The new FAIR post-stripper DTL

Alvarez 2.0

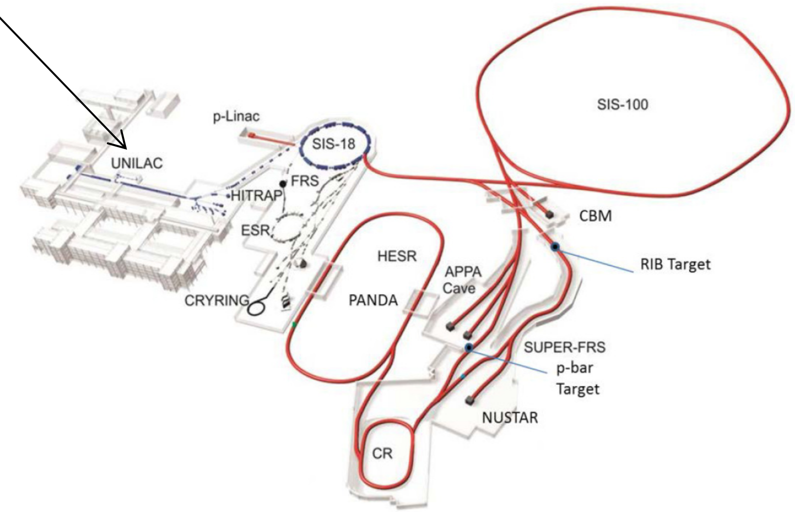
Outline

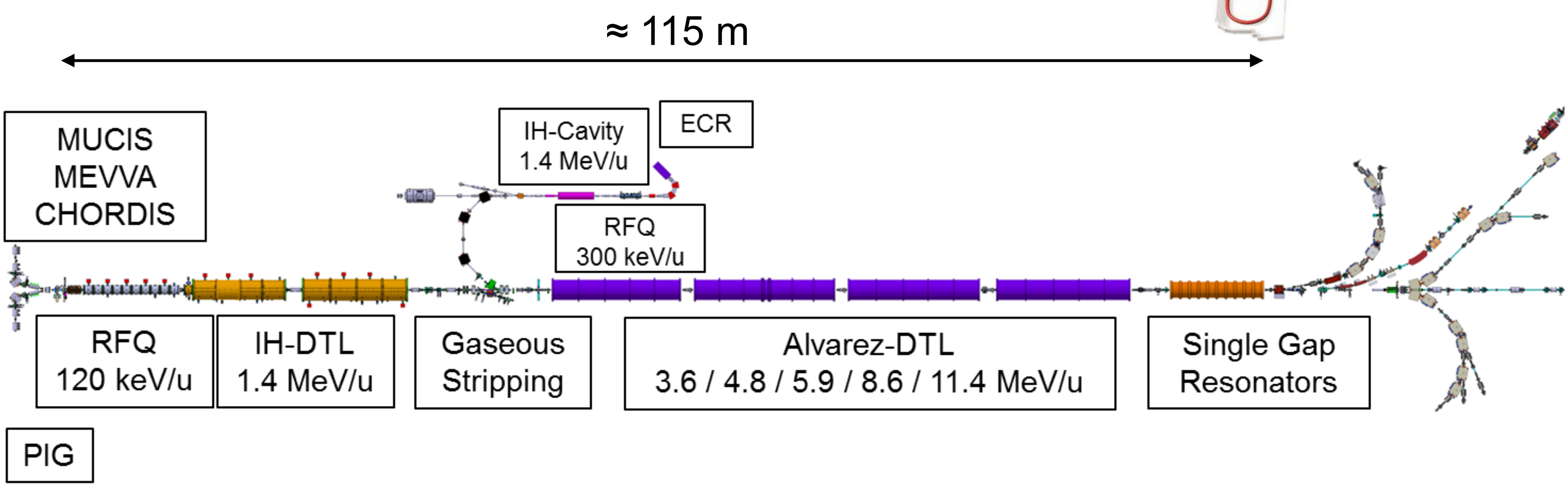
- Motivation
- Beam dynamics
- RF design
- FoS (First of Series) – 1st cavity section
- Schedule
- Summary

UNIversal Linear Accelerator UNILAC

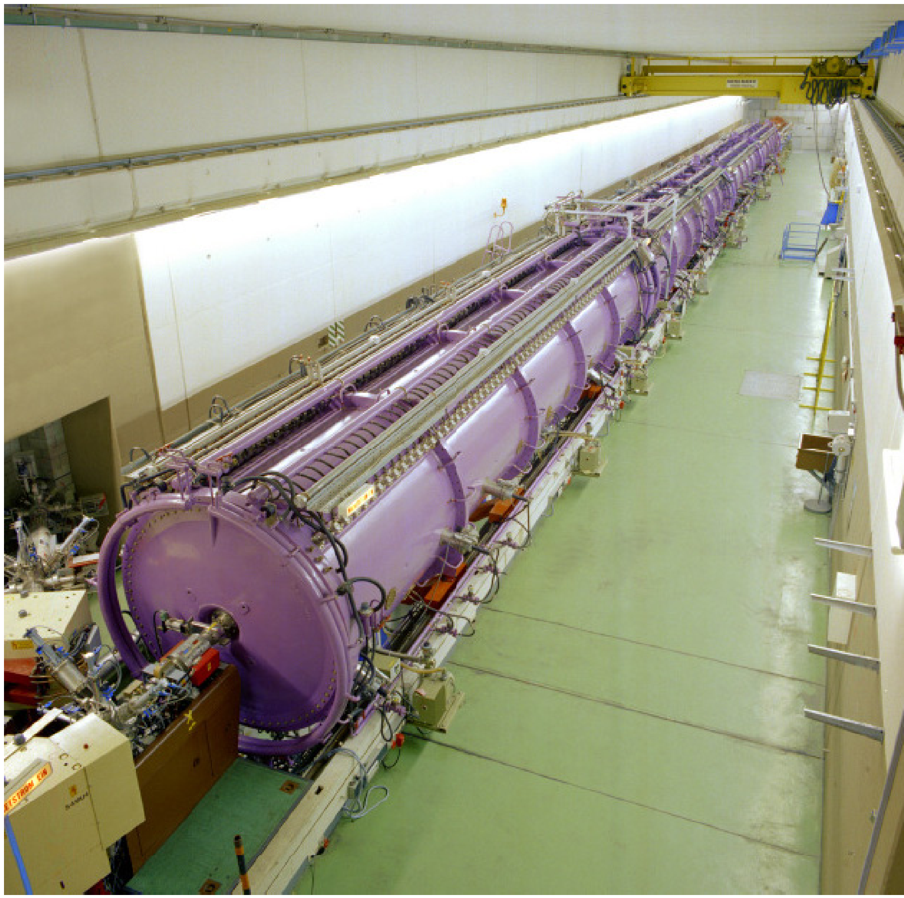
design parameters after upgrade

ion A/q	≤ 8.5, i.e. $^{238}U^{28+}$	
beam current (pulse) * A/q	1.76 (0.5% duty cycle)	mA
input beam energy	2.2	keV/u
output beam energy	3.0 - 11.7	MeV/u
operating frequency	36.136 / 108.408	MHz
length	≈ 115	m
beam pulse duration	≤ 1000	µs
beam repetition rate	≤ 10	Hz





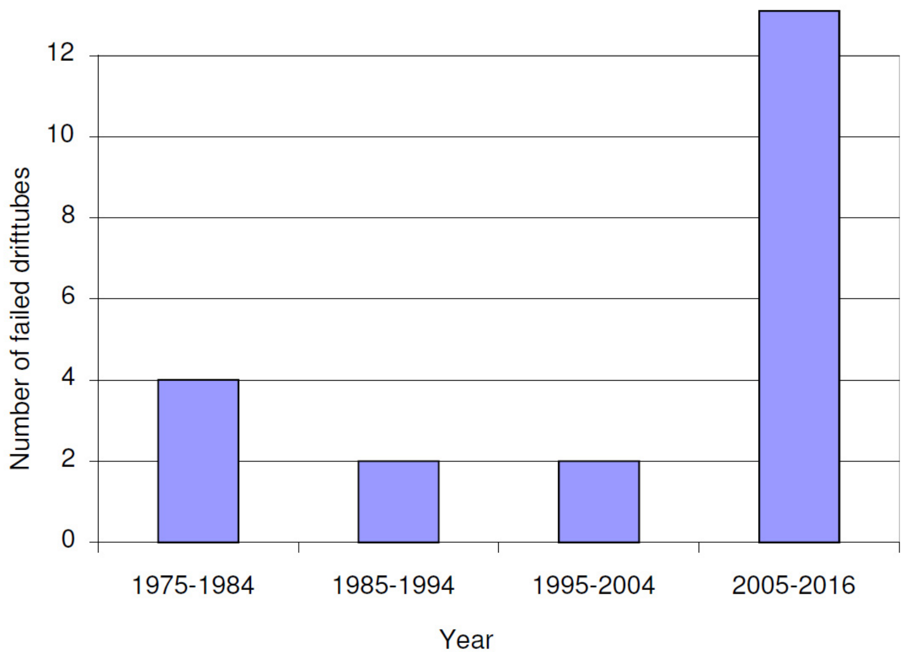
Alvarez DTL



What is the motivation for a new post stripper DTL?

1. FAIR goal
   - High current applications as required by FAIR (high intensity operation of heavy ions was not considered in the 1960‘s)

2. Operational risk
   - Alvarez DTL is in regular operation since 1978 (expected lifetime: ~20 years).
   - An increase in failures is observable.
   - Maintenance effort is increasing.



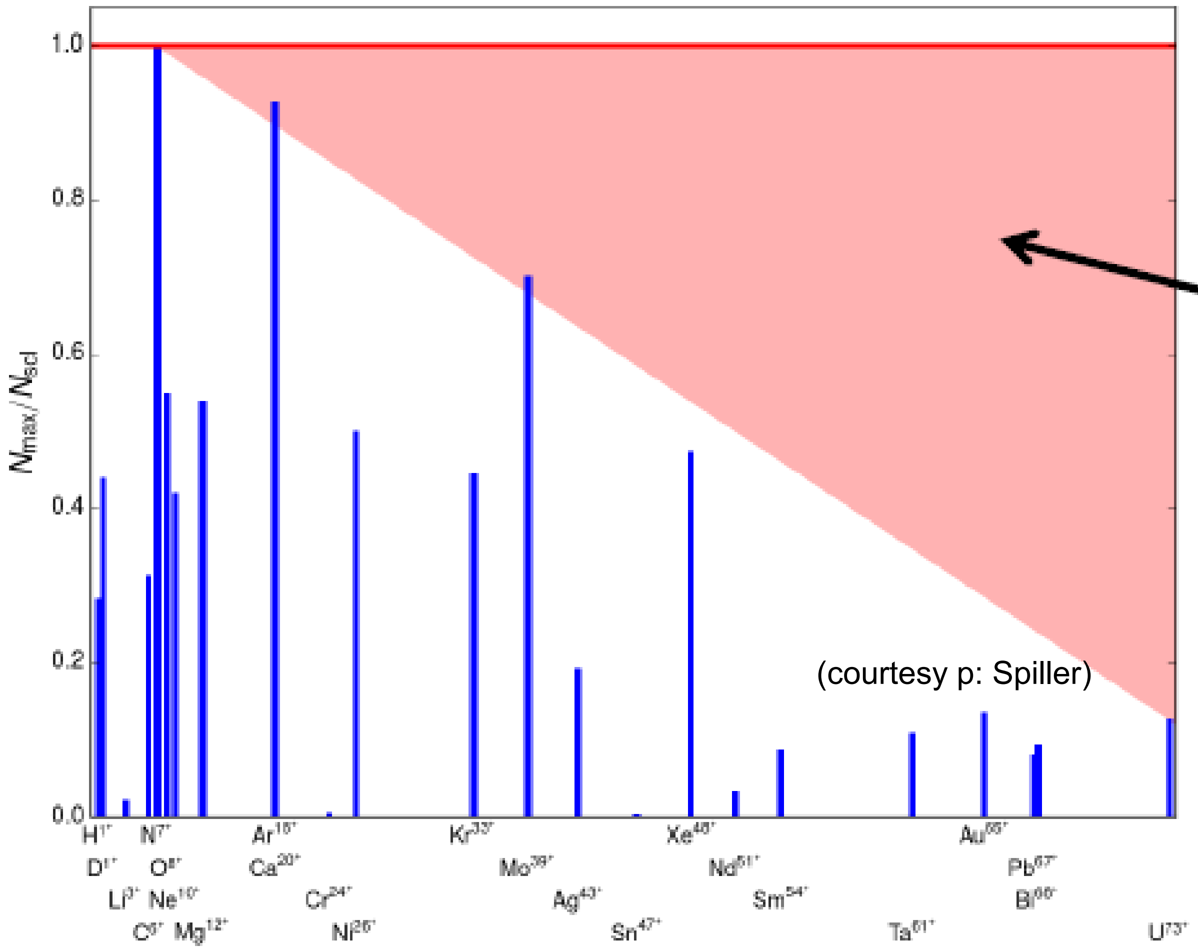
What are the operational risks?

	Tank and endplates	Drift tubes
Risks	i) Water leaks ii) Degradation of RF-properties iii) Failure of cooling system	i) Water leaks ii) Degradation of RF-properties iii) Failure of cooling system iv) Electrical shortcut of internal windings
Reasons	i) Corrosion (mild steel) ii) Aging of the Cu layer iii) Corrosion/Erosion products clog up the cooling channels	i) Erosion ii) Aging of the Cu layer iii) Corrosion/Erosion products clog up the cooling channels iv) Aging isolation
Counter-measures	i), ii) Substitution of tanks and endplates ii) Cu-stripping and re-Cu-plating iii) Rinsing	i)-iv) Substitution of drift tubes iii) Rinsing, closed stainless steel cooling circuit in 2013

Minimizing the operational risk means a one-to-one copy of the existing DTL

- no win of performance
- costs (and resources) for refurbishment
  are comparable to the costs of a new post-stripper DTL

What defines the FAIR goal?



FAIR goal
- „upgraded“ SIS18
space charge limit

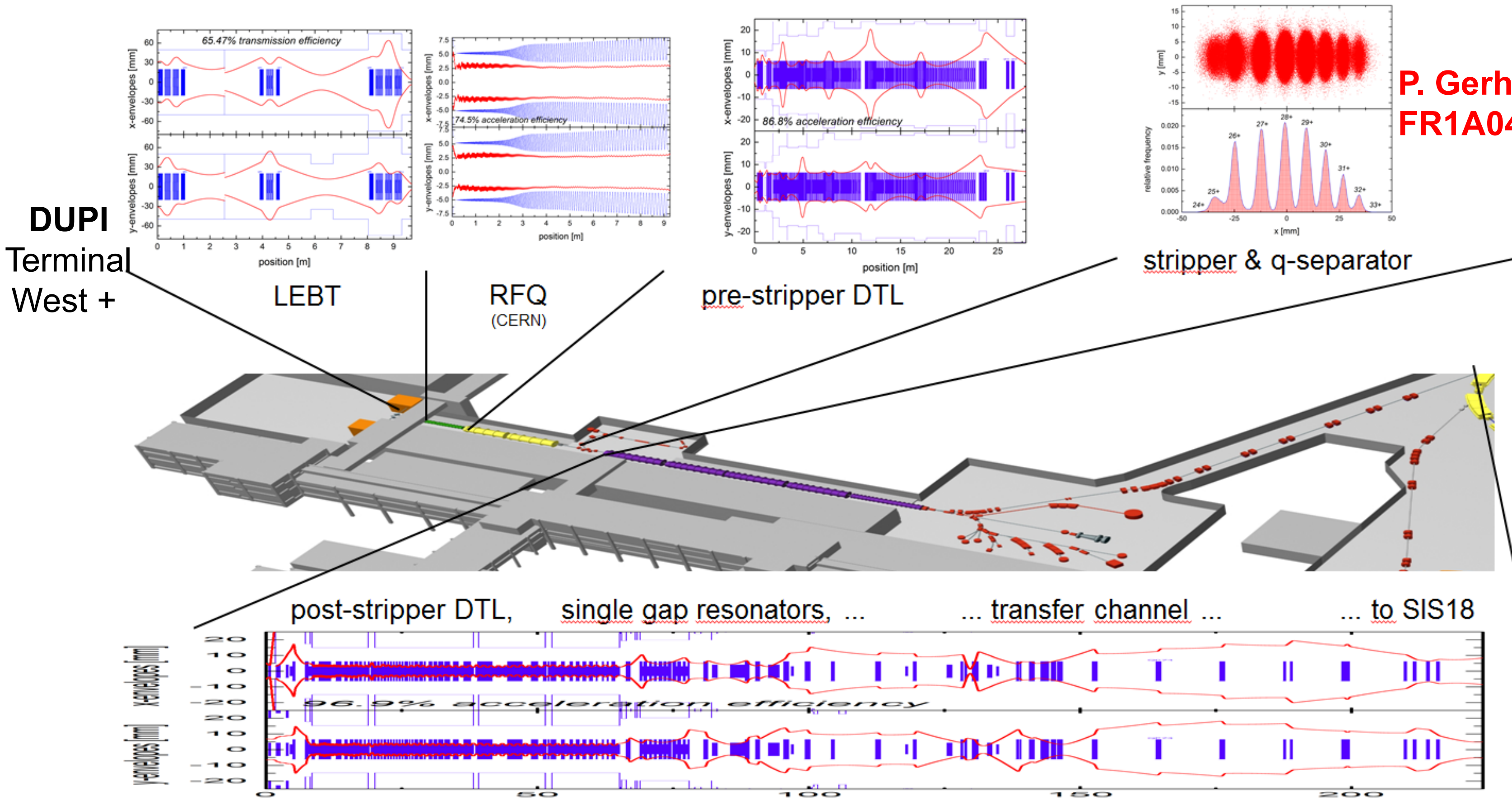
gap caused by design of UNILAC from 1960‘s, w.r.t. the post-stripper DTL:

- not a dedicated HC DTL (intertank sections)
- quadrupoles gradients are limited (phase advance)

How to reach the FAIR goal?

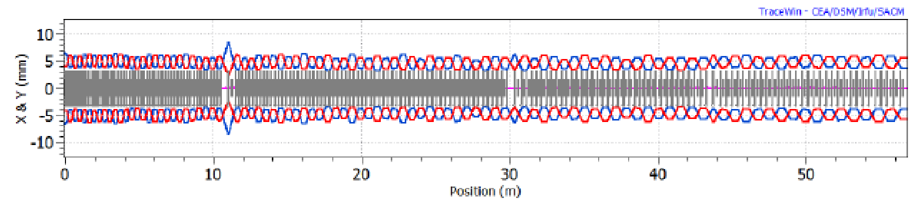
Extensive upgrade program along the UNILAC

- Upgrades are backed by front-to-end-simulations
  - prediction: an upgraded UNILAC reaches the FAIR requirements
  - tool for further optimisation, future commissioning and operation

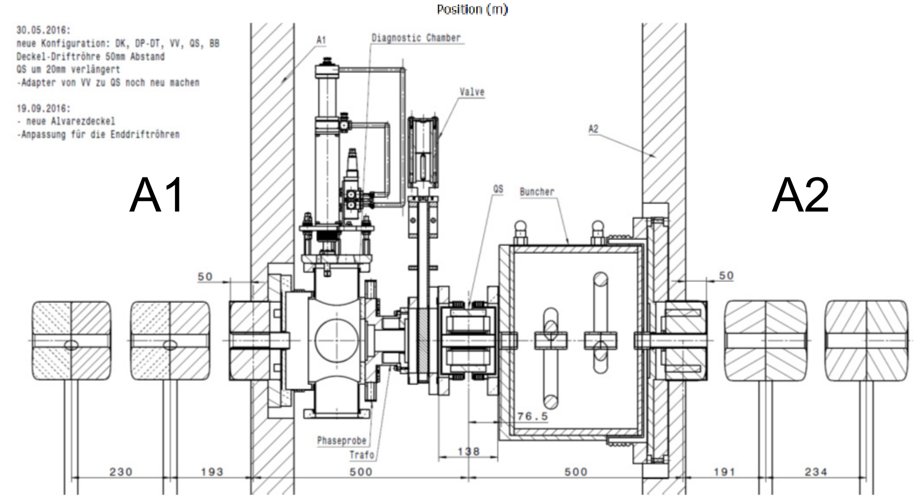


P. Gerhard et al.
FR1A04, 9:50 am

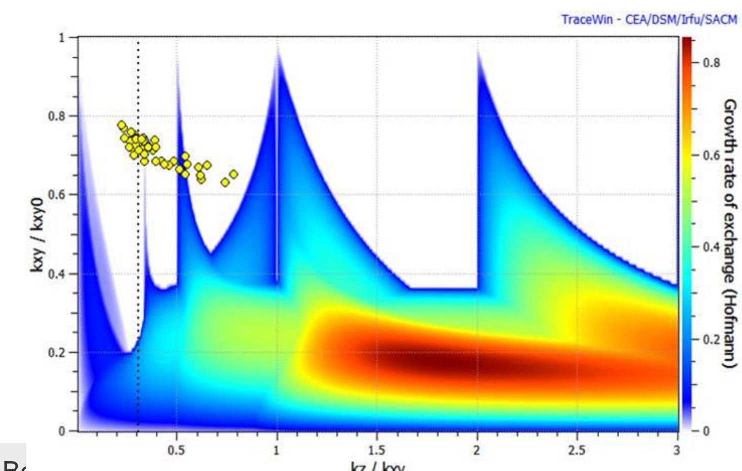
How to reach the FAIR goal with the new DTL beam dynamics layout?



- periodic focusing
(new design of the inter-tank sections takes care about strict periodicity)

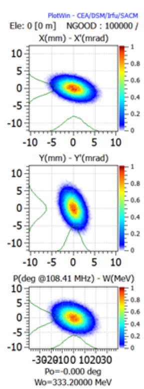


- avoid space charge driven emittance growth resonances
(higher quadrupole gradients)

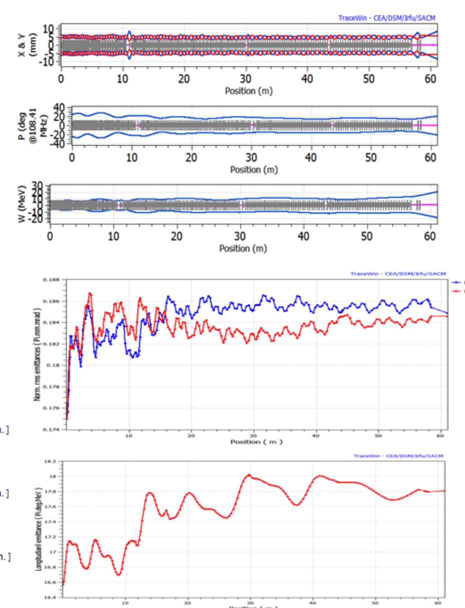


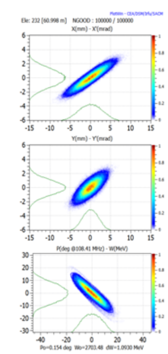
What are the results?

	FAIR	Zero current	Low energy	Larger long. emit.	Smaller long. emit.	Transvers. flat beam
Current, mA	16.5	**0**	**0**	16.5	16.5	16.5
Input ε_x (rms), mm mrad	0.175	0.175	0.175	0.175	0.175	**0.0875**
Input ε_y (rms), mm mrad	0.175	0.175	0.175	0.175	0.175	**0.35**
Input ε_z (rms), mm mrad	0.07	0.07	0.07	**0.14**	**0.035**	0.07
Output energy, MeV/u	11.4	11.4	**3.3**	11.4	11.4	11.4
Transmission, %	100	100	100	100	100	100
$\Delta\ \varepsilon_x$ (tot, 95%), %	7	0	0	7	8	16
$\Delta\ \varepsilon_y$ (tot, 95%), %	7	0	0	10	7	3
$\Delta\ \varepsilon_z$ (tot, 95%), %	10	0.7	1.7	5	11	4



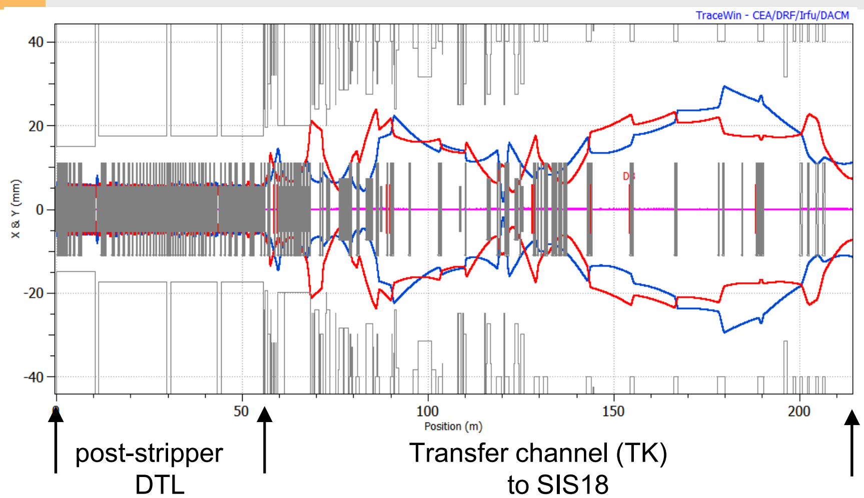
X-X'
Emit [rms] = 0.1750 Pi.mm.mrad [Norm.]
Emit [95.00%] = 0.9854 Pi.mm.mrad [Norm.]
Beta = 1.4578 mm/Pi.mrad
Alpha = 0.3780
Y-Y'
Emit [rms] = 0.1750 Pi.mm.mrad [Norm.]
Emit [95.00%] = 0.9904 Pi.mm.mrad [Norm.]
Beta = 0.5663 mm/Pi.mrad
Alpha = 0.3969
Phase-Energy
Emit [rms] = 16.5700 Pi.deg.MeV [Norm.]
Emit [95.00%] = 93.5925 Pi.deg.MeV [Norm.]
Beta = 3.8274 deg/Pi.MeV
Alpha = 0.3300





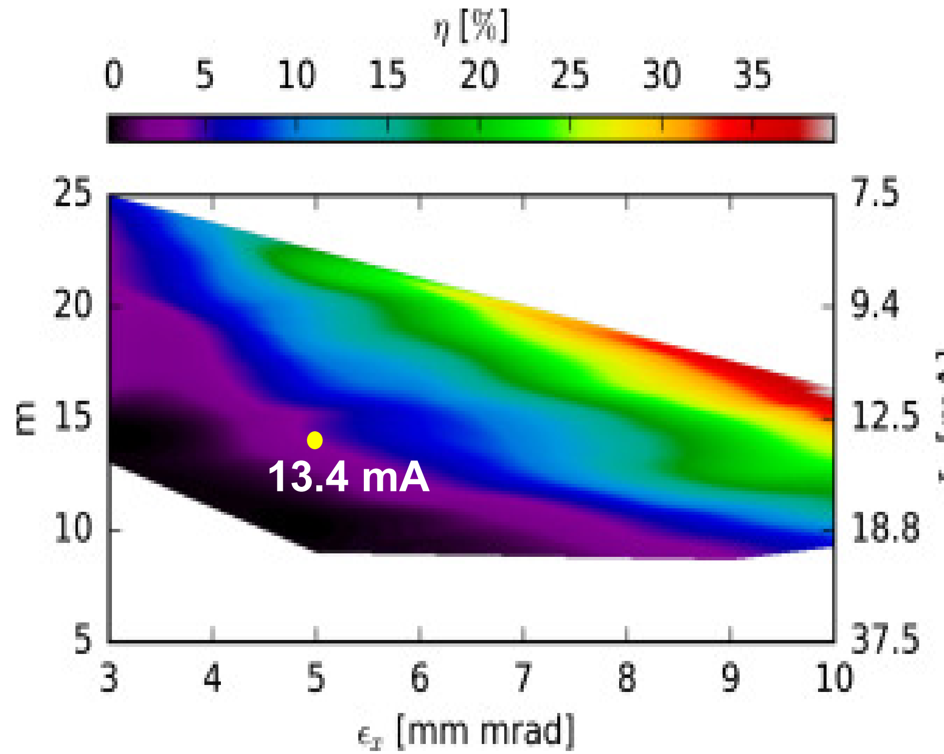
X-X'
Emit [rms] = 0.1846 Pi.mm.mrad [Norm.]
Emit [95.00%] = 1.0587 Pi.mm.mrad [Norm.]
Beta = 6.4791 mm/Pi.mrad
Alpha = -2.4920
Y-Y'
Emit [rms] = 0.1849 Pi.mm.mrad [Norm.]
Emit [95.00%] = 1.0611 Pi.mm.mrad [Norm.]
Beta = 2.9232 mm/Pi.mrad
Alpha = -1.2096
Phase-Energy
Emit [rms] = 17.8031 Pi.deg.MeV [Norm.]
Emit [95.00%] = 104.1962 Pi.deg.MeV [Norm.]
Beta = 2.6484 deg/Pi.MeV
Alpha = 2.3016

What is expected in front of SIS18?



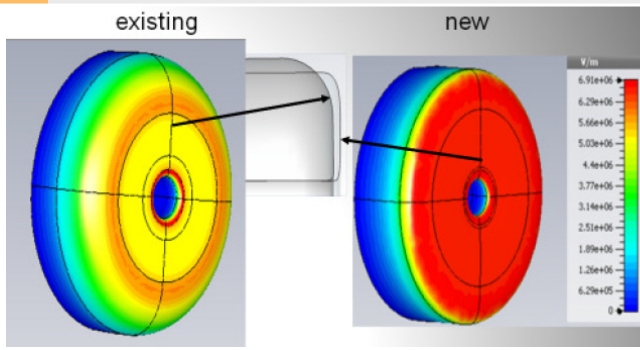
„realistic scenario“
- taking tolerances into account

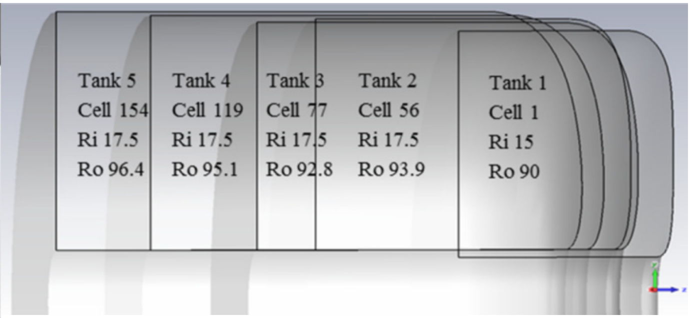
Quadrupole x,y displacement	± 0.15mm
Quadrupole x,y rotation	± 1°
Quadrupole z rotation	± 0.1°-0,4°
Gap voltage	± 1%
Gap phase	± 1°
Initial energy	± 0.5%
Input rms emittance (x,y,z)	± 15%
Input beam mismatches (x,y,z)	± 10%
Input Current	± 15%

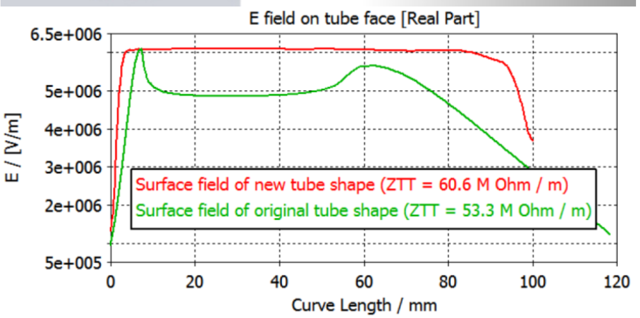


SIS18-multi-turn injection performance chart
S. Appel et al., Nucl. Instr. and Meth. A 852 73-79 (2017)

What is new concerning the rf-design?





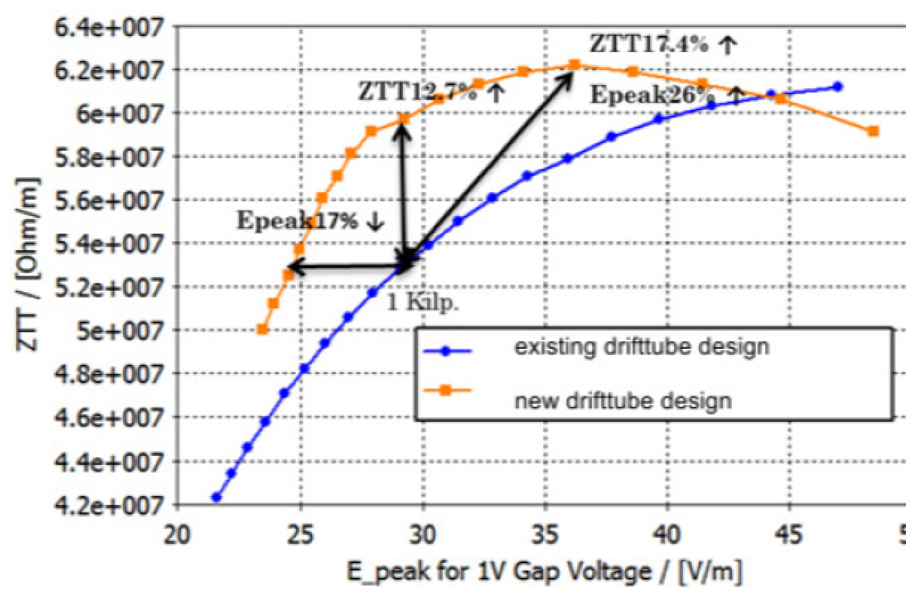


At 1.0 Kilpatrick (maximum surface field), ~13% increase in shunt impedance

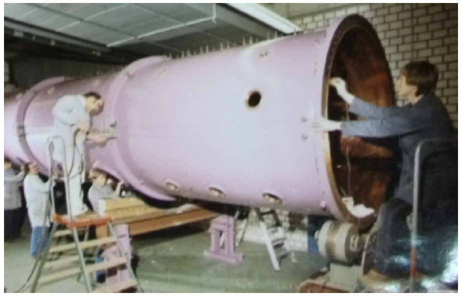
Modernisation
of UNILAC RF-systems

1.8 MW THALES
cavity amplifier prototype
(2ms rf pulse length @10Hz)

G. Schreiber, B. Schlitt, GSI



What are the challenges?



storage/assembling/testing areas on-site

expertise is retired

<u>Dimension of the cavities</u>

Cu-plating

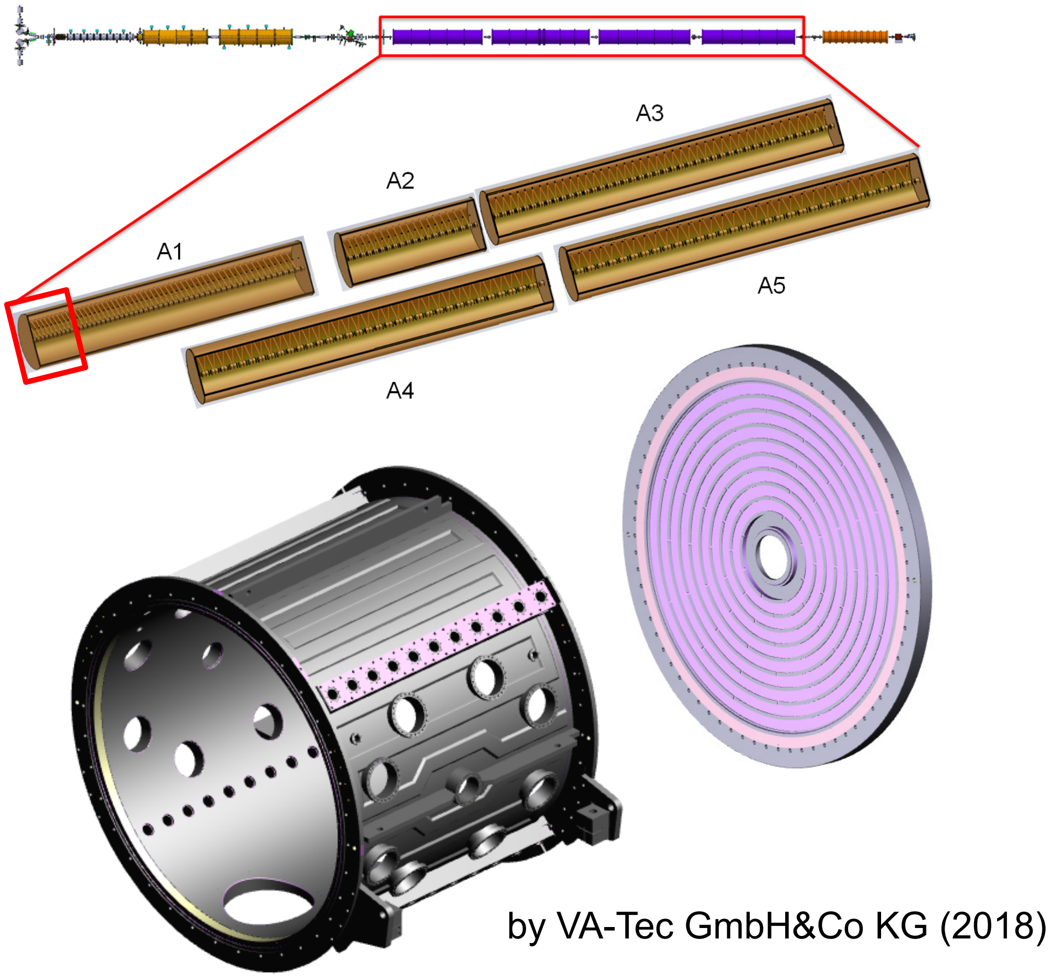
equipment is scrapped partly

<u>new drift tube design</u>
(tight spatial conditions, higher gradients)

<u>Regular beam time in parallel</u>

<u>FAIR project in parallel</u>

What is the First of Series (FoS)?



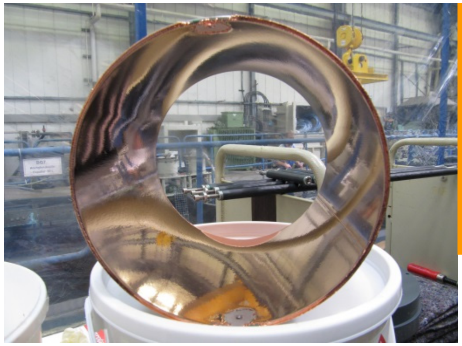
- Feb 2017:
  System-Decision:
  Alvarez type DTL
- Jul/Aug 2017:
  FoS funded with
  1.5 M€ until 2021
- Nov 2017:
  Procurement of components starts
- 2018-2020:
  R&D: System design
  process development
  preparation test stand
  delivery of components
- 2021
  Full performance tests
  -> rf characteristics
  -> pulsed quadrupoles
  -> cooling system

1st section of A1 cavity (11 + two ½ drifttubes)

What is the FoS-status?

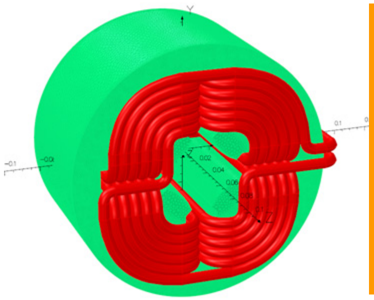
Dummy cavity (d_{out}=2.4, l=2.5m)

- fabrication:
  balance between effort in fabrication and acceptable tolerances
- Cu-plating (120µm Cu-layer):
  surface quality ex factory, alternative process, handling, etc.



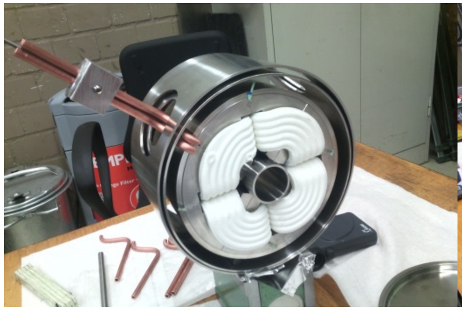
Cu-plating R&D

- new additive for elektrolyte
- Test pipes (200µm)



Pulsed quadrupole design (1st of ~200)

Gradient: 51 T/m	Conductor diameter: 5.5 mm
Effective length: 99.5 mm	Cooling channel diameter : 3.5 mm
Integral field (G* L_{eff})= 5.07 T	No. of windings: 5
Current: 1109.6 A	No.of cooling circuits: 1
Yoke material: VACOFLUX50	



Drift tube prototyping

know-how acquisition (feasibility, spare part production, welding, etc.)

How the schedule looks like?

strict boundary condition:
minimize the downtime

-> don‘t touch the existing if there is any uncertainty about the new Alvarez

-> sequential installation and commissioning

-> UNILAC downtime has to match the FAIR schedule

Q2/2021	**Successful FoS project, TDR & funding available**
Q2/2022	**Delivery of components/cavities starts**
Q2/2024	**All components in-house**
Q2/2024 + X	**De-installation of existing post-stripper DTL**
Q4/2024 + X	**Cavity-wise installation and commissioning**
Q4/2025 + X	**DTL commissioning w/o and with beam**

Summary

- Two aspects require the substitution
  - Operational risk
    refurbishment of the existing DTL means an one-to-one-copy
    -> no gain in performance, no significant cost savings
  - FAIR intensity requirements for heavy ion beams
    -> existing DTL is not designed for HC applications
    -> intertank-sections and limited quadrupole gradients

- Robust beam dynamics (focusing periodicity)
  - re-design of intertank-sections
  - higher quadrupole gradients

- RF-efficiency is increased by new drift tubes geometry

- FoS-Project is funded until 2021
  -> testing of innovations in design and fabrication
  -> procurement and development is in progress

- Kick-off for series production is a successful FoS project

- No immediate „urgency“ until the existing UNILAC is in operation,
  a delay X can be allowed w.r.t. the overall FAIR schedule and the project‘s progress

Thanks

Anna Rubin,
Xiaonan Du,
Manuel Heilmann,
Michael Kaiser,
Peter Gerhard,
Lars Groening
Marcel Rosan,
Jens Holluba,
Stephan Teich,
Markus Romig
Tanja Dettinger,
Frank Cours,
Norbert Bönsch,
Eberhard Merz
Stefan Jagsch,
Wilfried Sturm,
Vaishnavi Srinivasan,
Carsten Mühle
Bernhard Schlitt,
Gerald Schreiber,
...

Foto:Sep2018 by T. Middelhauve/FAIR