

Development of new Heavy Ion Linacs at GSI



L. Groening and S. Mickat

for the Linac Development Team at GSI

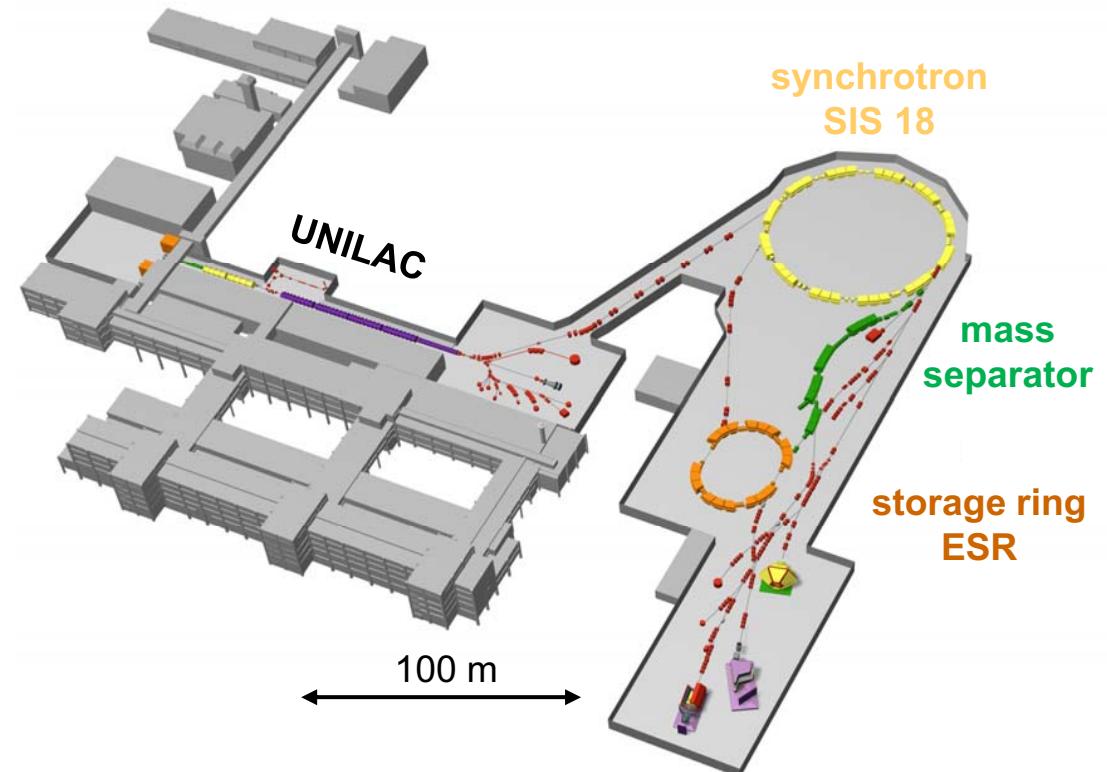
Development of new Heavy Ion Linacs at GSI



- Introduction to GSI
- Linac developments for:
 - upgraded UNILAC
 - design of a cw-linac
- Summary



- all ion species from protons to uranium
- protons to 4 GeV, uranium to 1 GeV/u
- parallel provision of three ion species at several energies to several users



Typical Beam Time Schedule at GSI

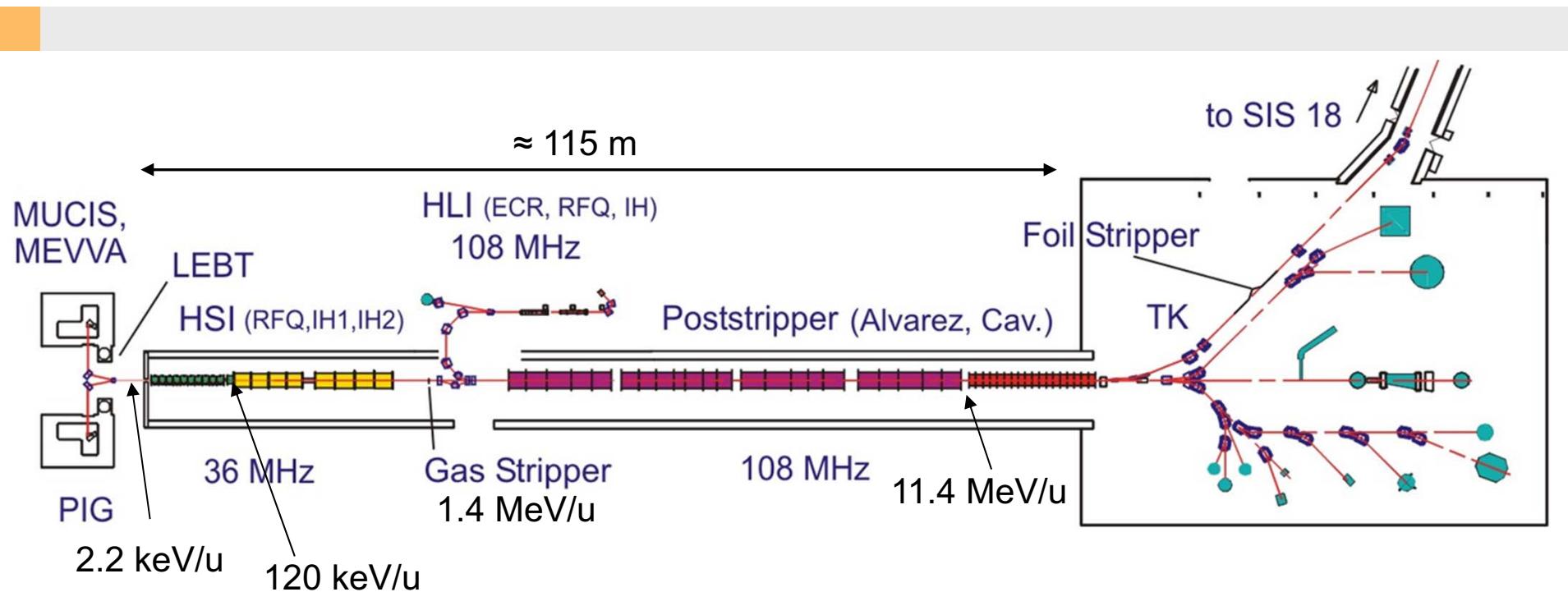


June 2016

Jun 2016	1 Mi	2 Do	3 Fr	4 Sa	5 So	6 Mo	7 Di	8 Mi	9 Do	10 Fr	11 Sa	12 So	13 Mo	14 Di	15 Mi	16 Do	17 Fr	18 Sa	19 So	20 Mo	21 Di	22 Mi	23 Do	24 Fr	25 Sa	26 So	27 Mo	28 Di	29 Mi	30 Do															
UNILAC 1	48-Ca U300 / UX8 Yakushev						197-Au UMAT / M-Branch Trautmann / Bender						12-C U304 / Clobanus / K		12-C UMAT / Trautmann /		197-Au UMAT / M-Branc Trautmann / Bender		48-Ca U295 / UY7 Laatiaoui / Block																										
UNILAC 2	48-Ca UMAT / Trautmann / B			48-Ca UMAT / UM3 Trautmann / Bend			197-Au UBIO Friedrich	197-Au UMAT Trautmann /	197-Au UMAT / Trautmann /		12-C UBI Friedric		197-Au UMAT / UX0 Trautmann / Toimil						48-Ca UMAT Trautmann /																										
UNILAC 3	48-Ca U295 / UY7 Block						197-Au U305 / UZ Rosmej			12-C U303 / UZ6 Cayzac / Blazevic			197-Au U306 / UZ6 Xu / Weyrich																																
UNILAC 4																																													
UNILAC 5																																													
SIS 1	238-U SDET / HTA Trautmann						124-Xe SB000 Spiller / St			124-Xe SDET / HTC Simon / Scheidenberger						124-Xe S Spiller		12-C SB Spiller																											
SIS 2	238-U SB0 Forck																																												
SIS 3	238-U SB0 Bozyk																																												
SIS 4	238-U SDET / HFS Scheidenberger / Simon																																												
SIS 5																																													
ESR 1	238-U SDET / ESR Steck / Litvinov																																												

- C, Au, and Xe provided in pulse-to-pulse switching mode
- up to eight physics experiments conducted in parallel

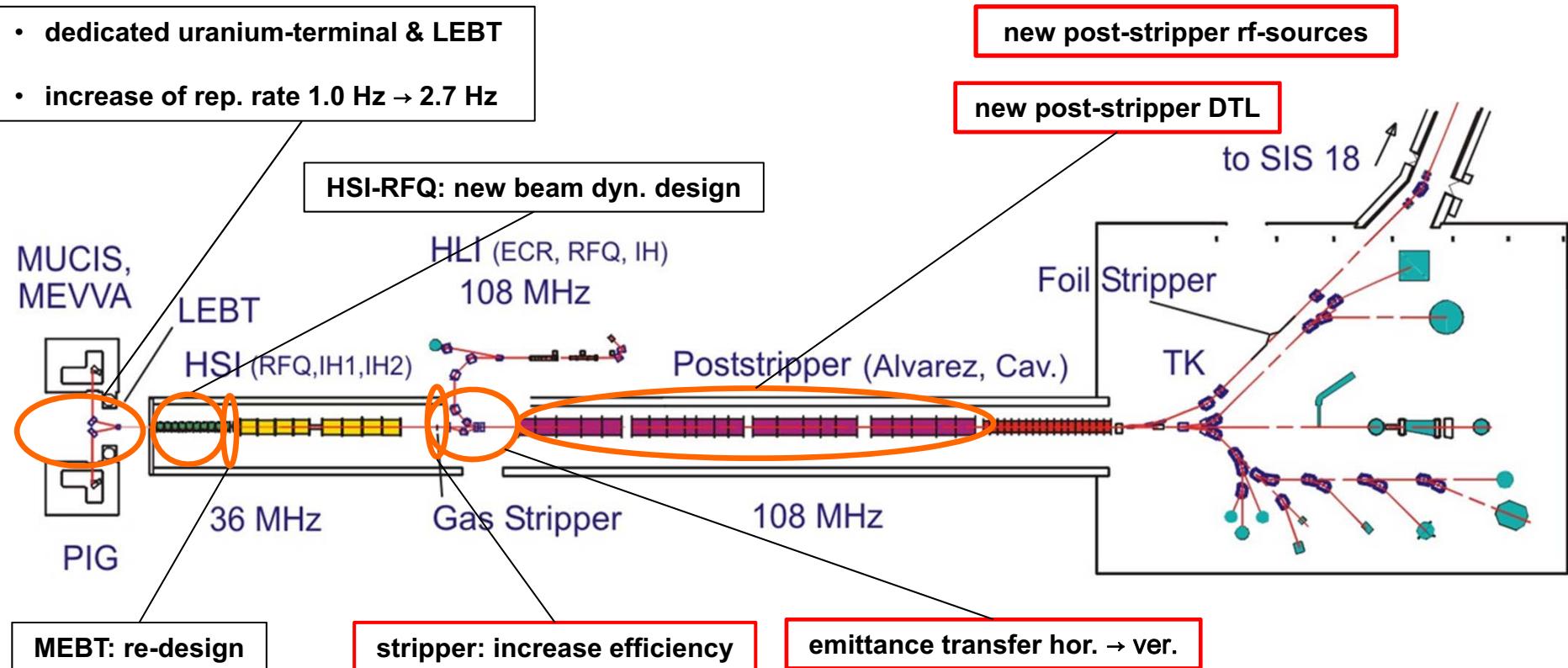
FAIR Injector: UNIversal Linear ACcelerator UNILAC



design parameters

ion A/q	≤ 8.5 , i.e. $^{238}\text{U}^{28+}$	
beam current (pulse) * A/q	1.76 (0.5% duty cycle)	mA
beam energy (adjustable)	3.0 - 11.7	MeV/u
normalized total output emittance, horizontal / vertical	$\lesssim (0.8 / 2.5)$	mm mrad
beam pulse duration	≤ 200	μs
beam repetition rate	≤ 10	Hz
operating frequency	36 / 108	MHz
length	≈ 115	m

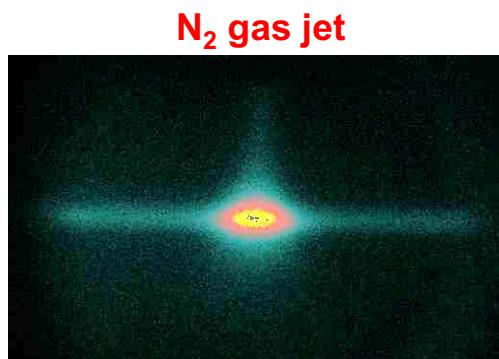
UNILAC Upgrade Activities



Heavy Ion Stripping



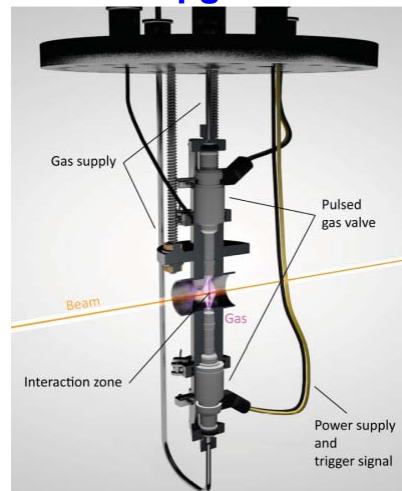
- intensive heavy ion beams → increase of „ionic charge“ by collision with matter (= STRIPPING, removal of electrons) → reduction of the required effective potential for acceleration
- collision of heavy ions with matter → e⁻-capture ($\sim Z^5$) and e⁻-loss ($\sim Z^4$)



**gas stripper section
@ 1.4 MeV/u**



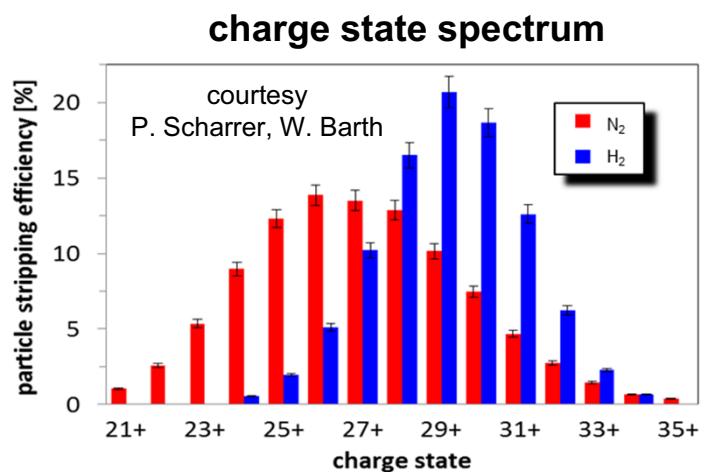
**H₂ (pulsed) gas cell
> 10 µg / cm²**



courtesy E. Jäger, A. Yakushev, J. Khuyagbaatar

beam energy loss:

U ²⁸⁺	N ₂ jet (max.)	14±5 keV/u
U ²⁸⁺	pulsed H ₂ stripper cell (1 valve, 7.5 MPa)	17±5 keV/u
U ²⁹⁺	pulsed H ₂ stripper cell (2 valves, 5.5 MPa)	27±5 keV/u



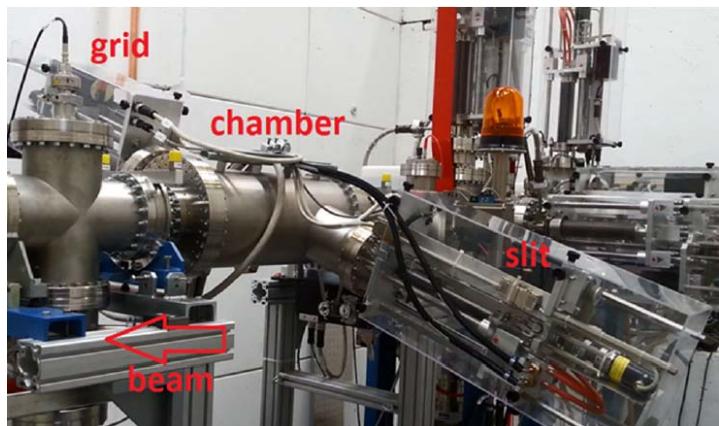
J. Radioanal. Nucl. Chem. 305, 913 (2015)
Phys. Rev. ST Accel. Beams **18** 040101 (2015)
P. Scharrer, et al.[@HIAT2015](#)
W. Barth, et al.[@IPAC2016](#)
W. Barth, et al.[@HB2016](#)

**Poster
TUPRC001**

Complete 4d Transverse Diagnostics



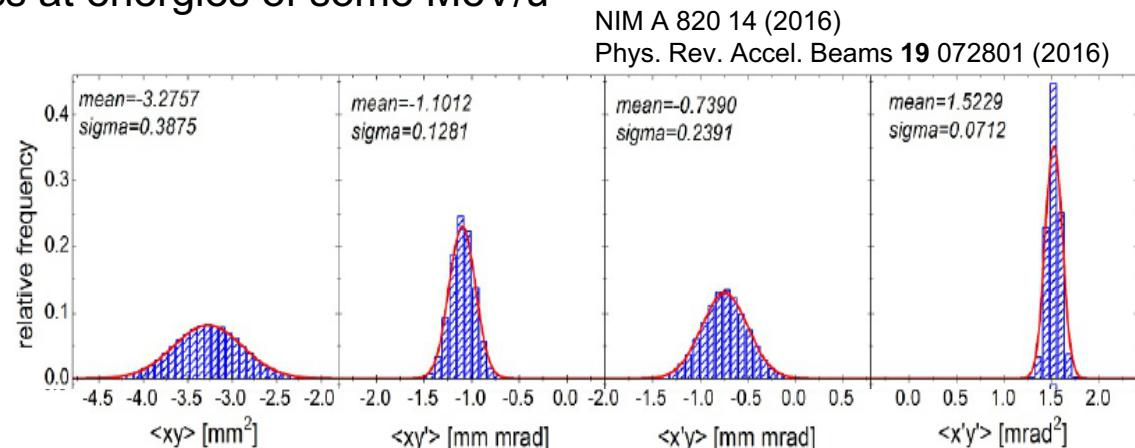
- hor. brilliance, i.e. I/ε_x , is crucial figure of merit for injector
- ε_x can be enlarged from unwanted hor. \leftrightarrow ver. beam correlations
- in turn, removal of correlations increases brilliance w/o beam loss
- requires full 4d transverse diagnostics at energies of some MeV/u



courtesy M. Maier

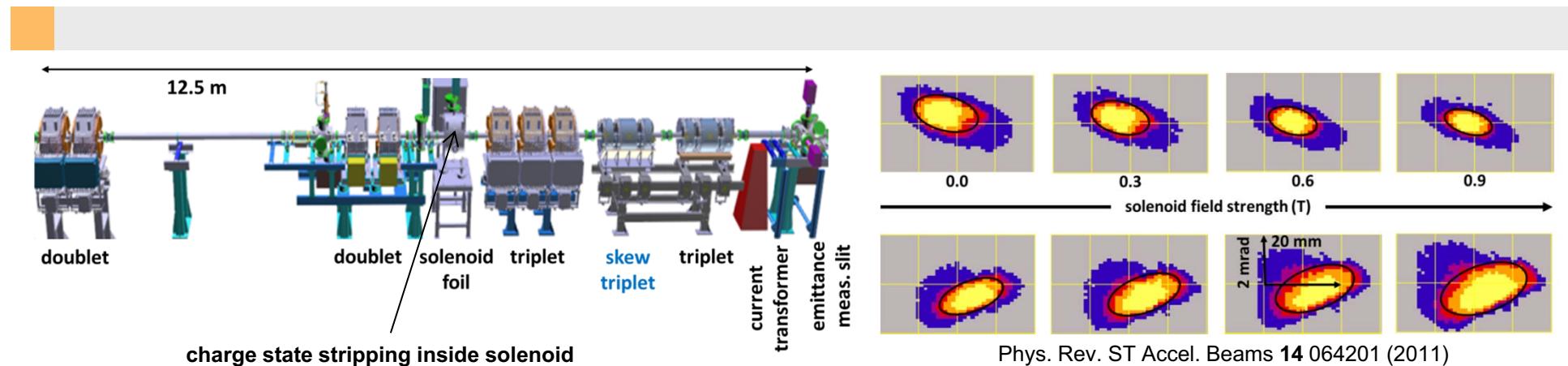
ROSE:
ROtating System for Emittance measurements

Talk
TH2A03



- all inter-plane correlations measured
- $^{83}\text{Kr}^{13+}$ at 1.4 MeV/u
- $^{238}\text{U}^{28+}$ at 5.9 MeV/u

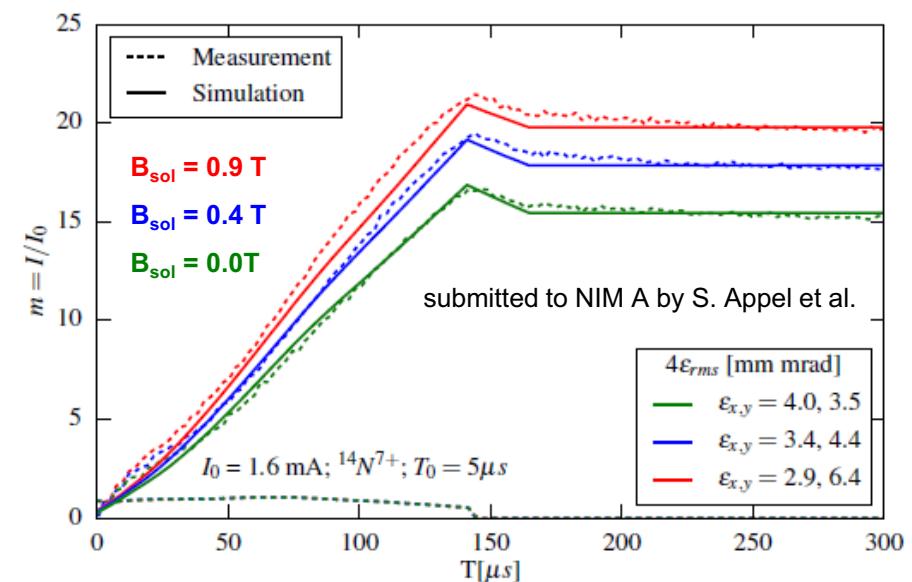
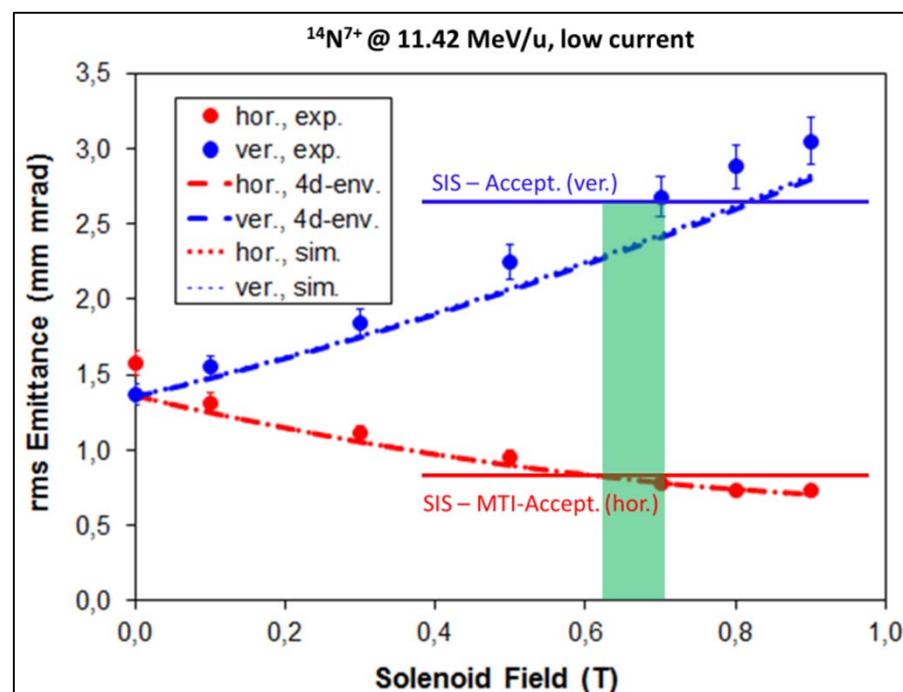
Transverse Emittance Transfer (EMTEX)



Phys. Rev. ST Accel. Beams **14** 064201 (2011)

Phys. Rev. ST Accel. Beams **16** 044201 (2013)

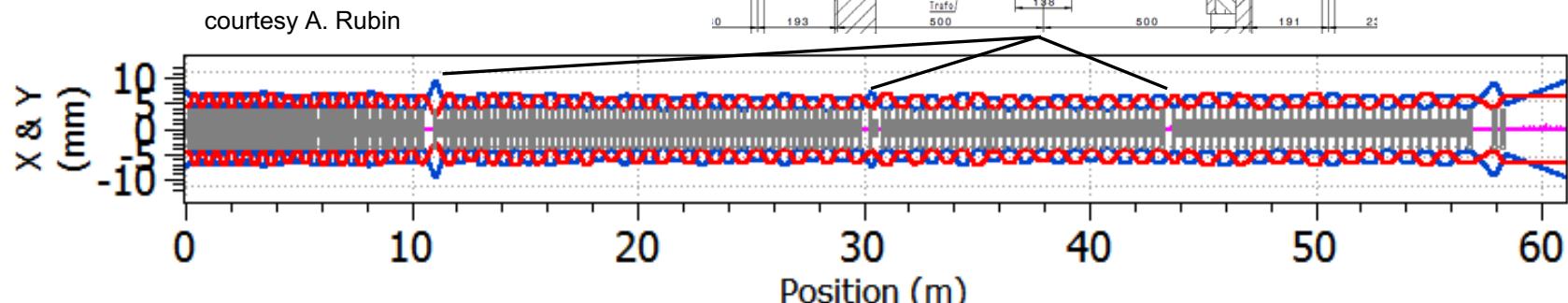
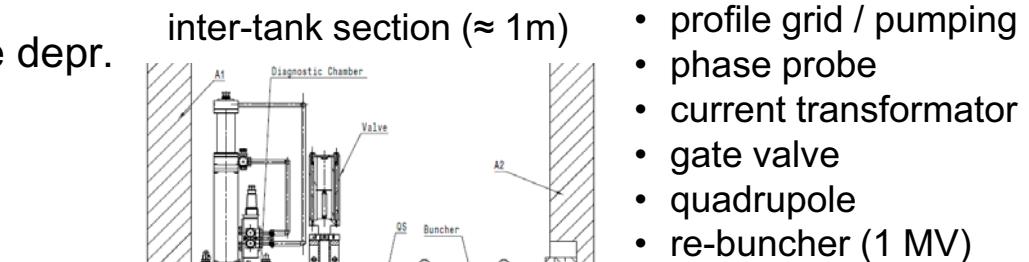
Phys. Rev. Lett. **113** 264802 (2014)



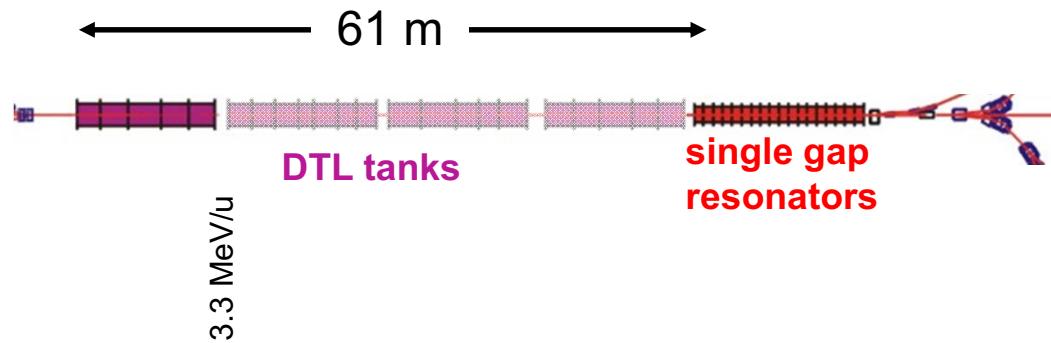
New Alvarez-Type DTL: Overall Layout



- five cavities for acceleration from 1.4 to 11.4 MeV/u, 184 cells
- pulsed em-quadrupoles
- 65° of transverse phase advance σ_0
- emittance growth $\leq 5\%$ at 35% transv. tune depr.
- inter-tank sections provide for
 - intermediate energies
 - diagnostics
 - reminder: UNILAC changes ion & energy almost every day!

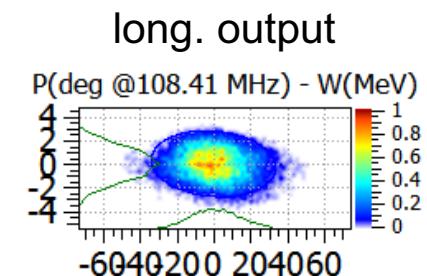
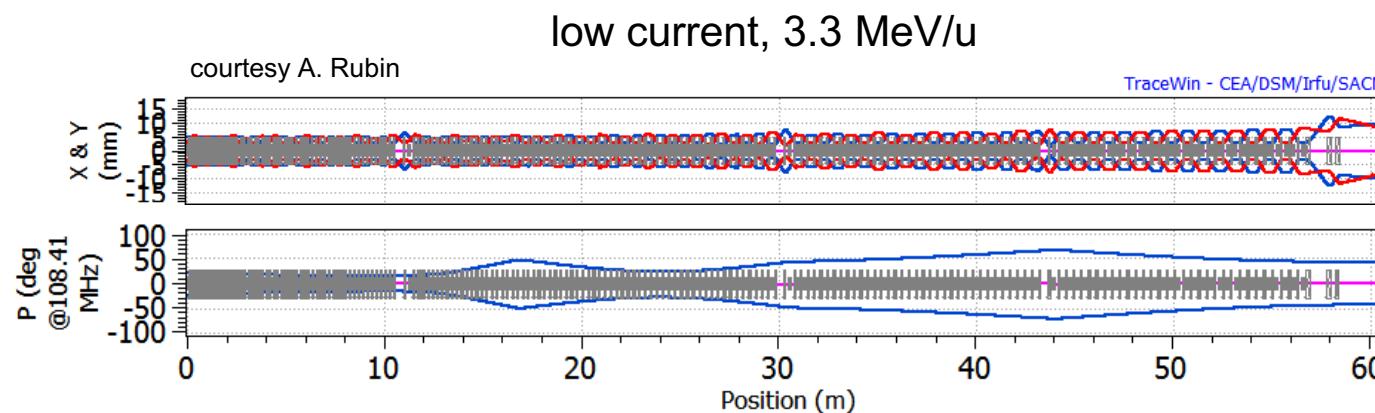


New DTL: Operation at Intermediate Energy



operation at 3.0 MeV/u output energy:

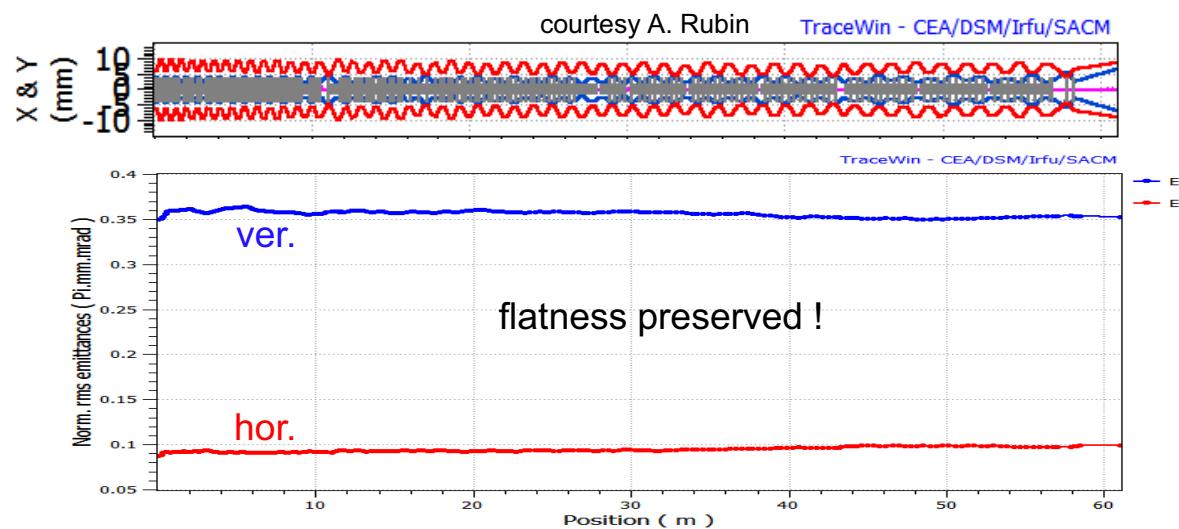
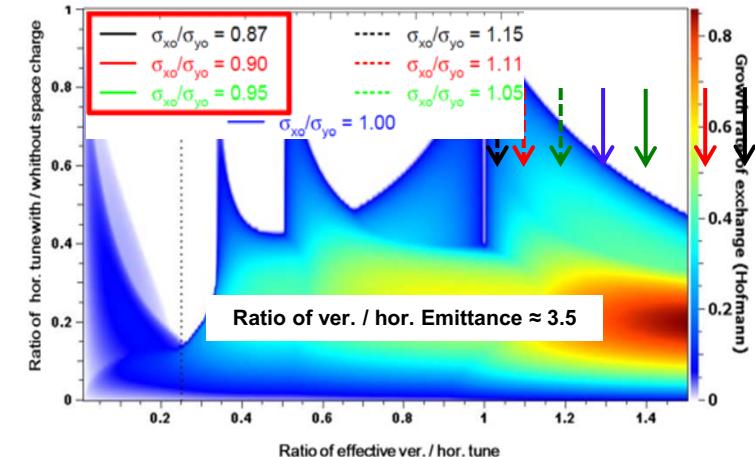
- no rf-power in last DTL tanks
- preserve short bunches along DTL
- decelerate in single gap resonators



New DTL: Asymmetric Transverse Focusing



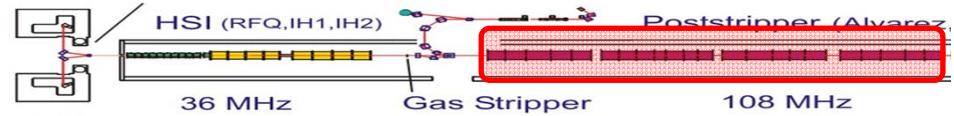
- focusing shall preserve beam emittance ratio (flatness)
- space charge drives re-equilibration of emittances
- mitigated by stronger focusing in ver. plane
- ver. focusing quads at stronger gradients w.r.t. hor. ones
- few % of increase of ver. quad gradients works



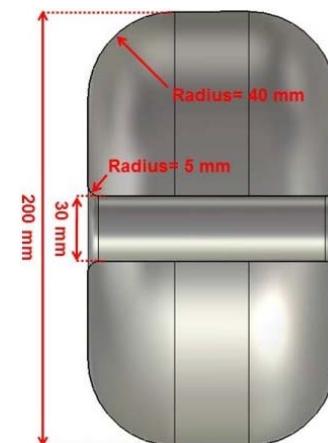
New DTL: Optimized Drift Tube Shape



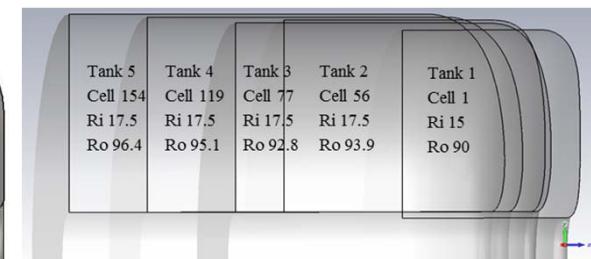
- improved shapes of drift tube end plates
- optimization of shunt impedance per surface field
- „freehand“-shape



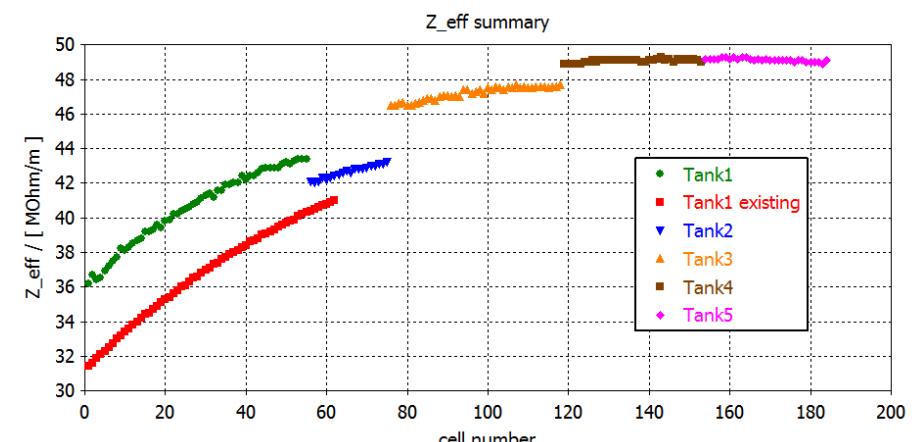
present



new



courtesy X. Du



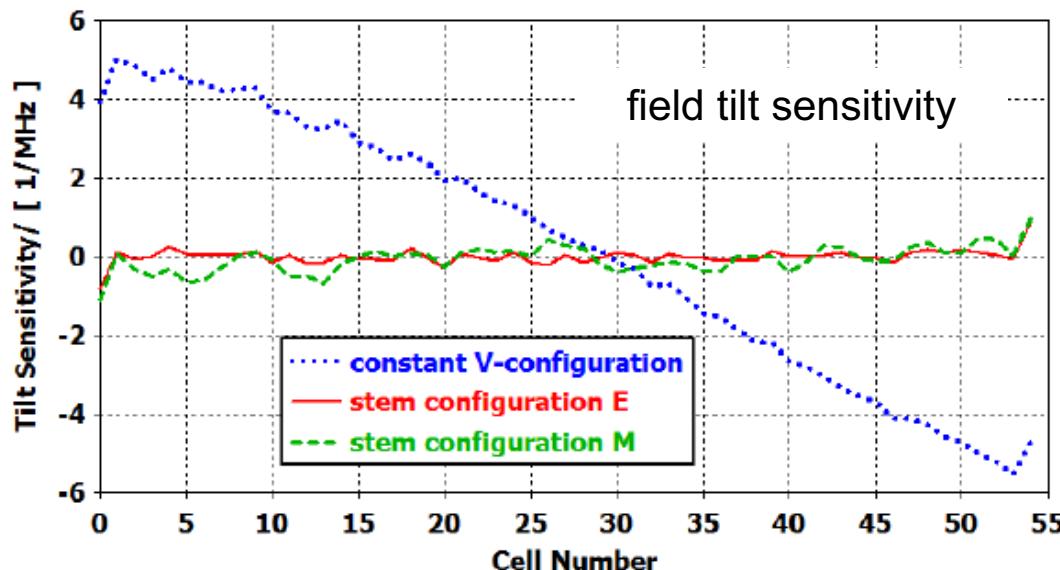
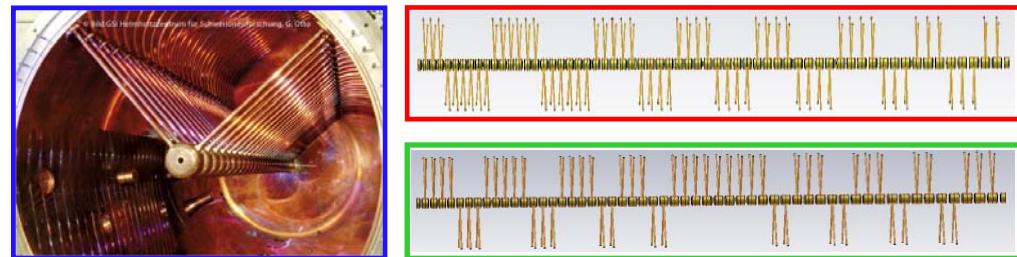
Design V5	tank I 20160713	tank II 20160713	tank III 20160713	tank IV 20160713	tank V 20160713	BBS 20160713
energy [MeV/u]	1.392 – 3.316	3.316 – 4.351	4.351 – 6.621	6.621 – 8.966	8.966 – 11.341	4.351
aperture radius [mm]	15	17.5	17.5	17.5	17.5	17.5
rf-phase [deg]	-30	-30	-30	-25	-25	+90
# cells	55	20	43	35	31	2
L _{gap} / L _{cell}	0.27	0.27 – 0.28	0.23 – 0.25	0.22 – 0.23	0.22 – 0.23	0.28
rf-length [m]	10.54	4.99	12.78	12.41	12.53	0.53
E _{surf,max} [E _R]	1.00	1.00	0.96	0.98	0.96	1.00
P _{loss,MWS} [MW]	0.885	0.555	0.870	0.842	0.853	0.121
P _{beam} [MW]	0.245	0.132	0.289	0.299	0.303	0
Q ₀	116000	113000	118000	117000	114000	52600
<Z _{eff} > [MΩ/m]	28.67	27.95	33.48	38.02	38.13	24.76
E _{eff-mean} (MV/m)	1.55	1.76	1.51	1.61	1.61	0
E _{eff-mean} (MV/m)			1.59			

New DTL: Field Stabilization through Stems



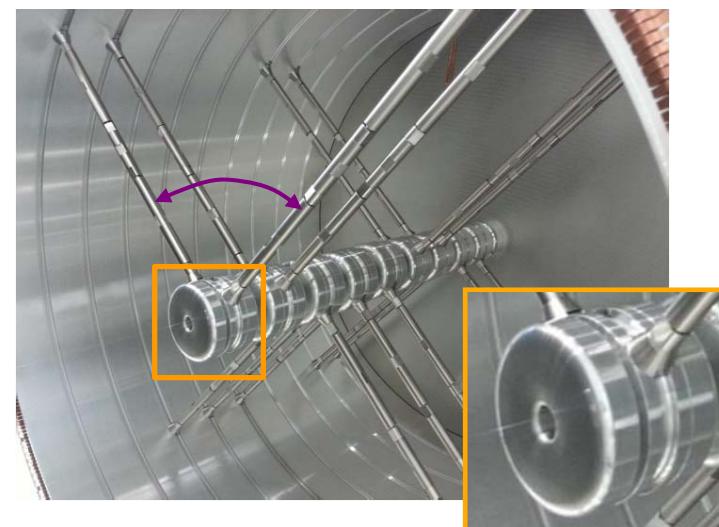
each drift tube is kept by two stems:

- provision of quad current and water cooling of tube & quad
- well-chosen orientations of stems suppress parasitic TM rf-modes



submitted to Phys. Rev. Accel. Beams by X. Du

courtesy A. Seibel



1:3 scaled cold model to probe experimentally:

- different stem orientations
- different drift tube surfaces

New DTL: Rf-System Modernization



- 1.8 MW rf cavity amplifier prototype
- 150 kW solid state driver amplifiers (prototype in preparation)
- control racks for high power amplifiers
 - modern PLC systems for amplifier control
 - new fast interlock and measurement units
 - commercial grid power supplies
 - to be used with existing amplifiers first and with new ones later
- re-use of existing powerful 1 MVA anode power supplies equipped with new PLC controls
- development of new digital LLRF systems based on MTCA.4



courtesy B. Schlitt,
G. Schreiber J. Zappai



Poster
THPLR025

THALES

struck innovative
systeme


Superconducting cw Heavy Ion Linac: Motivation & Design Parameters



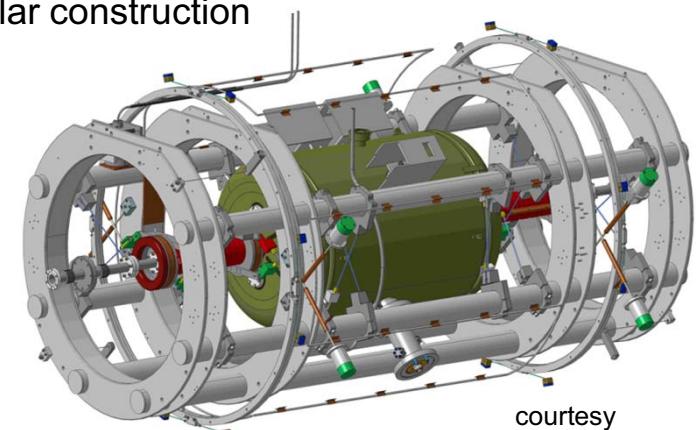
- reactions at Coulomb barrier → production of SHE
- operation: cw
- A/q: 6
- beam current: ≤ 1 mA
- injection energy: 1.4 MeV/u
- output energy: 3.5 - 7.3 MeV/u

Poster
THPLR033

production of element $^{115}\text{uuut}$:

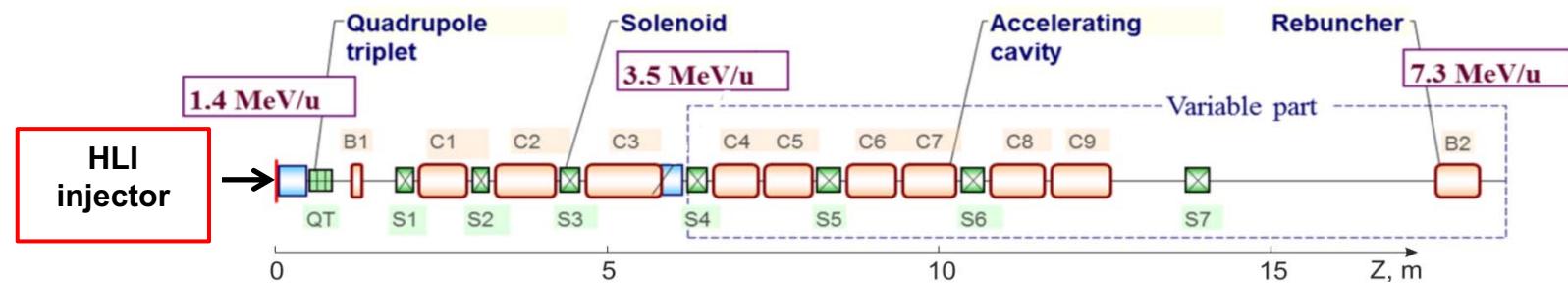
	GSI-UNILAC	cw-Linac
beam on target	3 weeks	2 days

- multi-gap CH-cavities
- small number of rf-cavities and short cavity lengths (up to 1 m)
- acc. gradient of 5 MV/m → compact linac design
- several cavities & solenoids per cryostat
- modular construction



courtesy
W. Barth, V. Gettmann

cw-linac layout (S. Minaev, 2009)



Superconducting cw Heavy Ion Linac: Layout and Timeline of R&D Phase



217 MHz CH demonstrator cavity



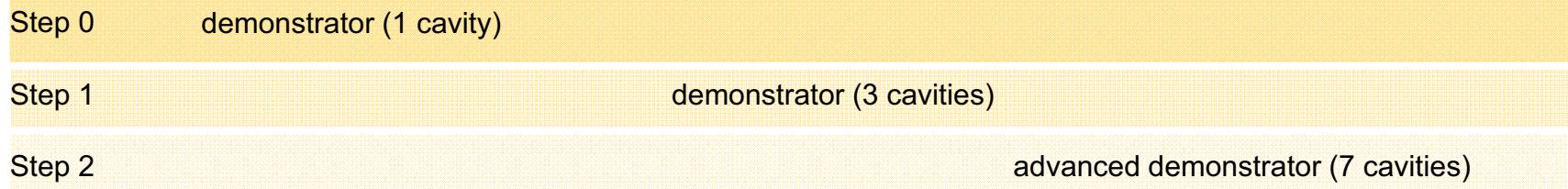
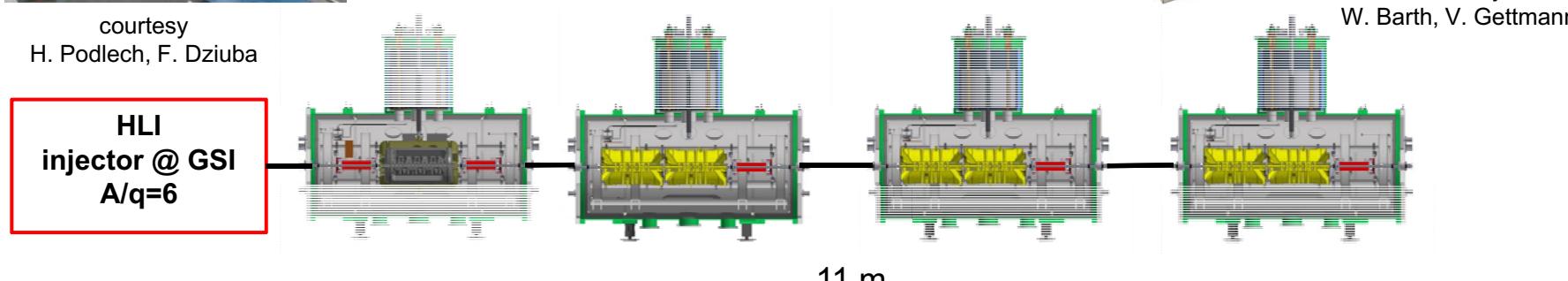
courtesy
H. Podlech, F. Dziuba

(M. Miski-Oglu @ ann. meeting
2016 of HGF-M&T, KIT/Karlsruhe)

cryomodule @ GSI test area



courtesy
W. Barth, V. Gettmann



Superconducting cw Heavy Ion Linac: Recent Status

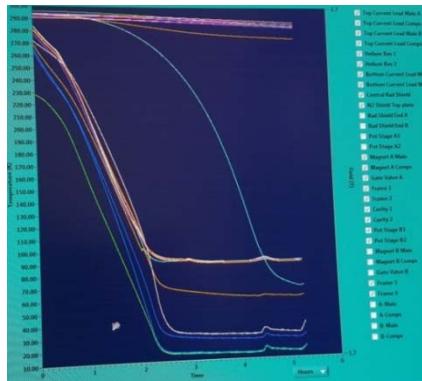


cryo module assembly (11/2015)



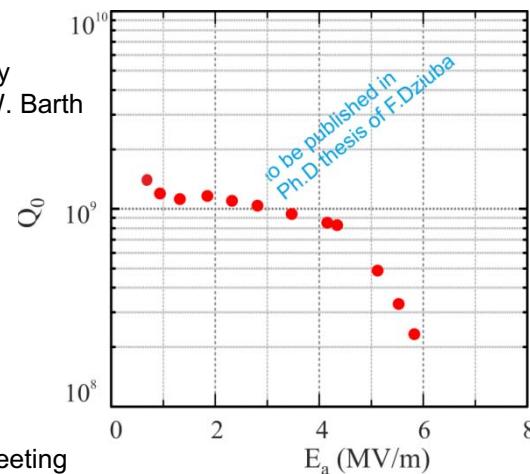
Poster
THPLR044

first cool down of cryostat to 4K
and ramp up of sc solenoids to 9.3 T



courtesy
H. Podlech, W. Barth

rf-testing (Frankfurt Univ.)



delivery status

108.4 MHz re-buncher



clean room
upgrade @ GSI
(class ISO 2)



high power
rf-coupler

Summary



- two heavy ion linacs are under design at GSI:
 1. nc, high intensity, low duty cycle DTL for ions from protons to uranium
 2. sc low current cw-linac for ions with $A/q \leq 6$
- to this end several developments are ongoing/accomplished:
 - significant enhancement of heavy ion stripping efficiency
 - full 4d transverse beam diagnostics
 - hor. → ver. emittance transfer w/o beam loss
 - asymmetric transverse focusing
 - drift tube shaping for increased shunt impedance
 - cavity field stabilization through stem orientation
 - sc CH-cavities
 - in-situ alignment set-up @ 4K

The Development Team ...



A. Adonin, W. Barth, M. Baschke, M. Basten, M. Bevcic, M. Busch, D. Dähn, X. Du, Ch.E. Düllmann, F. D. Dziuba, P. Gerhard, V. Gettmann, H. Hähnel, M. Heilmann, R. Hollinger, P. Horn, E. Jäger, M.S. Kaiser, J. Khuyagbaatar, M. Maier, M. Meister, M. Miski-Oglu, C. Mühle, H. Podlech, U. Ratzinger, A. Rubin, P. Scharrer, B. Schlitt, G. Schreiber, M. Schweda, A. Seibel, W. Sturm, H. Vormann, H. Welker, C. Xiao, A. Yakushev, S. Yaramyshev, J. Zappai, C. Zhang, O. Zurkan,

and many more



thank you !