Proton Driver Beam Requirements

Negative Hydrogen Source Implications

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Original material assemble and presented by Robert Welton, Linac 2002

Proton Driver Ion Source Considerations

Parameter Space	Synchrotron	Linac 1 (2 MW)	Linac 2 (0.5 MW)
• Pulse length	90 us	1200 us	3200 us
• Beam Current OUT	50 mA	26 mA	9 mA
• SOURCE Beam Current	63 mA	33 mA	12 mA
• Repetition rate	15 Hz	0.6 - 10 Hz	0.6 - 2.5 Hz
• Peek Duty Factor	0.13%	1.2%	0.8%
• Extraction Potential		65 kV	
• Emittance / Brightness		Optimize	
• maintenance interval		>1000 Hr or ~6 weeks	
• Cesium consumption		Minimize	
• Average Power Consumption		Minimize	
– For RF source 50kW		400-600 W	

Proven High brightness/ intensity H^- sources

- There are essentially 5 different types of H- sources that have proven themselves at major facilities:

Magnetron
(FNAL, BNL, ANL, DESY)

Surface conversion
(LANL, KEK)

Filament-driven volume
(TRIUMF, Jyväskylä)

Penning
(RAL, INR)

RF-driven volume
(DESY, SNS)

Summary of operational high intensity H^- sources

	Facility	Peak beam current	Ave. beam current	Rep. rate	Pulse length	Duty factor	Extraction potential	Maintaince interval
Magnetron	DESY-HERA	40 mA	20 uA	5 Hz	100 us	0.05%	18 kV	38 weeks
	BNL-AGS	35 mA	140 uA	7.5 Hz	500 us	0.40%	35 kV	~ 26 weeks
	ANL-IPNS	48 mA	96 uA	30 Hz	70 us	0.20%	20 kV	~ 2 weeks
	FNAL	60 mA	60 uA	15 Hz	66 us	0.10%	18 kV	~ 12 weeks
Multicusp RF (No Cs)	DESY-HERA	40 mA	20 uA	5 Hz	100 us	0.05%	18 kV	~ 41 weeks (?)
	SNS	50 mA	3000 uA	60 Hz	1000 us	6.00%	65 kV	~ 6 weeks
Penning	RAL-ISIS	35 mA	875 uA	50 Hz	500 us	2.50%	18 kV	~ 4 weeks
	INR-MMF	80 mA	2000 uA	100 Hz	250 us	2.50%	20 kV	~ 2 weeks
Multicusp surface converter	KEK-KENS	18 mA	72 uA	20 Hz	200 us	0.40%	into 750 kV col	~ 14 weeks
	LANL-LANSCE	20 mA	2400 uA	120 Hz	1000 us	12.00%	80 kV	~ 4 weeks
Multicusp filament	TRIUMF	1-5 mA	1-5000 uA	cw	cw	100.00%	25 kV	~ 6 weeks
	Jyvaskyla-LIISA	3 mA	3000 uA	cw	cw	100.00%	5.8 kV	~ 6 weeks

Summary of operational high intensity H^- sources

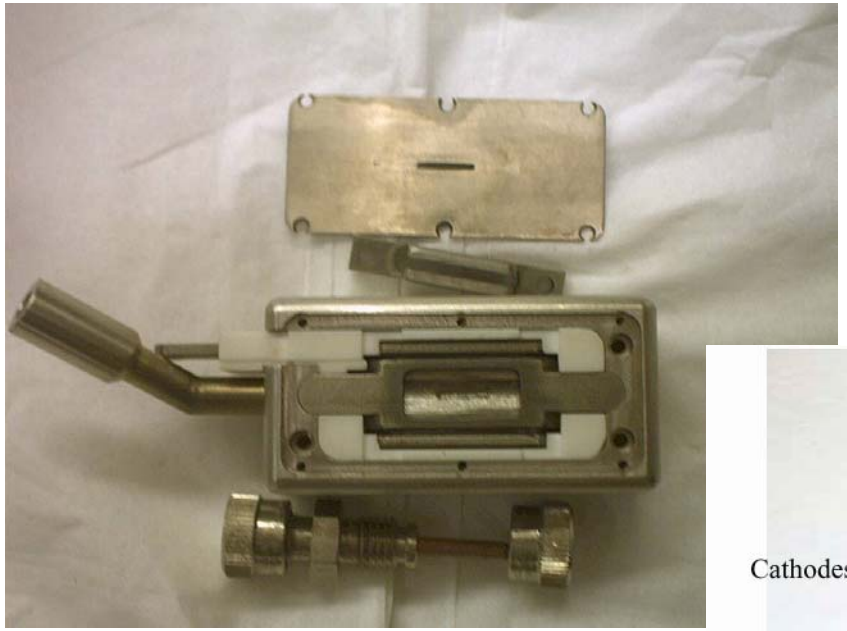
	Facility	Peak beam current	Ave. beam current	Emittance 90% x/y (norm)	Brightness 90% mA/ (mm mrad)^2	Peak power efficiency	Average power dissipated in source
Magnetron	DESY-HERA	40 mA	20 uA	1 π mm mrad	4	~ 8 mA/kW	3 W
	BNL-AGS	35 mA	140 uA	1.1 π mm mrad	3	~ 67 mA/kW	6 W
	ANL-IPNS	48 mA	96 uA	0.9 /1.4 π mm mrad	4	~ 9 mA/kW	10 W
	FNAL	60 mA	60 uA	0.9 /1.5 π mm mrad (Colm.)	4	~ 2.5 mA/kW	81 W
Multicusp RF (No Cs)	DESY-HERA	40 mA	20 uA	0.4 π mm mrad	25	~1 mA/kW	20 W
	SNS	50 mA	30 uA	0.8 π mm mrad (after LEBT)	8		
Penning	RAL-ISIS	35 mA	875 uA	0.7 / 0.9 π mm mrad	6	~ 6 mA/kW	150 W
	INR-MMF	80 mA	2000 uA	0.4 / 0.7 π mm mrad	22	~ 8 mA/kW	250 W
Multicusp surface converter	KEK-KENS	18 mA	72 uA	2 π mm mrad	0.5	~ 4.5 mA/kW	16 W
	LANL-LANSCE	20 mA	2400 uA	0.6 π mm mrad	6	~1.6 mA/kW	1300 W
Multicusp filament	TRIUMF	1-5 mA	1-5000 uA	0.5 π mm mrad	1	~ 20 mA/kW	2400 W
	Jyvaskyla-LIISA	3 mA	3000 uA	0.6 π mm mrad	1	~ 20 mA/kW	2400 W

Recommendations

- **Magnetron sources** are utilized for average H^- currents of **~100 μA** (**~60 mA** pulses). Source maintenance intervals can be quite long **~6500 hours** when dissipating only a few Watts of average power.
  - Great for 90 μs pulses
  - Source R&D required for 1 - 3 ms pulses. Need utilize a porous Molybdenum cathode. Work carried out at BNL showed this to be effective for CW operation. (Alessi, RSI 61, p625, 1990)

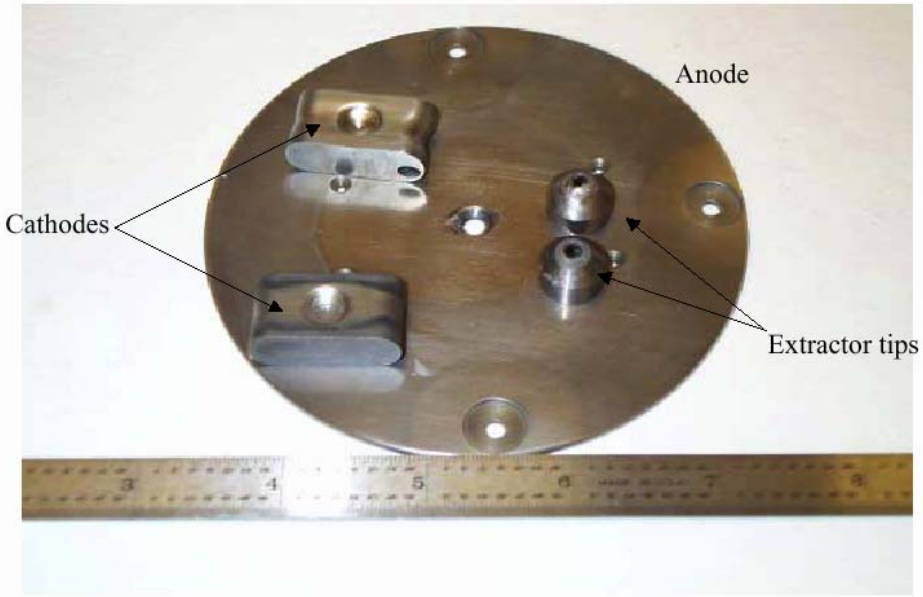
- **RF Multicusp** sources routinely deliver the highest average H^- currents up to **5 mA** in cw operation and **50 mA** in pulsed operation. Maintenance intervals **~1000h**
  - At least a factor of 2 higher brightness than magnetron
  - SNS design has demonstrated 1 ms pulses 50 mA at 6% DF.
  - R&D needed for 9 mA, 3 ms long pulse
  - Optimization needed for short 90 us pulse lengths.
  - Investigate using an external antena variant which has a longer maintenance period. Such a source is in operation at DESY
    - Main issues: cooling

The magnetron source (BNL)



FNAL source

BNL source



J. Alessi 4/10/02

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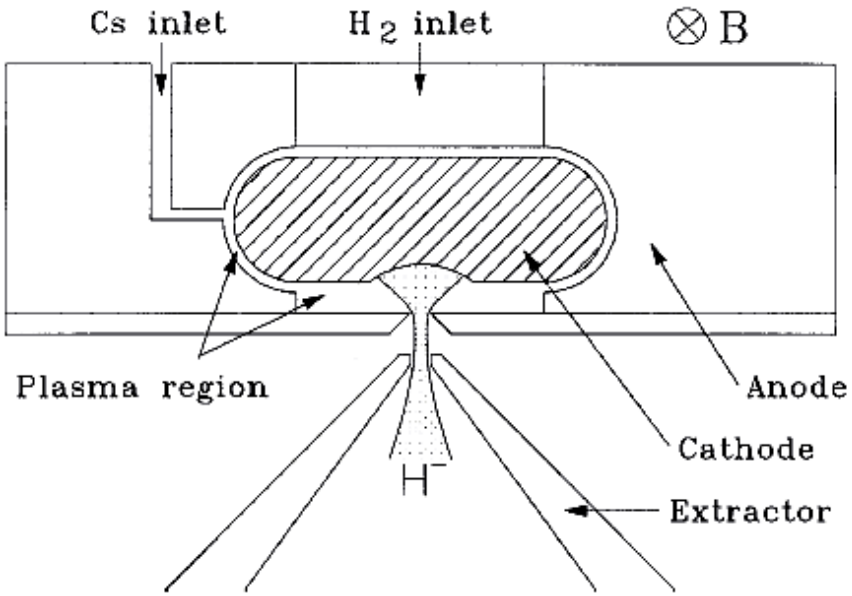
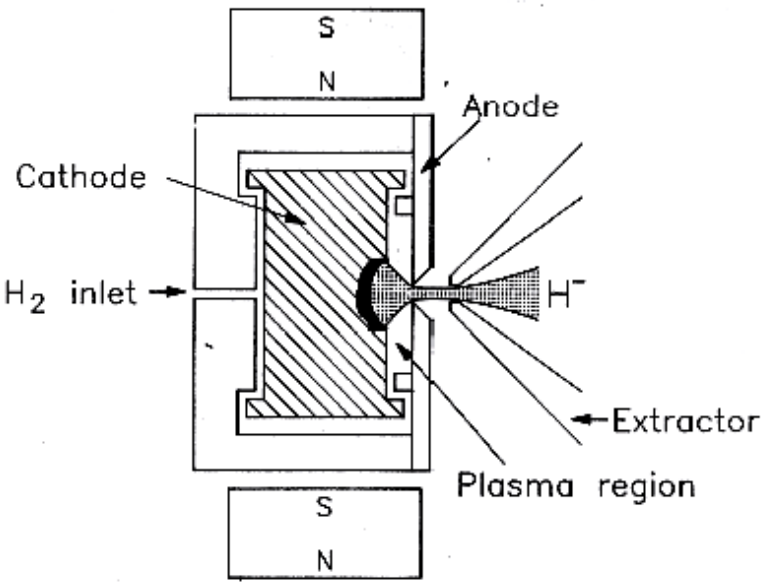
The magnetron source

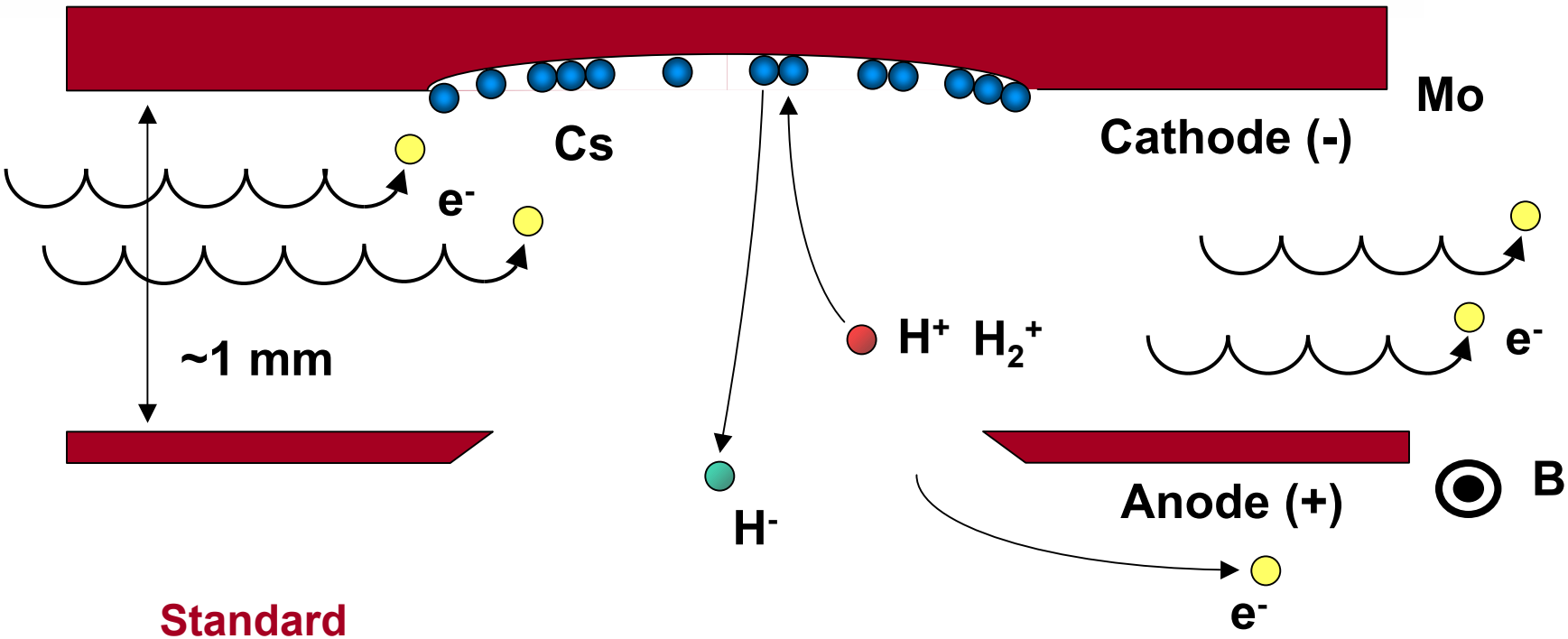
BNL source with circular aperture





- Used for high current ~100 mA low duty factor applications
- Invented at the Budker Institute called Planotron
- Used currently at FNAL, BNL, ANL, DESY
- Cold cathode

The magnetron source



Standard operating parameters

Pulse: 7.5Hz, 700 us
Duty factor: 0.4 %
Arc voltage: ~ 150 V
Arc current: ~ 8-18 A
Cs used: ~ 0.5 mg/hr
Scheduled Maintenance interval: 26 weeks

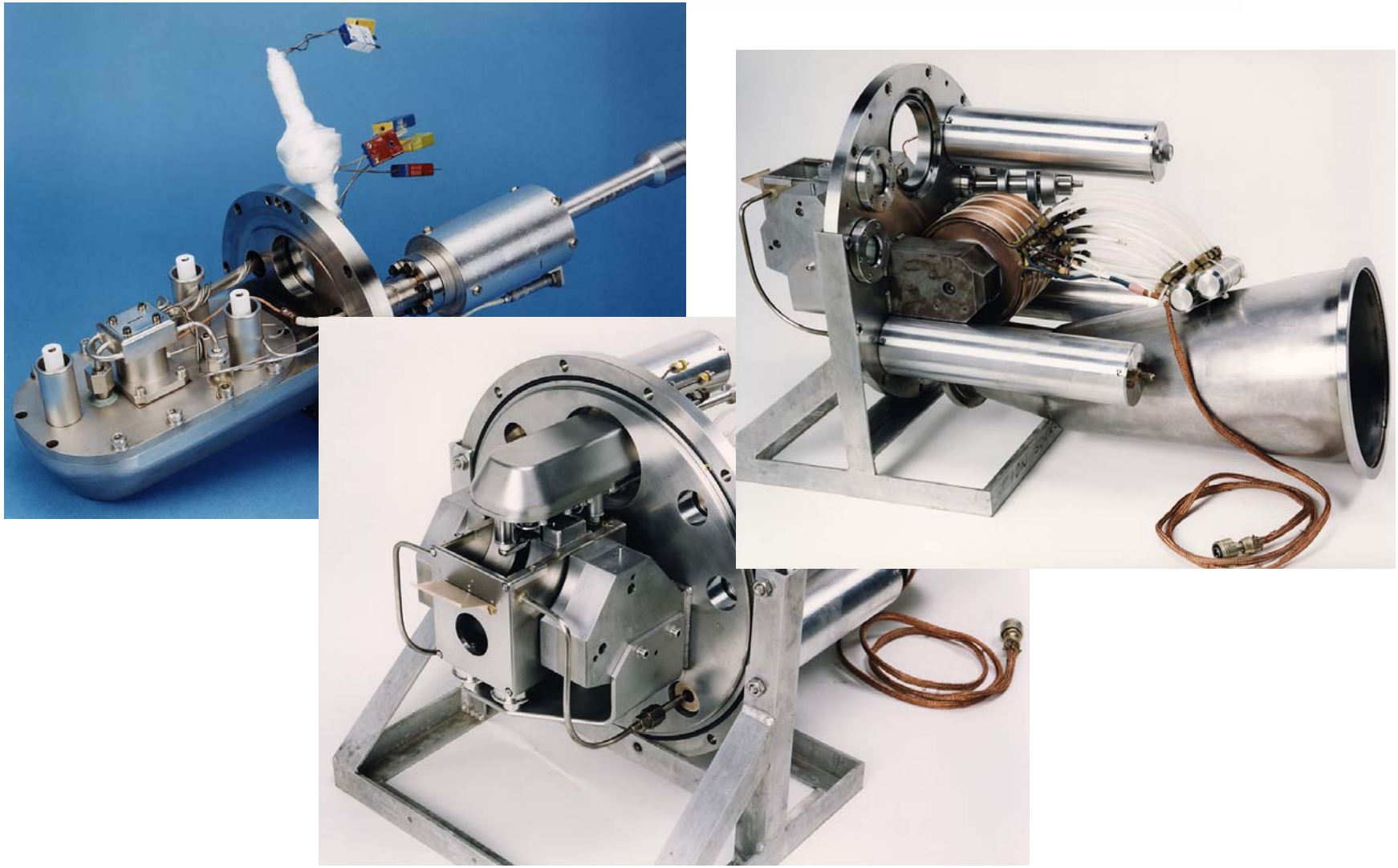
Plasma parameters

n_{H2} ~ 10^{16} cm^{-3}
n_e ~ 10^{13}-10^{14} cm^{-3}
Te ~ 1eV / 15 eV

Beam parameters

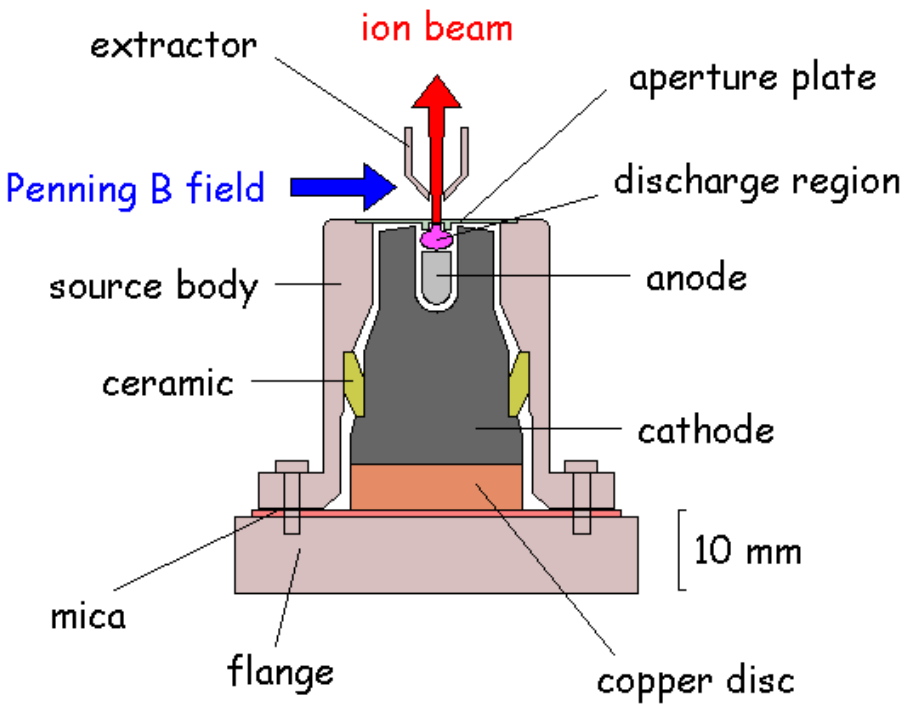
Pulse: 7.5Hz, 500 us
H^- current: ~ 35 (100) mA
Extract pot: 35 kV
ε_n(90%): ~ 1.1 π mm mrad

The Penning source (RAL-ISIS)



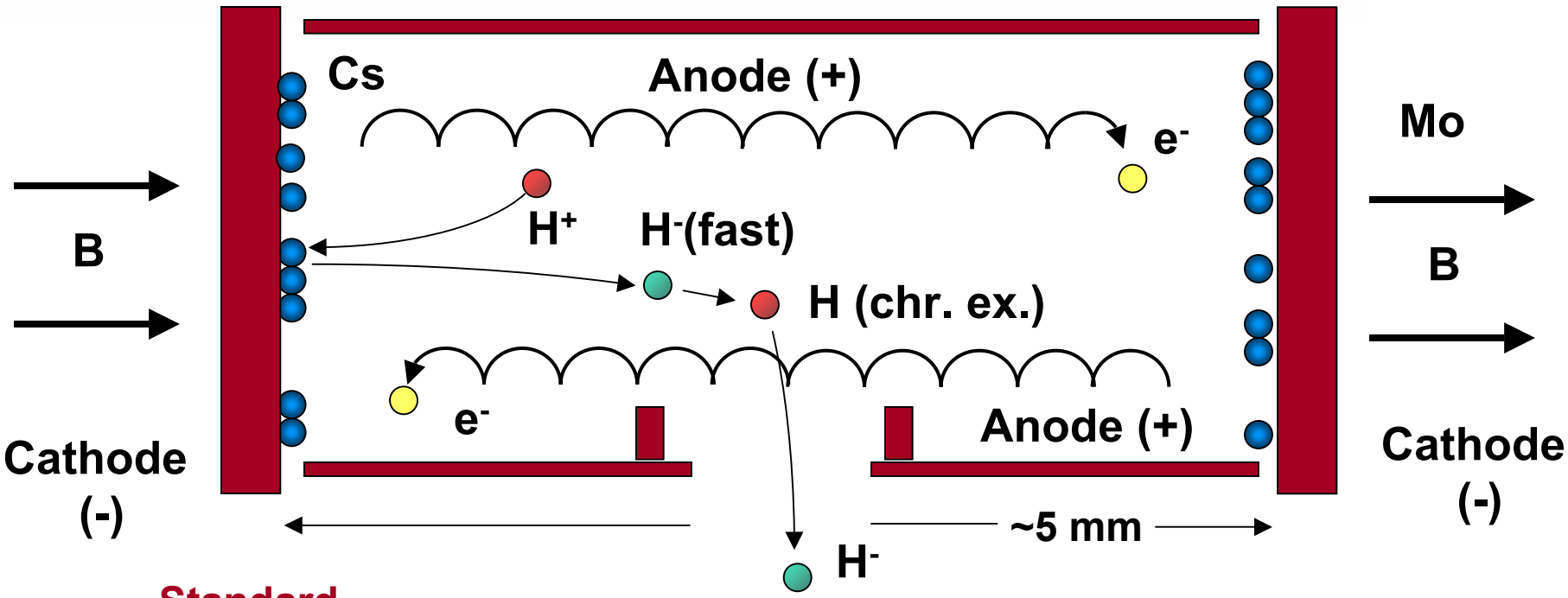
The Penning source

RAL-ISIS source



- Used for high current ~35-80 mA at higher duty factor 2-3%
- No ionization surfaces facing the extraction system
- Used currently at INR and RAL-ISIS, also invented at Budker
- Cold cathode

The Penning source



Standard operating parameters

Pulse:50Hz, 500 us
Duty factor: 2.5 %
Arc voltage: ~ 150 V
Arc current: ~ 40 A
Cs used: ~ 3 g/month
Main. interval: 4 weeks

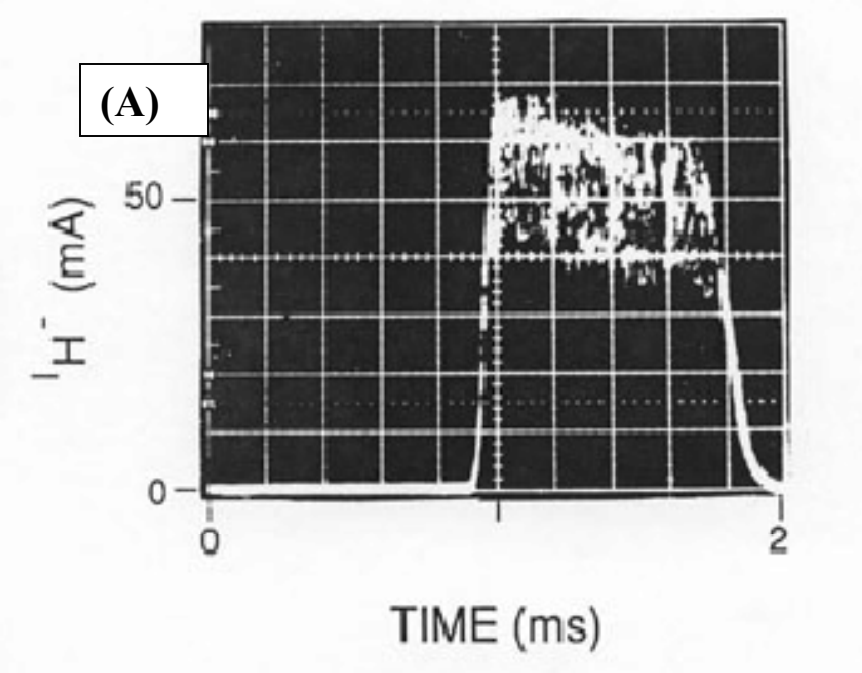
Plasma parameters

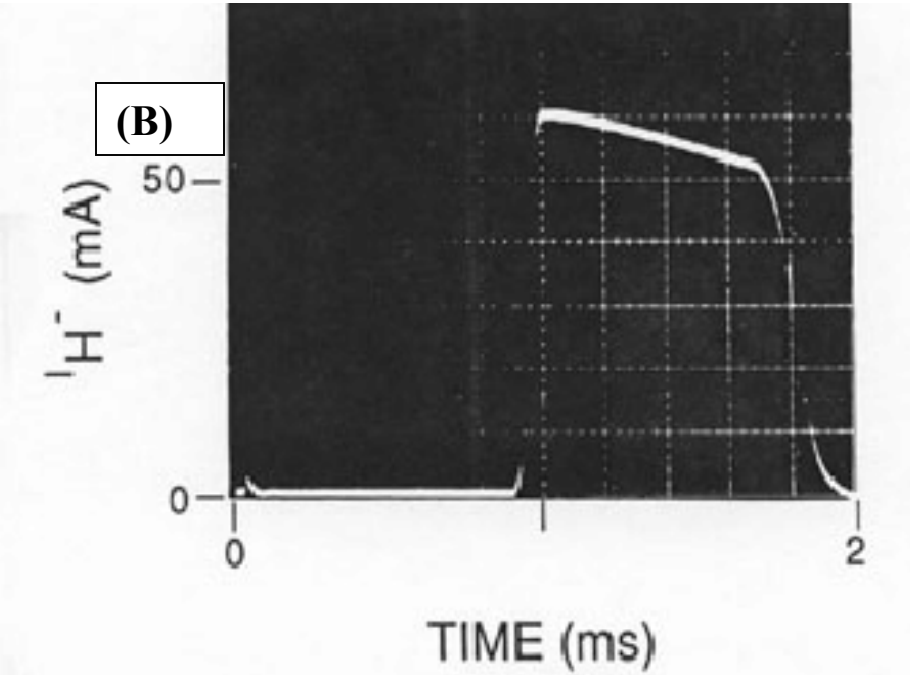
n_{H2} ~ 10^{16} cm^{-3}
n_e ~ 10^{12}-10^{13} cm^{-3}
Te ~ 1-5 eV

Beam parameters

Pulse: 50 Hz, 200 us
H^- current: ~ 35 (100) mA
Extract pot: 18 kV
ε_n(90%): ~ 0.8 π mm mrad

Beneficial effect of adding N_2 to 4X Penning discharge for beam noise reduction (1988).

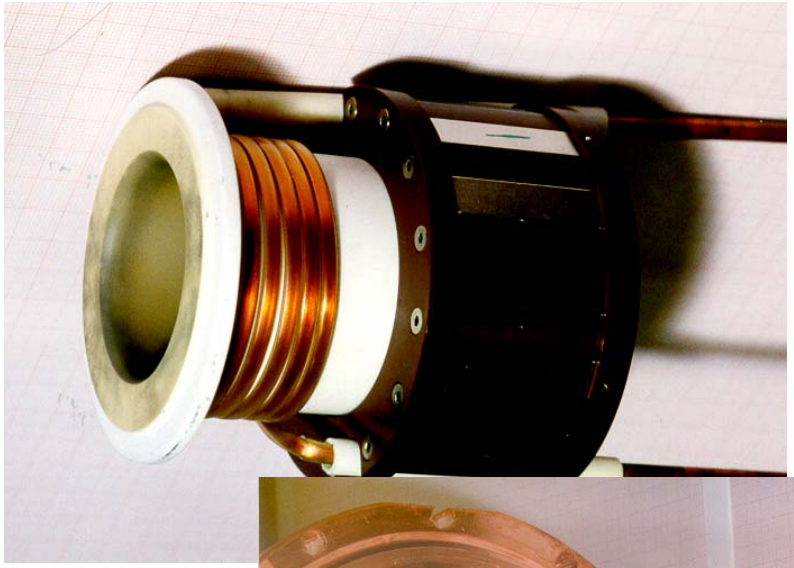


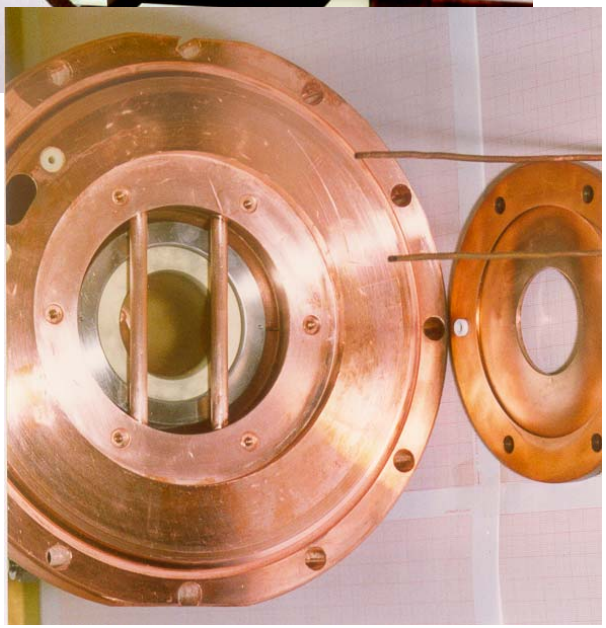


(A) H^- current with no N_2 gas added to the H_2 discharge. (A) and (B) used circular emitters.

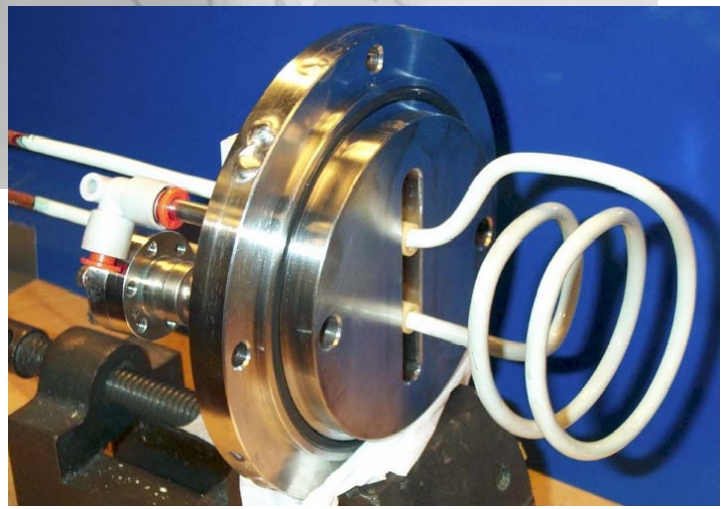
(B) H^- current with 0.5% N_2 added to H_2 discharge. All other ion source parameters the same as in (a). (effect discovered in 1988)

RF driven volume source





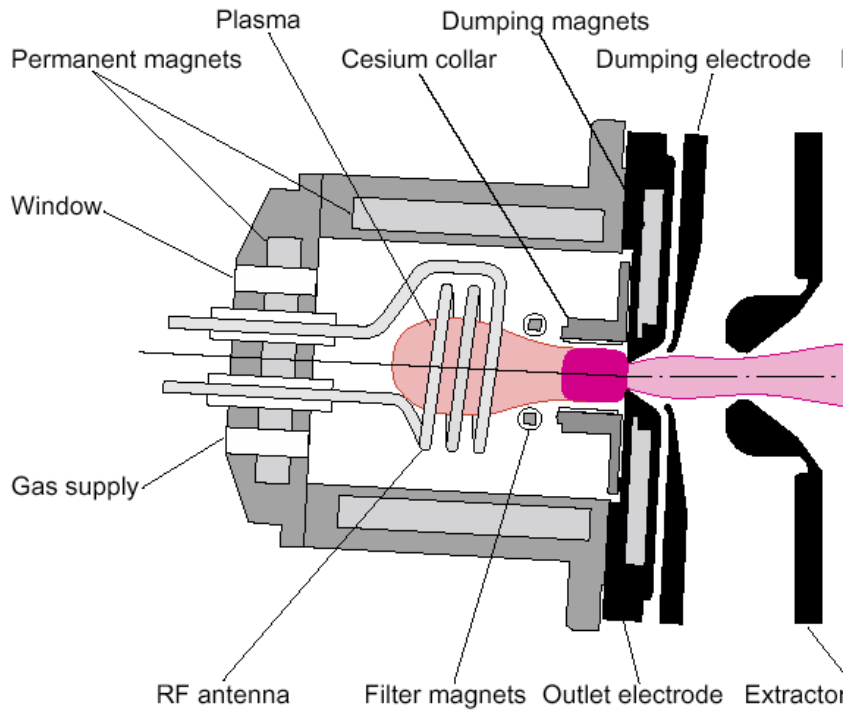
DESY source



SNS Ion Source - Revisited

The SNS ion source is a plasma device:

- **Plasma volume: ϕ ~ 10 cm l ~10 cm = 31cm^3**
- **Plasma density: ~10^{12} cm^{-3}**
- **Electron temperature: region 1~10 eV, region 2 ~1 eV**
- **Confinement: radial multicusp n=20, axial multicusp n=4**
- **Magnets: Cusps ~ 2500 Gauss, filter ~ 200 Gauss**

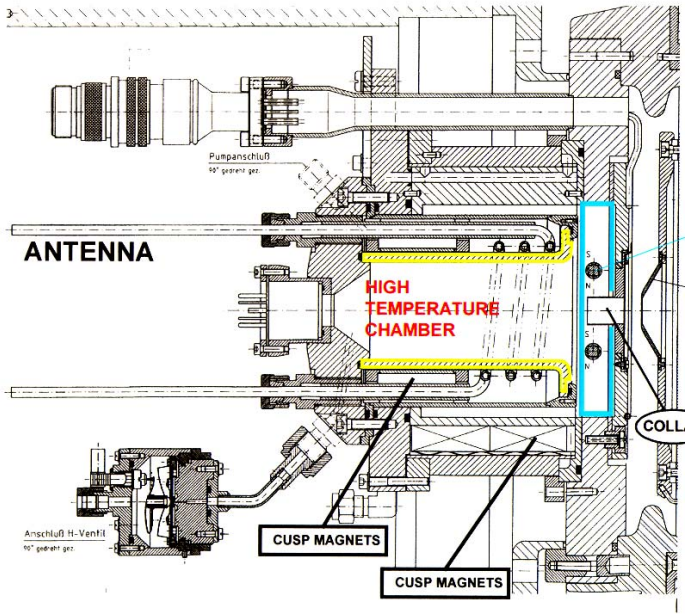


RF system:

- **2 MHz 80 kW (40 kW nominal) pulsed at 60 Hz / 1ms**
- **13.56 MHz 600W (100 W nominal) cw operation**

RF driven volume source

DESY source (t ~ 1050 days)



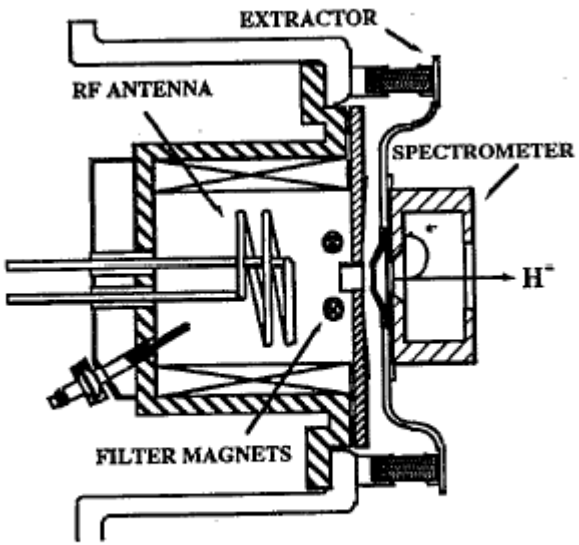
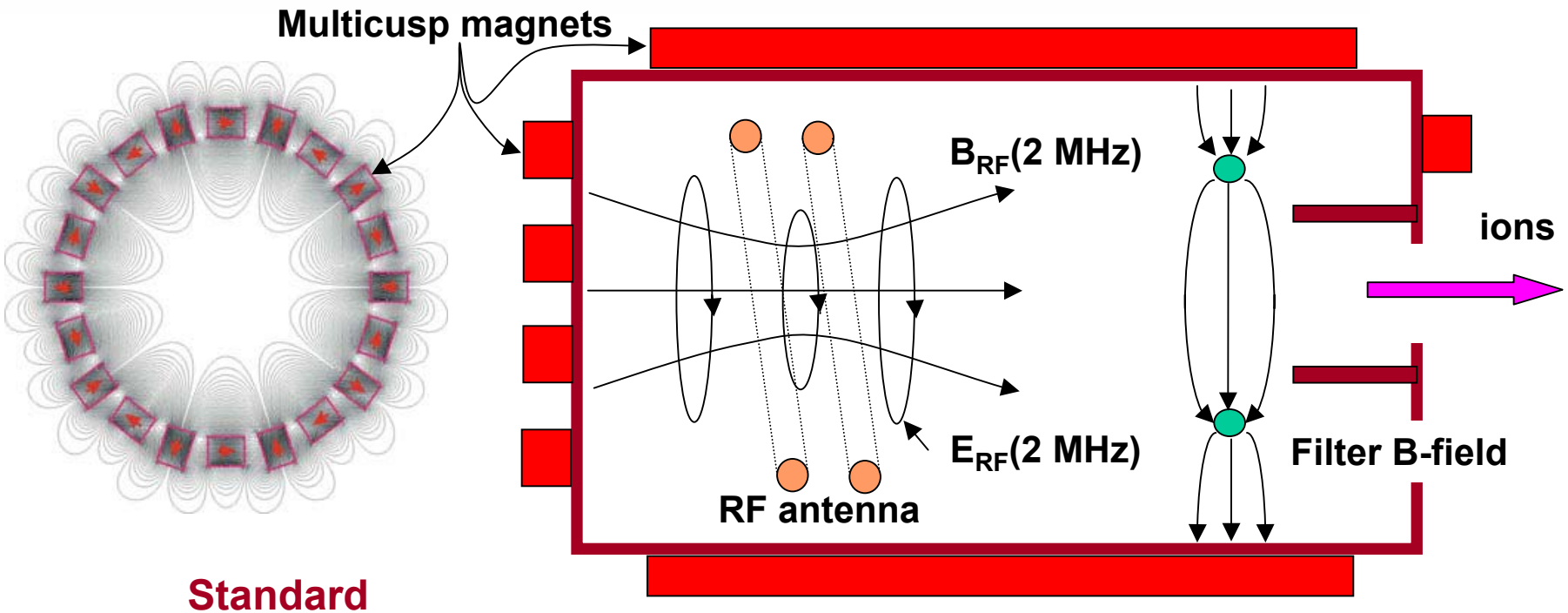


FIG. 1. SSC volume ion source.

SSC source (t ~ 52 days)

- Currently used for low duty factor applications (0.05-0.1%)
- Invented in present form at the LBNL
- Used at DESY, SSC (~52 days) and at the SNS shortly
- Both external and internal antennas used

RF driven volume source – E&M fields



Standard operating parameters (DESY)

Pulse: 5 Hz, 100 us
Duty factor: 0.05 %
RF power: ~ 40 kW
Cs used: ~ NA
Scheduled Maintenance interval: 41+ weeks

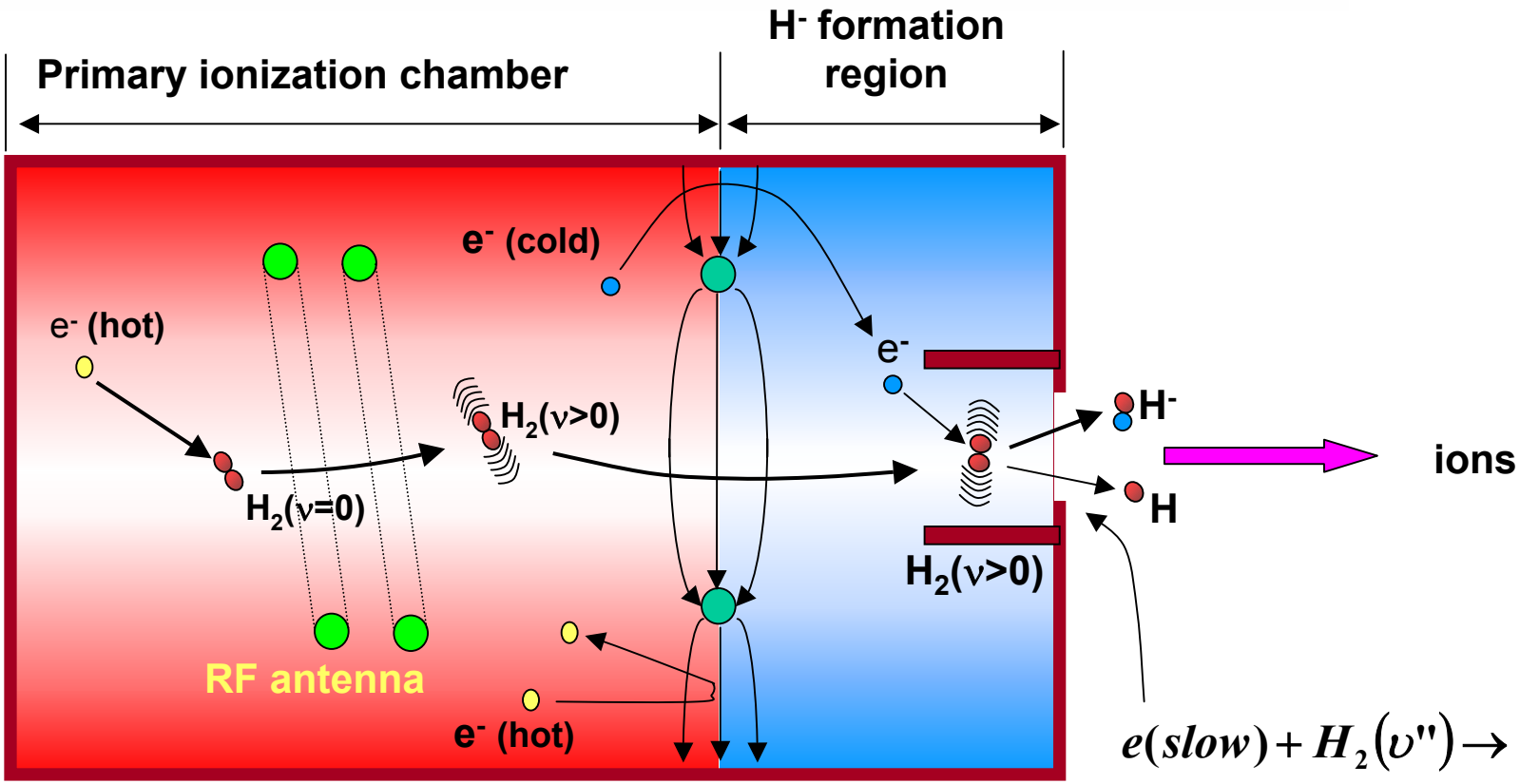
Plasma parameters

n_{H2} ~ 10^{14}- 10^{15} cm^{-3}
n_e ~ 10^{12}-10^{13} cm^{-3}
Te ~ 2eV / 15 eV

Beam parameters

Pulse: 5 Hz, 100 us
H^- current: ~ 40 (80) mA
Extract pot: 18 kV
ε_n(90%): ~ 0.4 π mm mrad

RF driven volume source – H^- formation



$$e(slow) + H_2(\upsilon'') \rightarrow H_2^- \rightarrow H + H^-$$

$$e(fast) + H_2(\upsilon''=0) \rightarrow H_2^* + e \rightarrow H_2(\upsilon'') + e + h\nu$$

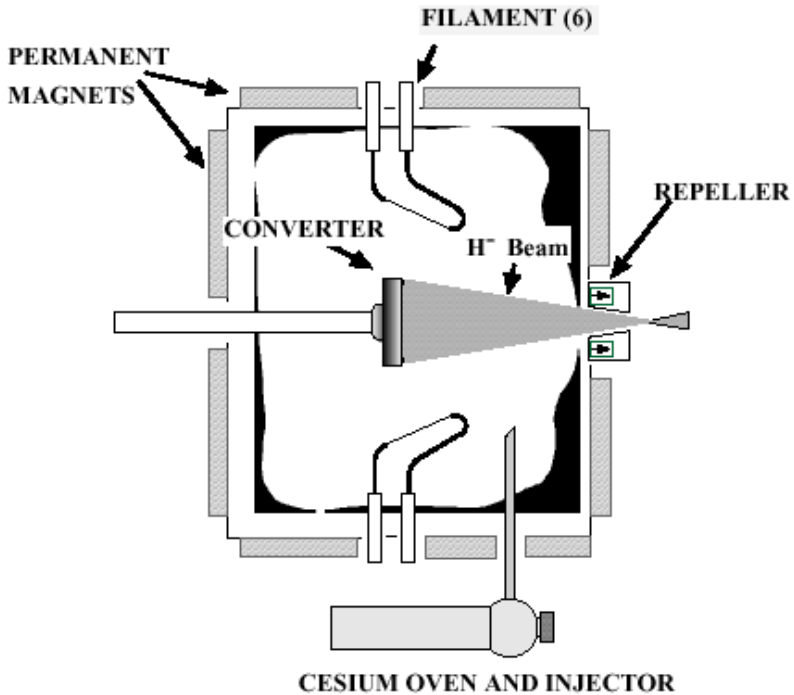
1999 High-Current H- sources

From J. Peters,
RSI 71, 2000, 1069

Institution	Current	Duty factor	emittance N,90%	Brightness	Source Type	Tested uninterrupted	consumption	Accelerator experience
Units	ma	%	Pi mm mrad	(mA/mm mrad)^2		run hours	Cs per day	years
DESY	60	0.05	0.98	6.4	magnetron	7224	2.8 mg	17
BNL	75	0.48	1.2	4.9	magnetron	4320		
RAL	35	2.5	0.3		Penning	960		16
BINP	80	2.5	0.1	670	Penning		24 mg	
LANL	16	12	0.53	5.8	converter with filaments	720	480 mg	
TRIUMF	20	100	0.75	3.6	volume with filaments	500	No Cs	
TRIUMF	20	100	0.52		volume with filaments		5 mg	10
Frankfurt U	120	6	~0.23		volume with filaments		29 mg	
LBNL	30	0.1	0.5	12	RF antenna in plasma	72-984	K	
LBNL	91	0.1	0.5	28	RF antenna in plasma		Cs	
DESY	40	0.05	0.4	7.2	RF antenna in air	7000	No Cs	

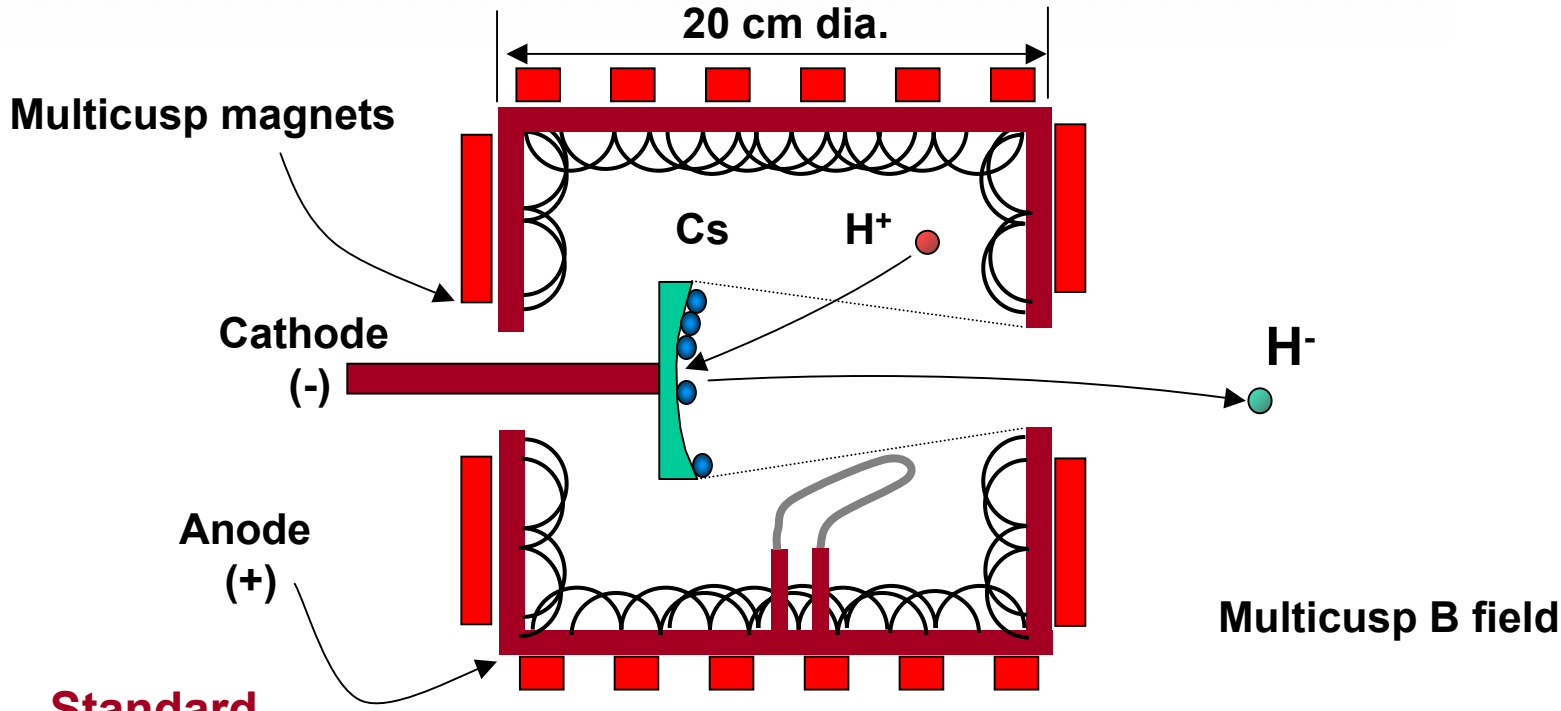
Multicusp surface conversion source

LANSCE operations source



- Used for much higher duty factor 12% operation at lower currents ~18 mA
- Multicusp confinement like volume sources but biased cathode added
- Invented in present form at LBNL
- Used at LANL and KEK

Multicusp surface conversion source



Standard operating parameters

Pulse:120Hz, 1000 us
Duty factor: 12 %
Arc voltage: ~ 100 V
Arc current: ~ 60 A
Cs used: ~ 30 mg/h
Main. interval: 4 weeks

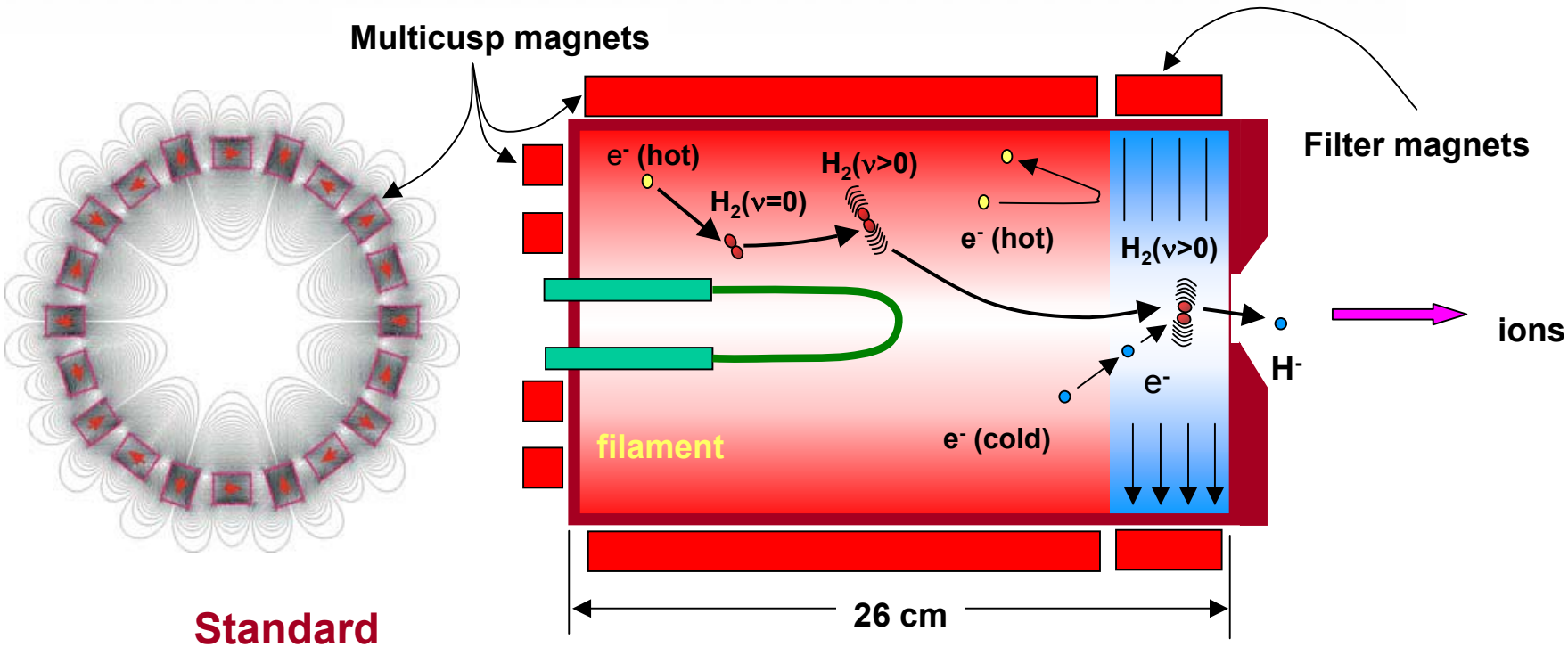
Plasma parameters

n_{H2} ~ 10^{13} cm^{-3}
n_e ~ 10^{11}-10^{12} cm^{-3}
Te ~ 1-5 eV

Beam parameters

Pulse: 120 Hz, 1000 us
H^- current: ~ 20 mA
Extract pot: 80 kV
ε_n(90%): ~ 0.6 π mm mrad

Filament driven volume source



Standard operating parameters

Pulse: cw
Duty factor: 100 %
Arc voltage: ~ 140 V
Arc current: ~20 A
Cs used: ~ NA
Scheduled maintenance interval: 6 weeks

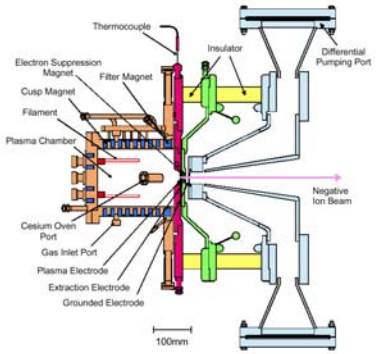
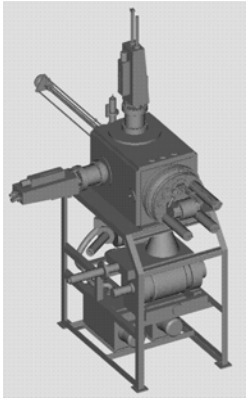
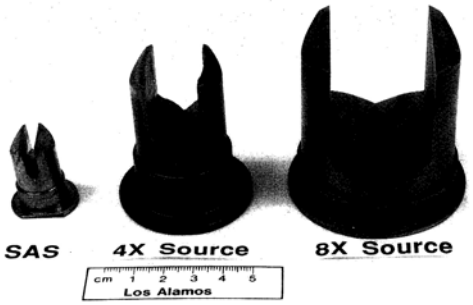
Plasma parameters

$n_{H2} \sim 10^{14}$ cm^{-3}
$n_e \sim 10^{12}$-10^{13} cm^{-3}
Te ~ 2eV / 15 eV

Beam parameters

Pulse: cw
H^- current: ~ 1-5 (15) mA
Extract pot: 25 kV
ε_n(90%): ~ 0.5 π mm mrad

Areas of promising ion source R & D

This survey has focused only on operational systems with long (several weeks) maintenance intervals. Source R&D efforts are ongoing since beam brightness, average beam power, and source lifetime requirements are not simultaneously met:

- **RAL-ISIS, several test benches, considerable expertise, wide European collaboration focus on Penning sources**
- **JAERI-KEK, good test capability, collaboration with fusion program excellent results (72 mA peak, 1.8 mA average current, 15 mA/(mm mrad)^2) from a filament driven multicusp source, efforts to improve lifetimes are underway in collaboration with ORNL**
- **LANL-LANSCE, strong test capabilities, good results from 4x and 8x penning sources (in 1987 4x source 250 mA peak, 1.25 mA average current, 25 mA/(mm mrad)^2, 2 days operational time)**
- **LBNL-ORNL, excellent results (50 mA peak, ~3 mA average current, 3 mA/(mm mrad)^2) from RF multicusp) demonstrated, strong modeling program, 2 test stands (ORNL) + 1 test (LBNL) planned, focus shifted to improving lifetime**