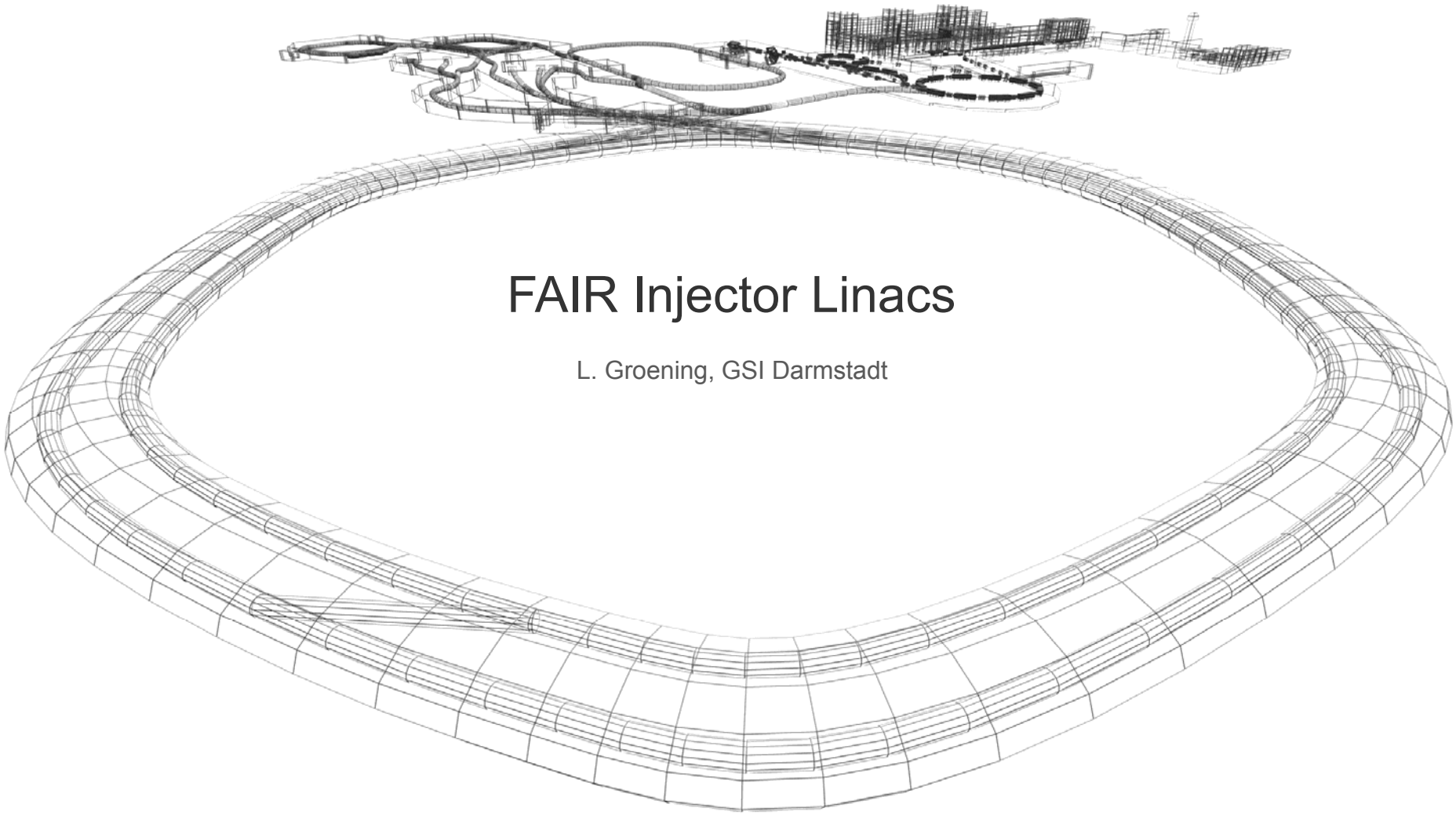
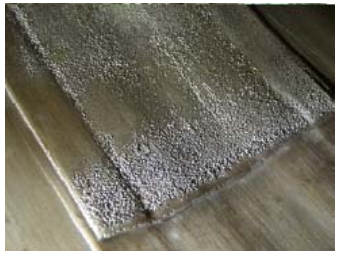


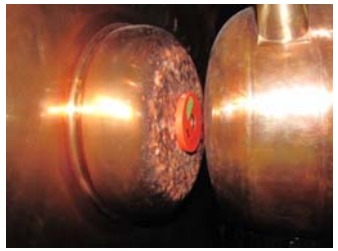
FAIR Injector Linacs

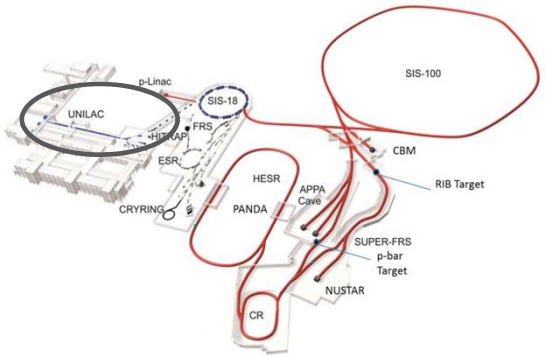
L. Groening, GSI Darmstadt

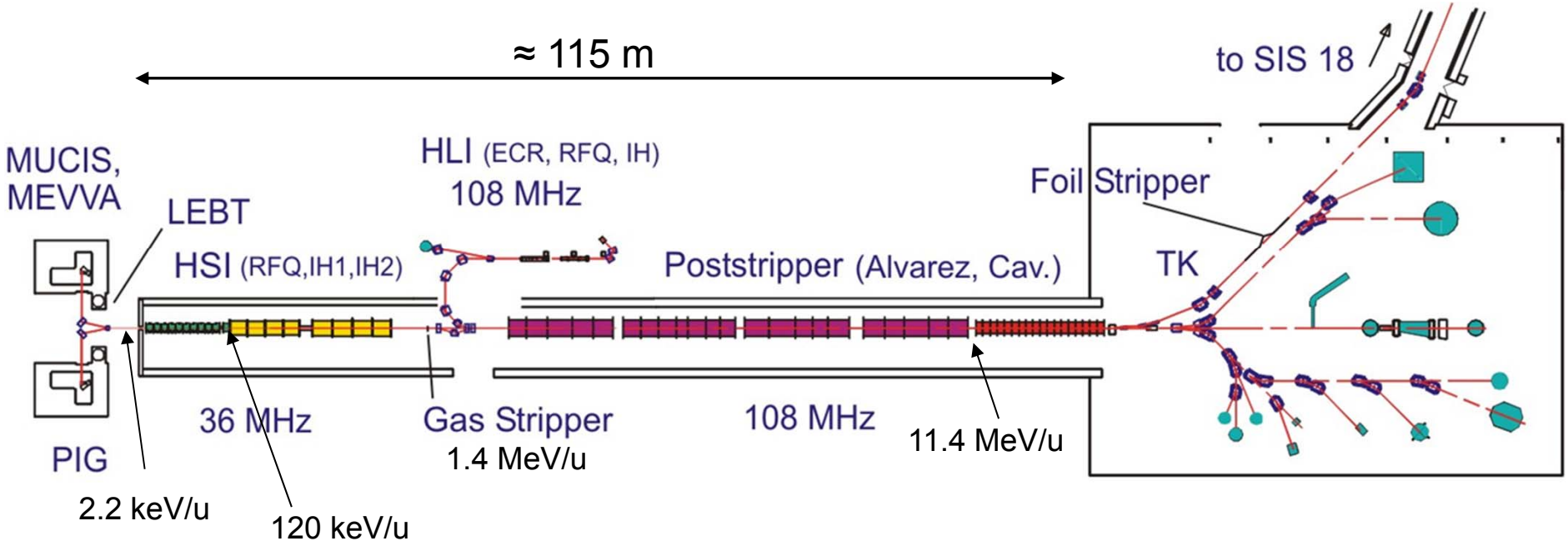
Universal Linear Accelerator UNILAC

post-stripper is in operation since more than 40 years.
Its age causes increase of down time





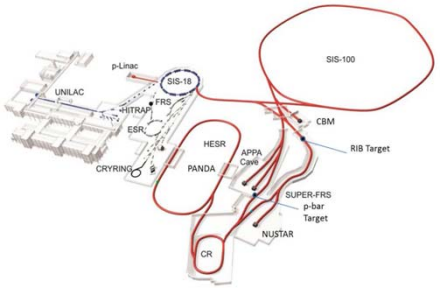




Future Requirements to UNILAC

design parameters after post-stripper replacement

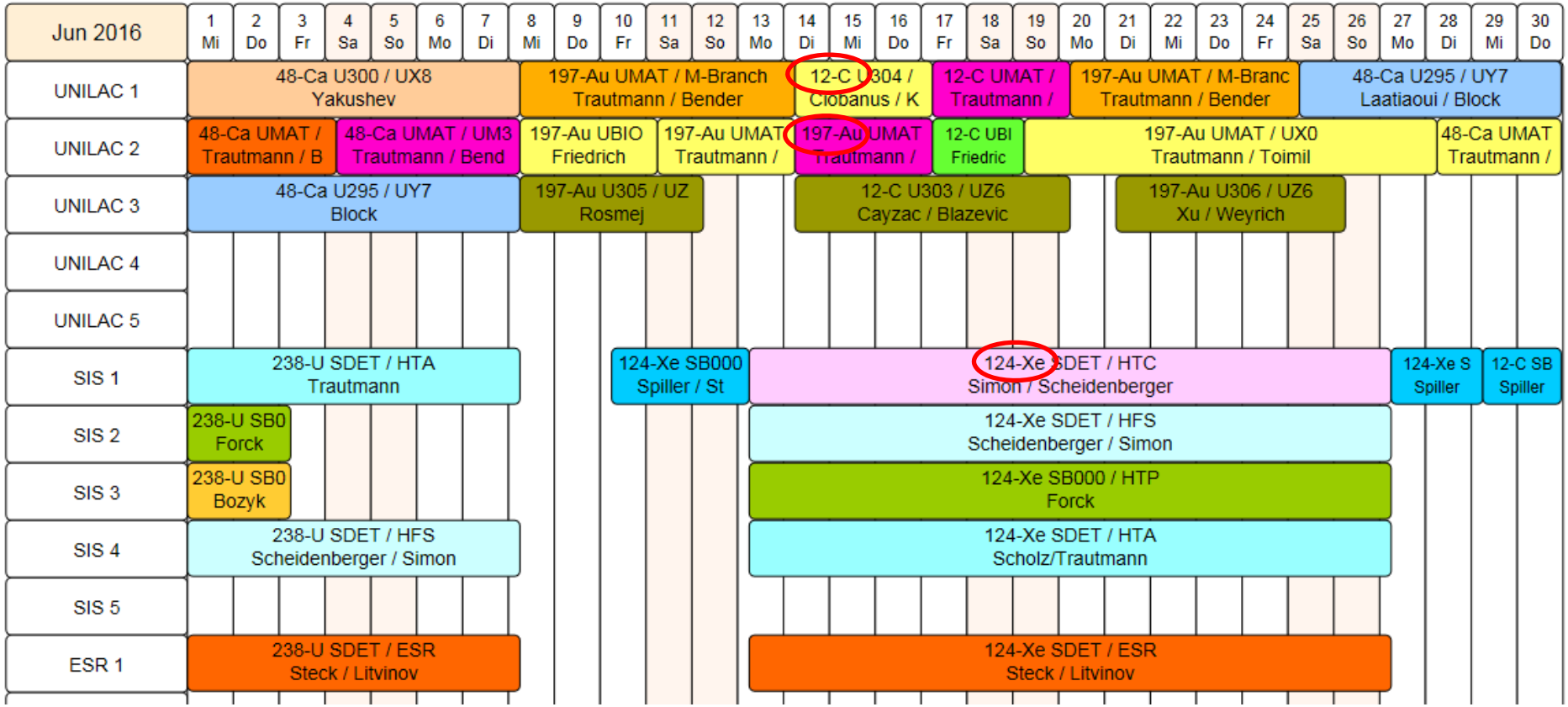
ion A/q	≤ 8.5, i.e. $^{238}U^{28+}$	
beam current (pulse) * A/q	1.76 (0.5% duty cycle)	mA
input beam energy	2.2	keV/u
output beam energy	3.0 - 11.7	MeV/u
normalized total output emittance, horizontal / vertical	0.8 / 2.5	mm mrad
beam pulse duration	≤ 1000	µs
beam repetition rate	≤ 10	Hz
operating frequency	36.136 / 108.408	MHz
length	≈ 115	m



- main task of UNILAC is to serve as injector for FAIR
- all ions with A>1 will pass the UNILAC`s post-stripper DTL
- fundamental concept for beam delivery to FAIR: very few pulses at very high intensity
- these few shots must be of best achievable quality

Typical Beam Time Schedule at GSI

June 2016



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

Users and Operation Modes:

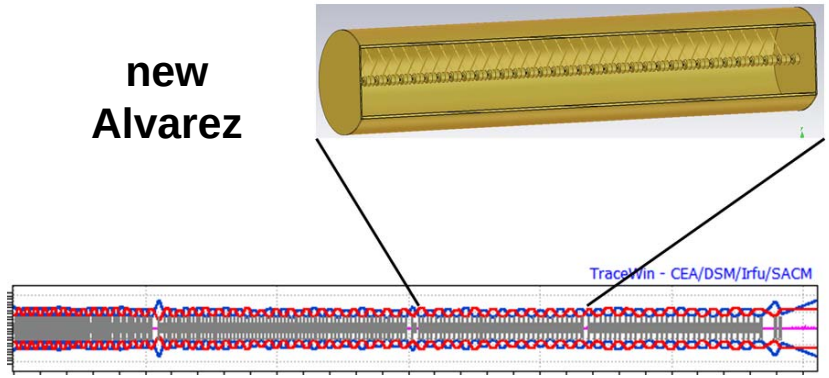
(inquired during dedicated workshop in Aug 2016)

User	Rate [Hz]	Ions	Pulse length [ms]	Intensity	Energy [MeV/u]	Comments
FAIR	≤ 2.7	p – U*	0.1	very high	11.4	FAIR requirements limit parallel operation for other users with existing post-stripper
super heavy elements	50	O – U*	5-cw	high	4-6**	experiments require continuous energy variation long beamtimes
nuclear spectroscopy	10-50	C – U*	0.1-5	high	3-7	
materials research	10-50	C - U	1-5	low – high	3-11	frequent changes of energy, intensity, exp. area
biophysics	1-50	p - U	0.1-5	very low – medium	3-11	flexible rep. rate + pulse length needed multiple short beamtimes
plasma physics	1-5	C - Ar	0.1	medium	1-4	multiple short beamtimes

*: require rare isotopes or specific ions
**: precise energy matching (keV/u), low Δp/p

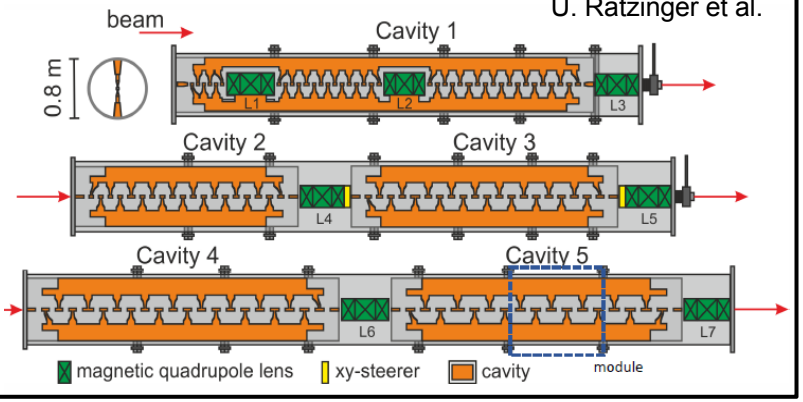
Aged post-Stripper DTL: Options

new Alvarez



IH (KONUS)

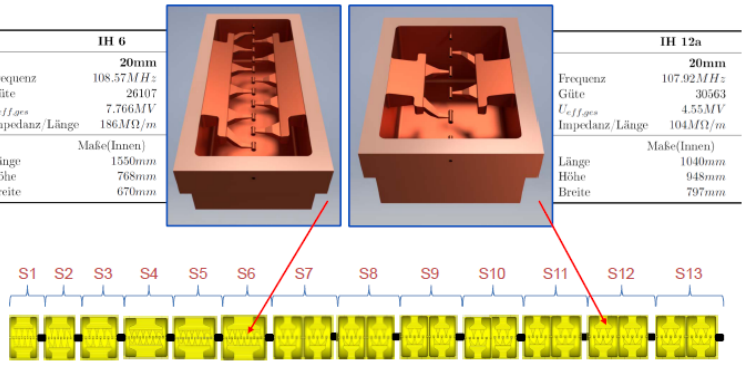
U. Ratzinger et al.



IH (Synchronous)

IH 6	20mm
Frequenz	108.57 MHz
Güte	26107
$U_{eff,ges}$	7.766 MV
Impedanz/Länge	186 MΩ/m
	Maße(Innen)
Länge	1550 mm
Höhe	768 mm
Breite	670 mm

IH 12a	20mm
Frequenz	107.92 MHz
Güte	30563
$U_{eff,ges}$	4.55 MV
Impedanz/Länge	104 MΩ/m
	Maße(Innen)
Länge	1040 mm
Höhe	948 mm
Breite	797 mm



H. Podlech et al.

Refurbishment

On-Site Expertise at GSI

Alvarez

IH (KONUS)

- GSI physicists & engineers simulated, designed, procured, copper-plated, tuned, and commissioned both types of DTLs
- staff operates both types at same machine simultaneously since 16/26 (HSI/HLI) years
- mechanicians maintain both types of DTLs

Post-Stripper DTL Options: Overall Benchmarking

<u>options were benchmarked to each other w.r.t.:</u>

- performance for different beam scenarios
- cost
- operational flexibility
- feasibility w.r.t. construction
- operational risks (surf. fields, instrumentation, ...)
- spare parts
- R&D efforts
- ...
- results summarized in a table of 34 items

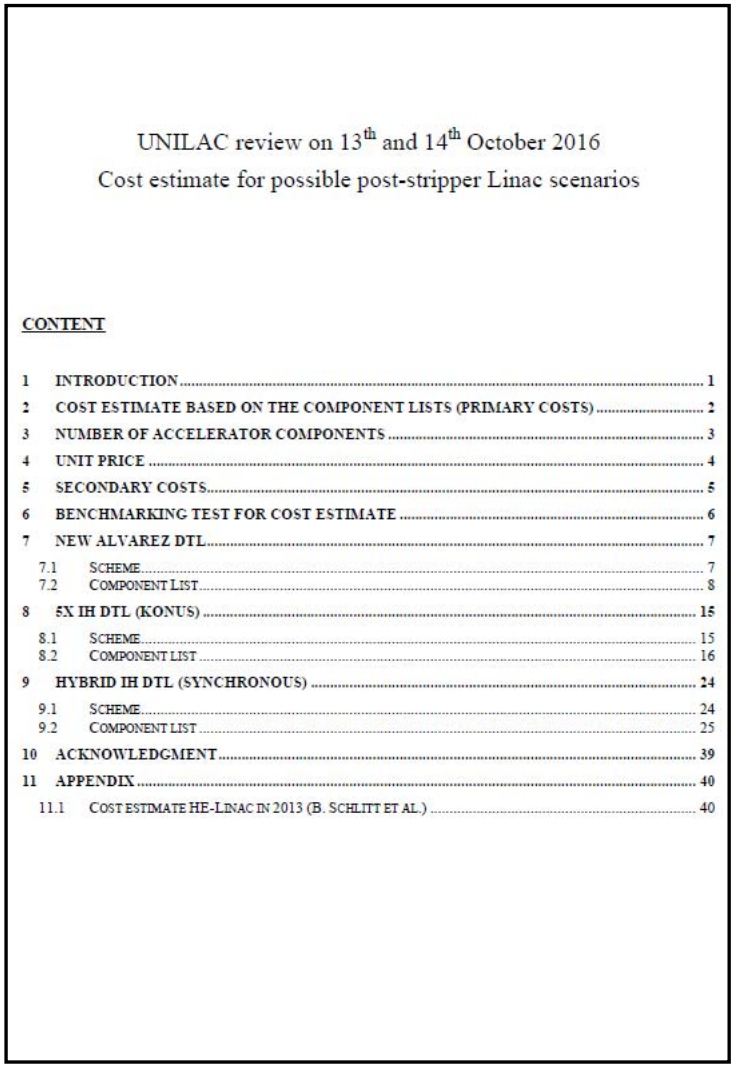
- the criteria & rules have been set by GSI directorate and commonly agreed by those placing a proposal

Criteria	New Alvarez	IH (KONUS)	IH (synchronous)	Alvarez (refurbished)
Beam Dynamics				
Six benchmarking cases are defined in Tab. 2. For each case is to be calculated (TraceWin):		TraceWin input files are not forwarded by U. Ratzinger et al, presented results are agreed between A. Rubin and H. Hähnel by using Hähnel's PC during a 1h meeting (23th Sep)	TraceWin input files for the 1st and 2nd scenario is forwarded only (27th Sep)	-
Scenario 1				
Transmission [%]	100%	100%	100%	-
Final emittances (95% tot., norm.)	1.058 mm mrad 1.061 mm mrad 104.19 MeV deg	1.62 mm mrad 1.64 mm mrad 107 MeV deg	1.262 mm mrad 1.228 mm mrad 111.67 MeV deg	-
Final bunch length (95% tot.)	± 16 deg	± 16 deg	± 26 deg	-
Scenario 2				-
Transmission [%]	100%	100%	100%	
...				
Mechanical Design and Operation[1]				
Overall length to final energy [m] DTL (TL)	57 (4)	23 (38)	35 (26)	
Max. Surface field [kilp.]	1	Not reported	Not reported	1
Max. pole tip magn. field [T]	0.8	1.03	1.1	0.66
Eff. real estate gradient [MV/m]	1.59	3.76	2.77	
Geometry & settings in TraceWin format	Both available	-Geometry from the report -Input TraceWin file not forwarded	-Geometry from the report -Input WinTrace file for the 1st and 2nd scenario only	-
# cavities (TL) incl. func. specs	5x Alvarez 4x Buncher (-) available	5x IH DTL (3x Buncher) available	20x IH DTL (1x IH-DTL) available	5
# rf-amplifiers	5x Alvarez	5x IH-DTL	20x IH DTL	5
...				
Req. spare parts	s. cost estimate	s. cost estimate	s. cost estimate	-
Risks	-not available in time for FAIR commissioning	-not available in time for FAIR commissioning -no operational experience with five long IH-cavities in series -few beam diagnostics	-not available in time for FAIR commissioning -no operational experience - designing expertise is limited to few external persons	Undefined downtime due to failure of overaged irreparable components

Post-Stripper DTL Options: Cost Benchmarking

- cost estimates based on:
  - component lists
  - functional specifications
  - budgetary offers
  - detailed procedure described in a report of 42 pages

- estimates done for all four options by
  - technical departments of GSI
  - same persons



UNILAC review on 13th and 14th October 2016

Cost estimate for possible post-stripper Linac scenarios

CONTENT

Post-Stripper DTL Options: Cost Benchmarking

	New Alvarez		IH (KONUS)		IH (Synchronous)		Refurbished DTL	
	[k€]		[k€]		[k€]		[k€]	
Total	**28.424**		**18.306**		**40.300**		**25.875**	
DTL	27.616		13.429		36.015		25.175	
Transfer line	108		4.177		3.585		-	
Cavities		15.135		3.835		7.980		15.135
Rf-systems		10.040		9.400		24.450		10.040
Magnets		120		1.440		2.055		-
Power converters		1.290		1.980		3.540		-
Instrumentation		126		218		306		-
Vacuum		388		264		460		-
Alignment		88		80		172		-
Infrastructure		537		389		637		-
Tunnel (Ventilation, Cooling, etc)	700		700		700		700	

Post-Stripper DTL Options: Beam Dynamics Benchmark Scenarios

at DTL entrance $^{238}U^{28+}$ @ 1.394 MeV/u, Gaussian distribution, TraceWin, hard edge quads

Scenario	Input				Output
	I [mA]	$\beta\gamma\varepsilon_{x,rms}$ [µm]	$\beta\gamma\varepsilon_{y,rms}$ [µm]	$\varepsilon_{\|\|}$ [MeV/u deg]	E_{fin} [MeV/u]
FAIR nominal	16.5	0.175	0.175	0.07	11.4
low current	0	0.175	0.175	0.07	11.4
low energy & current	0	0.175	0.175	0.07	3.3(Alv) / 3.9(IH)
doubled long. input emit.	16.5	0.175	0.175	0.14	11.4
half long. input emit.	16.5	0.175	0.175	0.035	11.4
half hor. / double ver. input emit.	16.5	0.0875	0.350	0.07	11.4

compare transmissions and emittance growth rates

Post-Stripper DTL Options: Beam Dynamics Benchmarking

norm. tot. 95%-emittance growth rates

Scenario	New Alvarez				IH (KONUS)				IH (Synchronous)			
	T [%]	$\Delta\varepsilon_x$ [%]	$\Delta\varepsilon_y$ [%]	$\Delta\varepsilon_l$ [%]	T [%]	$\Delta\varepsilon_x$ [%]	$\Delta\varepsilon_y$ [%]	$\Delta\varepsilon_l$ [%]	T [%]	$\Delta\varepsilon_x$ [%]	$\Delta\varepsilon_y$ [%]	$\Delta\varepsilon_l$ [%]
FAIR nominal	100	7	7	11	100	64	66	14	100	28	25	20
low current	100	0	0	1	100	4	2	20	100	1	0	10
low energy & current	100	0	0	2	100	5	3	89	no data provided			
double long. inp. emitt.	100	7	10	5	98	71	64	13				
half long. inp. emitt.	100	9	8	11	100	45	41	51				
double ver. inp. emitt. half hor. inp. emitt.	100	16	3	4	99	70	19	17				

Post-Stripper DTL Options: Dedicated Review

The outcome of the benchmarking has been presented to a dedicated Review Committee

The charge to the Committee was to assess:

- The beam performance, credibility and reliability of the presented options, to provide the required beam properties required for SIS18 injection in a reliable manner over several decades.
- Costs, effort to put into operation, maintenance effort.
- Service to UNILAC users other than SIS18.

Members:

- Frank Gerigk (CERN, Switzerland, chair)
- Robert Laxdal (TRIUMF, Canada)
- Andrea Pisent (INFN, Italy)
- Deepak Raparia (BNL, USA)
- Maurizio Vretenar (CERN, Switzerland)

Post-Stripper DTL Options: Dedicated Review

Appendix A: Agenda & presentations to the committee

Thursday, 13.10.2016

09:45	Welcome, Relevance of meeting for GSI Council	J. Blaurock
09:55	Presentation of Agenda	F. Gerigk/U. Weinrich
10:00	The UNILAC and its operation for the future	P. Gerhard
11:00	Refurbishment potential of existing Alvarez components	S. Mickat
11:30	Visit of UNILAC	P. Gerhard
12:00	Lunch	
13:00	Proposal "Alvarez type DTL"	L. Groening
	Proposal "KONUS IH-type DTL"	U. Ratzinger/H. Hähnel
	Proposal "synchronous IH-type DTL"	H. Podlech
16:00	Actual RF design for new post stripper	B. Schlitt/G. Schreiber
16:30	Closed session	F. Gerigk
18:30	End of meeting	
19:30	Dinner	

Friday, 14.10.2016

09:00	Closed session	F. Gerigk
11:30	Presentation of preliminary results	F. Gerigk
12:00	Lunch	
13:00	End of meeting and departure	

Post-Stripper DTL Options:

From final Report of Committee

General: *the beam dynamics performance is crucial for the decision on the injector*

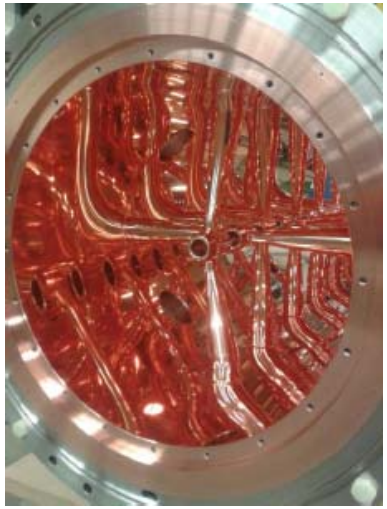
1. Refurbishment of existing post-stripper DTL
   - *the committee fully supports the replacement of the present post-stripper linac*
   - *a refurbishment is not a viable alternative and a replacement is recommended before the start of full FAIR user operation*

2. New Alvarez
   - *the committee agrees that a DTL (with FFDD focusing) offers very good guarantee for a smooth beam dynamics*
   - *the difficulty of rebuilding the Alvarez should not be underestimated ... and may yield a longer than expected fabrication and commissioning period as well as higher than expected cost*

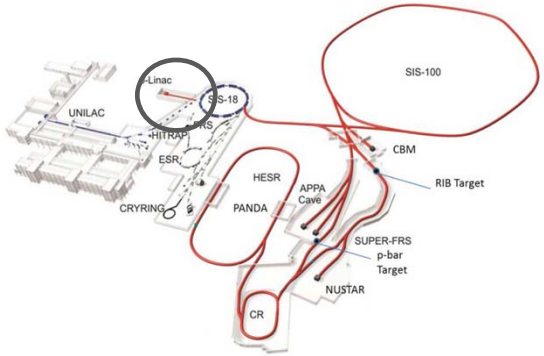
3. IH (KONUS)
   - *it is based on a proven construction design that presents limited risks for fabrication and tuning*
   - *the committee is not convinced that the proposed KONUS IH in conjunction with the existing pre-injector will fulfil FAIR requirements.*

4. IH (Synchronous)
   - *though interesting in concept we do not consider today's technology mature enough for this option*

Proton Linac: Overview



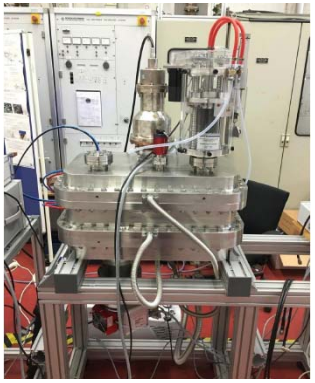
Beam Energy (MeV)	70
Design Current (mA)	70
Beam Pulse (µs)	36
Repetition Rate (Hz)	4
Frequency (MHz)	325.224
Beam Loading (peak) (MW)	4.9
RF Power (peak) (MW)	2.2
Klystron (3 MW Peak Power)	7
Solid State Amplifier	3
Total Length (RFQ + CH)	≈ 27 m



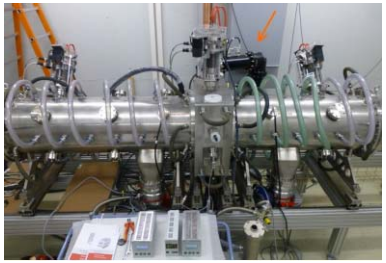
Proton Linac:
Current Status

- source/LEBT commissioning at CEA (Saclay) in Q2/Q4 2017

- ladder RFQ prototype successfully tested



- CCH prototype cavity rf-tuned and tested with high rf-power



- klystrons & power converters: contract with CNRS (Orsay) under preparation
- quadruple triplets in production

Summary

- Four options concerning the „aged post-stripper“ issue have been benchmarked
- Results were evaluated by dedicated review committee
- Further procedure is defined by the GSI Directorate
- Works on proton linac are ongoing