ESSnuSB Requirements on ESS linac

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NuFACT

Top Level Parameters

Design Drivers:

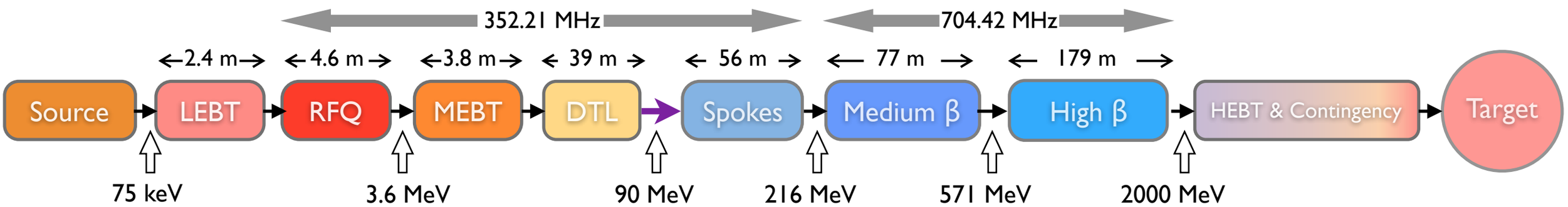
High average beam power	5MW
High peak beam power	125 MW
High availability	>95 %

Key Linac parameters:

Energy	2.0 GeV
Current	62.5 mA
Repetition rate	14 Hz
Pulse length	2.86 ms
Losses	<1W/m
Ions	p

Flexible/Upgradable design

Minimize energy consumption

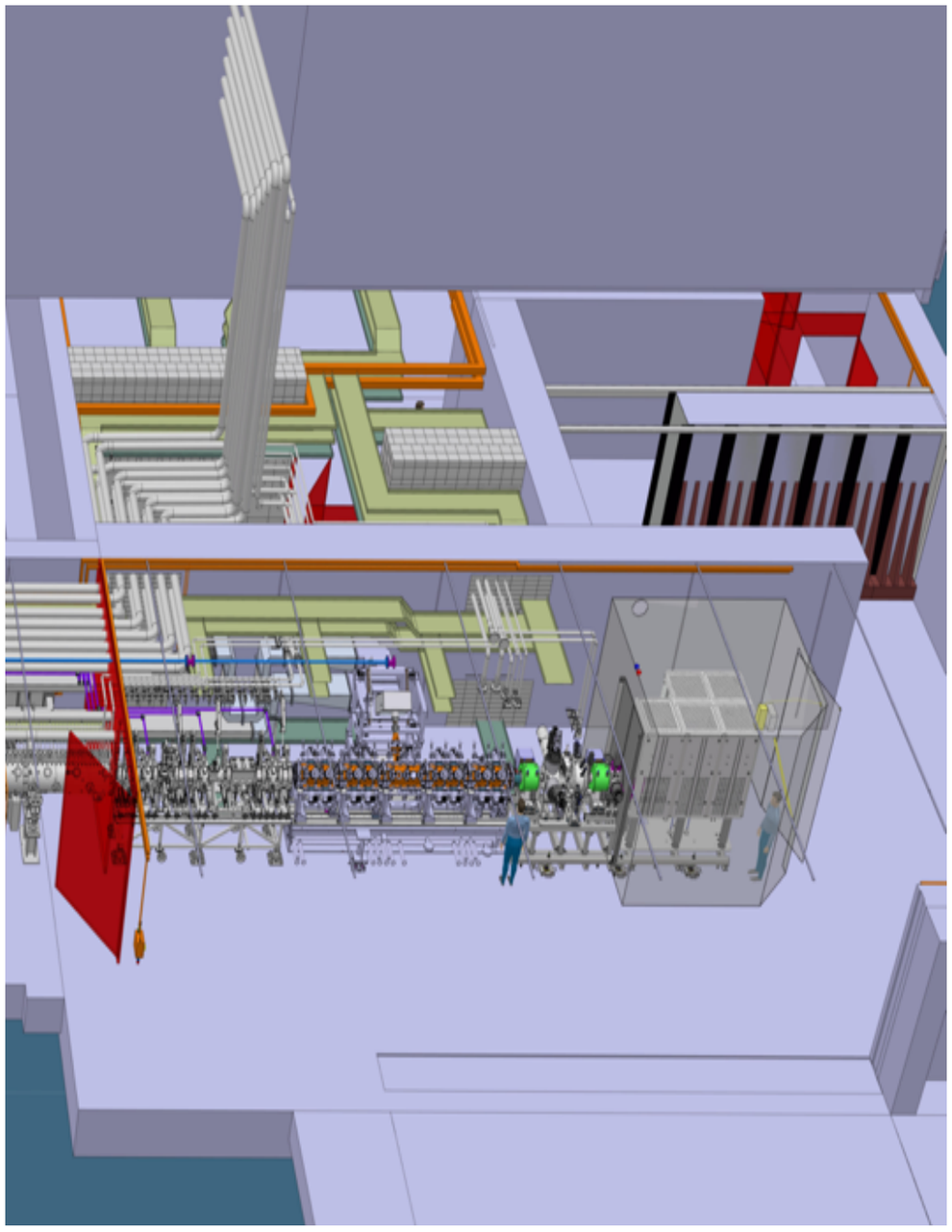


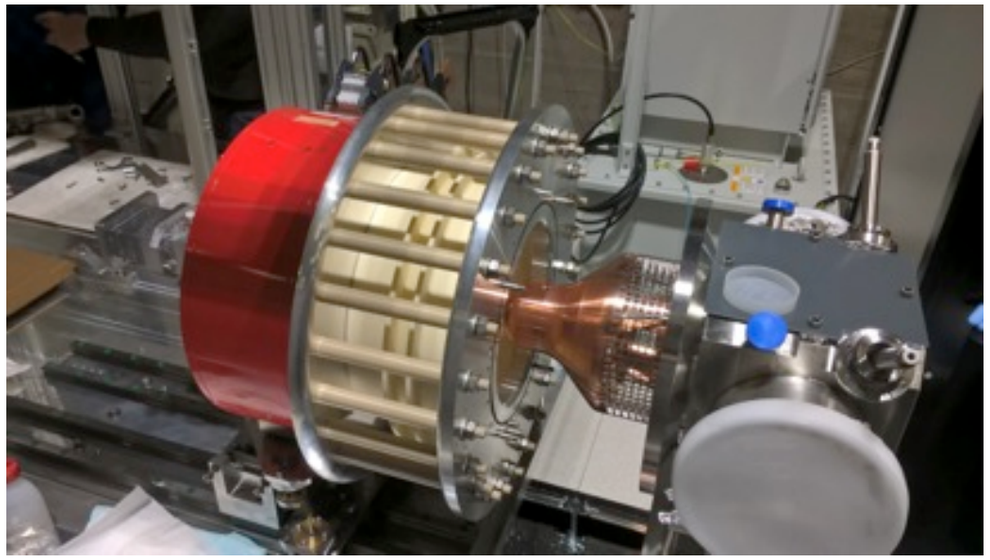
First proton beams ready in 2019,
User operation planned for 2023

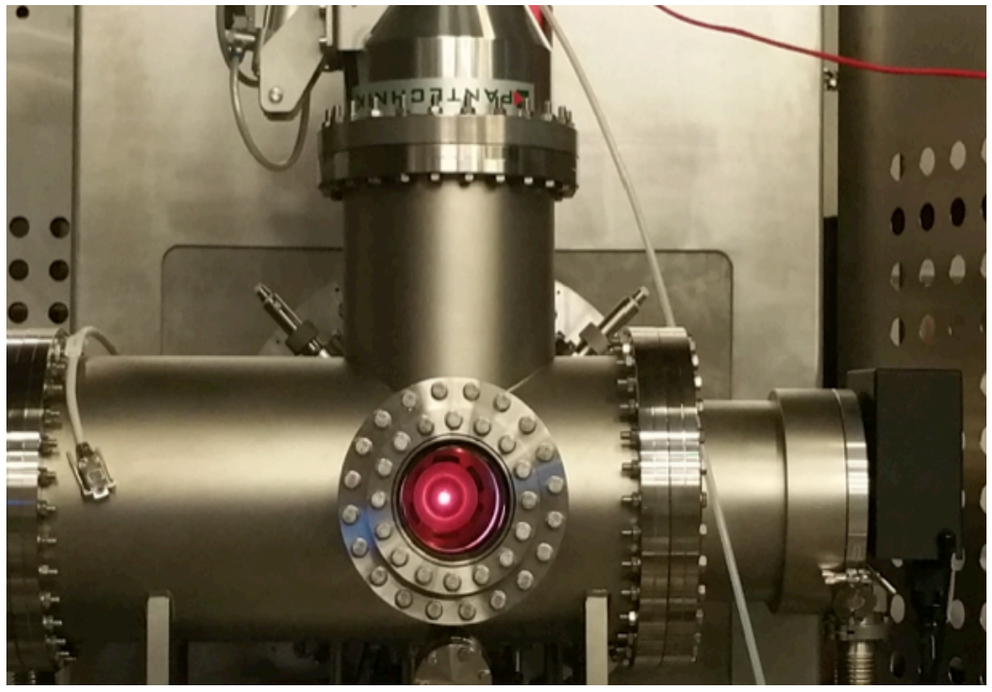
ESS SITE

KLYSTRON GALLERY

Ion Source: Microwave Discharge Ion Source

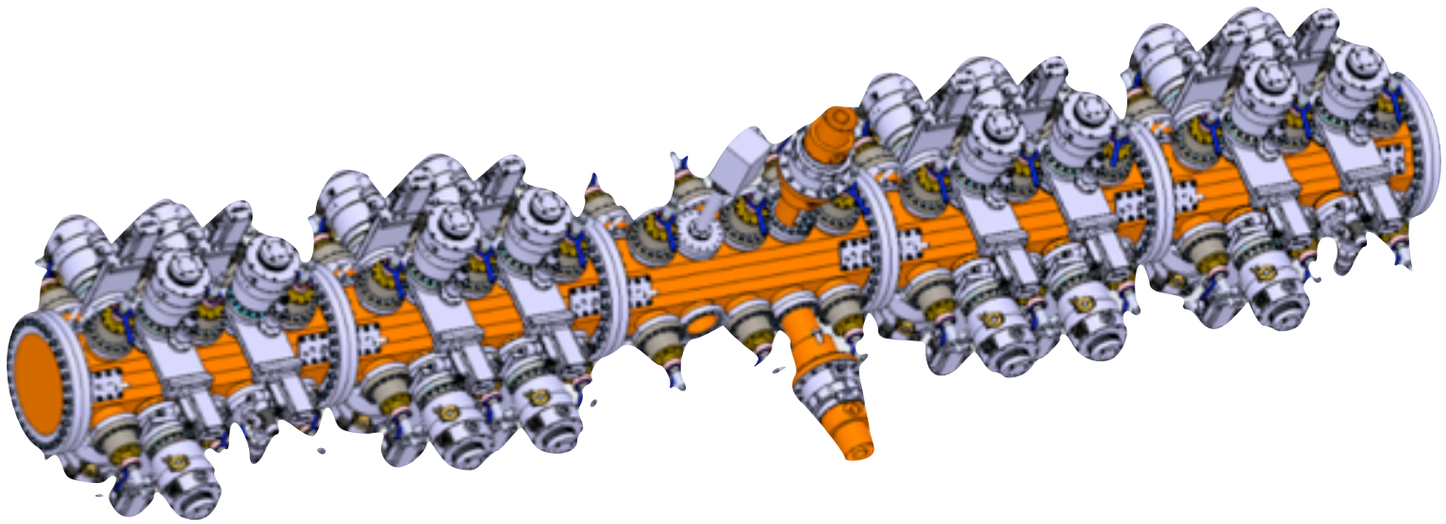


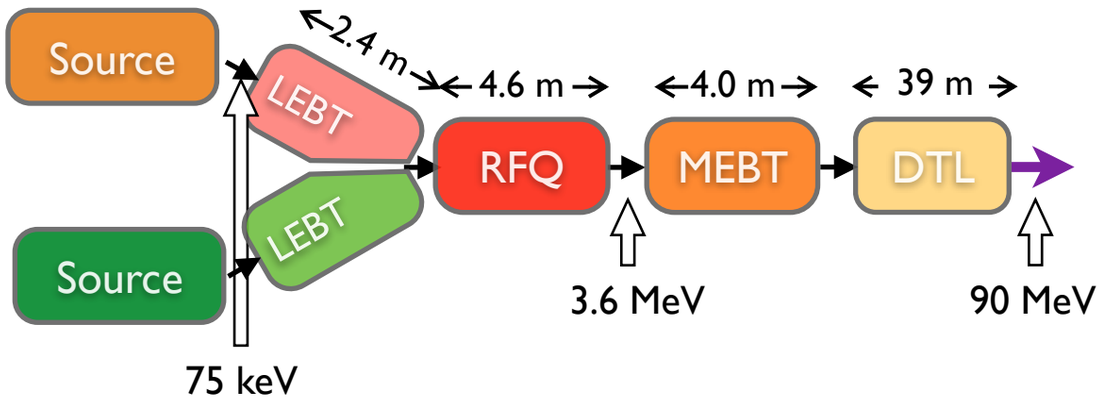


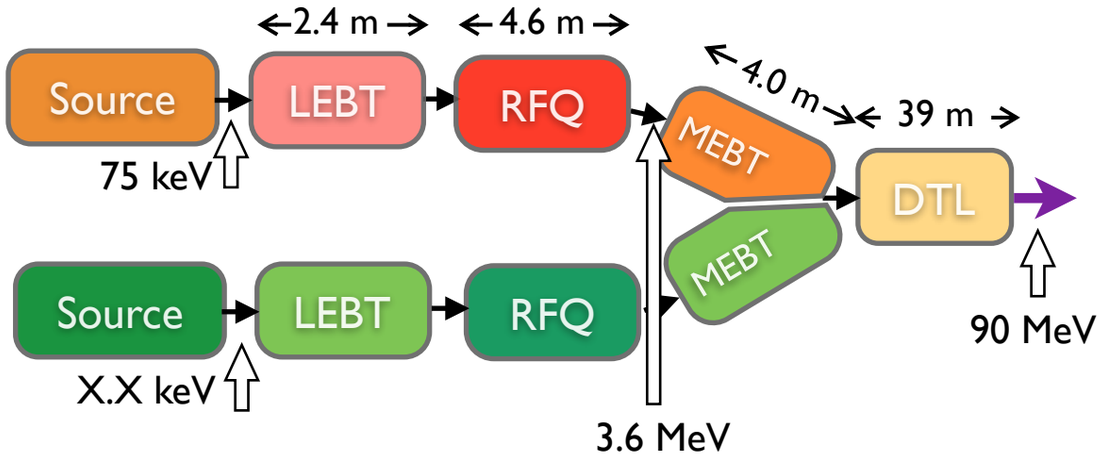


RFQ

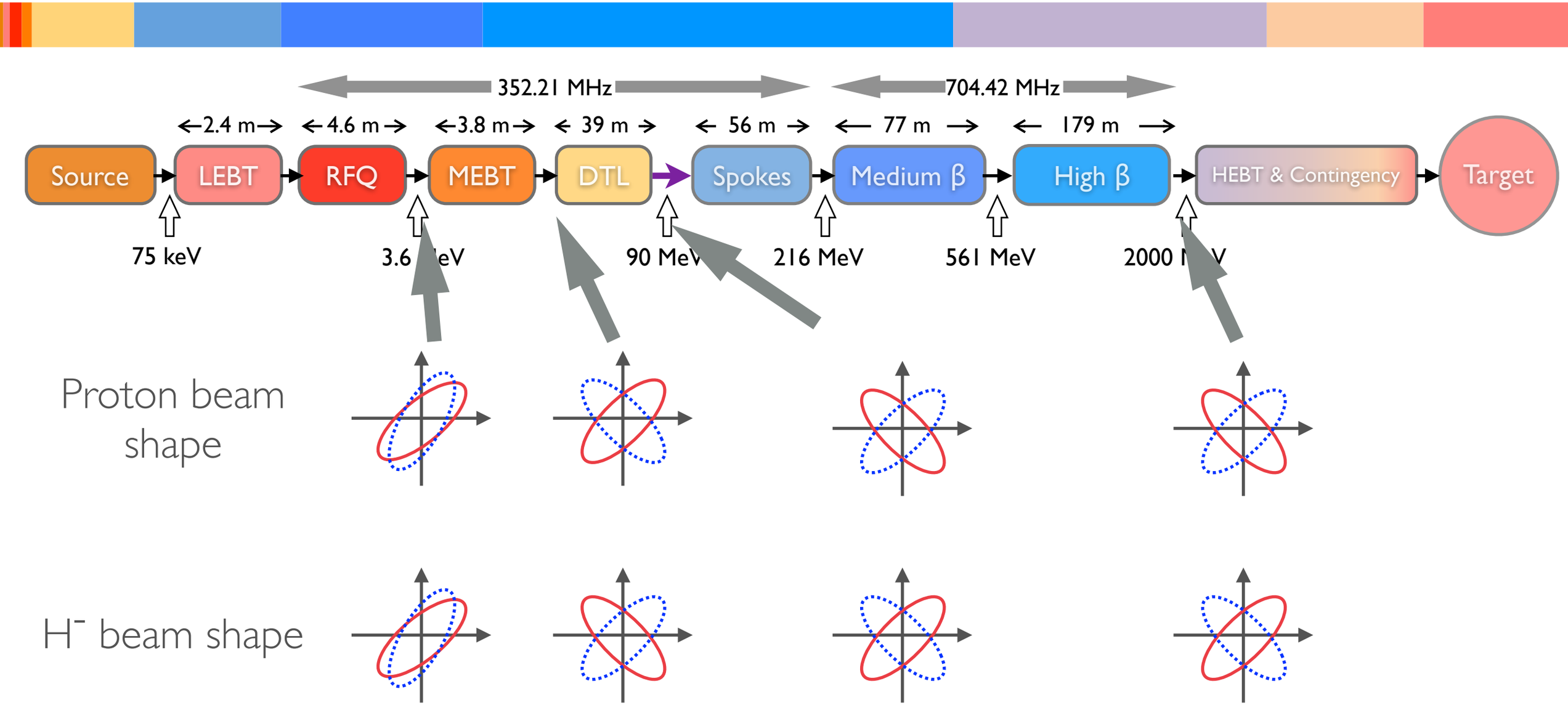
- Accelerates the beam from 75 keV to 3.62 MeV







TRANSVERSE FOCUSING



- P and H⁻ beams have opposite orientation at each interface (except at RFQ entrance/exit).
- Same polarity of quadrupoles could provide the right focusing.

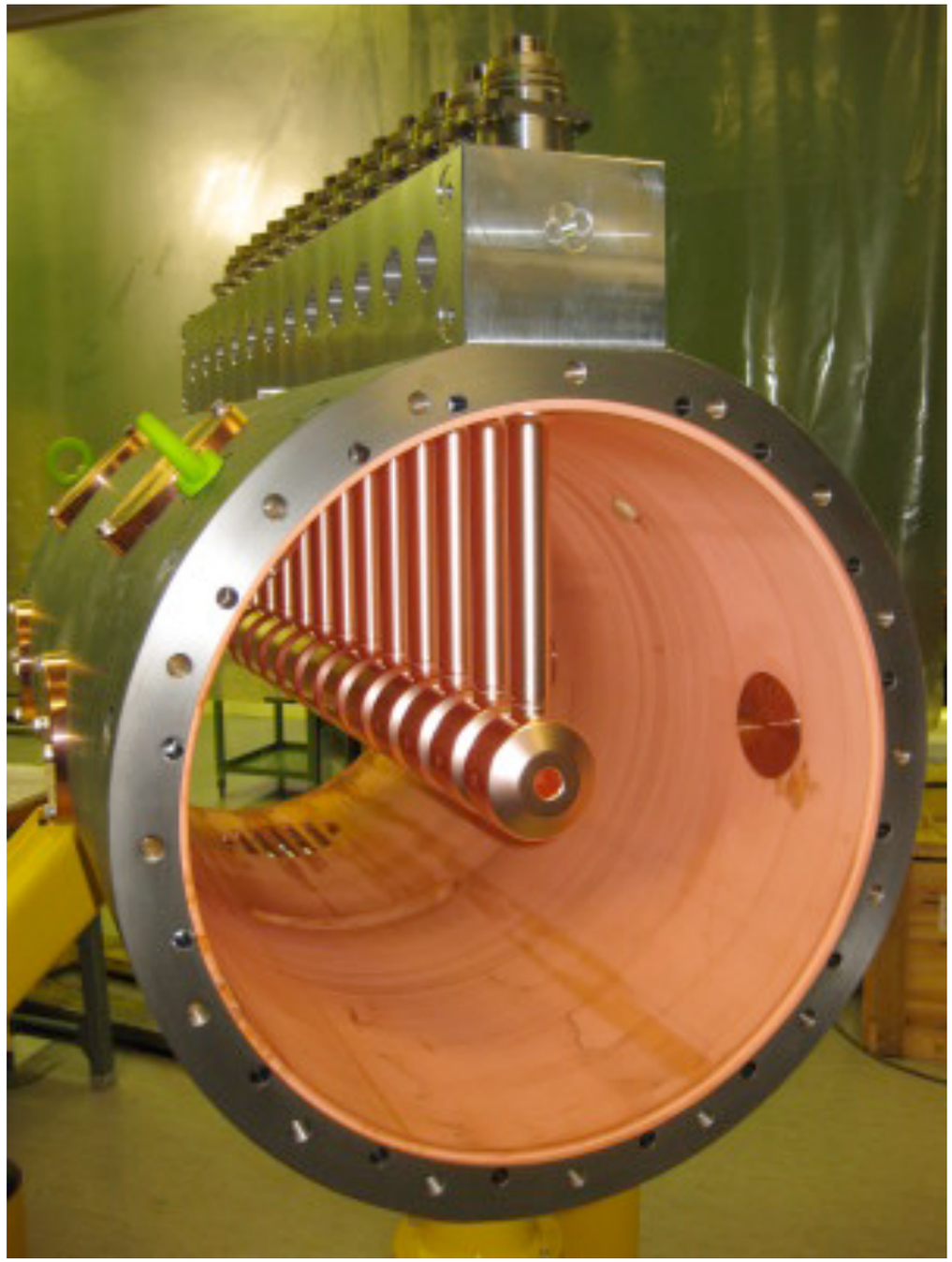
RFQ AND DTL

- The DTL is designed (very similar to CERN LINAC4) with a maximum duty cycle of 10%.

- Keeping the (RF) duty cycle below 10% would permit using the same DTL.

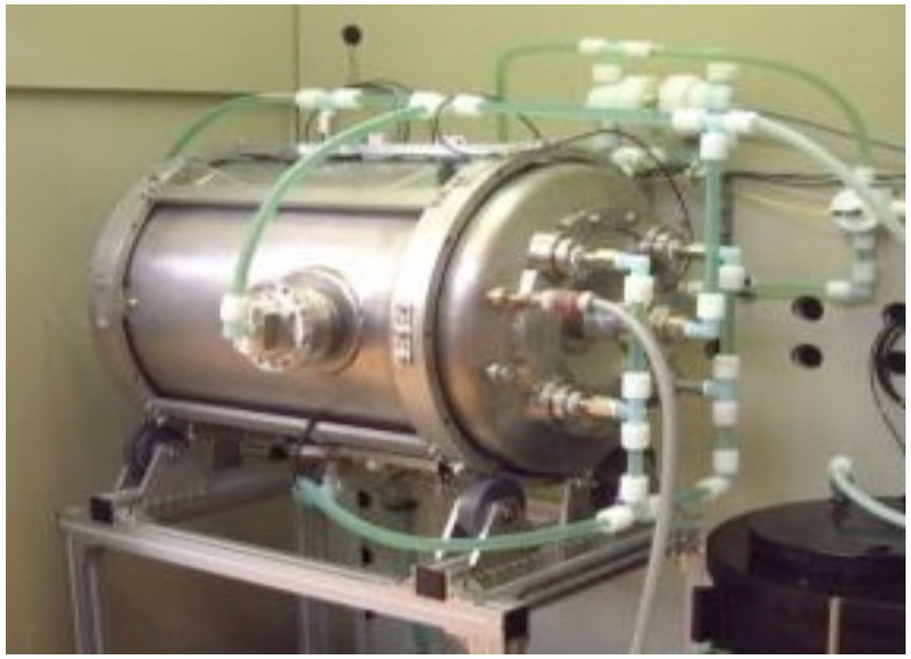
- The coupler cooling could be enough for increased duty cycle

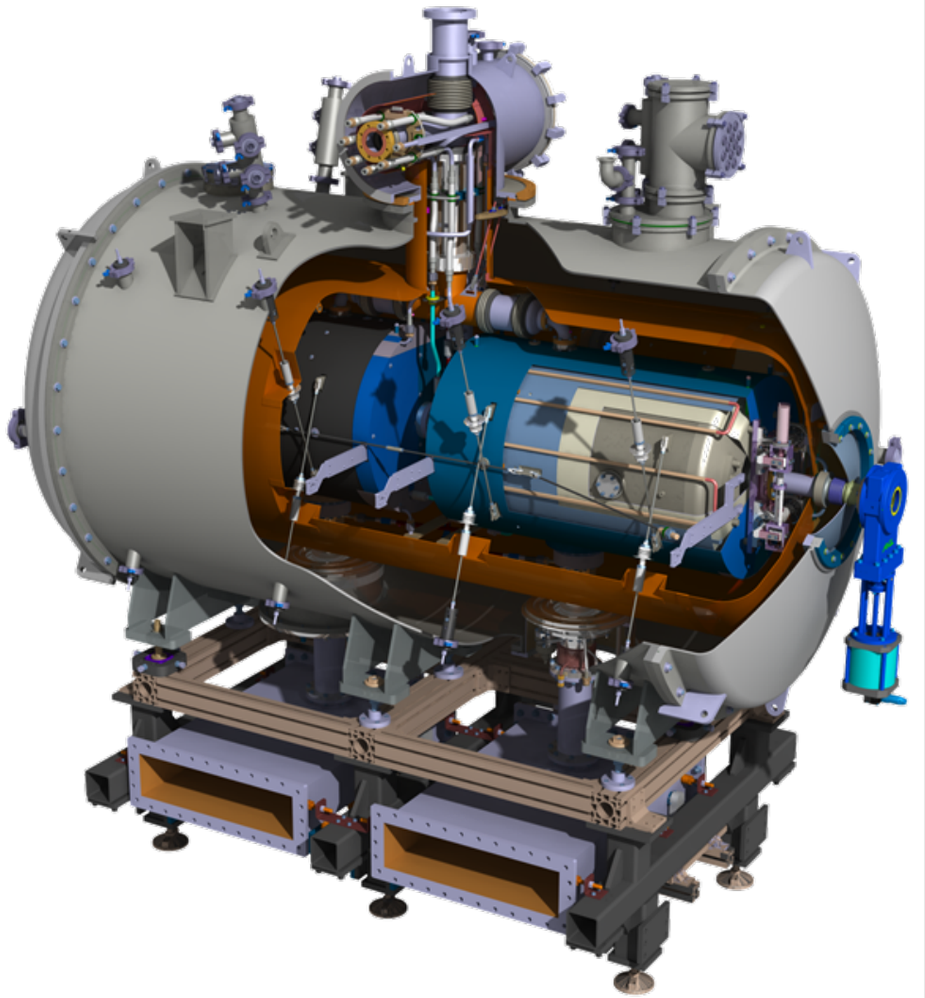
- RFQ may have a different (lower) limit.



SPOKE

- Quadrupole Doublet Focusing (DC Quad and Corrector)
- Starts with a differential pumping section (LEDP)
- Accelerates the beam from 90 to 216 MeV
- Double spoke, βopt = 0.5, E_{acc} = 9 MV/m

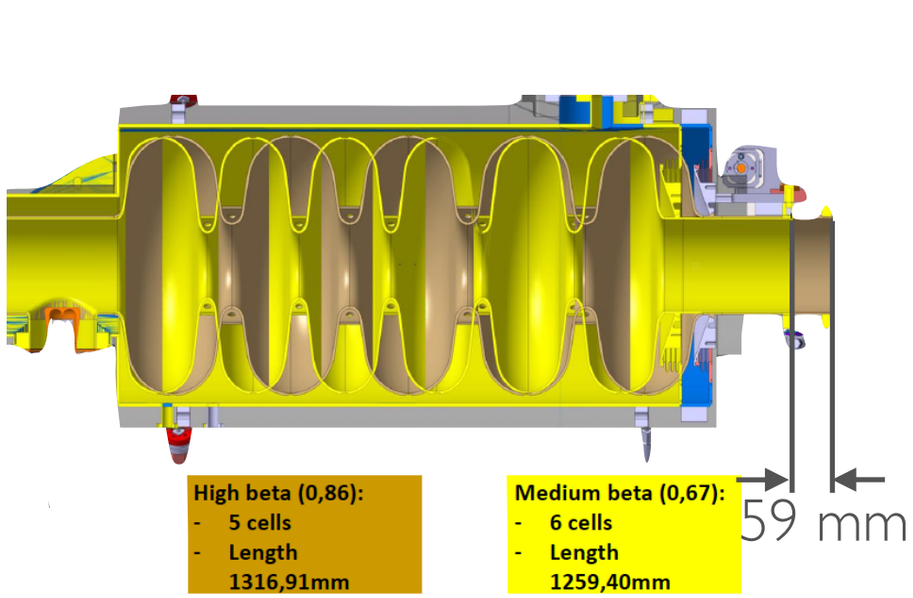


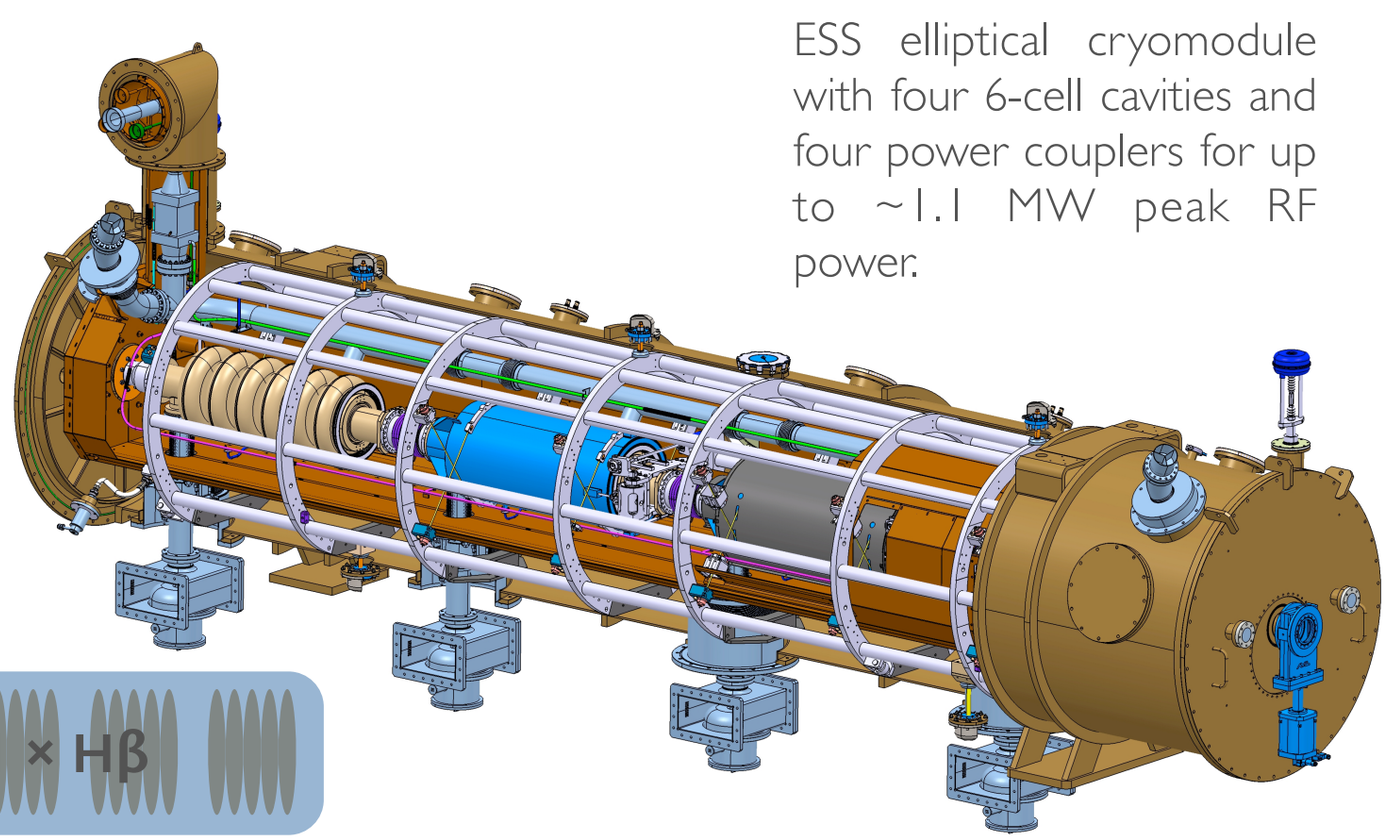


ESS Spoke cryomodule with two double spoke cavities, and two power couplers

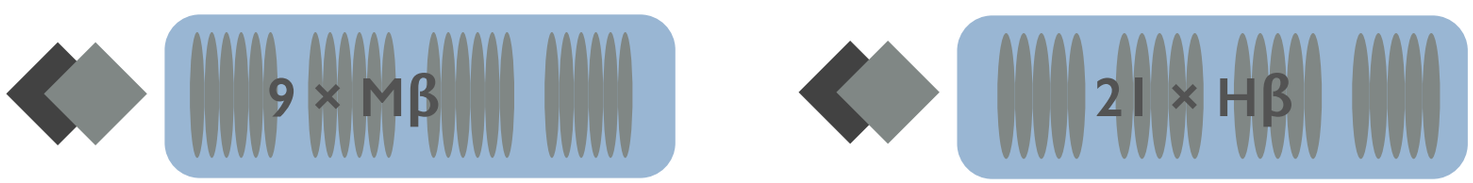
ELLIPTICALS

- Quadrupole Doublet Focusing
- Accelerates the beam from 216 MeV to 571 to 2 GeV in Two families:
  - 6-cell, $\beta g = 0.67$, $E_{acc} = 16.7$ MV/m
  - 5-cell, $\beta g = 0.86$, $E_{acc} = 19.9$ MV/m



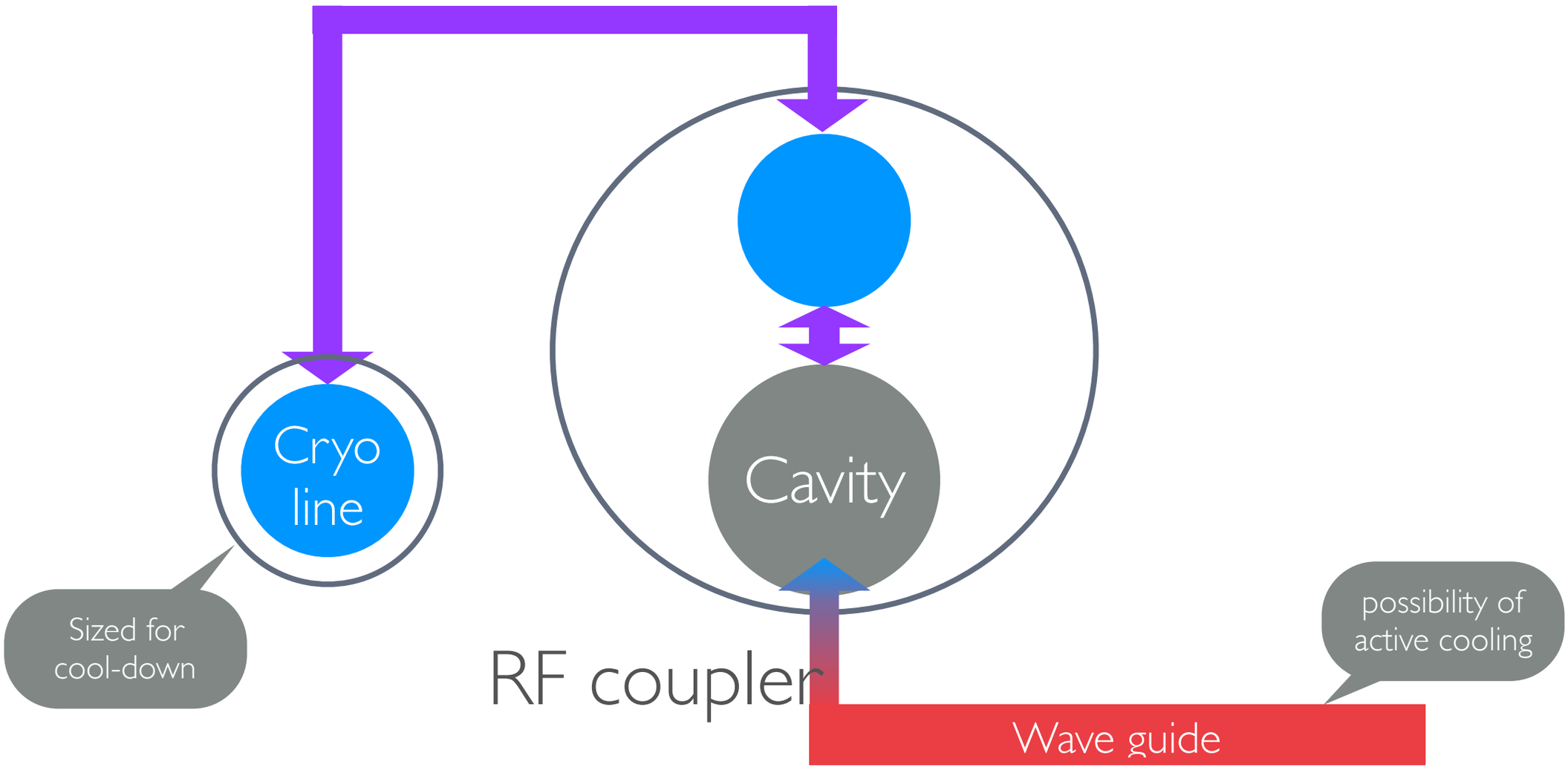


ESS elliptical cryomodule with four 6-cell cavities and four power couplers for up to ~1.1 MW peak RF power.



Cryomodules

- Spoke and Elliptical internal pipes?
  - These pipes should be OK, the jumper connectors could be a bottle neck at higher repetition rates (maybe not?).



Modulator

- The ESS modular topology of modulators would permit increasing the output power by increasing the size of capacitor charger.
  - If each modulator is feeding 4 klystrons (660 kVA case), there might be enough space saved to add the extra capacitor chargers.
  - If each modulator is feeding 2 klystrons (330 kVA case), there could be difficulties fitting the additional capacitor chargers in the gallery.
- In both cases the life time is reduced to ~half if they ran at 28 Hz
- A four times power increase does not seem feasible.

Thanks to Carlos Martins

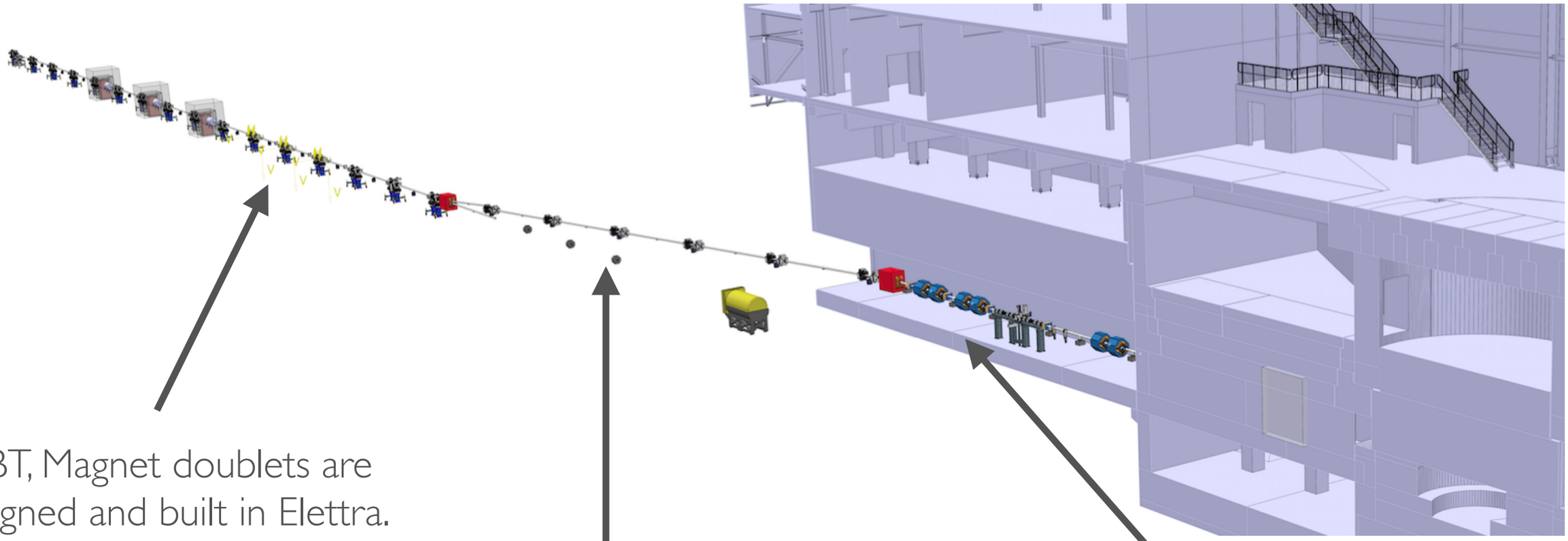
KLYSTRONS

- The current klystrons cannot be operated at four times the average power. (Klystrons could? be operated at a maximum of 10% RF DC).
  - However, klystrons could be replaced with new different ones at the end of their finite life. This requires early knowledge of such a need.

- The utilities such as water cooling should be increased.
  - To remove the excess heat one can alter the flow rates by changing the pipe sizes or increased pressure.
  - One can also increase the temperature gradient.

- Increasing the number of klystrons does not seem feasible due to space and utility restrictions

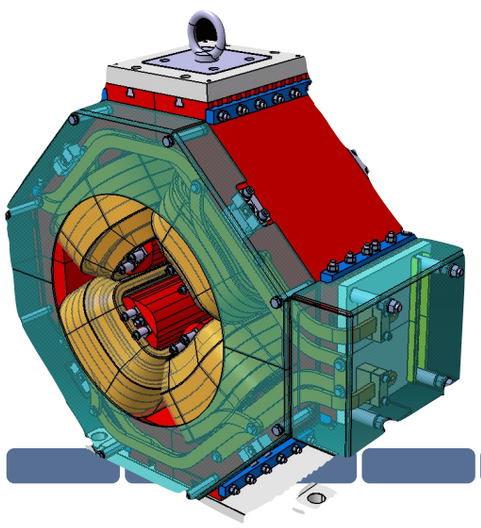
HEBT

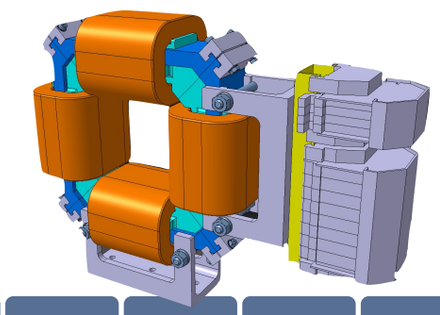


HEBT, Magnet doublets are designed and built in Elettra. 12 periods, identical length to HB cryomodules

A2T (DogLeg), Magnets are designed and built in Elettra. 6 periods, achromat.

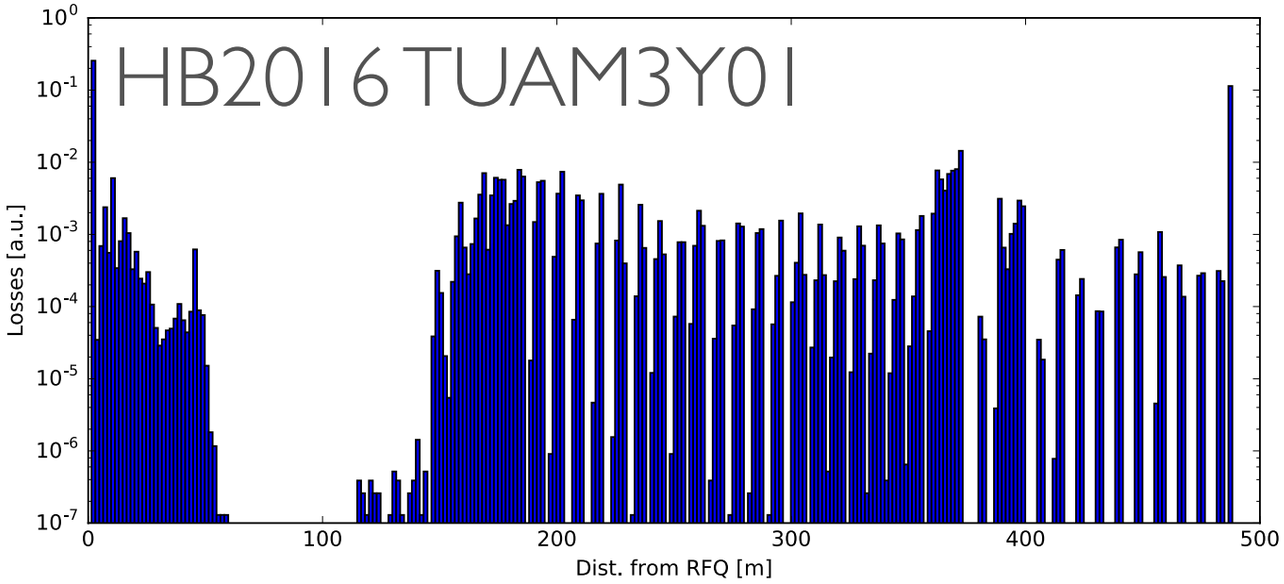
A2T Quadrupoles doublets are designed and built in Elettra, and Raster magnets are designed and built in Aarhus University

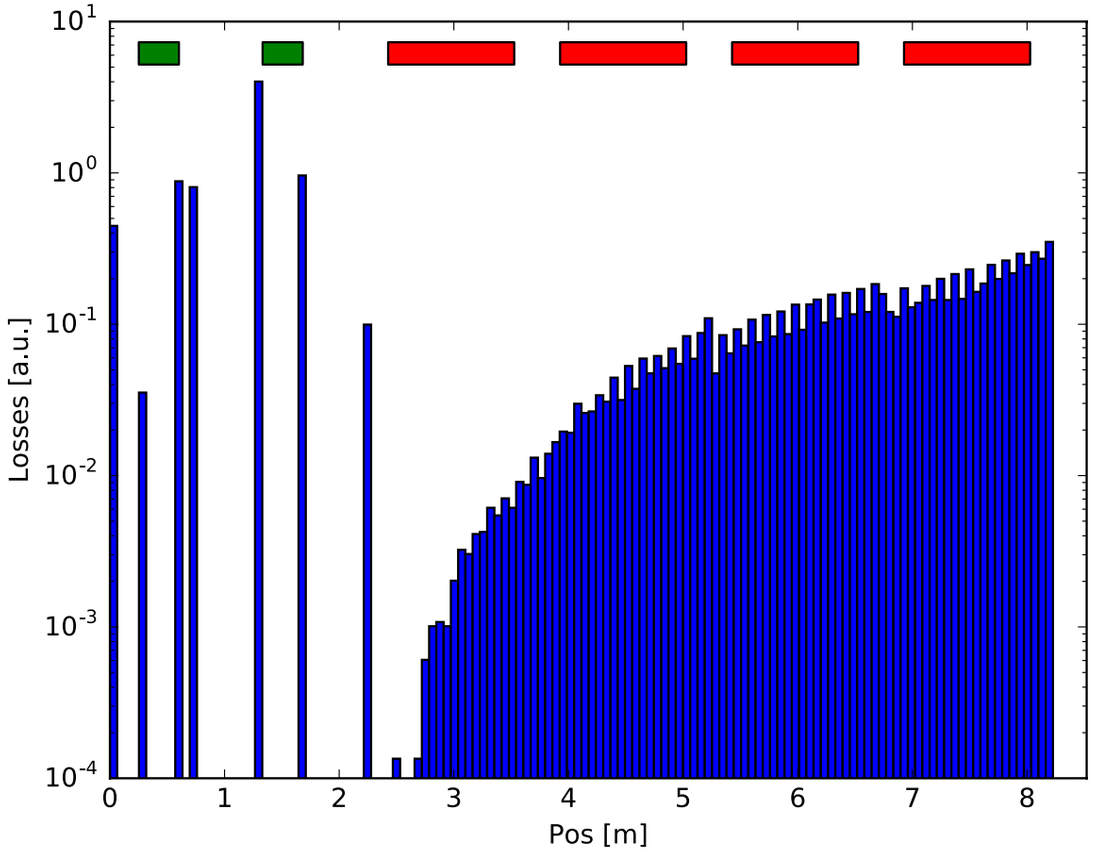




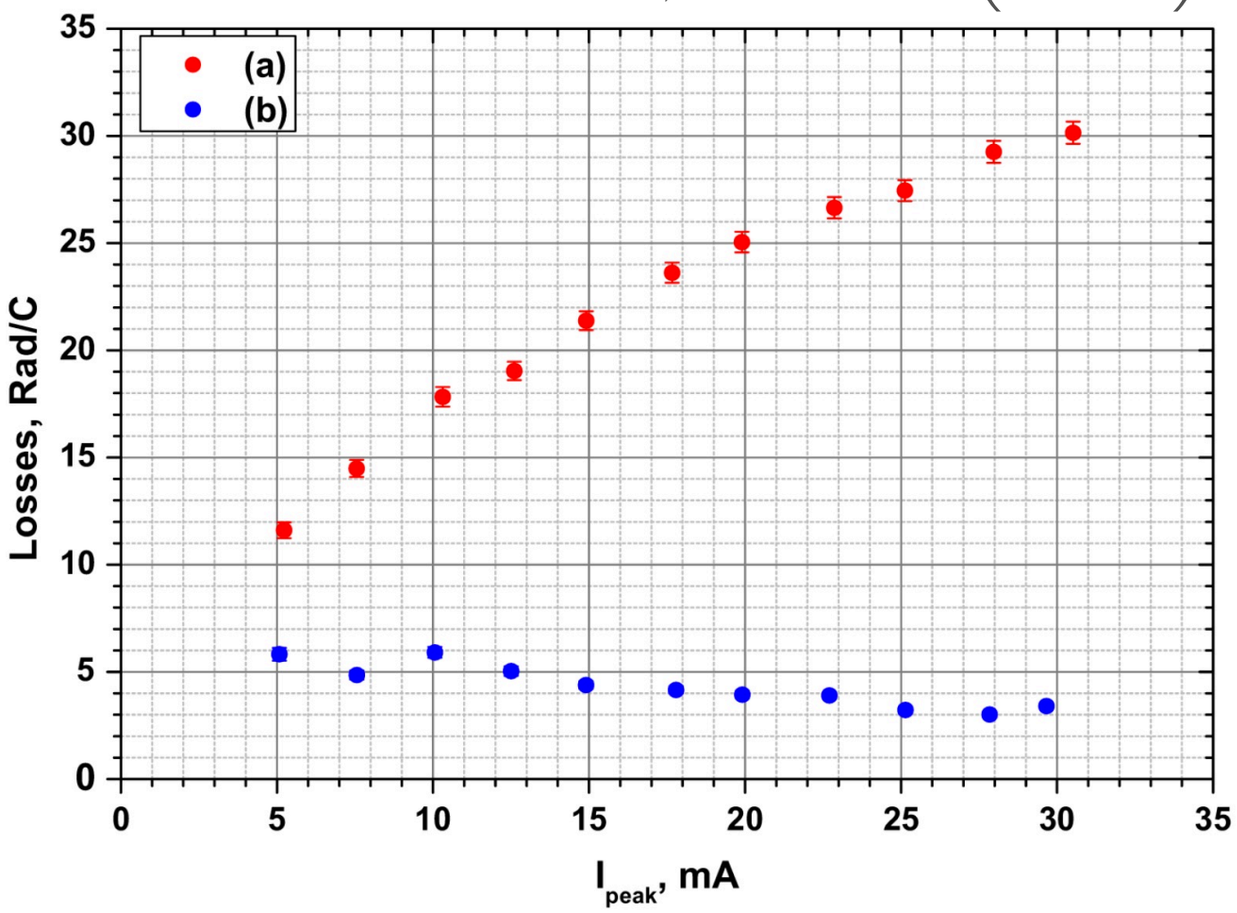
12 × Contingency

P Losses and H- Stripping



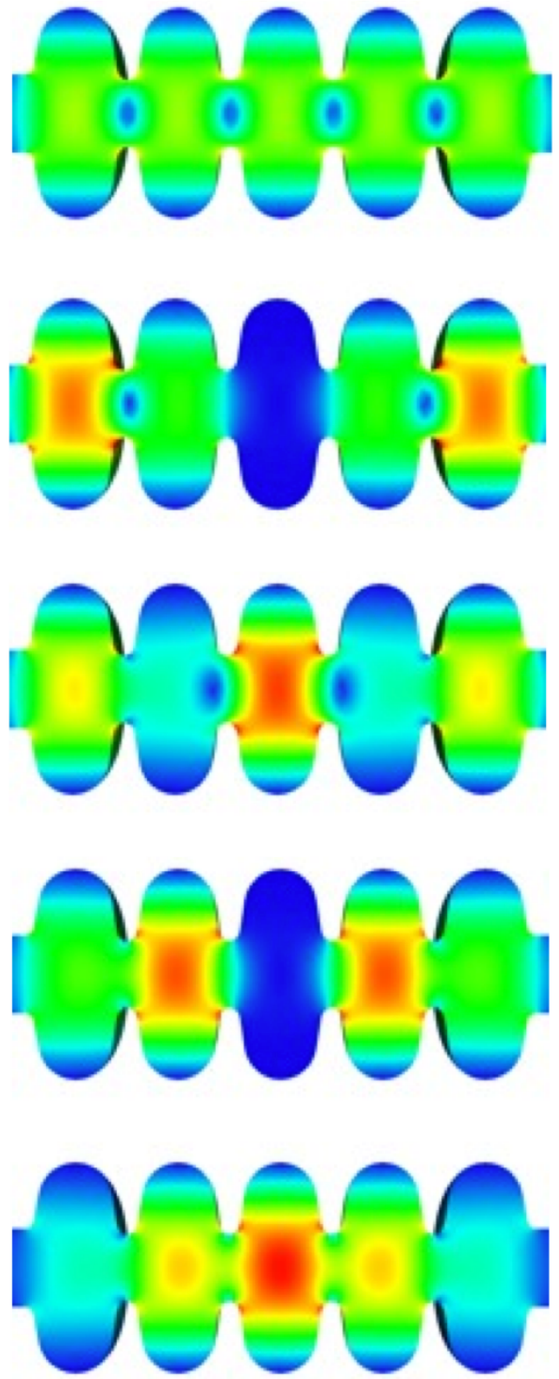


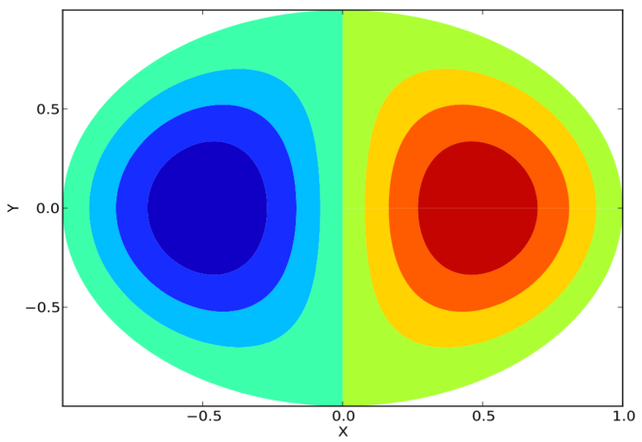
PRL **108**, 114801 (2012)

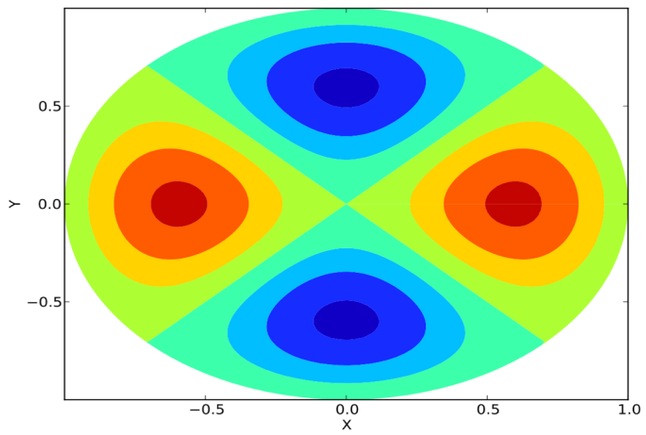


Higher Order Modes

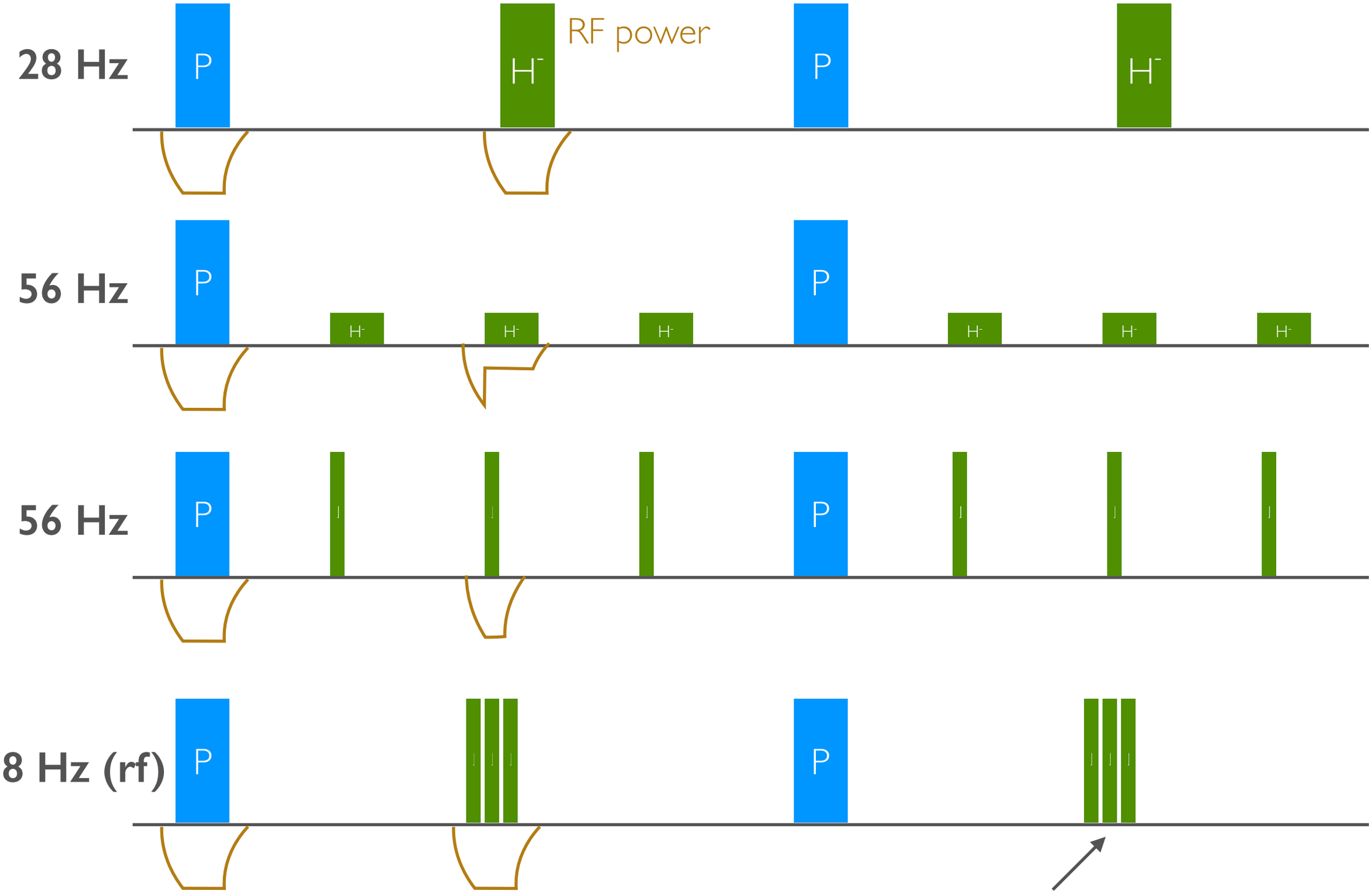
- Creating an extraction gap in the ring requires a high frequency chopping in the linac, which could excite HOMs in the SC cavities.







PULSE FREQUENCY



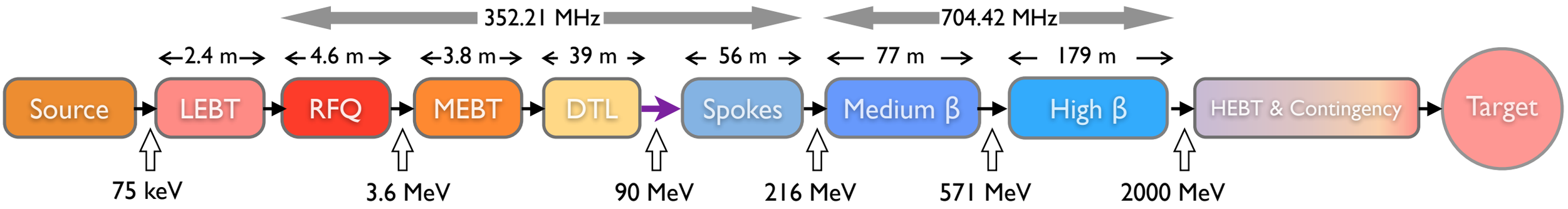
ESSnuSB upgrade Cases

- Scenario I
  - The ESSnuSB requires the ESS linac to provide an additional 5 MW of beam power, there are two scenarios being discussed for the additional 5 MW:
    - 28 Hz:
      - 14 Hz for neutron production + 14 Hz for neutrino production (5 MW to each destination)
    - 56 Hz:
      - 14 Hz for neutron production + 42 Hz for neutrino production (5 MW to each destination)

- Scenario II
  - Any energy upgrade beyond 2 GeV will simplify the delivery of a second 5 MW beam from the ESS linac.
    - With the energy upgrade to 2.5 GeV the increase of average power needed from the nominal Radio Frequency (RF) stations is ~60%, which looks feasible within the existing RF gallery space.
    - An energy upgrade to 3 GeV would further decrease the need for higher RF power from the existing stations to ~30%.
  - The high-beta superconducting cavities have a total filling time of around 0.3 ms, and for a beam duty cycle of 8%:
    - 28 Hz yields an RF duty cycle of 8.4%
    - 56 Hz yields an RF duty cycle of 9.45%

Extracted from the report by Frank Gerigk and Eric Montesinos, CERN-ADD-NOTE-2016-0050

ESSnuSB



H- source

SC cavities (couplers, cavities)

RF (Modulators, SSA, Tubes), LLRF

Beam physics (Halo, losses)

Operations, Reliability, Availability

CHANGES

	IS+LEBT	RFQ	MEBT	DTL	Spoke	Medium beta	High beta
New device	New	~New	~New	—	—	—	—
Cooling	—	Additional	Additional	Additional	Additional	Additional	Additional
Tunnel	Device capacity / pipes / temperature				Cryo-line/Cryomodule/Coupler/Waveguide		
Gallery	Cooling skids / Klystron cooling / pipes				Klystron cooling / pipes / skids?		
RF	—	Additional	Additional	Additional	Additional	Additional	Additional
		Klystron	Amplifier	Klystron	Klystrons / Tubes/LLRF		
		Modulator	PC	Modulator	Modulator / Power converters		
Cryo	—	—	—	—	Additional	Additional	Additional
					Cryoline / Cryo plant		

SUMMARY

- The identified major modifications for the doubling of the beam power via a higher repetition rate and higher beam energy are (in no particular order):
  - Three new electrical substations along the RF gallery.
  - A third main electrical station, alongside the 2 existing ones.
  - HV cable trenches and pulling of additional HV cables from the main station towards the new substations. New HV cables between the substations and the modulators in the RF gallery.
  - Installation of 8 new cryo modules and associated RF stations.
  - Change of klystron collectors, so that 60% more average power can be produced. If klystrons are at the end of their lifetime, they could be exchanged against more powerful models.
  - Installation of additional capacitor chargers to allow faster pulsing of the modulators. This is only possible if the modular design developed in-house is adopted.
  - Installation of a H- source + RFQ + MEBT + beam funnel alongside the existing protons source.
  - Exchange trim magnets and associated power supplies against pulsed versions
- The reviewers, Frank and Eric, did not find any show stoppers for the addition of 5 MW H- acceleration capability in the current state of the ESS linac.

Extracted from the report by Frank Gerigk and Eric Montesinos, CERN-ADD-NOTE-2016-0050