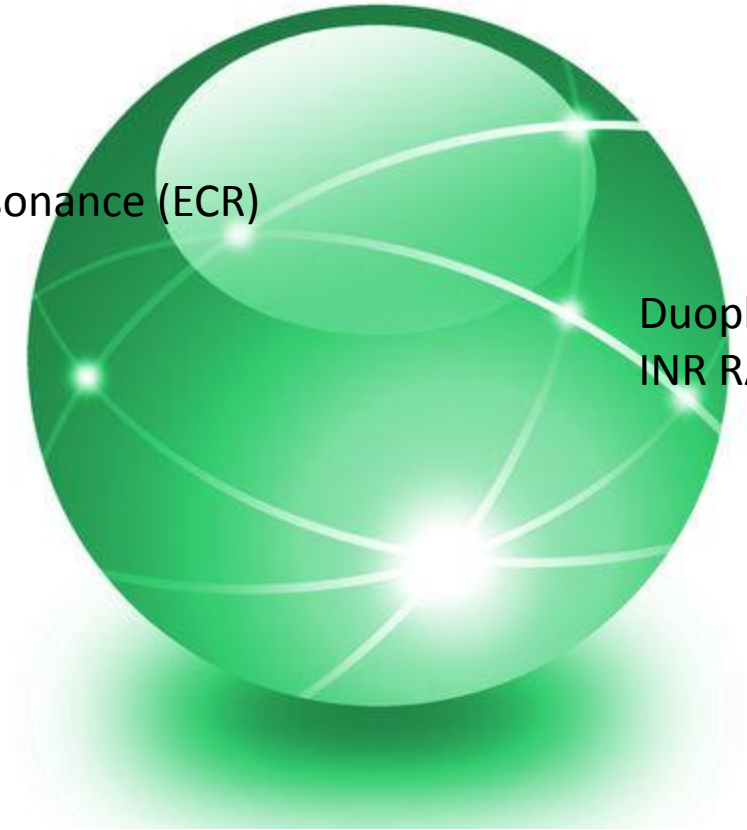
Survey of ion sources

- H+ ion sources
- Surface plasma H- production
- Volume H- production
- H- ion source types

There are basically 2 styles of H+ sources that are used in most labs

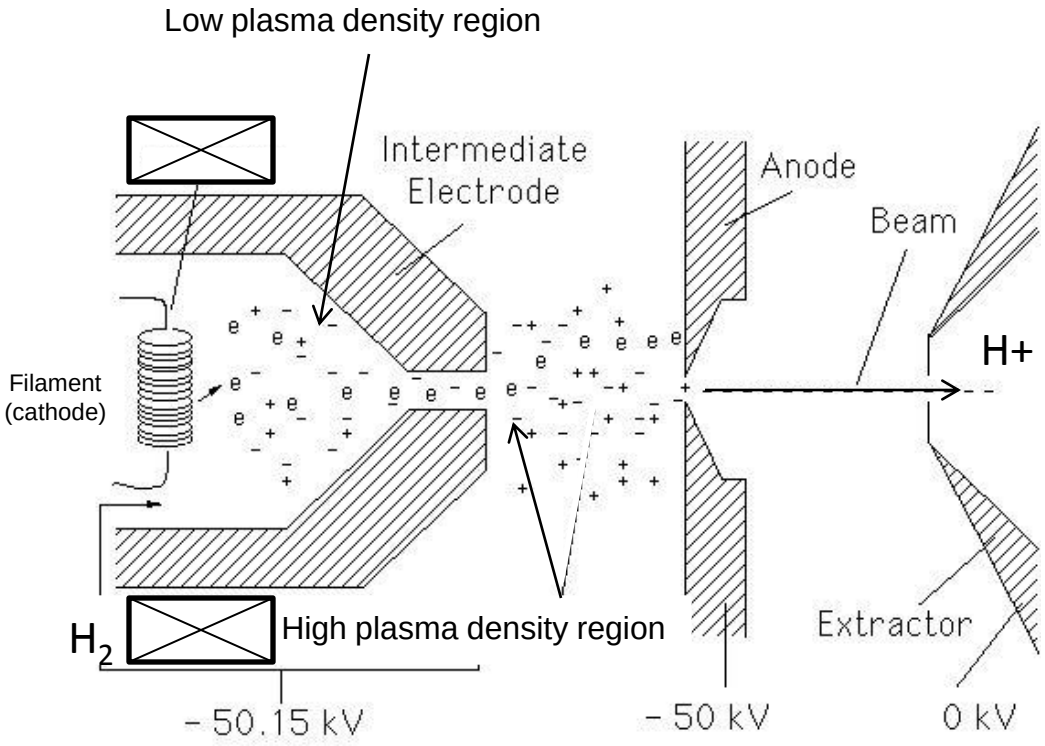
Electron Cyclotron Resonance (ECR)
ESS, SPIRAL2,FAIR



Duoplasmatron
INR RAS, FNAL HINS,

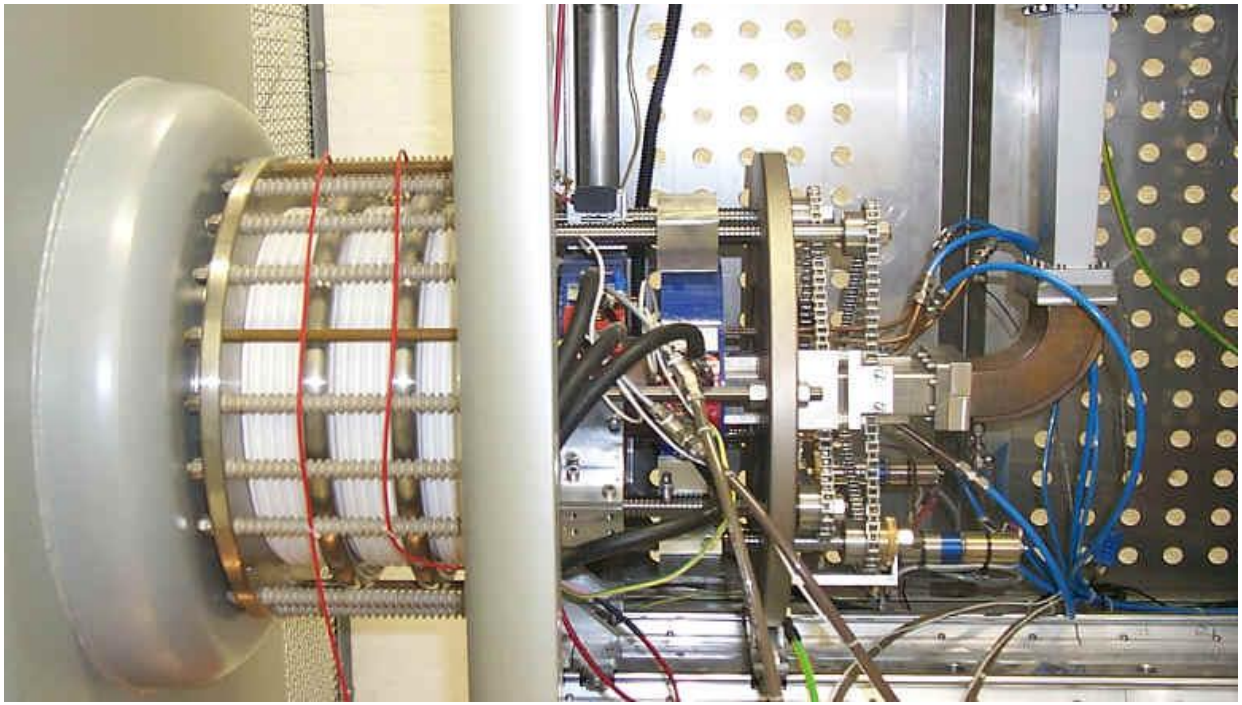
H+ sources

Duoplasmatrons

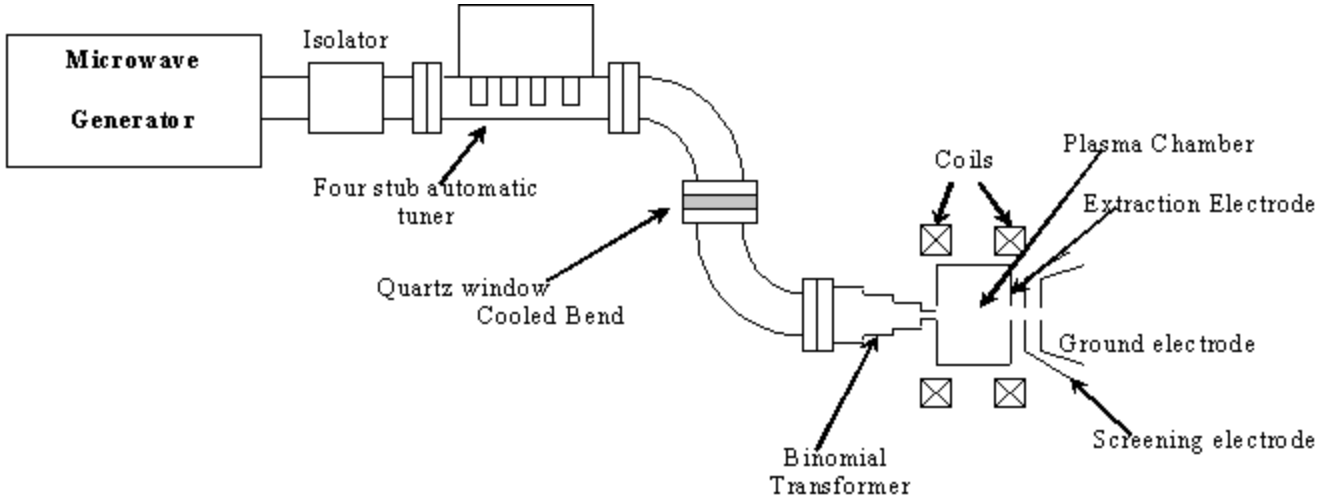


- A cathode is heated, giving off electrons they are attracted to the “intermediate electrode”. As they travel towards the electrode they collide with the surrounding gas (H_2 in this case)
- These collisions free additional electrons which collide with other particles
- The intermediate electrode squeezes down the electrons giving a dense plasma
- Low density plasma in the chamber/high density plasma outside the chamber gives the name duo-plasmatron
- The high negative potential on the anode pulls H+ out of the source

Microwave ECR sources



2.45GHz microwaves , which correspond to the electron cyclotron frequency are injected into the source volume which ionizes a low pressure gas into a plasma.



H+ sources

	Source type	Beam current	Pulse width	Rep rate
FAIR	ECR	70mA		4Hz
PEFP	Duoplasmatron	20mA	2ms	120Hz
ESS	ECR	60mA	2ms	20Hz
SPIRAL2	ECR	5mA		DC
IFMIF		140mA		DC
INR RAS	Duoplasmatron	50-120mA	200us	50Hz

Surface production Sources (SPS)

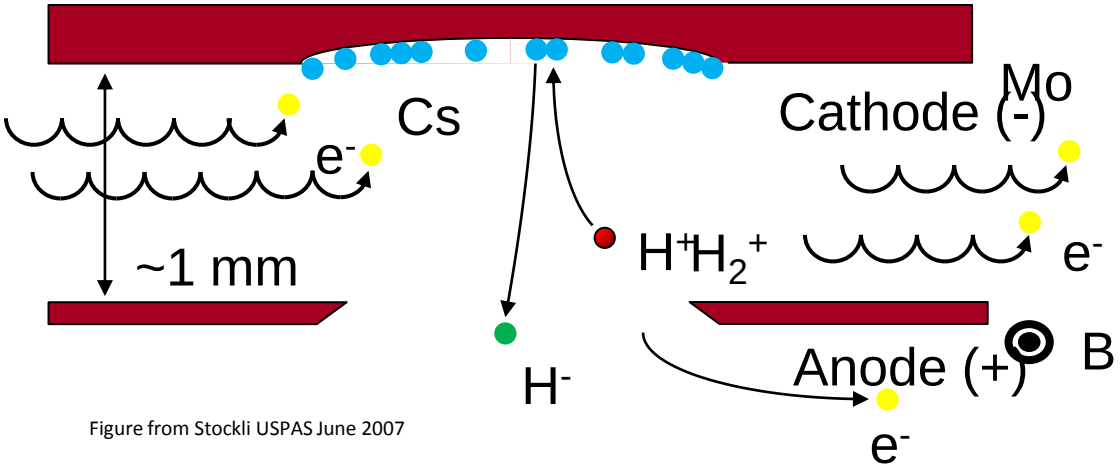
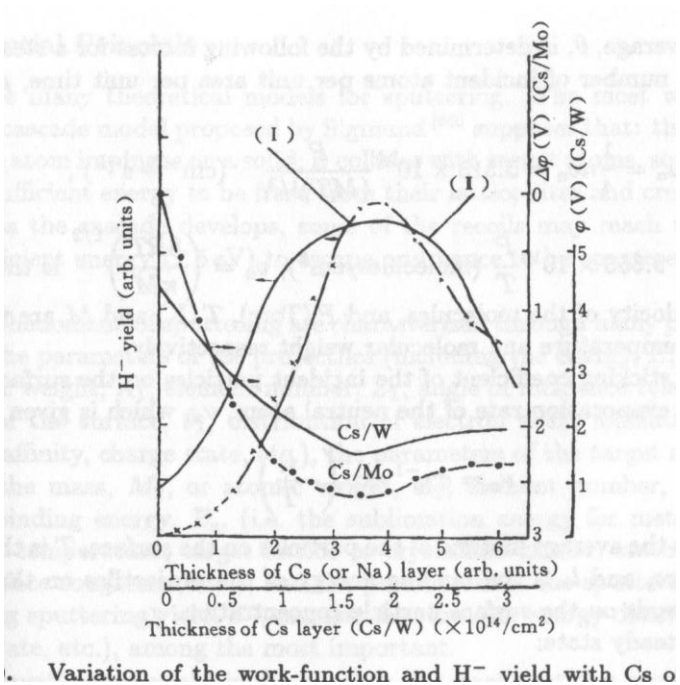


Figure from Stockli USPAS June 2007

- Mo has a host of loosely bound e- that take about 4.6eV to remove
- Cs lowers the surface work function to about 1.8eV with 0.6 mono-layer thickness
- Hydrogen affinity is about 0.75eV so most of the hydrogen particle leave the surface as H- ions
- This is why we use cesiated sources



Variation of the work-function and H⁻ yield with Cs o

Figure from ZHANG Ion Sources

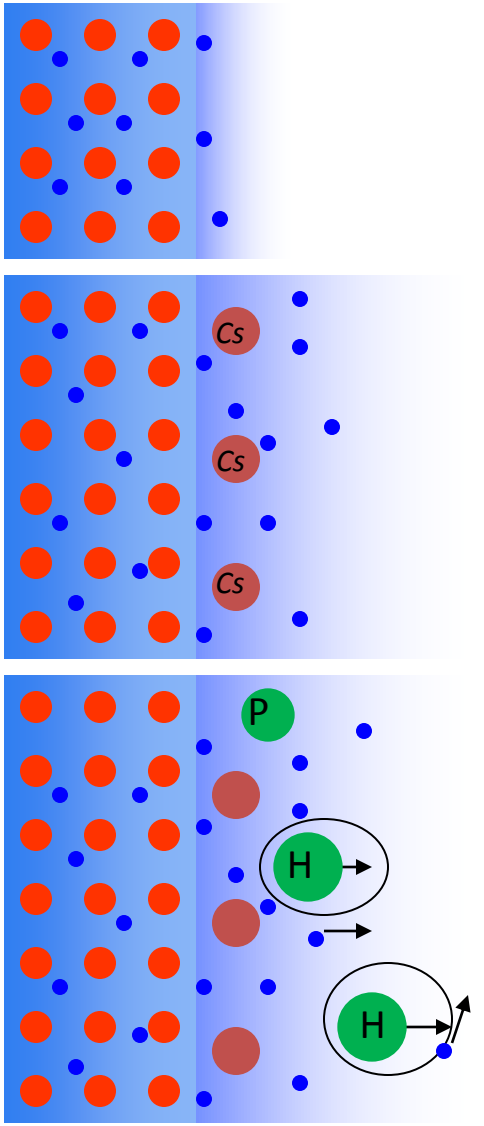


Figure from Stockli USPAS June 2007

Volume H- production

For volume sources, H- ion production relies on increased cross section for dissociative-attachment reaction (in the plasma volume) when molecules are excited to high vibrational states (v″>2).

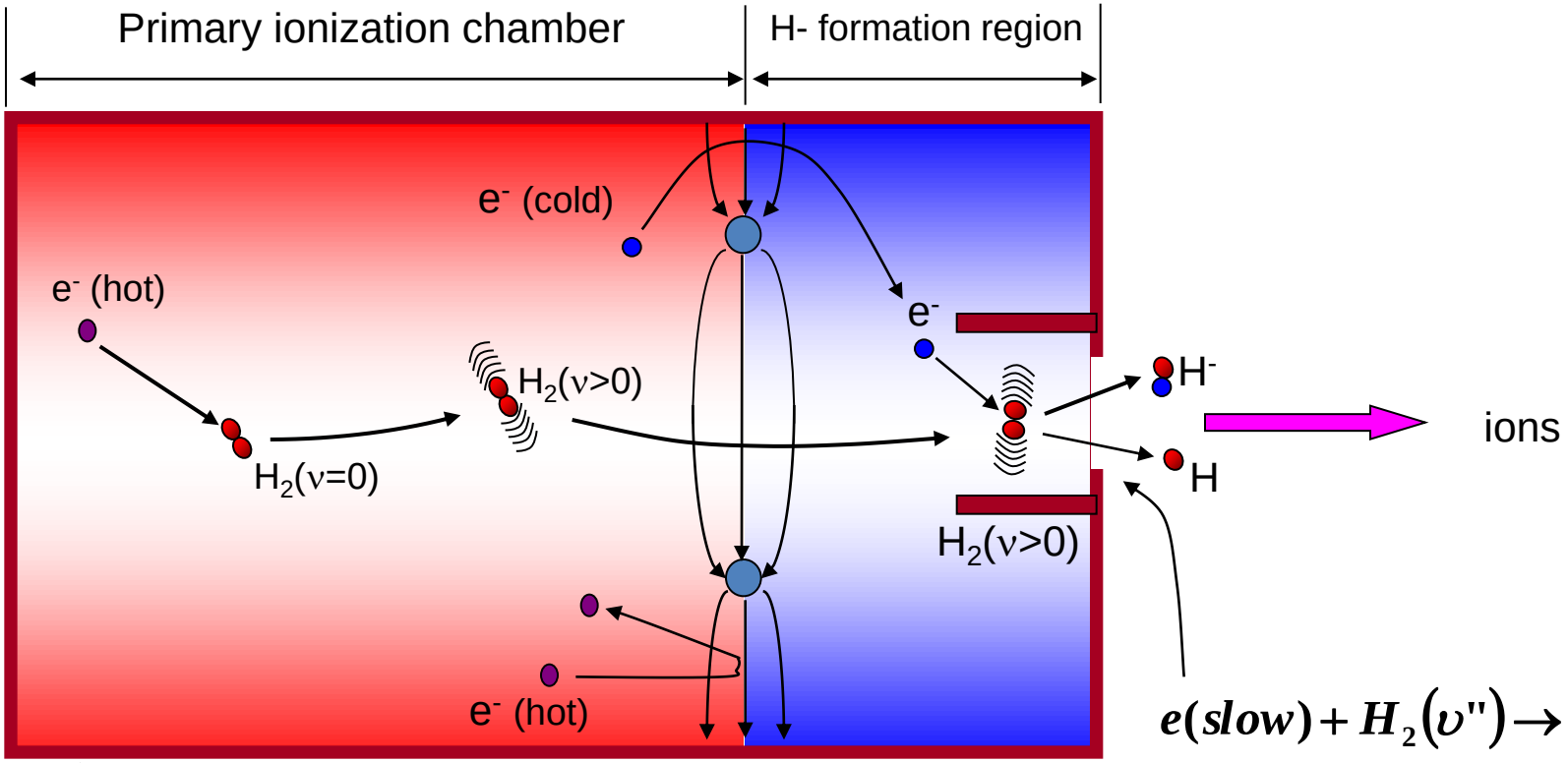
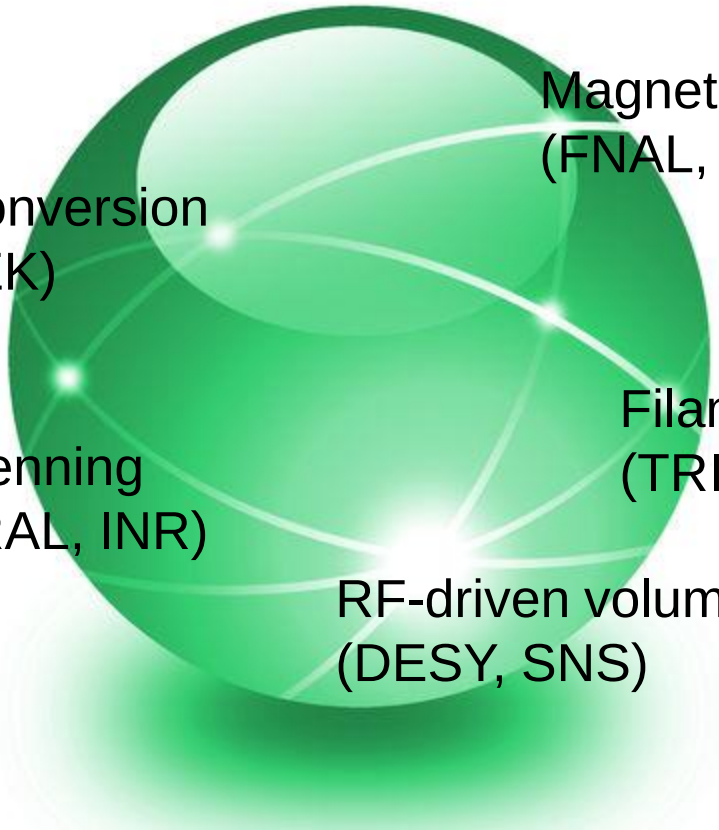


Figure from Stockli USPAS June 2007

There are basically 5 proven H- ion sources in use at major labs:



Magnetron
(FNAL, BNL, ANL, DESY)

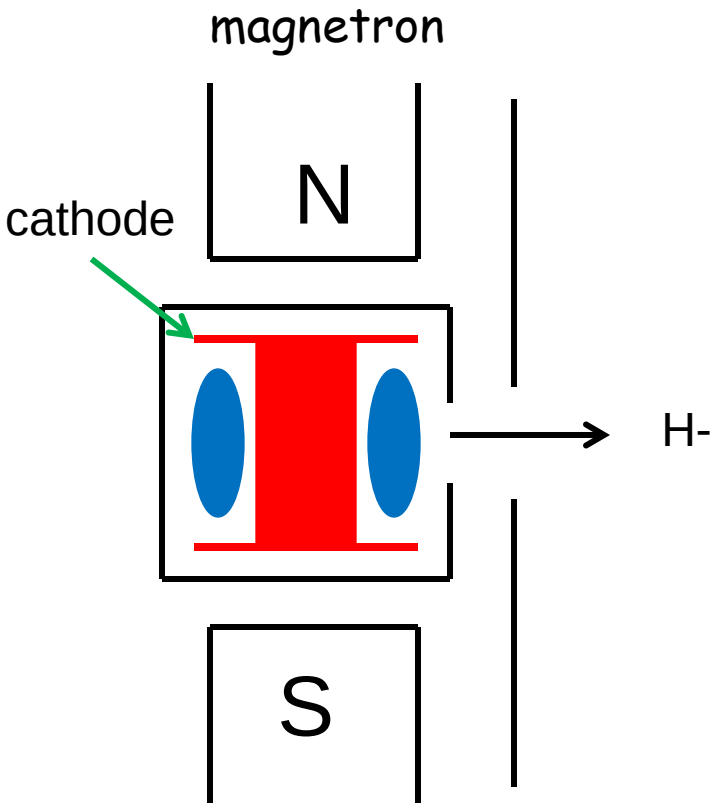
Surface conversion
(LANL, KEK)

Filament-driven volume
(TRIUMF, Jyväskylä)

Penning
(RAL, INR)

RF-driven volume
(DESY, SNS)

Magnetron sources

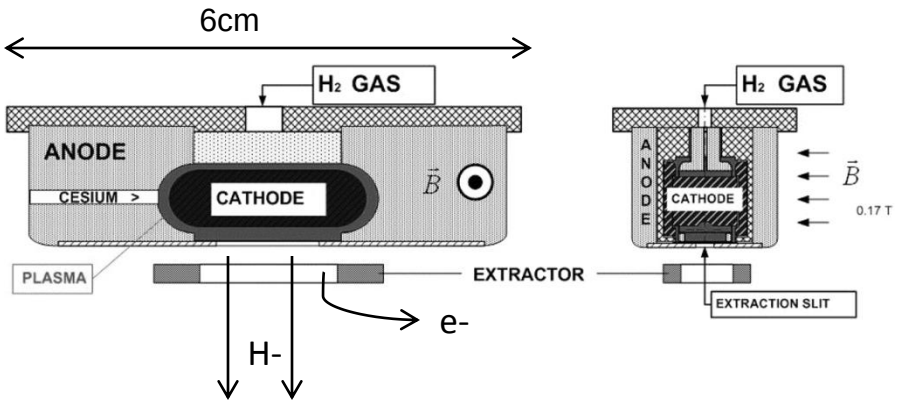


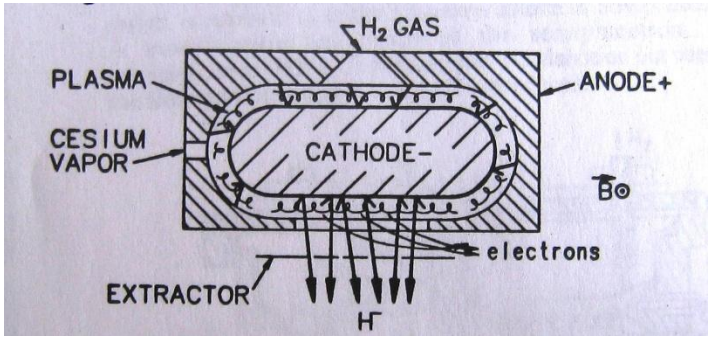
Plasma is generated by ExB motion of electrons

- H- are produced at the cathode surface then extracted (SPS Source)
- They are then pulled out of the source by the extractor

FNAL magnetron H- sources are used

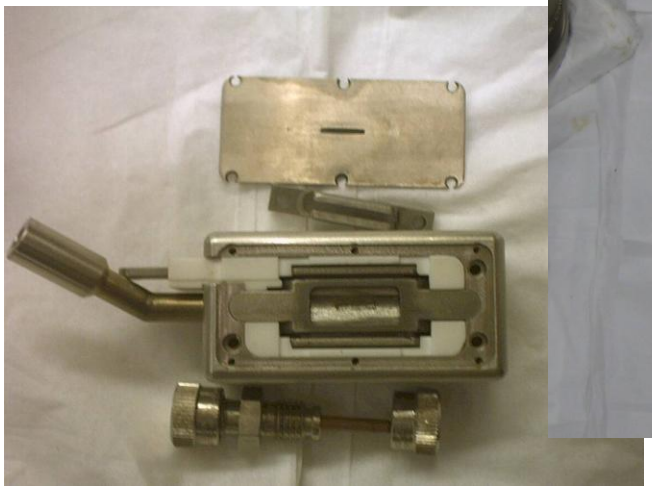
- In Cockcroft-Walton
- New source for Preinjector upgrade (RFQ project)



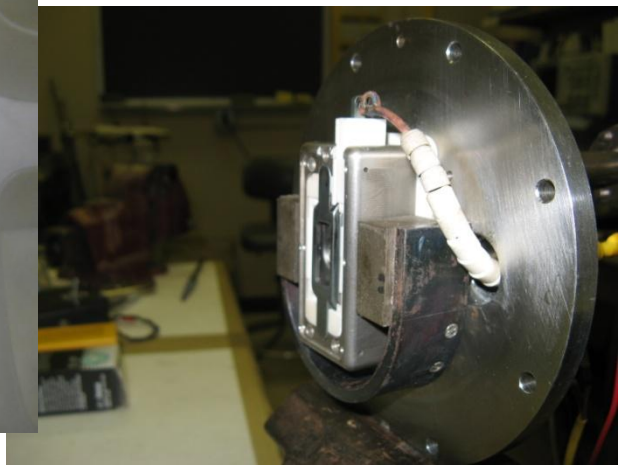


Magnetron sources

FNAL



BNL



Parameter	Value
H- beam current	50 - 60mA
Arc current	45 - 55A
Arc Voltage	115 – 145V
Extractor Voltage	15 – 18kV
Pulse width	80 usec
Rep Rate	15Hz
Duty factor	0.12%
Power efficiency	9mA/kW
Average lifetime	3.5 months

Parameter	Value
H- beam current	100mA
Arc current	10A
Arc Voltage	150V
Extractor Voltage	35kV
Pulse width	700 usec
Rep Rate	7.5Hz
Duty factor	0.5%
Power efficiency	67mA/kW !
Average lifetime	9 months

Penning sources

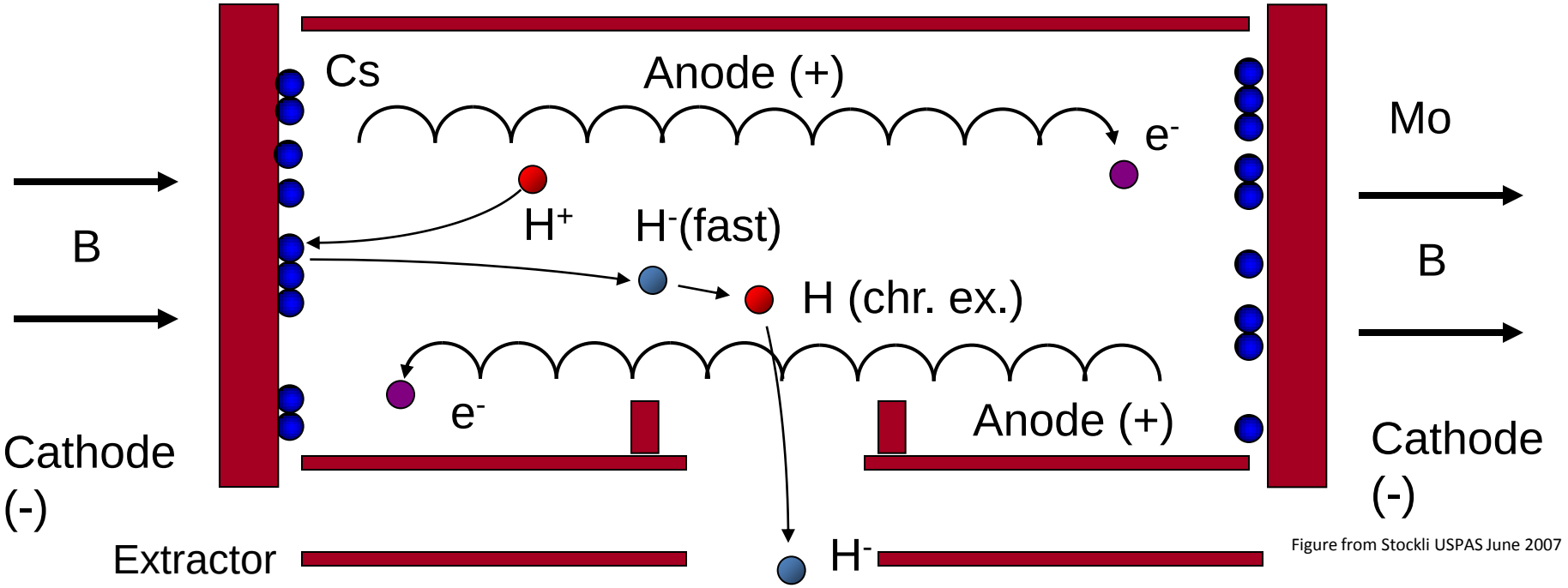


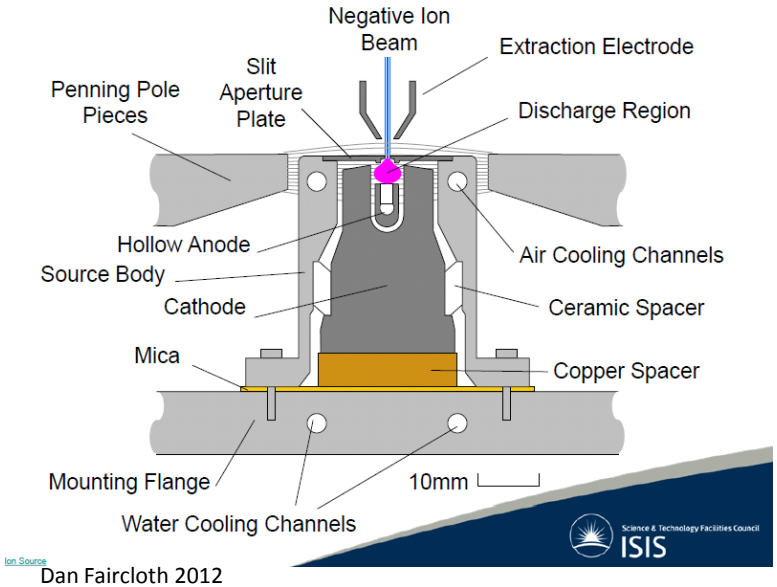
Figure from Stockli USPAS June 2007

$H^-(fast)+H(slow) \rightarrow H(fast)+H^-(slow)$

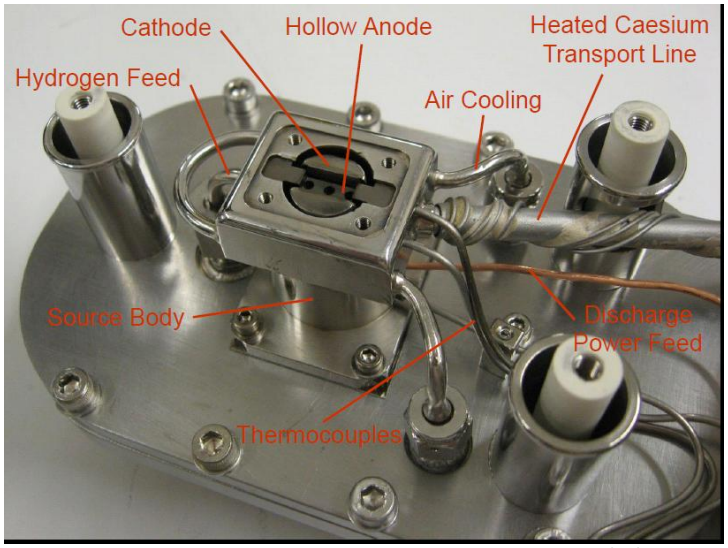
- H- ions produced on the cathode similar to magnetron
- Relies on charge exchange to produce slow H- ions for extraction
- One benefit: easy access to cathode allows cooling which in turn allows higher duty factors (possibly DC)

Penning sources

RAL ISIS penning source

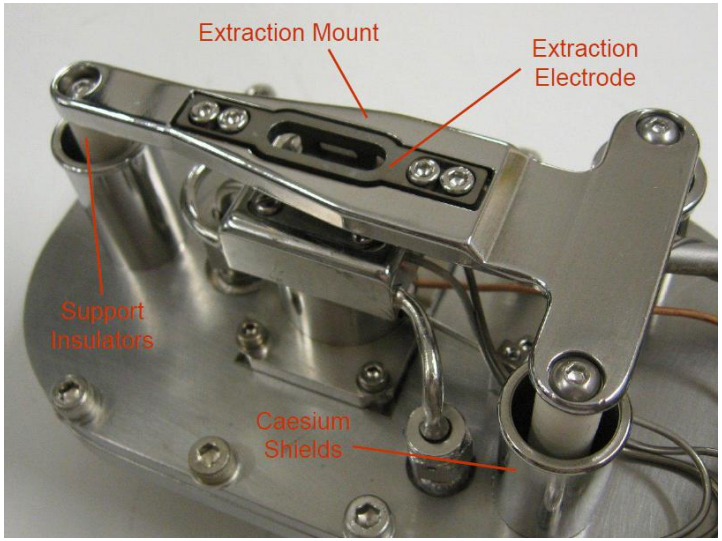


Dan Faircloth 2012



Dan Faircloth 2012

Parameter	Value
H- beam current	70mA
Arc current	50A
Extractor Voltage	17kV
Pulse width	2 msec
Rep Rate	50Hz
Duty factor	10%
Average lifetime	20 days



Dan Faircloth 2012

Mulit- cusp converter ion source

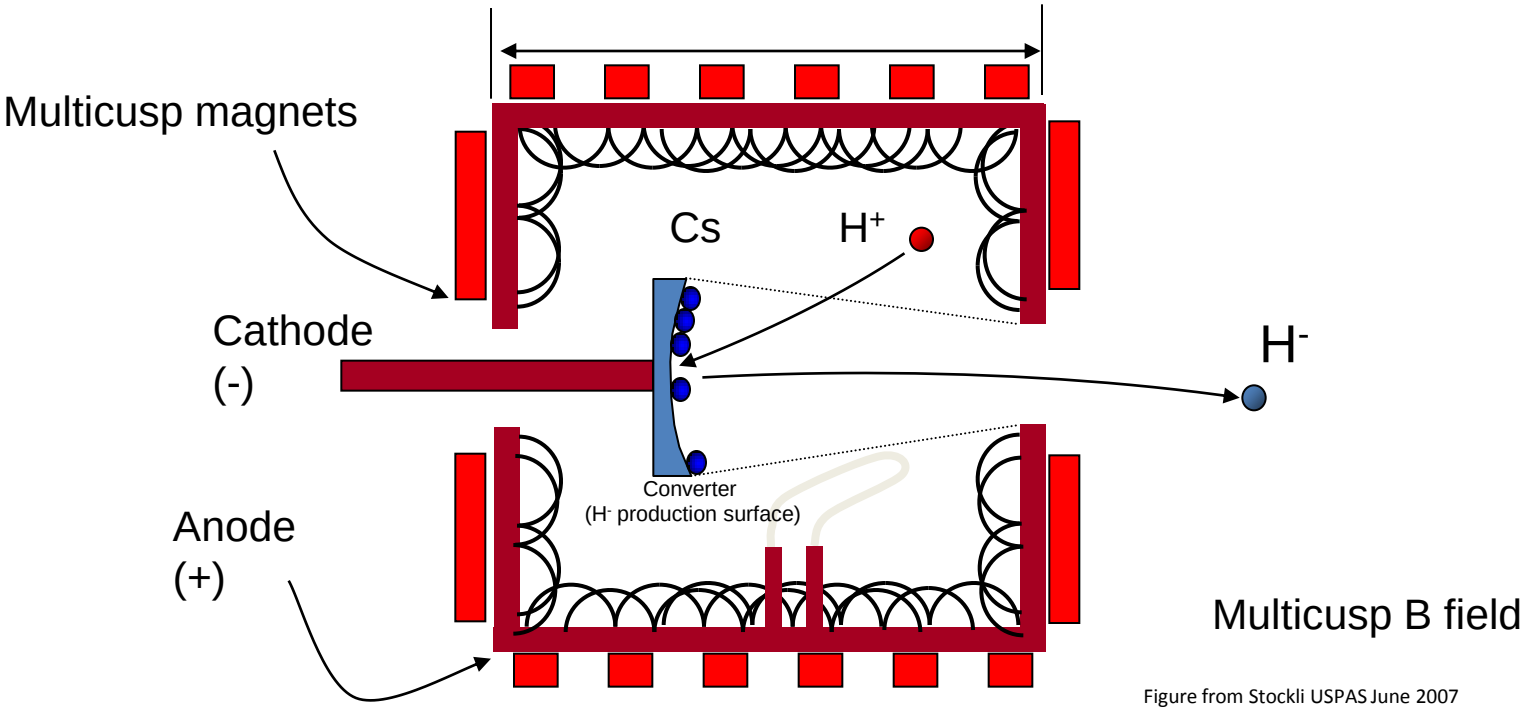
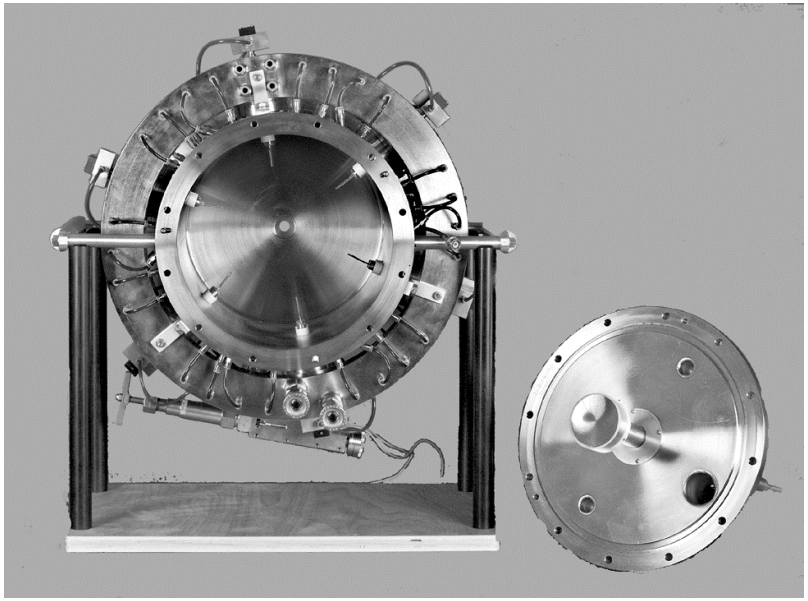
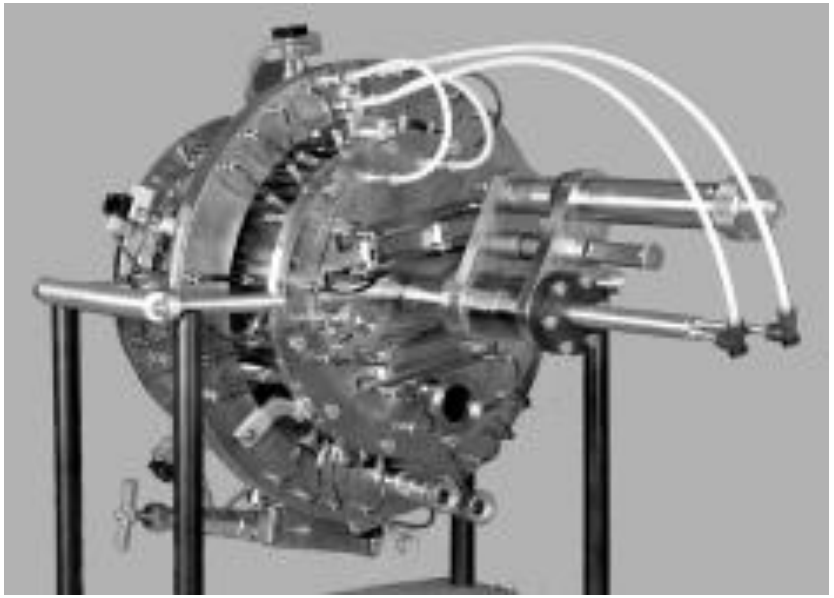


Figure from Stockli USPAS June 2007

- Large volume, low pressure plasma
- Cusp field minimizes electron loss to walls/confines plasma to center or source
- H+ ions created in plasma strike converter plate to produce H^- ions

Mulit- cusp converter ion source





Parameter	Value
H- beam current	20mA
Arc current	60A
Arc Voltage	100V
Extractor Voltage	80kV
Pulse width	1 msec
Rep Rate	120Hz
Duty factor	12%
Average lifetime	4 weeks
Power efficiency	3mA/kW

Filament driven volume source

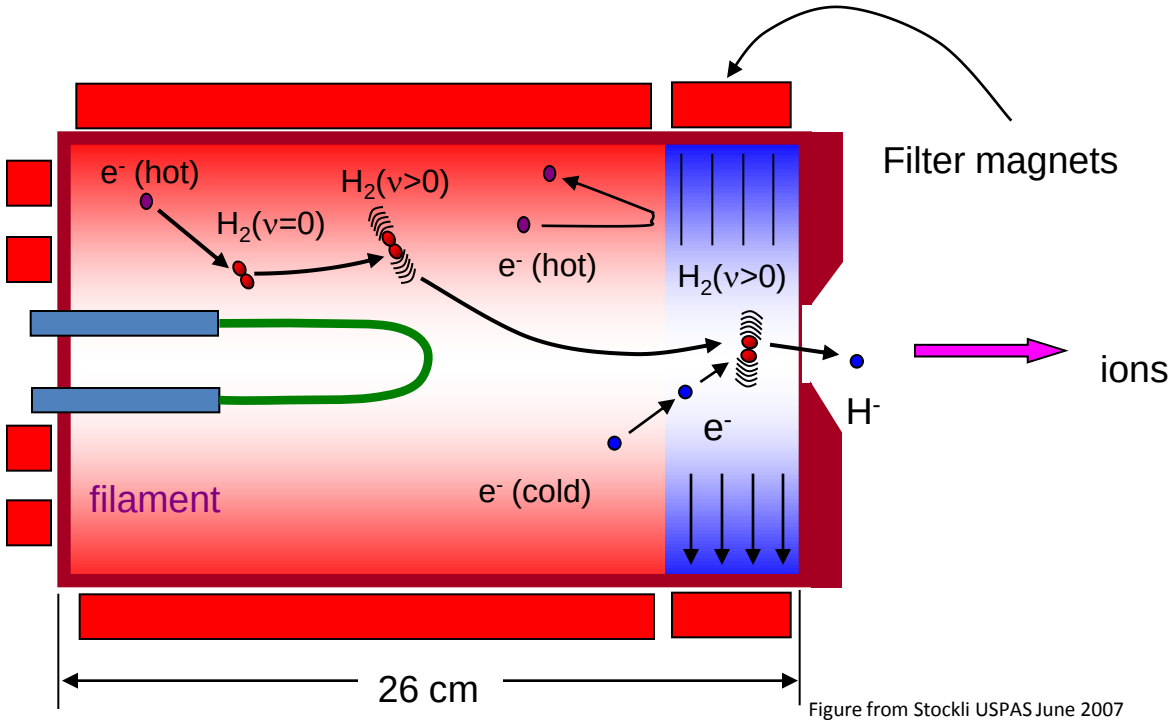


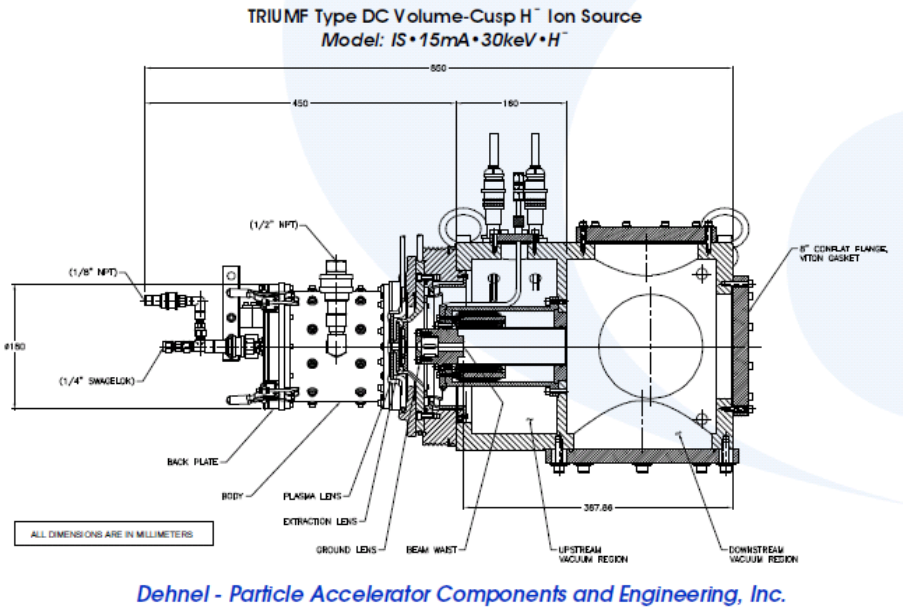
Figure from Stockli USPAS June 2007

- Filaments biased to create electrons with sufficient energy to excite hydrogen to high vibrational states
- Small volume area separated from larger volume by magnetic field to stop energetic e- from destroying the H- ions once they are produced
- Typically low current sources, but high duty factors (DC)

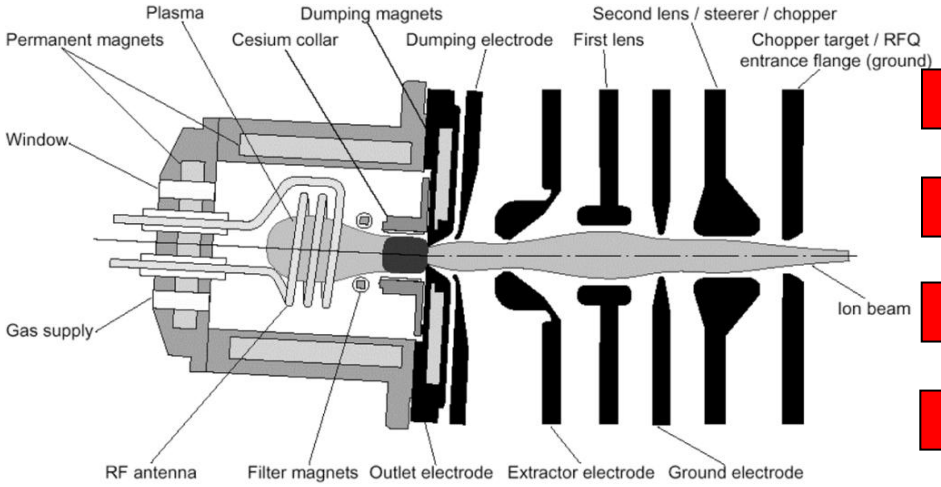
Filament driven volume source

Company called D-Pace manufactures filament driven volume sources ranging from 5mA to 15mA

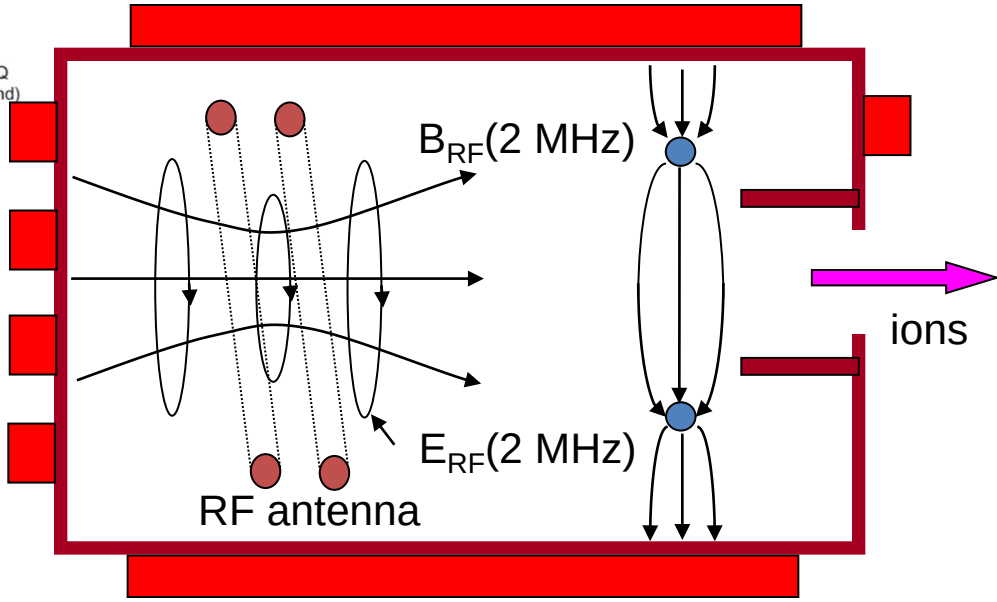
Parameter	Value
H- beam current	15mA
Arc current	45A
Arc Voltage	150V
Extractor Voltage	20 – 30kV
Rep Rate	DC
Duty factor	- -
Average lifetime	350hrs



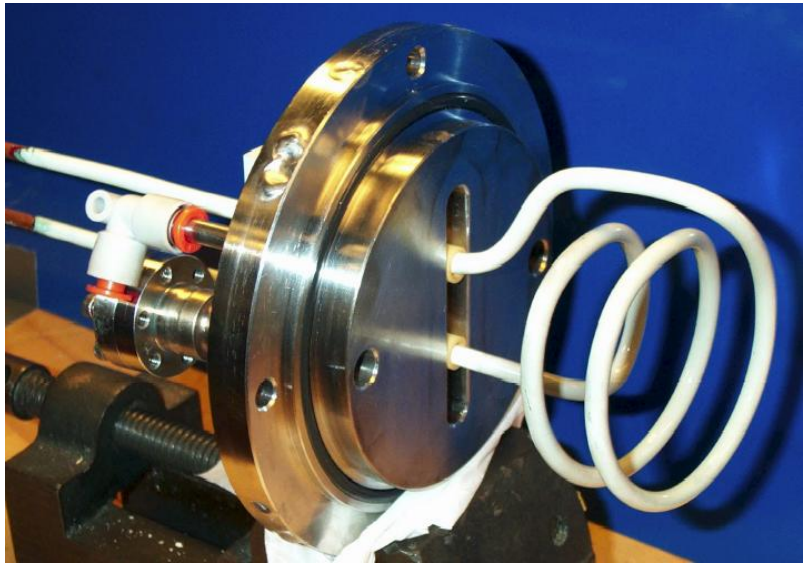
RF driven volume source



SNS multicusp RF ion source and LEBT



Filler magnet region



Parameter	Value
H- beam current	67mA
Pulse Width	1.23 ms
Beam Energy	65keV
Rep Rate	60Hz
Duty factor	100%
Average lifetime	~11 weeks

H- ion source parameters for different types of sources

Facility	Source type	LEBT type	Cs	Curr-ent (mA)	Pulse length (ms)	Rep Rate (Hz)	Extrac Aperat ∅(mm)	Normalized Emittance (rms)	Emittance Location	Life-time (weeks)	Energy (keV)
DESY (RF)	Multicusp ext. RF	2 solenoids	No	30 40	0.15	8	6.5	0.26 (90%) 0.43 (90%)	LEBT	>150	38
Fermi	magnetron	Dipole	Yes	~60	0.1	15	0.9x10	0.2/0.3	750 keV	~30	~20
BNL	magnetron	2 solenoids	Yes	~100	0.6	6.66 10	2	~0.4	LEBT	~30	35
ISIS	Penning	Dipole	Yes	~60 ~35	0.5	50	0.6x10	~1 ~0.15/0.29	Dipole exit 665 keV	~3	35
LANSCE	Surface converter	2 solenoids	Yes	~18 {40}	1	120	10 {8}	~0.14 (98%) {~0.3 (98%)}	LEBT	>4 -	80
J-PARC	Multicusp LaB_6 filam.	2 solenoids	No	20 35	0.5	25	9	0.15/0.18 (9?%) -	LEBT	>3	50
SNS Frontend	Multicusp int. RF	2 Einzel lenses	Yes	~20 41	< 1	1-5	7	0.12/0.14 (100%) 0.25/0.31 (100%)	Test LEBT exit	>11 -	65
SNS Teststand	Multicusp int. RF	2 Einzel lenses	Yes	33 41	1.23	60 10	7	0.18/0.26 (100%) 0.25/0.31 (100%)	Test LEBT exit	2.3 -	65
JAERI	Multicusp W-filament	NA	Yes	60 72	1	50	8	~0.21 (100%) -	Source exit	~0.5	70
Sumy	Inverse magnetron	NA	No	~50	0.1-1	1-10	5.4	-	-	$<10^6$ p	10-100

Figure from Stockli USPAS June 2007