

# An Operators Tool for Advanced Synchrotron Injection Diagnostics


W. Bayer, G. Fröhlich, W. Kaufmann, U. Scheeler, P. Schütt,  
Ch. Wetzel

GSI Helmholtzzentrum für Schwerionenforschung GmbH  
Darmstadt



– WAO 2010, Daejeon, South Korea –

13. April 2010

- 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



Template by D. Luzzo, Wikipedia





- 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

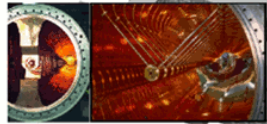
- giant equipment: accelerators & experimental detectors

# Accelerators at GSI



**Ion sources**  
(MUCIS/ MEVVA & Penning)

High current injector (HSI)



**UNILAC**

Low energy experimental hall

High charge injector (HLI) with ECR ion source

Alvarez DTL

Transfer channel

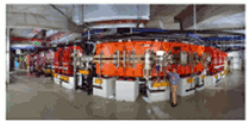
**PHILIX**



**SIS**

**FRS**

**ESR**



High energy experimental hall



# Accelerators at GSI



## Ion sources

(MUCIS/ MEVVA & Penning)

High current injector (HSI)



UNILAC

PHELIEX

Low energy experimental hall

High charge injector (HLI) with ECR ion source

Alvarez DTL

Transfer channel



SIS

FRS

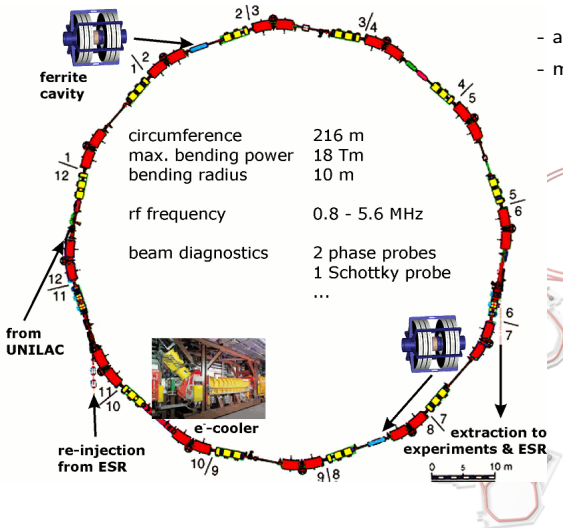
ESR



High energy experimental hall



# Schwerionen (Heavy Ion) Synchrotron SIS 18



- acceleration of ions from p to U

- maximum energies:

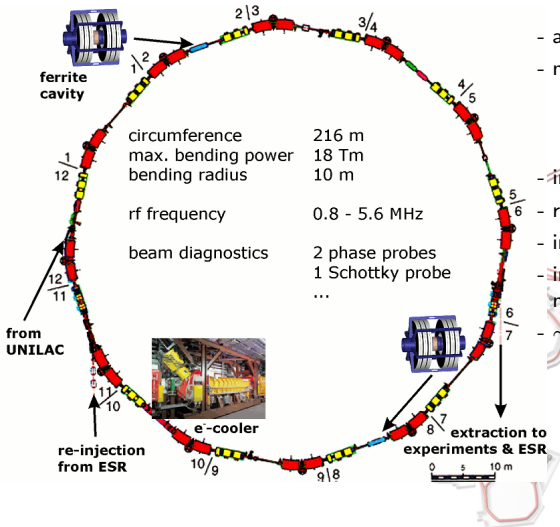
p → 4 GeV/u, i. e.  $\beta = 0.98$

$^{20}\text{Ne}^{10+}$  → 2 GeV/u, i. e.  $\beta = 0.95$

$^{238}\text{U}^{73+}$  → 1 GeV/u, i. e.  $\beta = 0.88$



# Schwerionen (Heavy Ion) Synchrotron SIS 18



- acceleration of ions from p to U

- maximum energies:

p → 4 GeV/u, i. e.  $\beta = 0.98$

$^{20}\text{Ne}^{10+}$  → 2 GeV/u, i. e.  $\beta = 0.95$

$^{238}\text{U}^{73+}$  → 1 GeV/u, i. e.  $\beta = 0.88$

- injection energy: 11.1 - 11.5 MeV/u

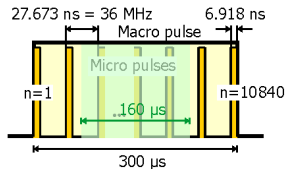
- revolution time at injection:  $\sim 4.6 \mu\text{s}$

- injection time: up to 160  $\mu\text{s}$

- injection scheme:

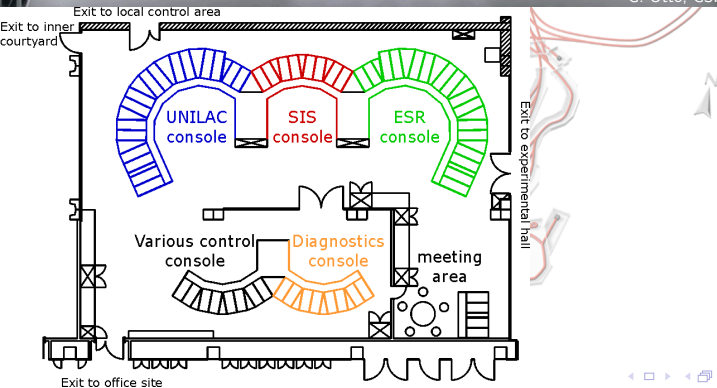
multiturn/ multi-multiturn

-  $\sim 165$  micro pulses @ 36 MHz per turn

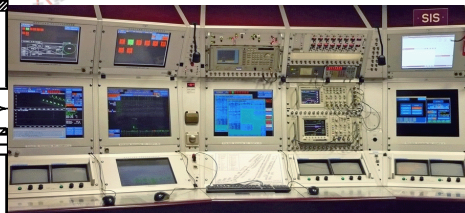
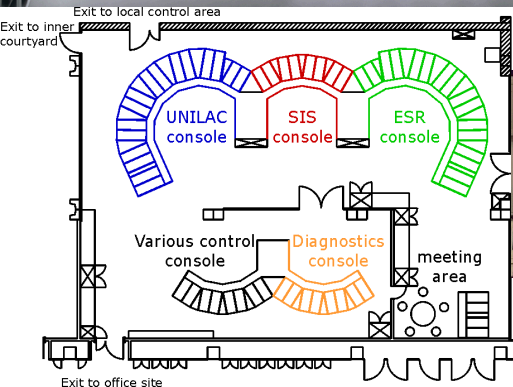




# Main Control Room



# Main Control Room



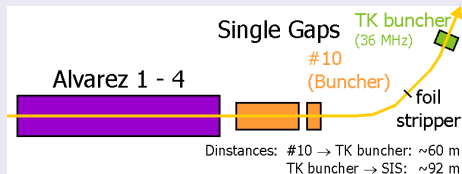
Main part of SIS console

## Maximisation of Beam Intensity During Beam Setup

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

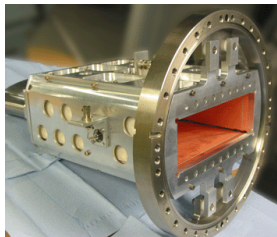
## Longitudinal Optimisations

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

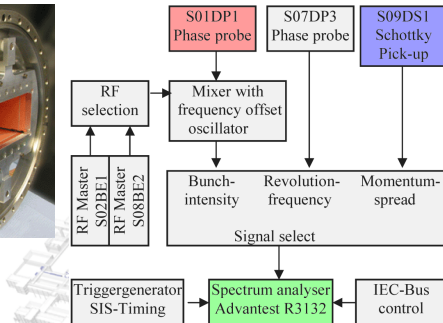


## Monitoring

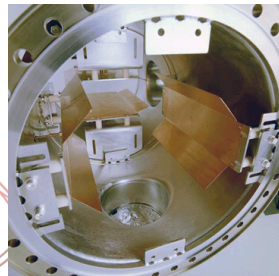
- beam intensity
- $\Delta p/p$
- ...



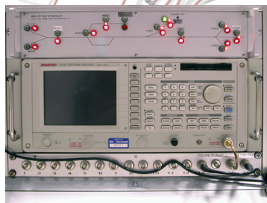
Phase probe of SIS



Schematic overview of DAQ



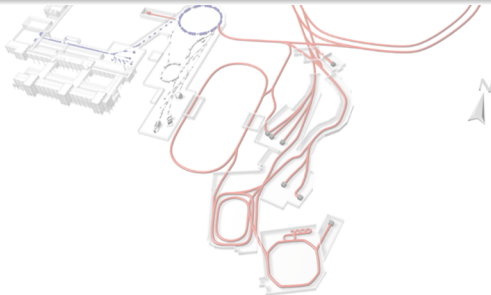
Schottky pick-up of SIS



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



## For Usage During Normal Operation ...

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

## 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

- 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

- 1989 – 1990: commissioning of SIS (high sensitive 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
- since 2001 upgrade measures to increase beam intensity
- improvement of beam quality  $\Rightarrow$  increased quality of machine setup
- mid 2005: decision Schottky analysis for non-experts



- 1989 – 1990: commissioning of SIS (high sensitive 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
- since 2001 upgrade measures to increase beam intensity
- improvement of beam quality  $\Rightarrow$  increased quality of machine setup
- mid 2005: decision Schottky analysis for non-experts
- mid 2006: 1<sup>st</sup> version of *SIS-BeamDiagnostics* software
- 2006 – 2009: testing phase; acquisition of requests for modifications
- 1<sup>st</sup> half-year 2009: revision of software
- since mid 2009: more & more usage of software during operation

- essential topics of 1<sup>st</sup> 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 (→ no official request)



SIS Strahldiagnose

SIS-Strahldiagnose      Programm Ende

GUI for device settings      GUI for measurements

Geräteeinstellungen      Messungen

Phasensonden      SIS Radio

Schottkysonde      Umlauffrequenz

Signalanwahl      Impulsschärfe

Phase probes →      ← Beam intensity monitoring

Schottky probe →      ← Revolution frequency

Selection of other input signals →      ← Schottky ( $\Delta p/p$ )

Information & message display

```
12:47 Bitte einen Moment warten...
12:47 S01DP1P INFO 00 %UFC-E, An addressed device is d
12:47 S05DP3P INFO 00 %UFC-E, An addressed device is d
12:47 S07DP4P INFO 00 %UFC-E, An addressed device is d
12:47 Wählen Sie eine Option ...
```

SIS Strahldiagnose

SIS-Strahldiagnose Programm Ende

GUI for device settings GUI for measurements

Geräteeinstellungen	Messungen
Phasensonden	SIS Radio
Schottkysonde	Umlauffrequenz
Signalanwahl	Impulsschärfe

Information & message display

```

12:47 Bitte einen Moment warten...
12:47 S01DP1P INFO 00 %UFC-E, An addressed device is c
12:47 S05DP3P INFO 00 %UFC-E, An addressed device is c
12:47 S07DP4P INFO 00 %UFC-E, An addressed device is c
12:47 Wählen Sie eine Option ...
    
```

Phase probes

Schottky probe

Selection of other  
input signals

Beam intensity monitoring

Revolution frequency

Schottky ( $\Delta p/p$ )

The screenshot shows the 'SIS Strahldiagnose' software window. At the top is a 'SIS Radio' button. Below it is a display area for particle kind, energy, and beam path, with a selection bar from 0 to 15 and the text 'alle aktive Beschleuniger'. The interface is divided into several sections: 'Trigger' with 'MB-Trig RampStart' and 'Verstärkung' (S01DP1P, dB, +) buttons; 'Advantest R3132' with 'Setup linear', 'Setup logarithmisch', and 'Sweep [ms]' (2000) buttons; 'Betriebskavität' with 'S02BE1' and 'S08BE2' buttons; and a 'Standardeinstellungen' button. At the bottom is a 'Status display' with buttons for 'S01DP1P', 'Mischer', 'R3132', 'Trigger', and 'Sig-Anw'. Annotations on the left and right point to these specific features.

Selection of virt. acc.

Gain settings

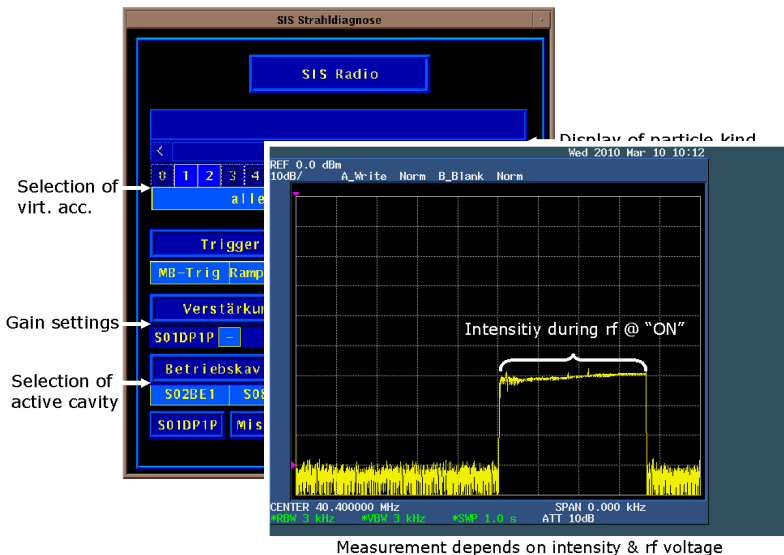
Selection of active cavity

Display of particle kind, energy & beam path

Sufficient settings of SA

Default settings

Status display



⇒ much higher sensitivity than that of a beam current transformer

**SIS Strahldiagnose**

**Impulsunschärfe**

Selection of virt. acc. < 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 >

**Trigger**

MB-Trig Flattop

Delay [ms] \_\_\_\_\_

Gate [ms] \_\_\_\_\_

Messzeit: ---ms

**Advantest**

Default Setup

Level [mV] - 0.2 +

Average - 1 +

Span kHz - 100 +

**Schottkysonde S09DX1S**

Platten - dB +

Summe - dB +

Test ein aus

Resonanzmode ein aus

Res.-Freq. - 23.8 +  
23-24.5 MHz

**Operation modes**

Messung Tuning

S09DX1S Trigger Signalwahl

Display of particle kind, energy & beam path

Sufficient settings of SA

special functions of SA

Status display

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

The screenshot displays the SIS Strahldiagnose software interface. The main window is titled "Impulsunschärfe". Below the title bar, there is a selection menu for virtual accelerators (virt. acc.) with options 0 through 15. To the right of this menu, a label indicates the "Display of particle kind, energy & beam path".

Below the selection menu, there is a "Trigger" section with a "MB-Trig" button set to "Flat". Below this, there are input fields for "Delay [ms]", "Gate [ms]", and "Messzeit: ---ms".

Further down, there is a "Schottkysonde" section with buttons for "Platten", "Summe", "Test", "Resonanzmode", "Res.-Freq.", and "23-24.5 MHz". Below this, there is a "Messung" button and a "S09DX1S" button.

On the right side of the interface, there is a plot showing the Schottky signal. The plot title is "Thu 2009 Jan 22 07:47". The plot shows two traces: a green trace and a yellow trace. The green trace is labeled "Buncher after DTL 'ON',  $\Delta p/p_{FWHM} \approx 1.1 \times 10^{-3}$ ". The yellow trace is labeled "Buncher after DTL 'OFF',  $\Delta p/p_{FWHM} \approx 3.1 \times 10^{-3}$ ". The plot also shows technical parameters: "Tune REF 707.1  $\mu$ V LIN A\_Avg Smp1 B\_View Norm MKR 25.2927 MHz 65.02  $\mu$ V", "CENTER 25.2711 MHz RBW 3 kHz VBW 3 kHz SWP 50 ms SPAN 200.0 kHz ATT 5 dB".

Annotations on the left side of the interface include: "Selection of virt. acc." pointing to the selection menu, "Settings of DAQ of Schottky probe" pointing to the "Schottkysonde" section, and "Operation modes" pointing to the "Messung" and "S09DX1S" buttons.

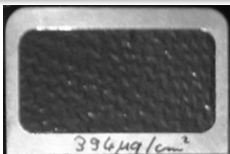
At the bottom of the plot area, there is a caption: "Losses at rf start much smaller when buncher 'ON'".

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

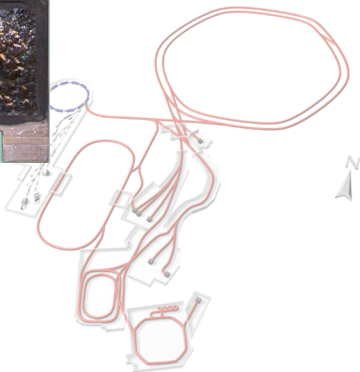
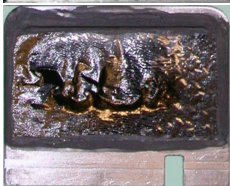


# SIS-BeamDiagnostics Software – Monitoring of Stripper Foils

Unused foil

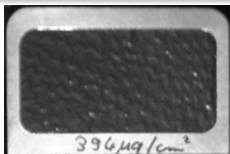


Sweeper foil after use with swept beam



# SIS-BeamDiagnostics Software – Monitoring of Stripper Foils

Unused foil

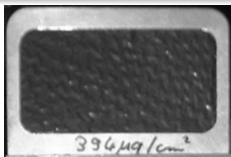


Sweeper foil after use with swept beam

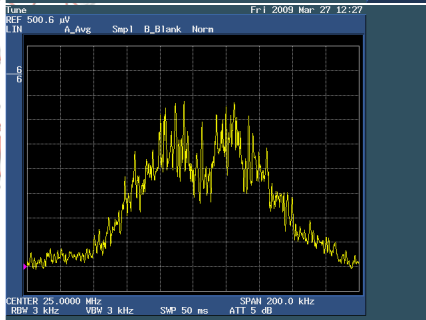
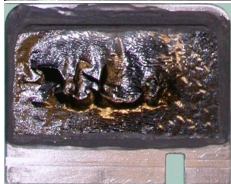


# SIS-BeamDiagnostics Software – Monitoring of Stripper Foils

Unused foil

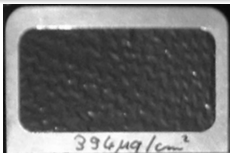


Sweeper foil after use with swept beam



# SIS-BeamDiagnostics Software – Monitoring of Stripper Foils

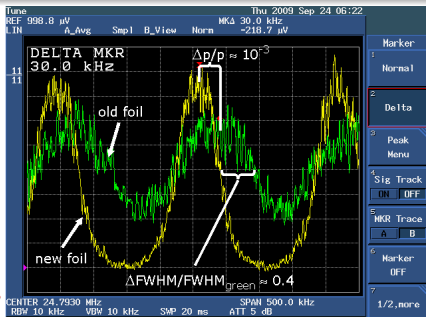
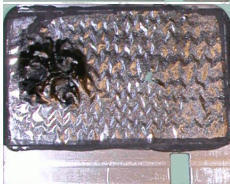
Unused foil

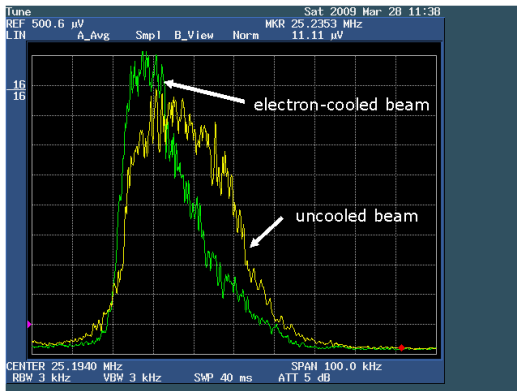


Sweeper foil after use with swept beam

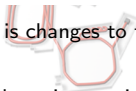


Sweeper foil after use with kicked beam





- 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



Yes, we can. . .



Yes, we can. . .

- development successful
- 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



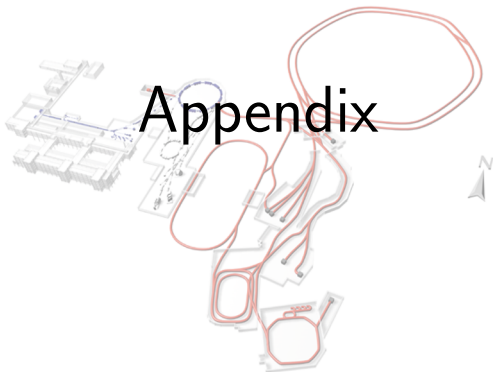
# Thank you for your attention!

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

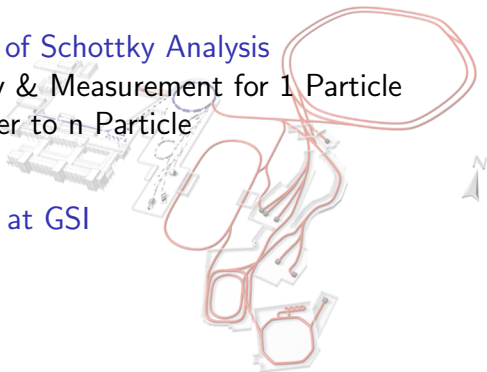
## Questions . . .



# Appendix



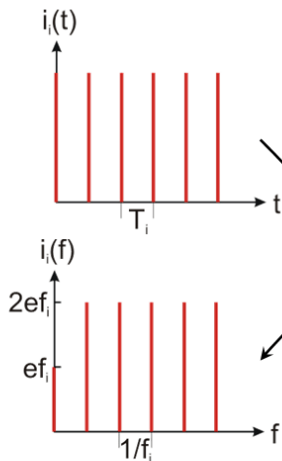
- 6 The Control System
- 7 Principle of Schottky Analysis
  - Theory & Measurement for 1 Particle
  - Transfer to n Particle
- 8 Research at GSI
- 9 UNILAC



## 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  $\mu$  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 construction tool to build code developed in-house)
  
- GUI intuitively operable
- look of new GUI similar to existent ones

Circulation of particle with  $Q = e$ :



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

Pick-up measures only positive frequencies:

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

not „seen“ by usual current measurement!

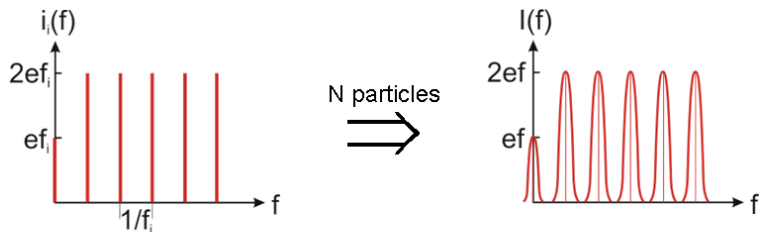
transition from theory to measurement:  
 $t \Rightarrow f$

= Fourier transf.

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

**$\Rightarrow$  frequency  $f$  is the real measuring quantity !**

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



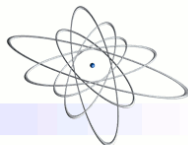
- N particles randomly azimuthal distributed along the ring each with a different momentum deviation  $\Delta p$  with respect to the reference particle.
- different  $\Delta p$  corresponds to different  $\Delta f$  due to the following relation:

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

$\eta \rightarrow$  characteristic of the ring!

## 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

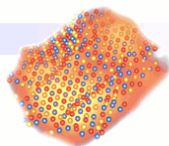
## Biophysics and Nuclear Medicine

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



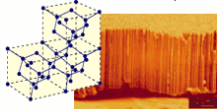
## Plasma Physics

- hot dense plasma
- ion plasma interaction



## Material Science

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

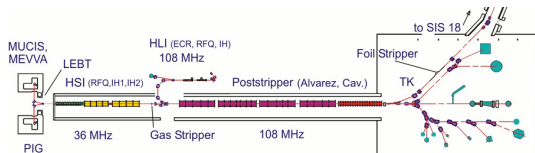


## Accelerator Technology

- ion sources
- linear accelerators
- synchrotrons and storage rings



by GSI Division of Public Relations



## Injectors

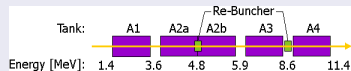
### High Current Injector (HSI)

- 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:  $-30^\circ$  (1<sup>st</sup> 3 tanks),  $-25^\circ$  (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

