An advanced Procedure for longitudinal Beam Matching for SC CW Heavy Ion Linac with variable output Energy

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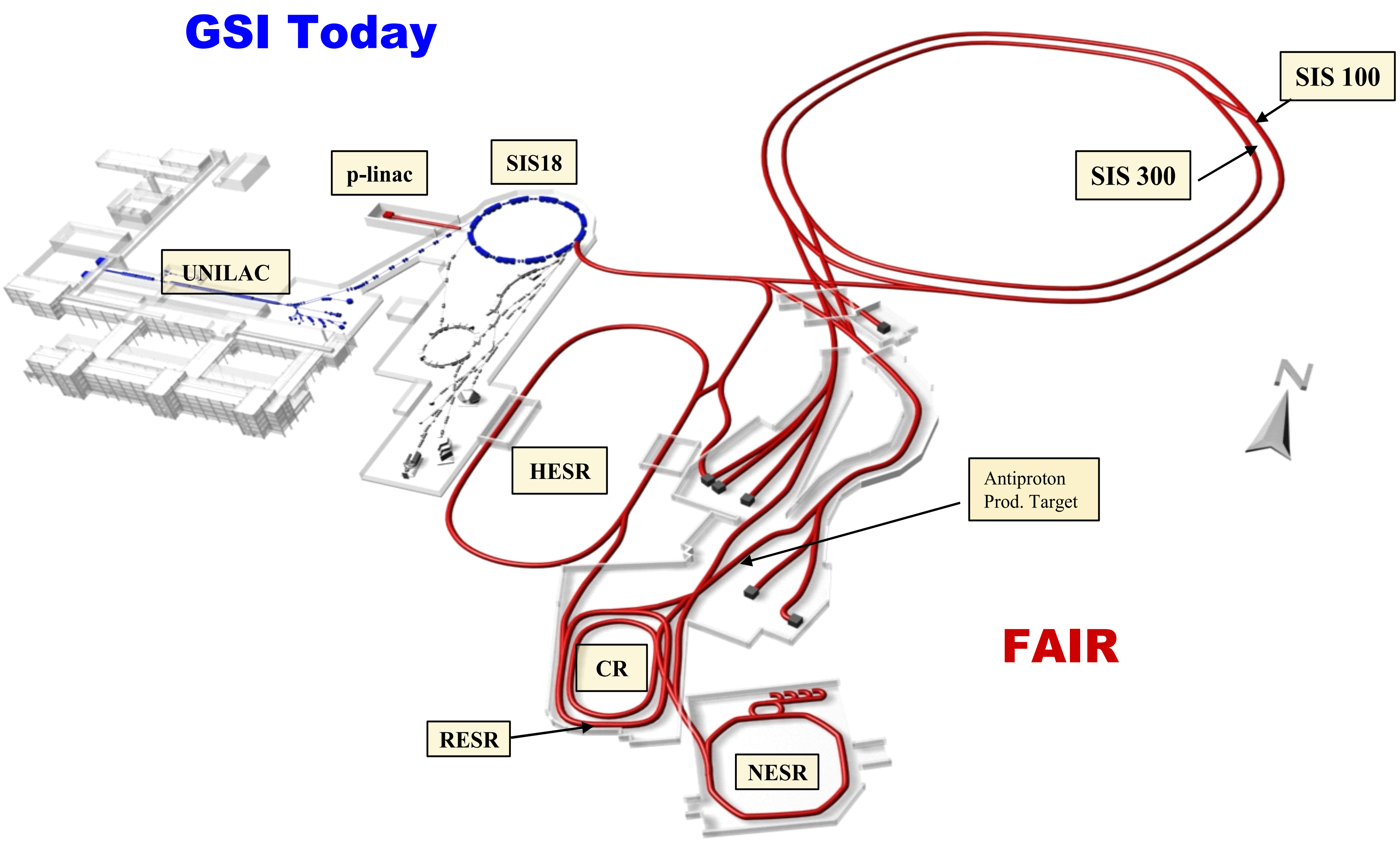
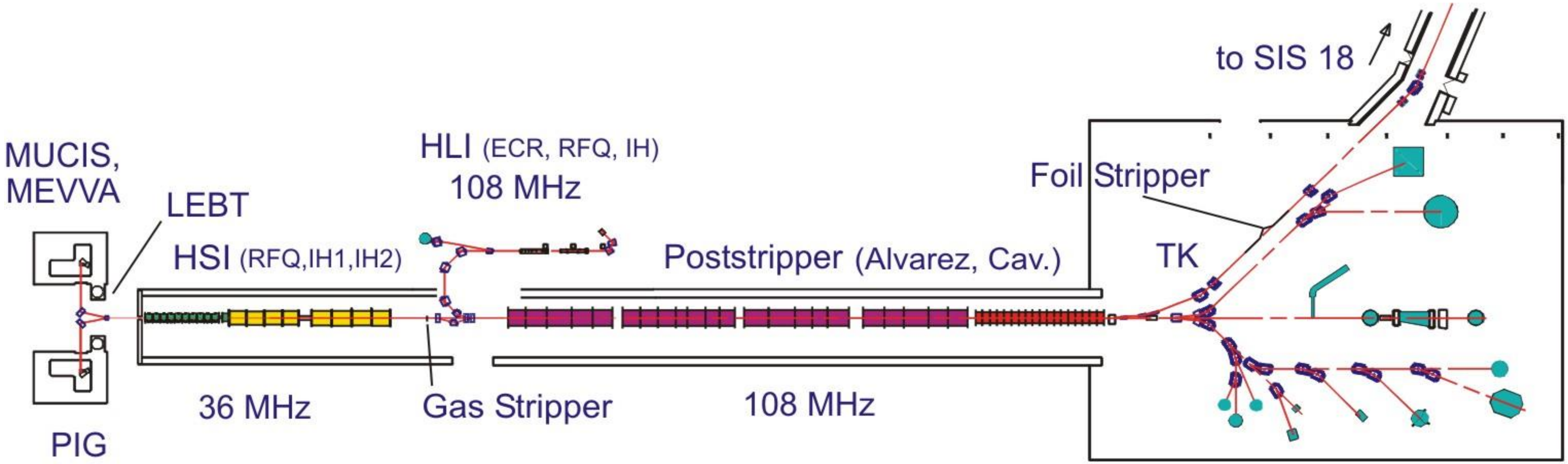


UNIversal Linear ACcelerator

UNILAC is foreseen
as an injector for FAIR

Beam time availability is
decreased for other programs:
- SuperHeavy Elements
- Material research
- Biophysics



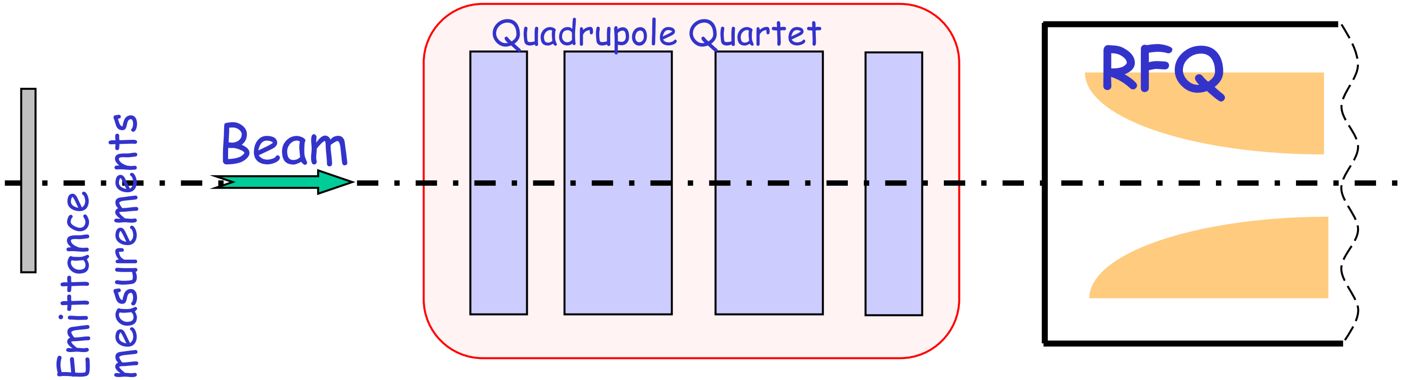
To a question of matching...

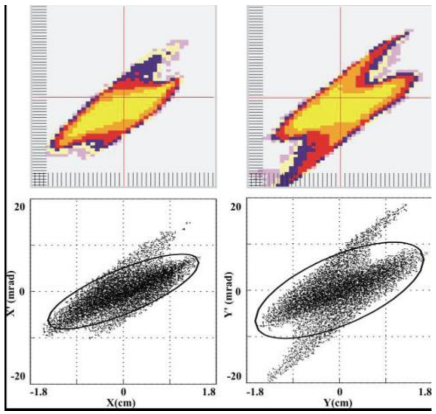
HB 2016 discussion

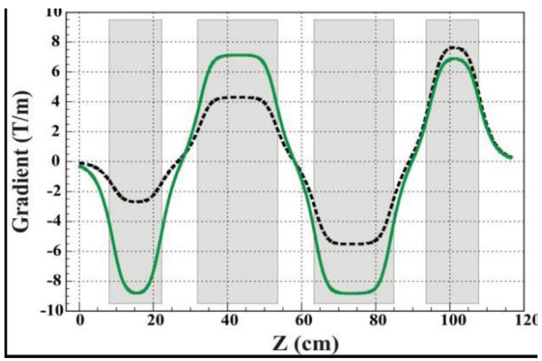
an example from GSI UNILAC

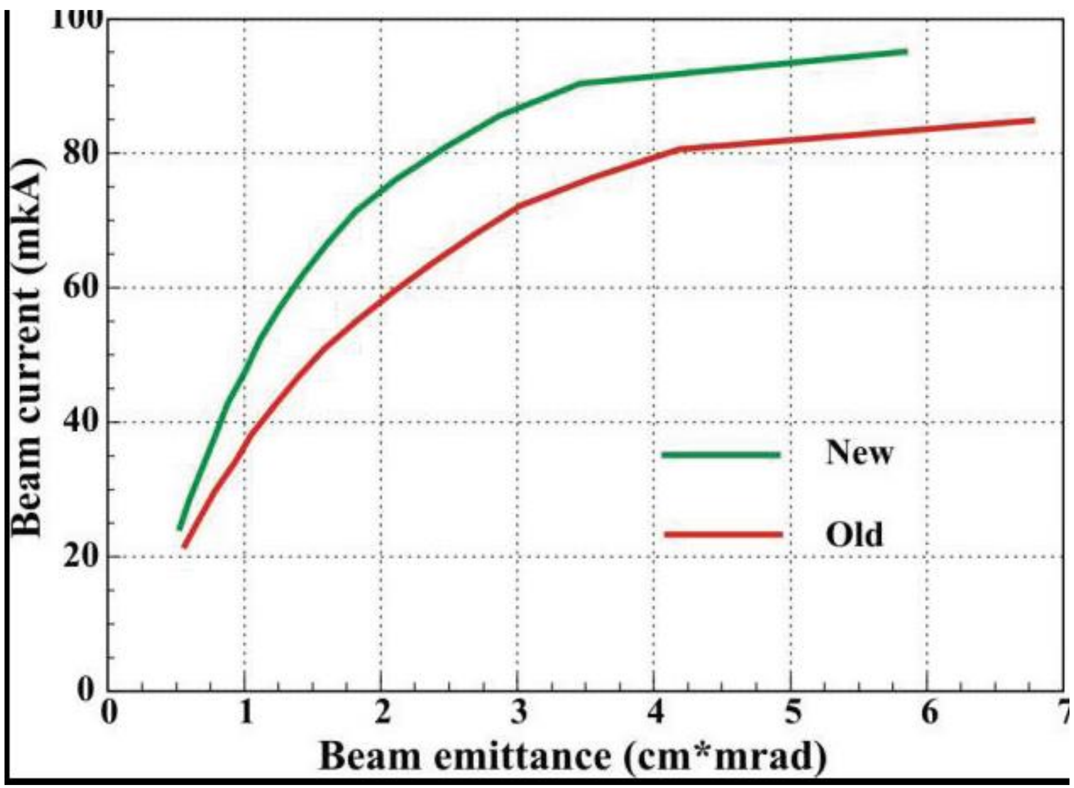
To a question of matching / HB 2016 discussion

LINAC 2014 and previous conferences

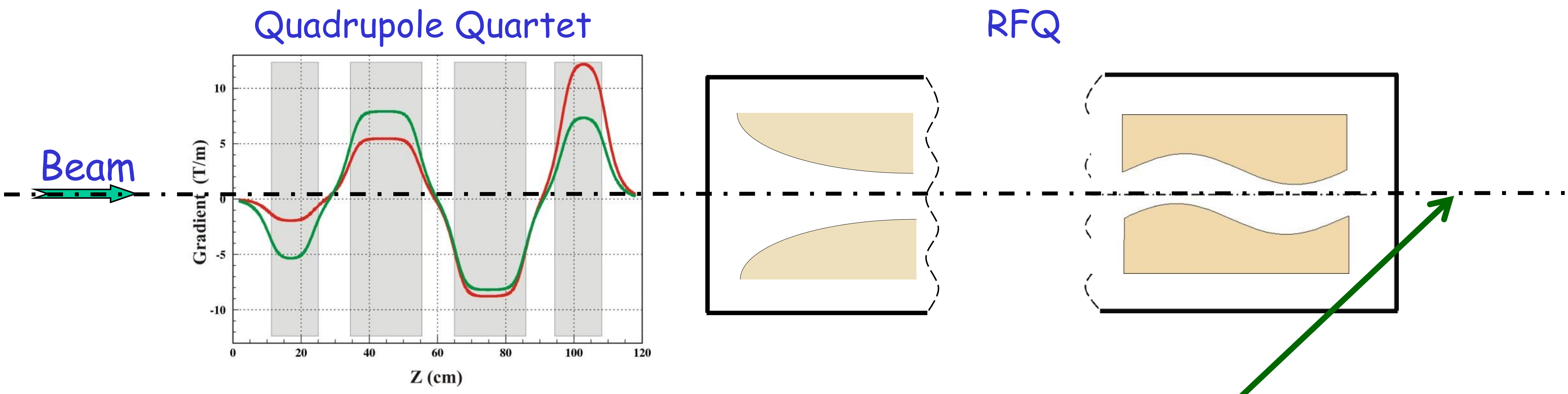








To a question of matching / HB 2016 discussion



The same beam (4 mA Ta^{4+}) the same machine settings
only four quadropoles changed

RFQ Particle transmission
experimental data

Old settings ≈ 50%
(L. Groening)

New settings ≈ 75%
(S. Yaramyshev)

Beam brilliance (*current / emittance)* **improvement**
beam dynamics simulations

horizontal & vertical - about factor of 2
longitudinal - about 60%

To a question of matching / HB 2016 discussions

High current uranium / argon beams

	transmission	emittance
"old" setting	75%	XX mm*mrad
"new" setting	70%	≈ 1/2 XX mm*mrad
		≈ 1/2 YY mm*mrad
		≈ 2/3 ZZ mm*mrad

Together with other measures lead to

- world record for uranium beam intensity
- reached beam brilliance required for FAIR

Winfried Barth, HB 2016, TUAM7Y11
High Current Uranium Beam Measurements at GSI-UNILAC for FAIR

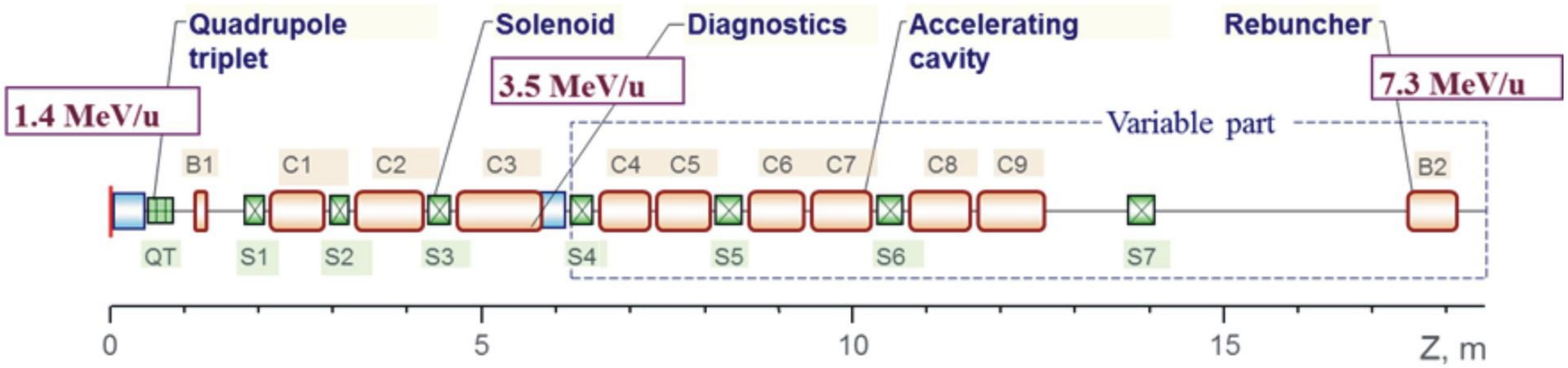
W. Barth et al., Physical Review ST AB 18(4),·050102 (2015)

And now back to CW linac longitudinal matching ...

New SC CW Linac at GSI

Heavy ion facility
Compact machine
Superconducting (SC)
Continuous wave (CW)
10 times higher intensity on target
Variable energy from 3.5 to 7.3 MeV/u

S. Minaev et al. (2009)



New feature (requirements): acceleration of ions with mass to charge ratio from 3 to 6, even to higher energy

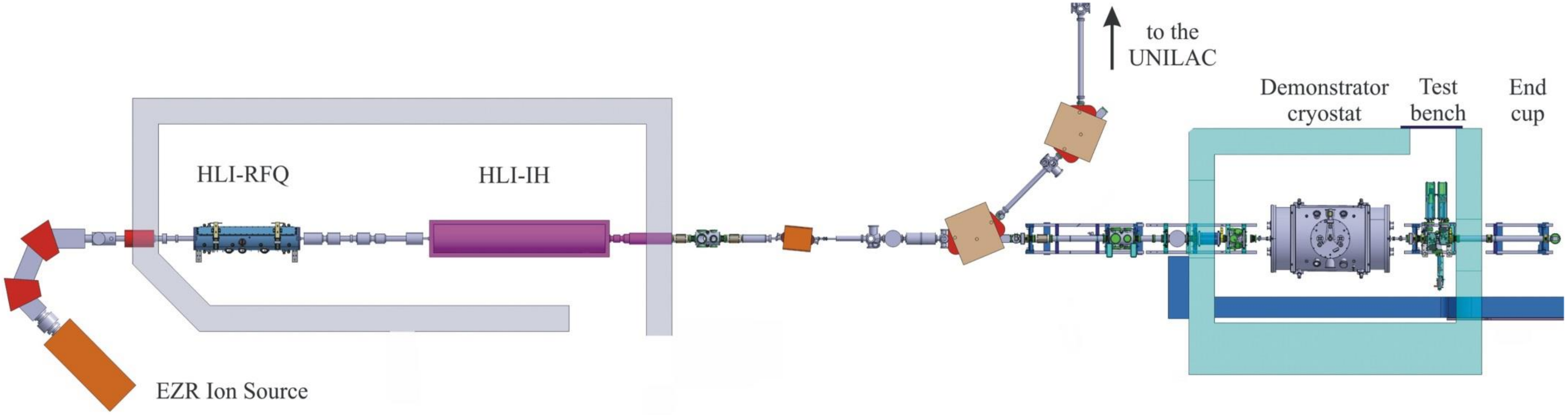
New SC CW Linac at GSI

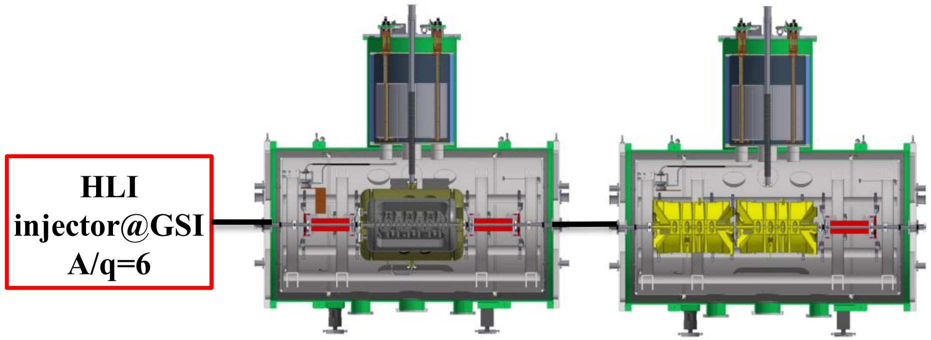
New feature (requirement):
acceleration of ions
with mass to charge ratio A/Z from 3 to 6,
even to energy higher than 7.3 MeV/u

New layout:
- 13 independently powered cavities instead 9 ones
- less number of gaps per cavity
- easier to fabricate
- more flexibility for output energy
- more complicate linac settings

Schematic layout of the CW Demonstrator at GSI

The commissioning of the CW-demonstrator
consisting of two superconducting solenoids
and the superconducting 15-gap CH-cavity
has already started in 2016



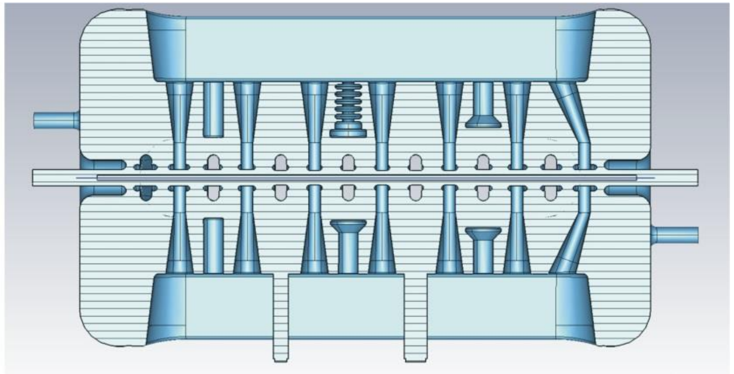


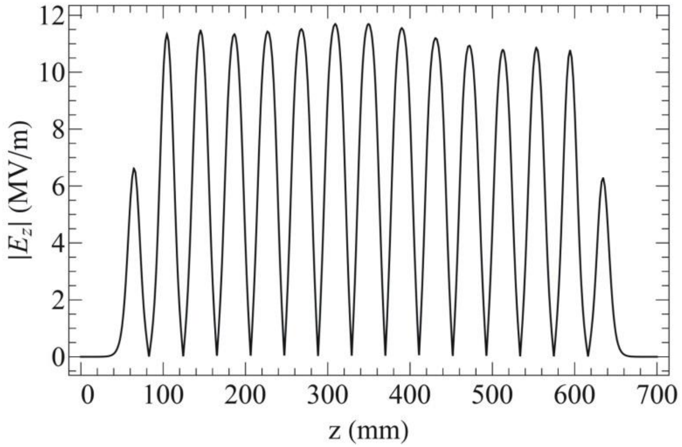
Two identical 8-gap CH cavities
are already ordered;
delivery to GSI is expected
until summer 2017

New SC cavities

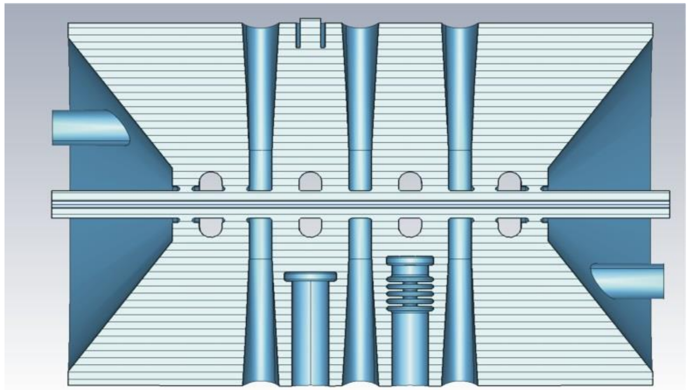
CST models:
M. Basten, F. Dziuba et al.

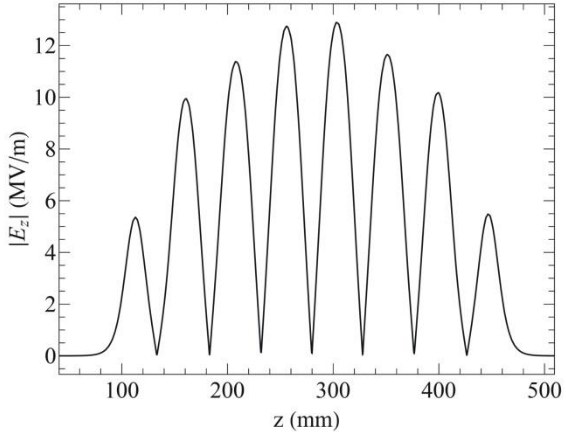
15-gap cavity





8-gap cavity





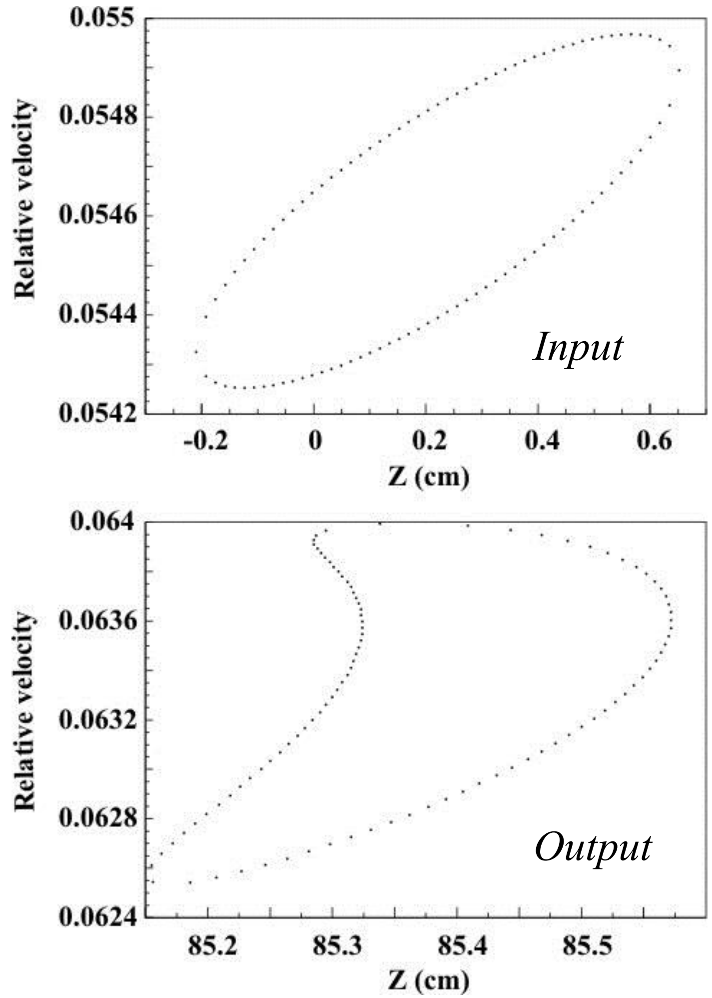
- cavity design is based on KONUS / EQUUS beam dynamics
- acceleration is not fully resonance

Longitudinal beam dynamics

KONUS / EQUUS beam dynamics allow for

- high acceleration gradient
- variable input energy
- variable output energy
- variable cavity voltage

Not fully resonance acceleration typically leads to a strong deformation of longitudinal beam emittance



Typical example of input and output particle distributions in longitudinal phase plane

Beam emittance representation

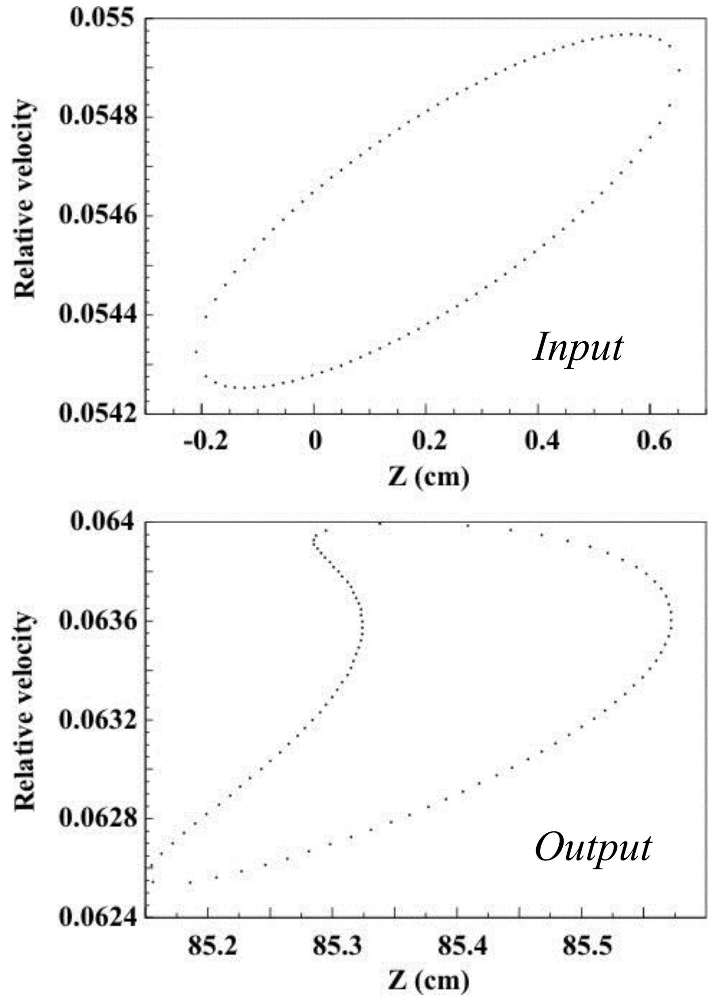
DYNAMION
beam dynamics simulations

100 macroparticles as an ellipse in longitudinal phase plane

Random input Twiss-parameters, central energy, central coordinate

Big number of such ellipses are simulated in one run

Analysis of output distribution is possible due to unique ID of particle



Typical example of input and output particle distributions in longitudinal phase plane

Analysis of output data

Series of points (Z, Z') could be approximated by an ellipse

$$cZ^2 + 2aZZ' + bZ'^2 = 1$$

Twiss-parameters α, β, γ could be obtained by means of least squares method

$$a = \frac{\alpha}{\sqrt{bc - a^2}} \qquad b = \frac{\beta}{\sqrt{bc - a^2}} \qquad c = \frac{\gamma}{\sqrt{bc - a^2}}$$

The parameter ε_i is enumerated
for each particle of the output 100-particle ensemble:

$$\varepsilon_i = \gamma Z^2 + 2\alpha ZZ' + \beta Z'^2$$

Mismatch factors

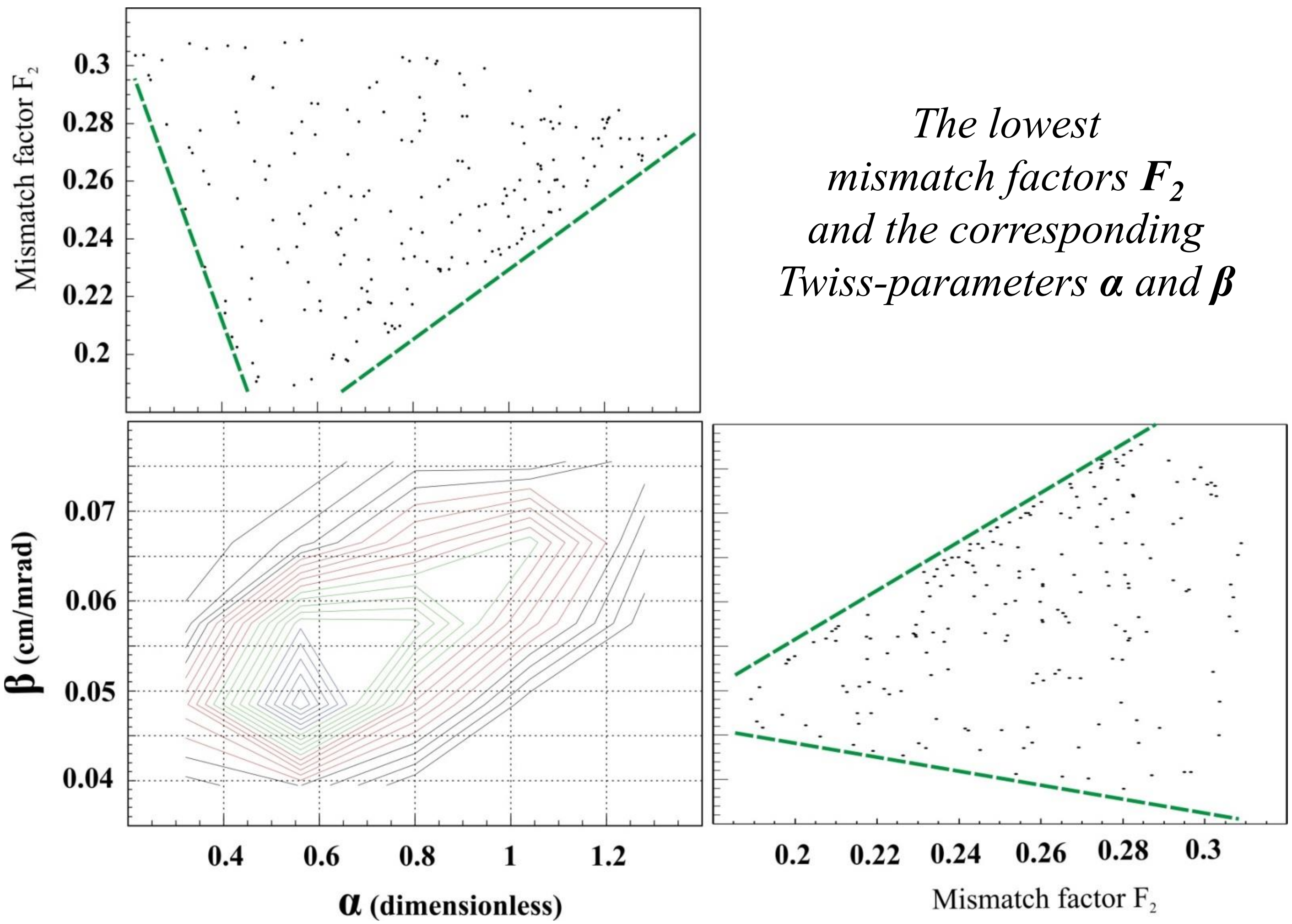
Three factors are calculated for each output 100-particle ensemble:

- emittance growth (F_1)
- deformation of elliptical shape (F_2)
- energy gain (F_3)

$$F_1 = \frac{\varepsilon_{\max}}{\varepsilon_{input}} \qquad F_2 = \frac{\varepsilon_{\max} - \varepsilon_{\min}}{\varepsilon_{input}} \qquad F_3 = \frac{\beta_{out} - \beta_{in}}{\beta_{in}}$$

where $\boldsymbol{\varepsilon_{max}}$ *and* $\boldsymbol{\varepsilon_{min}}$ *are the maximum and minimum values of the series* $\boldsymbol{\varepsilon_i}$ *;* $\boldsymbol{\varepsilon_{input}}$ *is total unnorm. longitudinal beam emittance;* $\boldsymbol{\beta_{in}}$ *and* $\boldsymbol{\beta_{out}}$ *are the input and output relative velocities, averaged on the 100-particle ensemble.*

Optimization for lower emittance deformation



The lowest mismatch factors $\boldsymbol{F_2}$ *and the corresponding Twiss-parameters* **α** *and* **β**

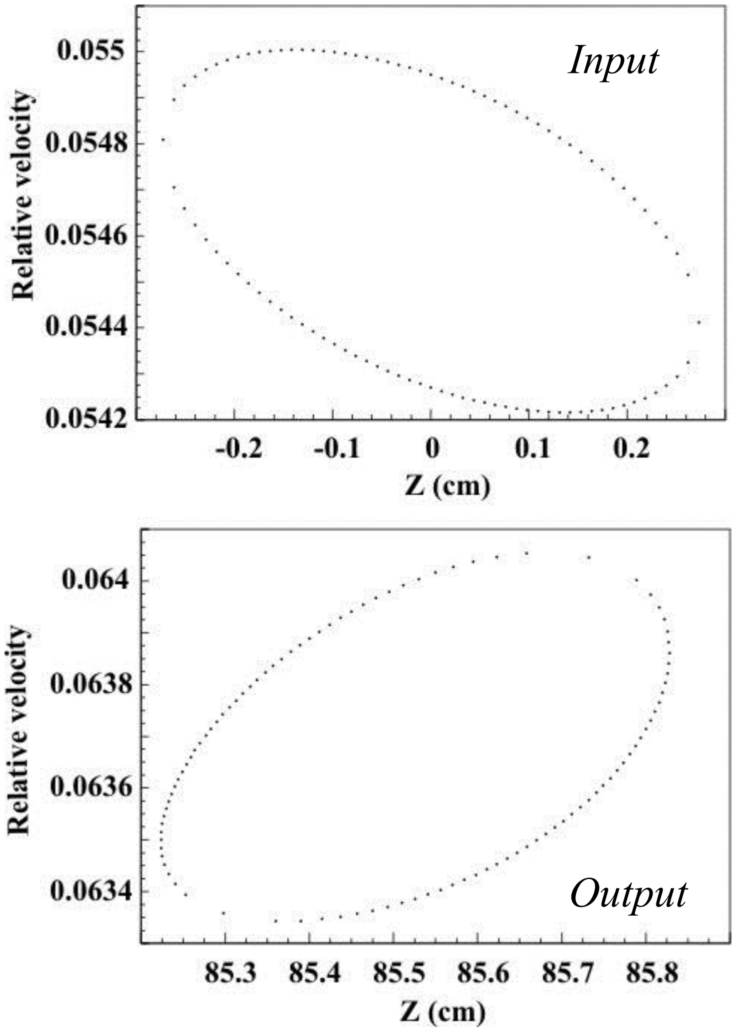
General mismatch parameter

$$f_g = F_1^p \cdot F_2^q \cdot F_3^{-s}$$

A general mismatch parameter
with the weight coefficients ***p, q, s***
could be constructed and used
in dependence of the required goal
in between of two limits:

- the highest acceleration
- the best beam quality

Well matched beam parameters



Particles are accelerated to a reasonable energy and the output distribution is close to an elliptical shape

The matched input beam characteristics are determined:

- Twiss-parameters
- energy of beam center
- coordinate of beam center (*cavity rf phase*)

Typical example of the matched input 100-particle ensemble and the corresponding output

Conclusion and Outlook

Dedicated algorithm for the longitudinal beam matching for a chain of DTL cavities is developed.

A flexible constructed mismatch parameter allows for machine optimization for a wide range of the ions with different mass to charge ratio, as well as for the required output beam energy from 3.5 to 7.3 MeV/u and higher (for medium ions).

The method is foreseen to be implemented for the new HIM/GSI heavy ion SC CW linac, comprised by 13 independently powered multi-gap cavities, developed at IAP.

Community experience

The new heavy ion SC CW linac project, conducted by HIM and GSI, is fully in line with other modern type and high efficient CW linac projects, mainly for proton and light ion acceleration, which are under development at different leading accelerator centers worldwide.

... these proceedings:

Sergey Polozov et al.,	*MOPL004*	*(MEPhI, Moscow)*
Rudolf Tiede et al.,	*WEAM1Y01*	*(IAP, Frankfurt)*
Dan Berkovits et al.,	*TUAM1Y01*	*(SARAF, Tel-Aviv)*

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