Energie, santé, applications sociétales

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Contents

Introduction

External source of radiation

- Medical imaging: radiography with X-rays 20–150 keV
  - X-ray planar imaging
  - computed tomography (CT)
  - Mammography
  - etc.
- Radiation therapy
  - X-rays, linacs 4–25 MeV
  - X-rays, sources ~1 MeV.
  - Electrons, linacs
  - Hadron therapy: proton and light ions

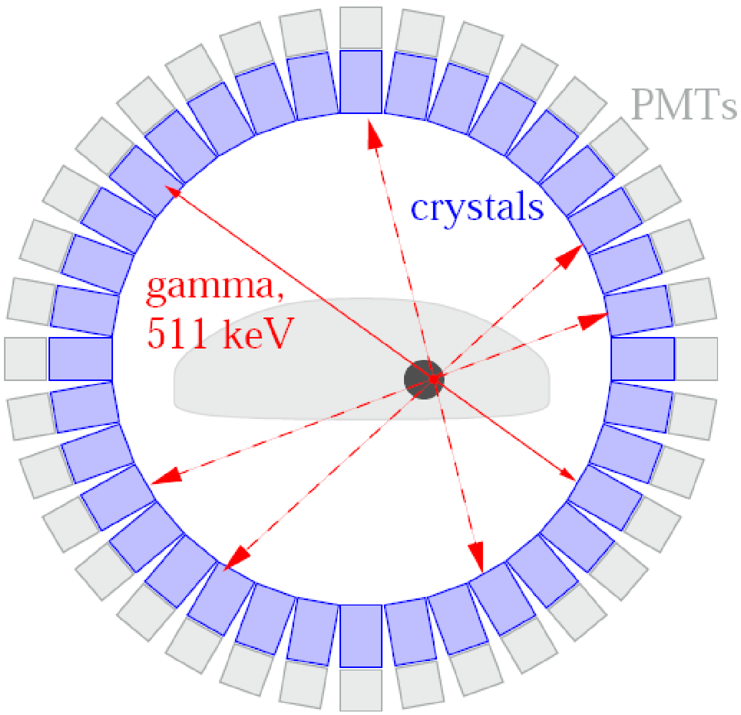
Internal source of radiation Nuclear Medicine

- Nuclear Imaging
  - Scintigraphy: single photon emission, 2d planar image.
  - SPECT: single photon emission computed tomography, 3d image
  - PET: positron emission tomography, double photon emmision, 3d image
- Therapy: international nuclear medicine
  - Unsealed source radiotherapy
  - Sealed source radiotherapy (brachytherapy; curietherapy).

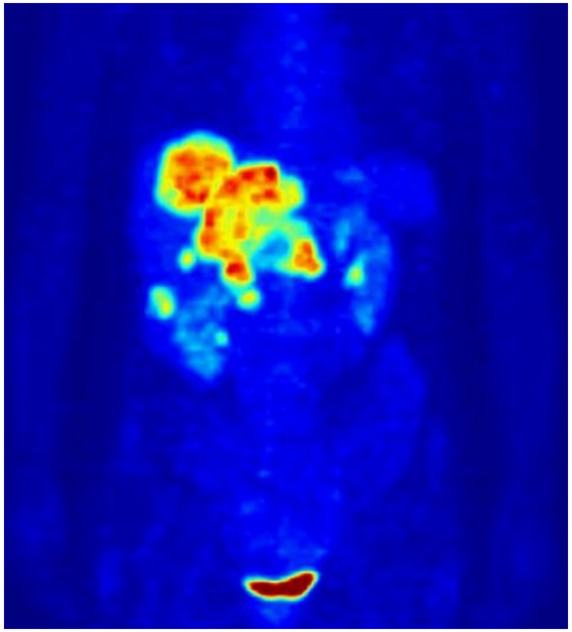
Radiation dosimetry

Positron Emission Tomography

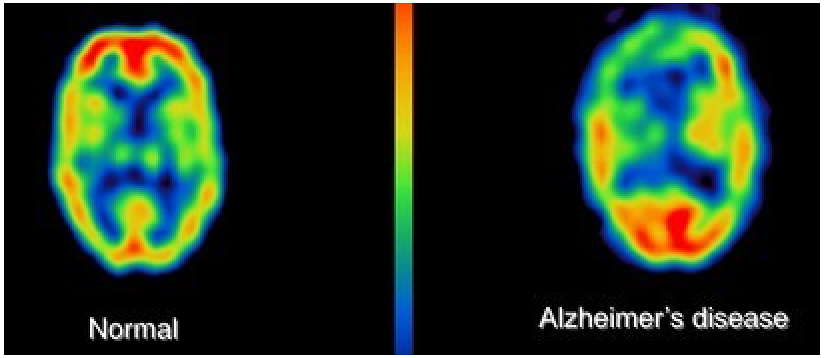
- PET is a nuclear imaging technique used widely in oncology, cardiology and neuropsychiatry.
- Use radioactive tracer (e.g. ^{18}F-FDG) emits positrons ⇨ annihilation with an electrons produces two 511 GeV back-to-back photons.
- Detect two photons in coincidence → reconstruct line-of-response (LOR) → 3D tracer distribution
- Background vs signal (full body scan)
  - Compton scattering (up to 50%)
  - Random coincidences (typically 25%)
  - True coincidence after selection (~25%)
- Limiting factors for spatial resolution
  - Positron range → 0.6 mm for FDG
  - Non-colliniarity limitation → ~1 mm for FDG
  - Respiration → ~5 – 10 mm
  - Low photofraction for scintillators ~20-30%



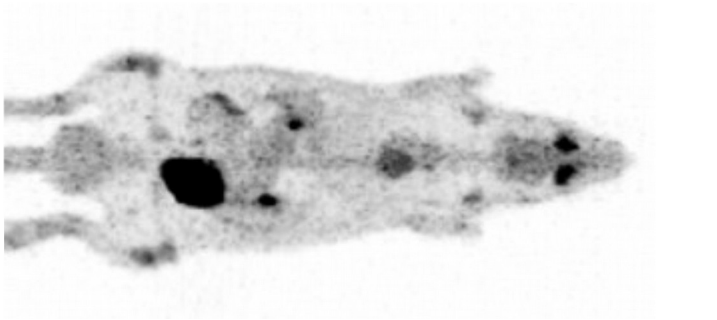
- Full body
  - Detects cancer, determines whether a cancer has spread in the body, determines if a cancer has returned after treatment.
  - Determines the effects of a heart attack, or myocardial infarction, on areas of the heart.
  - Initial activity: ~ 3 to 5 Mbq/kg → dose up to 15 mSv → ~6 years natural backg
  - Spatial precision ~4 mm³, FOV ~ 40 cm



- Brain size
  - Evaluates brain abnormalities, such as tumors, memory disorders and seizures and other central nervous system disorders
  - spatial precision 2.5 mm³, FOV ~20cm



- Pre-clinical / small animals
  - Research and drug test
  - Spatial precision 1 mm³, FOV ~10 cm



Research Axes in PET (1)

- Time-of-Flight (TOF) : measure a difference in time between two photons → improve S/B in image reconstruction
  - Commercial systems coincidence resolving time (CRT) of 350 ps (FWHM)
  - laboratory tests at the test bench: 150 ps (FWHM)
  - Gain subject dimension ~ 20 cm, CRT of 100 ps → factor 9 in statistics
- Improvement in scanner sensitivity by increasing the scanner solid angle → total body scan (US Explorer project)
  - Axial FOV: 215 cm

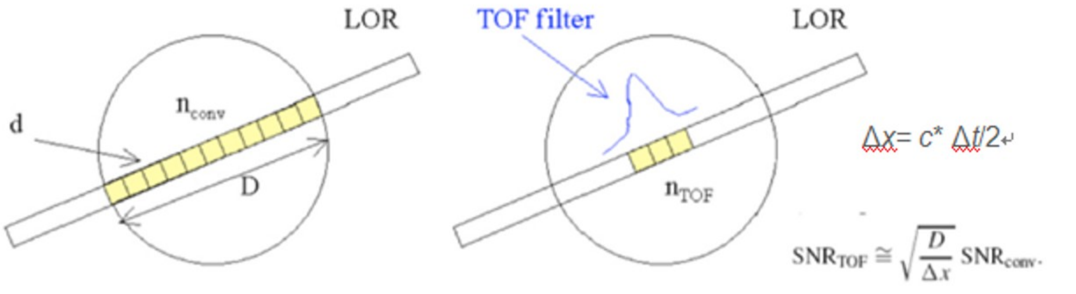
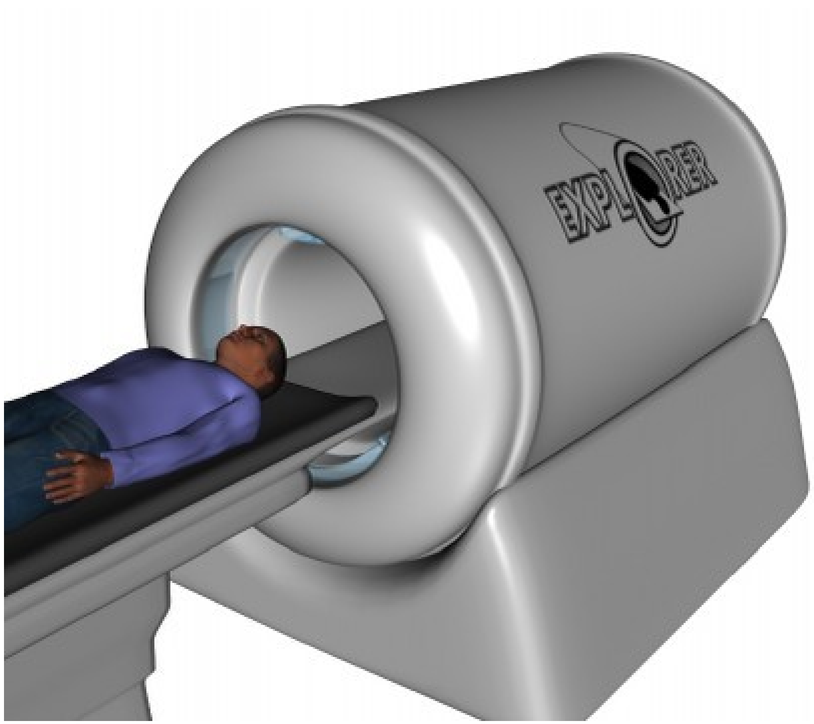
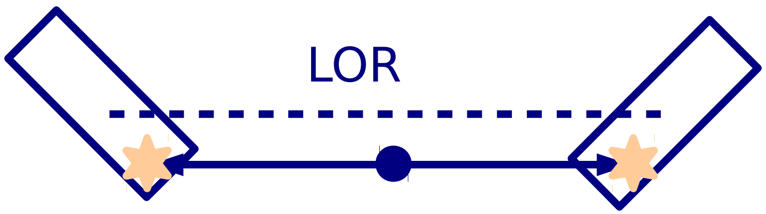


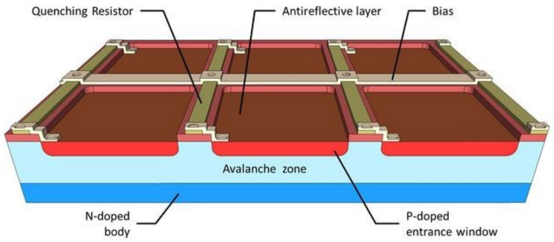
Image elements contributing to a LOR, for conventional PET (left) and TOF PET (right).



Research Axes in PET (2)

- Improving depth-of-interaction (DOI) parallax error
  - several-layer detection system
  - surface treatment
  - Crystals with dual read-out
- Silicon photo-multipliers (SiPM) development:
  - Pros: low price, compact size, low magnetic sensitivity, excellent amplitude and time resolutions
  - Cons: temperature dependence and the huge dark count rate
  - Digitial SiPM: integrated with a read-out circuit at the surface of one cell
- Spatial precision
  - Monolithic crystals (+DOI)
  - Movement detection
  - Combination PET/CT, PET/MRI





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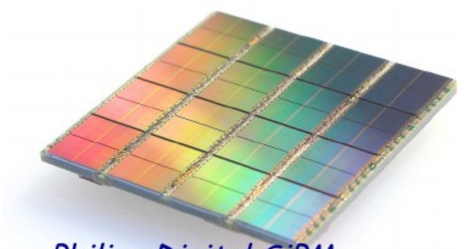
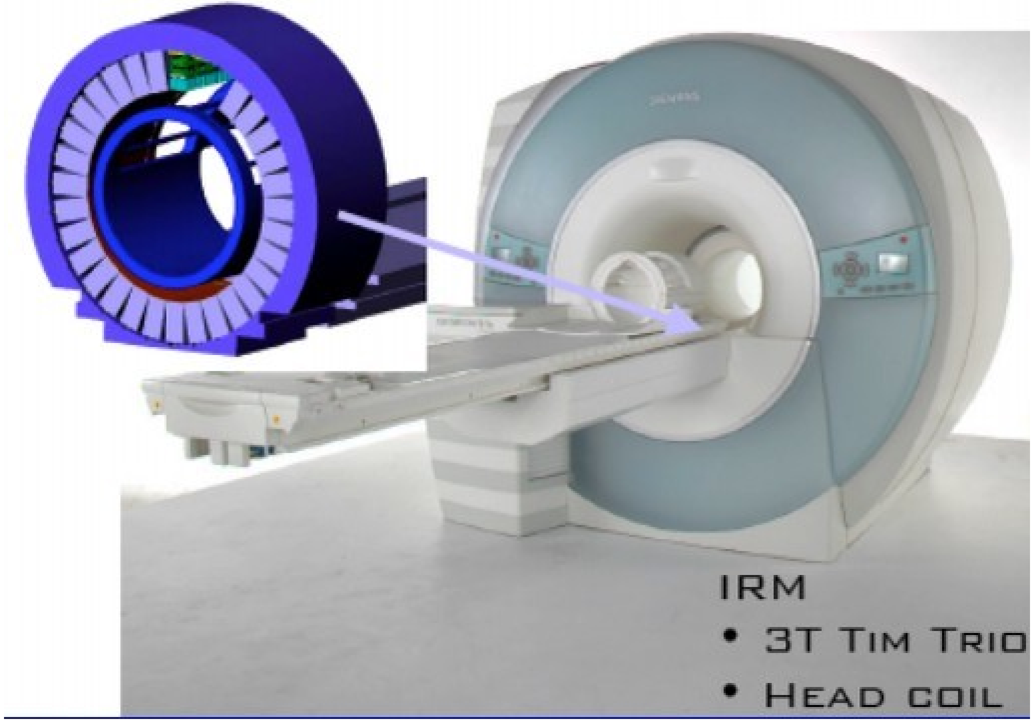


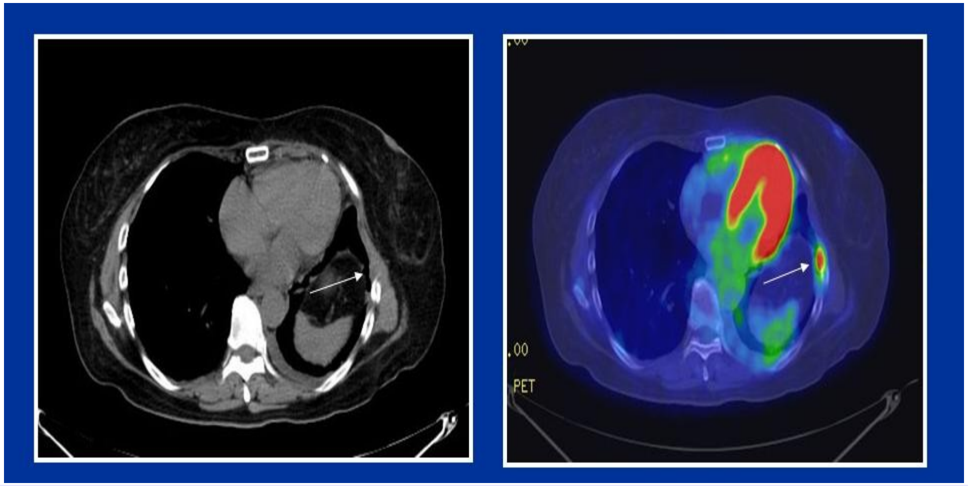
Philips Digital SiPM
32x32 mm2

Multimodalities

- Use of combined PET/CT and PET/MRI allow to combined two image
  - both anatomic and metabolic information
  - Use anatomical information to estimate attenuation correction in PET imaging
- Simultaneous image acquisition
- Shorter acquisition time
- Some geometrical constraints
- System interference (magnetic field!)

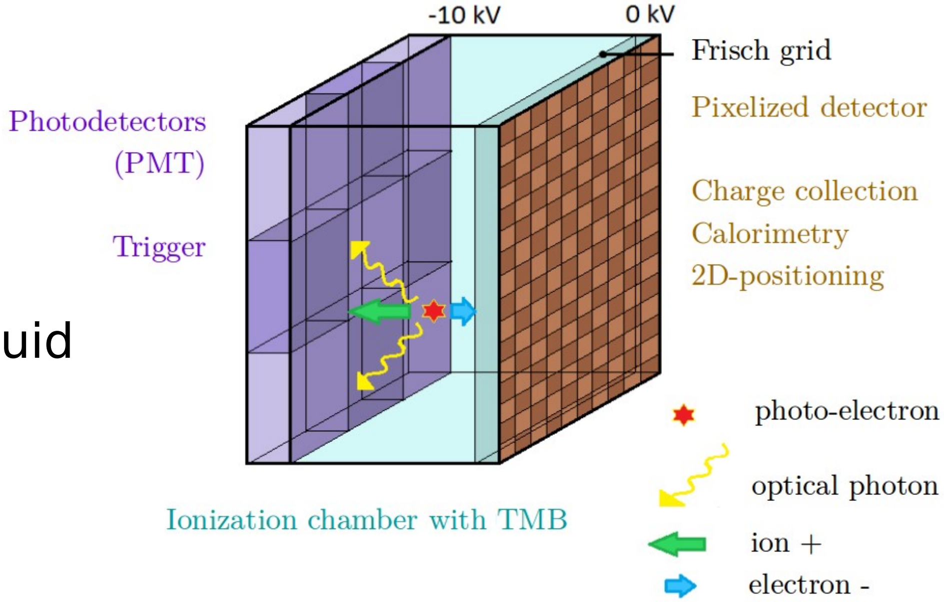


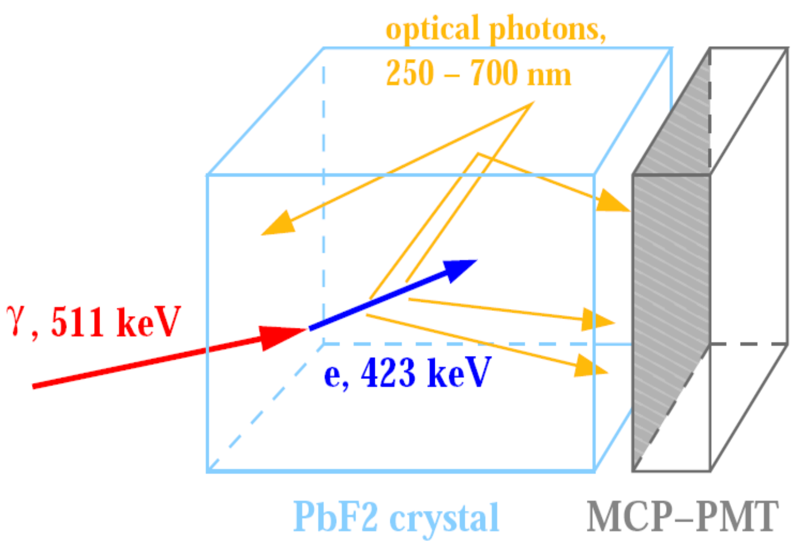
CT alone PET/CT



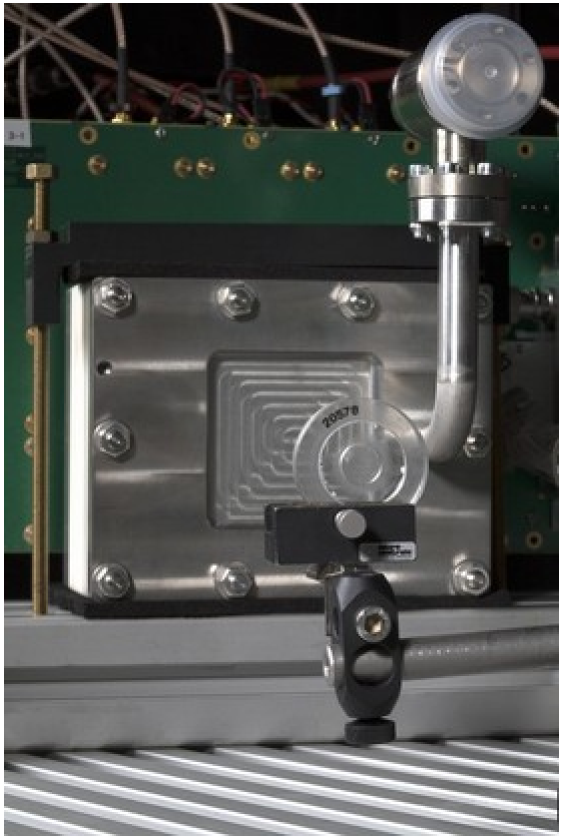
Current activities in Nuclear Imaging at DPhP

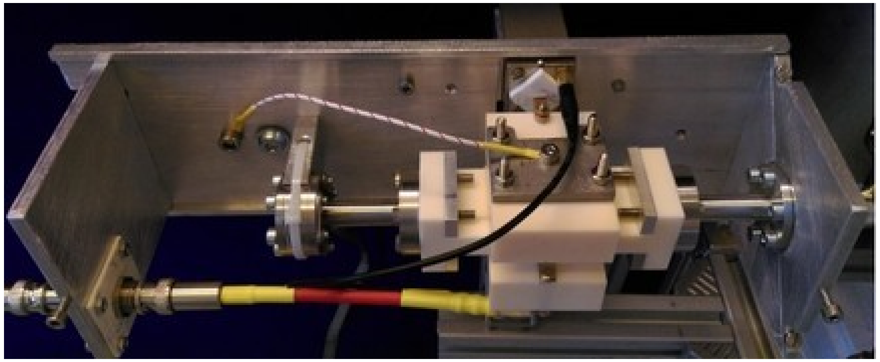
- **CaLIPSO**: development of the brain/animal size PET
  - High spatial resolution: 1x1x1 mm^3
  - High resolution in time
  - Innovative detection medium: TMBi liquid
- **PECHE**: development for TOF full-body size PET
  - High resolution in time
  - High density crystals as a detection medium
- Common to both projects: use of the **Cherenkov** light for the extreme precision in time.
- New project **ClearMind**: crystal based technique (supported by "bottom-up")
  - High resolution in time
  - High spatial resolution: ~1x1x1 mm^3
  - Use both Cherenkov and scintillation light



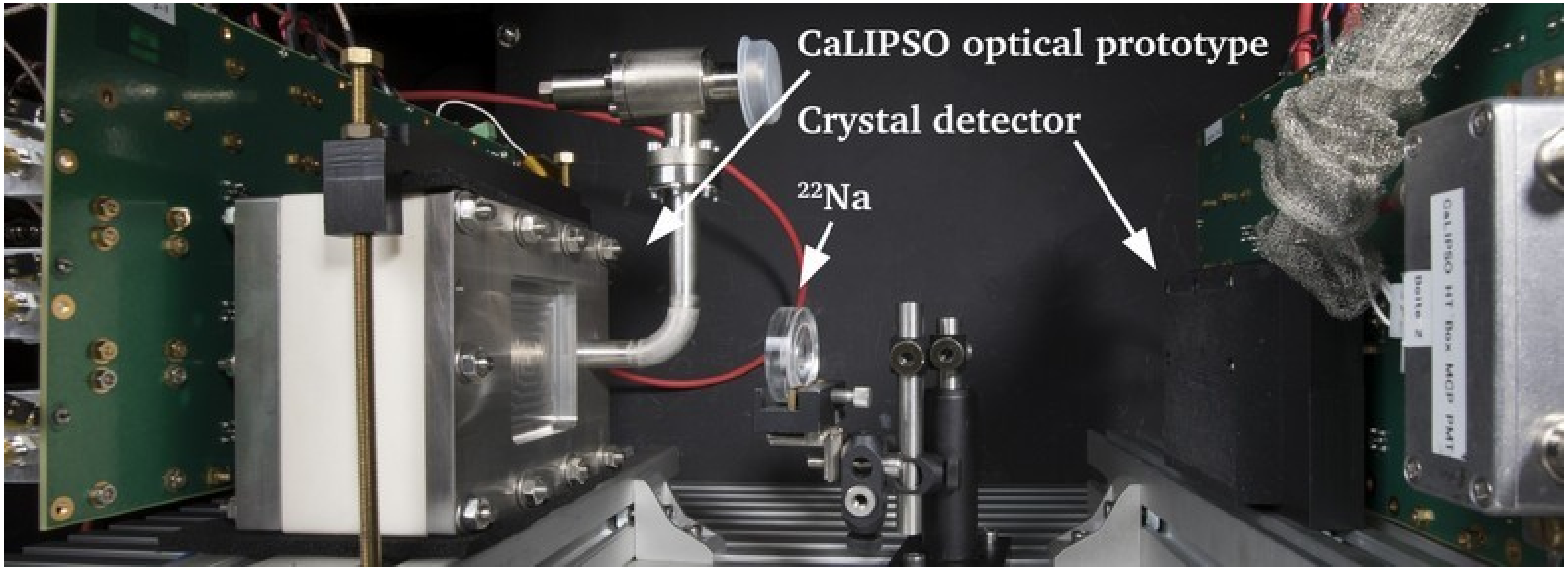


Current Status

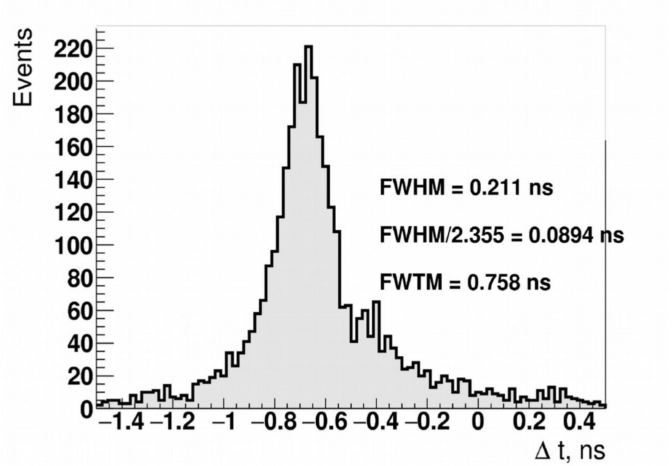


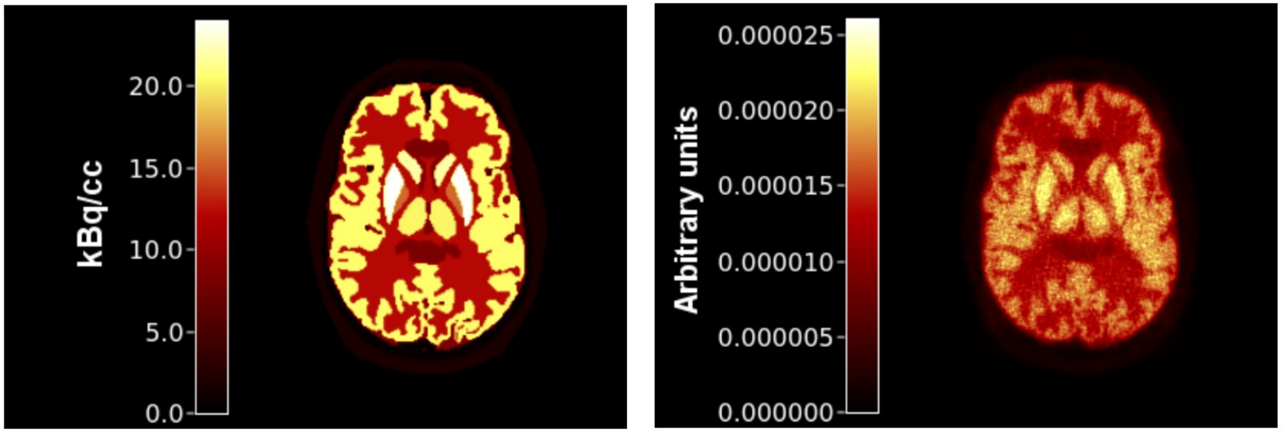


Some Results



Difference in time for two identical crystal detectors





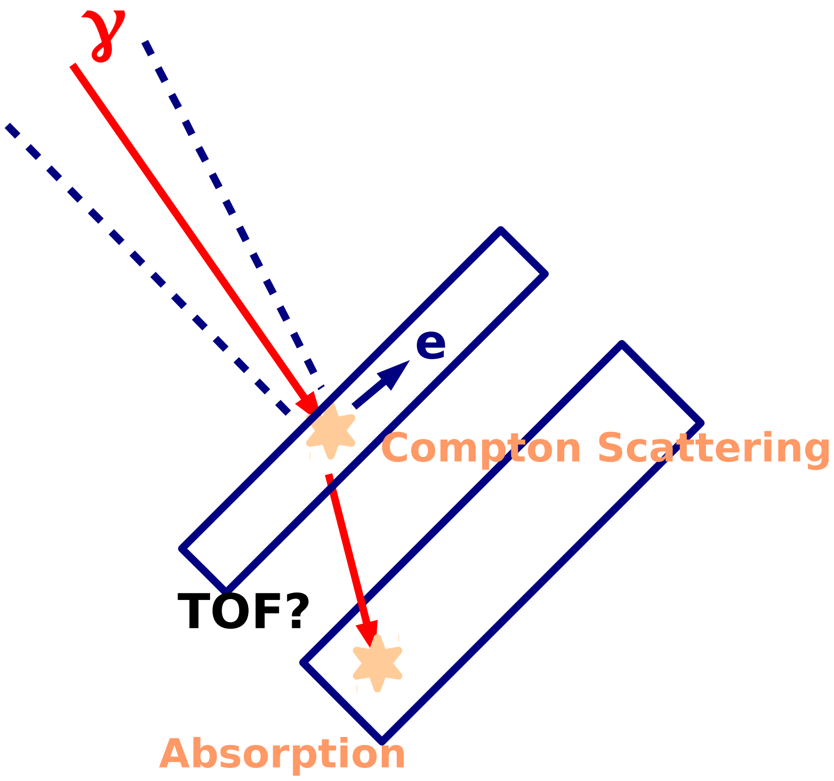
Simulated and Reconstructed Brain Image
on Zubal phantom with ^{18}F-FDG in CaLIPSO

Possible Further Development (1)

- Further development of the TOF technologies for PET using Cherenkov radiation. Large potential for the faster photo-mutlipliers
  - SiPM pixel: TTS 20 ps
  - Tynode photomultiplier expect to have a TTS ~ 10 ps
  - RF PMT TTS ~ 10 ps
- PET for the on-line monitoring for hadron-therapy
  - Steep dose profile, close to the critical organs, anatomical change during treatment, uncertainties in particle range.
  - Investigated the use of the short lived isotope (^{11}C, ^{15}O) generated by the hadron beam in a tissue
- Gaseous photo-multipliers using micrometers?
  - Large solid angle PET with a reasonable price.
  - Good synergy between the different IRFU departments

Possible Further Development (2)

- Detectors under development could be used as Compton cameras
  - CaLIPSO: could measure two vertex with good precision in the same volume
  - ClearMind: two layers geometry
- Possible use
  - In-vivo monitoring of the hadron therapy treatment using prompt-photons with energies > 1 MeV
  - Radiation monitoring in the context of nuclear decommissioning

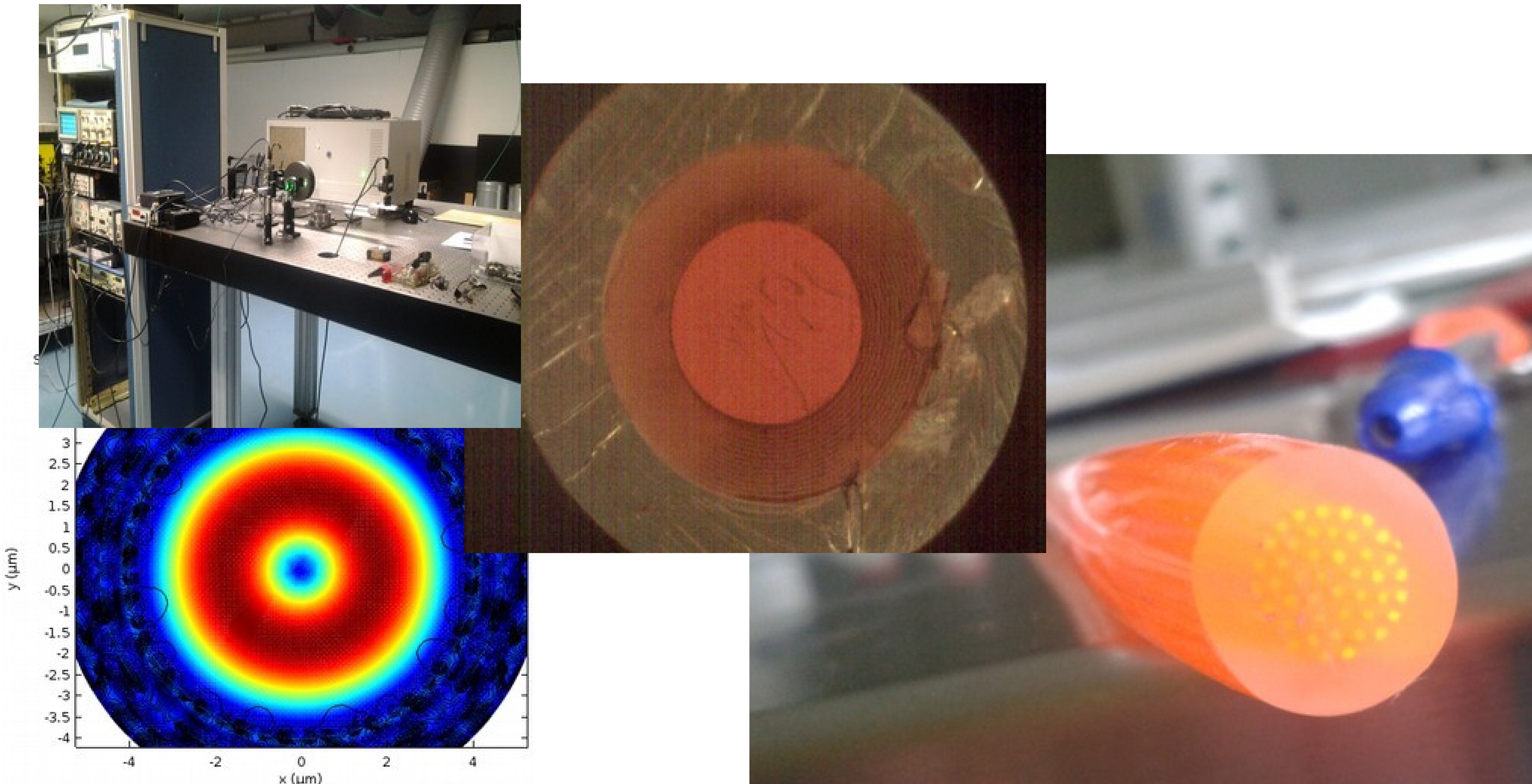


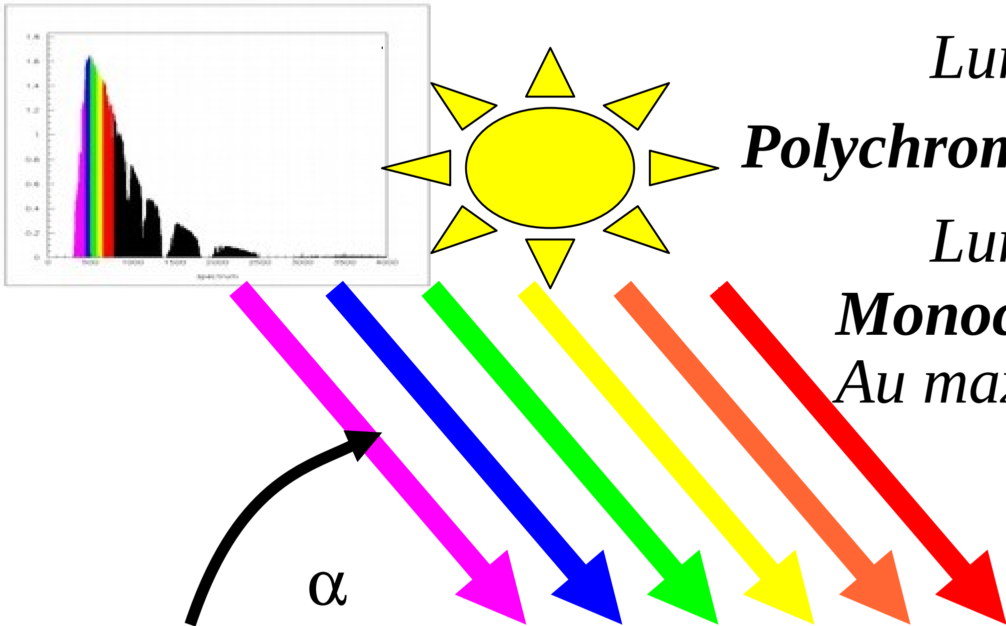
Possible Further Development (3)

- Use of the developed detectors for the Positron Annihilation Lifetime Spectroscopy (PALS) measurement in material science:
  - at pulsed accelerators
  - using the single-shot positron annihilation lifetime spectroscopy (SSPALS)
- Research on three-gamma detection in PET
  - CaLIPSO or ClearMind: efficient solid angle coverage, good precision
  - Development of new bio-markers, in particular Scandium-44(β^+ ,γ) , liquid xenon PET at Nantes.
  - Orto-positronium annihilation: 0.5% – ~10%, may be related to the cancer nature of the cell (free volume void, only in-vitro studies using PALS up to now)
- Transverse nature of these projects:
  - TOF technologies with Cherenkov radiation
  - Photo-multipliers (MCP-PMT, SiPM),
  - Fast electronics (GHz read-out boards, SAMPIC)

Societal and Security Application

Projet QUYOS
Un concentrateur solaire quantique à fibres optiques à retournement de photon
DSM-energie





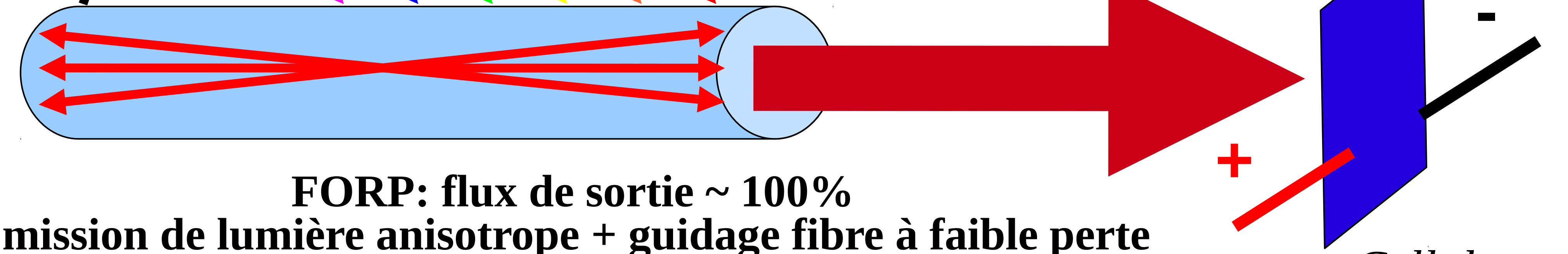
Lumière entrée: λ~[400-900] nm

Polychromatique et Omnidirectionelle

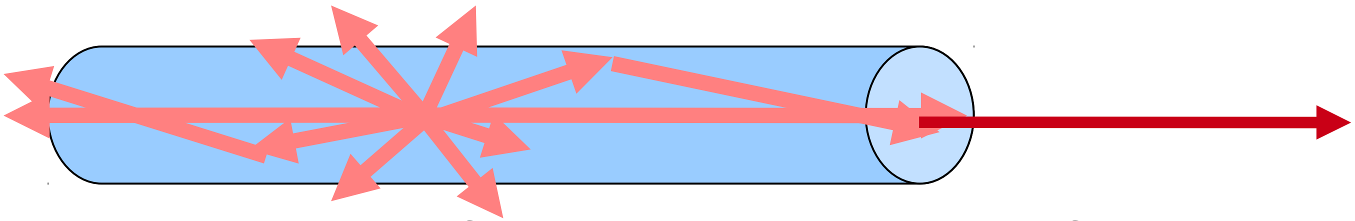
Lumière Sortie: λ ~ 950 nm

Monochromatique, monodirectionelle

Au maximum d'efficacité quantique du Silicium

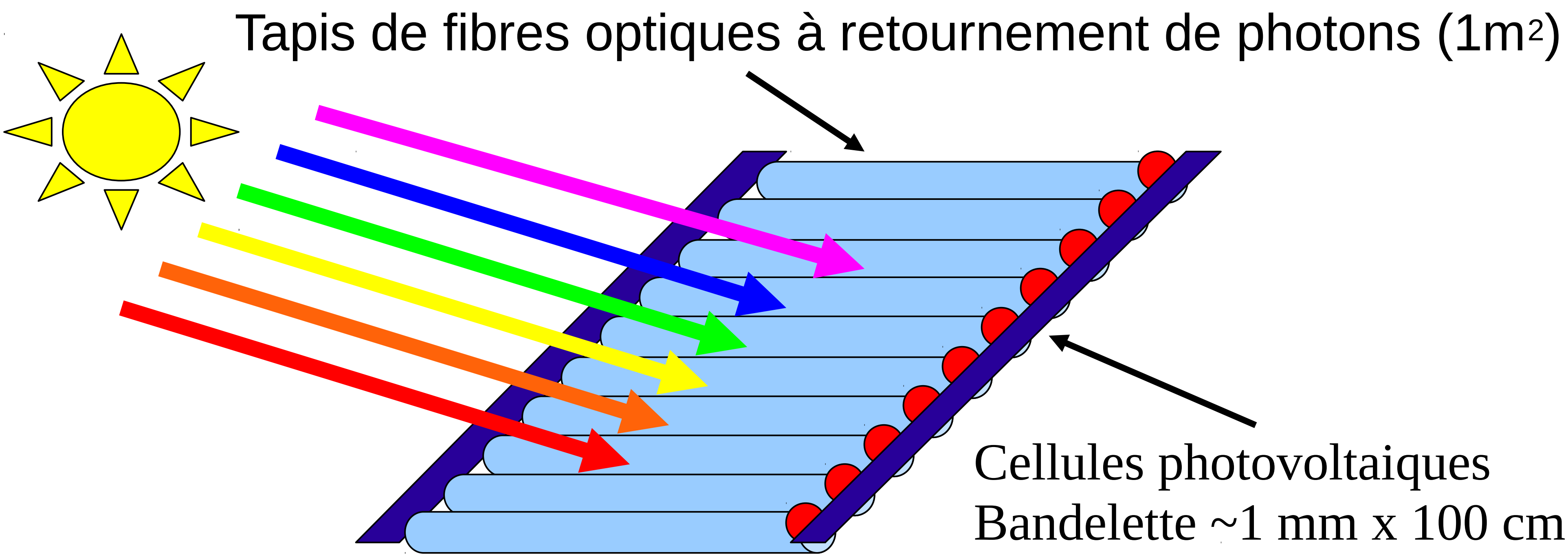


FORP: flux de sortie ~ 100%
Émission de lumière anisotrope + guidage fibre à faible perte



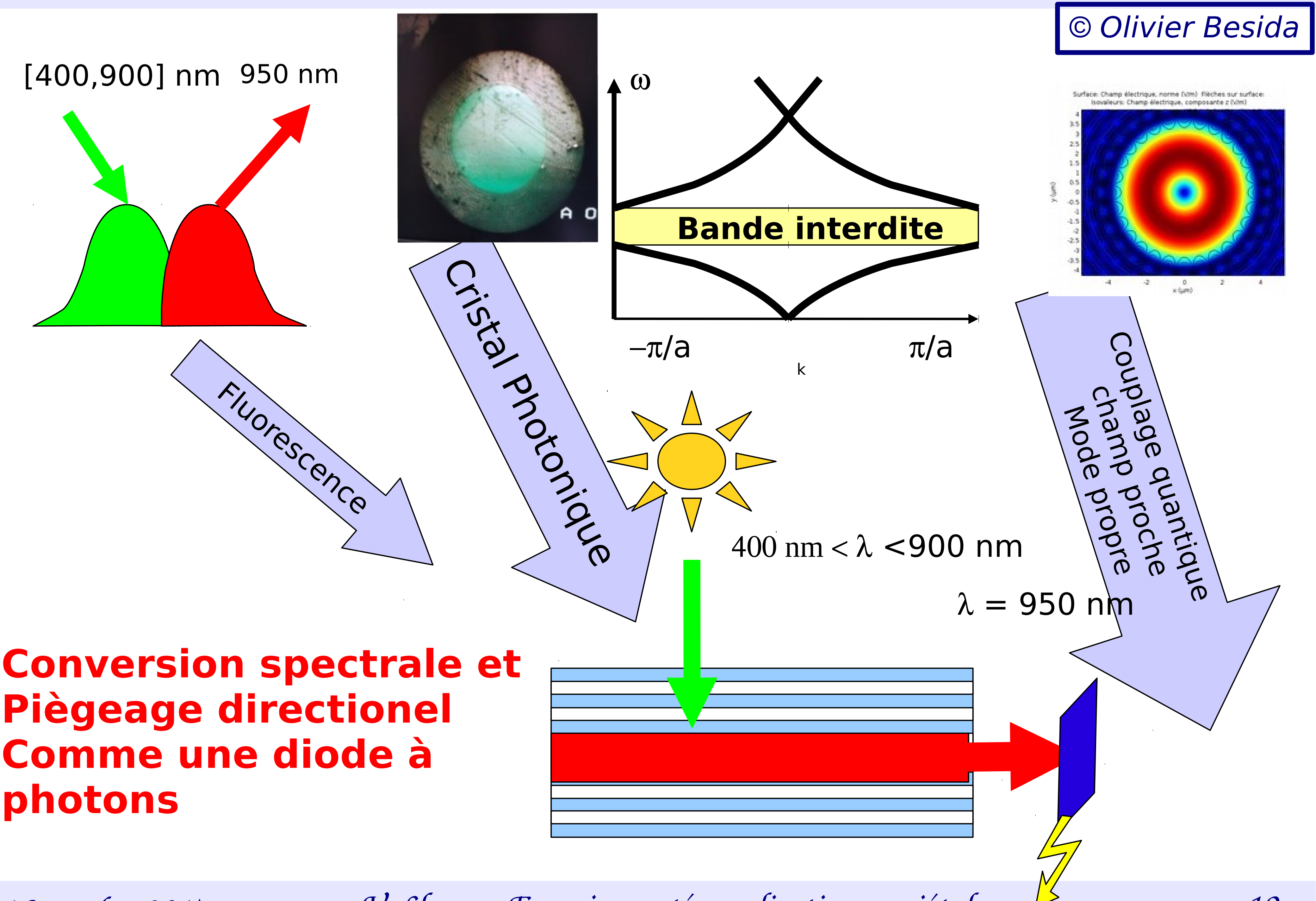
Fibre fluorescente Classique : flux de sortie ~ 4%

La rupture technologique: le concentrateur solaire quantique



Low Cost : 99% Plastique 1% Silicium 10€/m2
Haute efficacité attendue: 20-75%
Concentration solaire quantique: surface → perimètre

Principe du retournement de photons



QUYOS: Status And Perspectives

- Project is in the “proof-of-pricipal” stage.
- The new laboratory for fiber production has been inaugurated this summer.
- The first microstructured fibers are produced and tests are started.
- This technology has a huge potential for
  - Significantly reduce a cost of the solar energy
  - the nuclear plants tomography with the goal of non-proliferation
  - concentrating and use of the solar energy for laser induced hydrogen production
  - etc.

Potential Medical, Societal and Security Applications

TOF technologies for PET using Cherenkov radiation
Gaseous photo-multipliers using micrometers
PET for the on-line monitoring for hadron-therapy
Compton cameras for the on-line monitoring for hadron-therapy
Research on three-gamma detection in PET
QUYOS: solar energy
Neutrino Detectors for nuclear non-prolifirations
Compton Camera for the radiation monitoring and nuclear decommissioning
Detectors for Positron Annihilation Lifetime Spectroscopy