



# InGaAs Photodiodes

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On behalf of ARTEMIS/OCA & CAL  
& QPRWG of LISA Consortium



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# Outline

- ▶ InGaAs photodiodes
  - ▶ Structure description
  - ▶ Main applications
- ▶ Laser Interferometer Space Antenna (LISA) mission
  - ▶ Activities on InGaAs photodiodes
- ▶ LISA space environment
  - ▶ R&D on InGaAs radiation hardness

# InGaAs photodiodes

## Structure

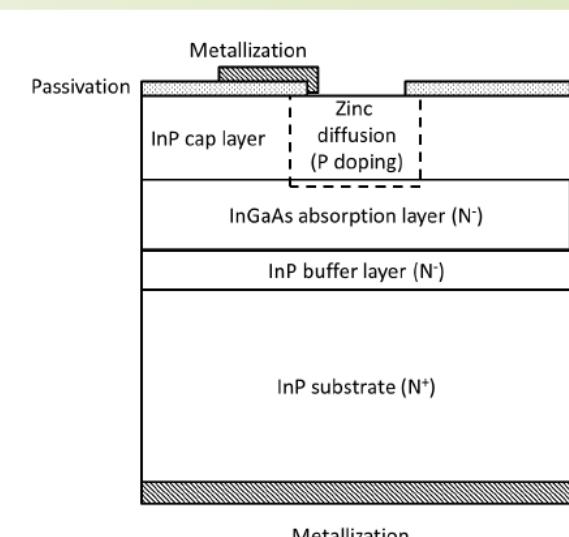
- ▶ n<sup>+</sup> type InP substrate
- ▶ Lightly n-doped InGaAs absorption layer
- ▶ p<sup>+</sup> layer: InP cap layer, doped with p-type Zn

## Ternary alloy InGaAs

- ▶ Low band gap energy of 0.75 eV
- ▶ Well adapted for 800 nm-1700 nm detection

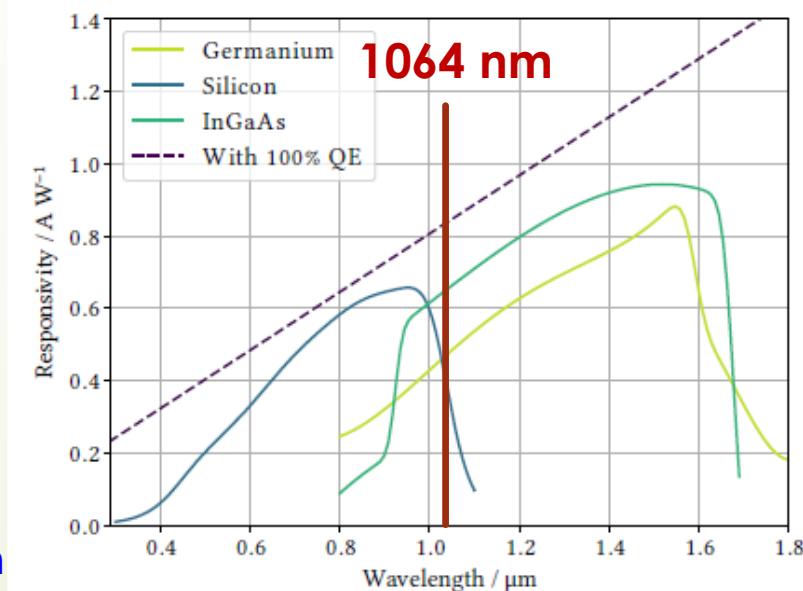
## Applications

- ▶ Laser interferometry (earth and space)
  - ▶ IFO measurements, beam alignment or power monitoring
  - ▶ VIRGO, LIGO, **LISA** & Grace-FO
- ▶ Inter & intra-satellite optical communication links
  - ▶ LIDAR
- ▶ Digital and optical data links & high speed optical wireless transmission
  - ▶ HL-LHC experiments (ex: CMS)



Schematic cross-section of a typical planar InGaAs/InP photodiode.

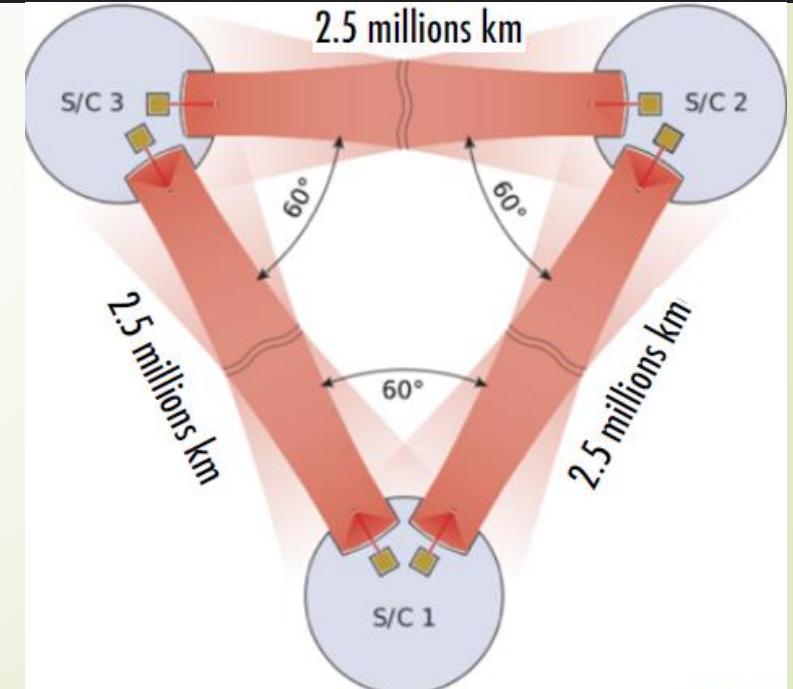
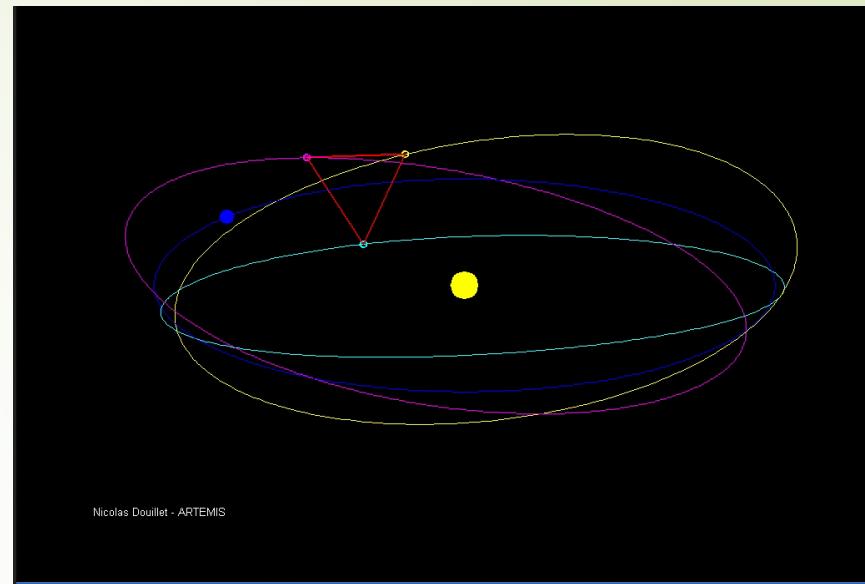
O. Gilard & al. HAL Id: 01883455



G. Fernandez Barranco, PhD Thesis, 2018

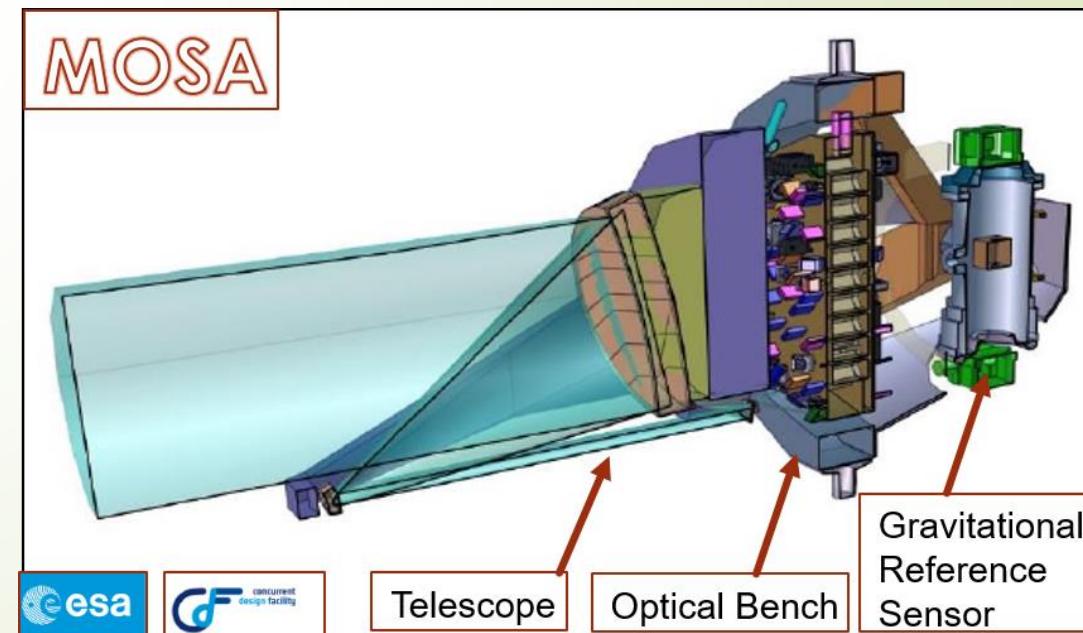
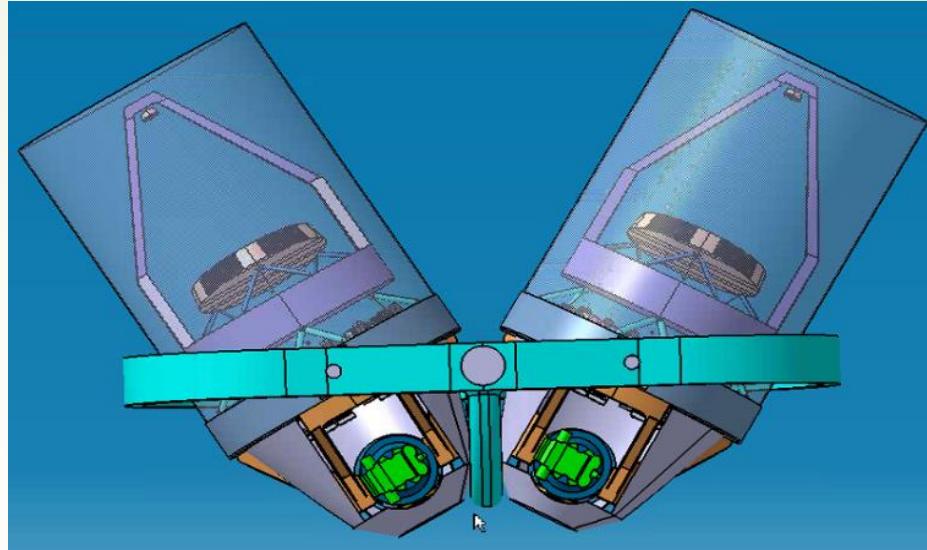
# LISA, ESA L3 mission, launch 2034

- ▶ Gravitational waves detection in mHz band
- ▶ Three satellites in triangular free flying formation
  - ▶ Orbit parameters
    - ▶ Distance to earth 50-65 million km
    - ▶ Arm length of constellation 2.5 million km
  - ▶ Launcher
    - ▶ Ariane 6.4
    - ▶ Mass at launch 7000 kg
  - ▶ Main mission phases
    - ▶ Nominal Science 4 years
    - ▶ Extended Science 6 years
  - ▶ Laser Interferometry method
    - ▶ Detect relative distance changes of  $10^{-21}$
    - ▶ few pm over 2.5 millions de km



# LISA instrument on each satellite

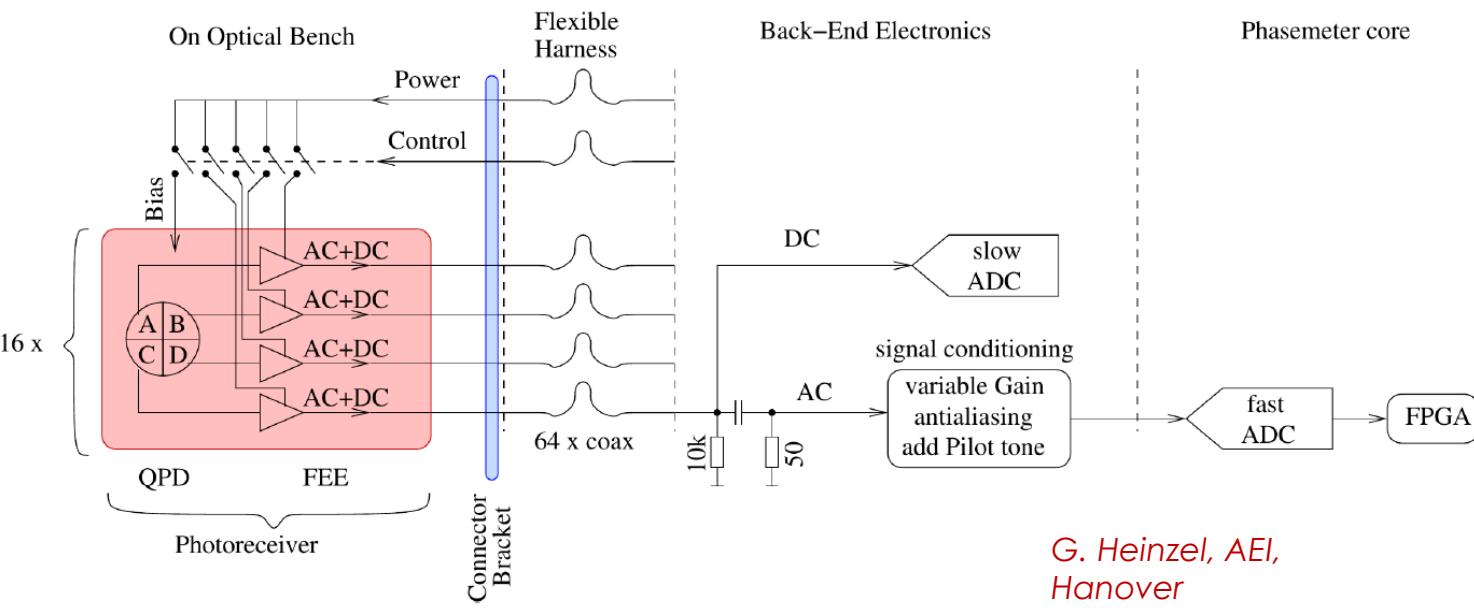
- ▶ 2x Optical systems (MOSA)
  - ▶ Telescope
  - ▶ Optical Bench (OB)
    - ▶ Photoreceiver sub-system
    - ▶ Gravitational Reference Sensor (GRS)
- ▶ Laser sources
  - ▶ 1064 nm wavelength; 2W optical power
- ▶ Diagnostic and environmental monitoring
- ▶ Measurement chain
  - ▶ Photoreceiver sub-system
  - ▶ Phasemeter and frequency distribution
  - ▶ Payload commanding and processing



# LISA Photoreceiver

- Assembly of InGaAs quadrant photodiode + FEE mounted on the optical bench
- IFO measurements
  - Distant beam:  $\sim 500 \text{ pW}$
  - Local beam: few mW
- QPD main characteristics
  - Large area: 1.5 to 2 mm
  - Low capacitance:
    - $C_{\text{seg}/2\text{mm device}} @ V_{\text{dep}} = 3.5 \text{ pF} \Leftrightarrow 4.5 \text{ pF/mm}^{16 \times}$
  - Small gap: 10-20  $\mu\text{m}$
  - Bandwidth: 2-30 MHz
  - Responsivity: 0.7 A/W
  - Radiation hardness
  - Mechanical and thermal stability
  - 10 years space lifetime
  - Secondary vacuum operation conditions

## Overview



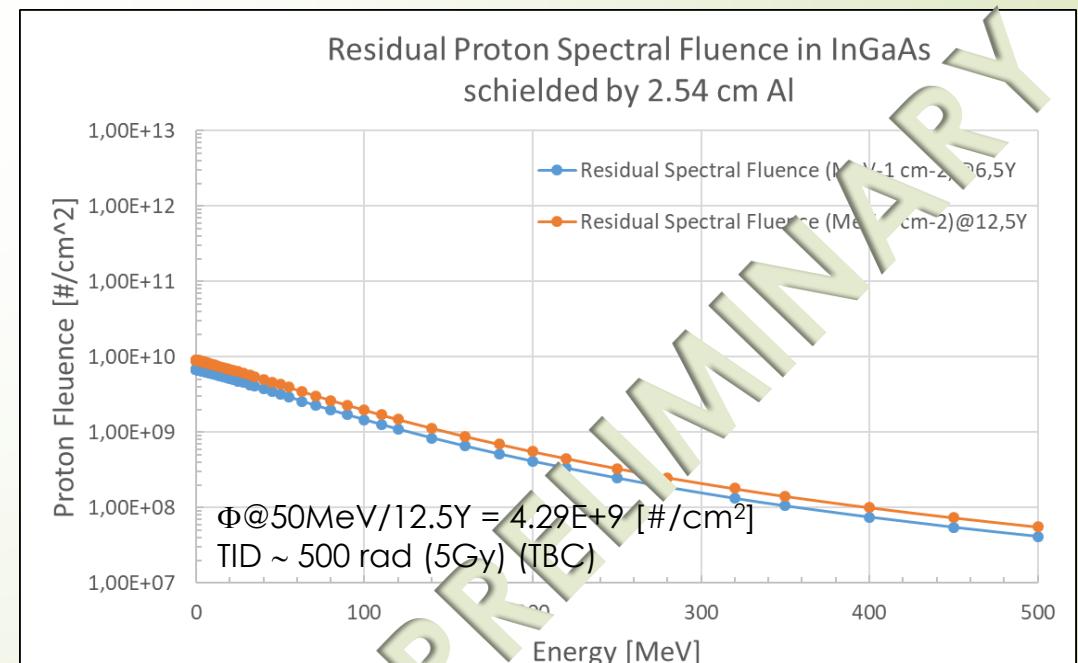
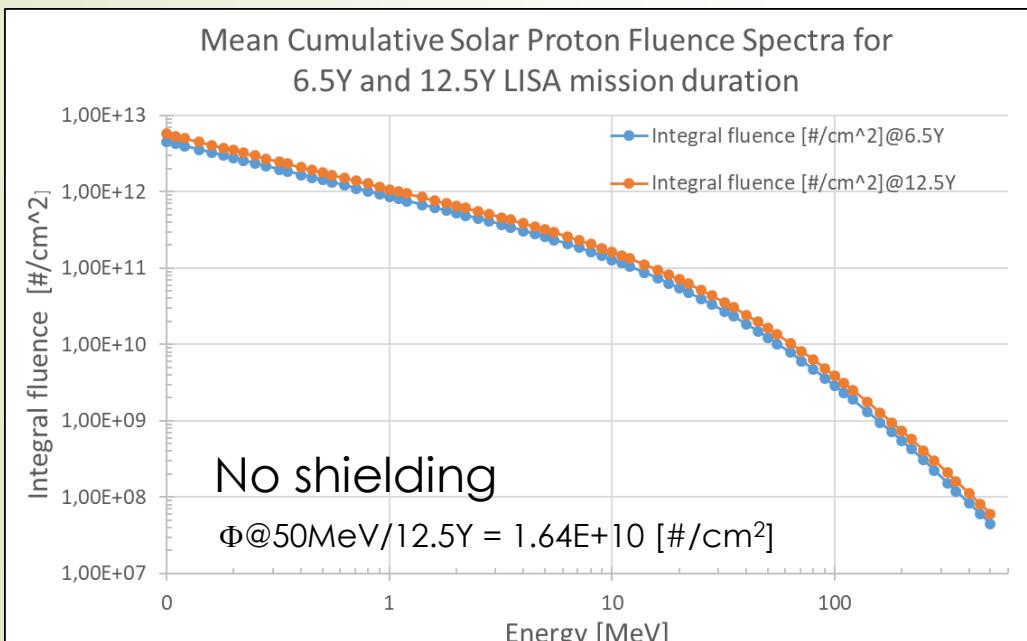
**Objectives:** LISA dedicated QPD design, fabrication & tests

# LISA Photoreceivers activities

- ▶ R&D on flight LISA InGaAs photodiodes
  - ▶ LISA Consortium Partners
    - ▶ Netherland: QPD& housing development + PA/QA
    - ▶ Belgium: ASIC FEE development, CMOS 65 nm technology
    - ▶ Japan: QPD & FEE (discrete components & ASIC) development
    - ▶ Germany: Discrete components FEE and development of testing facilities
    - ▶ France, OCA/ARTEMIS & Centre Antoine Lacassagne:
      - ▶ Objectives scientifiques & techniques: radiation hardness studies using proton beam
- ▶ Photoreceivers dedicated to AIVT optical ground support equipment
  - ▶ COTS InGaAs photodiodes
  - ▶ OCA/ARTEMIS, CPPM & IRFU involved
  - ▶ MOSA Assembly, Integration, Verification & Test (AIVT)
    - ▶ Main LISA France collaboration activity → CNES management
    - ▶ See Hubert's presentation on High precision optical metrology in mHz to Hz range

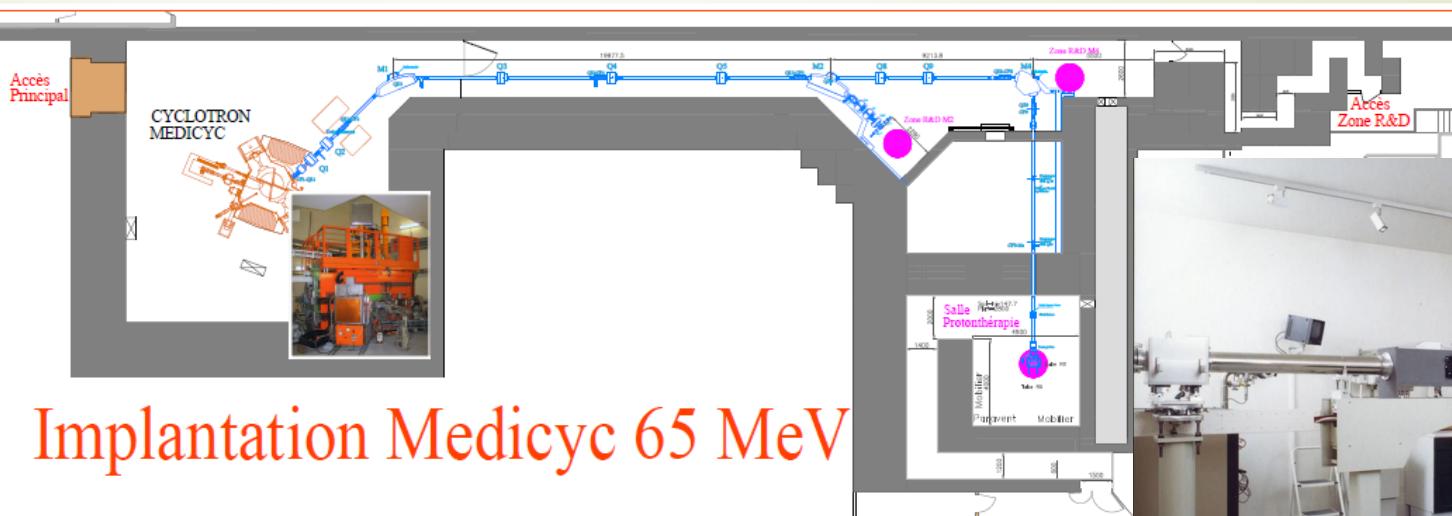
# Why proton irradiation of QPR?

- ▶ LISA will operate in the interplanetary space, at 1AU distance (150 millions km) far from Sun
- ▶ LISA radiation environment
  - ▶ Solar and planetary electromagnetic radiation
  - ▶ Plasma of solar winds
  - ▶ Radiation of solar energetic particles (protons): the most critical for the electronics components
    - ▶ Usual space rad hardness tests: Co-60; only Total Ionization Dose (TID) studies
    - ▶ Proton irradiation allows bulk damage studies

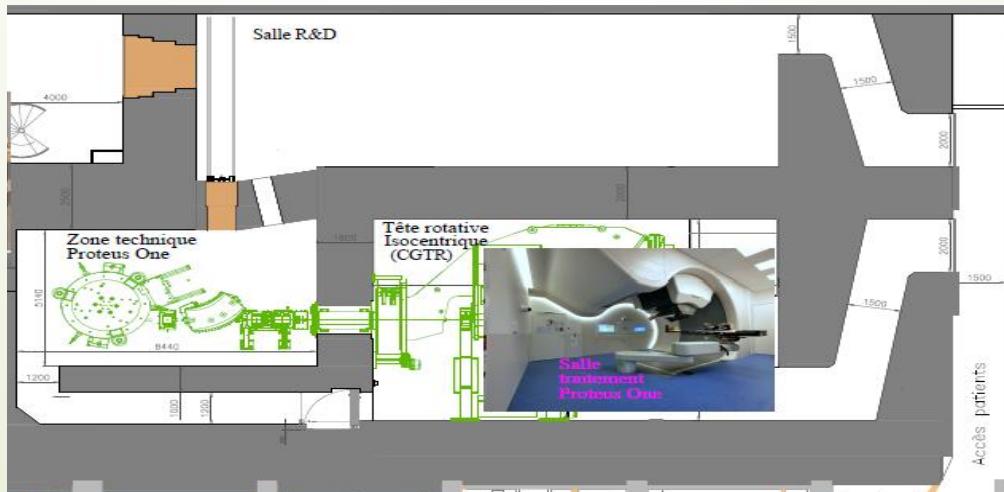


# Strategy: use protons facilities @ Nice

- Isochronous cyclotron P 65 MeV, Juin 1991 (MEDICYC)



- Super-conducting synchrocyclotron IBA PROTEUS ONE, P226 MeV, September 2016



## Isochronous cyclotron (Medicyc)

Proton BE		
Time structure	Macrostructure (ns)	Microstructure (ns)
	continuous	5 / 40 (25 MHz)
Dose rate	Minimum (Gy.min <sup>-1</sup> )	Maximum (Gy.min <sup>-1</sup> )
	1 (lower possible if adapted detection system)	100
Field size	Minimum (ϕ mm)	Maximum (ϕ mm)
	1	60
Energies	Min (MeV)	Max (MeV)
	0.1	65

X-rays 6 MV (~1 MeV)		
Dose rate	Minimum (Gy.min <sup>-1</sup> )	Maximum (Gy.min <sup>-1</sup> )
	2	-
Field size	Minimum (ϕ mm)	Maximum (ϕ mm)
	5	60

## Super-conducting synchrocyclotron (Proteus )

Proton HE		
Time structure	Macrostructure (ms)	Microstructure (ns)
	1	1.5 (63 MHz)
Dose rate	Minimum (Gy.min <sup>-1</sup> )	Maximum (Gy.min <sup>-1</sup> )
	2	-
Field size	Minimum (mm <sup>2</sup> )	Maximum (mm <sup>2</sup> )
	100x100	200x250
Energies	Min (MeV)	Max (MeV)
	100 (lower with range shifter)	226

Slide by courtesy of J. Herault & R. Trimaud (CAL)

# Deliverables and calendar

- Short term plan
  - 2023: LISA mission adoption
    - Each subsystem should attain Technology Readiness Level (TRL) of 4-5
    - InGaAs QPD runs with LISA specific design are actually on-going in NL & Japan
    - 2020: Irradiation and tests conditions to be established
      - Preparation of mechanical supports
    - 2021: InGaAs QPD proton irradiation tests planned
- Long term plan
  - 2025-2026: LISA InGaAs space qualification using proton beams
  - Irradiation & test procedures to be used for other applications (space or high energy physics)