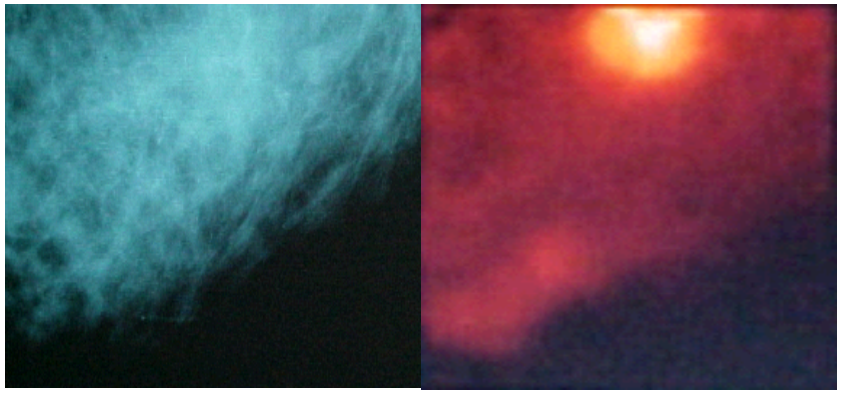
ClearPEM: an example of a collaborative project to develop a dedicated PET for breast imaging

E. Auffray,
CERN, EP-CMX
On behalf of the ClearPEM collaboration

Motivation

1/8 woman will develop breast cancer during her life
2nd cancer related cause of death for women

Conventional detection techniques (X-ray mammography) are inefficient, especially in dense breasts (common in women aged under 50 years).
With Positron Emission Mammography (PEM), possibility to detect tumors in dense breast and small tumors (<2mm)



X-ray Mammogramm **Positron Emission Mammogramm**

The X-Ray mammography picture reveals nothing special, whereas the tumor is clearly visible in the PEM case.

A dedicated PET scanner for breast imaging will allow better spatial resolution and better sensitivity than what can be achieved by a whole body PET

ClearPEM History

2001: the Crystal Clear collaboration launched the **ClearPEM** project

A Dedicated breast imaging PET scanner

The aim was to build a research tool with

- spatial resolution < 1.5mm
- sensitivity few %
- allowing to image the breast and the axilla
- compatible with biopsy
- compatible with adding other imaging modalities

ClearPEM History

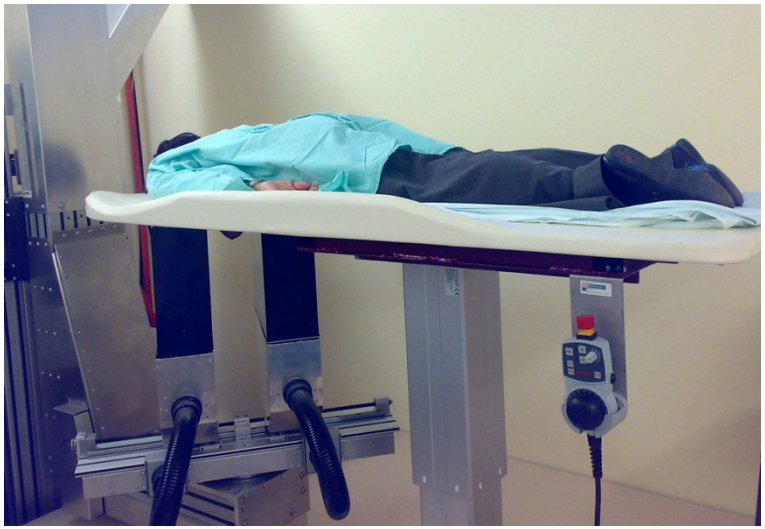
2001-2003: first prototype developed in Portugal in the frame of Crystal Clear Collaboration with 4 academic groups involved: CERN, LIP consortium, UNIMiB, VUB,

=> Creation of one startup: PETSys (Portugal)

Scanner installed in Porto hospital then in Coimbra

First images with patient

Tests also on small animals



ClearPEM History

2004: Launch of the **ClearPEM-Sonic** project in frame of CERIMED with cooperation of Crystal Clear Collaboration (CERN KT contract: K1660-KTT-PH-004P) :

Consortium of 11 partners:

- **6 Academic partners**:

  CERN, Univ. Aix-Marseille II, Univ Milano-Bicocca, VUB-Brussels, LIP-Lisbon, LMA-CNRS

- **2 Industrial partners**:

  PETsys, SuperSonic Imagine

- **2 Clinical partners**:

  AP-HM Marseille, Cancerpole PACA, Inst. Paoli Calmettes Marseille

Aim: develop a bimodal system:
Breast PET + Ultrasound

- Installed in Marseille Hopital Nord in Dec 2010
  Clinical trial on 20 patients
- Reinstalled in Dec 2013 in San Gerardo hospital, Monza, It, for a large clinical trial

ClearPEM-Sonic :

Objective: detect tumors of 1 to 2mm

ClearPEM :
Functional imaging

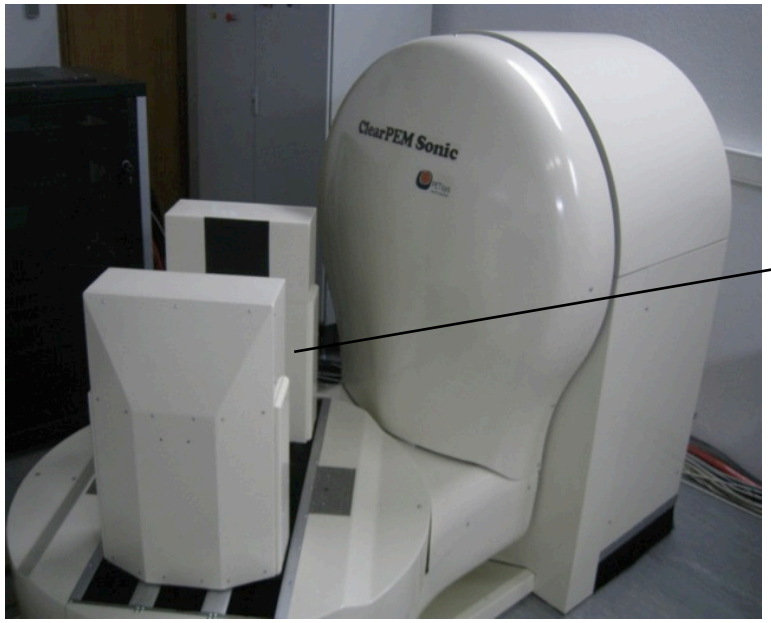
www.cern.ch/cerimed/

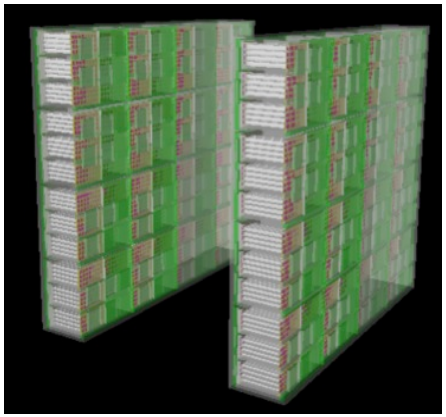
Ultrasound probe
Anatomic imaging

SuperSonicImagine Aixplorer
Morphological information
Conventional 3D Ultrasound imaging
Real time ShearWave Elastography
Local and global elasticity (specificity)
Acoustic signature and vascularization

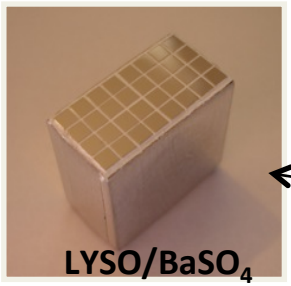
ClearPEM
Metabolic information (specificity)
Possibility to perform axillary exams
High system sensitivity
Very good spatial resolution

ClearPEM : Technologies developed by Crystal Clear

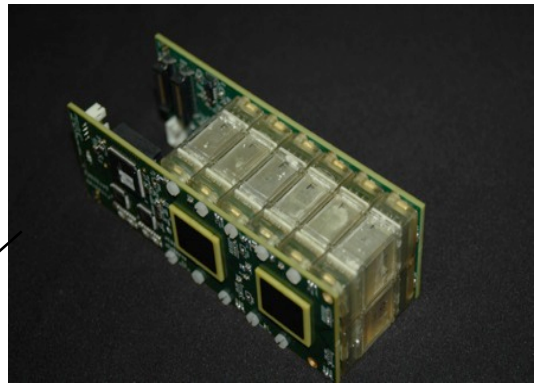




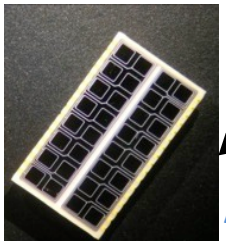
1 Plate 17,3x15,5x3cm =
16 SuperModules =
3072 crystals



Matrice



Module assembly



APD Array

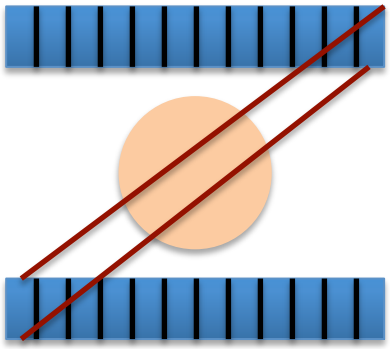
Technology :

- 2 plates
- 6144 LYSO:Ce crystals in 192 matrices
- Readout in both end with APD arrays
- Dedicated ASICs for fast readout

ClearPEM was the first PET using APDs !
A CERN CMS ECAL technology transfert

(see CERN courrier Article B. Frisch, July.August2013)

Depth of interaction (DOI) Capability



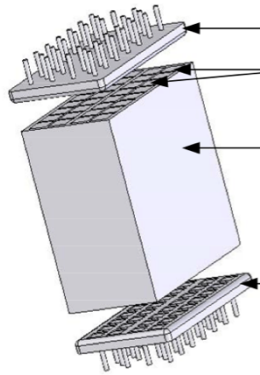
Without DOI capability:

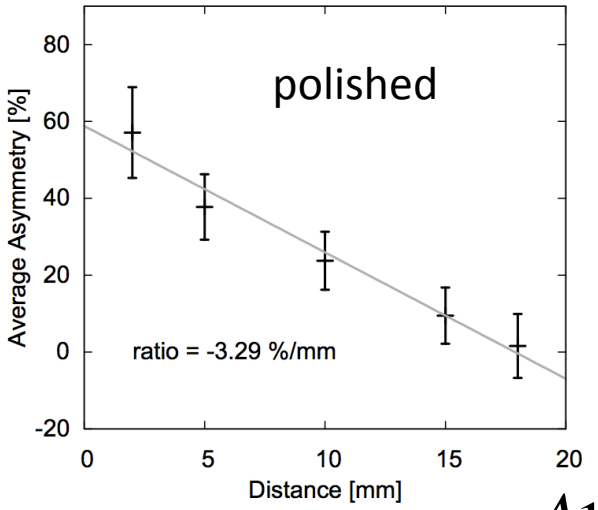
The parallax error will deteriorate the image quality due to misinterpretation of the real position of event

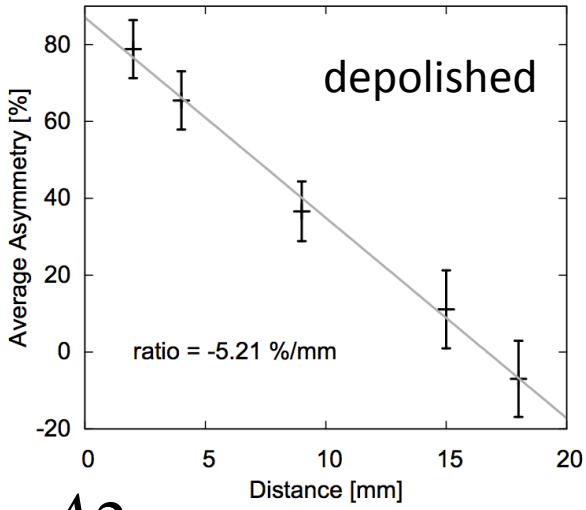
In ClearPEM DOI measurement is achieved with:

- A double side readout
- Depolishing of the lateral surface

⇒ Increases the assymetry in light yield extraction both crystal ends:







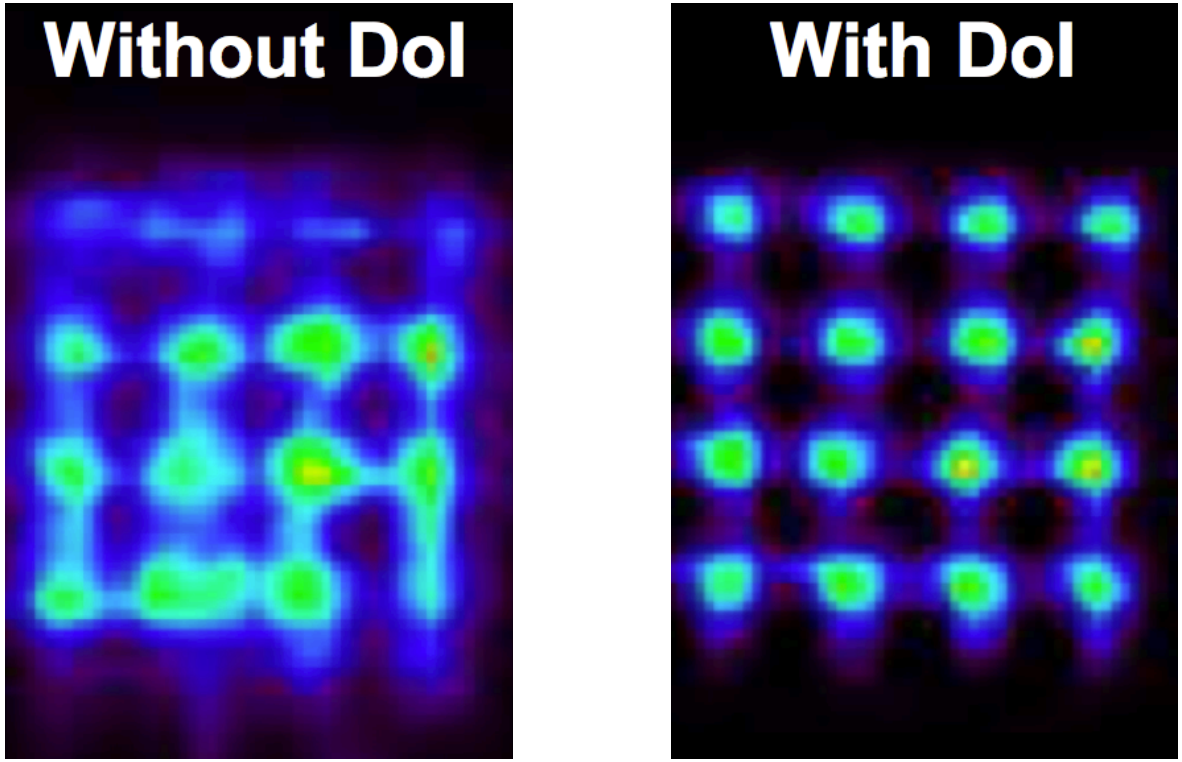
	LY (ph/meV)	α (%/mm)
Polished	18600	3.29
Depolished	17500	5.21

=> DOI: 3mm

$$Assymetry = \frac{A1 - A2}{A1 + A2}$$

B. Frisch, PhD Thesis, Technische Universitaet Wien, Vienna, 2012

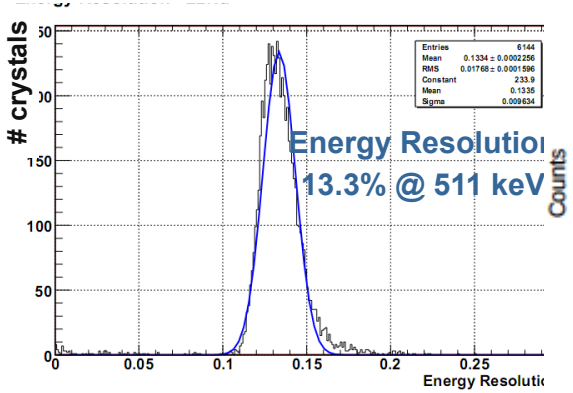
Impact of DOI capability on image quality

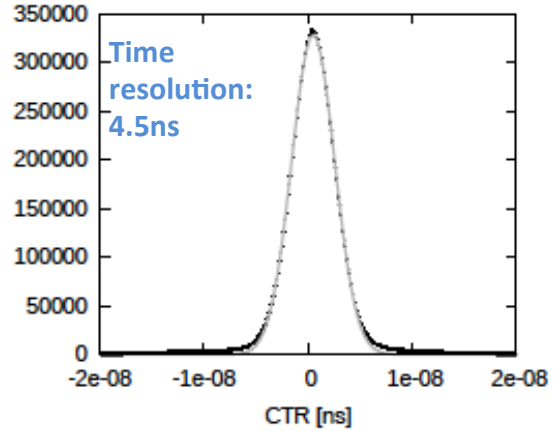


Reconstructed image from 1mm Na^{22} source moved along a grid with 5mm pitch with ClearPEM

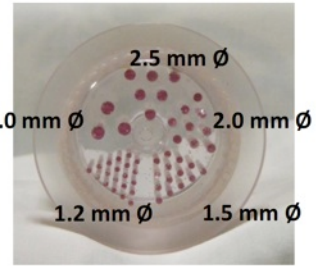
ClearPEM Performance

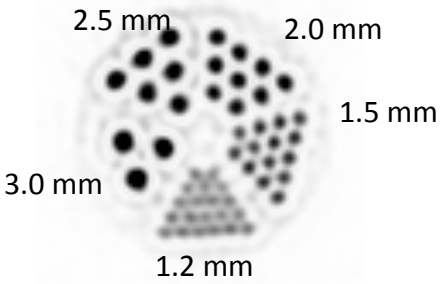
- Energy resolution: 13.3%
- Time resolution: 4.5ns



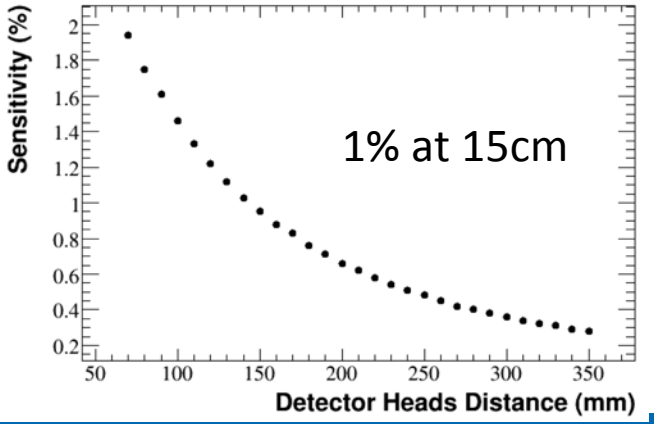


- Spatial resolution: 1.3mm





- Sensibility: 1%

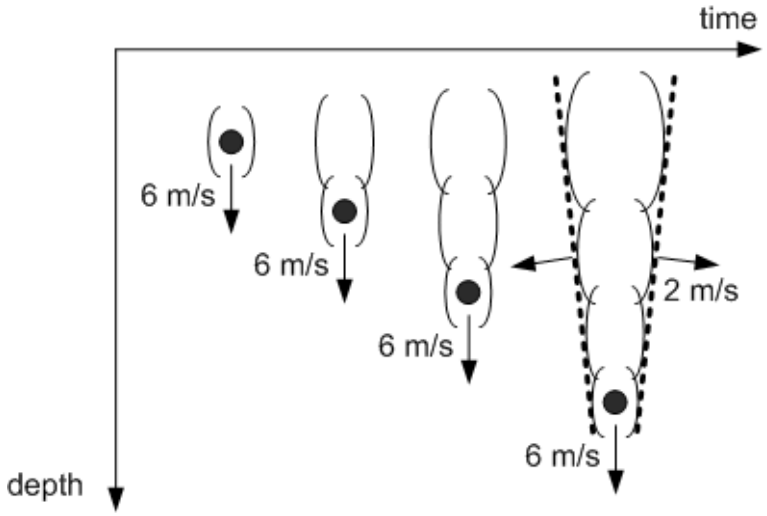


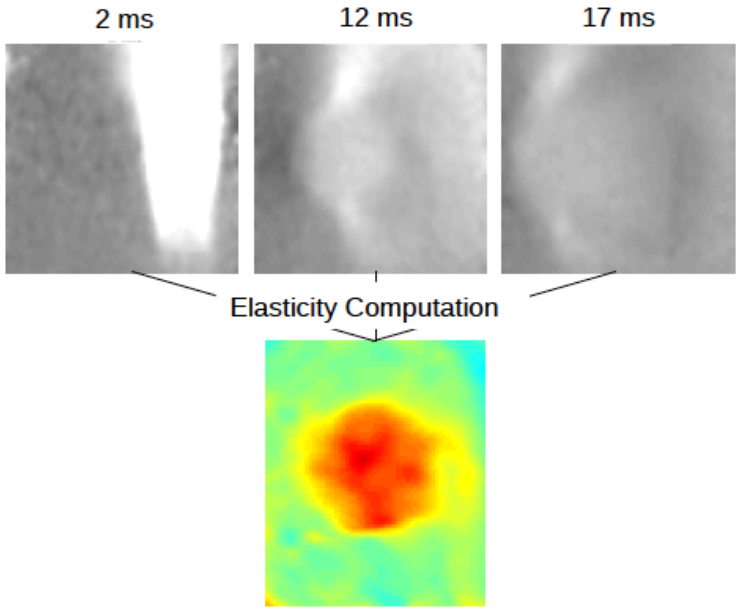
US new technology: Elastography

Focus ultrasound beam in tissue

Propagate focal point at supersonic speed in breast

Measure the deformation of the shock wave by a tumor





US System: SuperSonicImagine Aixplorer

SuperSonic Imagine Aixplorer:

- Real-time ShearWave ™ **elastography**: a unique technology to quantify elastic properties of tissues
- **3D imaging** with a conventional high frequency 3D mechanical linear probe for superficial application
- Acquisition of a 40*40*40mm^3 volume in less than 20s with high resolution B-mode and 3D SWE information
- Voxel size 100µm*100µm*75µm

Provides important information for breast tumour diagnosis and follow-up:

→ Morphology

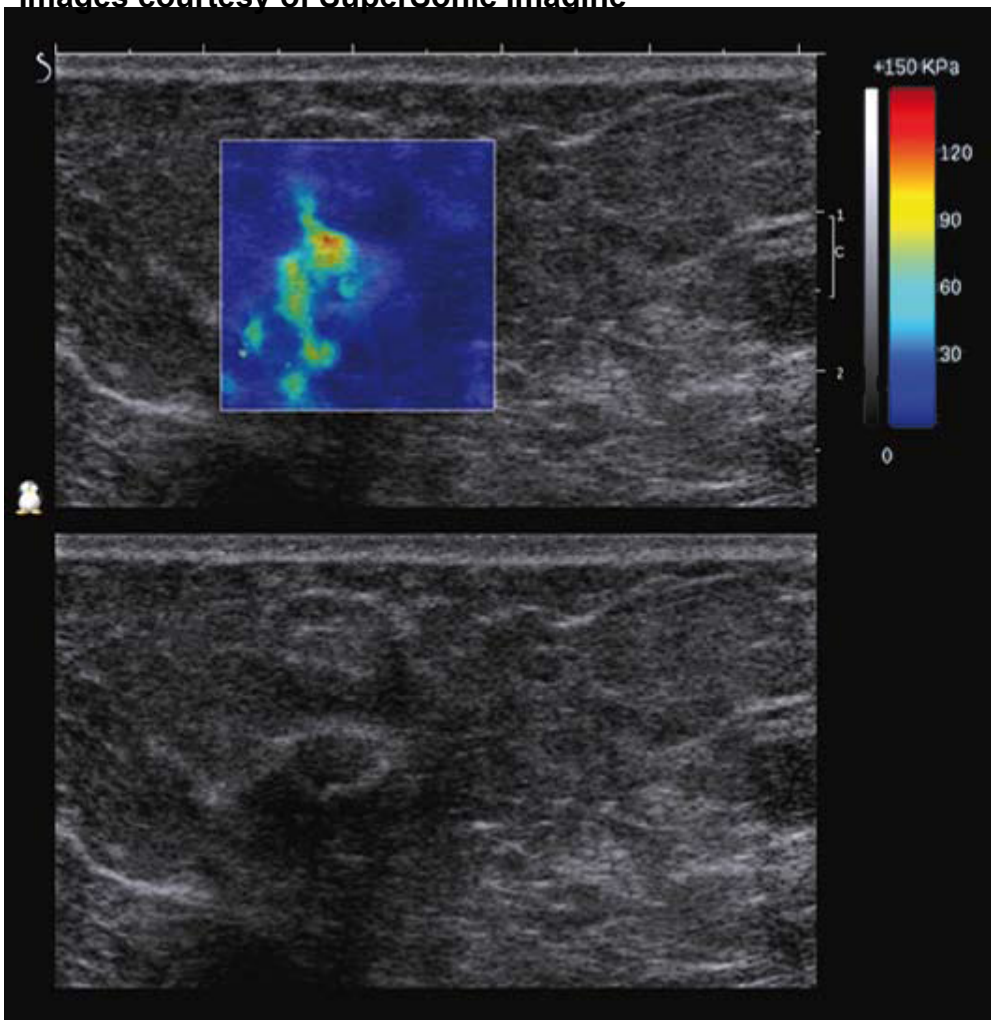
→ Size, shape and volume

→ Acoustic signature and vascularisation

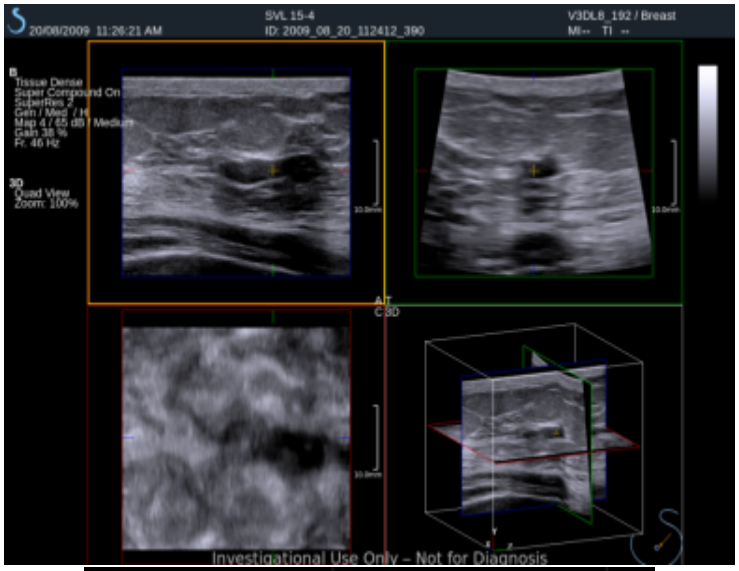
→ Local and global elasticity

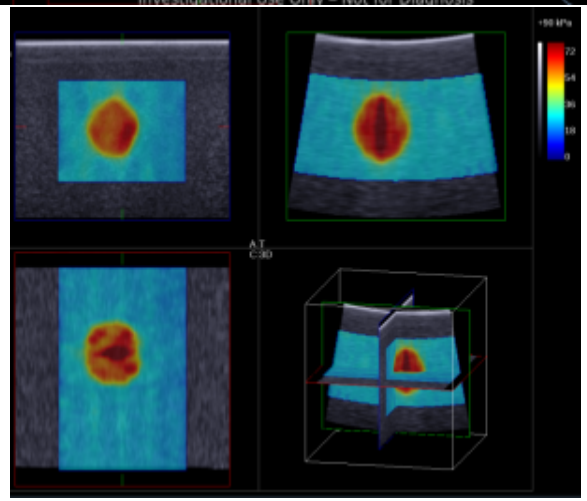
US system: 2D and 3D Information

Images courtesy of SuperSonic Imagine



2D image, millimetric lesion





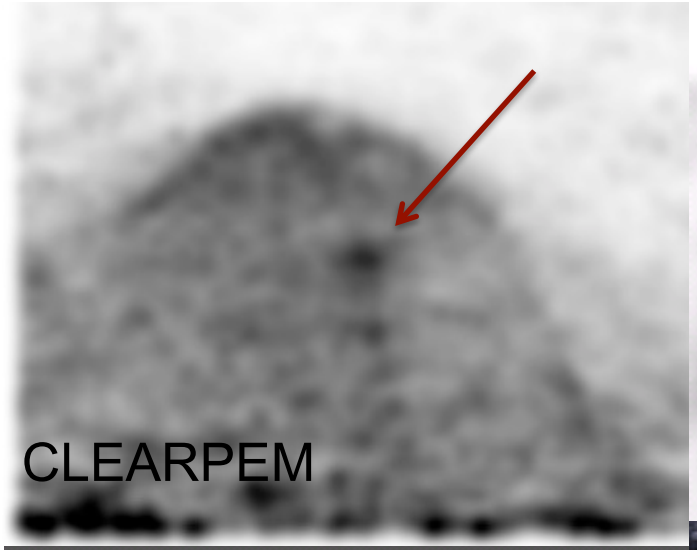
3D image, phantom lesion

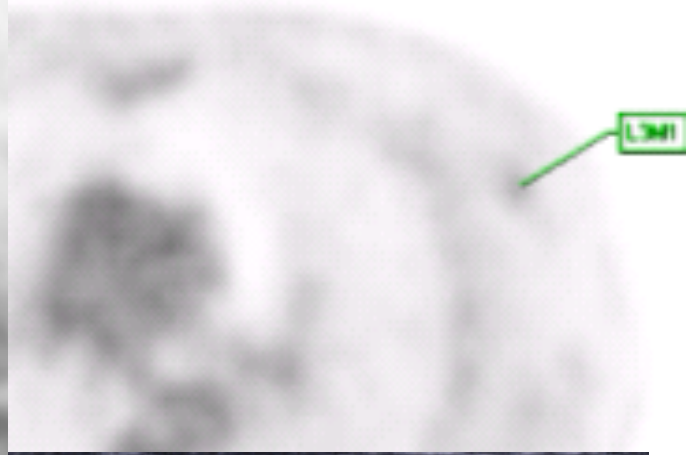
Phase 1: Clinical test

Phase 1 clinical study in Marseille:

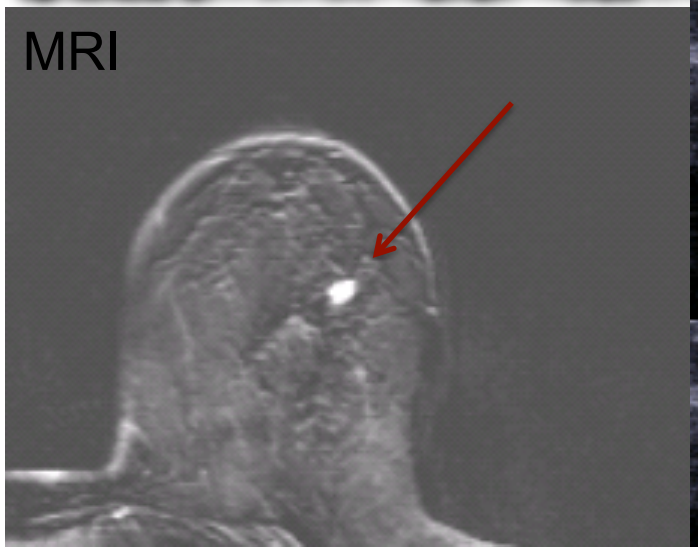
- 20 patients
- FDG injection for Whole-body PET

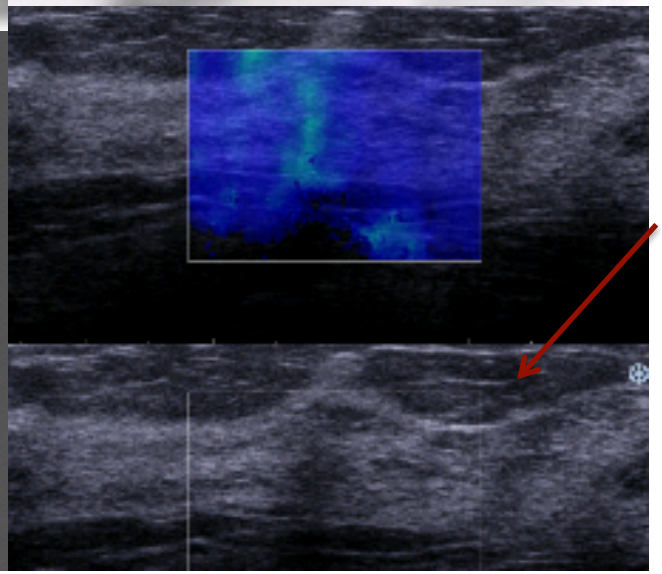
Clinical Test: Patient 1





WB
PET



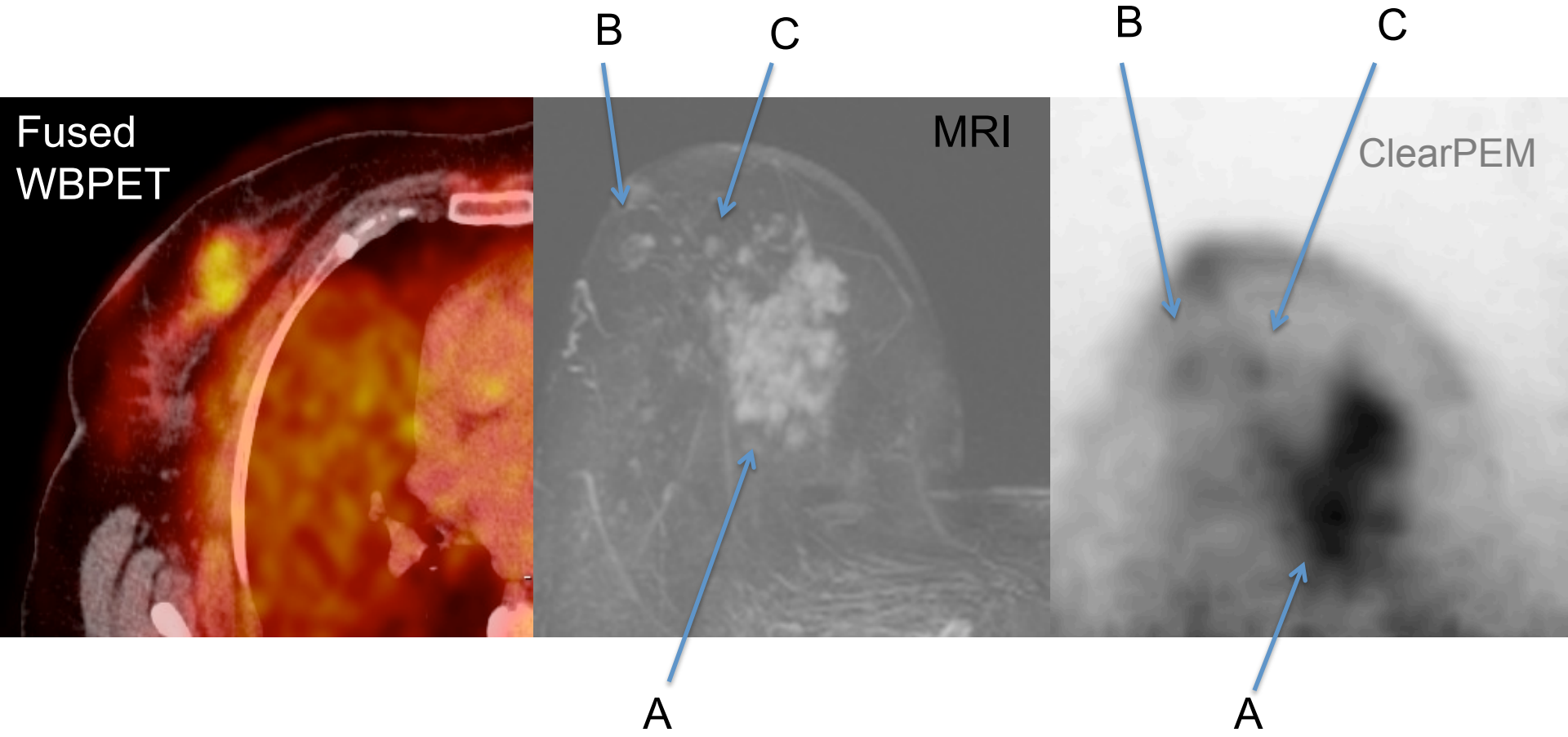


Elasto

echo

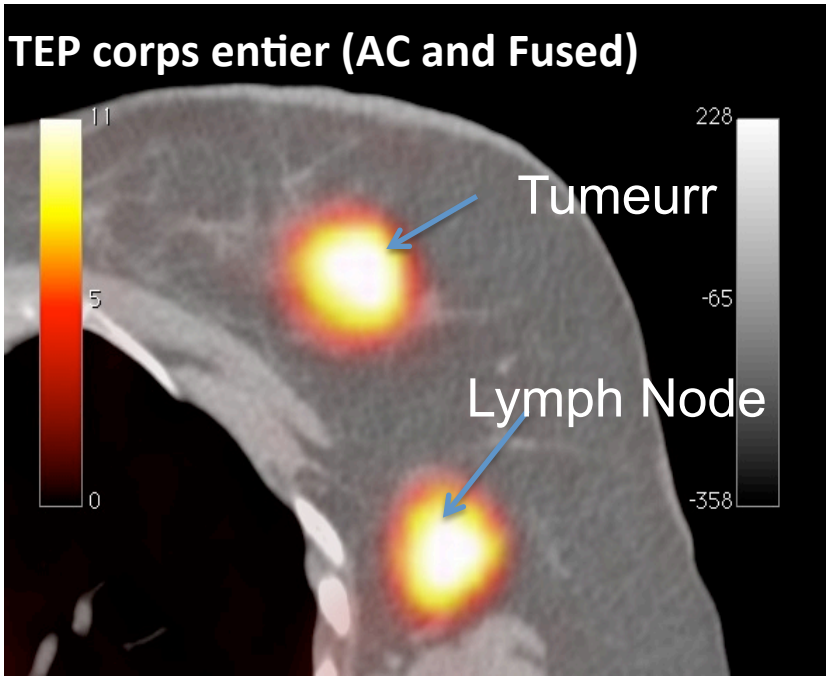
Controlateral lesion seen with PEM, MRI,US not by whole body PET

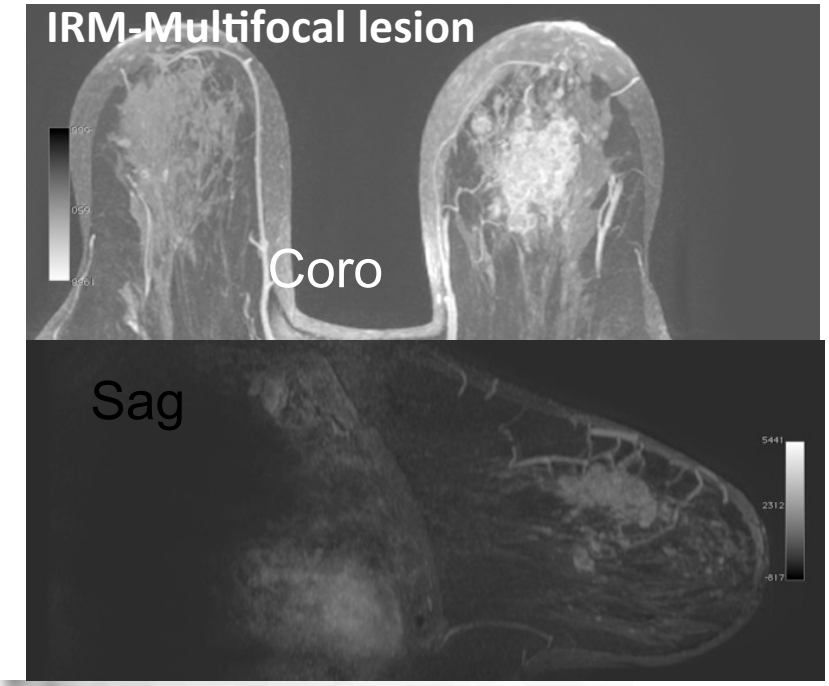
Clinical Test: patient 2

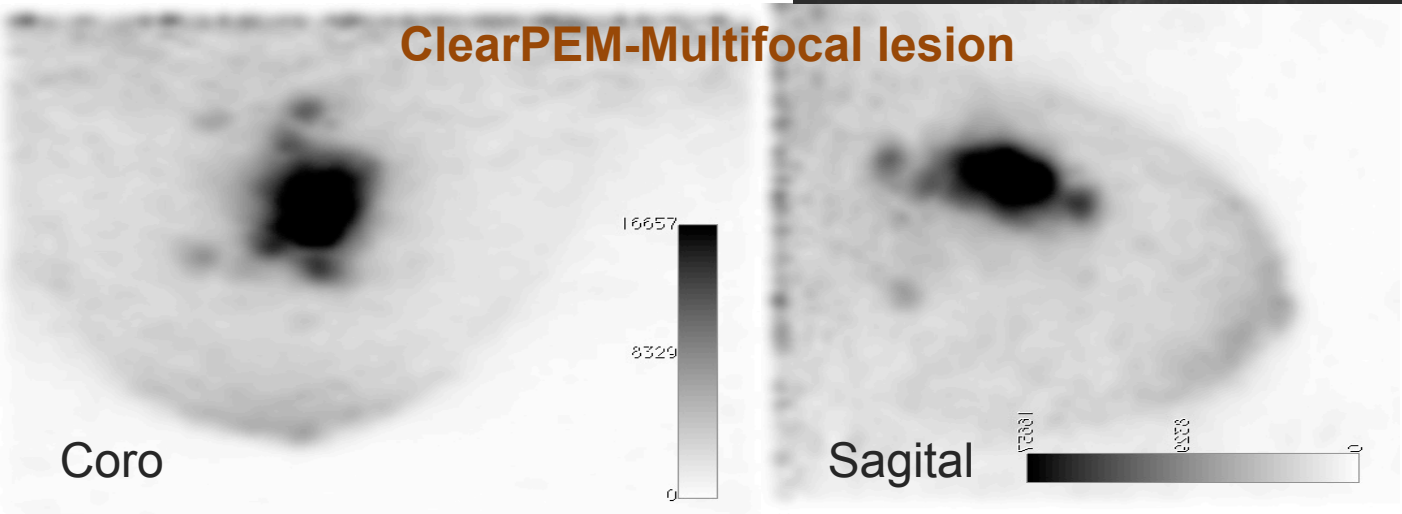


A: breast tumor confirmed by histology
B,C: additional lesion described as suspect with MRI and also PEM
but histology revealed no additional tumoral lesion (inflammatory lesions)

Clinical Test: patient 3



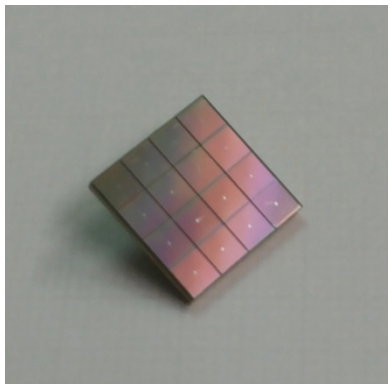




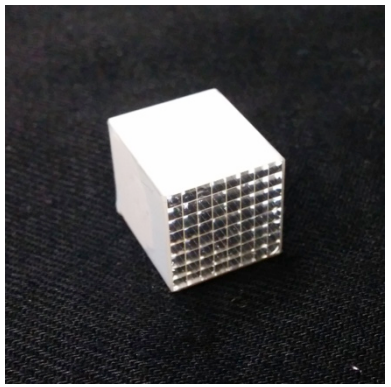
New ClearPEM Module

In 2014: develop a PET module that allows the same performances in term of spatial resolution and energy resolution with a reduced cost and better timing resolution

1. Replace APDs by SiPM
2. 4 to 1 coupling between the detector and the scintillators.
3. DOI capability with a single side readout.
4. Use Fast electronic developed by Petsys TOFPET ASIC (see EndoTOFPET-US & S. tavernier talks)
5. Easy to produce.



- 4x4 MPPC array from Hamamatsu
- Active area 3x3 mm^2
- Pitch 3.1 mm

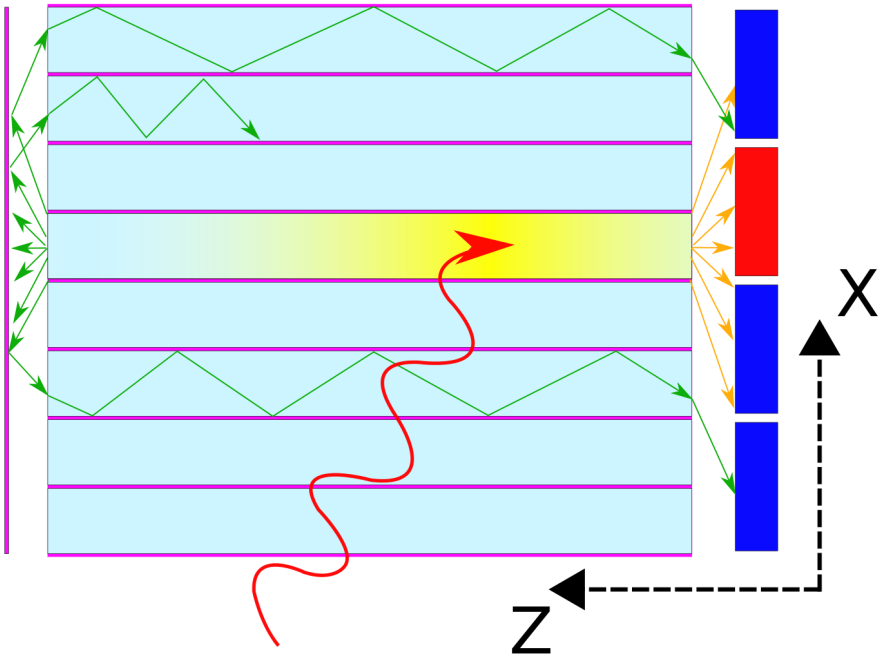


- Crystals: 1.53x1.53x15mm^3 LYSO
- Gaps 70 micron
- Separation foil: Vikuiti

=> New CERN KT contract: KM2912/KT/PH/004C

A new approach to have DOI information with single readout

Glass plate with reflector



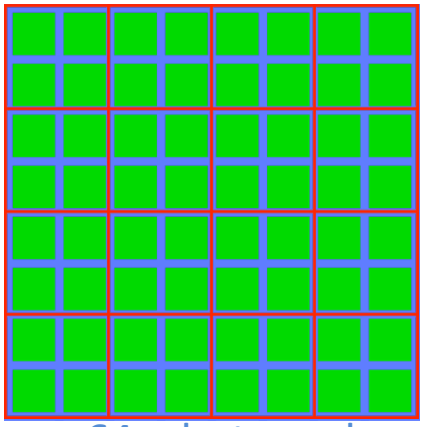
New method for the DOI:

- Only one side readout
- A light guide is placed on the top of the module (same dimension of the matrix)
- The reflector recirculates the light and redirects it to the MPPC array
- Optical treatment of the lateral surfaces of the crystals: depolishing.

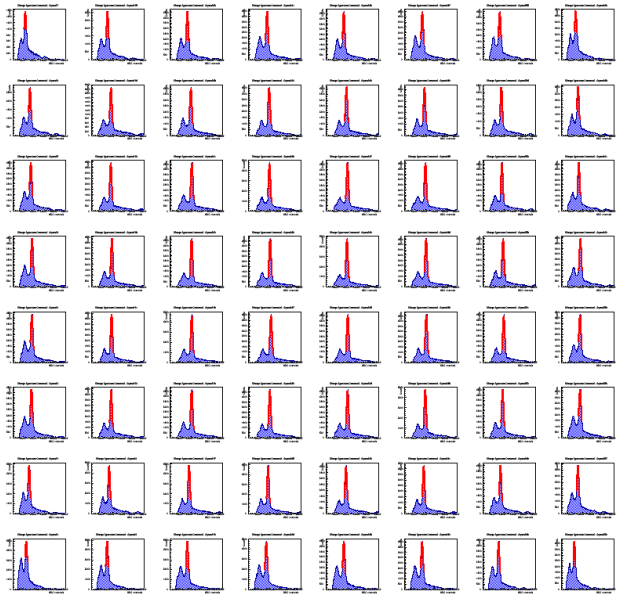
Patent: Ref. Numb. PTC/EP2015/074462

Identification of the crystals

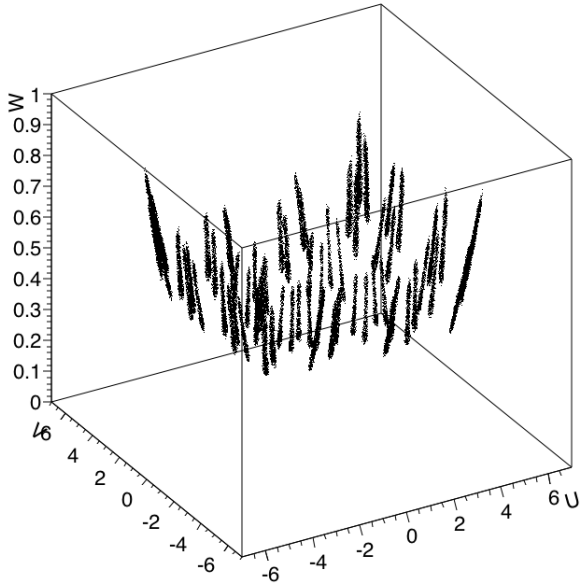
4 to 1 coupling
between the detector and the scintillators

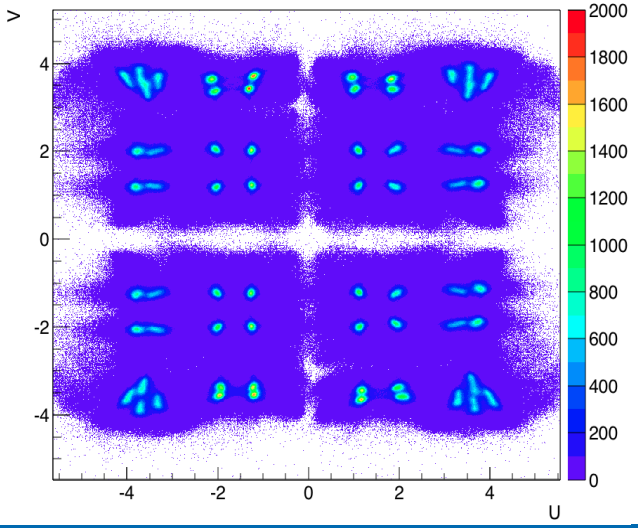


64 photopeaks

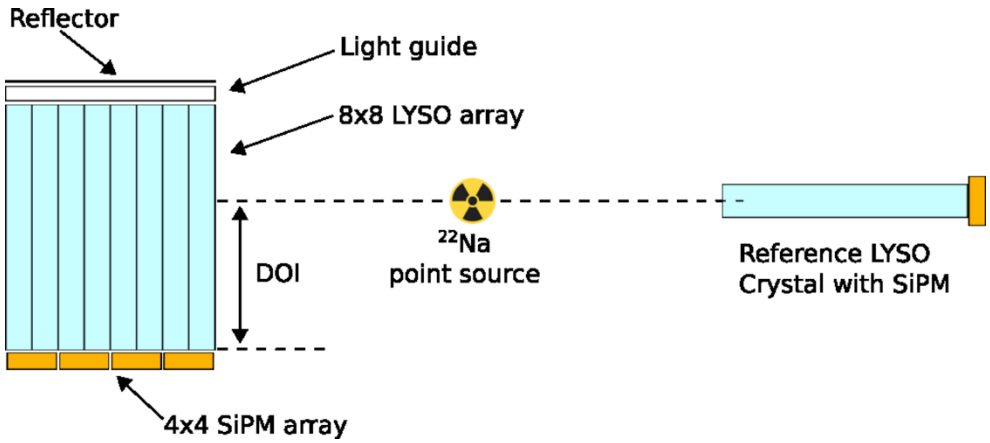


Reconstruction of the 64 crystal positions

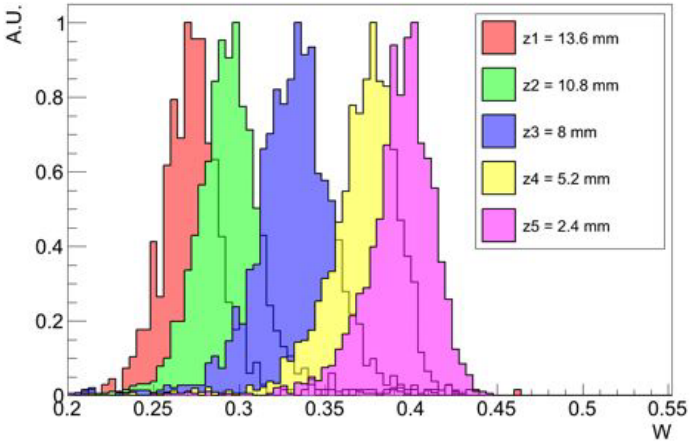




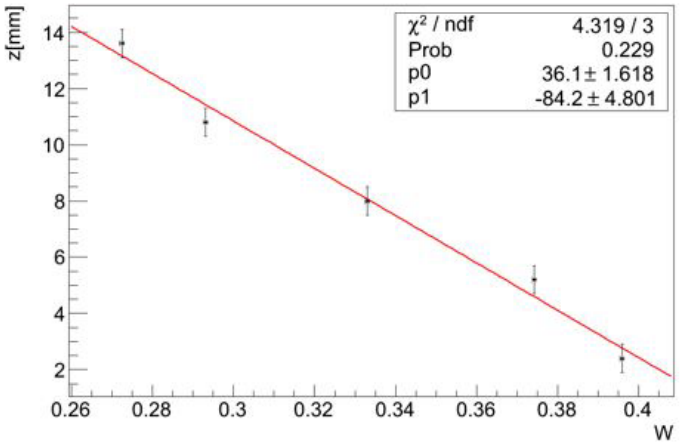
DOI measurement bench

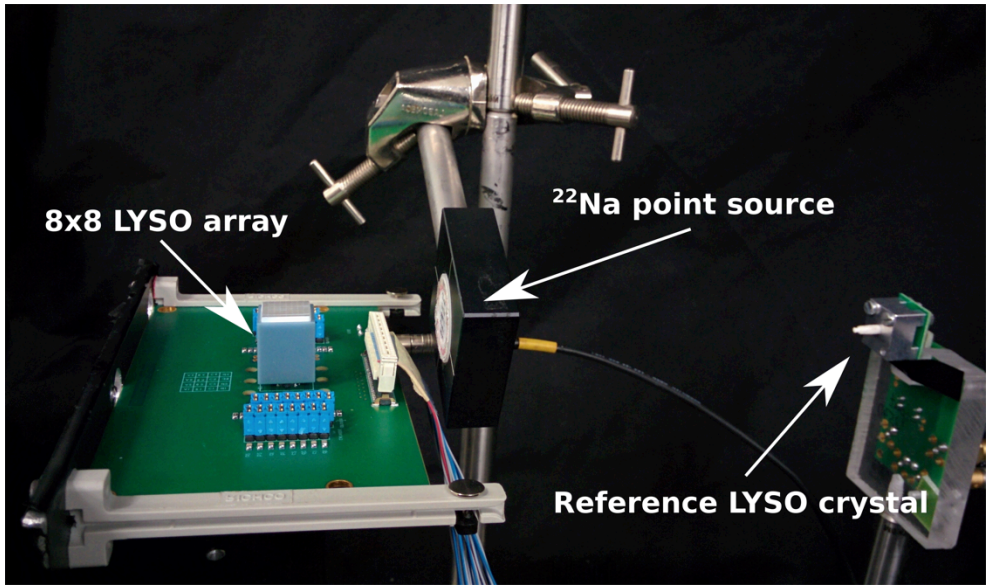


Vertical scan of the matrix
in 5 vertical regions

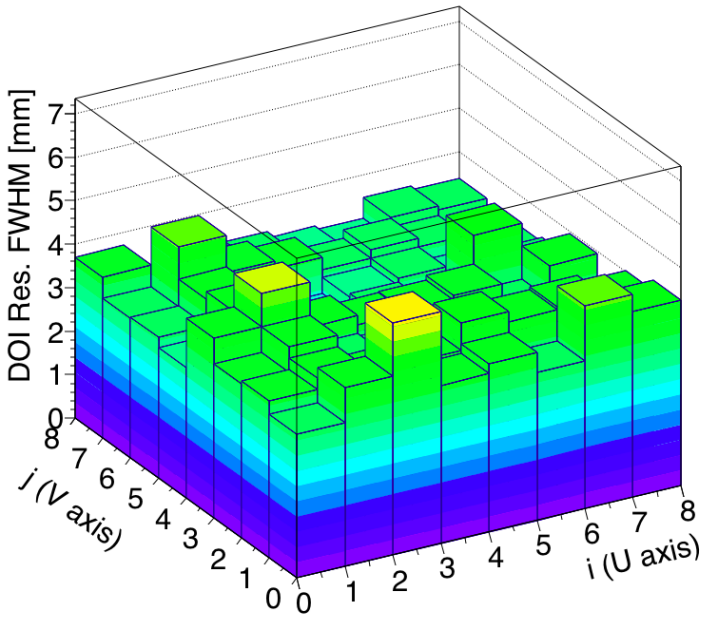


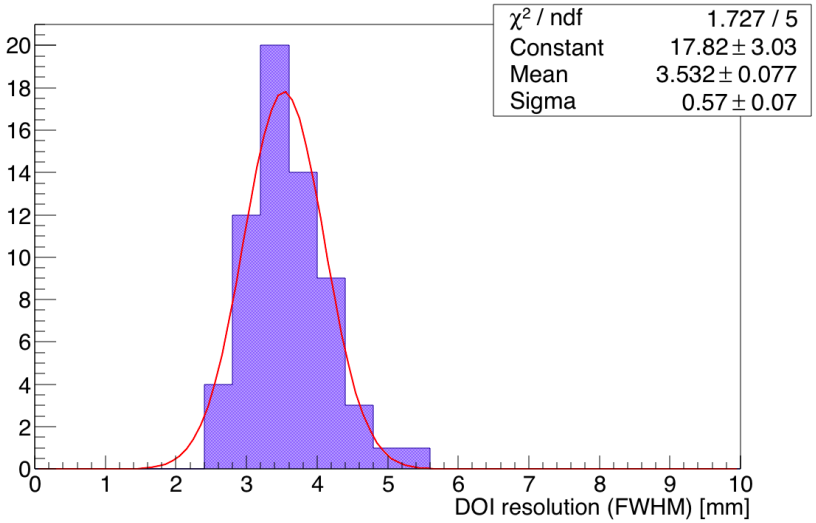
$$w = \frac{p_{max}}{}$$





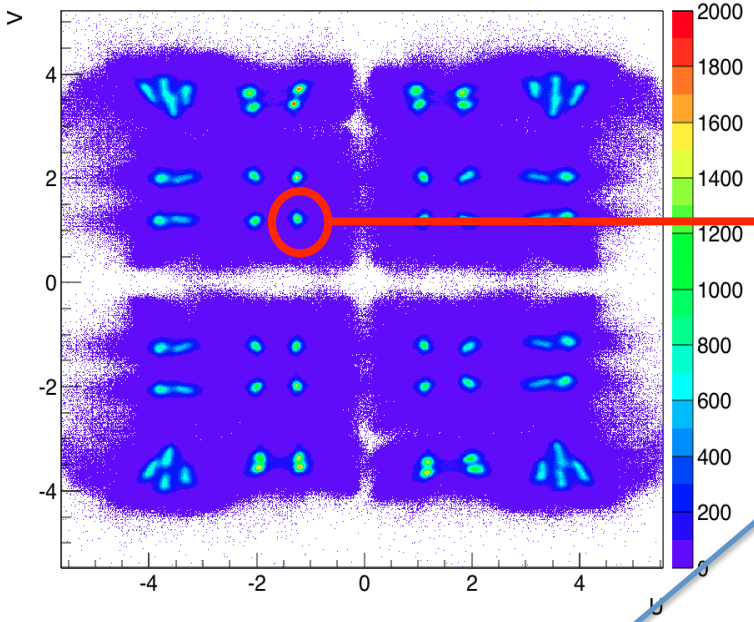
DOI measurements on 64 crystals

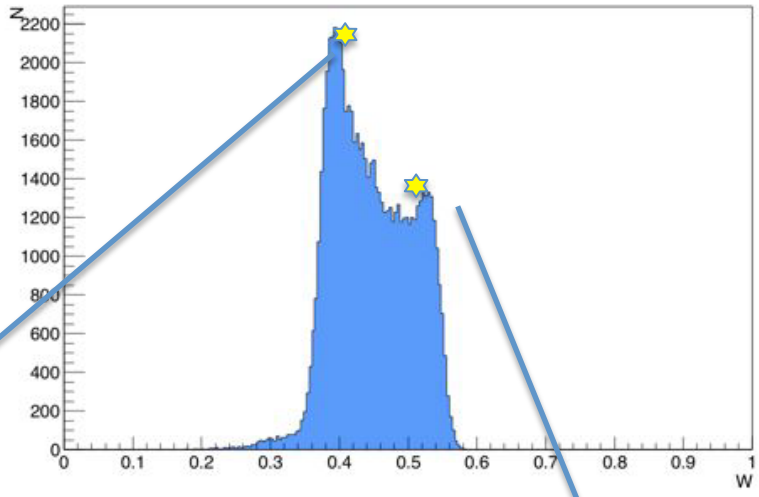




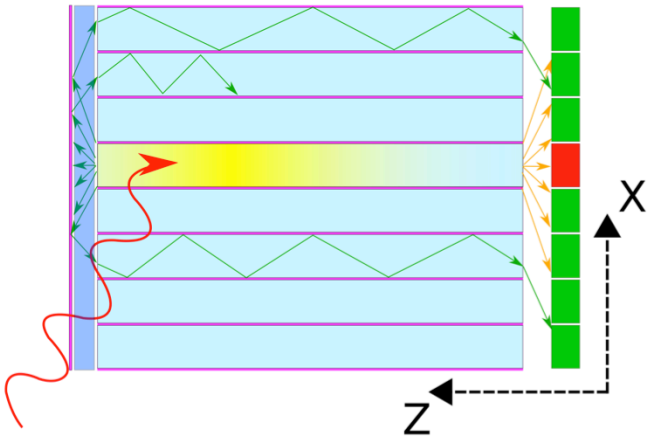
Average DOI 3.5mm

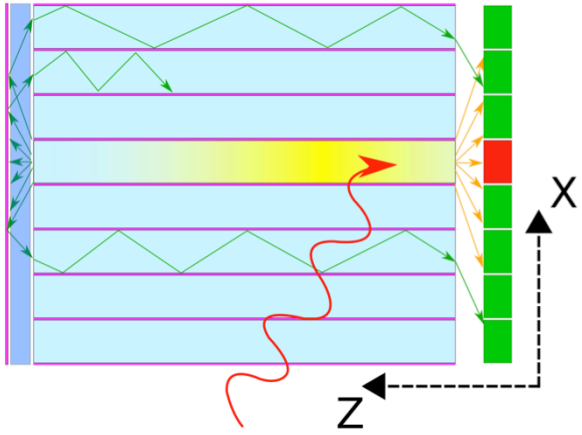
DOI measurements in situ





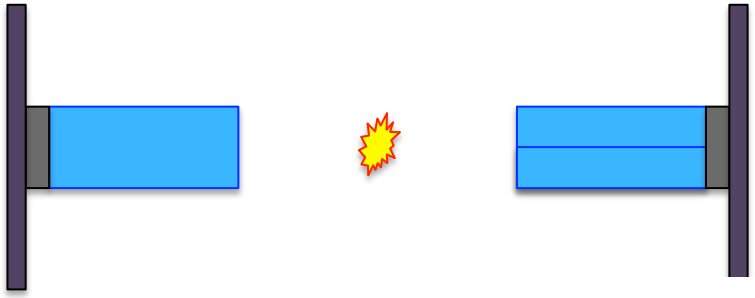
$$w = \frac{p_{max}}{P}$$

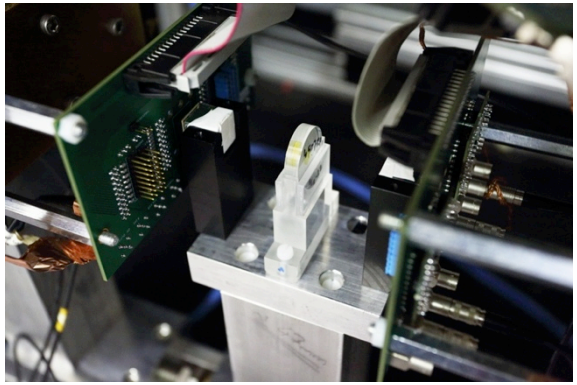


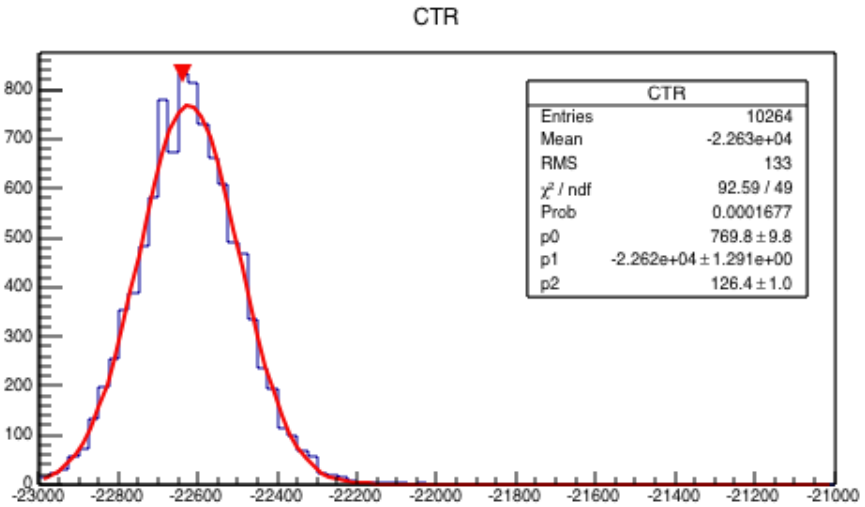


Preliminary results on coincidence time resolution CTR

One polished crystal (3x3x15 mm^3) in coincidence with the matrix readout with Nino board





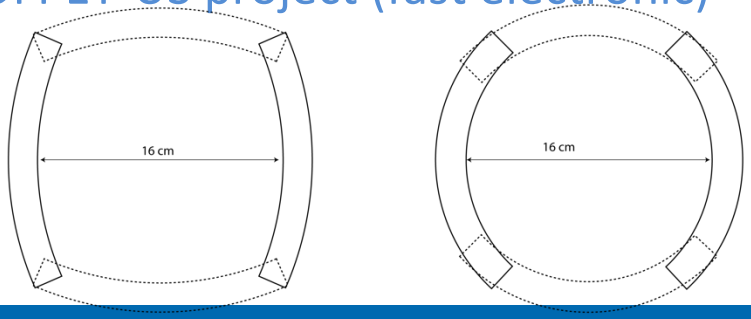


CTR less than 300 ps (FWHM) => expected time resolution for full system 500ps to be compared to 4.5ns of the current machine

Conclusion & perpectives

- **Development of dedicated breast imaging PET: ClearPEM:**
  - Spinoff of High energy experience
  - in a collaborative way including academia, industry and medical doctors
  - First prototypes have demonstrated feasibility and show excellent performance with some limitations: low sensisitivity close to the chest wall

- A commercial system requires to significantly bring down production costs in order to be competitive

⇒**Develop a new ClearPEM detection modules** with same performances but less expensive
  - ⇒ Simplification of Mechanic
  - ⇒ Replace APDs by commercially available SiPM arrays
  - ⇒ Benefit from synergies with the FP7 EndoTOFPET-US project (fast electronic)
  - ⇒ Compatible MRI

Possible geometry of a future ClearPEM