FCC-hh and Magnets: Summary

Vladimir Shiltsev

Fermilab

FCC-Week, June 9, 2023 9:50am-10:10am

Wednesday, June 7

10:30 AM → 12:00 PM **Future magnet developments**

Convener: Mike Lamont (CERN)

10:30 AM **Future HFM R&D directions** 30m

Speaker: Bernhard Auchmann (PSI/CERN)

11:00 AM **US high-field magnet program** 30m

Speaker: Soren Prestemon

11:30 AM **HTS developments** 30m

Speaker: Dr Amalia Ballarino (CERN)

Thursday, June 8

10:30 AM → 12:00 PM **FCC-hh accelerator**

Convener: Vladimir Shiltsev

10:30 AM **FCC-hh ring: overview of the new layout** 25m

Since the publication of the CDR, much progress has been made on the layout of the FCC-hh ring. Driven by the recent result of the ring placement studies and updates of the FCC-ee layout, major changes have been implemented in the FCC-hh ring layout. In this talk, I review the main features of the new layout, and I also provide an outlook of future studies and activities.

Speaker: Massimo Giovannozzi (CERN)

10:55 AM **New FCC-hh ring layout: arc and insertion optics** 20m

We present the latest developments in the optics design of the FCC-hh particle collider. The main change with respect to previous designs is the change of the arc cells from 12 to a 16-dipole FODO scheme which makes full use of the available aperture and increases the dipole filling factor. The updated design of insertions is also discussed, adapting the changes in the layout requirements from the placement study and are made compatible with the new arcs and their dispersion suppressors.

Speaker: Gustavo Perez Segurana (CERN)

11:15 AM **Collimation in FCC-hh** 20m

Speaker: Dr Roderik Bruce (CERN)

11:35 AM **Transfer lines for injection from LHC or scSPS, and comparison of injector options** 25m

Speaker: Wolfgang Bartmann (CERN)

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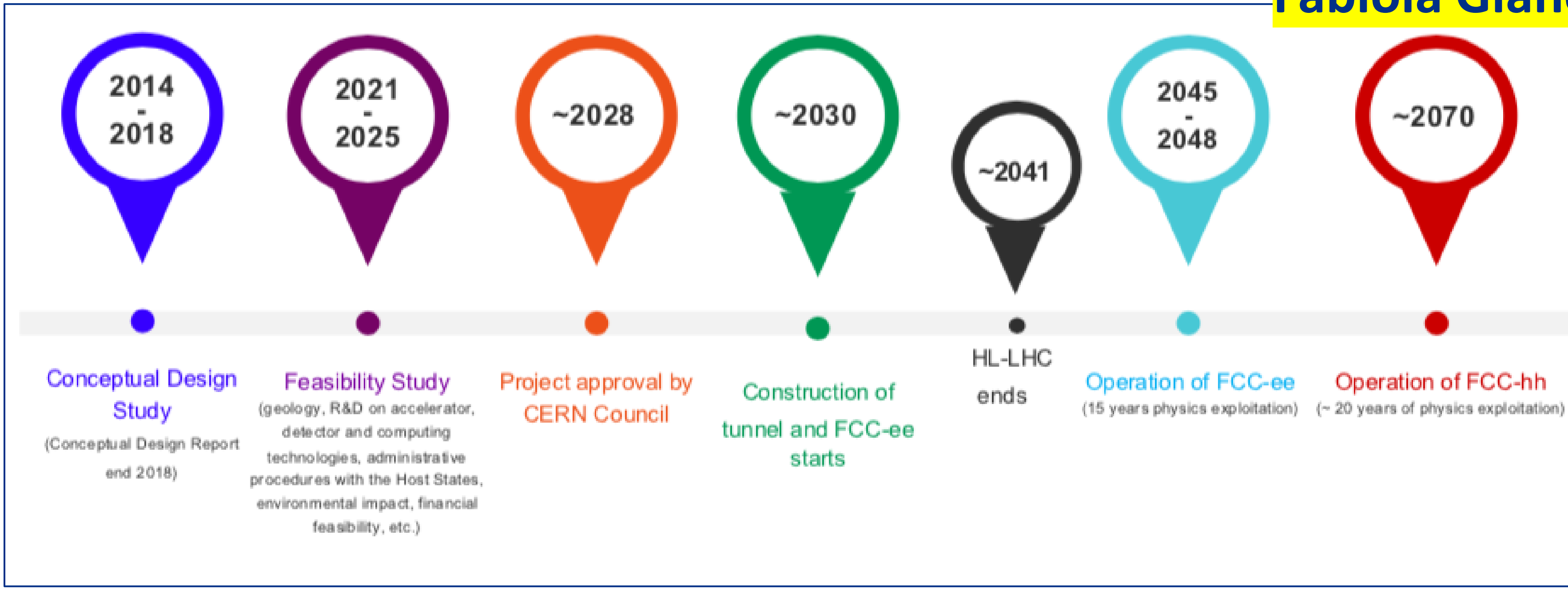
FCC-hh – Timeline (*Why worry now?)*

Fabiola Gianotti



1st stage collider, FCC-ee: electron-positron collisions 90-360 GeV
Construction: 2033-2045 → Physics operation: 2048-2063

2nd stage collider, FCC-hh: proton-proton collisions at ≥ 100 TeV
Construction: 2058-2070 → Physics operation: ~ 2070-2095

Assuming… FCC-ee will not happen, we may go directly to FCC-hh via the fastest path (Nb_3Sn). Timescale ~ 2060 : dictated by R&D and industrialisation of magnet technology, and cost

Challenges: Timeline

Akira Yamomoto EPPSU 2019

–**Nb3Sn**, **12~14 T:** 5~10 years for short-model R&D, and the following 5~10 years for prototype/pre-series with industry. It will result in **10 –20 yrs** for the construction to start,

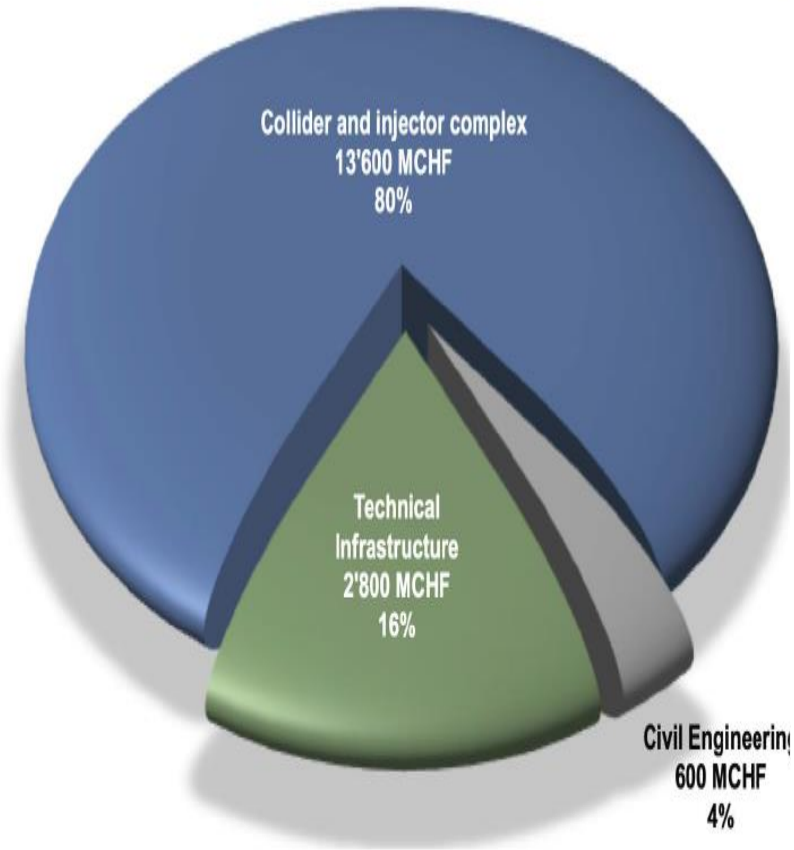
–**Nb3Sn**, **14~16 T:**10-15 years for short-model R&D, and the following 10 ~ 15 years for protype/pre-series with industry. It will result in **20 –30 yrs** for the construction to start

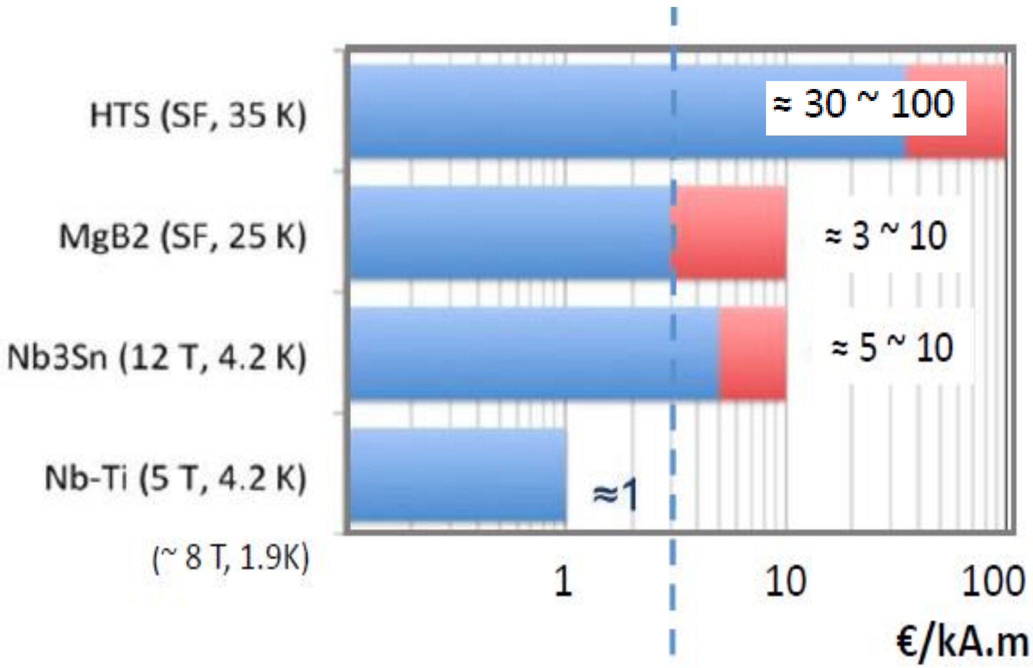
–**NbTi**, **8~9 T:**proven by LHC and **Nb3Sn,10 ~ 11 T** being demonstrated. It may be feasible for the construction to begin in > ~ 5 years.

Challenges: Cost

Cost of a magnet (rough, LHC):
~1/3 Cost of **conductor**
~1/3 Cost of **structure**
~1/3 Cost of **assembly**

Lucio Rossi





Akira Yamamoto EPPSU 2019

Snowmass'21 Implementation Task Force Report:

	CME (TeV)	Lumi per IP (10^34)	Years, pre-project R&D	Years to 1st Physics	Cost Range (2021 B$)	Electric Power (MW)
FCChh-100	100	30	>10	>25	30-50	~560

FCC-hh – Goals (*Now Updated*)

Michael Benedikt

Parameter	FCC-hh		HL-LHC	LHC
collision energy cms [TeV]	80-116		14	14
dipole field [T]	14 (Nb_3Sn) – 20 (HTS/Hybrid)		8.33	8.33
circumference [km]	90.7		26.7	26.7
beam current [A]	0.5		1.1	0.58
bunch intensity [10^{11}]	1	1	2.2	1.15
bunch spacing [ns]	25	25	25	25
synchr. rad. power / ring [kW]	1020-4250		7.3	3.6
SR power / length [W/m/ap.]	13-54		0.33	0.17
long. emit. damping time [h]	0.77-0.26		12.9	12.9
beta* [m]	1.1	0.3	0.15 (min.)	0.55
normalized emittance [μm]	2.2		2.5	3.75
peak luminosity [10^{34} $cm^{-2}s^{-1}$]	5	30	5 (lev.)	1
events/bunch crossing	170	1000	132	27
stored energy/beam [GJ]	6.1-8.9		0.7	0.36
integrated luminosity [fb^{-1}]	20000		3000	300

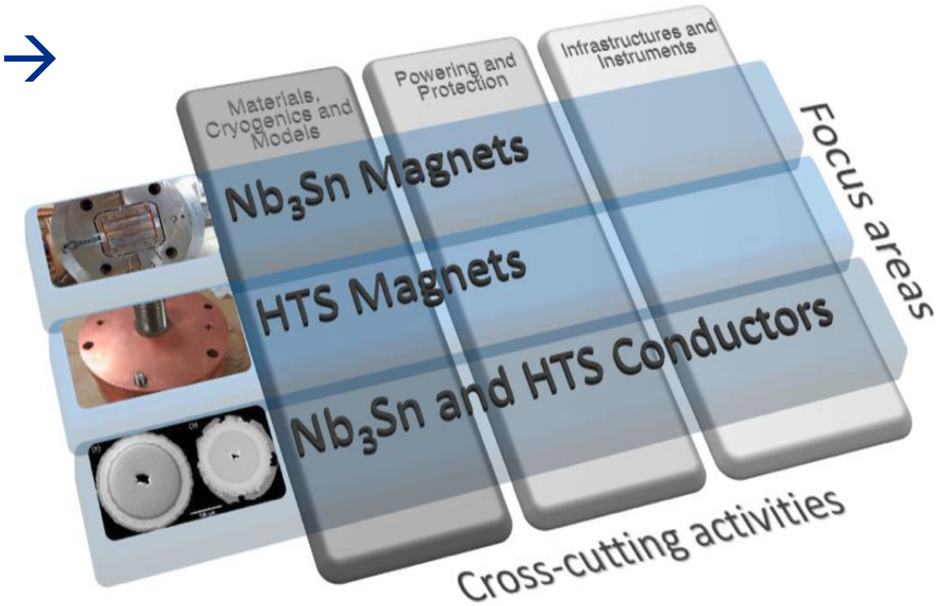
FCChh is part of the Feasibility Study funded from CERN budget: 100 MCHF total over 5 years; in addition: ~ 20 MCHF/year for high-field magnet R&D Additional funding from the European Commission and collaborating institutes (e.g., CHART collaboration with Switzerland).

High Field Magnet (HFM) Program - Europe

Bernhardt Auchmann

- 12 partners (labs, univ.)
- Three focused areas & goals →
  - Robust 12 T Nb3Sn magnets (Genova and CERN)
  - 16T common coil (15 T in 2025?)
  - Current density >1.5kA/mm2
  - HTS conductors and HFM
  - Cross cutting topics:

    Numerical models, materials, protection techniques, cryogenics, diagnostics, magnetic measurements, etc



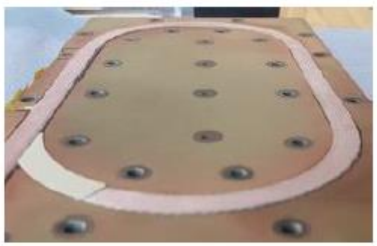
- Recent advances eg wax impregnation = no training! (slide)
  - Of course, there still questions remaining: will it be as good at very high fields? Is it rad-hard enough? etc

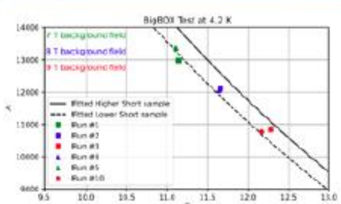
Wax Impregnation (1970's → recent U.Twente →)

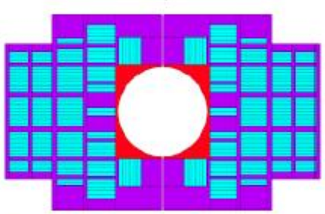
Feedback to Magnet Programs

PSI's BigBOX: a 13-turn stress-managed racetrack.

- No training with 12.3 T coil field, 150 MPa coil stress at BNL's DCC17 facility.







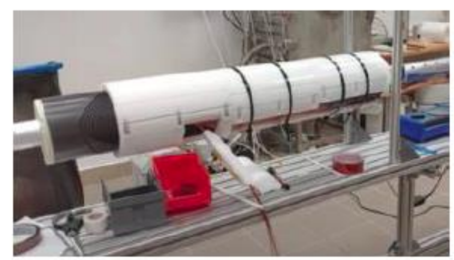
[Courtesy D. Araujo et al]

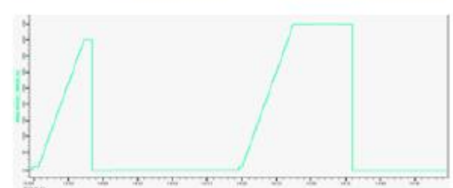
LBNL's wax impregnated sub-scale (5 T) CCT.

- First Nb_3Sn CCT without training.
- Follow-up magnet and test planned.

Wigner Inst. / CERN collaboration on SuShi septum for FCC-hh

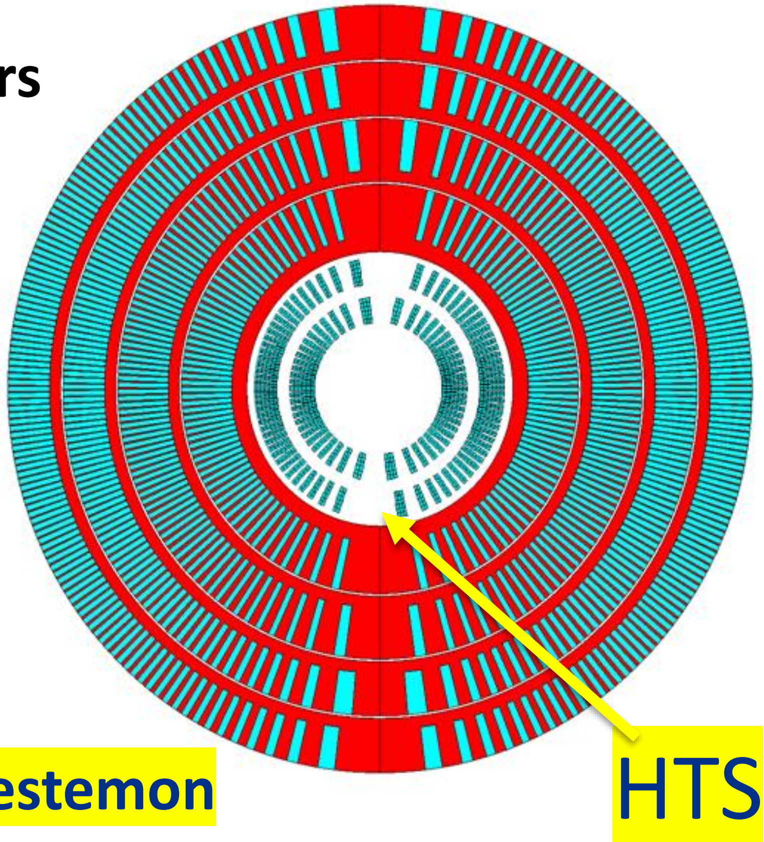
- Wax impregnated CCT required no training to nominal current.





Magnet Development Program (MDP) - US

- Three labs and University… FCChh and MuCollider
- Focus on stress management 14-16 T Nb3Sn
  - 120 mm aperture to fit 5T HTS insert
- Goal: in 3-4 years 16-17 T hybrid (Nb3Sn+REBCO) dipole
- Recent advances:
  - **14.5T FNAL 4-layer Nb3Sn → 2 layers**
  - **1st Nb_3Sn CCT coil wax impregnated had no quenches!**
  - **Diagnostics! E.g.:**
    - Rayleigh backscatter fiber optics for area-level strain monitoring
  - **Significant promise of REBCO**
- Challenges: total USHFM funding ~1/3-1/4 of that in Europe



agnets **Soren Prestemon**

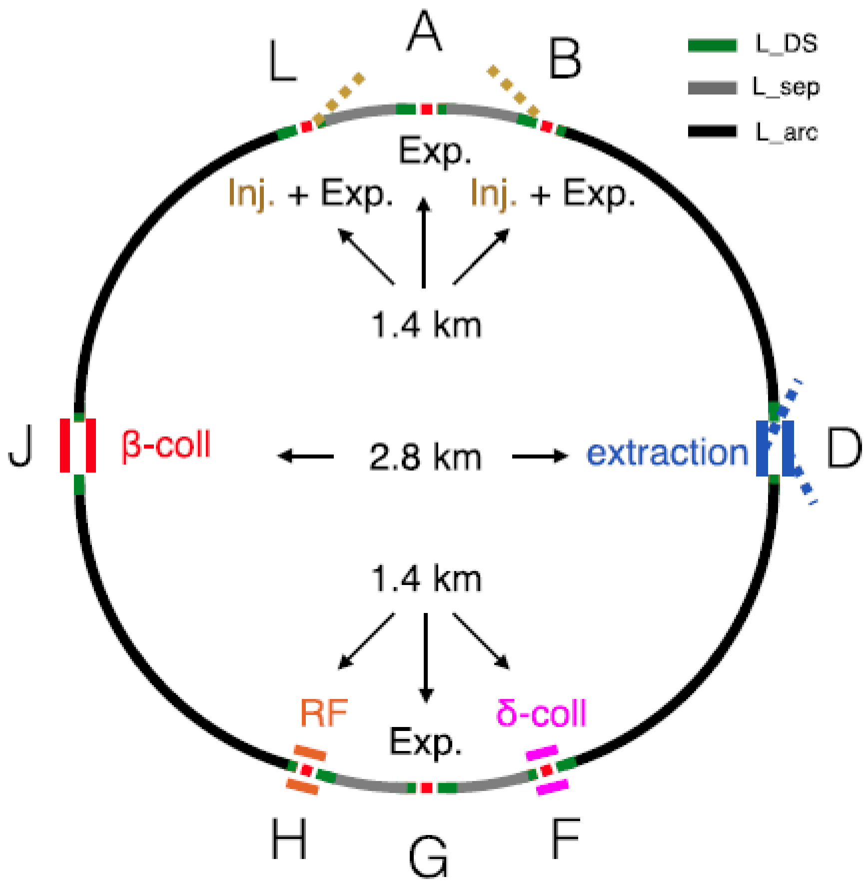
HTS Magnet Development

Amalia Ballarino

FCChh Optics Update

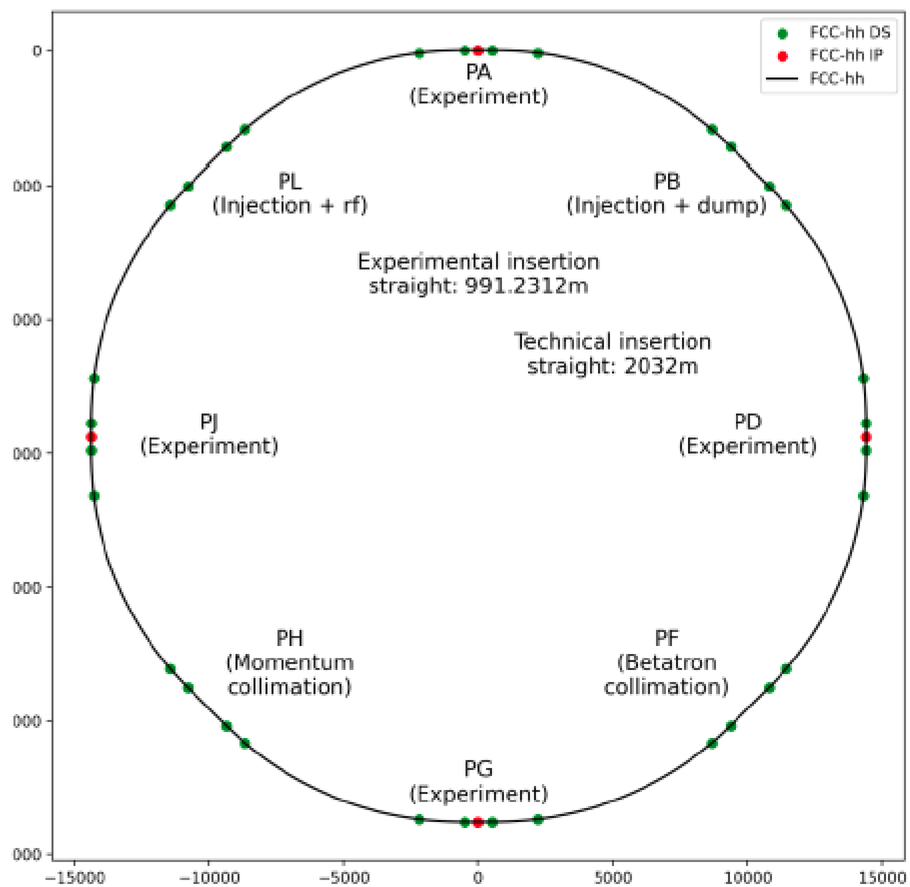
Massimo Giovanozzi
Gustavo Perez Segurana

In the FCCee footsteps: shorter *C*, less space for technical insertions, 4 IPs symmetry



Circumference: 97.75 km

energy (for 16 T dipoles): 48 TeV



Circumference: 90.66 km

FCChh Optics Update

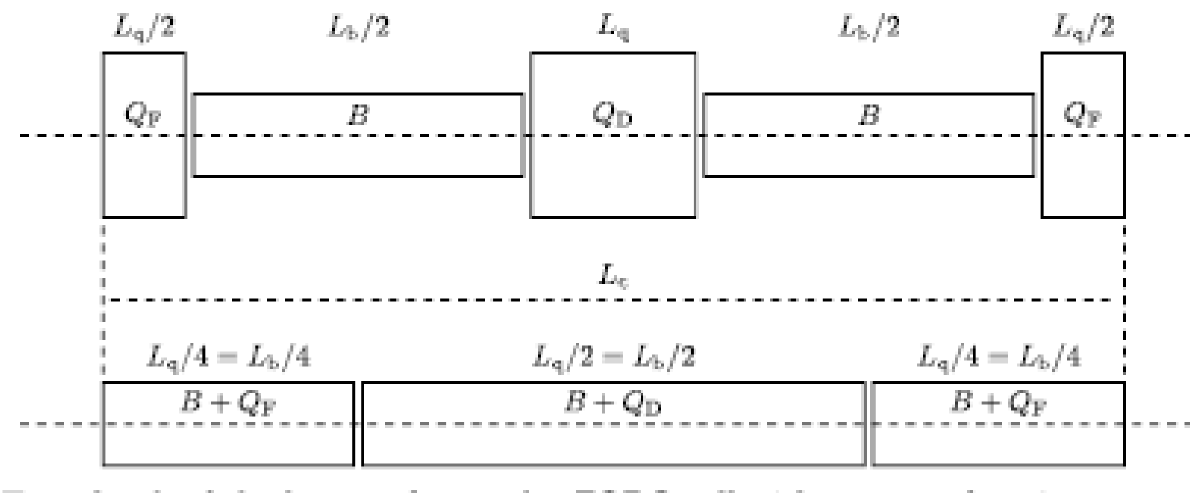
Massimo Giovanozzi
Gustavo Perez Segurana

Baseline change: **longer cells**

- 12 dipoles→16 per FODO, 213→276m
- packing factor 80%→84%

A non-baseline, alternative design of arcs and dispersion suppressors based on combined-function (CF) magnets

- has pros and cons
- needs further study

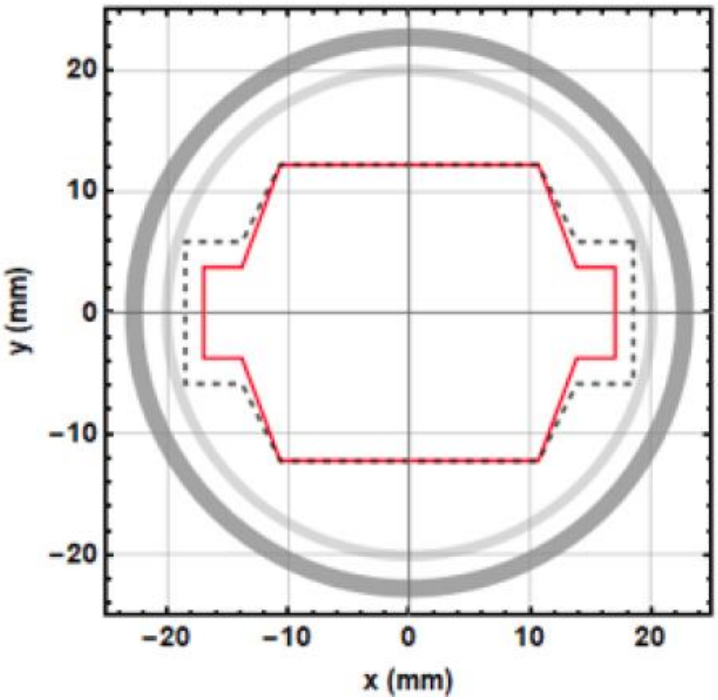


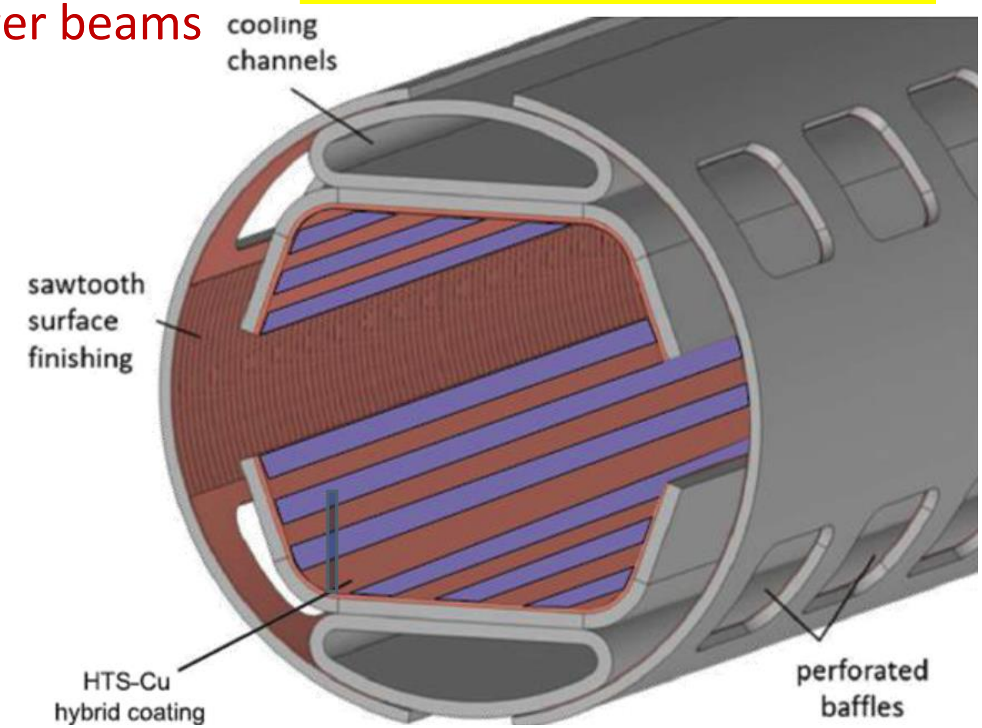
Sketch of separated-function (top) and combined-function (bottom) cells

Beam Screen Changes

Massimo Giovanozzi
Gustavo Perez Segurana

Longer cells → weaker focusing → larger beams





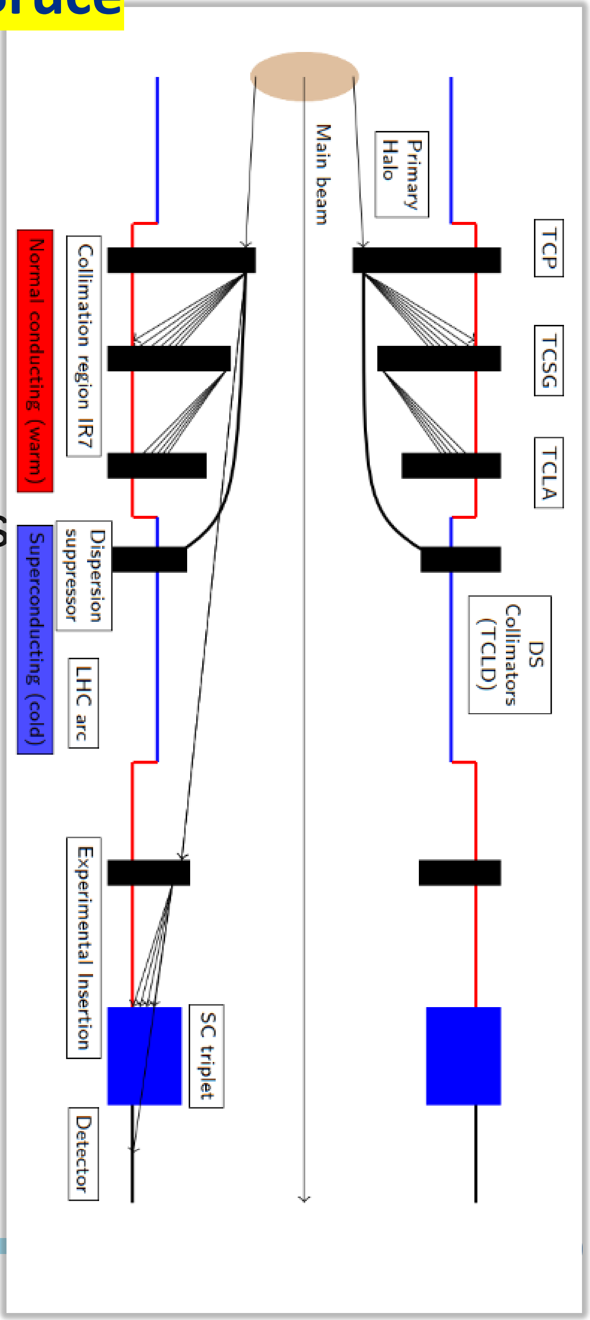
REBCO (HTS strips) - Cu coating to improve conductivity at high(er) temperature

A series of magnetic measurements are planned for October 2023 at CERN (SM18 facility) to probe the impact of the BS on the field quality.

FCChh Collimation

Roderick Bruce

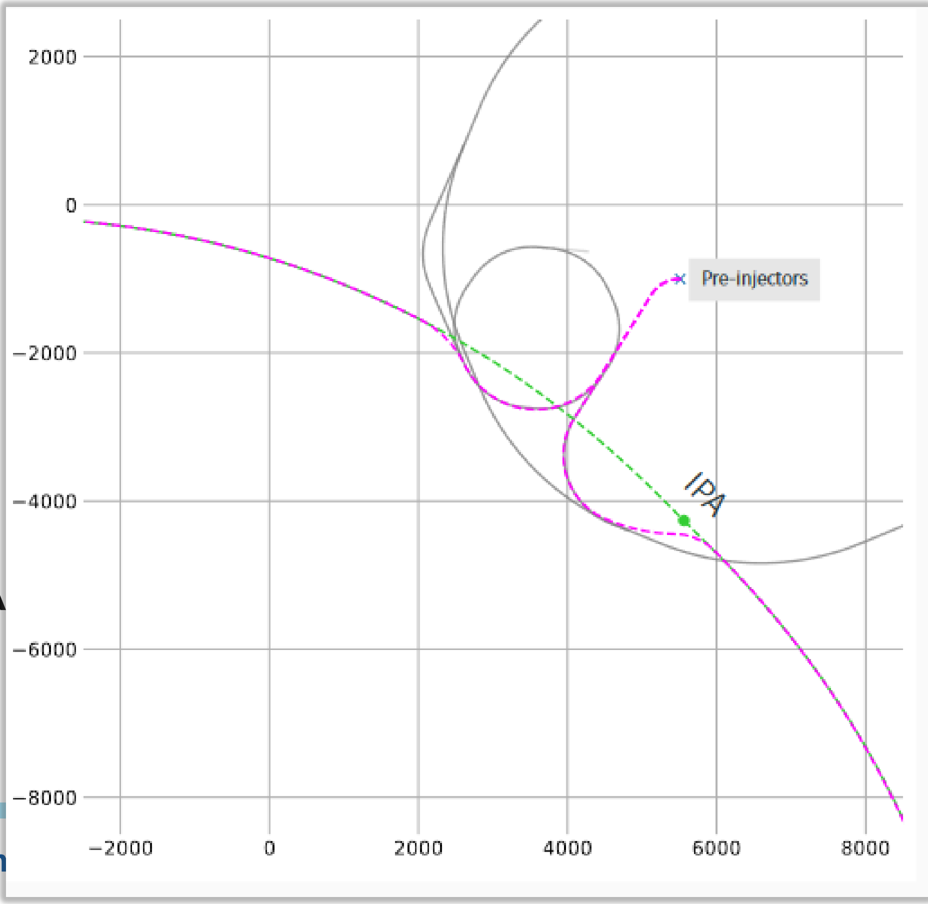
- LHC 0.36GJ beams → 8 GJ in FCChh
  - 11MW of losses to intercept
  - LHC gives assurance
  - Quench limits of "future magnets" - ?
- Still, some changes (wrt CDR):
  - Shorter *C* → 30% less space for collimators
  - New optics (12→16 dipoles/cell)
- Simulations show that:
  - No serious issues
  - Not 100% happy so far (old optics)
  - Need to redo calc's for new optics
- Some concern:
  - Aperture bottlenecks in new optics moved
    - from IRs to arcs/disp.suppressors – effect?



Hadron Injectors/Injection Lines

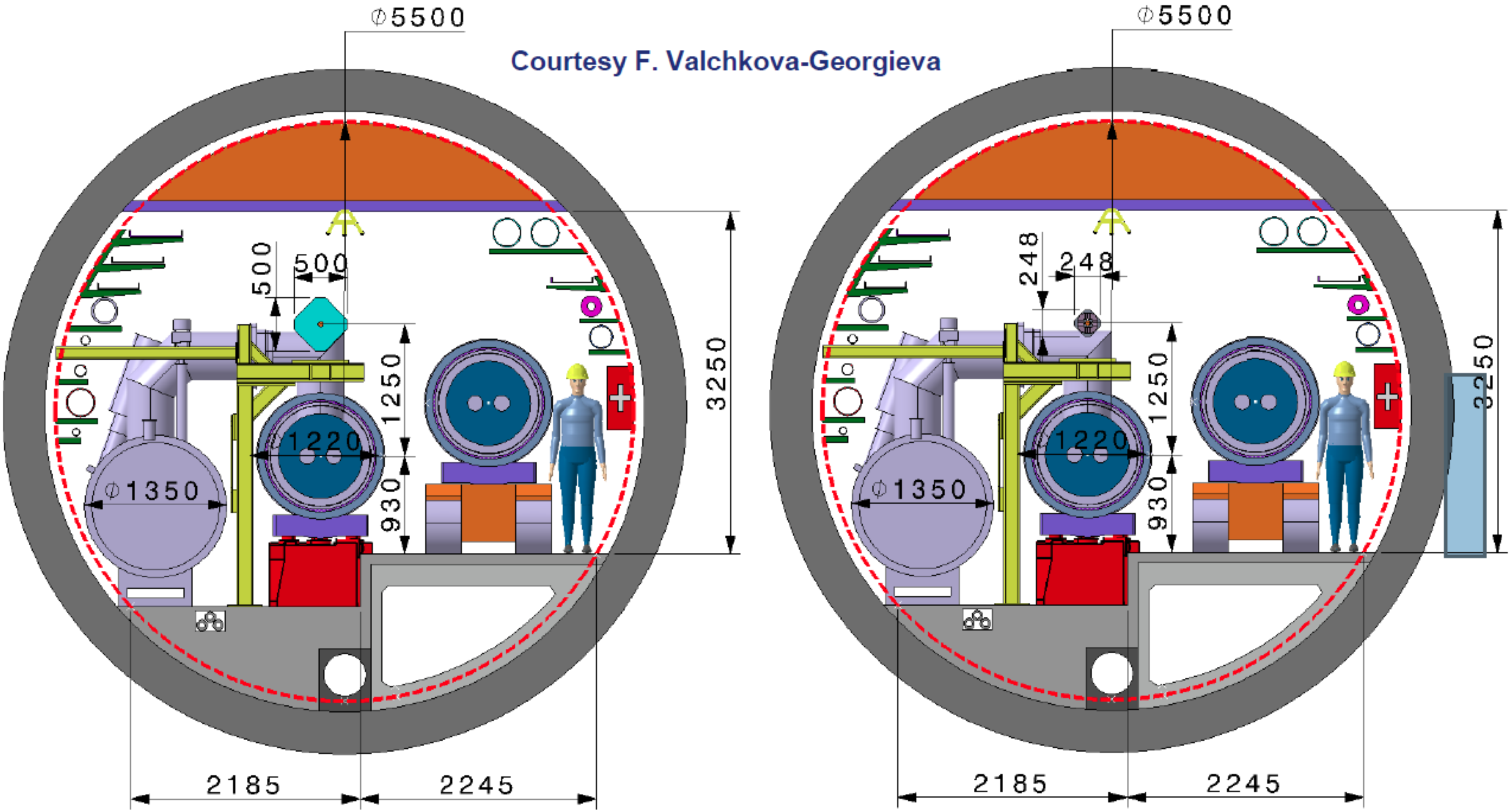
Wolfgang Bartmann

- Two energies/Three options (TBD later):
  - 1.3 scSPS (cheaper but - good enough for collider field quality?
  - 3.3 TeV (good but expensive?)
    - Either make LHC magnets ramp faster (now ~1000 s)
    - Or new 4T ring in LHC tunnel
- Reuse FCCee tunnels:
  - ~2 km each, ~8 T magnets
  - then ~10 km in collider 0.5-1T
- The latter can be PMs:
  - Smaller/cheaper (slide)
  - Lower power consumption
  - Experience at FNAL RR/CBETA
- Lot of other inj/dumps topics:
  - SUSHI (slide)



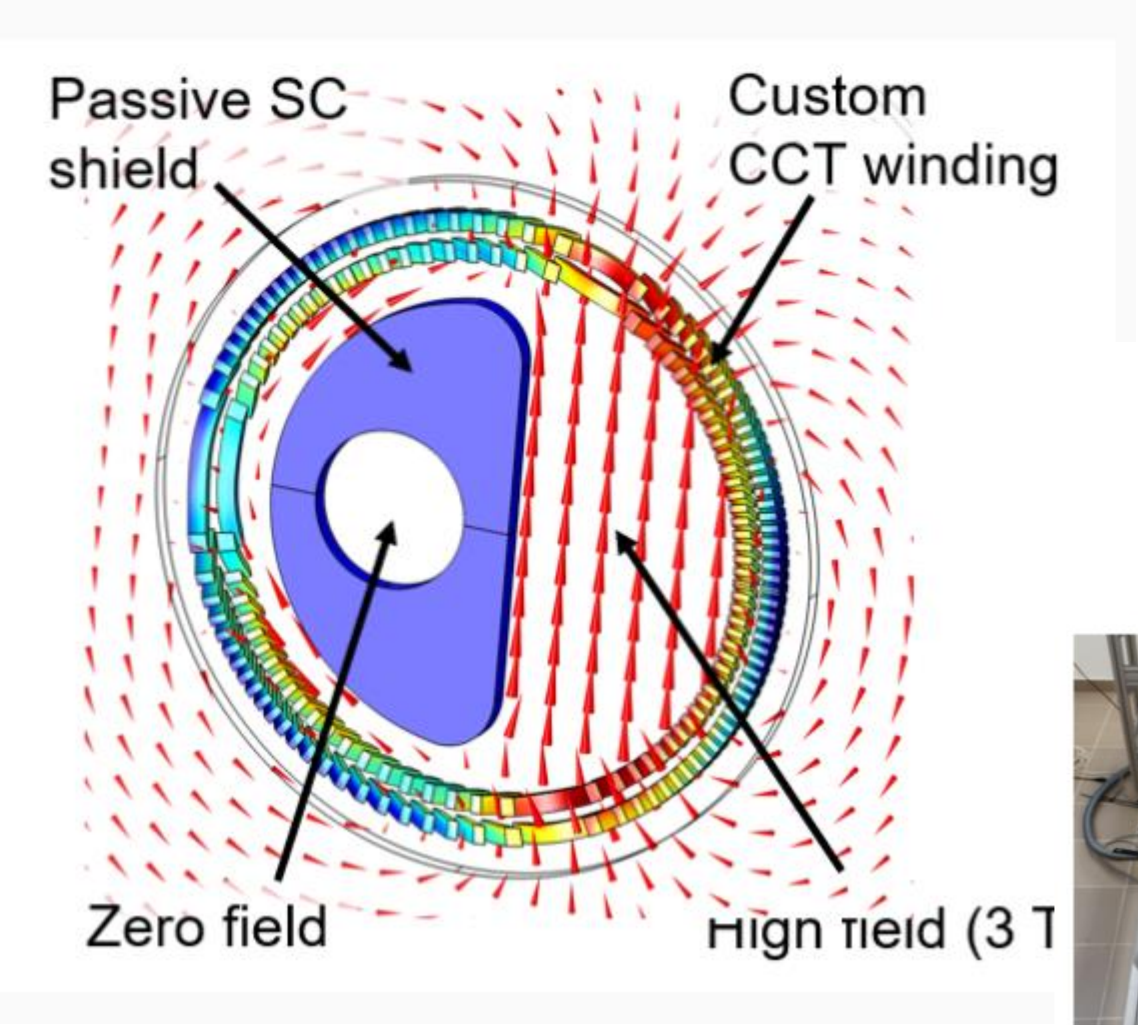
In the FCChh tunnel: Space consideration

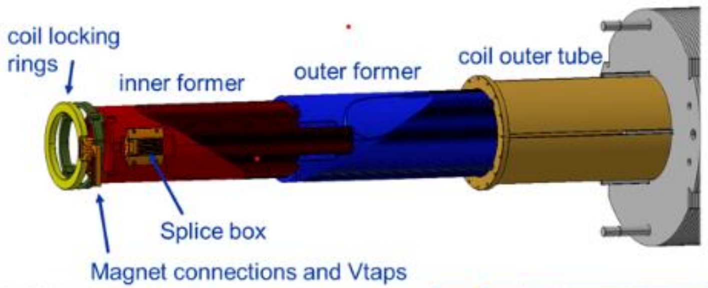
Normal conducting solution | Permanent magnet solution



SUSHI (Superconducting Shield) Dump Septum

Budapest/CERN





Coil after winding

Magnet being assembled

CCT magnet without shield was tested

Thank you for your attention!