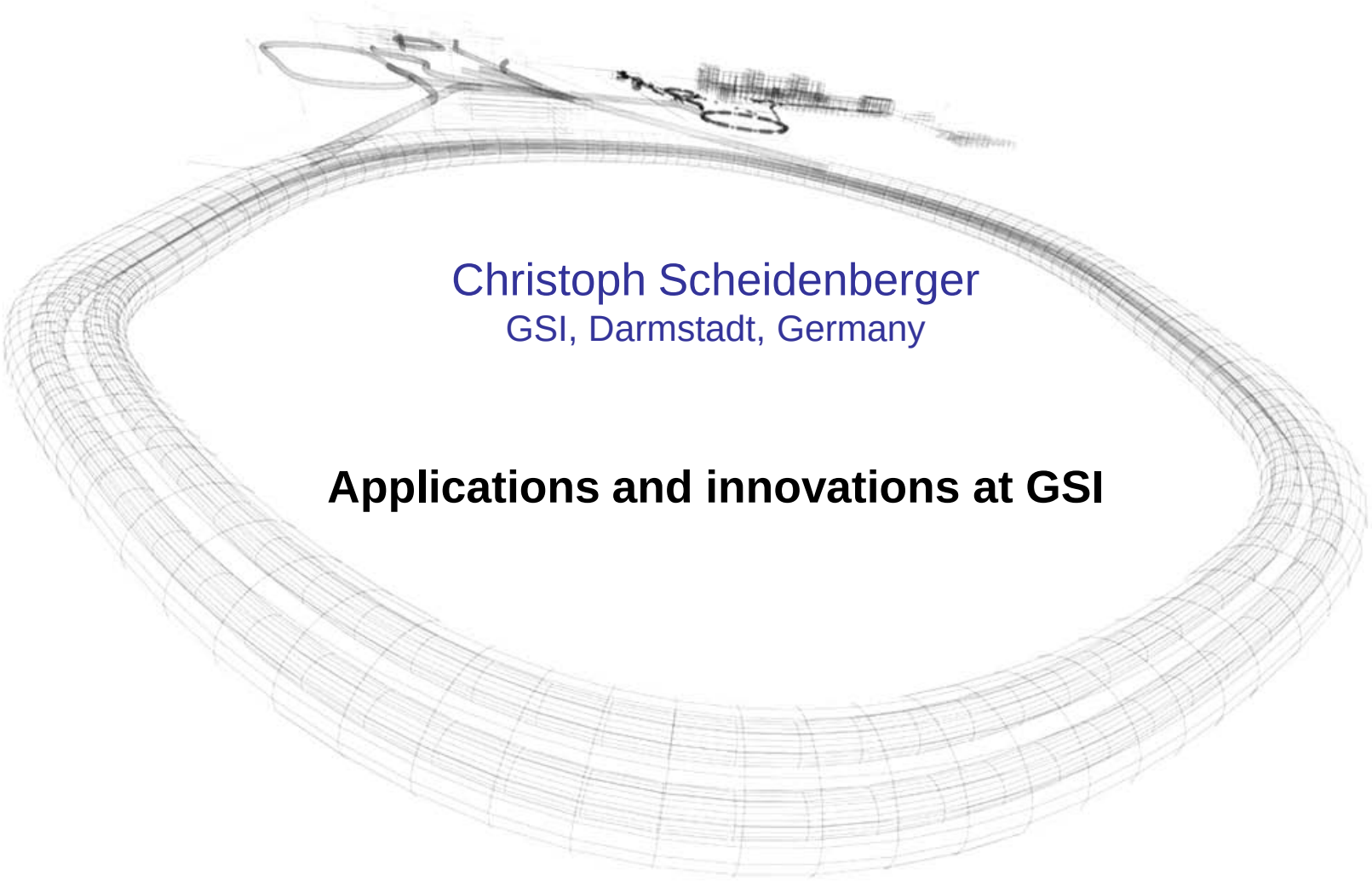


Christoph Scheidenberger
GSI, Darmstadt, Germany

Applications and innovations at GSI

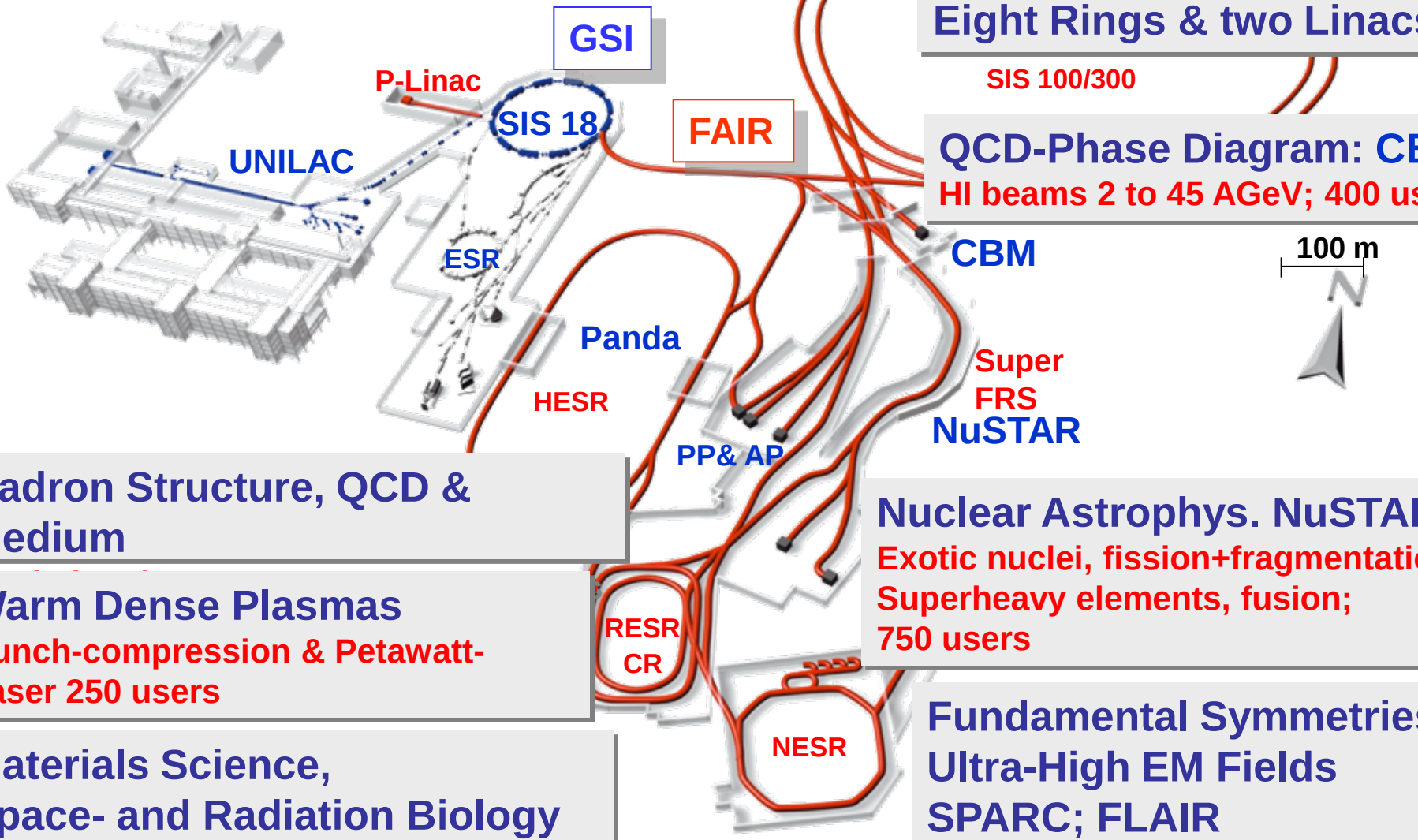
GSI today

GSI was founded in 1969 in Darmstadt (by the Federal Government of Germany and the State of Hesse) upon the initiative of the surrounding universities

- ~ 1050 employees, ~ 200 students and post-docs
- Large-scale accelerator and storage-ring complex
- Inauguration of UNILAC (1975) and of SIS (1990)
- High precision tests of quantum electrodynamics
- Discovery of super-heavy elements and exotic nuclei physics
- Explorations of phases of nuclear matter and its equation of state
- Cancer therapy with ion beams (1997-2007)

GSI and FAIR in 2020

FAIR physics pillars and FAIR project



Accelerator Physics: Eight Rings & two Linacs

QCD-Phase Diagram: CBM

HI beams 2 to 45 AGeV; 400 users

Hadron Structure, QCD & Medium

Nuclear Astrophys. NuSTAR

Exotic nuclei, fission+fragmentation;
Superheavy elements, fusion;
750 users

Warm Dense Plasmas

Bunch-compression & Petawatt-Laser 250 users

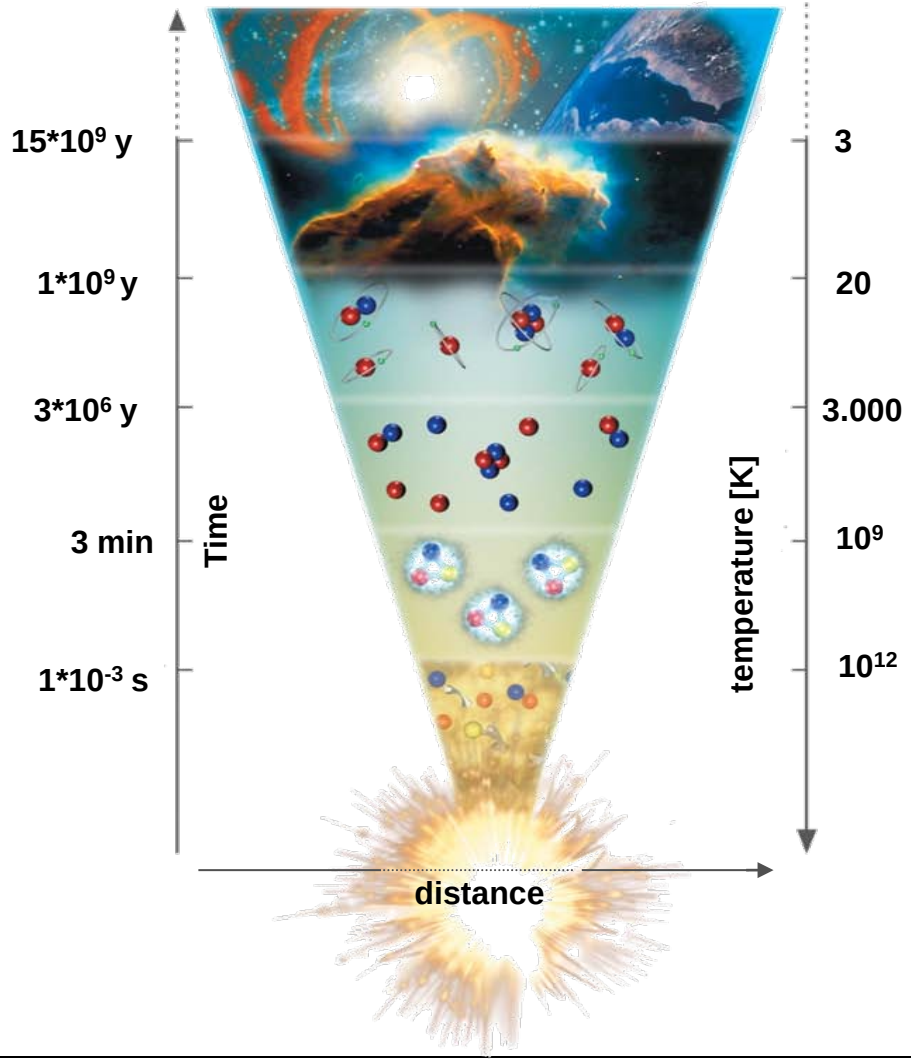
Fundamental Symmetries Ultra-High EM Fields SPARC; FLAIR

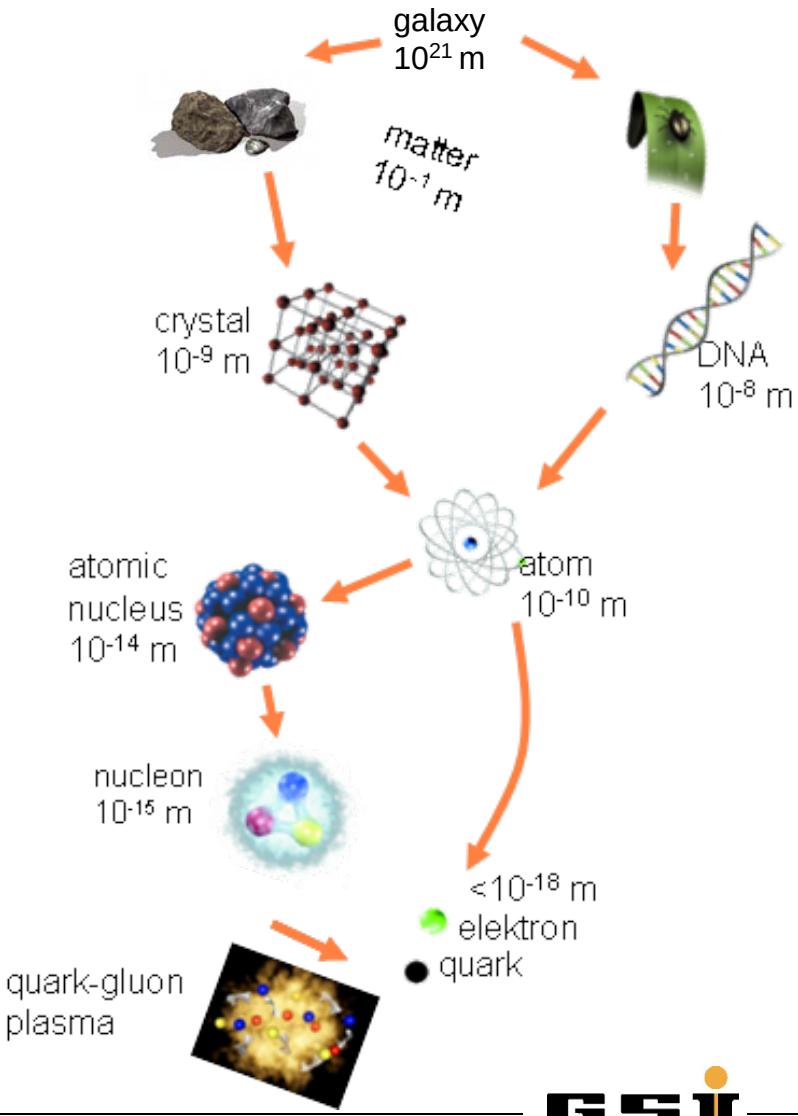
Antiprotons, Hi-Z ions; 250 users

Materials Science, Space- and Radiation Biology

(Ion- & antiproton- beams; 350 users

GSI+FAIR research objectives

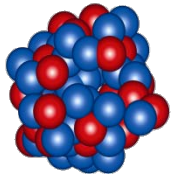


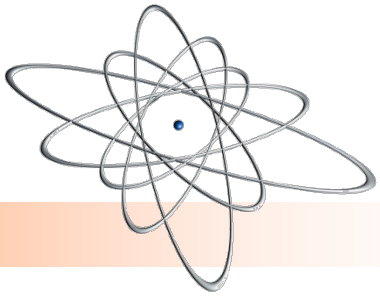


Research areas at GSI

Nuclear Physics (50 %)

- Nuclear reactions up to highest energies
- Superheavy elements
- Hot dense nuclear matter





Atomic Physics (15 %)

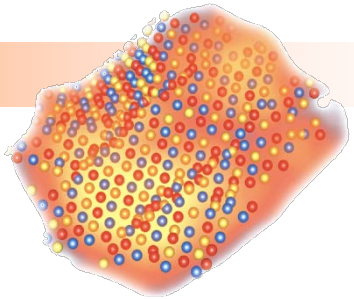
- Atomic Reactions
- Precision spectroscopy of highly charged ions

Biophysics and radiation medicine (15 %)

- Radiobiological effect of ions
- Cancer therapy with ion beams

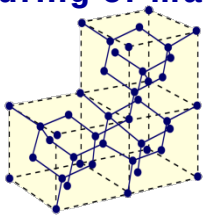
Plasma Physics (5 %)

- Hot dense plasma
- Ion-plasma-interaction



Materials Research (5 %)

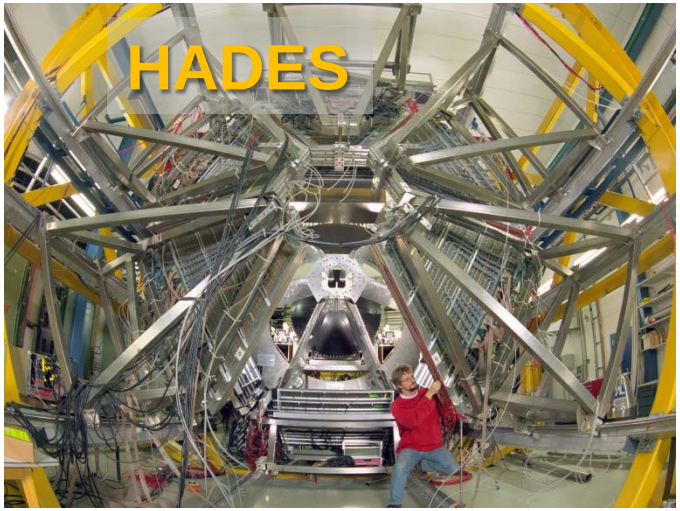
- Ion-Solid-Interactions
- Structuring of materials with ion beams

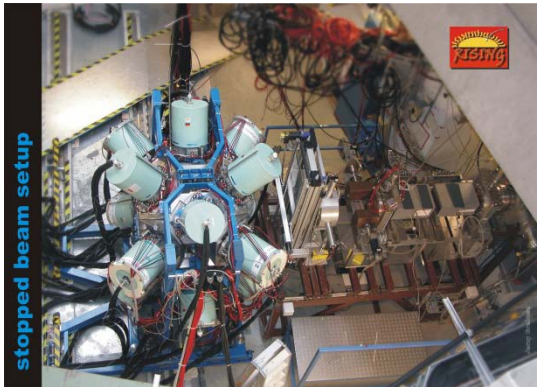


Accelerator Technology (10 %)

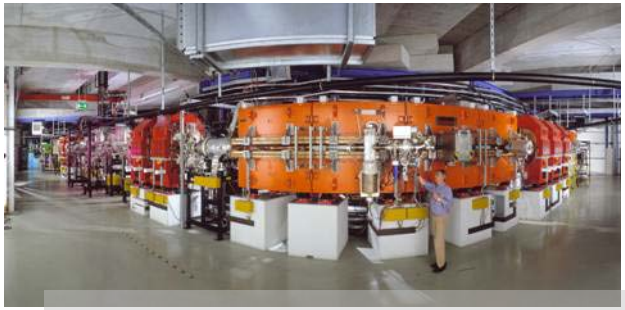
- Linear accelerator
- Synchrotrons and storage rings

Research infrastructure and instruments

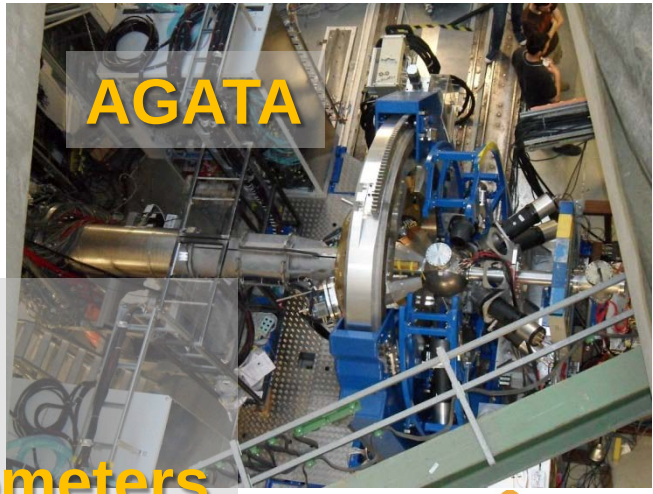




RISING



Accelerators
Storage rings,
Separators + spectrometers



Laboratories

Targets, detectors, IT, electronics

Target laboratory

- **Thin Films (10 nm ... 1 µm)**
  - preferably as self-supporting thin film
  - on a temperature-resistant interlayer
  - on a soluble interlayer
  - deposition by
    - –resistance heating
    - –thermal evaporation
    - –e-beam gun evaporation
    - –DC magnetron sputtering
    - –HF magnetron sputtering
    - –extracted ion beam sputtering

- **Cold Rolling (0.5 µm ... 1 mm)**
  - by cold rolling
  - between stainless steel sheets
  - from foil or molten down bead
  - in air
  - in argon glove box

- **Massive Targets (1 mm ... 10 cm)**
  - by parallel cutting
  - by lapping
  - by polishing

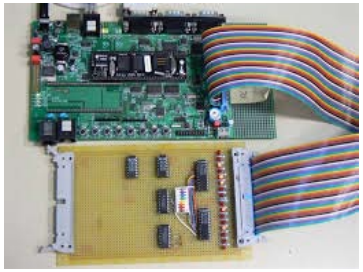
- **Analyses and Quality Control**
  - Optical Microscopy
  - Scanning Electron Microscopy
  - Balances
  - UV-VIS Photometer
  - Mechanical Measuring
    - –on flat table
    - –from both sides

- **Consulting and Support**
  - enriched material for ion sources
  - convert material
    - –from oxide in compound for easier evaporation
    - –from metal in compound for longer lifetime in the beam
    - –from oxide in metal for application in the ion source
  - contact person for questions concerning materials
  - analytics

Detector laboratory

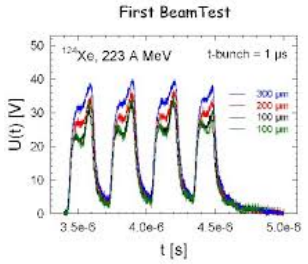
UHV detectors for ESR

Drift chambers for ALICE

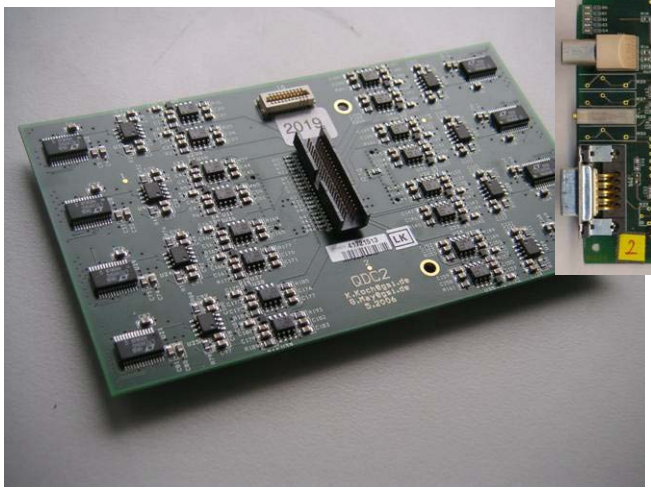


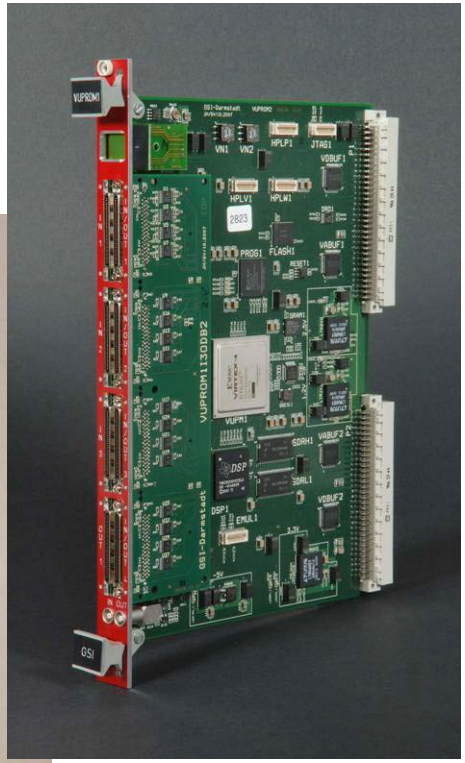
Electronic developments

- Detector developments
- Beam diagnostics, dosimetry
- R&D work
- Support of collaborations
- Analyses and quality control
- Consulting and support

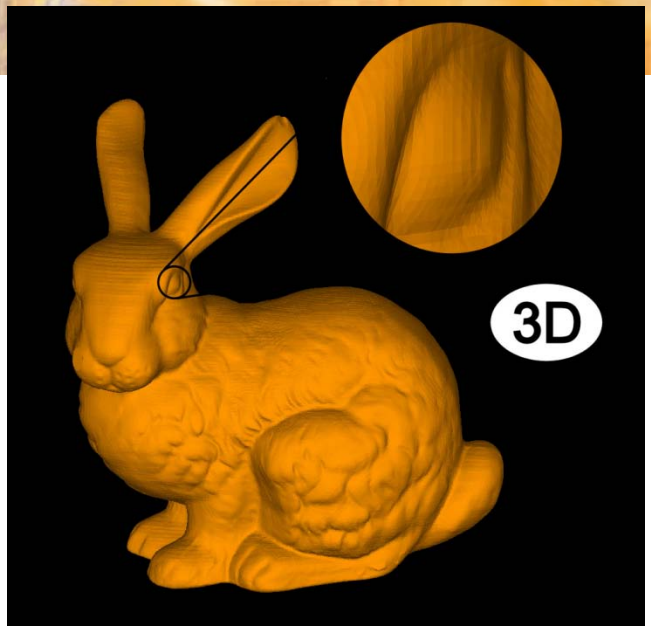


IT and electronics laboratory

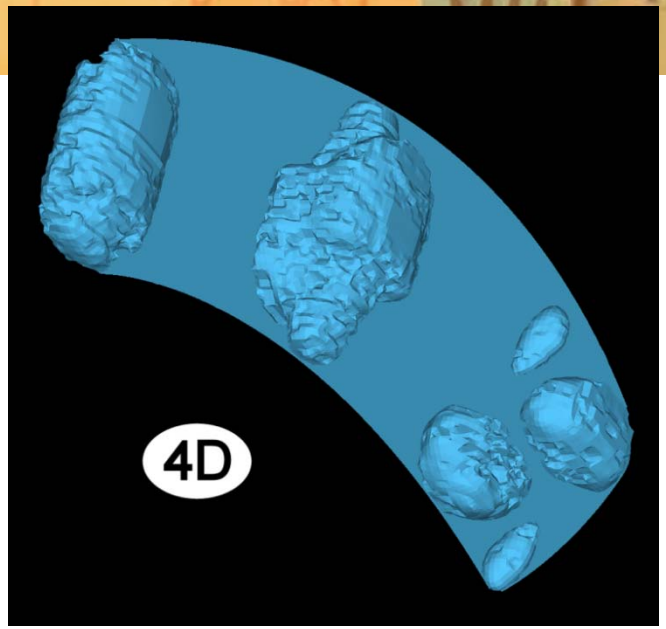




Graphic card for 4D-imaging



Stanford Terra-Cotta Bunny data set calculated by the new method.



Iso-therme time development projections for relativistic fluid model simulations.

Concept

Volume data already plays a significant role in many scientific areas, e.g. in medical diagnostics (MRT and CT scanners), and mathematical and physical simulations or technical measurements.

GSI developed a new method to aid analysis and interpretation of measured and simulated data.

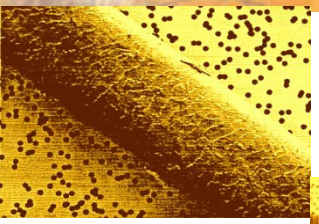
The procedure can be described in three main steps by means of an elementary cell or “atom”.

- Determination of the atoms in the data set.
- Connection of the single atoms, while their constituent vectors form closed cycles.
- Decomposition of generated cycles into simple pieces to build the final hyper-surface.

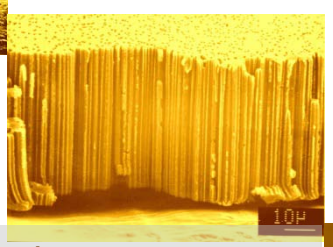
Material research and applications

Materials, surfaces, manipulation with ions

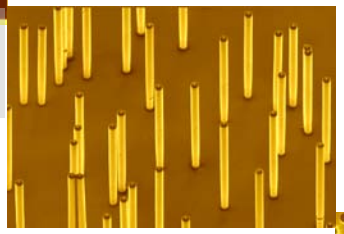
Overview on interesting applications and innovations

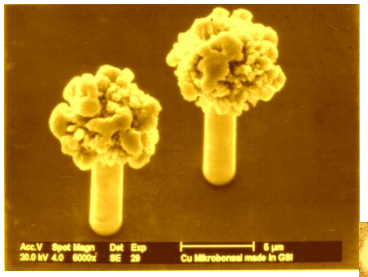


PET; polycarbonate, polyimide

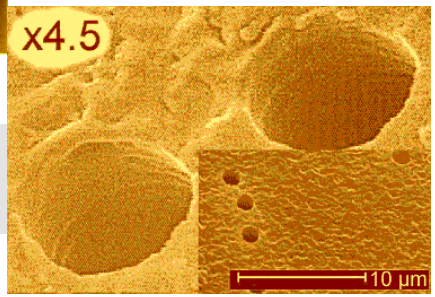


Pore thickness between
1 and 10^9 pores/cm^2

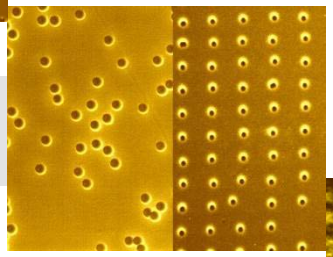


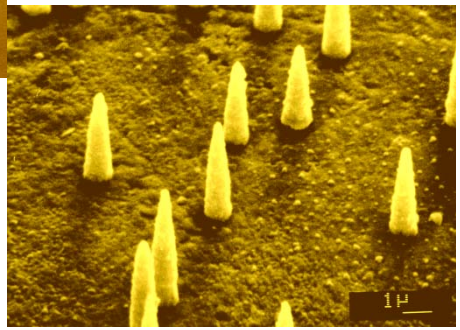


It is possible to create
a variety of pore forms



Pore dimensions between
5nm and 10µm





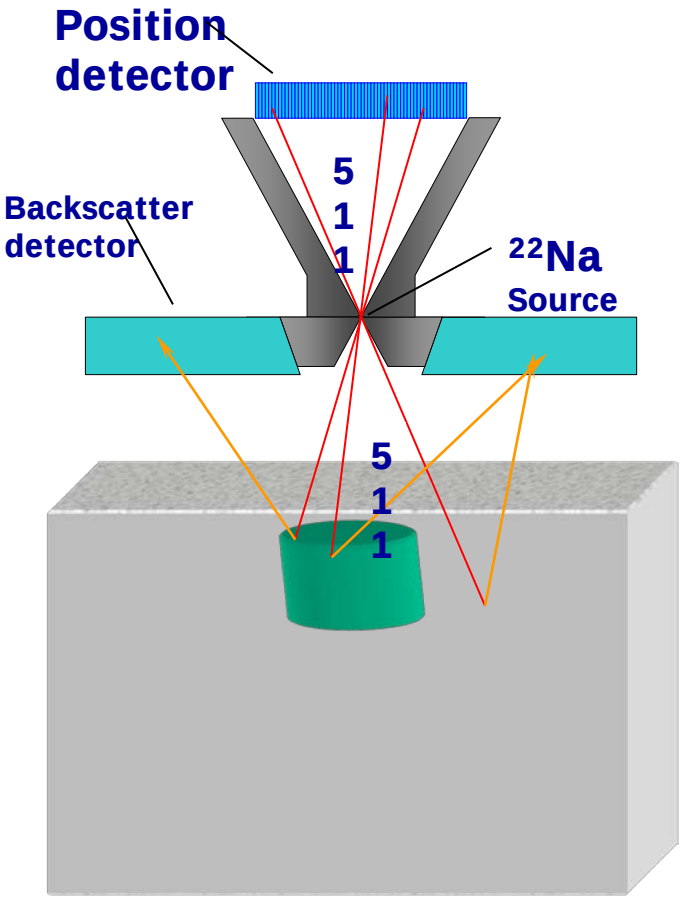
Applications:
Medicine: filter for blood
Materials: basics for scanning, quality management

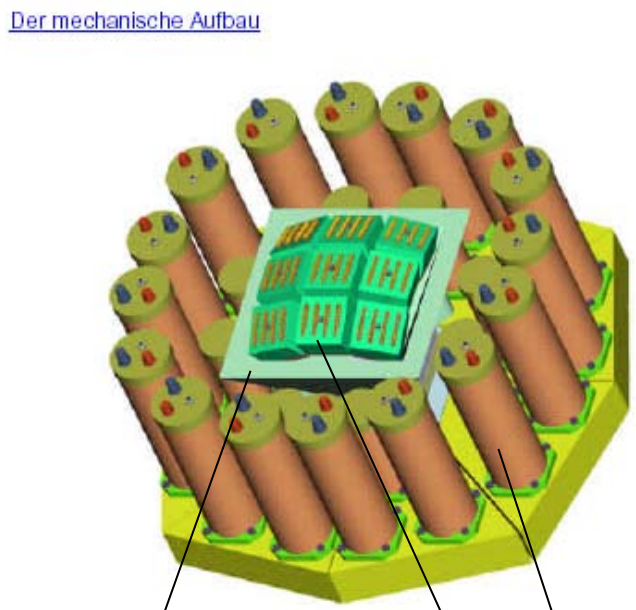
Gamma-ray imaging:

Landmine detection

Christoph Scheidenberger, GSI

Back-scattering imaging





Shielding of the ^{22}Na source

Back-scatter detector

Position detector

Prototype for verification

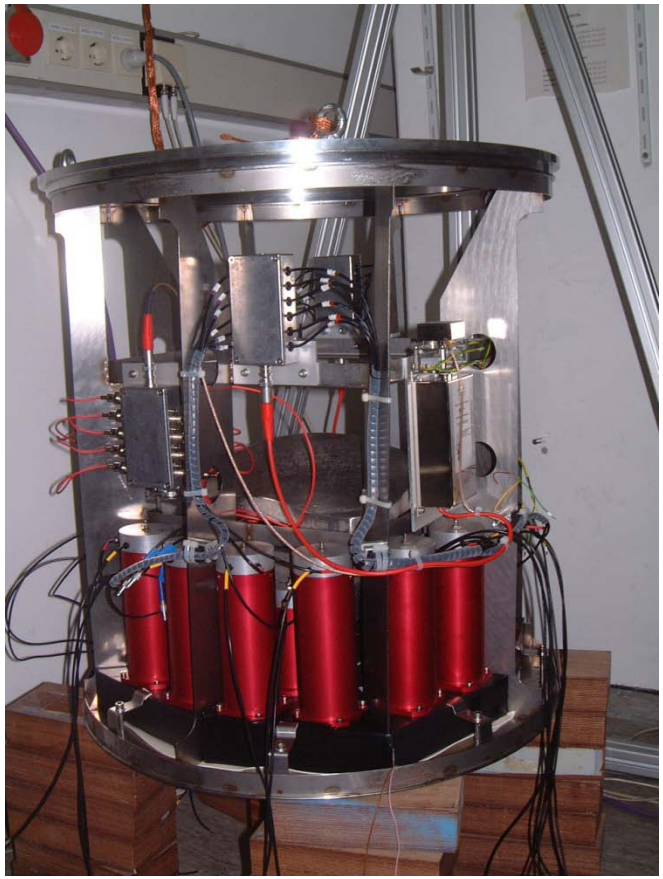
γ-Source:	10 MBq ^{22}Na
detection area:	≥ 20x20 cm^2
max. depth:	30 cm
eff. resolution:	60x60 pixels

Position Det. Rate ≈ 5 MHz

Backscatter Det. Rate ≈ 500 kHz

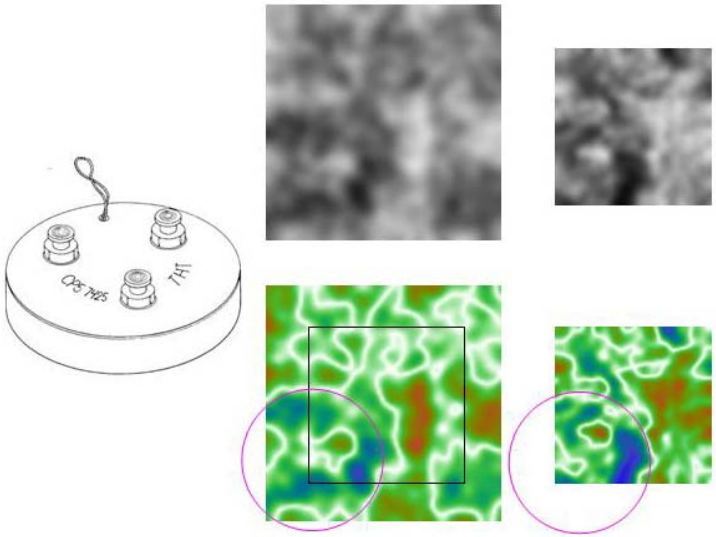
Scaled down Singles Trigger ≈ 500 kHz

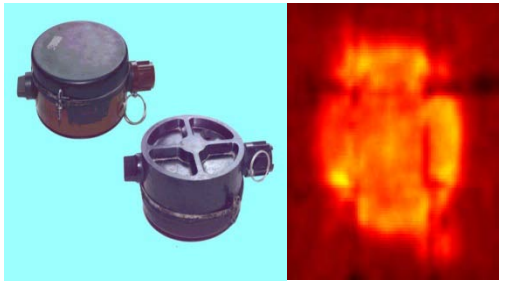
Pos-BS Koinzidenz Trigger ≈ 150 kHz



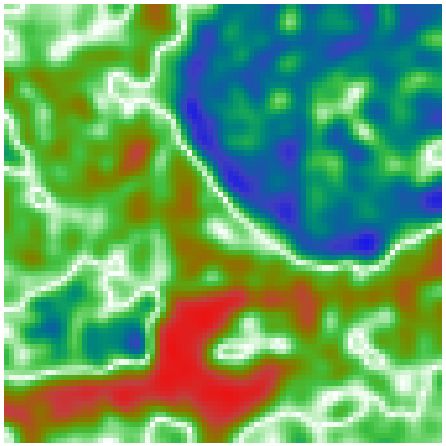
Application to mine detection

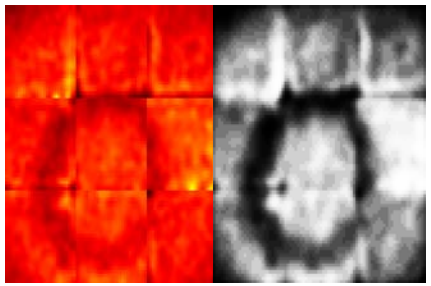
ATM in 10 cm depth





APM in
wet sand

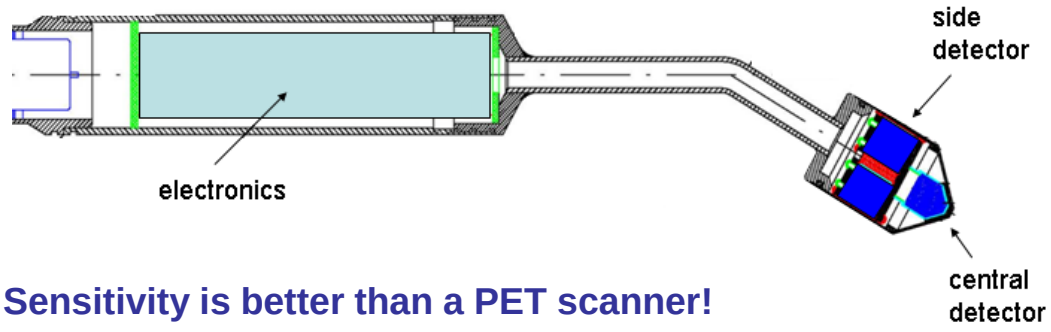




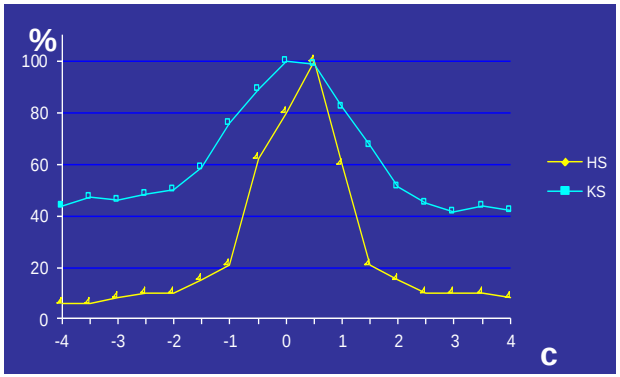
ATM in 10cm
depth (soil)

Medicine: tumor diagnosis and therapy

γ - locator: High energy PET probe



- Sensitivity is better than a PET scanner!



Clinical application:
head, neck, spine, liver, thyroid, thorax,...

Useful tool for the surgery:
sensitive, selective, fast....

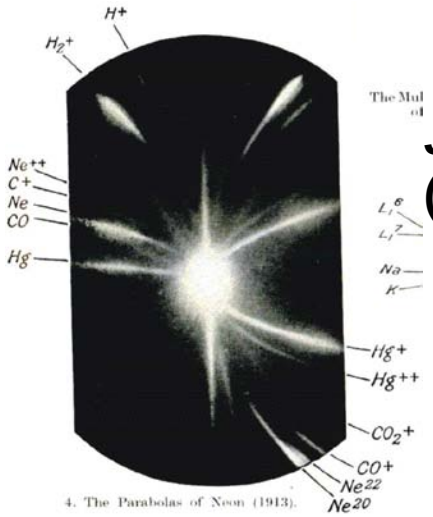
Mass spectrometry:

Medical imaging and in-situ analysis

Christoph Scheidenberger, GSI

The origin of mass spectrometry

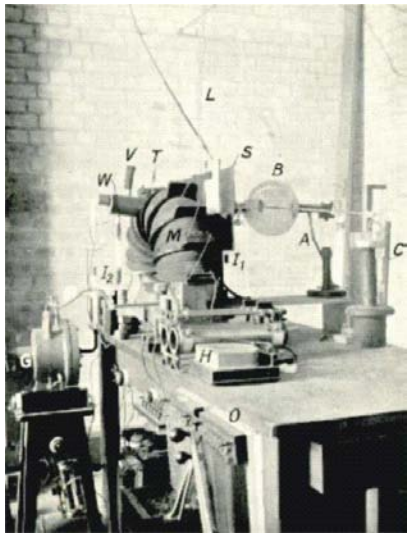
Discovery of isotopes



4. The Parabolas of Neon (1913).

J.J.Thomson (1913)

High resolution mass spectrographs



F.W.Aston (~1915...1925)
*** 212 isotopes discovered**
*** First mass systematics**
→ Packing fraction

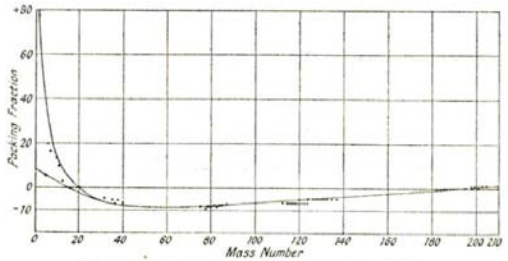
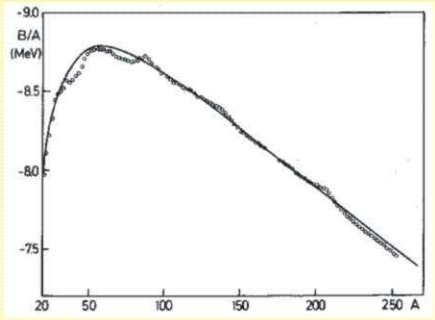


Fig. 20.—Aston's Original Packing Fraction Curve (1927).

Development of first mass model

Volume energy ~ A (*)
Surface " ~ $A^{2/3}$
Coulomb " ~ $-Z^2 / A^{1/3}$
Asymetry " ~ $-(Z - A/2)^2/A$

(*) $R \sim A^{1/3}$



C. F. v. Weizsäcker, H.A.Bethe (1935/36)

Modern approaches in nuclear physics

Indirect determination: reactions and decay

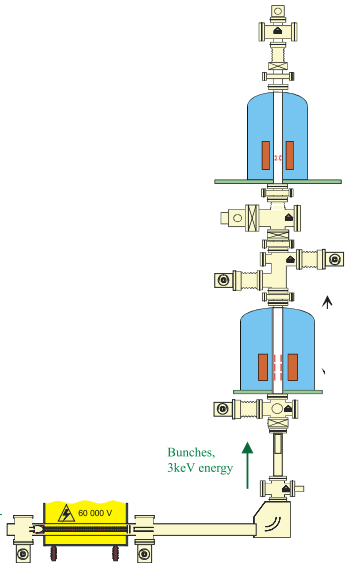
* Reactions
* Decay (α, β+, β-, ...)

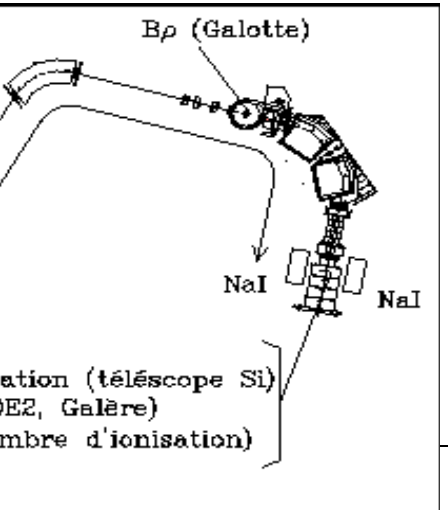
Direct measurements

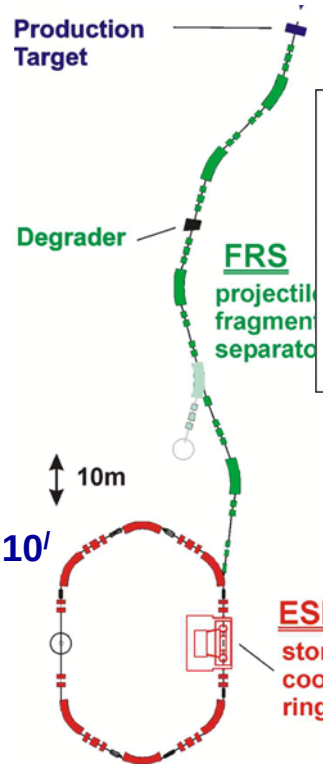
* RF Spectrometers
* Bρ-TOF Spectrometers
* Cyclotrons
* Ion traps
* Storage rings
* Electrostatic mirror systems

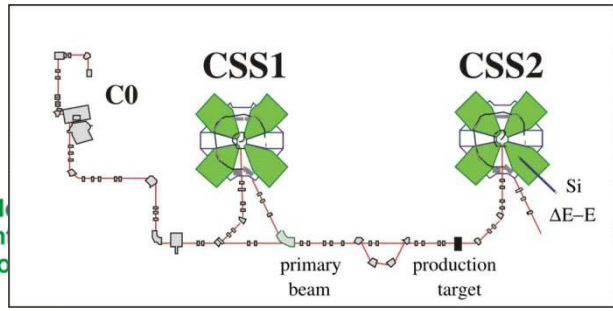
Performance parameters:

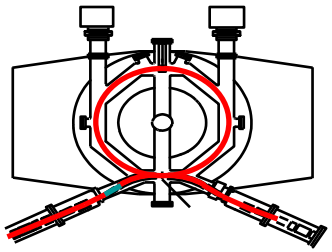
* Mass resolving powers 10^5...$10^{}$
* Precision > 10^{-10}
* $T_{1/2}$ > μs
* Sensitivity: few ions

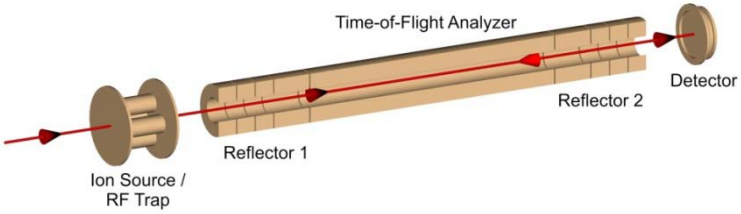












Example of modern devices for Analytical Mass Spectrometry

Commercial device in routine operation

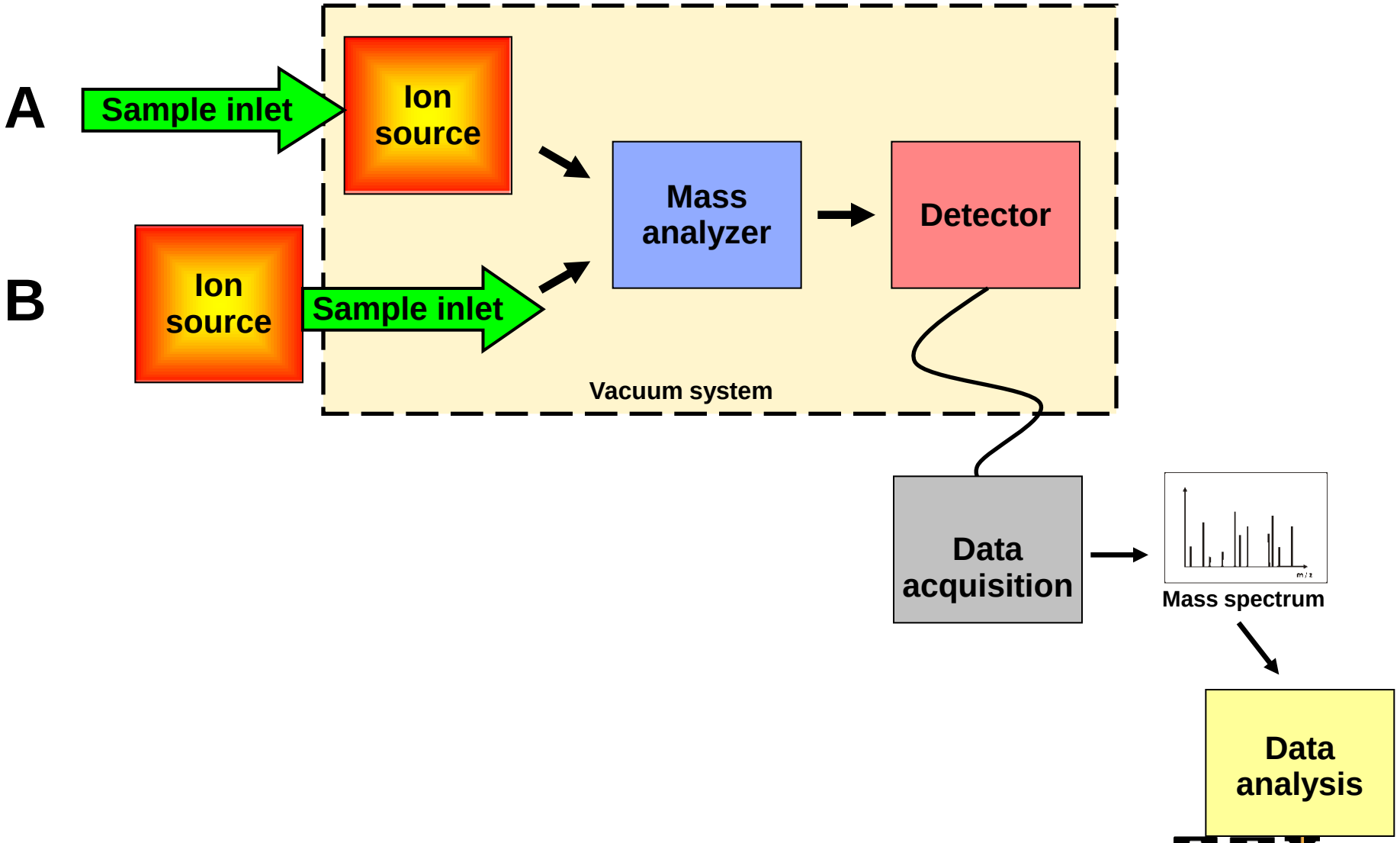
- Ready to use
- High throughput

- Large mass range
- Customized inlet /ionization system
- Stationary system

High-performance prototype for mobile in-situ analyses

- m/Δm > 100,000
- δm/m < 1 ppm
- Repetition rate ~ kHz
- Compatible with atmosph.press. ion sources
- Mobile, rugged setup

Scheme of mass spectrometers

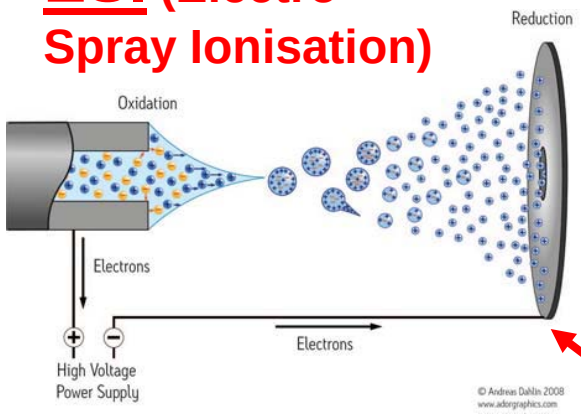


Ionization approaches for imaging

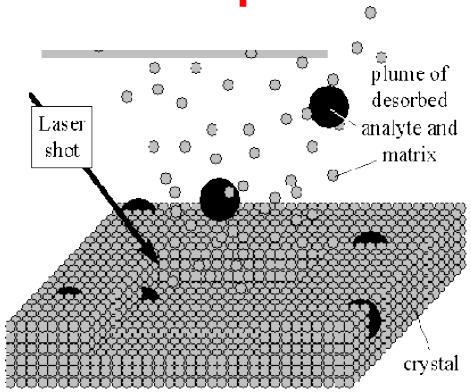
Sample collection
Material enrichment
Sample preparation

Production of charged particles/fragments, which are characteristic for the sample under analysis

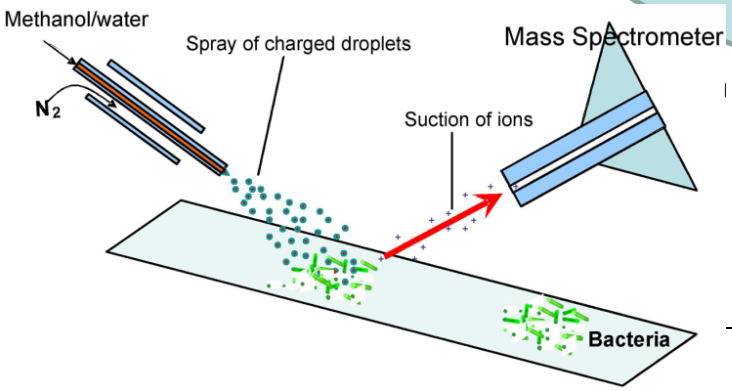
ESI (Electro-Spray Ionisation)



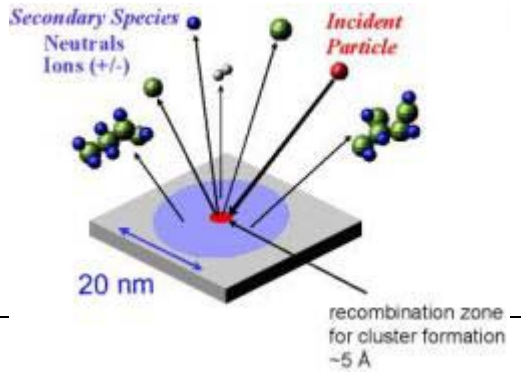
MALDI (Matrix-Assist. Laser Desorpt. Ionisat.)



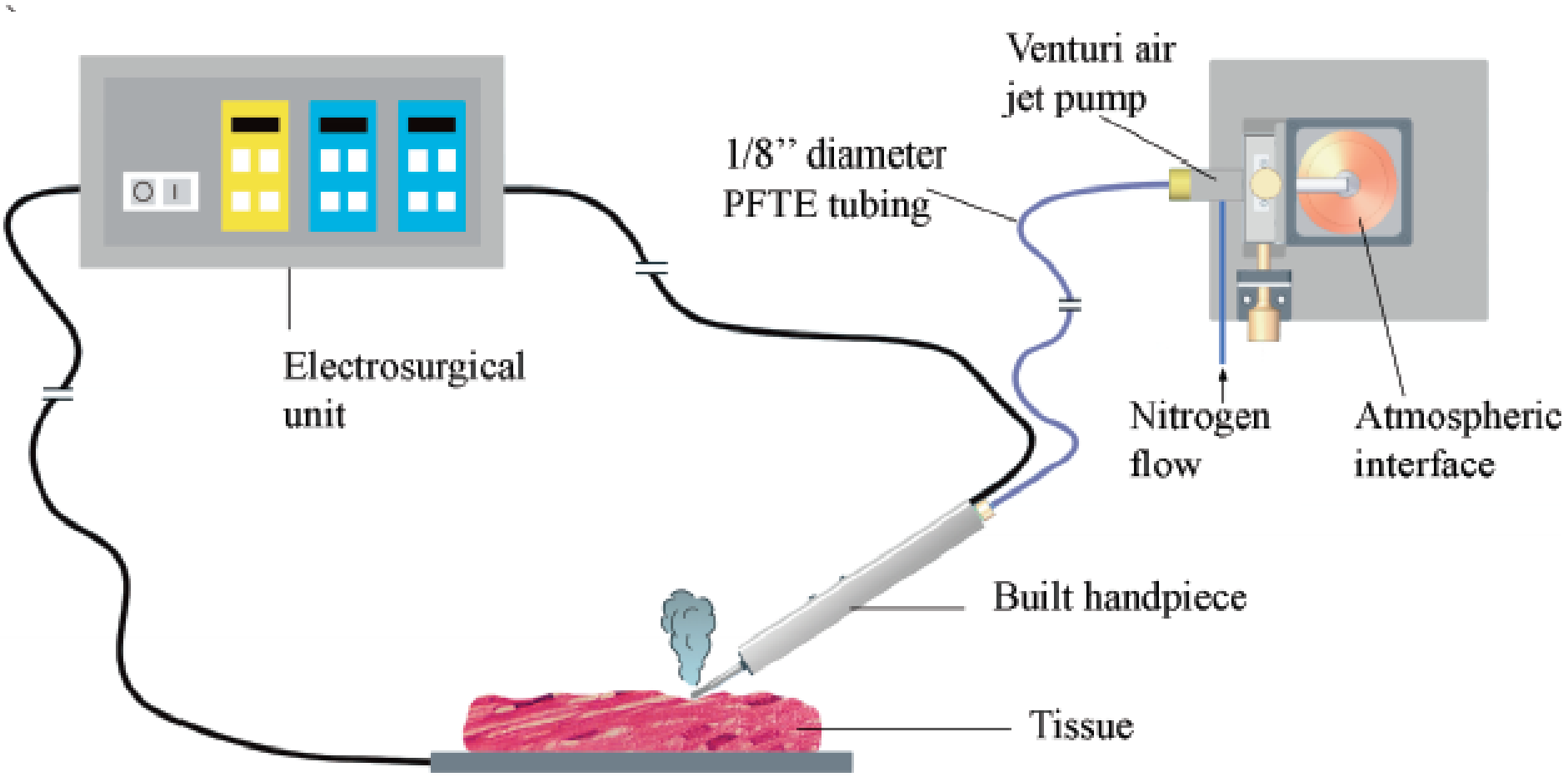
DESI (Desorption Electro-Spray Ionisation)



SIMS (Secondary Ion Mass Spectrom.)



Rapid Evaporation Ionisation Mass Spectrometry (REIMS)



Z. Takats, et al., Anal. Chem. 2010, 82, 7343-7350

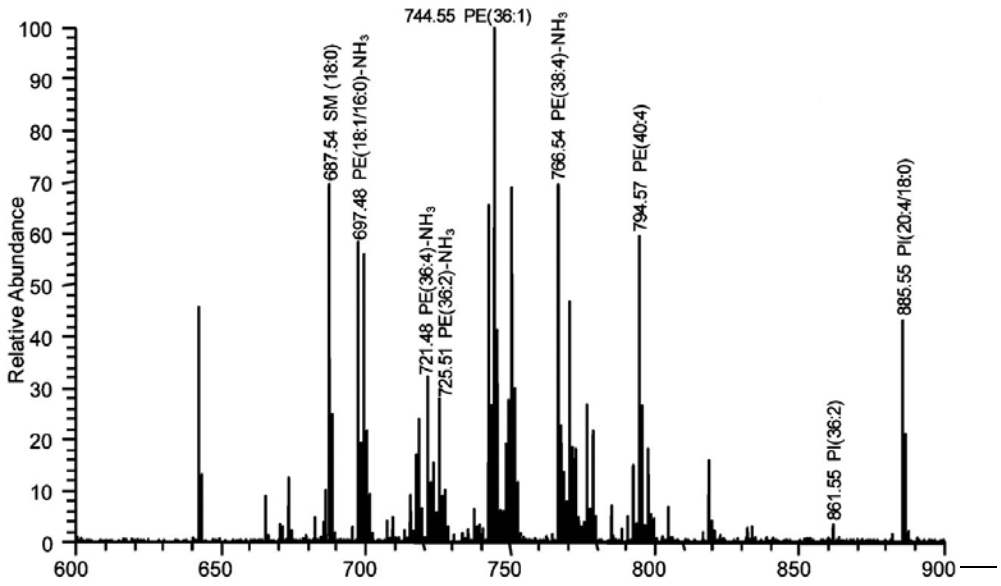
Application to real-time tissue recognition

Problem:

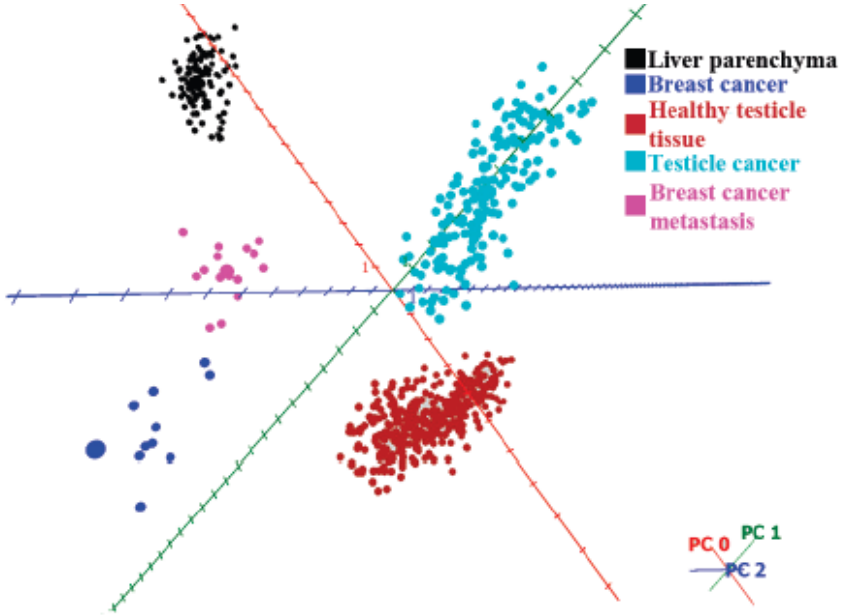
- **Histological examination of tissue is slow (hours)**
- **intraoperative, faster (~30 min.) techniques are less reliable**

Solution: REIMS

Identification of healthy and cancerous tissue in less than a second by principale component analysis (PCA) of the mass spectra



PCA (Principal Component Analysis, 60 dimensions)



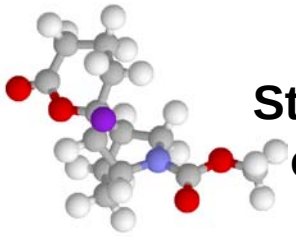
Other possible in-situ applications

Real-time tissue recognition

Identification of mycotoxins

Water monitoring at ‘hot spots’

LC/MS in soil science



Structure and composition of complex biomolecules

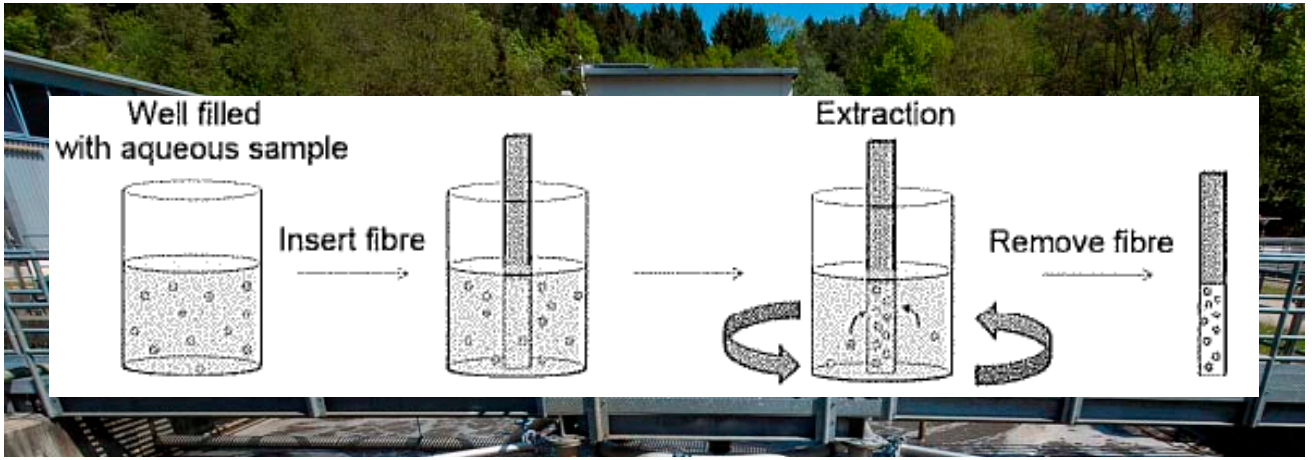
Climate impact research

- Modern mass spectrometry has many applications in life sciences, environmental research, safety and medicine
- Widely used are methods and components, which were developped for nuclear physics experiments
- Medical imaging is one particular application, which provides unique and complementary perspectives

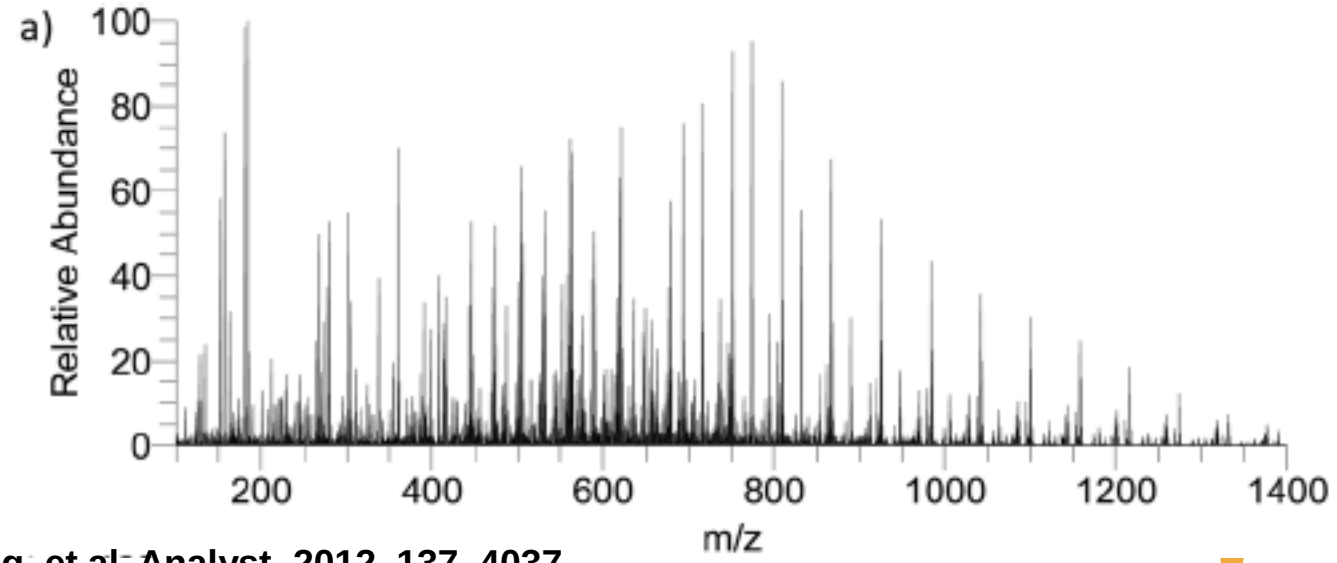
Application to wastewater monitoring at filter plants

Two-step process:

1. Enrichment of analyte by thin-film microextraction



2. Sample analysis by high resolution DESI-MS



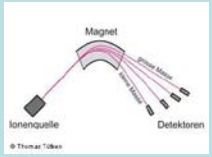
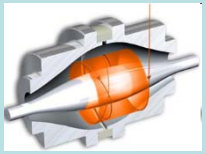
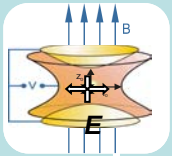
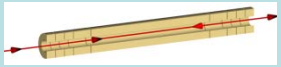
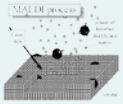
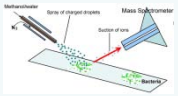
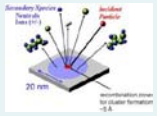
R. Düring, et al, Analyst, 2012, 137, 4037

Combinations for medical imaging

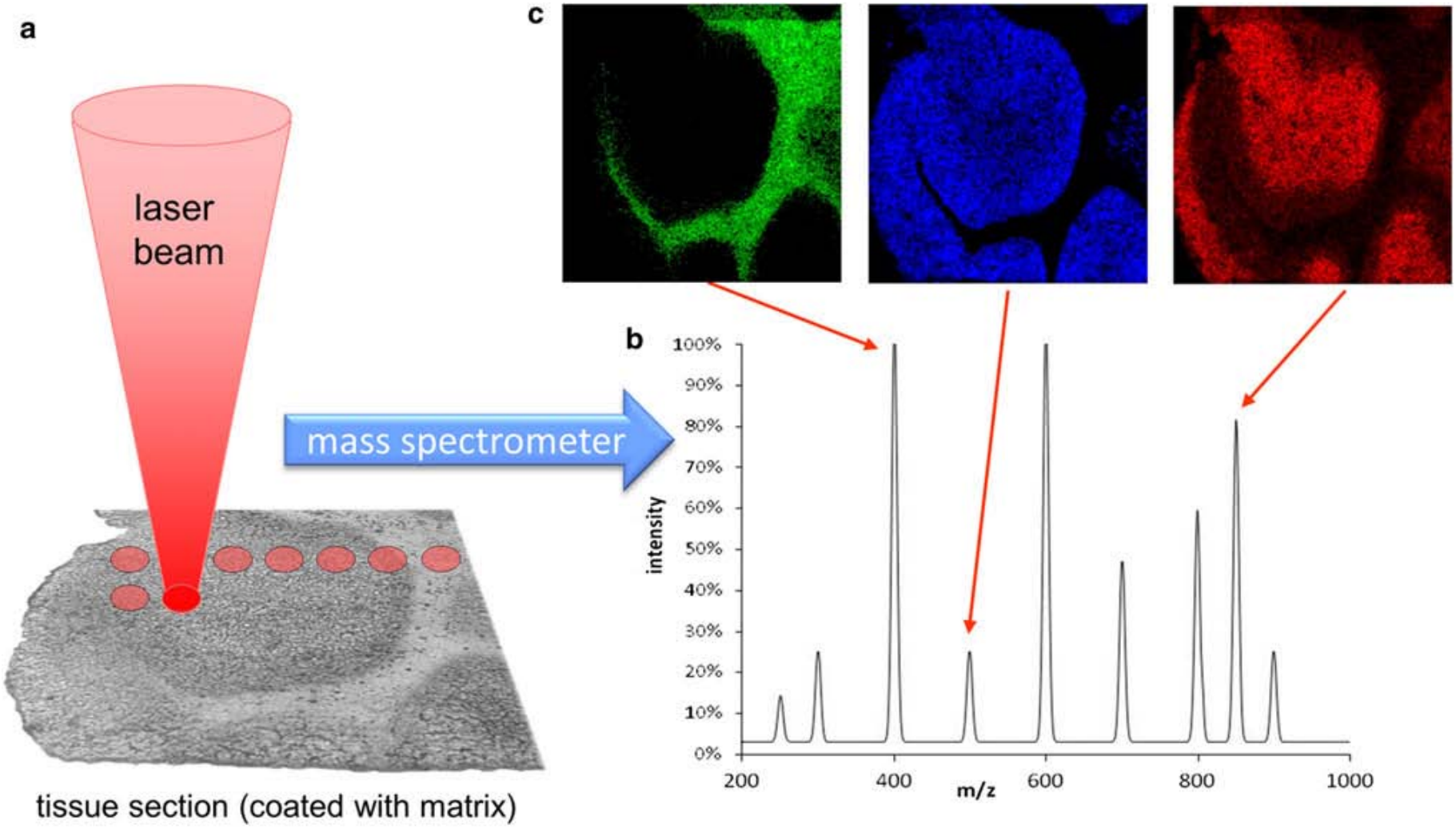
Each mass analyzer has strengths/weaknesses

In principle all combinations (ionization technique, analyzer) are possible

In practice, typical „pairings“ are quite useful:

	Magnetic sector	Orbitrap	Penning trap	Time-of-flight
				
MALDI		X	X	X	**X**
DESI		X	**X**	X	X
SIMS		**X**	X	X	**X**

Spatially resolved mass spectrometry of tissue



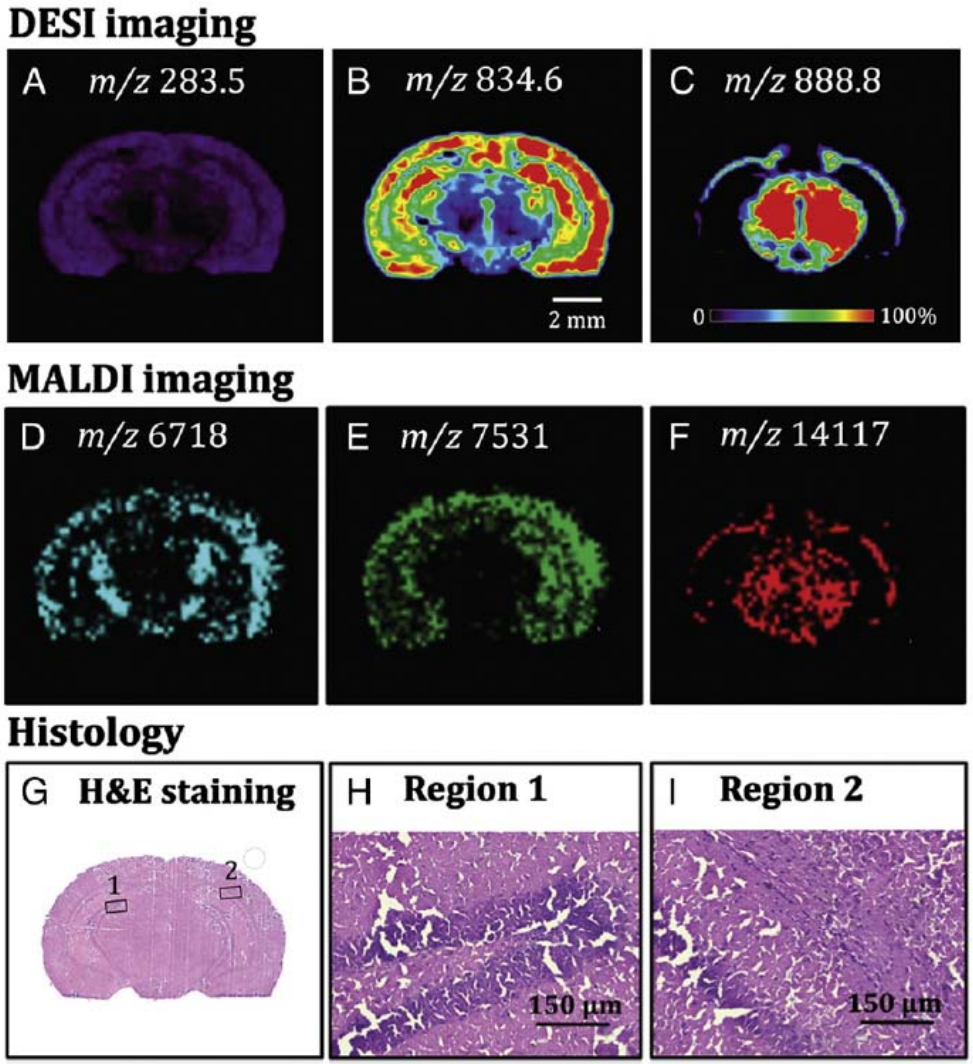
Multi-modal imaging of mouse brain

Mass peaks of ...

...different lipid species

...proteins

Conventional H&E stains



Complementary methods:

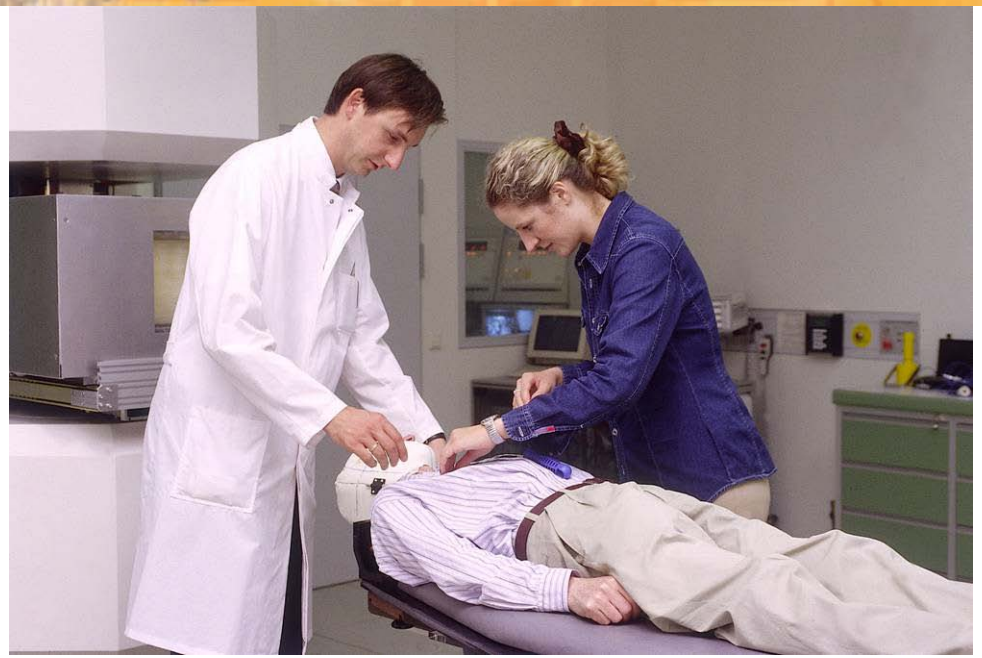
each method provides a unique perspective

L.S. Eberlin, et al., Anal. Chem. 2011, 83, 8366-8371

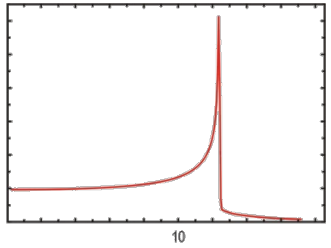
Irradiation:

Tumor treatment

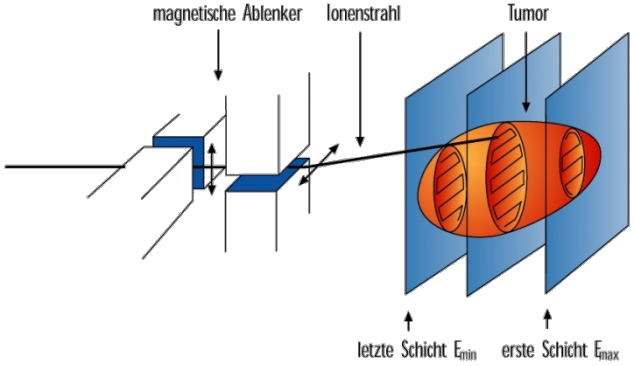
Tumor therapy with heavy ions



Bragg peak, rel. biol. efficiency



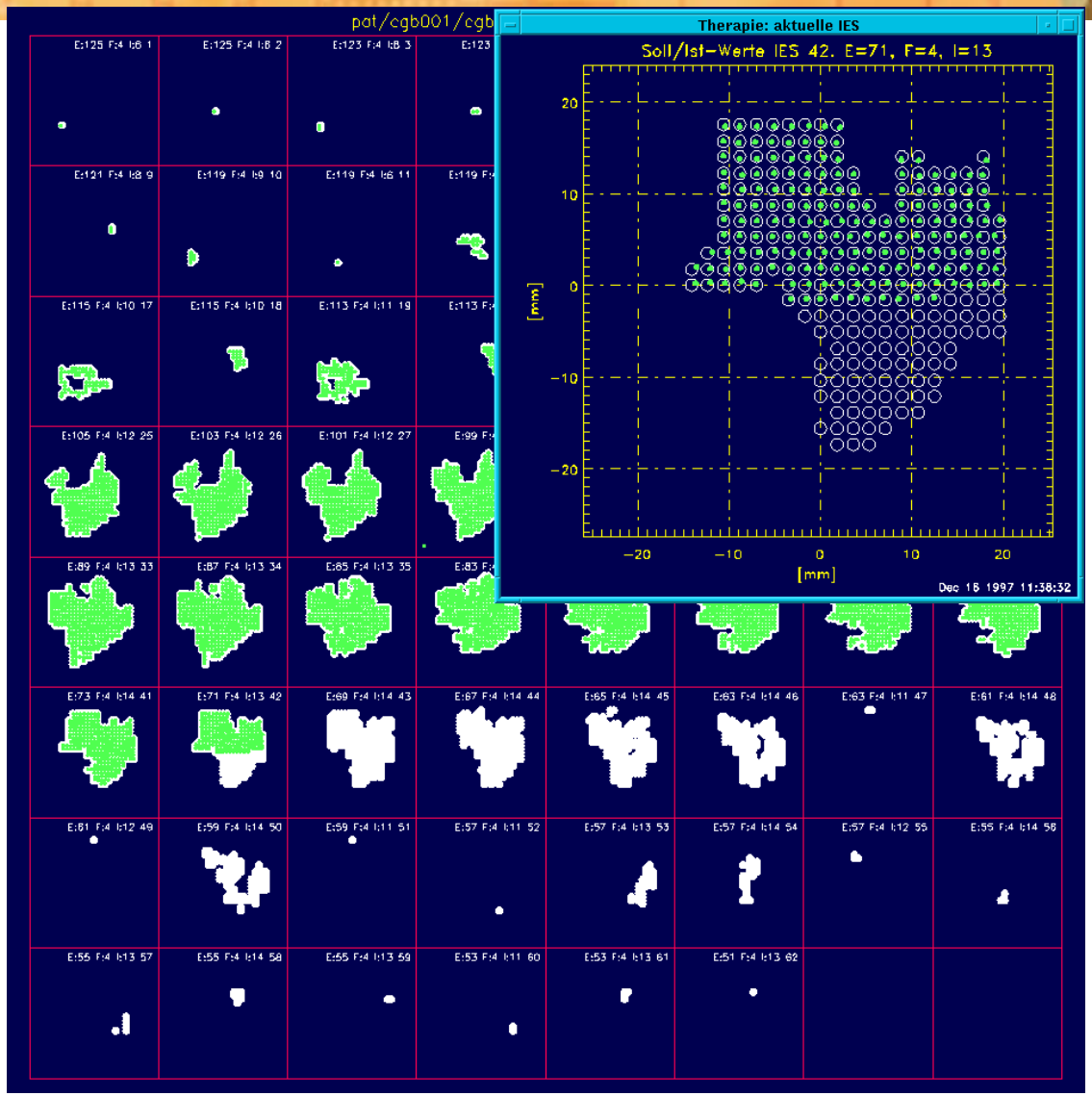
Raster scan for tumor conform irradiation



PET camera for profile and dosimetry

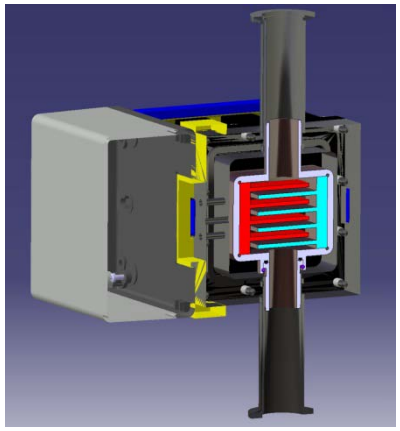
- Developed at GSI for >20 years
- >300 patients treated at GSI
- Clinical realization:
  Heidelberger Ion beam Therapy center
- Future direction: “moving targets”

Energy variation from pulse to pulse: necessary for tumor-conform treatment



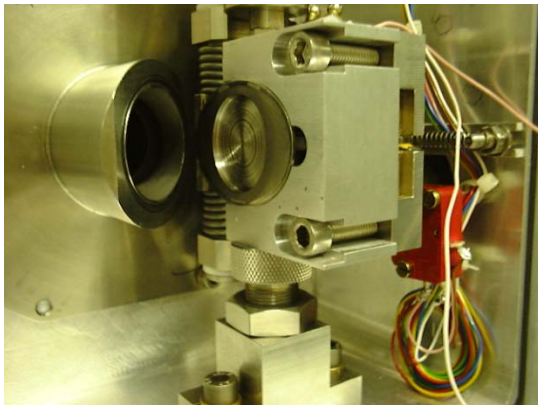
R&D for and construction of FAIR

Further applications and innovations...many more to come...



Peltier adsorption trap

High-energy neutron dosimeter for environmental research



Vacuum valve based on a pressure sensor

Remote handling, maintenance, repair in high-radiation areas

Further developments for vacuum and cryo-components…

- NEG coating (method, “dynamic” vacuum)
- Measurement technology for (ultra-)high vacuum
- Super-conducting cable, junctions
- .....

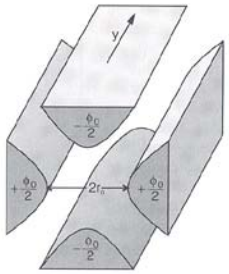
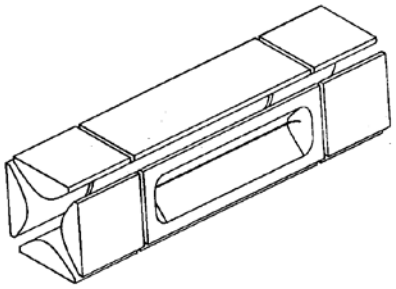
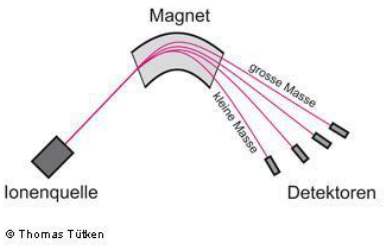
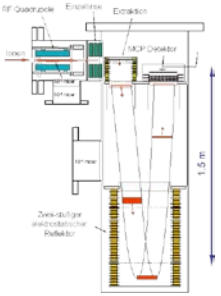
→ we expect many more innovations in the FAIR context (accelerators, detectors, materials, applications....)

Windows in the protestant church of Wixhausen

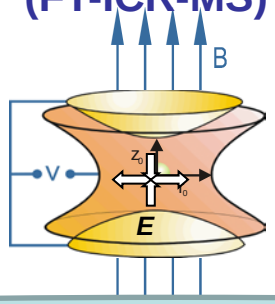
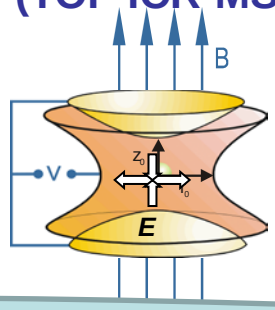
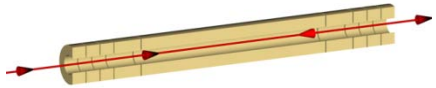
Thank you for your attention!

Reserve

Mass analyzers: low / medium resolving power

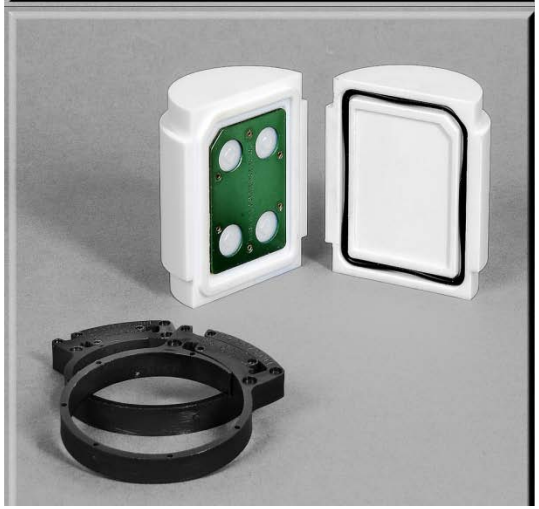
	RFQ mass filter	RF trap MS	Sector field MS	Single-pass Time-of-flight MS
				
Cycle time	~ s	~ 100 ms	~ 1 s	100 µs
Mass range	medium	medium	medium	broad
Scanning	yes	no	yes	no
Dynamic range	10^6	10^4	10^6	10^3...10^4
Resol. power m/Δm	10^3	10^3...10^4	10^4...10^5	10^3...10^4
Accuracy δm/m	~ 10 ppm	~ 10...100 ppm	~ 10 ppm	~ 10 ppm
Nuclear physics	no	no	(yes)	no
Analytical MS	yes	yes	yes	yes

Mass analyzers: high resolving power

	Orbitrap	Penning trap (FT-ICR-MS)	Penning trap (TOF-ICR-MS)	Multiple-reflection time-of-flight MS
				
Cycle time	~ 1 s	~ 1 s	~ 1 s	~ 10 ms
Mass range	broad	broad	very narrow	medium
Scanning	no	no	yes	no
Dynamic range	10^4…10^5	10^3...10^4	10	10^4
Resol. power m/Δm	10^5	10^5 ...10^6	10^6...10^7	10^5 ...10^6
Accuracy δm/m	~ ppm	~ ppm	~ 0.1…0.001 ppm	1...0.1 ppm
Nuclear physics	no	no	yes	yes
Analytical MS	yes	yes	no	yes

Overview on interesting applications and innovations

PE56Cu environmental dosimeter



Concept

The solution worked out at the GSI (Helmholtz Centre for Heavy Ion Research Darmstadt) is based on standard Harshaw-type TLD detector cards inset in a scattering body made from polyethylene. In two of the four crystals, copper is set as an additional filter. The combination of the measured dose of the two detector pairs leads to a response function, which bear a very close resemblance to the H*(10) measured value. This is achieved by two Cu-filters and allows its use in a very broad energy (10keV to 10MeV) and angular range. This behavior represents a significant improvement compared to commercially available solutions. Standard solutions follow the size of H*(10) only in a much smaller energy range from 100keV to 1MeV. In addition, by a special design, the dosimeter can be used under almost all weather and environmental conditions.

Transfer to the company **RadPro** International GmbH


Foto: A. Zschau / GSI
2658_16