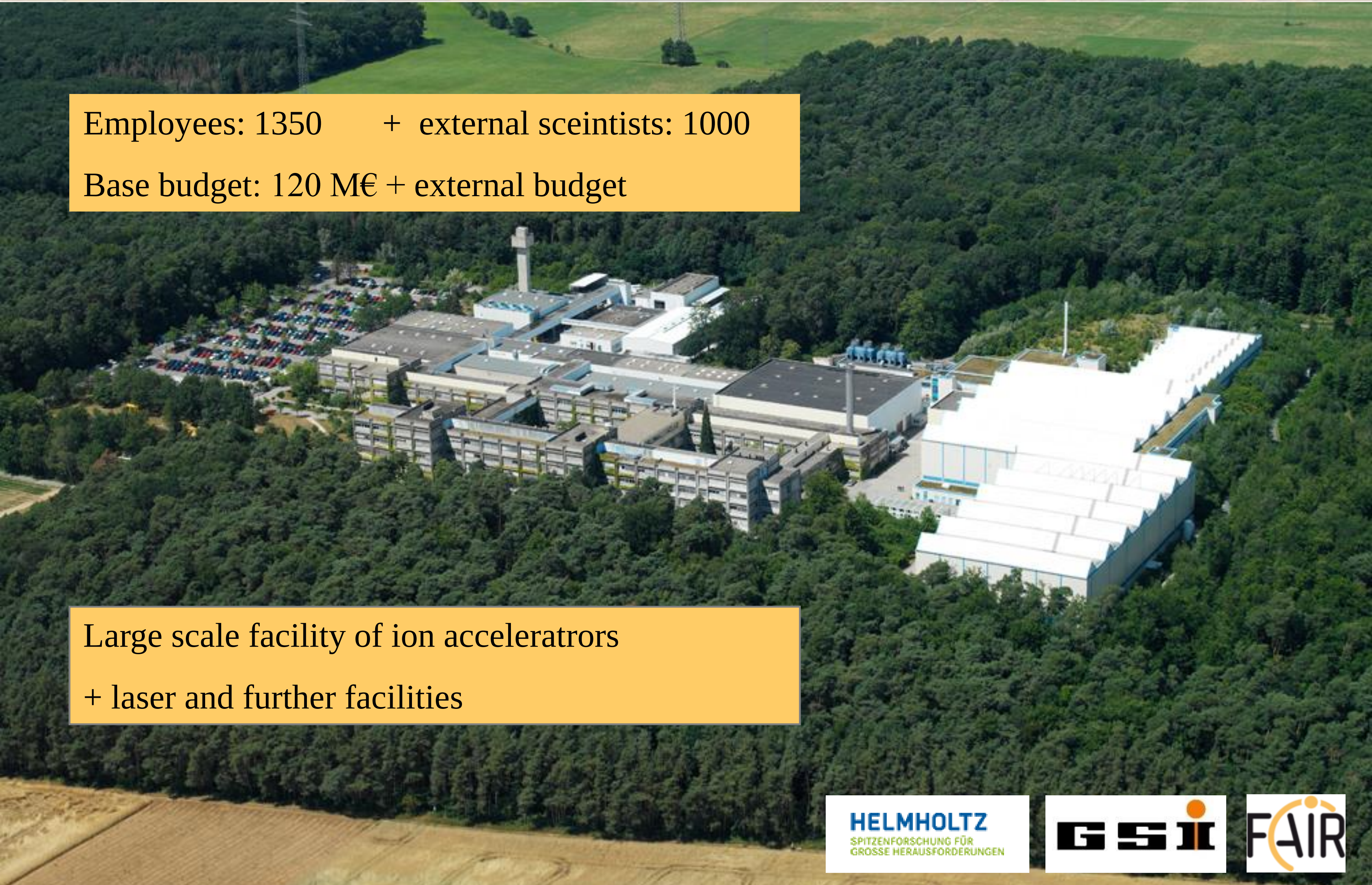
Gesellschaft für Schwerionenforschung
Helmholtz-Center for Ion Research



Employees: 1350 + external sceintists: 1000

Base budget: 120 M€ + external budget

Large scale facility of ion acceleratrors

+ laser and further facilities

GSI Heavy Ion Research Center

German national heavy ion accelerator facility in Darmstadt

Accelerators:

Acceleration of all ions

LINAC: up to 15 MeV/u

Synchrotron: up to 2 GeV/u

Research area:

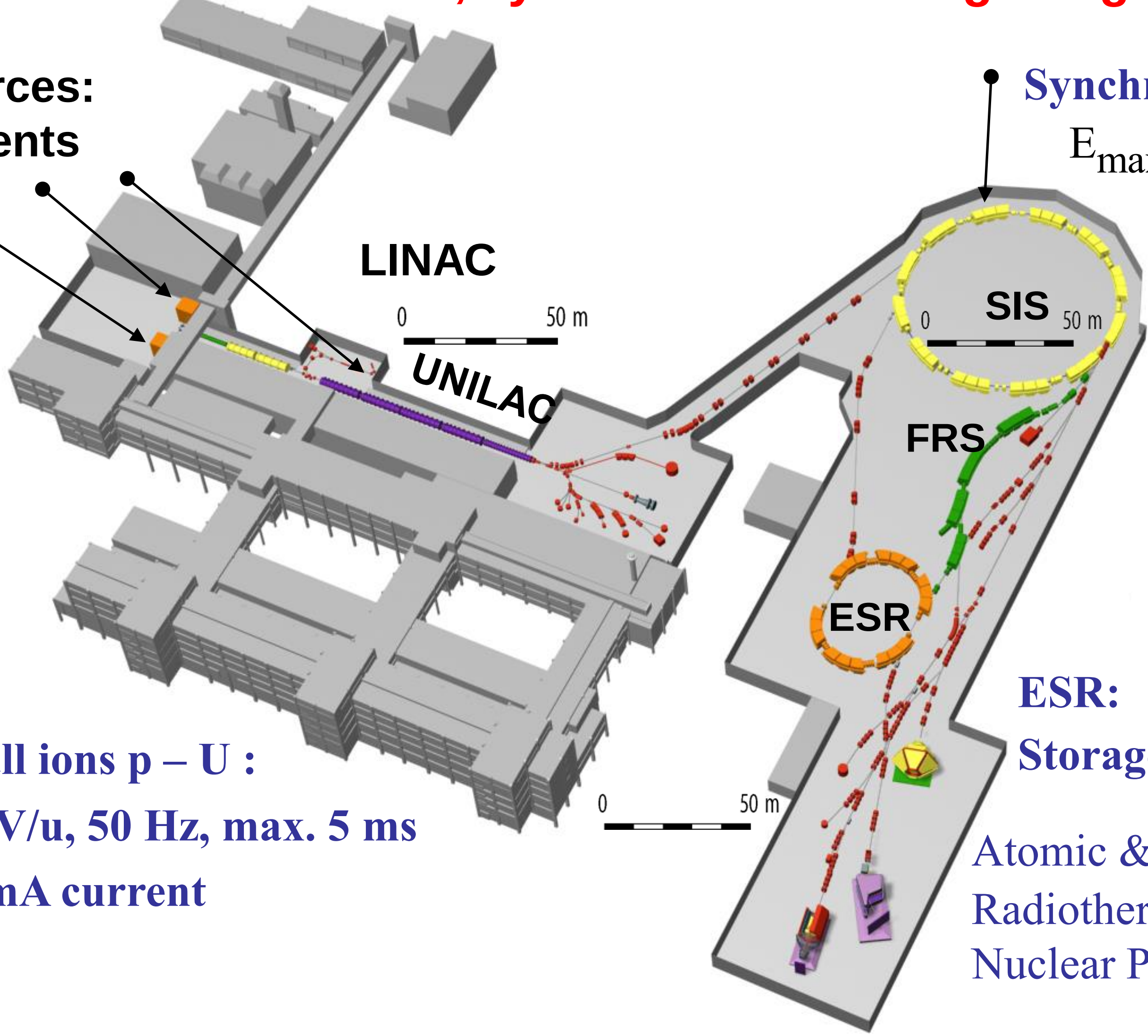
- Nuclear physics ≈ 60 %
- Atomic physics ≈ 20 %
- Bio physics (e.g. cell damage) incl. cancer therapy ≈ 5 %
- Material research ≈ 10 %

Extension by international FAIR facility

GSI is one of 18 German large scale research centers.

The GSI linear accelerator, synchrotron & storage ring for heavy ions

Ion Sources:
all elements



Synchrotron, Bρ=18 Tm

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

Achieved e.g.:

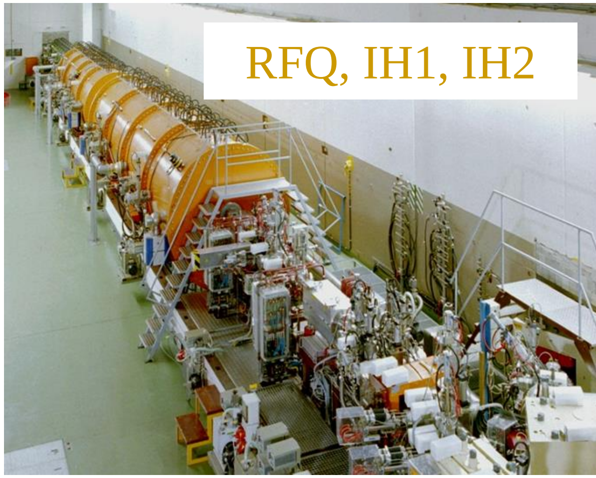
Ar^{18+}: $1 \cdot 10^{11}$
U^{28+}: $3 \cdot 10^{10}$
U^{73+}: $1 \cdot 10^{10}$

ESR:
Storage Ring, Bρ=10 Tm

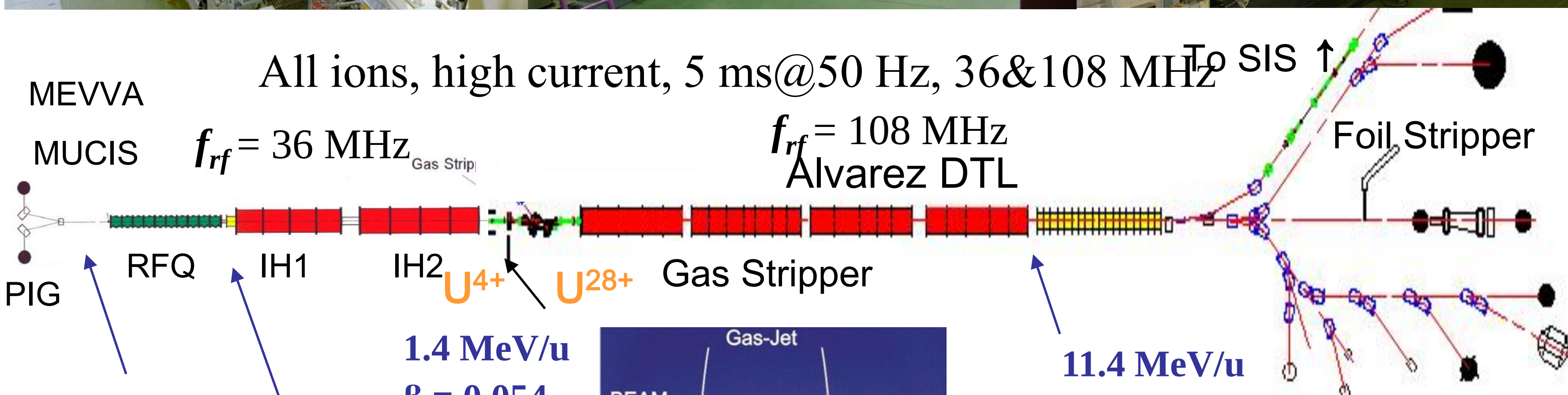
Atomic & Plasma Physics
Radiotherapy
Nuclear Physics

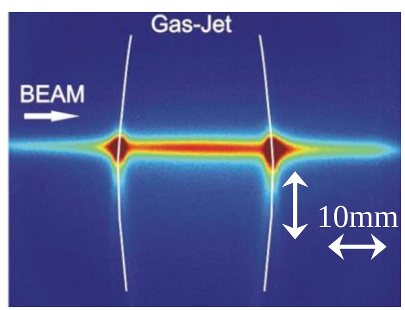
LINAC: all ions p – U :
3 – 12 MeV/u, 50 Hz, max. 5 ms
Up to 20 mA current

Excurse: UNILAC at GSI: Overview



All ions, high current, 5 ms@50 Hz, 36&108 MHz





Constructed in the 70th, Upgrade 1999,

→ **Injector for FAIR ion operation**

Das Periodensystem der Elemente

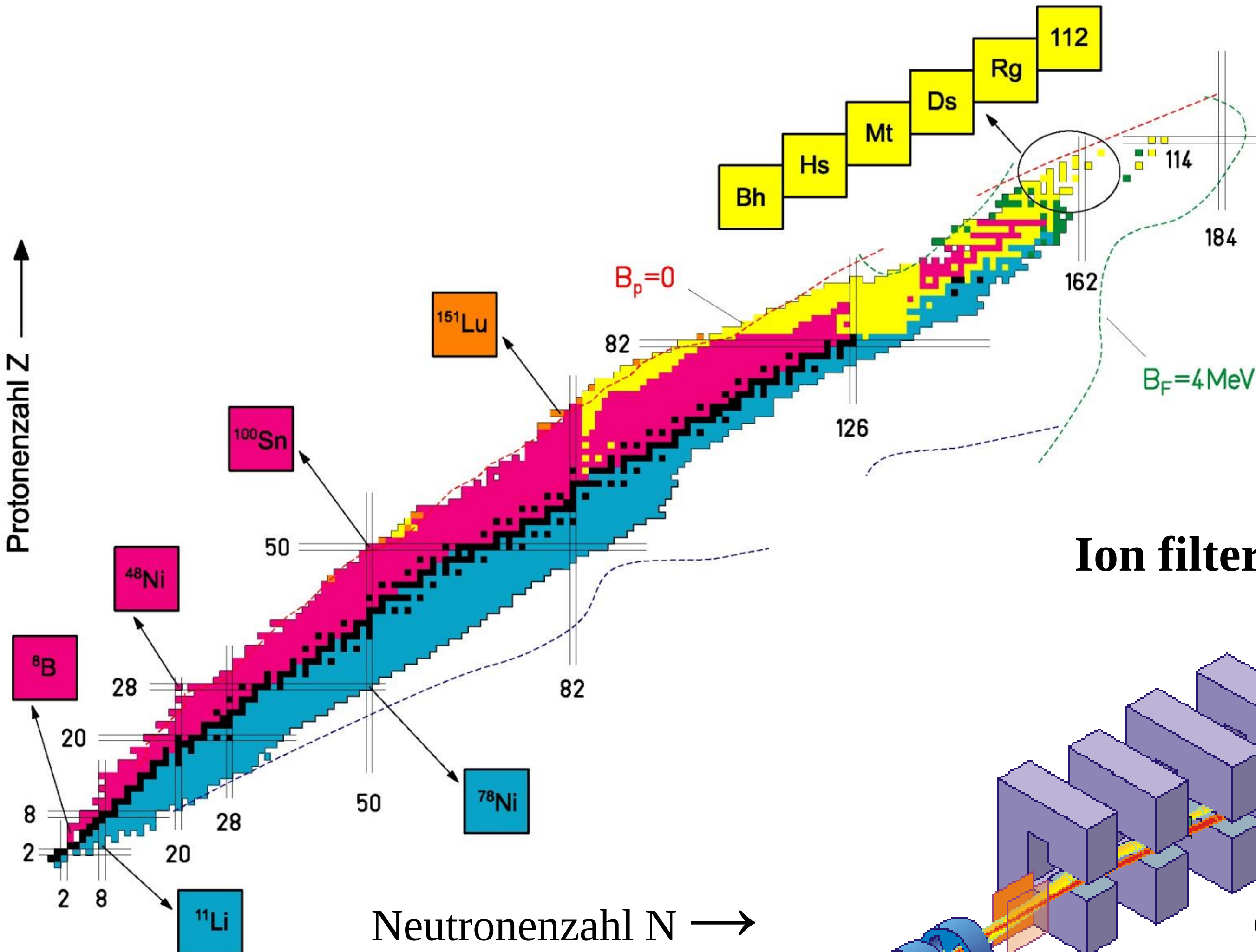
natural stable | natural, unstable | artificial, unstable | at GSI produced for first time, unstabil | at GSI confirmed, unstable

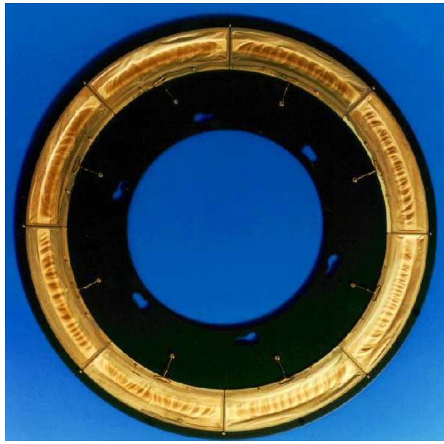
I	II												III	IV	V	VI	VII	VIII
H 1																		He 2
Li 3	Be 4												B 5	C 6	N 7	O 8	F 9	Ne 10
Na 11	Mg 12												Al 13	Si 14	P 15	S 16	Cl 17	Ar 18
K 19	Ca 20	Sc 21		Ti 22	V 23	Cr 24	Mn 25	Fe 26	Co 27	Ni 28	Cu 29	Zn 30	Ga 31	Ge 32	As 33	Se 34	Br 35	Kr 36
Rb 37	Sr 38	Y 39		Zr 40	Nb 41	Mo 42	Tc 43	Ru 44	Rh 45	Pd 46	Ag 47	Cd 48	In 49	Sn 50	Sb 51	Te 52	I 53	Xe 54
Cs 55	Ba 56	La 57	58-71	Hf 72	Ta 73	W 74	Re 75	Os 76	Ir 77	Pt 78	Au 79	Hg 80	Tl 81	Pb 82	Bi 83	Po 84	At 85	Rn 86
Fr 87	Ra 88	Ac 89	90-103	Rf 104	Db 105	Sg 106	Bh 107	Hs 108	Mt 109	Ds 110	Rg 111	Cn 112	Nh 113	Fl 114	Mc 115	Lv 116	Ts 117	Og 118

Ce 58	Pr 59	Nd 60	Pm 61	Sm 62	Eu 63	Gd 64	Tb 65	Dy 66	Ho 67	Er 68	Tm 69	Yb 70	Lu 71
Th 90	Pa 91	U 92	Np 93	Pu 94	Am 95	Cm 96	Bk 97	Cf 98	Es 99	Fm 100	Md 101	No 102	Lr 103

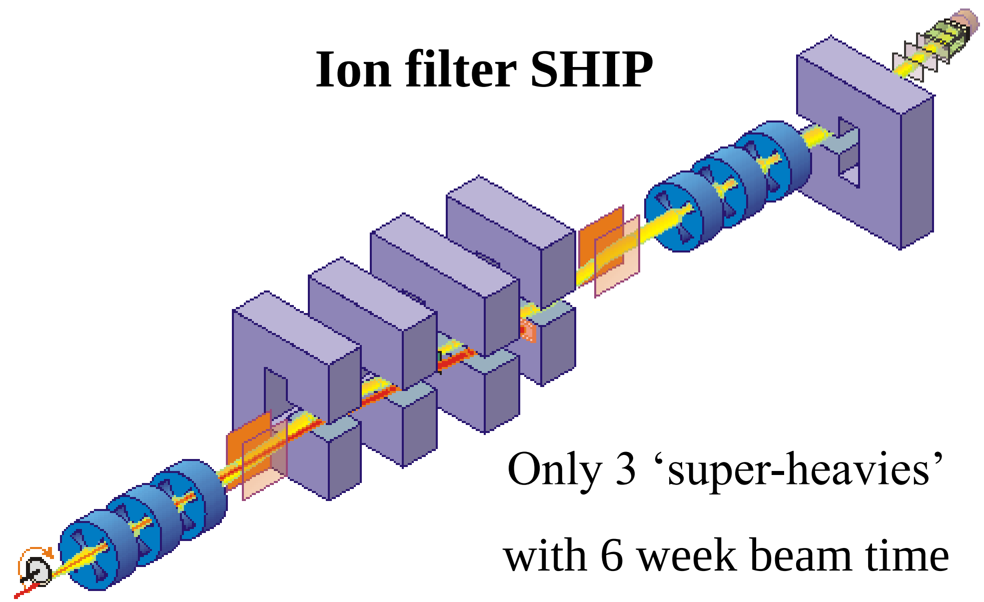
Bh 107 Bohrium | Hs 108 Hassium | Mt 109 Meitnerium | Ds 110 Darmstadtium | Rg 111 Roentgenium | Cn 112 Copernicium

Nuklidkarte: Superschwere Ionen





Ion filter SHIP

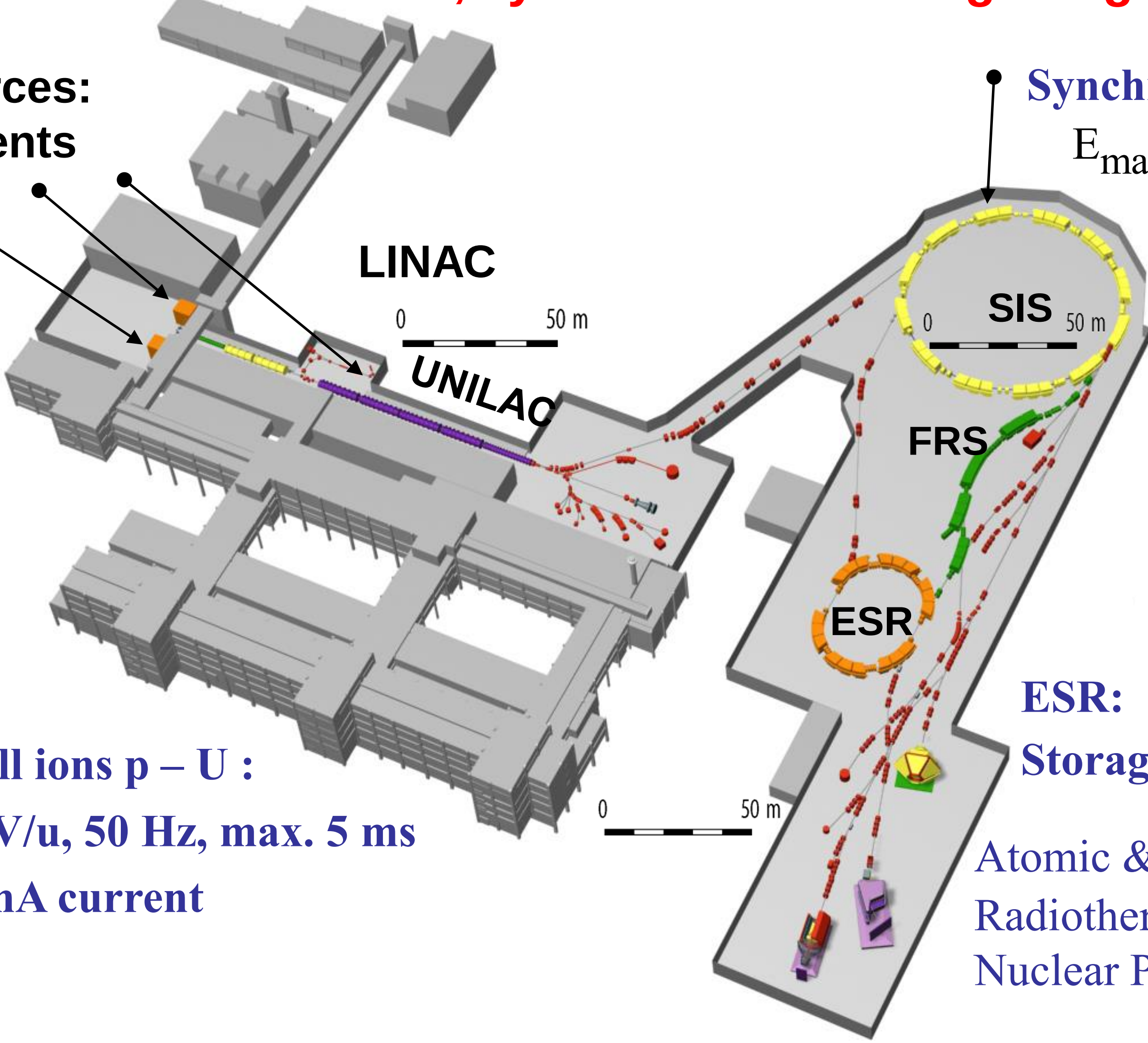


Only 3 'super-heavies'

with 6 week beam time

The GSI linear accelerator, synchrotron & storage ring for heavy ions

Ion Sources:
all elements



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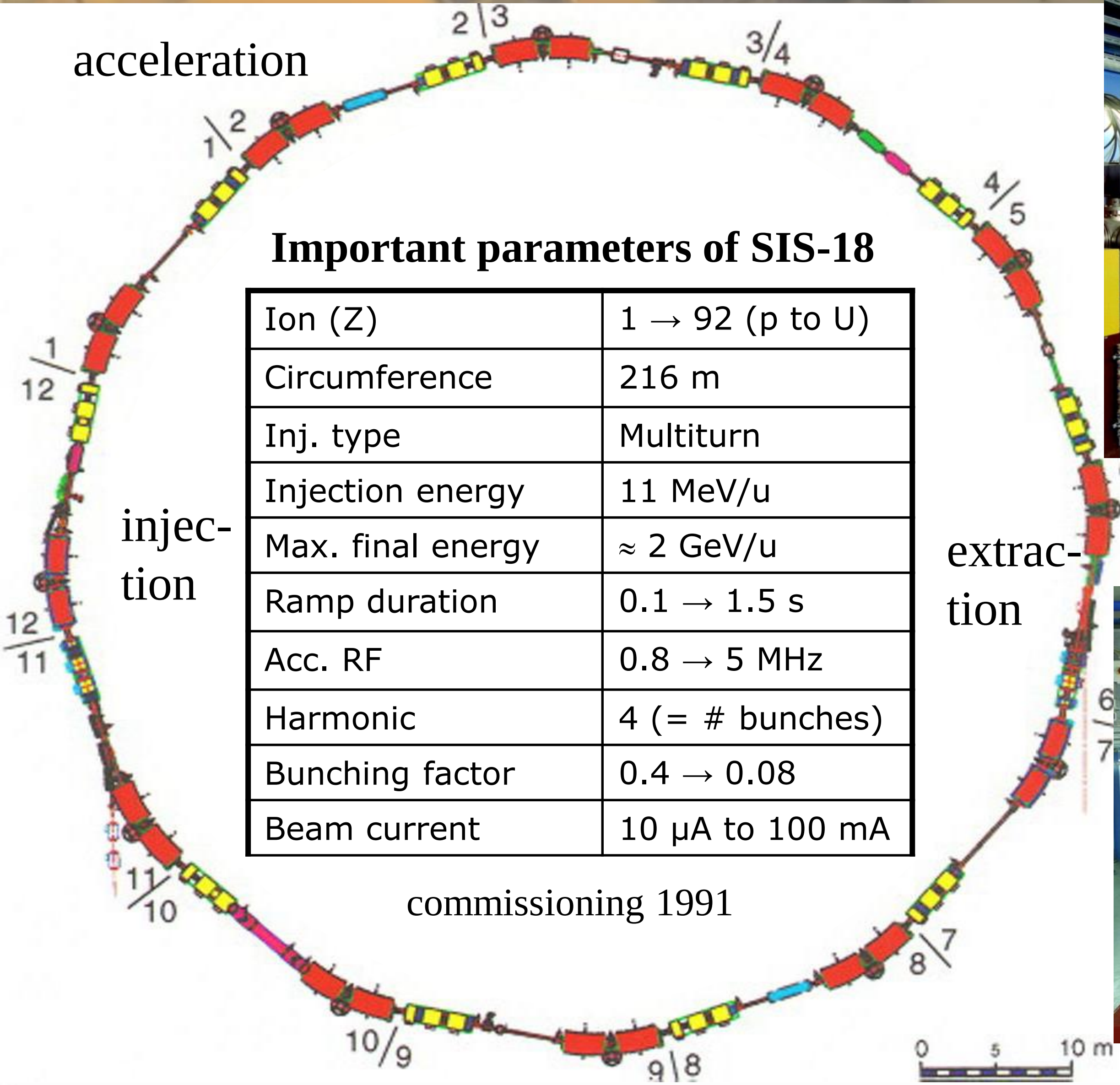


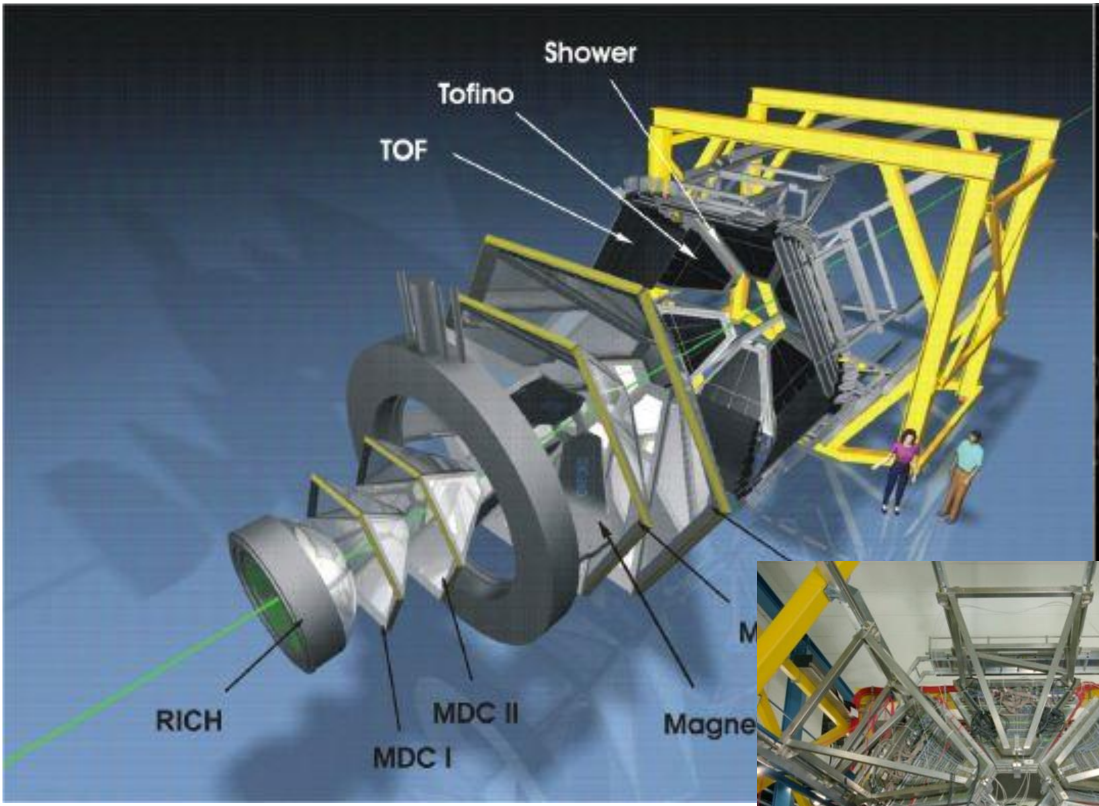
Important parameters of SIS-18

Ion (Z)	1 → 92 (p to U)
Circumference	216 m
Inj. type	Multiturn
Injection energy	11 MeV/u
Max. final energy	≈ 2 GeV/u
Ramp duration	0.1 → 1.5 s
Acc. RF	0.8 → 5 MHz
Harmonic	4 (= # bunches)
Bunching factor	0.4 → 0.08
Beam current	10 μA to 100 mA

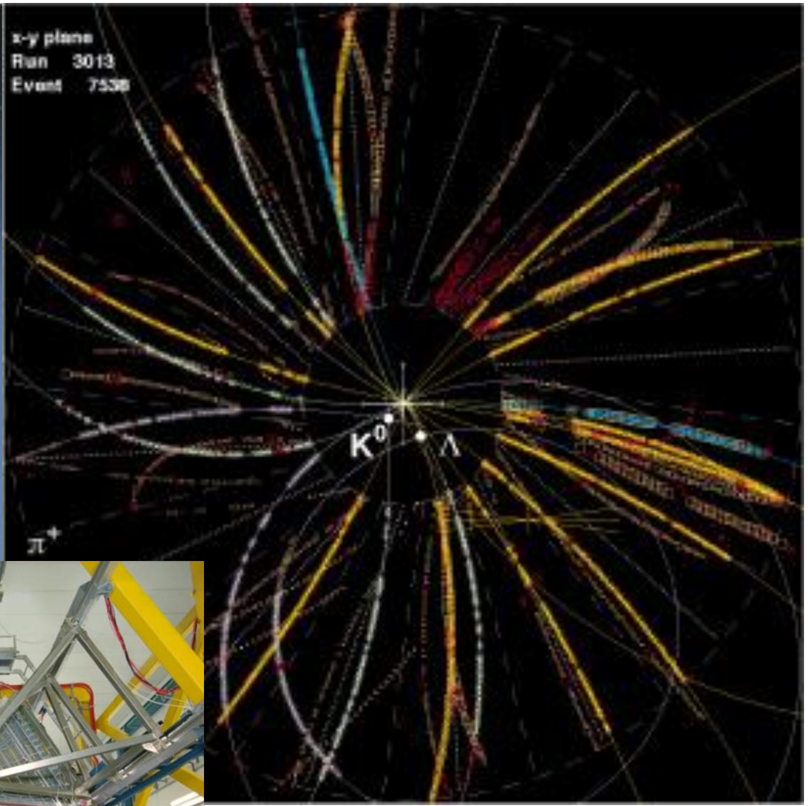
commissioning 1991

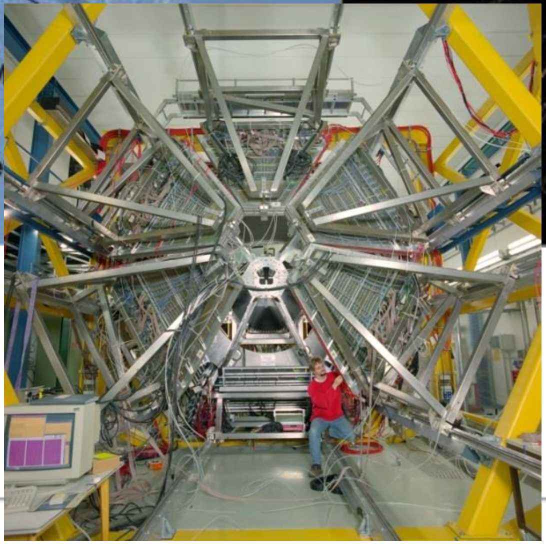
Detektors form barionic Matter

HADES Detector

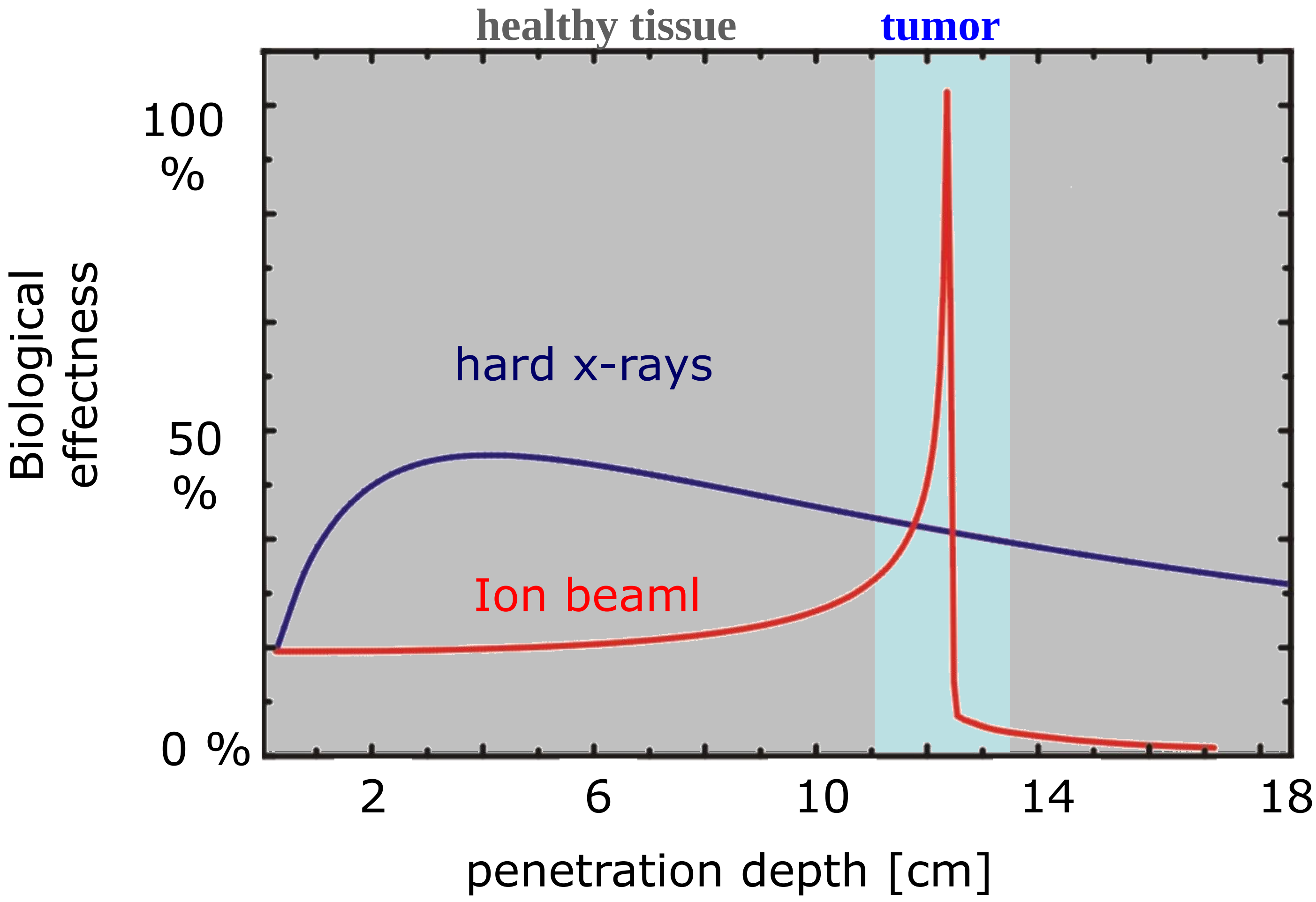


Reconstruktion of traces





Ion Treatment of Tumors



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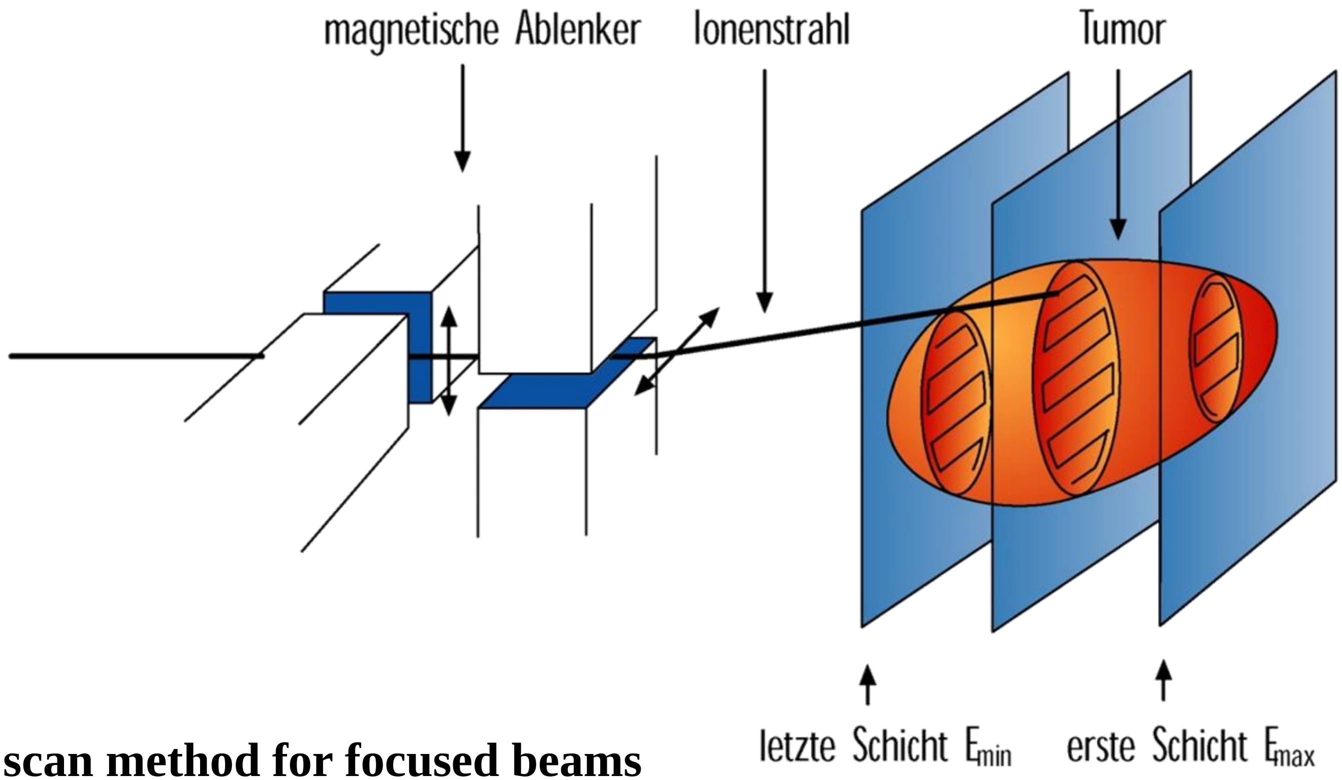


Raster scan method for focused beams

ca. 1975 - today: Investigation of biological damage of ion beams

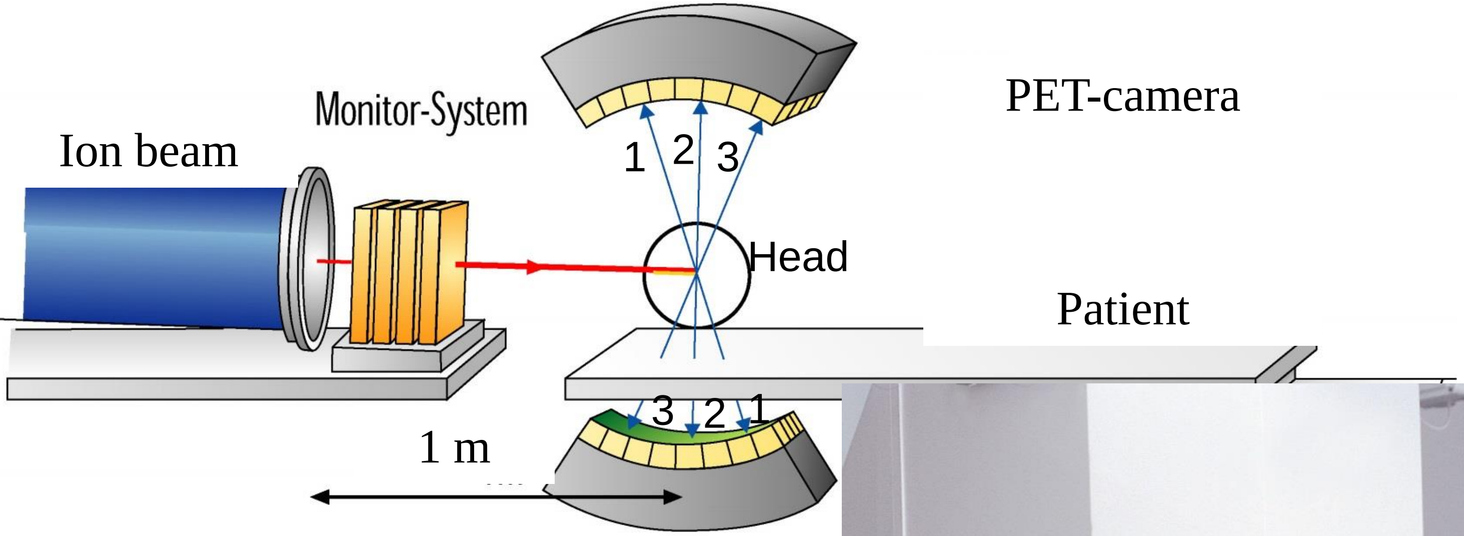
ca. 1990-97: technical realization for cancer therapy (first time in Europe)

1997-2007: treatment of 440 persons with brain tumors

ca. 2000-09: Construction of dedicated facility in Heidelberg (first ion center in Europe)

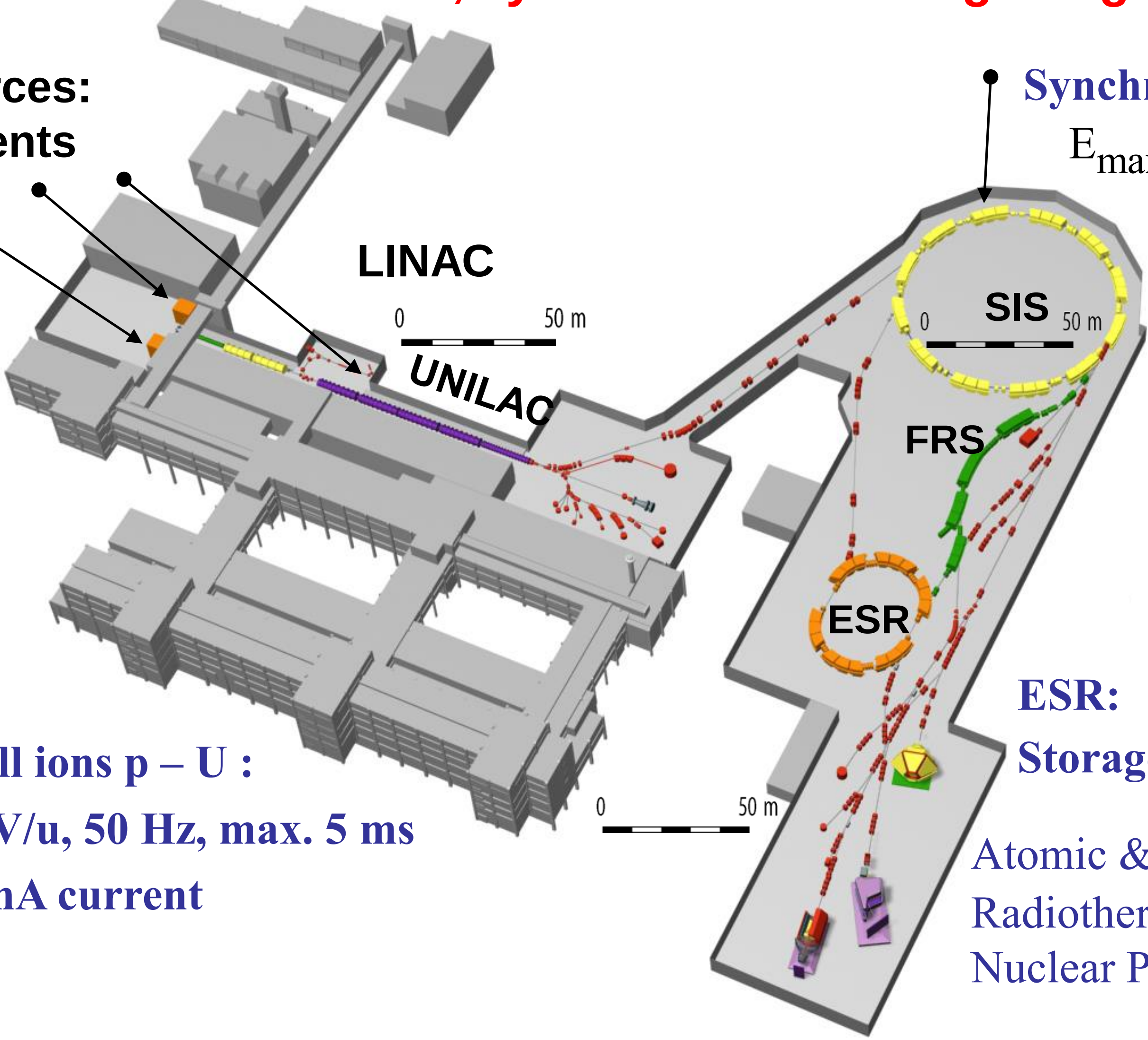
2009 - today: Treatment of about 800 patients per year

Accelerator Technology for Patient Treatment



The GSI linear accelerator, synchrotron & storage ring for heavy ions

Ion Sources: all elements



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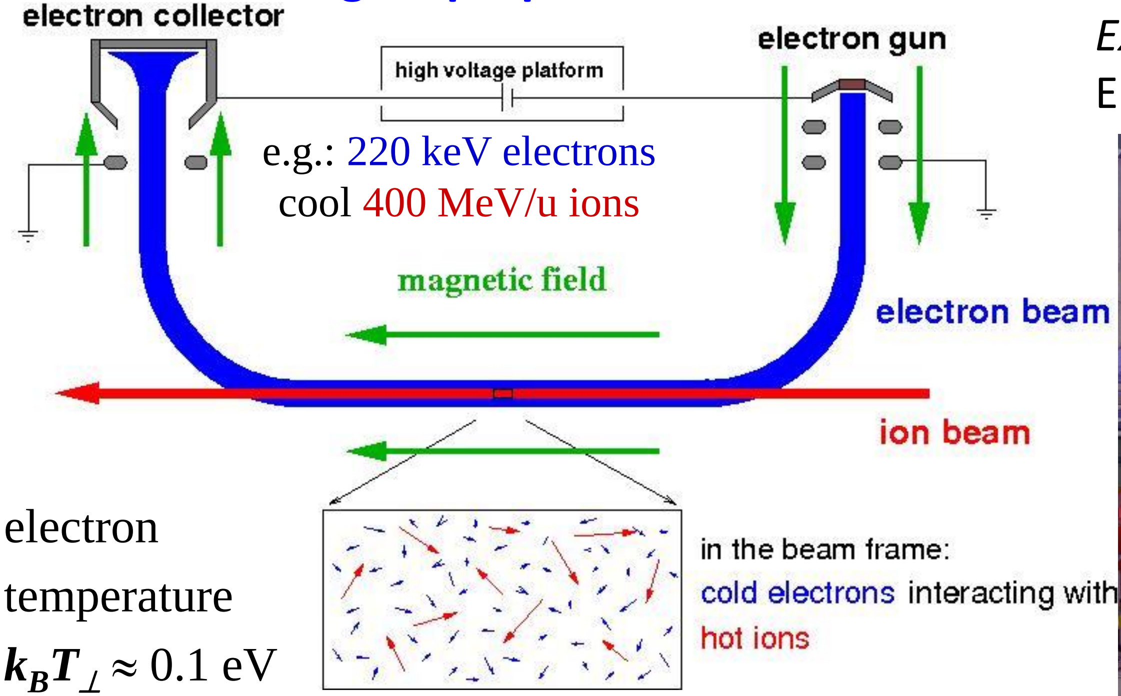
Electron Cooling at ESR: Improvement of Beam Quality

Electron cooling: Superposition ion and cold electron beams with the same velocity



electron temperature

$k_B T_\perp \approx 0.1$ eV

$k_B T_\parallel \approx 0.1 - 1$ meV

Example:

Electron cooler at GSI, U_{max} = 300 kV

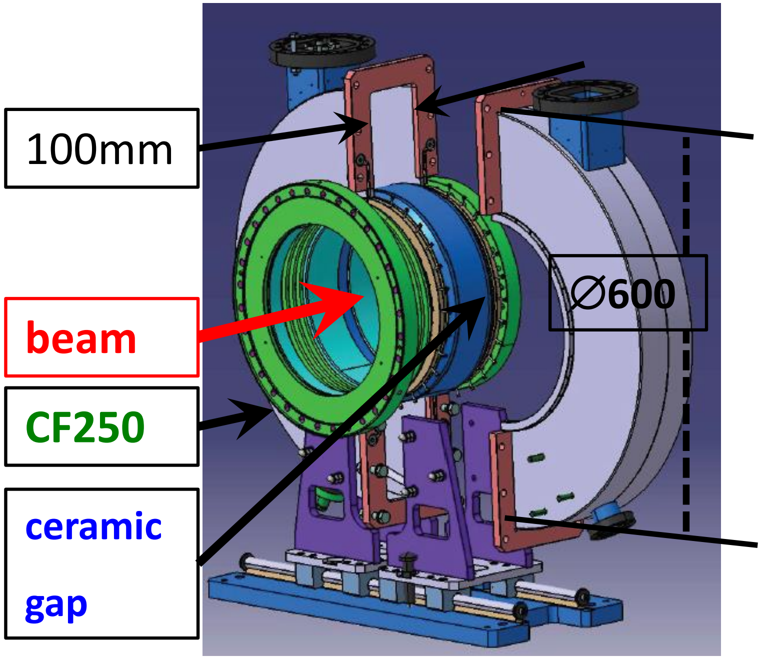
Physics:

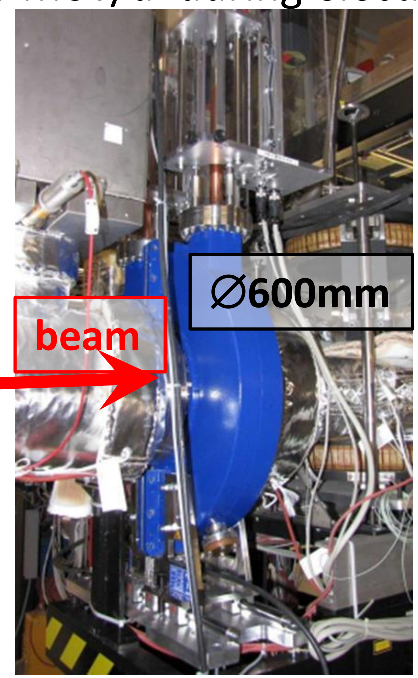
- Momentum transfer by Coulomb collisions
- Cooling force results from energy loss in the cold, co-moving electron beam

Cooling time: 0.1 s for low energy highly charged ions, 1000 s for high energy protons

Observation of *single* ions is possible:

Example: Storage of **six** $^{142}Pm^{59+}$ at 400 MeV/u during electron cooling

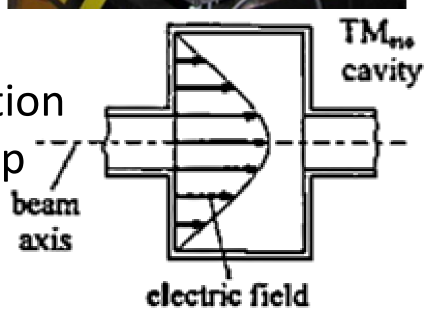




Outer $\varnothing_{out}$	600 mm
Beam pipe $\varnothing_{in}$	250 mm
Mode (monopole)	TM_{010}
Res. freq. f_{res} Variable by plunger	≈ 244 MHz ± 2 MHz
Quality factor Q_0	≈ 1200
Loaded Q_l	≈ 500
R/Q_0	≈ 30 Ω
Coupling	Inductive loop

Advantage:

- Sensitive down to single ion observation
- Part of cavity in air due to ceramic gap
- Can be sort-circuited to prevent for wake-field excitation



Example of Schottky Mass Spectroscopy for Nuclear Physics

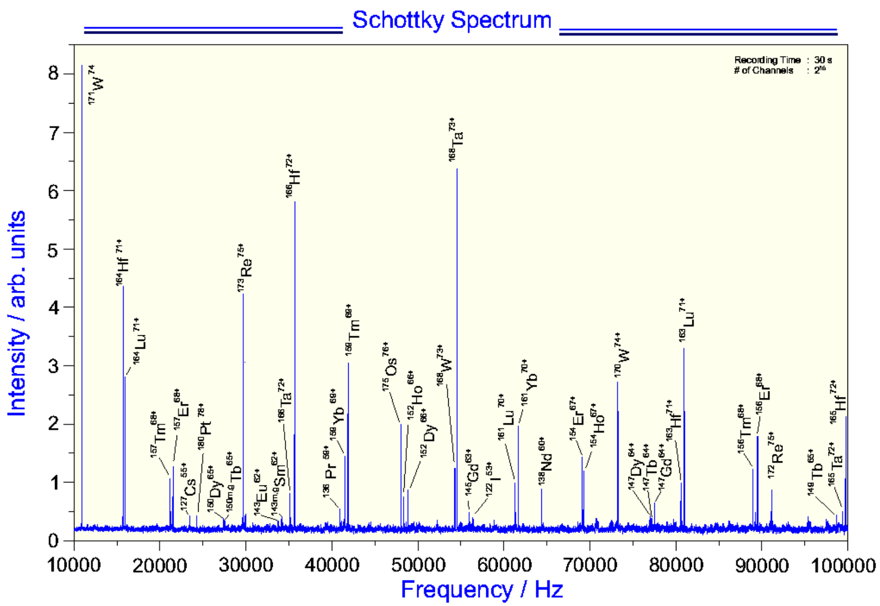
Typical experimental setup:

- High intensity beam of e.g. U^{73+} in synchrotron ≈ 1 GeV/u and send to a target
- Cocktail of rare isotopes filtered in 'Fragment Separator' injected into GSI ESR
- Stochastic pre-cooling , followed by electron cooling: $\Delta p/p_0 = 5 \cdot 10^{-7} \Leftrightarrow \Delta f/f_0 = 2 \cdot 10^{-7}$ typ.

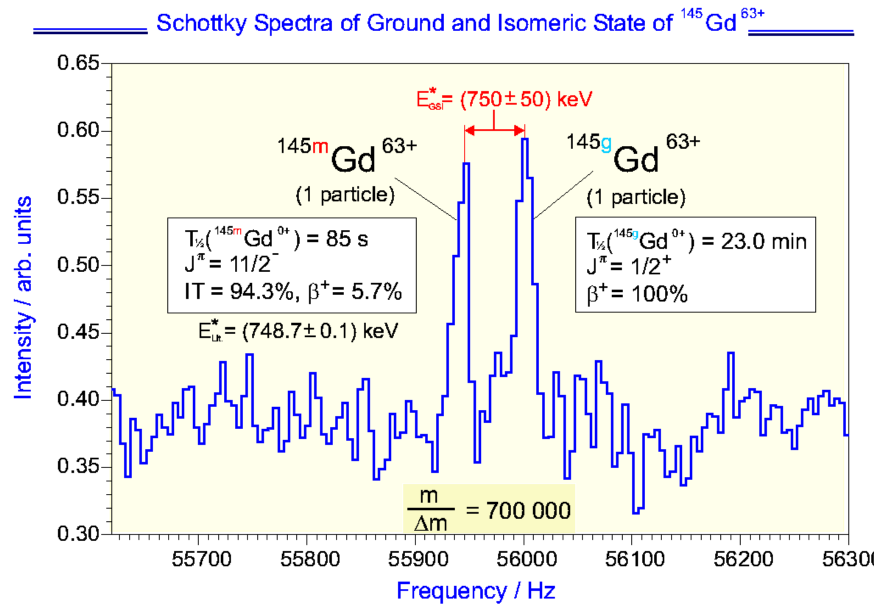
⇒ mass measurement of isotopes an excited states as a large experimental program

⇒ single isotope detection possible

Example: Broad band spectrum



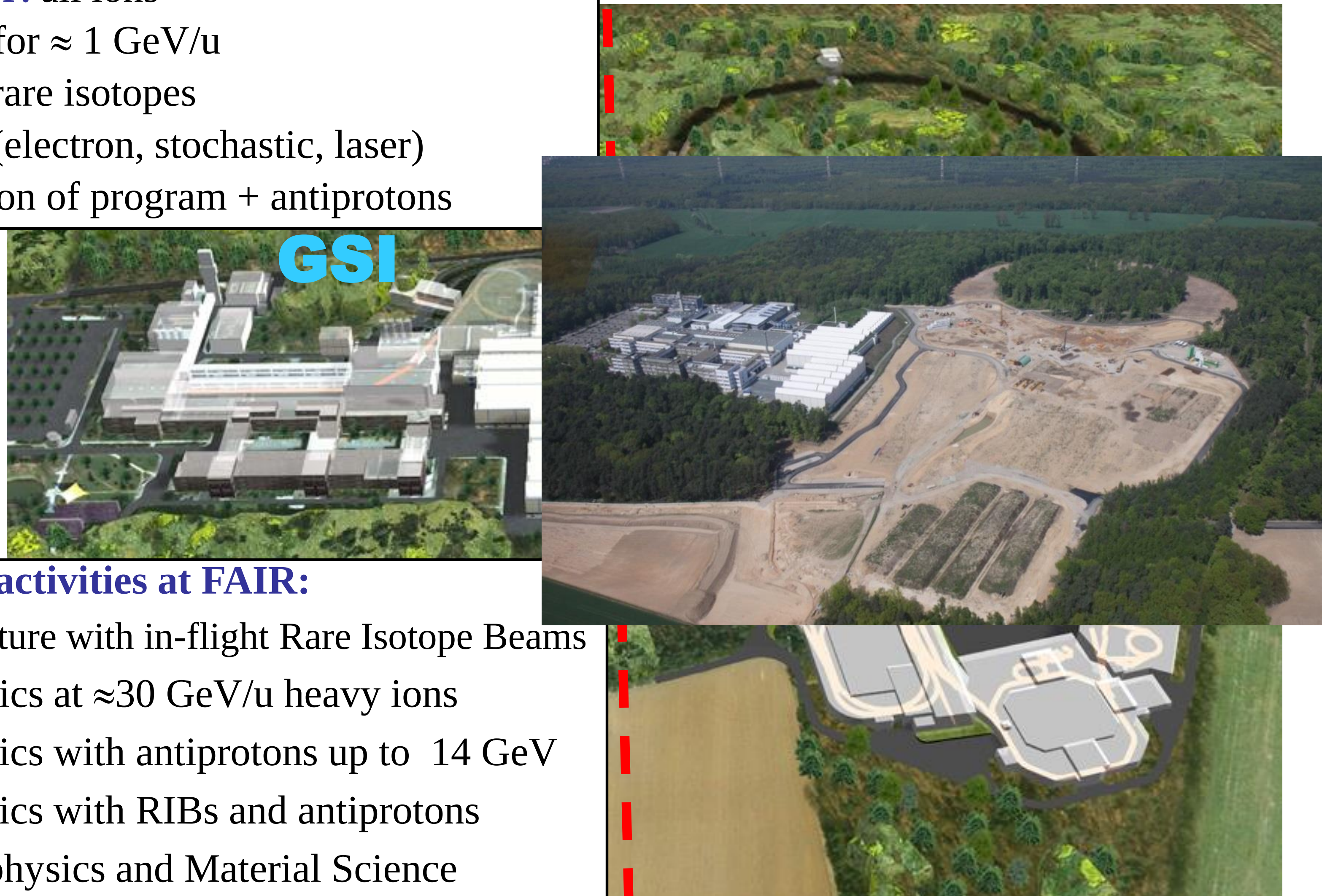
Example: High resolution spectrum



T. Radon et al., Phys. Rev Lett 78, 4701 (1997), M. Hausmann et al., NIM A 446, p. 569 (2000),
B. Sun et al., Nucl. Phys. A 834, 473 (2010)

GSI and FAIR in Future

GSI accelerator: all ions
high intensity for ≈ 1 GeV/u
production of rare isotopes
beam cooling (electron, stochastic, laser)
FAIR: extension of program + antiprotons



Main physics activities at FAIR:

- Nuclear Structure with in-flight Rare Isotope Beams
- Hadron Physics at ≈30 GeV/u heavy ions
- Hadron Physics with antiprotons up to 14 GeV
- Atomic Physics with RIBs and antiprotons
- Plasma, Biophysics and Material Science

GSI and FAIR in Future

UNILAC & SIS18:
as injector for ions after upgrade

p-LINAC: high current 70 mA, 70 MeV

SIS100: 100Tm, s-c magnets 2T
1-10 GeV/u
fast ramping 3 T/s
length 1084 m
design: **p 4*10^{13},**
U^{28+} 5*10^{11}
critical issue: dynamic vacuum

CR: stochastic cooling
of RIB and pbar

HESR: acc. of pbar to max. 14 GeV,
pellet target,
stochastic & e-cooling

HEBT: fast & slow extraction
for low & high currents.