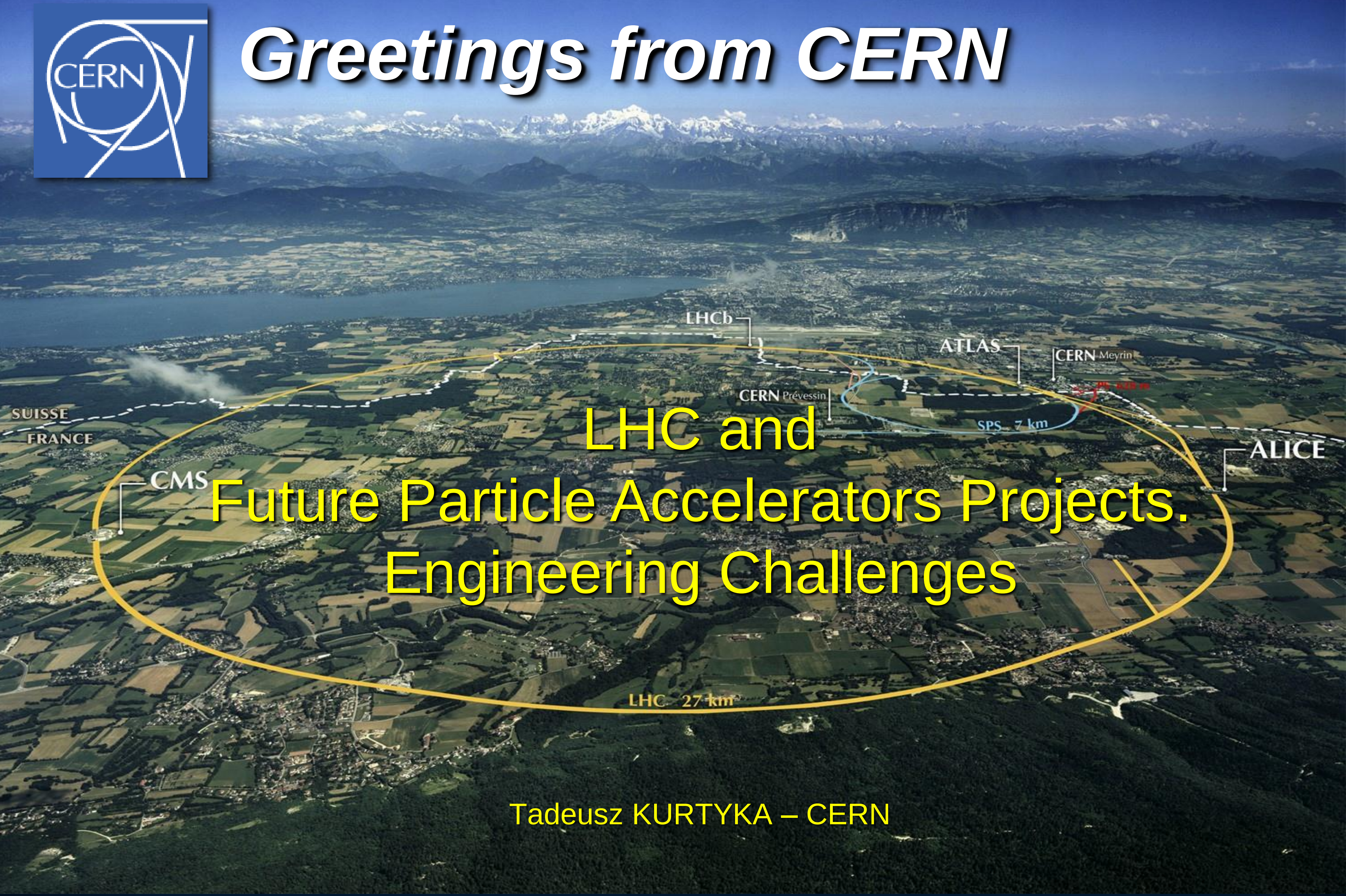
Greetings from CERN



LHC and
Future Particle Accelerators Projects.
Engineering Challenges

Tadeusz KURTYKA – CERN

Contents

1. Large Hadron Collider and its High Luminosity Upgrade (HL-LHC)

2. Projects and challenges of future particle accelerators:

 - Future linear colliders,
 - Future circular colliders,
 - New techniques of particle acceleration.

Collaboration aspects

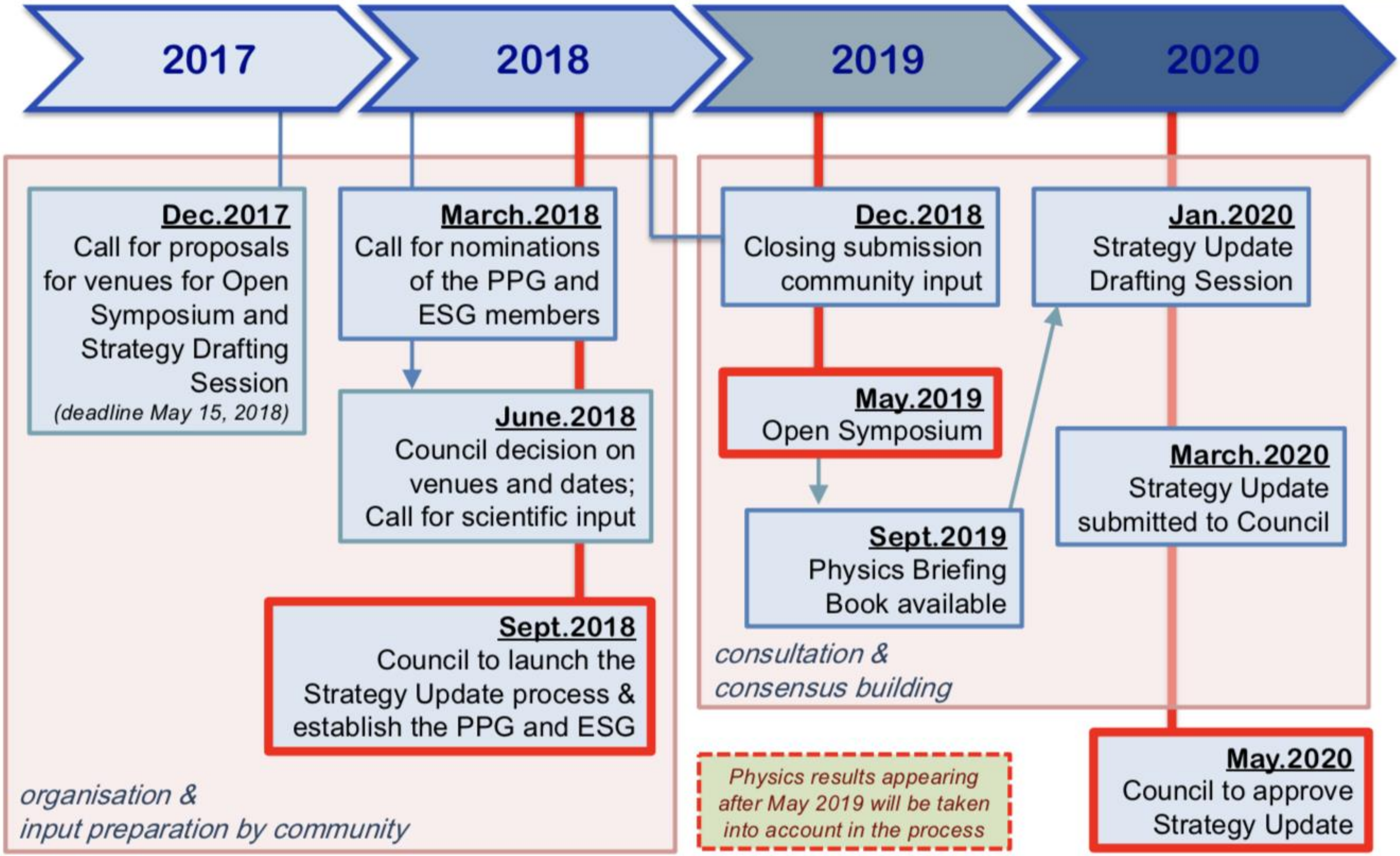
Official groundbreaking ceremony for LHC upgrade; HL-LHC. CERN, 15 June 2018

What is HiLumi?

The High Luminosity LHC (HL-LHC) is an upgrade of the LHC to achieve instantaneous luminosities a factor of five larger than the LHC nominal value. Following five years of design study and R&D, this challenging project requires now about ten years of developments, prototyping, testing and implementation; hence operation is expected to start in the middle of the next decade.

HiLumi
HL-LHC PROJECT

European Particle Physics Strategy *Update*



HL-LHC approved in September 2016; CERN needs to choose the next big project

- Hadron colliders

CERN: HE – LHC, pp 28 TeV - replace dipoles with 16T HTS Nb_3Sn → 20T
CERN: FCC – pp 100 TeV, 80 to 100 km tunnel, 16 to 20T magnets
China: SppC – pp 35 to 65 TeV, 60 km to 100 km tunnel with 12T HTS →24T

- Electron-positron colliders

Kitakami: ILC –linear collider, 250 GeV baseline (up to 31 km, upgrd. to 1 TeV)
CERN: CLIC – linear collider, 380 GeV to 3 TeV (up to 50 km)
CERN: FCC ee – circular collider, 240 to 350 GeV (80 to 100 km)
China: CEPC – circular collider, 240 GeV (50 to 100 km)

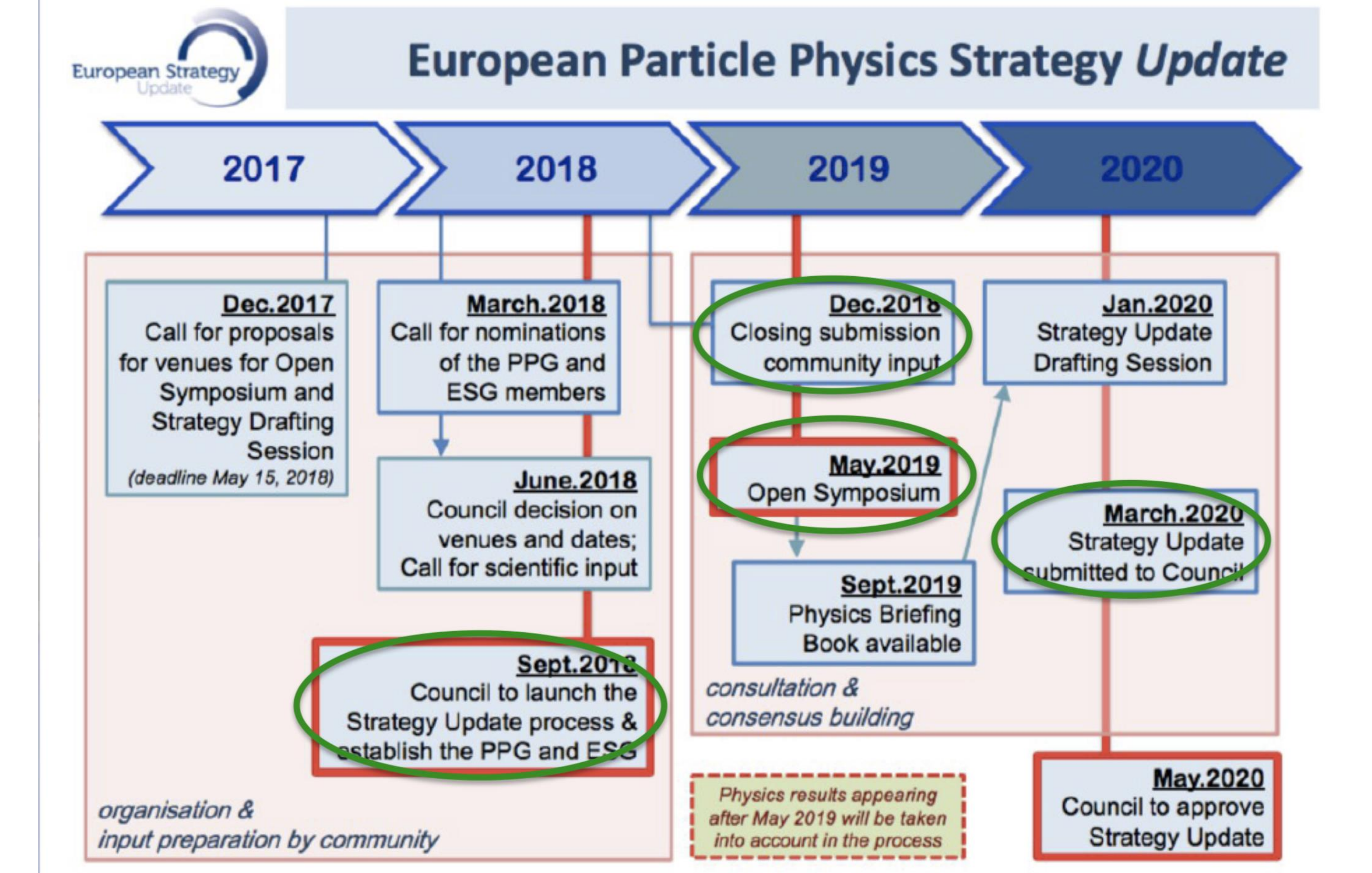
- Muon collider – Higgs factory and energy frontier

Circular collider – 120 GeV to 5 TeV, 300 m long (neutrino factory a bonus)

- ep/eA collider – origin of mass (confinement)

Add e or p linac/circular acc. to existing facilities: EIC (BNL,Jlab), LHeC, …, Chinese versions)

European Particle Physics Strategy *Update*



Timely Japanese government's positive 'expression of interest' is critical for ILC to be included in this process (latest by the end of this year)

From 9 to 13 April, some 500 scientists from 147 institutes met in Amsterdam for the 2018 **Future Circular Collider (FCC)** week. This fourth annual meeting of the FCC collaboration offered a vibrant space to discuss the latest research results and present technological breakthroughs that could pave the way for a new large-scale research infrastructure.

Geneva 25 October 2017: Declaration of Intent signed by SEE countries representatives "to create an international laboratory in the Region, following the spirit of CERN".

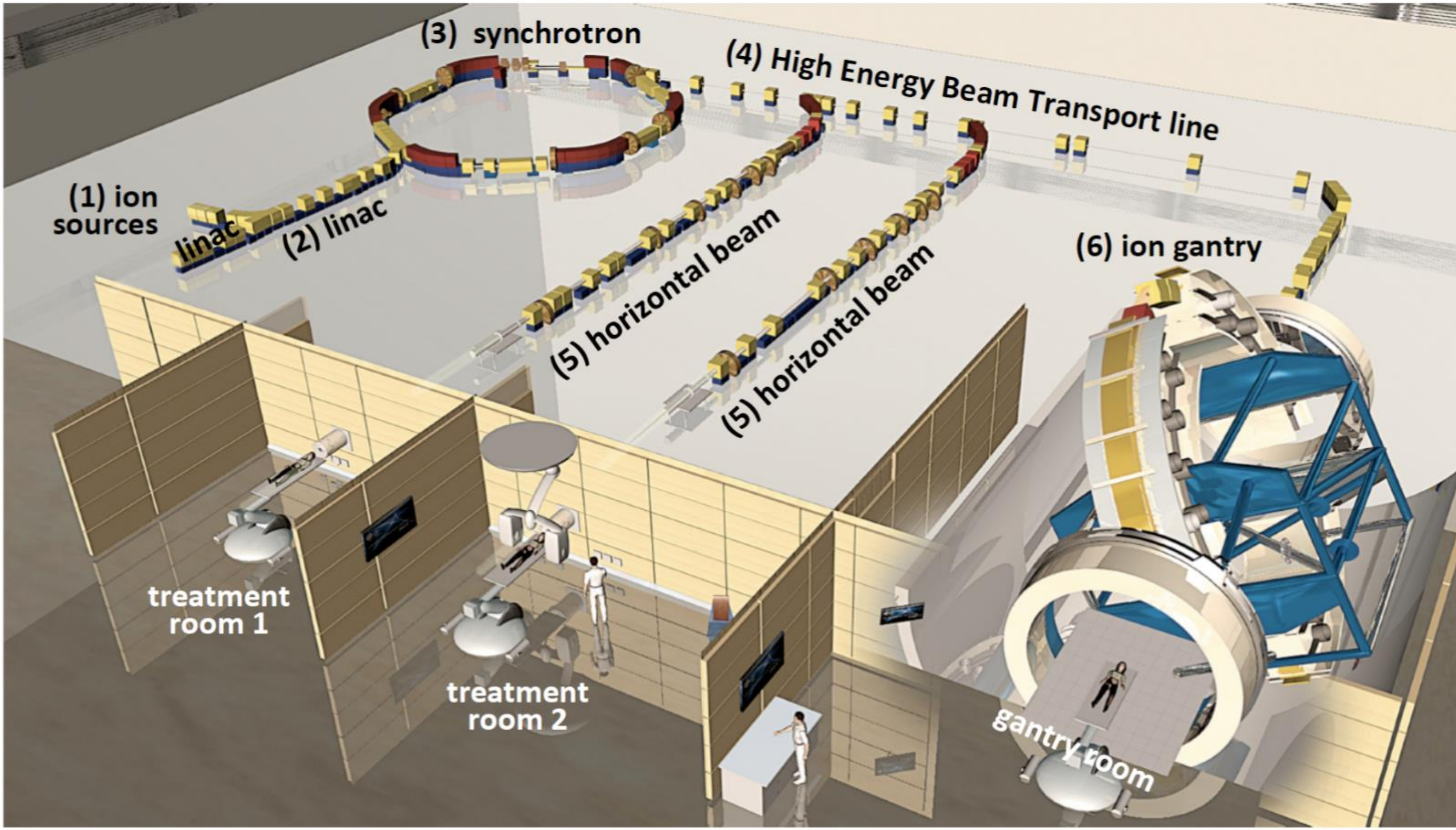
Basic concepts for a

SOUTH-EAST EUROPE INTERNATIONAL INSTITUTE FOR SUSTAINABLE TECHNOLOGIES (SEEIIST)

January 15, 2018

Representatives at the signing of the Declaration of Intent. (From left) Prof. Blazenka Divjak, *Minister of Science and Education, Republic of Croatia*, Prof. Vladimir Popovic, *State Secretary, Republic of Serbia*, Dr. Tomaz Boh, *State Secretary, Republic of Slovenia*, Mr. Ervin Demo, *Vice Minister of Education and Sports, Republic of Albania*, Mr. Shyqiri Bytyqi, *Minister of Education, Science and Technology, Kosovo**, Dr. Sanja Damjanovic, Minister of Science, *Montenegro*, Prof. Herwig Schopper, *Former Director General of CERN*, Prof. Renata Deskoska, *Minister of Education and Science, The FYR of Macedonia*, Mr. Andrija Pejovic, *Minister of European Affairs, Montenegro*, Dr. Adil Osmanovic, *Minister of Civil Affairs, Bosnia and Herzegovina*, Prof. Kostadin Kostadinov, *Advisor to the Minister of Education and Science, Republic of Bulgaria*, Prof. Costas Fountas, *Scientist, Hellenic Republic*.

Regional SEE Facility for Tumor Hadron Therapy and Biomedical Research (HTR) ?



Large Hadron Collider and its High Luminosity Upgrade (HL-LHC)

Large Hadron Collider and HL-LHC Upgrade

1983 first LHC proposal, launch of design study

1994 CERN Council: LHC approval

2010 first collisions at 3.5 TeV beam energy

2016 > collisions at ~design energy

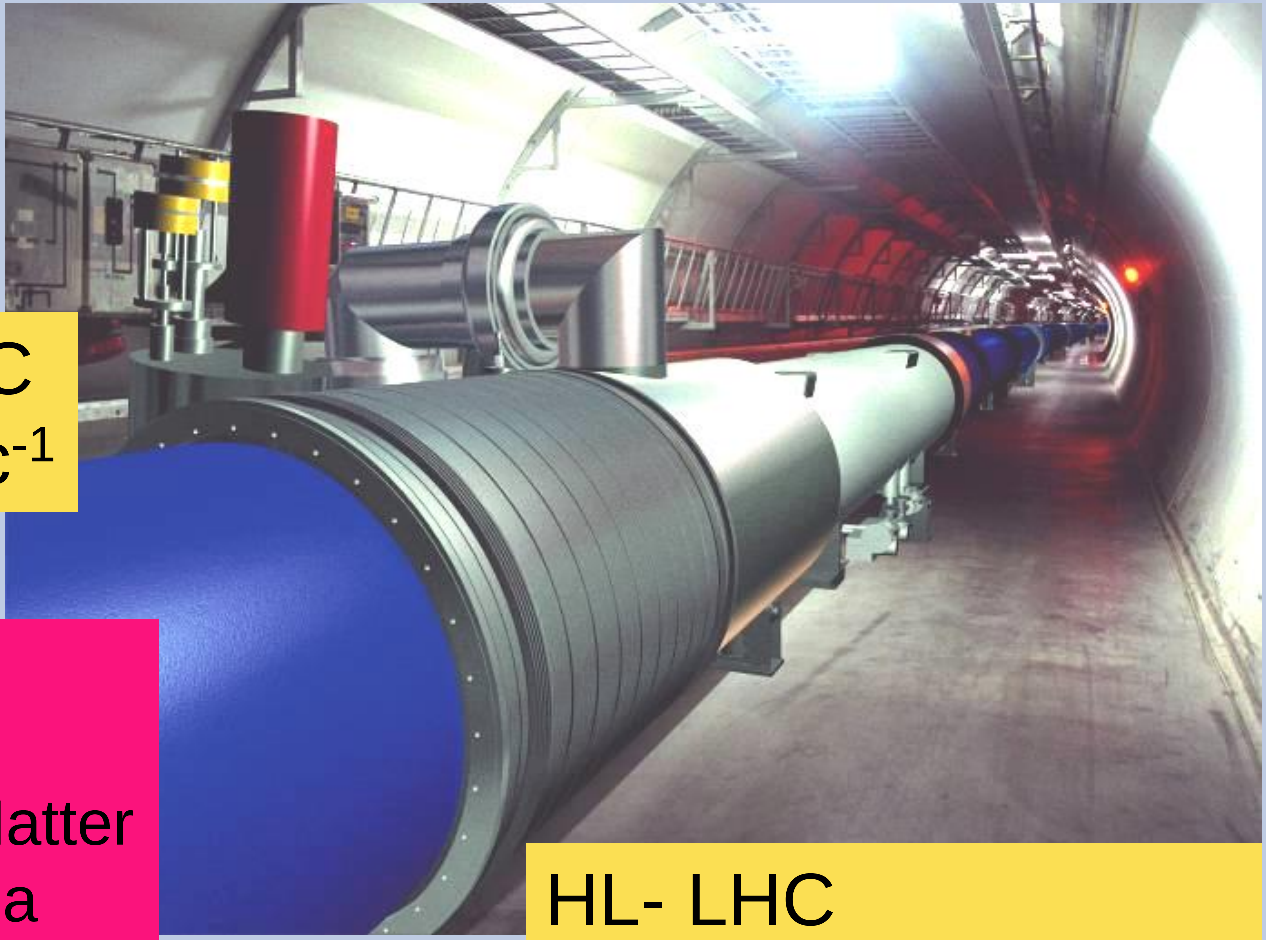
2018-2022 High Luminosity Upgrade (HL-LHC)

2022-2035 Physics Runs

now is the time to plan for >2040! –What future accelerator?

LHC - Large Hadron Collider

7 TeV + 7 TeV



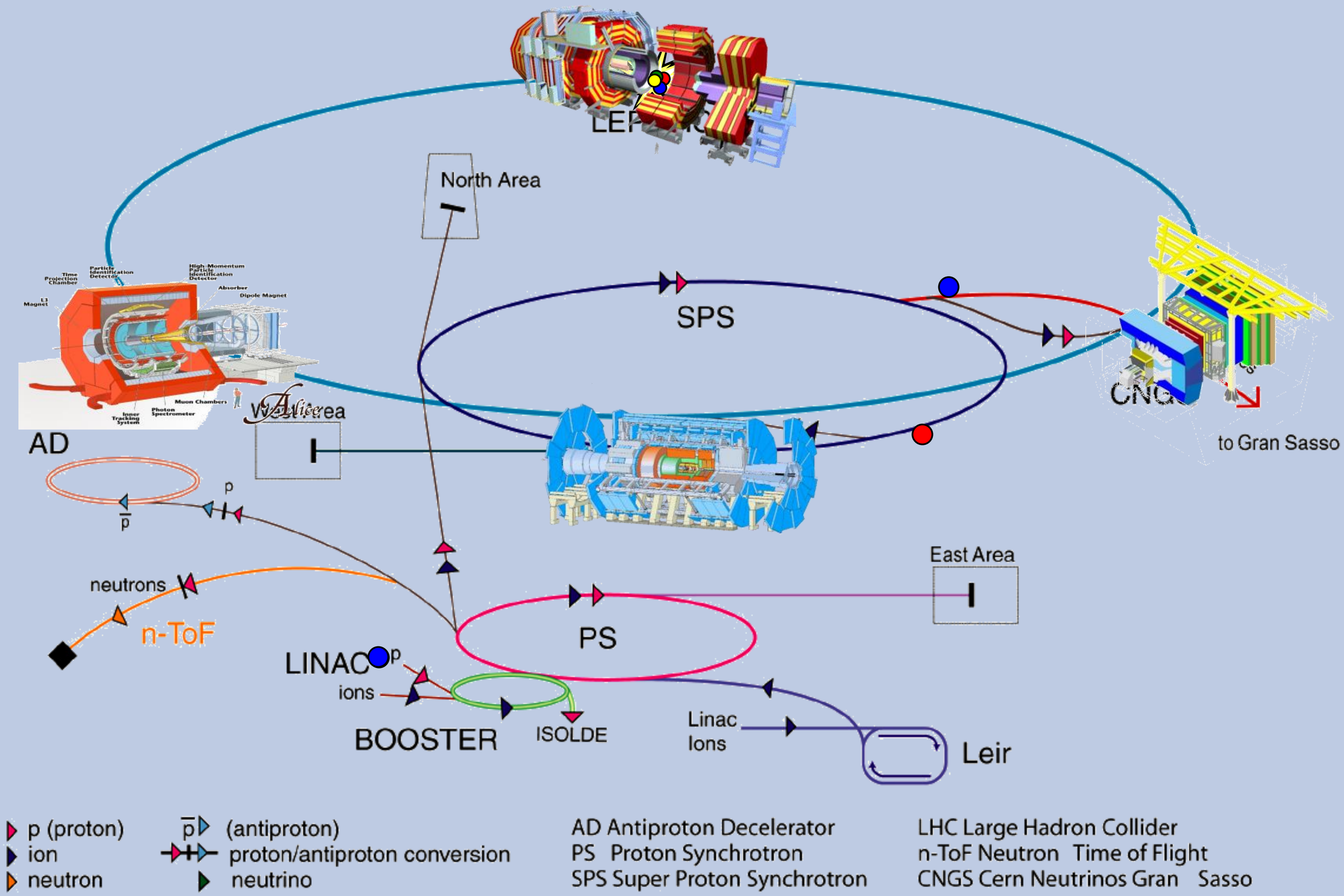
Luminosity LHC
L= $10^{34} cm^{-2} sec^{-1}$

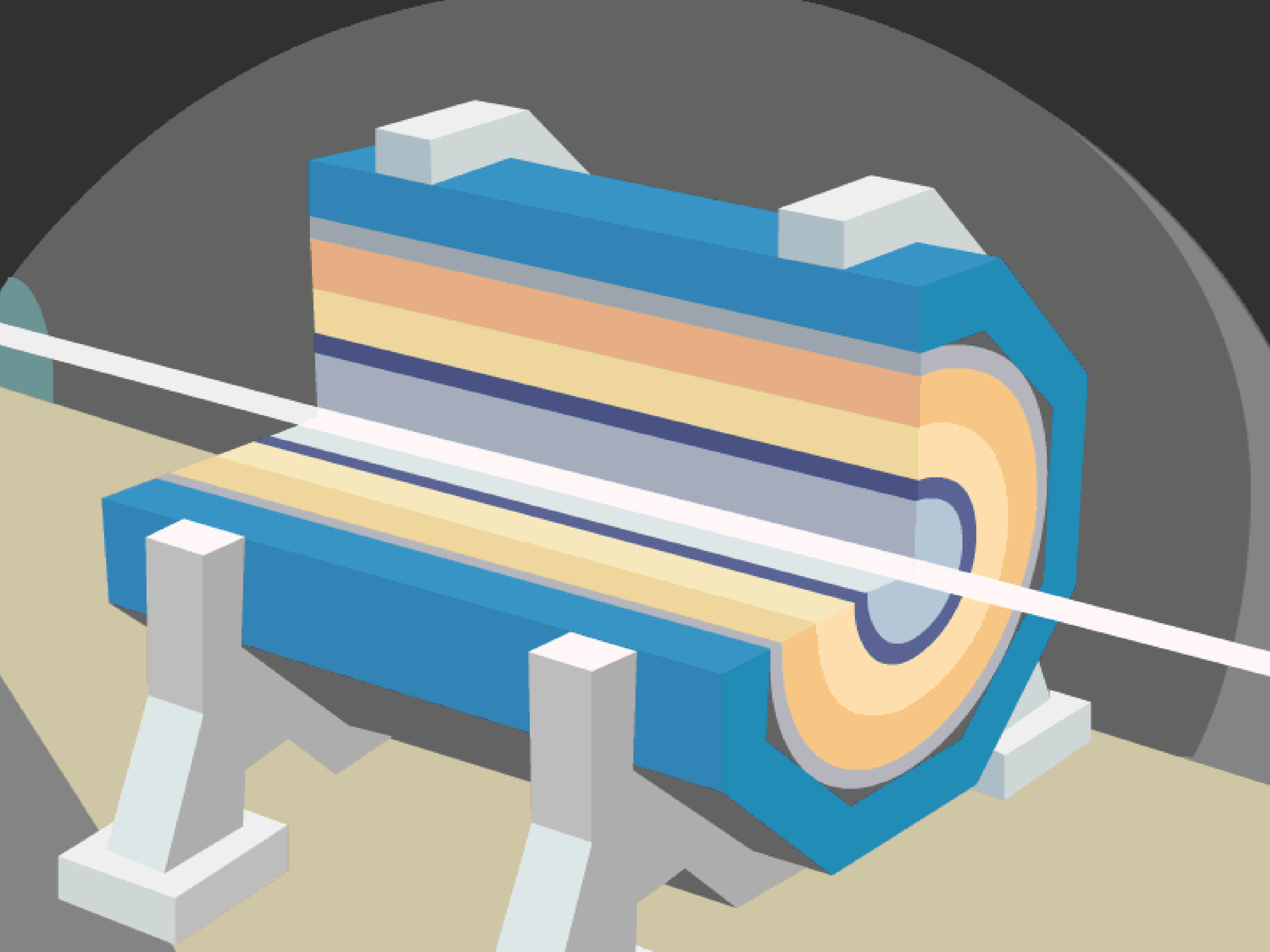
Primary targets:
- Origin of mass
- Nature of Dark Matter
- Primordial Plasma
- Matter vs Antimatter

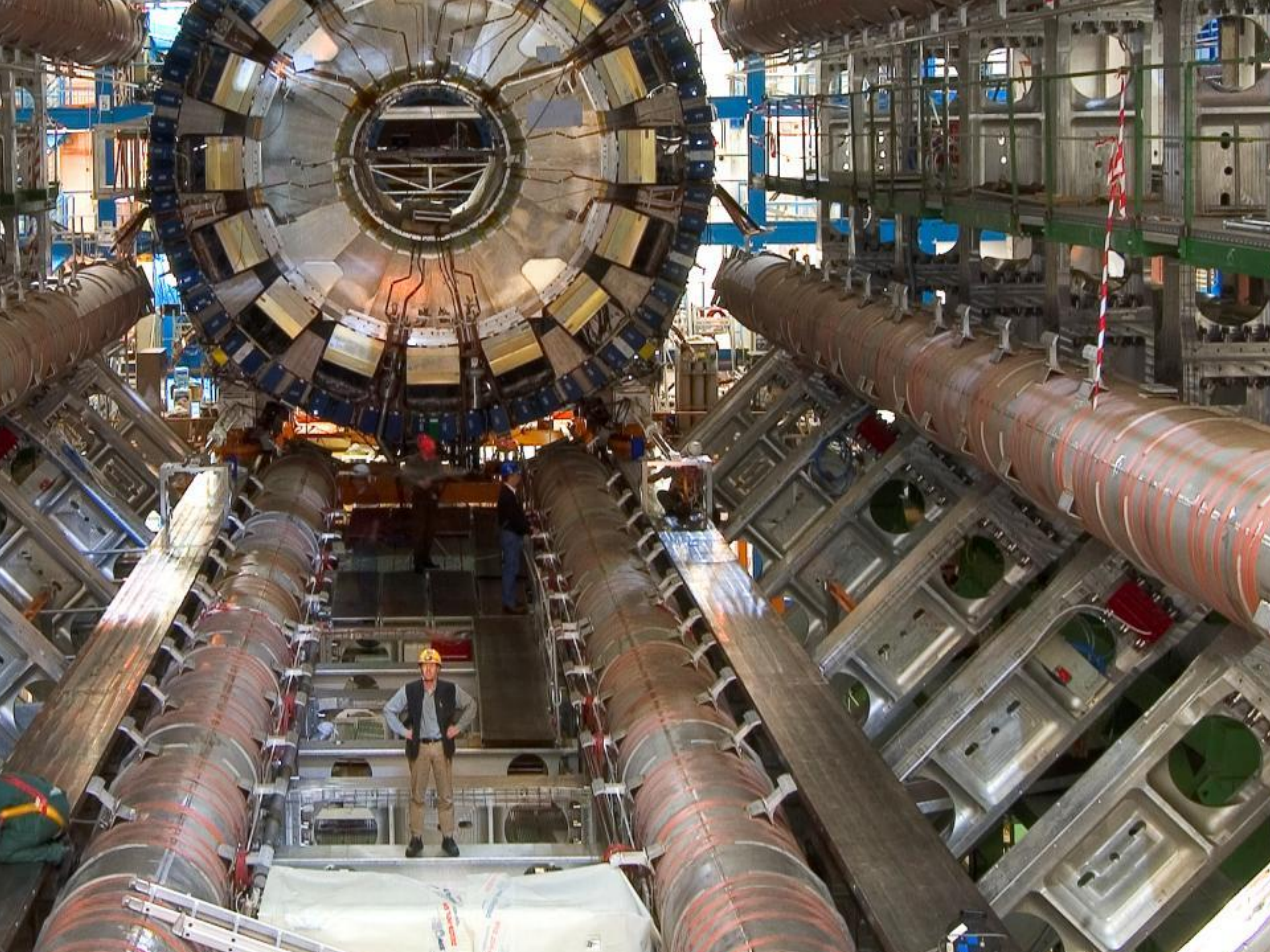
HL- LHC
L x 2, L x 5…L x 10?

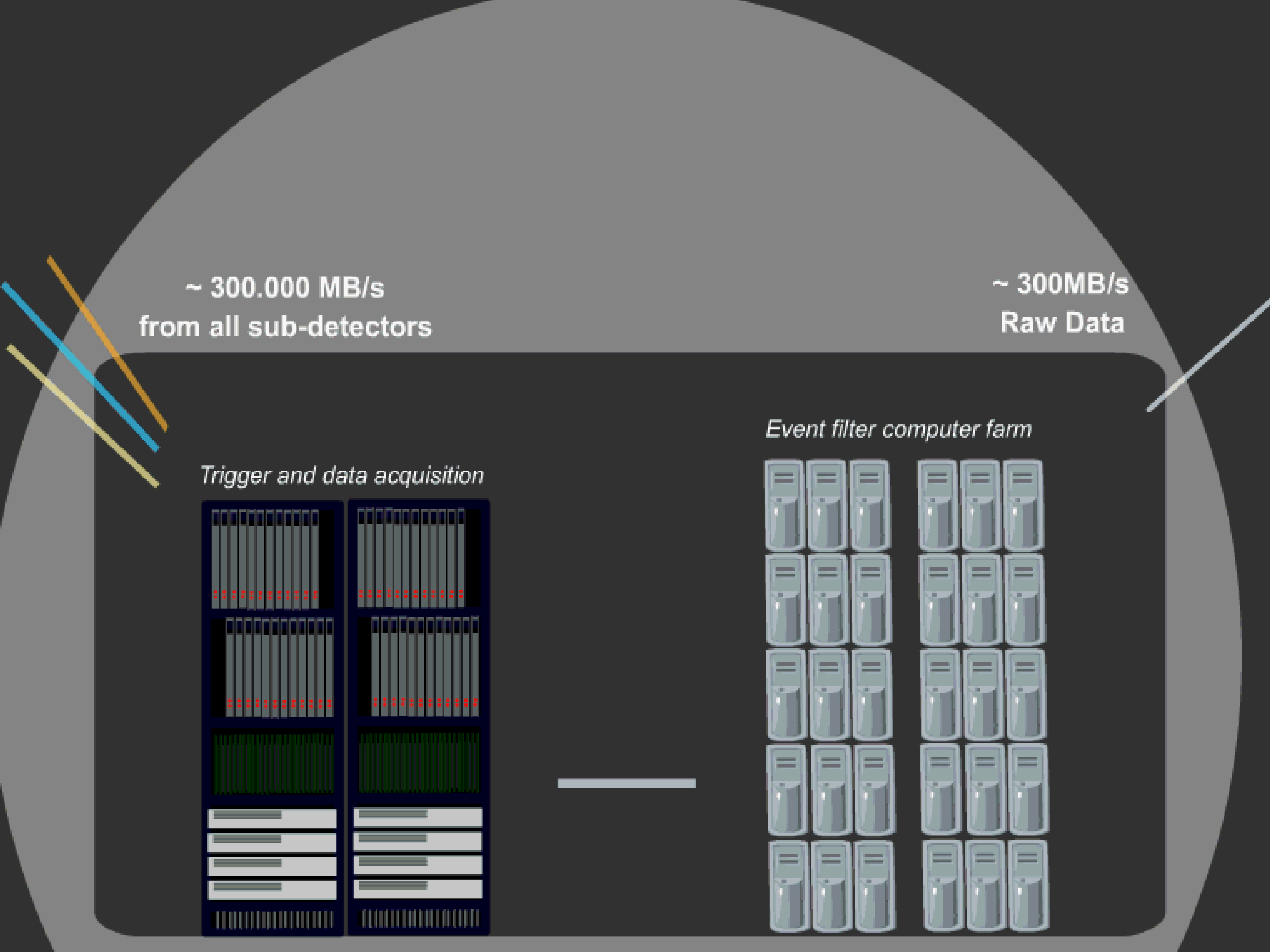
Large Hadron Collider

Collision of proton beams… …observed in giant detectors



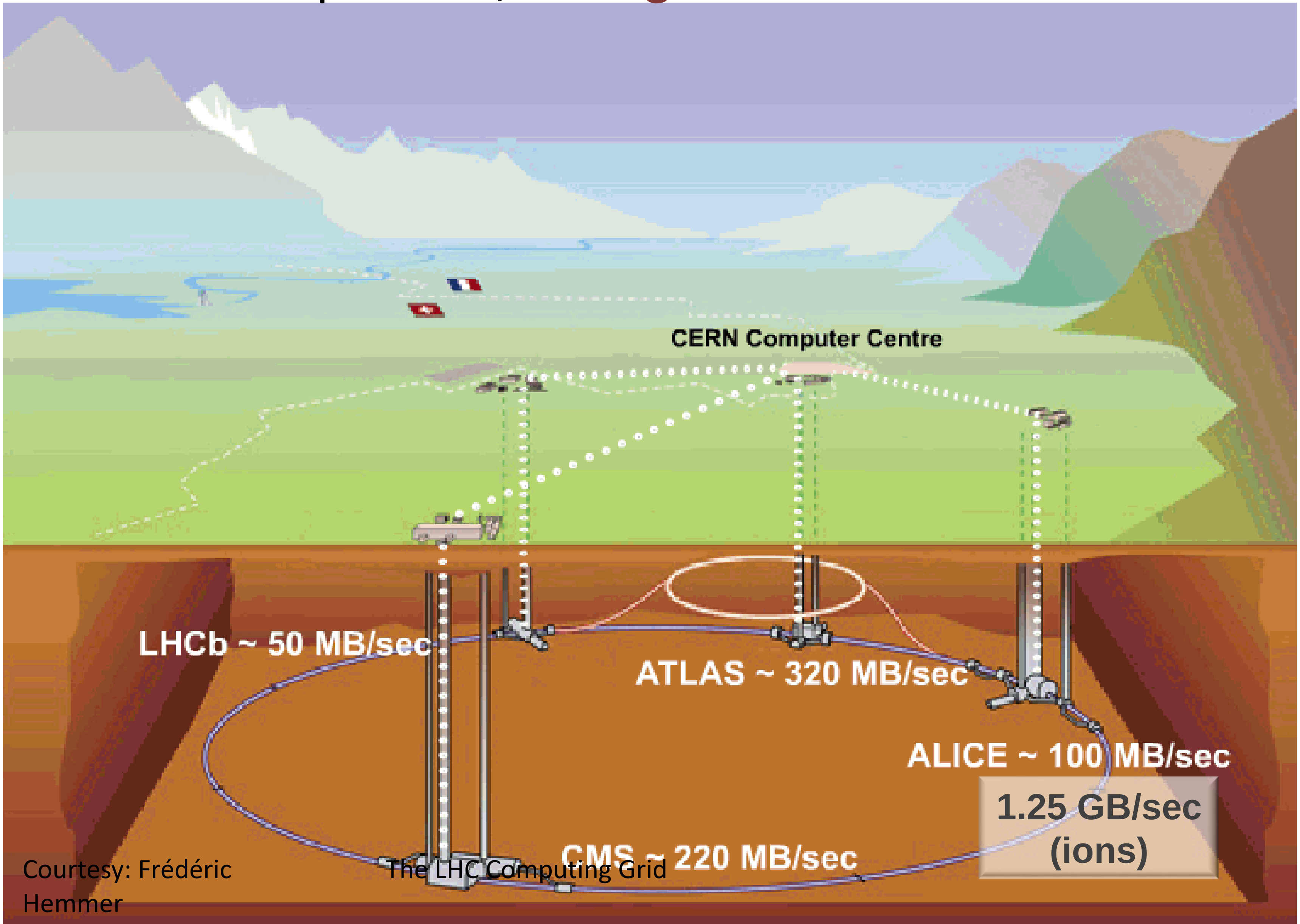





~ 300.000 MB/s
from all sub-detectors
~ 300MB/s
Raw Data
Event filter computer farm
Trigger and data acquisition

CERN Computer Centre

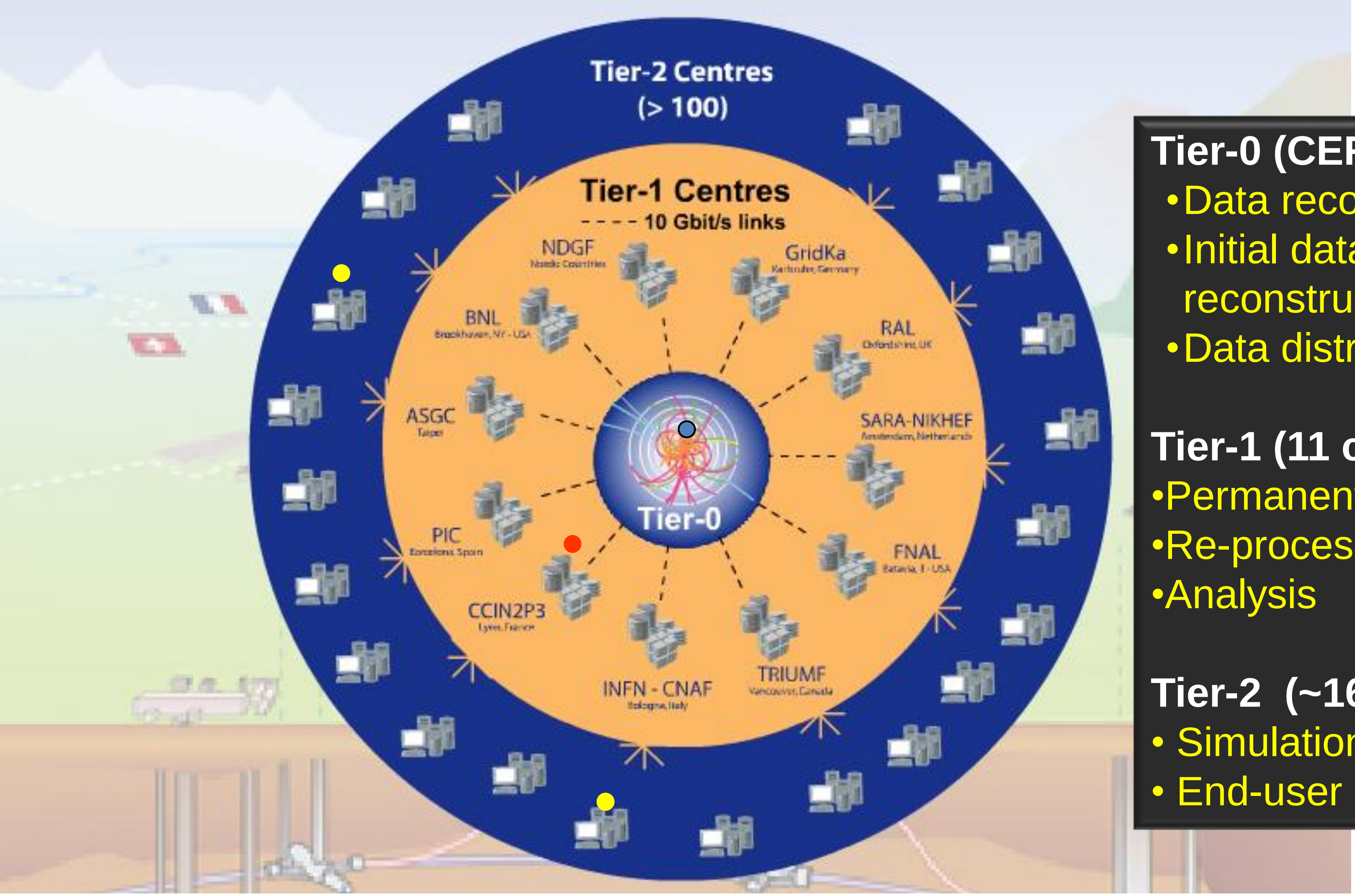
Acquisition, Storage & Distribution of Data



Courtesy: Frédéric Hemmer

The Worldwide LHC Computing Grid

An International Collaboration to distribute and analyse LHC data



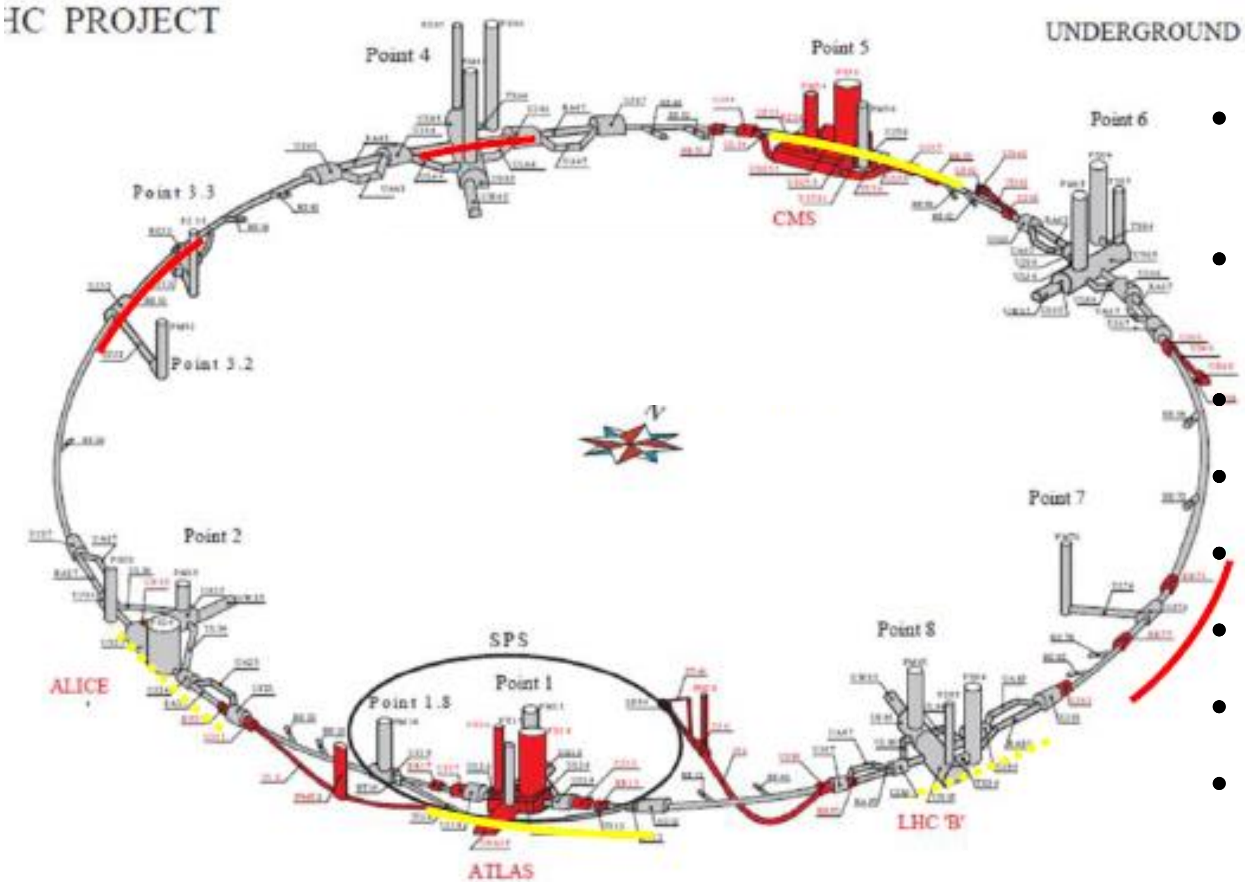
Tier-0 (CERN):
- Data recording
- Initial data reconstruction
- Data distribution

Tier-1 (11 centres):
- Permanent storage
- Re-processing
- Analysis

Tier-2 (~160 centres):
- Simulation
- End-user analysis

Courtesy: CERN IT Department

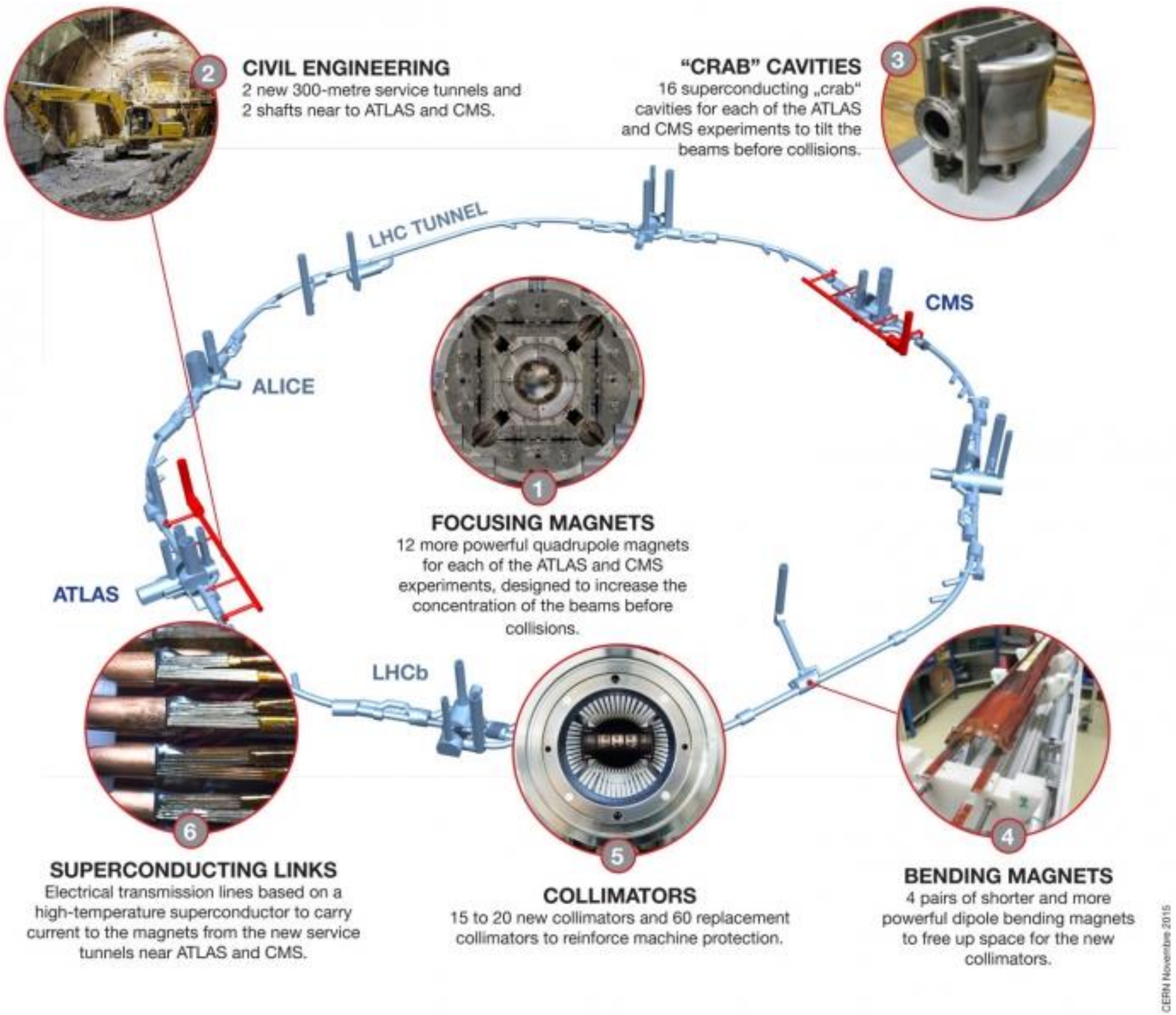
The HL-LHC Project



- New IR-quads (inner triplets)
- New 11 T Nb_3Sn (short) dipoles
- Collimation upgrade
- Cryogenics upgrade
- Crab Cavities
- Cold powering
- Machine protection
- …

Major interventions on more than 1.2 km of the LHC

Technological Challenges



HL-LHC Industry

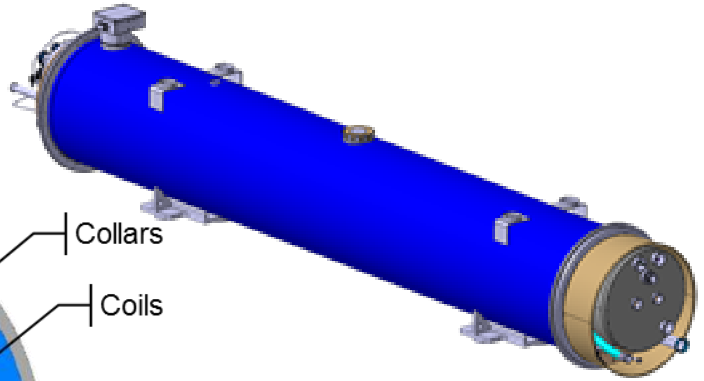
Industry Relations and Procurement Website for the HL-LHC project

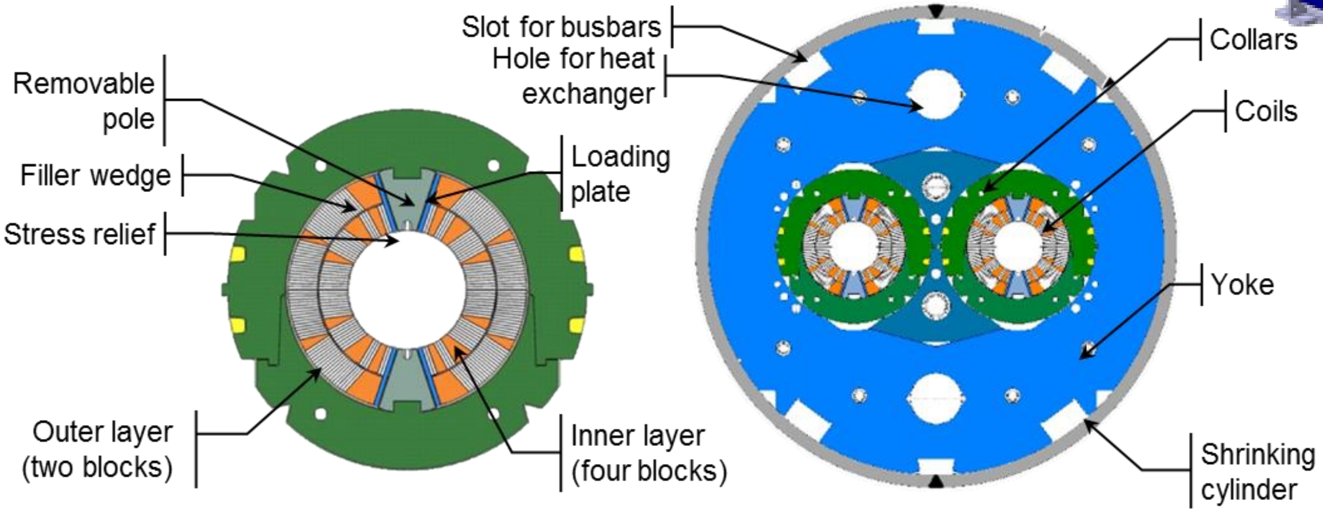
WP11 - 11T Dipole

Technologies: Magnets components and assemblies, Cryostats and subcomponents for cryogenic equipment, High precision assembling and manufacturing technologies, Raw materials

Main Materials: Composite materials, Copper, Iron, Low Carbon Steel, **Nb3Sn, Nb-Ti**, Stainless Steel

Key external factors: 1.9K, Radiation





Discovery 2012, Nobel Prize in Physics 2013

The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs *"for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider".*

Beyond LHC… what further global physics PROJECT?

- **Higgs “factory” e+e-**

Design Energy 2x175 GeV

(or better 2x250 GeV)

- **Future hadron colliders ?**
- **……………………………………**
- **Other ideas…?**

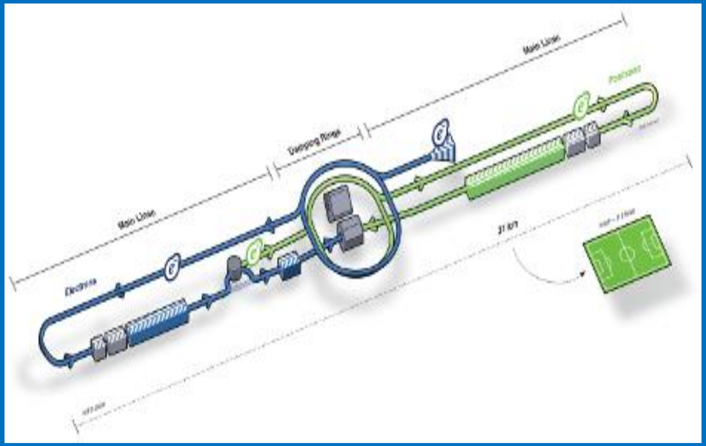
LHC… and what further? Future colliders will be still larger?!!

- **Higgs "factory" :**

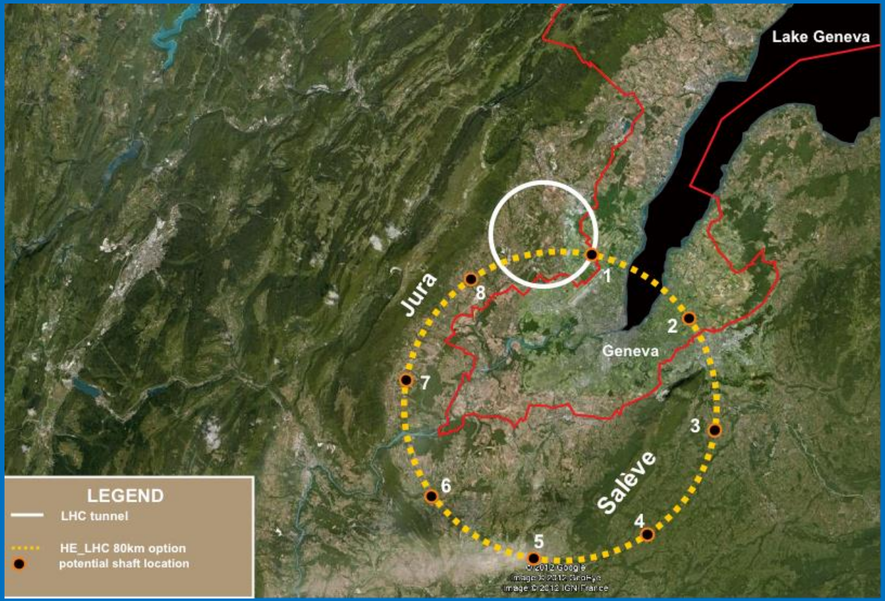
 - Linear or Circular e+/e- ?

 - Or, perhaps, Muon Collider
 could be much smaller!?

- Or…??



30-50 km International Linear Collider
15-50 km Compact Linear Collider

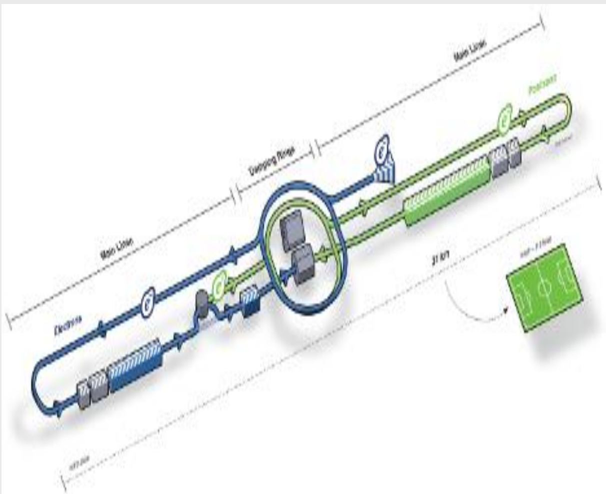


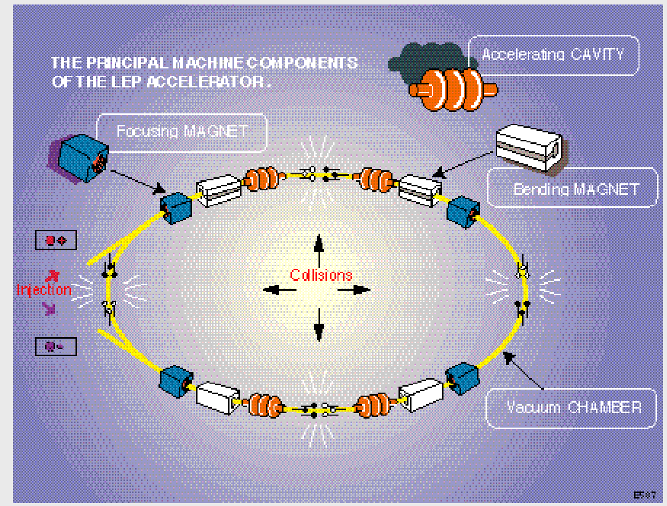
80-100 km FCC – Future Circular Collider (CERN)

But why these accelerators must be so big ?? !!...

Particle Physics Accelerator Experiments

Linear and Circular Colliders – Physical and Technological Limitations

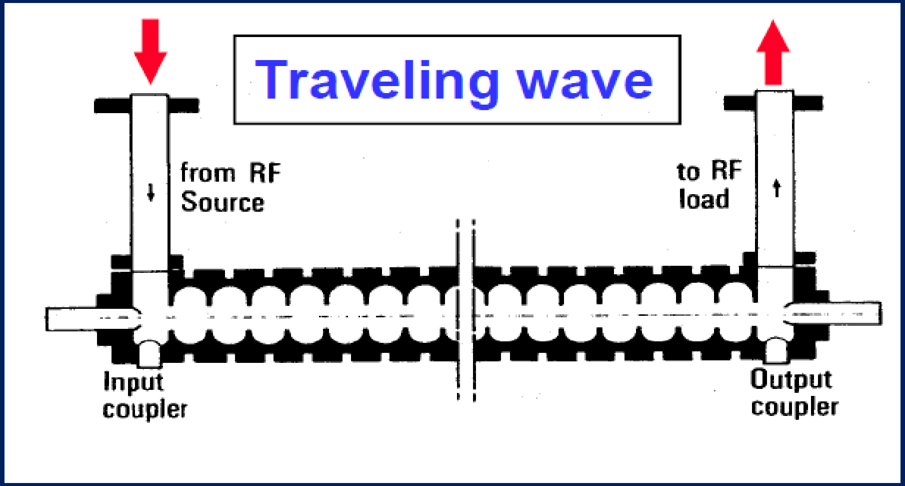


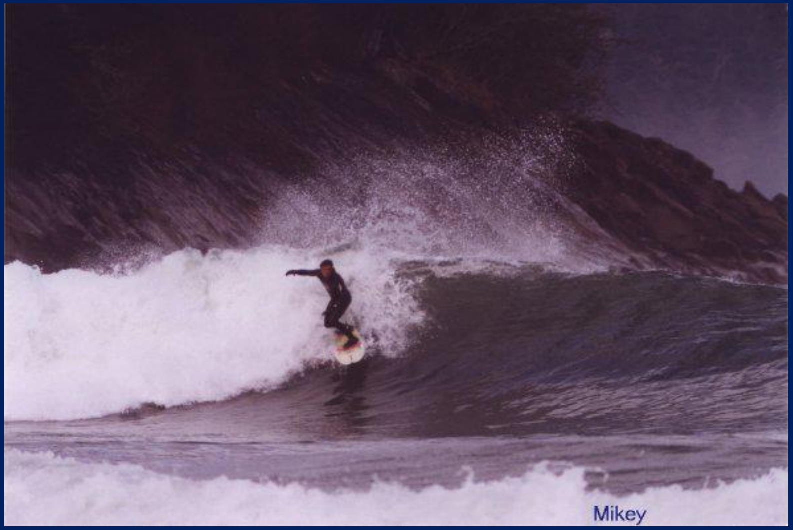


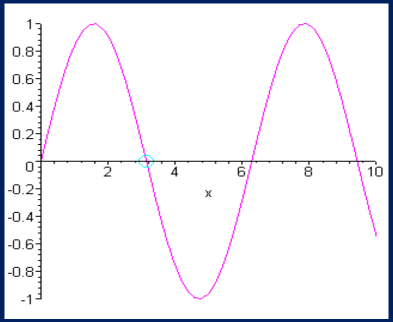
Electrical field developed by accelerating RF Cavities
(E ~ G L)
G = 30 – 100 MV/m

1. Magnetic field to bend and focus particle beams on circular trajectory (E ~ B R), Present limit: B=~10 T
2. Synchrotron radiation energy losses (very high for light particles!). Scales with gamma*4.

ACCELERATING RF CAVITIES

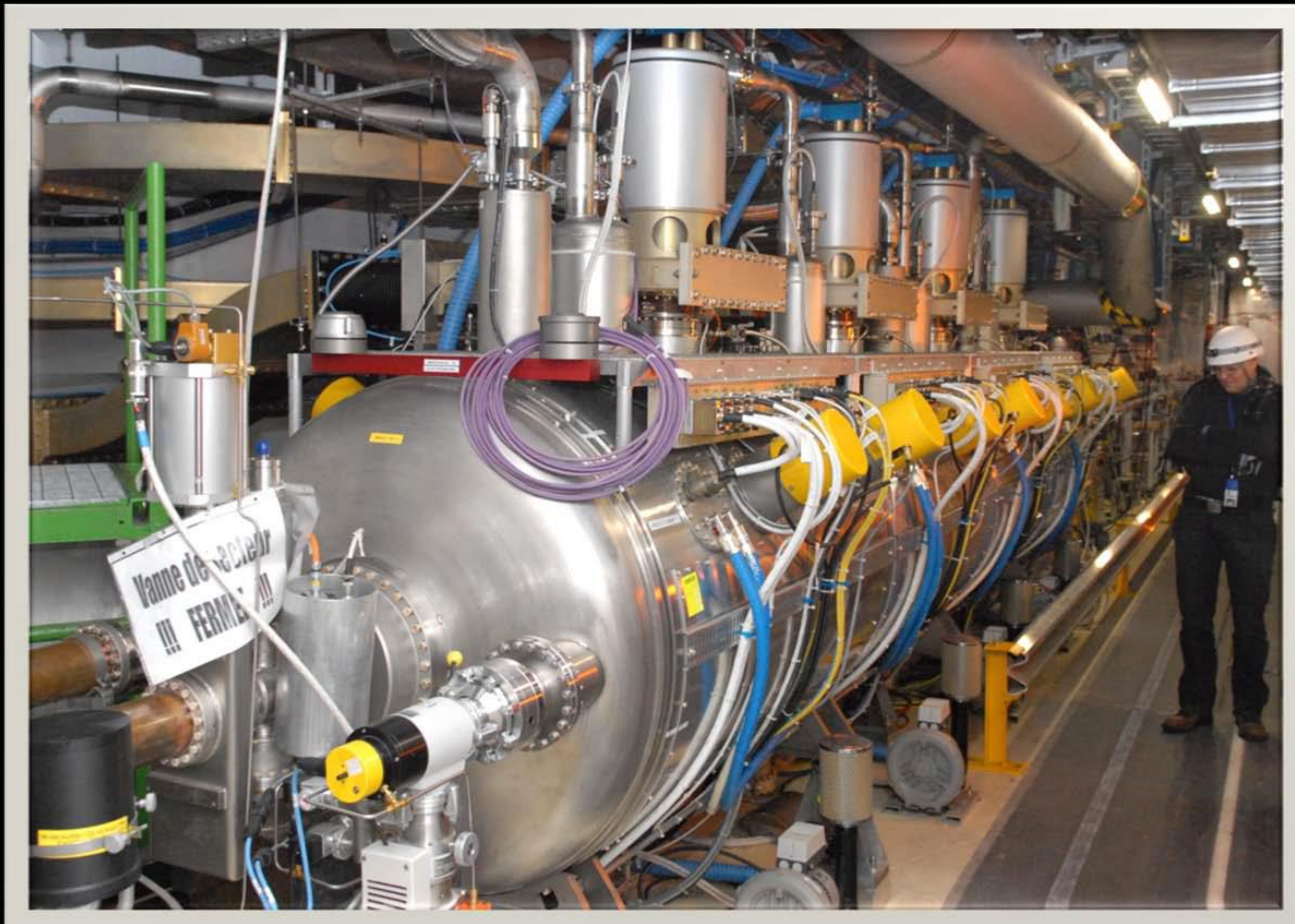






Accelerating gradient
up to 20 -30 MV/m
(superconducting cavities)

SC cavities in a cryostat (CERN LHC 400 MHz)



R&D on **future linear e-e+ colliders**

Competition of two concepts;

Length determined by efficiency (gradient) of RF cavities.

ILC – International Linear Collider, 0.5 TeV, based on Superconducting RF cavities (**gradient 31.5 MV/m**)

1st option Ecm=250 GeV

CLIC – Compact Linear Collider, developed by CLIC Collaboration (CERN), **0.5 -3 TeV** , based on warm RF cavities at 12 GHz with very high el. **gradient ~ 100 MV/m** .

1st option Ecm=380 GeV

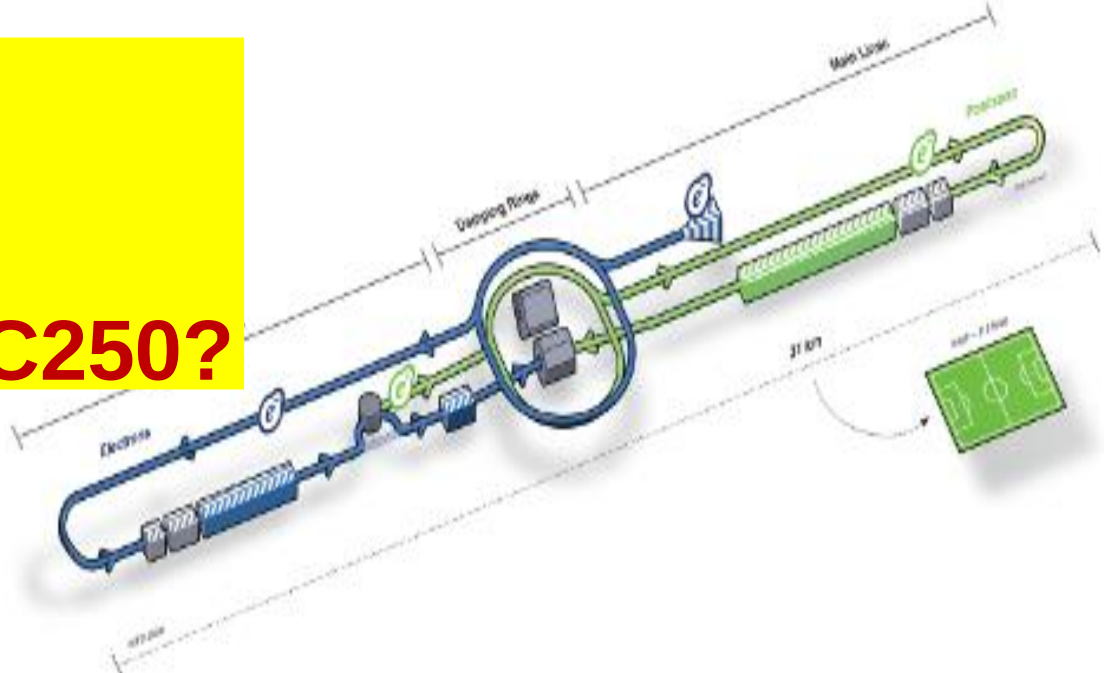
Competition but also cooperation CLIC + ILC :

Linear Collider Collaboration

ILC-International Linear Collider

If ILC, so where?

Japan?
..and first ILC250?



- **Collisions:** Between electrons <>positrons, in bunches of 5 nm
- **Energy: Up to 0.5 TeV with an option to upgrade to 1 TeV**
- **Acceleration Technology:** 16,000 superconducting accelerating cavities made of pure niobium
- **Length: Approximately 31 kilometres**
- **Accelerating Gradient:** 31.5 megavolts per metre

1.3 GHz Superconducting Cavities for ILC

- Gradient 31.5 MeV/m, restricted by quality of forming and welding techniques (surface roughness, impurities….) of bulk niobium

LINEAR COLLIDER COLLABORATION

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LC NEWSLINE

THE NEWSLETTER OF THE LINEAR COLLIDER COMMUNITY

4 OCTOBER 2018

CURRENT ISSUE
4 OCTOBER 2018

Getting lots of heads round the test beam data

LCWS2018: preparing for ILC realisation

The ILC Supporters – celebrities for the linear collider

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PREPRINTS

ARXIV PREPRINTS

1809.03520
Probing top-quark couplings indirectly at Higgs factories

1809.00285
CEPC Conceptual Design Report

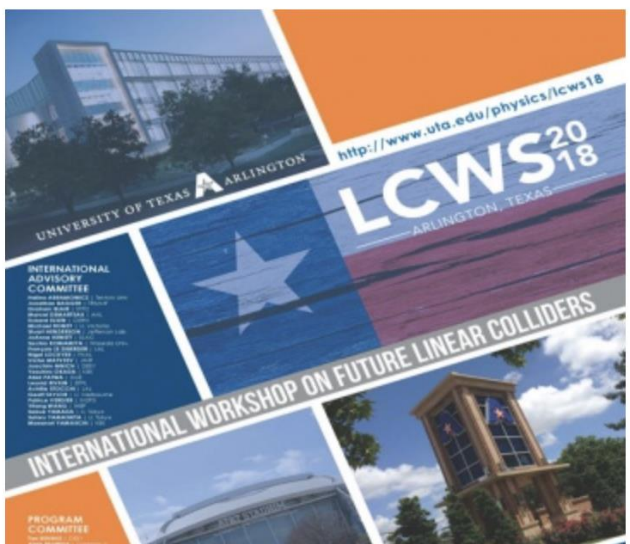
1808.09281
A highly granular SiPM-on-tile calorimeter prototype

1808.06209

DIRECTOR'S CORNER

LCWS2018: preparing for ILC realisation

by Jim Brau



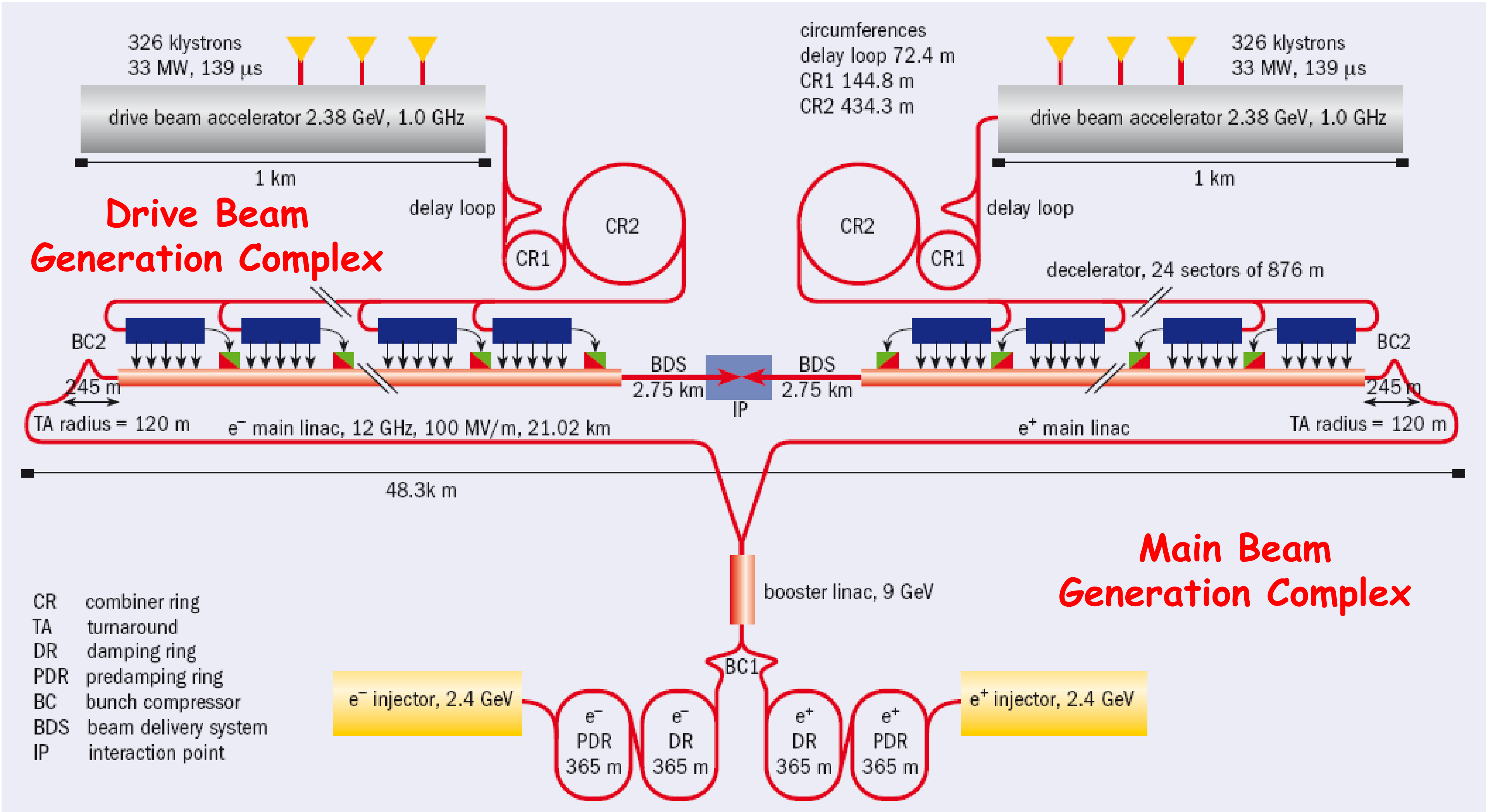
FEATURE

Nobel laureates speak for the ILC

by Rika Takahashi

Four Nobel laureates in Physics Sheldon Glashow, Barry Barish, Masatoshi Koshiba and Yoshinori Osumi publicly support the ILC project in a symposium held at the University of Tokyo last August. The ILC is “absolutely essential,” they said, and not just for particle physics.

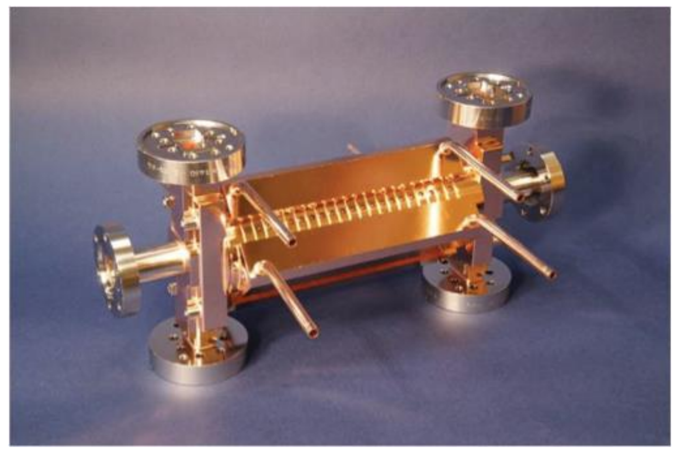
CLIC - Layout @ 3 TeV (not to scale)



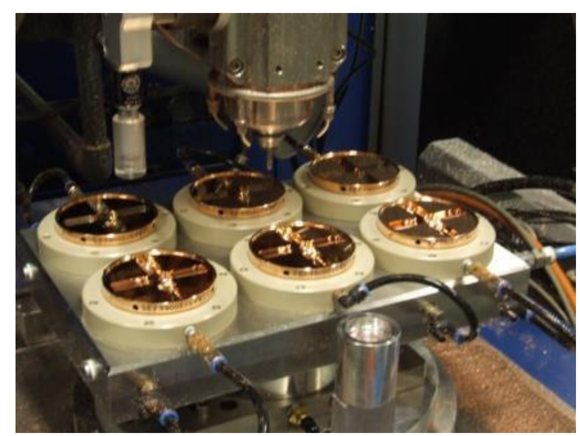
Courtesy of JP Delahaye

12 GHz Normal Conducting Cavities for CLIC

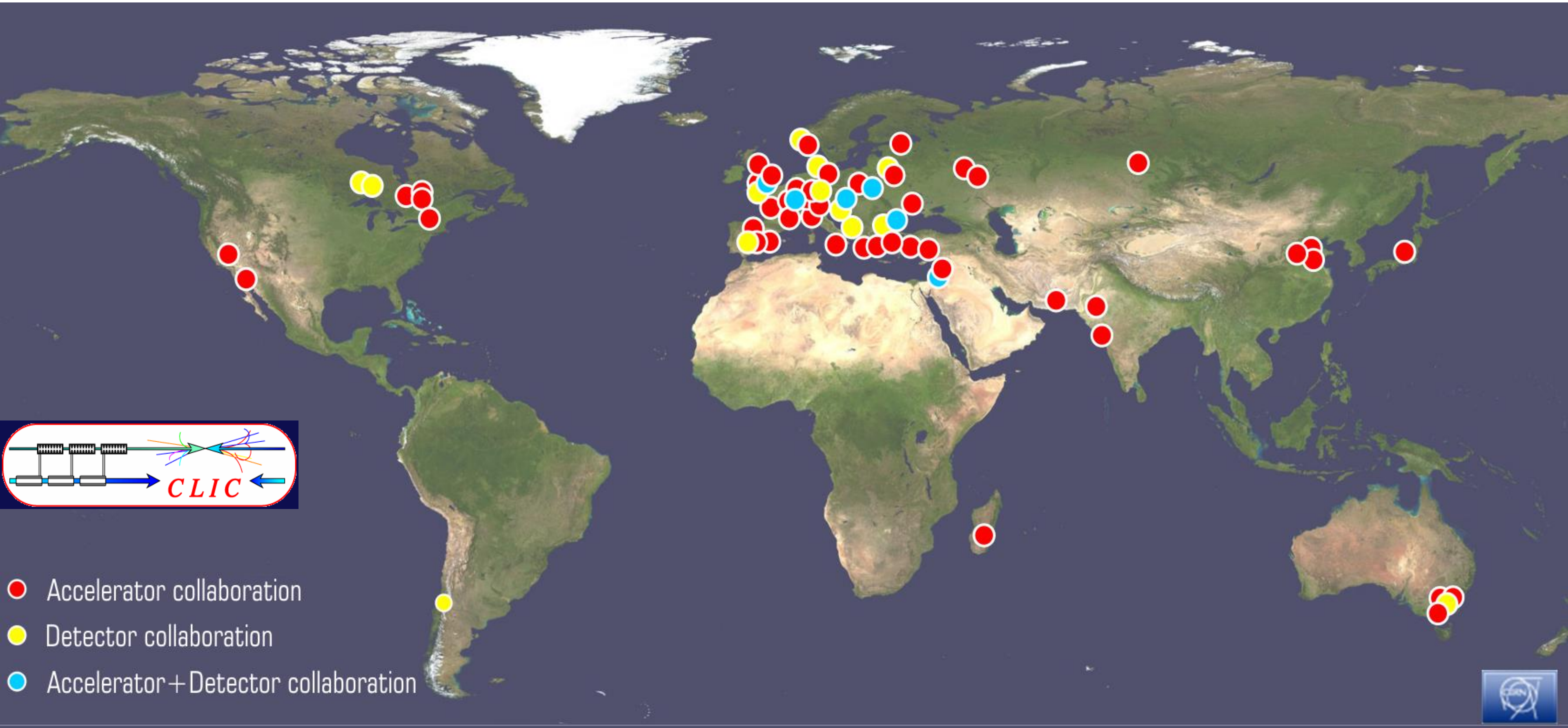
- Gradient 100 MeV/m, restricted by RF breakdowns,
- High quality copper material,
- Require micron precision turning and milling, e.g. High-speed diamond machining
- Require very rigorous brazing



Development done "in industry"



World-wide CLIC / CTF3 collaboration

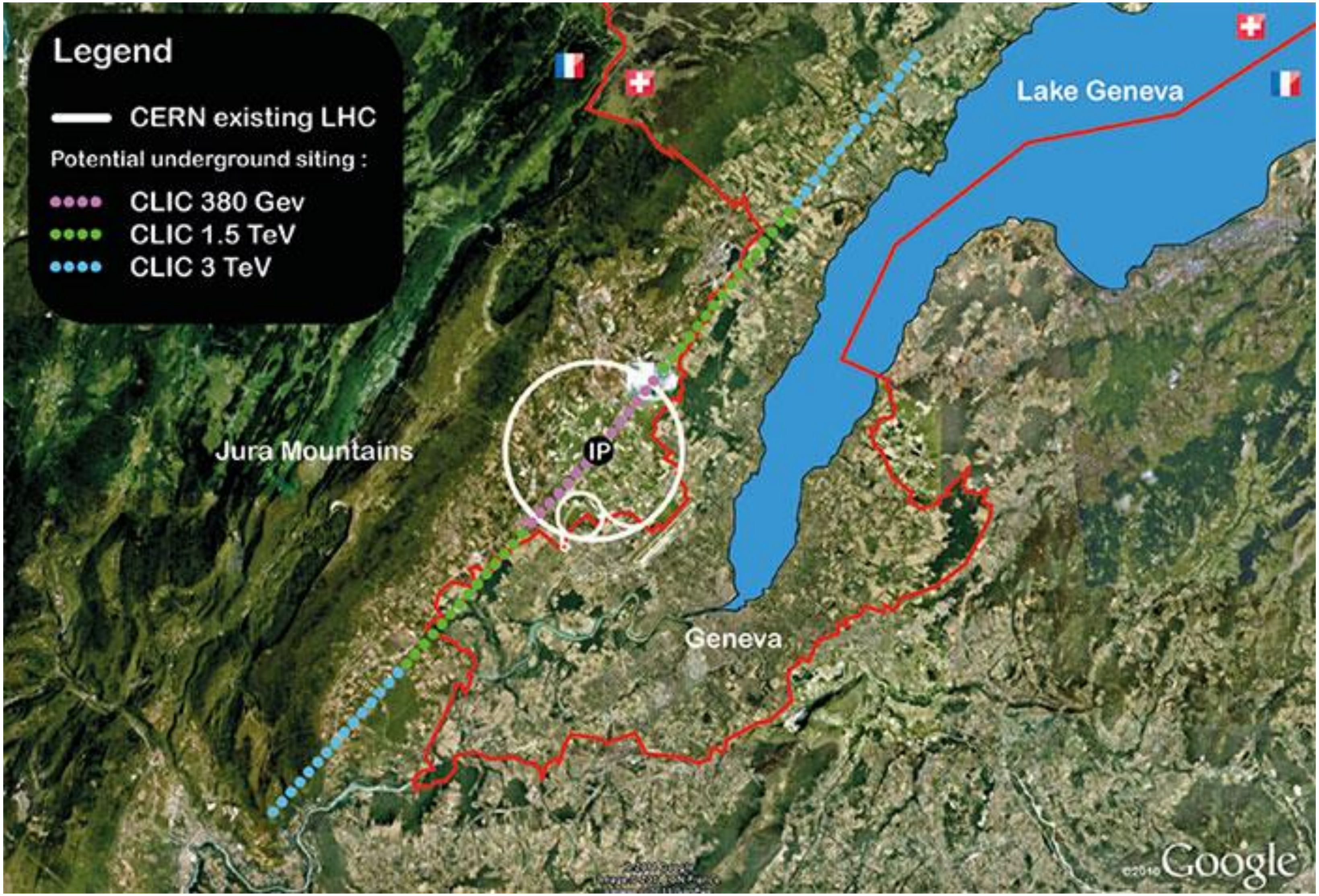


Compact Linear Collider (CLIC): CERN

Staged Option

e−e+, √s: 380 GeV, 1.5 TeV, 3 TeV

Length: 11 km, 29 km , 50 km



2013 - 2019 Development Phase

Development of a Project Plan for a staged CLIC implementation in line with LHC results; technical developments with industry, performance studies for accelerator parts and systems, detector technology demonstrators

2020 - 2025 Preparation Phase

Finalisation of implementation parameters, preparation for industrial procurement, Drive Beam Facility and other system verifications, Technical Proposal of the experiment, site authorisation

2026 - 2034 Construction Phase

Construction of the first CLIC accelerator stage compatible with implementation of further stages; construction of the experiment; hardware commissioning

2019 - 2020 Decisions

Update of the European Strategy for Particle Physics; decision towards a next CERN project at the energy frontier (e.g. CLIC, FCC)

2025 Construction Start

Ready for construction; start of excavations

2035 First Beams

Getting ready for data taking by the time the LHC programme reaches completion

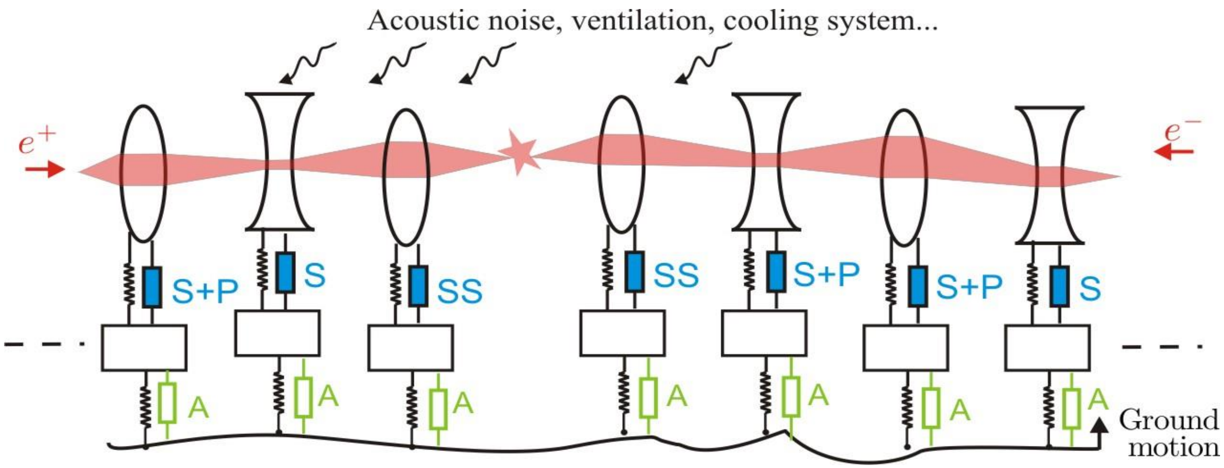
Linear e-e+ colliders
One more challenge - precise positioning and stabilization !

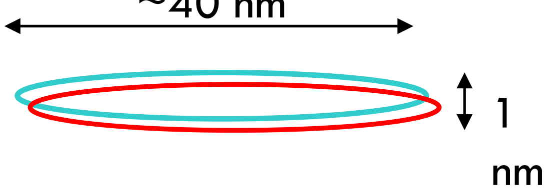
Extremely high accuracy of positioning and stabilization needed to the accuracy of nanometres against mechanical and "white noise" type seismic disturbances.

Active vibration isolation systems are therefore intensively studied and tested, e.g. for the Compact Linear Collider (CLIC) developed at CERN, with quite encouraging results.

Ground motion and luminosity

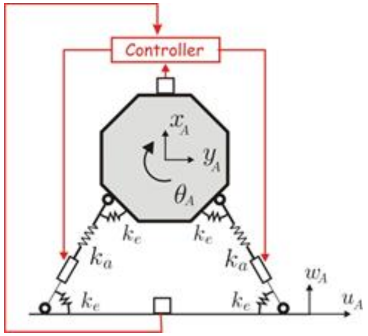
Active stabilisation strategy





Vibrations of the focusing elements have a significant effect on the luminosity and must be reduced !

Stiff parallel structure with inclined piezo actuators and flexural joints



Absolute vibrations are measured with inertial reference masses (*seismometers*)

Beyond LHC… what further global physics PROJECT?

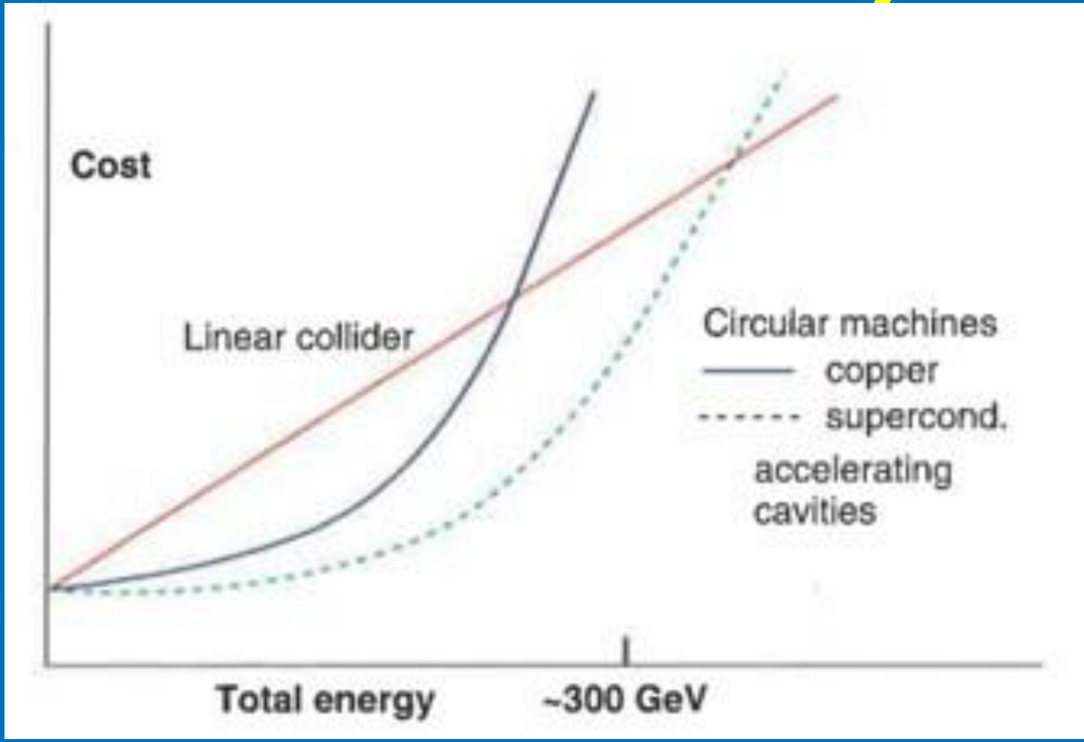
- **Higgs “factory”**

  Perhaps Circular e+/e- will be smaller and “easier”?

Unfortunately no!

Synchrotron Radiation is the main limitation for e+e- circular colliders

Higgs "factory" - cost
Linear or Circular e+/e-?



Reasonable limit for circular e-e+ colliders around 350 MeV ??

Other factors: Operational cost, electrical power necessary - for LHC 150 MW nominal, for future linear or circular colliders > 500 MW !

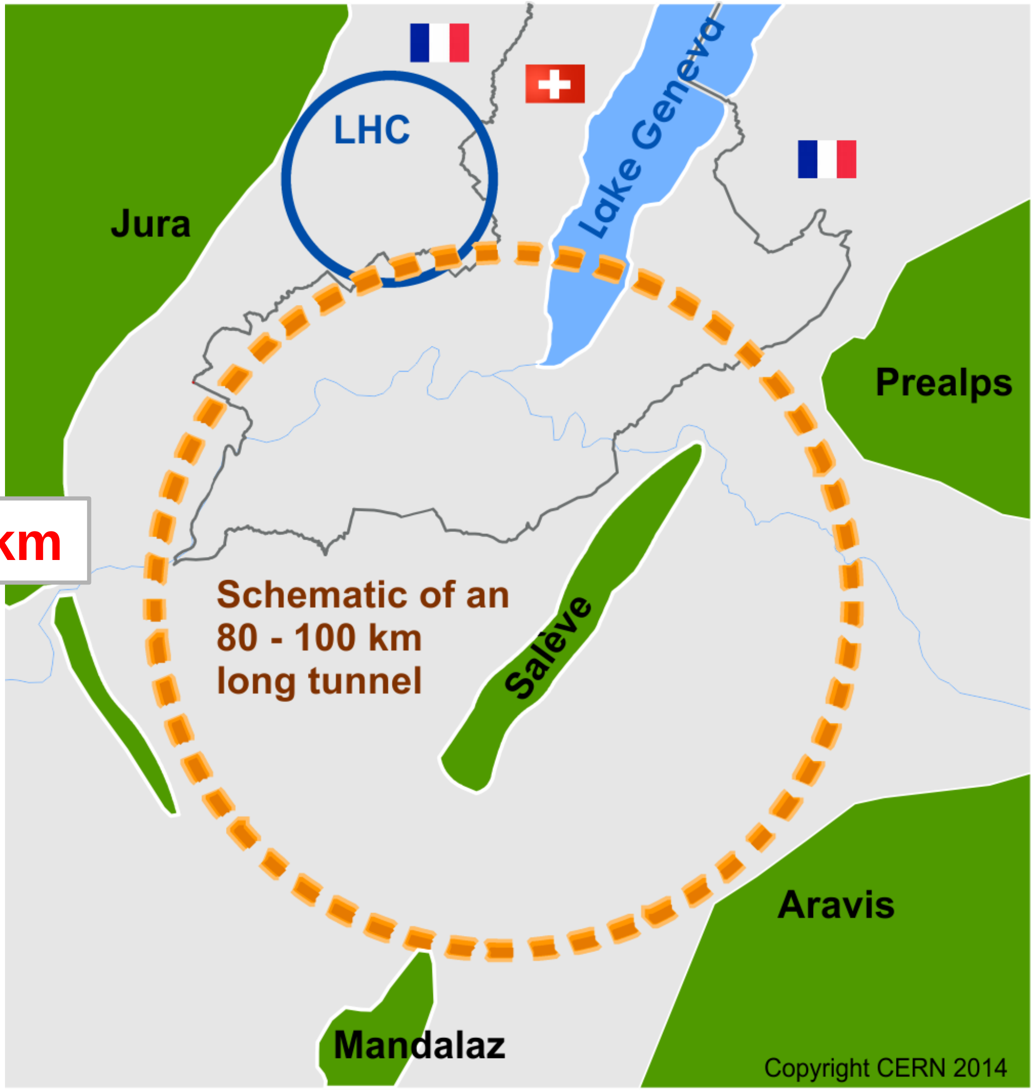
FCC - Future Circular Collider Study
GOAL: CDR and cost review in 2018

international FCC collaboration to study:

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

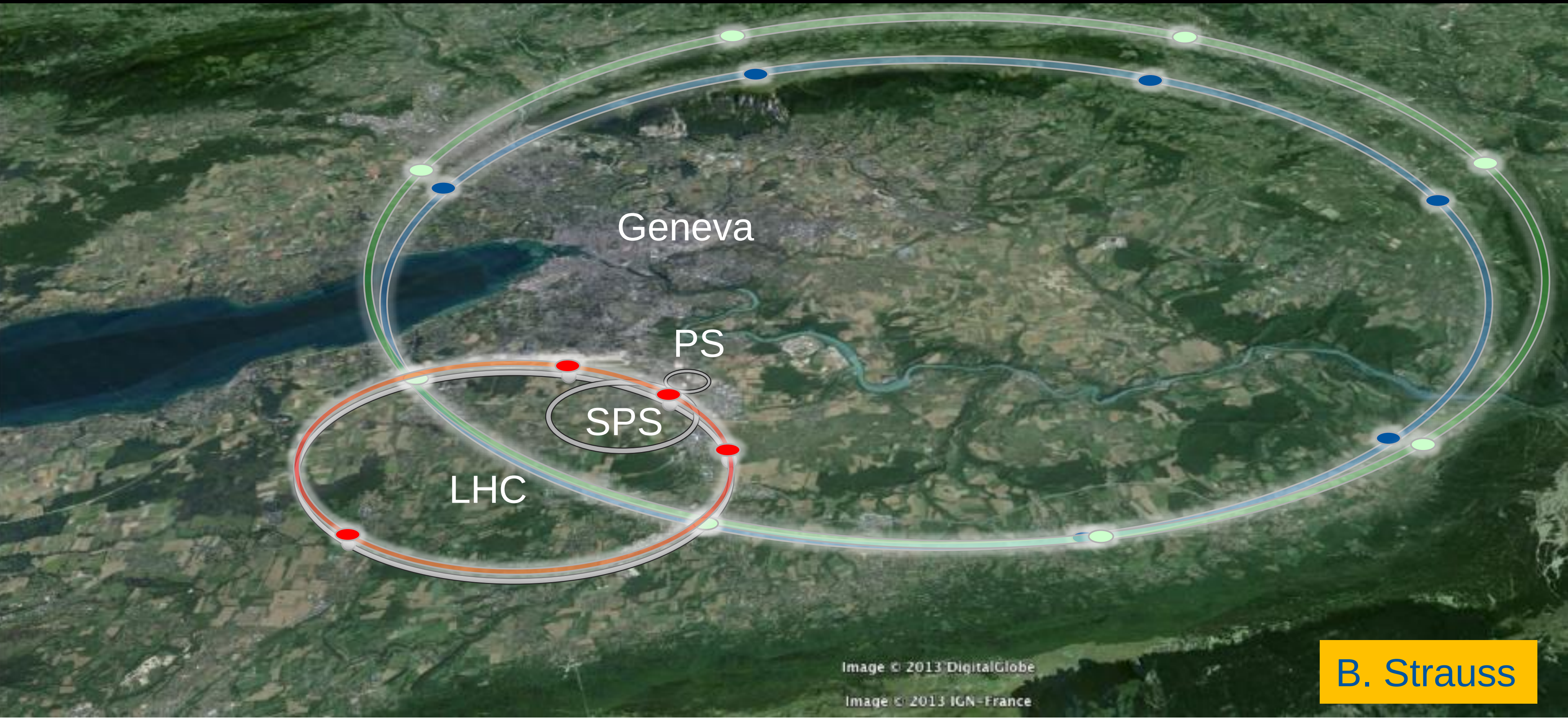
Ecm= 2 x 50=100 TeV *pp* in 100 km

- **80-100 km infrastructure** in Geneva area
- ***e⁺e⁻* collider (*FCC-ee*)** as intermediate step
- Ecm=2 x 175 =350 GeV max.

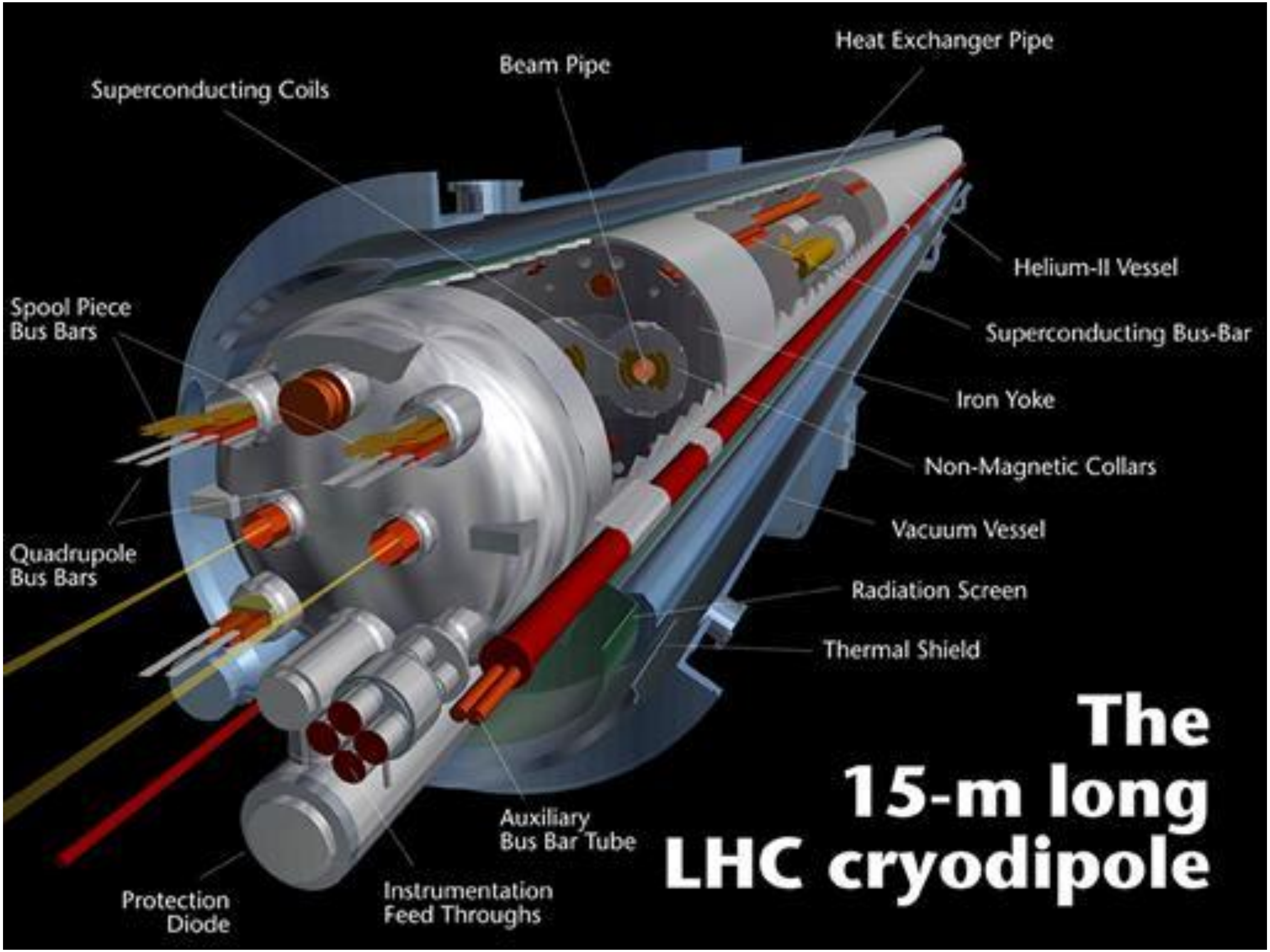


CEPC-Circular Electron Positron Collider study
(CAS-IHEP) 50-70 km
Base: e^+e^- collisions Ecm=240-250 GeV~2028;
Further option: pp collisions Ecm 50-70 TeV~2042

FCC-hh integration and options



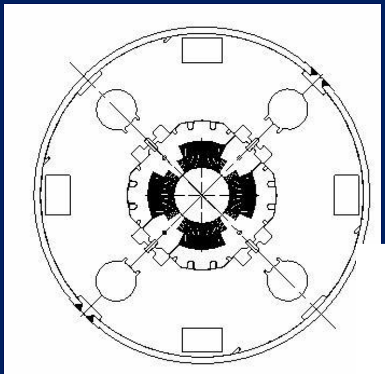
LHC	"HE-LHC"	FCC-hh (alternative)	FCC-hh (baseline)
27 km, 8.33 T	27 km, **20 T**	80 km, **20 T**	100 km, **16 T**
14 TeV (c.m.)	33 TeV (c.m.)	100 TeV (c.m.)	100 TeV (c.m.)

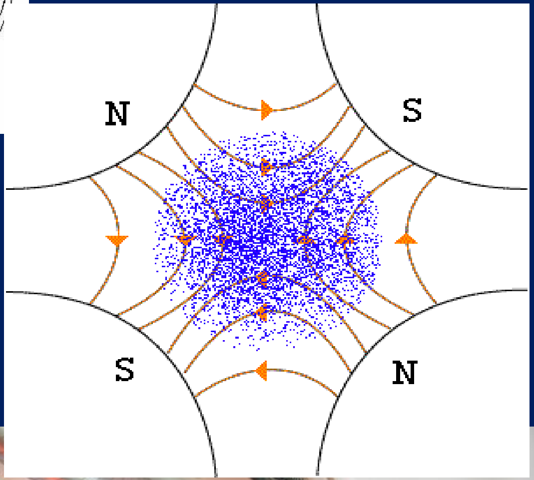


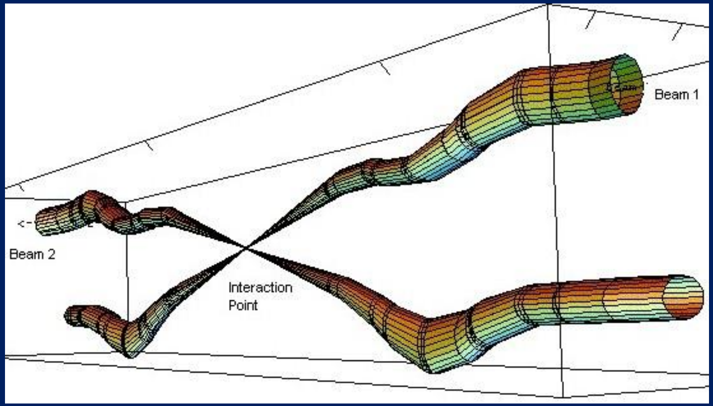
Bmax= 8.33 T, NbTi superconductor

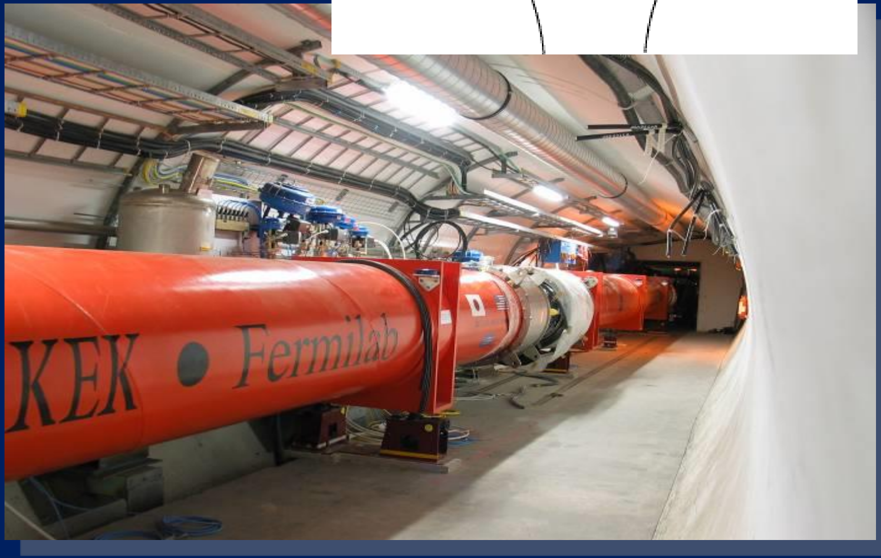
Beam focusing - LHC quadrupoles

- Superconducting
- Length about 3.5 m
- Many types
- Special type in the interaction points
- Other correctors: sextupoles, octupoles, decatupoles







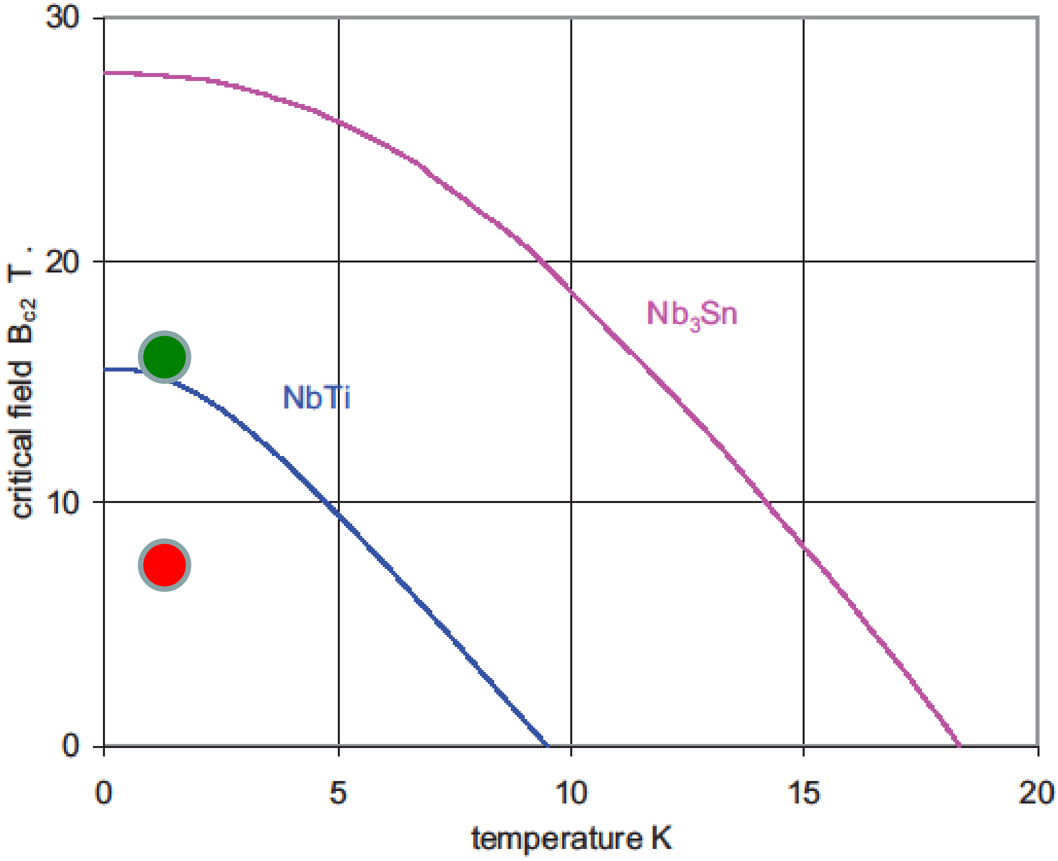


Technology Challenges
LHC and Future proton-proton colliders

New generation of SC magnets for HL-LHC and FCC hh needed!

Intensive R&D going on at CERN on superconductors and magnets based on Nb3Sn (baseline) and HTS.

Critical field & temperature of metallic superconductors

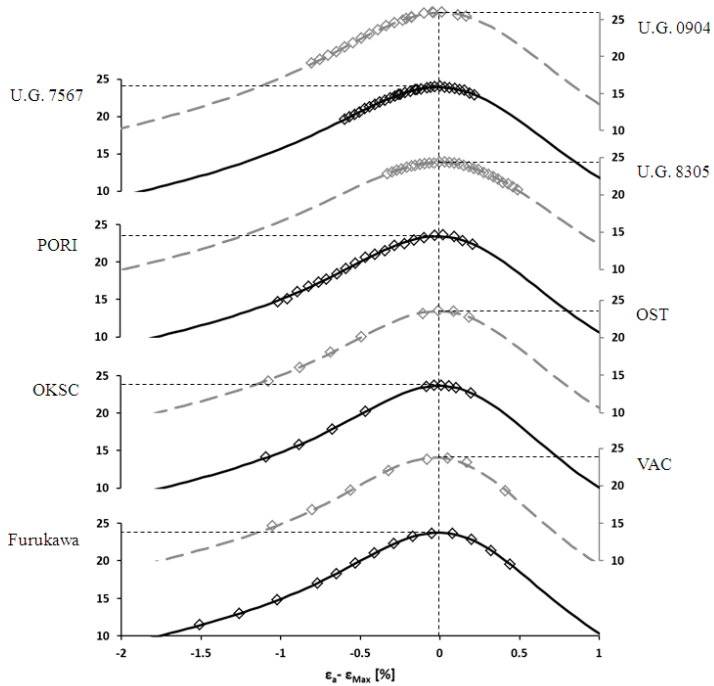


To date, all superconducting accelerators have used NbTi.

Of the intermetallics, only Nb_3Sn has found significant use in magnets

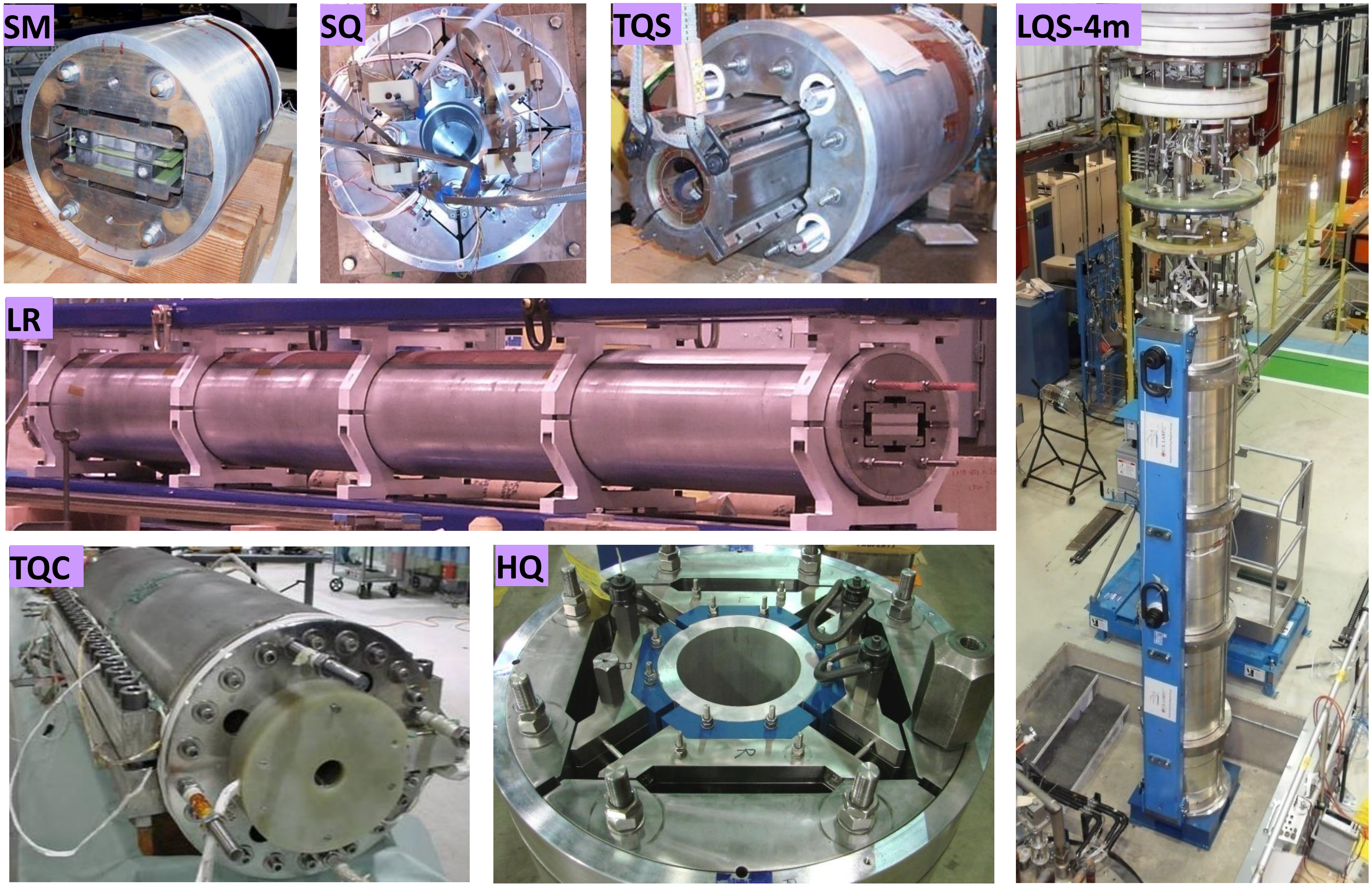
Nb_3Sn superconducting magnets-challenges

- Nb_3Sn is brittle and strain sensitive.
- Special technology of coil manufacturing (wind and react) > Special tooling, processing at high temperature
- Wires and cables exhibit strain degradation under mechanical loads



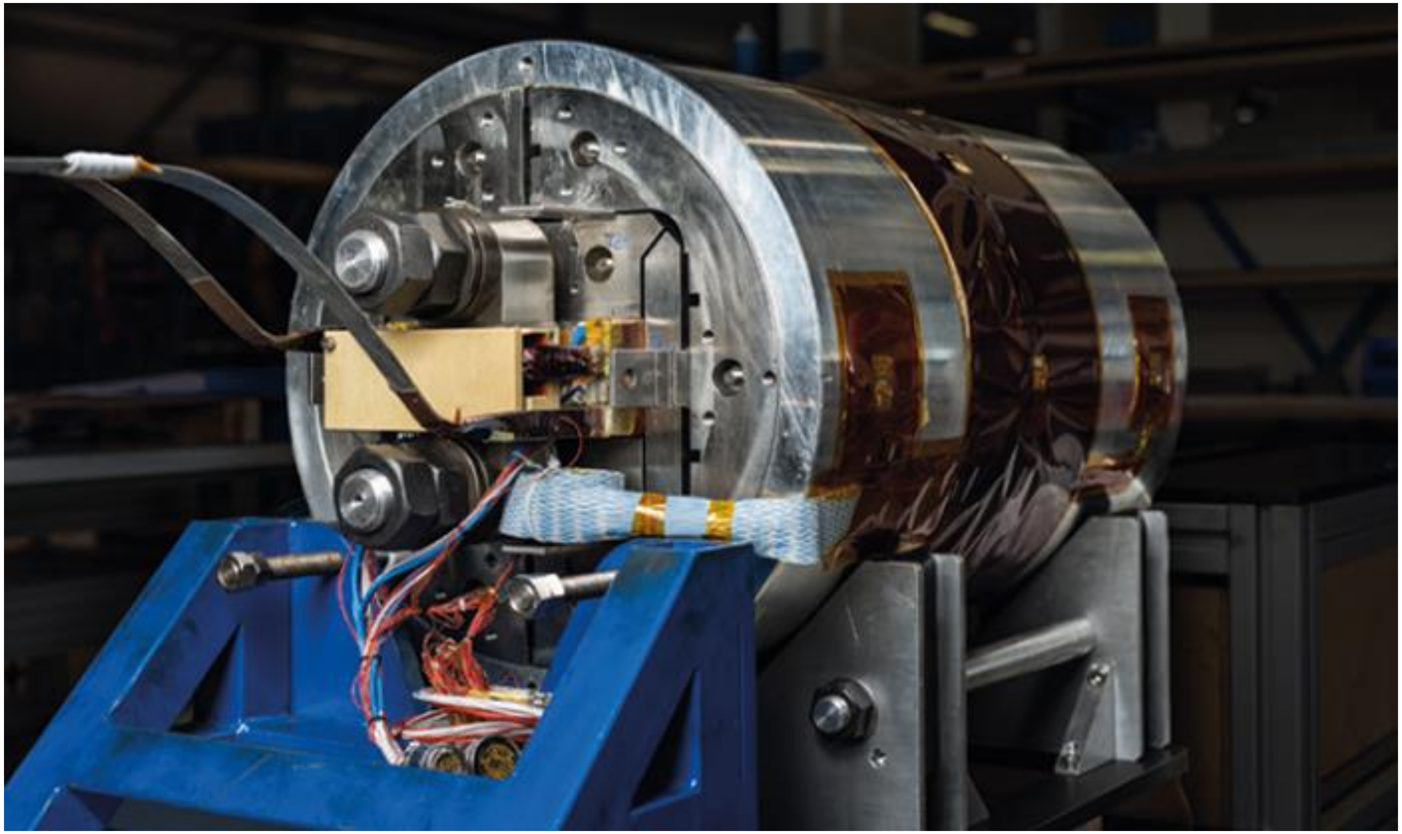
Performance degradation as a function of strain

LARP-CERN: new Nb3Sn magnets



New SC magnets for HL-LHC and and for Future Circular Collider

CERN - RMC_3 test magnet Nb3Sn reaches 16 T (2015)



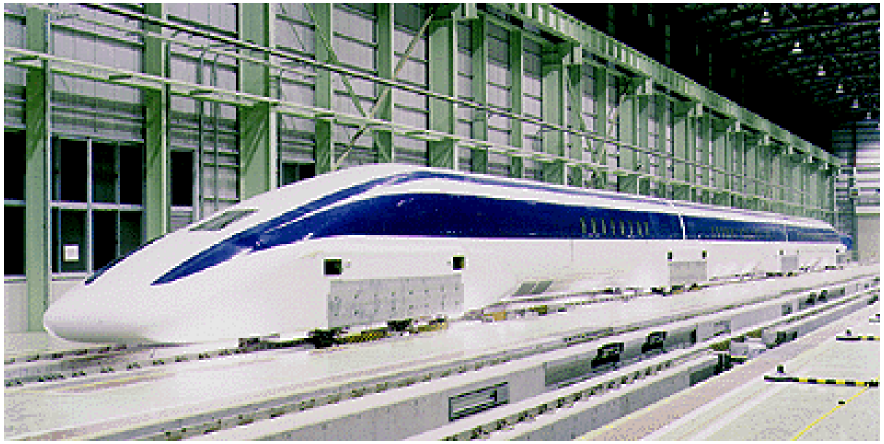
Impact on society
superconductivity and accelerators for health

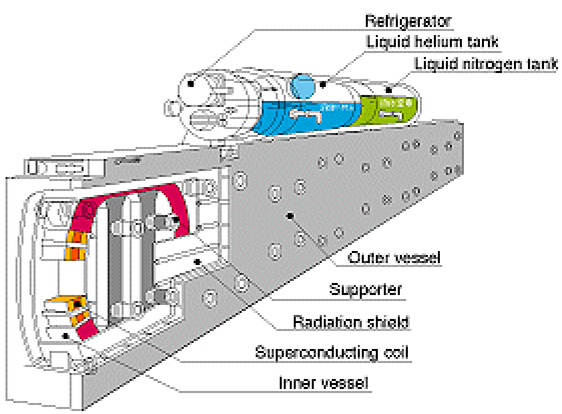
Over 25’000 MRI systems
in operation in the world

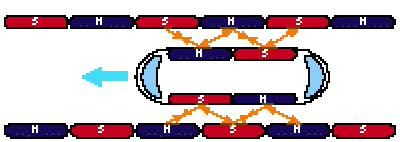
250 MeV superconducting
cyclotron for hadrontherapy

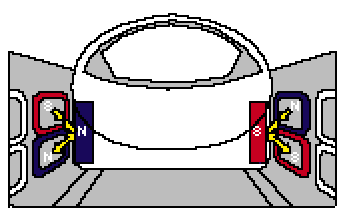
Impact on society

Superconducting MagLev train (603 km/h record – Japanese SCMaglev)



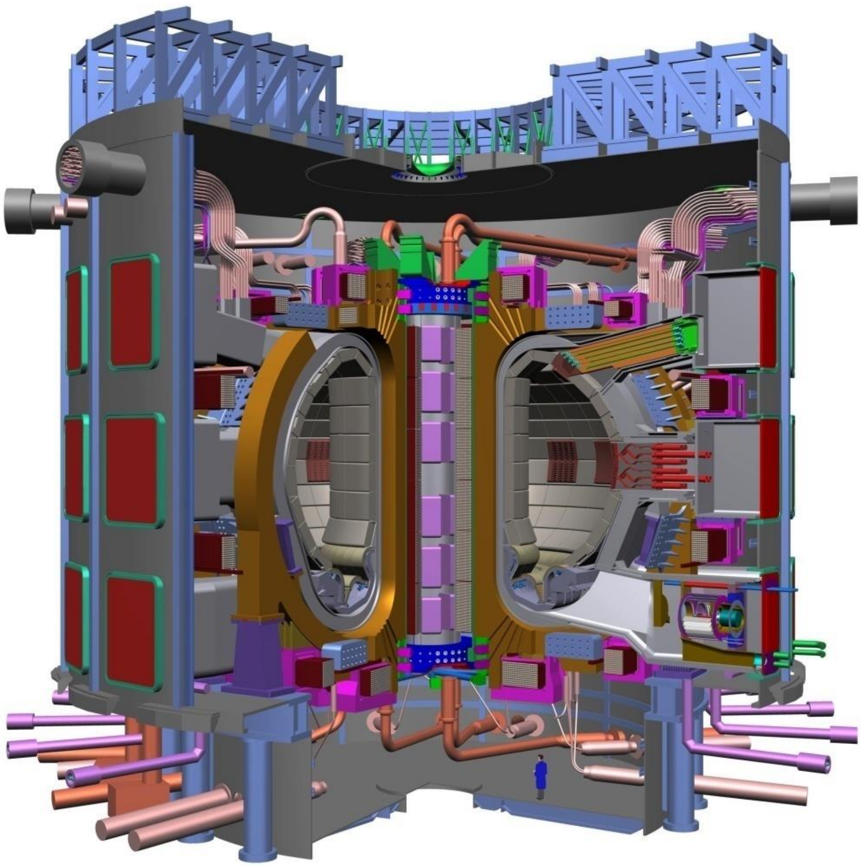






Impact on society
energy production and distribution

Magnetically confined nuclear fusion: ITER



138 kV, 574 MVA power line (LIPA) using high-temperature superconductors

But could these accelerators be smaller ?? !!...

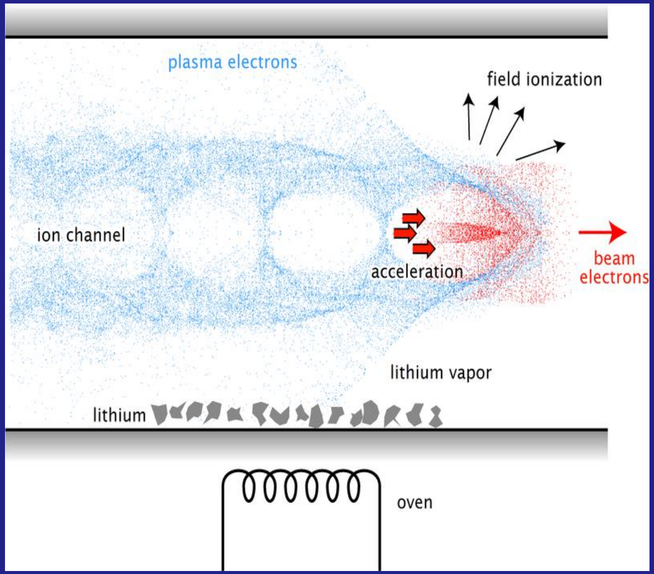
New (old) ideas: plasma wakefield acceleration
VERY HIGH Electric **Field Gradients**

- Plasma wakefield provoked by a driving beam (laser, electron, proton) creates a zone of separation of electrons from ions > a very high field gradient is formed.

Gradients:

Resonant cavity: ~30 MV/m

Plasma wakefield: ~100 000 MV/m !!!!



Acceleration record:
42 GeV on 85 cm
(Nature 445)!

for comparison:
SLAC: 50 GeV – 3 km!

Proton-driven plasma wakefield acceleration could accelerate electrons to the terascale.
The **AWAKE** project is set to verify this novel technique using proton beams at CERN.

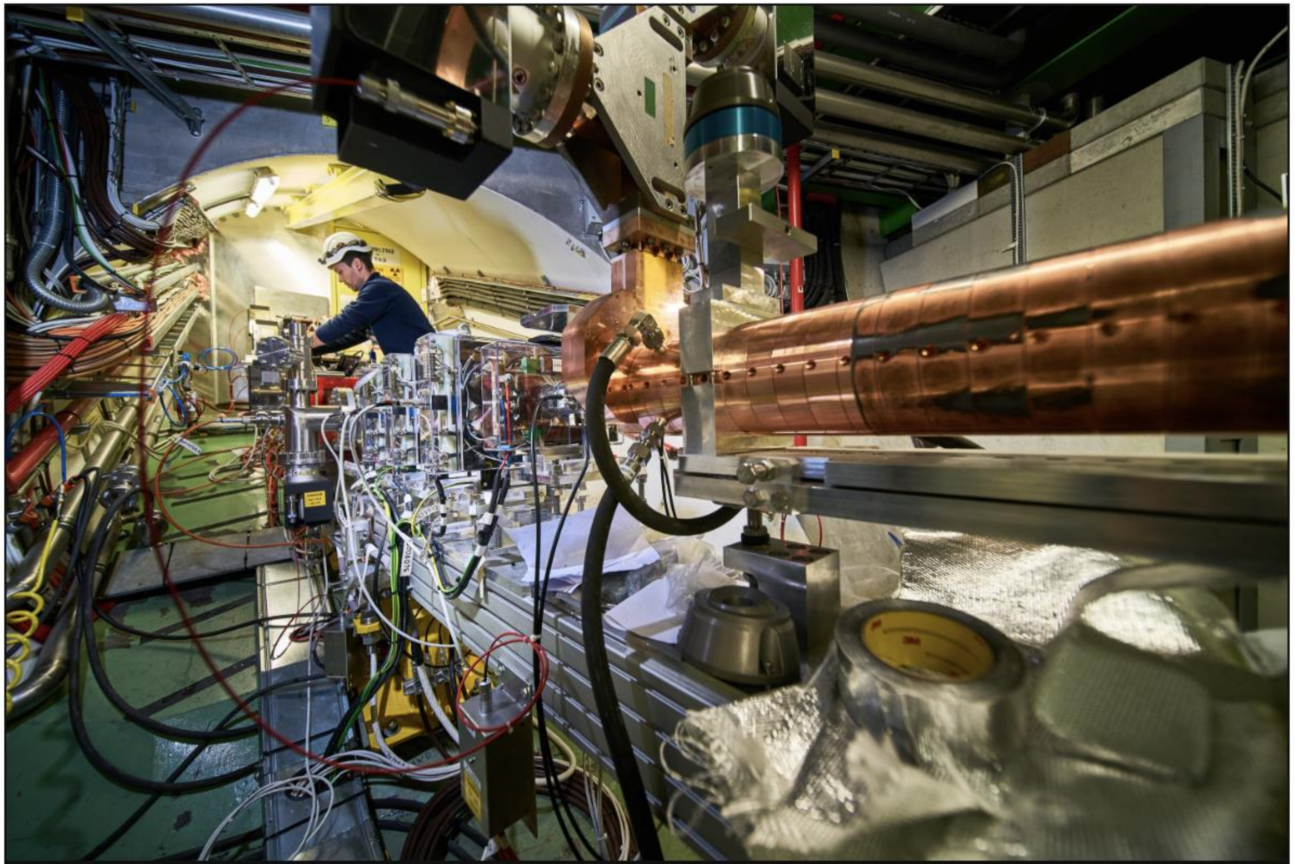
AWAKE successfully accelerates electrons

by Achintya Rao

Posted by Achintya Rao on 29 Aug 2018. Last updated 30 Aug 2018, 09.27.

Voir en français

"By accelerating electrons to 2 GeV in just 10 metres, AWAKE has demonstrated that it can achieve an average gradient of around 200 MV/m," AWAKE is now aiming to attain an eventual acceleration gradient of around 1000 MV/m (or 1 GV/m).



AWAKE's electron beam line (Image: Maximilien Brice/Julien Ordan/CERN)

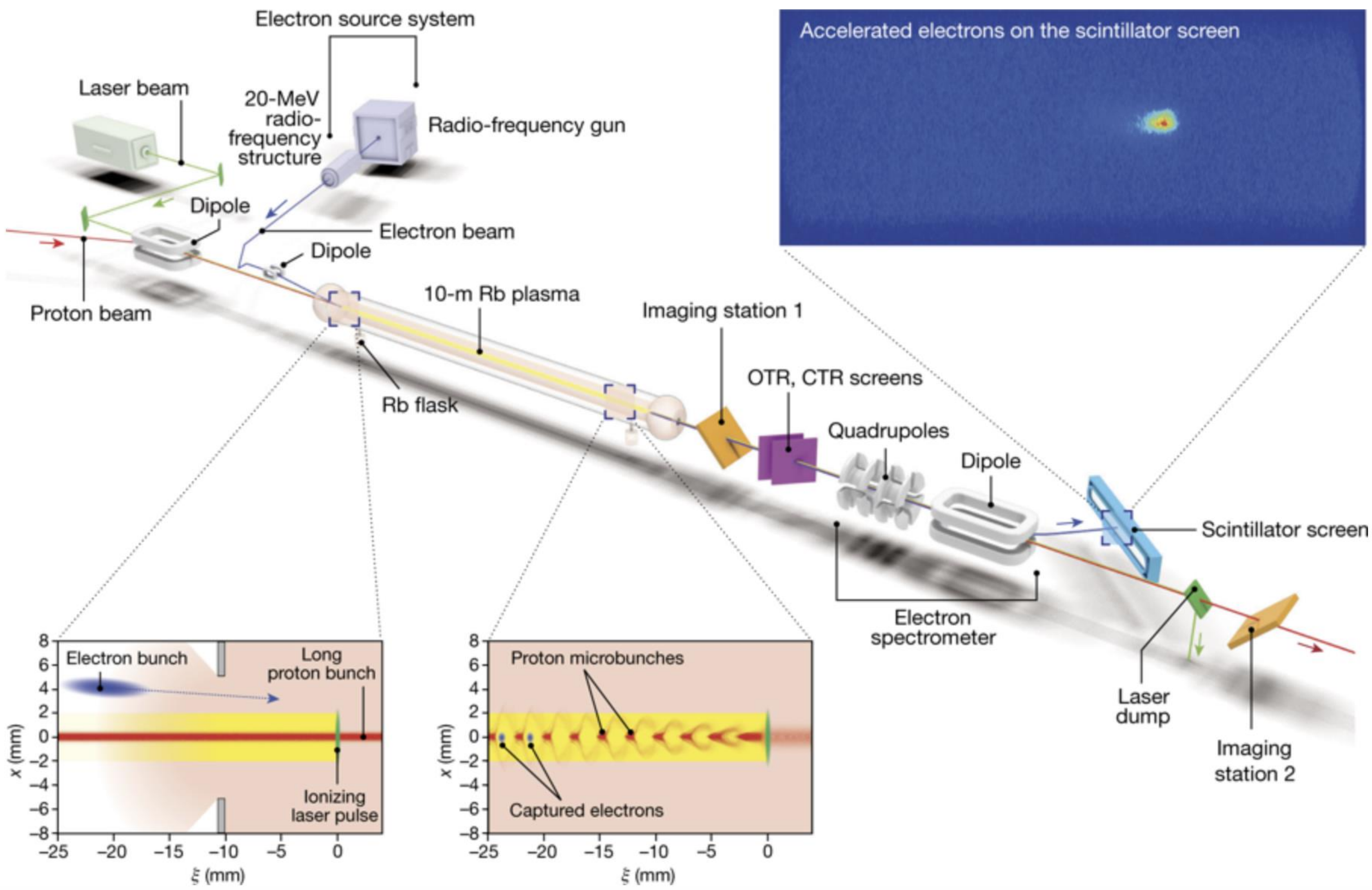
nature
International journal of science

Letter | OPEN | Published: 29 August 2018

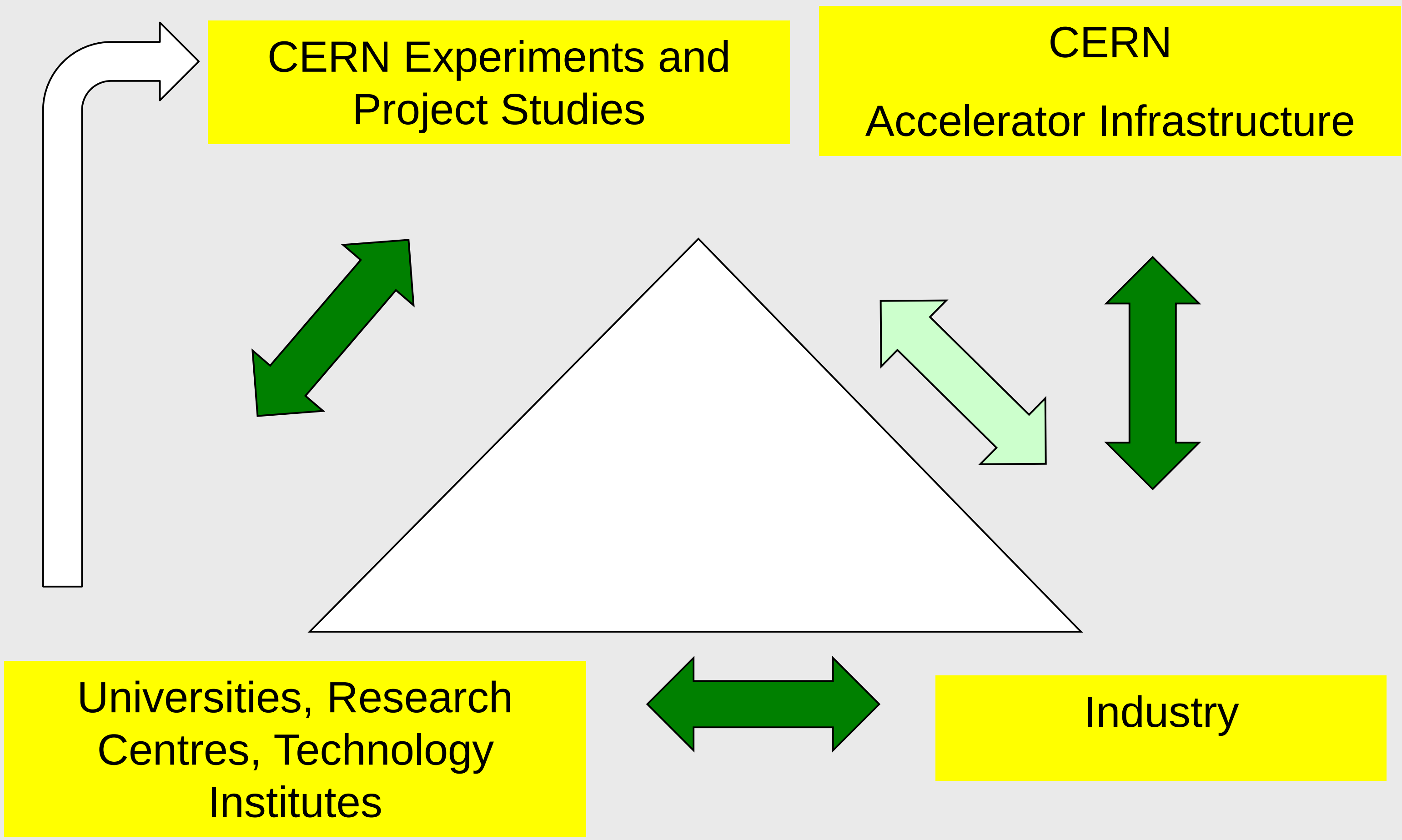
Acceleration of electrons in the plasma wakefield of a proton bunch

E. Adli, A. Ahuja, […] G. Xia

Nature **561**, 363–367 (2018) | Download Citation



CERN and CERN Experiments - Collaboration aspects



Accelerator projects – multidisciplinary tasks requiring collaboration of Physicists with top specialists from various branches of Engineering and Industry:

- Electrical
- Vacuum and UH Vacuum
- Mechanical
- Cryogenics
- Electronics and Controls
- Materials / Surface techniques
- Instrumentation
- Computing
- Civil Engineering, Survey specialists, Environmental expertise…

Acknowledgment

- To my colleagues from CERN for kindly providing their contribution to this presentation
-

together with
my best hopes

for widening the collaboration
with SEE Research centres
and industry

Thank you

and…

…see you one day at CERN !

#DEALS OCTOBER 30, 2017

Novartis to buy French cancer specialist AAA for $3.9 billion

ZURICH (Reuters) - Novartis has agreed to buy French-based **Advanced Accelerator Applications (AAA)** for $3.9 billion, giving it a platform in radiopharmaceuticals and access to a new therapy for the kind of cancer that killed Steve Jobs.

Financial Time

AAA, which was spun off from Europe's physics research centre CERN 15 years ago, specializes in "radiopharmaceuticals" for diagnosis and treatment of tumors.

AAA received European approval last month for **LUTATHERA**, a treatment for gastroenteropancreatic neuroendoctrine tumors.

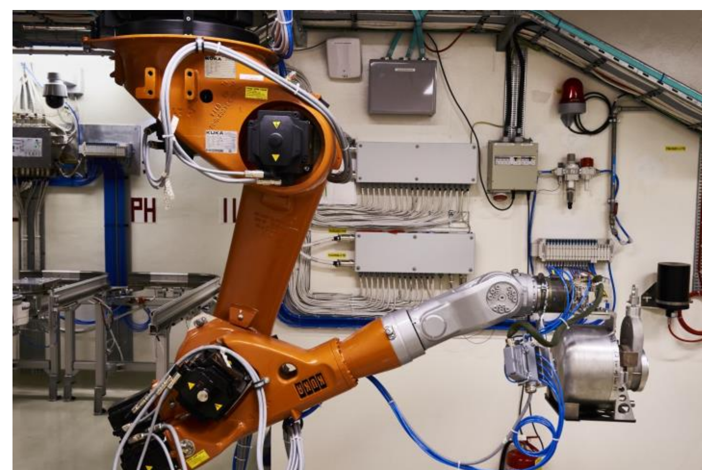
The ISOLDE Radioactive Ion Beam facility

The dedicated facility, called [CERN-MEDICIS (Medical Isotopes Collected from ISOLDE), uses radioactive isotopes produced at ISOLDE, CERN's nuclear physics facility, solely for the purpose of researching non-conventional radioisotopes for medical research.]

MEDICIS collaboration at ISOLDE already works !

New isotopes for medical research studied together with hospitals.

https://home.cern/fr/about/updates/2013/09/cern-produce-radioisotopes-health



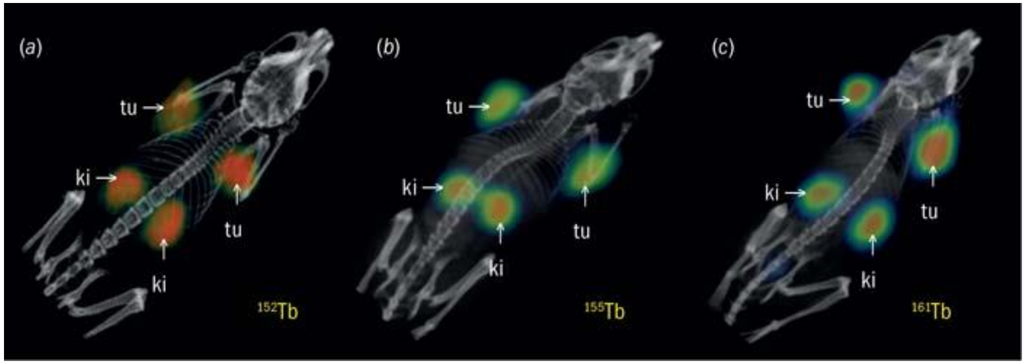
CERN COURIER http://cerncourier.com/cws/article/cern/52022
Jan 28, 2013

Terbium: a new 'Swiss army knife' for nuclear medicine

Diverse applications in nuclear medicine

A team of scientists from the Paul Scherrer Institute (PSI), CERN's ISOLDE facility and the Institut Laue-Langevin (ILL) has published results from a preclinical study of new **tumor-targeting radiopharmaceuticals based on the element terbium**. The results demonstrate the potential of providing a new generation of radioisotopes with excellent properties for the diagnosis and treatment of cancer.

Radiopharmaceuticals in which a radioactive isotope is attached to a carrier that selectively delivers it to tumor cells are used in two main ways, for diagnosis and for treatment.



Initiative for establishment of the International Institute for Sustainable Technologies in the Balkans with the mission of “Science for Peace.”

Preliminary scientific concept of this new Institute already exists, in the form of two very different options, both based on the construction of synchrotron.

The first option is ‘Synchrotron Light Source’ (Lund-type technology).

The second option is Hadronic Cancer Treatment and Research in Bio-medicine. This institute could be built on the model of CNAO-Pavia.