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XXX Cycle

Front-end ASICs design for X and gamma ray detectors read out
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## Supervisor: Prof. Amedeo STAIANO

Research context and motivation

- X and gamma rays are photons with higher energy, shorter wavelength, stronger penetration ability than the Ultraviolet and Visible light.

- X and gamma rays detection plays important role in fields like nuclear physics, medical diagnosis, astronomy observation, radiation detect…

- Penetrating radiation inevitably faces the challenge of improving the detection efficiency.

- Technological schemes for X or gamma ray detection can be mainly categorized as : Scintillator + conventional photon detector and high Z (atomic number) semiconductor.

- Applied Specific Integrated Circuits (ASICs) need to work closely to detectors to read out the signal with expected goals: count rate, timing or spatial resolution, power dissipation, robustness for work environment.
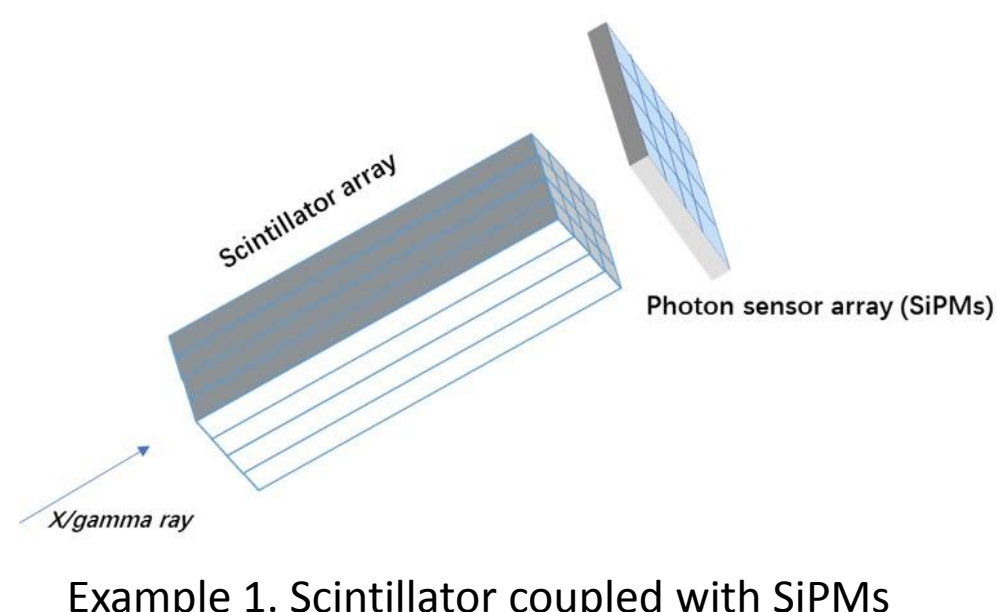
Example 1. Scintillator coupled with SiPMs
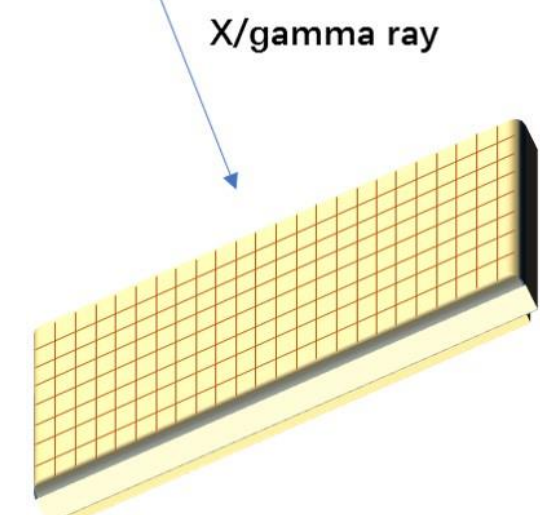
Example 2. High Z semiconductor detector (CdZnTe)

Addressed research questions/problems

- **Develop read out ASICs for SiPMs and CdZnTe detectors for high resolution X/gamma ray detection**

- **SiPMs** readout requires very high time resolution, aimed sensors provided by FBK (Fondazione Bruno Kessler), with the expectations and challenges:

  - SNR > 10, jitter < 1ns for 1 pe (1 cm^2 SiPM)
  - Dark count rejection
  - Working temperature at 77 K and 300 K
  - Adjustable gain and threshold per channel
  - Read out both positive and negative signals
  - Radiation tolerance

- **CdZnTe** detectors read out for gamma cameras, in collaboration with IHEP (Institute of High Energy Physics, China), requires very low noise and good time resolution, with the expectations and challenges:

  - Channels: 121 (for anode) + 2 (for cathode)
  - Input range: ~100 fC
  - Count rate > 10k per channel
  - ENC < 100e (Cd = 2 pF)
  - Adjustable shaping time and gain
 - Radiation tolerance

Adopted methodologies

- UMC 110 nm CMOS process
- Cadence IC design and simulation tools
- Test blocks of Very Front End (VFE) and basic digital modules to study their behavior at cryogenic temperature

Submitted and published works

- CHENG, Weishuai. "A Versatile Mixed-Signal Large Dynamic Range Front-End ASIC for High Capacitance Detectors." 2019 15th Conference on Ph. D Research in Microelectronics and Electronics (PRIME). IEEE, 2019.
- Cheng, W., et al. "A mixed-signal large dynamic range front-end ASIC for high capacitance detectors." Journal of Instrumentation 14.08 (2019): P08013.
- Rivetti, A., Alexeev, M., Bugalho, R., Cossio, F., Rolo, M.D.R., Di Francesco, A., Greco, M., Cheng, W., Maggiora, M., Marcello, S. and Mignone, M., 2019. TIGER: A front-end ASIC for timing and energy measurements with radiation detectors. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment.
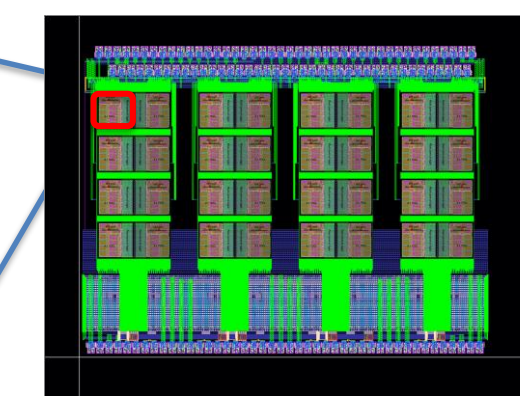
Novel contributions

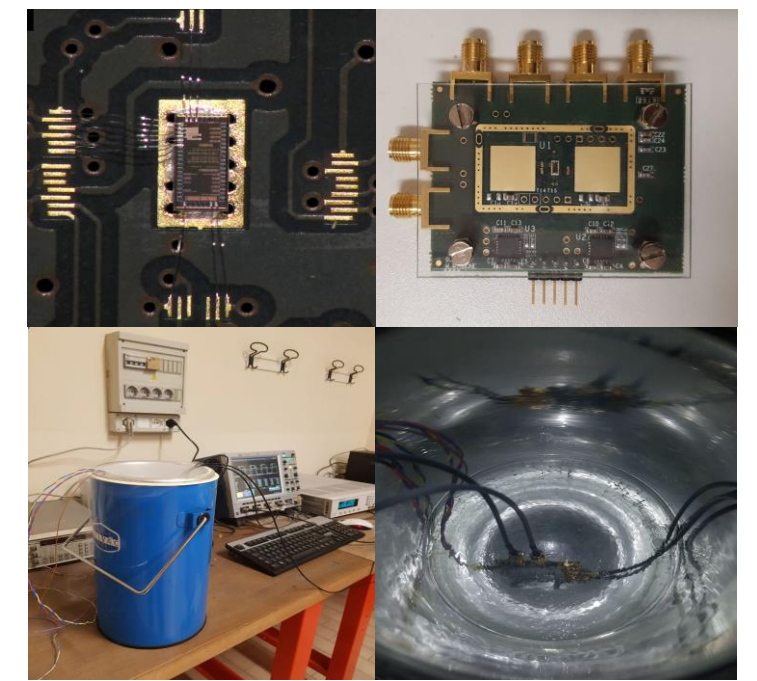- **ALCOR** (**A L**ow-power **C**hip for **O**ptical sensor **R**eadout):
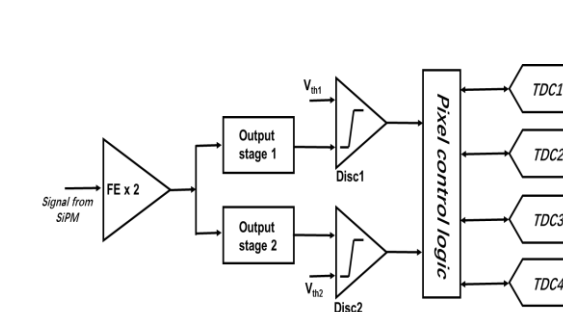
Pixel architecture
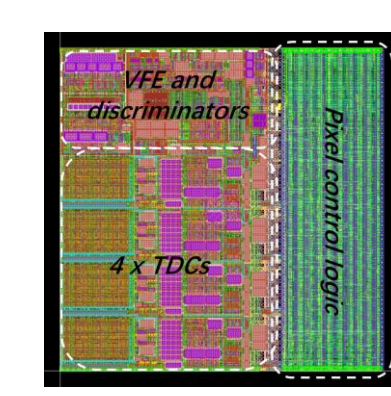
488 μm x 488 μm
Pixel layout constraints

4950 μm x 3780 μm
**Layout of full chip**
(Pixels 4 x 8)

Test chip studied in liquid nitrogen

- Low power high bandwidth pre-amplifier
- Configured to read out positive or negative signals
- 4 gains selectable for each output stage
- Dual thresholds for dark count rejection

- 4 TDCs for de-randomization
- Time over threshold (ToT) provides energy information
- Injection circuit provides test pulse
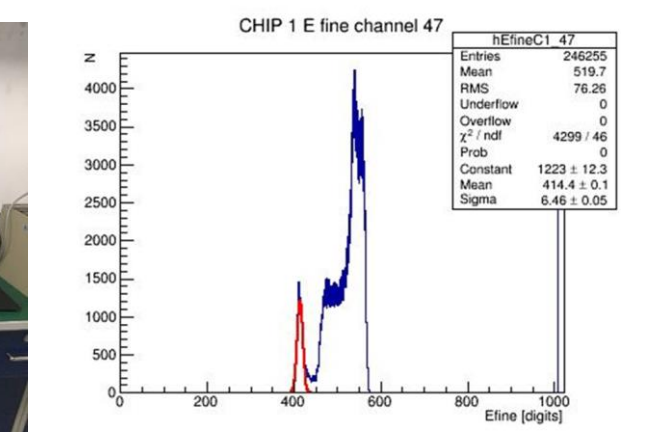
☐ **Tape-out in October 2019**

- **CZT detector read out ASIC:**
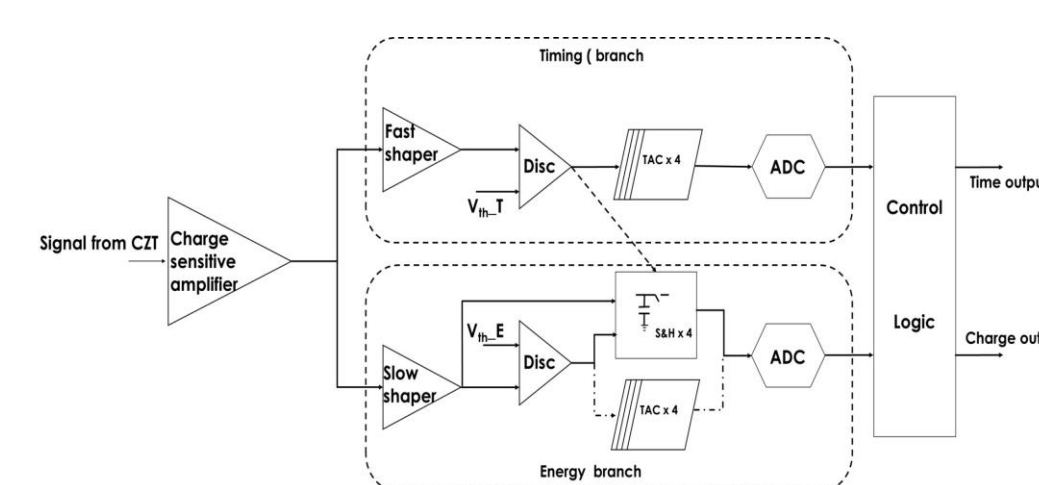
One channel architecture

Test environment and result with TIGER ASIC
(Radiation source: Cs^{137}, with energy resolution of about 5%)

- Share the scheme with **TIGER** (**T**urin **I**ntegrated **G**EM **E**lectronics **R**eadout, front-end ASIC for CGEM detector in BESIII experiment)
- Time stamp extracted from fast branch, energy from slow branch
- Low power TDCs and ADCs
- 64 channels integrated in one chip

- Low noise front-end: Charge Sensitive Amplifier (CSA) + shapers optimized for CZT detector capacitance, dark current and count rate
- Lower power dissipation
- Adjustable gain and shaping time

☐ **Tape-out in June 2020**

Future work

- ALCOR tape-out and electrical characterization, test with aimed SiPMs

- CZT readout ASIC tape-out and electrical characterization, test with aimed CZT sensors.

List of attended classes

- 02RHORV The new Internet Society: entering the black-box of digital innovations (6 hours, 19/12/2018)
- 01LCPIU Experimental modeling: costruzione di modelli da dati sperimentali (33 hours, 29/10/2018)
- 08IXTRV Project management (5 hours, 19/12/2018)
- 03QRHRV Microelectronics for radiation detection II (24 hours, 3/6/2019)
- 01SYBRV Research integrity (5 hours, 28/1/2019)
- 01SWQRV Responsible research and innovation, the impact on social challenges (5 hours, 26/8/2019)

POLITECNICO DI TORINO

PhD program in
Electrical, Electronics and Communications Engineering