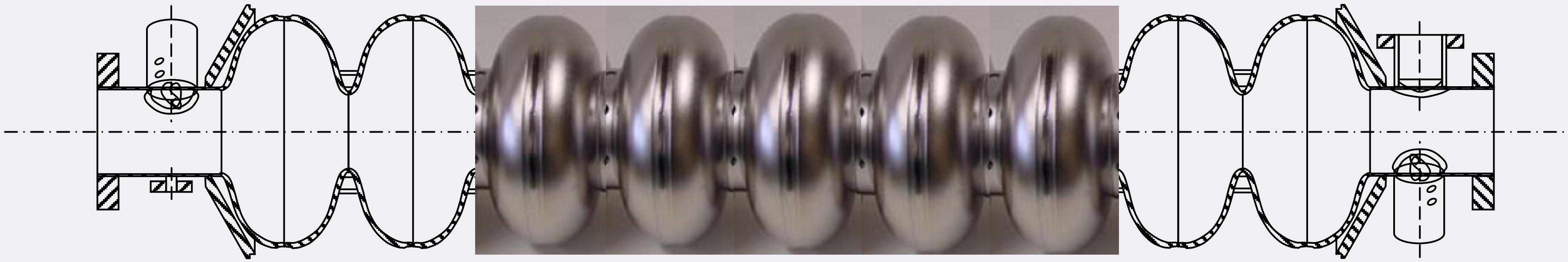
Review of the European XFEL Linac System

Beam Dynamics Meeting

Hans Weise / DESY

XFEL s.c. Cavities

cavity material		RRR 300 niobium
type of accelerating structure		standing wave
accelerating mode		TM010, π-mode
fundamental frequency	f_{RF} [MHz]	1,300
active length	L [m]	1.038
nominal gradient	E_{acc} [MV/m]	23.6
quality factor	Q_0	$>10^{10}$
cell-to-cell coupling	K_{cc} [%]	1.87
iris diameter	[mm]	70



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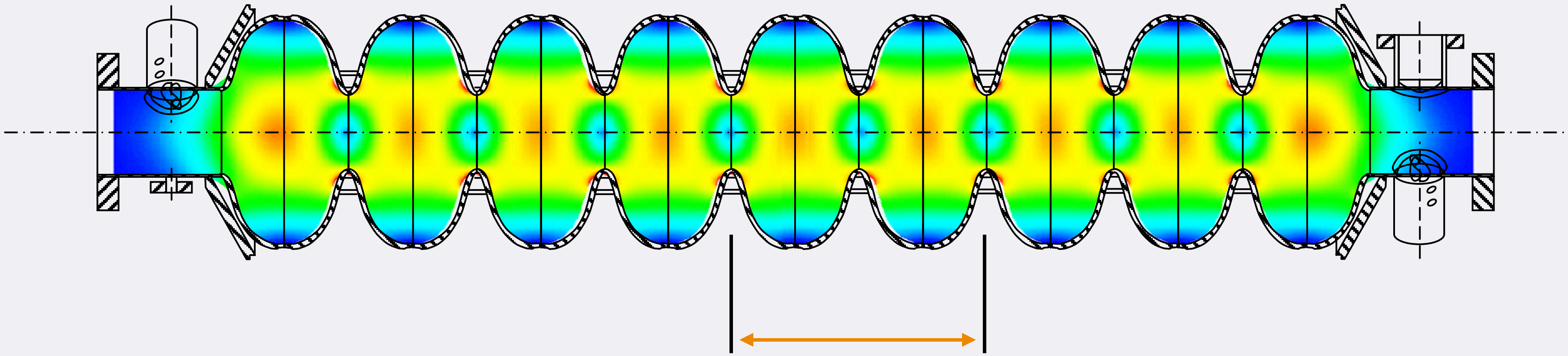

λ ≈ 23 cm ↷ 1.3 GHz

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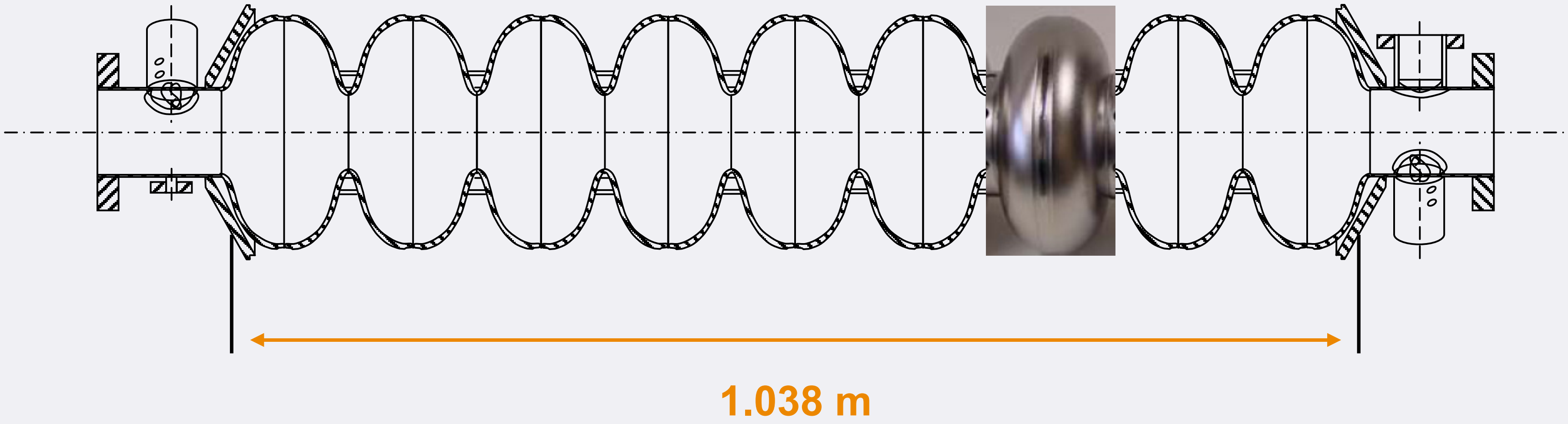

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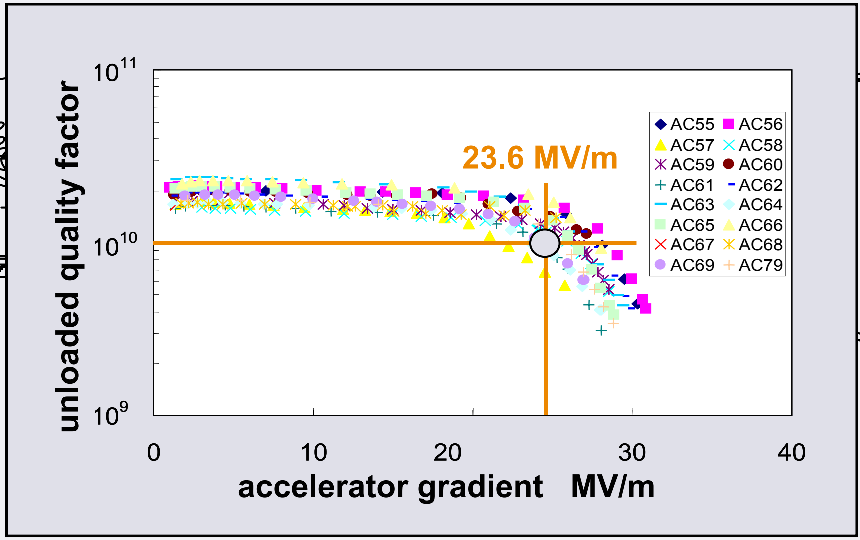

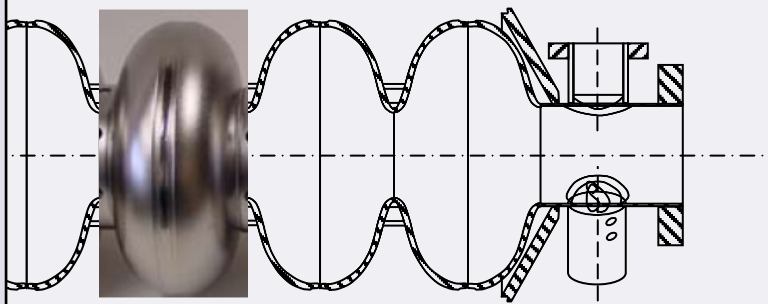

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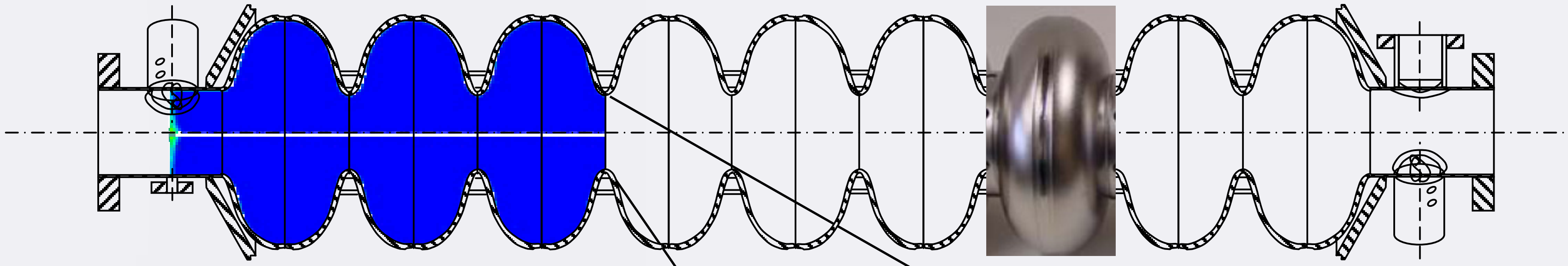


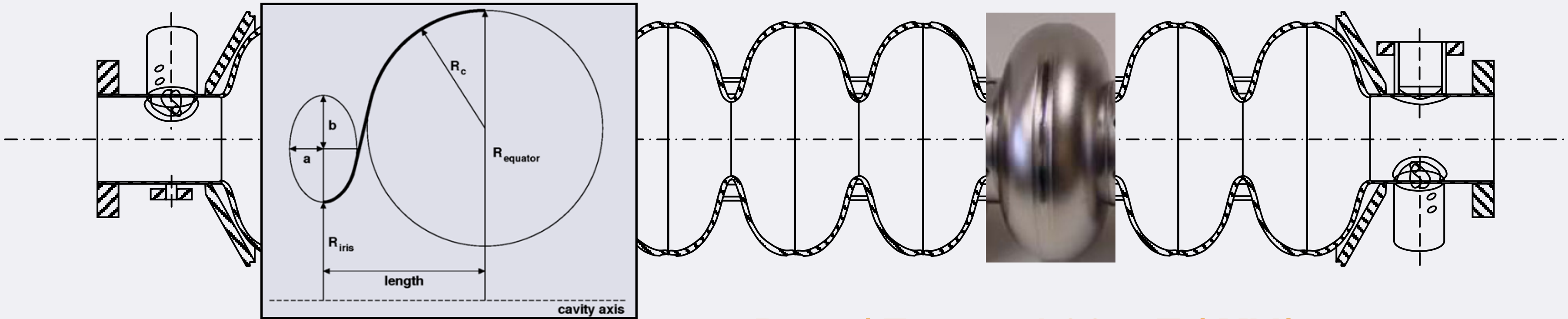
Wakefield excitation is reduced

$W_{\parallel} \sim f^2 \qquad W_{\perp} \sim f^3$

70 mm

XFEL s.c. Cavities

R/Q	[Ω]	1,036
E_{peak} / E_{acc}		2.0
B_{peak} / E_{acc}	[mT / MV/m]	4.26
Tuning range	[kHz]	± 300
$\Delta f / \Delta L$	[kHz / mm]	315
Lorentz force detuning constant	K_{Lor} [Hz / (MV/m)^2]	1
Q_{ext} of input coupler		4.6×10^6
cavity bandwidth f / Q_{ext}	[Hz] FWHM	283
fill time	[ms]	780
number of HOM couplers		2



optimized cavity shape

B_{peak} / E_{acc} = 4.26 mT / MV/m

↷ B_{peak} < 200 mT (B_c @ 2K)

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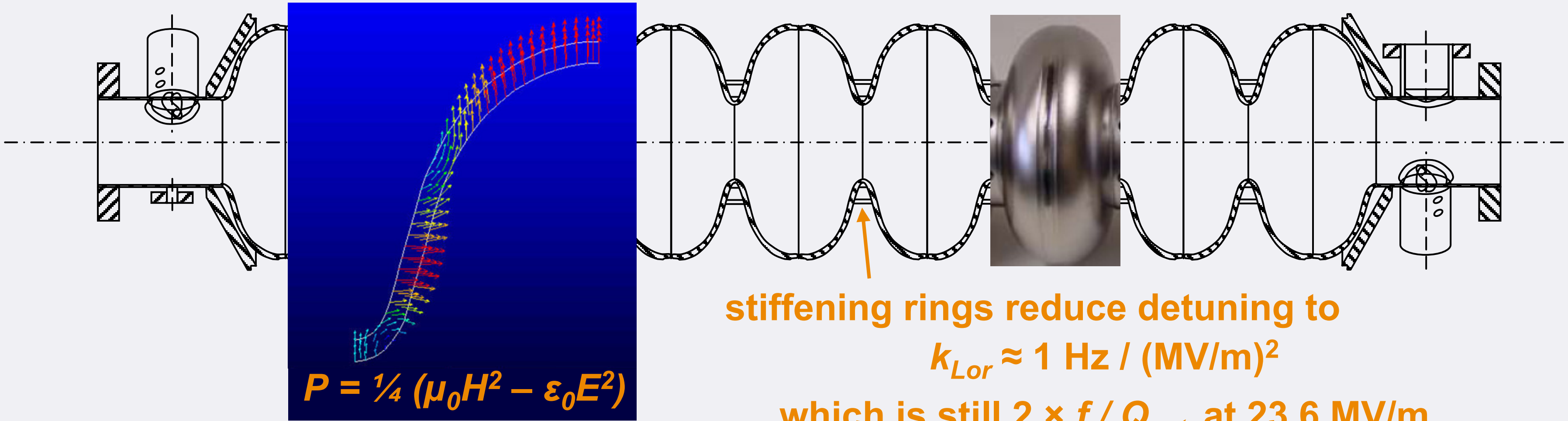

stiffening rings reduce detuning to
$k_{Lor} \approx 1$ Hz / (MV/m)^2
which is still $2 \times f / Q_{ext}$ at 23.6 MV/m

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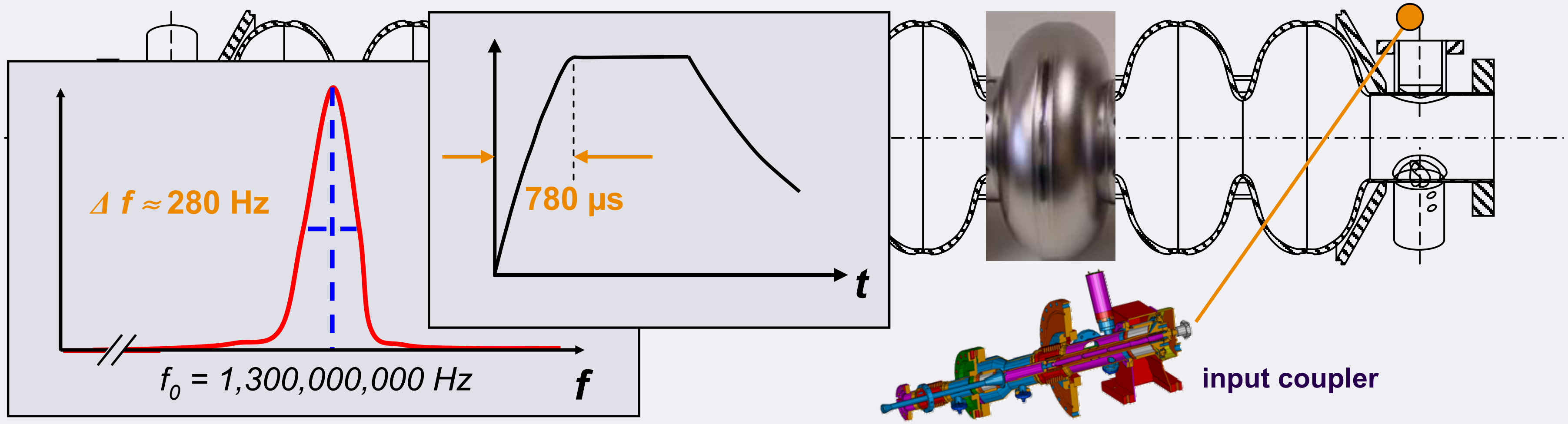

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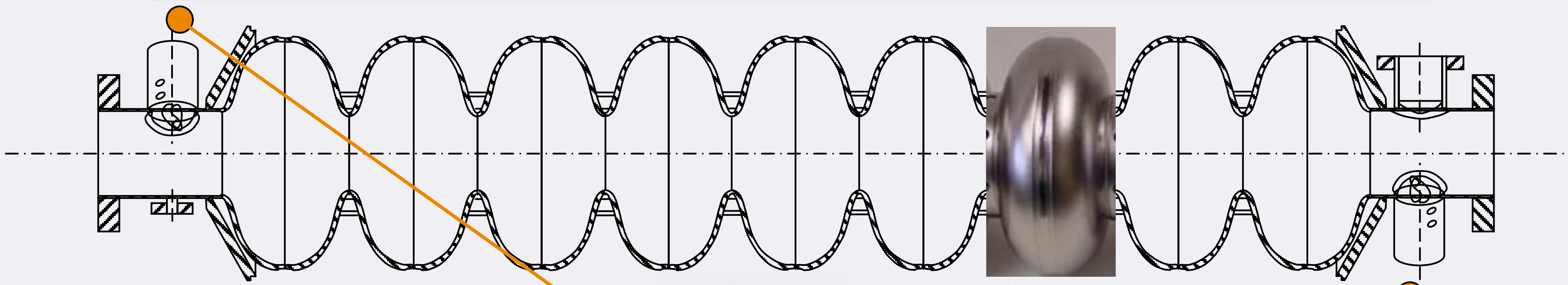
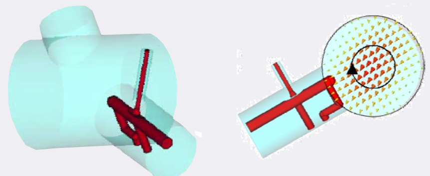
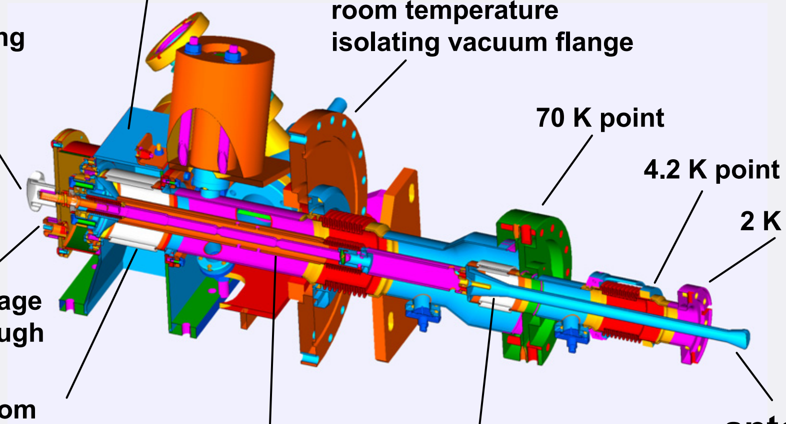


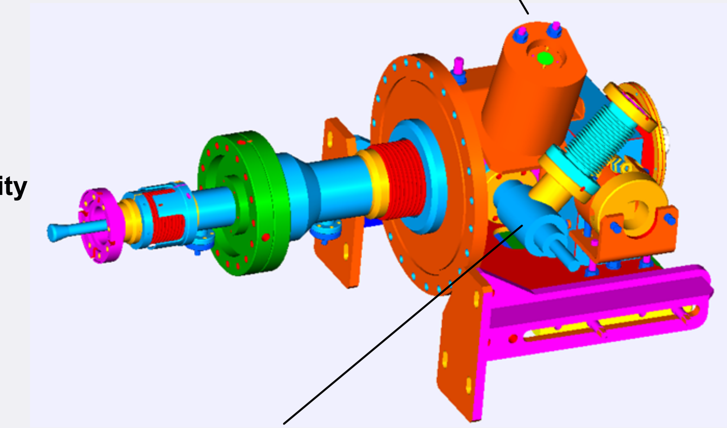
Higher Order Mode excitation has to be avoided.



HOM coupler

Auxiliaries – Main Power Coupler





At 20 GeV design energy 120 kW are required for the 650 µs long beam pulse; with 10 Hz rep rate and 720 µs filling time the average power amounts to 1.6 kW.

Q_{ext} can be varied in the range of 10^6 – 10^7. At 23.6 MV/m the optimum Q_{ext} is 4.6×10^6.

Couplers were tested to transmit 1.5 MW of peak RF power in traveling wave mode and 600 kW / 5 Hz in standing wave mode. In a 35 MV/m cavity test, one coupler was operated 2,400 hours at 2.5 kW average RF power.

The two window solution protects the cavity vacuum. Multipacting is suppressed by the coaxial line's design and additional bias voltage (up to 5 kV)

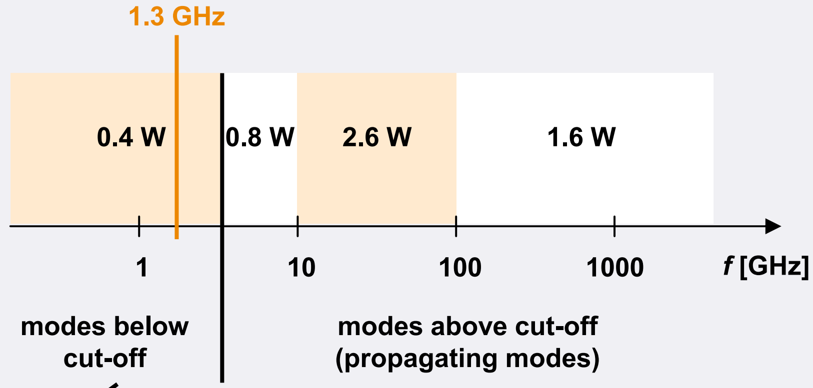
Industrial studies for 1,000 couplers are done at LAL Orsay. Recently the production of 30 couplers was supervised and the conditioning done at Orsay with great success.

Damping of Higher Order Modes (HOMs)

The spectrum of the electron bunch (σ_z = 25 µm) reaches high frequencies up to 5 THz.

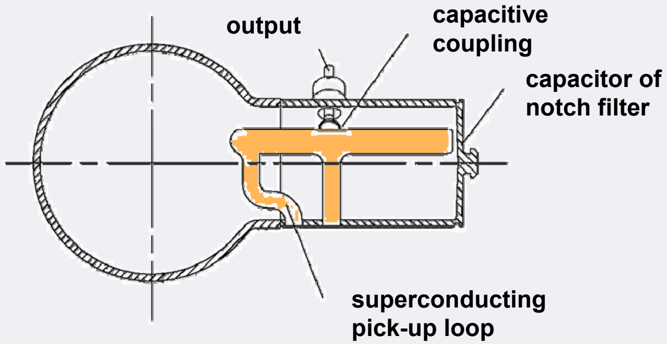
The standard accelerator module has an integrated loss factor of 135 V/pC.

The total power deposited by the nominal beam is 5.4 W per module.

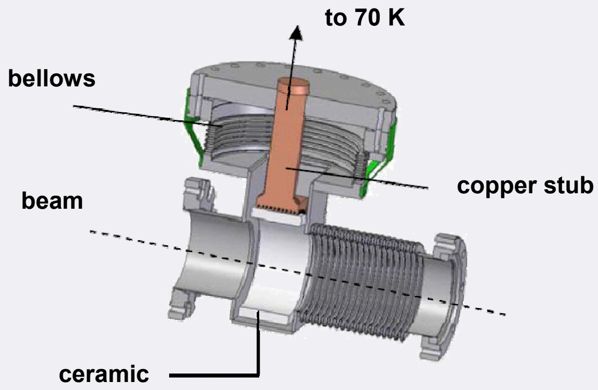


The design of the HOM coupler and the beam pipe absorber take into account a possible XFEL upgrade (more bunches / CW mode).

The HOM coupler was tested in CW mode. The absorber is specified for 100 W.

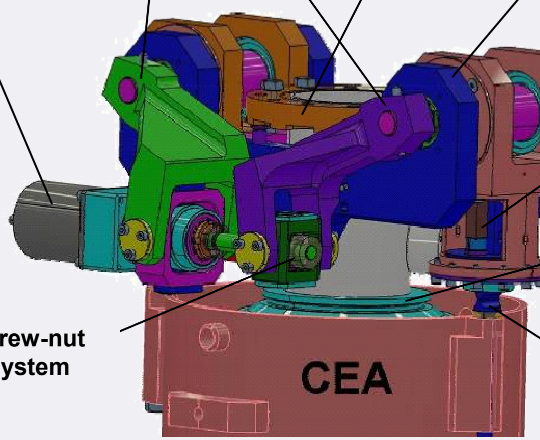


HOM coupler

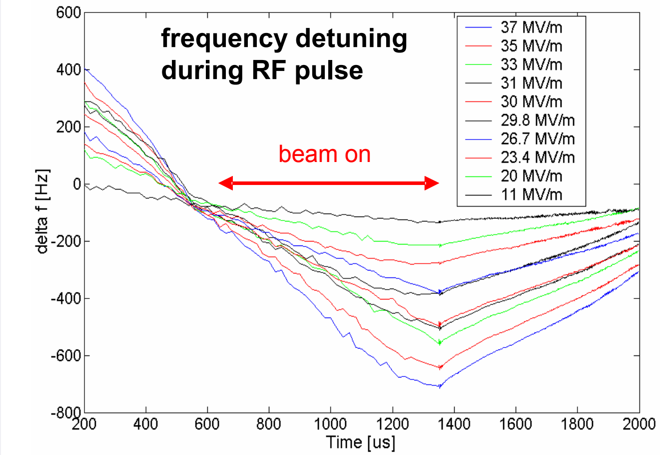


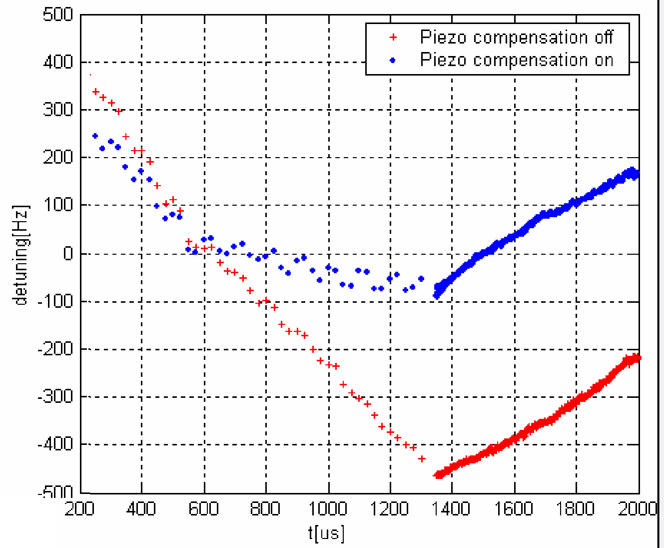
beam pipe absorber

Slow and Fast Tuner



The helium vessel acts as the mechanical reference (the titanium bellows is not shown)



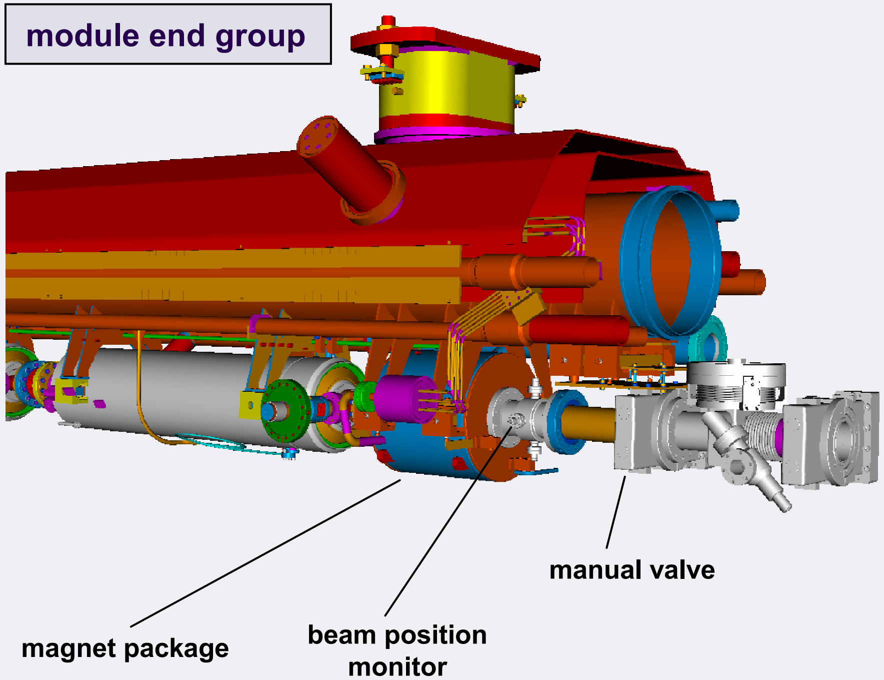


The slow tuner compensates for drifts; 400 kHz range , 1 Hz resolution

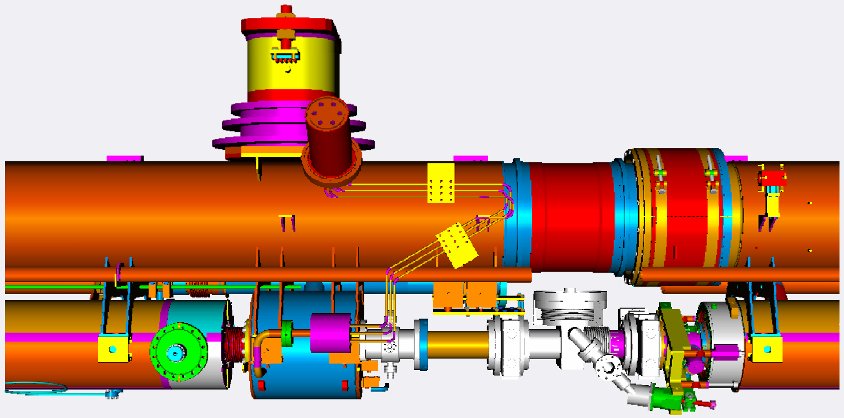
The fast tuner compensates the Lorentz-Force detuning during the RF pulse. It is based and piezo crystals.

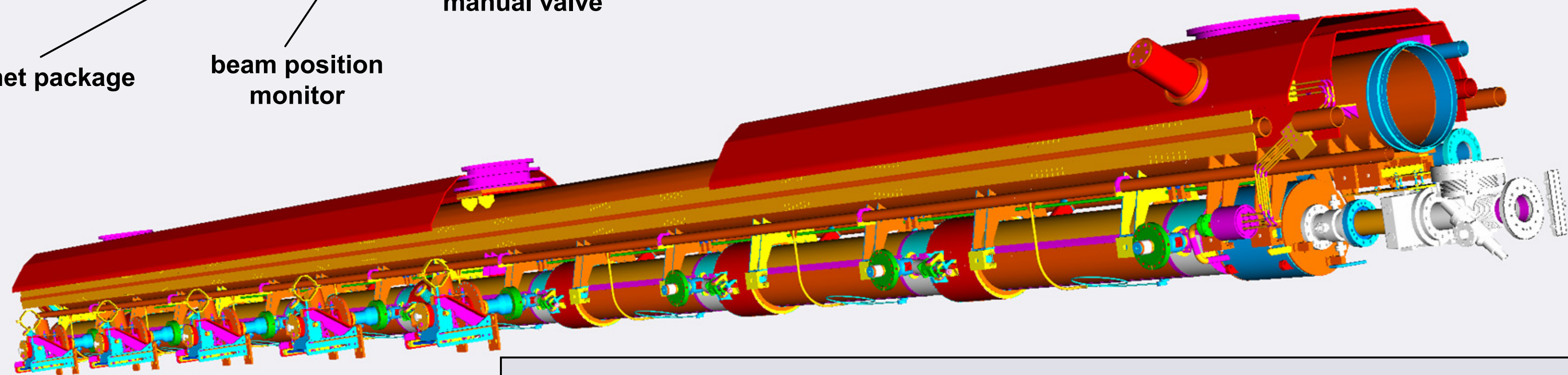
Accelerator Module (Cryomodule)

module end group



module to module connection.





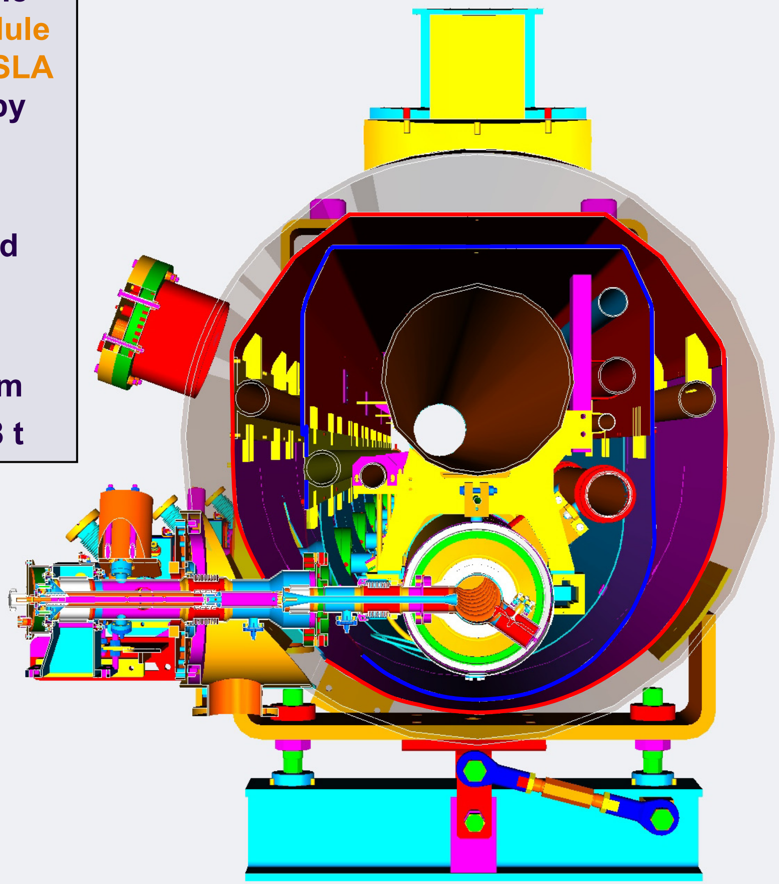
cold mass with cavities, magnet / BPM, HOM abs. beam pipe, valve.

Accelerator Module (Cryomodule)

The XFEL accelerator module is based on the 3rd cryomodule generation tested at the TESLA Test Facility and designed by INFN.

Already more than 10 cryo-modules have been built and commissioned for the TTF Linac.

Length	12.2 m
Total weight	7.8 t



38" carbon steel vessel

300 mm He gas return pipe acting as support structure

8 accelerating cavities

cavity to cavity spacing exactly one RF wavelength

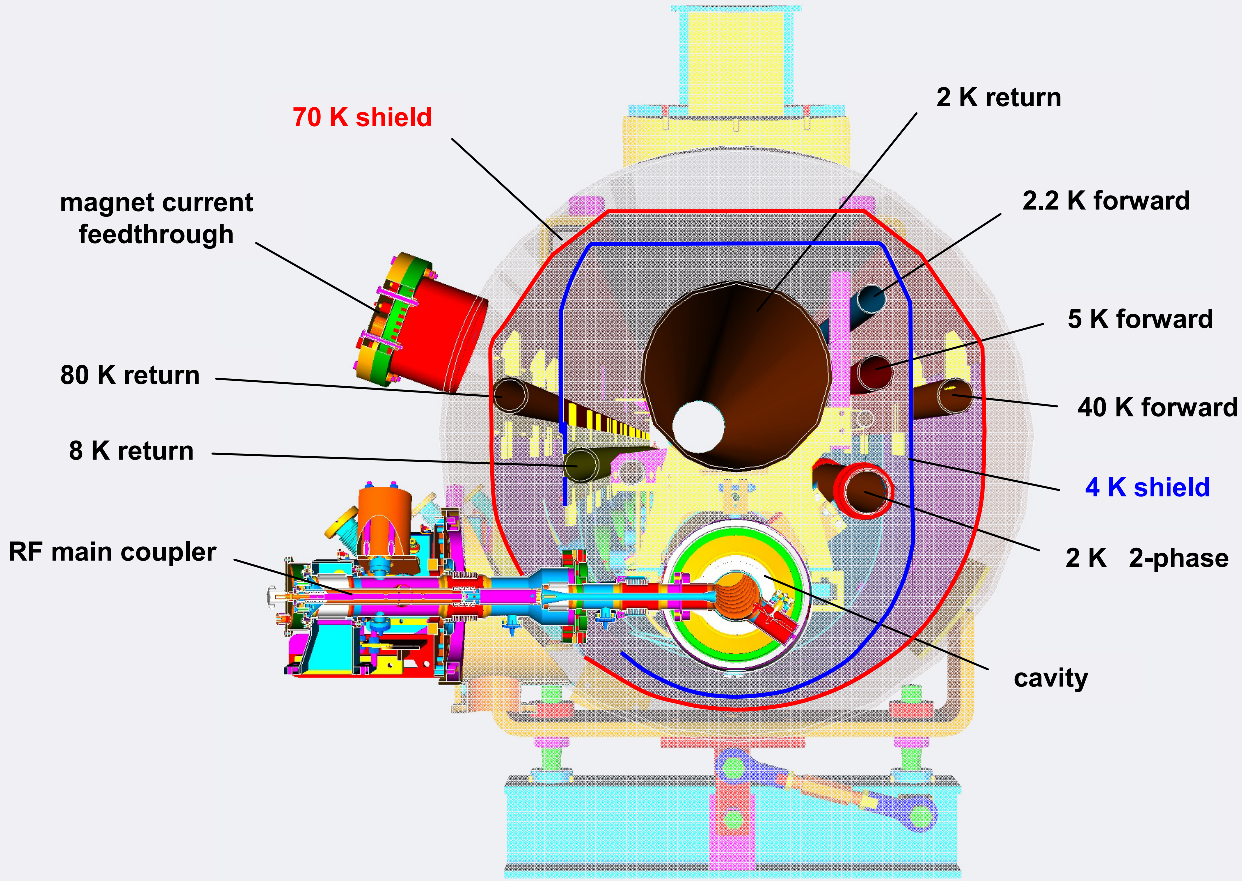
inter-module cavity to cavity spacing a multiple of one RF wavelength

one beam position monitor / magnet unit

manually operated valves to terminate the beam tube at both ends

longitudinal cavity position independent from the contraction / elongation of the HeGRP during cool-down / warm-up procedure

Accelerator Module (Cryomodule)



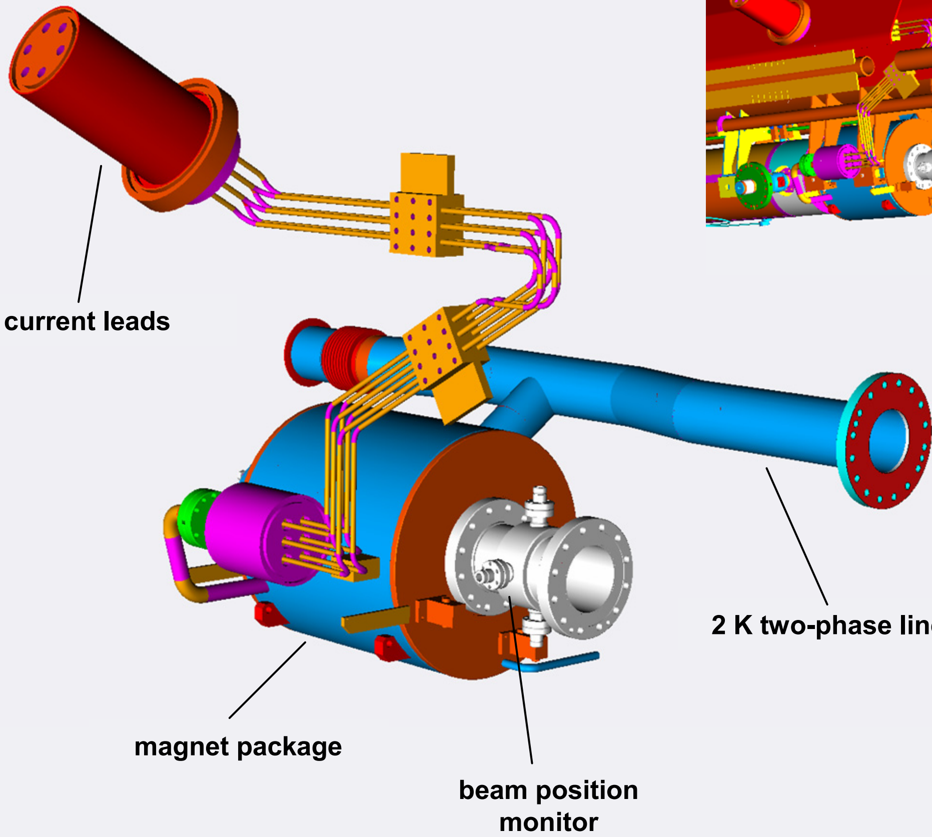
XFEL Magnet Package and Cold BPM

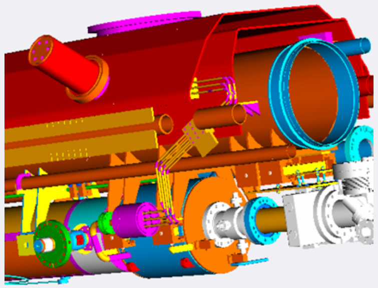
At the downstream end of the cavity string of each module a magnet package and an attached BPM is placed.

- **a super-ferric quadrupole**
- **a vertical and a horizontal dipole**
- **BPM is either re-entrant (SACLAY design) or pick-up (DESY design) type.**

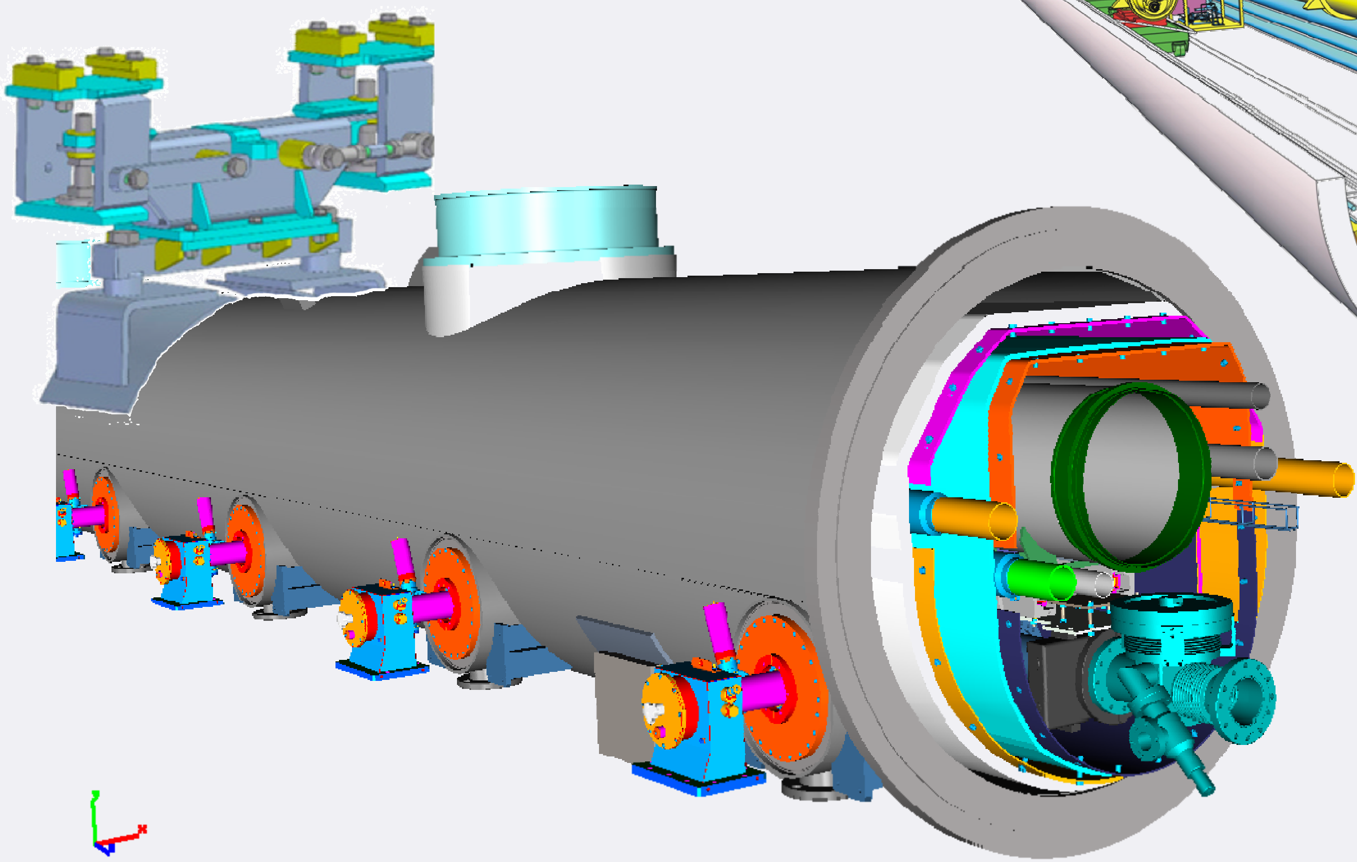
Quadrupole to BPM alignment is 0.3 mm and 3 mrad.

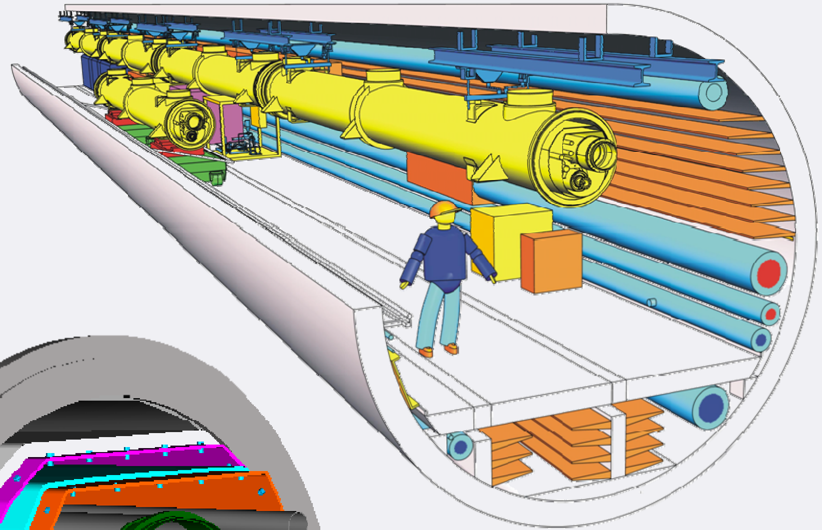
The magnet design is done in collaboration with CIEMAT. The current leads are based on the CERN design used at LHC.





XFEL Module Suspension



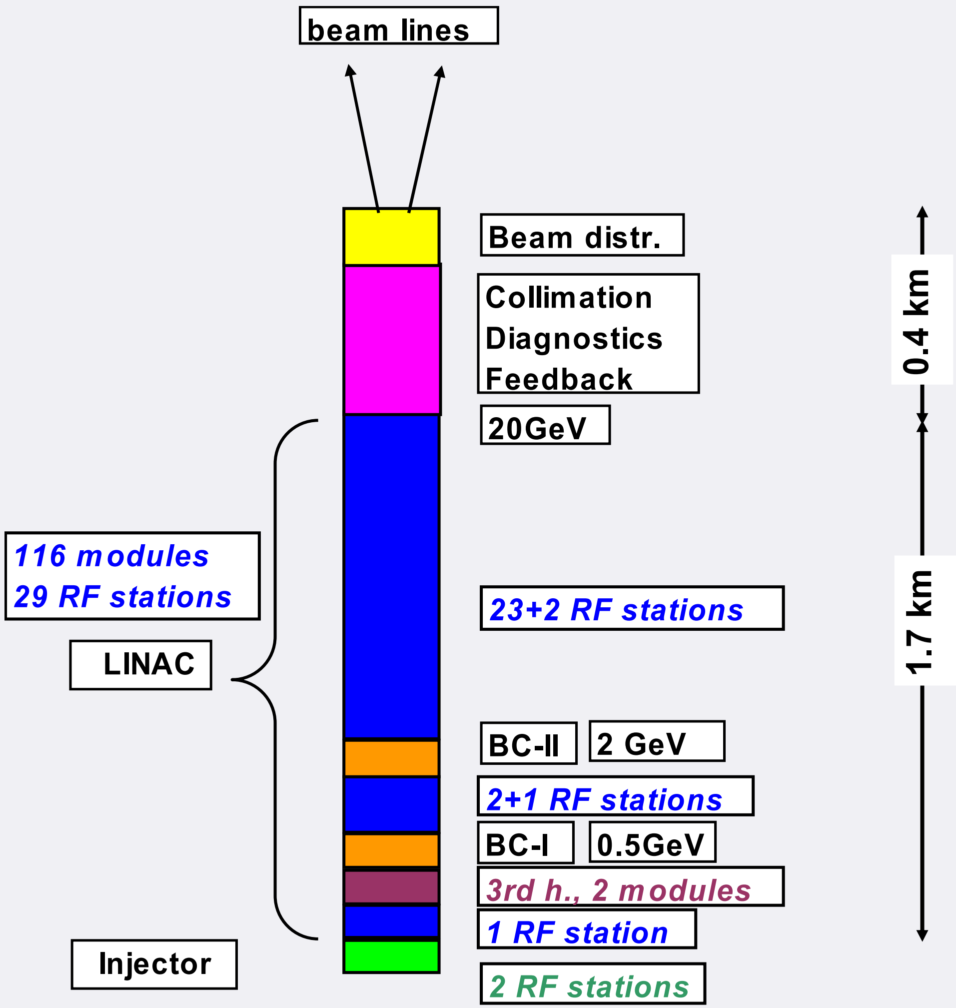


XFEL Accelerator Layout Supports Availability

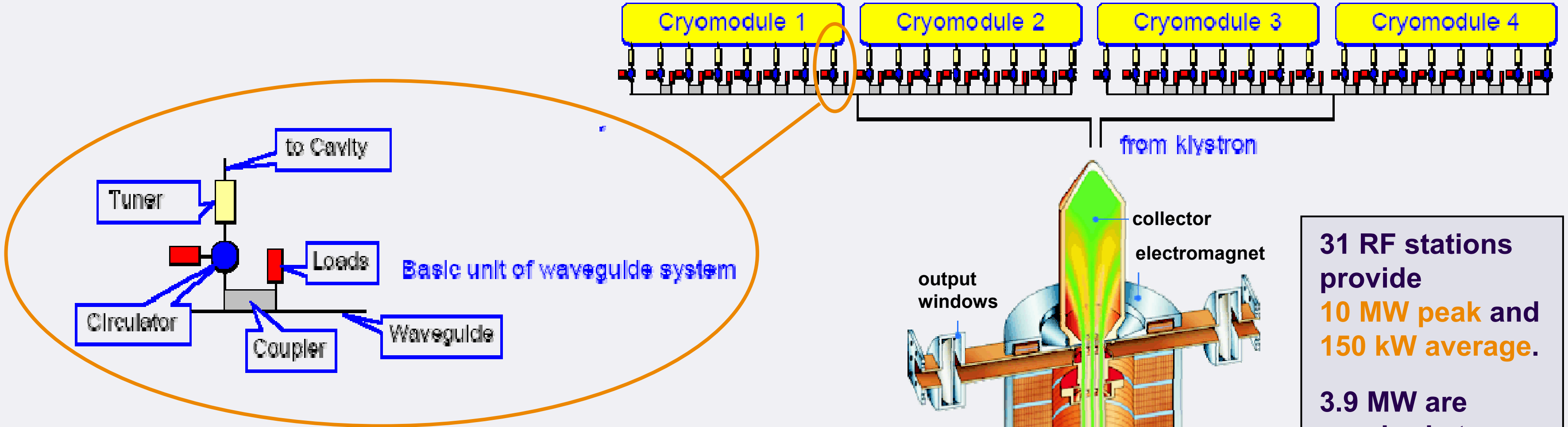
2 – 20 GeV
- (23 + 2) x 4 = 100 acc.modules
- 800 cavities at 21.7 MV/m or
- 736 cavities at 23.6 MV/m
- (23 + 2) RF stations inside tunnel

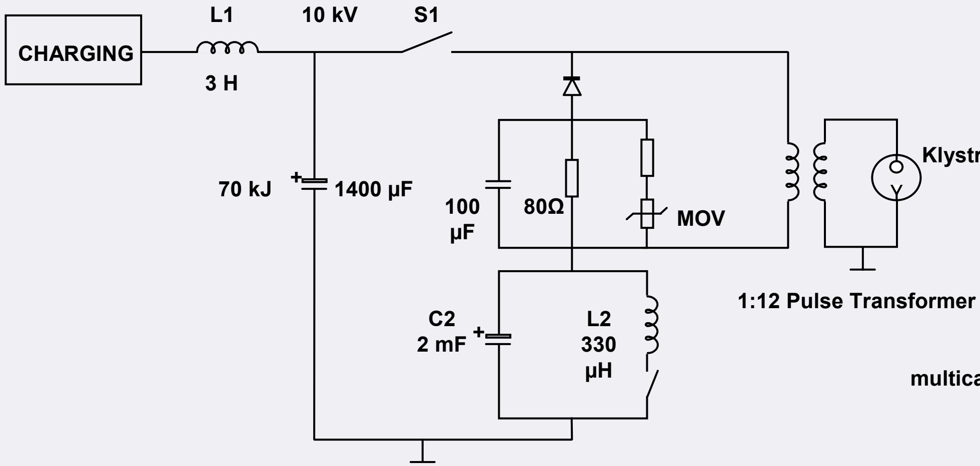
500 – 2000 MeV
- 12 acc.modules
- 96 cavities at 15.1 MV/m or
- 64 cavities at 22.6 MV/m
- (2 + 1) RF stations inside tunnel

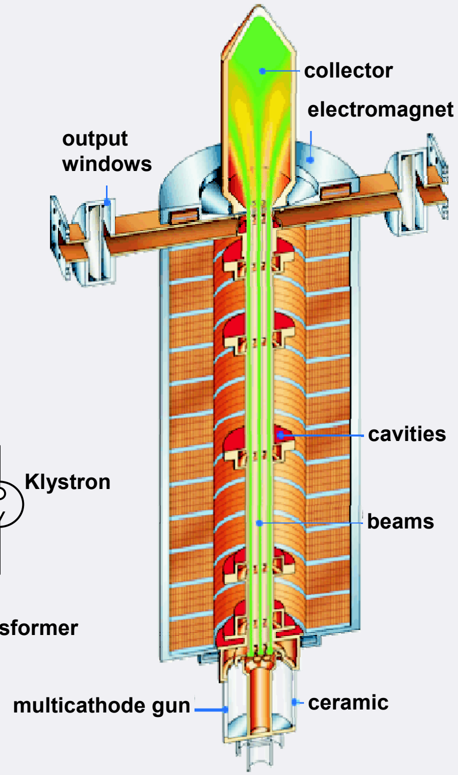
100 – 500 MeV
- 4 acc.mod.
- 32 cavities at 12.5 MV/m
- RF station outside tunnel



High Power RF System (Overview)







31 RF stations provide 10 MW peak and 150 kW average.

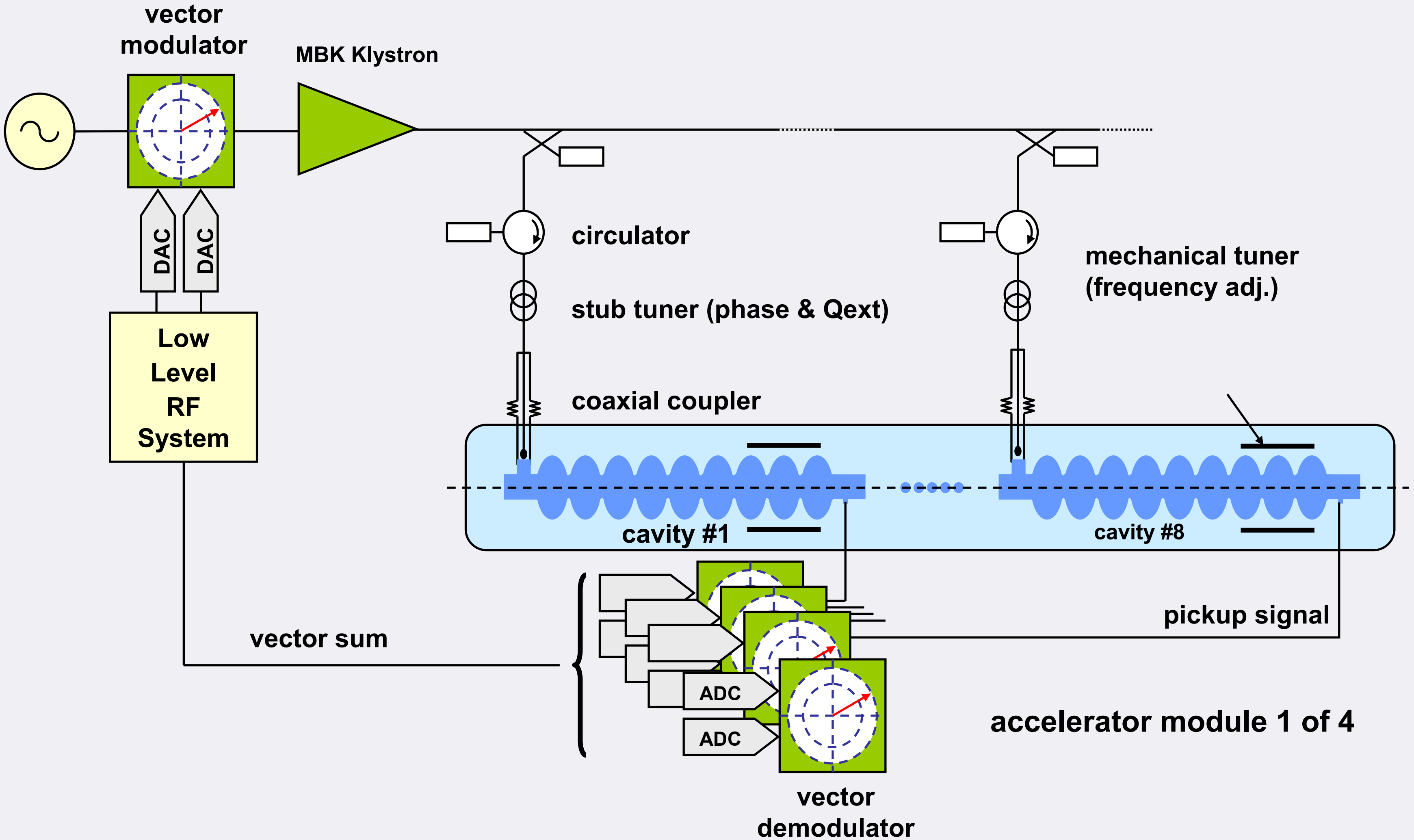
3.9 MW are required at nominal beam parameters and 20 GeV.

Incl. waveguide losses (6%) and regulation reserve (15%) 5.2 MW.

High Power RF System (Parameter)

		nominal	max
nbr. of sc cavities in main linac		928	
peak power per cavity	[kW]	122	230
gradient	[MV/m]	23.6	28.5
power per 32 cavities	[MW]	3.9	8.3
power per RF station	[MW]	5.2	10
nbr. of installed linac RF stations		29	
minimum nbr. of active linac RF stations		26	
nbr. of installed injector RF station		2	
RF pulse duration	[ms]	1.38	1.5
repetition rate	[Hz]	10	10 (50)
average klystron beam power	[kW]	153	250
av. RF power during operation	[kW]	71	150

Low Level RF Control



Low Level RF Control (Requirements)

Amplitude and Phase Stability

Design parameter are based on

- **bunch-to-bunch energy spread**
- **pulse-to-pulse energy spread**
- **bunch compression in the injector**
- **arrival time of the beam at the undulator**

The injector RF system needs 0.01% amplitude and 0.01 deg phase stability!!!

(stability of photon intensity)

Operational Requirements

Beside field stabilization, the RF system must provide

- **diagnostics for the calibration of gradient and beam phase**
- **measurement of the loop phase**
- **measurement of the cavity detuning**
- **control of the cavity frequency tuners (use fast tuner to correct Lorentz Force detuning)**
- **exception handling capability to avoid beam loss and to allow for maximum operable gradient**

  e.g. cavity quench detection

  'communicate' with spare RF stations
- **correct RF system parameters (feed forward tables) according to variable beam loading**