352MHZ SOURCE AND PLANS FOR FULL POWER TESTING OF PROTOTYPE SPOKE CRYOMODULE

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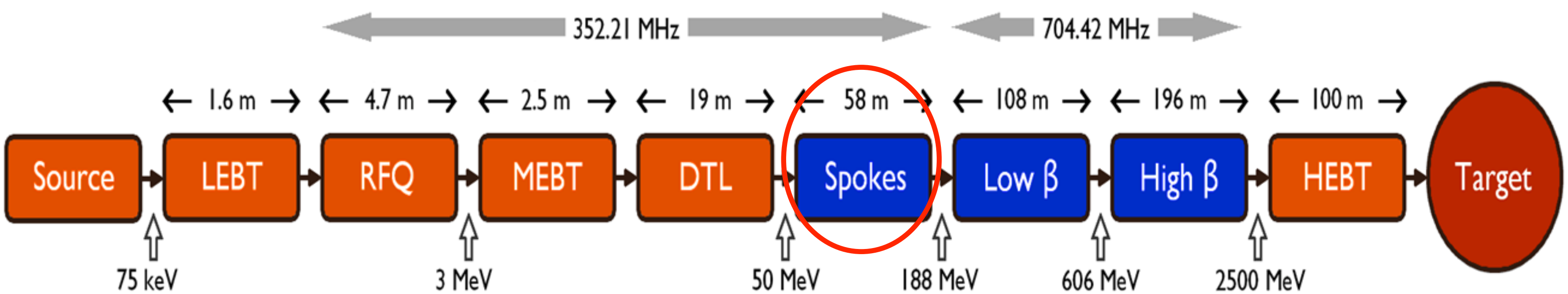
Summary

- Introduction
- FREIA Hall at Uppsala
- Importance of selection of RF source
- Selection of Tetrode as driver for spoke cavities. Why ?
- Selection of Solid state amplifier as predriver. Why ?
- Selection of half height WR2300 for RF distribution. Why ?
- System layout for full power testing of cryomodule.
- Schedule for testing.

European Spallation Source (ESS): world's most powerful neutron source
ESS linac will accelerate 50 mA beam of protons to 2.5 GeV

Specifications of superconducting 5 MW proton linac:
Pulse Length = 2.86 ms
Pulse Rate = 14 Hz
Beam Current = 50 mA
Energy = 2.5 GeV



Schematic of ESS linac

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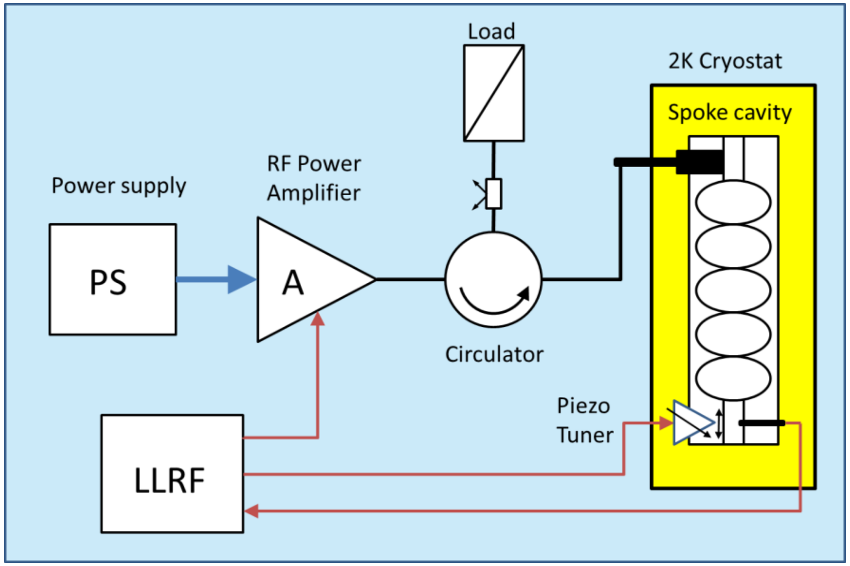
The baseline design for the RF system: Generation and distribution of the RF power from a single source to a single accelerating cavity[

The spokes section contains 36 superconducting spoke resonators at 352 MHz



Basic layout of an RF system.

Requirements of RF source

Maximum RF power for a spoke resonator = 245 kW

Considering LLRF overhead = 25%
RF loss in distribution system = 5%,
Power of RF source = 320 kW

Beam pulse width = 2.86 ms, repetition rate = 14 Hz, fill time of the cavity = 600 μs
duty factor of the amplifier = 4.9%

spoke cavity band-width ≈ 2 kHz
system band-width ≈ 100 times larger than spoke resonator band-width for tuning and regulation delay.
3 dB bandwidth > 200 kHz.

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Specifications of Spoke RF amplifier:

Frequency = 352.21 MHz
Power = 350 kW
Band-width = 200 kHz.
Pulse width = 3.5 ms
Pulse repetition rate = 14 Hz

No RF source exist at ESS specifications !

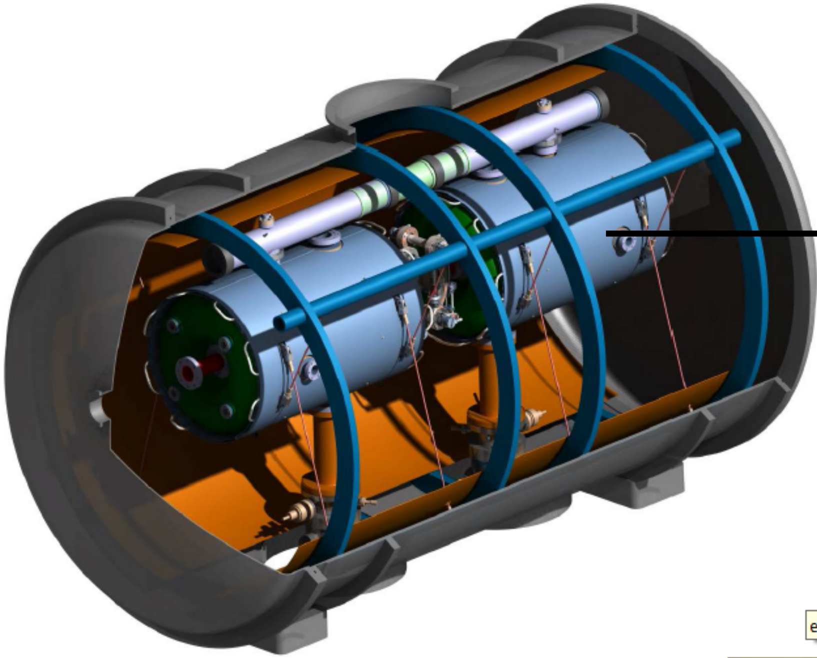
CPI

THALES

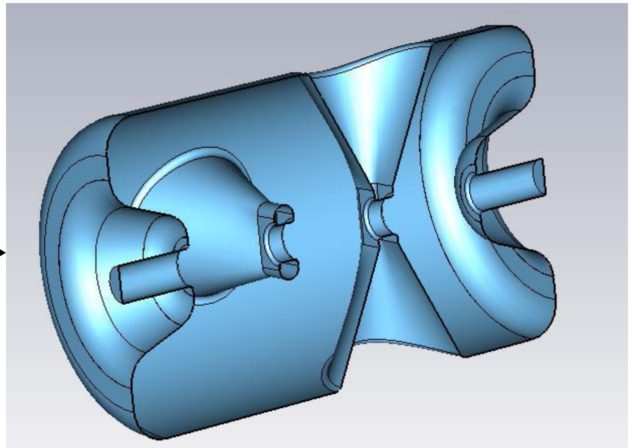
RF Source ?

BRUKER

Spoke Cryostat



New design being developed at IPN Orsay

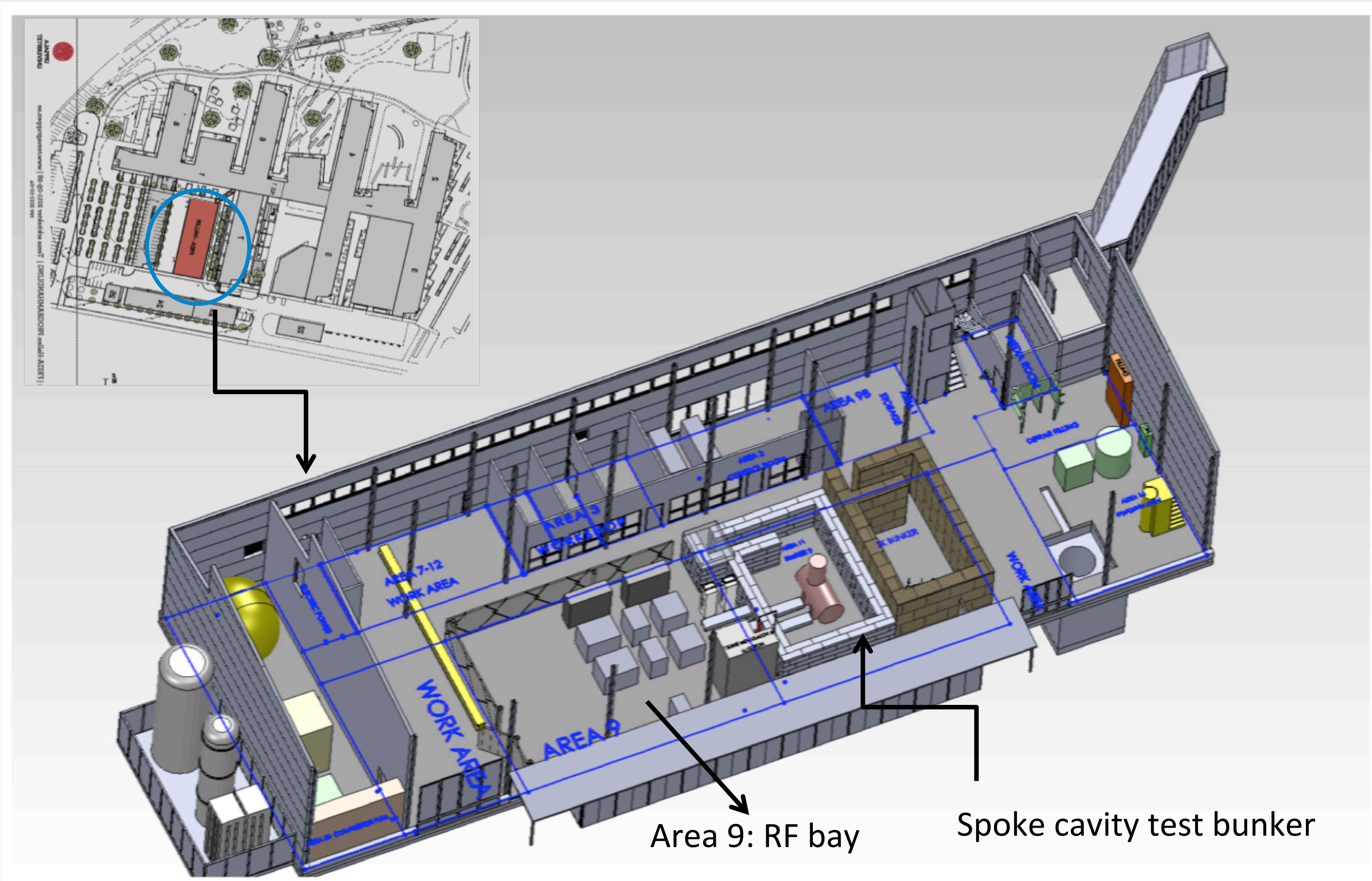


Power coupler

High power testing ?

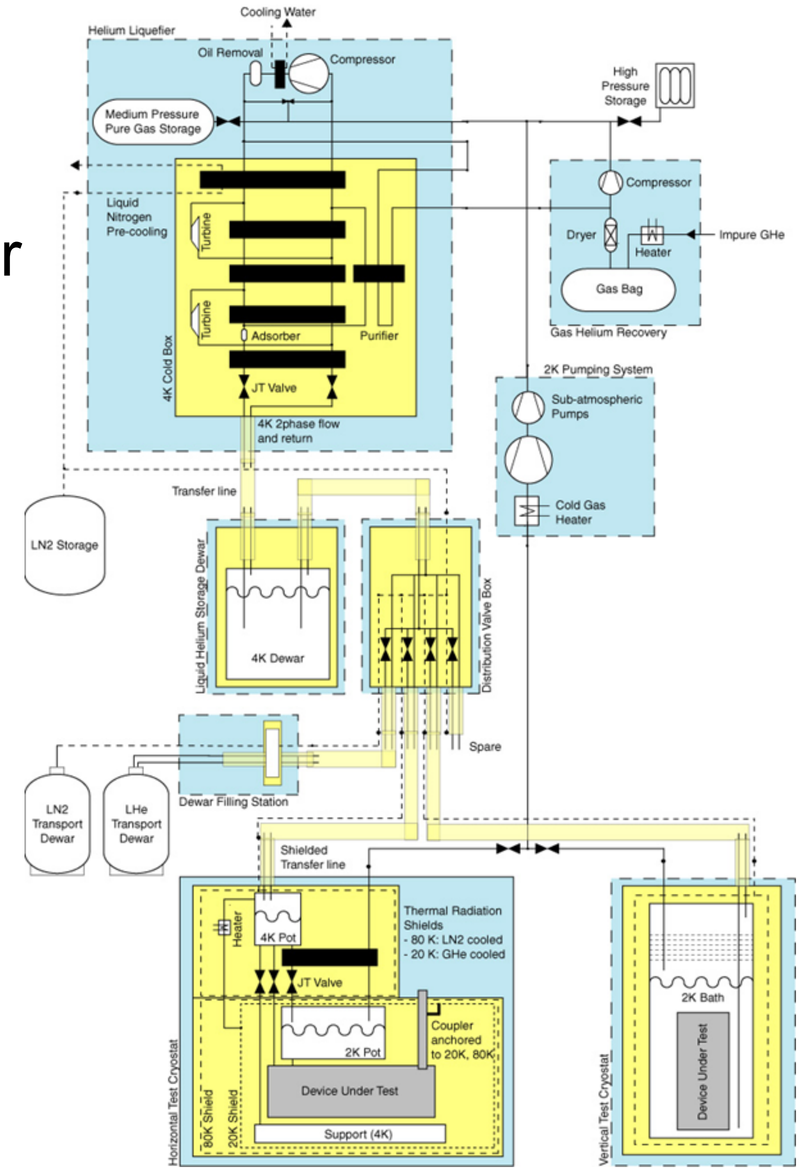
FREIA

(Facility for Research Instrumentation and Acelerator Development) at Uppsala University



Features of FREIA

- ❖1000 m² hall
- ❖Electrical input power = 1.2MW
- ❖Cooling capacity = 800kW power
- ❖Helium liquefier (>70 l/h) with LN2 pre-cooling
- ❖Distribution box to users
- ❖Impure gas recovery from users
- ❖RF amplifiers (two chains): 352 MHz, 350kW
- ❖RF Distribution system
- ❖Test cryostat vertical and horizontal
- ❖Test bunkers



Importance of selection of RF source

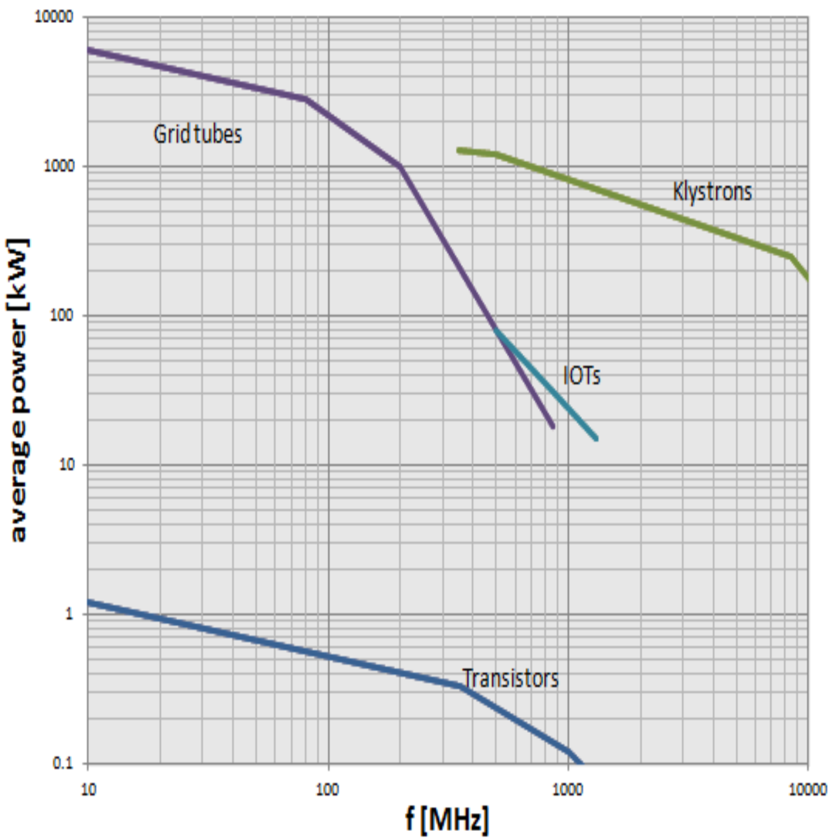
The capital and running cost of an accelerator is strongly affected by the RF power amplifiers:

Capital cost:

- cost of the amplifiers (including replacement tubes)
- gain of the power amplifier: number of stages of amplifier, thus affecting gallery requirements
- size and weight of the amplifiers determines the space required, thus influencing size and cost of gallery

Running cost

- efficiency determines the electric power required and also amount of cooling needed



Typical power sources used at 352 MHz are tetrodes, klystrons, IOTs and solid state amplifiers

Criteria of comparison:

Power distribution scheme
Lifetime
Efficiency
Gain
Availability
Infrastructure size
Costs

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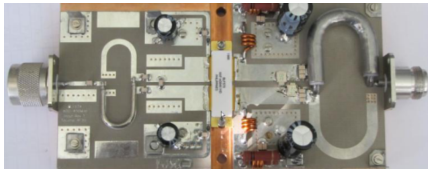
Klystron:

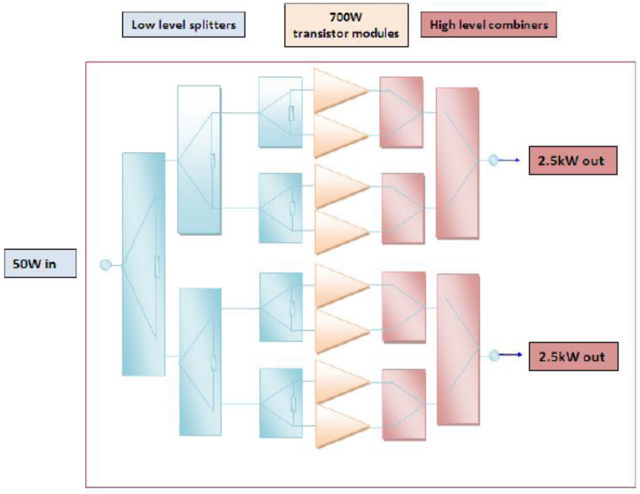
- Too big for 350 kW power
- Size: 1 m x 1 m, weight: few tons
- Efficiency: 60 – 65%
- Modulator needed for power-supply,100 kV
- Gain: 37 dB
- Predriver not needed
- Life time: 40-50 khours
- Circulator needed for handling reflection

Solid state amplifier

RF pallet of 700W power



RF 5kW power module



- 70 modules of 5 kW each that are combined
- High reliability due to use of circulators and hybrid couplers.
- Size: very big 20 m^2
- Efficiency: 65%
- Distributed power supply 50 V, >1000 A (low voltage, high current)
- Gain: 37 dB
- Predriver not needed
- Life time: about 50 khours

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IOTs

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2KDW250PA
Integral Cavity
267 MHz
300 kW CW, 73% η

SDI, Integral Cavity
425 MHz
500 kW pk., 70% η

- 2 IOTs of 200 kW each combined or single SDI IOT or 2KDW250PA to be modified
- High reliability due to use of circulators and hybrid couplers.
- Needs ceramic window
- Size: 1 m x 1 m, weight about 50 kg
- Efficiency: 65%
- DC power supply 30 kV
- Gain: 23 dB
- Predriver needed, 2 kW
- Life time: about 50 khours

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Tetrodes

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- Size of tetrode: ϕ = 17 cm, H = 21 cm
- Foot area decided by size of output cavity size < ϕ = 1 m, H = 1 m
- efficiency: 60-75 %, dependant on class of operation
- Power supply: DC power supply 22 kV
- Doesn't impose stringent requirements on anode power supply, as output power is insensitive to anode ripple
- Life time: 20-25 khours
- Easy replacibility in 2-3 hours

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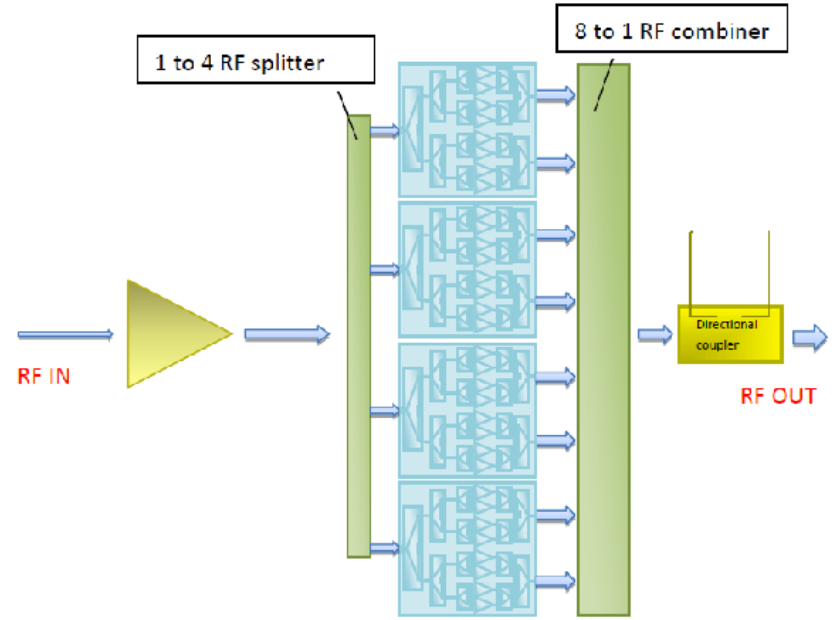
- Gain: 12 – 20 dB, needs a pre-driver with output power 20kW.
- can handle 100% reflection, a circulator is not needed

Thus Tetrode is the best choice at 352 MHz and 350 kW power.

Pre-amplifier (352 MHz, 20 kW)

- Can be either solid state amplifier or triode.



Solid state amplifier:

- Gain 73 dB, so only one stage
- Reliability: Modular system, so easy replacement possible.
- Efficiency: 70%

Triode

- Low Gain 20 dB, so consists of three amplifier stages. It requires pre-predriver triode (1 kW), and solid state low power amplifier (100 W)
- Complex system. 3 amplifier stages, their power supplies, protections, hence low reliability.
- Efficiency: 70%

Comparison of amplifier system

No.	Parameter	Tetrode	Klystron	IOT	Solid state amplifier
1.	Cost of driver tube (keuros)	*38*	300	313 for one tube	1000
2.	Cost of required accessories (keuros)	150	20	20	820
3.	Cost of power supply (keuros)	135	600	200	Included in 2
4.	Cost of preamplifier (keuros)	125	-	13	-
5.	Capital cost of total system (keuros)	448	900	850	1820

Efficiency of spoke cavity section of ESS and operating cost

Peak power delivered by tetrode = Ppk = 350 kW

Pps = Ppk/0.7 = 500 kW (with 70% efficiency of the tetrode amplifier)

D= 14 Hz x 3.5 ms = 4.9%

Average power delivered by power-supply = Pavg = 4.9% x 500 kW = 24.5 kW

RF power delivered to coupler in spoke section = Pcoupler = 4% x 245 kW = 9.8 kW (80% efficiency of coupler)

Power efficiency of spoke section = 40%

400 kEUR
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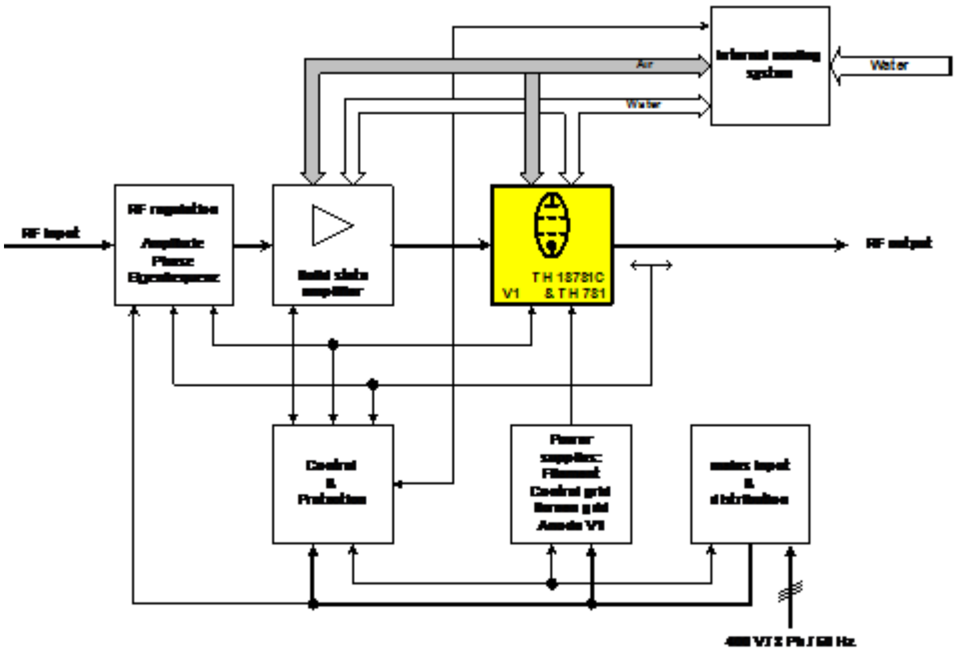
The total power consumption for the 36 spoke cavities is ,
Ptotal = 24.5 kW x 36 = 882 kW

Considering annual operation of 5200 hours
Total power consumption for a year is 4.6 GWh

At an electricity price of roughly 0.086 EUR/kWh,
Total operating cost of spoke cavity section for a year is
400 kEuros

TH 781



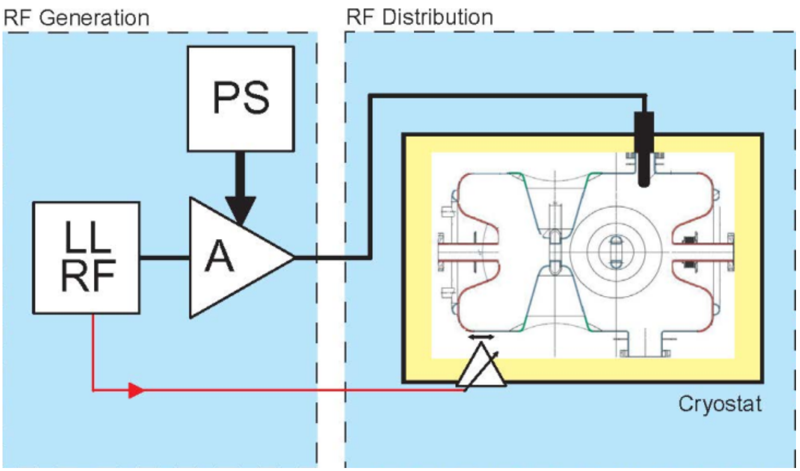
Block diagram of the 200kW RFQ amplifier

- ❖Installed in more than 15 institutes and companies.
- ❖Tested at frequencies from 72 to 217 MHz with RF power up to 200 kW CW
- ❖Tested upto 200 MHz, CW power few hundred kW, cavity 18781C.

How to proceed ?

❖Design and development of output cavity

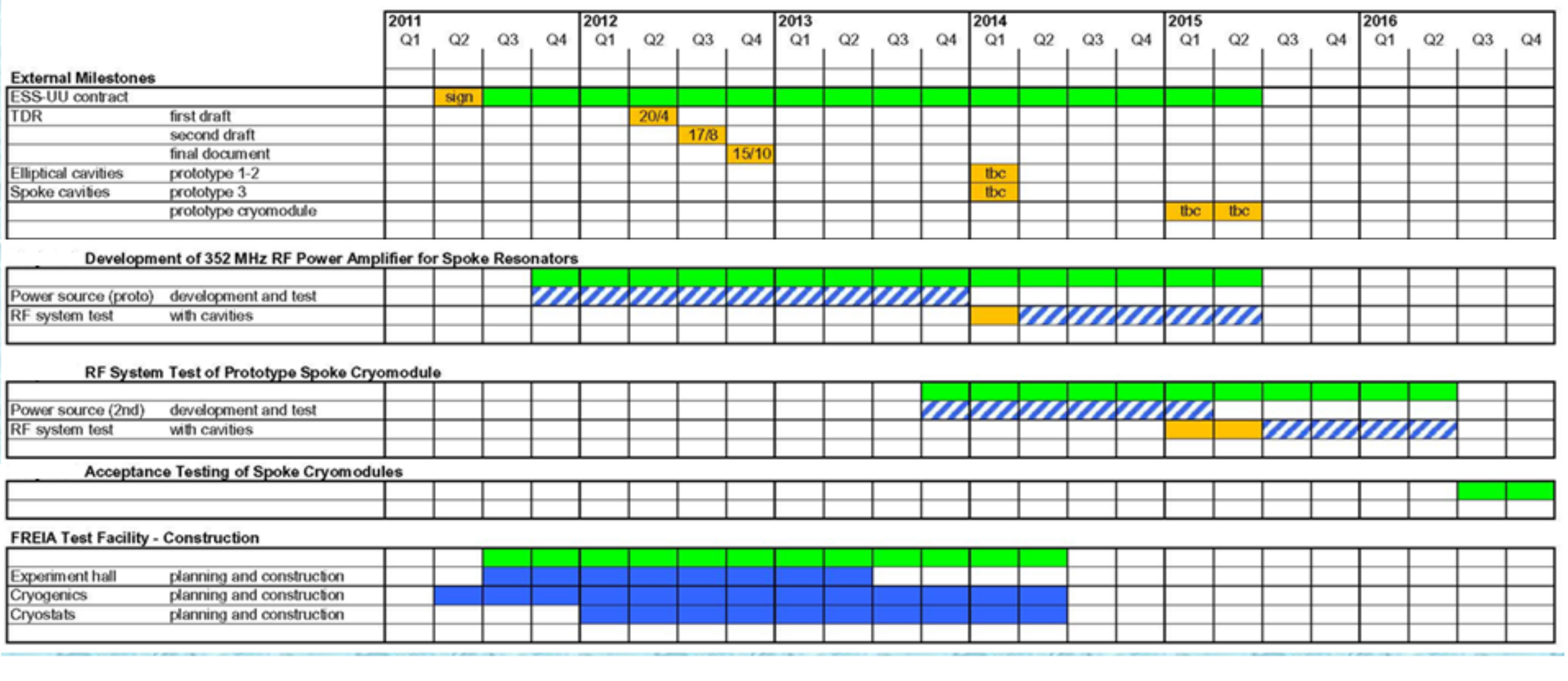
Proposed layout for testing prototype cryomodule



A: Amplifer:Tetrode, Solid state
PS: Power supply
LLRF: Low level RF
Waveguide: Half height WR2300
DDC: Dual directional coupler
Load: Dummy load
Adet: Arc detectors, no circulator

- Power handling capability WR2300 (23 inch x 11.5 inch) is few tens MW.
- Power requirement for the spoke cavities is only 350 kW, so a half height WR2300 waveguide (23 inch x 5.75 inch) can be used.
- Reduction of waveguide size and cost is achieved. Handling will be much easier.
- Aluminum shall be the preferred material
- As waveguides will be used in- door, uncoated waveguides can be used

Time-line to test spoke cryomodule



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Comments and suggestions are welcome !

Thank you !

Supporting slides

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Comparison between coaxial line and waveguide

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No.	Parameter	Coaxial line	Waveguide
1.	Standard	6 1/8 inch	WR2300
2.	Outside dimension	6 inch	23inch x 11.5 inch
3.	Material	Inner conductor : Copper Outer conductor : Aluminum Dielectric : Teflon / ceramic Inner conductor joint: Be Cu	Aluminum
4.	Loss in dB/m	> 0.0035	< 0.002
6.	Installation	Difficult	Easy
7.	Cost	3100 euro/m + cost of ceramic + cost of inner conductor joint	1900 euro/m