An Operators Tool for Advanced Synchrotron Injection Diagnostics

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Darmstadt

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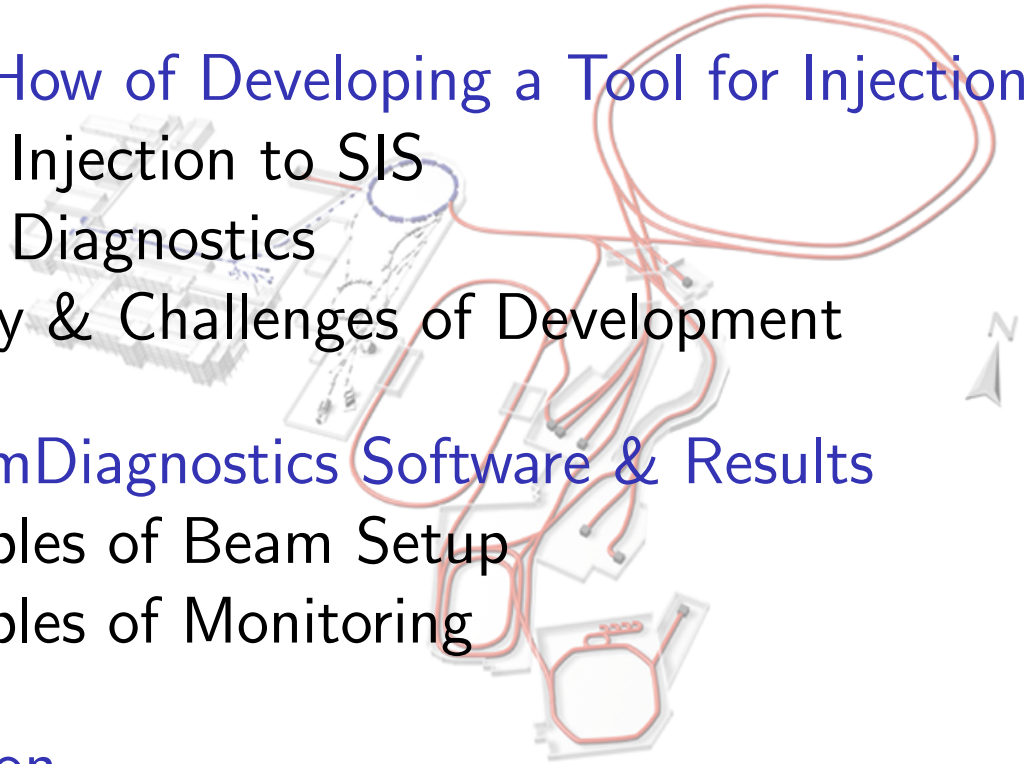
13. April 2010

Overview

1. Introduction to GSI
2. Main Control Room
3. Why & How of Developing a Tool for Injection Diagnostics
   - Beam Injection to SIS
   - Beam Diagnostics
   - History & Challenges of Development
4. SIS-BeamDiagnostics Software & Results
   - Examples of Beam Setup
   - Examples of Monitoring
5. Conclusion



Introduction to GSI

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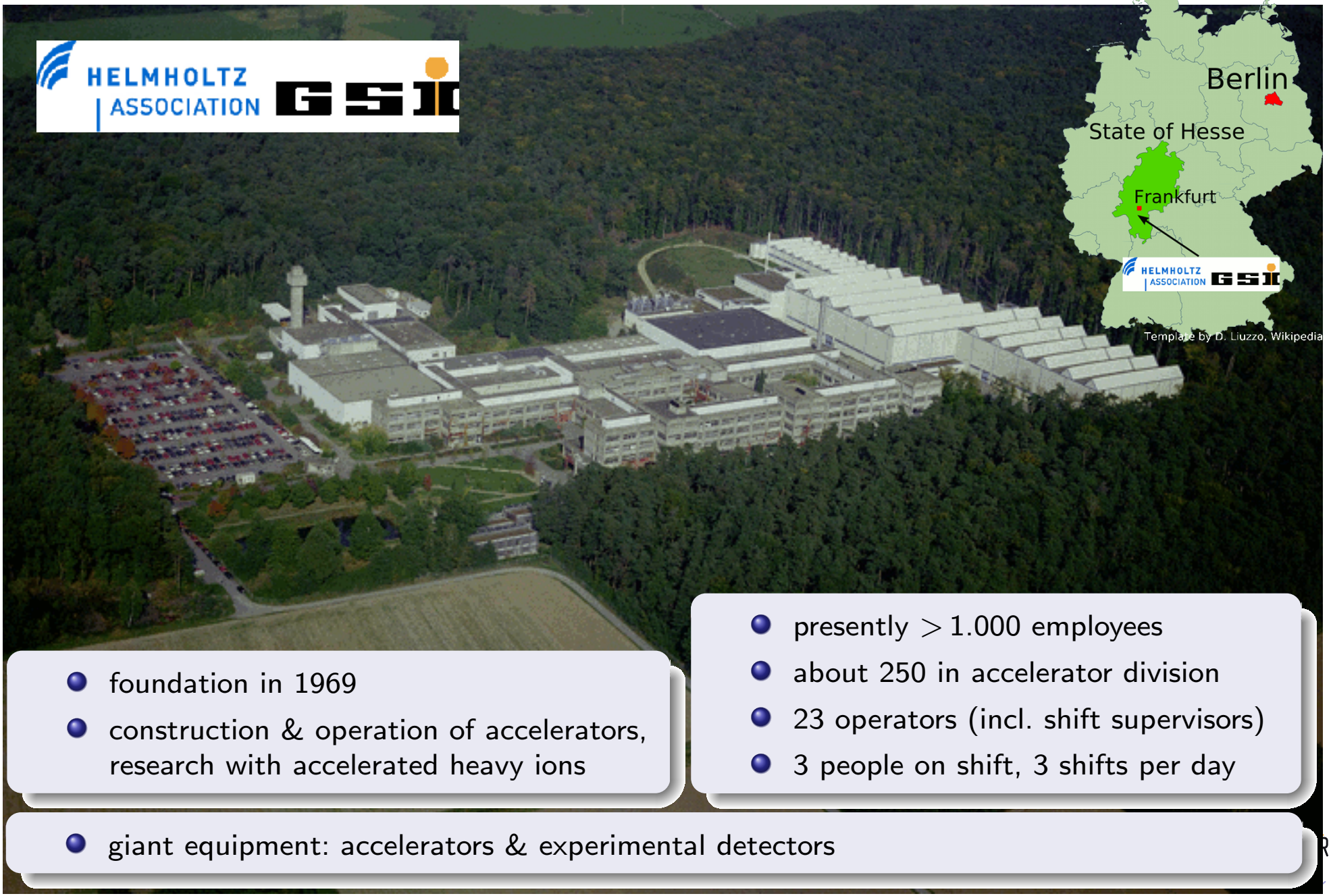
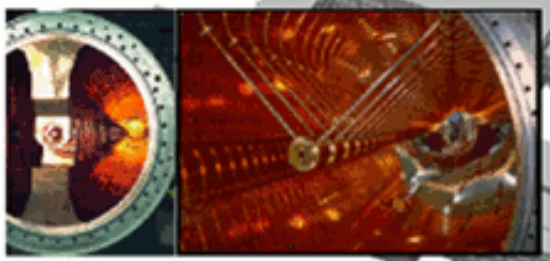


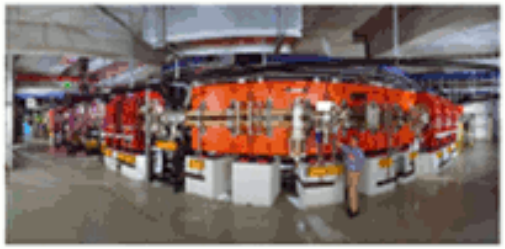
- foundation in 1969
- construction & operation of accelerators, research with accelerated heavy ions

- presently >1.000 employees
- about 250 in accelerator division
- 23 operators (incl. shift supervisors)
- 3 people on shift, 3 shifts per day

- giant equipment: accelerators & experimental detectors

Accelerators at GSI





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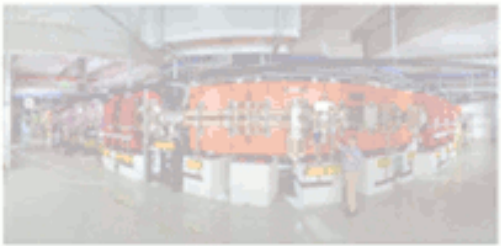


Ion sources
(MUCIS/ MEVVA & Penning)

High charge injector (HLI) with ECR ion source

Transfer channel

Alvarez DTL

High current injector (HSI)

UNILAC

SIS

FRS

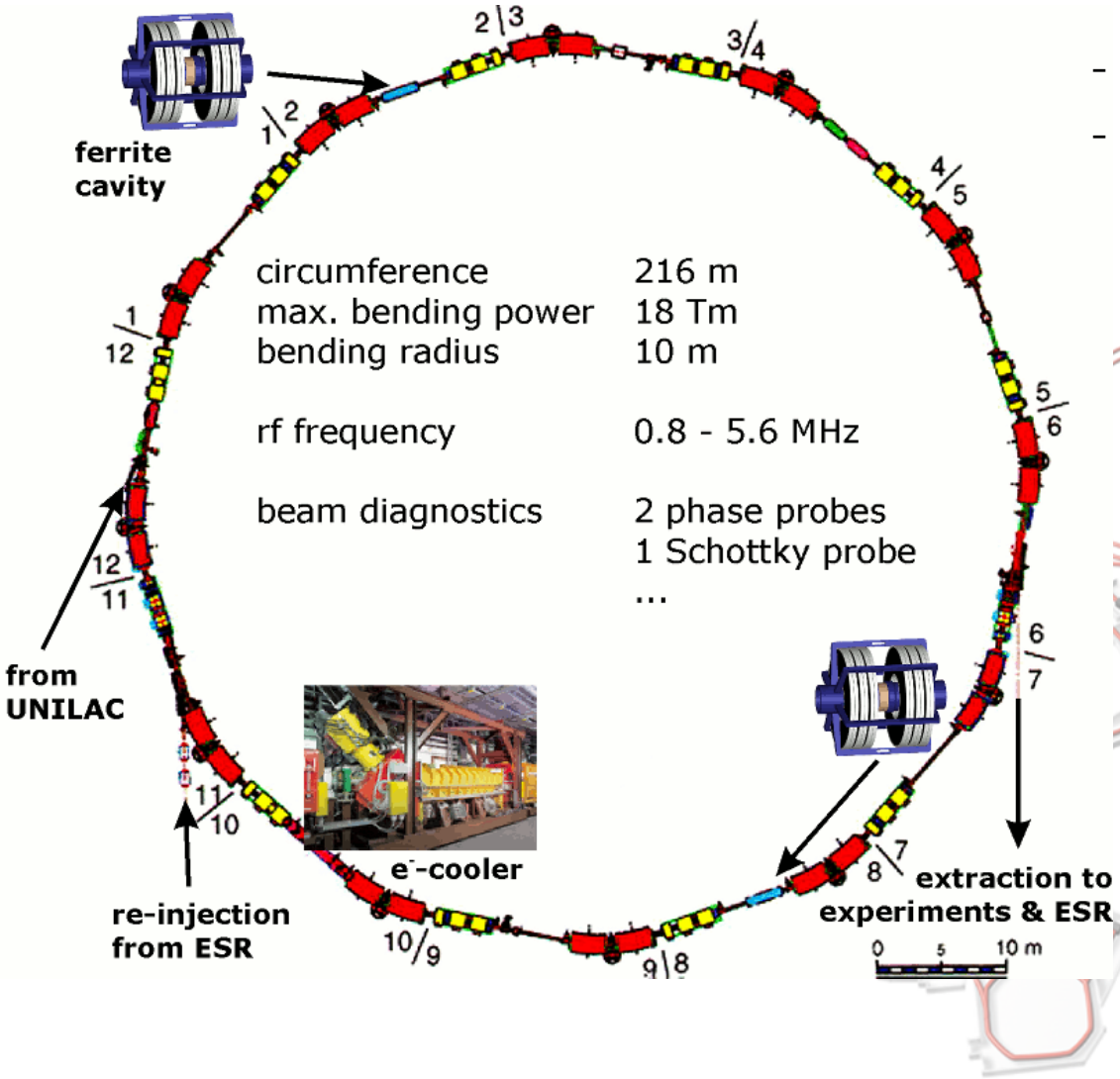
PHELIX

ESR

Low energy experimental hall

High energy experimental hall

Schwerlonen (Heavy Ion) Synchrotron SIS 18



- acceleration of ions from p to U
- maximum energies:

$$
\begin{aligned}
\mathrm{p} &\longrightarrow 4\,\mathrm{GeV/u},\ \text{i.e. } \beta = 0.98 \\
{}^{20}\mathrm{Ne}^{10+} &\longrightarrow 2\,\mathrm{GeV/u},\ \text{i.e. } \beta = 0.95 \\
{}^{238}\mathrm{U}^{73+} &\longrightarrow 1\,\mathrm{GeV/u},\ \text{i.e. } \beta = 0.88
\end{aligned}
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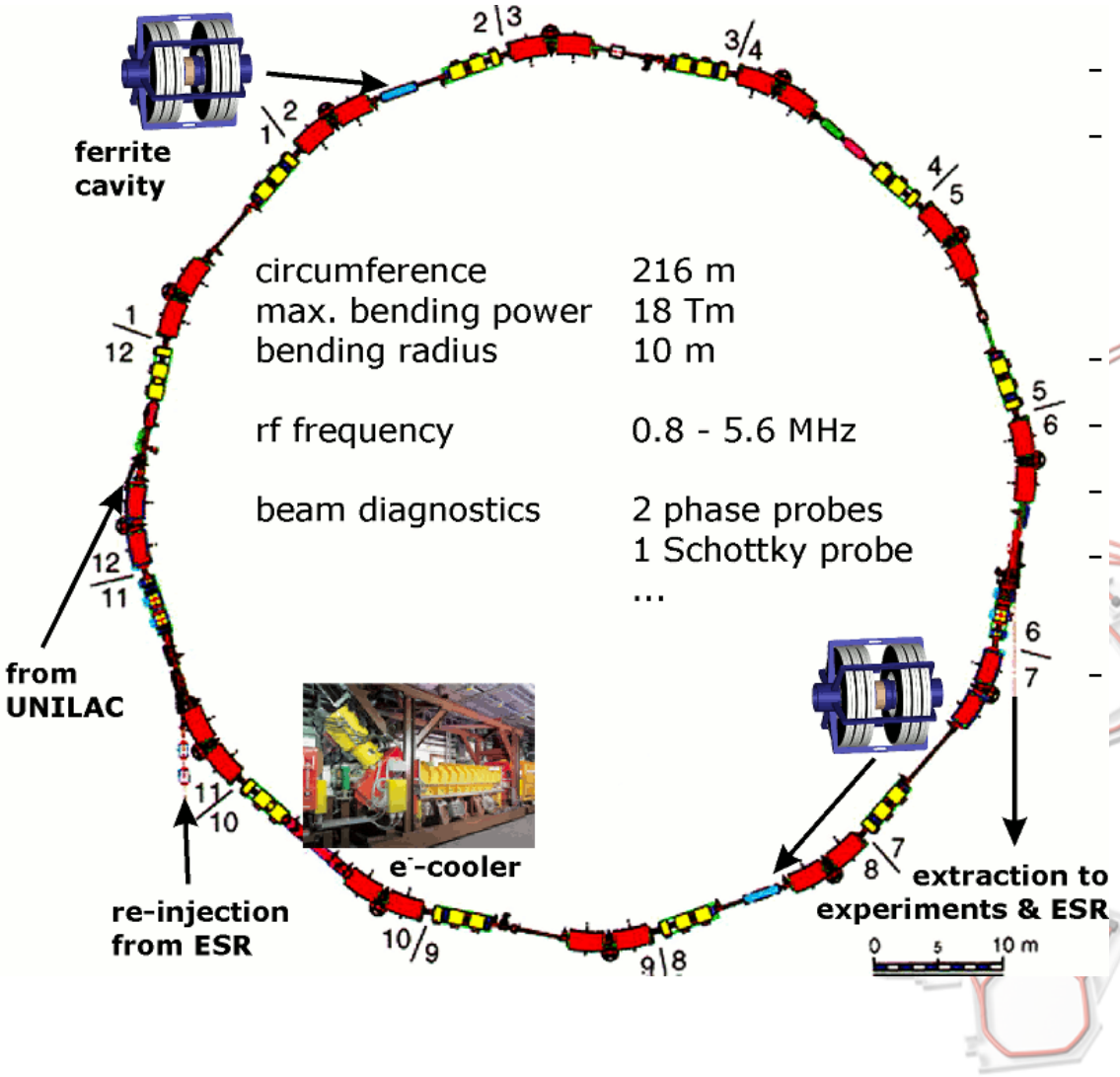

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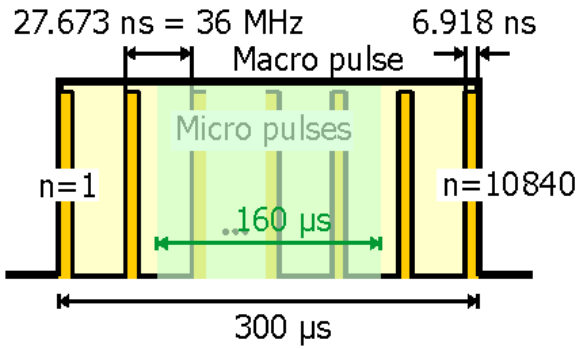
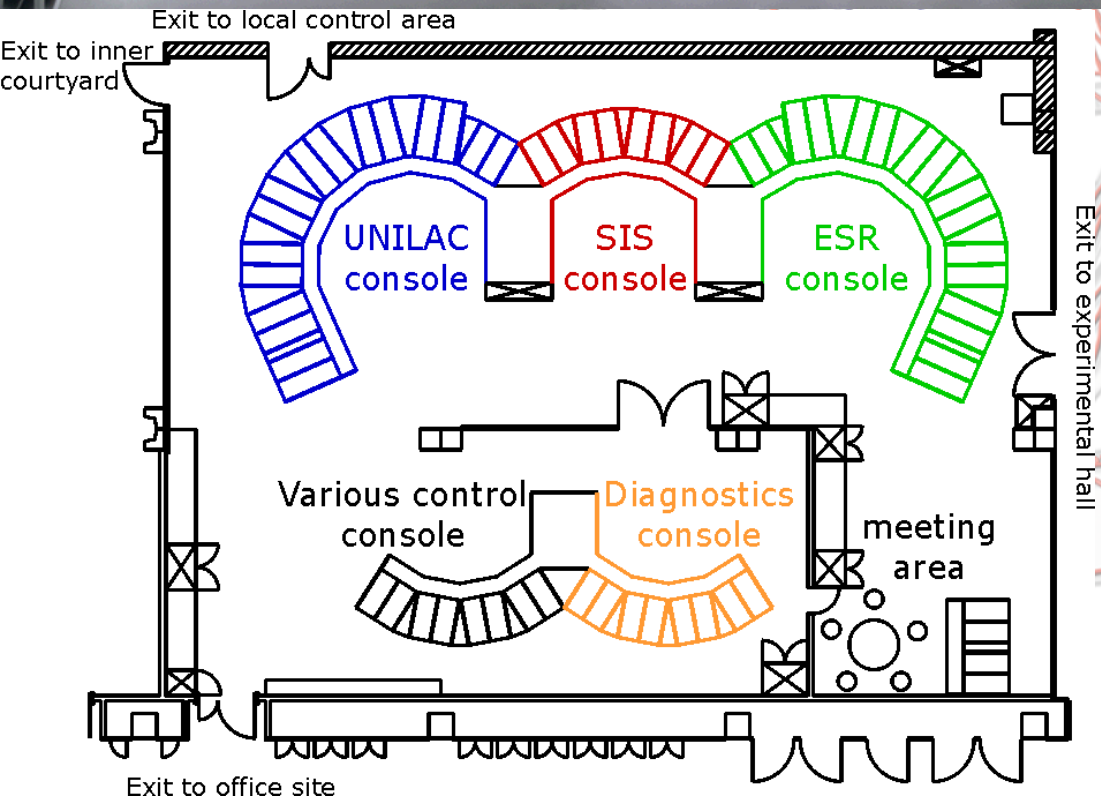
- injection energy: 11.1 - 11.5 MeV/u
- revolution time at injection: $\sim 4.6\,\mu$s
- injection time: up to 160 μs
- injection scheme: multiturn/ multi-multiturn
- $\sim$ 165 micro pulses @ 36 MHz per turn



Main Control Room



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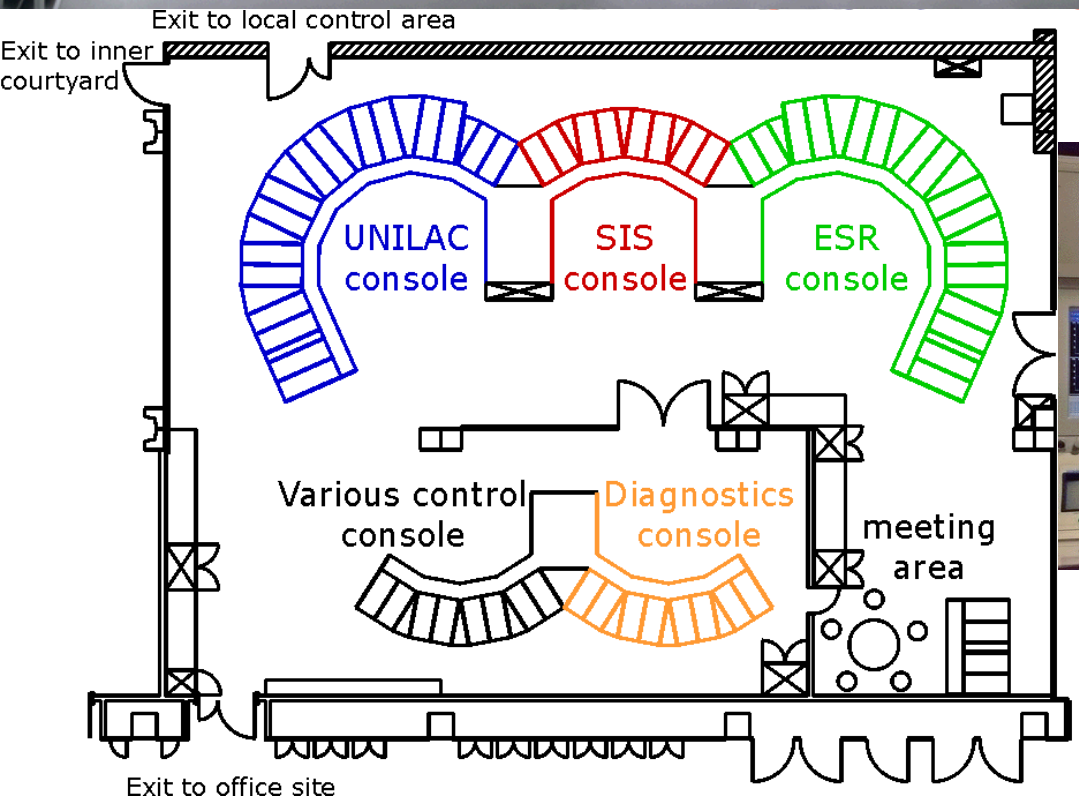
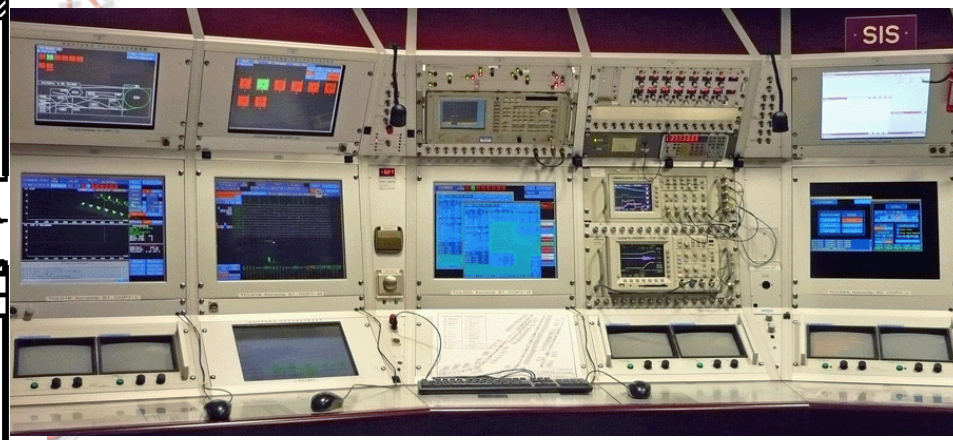




Main part of SIS console

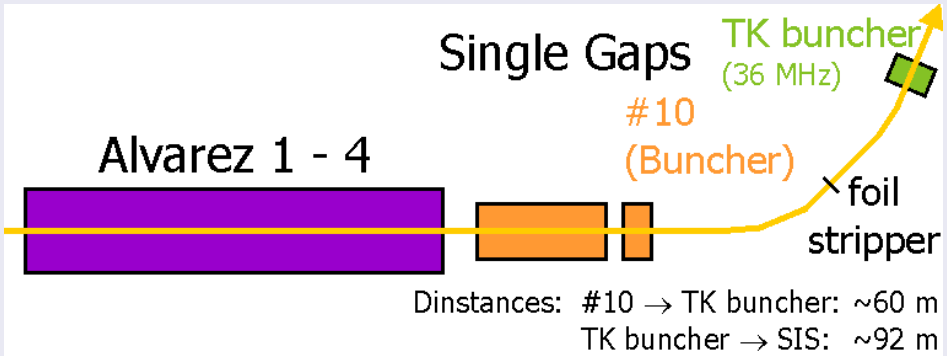
Operation of SIS

Maximisation of Beam Intensity During Beam Setup

- optimisation of focusing & steering along transfer channel (TK)
- observation of beam intensity measured by a phase probe

Longitudinal Optimisations

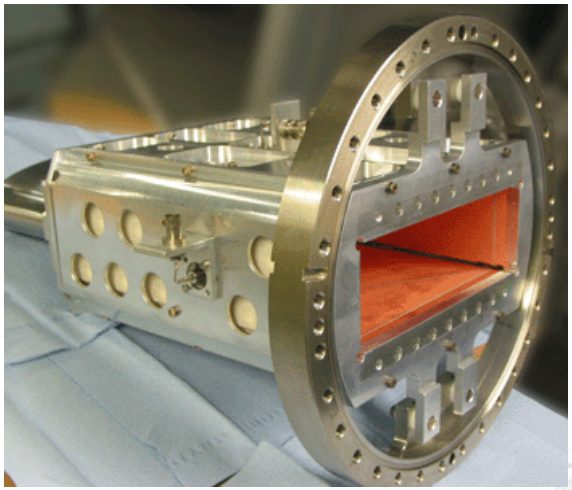
- adjustment of injection energy
- energy spread of UNILAC: $\pm 100\,\mathrm{keV/u}$
  acceptance of SIS: $\pm 23\,\mathrm{keV/u}$
- adaption of bunch length with 2 bunchers
- observation of Schottky signals



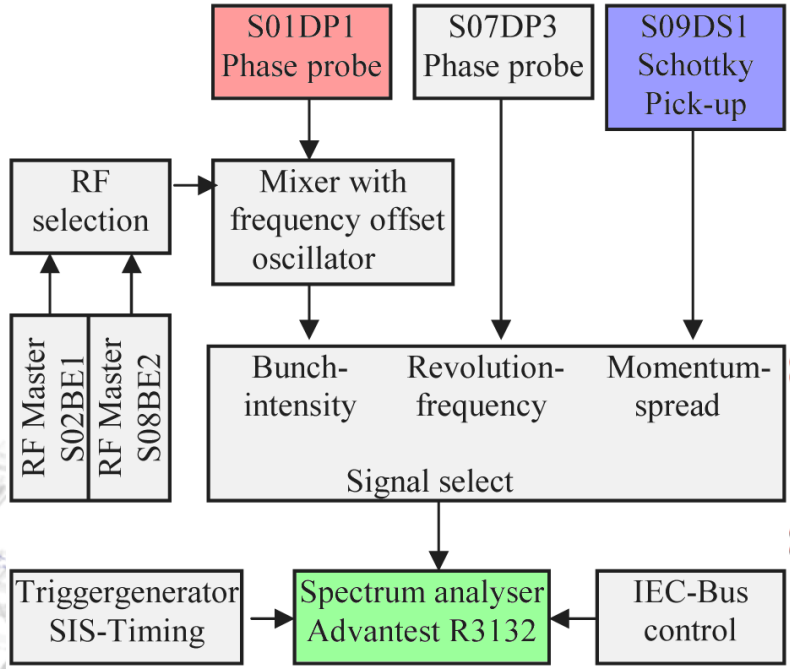
Monitoring

- beam intensity
- $\Delta p/p$
- ...

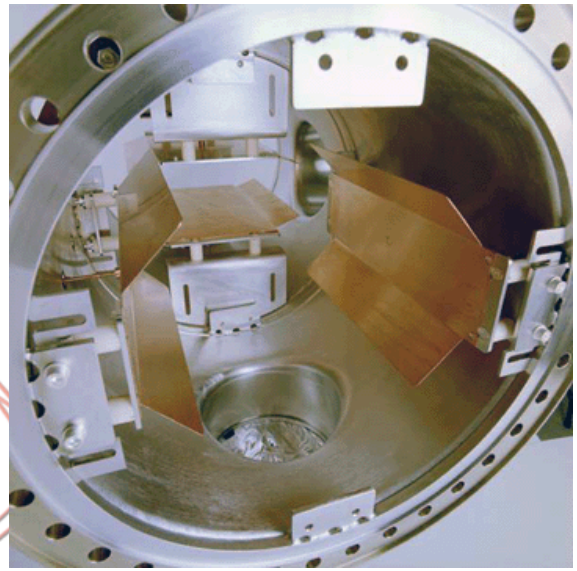
Beam Diagnostics



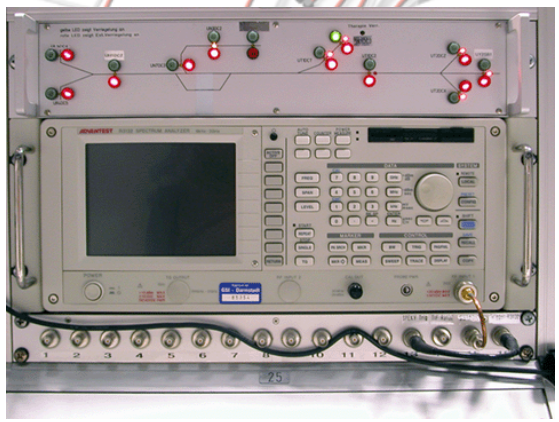
Phase probe of SIS



Schematic overview of DAQ



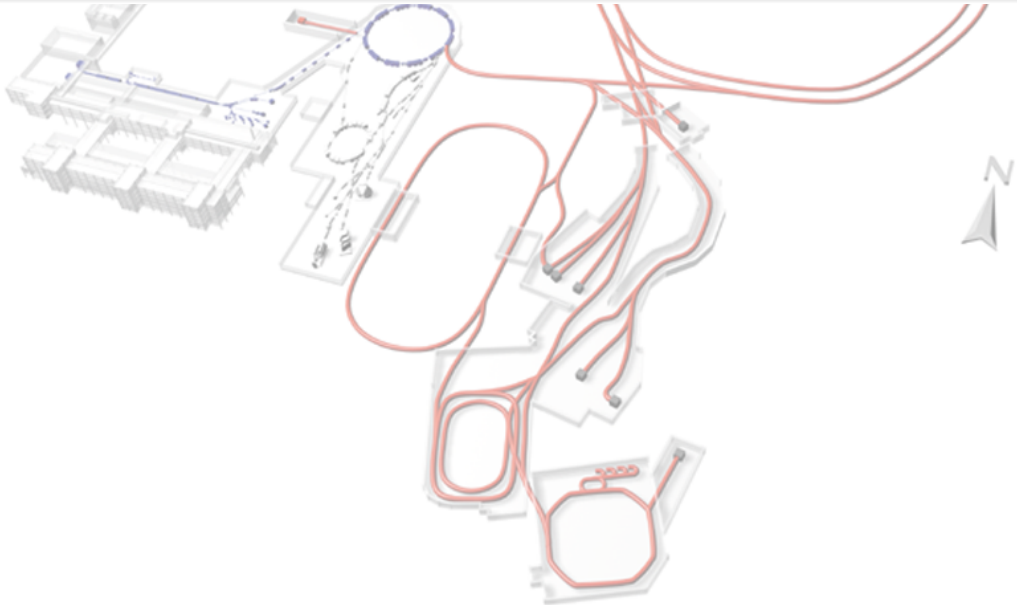
Schottky pick-up of SIS



Advantest R3132 Spectrum Analyzer 9 kHz - 3 GHz

For Usage During Normal Operation . . .

- development of front-end software to setup SA & DAQ
- requirements:
  - simplification of operation
  - suitability for monitoring



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Boundary Conditions

- front-end software must run on VMS (in future Linux)
- programming language Fortran95 (preferably)
- GUI development in X11/Motif (widget-set & widget construction tool to build code developed in-house)
- GUI intuitively operable
- look of new GUI similar to existent ones

History of Development

- 1989 – 1990: comissioning of SIS (high sensitve intensity measurement & Schottky scans with phase probe)
- 1990/ 1991: installation of dedicated Schottky pick-up probe & adequate DAQ
- up to 2005: Schottky analysis as expert tool mainly for machine development

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- improvement of beam quality $\Rightarrow$ increased quality of machine setup
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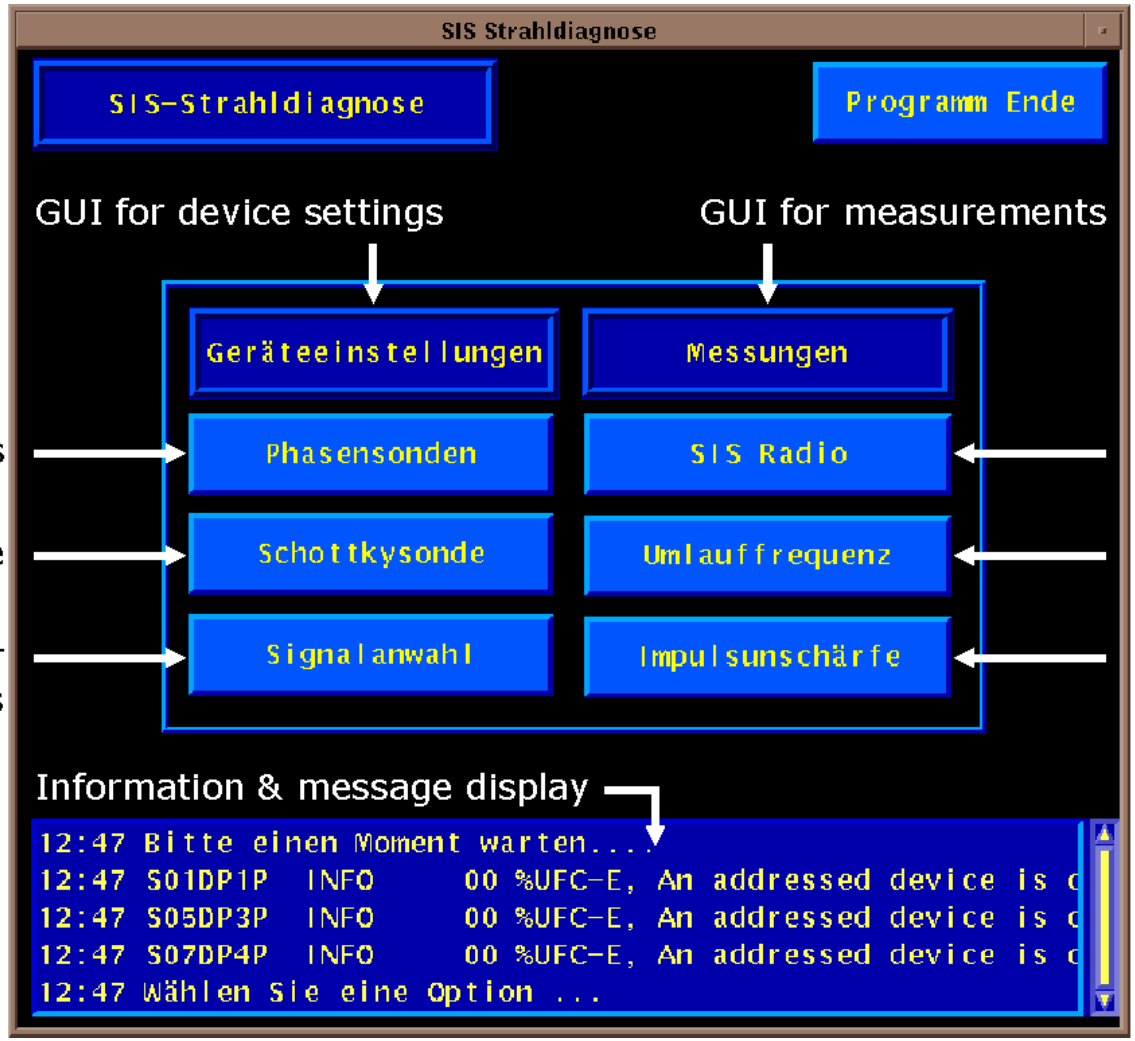
- mid 2006: 1st version of *SIS-BeamDiagnostics* software
- 2006 – 2009: testing phase; acquisition of requests for modifications
- 1st half-year 2009: revision of software
- since mid 2009: more & more usage of software during operation

Challenges During Development

- essential topics of 1st specification not realised as main control software of SIS is more or less standalone software
- GUI in parts not realised as specified due to limited possibilities of VMS, X11/Motiv & widget-set
- communication with Advantest 3132 SA via GPIB difficult, not all commands work
- main problem: Advantest 3132 SA cannot be set into local operation mode via GPIB command (contrary to manual)
- shift-work of DAQ developer impeded communication with software developer
- software development additionally slowed down due to low priority work ($\longrightarrow$ no official request)

SIS-BeamDiagnostics Software



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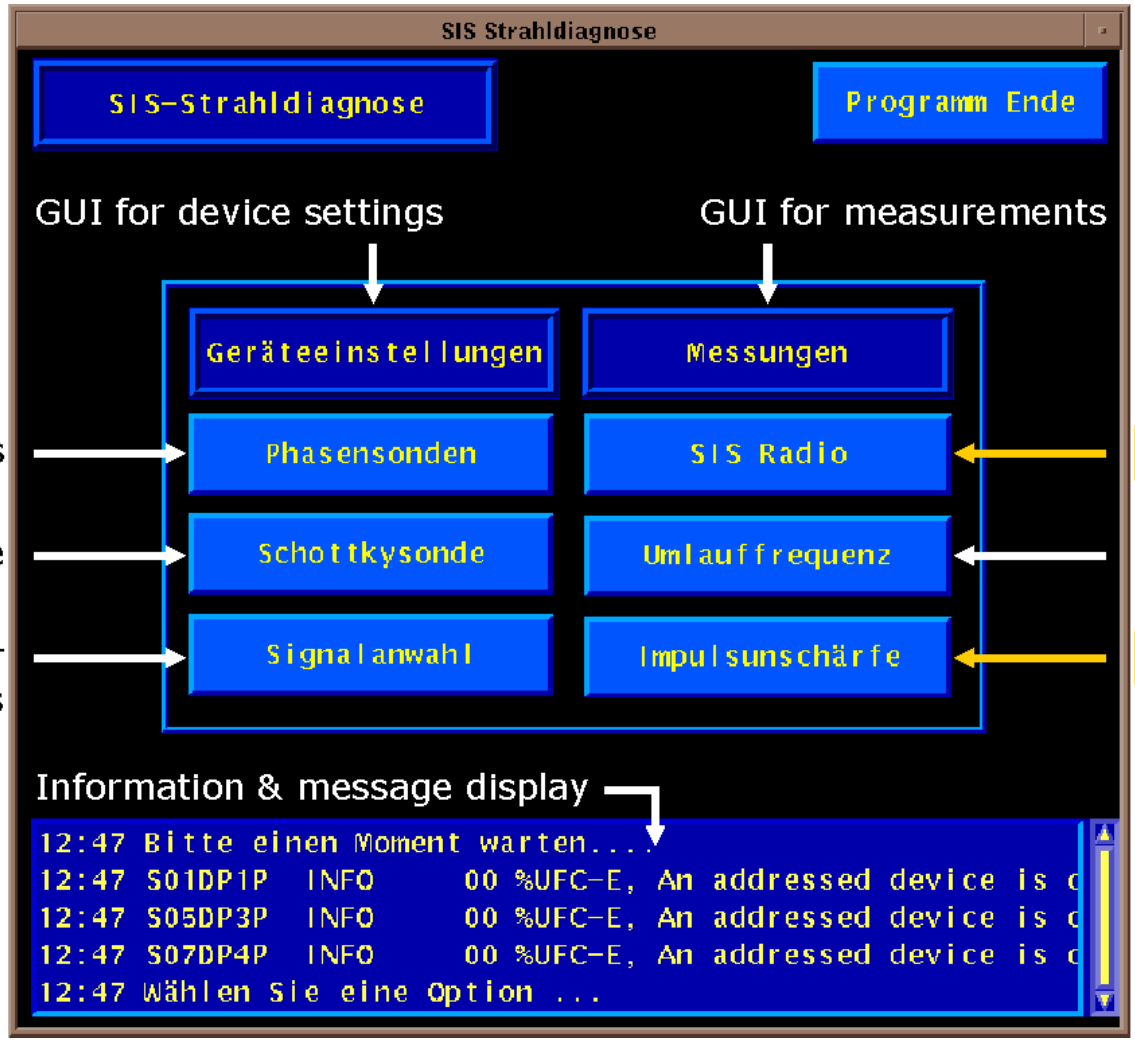
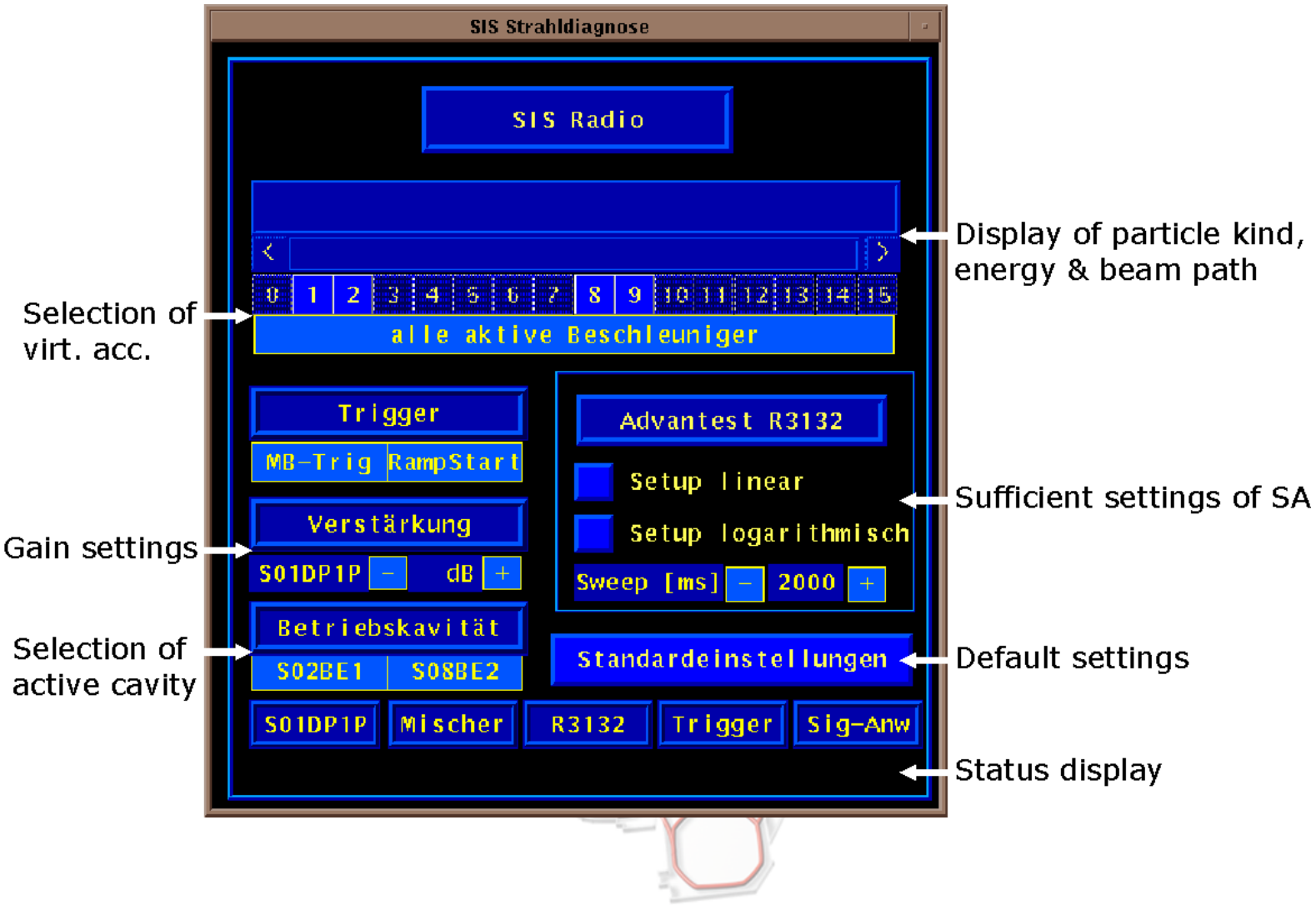


SIS-BeamDiagnostics Software – Intensity Measurement



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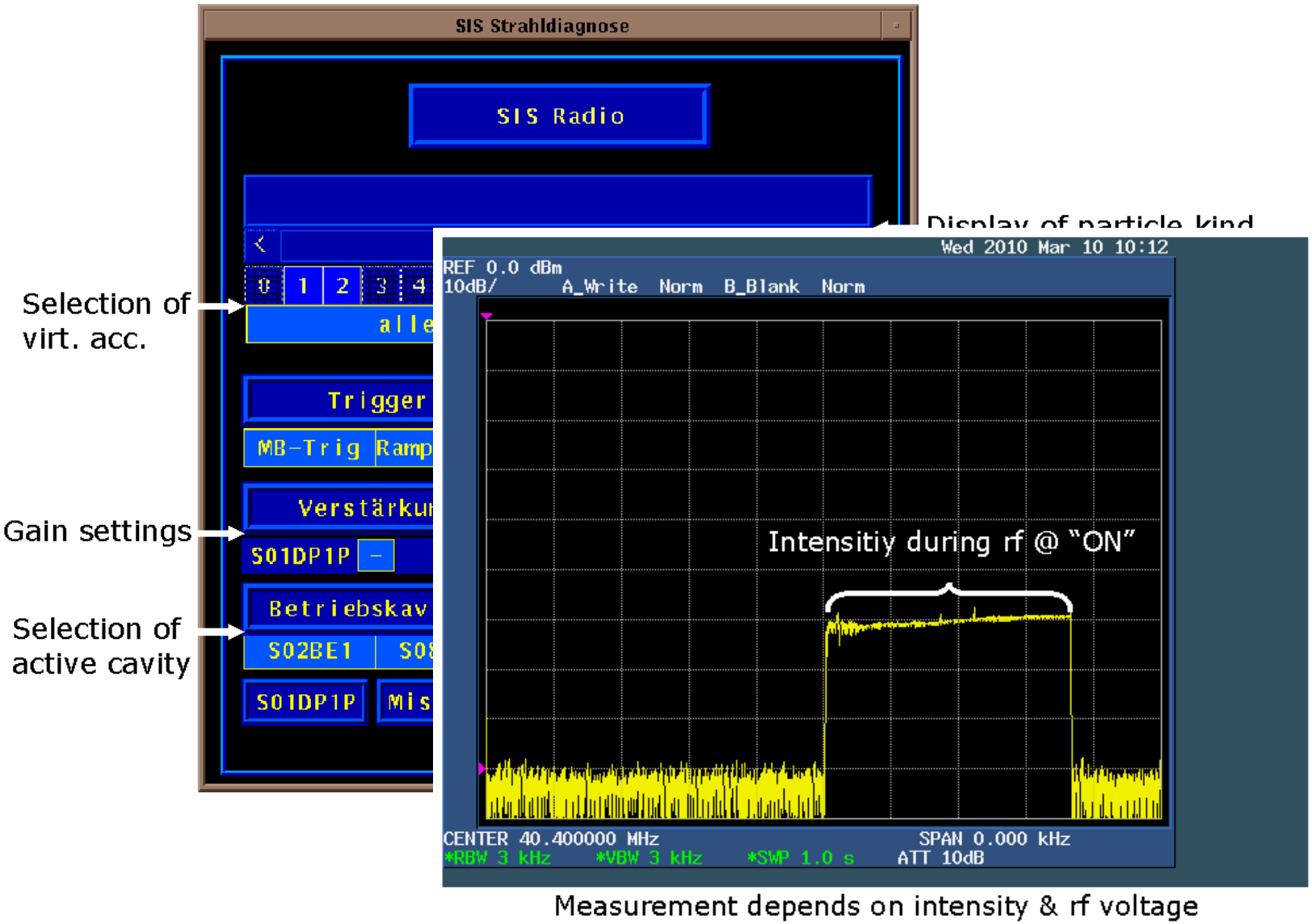


Measurement depends on intensity & rf voltage

$\Rightarrow$ much higher sensitivity than that of a beam current transformer

SIS-BeamDiagnostics Software – Schottky Analysis

Selection of virt. acc.

Display of particle kind, energy & beam path

Sufficient settings of SA

Settings of DAQ of Schottky probe

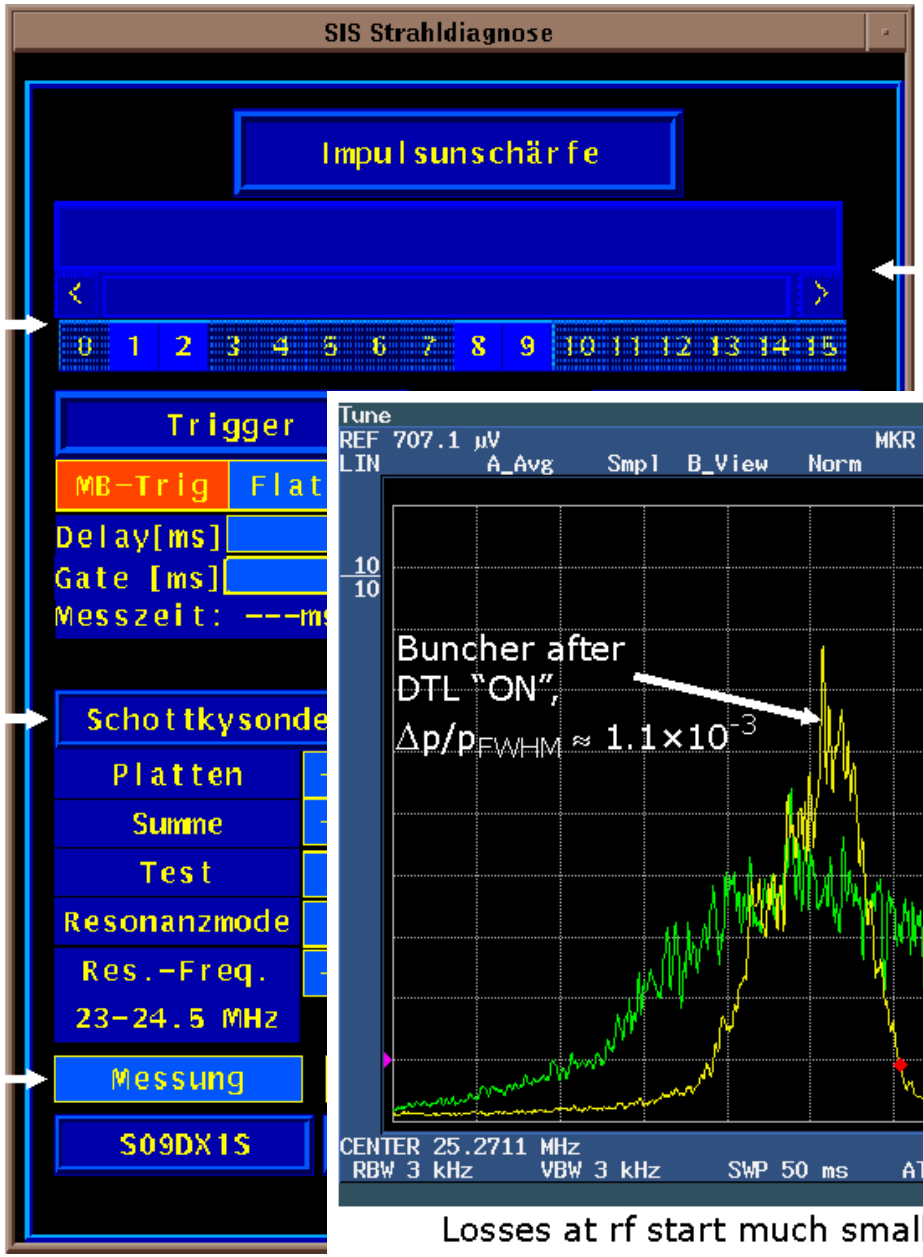
special functions of SA

Operation modes

Status display

Additional measurement mode for evaluation of $\Delta p/p$

SIS-BeamDiagnostics Software – Schottky Analysis



Selection of virt. acc.

Display of particle kind, energy & beam path

Settings of DAQ of Schottky probe

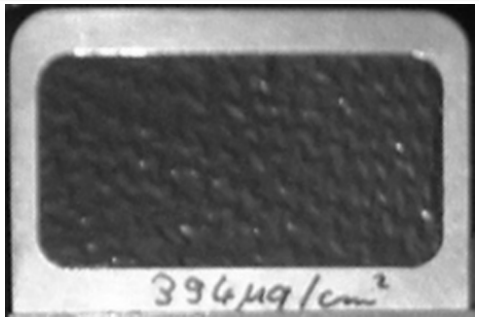
Operation modes

Losses at rf start much smaller when buncher "ON"

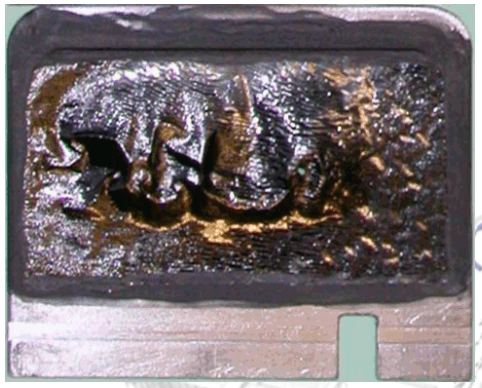
Additional measurement mode for evaluation of $\Delta p/p$

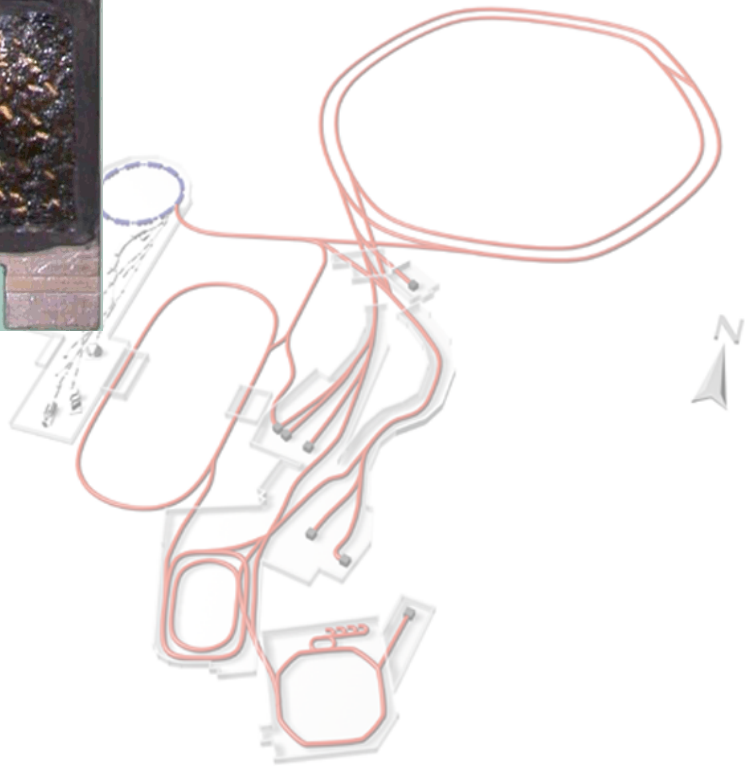
SIS-BeamDiagnostics Software – Monitoring of Stripper Foils

Unused foil



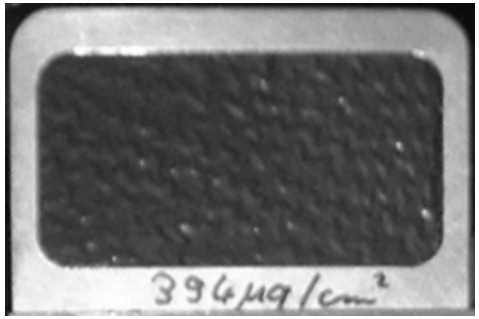
Sweeper foil after use with swept beam





SIS-BeamDiagnostics Software – Monitoring of Stripper Foils

Unused foil



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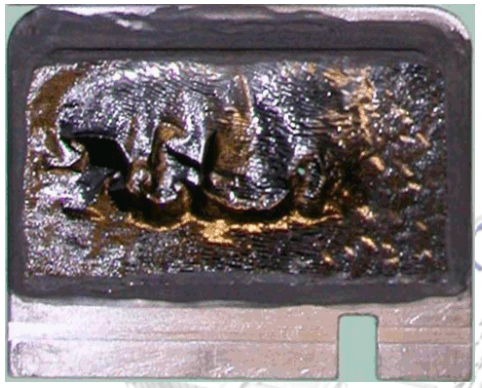

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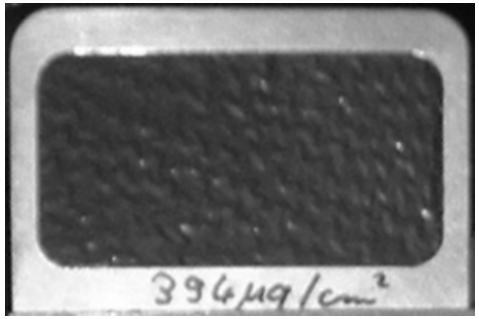

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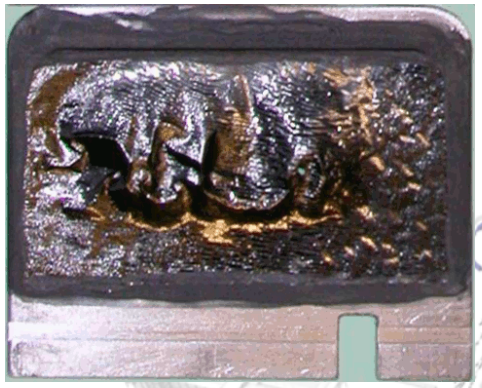

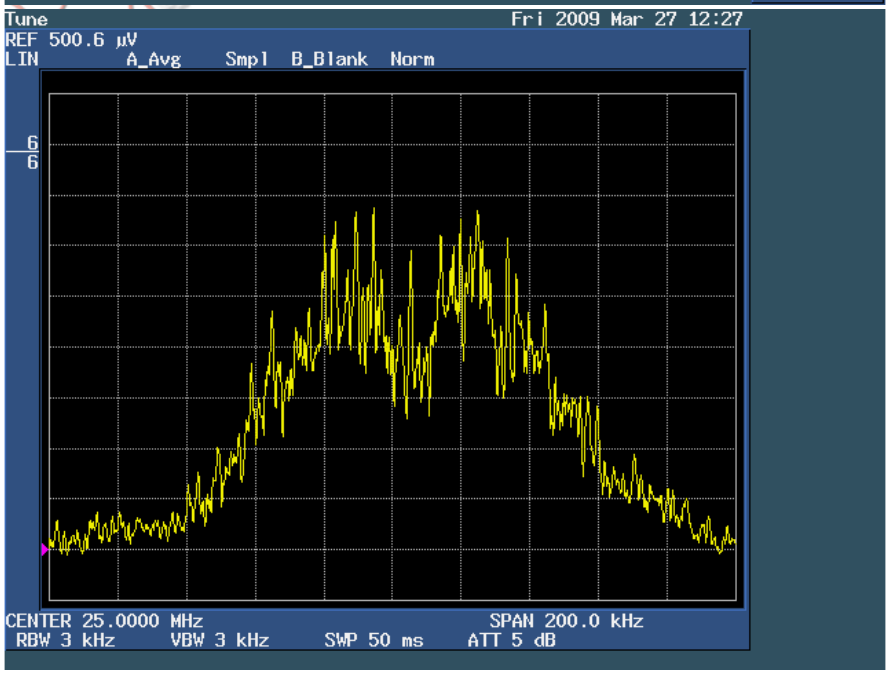

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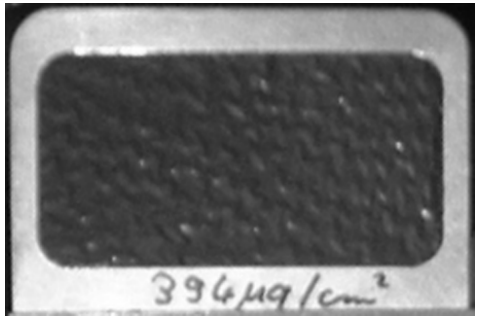

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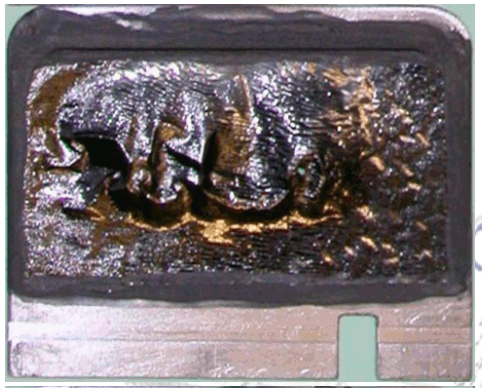
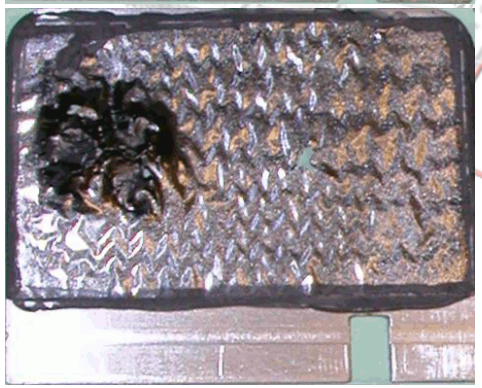
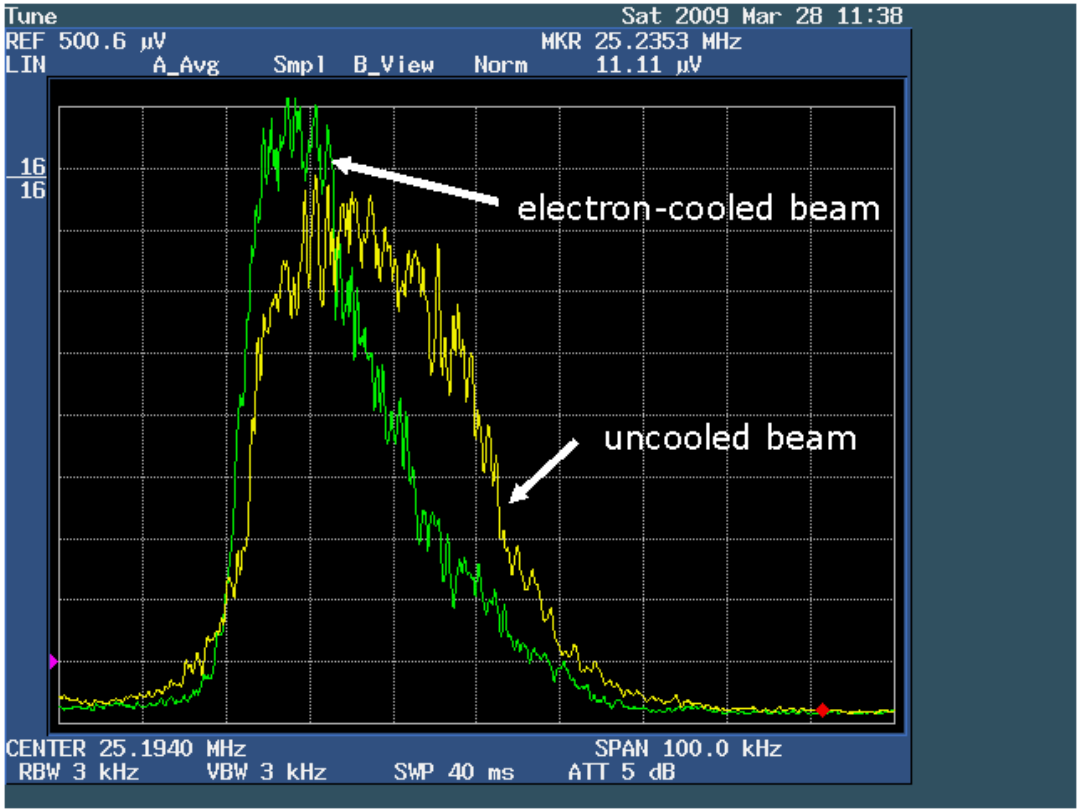


Sweeper foil after use with kicked beam



SIS-BeamDiagnostics Software – Monitoring of e^- Cooling



- due to electron cooling beam energy is changes to that of the cooler
- momentum spread is minimized
- Schottky analysis gives information about interaction region of e^- & ion beam

Conclusion

Yes, we can. . .

Conclusion

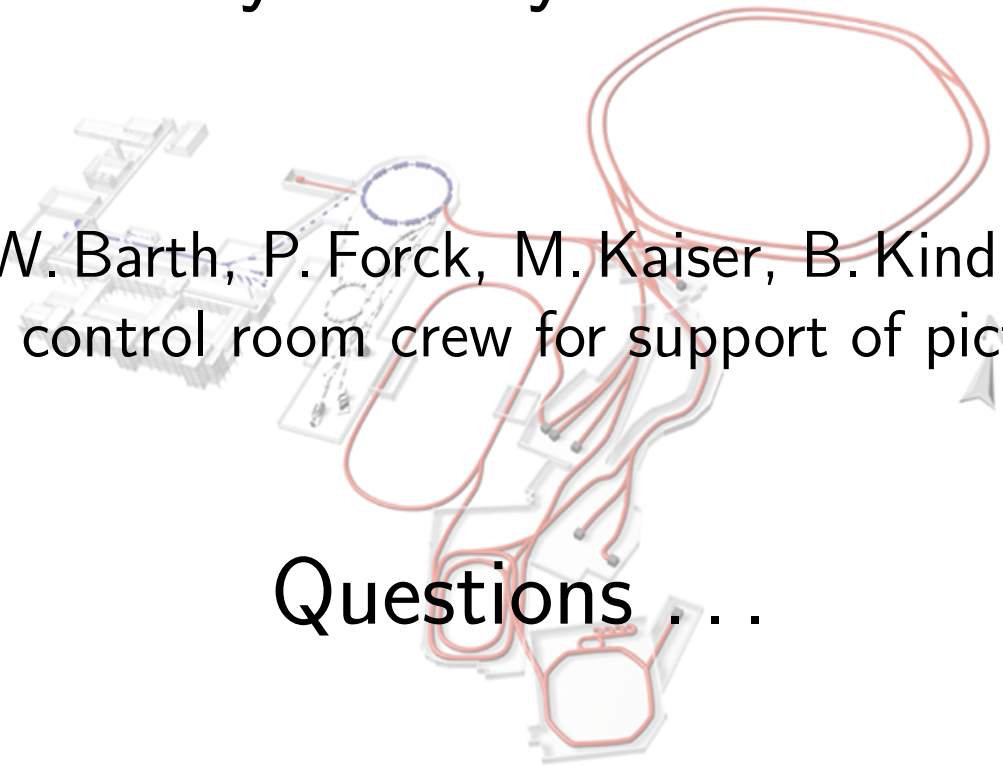
Yes, we can. . .

- development successfull
- measurement & monitoring tools often used by non-experts
- quality of beam delivery increased

but . . .

- was a good piece of work & took longer than estimated
- large commitment on side of operation group to fulfill most of needs
- several revision steps needed
- now it is known what could have been done better/ different

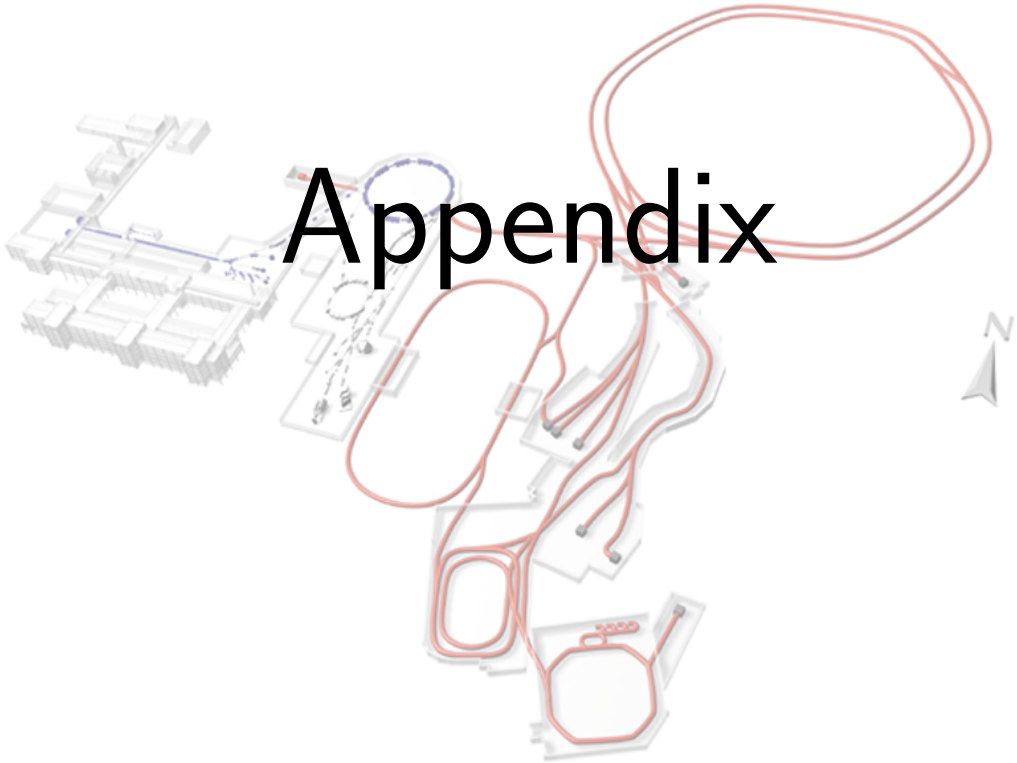
Thank you for your attention!



Thanks to W. Barth, P. Forck, M. Kaiser, B. Kindler, P. Kowina
& main control room crew for support of pictures etc.

Questions . . .

Appendix

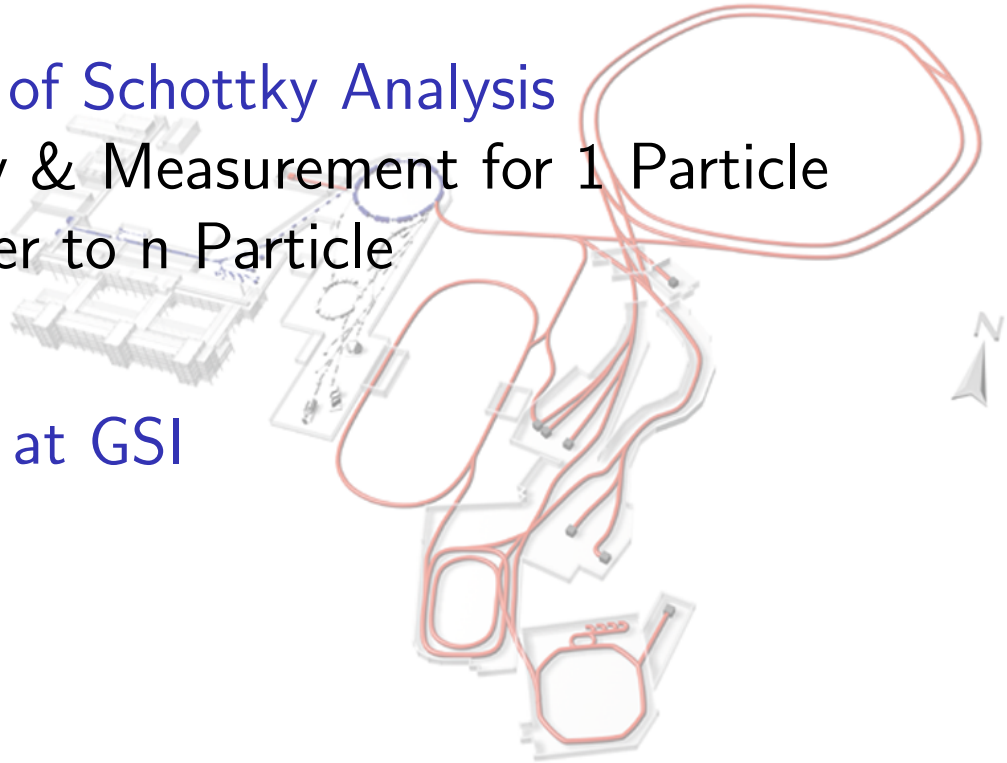


6 The Control System

7 Principle of Schottky Analysis
- Theory & Measurement for 1 Particle
- Transfer to n Particle

8 Research at GSI

9 UNILAC



Boundary Conditions for Developments

- components predominantly in-house developments
- communication of devices mainly via MIL-STD-1553 (MIL-Bus)
- data processing mainly via control units & group μ processors
- dedicated beam diagnostics communicate also via RS232, IEEE, LAN, ...
- for dedicated measurements still analog signals are necessary
- but of course usage of digital measurement equipment, too

- front-end software must run on VMS (in future Linux)
- programming language Fortran95 (preferably)
- GUI development in X11/Motif (widget-set & widget constuction tool to build code developed in-house)

- GUI intuitively operable
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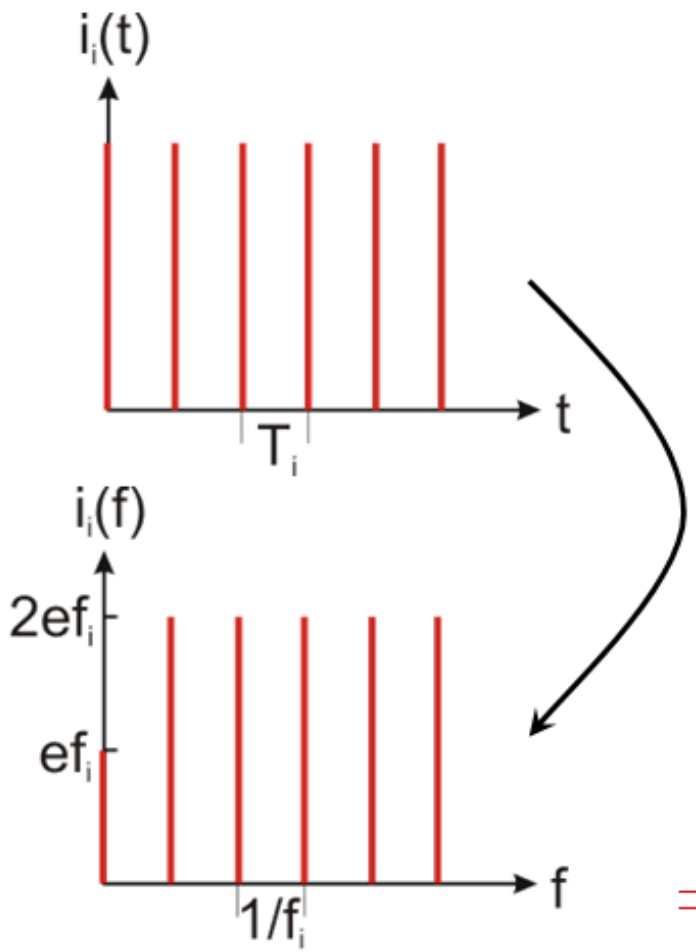
↪ Appendix

Principle of Schottky Analysis – Coasting Beam

Circulation of particle with Q = e:



transition from theory to measurement: $t \Rightarrow f$ = Fourier transf.

Current: $i_i(t) = ef_i \sum_{h=1}^{\infty} \delta(t - hT_i) = ef_i \sum_{h=-\infty}^{+\infty} e^{2\pi i h f_i t}$ *)

Pick-up measures only positive frequencies:

$$i_i(t) = ef_i + 2ef_i \sum_{h=1}^{\infty} \cosh\omega_i t$$

not „seen“ by usual current measurement!

$$i_i(f) = ef_i \cdot \delta(t=0) + 2ef_i \sum_{k=1}^{\infty} \delta(f - kf_i)$$

⇒ **frequency f is the real measuring quantity !**

*) $f(x) = \delta(x - x_0) = \begin{cases} 0 \text{ für } x \neq x_0 \\ 1 \text{ für } x = x_0 \end{cases}$

↪ Appendix

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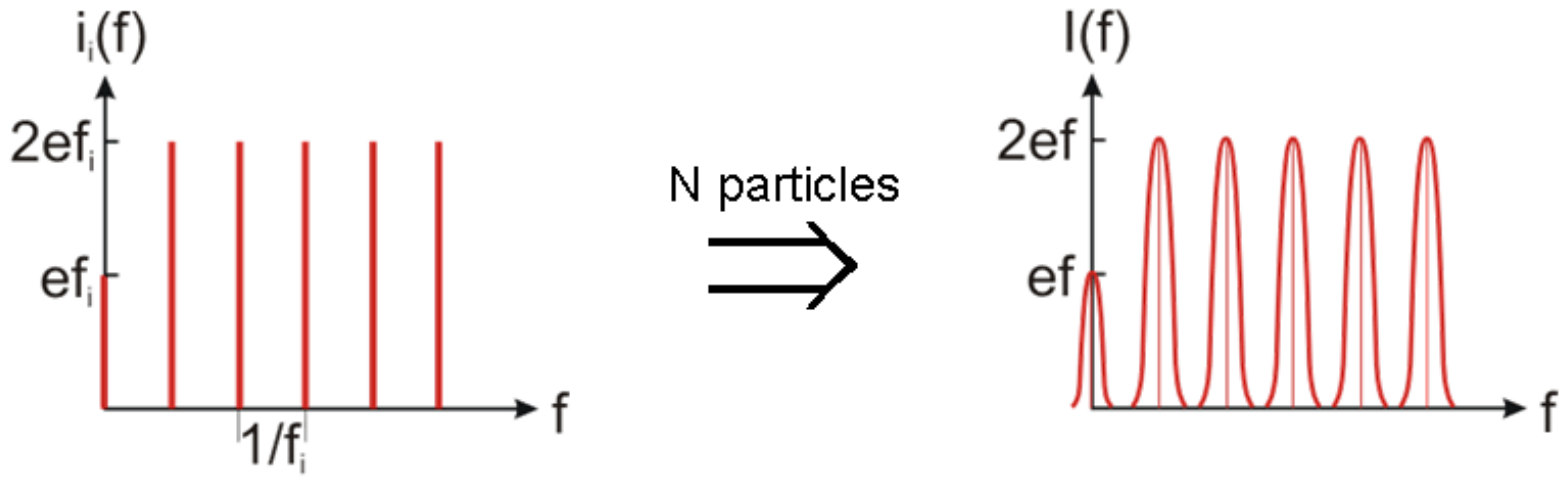


- N particles randomly azimuthal distributed along the ring each with a different momentum deviation Δp with respect to the reference particle.
- different Δp corresponds to different Δf due to the following relation:

$$\frac{\Delta f}{f} = \eta \cdot \frac{\Delta p}{p} \quad \text{with} \quad \eta = \frac{1}{\gamma^2} - \frac{1}{\gamma_{tr}^2} \quad \text{(frequency dispersion)}$$

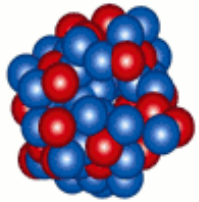
$\eta \longrightarrow$ characteristic of the ring!

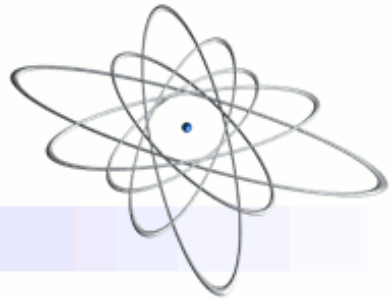
↪ Appendix

Research at GSI

Nuclear Physics

- nuclear reactions at low up to highest energies
- super-heavy elements
- hot dense nuclear matter





Atomic Physics

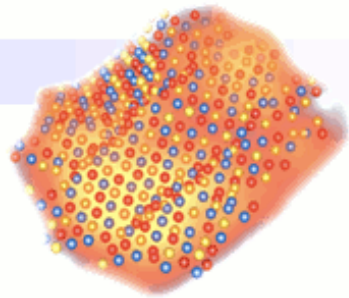
- atomic reactions
- precise spectroscopy of high charged ions

Biophysics and Nuclear Medicine

- radio-biological effectiveness of ions
- cancer therapy with ion beams

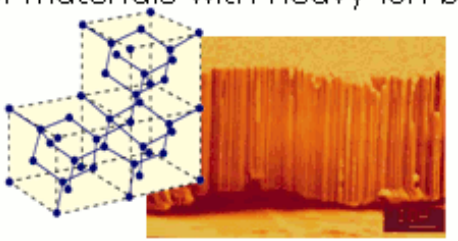
Plasma Physics

- hot dense plasma
- ion plasma interaction



Material Science

- interaction of ions with solids
- structuring of materials with heavy ion beams



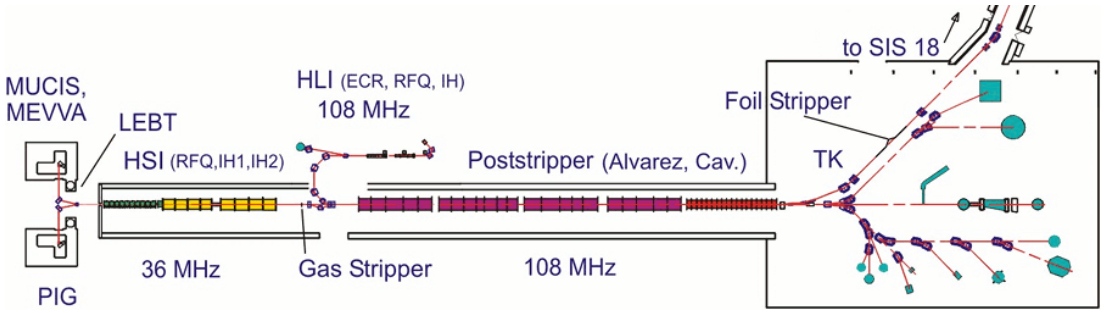
Accelerator Technology

- ion sources
- linear accelerators
- synchrotrons and storage rings

by GSI Division of Public Relations

↪ Appendix

UNIversal Linear ACcelerator UNILAC



Injectors

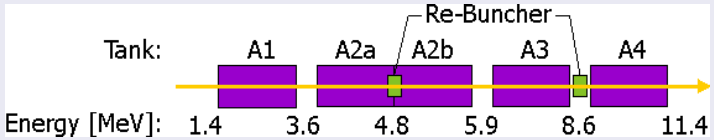
High Current Injector (HSI)

- high current ion source (MUCIS/ MEVVA), 5 Hz & 1 ms
- Penning ion source (PIG), 50 Hz & 5 ms
- injection energy: 2.2 keV/u
- acceleration/ bunching by 1 RFQ & 2 IH structures
- end energy: 1.4 MeV/u
- rf operation at 36 MHz
- increase of charge state by gas stripper

High Charge Injector (HLI)

- ECR ion source, 5 Hz & 1 ms
- injection energy: 2.2 keV/u
- acceleration/ bunching by 1 RFQ & 1 IH structure
- rf operation at 108 MHz
- end energy: 1.4 MeV/u

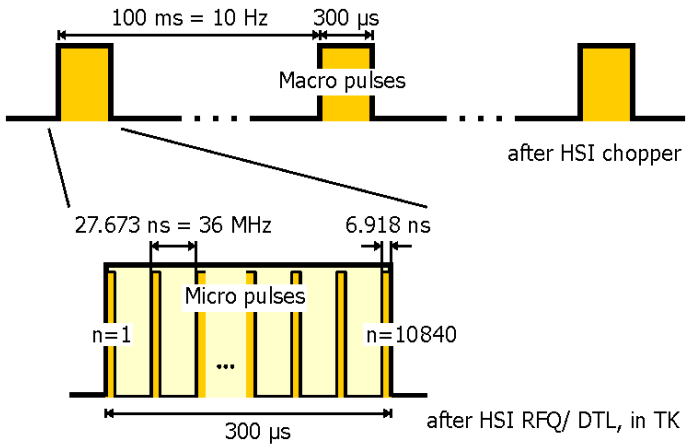
Alvarez DTL



- 5 independent rf-tanks + 2 re-bunchers
- 108 MHz, 50 Hz, 5 ms
- 192 rf-cells
- fixed phase acceleration
- rf-phase: -30° (1st 3 tanks), -25° (last ones)
- end energy: 11.4 MeV/u

- 10 single gap resonators to adapt energy
- increase of charge state by foil stripper for SIS in transfer channel (TK)

Timing for beam transport to SIS 18



↪ Appendix