FREIA
Facility for Research Instrumentation and Accelerator Development

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Why FREIA?

Several circumstances

• test stand for RF systems needs large experiment space and bunker
• closure of CELSIUS and its hall
• university’s helium liquefier in need of replacement

University decides on new construction at the Ångström laboratory
Facility for Research Instrumentation and Accelerator Development

• Cryogenic centre (kryocentrum):
  - liquid helium and liquid nitrogen production and distribution
  - horizontal test cryostat

• RF test stands (ESS RF development)
  - 352 MHz RF source prototyping for ESS spoke cavities
  - spoke cryomodule prototyping and acceptance testing at full power

• General infrastructure
  - small workshop with “clean” room (preparation vacuum chambers)
  - control room for operation cryo plants, RF systems and experiments
  - concrete bunkers for RF and neutron experiment stations
Concentrating on RF and instrumentation ...

- Cyclotron (since 1948)
- CTF3 / CLIC
  - Two-beam Test Stand & RF breakdown issues
  - FP6-EuroTeV, FP7-EuCARD
  - NorduCLIC
- FEL
  - FLASH Optical Replica Synthesizer,
  - XFEL Laser Heater
  - Stockholm-Uppsala FEL Centrum
- ESS
  - RF systems
- single pass linear proton accelerator
  - 5 MW p+: 50 mA, 2.5 GeV, 14 Hz, 2.86 ms
  - < 1 W/m losses
  - 95% user beam time reliability
- ~200 RF systems (352 + 704 MHz)
  - NC or SC accelerating cavity
  - RF source, amplifiers, distribution, controls
- auxillary systems
  - cryogenics, water and air cooling
Why RF Development and Testing?

• **Validation technical design and performance**
  - validation under close-to-realistic conditions
  - ensure reliability & contingency
  - ease of installation & maintenance

• **Optimization technical design**
  - improve cost, energy and resource effectiveness for construction & operation

• **Acceptance testing of series components**
  - RF system: power source, amplifiers, distribution and controls
  - complete cryomodules with multiple cavities & components

• **Training of staff**
  - participate in testing to prepare for operation
Where do we fit in ...

### ESS Test Stand Matrix

<table>
<thead>
<tr>
<th>P0 Structures</th>
<th>f [MHz]</th>
<th>P [kW]</th>
<th>Pupg [kW]</th>
<th>cryo</th>
<th>prototype low power where when</th>
<th>high power where when</th>
<th>series low power where when</th>
<th>high power where when</th>
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<tbody>
<tr>
<td>ion source</td>
<td></td>
<td></td>
<td></td>
<td>--</td>
<td>LNS</td>
<td>LNS</td>
<td>on site</td>
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<tr>
<td>LEBT buncher</td>
<td>352</td>
<td>10</td>
<td></td>
<td>--</td>
<td>LNS ?</td>
<td>LNS ?</td>
<td>on site</td>
<td></td>
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<tr>
<td>RFQ</td>
<td>352</td>
<td>1000</td>
<td></td>
<td>--</td>
<td>CEA</td>
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<td>on site</td>
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<tr>
<td>MEET</td>
<td></td>
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<td>ESS-B ?</td>
<td>ESS-B ?</td>
<td>on site</td>
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<tr>
<td>DTL</td>
<td>352</td>
<td>2100</td>
<td></td>
<td>--</td>
<td>LNL</td>
<td>CERN</td>
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<tr>
<td>spoke resonators</td>
<td>352</td>
<td>400</td>
<td>800</td>
<td>y</td>
<td>IPNO</td>
<td><strong>UU</strong></td>
<td>UU ?</td>
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<tr>
<td>medium beta elliptical</td>
<td>704</td>
<td>500</td>
<td>1000</td>
<td>y</td>
<td>CEA ?</td>
<td>CEA ?</td>
<td>DESY ?</td>
<td>DESY ?</td>
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<tr>
<td>high beta elliptical</td>
<td>704</td>
<td>900</td>
<td>1800</td>
<td>y</td>
<td>CEA</td>
<td><strong>UU</strong></td>
<td><strong>UU</strong></td>
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<table>
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<tr>
<th>P1 Couplers</th>
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<td>spoke resonators</td>
<td>352</td>
<td>800</td>
<td>1600</td>
<td>--</td>
<td>IPNO</td>
<td>CEA</td>
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<tr>
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<td>704</td>
<td>650</td>
<td>1300</td>
<td>--</td>
<td>CEA ?</td>
<td><strong>UU</strong></td>
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<tr>
<td>high beta elliptical</td>
<td>704</td>
<td>1200</td>
<td>2500</td>
<td>--</td>
<td>CEA</td>
<td><strong>UU</strong></td>
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<td>--</td>
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<tr>
<td>modulator</td>
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<td>5600</td>
<td>--</td>
<td>--</td>
<td><strong>UU</strong></td>
<td>--</td>
<td>--</td>
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<tr>
<td>NC linac</td>
<td>1 mod. + 1 kl. + RFQ/DTL</td>
<td>352</td>
<td>2800</td>
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<td>--</td>
<td><strong>UU</strong></td>
<td>--</td>
<td>--</td>
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<tr>
<td>spoke</td>
<td>1 source (tbd) + 1 spoke</td>
<td>352</td>
<td>400</td>
<td>--</td>
<td>--</td>
<td><strong>UU</strong></td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>elliptical</td>
<td>1 mod. + 2 kl. + 2 cavities</td>
<td>704</td>
<td>1300</td>
<td>--</td>
<td>--</td>
<td><strong>UU</strong></td>
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<tr>
<th>P3 Cryomodule</th>
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<td>2 cavities</td>
<td>352</td>
<td>2x P2</td>
<td>y</td>
<td>IPNO</td>
<td><strong>IPNO/UU</strong></td>
<td><strong>UU</strong></td>
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<tr>
<td>SPL prototype</td>
<td>4 cavities</td>
<td>704</td>
<td>1x 1500</td>
<td>y</td>
<td>CERN</td>
<td>CERN</td>
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<tr>
<td>low beta elliptical</td>
<td>6 cavities</td>
<td>704</td>
<td>6xP2 or 1x5000</td>
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<td>DESY ?</td>
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<tr>
<td>high beta elliptical</td>
<td>8 cavities</td>
<td>704</td>
<td>8xP2 or 2x5000</td>
<td>y</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>DESY ?</td>
</tr>
</tbody>
</table>
What?

- 352 MHz RF system (WP8, WP19)
- 352 and 704 MHz RF distribution (WP8)
- Test prototype spoke at high power (WP19)
- Test prototype spoke cryomodule at high power (WP19)
- Later: acceptance testing spoke cryomodules
- Other options...
How?

1. space
   - 1000 m² FREIA hall, 500 m² at TSL
2. electricity, air conditioning, water cooling
3. cryogenic cooling (LHe)
4. radiation protection shielding (neutrons, X-rays)
5. specific test equipment
   - cryostat
   - RF power
6. people
FREIA ... how it will look like

- cryogenics
- bunkers
- air & water cooling
- cryostats
- cryogenics
FREIA ... the fine details

cryogenics bunkers
compressor area
cryostats
RF system
bunkers
cryogenics
Construction Progress

25 June 2012

14 May 2012

1 July 2013
FREIA Cryogenic Centre

• **Multiple users**
  - transport dewar filling station
  - horizontal test cryostat or ESS cryomodule
  - vertical test cryostat (future extension)

• **Helium liquefier**
  - ~100 l/h peak load at 4 K
  - ~2000 l storage dewar
  - ~8 g/s, 80 W peak load at 2 K

• **Helium recovery system**
  - 30 m³/h average
  - 50 m³/h peak load (minutes)

• **Liquid nitrogen**
  - helium liquefier pre-cooling
  - cryostat thermal radiation shield cooling
  - distribution to external users

supported by Wallenberg foundation

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FREIA Horizontal Test Cryostat

- internal volume (3.5 m x 1.1 m)
  - for 1 or 2 spoke or elliptical cavities
- operation temperature range 1.5 – 4.2 K
- based on existing designs
  - CHECHIA, CryoHoLab, HoBiCat

supported by Wallenberg foundation
**RF source development**

- 350 kW power amplifier
  - tetrode based: TH781
    - development new output cavity
    - confirm 352 MHz operation
    - short time to prototype
    - low capital cost
  - solid-state based: on ESRF work
    - development cavity combiner
    - development controls
    - 0.8 to 1.0 kW SSA (NXP, Freescale)
    - longer time to prototype
    - promises high reliability
    - promises fast MTTR

**Prototyping and soak testing**

- soak test with LLRF and water load
- then with SC spoke cavity

**External contributions**

- LLRF (Lund University)
- spoke cavity (IPN Orsay) incl. power coupler and tuner
FREIA Spoke Cryomodule Prototyping

- **Prototype complete RF system and cryomodule combination**
  - two power amplifiers and RF distribution (Uppsala University)
  - requires construction 2nd amplifier prototype
  - LLRF (Lund University)
  - cryomodule with two spoke resonators (IPN Orsay)
    - incl. power coupler and tuners
- **Study high power behaviour**
  - Lorenz force detuning, compensation by tuner
  - dynamic load, electron emission and multipactoring
  - LLRF controls, amplitude and phase stability
  - soak test

Peak fields @ 8 MV/m
- $E_{\text{surf}} = 35$ MV/m
- $B_{\text{surf}} = 56$ mT
Deformation 0.25 mm
Cryo loss = 15 W
Future ESS Development projects

**Spoke Cryomodule Testing**
- acceptance testing of production series before installation
- up to 36 cryomodules
- 6 to 8 weeks per module
  - installation
  - cooldown & cryo tests
  - full RF power tests
  - warm-up and remove

**Pulse Modulator Testing**
- soak testing of high voltage pulse modulators
- 3 models from 3 companies
- validation of design, technical specifications and reliability
- will determine choice for series production by 2 companies
- most expensive single part of 704 MHz RF system, total need ~100 modulator for 200 klystrons
- similar tests to be foreseen for klystron, circulator, load, ...
**Possible other Future Projects**

**SIGURD**

**Set-up and Instrumentation for GHz Research and Development**

**RF breakdown research**
- high gradient normal conducting accelerators
- RF breakdown pattern, rate, relation to gradient, memory effects
- pulse heating, plasma formation, dark currents, breakdown currents
- link to theory developments (Helsinki University)
- post-mortem analysis of structures in SEM at Microstructure Lab.

**Neutron Generator**

**Access to neutron**
- neutron tomography and detector tests
- student exercises and projects
- physics experiments in combination with Ge gamma-detector
  - nuclear fission
  - activation analysis

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Summary

- FREIA is building a bridge between fundamental scientific research and applied physics and scientific instrumentation.
- FREIA RF development project enables construction of ESS for material science research, also by Uppsala scientists.
- FREIA will host an enlarged Cryo Centre.
- FREIA opens new opportunities for unique scientific projects in Uppsala.

Thanks to university, faculty, physics & astronomy department and the FREIA team.

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