



### Vertrauen und gegenseitiges Verständnis

Im Kindergarten des CERN lernen die Kinder, weltweit zu sein und die Welt auf spielerische Art und Weise zu entdecken. Im Bereich der wissenschaftlichen Forschung werden Fortschritte erstelle, wenn Menschen mit unterschiedlichem kulturellen und geografischen Hintergrund zusammenarbeiten. Die großen Forschungseinrichtungen leisten einen Beitrag zur Bildung der kommenden Generationen. Sie bieten jedes Jahr Tausenden von jungen Menschen die Möglichkeit, neue Kompetenzen in einem dynamischen internationalen Umfeld zu erwerben. Die Kooperation im Rahmen des FCC ist äußerst vielfältig: 50 Einrichtungen aus mehr als 35 Ländern und mehr als 25 Unternehmen arbeiten gemeinsam an der Gestaltung der internationalen Forschungsinfrastruktur, welche den LHC ablösen könnte.



### Blick in die Zukunft

Die Machbarkeitsstudie für den zukünftigen Ringbeschleuniger (Future Circular Collider, FCC) sieht sich 1931 einmündigen Forschungsinfrastuktur vor, die mehrere Teilschulungsbeschleuniger enthalten könnte. Vorausgesetzt, die Machbarkeitsstudie kommt zu einem positiven Ergebnis und die CERN-Mitgliedsstaaten haben das Vorgehen 2024, können die Bauarbeiten Anfang der 2030er Jahre beginnen. Das Kernstück des FCC-Projekts bildet ein neuer Tunnel mit einem Umfang von rund 100 km im französisch-schweizerischen Grenzgebiet rund um Genéve. Die erste Schritt wäre der Bau einer Elektron-Positron-Ringbeschleuniger, eine richtige Higgs-Fabrik. Damit wären Messungen von noch höherer Genauigkeit möglich, um alle bekannten Teilchen des Standardmodells bis ins Detail zu untersuchen.

Der bereits bestehende Tunnel des Large Hadron Collider (LHC) durchqueren Längs für einen Umfang von 27 km. Die neue geplante Tunnel für die großen FCC-Forschungsbeschleuniger ist ein geschlossener Kreis umgeben. © CERN FCC



### Energie und Felder

Nach heutigem Wissensstand besteht das Universum aus energetischen Feldern, zum Beispiel dem elektromagnetischen Feld, dem Gravitationsfeld und dem Brout-Englert-Higgs-Feld. Diese Felder wechselwirken miteinander und tauschen dabei Energie aus, die wir in Form von Teilchen erkennen können. Bildlich dargestellt sind diese Teilchen wie Mahlblumen, die sich in einem Getreidfeld vom Hintergrund abheben. Die Teilchen geben uns Aufschluss über die Grundgesetze der Natur, doch es ist derzeit noch nicht möglich ein Gesamtbild zu erhalten. Leistungsfähigere Teilchenbeschleuniger könnten dazu beitragen, einige der verborgenen Bereiche des Universums ans Licht zu bringen.

# 2025 FCC Week Summary:

## FCC-hh and High Field Magnets

Mike LAMONT (CERN), Vladimir SHILTSEV (NIU), Pierre VEDRINE (CEA)

FCC Week 2025 · May 23 · Vienna, Austria

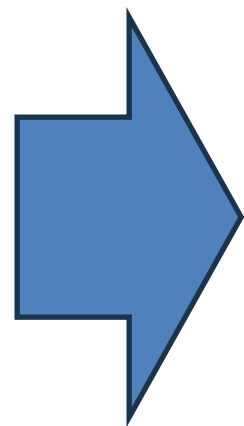
<https://fccweek2024.web.cern.ch>

10 - 14 June  
**FCC  
WEEK**  
2024



**SAN  
FRANCISCO**

Venue: The Westin St. Francis



19-23 MAY  
**FCC  
WEEK**  
2025



↙  
**HOFBURG  
VIENNA**



Vladimir SHILTSEV

Future Circular Collider  
Feasibility Study Report

**627 Pages**

Volume 2

Accelerators, Technical Infrastructure  
and Safety

March 31, 2025

arXiv:2505.00274

Submitted to the European Physics Journal ST, a joint publication of EDP Sciences,  
Springer Science+Business Media, and the Società Italiana di Fisica.

**FCCee: 498 pages**

Estimated investment costs in 2024 Swiss Francs.



**Domain**

**Cost  
[MCHF]**

**FCC-ee total, including four experiments**

**15 320**

The investments are distributed over a time frame of about 15 years.

**FChh: 57 pages**

**Domain**

**Cost  
[MCHF]**

**FCC-hh total**

**18 880**

The investments are distributed over a time frame of about 15 years.

# Stage 2: Hadron Collider *FCC-hh*

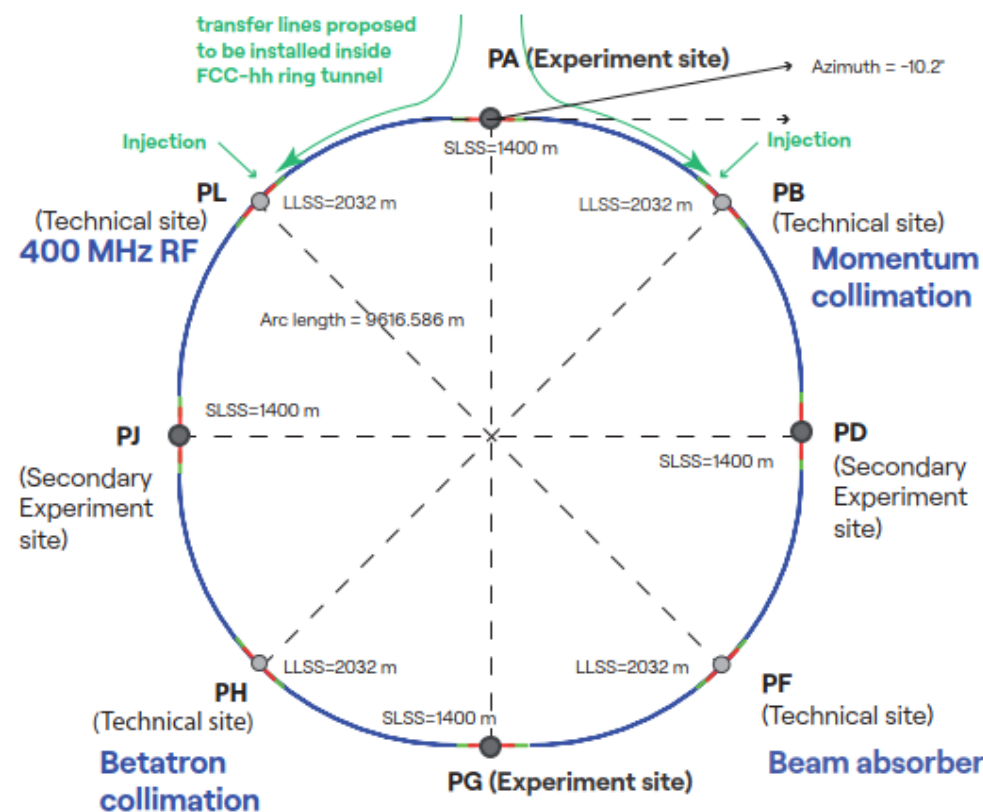


- Parameter optimization to lower electricity consumption (*~max. consumption of FCC-ee*)
- Magnetic field considered realistic with today's technologies (Nb<sub>3</sub>Sn, *~14T, 1.9 K*)

## Main parameters FSR 2025

parameter	FCC-hh	FCC-hh CDR	HL-LHC
collision energy cms [TeV]	<b>85</b>	<b>100</b>	14
dipole field [T]	<b>14</b>	<b>16</b>	8.33
circumference [km]	<b>90.7</b>	<b>97.8</b>	26.7
beam current [A]	0.5	0.5	1.1
synchr. rad. per ring [kW]	<b>1200</b>	<b>2400</b>	7.3
peak luminos. [ $10^{34} \text{ cm}^{-2}\text{s}^{-1}$ ]	30	30	5 (lev.)
events/bunch crossing	1000	1000	132
stored energy/beam [GJ]	6.5	8.3	0.7
integr. luminosity / IP [ $\text{ab}^{-1}$ ]	20	20	3

## FCC-hh functional layout



# Accelerator Complexity Score (ASC)

Scale · Diversity · Complexity · Novelty of Subsystems & Effects



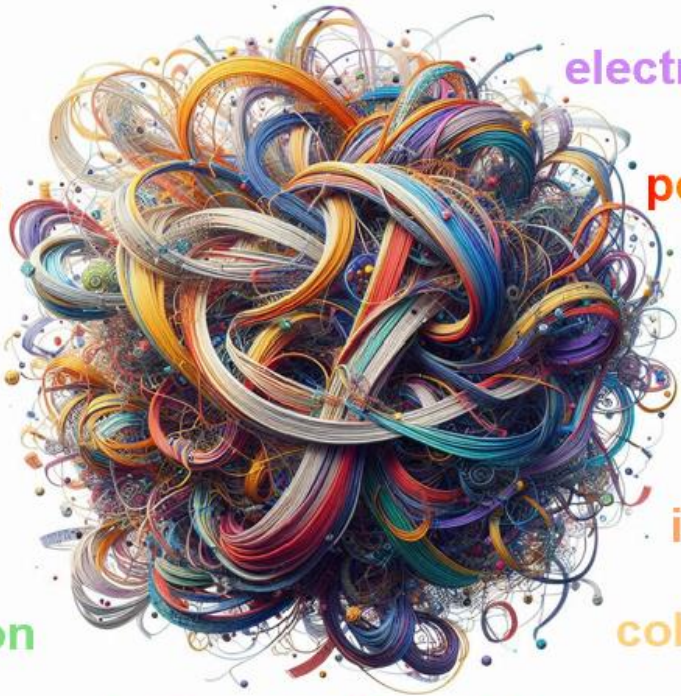
**FCC e+e- ASC≈11.0**

**FCC pp ASC≈12.0**

**ASC<sub>LHC</sub>=10**

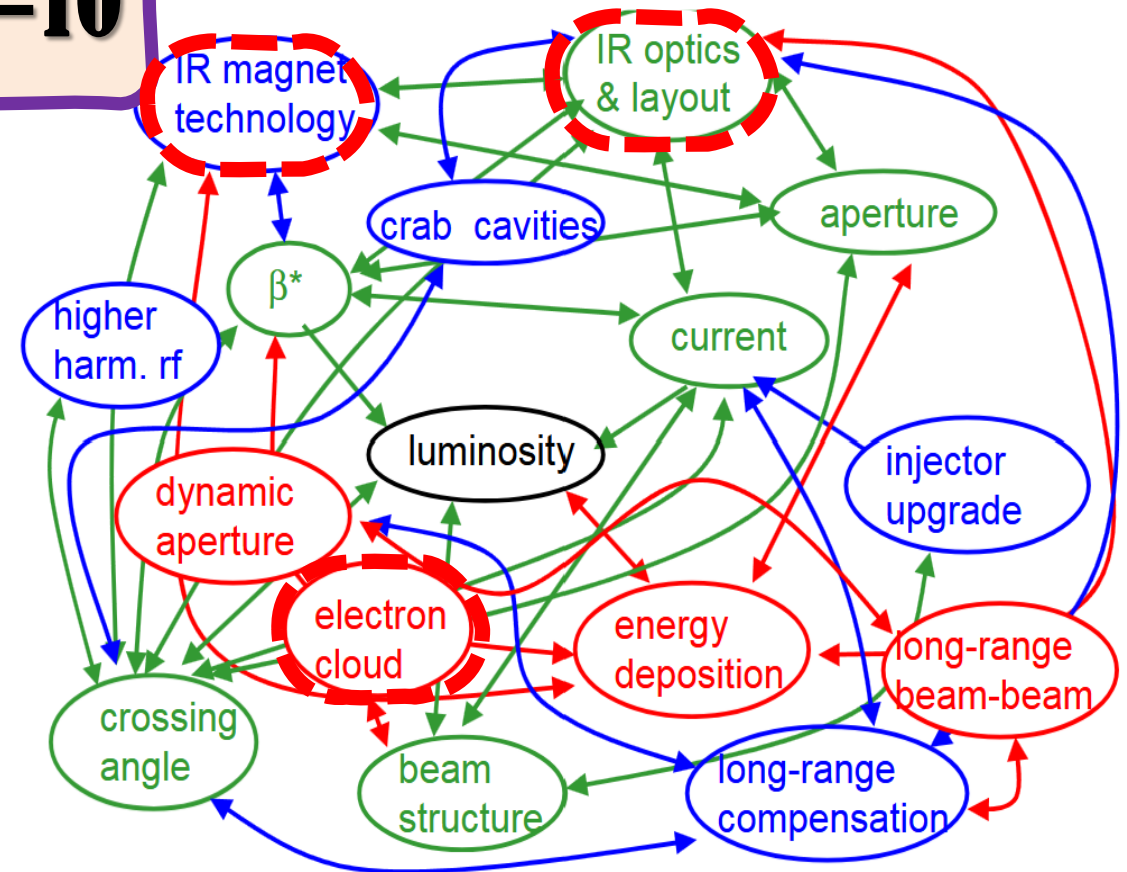
errors & misalignments

optics  
impedances  
beam-beam  
magnets  
radiation



electron cloud  
polarization  
RF  
MDI  
injectors  
collimation

lattice nonlinearities



Peter Kicsiny

Vladimir SHILTSEV

Frank Zimmermann

# FCChh & HFM: 13 Talks @FCC Week 2025



## FCC-hh accelerator: baseline & cryogenics

chair: V.Shiltsev/NIU, 10h30-12h00

**Feasibility Study Baseline Layout and Prospects for FCC-hh**, Gustavo Perez Segurano/U Malta

**Hybrid REBCO-Cu coating for the FCC beam screen to achieve low surface impedance and high magnetic field homogeneity**, Joffre Gutierrez Royo/ICMAB-CSIC

**TI-1223 Superconducting Films for Beam Screen Coatings in FCC: Synthesis and Performance Validation**, Emilio Bellingeri/CNR-SPIN

**Cryogenic baseline and advancements on the 4.5 K option for FCC-hh using Nb3Sn magnets**, Patricia Borges de Sousa/CERN

## High-Field Magnets (1)

chair: P.Vedrine/CEA 13h30-15h00

**Overview of LTS HFM magnet and conductor activities**, Ezio Todesco/CERN

**Protection of LTS and HTS magnets and circuits for FCC-h**, Arjan Verweij /CERN, Jan Uythoven/CERN

**HTS magnet R&D for next-generation accelerators at IHEP**, Qingjin Xu

**Progress towards HTS HFM magnet and conductor strategy**, Dr Amalia Ballarino/CERN

Vladimir SHILTSEV

## High-Field Magnets (2)

chair: M.Lamont/CERN, 15h30-17h00

**Status of US MDP**, Paolo Ferracin /LBNL

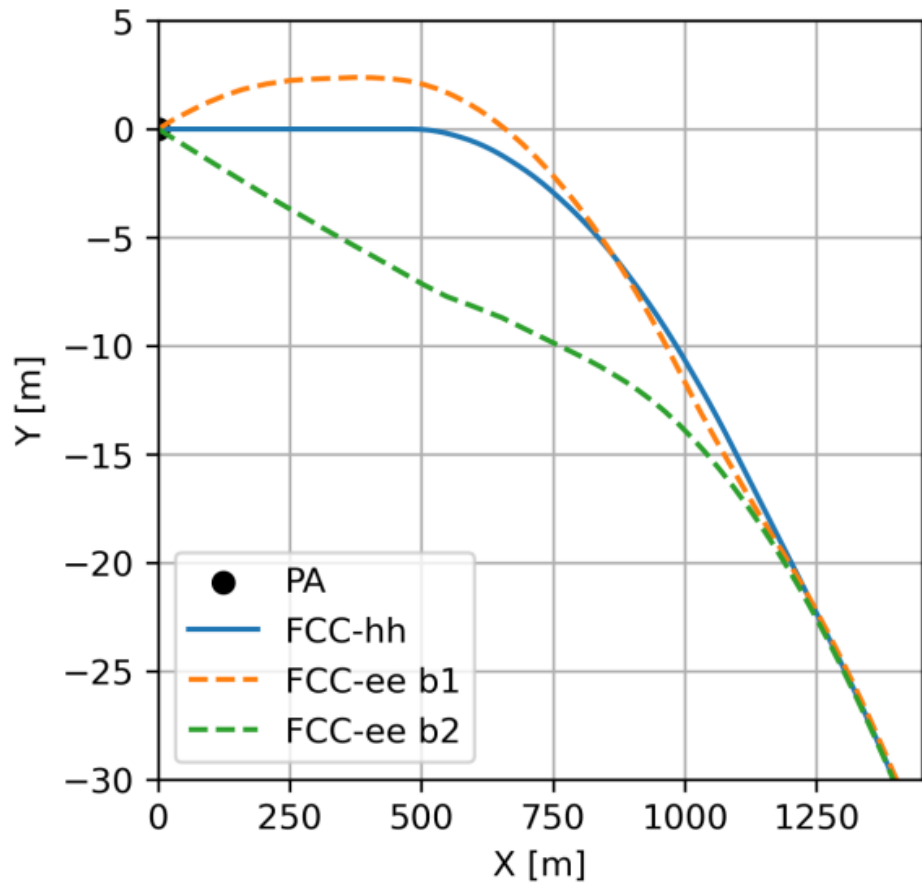
**Status of HFM development at CEA**, Etienne Rochepault /Université Paris-Saclay

**Status of HFM development at CIEMAT**, Fernando Toral/CIEMAT - Centro de Investigaciones Energéticas Medioambientales y Tec.

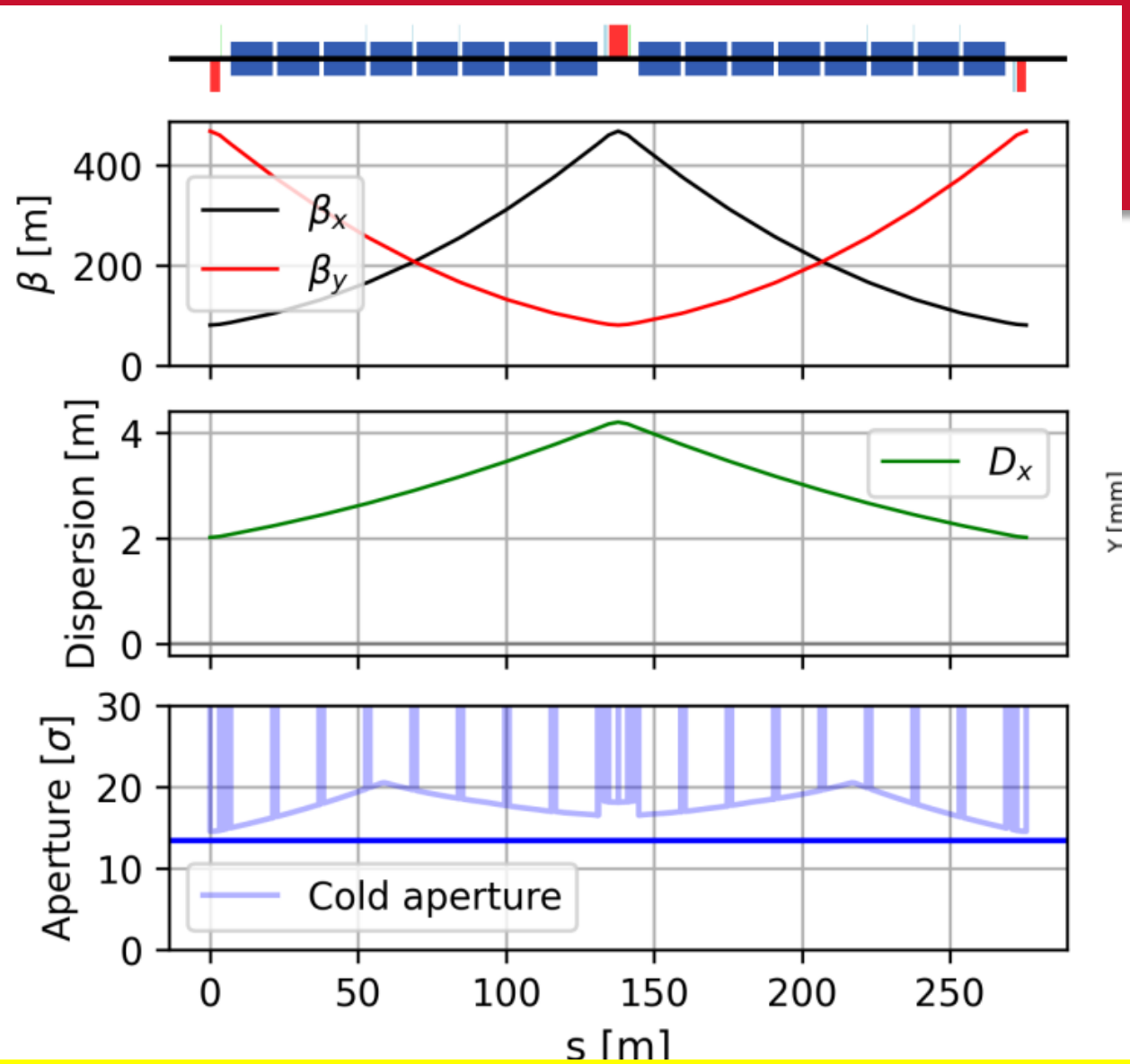
**Status of HFM development at INFN**, Alessandra Pampaloni/INFN Genova

**Status of HFM development at PSI**, Bernhard Auchmann/PSI

# FCC-hh layout & optics



geometry of FCC-hh and FCC-ee at PA



3.3TeV injection; 14.87m dipoles, 14T, longer cells  $\rightarrow$  275 m  
 Filling factor: 80%  $\rightarrow$  83%  $\rightarrow$  85% (? future)... to explore:  
 Longer magnets? Combined function magnets?

# New FCC-hh baseline and power consumption



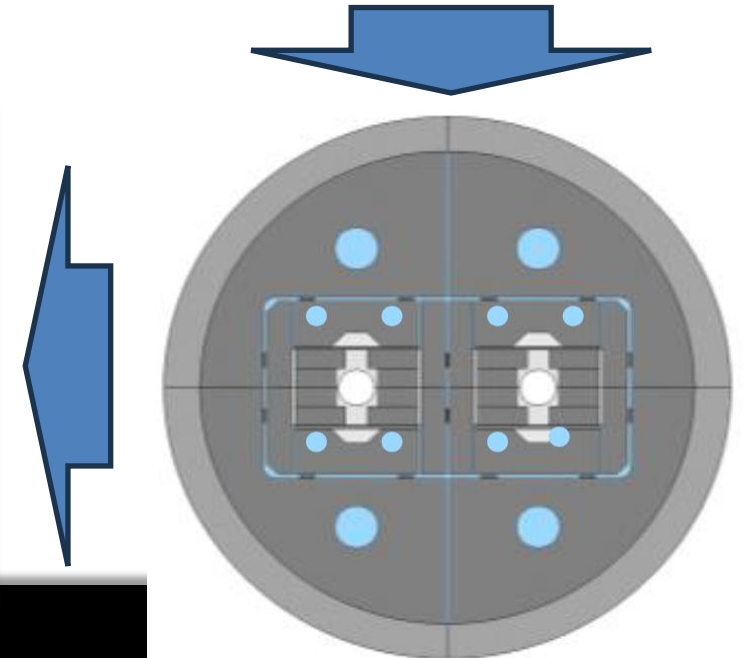
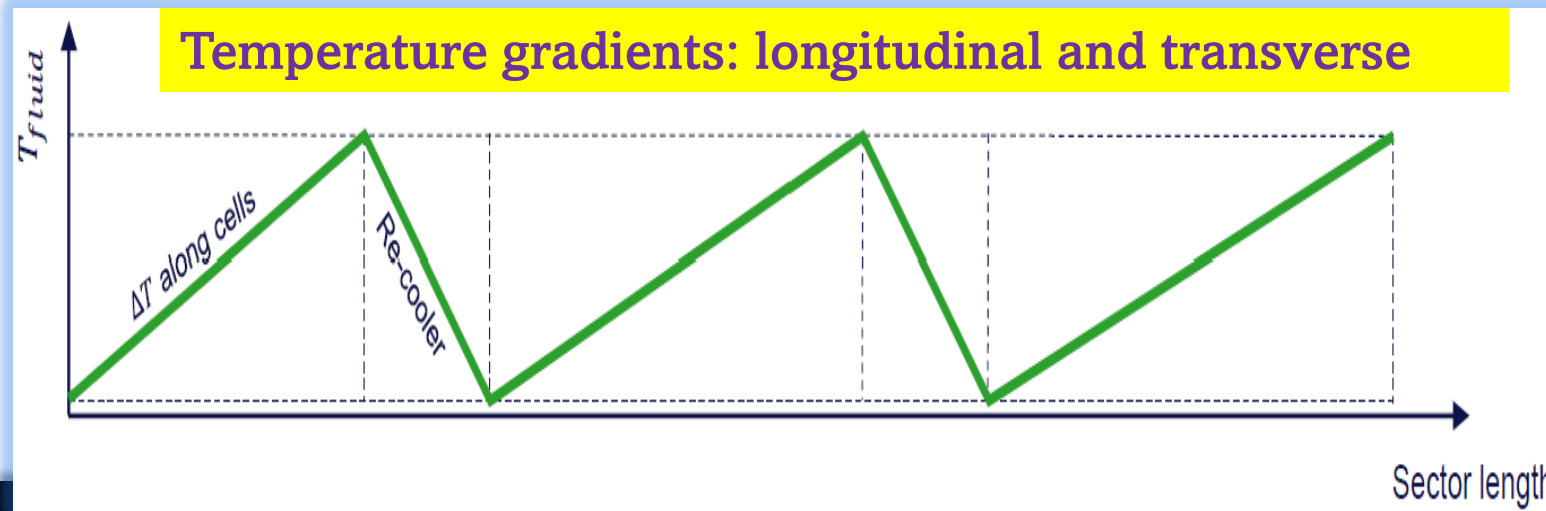
## Technical system choices and areas for optimization:

- **Cold mass** either at 1.9 K with superfluid He (studied in CDR, cf. LHC) or with **4.5 K with forced flow**
- Temperature of beam vacuum system (beam screen) + Cryogenics eco mode during shutdowns

FCC 91 km	Nb <sub>3</sub> Sn 14T	Nb <sub>3</sub> Sn 14T
Magnet temperature	1.9 K	4.5 K
Electric energy/yr	< 2.5 TWh	< 2.0 TWh

**4.5 K Allows LOWER Capital Cost + Lower Ops Cost + Less He inventory**

**But** Lose effective heat conductivity of He II (1000x that of Cu at same  $T$ ) → *forced flow*



# FCC-hh: Beam Screen – HTS Options



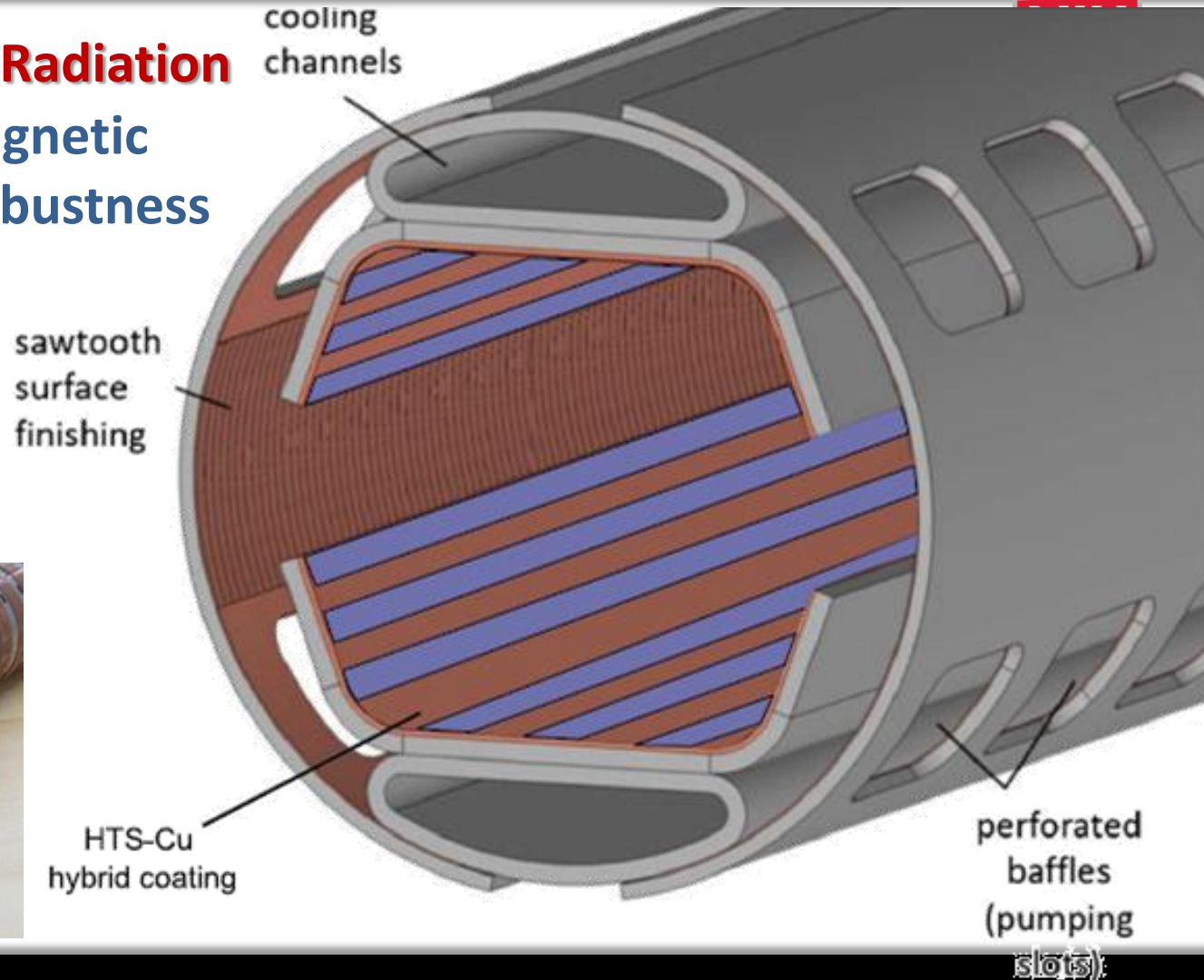
**Screen** : shields magnets from Synchrotron Radiation

to achieve low surface impedance + high magnetic field homogeneity + low SEY + mechanical robustness

→ just Copper might not be sufficient

**Option 1:** Hybrid REBCO – Cu coatings  
40K – 60K and 14(16)T, allows to operate the system with the consequent decrease in running cost.

**Option 2:** Thallium-1223  
has even higher  $T_c \sim 120K$ , electro-chemical deposition, but toxic, volatile



# High Field Magnet R&D – International Landscape



- Global programmes **advancing Nb<sub>3</sub>Sn and HTS technologies** for future high-energy colliders (e.g. FCC-hh)
- **Diverse magnet concepts:** cos-theta, block coil, common coil, hybrid LTS/HTS
- **Shared aims:** 14 T operational field, 50 mm aperture, scalable designs, reduced training, enhanced diagnostics

- **Participating Institutes:**

- US MDP (BNL, FNAL, LBNL, NHMFL)
- CEA Paris-Saclay
- CIEMAT (Spain)
- INFN (Italy)
- PSI (Switzerland)

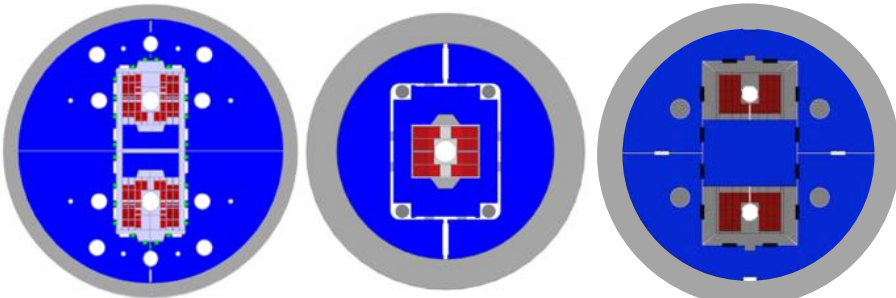
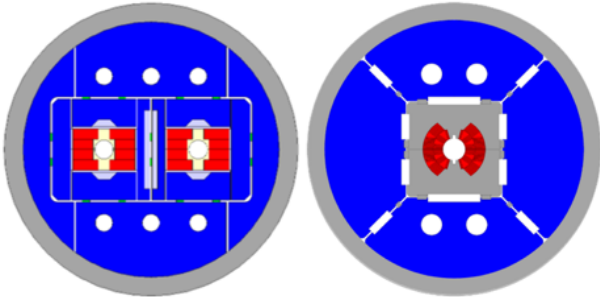


# FCC-hh High-Field Magnet R&D ongoing



## Nb<sub>3</sub>Sn:

- 12-T and 14-T short demonstrators
- Different coil geometries
- Tests scheduled for 2026



- **4 options studied** in parallel in the European HFM programme
  - **12 T magnet at 77 TeV** ; at least 5-20 % cheaper for only 10 % less energy
  - **Operation at 4.5 K** with 30% reduction in power consumption
  - **20 m long magnets 25% cheaper** i.e. less magnet to produce and possible 4% gain in TeV, etc.
  - **Hybrid Nb<sub>3</sub>Sn/NbTi magnet**; for 14 T magnet, half of the coil can be in NbTi, i.e. reducing the cost of the conductor and the hysteresis loss.
- **16 T hybrid Nb<sub>3</sub>Sn/HTS magnets** are being developed at IHEP in China, combining Nb<sub>3</sub>Sn outsert between 13 T and 10 T, and HTS insert between 3 T and 6 T. Several tests have been performed, showing problems and damage during the tests due to the lack of strong coupling between HTS and LTS coils during quenching ...

# Nb<sub>3</sub>Sn & Hybrid Magnet Progress



- **US MDP:**
  - Large-aperture Nb<sub>3</sub>Sn dipoles (up to **14 T**)
  - Hybrid magnet (HM1) test mid-2025
  - Advanced modelling and quench diagnostics
- **CEA:**
  - R2D2 (block coil) in assembly; F2D2 aims at **14 T** with field quality
- **INFN:**
  - FalconD 12 T cos-theta dipole design completed; next: **14 T**, 4-layer model
  - New CERN-INFN agreement includes HTS concept development
- **CIEMAT:**
  - Common coil models: ISAAC (low-preload, existing coils), DAISY (Nb<sub>3</sub>Sn/NbTi hybrid demonstrator in prep)

# FCC-hh High-Field Magnet $Nb_3Sn$ and HTS R&D ongoing



## HTS R&D in various domains:

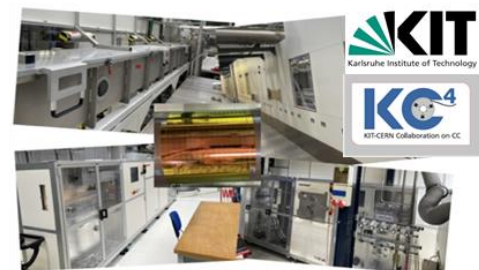
- REBCO and IBS Conductor R&D
- Racetrack coil developments

The HFM HTS strategy is to "demonstrate the suitability of high temperature superconductors (HTS) for accelerator magnet applications, providing proof-of-principle of HTS magnet technology beyond the  $Nb_3Sn$  range, with a target of over 20 T".

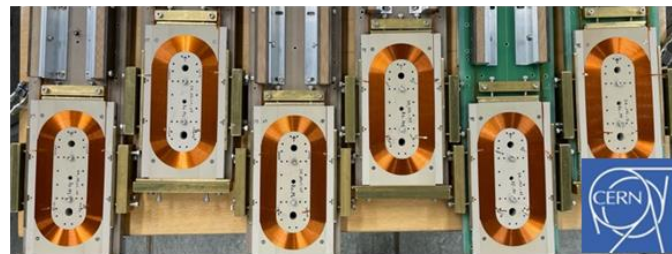
Parallel development of HTS conductor and iron-based superconductor (Ba-122): The latter is superior to  $Nb_3Sn$  in terms of critical field and temperature, and superior to HTS in terms of lower anisotropy, improved grain connectivity and lower cost. IBS is being developed in China and Italy (SPIN).

The current focus is on small 5 T - 10 T REBCO coils. This is a necessary intermediate step towards higher fields and accelerator quality magnets.

The HTS magnet effort is well established in Europe with 9 contributors today to study different aspects of the technology.



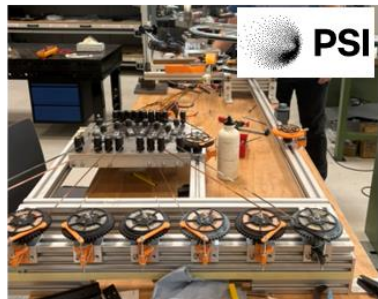
REBCO coated-conductor R&D line at KIT.



Insulated tape-stack coils for assembly in common-coil config at CERN.



Iron-based SC powder synthesis and R&D tape fabrication at CNR SPIN



Fabrication of racetrack from solder-impregnated tape-stack cable at PSI.



CEA process development for metal-insulated racetrack coils.

# HTS Development and Outlook



- **PSI:**

- LTS: Stress-managed magnet series (BigBOX, SMACC1)
- HTS: REBCO subscale coils progressing toward 4–5 T
- R&D on cryogenic efficiency, AC loss modelling, REBCO scaling

- **CEA:**

- MI REBCO racetrack coils reach >12 T (peak), withstand quenches
- Scaling up to 600 mm NARSIL demonstrator

- **INFN:**

- Designing a subscale REBCO dipole targeting 10 T at 20 K with a 50 mm aperture.

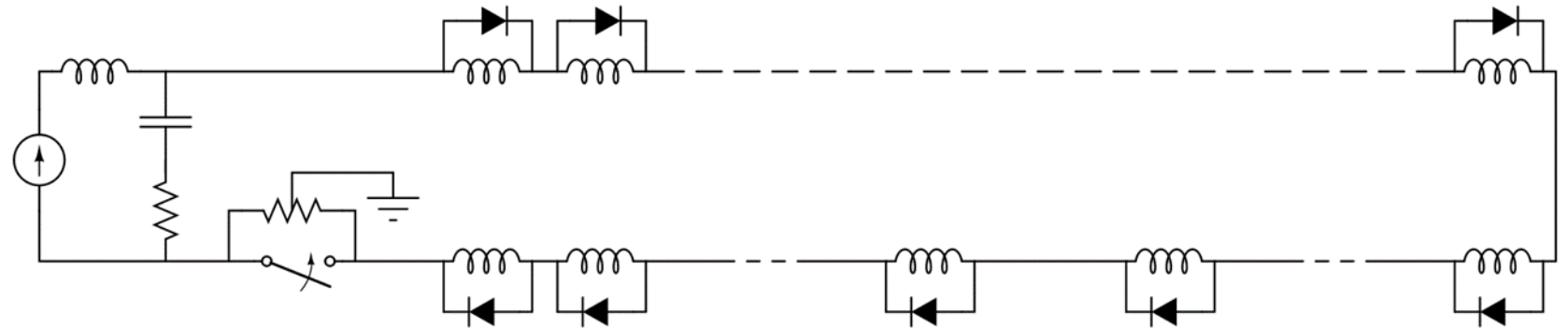
- **Common Threads:**

- Stress management, diagnostics, and energy extraction are critical
- Hybrid approaches are gaining traction, but HTS maturity for accelerator quality still under scrutiny

# Protection of LTS and HTS magnets and circuits for FCC-hh



- Changing the magnet parameters does not change the protection strategy for **Nb<sub>3</sub>Sn magnets** developed in the previous FCC studies.
- **New Nb<sub>3</sub>Sn magnet protection devices** are proposed as the recently developed Energy Shift with Coupling (ESC) method, which is based on magnetic coupling. However, ESC units are quite large, so sufficient space should be provided to locate these systems close to each magnet, supported by calculations using different codes.
- The power supply and protection circuits are similar to those of the LHC, and the number of power converters is being optimized.



**For HTS magnet protection**, differences in enthalpy margins, which are higher, have a strong effect, i.e. small mechanical movements do not trigger quenches, quench detection time is much shorter, etc.

The protection and power supply of HTS magnets is very different from that of Nb<sub>3</sub>Sn magnets. **Three protection concepts could be envisaged: active protection (using ESC, QHs), self-protection using NI, MI insulation, quench-free concept.** A rigorous R&D programme is needed to decide on the best concept.



## 100 Kilometer lang und 150 bis 400 Meter tief

Der Tunnel des zukünftigen Ringbeschleunigers könnte an einigen Stellen bis zu 400 Meter tief unter der Erde verlaufen – das ist etwa so tief wie der Eiffelturm hoch ist. Die Grabungen für den Tunnel würden unterhalb einer felsigen Schicht im Untergrund der Region Genf und des französischen Grenzgebiets erfolgen. Zusammen mit dem Bau der damit verbundenen Oberflächeninfrastruktur wäre dies eine enorme Herausforderung für den Hoch- und Tiefbau. Zunächst müssten internationale Forschungs- und Entwicklungsarbeiten durchgeführt werden, um geeignete Methoden für die Tunnelaushebung und die Wiederverwertung des Aushubmaterials zu ermitteln. Über Schächte mit 15 Meter Durchmesser, also etwa so groß wie die Grundfläche eines Einfamilienhauses, könnte man von der Oberfläche aus in den Tunnel gelangen. Im Tunnel selbst befänden sich neben dem Beschleuniger alle erforderlichen elektrischen Anlagen und Kabel für die Übermittlung der Daten und die Fernüberwachung. Dadurch wären

***Thanks to the  
speakers!***  
***Thank you for  
your attention!***

