Towards a picosecond fully-photonic detector module for direct 3D PET and future HL colliders

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Why?

- Generalization of Personalized/Precision medicine requires a transformation of current in-vivo molecular imaging:
  - Major reduction on radiation dose applied to patient
  - Reduction of scanning time
  - Improvement of image quality (resolution, contrast, multi-parametric, etc.)

Where are we?

- A full-body PET scan requires a radiation dose equivalent to the "public" limit for radiation installations:
  - It is a safe amount, but
  - Its is larger than a CT scan, and
  - It requires a risk assessment that limits its application to few critical diseases.
- **Current commercial systems** have introduced Time of Flight information to reduce the noise in the image (*Coincidence Time Resolution* ~350 ps)

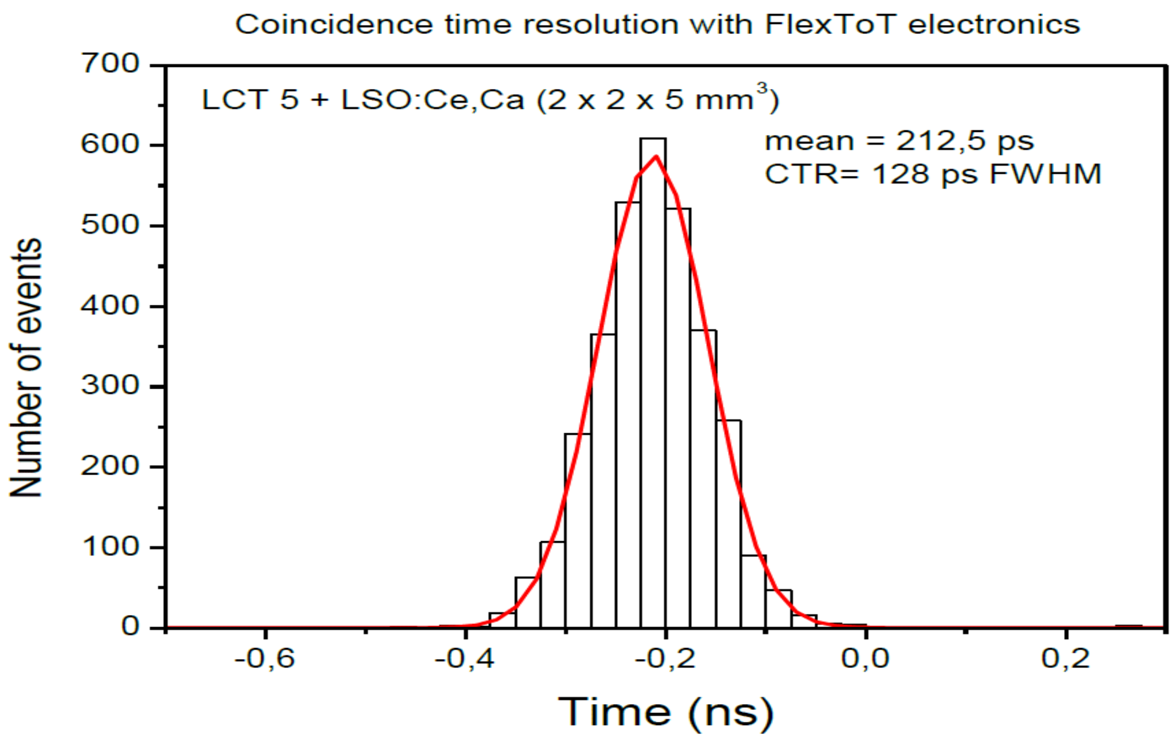
Where do we want to go?

- A way to achieve it is pushing time-of-flight *Coincidence Time Resolution (CTR) to ~10 ps,* ***enabling direct 3D imaging*** [1].

Present R+D

- Current PET technology based on scintillators has several limitations limiting CRT > 100 ps
- For sub-100 ps time resolution, mechanisms involving the production of prompt photons need to be considered [2]:
  - Photonic crystals offer attractive perspectives: higher light yield [3] and use of Cherenkov radation [4]
  - Prompt emission is weak (few photons) and in UV region
- **New advances are required** in photodetector and FE aiming for an overall SPTR�10 ps and enhanced UV sensitivity.

State of the art

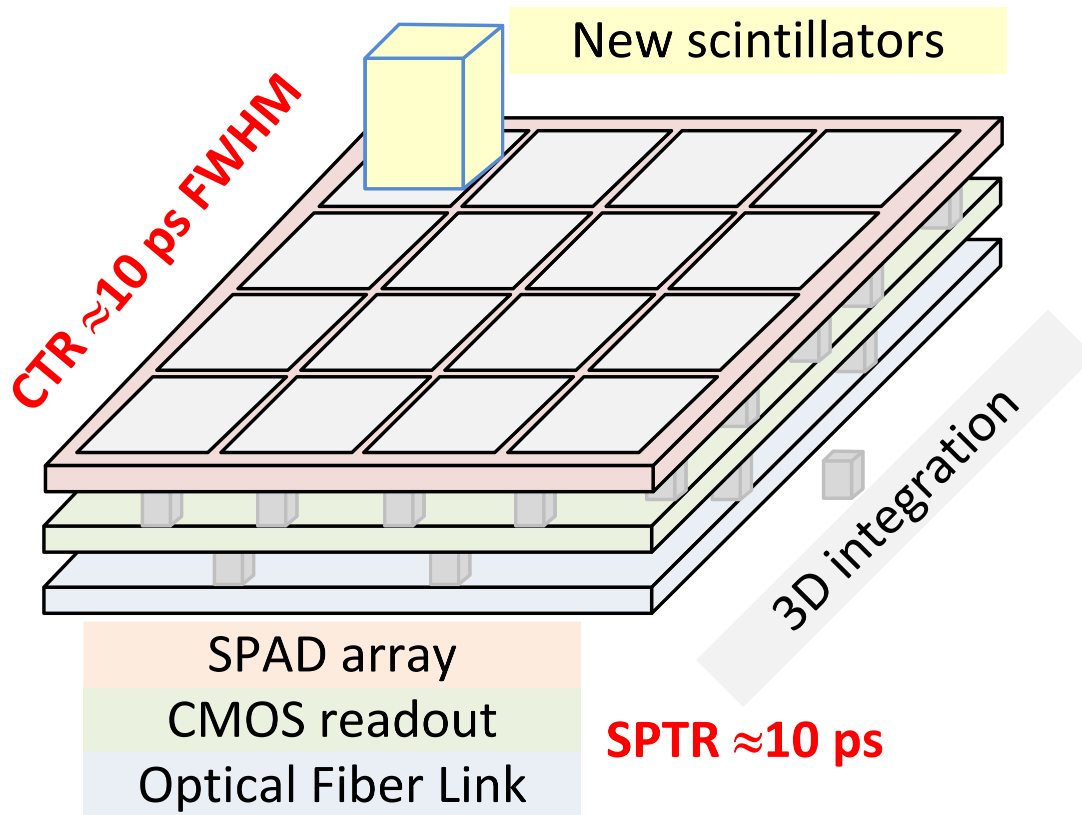


CRT~100 ps //SPTR~100 ps

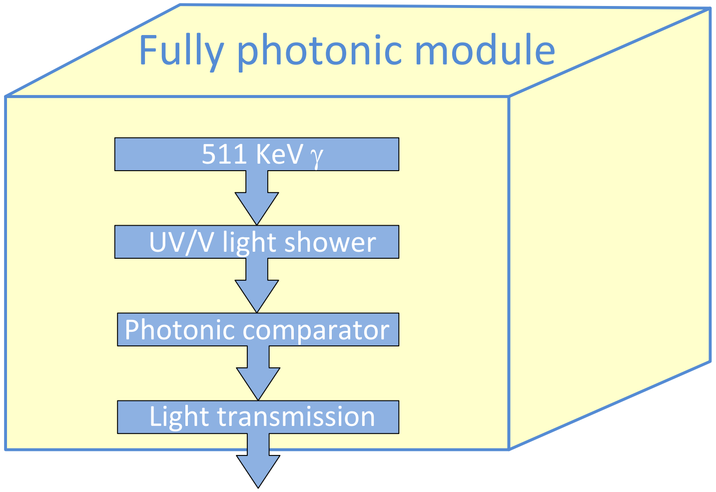
LYSO + SIPM + ASIC

Next steps towards 10 ps

- “Digital” SPAD based sensor optimized for prompt light emission which provides the time of arrival of the n first impinging photons
  - High quality process SPAD process [5]
  - CMOS front end and readout electronics.
  - Optical link integration
  - Integration techniques: 3D, system on a chip and multi-chip-modules
- **Sensor on a Chip**


New scintillators
CTR ≈10 ps FWHM
3D integration
SPAD array
CMOS readout
Optical Fiber Link
SPTR ≈10 ps

But, what next



- **Fully photonic module**
  - Detection [3]
  - Processing [6]: comparators [7]
  - Light transmission (optical fiber)
- Photonic crystals might be a promising alternative

Conclusion

- Many technological challenges will be faced, but optical processing elements such as comparators are being developed [7].
- This is an endeavour for the next 10 years, many new amazing possibilities will open for:
  - *high-energy physics colliders, such as HL-LHC or CLIC, with a bunch-crossing rate of 2 GHz*, as well as
  - ***direct 3D PET in medical imaging***.
  - Fast communication networks
  - LIDAR systems for self-driven automobile
- **Do you want to join us in this amazing trip?**

References (Thanks)

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- [4] Ginis, Danckaert, Veretennicoff, & Tassin, "Controlling Cherenkov radiation with transformation-optical metamaterials." Physics Review Letters 113, 167402 (2014).
- [5] Cova, S. and Lacaita, A. and Ghioni, M. and Ripamonti, G. and Louis, T. A "20-ps timing resolution with single-photon avalanche diodes", Review of Scientific Instruments, vol. 60, 1104-1110, 1989.
- [6] Joannopoulos, J. D., Johnson, S. J., Winn, J. N. & Meade, R. D. Photonic crystals: Molding the Flow of Light (Princeton University press, Princeton, 2008).
- [7] C. Lu et alt. "Chip-integrated ultrawide-band all-optical logic comparator in plasmonic circuits", Nature, 3869 (2014)