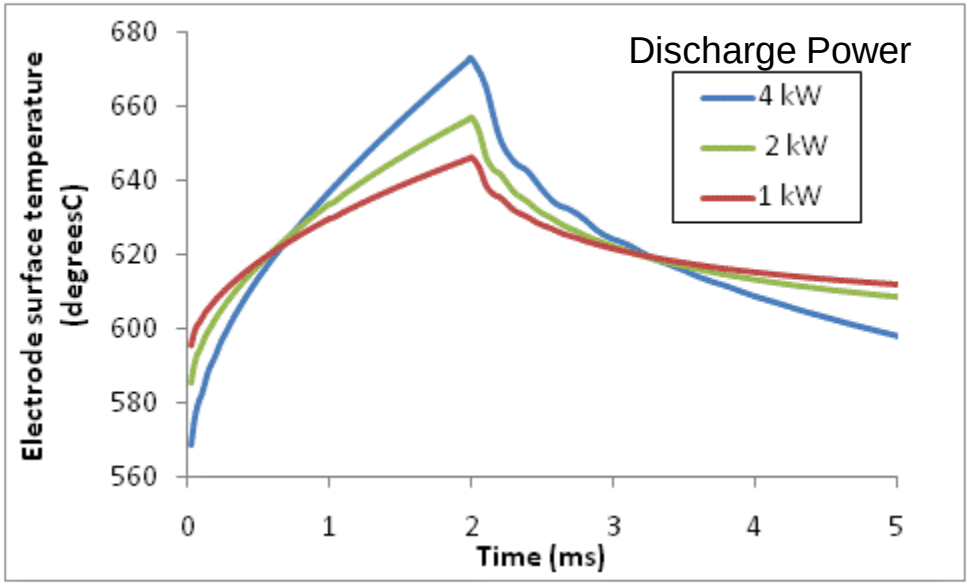
Possible Explanation of Droop:

1. Increased Plasma Density

- Increased H^+ and Cs^+ bombardment sputters Cs from cathode surface.

- More H^- are stripped on their way to the extraction region.

2. Electrode Surface Temperature Rise



Transient 3D FEA calculations of electrode surface temperature

Higher discharge currents

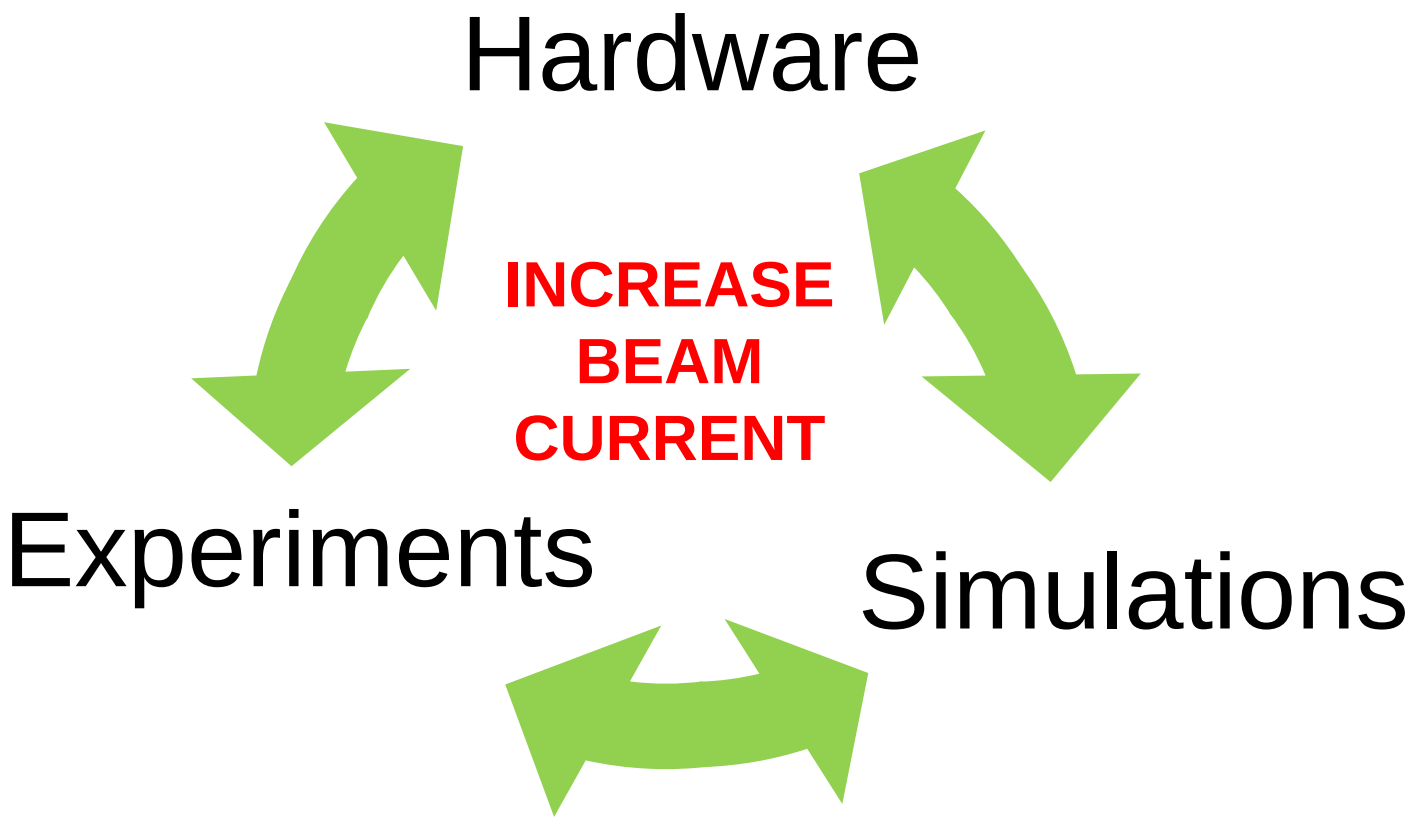
↓

Greater surface temperature rise during the pulse

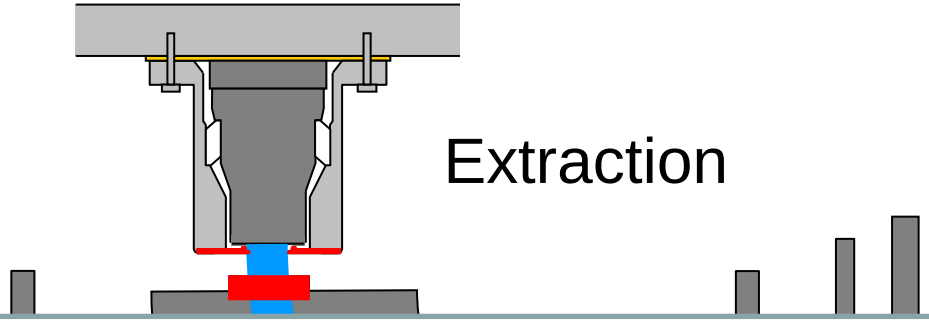
↓

Surface Cs coverage pushed away from optimum

The Development Cycle

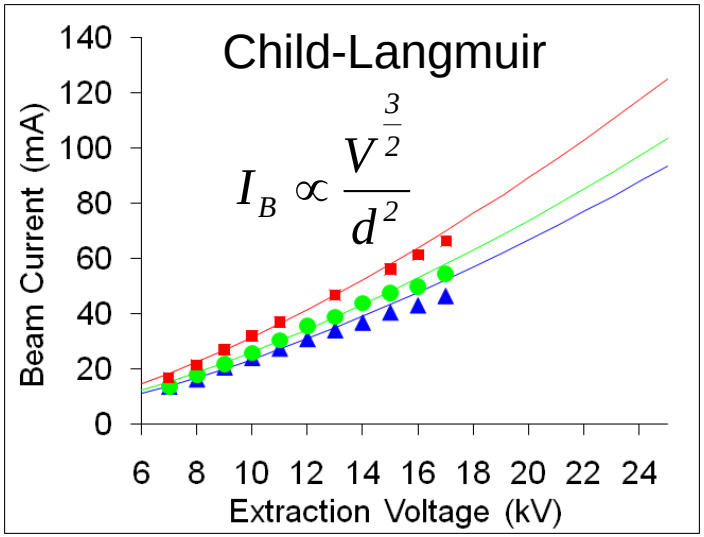


Extraction and Transport

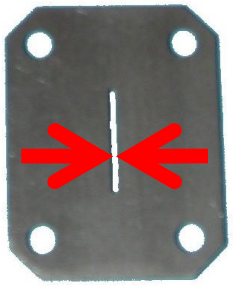


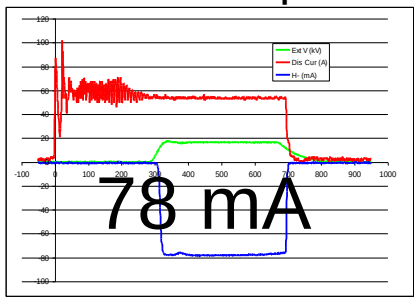
Voltage, Geometry and Meniscus

Increase voltage from 17 to 25 kV

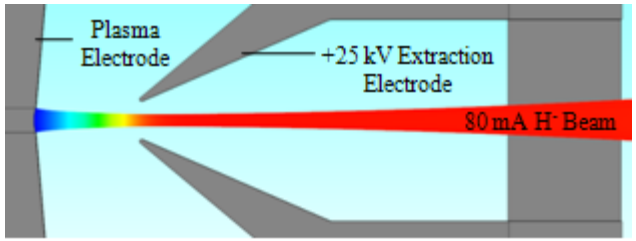


Widen plasma electrode aperture





Meniscus Studies

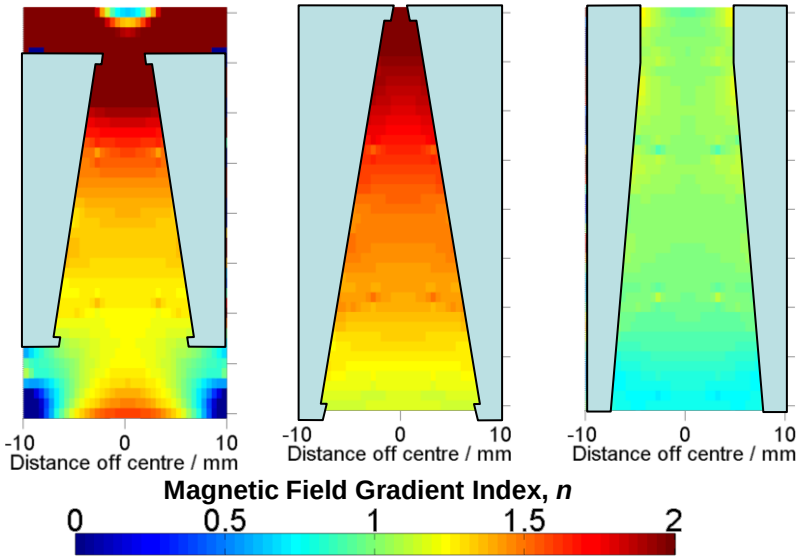


Work in progress…

Magnet Redesign

Dipole has a focusing component

Field gradient index $n = -\frac{R_e}{B_e}\left(\frac{dB}{dR}\right)$



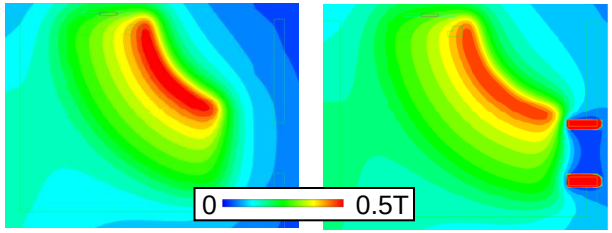
Beam expands under space charge

Exact degree of compensation unknown

Optimum field gradient index n = 1.2 determined by experiment

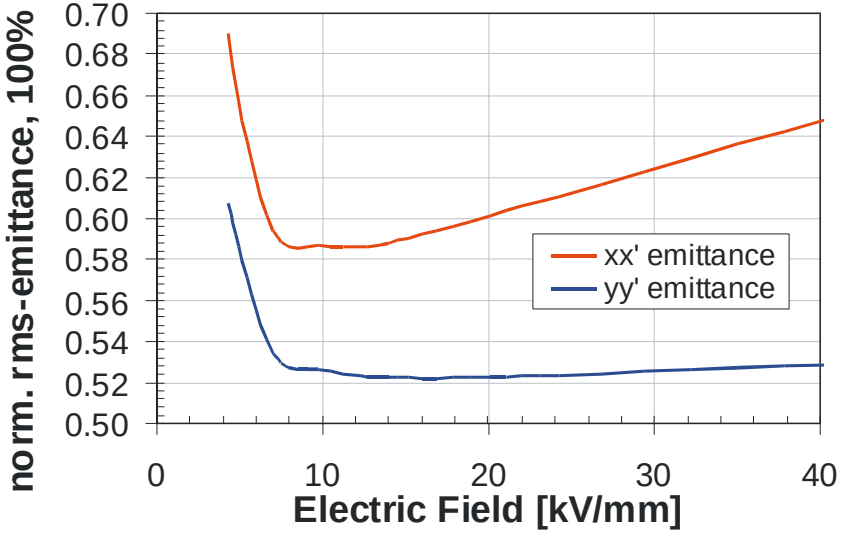
Size of good field region increased

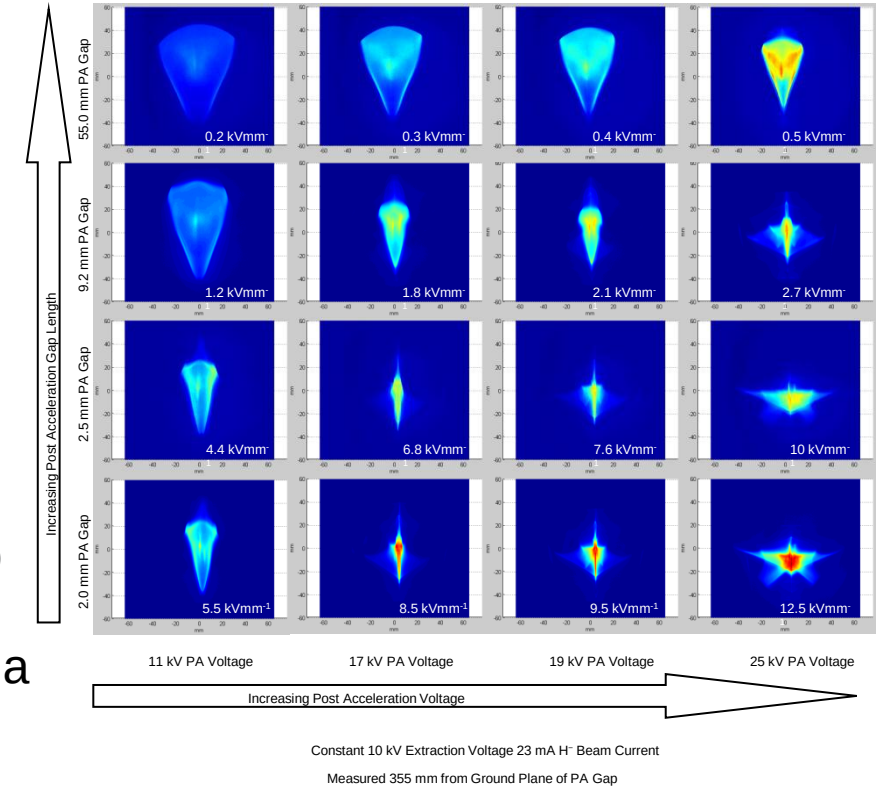
Field must be adequately terminated



Significant improvement in emittance

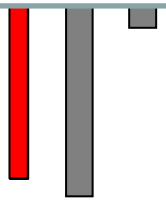
Optimize Gap





Minimum emittance growth occurs for a post acceleration field of 9 $kVmm^{-1}$

Post Acceleration



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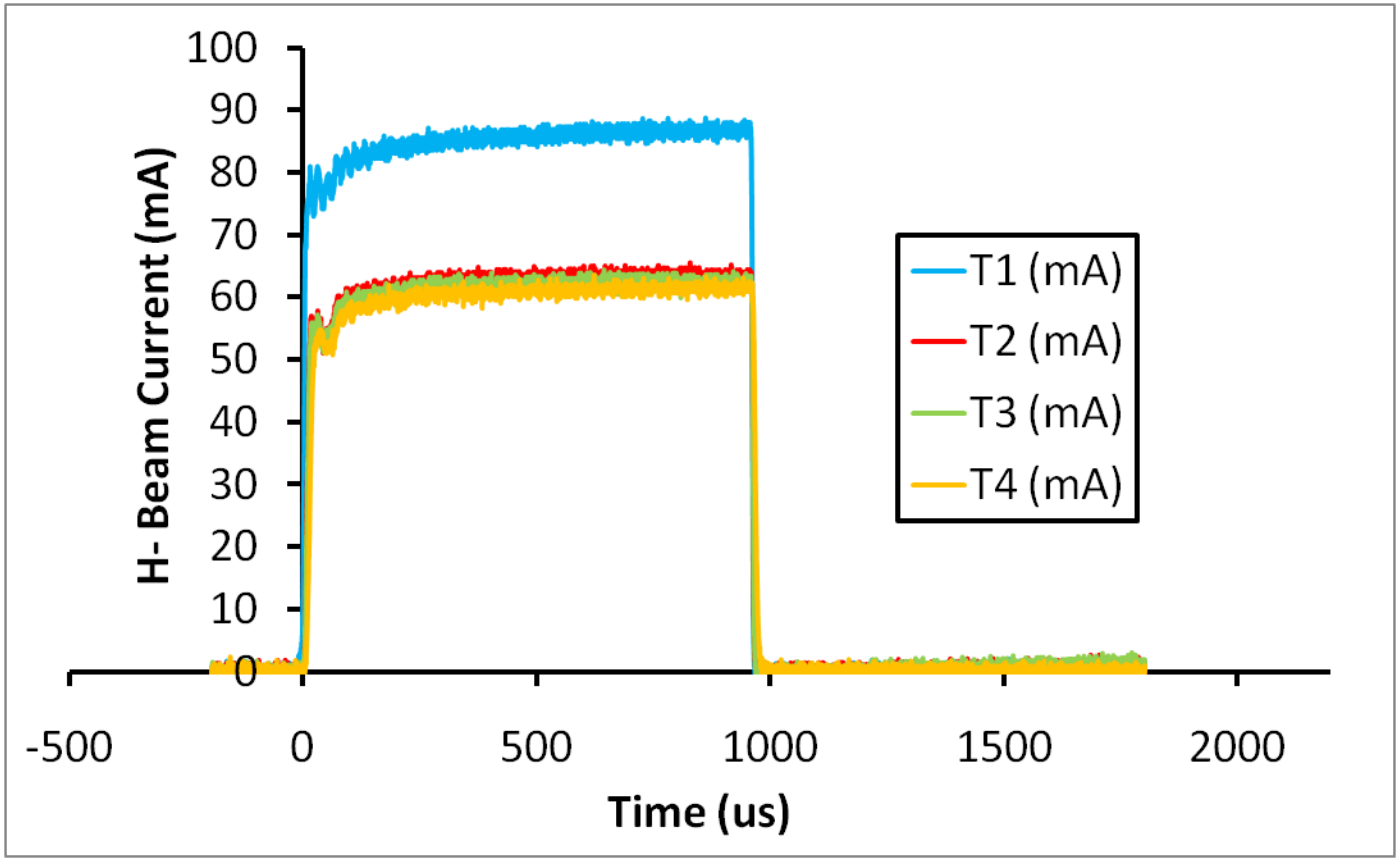
62 mA 1ms 50 Hz Operation



1.2 ms 60 A discharge, 19.6 kV extraction voltage, 65 keV beam, 180°C caesium oven, 16 mLmin^{-1} H_2

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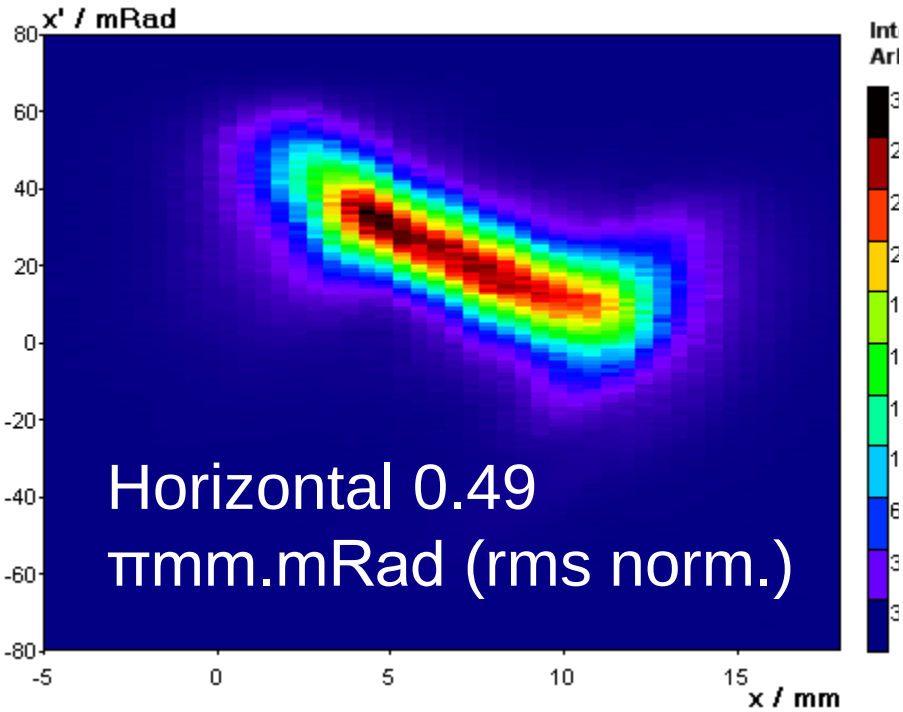
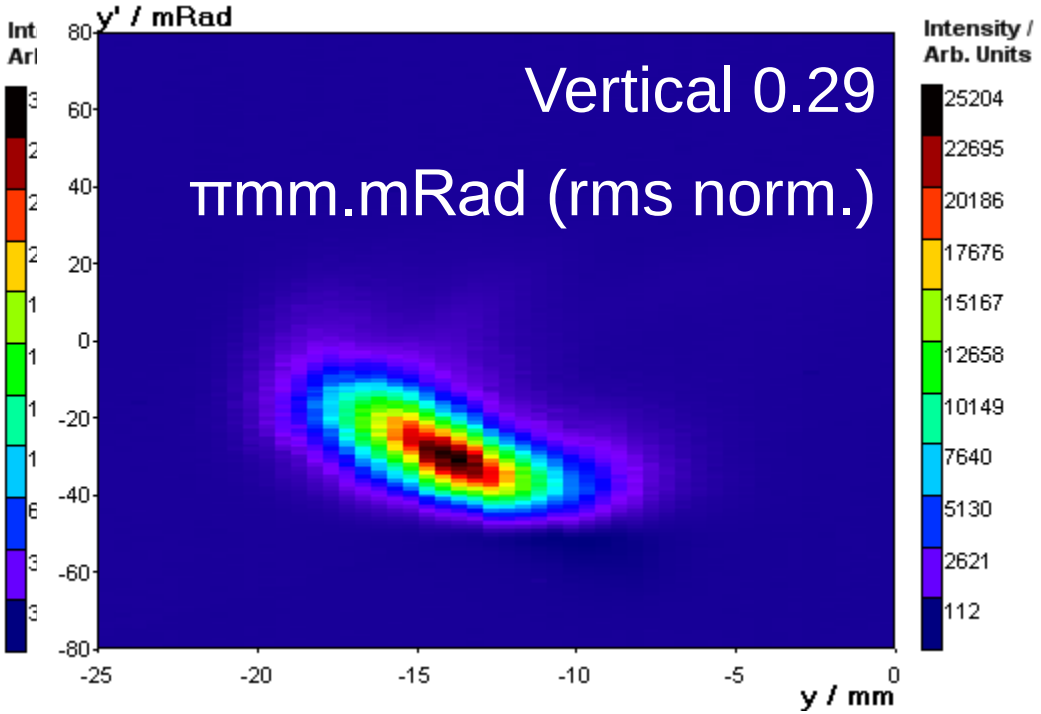
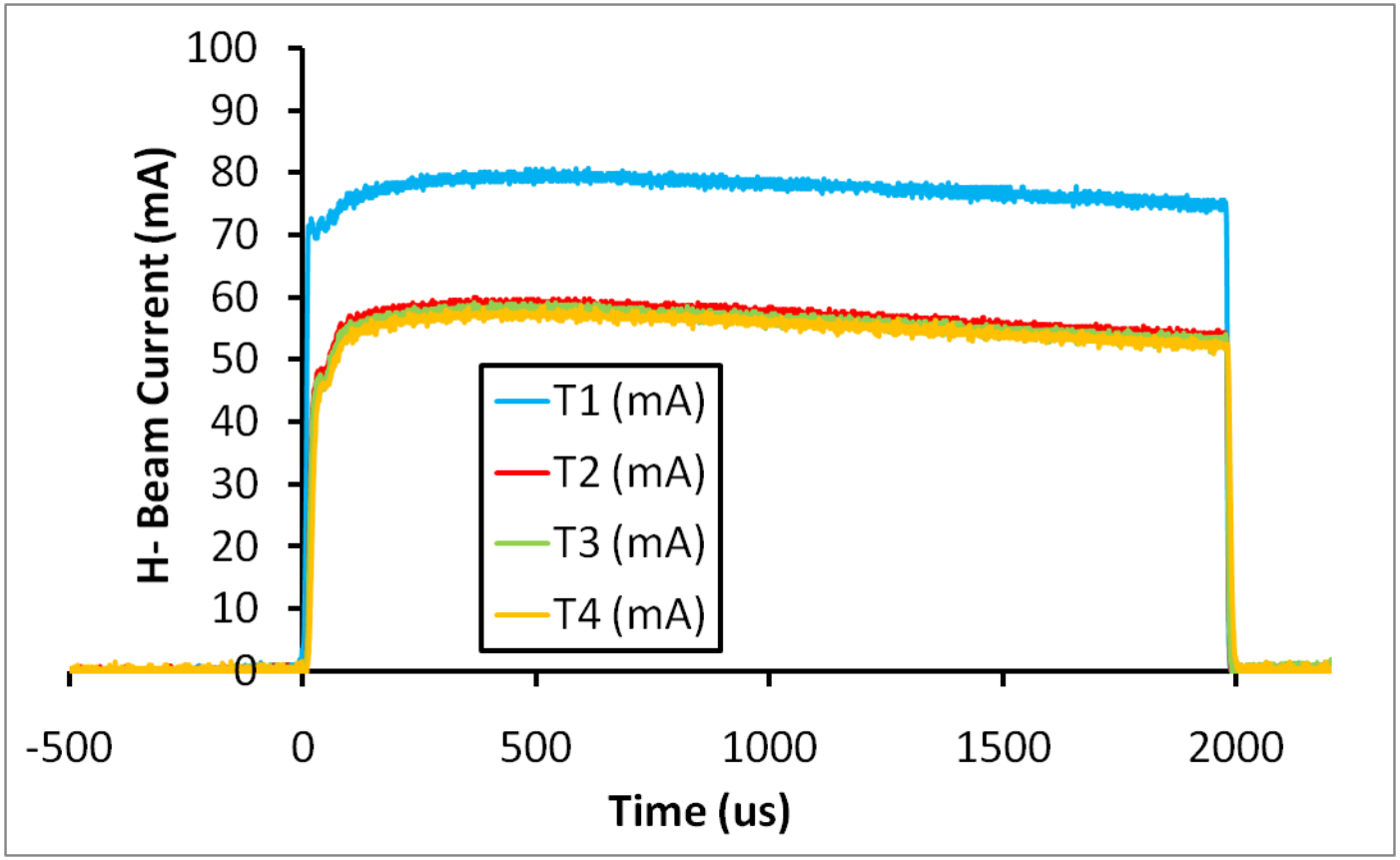
Emittances


x' / mRad
80
60
40
20
0
-20
-40
-60
-80
-5
0
5
10
15
x / mm
Horizontal 0.49
πmm.mRad (rms norm.)


y' / mRad
80
60
40
20
0
-20
-40
-60
-80
-25
-20
-15
-10
-5
0
y / mm
Vertical 0.29
πmm.mRad (rms norm.)
Intensity / Arb. Units
25204
22695
20186
17676
15167
12658
10149
7640
5130
2621
112

60 mA 2ms 25 Hz Operation



2.2 ms, 64 A discharge, 19.6 kV extraction voltage, 65 keV beam, 190°C caesium oven, 16 mLmin^{-1} H_2

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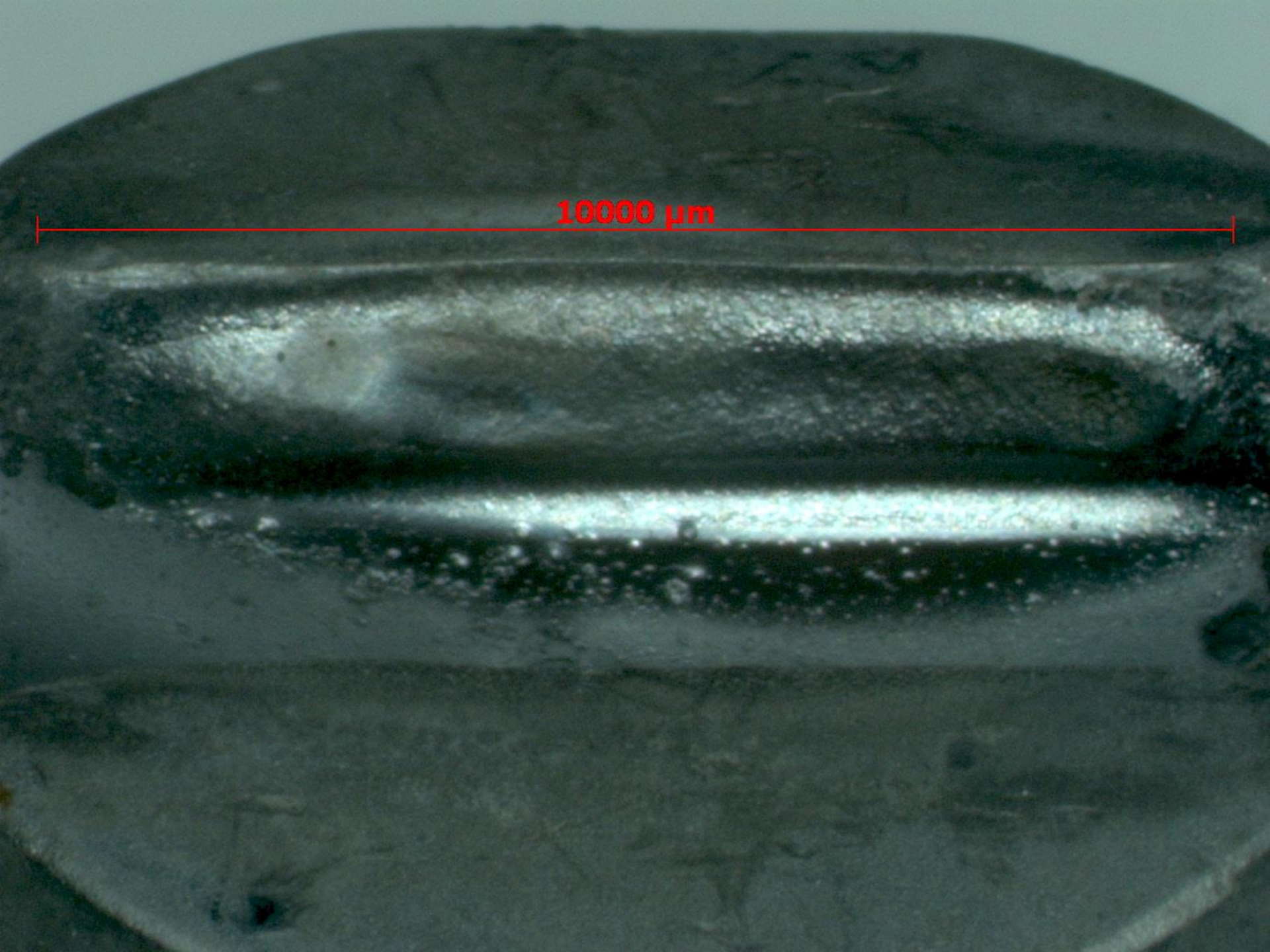
Reliability

Failure Modes

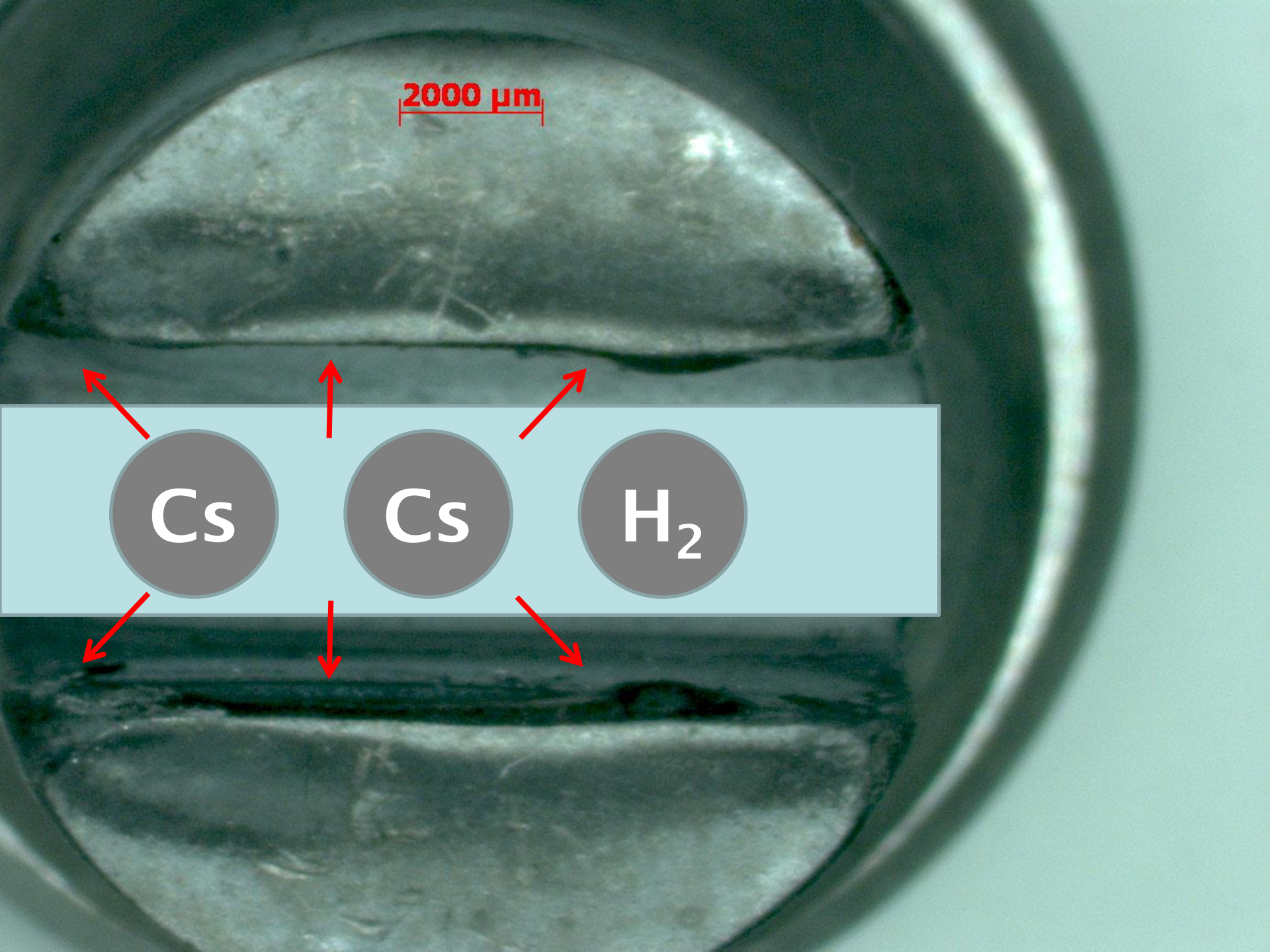
- Blocked Aperture Plate
- Shorted Electrodes
- Blocked Caesium Tube
- Failed Heaters
- Failed Piezo Hydrogen Valve
- Ancillary Equipment Failure

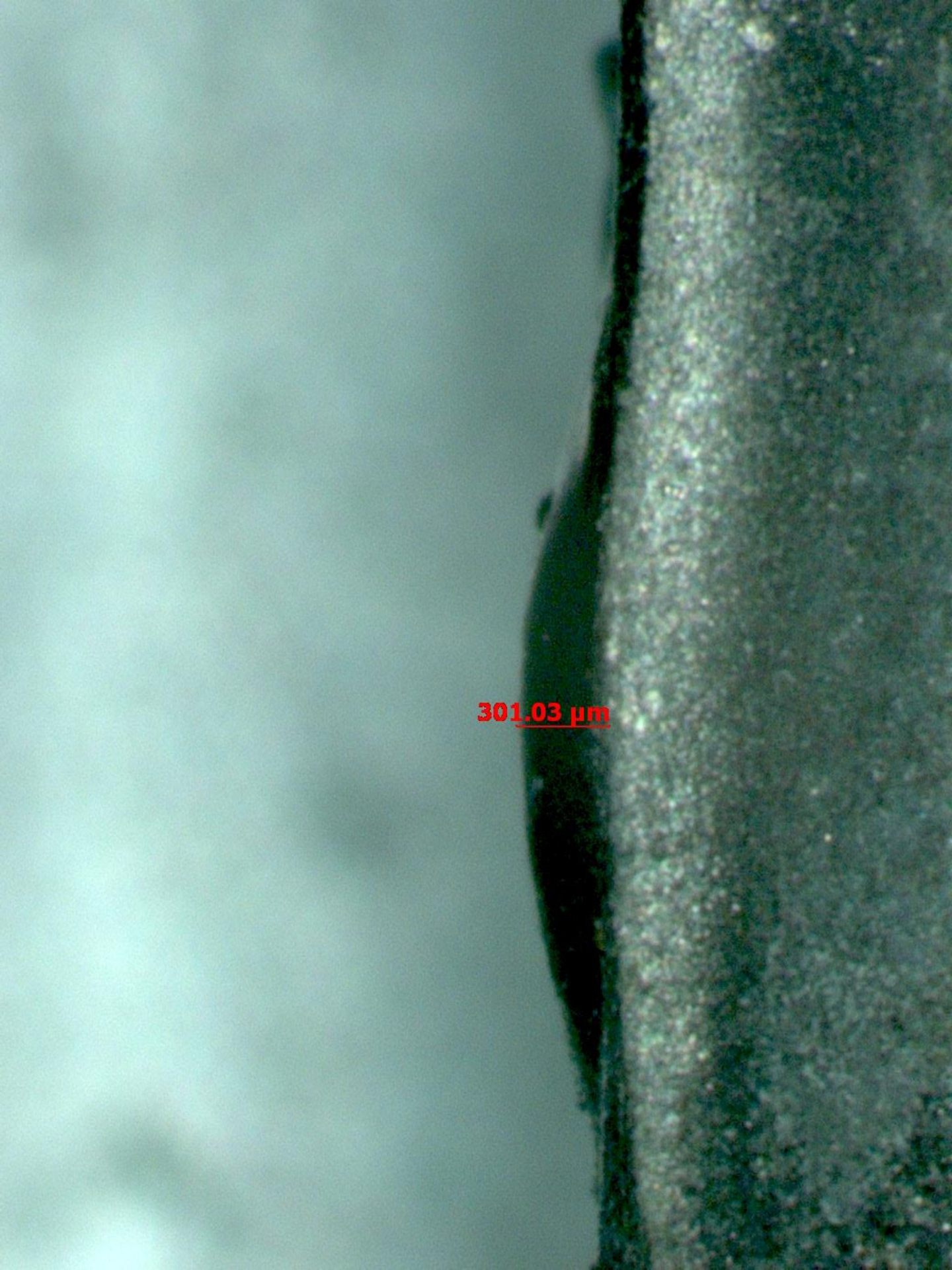
26 Day Electrode Wear


2000 µm


10000 µm

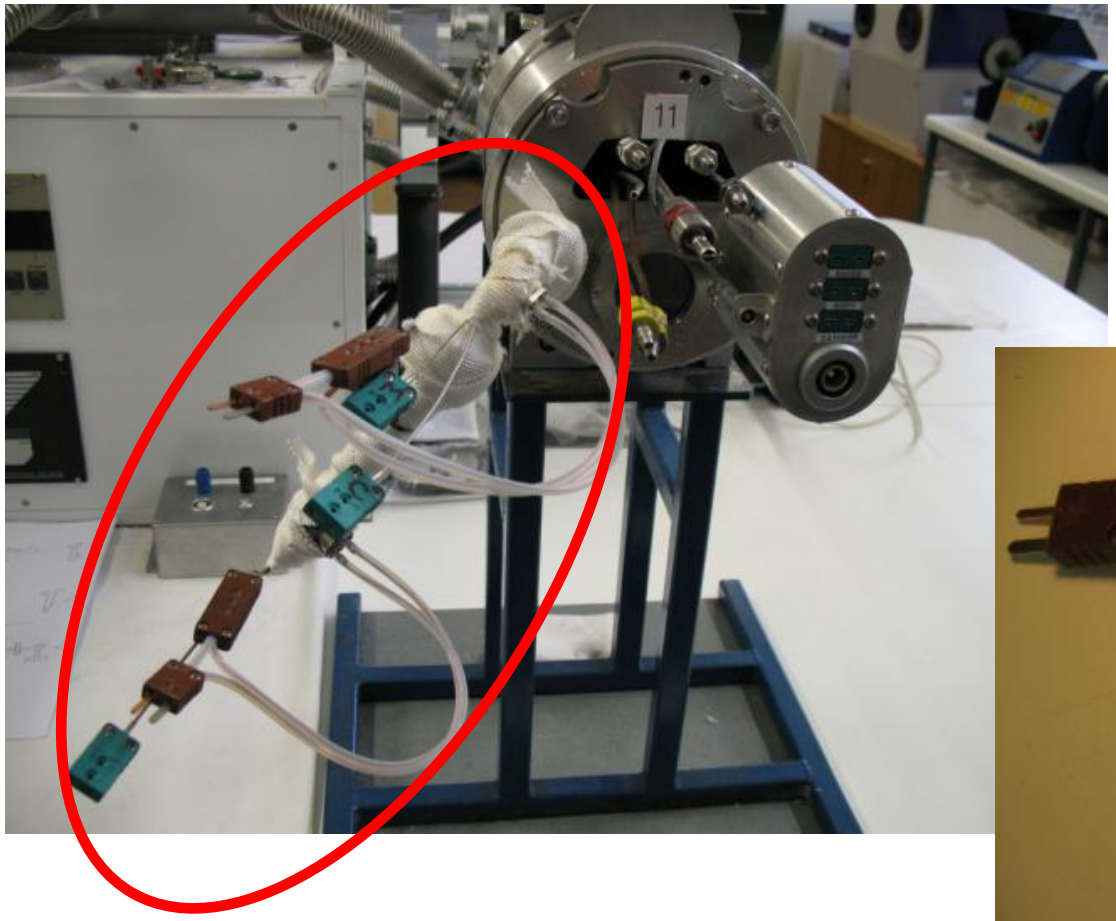

2000 µm


2000 µm
Cs
Cs
H_2


301.03 µm

Is NF_3 the answer?

Caesium delivery



Caesium oven 140-190°C
Transport line 300°C

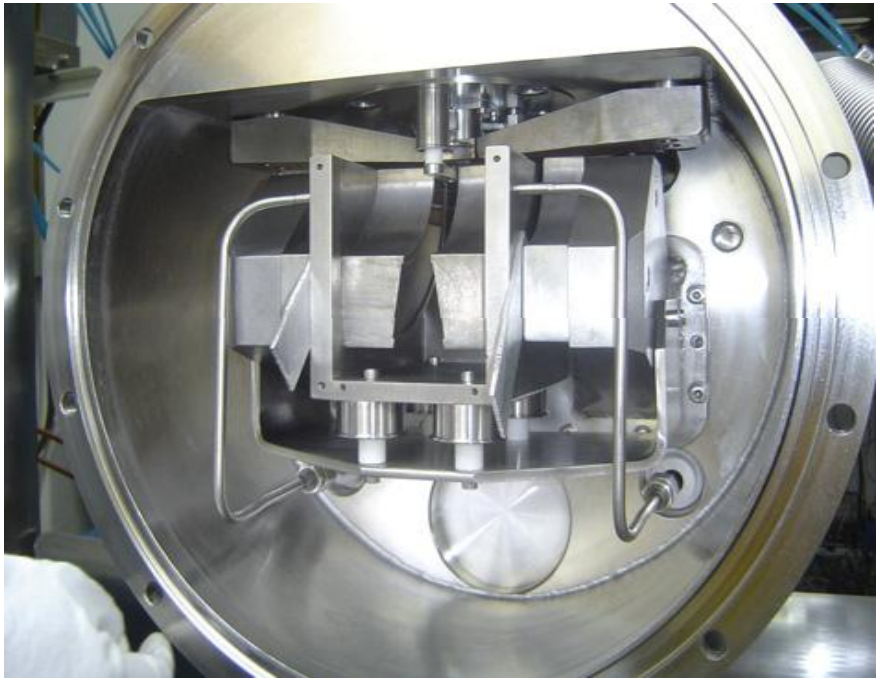
Thermal cut out switches now prevent caesium accidents


Caesium
Boiler

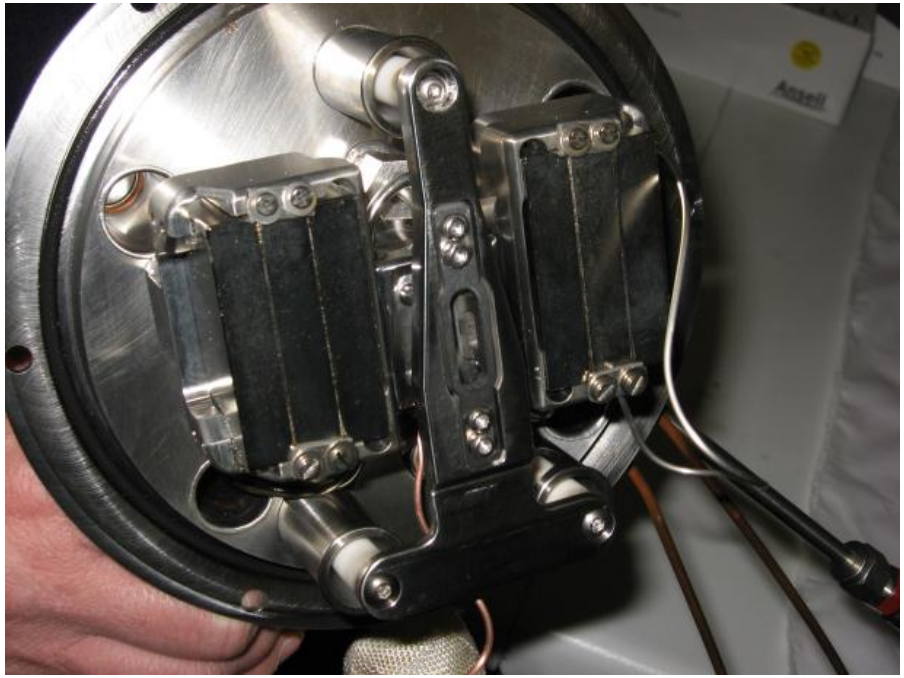
The Future

- Up-rated extraction supply
- Extraction modelling
- Better understanding of the plasma
  - PhD research project
  - Optical spectroscopy
  - Plasma modelling
- Scaled source
- Understand lifetime limitations

ISIS Source around the World



Chinese Spallation Neutron Source



ESS Bilbao

Thank you for your attention

Questions, Comments?