HTS MAGNETS FOR THE SHORT STRAIGHT SECTIONS

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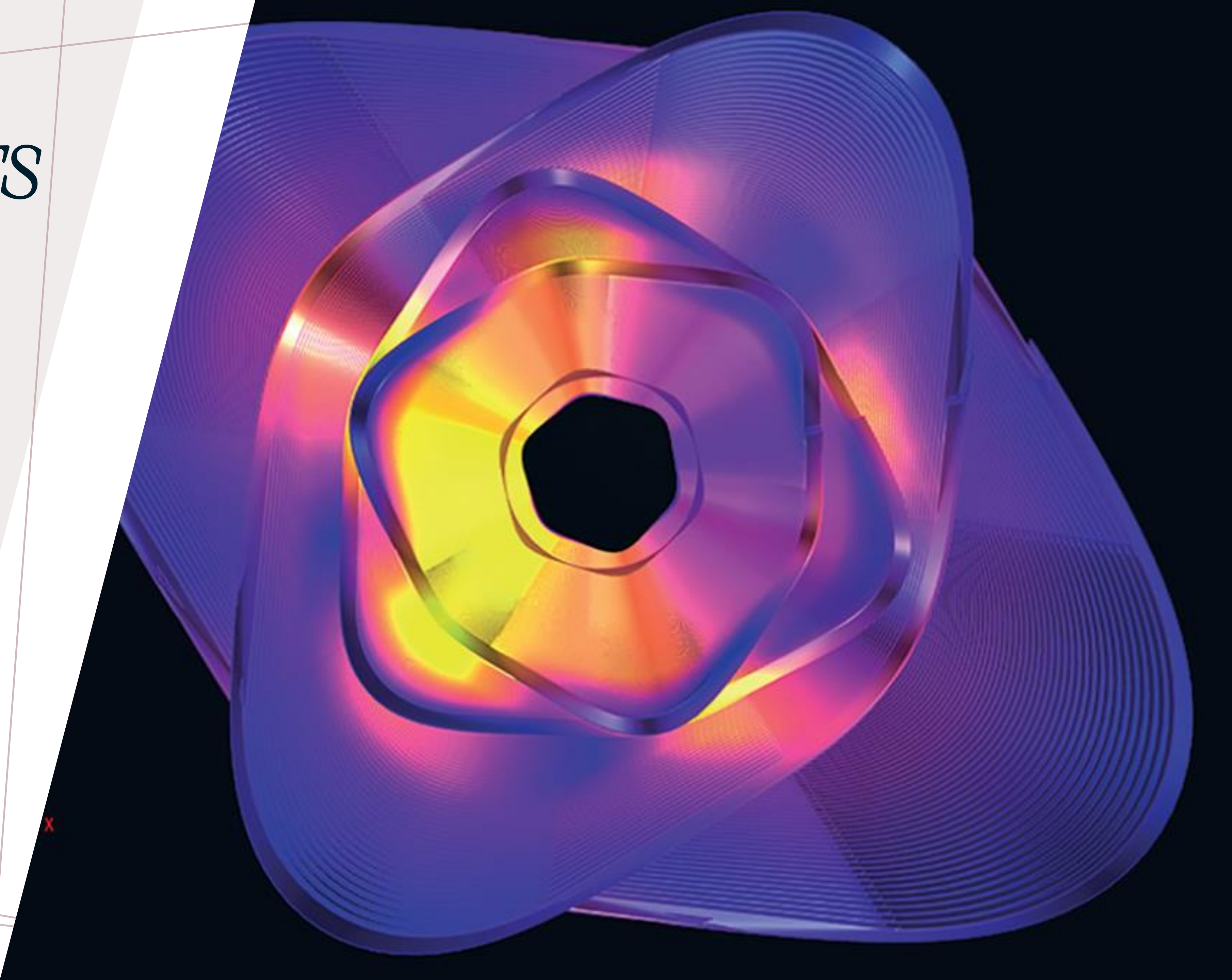


CERN · PAUL SCHERRER INSTITUT PSI · CHART · FUTURE CIRCULAR COLLIDER

THE BIG PICTURE

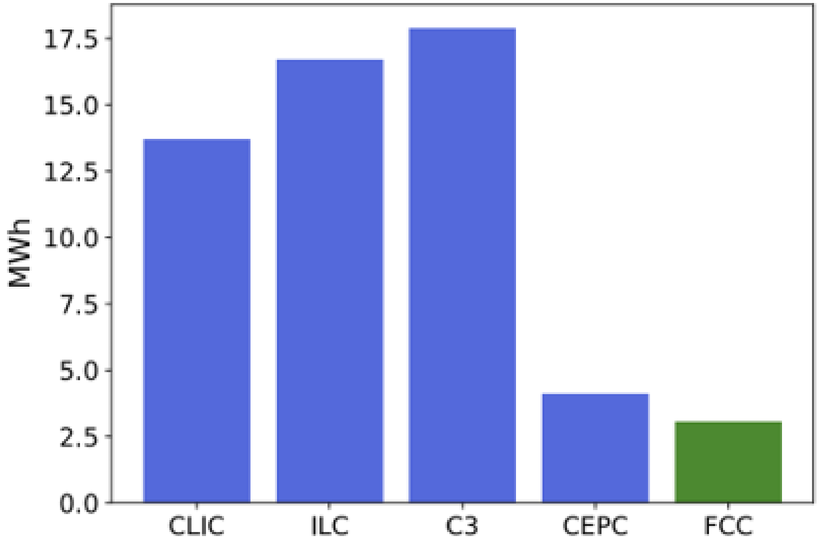
FCC-ee:

- the most energy-efficient accelerator proposed
- smallest CO2 footprint

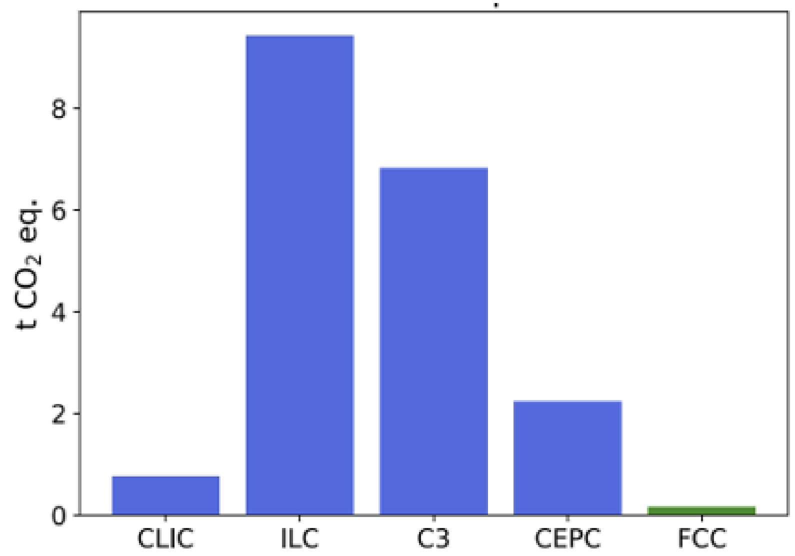
HTS4:

- Even more sustainable
- increased performance
- state-of-the-art technologies: leading role in our respective fields

Carbon Footprint Per Higgs Produced



Energy Production Per Higgs Produced



POWER CONSUMPTION

Normal Conducting Magnets:

- Ohmic Losses
- Heat removal with cooling and ventilation system

CV removes 256MW of heat:

- storage and booster magnets (100MW at top)
- storage and booster RF (148MW at top)
- experiments (8MW)

- The share of storage ring magnets (without booster magnets) on CV is **~35%**
- The CV system needs 40.2MW in total:
  - The storage ring magnets require **14 MW**

Total contribution of the collider ring magnets:

- **~100MW** at the top (89MW + 14MW)
- **~3/4** of which come from quads and sextuples

Storage Ring	**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%
Dipoles (MW)	0.8	2.6	5.8	13.3
Quadrupoles (MW)	1.4	4.3	9.8	22.6
Sextupoles (MW)	1.3	3.9	8.9	20.5
Power cables (MW)	1.2	3.8	8.6	20
Total magnet losses	4.8	14.7	33.0	76.4
Power demand (MW)	5.6	17.2	38.6	**89**

Cooling and ventilation	**Z**	**W**	**H**	**TT**
Beam energy (GeV)	45.6	80	120	182.5
CV Power (MW)	33	34	36	**40.2**

FCC-EE: THE POWER CHALLENGE

FCC-ee Conceptual Design Report (CDR):

Energy Range	Magnets	Field	Units in arc
tt	QF/QD	11.8 (T/m)	2836
H	QF/QD	7.75 (T/m)	2836
tt	SF/SD	<800 (T/m^2)	2336
H	SF/SD	<526 (T/m^2)	2336

All magnets are ***normal conducting***

Energy Range	Magnets	Field	Units in arc
Z	QF/QD	1.45 (T/m)	1420
W	QF/QD	0.95 (T/m)	1420
Z	SF/SD	<140 (T/m^2)	600
W	SF/SD	<92 (T/m^2)	600

- Efforts for a '**power saving**' design for the quads:
  - 50% saving, but with compromises

- **Quadrupoles and Sextuples**:
  - Mainly responsible for power losses
  - Big and Heavy

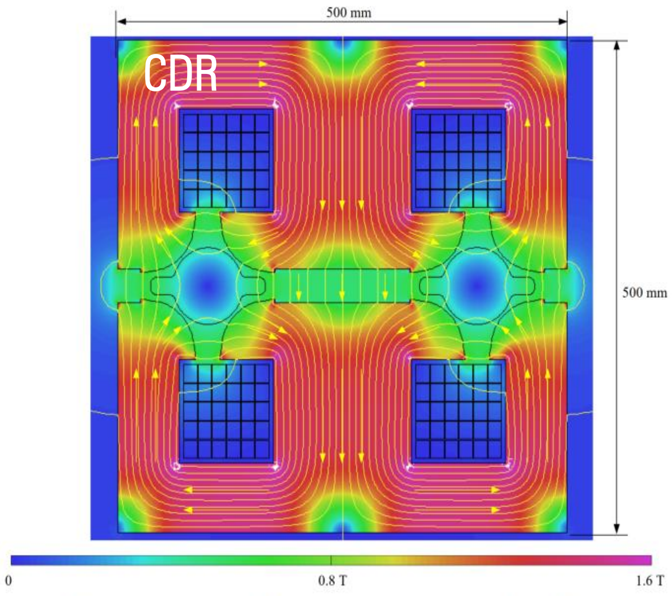


Figure 3.3: Cross-section of the FCC-ee main quadrupole, for a 10 T/m gradient.

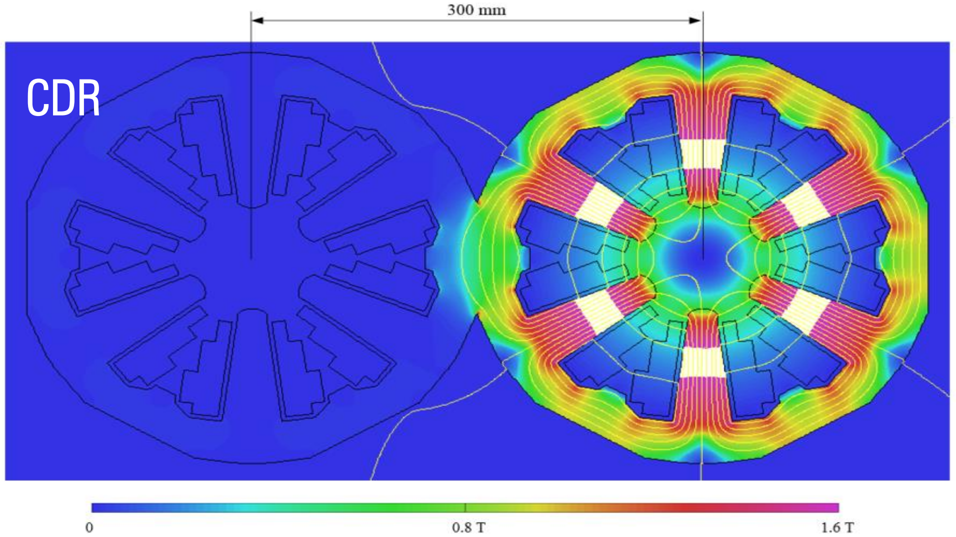


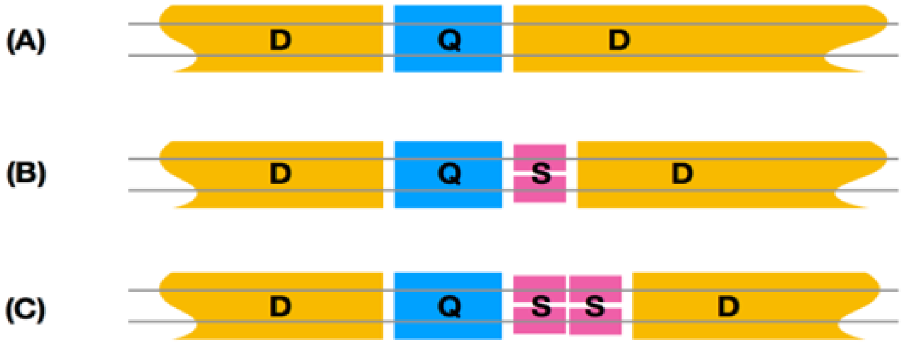
Figure 3.6: Cross-section of the FCC-ee main sextupole magnet. The position of the sextupole for the other beam is outlined on the left.

OUR PROJECT'S IDEA

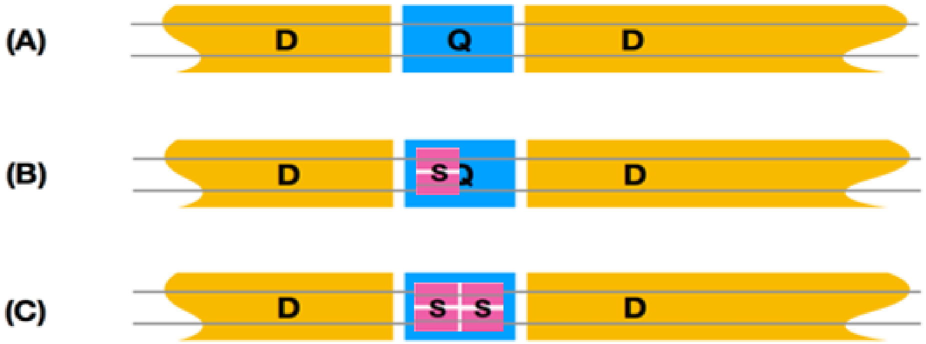
- Use of **HTS** (**high temperature superconducting)** magnets
  - Energy spent only for cooling the magnets (zero Ohmic losses)
  - Operation at ~40K

- "**Nesting**" quadrupoles and sextuples
  - more space available for bending – increased accelerator's performance
  - Potential power reduction for these systems: ~90%
  - 2836 cryostats (one per SSS), 3.5m long each

CDR:



OUR PROPOSAL:



Half cell length:

- tt and H: 26.05 m
- W and Z: 52.1 m

OTHER POTENTIAL GAINS

Nested system:

- Packing factor increase by **7%**
  - For the same luminosity, RF power can be reduced by 7%

- Higher packing factor – reduction of total voltage needed by the RF by **7%**

- **Total gain ~14%** in the price of the RF system (its total price ~order of 1Bn CHF)
  - magnet systems price: ~25% of the total RF system price:
    ~56% of the cost of the SSSs would come from the reduction in the RF costs

- Aim: Production of the superconducting SSSs in the **same price envelope** as in the CDR

The optics design is much more flexible:

- No requirement for fixed polarity electron/positron quadrupoles
- Sextuples available in all SSSs
- Opens the path for 100% filling factor and tapering management

This is a big change in the design of FCC!

Many systems are affected such as:

- photon stopper design
- radiation environment in the tunnel
- BPM design
- optics

COULD WE DO EVEN BETTER?

- Move the power supply inside the cryostat, instead of the traditional cold magnet/warm power supply (FCCee - CPES project)

- Include a nested dipole covering the entire length of the SSS
  - Another potential gain of 7% in packing factor, reaching almost 100%
  - A nested dipole system (individually powered) solves all our tapering needs (maximum dipole strength needed at the top is ~30%)

The inclusion of a nested dipole system is not the baseline solution now

- possible future improvement (an extra complication as well)

THE PROJECT

Swiss Accelerator Research and Technology

A **proposal** was submitted and approved by the Swiss accelerator research and technology forum CHART in April 2022:

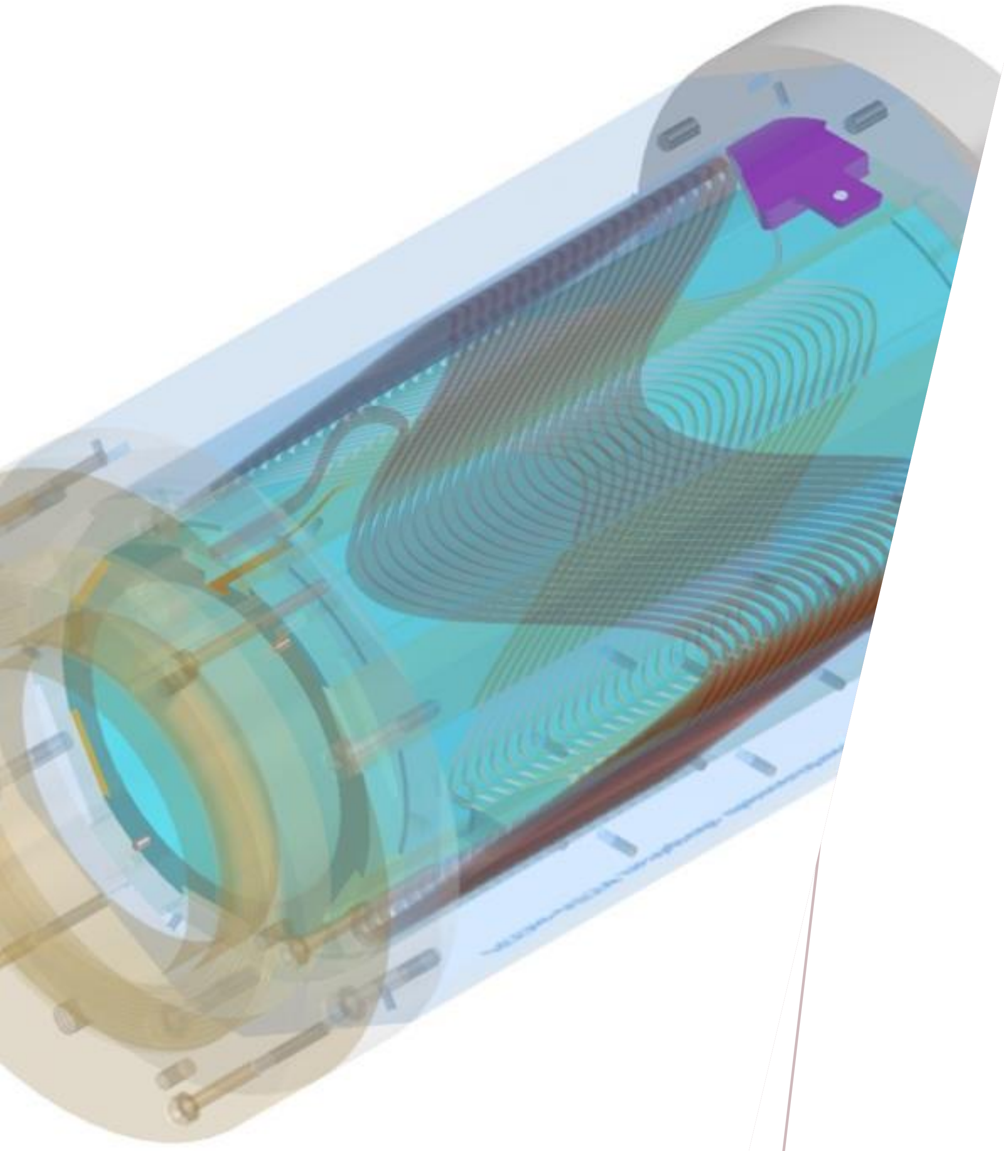
CHART Proposal Form

FULL TITLE	**FCC-ee High-Temperature-Superconducting Short Straight Section**
SHORT TITLE (max. 20 chars)	**FCCee HTS4**
Principal Investigator	**Dr. Michael Koratzinos**

- Project **duration**: 3 years (starting 1/7/2022)
- **Deliverables:**
  - Beam dynamics report
  - Enabling technologies report
  - One or more demonstrator hardware
  - One prototype designed, manufactured and tested
- Our sister project, **FCC-ee CPES**, investigating the possibility of a cold power supply system, was also approved at the same session

FCCee--HTS4 Team:

Bernhard Auchmann (PSI)
Jaap Kosse (PSI)
Vicky Batsari (CERN)
Adrien Thabuis (CERN)
Mike Koratzinos (CERN/PSI)



FCC-EE - HTS4 IN A NUTSHELL

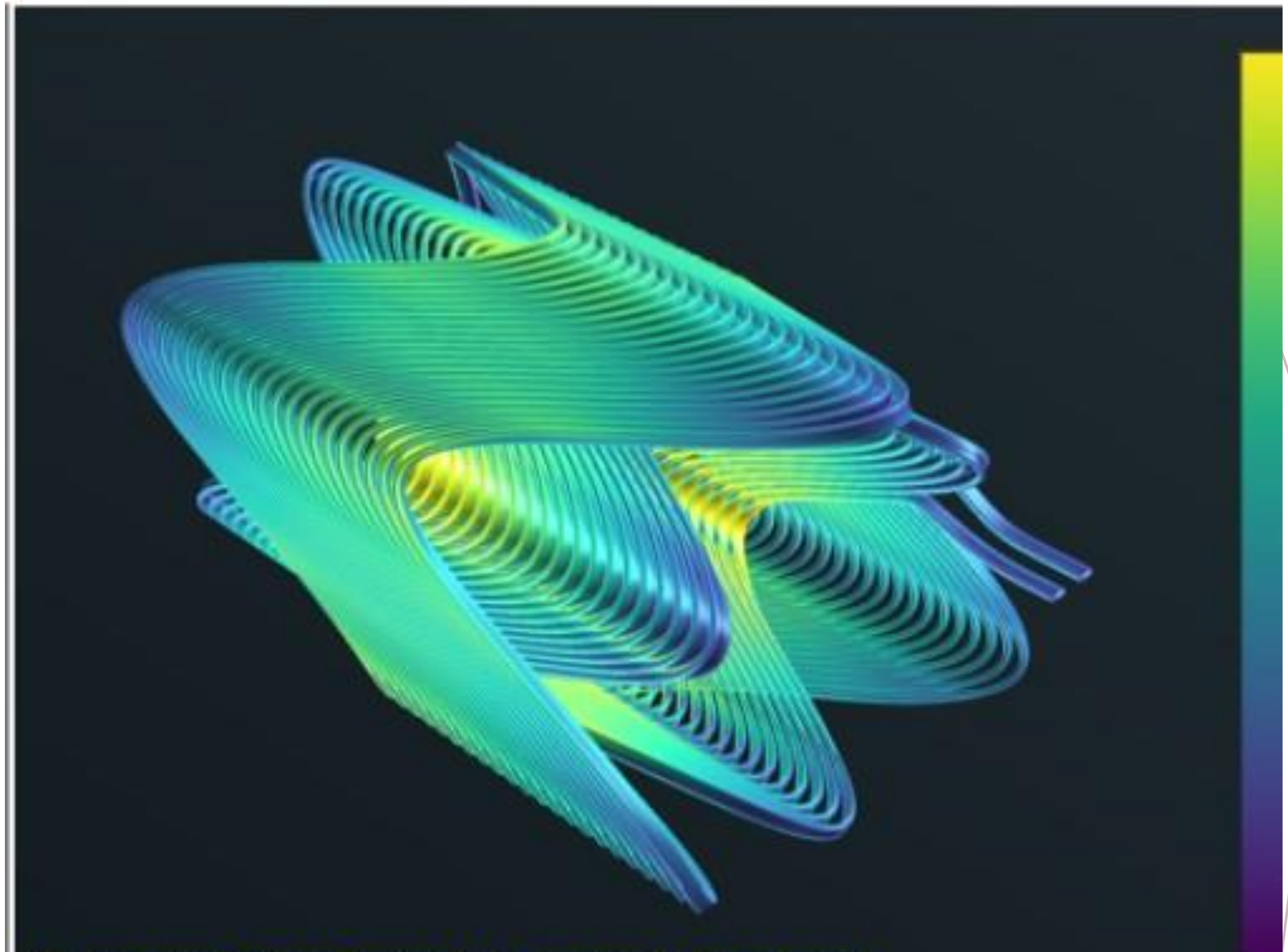
- Investigates the replacement of all FCCee short straight sections (SSSs) that contain arc quads, arc sextuples and assorted correctors by superconducting ones
- Nests the sextuples and quadrupoles in the same unit
- Uses HTS conductors (ReBCO tapes)
- Operates at around 40K
- Investigates all integration issues
- Produces a ~1m prototype

SSS MAIN PARAMETERS

- **Quadrupoles** length: **2.9m**
  - Quads **should not be shorter**, due to Synchrotron Radiation (SR) issues

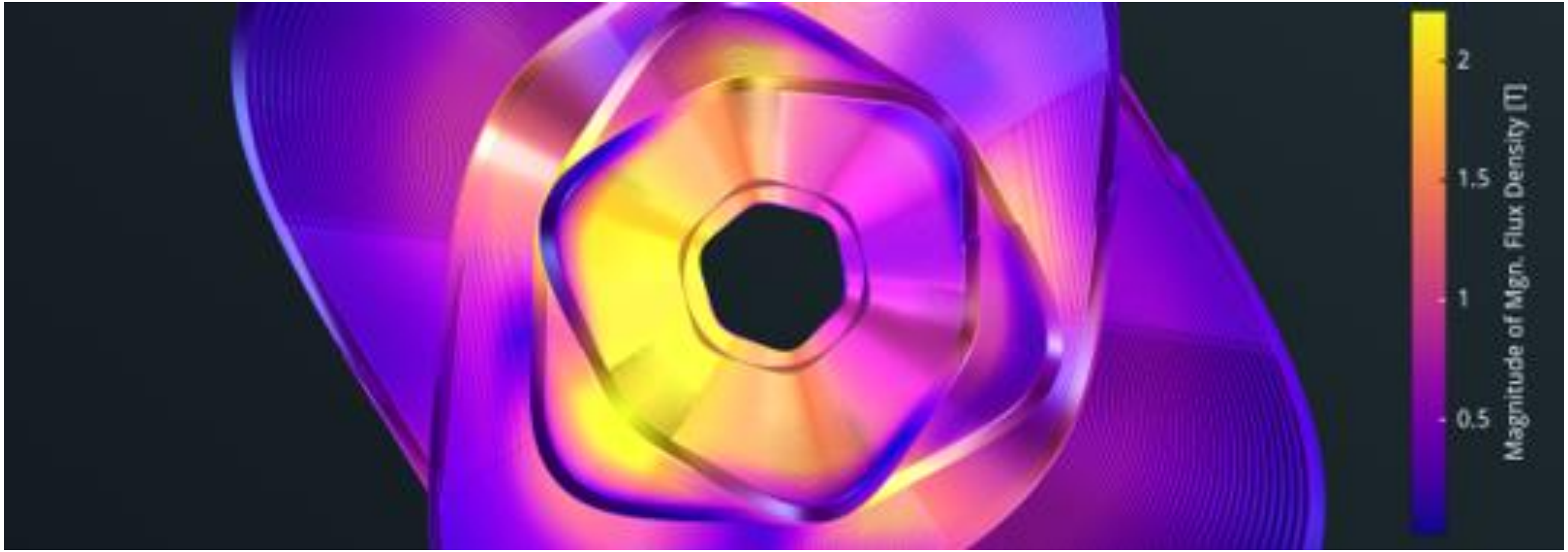
- **Sextuples** length: **1.3m**
  - Sextuples can be made stronger and shorter at will

- Together with necessary gaps and with all services, the **SSS length** will be **3.5m**



A nested quadrupole-sextuple magnet

SO NOW,
TIME FOR MORE DETAILS…



THANK YOU!