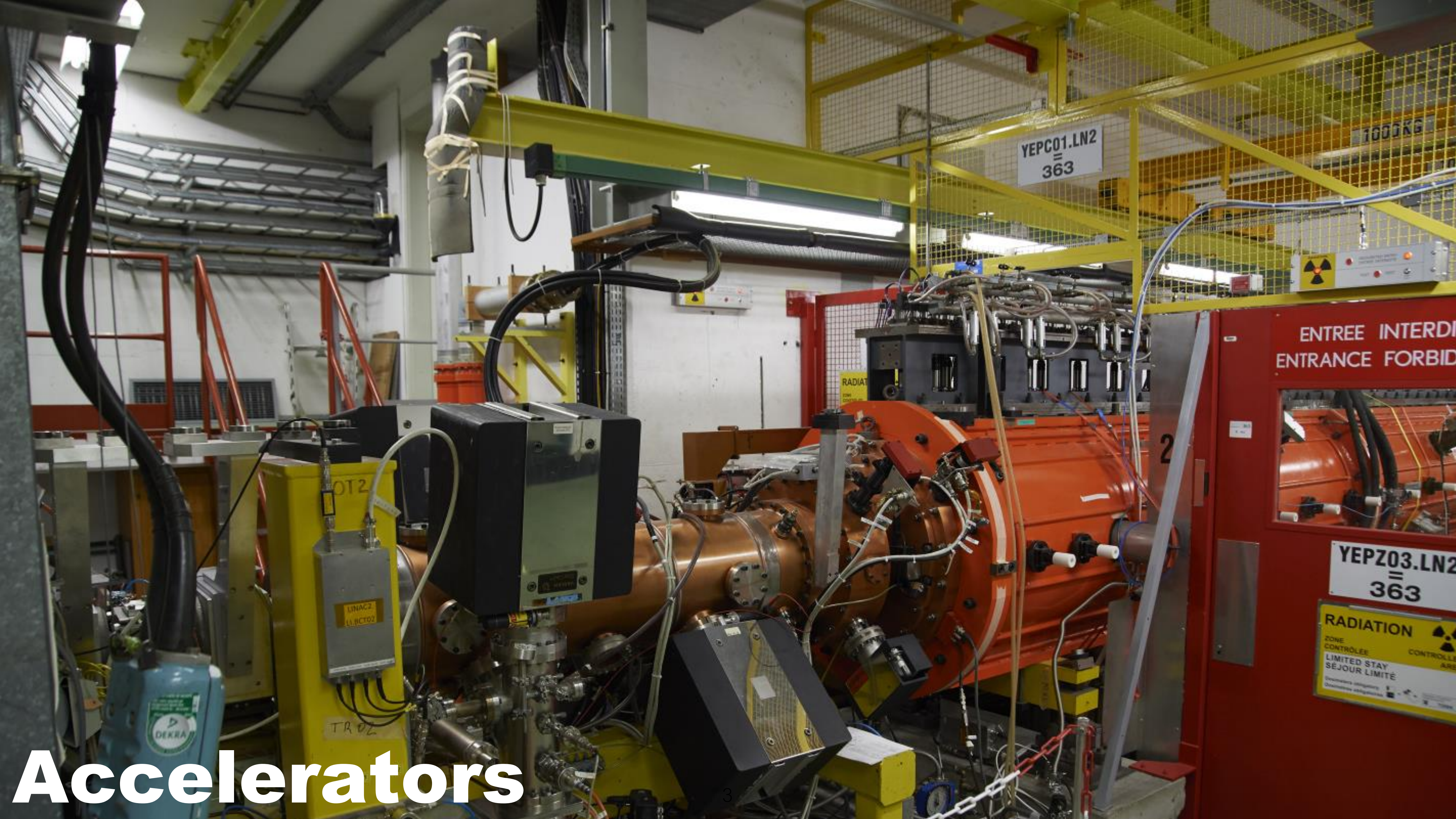
CERN Accelerators From Fundamental Research To Life Science

Noora-Mari Pienimäki
CERN Knowledge Transfer Group

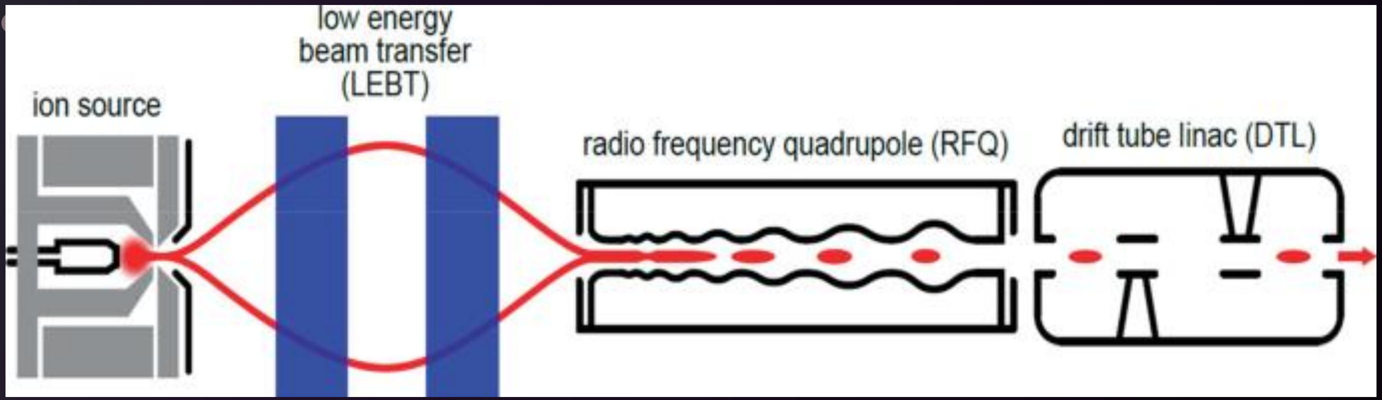
CERN: the world’s biggest laboratory for particle physics.

To uncover what the universe is made of and how it works

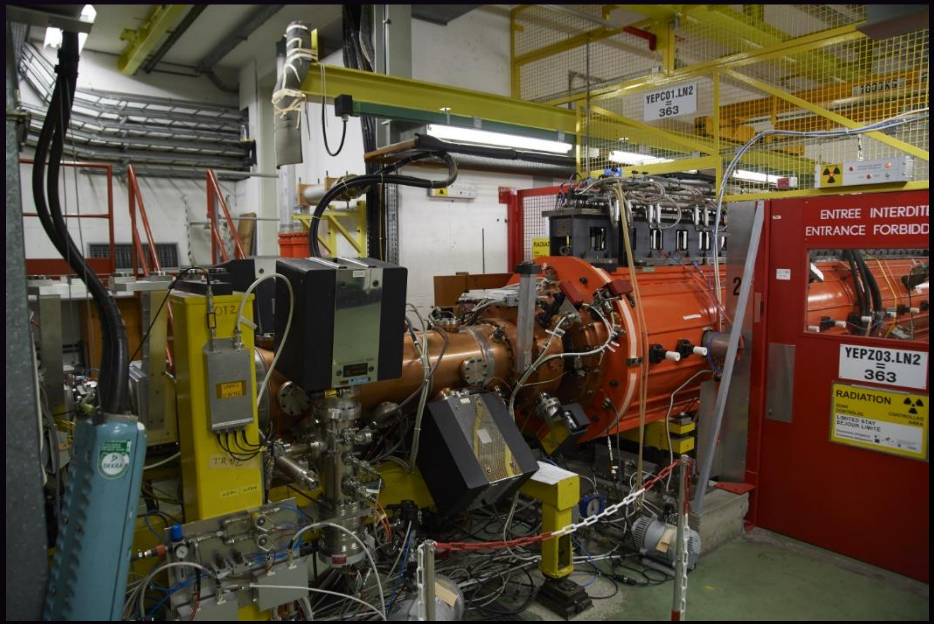


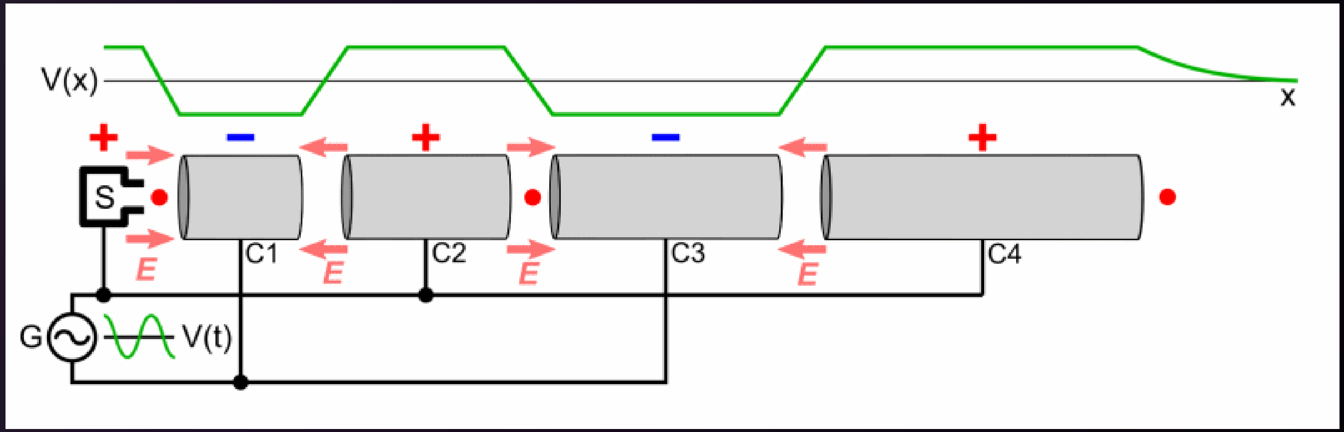
Accelerators

Accelerators in a nutshell

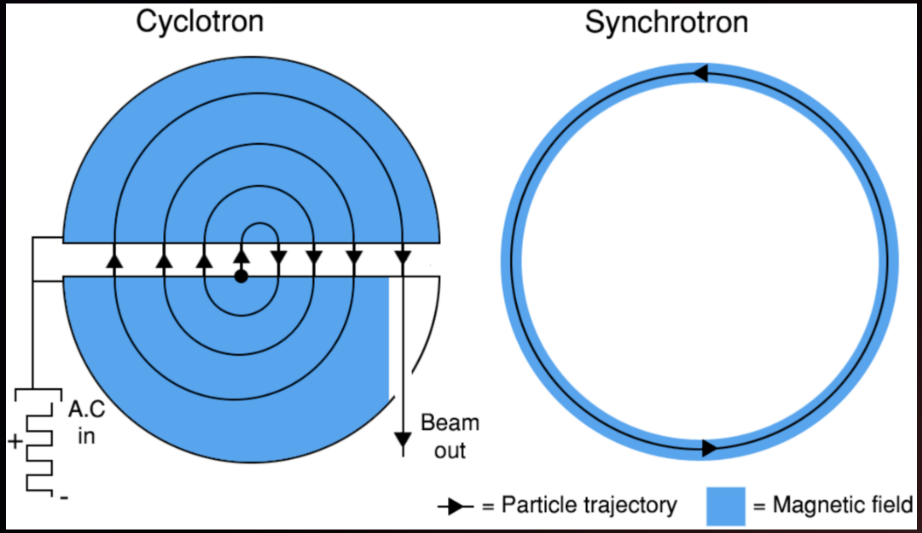


https://link.springer.com/chapter/10.1007/978-3-031-40967-7_1





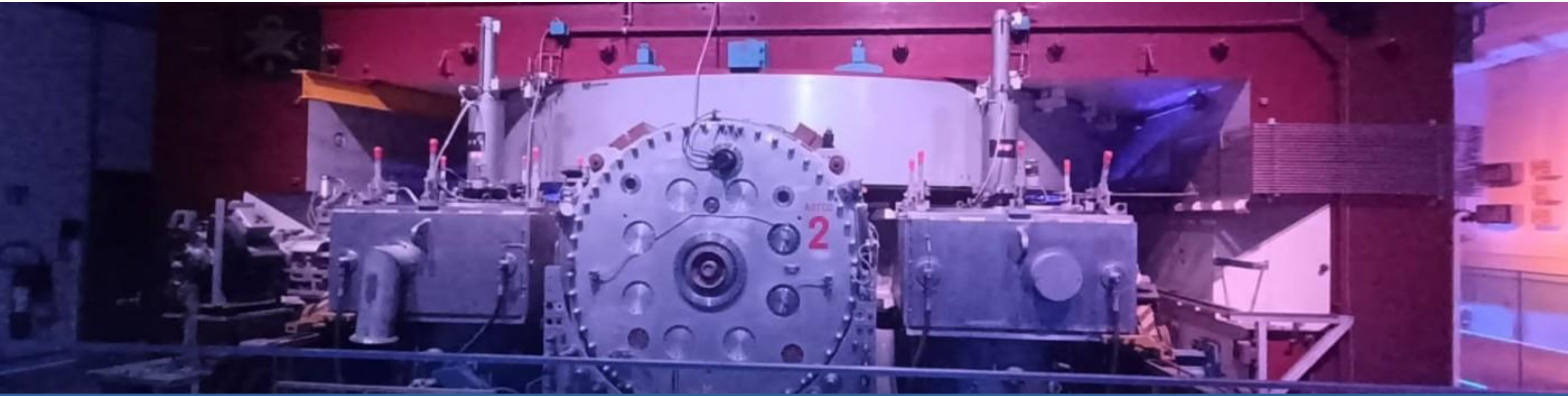
https://en.wikipedia.org/wiki/Particle_accelerator#/media/File:Linear_accelerator_animation_16frames_1.6sec.gif



https://discover.hubpages.com/education/Particle-Accelerators

A little bit of history

- **Synchrocyclotron (SC)** – 1957–1990 (600MeV)
- **Proton Synchrotron (PS)** – 1959–present (28 GeV)
- **Proton Synchrotron Booster (PSB)** - 1972-present
- **Super Proton Synchrotron (SPS)** – 1976–present
- **Large Electron-Positron Collider (LEP)** (1989-2000)
- **Large Hadron Collider (LHC)** (2008-Present)

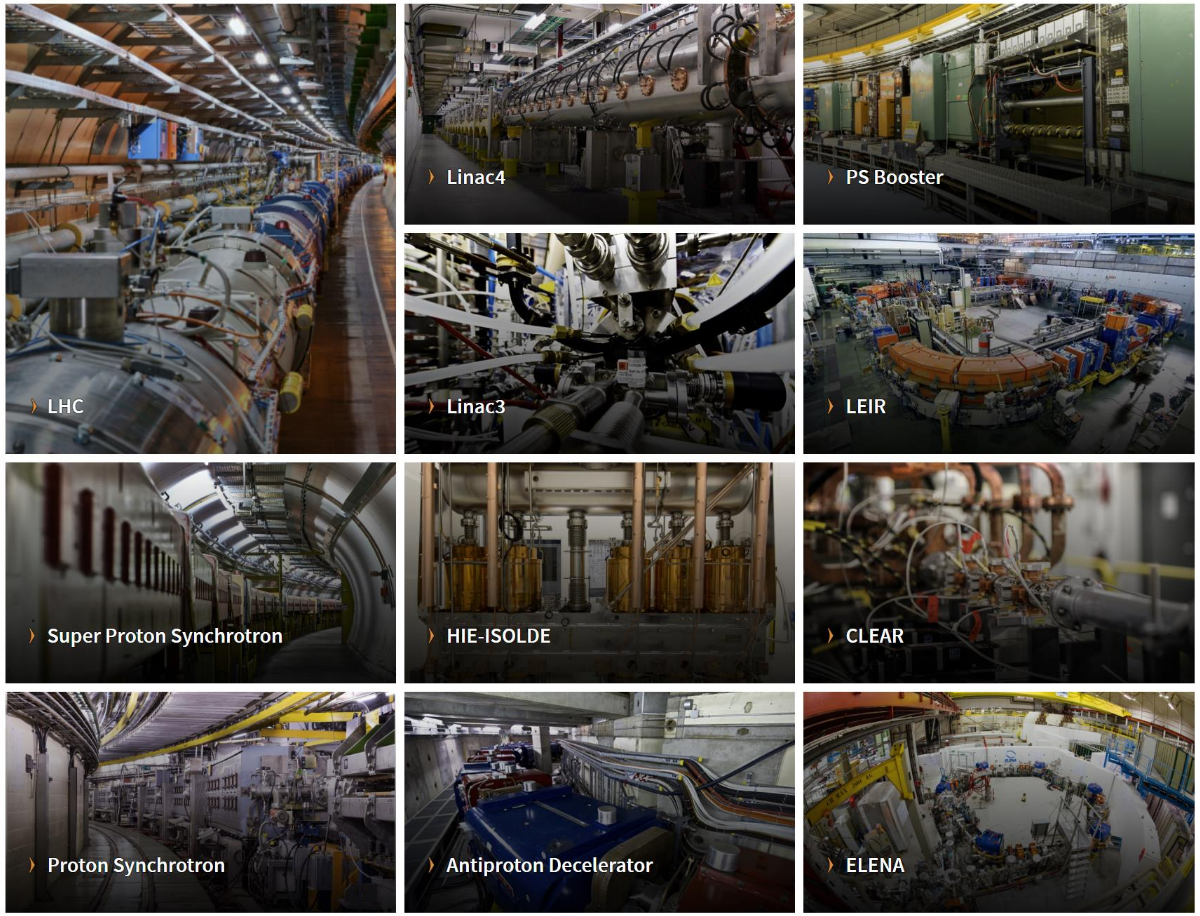


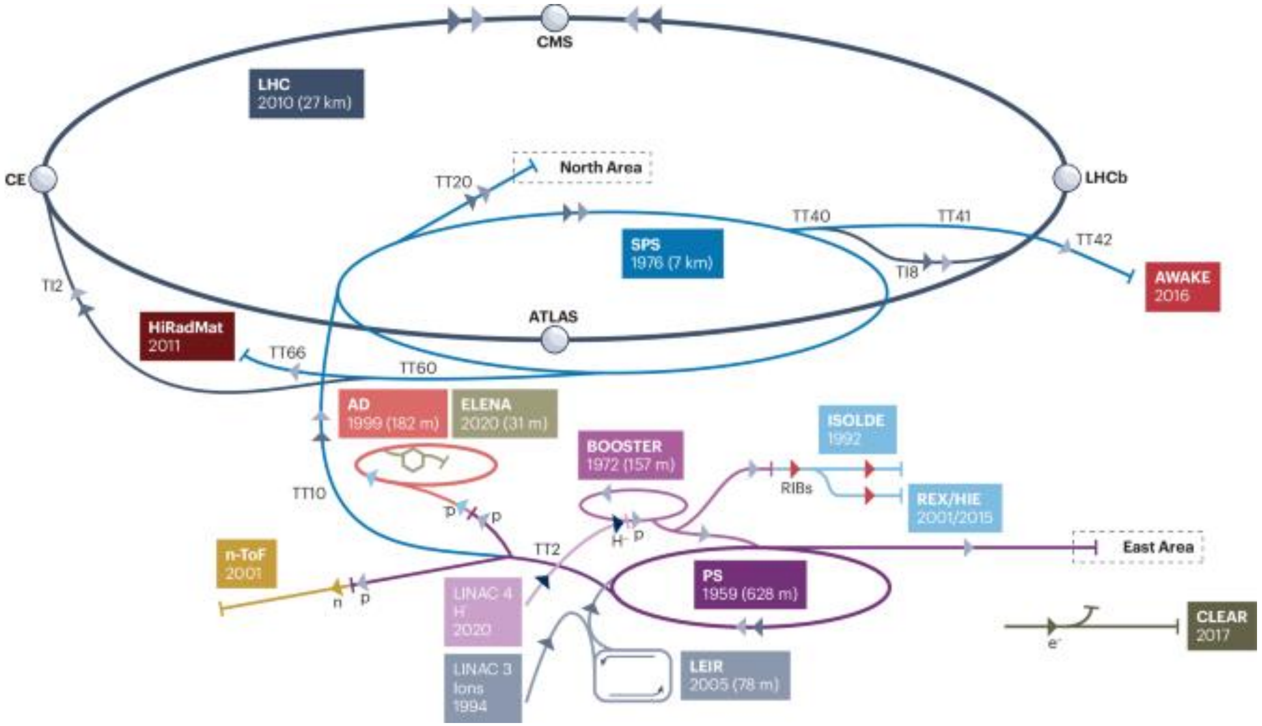
Other significant accelerators

- 1958-1990 Linac 1
- 1978-2018 Linac 2
- 1982–1996 Low Energy Antiproton Ring (LEAR)
- 2000: Antiproton Decelerator (AD) + ELENA
- 2017: Linac 4 & CLEAR

Accelerators in operation at CERN

Current accelerators





LINAC 4 - The big picture: LHC luminosity

$$\mathcal{L} = \frac{\gamma}{4\pi} \times f_r \times \frac{F}{\beta^*} \times n_b \times N_b \frac{N_b}{\varepsilon_n}$$

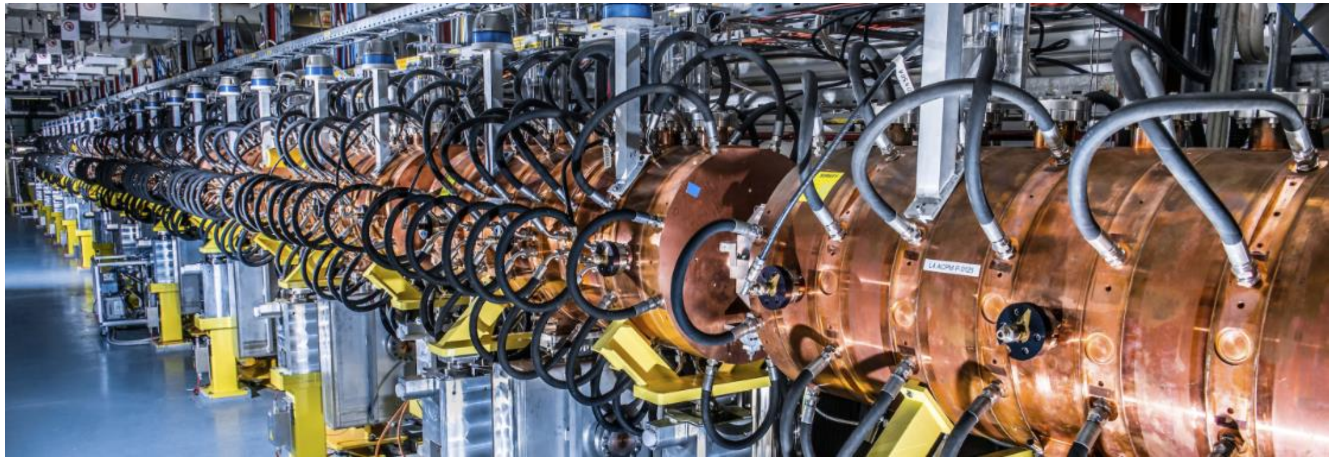
From optics at Interaction point

From machine design and limitations (e cloud)

Brightness from Injectors : defined at low energy

High Luminosity LHC

N_b	number of particles per bunch
n_b	number of bunches
f_r	revolution frequency
ε_n	normalised emittance
β^*	beta value at Ip
F	reduction factor due to crossing angle

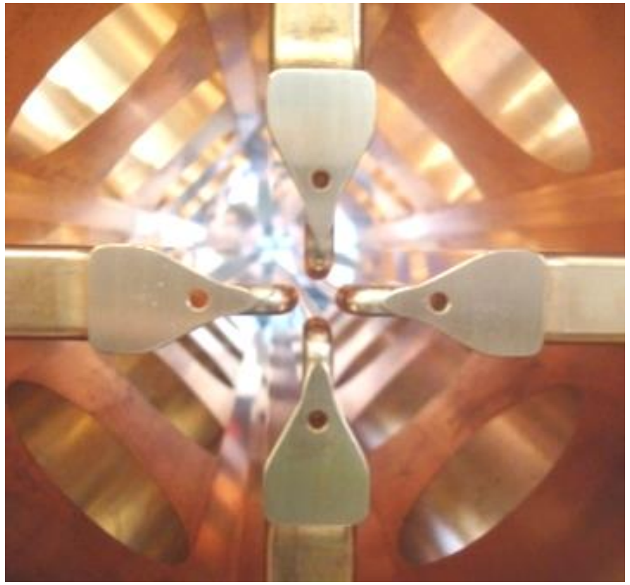


Linac 4 in figures

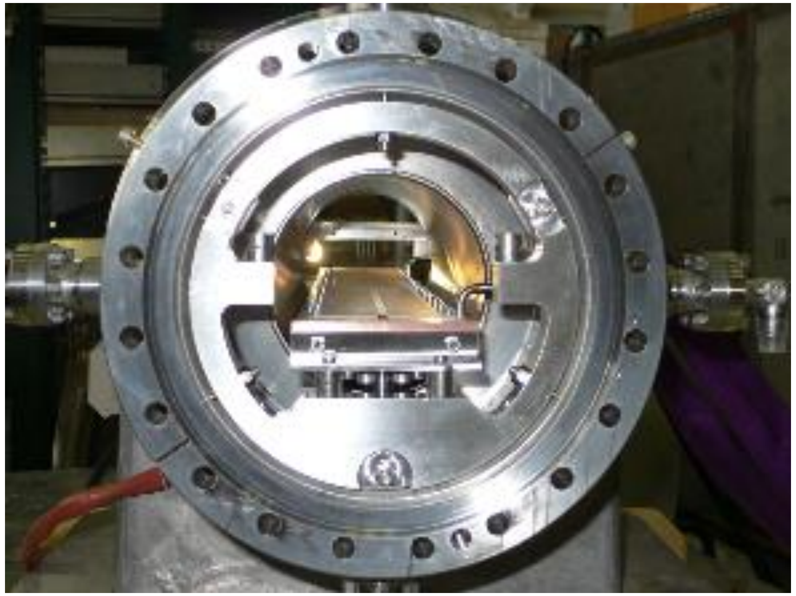
- 86 metres long, of which 76 metres are for acceleration
- 120 km of cables
- 173 quadrupole magnets (including 126 permanent magnets)
- 27 RF cavities
- 17 klystrons (of which 9 come from LEP) for RF power

Innovations in LINAC4

several innovations; ion source, two high-energy accelerating structures (CCDTL and PIMS), and its focusing system, which uses 126 permanent magnets.



3 MeV/ 352 MHz/ 3 m long RFQ
Commissioned with beam 2013

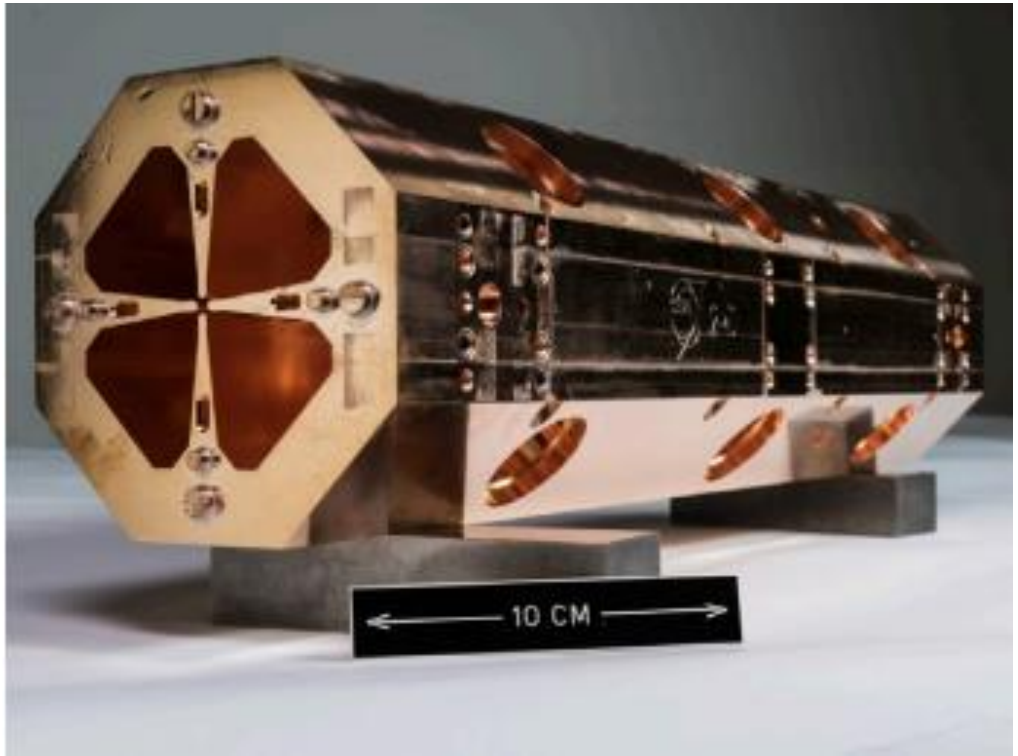


Fast chopper, validated 2013
Risetime<10nsec/ extinguish factor 100%

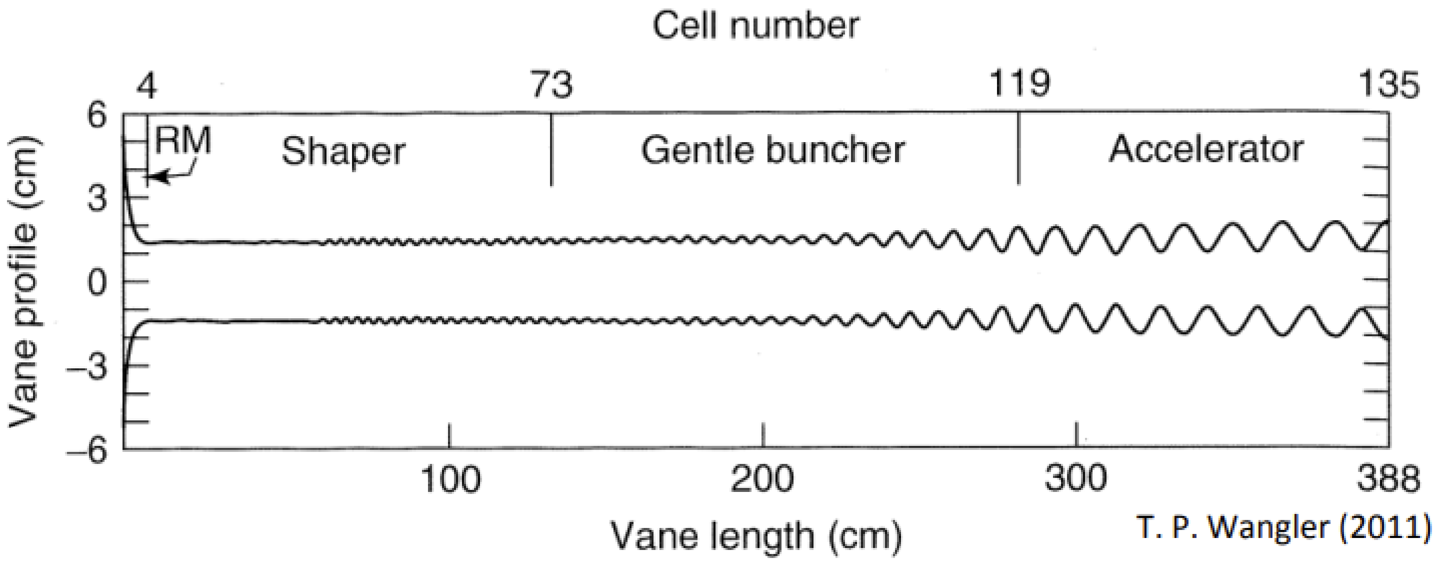
Permanent Magnet Quadrupole for the Drift Tube LINAC , 60 mm in diameter and 80 mm in length
Produced in European industry for the first time for LINAC4

RFQ

Uniquely combines acceleration + focusing + bunching in one device



From a few keV up to a few MeV



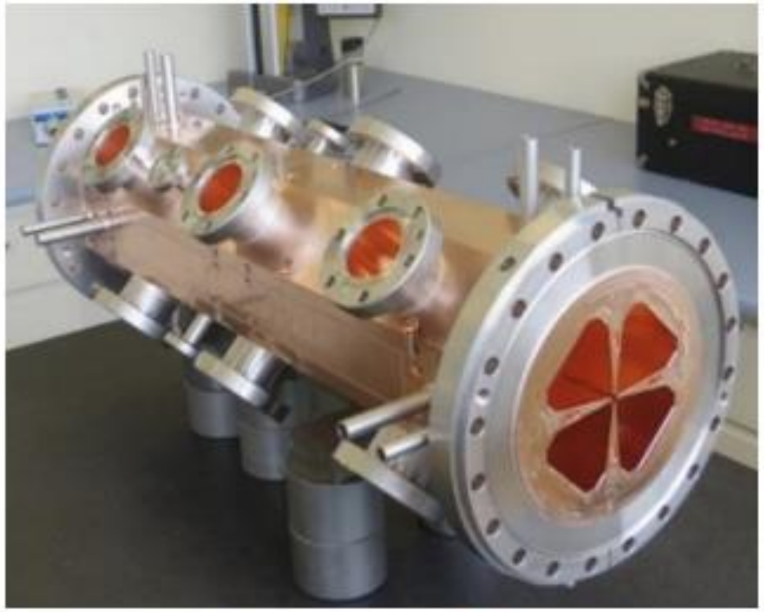
https://indico.cern.ch/event/958382/contributions/4039619/attachments/2168370/3660261/RFQs-CAS%20MME-Jan2020_01.pdf

All good things come in threes

352 MHz

750 MHz

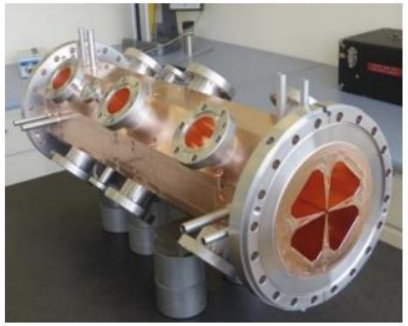
Linac4 (2010)



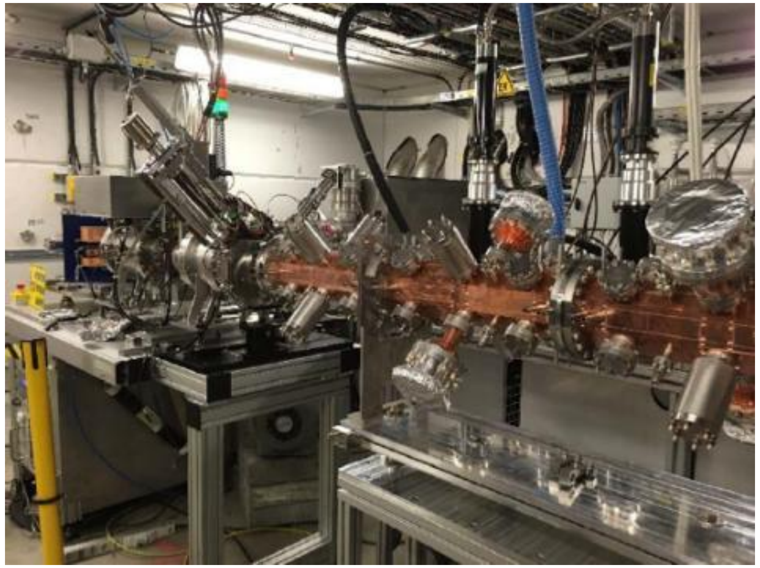
HF-RFQ (2016)

PIXE-RFQ (2019)

50keV to 5 MeV : missing link in a 3GHz LINAC based hadron-therapy facility



HF-RFQ (2016)



Bunch-to-bucket injection

- Frequency must be a sub-harmonic of 3GHz (600,750 or 1000Mhz)

- Unexplored frequencies for a pre-injector :
  - Short wave-lenght/rfq length and tunability can be an issue
  - Small dimension and machining tolerances

Advantages:

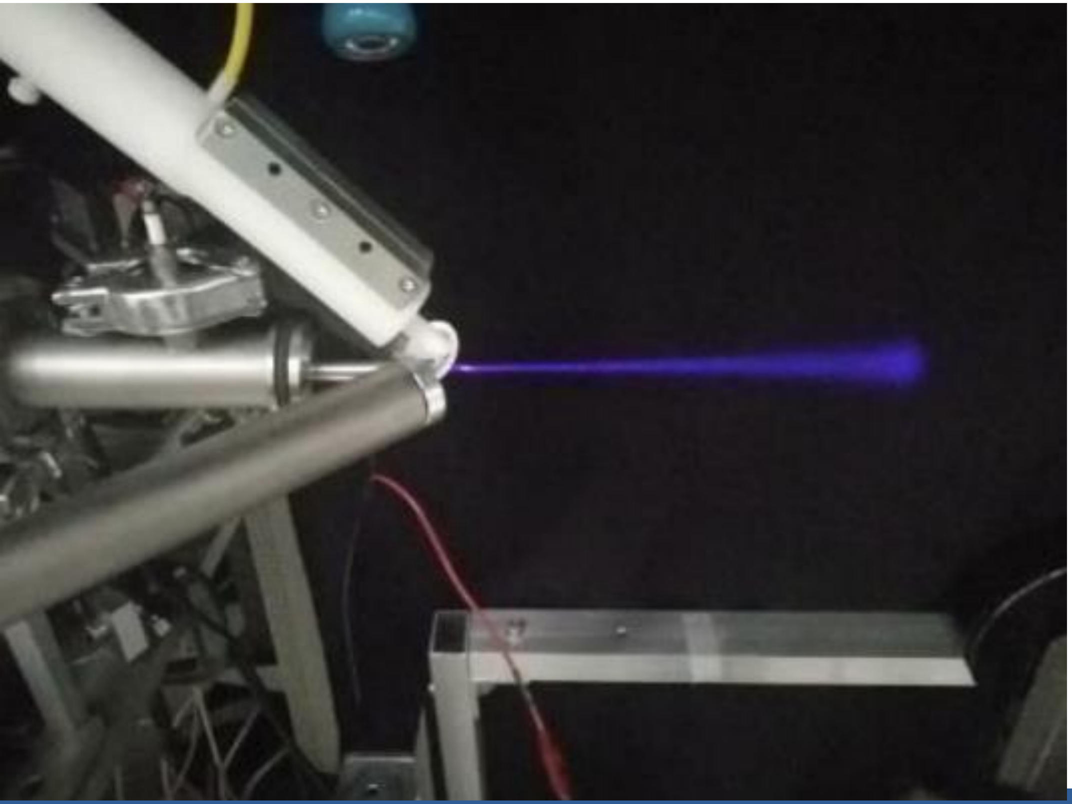
- Very compact system
- Lossless transfer to higher frequency
- All losses below 100keV

Low energy accelerator - The RFQ only -

INFN CHNet Istituto Nazionale di Fisica Nucleare Cultural Heritage Network

CERN technology

Material analysis with PIXE-PIGE; MACHINA

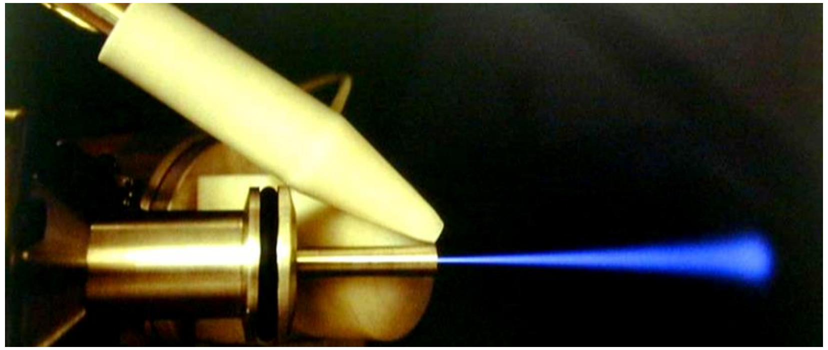


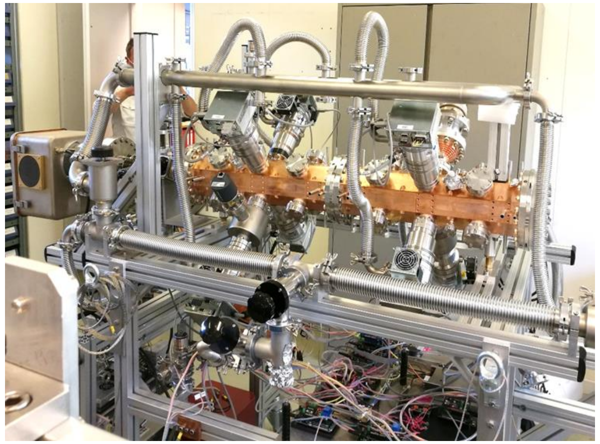
Madonna dei Fusi, Leonardo da Vinci, courtesy OPD, Florence

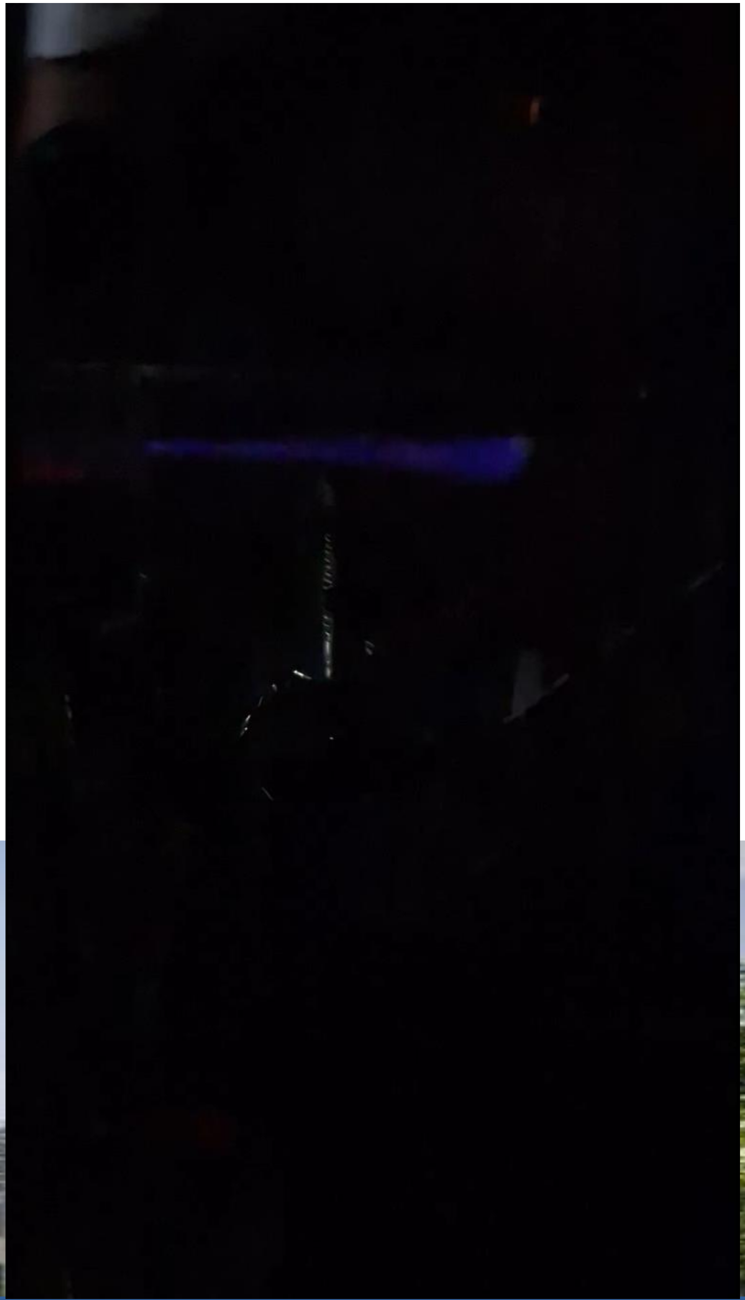
Source and RFQ parameters	
RF Frequency	750 MHz
Input	20 keV
Output Energy	2 MeV
Length	1m
Vane voltage	35kV
Peak RF power	100kW
Duty cycle / max	0.4% /(5%max)
Input/Output Pulse Current	100/30 μA
Transv. emittance 90%	0.1 pi mm mrad
Average aperture (r0)	1.4 mm
Maximum modulation	2.8

ELISA Experimental Linac for Surface Analysis

A miniature proton accelerator for Science Gateway



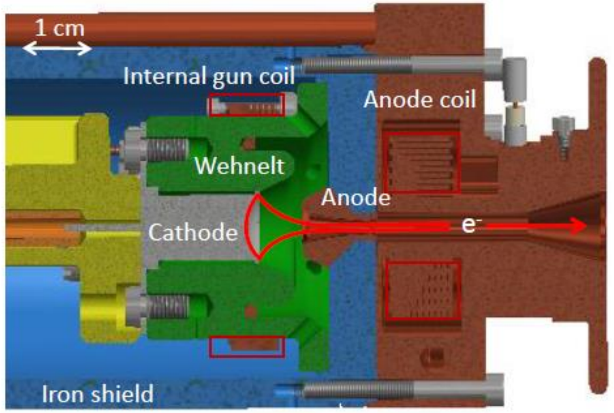




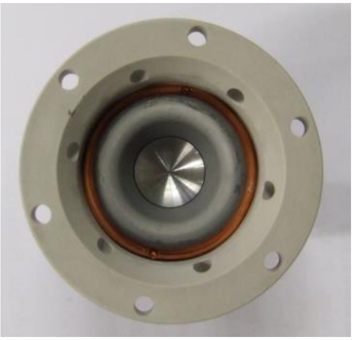
NEXT challenge : accelerate Carbon in a LINAC

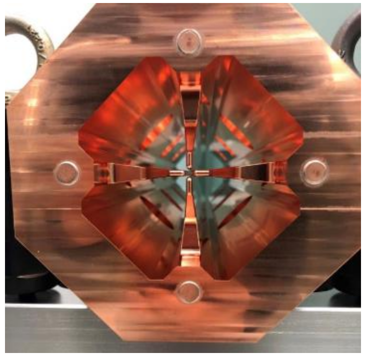
1- Source of fully stripped carbon ion with sufficient quality for use in a medical facility

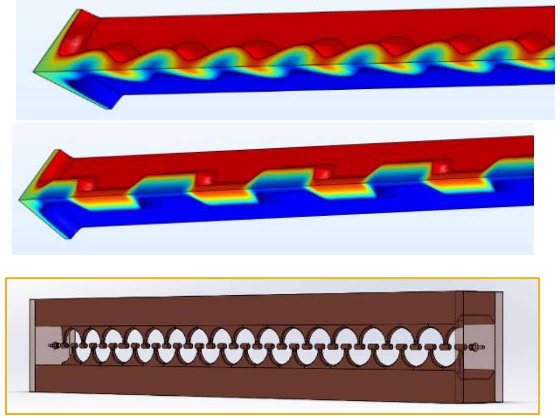
MED GUN



MEDeGUN mechanical design



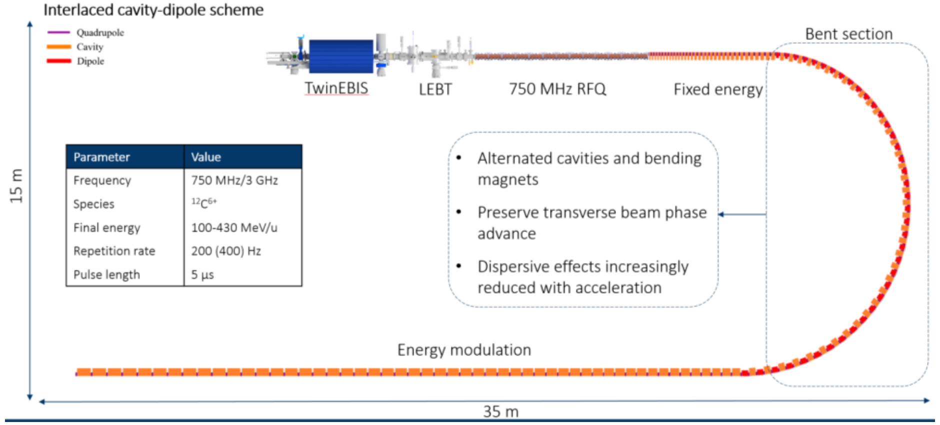




RFQ and IH

2- An efficient and easy to use pre-injector

Bent linac



Parameter	Value
Frequency	750 MHz/3 GHz
Species	$^{12}C^{6+}$
Final energy	100-430 MeV/u
Repetition rate	200 (400) Hz
Pulse length	5 μs

3- LINAC with a "hospital-friendly" footprint , adaptable to existing buildings and allowing intermediate station for e.g. Radioisotope production

Proton-Ion Medical Machine Study (PIMMS)

Originated by Ugo Amaldi, Meinhard Regler and Phil Bryant

- **Optimised the design of synchrotron accelerators used in both heavy ion and proton therapy.**

- From PIMMS (Proton Ion Medical Machine Study) @ CERN, with TERA and INFN, → CNAO proton and ion accelerator and further to MedAustron hadrontherapy centers nowadays treating together >7k patients

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
CERN - PS DIVISION

CERN/PS 2000-007 (DR)

PROTON-ION MEDICAL MACHINE STUDY (PIMMS)
PART II

Accelerator Complex Study Group*
supported by the Med-AUSTRON, Onkologie-2000 and the TERA Foundation
and hosted by CERN

ABSTRACT

The Proton-Ion Medical Machine Study (PIMMS) group was formed following an agreement between the Med-AUSTRON (Austria) and the TERA Foundation (Italy) to combine their efforts in the design of a cancer therapy synchrotron capable of accelerating either light ions or protons. CERN agreed to support and host this study in its PS Division. A close collaboration was also set up with GSI (Germany). The study group was later joined by Onkologie-2000 (Czech Republic). Effort was first focused on the theoretical understanding of slow extraction and the techniques required to produce a smooth beam spill for the conformal treatment of complex-shaped tumours with a sub-millimetre accuracy by active scanning with proton and carbon ion beams. Considerations for passive beam spreading were also included for protons. The study has been written in two parts. The more general and theoretical aspects are recorded in Part I and the specific technical design considerations are presented in the present volume, Part II. An accompanying CD-ROM contains supporting publications made by the team and data files for calculations. The PIMMS team started its work in January 1996 in the PS Division and continued for a period of four years.

*Full-time members: L. Badano[1], M. Benedikt[2], P.J. Bryant[2] (Study Leader), M. Crescenti[1], P. Holy[3], A. Maier[2)+4)], M. Pullia[1], S. Reimoser[2)+4)], S. Rossi[1],
Part-time members: G. Borri[1], P. Knaus[1)+2)]
Contributors: F. Gramatica[1], M. Pavlovic[4], L. Weisser[5]
1) TERA Foundation, via Puccini. 11, I-28100 Novara.
2) CERN, CH 1211 Geneva-23.
3) Oncology-2000 Foundation, Na Morani 4, CZ-12808 Prague 2.
4) Med-AUSTRON, c/o RIZ, Prof. Dr. Stephan Korenstr.10, A-2700 Wr. Neustadt.
5) Sommer & Partner Architects Berlin (SPB), Hardenbergplatz 2, D-10623 Berlin.

Geneva, Switzerland
May 2000

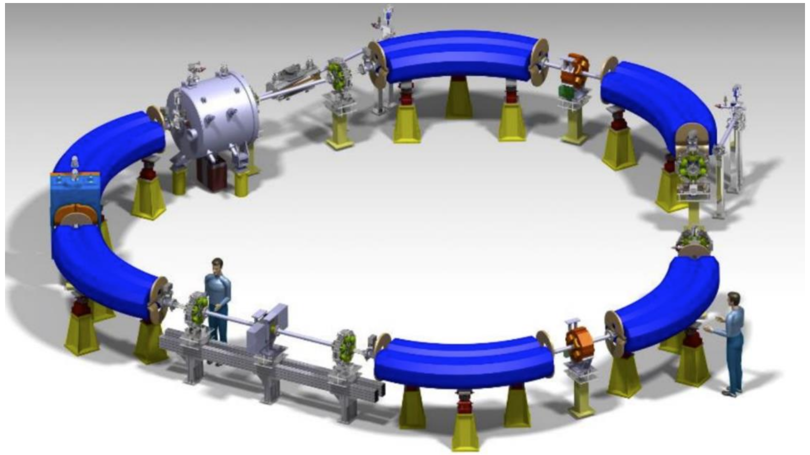
PIMMS

August 2000

Next Ion Medical Machine Study (NIMMS)

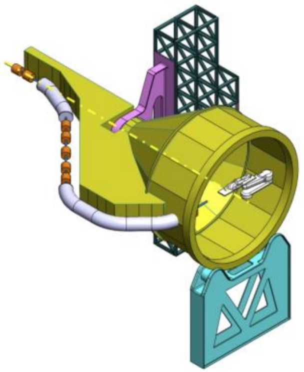
CERN launched NIMMS in 2018 with focus on ion therapy, to avoid competition in the proton market.

Studying:
Compact synchrotrons, Superconducting magnets, Superconducting gantries, High frequency ion linacs



Identified:
- bottlenecks for implementation of a new carbon ion centre in Europe and redirect R&D towards compact hospital-size solutions supported by the medical community.

Developed:
- **Conventional carbon synchrotron** with advanced features for the needs of SEEIIST (Yellow Report CERN-2024-04).
- Initial design of a “**helium synchrotron**” (HeLICS=Helium and Light Ion Compact Synchrotron).
- The design of a **compact linac** for production of 211At for targeted alpha therapy of cancer and other isotopes.



CLIC (Compact Linear Collider)

Concept, design, and technical R&D for next-gen, multi-TeV linear collider

Required development of high-gradient accelerator technology
More compact, efficient, affordable

Promote industrial base and application of CLIC technologies as part of R&D strategy

Accelerating structure prototype for CLIC:

- *12 GHz*
- *100 MV/m*
- *L~25 cm*

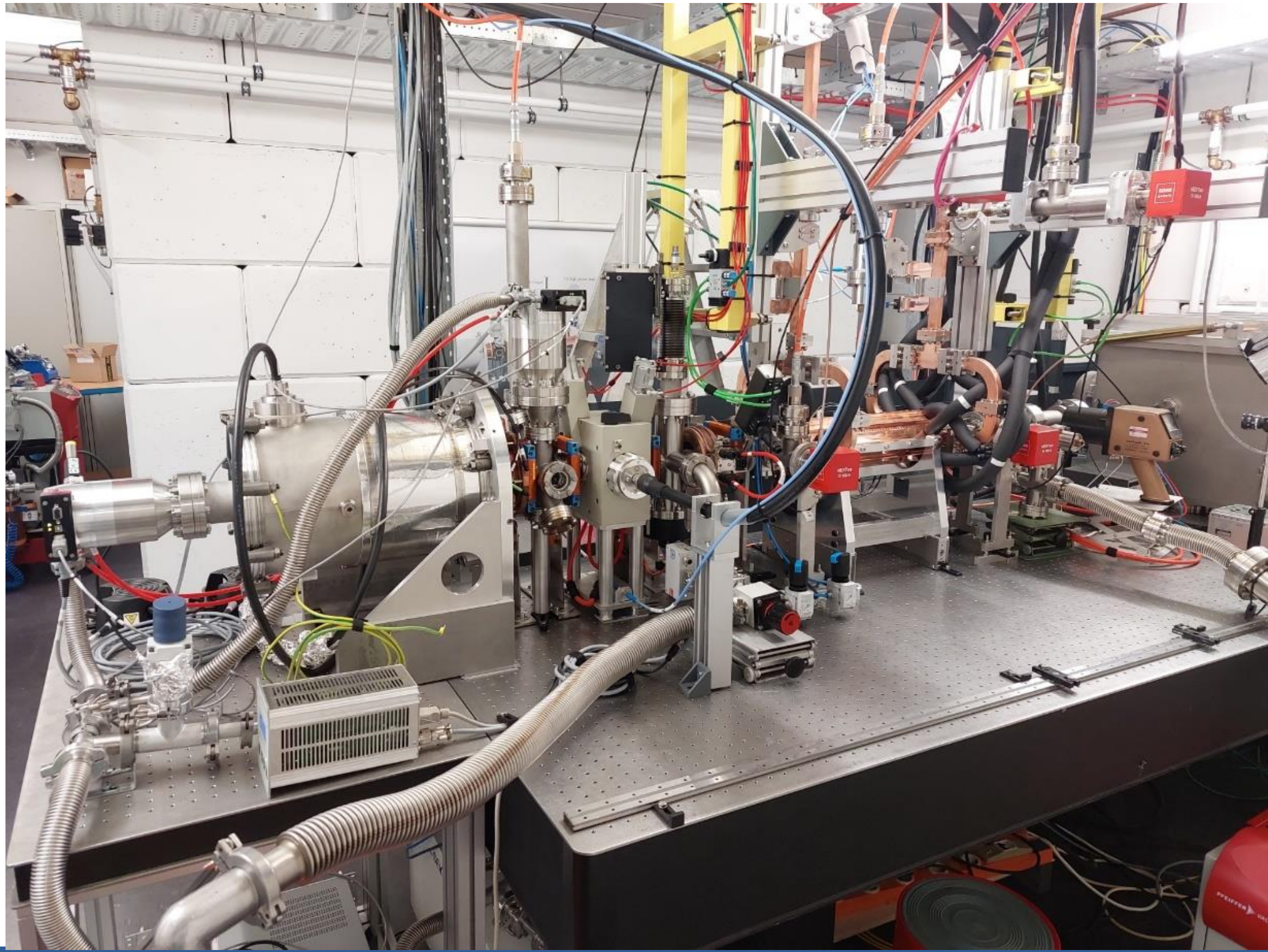
Research / Industrial - Smart*Light

Collaboration with Eindhoven University of Technology

- **30 MeV electrons producing 40 keV X-rays** through laser interaction
- Upgrading to **Smart*Light 2.0 with 60 MeV and 100x higher repetition rate**
- **Table-top device** in operation

Accelerator technology

- **Single X-band** accelerating structure
- 6 MW X-band klystron with **pulse compressor**



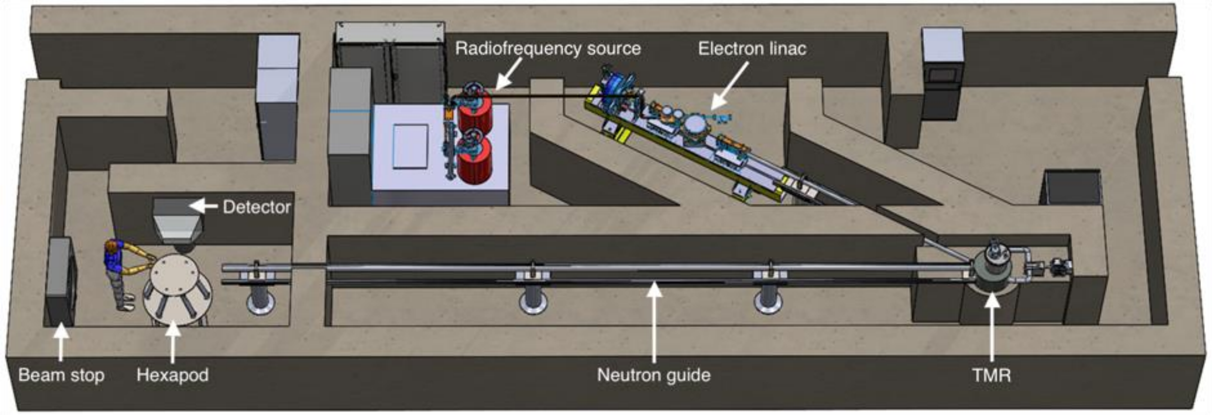
VULCAN (Versatile ULtra-Compact Advanced Neutron Generator)

CERN-DAES-DTI-Xnovotech collaboration

Target-moderator-reflector for converting electrons to thermal neutrons for Stress-strain measurements
Proof of concept testing in CLEAR (CERN 200 MeV electron linac)

Accelerator technology

- 35 MeV, kW-scale electron linac
- High-gradient accelerating structures and pulse compressor optimized for compactness, cost, beam power and efficiency
- High-power, high-efficiency klystrons



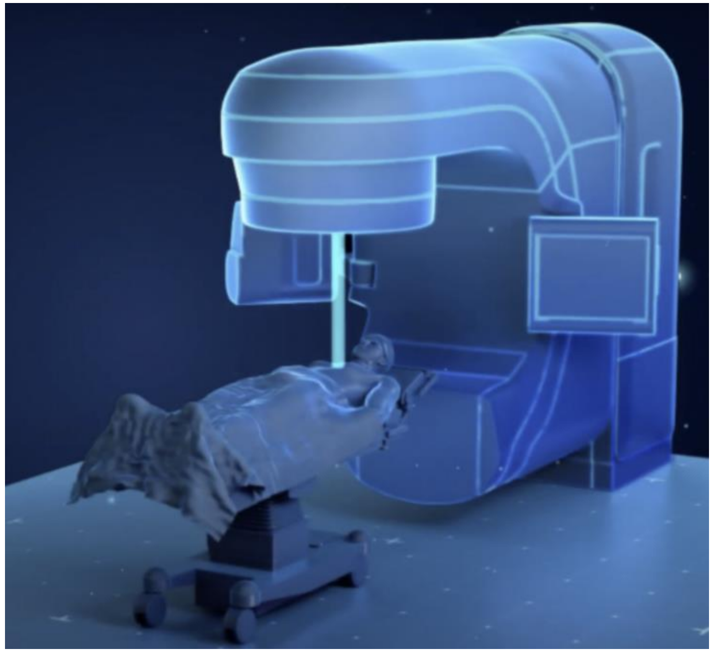
STELLA (Smart Technologies to Extend Lives with Linear Accelerators)

CERN-ICEC-STFC-Lancaster University-Oxford University-Cambridge University collaboration

New LINAC Prototype: more robust, modular and easier to maintain and operate than current systems.

Software Integrated Platform: Leveraging machine learning and AI. Software that accurately predicts faults, streamlines maintenance and provides physicians with a helping hand.

Training and Servicing: STELLA will create solutions in training and servicing for local expertise to grow and for the downtimes of RT facilities to be greatly reduced.



Accelerator technology

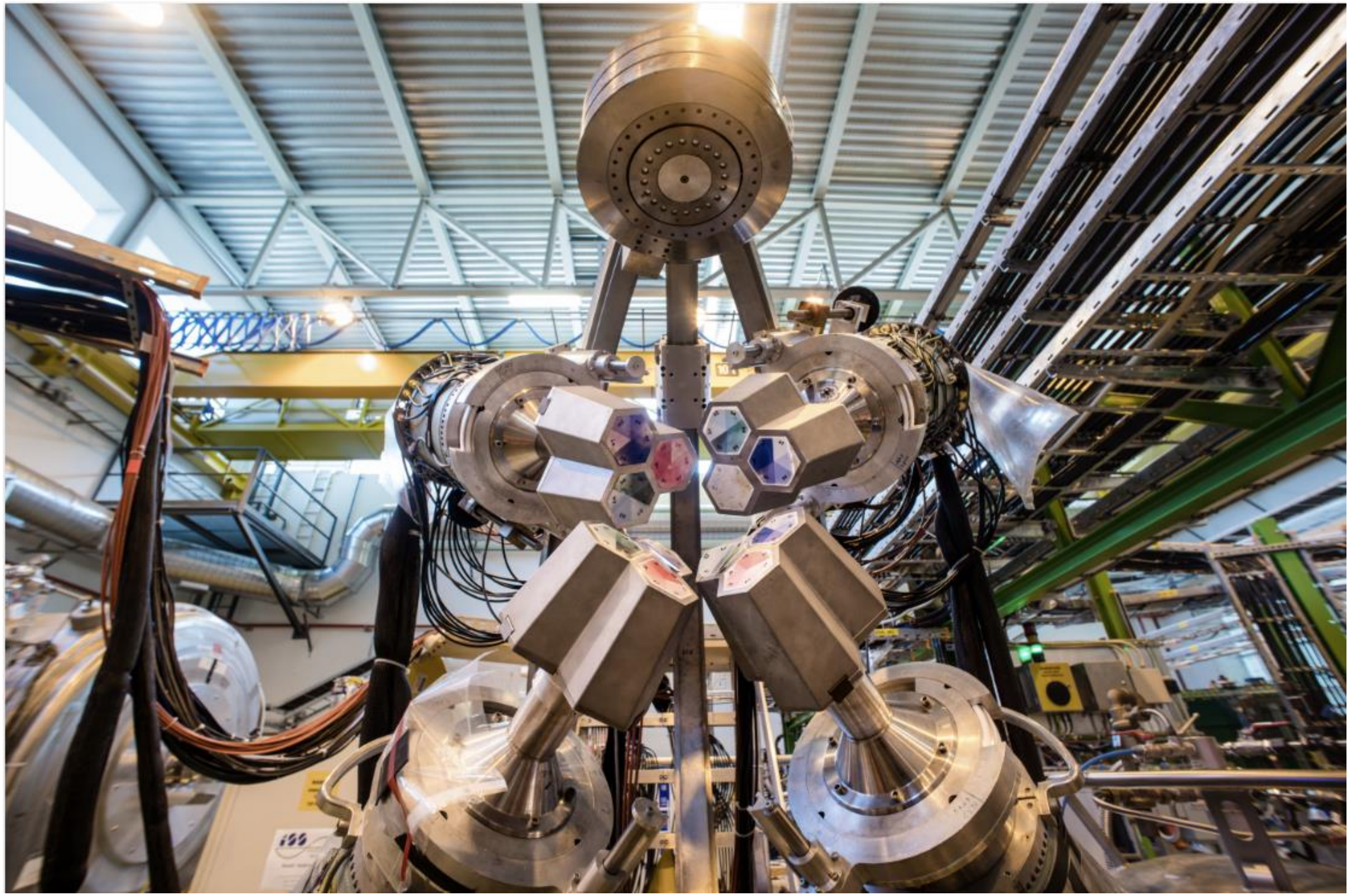
- Single high-capture, high-gradient accelerating structure
- Long lifetime RF power source
- Modular, upgradable (hardware and software)

HIE-ISOLDE

HIE = High-Intensity and Energy
ISOLDE = Isotope mass Separator On-Line

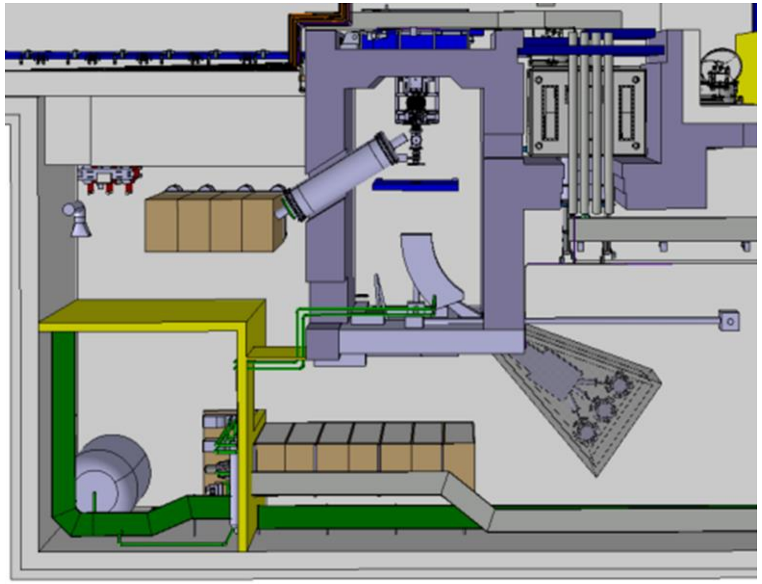
A **unique nuclear research facility**, which produces radioactive nuclei (ones with too many, or too few, neutrons)

Research a range of topics, from studying **the properties of atomic nuclei** to **biomedical research** and to **astrophysics**.



MEDICIS (Medical Isotopes Collected from ISOLDE)

Designed to produce unconventional radioisotopes with the right properties to enhance the precision of both patient imaging and treatment.



Courtesy T. Cocolios

TÉCNICO LISBOA

1862 RIGA TECHNICAL UNIVERSITY

CHUV Centre hospitalier universitaire vaudois

HUG Hôpitaux Universitaires Genève

PSI

Arronax Nantes

KU LEUVEN

Where do we use these accelerators?

Research

- Particle physics
- Nuclear physics
- Neutron sources
- Light sources
- ...

Healthcare

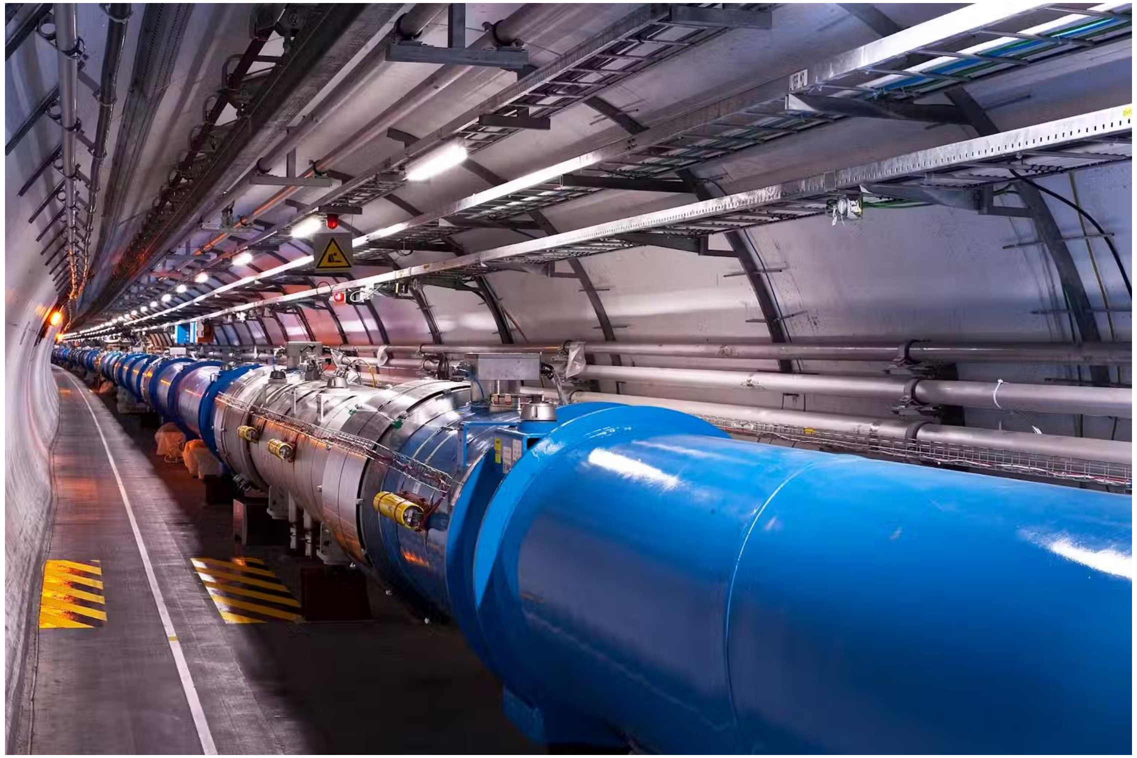
- Radioisotopes
- Radiotherapy
- Diagnostics
- Sterilization
- ...

Industry

- Radiation hardness testing
- Imaging
- Sterilization
- Material analysis
- ...

Environment

- Ion implantation
- Irradiation of seeds
- Pollution control
- Water purification
- ...



Thank you!

Questions?

Visit KT.CERN

noora-mari.pienimaki@cern.ch

Subscribe the KT newsletter

@cern-innovation-partnerships

@CERNVenture

Subscribe to the KT newsletter
Visit KT.CERN

Follow us on social media
#CERNKT