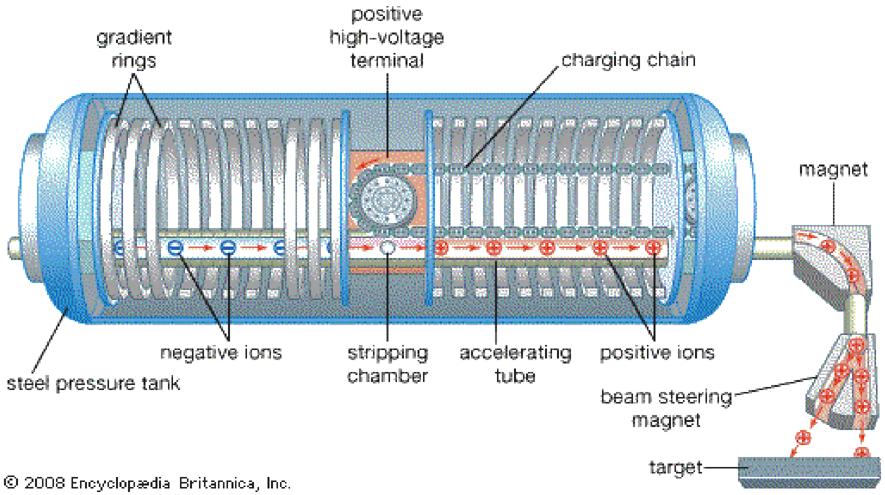
Negative Ion Source Technology for Accelerators

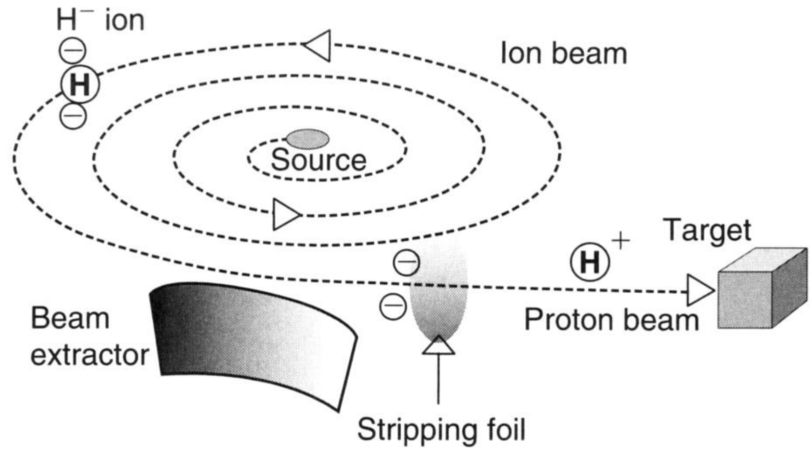
Dr Dan Faircloth
Low Energy Beams Group Leader - ISIS
Rutherford Appleton Laboratory
Science and Technology Facilities Council

Applications

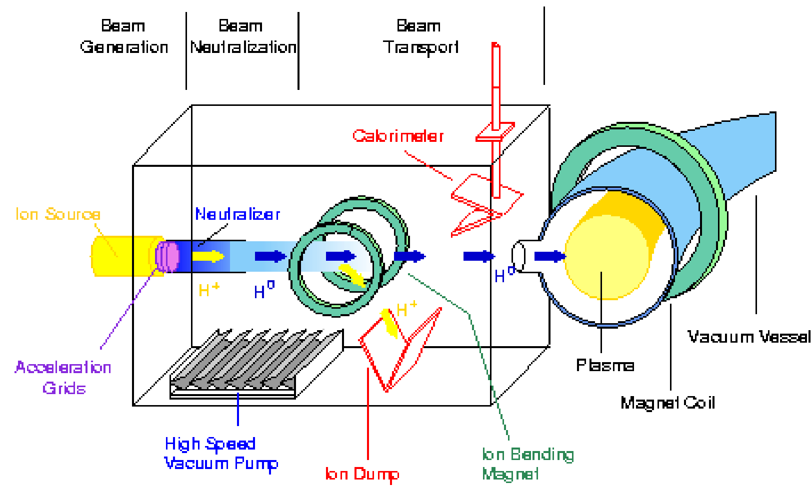
Tandem accelerators



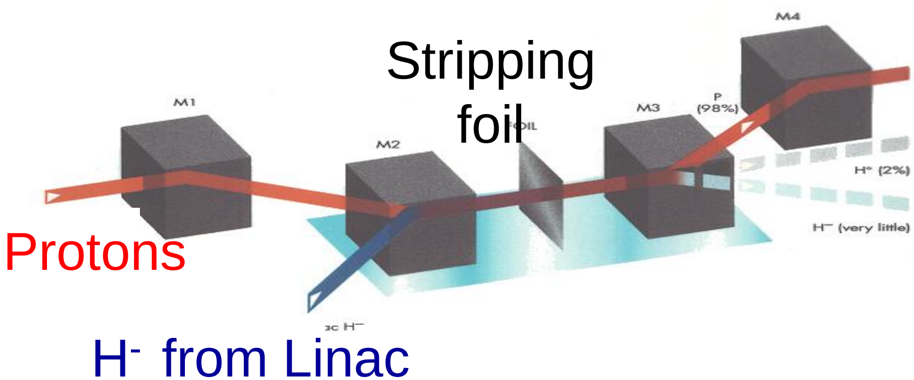
Cyclotron extraction



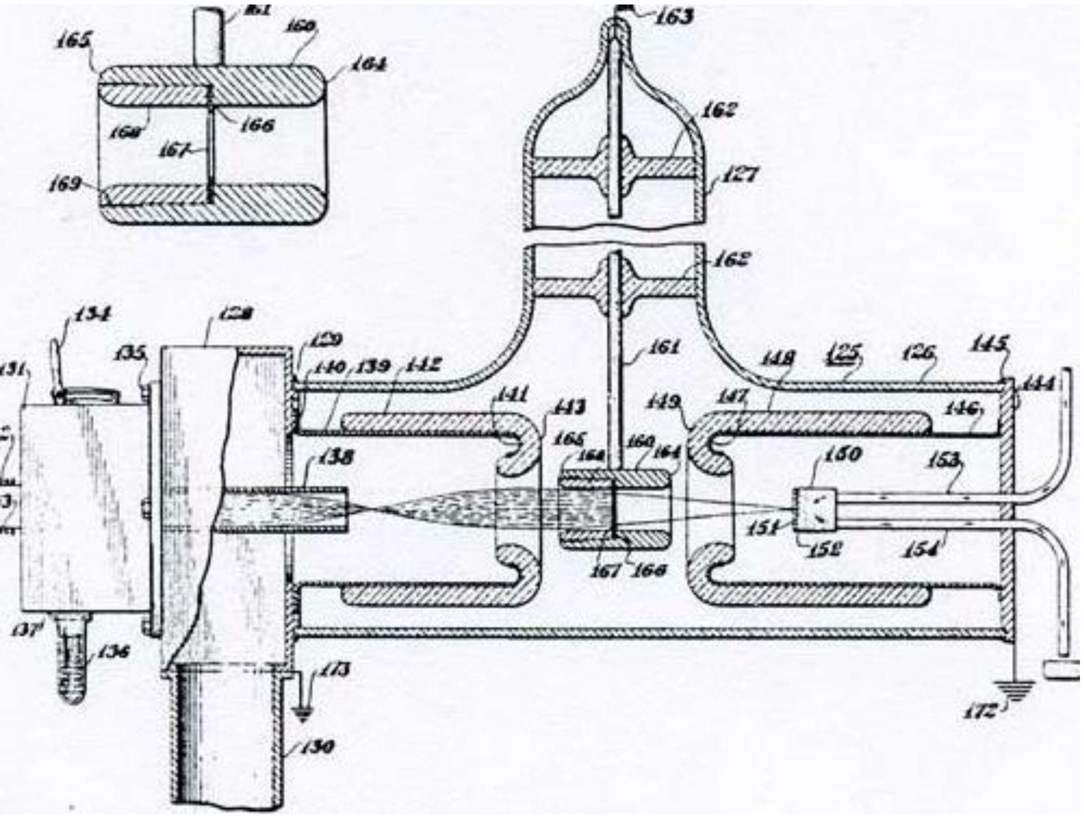
Neutral Beams



Multi-turn injection into rings



Other negative ions are used for material modification and characterization



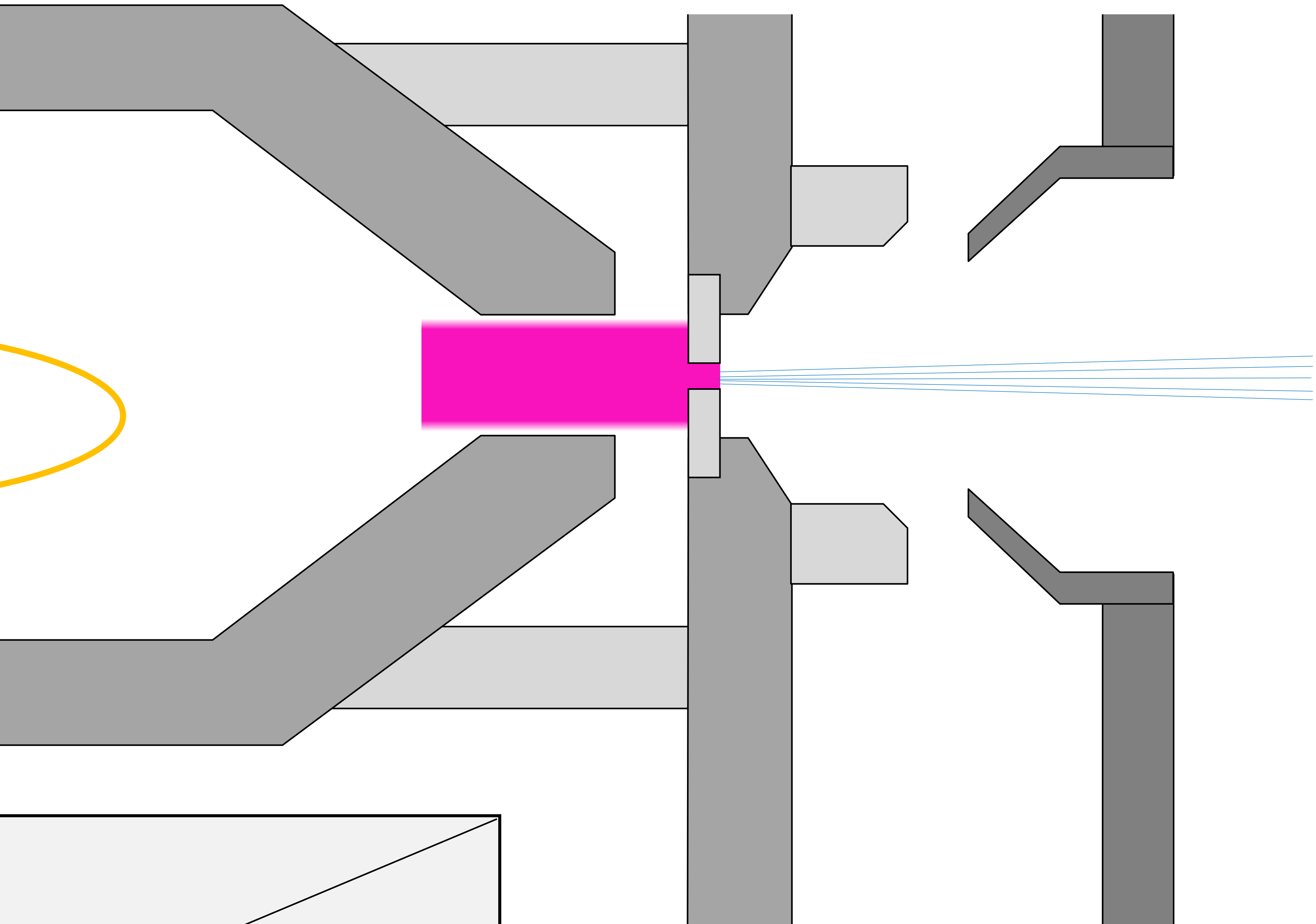
A 1937 tandem with a charge exchange gas cell

Early attempts at producing negative ion beams:

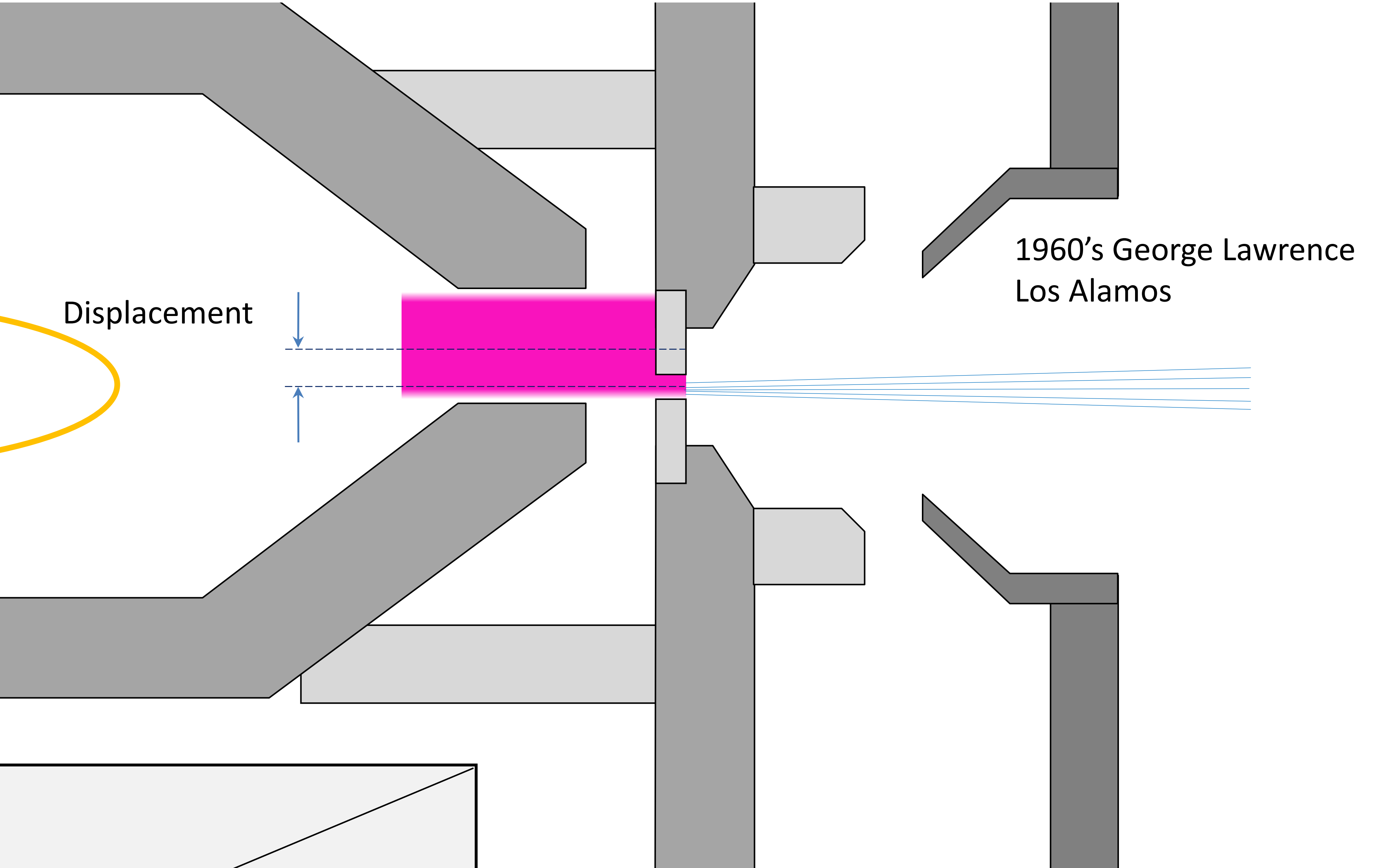
- Charge exchange of positive beams

  gas cells- very inefficient <2%
- Low work function oxide coated filament - very low current
- Extraction from existing ion sources…

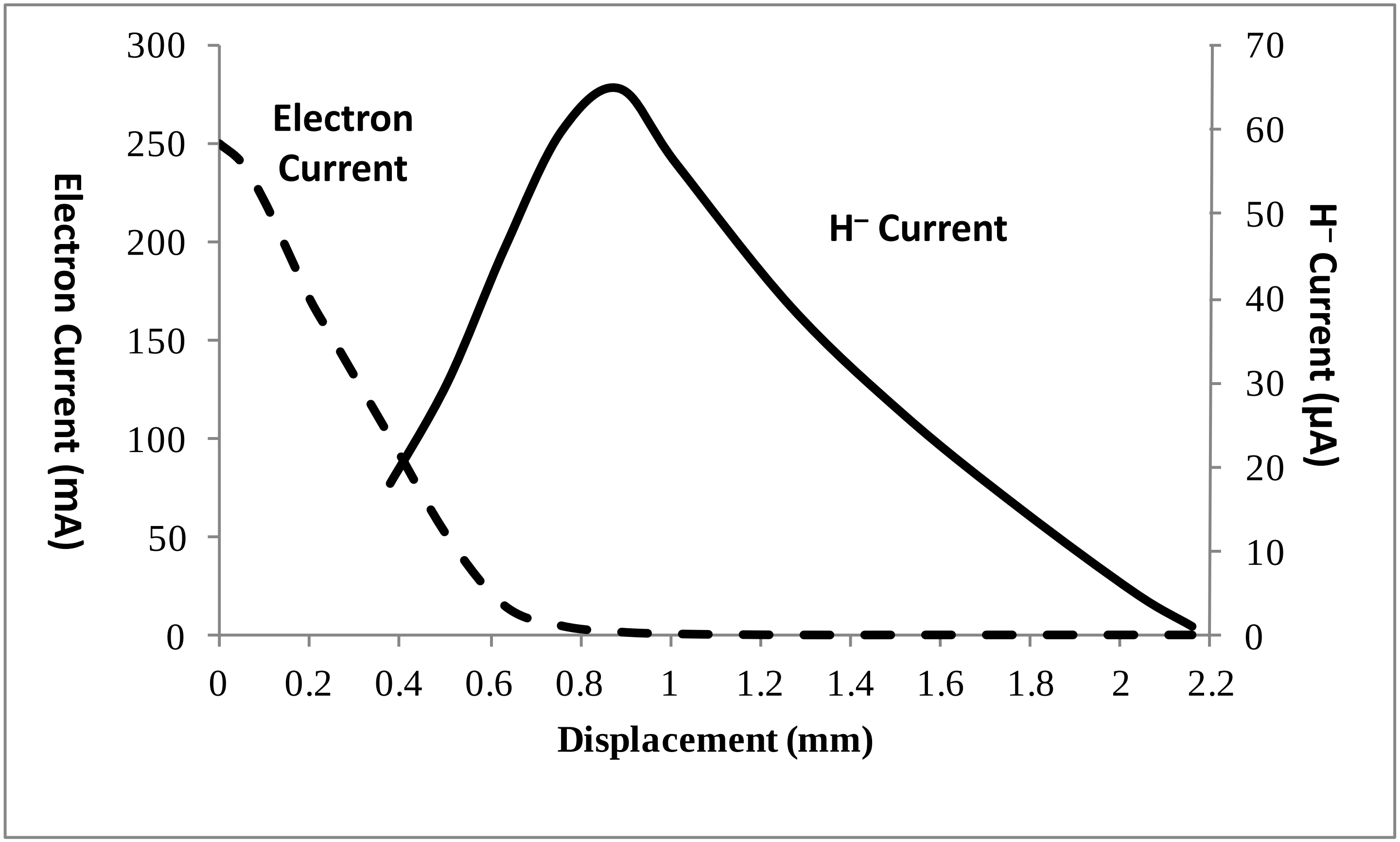
Off Axis Duoplasmatron Extraction



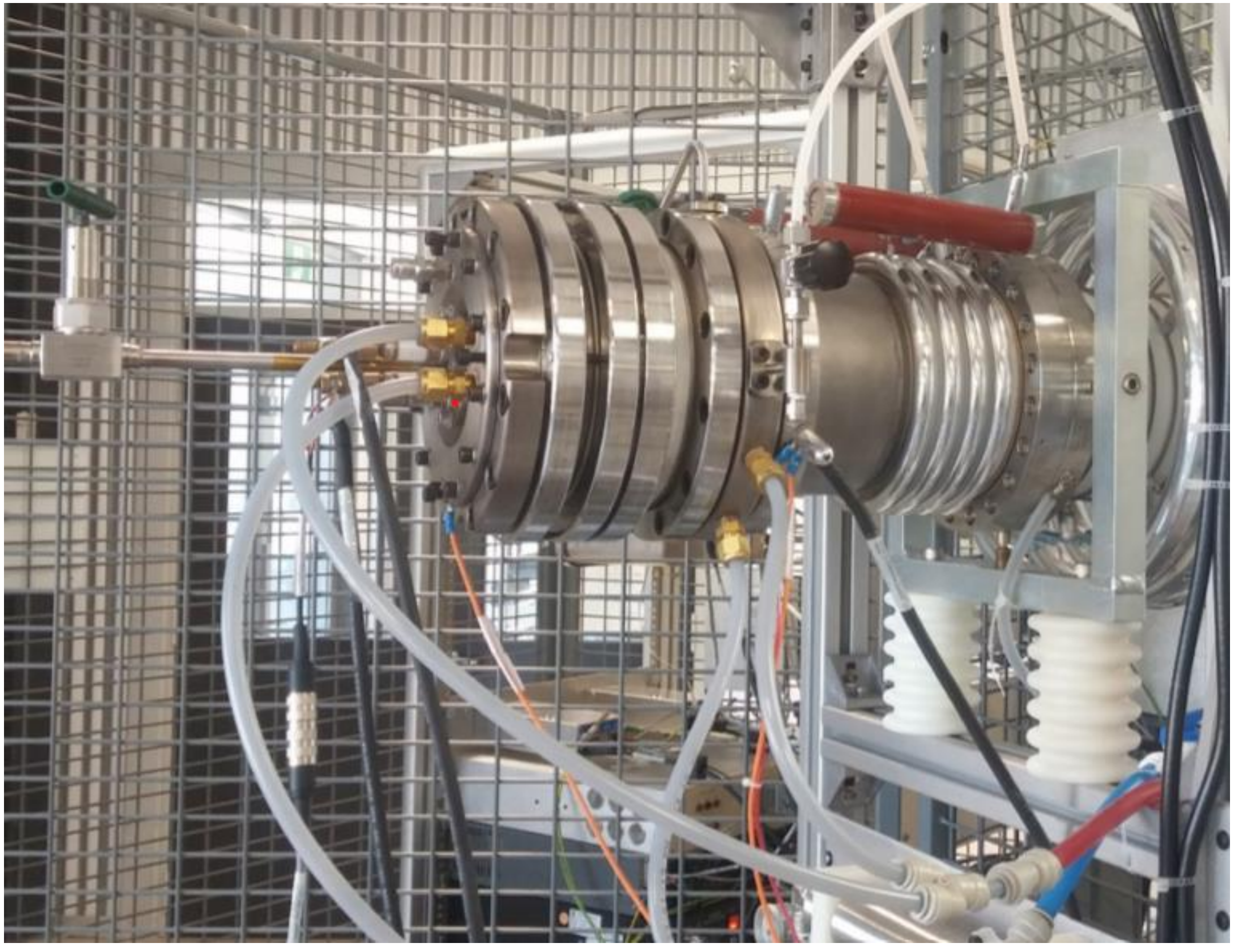
Off Axis Duoplasmatron Extraction



Off Axis Duoplasmatron Extraction



Off Axis Duoplasmatron Extraction



National Electrostatics Corp.

Direct Extraction Negative Ion Duoplasmatron

30 µA DC
H^- current

displaced
intermediate
electrode
duoplasmatron

Early 1970s Budker Institute of Nuclear Physics Novosibirsk

Production of H^{-} ions by surface ionisation with the addition of cesium

Surface Plasma Sources (SPS)

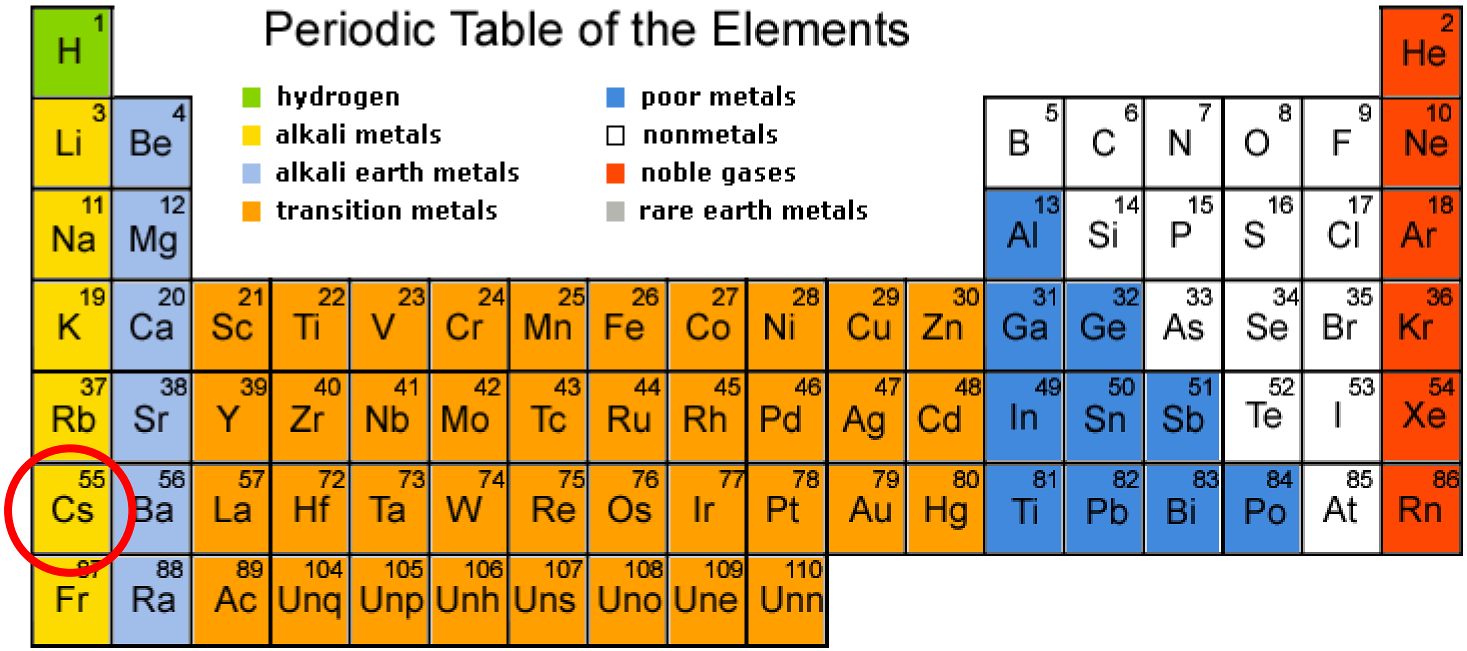
Gennady Dimov

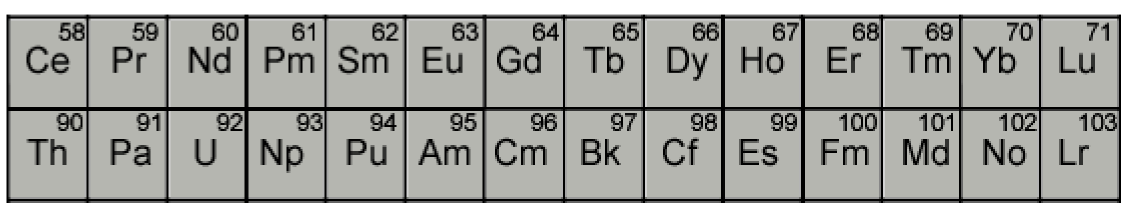
Yuri Belchenko

Vadim Dudnikov

Cesium! – The magic elixir

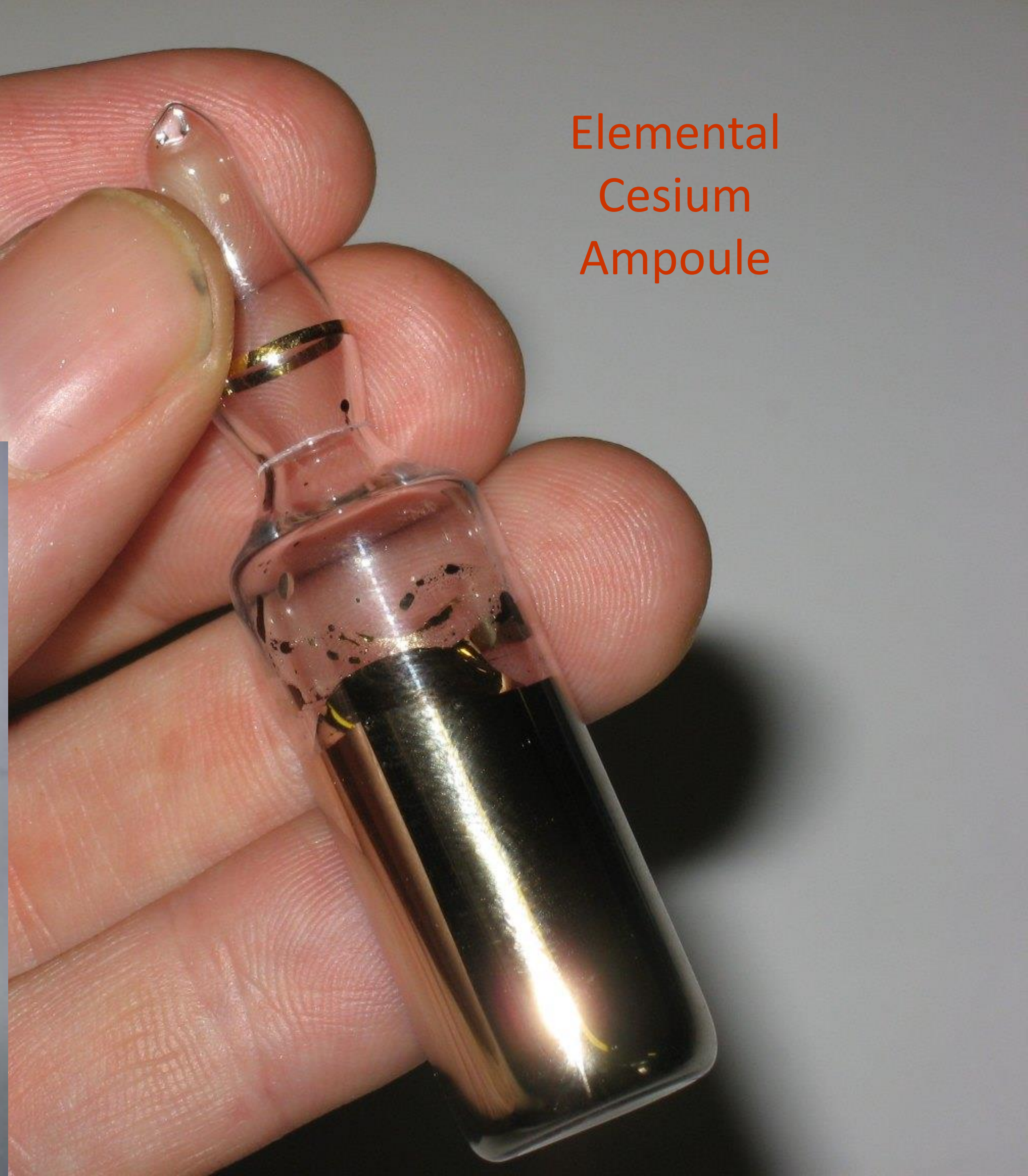
More reactive





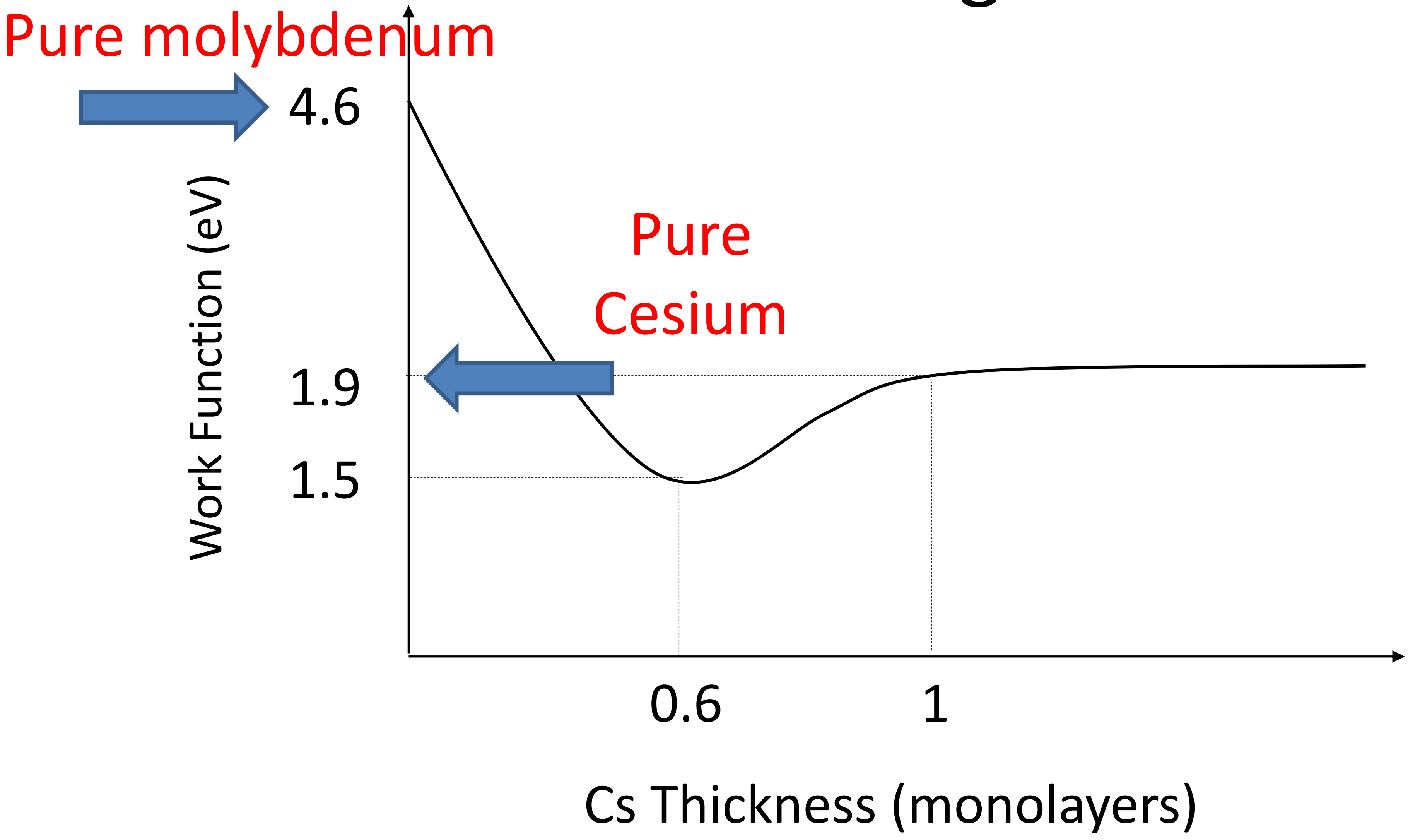
1 electron in the outer orbital

An amazing donor of electrons
= great for making negative ions

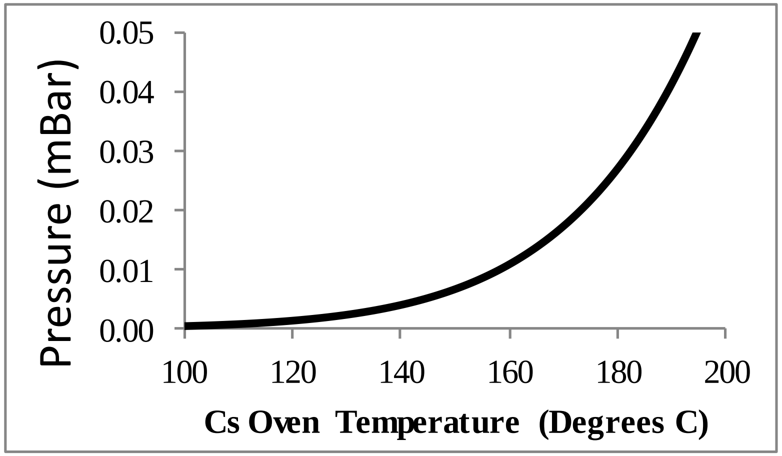

Elemental
Cesium
Ampoule

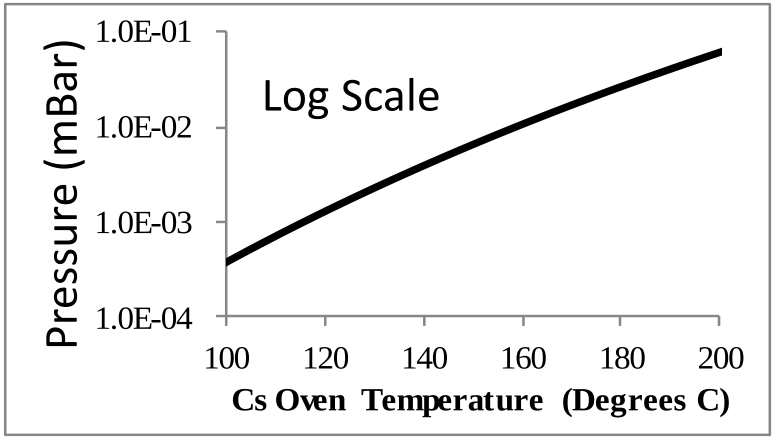

Cesium
Chromate
Cesium chromate

Cesium Coverage



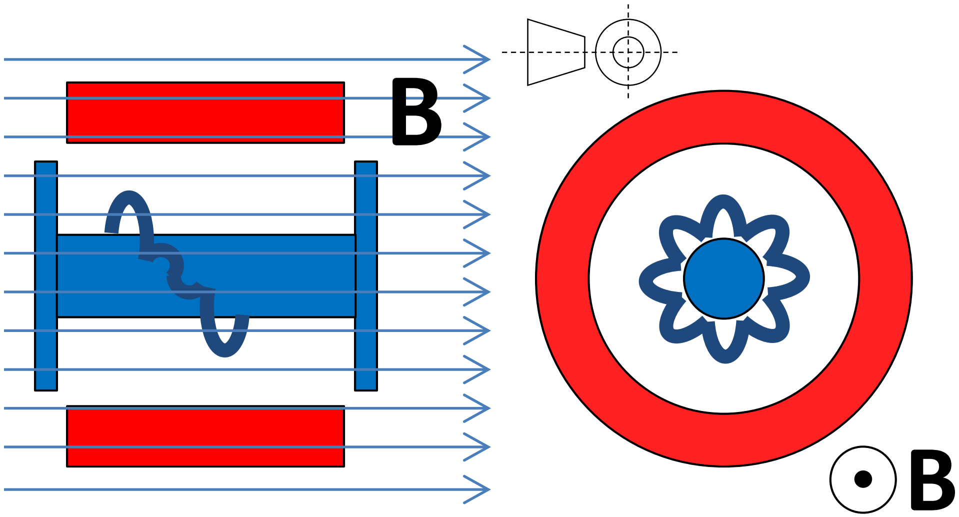
Control cesium oven temperature to vary cesium vapor pressure to control cesium coverage

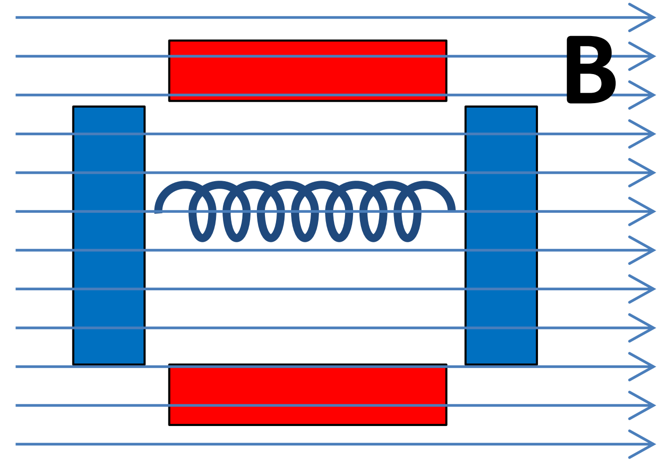




or vary cesium chromate cartridge temperature

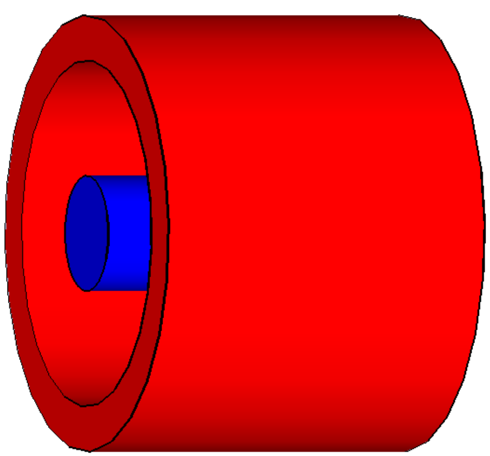
Fundamental Geometry

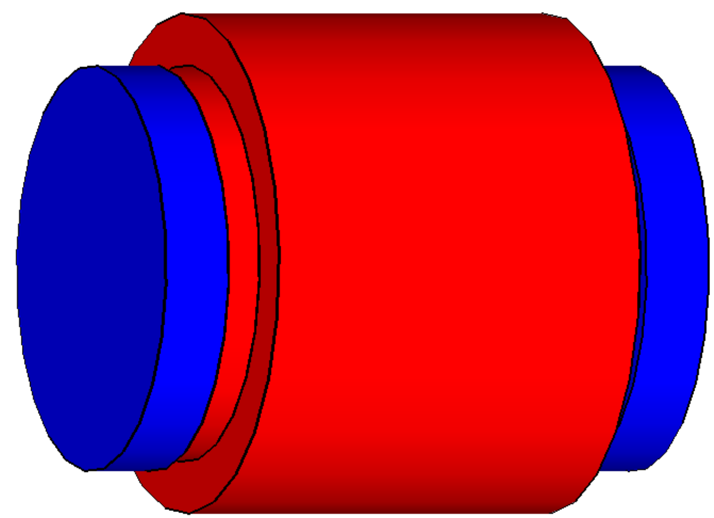




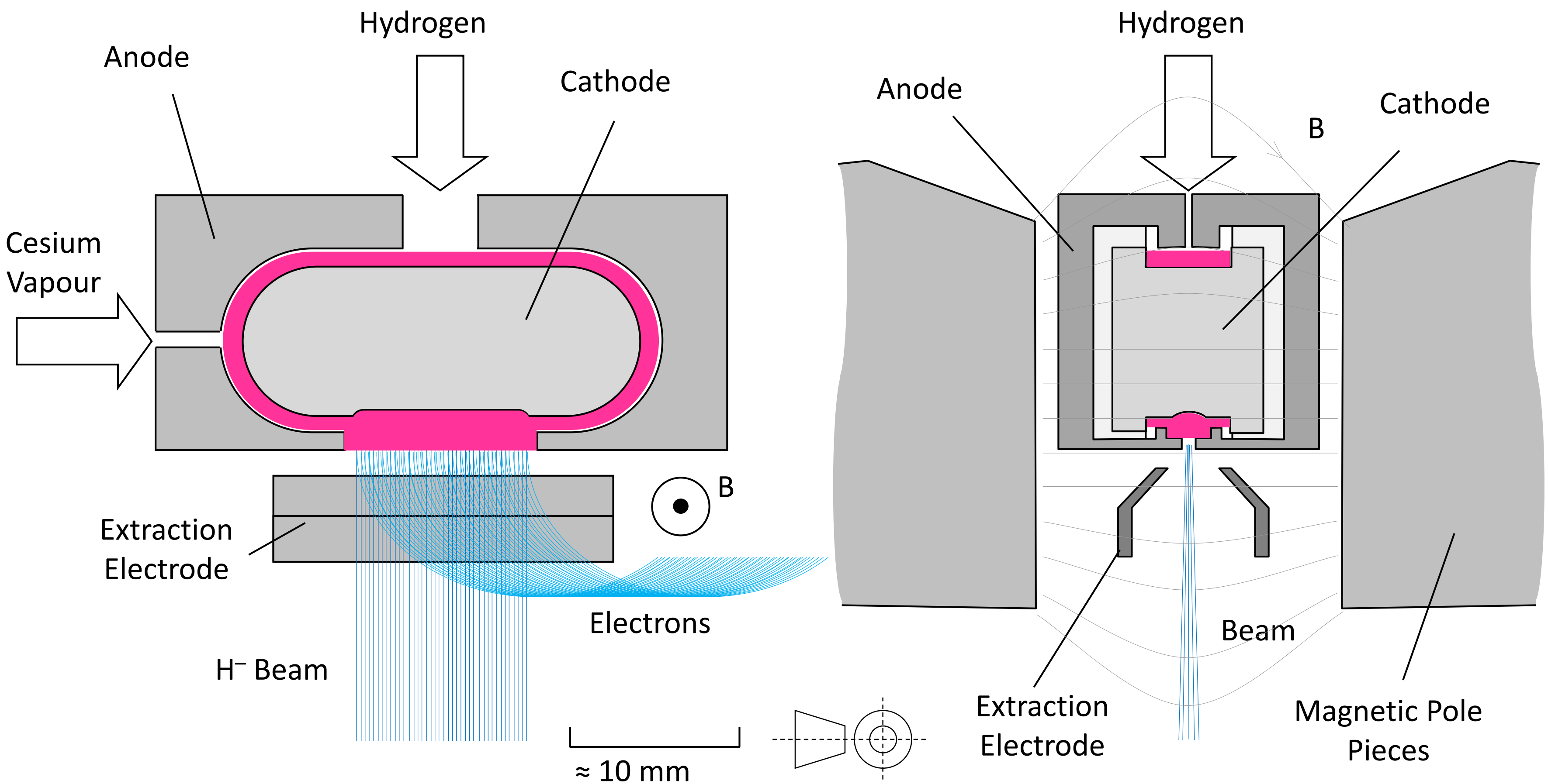
Magnetron

Penning

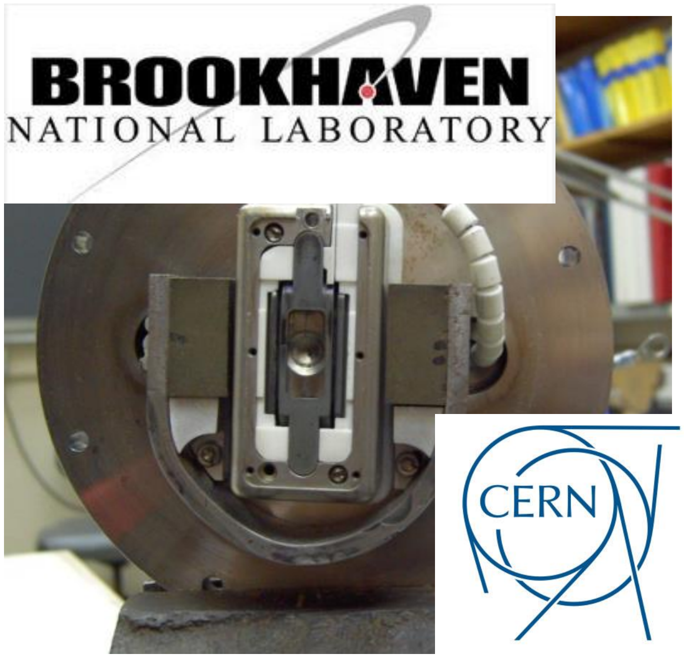


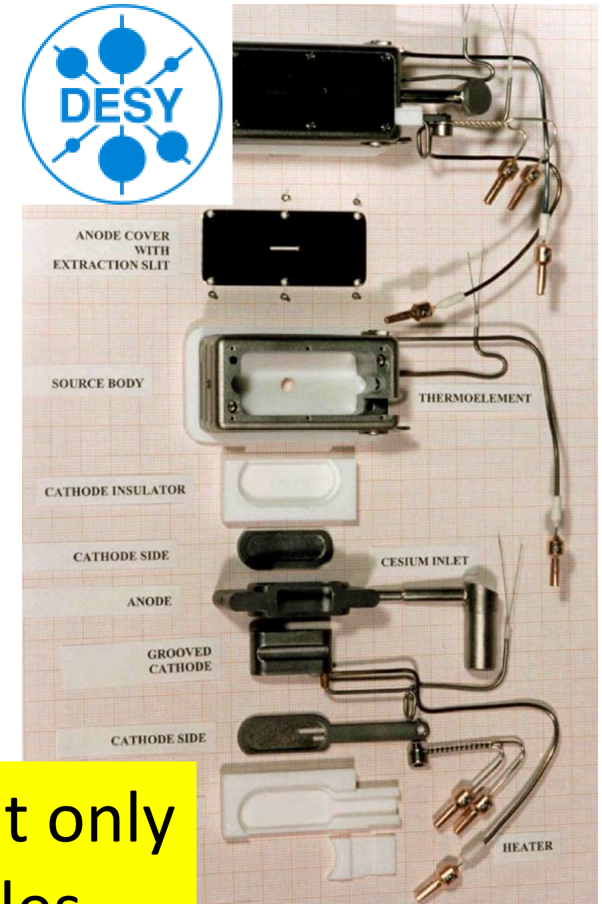


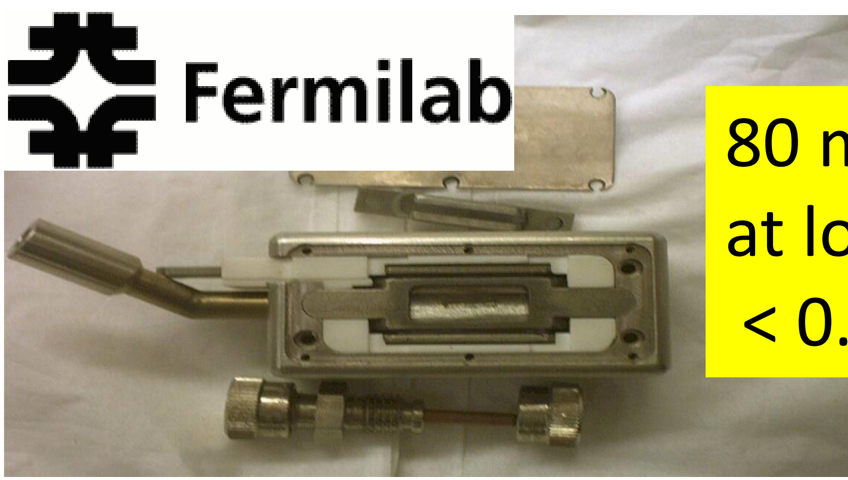
Magnetron Surface Plasma Source



The Magnetron is a popular source

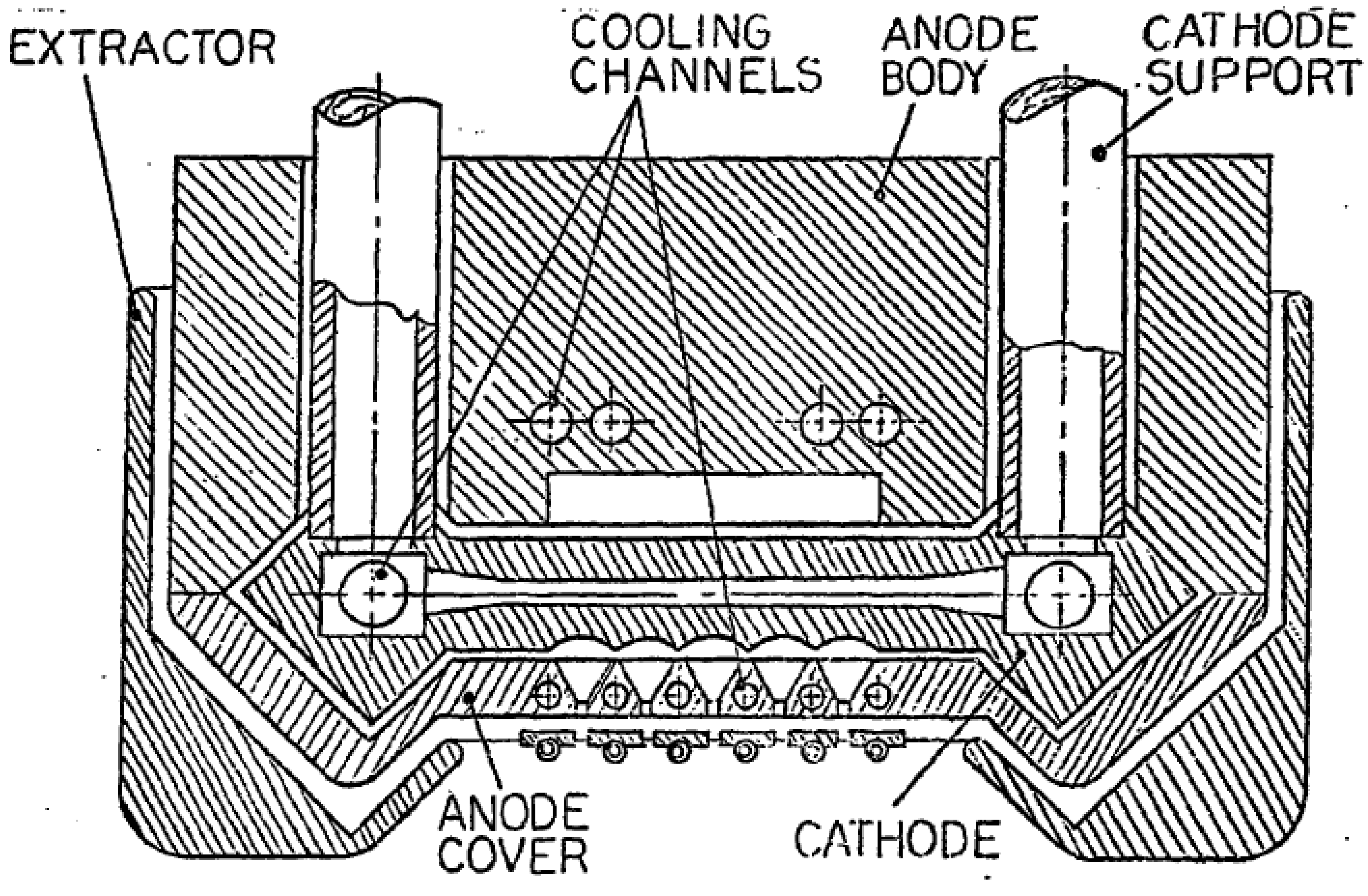




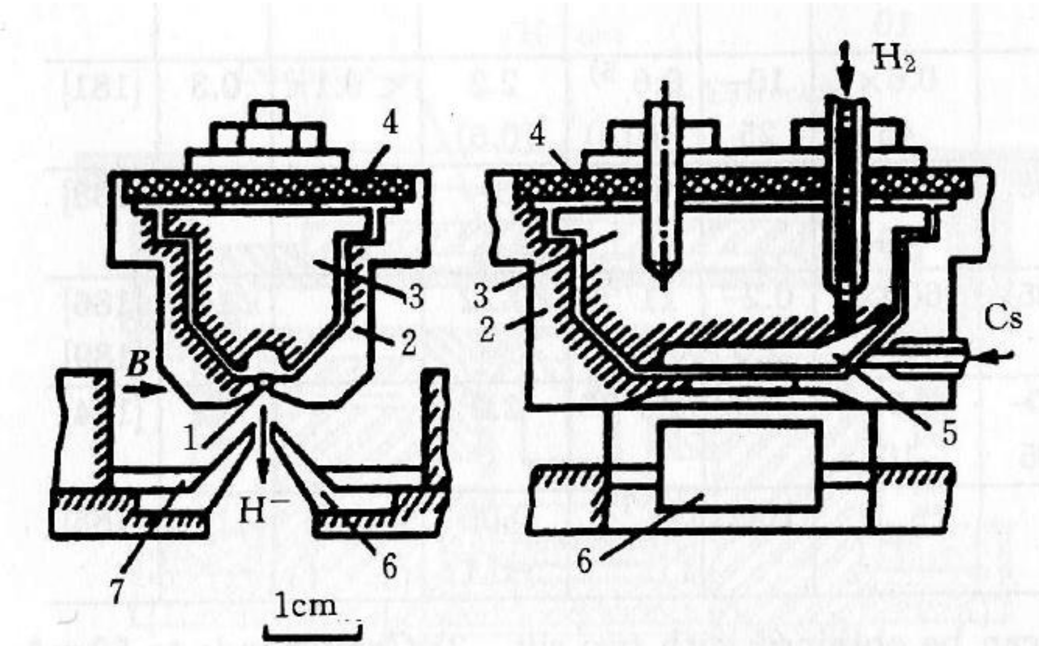


80 mA of H^- but only at low duty cycles < 0.5%

BNL 2 A Beam H^- Magnetron for NBI



Budker Semiplanotron



1—Emission slit, 2—Anode, 3—Cathode, 4—Insulator, 5—Cathode cavity, 6—Extracting electrode, 7—Iron inserts.

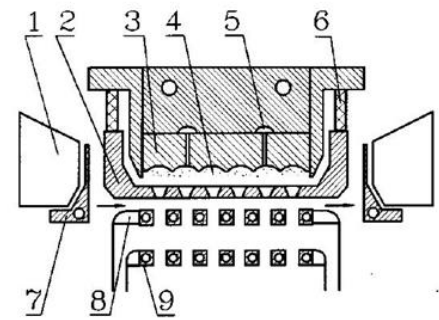


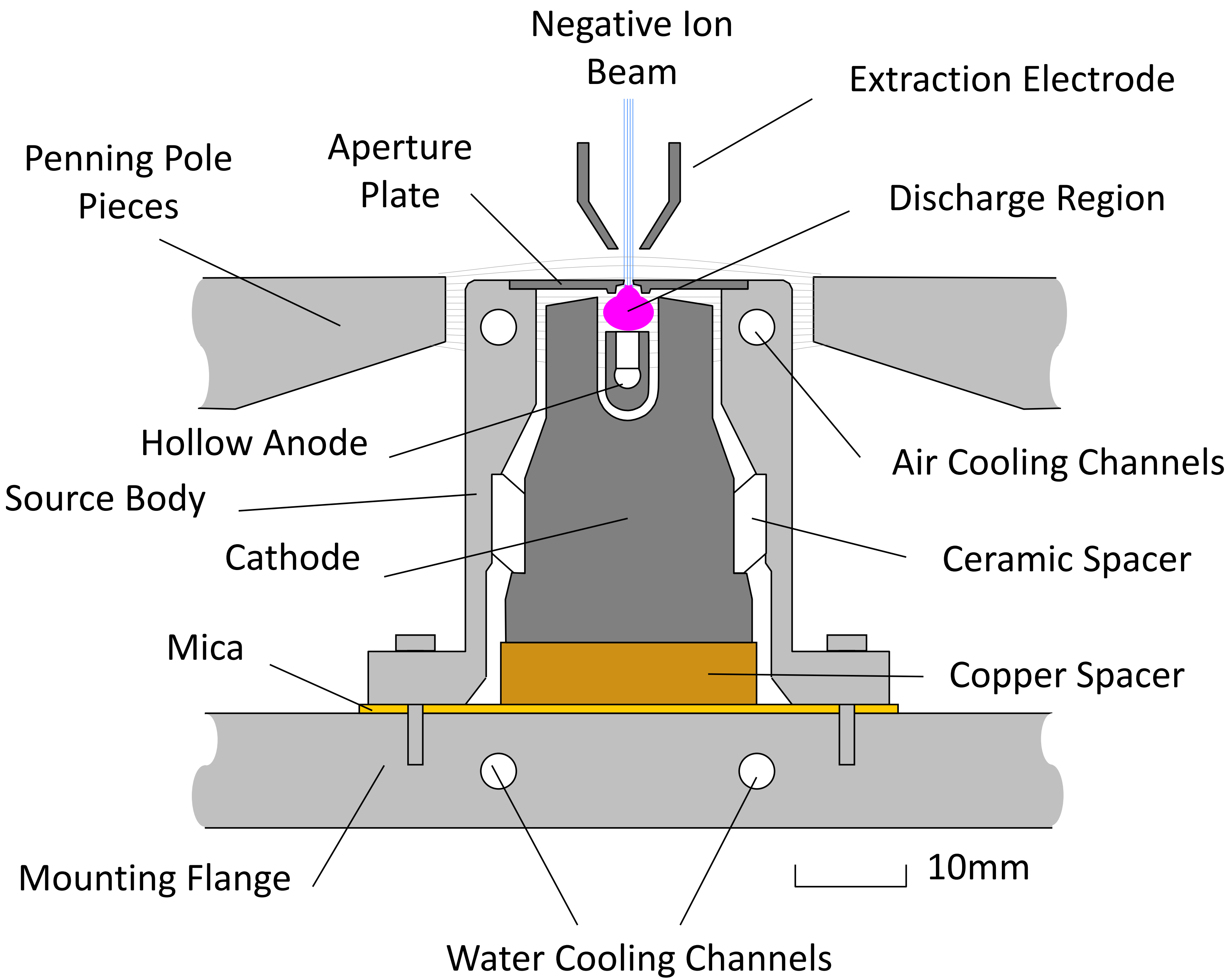
FIG. 1. A principal view of the Honeycomb surface-plasma source with a semiplanotron geometry of discharge electrodes. Magnetic field direction is shown by arrows: 1—magnet pole, 2—anode, 3—cathode, 4—plasma layer, 5—cavities for H_2 and Cs feed, 6—insulator, 7—electron collector, 8—multirod extractor, 9—multirod accelerating electrode.

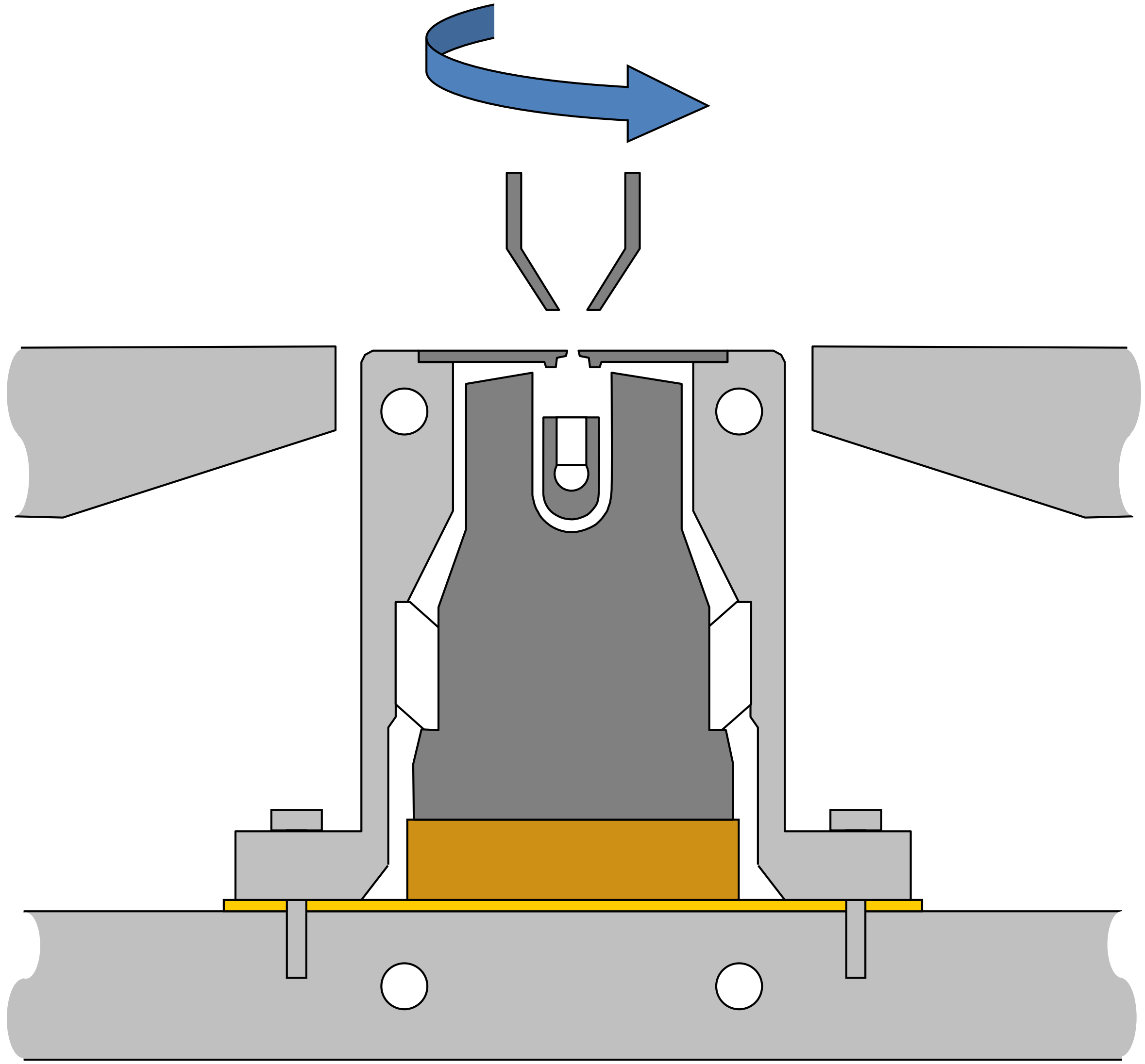
11 A Semiplanotron for NBI

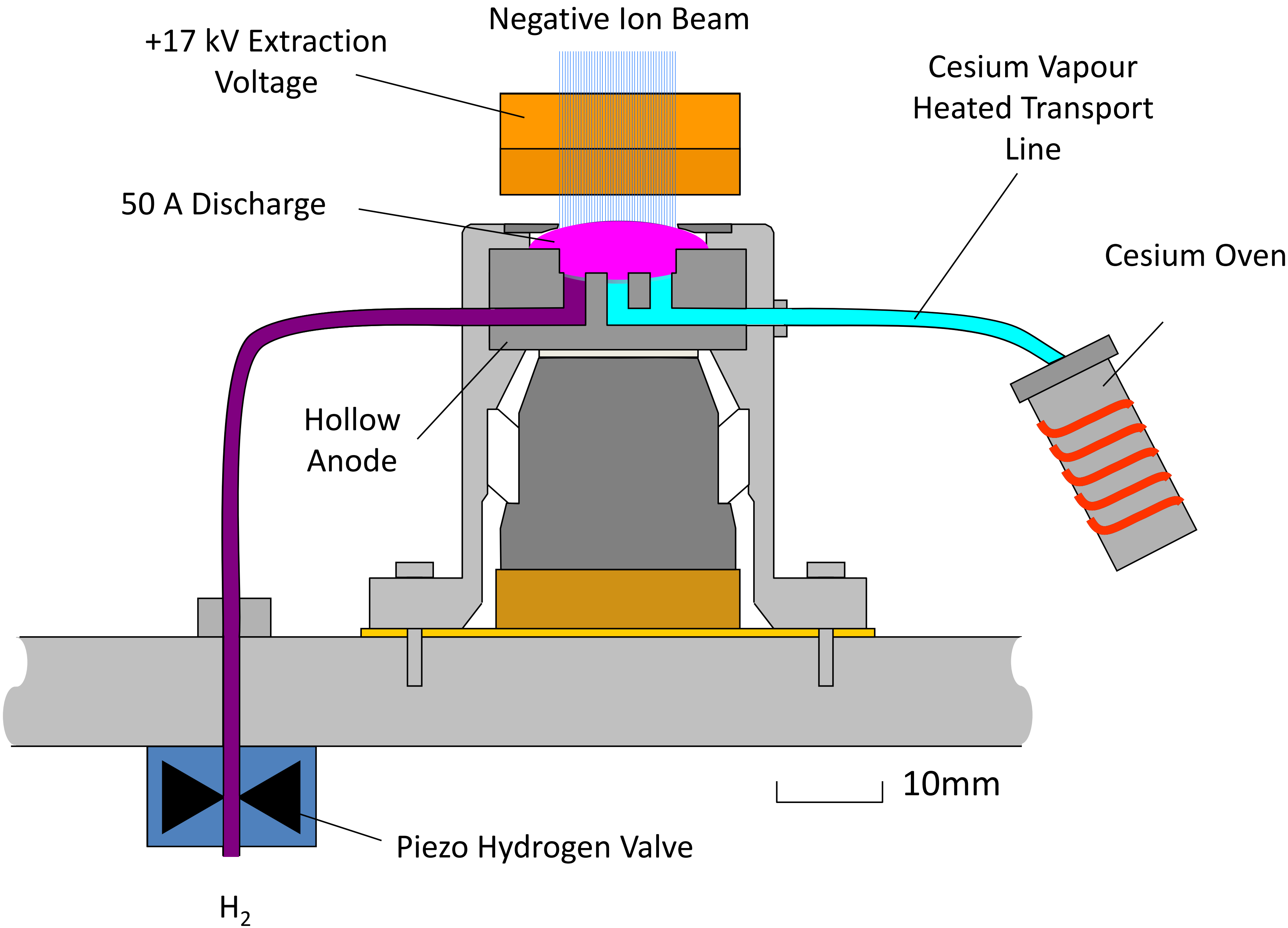
Planotron = magnetron

Penning SPS Ion Sources

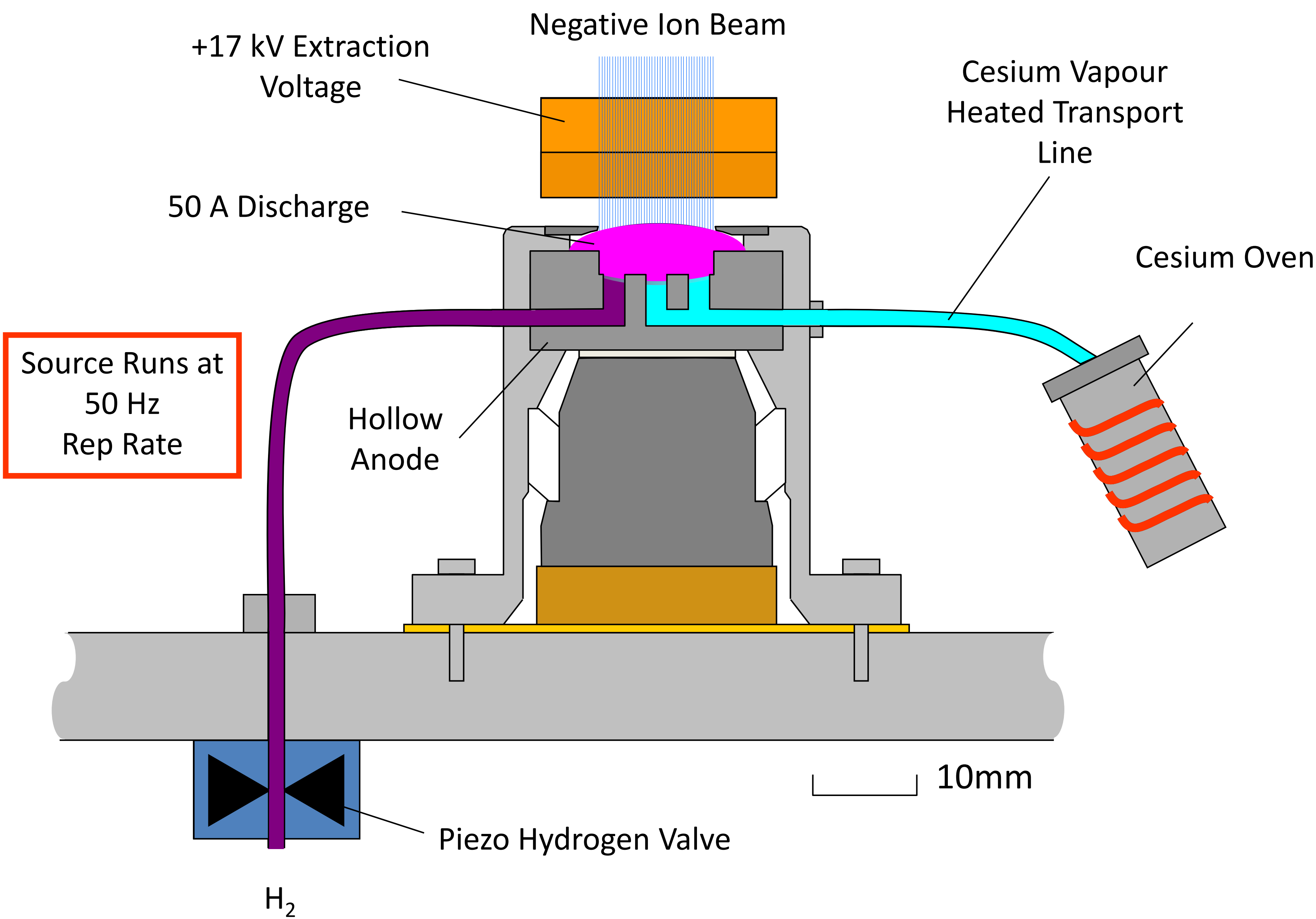
- Invented by Dudnikov at BINP in the 1970’s
- Low noise
- Scaled versions developed by LANL in the 80’s and 90’s
- DC hollow cathode sources developed by Belchenko et al. at BINP
- Still used for operations by Moscow INR and ISIS

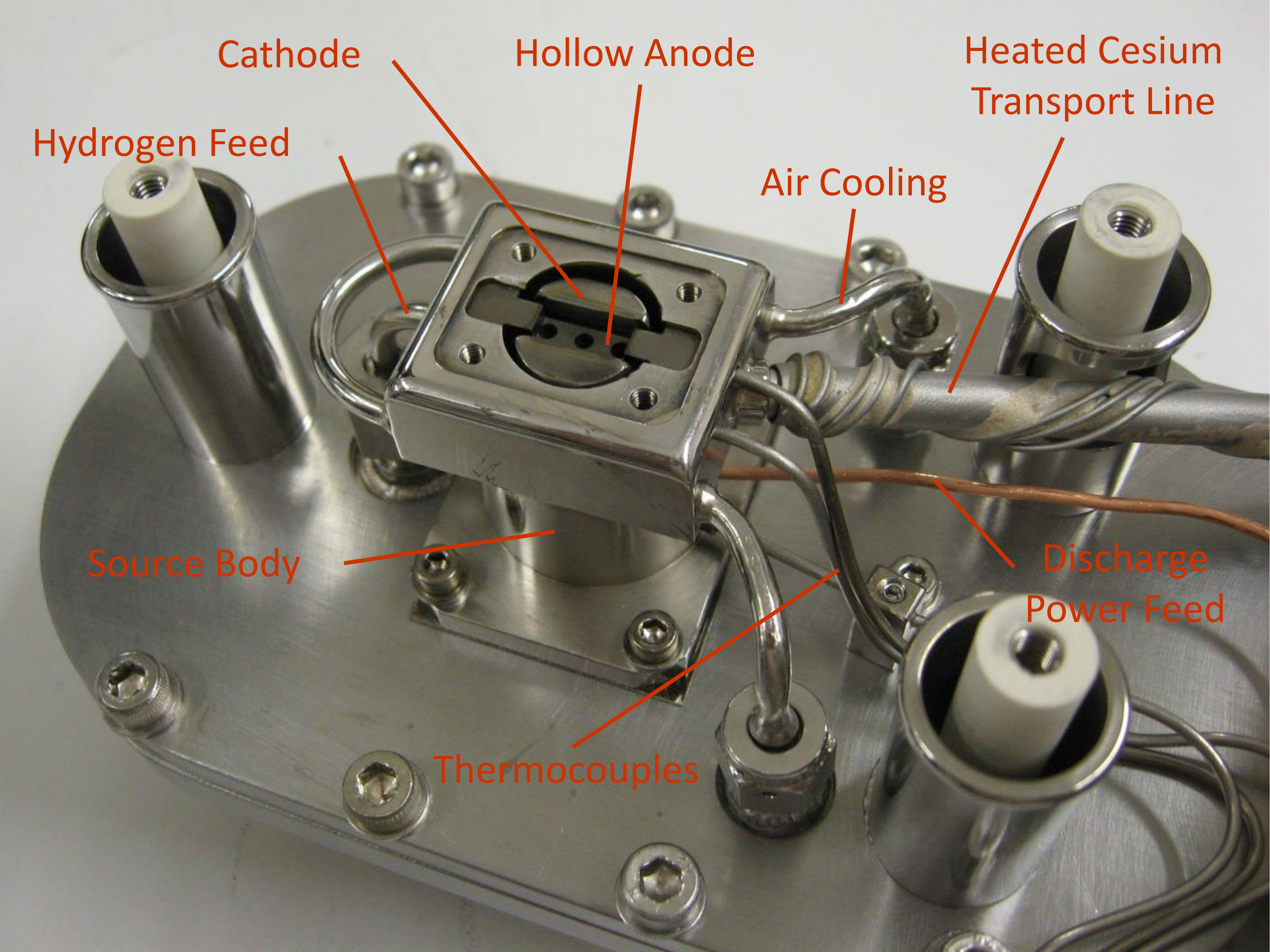

Negative Ion
Beam
Extraction Electrode
Penning Pole
Pieces
Aperture
Plate
Discharge Region
Hollow Anode
Air Cooling Channels
Source Body
Cathode
Ceramic Spacer
Mica
Copper Spacer
Mounting Flange
10mm
Water Cooling Channels

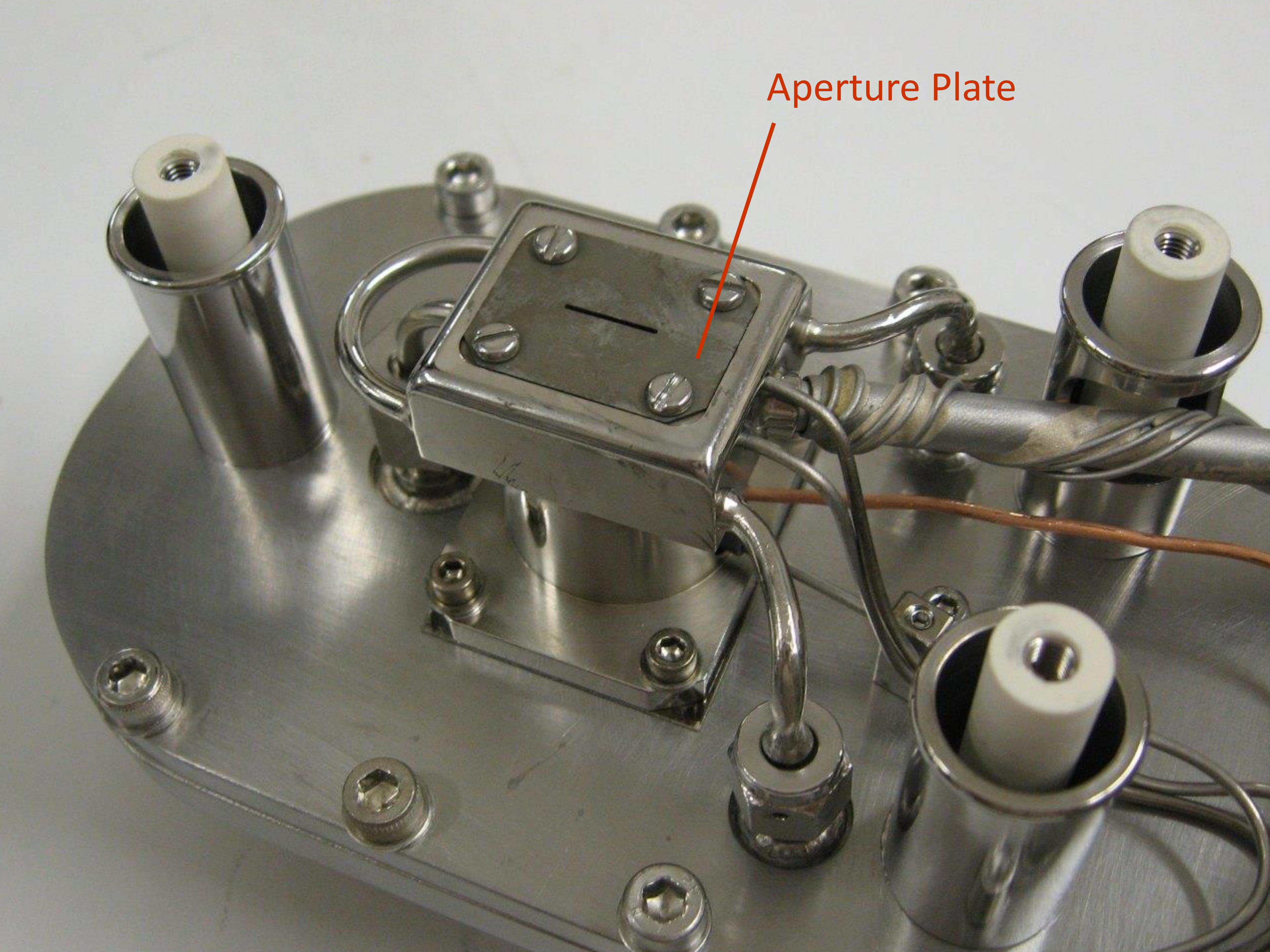


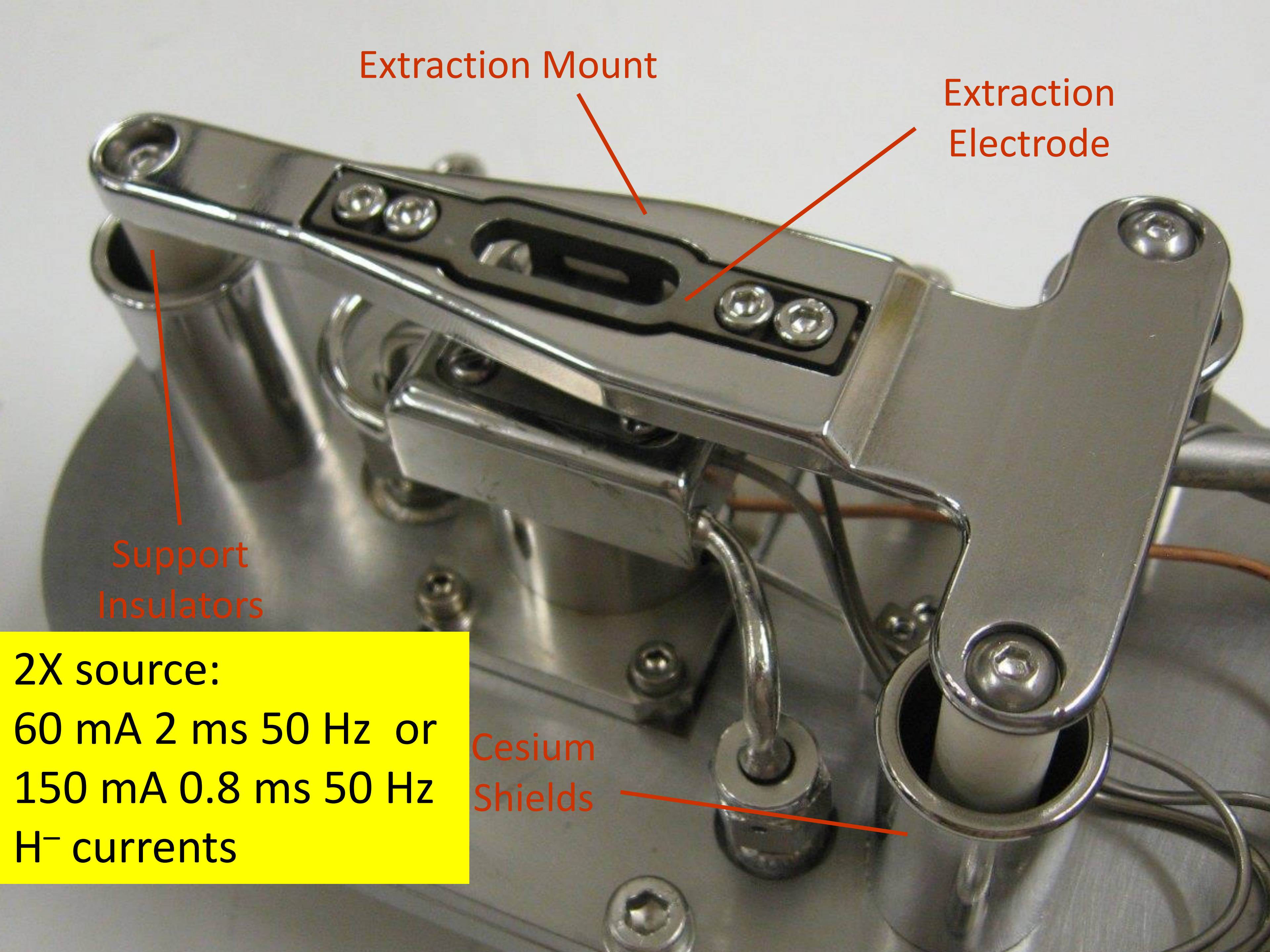


Negative Ion Beam
+17 kV Extraction Voltage
Cesium Vapour Heated Transport Line
50 A Discharge
Cesium Oven
Hollow Anode
10mm
Piezo Hydrogen Valve
H2

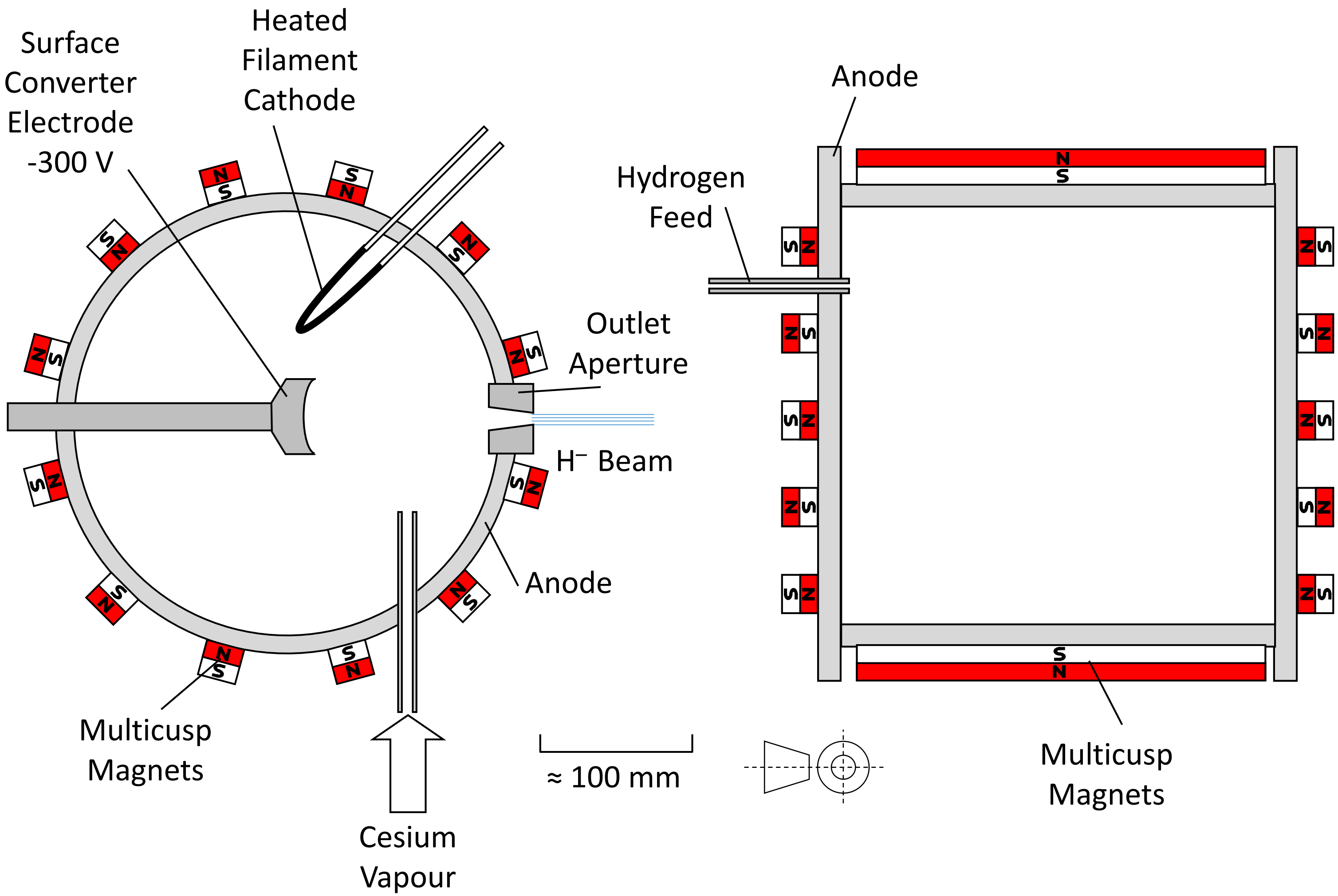

Negative Ion Beam
+17 kV Extraction Voltage
Cesium Vapour Heated Transport Line
50 A Discharge
Cesium Oven
Source Runs at 50 Hz Rep Rate
Hollow Anode
10mm
Piezo Hydrogen Valve
H_2

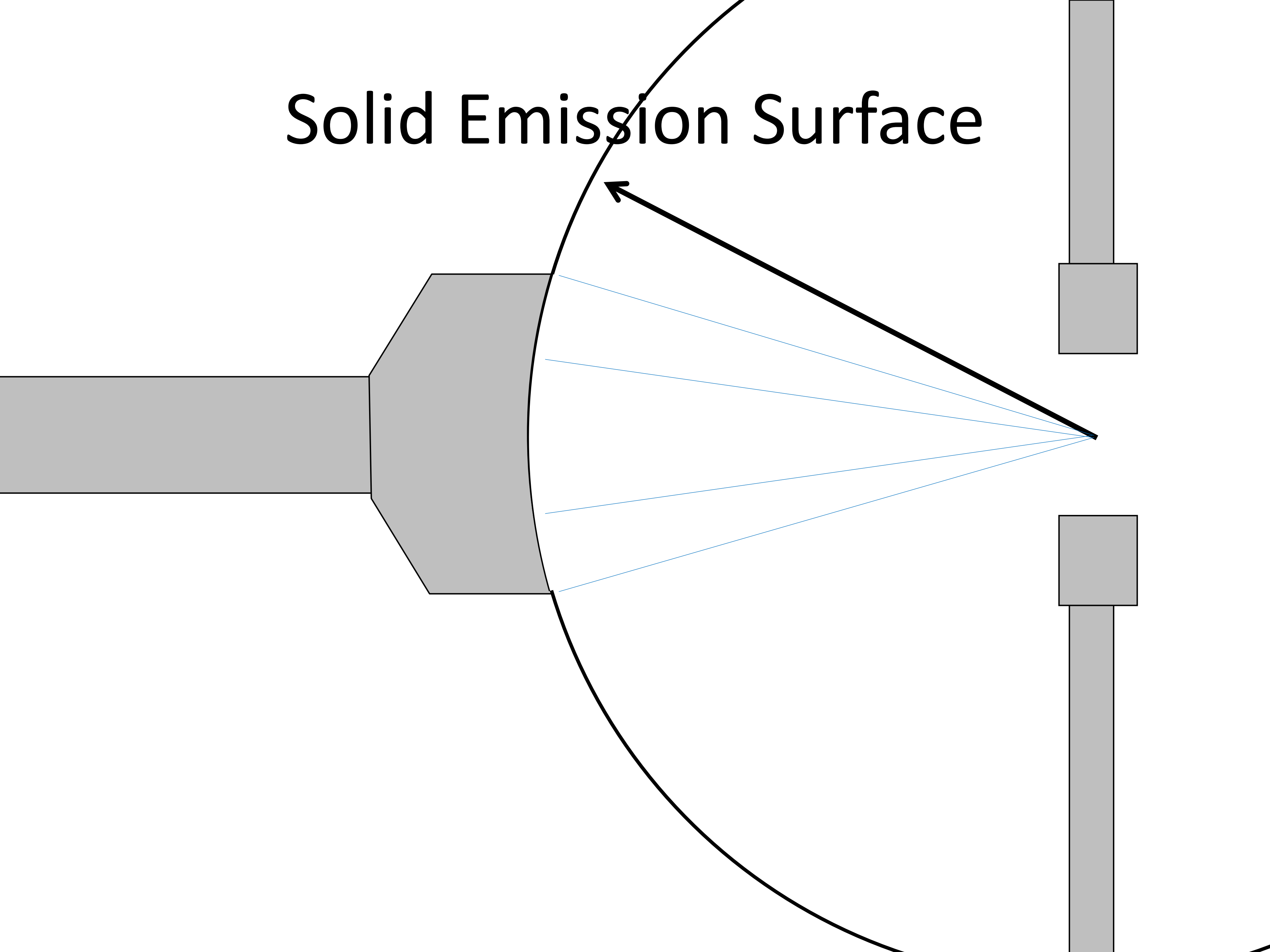

Cathode
Hollow Anode
Heated Cesium
Transport Line
Hydrogen Feed
Air Cooling
Source Body
Discharge
Power Feed
Thermocouples


Aperture Plate

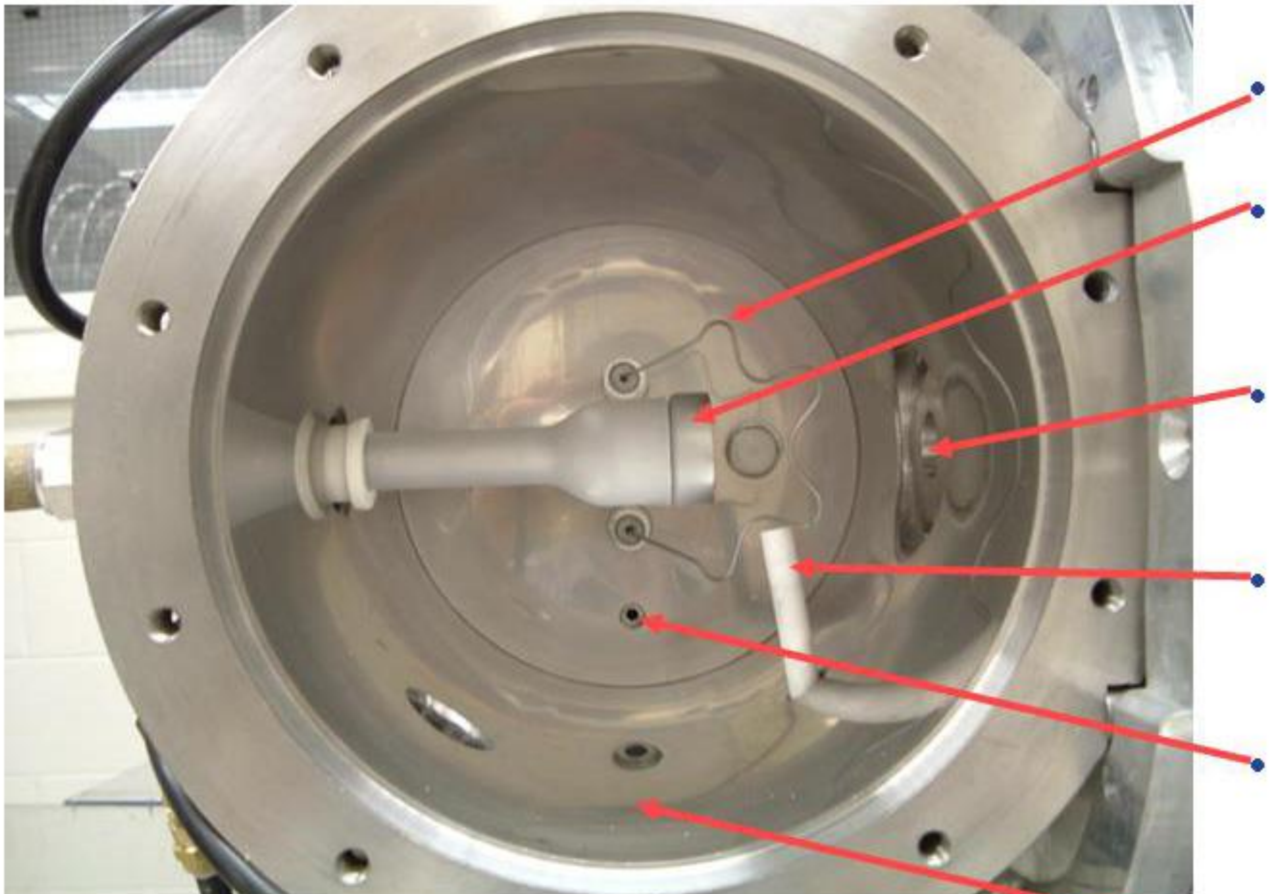

Extraction Mount
Extraction
Electrode
Support
Insulators
Cesium
Shields
2X source:
60 mA 2 ms 50 Hz or
150 mA 0.8 ms 50 Hz
H⁻ currents

Filament Cathode Multicusp Surface Converter Source

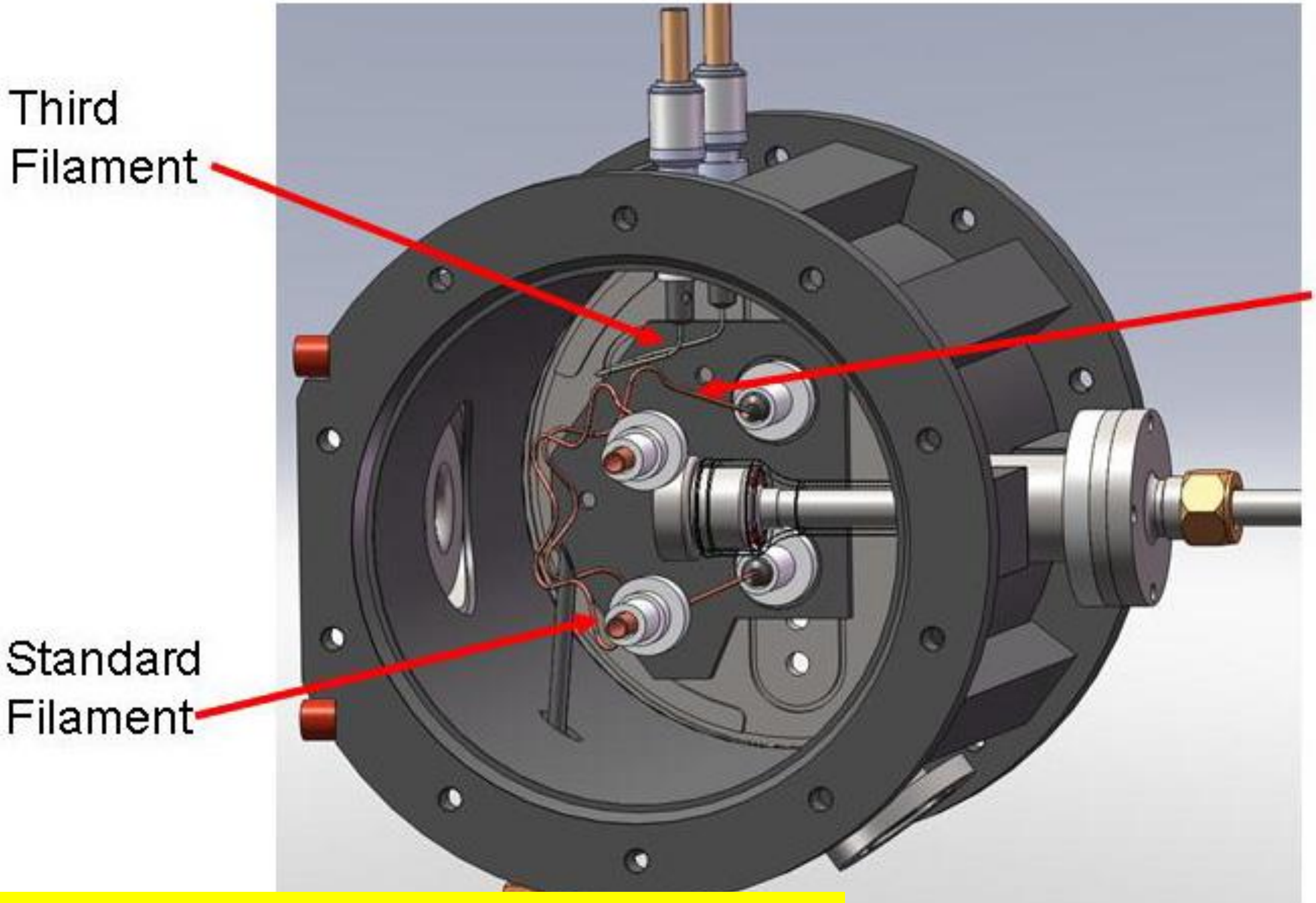



Solid Emission Surface

Filament Cathode Multicusp Surface Converter Source

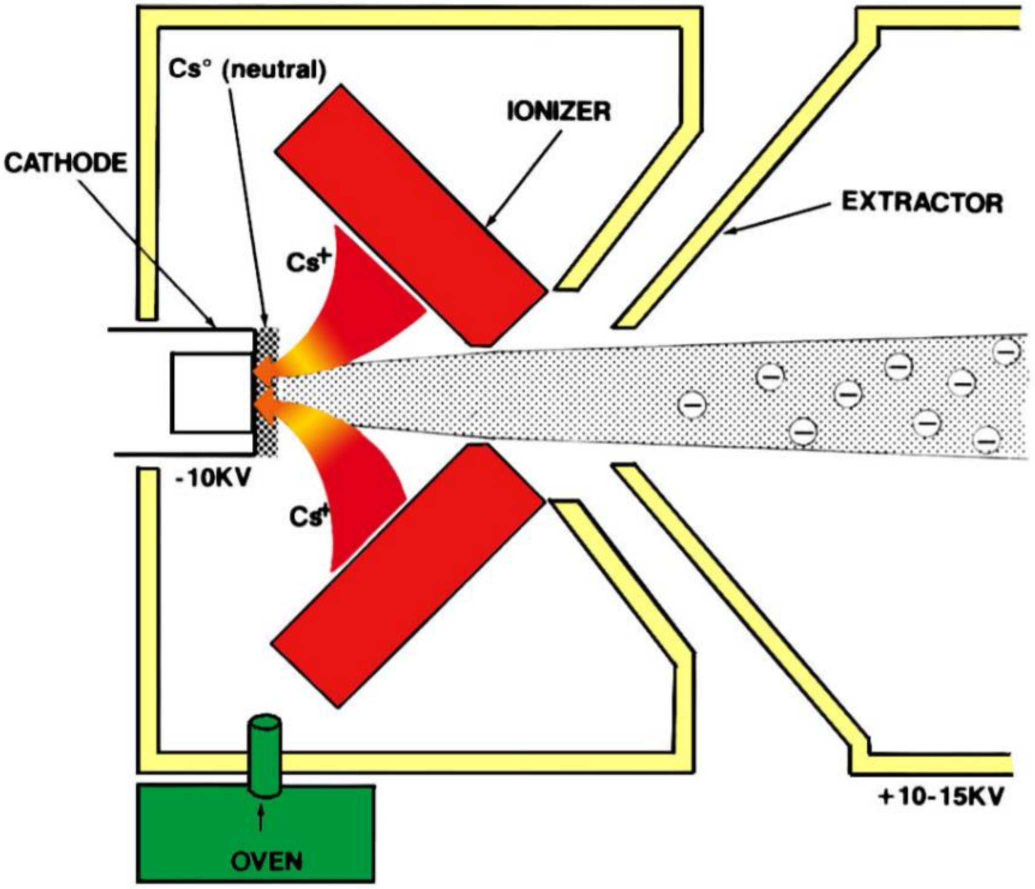


16-18 mA 1 ms 120 Hz



LANL with multiple filaments:
1 A of H^-

SNICS (Source of Negative Ions by Cesium Sputtering) Middelton et al



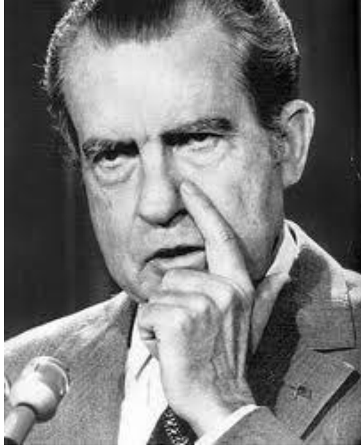
Currents in µA

H-130	Si– 430	As– 60	Cs– 1.5
D– 150	P– 125	Se– 10	CeO– 0.2
Li– 4	S– 100	Br – 40	NdO– 0.3
BeO– 10	Cl– 100	Sr – 1.5	EuO– 1.0
B– 60	CaH3– 0.8	Y– 0.66	ErO– 10
B2– 73	TiH– 10	Zr – 9.4	TmO– 1.0
C– 260	VH– 25	Nb– 7	YbO– 1.0
C2– 40	Cr– 5	Mo– 5	Ta– 9.5
CN– 12	MnO– 4	Rh– 5	TaO– 6
CN–(15N) 20	Fe– 20	Ag– 13	W– 2.5
O– 300	Co– 120	CdO– 7	Os – 15
F– 100	Ni– 80	InO– 20	Ir – 100
Na– 4.0	Cu– 160	Sn– 20	Pt – 250
MgH2– 1.5	ZnO– 12	Sb– 16	Au– 150
Al– 7	GaO– 7	Te– 20	PbO– 1
Al2– 50	Ge– 60	I– 220	Bi– 3.5

Produces a large range of different negative ions

National Electrostatics Corp.

1970s Cesium Revolution!



- Soviets spread the word and develop sources
- BNL Krsto Prelec et al. develop the magnetron for NBI
- LANL Paul Allison et al. develop the Penning
- Berkley Ehlers+Leung develop Surface Converter sources
- Fermilab Chuck Schmidt et al. develop the BNL magnetron for accelerators

Marthe Bacal
Ecole Polytechnique
mid 1970’s

Volume Production

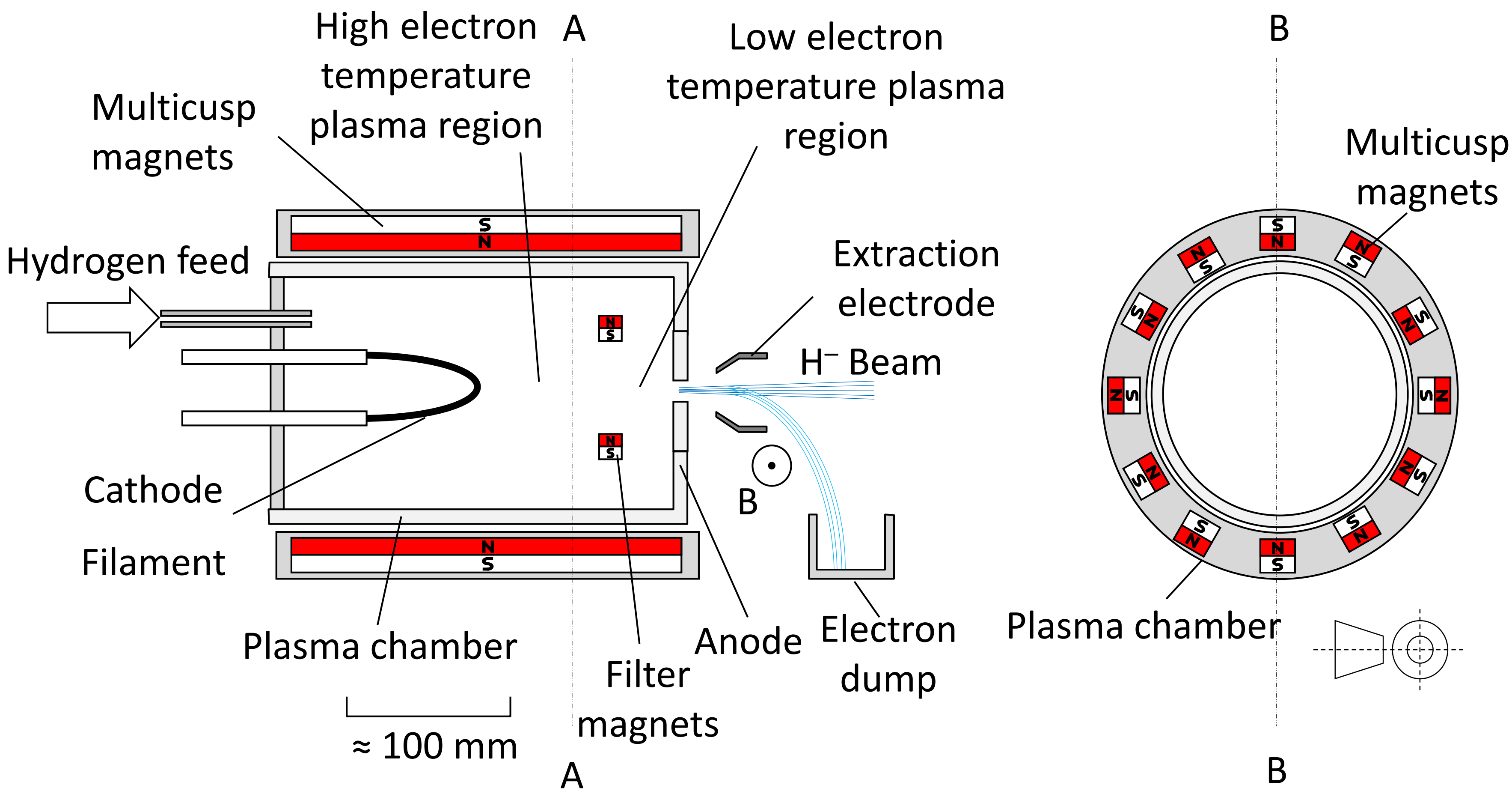
$$H_2^* + e\ (\leq 1\ \text{eV}) \rightarrow H^- + H^0$$

Dissociative attachment of low energy electrons to rovibrationally excited H_2 molecules

Developed by Ehlers + Leung at LBNL

Torvis- Brookhaven National Laboratories
by Prelec and Alessi
… and many others

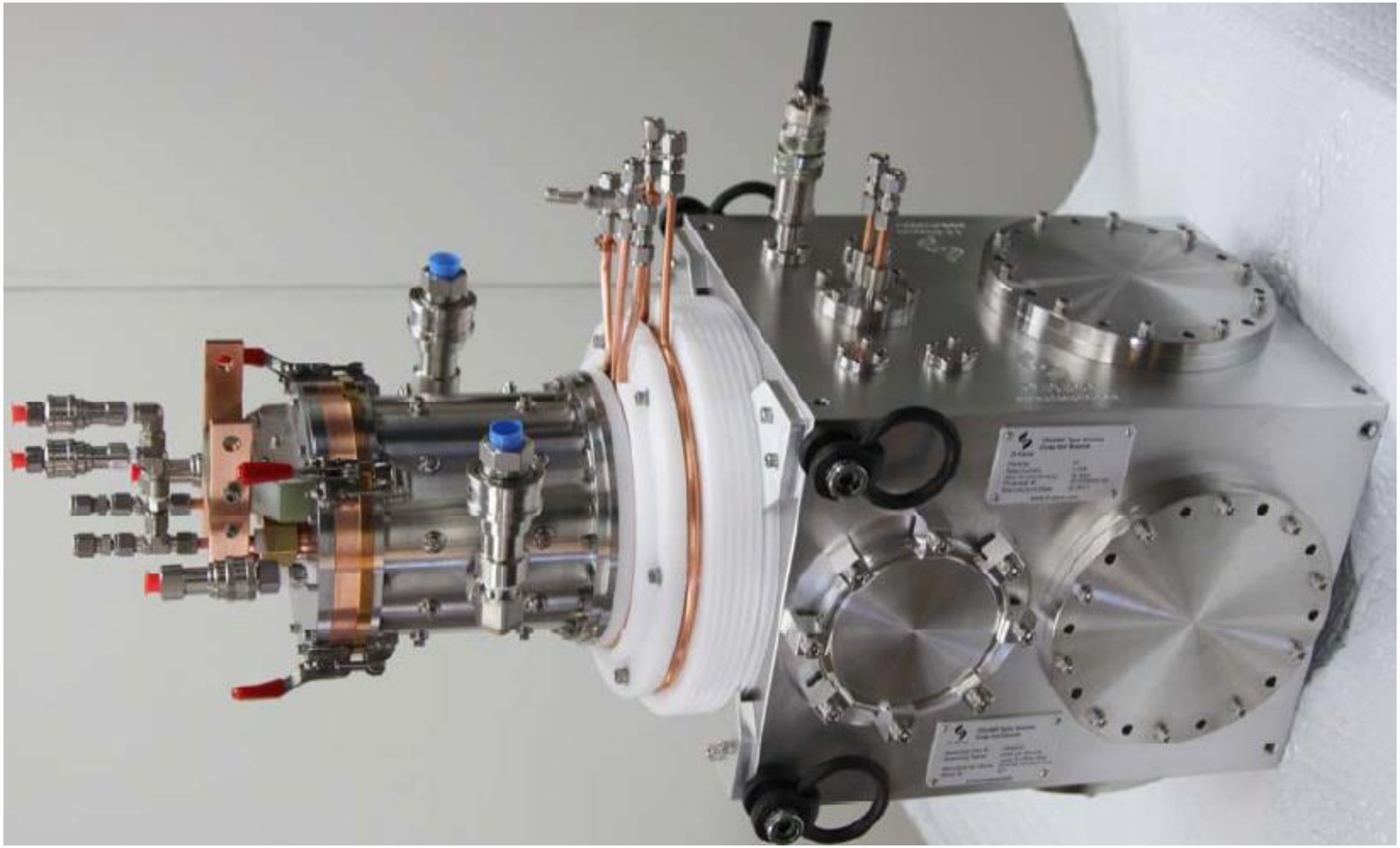
Multicusp Filament Volume Source

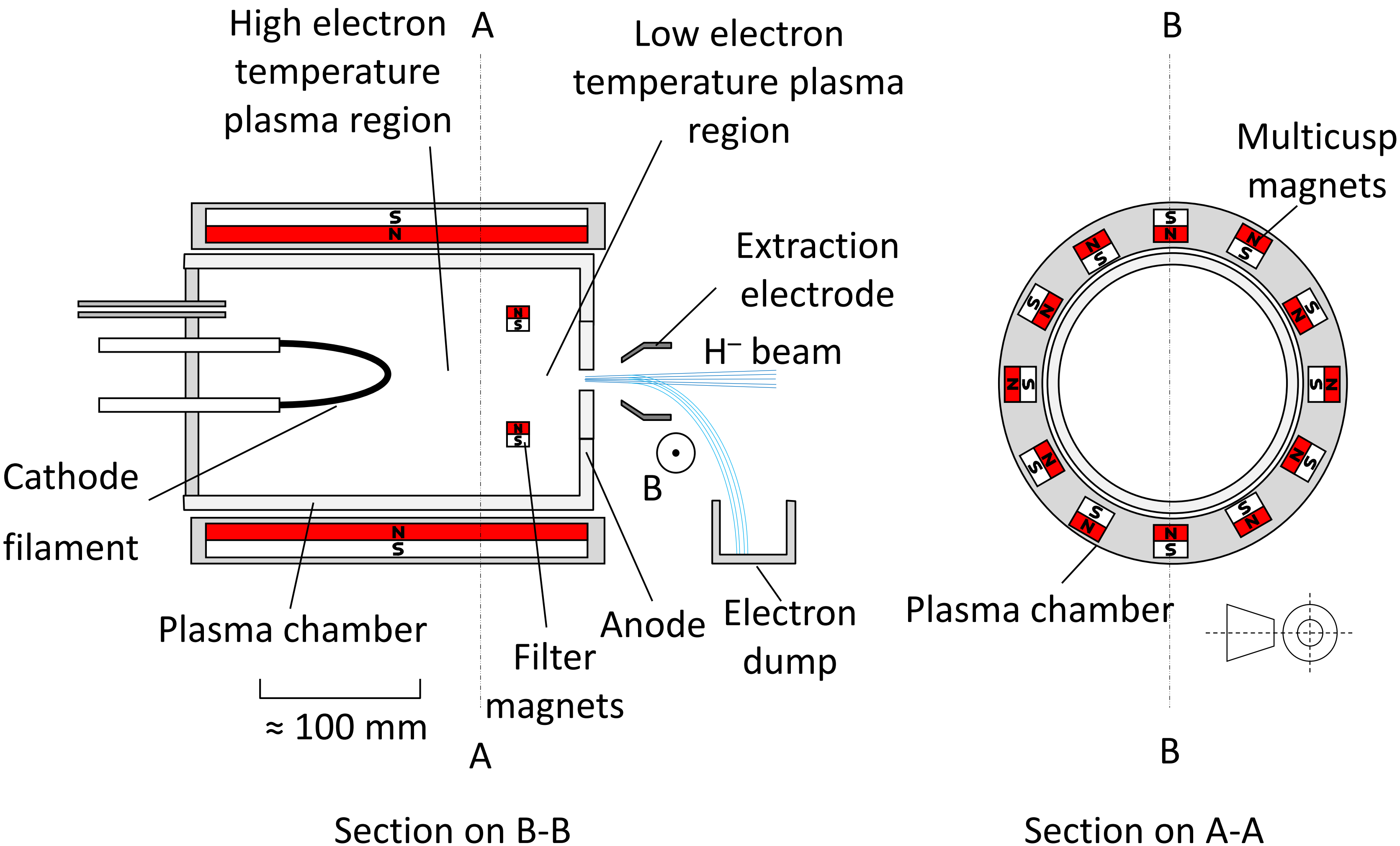


Section on B-B

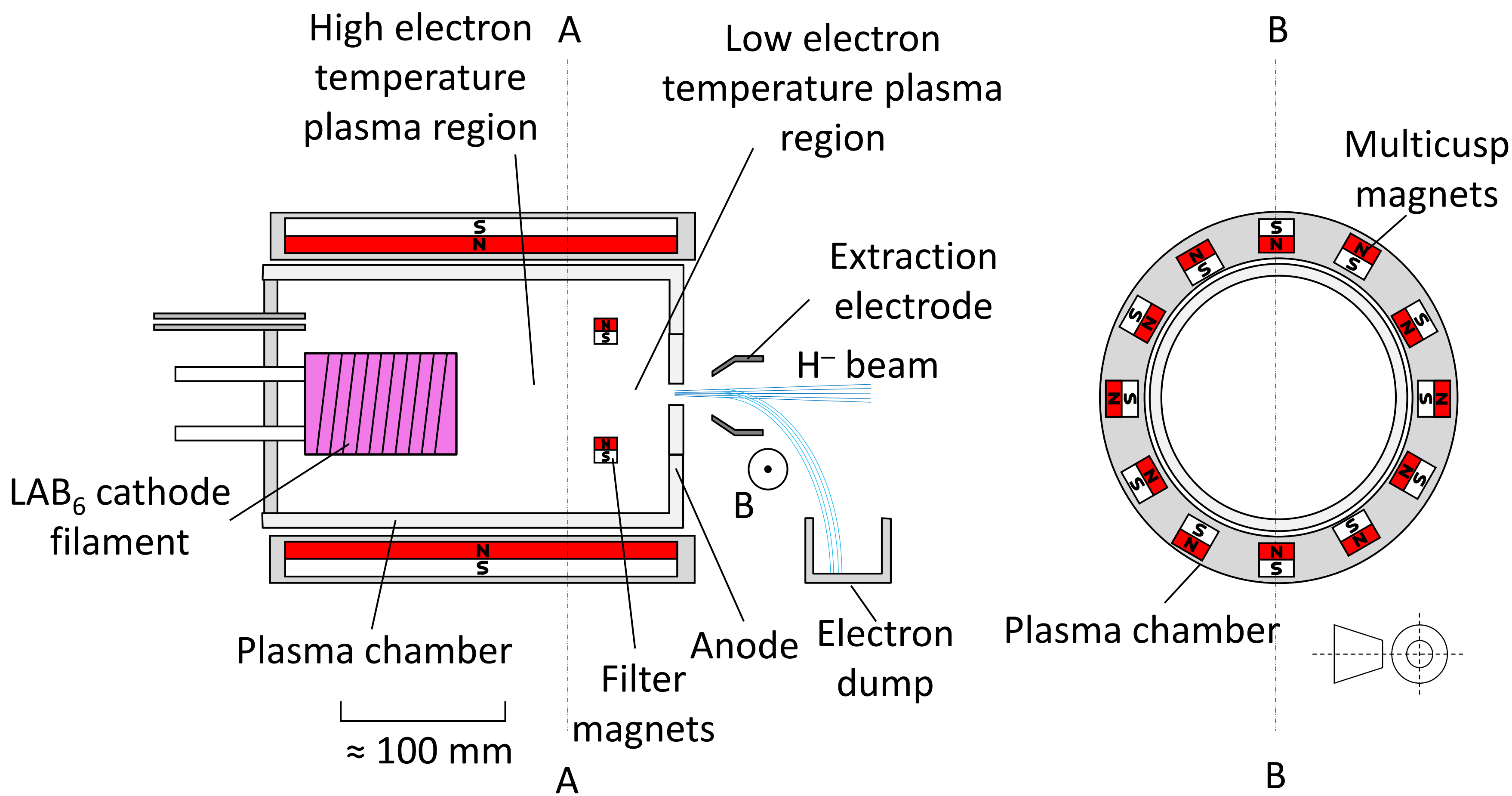
Section on A-A

15 mA DC H^- Multicusp Volume Source




High electron temperature plasma region
A
Low electron temperature plasma region
B
Multicusp magnets
Extraction electrode
H⁻ beam
S
N
Cathode filament
B
Plasma chamber
Filter magnets
Anode
Electron dump
Plasma chamber
≈ 100 mm
A
B
Section on B-B
Section on A-A

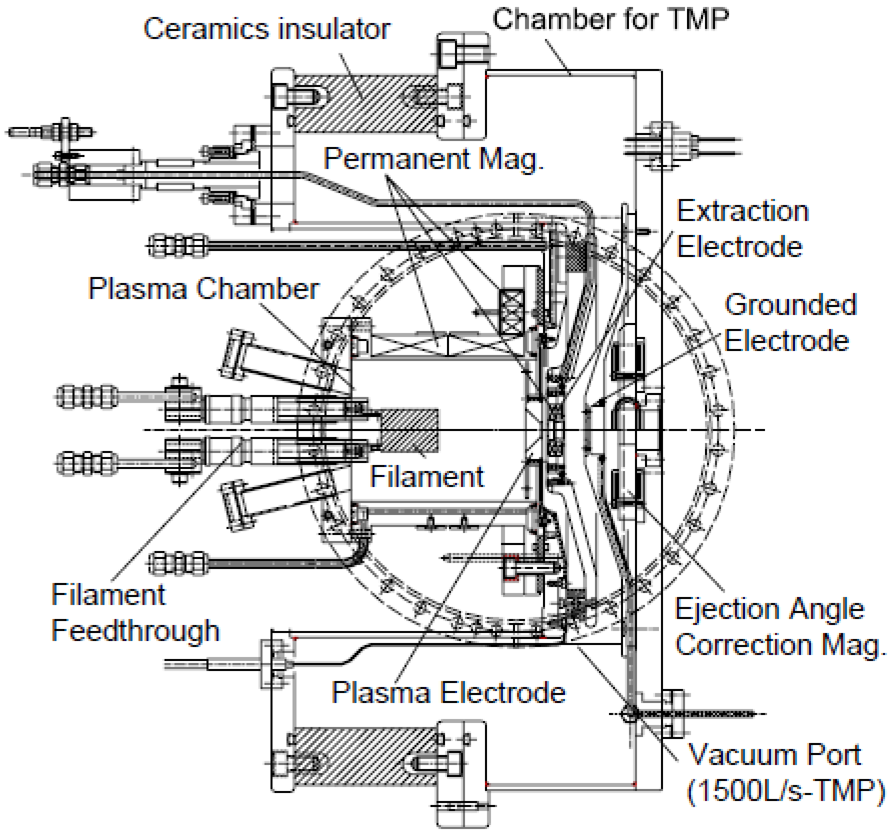
LAB_6 Filament Volume Source

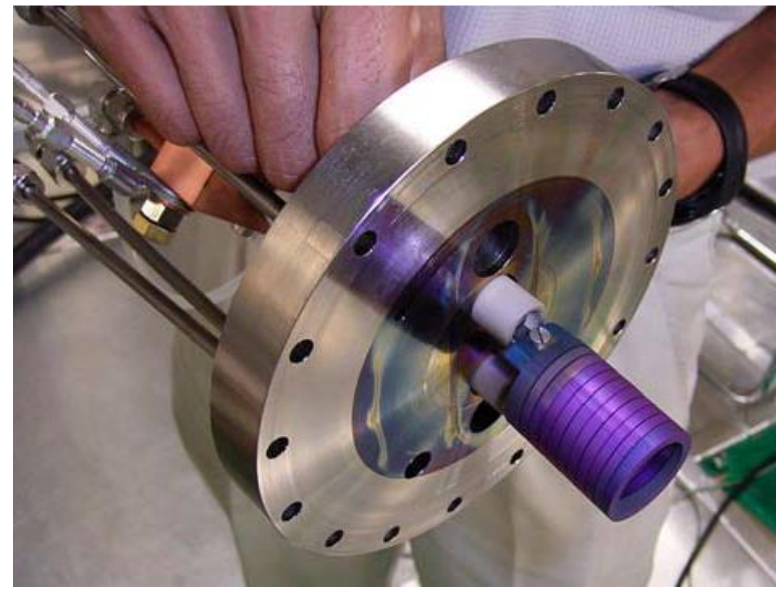


Section on B-B

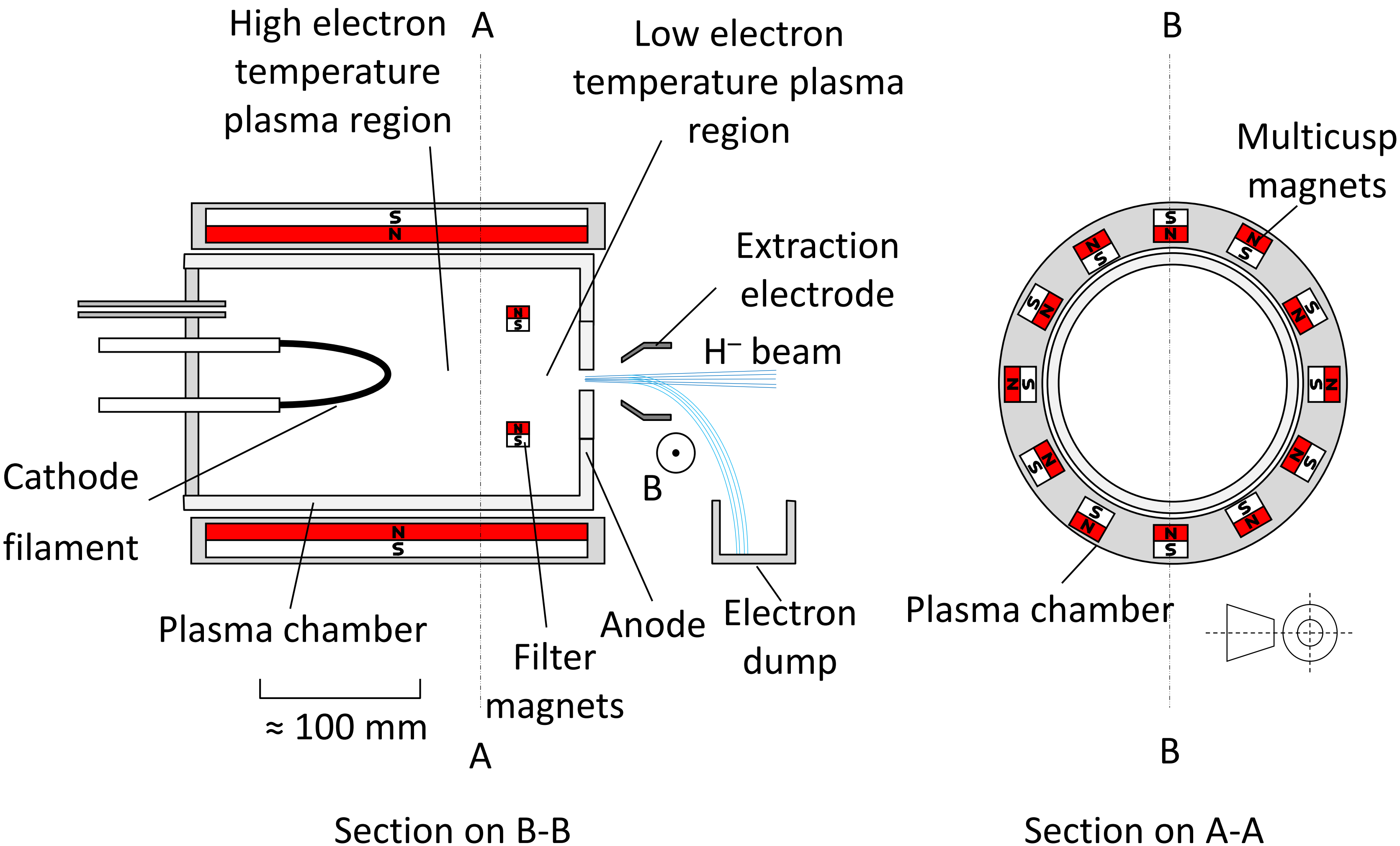
Section on A-A

LAB$_6$ Filament Volume Source

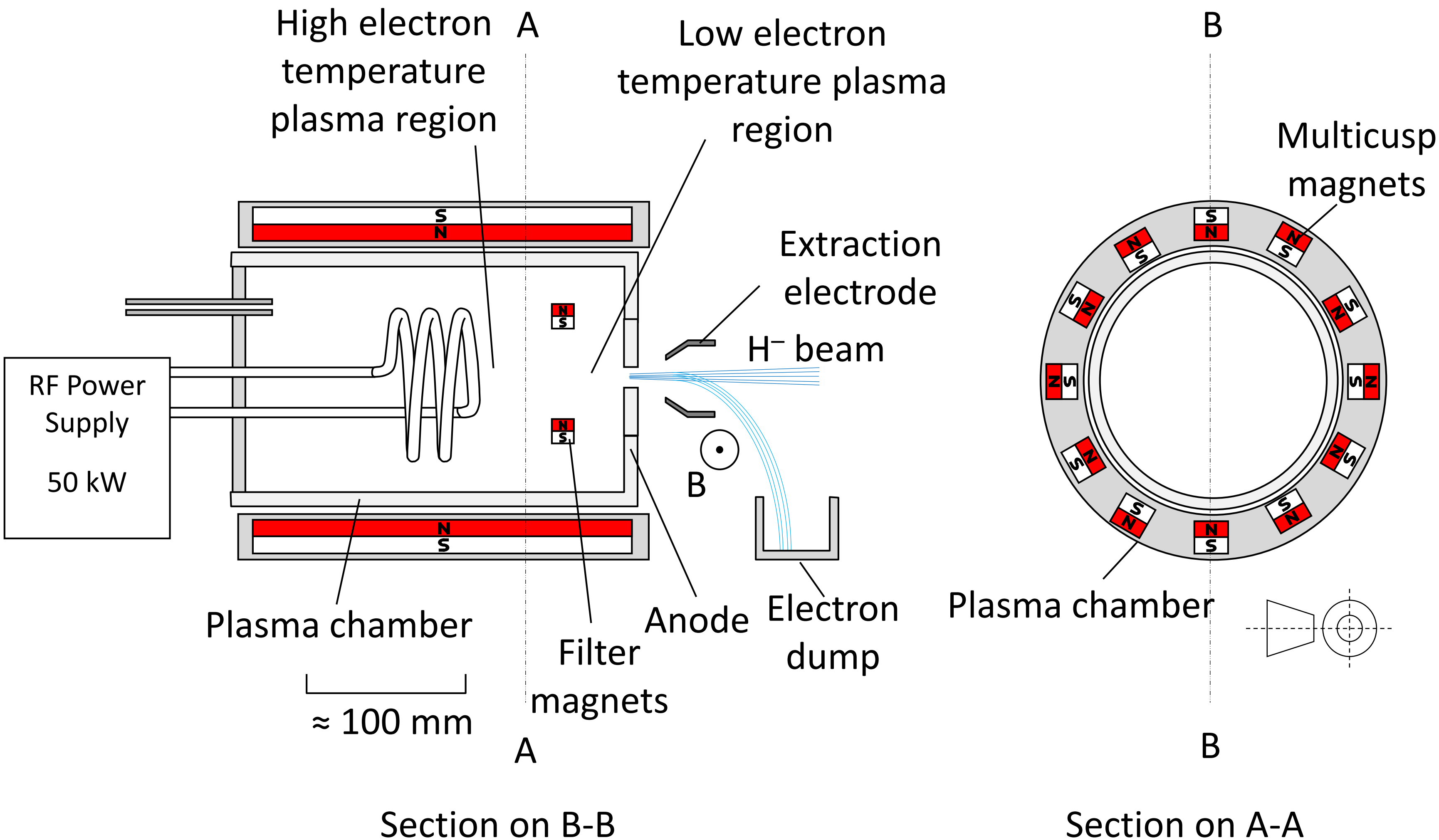




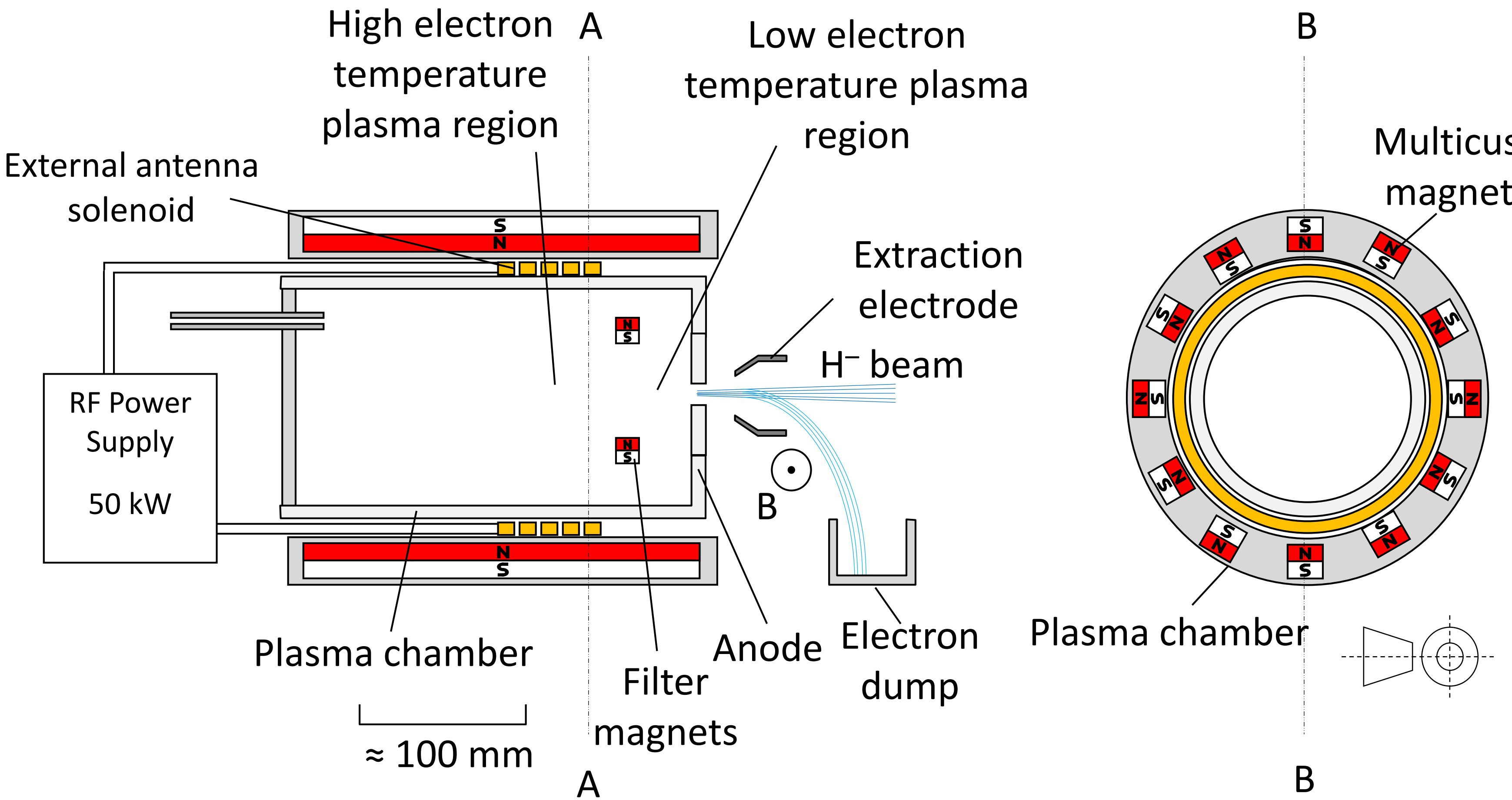
36 mA @500 μs 25 Hz


High electron temperature plasma region
A
Low electron temperature plasma region
B
Multicusp magnets
Extraction electrode
H⁻ beam
Cathode filament
Plasma chamber
Filter magnets
Anode
Electron dump
Plasma chamber
≈ 100 mm
A
B
B
Section on B-B
Section on A-A
S
N

Internal RF Solenoid Antenna Volume Source



External RF Solenoid Antenna Volume Source

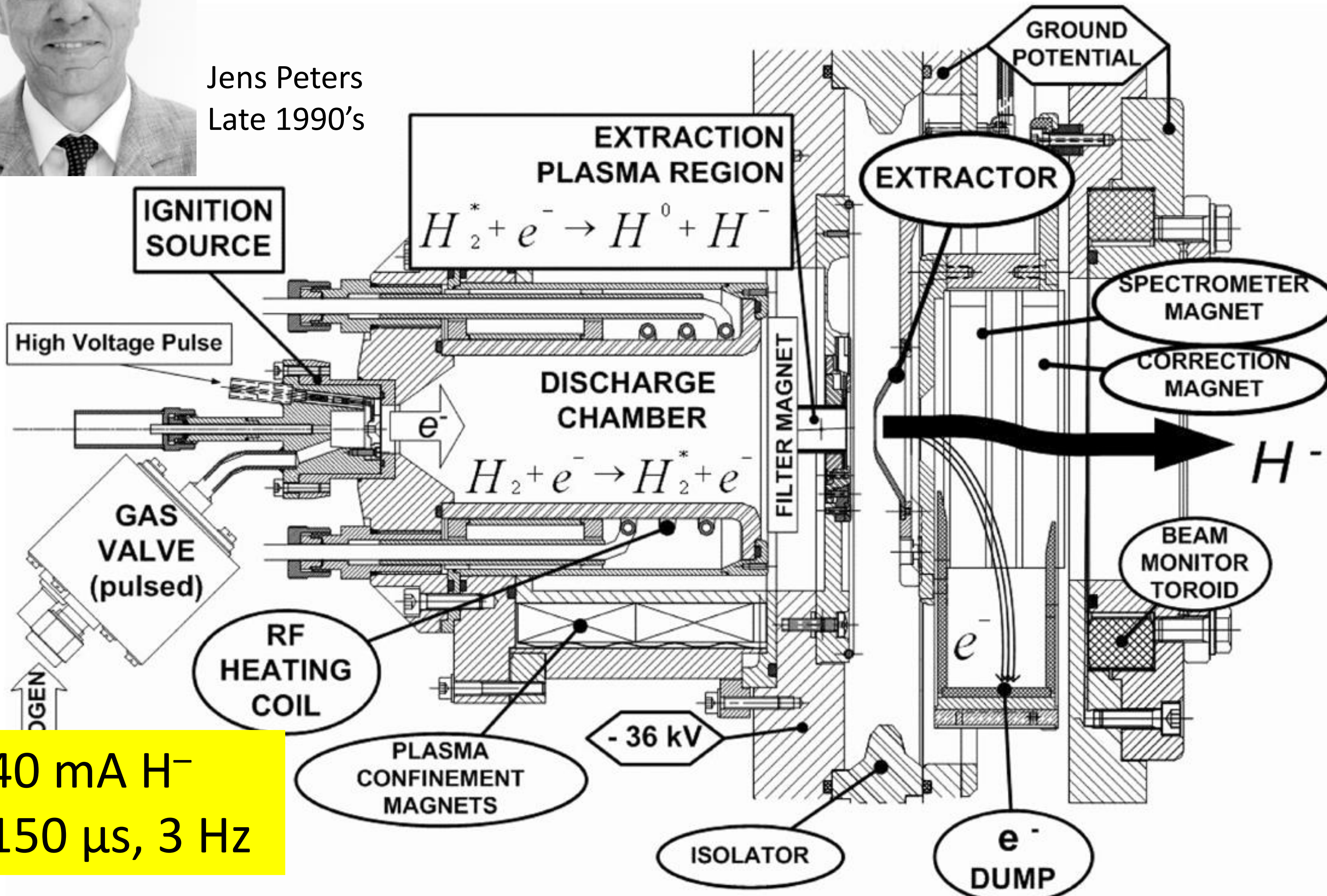


Section on B-B

Section on A-A

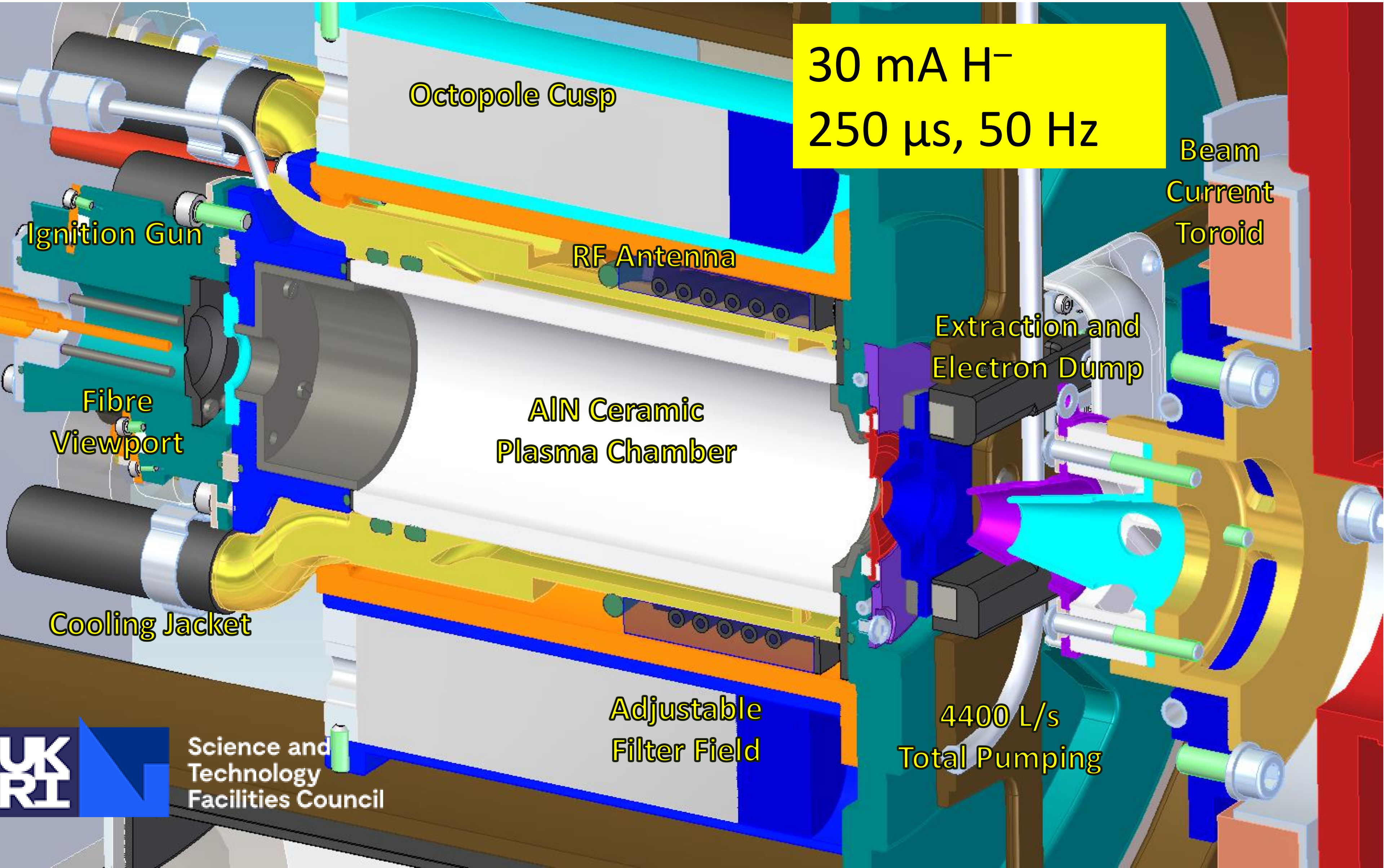
DESY Source

Jens Peters
Late 1990's

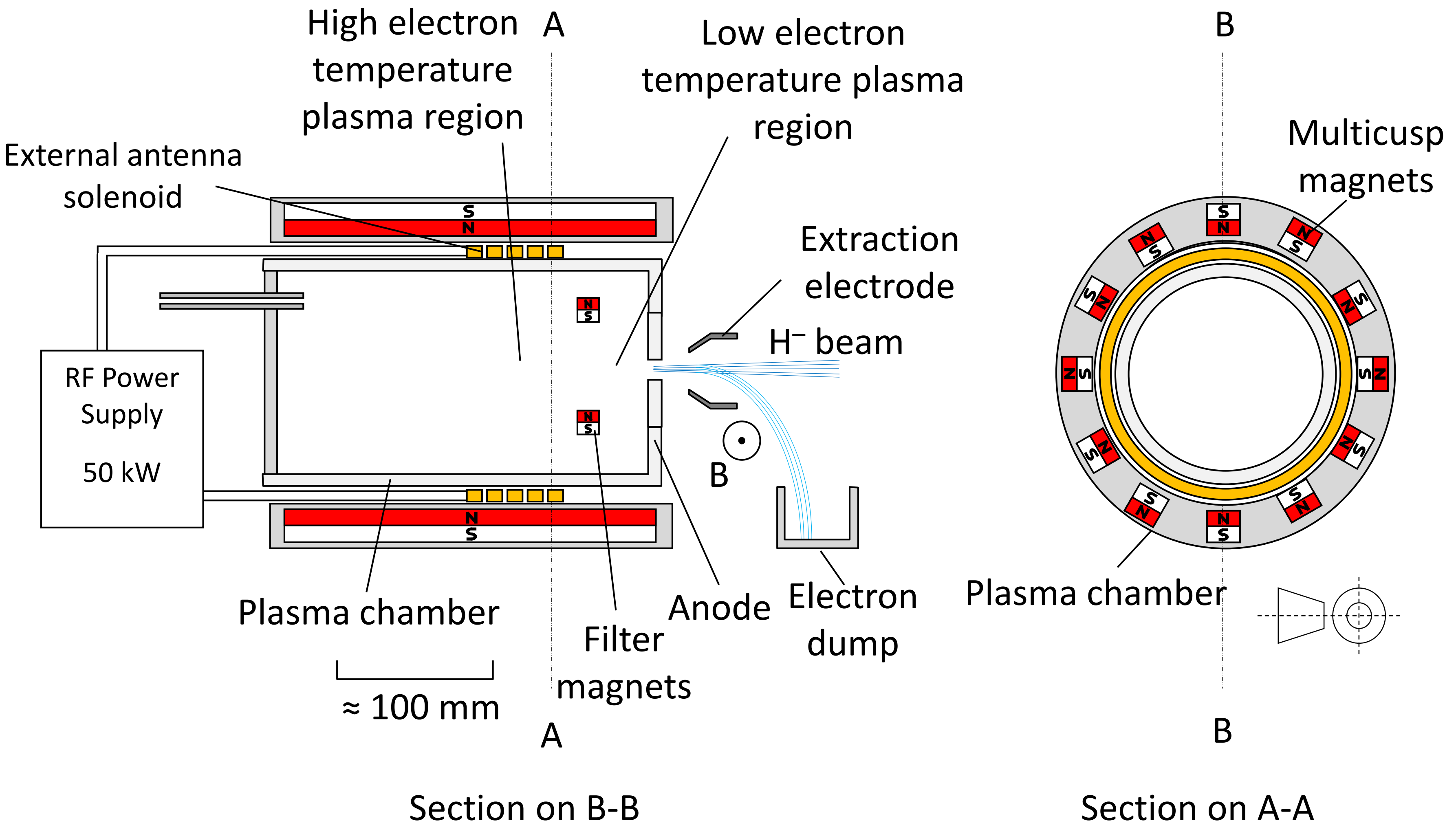


40 mA H^-
150 µs, 3 Hz

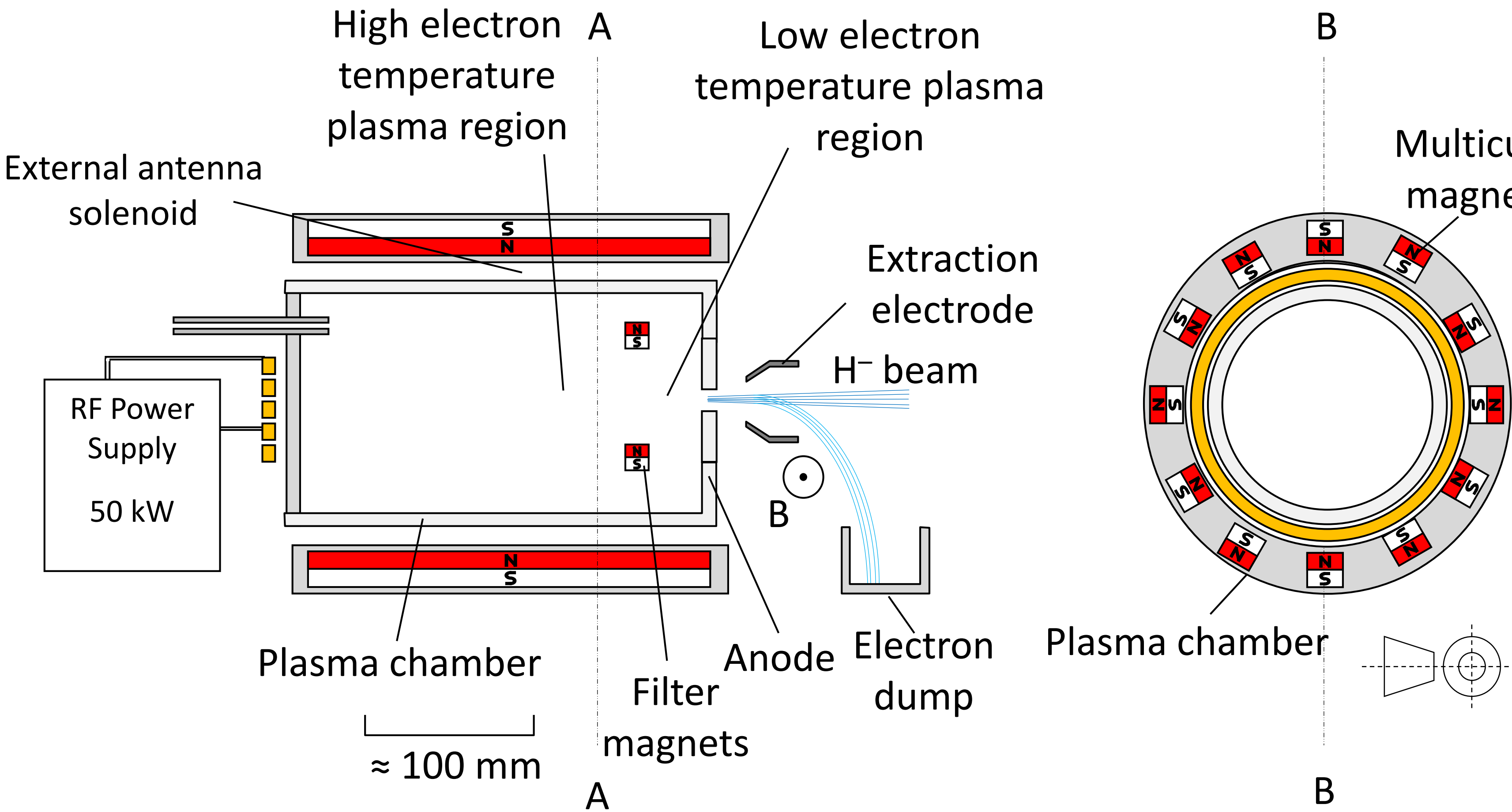
ISIS RF H^- Ion Source (under construction)



External RF Solenoid Antenna Volume Source



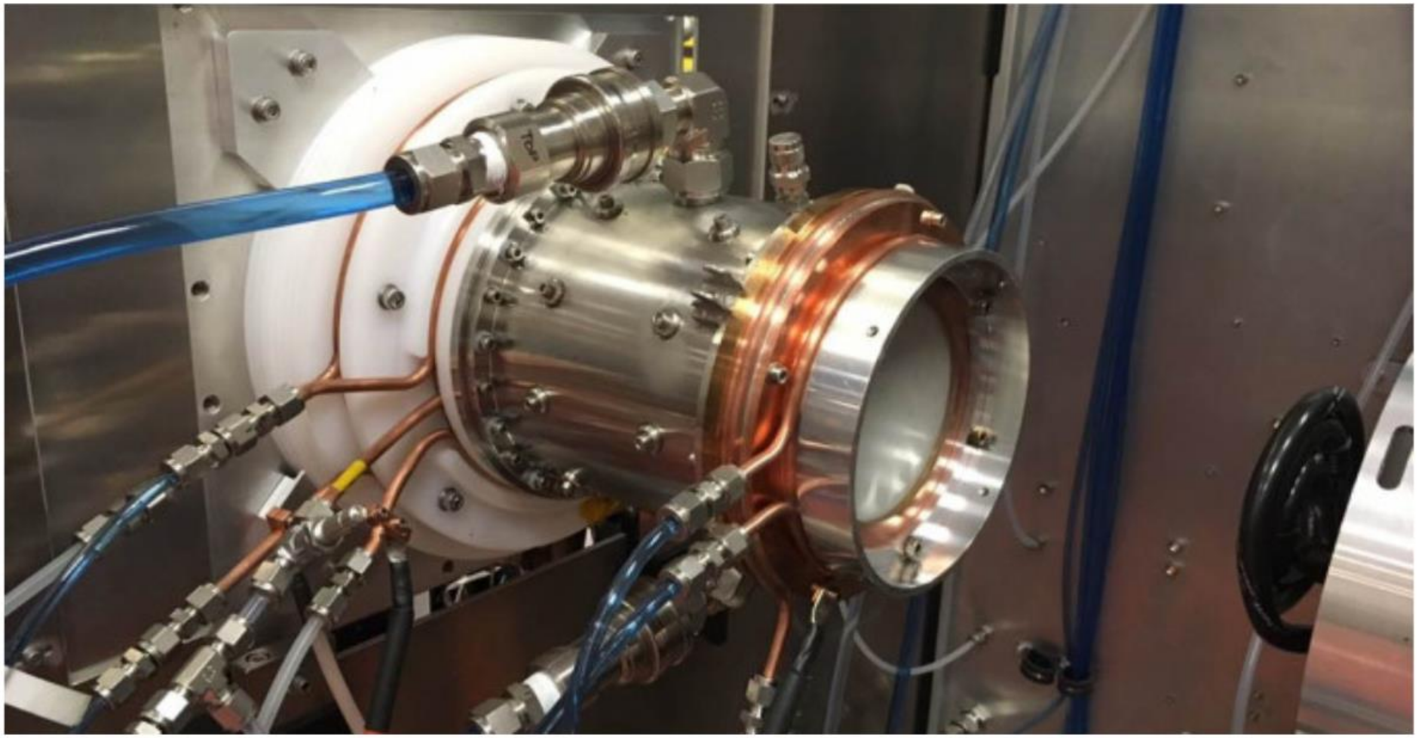
External RF Pancake Antenna Volume Source



Section on B-B

Section on A-A

External RF Pancake Antenna Volume Source

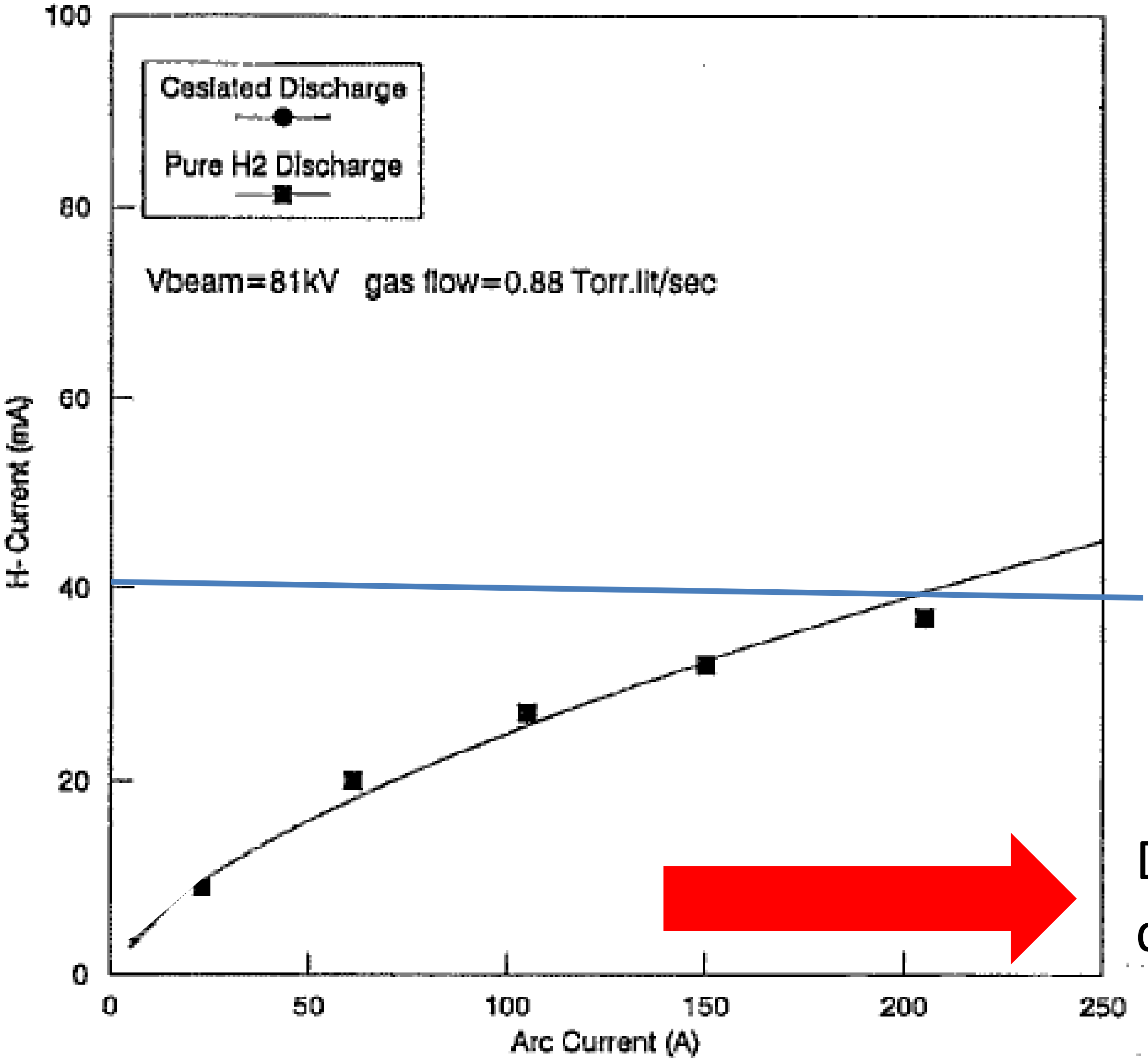


D-Pace

JYVÄSKYLÄN YLIOPISTO
UNIVERSITY OF JYVÄSKYLÄ

7.5 mA H^- DC

Holmes et. al. Culham UK



Add Cesium

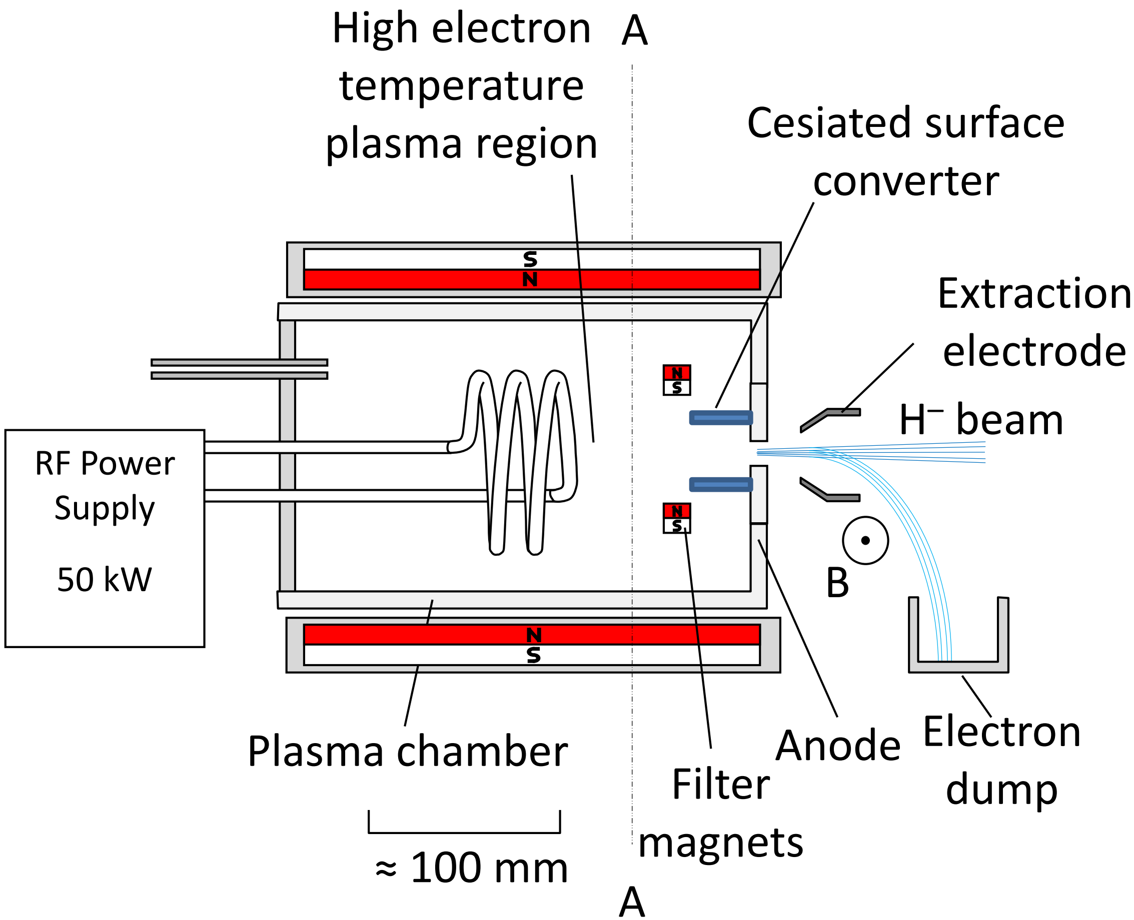
40 mA = apparent limit of the volume process

Destruction process dominate

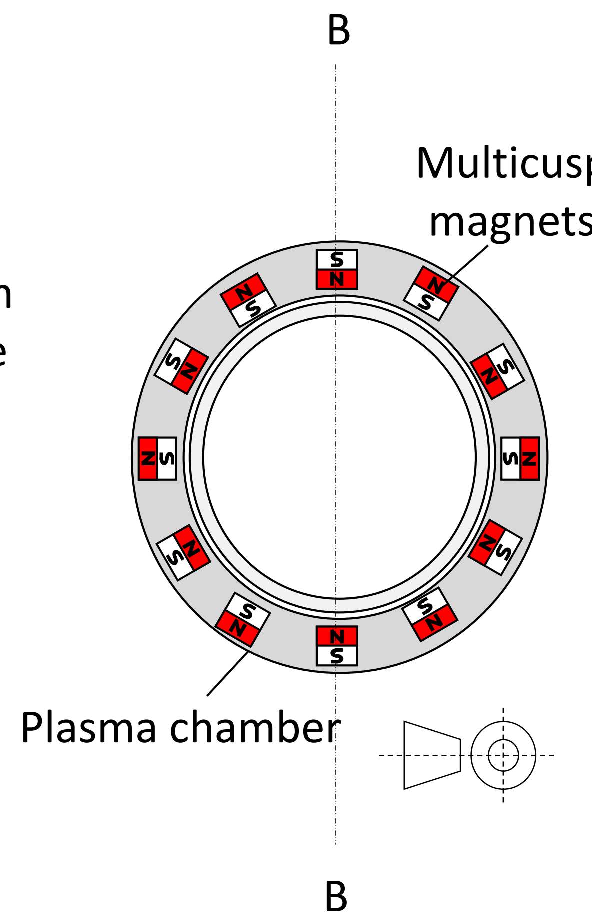
Best of both worlds?

Volume + Surface

Internal RF Solenoid Antenna Volume Source with Surface Converter



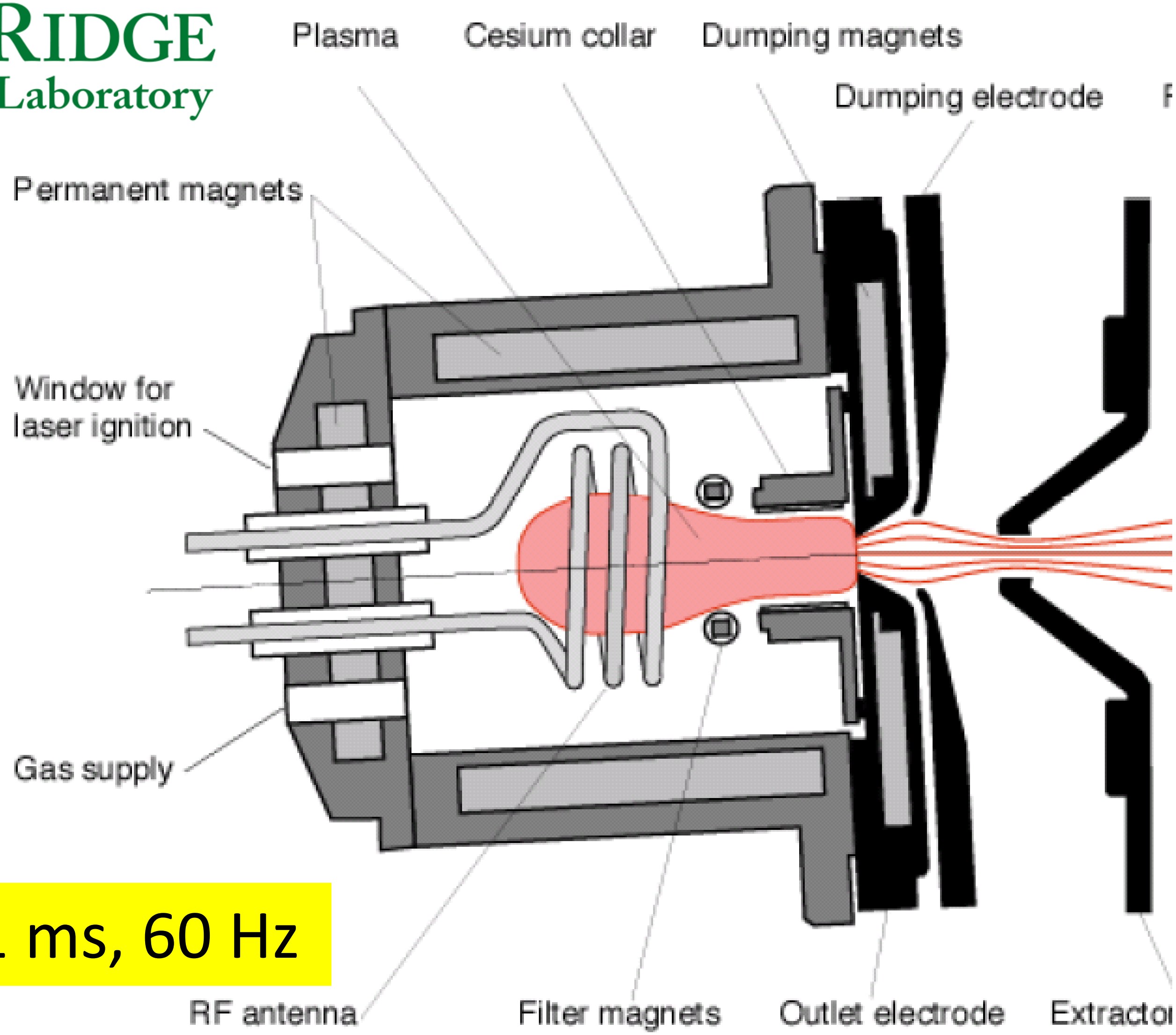
Section on B-B



Section on A-A

SNS Internal RF Solenoid Antenna Volume Source with Surface Converter

Cesium Chromate Cartridges

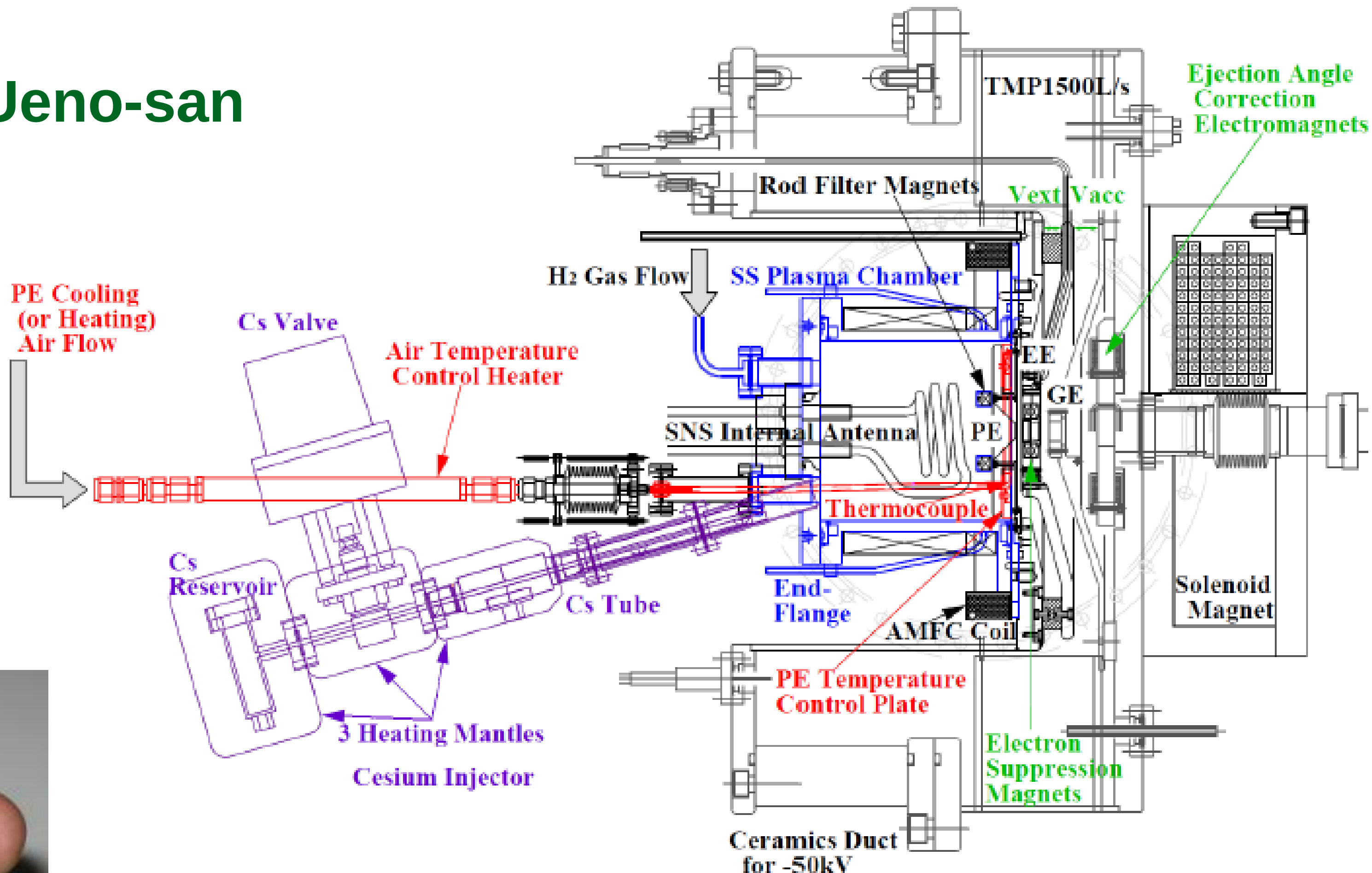


Martin Stockli

60 mA H^- 1 ms, 60 Hz

Cesiated Internal RF Solenoid Antenna Volume Source with Surface Converter

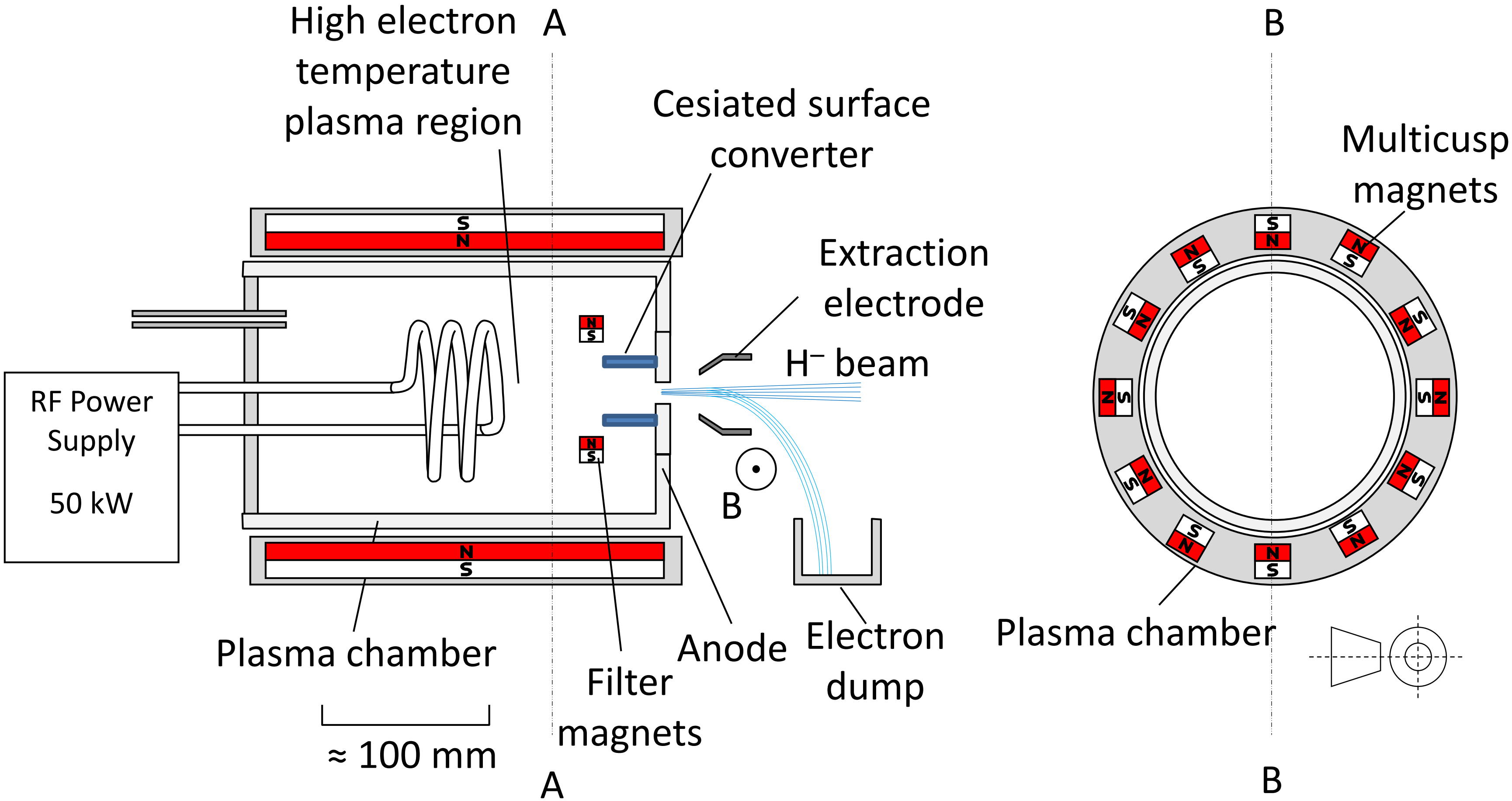
Ueno-san



Elemental Cs

110 mA H^- 0.6 ms 25 Hz

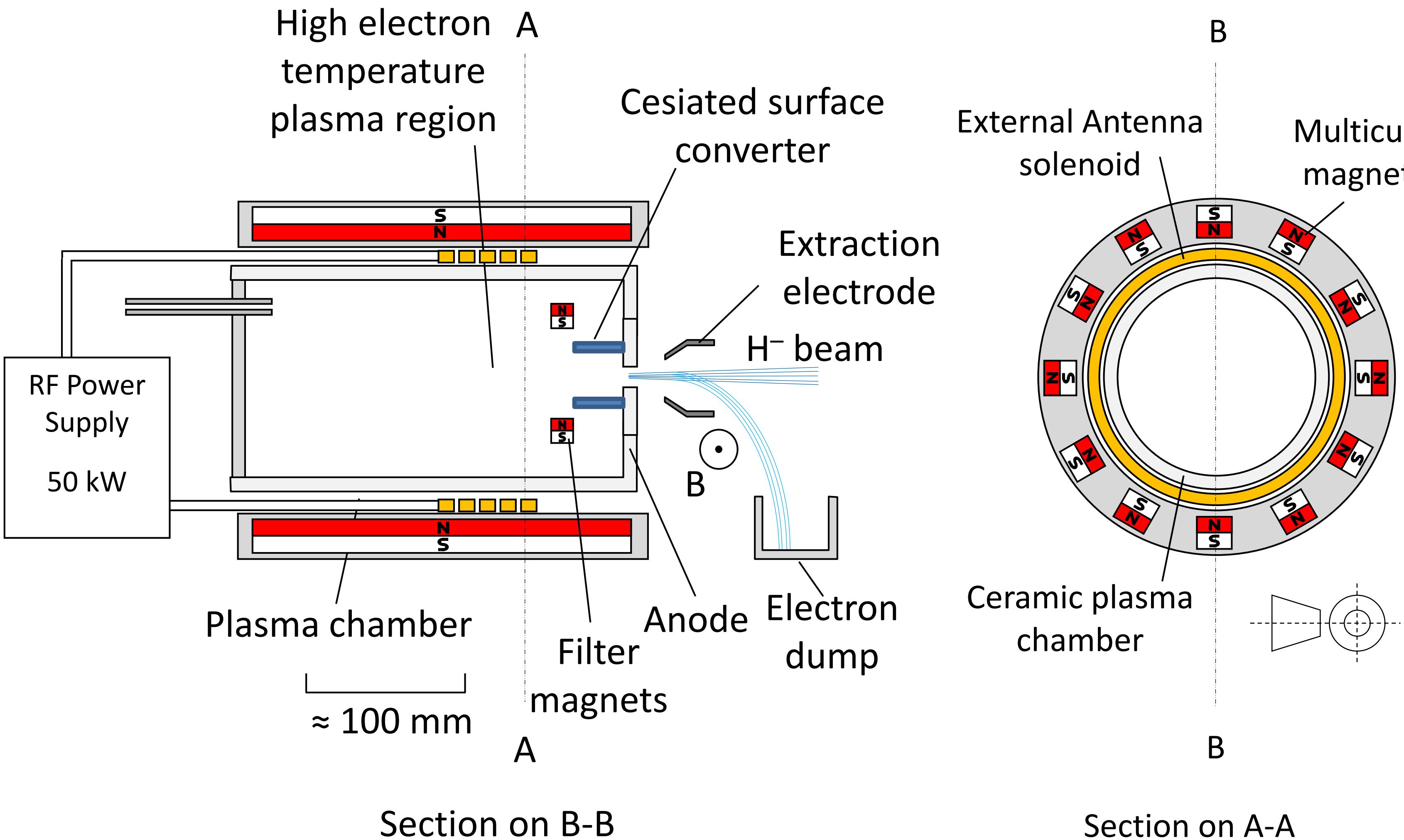
Internal RF Solenoid Antenna Volume Source with Surface Converter



Section on B-B

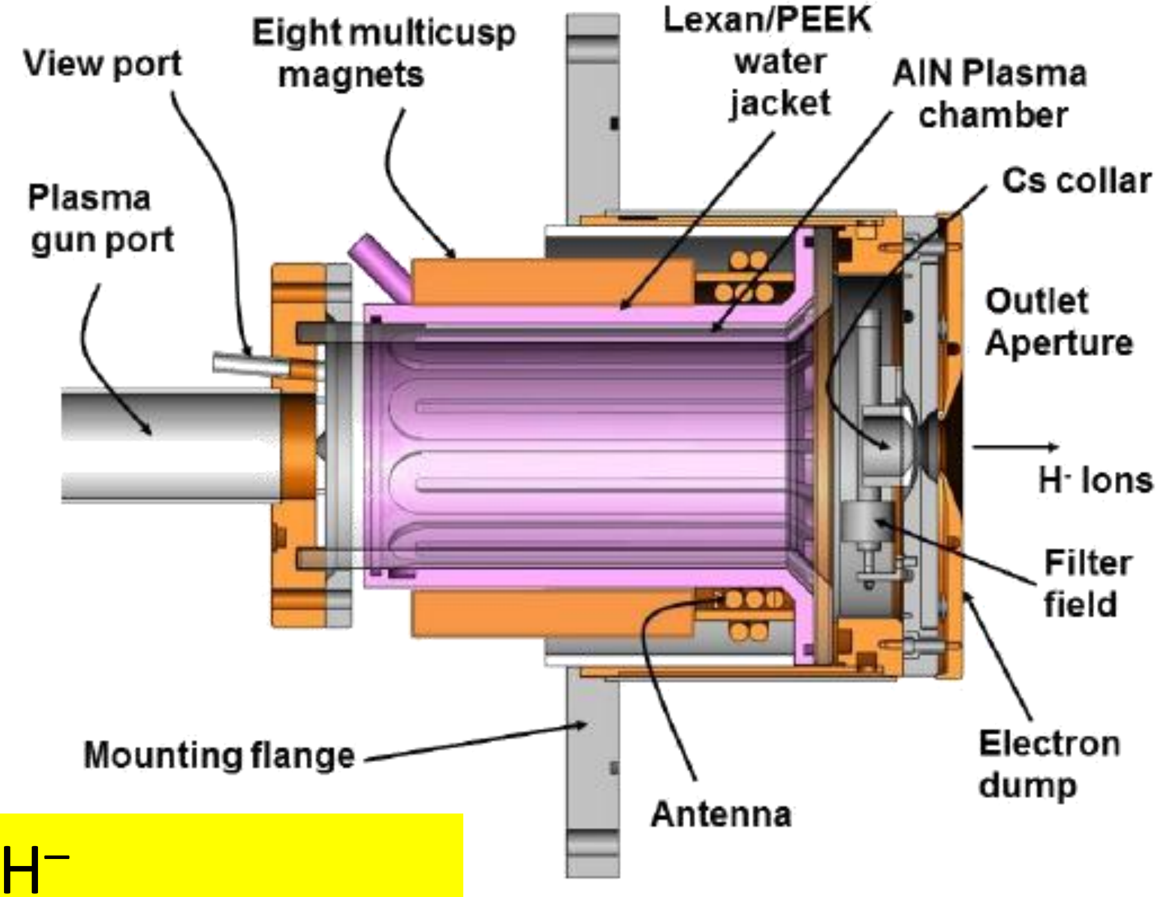
Section on A-A

External RF Solenoid Antenna Volume Source with Surface Converter



Cesiated External RF Solenoid Antenna Volume Source

Rob Welton



40 mA H^-
1 ms, 60 Hz

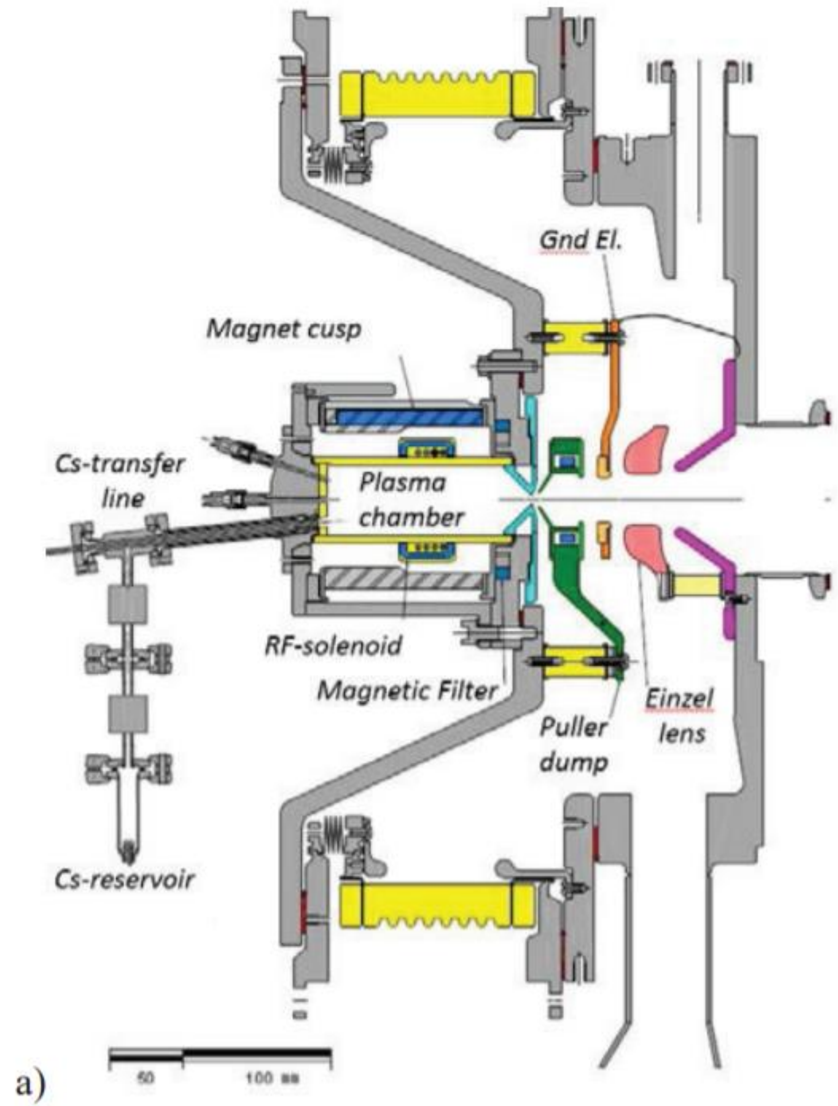
Cesium Chromate Cartridges

Cesiated External RF Solenoid Antenna Volume Source

Jacques Lettry

Elemental Cs

50 mA H^-
0.5 ms, 3 Hz



Thank you for listening

Enjoy spotting the developments being presented at NIBS2020:

Higher currents

Novel materials

New technologies