Heavy Ion Therapy Research Integration

ADAM and LIGHT

ALBERTO DEGIOVANNI

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101008548

"This material was prepared and presented within the HITRIplus **Specialised Course on Heavy Ion Therapy Research,** and it is intended for personal educational purposes to help students; people interested in using any of the material for any other purposes (such as other lectures, courses etc.) are requested to please contact the authors:

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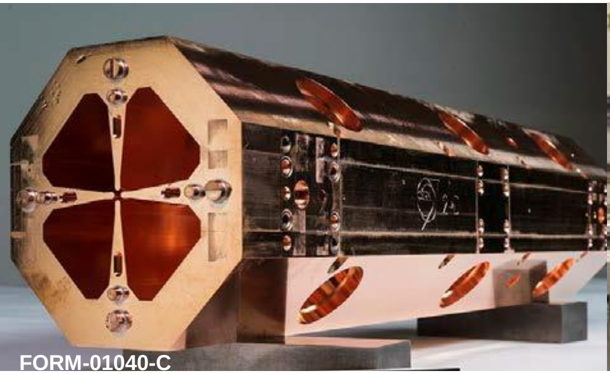
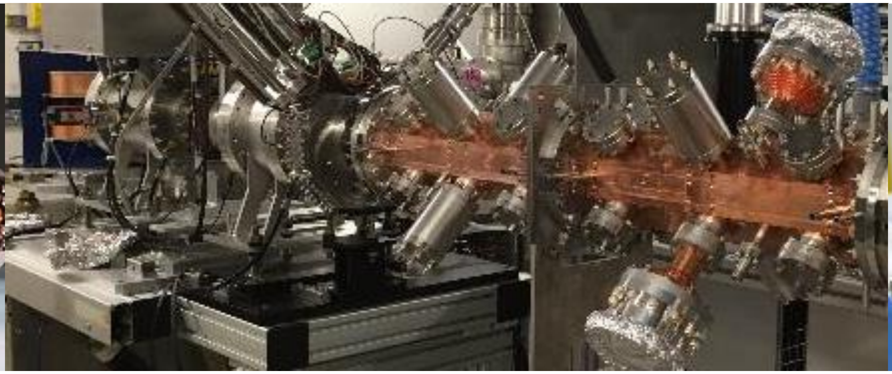
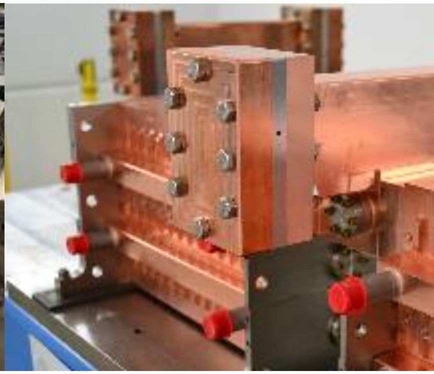
08.07.2022

ADAM
an ADVANCED ONCOTHERAPY company
CERN spin-off

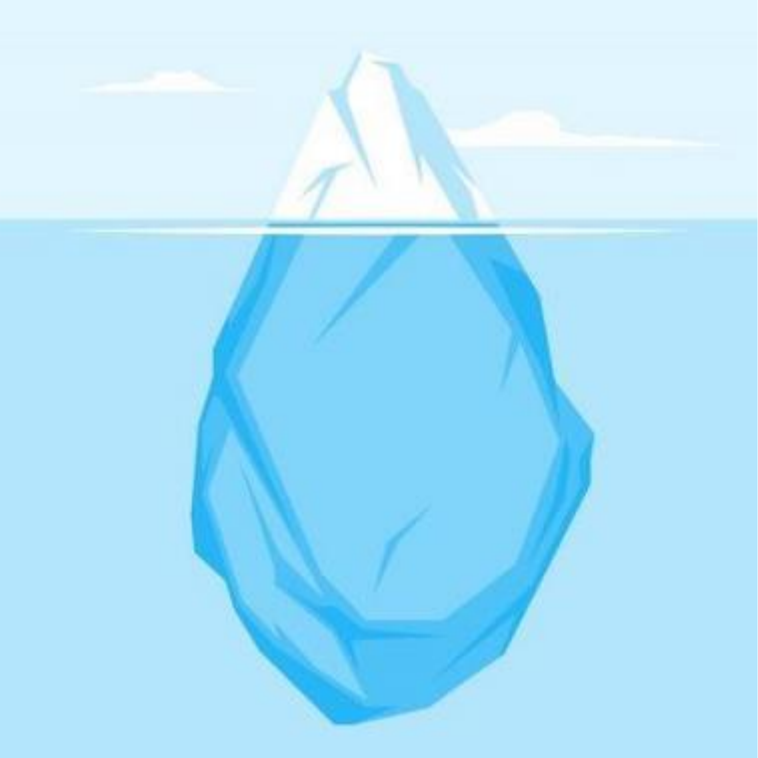
… LIGHT and ADAM

Linac for Image Guided Hadron Therapy and
Applications of Detectors and Accelerators to Medicine SA

Outlook:

1. The LiGHT accelerator "product"
2. The industrialization process



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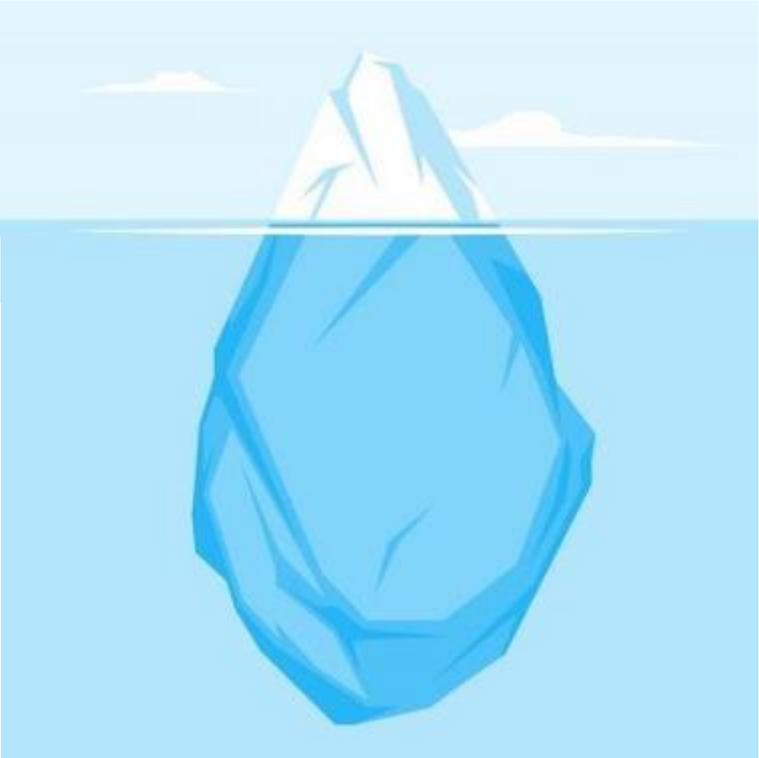
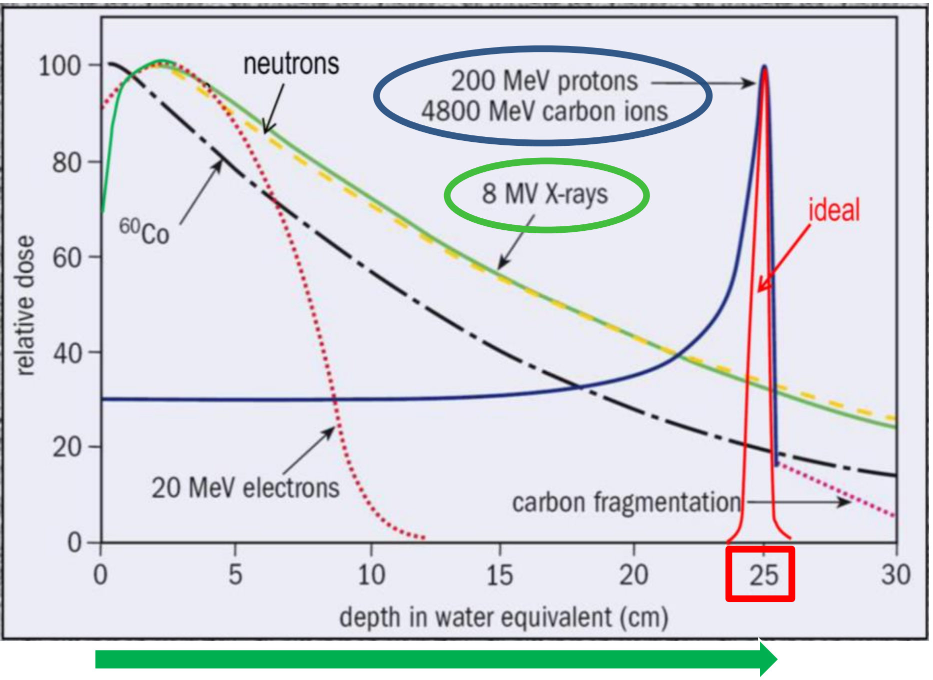
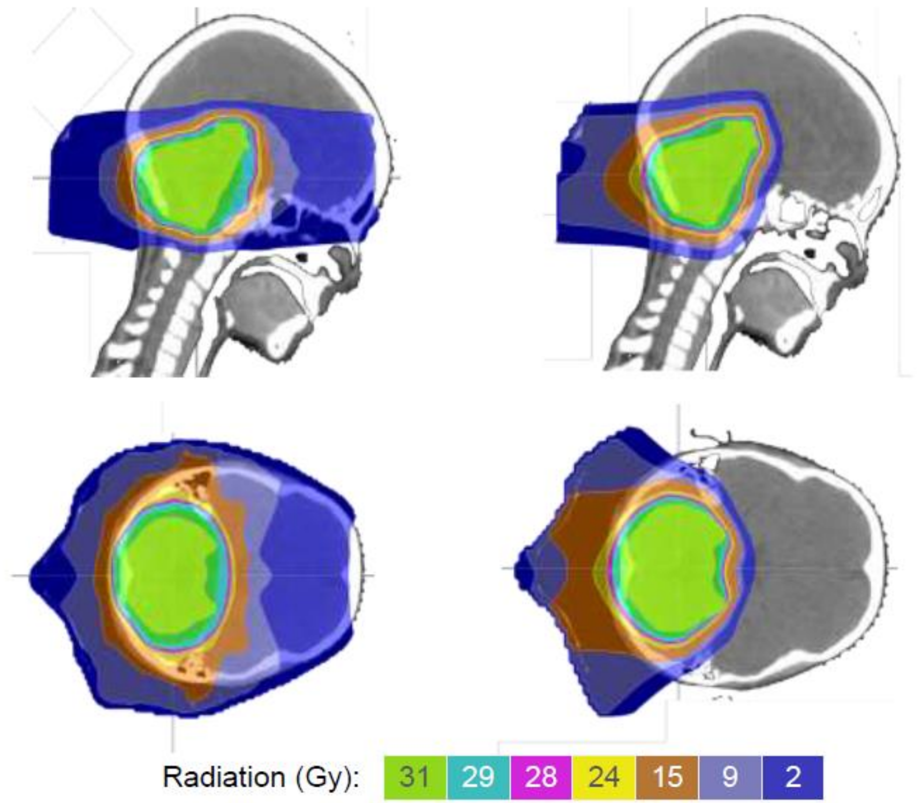


Clinical motivation – Photon vs proton therapy for cancer treatment



Radiation beam in matter

Photon Therapy (X-rays) | Proton Therapy

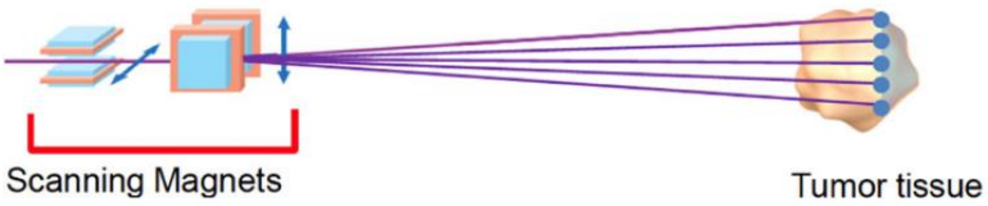


Source: American Society of Clinical Oncology & BCG

From clinical needs to beam and system requirements

Energy: 70-230 MeV

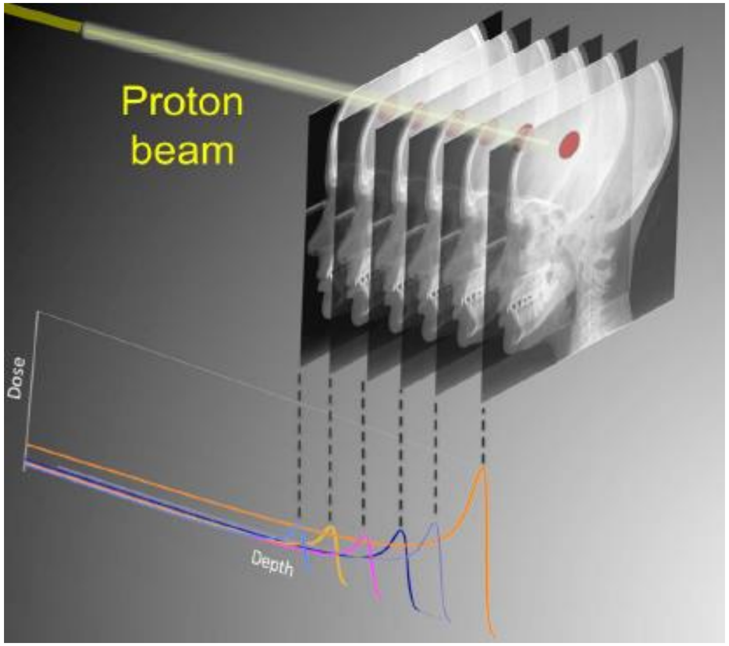
Current: ~1 nA
(~ 6 Billion protons per second)



The requirements of the beam spots of the LIGHT system include: variable charge, variable energy and variable spot position

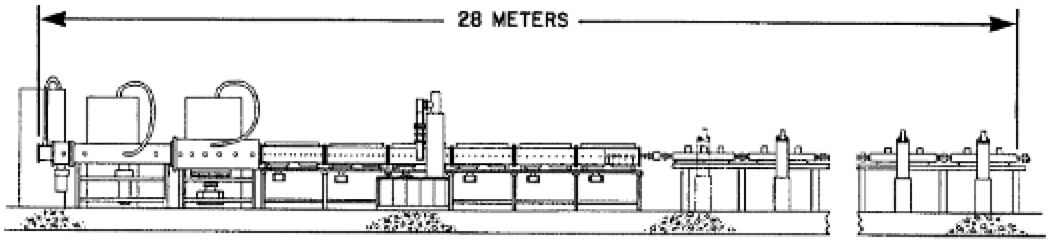
Beam spots with:

- **Variable charge:** ~ 1-250 Million protons in a pulse
- **Variable energy:** 70-230 MeV (in depth scanning between 3 and 32 cm)
- **Variable spot position:** spot can be moved transversally up to a 30x30 cm^2 field



The high-frequency linac technology choice

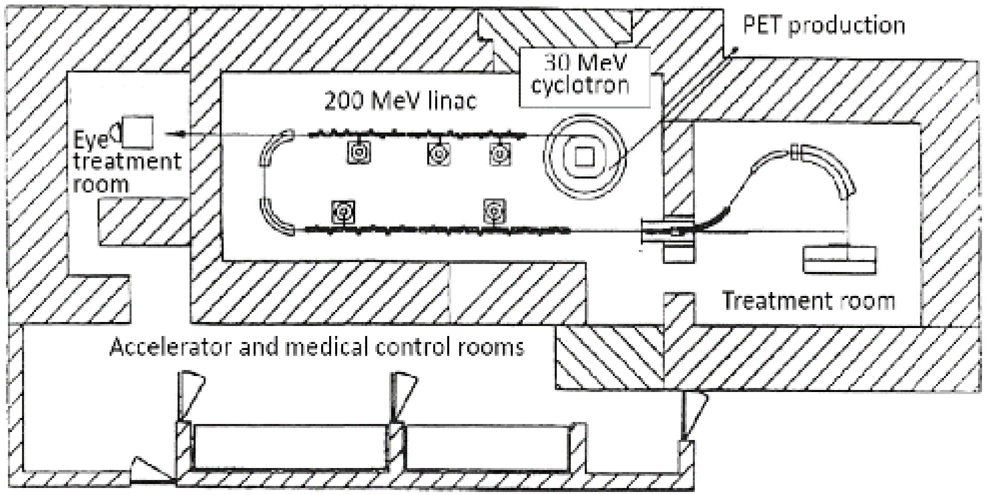
1991: first "all-linac" approach to proton therapy



Schematic layout of the model PL-250 proton therapy linac designed in 1991 by R. Hamm, K. Crandall and J. Potter

R. W. Hamm, K. R. Crandall and J. M. Potter, Preliminary design of a dedicated proton therapy linac, in *Proc. PAC90*, Vol. 4 (San Francisco, 1991), pp. 2583–2585.

1994: "cyclinac" approach to proton therapy



U. Amaldi, The Italian hadrontherapy project, in *Hadron Therapy in Oncology*, eds. U. Amaldi and B. Larsson (Elsevier, 1994), p. 45.

review paper

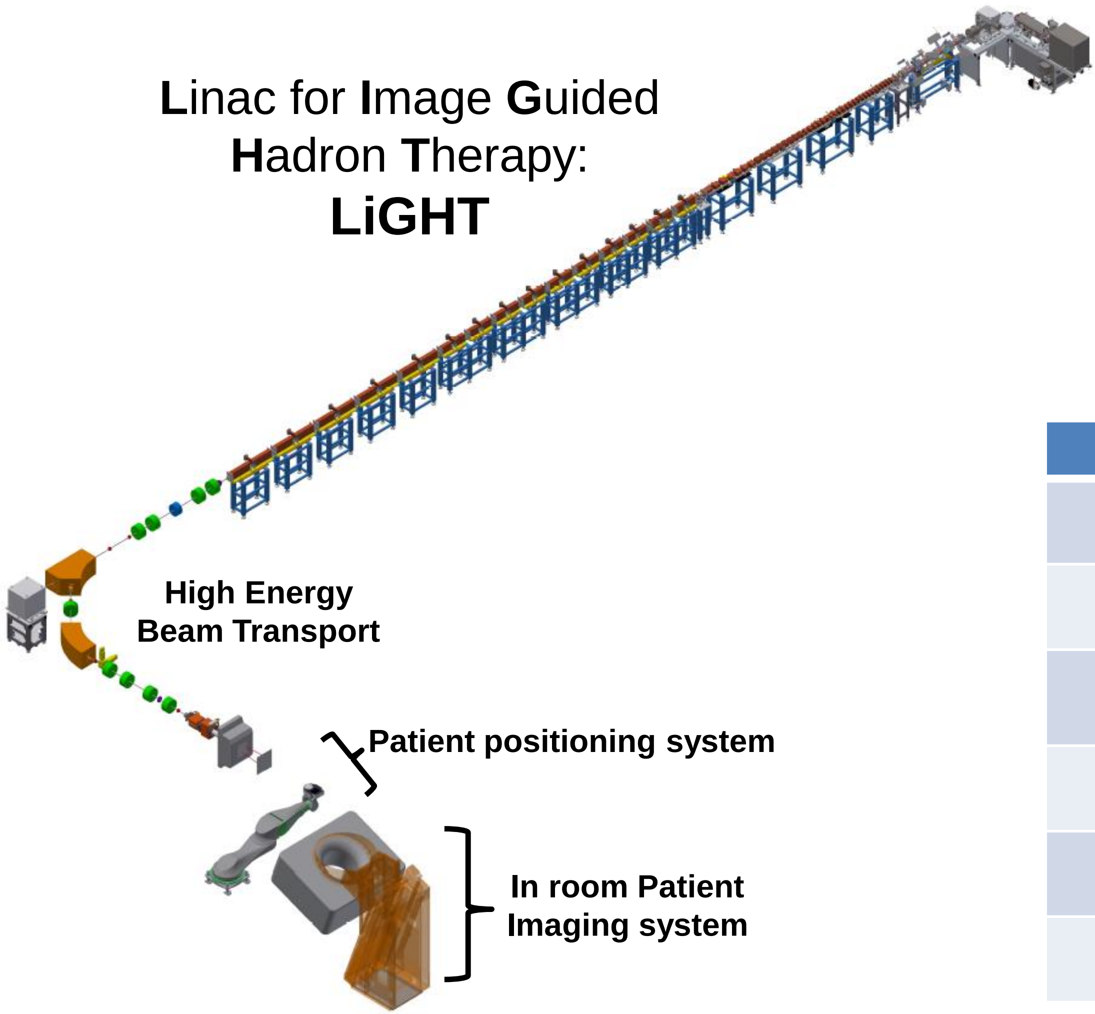
High Frequency Linacs for Hadrontherapy

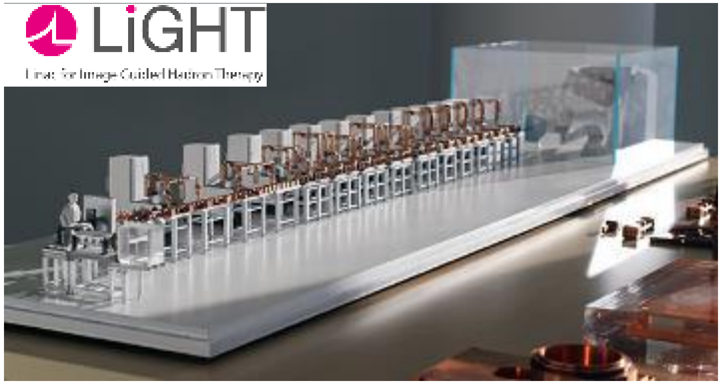
Ugo Amaldi   Saverio Braccini   Paolo Puggioni

Reviews of Accelerator Science and Technology
Vol. 2 (2009) 111–131

The LIGHT Beam Production System

Linac for **I**mage **G**uided **H**adron **T**herapy:
LiGHT

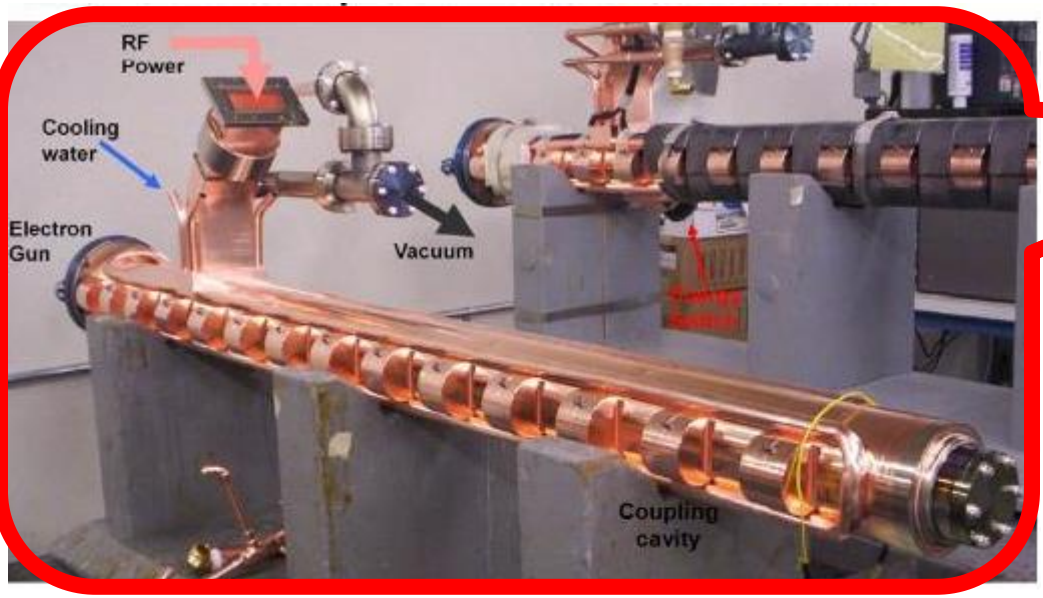


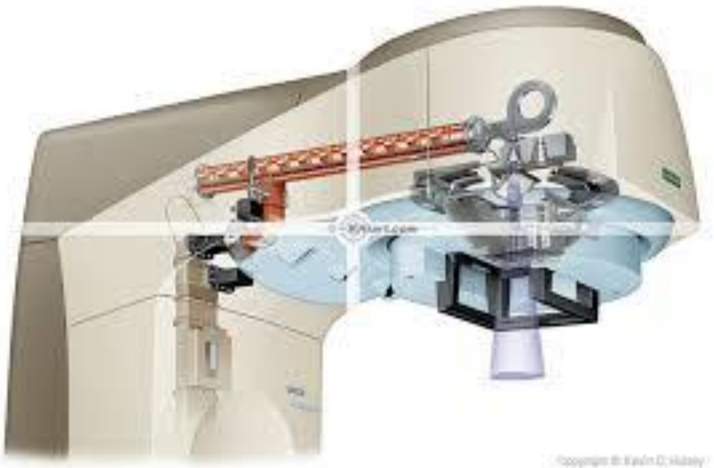


Parameter	Value	Unit
Length	~25	m
Max. Energy	230	MeV
Output Peak Current (at the end)	0.3 - 40	µA
Pulse Length	0.5-2	µs
Max. Repetition Rate	200	Hz
RF Frequency	2997.92	MHz

- **Why 3 GHz ?**

3 GHz electron linac for «conventional» radio-therapy





- Energy range of linacs: 4-25 MeV
- Electrons are accelerated by microwaves (10^3-10^4MHz)
- Philips SL-75/5: S-band 2856 MHz, MW cavities dimensions - lenght 3 cm, radius 5 cm, electrons 5 MeV, tungsten target

- **Why 3 GHz ?**

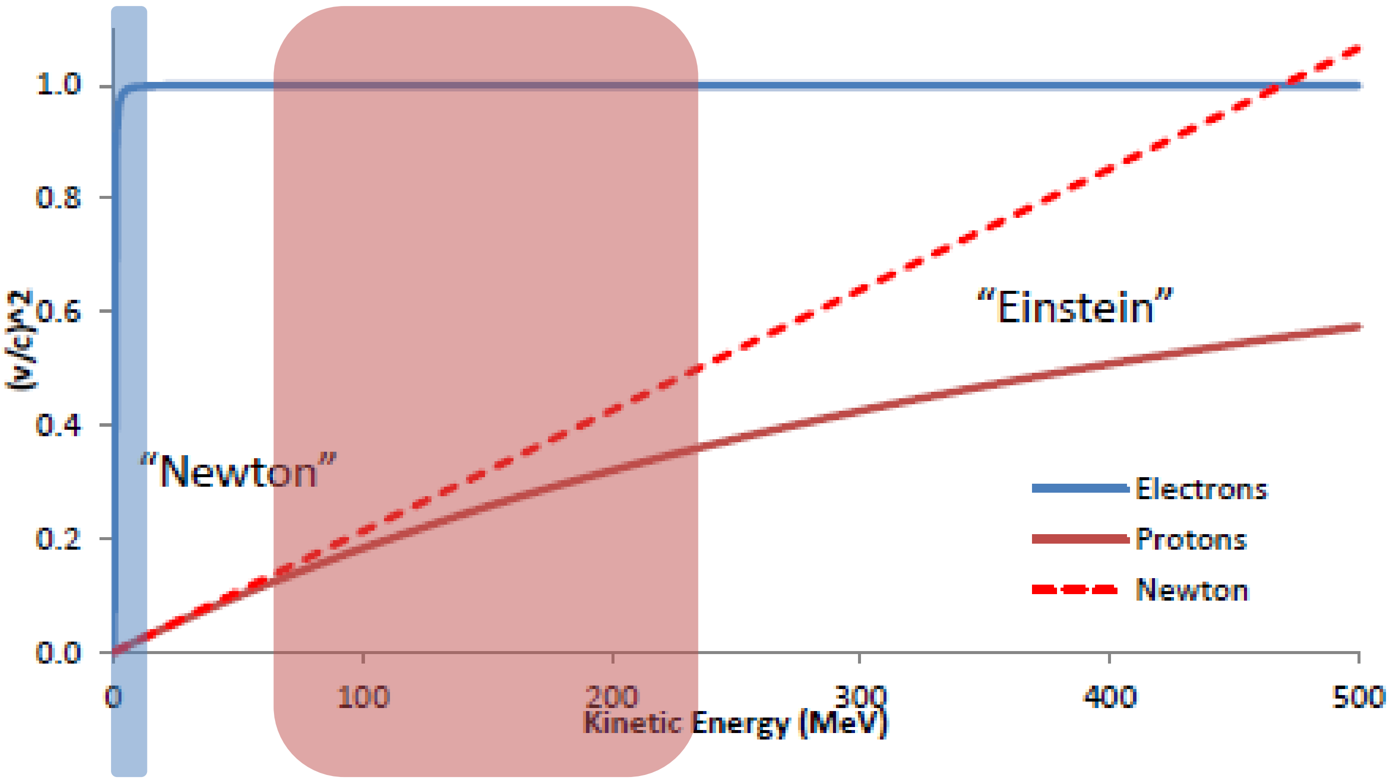
→medical linacs used in conventional radiotherapy are based on 3 GHz structures

→RF power sources and network components are readily available

- **From 3 GHz electron linacs to 3GHz proton linacs**

From electron linac to proton linacs → speed and energy

Electron:
$m_e = 0.511$ MeV/c^2 $\quad \beta \to 1$



J. Lallement, JUAS2015

Protons
$m_p = 938.27$ MeV/c^2 $\quad \beta = 0.37 – 0.60$

- **Why 3 GHz ?**

→medical linacs used in conventional radiotherapy are based on 3 GHz structures

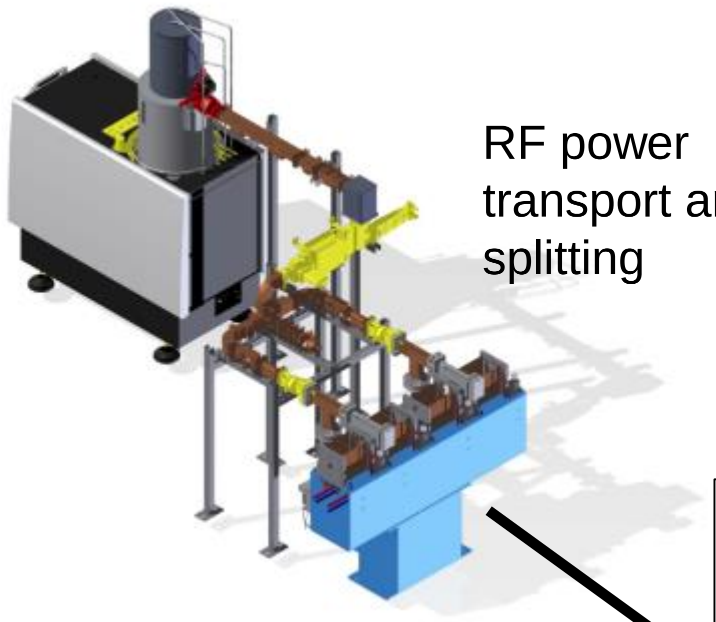
→RF power sources and network components are readily available

- **From 3 GHz electron linacs to 3GHz proton linacs**
  - Rest mass of protons is ~ 2000 bigger than the rest mass of electrons
  - Energy gain required is 10 times bigger: 20 MeV → up to 230 MeV

→ Multiple units with increasing speed of the beam

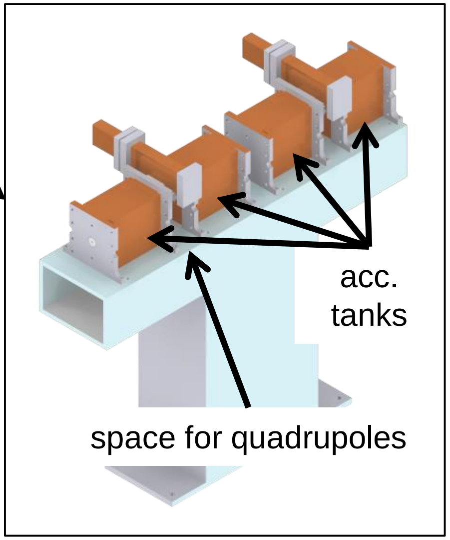
Cell Coupled Linac structures – unit

RF power source

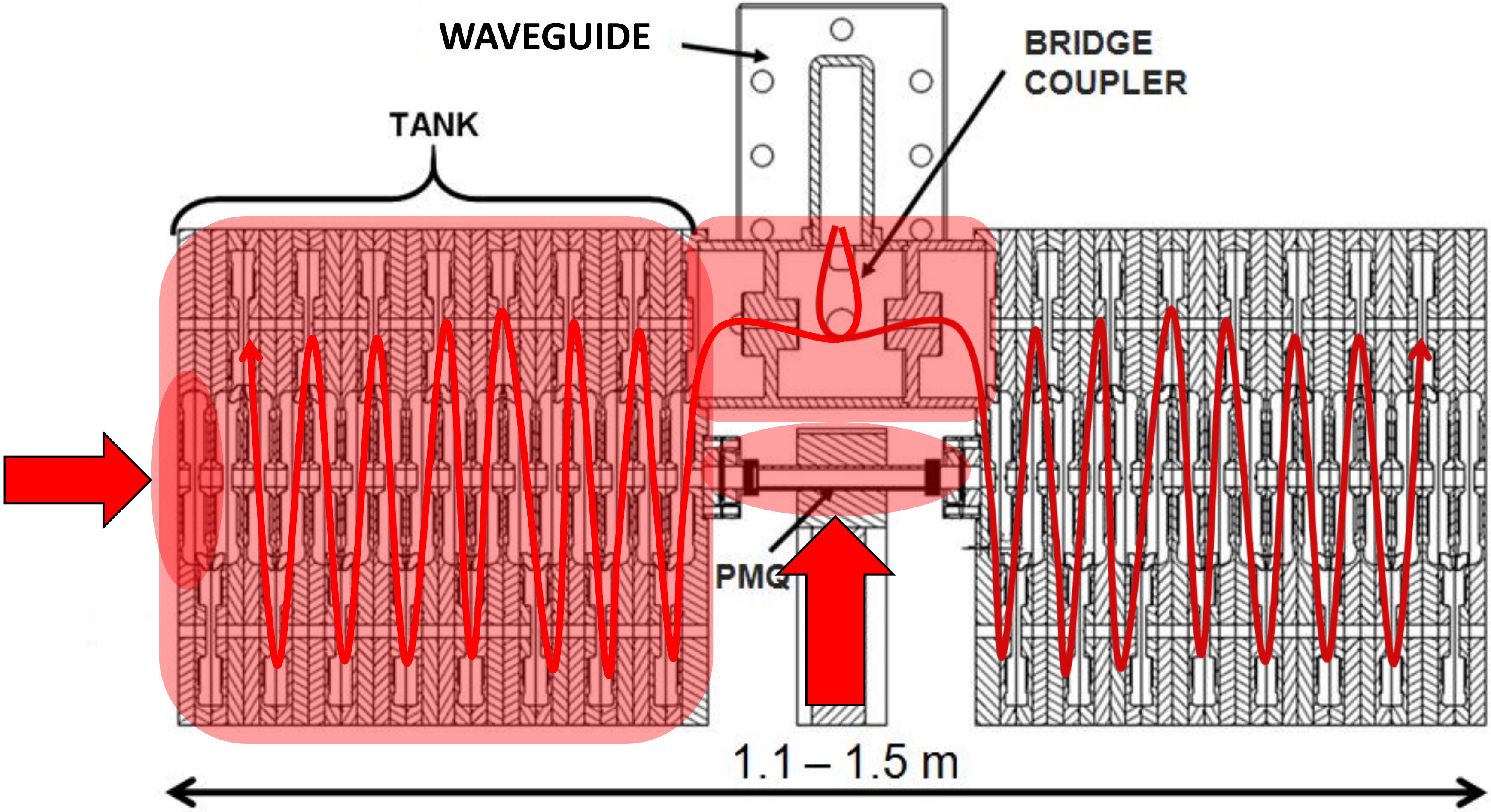


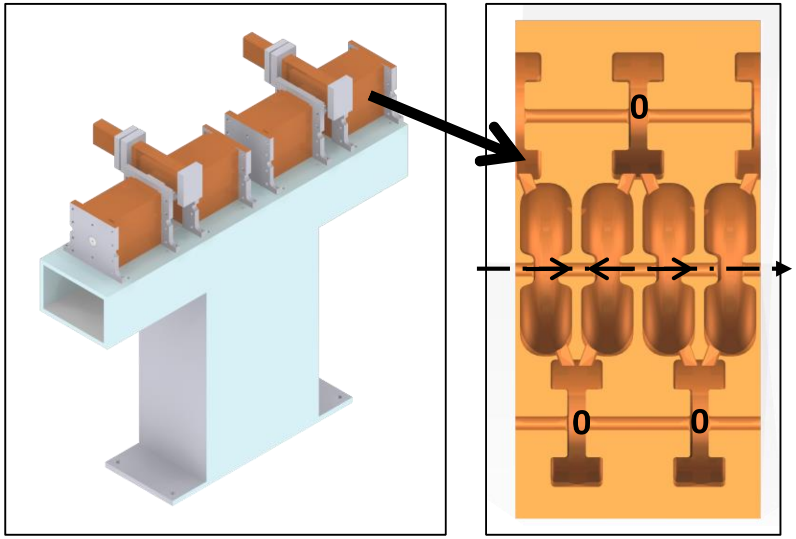
RF power transport and splitting

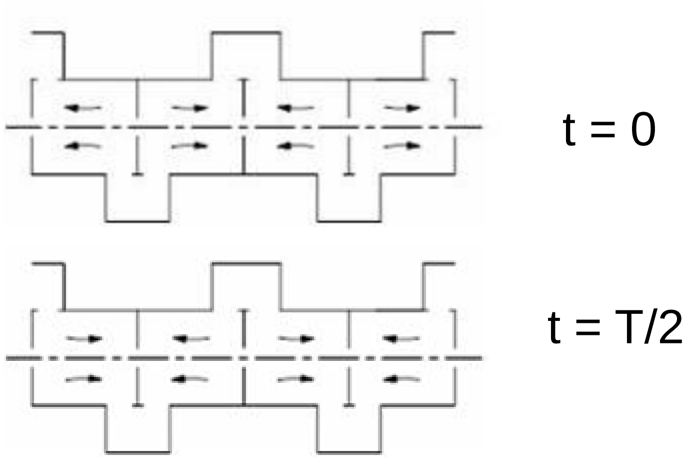
accelerating module



Accelerating modules







- **Linear accelerating structure:**
  - *Standing wave*
  - *π/2 phase advance*
  - *biperiodic structure (with coupling cells on the side)*

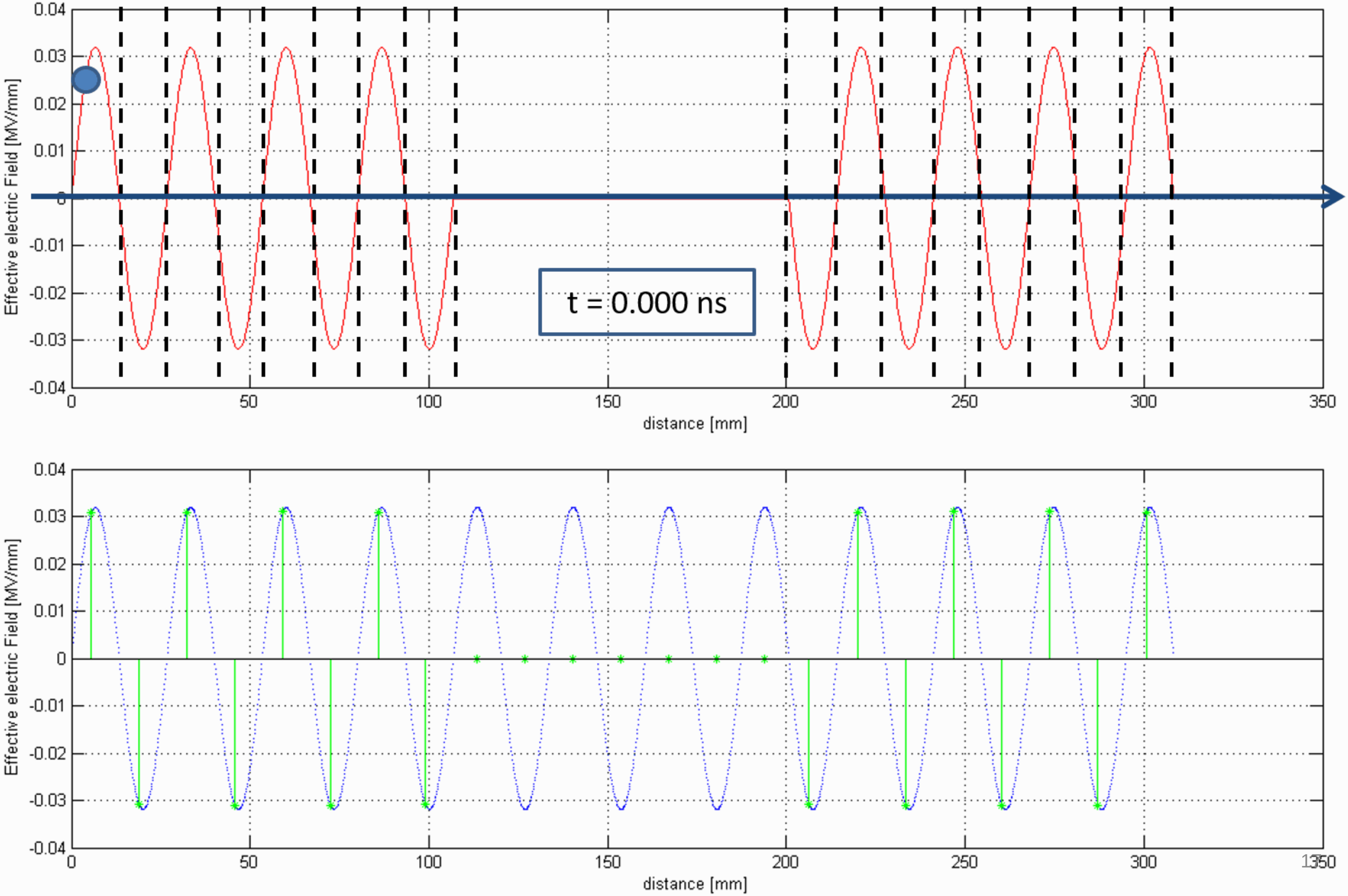
- **Synchronicity condition:**

$$L = v \cdot \frac{T}{2} = \beta c \frac{\lambda}{2c} = \frac{\beta\lambda}{2}$$

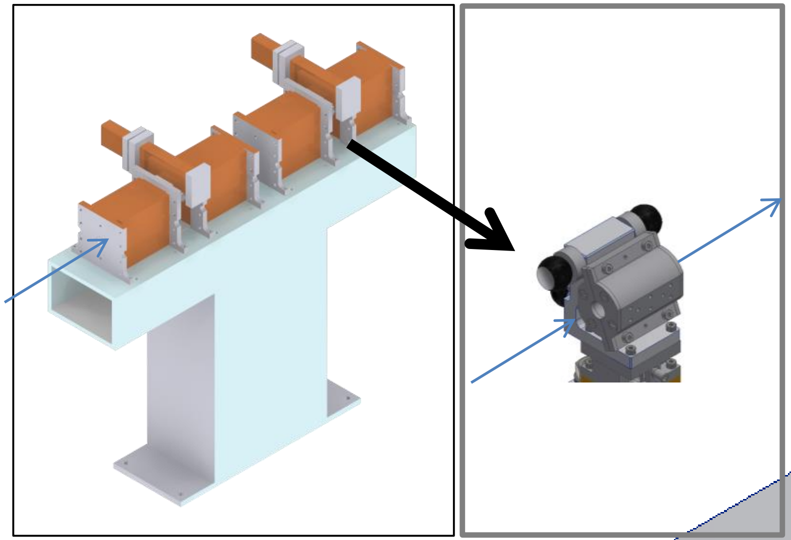
- **Energy gain (per cell):**

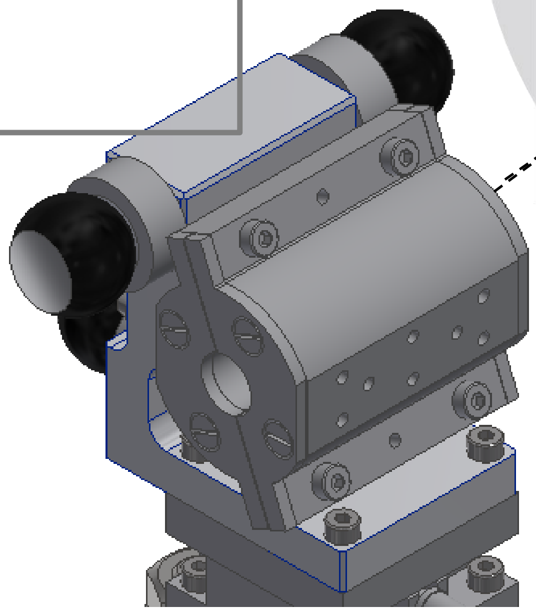
$$\Delta W = q E_0 T \cdot L \cos\varphi$$

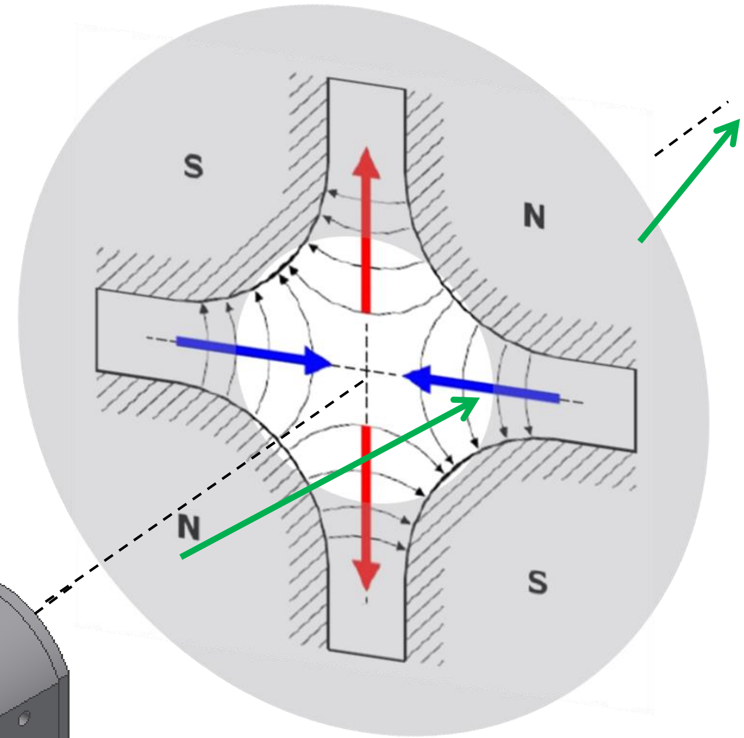
Example of synchronous particle motion (in a 5.7 GHz linac)



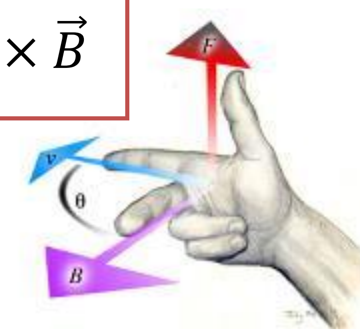
Permanent Magnet Quadrupoles for transverse focusing







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

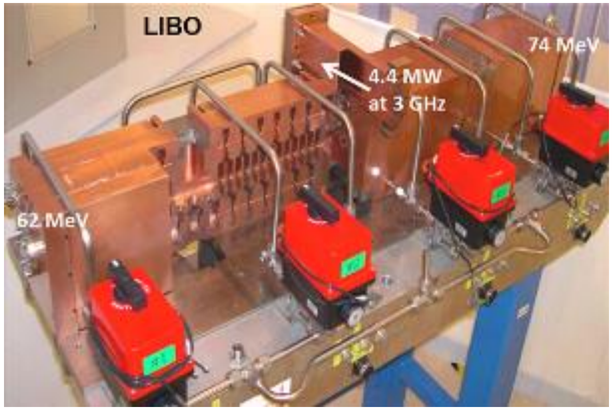


- **PMQ** are needed to keep the beam **focused**
- Given a **quadrupolar magnetic field** distribution**, the Lorentz force** acts on the moving charge **focusing in one plane and defocusing in the other**

From LIBO to the first unit of LIGHT

- **LIBO (Linac Booster) prototype by TERA-CERN-INFN**
  - Built in 1999-2000
  - First proof of principle

- **First Unit of LIGHT (ADAM)**
  - first industrial 3 GHz linac unit for Proton Therapy
  - Optimized for industrial production
  - Produced following industry standards in 2009-2010



Amaldi et al., NIM A(521), 512-529, 2004

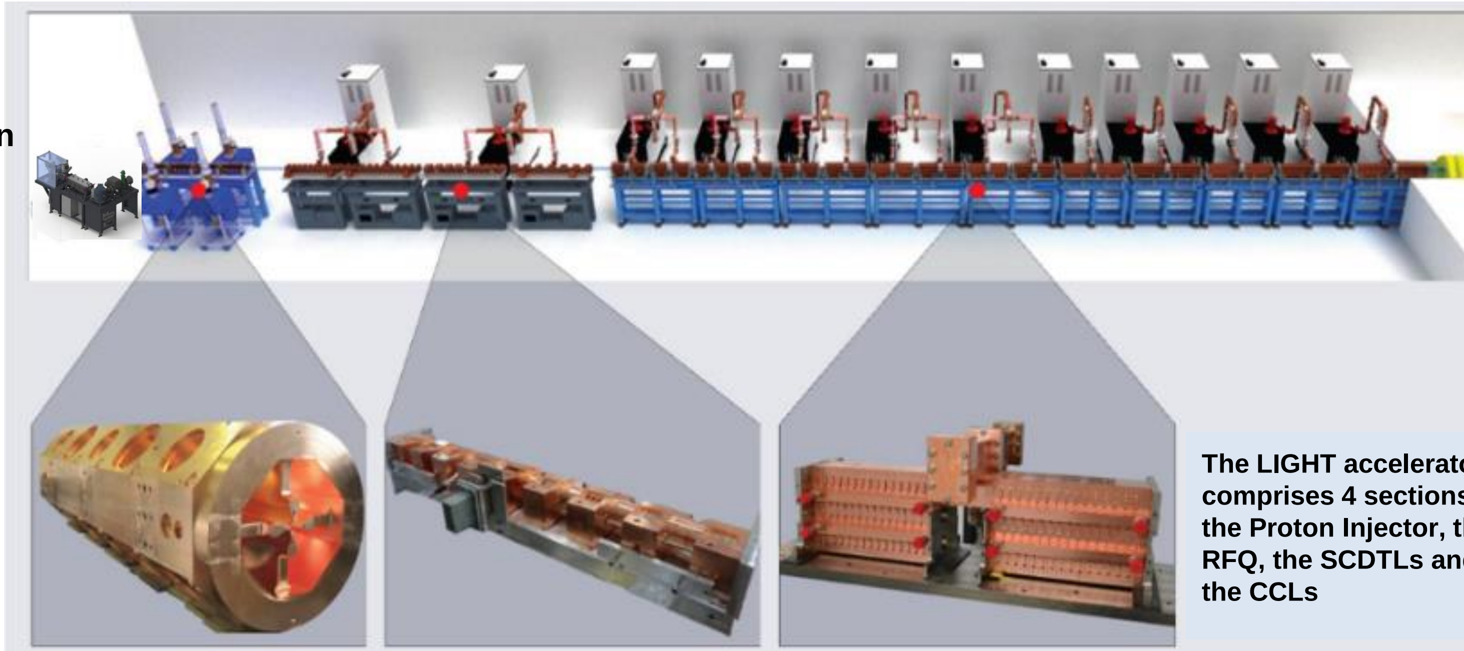
LIGHT – linac technology

-> **Pulsed beam** at 200 Hz

-> **Active energy modulation** (i.e no mechanical degrader)

-> **Pencil beam scanning** or “spot scanning”

-> **Modularity & flexibility**



The LIGHT accelerator comprises 4 sections: the Proton Injector, the RFQ, the SCDTLs and the CCLs

Proton Injector

- **Pantechnik** (at Geneva)
- **Dreebit** (at Daresbury)
- **AVO-ADAM:** adapt and optimize for variable intensity

RFQ: Radio-Frequency Quadrupole

- **CERN-ADAM** (2013-2015)
- 1st prototype, unique in the world
- Industrialization: **AVO-ADAM**

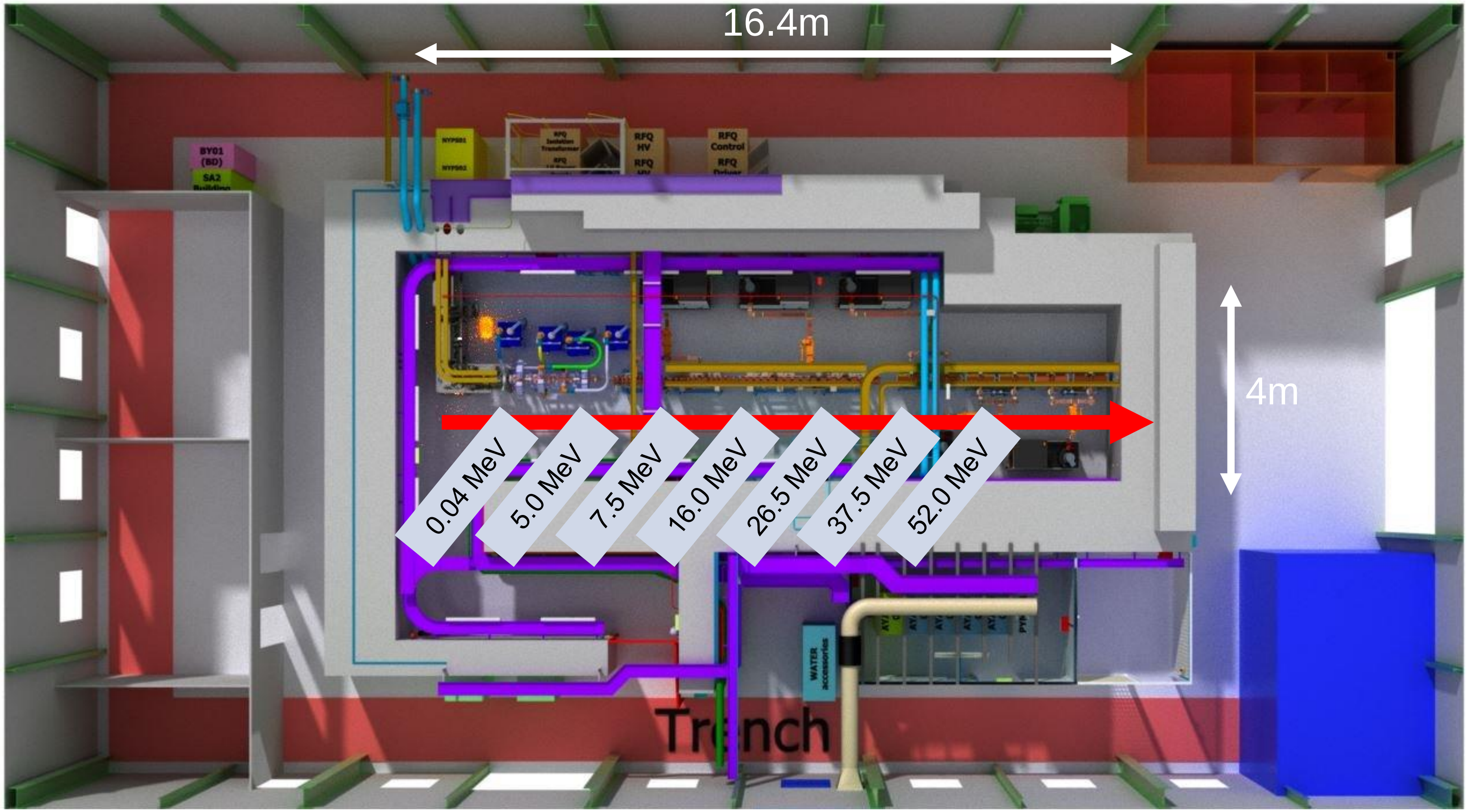
SCDTL: Side Coupled Drift Tube Linac

- **ENEA** concept (Picardi et al. 1996)
- Tested with beam in ENEA Frascati (IMPLART project) since 2011
- Industrialization: **AVO-ADAM**
- Mass production: **AVO-ADAM**

CCL: Coupled Cavity Linac

- **TERA-CERN-INFN** concept (LIBO, 1998-2000)
- Tested **with beam** in Catania in 2002
- Industrial design: **ADAM** (first Unit, 2010)
- Mass production: **AVO-ADAM**

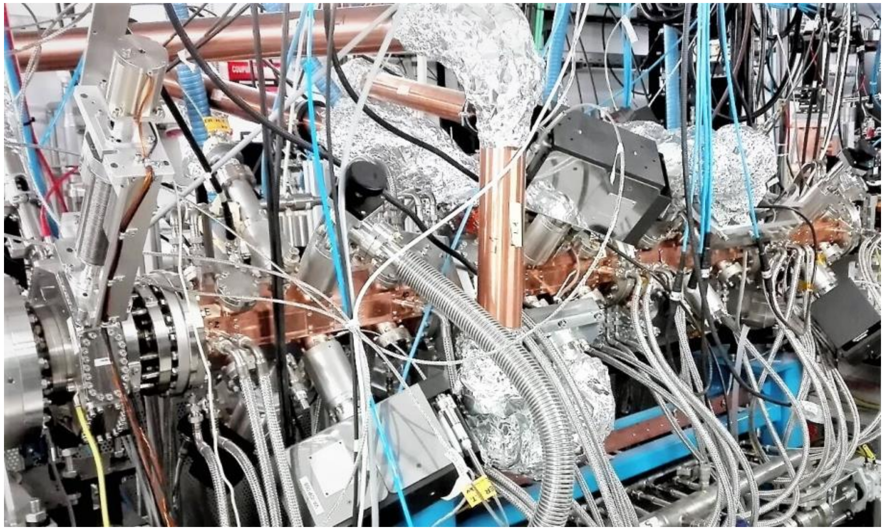
LIGHT Linac Technical Feasibility - Geneva



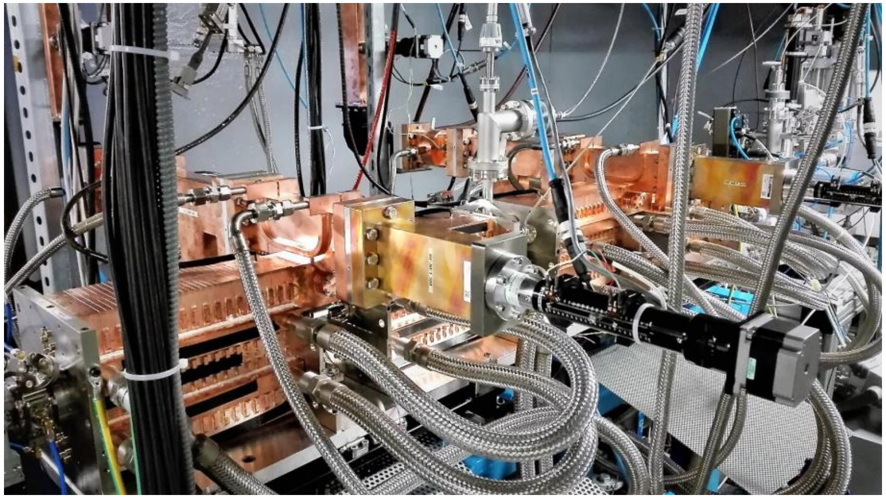
Integration:	Source	RFQ	SCDTL1	SCDTL 2	SCDTL3	SCDTL4	CCL1-2
B. energy:	40 keV	5 MeV	7.5 MeV	16 MeV	26.5 MeV	37.5 MeV	52 MeV

LIGHT Linac Technical Feasibility - Geneva

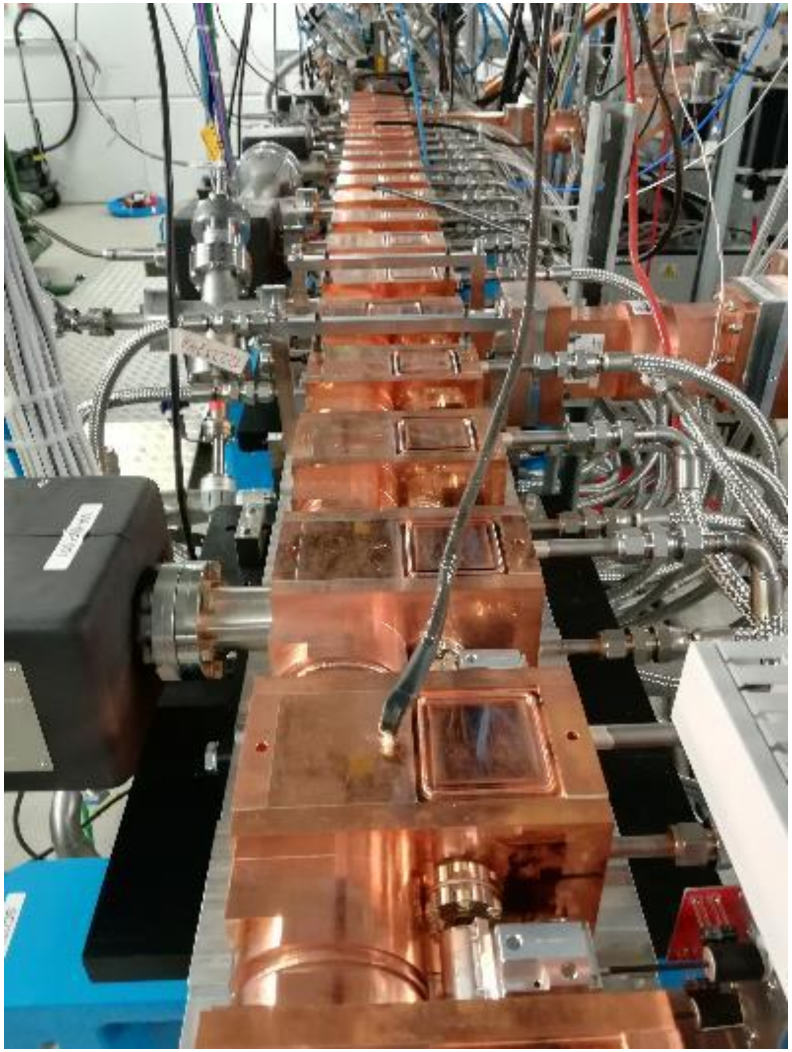
RFQ and its coaxial power lines



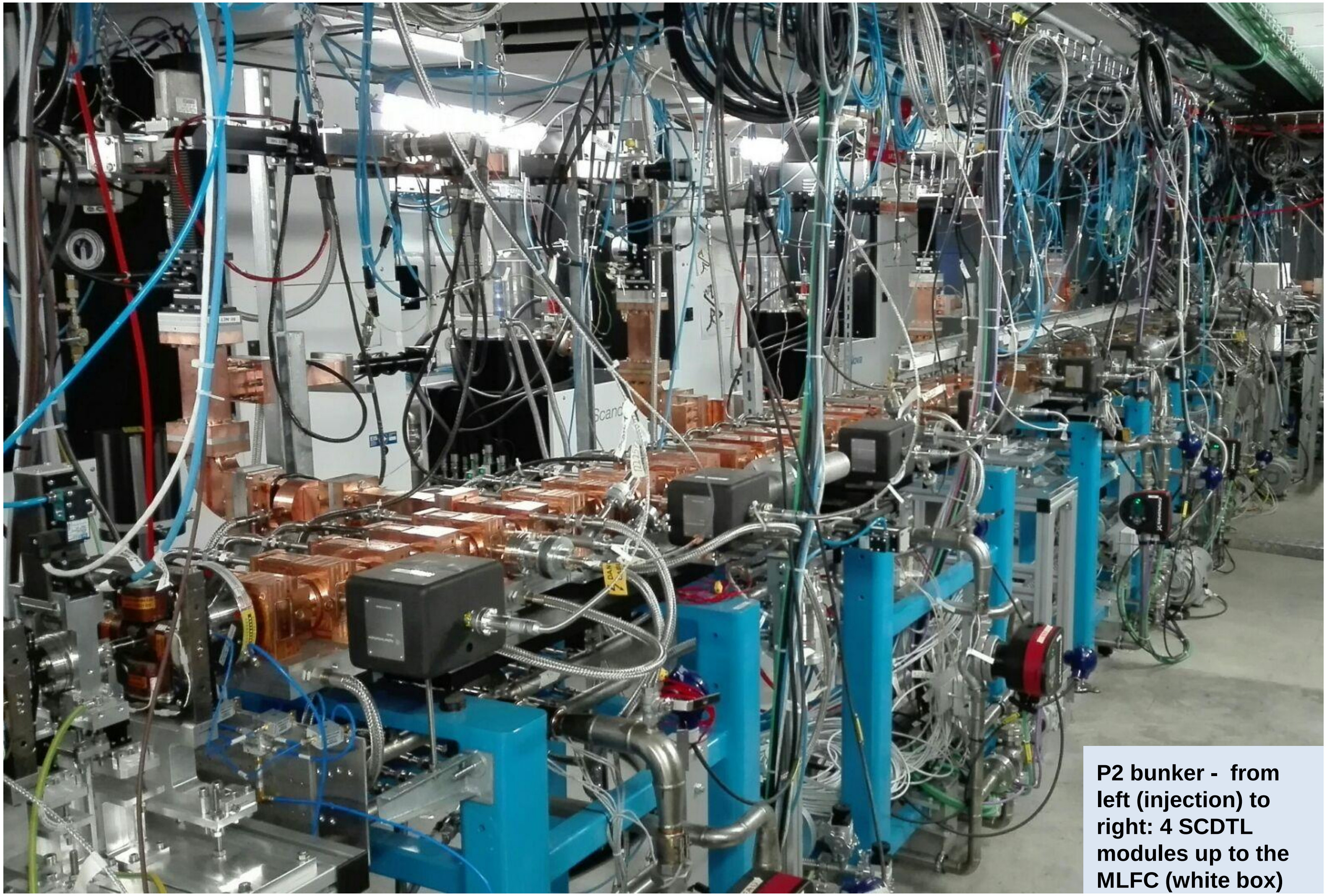
CCLs modules



SCDTLs modules: accelerating tanks



LIGHT Linac Technical Feasibility - Geneva



P2 bunker - from left (injection) to right: 4 SCDTL modules up to the MLFC (white box)

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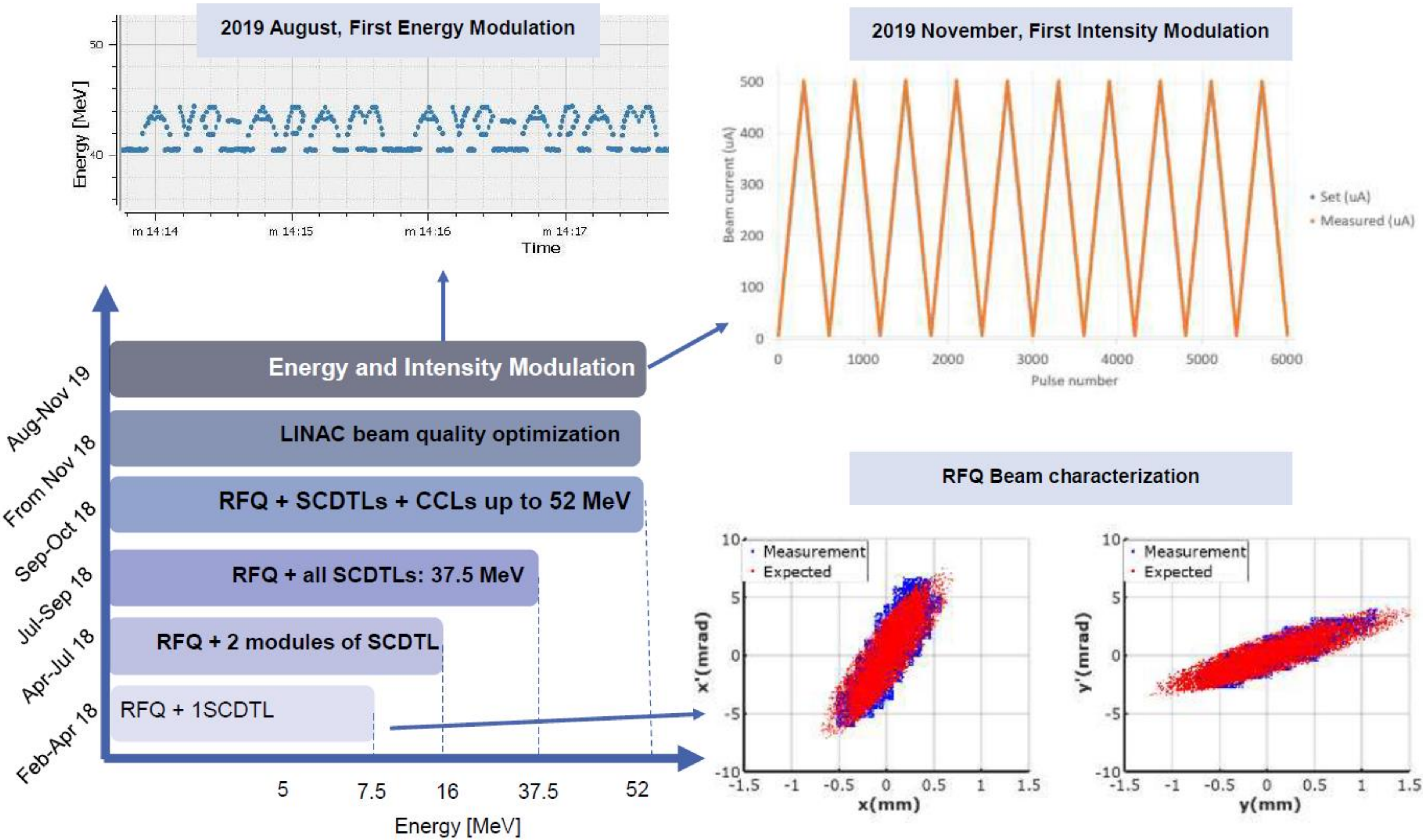
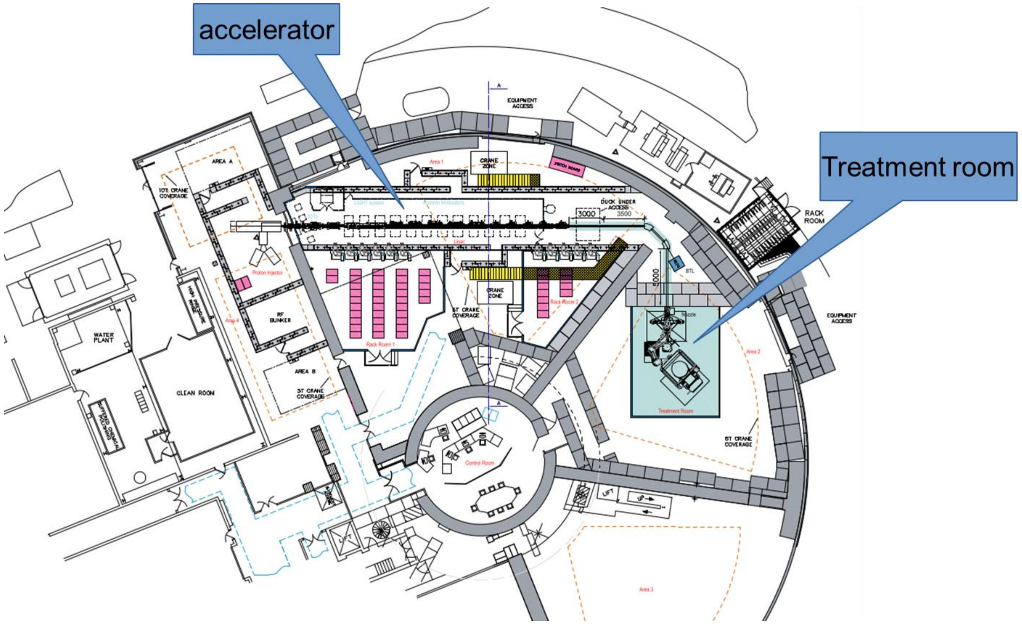


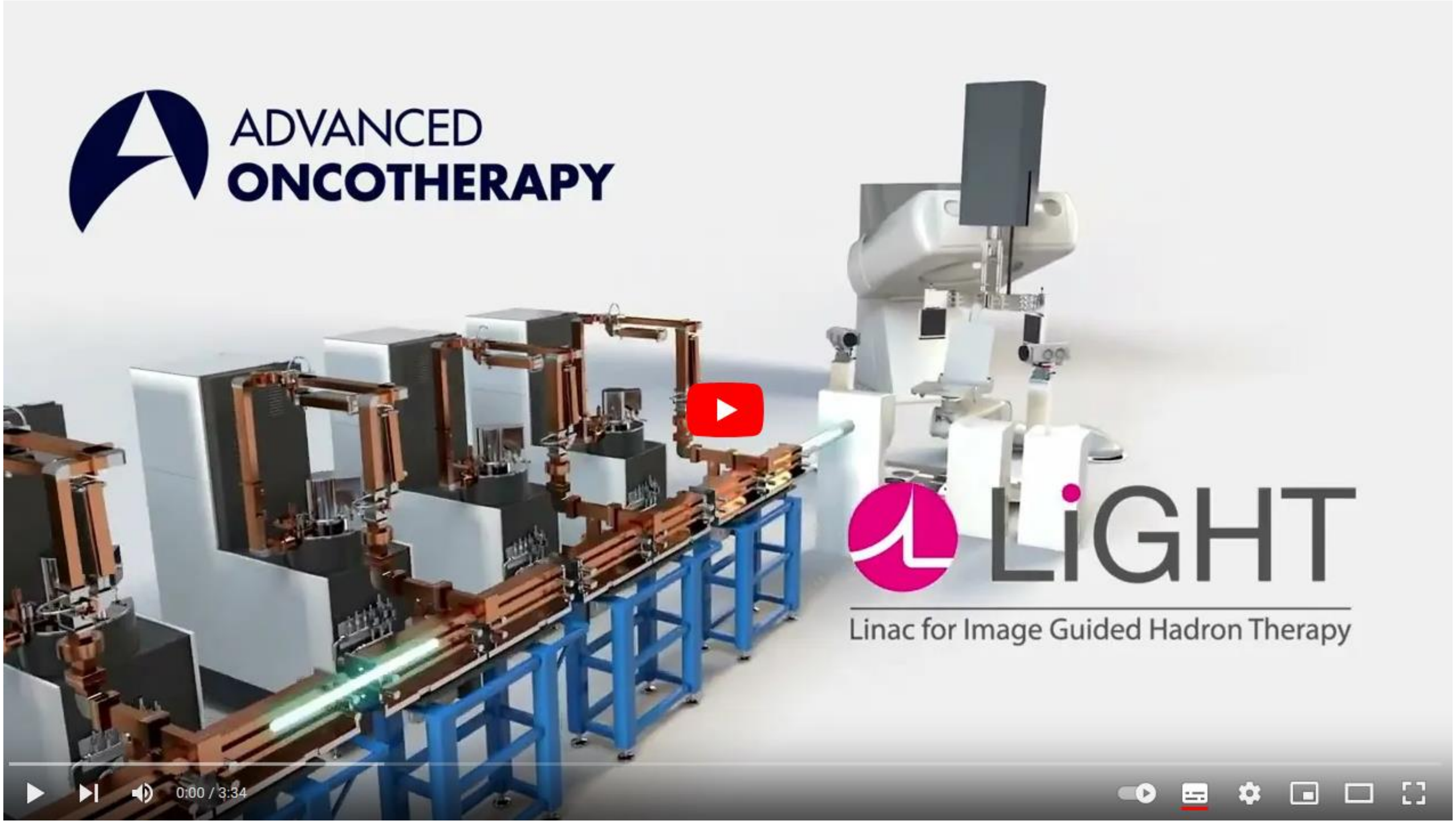
LIGHT Full-Scale Integration at 230 MeV

STFC Daresbury laboratory, Daresbury, Warrington

Science & Technology Facilities Council

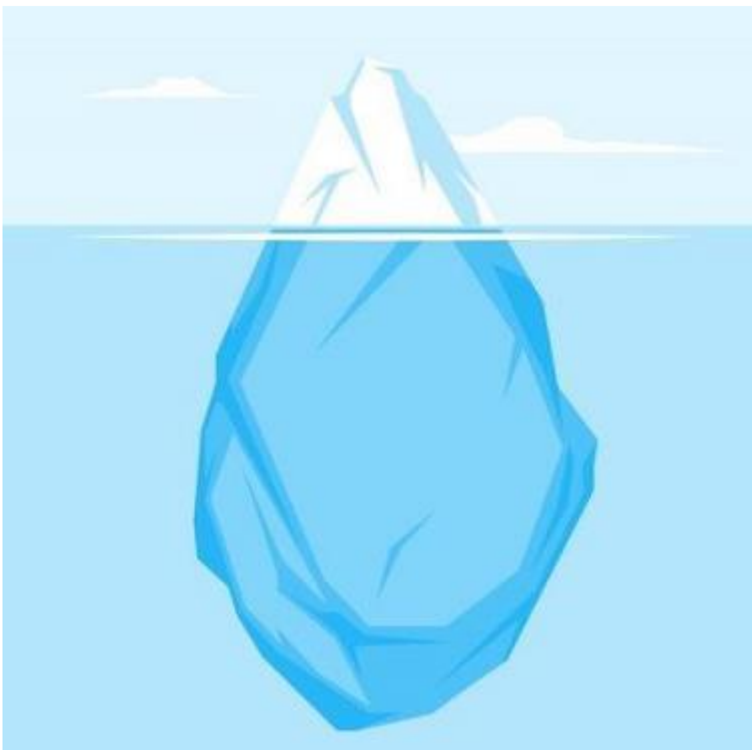


- **Daresbury Integration Site (DIS):** technical test site in UK
- **End-to-end testing:** Accelerator & Medical technical systems
- After the complete installation and integration → **V&V tests**
- **Partnership with University Hospital Birmingham NHS Foundation Trust ("UHB")**, aiming at treating patients in Daresbury in the context of our certification plan



https://www.youtube.com/watch?v=07TFUL5DzMU

1. The LiGHT accelerator “product”
2. **The industrialization process**



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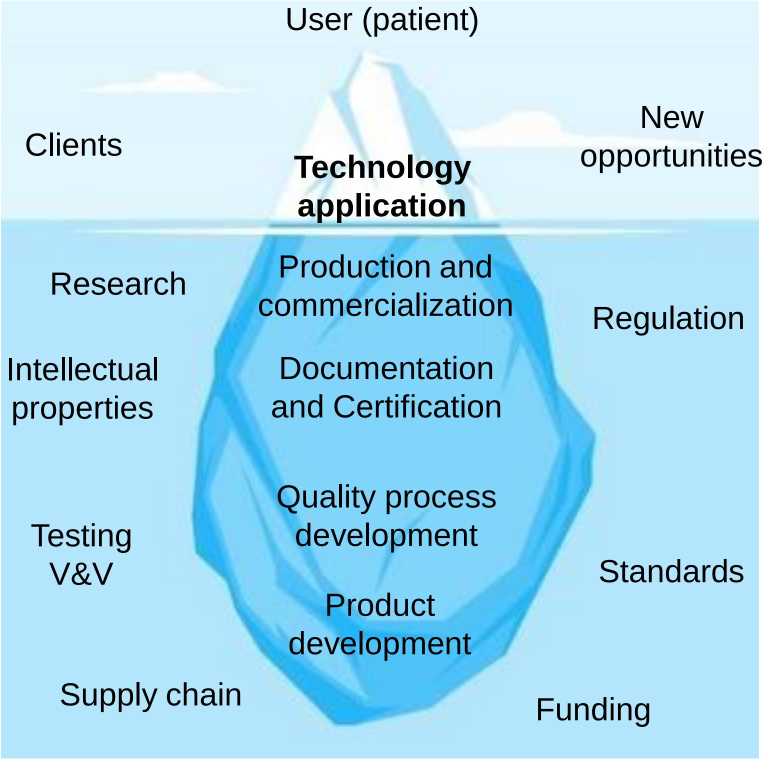
The technology application…

Medical Industry

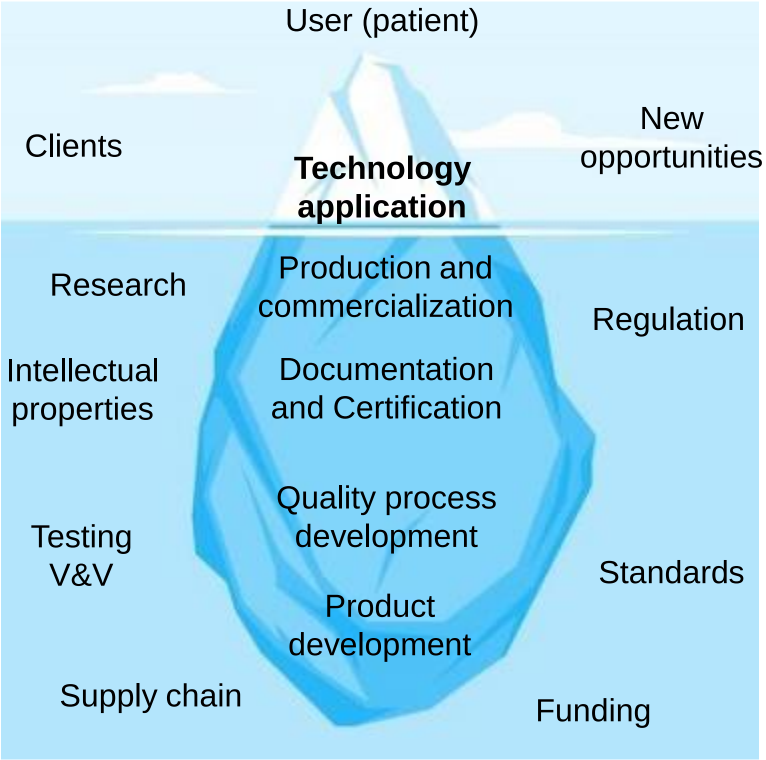
The technology application…and what is behind it

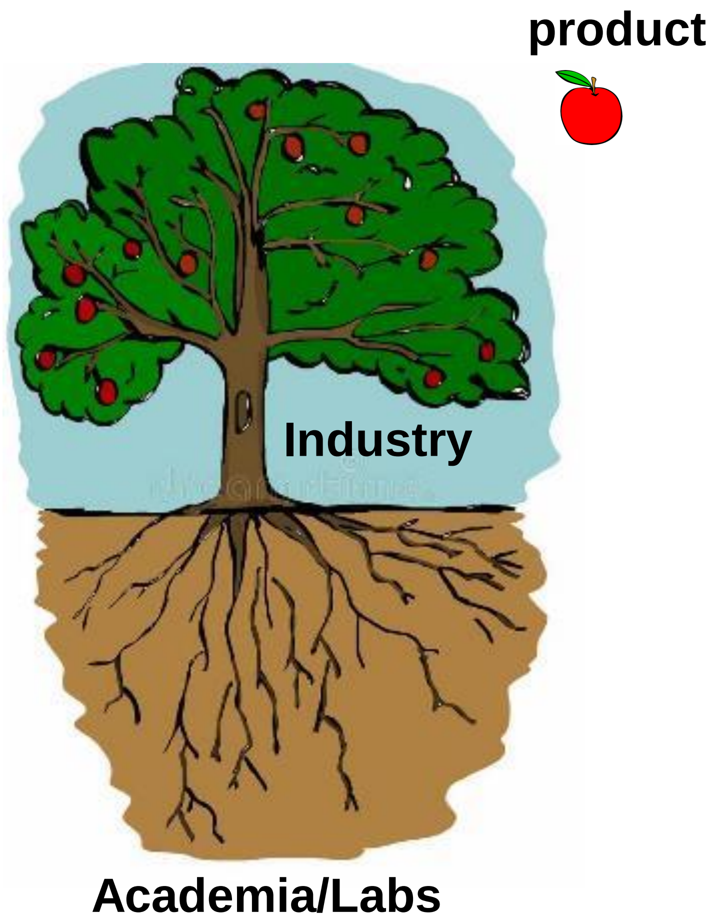
Medical Industry



The technology application…and what is behind it

Medical Industry

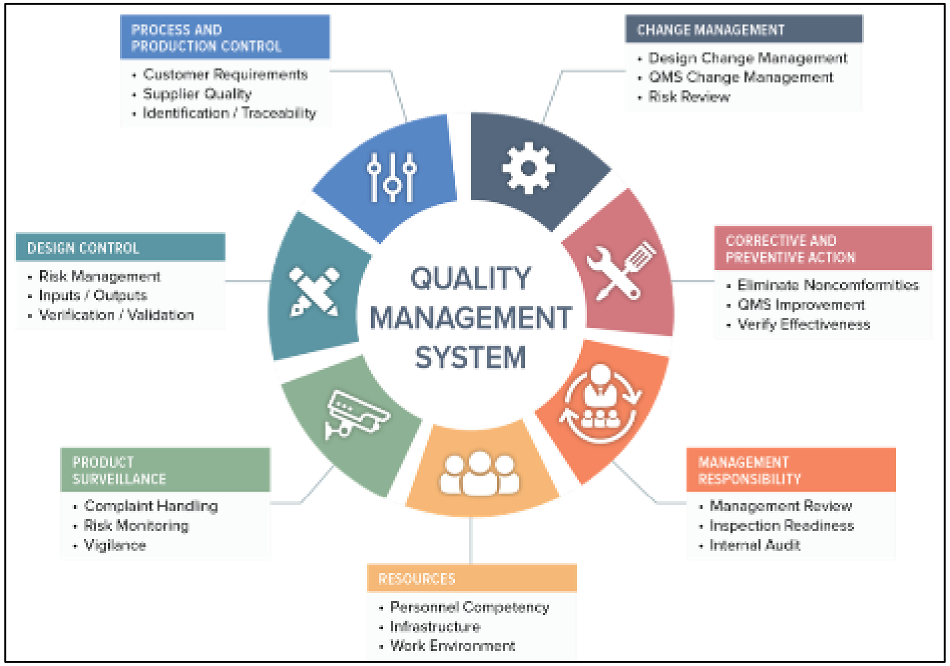


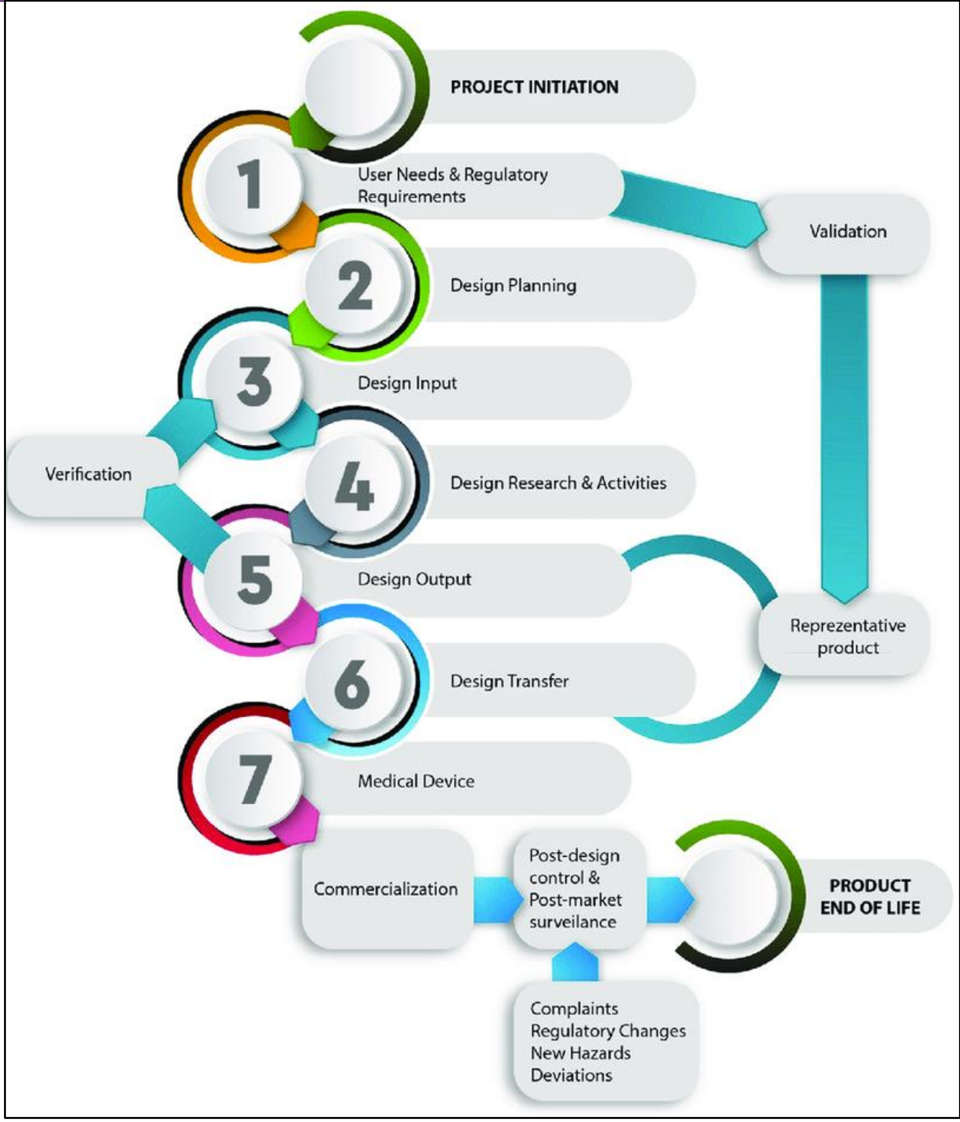


Industry Standards for Medical Device

ISO-13485 Medical devices framework

It relies on **Quality Management System** and on **process**





The Design and Development Roadmap – from concept to market

Concept Screening

Evaluation

- Literature
- Patents
- Predicates
- User needs analysis
- Complaint review

Concept

- Concept Development
- Prototyping

Product Development

Product Development

- Product Design
- Simulations
- Product Testing
- Functional Tests

Verification and Validation

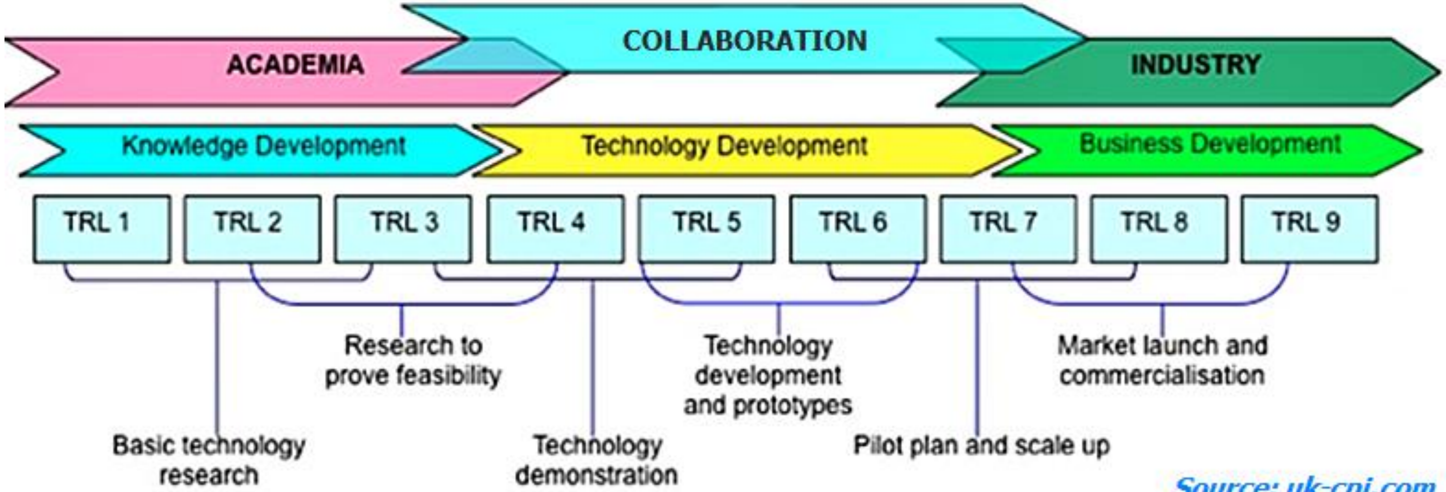
- Design Verification
- Design Validation

Launch

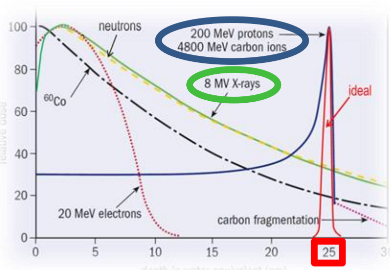
Market introduction

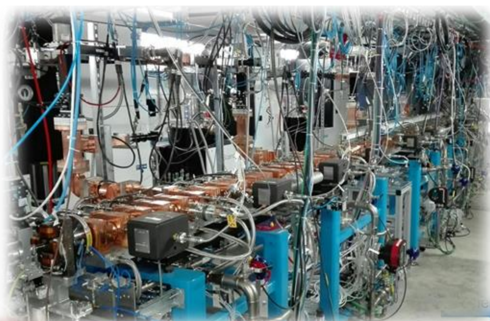
- Regulatory Submission
- Complete Design Transfer
- Pre Series Production

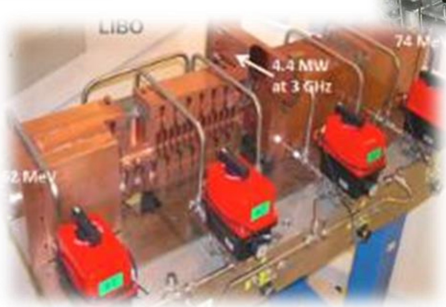
The Innovation Chain: converting science into wealth

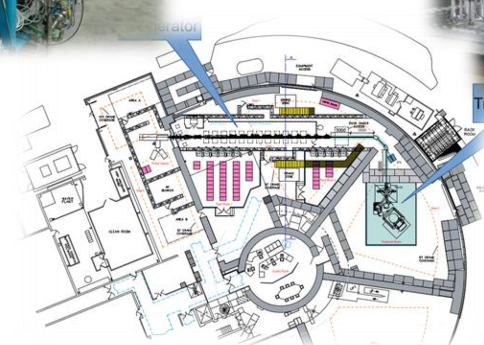


Source: uk-cpi.com

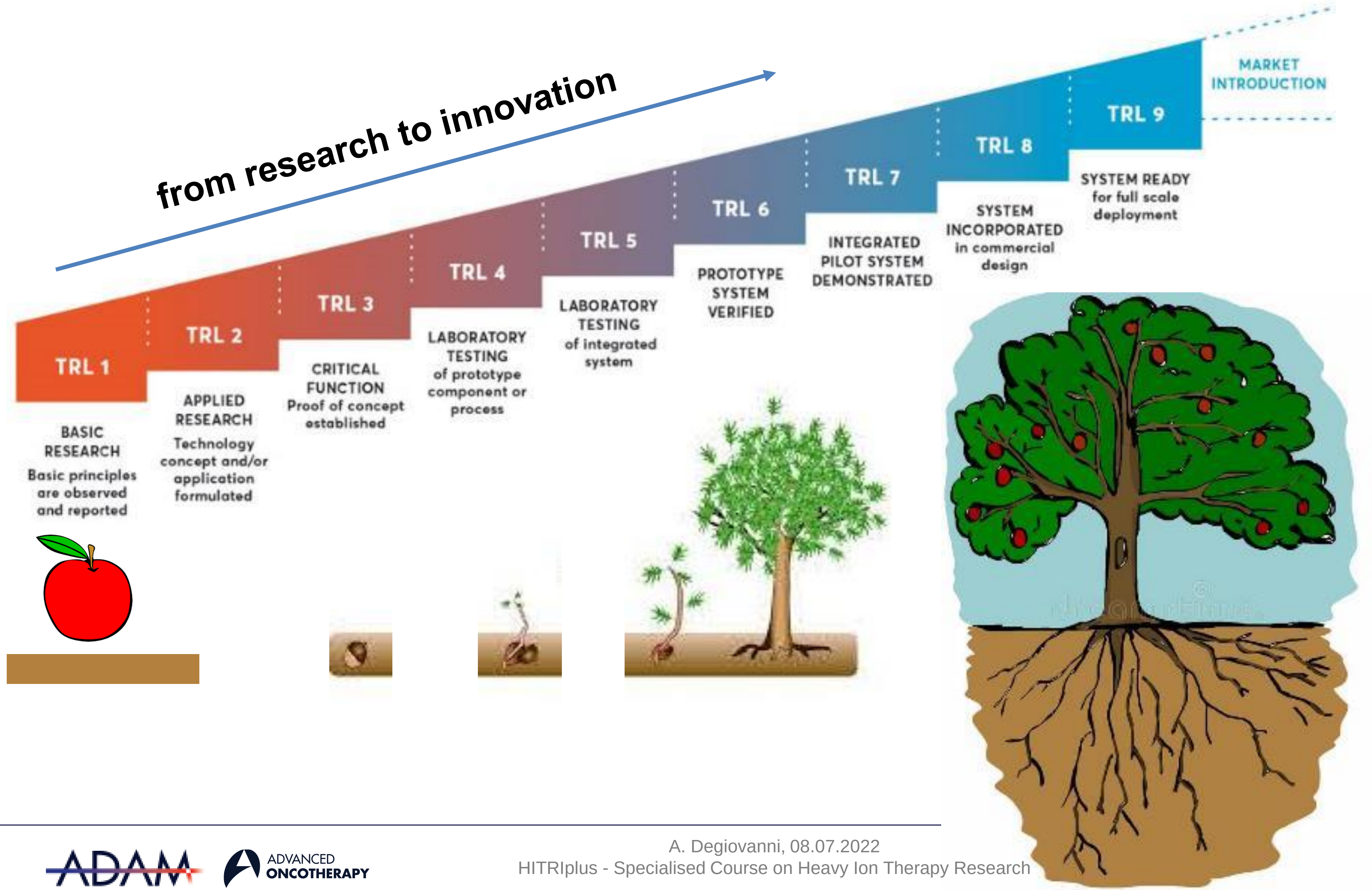




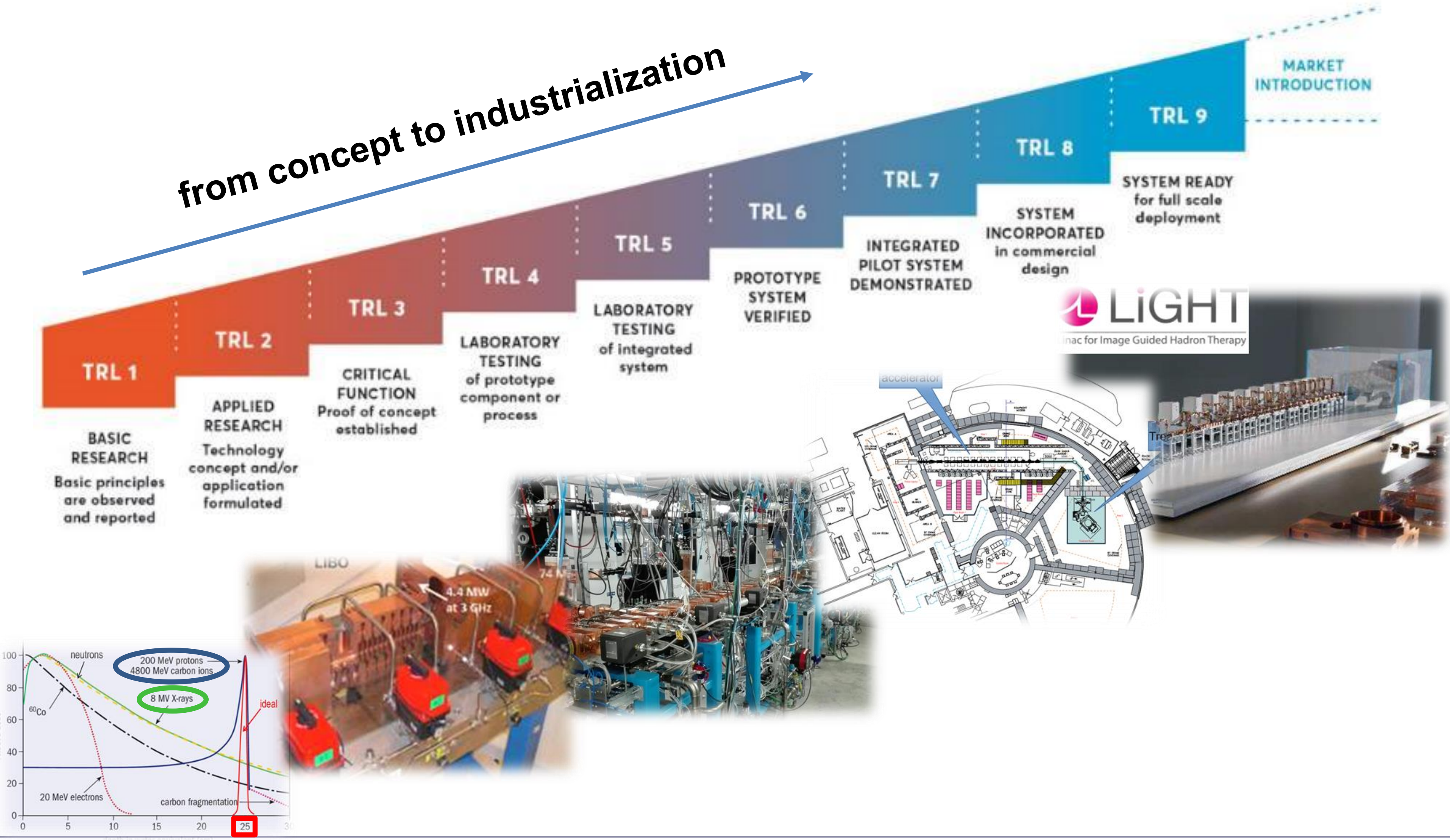




Accelerators and Innovation



The case of LIGHT



Thank you for your attention!

Questions ?

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101008548