Future Circular Collider Study Overview for EASITRAIN

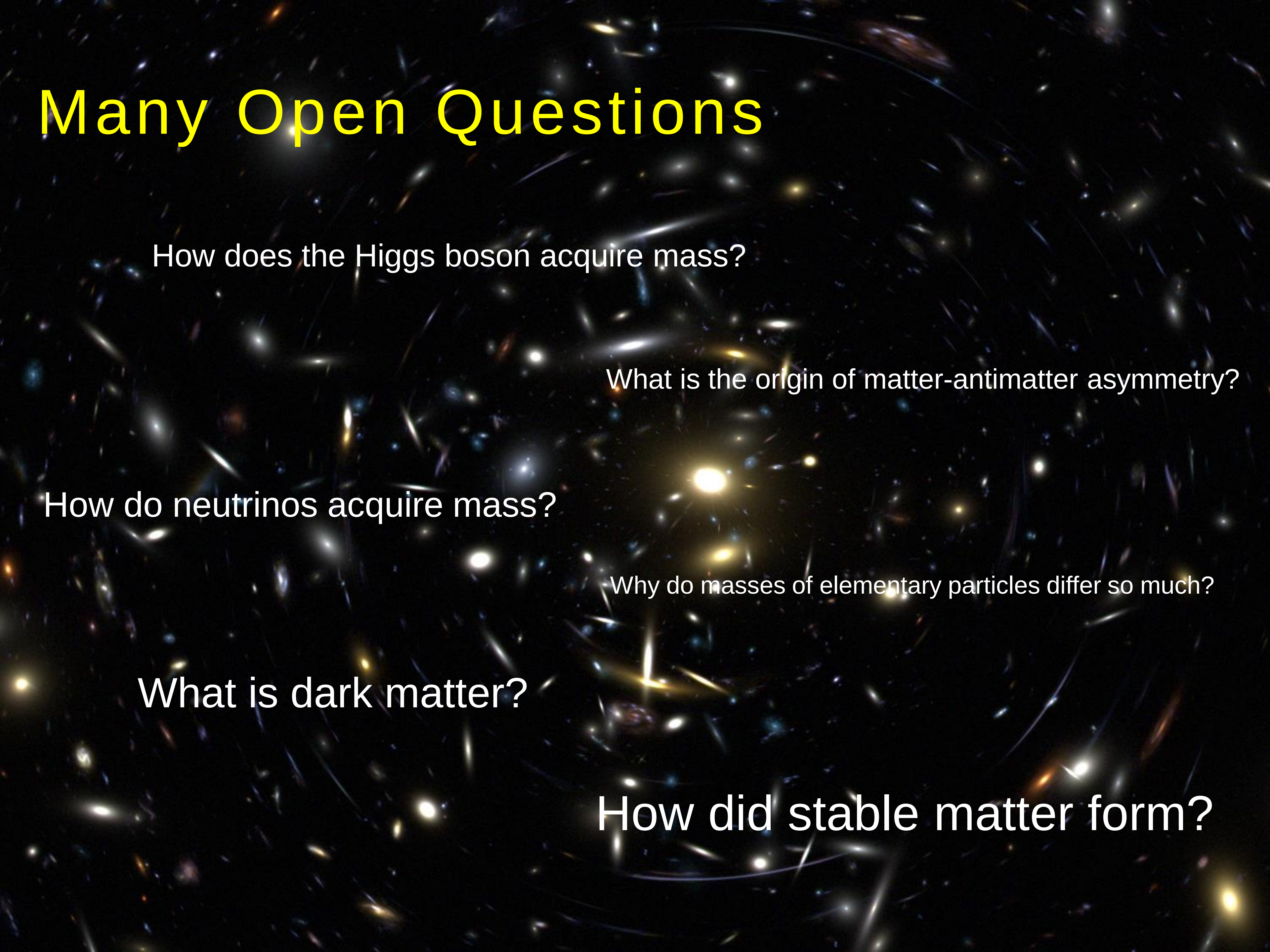
CERN, 5 March 2018
J. Gutleber, ATS/DO


WHY

The goal of particle physics is to **understand the fundamental building blocks that make up the world** we live in. With the discovery of the Higgs boson, the story is really only just beginning to get interesting: Only 5% of the Universe are explained by the Standard Model of Particle Physics.

What about the other 95%?

Many Open Questions



How does the Higgs boson acquire mass?

What is the origin of matter-antimatter asymmetry?

How do neutrinos acquire mass?

Why do masses of elementary particles differ so much?

What is dark matter?

How did stable matter form?

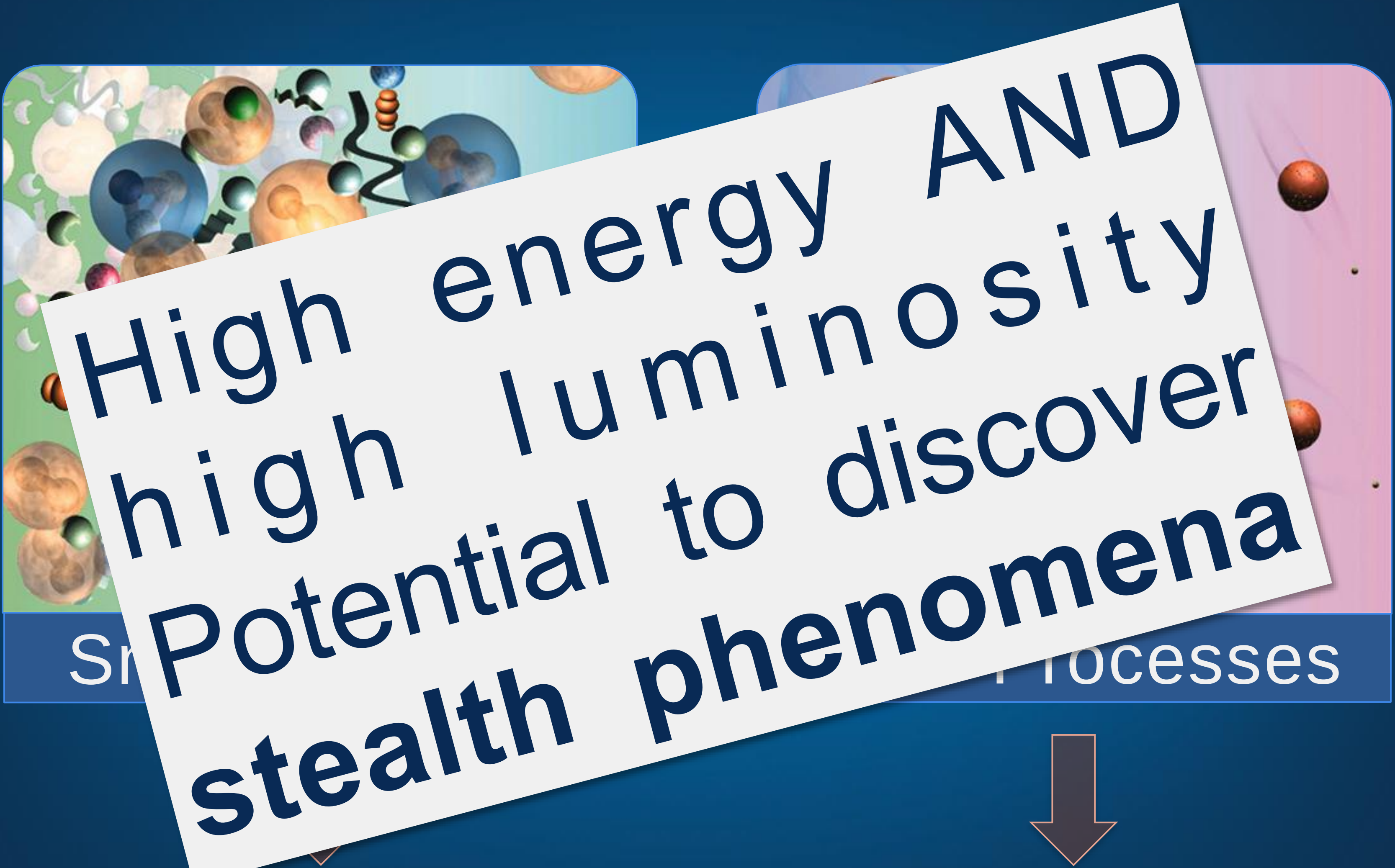
Strategy Update 2013

"CERN should undertake **design studies** for accelerator projects in a **global context**, with emphasis on proton-proton and electron-positron **high-energy frontier** machines."

The European Strategy for Particle Physics, May 2013

Have material as sound decision support for the post-LHC era by 2019

Roads to Discovery



High energy AND high luminosity

Potential to discover **stealth phenomena**

Higher Energy

Higher Luminosity

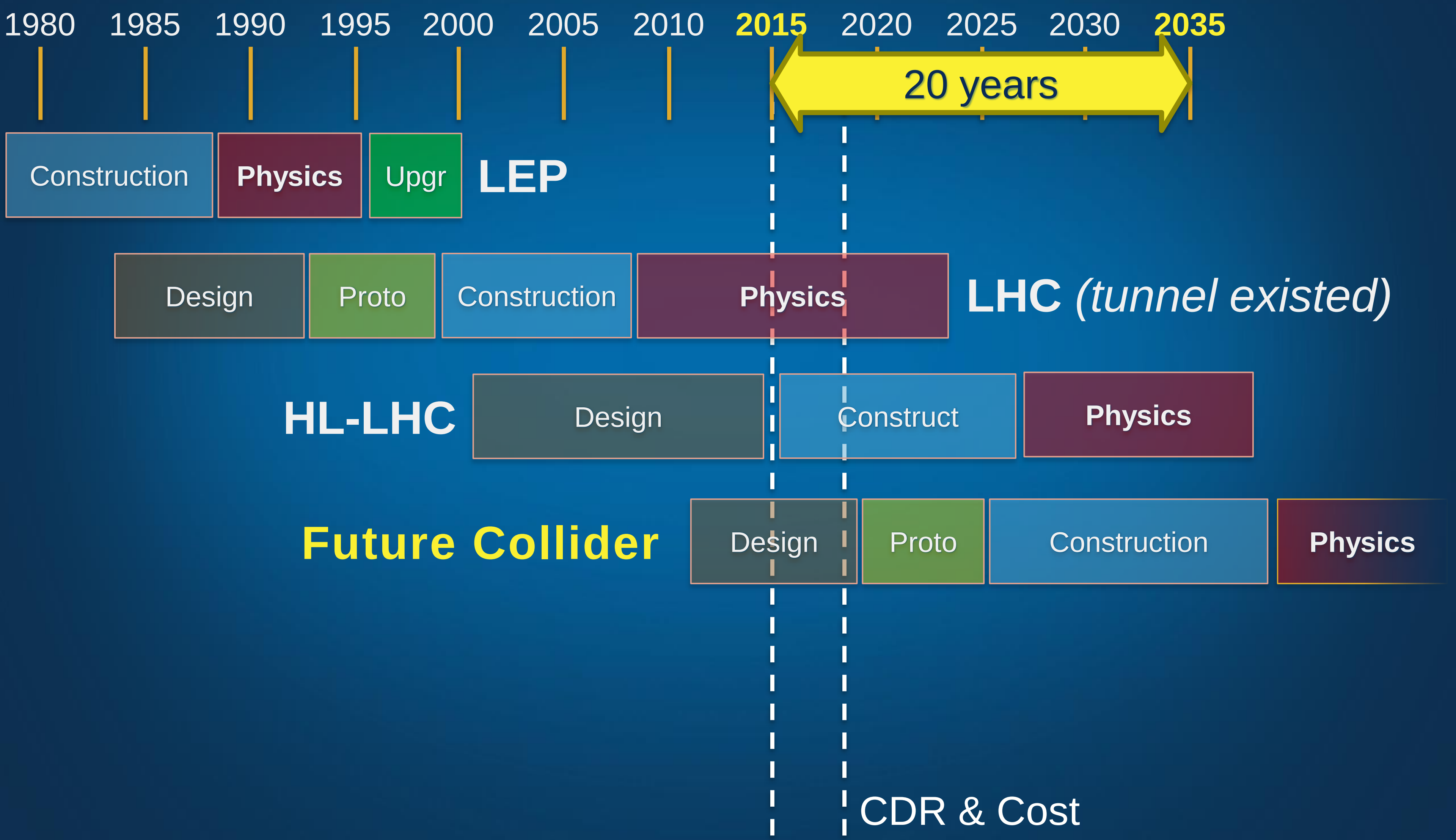
Future Circular Collider Study

- **Conceptual Design Study**
- **Scenarios** for a **post-LHC Research Infrastructure**
- Carried out with more than **120 partners worldwide**
- Launched in 2014
- **Hosted and coordinated by CERN**
- Conceptual design **report by 2018**

Large Hadron Collider (26 km)

Future Circular Collider (100 km)

CERN Circular Collider Timescale



1980 1985 1990 1995 2000 2005 2010 **2015** 2020 2025 2030 **2035**

20 years

LEP: Construction | **Physics** | Upgr

LHC *(tunnel existed)*: Design | Proto | Construction | **Physics**

HL-LHC: Design | Construct | **Physics**

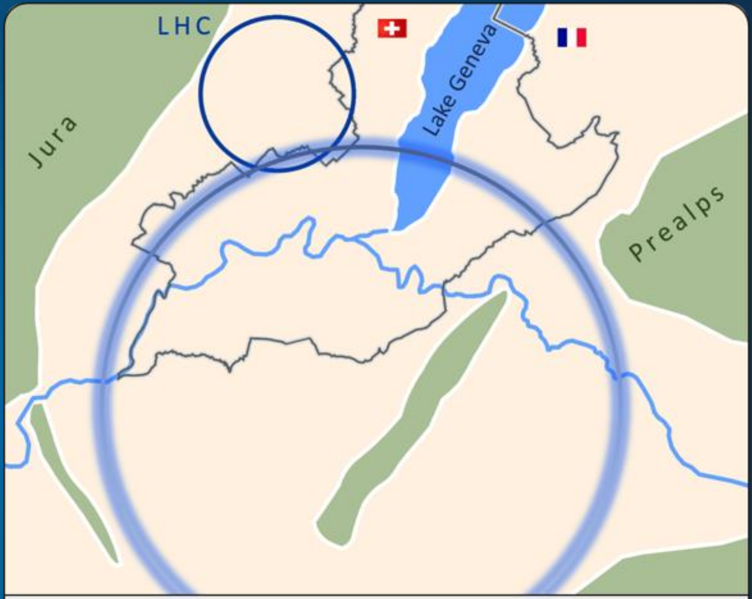
Future Collider: Design | Proto | Construction | **Physics**

CDR & Cost


WHAT

Key Parameters

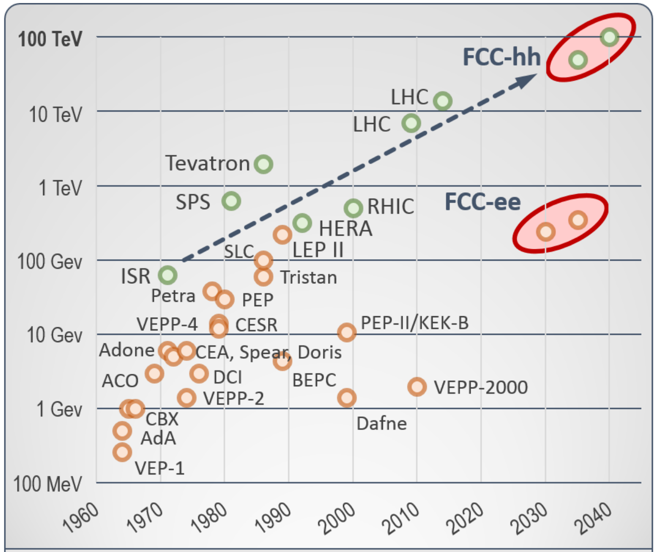
- **pp** collider (FCC-hh)
  - Defines infrastructure requirements
  - **16 Tesla** magnets →
    - **100 TeV** centre of mass in
    - **100 km** long tunnel
- **e^+e^-** collider (FCC-ee)
  - Potential intermediate step
  - **Extreme luminosities** at 90–350 GeV



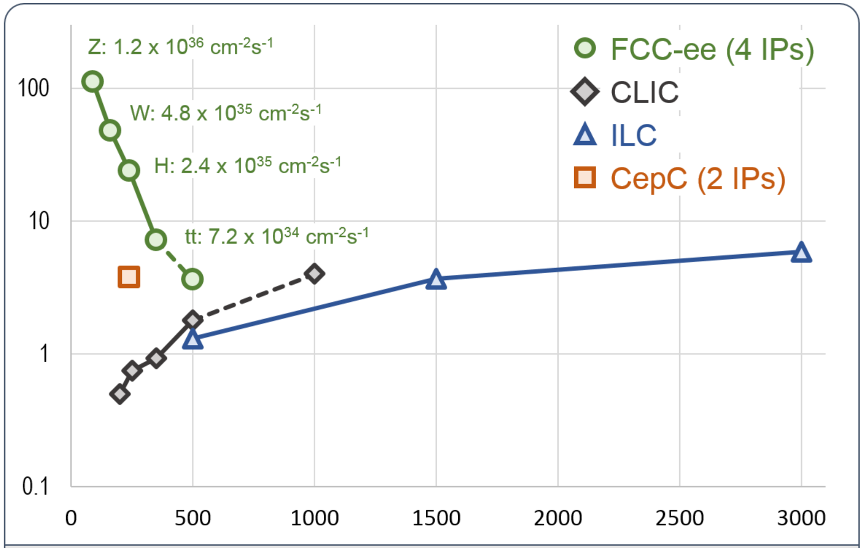
Schematic of an 80 – 100 km long tunnel

- Infrastructures
  - **Leverage** existing CERN accelerator complex, know-how and successful management of largest-scale science projects
  - **Build on** a history of **international trust and collaboration** across cultures, political systems

Energy & Luminosity Frontiers



Collision energy increases exponentially with time



Luminosity [10^{34} $cm^{-2}s^{-1}$] vs. energy [GeV] of lepton collider options

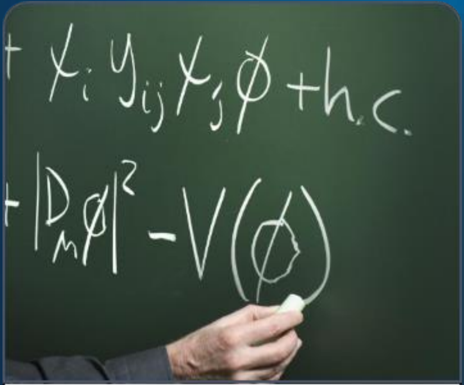
- Sustainable paths to expand current energy and luminosity frontiers
- Reach out to 100 TeV within 21st century

Study Scope

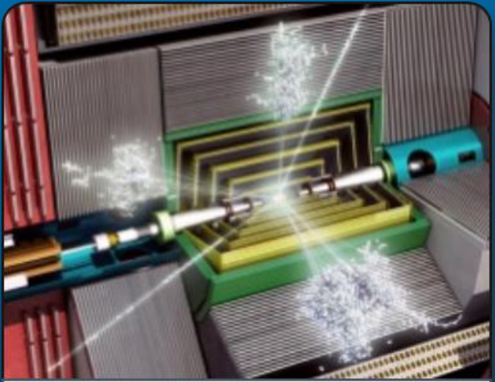
Collider Designs

Infrastructures

R&D Programs



Physics Cases



Experiments

Cost Estimates

Study Scope

Guide to Cost-Benefit Analysis of Investment Projects

Economic appraisal tool for Cohesion Policy 2014-2020

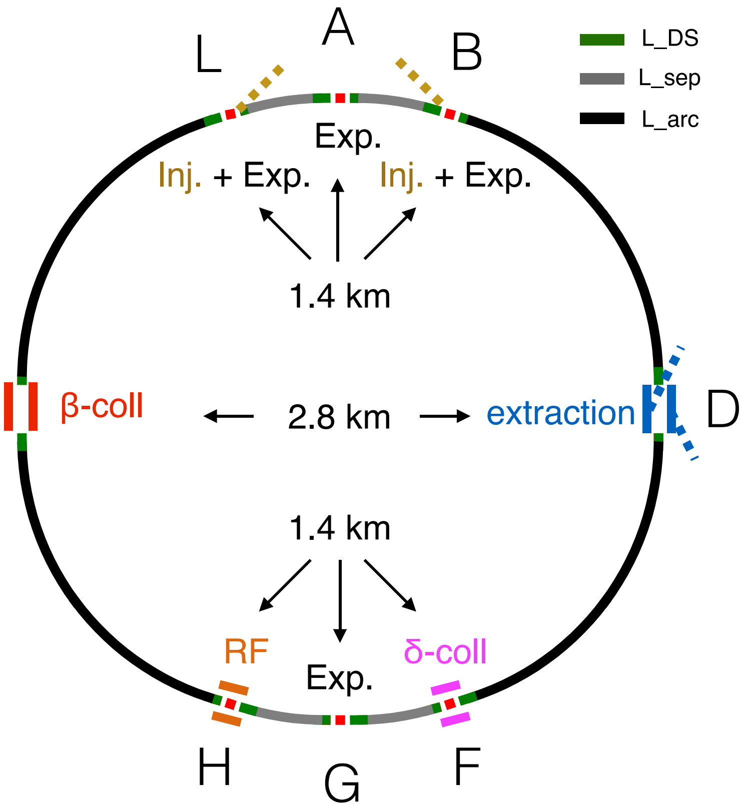
Cost/Benefit Analysis

Realisation Plans

Implementation

FCC-hh Layout and Optics

- Two high-luminosity experiments (**PA** & **PG**)
- Two additional experiments + injection (**PL** & **PB**)
- Two collimation insertions
  - Betatron cleaning (PJ)
  - Momentum cleaning (PF)
- Extraction insertion (PD)
- Clean insertion with RF (PH)
- LHC or SPS as injector



- **Perimeter 97.75 km**
- Injections upstream of experiments PL, PB
- **Separation of extraction region and high-radiation collimation areas**
- **Beam dynamics studies confirm design goals**
- **Focus on optimization of collimation system and extraction system**

FCC-hh Collider Parameters

Parameter	FCC-hh		HE-LHC	HL-LHC	LHC
collision energy cms [TeV]	100		27	14	14
dipole field [T]	16		16	8.33	8.33
circumference [km]	97.75		26.7	26.7	26.7
beam current [A]	0.5		1.12	1.12	0.58
bunch intensity $[10^{11}]$	1	1 (0.2)	2.2 (0.44)	2.2	1.15
bunch spacing [ns]	25	25 (5)	25 (5)	25	25
synchr. rad. power / ring [kW]	2400		101	7.3	3.6
SR power / length [W/m/ap.]	28.4		4.6	0.33	0.17
long. emit. damping time [h]	0.54		1.8	12.9	12.9
beta* [m]	1.1	0.3	0.25	0.20	0.55
normalized emittance [μm]	2.2 (0.4)		2.5 (0.5)	2.5	3.75
peak luminosity [10^{34} cm^{-2}s^{-1}]	5	30	25	5	1
events/bunch crossing	170	1k (200)	~800 (160)	135	27
stored energy/beam [GJ]	8.4		1.3	0.7	0.36

FCC-ee Collider Parameters

Parameter	Z	W	H (ZH)	ttbar
cm collision energy [GeV]	91	160	240	350
beam current [mA]	1400	147	29	6.4
no. bunches	71000	7500	740	62
bunch intensity [10^{11}]	0.4	0.4	0.8	2.1
bunch spacing [ns]	2.5 / 5.0	40	400	5000
SR energy loss / turn [GeV]	0.036	0.34	1.71	7.72
total RF voltage [GV]	0.25	0.8	3.0	9.5
long. damping time [turns]	1280	235	70	23
horizontal beta* [m]	0.15	1	1	1
vertical beta* [mm]	1	2	2	2
horiz. geometric emittance [nm]	0.27	0.26	0.61	1.33
vert. geom. emittance [pm]	1.0	1.0	1.2	2.66
bunch length with SR & BS [mm]	4.1	2.3	2.2	2.9
luminosity [10^{34} cm^{-2}s^{-1}]	130	16	5	1.4

FCC-hh Detector – New Reference Design

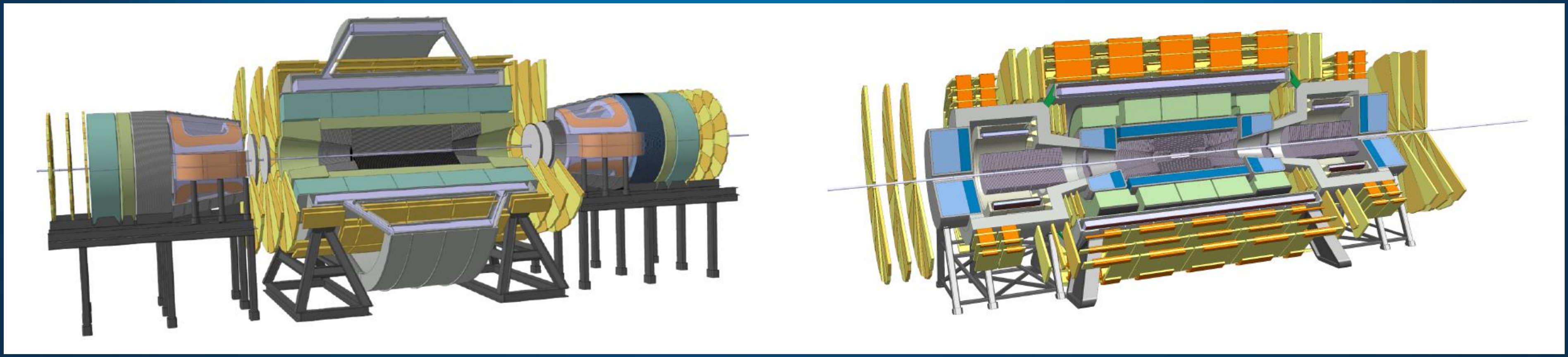
6 T, 12 m bore solenoid, 10 Tm dipoles, shielding coil

- 65 GJ stored energy
- 28 m diameter
- >30 m shaft
- multi billion project

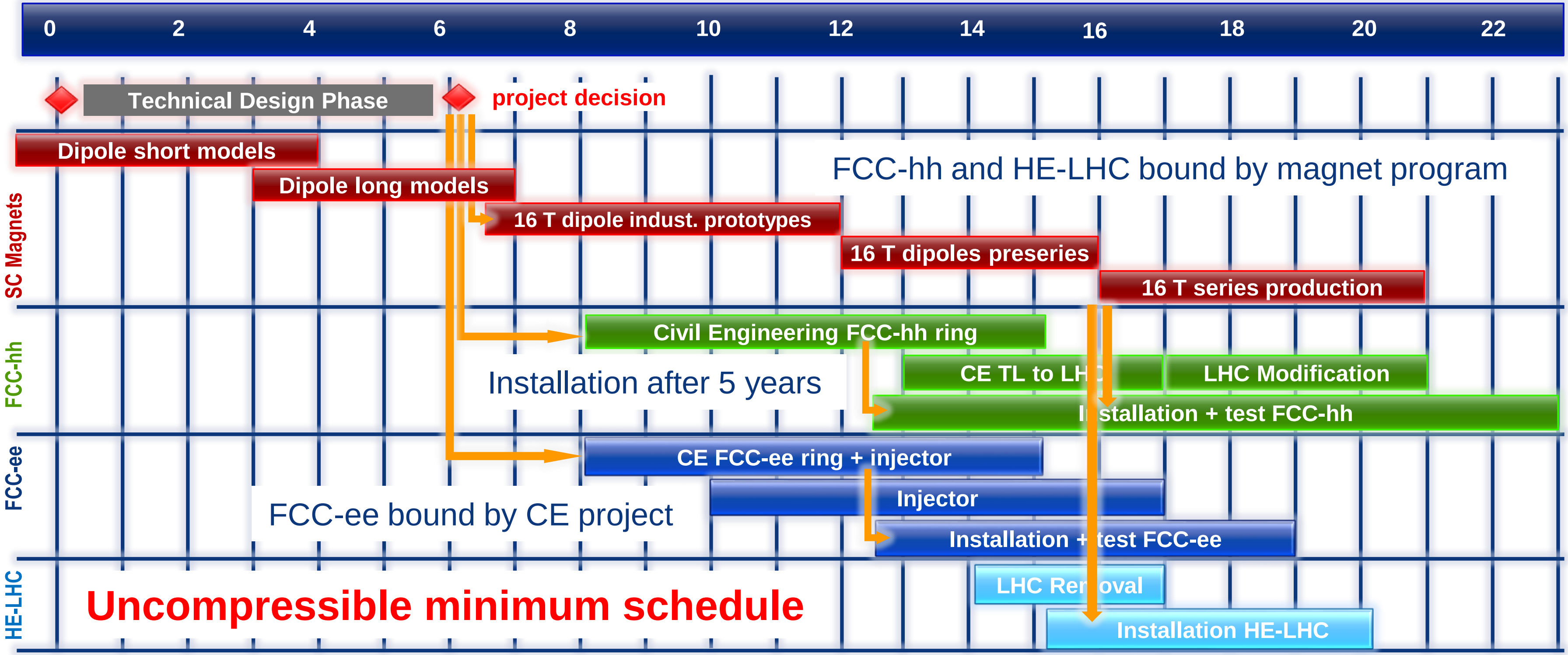
→

4 T, 10 m bore solenoid, 4 T forward solenoids, no shielding coil

- 14 GJ stored energy
- rotational symmetry for tracking!
- 20 m diameter (~ ATLAS)
- 15 m shaft
- ~1 billion project



Technical Schedule Considerations



0 2 4 6 8 10 12 14 16 18 20 22

Technical Design Phase

project decision

SC Magnets

Dipole short models

Dipole long models

16 T dipole indust. prototypes

16 T dipoles preseries

16 T series production

FCC-hh and HE-LHC bound by magnet program

FCC-hh

Civil Engineering FCC-hh ring

CE TL to LHC

LHC Modification

Installation + test FCC-hh

Installation after 5 years

FCC-ee

CE FCC-ee ring + injector

Injector

Installation + test FCC-ee

FCC-ee bound by CE project

HE-LHC

LHC Removal

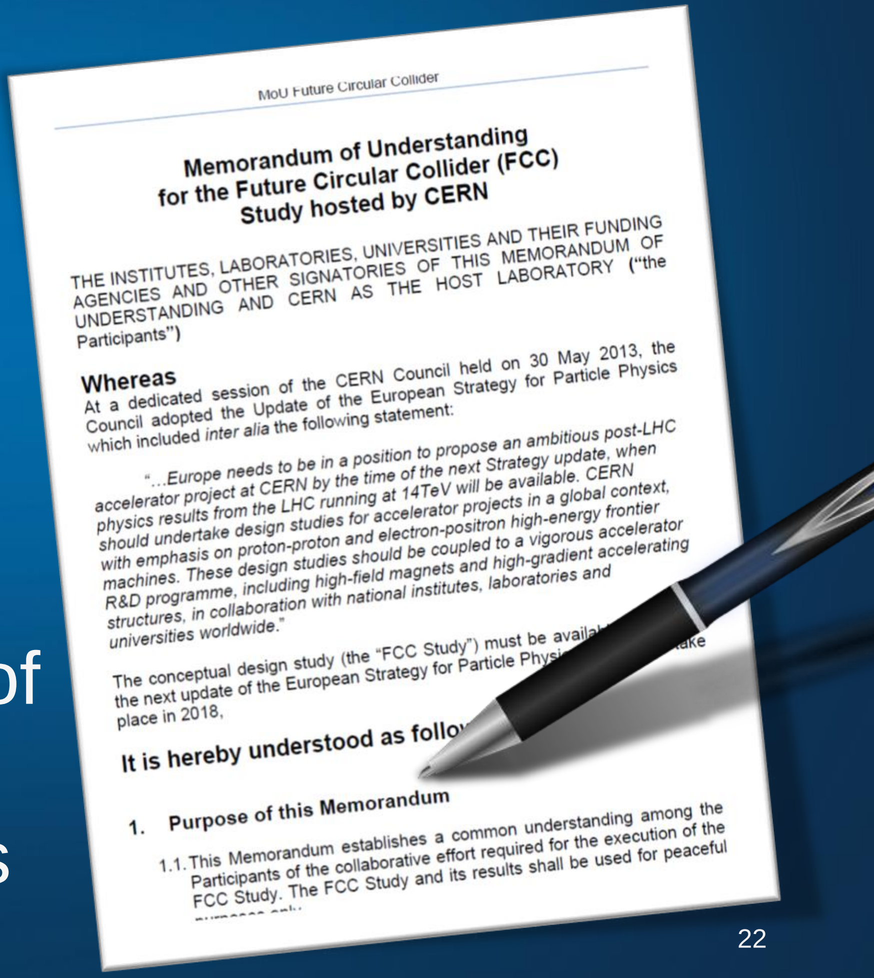
Installation HE-LHC

Uncompressible minimum schedule

Who

The Collaboration

- **Only a world-wide collaboration** can realize an infrastructure of such kind
- **Self governing**, topically **complementary** and geographically **balanced**
- Incremental & open to **academia and industry**
- Partners own commonly the infrastructure
- Catalyzing development of products based on cutting-edge technologies



MoU Future Circular Collider

Memorandum of Understanding
for the Future Circular Collider (FCC)
Study hosted by CERN

THE INSTITUTES, LABORATORIES, UNIVERSITIES AND THEIR FUNDING AGENCIES AND OTHER SIGNATORIES OF THIS MEMORANDUM OF UNDERSTANDING AND CERN AS THE HOST LABORATORY ("the Participants")

Whereas

At a dedicated session of the CERN Council held on 30 May 2013, the Council adopted the Update of the European Strategy for Particle Physics which included *inter alia* the following statement:

> *"…Europe needs to be in a position to propose an ambitious post-LHC accelerator project at CERN by the time of the next Strategy update, when physics results from the LHC running at 14TeV will be available. CERN should undertake design studies for accelerator projects in a global context, with emphasis on proton-proton and electron-positron high-energy frontier machines. These design studies should be coupled to a vigorous accelerator R&D programme, including high-field magnets and high-gradient accelerating structures, in collaboration with national institutes, laboratories and universities worldwide."*

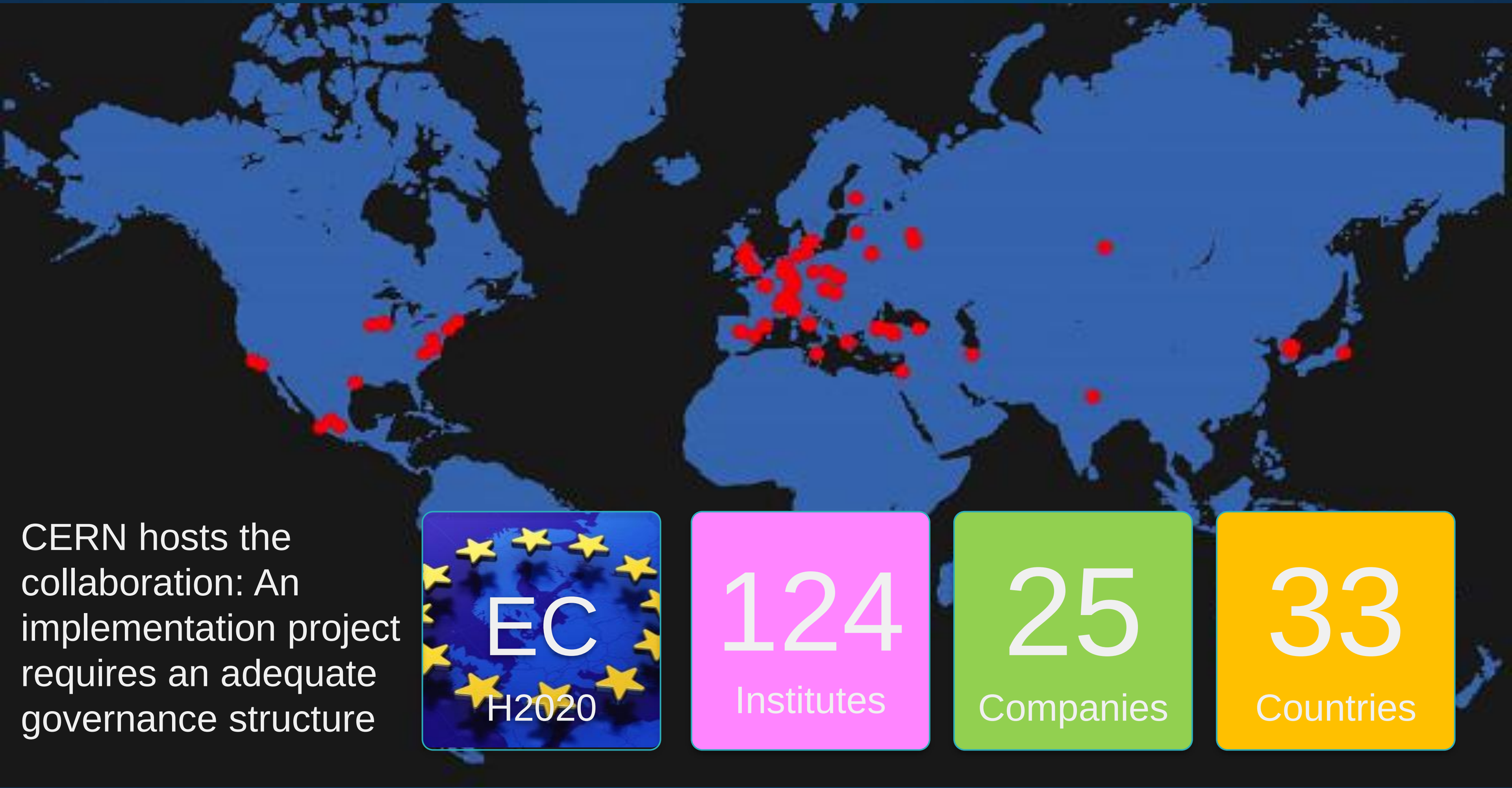
The conceptual design study (the "FCC Study") must be availa ake the next update of the European Strategy for Particle Physi place in 2018,

It is hereby understood as follo

1. **Purpose of this Memorandum**

1.1. This Memorandum establishes a common understanding among the Participants of the collaborative effort required for the execution of the FCC Study. The FCC Study and its results shall be used for peaceful purposes only.

Collaborations



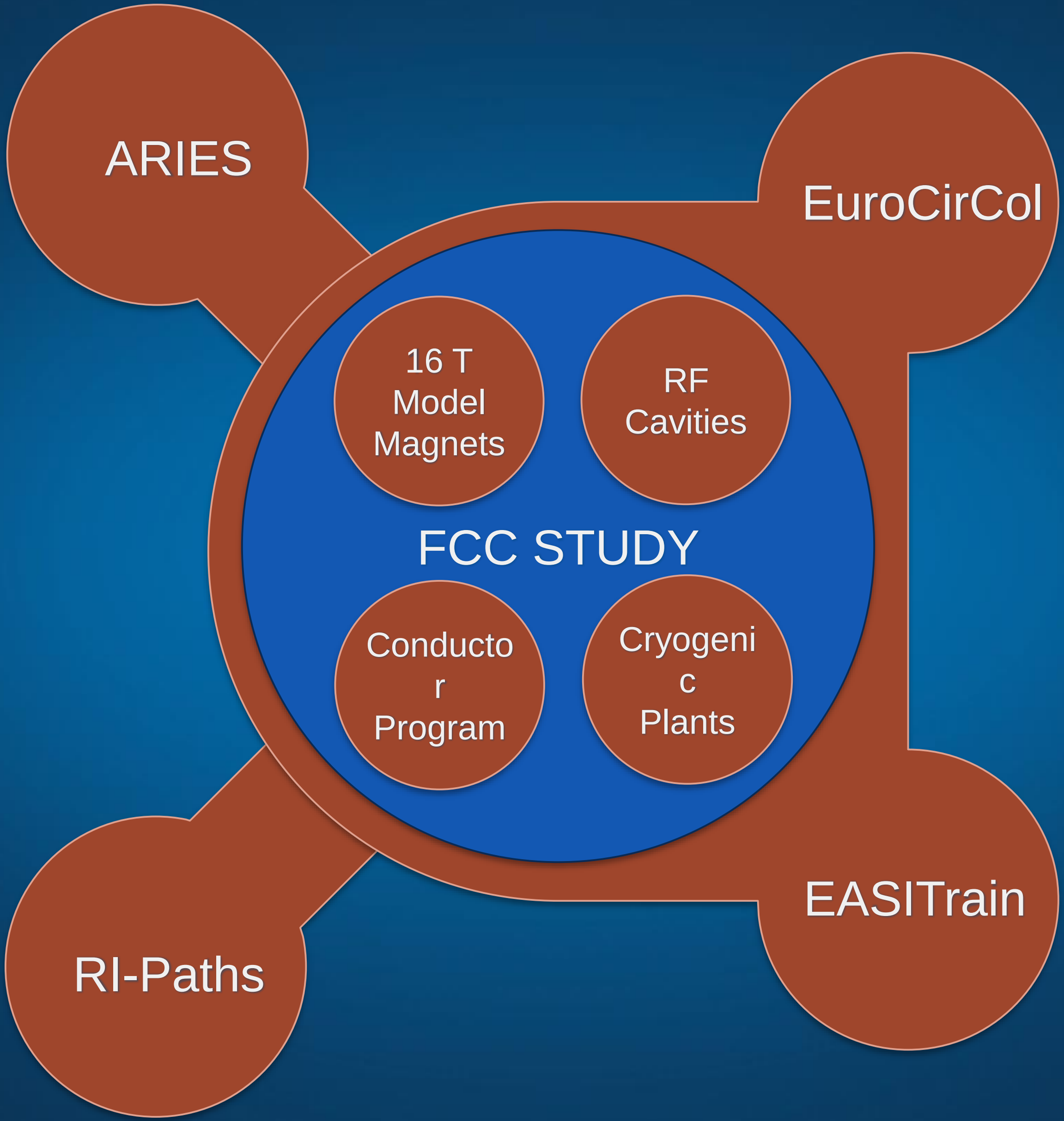
CERN hosts the collaboration: An implementation project requires an adequate governance structure

EC
H2020

124
Institutes

25
Companies

33
Countries



ARIES

EuroCirCol

16 T Model Magnets

RF Cavities

FCC STUDY

Conductor Program

Cryogenic Plants

EASITrain

RI-Paths

H2020 Projects

- EuroCirCol
  - Hadron collider design,
    16 Tesla magnet, Cryogenic beam vacuum system
- **EASITrain**
  - Superconductivity and cryogenics
- ARIES
  - Accelerator technologies
- RI Impact Pathways
  - Cost Benefit Analysis of Research Infrastructures


EASITrain

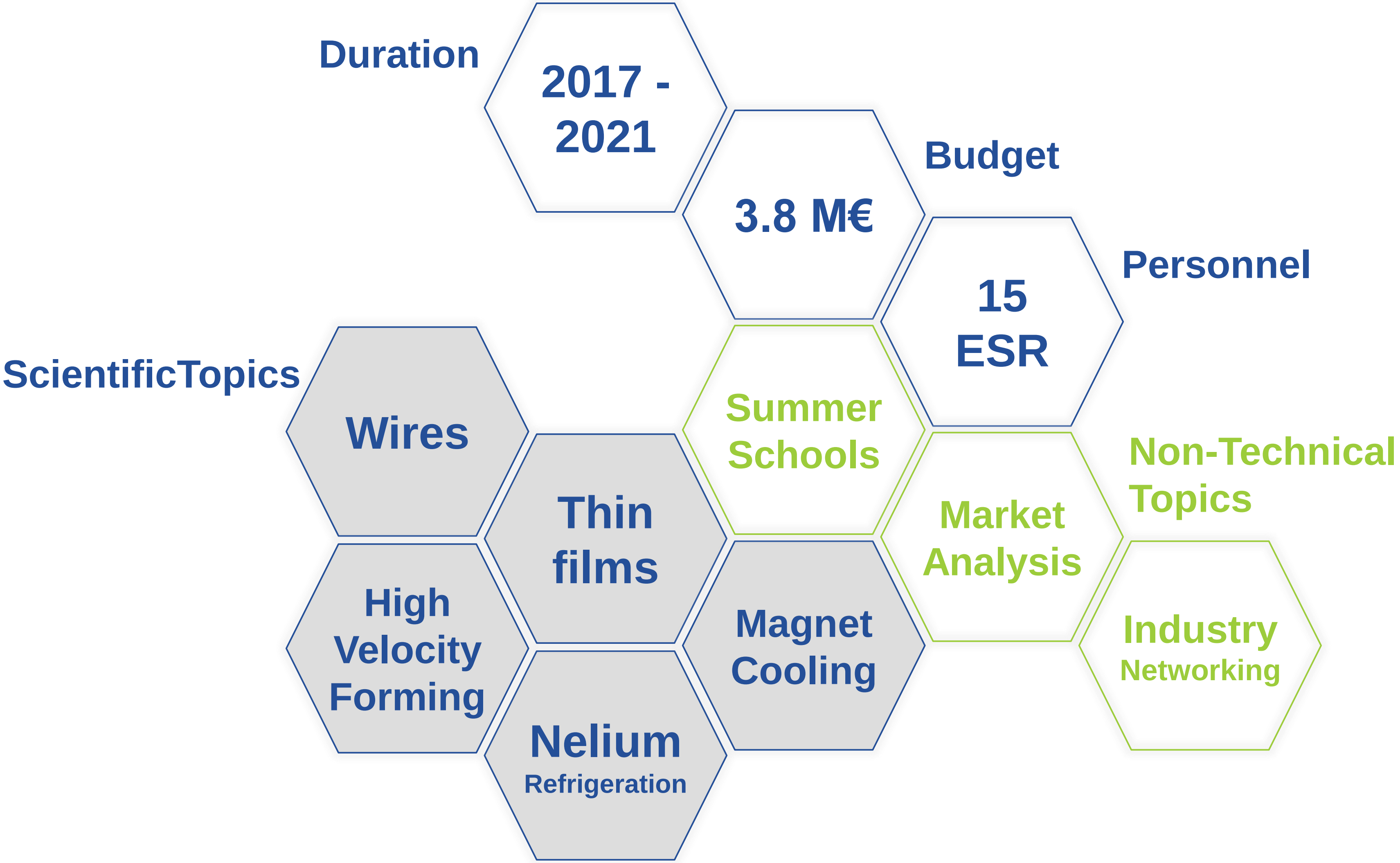
EASITrain

European Advanced Superconductivity Innovation and Training

A Marie Skłodowska-Curie Actions
Innovative Training Network
coordinated by CERN

easitrain.web.cern.ch
@EasiTrain

European Commission



Duration

2017 - 2021

Budget

3.8 M€

Personnel

15 ESR

ScientificTopics

Wires

Thin films

High Velocity Forming

Nelium Refrigeration

Magnet Cooling

Non-Technical Topics

Summer Schools

Market Analysis

Industry Networking

Beneficiaries and Partners

Beneficiaries

BRUKER
cea
Columbus Superconductors
HZB Helmholtz Zentrum Berlin
SPIN
Universität Stuttgart
I-CUBE
INFN
TECHNISCHE UNIVERSITÄT DRESDEN
TU WIEN TECHNISCHE UNIVERSITÄT WIEN
UNIVERSITÄT SIEGEN
WU WIRTSCHAFTS UNIVERSITÄT WIEN VIENNA UNIVERSITY OF ECONOMICS AND BUSINESS
CERN

Partners

Bmax power to shape
ASG Superconductors
BILFINGER Babcock Noell GmbH
CemeCon The Tool Coating
IEEE Advancing Technology for Humanity
MAN Diesel & Turbo
TERRA MATER Factual Studios
Red Bull MEDIA HOUSE
research instruments
SIGMAPHI MAGNETS AND BEAM TRANSPORT
UNIVERSITÀ DEGLI STUDI DI GENOVA
Criotec IMPIANTI S.r.l.
AIR LIQUIDE™

Other Associates

Fraunhofer VENTURE
CERN
HiLumi HL-LHC PROJECT
ARIES
Ideas

Hopefully more over the project period to create a strong and durable network!

Project Organisation

- Project Leader: **Amalia Ballarino**
- Deputy: **Michael Benedikt**
- Project Office: **Johannes Gutleber**
- Communications: **Panagiotis Charitos**
- Administration: **Emilie David**

Your Gate to the Project

WEB
http://cern.ch/fcc/easitrain

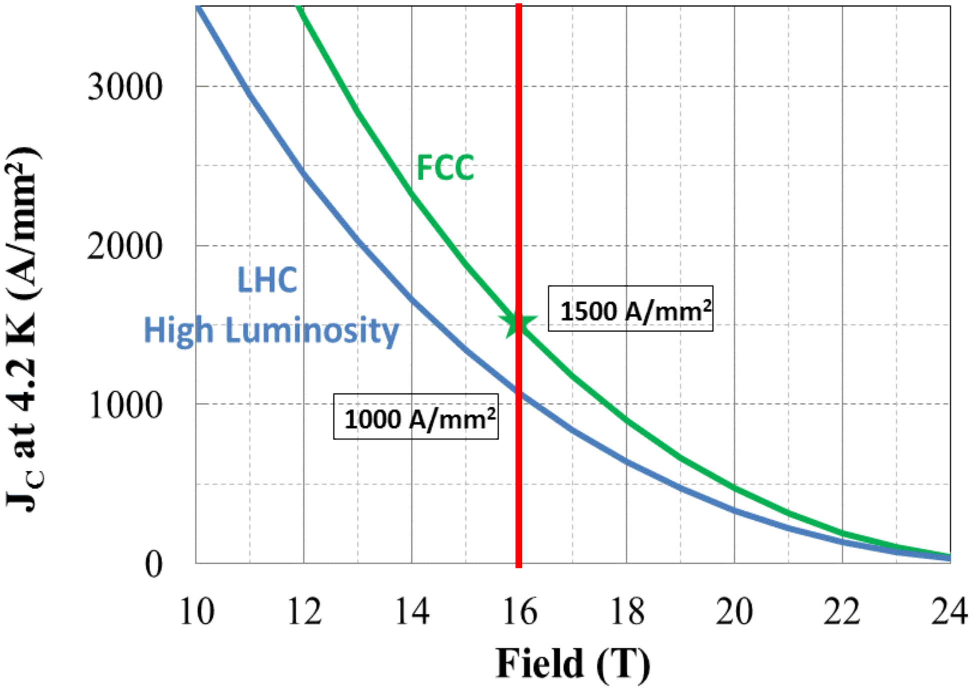
E-group (your colleagues)
easitrain-esr-contacts@cern.ch

E-group (project related)
easitrain-office@cern.ch

Your Contribution to FCC

Nb_3Sn Conductor Development Program

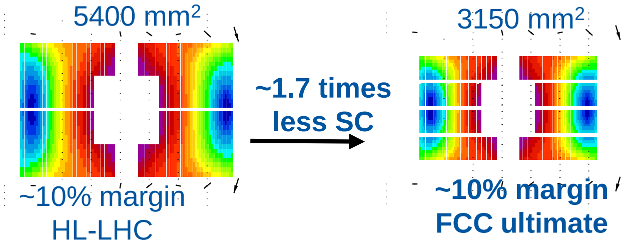
Nb_3Sn is one of the key cost & performance factors for FCC-hh / HE-LHC



Development goals:

- J_c increase (16 T@4.2 K) > 1500 A/mm² i.e. 50% increase wrt HL-LHC wire
- Reference wire diameter 1 mm
- Potentials for large-scale production and cost reduction

Impact on coil section and conductor mass



5400 mm²

~10% margin
HL-LHC

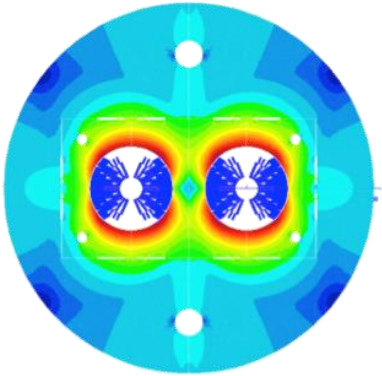
~1.7 times less SC

3150 mm²

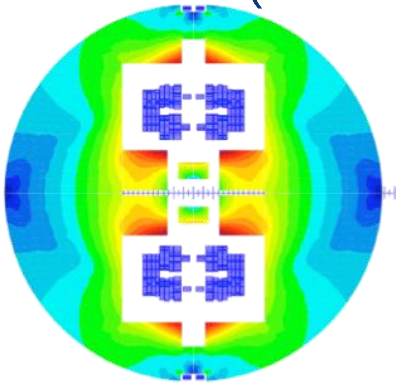
~10% margin
FCC ultimate

16 T Dipole Design Activities

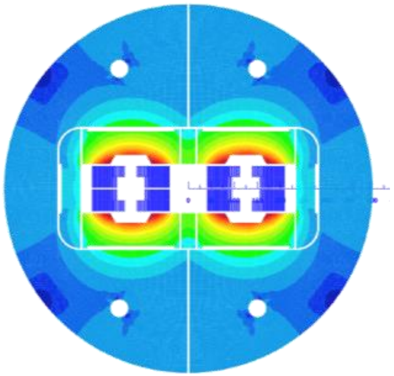
Cos-theta (**INFN**)



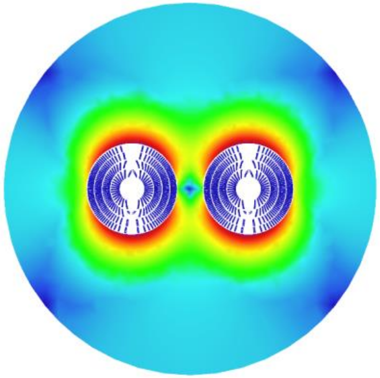
Common coils (**CIEMAT**)

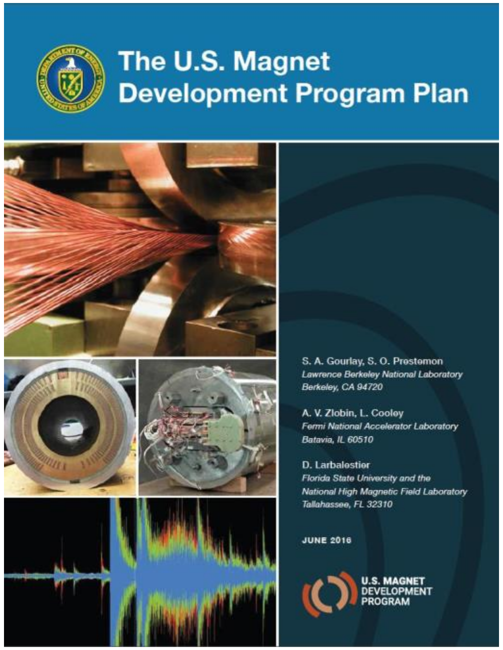


Blocks (**CEA**)



Canted Cos-theta (**PSI**)





The U.S. Magnet Development Program Plan

S. A. Gourlay, S. O. Prestemon
Lawrence Berkeley National Laboratory
Berkeley, CA 94720

A. V. Zlobin, L. Cooley
Fermi National Accelerator Laboratory
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D. Larbalestier
Florida State University and the
National High Magnetic Field Laboratory
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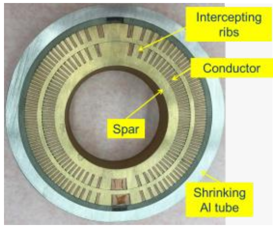
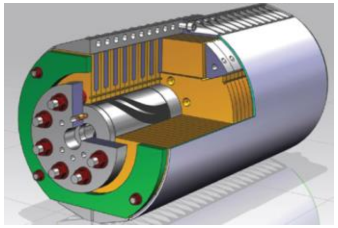
JUNE 2016

U.S. MAGNET DEVELOPMENT PROGRAM

LBNL



FNAL

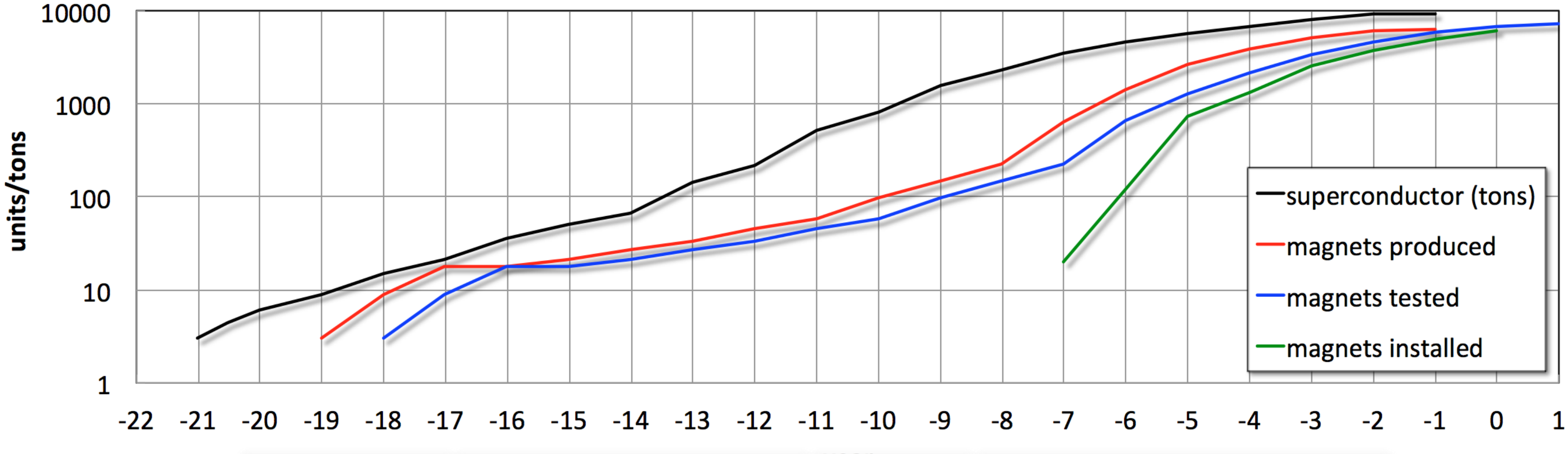


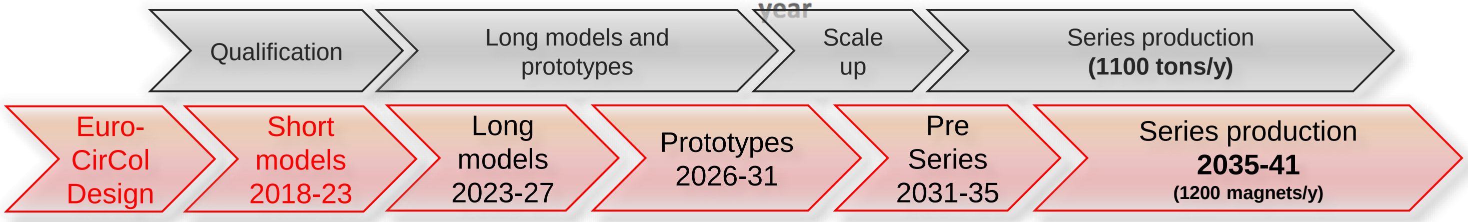
Short model magnets (1.5 m lengths) built from 2017 - 2023

16 T Magnet R&D Schedule is Driver

Duration of magnet program: ~20 years

Continue HL-LHC Nb_3Sn program with long models with industry from 2023/24





Qualification

Long models and prototypes

Scale up

Series production **(1100 tons/y)**

Conductor

Euro-CirCol Design

Short models 2018-23

Long models 2023-27

Prototypes 2026-31

Pre Series 2031-35

Series production **2035-41** **(1200 magnets/y)**

Magnet

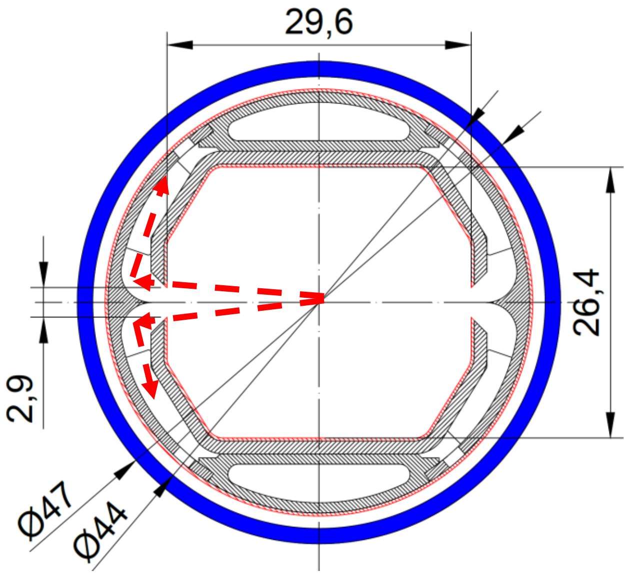
EASITrain Contributions

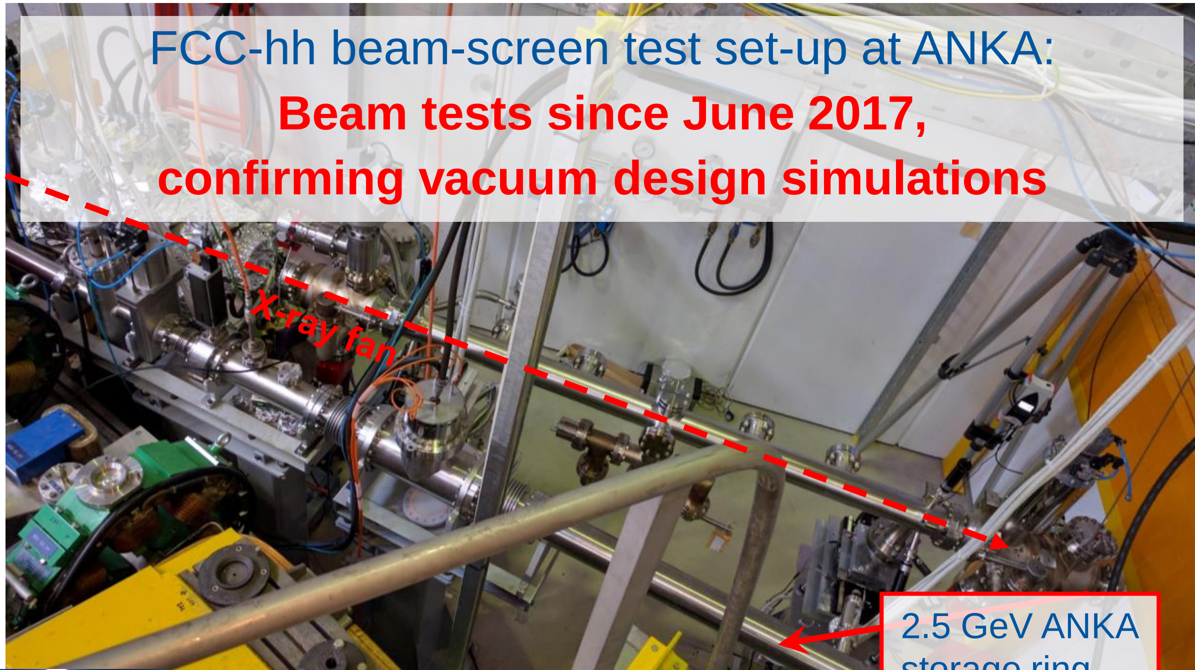
- The magnet **program needs key persons in academia and industry to the prepare the future**
- Even if specific RD topics are partially different (e.g. MgB2, HTS at low temperatures)…
  - Training is essential to **establish future R&D lead personnel**
  - Creation of a **stable relationships at international level** is important
  - Preparation of **partnerships with industry** is necessary
- Technology is also **needed for other machine elements**
  - E.g. electricity distribution
- We require **work towards use and inustrialisation at large and beyond the particle accelerator world**
  to obtain the required quantities at acceptable cost
  - > 7400 tons of conductor for > 4800 magnets

FCC-hh Cryogenic Beam Vacuum System

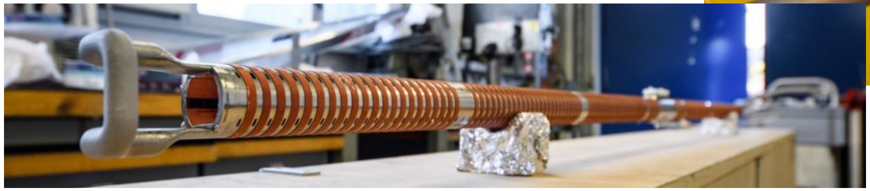
Synchrotron radiation **(~ 30 W/m/beam (@16 T field)** (cf. LHC <0.2W/m) **~ 5 MW total load in arcs**

- **Absorption of synchrotron radiation at ~50 K** for cryogenic efficiency (5 MW →100 MW cryoplant)
- Provision of beam vacuum, suppression of photo-electrons, electron cloud effect, impedance, etc.



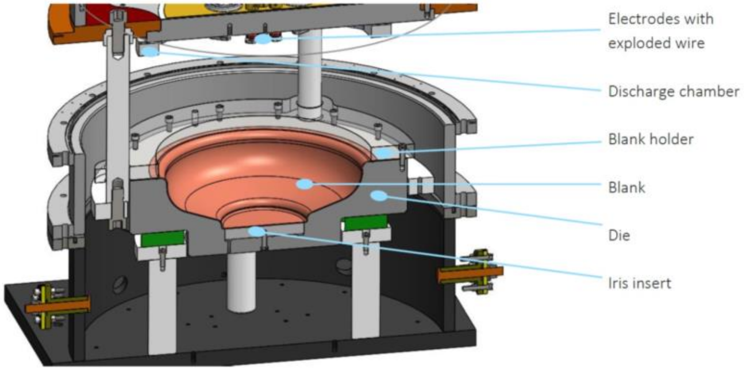

FCC-hh beam-screen test set-up at ANKA:

Beam tests since June 2017, confirming vacuum design simulations

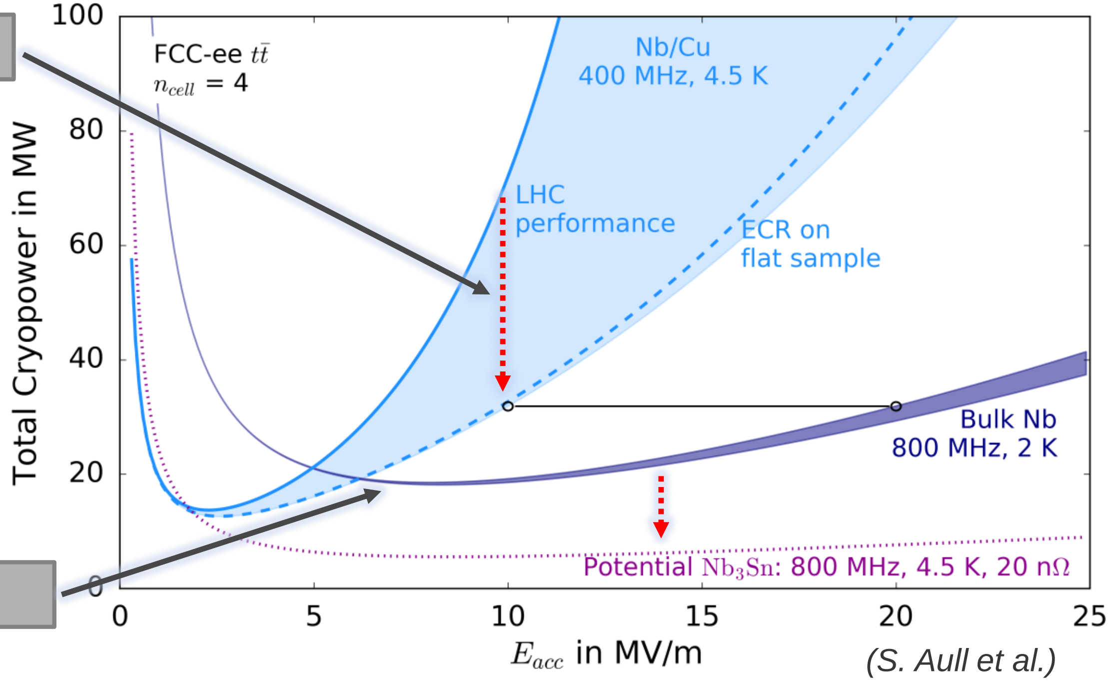


For FCC-ee Nb/Cu Cavities

- High Quality factor
- Lower cryo power needs
- Cheapter manufacturing



Nb/Cu R&D program



(S. Aull et al.)

A15 R&D program

INFN Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Legnaro

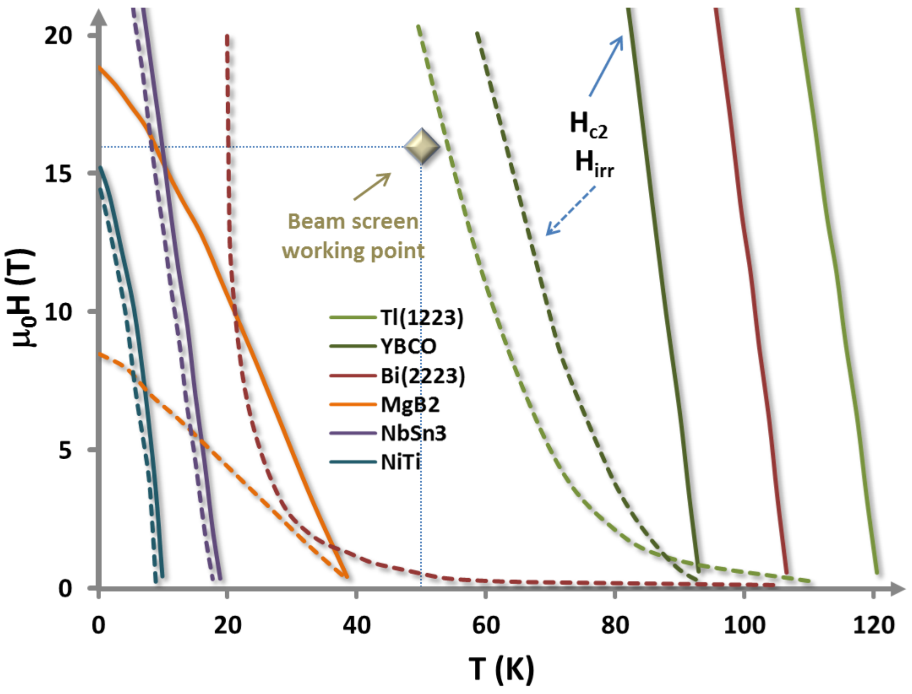
iCUBE

Bmax power to shape

Jefferson Lab
Thomas Jefferson National Accelerator Facility

Budker Institute of Nuclear Physics

HTS Coating as Impedance Mitigation



Data from:

Nature 414, 368-377 (15 November 2001)
High-Tc superconducting materials for electric power applications
David Larbalestier, Alex Gurevich, D. Matthew Feldmann & Anatoly Polyanskii

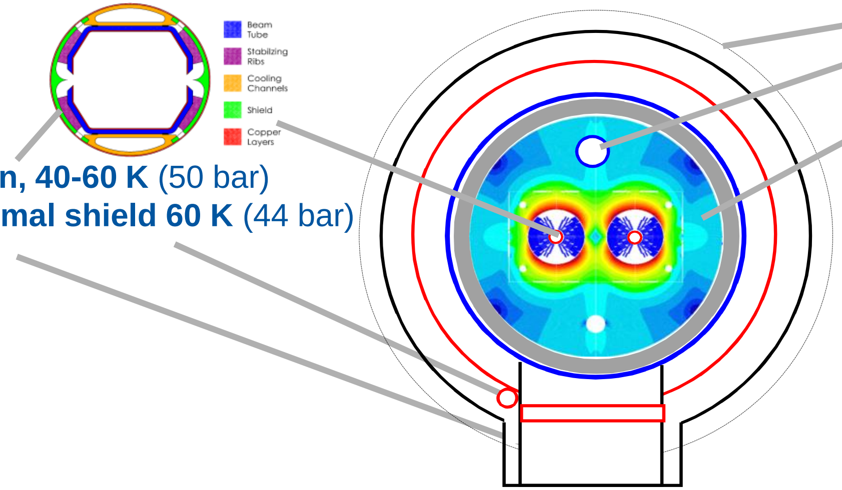
Superconductor Science and Technology, Volume 11, Number 8
Synthesis and properties of fluorine-doped Tl(1223): bulk materials and Ag-sheathed tapes
E Bellingeri, R E Gladyshevskii, F Marti, M Dhallé and R Flükiger

Beam screen of ~30mm diameter.

Assuming a film thickness / skin depth of 1 µm the HTS material should have a critical current density

Jc of about 25 kA/cm^2 (2.5x10^8 A/m^2) at 50 K and 16T

FCC-hh Cryogenics Parameters and Layout



Vacuum vessel
Bayonet heat exchanger, 1.85 K saturated
Cold mass, 1.9 K (1.3 bar)

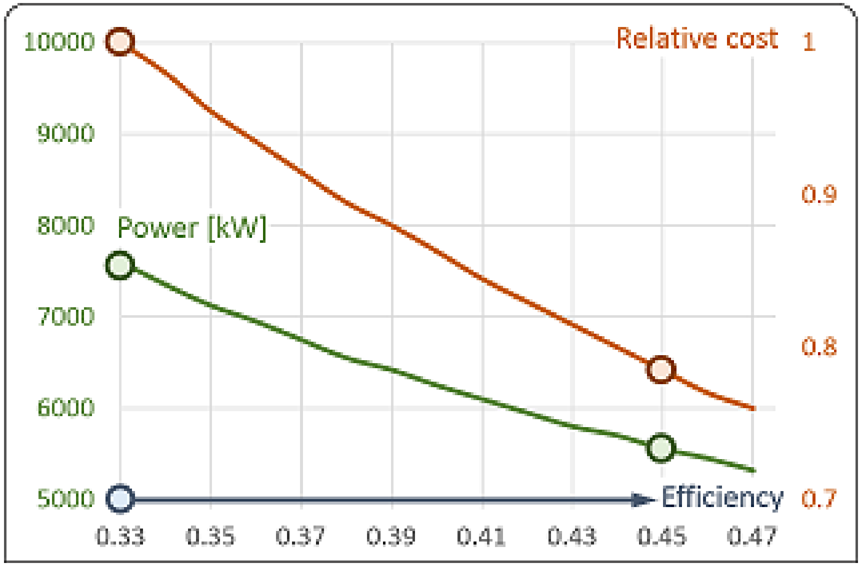
Beam screen, 40-60 K (50 bar)
Magnet thermal shield 60 K (44 bar)
Support post

Temperature level	[W/m]
1.9 K, magnet cold mass - Beam losses - Resistive heating of splices	**1.4**
40-60 K, beam screen, thermal shield - Synchrotron radiation - Beam Image current	**71**

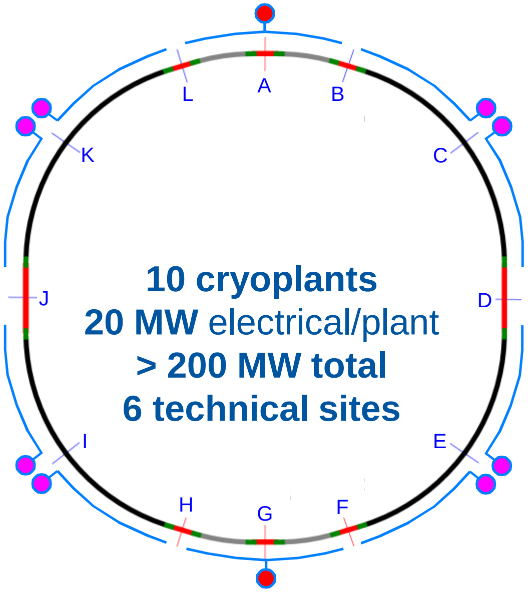
Total load
1 MW equivalent @4.5 K

Cryoplant	40-60 K	1.9 K
🔴	592 kW	11 kW
🟣	618 kW	12 kW

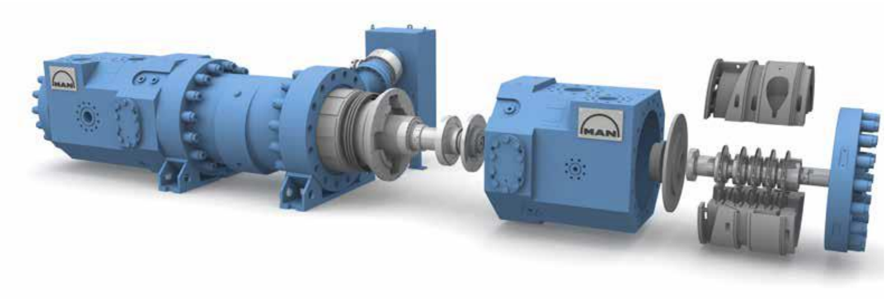
Neon-Helium Refrigeration and Machinery



Cryoplants layout



10 cryoplants
20 MW electrical/plant
> 200 MW total
6 technical sites



Work Packages

WP	Name	Lead		Co-Lead	
1	**Management**	CERN	**A. Ballarino**	CERN	**M. Benedikt**
2	**Materials**	TUW	**M. Eisterer**	CERN	**S. Hopkins**
3	**Manufacturing**	INFN	**V. Palmieri**	CERN	**S. Calatroni**
4	**Cryogenics**	TUD	**C. Haberstroh**	CEA	**F. Millet**
5	**Valorisation**	WUW	**P. Keinz**	CERN	**J. Gutleber**
6	**Training**	CNR	**M. Putti**	WUW	**P. Keinz**
7	**Communications**	CERN	**P. Charitos**	TM	**M. Mosslechner**
Overall project coordination				CERN	**J. Gutleber**

Materials

- Assess the **quality**, superconducting **properties** of **wires** and **thin-films** under cryogenic operation conditions
- Identify, analyse and describe the **impacts of manufacturing processes** on the material properties
- **For magnets:** Nb_3Sn wires, MgB_2 wires, HTS wires at low temperatures
- **For RF cavities:** Nb_3Sn, NbN
- For **beam screen:** Thallium Tl-1223/1212

Manufacturing

- Optimise **production processes** for superconductors for quality and to pave the way for cost effective production at large scale
- Assess the impacts of production processes on the superconducting properties
- **MgB_2 wire production**
- **Coating for RF cavities** (e.g. interface substrate/coating)
- **Thin-film production recipe** for Thallium
- **Electro-hydraulic forming** with metals

Cryogenics

- Develop the **Nelium cycle** for refrigeration down to 40-60 K
- Develop a suitable **turbocompressor** design for Nelium and gain practical experience at a test stand
- Develop a **catalogue of SC magnet cooling architectures**
- Optimise **SC magnet heat extraction schemes**

Valorisation

- **Identify and assess** the **potentials of superconductor applications** using economics approaches with **focus on downstream users**
  - Enlargement of existing relevant markets with cost/performance improvements, e.g. medical imaging, chemical analysis, particle therapy
  - Identification of new markets (e.g. fruit sorting, loudspeakers, cargo scanning) and development of market entry strategies
  - Assessment of the “industrial” scientific market, e.g. XFELs, NMRs
- Creation of a **reference curriculum for an interdisciplinary PhD program** on superconductivity applications
  - Understand how it can be implemented (e.g. EJD)
- **Technology roadmap for EU and national decision bodies** encompassing upstream and downstream industries

Training

- Interdisciplinary and intersectoral training
  - Three 2-weeks **long summer schools**,
  - 2 weeks **intro training** at CERN
  - Lectures, courses to obtain **ECTS points**
- **Transferrable skills**
  - Work health and safety, Project management, presentation techniques, job search and application, intellectual property management and protection, writing grant proposals, how to engage the public in scientific projects, personality development
- **Career Development Plan & Secondments**
  - Personalised training plan and meaningful exposure to industry

Communications

- Planned **scientific and non-scientific dissemination** of results
- Develop a **plan and actions to engage the public** in matters related to superconductivity and cryogenics
- With the **help of media companies**, develop **key messages** for different audiences that work, accompany the early stage researchers and gather material (the value of training in an international science project for the ESRs, for the scientific domain, the European industry, for the entire society)
- **Work with industry** to identify **opportunities for** engagement in common **future projects**, create **support from interest groups**

CERN Idea Square | September 22-24, 2017

SUPERCONDUCTOR HACKATHON

CONNECTING TECHNOLOGY & BUSINESS

- 3 teams / 18 students
- Conceive concepts for new industrial applications
- Preparation work since Feb. 2017
- Satellite event of EUCAS 2017 (GVA)
- Hosted by IdeaSquare
- With support from industry experts, leading technology professors and economists

EASISchools

- 2 week intense schools in cooperation with another organisation
  - 1 week technical training
  - 1 week transferrable skills training
- First EASISchool in Vienna (Austria**), 3.9.-14.9., 2018**
- 15 participants from EASITrain, same amount or a bit more from outside to co-fund the school
- School 1 in Austria focuses on
  - Superconductivity
  - Interplay of elements that govern application performances
  - Possibility for students to gain ECTS points (e.g. seminar)
- Visits
  - MedAustron ion-therapy facility (CERN project 2008-2014)
  - Atominstitute TU Vienna