Development of H-Mode Cavities for the FAIR Project

LINAC 2012

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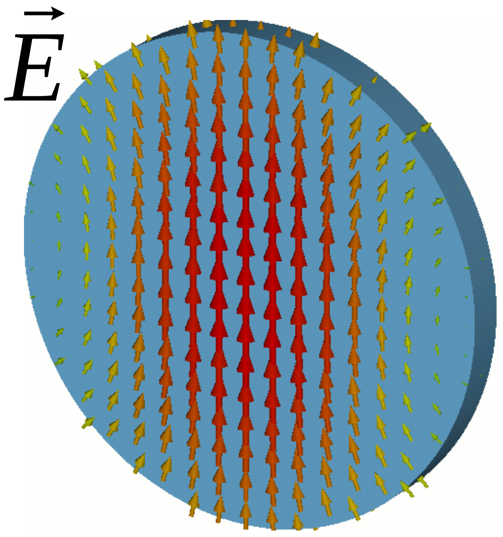
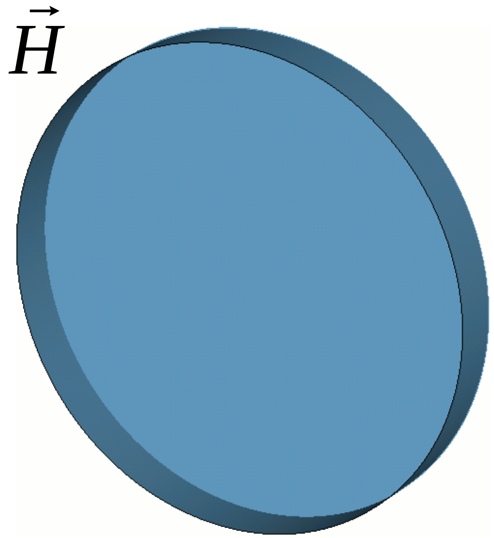
Outline

- **H-Mode Cavities**
  - TE modes
  - Physical Properties
  - Beam Dynamics
  - Shunt Impedance Charts
- **Linac Upgrade @ GSI for FAIR**
  - Proton LINAC
  - High Energy LINAC
  - Super Heavy Element cw LINAC

From Pillbox to IH-Mode DTL





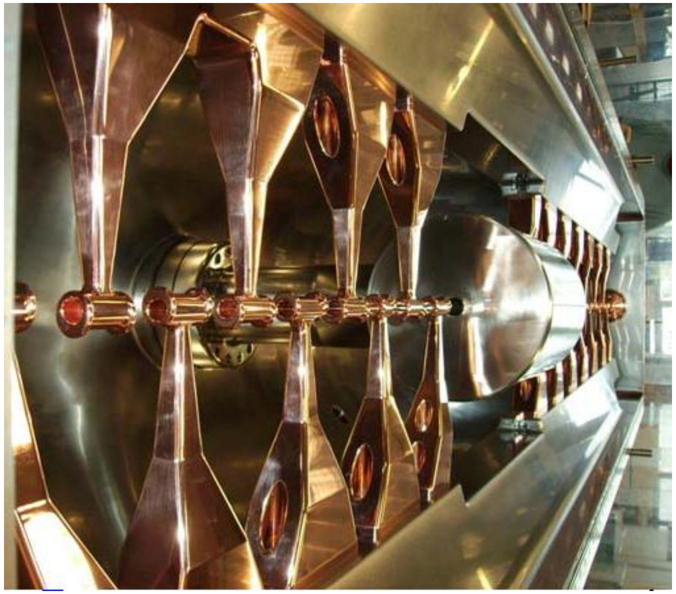
TE11 Mode in a pillbox

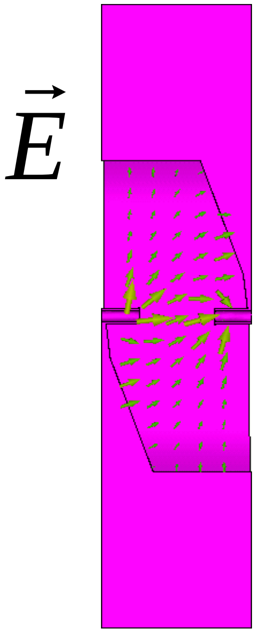
H-Field Parallel to beam Axis

No E-Field component for acceleration

Insertion of stem and drift tube

Perpendicular to the axis

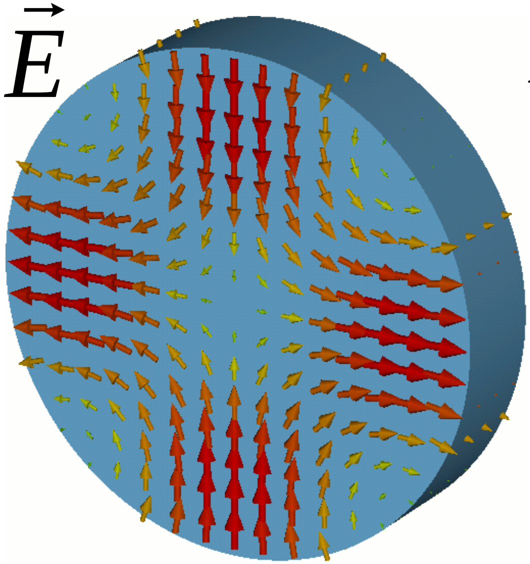


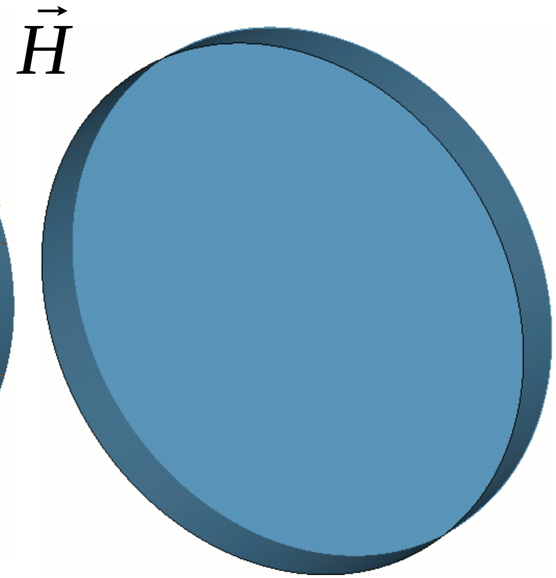


Axial component of E-Field generated !

Acceleration possible!

From Pillbox to CH-Mode DTL

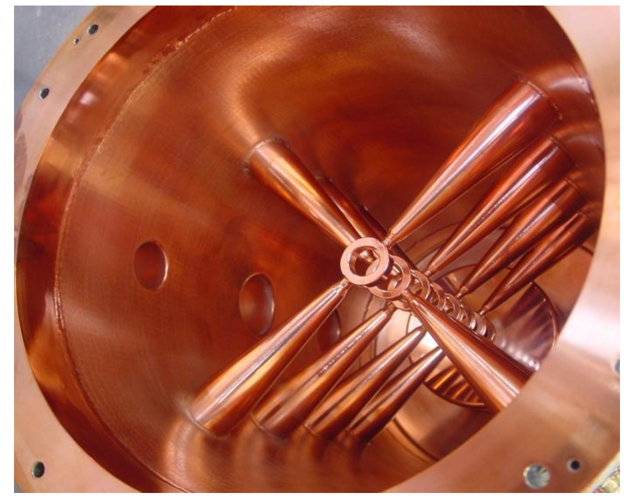


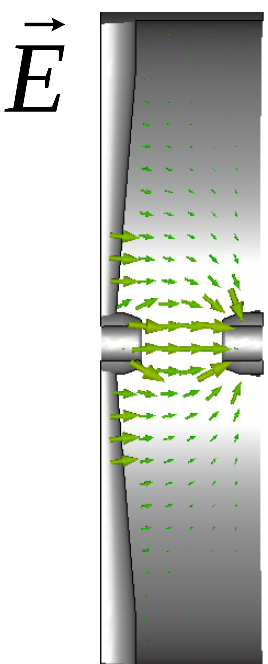


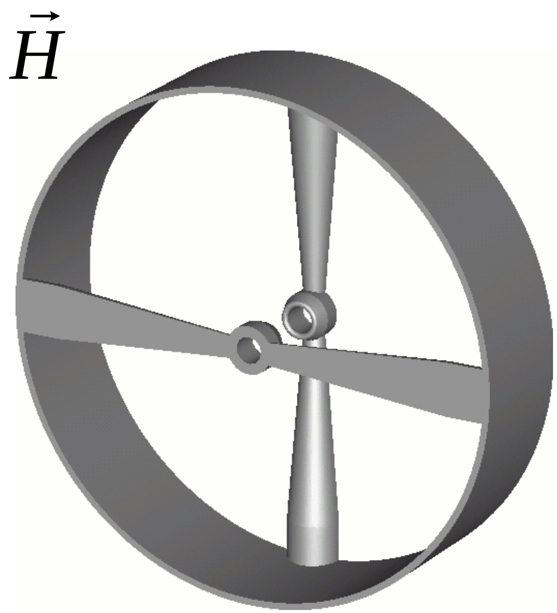
Pillbox exited on TE_{21} Mode

Suited for higher frequency

Superconducting option possible





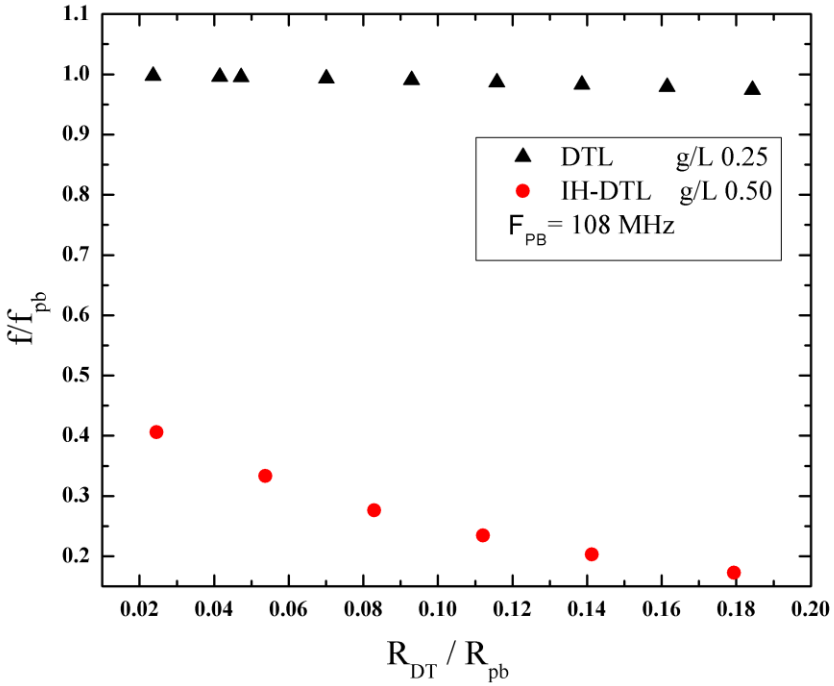


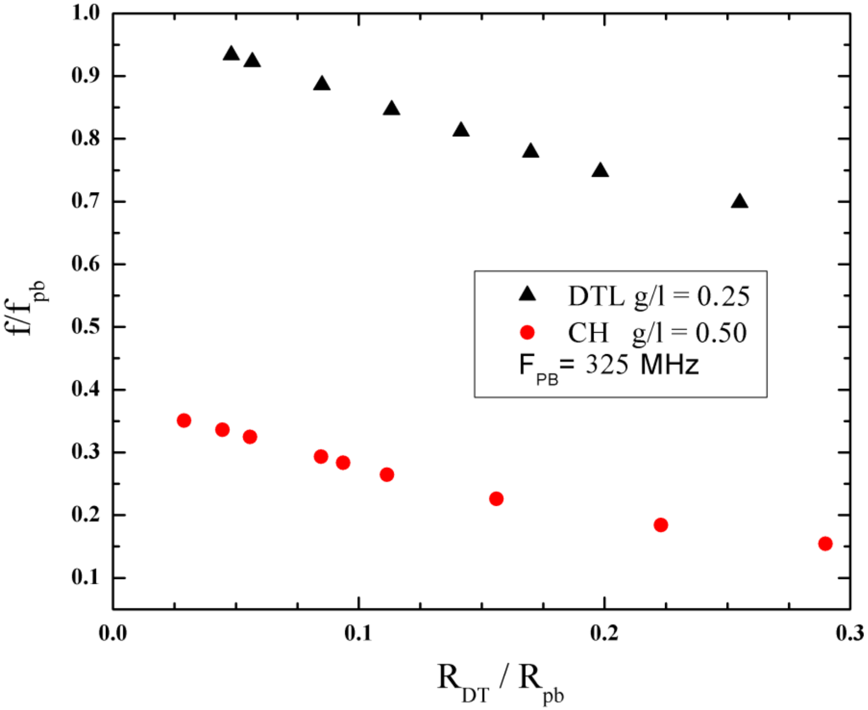
H-Mode DTL: RF Properties

The acceleration structure strongly modifies the E field distribution

Very High capacitive load

Capacitive Load: H-Mode vs E-Mode DTL





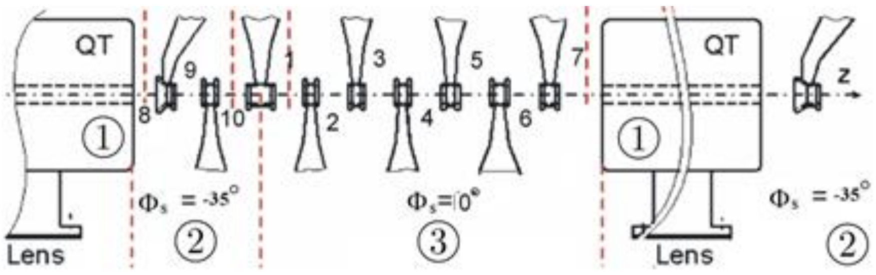
Capacitive Load and electric field concentrated mainly on the beam axis

H-Mode DTL profits significantly by a slim tube geometry

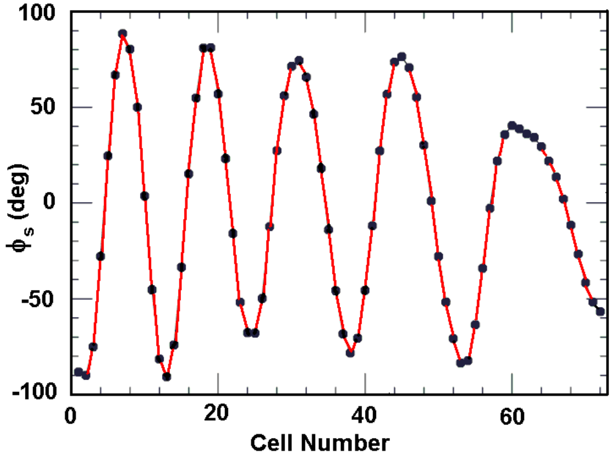
Beam Dynamics

- **Separated function beam dynamics**

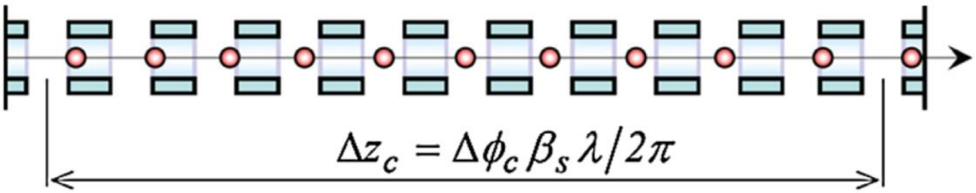
KONUS

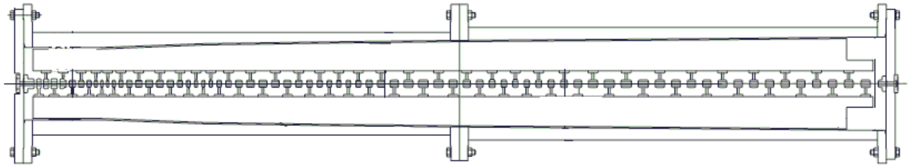


APF

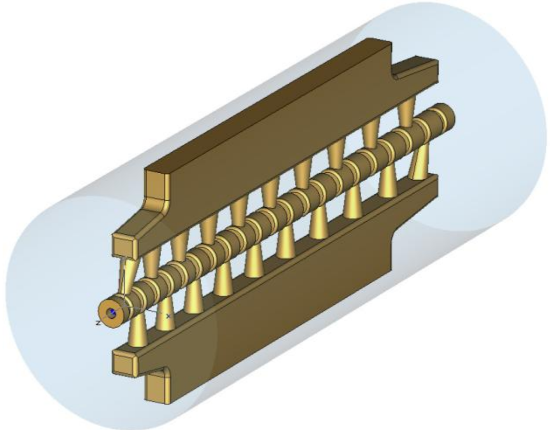


EQUUS





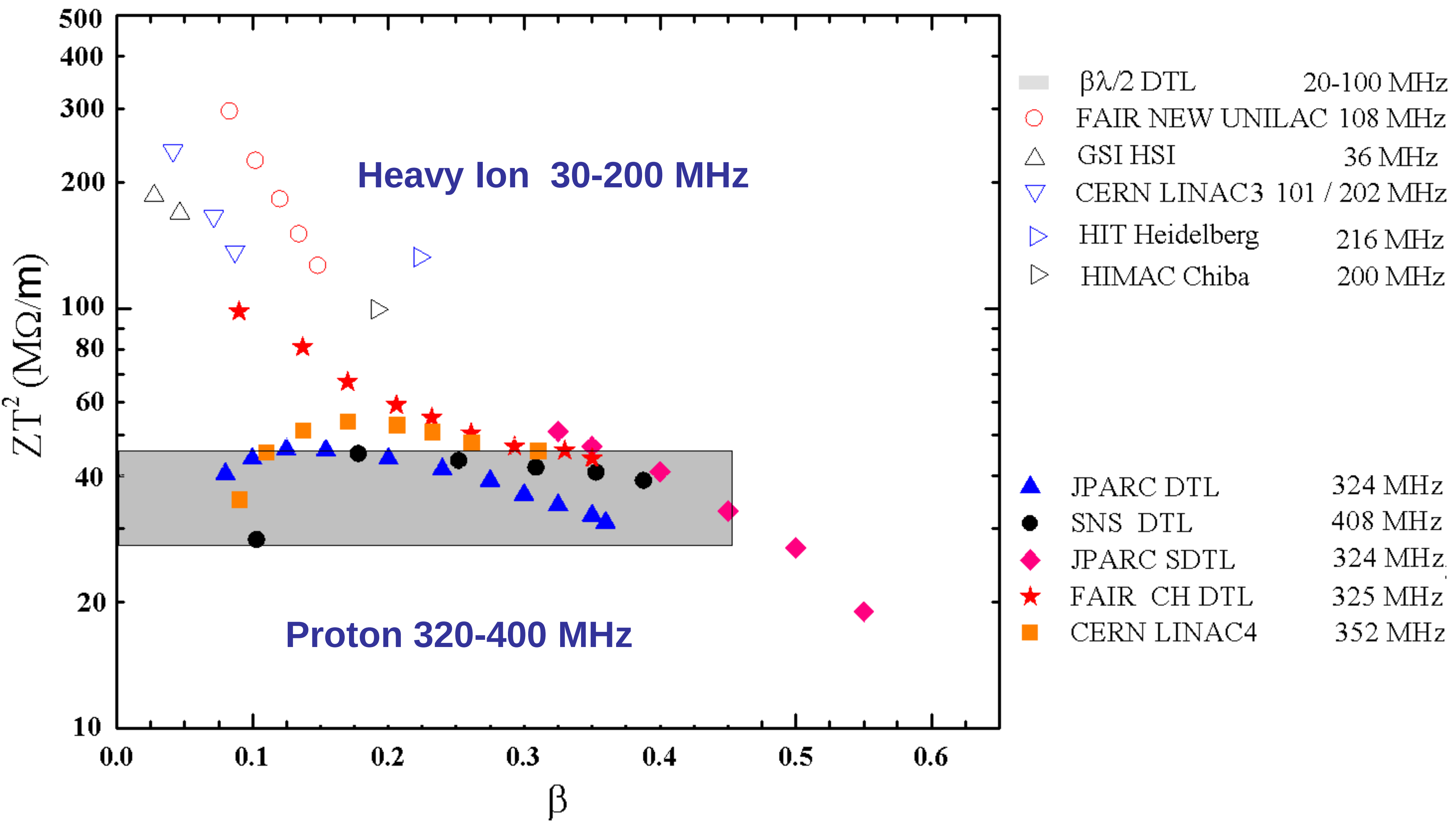
- **Periodic Beam Dynamics with Slim Permanent Magnet**



Proposed as replacement for the LANSCE Linac

Extremely tight tolerances T= 200 T/m !
Reduced beam aperture

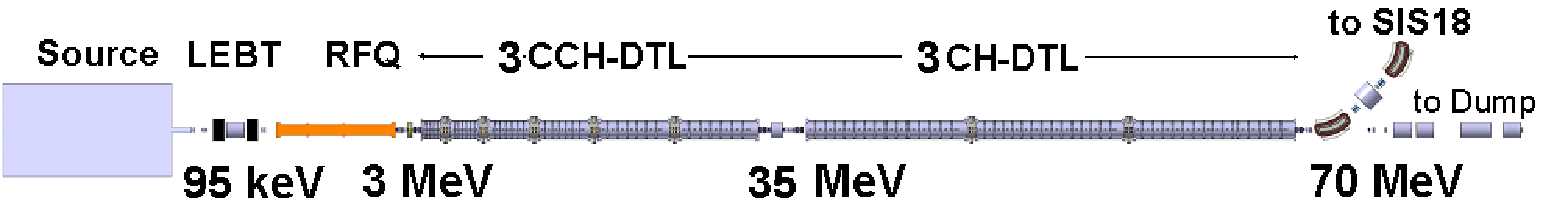
Shunt Impedance Chart



IH-DTL Established as standard solution for Heavy Ion

CH-DTL Valid alternative to DTL for Proton Linac up to 100 AMeV

THE FAIR P-LINAC



Beam Energy (MeV)	70
Beam Current (mA)	35 - 70
Beam Pulse (µs)	36
Repetition Rate (Hz)	4
Frequency (MHz)	325.224
Norm. Emittance at output (µm)	2.1 / *4.2*
Momentum Spread	$\leq \pm 10^{-3}$
Beam Loading (peak) (MW)	4.9
RF Power (peak) (MW)	2.2
Klystron (3 MW Peak Power)	7
Solid State Amplifier (50 kW)	3
Total Length (RFQ + CH)	≈ 27 m

DTL Section consists in

- 3 Coupled CH DTL
- 3 Standard CH-DTL

Cavity	Energy (MeV)	Gaps	L (m)
1	3 - 12	22	1.7
2	12 - 24	27	2.7
3	24 - 37	32	4
4	37 - 48	20	2.9
5	48 - 59	21	3.1
6	59 - 70	21	3.4

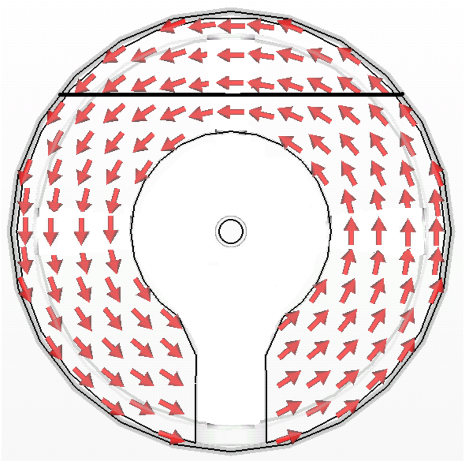
Related poster: THPB034 L. Groening

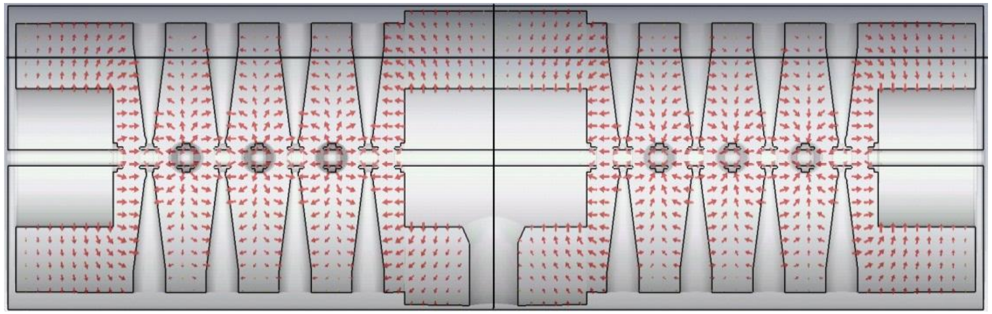
The Coupled CH-DTL

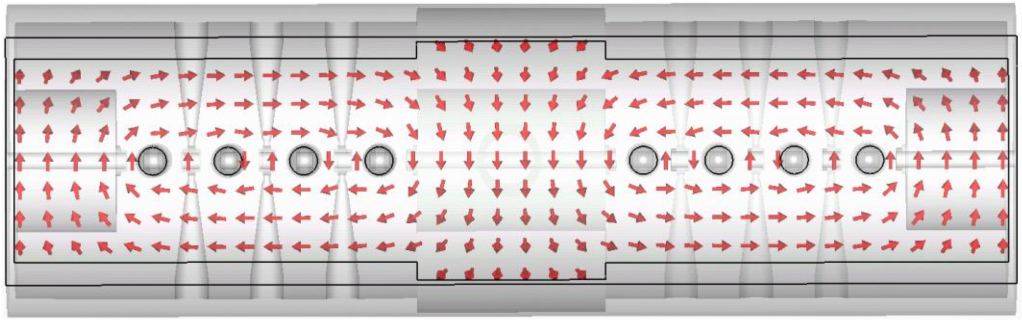
At lower β

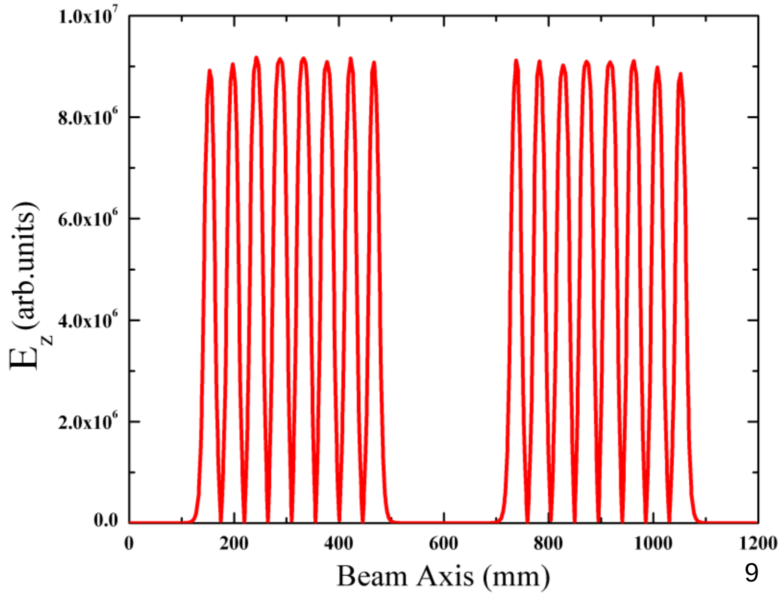
- KONUS requires shorter focusing period
- Very high Shunt impedance
- Commercial 3 MW Klystron available

Coupled structure at low beta !



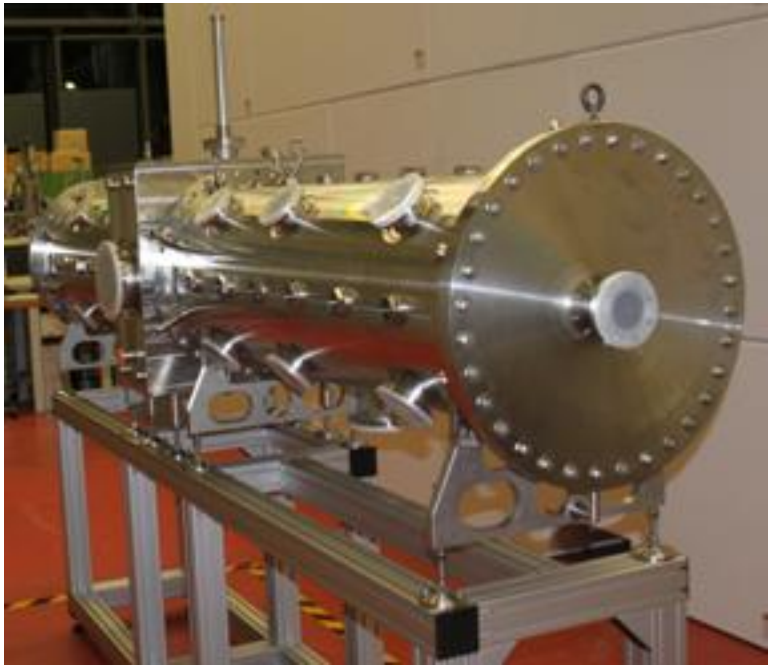


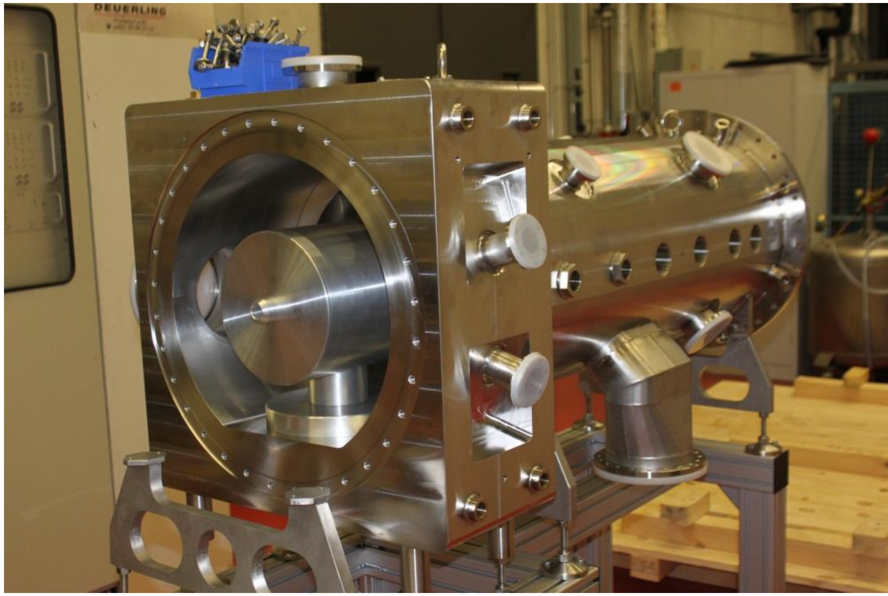




FAIR Prototype

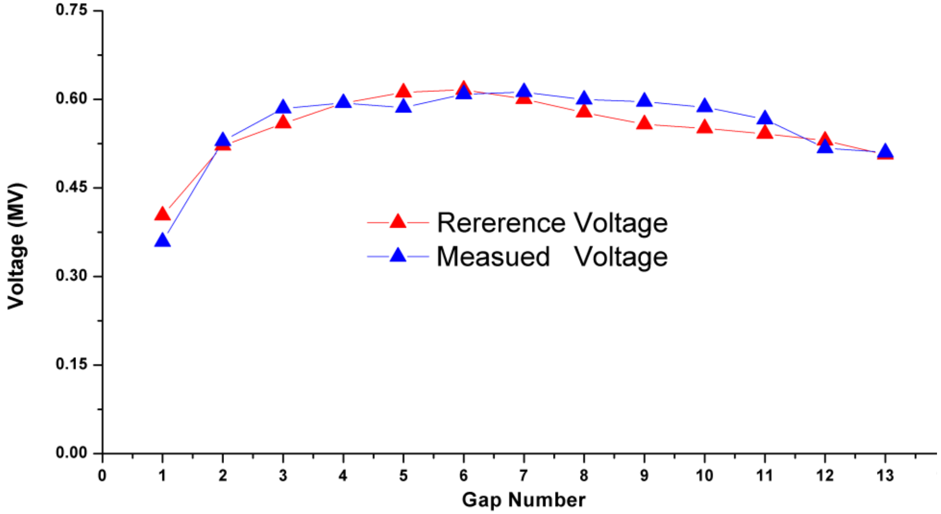
Gap	27 (13+14)
Energy Range	11.7-24.3 MeV
β	0.15-0.22
Q_0	15300
Length (m)	2.7
ZT^2	60
RF Losses	1.37
Beam Loading	882 kW (at 70 mA, required 35)
Total Power	1.810 - 2.25 MW (2.7 Available)

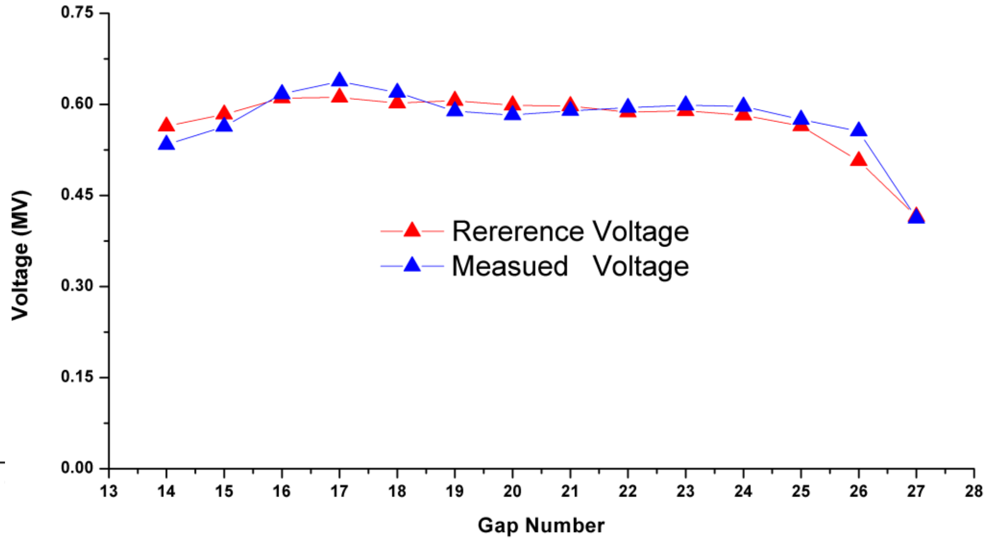


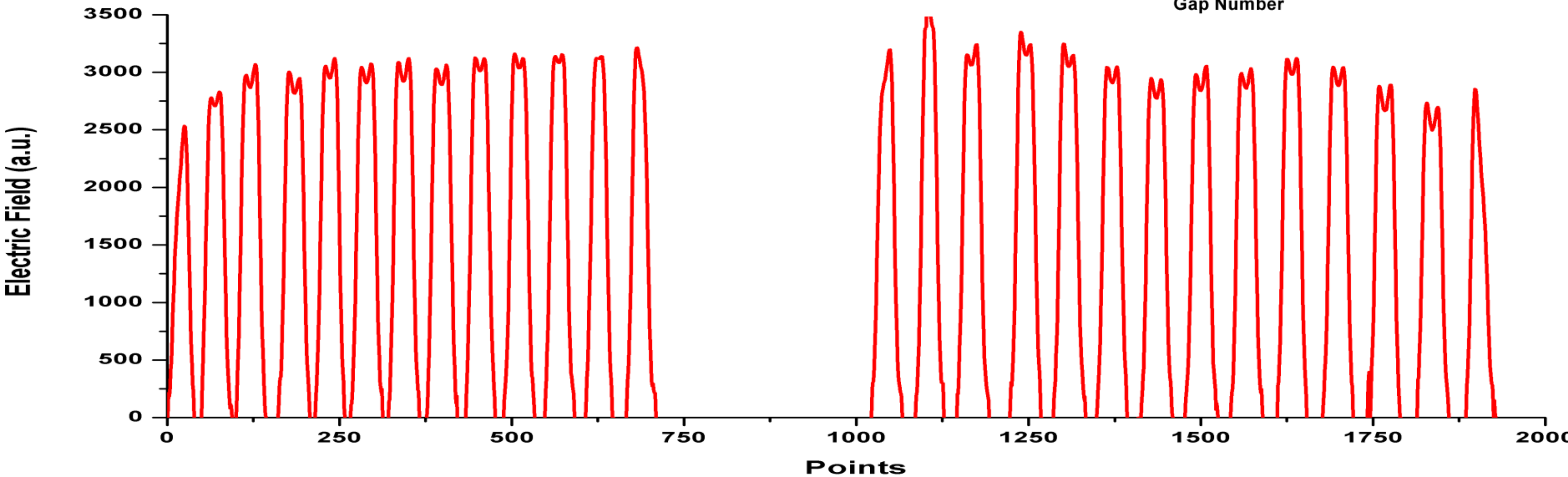


FAIR Prototype

- **Cavity tuned at : 325.16 against 325.224 MHz of operation**
  - ε_{air}=1.005 $f \propto \varepsilon^{1/2}$
  - Beam dynamics verified with measured voltages

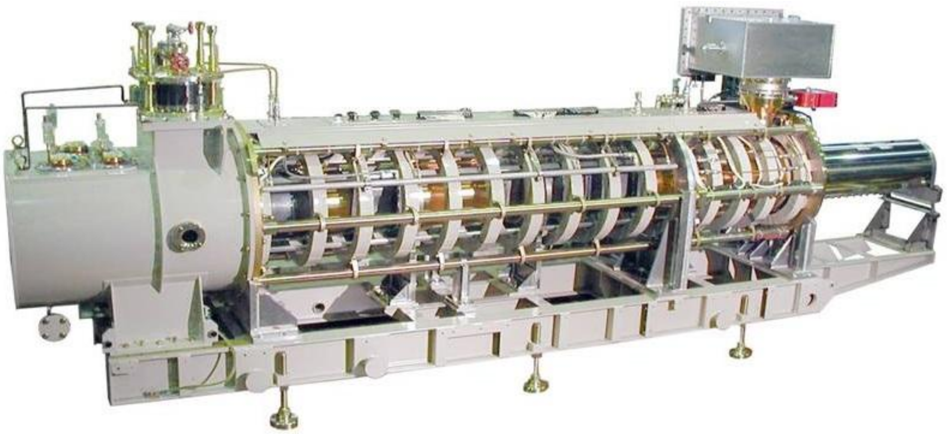






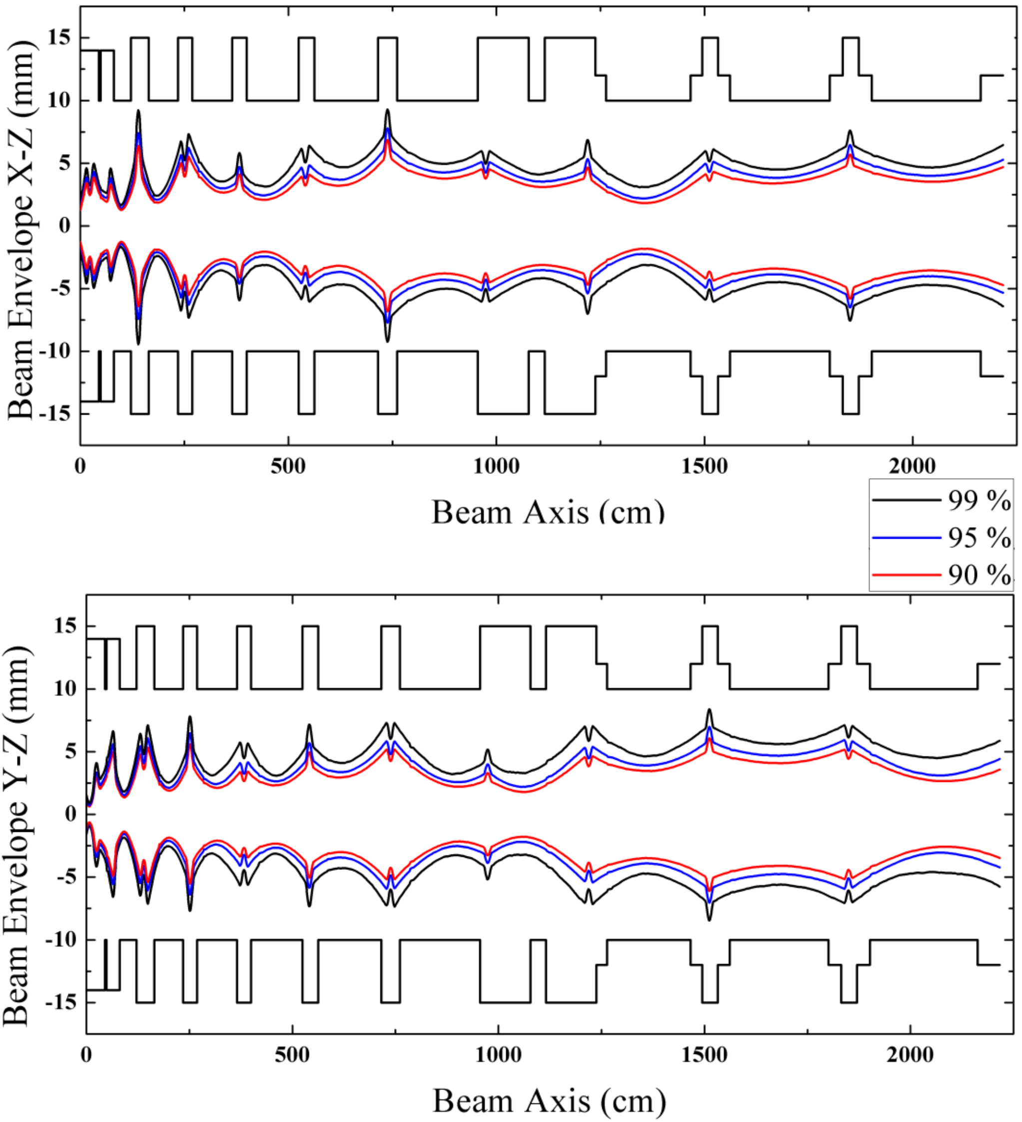
Status

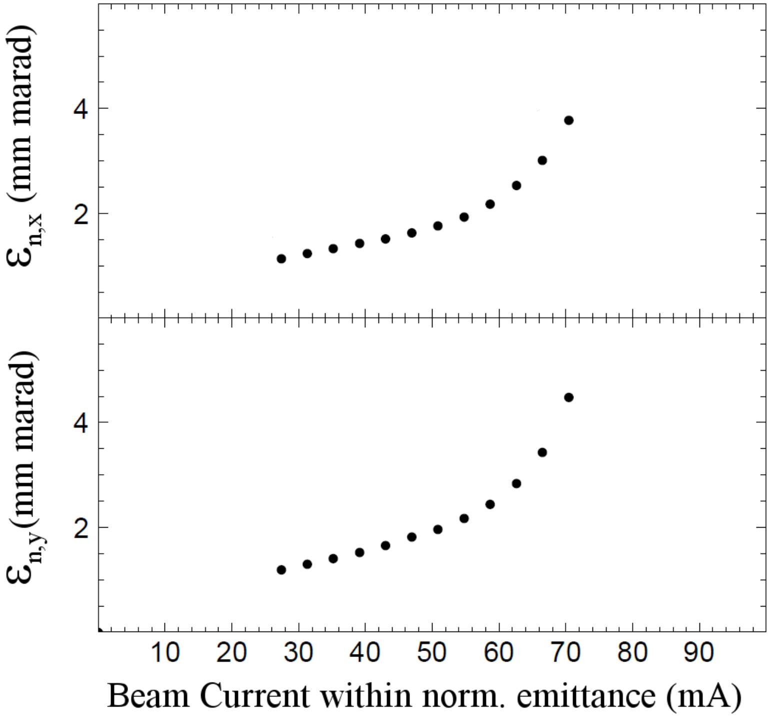
- Stainless Steel Stems ready!
- Stainless Steel Drift Tubes in production
- Copper plating performed in late 2012/ early 2013
- 3 MW Klystron delivered. Power Supply is expected for end 2012
- New GSI Test Bench ready for full power RF Test



FAIR PLINAC

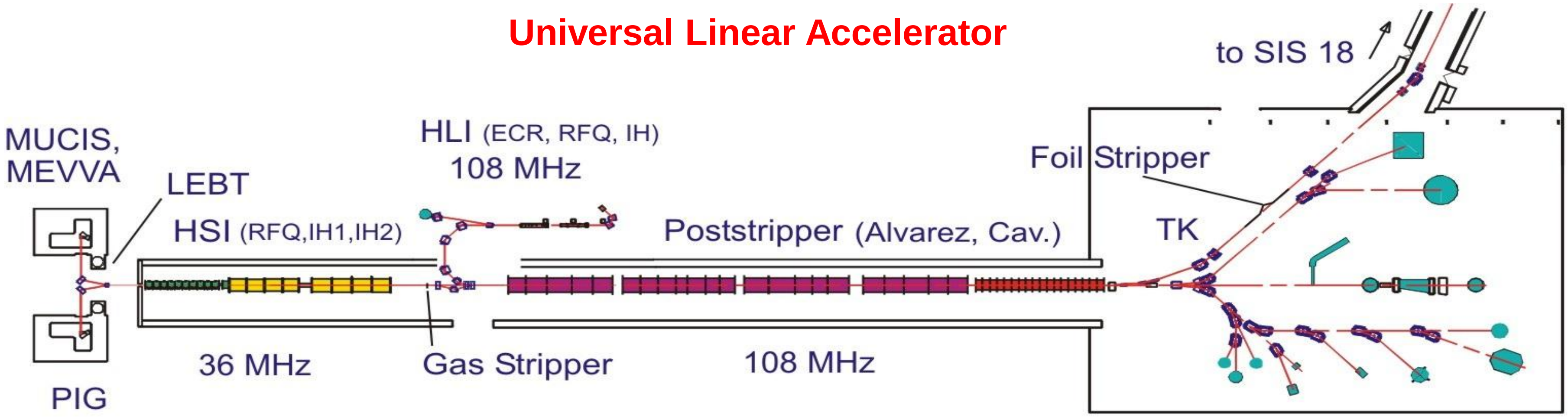
Beam Dynamics, Brilliance analysis





UNILAC

Universal Linear Accelerator



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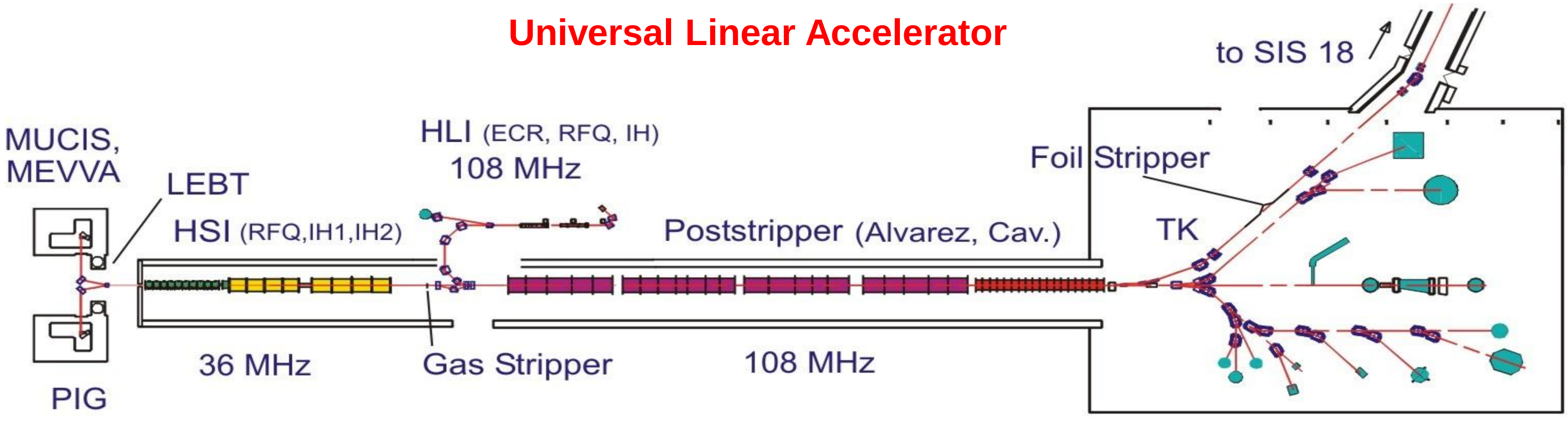

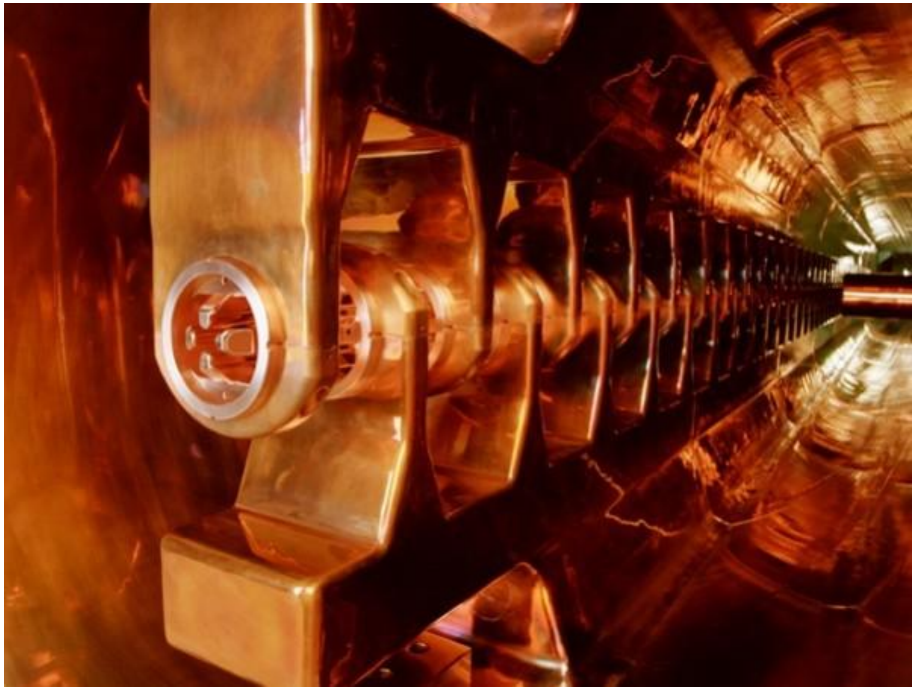

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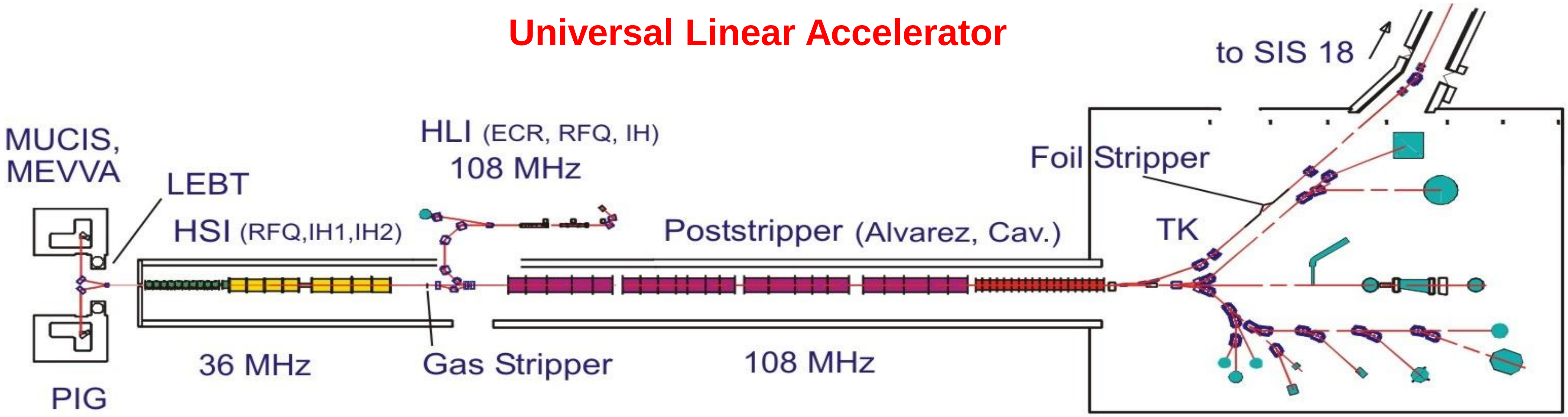
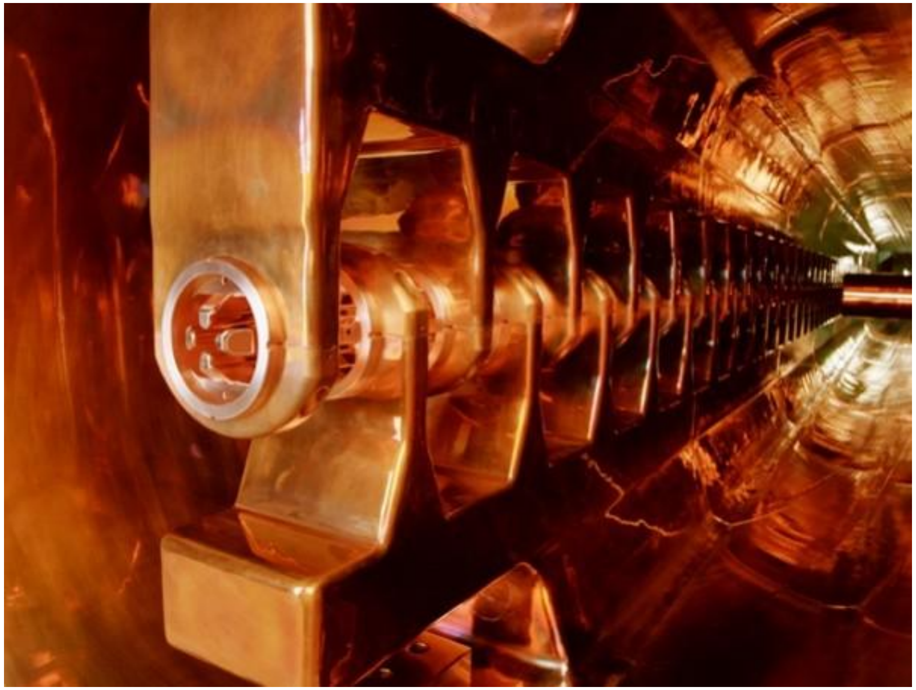




4-Rod IH-RFQ

2.2 – 120 keV/u

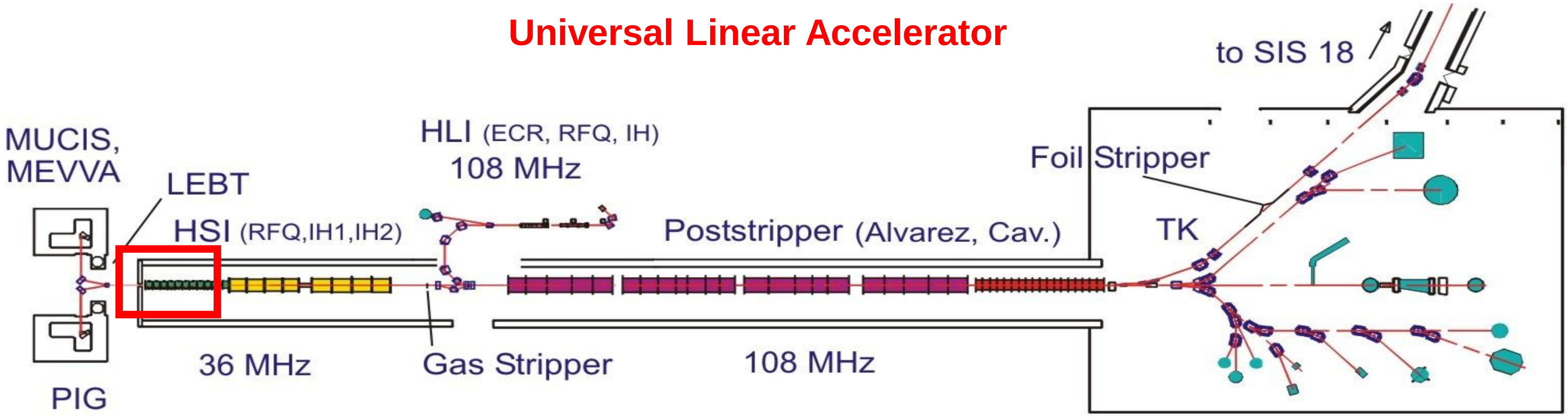
Built in 1999

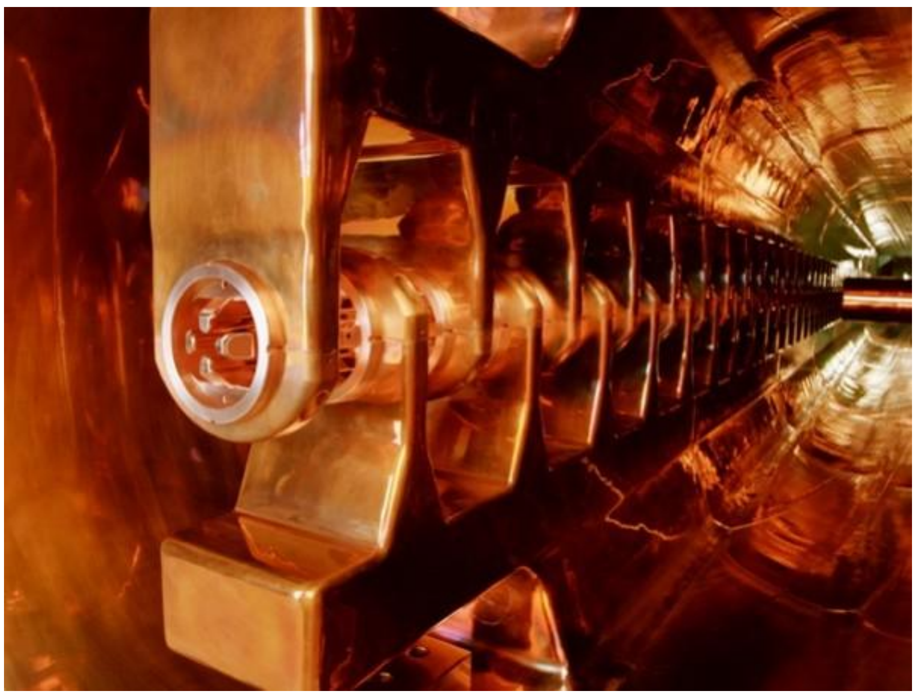
A/q $\leq$ 65 (U^{4+})

I (mA)= 0.25 A/q

UNILAC

Universal Linear Accelerator





4-Rod IH-RFQ

2.2 – 120 keV/u

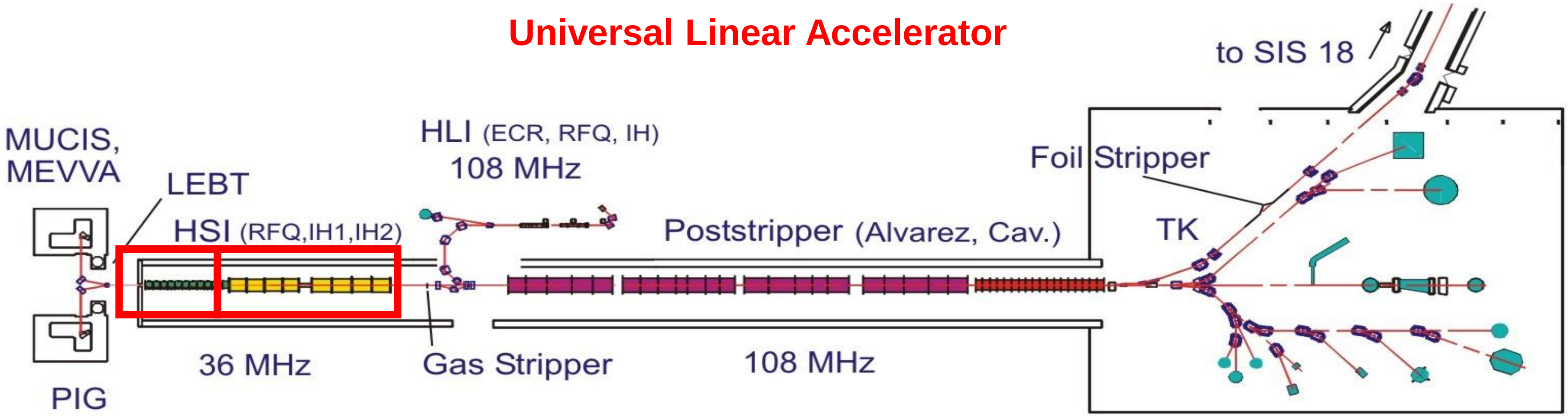
Built in 1999

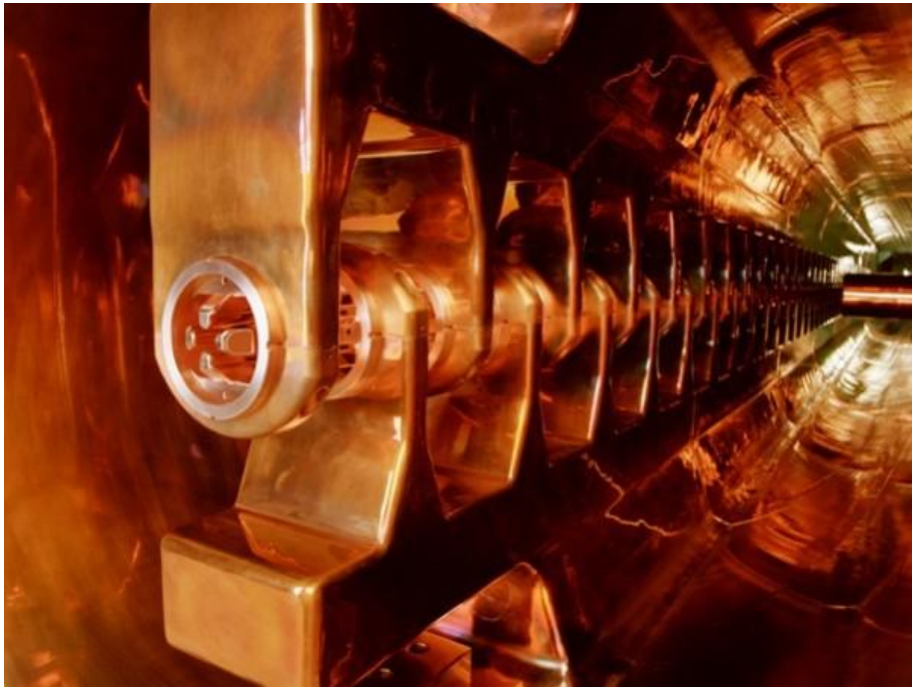
A/q $\leq$ 65 (U^{4+})

I (mA)= 0.25 A/q

UNILAC

Universal Linear Accelerator





4-Rod IH-RFQ

2.2 – 120 keV/u

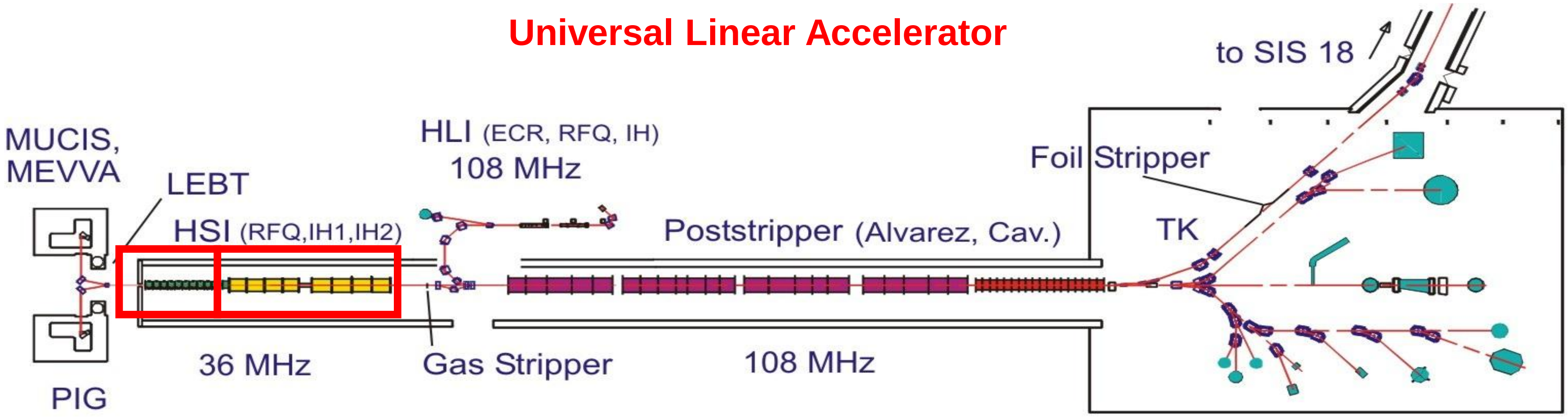
Built in 1999

A/q ≤ 65 (U^{4+})

I (mA)= 0.25 A/q

UNILAC

Universal Linear Accelerator



IH 1 & IH 2

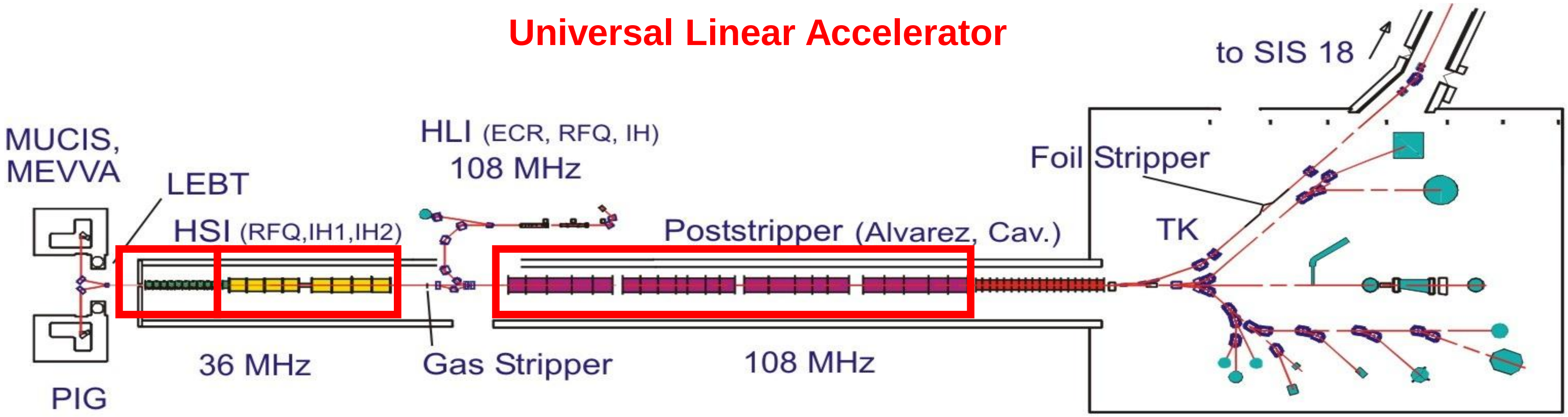
120–743 keV/u -1.4 MeV/u

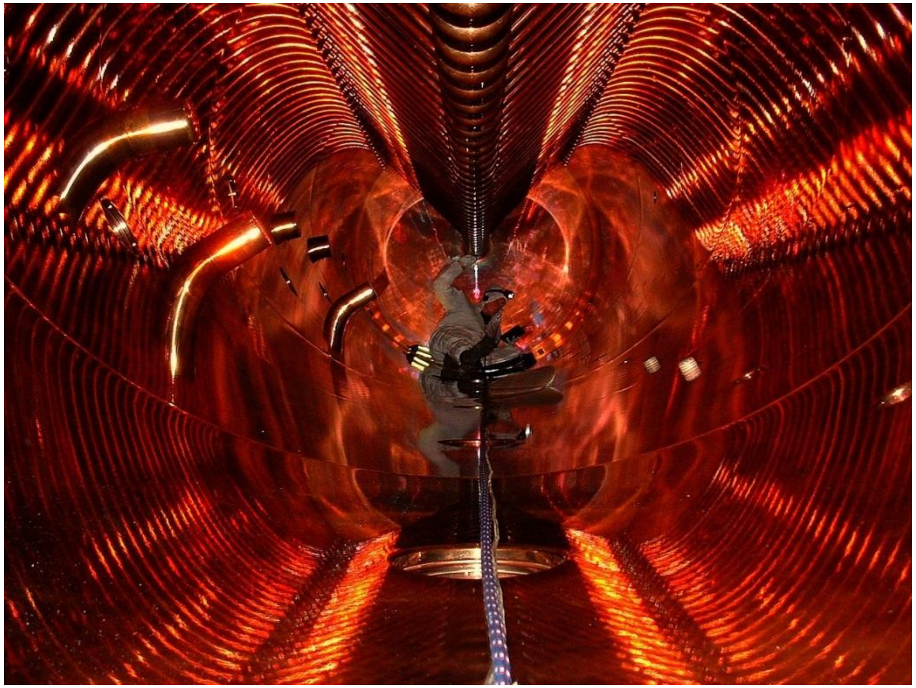
Built in 1999

I (mA)= 0.25 A/q

UNILAC

Universal Linear Accelerator





5 Alvarez Type DTL

1.4 – 11.4 MeV/u

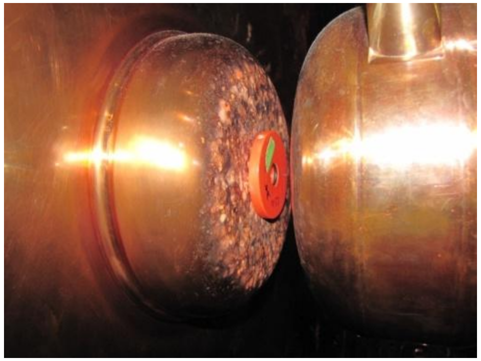
Built in 1975

178 DC Quadrupole

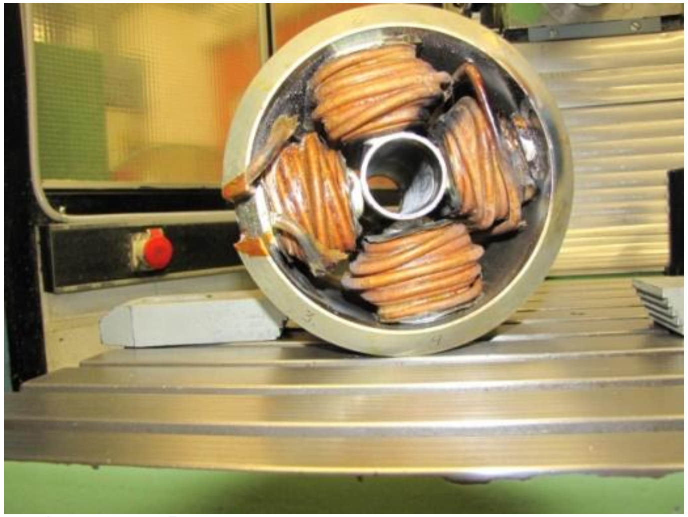
A/q$\leq$ 8.5 (U^{28+})

Present Linac Limitations

- **40 years at high duty factor (25 %)**
  - **Massive Sparkovers**
  - **Beam induced surface defects**
  - **Vacuum leaks**



- **DC Quadrupoles**
  - Limited flexibility for multi-beam operation
  - Ground faults of the coils
  - Heat dissipation problematic

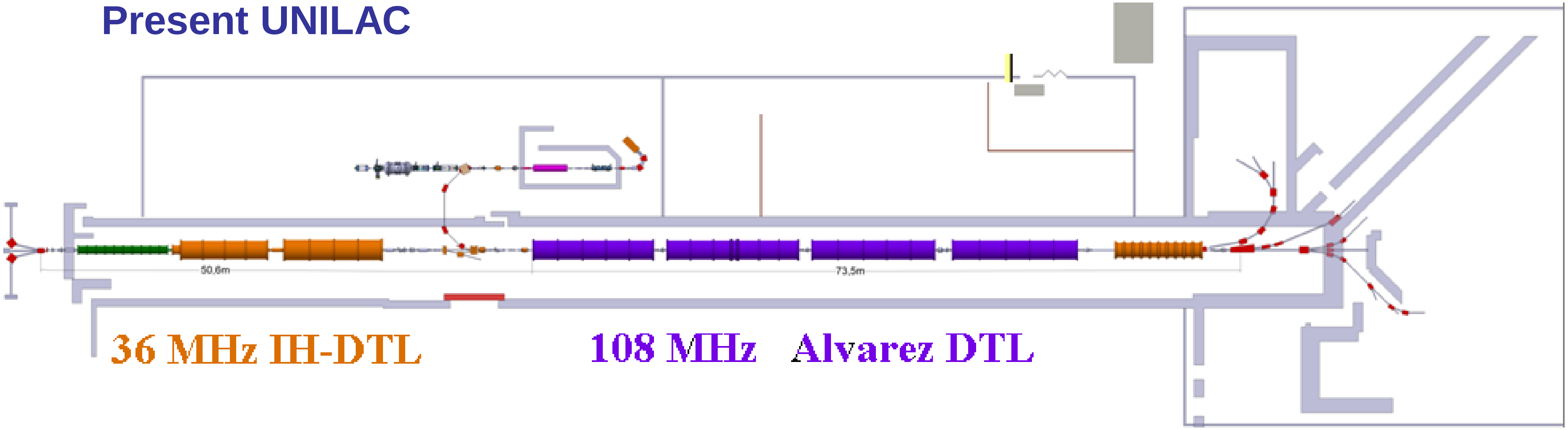


- **FAIR Requirements (High Intensity, low duty factor)**
  - Too high for protons
  - Challenging for heavy ion
  - Not compatible with SHE program

Massive injector upgrade required !

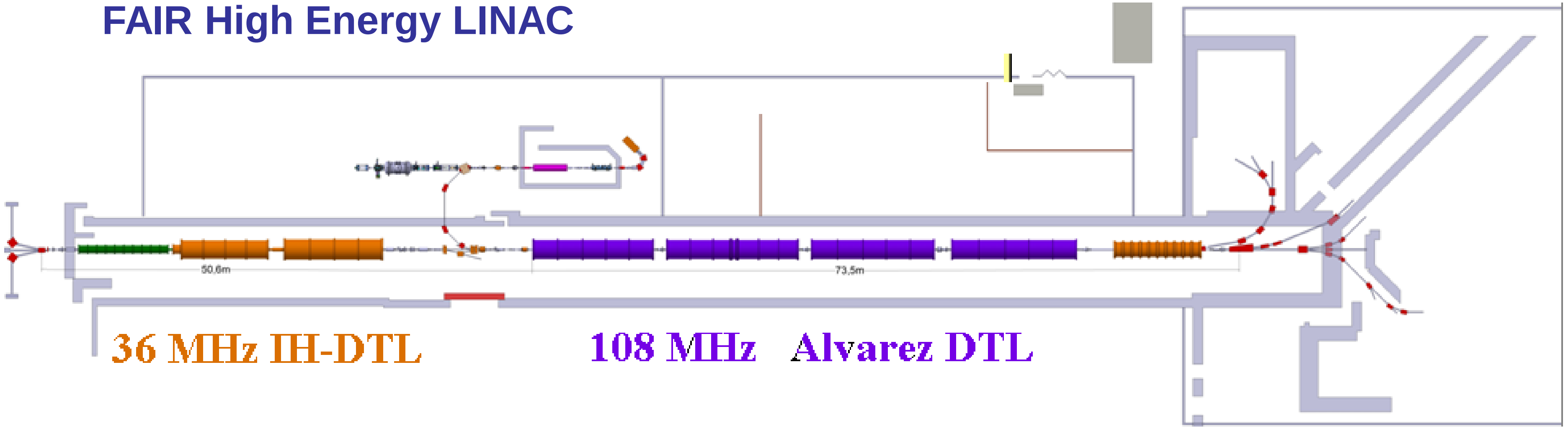
UNILAC Upgrade

Present UNILAC

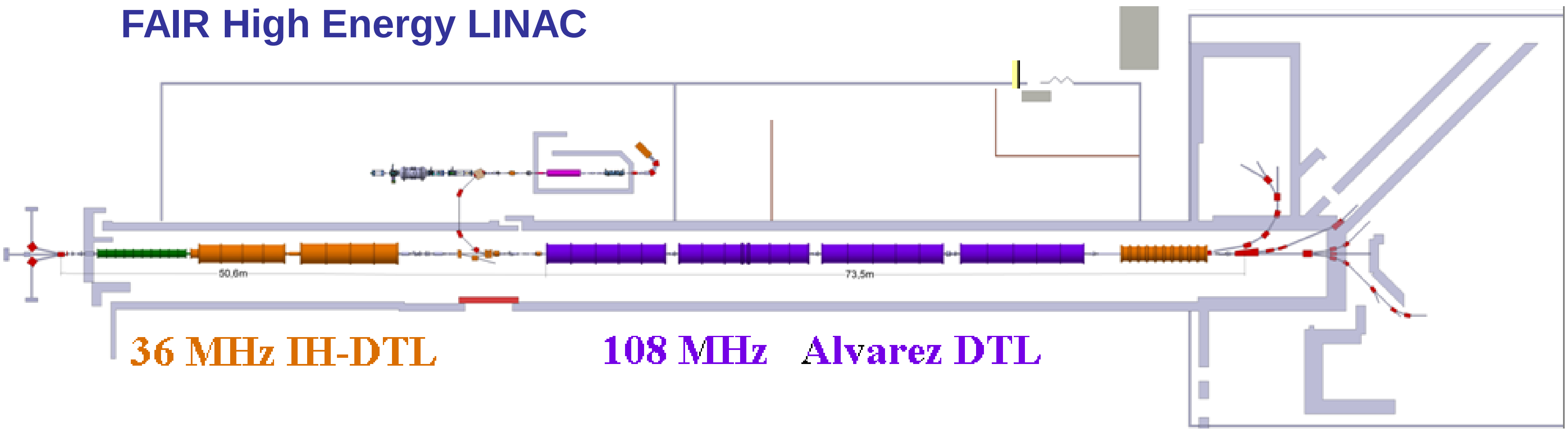


UNILAC Upgrade

FAIR High Energy LINAC

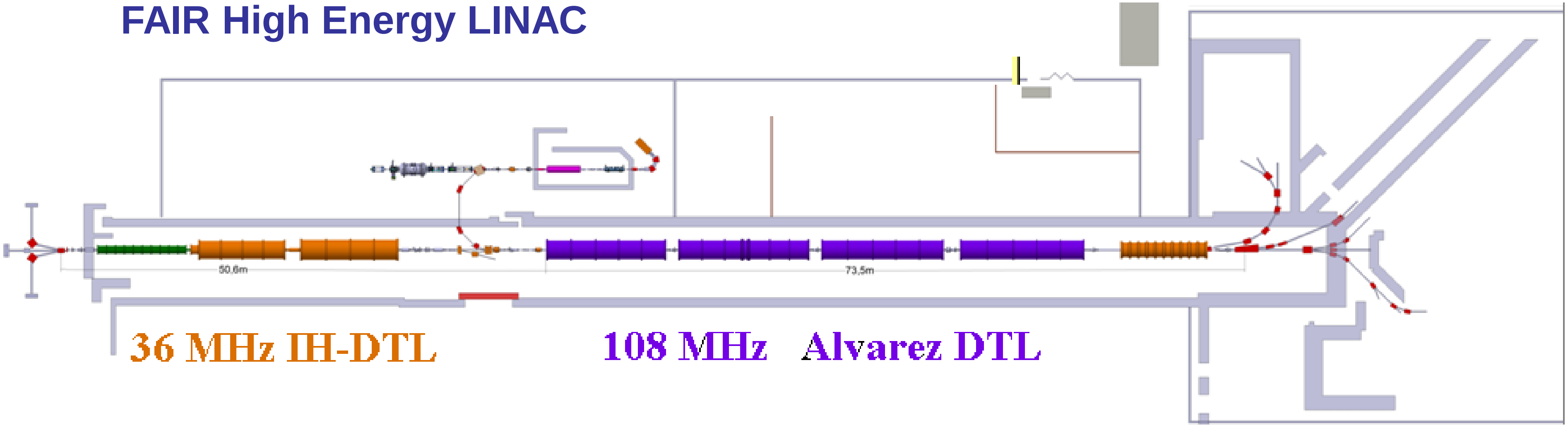


UNILAC Upgrade



UNILAC Upgrade

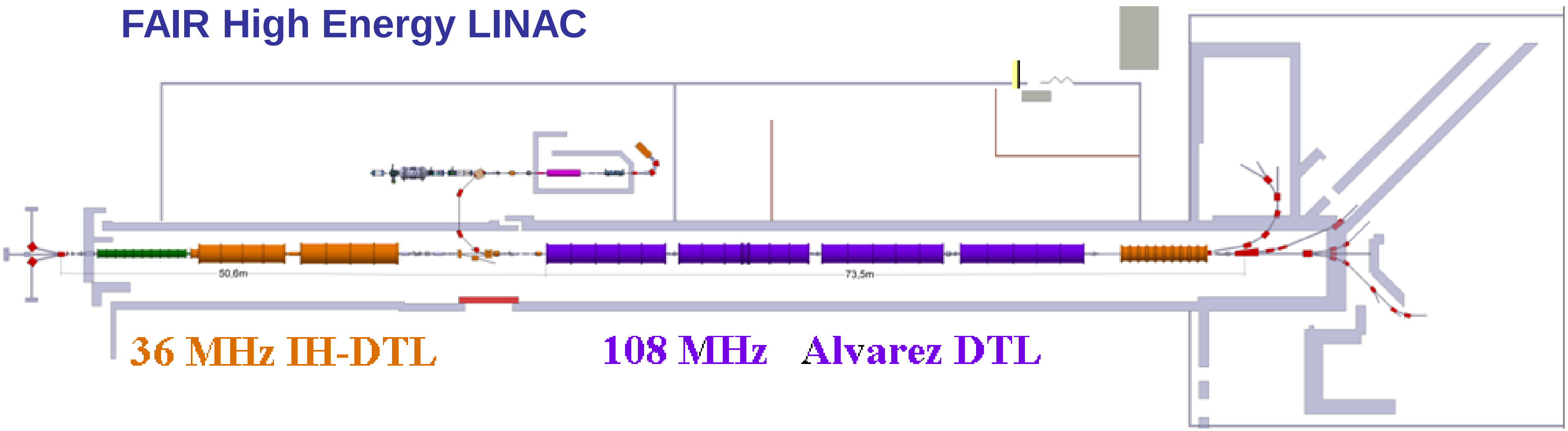
FAIR High Energy LINAC



STEP 1

- New HV Terminal and LEBT to achieve 20 mA for U^{28+} after the stripper

UNILAC Upgrade



STEP 1

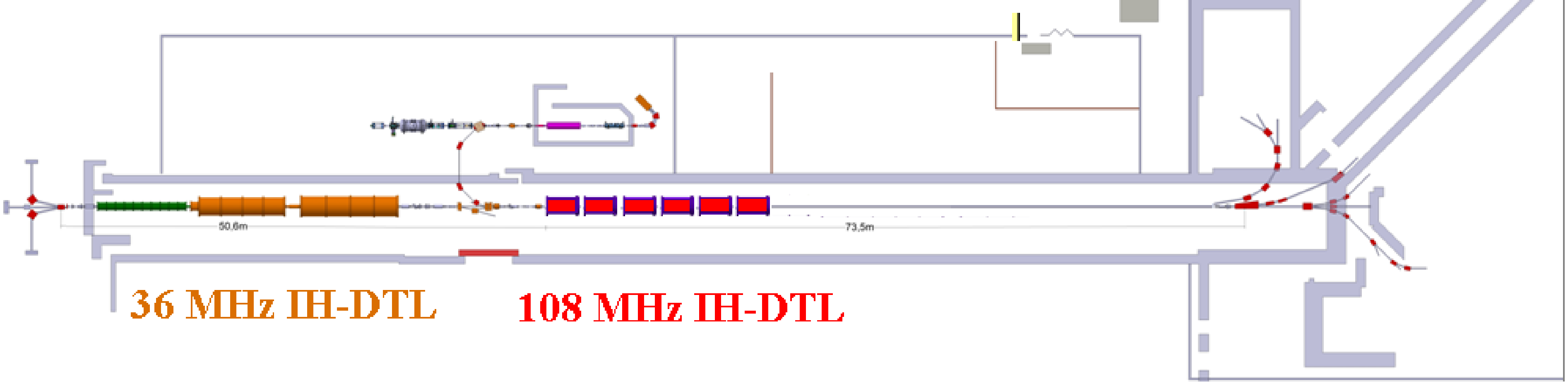
- New HV Terminal and LEBT to achieve 20 mA for U^{28+} after the stripper

STEP 2

- Replacement of the 90 MV DTL with 6 IH-DTL to 11.4 AMeV

UNILAC Upgrade

Present UNILAC
FAIR High Energy LINAC



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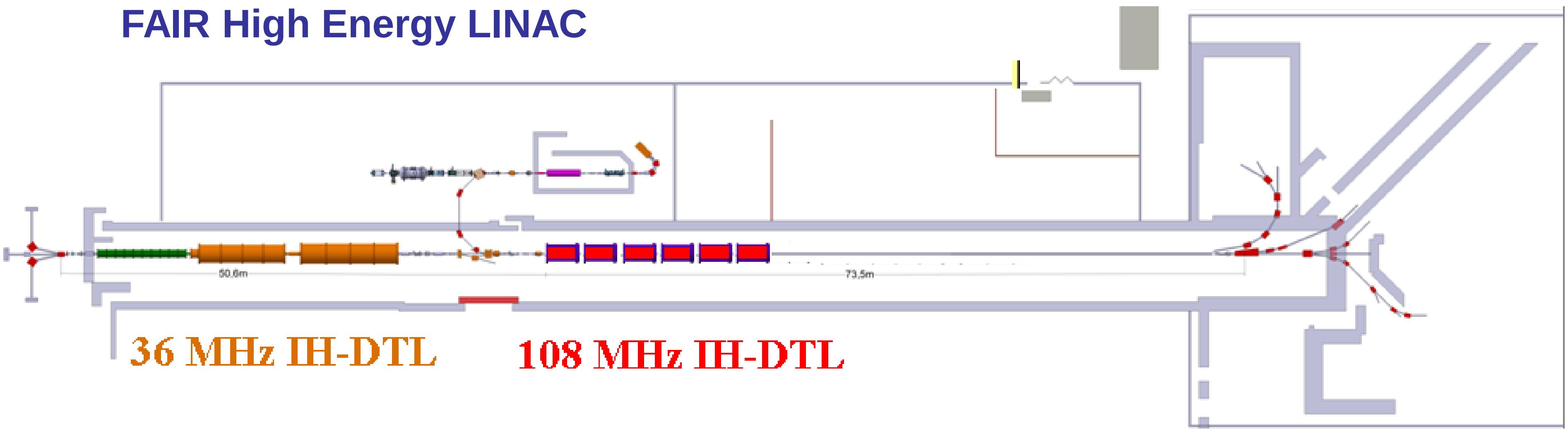

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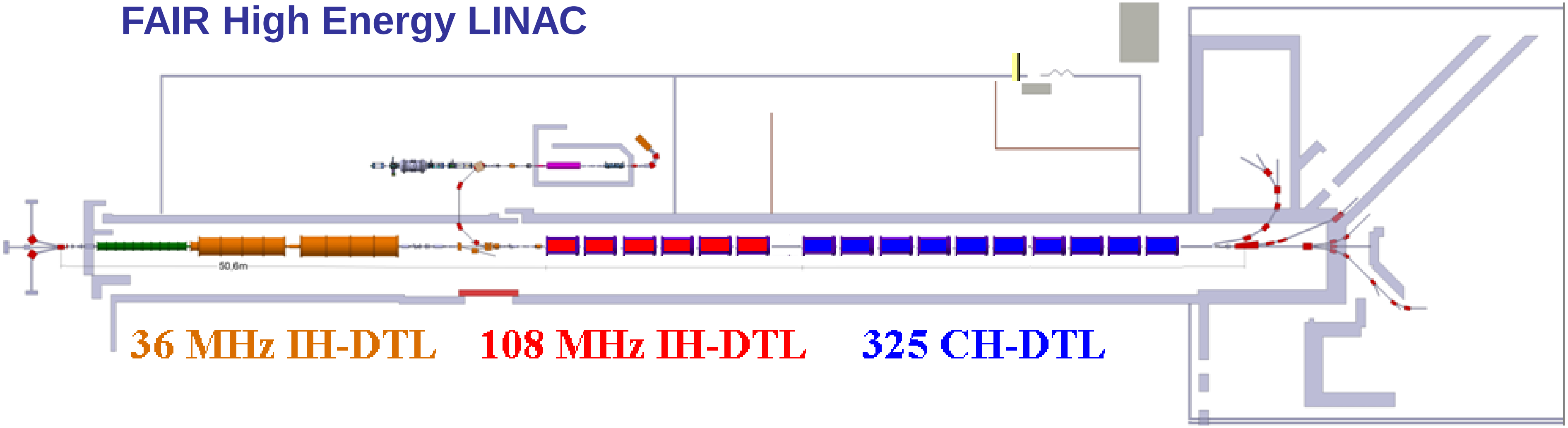
Optional

- Enough free space in tunnel for future energy upgrade

UNILAC Upgrade

FAIR High Energy LINAC



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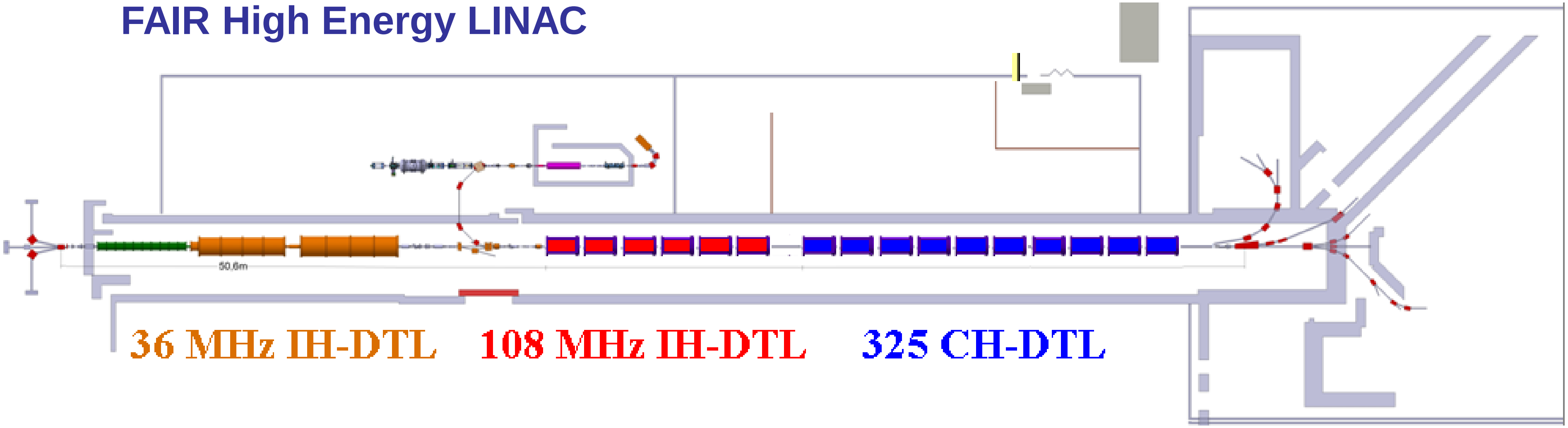

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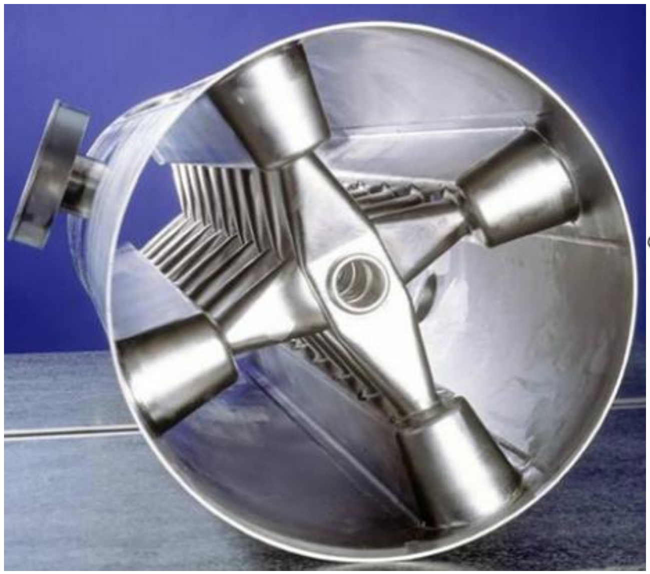
Design machine for Low Duty Factor

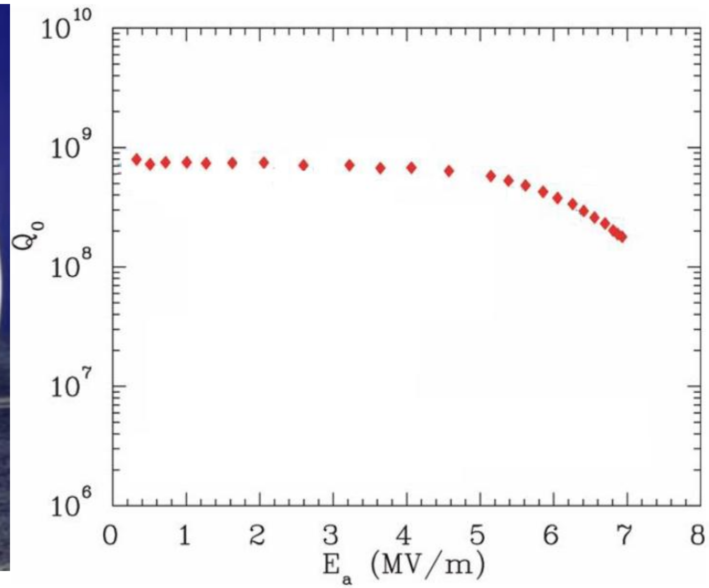
CW Heavy-Ion SHE-Linac at GSI

A cw LINAC is strongly requested from users in the SHE Program

At low energy, a cw LINAC made of multigap s.c. is the best solution

SUPERCONDUCTING CH-DTL



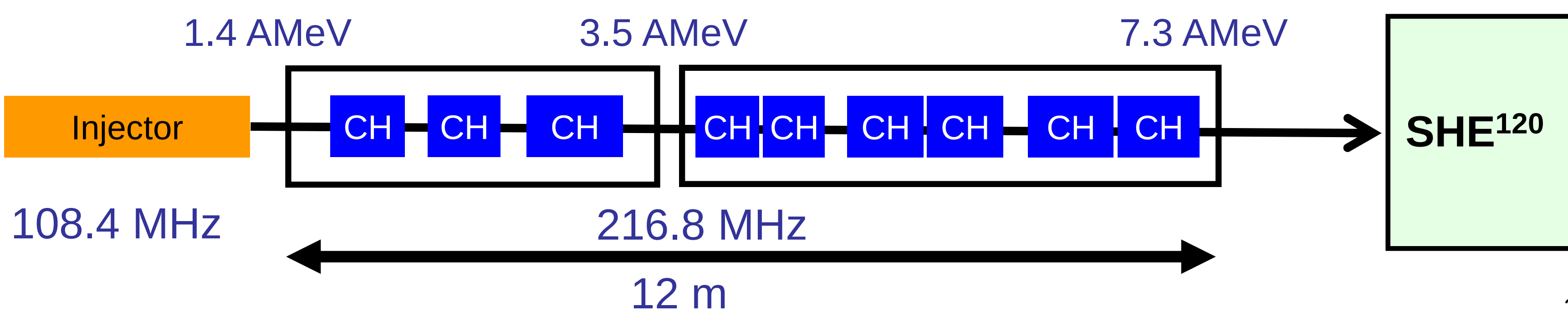


High estate gradient

Large energy gain/cavity

Less focusing elements

Related Oral Poster from H.Podlech on Thursday, THPB009 D. Maeder



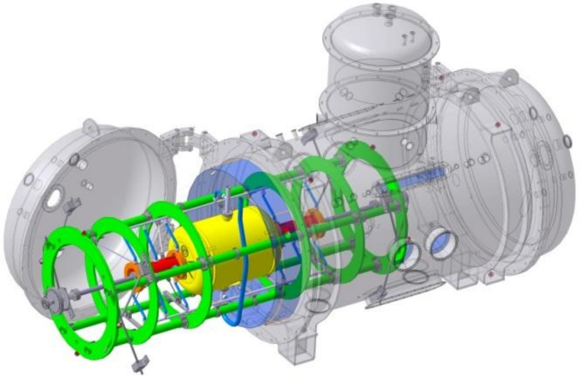
Demonstrator

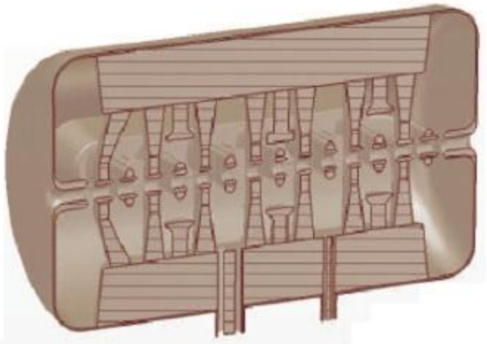
- **Stage 1: Upgrade of the existing HLI Injector**
  - A new 18GHz ECR ion source
  - A new CW 4-Rod RFQ
  - Status: under commissioning

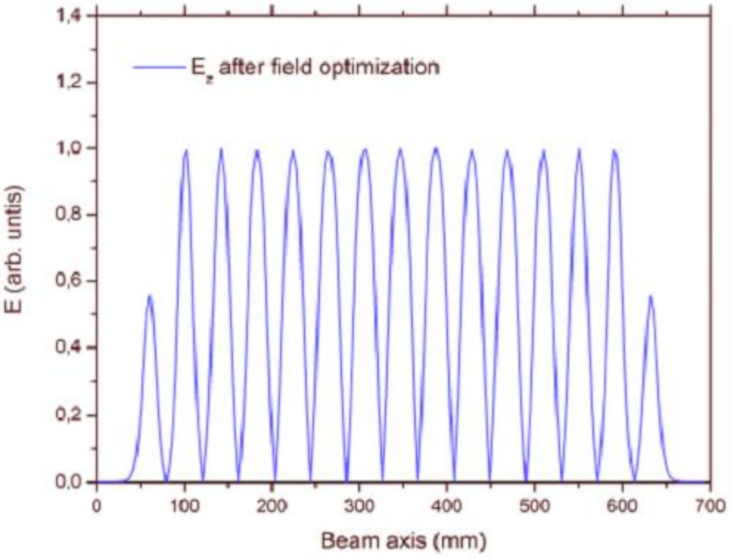
Related Oral Poster

THPB035 P. Gerhard

- **Stage 2: Construction of the first cryogenic module**
  - First CH-DTL, 2 s.c. Solenoids, Cryostat
  - Status: cavity under construction, cryostat ordered







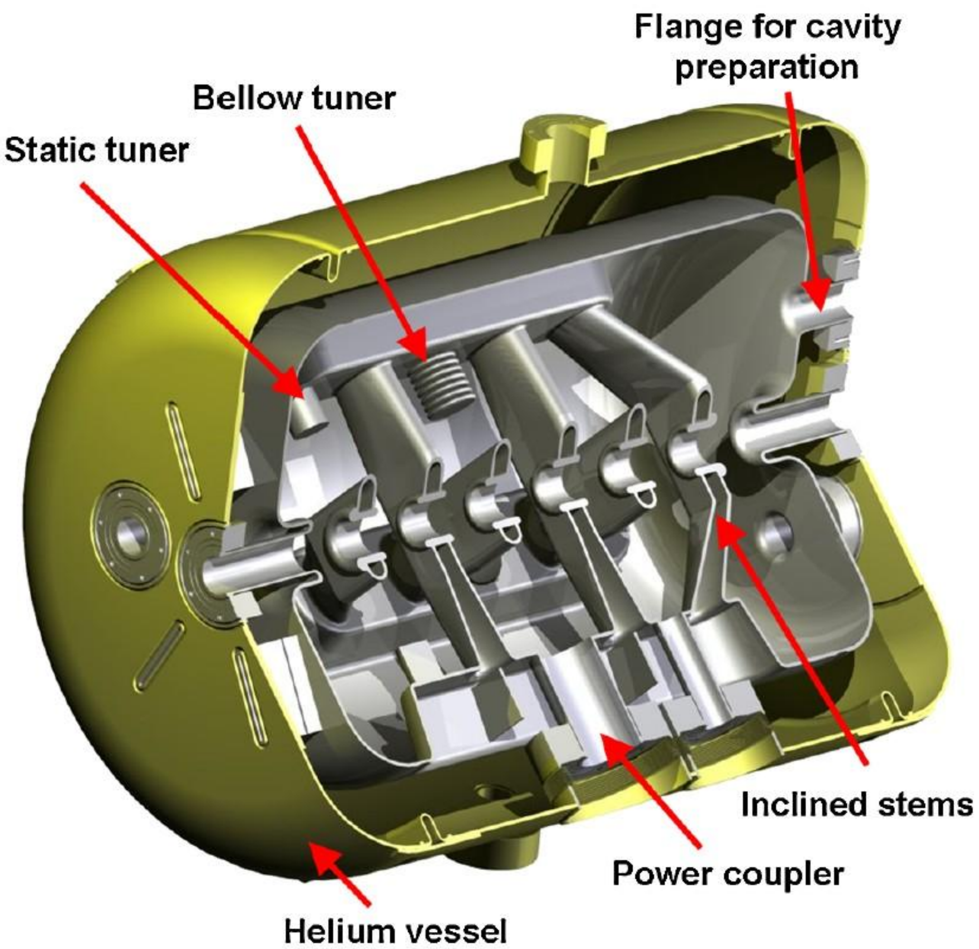
Gap	**15**
Gradient	**5.1 MV/m**
Length	**0.69 m**
Gap length	**40.8 mm**
Aperture	**20 mm**
Eff. Gap Voltage	**225 kV**

Related Poster:

TUPB074 W. Barth

SUPB071 F.Dziuba

SUPERCONDUCTING CH-DTL: General R&D at IAP Frankfurt



325 MHz, s.c. CH-DTL 5MV/m

- 7 equidistant gaps @ 11.4 AMeV
- Inclined stem to tune the end cell
- slow/fast bellow tuner
- Cavity under production!

Related Poster

TUPB071: M.Bush

Pulsed beam test planned behind the UNILAC

Summary

- **H-Mode cavities shows great potential in the low to medium β profile**
  - IH-DTL is established as standard solution for heavy ion
  - Innovative coupling scheme developed for lower betas
  - CH-DTL can become a valid alternative to classical E-Mode DTL
- **FAIR LINAC UPGRADE entirely based on IH-DTL and CH-DTL**
  - A new dedicated 70 MeV CH-DTL is under construction
  - A replacement of the 90 MV UNILAC DTL is under investigation
  - First s.c. 19 gaps CH-DTL built at IAP Frankfurt
  - A cw s.c. prototype LINAC under construction
  - A 325 MHz s.c. CH-DTL under construction.