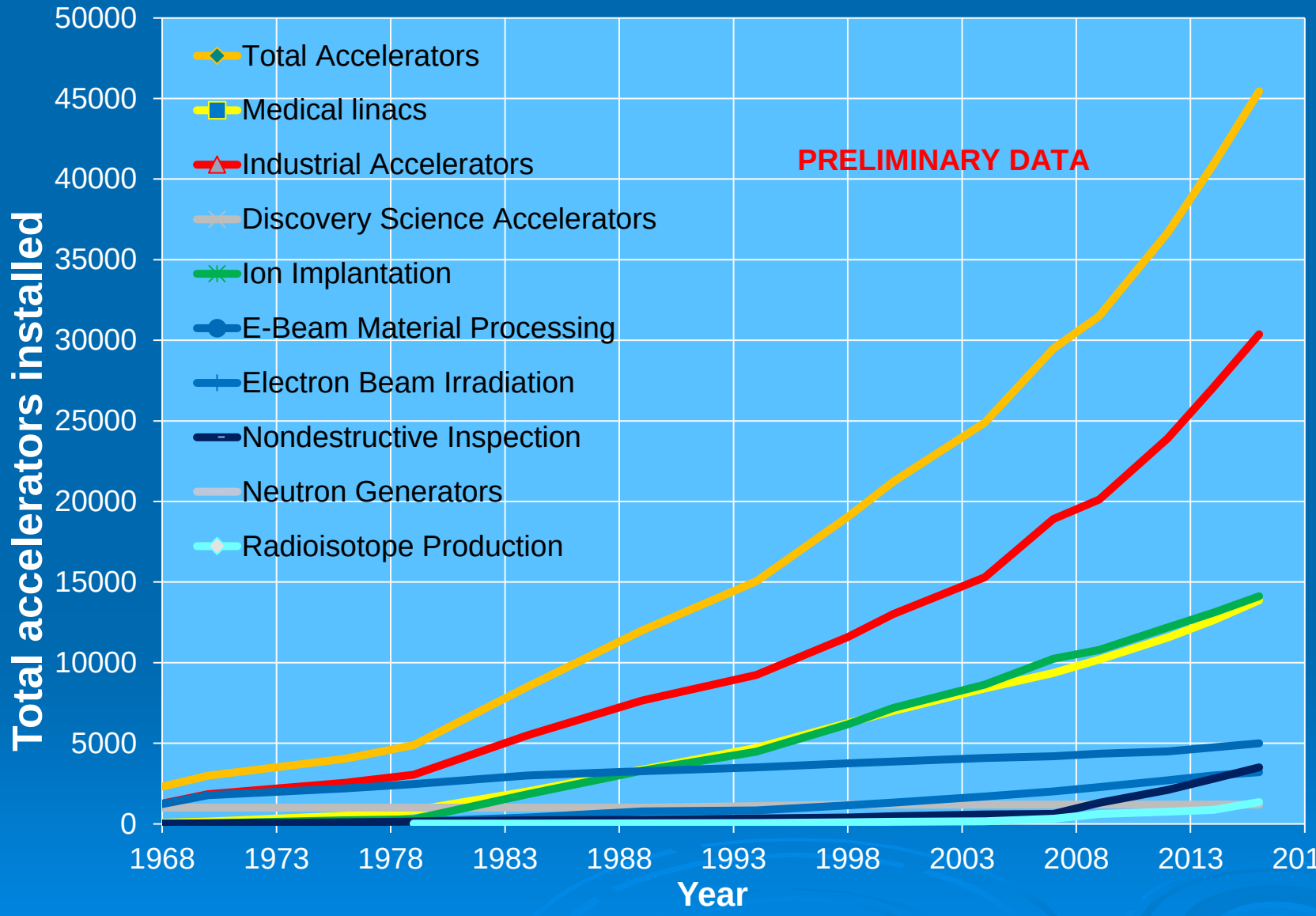
Accelerators Installed Worldwide



Total sales of accelerators is ~US$5B annually

About 47,000 systems have been sold,
> 40,000 still in operation today

More than 100 vendors worldwide are in the accelerator business.

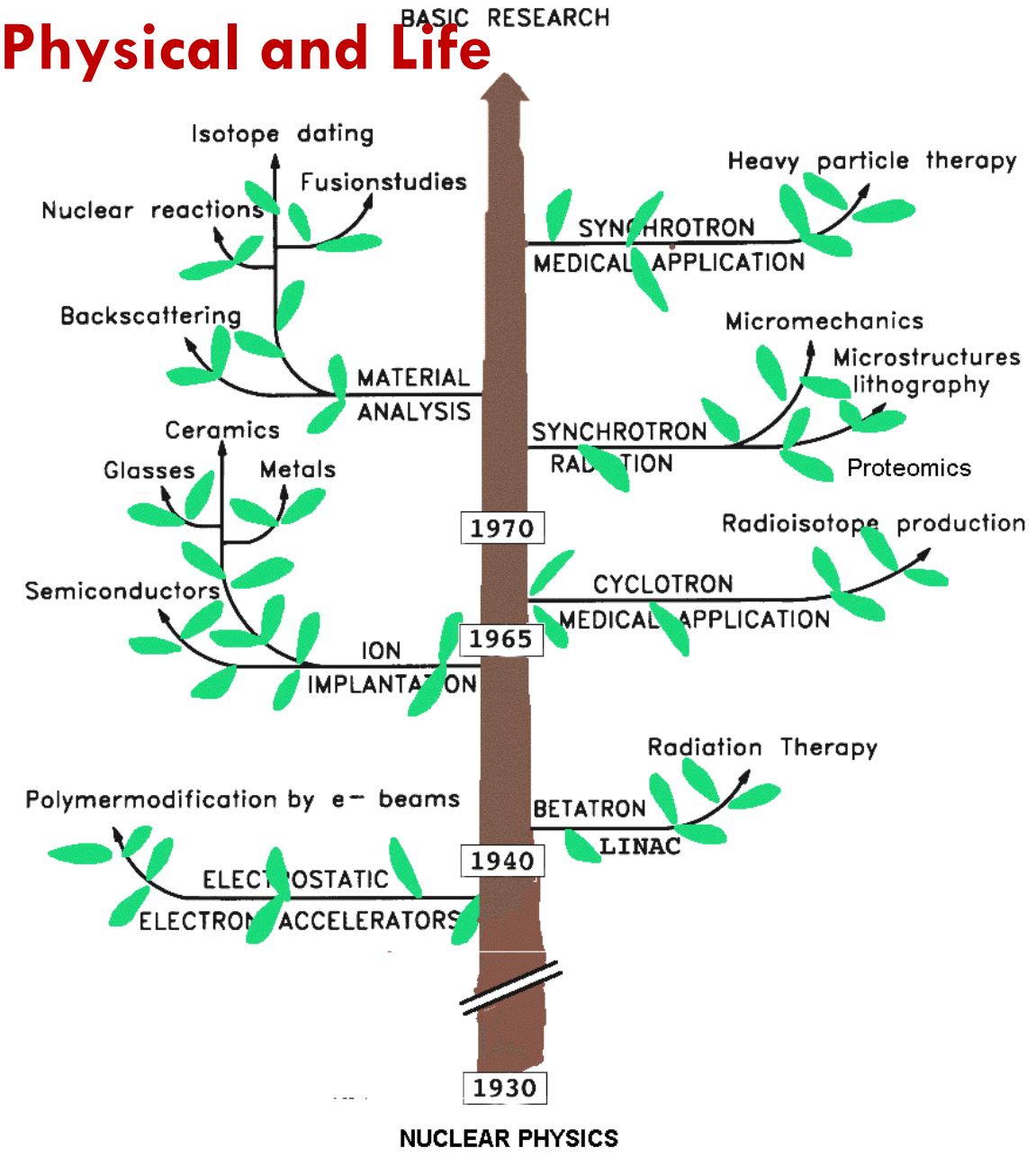
Vendors are primarily in US, Europe and Japan, but growing in China, Russia and India

R. Hamm, Accelerator-Industry Co-Innovation Workshop, Feb 6, 2018, Brussels, Belgium

The role of accelerators in Physical and Life Sciences

"Instruments have a life of their own.
They do not merely follow theory; often they determine theory, because instruments determine what is possible, and what is possible determines to a large extent what can be thought. The telescope, the microscope, the chronograph, the photograph: all gave rise to a blossoming of theoretical understanding not possible before their invention"

Hankins & Silverman,
Instruments and the Imagination

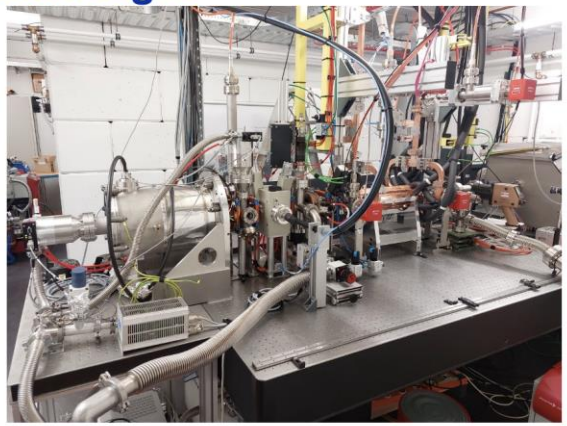


We now have a growing local accelerator R&D community ? Can we imagine a future accelerator (or several) in Norway during the next decade ?

- Medical systems surely, but not easy to engage local accelerator experts at scale at such a facility. They are mainly delivered as complete systems, medically qualified (e.g. from protons to ions, maybe FLASH of various flavours, maybe also for some isotopes – PET, Theranostics).
- Larger research machines as synchrotrons or FELs too ambitious (community, cost, etc).
- Let us look at compact electron linacs and some potential uses. There are design challenges to address and optimisation needed for specific applications, there are industrially available parts but often not complete systems.
- Can such linacs serve as research facility where both accelerator (and detector) experts can thrive, and engage a user community in academia, research or industry ?
- What is small: size 2-15m, price 5-10 MCHF, electron energy 5-50 MeV (with plasma maybe much more). Covers medical systems, isotopes, irradiation, ICS, neutron production and more.
- In Norway we have expertise in machines using normal conduction RF and plasma, but also SCRF conceivable - and we have experience in use of the such machines (e.g. CLEAR)
- Some examples to consider, not exhaustive, in the following

Research / Industrial - Smart*Light

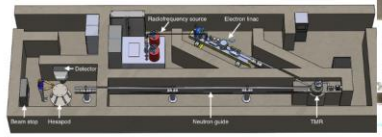
- **Dutch-Flemish collaboration, at Eindhoven University of Technology**
  - Inverse Compton Scattering
  - 30 MeV electrons producing 40 keV X-rays through laser interaction
  - Upgrading to Smart*Light 2.0 with 60 MeV and 100x higher repetition rate
  - Table-top device in operation
- **Accelerator technology**
  - Single X-band accelerating structure
  - 6 MW X-band klystron with pulse compressor

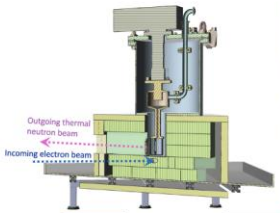


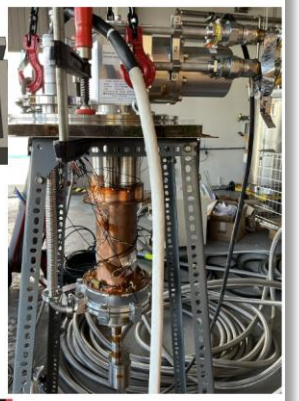
TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

Industrial - VULCAN (Versatile ULtra-Compact Advanced Neutron Generator)

- **CERN-DAES-DTI-Xnovotech collaboration**
  - 35 MeV, kW-scale electron linac
  - Target-moderator-reflector for converting electrons to thermal neutrons
  - Stress-strain measurements, battery & fuel-cell investigations
  - Proof of concept testing in CLEAR this year, complete prototype construction by mid-late 2020s
- **Accelerator technology**
  - High-gradient accelerating structures and pulse compressor optimized for compactness, cost, beam power and efficiency
  - High-power, high-efficiency klystrons

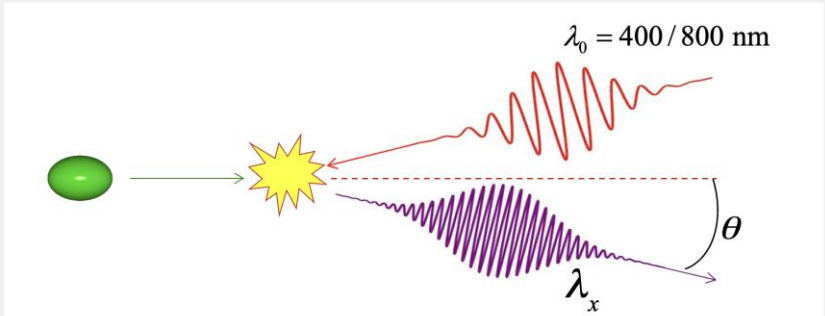






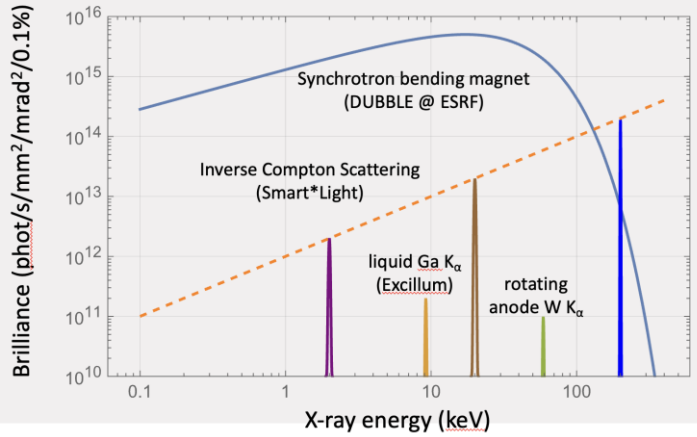
CERN DAES xnovotech

X-ray generation by Inverse Compton Scattering (ICS)



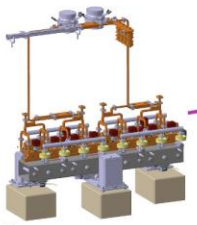
$$\lambda_x = \frac{\lambda_0}{4\gamma^2}(1+\gamma^2\theta^2)$$

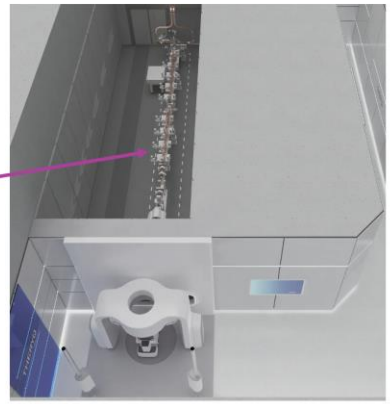
Brilliance



Medical - DEFT (Deep Electron Flash Therapy)

- **CERN-CHUV-THERYQ collaboration**
  - VHEE (100 – 250 MeV)
  - FLASH (>40 Gy/s, < 100 ms)
  - Clinical trials planned for 2025
- **Accelerator technology**
  - S-band photoinjector
  - X-band accelerating structures mounted on girders
  - X-band klystrons with pulse compressor

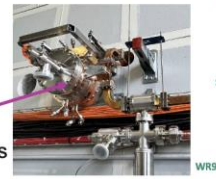


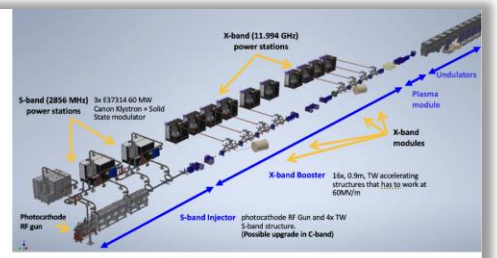


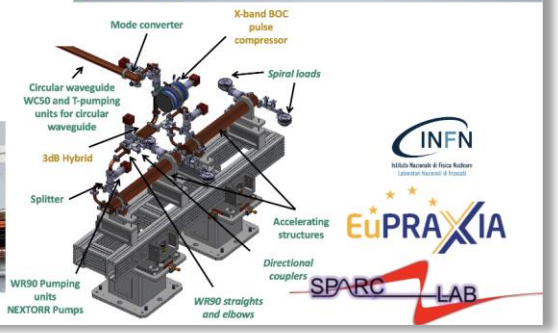
CERN CHUV THERYQ

Research - EuPRAXIA@SPARC_LAB

- **41 laboratory collaboration, hosted at INFN Frascati**
  - FEL facility driven by plasma acceleration
  - 1 GeV X-band electron linac driver of a plasma wakefield accerator
  - Expected ready for operation in 2028
- **Accelerator technology**
  - S-band injector
  - 50 MW X-band klystrons
  - X-band pulse compressor
  - X-band accelerating structures



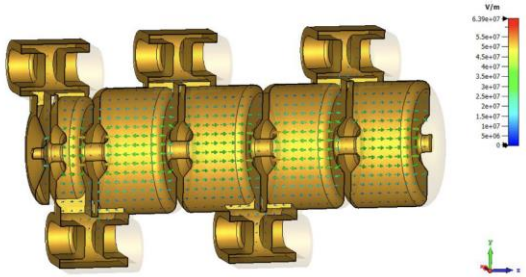




INFN EuPRAXIA SPARC LAB

Medical - STELLA (Smart Technologies to Extend Lives with Linear Accelerators)

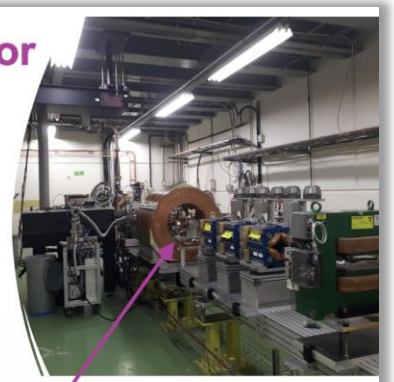
- **CERN-ICEC-STFC-Lancaster University-Oxford University-Cambridge University collaboration**
  - 6 MeV electron linac for x-ray radiotherapy
  - Optimised for LMICs
  - Prototype construction by late 2020s
- **Accelerator technology**
  - Single high-capture, high-gradient accelerating structure
  - Long lifetime RF power source
  - Modular, upgradable (hardware and software), maintainable design ethos.

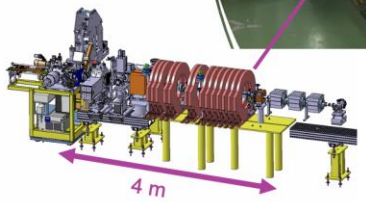


CERN International Cancer Expert Corps Partnering to transform global cancer care UKRI Science and Technology Facilities Council Lancaster University UNIVERSITY OF CAMBRIDGE

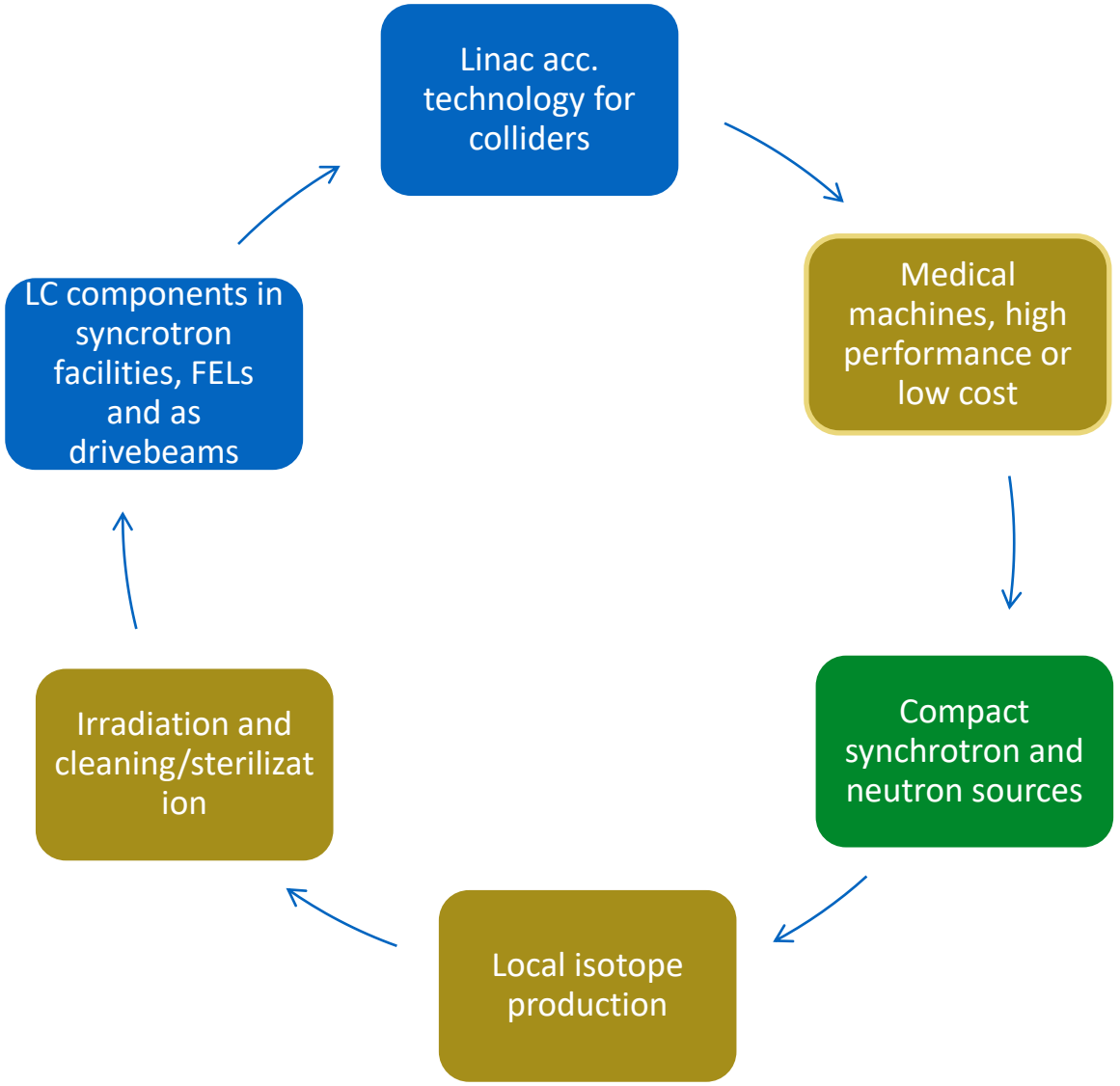
Research – CLEAR / AWAKE Injector

- **Hosted at CERN**
  - Demonstrate velocity bunching and emittance preservation with X-band
  - Standardise as injector for many applications
  - Currently undergoing experimentation in CERN's CLEAR facility to utilise as an ICS
- **Accelerator technology**
  - S-band injector system with RF-gun
  - X-band bunching and accelerating structures





CERN


Linac acc. technology for colliders
Medical machines, high performance or low cost
Compact synchrotron and neutron sources
Local isotope production
Irradiation and cleaning/sterilization
LC components in syncrotron facilities, FELs and as drivebeams