RF Ion Source Topics Discussed at DESY

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In 2005 Fermilab, SNS, DESY and CERN formed a collaboration to test the DESY external antenna Radio Frequency (RF) H^- ion source with an 80 kW, 2 MHz amplifier provided by the SNS. With the SNS amplifier installed the DESY source produced a 3 ms long pulse at 0.25 Hz during this site visit. The initial H^- beam current was 30 mA drooping to 25 mA by the end of the pulse. This test effectively met the current requirement for the Fermilab Proton Driver, option A in table I, and comes very close to meeting the option B, CERN and BSNS requirements.

Table I: Anticipated machine parameters for H^- beams as compared to typical DESY operating parameters. *Data provided by Huashun Zhang.

Lab	Current ma	Emittance pi-mm-mr (rms, nor.)	Pulse length ms	Rep. Rate Hz	LEBT energy keV
DESY	45	.25	0.15	8	35
SNS	100	≤ 0.35	1.23	60	65
CERN Phase A / B	40 / 80	0.25	0.4 / 0.7	1 / 2	95
Fermilab Option A / B	12 / 45	0.24	3.2 / 1.2	2.5 / 10	50
BSNS* Beijing, China	40	0.2	0.2	25	75

Below follows a list of topics which were discussed during this site visit:

Advantages of the DESY unceciated RF source:

- No Cesium system
- Relatively low emittance
- Fast startup; consisting of pumping down and HV conditioning
- Long lifetime

Disadvantages of the DESY unceciated RF source:

- Amps of electrons dumped at extraction energy

Availability of mechanical drawings or sketches:

- A current set of drawings is not available.
- All the drawings were created in an old CAD program which is not compatible with modern programs. The best immediate option would be to get a complete set of prints and then have them redrawn. This requires some effort on the DESY group to insure that the latest modifications are included, but this has not been high priority for them. The DESY group is also planning to redraw these files in IDEAS or SOLID EDGE.
- A formal agreement between DESY and CERN regarding the ion source is being prepared which will act as a benchmark for other collaborations. It is hoped that this agreement will be competed before the summer of 2006.

Electrical system configuration drawings or sketches: Not available at this time

Some basic components: (see pictures 1 and 2 below)

- Extractor voltage
- HV isolation
- Gas valve pulse voltage
- Hollow Anode Arc supply
- 2 MHz RF supply
- Matching network
- Electron Dump bias (if desired)
- Controls

Component list: Not available

A rough cost estimate in dollars **for the 95 kV system proposed at CERN**. Only 5% contingency is included (provided by Thomas Meinschad, it is hoped that a better cost estimate will be available in the summer of 2006.)

- 100 K for RF power supply
- 100 K for vacuum equipment
- 100 K for ion source
- 120 K for HV power supplies and isolation

Source stability under desired conditions

What was the test period for 3 ms pulses?

- Original test less than 1 day
- During this visit, four 8 hour test periods, with 0.25 Hz rep rates were carried out.

How good is the pulse to pulse stability?

- Running at 0.25 Hz; pulse to pulse changes, including beam modulation and electronic noise appears to be about 10%. It is thought that the electrical noise dominates this measurement. A magnetron typically produces 5-10% modulation and it is expected that the RF source can do better.

What is the cause of current droop during the pulse: See figure 1

- It is believed that droop of the extraction voltage and RF power contributes. Both of these circuits have large caps which sustain the voltage. Jens proposed a compensation cap and associated circuitry to maintain the extraction voltage but this would require modifications to the power suppli8es which are not warranted at this time.

Changes needed to achieve a duty factor (df) of 1 or 1.2%:

Air cooling considerations, is this straight forward?

- Based on a very simple model generated by Robert Welton, which assumes 1 kW of RF power per 1 mA and uniform heating of the ceramic, for a 45 mA beam at 1.2% df you need to dissipate approximately 530 watts. Based on this model water cooling is necessary.

- Jens suggests that thermal measurements should be carried out because uniform heating is only an approximation and it is not certain that all the RF power ultimately ends up in the ceramic.

- The forward and reflected power was measured on the DESY RF source for a 3 ms pulse (also see figure 1). Table II summarizes a minimal power case where the plasma was on the verge of extinction.

Table II: RF power for a 3 ms pulse.

H- (mA)	Time (µs)	Forward power	Reflected power	Absorbed power	Ave. Abs. power 1.2% df
38	100	19.7 kW	3.7 kW	16.0 kW	301 watts
	1500	13.1 kW	0.64 kW	12.5 kW	150 watts
17	2900	11.5 kW	0.57 kW	11.0 kW	132 watts

- Based on Table II, the DESY ceramic should be able to handle the average heat load for the Proton Driver 3 ms, 12 mA beam option (similar to 17 mA row). Twice as much power is needed to produce a 1 ms 45 mA pulse (similar to 38 mA row). In this case, it may be necessary to make some design changes to insure the Viton o-rings don't melt. This might involve reshaping the ceramic to move the o-ring farther from the heat source or to adding air or water cooling.

Estimation of lifetime

Have you observed any component wear to date?

- Over 2 years the only observed wear has been on the extraction aperture, which is replaced from time to time.
- During this visit the HV insulator needed to be replaced. A conductive plating appears to have developed over time leading to the HV break down.
- No serious internal component wear has been seen.
- It is not certain how an increased duty factor would affect failure modes.

Extraction considerations for 50 KV

Probable staged Accel-Accel design?

- This is up to us!
- In CERN simulations of 2 acceleration stages they have seen additional emittance growth associated with the second stage but detailed studies have not yet been carried out to see if this can be corrected.

Emittance numbers:

- Based on our joint review paper: 0.25 pi mm mrad norm. RMS at 40 mA (D. Moehs, J. Peters, J. Sherman, IEEE Trans. Plasma Science, v. 33, Dec. 2005)
- Where was this measured in relation to the source?
  - This is measured before the first solenoid magnet.
- What if any is the expected change with current, 12 mA vs 45 mA.
  - See Figure 2 the original data is from Jens Peters, Rev. Sci. Inst., v. 75, p. 1709 (2004). I have extened the x-axis and added the optimized DESY emittance datum point at 40 mA (2 Mhz) from; D. Moehs, J. Peters, J. Sherman, IEEE Trans. Plas. Sci., v. 33, p. 1786, (2005) and Martin Stockli provided the SNS data which will be published in Rev. Sci. Inst., v. 77 (2006). Note: Apart from the 40 mA datum point, the bulk of the DESY data from RSI 75 is from a study of current vs. frequency not an emittance study. Furthermore the SNS data was collected after the LEBT, which is thought to be responsible for the large growth between 30 and 40 mA, while DESY data was collected after the ion source. Despite these inconsistencies it is worth noting that the DESY emittance is roughly constant over a reasonable range, 5 to 40 mA (0.25 – 0.3 π mm- mrad, NORM, RMS with a 90% threshold), and is close to the Proton Driver requirement of 0.24 π mm- mrad (at 100% NORM, RMS). It is expected that with some optimization, such as a reduced aperture, this source could meet our emittance requirement. The significant difference between the SNS data and the DESY data is not well understood at this time. Comparing ion source emittances is dangerous as they are measured in different locations using different types of hardware and data analysis techniques!

- What if any is the expected change for long pulses 1 and 3 ms?
    - For a space charge neutralized beam using a magnetic LEBT see figure 3 in my BNL trip report. Some rotation is expected in the first 10-100 microseconds as the beam is neutralized.

General requirements:

Power: Similar to Magnetron except for addition of RF amplifier:
The SNS RF Amplifier requires 25 A at 220 V

Water: Cooling for the E-dump and for the RF antenna

Tandem source for arc ignition:

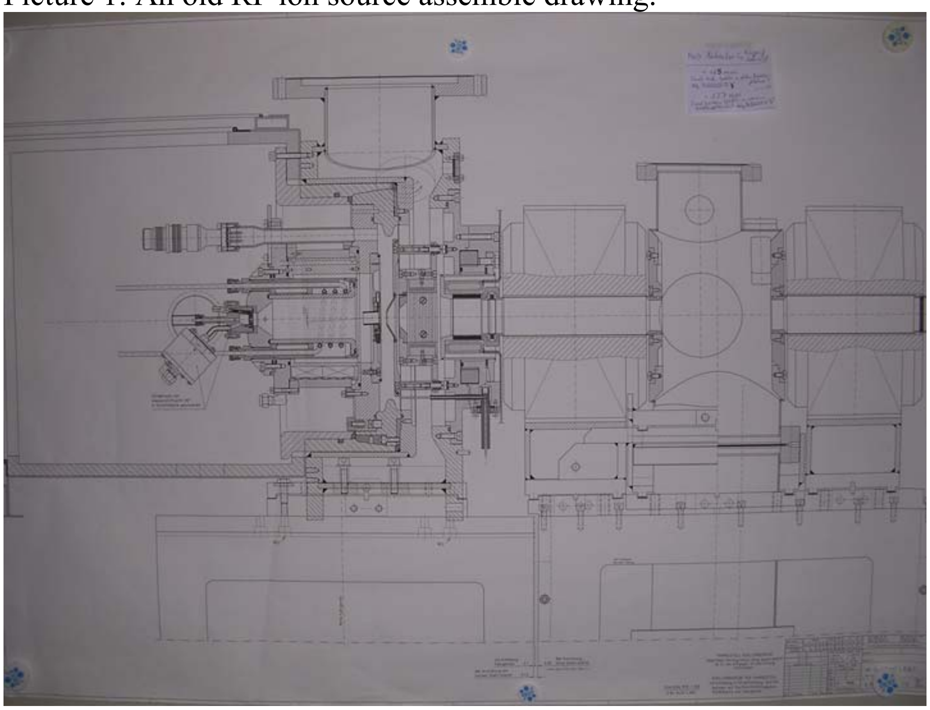
Would it be beneficial to run this through the entire gas injection period?

- Rob Welton has shown that this makes a huge difference at the SNS.
- Jens indicates that this just isn't needed for the DESY application. A test could be made at a late time.

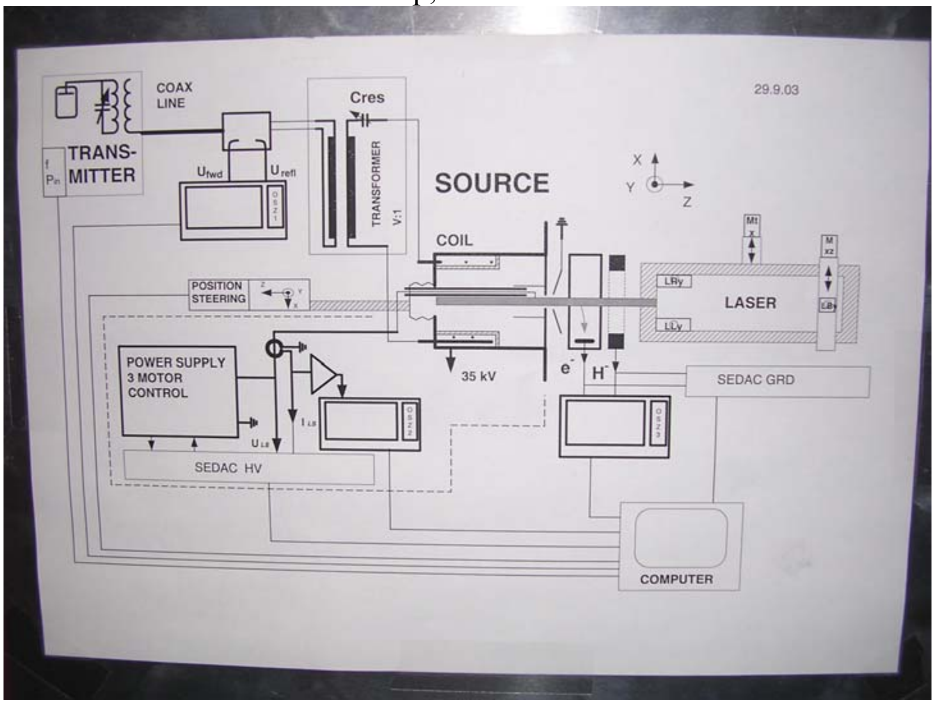
How much earlier is the gas pulse as compared to H- extraction?

- Several 1.5 ms (see figure 3); this is due to the distance of piezoelectric valve from source.

Picture 1: An old RF ion source assemble drawing.



Picture 2: A laser experiment carried out on the RF source.
Also shown is the basic RF setup, HV and read backs.



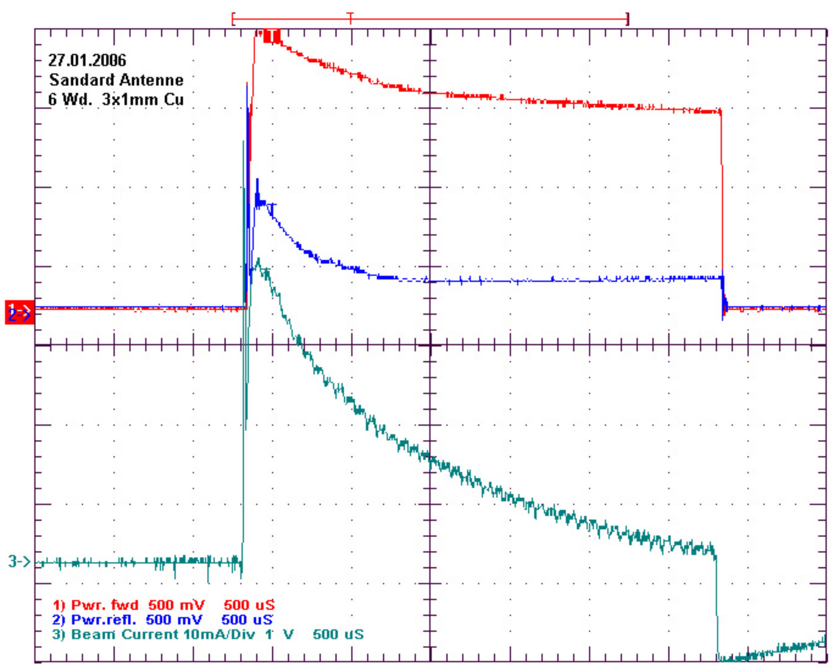


Figure 1. The droop in beam current (green trace) and forward power (red trace) for a 3 ms pulse.

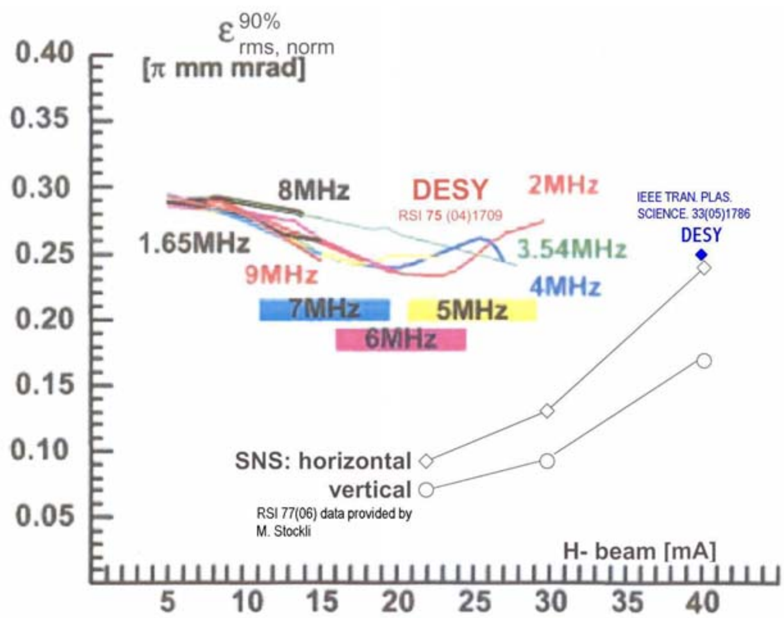


Figure 2. Emittance data as a function of current for DESY and the SNS.
Note: Apart from the 40 mA datum point, the bulk of the DESY data from RSI 75 is from a study of current vs. frequency not an emittance study. Furthermore the SNS data was collected after the LEBT while DESY data was collected after the ion source.

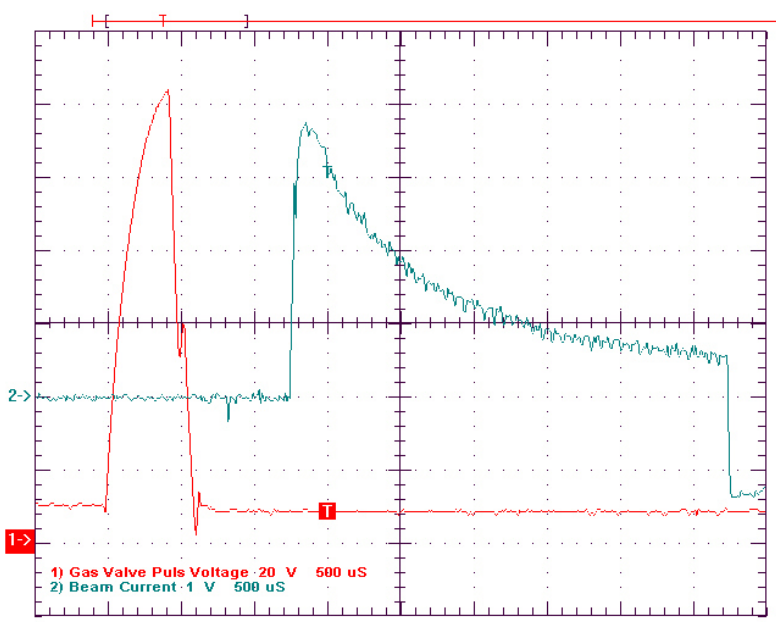


Figure 3. A timing plot of the gas pulse in relation to the 3 ms beam pulse.