# Exhibit Title:

# CMOS single-photon time-correlated SPAD arrays for biomedical applications

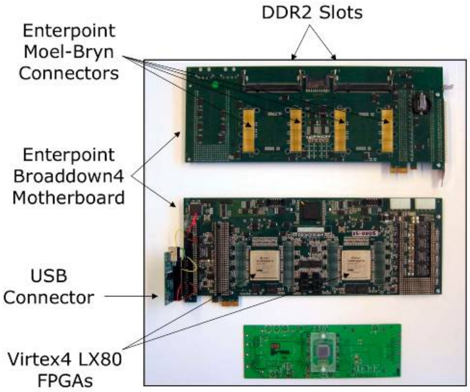
**Background**: A core group of European universities and research centres (EPFL Lausanne/TU Delft, University of Edinburgh and Fondazione Bruno Kessler, Trento) have laid in the past years, together with industrial partner STMicroelectronics, the foundations for SPAD based (Single Photon Avalanche Diode) single-photon time-correlated imagers and 2D arrays. The core technology has been pioneered in the European FP6 MEGAFRAME project, and it now being transitioned to biomedical imaging systems, in particular PET (Positron Emission Tomography), in the European FP7 SPADnet project.

**Aim of exhibition**: Showcase single-photon time-correlated imaging technology with the MEGAFRAME camera demonstrator (developed in the FP6 FET Open MEGAFRAME project, www.megaframe.eu) and the SPADnet module development work (FP7 ICT Photonics, ongoing, www.spadnet.eu).

**Description of your product or prototype or demonstration:**

The MEGAFRAME camera, available in two versions (32x32 and 128x160), contains pixels which can detect a single photon a million times per second. In addition, the camera is also capable of computing their time of arrival with picosecond precision over an array of up to twenty thousand pixels operating simultaneously and independently. The SPADnet module will contain an array of tessellated single-photon TSV chips, connected in a token ring structure. The exhibit will feature, if space constraints allow:

- Showcase recent prototypes of the MEGAFRAME system (see Figure 1). Interact with single photon camera (TBC).
- Illustration of characteristics and performance obtained with various generations of single photon detectors (illustrating all the development chain over the years).
- Illustrate transformative potential of foundational research (from first prototypes to MEGAFRAME results to SPADnet targets).
- Application opportunities in various fields, Project flyers and posters.
- Description of individual SPADnet components and corresponding major breakthroughs.



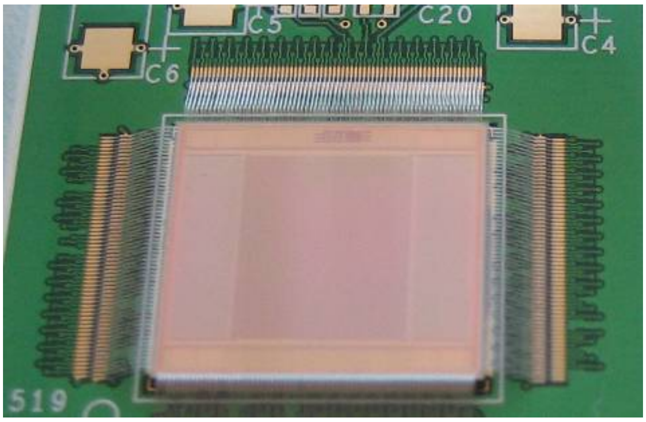



**Figure 1. Left: FPGA card set for the 160x128 imager. The card set consists of an Enterpoint mother card with a dual VirtexIV FPGA and fast communication modules and a daughter card with a built-in chip-on-board. Right: Chip-on-board bonding of the 160x128 image sensor to the daughter card.**

**Description of the photonics technologies involved with your product.**

Single photon imaging has gradually progressed from the design of single pixels, to small matrices, and eventually large arrays with photon counting and/or timing capabilities. Foundational research at lab level has allowed the first and second step, whereas the final real breakthrough was made possible by visionary thinking and FET Open support. As a result, single-photon time-correlated cameras can nowadays be implemented in a standard complementary metal oxide semiconductor (CMOS) process such as the one used in commercial cellphone cameras.

Thanks to fully parallel pixel architecture and fast readout it is possible to achieve very high image throughput with superior dynamic range, noise performance and timing accuracy. Advanced integrated optics is used to collect photons even at extremely low light illumination, while massively parallel processing is employed to access and process high data volumes (see Figure 2).

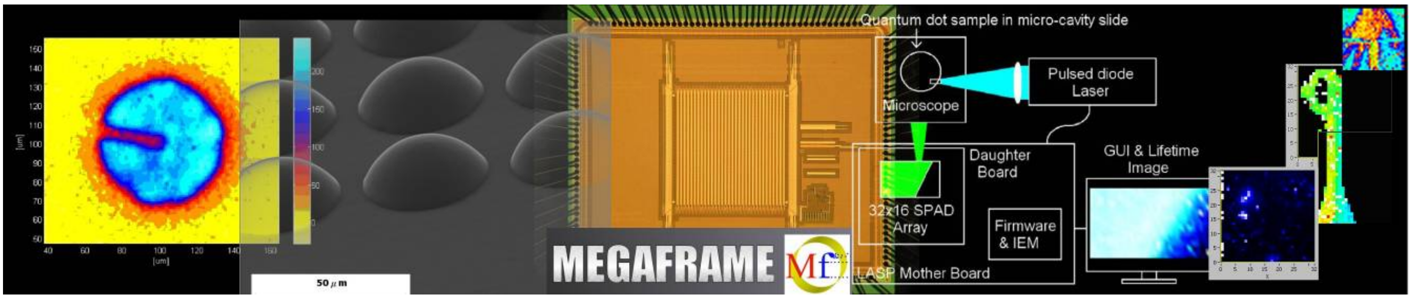



**Figure 2. Main system features (bottom-up display). From left to right: SPAD pixel; microlenses; sensor array (32x32 version); system level overview; examples of results (lifetime images in selected applications)**

In the case of the SPADnet developments, the challenge is to scale the photonic components to large formats, using advanced integrated optics and innovative packaging techniques based on through silicon vias (TSVs) to tessellate several tens of dies in abutment style, and decompose a large format imager to a network of independent arrays (see Figure 3).

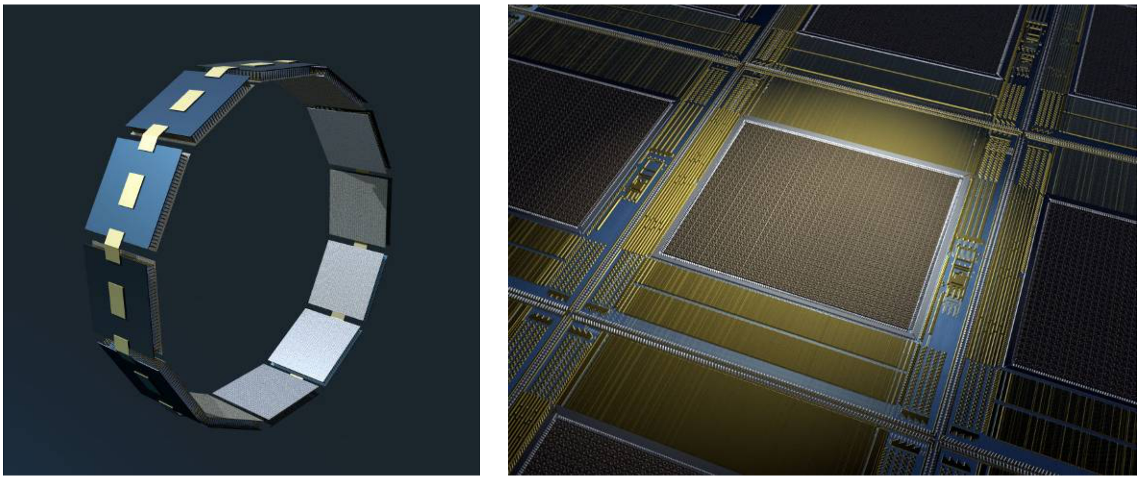


**Figure 3. Left: Conceptual design of a possible SPADnet full pre-clinical PET implementation. Right: Conceptual layout of the SPADnet sensor array building up a single module (tessellating several tens of dies in abutment style using TSVs).**

**Description of the purpose of the product and the potential market.**

MEGAFRAME: The new imaging system was and is being evaluated in a number of imaging paradigms requiring time-correlated methods. Resolutions and frame rates at least ten times higher than today's solutions have been achieved. These are enabling technologies for the particularly exciting research field of direct cellular imaging. Future advances are expected in proteomics, systems biology and drug discovery that are dependent on such improved understanding of intra-cellular processes.

In SPADnet, the prime objective is to develop a scalable photonic component for large format, rare-event imaging, paving the way to a new generation of smart, CMOS-based large area networked image sensors for photon-starved biomedical applications, with the aim of building ring-assembly modules for Positron Emission Tomography (PET) imaging. In the long term, we expect to see this smart, large area, focal plane technology supplant monolithic approaches in diverse photon-starved imaging areas such as X-ray, SPECT, CT, nuclear colliders, particle physics, ground-based telescopes and space-borne astronomy.

**Description of your institution, research centre or company, and the funding of the project which led to your innovation.**

The core group of European universities and research centres (EPFL Lausanne/TU Delft, University of Edinburgh and Fondazione Bruno Kessler, Trento) mentioned in the "Background" description above have pioneered SPAD based single photon detector design and applications. The main industrial partner, STMicroelectronics and in particular its Imaging Division and Crolles foundry, is one of the leading microelectronics group worldwide. This expertise has been and is being complemented by experts in the respective domains such as CEA-LETI in Grenoble (micro-optics and system assembly), University of Pavia (optical concentrators), Mediso in Budapest (SME manufacturing medical physics detectors, providing end user expertise), and University of Budapest (scintillator design).

The core funding in the MEGAFRAME and SPADnet project comes from the European Commission, and has been complemented with additional grants as well as substantial own effort by the industrial partners.

**Description of the team itself, its members and their primary activity (student, grad student, professor, researcher, other).**

The core group of European universities and research centres is lead by Prof Edoardo Charbon (EPFL - people.epfl.ch/edoardo.charbon and TUDelft - ens.ewi.tudelft.nl/People/bio.php?id=43), Dr Robert Henderson (Edinburgh - www.see.ed.ac.uk/drupal/imns/research.html), and Dr David Stoppa (FBK Trento - soi.fbk.eu/en/home). Prof Charbon in particular has been coordinating both MEGAFRAME and SPADnet, with assistance by Dr Claudio Bruschini at the project management level. Both project feature an overall effort of several 100s person-months.

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