UPPSALA UNIVERSITET

FREIA

ESS Spoke RF Source
Introduction: Overview and Context

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for the FREIA Team

Review ESS Spoke RF Source

11 – 12 December 2012

Concentrating on RF and instrumentation …

- Cyclotron (since 1948)
- CELSIUS ring (1984 – 2006)
- CTF3 / CLIC
  - Two-beam Test Stand & RF breakdown issues
  - FP6-EuroTeV, FP7-EuCARD
  - NorduCLIC

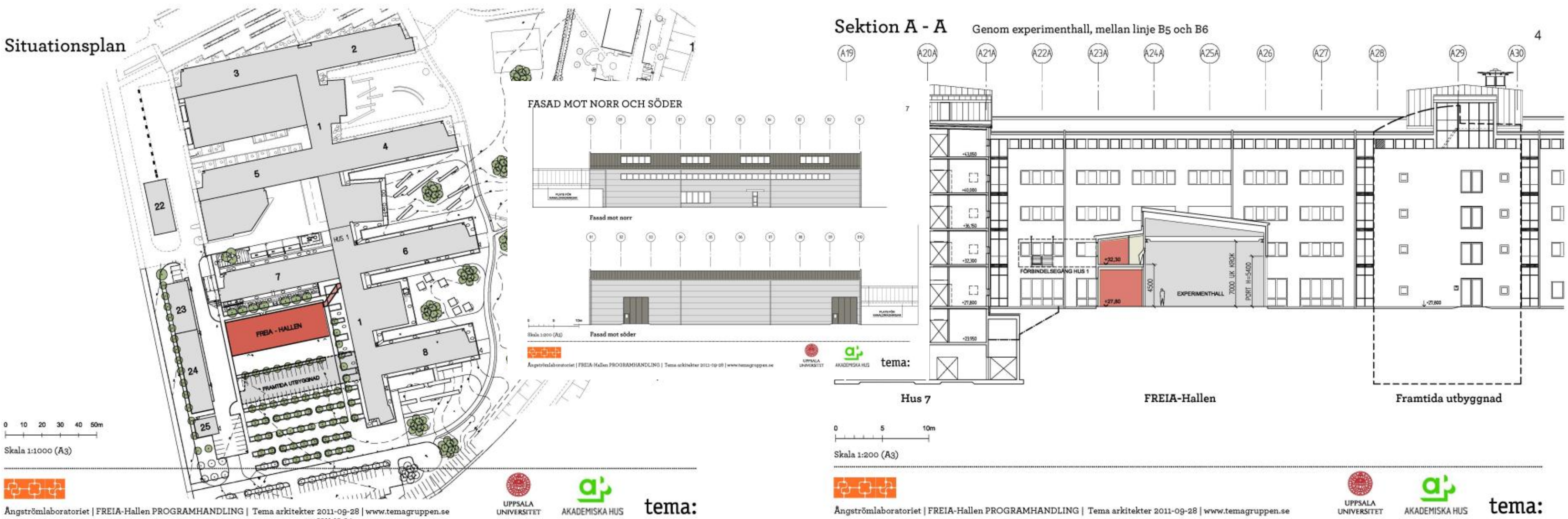
- FEL
  - FLASH Optical Replica Synthesizer,
  - XFEL Laser Heater
  - Stockholm-Uppsala FEL Centrum
- ESS
  - RF systems
- FP7-TIARA

Why FREIA?

Several circumstances

- test stand for RF systems needs large experiment space and bunker
- university’s helium liquefier in need of replacement

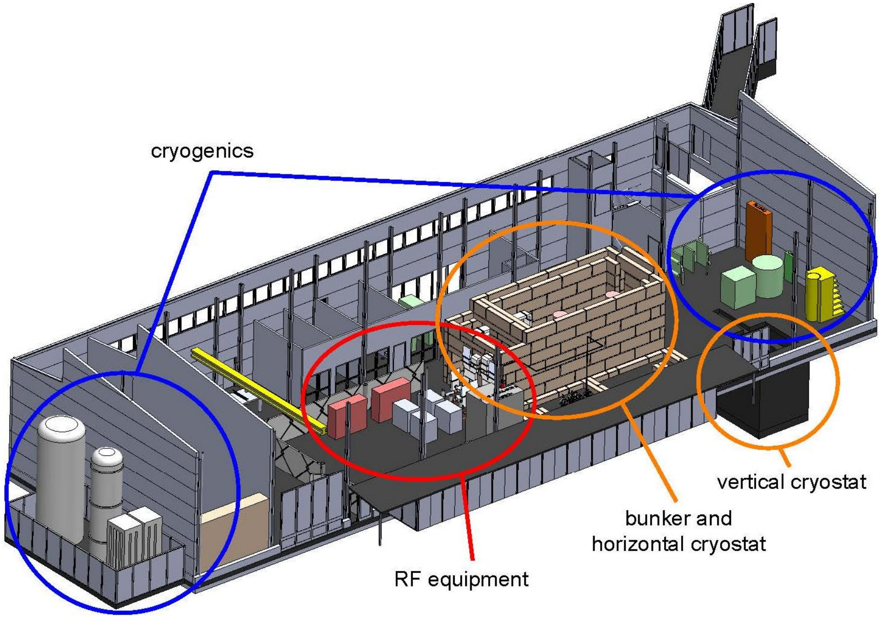
University decides on new construction at the Ångström laboratory



What FREIA?

Facility for Research Instrumentation and Accelerator Development

- General Infrastructure
  - LHe and LN2 production and distribution
  - small workshop, control room
  - concrete bunkers
- RF test stands
  - 352 MHz RF source for ESS spoke cavities
  - horizontal test cryostat (vertical in future)
- Neutron generator
  - neutron tomography, detector tests
  - student exercises and projects

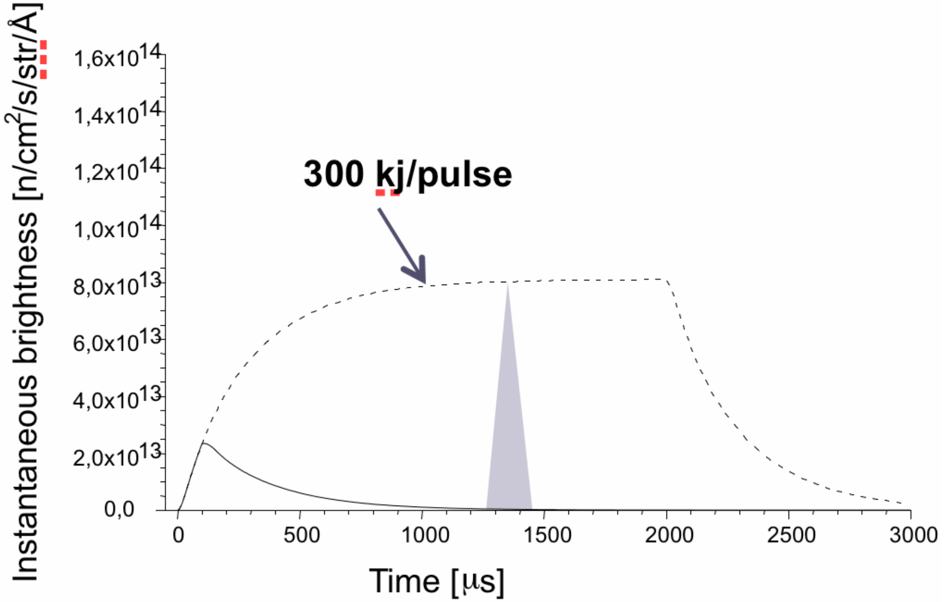


Why ESS?

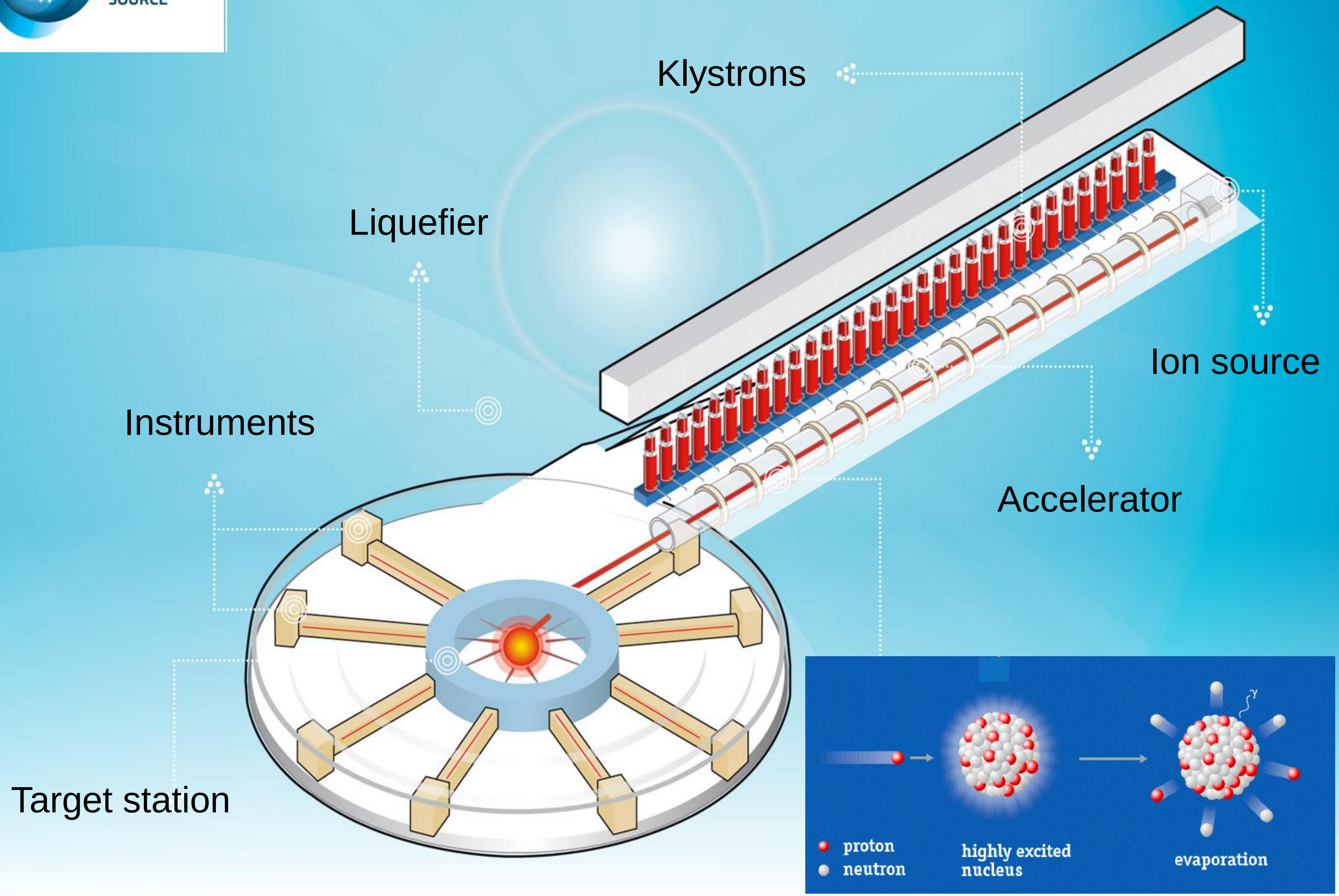
- Many research reactors in Europe are aging & will close before 2020
  - Up to 90% of their use is with **cold neutrons** (<0.025 MeV)
- There is a urgent need for a new high flux **cold neutron** source
  - Most users are fully satisfied by a **long pulse** source
  - Existing **short pulse** sources (ISIS, JPARC, SNS) can supply the present and imminent future need of short pulse users

"Pulsed cold neutrons will always be long pulsed as a result of the moderation process"

F. Mezei, NIM A, 2006

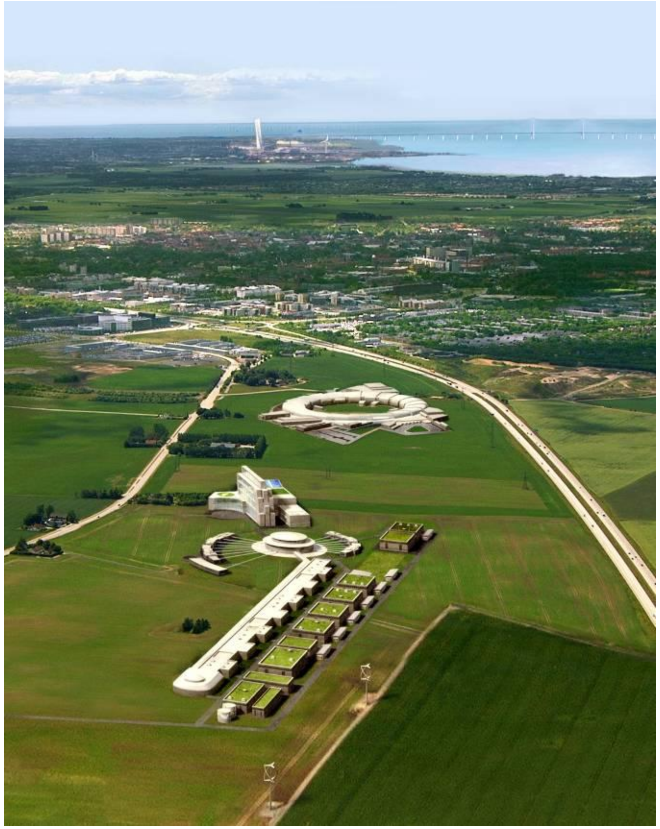


How ESS?


Klystrons
Liquefier
Ion source
Instruments
Accelerator
Target station
proton
neutron
highly excited nucleus
evaporation

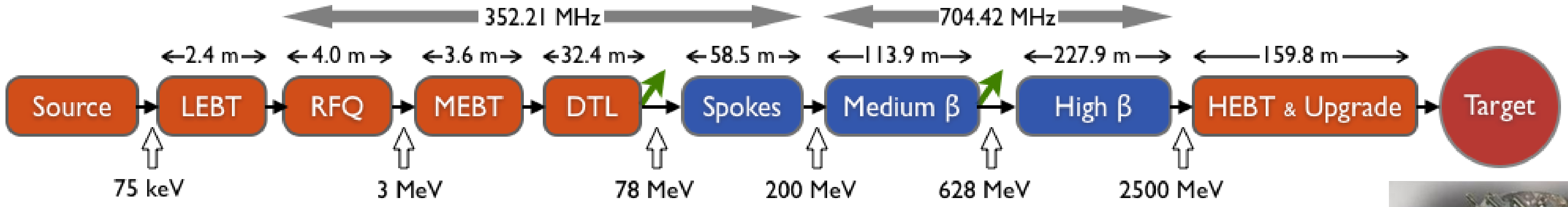
The European Spallation Source (ESS)

- Lund, Sweden, next to MAX-IV
  - 17 member states
- 5 MW pulsed neutron source
  - 14 Hz rep. rate, 4% duty factor
  - >95% reliability for user time
- Cost estimates (2008 prices)
  - 1,5 G€ / 10 years
  - 50% by Sweden, Denmark, Norway
- Time frame:
  - 2019 first neutrons
  - 2019 – 2025 consolidation and operation
  - 2025 – 2040 operation

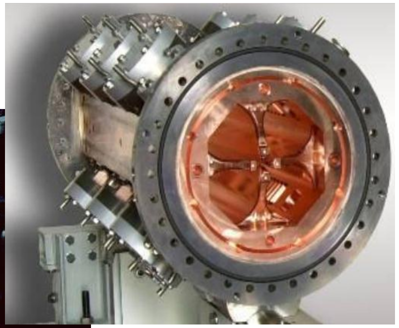


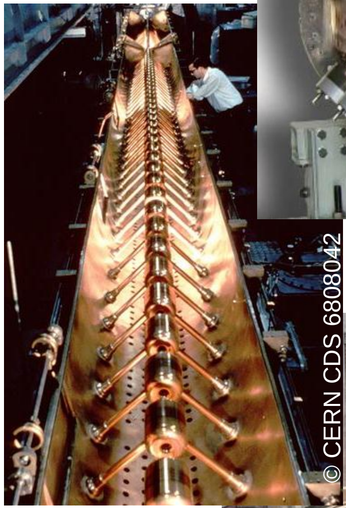
- High intensity allows studies of
  - complex materials, weak signals, time dependent phenomena

The ESS Accelerator



- 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
- normal conducting (room temperature)
  - electron cyclotron resonance source (ECR)
  - radio-frequency quadrupole (RFQ)
  - drift tube linac (DTL)
- superconducting (liquid helium temperature)
  - double spoke resonators (DSR)
    with high velocity acceptance
  - elliptical cavities





ESS-UU Collaboration

- **2009**
  - ESS has need for R&D and test stand,
    - but small staff, no buildings, existing test stands occupied
  - start discussion with UU on 704 MHz RF development
  - proposal for ESS dedicated test facility at UU
- **2011**
  - Spring:
    - ESS-UU contract on 704 MHz RF R&D
    - ESS changes to 14 Hz rep rate, 2.89 ms beam pulse
  - Fall:
    - ESS changes pulse modulator strategy → delays UU test stand
- **2012**
  - UU starts work on 352 MHz RF for spoke resonators
    - spoke resonators require new power source development
    - spoke resonators have never been used in an accelerator
  - and prepare for cryomodule testing (prototype and final)

Where do we fit in…

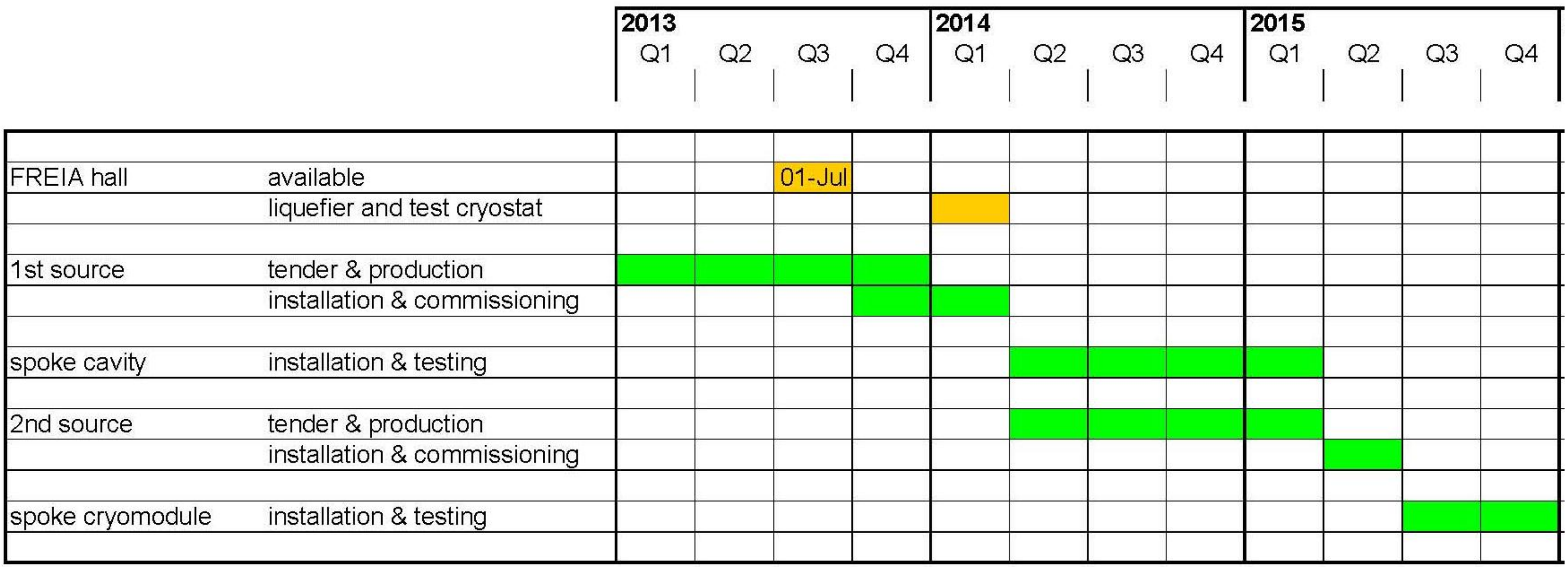
ESS Test Stand Matrix			f	P	Pupg	cryo	prototype				series			
							low power		high power		low power		high power	
			[MHz]	[kW]	[kW]		where	when	where	when	where	when	where	when
P0	**Structures**													
	ion source		--	--	--	--	LNS		LNS				on site	
	LEBT buncher		352	10		--	LNS ?		LNS ?				on site	
	RFQ		352	1000		--	CEA		CEA				on site	
	MEBT		--	--	--	--	ESS-B ?		ESS-B ?				on site	
	DTL		352	2100		--	LNL		CERN (Linac4)				on site	
	spoke resonators		352	240	800	y	IPNO		**UU**		??		--	
	medium beta elliptical		704	500	1000	y	CEA ?		CEA ?		DESY ?		--	
	high beta elliptical		704	900	1800	y	CEA		CEA ?		DESY ?		--	
P1	**Couplers**													
	spoke resonators		352	800	1600	--	IPNO		CEA		??		??	
	medium beta elliptical		704	650	1300	--	CEA ?		CEA ?		??		??	
	high beta elliptical		704	1200	2500	--	CEA		CEA ?		??		??	
P2	**RF System**													
	modulator		--	5600		--	--	--	ESS		--		ESS	
	NC linac		352	2800		--	--	--	ESS		--		ESS	
	spoke		352	300		--	--	--	**UU**		--		ESS	
	elliptical		704	1300		--	--	--	ESS		--		ESS	
P3	**Cryomodule**													
	spoke	2 cavities	352	2x 300		y	IPNO		**UU**		??		**UU ?**	
	SPL prototype	4 cavities	704	1x 1500		y	CERN		CERN		--		--	
	ESS prototype	4 cavities	704	? ? ?		y	CEA		CEA		--		--	
	low beta elliptical	6 cavities	704	6x650		y	--	--	--	--	ESS		ESS	
	high beta elliptical	8 cavities	704	8x1200		y	--	--	--	--	ESS		ESS	

UU Responsibility for ESS Accelerator

1) **Contribution to the Technical Design Report**
   - design concept 352 MHz spoke source
   - design concept RF distribution
2) **Contribution to the construction planning effort**
   - survey test stand infrastructure and requirements
   - study of upgrade scenarios RF systems for ESS power upgrade
3) **Development 352 MHz RF power source for spokes**
   - 1st prototype, soak test with water load and SRF spoke resonator, incl. LLRF
4) **System test prototype spoke cavity**
   - high power test fully dressed cavity (in test cryostat)
5) **System test prototype spoke cryomodule**
   - high power test complete prototype spoke cryomodule (2 cavities)
6) **Acceptance testing spoke cryomodules (under discussion)**
   - for all final cryomodules before installation

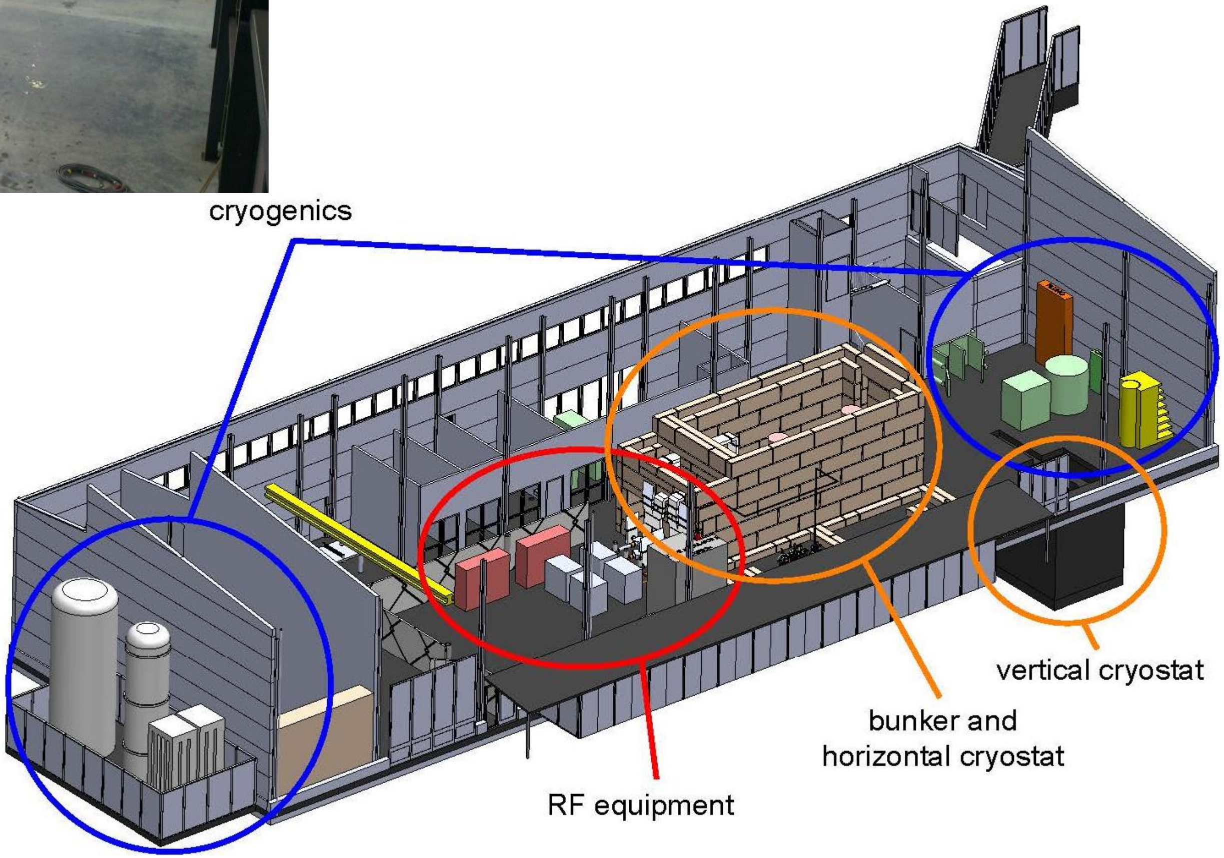
Planning Time Line

- 2016: start tendering for construction
- 2015: results of prototype cavity must be available
- 2014: FREIA infrastructure and RF source must be available



Construction Progress

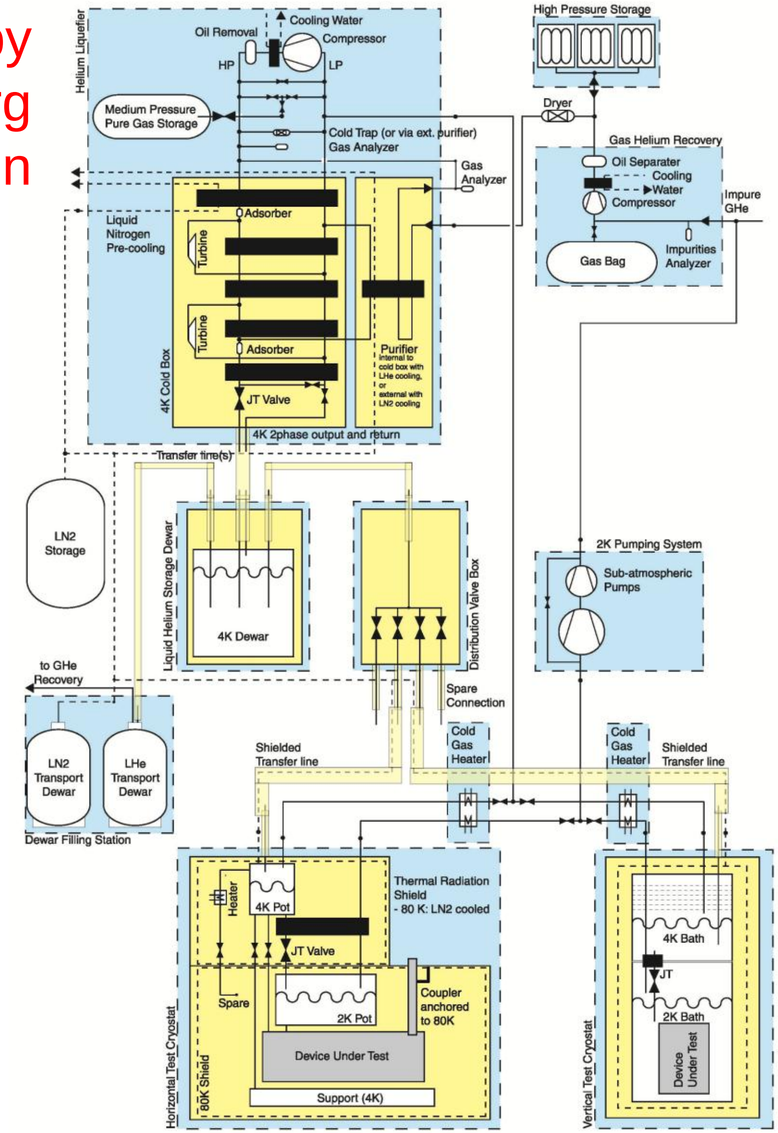
Inside the Hall



FREIA Cryogenic Centre

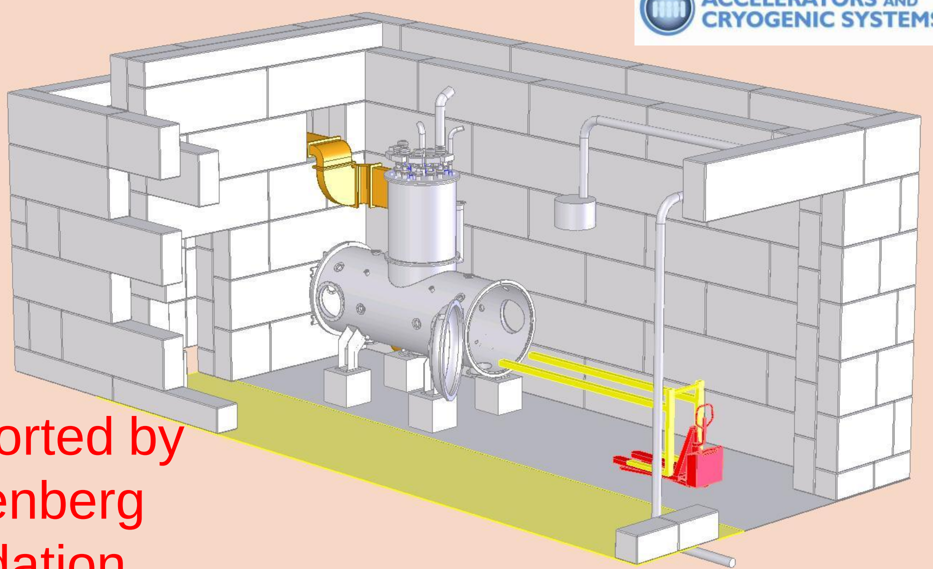
supported by Wallenberg foundation

- **Multiple users**
  - transport dewar filling station
  - horizontal test cryostat
    or ESS cryomodule
  - vertical test cryostat (future extension)
- **Helium liquefier**
  - 140 l/h peak load at 4 K
  - 2000 l storage dewar
  - ~8 g/s, 80 W peak load at 2 K
- **Helium recovery system**
  - 80 m3/h average
  - 100 m3 gas balloon
- **Liquid nitrogen**
  - helium liquefier pre-cooling
  - cryostat thermal radiation shield cooling
  - distribution to external users



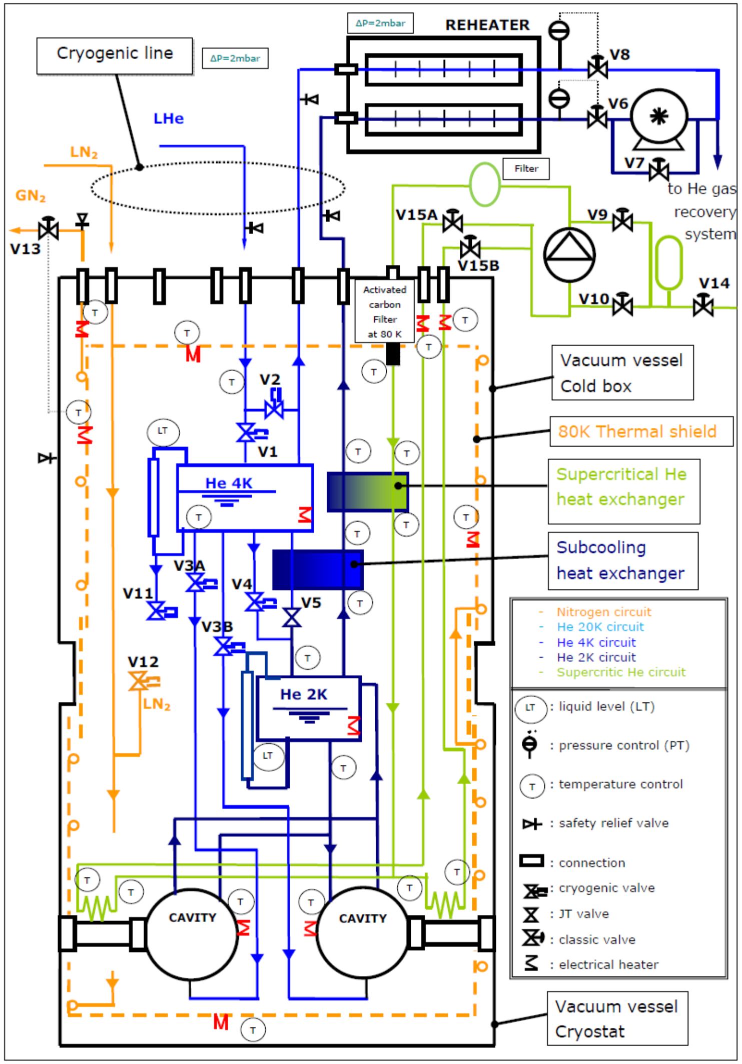
FREIA Horizontal Test Cryostat

- internal volume (3.5 m x Φ 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



ACCELERATORS AND CRYOGENIC SYSTEMS

supported by Wallenberg foundation



ESS Spoke Testing

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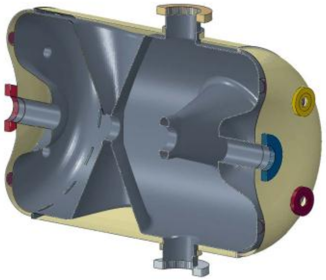
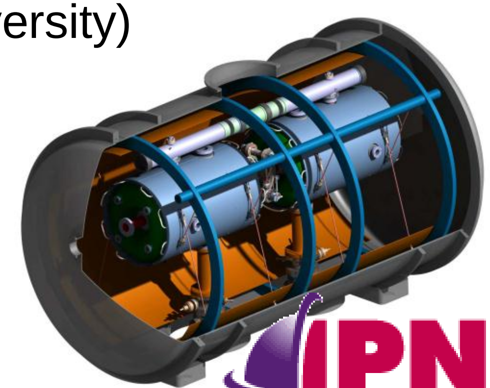
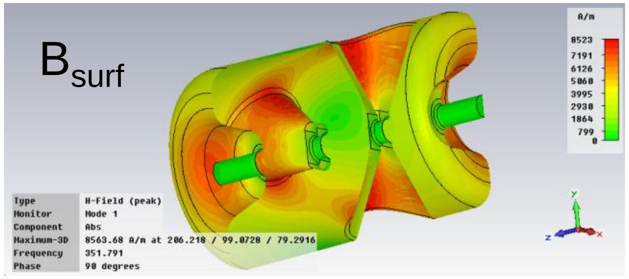
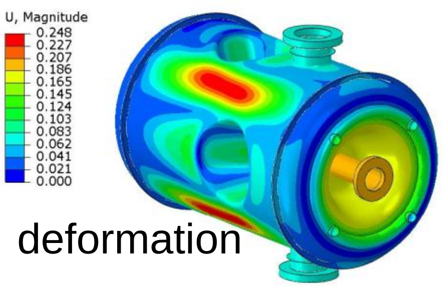


- **Prototype spoke cavity**
  - one power amplifier and RF distribution (UU)
  - fully dressed cavity (IPNO) in test cryostat (UU)
- **Prototype spoke cryomodule**
  - two power amplifiers and RF distribution (Uppsala University)
  - LLRF (Lund University)
  - cryomodule with two spoke resonators (IPN Orsay)
- **Study high power behaviour**
  - Lorenz force detuning, compensation by tuner
  - dynamic load, electron emission and multipactoring
  - LLRF controls, amplitude and phase stability
  - soak test



IPN INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY





deformation

Peak fields @ 8 MV/m
- E_{surf} = 35 MV/m
- B_{surf} = 56 mT

Deformation 0.25 mm

Cryo loss = 15 W

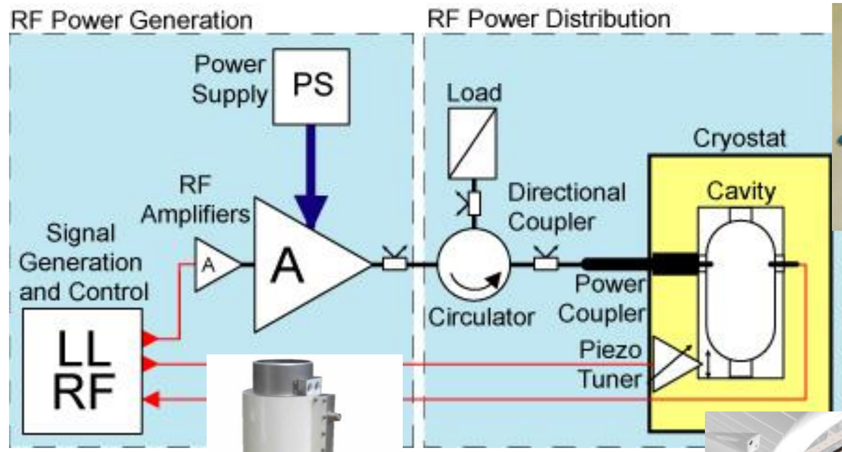
FREIA 352 MHz RF Source

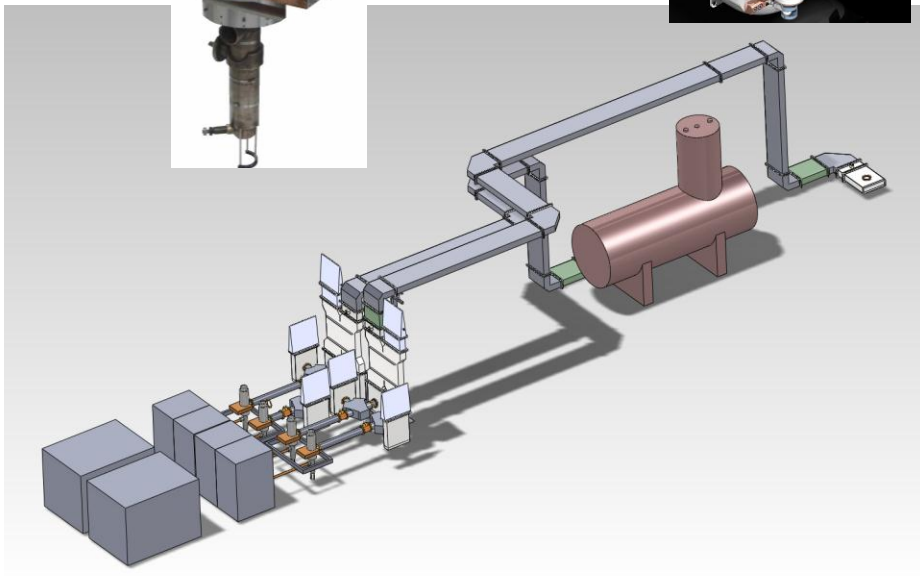
RF source development

- 300 kW power amplifier
  - for FREIA testing (1~2pc)
  - for ESS linac (28pc)

- tetrode based: 2xTH595
  - available solution
  - confirmed 352 MHz, 200 kW, 4.6% DF
  - fall-back for ESS power source
  - low capital cost

- solid-state based:
  - no commercial available solution
  - development required
    (collaboration with FP7-CRISP)
  - promises high reliability, fast MTTR





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Spoke RF Source Requirements

Frequency	352.21	MHz
Repetition rate	14	Hz
Beam pulse length	2.86	ms
RF pulse length	3.5	ms
Power to beam, max.	240	kW
Power to cavity, max.	270	kW
Power overhead for control	15	%
Power overhead for losses in distribution	5	%
Power output amplifier	300	kW
Bandwidth at 3 dB	>250	kHz

Summary

- FREIA will
  - test RF spokes for ESS
  - develop spoke RF source for test and ESS linac
- 1st prototype spoke cavity to arrive mid-2014
  - RF source and infrastructure must be available beforehand
- Review of spoke RF source
  - chosen tetrode solution for FREIA source and ESS fall-back
  - working on solid-state development
    - possible 2nd source for cryomodule testing
    - alternative for ESS linac