Medical applications

- Different types of radiation (X, γ, β, p, heavy ions..)
- Broad energy range (~keV – 100 MeV)
- Application-specific requirements

Making an comprehensive summary is a very difficult task!

First challenge:
Find a way to group the **many ongoing activities** into 3 areas

1) Treatment monitoring and optimisation
P. Cerello

2) Dosimetry, quality assurance and radiotherapy
G. Petringa

3) X-ray and gamma (and β) **imaging**
L. Brombal

Thanks to the Conveners for the review work and to all the contributors!

Imaging applications: challenges and innovation

X-rays

Spectral imaging /Phase contrast

- High spatial resolution
- Spectroscopic capabilities @ high photon rate
- Broad field of view
- Cost-effective

γ-rays

SPECT

- High interaction-efficiency scintillator (for high-energy photons)
- Broad field of view
- Cost-effective

SPECT – treatment dosimetry

- Thin and lightweight
- Rugged
- biocompatible

PET -> Time of Flight (ToF)

- High time resolution
- Broad field of view
- Cost-effective

β radiation

Bio-medical microscopy

- High spatial resolution
- Fast readout
- Broad field of view
- Cost-effective

Radio-guided surgery

- compact
- Hand-held device
- High-sensitivity

Imaging applications: challenges and innovation

Detector	Experiment	Description	Critical item for R&D	Expected time
Timepix4 - hybrid pixel detector	MEDIPIX4-CSN5	4-side buttable large spectroscopic, time resolving imaging detector	Spectroscopic, High spatial and time resolution (ToA), TSV technology	Timepix4 bump-bonded available, TSV 2023
Medipix4 - hybrid pixel detector	MEDIPIX4-CSN5	4-side buttable large, multi-threshold photon-counting imaging detector	Multi-threshold photon-counting High count rate (clinical) TSV technology	Medipix4 2023, TSV 2023
OMHP detector	PEROV	hybrid organic-inorganic semiconductor	Deposition of perovskyte microchannels on CMOS substrate -> scalability	Proposal in preparation Prototype end of 2025
ALPIDE Monolithic Si pixel CMOS	ISOLPHARM	Large area, high resolution beta imager	Scalability for large area	2024
SiPM	FBK – INFN TBD	SiPM coupled to fast LSO scintillator for ToF-PET	TSV for large area scalability	Demonstrator in 2025
aromatic hydrocarbon isomer scintillator ; readout SiPMs array	WIDMapp	Wearable detectors for beta and gamma radiation	Detector engineering beyond prototype ▫ Extended tests on patients	2027
Scintillating crystal of p-terpheynyl	CHIRONE/CHIR2	Beta detector for radioguided surgery	Extended tests in-vivo and on patients	2027

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Dosimetry, Quality Assurance and radiotherapy: challenges and innovation

FLASH-RT

Ultra-high dose rates (> 50 Gy/s)

- On-line absolute and relative dosimetry
- Linearity up to (at least) MGy/s
- High resistance to radiation damage
- High time resolution (hundreds ns or higher)

MICRODOSIMETRY

Better estimation of the Relative Biological Effectiveness (RBE)

- Treatment Planning Software optimization
- Simultaneous dosimetric and microdosimetric characterization of clinical proton/ion beams
- Small size and near tissue equivalence
- No (or low) energy dependence

NEW DEVICES FOR DOSIMETRIC PURPOSES

High accuracy (<2 %) dosimetry of clinical beams

- Dosimetry without perturbing the incoming radiation beam
- On-line proton/ion range measurements (Bragg peak reconstruction)
- Simultaneous dosimetric and microdosimetric characterization of clinical proton/ion beams

Dosimetry, Quality Assurance and radiotherapy

Detector	Experiment	Comment/description	Critical items for R&D	Expected time
Mixed	FRIDA	Calorimeter, scintillators, SiC dosimeters	- Real-time FLASH-RT dosimeters - Absolute dosimetry for FLASH-RT (guidelines and code of practice)	2025
UCD	LEMRAP	Waterproof solid state device (patented by INFN)	- Real-time FLASH-RT dosimeter - Linear response up to 6.5 MGy/s	2025 (actually in the final prototype stage)
DIAMOND I	DIODE	Single crystal diamond detector	- Fast response - Reduction of the experimental uncertainties (e.g. those associated with the detector positioning)	2024
TEPC	MUSICA	Tissue-Equivalent Proportional Counters	- Isotropic response - Implementation of microdosimetry in Italian new BNCT facilities	2025
DIAMOND II	3D-DOSE	Sinthetic diamond (both scCVD and pcCVD)	- Bigger active surface at lower costs with respect to the conventional diamond detectors (potentially pixelated detectors)	2027
A-Si:H	HASPIDE	Hydrogenated Amorphous Silicon Devices	- Deposition of the material as a thin layer of few micrometers (1-10) over many substrates, including flexible ones like Kapton	2024
SiC	PRAGUE/DoT-SiC	Silicon Carbide detectors	- Real-time proton range measurements - Dosimetric/microdosimetric measurements	2023 (actually in the final prototype stage)

Treatment monitoring and optimization: challenges and innovation

Treatment monitoring

Beam monitoring (intensity and direction)

charged particle therapy

- Fast response,
- high counting rate
- Good timing
- Higher sensitivity
- Pile-up reduction
- Radiation hardness

Range verification

charged particle therapy

- Fast response
- in-vivo verification
- dose profile for secondary fragments
- integration with beam monitoring

Treatment optimization

Boron Neutron Capture Therapy

neutron therapy

- in-vivo dosimetry by single photon detection
- SPECT and Compton imaging

Nuclear Fragmentation

charged particle therapy

- large acceptance, high efficiency
- isotope resolution

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Treatment monitoring and optimization

DET	experiment	Comment/ description	Critical items for R&D	Expected time
LGAD	MoveIt	UltraFastSiliconDetector prototype for beam monitoring		Completed
LGAD	EX-FLU	Radiation tolerant Silicon detectors	Radiation resistance	2025
Scintillators	INSIDE	Development and Clinical Validation of an Online Hybrid Range Verification System – PET & Tracker		Completed – ongoing clinical trial
Si pixel + plastic scint.	PAPRICA	Online RVS based on pair production	Detector development	2024
LGAD + Scintillators	I3-PET	Online Hybrid RVS – UFSD & PET		Completed
LGAD + LaBr3 scintillators	MERLINO	Online Hybrid RVS – UFSD & Prompt photons – for the direct measurement of the Bragg curve	Time resolution DAQ rate	2024
T.B.D.	SIG	Design of the Online DDS & RVS for the CNAO Superconducting Ion Gantry	UFSD/LGAD radiation resistance and size Crystal time resolution	2025
I.C.	FRIDA/FlashDC	Online beam monitor for FLASH RT based on air fluorescence	Detector performance & design	2025
CZT scintillators	ENTER-BNCT	Online monitoring for BNCT	Detector development	2024
mixed	FOOT	Measurement of Target fragmentation at Particle Therapy Energies	Magnet – Calorimeter response vs fragment Z – TOF system	2023