



# L'acceleratore in miniatura

Un viaggio nel mondo degli acceleratori lineari e delle loro applicazioni: come la società può approfittare delle tecnologie sviluppate per l'LHC e per i grandi acceleratori

Maurizio Vretenar, CERN



- ▣ Quanti acceleratori di particelle ci sono al mondo (quelli veri, non i tubi catodici)?

Piu' di 30'000 !



- E quali sono i 2 campi di applicazione piu' comuni (circa 10'000 acceleratori ciascuno)?

La medicina (diagnosi e trattamento con raggi X o elettroni)

L'industria dei semiconduttori (drogaggio per implantazione di ioni)



# 1. Applicazioni degli acceleratori



# Existing accelerators



<b>Recherche</b>		<b>6%</b>
	Physique des particules	0,5%
	Physique nucléaire, de l'état solide, des matériaux	0,2 a 0,9%
	biologie	5%
<b>Applications médicales</b>		<b>35%</b>
	Diagnostic/traitement par X ou électrons	33%
	Production de radio-isotopes	2%
	Traitement par protons et ions	0,1%
<b>Applications industrielles</b>		<b>60%</b>
	Implantation d'ions	34%
	Découpage et soudure par électrons	16%
	Polymérisation, ...	7%
	Traitement par neutrons	3.5%
	Tests non destructifs	2,3%



# L'acceleratore piu' diffuso



Linac (acceleratore lineare) di elettroni per la radioterapia (trattamento del cancro con raggi X)

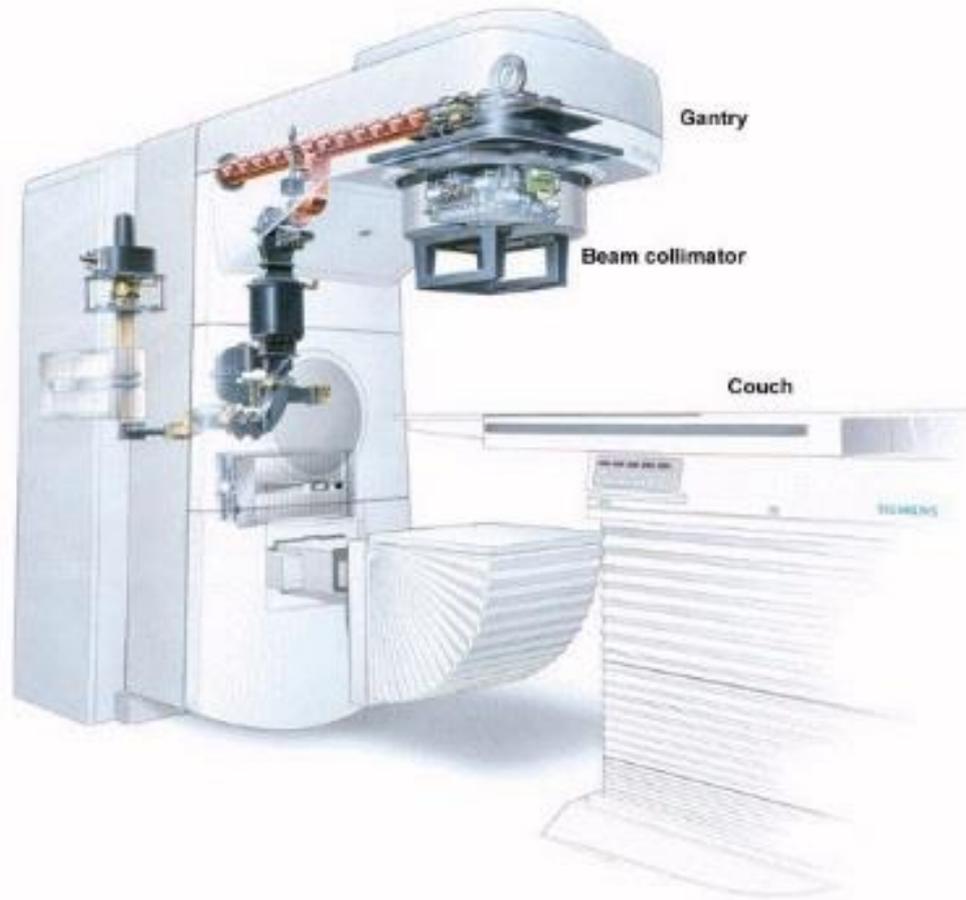
Circa 8'000

(Linac = Linear Accelerator)

La maggioranza degli acceleratori utilizzati al di fuori del campo della ricerca sono lineari: la bassa energia richiesta non rende necessario l'uso di grandi acceleratori circolari.



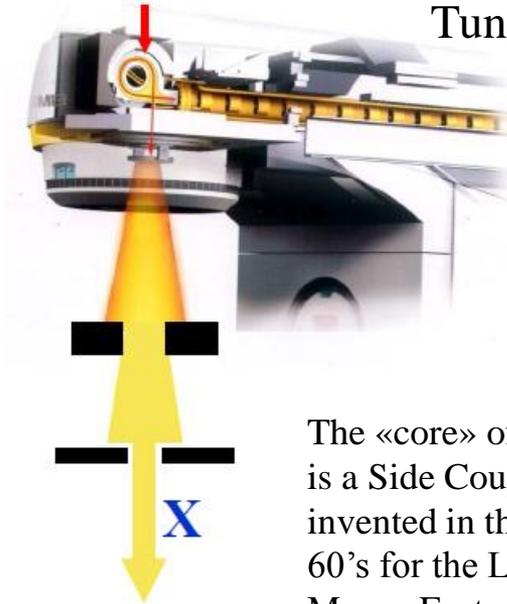
# Radiotherapy linac



electrons

5 – 25 MeV

Tungsten target



The «core» of the system is a Side Coupled Linac invented in the US in the 60's for the Los Alamos Meson Factory

**2000 patients/year every  
in 1 million inhabitants**

Commercialised by several companies, available in all major hospitals



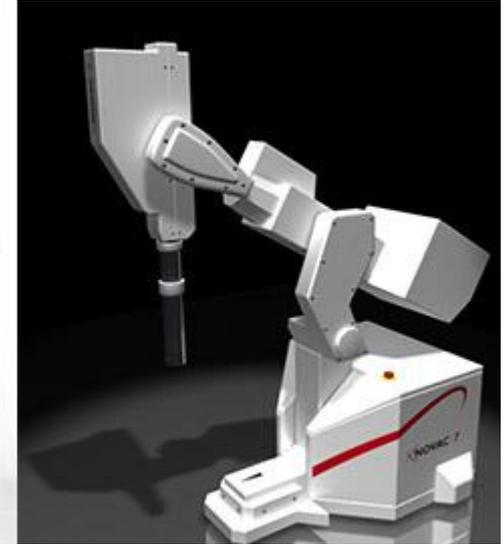
# IORT = Interoperative Radiation Therapy



Un esempio di applicazione avanzata degli acceleratori alla medicina (e un'eccellenza italiana!)

Tecnica radioterapica che permette di erogare una dose elevata di radiazioni subito dopo l'asportazione del tumore, nel corso dell'intervento chirurgico.

Acceleratore compatto sviluppato dall'ENEA a Frascati negli anni '90 in collegamento con il gruppo di oncologia del Prof. Veronesi, ora commercializzato dalla Sordina (Vicenza). Si sta affermando in tutto il mondo, in particolare per il trattamento del tumore al seno.



<b>Energia</b>	<b>3 - 9 MeV</b>
<b>Corrente di picco</b>	<b>1.5 mA</b>
<b>Frequenza di ripetizione</b>	<b>1-30 Hz</b>
<b>Durata dell'impulso</b>	<b>4 <math>\mu</math>sec</b>
<b>Frequenza RF</b>	<b>2.998 GHz</b>
<b>Tipo di Struttura</b>	<b>SW in rame OFHC brasata</b>
<b>Modo di operazione</b>	<b><math>\pi/2</math></b>
<b>No. cavità acceleranti</b>	<b>11</b>
<b>Lenti magnetiche</b>	<b>nessuna</b>
<b>Lunghezza</b>	<b>50 cm</b>
<b>Peso</b>	<b>25 Kg</b>





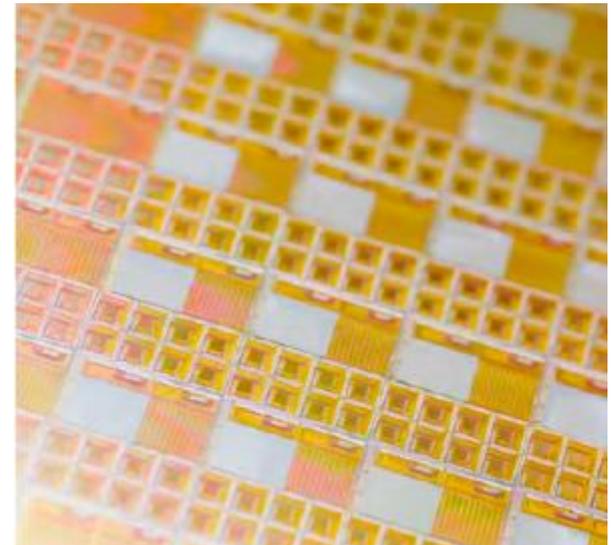
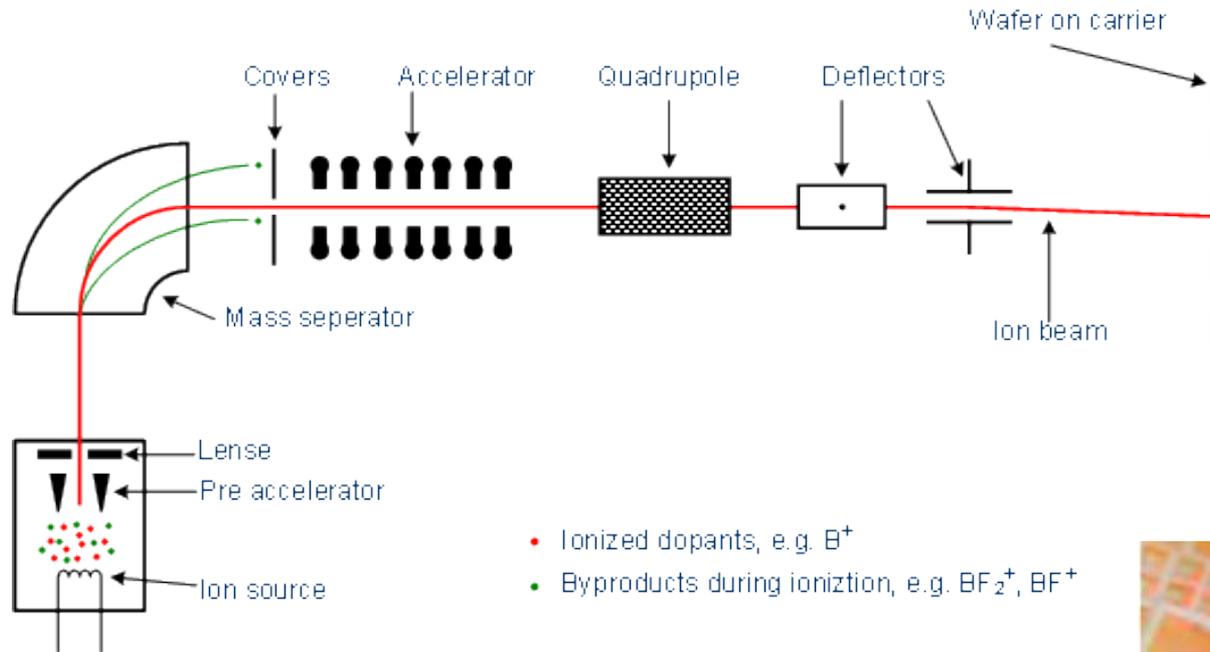
# Industrial applications of linacs



	Goal	Examples	Accelerator
Material processing (electrons)	Improve polymer resins inducing cross-linking of polymer chains → higher stress resistance	Heat-shrinkable films for food packaging, tires and cable insul. Gemstone irradiation	Electrons, 100 keV-10 MeV
Sterilization	Kill microroganisms	Sterilization of medical products Food processing (public acceptance!)	Electrons, ~10 MeV
Wastewater treatment	Distruction of organic compounds	Russia, Korea, USA, Brazil	Electrons, ~10 MeV
Non-destructive testing	Detect discontinuities in a material (cracks, etc.)	Inspection of pipelines, ships, bridges, etc. (depth + variable energy)	Electrons for X-rays, 1-15 MeV, portable (9 GHz)
Cargo inspection	Screening of trucks or containers for illegal objects	Many ports, customs, etc.	Electrons for X-rays, 3-6 MeV
Ion implantation	Alter near-surface properties of semiconductors (doping)	Semiconductor industry (arsenic, boron, indium, phosphorus,...)	Ions, from low to high energy (5 MeV)
PET isotope production	Production of radiotracers for Positron Emission Tomography	Linacs are smaller and have less res. activation than cyclotrons	Protons, 7 MeV
Neutron testing	Neutron generation for non-destructive inspection	Inspection of materials, cargo, etc.	Protons, 1-10 MeV

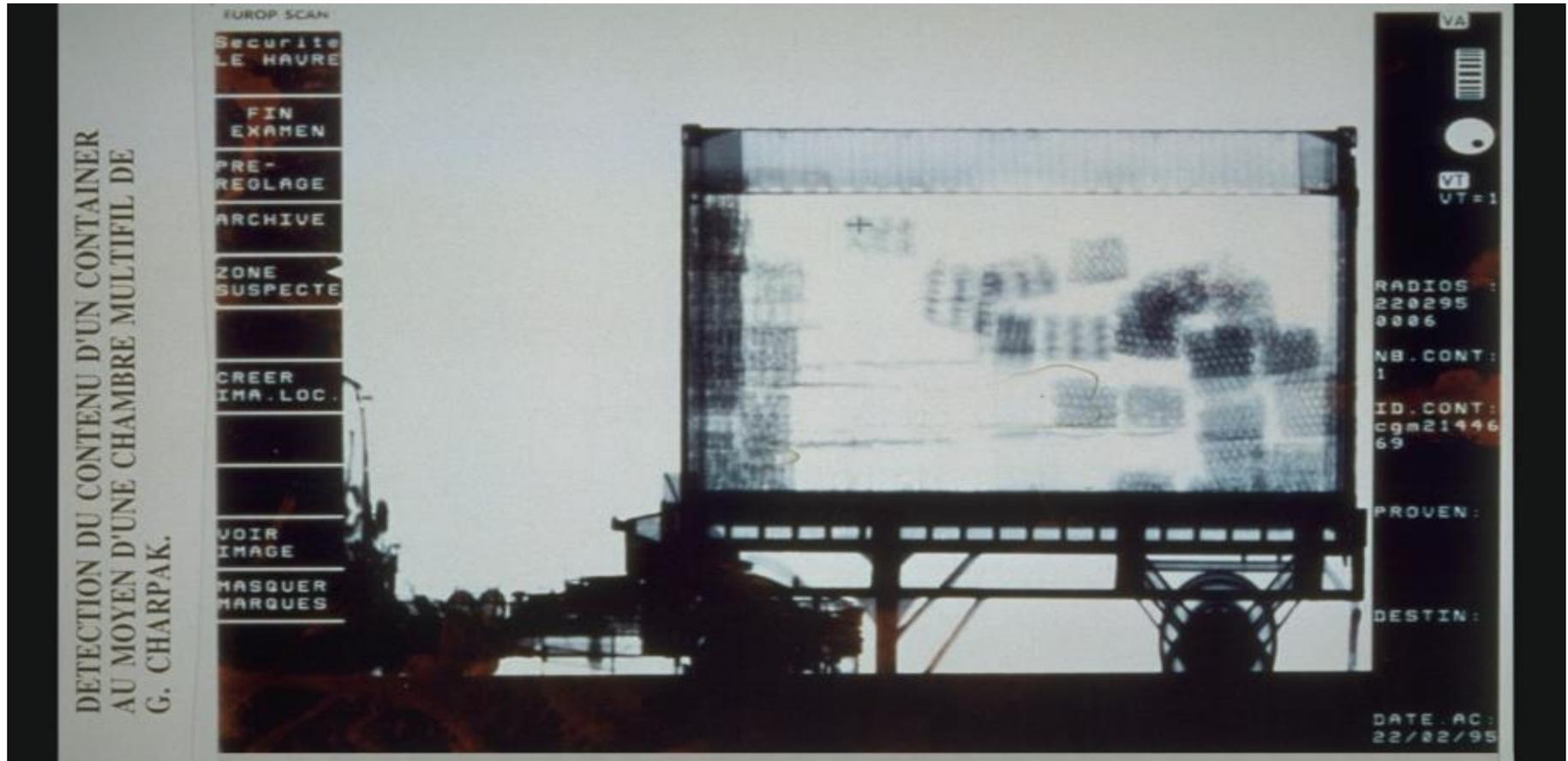


# Ion implantation system





# Cargo screening





# Accelerators for society



what does the man in the street need?  
More and better science – we all agree –  
but the priority is more and better life



*Activity within  
Integrated Projects  
supported by the  
European Union:  
EuCARD2, ARIES.*

People in the street need the LHC (and now the FCC...) but need as well more and better medical isotopes, better materials, better semiconductors, improved security, etc.





# The new ARIES Project



## ARIES

Accelerator  
Research and  
Innovation for  
European  
Science and Society



- Integrated Activity project aiming at developing technologies for the next generation of particle accelerators.
- Consortium of 42 Laboratories, Universities and Industries from 18 EU countries (+CERN).
- Approved in August 2016 by the European Commission (Horizon2020) for the period 2017/21 with a contribution of **10 M€**.



Includes an «Application» Network concentrated on 2 specific applications:

1. Technology of compact low-energy electron accelerators and their applications for environment and industry (treatment of water and flue gases, treatment of agricultural waste, etc.)
2. Radioisotope production with accelerators: compact accelerators for PET isotope production in hospital, accelerator production of Tc for SPECT tomography and of therapeutic isotopes.



## 2. Acceleratori Lineari



# Acceleratori lineari



Acceleratori Lineari a Radio-Frequenza: un elemento dove delle particelle elementari acquistano energia muovendosi su una traiettoria rettilinea sotto l'azione di campi elettrici variabili a frequenza radio (da qualche MHz a qualche GHz).

Gli acceleratori lineari coprono la parte iniziale del processo di accelerazione di un fascio di particelle, fino a energie dell'ordine di 10-500 MeV per protoni e 1 GeV per elettroni.

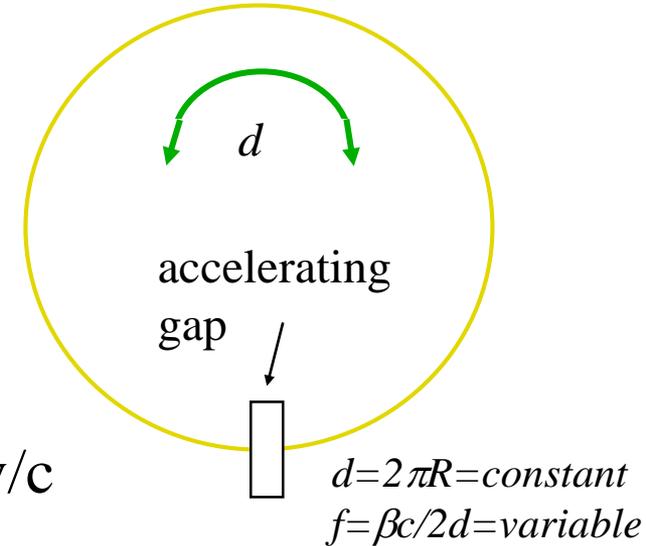
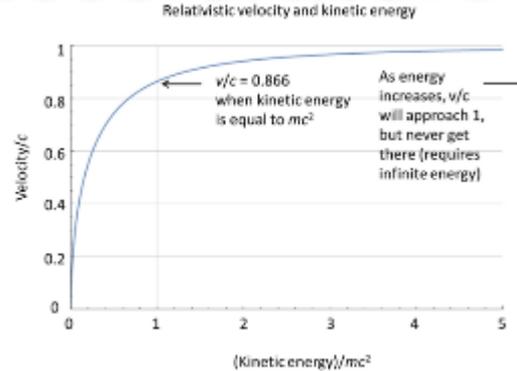
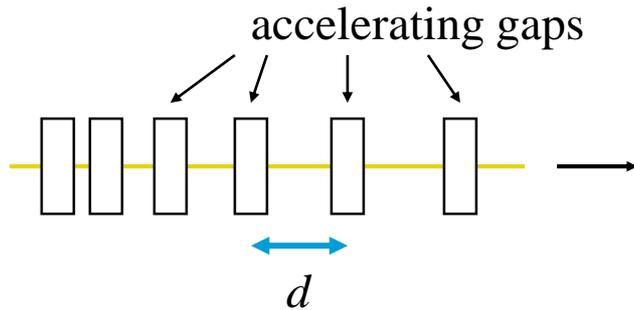
Assieme ai ciclotroni, sono gli acceleratori piu' adatti per le applicazioni mediche e industriali che richiedono energie non molto elevate.

LHC = energia piu' alta possibile (massa delle nuove particelle prodotte)  
intensità piu' alta possibile (numero delle nuove particelle prodotte)

Applicazioni = energia appena sufficiente a interagire con i nuclei atomici,  
basse intensità per evitare danni ai tessuti e/o ai materiali.



# Linear and circular accelerators



$$d = \beta \lambda / 2 = \text{variable}$$

$$f = \text{constant}$$

$$d = \frac{\beta c}{2f} = \frac{\beta \lambda}{2}, \quad \beta c = 2df$$

$$\beta = v/c$$

## Linear accelerator:

Particles accelerated by a sequence of gaps (all at the same RF phase).

Distance between gaps increases proportionally to the particle velocity, to keep synchronicity.

Used in the range where  $\beta$  increases.  
"Newton" machine

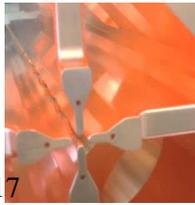
## Circular accelerator:

Particles accelerated by one (or more) gaps at given positions in the ring.

Distance between gaps is fixed. Synchronicity only for  $\beta \sim \text{const}$ , or varying (in a limited range!) the RF frequency.

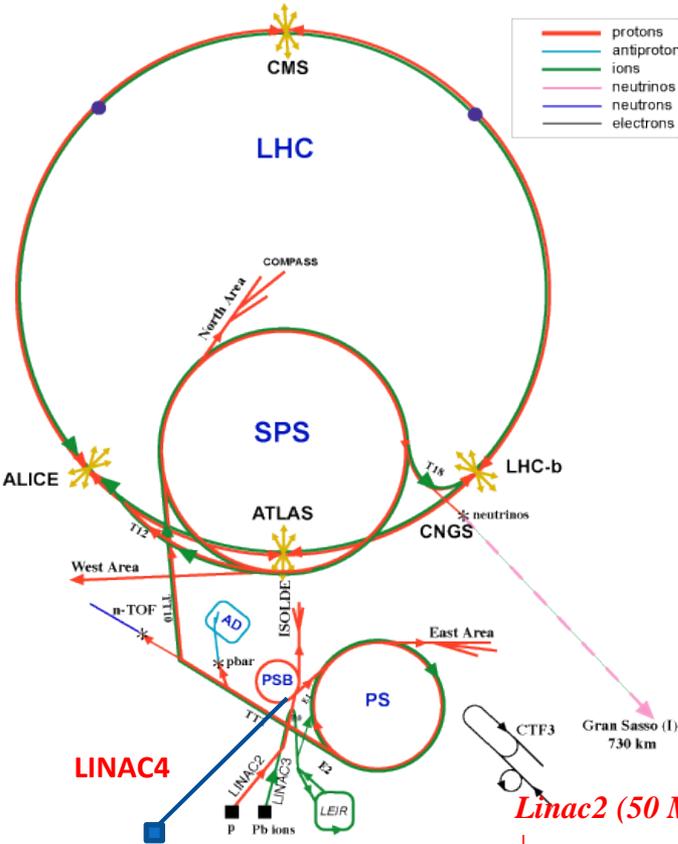
Used in the range where  $\beta$  is nearly constant.  
"Einstein" machine

Note that only linacs are real «accelerators», synchrotrons are «mass increaser»!



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# Linac4, the new LHC injector



**LHC Injection chain:** 4 accelerators. The first one is a 30 m linear accelerator, **Linac2** (commissioned in 1978), accelerating protons at 50 MeV for injection into the PS Booster. Linac2:

1. Has a low energy that limits the intensity in the PSB (and the LHC luminosity);
2. Experiences persistent vacuum problems (leaks) rising concerns for its future;
3. Is one of the 2 last injectors in the world still using protons: all modern machines went to H- ions (easier injection, less expensive linac, lower beam loss)

→ decision in 2007 to build a new linac, **Linac4**

**Linac2 (50 MeV)**  
 ↓  
**PS Booster (1.4 GeV)**  
 ↓  
**PS (25 GeV)**  
 ↓  
**SPS (450 GeV)**  
 ↓  
**LHC**





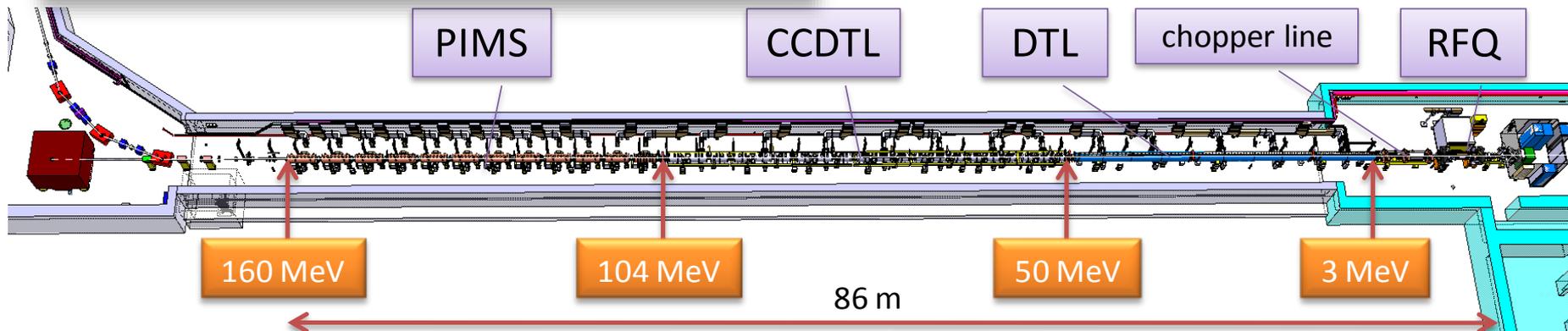
# Linac4 Parameters and Layout



Pre-injector (source, magnetic LEPT, 3 MeV RFQ, chopper line), 3 types of accelerating structures at 352 MHz (Drift-Tube Linac 50 MeV, Cell-Coupled Drift Tube Linac 102 MeV, Pi-Mode Structure 160 MeV), beam dump at linac end with switching magnet towards transfer line to PSB.

Ion species	H <sup>-</sup>	
Output Energy	160	MeV
Bunch Frequency	352.2	MHz
Max. Rep. Frequency	2	Hz
Max. Beam Pulse Length	0.4	ms
Max. Beam Duty Cycle	0.08	%
Chopper Beam-on Factor	65	%
Chopping scheme:	222 transmitted / 133 empty buckets	
Source current	80	mA
RFQ output current	70	mA
Linac pulse current	40	mA
Tr. emittance (source)	0.25	$\pi$ mm mrad
Tr. emittance (linac exit)	0.4	$\pi$ mm mrad

	Energy [MeV]	Length [m]	RF Power [MW]	Focusing
RFQ	0.045 - 3	3	0.6	RF
DTL	3 - 50	19	5	112 PMQs
CCDTL	50 - 102	25	7	14 PMQ, 7 EMQs
PIMS	102 - 160	22	6	12 EMQs





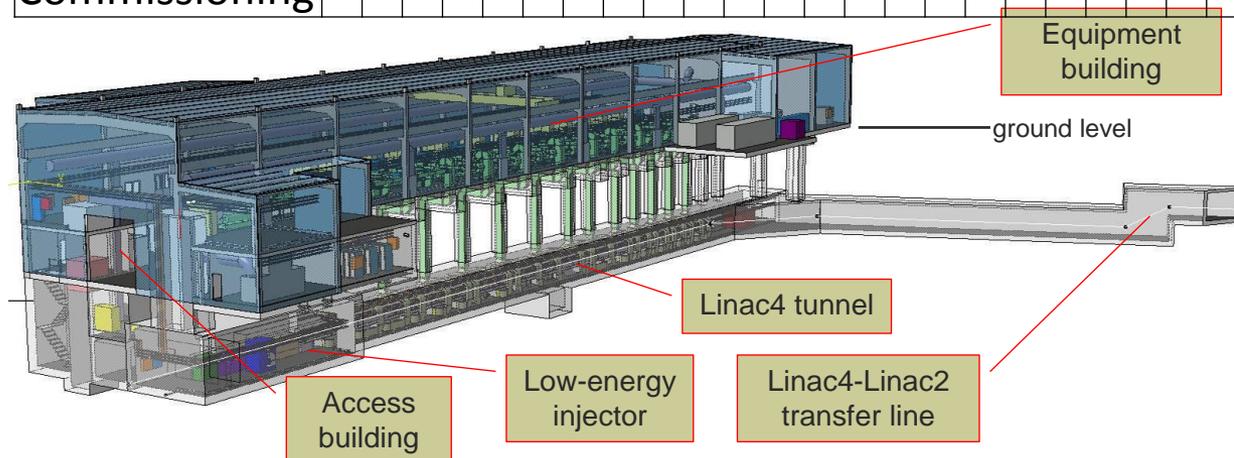
# The Linac4 Project



Approved by CERN Council in June 2007, started on 1 January 2008 first step of the LHC Luminosity upgrade

**Scope:** 160 MeV H<sup>-</sup> linear accelerator replacing Linac2 as injector to the PS Booster (PSB), to increase beam brightness (current/emittance) out of the PSB by a factor of 2 for the benefit of LHC (low current/low emittance) and of high-intensity beam users (high current/high emittance).

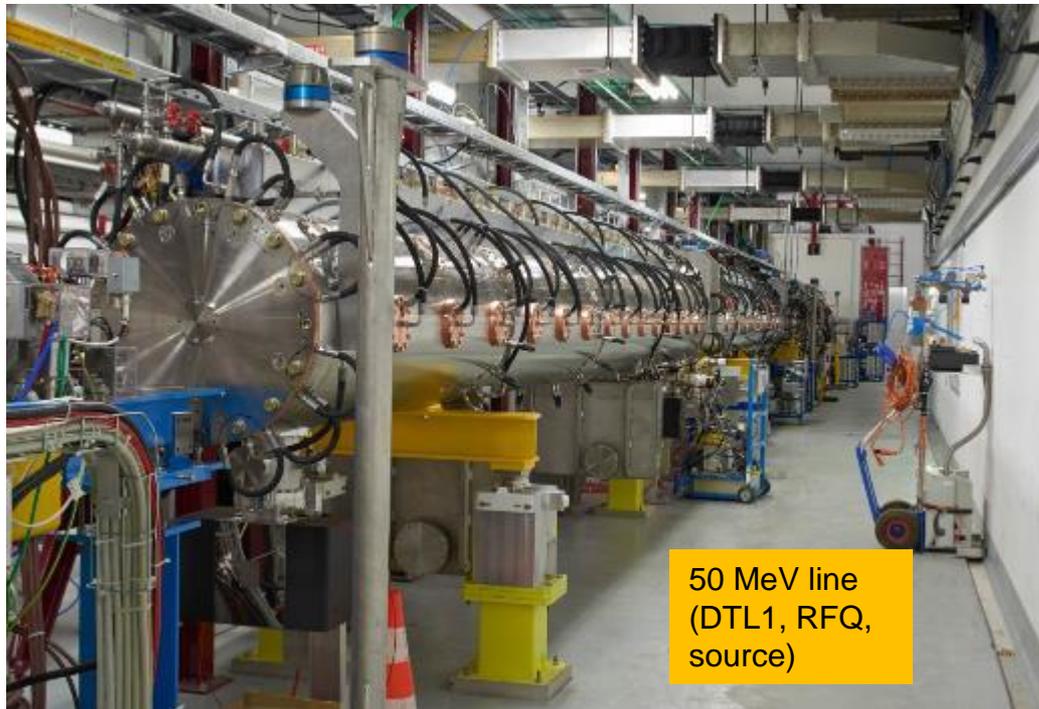
Project Phases	2008	2009	2010	2011	2012	2013	2014	2015	2016
Design	■	■	■	■					
Construction		■	■	■	■	■	■	■	
Installation				■	■	■	■	■	■
Commissioning							■	■	■



- ☞ About 100m in length, connection to the PSB and option of a future extension to higher energy.
- ☞ Linac tunnel 12 m underground, surface building for RF and other equipment, access module at low energy.



# Some views of Linac4



50 MeV line  
(DTL1, RFQ,  
source)

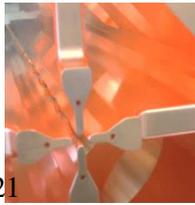


PIMS section



CCDTL  
(100 MeV)

Hot news (11.10.2016):  
155 MeV energy (out of 160 MeV)  
reached last week, full energy  
expected this week

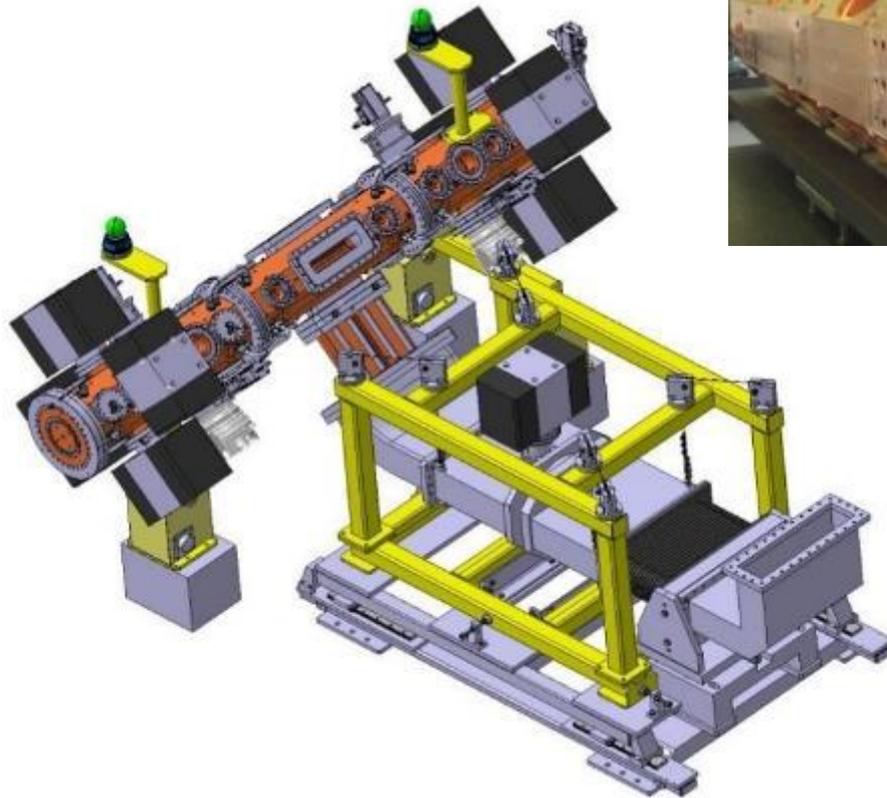


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# The Linac4 Radio Frequency Quadrupole (RFQ)

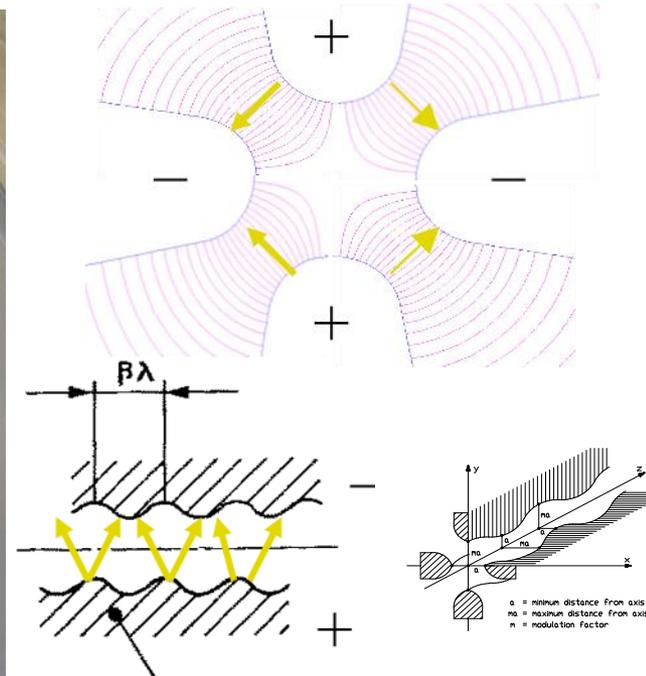
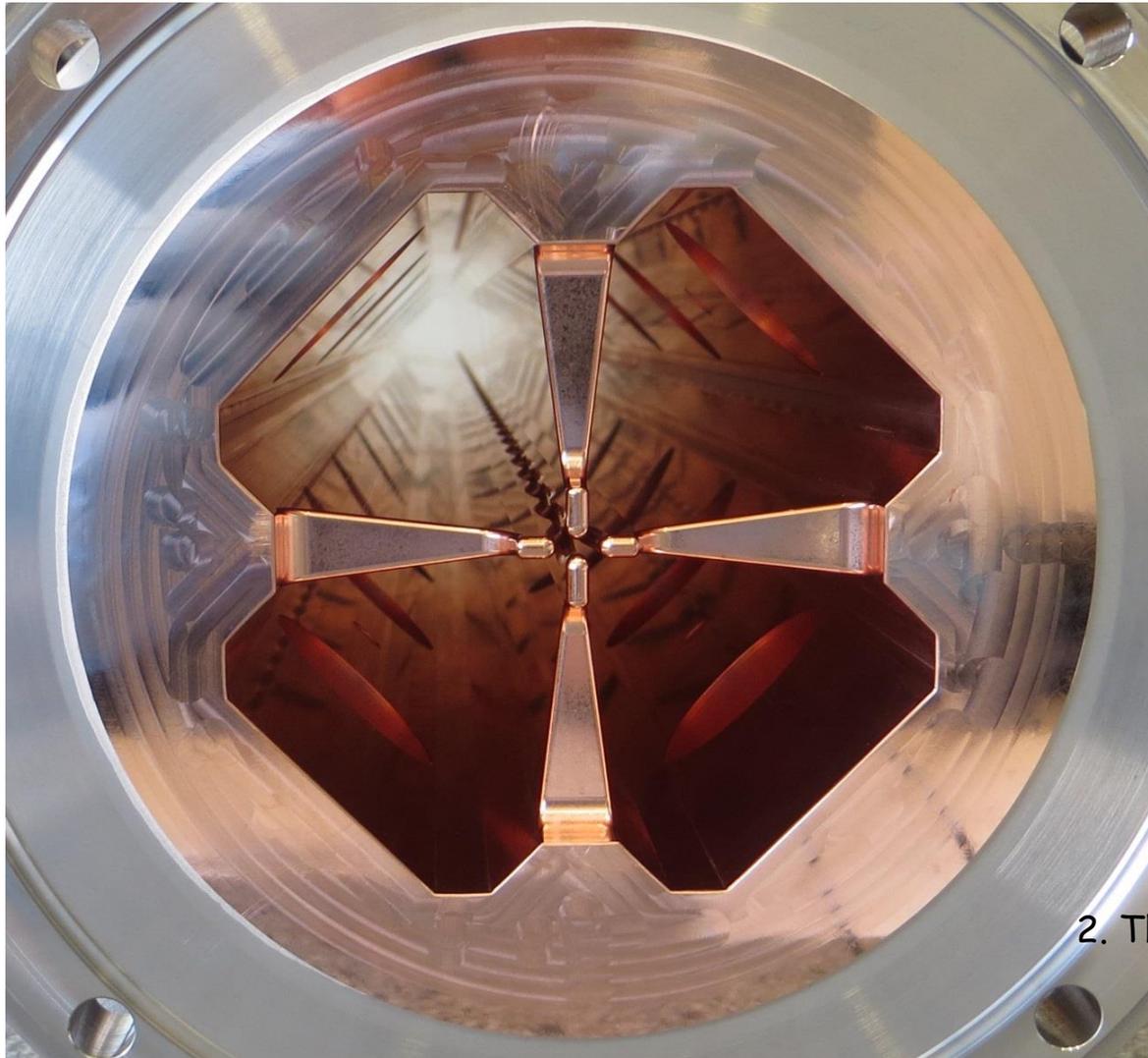


The Radio Frequency Quadrupole (RFQ) is the first accelerator in Linac4 (3m, up to 3 MeV). It focuses bunches and accelerates the beam in a quadrupolar focusing channel inside an RF resonator.





# Looking into an RFQ



Modulated vane

Adjacent vanes ( $90^\circ$ )

1. Four electrodes (vanes) excited in an RF Quadrupole mode  $\rightarrow$  Electric focusing channel.
2. The vanes have a longitudinal modulation with period =  $\beta\lambda \rightarrow$  longitudinal component of the electric field for acceleration and bunching.



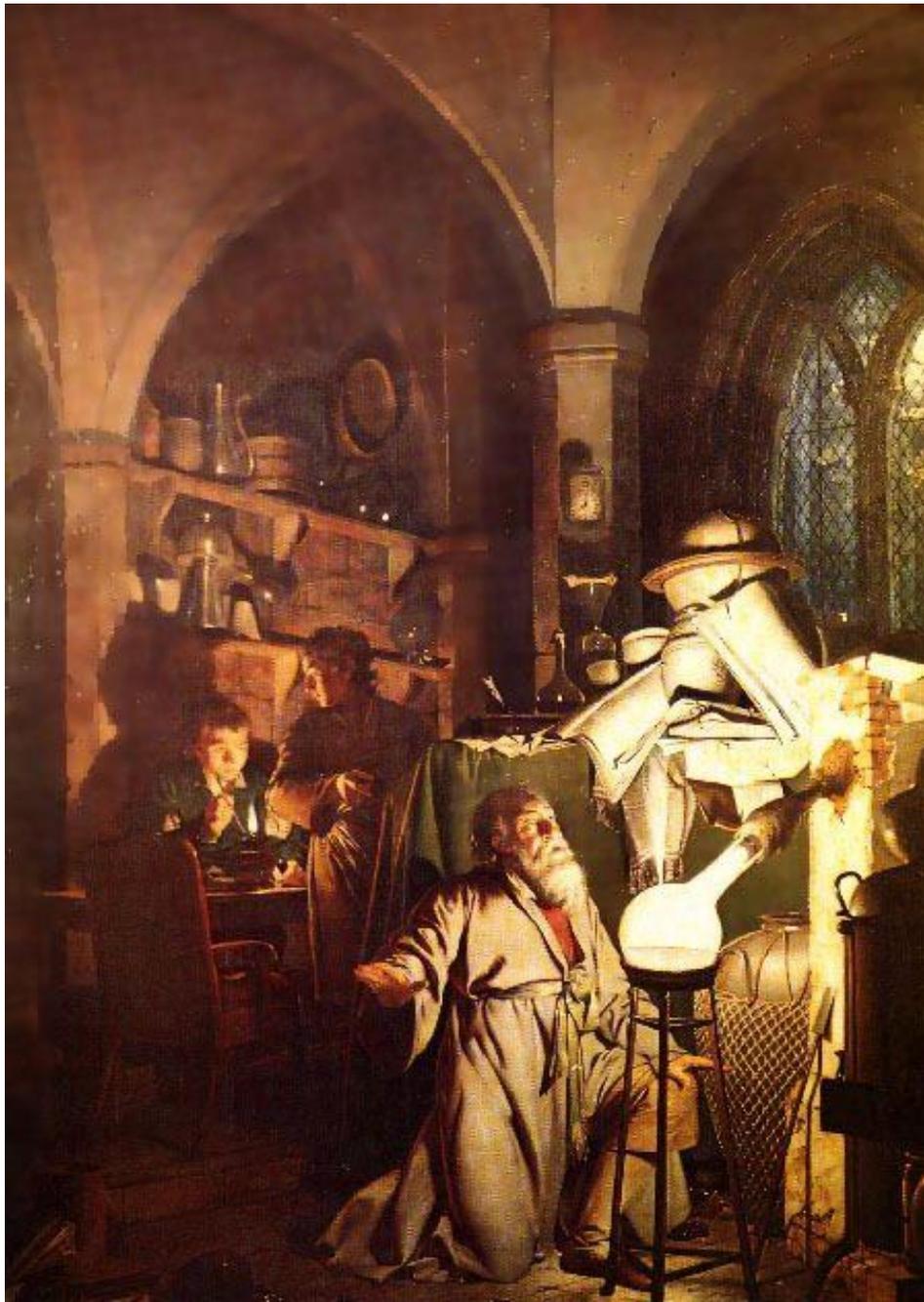
## 3. Dal Linac4 alla società...



# Starting with a vision...



- Particle accelerators are not only scientific instruments, they are unique **tools to interact with atomic nuclei** and subatomic particles.
- The technologies related to manipulations of the atomic structure of the matter offer many **opportunities for society that are only partially exploited**, because of cost, of “radiophobia”, and of lack of contacts between laboratories and industry.
- There are now new opportunities: cost of key technologies is **decreasing**, better regulation and understanding of radiation are slowly increasing the **social acceptance of nuclear-related technologies**, more attention is given to **technology transfer from science to society**.
- There is space for bringing more accelerator technology out of scientific laboratories to society: what is needed are **compact, easy to operate, low radiation and low cost proton (and ion) accelerators** able to cover several medical and industrial applications.
- Among the different applications, **medicine has the priority**. Medicine is becoming the main technology driver of 21st century (as defense was the technology driver of 20th century).



Particle accelerators can realise the dream of the ancient alchemists: transform the matter!



# The miniature accelerator



The **miniature particle accelerator** should:

- Bring protons above Coulomb barrier (energy > few MeV).
- Fit in a standard size room, with no concrete bunker around.
- Allow you to stay next to it while it works (low radiation)
- Be cheap, reliable and maintenance-free

The best accelerator corresponding to these specification is the **Radio Frequency Quadrupole linear accelerator** :

- Energies up to 10-15 MeV.
- Linear, small dimensions, limited weight.
- Controlled beam optics with no beam loss outside of the target: only the target needs to be locally shielded.
- Not expensive if built on large scale, one-piece device with virtually no maintenance.

Cyclotrons, the accelerators presently used for isotope production, are limited by beam loss and induced radiation and need large concrete shielding and/or an underground installation.



Broader goal:  
bring  
accelerators  
out of scientific  
laboratories  
into medical  
and industrial  
environments



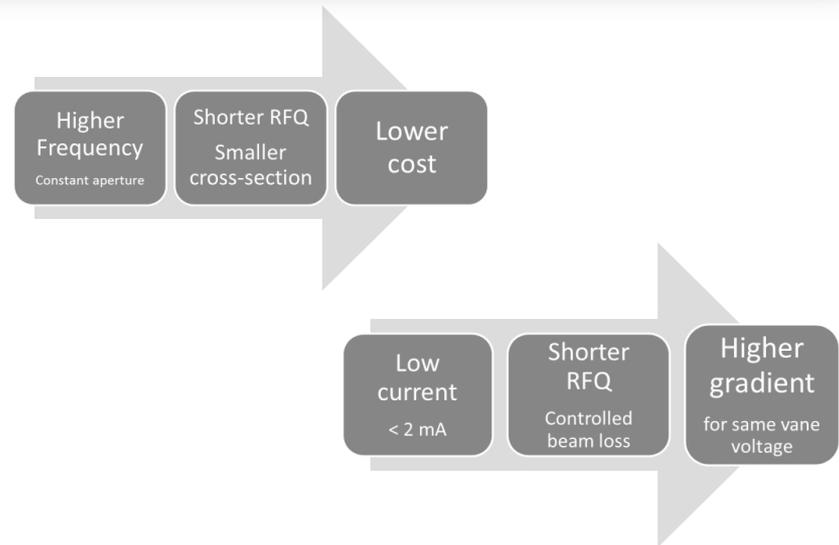
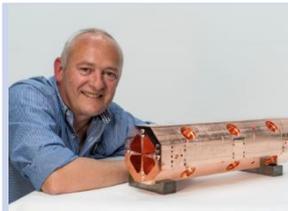
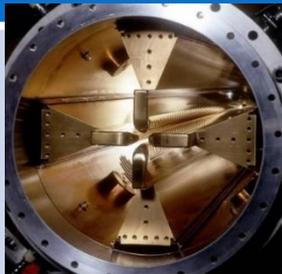
# Pushing the RFQ limits



## THE KEY TO SMALLER DIMENSIONS : HIGHER FREQUENCY

Initial RFQs in the 200 MHz frequency range, later, 400 MHz range (Linac4).  
 A new compact RFQ reaching the high frequency range 700 – 800 MHz

1988-92 Linac2 RFQ2 202 MHz 0.5 MeV /m Weight : 1000 kg/m Ext. diameter : 45 cm	2008-13 LINAC4 RFQ 352 MHz 1MeV/m Weight : 400kg/m Ext. diameter : 29 cm	2014-16 HF-RFQ 750MHz 2.5MeV/m Weight : 100 kg/m Ext. diameter : 13 cm
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	Frequency	Energy	Length	Gradient	Current
Linac4 RFQ	352 MHz	3 MeV	3 m	1 MeV/m	90 mA
HF-RFQ	750 MHz	5 MeV	2 m	2.5 MeV/m	400 $\mu$ A

Fabrication cost per meter about 50% for HF-RFQ

### New High-Frequency (HF) RFQ at 750 MHz ADVANTAGES:

- Smaller, less expensive construction
- Shorter, more cells/unit length

### LIMITATIONS:

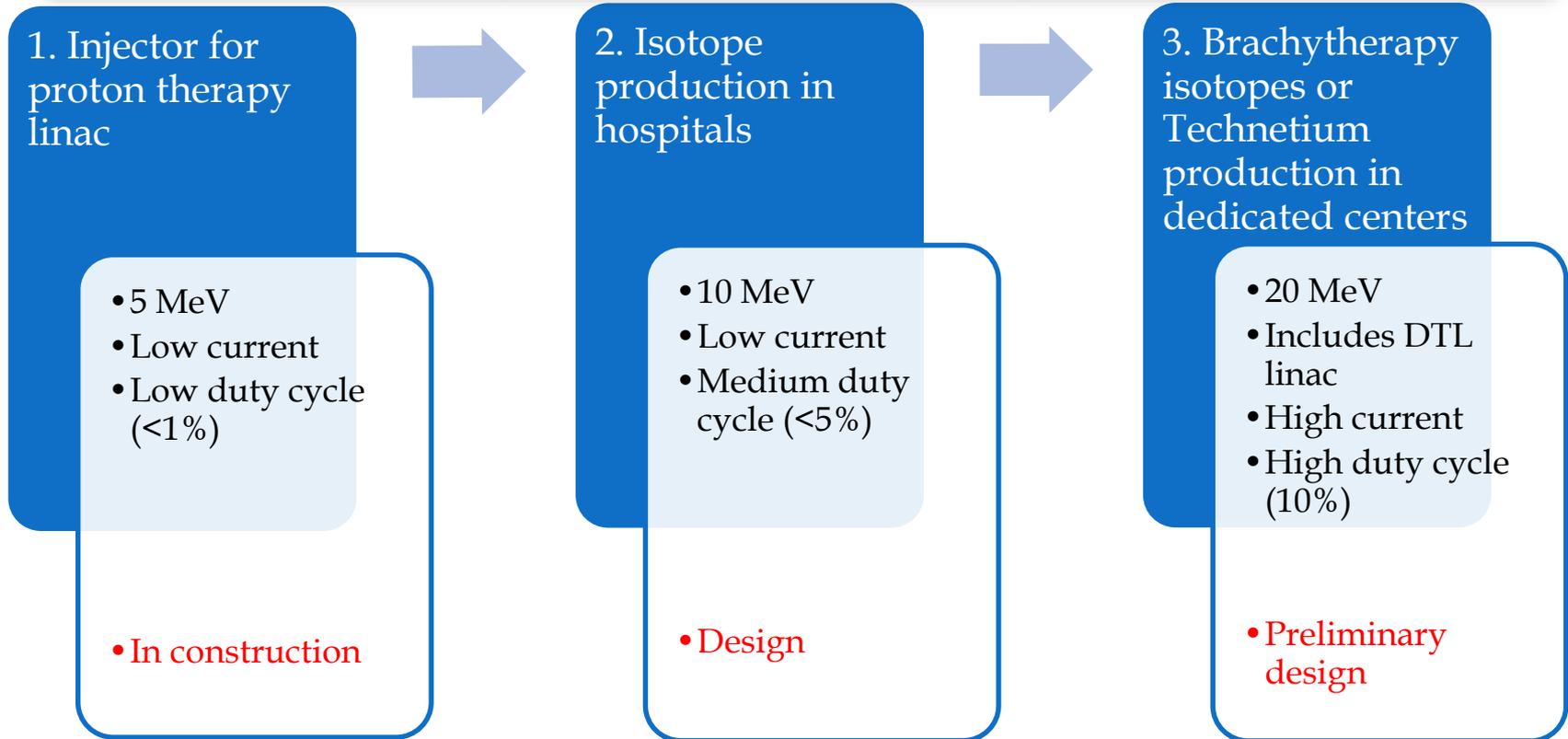
- Limited current
- Shunt impedance as in conventional RFQs



# Technological Roadmap



Develop a modular high-frequency RFQ covering 3 medical applications:



Additional step outside of medical applications:

**Portable 3 MeV accelerator** for PIXE and PIGE spectrometric analysis of artwork in museums or of components in an industrial environment



# After ideas... you need people and money



- The construction of the compact RFQ has been funded by the new CERN Office for Medical Applications.
- A competent part-time team has been adventurously set up
- Design and construction of the prototype compact RFQ has started at the end of 2013.
- Construction has been completed in summer 2016.
- The RFQ is now on loan to a proton therapy company (a CERN start-up) that will use it in front of a new compact proton therapy linac to be installed in hospitals worldwide.
- Beam tests will start before the end of 2016.



# The RFQ for proton therapy design and challenges



## Long list of **challenges**:

- Provide enough **focusing**, maximize **acceptance**.
- Best **compromise length / transmission**: accelerate only what can be captured, eliminate the rest at low energy
- Machining the modulation in the **short initial cells**.
- Reduce sensitivity to errors to keep **conventional machining tolerances**.
- Limit the **peak RF power**.
- Achieve the required **RF field symmetry** in presence of the longitudinal modes related to the length (**several times  $\lambda$** )

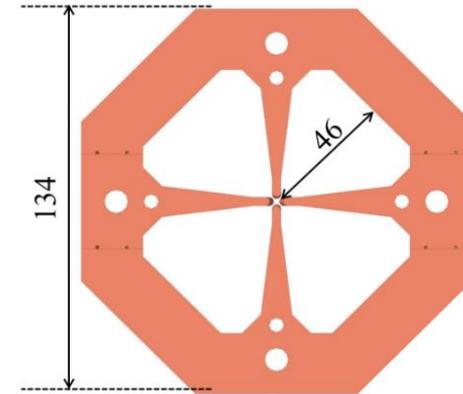
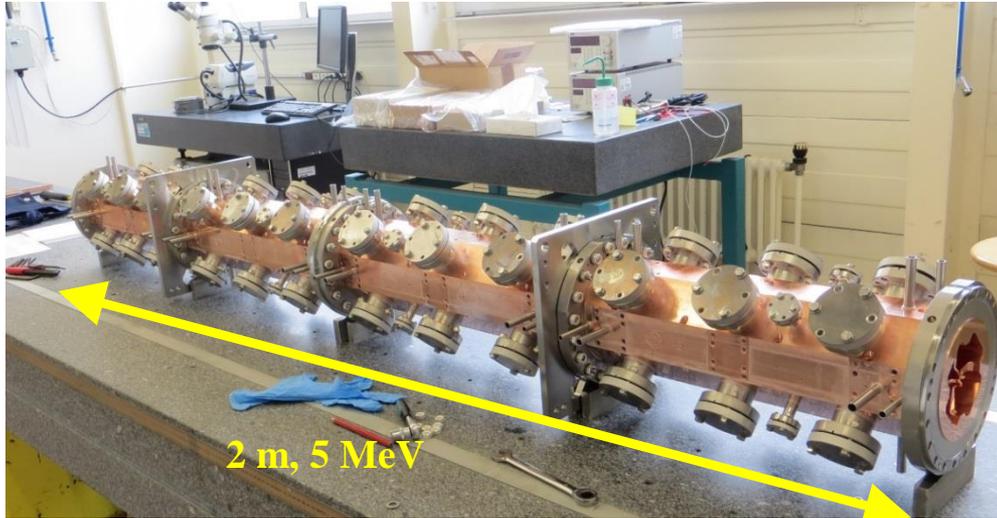
## Source and RFQ parameters

RF Frequency	750 MHz
Input Energy	40 keV
Output Energy	5 MeV
Length	2 m
Vane voltage	65 kV
Peak RF power	400 kW
Duty cycle / max	0.4 % / (5 %max)
Input/Output Pulse Current in 3 GHz acceptance	100/30 $\mu$ A
Transv. emittance 90%	0.1 $\pi$ mm mrad
Average aperture ( $r_0$ )	2 mm

*Approaching an unexplored frequency!*



# General design - a multi-purpose RFQ



Machining tolerances  $\pm 20 \mu\text{m}$  (cavity),  $\pm 10 \mu\text{m}$  (vane tip).  
Assembly tolerance for the four vanes  $\pm 15 \mu\text{m}$ .

- Full **modularity**: 500 mm identical modules, different only by the vane modulation.
- **Multiple RF inputs** (1/module) to use multiple low-power amplifiers (using the RFQ as RF combiner).
- **Brazed technology**, based on the thermal treatment procedure developed for Linac4 to avoid deformations.
- Machining **tolerances** at the same level as the Linac4 RFQ, to use conventional CNC machines in a standard workshop.
- Design the module for the **maximum duty cycle** allowed by a simple cooling design (2 channels/vane).

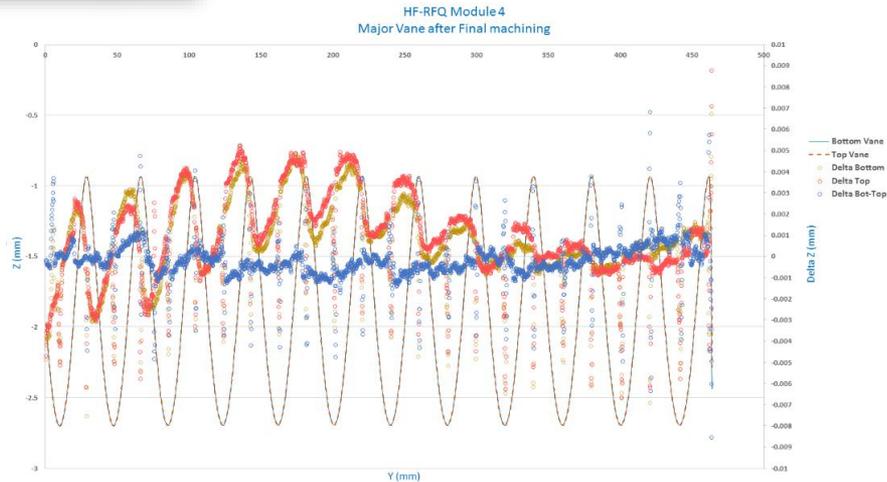




# Machining



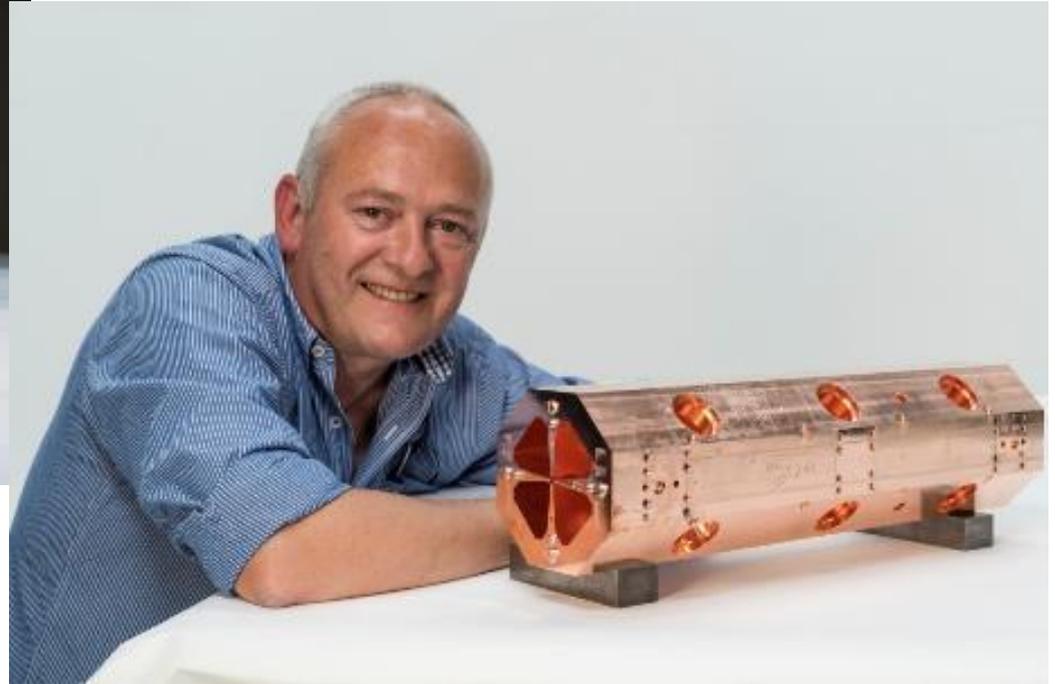
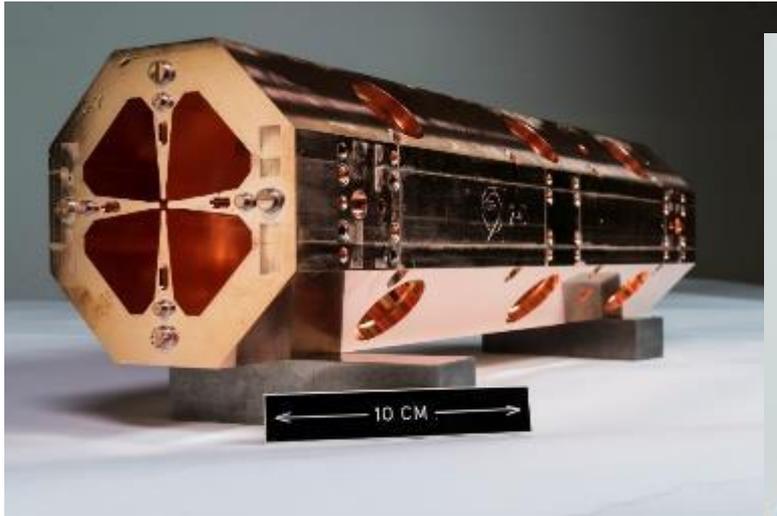
Fabrication entirely done in the CERN Workshop!



Machining errors on vane tips within  $\pm 5 \mu\text{m}$  (specs  $\pm 10 \mu\text{m}$ )



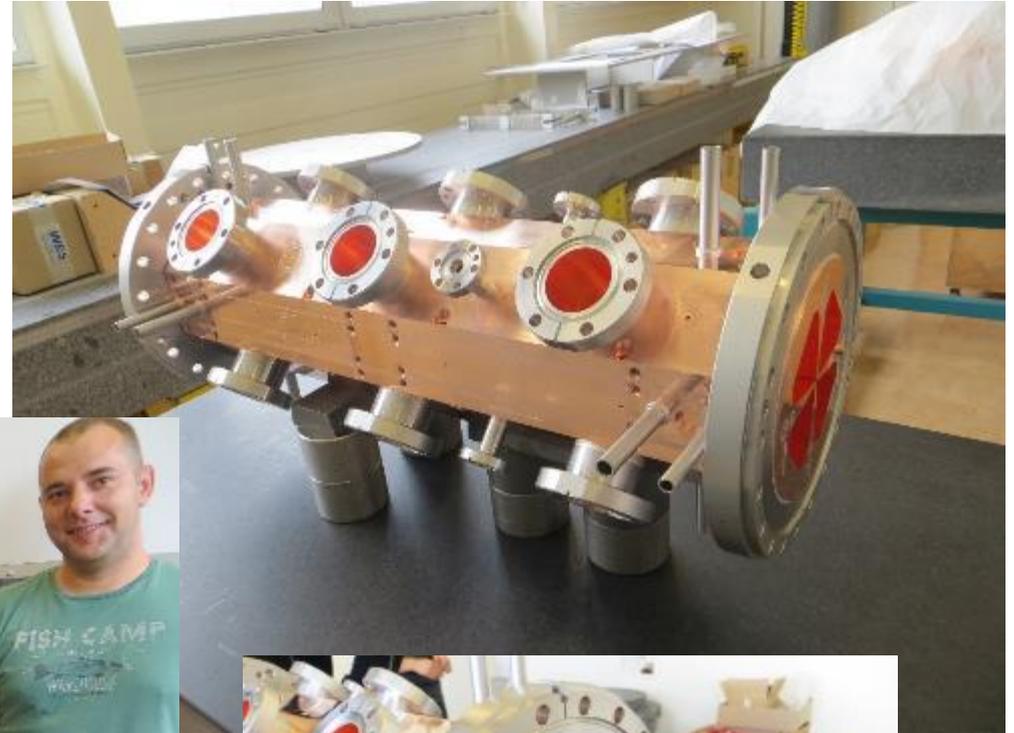
# The first completed module



The first RFQ module with S. Mathot, in charge of the mechanical construction.



# First fully equipped modules





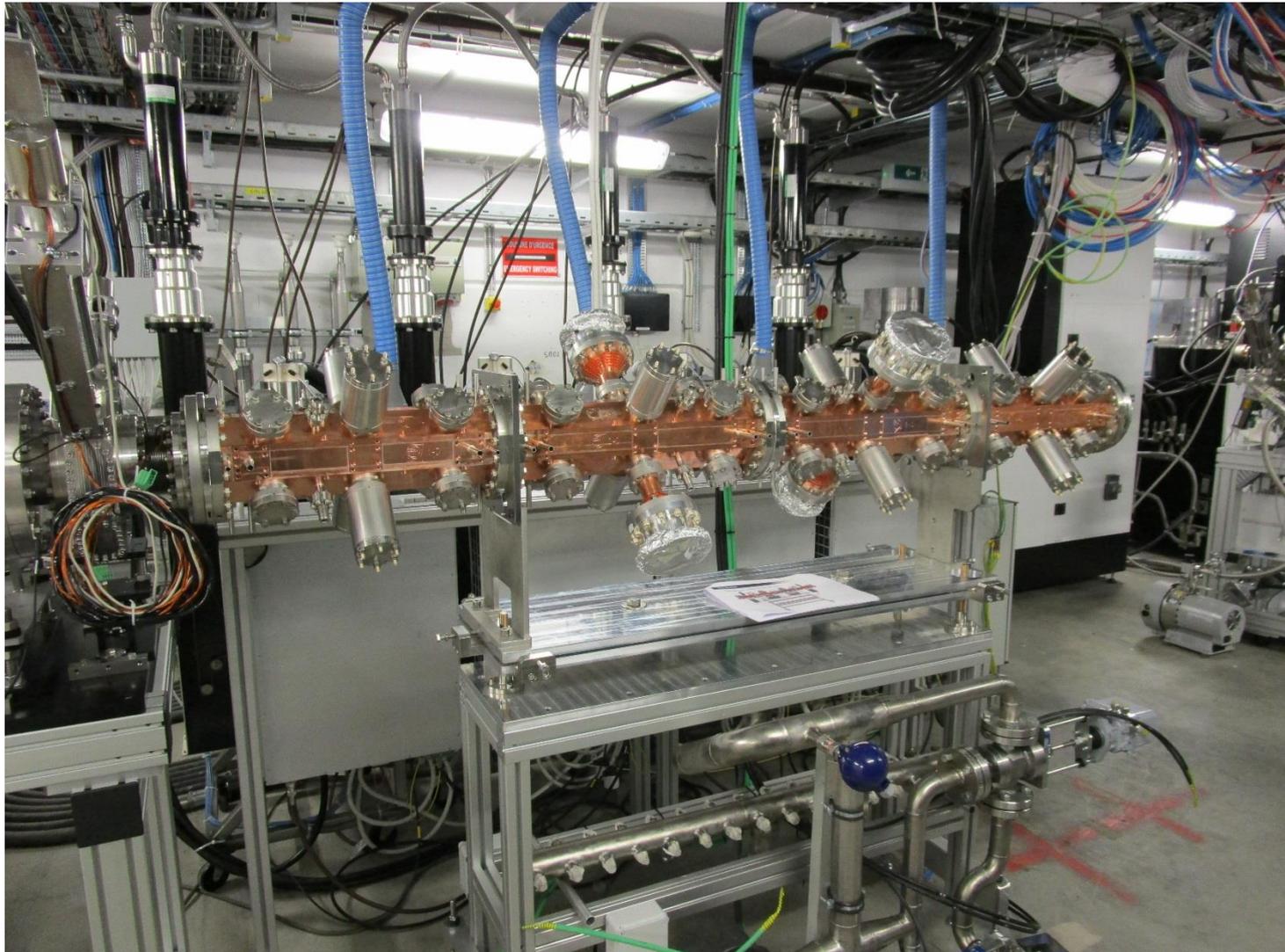
# Transport of the 5 MeV RFQ to the beam testing area



14 September 2016



# The RFQ installed in the beam test area





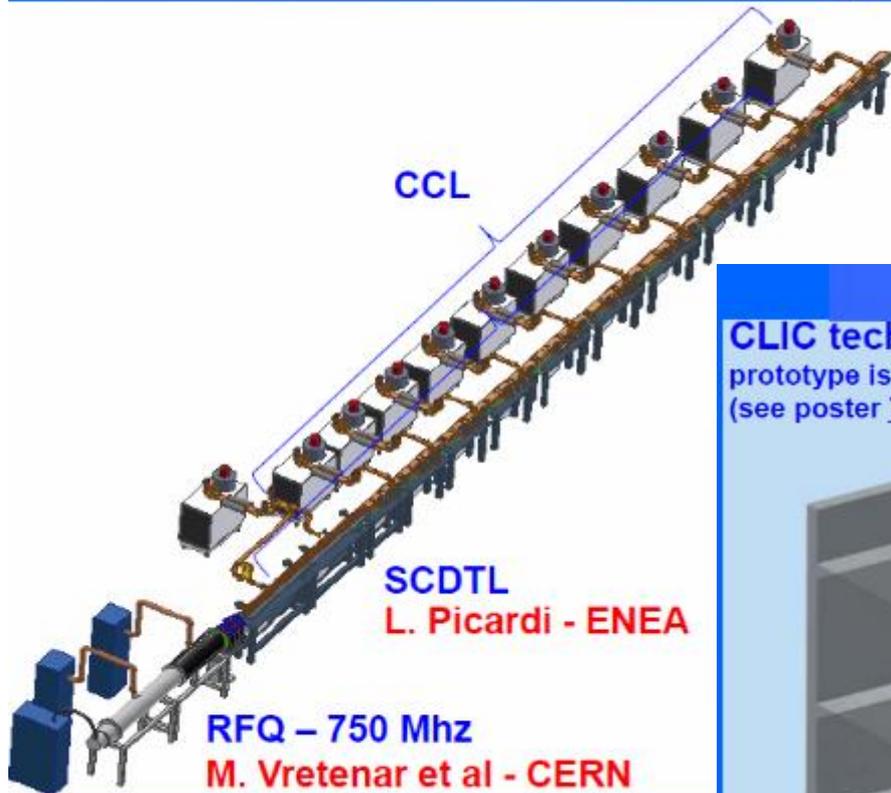
## 4. Applicazioni del mini-RFQ



# RFQ for Proton therapy



The all-linac LIGHT is being built at CERN by A.D.A.M.

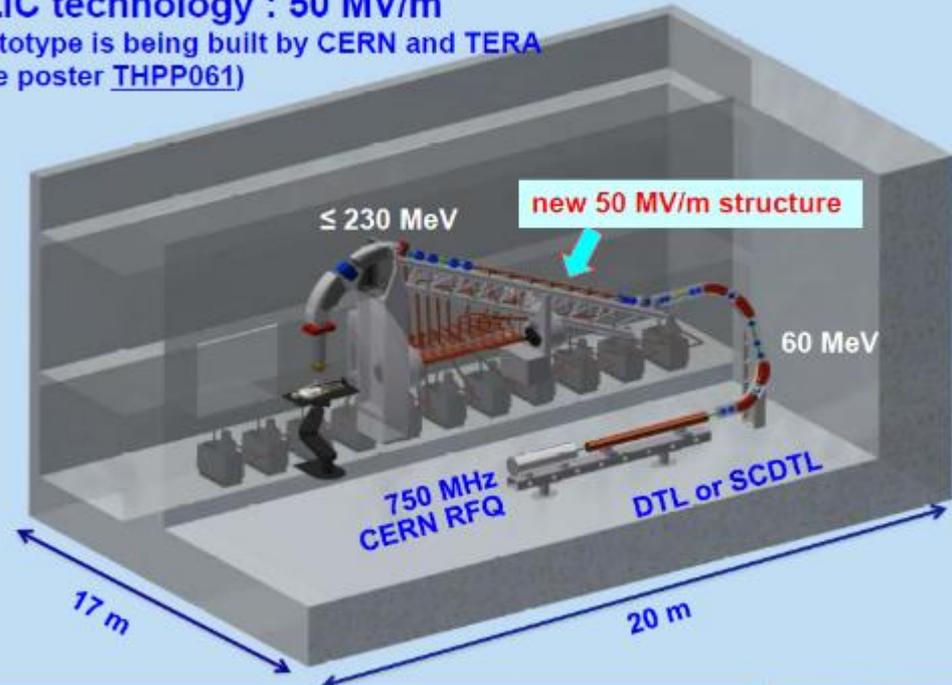


proton pulses @ 200 Hz

2 examples of proton therapy linacs using the HF-RFQ as injector

TULIP 2-0 by CERN and TERA

CLIC technology : 50 MV/m  
prototype is being built by CERN and TERA  
(see poster [THPP061](#))

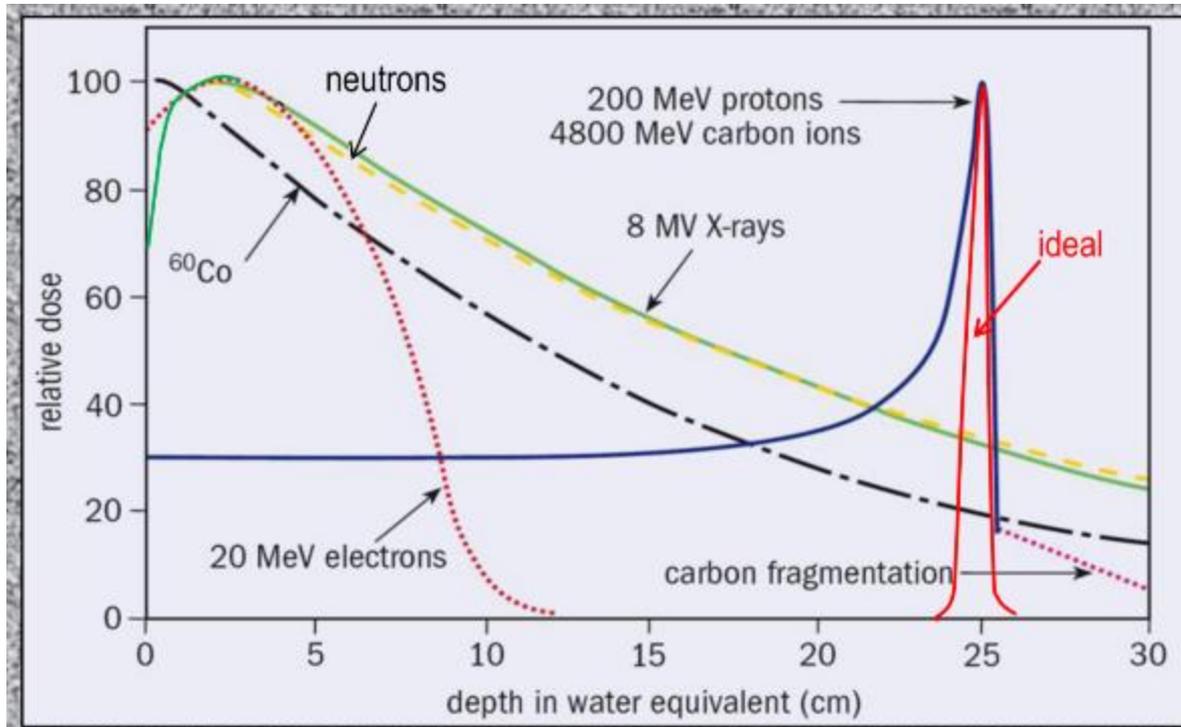




# Hadrontherapy



‘Hadrontherapy’: cancer therapy modalities which irradiate patients with beams of hadrons. The “Bragg peak” allows to concentrate the radiation dose on a deep tumour, minimising the dose to the adjacent tissues. Hadrontherapy is an alternative to usual irradiation with X-rays from e-linacs.



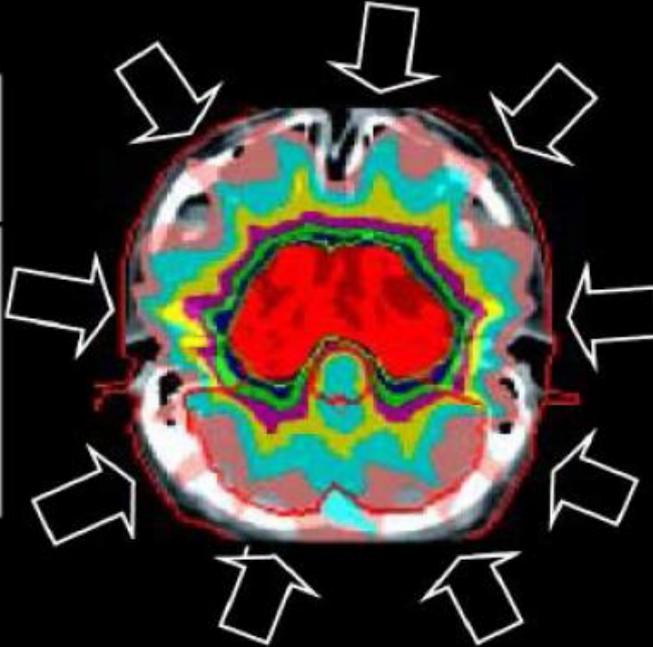
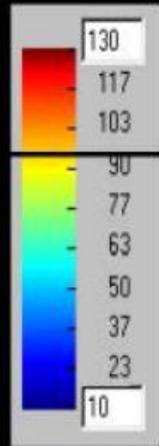
Most used hadrons:  
protons and carbon ions.

- Protontherapy is rapidly developing: more than 65'000 patients treated, 5 companies offer turn-key solutions.
- Carbon ions, used for about 6000 patients, have a larger radiobiological effectiveness and require more radiobiological and clinical studies to define the best tumour targets.

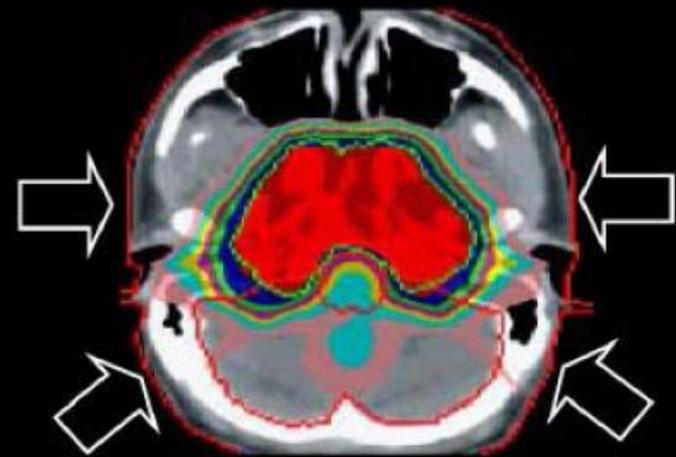


## Advantages of hadrontherapy: 1. normal tissues are spared

9 X-rays beams



4 protons or carbon ions beams



Courtesy PSI -- Villigen

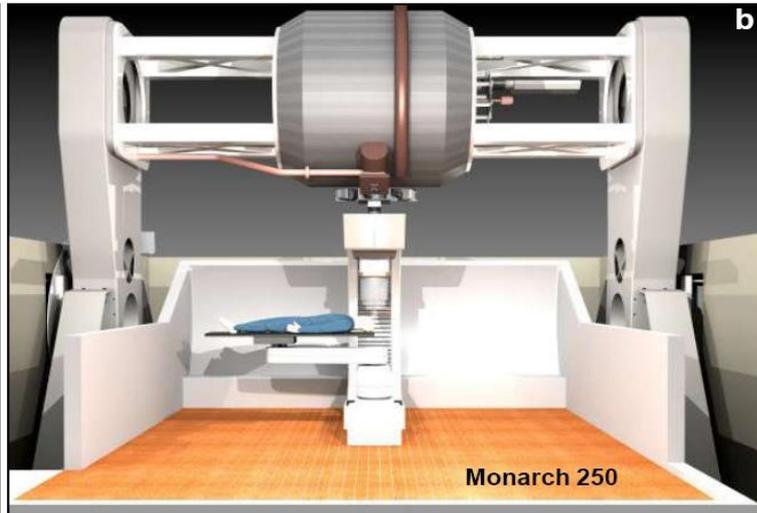


# New challenges in hadrontherapy accelerators

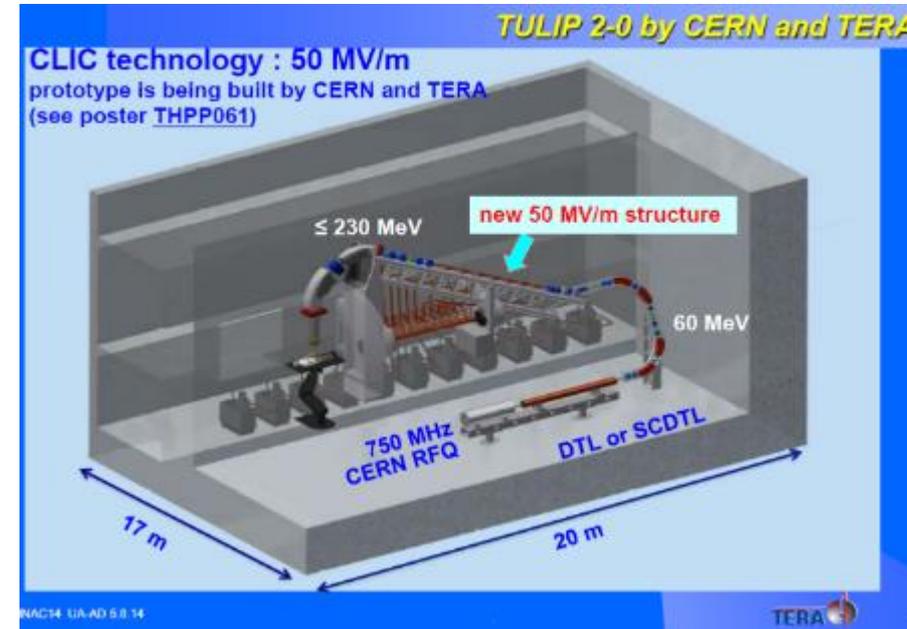


Challenges for the new generation machines:

1. More compact (to fit in conventional hospitals): often cyclotron based, trend to single-room facilities.
2. Avoid complicated and expensive gantries.



*First single room facility: Still River synchrocyclotron rotating around the patient*

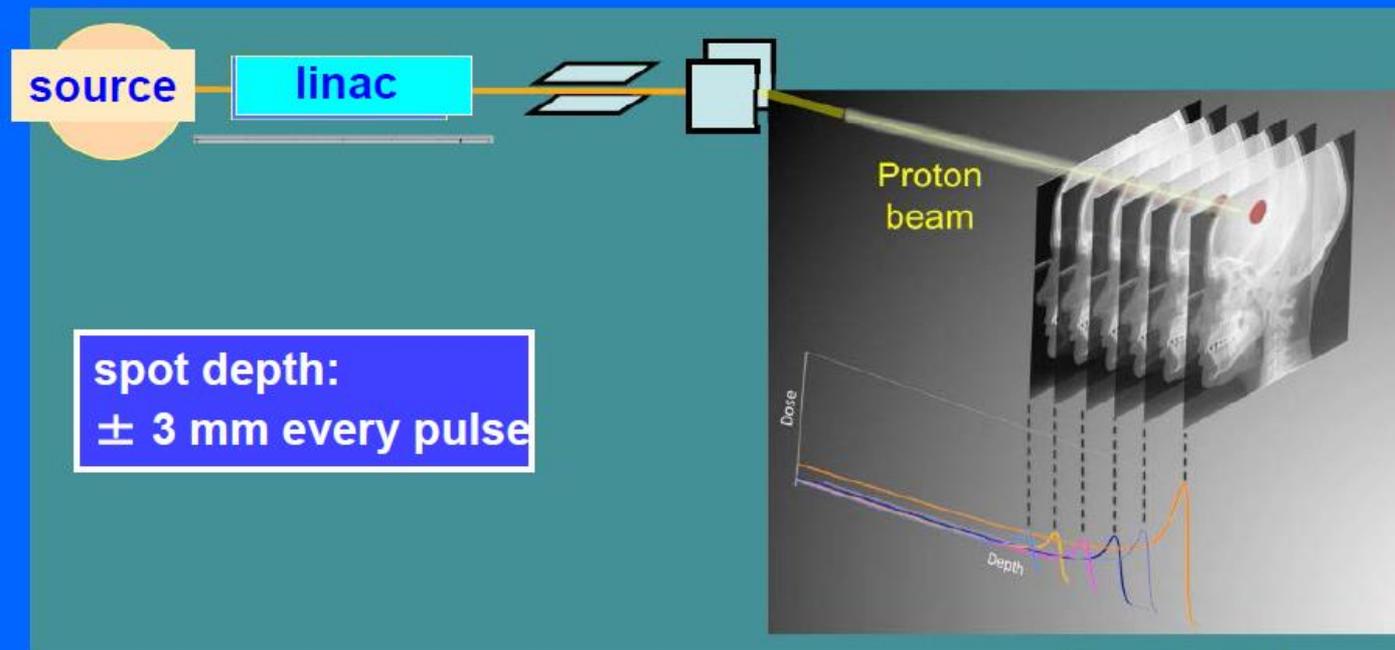


*The TULIP concept (TERA Foundation), compact linac rotating around the patient.*



**The dose deposition depth can be adjusted every 3 ms**

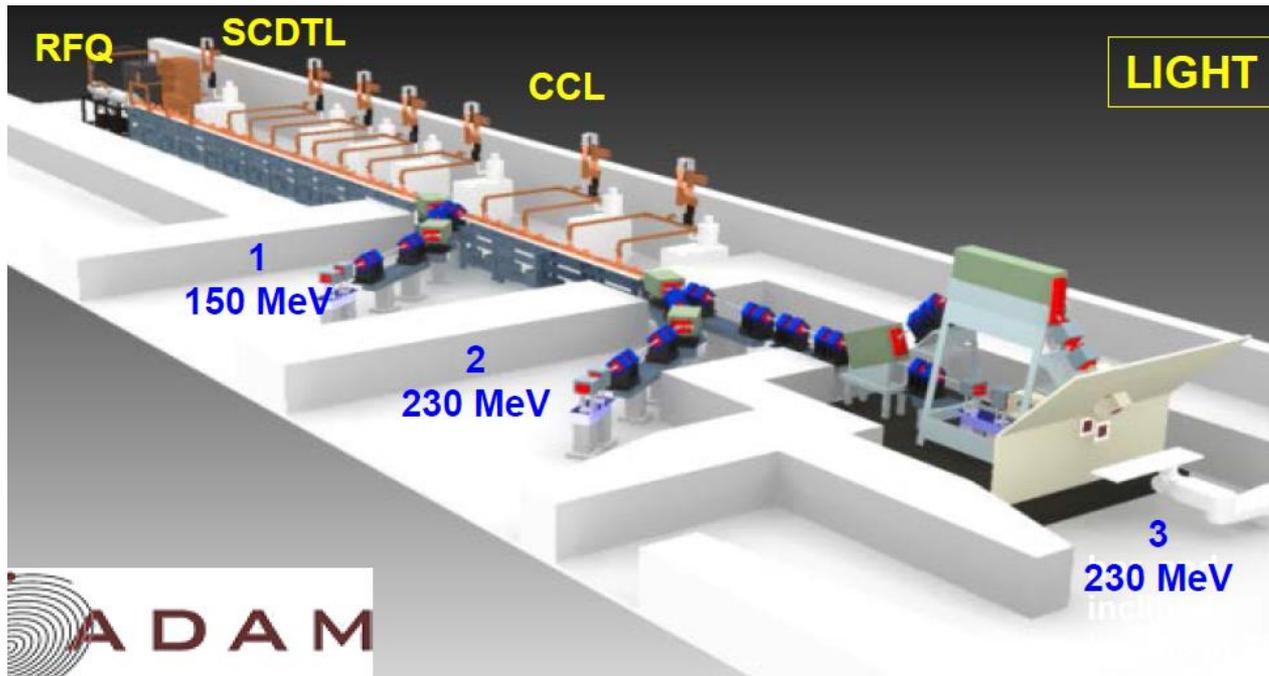
The linac pulses 200-300 times per second



To follow moving organs in 4D - with **spot scanning**, **motion feedback** and more than **10 paintings** - the beam time structure of linacs is better than the ones of cyclotrons and synchrotrons



# ADAM and CERN



- ADAM, a spin-off company of CERN initially started by Ugo Amaldi and his TERA Foundation, is building a prototype proton therapy linac (LIGHT).
- CERN contributes with the RFQ.
- Beam commissioning of the RFQ at the ADAM test stand at CERN

*Interest for small proton therapy facilities to be installed in existing hospitals. Linacs allow fast cycling with energy variability (precision 4D scanning of a moving organ).  
3 GHz structures take the beam only from  $\approx 5$  MeV energy  $\rightarrow$  need a high-frequency injector.*



In 2014 CERN has signed an agreement with the ADAM Company (Application of Accelerators and Detectors to Medicine, part of the AVO – Advanced Oncotherapy – group from UK) to allow them using the prototype RFQ in their LIGHT proton therapy linac.

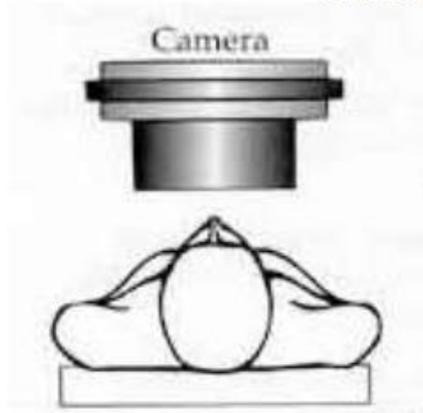
Recently (contract signed in August 2015) ADAM has purchased from CERN a license to use the compact RFQ technology for the construction of proton therapy linacs.



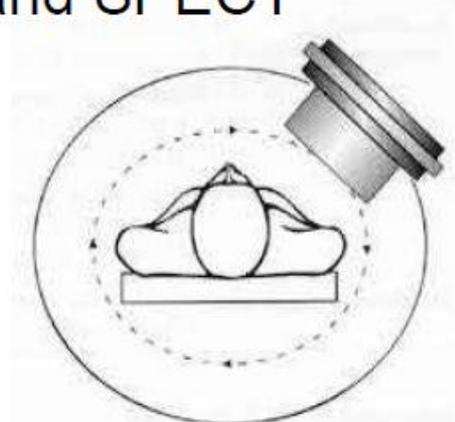
# Tomography



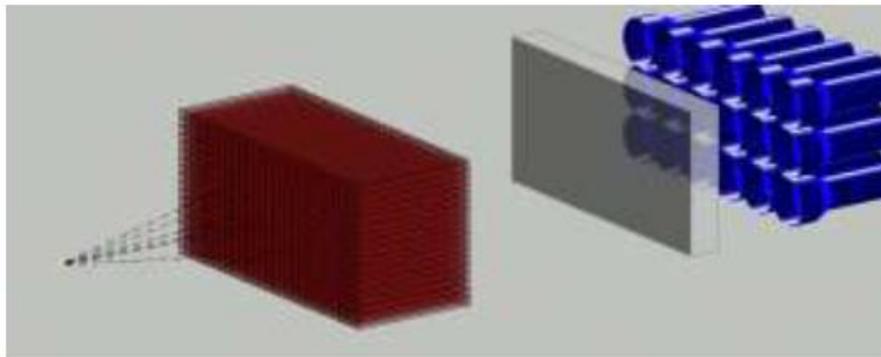
## Scintigraphy and SPECT



**2D: planar scan  
(Gamma camera)**



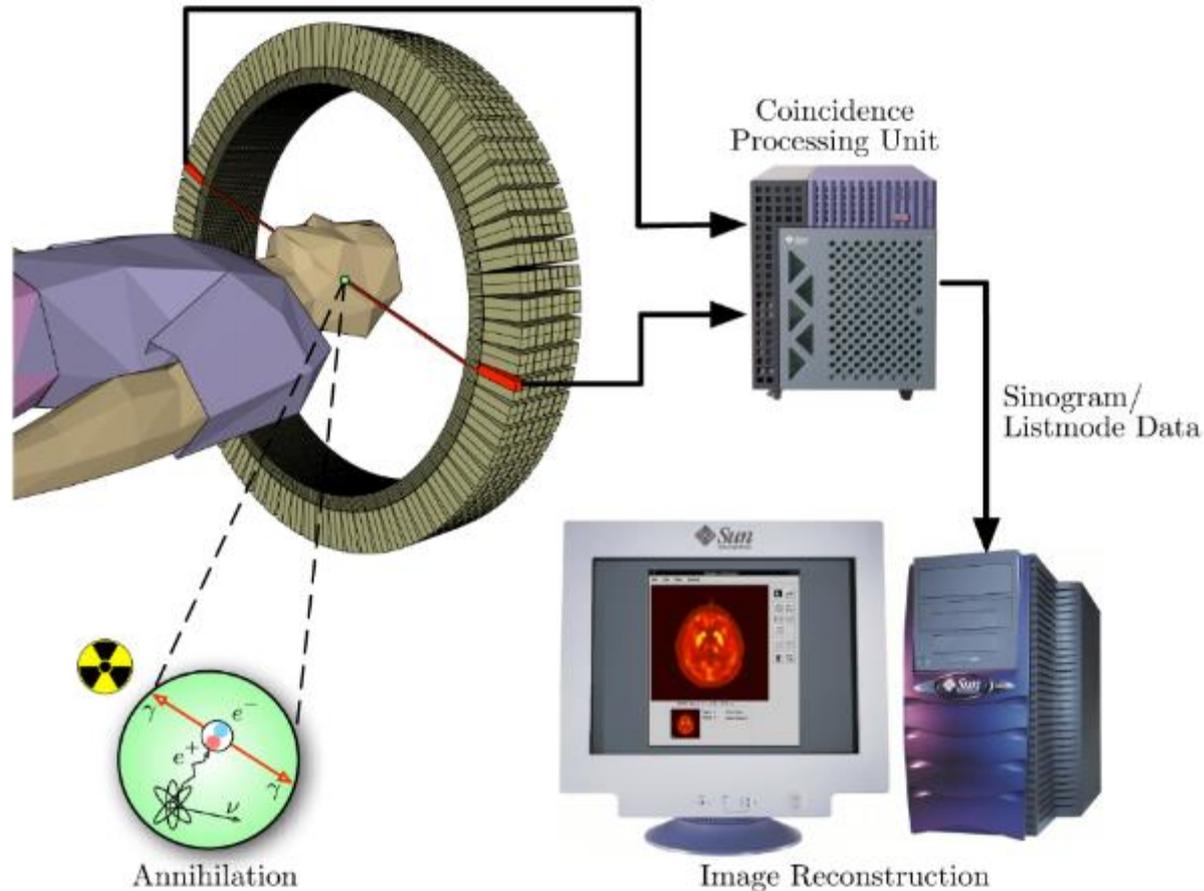
**3D: SPECT: Single Photon Emission  
Computer Tomography**



$E_{\gamma} > 60 \text{ keV}$   
 $E_{\gamma} < 400 \text{ keV}$



# Positron Emission Tomography



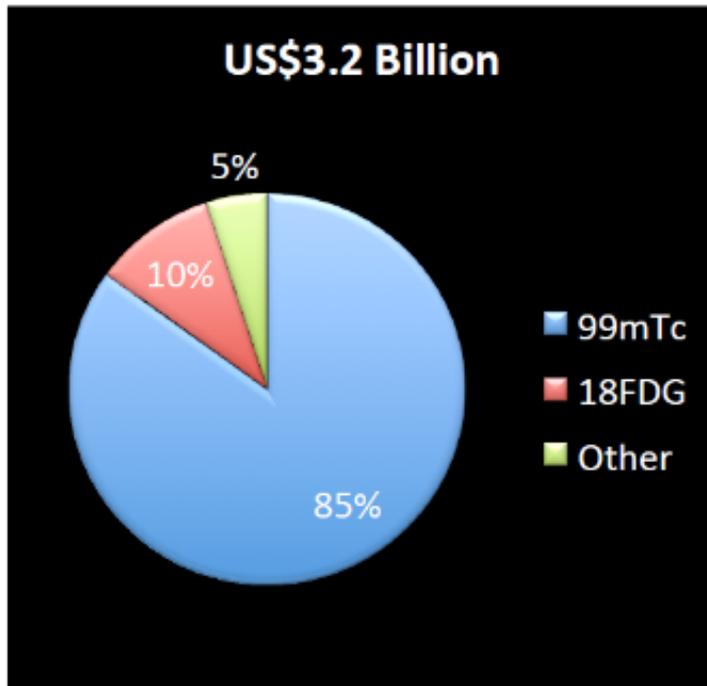


# Isotope production

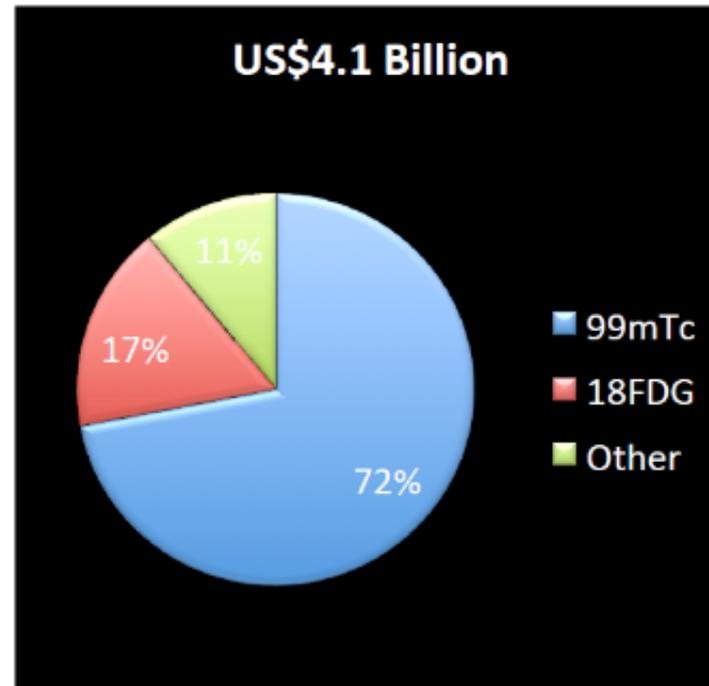


## Global Radiopharmaceutical Diagnostic Market (1,2,3)

2010



2017



1 Global Radiopharmaceuticals Market (PET/SPECT Imaging & Therapy) – Current Trends & Forecasts (2010 – 2015); MarketsandMarkets, August 2011

2 BMI - Business Monitor International Ltd, Molybdenum-99: Privatising Nuclear Medicine, Special Report 2011

3 Interim Report on the OECD/NEA High-Level Group on Security of Supply of Medical Radioisotopes, The Supply of Medical Radioisotopes, OECD 2012

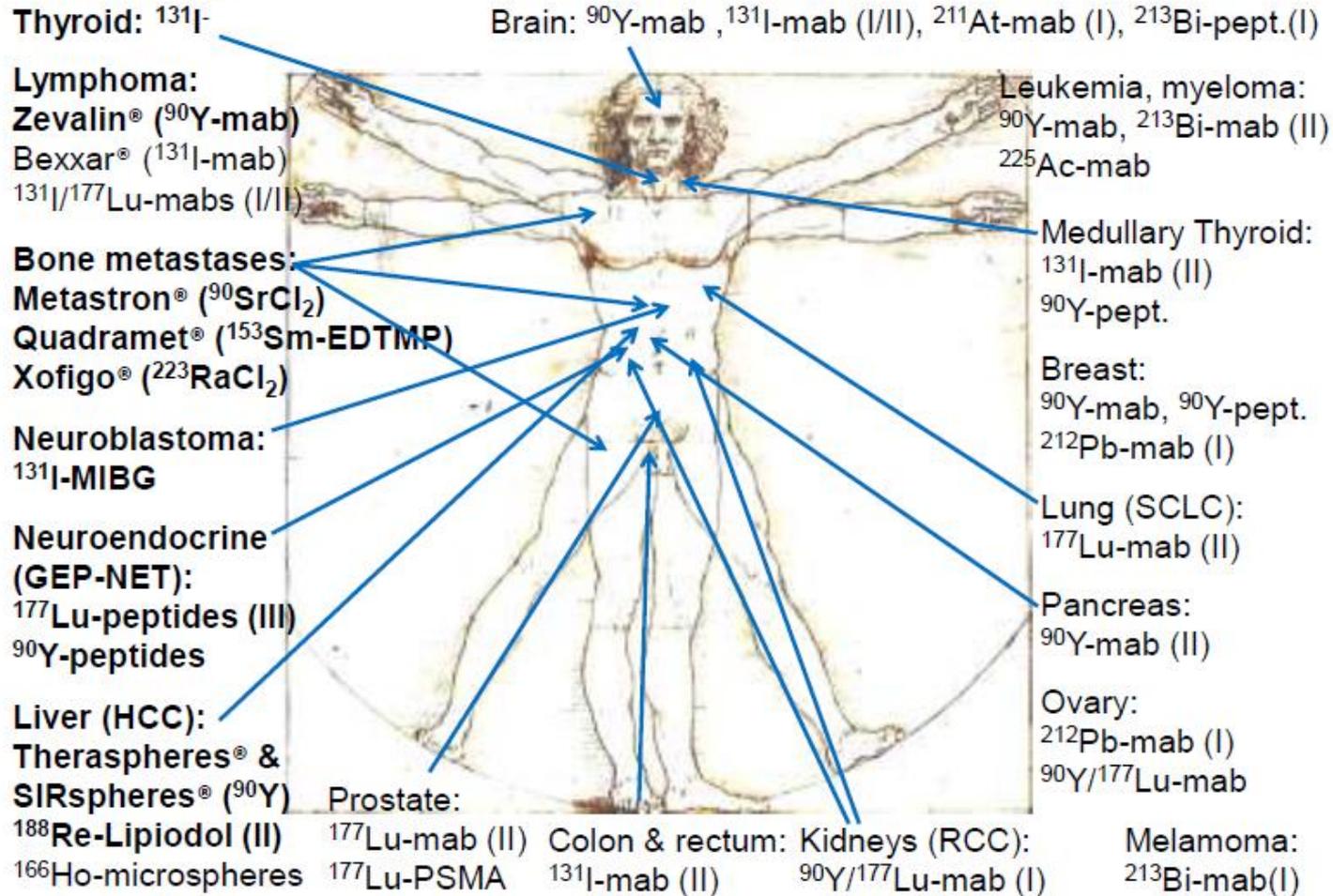
*Courtesy of H. Owen, Manchester University*



# Advanced Radiotherapy

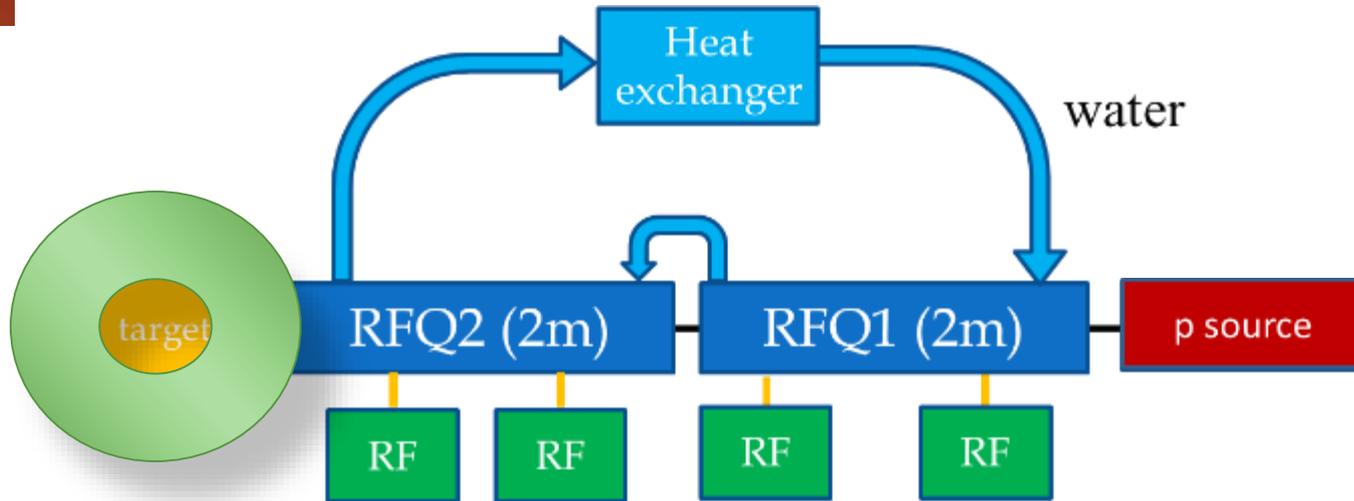


## Targeted radionuclide therapies in the clinic





# The isotope RFQ system



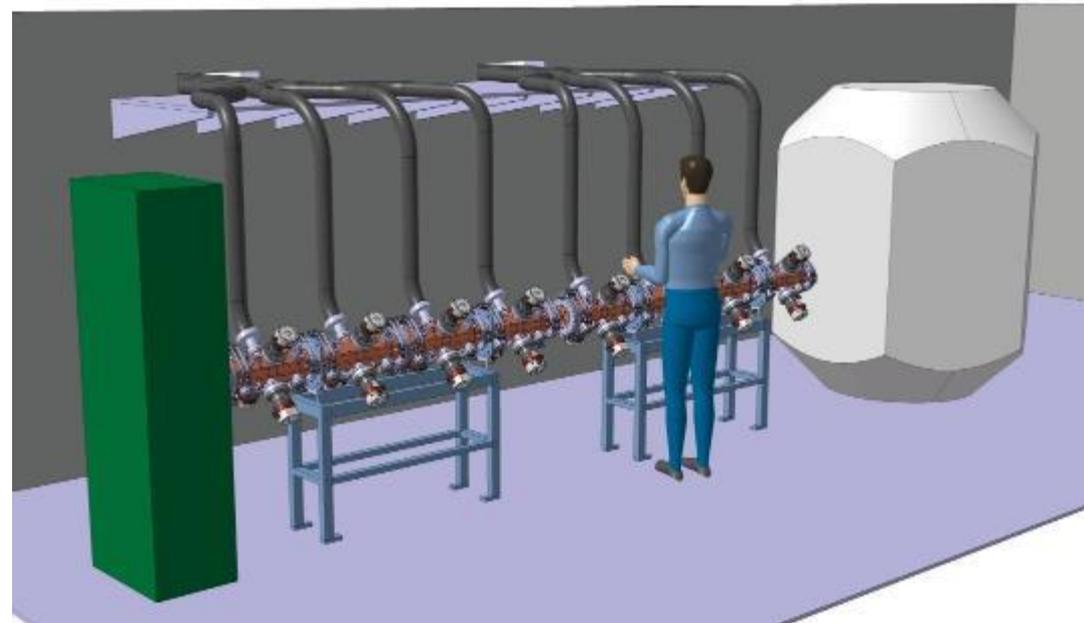
## To be installed in hospitals

2 (or more) movable targets.

Target shielded by layers of iron and borated (6%) polyethylene, overall radius <0.9 m.

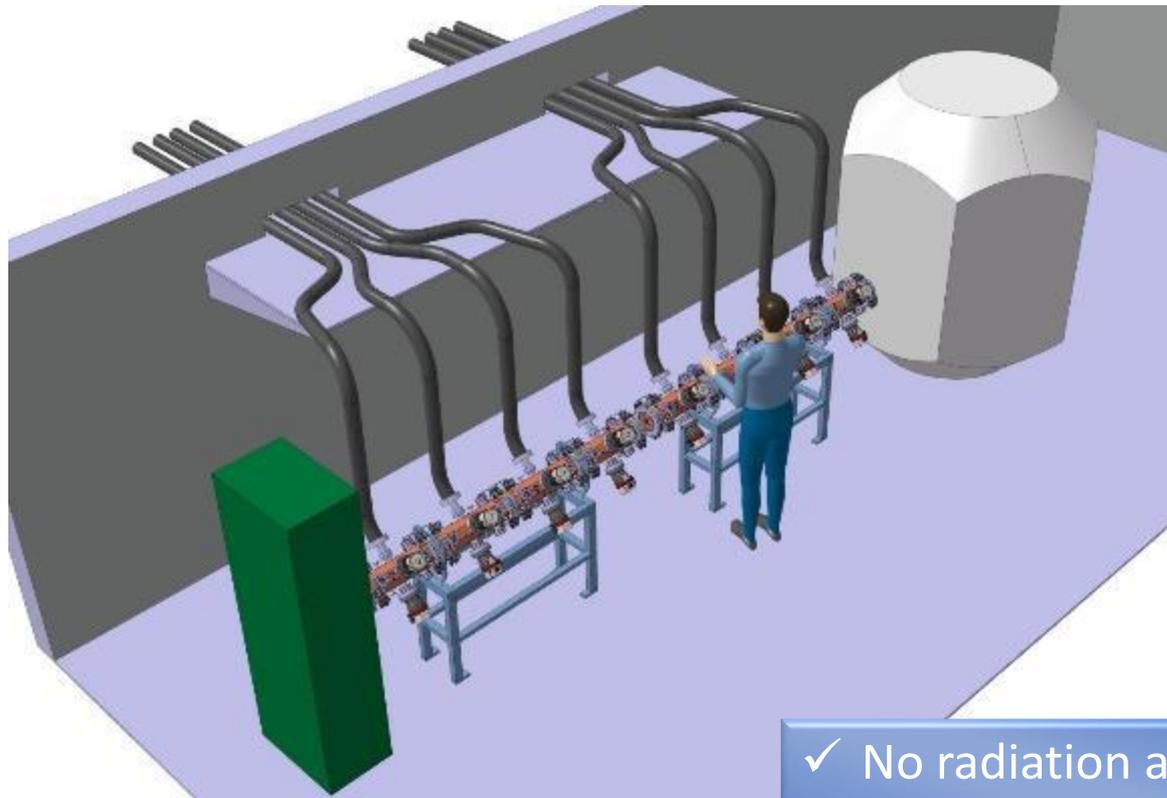
Maximum calculated dose at shielding  $2 \mu\text{Sv/h}$

Weight: 400 kg total (2 RFQs)





# Parameters for compact isotope RFQ system



2 RFQs

Input energy = 40 KeV

Total Length = 4.0 m

Output Energy = 10 MeV

Frequency 750 MHz

Average current = 20  $\mu$ A

Peak current = 500  $\mu$ A

Duty cycle = 4 %

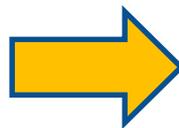
Peak RF power < 800 kW

Total weight (RFQ): 500 kg

Mains power < 65 kW

Cooling ~ 100 l/min

Production for PET  
scans of  $^{18}\text{F}$  and  $^{11}\text{C}$



- ✓ No radiation around accelerator and target.
- ✓ Easy operation (one button machine).
- ✓ High reliability
- ✓ Minimum footprint (15 m<sup>2</sup>)



# Ion beam analysis



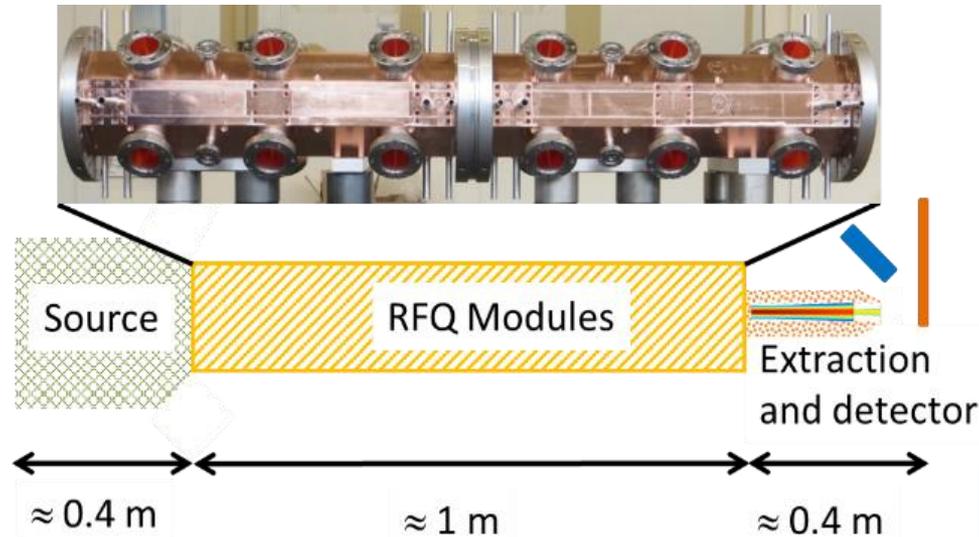
A small **portable accelerator** delivering 3 MeV protons equipped with a PIXE detector (Proton Induced X-ray Emission), used for non-destructive in-situ analysis in the domains of:

- Archeometry (surface composition of cultural artefacts: paintings, jewellery, etc.)
- Liquids & aerosols analysis
- Continuous quality control in industry (Metallurgy, thin films, ...)

Ion Beam Analysis is presently performed with large electrostatic accelerators based in research centres. An RFQ-based portable accelerator could be installed in small museums or for artefacts that cannot be displaced.



Stained glass panel analysed by PIXE/PIGE/RBS with 3-MeV protons



Energy	3 MeV
Length	1 m
Peak current	100 $\mu$ A
Duty cycle	1 %
Average current	1 $\mu$ A
RF power, average	2 kW

3 MeV - Length 1 m  
Weight 100-150 kg  
(+ 2 or 3 racks for the RF system)

Starting a collaboration with INFN (Florence)



# Ion Beam Analysis of Cultural Heritage with a portable RFQ





## Ions with $q/m = 1/2$



The RFQ modulation can be designed for the acceleration of **charge-to-mass  $\frac{1}{2}$  ions** for 3 fields of application:

- Acceleration of **alpha particles** for **advanced brachytherapy** (local irradiation by an alpha emitter on the tumour). Techniques considered to be the new frontier of nuclear medicine; large scale production will require dedicated linacs.
- Acceleration of **fully stripped Carbon ions** ( $C^{6+}$ ) to inject in an advanced (linac or synchrotron) accelerator for **Carbon ion therapy**. Only carbon ions can treat radio-resistant tumours.
- Acceleration of **deuterons** for **neutron production**, with a wide range of applications in several fields.



# 5. L'acceleratore in miniatura: dal sogno alla realtà?

# CERN Bulletin

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Issue No. 26-27/2015 - Monday 22 June 2015

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The miniature accelerator 

Report from Council

LHC Report: Start of intensity ramp-up before a short breather

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Working towards coordination of detector development in Europe

Ribbon-cutting ceremony for Building 774

CAS Accelerators for Medical Applications in Vösendorf, Austria

Gold Rush in Mol at the 15th ASCERI Atomiade

Excellent results for CERN runners

Computer Security: "New\_invoice.zip"

Michele Ferro-Luzzi (1938-2015)

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## THE MINIATURE ACCELERATOR

The image that most people have of CERN is of its enormous accelerators and their capacity to accelerate particles to extremely high energies. But thanks to some cutting-edge studies on beam dynamics and radiofrequency technology, along with innovative construction techniques, teams at CERN have now created the first module of a brand-new accelerator, which will be just 2 metres long. The potential uses of this miniature accelerator will include deployment in hospitals for the production of medical isotopes and the treatment of cancer. It's a real David-and-Goliath story.



*Serge Mathot, in charge of the construction of the "mini-RFQ", pictured with the first of the four modules that will make up the miniature accelerator.*

The miniature accelerator consists of a radiofrequency quadrupole (RFQ), a component found at the start of all proton accelerator chains around the world, from the smallest to the largest. The LHC is designed to produce very high-intensity beams at a very high energy, but its little brother is content to produce beams at low speeds, containing particles which, after travelling two metres, have an energy of 5 MeV. "When we took up the challenge of creating the first high-frequency compact RFQ accelerator, with the support of the



# Spreading over the internet...



Since a first article on this activity was published on the CERN Bulletin in June, the information has been retweeted more than 1'000 times and reported by dozens of on-line science journals and blogs...



Science Health

## Cern developing 'mini LHC' particle accelerator to treat cancer

By Hannah Osborne  
August 3, 2015 18:04 BST



Serge Mathot, in charge of the construction of the mini-IFQ, pictured with the first of the four modules that will make up

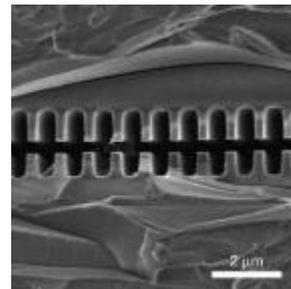
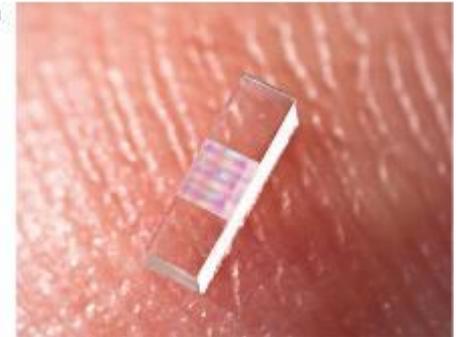
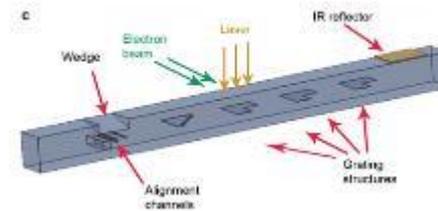
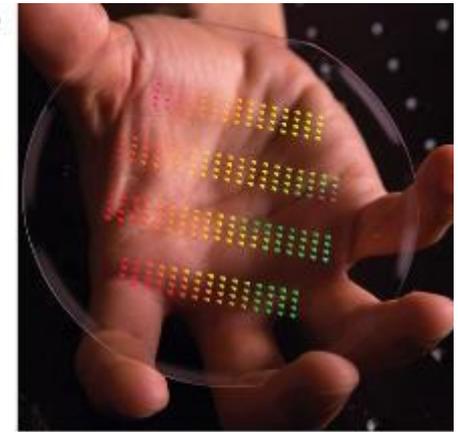
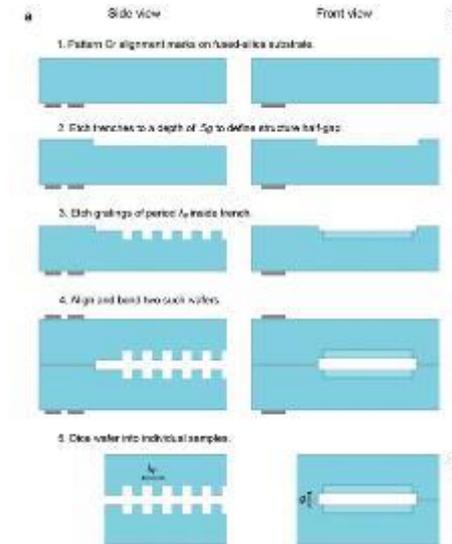




# Other roads to the miniature accelerator



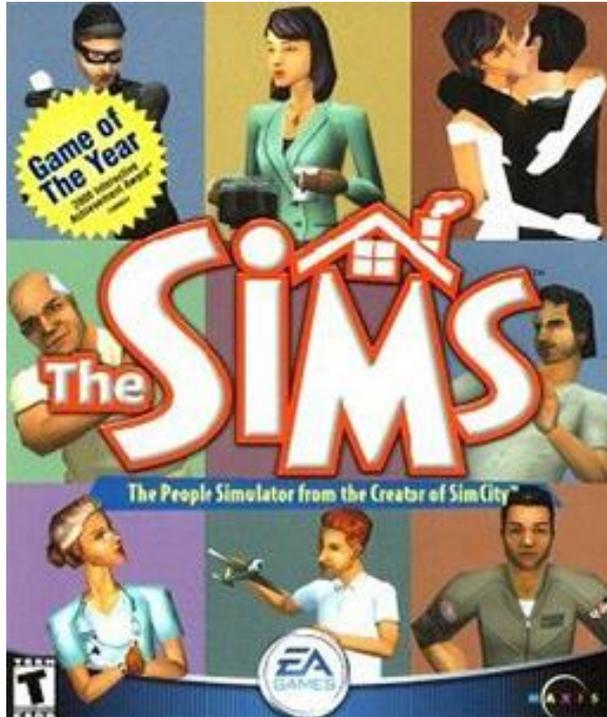
AMIT superconducting cyclotron  
(CIEMAT, Spain, with CERN contribution)



Dielectric Laser Accelerator,  
electrons (Stanford)



# The miniature accelerator in the virtual world





**Grazie per la vostra  
attenzione**

**[Maurizio.Vretenar@cern.ch](mailto:Maurizio.Vretenar@cern.ch)**