Development of H-Mode Cavities for the FAIR Project

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IAP, Goethe University, Frankfurt am Main
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**

**EQUUS**

\[ \Delta z_c = \Delta \phi_c \beta_s \lambda / 2\pi \]

**APF**

- Periodic Beam Dynamics with Slim Permanent Magnet

Proposed as replacement for the LANSCE Linac

Extremely tight tolerances \( T = 200 \text{ T/m} \)

Reduced beam aperture
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**

Source: LEBT → RFQ → 3 CCH-DTL → 3 CH-DTL → to SIS18 → to Dump

| Source | Beam Energy (MeV) | Beam Current (mA) | Beam Pulse (µs) | Repetition Rate (Hz) | Frequency (MHz) | Norm. Emittance at output (µm) | Momentum Spread | Beam Loading (peak) (MW) | RF Power (peak) (MW) | Klystron (3 MW Peak Power) | Solid State Amplifier (50 kW) | Total Length (RFQ + CH) | Cavity | Energy (MeV) | Gaps | L (m) |
| LEBT | 95 keV | 3 MeV | 35 MeV | 70 MeV | 36 | 2.1 / 4.2 | ≤ ± 10⁻³ | 4.9 | 2.2 | 7 | 3 | ≈ 27 m | 1 | 3 - 12 | 22 | 1.7 |
| RFQ | 3 MeV | 35 - 70 | 36 | 4 | 325.224 | | | | | | | | 2 | 12 - 24 | 27 | 2.7 |
| 3 CCH-DTL | 35 MeV | | | | | | | | | | | | 3 | 24 - 37 | 32 | 4 |
| 3 CH-DTL | | | | | | | | | | | | | 4 | 37 - 48 | 20 | 2.9 |
| | | | | | | | | | | | | 5 | 48 - 59 | 21 | 3.1 |
| | | | | | | | | | | | | 6 | 59 - 70 | 21 | 3.4 |

**DTL Section consists in**
- 3 Coupled CH DTL
- 3 Standard CH-DTL

Related poster: THPB034 L. Groening
The Coupled CH-DTL

At lower $\beta$

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

Coupled structure at low beta!
## FAIR Prototype

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gap</td>
<td>27 (13+14)</td>
</tr>
<tr>
<td>Energy Range</td>
<td>11.7-24.3 MeV</td>
</tr>
<tr>
<td>$\beta$</td>
<td>0.15-0.22</td>
</tr>
<tr>
<td>$Q_0$</td>
<td>15300</td>
</tr>
<tr>
<td>Length (m)</td>
<td>2.7</td>
</tr>
<tr>
<td>$ZT^2$</td>
<td>60</td>
</tr>
<tr>
<td>RF Losses</td>
<td>1.37</td>
</tr>
<tr>
<td>Beam Loading</td>
<td>882 kW (at 70 mA, required 35)</td>
</tr>
<tr>
<td>Total Power</td>
<td>1.810 - 2.25 MW (2.7 Available)</td>
</tr>
</tbody>
</table>
FAIR Prototype

- **Cavity tuned at:** \(325.16\) against \(325.224\) MHz of operation
  - \(\varepsilon_{\text{air}} = 1.005\) \(f \propto \varepsilon^{1/2}\)
  - 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

Beam Envelope X-Z (mm)

Beam Axis (cm)

Beam Envelope Y-Z (mm)

Beam Axis (cm)

\[ \varepsilon_{nx}, \varepsilon_{ny} \text{ (mm mrad)} \]

Beam Current within norm. emittance (mA)
UNILAC
Universal Linear Accelerator
UNILAC
Universal Linear Accelerator
**UNILAC**

Universal Linear Accelerator

- **MUCIS, MEVVA**
- **LEBT**
- **HSI (RFQ, IH1, IH2)**
- **36 MHz**
- **Gas Stripper**
- **108 MHz**
- **HLI (ECR, RFQ, IH)**
- **108 MHz**
- **Poststripper (Alvarez, Cav.)**
- **Foil Stripper**
- **TK**
- **to SIS 18**

**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

- **MUCIS, MEVVA**
- **LEBT**
- **HSI** (RFQ, IH1, IH2)
- **36 MHz**
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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 ≤ 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!
Present UNILAC

36 MHz IH-DTL

108 MHz Alvarez DTL
UNILAC Upgrade

FAIR High Energy LINAC

36 MHz IH-DTL

108 MHz Alvarez DTL
STEP 1

- New HV Terminal and LEBT to achieve 20 mA for U^{28+} after the stripper
STEP 1

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STEP 2

- Replacement of the 90 MV DTL with 6 IH-DTL to 11.4 AMeV
STEP 1
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STEP 1
• New HV Terminal and LEBT to achieve 20 mA for $^{28}_U$ after the stripper

STEP 2
• Replacement of the 90 MV DTL with 6 IH-DTL to 11.4 AMeV

Optional
• Enough free space in tunnel for future energy upgrade
UNILAC Upgrade

FAIR High Energy LINAC

36 MHz IH-DTL  108 MHz IH-DTL  325 CH-DTL

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

Optional
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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

Optional

- Enough free space in tunnel for future energy upgrade

Design machine for Low Duty Factor
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

Injector
108.4 MHz
1.4 AMeV
3.5 AMeV
7.3 AMeV

216.8 MHz
12 m

SHE120
Demonstrator

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

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

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<tbody>
<tr>
<td>Gap</td>
<td>15</td>
</tr>
<tr>
<td>Gradient</td>
<td>5.1 MV/m</td>
</tr>
<tr>
<td>Length</td>
<td>0.69 m</td>
</tr>
<tr>
<td>Gap length</td>
<td>40.8 mm</td>
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<tr>
<td>Aperture</td>
<td>20 mm</td>
</tr>
<tr>
<td>Eff. Gap Voltage</td>
<td>225 kV</td>
</tr>
</tbody>
</table>

Related Oral Poster
**THPB035 P. Gerhard**

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 $\beta$ 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.