Design Studies for a New Heavy-Ion Injector Linac for FAIR

B. Schlitt, G. Clemente, W. Barth, W. Vinzenz

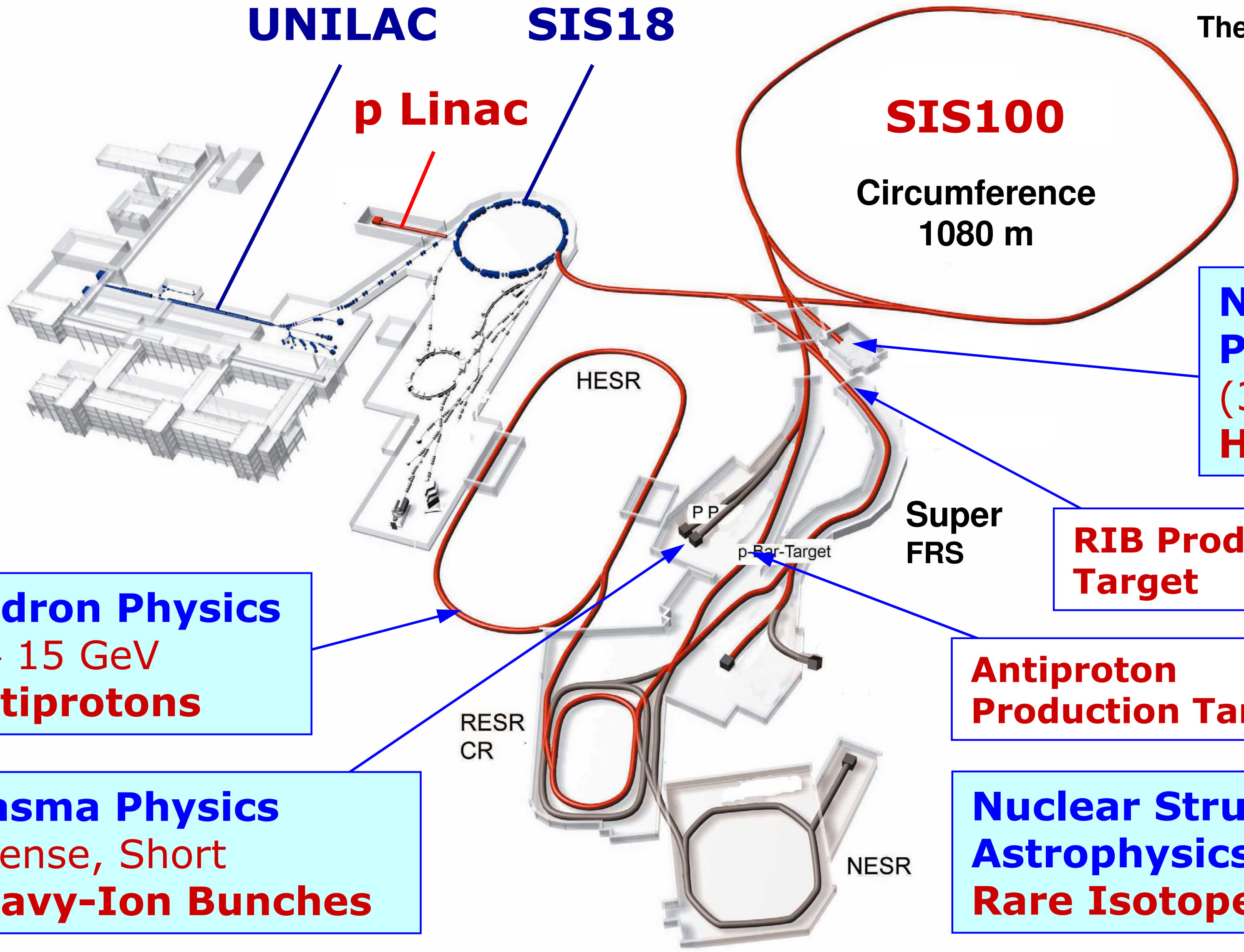
GSI, Darmstadt, Germany

Contents

- FAIR project and design intensities
- UNILAC: Present constraints and proposals
- Acceleration of intermediate charge states
- Conceptual heavy-ion high energy linac study
- Conclusions

FAIR
Facility for Antiproton and Ion Research

Green Paper
The Modularized Start Version,
GSI, October 2009



Nuclear Matter Physics
(30 – 45 GeV/u)
Heavy-Ion Beams

RIB Production Target

Antiproton Production Target

Hadron Physics
0 – 15 GeV
Antiprotons

Plasma Physics
Intense, Short
Heavy-Ion Bunches

Nuclear Structure & Astrophysics
Rare Isotope Beams (RIBs)

FAIR Design Beam Intensities

Intense primary heavy-ion beams for RIB production:

	UNILAC	SIS18 (today / required)	SIS100
Reference primary ion	U^{28+}	U^{28+}	U^{28+}
Reference end energy	11.4 MeV/u	200 MeV/u	1.5 GeV/u
Ions per cycle / beam current	**15 emA**	**2 E10 / 1.5 E11**	**4 E11**
Cycle rate (1/s)	2.7	**1** / 2.7	0.5

- **Intensity for experiments factor 100 over present**
- **Four SIS18 cycles into one SIS100 cycle**

→ **Upgrade program for UNILAC & SIS18**

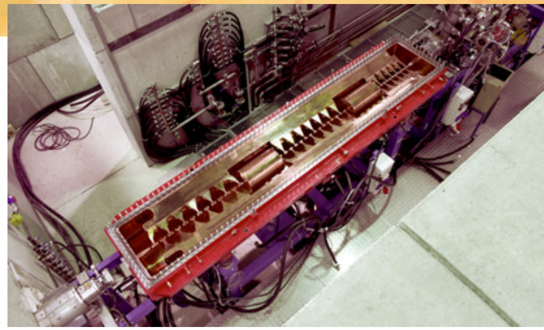
Proton beams for pbar physics program:

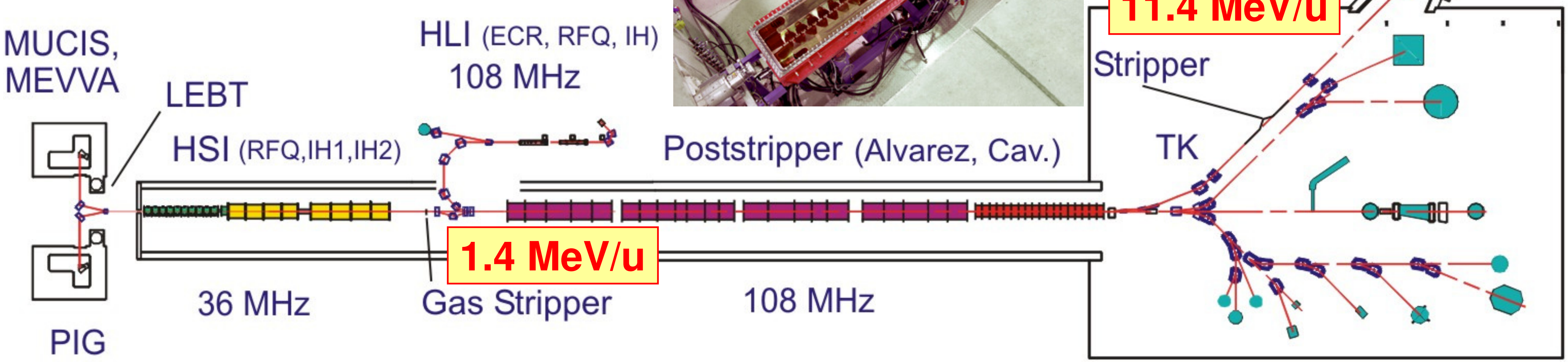
	LINAC	SIS100
Reference end energy	70 MeV/u	30 GeV
Ions per cycle / beam current	**70 mA**	**4 E13**

→ **Separate proton linac injector**

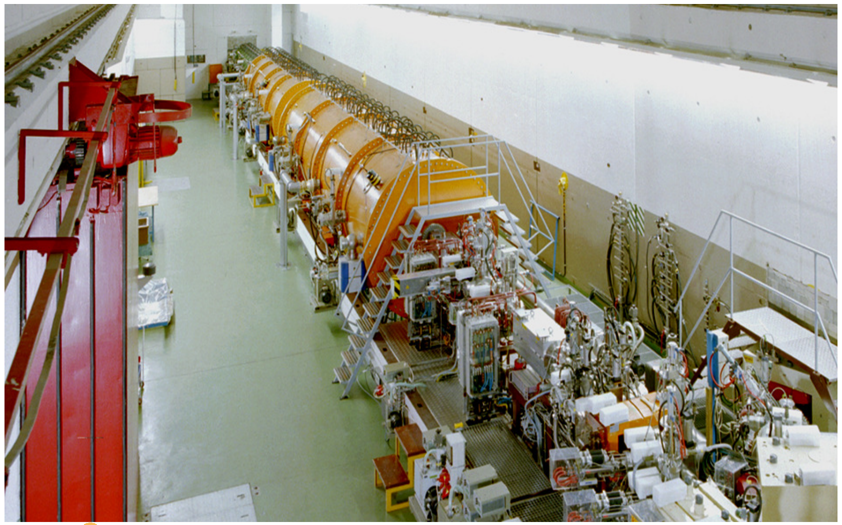
GSI UNIversal Linear ACcelerator UNILAC

High Charge State Injector (1991)

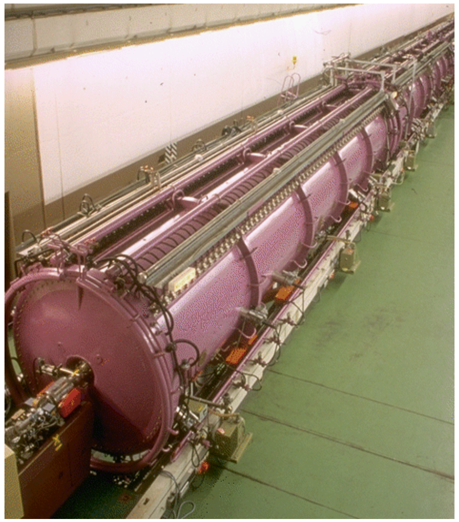




High Current Injector (1999)

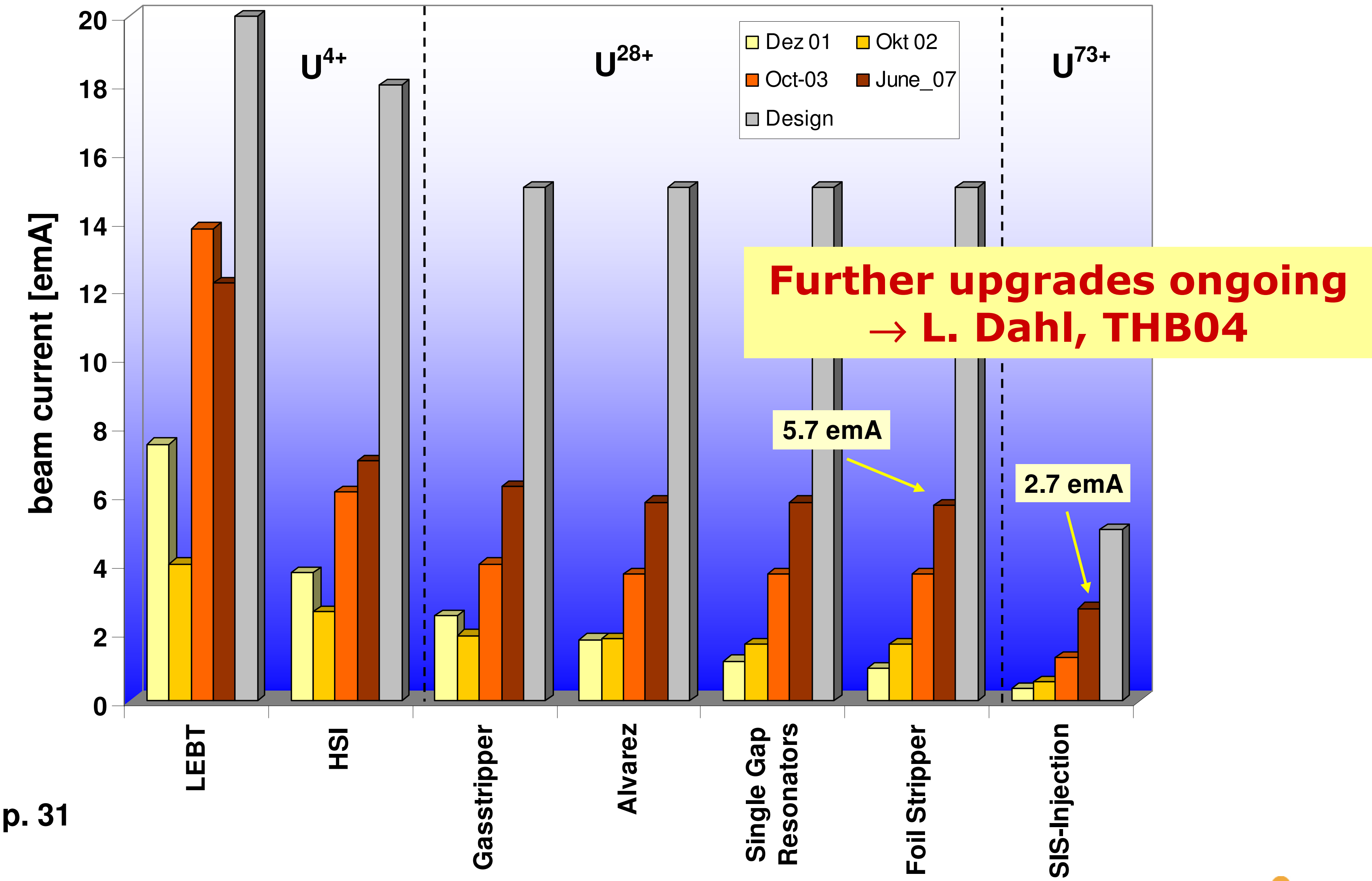


Alvarez (1975)



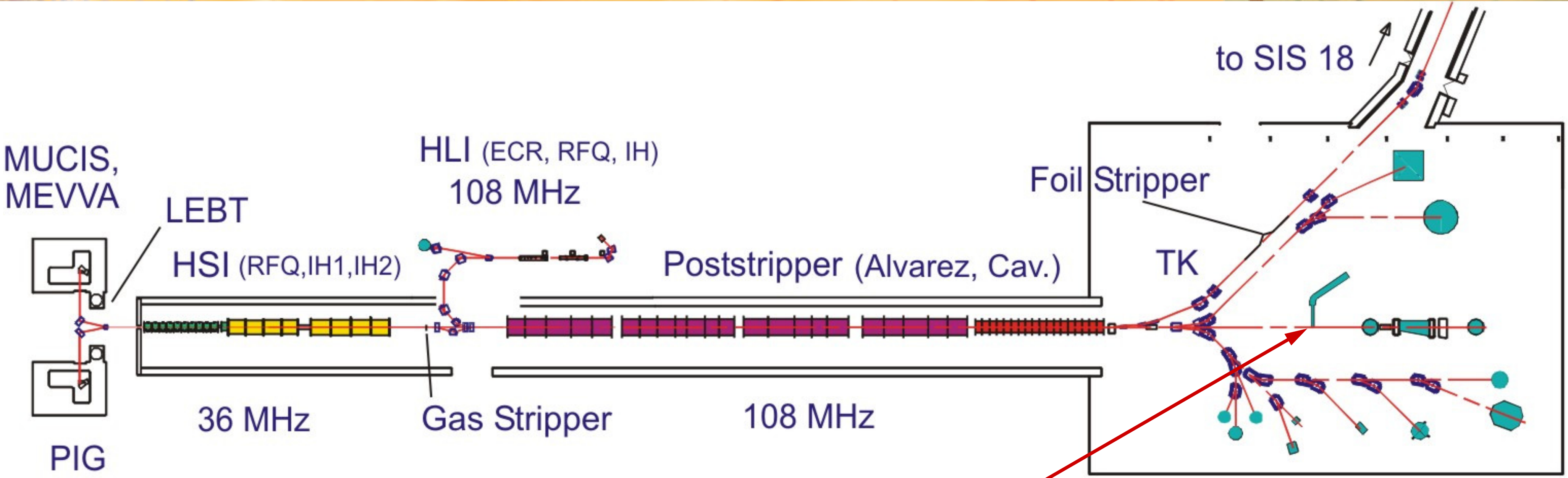
Single Gap Resonators (1975)

UNILAC Upgrades for FAIR



W. Barth, LINAC08, p. 31

Multi-Beam Operation at the UNILAC



FAIR requirements:

- Extremely high pulse intensities
- Highest magnetic rigidities
- Highest RF and focusing fields
- Low repetition rate (max. 3 Hz) and duty cycle (< 0,1 %) (100 µs pulse length)

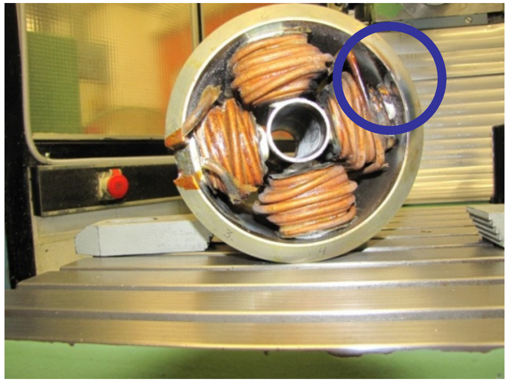
Super-Heavy Element Program:

- High duty cycle required → 100 %
- High average intensities
- High average RF power, DC magnets
- Presently available:
  25 % duty cycle
  (5 ms pulse length @ 50 Hz)

Operation Limitations & Repair Program

178 Tank-Quadrupoles

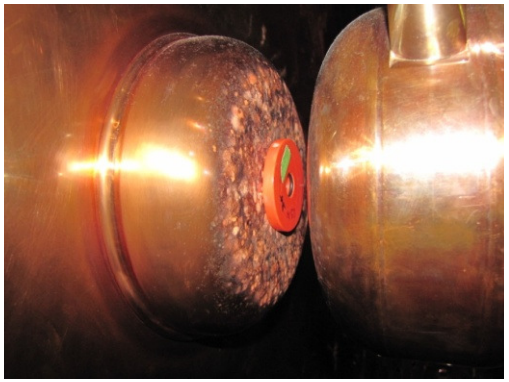
ground faults (coils), water & vakuum leaks (coils, drift tubes, supports)

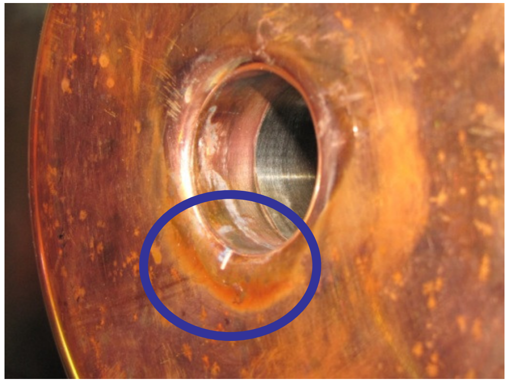


Leak Tightness of all Tanks

Drift Tubes

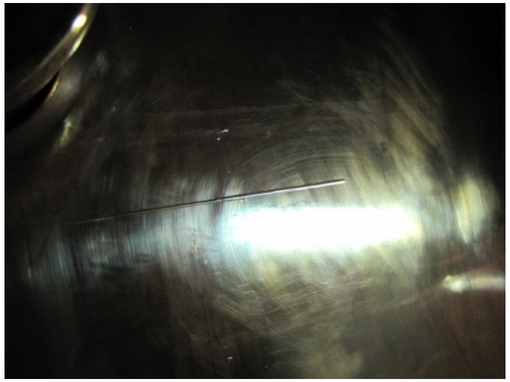
massive sparkovers **beam induced surface defects**





Copper Surface Quality

inner tank blanket at different positions

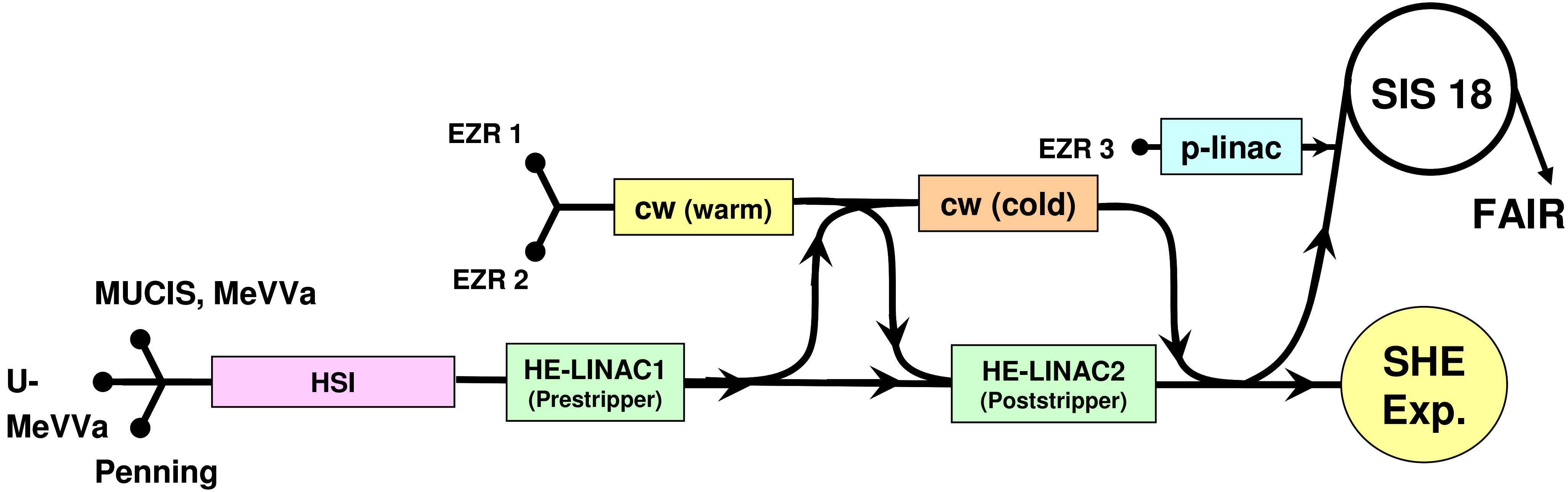


Present Linac Limitations

- Most of the Alvarez tanks and all single gap resonators **in operation since 1975**
- **Increasing operation limitations, breakdowns & maintenance**
  - ⇒ Issue of machine reliability
  - ⇒ Substitution of the DTL cavities
- **Operation of quadrupoles only in dc-mode**
  - ⇒ Limited flexibility for multi-beam operation
  - ⇒ Limitations due to high power dissipation for strong focusing fields
- **Max. duty factor limited to 25 %**

→ **Massive injector upgrade required !**

Proposed Future GSI Linac Environment

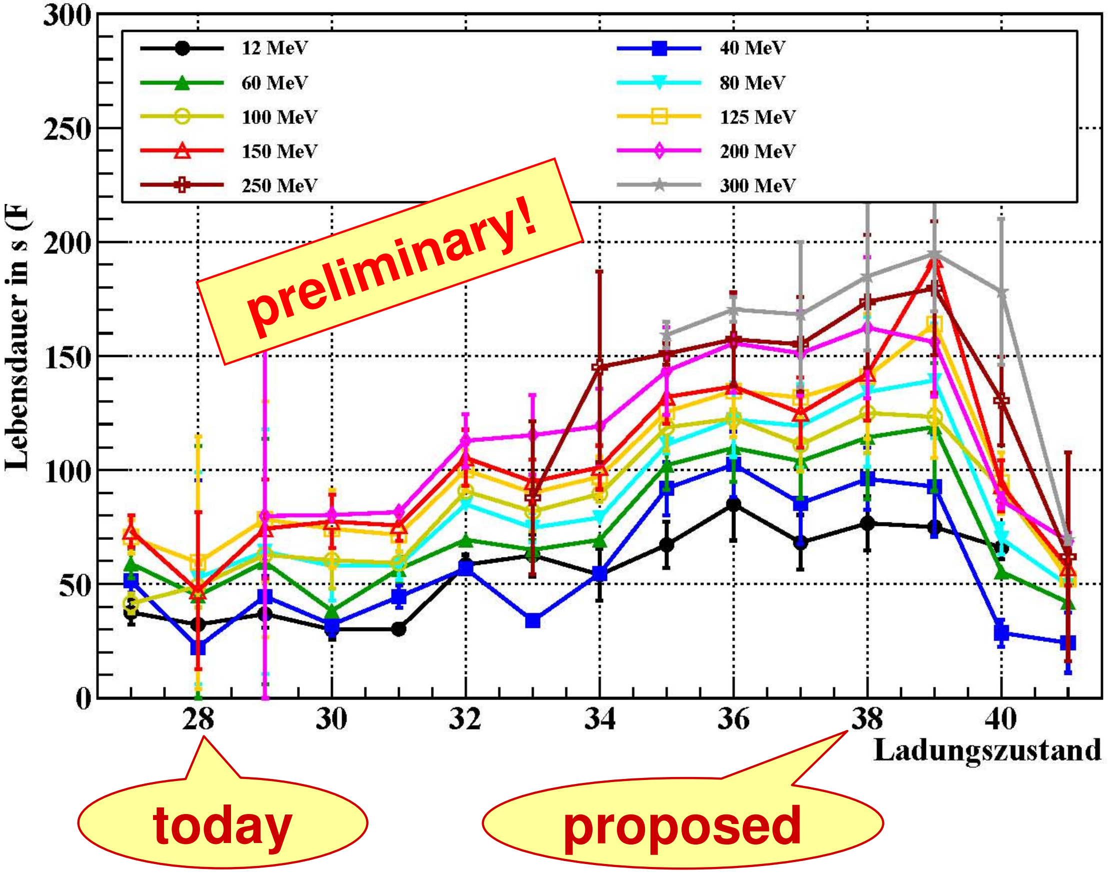


- **Proton Linac Injector for FAIR**
  70 MeV, 70 mA, 325 MHz, 0.1 % Duty Cycle
- **Heavy-Ion High Energy (HE) Linac Injector for FAIR**
  Replacement of UNILAC Post-Stripper Section, Low Duty Cycle
- **SC CW Heavy-Ion Linac for Super-Heavy Element Program**
  3.5 – 7.3 MeV/u, 1 mA, 217 MHz, 100 % Duty Cycle

→ **S. Mickat, WEC03**

Acceleration of Intermediate Charge States in SIS18

Increased Lifetimes for Higher Charge States



Lifetime measurements at SIS18 by
L. Bozyk, P. Puppel, P. Spiller, GSI

Space Charge Tune Shift

$$\Delta Q_y^{sc} \propto N \cdot \frac{q^2}{A} \cdot \frac{1}{\beta^2 \gamma^3}$$

For the same injection energy:

$U^{28+} \rightarrow U^{38+} \Rightarrow \Delta Q \rightarrow +85\%$

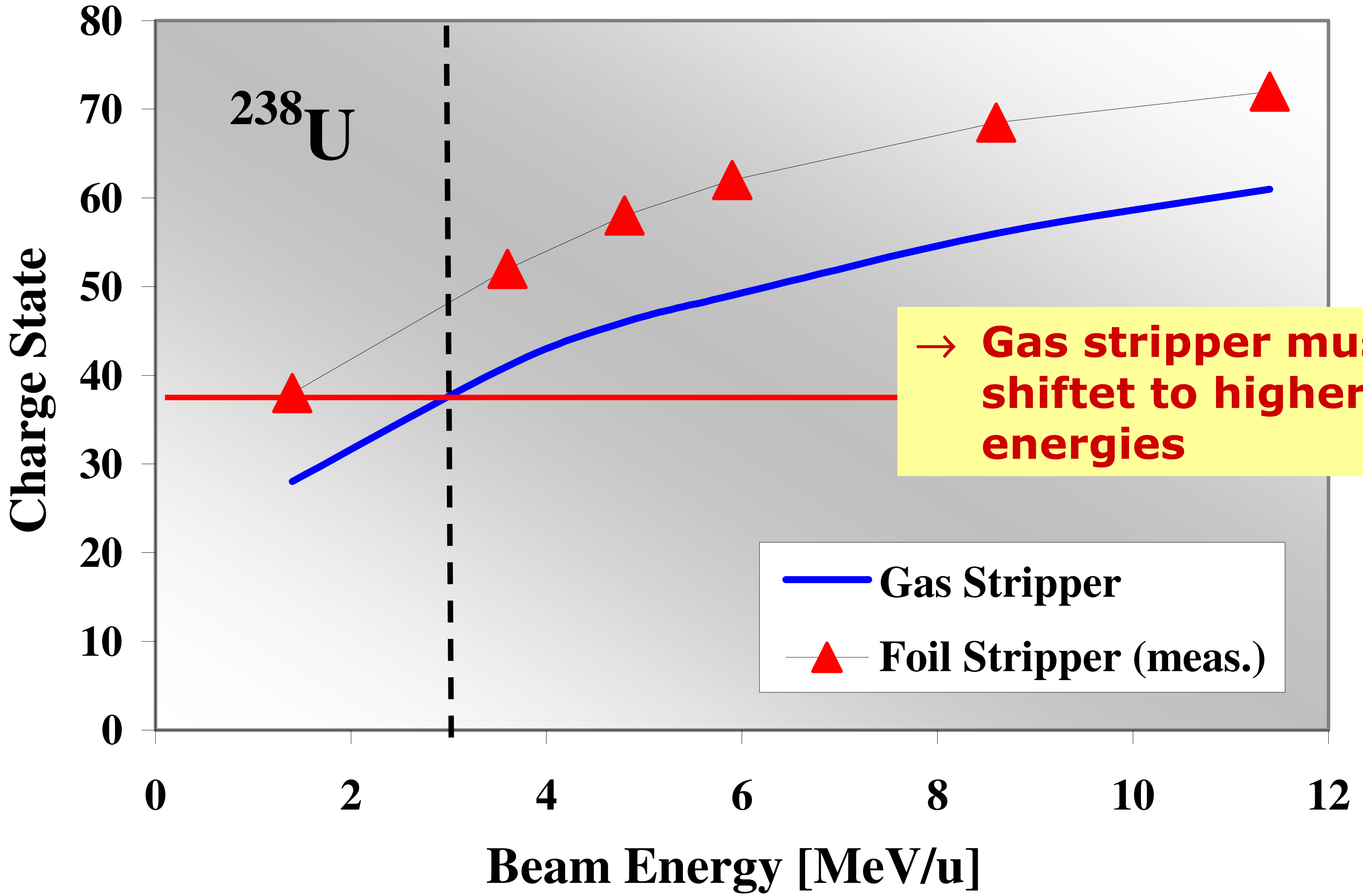
Compensation by higher injection energy:

- **15 mA, U^{28+}, 11.4 MeV/u: $\Delta Q \approx 0{,}51$**
- **20 mA, U^{38+}, 22 MeV/u: $\Delta Q \approx 0{,}48$**

... for higher injection energy:

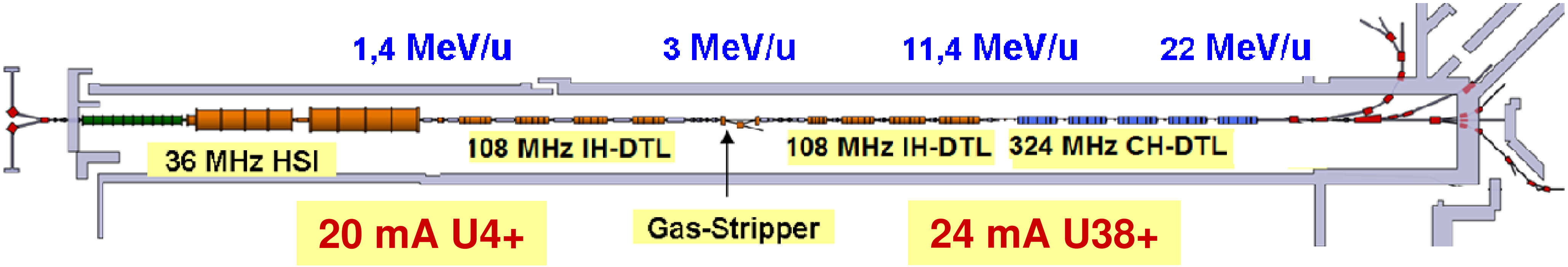
$\rightarrow$ smaller emittance ($\propto 1 / \beta$)
$\rightarrow$ shorter injection pulse

Uranium Charge States vs. Beam Energy



→ **Gas stripper must be shiftet to higher beam energies**

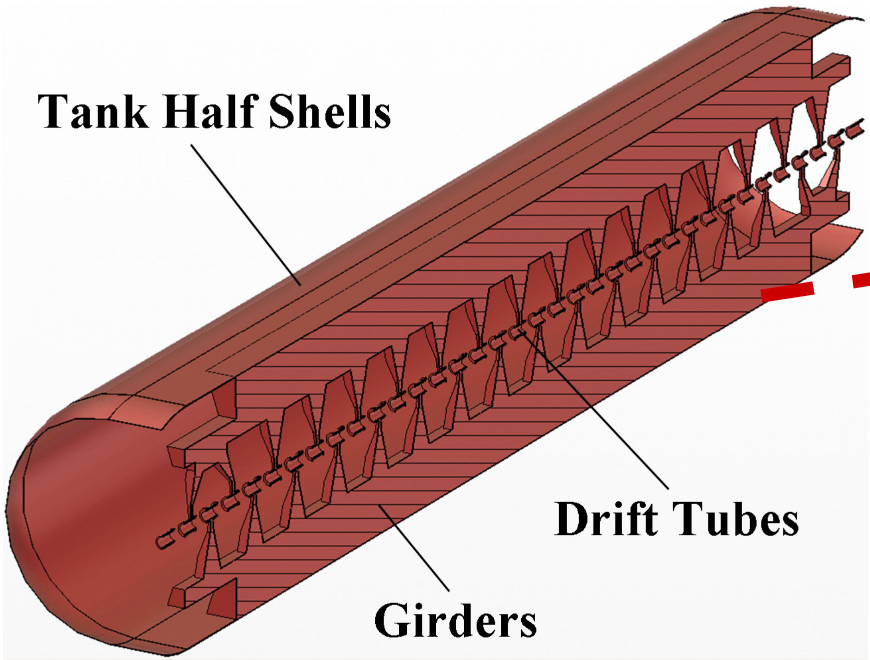
Investigated High-Energy (HE) Linac Concept



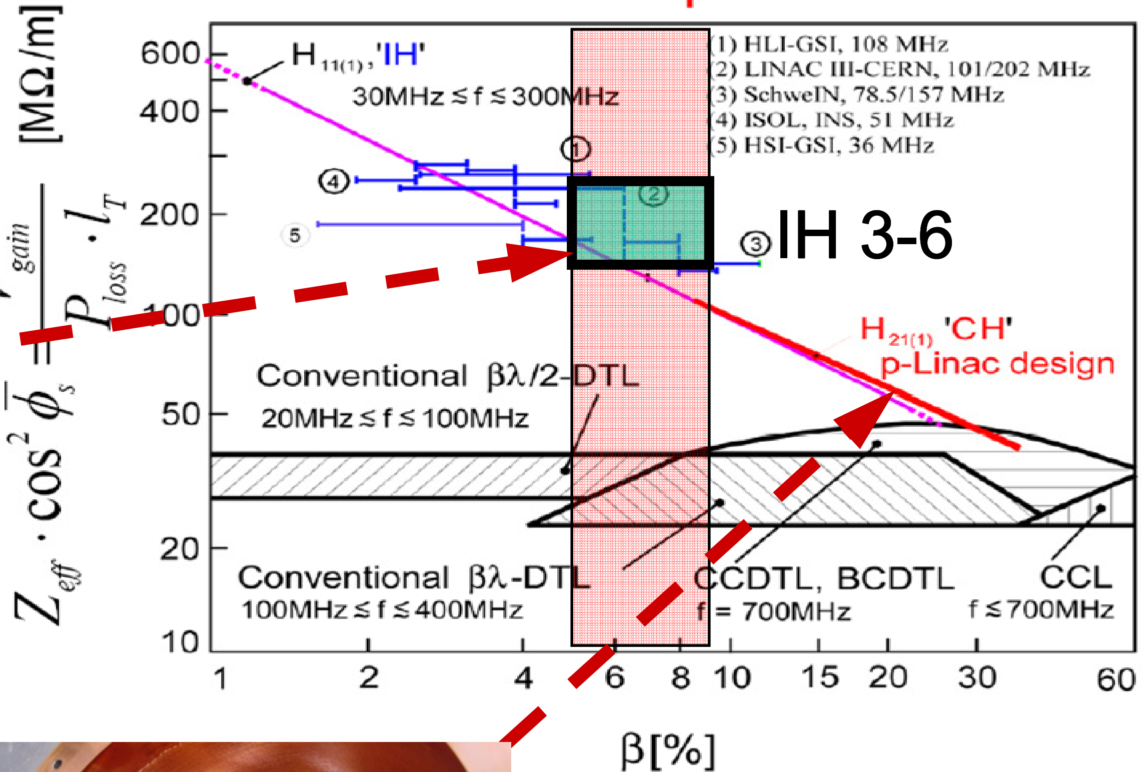
- **1st Stage: 108 MHz IH-DTL up to 11.4 MeV/u (replacing exist. post-stripper)**
  Gas stripper moved to 3 MeV/u, charge separater can be re-used
  4 new pre-stripper IH tanks: 95 MV, 20 mA U^{4+}, A/q ≤ 59.5
  4 new post-stripper IH tanks: 53 MV, 24 mA U^{38+}, A/q ≤ 6.26
- **2nd stage: Energy upgrade to 22 MeV/u by 325 MHz CH-DTL structures**
  5 to 6 CH tanks: 67 MV, 24 mA U^{38+}
  Extension of existing building for 325 MHz klystron gallery
- **Separated function lattice, only external magnetic quadrupol triplets**

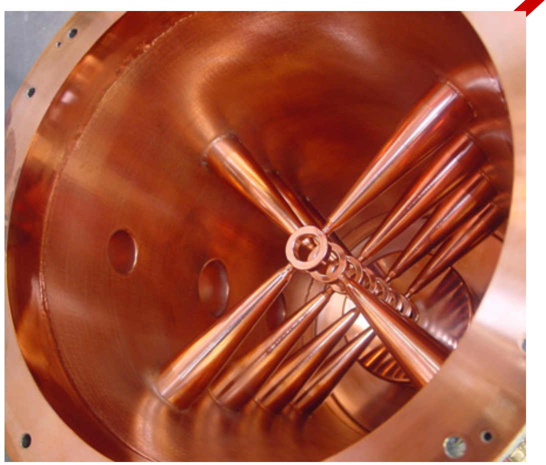
Proposed H-Mode Structures

108 MHz IH-DTL



Shunt Impedances

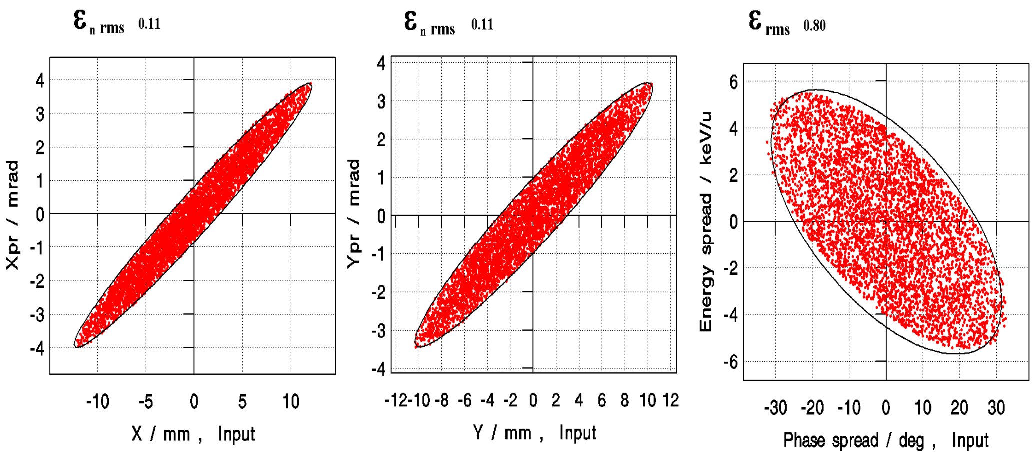


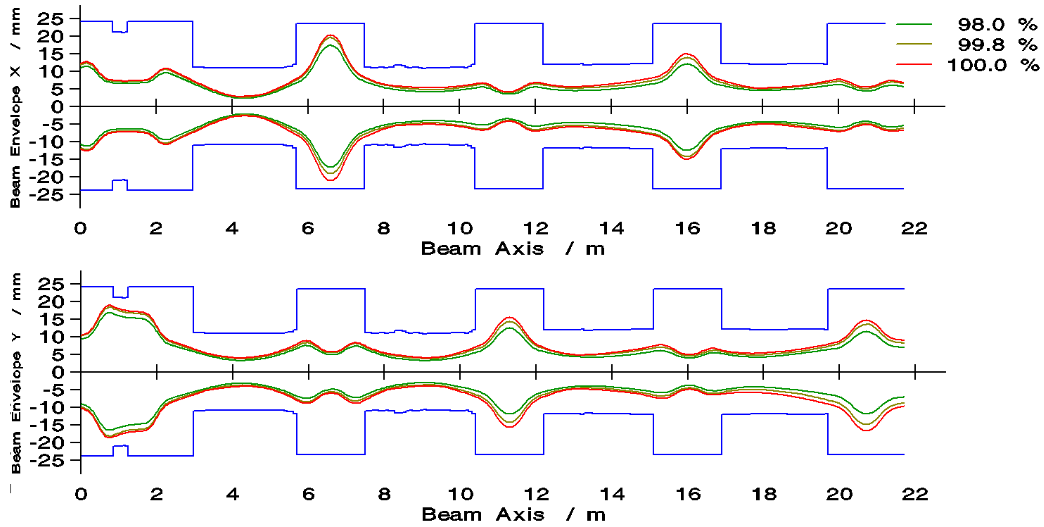


325 MHz CH-DTL Hot Model

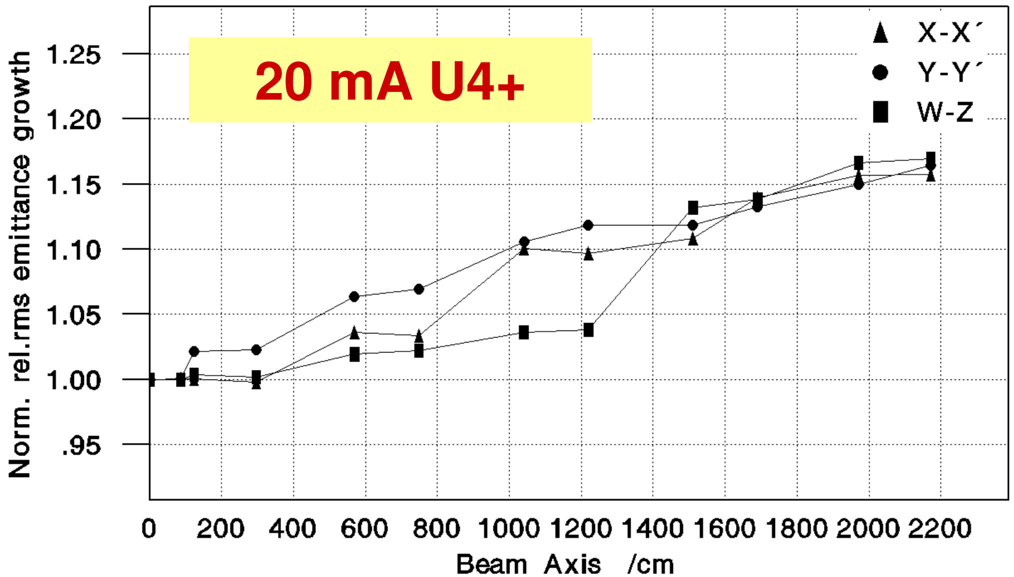
G. Clemente et al., Phys. Rev. ST-AB 14, 110101 (2011)

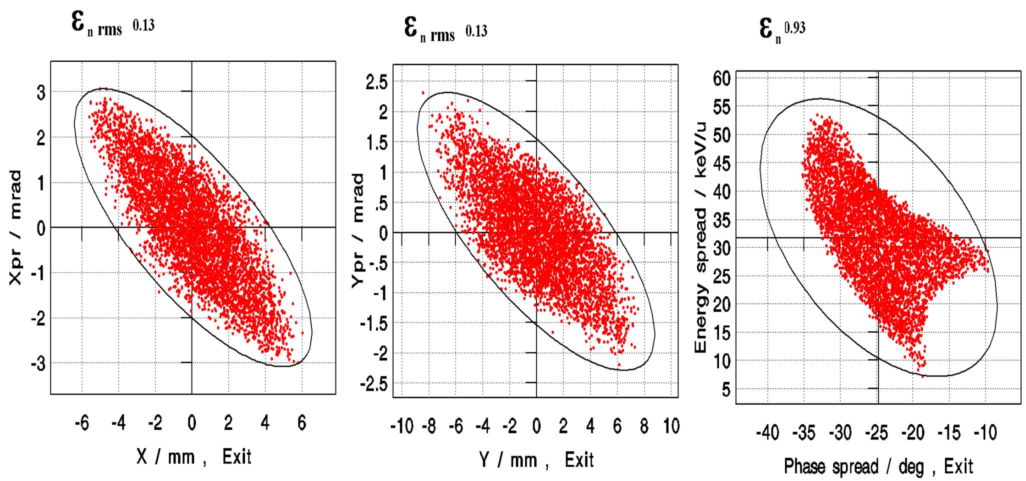
Pre-Stripper Beam Dynamics (KONUS)





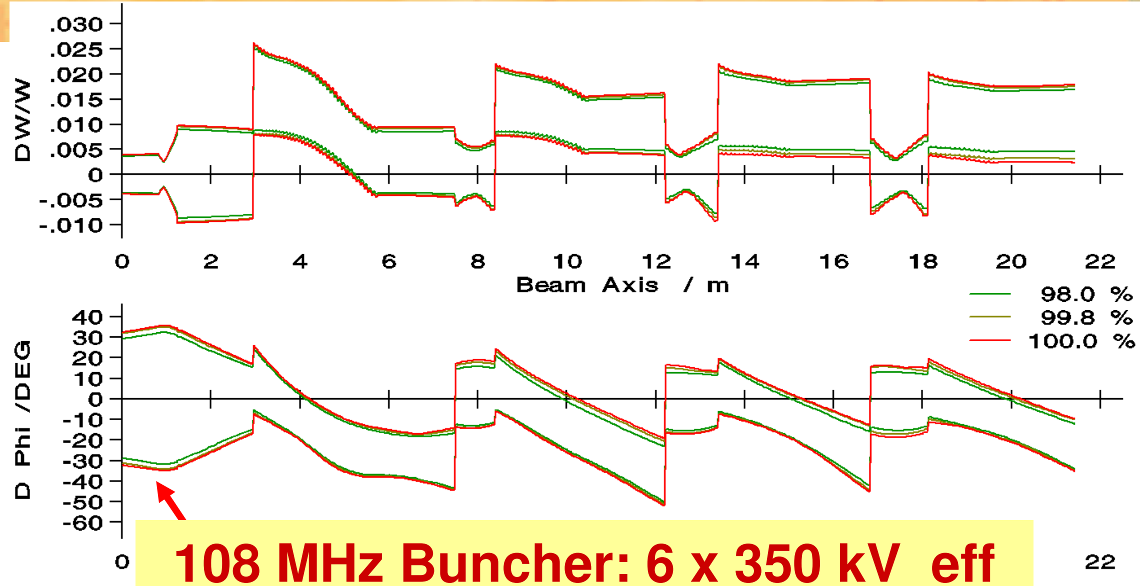
By G. Clemente, GSI





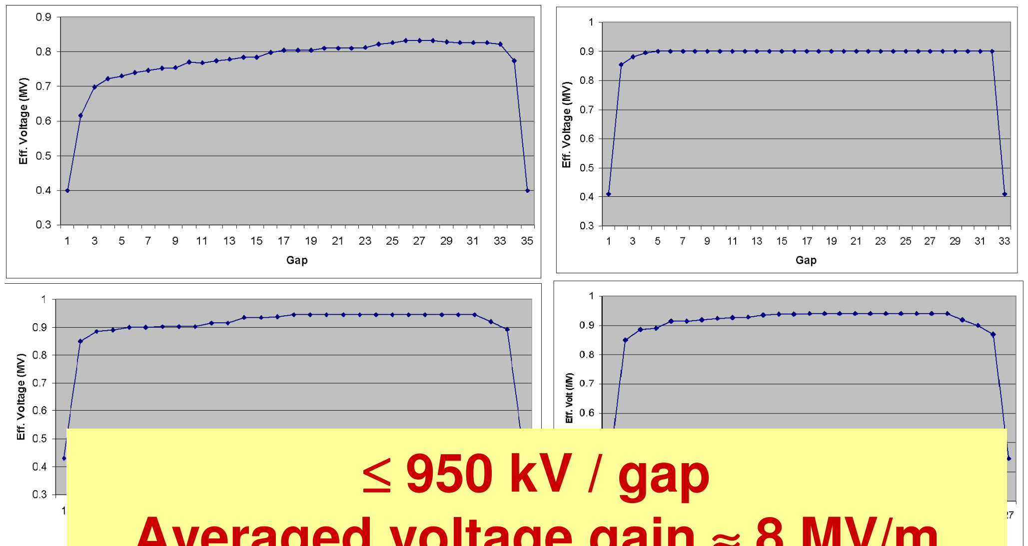
Pre-Stripper Design

20 mA U4+



108 MHz Buncher: 6 x 350 kV_eff

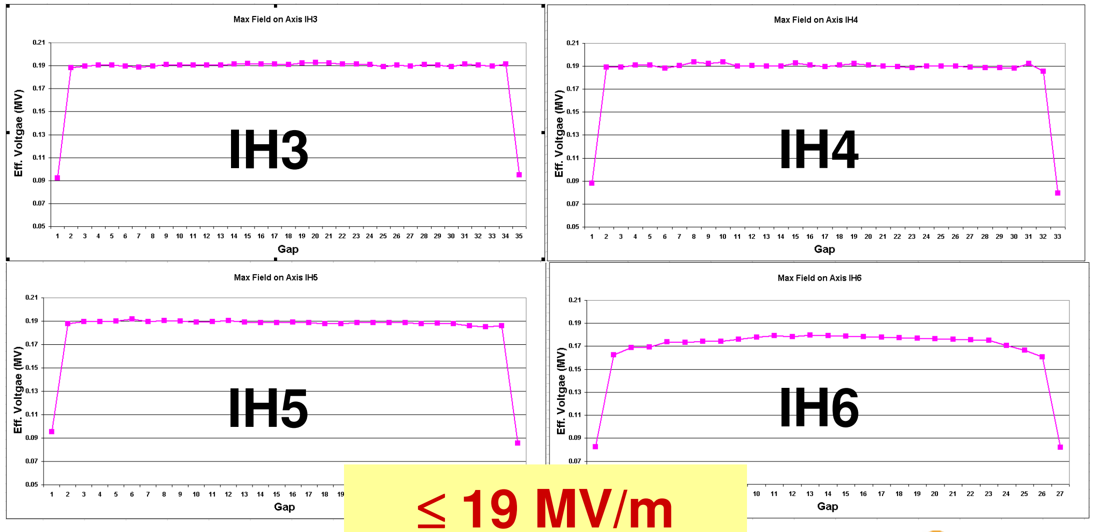
Effective Voltage Distribution



≤ 950 kV / gap

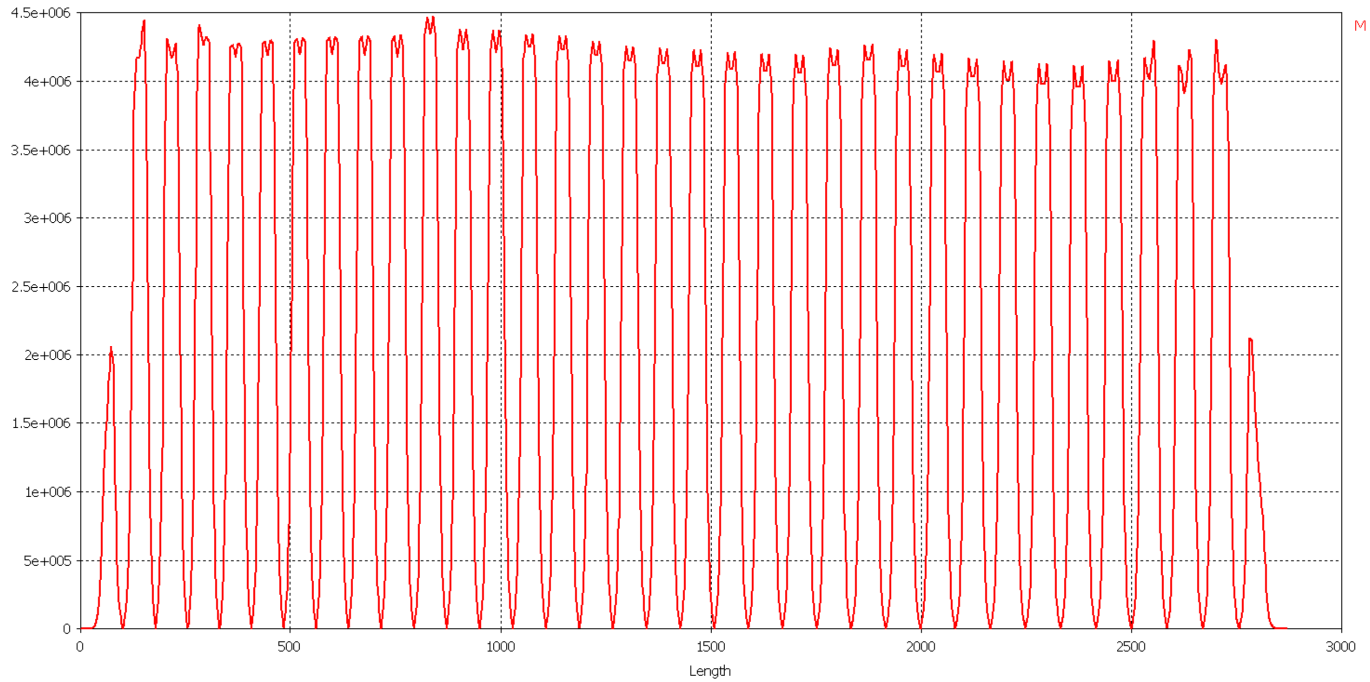
Averaged voltage gain ≈ 8 MV/m

Max Electric Field on Axis

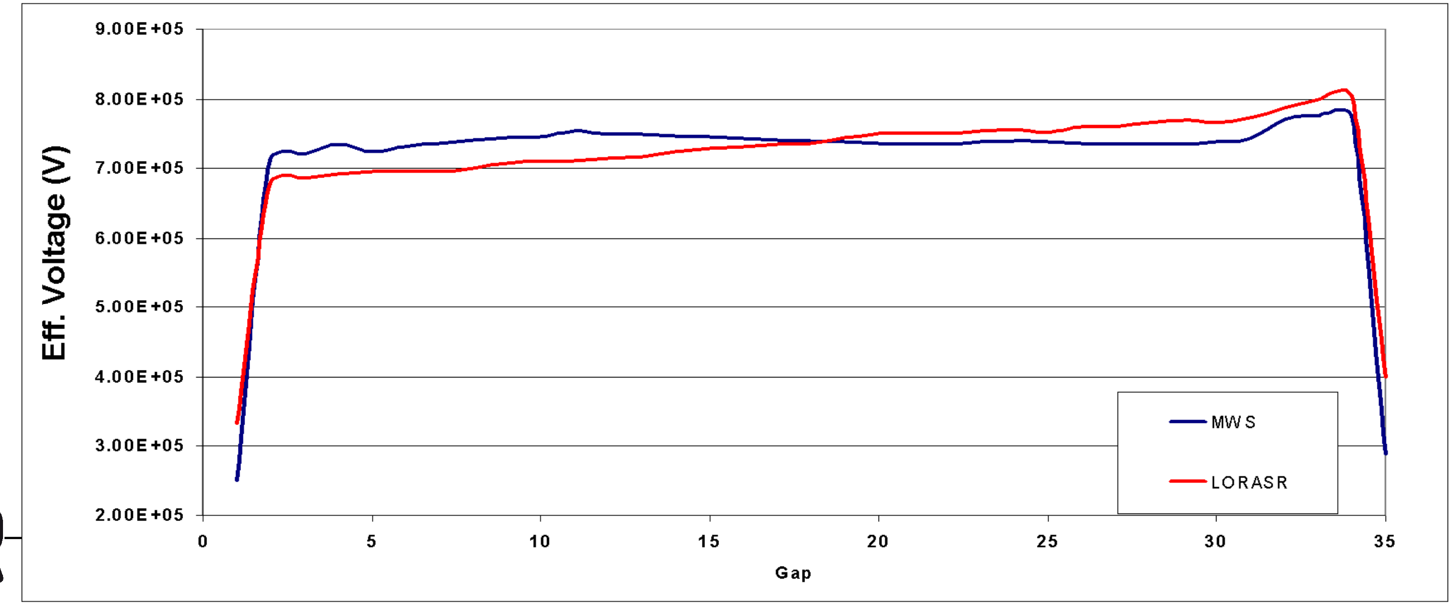


≤ 19 MV/m

Microwave Studio Simulations (IH3)



Electric field distribution



Voltage distribution

Stage 1: 108 MHz IH-DTL Linac

Cavity	ΔW (MeV/u)	P_{beam} (kW)	V_{eff} (MV)	Gaps	Beam Aperture	Length (m)
			Pre-Stripper (U4+)			
IH3	0.40	454	25	35	22	~ 2.9
IH4	0.45	538	28.7	33	22 – 24	~ 3.1
IH5	0.416	500	26.8	30	24	~ 3.1
IH6	0.346	416	23.9	27	24	~ 3.0
			Post-Stripper (U38+)			
IH7	1.80	271	11.5	14	35	~ 1.8
IH8	2.37	356	15.9	19	35	~ 3.0
IH9	2.20	330	15.3	18	35	~ 3.3
IH10	2.20	330	15.0	18	35	~ 3.7

Total RF power demands for each cavity including beam power < 1.3 MW

Conclusions

- **Replacement of existing UNILAC post-stripper by new linac optimized for FAIR injection**
  low duty cycle, short pulses, fixed end energy
- **Presented HE linac study very costly and huge efforts**
  215 MV, shift of gas-stripper section, extension of RF gallery
- **Alternative option:**
  108 MHz IH-DTL for U28+ up to 11.4 MeV/u
  85 MV, about 5 new IH tanks, no higher charge state
- **Investigation of alternative stripper options to increase charge state without extension of present pre-stripper**
  plasma stripper, Li film stripper ?, (foil stipper)
- **Prototype IH & CH structures will be designed & constructed**

Timeline

2017	Commissioning start of FAIR accelerators using ion beams from existing UNILAC
2019	FAIR proton linac commissioning
2022	First heavy ion beams from new high-energy linac for FAIR (using proton beams for FAIR during installation and commissioning of the HE linac)

Thank you for Attention !