Advanced beam dynamics simulations with the DYNAMION code for the upgrade and optimization of the GSI-UNILAC

S. Yaramyshev, W. Barth, G. Clemente, L. Dahl, L. Groening, S. Mickat, A. Orzhekhovskaya, H. Vormann, GSI, Darmstadt;

A. Kolomiets, S. Minaev†, ITEP, Moscow;

U. Ratzinger, R. Tiede IAP, Frankfurt

DYNAMION code

- has been written in Institute for Theoretical and Experimental Physics (ITEP, Moscow) for the simulations of the beam dynamics in high current linacs (1985);

- development since 1993 was supported by GSI Helmholtzzentrum fuer Schwerionenforschung (Darmstadt)

- significant improvement during last years was done at GSI in collaboration with ITEP

High level of DYNAMION reliability was demonstrated by numerous comparisons of measured data and simulated results for the operating linacs in ITEP, GSI, CERN, INFN, ANL and other leading centers

S. Yaramyshev et al, "Development of the versatile multi-particle code DYNAMION", Nuclear Inst. and Methods in Physics Research A, Vol 558/1 pp 90-94, (2006)

E-mail: S.Yaramyshev@gsi.de

Main features

- time integration of **3-D equation of particle motion** in the most common form;

- **end-to-end** simulations of beam dynamics in a linac, consisting of the arbitrary sequence of the RFQs, DTLs and transport lines can be done **in one run;**

- **external** electrical field in an RFQ and DTL is calculated inside the code solving the Laplace equation **for the real topology** of the elements;

- **transport lines** may include magnetic and electrical lenses (quadrupole, octupole, etc.), bending magnets, solenoids, slits, steerers, apertures, stripper sections, etc ...

Can be used in the code:

- **external** electromagnetic fields, **measured** or **simulated** by special codes;

- **multi-charged** beam (particles with different mass to charge ratio);

- input particle distribution from **measured emittance** or other calculations;

- **misalignments** of the elements.

Space charge solvers

3-D space charge treatment:

- Particle-particle interaction with a special routine to avoid artificial collisions;

* Special treatment of continuous beams and of the bunching process.

- PIC solver (*T. Tretyakova, ITEP, Moscow).*

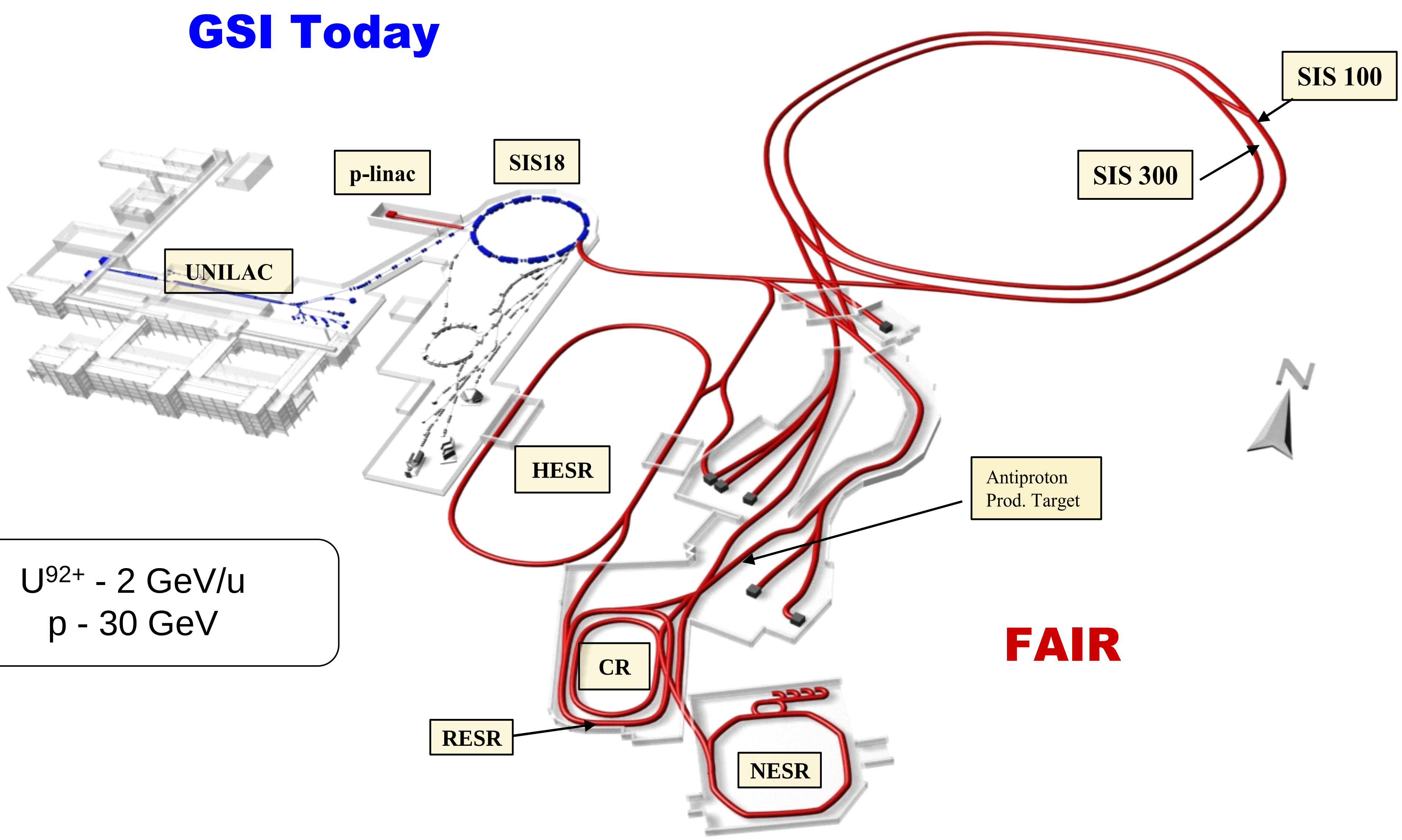
- Semi-analytical solver (*A. Orzhekhovskaya, GSI, Darmstadt).* *TUO2A02*

Analysis of the results:

- each particle has an **unique ID-number**, i.e. a detailed analysis of its trajectory is available;

- local **phase advance** for each particle can be calculated in parallel with the beam dynamics simulations.

Facility for Antiproton and Ion Research at Darmstadt

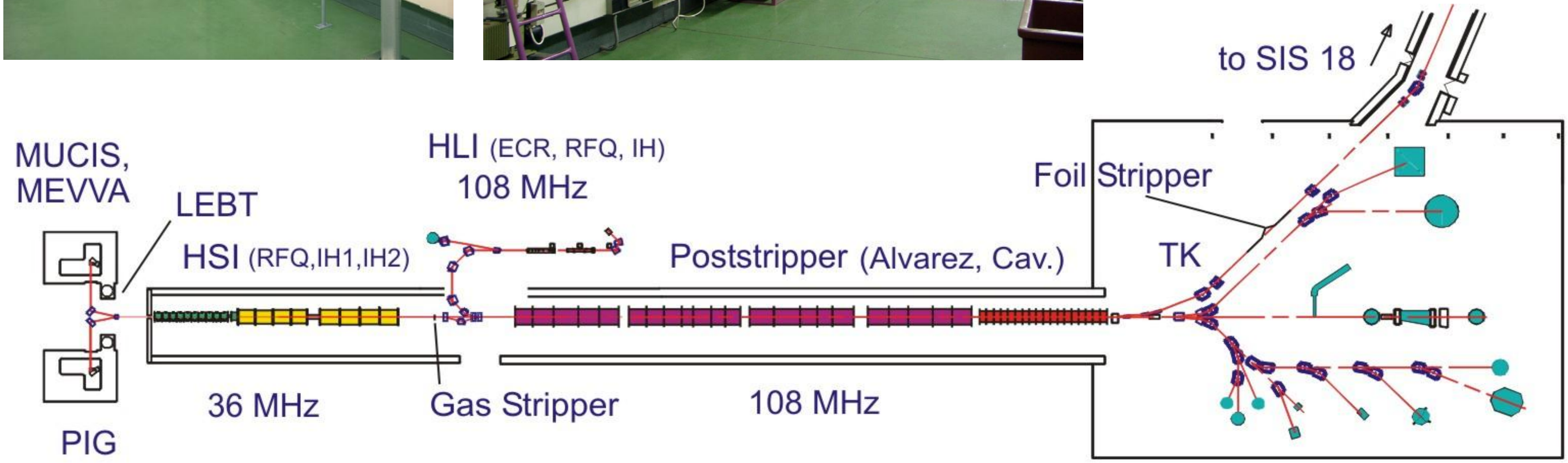


U^{92+} - 2 GeV/u
p - 30 GeV

UNIversal Linear ACcelerator

An injector for FAIR

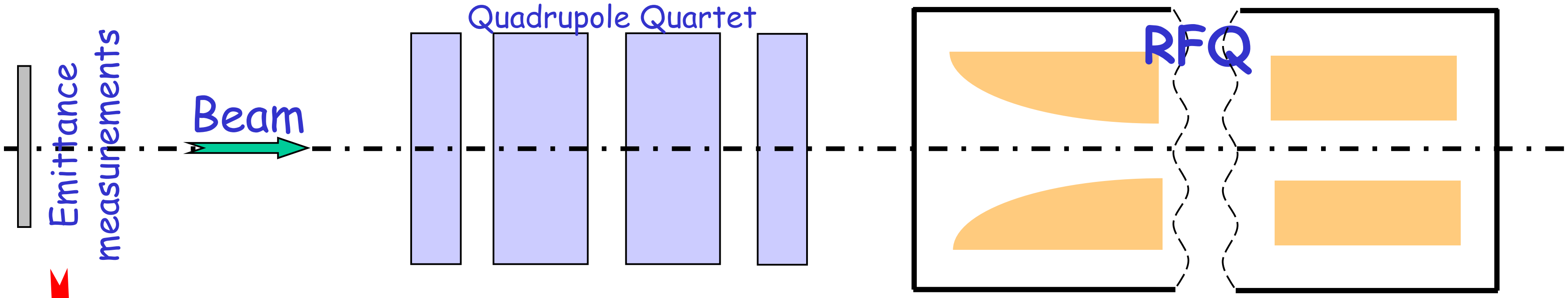
An increase
of the beam brilliance
up to a factor of 5
is required



Status of the UNILAC front-end before upgrade in 2004

Design beam current behind RFQ (1999)

15 mA



No space for beam diagnostics !

measured U^{4+} beam current 15 mA

Measured beam current behind RFQ

8.3 mA

- particle distribution: measured emittance
- measured gradients in quadrupoles
- realistic electrical field in the RFQ
- measured voltage in the RFQ
- measured RFQ misalignments

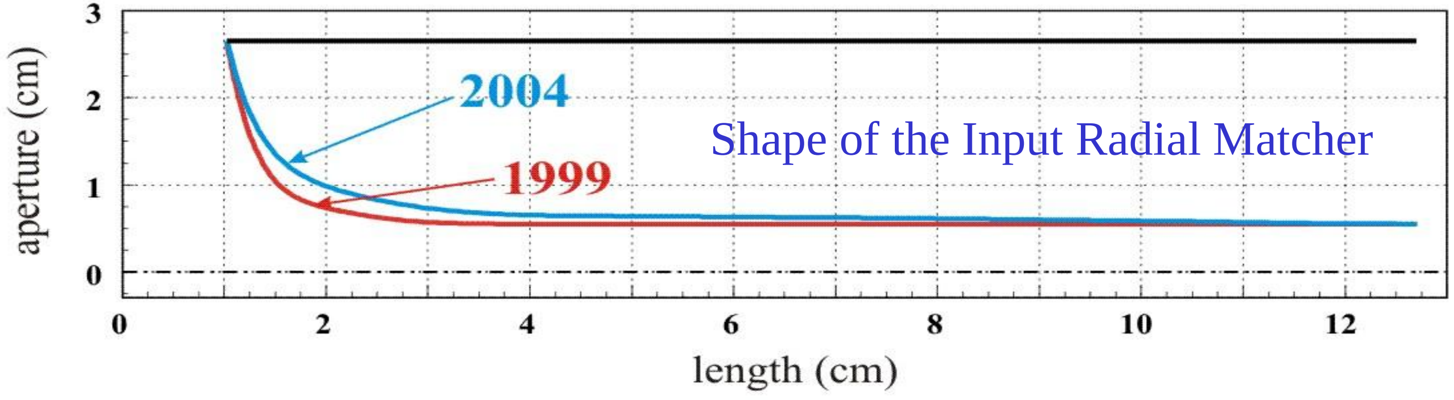
Calculated beam current behind RFQ

8.7 mA

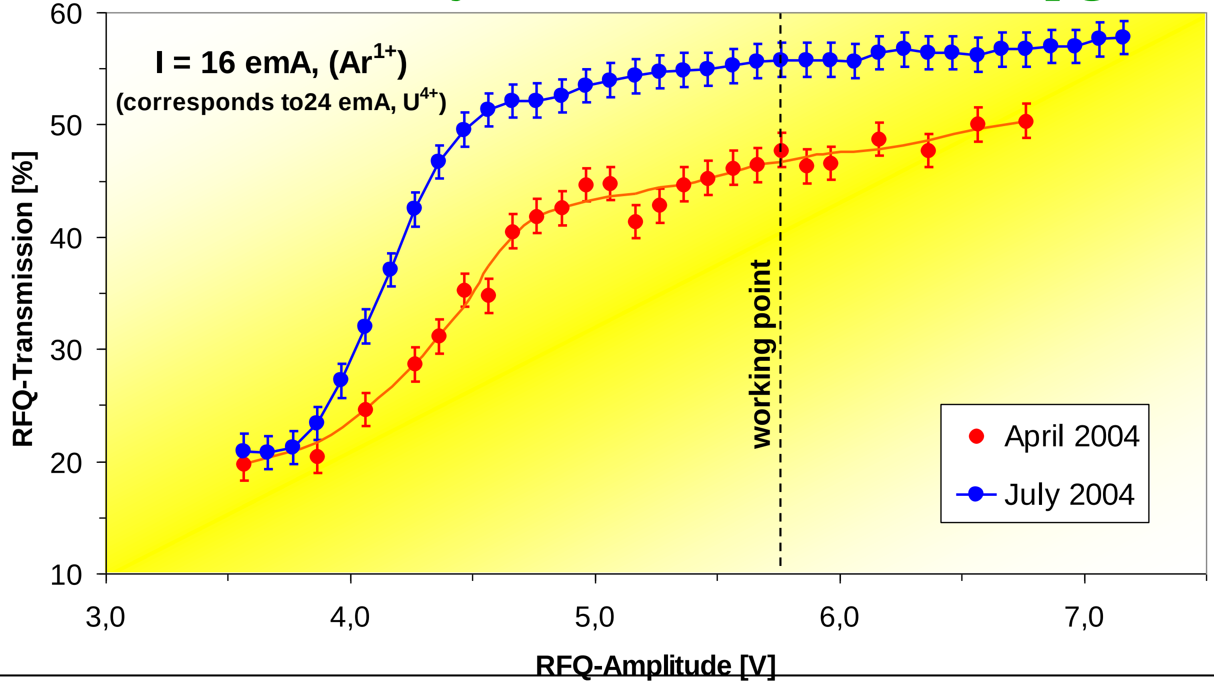
Upgrade 2004

≈10 cm *(HSI-RFQ length is 9.3 m)*

Heavy Ion
High Current
GSI-HSI-RFQ

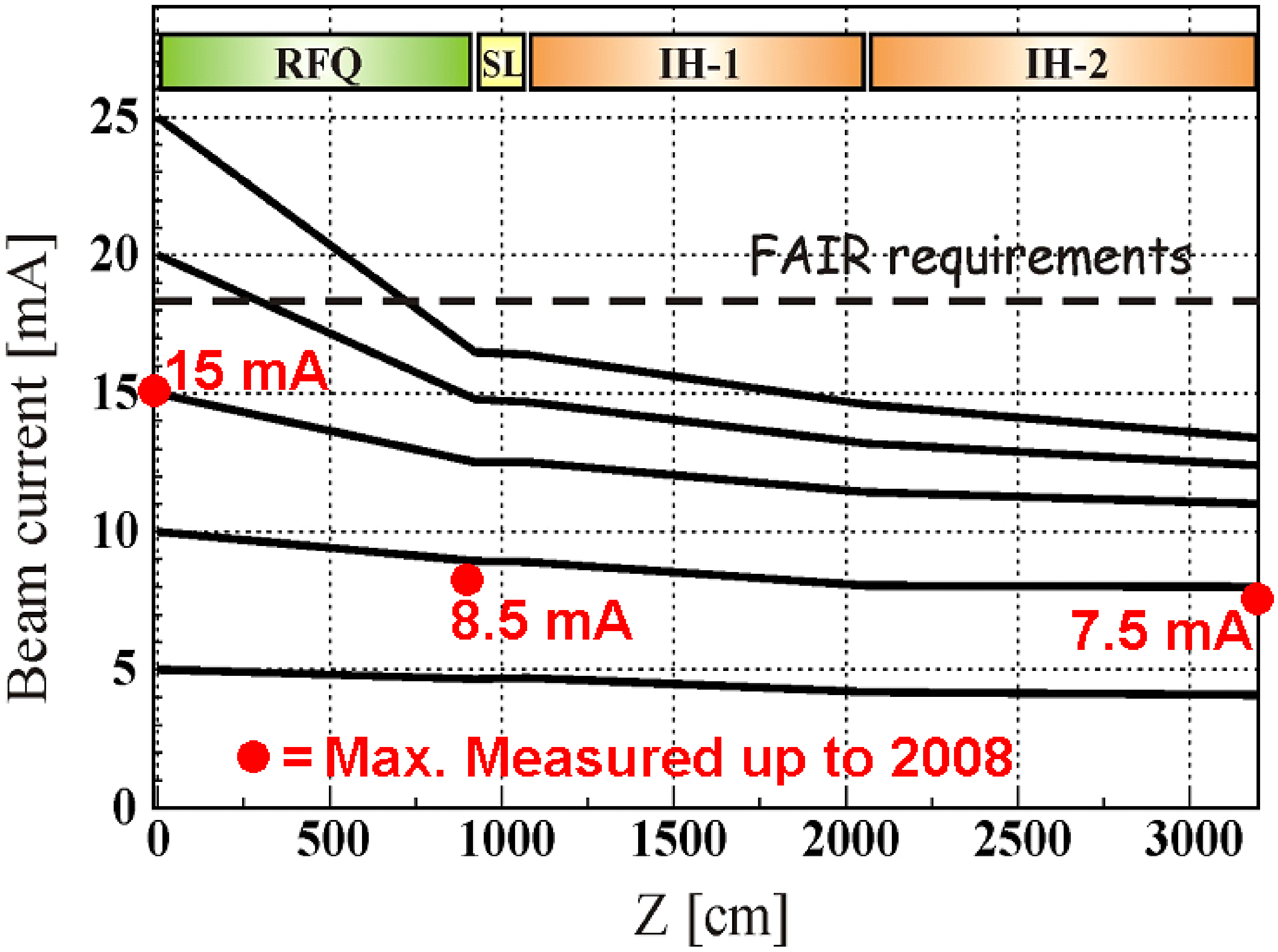


The predicted increase of particle transmission (≈15%) confirmed by measurements after upgrade



Beam current along High Current Injector (HSI)

U^{4+} beam; 2.2 keV/u - 1.4 MeV/u



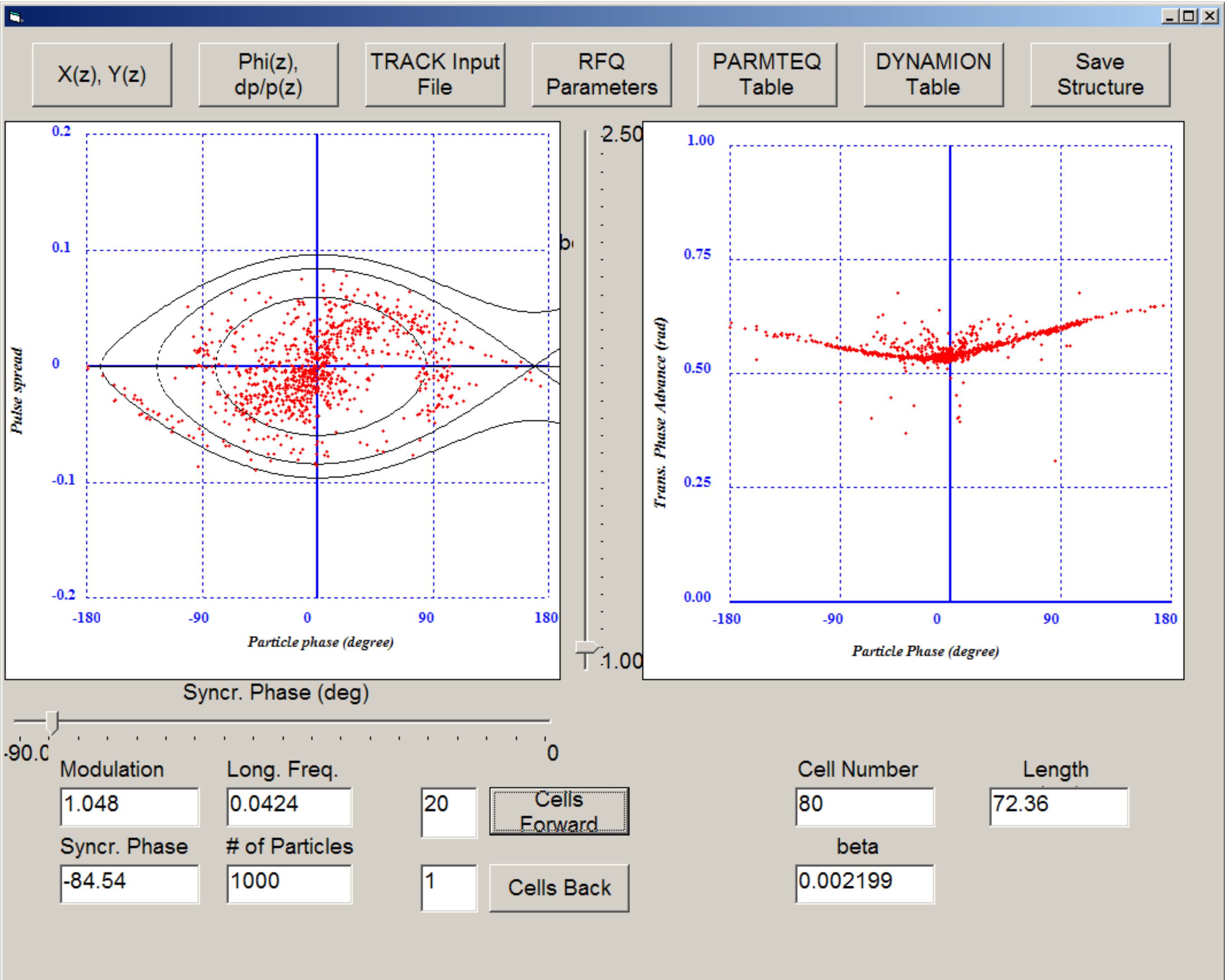
An essential upgrade of the RFQ electrode profile is necessary.

DESRFQ – a Code for Design of Radio Frequency Quadrupole

A.A. Kolomiets, T.E. Tretjakova, S.G. Yaramyshev*
Institute for Theoretical and Experimental Physics (ITEP)
Moscow, Russia

** on leave from ITEP*

DESRFQ Window for Interactive Work

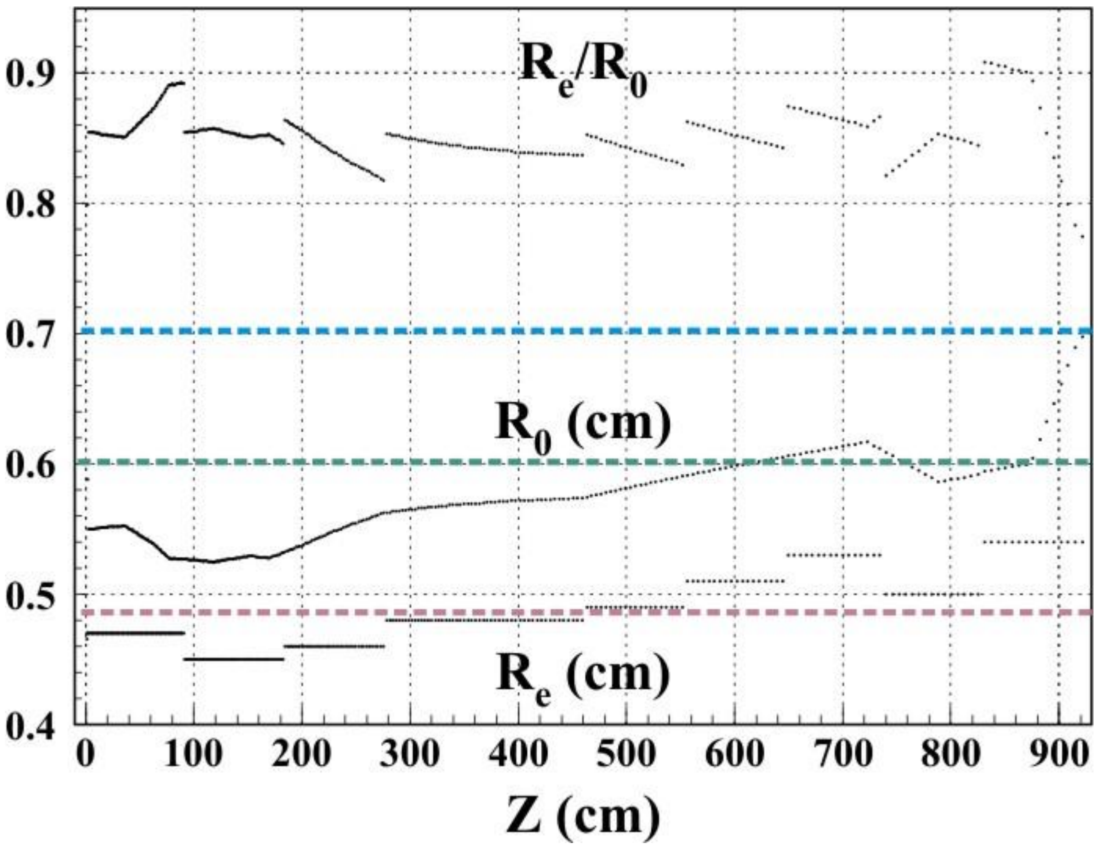


DESRFQ code is

- advanced
- interactive
- object-oriented
- visualized
- user-friendly

Main RFQ parameters

The baseline design was optimized for an U^{4+} beam current of 20 mA and an emittance of 280 mm*mrad



	New	Old
Voltage, kV	155.0	125.0
Average radius, mm	6.0	5.2 ÷ 7.7
Electrode width, mm	8.4	9.0 ÷ 10.8
Max. field, kV/cm	312	318
Modulation	1.012 ÷ 1.93	1.001 ÷ 2.09
Synch. Phase, degree	-90 ÷ -28	-90 ÷ -34
Average aperture, mm	4.1	5.5÷3.8÷4.8
Norm. transverse acceptance, mm*mrad	0.86	0.73
Electrode length, mm	9217.4	9217.4

Dedicated GSI - ITEP collaboration

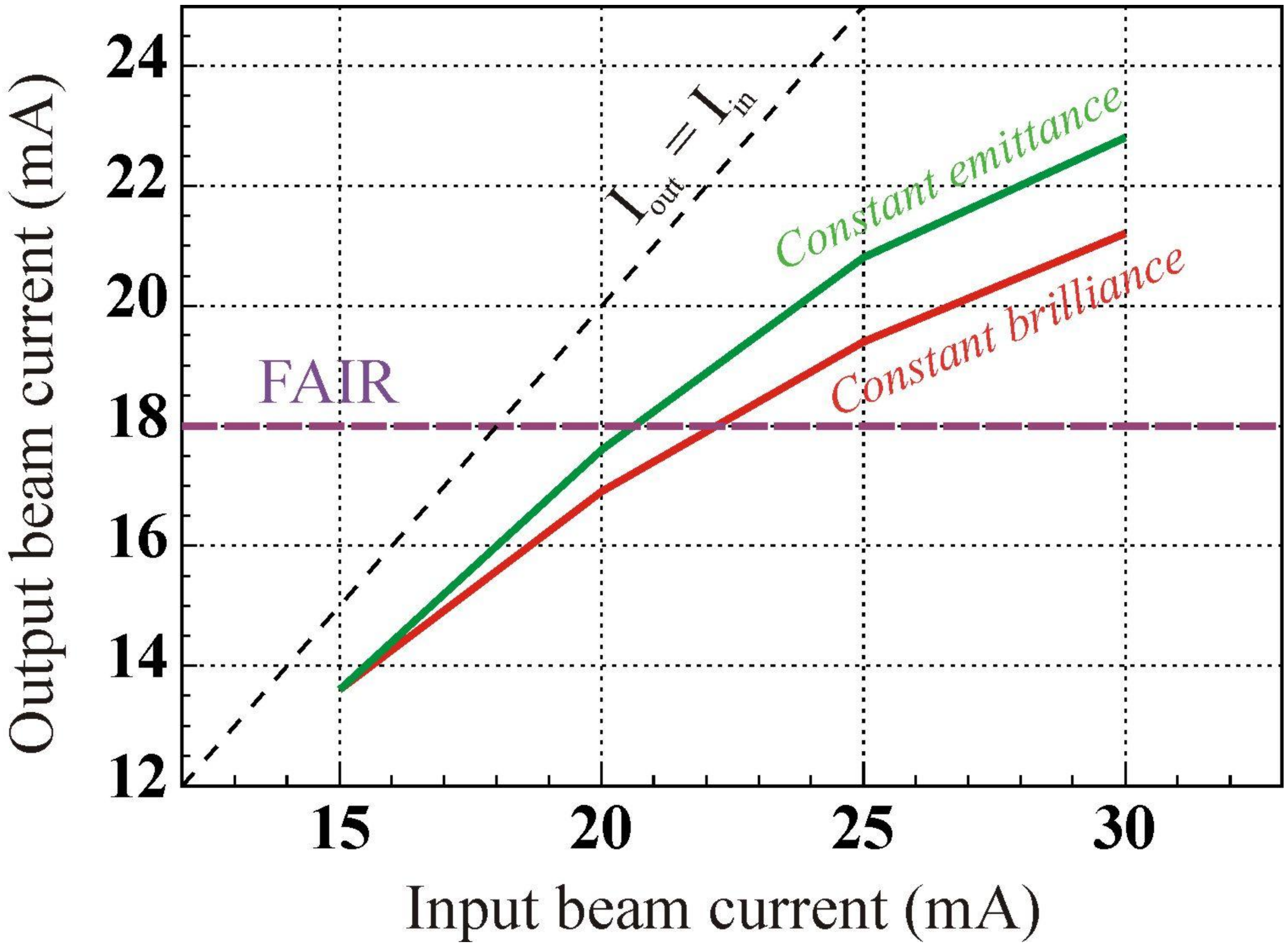
Four years INTAS Project

Performance of the new RFQ

Constant emittance
200 mm*mrad

Constant brilliance
15 mA / 200 mm*mrad

(measured data)



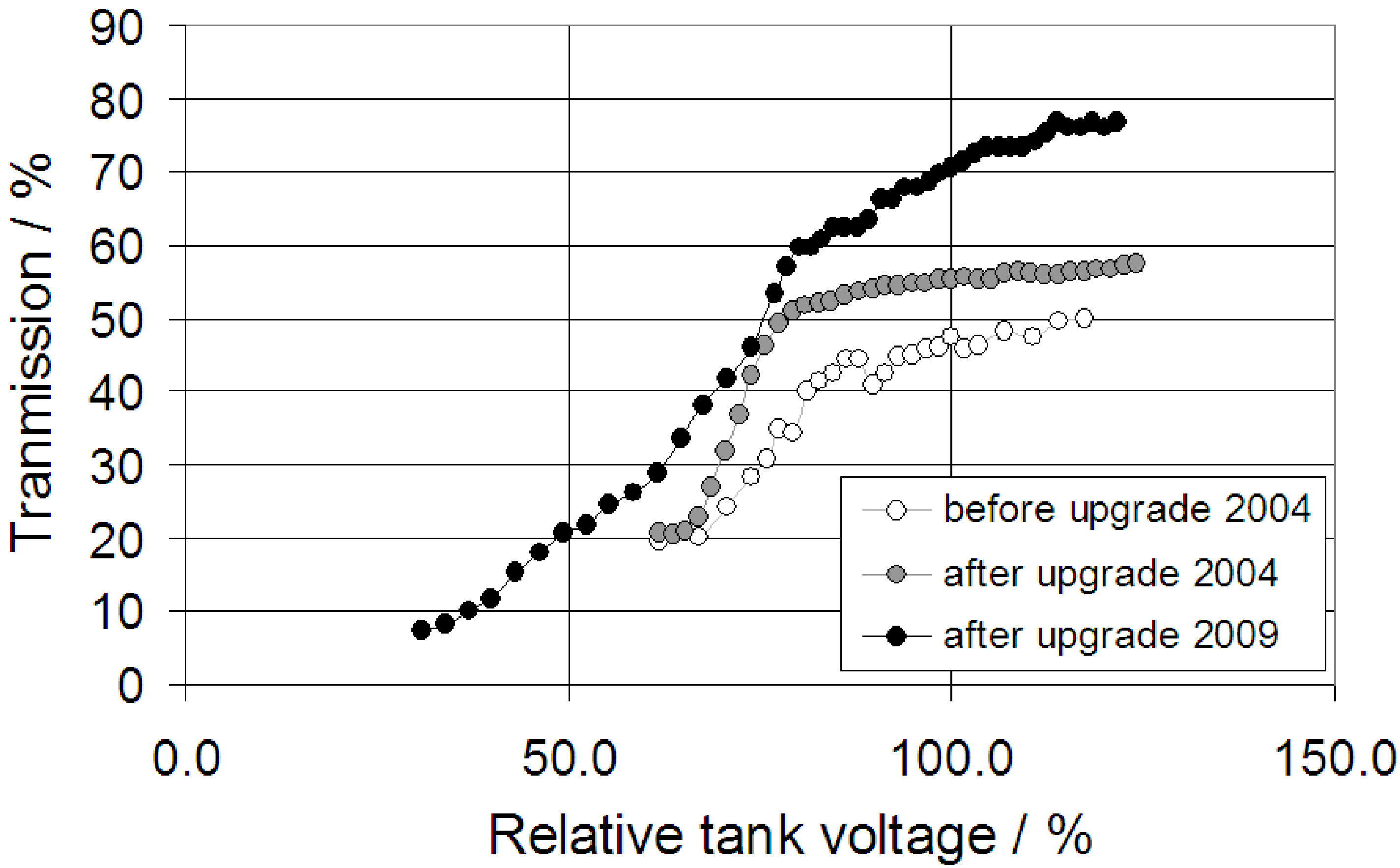
Requirements for FAIR: beam current behind RFQ more than 18 mA

RFQ commissioning 2009

Front-end transmission in 1999 / 2004 / 2009

High current

Ar^{1+} beam

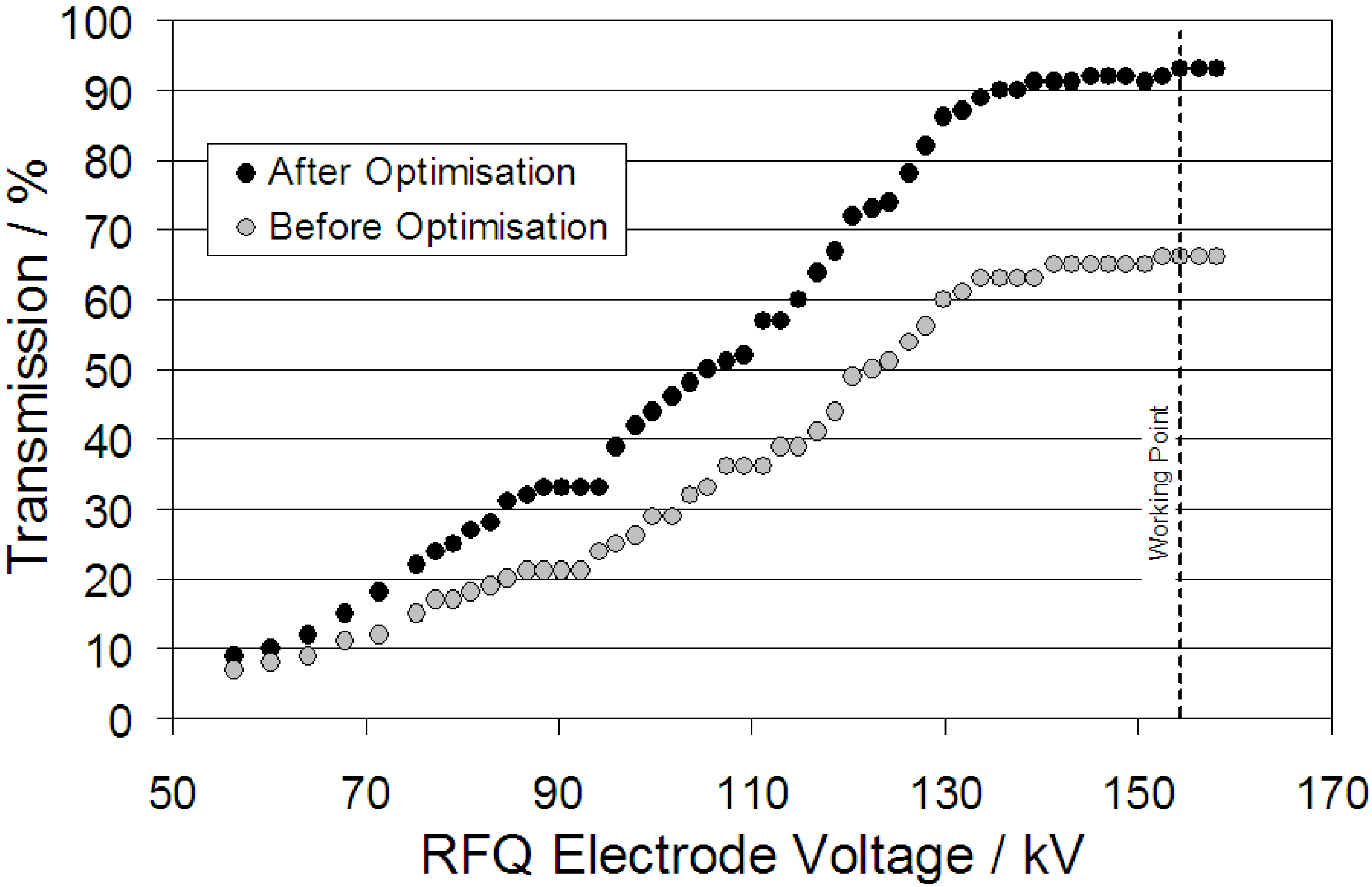


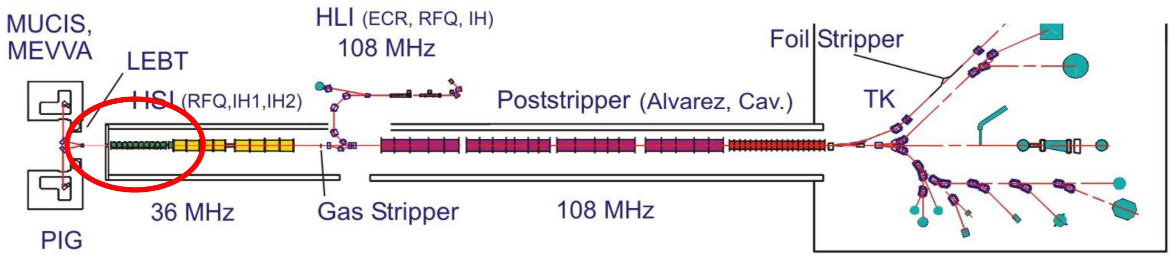
2010: further LEBT optimization with improved performance of the front-end system

Front-end optimization in 2010

UNILAC mainly serves for experiments. Time for machine optimization is strongly limited.

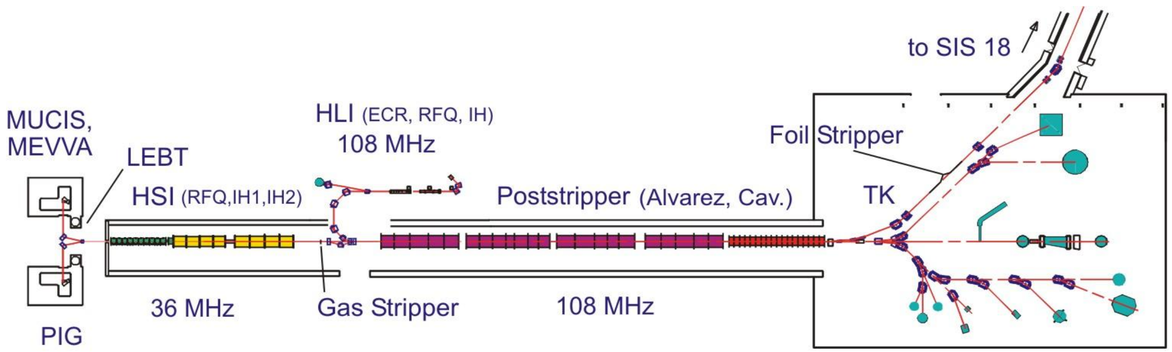
7 mA U^{4+} beam current



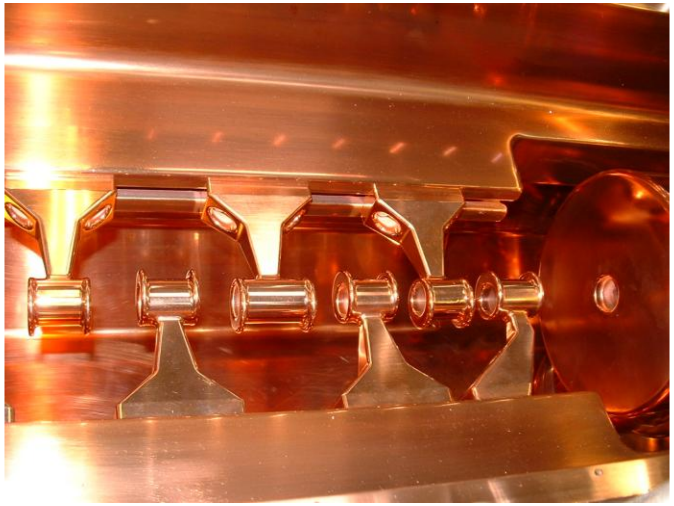


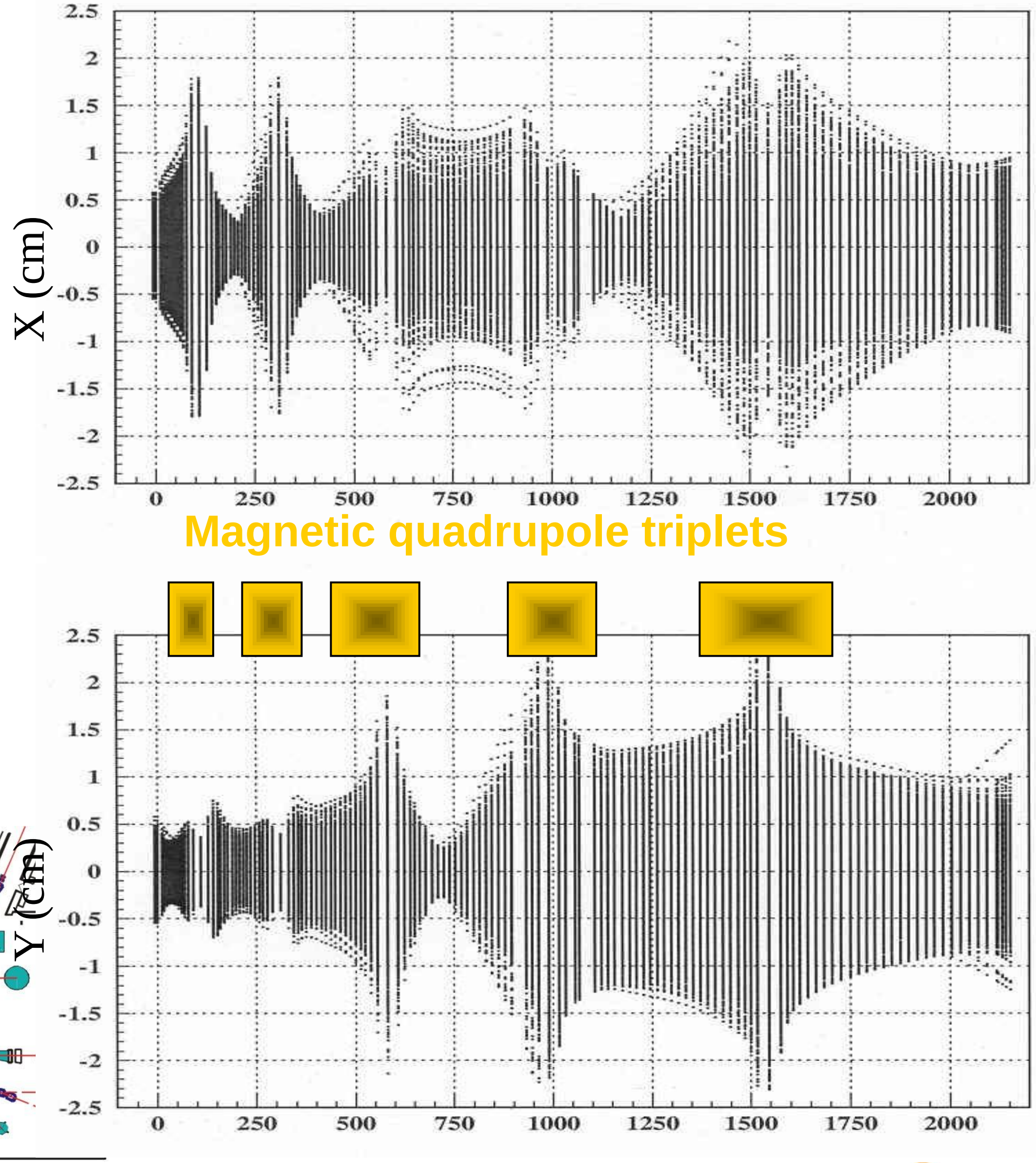
End-to-end simulations for UNILAC

End-to-end simulations for the whole linac
(from ion source output to the synchrotron entrance)
allow for the study and optimization of the overall
machine performance as well as for calculation
of the expected impact of different upgrade measures,
proposed to improve the beam brilliance.

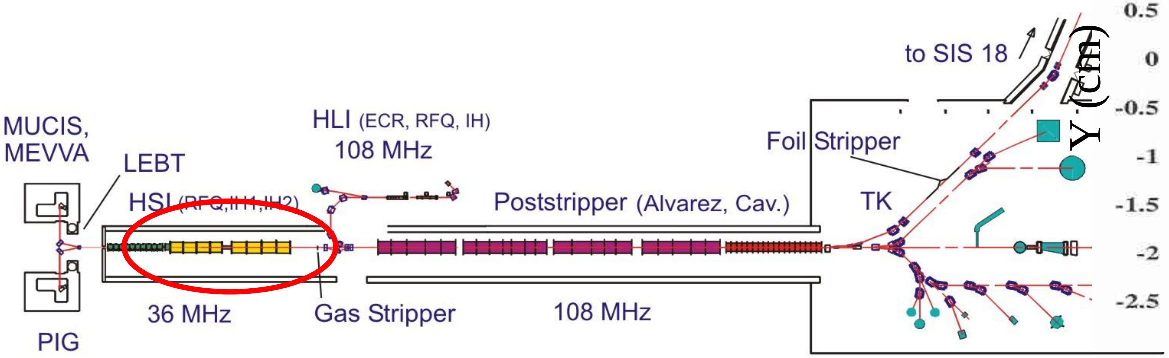


IH-DTL section

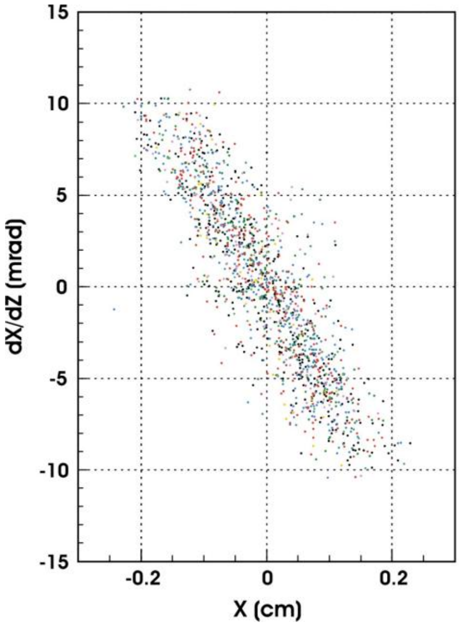


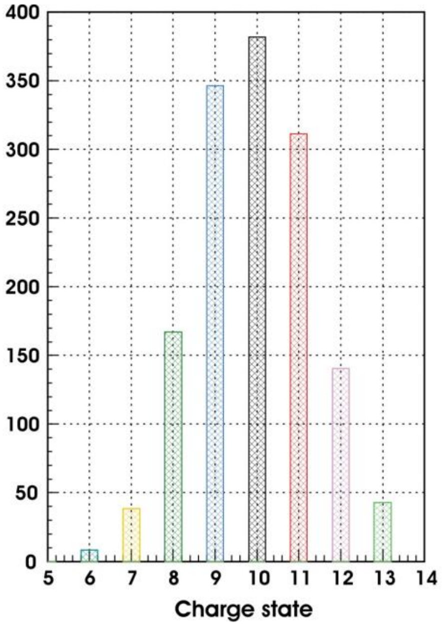


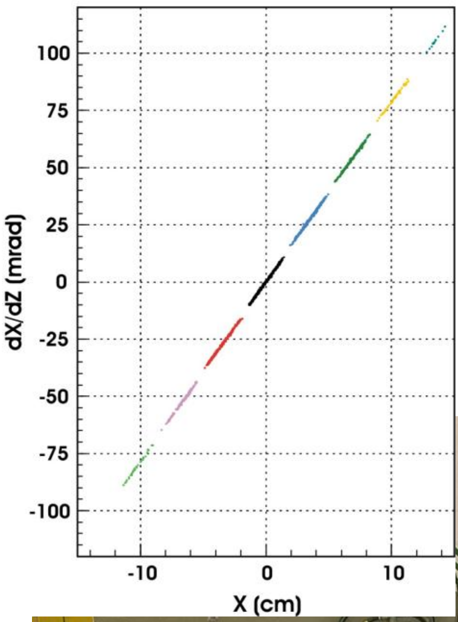
Recently a bottleneck of the HSI is shifted to the 6D beam matching to the IH-section.



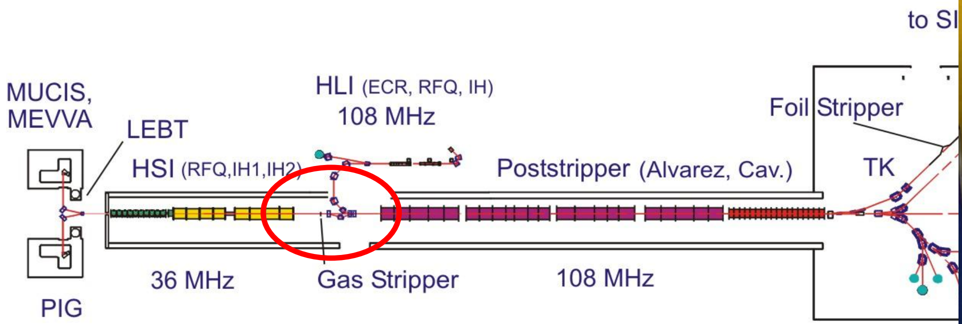
UNILAC gas stripper section

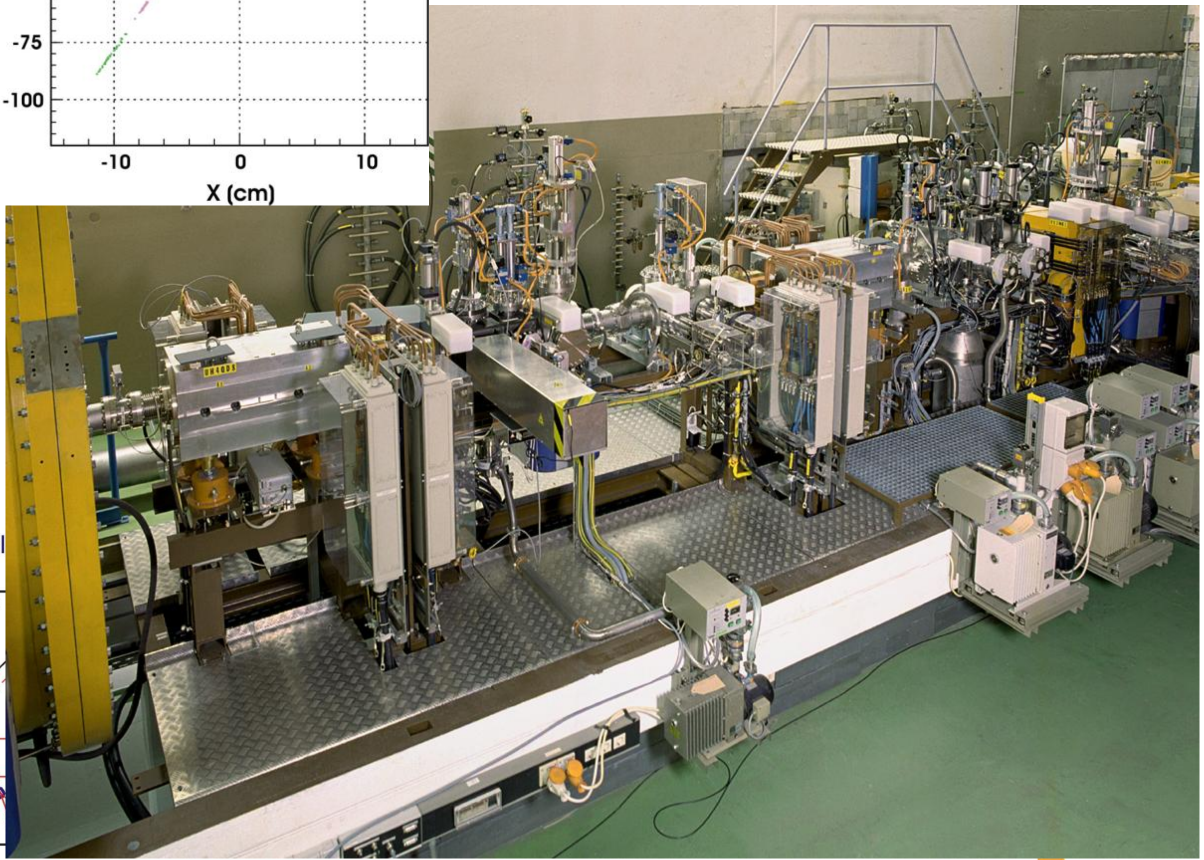






Charge state separation simulated with DYNAMION

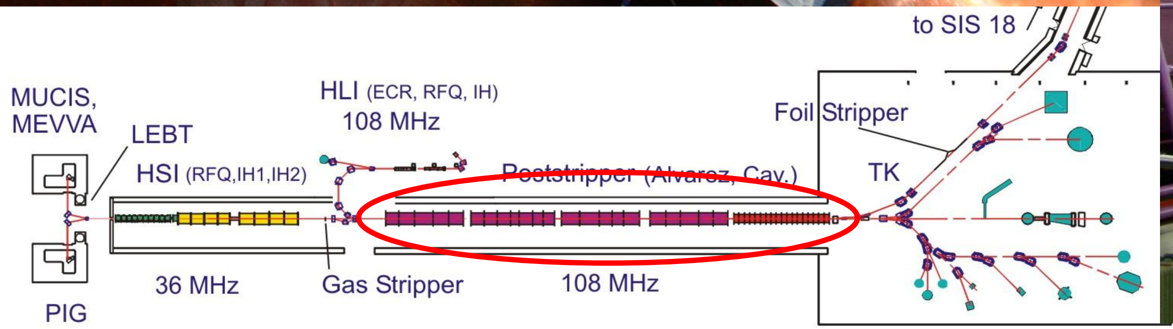




Alvarez postaccelerator

Advanced procedure for the beam matching to DTL (*Lars Groening*)

Numerous study with DYNAMION code, analysis of resonances, machine optimization



Conclusion

- The HSI-RFQ with a newly designed electrode profile has been successfully commissioned in 2009. *H. Vormann et al., LINAC 2010*
- A machine record: 8.5 mA Ar^{1+} beam current behind the High Current Injector.
- A machine record: 6.0 mA U^{39+} at full UNILAC energy. *W. Barth et al., LINAC 2010*
- The beam dynamics for the front-end was studied with the DYNAMION code.
- The beam intensity of 18 mA of U^{4+} ions behind RFQ (required for the FAIR program) can be reached.
- End-to-end simulations of beam dynamics in UNILAC, consisting of the sequence of the RFQs, DTLs and transport lines, can be done in one run.
- All types of accelerating structures and focusing elements can be simulated with high accuracy and reliability.
- The DYNAMION code is an advanced tool for end-to-end simulation for the whole linac, the study and optimization of the overall machine performance as well as for the calculation of the expected impact of different upgrade measures.