

# The 100µPET project:

an ultra high resolution small-animal PET scanner

15th Pisa meeting on Advanced Detectors 22 – 28 May 2022 Mateus Vicente on behalf of the 100µPET collaboration

### Introduction



UNIVERSITÉ



enzo Paolozzi

aboratory test

2



Swiss National ppe lac Science Foundation

\_mvicente@cern.ch

### Silicon pixel detectors at UNIGE

Long tradition at UNIGE with hybrid silicon detectors: 

2016

200ps

- pixel detectors for ATLAS IBL and ITk upgrade; strips (ATLAS SCT, AMS, DAMPE)
- In 2015: kick-off R&D on monolithic pixel sensors in SiGe BiCMOS technology
  - Aiming at MAPS with timing resolution below 100ps (for MIPS)
    - **MONOLITH** project, see poster on Solid State Detectors session

talk by Magdalena Munker ("Trento" Workshop 2022)

**FASER pre-shower** detector, see poster on FE, Trigger, DAQ and Data Management session talk by Lorenzo Paolozzi ("Trento" Workshop 2022)



### innovat for high performa microele

**Didier Ferrere** · System integr Laboratory tes

Mateus Vicen System integr

Laboratory tes

Jihad Saidi

 System simula Laboratory test



- Sensor design Analog electro

Pierpaolo Val Lead chip des Digital electro

Breakfast and S

Monolithic prototype ASICs for timing purposes 2021 2019 2018 2017 PicoAD p0 ATTRACT noGAIN 50ps 36ps 20ps 110ps Hexagonal pixels 65µm 1 and 0.5 mm<sup>2</sup> pixels Hexagonal pixels 65µm side 30 pixels 500x500µm<sup>2</sup> Same pixel/Electronics of and 130um side · Discriminator output 100ps TDC +I/O logic 30ps TDC +I/O logic ATTRACT Discriminator output Analog channels





**Didier Ferrere** 

### Positron Emission Tomography (PET)

- PET is a nuclear medicine method to study metable
  - Radiotracer is injected in a body; Positrons from the Todiace dis uttitie fright resolution the todiace discussion and detected in coincidence. Two back-to-back 511 KeV photons are emitted and detected in coincidence. Dy EXPIOILING much improved spatial, DOI and time resolutions Lines-of-Response (LoR) are defined by the volume between the sensitive elements detecting the two photons





Swiss Natiginal ppe lace Science Foundation

mvicente@cern.ch

### Positron Emission Tomography (PET)

- To access ultra-high resolution molecular imaging  $\rightarrow$  Reduce the LoR volumes by exploiting:
  - Better timing resolution for coincidence measurement; Improved depth-of-interaction measurement;
  - $\square Improved spatial resolution with higher detection volume granularity \rightarrow HEP based silicon pixel detectors$ 
    - The higher 100UPET aroundarity will reduce the noise-like combinatorics artifacts during projection of LoRs



System simulation
 Laboratory test

**Mateus Vicen** 

System integr



# The Thin Time-of-Flight (TT-PET) project

The 100µPET predecessor – from 2016-19



UNIVERSITÉ

DE GENÈVE

Swiss Nationalppe lace Science Foundation

# The Thin Time-of-Flight (TT-PET) project

The 100µPET predecessor – from 2016-19

- Performance fully simulated
- E. Ripiccini et al., arXiv:1811.12381
- Imaging reconstruction produced
- D Havakawa PhD thesis link

9a

**TT-PET Image Reconstruction** 





**Iterative Reconstruction** 1.2 mm 1.0 mm 2.0 mm 0.9 mm 0.5 mm 0.7 mm

### Silicon pixel area [µm<sup>2</sup>] 500×500 n **Point-spread function** MLEM computation method Z position [mm] 0 X position [mm] 0 5 10 15 0 0.57 0.56 Radial 0.59 0.52 0.65 0.61 FWHM 0.60 0.60 0.67 0.71 0.64 0.65 Tangential [mm] n Axial 0.50 0.49 0.50 0.51 0.45 0.45





 System simula Laboratory test

UNIVERSITÉ DE GENÈVE

FACULTÉ DES SCIENCES

Swiss National ppe lac **Science Foundation** 

\_mvicente@cern.ch

### **Didier Ferrere**

- · System integr
  - Laboratory tes



12.5

10

0.60

0.65

0.45

5

### Lorenzo Paol

15

0.56

0.70

0.45

desigr electro

b Val

p des

lectro

t and S



I Breakfast and Science Seminar

28/09/2021

# The Thin Time-of-Flight (TT-PET) project



### Is it the time for a change of paradi

- Performance fully simulated
- E. Ripiccini et al., arXiv:1811.12381
- Imaging reconstruction produced
- D. Hayakawa PhD thesis, link

9c

<u>Point Spread Function</u> (iterative <u>MLEM</u> method) =  $0.18 \text{ mm}^3$ 

The 100µPET predeces

<u>Change of paradigm in PET imaging is possible with</u> <u>monolithic pixel detectors</u>

- Can we do better? Must reduce even further the "LoR volume"
  - Either by pushing the timing resolution to << 30 ps</p>
  - or by having better spatial resolution





\* Filtered Back Projection imaging reconstruction method

9d

### The 100µPET scanner

10



mvicente@cern.ch

Mateus Vicen
System integr

Laboratory tes

**Ferrere** 

em integr pratory tes

**Jihad Saidi** 

UNIVERSITÉ

### New SINERGIA project evolving from the TT-PET I Swiss National ppe lack Science Foundation

- **Simplified** and **improved** scanner design, <u>avoiding acceptance inefficiency</u> from cooling blocks
  - <u>Monolithic</u> 100μPET detector ASIC: 2.5 x 3 cm<sup>2</sup> active pixel matrix; 100 μm pixel pitch; 250 μm thick active silicon sensor
  - Single silicon detection layer composed by 2x2 chips assembled, covering 30 cm<sup>2</sup>
  - 4 "towers" compose the scanner. 60 detection layers on each tower = 960 chips!
    - Large number of services and interconnections, requiring innovative design. <u>Two possible designs</u> under study
      - 5 silicon detector layers (20 chips) stacked on a PCB, staggered for wire-bonding. 12 modules are stacked in a tower
      - 1 detection layer (2x2 chips) are interfaced to a FPC via <u>ACF bonding</u>. 60 FPC/ASIC layers are stacked in a tower



















## 100µPET scanner sensitivity and resolution

Simulation – Full scanner and e<sup>+</sup>e<sup>-</sup> annihilation

Monte Carlo simulations has shown a disruptive jump in the scanner's resolution and sensitivity

Efficiency can be increased with absorber layers

13a

It is a compromise between efficiency and resolution







Pierpaolo Val
 Lead chip des
 Digital electro

UNIVERSITÉ DE GENÈVE

FACULTÉ DES SCIENCES

Swiss Natiginal ppe lace Science Foundation

mvicente@cern.ch

G. lacobucci - CIBM Breakfast and S

# 100µPET scanner sensitivity and resolution

Simulation – Full scanner and e<sup>+</sup>e<sup>-</sup> annihilation

Monte Carlo simulations has shown a disruptive jump in the scanner's resolution and sensitivity

Efficiency can be increased with absorber layers

13b

It is a compromise between efficiency and resolution





Swiss National ppe lace Science Foundation

mvicente@cern.ch

Mateus Vicen
System integr

Laboratory tes

### **Detector ASIC prototyping**





- Hexagonal 65 µm wide pixel (equivalent to ~100µm XY pitch) for R&D investigation
- Tested at CERN SPS H8 beam-line in Q2 2021

14

- >99.5% detection efficiency (on both prototypes)
- Timing resolution of **36 ps** $^*$  (without gain) and **20 ps** $^{**}$  (with gain layer, preliminary) п. \*G. lacobucci et al 2022 JINST 17 P02019 (no gain prototype)

\*\*First PicoAD prototype. Sensor and front-end design still to be optimized + ps TDC



UNIVERSITÉ **DE GENÈVE** 

FACULTÉ DES SCIENCES

Swiss Natiginal ppe lac Science Foundation

mvicente@cern.ch

Mateus Vicen

System integr

Jihad Saidi

**Didier Ferrere** System

Laboratory tes

simula Laboratory tes

integr

Laboratory tes



15

- **PET scanners** are an important diagnostic tool that has been improving in an astounding way over the y and will continue to improve
- Monolithic pixelated silicon sensors have the potential to enable <u>ultra-high-resolution molecular imagination</u>
- The 100µPET SNSF SINERGIA project will deliver a small-animal scanner based on silicon technology wi expected 0.04 mm3 volumetric spatial resolution, one order of magnitude improvement
  - In the whish-list: add TOF  $\lesssim$  10ps, when delivered by the MONOLITH project
- Innovative ASIC design and module construction techniques are being developed
  - Silicon-sensor technology will continue to improve and its cost will go down
    - In the future, scanners larger than those for small-animals could be envisaaed



### **Didier Ferrere**

- · System integr Laboratory tes
- - Lorenzo Paol Sensor design Analog electro



**Pierpaolo Val**  Lead chip des Digital electro

G. lacobucci - CIBM Breakfast and S

 System simula Laboratory test

### **Mateus Vicen** System integr Laboratory tes

UNIVERSITÉ DE GENÈVE FACULTÉ DES SCIENCES

mvicente@cern.ch

Swiss Natiginal ppe lac Science Foundation