High Current Ion Sources for Accelerators

- Future High Intensity Accelerator Requirements
- Proton Sources
- H- Sources
- Summary

Source Requirements

	Particle	current (mA)	pulse length (ms)	rep-rate (Hz)	Duty Factor	average current (mA)	e (mm.mrad - rms - norm)
IPHI	p+	100	CW	CW	100%	100	
TRASCO - Italy	p+	30	CW	CW	100%	30	
ESS	H-	65	1.2	50	6%	3.9	0.3
CERN - SPL	H-	50	1.5	50	7.5%	3.75	0.25
SNS	H-	50	1	60	6%	3	0.2
JKJ Project	H-	30	0.5	50	2.50%	0.75	
ADDS	H-	25	0.5	25	1.25%	0.3125	

Simultaneously provide

- High Current
- Duty Factor
- Brightness
- High Reliability

All emittances are:

1rms, normalised in mm.mrad

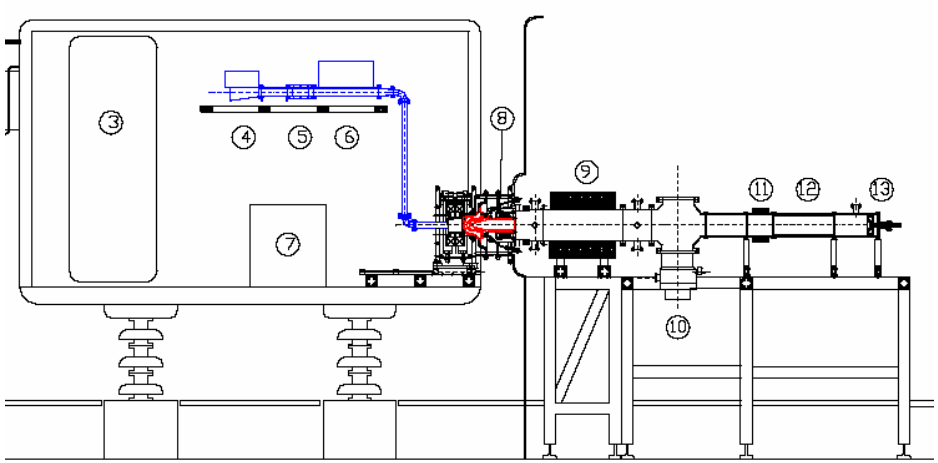
(beams may not be Gaussian)

Proton Sources - 2.45 GHz ECR - Status

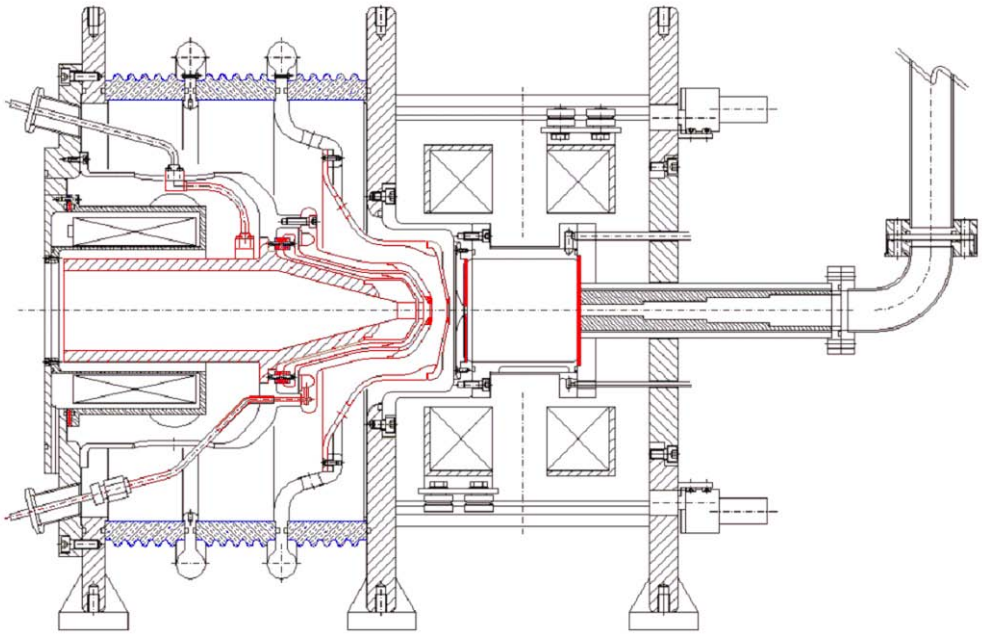
	CEA	TRIPS	LANL - LEDA	CEA
Type	2.45GHz ECR	2.45GHz ECR	2.45GHz ECR	2.45GHz ECR
Particle	p+	p+	p+	D+
Current (mA)	130	60	117	129
Duty Factor	100%	100%	100%	0.002
Dischange Power (W)	800	1000	800	900
Emittance	0.15†	0.18†	0.2	
H+/D+ Fraction	83%	90%	90%	96%
Lifetime (hrs)	336	142	480	

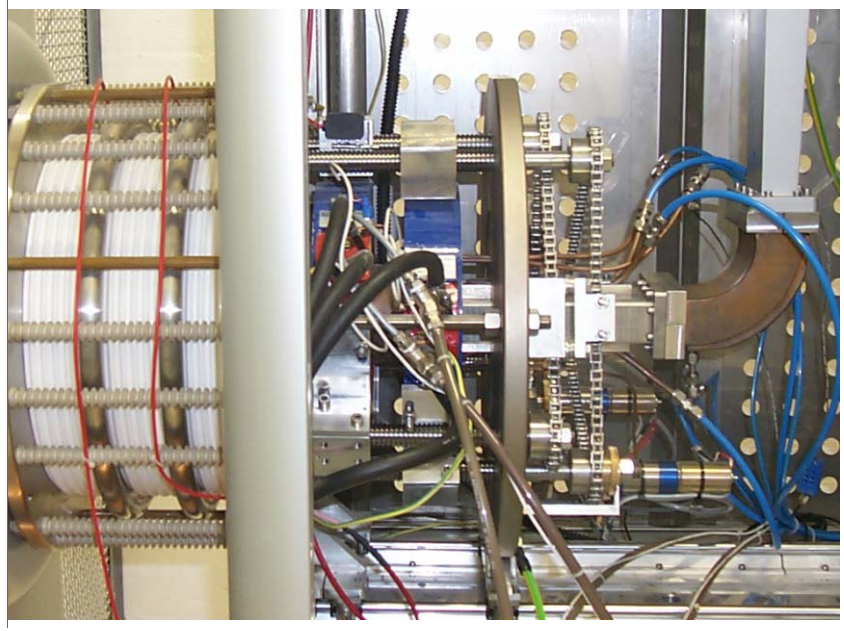
† Emittances are r-r'
Estimated (90% proton fraction)
Lifetime results are for available tests, not including HV sparking.
CEA Deuteron beam tests limited to avoid activation.

Proton Sources - 2.45 GHz ECR - Status



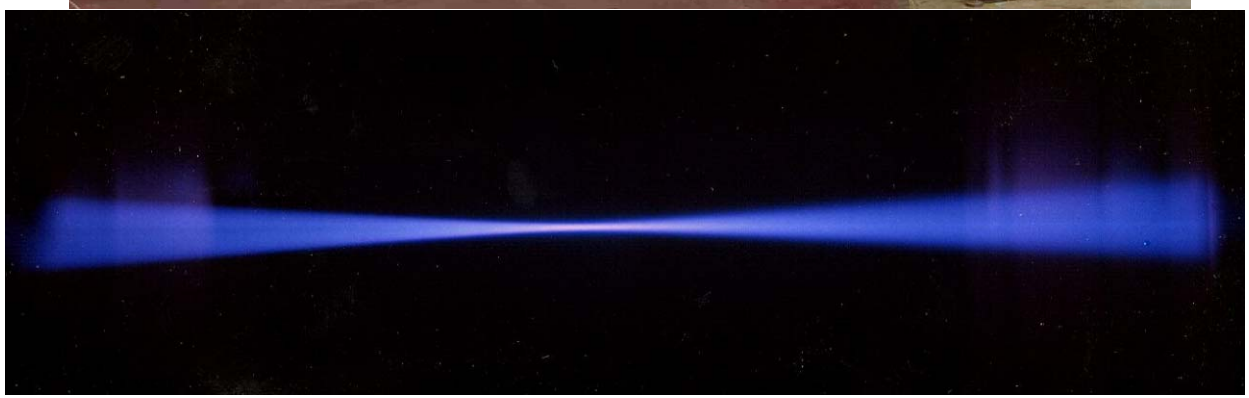
L. Celona, TRIPS,
TRASCO, INFN, Italy





Proton Sources - 2.45 GHz ECR - Status

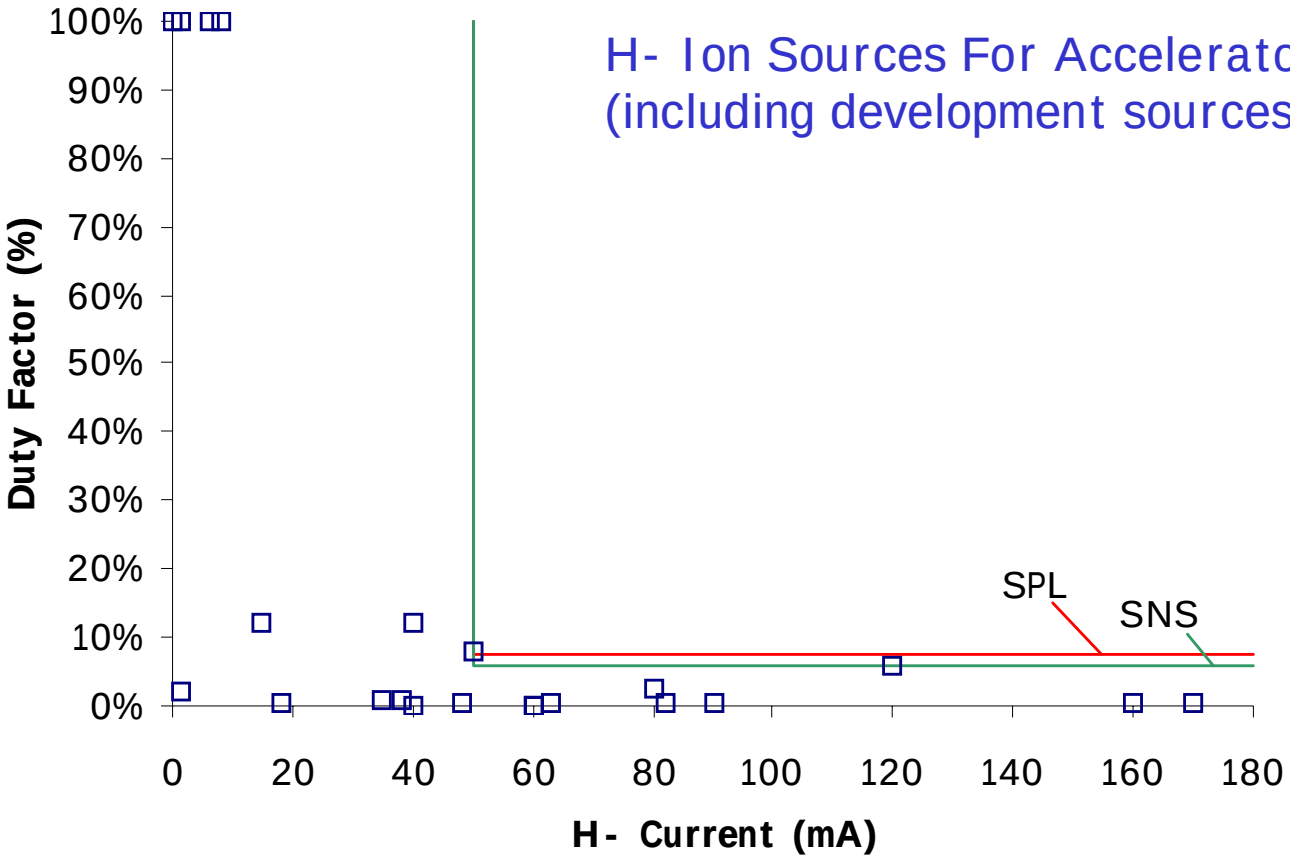
R. Gobin,SILHI,
CEA Saclay,
France



Proton Sources - 2.45 GHz ECR - Status

- Production efficiency >100 mA/kW.
- Beam lifetime tests limited - no long term user!
- CEA change Boron Nitride window between runs. Estimate 6 months in operation.
- Source up-time requirements are as close to 100% as possible.
- Use EMI resistant electronic systems and auto reset to achieve 99.8% (CEA and INFN).
- New Permanent Magnet -TRIPS design with no power on the platform. Will use 2 sources for high up-time – with a 30^{o} bending switchyard.
- CW or pulsed operation.

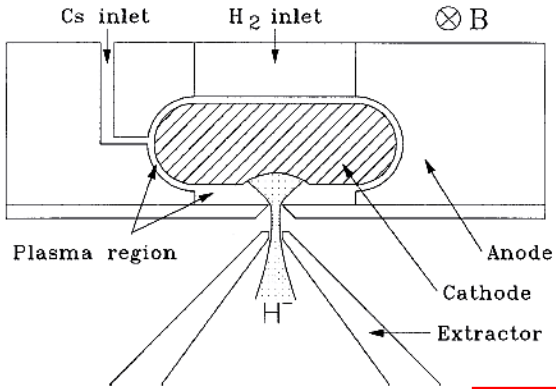
H- Ion Sources

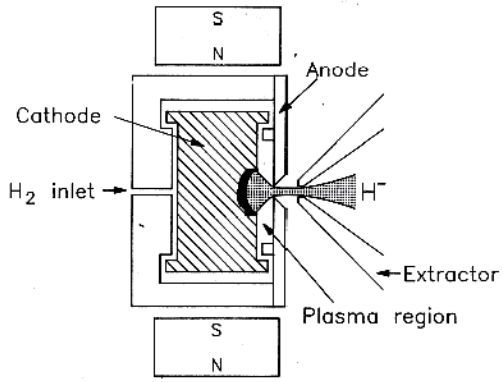


Production Efficiency.

H- Ion Sources - Magnetron - Status

BNL Magnetron - Circular aperture





J Alessi, BNL

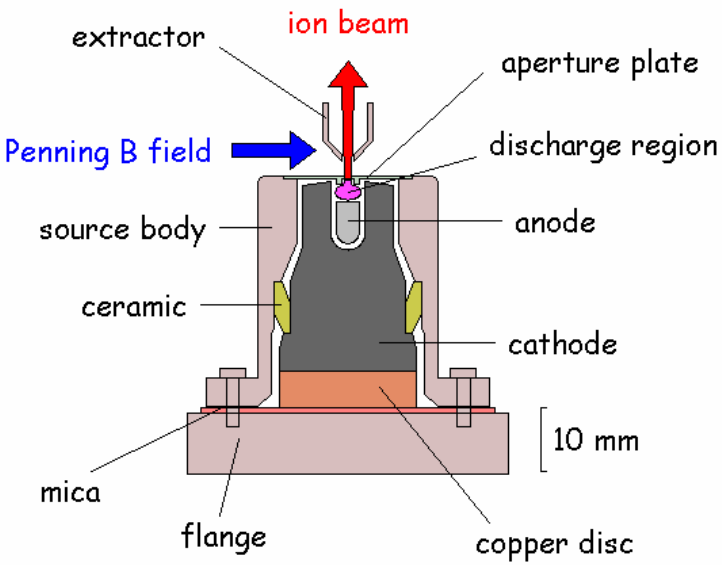
	BNL	ANL	FNAL	DESY
Type	Magnetron	Magnetron	Magnetron	Magnetron
Particle	H-	H-	H-	H-
Current (mA)	90	48	60	60
Pulse Length (ms)	0.7	0.07	0.066	0.075
Rep-Rate (Hz)	7.5	30	15	6
Duty Factor	0.5%	0.21%	0.10%	0.05%
Average Current (mA)	0.47	0.101	0.059	0.027
Dischange Power (W)	2475	7000	9750	
Emittance	0.27, 0.27	0.22, 0.35	0.2, 0.33	0.38, 0.29
Cesiated	yes	yes	yes	yes
Cesium (mg/day)	12	5	10	2
Lifetime (hrs)	4368	2184	2016	6384

H- Ion Sources - Magnetron - Status

- BNL production efficiency ~36 mA/kW.
- A 5% df source could consume 130W average.
- Cesium coverage could be maintained with high df with porous cathodes.
- Pulsed gas may be a problem for higher duty factors and high extraction voltages
- Little active investigation to increase the pulse length.

J Alessi, BNL
D Moehs, FNAL

H- Ion Sources - Penning - Status



J Thomason, RAL

	RAL	INR-MMF	INP Medical‡
Type	Penning	Penning	Penning
Particle	H-	H-	H-
Current (mA)	35	80	8
Pulse Length (ms)	0.2	0.25	CW
Rep-Rate (Hz)	50	100	CW
Duty Factor	1.0%	2.5%	100%
Average Current (mA)	0.35	2	8
Dischange Power (W)	4000		630
Emittance	0.12, 0.17	0.09, 0.15	0.3, 0.4†
Cesiated	yes	yes	yes
Cesium (mg/day)	0.1	24	40
Lifetime (hrs)	1200	336	140

‡ Proto-type
† Emittance measured at 5mA

H- Ion Sources - Penning

- Production efficiency 8 - 12 mA/kW.

ISIS - RAL

- Improved physics and MAFIA modelling
- More controlled Penning discharge
- Component geometry changes
- Thermal modelling with ANSYS – shows a 40^{o}C rise during discharge.
- Improved cooling for 1.2 and 2.5 ms pulses to offset heating and demand for Cs
- Extraction at higher potential (presently 35kV extraction on 600kV platform)
- Higher duty factor extraction and arc PSUs
- Scale to 4X - LANL source.

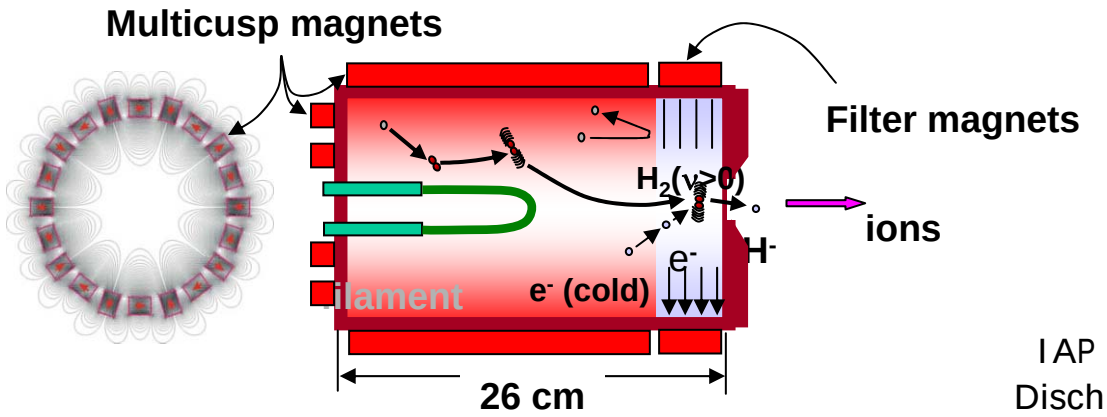
J Thomason and D Faircloth, RAL

H- Ion Sources - Penning – LANL scaling

Type	1X - Slit	1X - Circ	4X - Slit	4X - Circ	8X
Particle	H-	H-	H-	H-	H-
Current (mA)	160	82	170	63	120
Pulse Length (ms)	1	1	1	1	
Rep-Rate (Hz)	5	5	5	5	
Duty Factor	0.5%	0.5%	0.5%	0.5%	
Average Current (mA)	0.8	0.41	0.85	0.315	
Dischange Power (W)	18000	18000	19800	19800	39200
Emittance	0.06, 0.17	0.053, 0.056	0.15, 0.29	0.20, 0.19	0.15, 0.14
Cesiated	yes	yes	yes	yes	yes
Cesium (mg/day)	-	-	-	-	-
Lifetime (hrs)	-	-	-	-	-

- 4X source has produced 250mA.
- 5% duty factor – 105mA source is feasible [J. Sherman].
- A 4X source ran at 6% duty factor (~1 day without extraction).
- 8X CW source was built, but not tested due to funding limitations.

H- Ion Sources – Filament Multi-cusp



Sketch: M Stockli,
R Welton, SNS

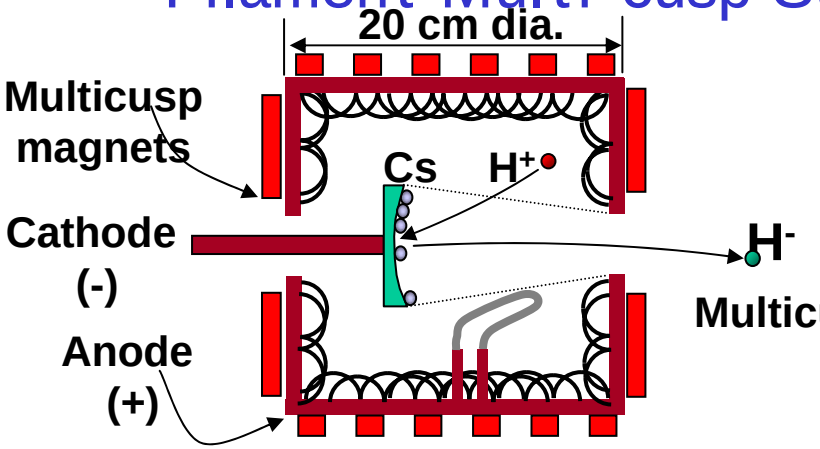
	IAP Disch.	TRIUMF Disch.	Jyväskylä Disch.	JKJ Disch.
Type	Multi-cusp	Multi-cusp	Multi-cusp	Multi-cusp
Particle	H-	H-	H-	H-
Current (mA)	120	6†	1.5	38
Pulse Length (ms)	1.2	CW	CW	0.36
Rep-Rate (Hz)	50	CW	CW	25
Duty Factor	6%	100%	100%	0.9%
Average Current (mA)	7.2	6†	1.5	0.342
Dischange Power (W)	47500	5000	1100	35000
Emittance	0.07‡	0.16, 0.16		0.1
Cesiated	yes	no	no	no
Cesium (mg/day)	50	N/A	N/A	N/A
Lifetime (hrs)	190 ¶	600	200	100
Filament	Tungsten		Tantalum	LaB6

‡ Estimation from optical measurement.
† Production of 20mA.
No lifetime tests at this current.
§ Measurements on a similar source, not in Jyväskylä
¶ 190hrs measured at 40kW disch. Estimate 14 days possible

H- Ion Sources – Filament Multi-cusp

- Arc Multi-Cusp sources are one method to produce high currents of H- ions @ 1 – 2 mA/kW.
  The Frankfurt source produced 120mA.
  $I_{H-} \propto P_{ARC}$. No sign of saturation.
- Work well in CW mode, despite the short lifetime.
- TRIUMF source has shown 20mA is possible – shorter lifetime.
- The cathode erosion problem has not been solved. Tungsten, tantalum and LaB_6 cathodes all rapidly deteriorate.
- Cesium seeding increases the H- current.
- No plans to return the Frankfurt source to operation.

H- Ion Sources
Filament Multi-cusp Surface Converter - Status



Sketch: M Stockli,
R Welton, SNS

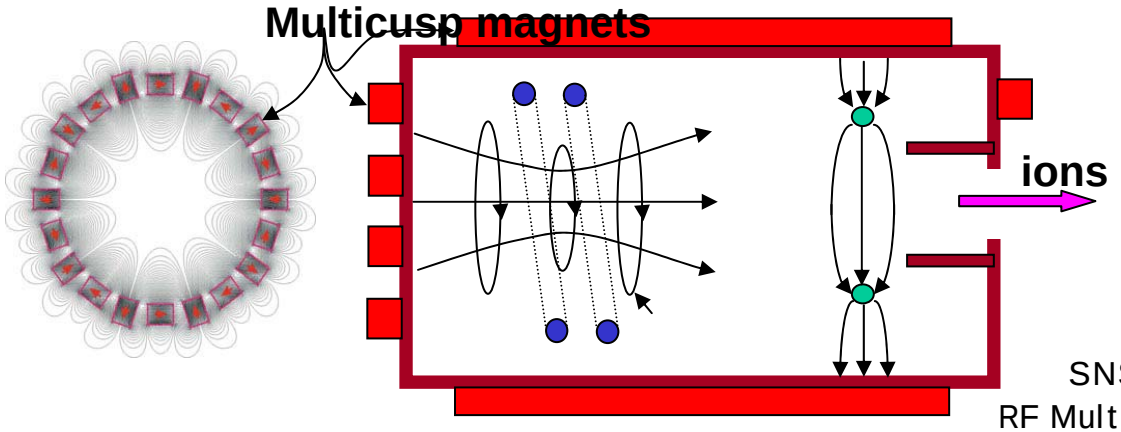
See poster TUPLT160 For latest LANSCE results

	LANSCE Converter Multi-	LANSCE Converter Multi-	KEK-KENS Convertor Multi-
Type	Cusp - Radial	Cusp - Axial	Cusp
Particle	H-	H-	H-
Current (mA)	18	40	18
Pulse Length (ms)	1	1	0.2
Rep-Rate (Hz)	120	120	20
Duty Factor	12.0%	12.0%	0.4%
Average Current (mA)	1.8	4.8	0.072
Dischange Power (W)	7000	32000	4000
Emittance	0.16	0.35	0.43
Cesiated	yes	yes	yes
Cesium (mg/day)	110		
Lifetime (hrs)	672		2352

H- Ion Sources
Filament Multi-cusp Surface Converter - Status

- Production efficiency 2 – 4 mA/kW.
- Suffer from lifetime of the filaments.
- LANSCE upgrade source achieves 40mA, ε=0.35mm.mrad (rms norm) is too large.
- R&D continues on the present source radial to achieve higher currents.
- RF version of the surface converter was unsuccessfully tried at LANL.

H- Ion Sources – RF Multi-cusp – Status



Sketch: M Stockli,
R Welton, SNS

	SNS RF Multi-cusp	DESY RF Multi-cusp	Seoul National University RF Multi-cusp -
Type	2MHz	2MHz	13.56 MHz
Particle	H-	H-	H-
Current (mA)	50	40	0.2
Pulse Length (ms)	1.3	0.1	CW
Rep-Rate (Hz)	60	5	CW
Duty Factor	7.80%	0.05%	100%
Average Current (mA)	3.9	0.02	0.2
Dischange Power (W)	50000	20000	1500
Emittance	0.17	0.18, 0.16	
Cesiated	yes	no	no
Cesium (mg/day)	<<1	-	-
Lifetime (hrs)	TBD	25000	
Antenna	Internal Coated	External	External†
Operation Since	TBD	1999	None

† Transformer Coupled Plasma

H- Ion Sources – RF Multi-cusp

- DESY source has exceptional reliability. Metal layer build up. Note: 25,000 hrs equiv. to 160hrs for the SNS duty factor.
- SNS – test with a DESY style external antenna (end 2004, beginning 2005).

- DESY made measurements for frequency range 1.65 – 9MHz. 2MHz (with 6.5 winding antenna) gave the highest current (especially when fixed at 26kW).

- DESY – Measurements of the H- distribution in the plasma will be made.
- SNU – Source to be mounted on Tandem in 2004. Hoping to improve current.

H- Ion Sources – 2.45 GHz (ECR)

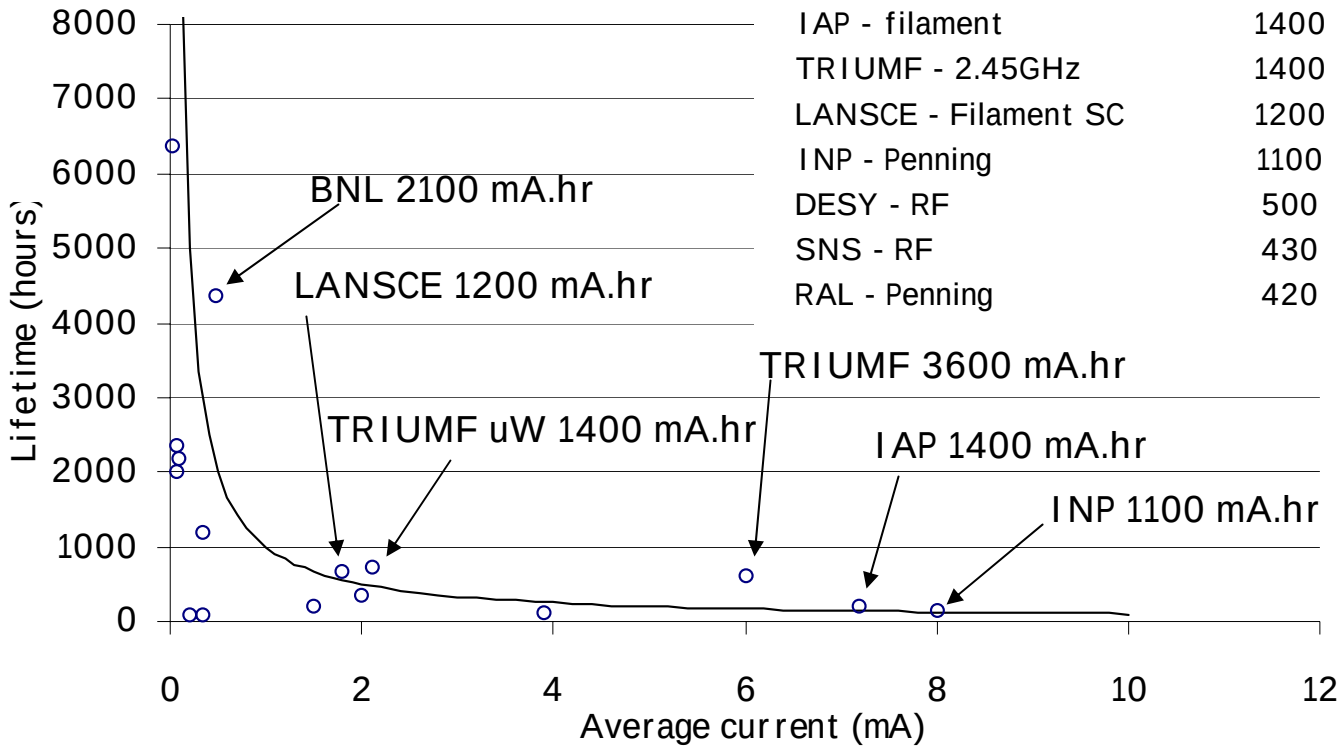
- Based on success of 2.45 GHz ECR as a proton source. Well known that 1kW, CW microwave/ECR source can be built.
- ANL used a tantalum liner to produce the best results.
- TRUIMF have tested continuous operation for 1 month.
- Will higher frequencies help?
- Is 10 – 20 kW needed for 50mA?

	ANL	TRIUMF 2.45GHz	CEA 2.45GHz
Type	2.45GHz	Multi-cusp	ECR
Particle	H-	H-	H-
Current (mA)	4†	2.1	1.4
Duty Factor	100%	100%	2%
Dischange Power (kW)	2	0.5	1
Prod. Efficiency (mA/kW)	2	4.2	1.4
Lifetime (hrs)		720	

† current scaled after spectrometer measurement.

Summary

	Lifetime x current (mA .hours)
TRIUMF - Filament	3600
BNL - Magnetron	2100
IAP - filament	1400
TRIUMF - 2.45GHz	1400
LANSCE - Filament SC	1200
INP - Penning	1100
DESY - RF	500
SNS - RF	430
RAL - Penning	420



Summary

Protons

- >100mA, CW, low emittance sources available.
- Reliability needs to be proved - no concerns.

H-

- High currents and high duty factors not available at the same time.
- Choice of source type to fulfil this role is unclear.
- Filament, magnetron, Penning, RF etc. all possible.

Acknowledgements

J. Alessi, Y. Belchenko, V. Dudnikov, D.Faircloth, R. Gobin, D. Küchler, P.Heikkenen, C. Hill, Y.S. Hwang. D. Moehs, J.Peters, G. Rouleau, J. Sherman, T. Steiner, V. Stipp, M. Stockli, A.Ueno, K. Volk and R. Welton.

http://cern.ch/scrivens/h-/IonSources.xls