WP12.1 - A Strategy for Implementing Novel Societal Applications of Accelerators

Objectives

- **Task 12.1: A Strategy for Implementing Novel Societal Applications of Accelerators**
  - Study some new and important societal applications of accelerators with the aim of developing roadmaps for their innovation: novel forms of radiotherapy for cancer treatment, reduction of environmental pollution, new imaging techniques, improved methods for radioisotope production.

  - Develop a strategy to deliver these roadmaps.

  - Study the barriers which discourage the use of accelerators in industry.

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12.1 Sub-Tasks

- Sub-task 1. Coordination and Communication

  (Rob Edgecock - HUD)
- Sub-task 2. Novel forms of radiotherapy

  (Angeles Faus-Golfe - CNRS)
- Sub-task 3. Environmental applications of electron beams

  (Toms Torims – RTU
  Andrzej Chmielewski - INCT)
- Sub-task 4. Accelerator imaging

  (Graeme Burt - ULANCS)
- Sub-task 5. Accelerator production of radioisotopes for imaging and therapy

  (Conchi Oliver – CIEMAT
  Diego Obradors-Campos)
- Sub-task 6. Barriers to accelerator adoption by industry

  (Andrzej Chmielewski – INCT
  Andrea Sagatova – STU)

Coordination

- **Main change:**

  Deputy coordinator: Andrea Sagatova

12.1 Deliverable and Milestones

D12.1	Strategy for Implementing Novel Societal Applications of Accelerators	HUD	R	M28

MS57	Projects identification for development funding	12.1	M10	Abstract of proposals
MS58	Completion of strategy documents for each application area	12.1	M40	Report

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12.1 Mini-milestones

MS	Description	Lead		Type
3.1	Selection of environmental topics to focus on, taking into account Horizon Europe priorities	RTU	M3	Talk
6.1	Plans for task 6.1	INCT	M3	Talk
2.1	Identification of novel RT possibilities and plan for study and selection	CNRS	M4	Talk
3.2	Plans for project studies	RTU	M5	Talk
4.1	Selection of imaging topics to study	ULANCS	M6	Talk
5.1	Identification of requirements for future isotopes and plans for sub-task 5	CIEMAT	M8	Talk
4.2	Plan for imaging topic studies	ULANCS	M8	Talk
2.2	Possible projects for proof of concept funding	CNRS	M9	Abstract
3.3	Possible projects for proof of concept funding	RTU	M9	Abstract
4.3	Possible projects for proof of concept funding	ULANCS	M9	Abstract
5.2	Possible projects for proof of concept funding	CIEMAT	M9	Abstract
6.2	Possible projects for proof of concept funding?	INCT	M9	Abstract
1.1	Selection of projects for POC proposals	HUD	M10	List
MS57	**Projects identification for development funding**	**HUD**	**M10**	**Report**
1.2	**Task 12.1 Annual Meeting**	**HUD**	**M12**	
6.3	Factors reducing the use of accelerators by industry	INCT	M12	Talk
3.4	Strategy for delivering environmental applications	RTU	M16	Report
6.4	Recent examples of companies using accelerators	INCT	M20	Talk
2.3	Selection of most promising novel RT modalities	CNRS	M24	Talk
1.3	**Task 12.1 Annual Meeting**	**HUD**	**M24**	
3.5	Roadmaps for delivering environmental applications	RTU	M26	Report
D12.1	**Strategy for Implementing Novel Societal Applications of Accelerators**	**HUD**	**M28**	**Report**
4.4	Strategy for delivering imaging applications	ULANCS	M32	Report
2.4	Strategy for delivering promising novel RT	CNRS	M36	Report
1.4	**Task 12.1 Annual Meeting**	**HUD**	**M36**	
5.3	Strategy for delivering novel radioisotopes	CIEMAT	M38	Report
6.5	Possible solutions to problems	INCT	M40	Report
MS58	**Strategy for Implementing Novel Societal Applications of Accelerators**	**HUD**	**M40**	**Report**
2.5	Roadmap for delivering novel RT	CNRS	M42	Report
4.5	Roadmap for delivering imaging applications	ULANCS	M44	Report
5.4	Roadmap for delivering novel radioisotopes	CIEMAT	M46	Report
1.5	**Task 12.1 Final Report**	**HUD**	**M48**	**Report**
1.6	**Task 12.1 Annual Meeting**	**HUD**	**M48**	

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Task 12.1 - Sub-Task 6: Barriers to accelerator adoption by industry / M1 – M48 (INCT, STU)

Done:

Study on technological, financial and knowledge barriers:

Barriers identified:

- The technologies that are in principle feasible and proven from research accelerators on laboratory scale must be available at reasonable cost before they can be used in machines for industrial and societal applications.
- Absence of in-house specialized and auxiliary facilities and equipment for accelerator service and maintenance.
- Absence of in-house accelerator experts and staff for accelerator operation, service and maintenance.

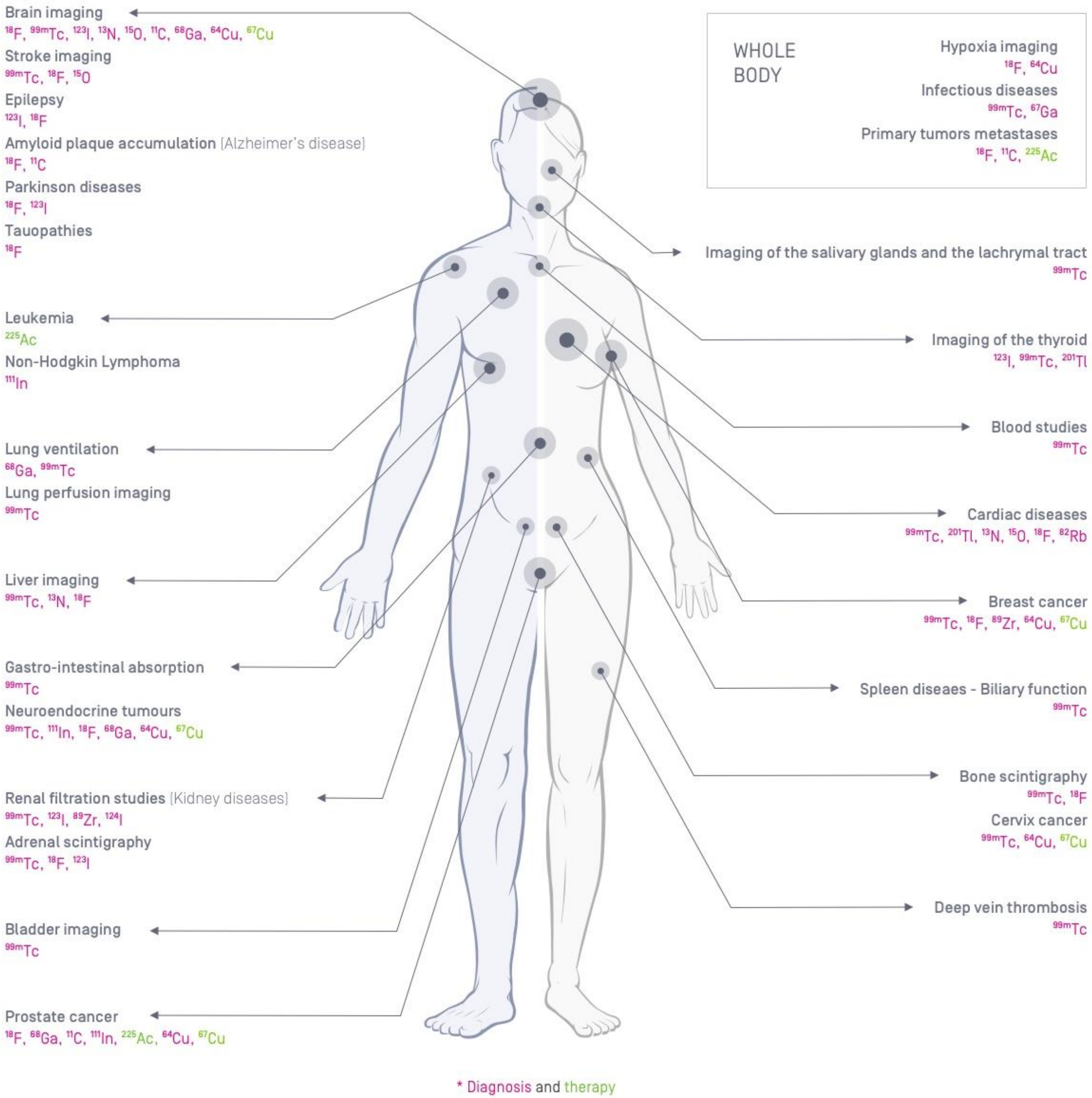
Solution:

- Offering machines which are reliable, reproducible, simply operable, compact & cost-effective.
- Development of the remote customer-support technologies to increase efficiency.
- Introduction of dedicated educational schemes and study programs bringing accelerator experts and IT engineers together.

Plans for future:

- Study on legislative and security barriers.
- Case study on PCB decontamination in oil and in the environment

Task12.1.5: Diagnostics tracers & Radiotherapeutics



Current radioisotopes

- **Diagnostic radiopharmaceuticals:**
  Diagnostic procedures for identifying the presence and extent of malignancy.

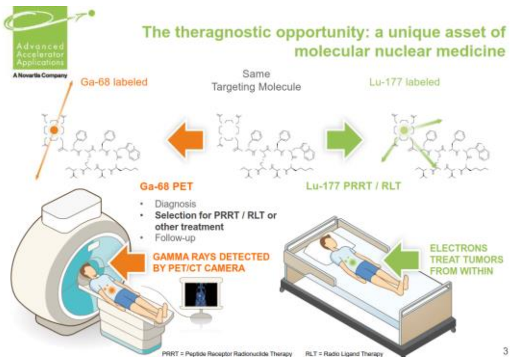
- **Therapeutic radiopharmaceuticals:**
  Treat numerous cancers and other diseases. The radioactive agent delivers radiation specifically targeted cancer cells, with a minimal effect oh healthy cells.

- **Theranostics :**
  Integration of diagnosis and therapeutics. Molecular imaging and diagnosis can be followed by personal treatment utilizing the same targeting molecules.

If you can see it you can treat it

Task12.1.5: Summary of state of art

- Progress in nuclear medicine tightly linked to the development of the new radiopharmaceuticals and efficient production of relevant radioisotopes.
- Impressive progress in the radioisotope production technologies owing to the introduction of high-energy and high-current cyclotrons and the growing interest in the use of linear accelerators for radioisotope production.
- Access to several radionuclides, including gallium-68, copper- 64 and zirconium-89. Development of high power electron accelerators resulted in availability of theragnostics beta emitters such as scandium-47 and copper-67.
- Scientists and professional working in nuclear medicine has given special attention to α-emitting radionuclides as astatine-211, bismuth-212, bismuth-213, actinium-225, radium-223, lead-212, thorium-227 and terbium-149.
- Milestones in RI field: Development of technetium-99m radiopharmaceuticals, automated synthesis of fluorine-18 labelled compounds, radiopharmaceuticals labelled with gallium-68, labelled peptides and monoclonal antibodies for accurate diagnostics and treatment tumours. Biomolecules development for specific molecular target and labelled with theragnostic radionuclides provide significant information for diagnosis, therapy, dosimetry and post therapy planning making personalised medicine.



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Task12.1.5: Activities carried out

- ❑ Regular monitoring and continuous analyses of the radiopharmaceutical market and needs, identifying new developments and trends.
- ❑ Attendance at the following seminars and meetings:

  - *State of art of Positron Emission Tomography (PET) technology and current challenges*. Maurizion Conti, (director, PETPhysics and Reconstruction, Siemens Healtineers). 06-09-2021.

  - 2021 Isotope User meeting managed by U.S. Department of Energy Isotope Program focused in four sessions of the the following emerging alpha and beta emitters:

    - Actinium-225
    - Astatine-221
    - Lead-212
    - Copper-67.

Task12.1.5: Next steps

- Establish collaborations with scientists and professionals working in the field of production of radioisotopes and radiopharmaceuticals to address common problems. Feedback from users, clinicians, etc.

- Continuous market research/analysis to get a view of an important points related to the emerging radioisotopes, trends, and identify synergies with respect to the demand of these radionuclides and accelerator technology that will require innovations to reduce cost and increase the capability of production methods in a efficient manner.

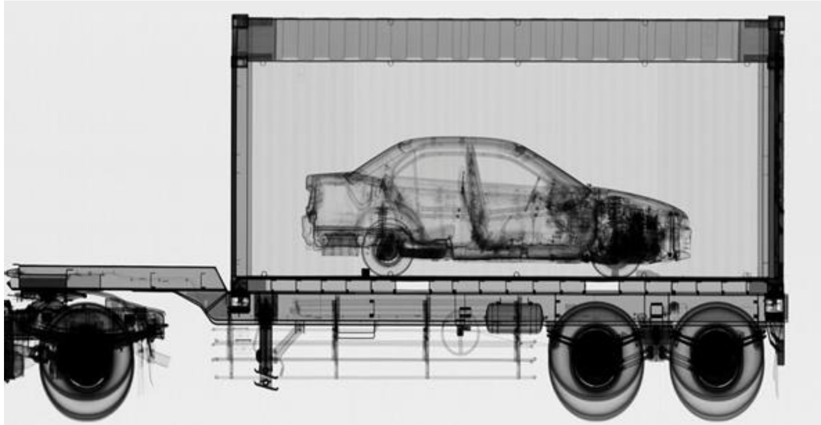
- Webinar / Workshop / (funding dependency) : ***Radiopharmaceutical market and future trends***. To provide scientists and professionals working in the fields of production of radioisotopes and radiopharmaceuticals an international forum for discussing the most recent developments in the field. Several topics could be covered including development, production, and uses of diagnostic, therapeutic and theragnostic radioisotopes as well as issues related to their production.

Sub-task 4: Accelerator imaging (ULANCS):

- This sub-task will explore innovation in the use of particle beams for imaging, in particular in the security and medical areas. The applications to be studied are:
- 4.1 X-ray cargo scanning and non-destructive testing (ULANCS, RPS, NCBJ)
- 4.2 Ion beam analysis (DYN, CERN, Liverpool)
- 4.3 Medical imaging (ULANCS)
- 4.4 Compact Compton sources (TUE, STFC)

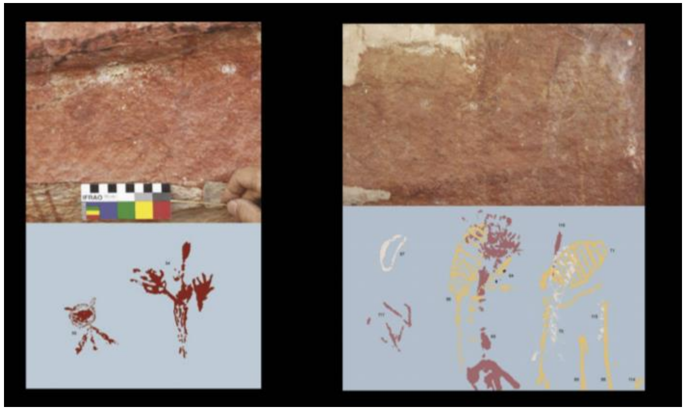
X-ray cargo scanning and non-destructive testing

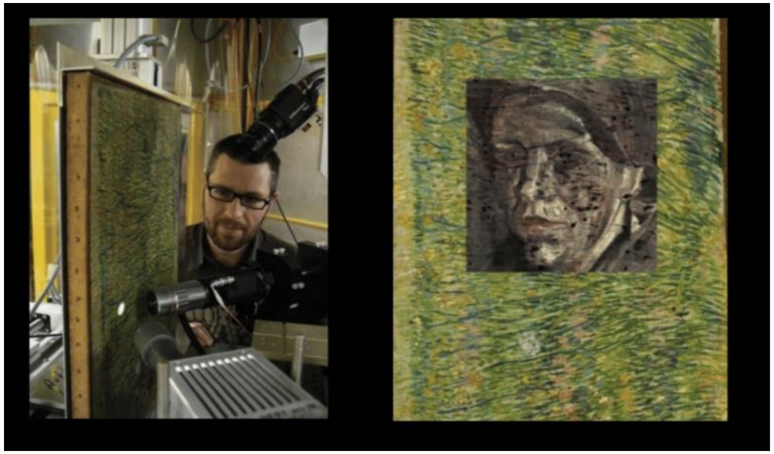
- Existing field with key industrial players
- Based on brem. Sources of X-rays and emerging neutron sources
- What are the advances that will shape that market in the next few years?
- Is there any disruptive technologies?
- Are their challenges without solutions?
- Are their better ways of addressing the special nuclear material and nuclear resonance florescence applications?
- Will compact muon sources shrink enough to find an application.



Ion beam analysis for cultural heritage

- New compact RFQ-based ion sources have been developed and are being developed for applications
- What applications are their that this technology can target?
  - Rock art?
  - Paintings and statues
- Can the technology be improved?





Graeme Burt

Medical imaging

- Proton radiography
  - Full body imaging needs 350 MeV, can this be addressed without a separate machine?
  - What other accelerator medical imaging applications should we consider? MeV photon CT?
- Plasma based X-ray imaging
  - Plasma technology offers compact coherent X-ray sources which higher resolution than current X-rayt scanners?
  - What is needed to break this technology through to the market
- Prompt Gamma
  - Range verification technology in radiotherapy

Compact Compton sources

- Development of high brightness sources for Compton imaging
- How compact can these accelerators be
- Is scaling to high current possible (with an ERL)?
- What are the applications/market for these devices
- Can a user case be made for a facility?

ST3 Feasibility study for eb processing facility

INSTITUTE OF NUCLEAR CHEMISTRY AND TECHNOLOGY

ELABORATION

AUTHOR: ZBIGNIEW ZIMEK
TITLE: Upgraded pre-feasibility study of setting up an electron beam facility
Project / agreement / (*title and number*): Logstor order nr 4501015736
Completed on October, 2021
Division: Centre for Radiation Research and Technology, INCT

ELABORATED BY	CHECKED	APPROVED
Dr. Zbigniew Zimek Head of Center for Radiation Research and Technology, INCT	Prof. H.Lewandowska-Siwkiewcz Head of Polimer Lab Center for Radiation Research and Technology, INCT	Prof. A.G.Chmielewski Director of the Instytute of Nuclear Chemistry and Technology
Date and signature: 15.10.2021	Date and signature: 26.10.2021	Date and signature: 27.10.2021 Dyrektor Instytutu Chemii i Techniki Jądrowej prof. dr hab. inż. Andrzej G. Chmielewski

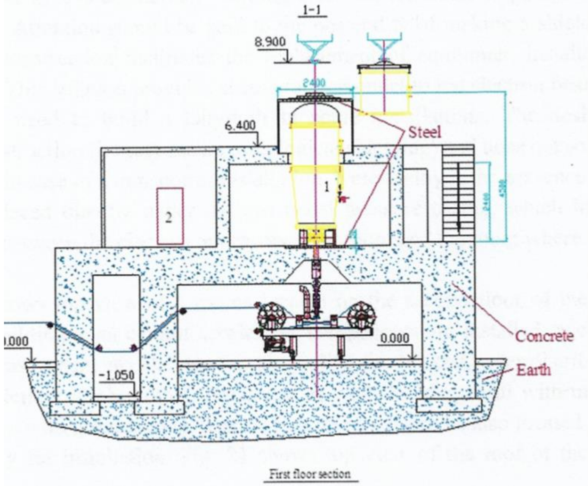
Attachment No 1.

Radiation technologies, requirements, potential market, adaptation to primary process conditions

Zbigniew Zimek
INCT

Content

Warsaw, October 2021



- Prepared and submitted to EU projects related to electron accelerator research and applications

Horizon Europe

THE NEXT EU RESEARCH & INNOVATION PROGRAMME (2021 – 2027)

European Commission

- **Call: HORIZON-EURATOM-2021-NRT-01** (Nuclear Research and Training)
- **Topic: HORIZON-EURATOM-2021-NRT-01-11: Cross-sectoral synergies and new applications of nuclear technologies**
- **Type of Action: EURATOM-IA**
- **Proposal number: 101061694**
- **Proposal acronym: RADOV**
- **Proposal title: RADiation harvesting of bioactive peptides from egg prOteins and their integration in adVanced functional products**
- **Abstract:** RADOV moves from the well-established radiation process applications in food irradiation for disinfection and shelf-life increase, and from several decades of fundamental studies of the biological effects of radiation in vivo, to explore completely new routes for the production of bioactive peptides from egg proteins based on radiation-induced fragmentation, and new product prototypes that incorporate egg protein-derived peptides. High energy radiation from electron accelerators will be used to produce peptides and the collection of the results acquired regarding the peptide structure, irradiation conditions, and related bioactivity properties will be one vital output of the project. To expand the application of ionizing radiation and to demonstrate the broad scope of its applications, new products containing bioactive proteins/peptides will be designed and developed with the use of electron beam irradiation to manufacture them. In particular, two target products will be developed as demonstrators of egg-derived AMPs by radiation-induced fragmentation: peptide-laden antimicrobial/antioxidant hydrogel wound dressings and peptide-grafted active food packaging film.

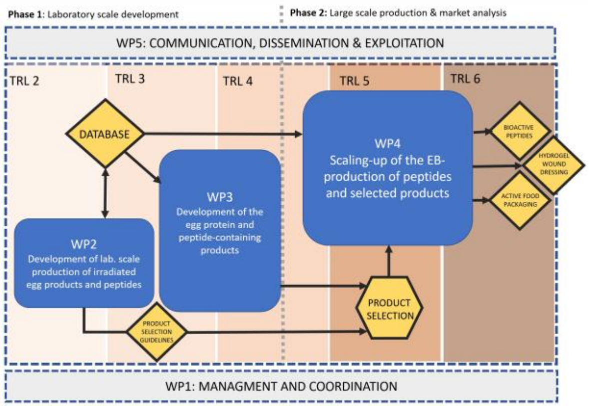
- **Submission date:** 07.10.2021
- **Duration:** 48 months
- **Total budget:** 2 136 893.00 €
- **Participants:**

6 scientific institutions:

- Institute of Nuclear Chemistry and Technology (Poland) –**Coordinator**
- KTH Royal Institute of Technology (Sweden)
- University of Palermo (Italy)
- Italian National Research Council (Italy)
- University of Huddersfield (UK)
- The Association of Instituto Superior Técnico for Research and Development (Portugal)

3 industrial partners:

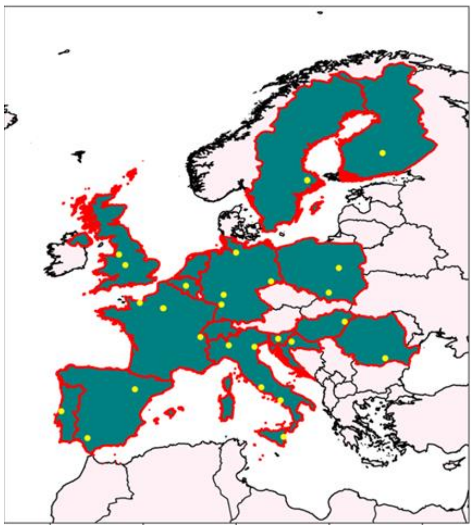
- KIKGEL Sp. z o.o. (Poland)
- DEKOFILM POLSKA SP. Z O.O. (Poland)
- E.P.S. S.p.A. Egg Powder Specialists (Italy)



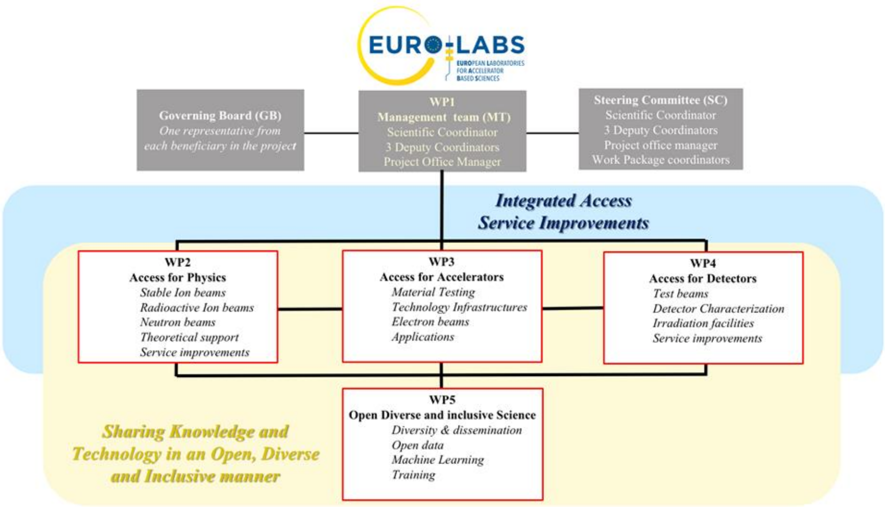
RADOV project structure

- **Call: Research infrastructure services to support health research, accelerate the green and digital transformation, and advance frontier knowledge HORIZON-INFRA-2021-SERV-01**
- **Type of Action: HORIZON-RIA HORIZON Research and Innovation Actions**
- **Proposal acronym: EURO-LABS**
- **Proposal title: EUROPEAN LABORATORIES FOR ACCELERATOR BASED SCIENCE**
- **Abstract:** This proposal responds to the call for Research Infrastructure (RI) services advancing frontier knowledge and is driven by the European strategy for Nuclear Physics (NP) and High-Energy Physics (HEP). The goal is to provide transnational access to a major fraction of the state-of-the-art EUROpean Laboratories for Accelerator Based Sciences (**EURO-LABS**), part of a network of leading laboratories across Europe, to users for conducting state-of-art-research. This access will enable research at the technological frontiers in accelerator and detector development and for exploring new physics ideas. It will also complement a focused project-driven approach, thus bringing together the three extended communities engaged in nuclear physics, and accelerator and HEP detector technology.

- **Submission date:** 23.09.2021
- **Duration:** 48 months
- **Total budget:** ~15 000 000.00 €
- **Coordinatior:** Istituto Nazionale di Fisica Nucleare (INFN) (Italy)
- **34** participating organizations
- **INCT** – leader of task “Applications” in WP 3.



Map of research infrastructure involved in EURO-LABS



EURO-LABS project structure

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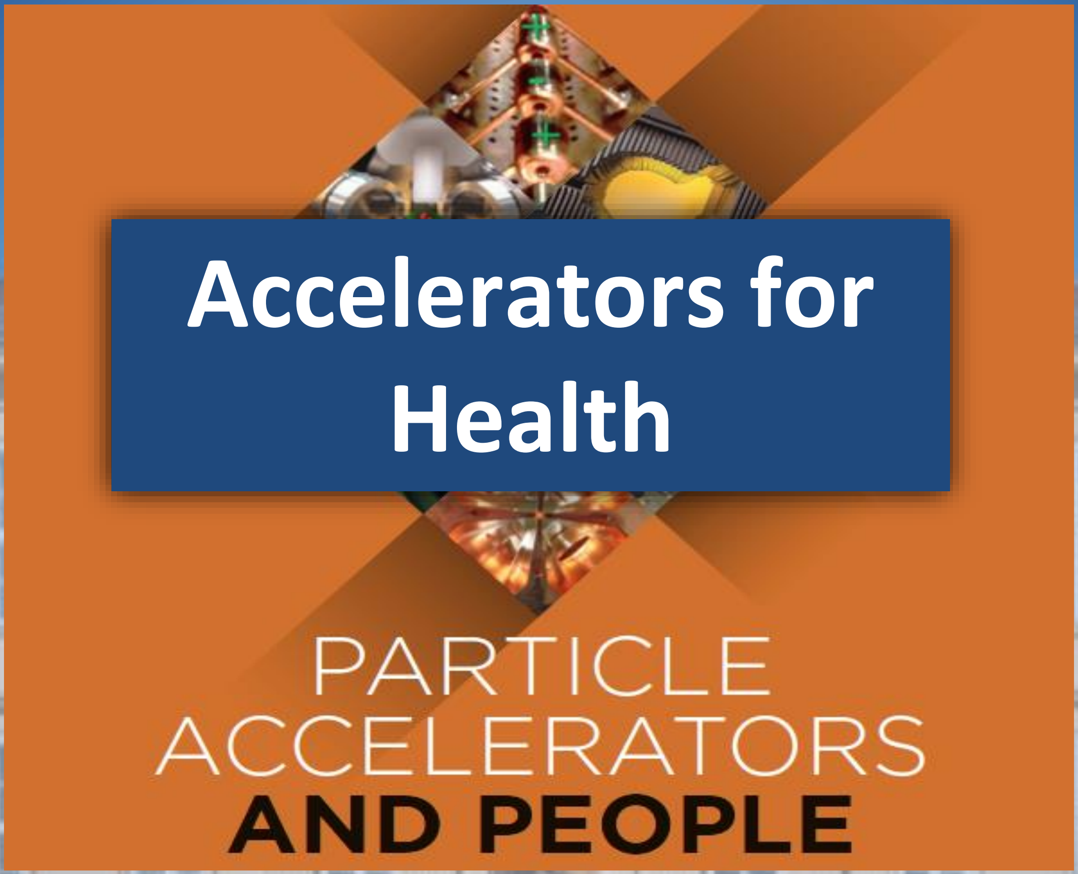
Accelerators for Health



From Current to Dream machines

Dr. A. Faus-Golfe

SCRF CEA

FFAG -EMMA

plasma cell - EuPRAXIA

terahertz accelerator module DESY

DEVELOPMENTS IN ACCELERATOR TECHNOLOGY

Current applications, especially in HEALTH and INDUSTRY, tend to use rather OLD TECHNOLOGY, and their performance, especially for newer applications, can be LIMITED by this. Much research is now going into developing more EFFICIENT, better PERFORMING and more COMPACT machines exploiting NEW APPROACHES to particle acceleration.

- **SUPERCONDUCTING (SC) magnets and RF cavities after 30 years of use in research start to be exploited in the commercial manufacture of accelerators.**
- **NEW COMPACT ACCELERATOR CONFIGURATIONS**
  - **Fixed Field Alternating Gradient Accelerator (FFAG).**
  - **Linear accelerator (linac).**
  - **Laser plasma acceleration (LPAs)** (100 GeV/m).
  - **Terahertz acceleration** (400 GHz with 1.5 cm long, 1mm wide).

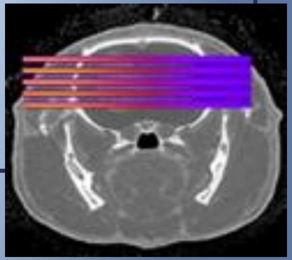
CHALLENGES IN RADIOTHERAPY

New RT approaches

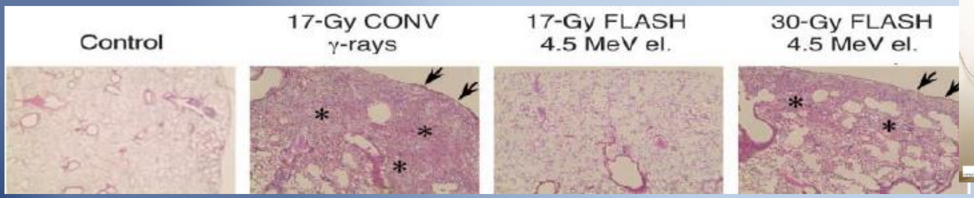
- ***RT treatment of some radio resistant tumours, pediatric cancers and tumours close to a delicate structure (i.e. spinal cord) is currently limited***
- **One of the main challenges is to find approaches to increase the normal tissue resistance**
- **Standard RT is restricted to the few temporal and spatial schemes, dose rates, broad field sizes: mainly photons, 2 Gy/session, 1 session/day, 5 days/week, dose rates ~ 2 Gy/min, field sizes > cm^2, homogeneous dose distributions**

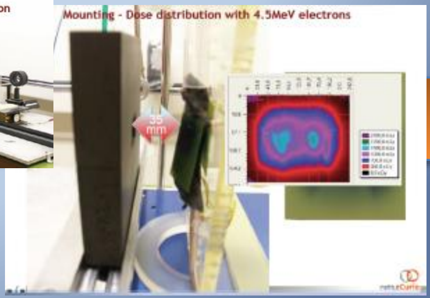
- ***Possible strategies to spare normal tissue***
- **Different dose delivery methods: Grid Mini-beam or FLASH RT**
- **Different particle types: Very High Energy Electrons (VHEE)**

Mini-beams



FLASH RT

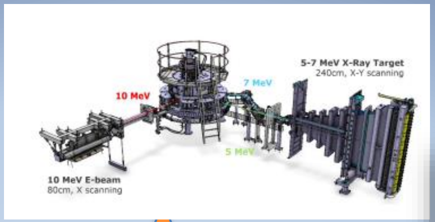




FLASH spares lung at doses known to induce fibrosis in mice following conventional dose-rate irradiation (CONV).

VHEE-FLASH R&D Operating Facilities

CLEAR CERN

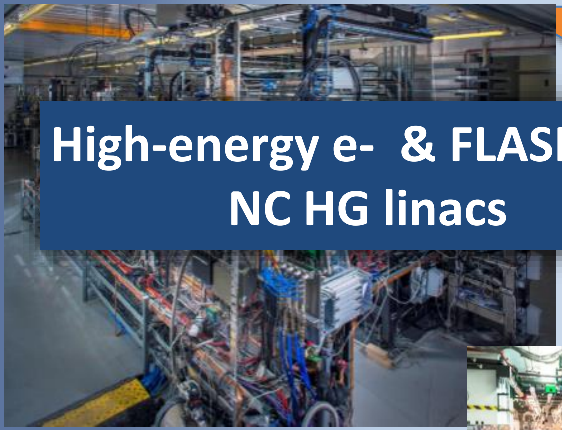


FEERIX/ AERIAL

Low-energy e- & FLASH
Cyclos & linacs

FLASH IC

ORIATRON CHUV

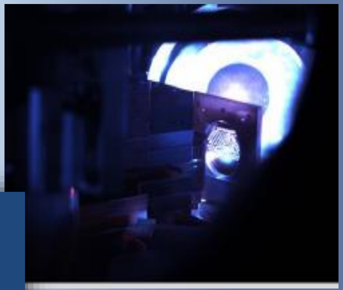


High-energy e- & FLASH
NC HG linacs

CLARA STFC CI

PTB Berlin

AWA Argonne

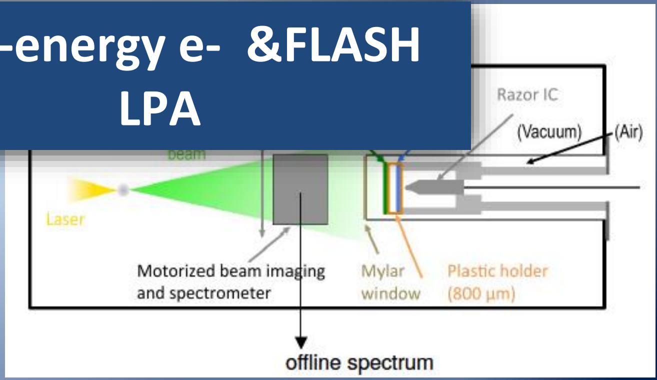


ELBE HZDR

High-energy e- & FLASH
SC linacs

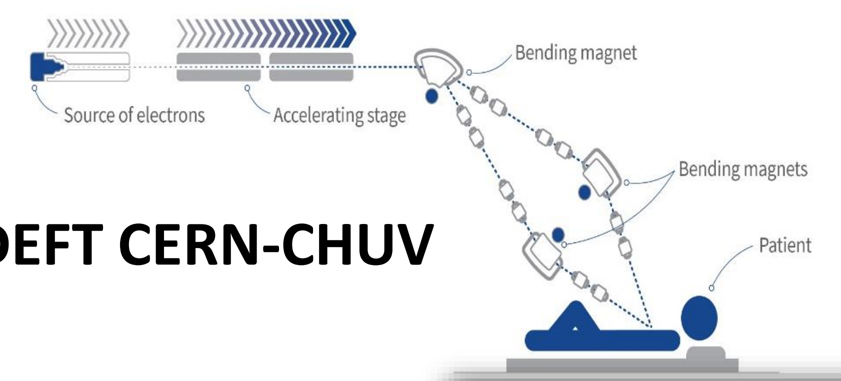
LOA Salle Noire IPP

High-energy e- &FLASH
LPA

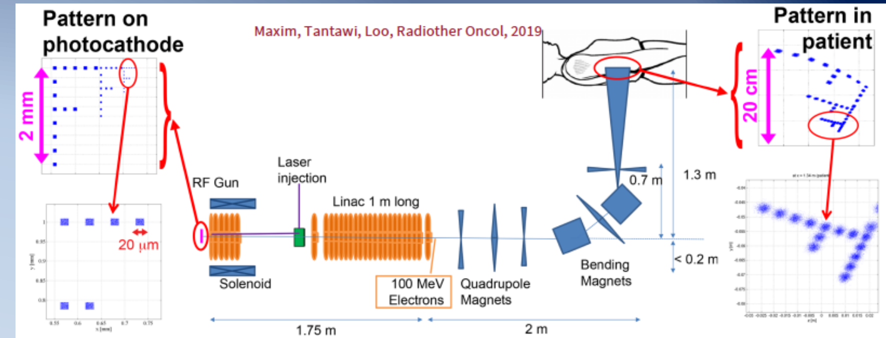


VHEE-FLASH under design Facilities

DEFT CERN-CHUV

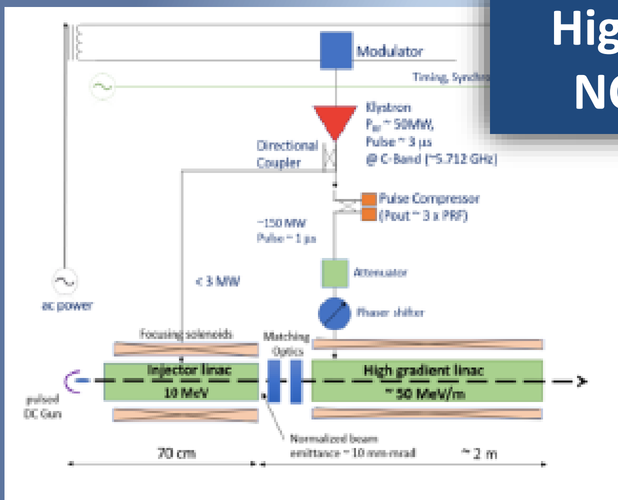


e-beam PHASER SLAC



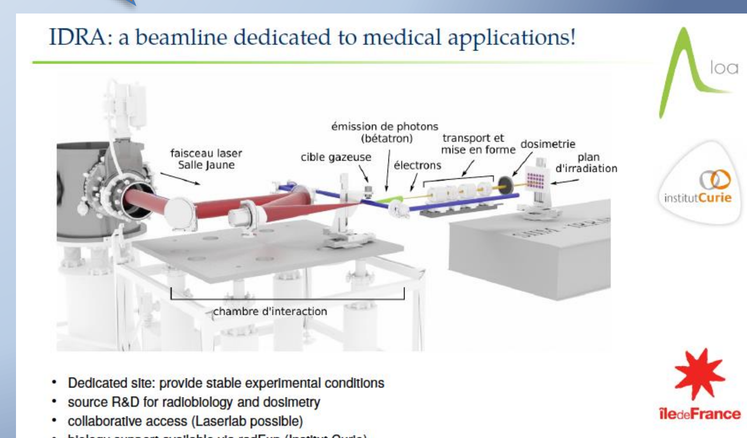
High-energy e- NC HG linacs

FRIDA Sapienza-INFN



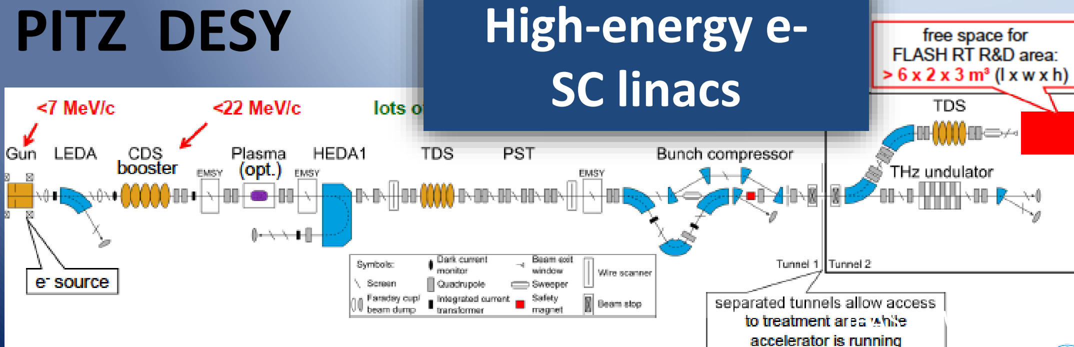
High-energy e- LPA

IDRA LOA IPP



High-energy e- SC linacs

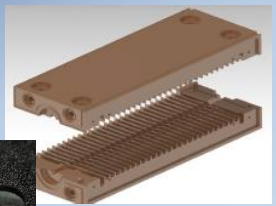
PITZ DESY

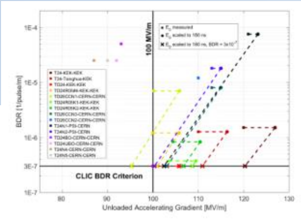


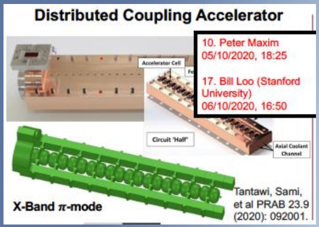
Normal Conducting RF

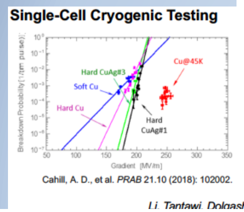
>100 MeV/m is now achievable in labs

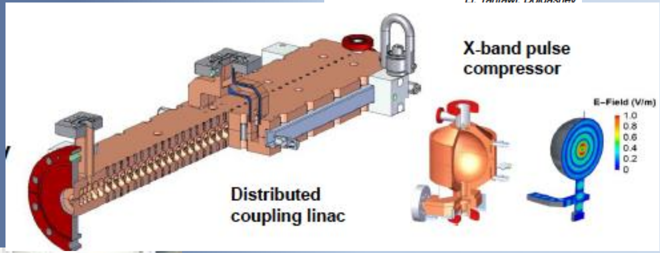
12 GHz RF structure

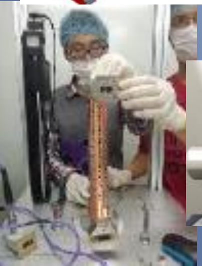




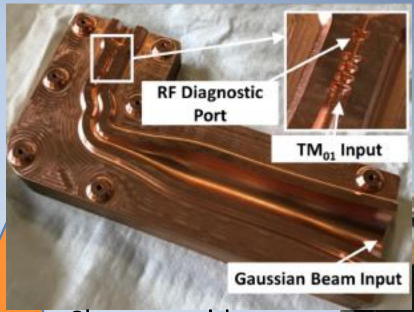


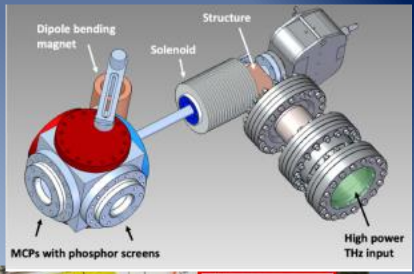




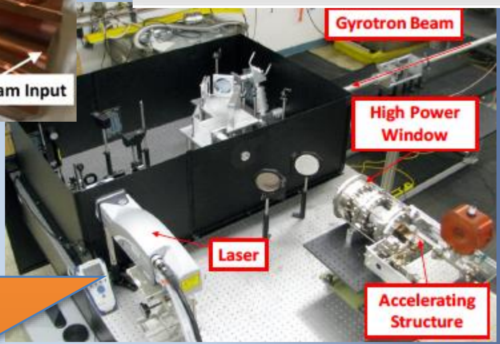


110 GHz RF structure



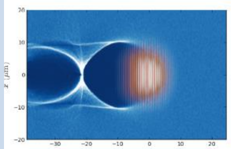


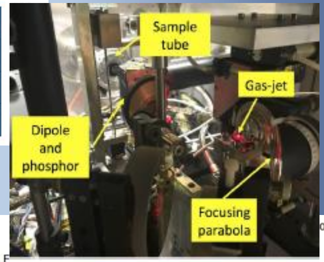
Short tunable pulse length Laser

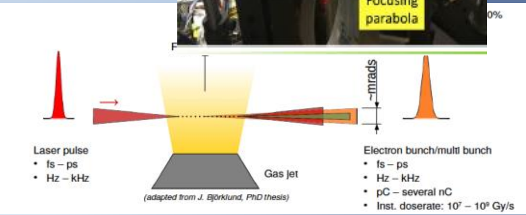


VHEE Technologies

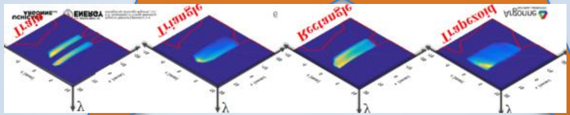
Laser-Driven e⁻

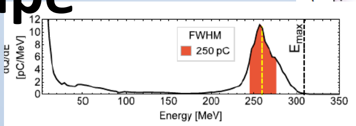


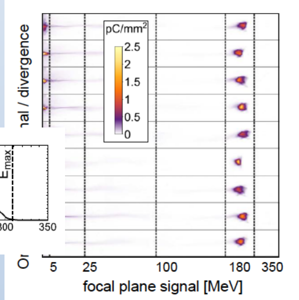




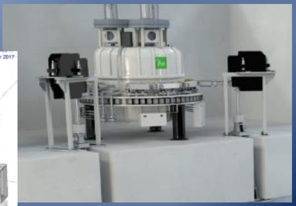
Longitudinal shape





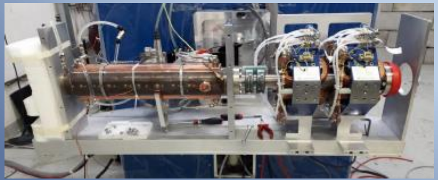


Rhodotrons

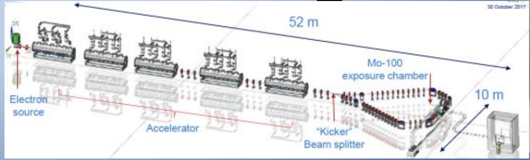


5.712 GHz RF structure

2.998 GHz RF structure



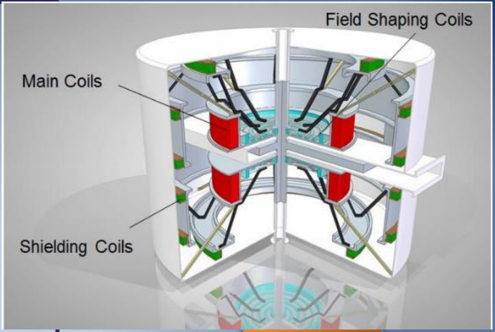
Super Conducting RF



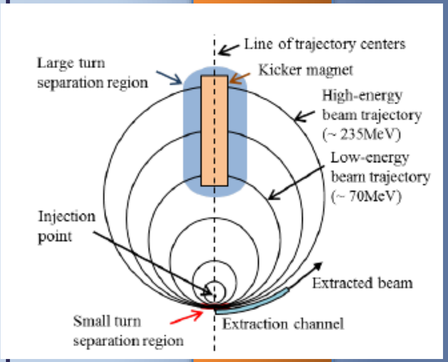
FURTHER DEVELOPMENTS FOR p/IONS

State of the Art

- **Energy-variable cyclotrons: with lighter, high-field SC or iron-free magnets, combined p-^{3}He/^{4}He and FLASH ready.**
- **SC fast ramped synchrotrons: flexible accelerator with high bandwidth of magnet rigidities, use of SC magnets (NIMMS, HITRI+), modern control systems to enhance the duty cycle (Time Sensitive Networking (TSN) HIT-HITRI+), FLASH option?**
- **Linacs options for p/ions: NCRF with high-gradients (20-50 MV/m) and high-frequencies (3 GHz), small average current (1nA p /0.2 nA C), fast active energy variation with a modular approach and electronically controlled (pulse-to-pulse basis), small transverse dimension (large energy acceptance), FLASH ready??**



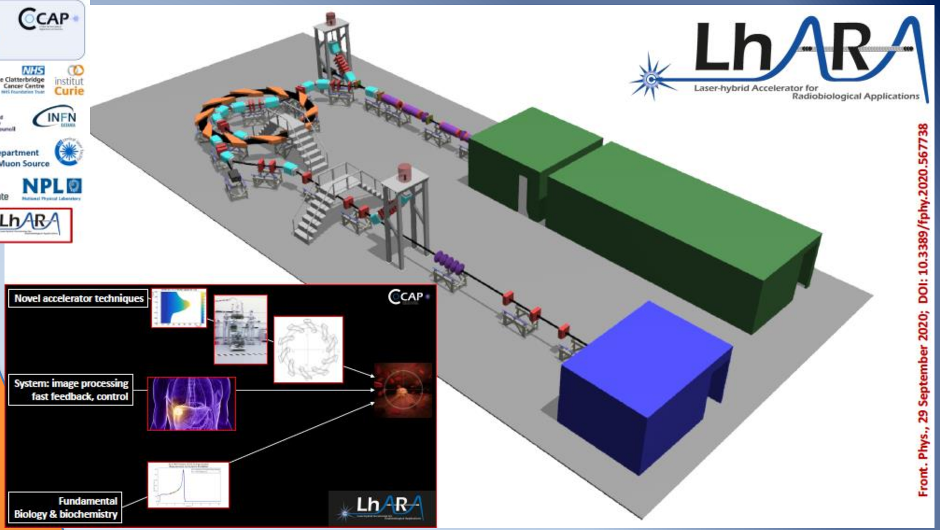
SC-Iron free cyclotron for Hadron therapy (MIT)



New isochronous accelerator concept (Hitachi)

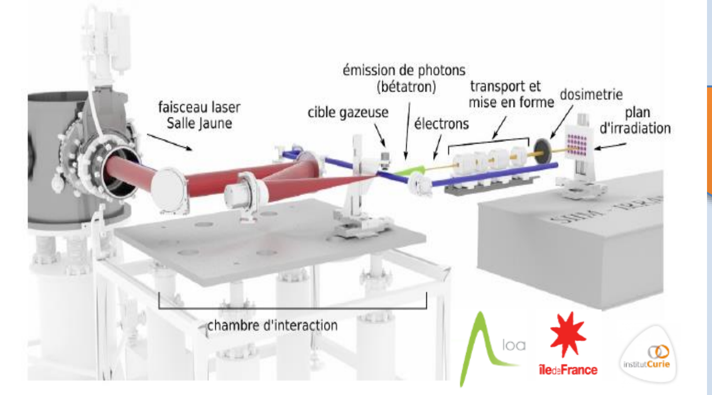
Linac for Image Guided Hadron Therapy (ADAM-AVO)

Laser and laser-target vessel are housed in a shielded bunker. The capture line, composed of three Gabor lenses emerges, from the bunker and guides the p/ions beam to the acceleration system and biological research laboratories.



LhARA: Laser-hybrid Accelerator for Radiobiological Applications

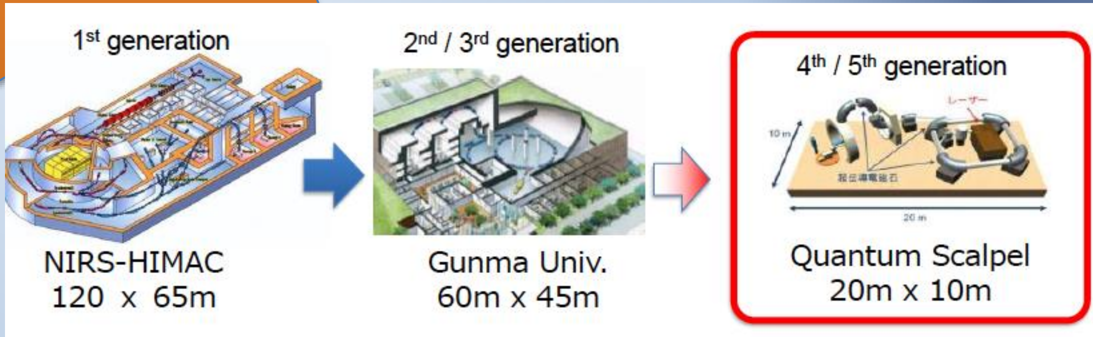
Dream Facilities



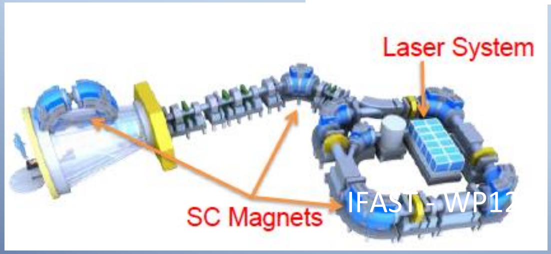
IDRA: a beamline dedicated to medical applications

QST

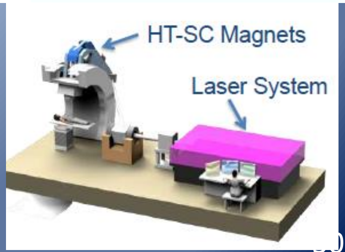
Quantum Scalpel



Quantum Scalpel 1.0: Laser driven ion injector, NbTi-SC Synchrotron, HT-SC Rotating Gantry, Two-room treatment device



Quantum Scalpel 2.0: Laser driven ion accelerator, HT-SC Rotating Gantry,Single-room treatment device



Conclusions

- Task 12.1 has made a good start
- Plans are well-defined and work has started
- First milestone is development fund proposals
- Discussions and preparations have begun
- Proposals for funding have already been submitted to Horizon Europe
- More expected
- Abstracts submitted to IAEA:

  International Conference on Accelerators for Research and Sustainable Development: From Good Practices Towards Socioeconomic Impact

- RE now on iiA Team