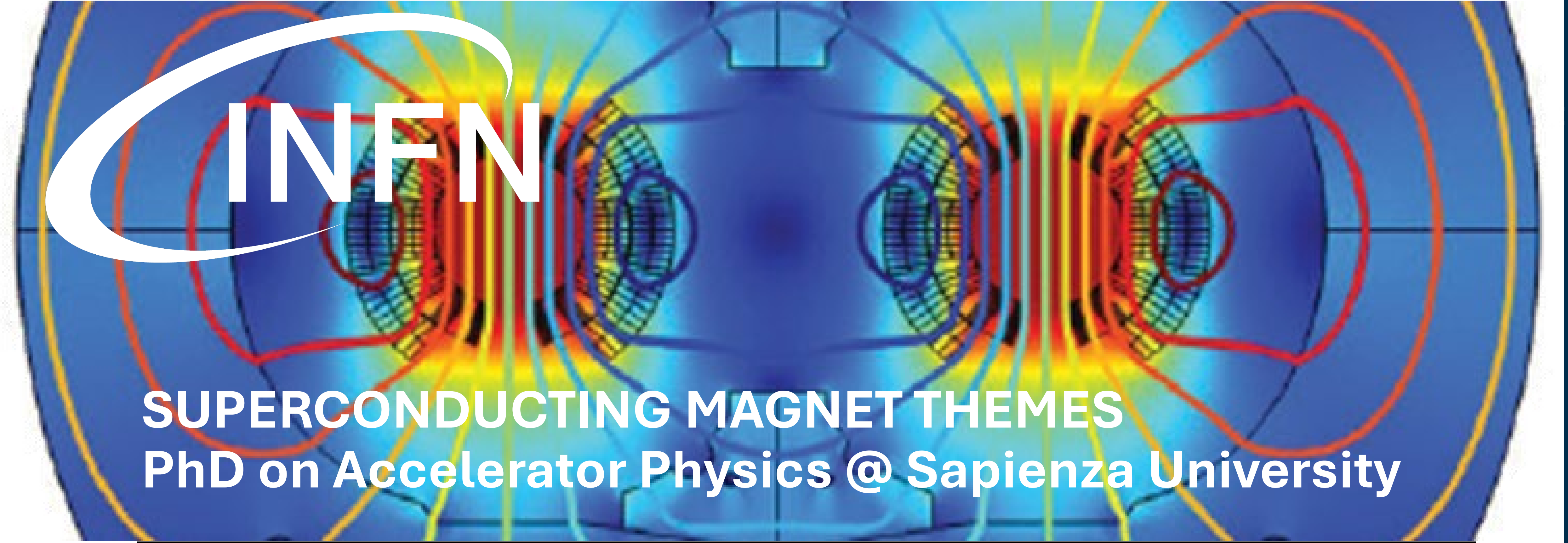

SUPERCONDUCTING MAGNET THEMES
PhD on Accelerator Physics @ Sapienza University

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THESE SLIDES ARE MOSTLY TAKEN FROM LAST YEAR PRESENTATION BY L.ROSSI

INFN Outline

- SC magnets for the Muon Collider
- SC magnets for medical applications
- SC magnets for high energy physics

General information

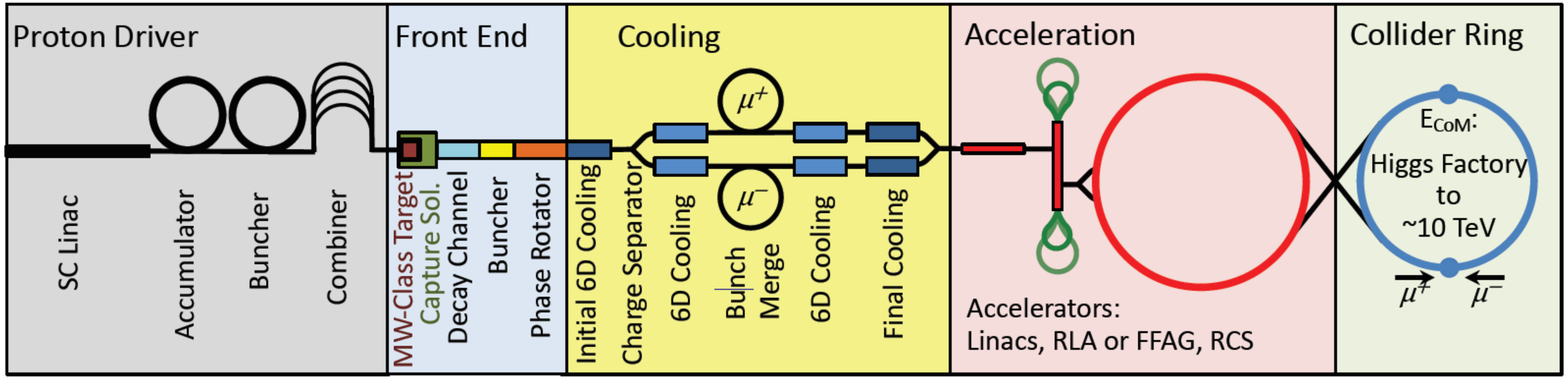
- The thesis locations can be:
  - **Milano,** at the LASA Laboratory of University and INFN
  - **Genova,** at the Physics Department
- To get more information you can contact (but many more people are involved):
  - Stefania Farinon stefania.farinon@ge.infn.it
  - Lucio Rossi lucio.rossi@mi.infn.it
  - Marco Statera marco.statera@mi.infn.it
- As mentioned by G.Cavoto, two related courses will be offered:
  - Design of superconducting magnets (S.Farinon)
  - Applied Cryogenics (R.Musenich)

SC magnets for the Muon Collider

International
MUON Collider
Collaboration

The Muon Collider

- The **Muon Collider** represents a rising hope for an energy-frontier collider, offering both high energy and high precision.
- Its design is entirely dictated by the **muon lifetime**, which is just **2.2 μs at rest**, and the critical need for rapid and efficient cooling!



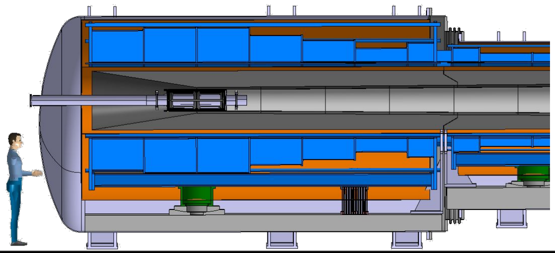
Short intense proton bunches produce muons that are captured	**6D - Ionization cooling of muon in matter**	Acceleration to collision energy	Collision

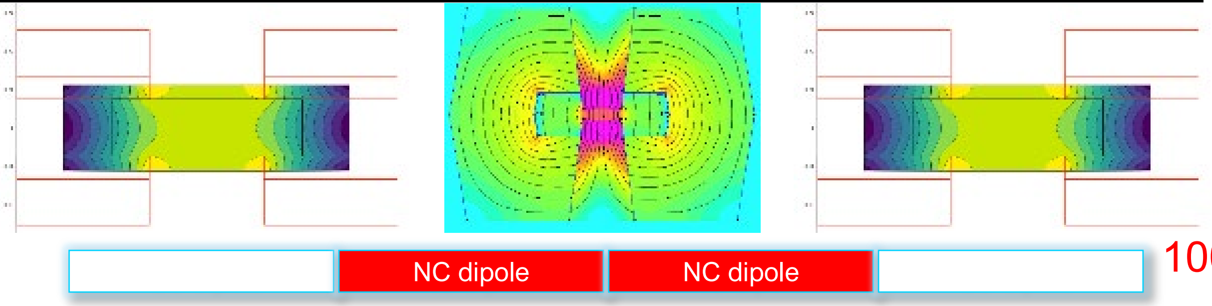
- Fast and efficient cooling of muons is essential to transform a "cloud of particles" into a cold, focused beam. The cooling cell is the most critical component of the accelerator—without cooling, there are no muons to collide. The cooling process works by absorbing energy in all directions and then restoring energy in a single direction. This requires: Efficient absorbers, Large-acceptance RF cavities, Strong, **very large-acceptance superconducting magnets** for focusing

Muon collider magnets

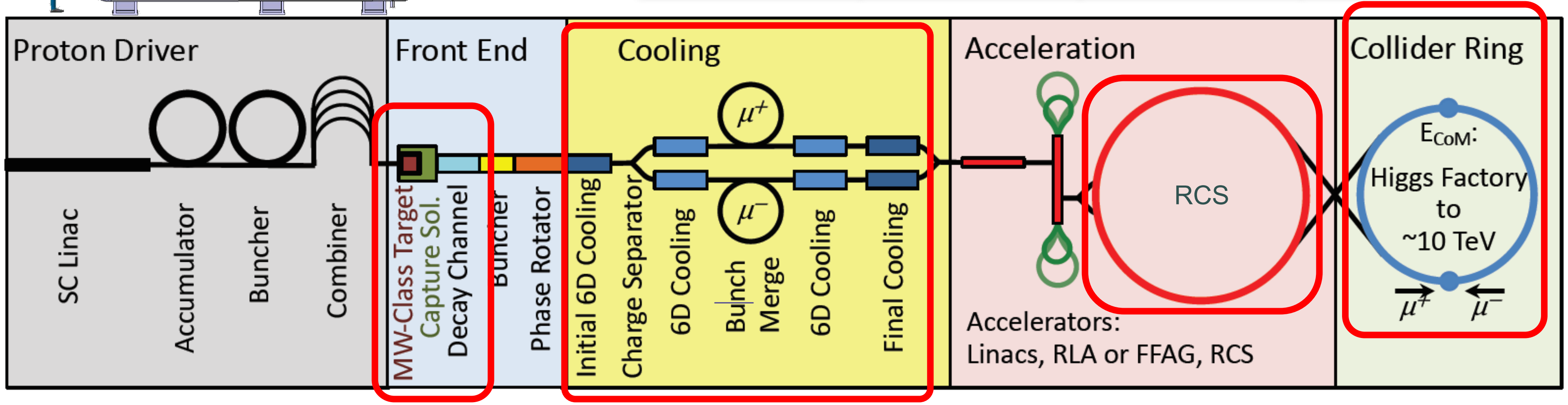
NC ±1.8 T, 400 Hz
100 mm x 30 mm

20 T, 200 mm
Radiation heat load ≈ 5…10 kW
Radiation dose: 80 MGy

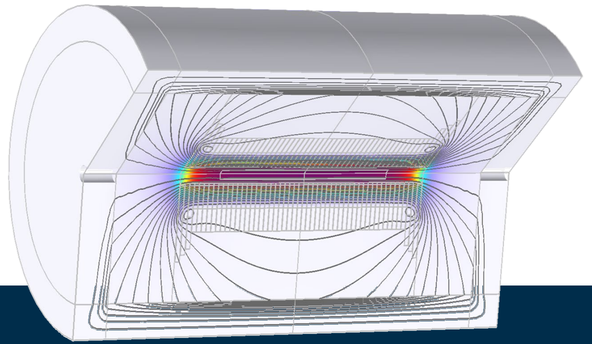




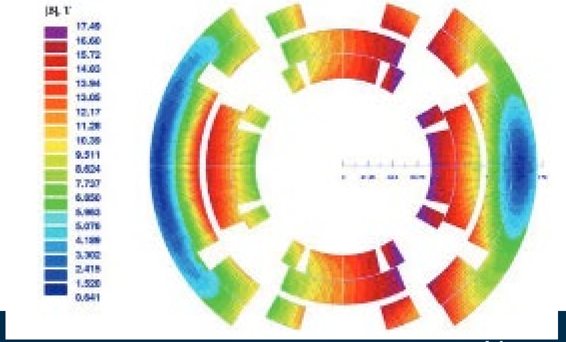
SC < 10T
100 mm x 30 mm



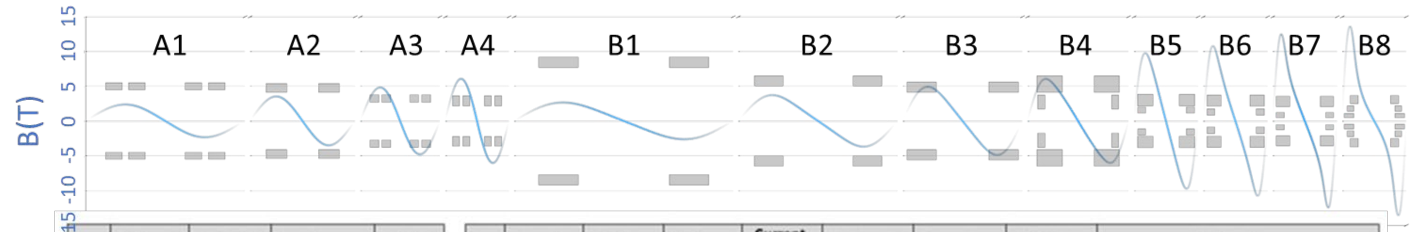
> 40 T, 60 mm



16 T peak, 160 mm
Radiation heat load ≈ 5 W/m
Radiation dose ≈ 20…40 MGy

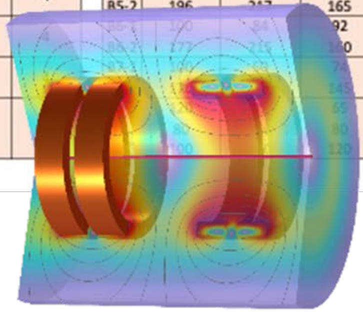


6D Cooling Cells (HTS @ 20 K)



Stage	Cell length	Peak axis B	Stored energy	Coils/cell
	(m)	(T)	(MJ)	(-)
A1	2	2.4	5.4	4
A2	1.32	3.5	15.4	2
A3	1	4.8	7.2	4
A4	0.8	6.1	8.4	4
B1	2.75	2.6	44.5	2
B2	2	3.7	24.1	2
B3	1.5	4.9	29.8	2
B4	1.27	6	24.4	4
B5	0.806	9.8	12	4
B6	0.806	10.8	8.2	[illegible]
B7	0.806	12.5	5.7	[illegible]
B8	0.806	13.6	1.4	[illegible]

Coil	Length	Radius	Thickness	Current density	Peak coil B	Hoop stress	Radial stress	Technology		
	(mm)	(mm)	(mm)	(A/mm^2)	(T)	(MPa)	(MPa)	Nb-Ti 4K	Nb_3Sn 4K	HTS 4K/20K
A1-1	210	450	100	63.25	4.1	34	-4.6	✓	✓	✓
A2-1	260	410	130	126.6	9.5	137	-28.3		✓	✓
A3-1	110	270	110	165	9.4	138	-28.5		✓	✓
A4-1	90	220	140	195	11.6	196	-49.4		✓	✓
B1-1	500	770	150	69.8	6.9	95	-13.5	✓	✓	✓
B2-1	360	500	150	90	8.4	114	-20.1		✓	✓
B3-1	370	410	150	123	11.2	174	-36.6		✓	✓
B4-1	92	175	200	94	9.2	231	-0.1/19.7		✓	✓
B4-2	320	410	240	70.3	7.8	66	-23.5		✓	✓
B5-1	100	113	88	157	13.9	336	-0.7/21.1		...	✓
B5-2	[illegible]	[illegible]	165	168	12.3	159	-55.7		✓	✓
[illegible]	[illegible]	[illegible]	[illegible]	185	14.2	314	-1.4/22.3		...	✓
[illegible]	[illegible]	[illegible]	[illegible]	155.1	10.3	118	-43.1		✓	✓
[illegible]	[illegible]	[illegible]	[illegible]	198	14.3	244	-1.1/20.7		...	✓
[illegible]	[illegible]	[illegible]	[illegible]	155	10.1	119	-37.4		✓	✓
[illegible]	[illegible]	[illegible]	[illegible]	220	15.1	119	-3.0/22.1		...	✓
[illegible]	[illegible]	[illegible]	[illegible]	135	6.2	110	-2.4/4.5	✓	✓	✓
[illegible]	[illegible]	[illegible]	[illegible]	153	6.2	41	-22.9	✓	✓	✓

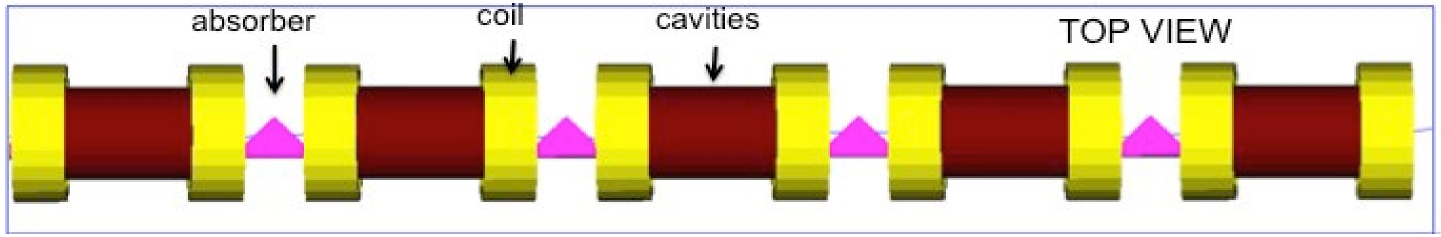


Coil size

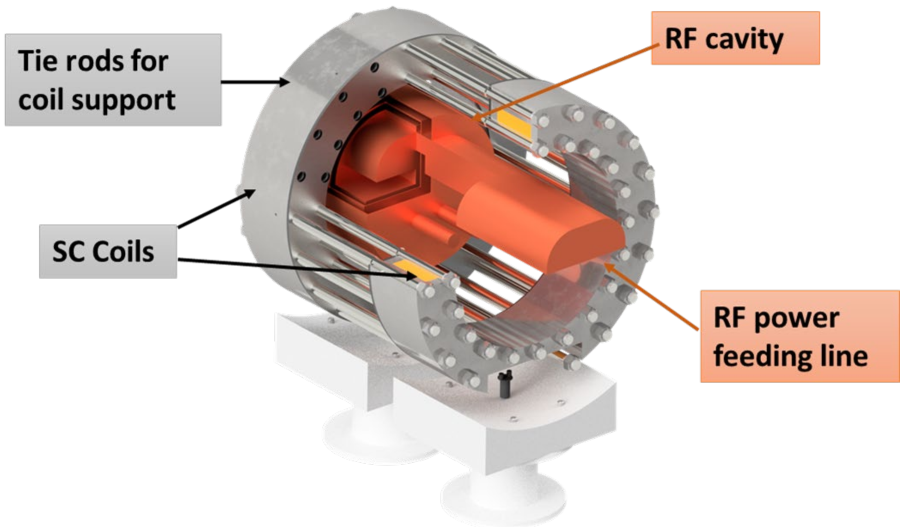
Quench protection

Margin

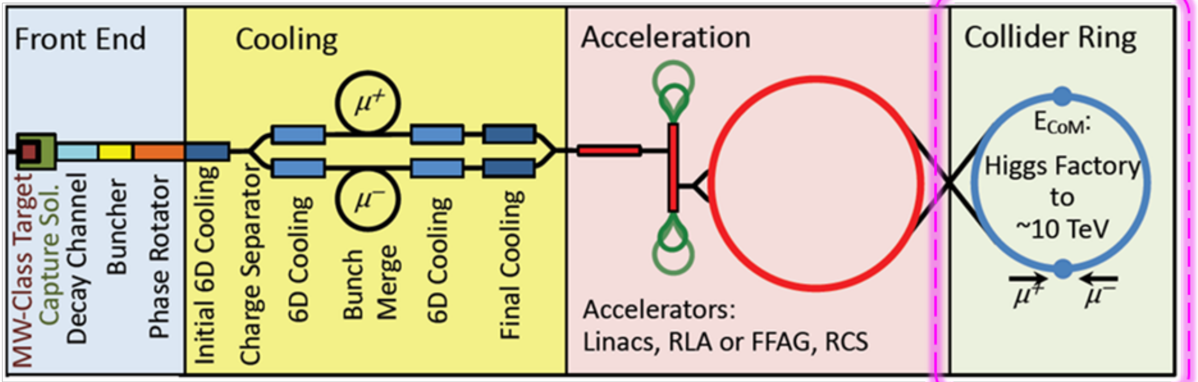
Mechanics



Facility under design at LASA lab
7 T splice coil in HTS, cryogen-free, for RF cavity test



Collider Magnets Requirements

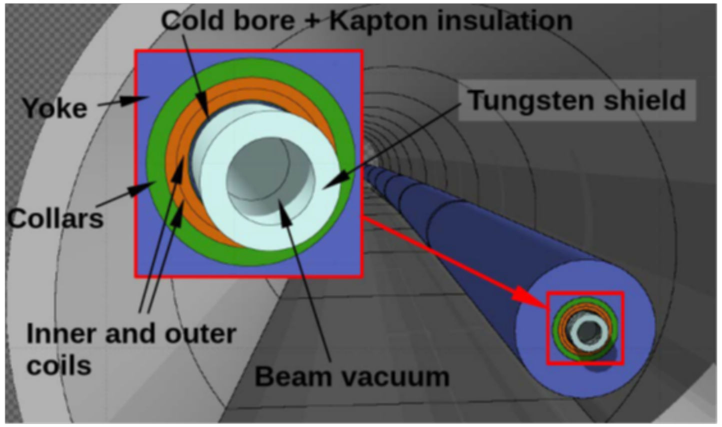


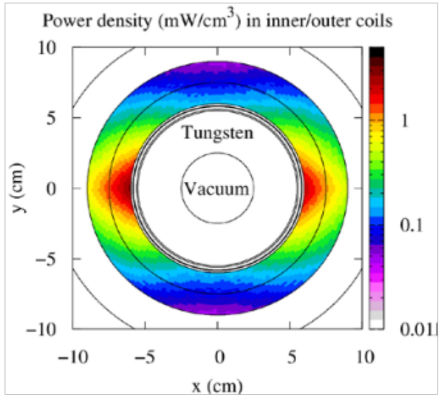
Field: 16 T peak (IR 20 T)

Length: 10…15 m (x 700)
Space between magnets: 300 mm
Radiation heat load: 5 W/m
Cumulative dose: 20…40 MGy

Courtesy of Patricia Borges de Sousa
https://indico.cern.ch/event/1250075/contributions/5357594/

Aperture

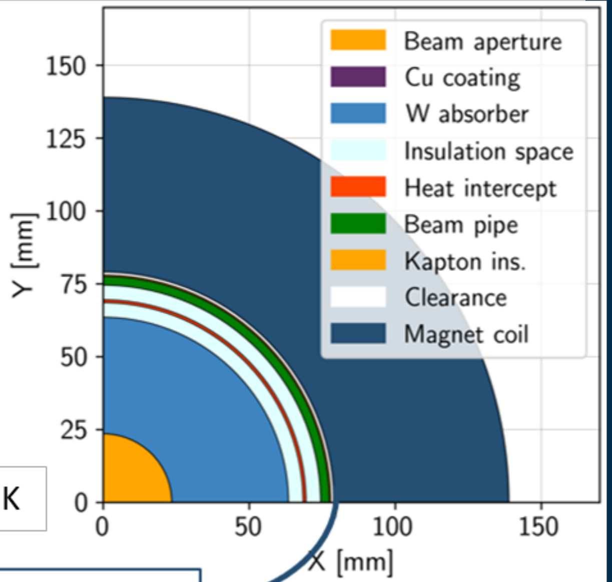




Beam aperture (5σ)	23.5 mm radius
Cu layer beam screen	0.01 mm thick
Tungsten absorber	40 mm thick
Insulation space	5 mm thick
Heat intercept	1 mm thick
Insulation space	5 mm thick
Beam pipe	3 mm thick
Kapton insulation	0.5 mm thick
Clearance	1 mm thick
Coil pack*	(60 mm thick)

*thickness TBD, placeholder

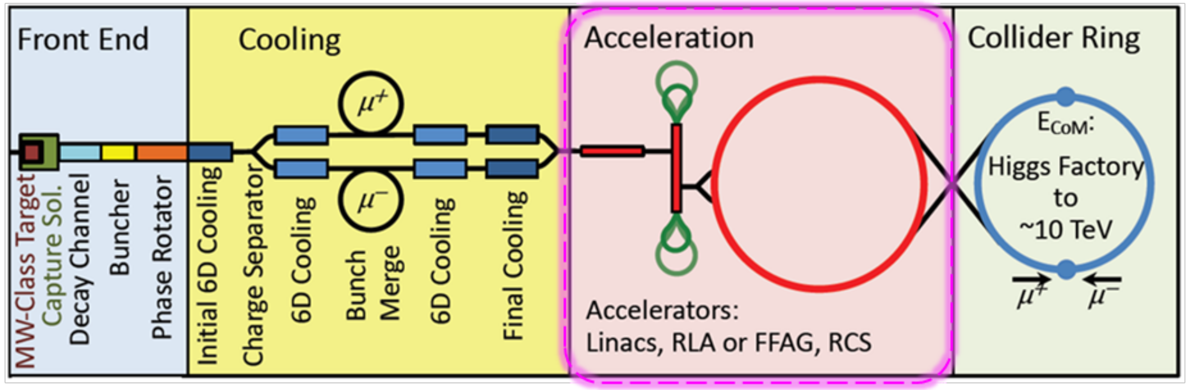
Assuming 10 TeV machine and coil at 4.5 K



Coil aperture 158 mm

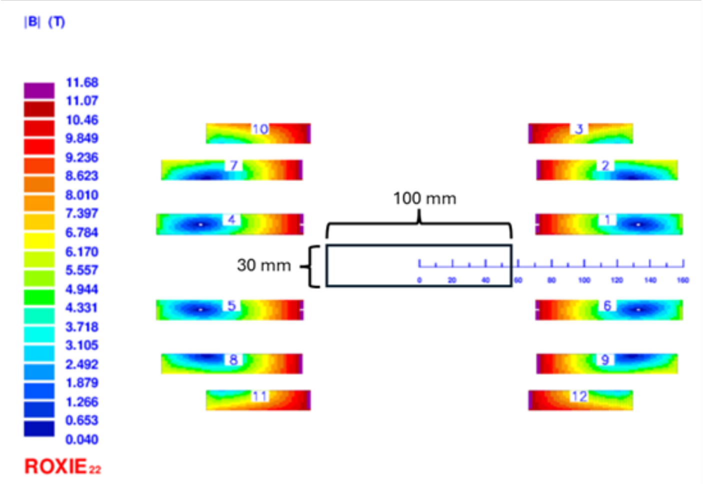
! Need for large fields in large apertures → discussion on parameter limits

INFN Accelerator magnets



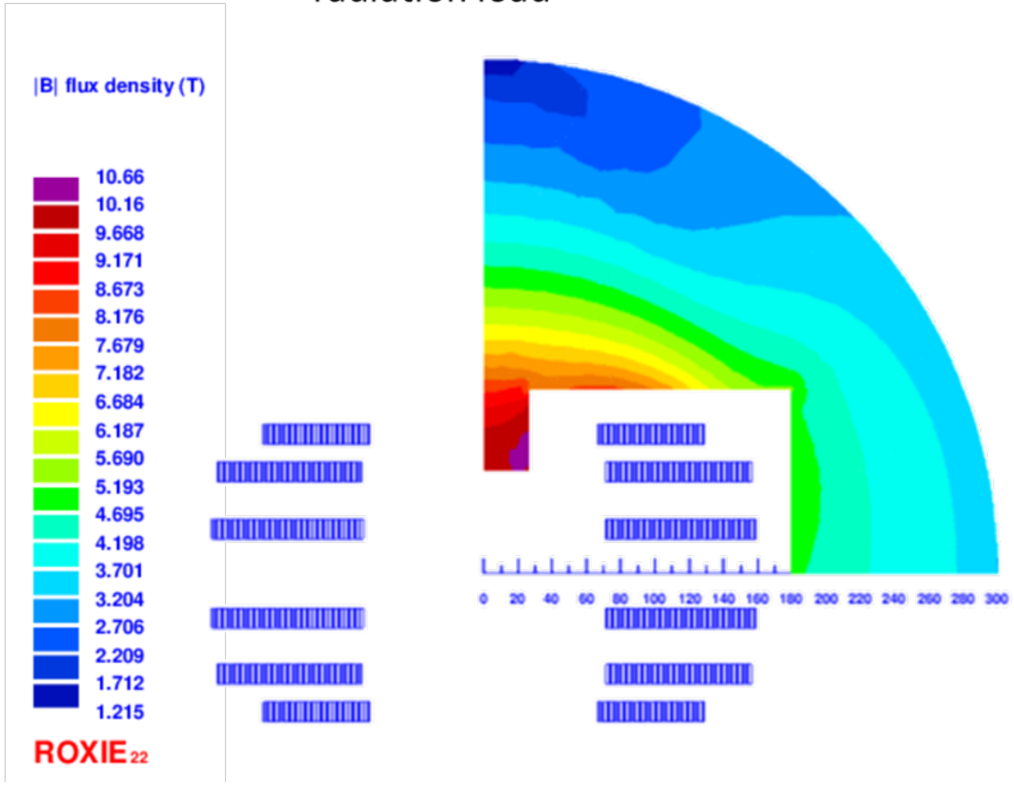
Field: 10 T

Aperture: large aspect ratio 100 mm×30 mm
no conductor on the midplane due to radiation load



$$B_0 = 10\,T$$

Field homogeneity @ 25mm = 0.425%



SC magnets for medical applications

What's next for particle therapy?

- Multiple ions delivered with light-weighted Gantry
- Rotatable gantry allows non-coplanar irradiation, enhancing effectiveness
- Treatment rooms equipped with patient imaging
- Dose Delivery and Range Verification Systems abl to adapt online the dose delivered

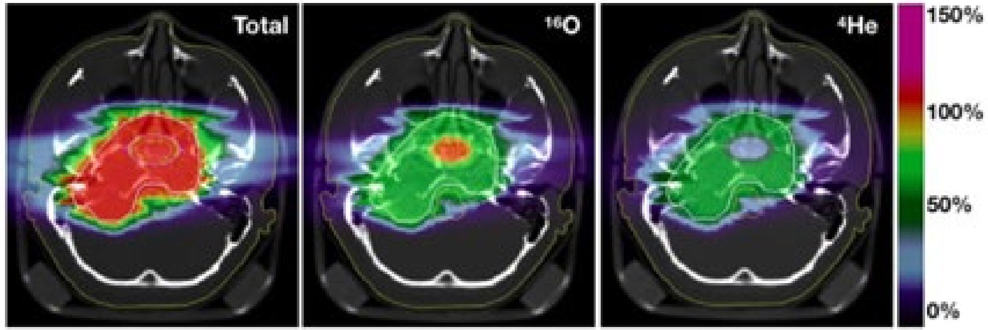
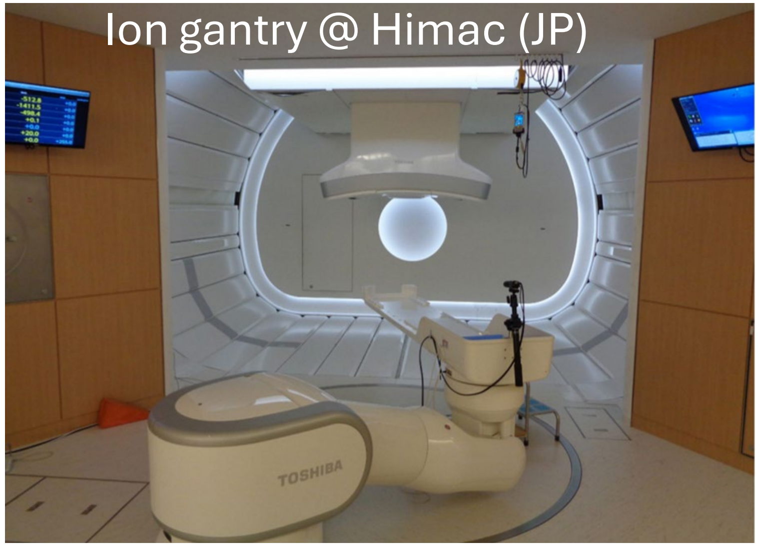
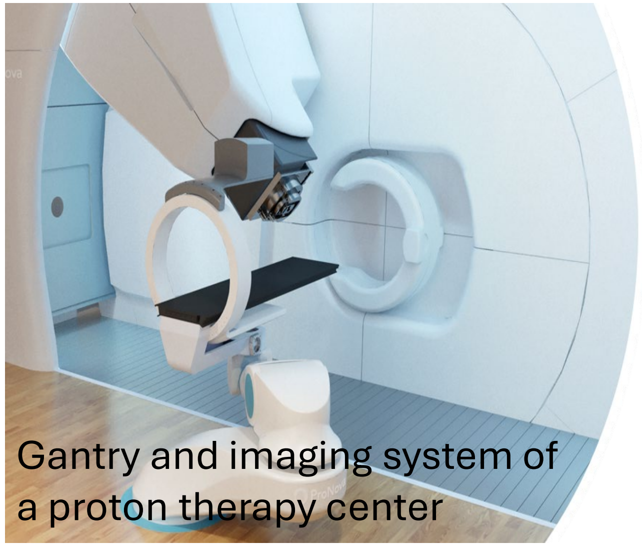
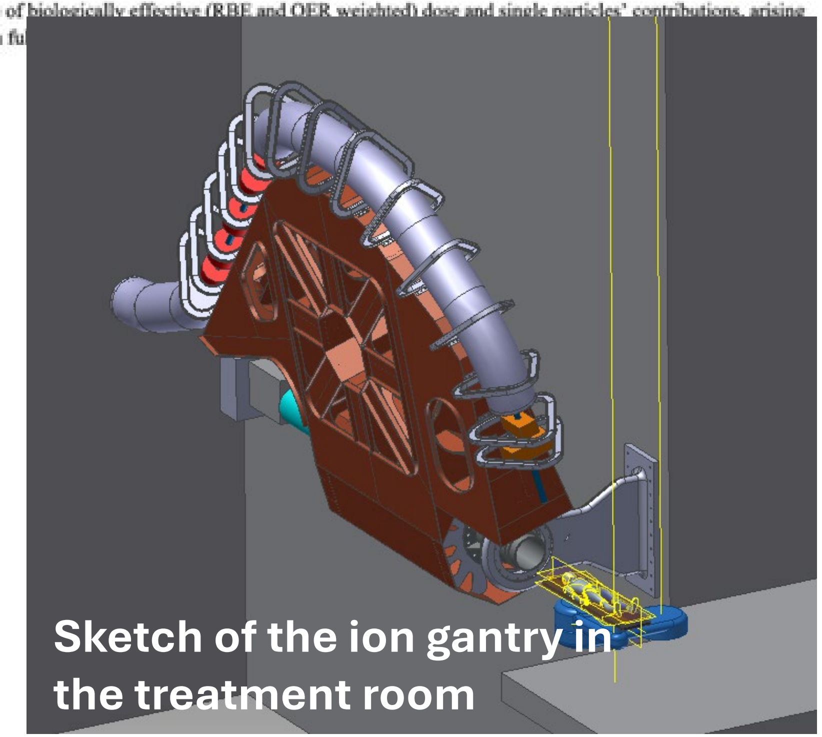


Figure1: Total profile of biologically effective (RBE and OER weighted) dose and single particles' contributions, arising from the Multiple-ion fu

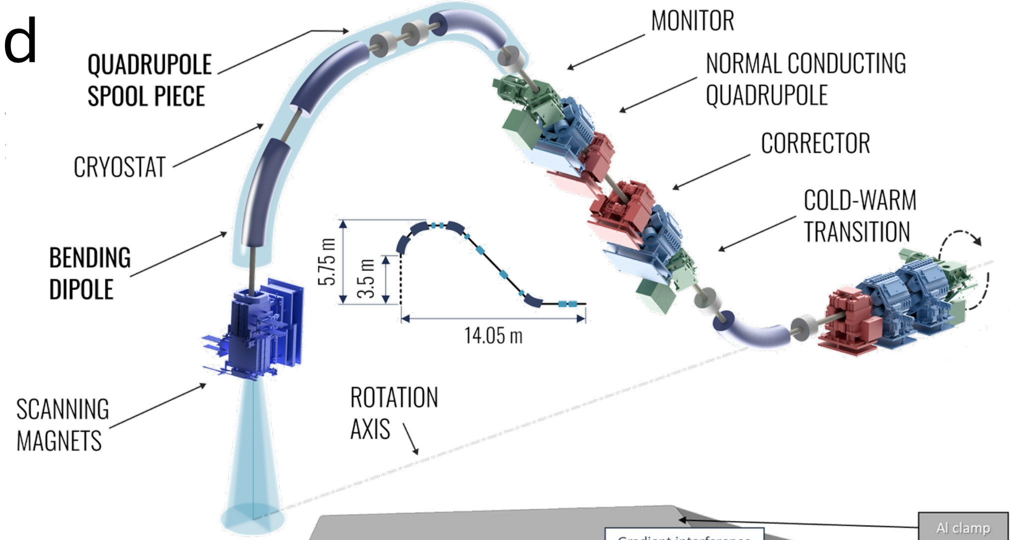

Ion gantry @ Himac (JP)

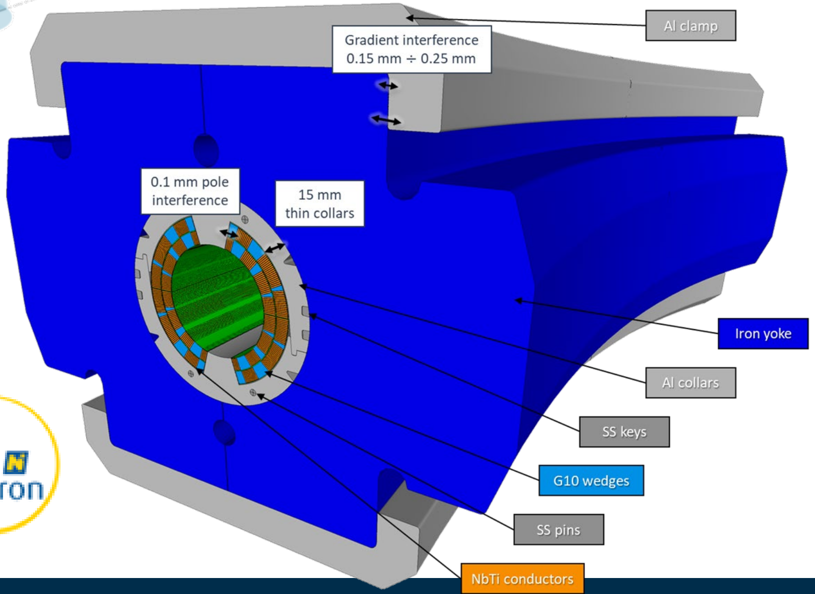

Gantry and imaging system of a proton therapy center


Sketch of the ion gantry in the treatment room

SIG WP2

- Design, construction and test of a curved superconducting demonstrator magnet (SDM-c) for ion gantries
- Main demo. magnet params
  - NbTi superconducting Rutherford cable
  - Cos-θ coils
  - Pure dipolar field: 4 T
  - Bore diameter: 80 mm
  - Small curvature radius: 1.65 m (Challenge #1)
  - Angular sector: 30°
  - High field ramp-rate: 0.15 T/s - 0.4 T/s (Challenge #2)
  - Compatible with conduction cooling (no LHe) but no optimization (Challenge #3)





HITRIplus WP8 – Superconducting magnet design

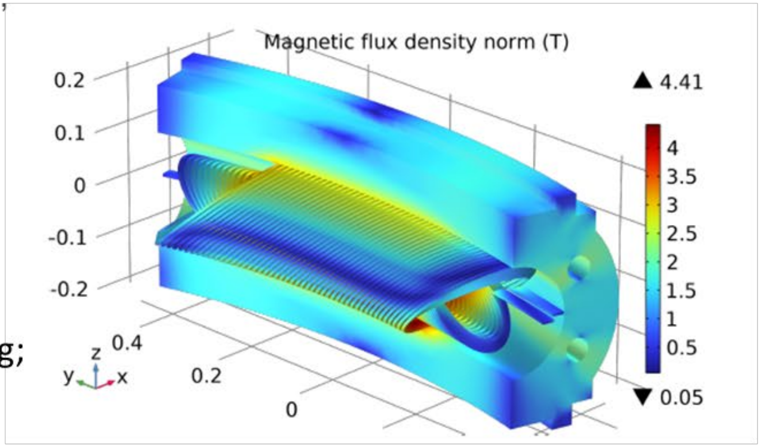
Construction and test of a small demonstrator for feedback useful for accelerator as well as gantry final magnet design.

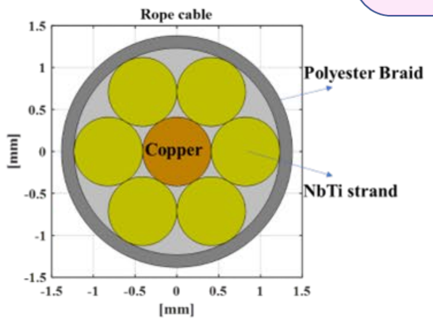
The decision to explore a **curved CCT layout magnet based on NbTi** (Low losses strand) and conductor (rope 6+1 strands);

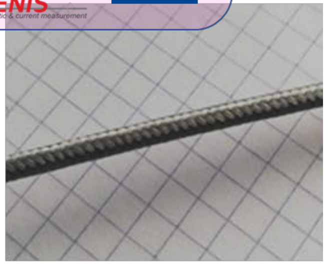
Main Parameters of demonstrator:

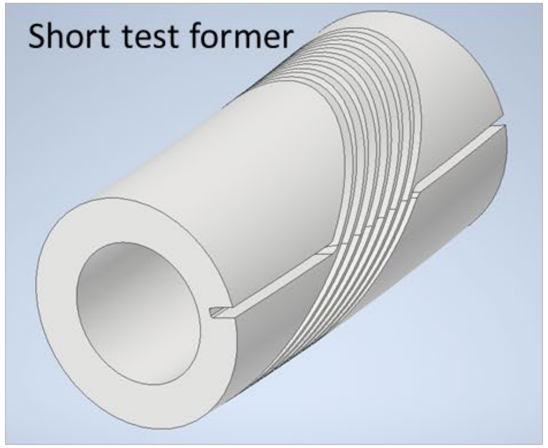
- **4 T pure dipole, Top of 4.7 K**;
- Bore diameter: 80 mm;
- Curvature radius: **1.65 m;**
- Angular sector: 30°;
- High field **ramp-rate: 0.4 T/s**;
- Compatible with conduction cooling;
- Wax impregnation test;
- Priority is to construct the curved former (AlBr);

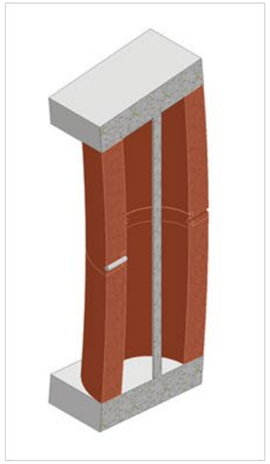
The challenge is the heat extraction generated by superconductor and former (AC losses) without LHe cooling

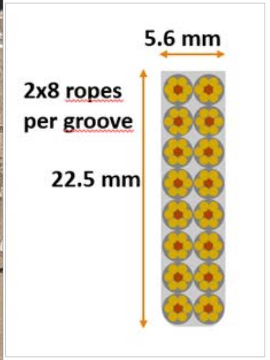










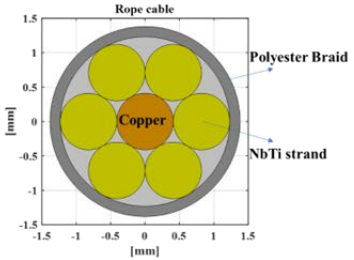


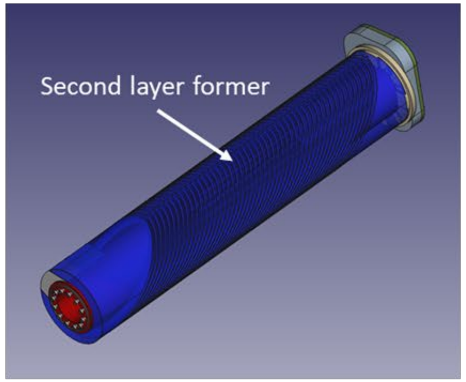
I.FAST WP8 – Innovative superconducting magnets

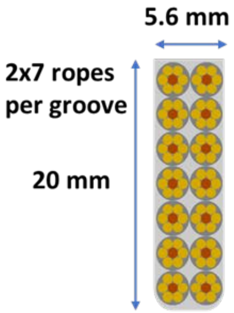
Exploring **Canted Cosine Theta with HTS superconductor (main goal),** preceded by a **combined function CCT based on LTS**

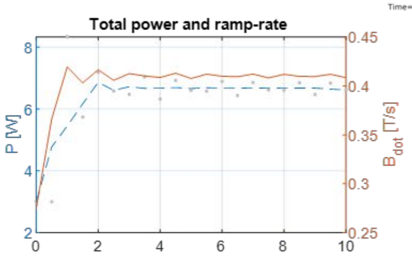
Construction of the two demonstrators: winding and magnet assembly, magnet test and validation:

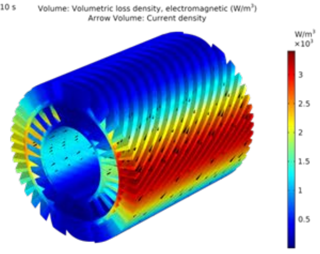
Combined CCT based on LTS (rope 6 NbTi + 1 copper strand as HITRIplus):
- 4 T dipole + 5 T/m quadrupole (important feature to test it for CCT);
- Demonstrator for testing the combined feature of CCT and thermal study of AC losses (0.4 T/s);

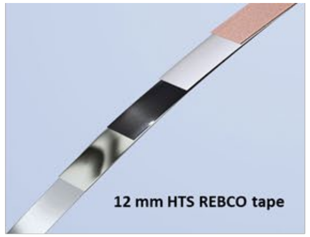




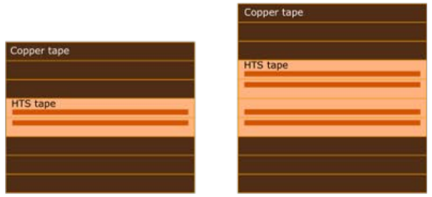


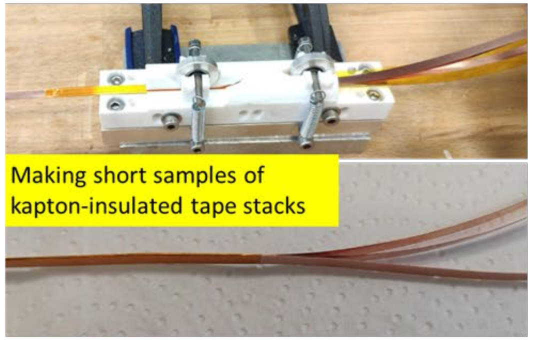


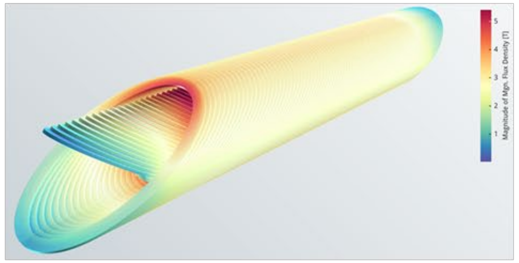




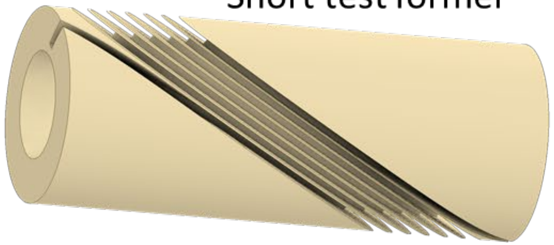
CCT based on HTS (REBCO tape 4 mm wide):
- 4 T dipole with a new Top of 20 K (> 10 K of margin);
- Frenet-Serret frame used for the conductor (avoid hard way bending);
- Straight geometry just to start the study (HTS is already difficult enough);
- Two design options: 2-tapes (980 A) and 4-tapes cable (1990 A);
- Quench protection is demanded (Cu stabilizer added for this);





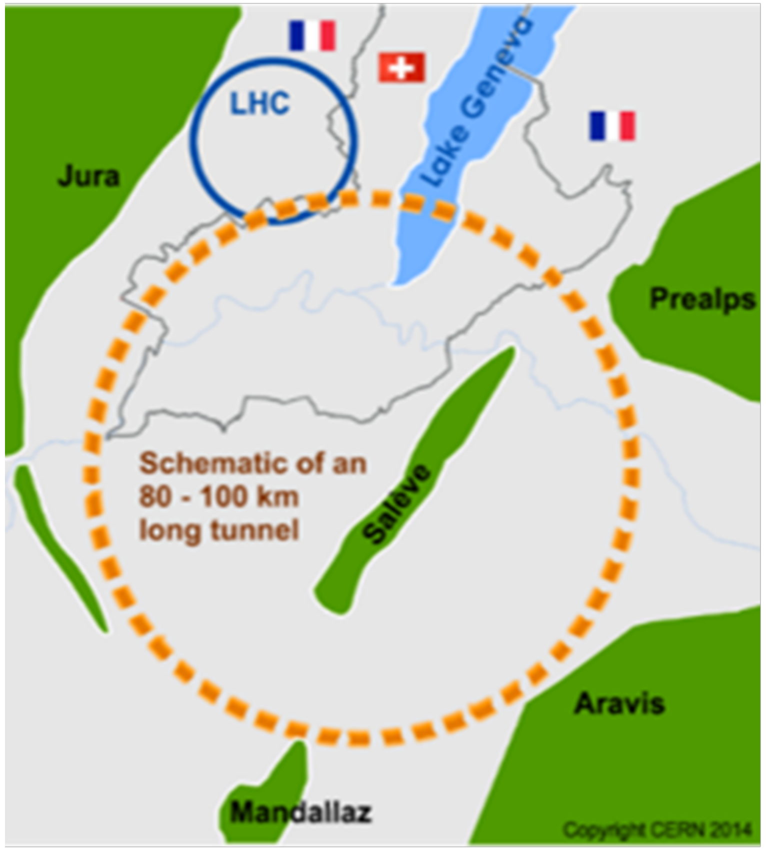


Short test former



SC magnets for high energy physics

The FCC integrated program

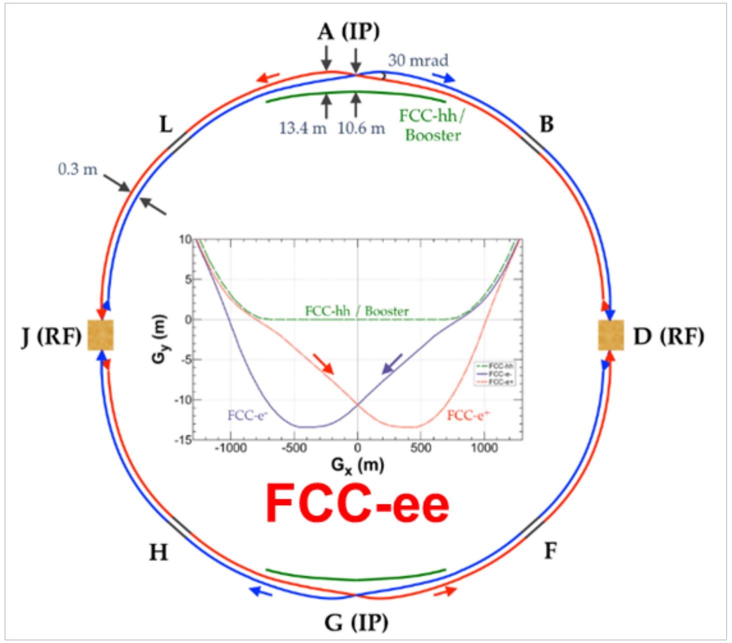


2020 - 2040

Phase 1 : FCC-ee

collider electron - positon

Higgs, Z, W, ttbar

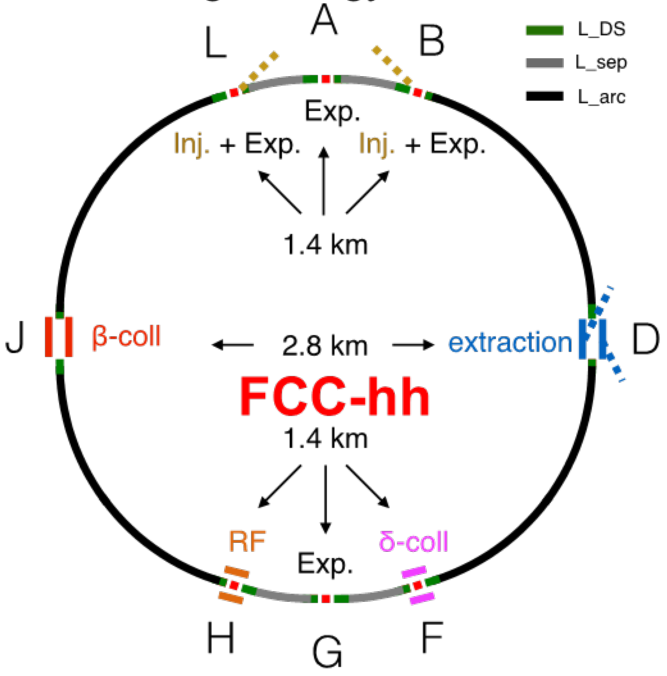


2040 - 2055

Phase 2 : FCC-hh

collider proton - proton

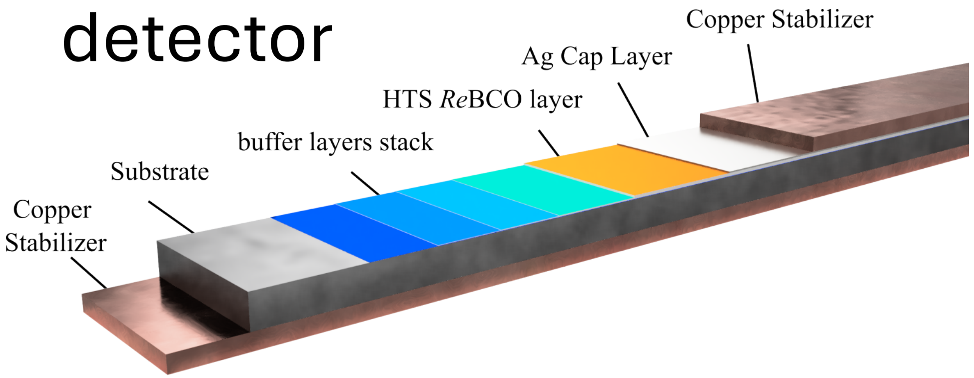
High energy frontier

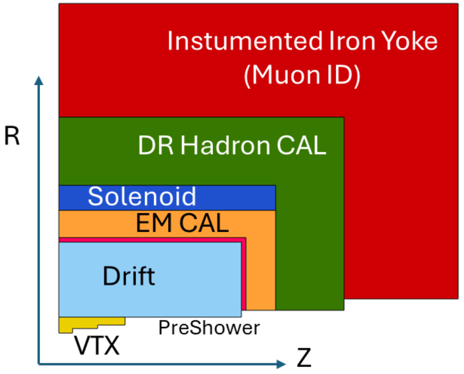


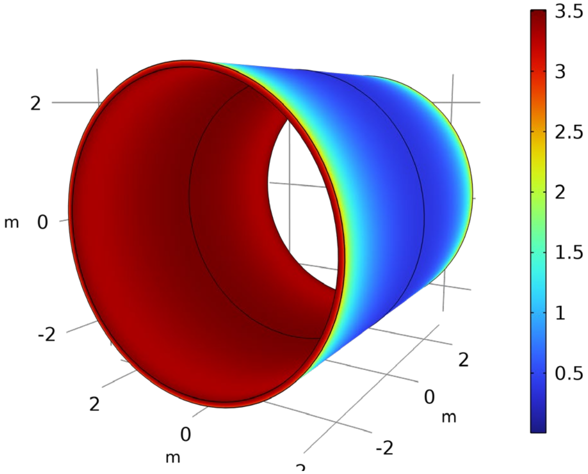
2060 - 2090

FCC-ee magnets

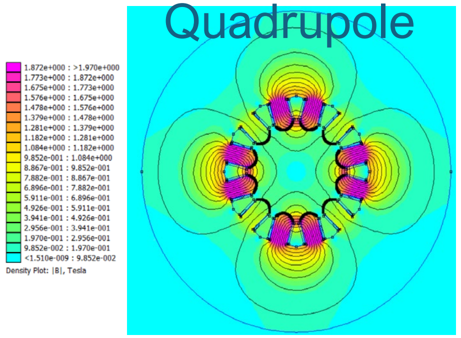
- 3T HTS solenoid for the IDEA detector

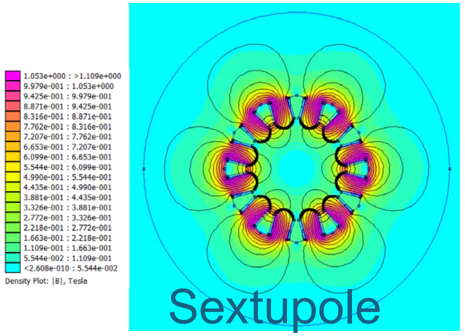




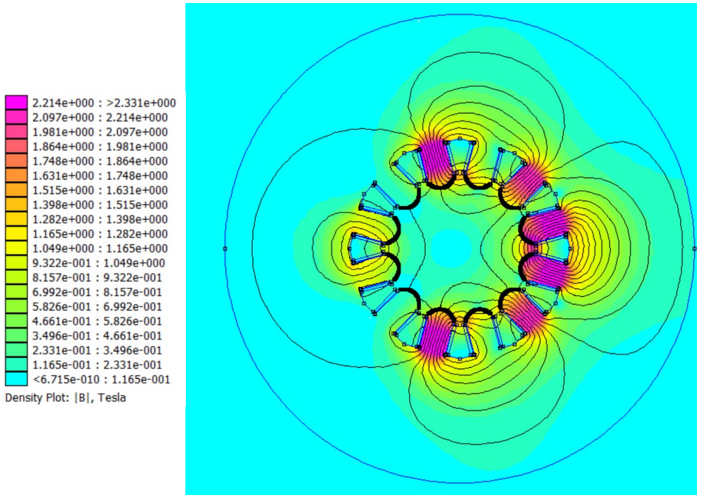


- HTS superferric combined function quadrupole and sextupole magnet



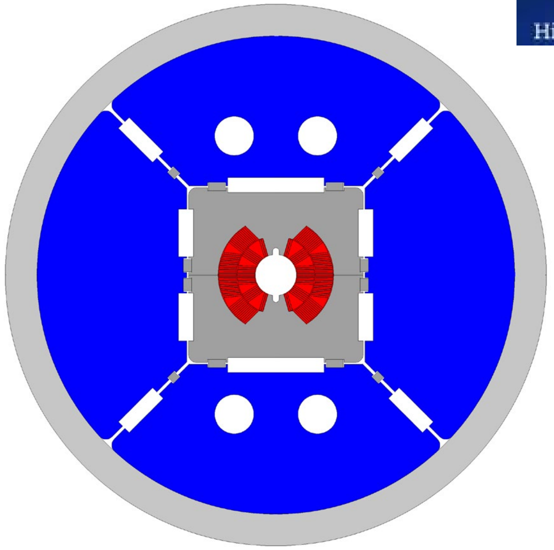


Combined mode



FCC-hh magnets

- The FalconD project involves the development and construction of a short model Nb_3Sn dipole with the following specifications:
  - Single aperture with an inner bore of 50 mm.
  - 2-layer cos-theta coil, providing a bore field of 12 T at 1.9 K.
  - Mechanical assembly using bladder & key technology.
  - The total coil length is 1.5 m.



Furnace for coil heat treatments

SS end spacers

Thanks for the attention