Photon Detection in Medical Imaging

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16.Feb.2011

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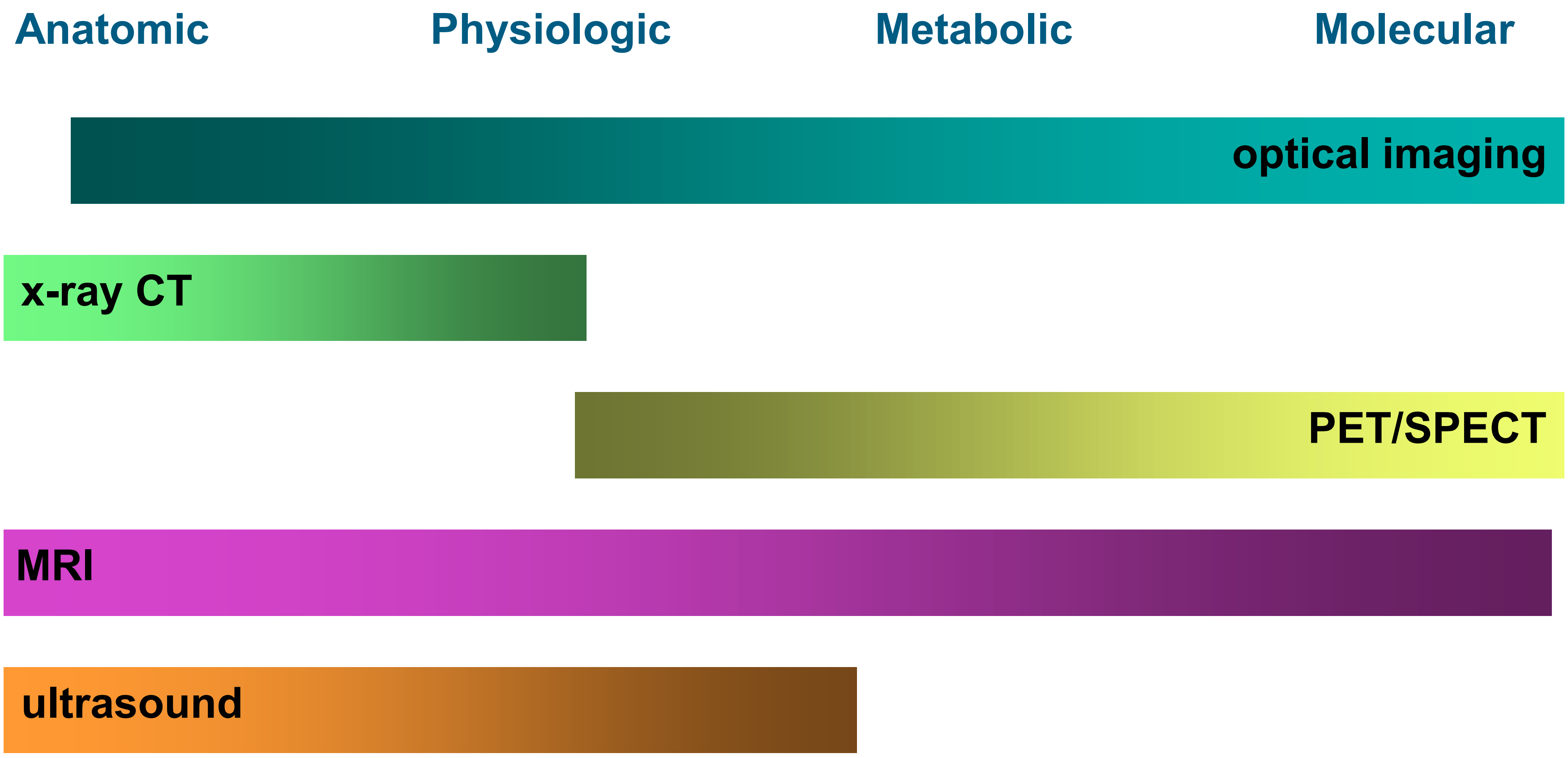
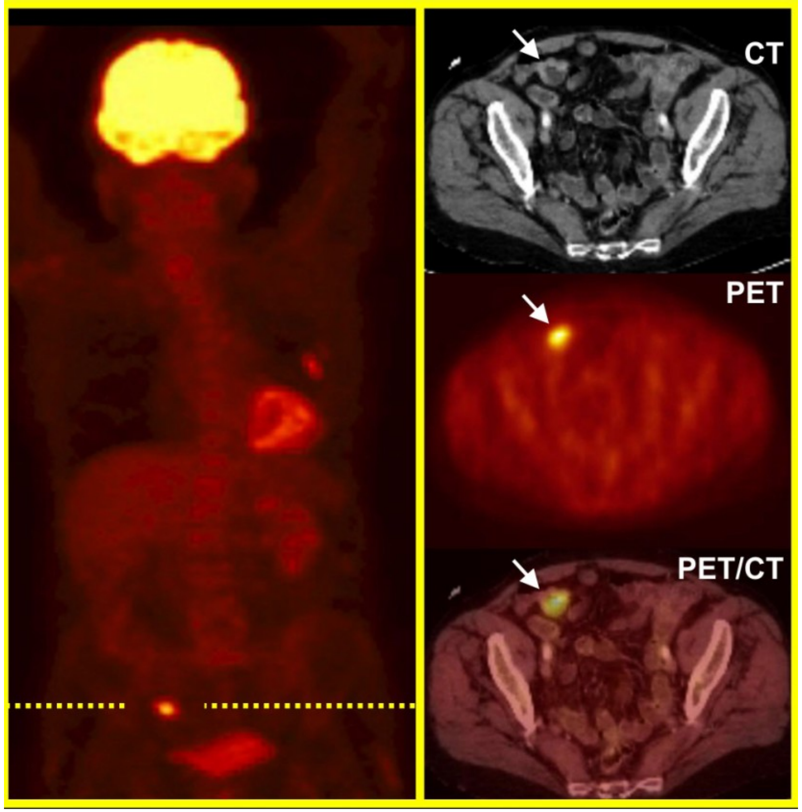
In Vivo Medical Imaging Technologies



Positron-Emission-Tomography

PET quantitatively and non-destructively measures the 3-D distribution of radiolabeled biomolecules *in vivo*



Metastasis of a malignent melanoma
D.Townsend, 1995

Challenges in Emission-Tomography

fundamentals:

a) to obtain as many counts as possible

→ **high sensitivity**

b) to localize these counts as accurately as possible

→ **high spatial resolution**

→ **high temporal resolution**

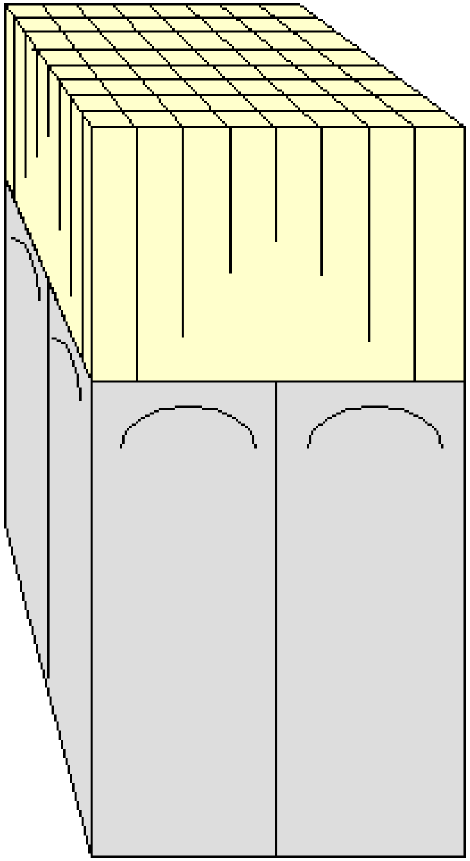
Approaches

- **Scintillation Detector**
  - Photomultiplier tube (PMT)
  - Avalanche photodiode (APD)
  - Silicon photomultiplier (SiPM)

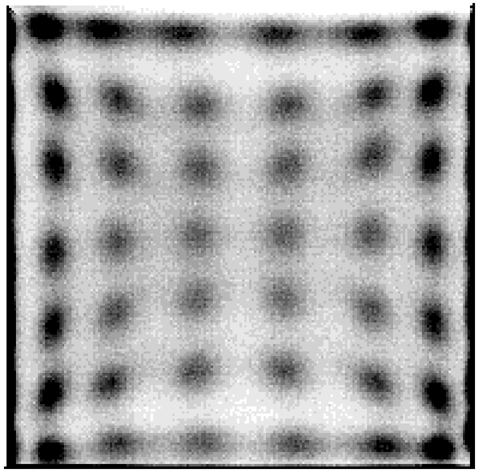
- **High Density Semiconductors**
  - CdTe or CZT
  - Ge
  - TlBr

1986 - The block detector

A large number of scintillation crystals are coupled to a smaller number of PM-tubes. In the block detector, a matrix of cuts are made to define the detector elements.
The light produced in each crystal will produce a unique combination of signals, which will allow the detector to be identified.



M Dahlbom, UCLA



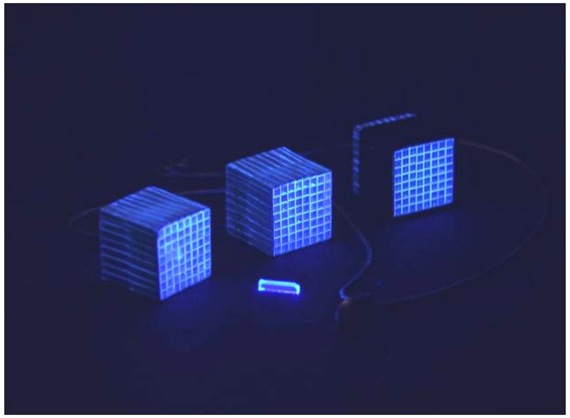
Flood response for a block detector

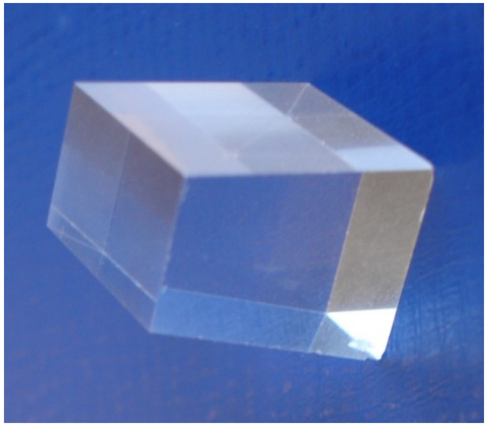
PET Scintillators

Scintillator	90% efficiency (cm)	Light output (photons/MeV)	Decay time (nsecs)
BGO	2.4	7,000	300
BaF_2	5.1	2,000	0.8
CsF	5.4	1,900	4
LSO, LYSO	2.6	25,000	42
$LaBr_3$	4.9	60,000	27
LuI_3	4.1	100,000	30

PET Scintillators

from a pixelated to a monolithic block concept

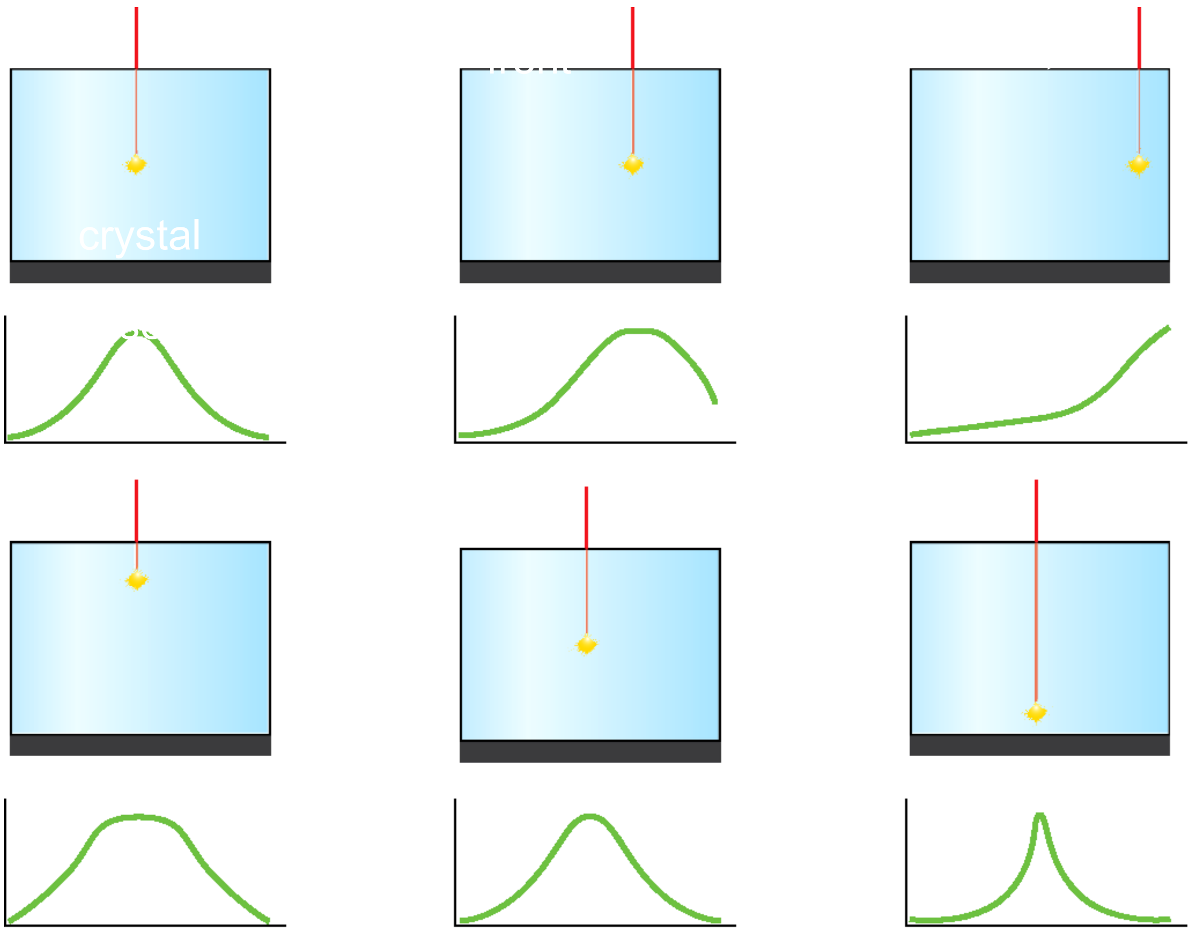




- Increase sensitivity (no inter-crystal separations, reduced dead space)
- 3D position information embedded in the light distribution
- extract parallax-corrected incidence coordinates with good accuracy
- continuous coordinates
- easy to manufacture and to assemble

Impact on the dynamic range of a photon detection system
(from a few photons up to 1000ph/event)

Monolithic scintillator detectors

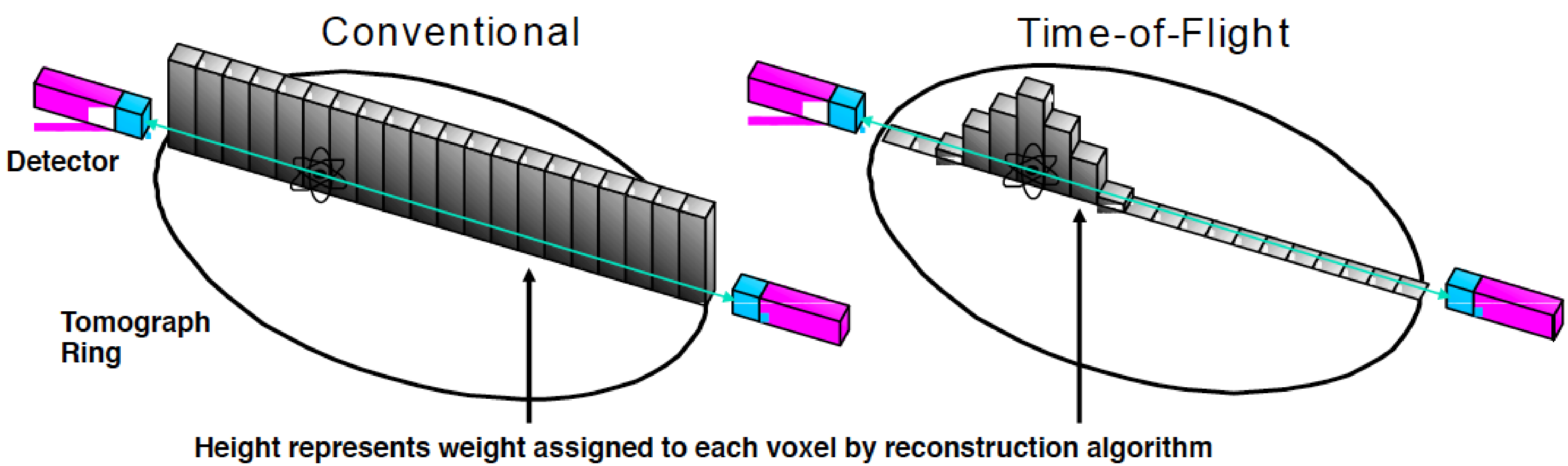


Light distribution depends on the entry point on the front surface…

and on the depth of interaction (DOI).

Data courtesy by D.Schaart

Adding Time-of-Flight to Reconstruction
➔ Faster Convergence



Data courtesy by W.Moses

Conventional:

- Detected event projeted to all voxels between detector pairs
- Lots of coupling between voxels

→ Many iterations to converge

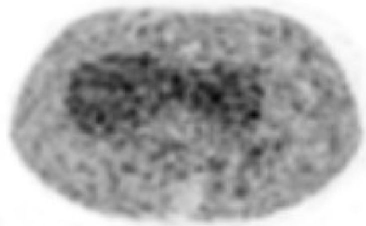
Time-of-Flight:

- Detected event projeted **only to** voxels consistent w measured time
- Little coupling between voxels

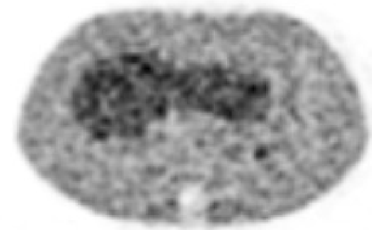
→ Few iterations to converge

Whole Body – Time of Flight Simulation

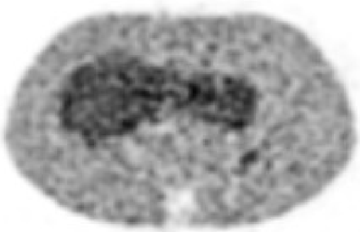
Phantom
(1:2:3 body:liver:tumor)



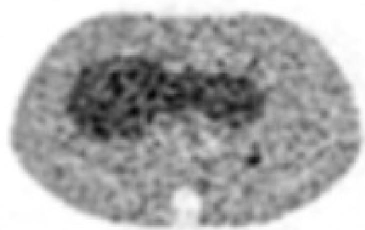
Conventional



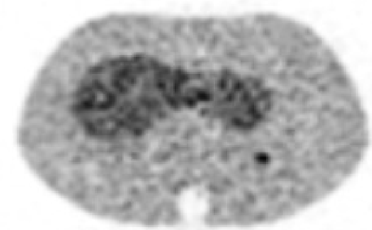
1.2 ns



700 ps



500 ps



300 ps

Data courtesy by Mike Casey, CPS Innovation

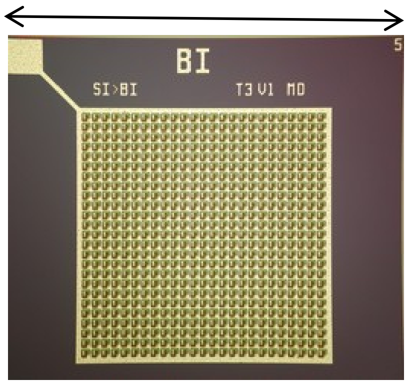
Clear improvement of contrast enhancement visually!

SiPM – Silicon Photomultiplier

Features

- High gain
- **Fast response time**
- Low bias voltage (tens of volts)
- **Insensitive** to magnetic field
- **Compact** and rugged
- Small nuclear counter effect

- Non-linearity at higher light levels
- Dark noise a problem at very low light levels
- Less mature technology



Avalanche Photodiode *working in limited Geiger mode, courtesy by FK-irst, Italy*

SiPM – Development Platform in Medical Imaging

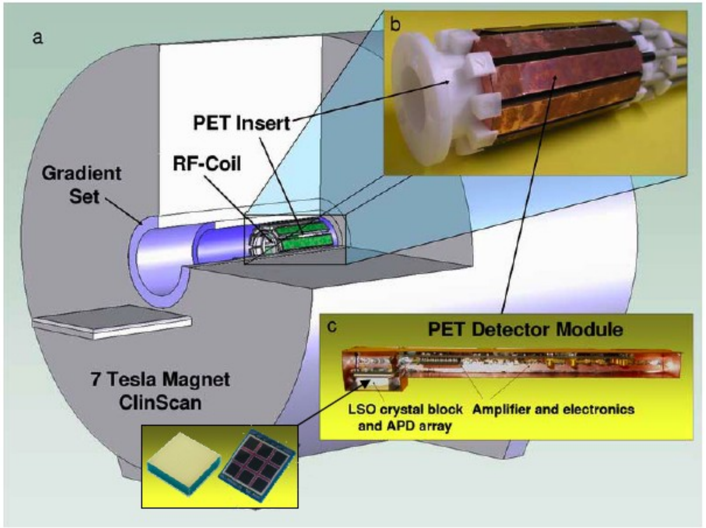
Current developments

1. Small Animal PET Scanner

2. Hybrid PET/MR preclinical/clinical scanner

3. PEM (PET for Mammography)

4. Prostate scanner

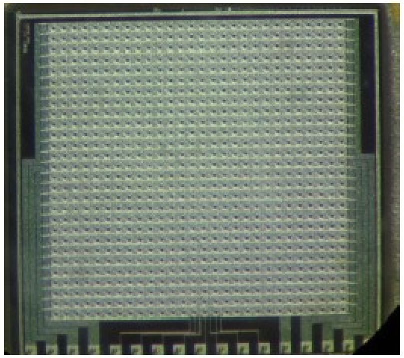


Slide Courtesy: Judenhofer

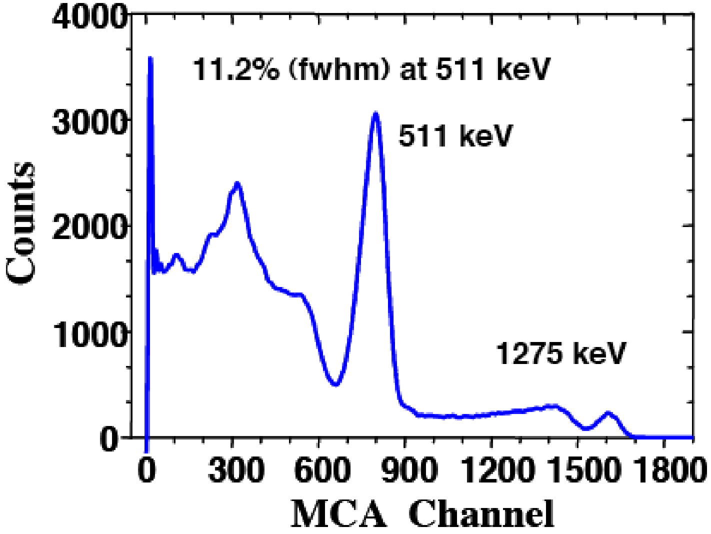
Solid State Photomultipliers (SSPMs)

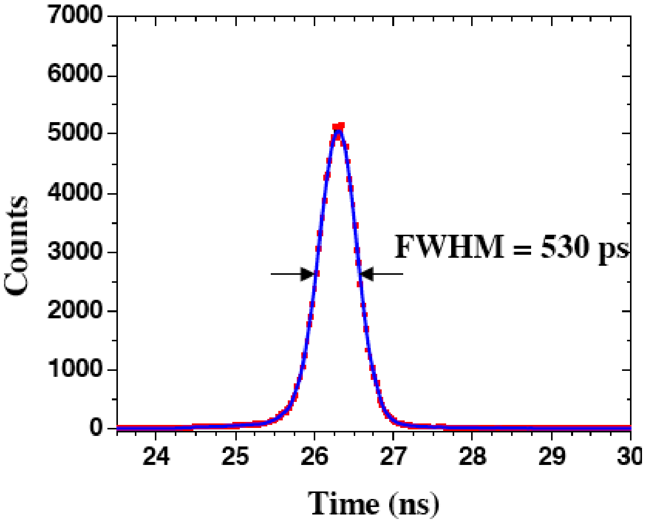
CMOS process

- Lower cost for mass production
- On-chip integration with electronics possible



3x3 mm² SSPMs, ~800 pixels



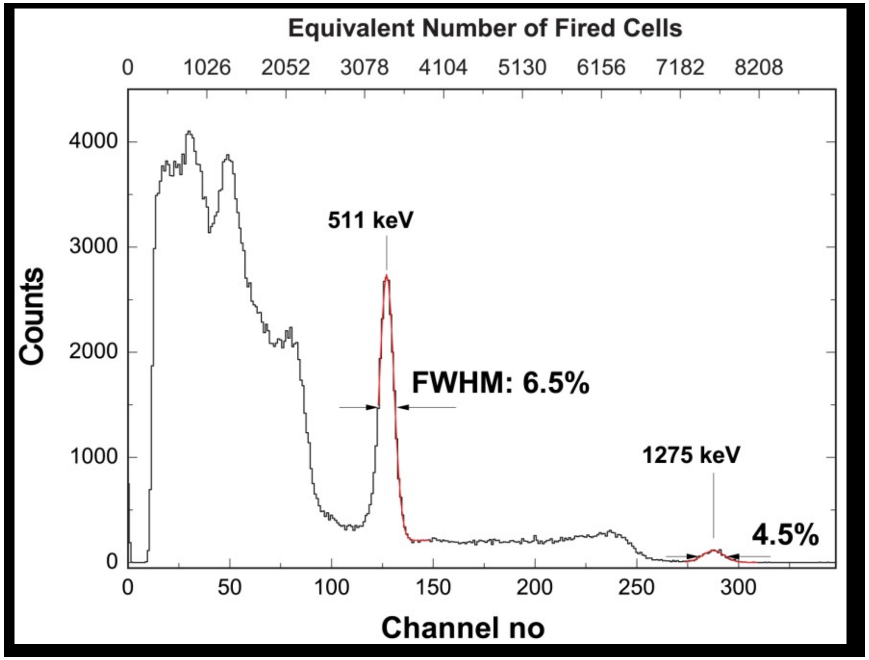


Data courtesy by S.Cherry, UC-Davis

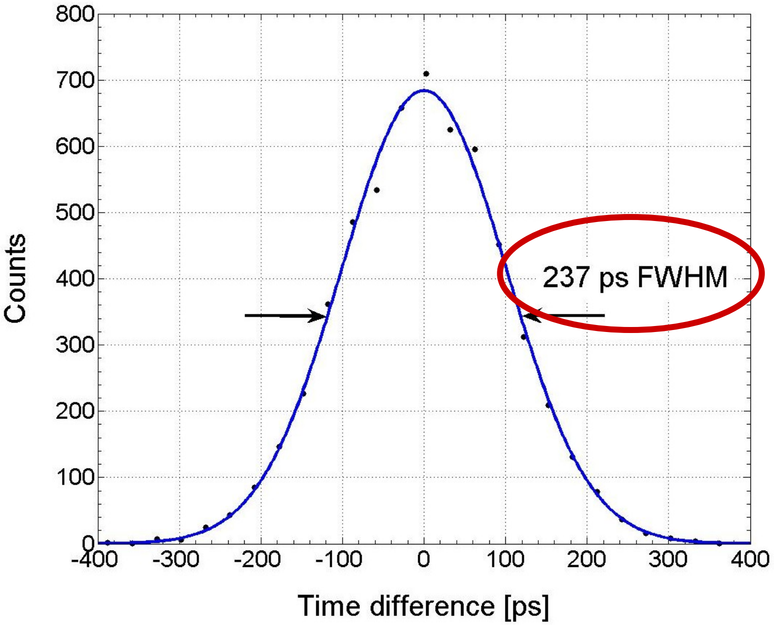
$LaBr_3:Ce^{3+}$ with SiPMs: First results

(data from D.Schaart et al., IEEE Oct.2008)

3 x 3 x 5 mm^3 $LaBr_3:Ce^{3+}$ on 3 x 3 mm^2 Hamamatsu S10362-33-025C SiPM



^{22}Na pulse height spectrum



Coincidence timing spectrum
(two $LaBr_3:Ce^{3+}$/SiPM detectors)

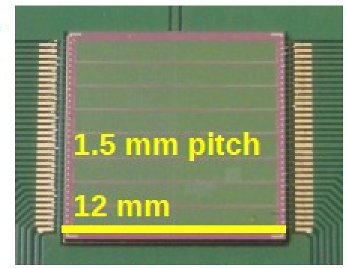
SiPM – Small Animal PET Scanner

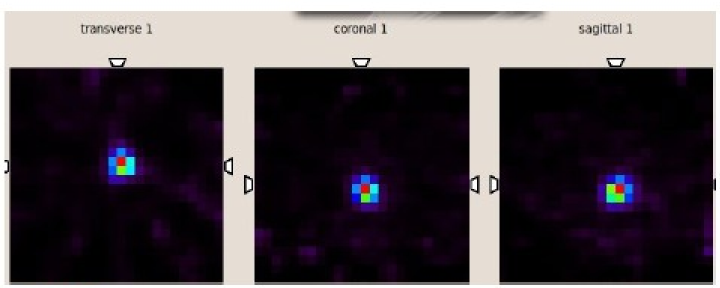
IRIS group @ IFIC, Valencia

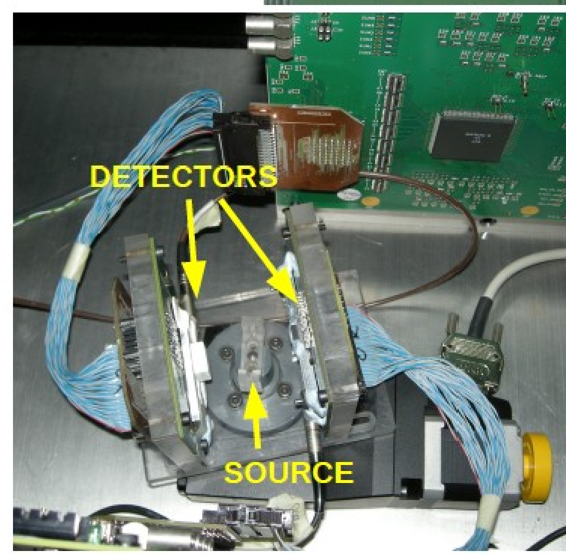
CSIC

VNIVERSITAT DE VALÈNCIA

- **ASPID project:** Application of Silicon Photomultipliers to Imaging Devices.
- Collaborating with University of Pisa and INFN Pisa in the development of a small animal PET scanner.
- Continuous LYSO crystals and monolithic, 64 pixel SiPM matrices from FBK-irst (AdvanSiD, Italy).
- Readout: MAROC2 ASIC from LAL, Orsay.
- First prototype developed and preliminary images reconstructed.







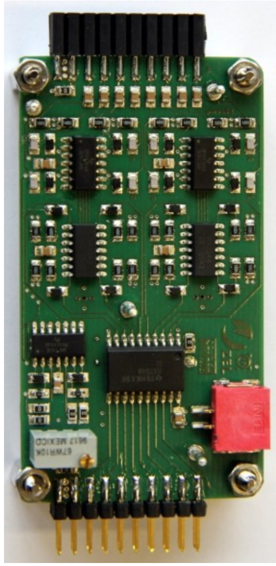
MARIE CURIE ACTIONS

G. Llosá et al. 2010 IEEE NSS MIC Conf. Record. M19-70.

PET/MR Electronics in Development @ Juelich

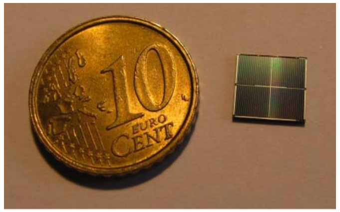
Intelligent Sensor

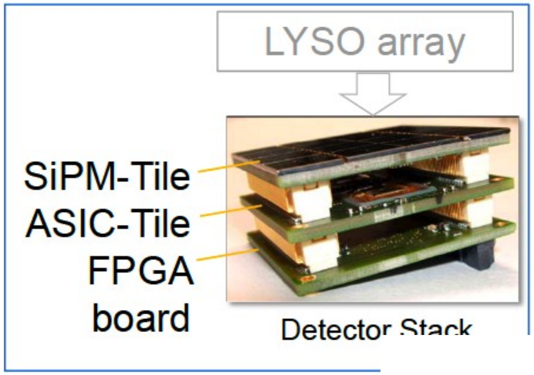
- Lower cost for mass production
- On-chip integration with electronics possible
- MR compatibility
- Active quenching for fast response (≈ps range)



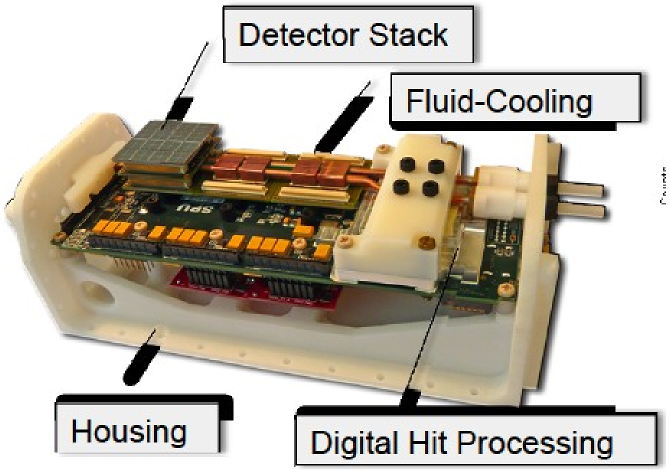
Q2t
with
active threshold
@ Juelich, Germany

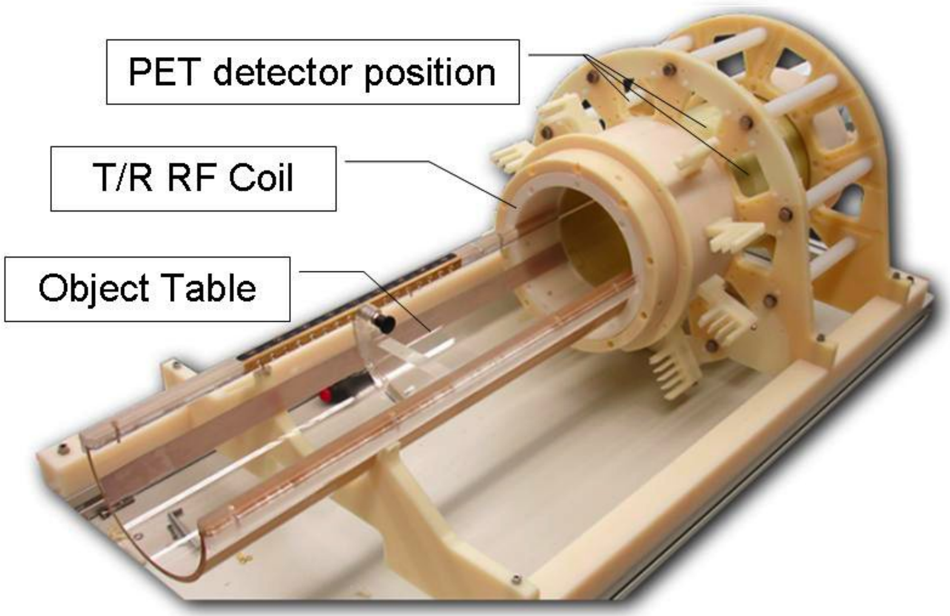
PET Insert @ Philips Research, Digital SiPM





SiPM-Tiles:
- 32.7 x 32.7 mm^2-4x4 monolithic SiPM arrays
- each monolithic array with 2x2 pixels with 4x4 mm^2 diode





Slide Courtesy: V.Schulz

PET Insert @ Philips Research, Digital SiPM

- Direct digitalization to offer best ToFperformance
- Detector Stack:
  SiPM arrays with individual TDC/ADCs (on ASIC)
- Onboard hit processing
  (sorting, hit processing, gain corr., walk-corrections, …)
- Scalable PET detector design

  ➔ One technology for clinical and preclinical systems

Motivation to Combine PET and MRI

Strengths

- “Near-perfect” registration of structural and molecular imaging data
- Anatomically-guided interpretation of PET data
- Anatomic priors for PET reconstruction and data modeling
- PET can be combined with advanced MRI techniques such as DWI, DCE MR, MRS, cell tracking and MR molecular imaging agents

Weaknesses

- Technically difficult and likely expensive
- Uncertainty regarding throughput, cost effectiveness and ultimate clinical role

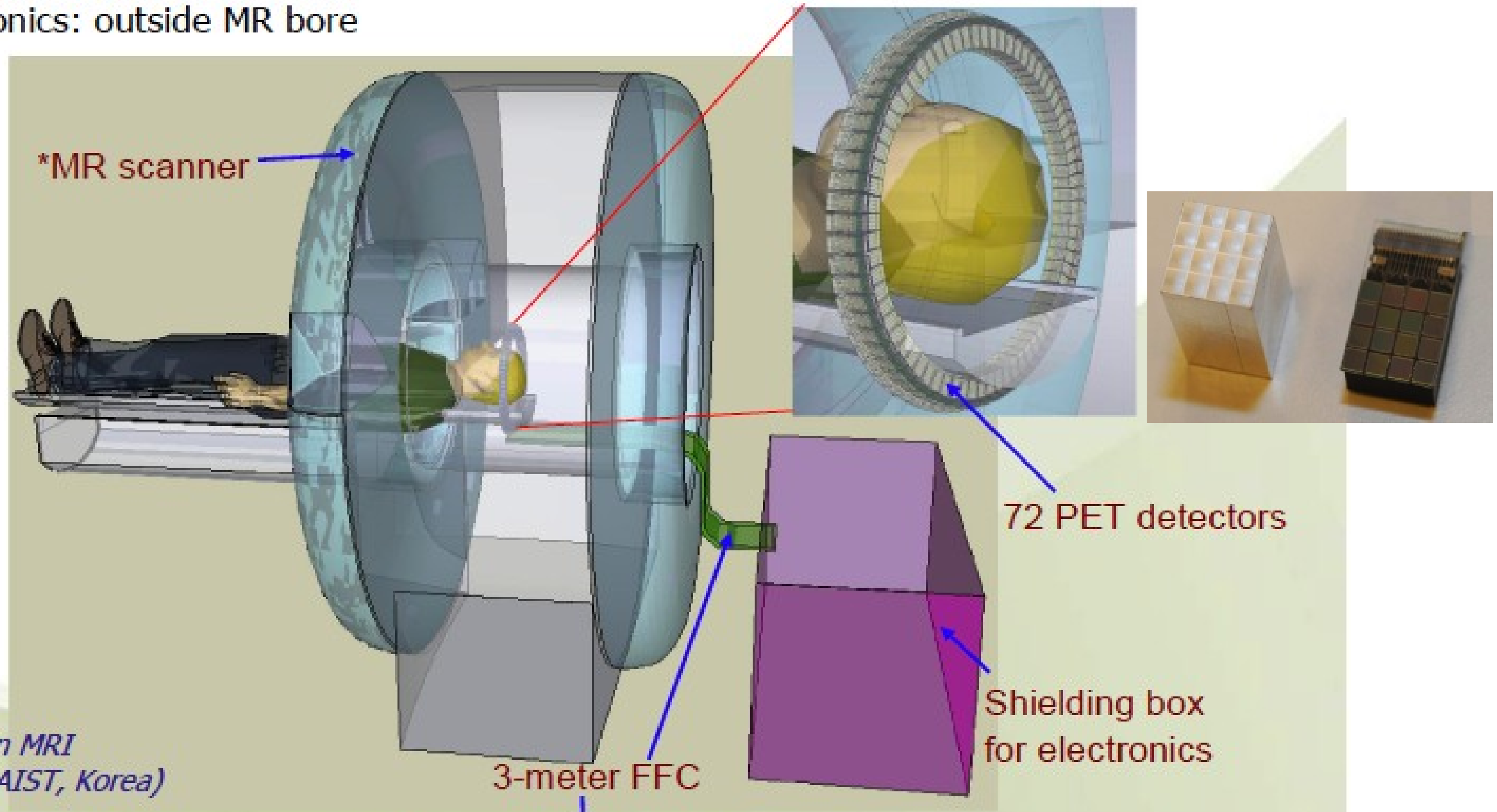
SiPM – Small Animal PET Scanner

Based on SiPM array

Slide Courtesy: Yamamoto, Kobe 2010, Japan

SiPM – BrainPET Scanner

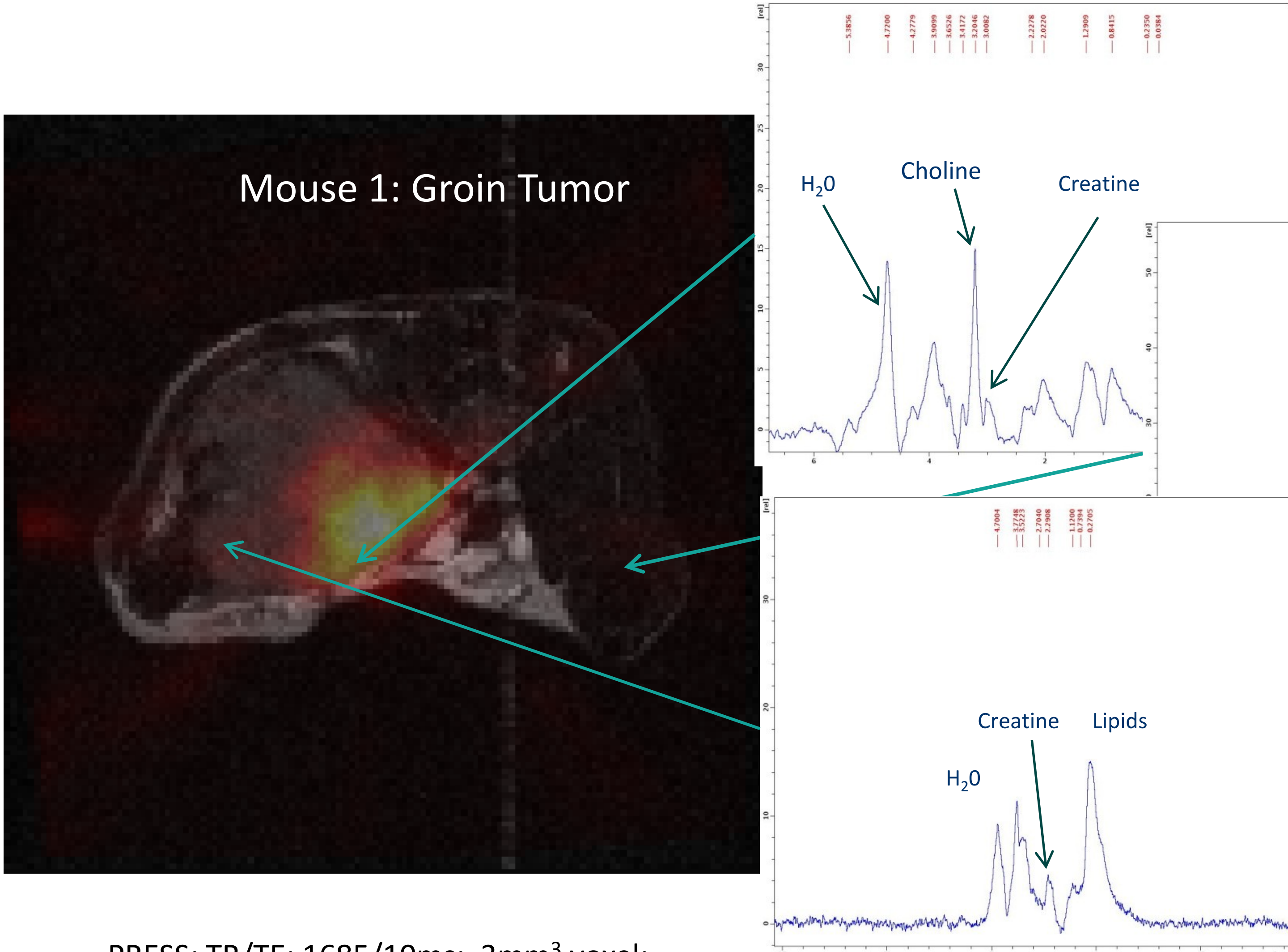
- PET detector ring located inside MRI
  - PET detector: between RF and gradient coils
  - PET electronics: outside MR bore

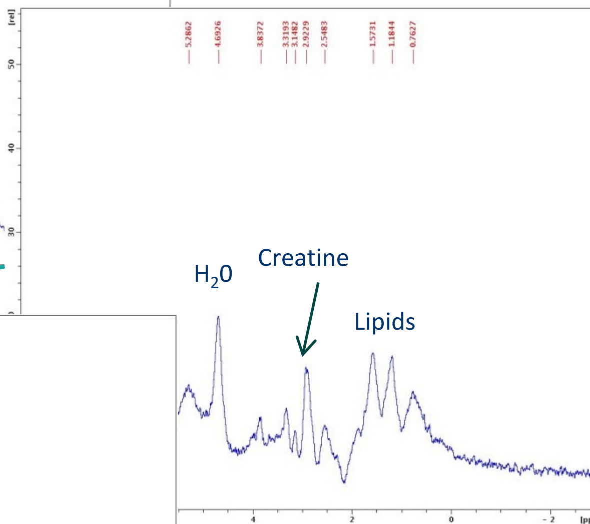


** FORTE 3.0T Human MRI*
(ISOL Technology, KAIST, Korea)

Will be presented by Jihoon Kang

FDG-PET guided MRS





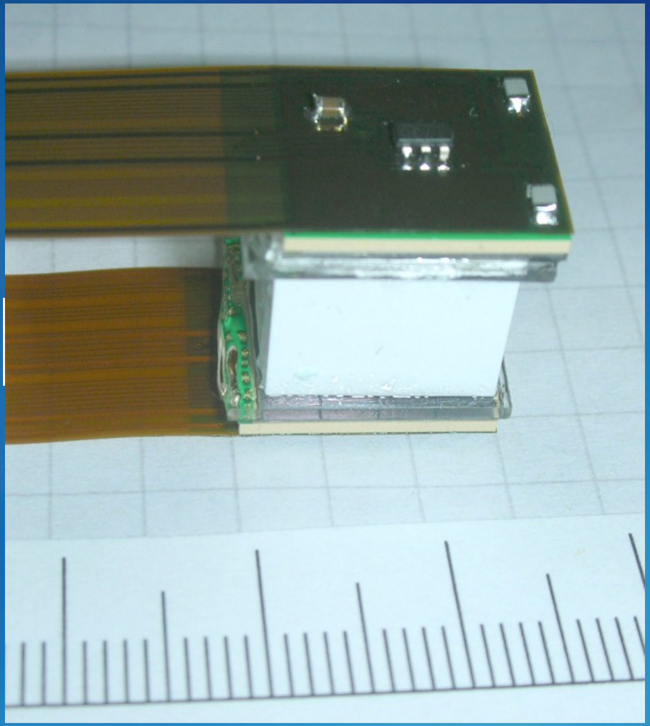
Region	Cho/Cr
High FDG Tumor	3.1
Low FDG Tumor	1.7
Muscle	Negligible

PRESS: TR/TE: 1685/10ms; 3mm^3 voxel; VAPOR H_2O suppression

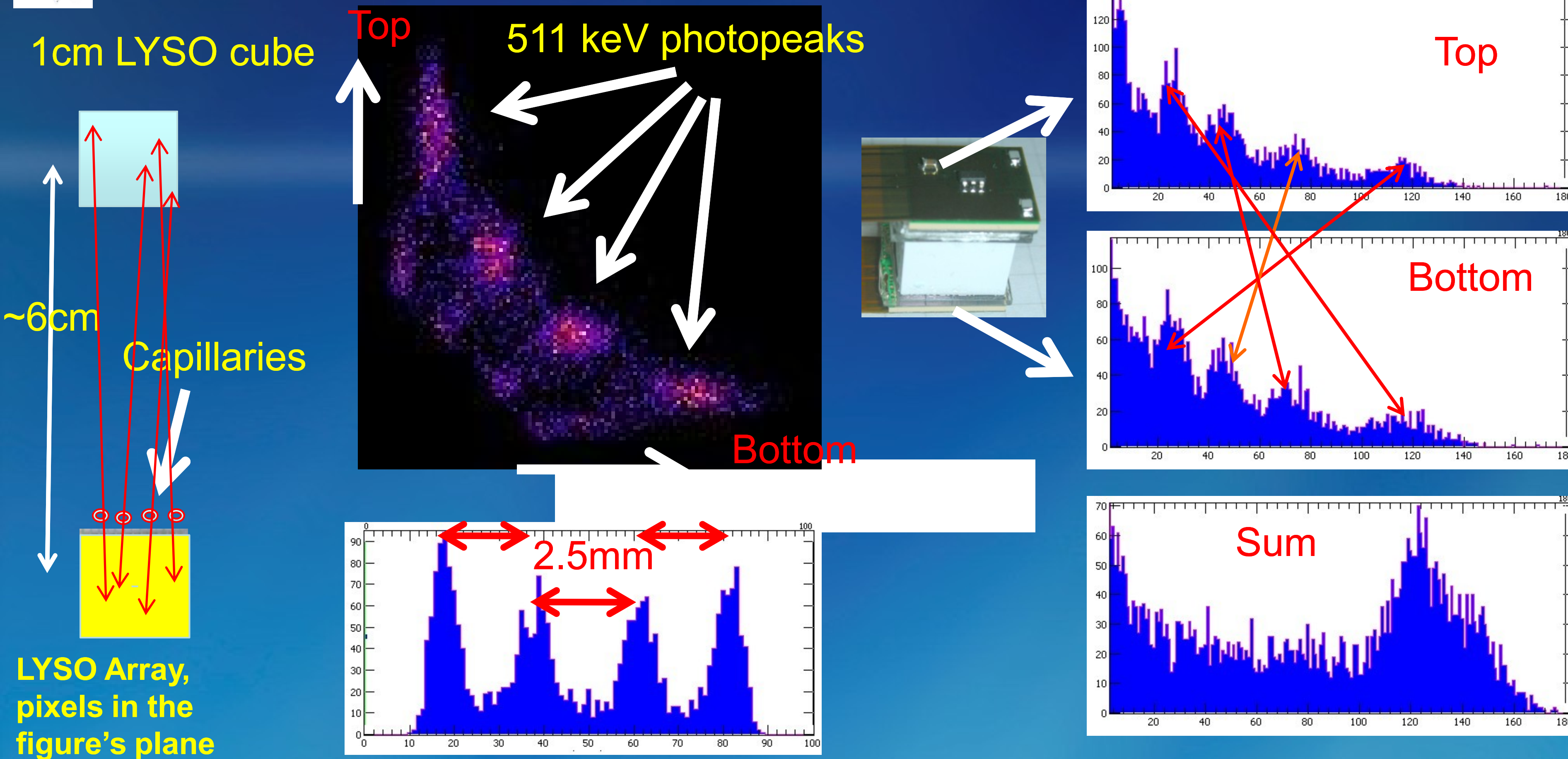
High Choline may suggest high membrane turnover rate = cell proliferation

Slide Courtesy: S.Cherry

Prostate PET DOI Probe With Monolithic MPPC Modules



DOI module during assembly (please note the still inaccurate positioning of the components). 1mm glass spreader windows used between the scintillator and the monolithic MPPC arrays. Optical grease coupling. Total thickness under 20mm, including the components visible at the back of the MPPC arrays.



The 2D plot at top displays the signal relationship between the top and bottom MPPC array outputs for the four F18-solution-filled capillaries spaced at 2.5mm center-to-center (0.5mm i.d., 1.25mm o.d.). Four 511 keV collimated beams were produced by electronic collimation in coincidence with a 1cm LYSO cube attached to a small PMT (left). The bottom center histogram shows event per event ratio of the top output vs sum of the top and bottom outputs. At right are shown energy spectra obtained for the top, bottom and sum signals. The correlations between the capillary beam peaks in both energy spectra are also shown. Estimated DOI resolution :<=1mm FWHM.

Summary

- Clinical PET instrumentation seems to be scintillator oriented also for the future
- After more than 20 years the block detector is going to be overcome by other approaches
- The development of the electronic now is mature enough to open once again the possibility for a new rise of one-to-one coupling
- TOF is growing slowly: faster scintillators and high quantum efficiency PhotoDetectors are required.
- A multimodality approach (PET/MR) will be more and more requested in the clinical practice.
- The **SiPM seems to be the choice for future systems** being MR compatible, compact and with high performance.

Acknowledgments

Thank's to:

P.Bruyndonckx and S.Tavernier
@VUB, Belgium

J.Perez and P.Rato Mendes
@CIEMAT, Spain

H.Larue, C.Parl, M.Streun (ZEL)
N.J.Shah, H.Herzog and U.Pietrzyk (INM-4)
@Forschungszentrum Jülich

D.Townsend, P. Lo Guo-Qiang, D. Ning
@SBIC, Singapore

S.Majewski
@West Vergina University

and to all the others, which spend some slides for this presentation

Thank you

for your attention !!

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