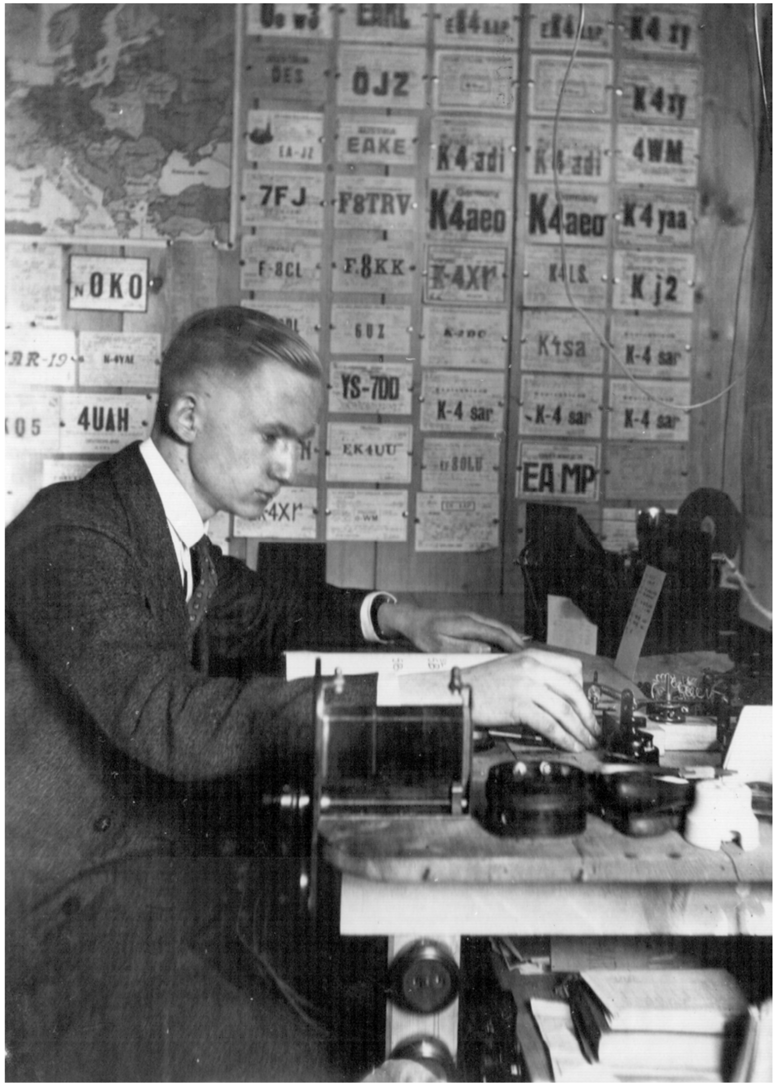
The Story of the GSI Accelerators

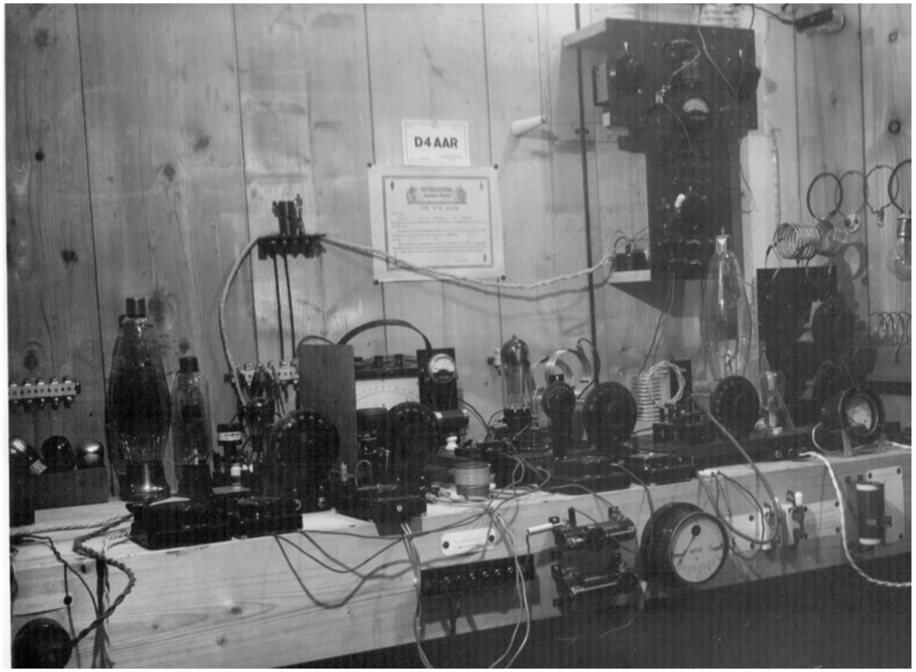
Norbert Angert

- From the Heidelberg study group to the first uranium beam
- Extension of the facility in the 1980s, high energy is not all
- Developments in the 1990s, exploiting the potential, preparing the future

To stories belong always persons



Radio Amateur
Christoph Schmelzer in the early 1930s



1935	PhD in Physics, Max Wien /Jena
1939	Techn.-Phys. Institute, Georg Goubau /Jena (Rf developments, antennas, etc.)
1948	Heidelberg University, Walther Bothe (First contact to accelerators)
1952	Member of study group for CERN PS
1954	Geneva, Head RF group, PS deputy
1960	Heidelberg, Prof., Inst. Appl. Physics (Heavy ion linac development, Laser)
1970	Scientific Director of GSI
1978	Retirement

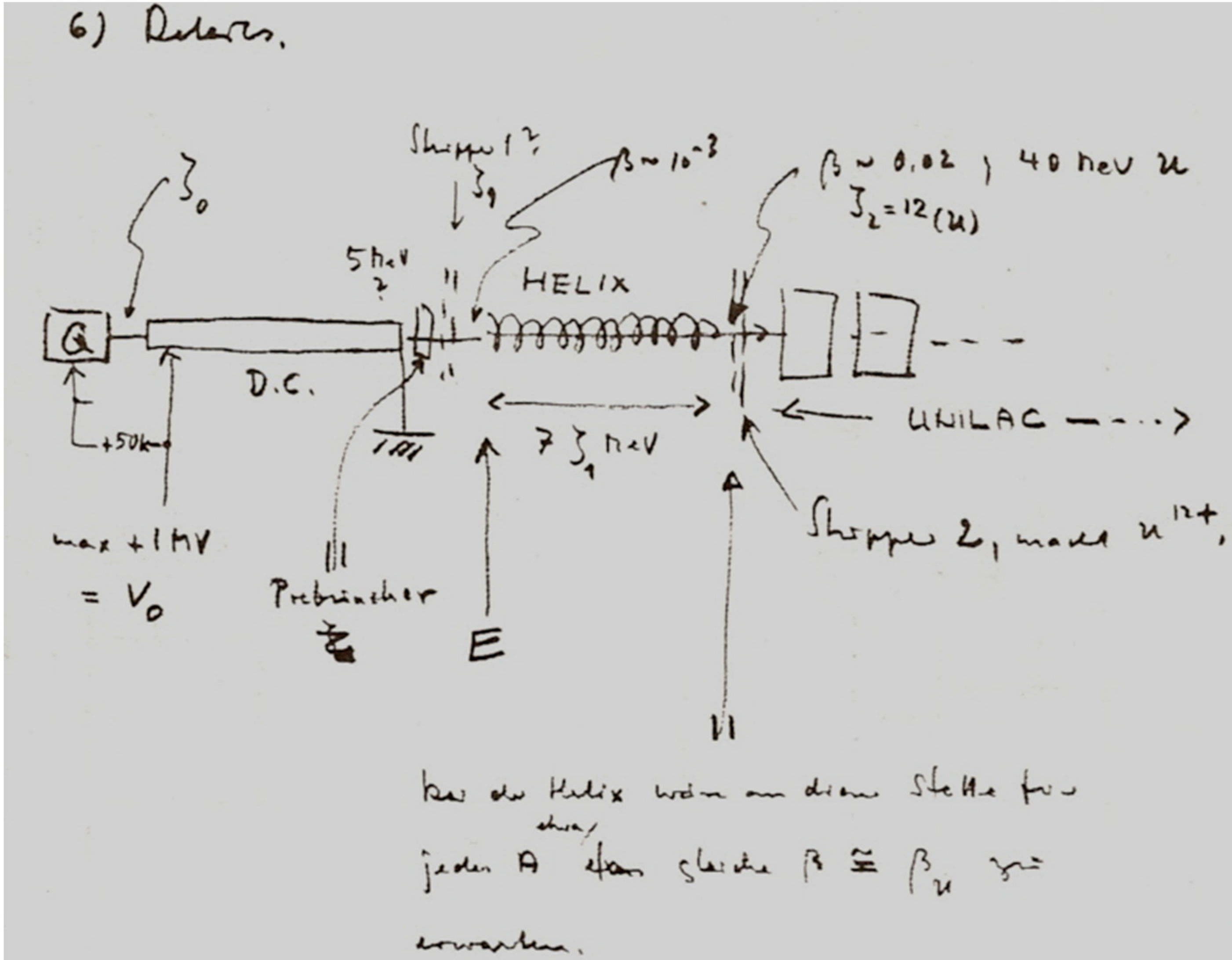
Motivation and Proposal

- Increasing interest in experiments with heavy ions since the mid 1950s
- Nuclear shell model extrapolation suggested the existence of a stability island around Z = 120
- Proposals for appropriate accelerators in the USA, France and Soviet Union (cyclotron, synchotron, Tandem van de Graaff, and combinations)
- Schmelzer`s proposal:UNIversal Linear ACcelerator begin of 1960s, UNILAC
- Acceleration of ions of all elements up to uranium to energies of about 10MeV/u

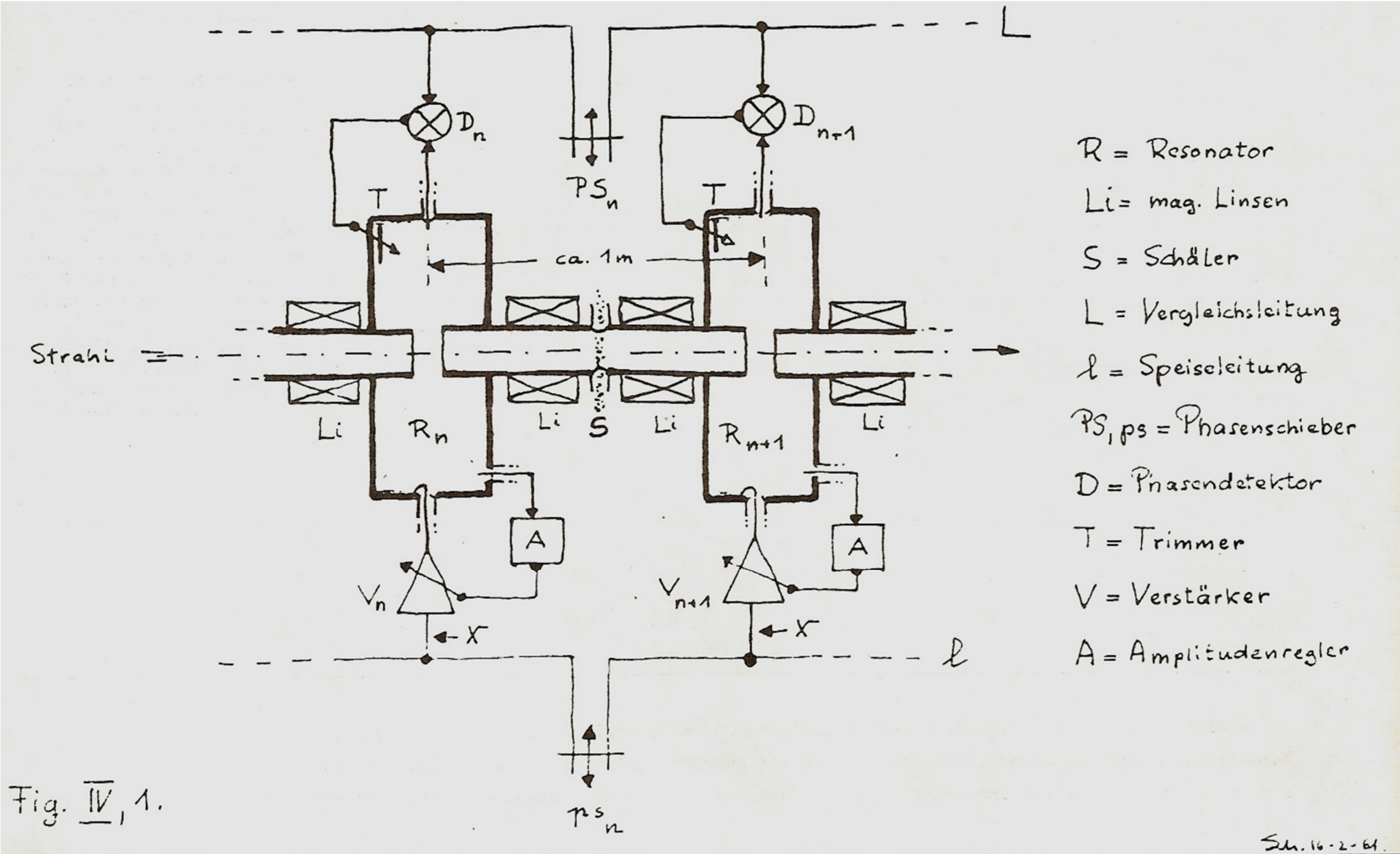
Schmelzer`s Requirements for a Universal Heavy Ion Accelerator

- Accelerator for ions of all elements up to uranium
- Energy at least 7 MeV/u, threshold for nuclear reactions with any target atoms
- Independent rf-cavities with phase control allowing different velocity profiles
- Output energy variable in a wide range (2 to 10 MeV/u), and stable within 10^{-3}
- Energy spread of the beam better than 10^{-3}
- No contamination from other energy components in the beam
- Beam intensity higher than $6x10^{12}$/s
- Fast change of ion species possible

Early studies in Heidelberg



Early studies in Heidelberg



Sch.16-2-61

Studies proposed by Ch. Schmelzer in 1960/61

- Stripping data, average charge states
- Phase control of cavities
- Particle dynamics, phase stability during acceleration
- Focusing and filtering of wrong charge-to-mass particles
- Tolerances for acceleration and focusing system
- Low energy and injection section
- Ion sources for high charge states

1960/61 **Schmelzer** started with few students.

1962 Reconstruction of the institute building was completed,
offering more rooms for students.

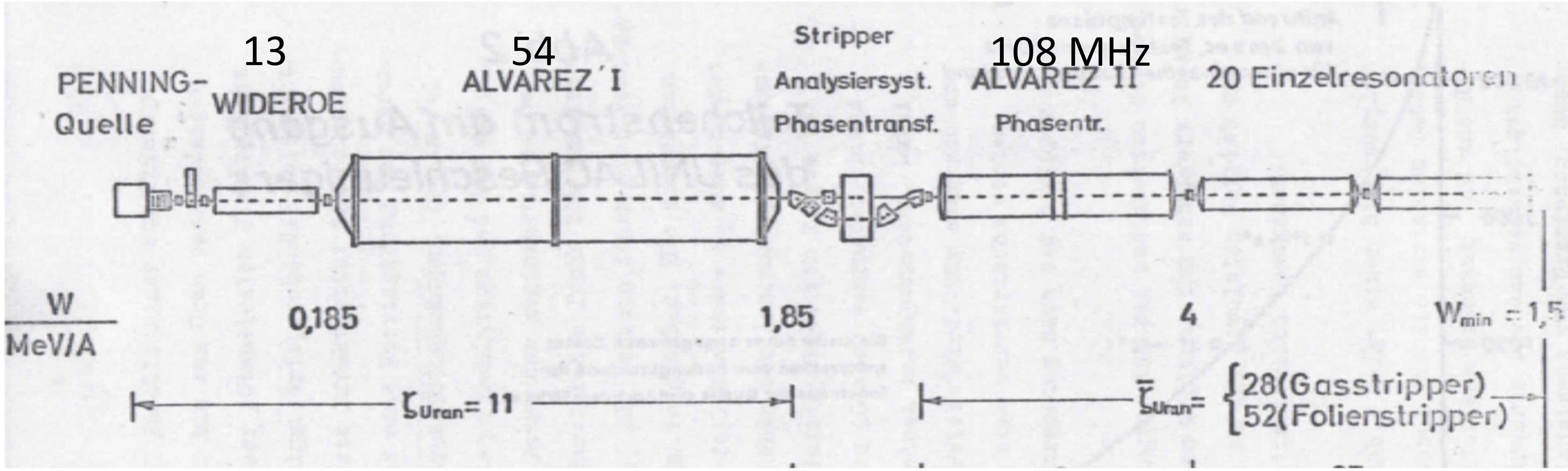
1964 Study group could be established with engineers , technicians and more students
Dieter Böhne (28) with a doctor degree in rf-engineering
(and some semesters mechanical engineering)
was the head and motor of the study group.

Böhne focused on following tasks:
Optimisation of Schmelzer`s accelerator layout
Development of technical solutions for the Unilac components
Looking for cost optimized and simple technical solutions ,

supported by inventive engineers
and
by Klaus Blasche (begin at 22) and student in particle dynamics

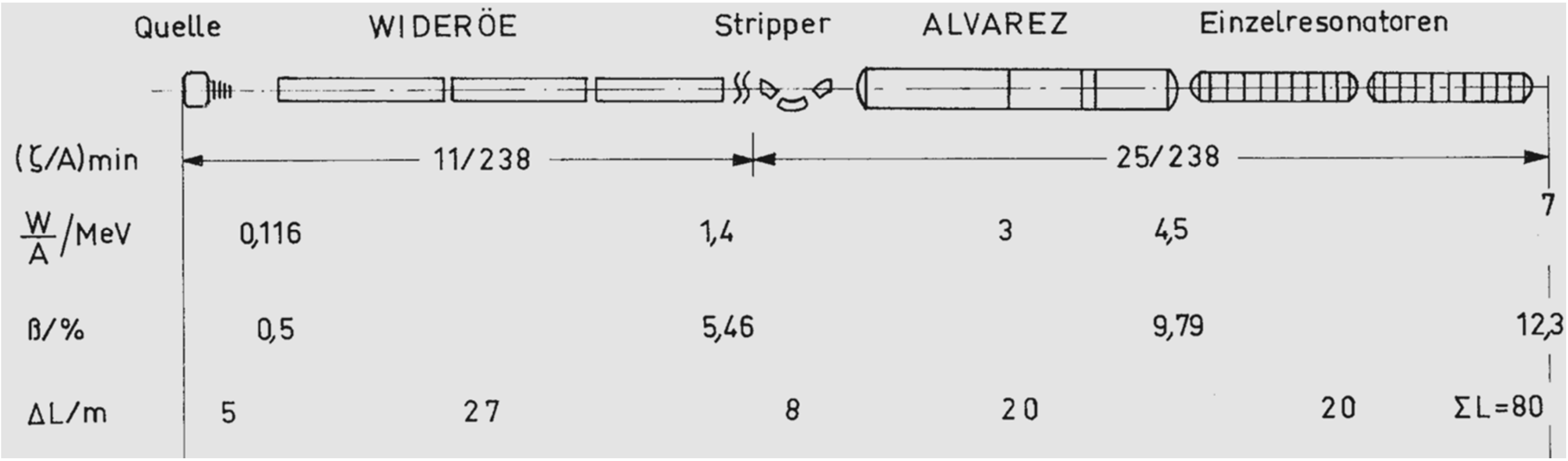
1968 Book with technical solutions (E.Malwitz)

Drawing office of the Unilac study group in the barracks on the area of the Max-Planck-Institute Heidelberg for Nuclear Physics (Bierhelder Hof)



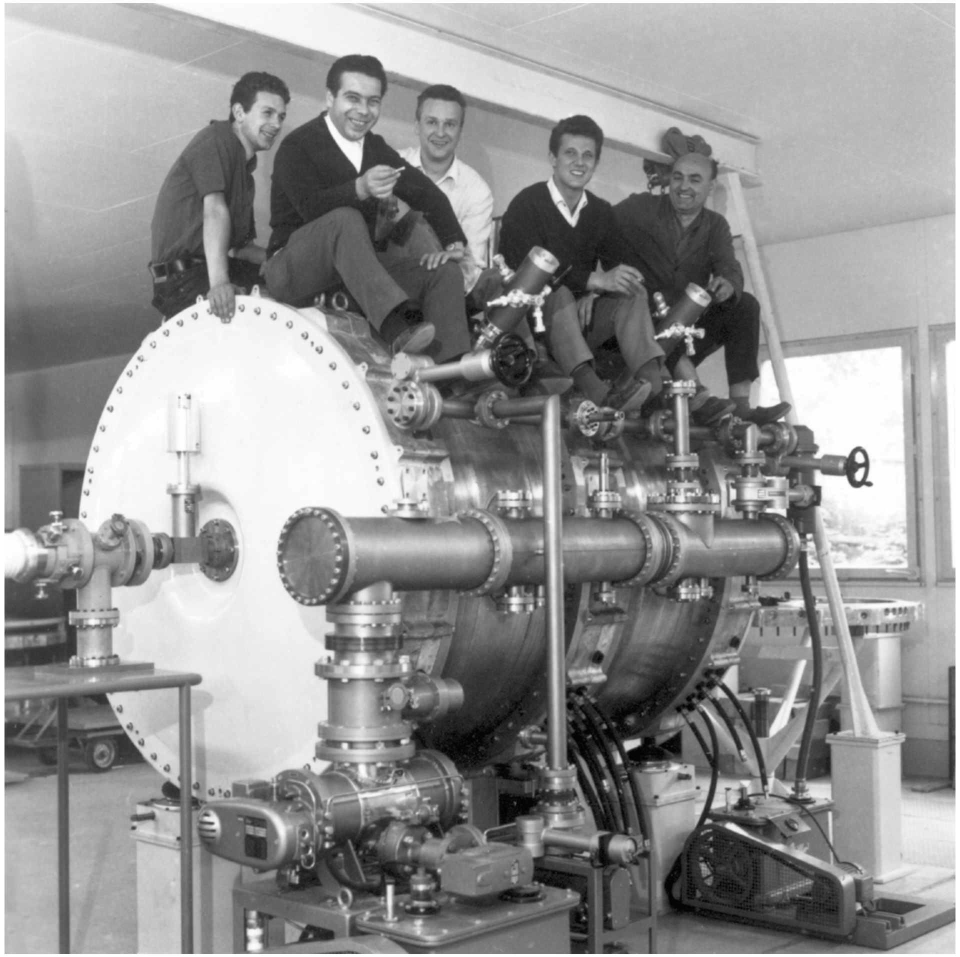
Unilac layout 1966

Stripping data!



Unilac layout 1968, 6a

Single gap cavity prototype at the Max-Planck-Institut in Heidelberg



The photo shows one example of the technical studies:

A prototype cavity for

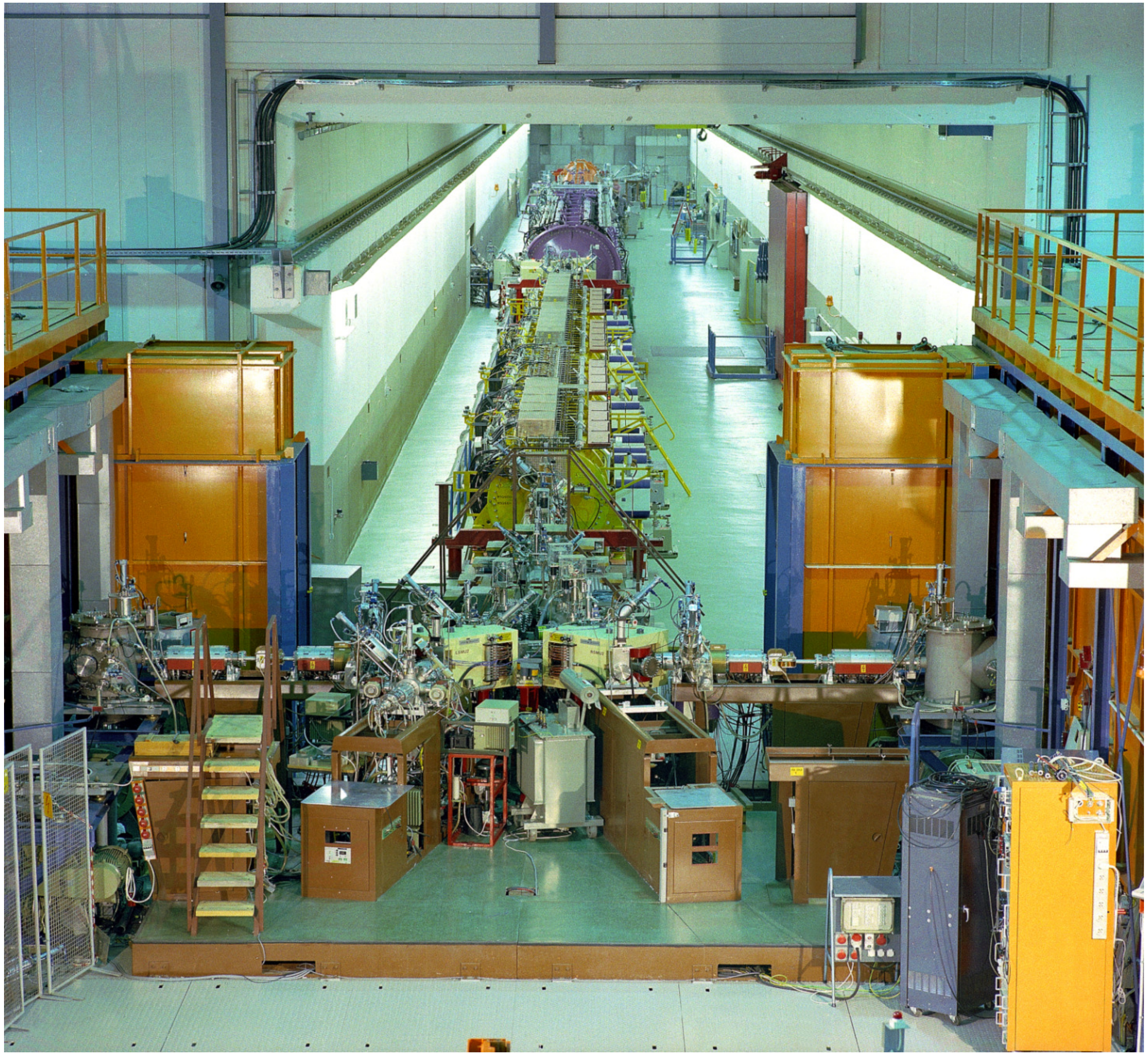
- measurement of max. gap fields
- vacuum design
- rf coupling

The essential features of layout and technical design were more or less fixed in 1968.

Dieter Böhne was at that time 33 Christoph Schmelzer 60 years old. The engineer and the physicist were very complementery to each other.




GSI founded 17.12.69

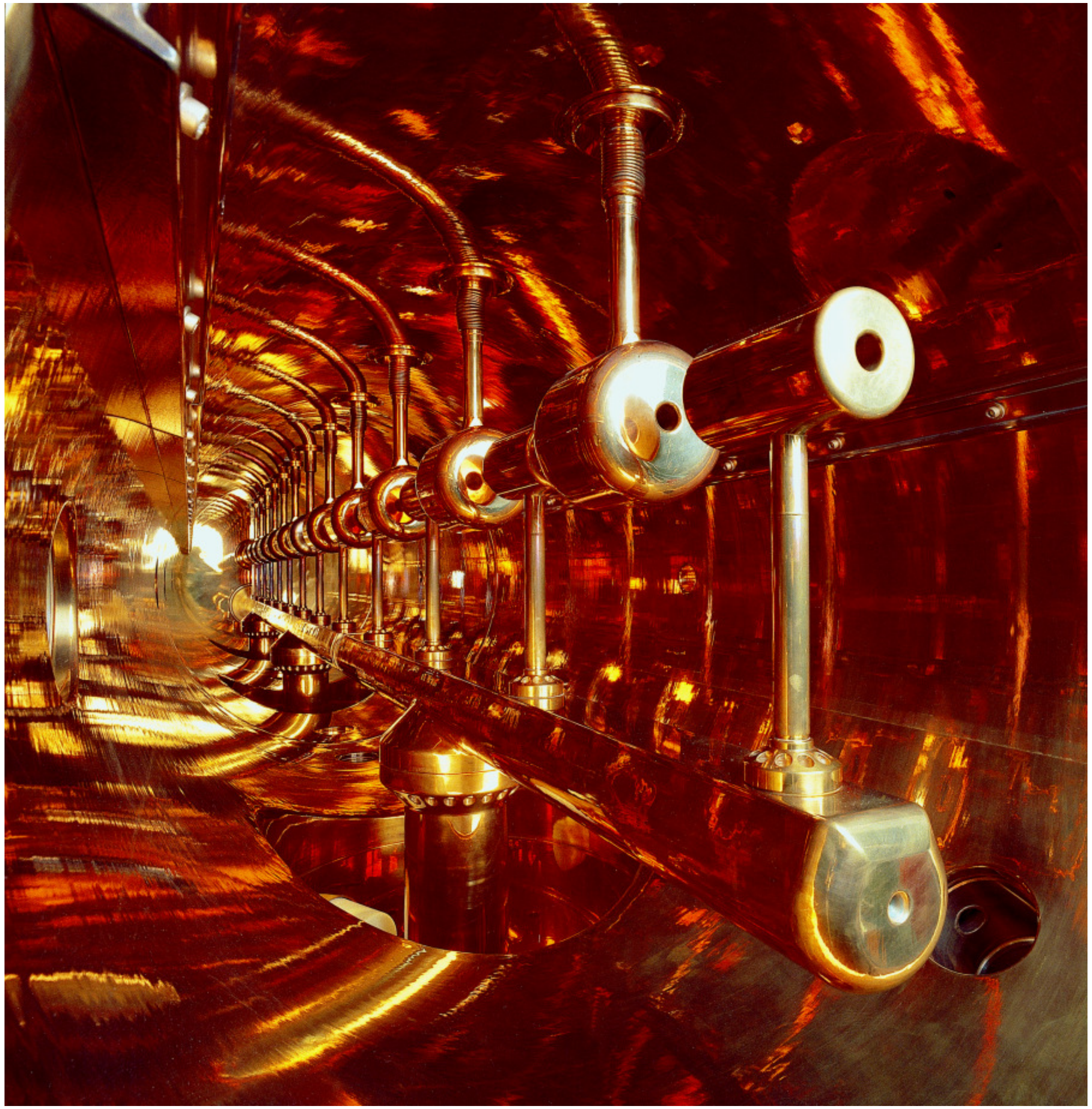


Start Unilac construction end of 1971

First acceleration in Alvarez tanks 1 + 2, August 1975

First uranium beam with several single gaps April 1st 1976 (Penning ion source available)

Coaxial type Wideröe structure, prestripper accelerator up to 1998.



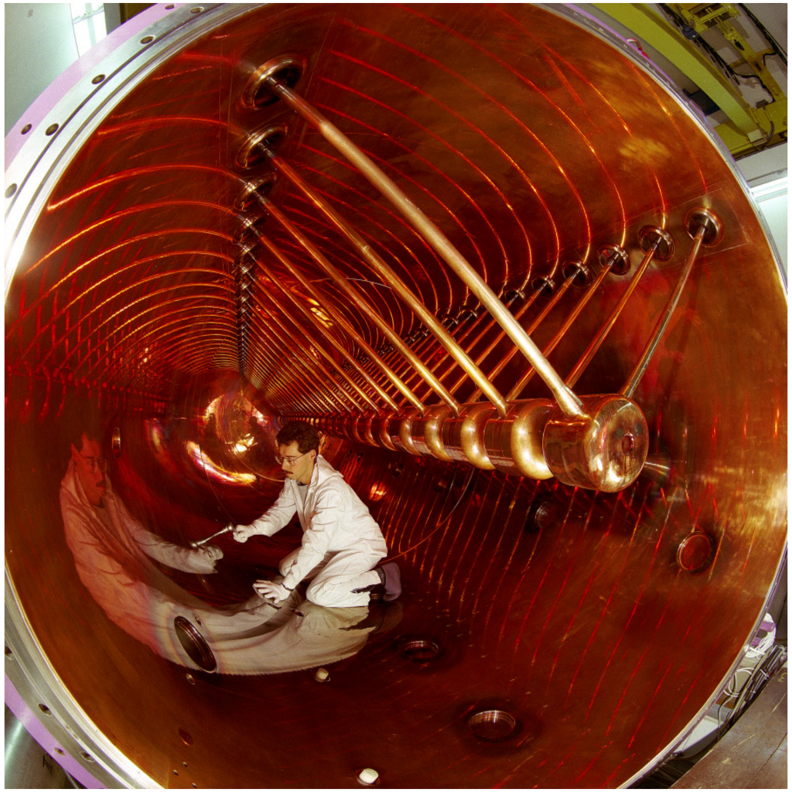
Only outer drift tubes had magnetic quadrupoles.

Focusing was marginal.

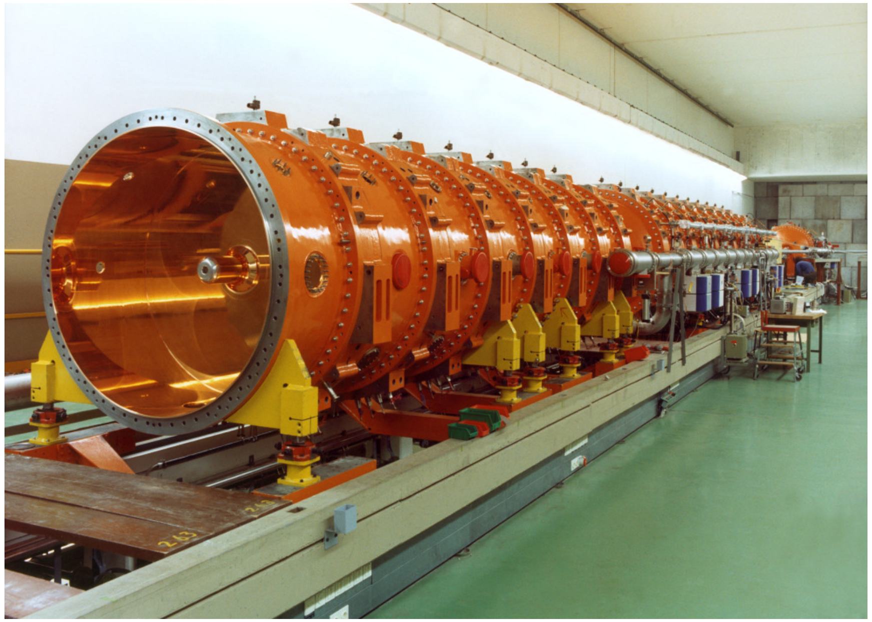
$3\pi/\pi$ structure in 1st tank in order to reach sufficient magnetic focusing.

Originally, electrostatic focusing was proposed there; last minute decision (45^0)

Still existing poststripper accelerator sections during construction phase



Alvarez structure



Single gap cavity chain

After completion of the Unilac

E. Malwitz, B. Franzke, K. Blasche, Ch. Schmelzer, D. Böhne, N. Angert, and H. Gaiser
„Old“ Heidelberg crew

Extended Unilac improvement program (examples)

Ion sources

From foil stripper for very heavy ions to stable gas jet stripper operation (U^{40+} to U^{28+})

All RF-systems, especially Alvarez final amplifier stages, rf-lines, couplers, windows, tuning…

Accelerator control system

In parallel:First synchrotron proposal 1976, jointly by exp./acc.

12 Tm synchrotron, SIS12, has been proposed,

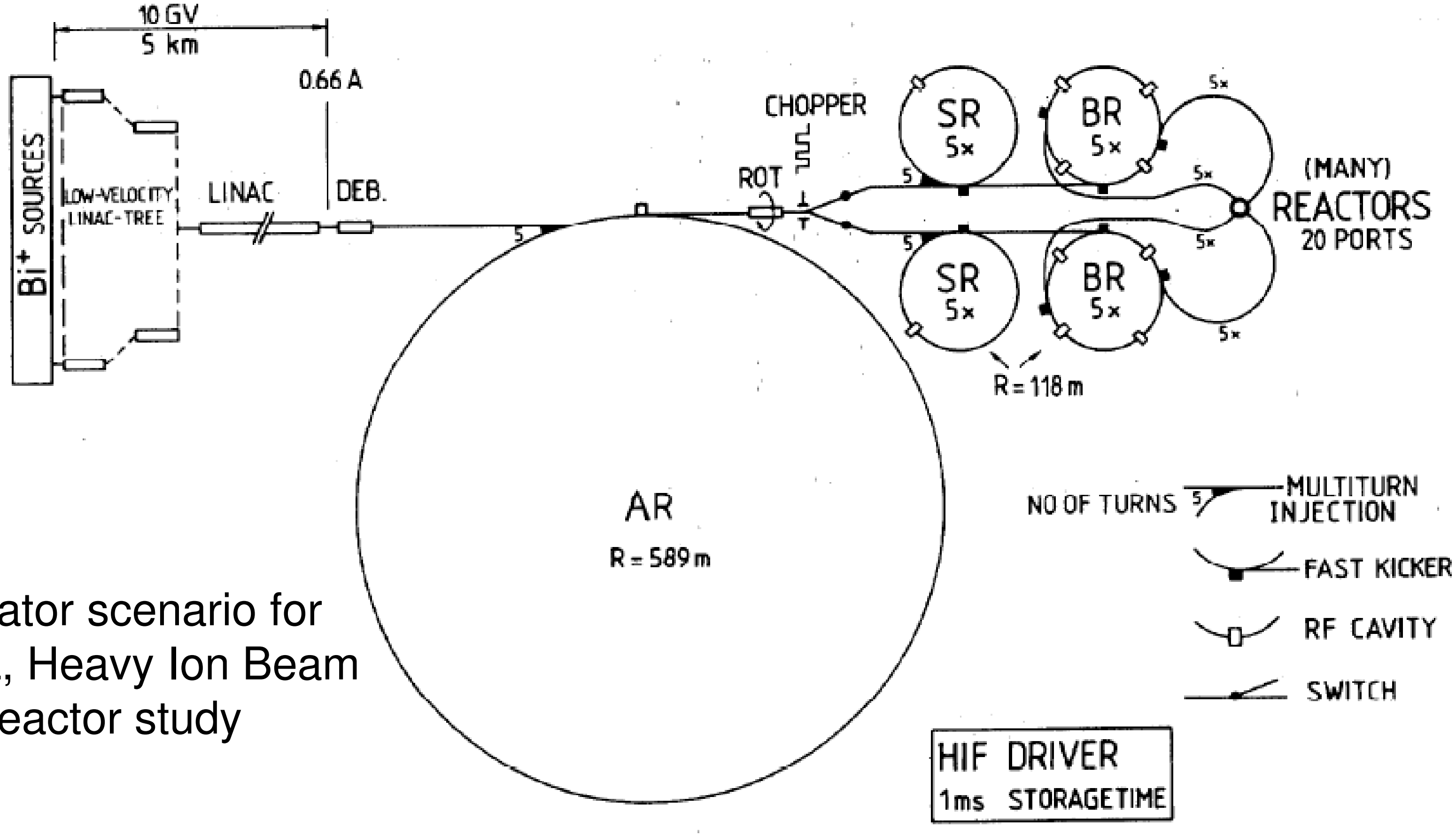
superconducting high energy synchrotron (10 GeV/u) for relativistic beams was envisaged.

→ „Synchrotron times“

Farewell to Christoph Schmelzer and inauguration of Gisbert zu Putlitz
September 1978

Incidental remark

GSI took part in Heavy Ion Fusion studies since 1978 (Rudolf Bock):High current ion sources, linacs, large accummulator ring, storage rings and buncher/compressor rings



Accelerator scenario for HIBALL, Heavy Ion Beam driven reactor study

Synchrotron and storage ring times

1979: One stage 100 Tm ring, partly stripped ions, large energy swing,
Energy doubling of the Unilac as injector proposed

1981: Two stage synchrotron proposals, SIS18/SIS100 and others, cost problem

1982: Proposal for relativistic oxygen ions in the CERN PS complex (R. Stock)

1983: Accepted, CERN, LBL, GSI ,CENG realised (O/S beams in SPS 1986/87)

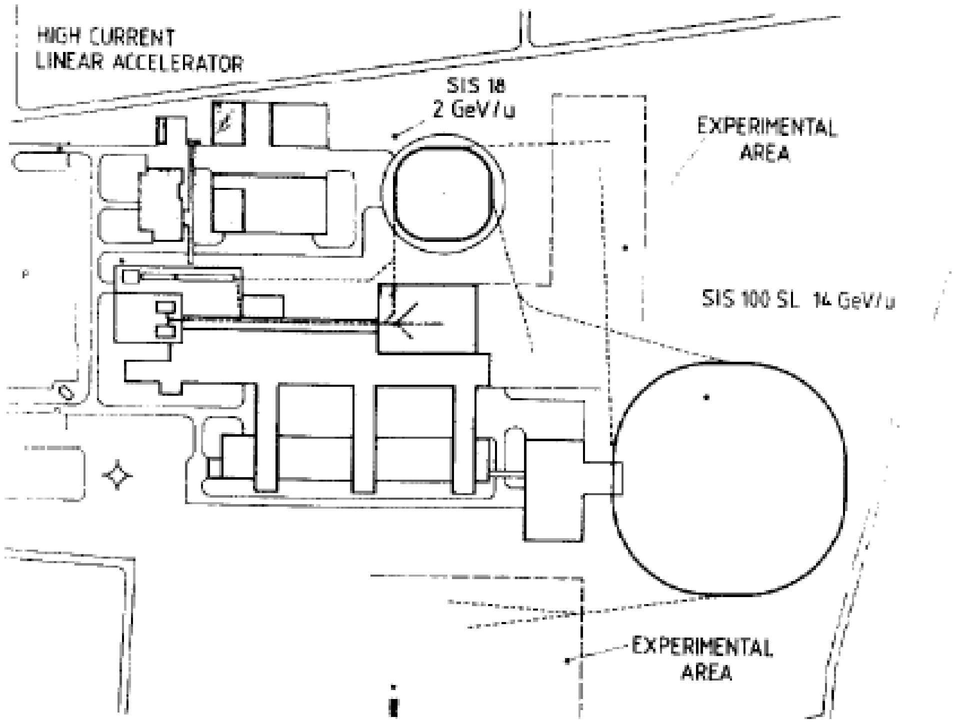
1983: Triggered by heavy ion fusion:Storage ring proposed (I. Hofmann)

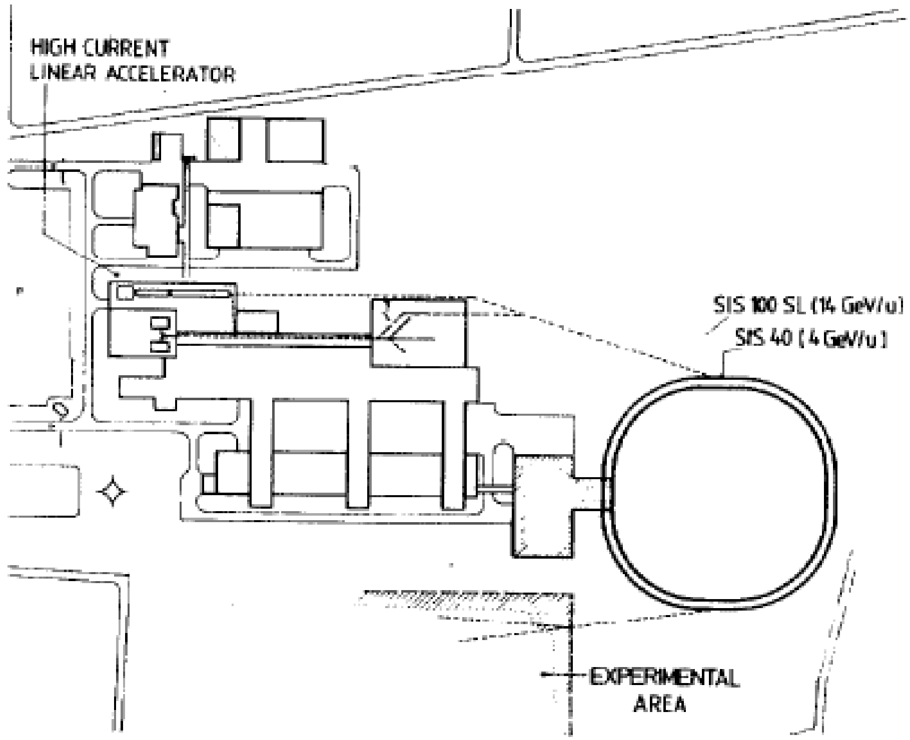
Evolution of the storage ring towards an Experimental Storage Ring ESR

1984: ESR enlarged and altered (Paul Kienle, Bernhard Franzke)

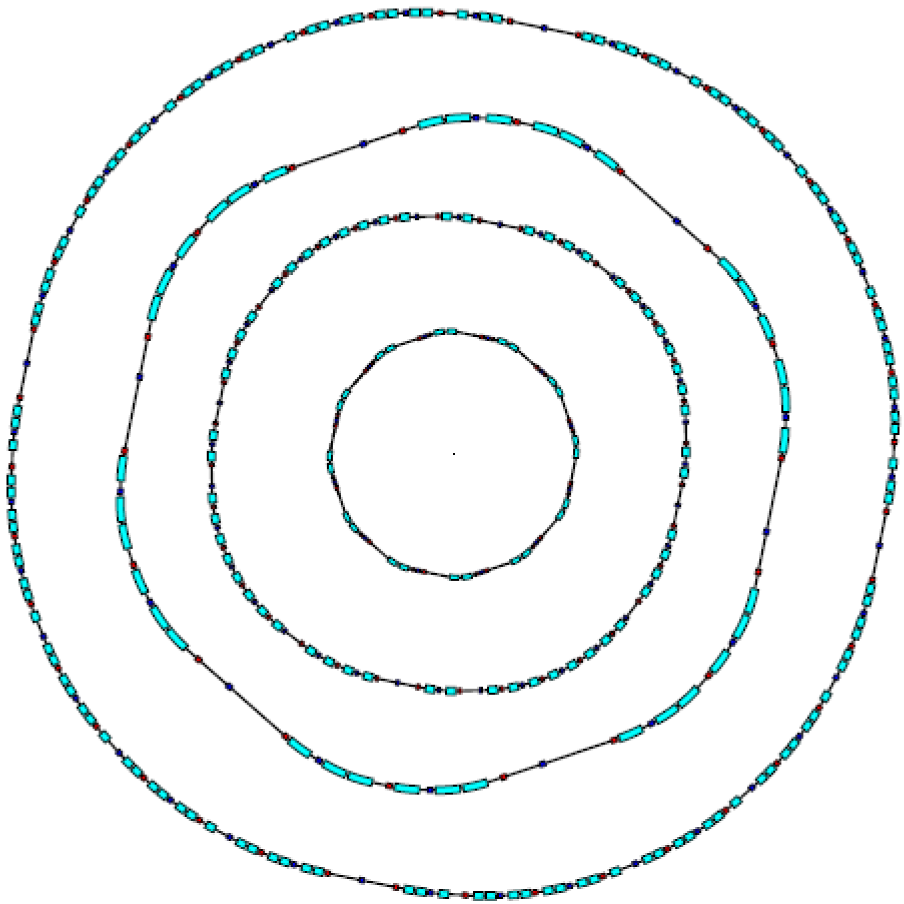
Proposal for SIS18/ESR, together with Fragment Separator FRS

1985: Approval



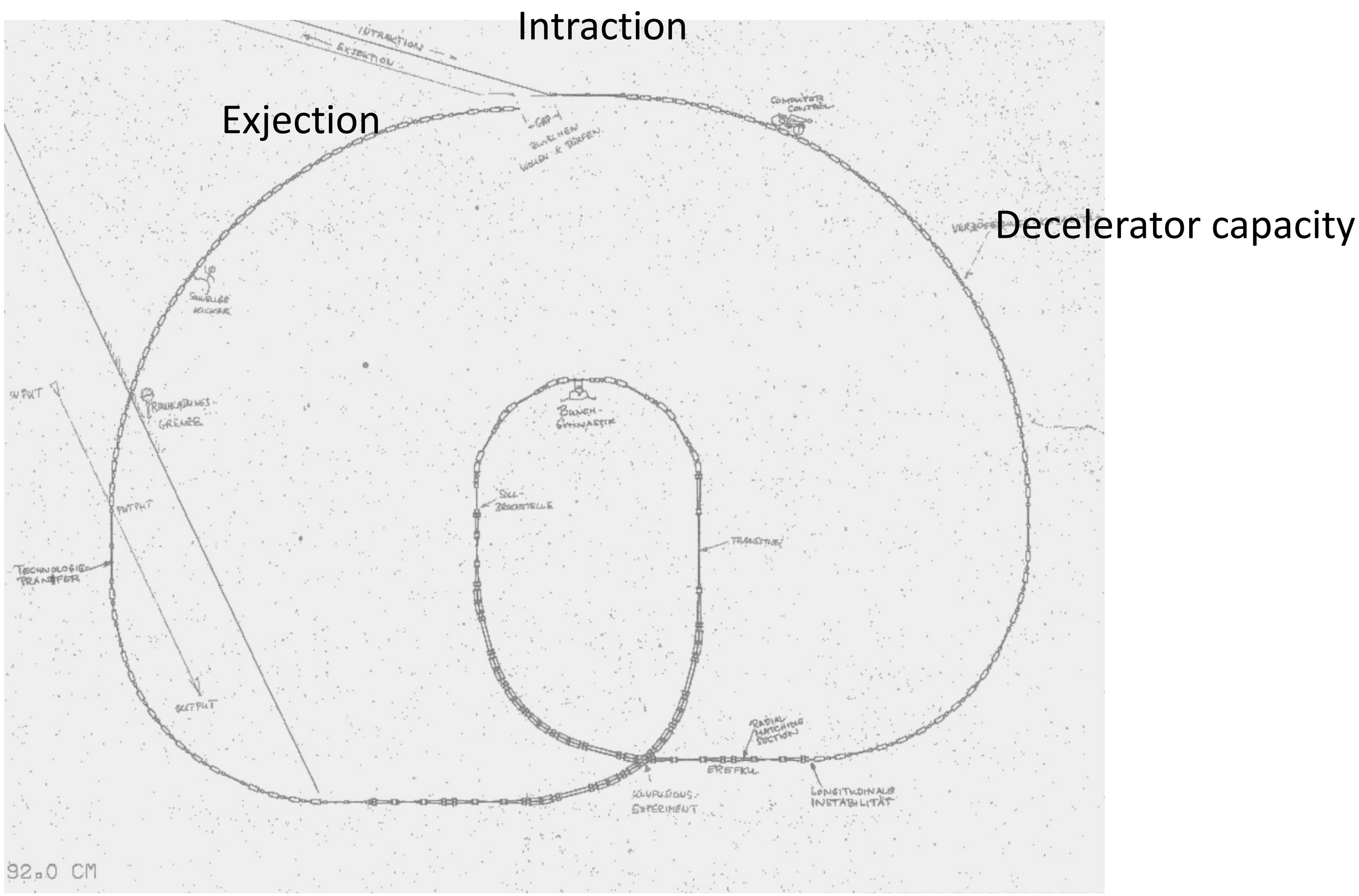


Two stage synchrotron proposals for relativistic heavy ions 1981



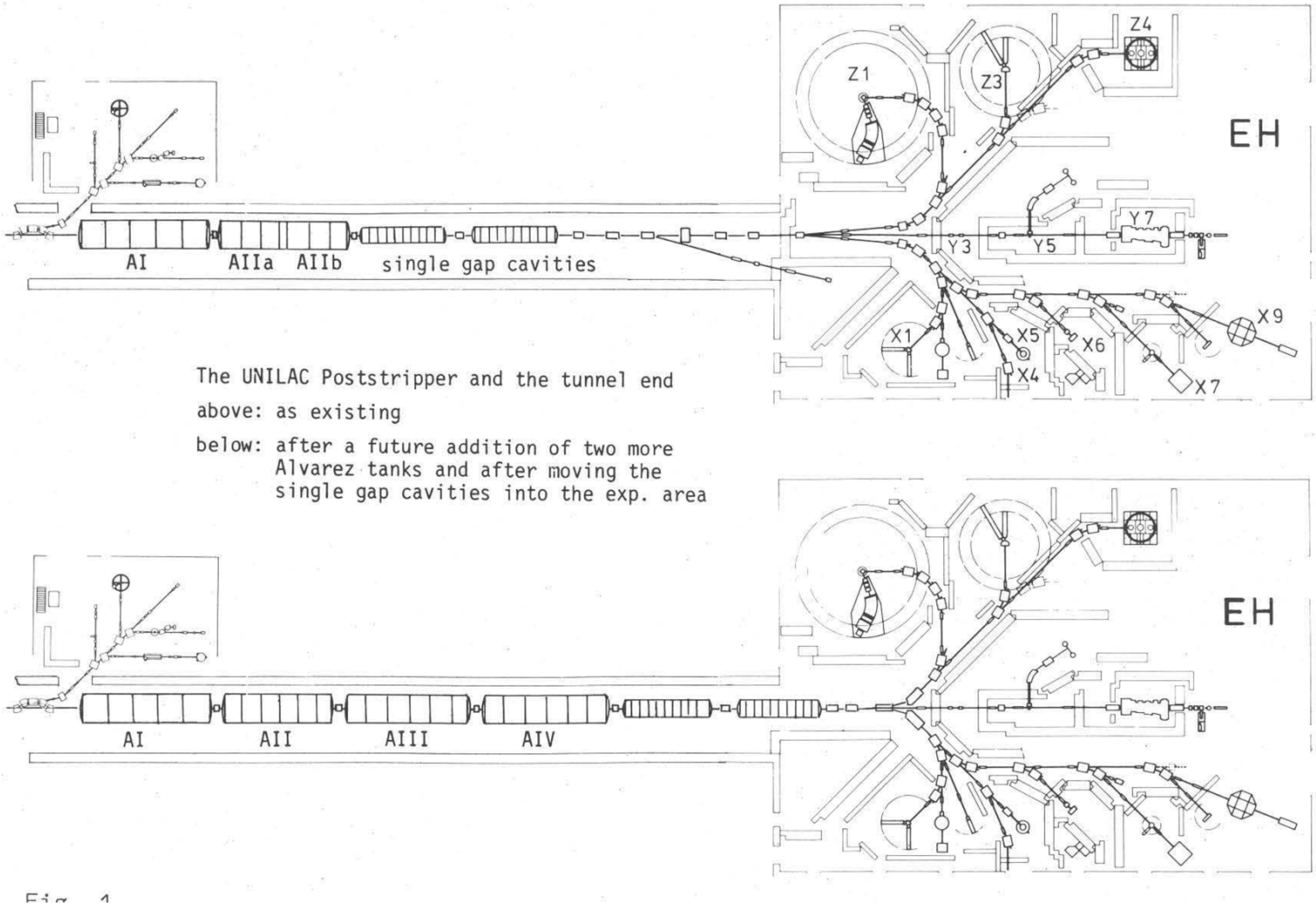
SIS18 – SIS40 – SIS65 – SIS100

Selection of synchrotron rings studied in the years 1976 to 1983, B. Franczak

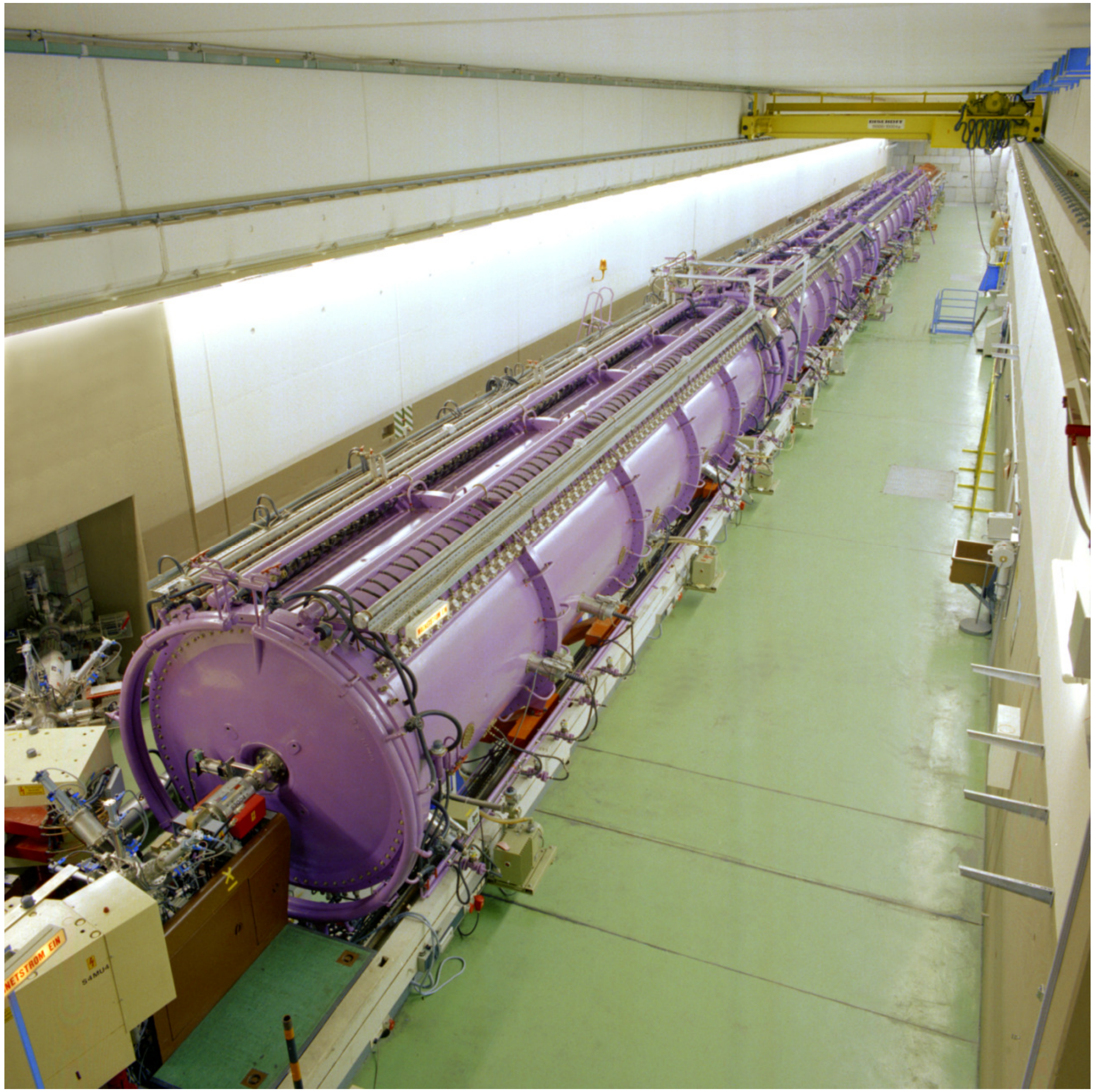


Attempt of a somewhat frustrated synchrotron designer to escape into a parallel synchrotron universe, B. Franczak

Unilac Upgrade 1981/1982



Extension of the Alvarez section for 11. 4 MeV/u



03.08.**1981** start shut down

.

13./20.08 installation A3/A4

15./25.10 rf tests

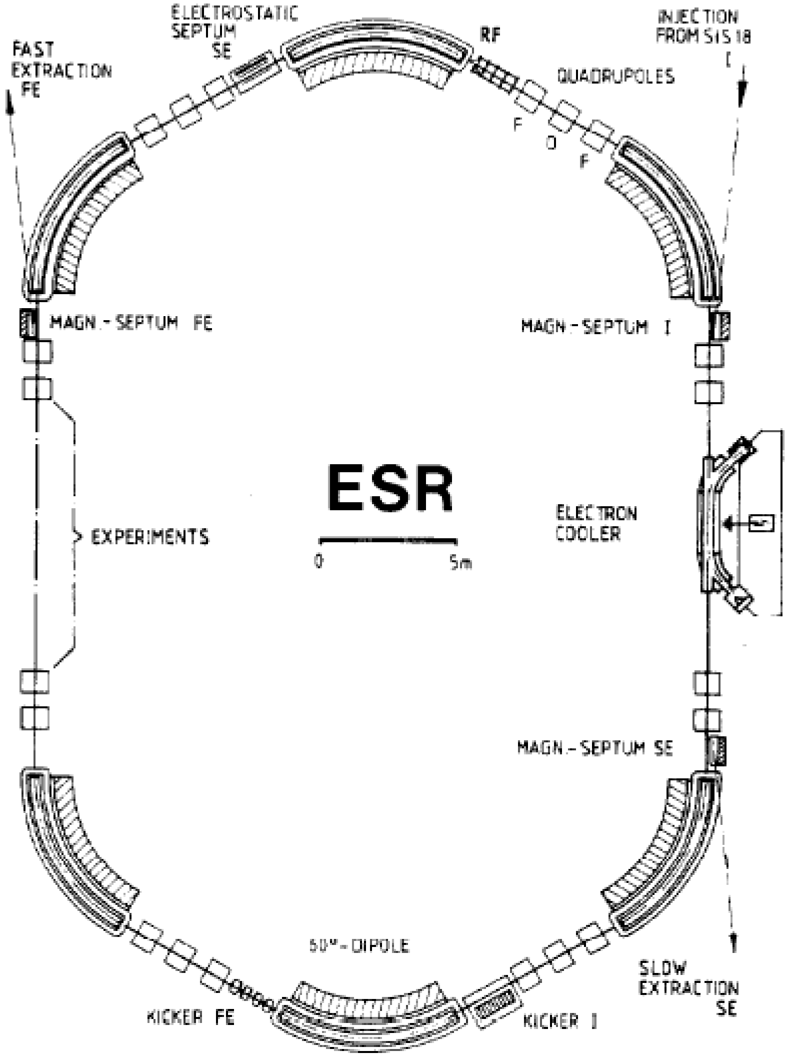
04.01.**1982** 1st experiment

26.02. 15 MeV/u Krypton

Preparing the next (whatever) step for an extension of the GSI facility:
Prototype magnet for a 18Tm synchrotron (1983)

Paul Kienle followed Gisbert zu Putlitz as Scientific Director, 1984 -1992

ESR prehistory



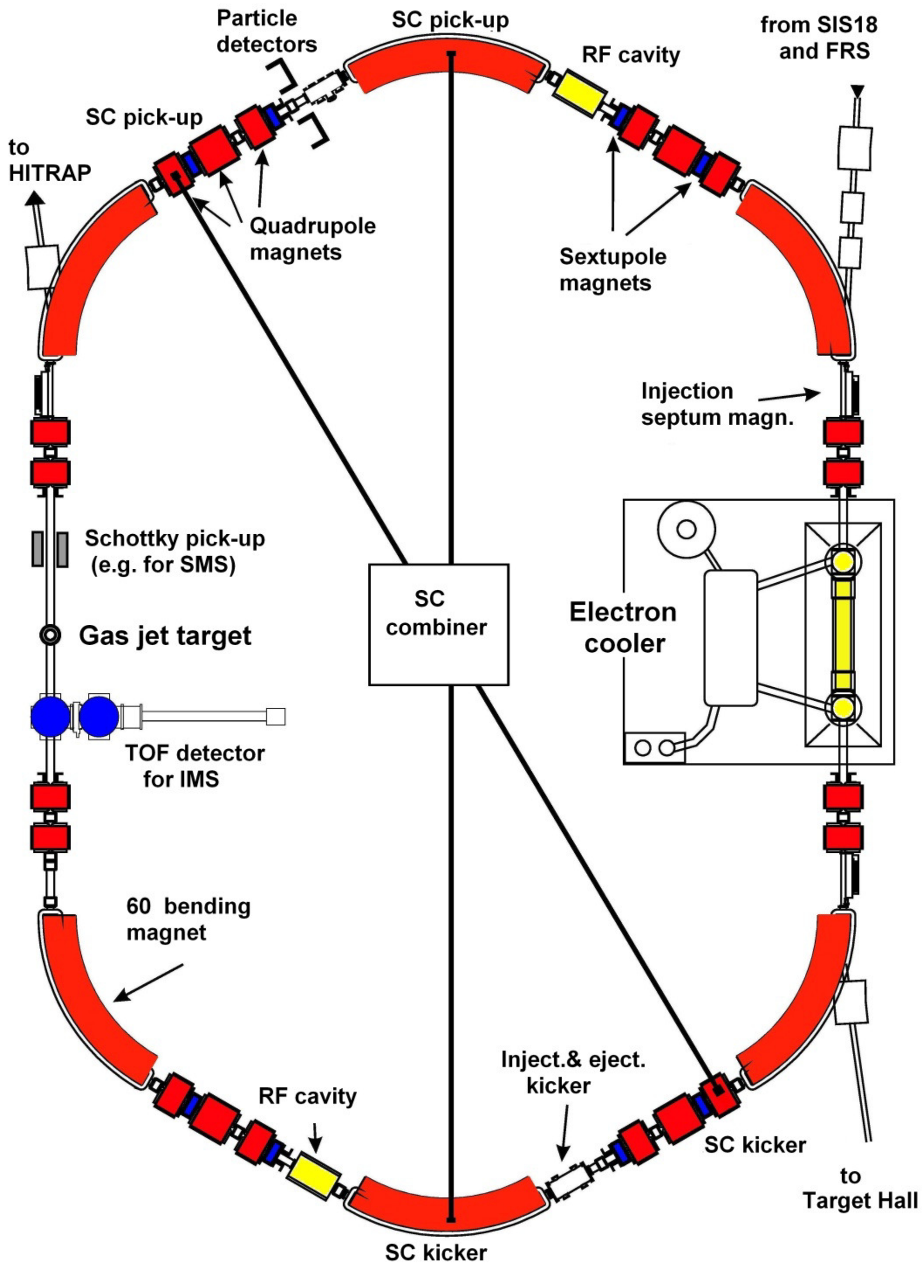
To become independant of the fate of the synchrotron plans, the heavy ion fusion study group proposed 1983 a small experimental storage ring in order to study beams at highest phase spase density.

Electron cooling of p-beams was demonstrated at Novosibirsk, and later in the second half of the 1970s at the CERN ICE-ring and LEAR (p/p̄), also stochastic cooling in the ICE ring.

Bernhard Franzke implemented the new ideas in the experimental storage ring design, offering thereby more than only beam study options.

Since 1983 intense discussions were going on between accelerator and experiment groups on possible experiments.

In 1984 the ring was continuously increased and altered; great interest from atomic and nuclear physics. Paul Kienle was the driving force.



Specifics of the ESR

Storage of fully stripped Uranium
(implies energy of ≥500 MeV/u)

Excellent beam quality by
beam cooling with electrons

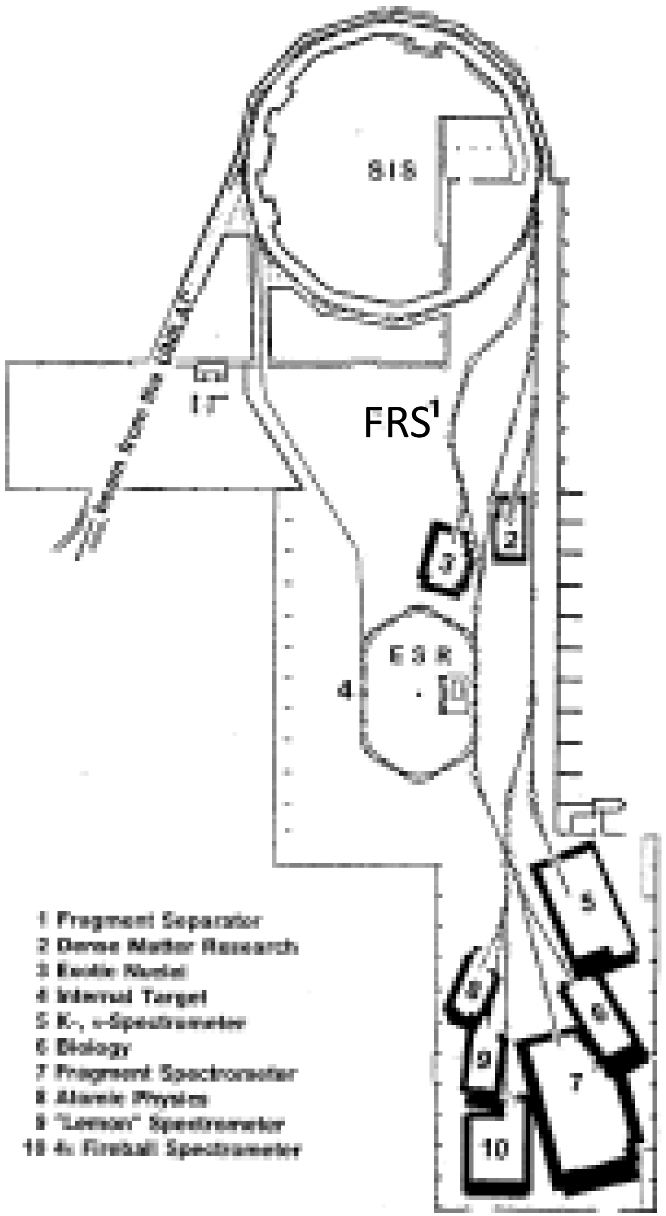
Large ring acceptance
Stochastic precooling
for „hot“ fragment beams

Long storage times

Internal gas target
Cooler electrons for experiments
Windows for laser-beam interaction
Storage of two beams (crossing)
Large energy range, deceleration

High luminosity = small ring

Half circumference SIS18, 10 Tm



The SIS/ESR Project at GSI

B. Böhne, K. Blasche, B. Franzke, H. Prange

Scope of the Project

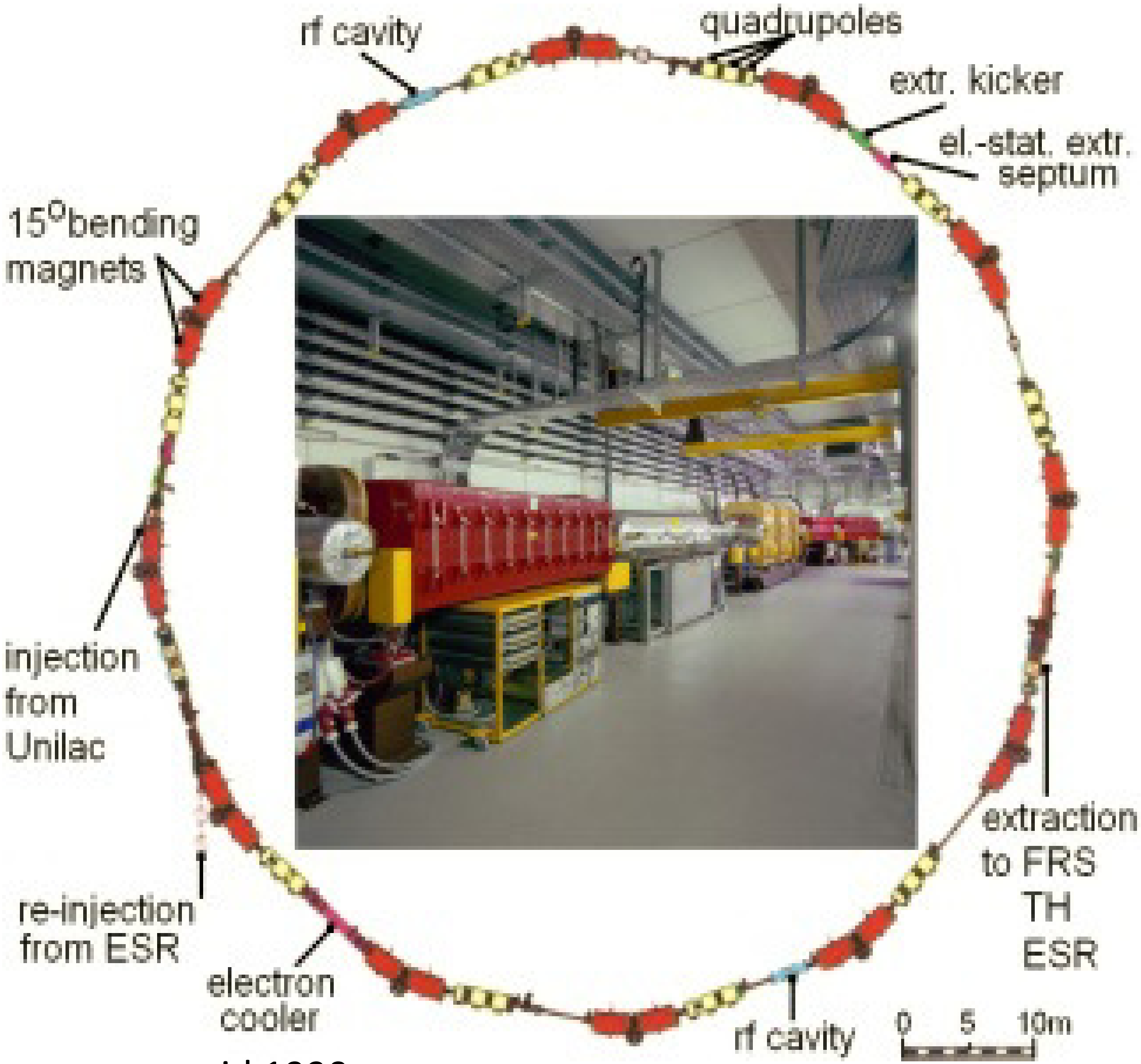
1. Modification of the Unilac
   - Energy switching
   - High current injector
   - Transferline Unilac to SIS18
2. 18Tm synchrotron SIS18 and control system for the whole complex, up to 16 diff. settings
3. Experimental Storage Ring (ESR)
4. All beam transferlines (to rings, experiments)
5. Buildings, including supplies and facilities

Total project cost, incl. experiments: 275 MDM

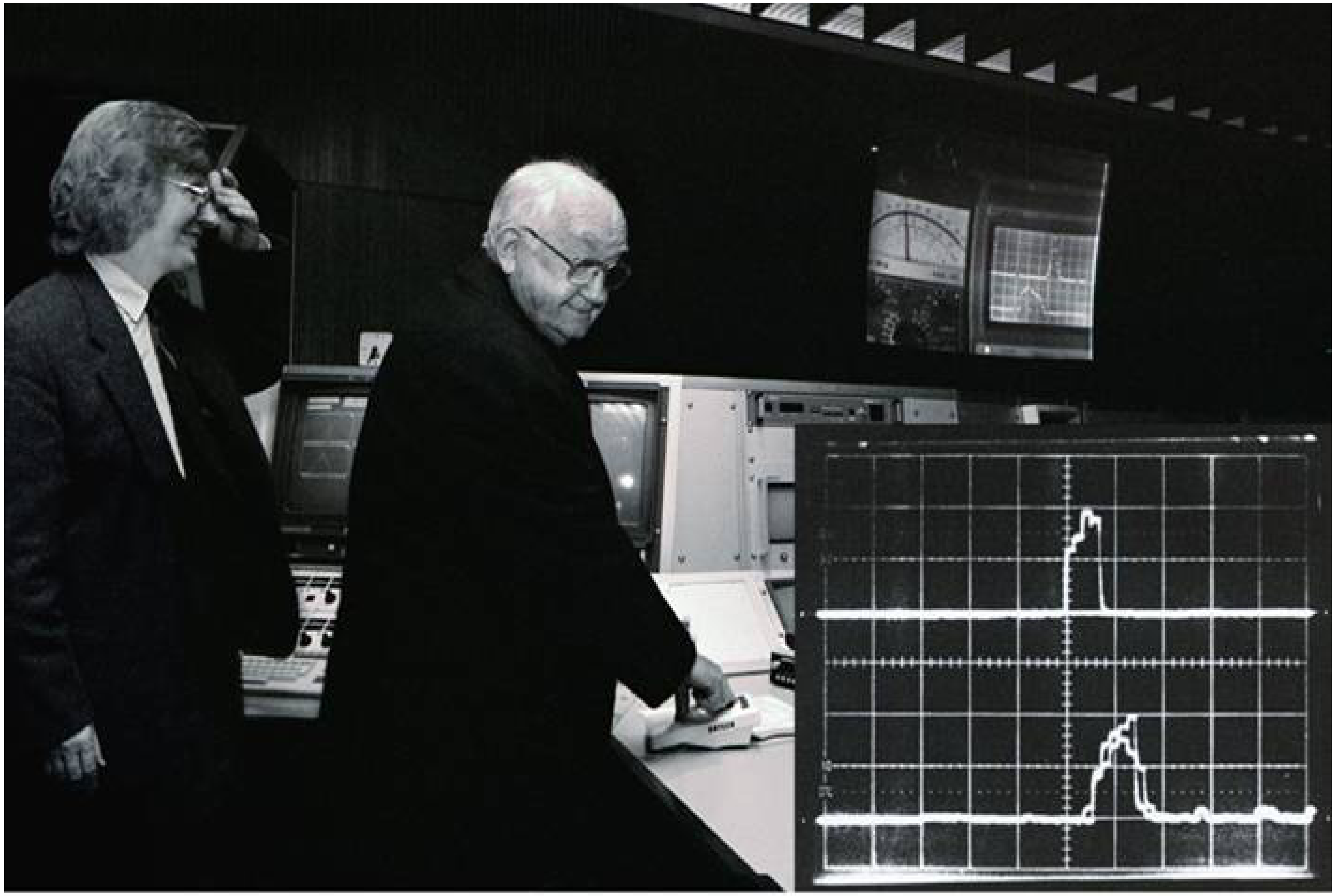
50. Birthday of Dieter Böhne September 1985

Congratulation to the project strategist

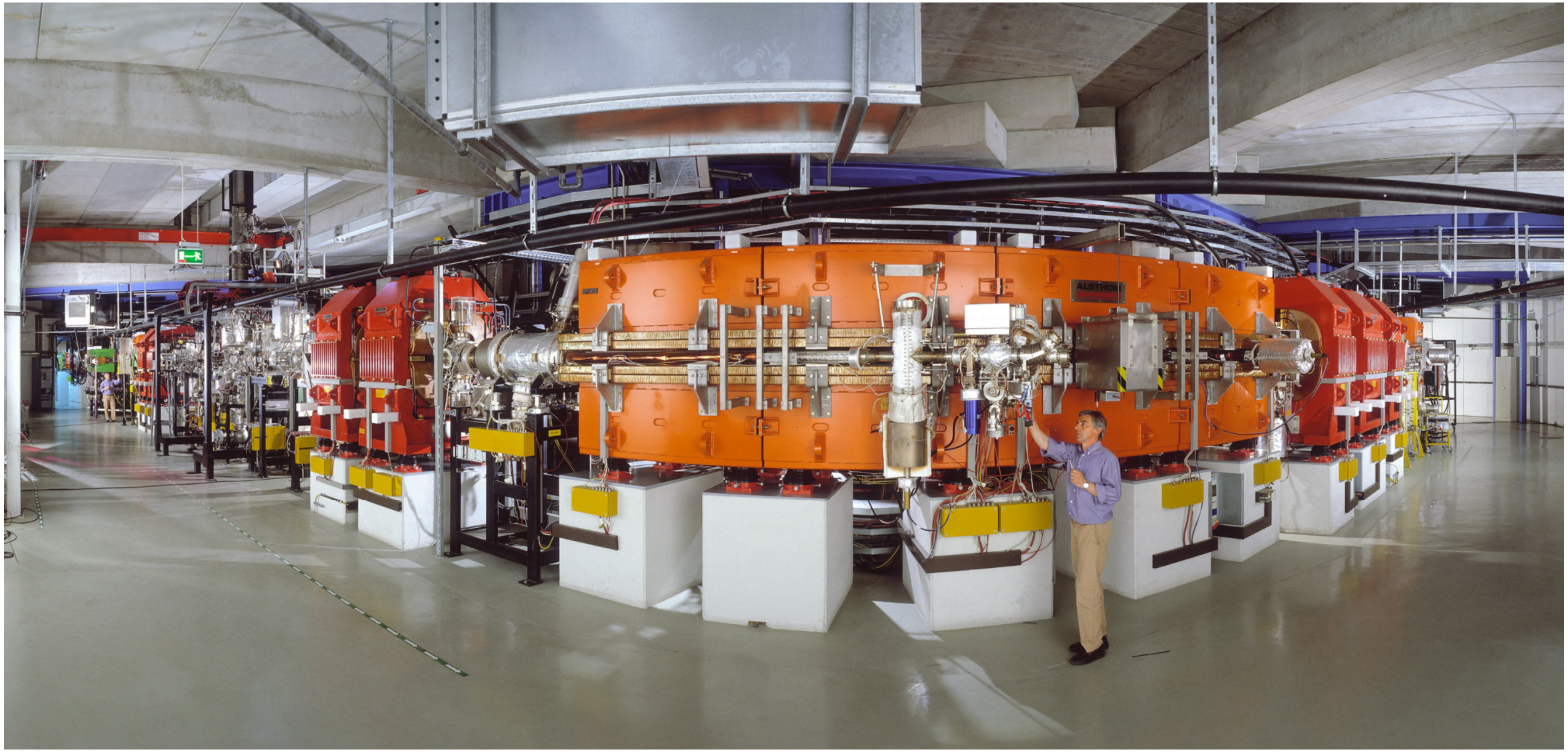
SIS18



mid 1990s



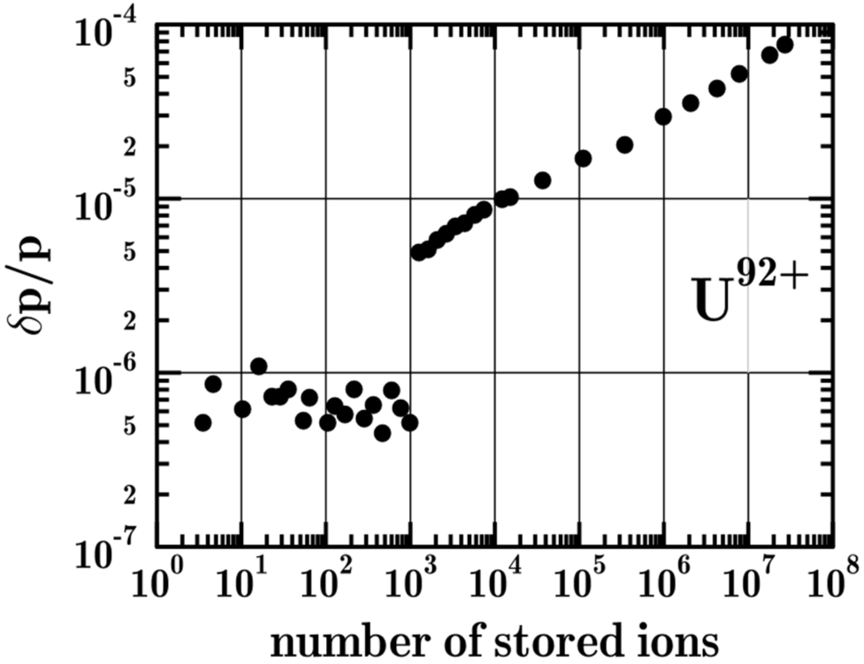
Paul Kienle: First turn in SIS18, 23.11.88, gift to Christoph Schmelzer on his 80th birthday



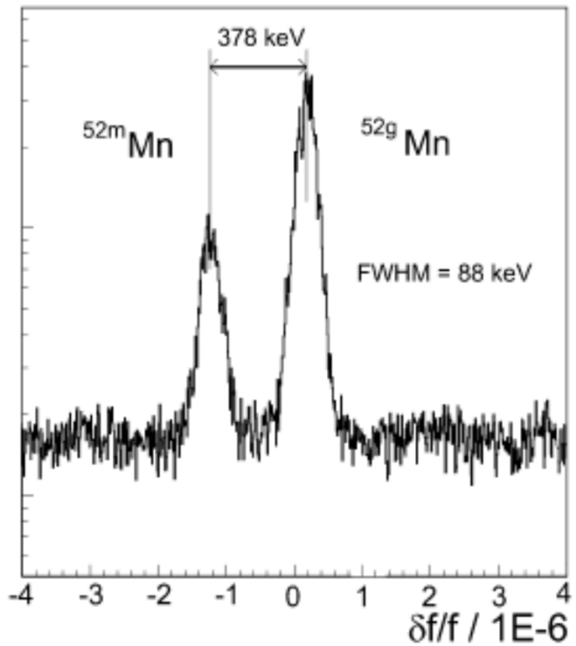
Experimental Storage Ring (ESR), 60^0 bending magnet and straight internal target section

ESR Electron cooler, operating in a wide ion beam energy range, 3 – 490 MeV/u

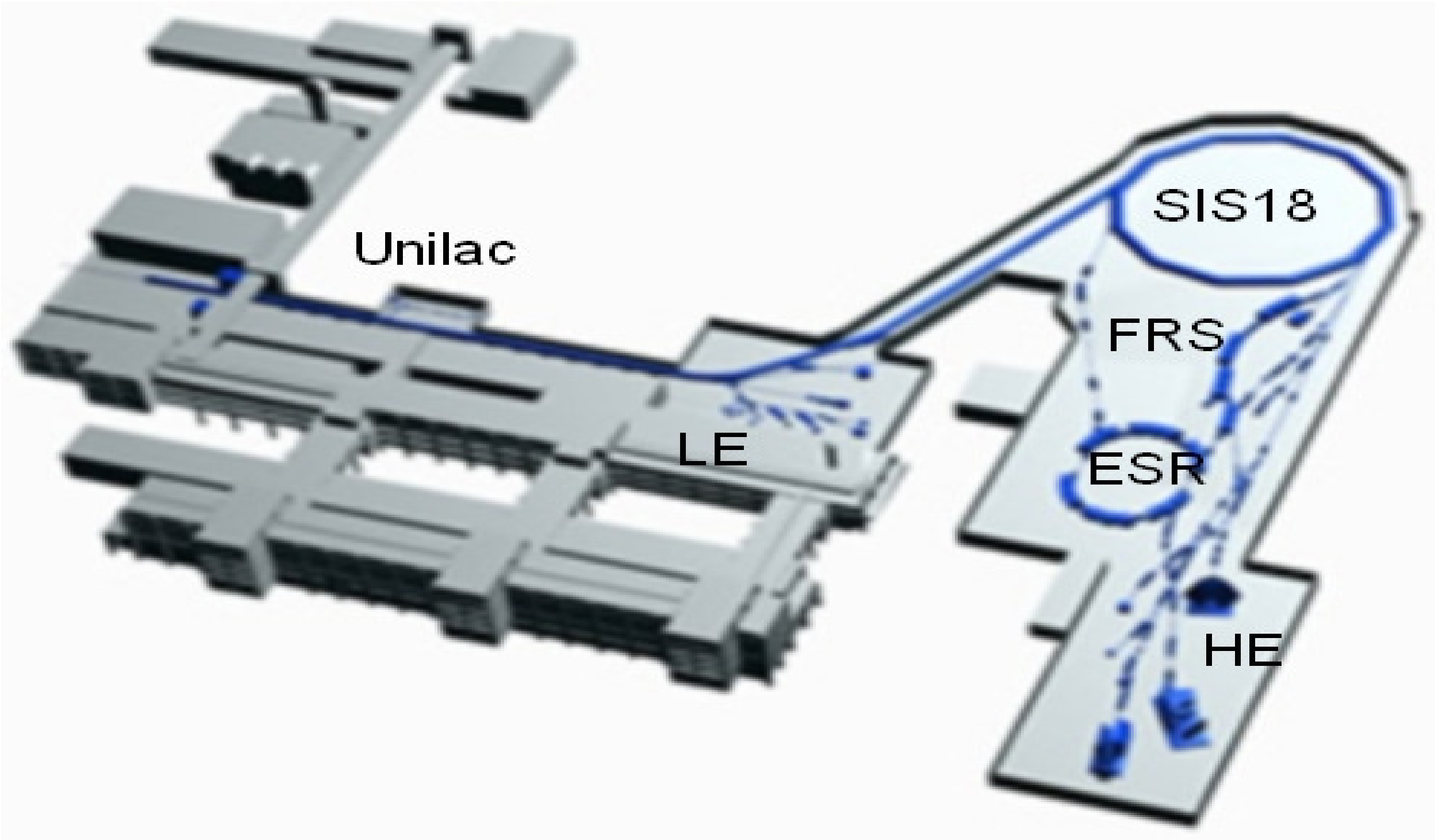
Impressing demonstrations of electron beam cooling in the ESR



Experimental momentum spread plotted against the number of stored ions in the ESR for fully stripped electron cooled uranium ions at 360 MeV/u.

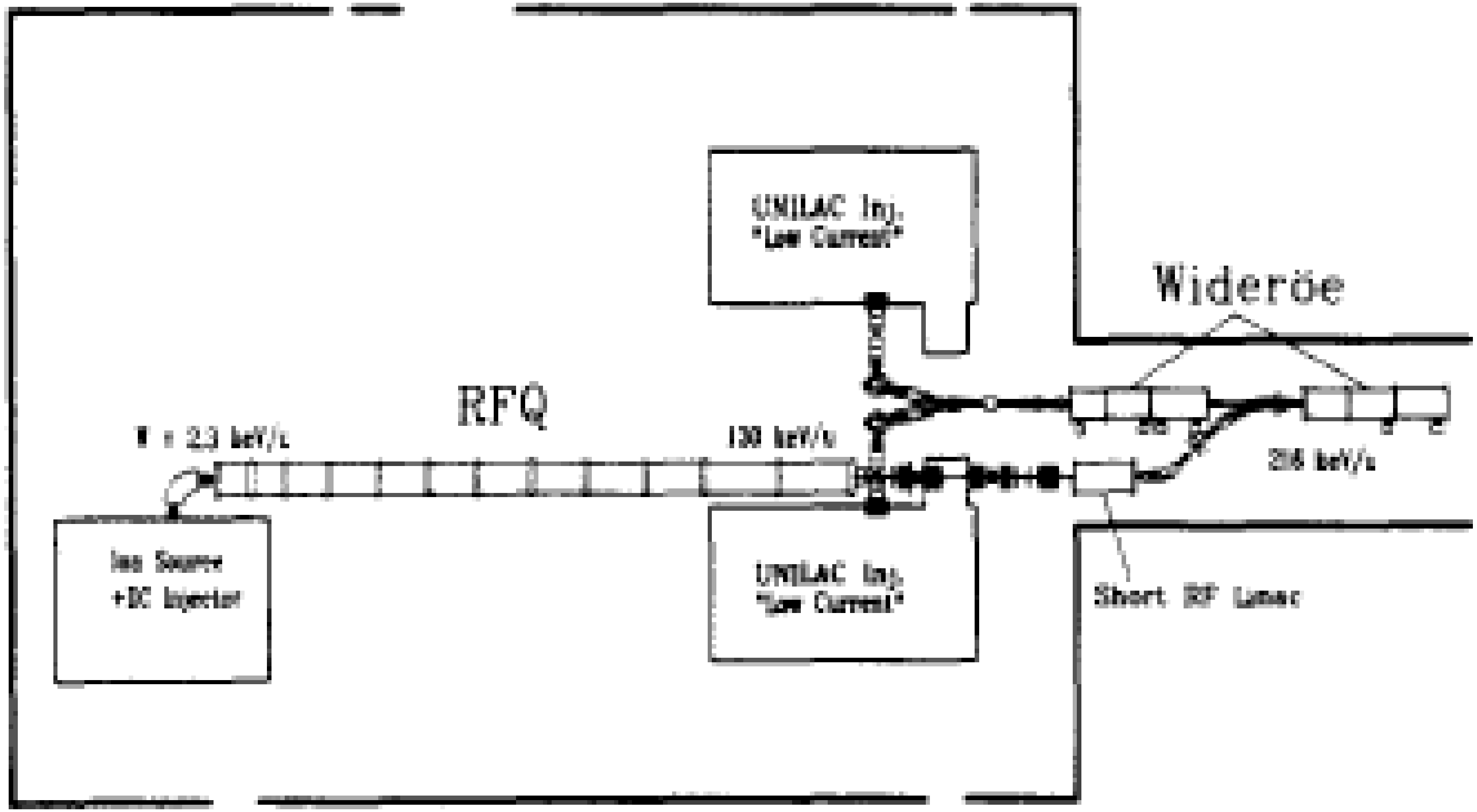


High-resolution mass spectra of electron cooled ^{52}Mn ions at the ground (right) and isomeric (left) states in the ESR



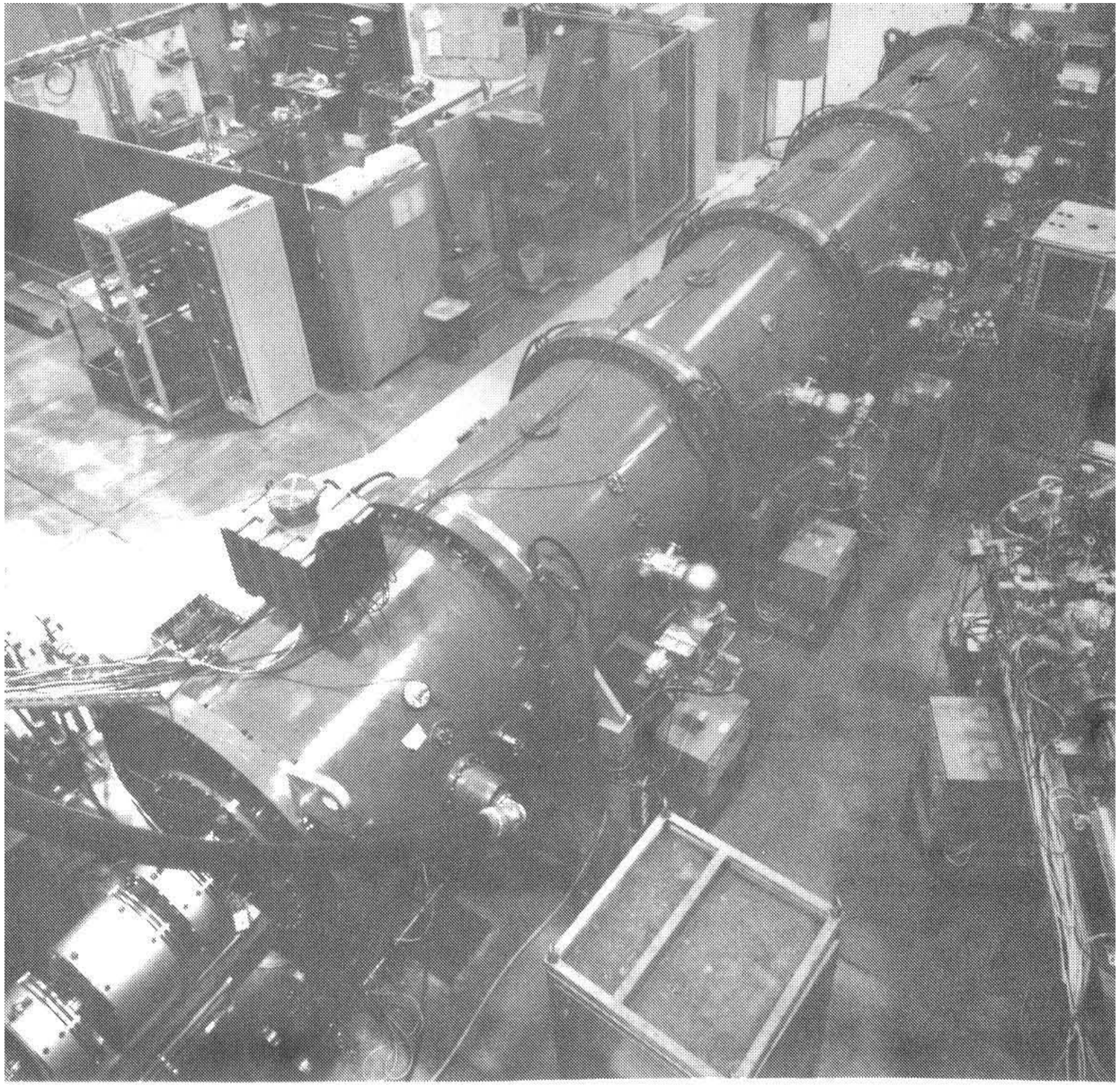
SIS/ESR project

Proposal autumn 1984
Approval April 1985
Start construction in autumn 1986
1st turn in SIS18 November 1988
2 GeV/u Ne beam in SIS18 summer 1989
E-cooled Ar beam in ESR spring 1990



New high current injector project, status 1986.
The last of a half-dozen high current injector proposals to achieve 100 times higher intensities for the heaviest ions.
Was not realised within the SIS/ESR project

Front end of the planned high current injector

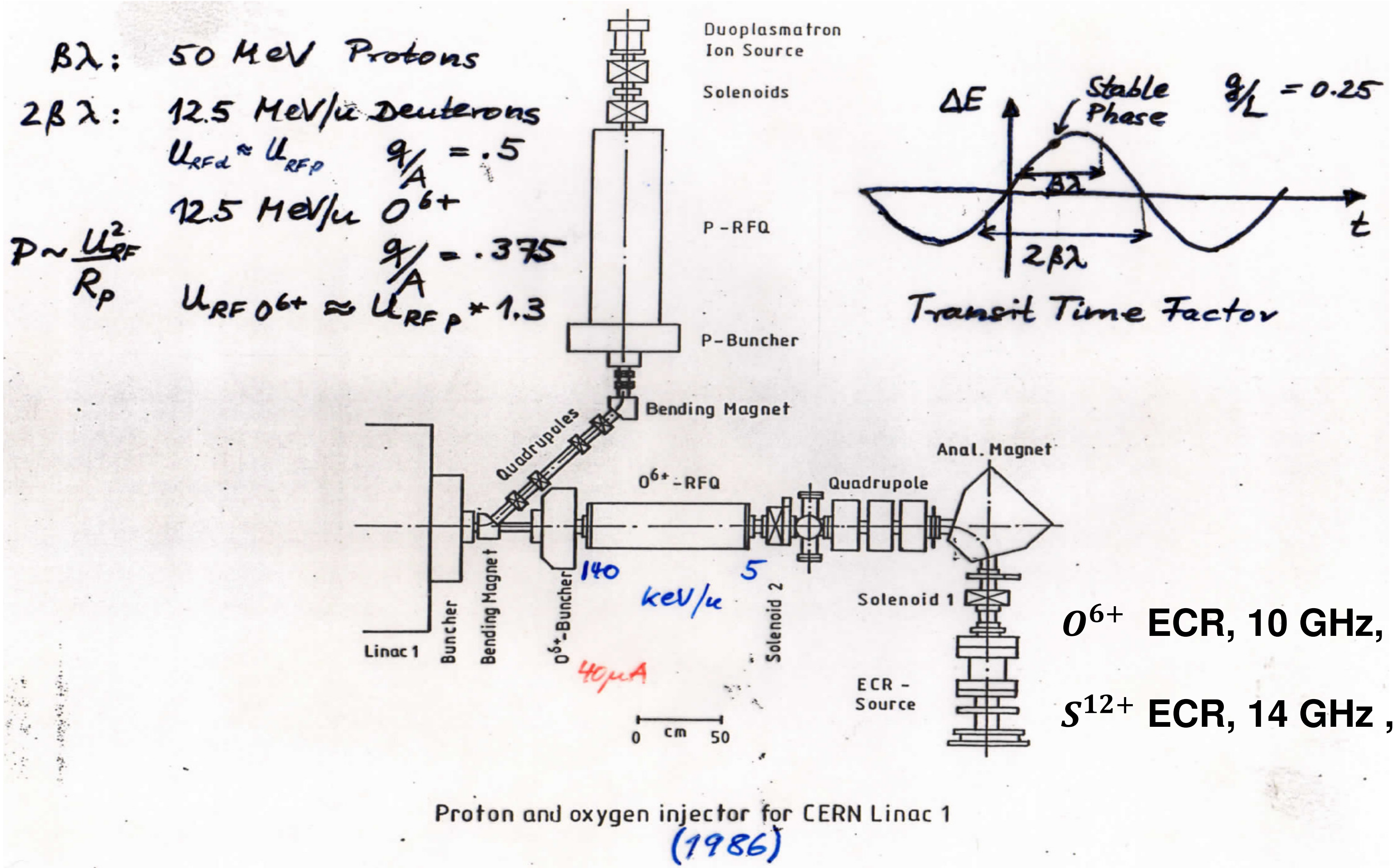


Five out of 12 modules of the so-called MAXILAC had been already built for the acceleration of U^{2+}.

After stripping, inflection into the 2nd Wiederöe tank (216 keV/u) should follow.

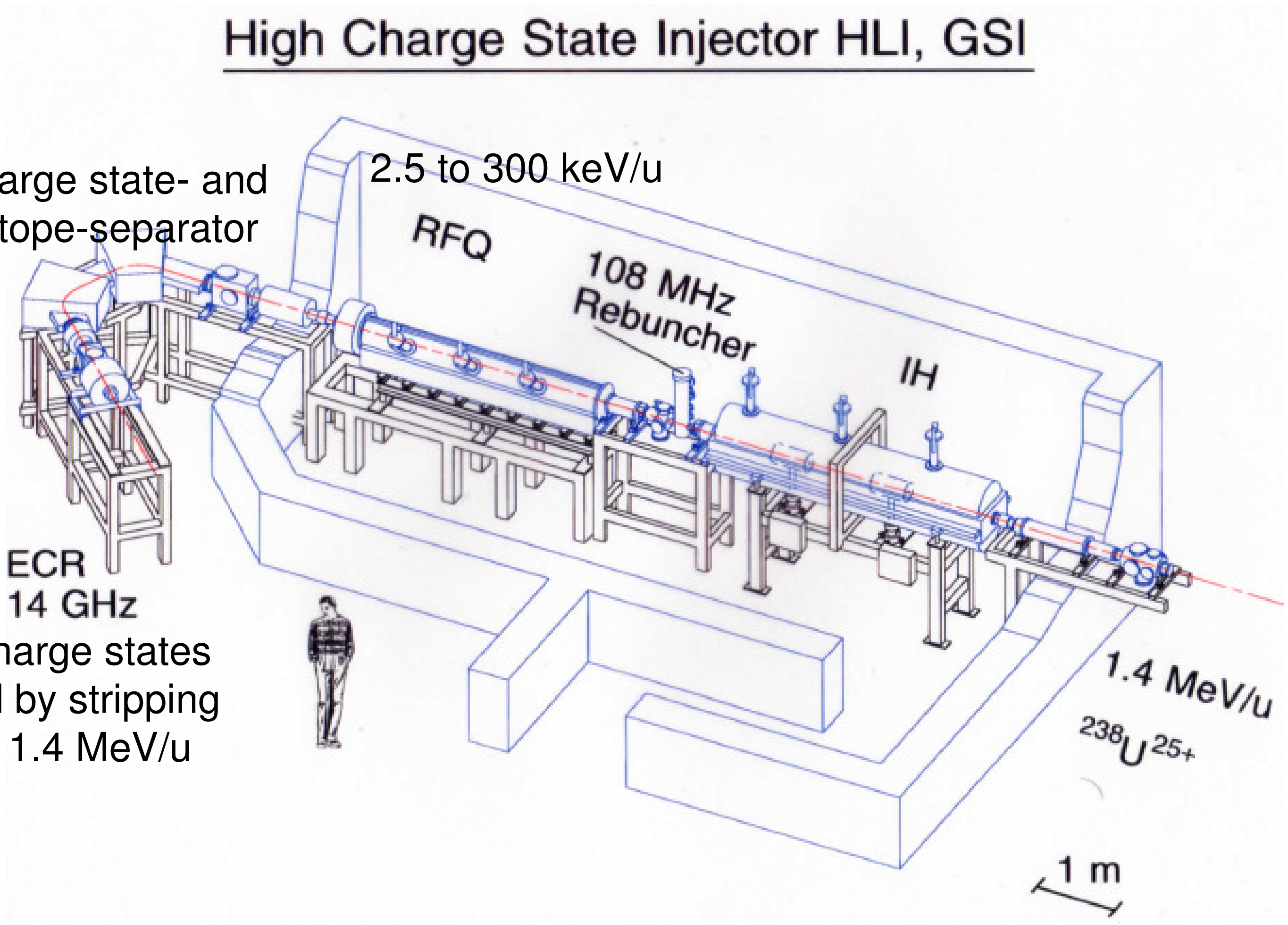
However, tests showed, that the expected intensity gain was out of reach: Emittance growth, partially compensated space charge.

Way out:New post-stripper injector with CERN O/S ECR experience.



O^{6+} ECR, 10 GHz, 1986

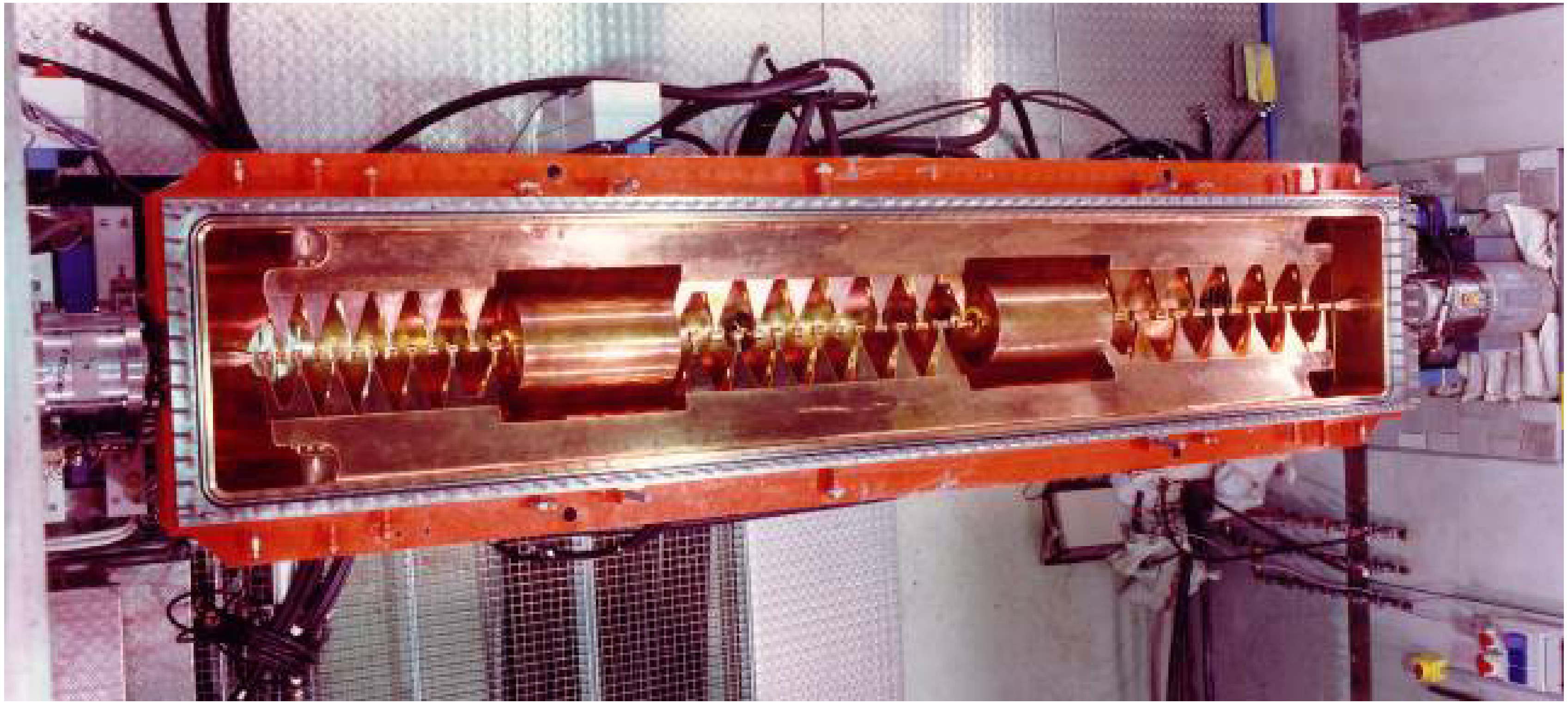
S^{12+} ECR, 14 GHz , 1987



Produces charge states as achieved by stripping in gas-jet at 1.4 MeV/u

Allows fast switching between two ion species in the post-stripper linac

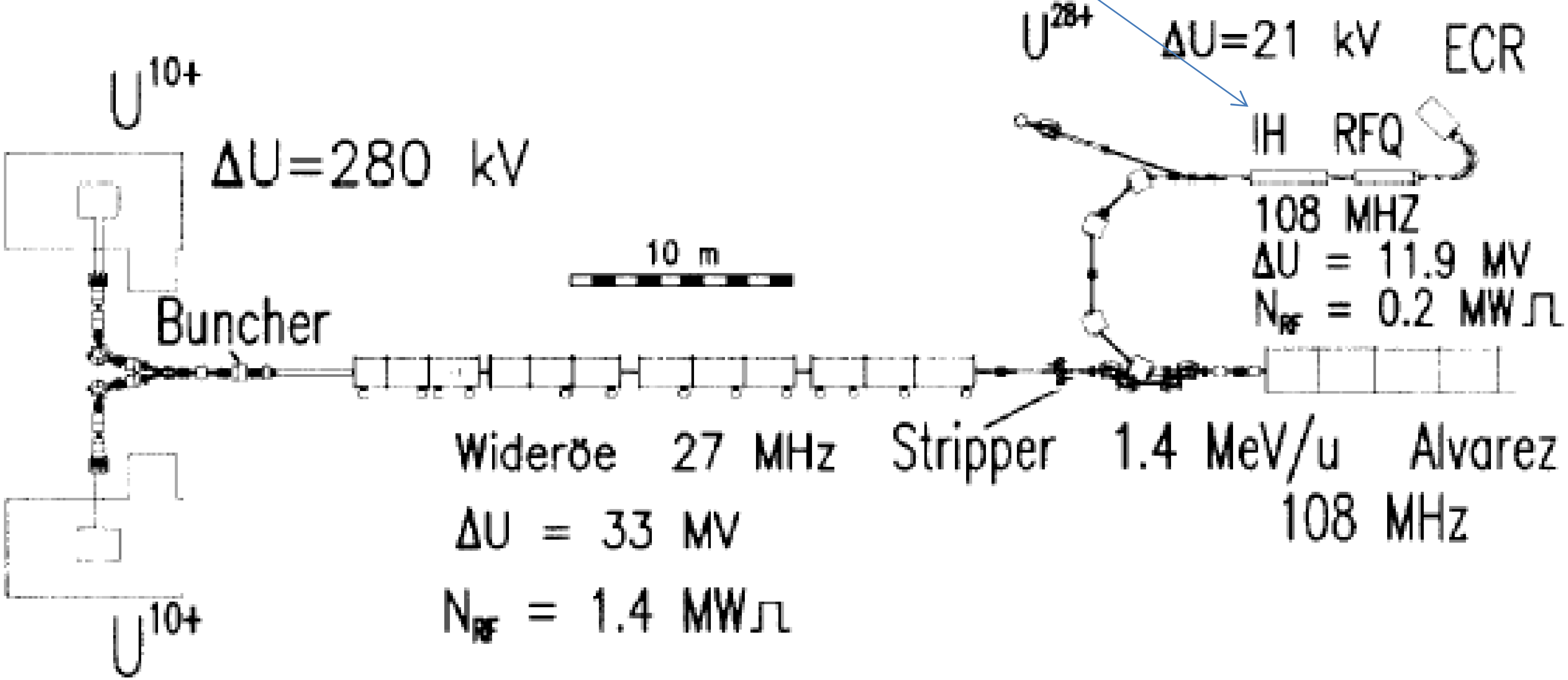
108 MHz IH structure of the High Charge State Injector,
.3 to 1.4 MeV/u, 10.3 MV, 140 kW, 50% duty cycle



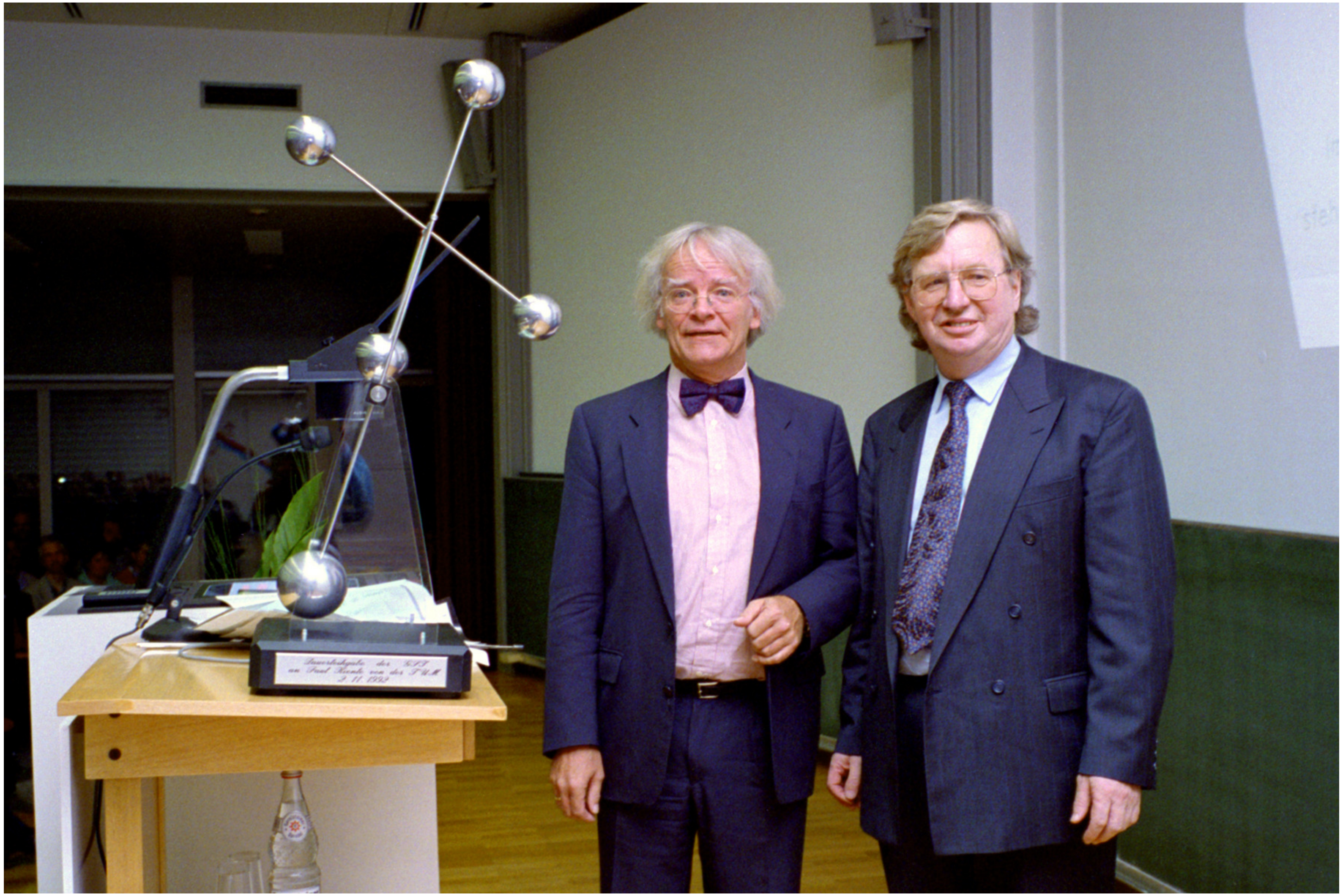
First IH structure with internal triplets (U. Ratzinger).

High charge state injector,
in operation since mid 1991

Beams for
Z = 110 to 112

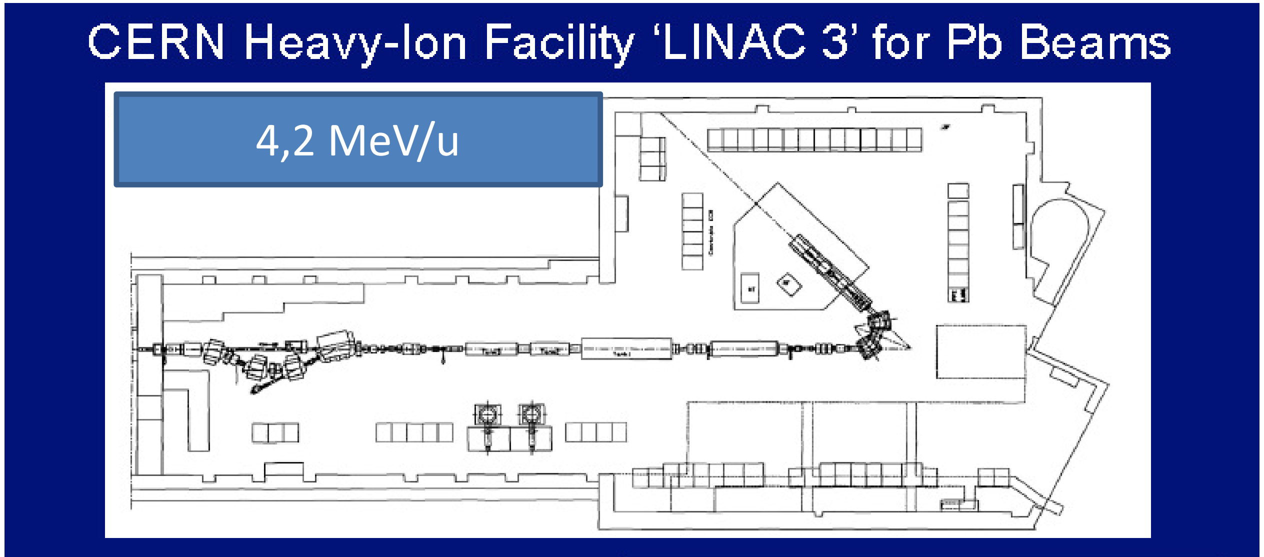


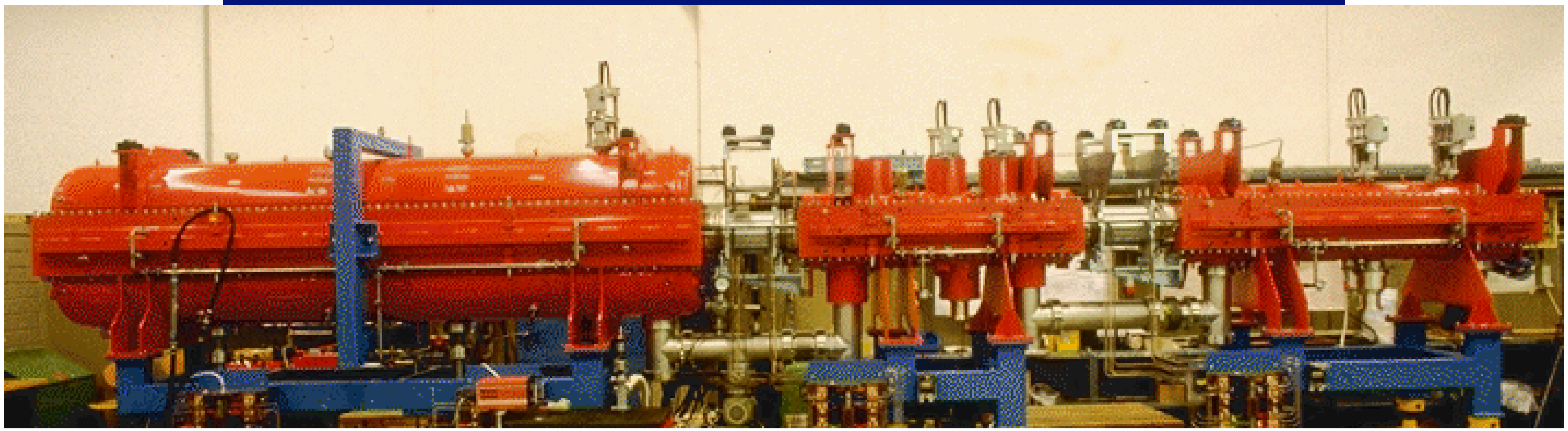
Beams for
Z = 107 to 109



Hans Specht, Scientific Director 1992 to 1999, saying good-bye to Paul Kienle

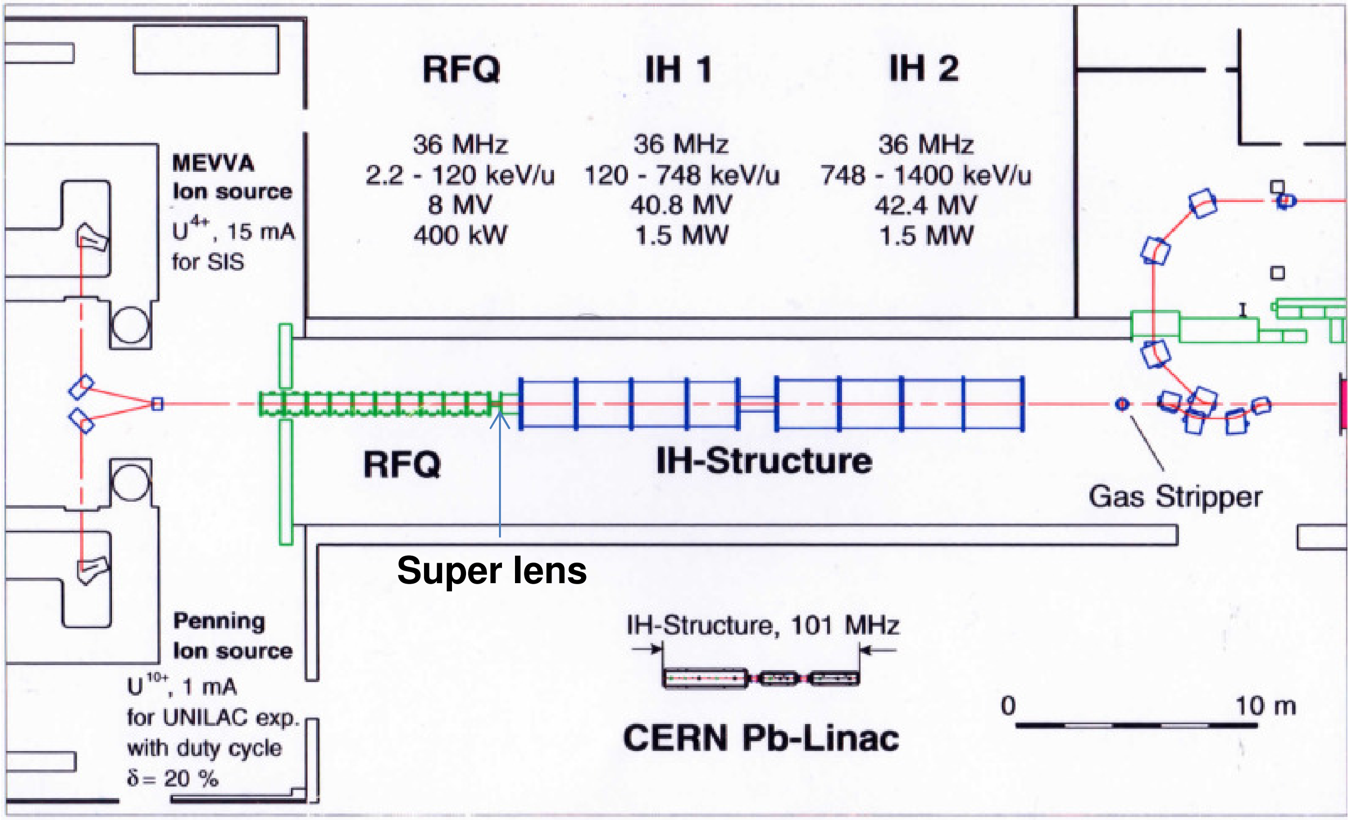
CERN Linac 3, 33 MV, 1% duty cycle





GSI contribution to CERN Pb-linac:101 / 202 MHz IH linac, in operation since 1994

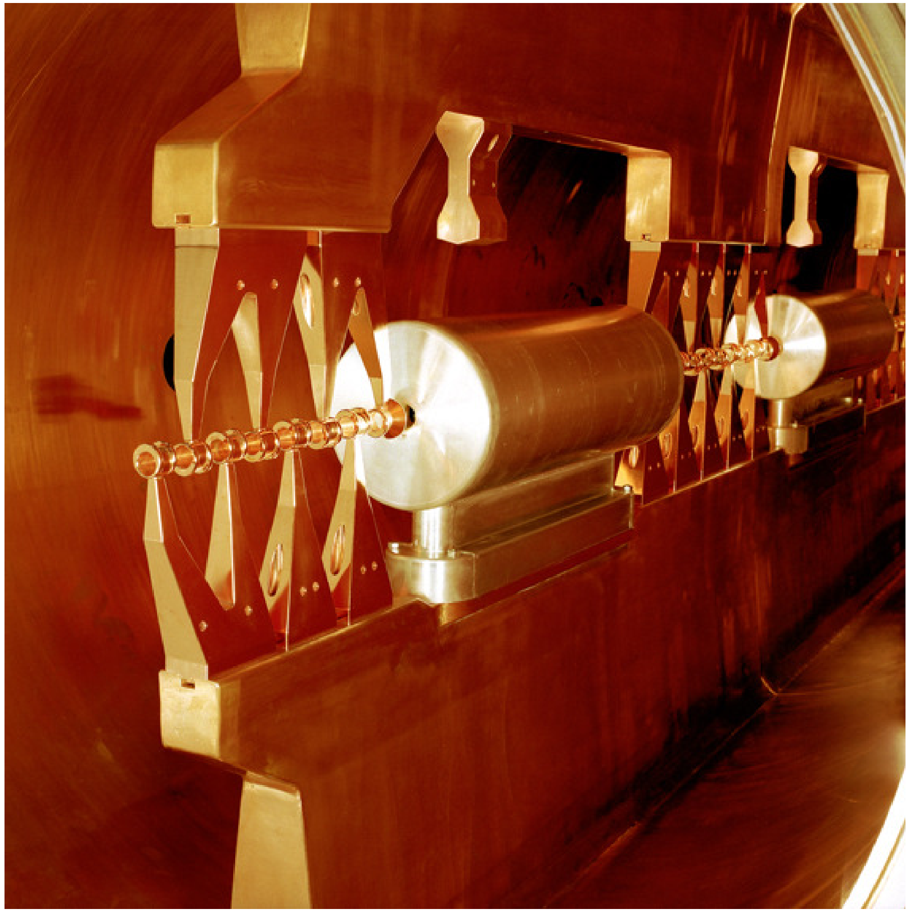
Replacement of the Wideröe pre-stripper structure by an IH High Current Linac



17. Dec.1998	Last beam from the Wideröe structure
March 1999	Beam injection into the 2.2 keV/u transport line
28. April	Acceleration by the IH-RFQ
31. May	Beam injection into the Super Lens
22. July	Acceleration by the IH 1
06. Sept.	Acceleration by the IH 2, beam transport to the stripper
February 2000	U4+ beam from the MEVVA

GSI High Current Injector, allowing two beam prestripper operation, 10 Hz/100µs, A/q = 65; 50 Hz/5ms, A/q = 26

Celebrating completion



In operation since 1999, 36 MHz IH structure, 15 mA U^{4+}, 91 MV

It was no secret that Hans Specht saw the future of relativistic heavy ion physics at CERN

But:

He saw potential for the application of energetic heavy ions at GSI on the following two fields:

- Heavy Ion Fusion
- Cancer Therapy

Heavy ion fusion, as indicated before, is a business with large linacs and rings, and low charge state ions.

Cancer therapy calls in several respects for specific requirements to be fulfilled at an existing accelerator facility for fundamental research .

Dealing with large rings
for heavy ion fusion triggered
also new ideas for their
potential use in basic research

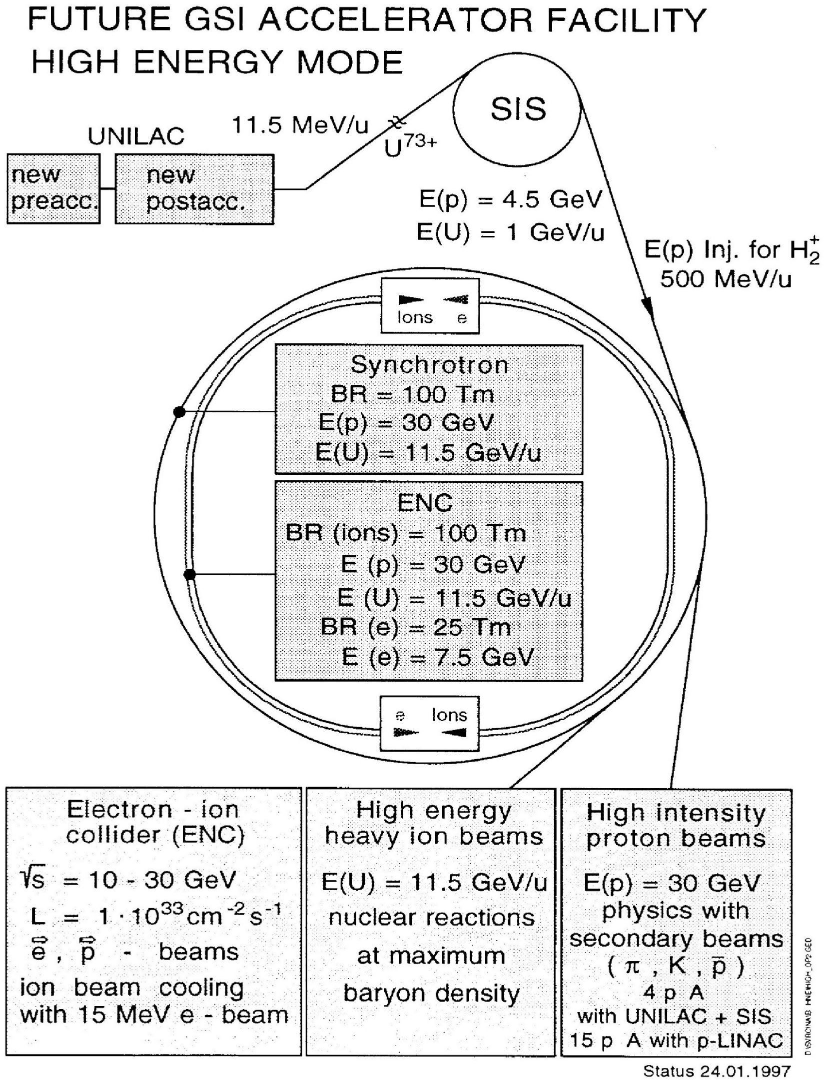


Figure 1: The *high energy* scenario: The accelerator and beam parameters are indicated as well as the research fields which would benefit from this mode of accelerator operation.

Status of discussions 1997

Specific requirements to be fulfilled at the existing accelerator facility for cancer therapy

Up to mid 1990s accelerator operation with **16 'virtual accelerators' could be provided** for a change of beam parameters (energy, intensity,..) from pulse to pulse.

Ion species:	C^{6+}
Injector:	High charge state injector
Ion energy	80 …..430 MeV/u
Extraction time	2s
Beam diameter	4……..10mm(hor./vert.)
Max. position deviation	1mm

Energy steps	**255**
Intensity steps	**15**
Beam diameter steps	**7**

Realized in the years 1995 to 1997

Benefits from the upgrade of the accelerators for save therapy operation

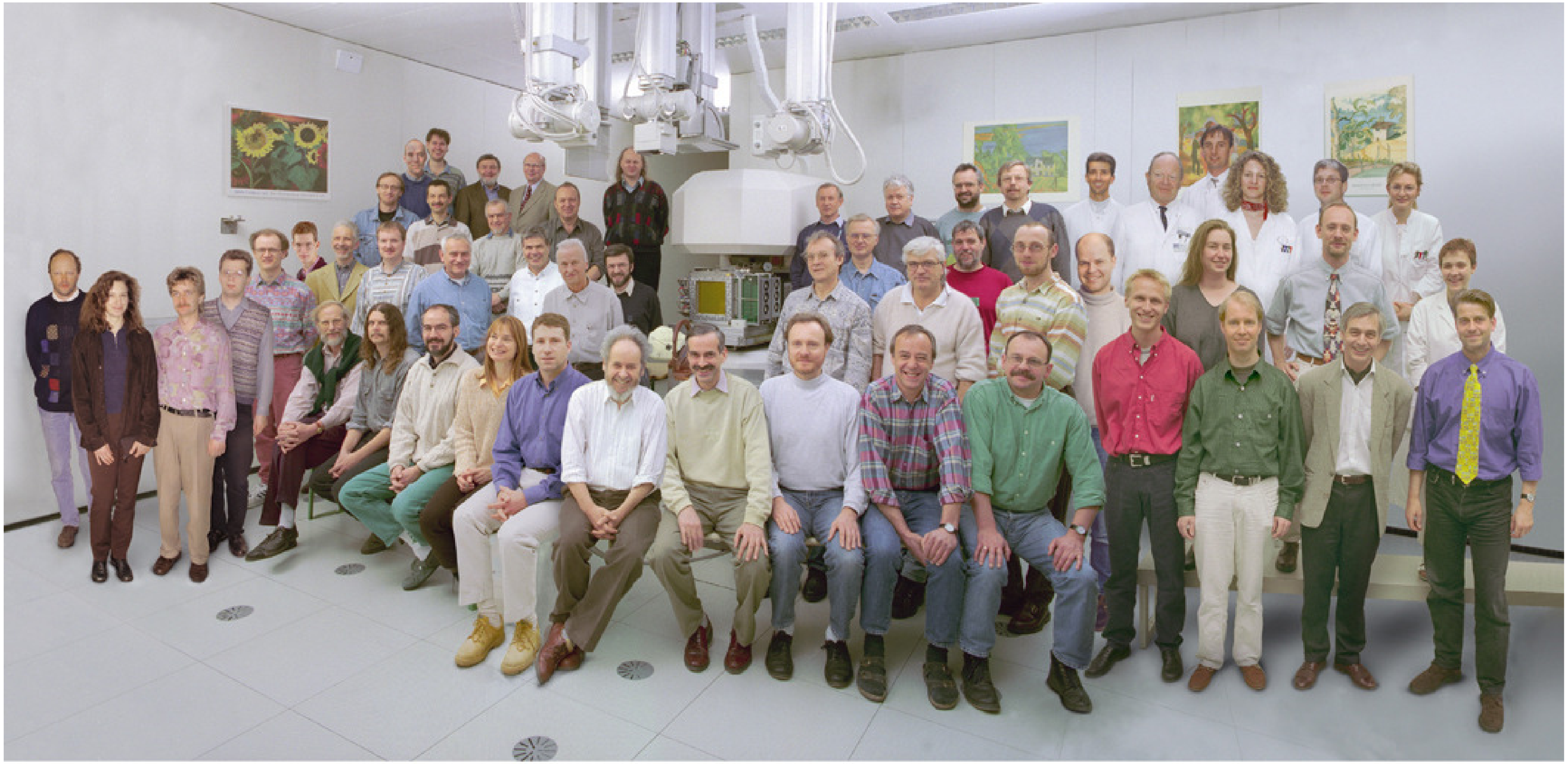
- Reproducibility was a must, not only from shot to shot, but also from each irradiation session to the following
- Precision was a must
- That meant the way from the ECR ion source to cave M, the patient, had to be under full control
- Complete understanding of all changes on this way as e. g. movements of shieldings, neighbouring magnet fields, was a must. All data had to be documented because of the special rules for patient treatment
- Improvement of the spill structure for slow synchrotron extraction (macro- and micro-structure) by special measures
- All these measures lead to a great improvement of performance for all
- **Story**: At the day of the first patient treatment GSI was a forbidden area for persons not involved. The IT-boss stopped the GSI internet connection

Additional positive results and effects

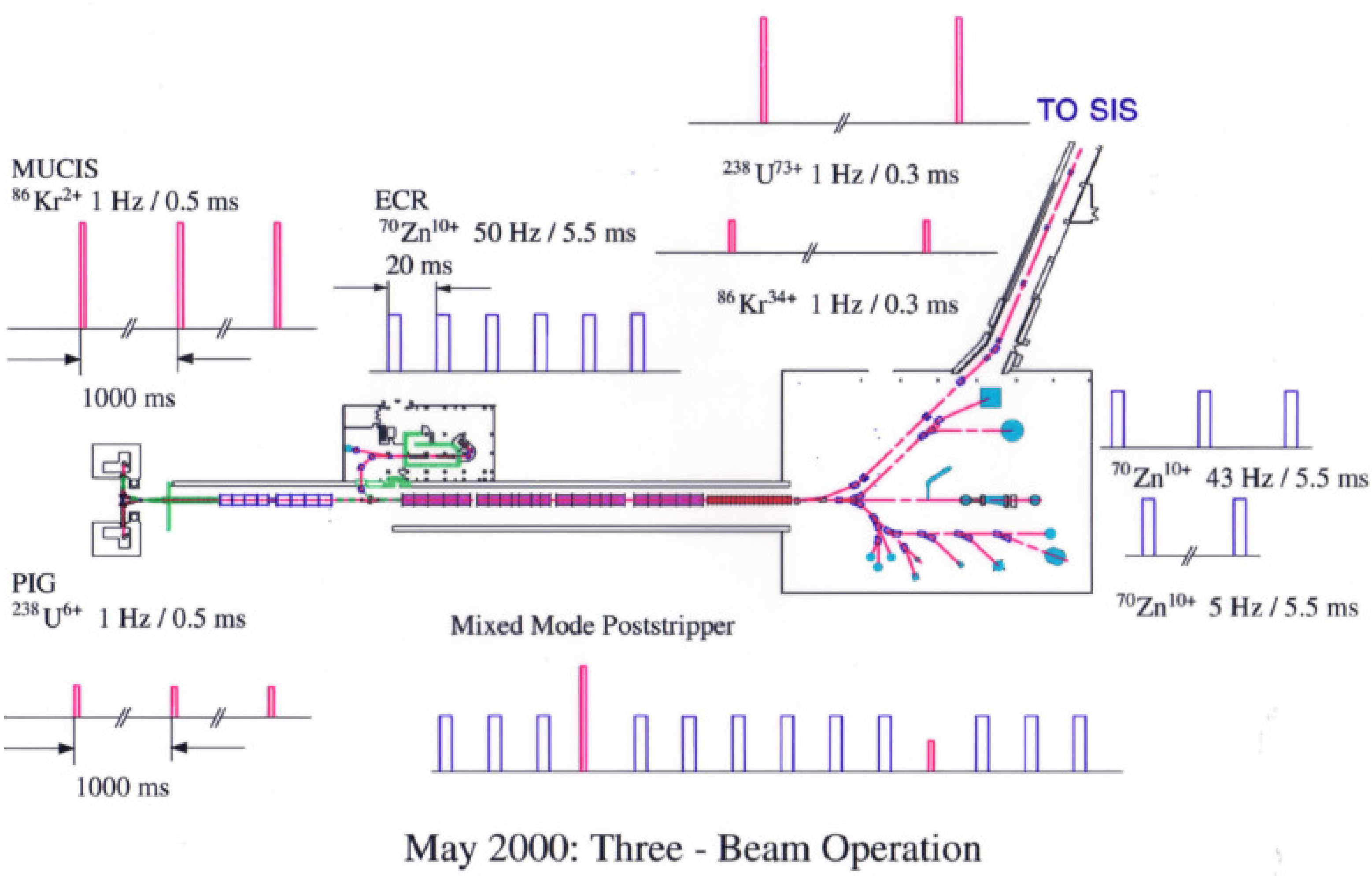
- No accident in all the years since 1997
- Public and politics were deeply impressed, also by
- Technology transfer to industry
- Therapy did not affect or kill the research program (was a great concern previously)
- Both, operation for experiments and patient treatment, was run successfully in parallel
- Very good example for interdisciplinary cooperation, inside and outside GSI

Remember for the „Story of FAIR“ in 20 years

Cancer therapy with ion beams



Heavy-Ion Therapy at GSI
Collaboration: FZ Rossendorf - GSI Darmstadt - Radiol. Klinik Heidelberg - DKFZ Heidelberg



Presenting the accelerator layout for FAIR to the committee of the Wissenschaftsrat in autumn 2001 special emphasis was put on the importance of the flexible Unilac Three-Beam Operation for independent experiments at the Unilac, SIS and ESR.

Some private remarks, when looking back over the 40 years I was involved in that story

The story of the GSI accelerators is a story of :

Fortunate decisions
There were other proposals on the market in the 60ties: Synchrotron, cyclotrons, etc. studied carefully at that time with respect to the requirements and future perspectives

Fortunate incidents and coincidences

New developments occuring/being available at the right time

Fortunate cooperations

GSI was lucky with directors, capable individuals and teams on all levels

In this sense, best wishes for the GSI-FAIR future.

Thanks to

L. Dahl
H. Eickhoff
E. Malwitz
B. Franczak
B. Franzke
I . Hofmann
G. Otto
H. Ramakers
U. Ratzinger

for their help in recalling events to my mind and contributing and supplementing memories or/and photos