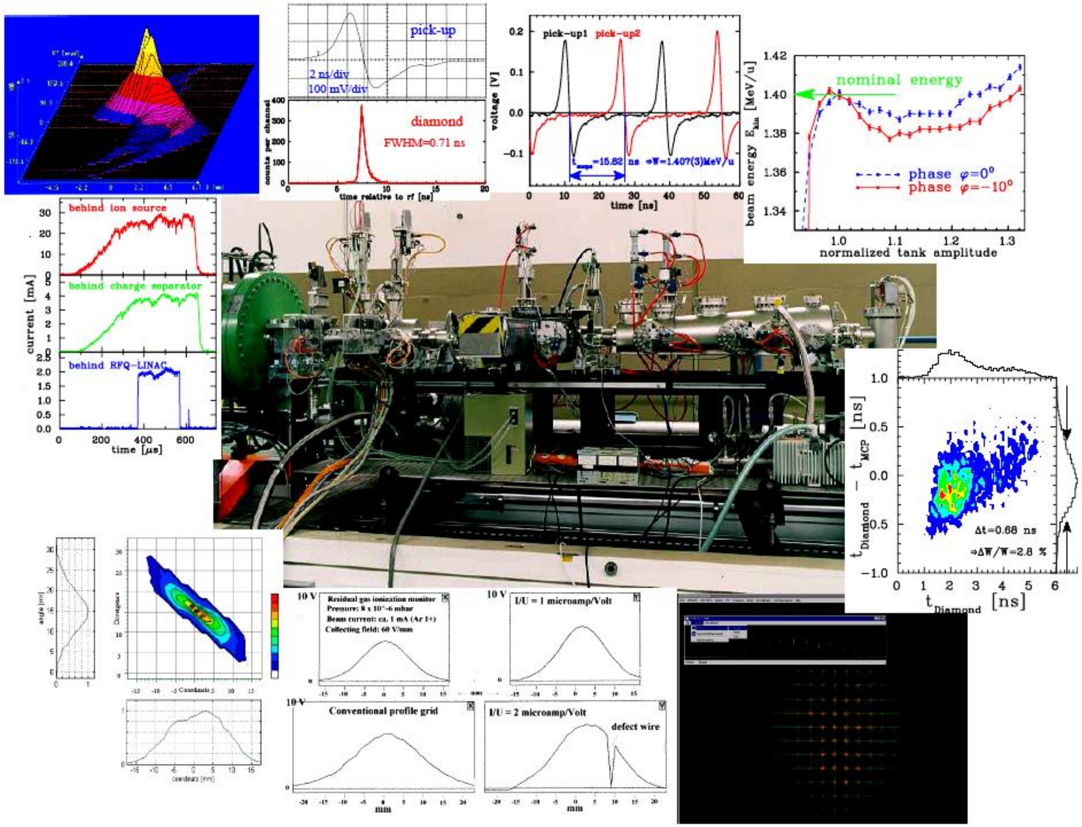
Beam Diagnostics and Instrumentation

JUAS 2014, Archamps

Peter Forck

Gesellschaft für Schwerionenforschung (GSI)



Diagnostics is the 'organ of sense' for the beam.

It deals with *real* beams in *real* technical installations including all imperfections.

Four types of demands leads to different installations:

- Quick, non-destructive measurements leading to a single number or simple plots.
  Used as a check for online information. Reliable technologies have to be used.
  Example: Current measurement by transformers.
- Instruments for daily check, malfunction diagnosis and wanted parameter variation.
  Example: Profile measurement, in many cases 'intercepting' i.e destructive to the beam
- Complex instruments for severe malfunctions, accelerator commissioning & development.
  The instrumentation might be destructive and complex.
  Example: Emittance determination.
- Instruments for automatic, active beam control.
  Example: Closed orbit feedback using position measurement by BPMs.

A clear interpretation of the results is a important design criterion.

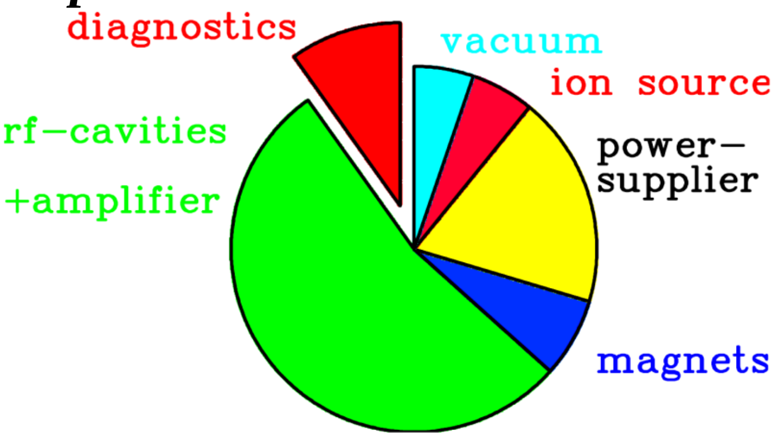
Non-destructive ('non-intercepting') methods are preferred:

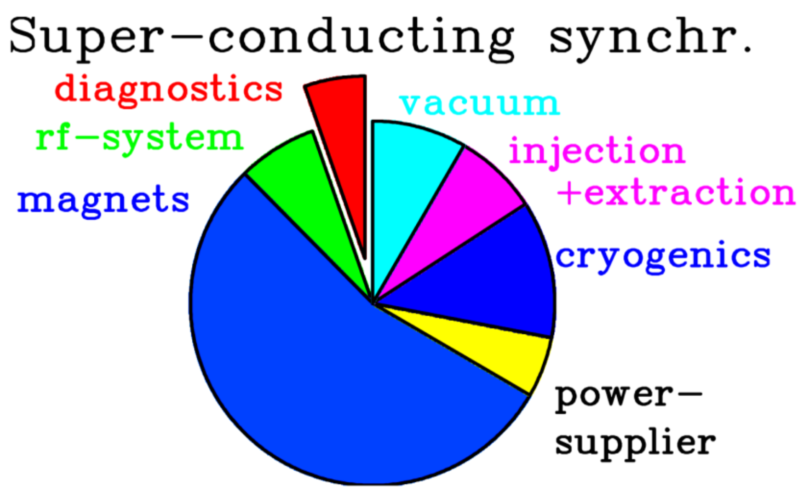
- The beam is not influenced
- The instrument is not destroyed.

The cost of diagnostics is about 3 to 10 % of the total facility cost:

- ≈ 3 % for large accelerators ***or*** accelerators with standard technologies
- ≈ 10 % for versatile accelerators ***or*** novel accelerators and technologies.

Cost Examples:





The amount of man-power is about 10 to 20 %:

- very different physics and technologies are applied
- technologies have to be up-graded, e.g. data acquisition and analysis
- accelerator improvement calls for new diagnostic concepts.

Relevant physical Processes for Beam Diagnostics

➢**Electro-magnetic influence by moving charges:**
→ **classical electro-dynamics, voltage and current meas., low and high frequencies**
Examples: Faraday cups, beam transformers, pick-ups

➢**Emission of photon by accelerated charges: (only for relativistic electrons)**
→ **classical electro-dynamics, optical techniques (from visible to x-ray)**
Example: Synchrotron radiation monitors

➢**Interaction of particles with photons:**
→ **optics, lasers, optical techniques, particle detectors**
Examples: laser scanners, short bunch length measurement, polarimeters

➢**Coulomb interaction of charged particles with matter:**
→ **atomic and solid state physics, current measurement, optics, particle detectors**
Examples: scintillators, viewing screens, ionization chambers, residual gas monitors

➢**Nuclear- or elementary particle physics interactions:**
→ **nuclear physics, particle detectors**
Examples: beam loss monitors, polarimeters, luminosity monitors

➢**And of cause accelerator physics for proper instrumentation layout.**

Beam diagnostics deals with the full spectrum of physics and technology,
⇒ this calls for experts on all these fields and is a challenging task!

Beam Quantities and their Diagnostics I

LINAC & transport lines: Single pass ↔ **Synchrotron:** multi pass

Electrons: always relativistic ↔ **Protons/Ions:** non-relativistic for E_{kin} < 1 GeV/u

Depending on application: Low current ↔ high current

Overview of the most commonly used systems:

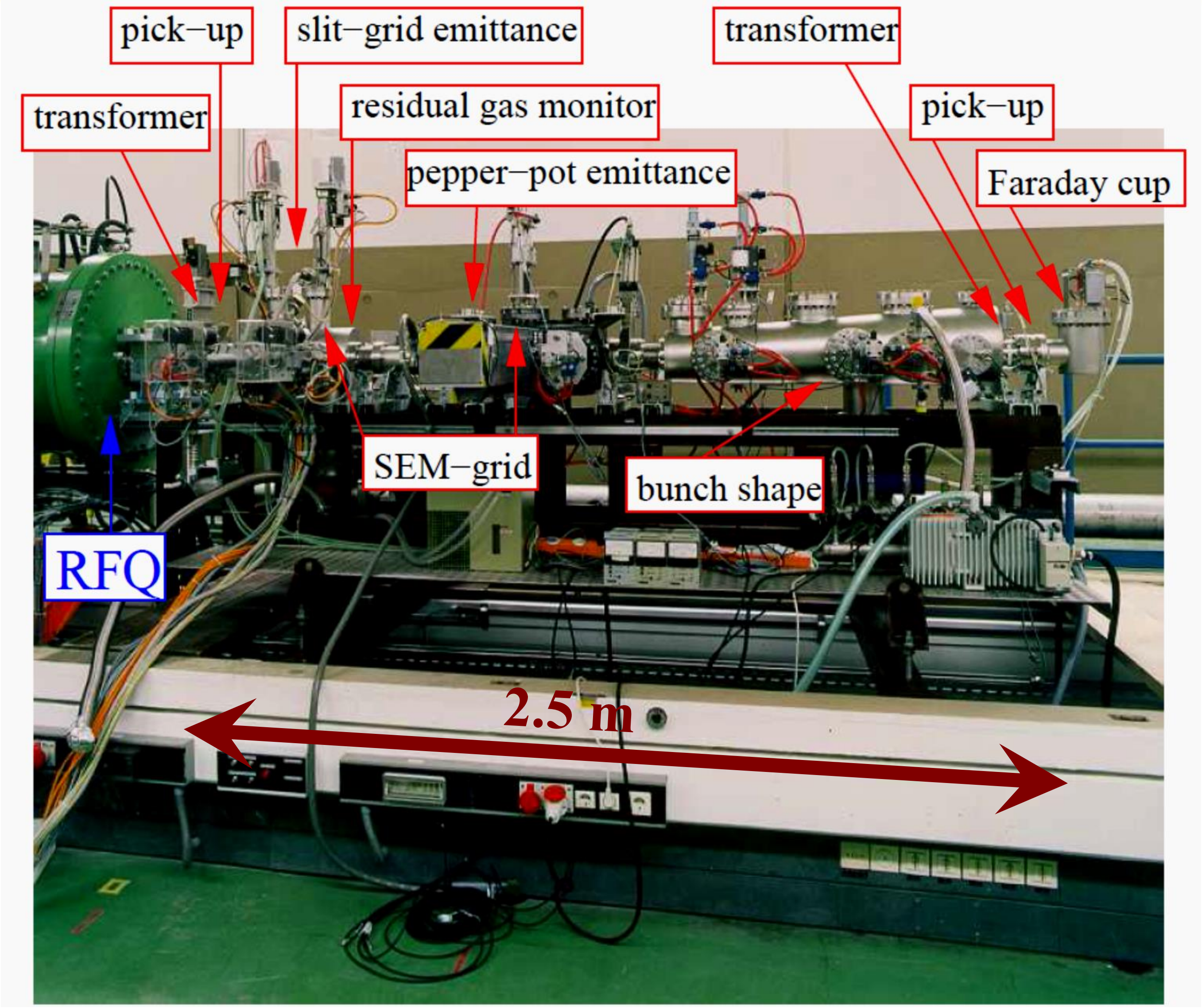
Beam quantity		LINAC & transfer line	Synchrotron
Current *I*	*General* *Special*	**Transformer, dc & ac** **Faraday Cup** **Particle Detectors**	**Transformer, dc & ac** Pick-up Signal (relative)
Profile x_{width}	*General* *Special*	**Screens, SEM-Grids** **Wire Scanners, OTR Screen** MWPC, **Fluorescence Light**	**Residual Gas Monitor** **Wire Scanner,** **Synchrotron Light Monitor**
Position x_{cm}	*General* *Special*	**Pick-up (BPM)** Using position measurement	**Pick-up (BPM)**
Transverse Emittance ε_{trans}	*General* *Special*	**Slit-grid** **Quadrupole Variation** **Pepper-Pot**	**Residual Gas Monitor** **Wire Scanner** Transverse Schottky

Beam Quantities and their Diagnostics II

Beam quantity		LINAC & transfer line	Synchrotron
Bunch Length $\Delta\varphi$	*General* *Special*	**Pick-up** **Secondary electrons**	**Pick-up** **Wall Current Monitor** **Streak Camera** **Electro-optical laser mod.**
Momentum p and Momentum Spread $\Delta p/p$	*General* *Special*	**Pick-ups (Time-of-Flight)** Magnetic Spectrometer	**Pick-up (e.g. tomography)** Schottky Noise Spectrum
Longitudinal Emittance ε_{long}	*General* *Special*	**Buncher variation** Magnetic Spectrometer	 **Pick-up & tomography**
Tune and Chromaticity Q, ξ	*General* *Special*	--- ---	**Exciter + Pick-up** Transverse Schottky Spectrum
Beam Loss r_{loss}	*General*	**Particle Detectors**	
Polarization P	*General* *Special*	Particle Detectors Laser Scattering (Compton scattering)	
Luminocity L	*General*	Particle Detectors	

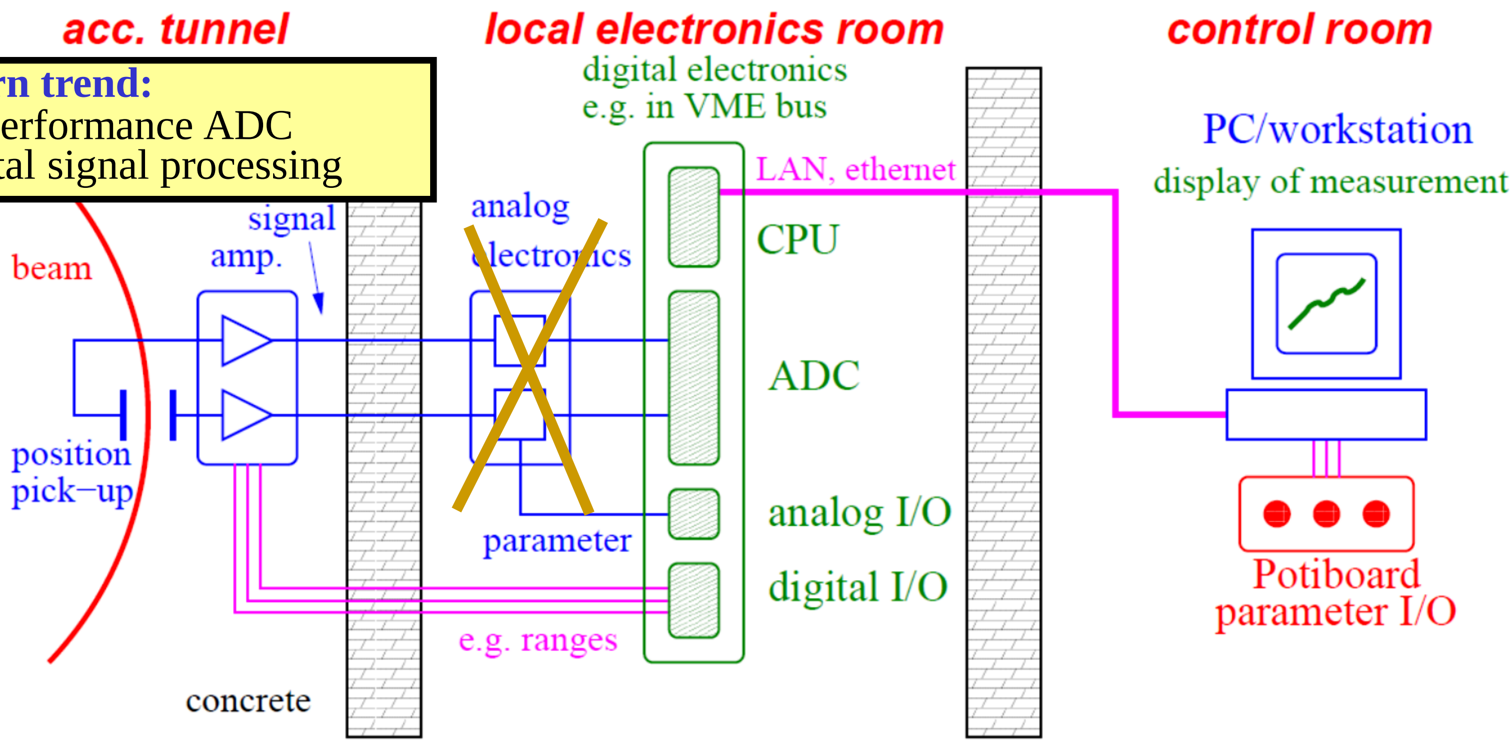
- Destructive and non-destructive devices depending on the beam parameter.
- Different techniques for the same quantity ↔ Same technique for the different quantities.

Example: Diagnostics Bench for the Commissioning of an RFQ



Typical Installation of a Diagnostics Device

Modern trend:
High performance ADC
& digital signal processing



accelerator tunnel:
→ action of the beam to the detector
→ low noise pre-amplifier and first signal shaping

local electronics room:
→ analog treatment, partly combining other parameters
→ digitalization, data bus systems (GPIB, VME, cPCI...)

control room:
→ visualization and storage on PC
→ parameter setting of the beam and the instruments

The result helps to align the accelerator!

Some experimental device parameters are also shown to prove the functionality.

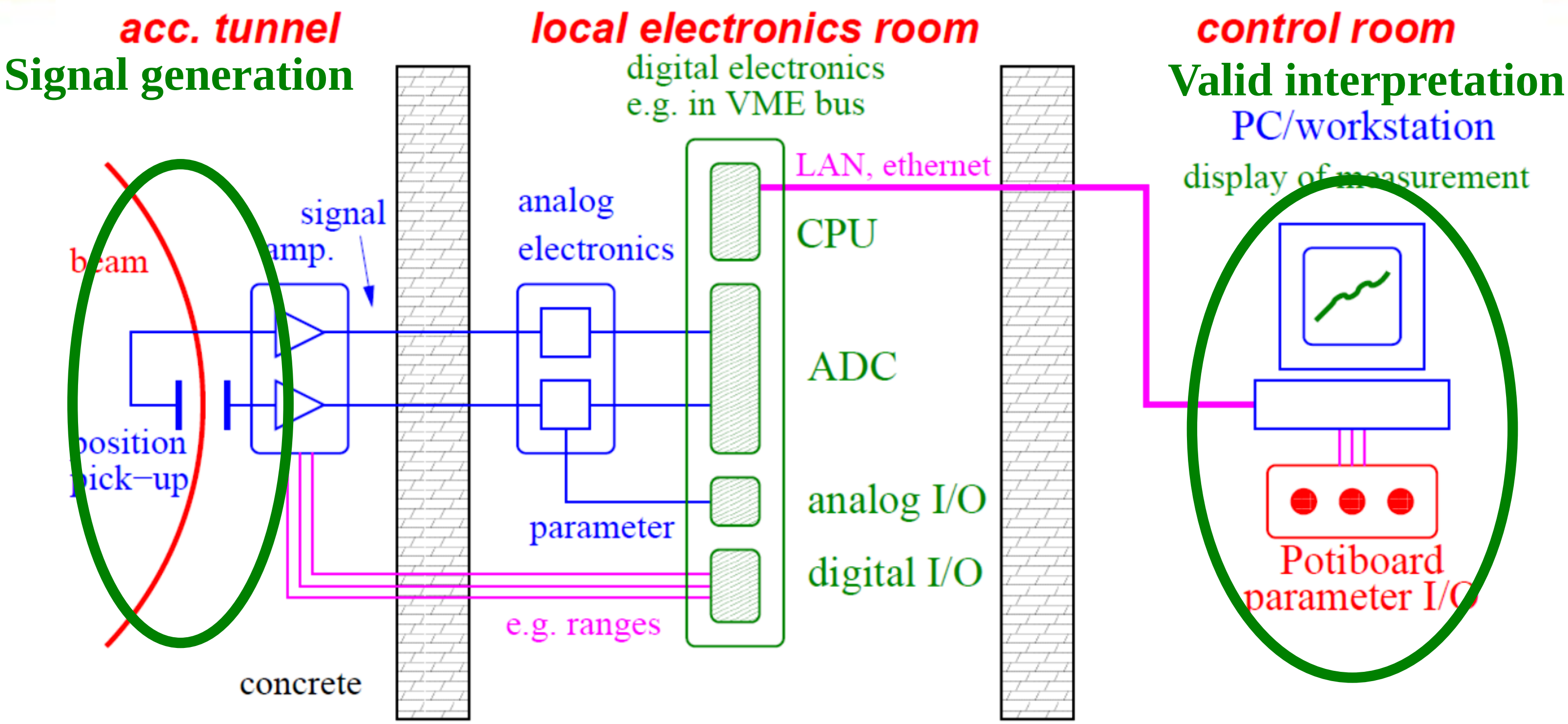
The ordering of the subjects is oriented by the beam quantities:

- **Current measurement:** Transformers, cups, particle detectors
- **Profile measurement:** Various methods depending on the beam properties
- **Transverse emittance measurement:** Destructive devices, determination by linear transformations
- **Pick-ups for bunched beams**: Principle and realization of rf pick-ups, closed orbit and tune measurements
- **Measurement of longitudinal parameters:** Beam energy with pick-ups, time structure of bunches for low and high beam energies, longitudinal emittance
- **Beam loss detection:** Secondary particle detection for optimization and protection

It will be discussed: The action of the beam to the detector, the design of the devices, generated raw data, partly analog electronics, results of the measurements.

It will not be discussed: Detailed signal-to-noise calculations, analog electronics, digital electronics, data acquisition and analysis, online and offline software....

General: Standard methods and equipment for stable beams with moderate intensities.

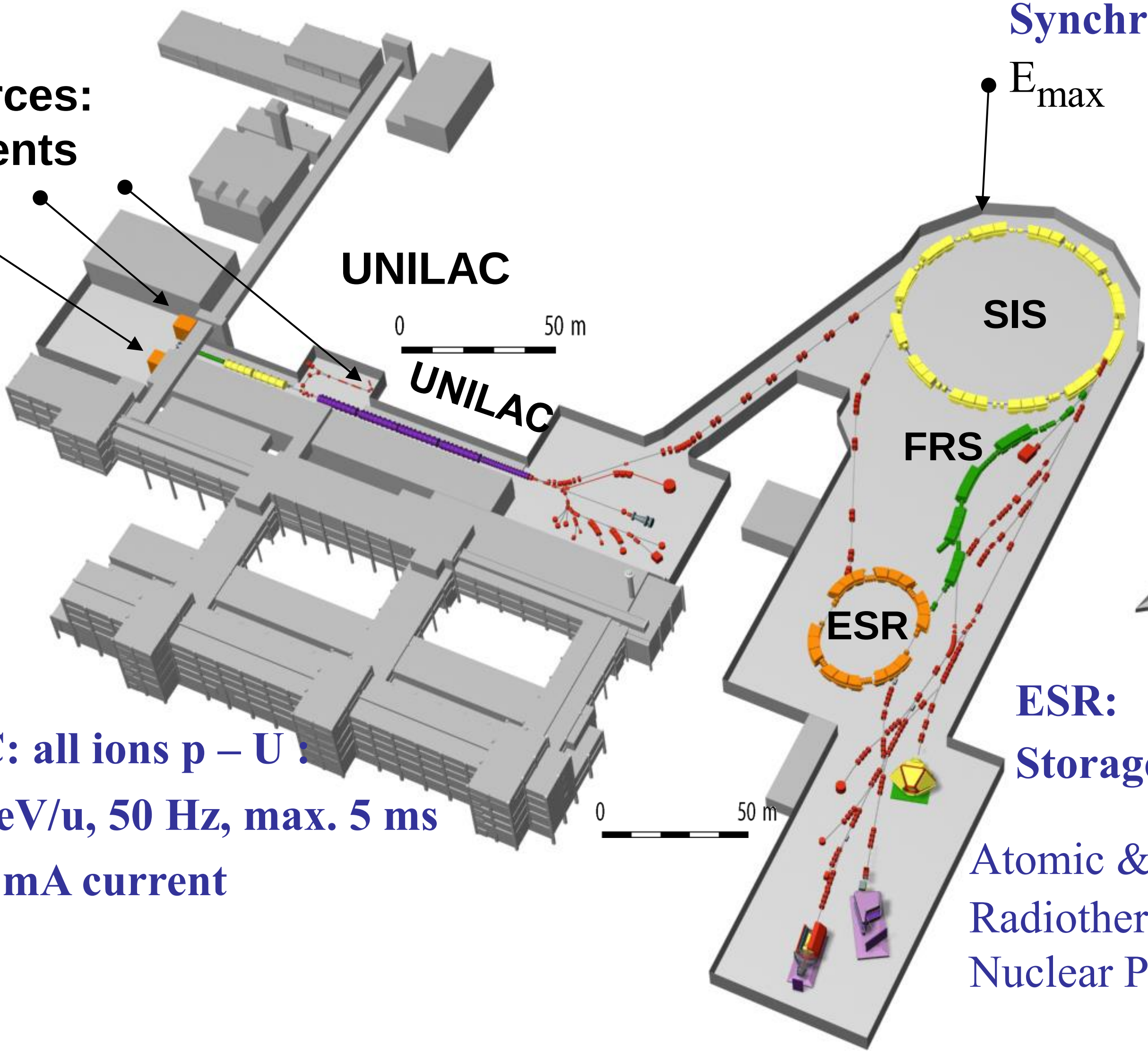


The goal of the lecture should be:

- **Understanding the signal generation of various device**
- **Showing examples for real beam behavior**
- **Enabling a correct interpretation of various measurements.**

The Accelerator Facility at GSI

Ion Sources:
all elements



Synchrotron, Bρ=18 Tm

E_{max} p: 4.7 GeV
U: 1 GeV/u

Achieved e.g.:

Ar^{18+}: $1\cdot10^{11}$
U^{28+}: $3\cdot10^{10}$
U^{73+}: $1\cdot10^{10}$

UNILAC: all ions p – U :
3 – 12 MeV/u, 50 Hz, max. 5 ms
Up to 20 mA current

ESR:
Storage Ring, Bρ=10 Tm

Atomic & Plasma Physics
Radiotherapy
Nuclear Physics