CAS **Course on Ion Sources**

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CASE STUDY

Case Study

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Goal of this course is to investigate different ion sources, showing their specific features and the environment to operate these ion sources.

All aspects should be taken into account. However, because of the limited time, it will not be possible to finish a complete planning, constructing, and commissioning. Nevertheless, to have a complete working list, a list of required resources, a list of estimated costs, and a time plan would be desirable.

This list should be presented at the end of the course to the audience. If possible, these contributions will be added to the proceedings.

The list of selected ion sources to be investigated are given in the following table (next slight).

Your investigation should not include the accelerator!

Only the ion source including the beam line, respectively the spectrometer is to be covered.

CASE STUDY

- Ion source for hadron therapy. 100 particle-µA of p, He, C. Ion source, low energy beam line, linac, synchrotron. Pulsed operation, 1 Hz, 1 ms.
- Ion source for atom/nuclear physic experiments with low cross section, velocity in the range of 1-10MeV/u, required elements ^{50}Ti, ^{48}Ca. High duty cycle linac.
- Ion source for material science, required elements U, Pb, Au, optional N, Ar. High duty cycle linac.
- Ion source for antiproton production, p, 100mA, 100MeV. Low duty cycle 1 Hz, 1 ms pulse length (ion source, linac, synchrotron, target).
- Ion source for heavy ion acceleration within LHC. Required elements Xe, Au, Pb, U for a linac with maximum $m/q < 8.5$. Low duty cycle 1Hz, 1ms pulse length.
- Ion source for negative ion acceleration. Low duty cycle 1Hz, 1ms pulse length.
- Ion source for heavy ion acceleration. 100% duty cycle. Required elements Xe, Au, Pb, U for an existing cyclotron.
- Laser ion source for a linac and a synchrotron. Pulsed operation 1Hz, 1ms. Alternatively, a LIS injecting directly in a synchrotron.
- Ion source for radioactive ion beams (charge breeding).

Your responsibility will be:

- design
- commissioning
- operation

for this injector.

Check the following table of points to be considered on completeness, bring items in the correct order, add some of your own ideas…

- Theoretical design
- Physical design
- Costs for investment, personal, operation.
- Project planning, resource planning.
- Parts commercial available or own design?
- Space requirements?
- Media requirements?
- Safety issues (electrical, chemical, radiation, ...)
- Diagnostic (requirements?)
- Control system (requirements?)
- Operator training
- Operation (assume operating times of 24h per day, 7d per week).
- Documentation (simple text files or artificial intelligence (AI) project?)
- Service (spare parts?)
- Further development (test bench required?)

Some further words to the shown table of topics:

Theoretical design: typically, these are the requirements for the ion source: a given charge state of a specific element; intensity or particle number, a given constraint of the 6D phase space: profile, emittance, momentum spread. For the beam line between the source and the specific application similar requirements might exist: acceptance in different projections. Mass resolution, momentum acceptance. Transport environment. …

Physical design:

Beam line layout; transport issues (electric lenses, magnetic lenses, post acceleration, …)

Vacuum layout (type of pumps, pumping speed, …)

Media requirements (electrical power, cooling, space for the installation, including necessary power supplies…)

Interlock systems

Safety issues:

- Mechanical Safety
- Electrical Safety
- Chemical Safety
- Radiation Safety
- More …

  for example: who is responsible, who is paying, who is going to court if something serious happens?

Control program: each power supply and each diagnostic tool should be remotely accessible. Several tasks could be provided which are not available by single components. Examples:

power on/off for the total equipment, scaling of the beam line, …, simultaneously ramping of different components, e.g. recording of a mastered spectrum, recording of response functions, e.g. recording of the intensity of a specific charge state when one parameter (gas pressure, discharge power, …) is changed.

Resource planning:

Necessary time for the design phase needs to be estimated as well as time for development tasks. A time plan for development or experiments however is questionable! Example: there is absolutely no advantage if a farmer tries to optimize sewing, growing, and harvest on his fields by a project plane. He depends on mother nature, not on project plans. Experimental results cannot be planned. Of course minimum time estimations are possible.

Three skilled people are not sufficient to provide a 24h/7d operation (maximum allowed working times, holidays, illness, …), but how many are necessary?

Training for operators:

What are critical issues during operation? How much training is required to introduce operators (typically skilled technicians, but no ion source specialists) and how often?

Service:

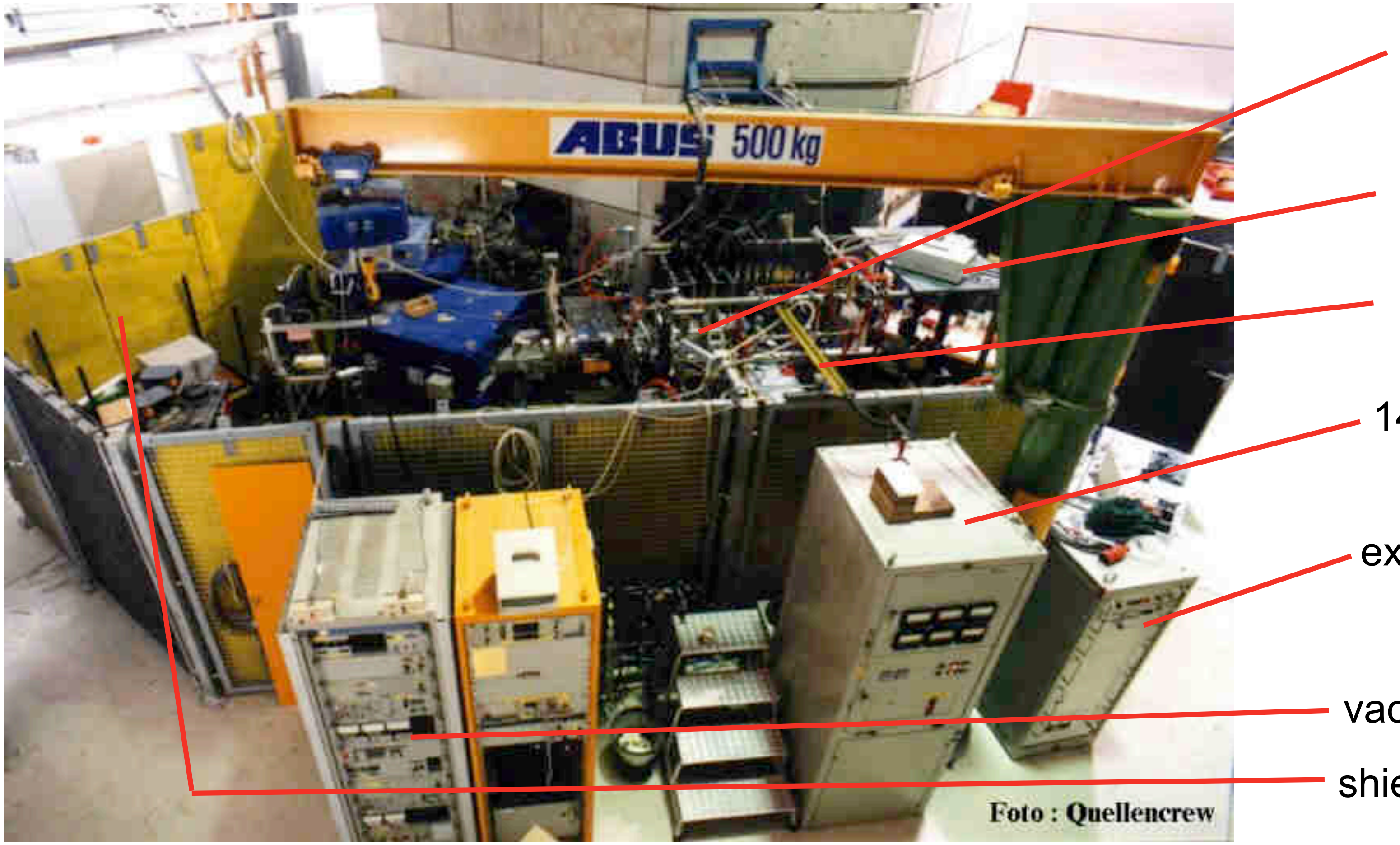
Service on failure only or periodically?

Is a **test bench required?** This is a critical question.

- You can save money and other resources if your answer is no. However, there would be no possibility to test specific things without interruption of the accelerator.
- With additional money and additional resources a test bench would give the possibility to improve the function of the accelerator.
- To convince the responsible person, a good argument is to have spare parts available in case of damaged components of the injector.

An example

(not complete, just ideas)



ion source

oven power supply

rf feeding

14.5GHz klystron

extraction ps

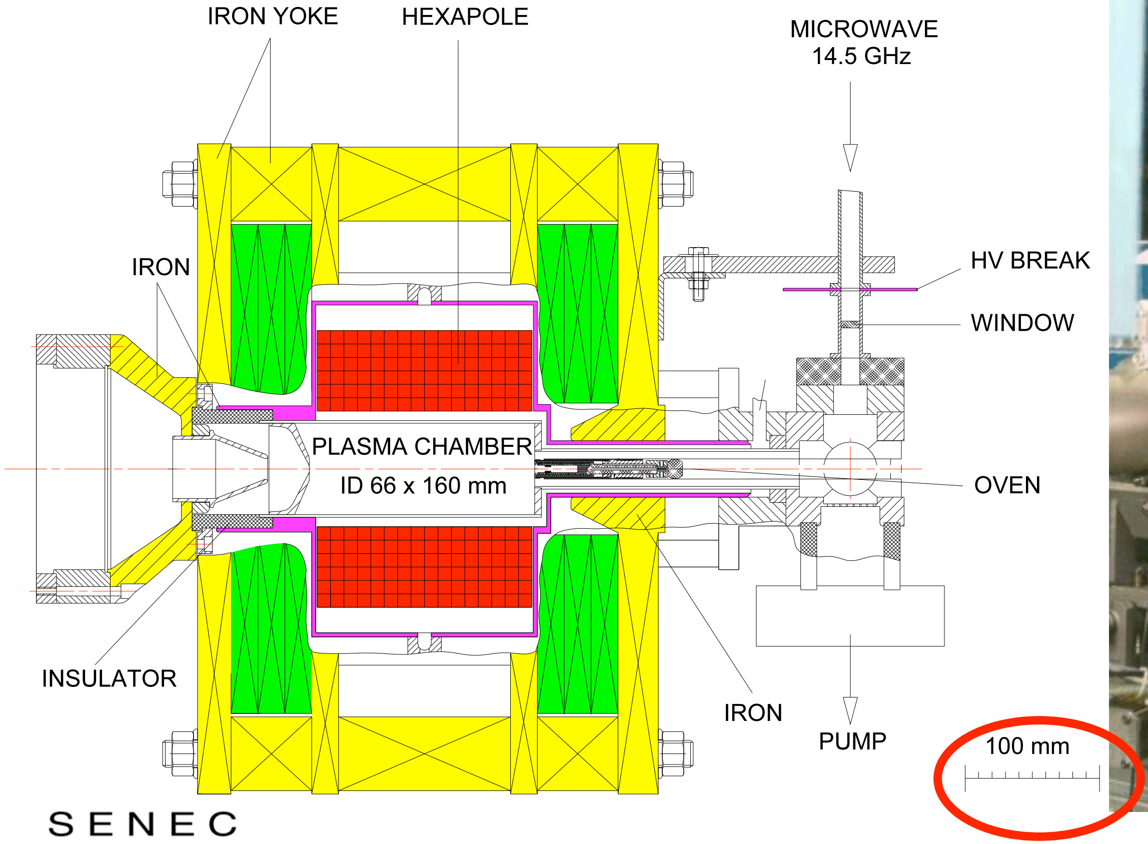
vacuum control

shielding

Foto : Quellencrew

High charge state injector at GSI

ECR of CAPRICE Type, 14.5 GHz. 1990



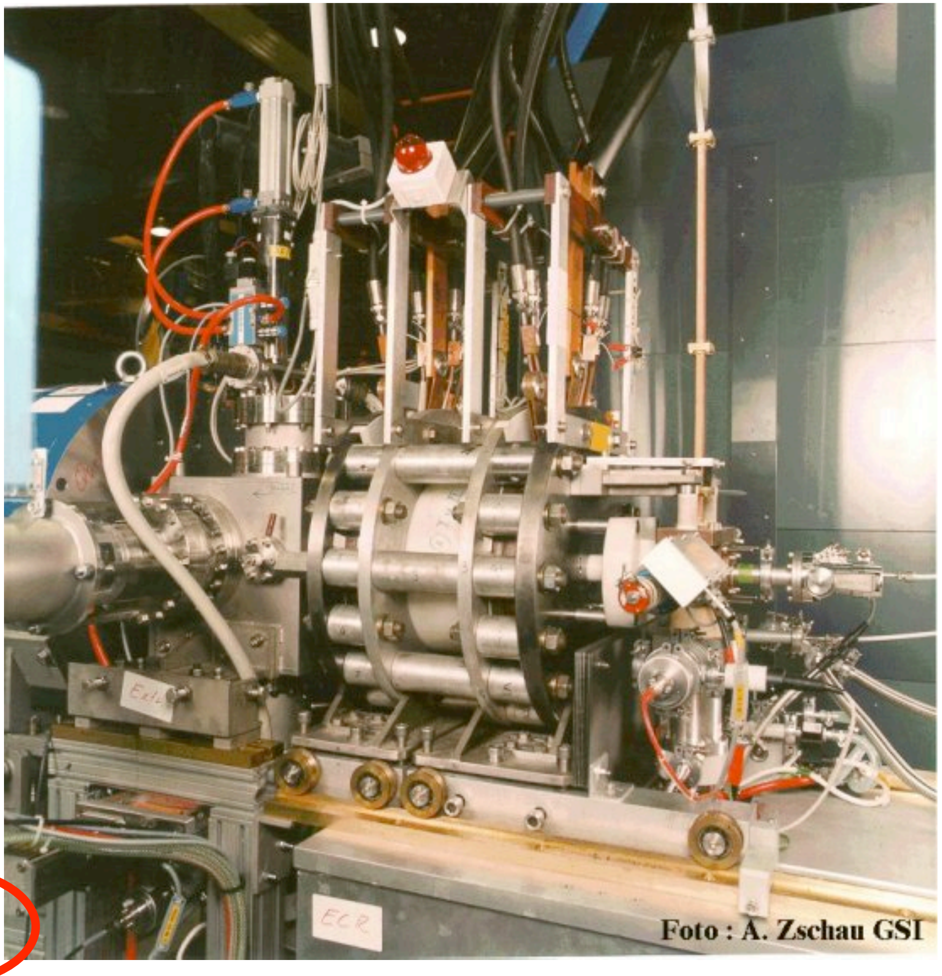
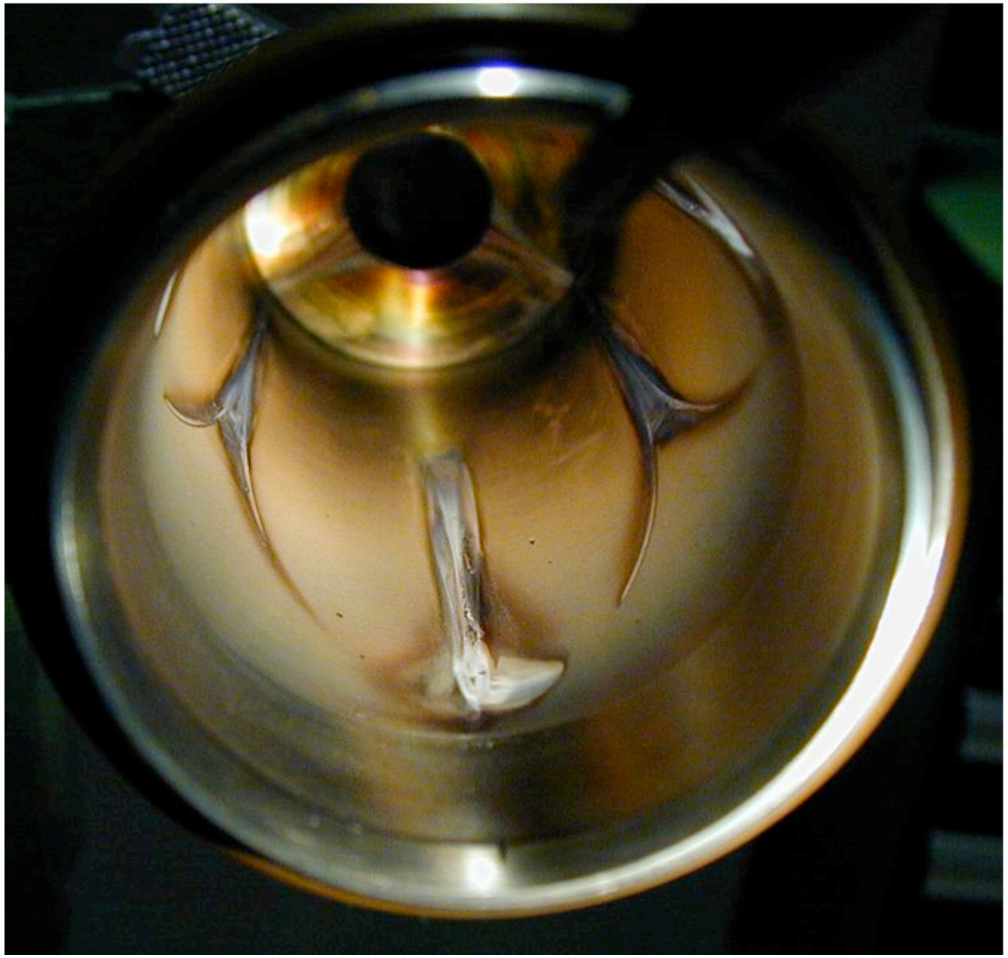


Foto : A. Zschau GSI



extraction electrode

gaseous operation

plasma chamber

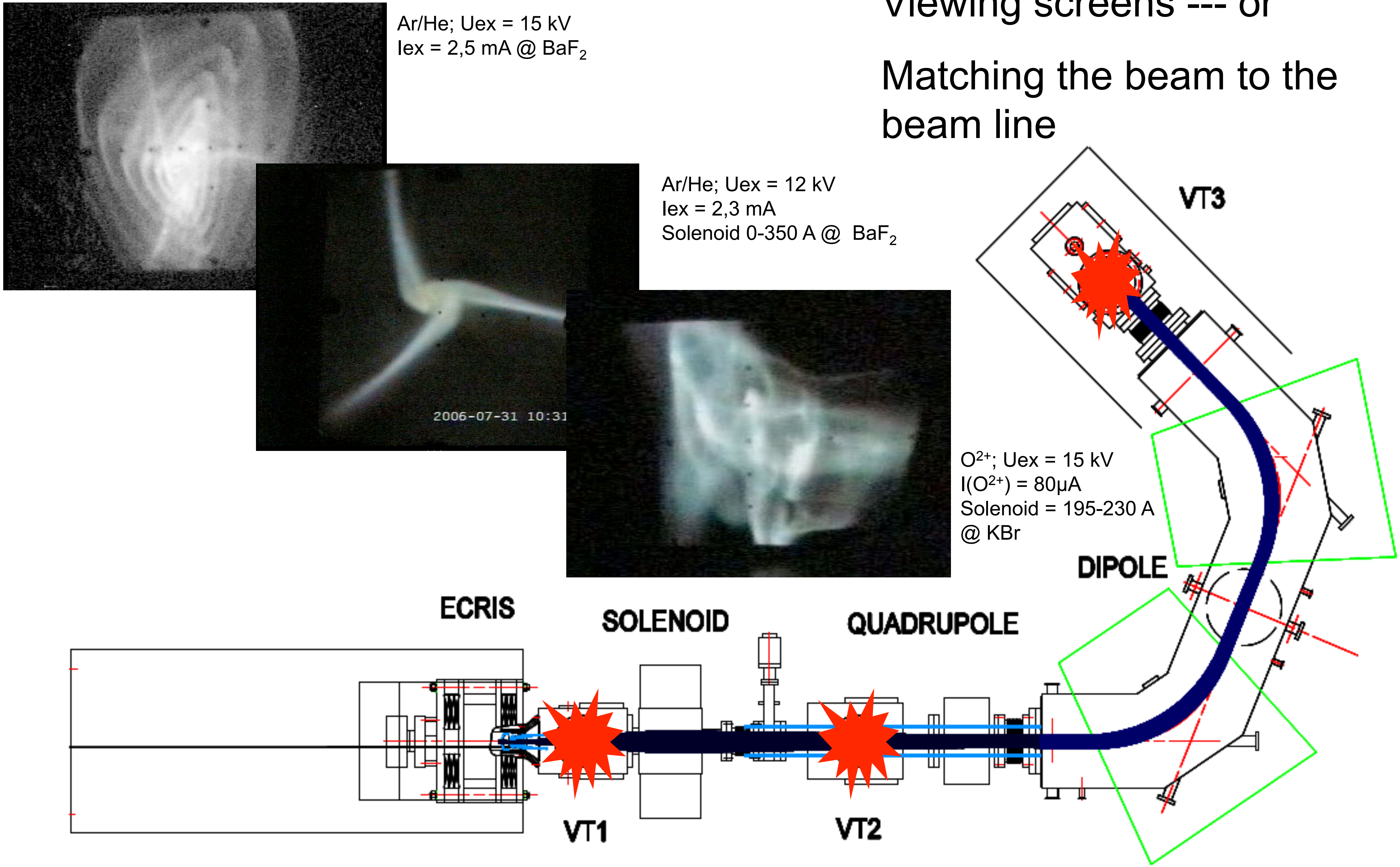
extraction electrode

metal operation

plasma chamber

Viewing screens --- or

Matching the beam to the beam line



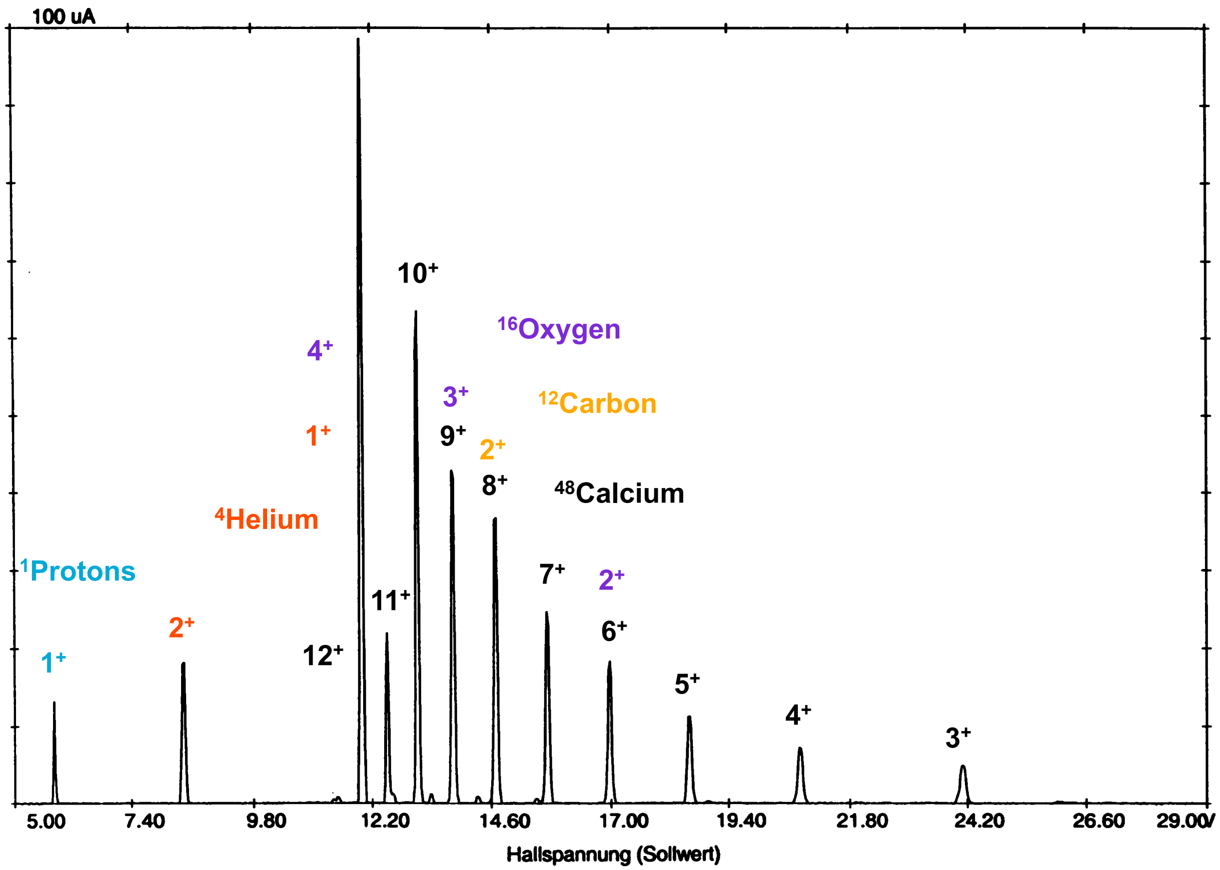
Ar/He; Uex = 15 kV
Iex = 2,5 mA @ BaF_2

Ar/He; Uex = 12 kV
Iex = 2,3 mA
Solenoid 0-350 A @ BaF_2

O^{2+}; Uex = 15 kV
$I(O^{2+})$ = 80μA
Solenoid = 195-230 A
@ KBr

CASE STUDY

Massenspektrum   HLI   gemessen am 22-JUN-2010 16:09   U05 48CA 10+

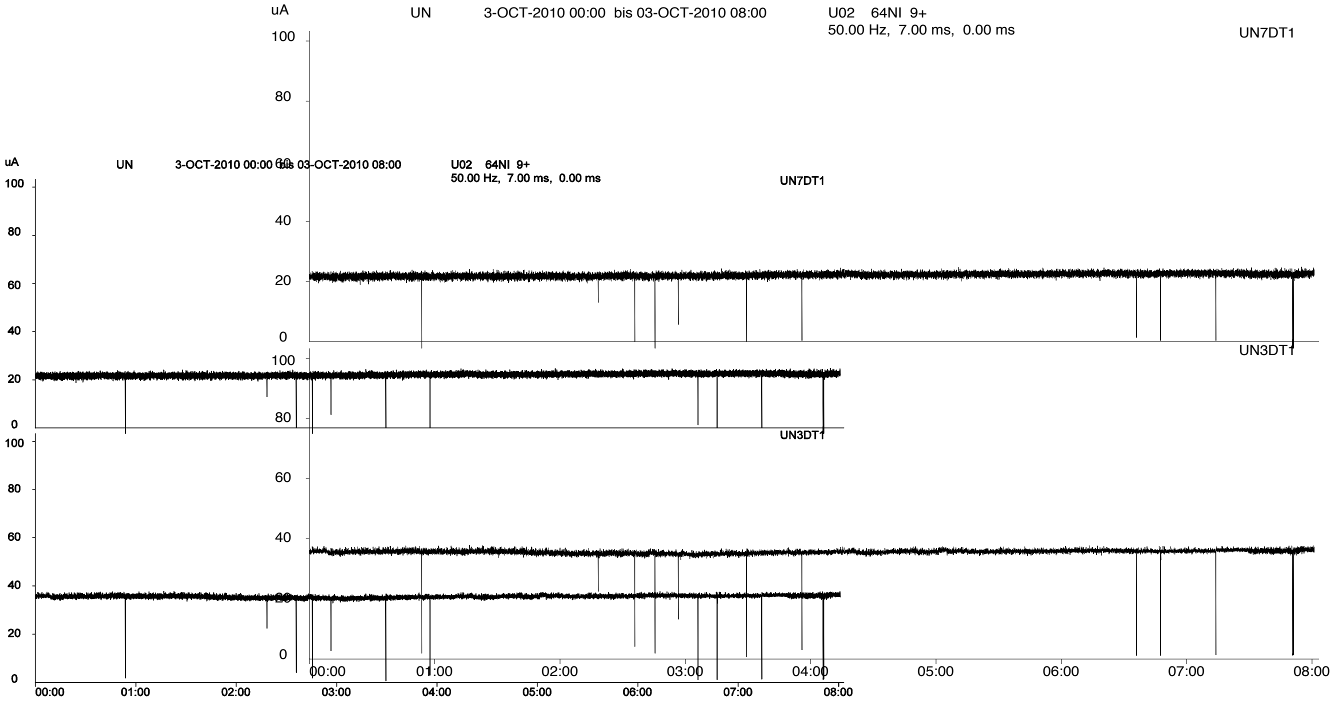


```
Messort: UN3DC2
Messber.: 1.0E-04 A
Int.zeit:  0.5 ms
Messpulslänge:  5.00 ms
Messpulsvorlauf:  0.00 ms
Quellenpulsrate: 50.00 Hz
Quellenpulslänge:  7.00 ms
Quellenpulsvorlauf:  0.00 ms
UN3DS2H:   -6.1 ,    6.0 mm

UN2IG> :   482.0 W
UN2IG< :    10.2 W
UN2IZ2E :  2006. V
UN2IZ2E :  0.003 mA
UN2IM1 : 1159.5 A
UN2IM2 : 1234.0 A
UN2IZ1G1:   5.83 V
UN2IZ1G3:  14.20 V
UN2IZ1O1:   0.44 V
UN2IZ1O1:  0.304 A
UN2IZ1O2:   0.44 V
UN2IZ1O2:  0.304 A
UN2IZ1E: 12000. V
UN2IZ1E:   0.97 mA
UN3MU1  von  5.000 A
      bis 29.000 A
 1000 Punkte

Master ein
```

list of ion source parameters

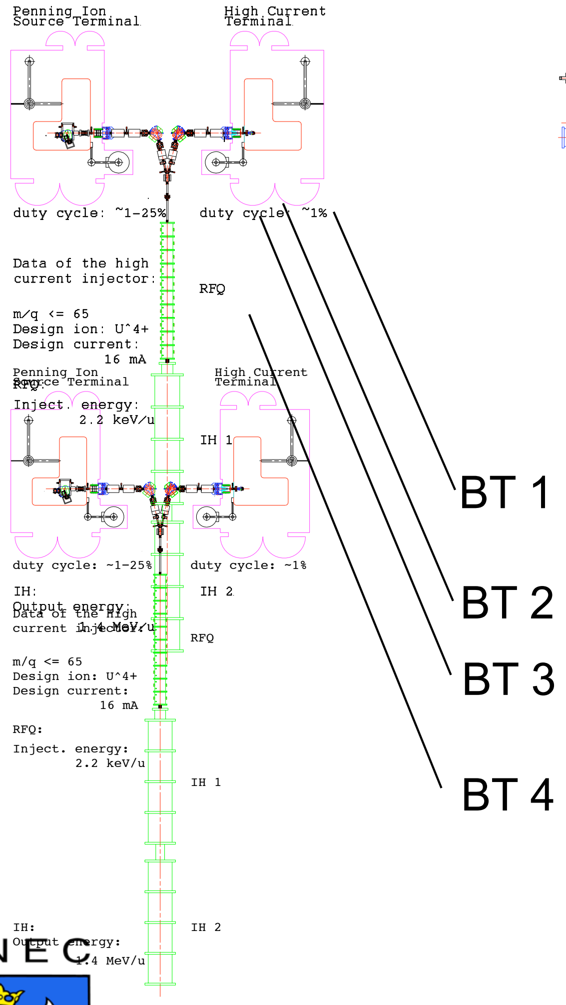


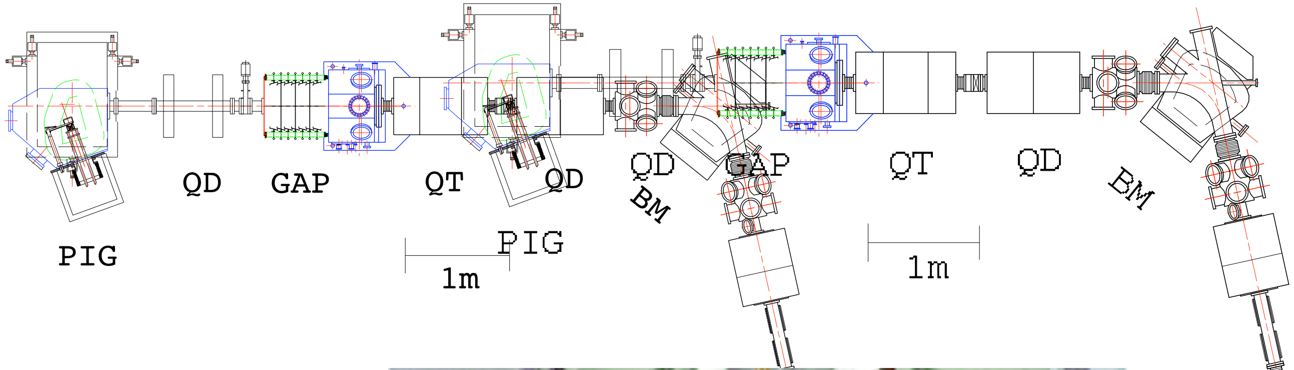
protocol of injected/ accelerated ion beam current over time (8 hours):

- button: analyzed $^{64}Ni^{9+}$ current at 2.5kev/u
- top: accelerated $^{64}Ni^{9+}$ current at 1.4MeV/u

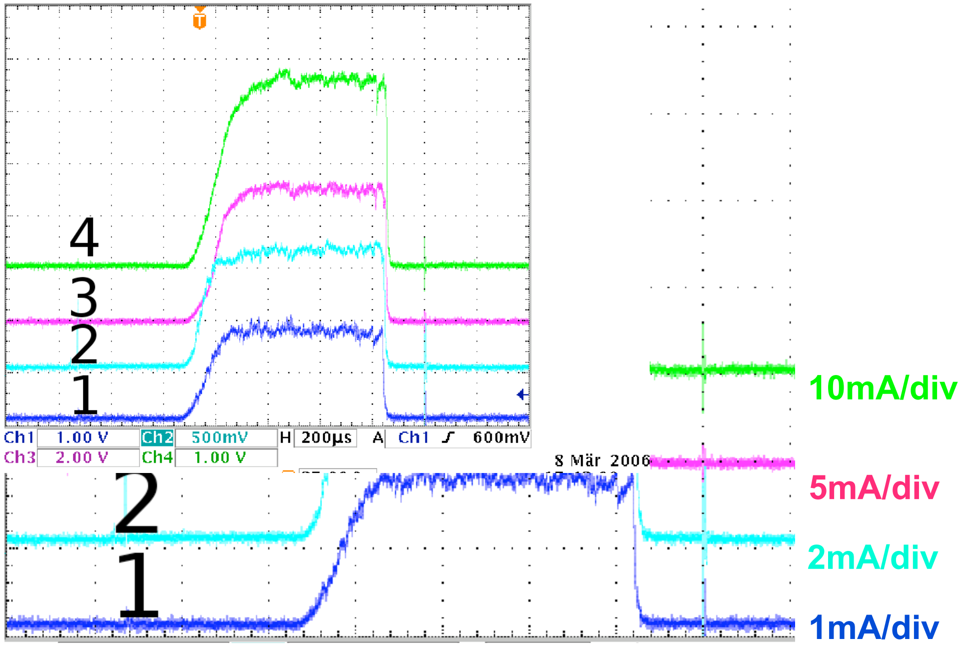
Another example

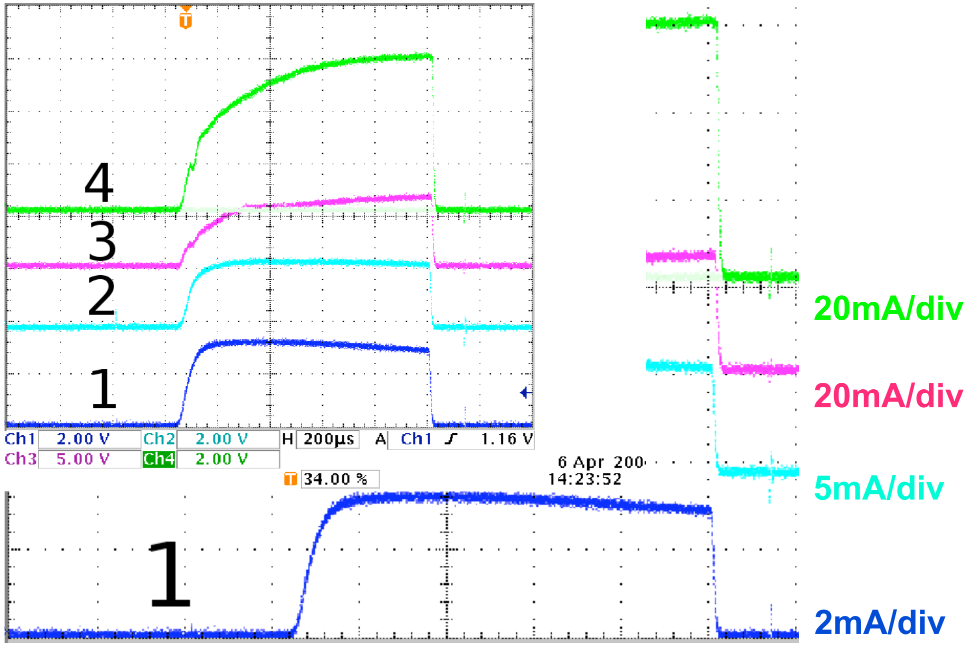
High current injector (GSI): two terminals are serving simultaneously the linac (more precise: from pulse to pulse). One terminal is equipped with a Penning ion source, the other with a high current source. For metals a MEVVA ion source is installed, for gases a bucket ion source. The following linac restricts the maximum mass to charge ratio either to 65 for low duty cycle operation (synchrotron mode), respectively to 25 for high duty operation (linac mode). Because the geometry of the linac is fixed, only the rf-amplitude can be varied. Therefore, the velocity for all ions to be accelerated has to be the same (here 2.2keV/u). The required total voltage from protons up to uranium is split between extraction voltage and post acceleration voltage.


Penning Ion Source Terminal
High Current Terminal
duty cycle: ~1-25%
duty cycle: ~1%
Data of the high current injector:
m/q <= 65
Design ion: U^4+
Design current: 16 mA
RFQ
RFQ:
Inject. energy: 2.2 keV/u
IH 1
IH 2
IH:
Output energy: 1.4 MeV/u
BT 1
BT 2
BT 3
BT 4

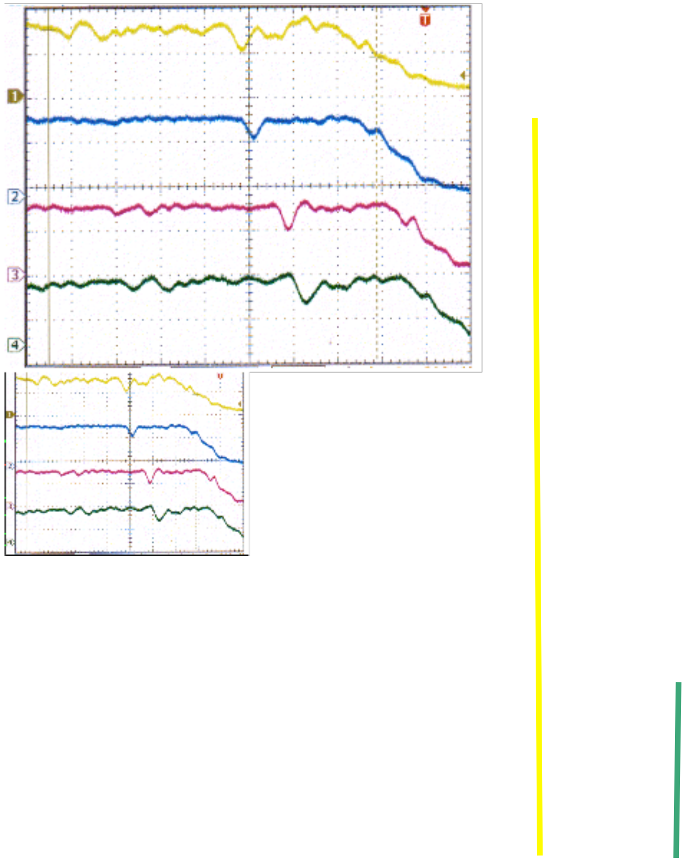

PIG
QD
GAP
QT
QD
PIG
1m
QD
BM
GAP
QT
QD
BM
1m

Ni^{2+} beam from a MEVVA N_2^+ beam from a MUCIS





200 µs/div

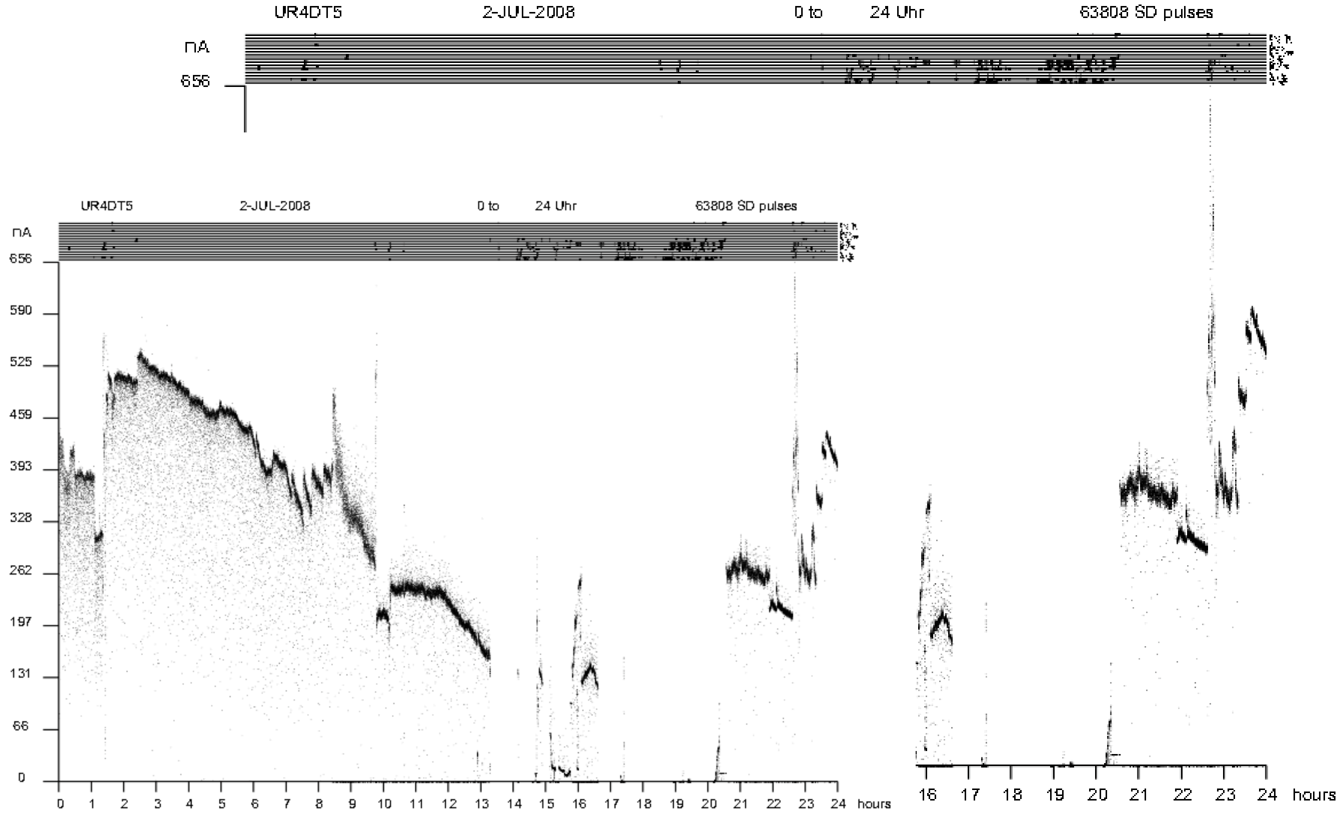


10 µs/div

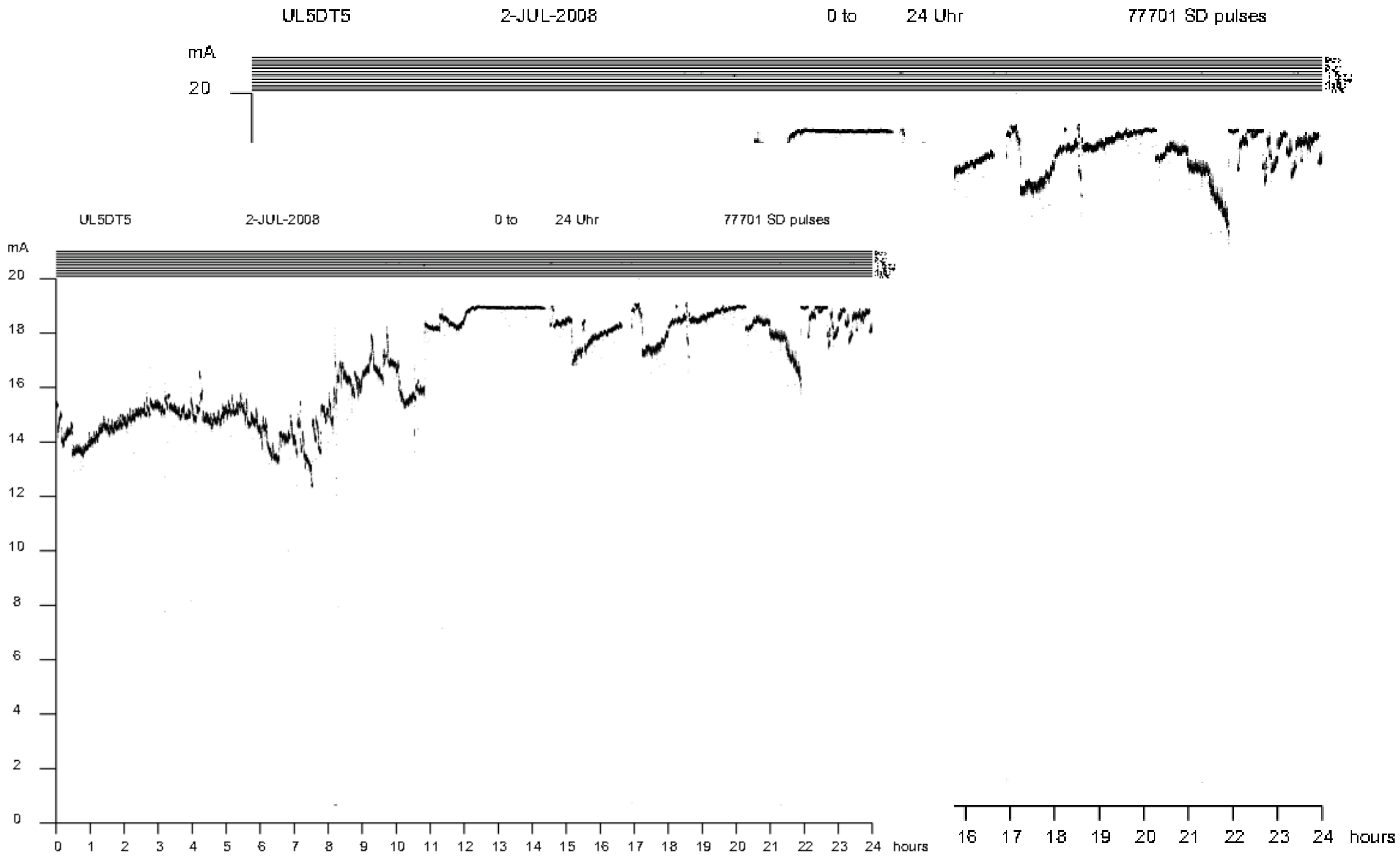
flight time !

Typical ion source current with time for a Penning ion source.

13:00 to 20:00 exchange of ion source.



Typical ion source current with time for a volume ion source for Ar^+.



Safety issues:

mechanical safety: e.g. elevation platform without barrier.

electric safety: high voltage, and/or high current power supplies (>24Volt, >15mA).

radiation savety: led shielding against X-rays, fences around the beam line against neutrons ($1/r^2$ –law), climate control against poisen dust. Controlled service area.

chemical safety: air control (hydrogen operation).

Just to mention a few…

Last, but not least: further reading, further information, further help:

- The Physics and Technology of Ion Sources, edited by I.G. Brown; John Wiley & Sons, ISBN 0-471-85708-4 (1989)
- The Physics and Technology of Ion Sources, edited by I.G. Brown; John Wiley & Sons, ISBN 3-527-40410-4 (2004)
- Handbook of Ion Sources; edited by B.H. Wolf; CRC Press, ISBN 0-8493-2502-1 (1995)
- Electron Cyclotron Resonance Ion Sources and ECR Plasmas, R. Geller, IOP Publishing, ISBN 0-7503-0107-4 (1996).
- Proceedings of the bi-annual International Conference on Ion Sources, Review of Scientific Instruments.
- Proceedings of the bi-annual International Workshop on ECRIS, Jacow.
- google.
- wikipedia.
- home pages of labs dealing with ion sources.
- lecturers of CAS.