GSI UNILAC Preparation and the New Proton Linac for FAIR Operations

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- The FAIR Project
- UNIversal Linear ACcelerator UNILAC
- Proton Linac

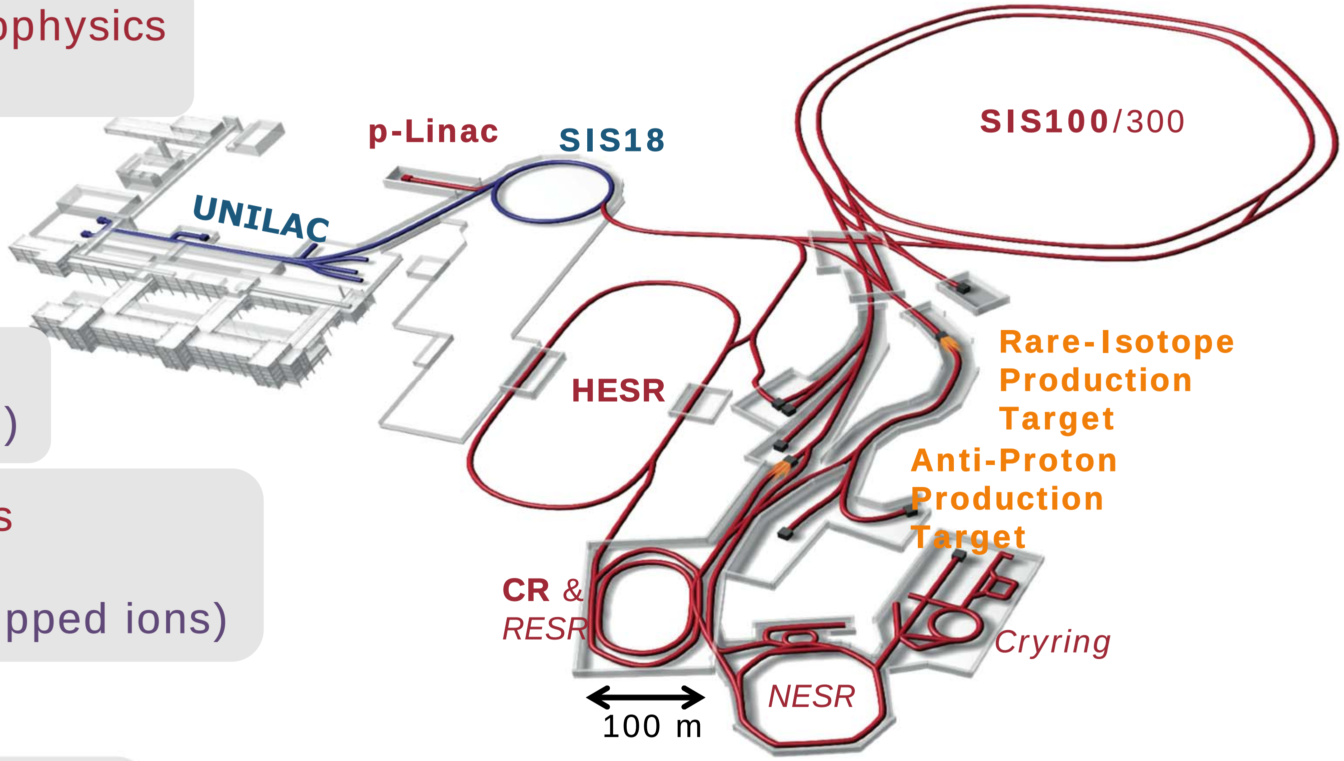
FAIR Facility for Antiproton and Ion Research

Nuclear Structure & Astrophysics
(Rare-isotope beams)

Hadron Physics
(Stored and cooled
14 GeV/c anti-protons)

QCD-Phase Diagram
(HI beams 2 to 45 GeV/u)

Fundamental Symmetries
& Ultra-High EM Fields
(Antiprotons & highly stripped ions)



Dense Bulk Plasmas
(Ion-beam bunch compression
& petawatt-laser)

Materials Science & Radiation Biology
(Ion & antiproton beams)

Accelerator Physics

courtesy B. Sharkov

FAIR Facility for Antiproton and Ion Research

Primary Beams SIS 100

- 2 × 10^{11} U^{28+} ions/s; 1.5 GeV/u
- 10^{10}/s $^{238}U^{92+}$ up to 11 GeV/u
- 2 × 10^{12} protons/s; 29 GeV

Secondary Beams

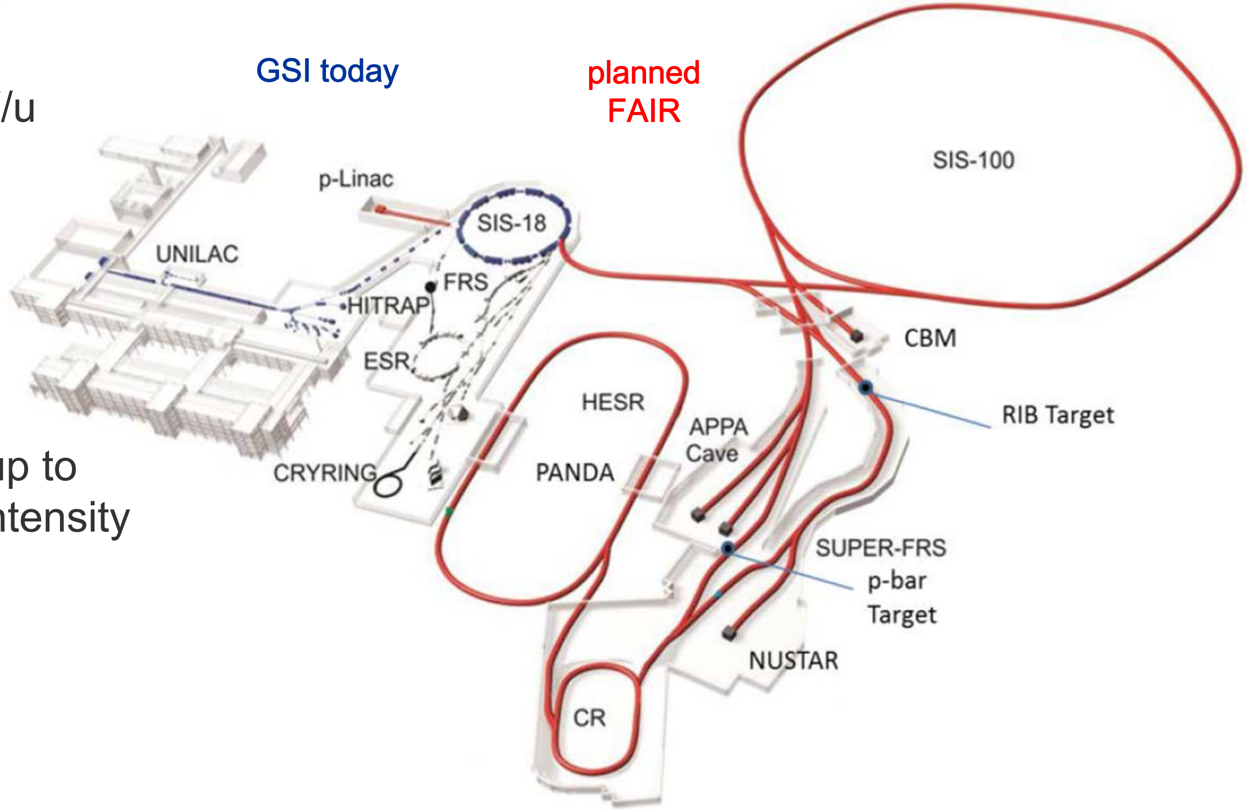
- range of radioactive ion beams up to 1.5 - 2 GeV/u; up to a factor of 10'000 higher in intensity than presently
- antiprotons 1.5 - 14.1 GeV

Storage and Cooler Rings

- radioactive ion beams
- antiproton beams:

  CR: 10^{8} antiprotons; 3 GeV

  HESR: 10^{10} antiprotons; 1.5 - 14.1 GeV



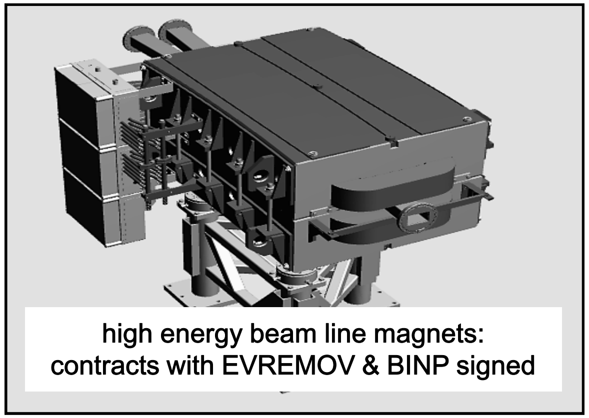
Technical Challenges

- Rapid cycling superconducting magnets
- rf-systems and control
- Beam lifetime (dynamic vacuum)
- Cooled beams

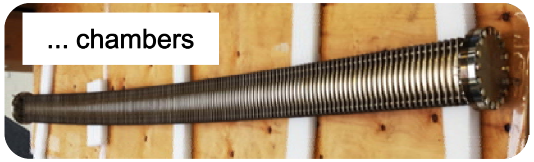
Status of FAIR Accelerators

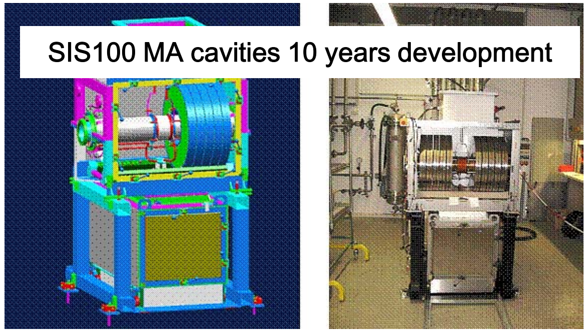
talk TUBB2 this afternoon

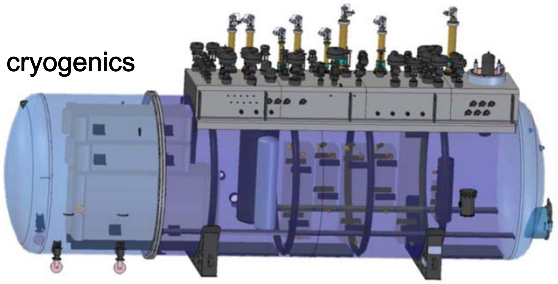

magnet testing area preparation

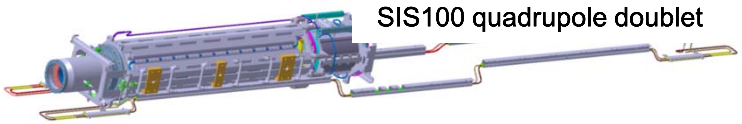

high energy beam line magnets: contracts with EVREMOV & BINP signed

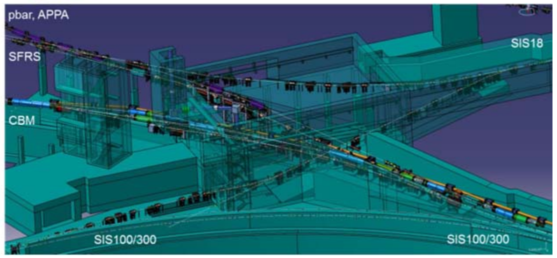
SIS100 dipole ...


... chambers


SIS100 MA cavities 10 years development


cryogenics

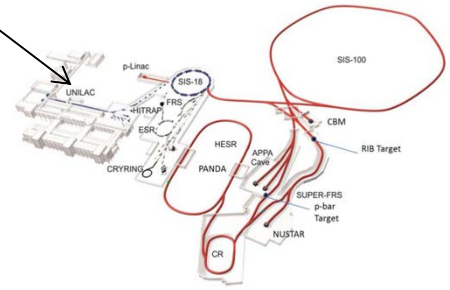

SIS100 quadrupole doublet




radiation hard magnets & staff

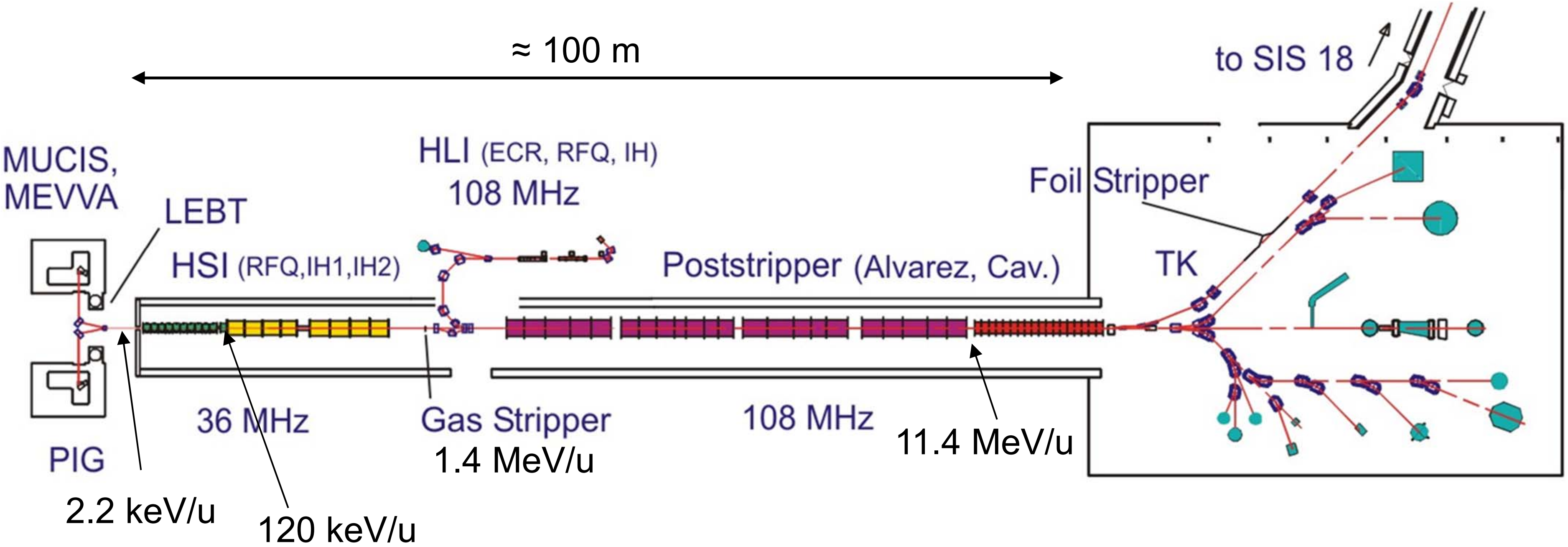
Title	Poster ID
pulsed quadrupoles	WEPMA021
SIS100 dipoles	WEPMA020
high energy beam transp. system	THPF012
status SIS100	THPF015
heavy ion induced absorption	THPF010
cryogenic surfaces in SIS100	THPF009

UNIversal Linear ACcelerator UNILAC

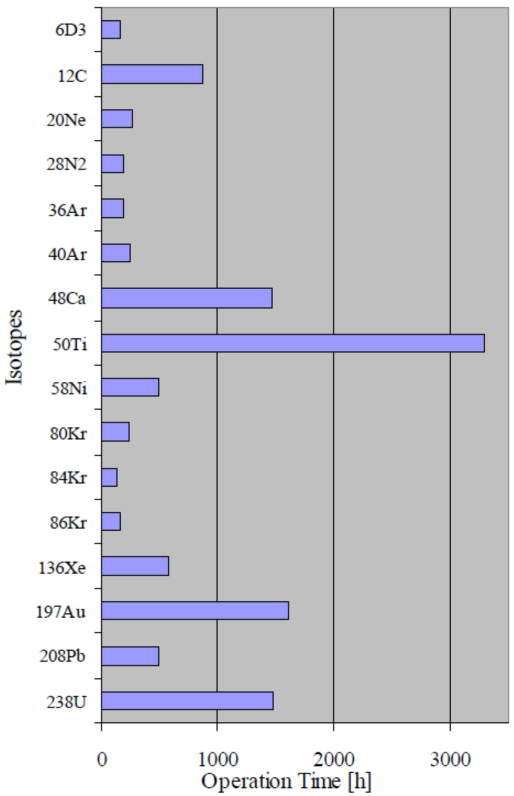


design parameters

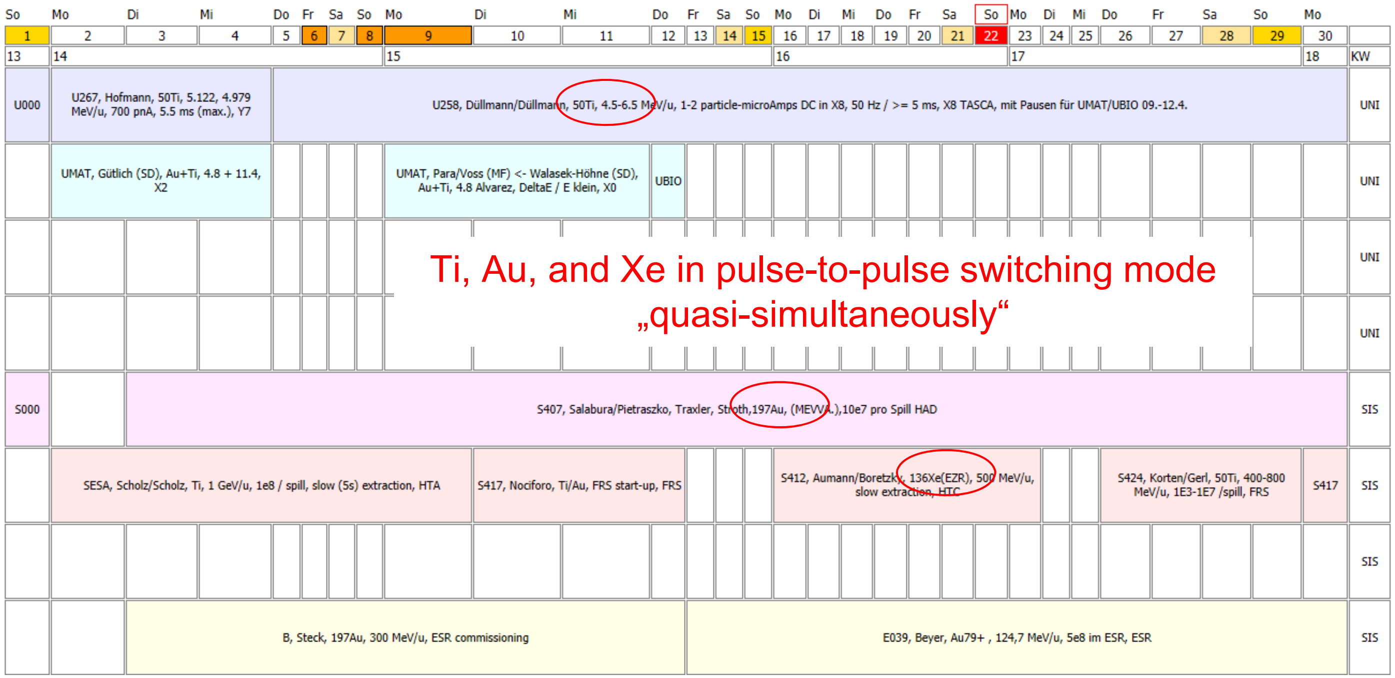
ion A/q	≤ 8.5, i.e. $^{238}U^{28+}$	
beam current (pulse) * q/A	1.76 (0.5% duty cycle)	emA
input beam energy	1.4	MeV/u
output beam energy	11.4	MeV/u
normalized total output emittance, horizontal/vertical	0.8 / 2.5	mm mrad
beam pulse duration	≤ 5000	μs
beam repetition rate	≤ 50	Hz
operating frequency	108.408	MHz
length	≈ 100	m



statistics 2012



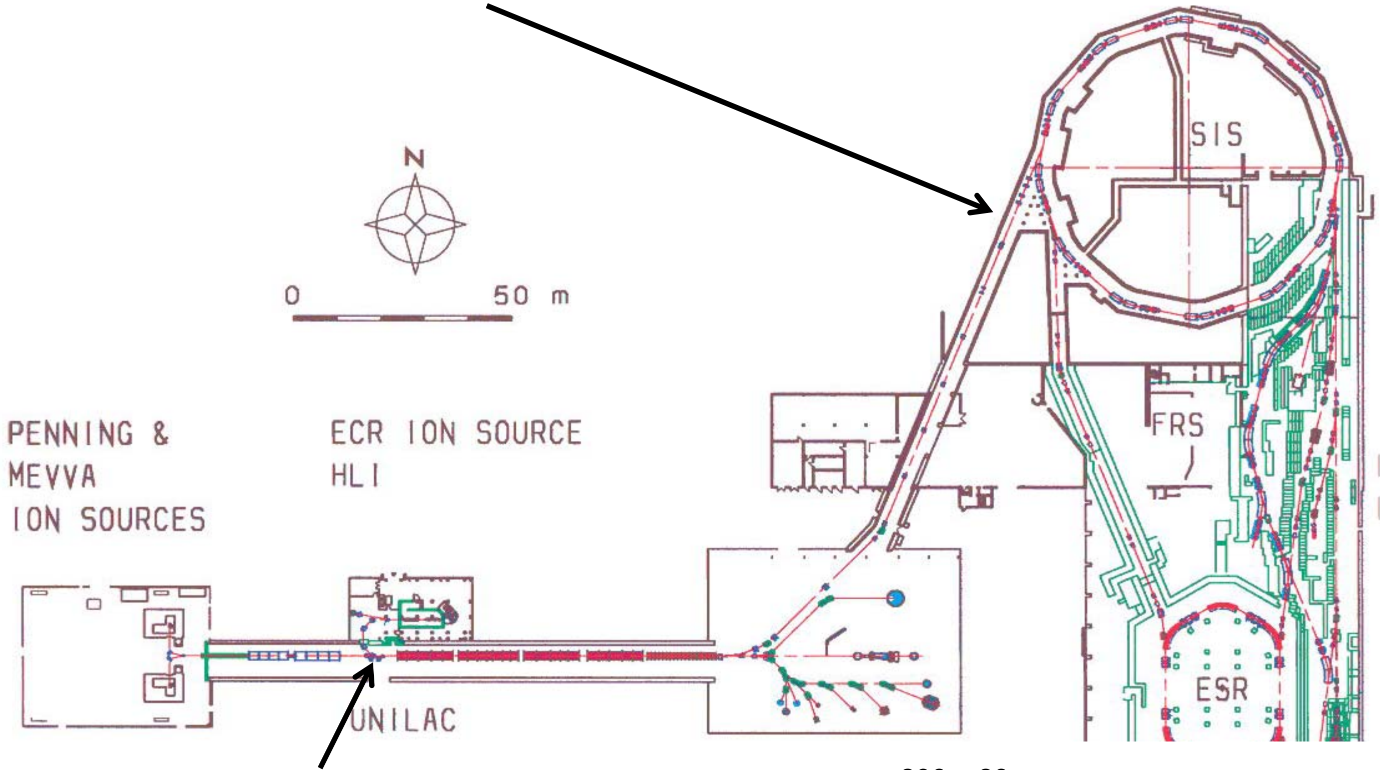
beam time schedule April 2012



2013-2014 saw considerable maintenance works

UNILAC: Achieved Currents

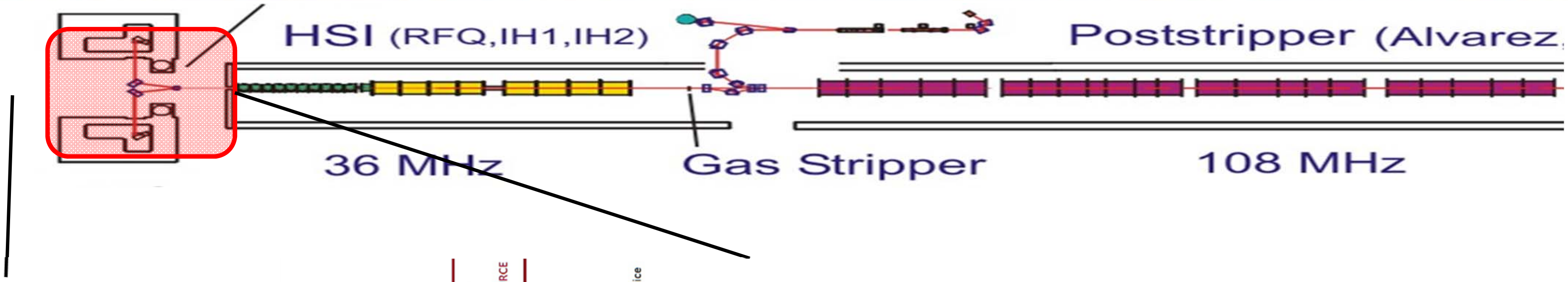
- June 2007: current of 6.0 mA $^{238}U^{27+}$ at the entrance to SIS18 was achieved

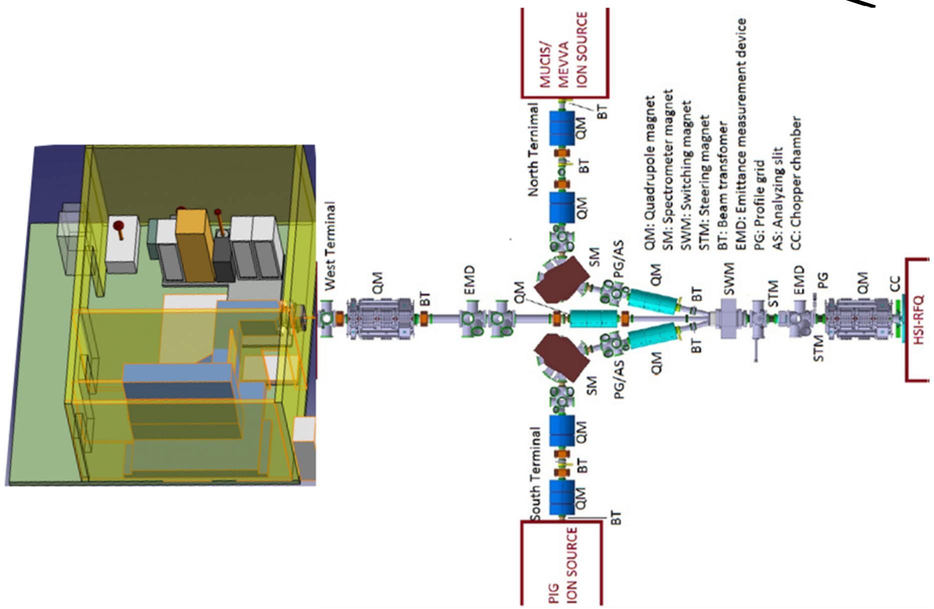


- Nov 2014: current of 7.7 mA within 1.5 mm mrad $^{238}U^{28+}$ at stripper section was achieved

- although UNILAC did not achieve yet the target value of 15 mA, this machine keeps holding the uranium intensity world record and might do so for many years

UNILAC Upgrade: Dedicated Uranium Source & LEBT

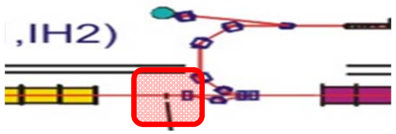




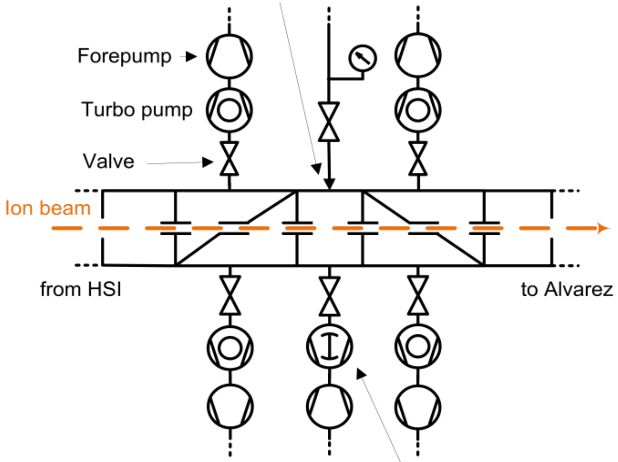
NIM A 788 173 (2015)

- new „Terminal West“ under design
- will provide exclusively ^{238}U
- improved (compact) extraction system
- LEBT is w/o bends (hex-pole fringes, dispersion)
- no dispersive separation of charge states (3^+,4^+)
- just chromatic separation (envelopes + irises)
- compromise between:
  - vast ion species portfolio
  - saftety issues wrt uranium operation/handling

UNILAC Upgrade: Pulsed H_2-Stripper: $U^{4+} \rightarrow U^{28+}$

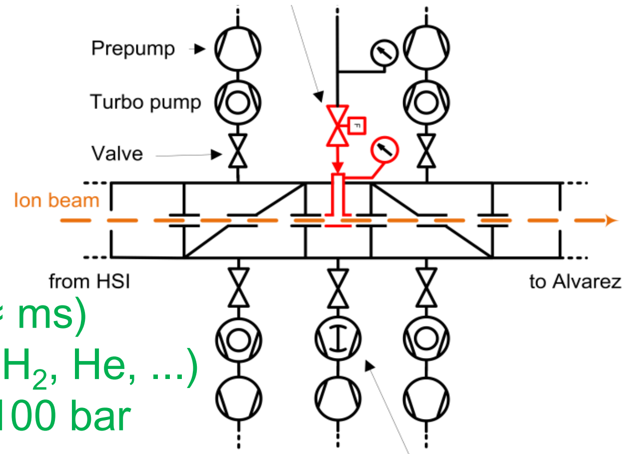


present



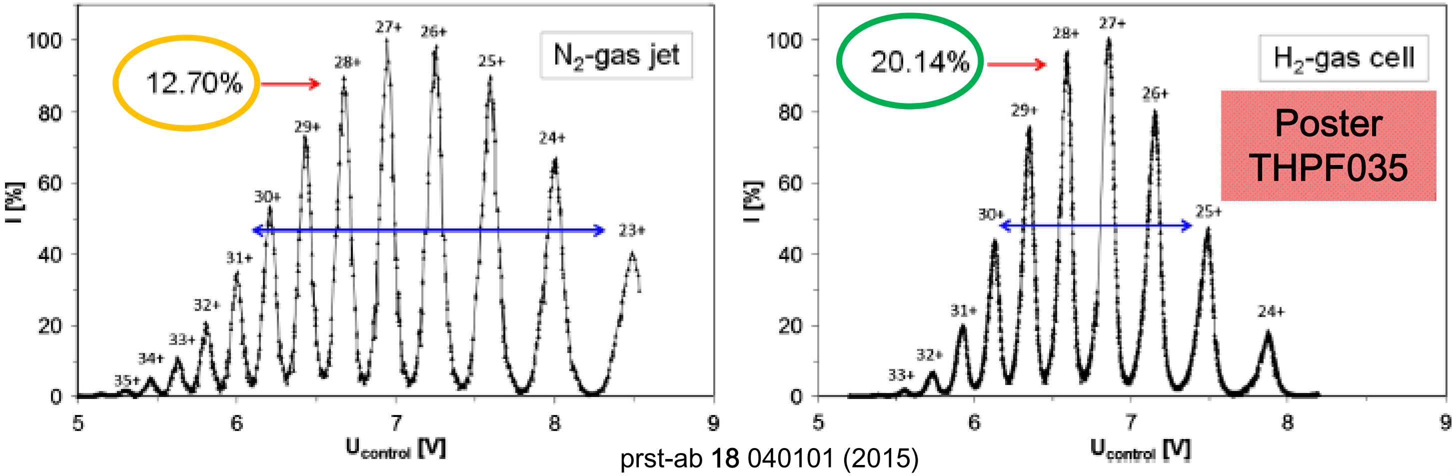
- continuous jet
- nitrogen
- 4 bar

new



- pulsed jet (≈ ms)
- light gases (H_2, He, ...)
- pressure ≳ 100 bar

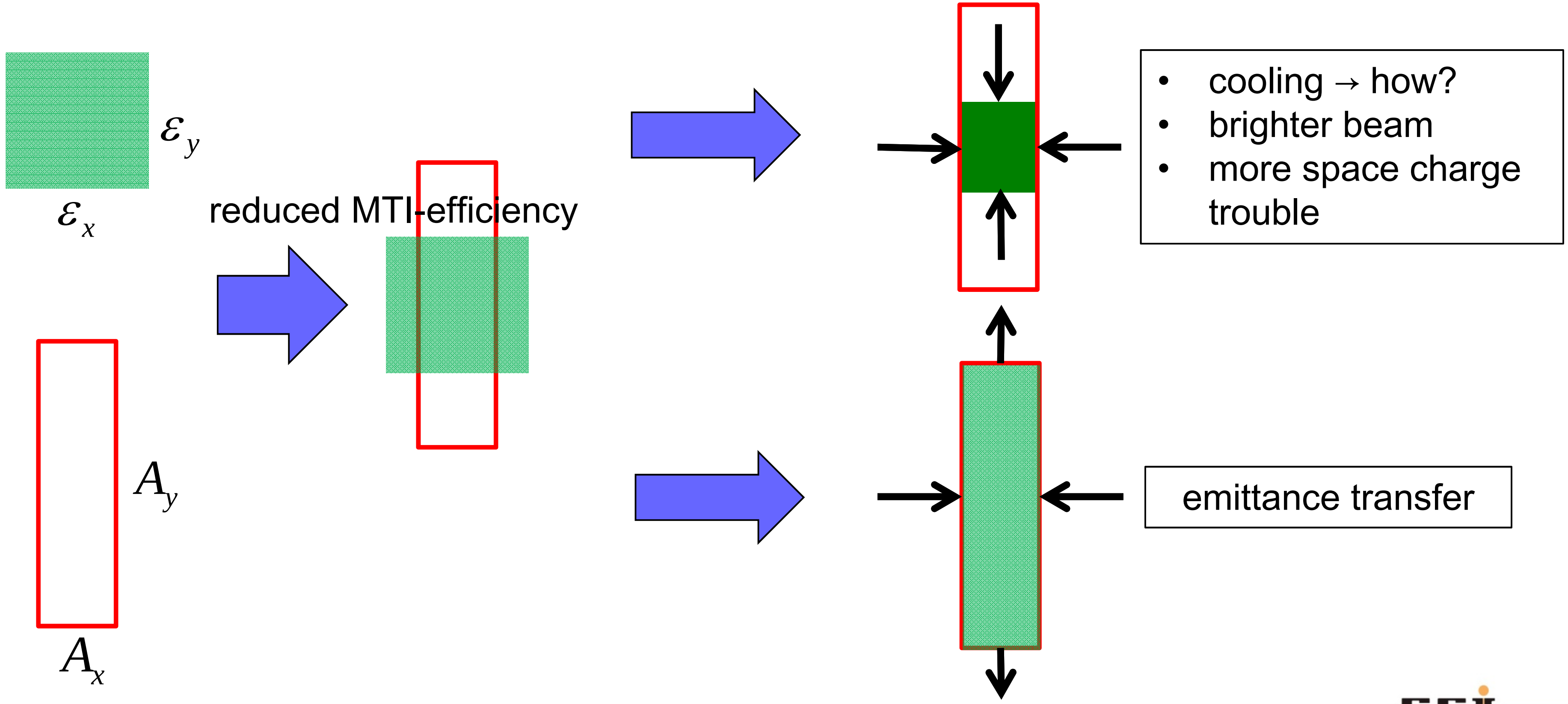
increased stripping efficiency to q=28+



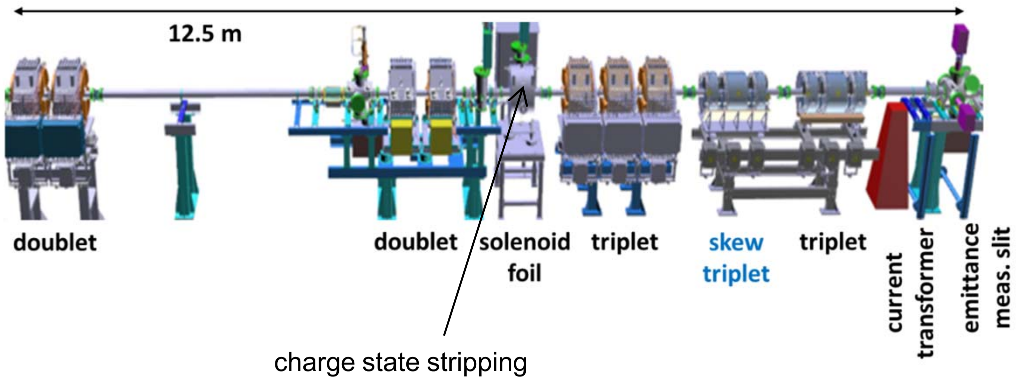
prst-ab **18** 040101 (2015)

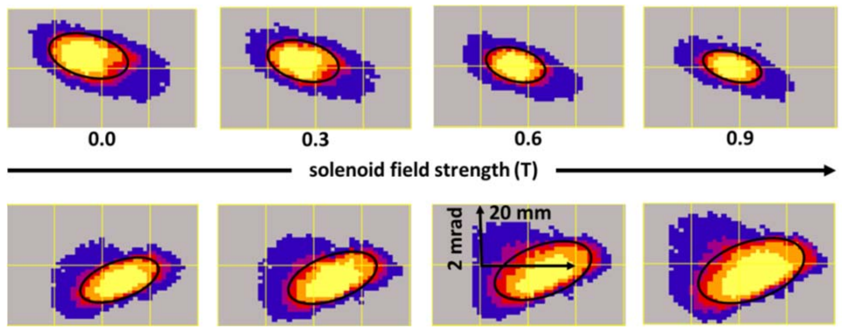
Linac Emittances vs effective Ring Acceptances

- "round" beam is provided by injector linac $\varepsilon_x \approx \varepsilon_y$
- flat beams might be required by rings (MTI) $A_x < A_y$

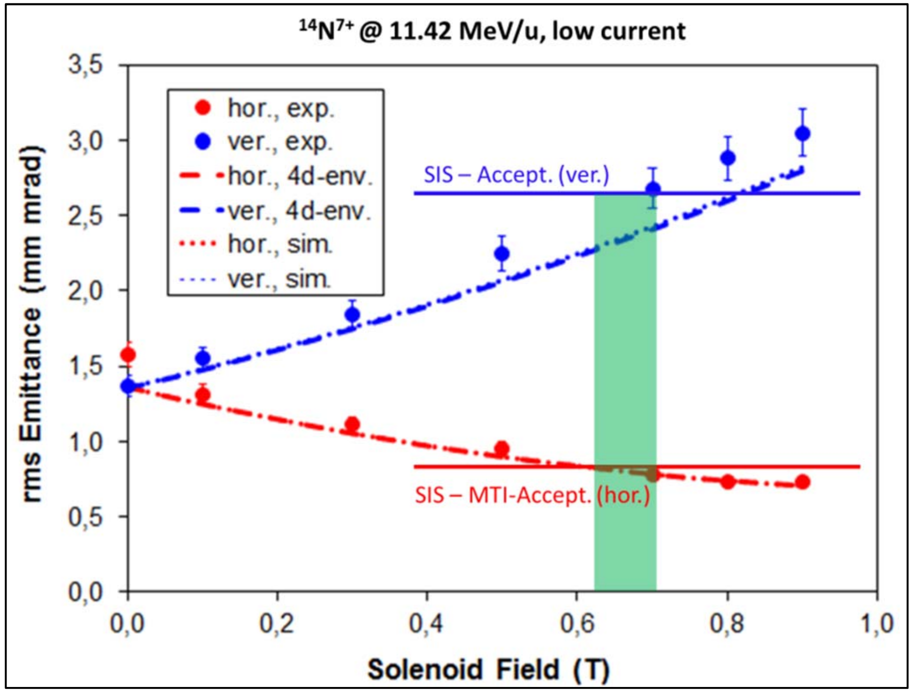


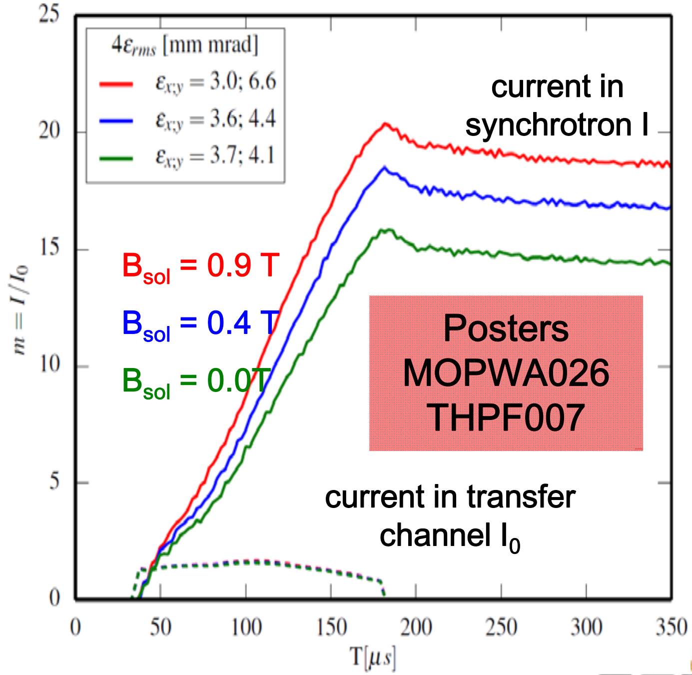
UNILAC Upgrade: Provision of Flat Ion Beams (optional), Proof of Principle EmTEx





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

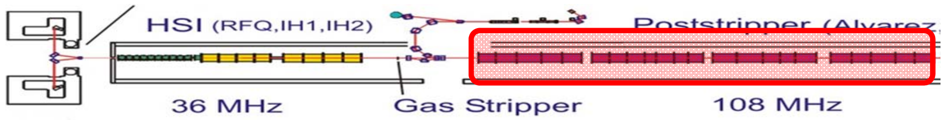




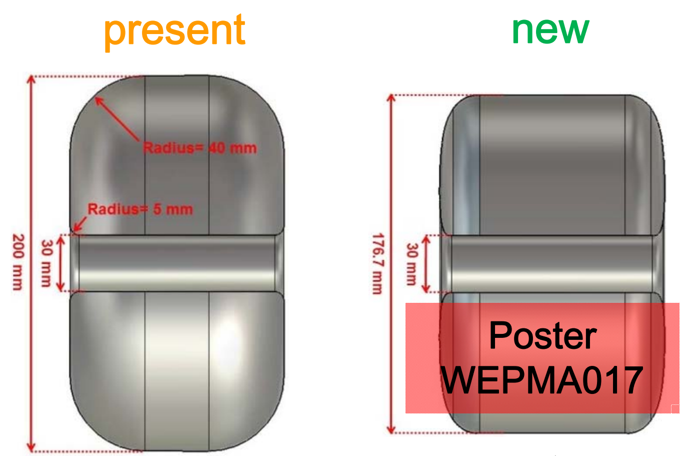
UNILAC Upgrade: New Alvarez Cavities

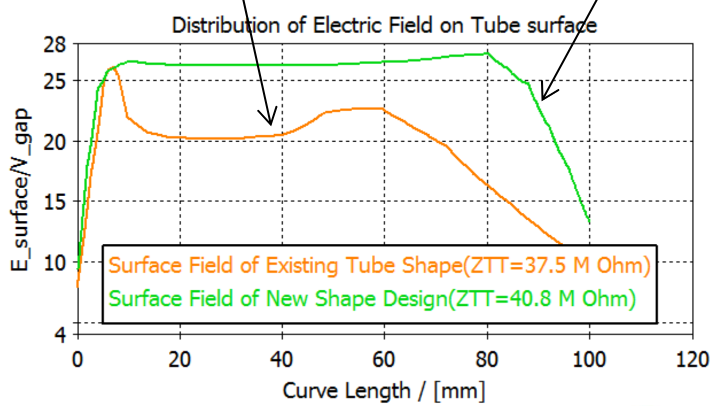
- improved shapes of drift tube end plates
- optimizition of shunt impedance per surface field
- „freehand-shape“
- manufacturers:
  - „freehand-shape is no considerable cost driver“
  - feasible at same tolerances as const-R-shapes
- beta profile of tank I (new wrt present)
  - same length & energy gain but 18% less rf-power (unloaded)

  8% higher surface field



	tank I	tank II	*tank III*	*tank IV*
energy range [MeV/u]	**1.39 – 3.56**	**3.56 – 5.69**		- 11.4
# cells	**61**	**40**		
L_{gap} / L_{cell}	**0.26 – 0.27**	**0.24 – 0.25**		
rf-length [m]	**12.2**	**11.0**		
$E_{surf,max}$ [E_K]	**1.03**	**1.03**		1.03
$P_{loss,MWS}$ [MW]	**0.92**	**0.94**		
P_{beam} [MW]	**0.28**	**0.27**		
<Z_{eff}> [MΩ/m]	**15.2**	**15.9**		



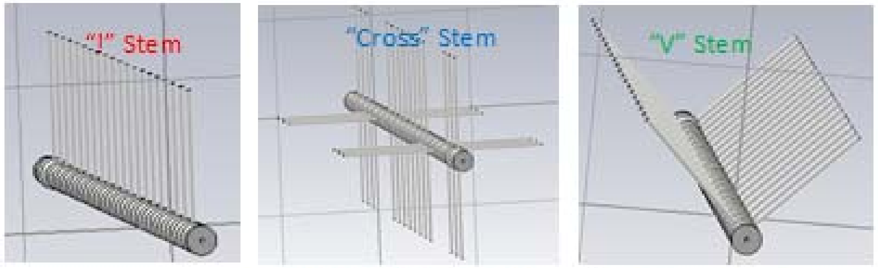


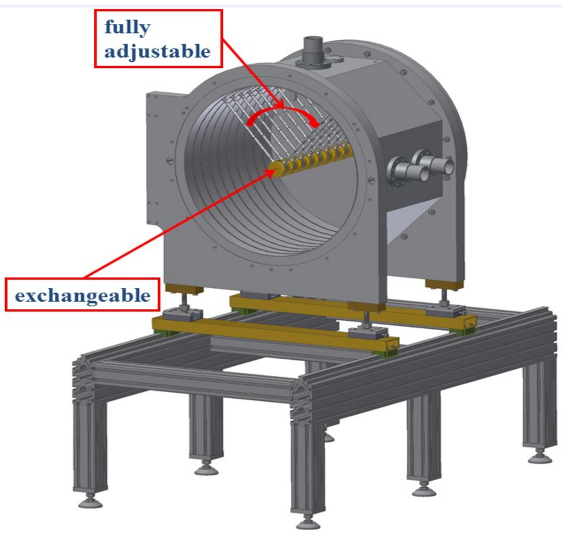
UNILAC Upgrade: DTL Cavity Stem Orientations

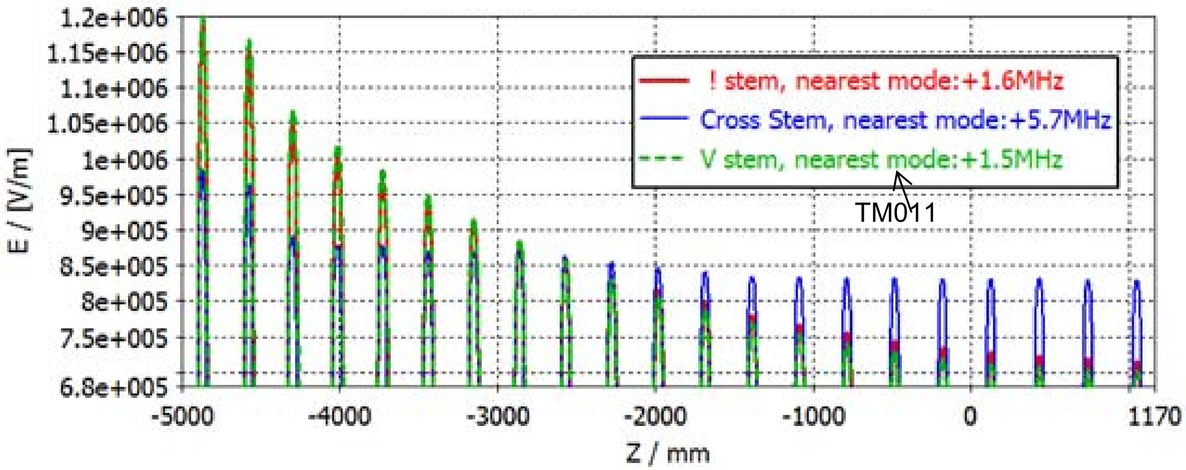
each drift tube is kept by two stems (as today):

- facilitates provision of quad current and water cooling of tubes & quads
- well-considered orientations of stems mitigate parasitic TM rf-modes

robustness of field flatness wrt perturbations of inter drift tube capacities





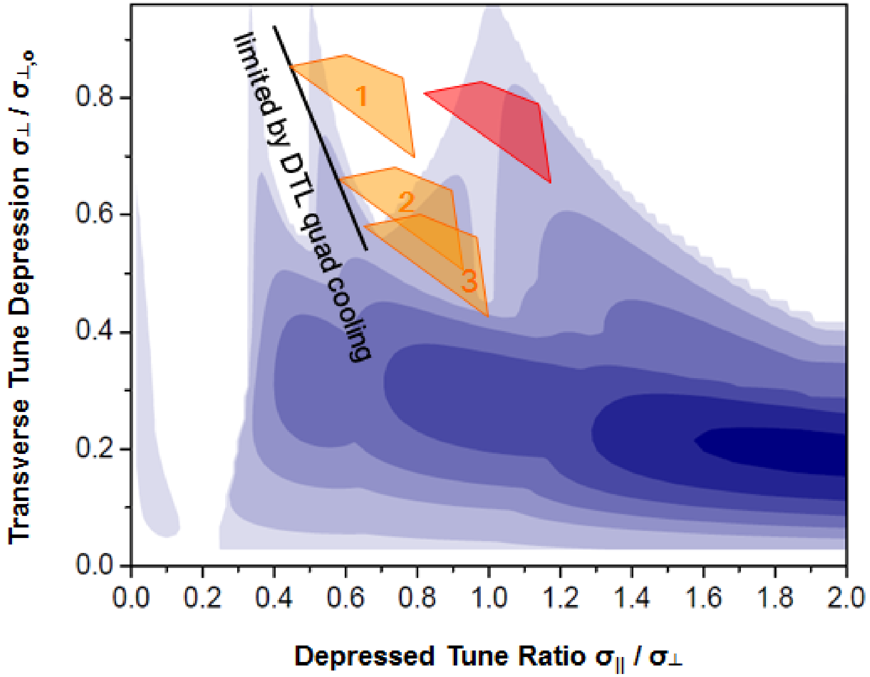


1:3 scaled cold model under production to probe experimentally:

- different stem orientations
- different drift tube shapes

UNILAC Upgrade: Stronger Transverse Focusing

- today transv phase advance is limited to σ_0 = 53° (zero current) with $^{238}U^{28+}$
- too low in order to avoid parametric resonances (Hofmann‘s stability chart)



todays range of Ar-equivalent ^{238}U-operation

range of FAIR ^{238}U-operation depends on US4 emittances:

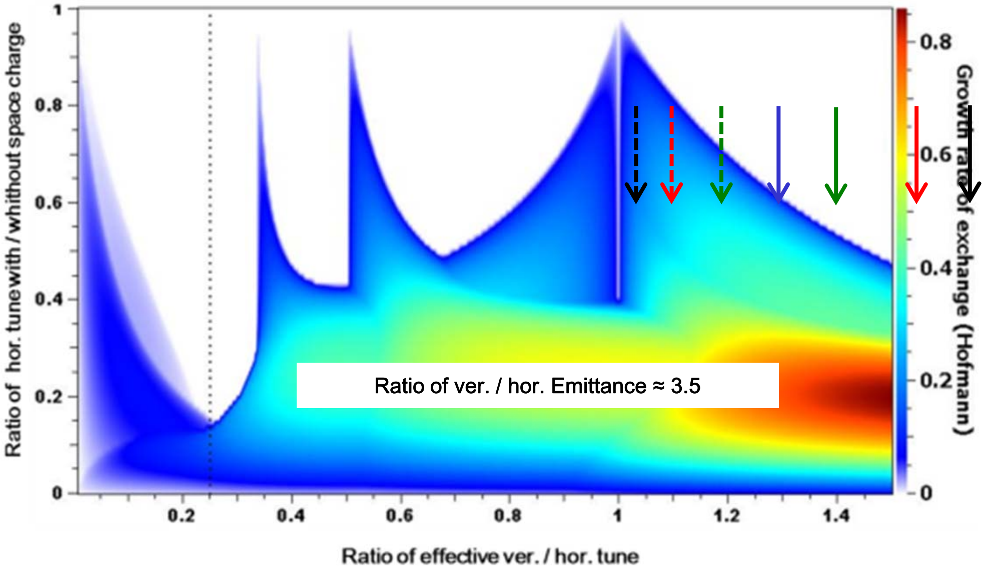
1. $\varepsilon_x = 0.8$, $\varepsilon_y = 2.5$, $\varepsilon_{||}/\varepsilon_\perp$ (HIPPI)
2. $\varepsilon_x = 0.8$, $\varepsilon_y = 0.8$, $\varepsilon_{||}/\varepsilon_\perp$ (HIPPI)
3. $\varepsilon_x = 0.7$, $\varepsilon_y = 0.7$, $\varepsilon_{||}/\varepsilon_\perp$ (HIPPI)

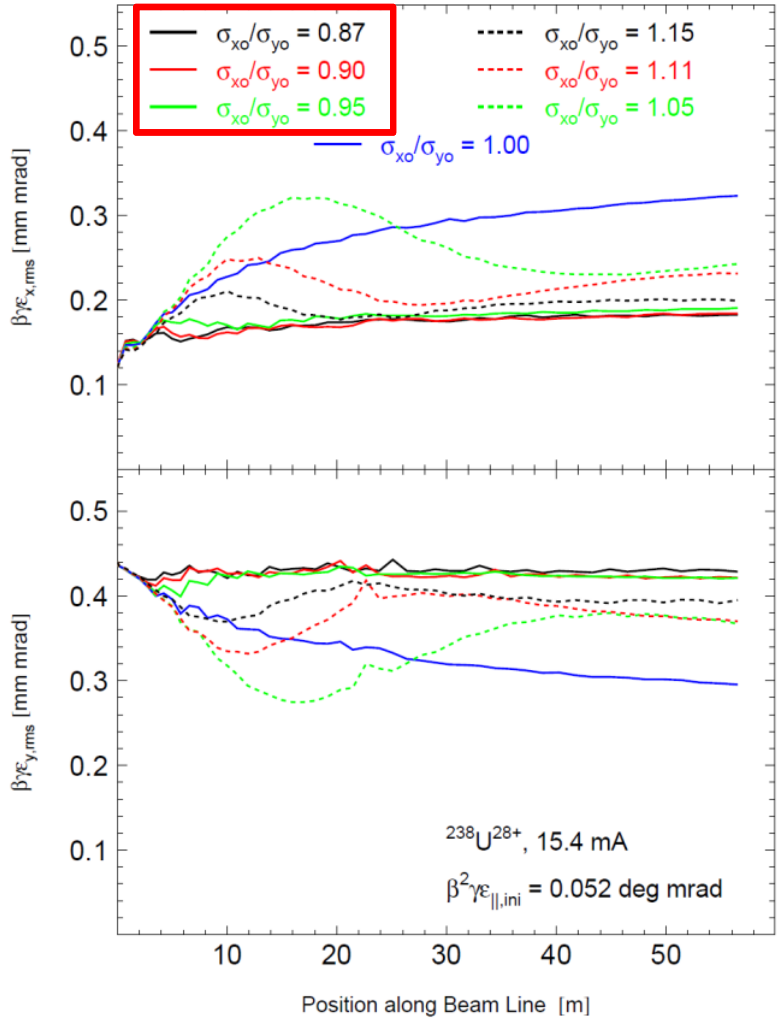
(keeping margin for growth along DTL)

- to improve position in stability chart, move:
  - upwards: do emittance transfer while keeping 4d-emittance
  - left: increase transverse focusing strength $\sigma_0 \rightarrow 67°$

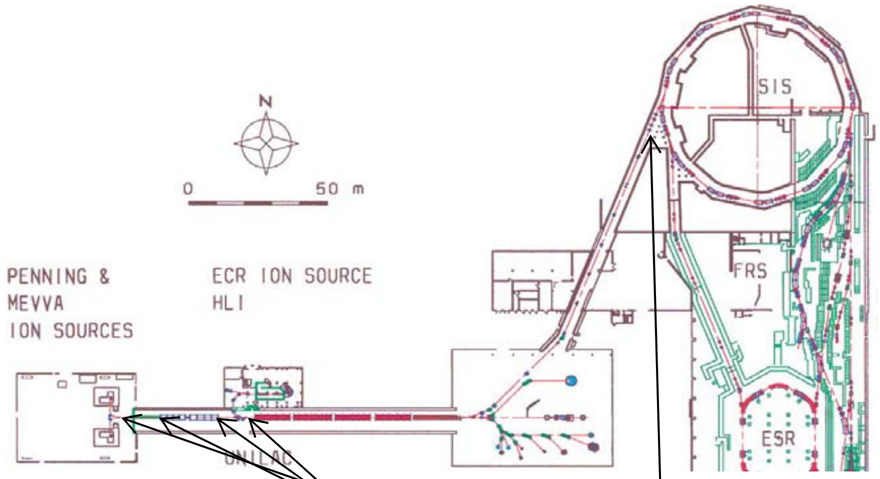
UNILAC Upgrade: Asymmetric Transverse Focusing
(optional)

- focusing shall preserve beam emittance ratio (flatness)
- space charge drives re-equilibration of emittances
- can be mitigated by stronger focusing in ver plane
- ver focusing quads with stronger gradients wrt hor ones
- few % of increase of ver quad gradients is sufficient





UNILAC Upgrade: Estimate of attainable $^{238}U^{28+}$ Performance, Schedule



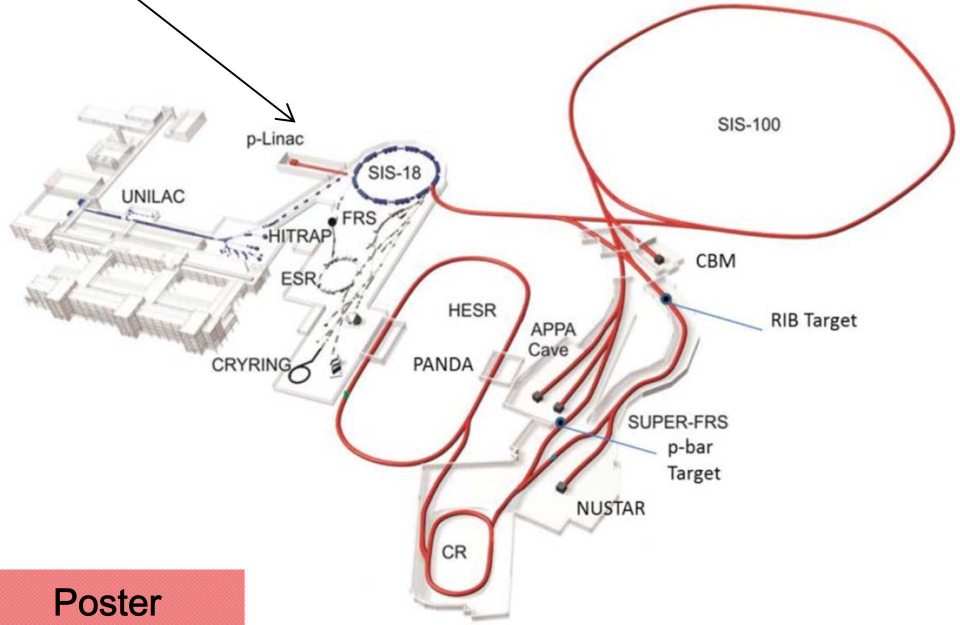
2014/15	concepts
2015	prototyping conceptual design
2016/17	final design
2017/18	tendering
2018/19	fabrication
2020	assembly
2021	commissioning

beamline section	current change factor	rel. emit. growth [%]	brilliance change factor	current [mA]	hor. emittance (norm., tot.90%)	upgrade activity
				18,0	0,38	source development
LEBT + RFQ	0,9	15	0,78			RFQ upgrade
				16,2	0,44	
MEBT + IH-DTL	0,9	70	0,53			new MEBT
				14,6	0,74	
gaseous stripper (to A1)	1,26	15	1,10			routine operation pulsed stripper
				18,4	0,85	
EmTEx	0,9	-60	2,25			installation
				16,5	0,34	
Alv-DTL, transf. to SIS18	0,85	50	0,57			new DTL
				14,1	**0,51**	
target value				**15,0**	**0,56**	

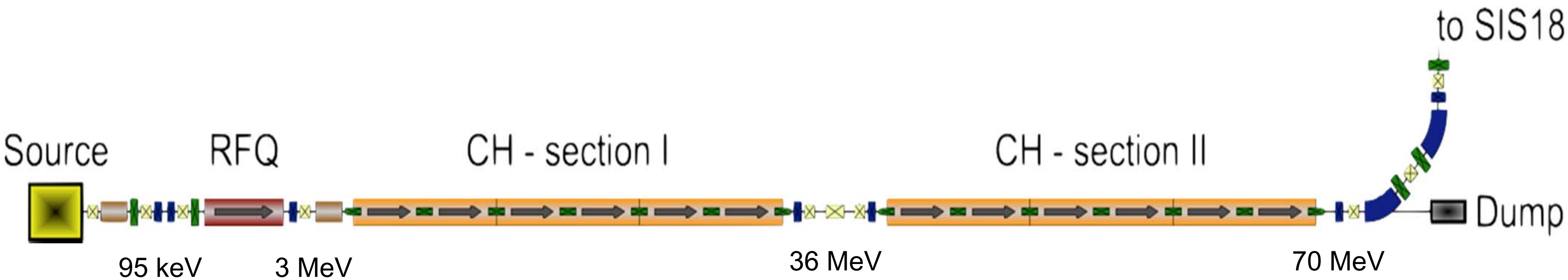
FAIR Proton Linac

design parameters

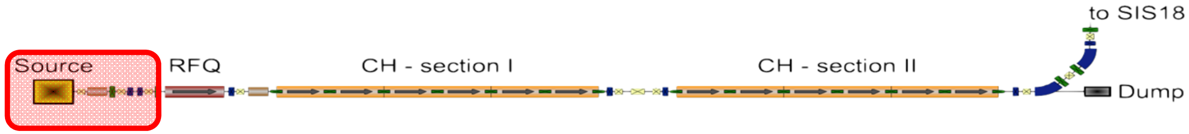
Beam Energy (MeV)	70
Design Current (mA)	70
Beam Pulse Length (μs)	36
Repetition Rate (Hz)	4
Frequency (MHz)	325.224
Norm. Emittance (μm)	4.2
Beam Loading (peak) (MW)	4.9
RF Power (peak) (MW)	2.2
# of Klystrons (3 MW Peak Power)	7
# of Solid State Amplifiers (45 kW)	3
Total Length	≈ 27 m



Poster
THPF011

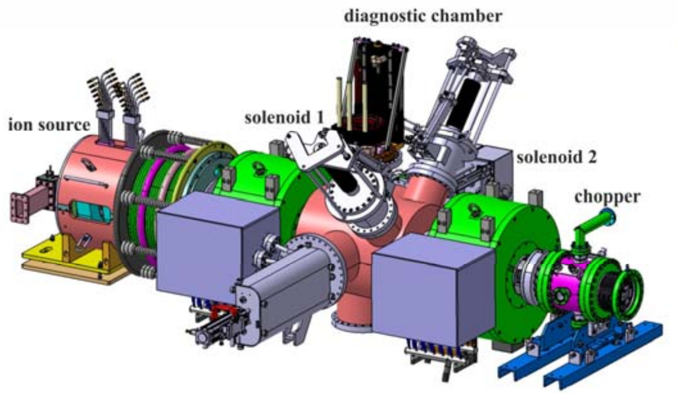


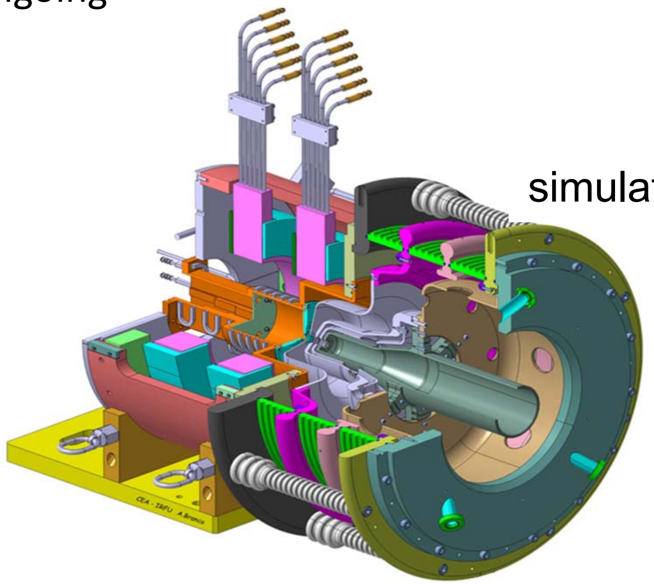
Proton Linac: Source & LEBT



Beam Intensity (mA)	100
Beam Energy (keV)	95
Proton Fraction (%)	> 85

- designed, built, and to be commissioned at CEA/Saclay
- source is assembled
- solenoids and diagnostics chamber assembled
- chopper is under construction
- power supplies are ordered
- beam commissioning of LEBT with beam planned in Q1/2016
- installation of control system is ongoing

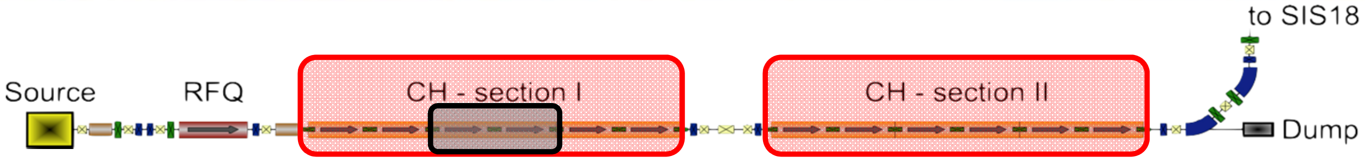


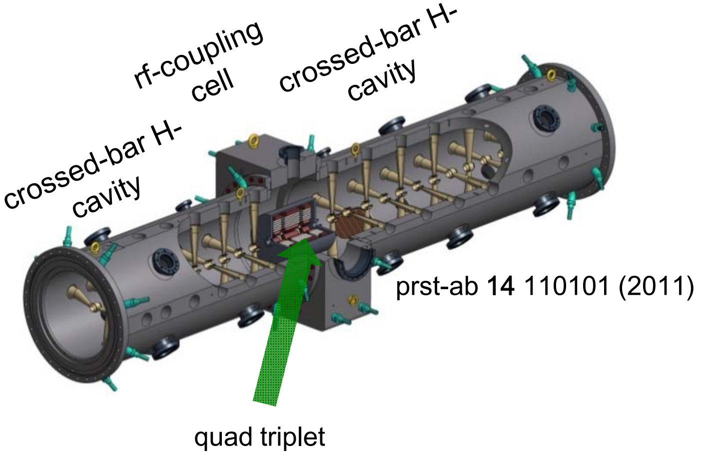


simulation of beam extraction

Poster
WEPWA002

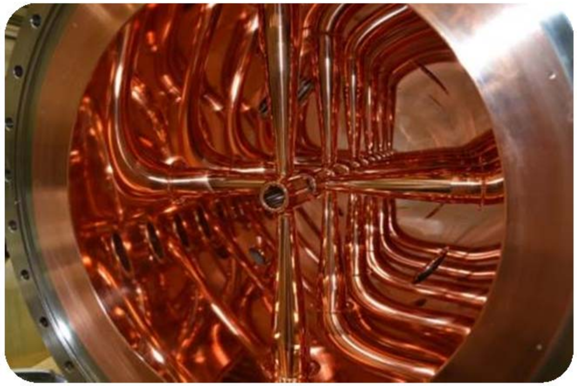
Proton Linac: Cavities



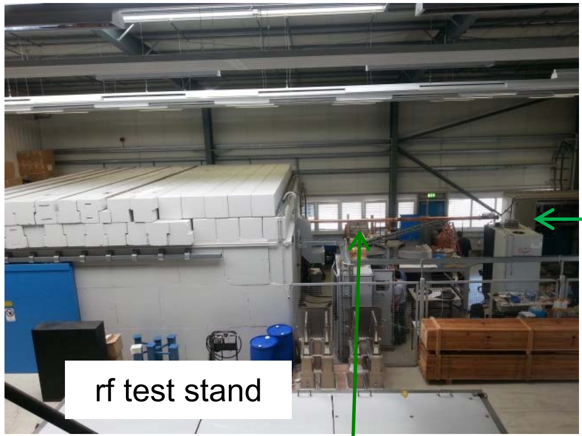


- CH prototype cavity at GSI since end of 2013
- issues concerning Cu-plating investigated and solved
- low level-rf measurements started
- high power tests after klystron is prepared

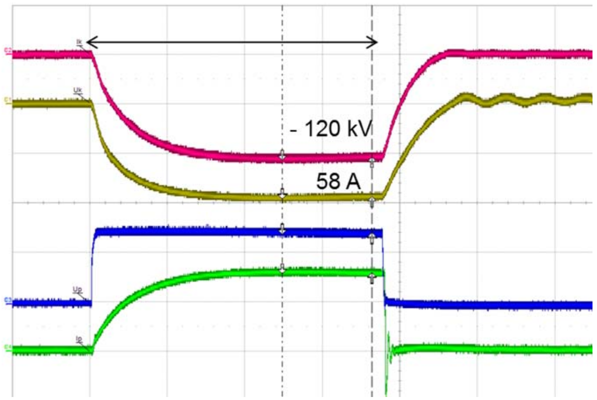
EB-welding tests



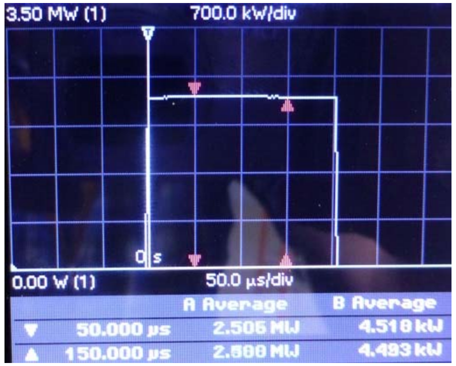
Proton Linac: Rf-Power Sources



- CERN modulator arrived and is under operation
- 2.5 MW power from klystron achieved
- GSI modulator design is under preparation based on the CERN layout
- 45kW amplifier for the buncher successfully tested on resonant load



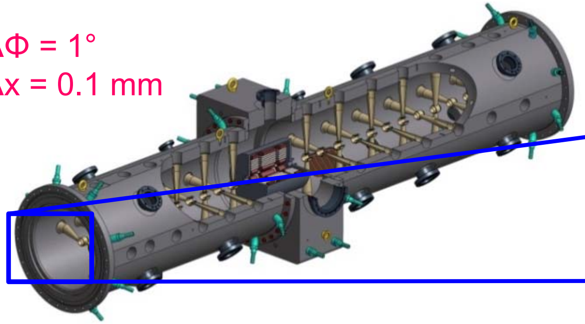
Poster WEPMA022

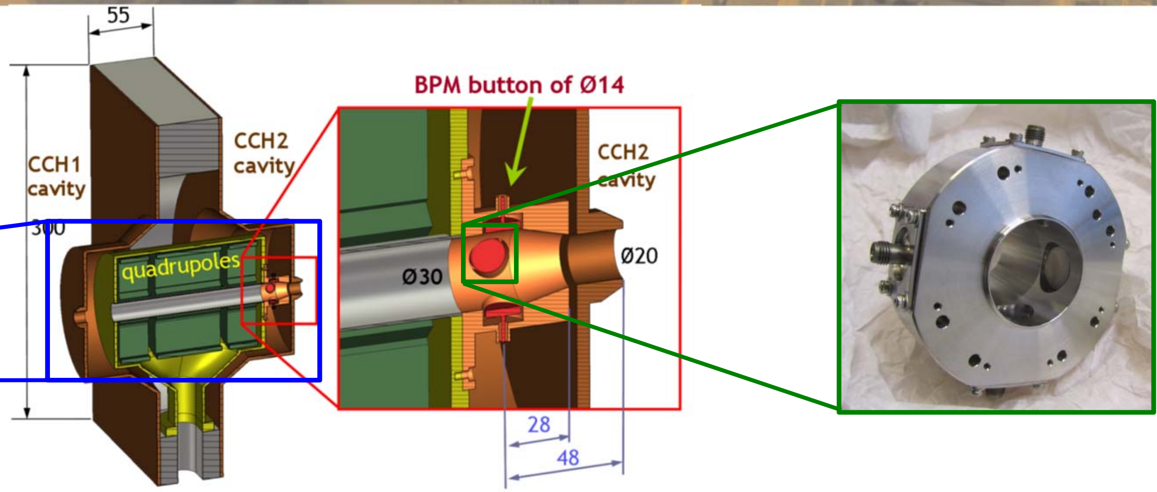


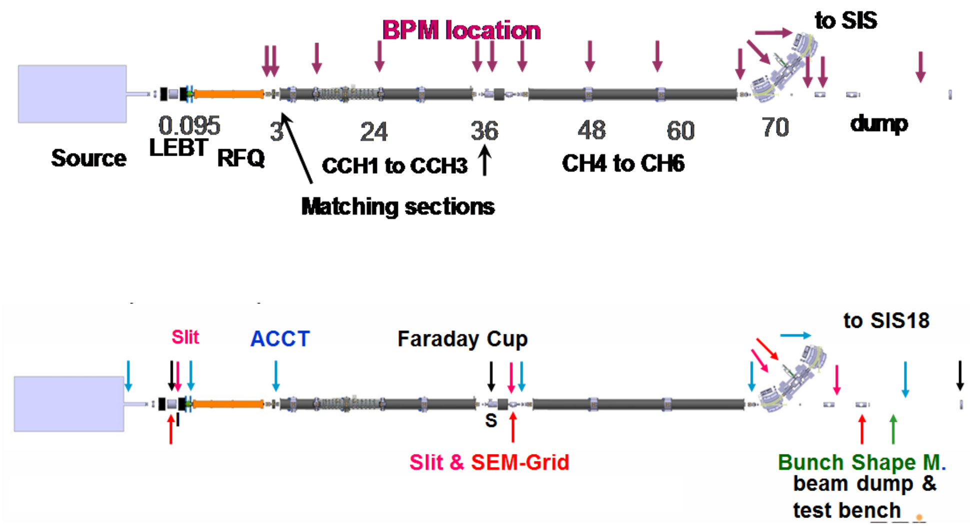
Proton Linac: Beam Instrumentation

combined BPM & phase probe
(CEA/Saclay, TU-Darmstadt, GSI)

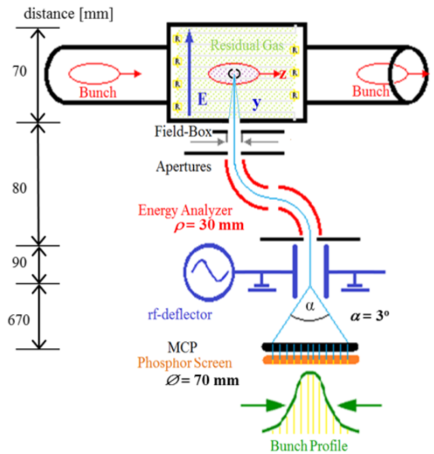
$\Delta\Phi = 1°$
$\Delta x = 0.1$ mm

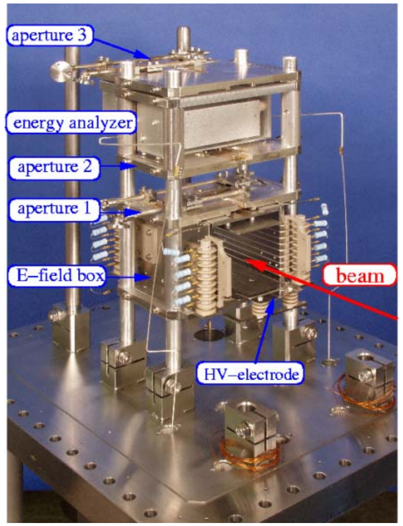






non-intercepting bunch shape monitor
(INR Moscow, GSI)





Summary

- FAIR Accelerators
  - R&D finished
  - status: writing specs, tendering, testing
  - all machines commissioned in 2022

- UNILAC Upgrade:
  - dedicated uranium LEBT
  - increase of stripping efficiency using pulsed H_2 jet ≥ 150 bar
  - completely new post stripper Alvarez DTL
    - provision of hor flat beams for MTI optimization (optional)
    - optimized DT shape wrt shunt impedance per surface field
    - varying stem orientations for parasitric mode damping
    - increase of transv focusing to avoid space charge driven resonances
  - upgrade finished in 2020

- Proton Linac
  - prototyping of crossed-bar H-cavities almost finished
  - first MW-Klystron power in 2015
  - new development of combined BPMs & phase probes
  - missing components will be tendered before summer 2016
  - commissioning in 2020

Thank you !