FUTURE CIRCULAR COLLIDER

ENERGY AND SUSTAINABILITY FOR FUTURE CIRCULAR COLLIDER

Industry meeting
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Jean-Paul Burnet (CERN)

Technical and Infrastructure Working Group
Electricity & Energy Management Work Package

http://cern.ch/fcc

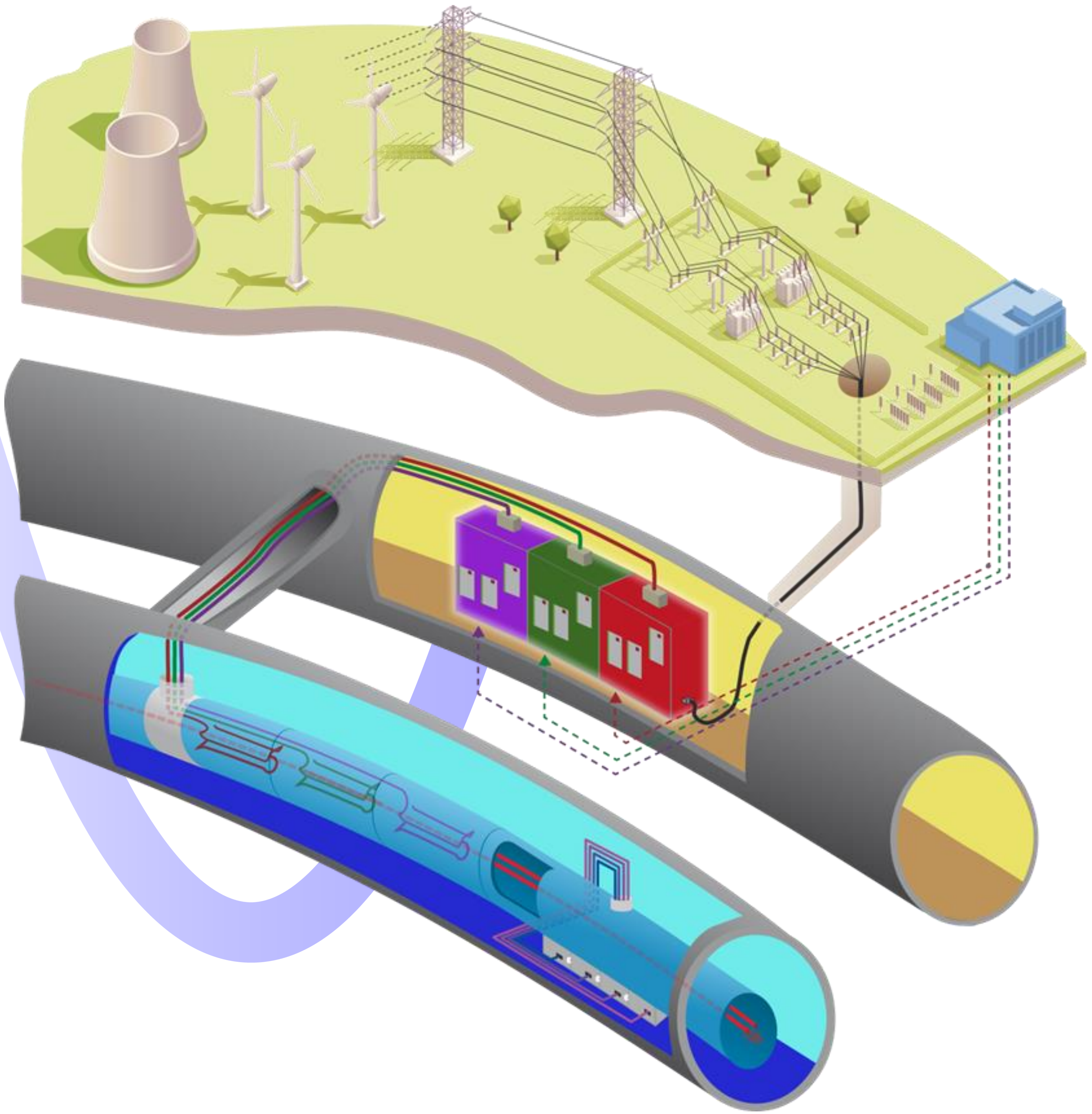
Abstract

The FCC-ee will be the largest accelerator ever built with kilometres of different accelerator devices.
The identification of the main loads is crucial for designing the electricity infrastructure and for evaluating its energy consumption.
An update of the FCC power demand is ongoing with the evaluation of its annual energy consumption depending on the operation modes of the machine.
The next step is to identify how energy consumption can be reduced, by design and optimization of equipment and systems, and by optimization of the operation mode of the accelerators and their infrastructures.
The goal is to identify where the effort needs to be focused to minimise the environmental impact of the project.

Content

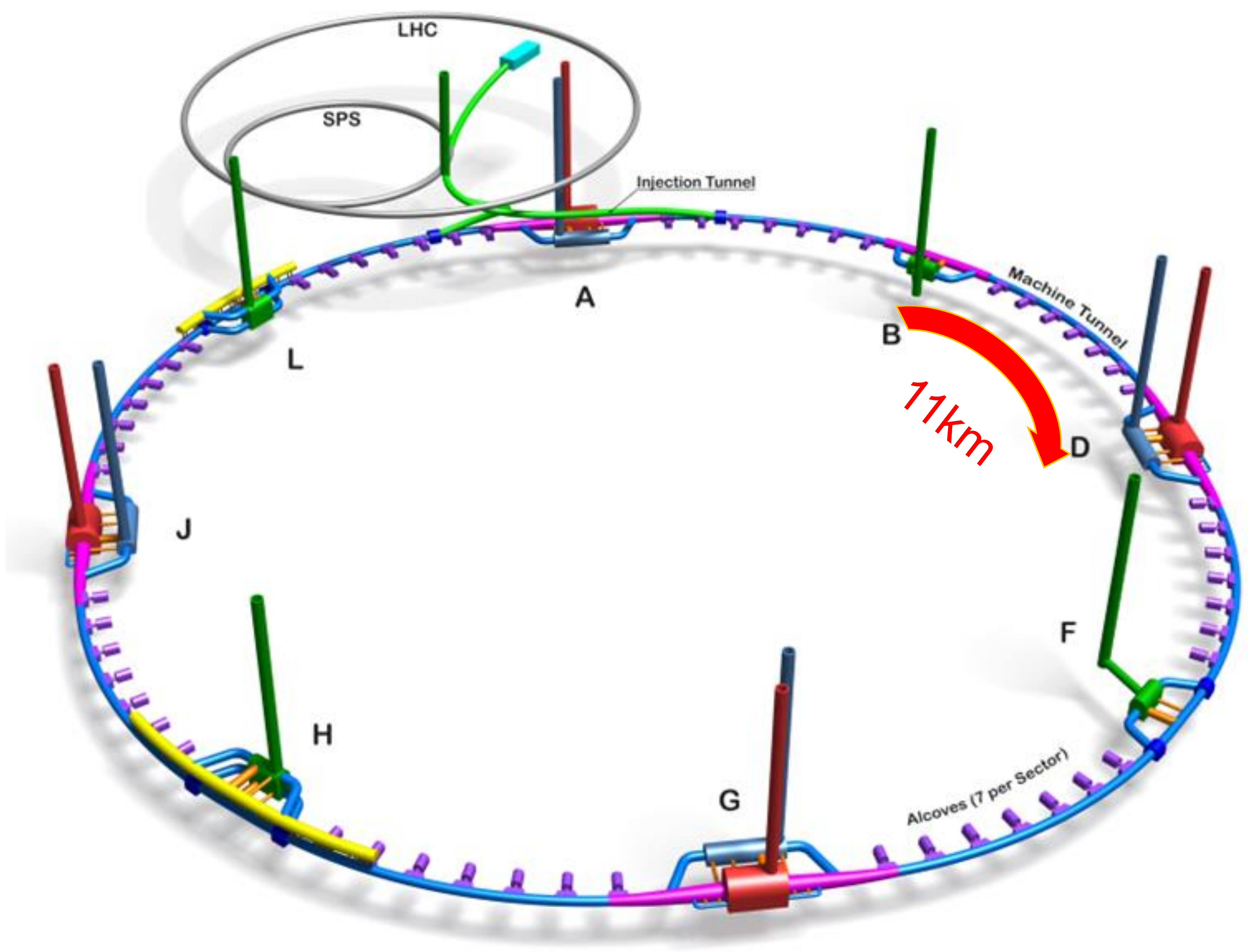
- FCC-ee a very large machine
- FCC-ee power demand
- FCC-ee as sustainable accelerator
- FCC electricity consumption 2036-2065

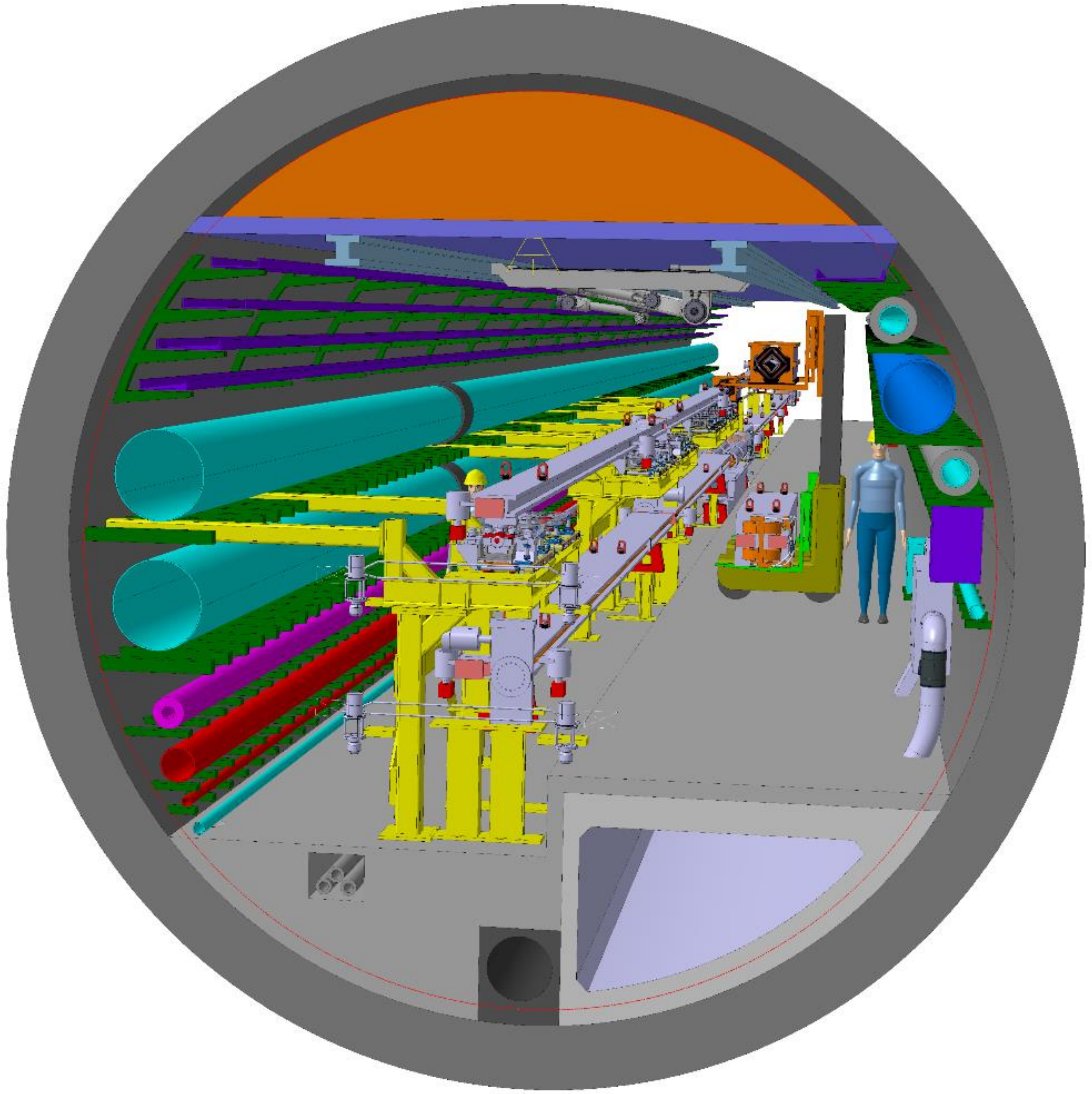
FCC-EE A VERY LARGE MACHINE



A very large machine

8 Arcs of 11km, full of magnets, pipes, cables…

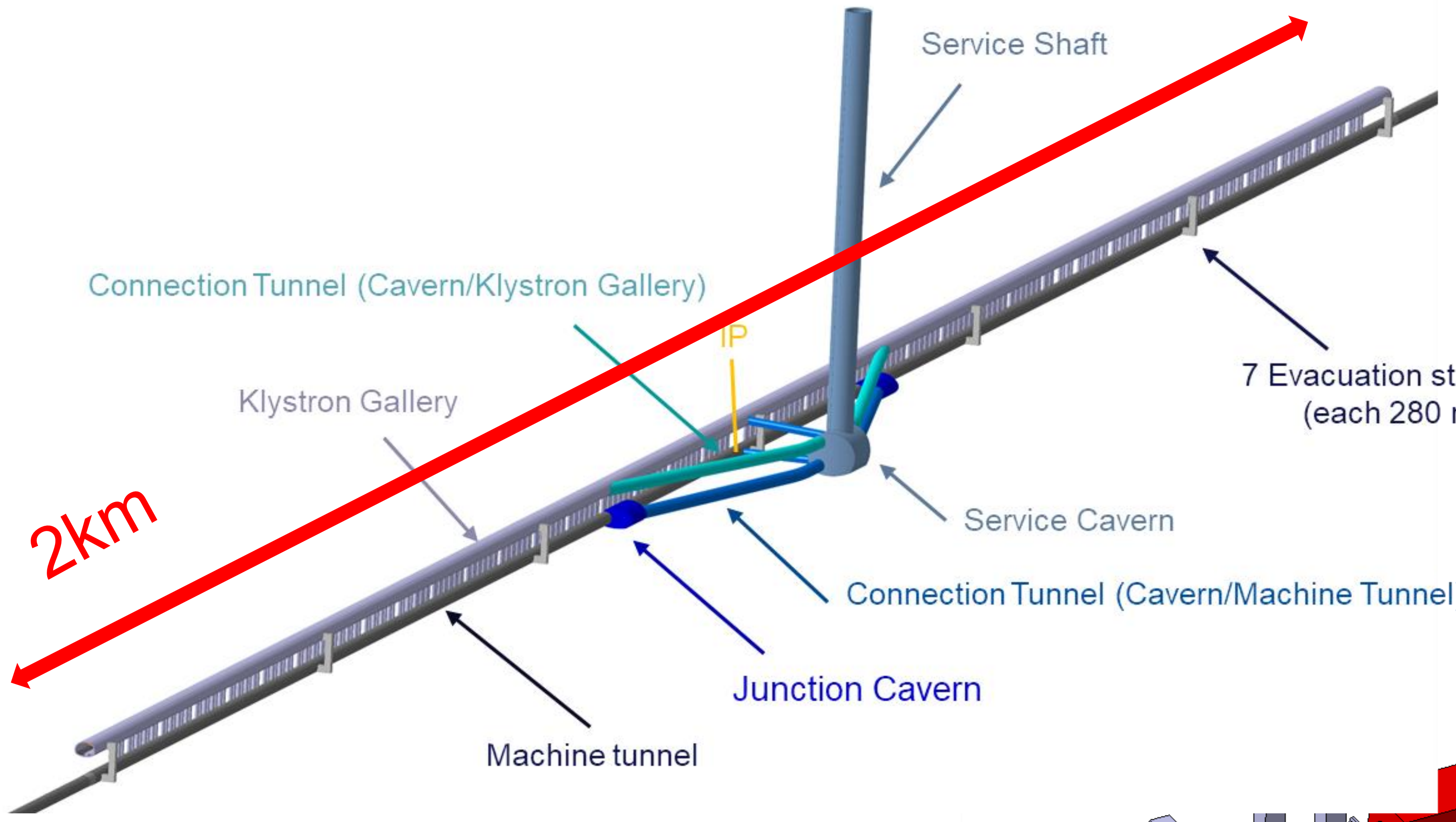


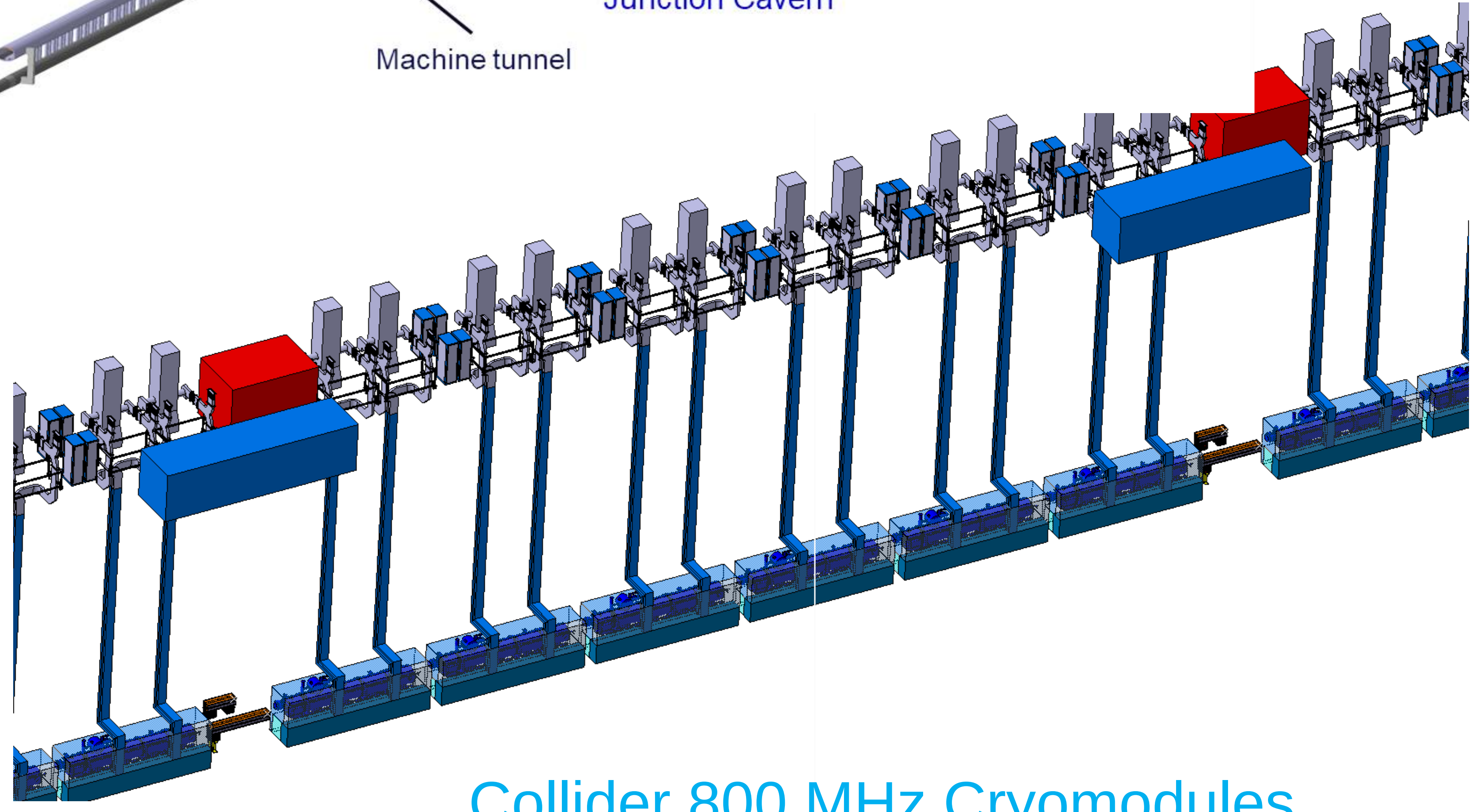


91km tunnel, 230m underground, 8 access points, 40 hectares of surface sites

A very large machine

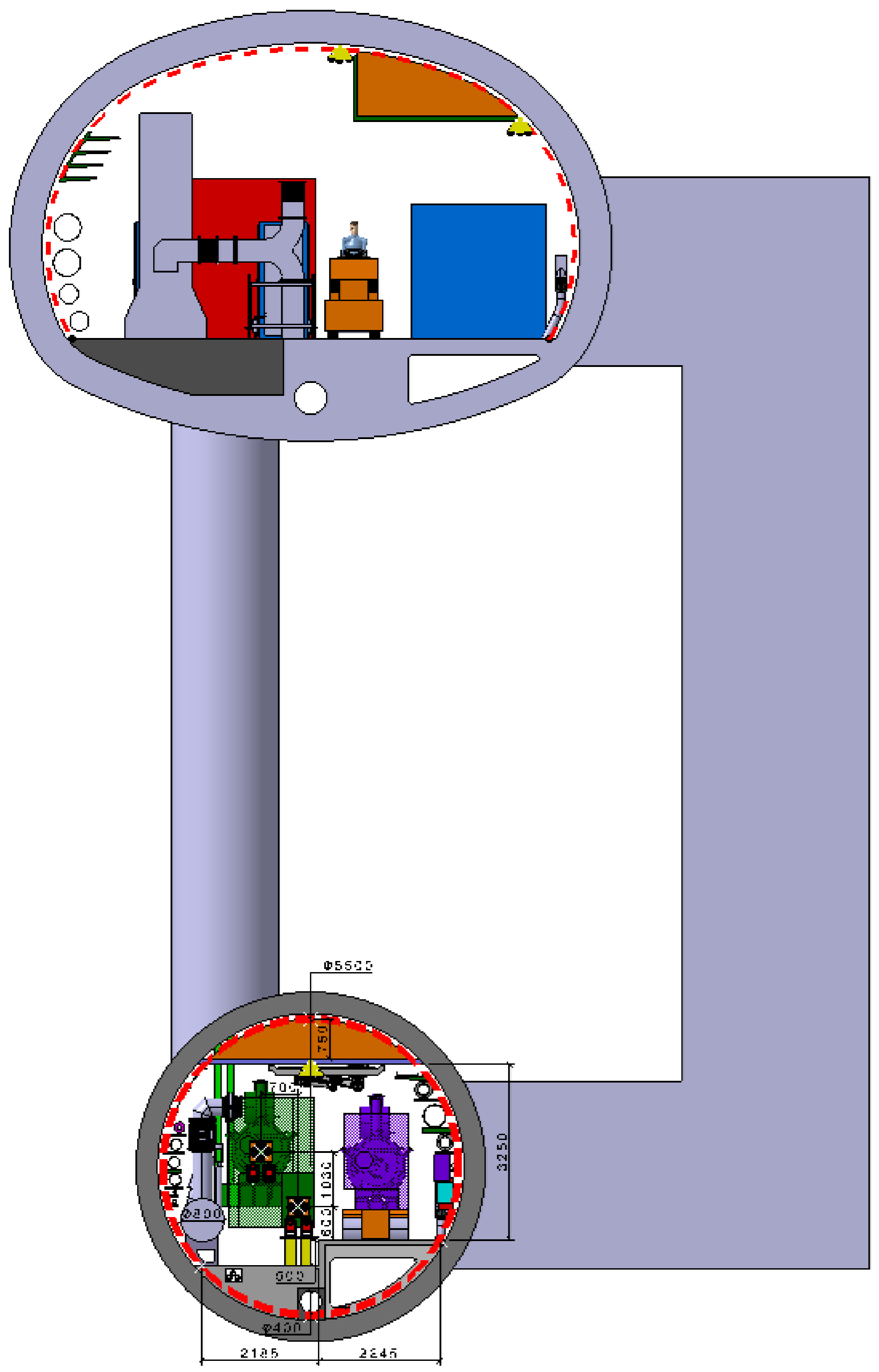
2 straight sections, full of superconducting radiofrequency cavities



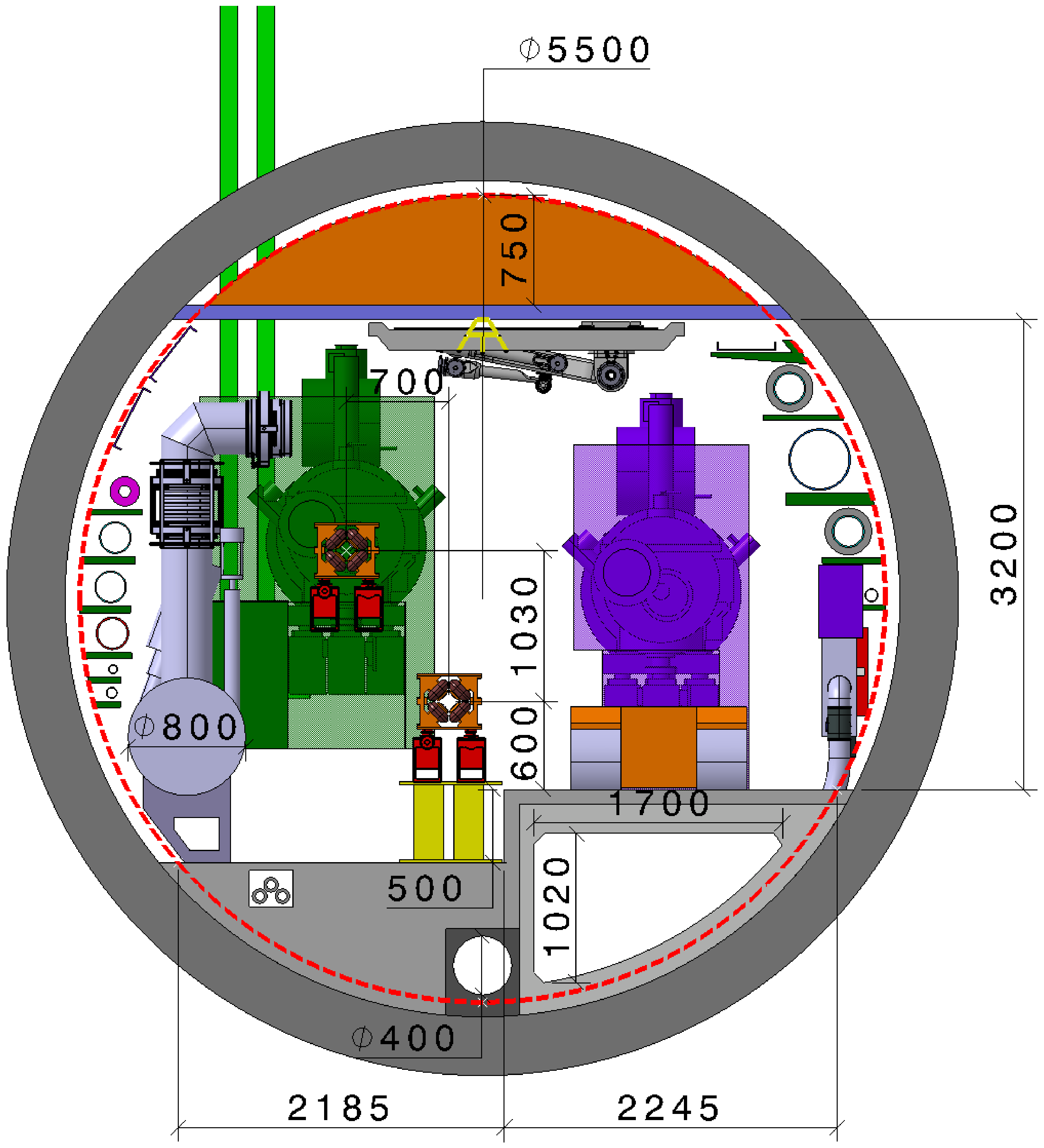


Collider 800 MHz Cryomodules

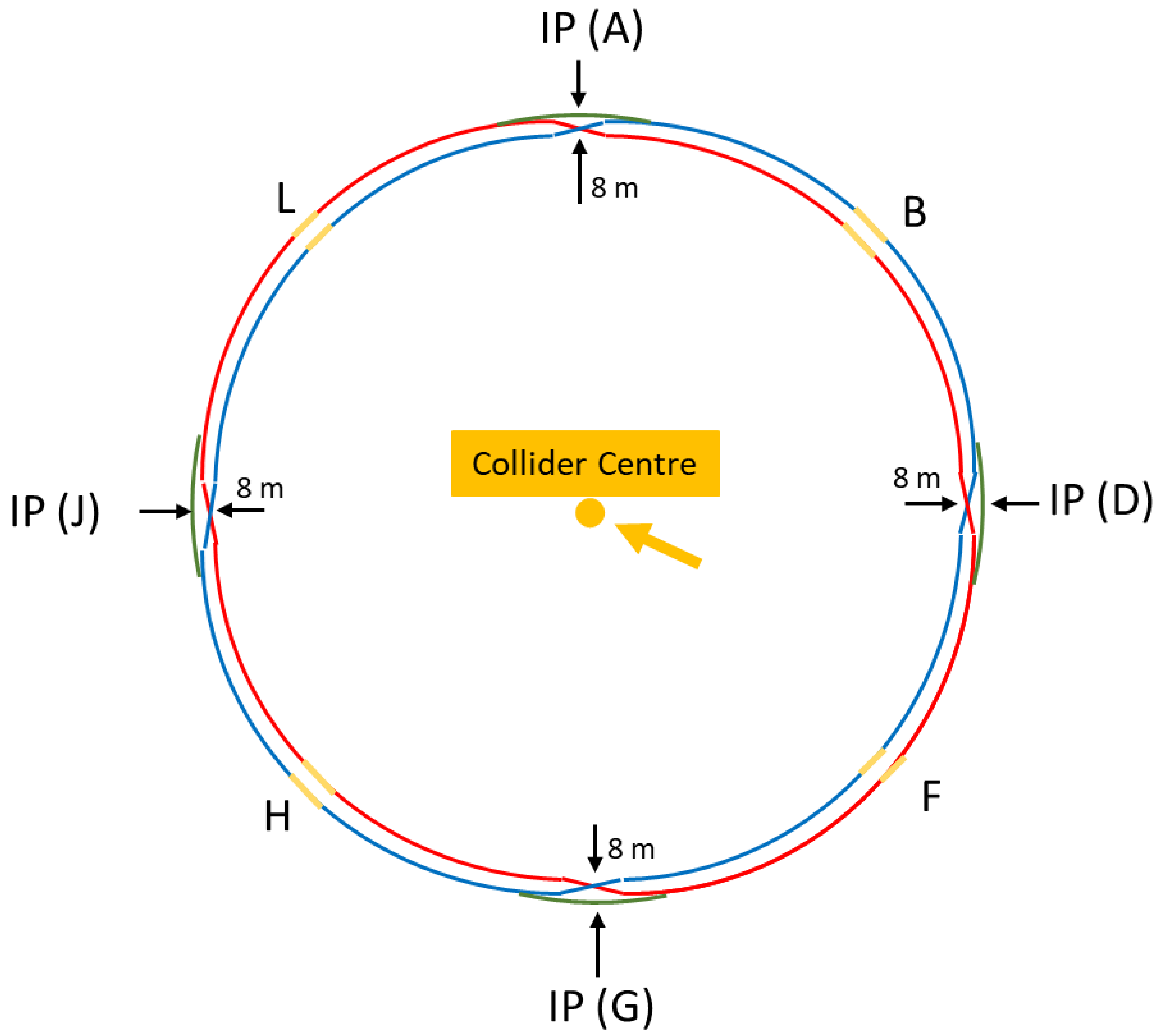
Klystron, circulator & rack



Waveguide

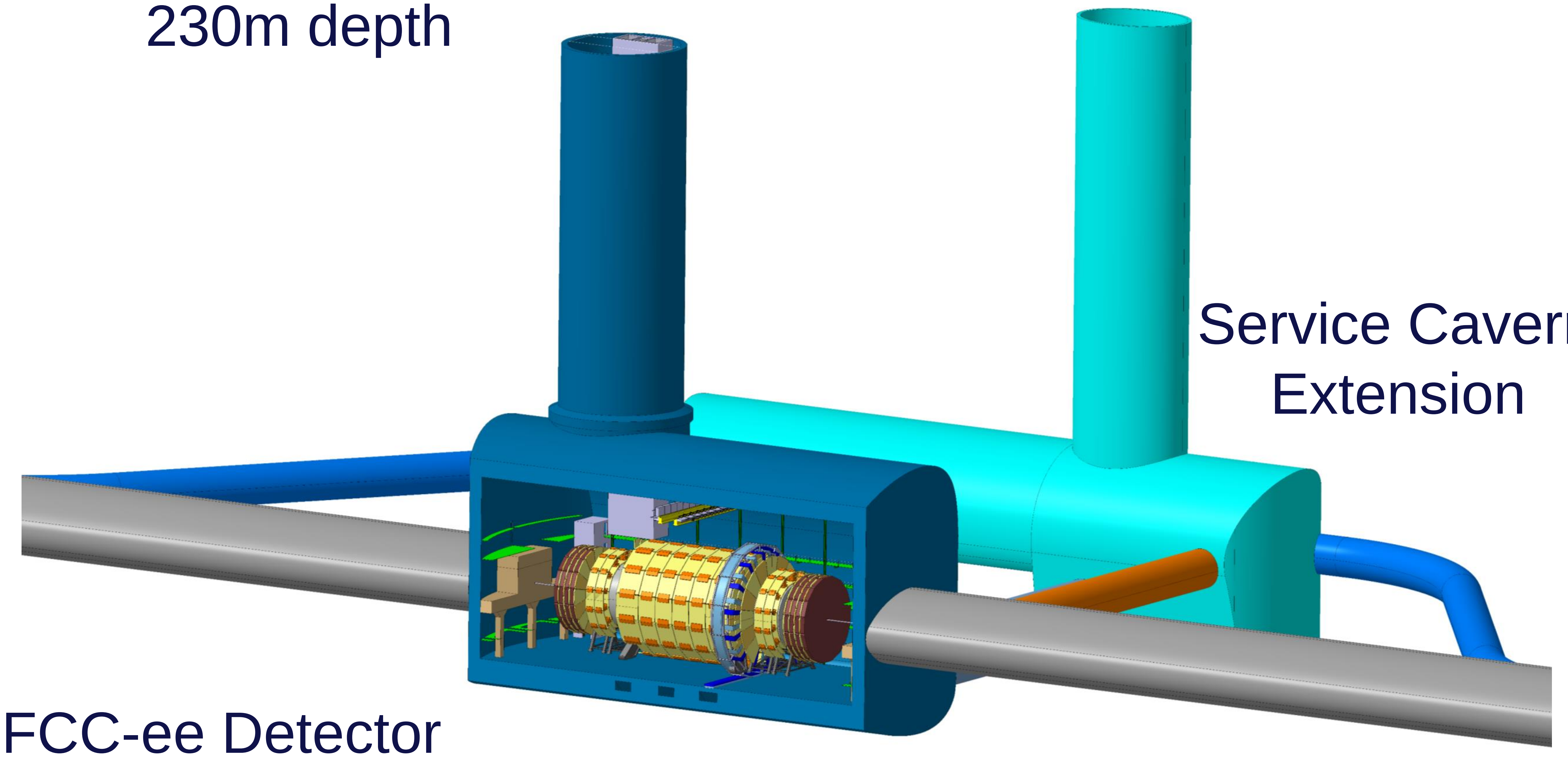


A very large machine



Arc section full of magnets

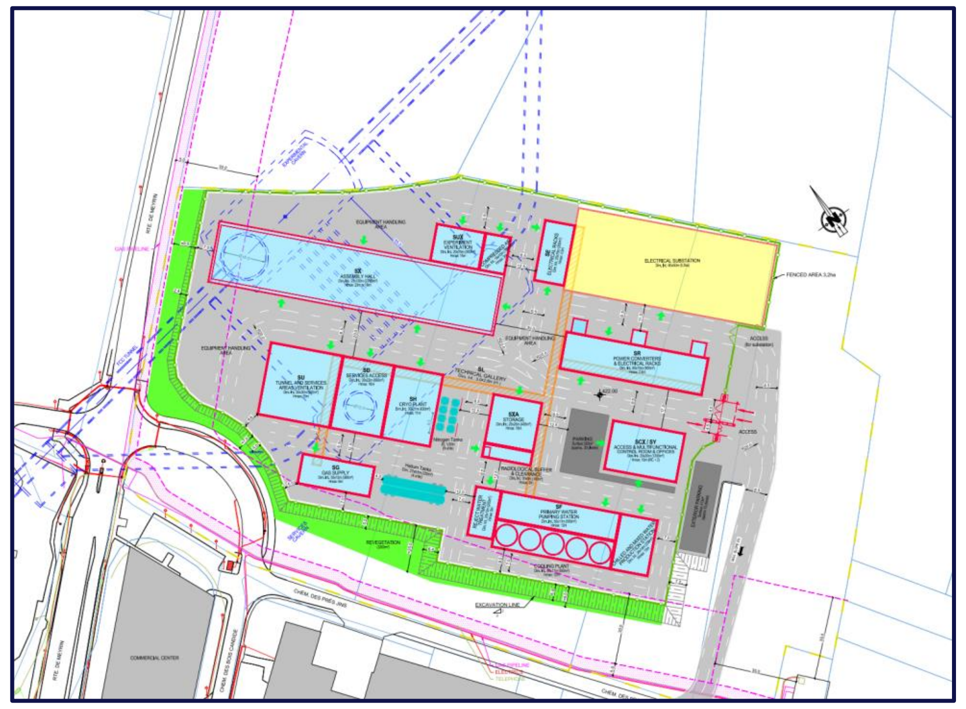
Four experiments at interaction points



A very large machine

8 surface sites, 40 hectares

For technical infrastructures, experiments and access
Cooling towers
Ventilation building
Cryogenics building
Electrical sub-station
Data-centres
Detector assembly hall
Pump stations
…

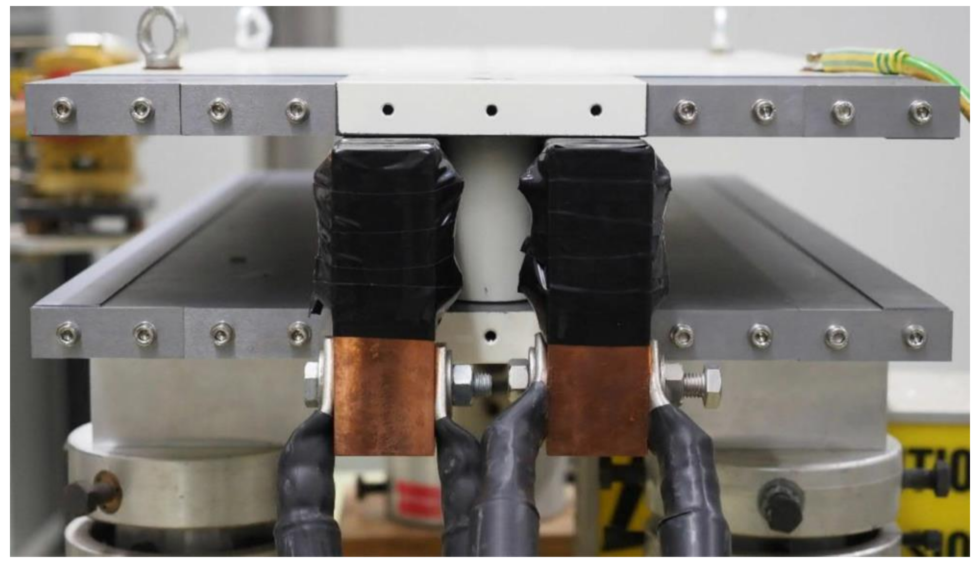


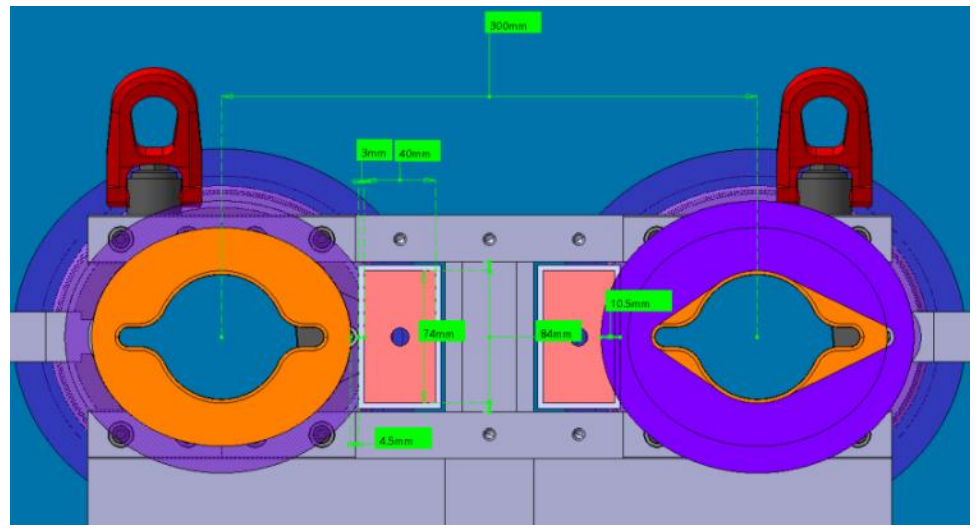
Accelerator technologies

FCC-ee main accelerator systems

Superconducting radiofrequency cavities
RF amplifiers (klystrons, solid-states)
Cryogenics
Magnets
Power supplies
NEG-coated vacuum chambers, 270km
Ultra-high vacuum pumps
Beam instrumentations

…





All powered by electricity

Power demand estimation by operation mode

2023		Z	W	H	TT
Beam energy (GeV)		45.6	80	120	182.5
Magnet current		25%	44%	66%	100%
Power ratio		6%	19%	43%	100%
PRF EL (MW)	Storage	146	146	146	146
PRFb EL (MW)	Booster	2	2	2	2
Pcryo (MW)	Storage	1.2	11.5	11.5	27.6
Pcryo (MW)	Booster	0.35	0.80	1.50	7.40
Pcv (MW)	all	25	26	28	33
PEL magnets (MW)	Stroage	6	17	39	89
PEL magnets (MW)	Booster	1	3	5	11
Experiments (MW)	Pt A & G	10	10	10	10
Data centers (MW)	Pt A & G	4	4	4	4
General services (MW)		26	26	26	26
Power during beam operation (MW)		**222**	**247**	**273**	**357**

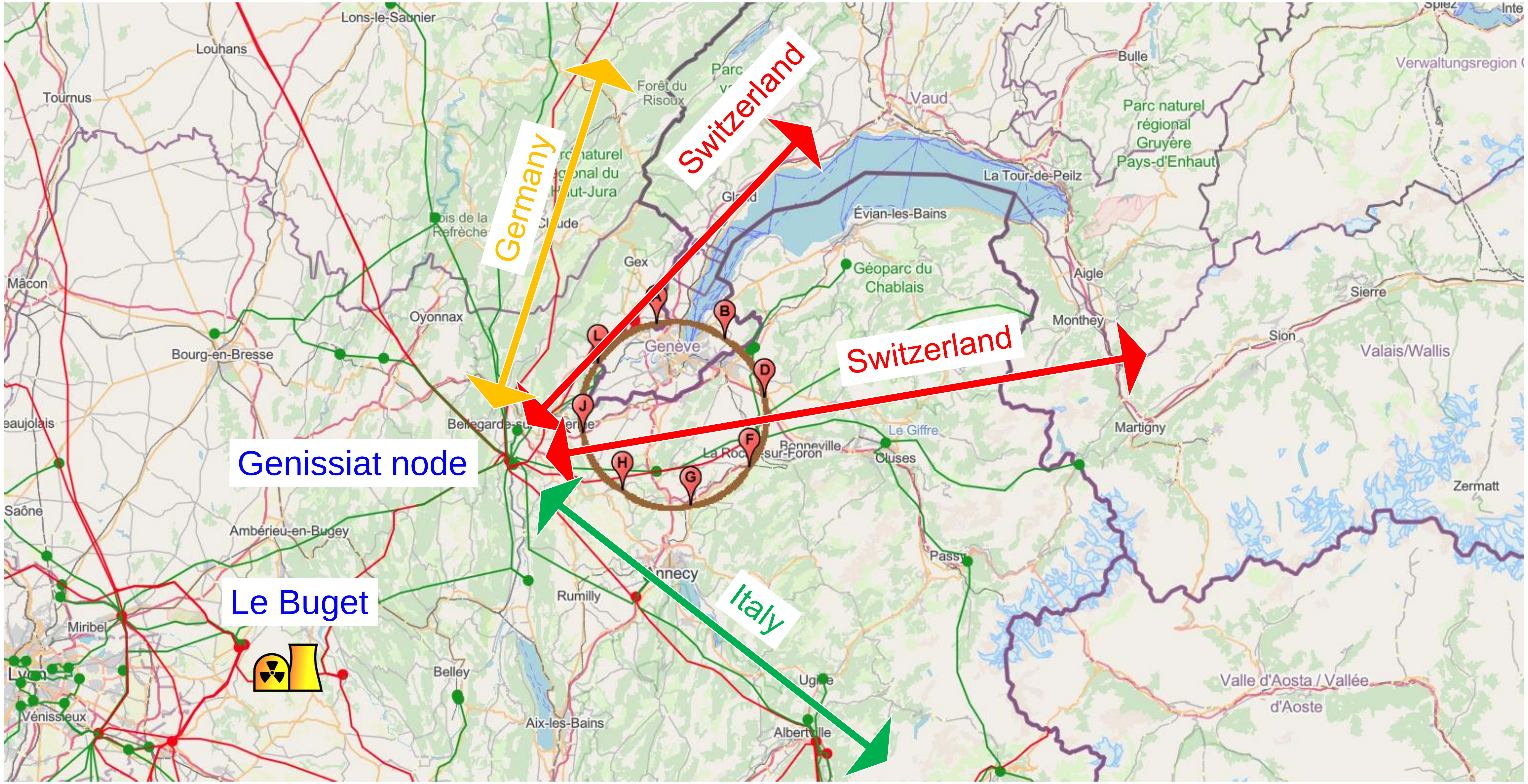
Request to grid operator for delivery points

CERN close to strong network connection

FCC well situated on a strong electricity node.

but priority of these 400 – 225 kV lines are for energy exchange between countries.

Red lines : 400kV
Green lines: 225kV



SUSTAINABLE ACCELERATOR

FCC as sustainable accelerator

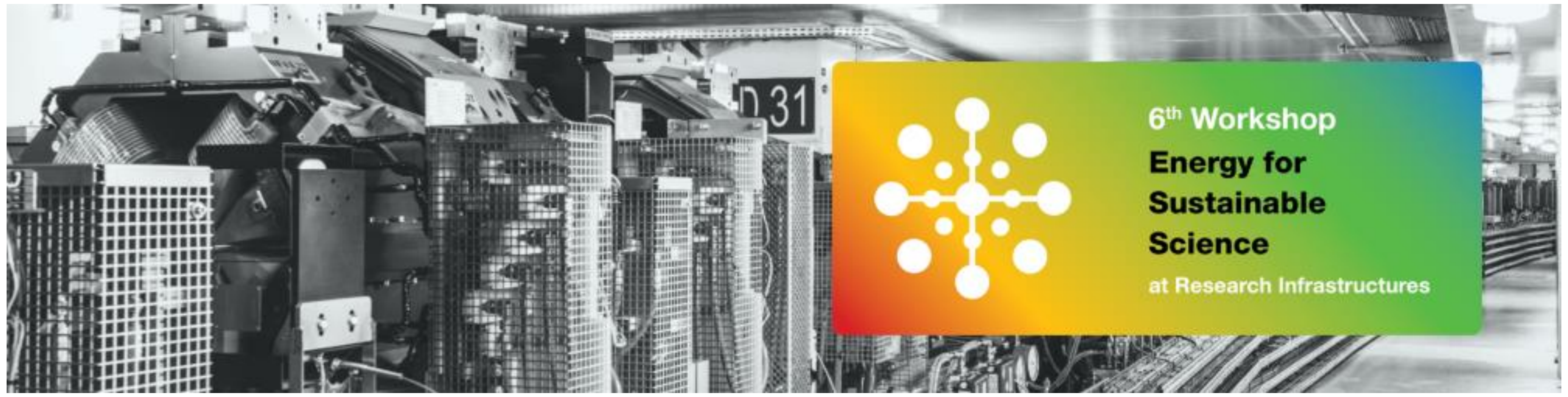
A sustainable accelerator needs to **minimize its impact** on

- Environment (Energy, CO_2 and water footprint, emissions, waste etc…)
- availability of resources (e.g. minimization of materials extracted),

While **maximizing the value** returned to society:

- Serious and valuable Scientific programme
- Generation of knowledge and transfer of Technology
- Training of students, professionals, Teachers…
- Social Justice

https://indico.esrf.fr/event/2/



Focus on energy saving, RF power

R&D on high-efficiency klystron

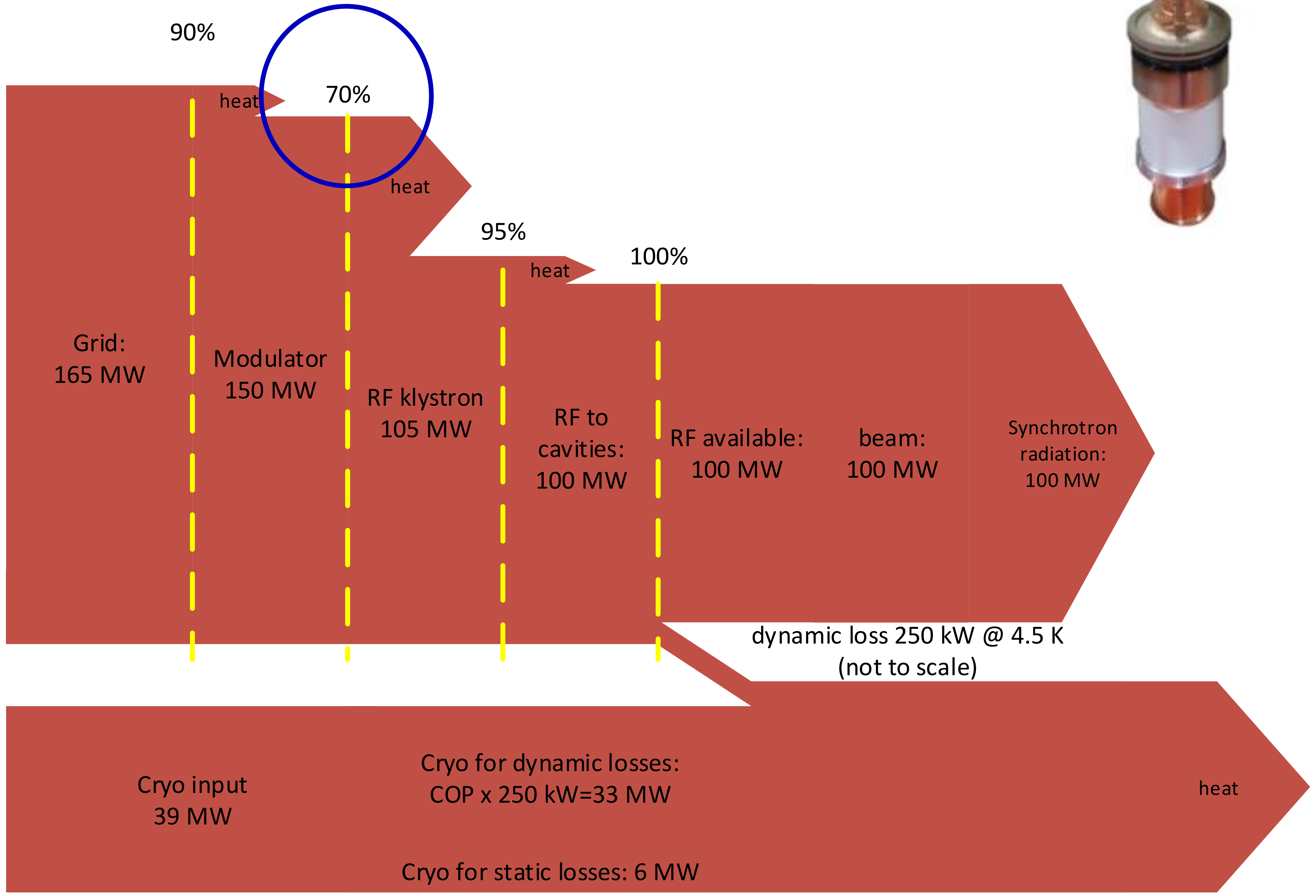
today klystron efficiency is 50%.
Klystron needs to be water cooled.

CERN launched a R&D program on High-Efficiency Klystron for CLIC.

This R&D program is done in collaboration industries.

First prototype received, reached 57% of efficiency.

Target for FCC 80%.



Focus on energy saving, RF power generation

Radiofrequency systems are the biggest loads

Power demand for RF Storage ring Z, W, H
P_{RF} = 100MW
P_{EL} = 100 / ηklystron / ηmodulator / ηdistribution
P_{EL}= 100 / 0.8 / 0.9 / 0.95 = 146MW

Booster
P_{RF} = 15% P_{RF} storage (1 beam) = 7.5MW
P_{EL} = 7.5 / ηklystron / ηmodulator / ηdistribution
P_{ELav} = P_{EL} * booster duty cycle = 1.7MW

The Booster duty cycle has a huge impact on its power demand. With a low duty cycle, the power demand is very low.

With 55% efficiency, the RF power demand is be 212MW, 66MW reduction expected
300GWh/y of energy saving

Storage ring	Z	W	H	TT
Beam Energy (GeV)	45.6	80	120	182.5
PRF (MW)	100	100	100	100
Klystron efficiency	0.8	0.8	0.8	0.8
PRF EL (MW)	146	146	146	146

Booster	Z	W	H	TT
Beam Energy (GeV)	45.6	80	120	182.5
PRFb (MW)	7.5	7.5	7.5	7.5
Klystron efficiency	0.8	0.8	0.8	0.8
Booster duty cycle	0.15	0.15	0.15	0.15
PRFb EL (MW)	2	2	2	2

CERN has a R&D program on High-Efficiency Klystron, today efficiency at 50%, target 80%

Focus on reduction of water intake and treatment

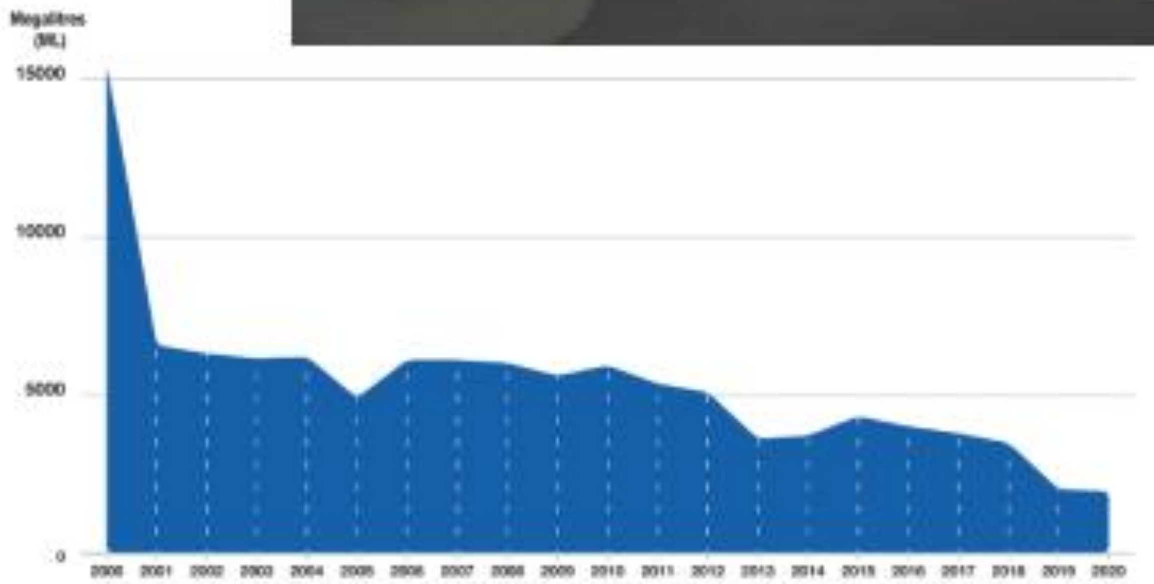
As example

6th Workshop
Energy for Sustainable Science
at Research Infrastructures

Water, reduction in consumption and treatment of effluents from cooling towers

Objectives of the project

- Avoid strong increase of the CERN water consumption (see CERN environmental report) despite the constant increase of cooling needs
- Re-use and recycle water
- Reduce the impact of cooling tower water treatment in the environment



- CERN follow French law in matter of Legionella risk
- For the prevention against Legionella growth, water treatment is regulated in the circuit according to the guidelines (bests practices) provided by the French ministry of the Environment
- Water concentrated in salts and containing residuals of the products used to prevent bacteria is released as effluent

t of effluents from cooling towers| Workshop Energy for Sustainable Science 5

ESSRI - 2022 @ESRF, report on parallel session 4 10

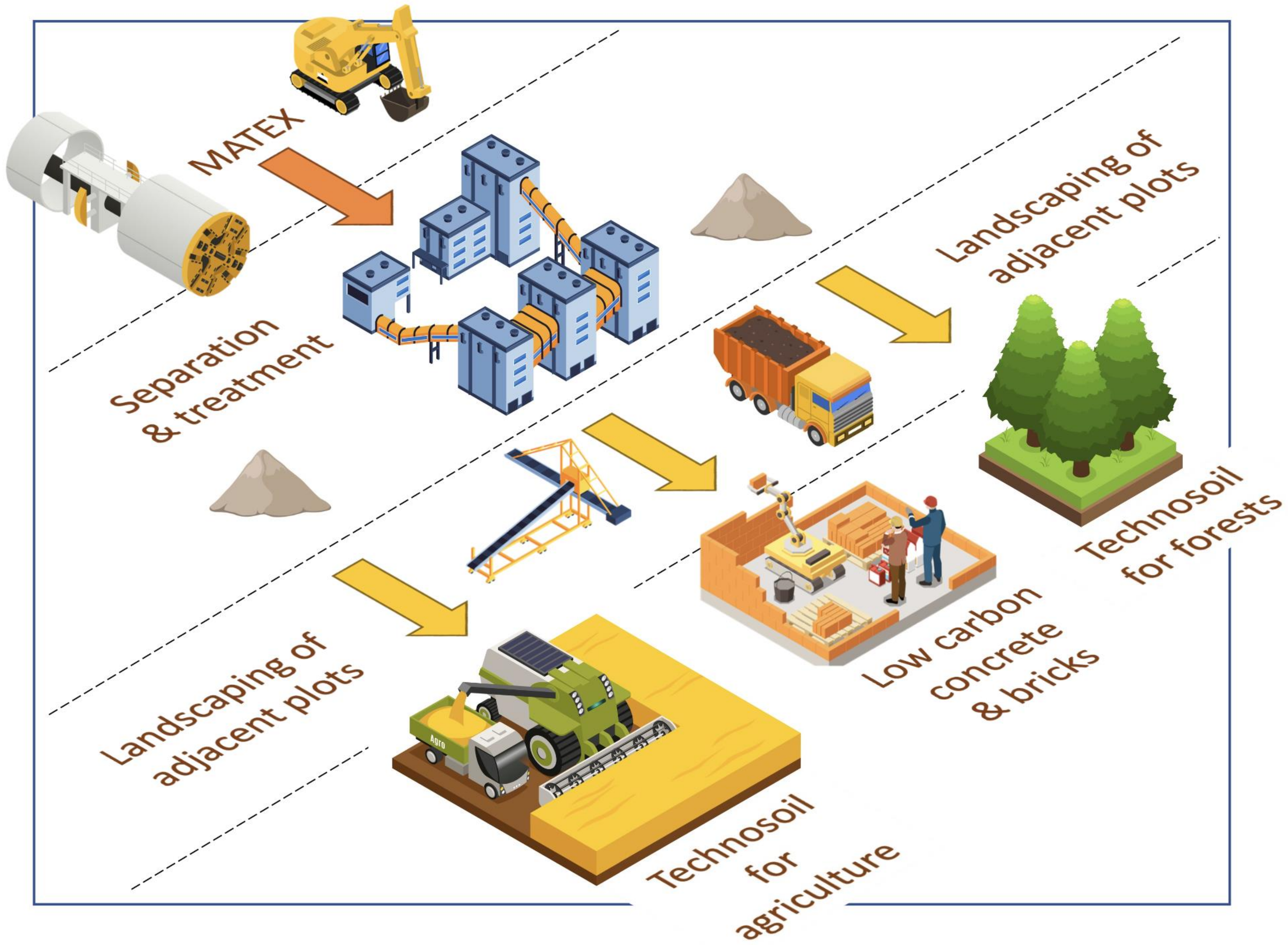
Focus on reuse of excavated materials

A ”locally innovative” approach

The priority for FCC is to propose a large re-use of excavated materials including carbon capture potentials (continue the Mining the Future, which was seen by the EC as an excellent initiative).

Aim is re-use the material locally, minimising the global nuisances (transport) and using soil for agriculture and re-forestation as part of the Avoid - Reduce - Compensate principle.

Work is ongoing since December 2022 to etablish the framework for a real-scale demonstration of the innovative solutions.

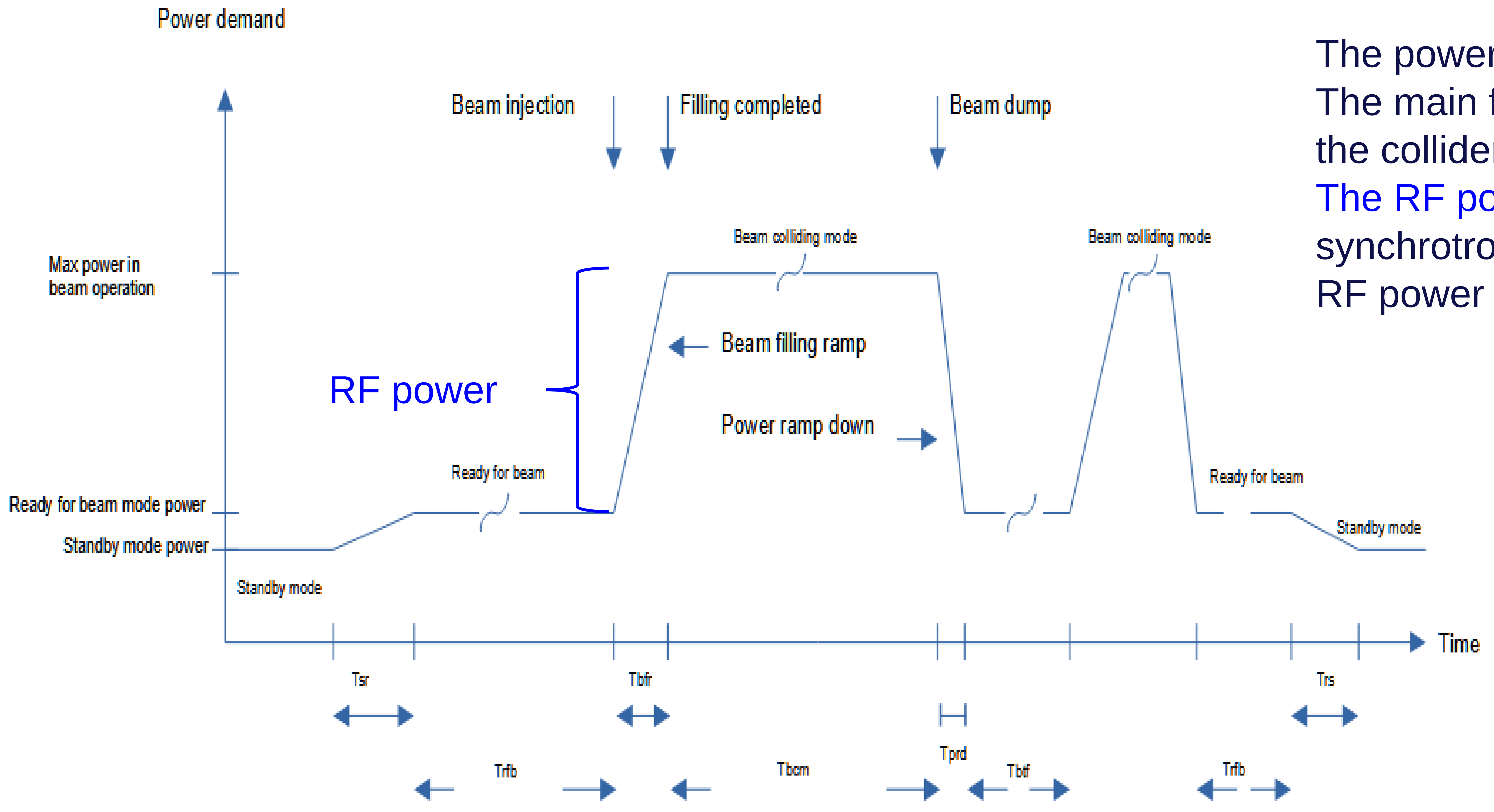


FCC-EE ENERGY CONSUMPTION

Power cycle during beam operation

Beam operation

The collider will operate 24h 7 days a week during the beam operation (185 days).
The beam operation can be stopped for a technical stop or by fault.



The power demand varies during the beam operation.
The main factors are the beam presence and beam current in the collider.
The RF power compensates for the losses due to the synchrotron radiations. When the machine is fully charged, the RF power is maximum.

- Standby mode: All infrastructure systems ON, Booster, and Collider OFF.
- Ready for Beam: All infrastructure systems ON, Booster ON, and magnet Collider ON.
- Beam Colliding mode: All infrastructure systems ON, Booster ON, Collider ON (Magnet and RF systems).

Power demand during the year

Power demand based on machine schedule

It is possible to calculate the power demand for each period of the schedule.
It depends on which systems are powered during each period.

Power during, in MW	Z	W	H	TT
shutdown	30	33	34	41
Technical stop	67	78	81	108
Downtime	67	78	81	108
Commissioning	144	163	177	233
Machine Development	96	121	147	231
Beam operation	222	247	273	357

- Shutdown: reduced power of all infrastructure systems, cryogenics at 20%, cooling at 50%, accelerators OFF.
- Commissioning: All infrastructure systems, and cryogenics at nominal. Start of accelerator systems, Booster ON, Collider at 50% load.
- Physics operation: all systems are ON. The electricity grid is loaded at 100%.
- Downtime: All infrastructure systems, and cryogenics at nominal. Booster and Collider systems are OFF.
- Technical stops: All infrastructure systems, and cryogenics at nominal. Booster and Collider systems are OFF.
- Machine development: all systems are ON. Reduced RF power to 15%, no physics.

Power demand during Z operation mode

Z machine schedule

The machine’s schedule defines different periods during the year.
The table below presents the power demand during the year for the Z mode.

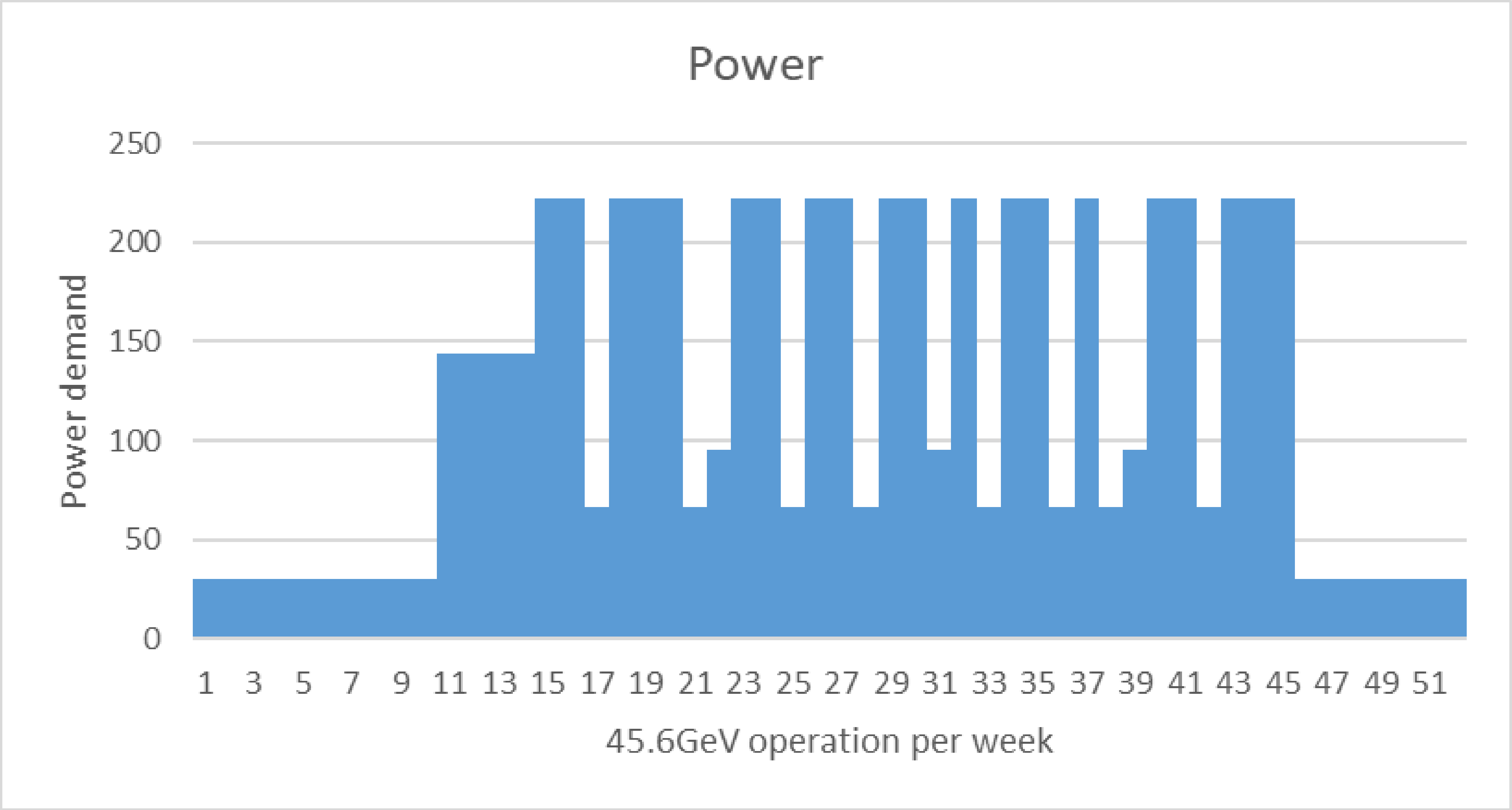
Z operation mode			Beam Operation	Commissioning	Machine Development	Technical Stop	Winter Shutdown			
Beam operation	139	3336	222					740530	MWh	69%
Downtime with machine acces	16	384	67					25542	MWh	2%
Downtime between cycle	16	384	74					28256	MWh	3%
Downtime long stop	14	336	67					22350	MWh	2%
Hardware + Beam commissioning	30	720		144				103859	MWh	10%
MD	20	480			96			46005	MWh	4%
technical stop	10	240				67		15964	MWh	1%
Shutdown	120	2880					30	86410	MWh	8%
	365	8760						**1.07**	**TWh**	

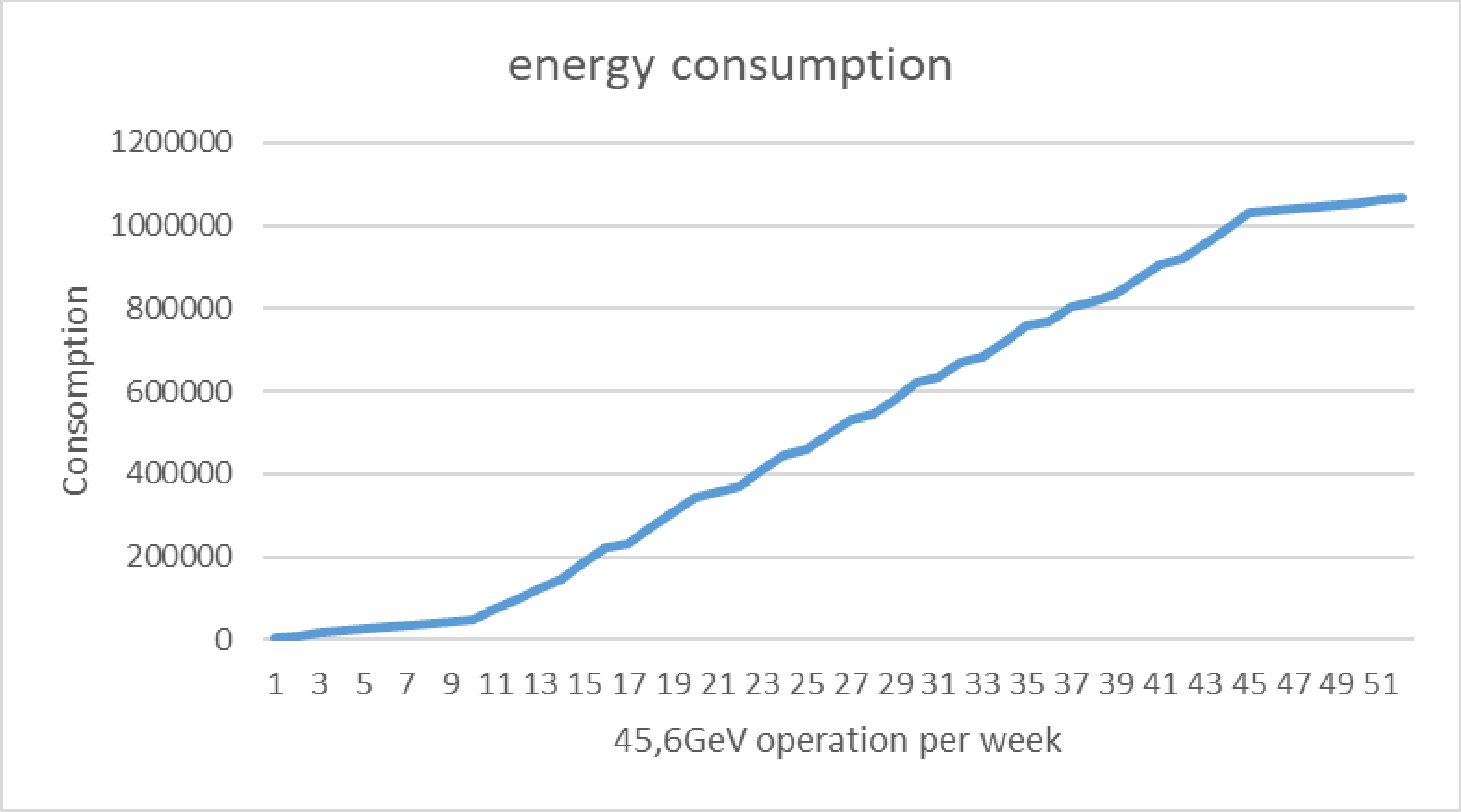
92% of the energy is consumed during Beam period.

Power demand during Z operation mode

Z machine schedule, 2045 - 2048

Power demand during the year is shown below as well as the energy consumption during the year.



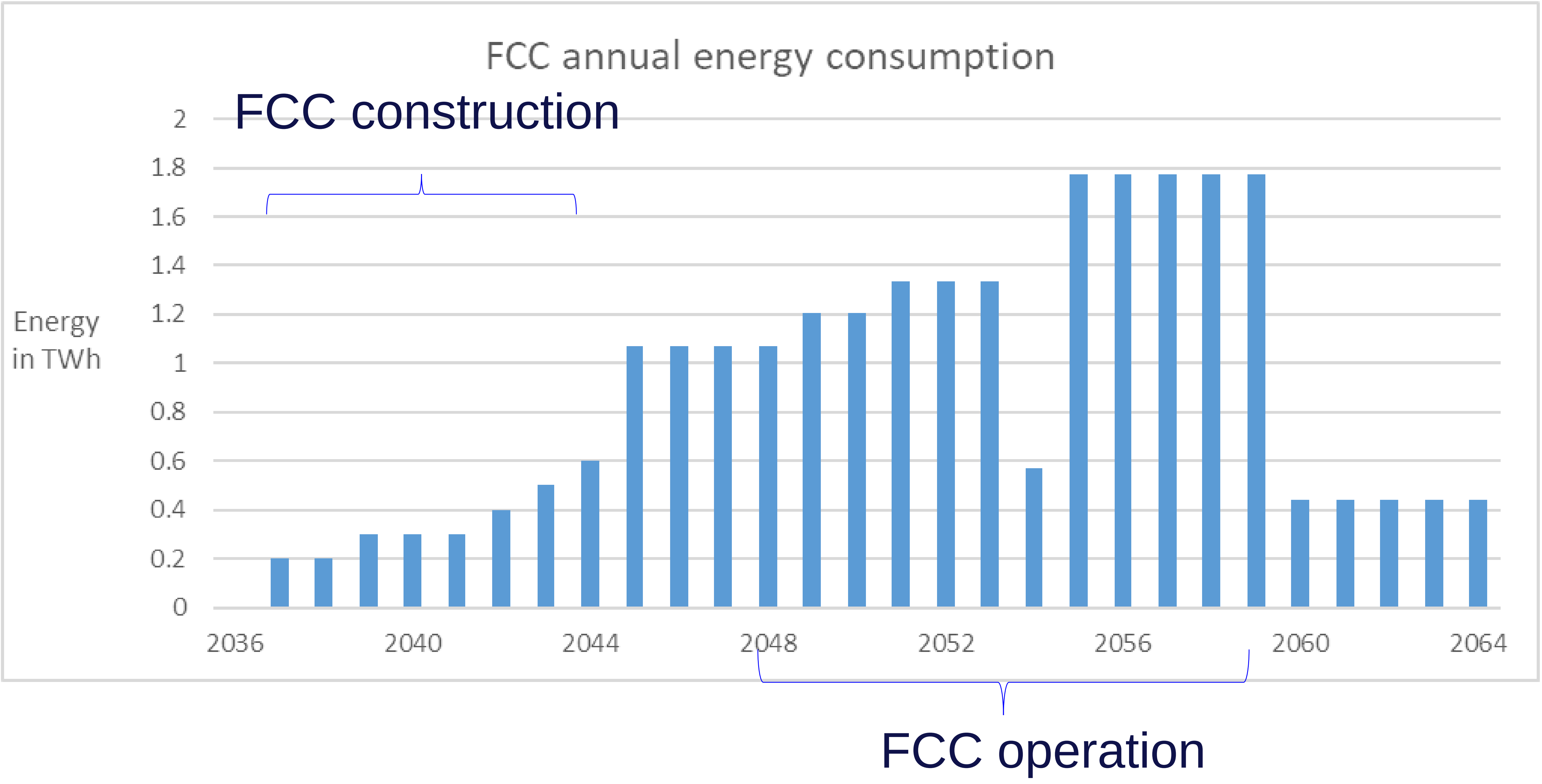


FCC ELECTRICITY CONSUMPTION 2036-2065

FCC electricity consumption 2036 - 2065

Electricity for FCC

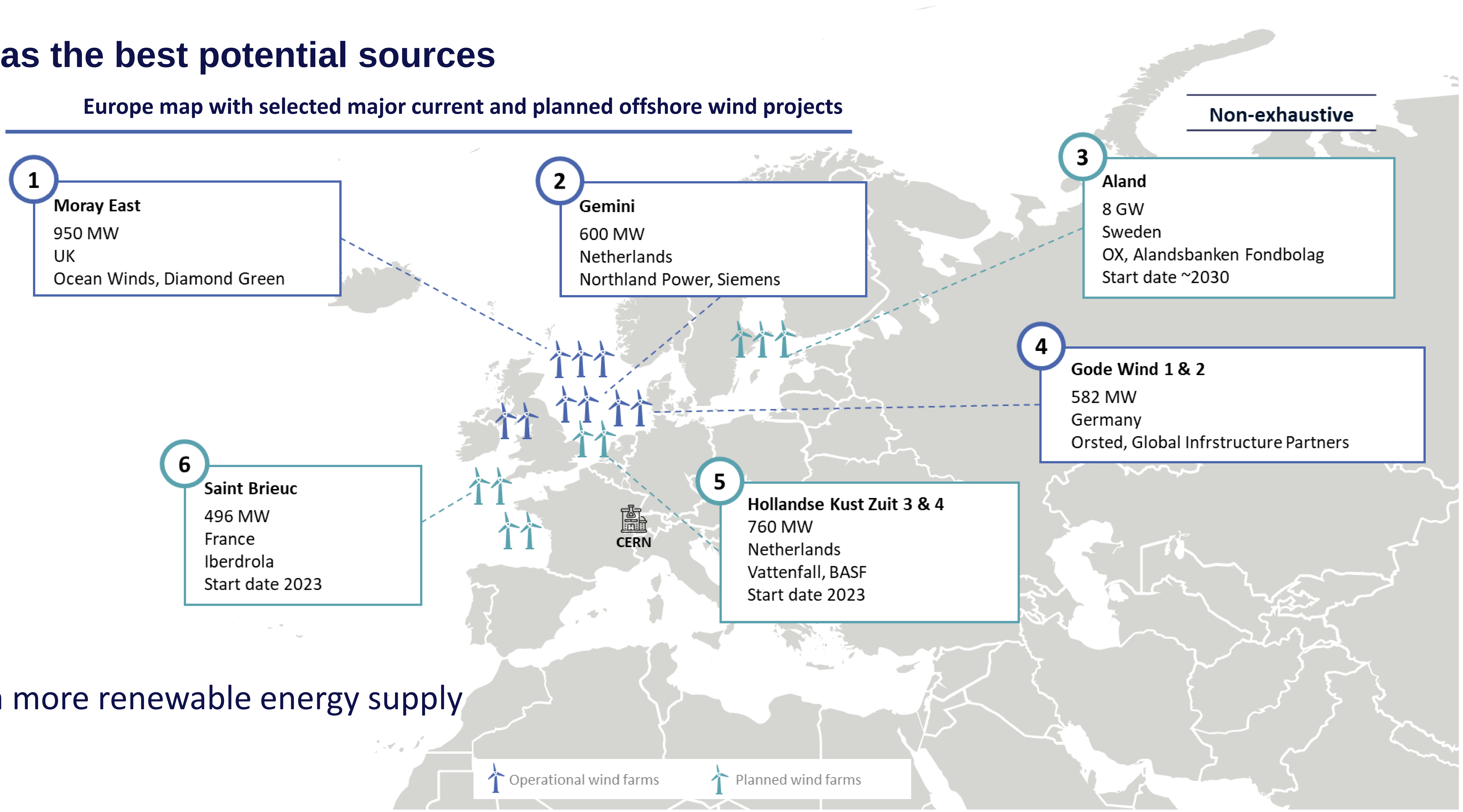
First consumption started with construction, then commissioning and operation.
Based on runs (beam operation) and long shutdowns (maintenance and upgrade).



FCC construction will start in 2036, with 0.2 to 0.5 TWh / year, for civil engineering and the start of the infrastructure operation. FCC operation will start in 2045.

FCC renewable energy supply

Offshore wind farms as the best potential sources



CERN is moving forward to a more renewable energy supply

FCC SUSTAINABILITY AND INDUSTRIES

Optimization of all systems

Focus on sustainability

Recall 90% of the energy consumption is during beam operation. Infrastructure consumption is less than 10%.

accelerator technologies (cavities, magnets...) will be designed with a focus on energy savings.
Low-loss magnets
Optimisation of power cabling
High-efficiency klystrons
Low static losses of RF cavities
High-Q cavities
High-efficiency cryogenics compressor

Standard industrial supplies will also be focused on sustainability.
Example, drive systems on ventilation systems for energy savings.

Ways to reduce energy consumption

Focus on reduction of the energy consumption

The management of the accelerator systems and of the infrastructure has a large impact on energy consumption.

Usually, priority to physics but with special care to energy consumption.

Always too much energy consumed without beams, an energy-saving strategy shall be developed.

Economic mode for magnets (Switch-off magnets during short or long stops)
Economic mode for cryoplant (Static losses represent less than 10%, can we operate compressor at 20% for long stop?)
Economic mode for cooling and ventilation

can we reduce the tunnel ventilation when nobody is inside or regulated it on temperature? Different from fixed speed.
can we adapt the water flow rate depending on the power dissipation? Motor drive systems regulated on power demand.
can we modulate the cooling tower with the power dissipation? Motor drive systems regulated on power demand.

Economic mode for experiments

can we identify some systems that can be put in economic mode during shutdown?
…

Smart operation of infrastructures and accelerators

Summary

- ➢ FCC is a very large machine
- ➢ Sustainability is a key aspect of project
- ➢ All designs and R&D are focus on energy savings to reduce the power demand and the energy consumption
- ➢ FCC includes renewable energy supply

Toward sustainable accelerators

https://hse.cern/environment-report-2019-2020

Thank you for your attention