Future Circular Collider Study

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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.

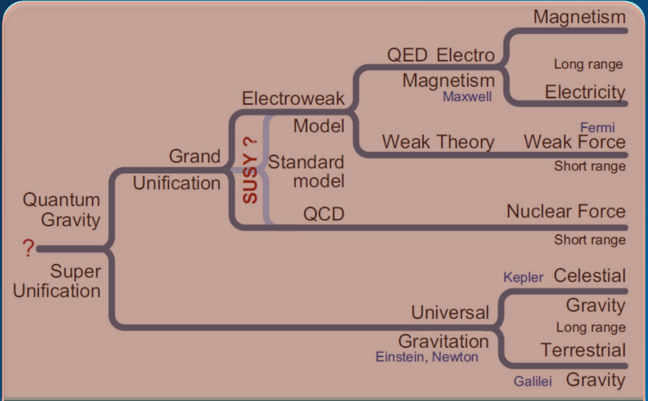
What about the other 95%?

Strategy Update 2013

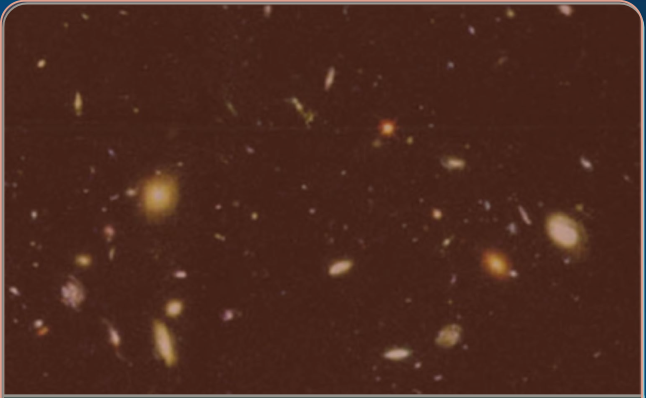
The European Strategy for Particle Physics, May 2013

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

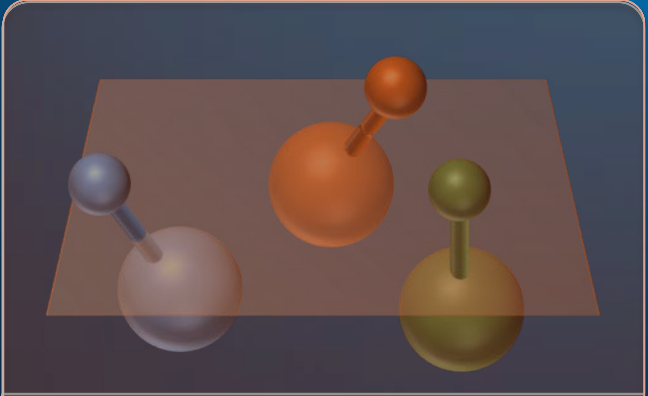
Open Questions



What are the fundamental laws that govern nature?



What is dark matter?

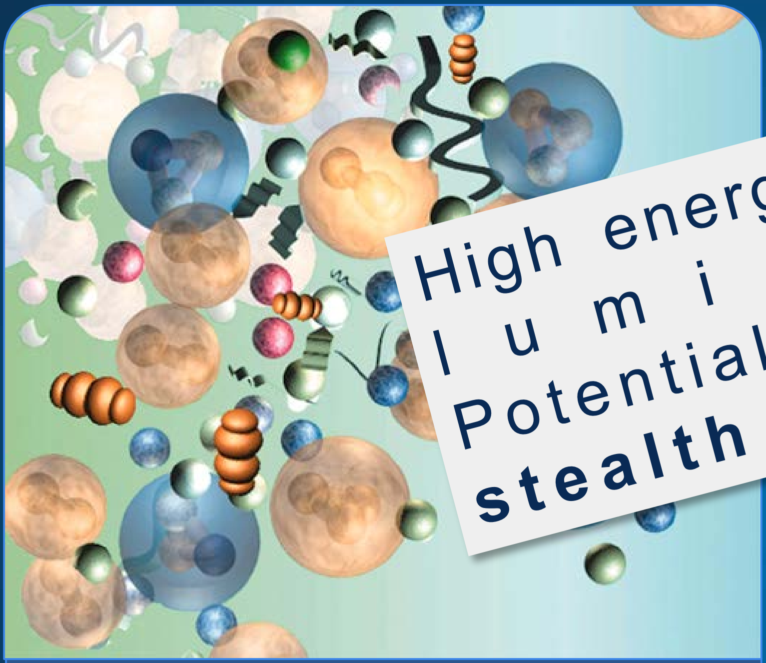


Do supersymmetric particles exist?

What are the smallest constituents of matter?

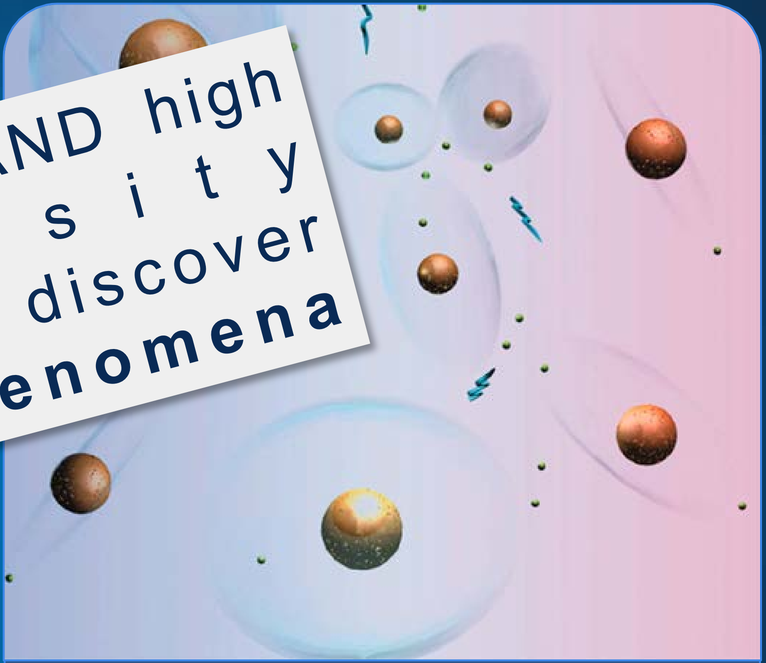
Roads to Discovery

High energy AND high
l u m i n o s i t y
Potential to discover
stealth phenomena



Smaller Scales

Higher Energy



Rare Processes

Higher Luminosity

?

WHAT

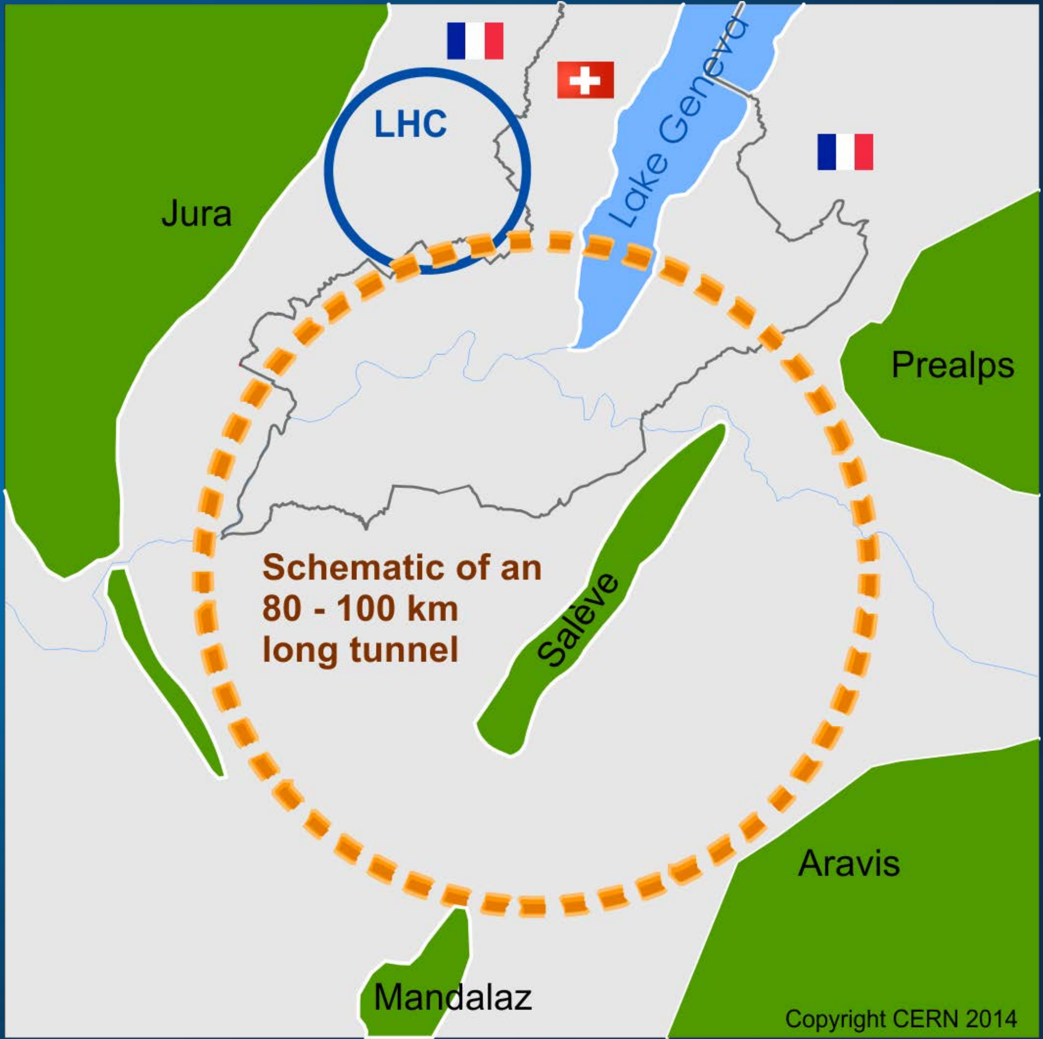
Future Circular Collider Study
SCOPE: CDR and cost review for the next Europen Strategy Update (2018)

Forming an international collaboration to study:

- ***pp*-collider (*FCC-hh*)**
  → defining infrastructure requirements

~16 T ⇒ 100 TeV *pp* in 100 km
~20 T ⇒ 100 TeV *pp* in 80 km

- **80-100 km infrastructure** in Geneva area
- **e^+e^- collider (*FCC-ee*)** as potential intermediate step
- ***p-e* (*FCC-he*) option**

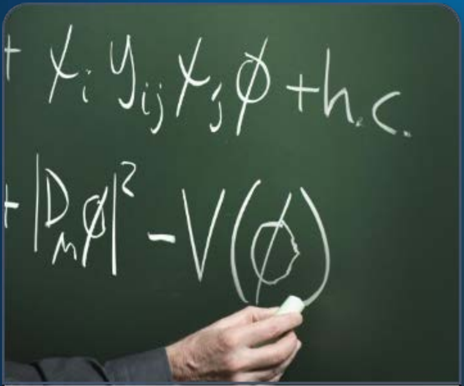


Conceptual Design Scope

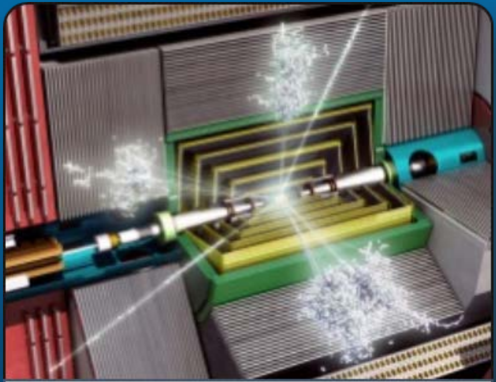
Collider Designs

Infrastructures

R&D Programs



Physics Cases



Experiments

Cost Estimates

Study Setup

Geographically Balanced

Worldwide

Topically Complementary

Excellence

- Hosted and coordinated by CERN
- Carried out with international partners
- Implements high-priority recommendation of *European Strategy for Particle Physics*


HOW

Accelerator Technologies

Well suited to collide light particles (electrons-positrons)
Little energy loss due to synchrotron radiation
Particles are collided only once

Linear

Circular, infinite path with continuous acceleration
Particles are collided multiple times in multiple interaction points

Circular

Circular Collider Studies

100 km

Circular Colliders

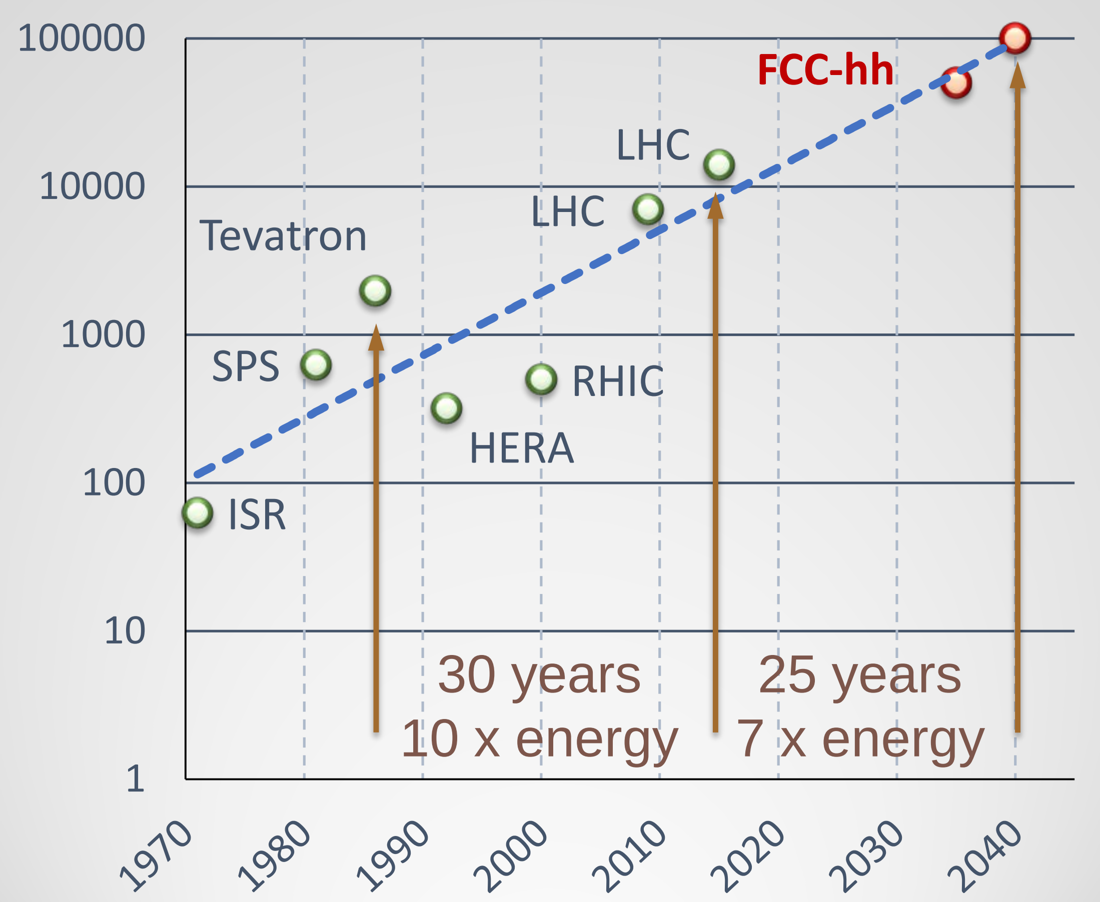
53 km

Chinese ep Collider

- World-wide, collaborative
- Assess feasibilities of multiple options (hh,ee)
- Evaluate benefits vs. cost of multiple options
- Open gates to New Physics discoveries

- Chinese national project
- Design for constructing electron-positron collider from 2020 onwards
- Primary goal to precisely measure Higgs properties
- pp collider at later stage

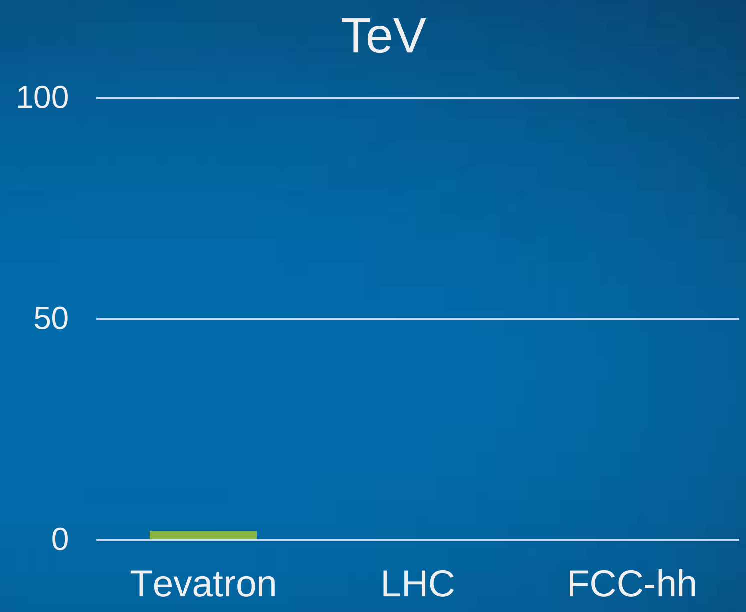
Energy Evolution (pp)



Hadron collider energy evolution [GeV vs. year]

Tevatron (retired)

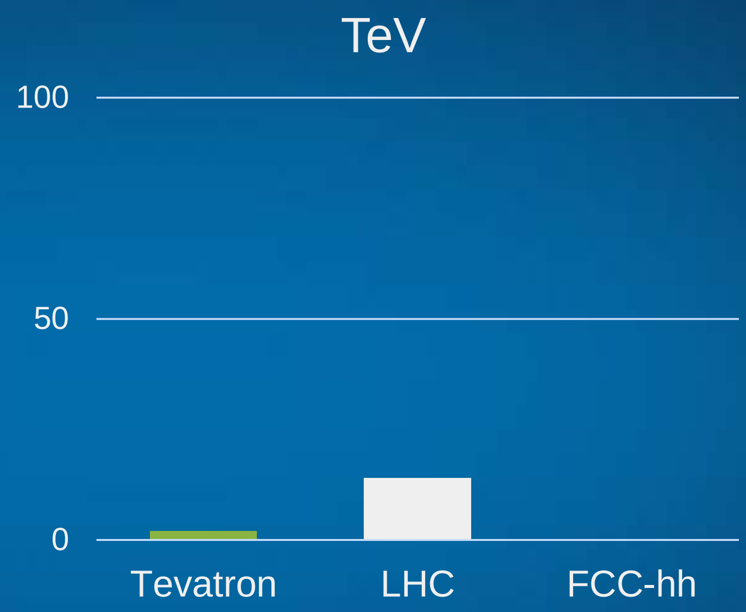
Circumference: **6.2 km**



Energy: **2 TeV**

Large Hadron Collider

Circumference: **27 km**



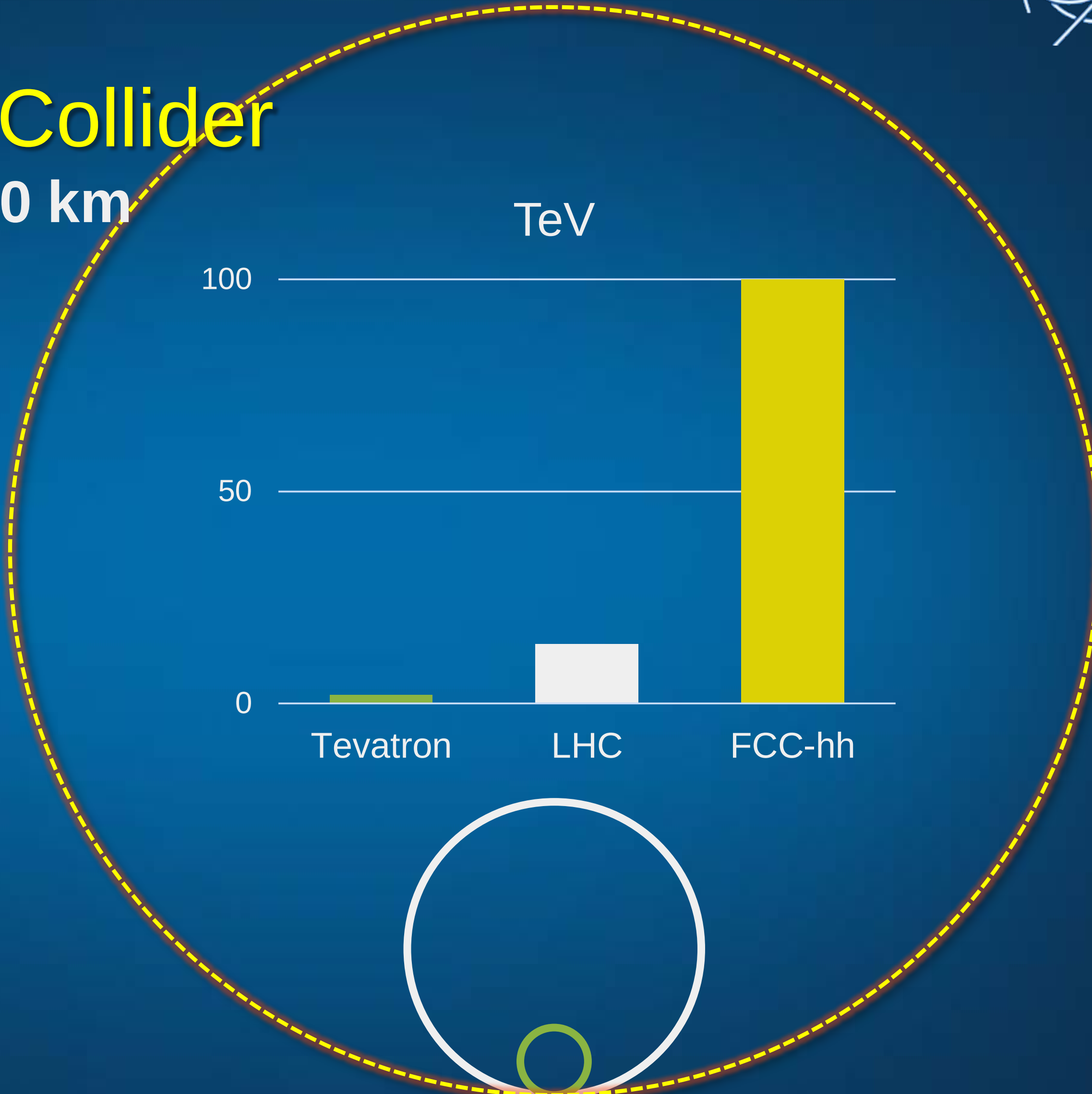
Energy:

- 14 TeV (pp)

- 209 GeV (LEP: e^+e^-)

Future Circular Collider

Circumference: **80-100 km**



Energy:

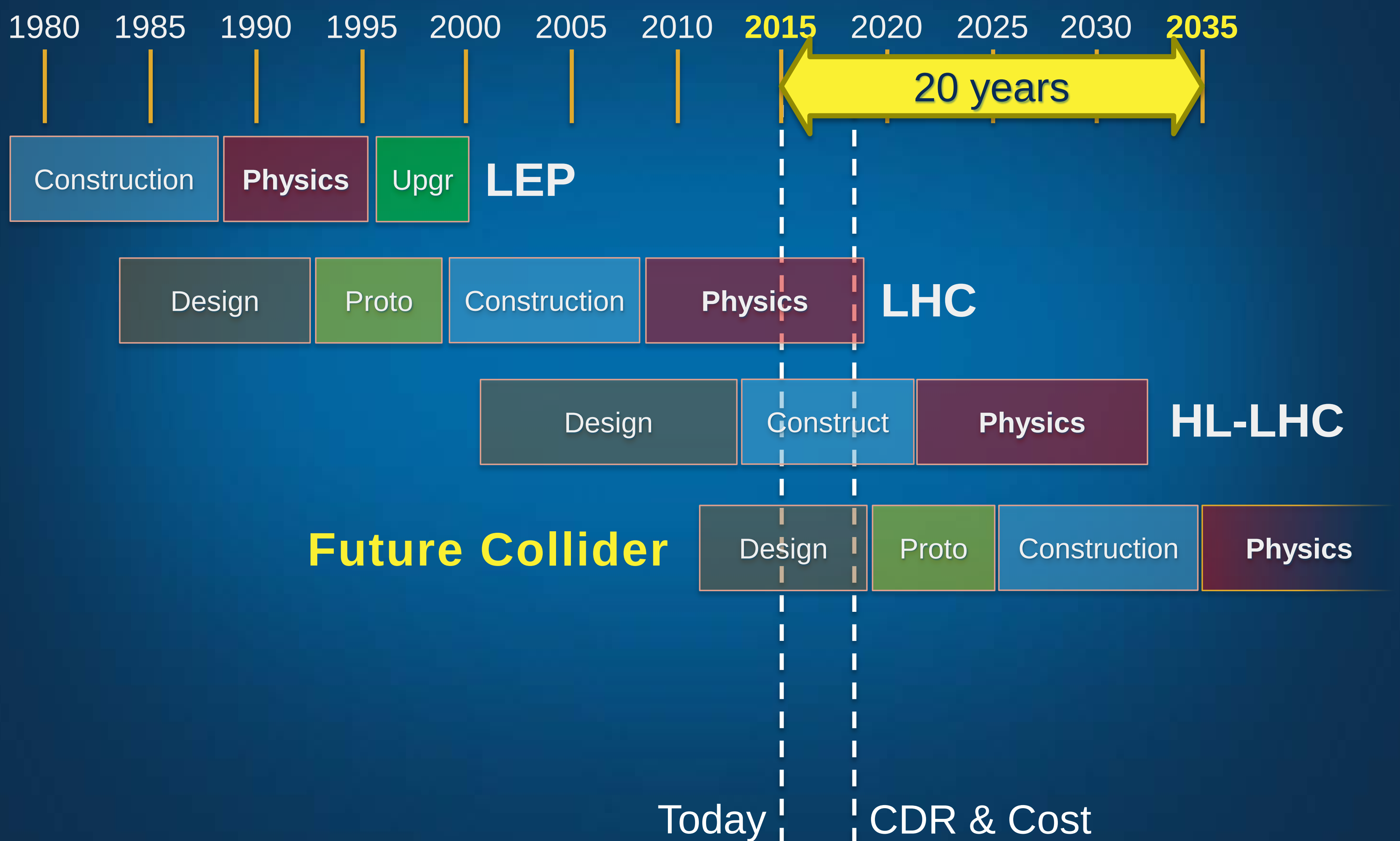
- **100 TeV (pp)**
- **>350 GeV (e^+e^-)**

FCC-hh Key Parameters

Parameter	FCC-hh	LHC
Energy [TeV]	100 c.m.	14 c.m.
Dipole field [T]	16	8.33
# IP	2 main, +2	4
Luminosity/IP$_{main}$ [cm^{-2}s^{-1}]	5-10 x 10^{34}	1 x 10^{34}
Energy/beam [GJ]	8.4	0.39
Synchr. rad. [W/m/apert.]	28.4	0.17
Bunch spacing [ns]	25 (5)	25

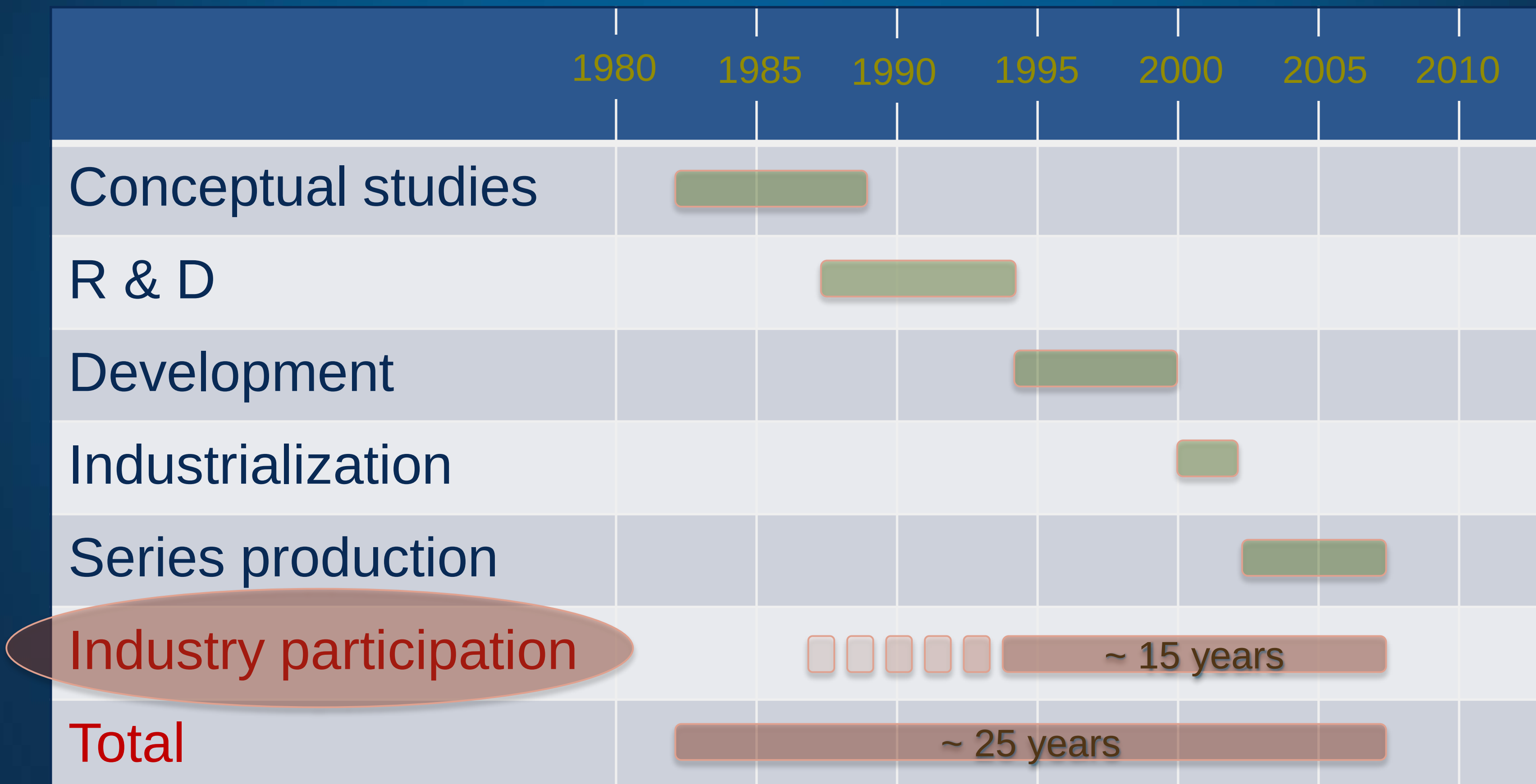
Preliminary, subject to evolution

CERN Circular Collider Timescale



Time Indicator

Case: LHC superconducting dipole magnets



Layout Studies

ARUP

Alignment | Shaft Tools

Choose alignment option: 93km quasi-circular

Tunnel depth at centre: 286mASL

Gradient Parameters

- Azimuth (°): -15
- Slope Angle x-x(%): .3
- Slope Angle y-y(%): 0

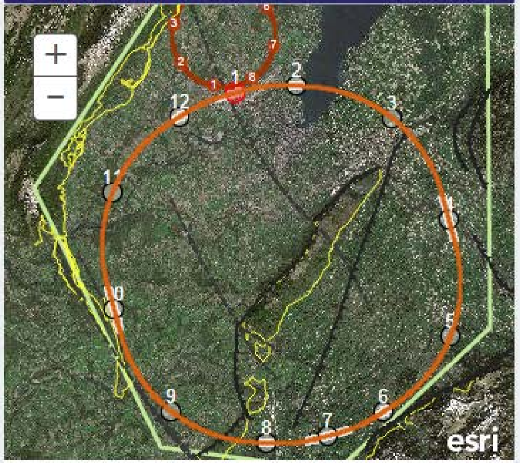
CALCULATE

Alignment centre

X: 2498923 Y: 1106695

LHC Intersection	IP 1	IP 2
Angle	1°	-1°
Depth	542m	542m

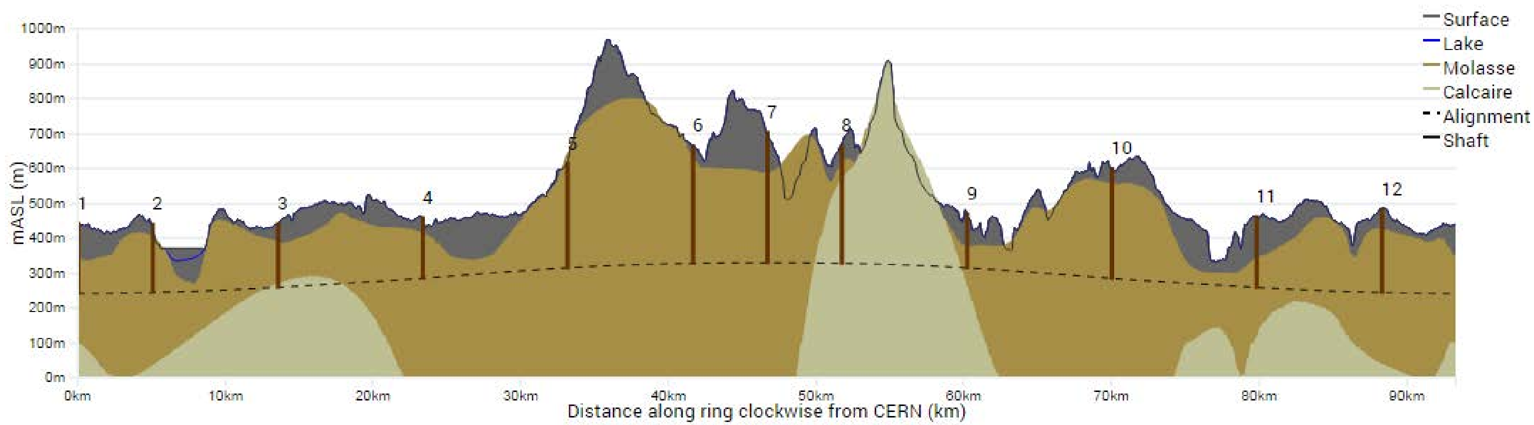
Alignment Location



Geology Intersected by Shafts | Shaft Depths

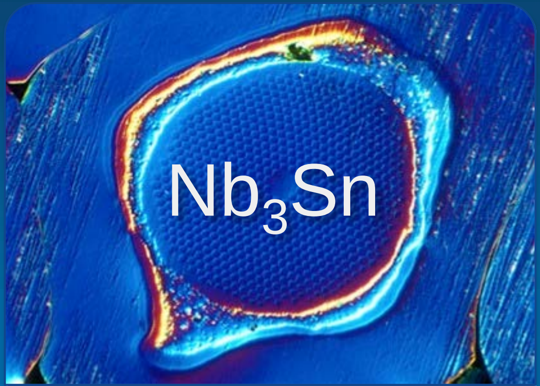
Shaft	Shaft Depth (m) Actual	Min	Mean	Max	Geology (m) Moraine	Molasse	Calcaire
1	200	195	197	200	92	108	0
2	196	143	181	211	34	162	0
3	183	175	184	194	53	121	9
4	174	146	166	178	44	130	0
5	299	286	311	350	0	325	0
6	336	325	339	350	35	302	0
7	374	349	377	412	119	256	0
8	337	318	341	366	44	56	237
9	155	131	145	167	94	61	0
10	315	305	320	336	46	269	0
11	203	199	202	204	122	81	0
12	239	229	238	243	58	181	0
Total	3014	2801	3001	3211	741	2052	247

Alignment Profile



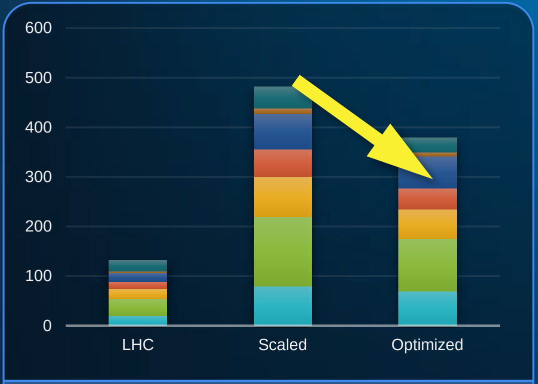
Push Technologies

High-field Magnets



Novel Materials and Processes

Large-scale Cryogenics

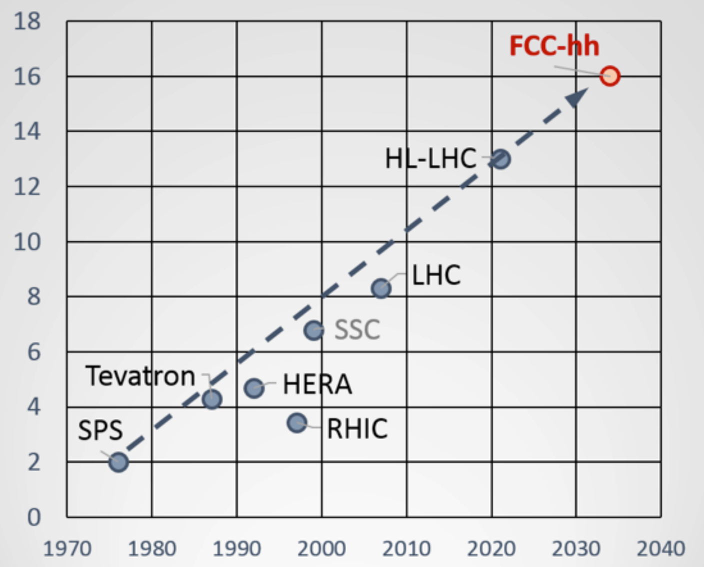


Power Efficiency

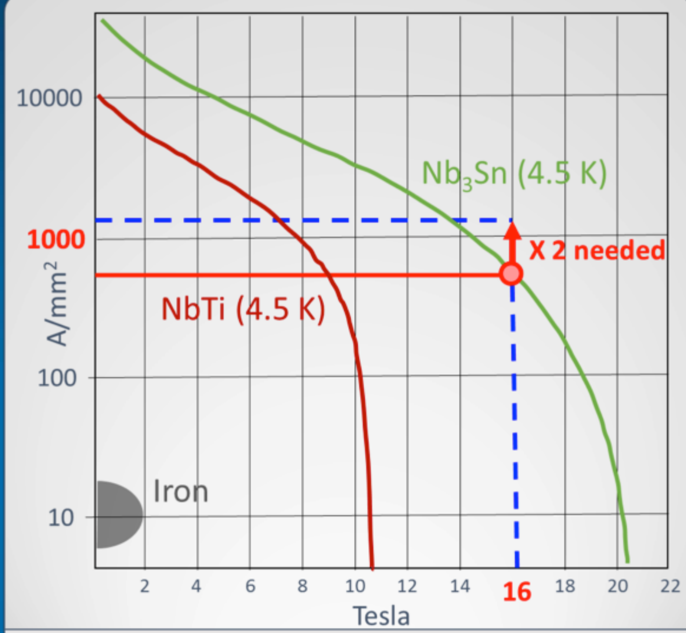
Reliability & Availability

Global Scale Computing

Magnets: Key Enabler



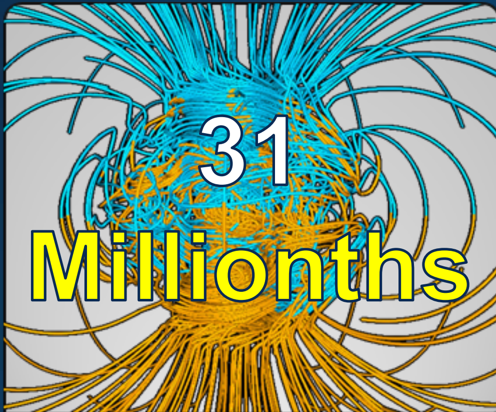
Nominal accelerator magnet field [Tesla] vs. time [Year]



Critical current density vs. magnetic field

- Hadron collider needs superconducting magnets with 16 T field
- Conductor makes today 2/3 of magnet cost
- GOAL: increase performance of Nb_3Sn low-temperature superconductor technology for 16 Tesla operation
- Work with industry on high-volume production, sustainable cost

Tesla and Magnetic Fields

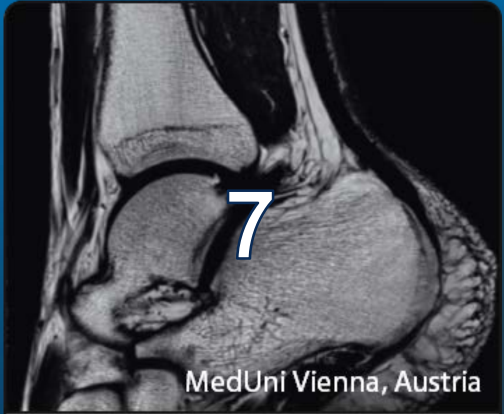


Earth Magnetic Field

Magnetic Button

Iron Magnet

M R I

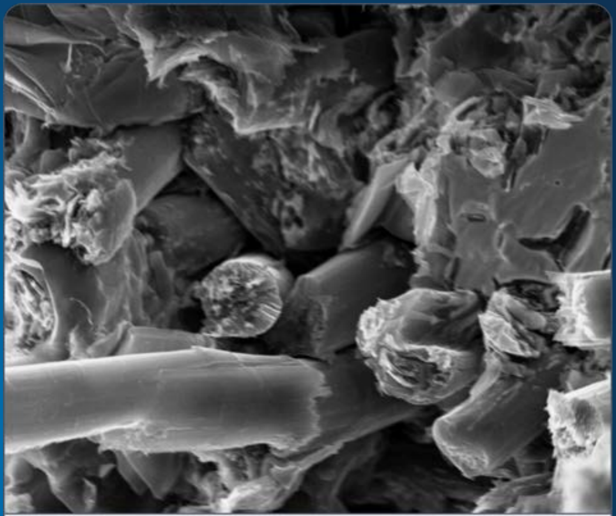


Ultra high-field MRI

LHC Dipole Magnet

Materials & Processes

- Novel materials for robust collimators
- SC materials for RF cavities
- High quality at large scale
- High precision at large surface
- Cost control at large volumes
- Additive manufacturing for seamless structures
- Additive manufacturing for multi-layer structures
- Form new partnerships with industry



Molybdenum Graphite composite for collimators

Work Methodology

- Technical and organizational challenges call for a worldwide, collaborative approach
- Assume that only one single infrastructure in the world of such kind is sustainable

*The **success of the LHC is proof of the effectiveness** of the European organisational model for particle physics, founded on the sustained long-term commitment of the CERN Member States and of the national institutes, laboratories and universities closely collaborating with CERN. **Europe should preserve this model**...*

The European Strategy for Particle Physics, Update 2013, page 1

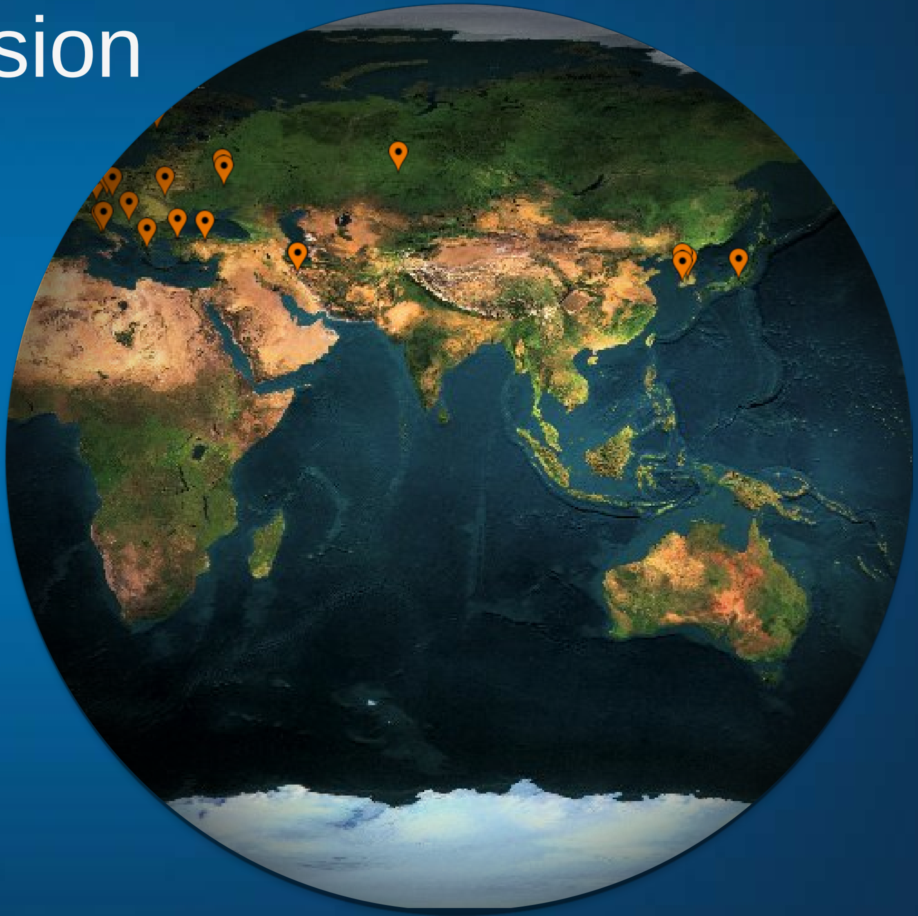
International Collaboration

- Member States and beyond
- Geographically well-balanced
- Topically complementary

- Promote ownership among Participants
- Provide visibility to Member States
- Create opportunities for next phase

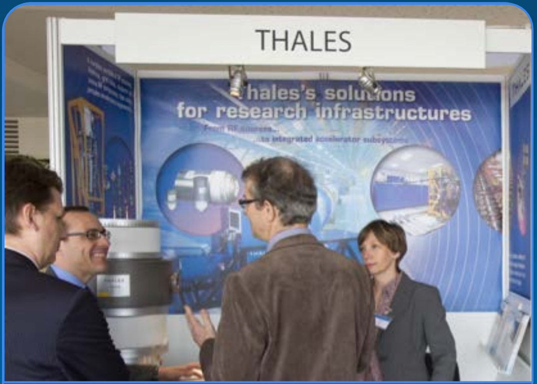
Collaboration Status (2/2015)

- 61 research centers & universities
- European Commission
- 23 countries



Strengthen Europe

In-field training



Showcases for leading industries

Opportunities for SMEs

Visibility for National Institutes

Higher Education

Focus of world-wide research

Progress with Industry

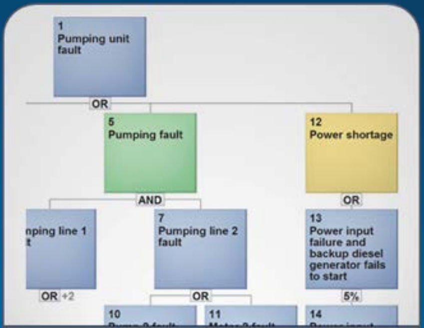
Nb3Sn Conductors
Push performance, lower cost

Reduced size of ion-sources and accelerators for radionuclide production and ion therapy

Affordable, compact Nuclear Magnetic Resonance analysis

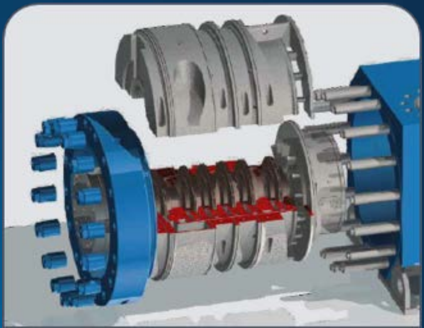
Seamless Structures
(Multilayer & 3D printing)

Higher reliability and reduced cost for accelerators, complex structures in automotive, energy and aerospace at lower price and lower maintenance needs



Reliability Availability Maintainability Safety

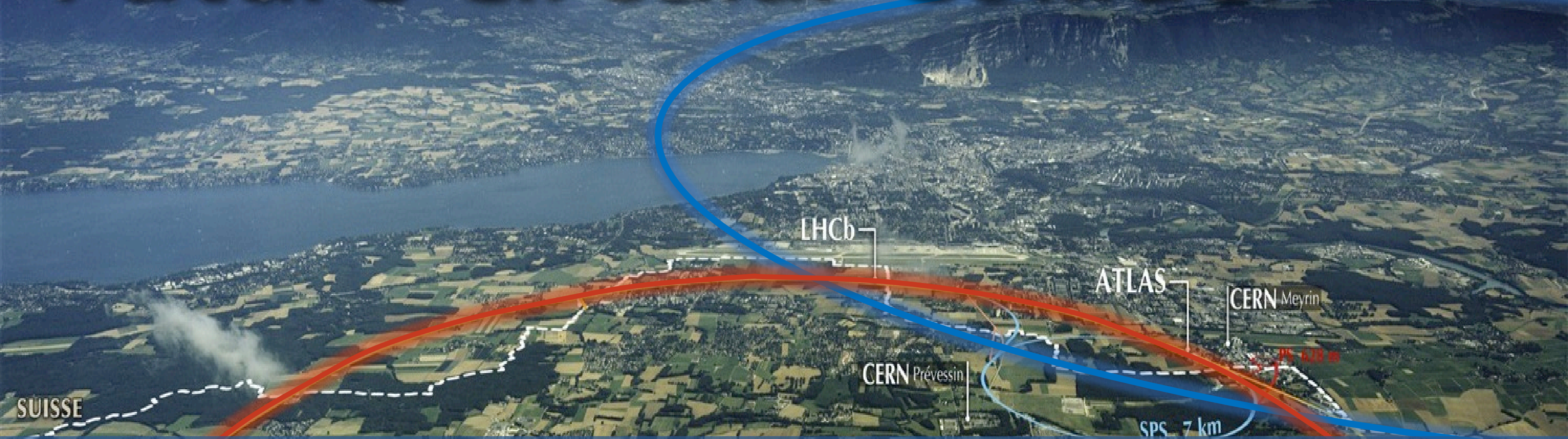
Open tools to assess cost versus gain of RAMS measures, open access reliability databases, direct application in automotive, public transport, oil & gas industries



Efficient Cryogenics
(Coolants & compressors)

Durable compressors for natural gas and subsea, high efficiency hydrogen liquefaction, more compact superconducting devices (NMR, MRI)

Future Circular Collider



Large scale research and technical infrastructure conceptual design study 2014 – 2019

Driven by international contributions

Establish long-term liaisons with industry

Strengthen long-term attractiveness of Europe as leading large-scale research location