



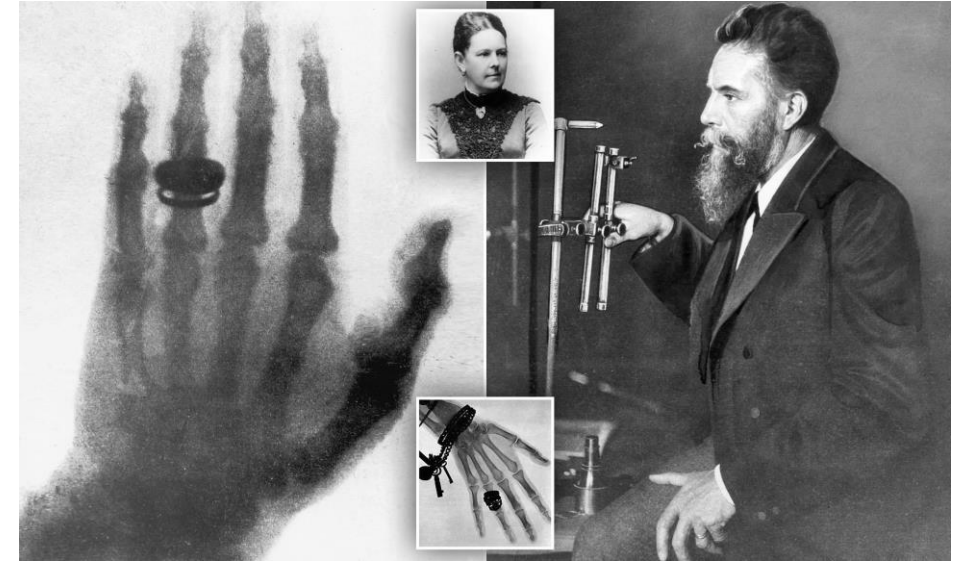
Particle Accelerators

Mike Lamont
International High School Teacher Programme
2nd July 2024

The First Historical Particle Accelerators

Nobel Laureate Wilhelm Conrad Röntgen

- “Cathode rays” emitted by a heated cathode impinging on an anode produced X-rays



First human X-ray of Röntgen's wife Bertha's hand (1895)

J.J. Thomson

e^-

Electrodes D+E : electric field
External coils: magnetic field

Cathode ray experiments (~ TV)

★ ★ 'Rays' are charged corpuscles*
with unique charge/mass ratio

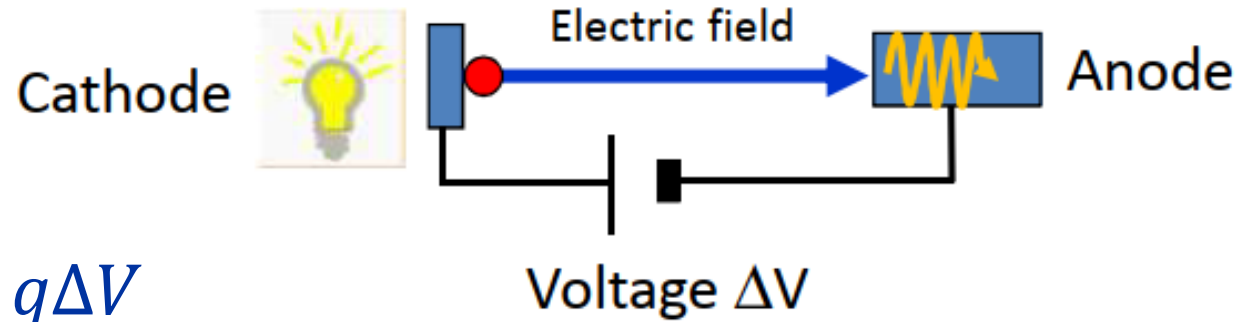
Nobel Laureate J.J. Thomson

- 1897 - Thomson showed cathode rays were composed of negatively charged particles (electrons)
- Calculated to be much smaller than atoms with a very large charge-to-mass ratio

Acceleration – The Simple Case

Wilhelm Conrad Röntgen's first historical particle accelerator

- Vacuum tube containing a cathode connected to negative pole of DC voltage generator
- Electrons emitted by the heated cathode were accelerated while flowing to the positive anode
- Collisions between these energetic electrons and the anode produced X-rays



Particle energy usually expressed in electron-volt [eV]

1 eV (1.6×10^{-19} J) equal to energy gained by an electron accelerated through an electrostatic potential of 1 volt

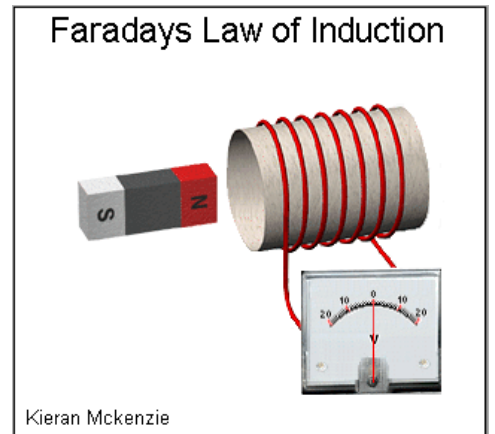
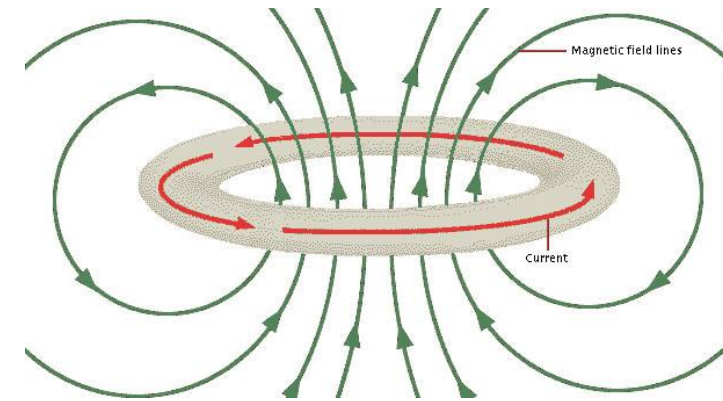
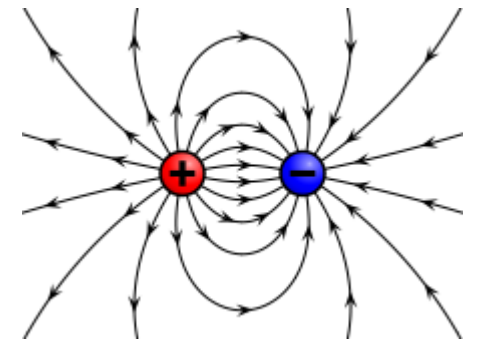
Maxwell's equations

$$\nabla \cdot E = \frac{\rho}{\epsilon_0}$$

$$\nabla \cdot B = 0$$

$$\nabla \times E = -\frac{\partial B}{\partial t}$$

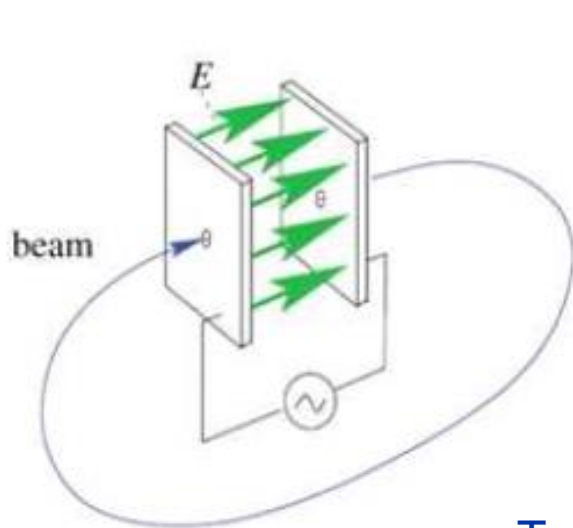
$$\nabla \times B = \mu_0 J + \mu_0 \epsilon_0 \frac{\partial E}{\partial t}$$



The Principles behind Particle Accelerators

- **Lorentz Force**

- Particles accelerated via electric fields and bent or focused using magnetic fields



Electric Field

$$\frac{d\vec{p}}{dt} = q(\vec{E} + \vec{v} \times \vec{B})$$

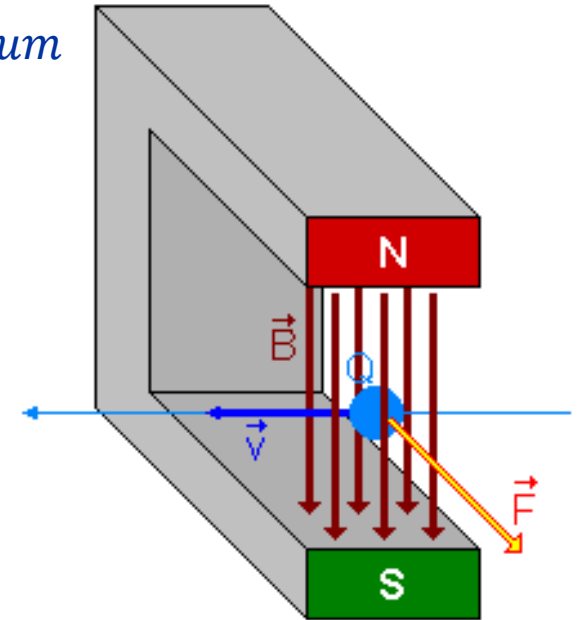
\vec{p} = momentum
 \vec{v} = velocity
 q = charge

Acceleration

To accelerate we need a force in the direction of motion

Bending & Focusing

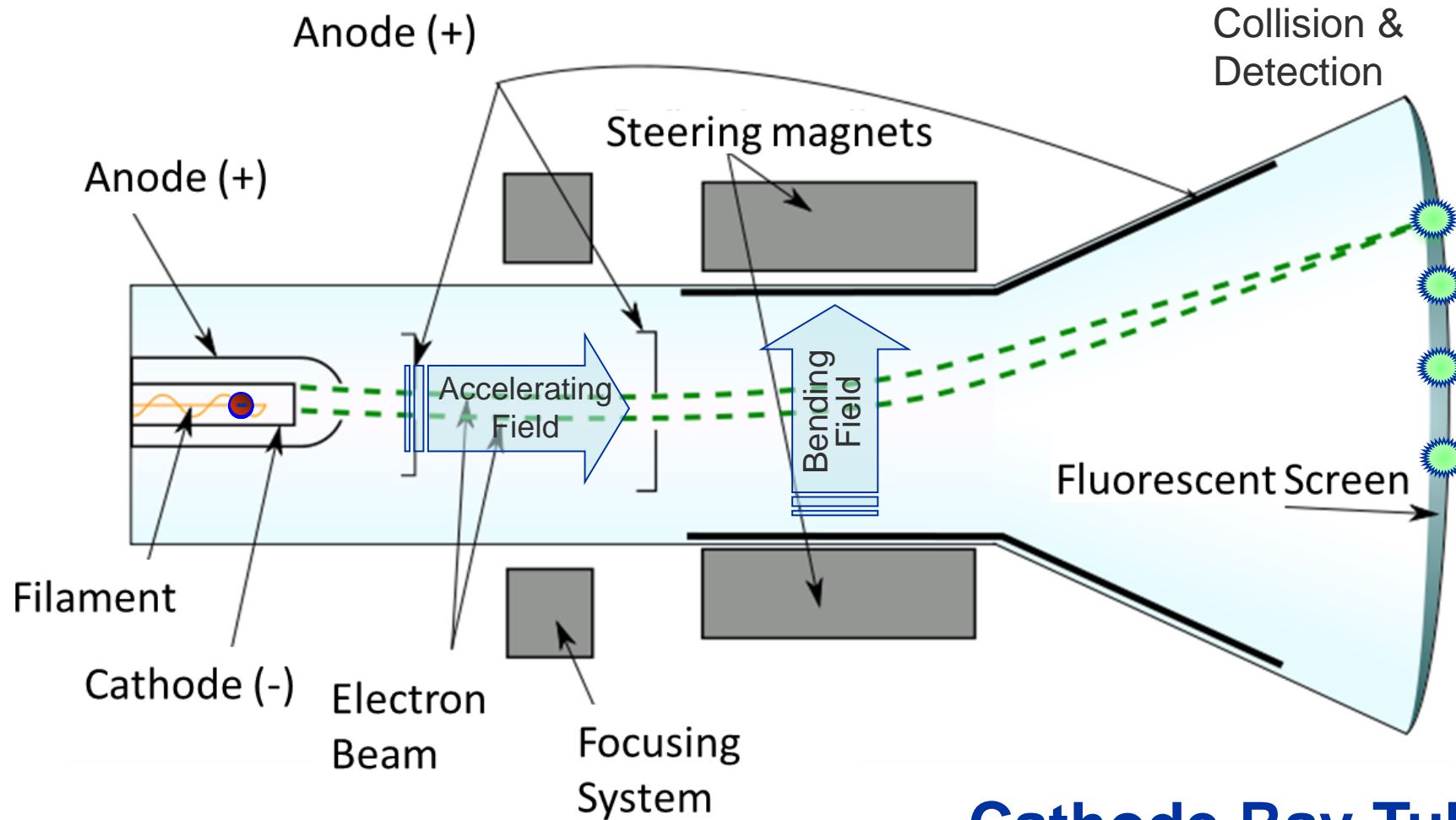
Perpendicular to motion
⇒ Change in momentum but no acceleration



Magnetic Field

The Principles behind Particle Accelerators

How do accelerators work?



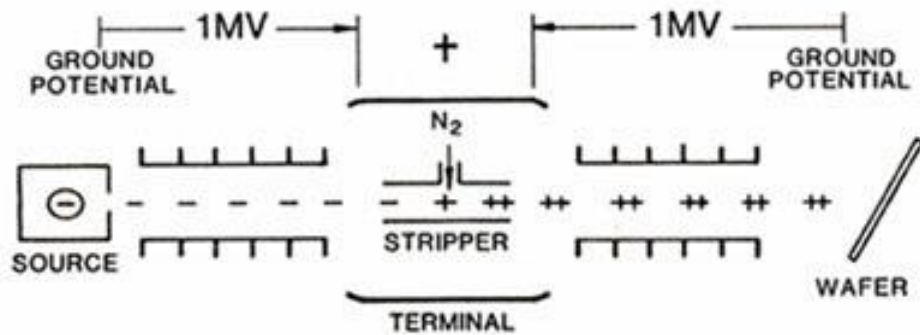
Essential Ingredients

- *Accelerating gradient*
- *Magnetic field*
- Vacuum system
- Power system
- Control system
- *Detectors*

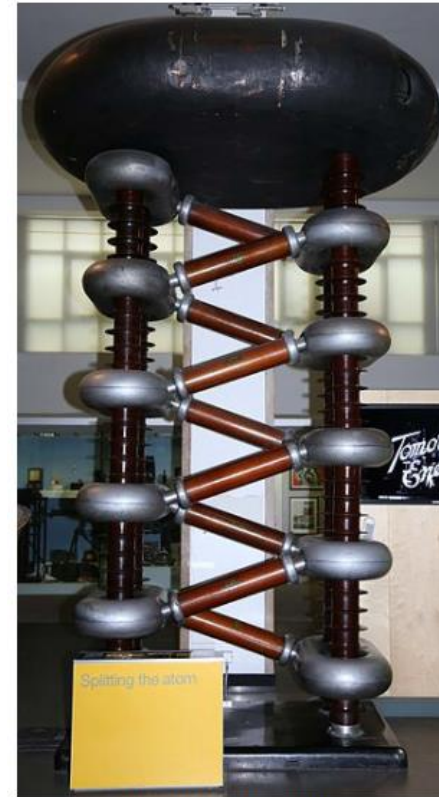
Cathode Ray Tube (Old TV set)

Electrostatic Accelerators

- To increase achievable maximum energy
 - Cockroft and Walton built a cascade generator
 - Van de Graaff built a generator with a dielectric belt transporting positive charges to an isolated electrode hosting an ion source
 - In air versions reached 2-3 MV while later versions under isolating gas atmospheres reached up to 25 MV
 - Main limitation: the breakdown at the charged terminal
 - Tandem versions allowed doubling the energy

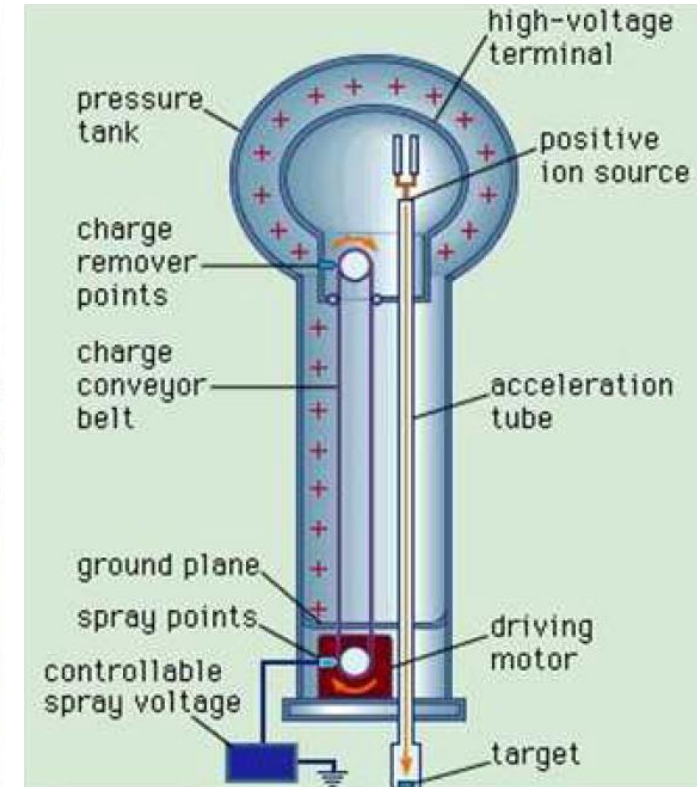


Tandem DC Accelerator



Cockcroft-Walton generator in the London Science Museum - Wikimedia Commons

Cockcroft-Walton Cascade Generator



Van de Graaff Generator

Radio Frequency Linear Accelerators (LINACs)

- To overcome the breakdown limitation Rolf Widerøe used a Radio Frequency (RF) generator originally proposed by Gustav Ising in 1924
 - For his Thesis at Aachen University (1928) built the first radio frequency LINAC

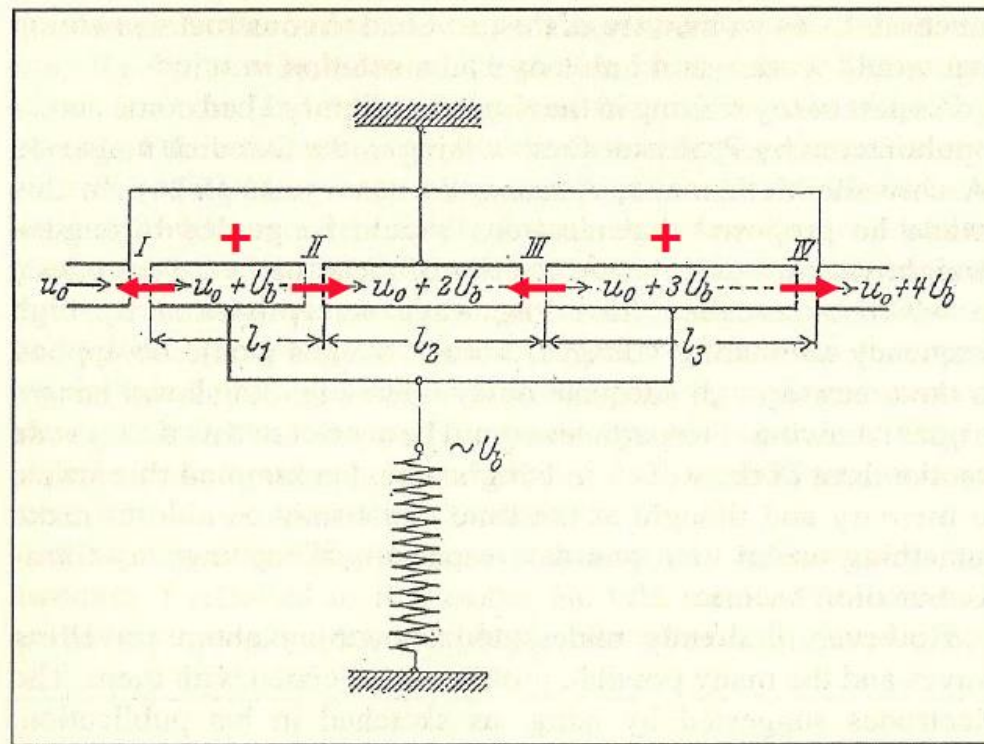


Fig. 3.5: The principle of the 'drift-tube' as illustrated in Widerøe's thesis [Wi28].



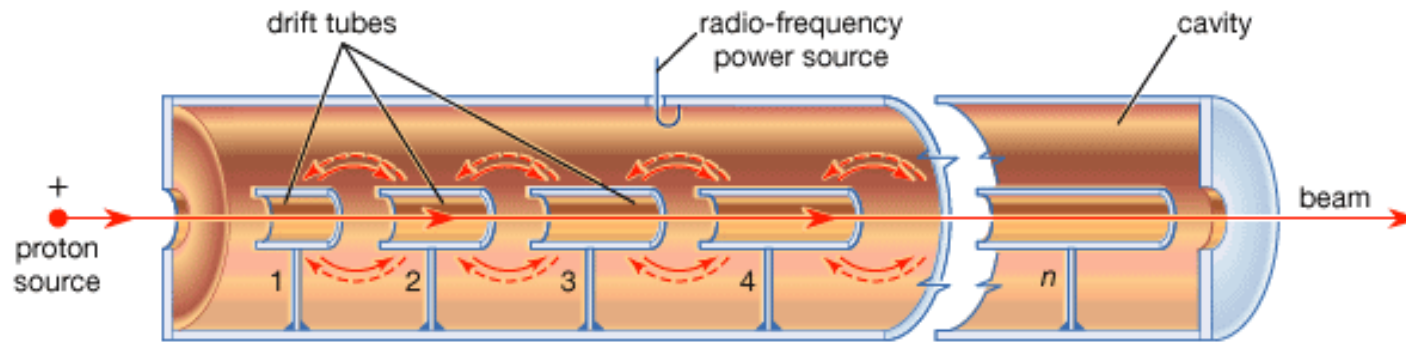
Scanned at the American Institute of Physics

Rolf Widerøe 1928

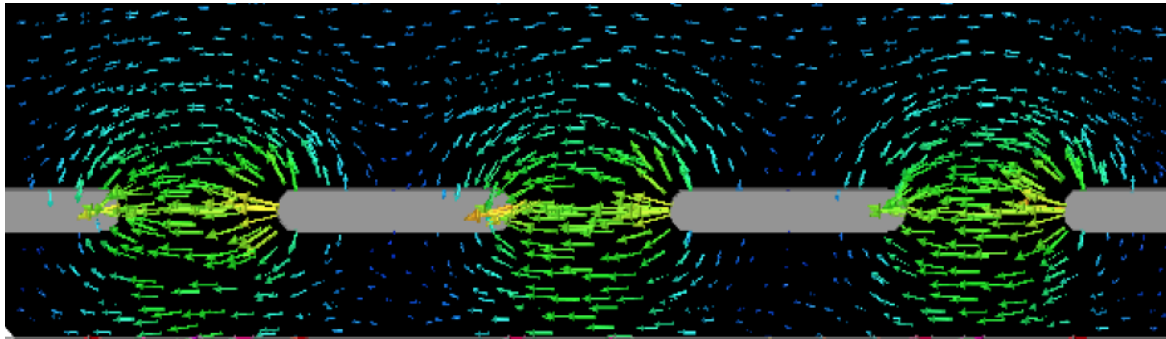
Radio Frequency Linear Accelerators (LINACs)

- **Drift Tube LINAC**

- Particles accelerated by a sequence of gaps
- Distance between gaps increases proportionally to the particle velocity, to keep synchronicity
- Used in the range where velocity increases rapidly



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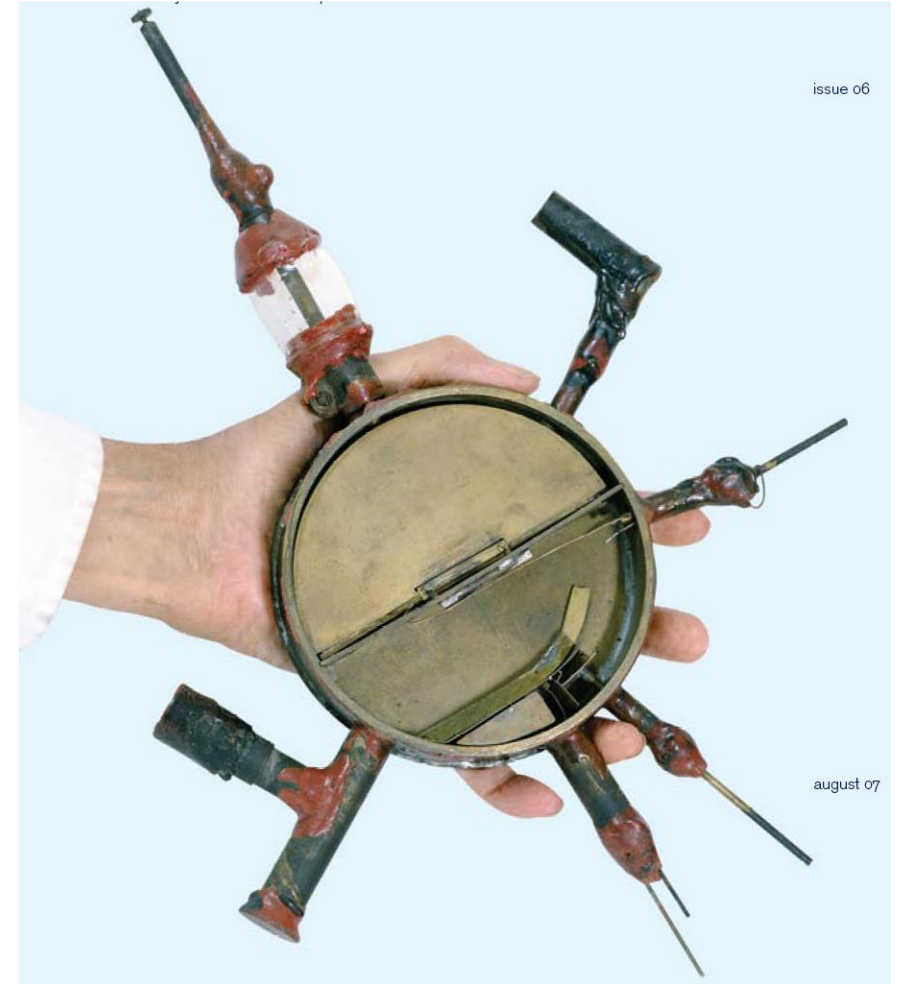


The First Circular Accelerator

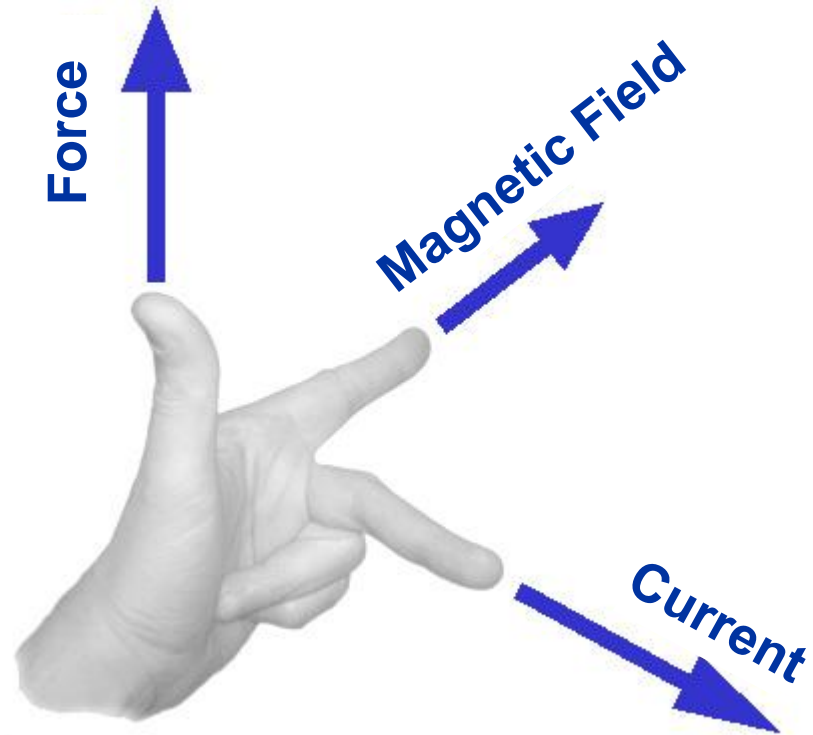
- Lawrence and Livingston's 80 keV cyclotron (1930)



Ernest O. Lawrence

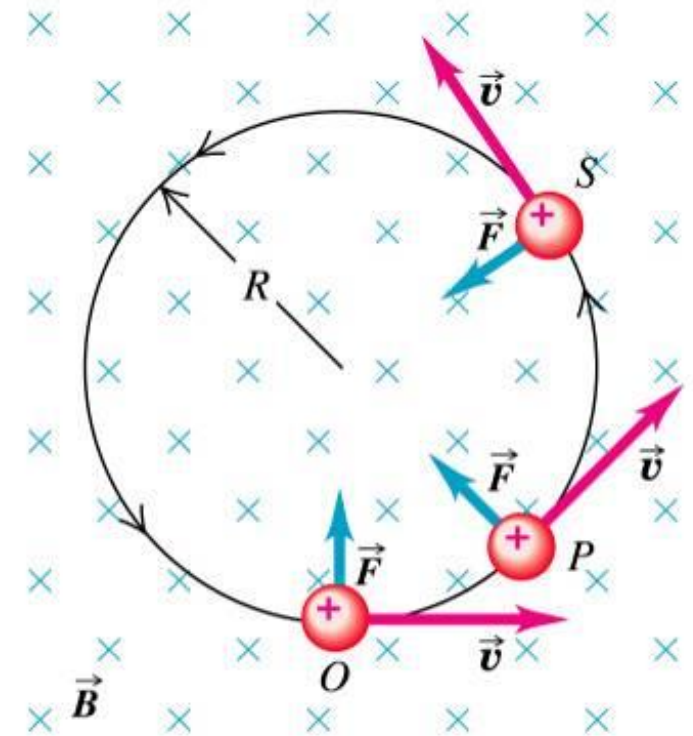


Circular Accelerators

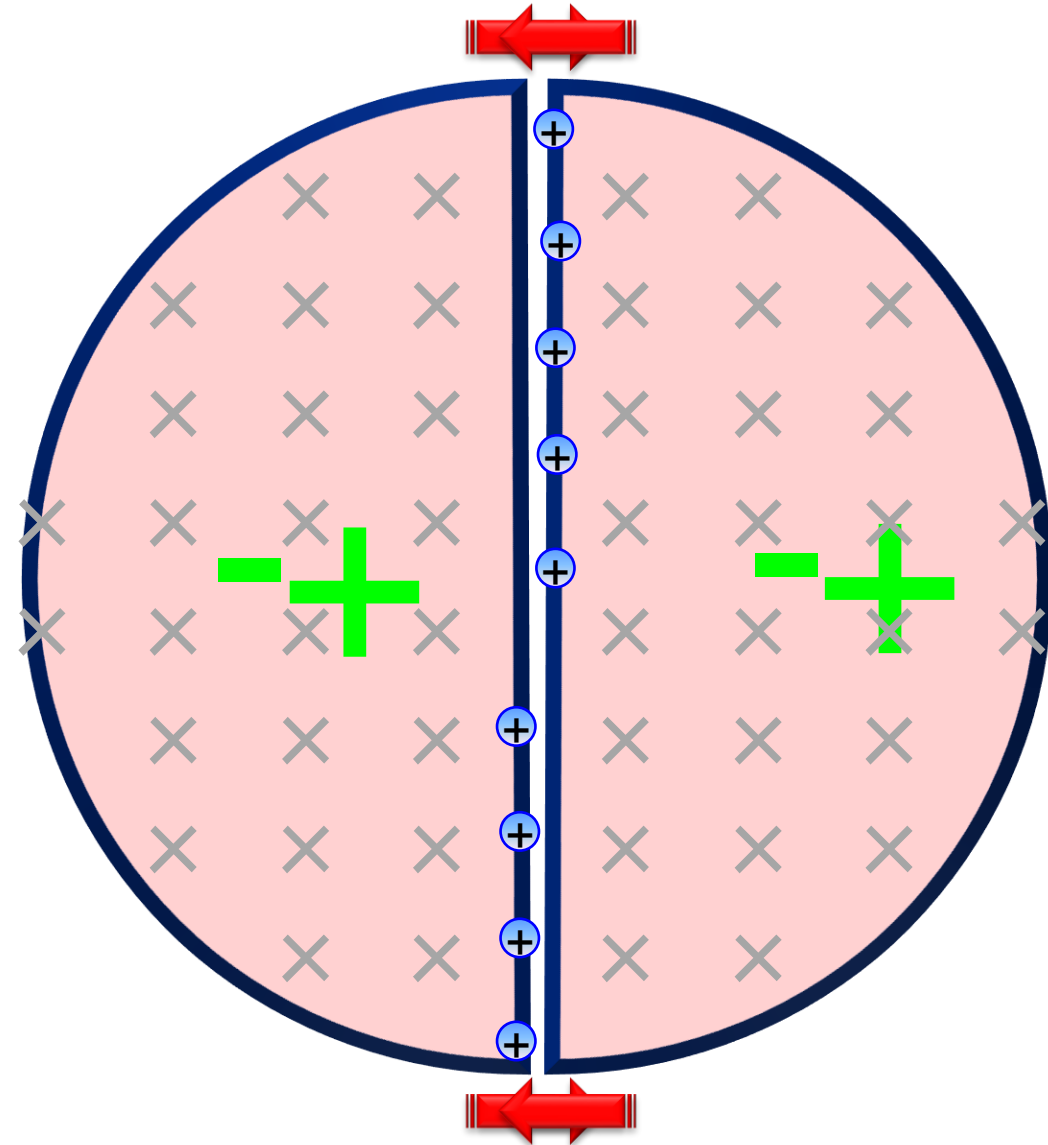
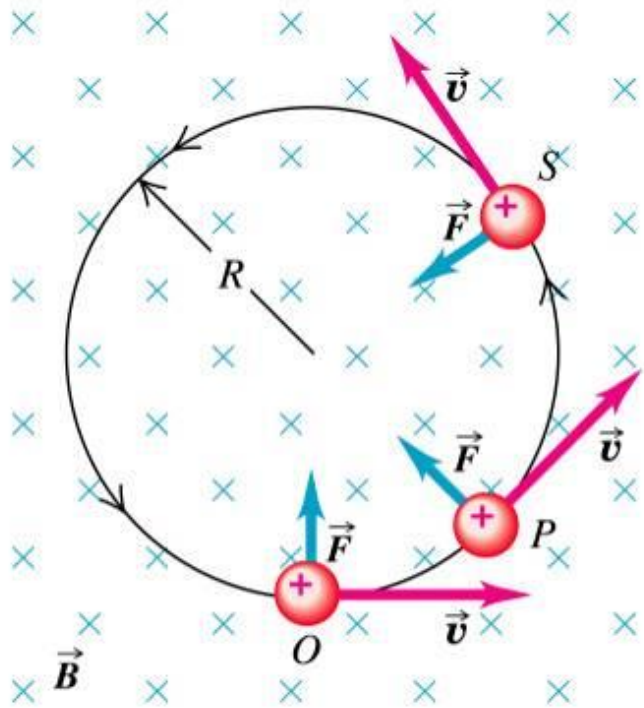


$$\mathbf{F} = q\mathbf{v} \times \mathbf{B}$$

$$R = \frac{mv}{qB}$$

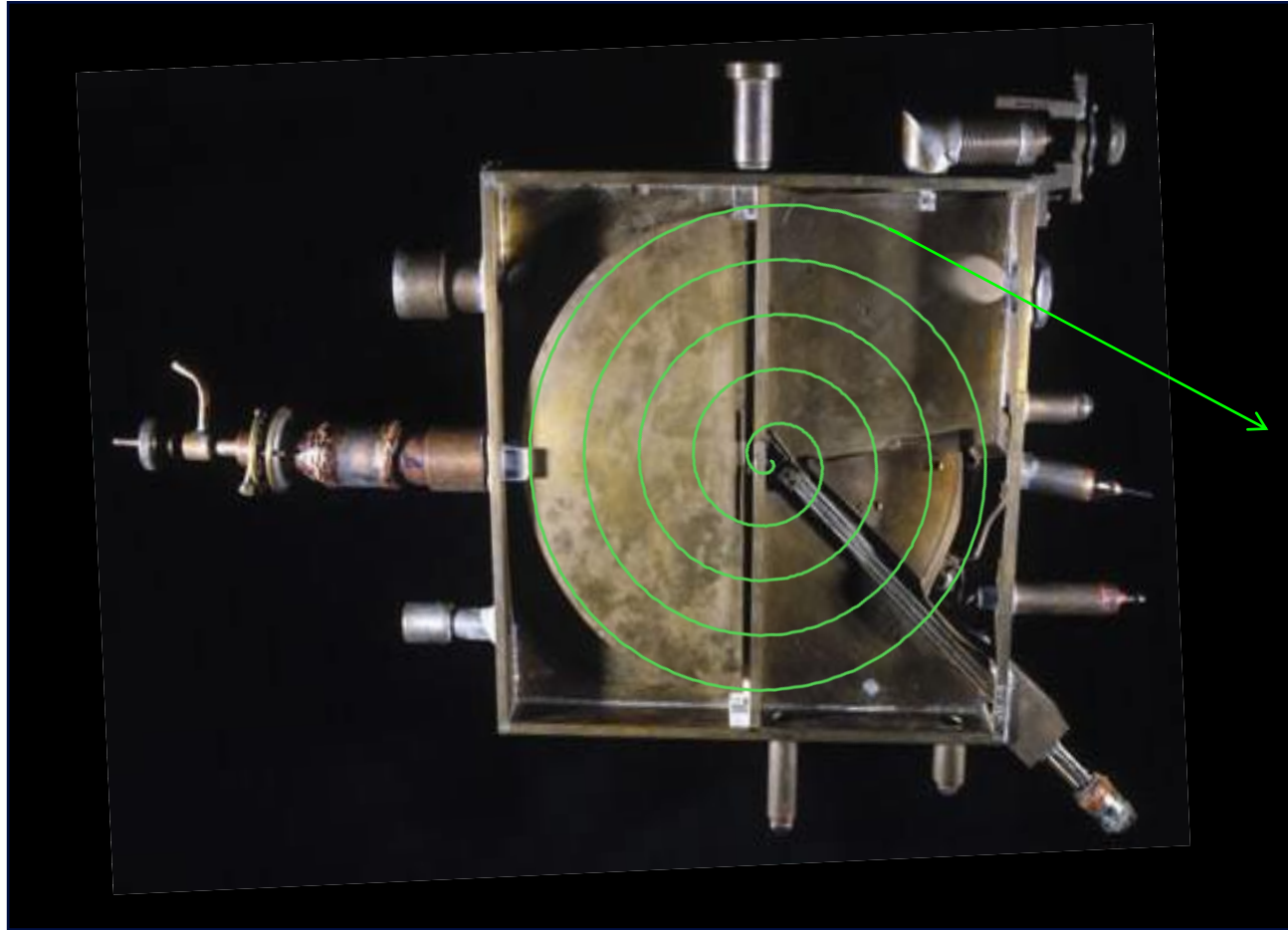


Circular Accelerators - Cyclotron



- A moving charged particle will follow a circular path in a magnetic field

Cyclotron



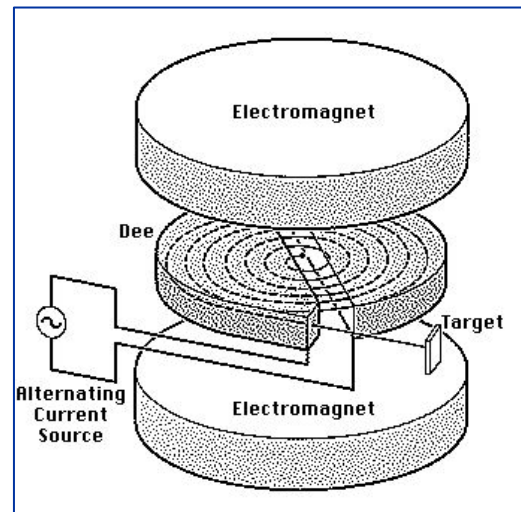
- **This 10" version managed to reach an energy of 1 MeV (Mega Electron Volts)**
 - The energy of an electron if accelerated by 1 million volts

Circular Accelerators

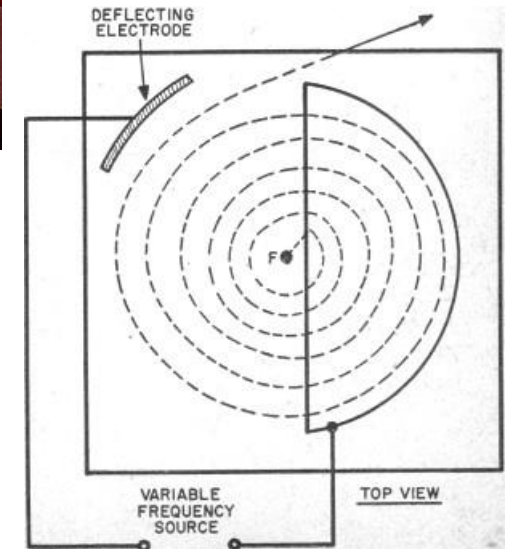
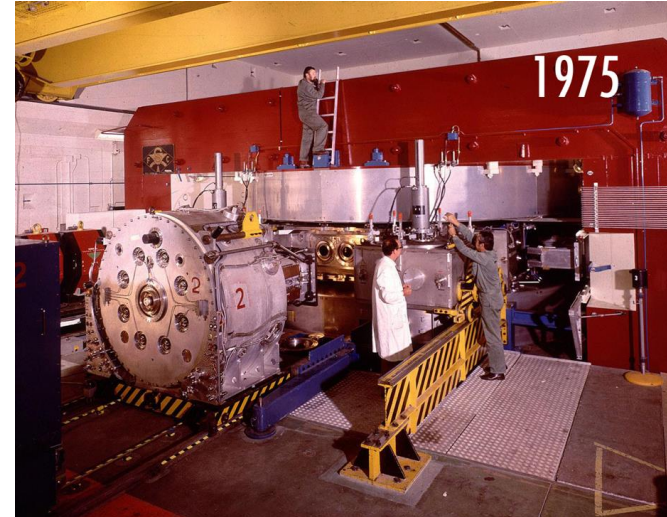
- Cyclotron



Livingston and Lawrence standing beside the 27 inch cyclotron, built in 1934

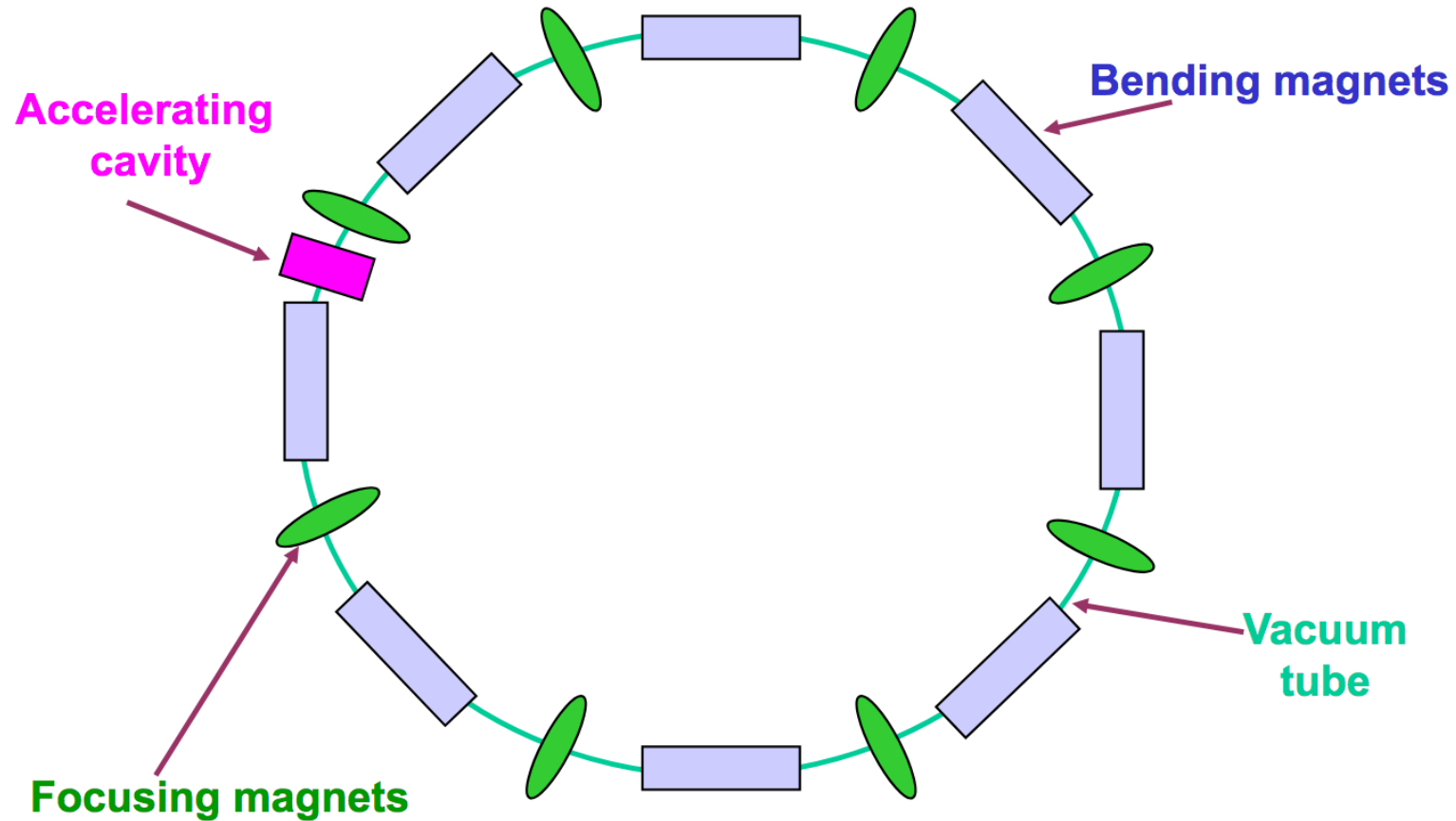


- Synchro-Cyclotron

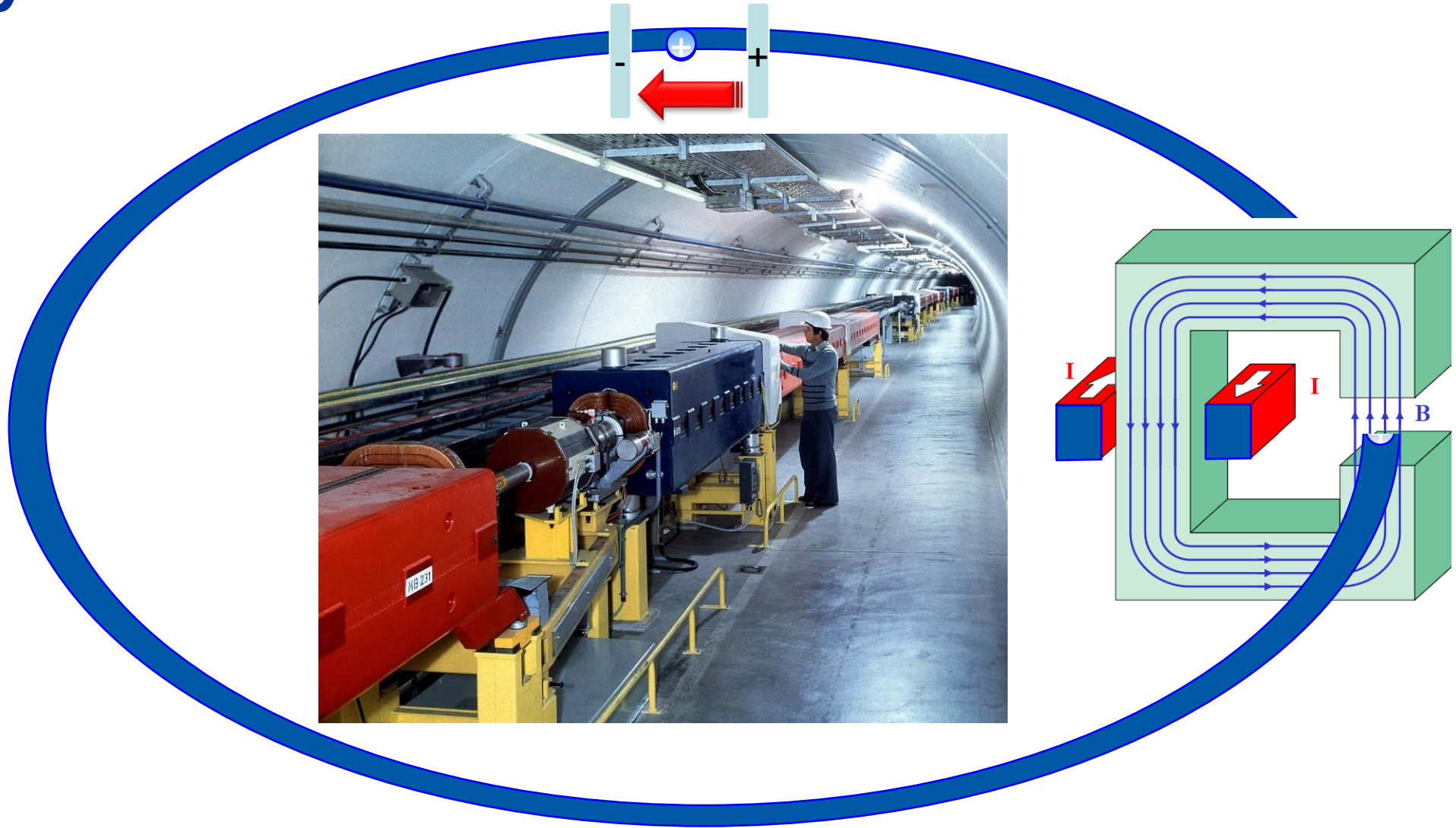


Circular Accelerators – The Synchrotron

- The basic principle of the synchrotron is to maintain the accelerated particles at a constant orbital radius



The Synchrotron



The magnetic field increases with energy so that the particle follows the same path

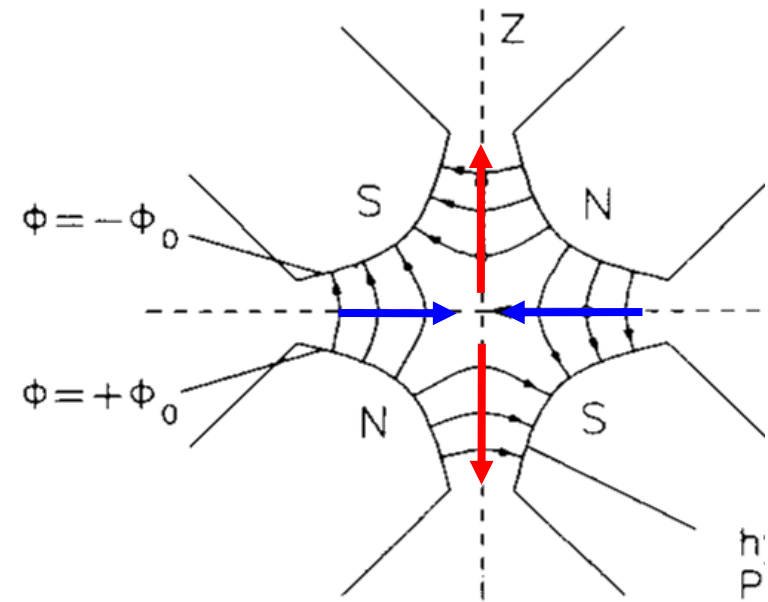
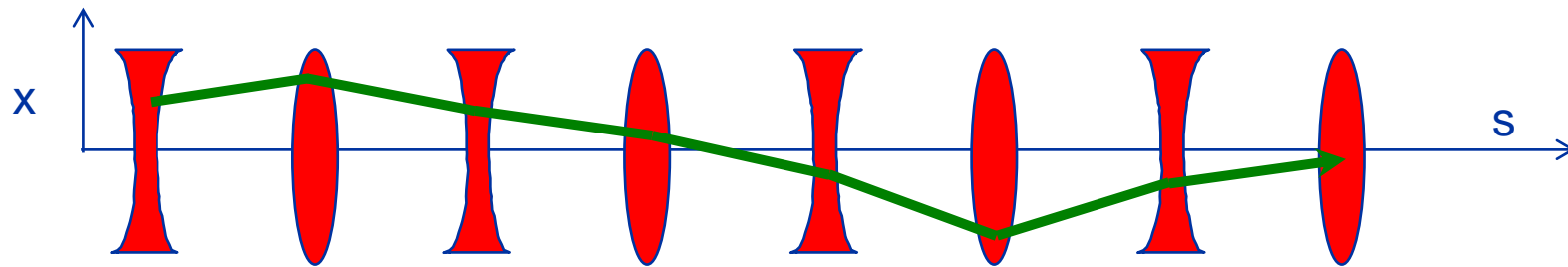
LHC tunnel



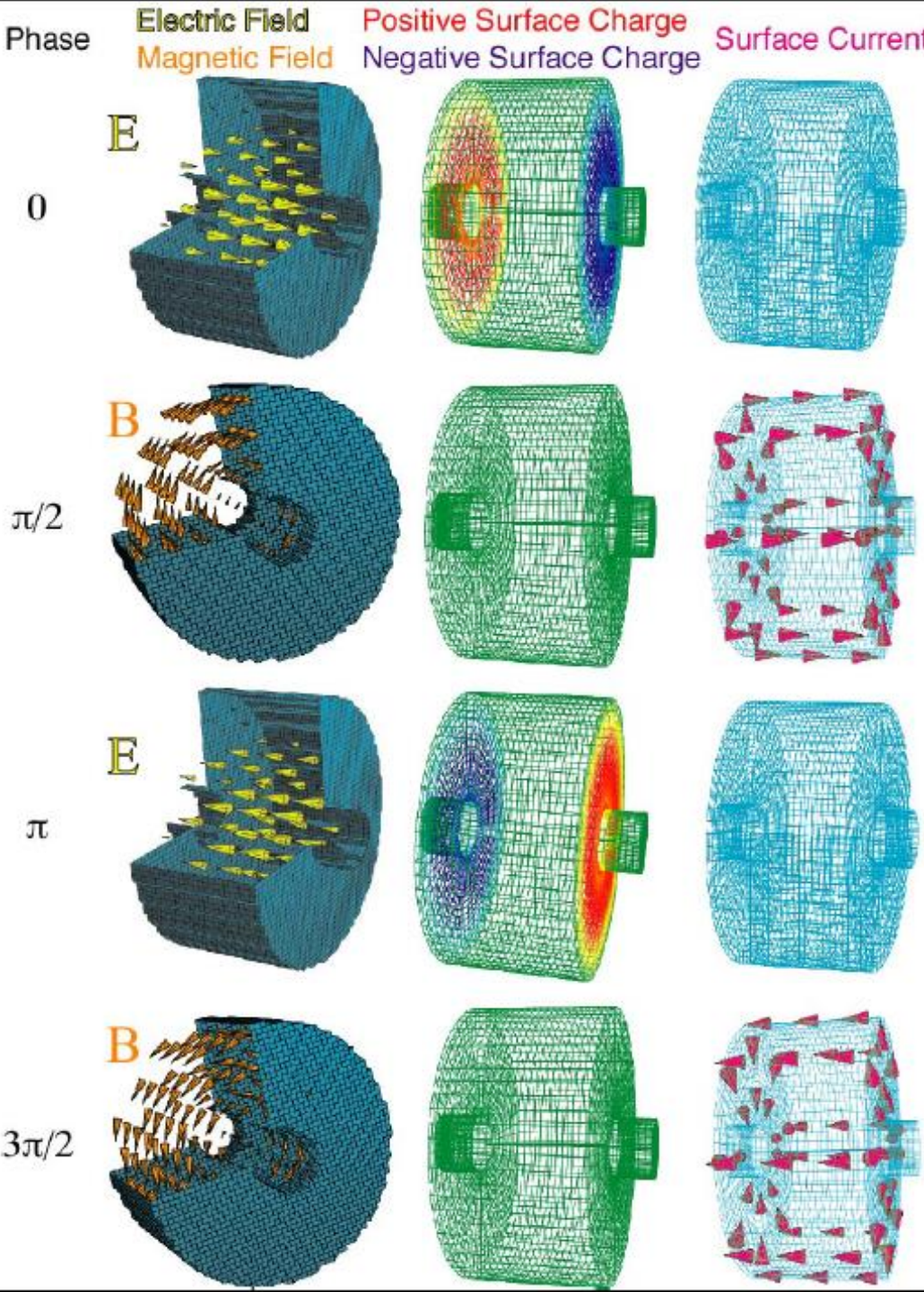
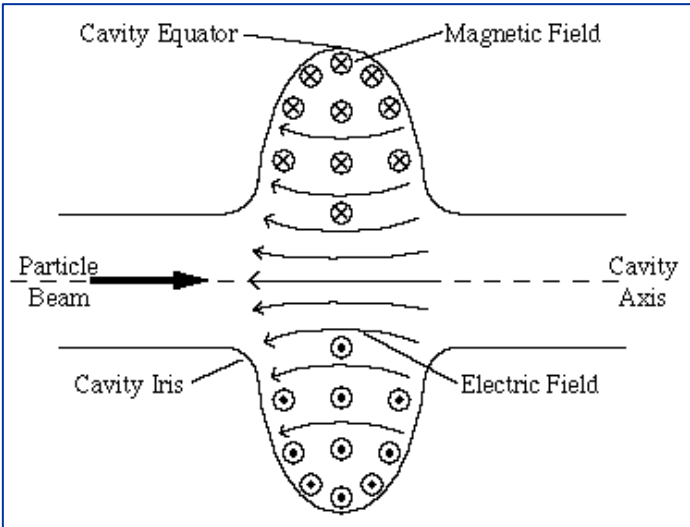
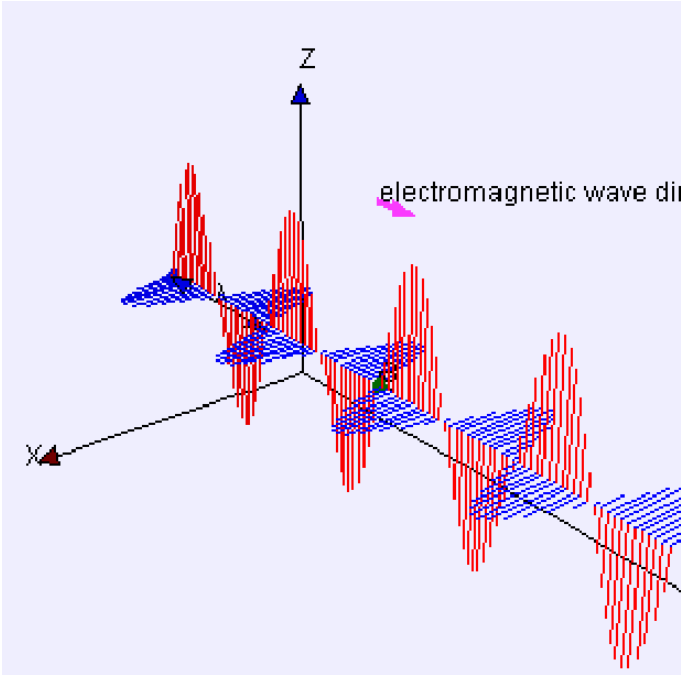
Video 1'22"

Quadrupole Magnets

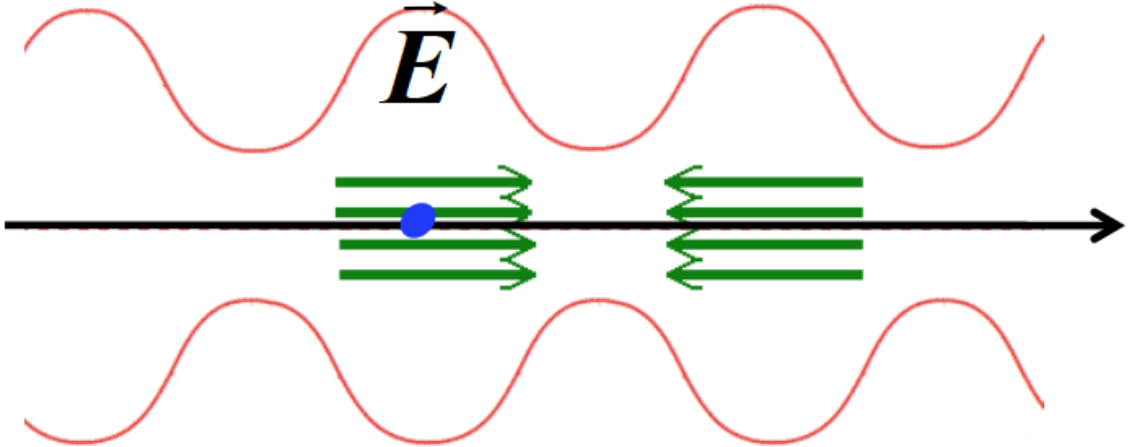
- A quadrupole magnet will focus in one plane and defocus in the other
 - Convention: a “focusing” quadrupole focuses in the horizontal plane
- A series of focusing and defocusing magnets can be used to constrain the charged particle in both planes
- A synchrotron is mostly regular cells of bending, focusing and defocusing magnets
 - with some space left for beam acceleration, injection, extraction and sometimes an experiment



Radio Frequency (RF)

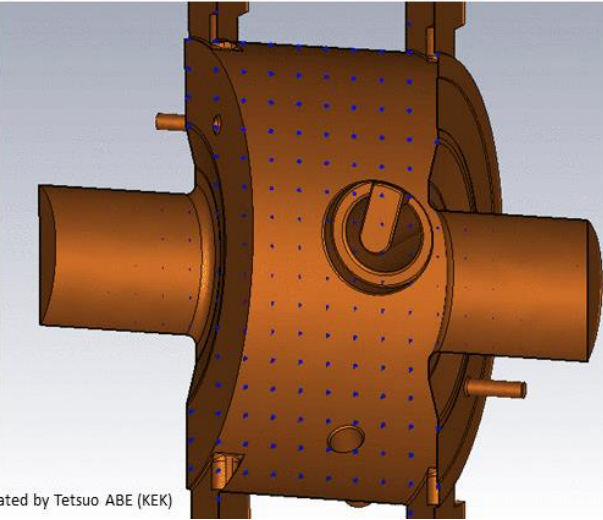
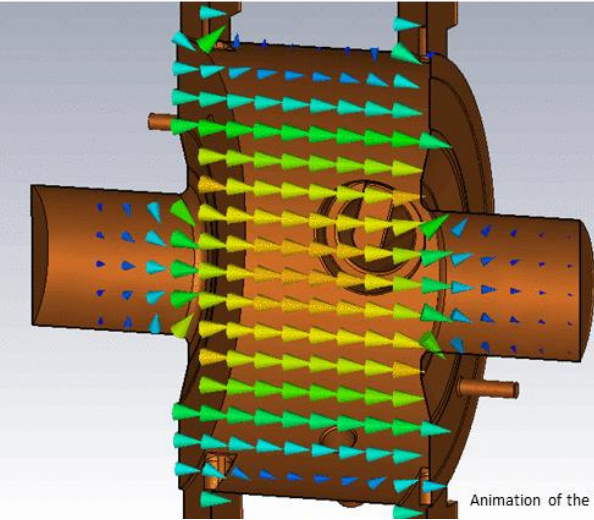


RF cavities



(a) Electric field

(b) Magnetic field



Animation of the TM₁₀ mode, created by Tetsuo ABE (KEK)

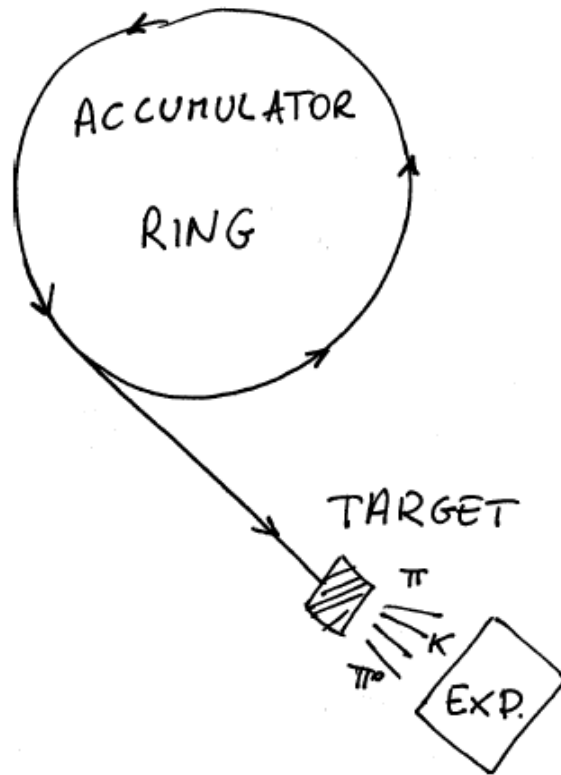


4 LHC cavities per module

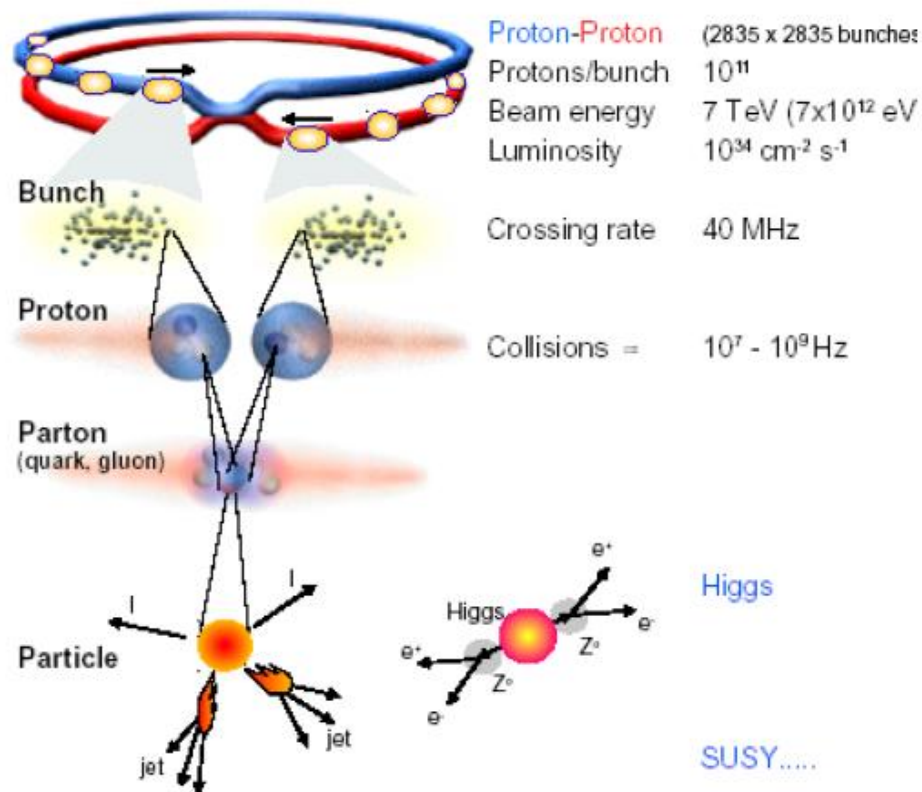


Different Approaches: Fixed Target v Collider

Fixed Target



Storage Ring / Collider

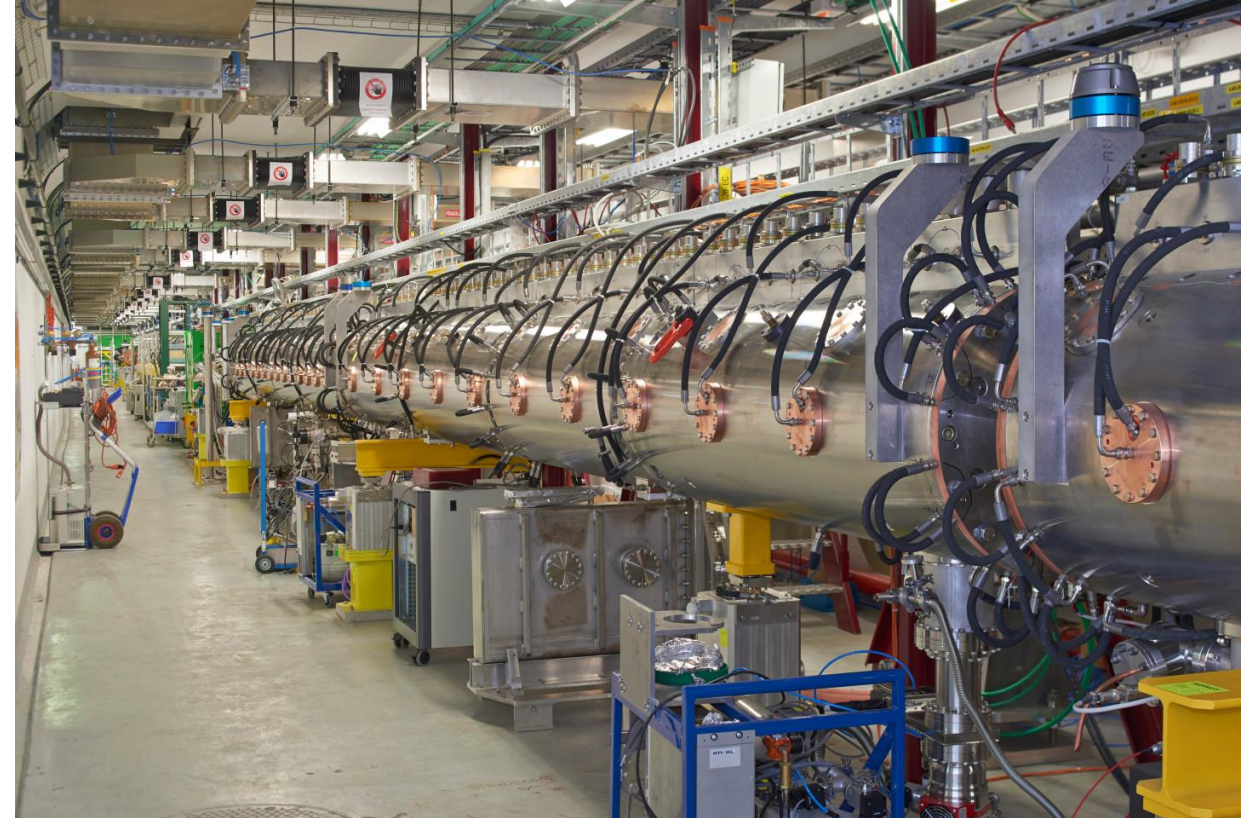


$$E_{CM} = \sqrt{2(E_{beam}mc^2 + m^2c^4)} \ll E_{CM} = 2(E_{beam} + mc^2)$$

Drift Tube LINACs at CERN



LINAC2 in service from 1978-2018
Accelerating tank 1 shown here
provided an energy gain of 10 MeV



LINAC4 DTL modules providing
acceleration from 3 MeV to 50 MeV
on-line since 2020

The Proton Synchrotron (PS)

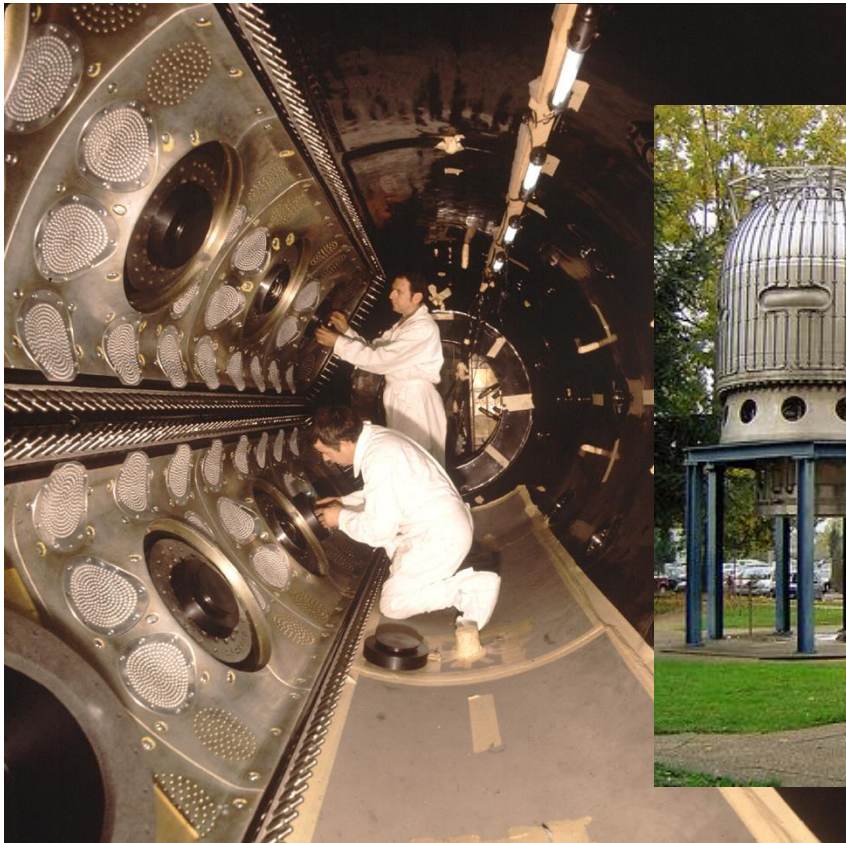
CERN's first synchrotron is still providing beams to the complex!

- **The PS first accelerated protons on 24 November 1959**
 - For a brief period it was the world's highest energy particle accelerator
 - Now accelerates beams to an energy of 26 GeV
 - Over the years it has undergone many modifications
 - The intensity of its proton beam has increased a thousandfold



Gargamelle and the Proton Synchrotron

- **1974: discovery of weak neutral currents**
 - Gargamelle (freon) bubble chamber looking for neutrinos from collision with fixed target from the PS
 - Distinctive signatures of Z boson & neutrino interaction (weak interaction)
 - Only known mechanism for elastic scattering of neutrinos in matter



Intersecting Storage Rings (ISR)

- **1971 to 1984**
 - Fed by the PS
 - World's first hadron collider
 - proton-proton & proton-antiproton
 - Maximum centre of mass energy of 62 GeV
 - Equivalent to 2TeV beam hitting a target
 - Much of the time spent on research to improve the machine itself paving the way for later colliders

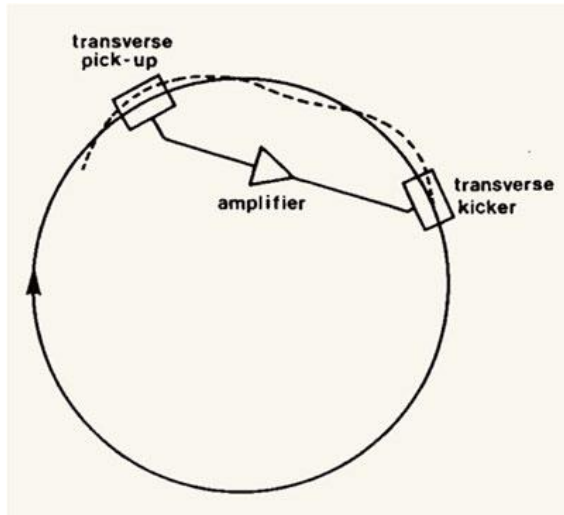
Interaction point
with crossing angle



S. Van Der Meer CERN/ISR-PO/72-31

4. FINAL NOTE

This work was done in 1968. The idea seemed too far-fetched at the time to justify publication. However, the fluctuations upon which the system is based were experimentally observed recently. Although it may still be unlikely that useful damping could be achieved in practice, it seems useful now to present at least some quantitative estimation of the effect.



With a mild push from friends and colleagues, Simon finally published the first internal note on **stochastic cooling** in 1972

Essential technique to create the dense anti-proton beams required for proton-antiproton collisions

The Antiproton Accumulator (AA)

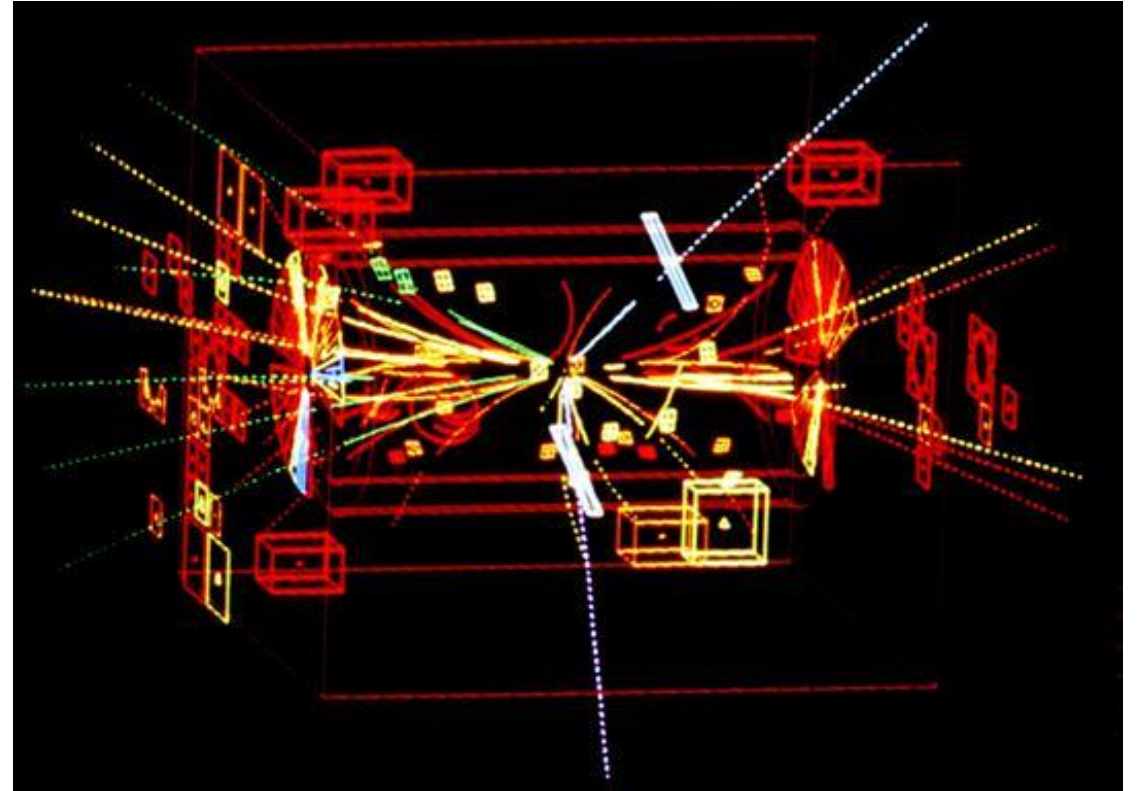
- **Built to provide antiprotons to the Super Proton Synchrotron (SPS)**
 - Antiprotons created by firing 26 GeV/c protons from the PS onto a target
 - Stochastic cooling used to decrease momentum spread of emerging antiprotons
 - Process repeated over a day to produce an intense antiproton beam that was ultimately transferred to the SPS



Simon van der Meer in the Antiproton Accumulator Control Room, 1984

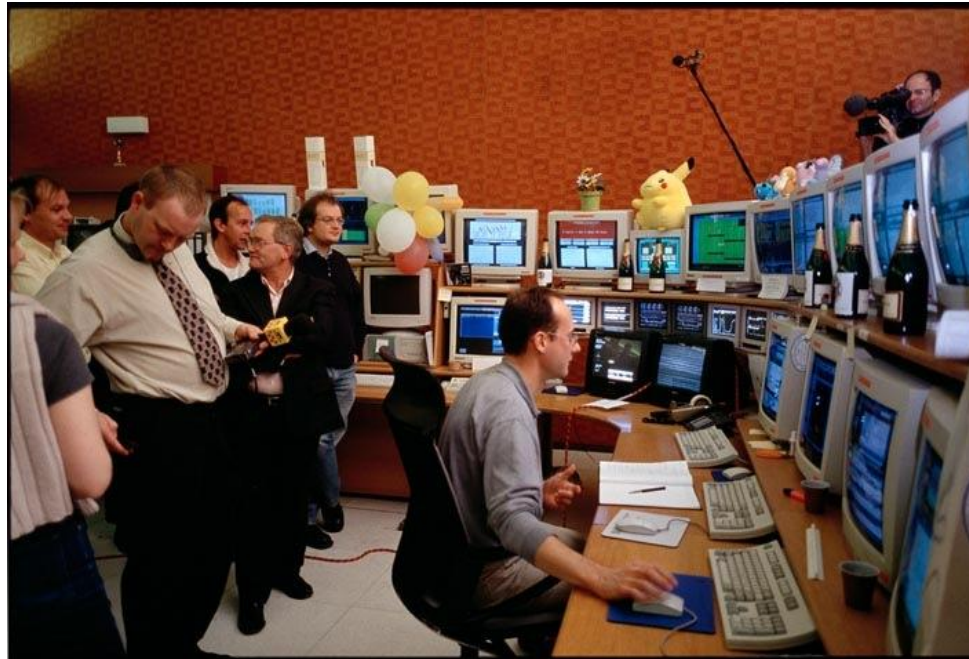
The Super Proton Synchrotron (SPS)

- The 6.9 km SPS became the workhorse of CERN's particle physics programme in 1976
 - Used for both fixed target experiments & from 1981 - 1991 as a hadron (proton–antiproton) collider
 - Nobel-prize-winning discovery (C. Rubbia & S. van der Meer) of W^+ , W^- and Z^0 particles in 1983



The Large Electron-Positron Collider (LEP)

- 27 km LEP built to do precision physics on the W and Z
 - Largest electron-positron accelerator ever built (to date!)
 - Operated 1989 - 2000
 - Produced 18 million Zs and 80,000 Ws (1989-2000)



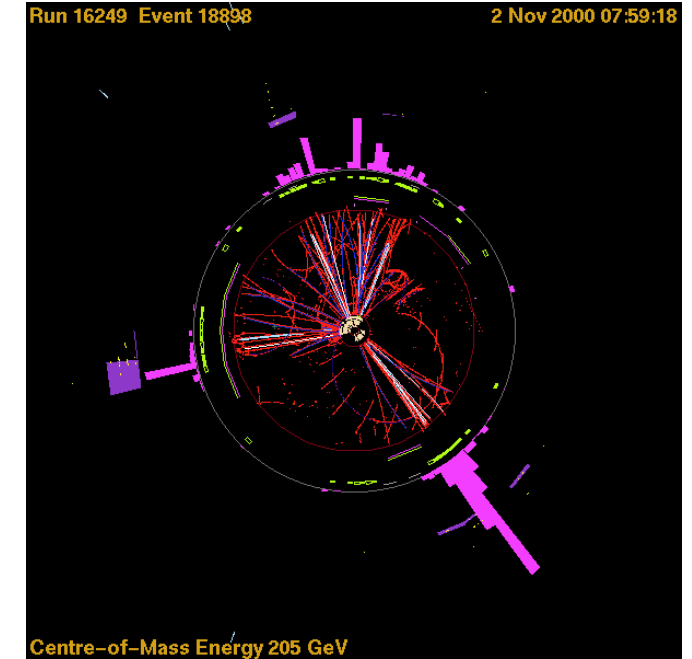
```
111 CFRN SL 02-08-99 11:26:44
LEP Run 6022 data of: 02-08-99 11:26:34
-**-** STABLE BEAMS **-**

E = 100.010 GeV/c Beam In Coast: 0.1
Beams e+ e-
I(t) uA 2040.6 2345.9
tau(t) h 6.30 7.36

LUMINOSITIES L3 ALEPH OPAL DELPHI
L(t) cm^-2*ns^-1 53.5 51.4 55.6 45.0
/L(t) nb^-1 11.5 11.0 8.7 12.2
Bkg 1 0.80 1.21 0.00 1.82
Bkg 2 0.86 0.53 0.96 2.28

COMMENTS 02-08-99 11:26
COLLIMATORS AT PHYSICS SETTINGS

FIRST PHYSICS AT 100 GEV
WHAT ABOUT THAT???
```



LEP/LHC tunnel named as one of the 50 most iconic tunnels in the world

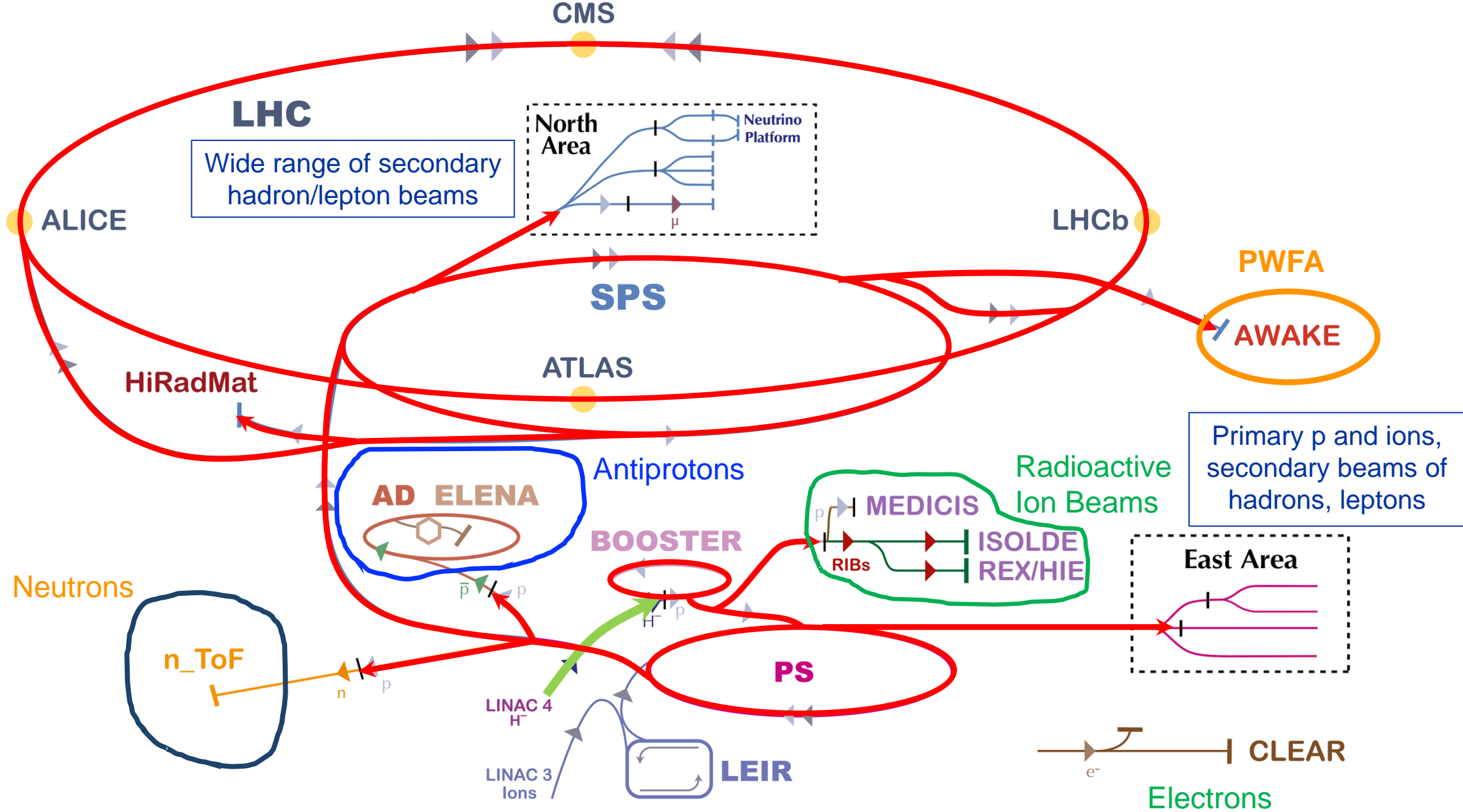
27-km LEP tunnel excavated between 1985 and 1988 using three tunnel boring machines

One of the “most remarkable feats of civil engineering” according to ITA (International Tunnelling and Underground Space Association*)

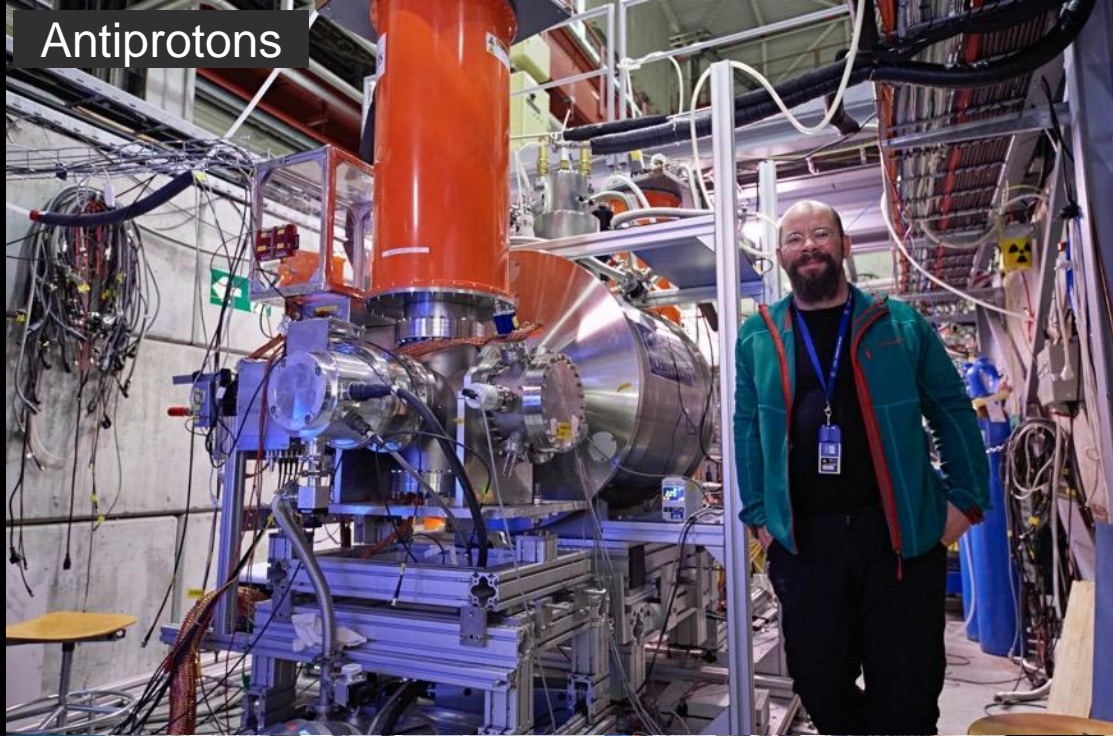
On the occasion of its 50th anniversary, ITA published a commemorative book listing the 50 most iconic tunnels in the world, including the LEP/LHC tunnel (list also includes the Gotthard Base Tunnel and the Channel Tunnel)

* Founded in 1974 by the initiative of 19 Nations, ITA’s mission is to lead, advocate and facilitate the development of sustainable and innovative solutions for increased, optimised, safe and equitable use of Underground Space.

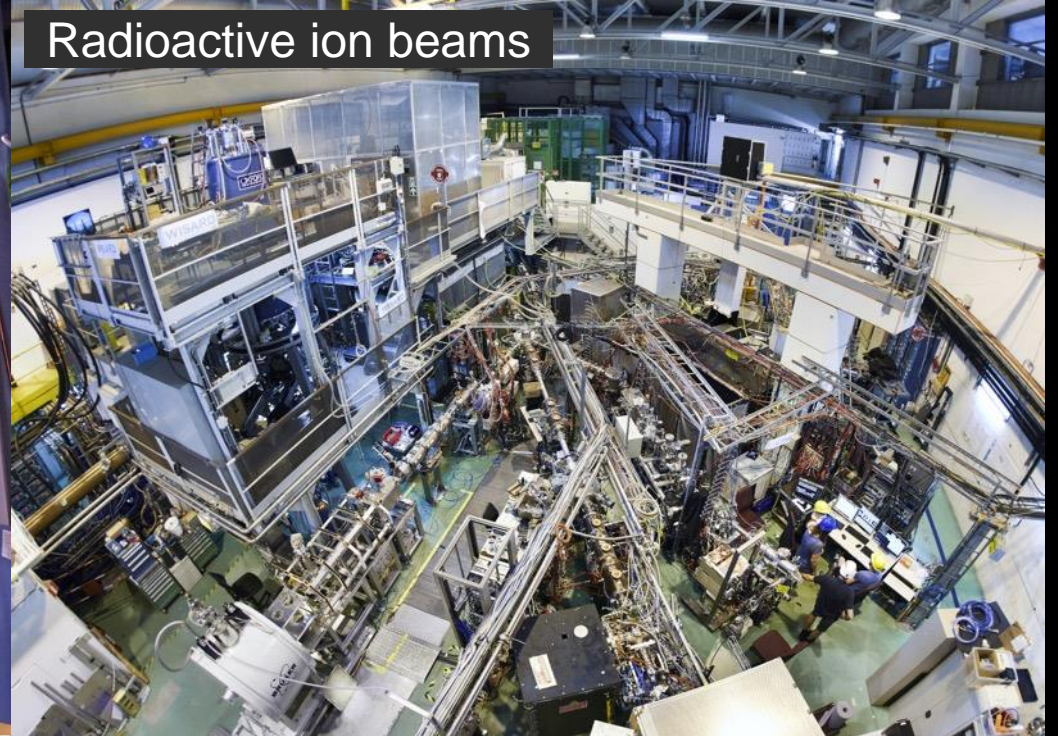




Antiprotons



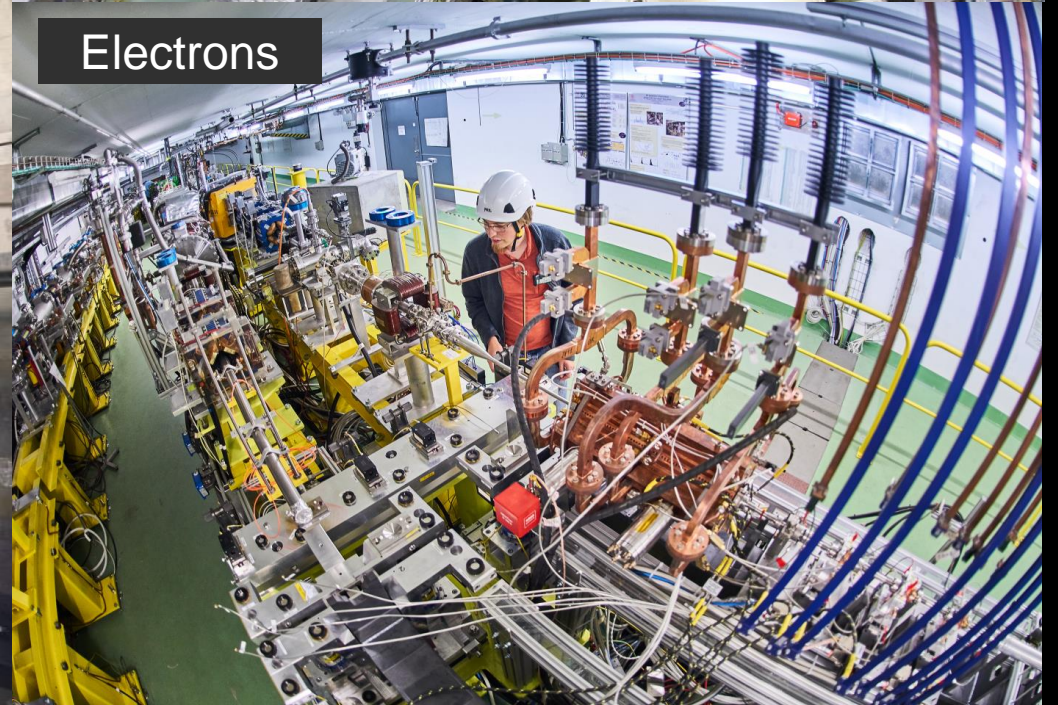
Radioactive ion beams



Protons



Electrons



Liquid Helium

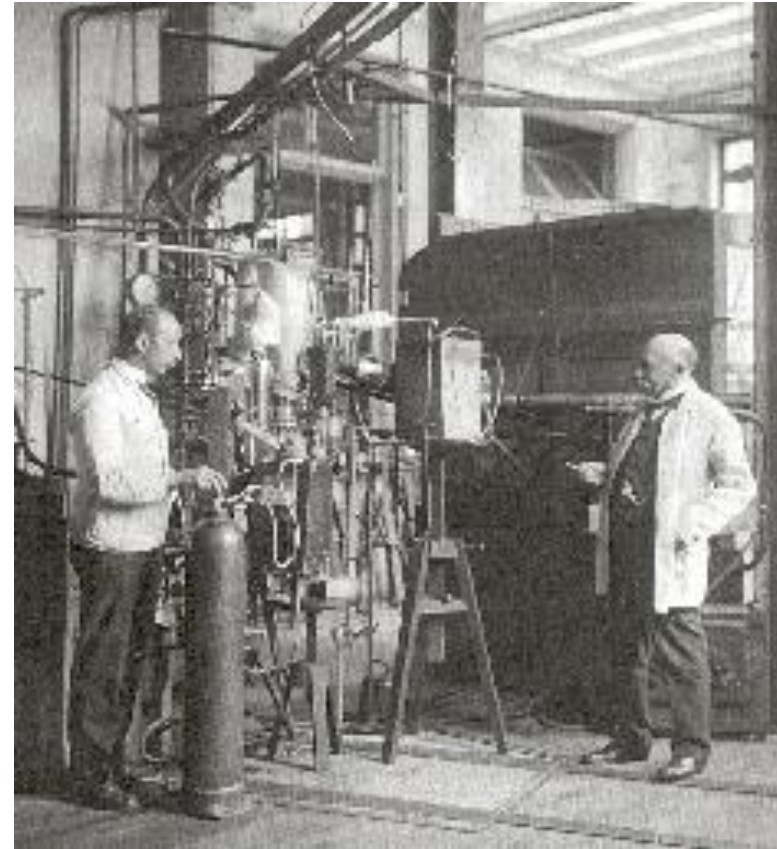
- Helium first liquified at the physics laboratory of Leiden in the Netherlands

Heike Kamerlingh Onnes



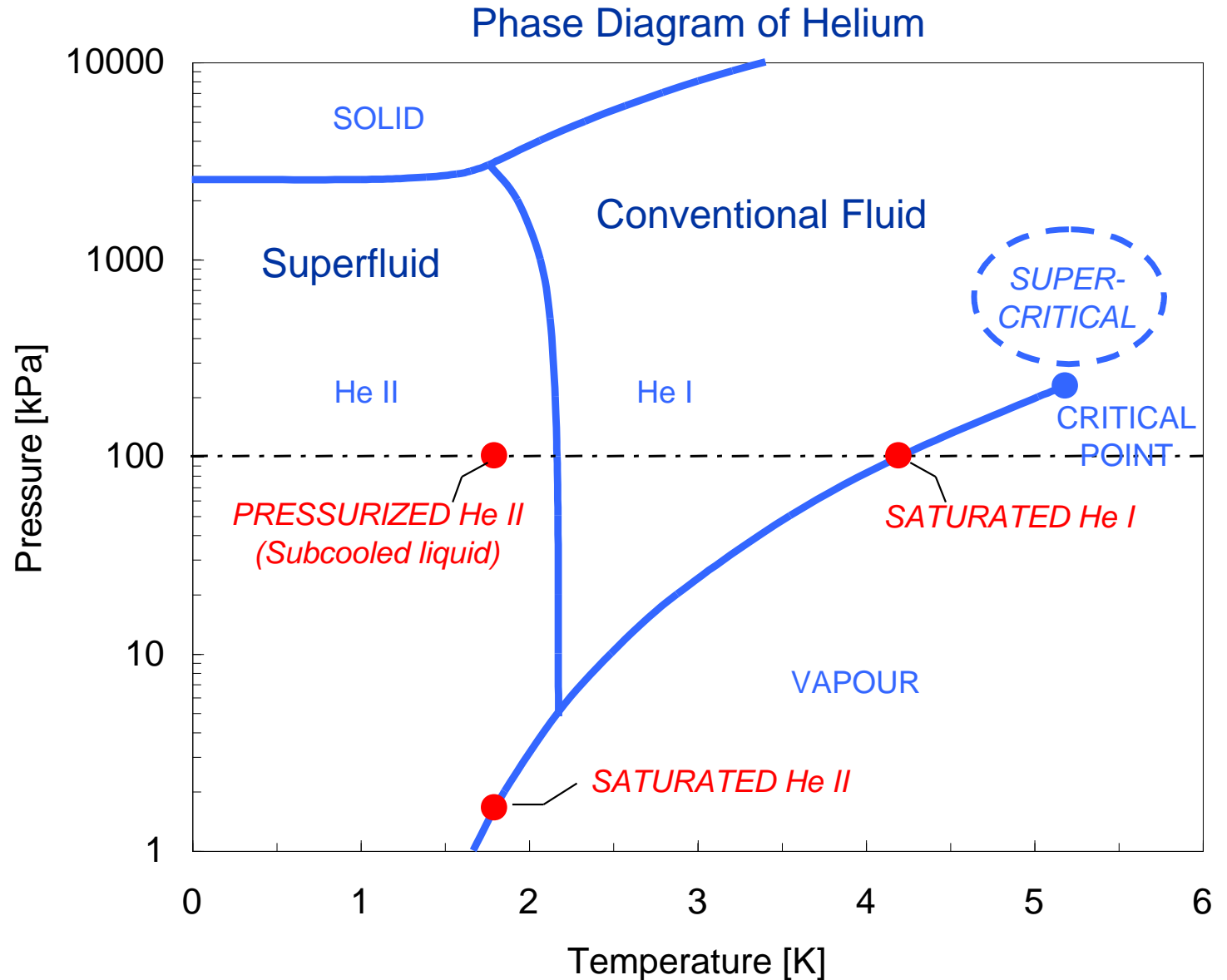
“Door meten tot weten”
To knowledge through measurement

10 July 1908



Liquid Helium

- The remarkable properties of superfluid helium, He II
 - Very high thermal conductivity (3000 times that of copper)
 - Very low coefficient of viscosity... can penetrate tiny cracks, deep inside the magnet coils to absorb any generated heat
 - Very high heat capacity... stabilises small transient temperature fluctuations

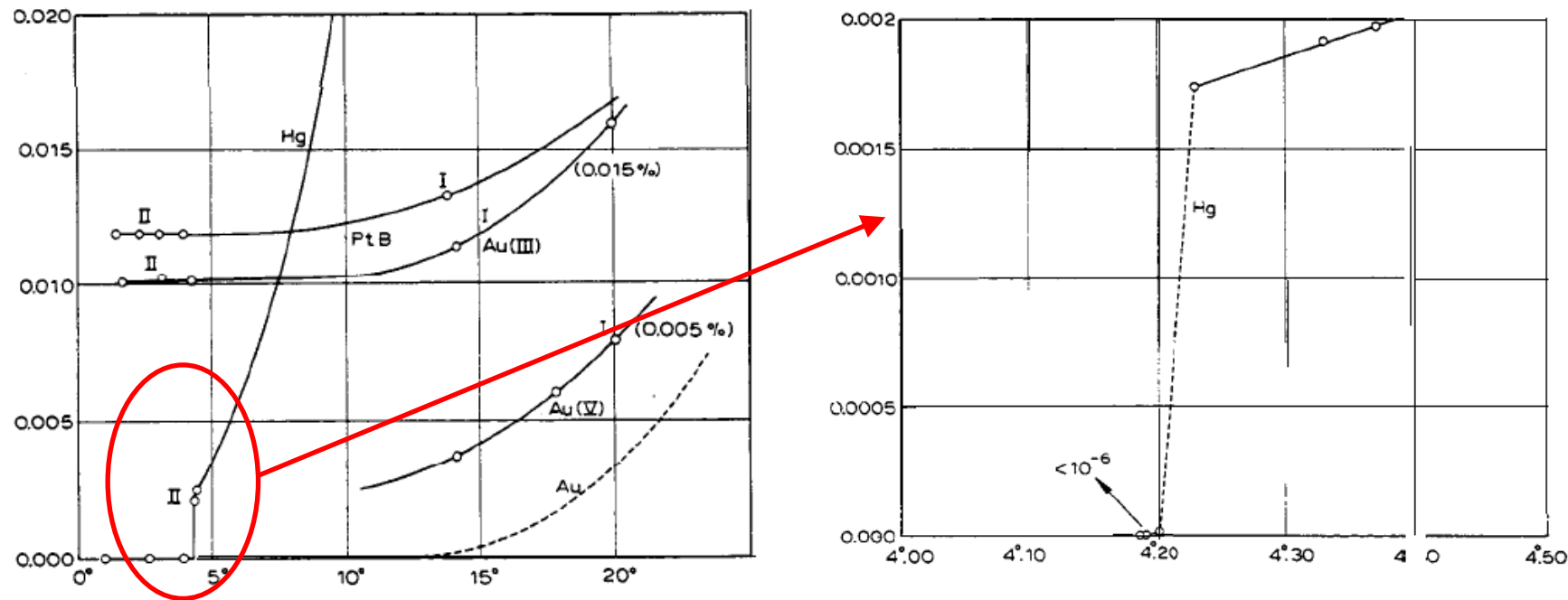




Video 1'44"

Superconductivity

- On 8 April 1911, Kamerlingh Onnes found that at 4.2 K the resistance in a solid mercury wire immersed in liquid helium suddenly vanished

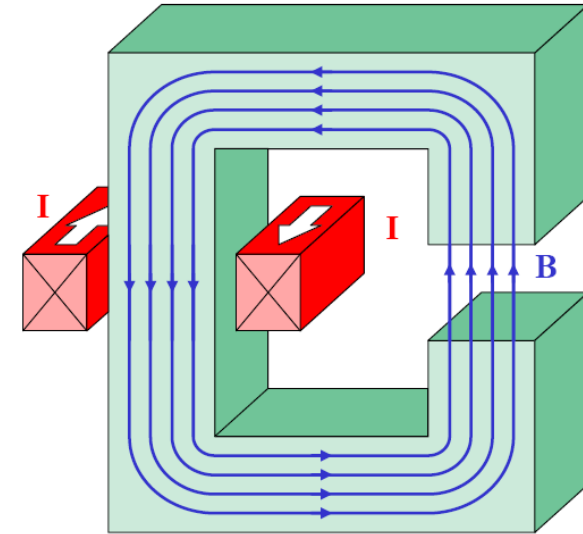


Thus the mercury at 4.2°K has entered a new state, which, owing to its particular electrical properties, can be called the state of superconductivity.

Why use superconductivity?

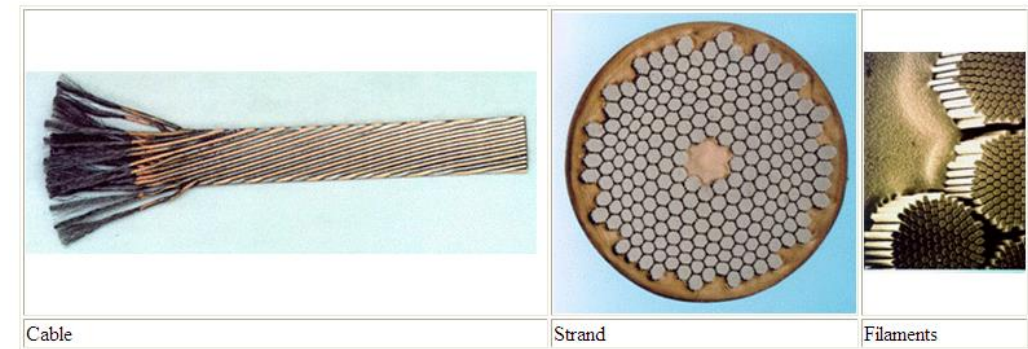
Iron Yoke Magnets

- Good to reduce current required
- Iron guides the magnetic field
- BUT – iron saturates at around 2 T (Tesla)
 - For an accelerator with fixed magnetic field
 - Increasing the energy = increasing the size



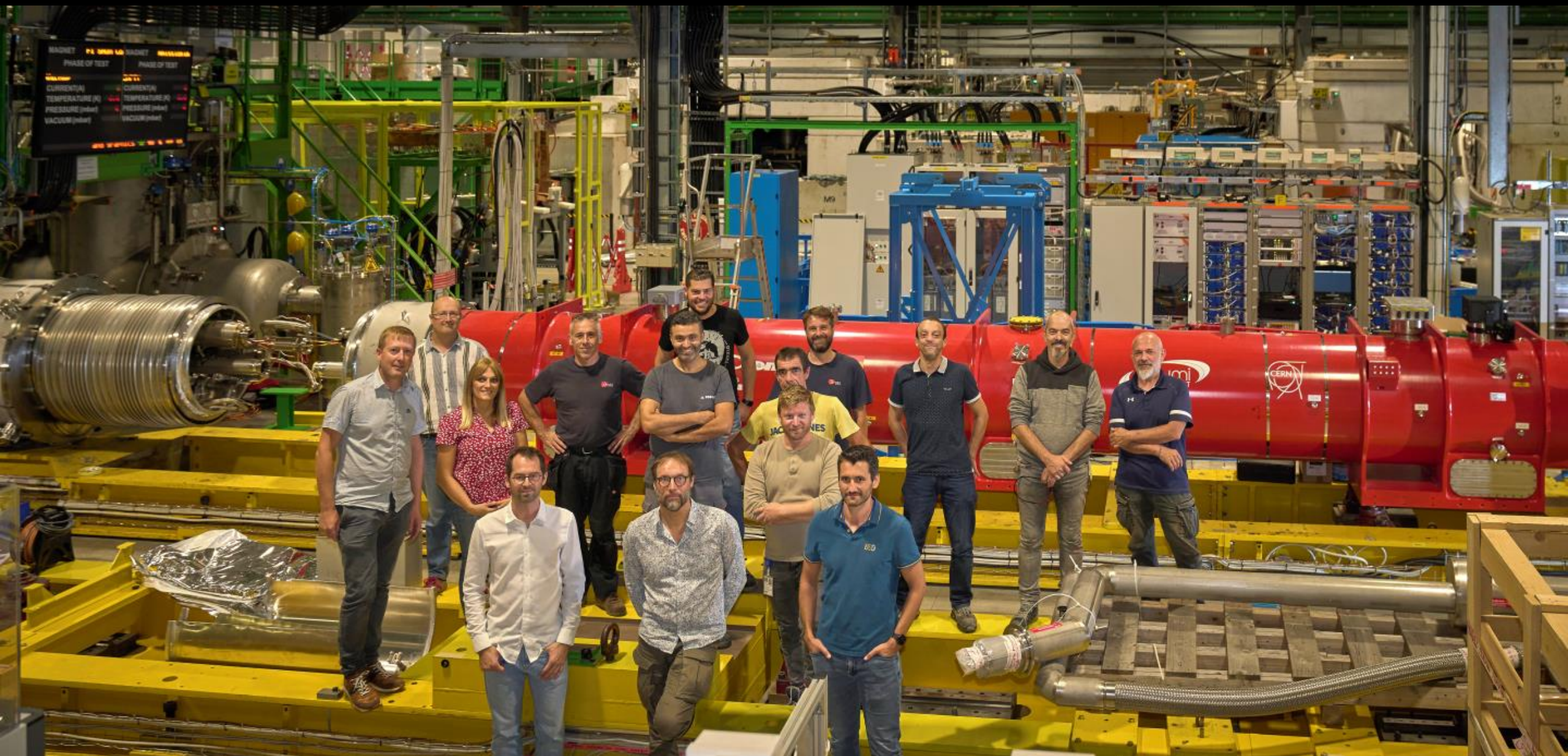
Superconducting Magnets

- Virtually lossless (no resistance!)
 - Can carry very high currents to create high magnetic fields
 - ~8 T in LHC
 - BUT the wire needs to be cooled to near absolute zero





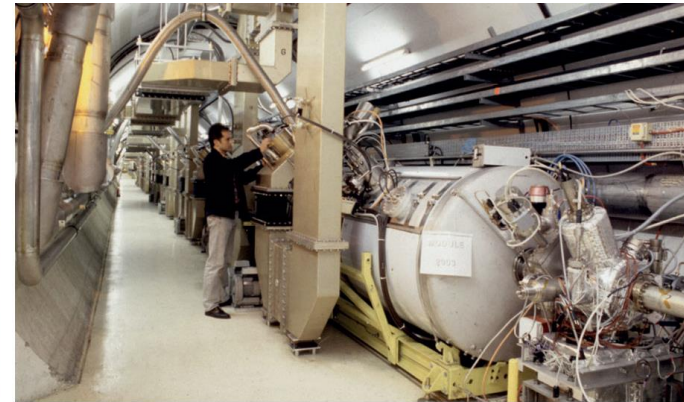
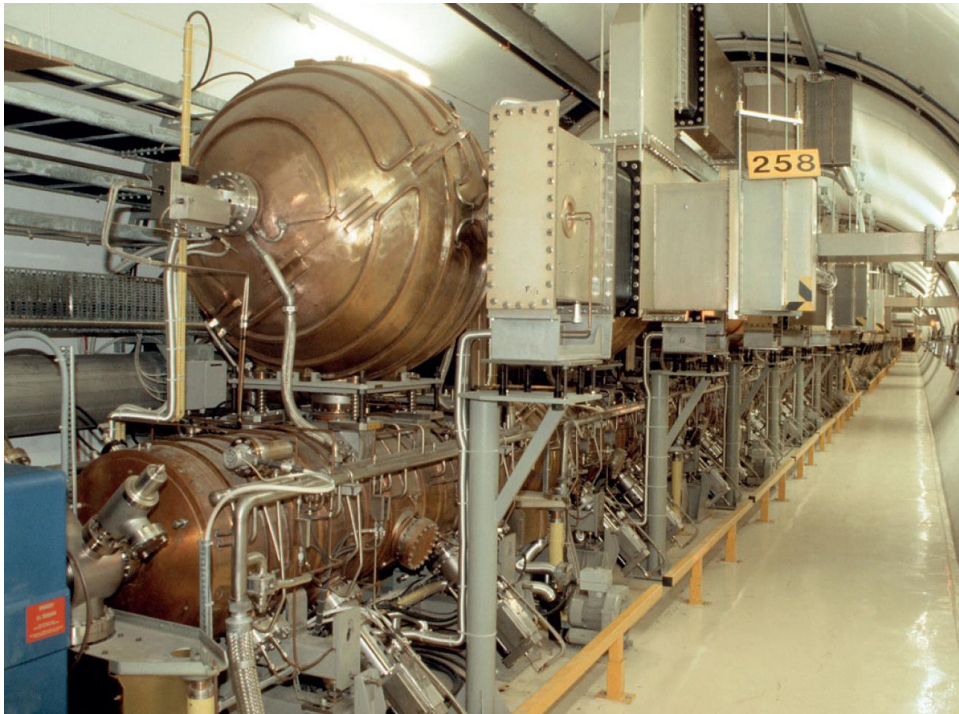
CERN staff sitting on the first PS main magnet at the École de Physique 1955




CERN staff in front of one of the first High Luminosity LHC quadrupoles 2023

Superconducting Acceleration Cavities

- **Superconducting radio frequency (SRF)**
 - Ultra-low electrical resistivity of superconducting material allows an RF resonator to store energy with very low loss over a narrow bandwidth so that nearly all the RF power goes to the beam
 - Copper cavities used to accelerate particles in LEP later replaced by superconducting niobium RF cavities to double the collider's energy beyond the pair-production threshold for W bosons

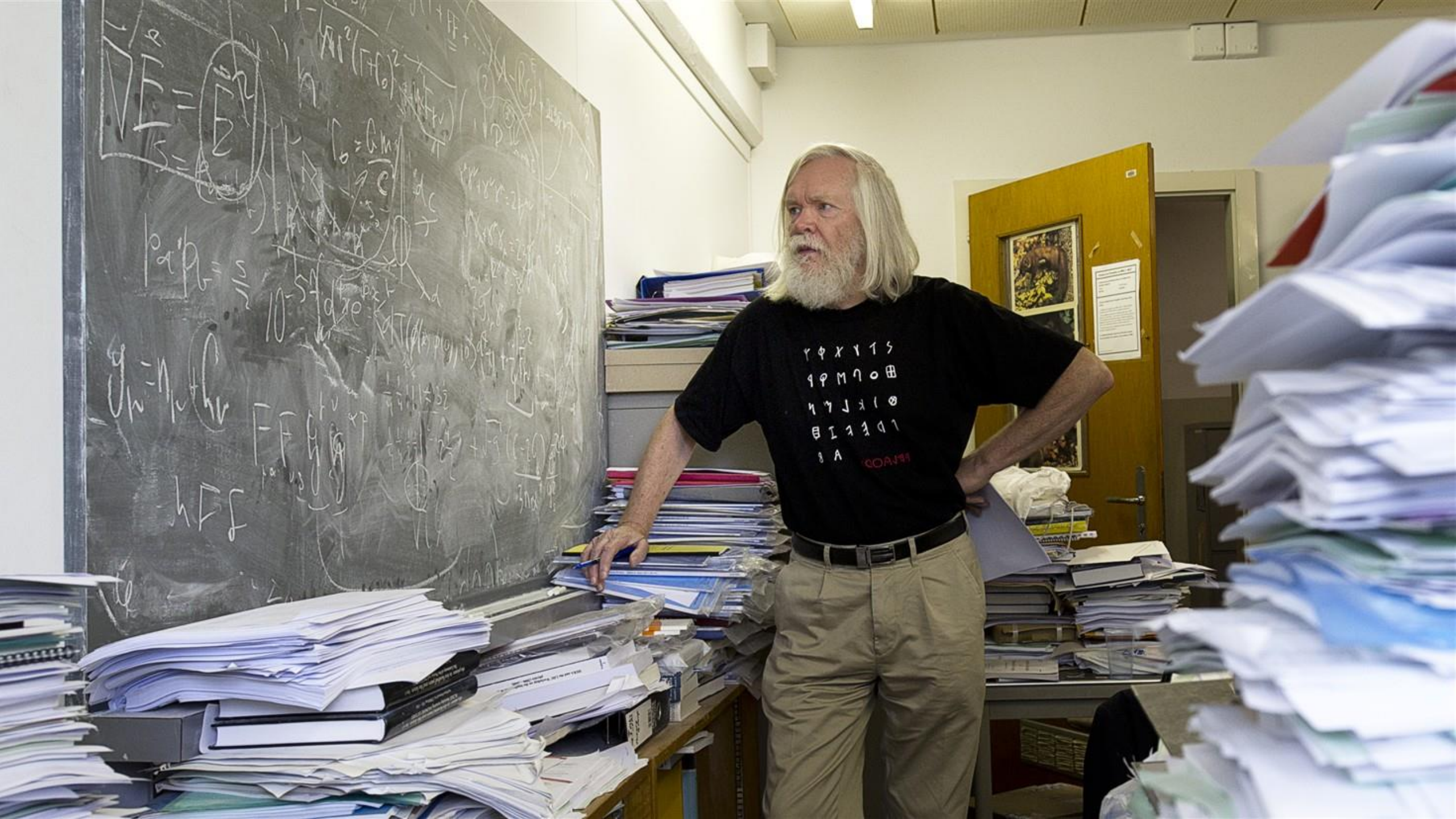


A large group of people, likely researchers and staff, are posed for a group photo in a vast, complex industrial facility. The facility is filled with intricate machinery, including metal scaffolding, walkways, and large pipes. The lighting is a mix of blue and yellow, creating a high-tech atmosphere. A prominent blue text box is overlaid on the upper portion of the image, containing the text: "Our goal is to understand the most fundamental particles and laws of the universe." The people are arranged in many rows, filling the lower half of the frame. The background shows the scale of the facility, with high ceilings and complex structural elements.

Our goal is to understand the most fundamental particles and laws of the universe.



We kids ask
basic and deep questions
How did the Universe begin?
What is its fate?
What is made of?
What are the basic laws?
Why do we exist?
Where do we come from?
What can I do Daddy?



$\sqrt{11} = \sqrt{11}$

$\rho \alpha \rho = \dots$

$10^{-5} d \dots$

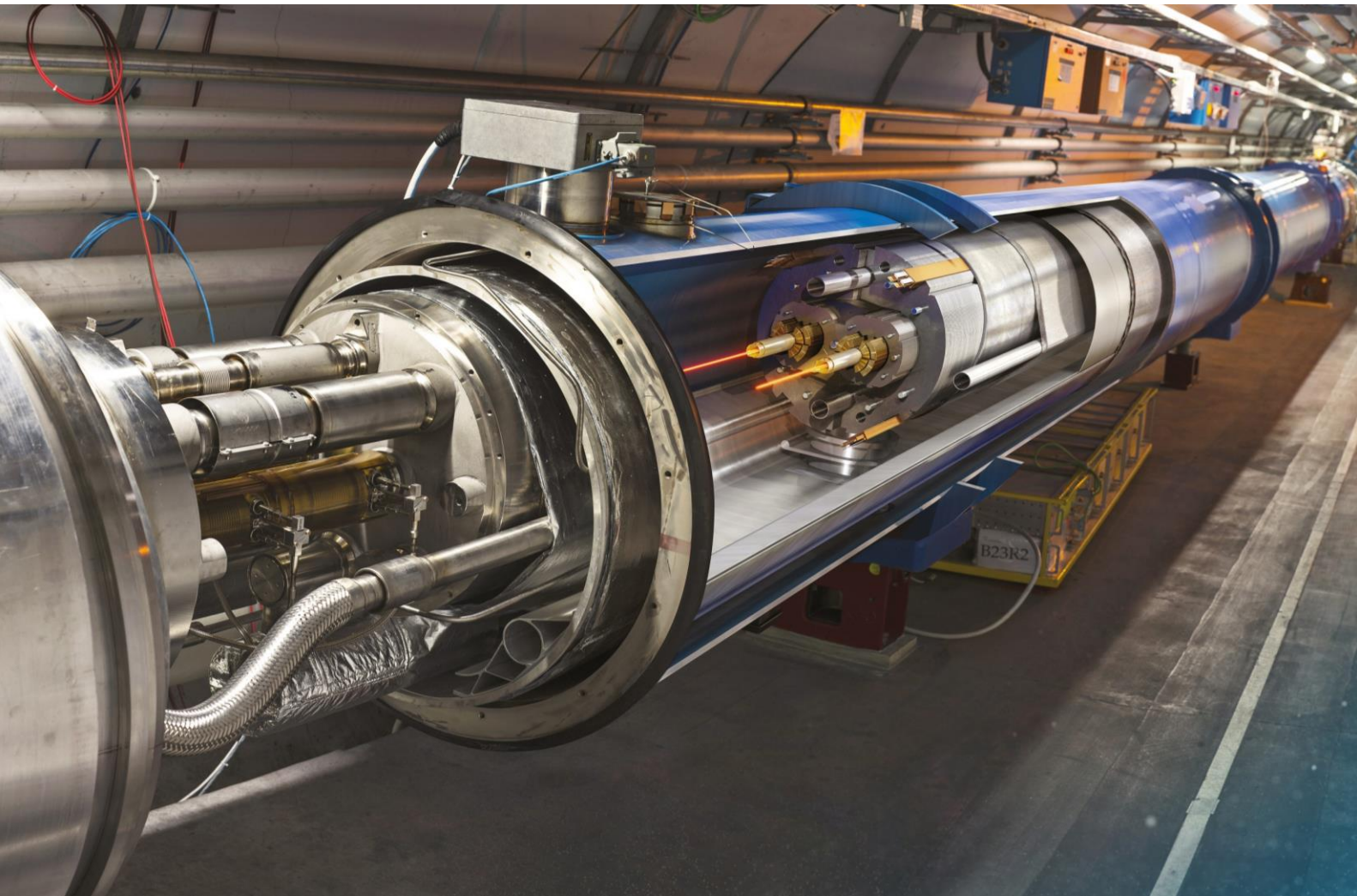
$g = n \dots$

$h F F$

\dots

γ	φ	χ	γ	τ	ς
ρ	ρ	μ	η	ο	⊕
η	γ	λ	κ	ι	⊗
θ	ι	τ	ι	δ	ι
λ	α				

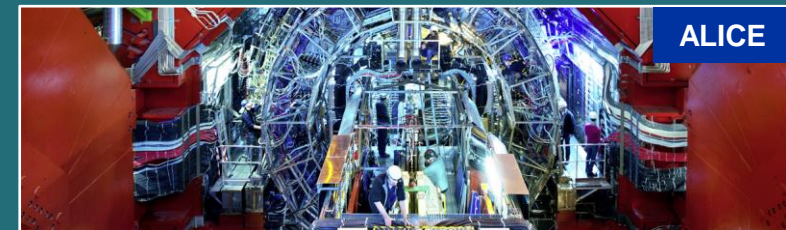
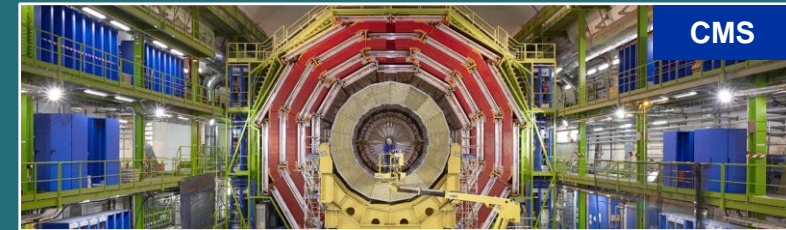
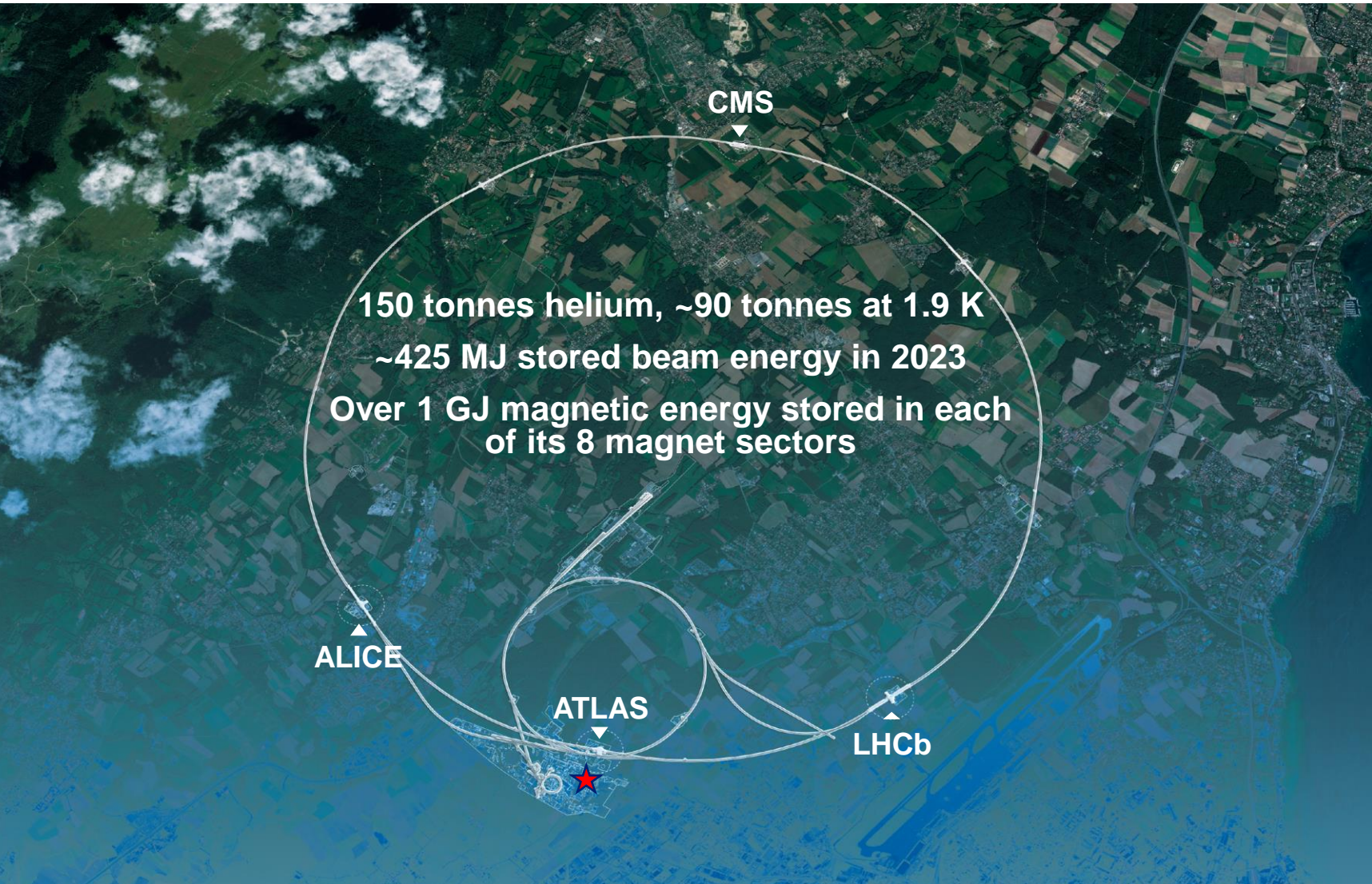
FRANCO



The Large Hadron Collider

- 27 km in circumference
- About 100 m underground
- 2 beams of trillions of protons travelling at 0.999999991 times the speed of light in opposite directions
- Superconducting radiofrequency system to accelerate the beams
- NbTi Superconducting magnets operating at $-271.3\text{ }^{\circ}\text{C}$ to bend them in a circle
- Largest beam vacuum system worldwide
- Advanced powering, machine protection systems, beam diagnostics & control
- 4 large experiments

The LHC and its Detectors





Announcement of Higgs
discovery July 4th 2012



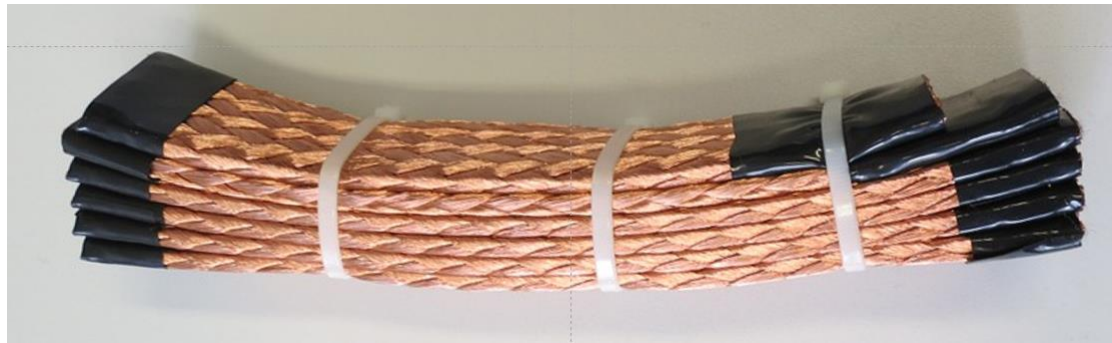
with a quadrillion collisions...

Why is the LHC Superconducting?

- A standard household power cable can carry 13 Amps of current
 - 13 Amps at Room Temperature



- A magnet strong enough for the LHC needs 13'000 Amps
 - 13'000 Amps at Room Temperature



- 13'000 Amps at -271 °C

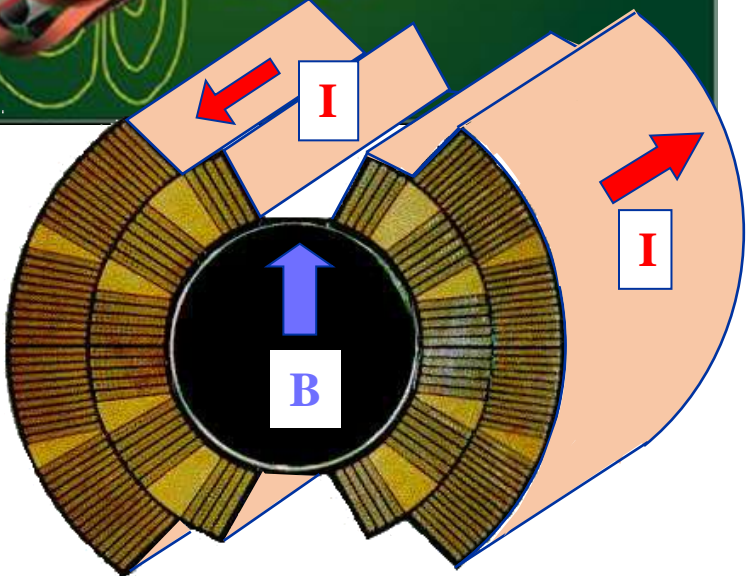
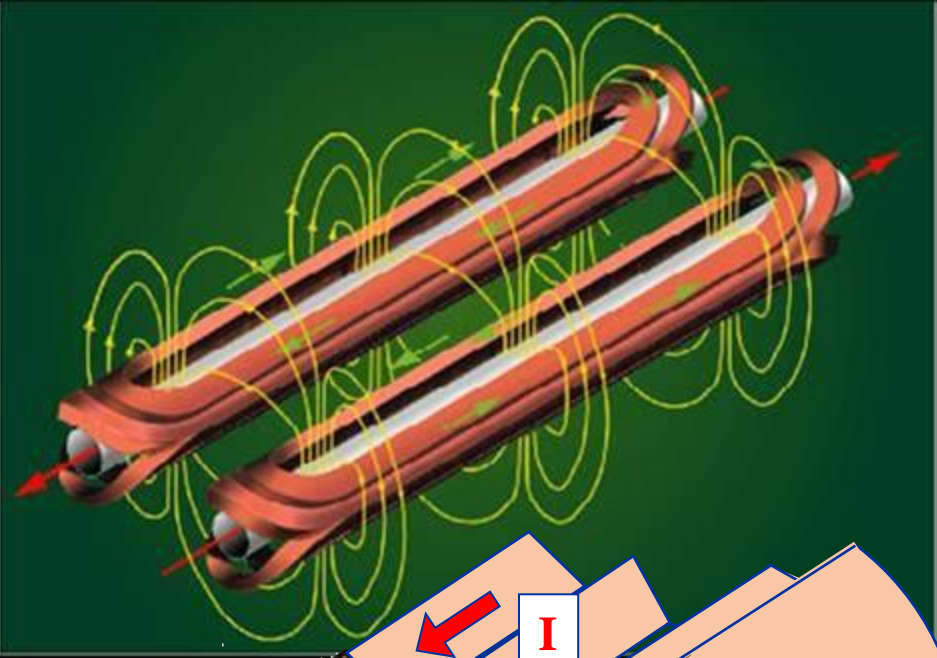
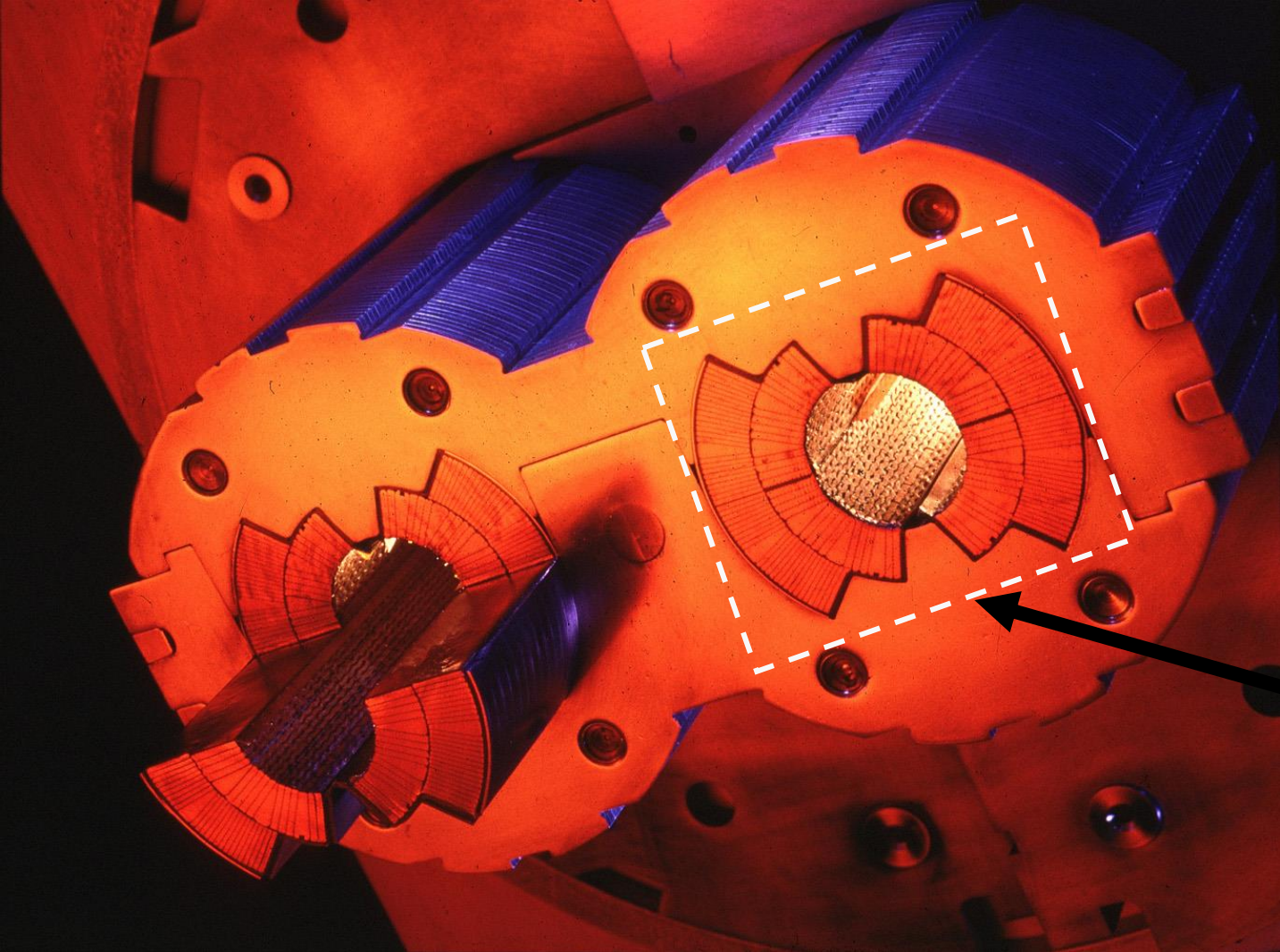


- Using superconducting cable operating at 2 Kelvin (-271 °C) was the only way to produce magnets for the LHC

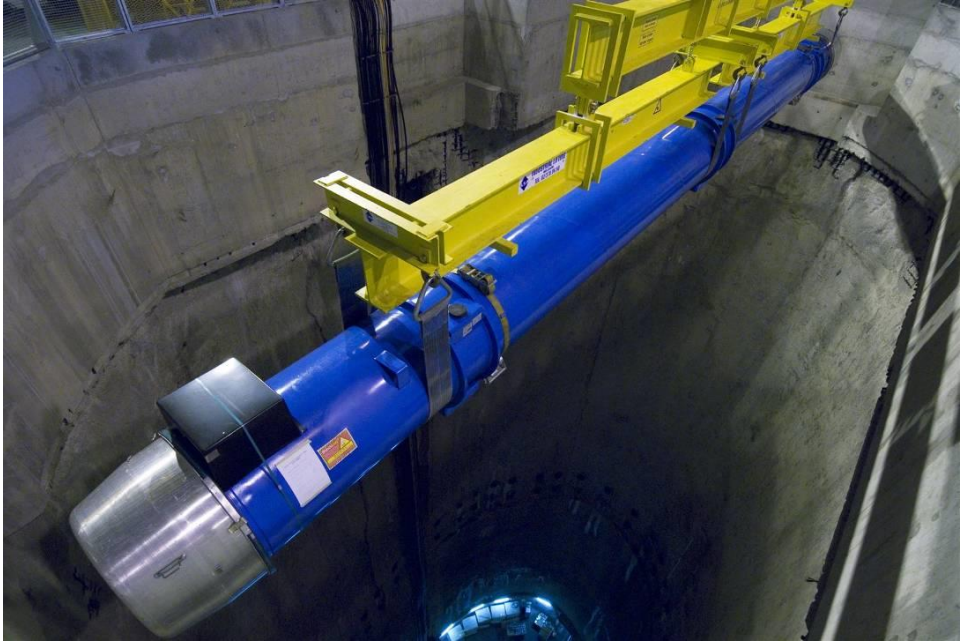
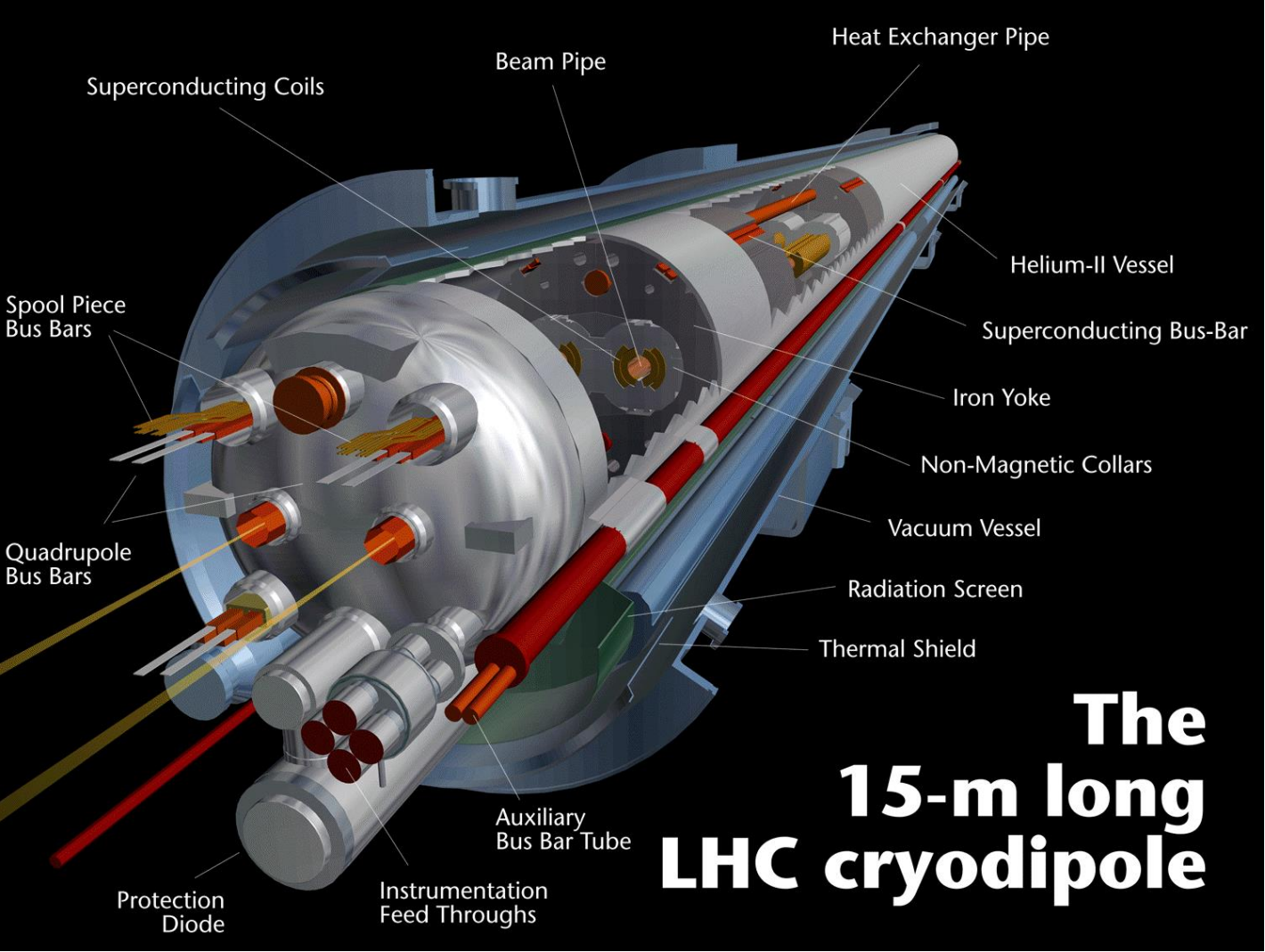


Scale

LHC Dipole Magnets



LHC Dipole Magnets



LHC Dipole Magnets – the long road to success



Cooling the Magnets

CRYOGENICS

- 24 km of superconducting magnets @1.9 K
- 88 tons of superfluid helium at 1.9 K

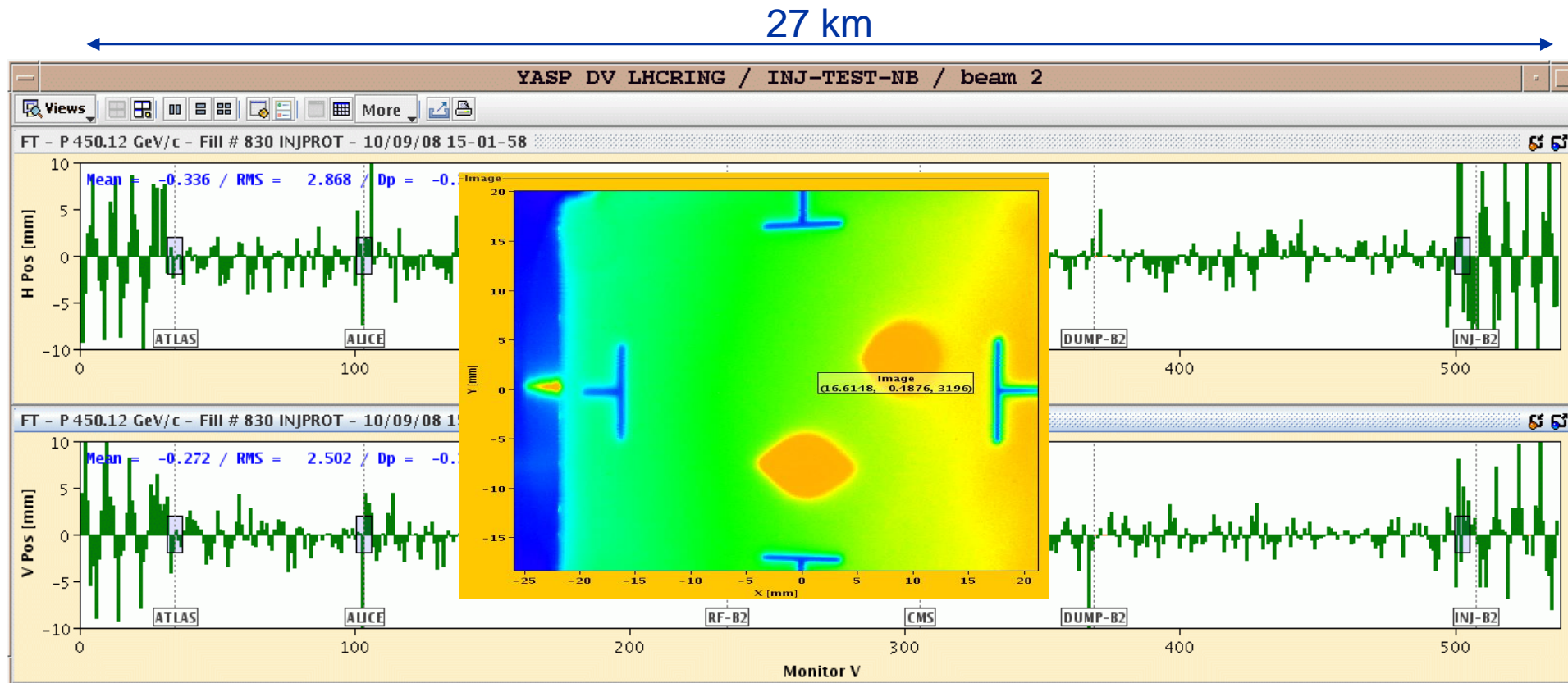
Acceleration in the LHC

- **The acceleration section of the LHC is only 30 m in length**
- **Contains 2 modules made of 4 cavities per beam**
 - Providing up to $2 \times 4 \times 2 \text{ MV} = 16 \text{ MV}$ of accelerating gradient
- **It LHC takes ~30 minutes to reach top energy (~20 million turns)**
 - Driven by how fast the magnetic field can be ramped-up rather than how fast we can accelerate



Controlling the Beams

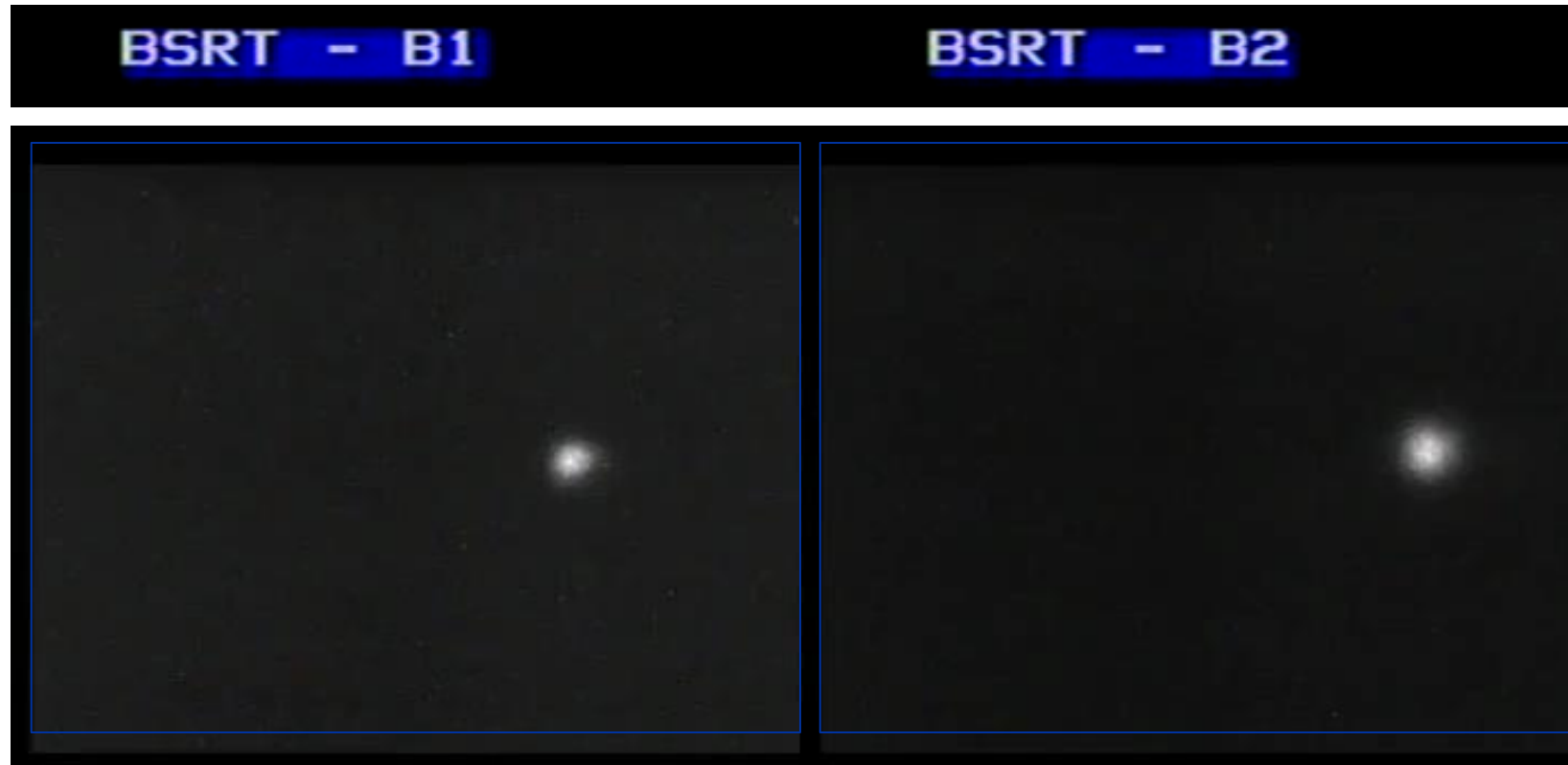
- **Beam Instrumentation - over 500 position monitors per beam**
 - Automatic feedback systems measure the beams & correct trajectories by adjusting magnetic field to keep them within 10 microns of desired position



Controlling the Beams

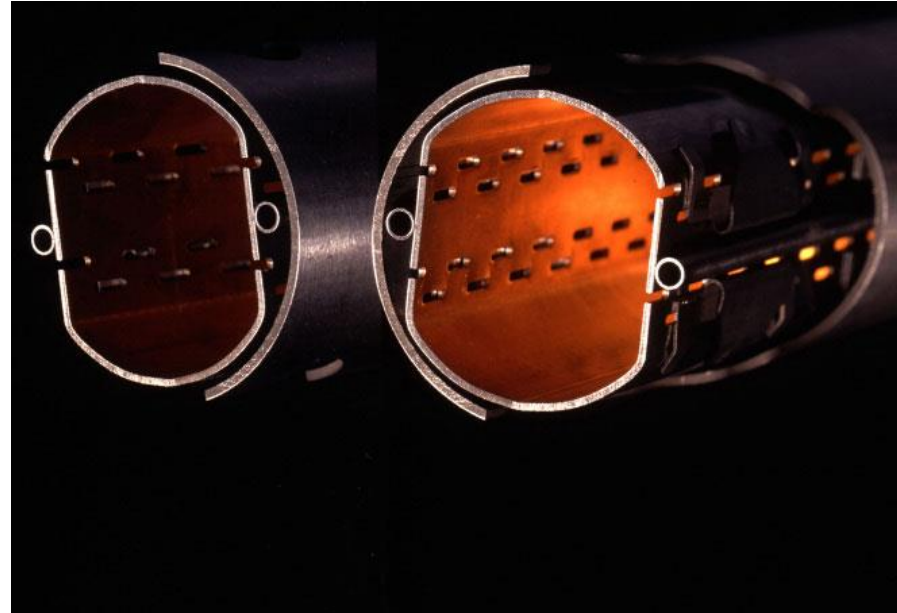
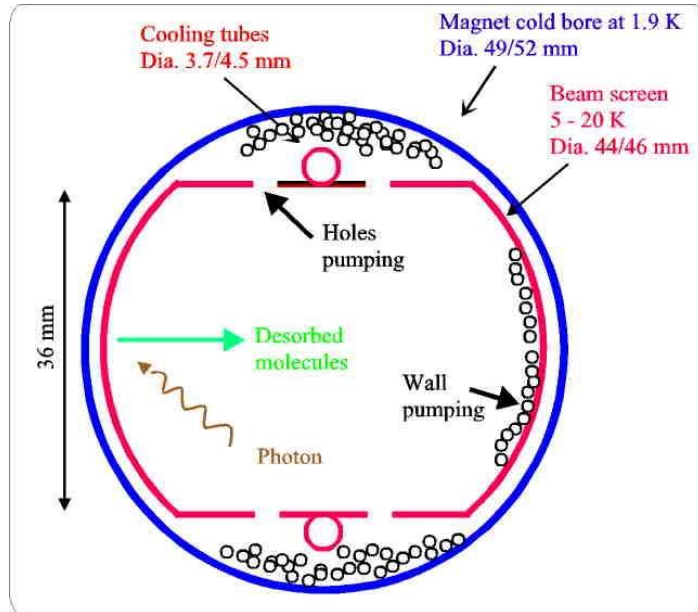
- **Synchrotron light monitors**

- The protons have such a high energy that they emit light when bent by the magnetic field
 - “synchrotron radiation”
- Looking at this light allows us to measure the size of the individual proton bunches in the LHC



LHC Vacuum

Beam vacuum $\sim 10^{-10}$ mbar (~ 3 million molecules/cm³)



- **Cold**

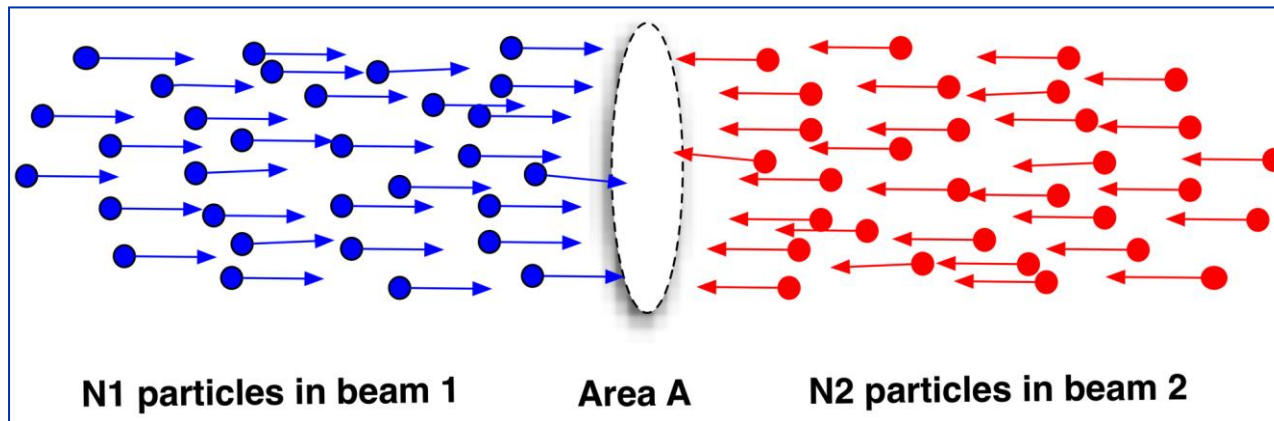
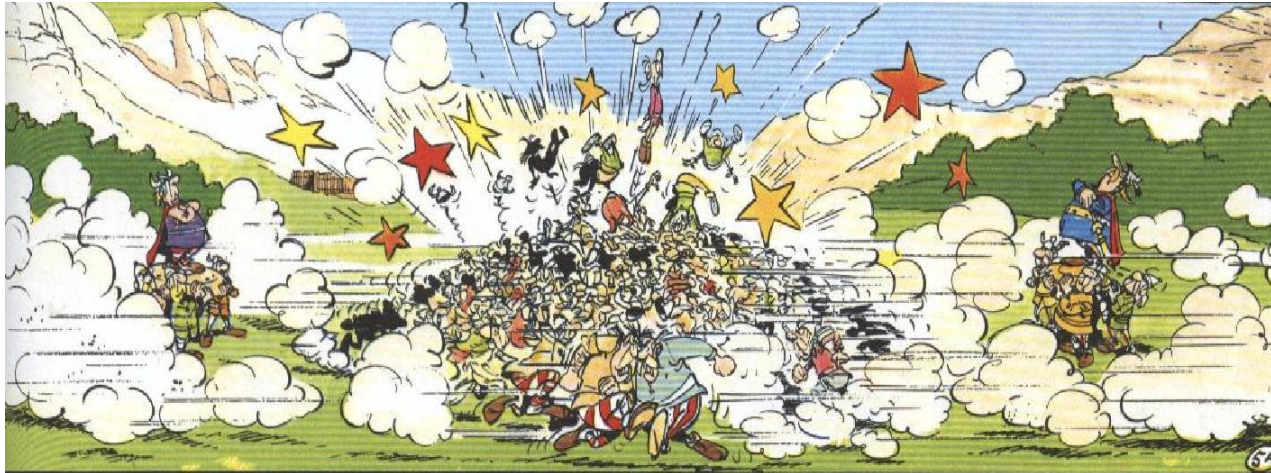
- Pumping is insured by cold surfaces for all gases except helium
- Low initial pressures are required before cool-down and this is ensured by turbo molecular pumps

- **Warm**

- Non-evaporable getter (NEG) provides most of the pumping capacity

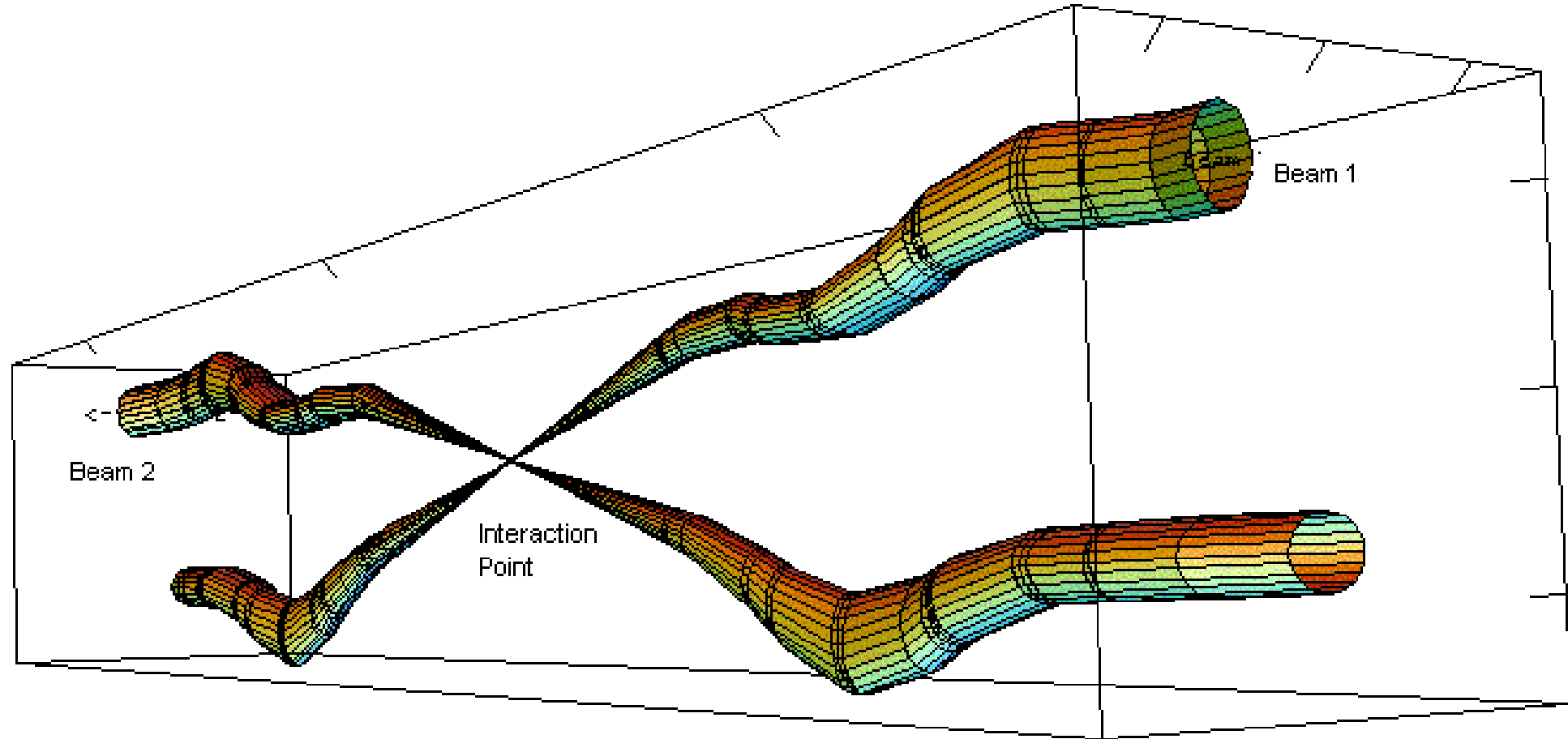
Aim of the Game

- To deliver the maximum number of collisions at the maximum beam energy for maximum physics reach – **LUMINOSITY Counts!**



The Squeeze

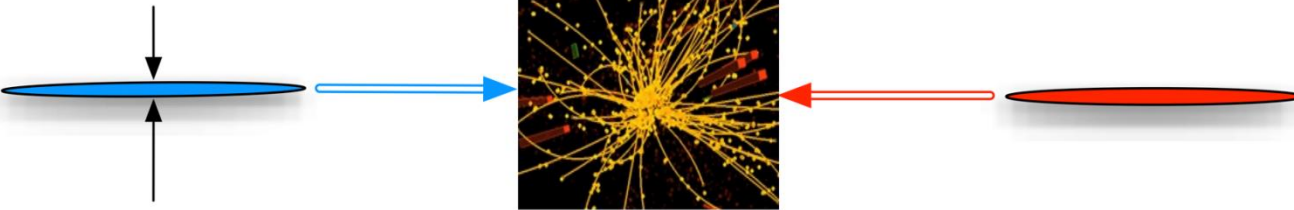
- Focusing the beams at the interaction point



Collisions in the LHC

140,000,000,000 protons a bunch
~30 collide at each bunch crossing

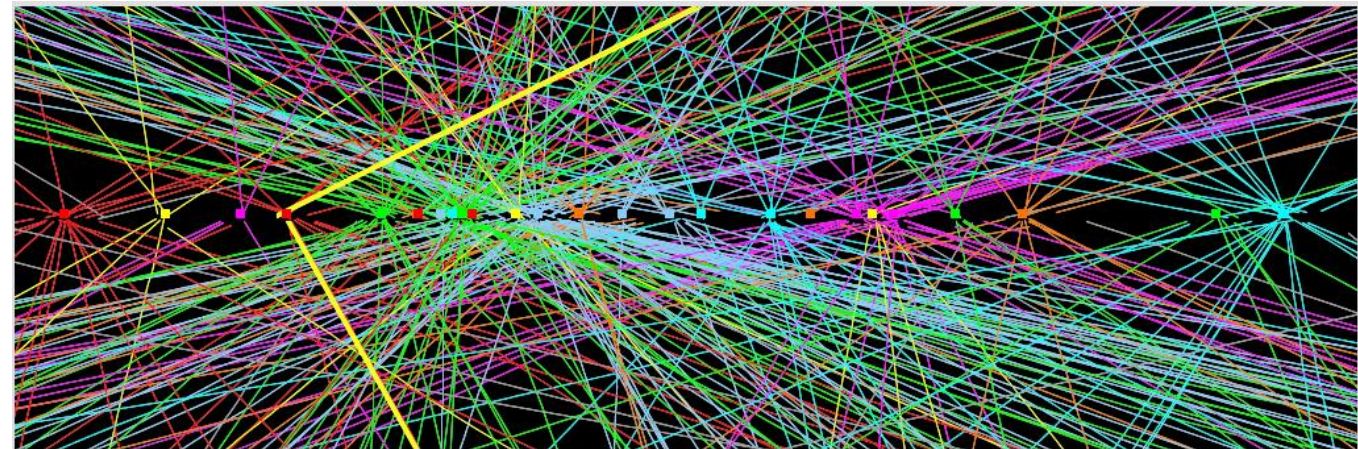
60 micron



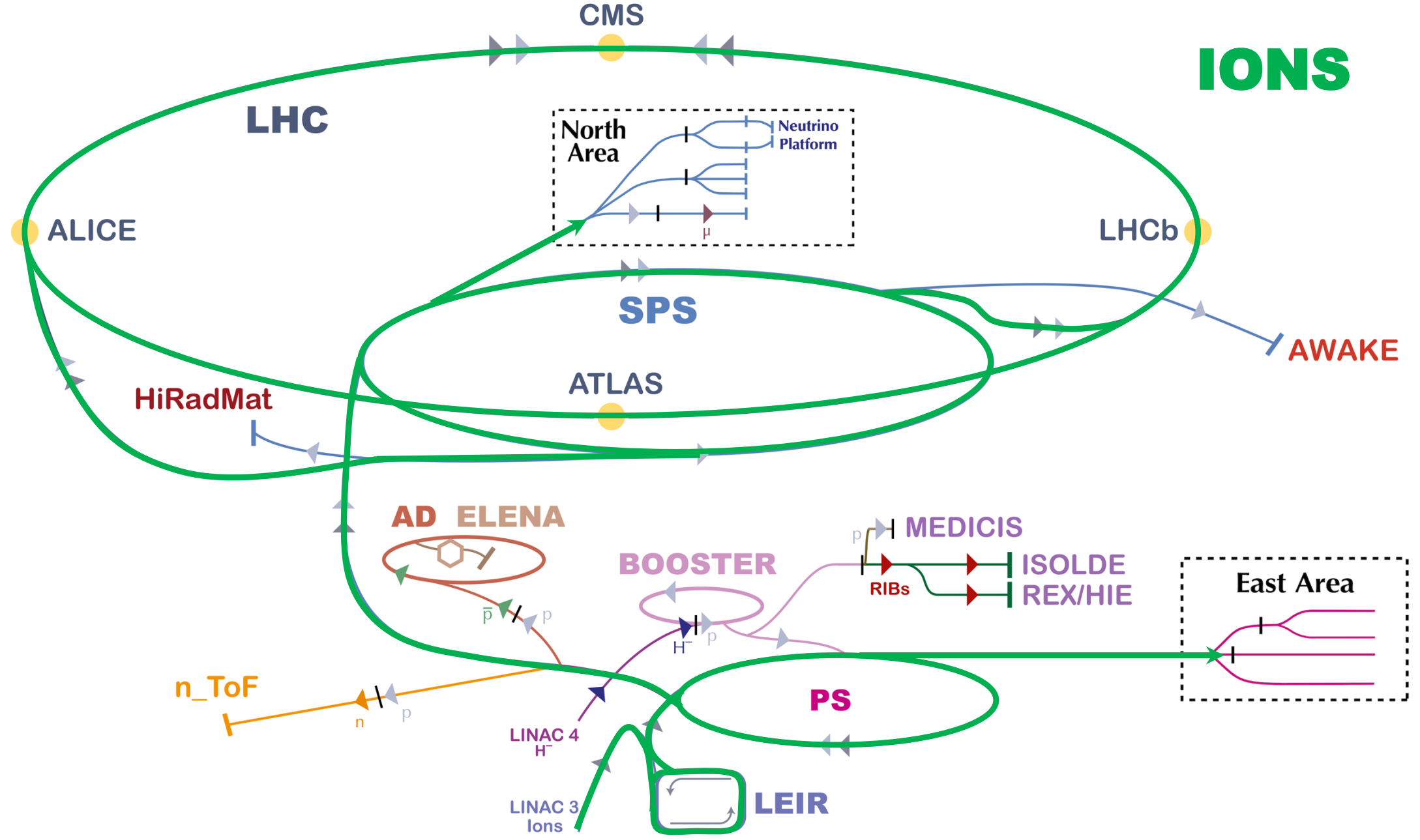
Now regularly operating with

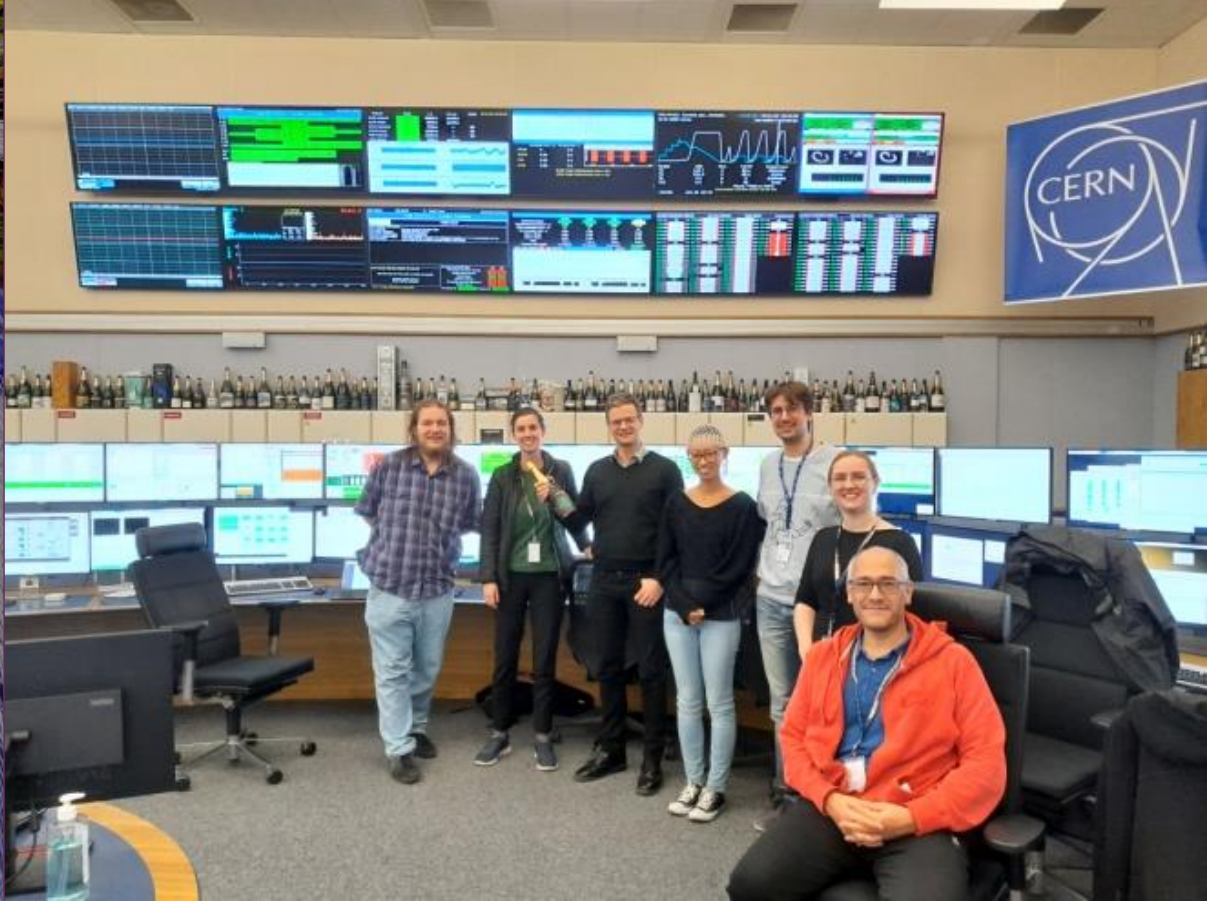
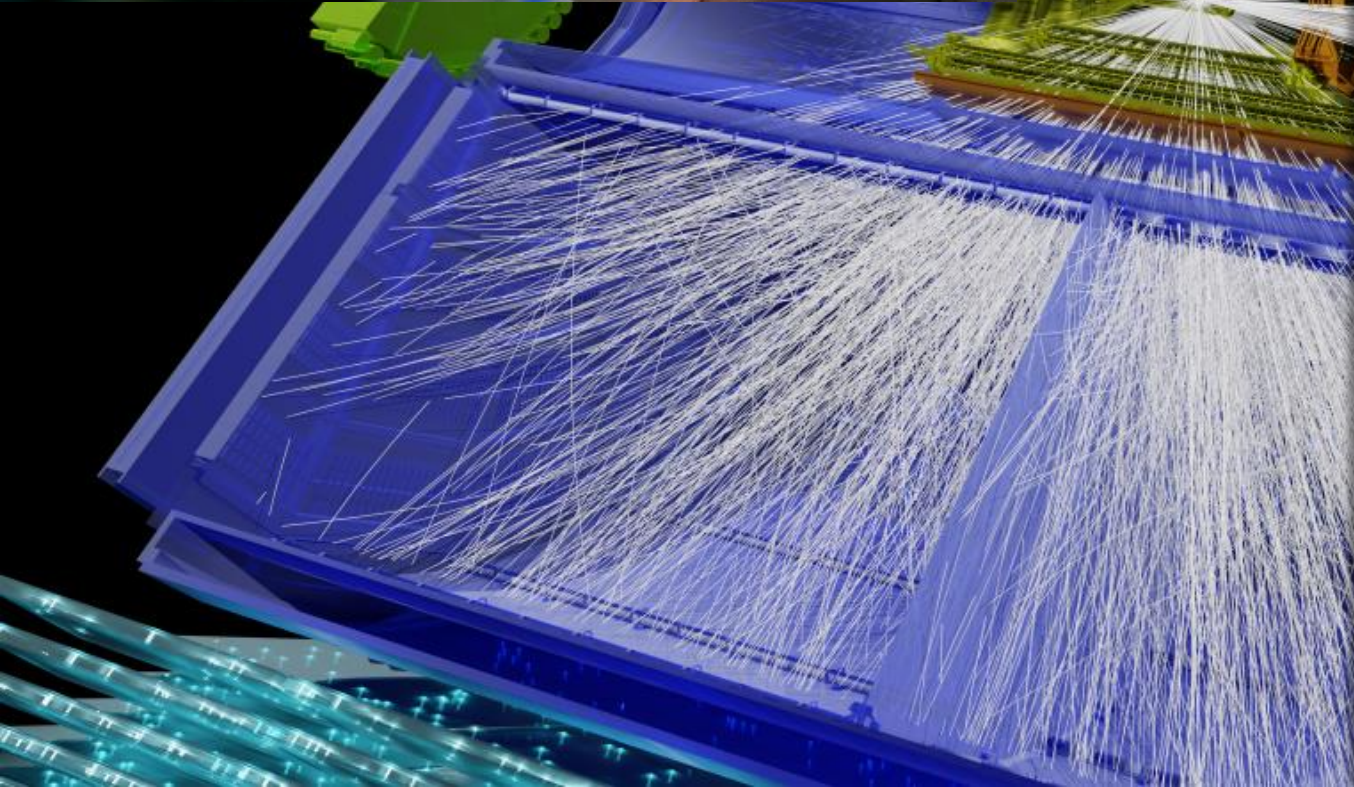
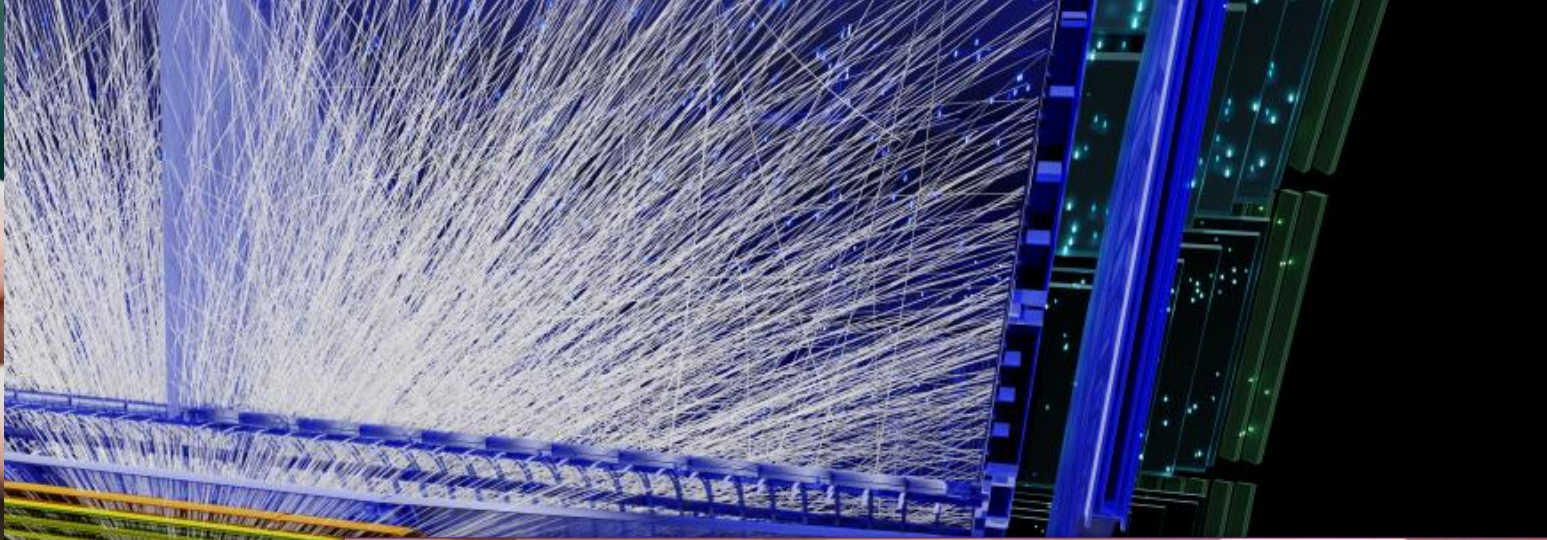
- 1.6×10^{11} protons per bunch
- Over 2000 bunches
- Up to 65 collisions per bunch crossing
- 1.5 billion collisions per second

~30 collisions per crossing
11,000 crossings per second per bunch
1380 bunches
~400 million collisions per second



IONS





What next for the LHC?

- **Studying the Higgs particle in detail**

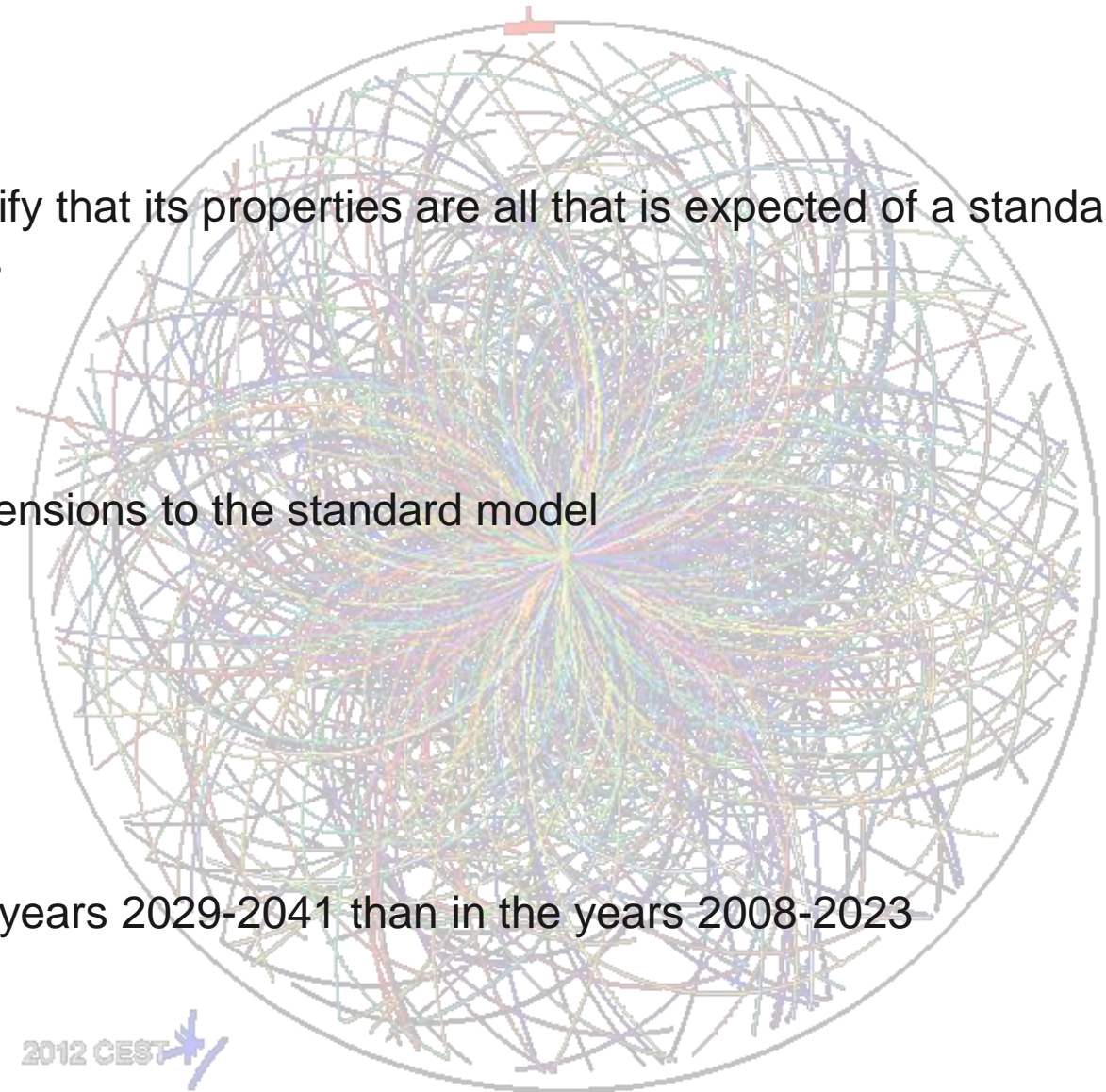
- It will take time and much more data to verify that its properties are all that is expected of a standard model Higgs Boson, portal for new physics

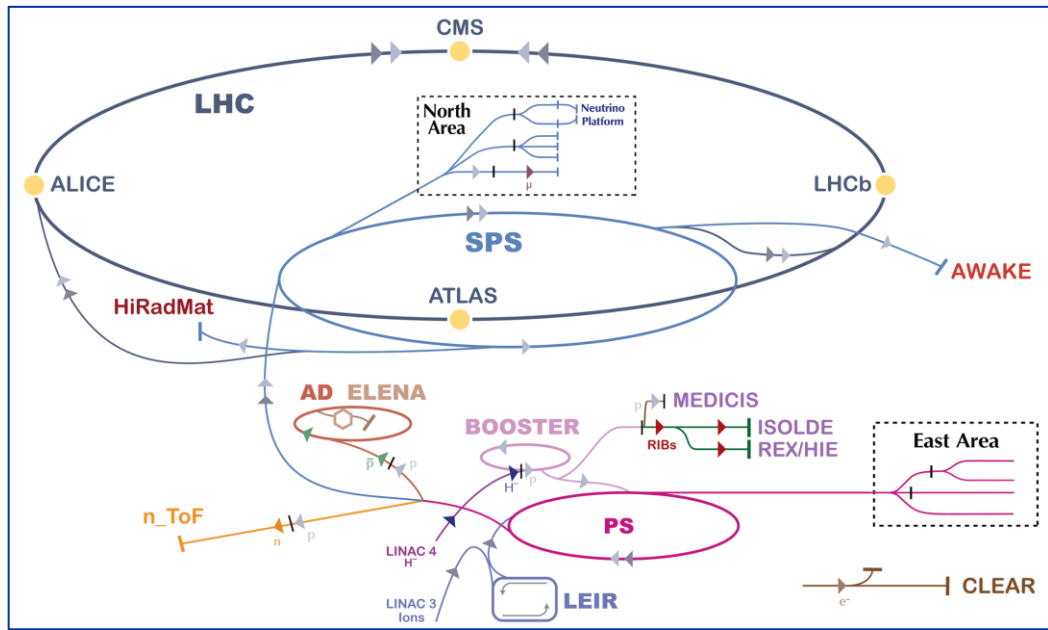
- **Looking for new physics**

- Constraining theoretical alternatives or extensions to the standard model
- All this relies on much more data

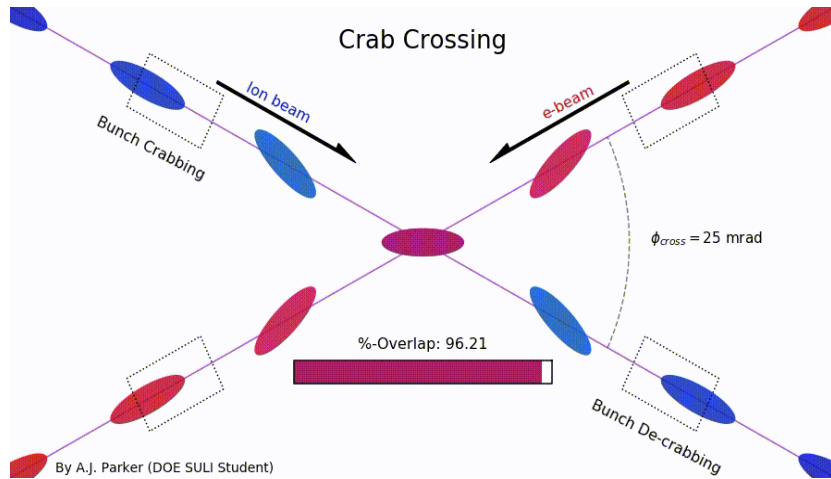
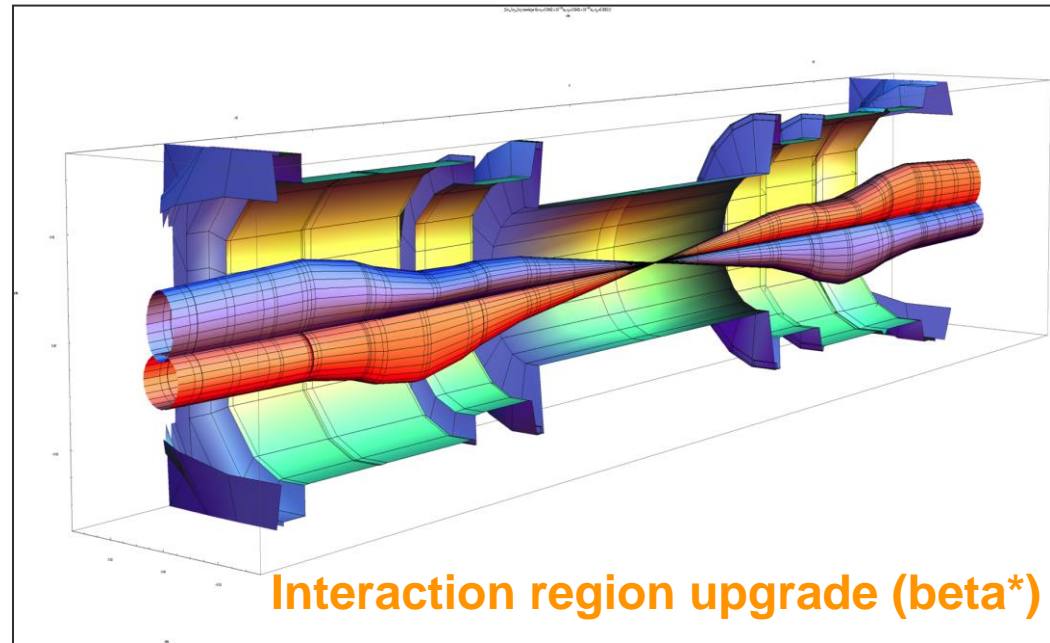
- **Upgrading to High Luminosity LHC**

- Foreseen for 2026-28
- Aim is to collect 10 times more data in the years 2029-2041 than in the years 2008-2023

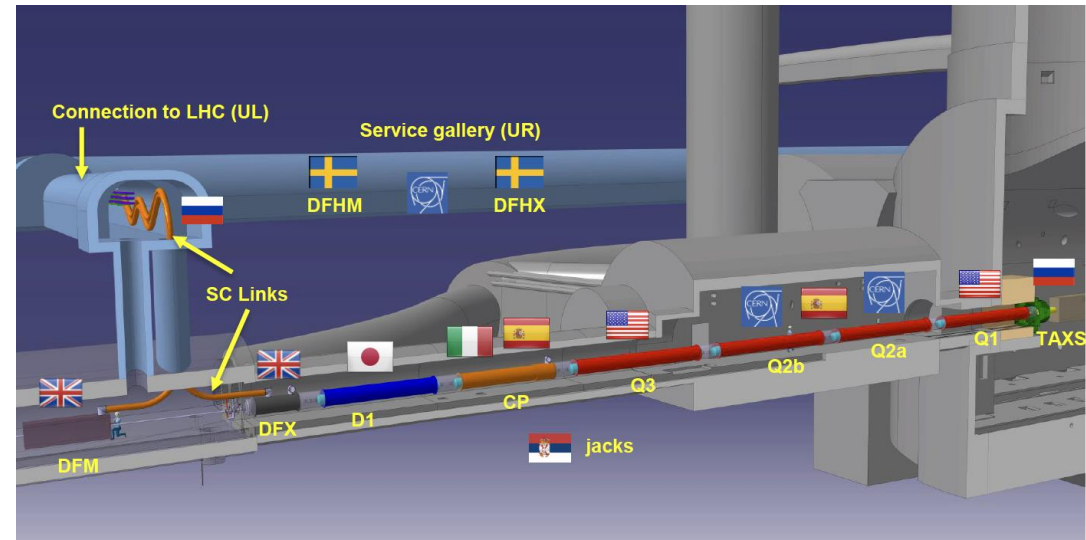




Injector upgrade (bunch population, emittance)



Crossing angle compensation (crabs)



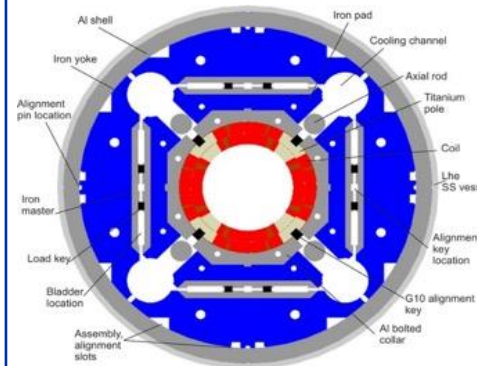
Operate in a high luminosity regime

Final focus quadrupoles

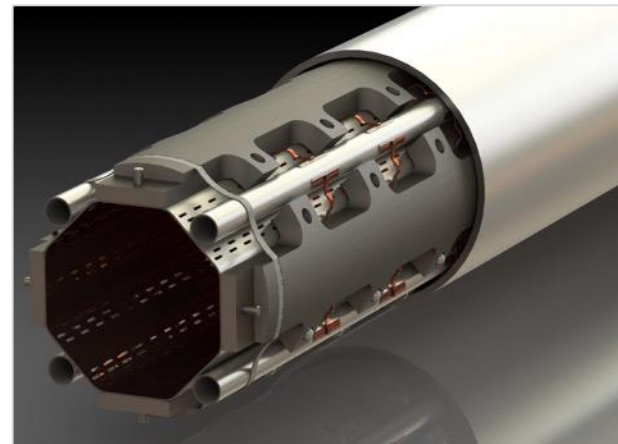
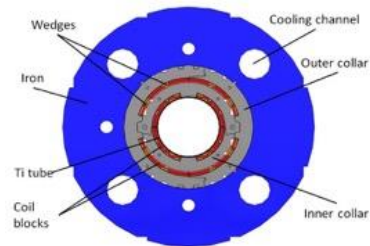
New wide-aperture

- **Nb₃Sn technology** → Larger operational peak fields (~12 T)
- **Large aperture:** 150 mm
 - Allows for **smaller beam size** at the experiments
 - Allows introducing **tungsten shielding** to protect the magnet from radiation generated by collisions
- **Series production in progress**

Final focus quadrupole (MQXF)



Dipole corrector



HEP options – (some of) the tools of the trade

Hadron (protons, ions) colliders

- Messy collisions
- High luminosity
- High energy – good for **discovery**

Circular e+e- Colliders

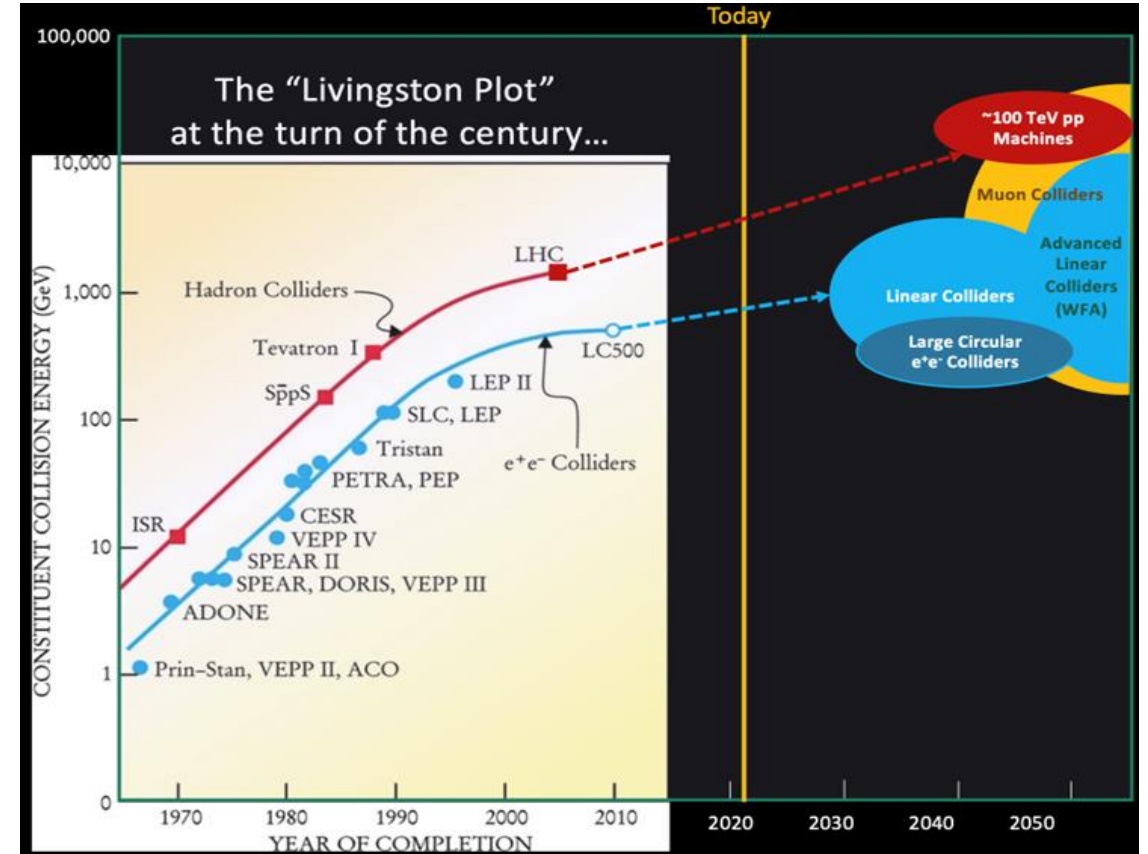
Reuse tunnel

- Clean collisions – good for **precision**
- Multi-pass – high luminosity
- Energy eventually limited by synchrotron radiation
- Multiple Interaction Points

Linear e+e- Colliders

Extend

- Insignificant synchrotron radiation
- 1 Interaction Point, 1 or 2 experiments
- Single pass, nanometre beam sizes at IP



M. Palmer, MT21

Future Options at CERN

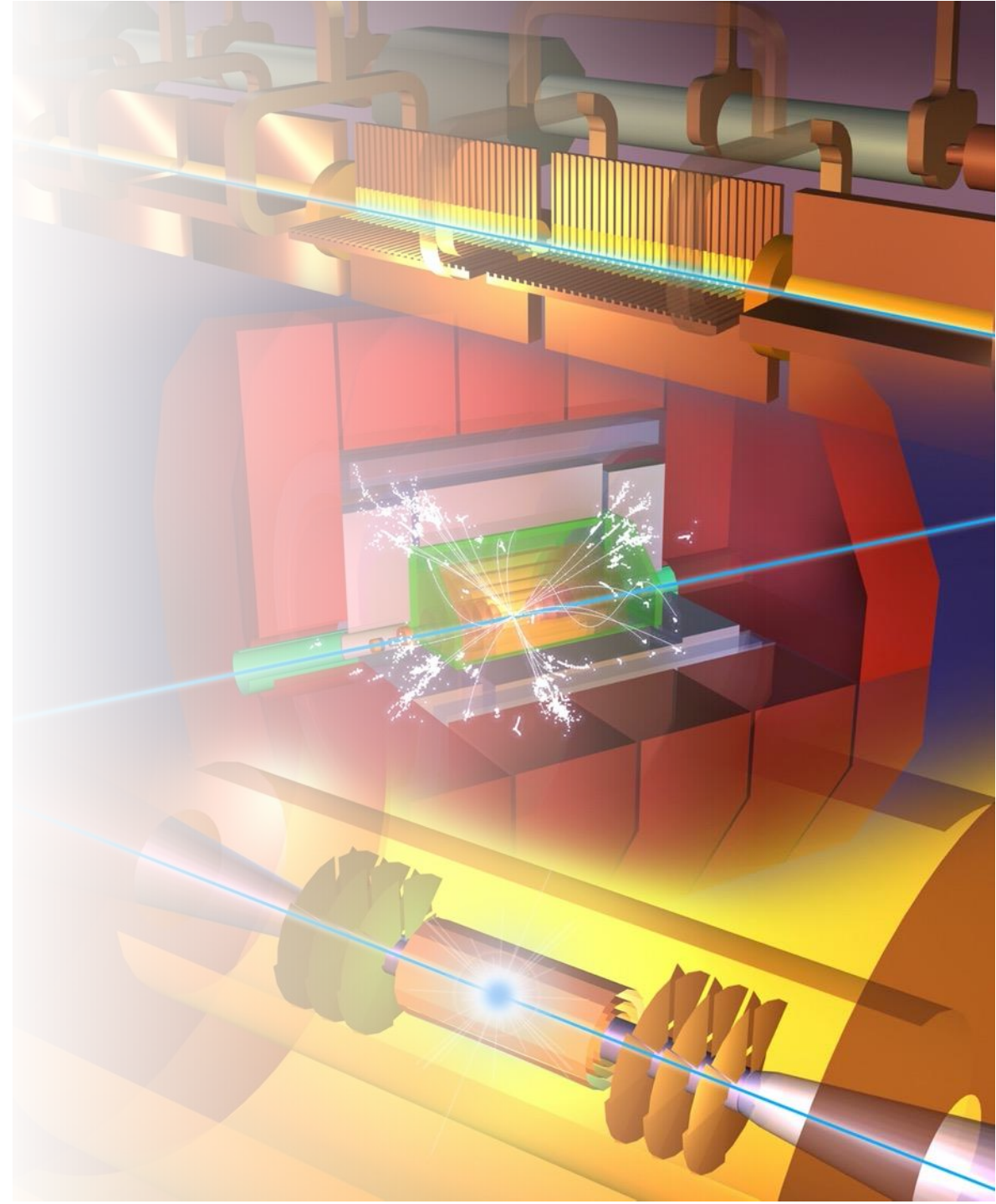
Within specified timeframe (start ops. ~2045)

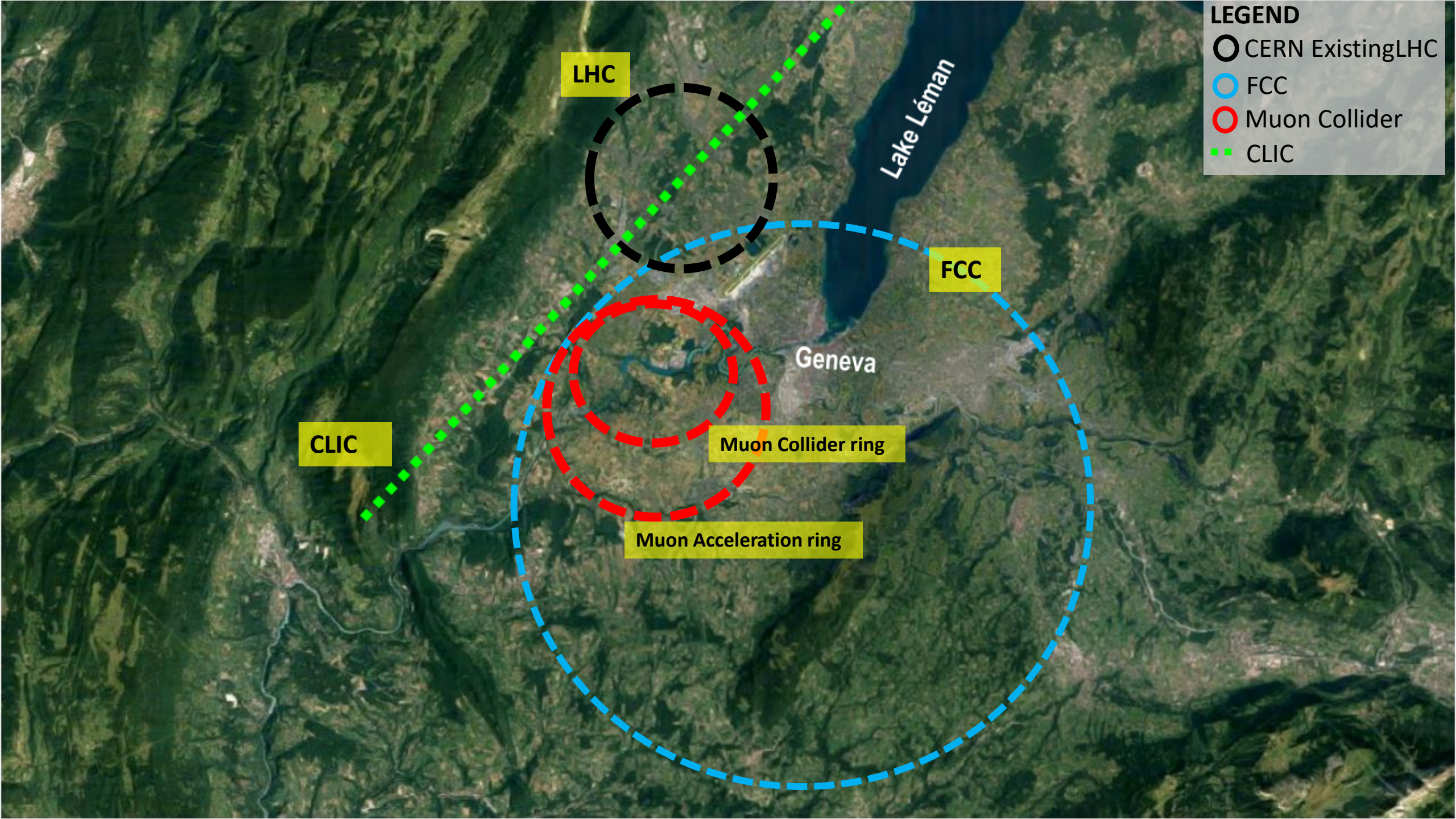
- **FCC-ee**
- **CLIC**

Outside specified timeframe

- **FCC-hh** - natural continuation of FCC programme
- **Muon Collider**

Options possibly in timeframe but not at CERN: ILC, CEPC





LEGEND

- CERN Existing LHC
- FCC
- Muon Collider
- CLIC

LHC

FCC

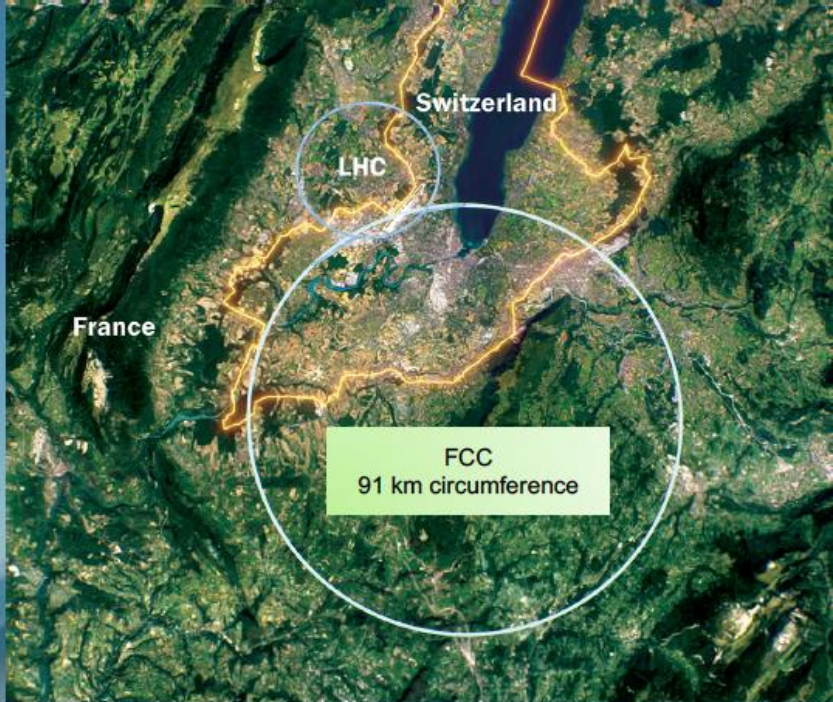
CLIC

Muon Collider ring

Muon Acceleration ring

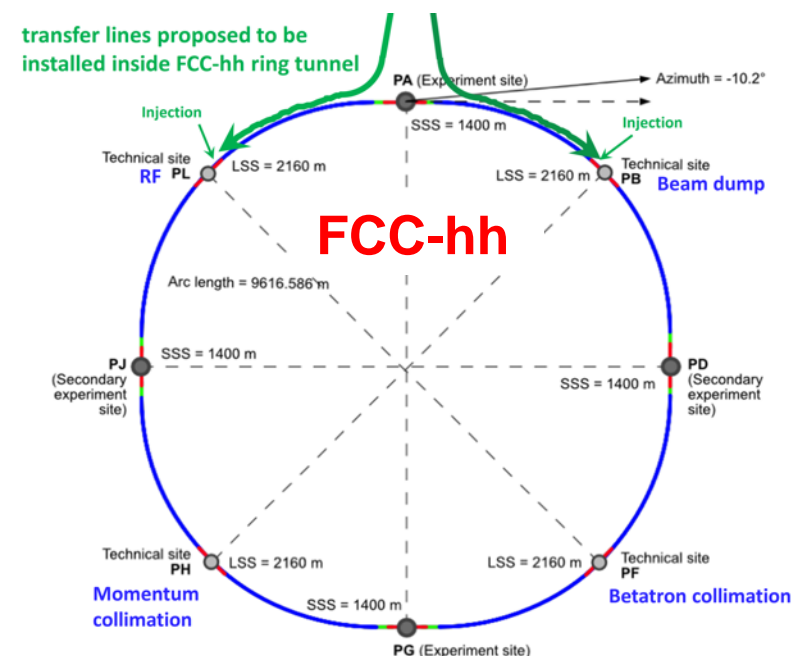
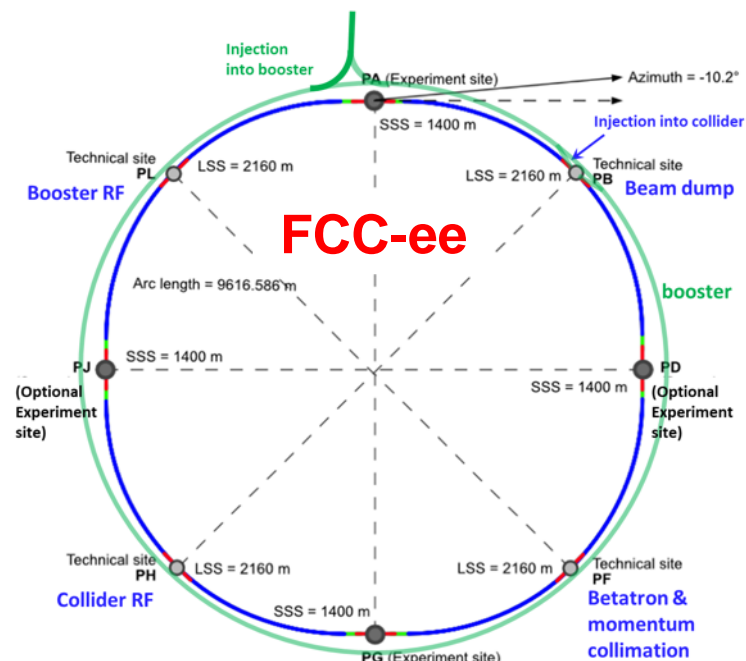
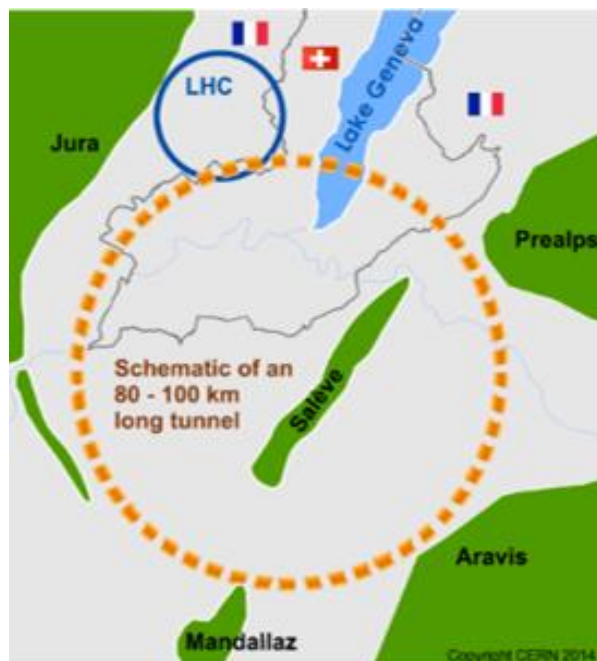
Geneva

Lake Léman



Comprehensive long-term program maximizing physics opportunities:

- Stage 1: **FCC-ee** (Z, W, H, $t\bar{t}$) as Higgs factory, electroweak & top factory at highest luminosities
- Stage 2: **FCC-hh** (~100 TeV) as natural continuation at energy frontier, with ion and eh options



2020 - 2040

2045 - 2063

2070 - 2095

Underground Civil Engineering Schematic

Tunnel Circumference: 90.7 km

Excavated vol: 6.2 Mm³ (in the ground)

Access shafts: 12

Large experiment areas: 2

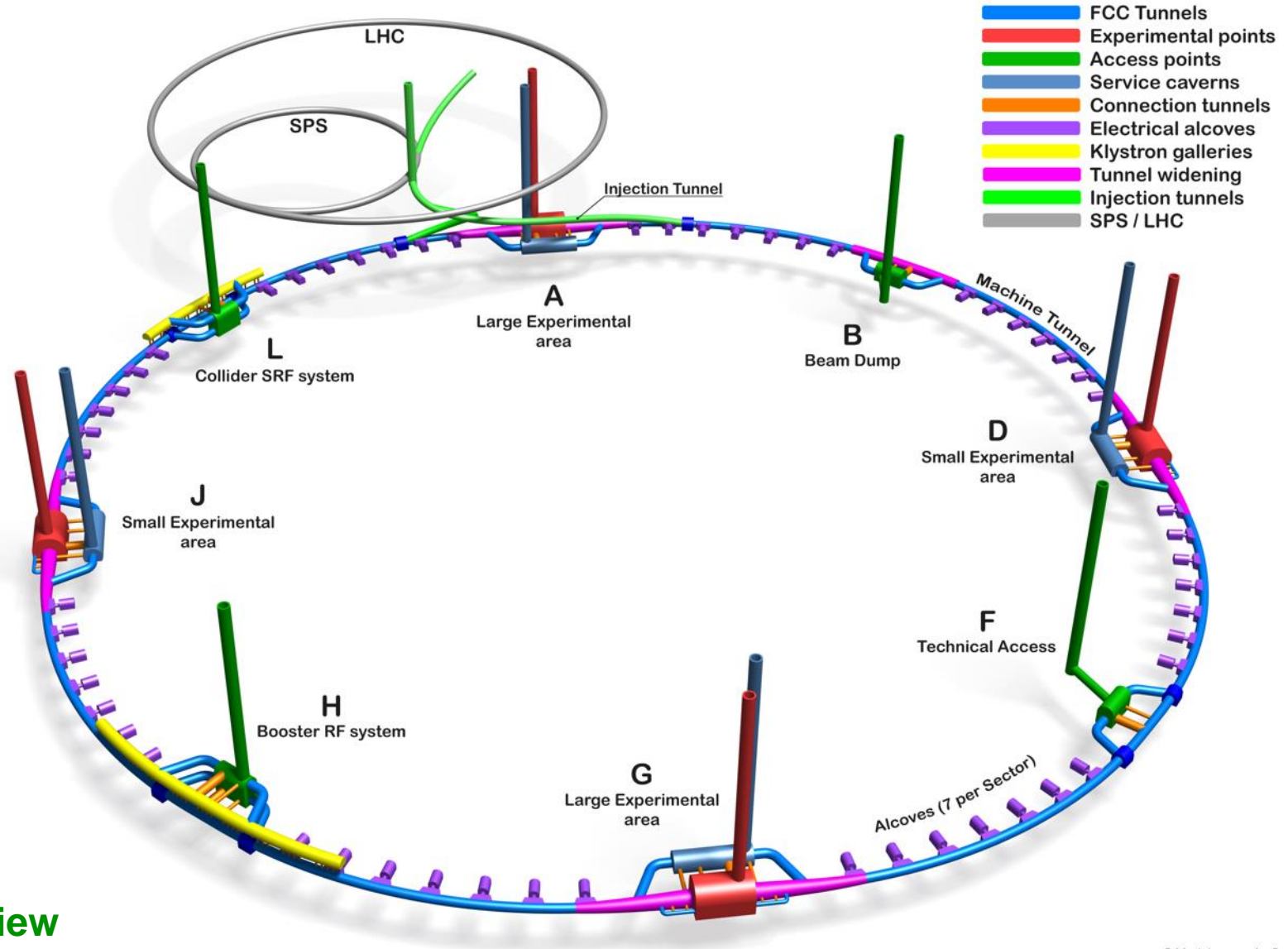
Small experiment areas: 2

Technical points: 4

Deepest shaft: 400 m

Average shaft depth: 243 m

FCC Feasibility Study Mid-Term Review
well received by CERN Council Feb. 2024



[Not to scale]

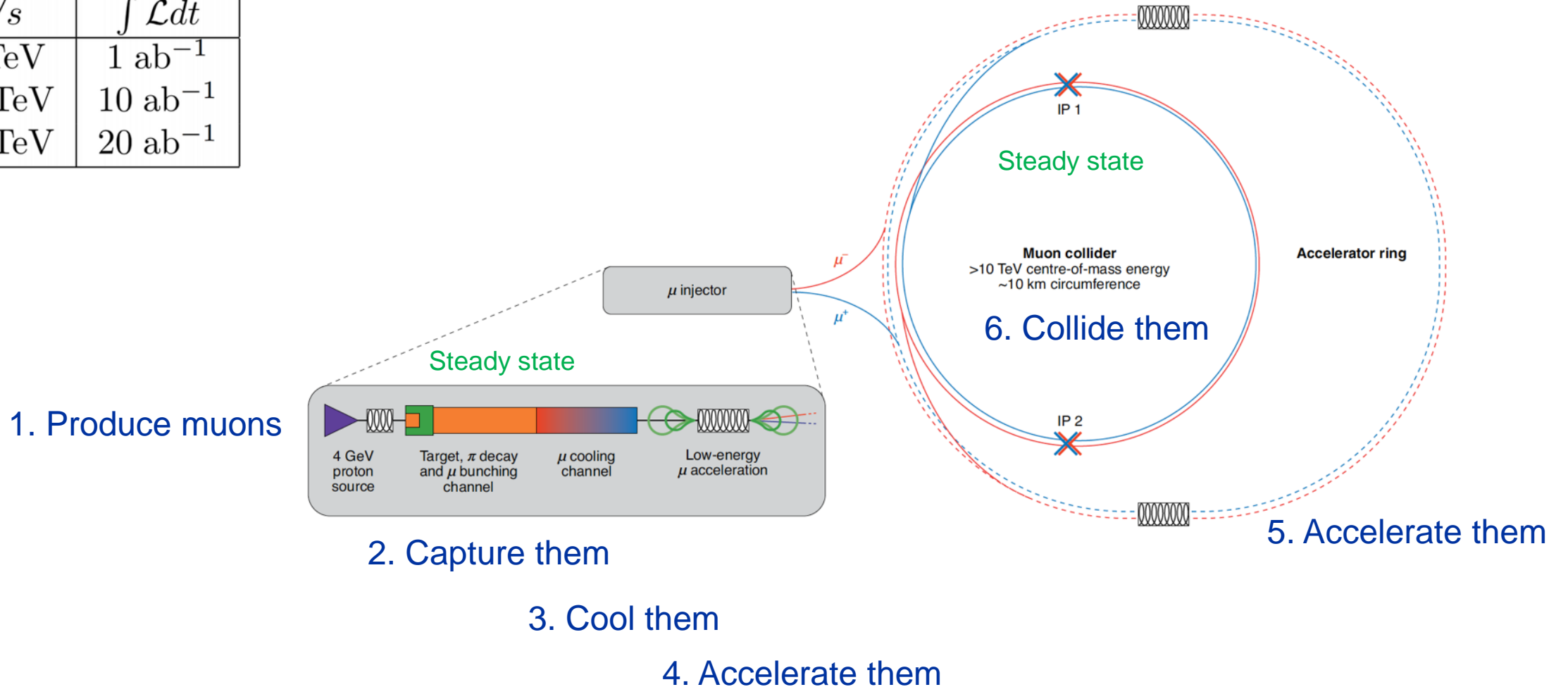
Muon Collider

Large mass ($207 m_e$) suppresses synchrotron radiation => circular collider

Fundamental particle yields clean collisions & requires less energy than protons

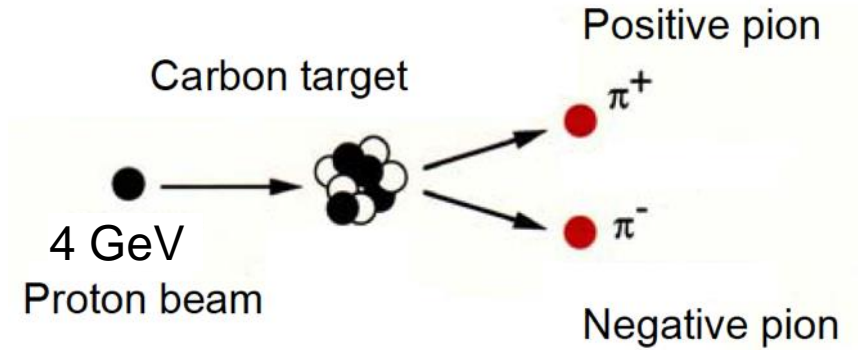
But lifetime at rest is only $2.2 \mu\text{s}$ (fortunately increases with energy)!

\sqrt{s}	$\int \mathcal{L} dt$
3 TeV	1 ab^{-1}
10 TeV	10 ab^{-1}
14 TeV	20 ab^{-1}



Pion (π) production:

Proton + carbon target $\rightarrow \pi^{+/-} + X$



Pion decay:

$$\pi^+ \rightarrow \mu^+ + \nu_{\mu}$$

$$\pi^- \rightarrow \mu^- + \bar{\nu}_{\mu}$$

(Lifetime: 26 nsec.)

Muon decay

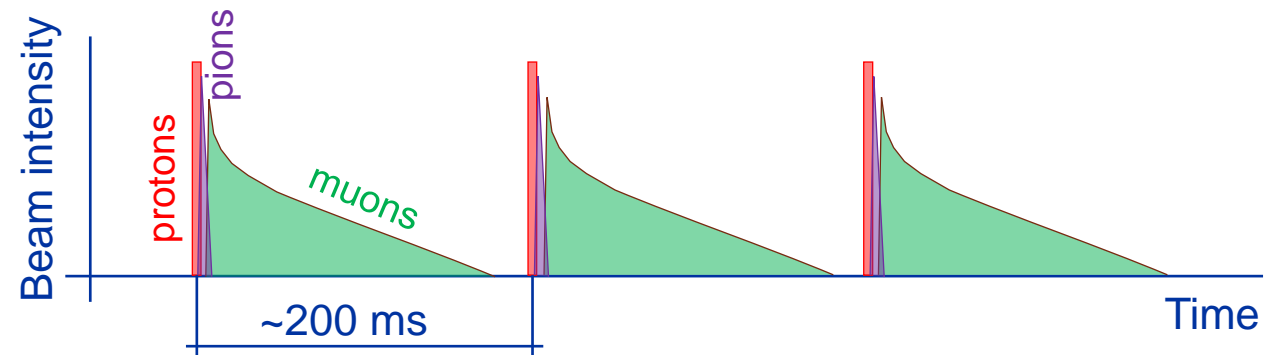
$$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_{\mu}$$

$$\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_{\mu}$$

(Lifetime: 2.2 μ sec.)

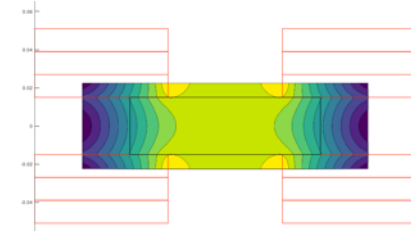
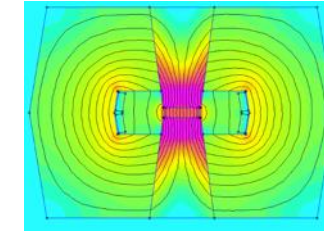
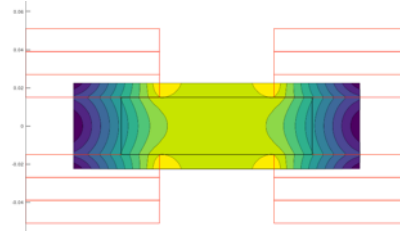
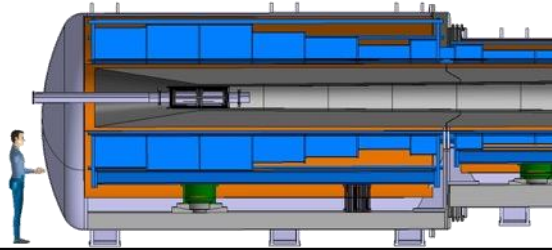
At 3 TeV – lifetime is 63 ms

At 10 TeV - lifetime is 210 ms

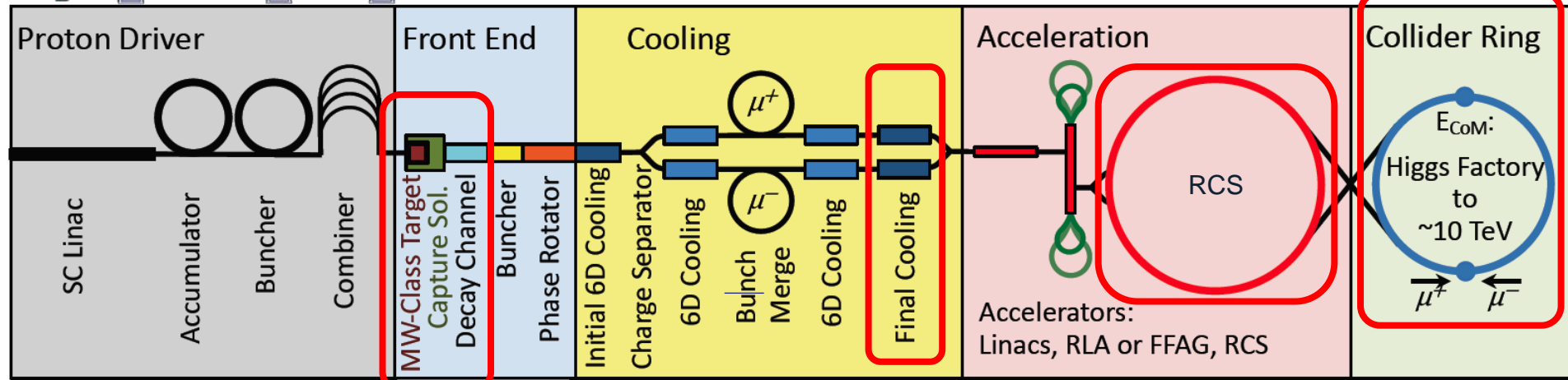


Muon Collider magnets

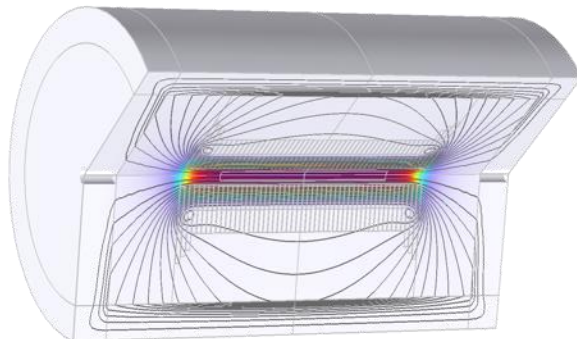
20 T, 200 mm
 Radiation heat load $\approx 5 \dots 10$ kW
 Radiation dose: 80 MGy



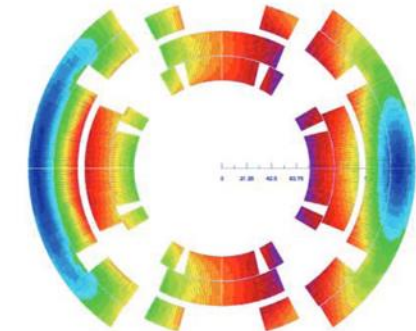
SC dipole NC dipole NC dipole SC dipole



> 40 T, 60 mm

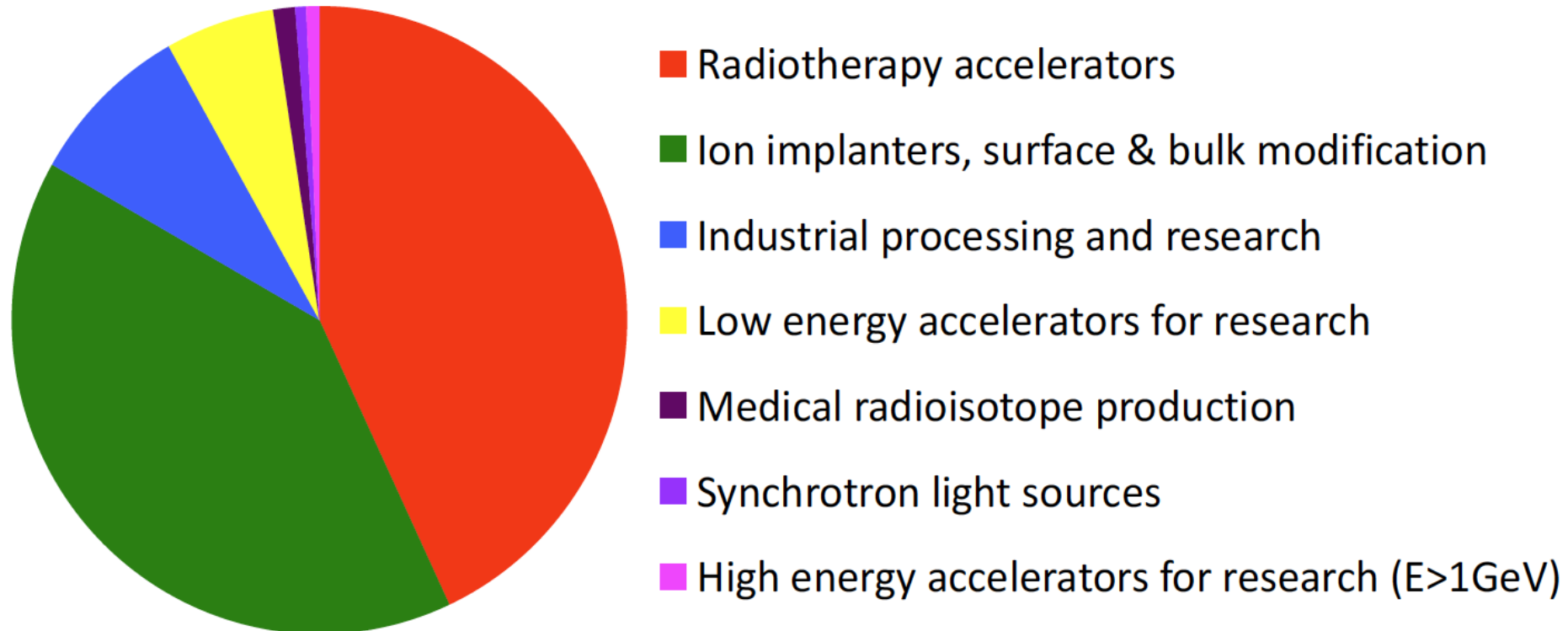


16 T peak, 160 mm
 Radiation heat load ≈ 5 W/m
 Radiation dose $\approx 20 \dots 40$ MGy



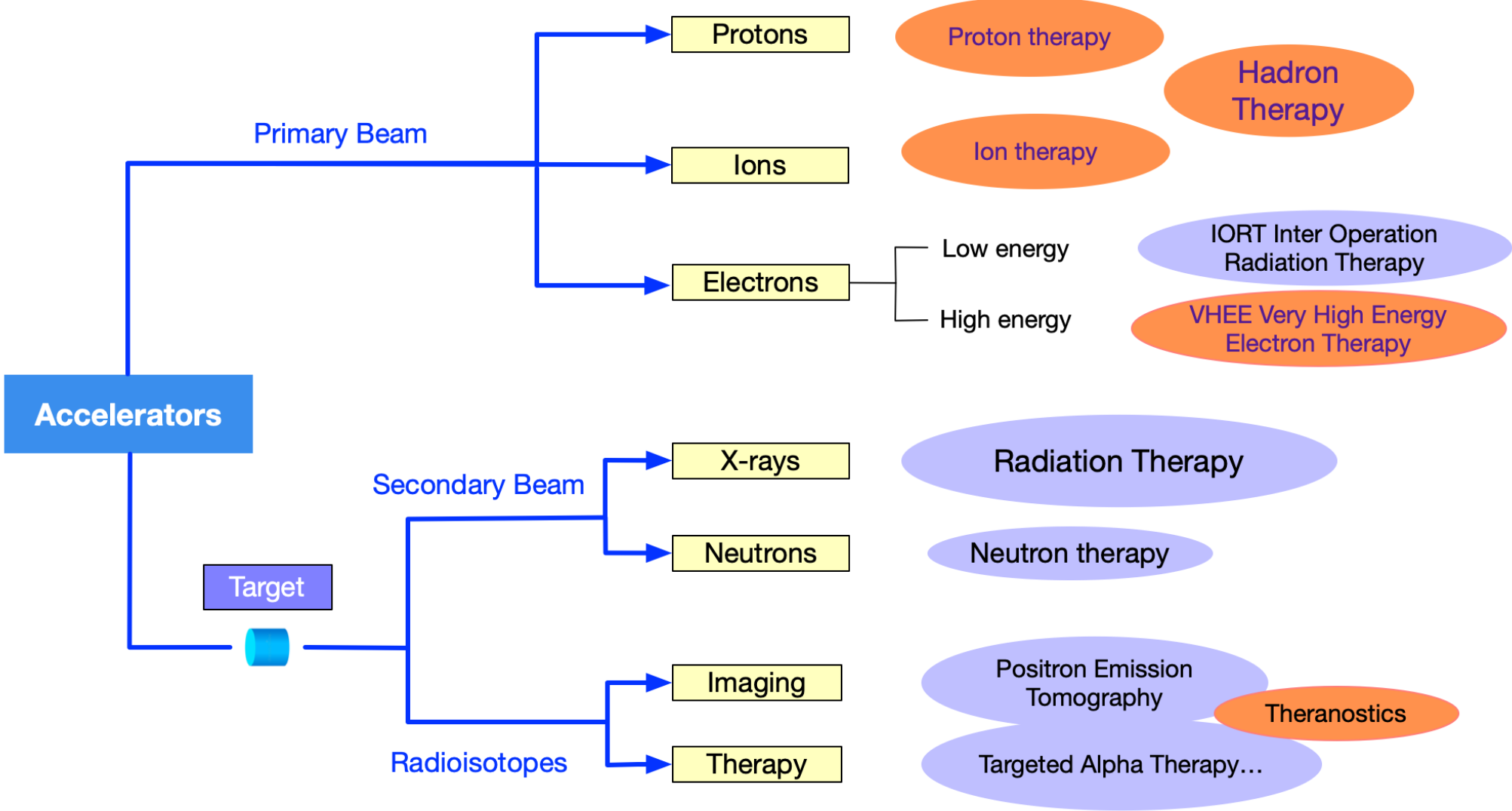
- *“A beam of particles is a very useful tool...”*

-Accelerators for Americas Future
Report, pp. 4, DoE, USA, 2011



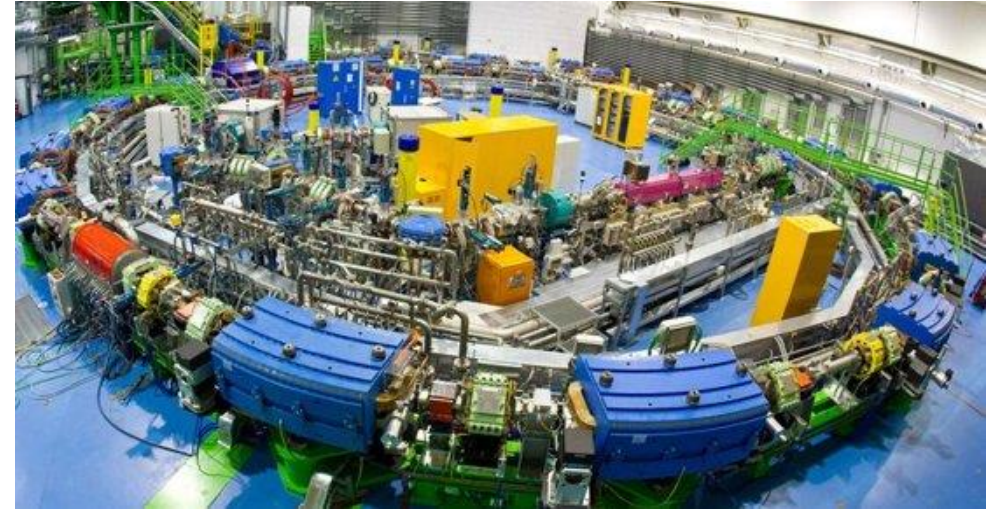
There are roughly 35,000 accelerators in the world
(Above 1 MeV...)

Accelerators versus Cancer

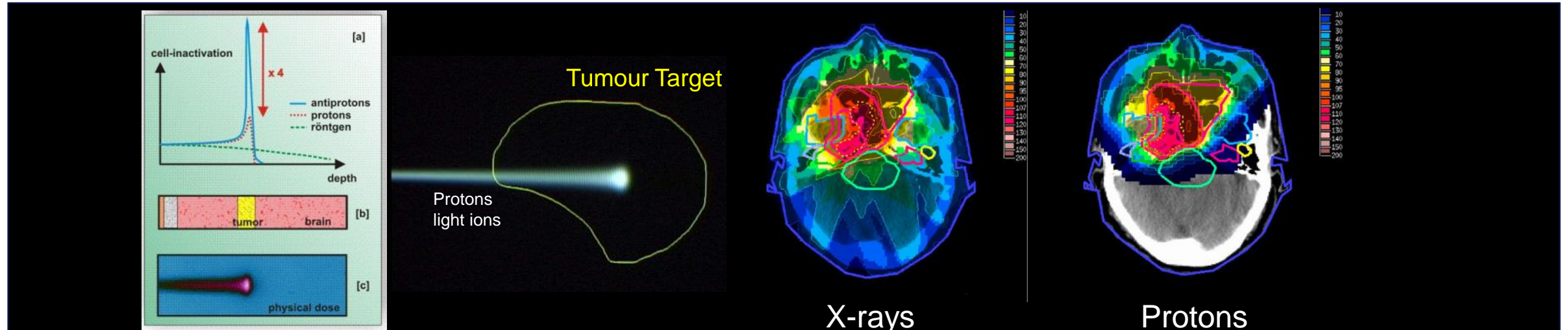


Medical Applications

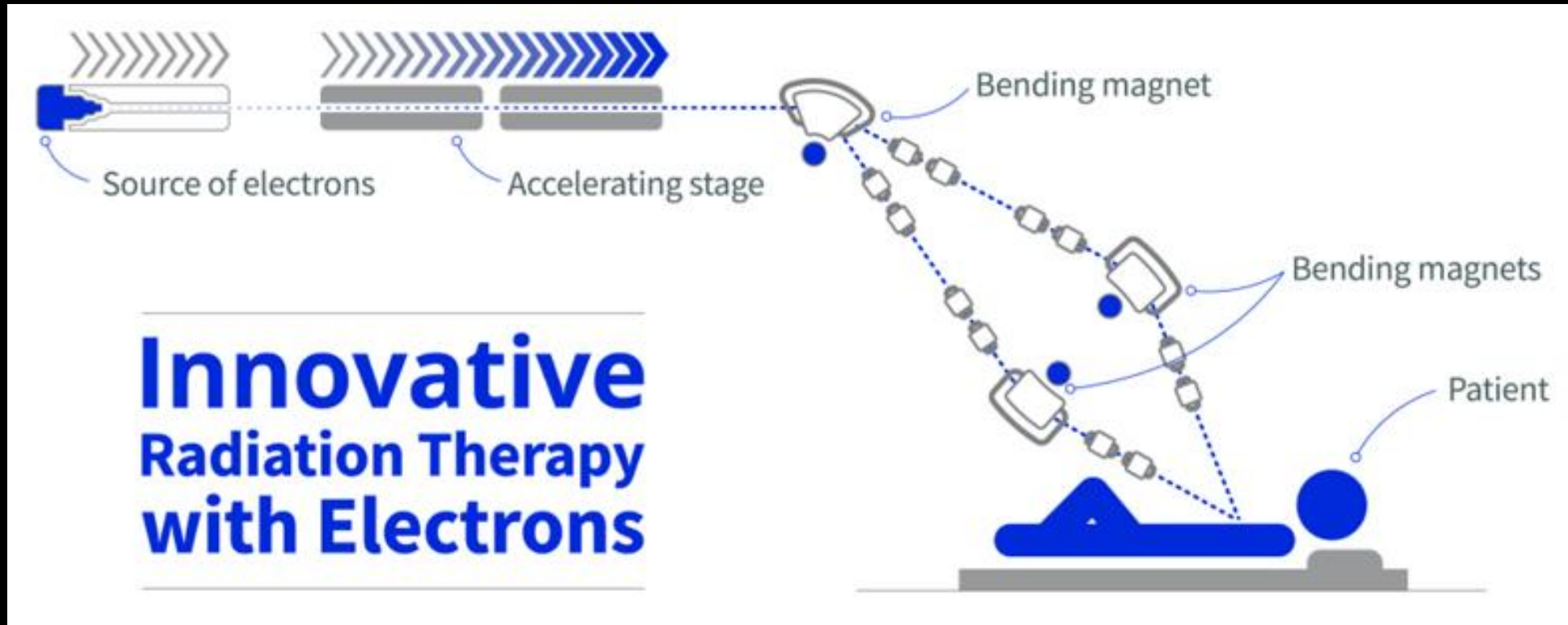
- **Accelerating particle beams**
 - ~30'000 accelerators worldwide
 - ~17'000 used for medicine
- **Hadron Therapy**
 - >170'000 patients treated worldwide (81 facilities)
 - 16 facilities in Europe
 - >21'000 patients treated with carbon ions
 - Leadership in Ion Beam Therapy in Europe & Japan



National Hadron Therapy Centre (CNAO), Pavia, Italy



Very High Energy Electrons (VHEE)

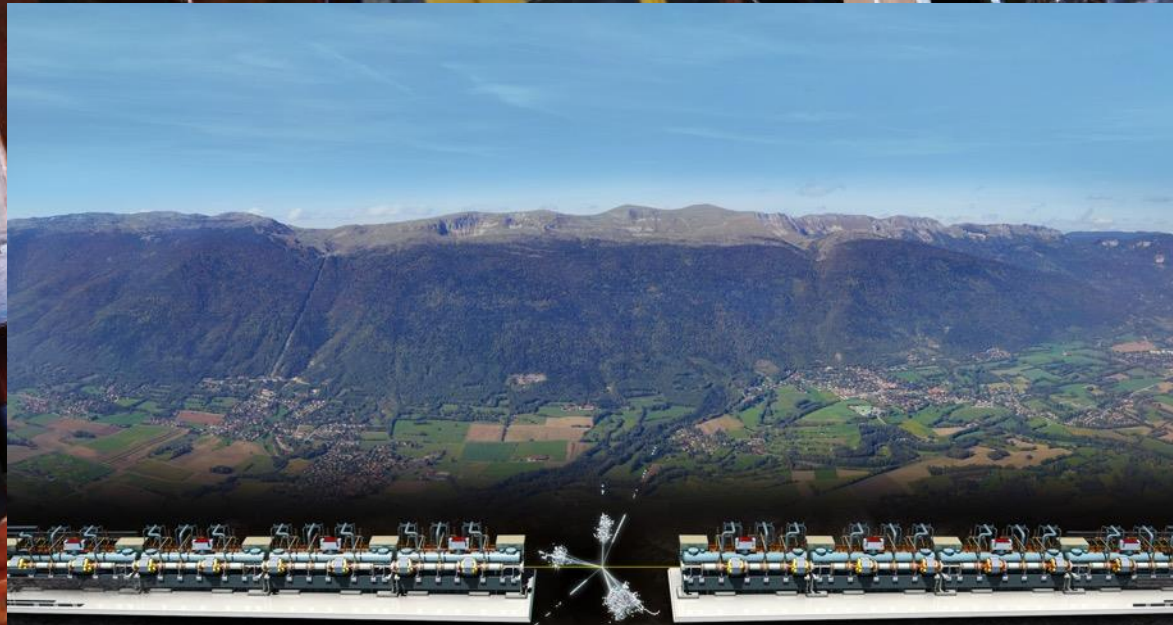


Oncologists believe that ultrafast bursts of electrons damage tumours more than healthy tissue. This is known as the “FLASH effect”.

That's not Very High Energy Electrons...

Producing a high dose of electrons using a unique accelerator based on CLIC (Compact Linear Collider) technology.

Precisely controlled, intense electron beams
Compact high accelerating gradients



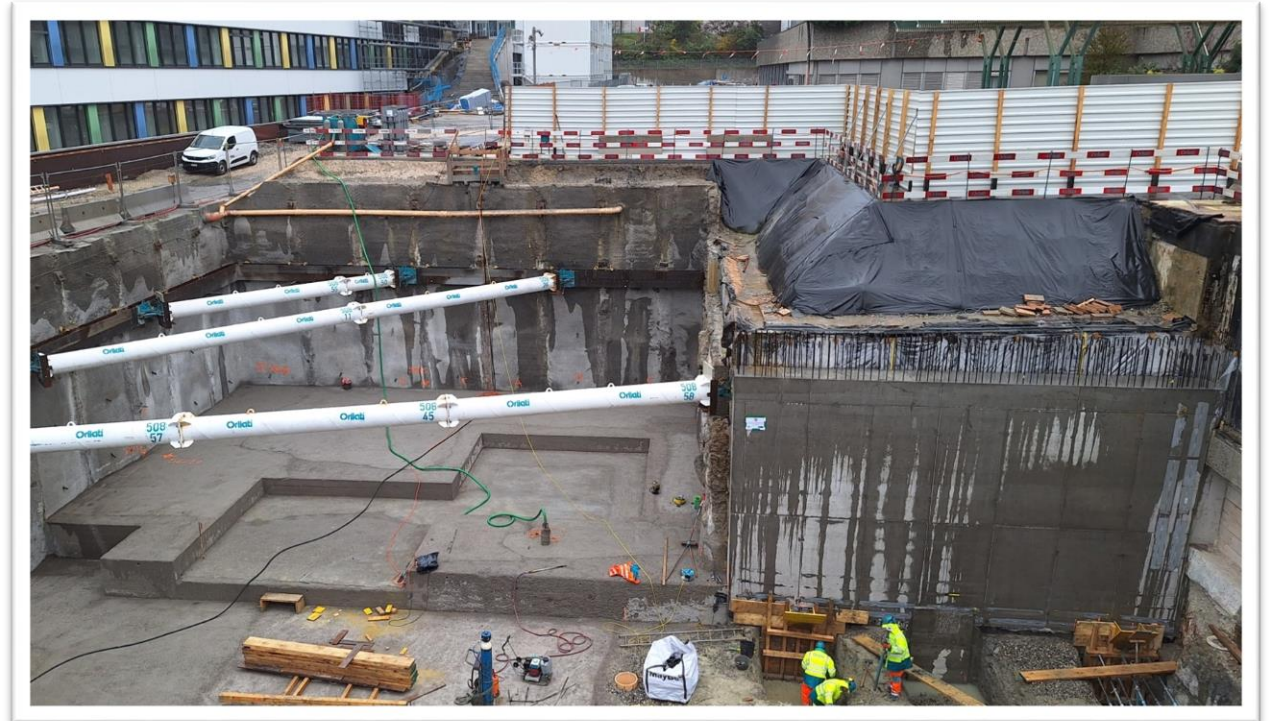
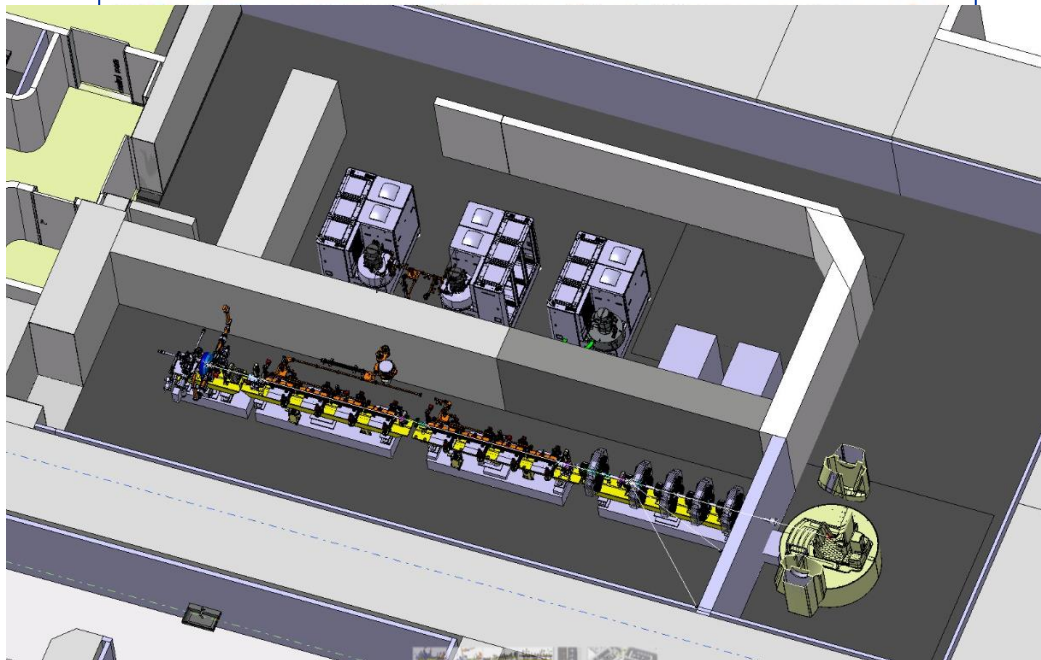
FLASH Therapy with VHEE

CHUV, CERN together with an industrial partner THERYQ (ALCEN group) in process of constructing facility for clinical trials – industrialization foreseen

CERN and Lausanne University Hospital collaborate on a pioneering new cancer radiotherapy facility

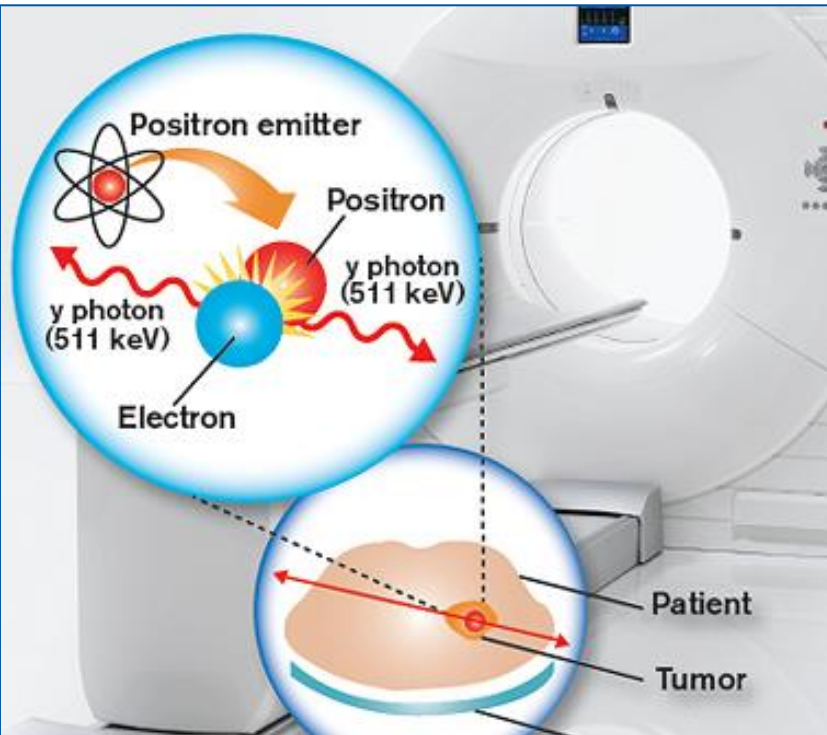
CERN and the Lausanne University Hospital (CHUV) are collaborating to develop the conceptual design of an innovative radiotherapy facility, used for cancer treatment

15 SEPTEMBER, 2020



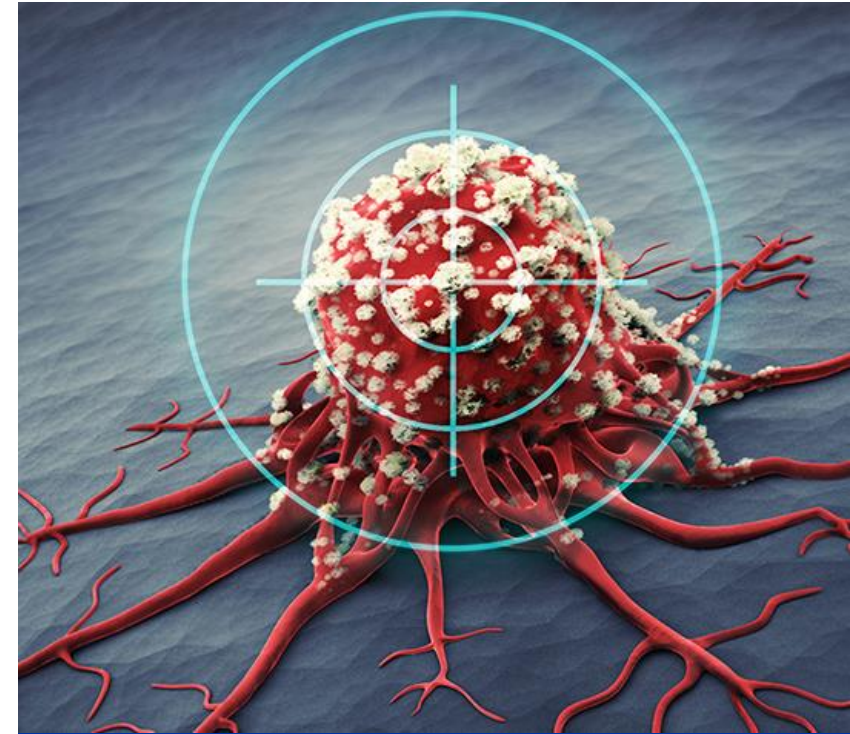
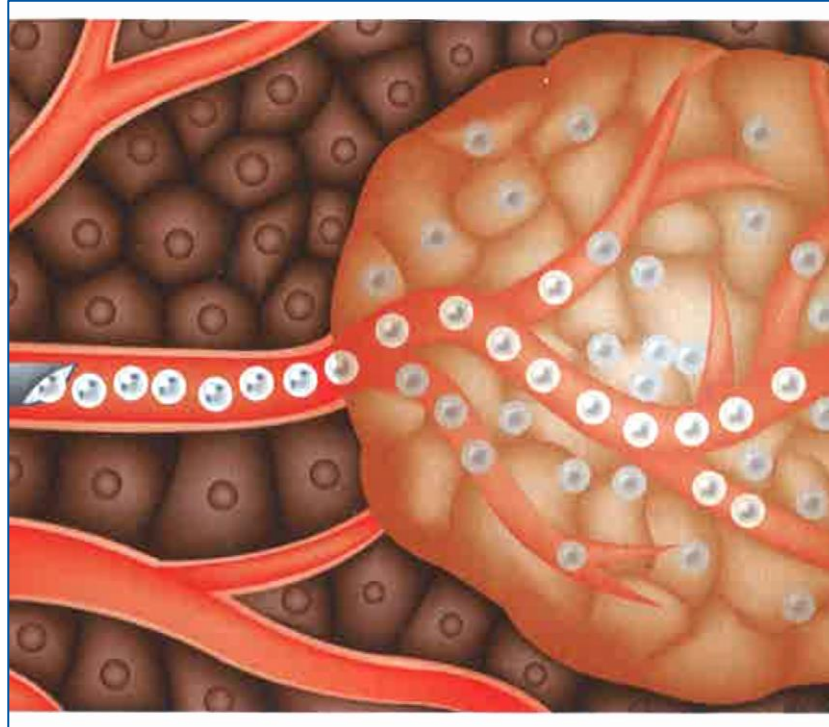
Bunker under construction in Lausanne, first clinical trials in 2027

Use of medical radionuclides



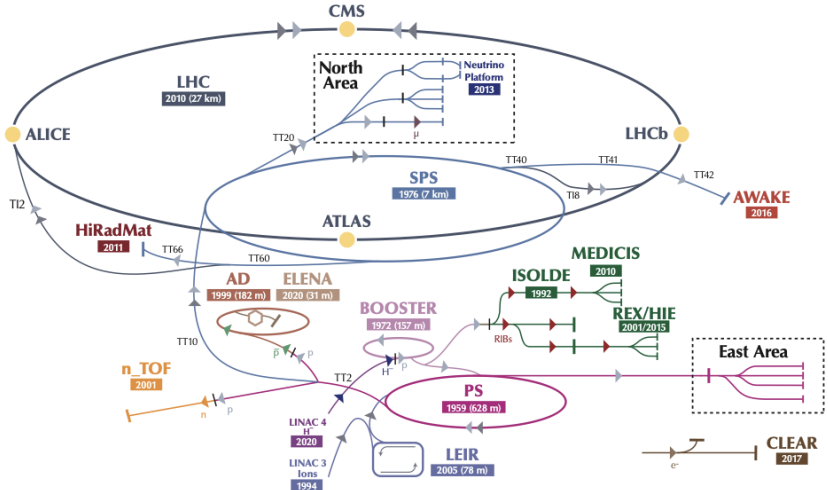
Diagnostic, where the radioisotope allows doctors to visualize a tumour's precise location and contours within the body

Therapeutic, where doctors use the radionuclide to deliver cancer-killing radiation directly to tumour cells

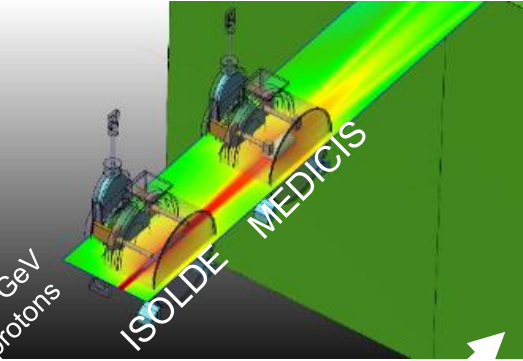


The **theragnostic** radionuclide agent allows a doctor to both visualize and treat a tumour simultaneously.

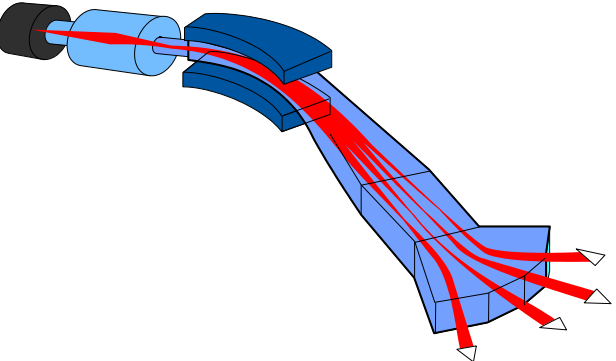
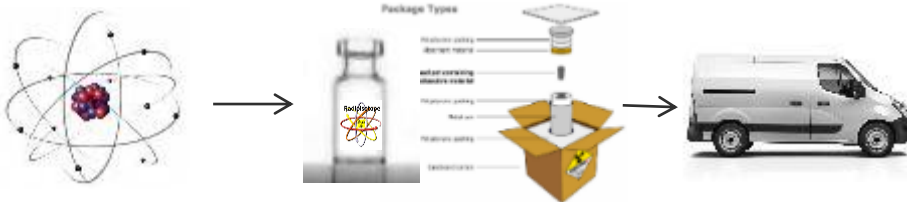
MEDICIS in one slide!



“Free” proton beam



Non-conventional isotopes are collected by mass separation for novel medical applications



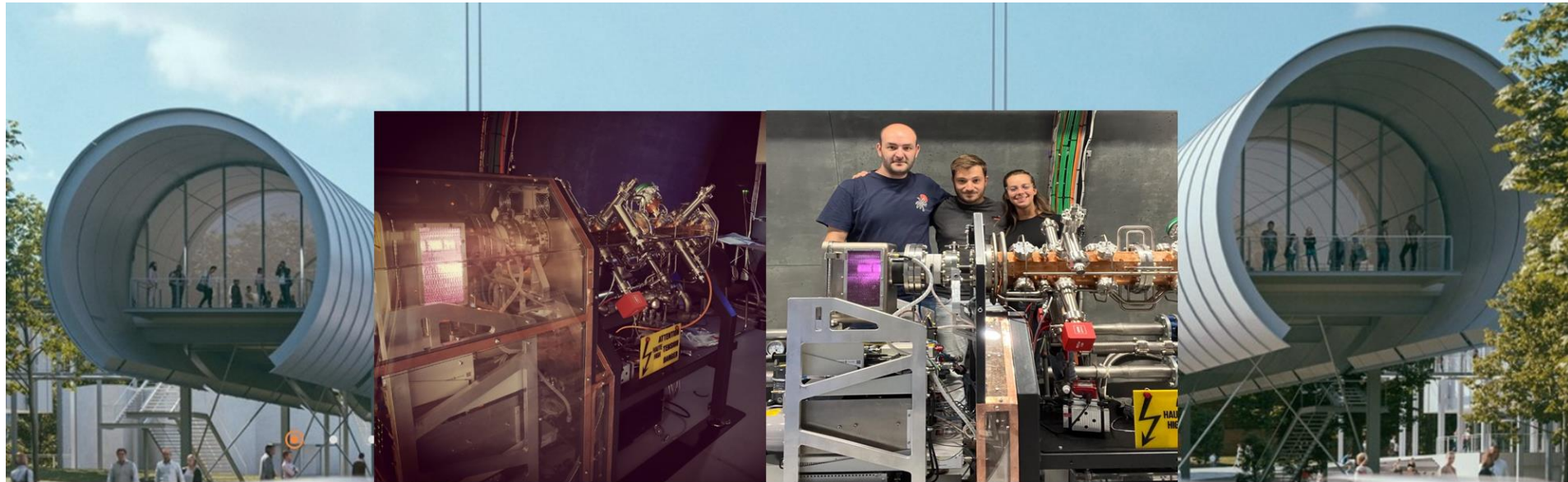
The only dedicated medical isotope mass separation facility in Europe.

From CERN-MEDICIS to the lab/Hospital (Countries: BE, CH, FR, PK, PT, LV, UK)



Surface Science

- **Particle-induced X-ray emission (PIXE)**
 - Powerful, non-destructive elemental analysis technique
 - When exposed to particle beam, atomic interactions occur that give off EM radiation of X-ray wavelengths
 - Routinely by geologists, archaeologists, art conservators and others to help answer questions of provenance, dating and authenticity
- **CERN's very own working PIXE accelerator, ELISA, can be seen in the Science Gateway**



Next time someone asks you what accelerators are for...

“A beam of the right particles with the right energy at the right intensity can shrink a tumor, produce cleaner energy, spot suspicious cargo, make a better radial tire, clean up dirty drinking water, map a protein, study a nuclear explosion, design a new drug, make a heat-resistant automotive cable, diagnose a disease, reduce nuclear waste, detect an art forgery, implant ions in a semiconductor, prospect for oil, date an archaeological find, package a Thanksgiving turkey or...

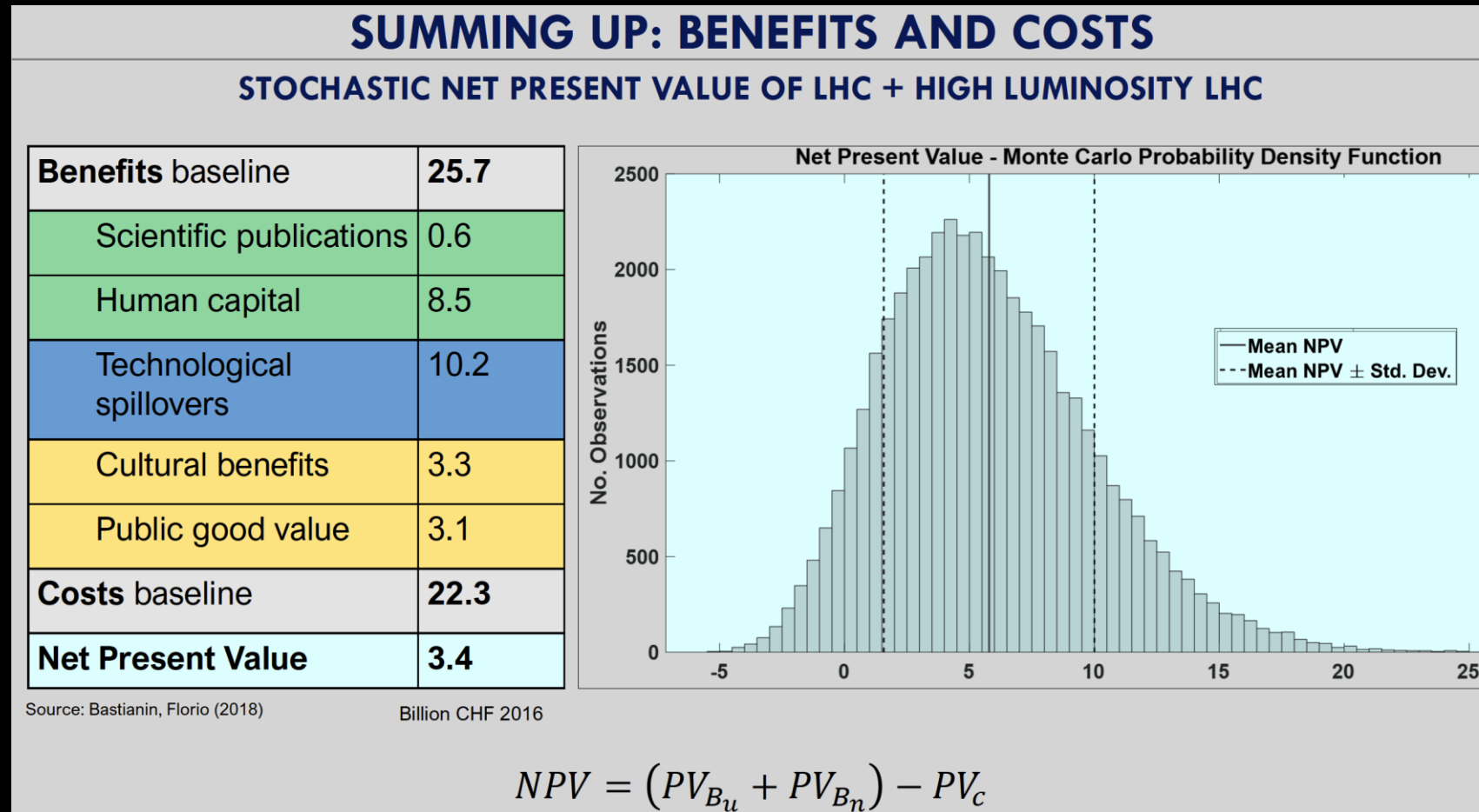
...discover the secrets of the universe.”



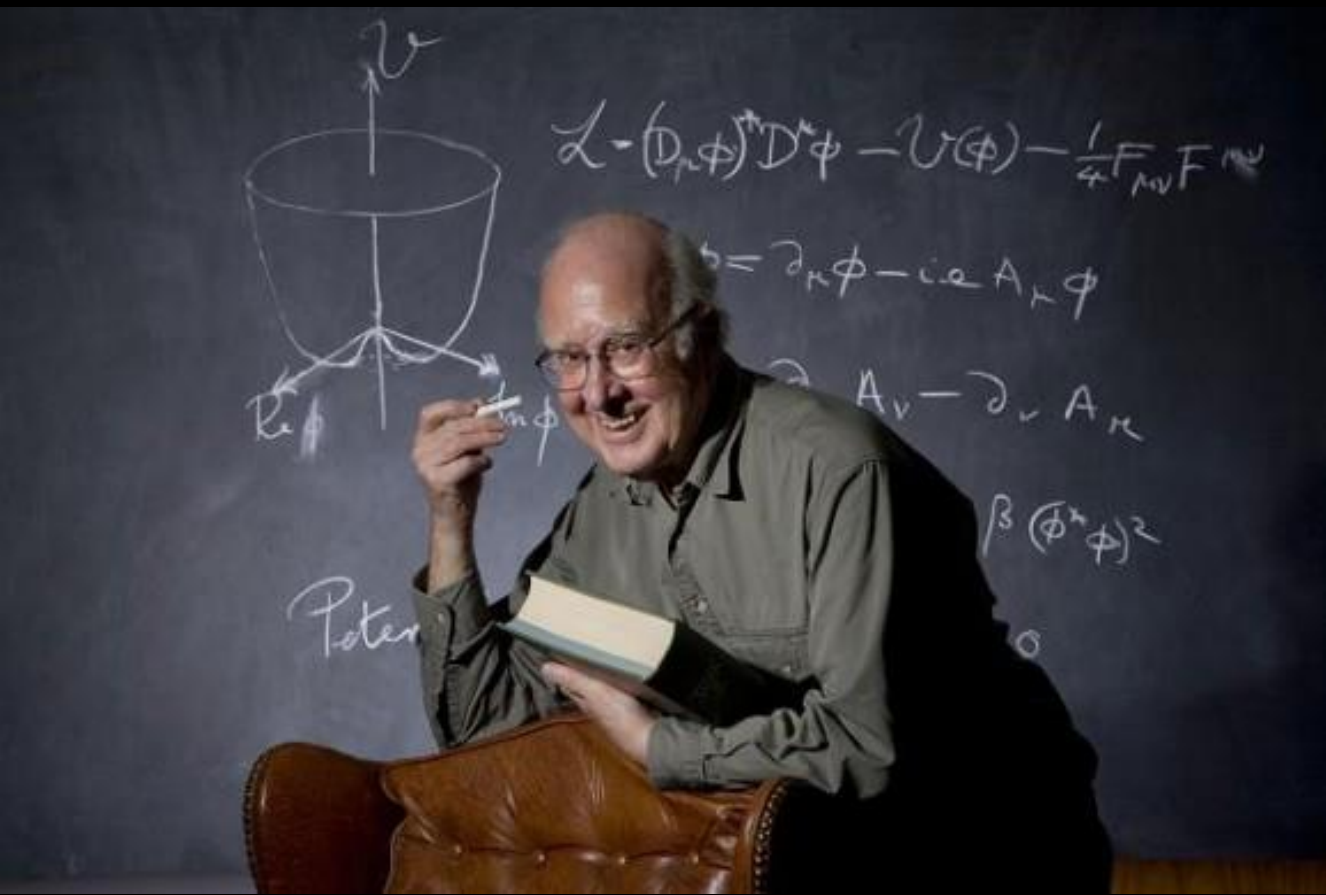
-Accelerators for Americas Future
Report, pp. 4, DoE, USA, 2011

Social Cost-Benefit Analysis of LHC and HL-LHC

Massimo Florio with Andreas Bastianin (2018)



“The surprising finding is that a machine as costly as the LHC, entirely devoted to describe things for which we currently have no use, passes a cost-benefit test.”



Physics is Beautiful and Useful!