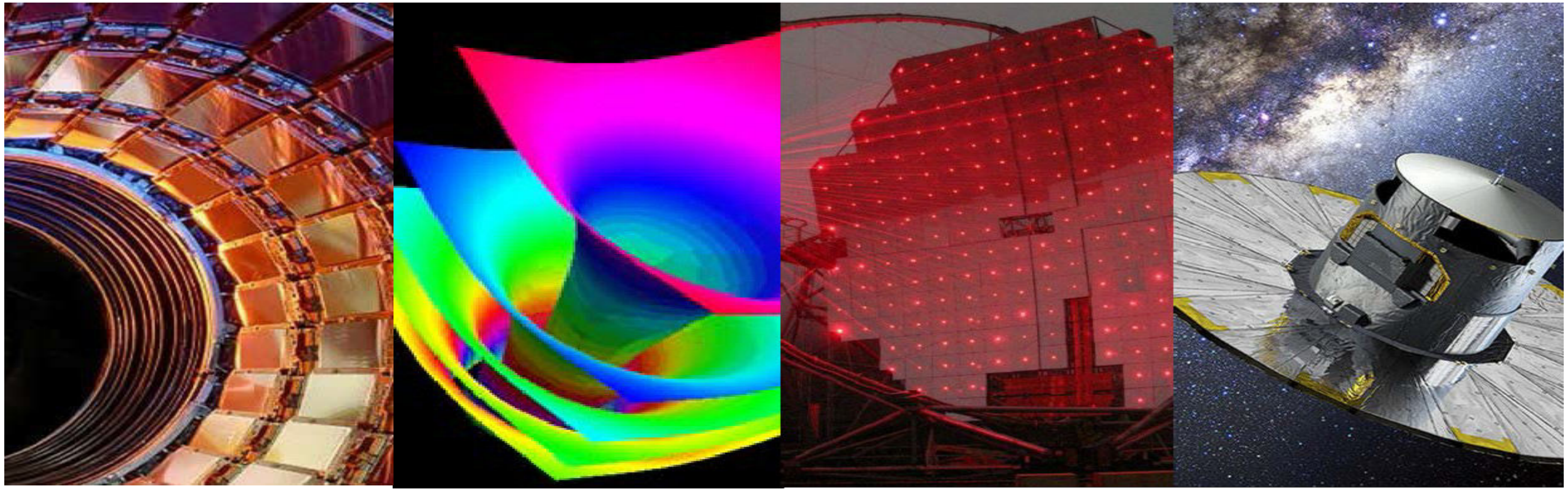


Towards a sub-100 ps ToF-PET module using the FastIC+ ASIC

D. Mazzanti, S. Gómez, J. Mauricio, J. Alozy, F. Bandi, M. Campbell, R. Dolenec, G. El Fakhri, J. M. Fernández-Tenllado, A. Gola, D. Guberman, S. Majewski, R. Manera, A. Mariscal-Castilla, M. Penna, R. Pestotnik, S. Portero, A. Paterno, A. Sanuy, J. J. Silva, R. Ballabriga and D. Gascón

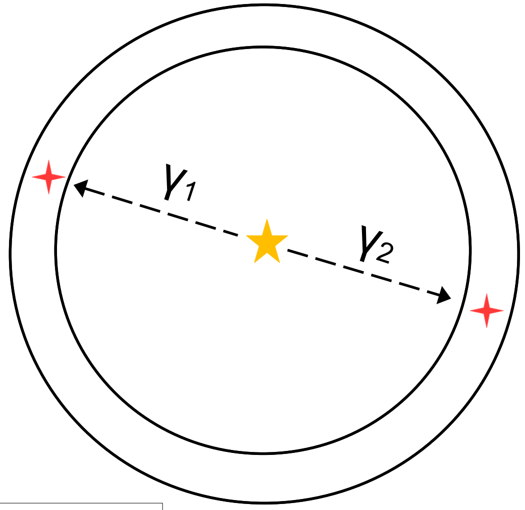
ICCUB – Universitat de Barcelona

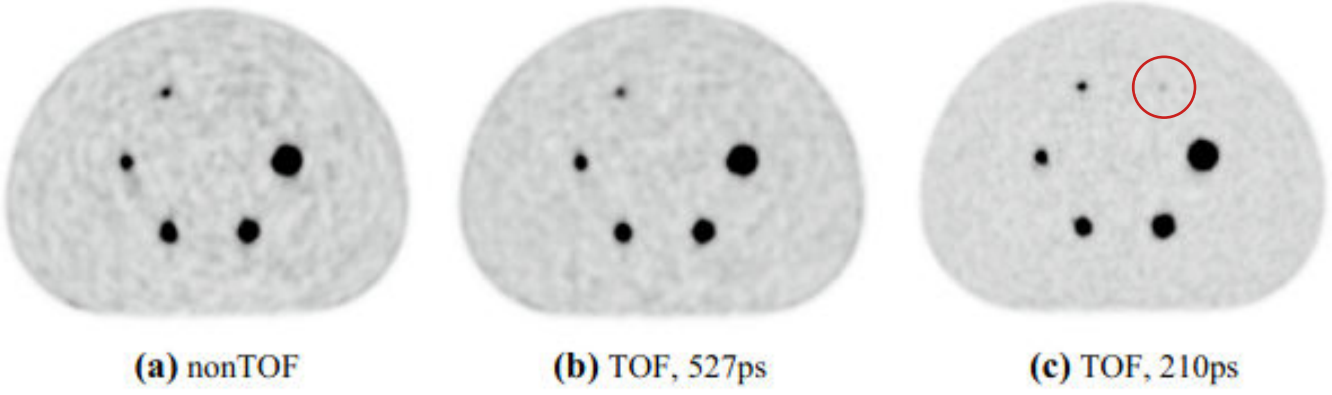
FATA Conference 2025

9/10/2025

Introduction – What is Positron Emission Tomography?

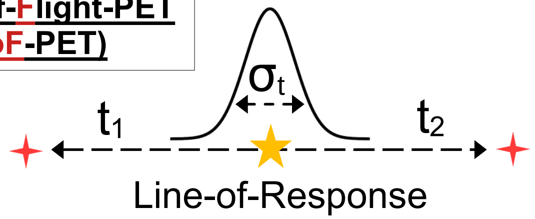
- **P**ositron **E**mission **T**omography is an imaging technique that detects pairs of 511 keV photons emitted from electron-positron annihilation, allowing the **reconstruction of functional images of the body**.





Conti & Bendriem, The new opportunities for high time resolution clinical ToF-PET, 2019

Time-of-Flight-PET (ToF-PET)



→ $\Delta t = t_2 - t_1 \equiv$ **Coincidence Time Resolution (CTR)**

CTR ↓ → Better localization of interaction → Better reconstruction → **Better image quality**

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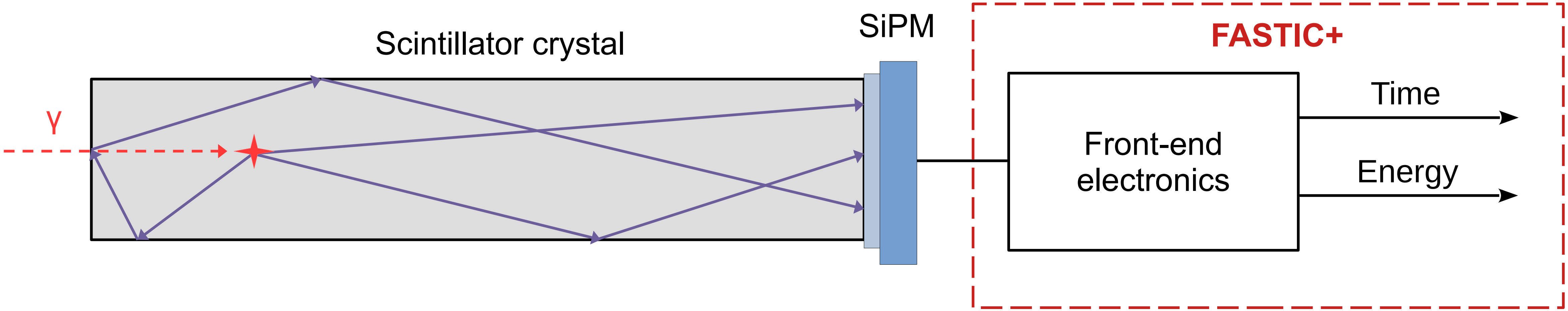
Introduction – Detection chain



Front-end electronics → **High bandwidth** and **low electronic noise** help reducing the electronic jitter

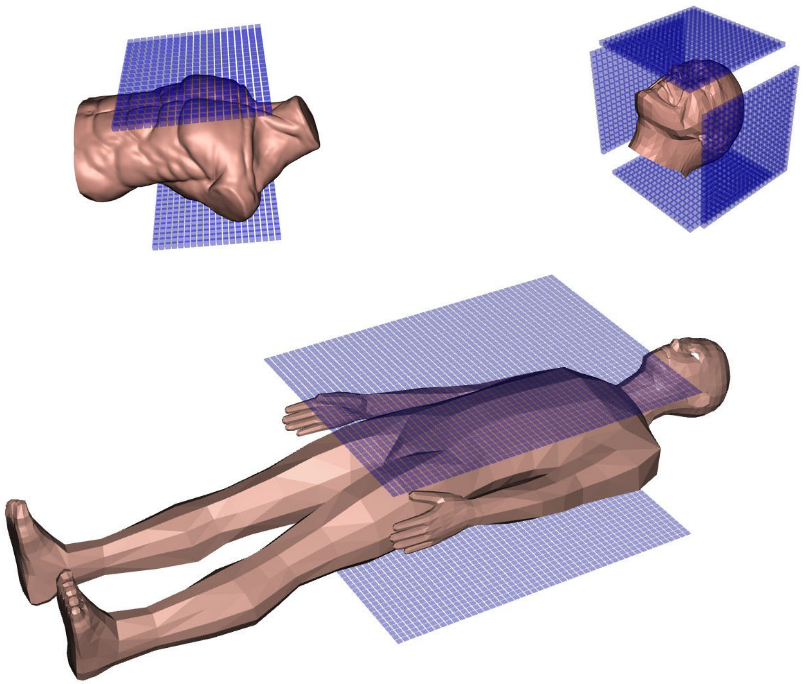
To build a scanner, they NEED to
- Have **low power consumption**
- Be **compactness**
- Be **low-cost** solutions

<u>ASICs offer a scalable solution!!</u>

Introduction – PETVISION Project

- **Goal**: develop a highly sensitive, flexible, cost-accessible and modular ToF-PET scanner with a sub-100 ps CTR at system level
- System is based on two planar and opposite detector panels.

Total body PET Imager prototipe



Institut "Jožef Stefan" Ljubljana, Slovenija

ICCUB Institut de Ciències del Cosmos UNIVERSITAT DE BARCELONA

ONCO VISION

PET VISION

Yale

FONDAZIONE BRUNO KESSLER FUTURE BUILT ON KNOWLEDGE

CERN

MRI Klinikum rechts der Isar Technische Universität München

TUM

i3M Instituto de Instrumentación para Imagen Molecular

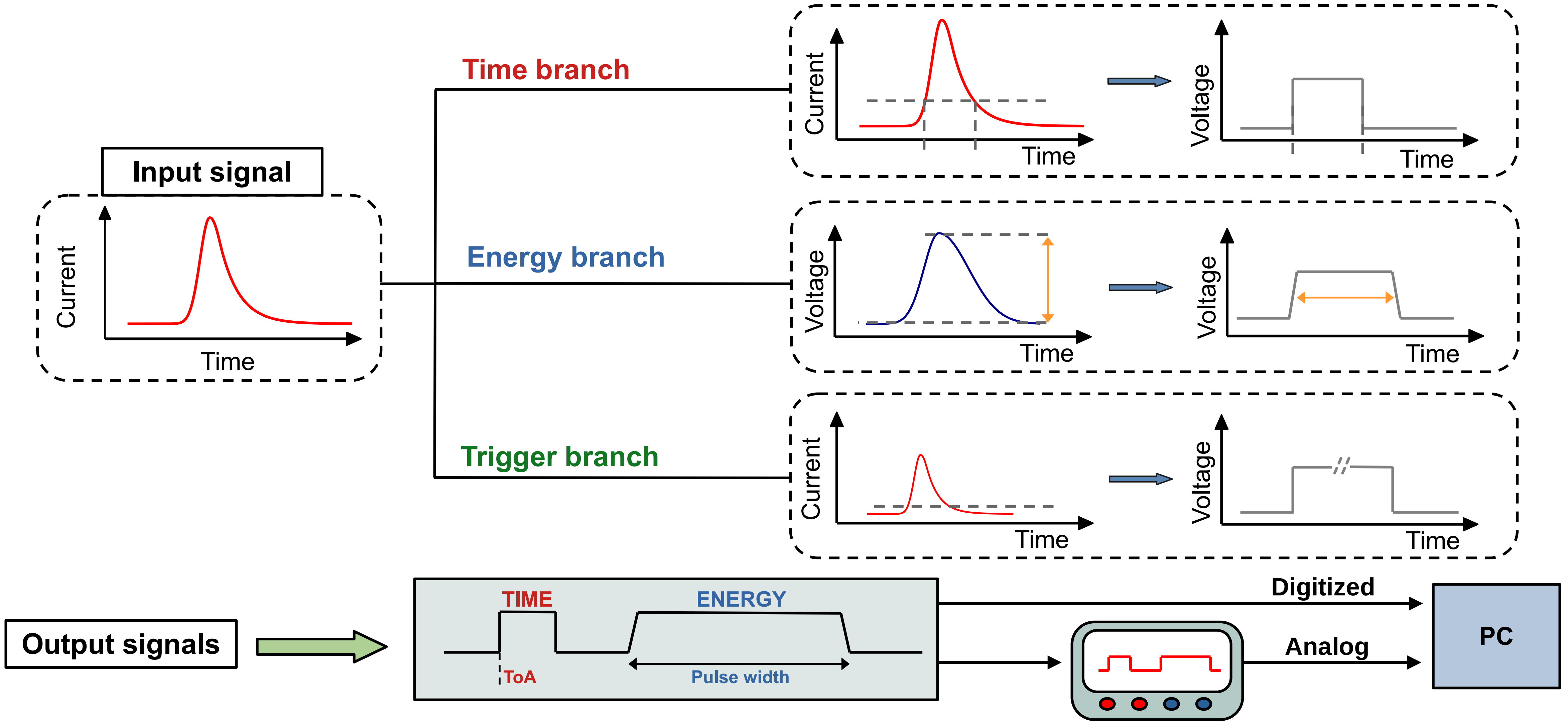
FastIC+ - What is it?

FastIC+ goal is to optimize the performance of ToF-PET modules with a technology that can be easily scaled to full-body scanners:

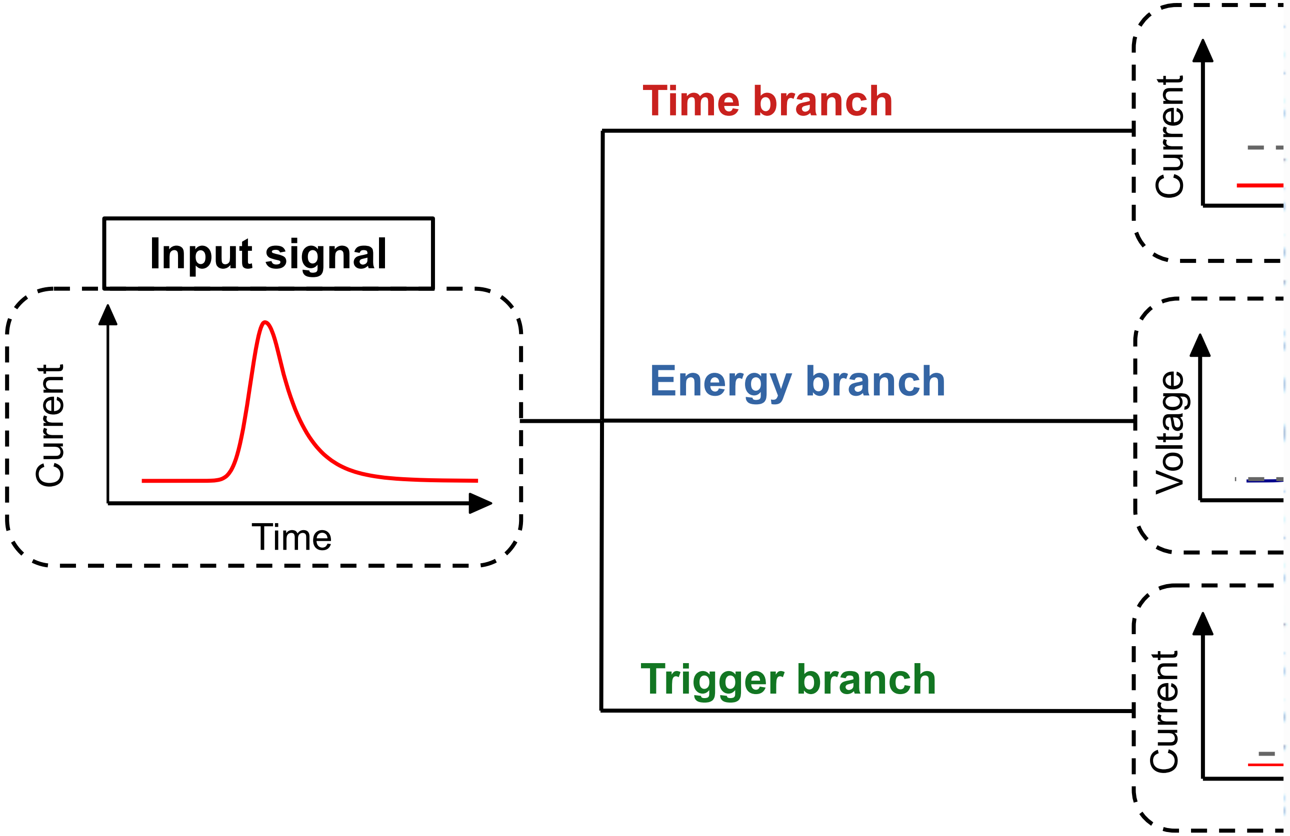
- Multi-channel front end with **internal digitization**
  - 8 input channels per chip ⟶ **output as binary pulses** that can be acquired by the TDC
- **Highly configurable**
- **Low-power consumption** ⟶ **~12.5 mW per channel**
- **Compact electronics** ⟶ **< 1 mm^2 per readout channel**
- **Low fabrication cost**
- **Read-out** of photosensors with **picosecond time resolution** and **intrinsic gain**

OBJECTIVE ⟶ Achieve < 100 ps CTR for ToF-PET applications

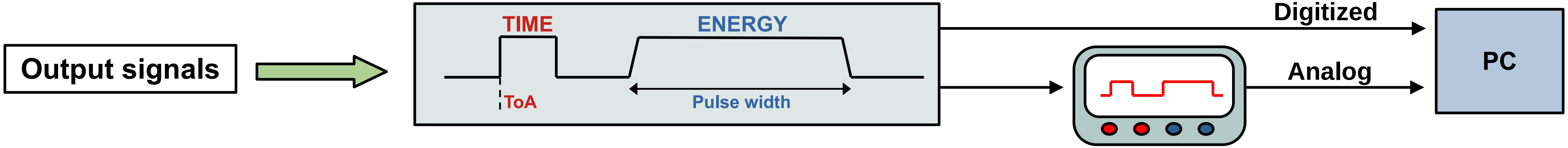
FastIC+ - Architecture scheme



FastIC+ - Architecture scheme



ASIC	CH	TYPE	TIMESTAMP_PS	PULSE_WIDTH_PS
0	8	0	86775048	5000000
0	0	3	86810034	28906
0	8	0	96775097	5000000
0	0	3	96809716	44531
0	8	0	106775146	5000000
0	0	3	106809912	41406
0	8	0	116775219	5000000
0	0	3	116810253	29296
0	8	0	126775244	5000390
0	0	3	126865014	24218
0	8	0	136775366	5000000
0	0	3	136791113	58203
0	8	0	146775439	5000000
0	0	3	146810400	28906
0	0	3	156544311	19921
0	8	0	156775463	5000000
0	0	3	166733520	25781



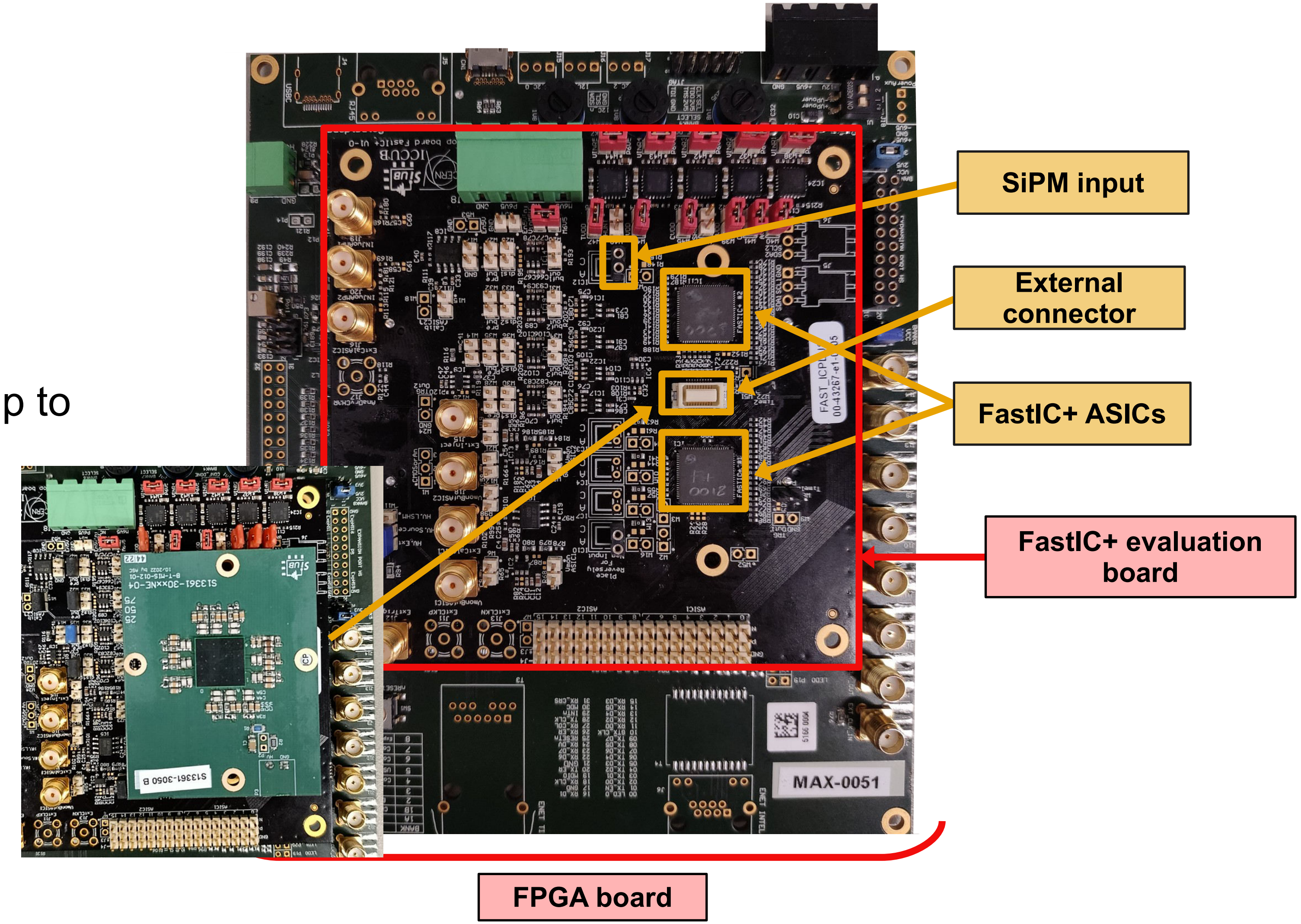
FastIC+ - Evaluation board

FastIC+ evaluation board

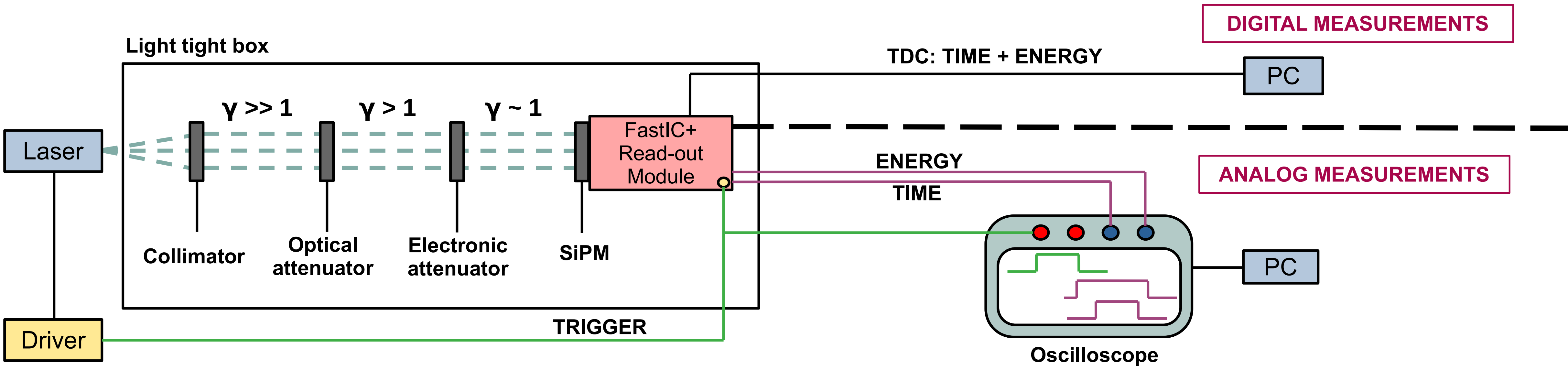
- Holds 2 different ASICs
- Can readout up to 16 channels
- Allows for an external trigger injection
- Can readout form single-pixel channels up to SiPMs arrays

FPGA board

- Programs both ASICs
- Controls the acquisition



FastIC+ performance – SPTR experimental set-ups

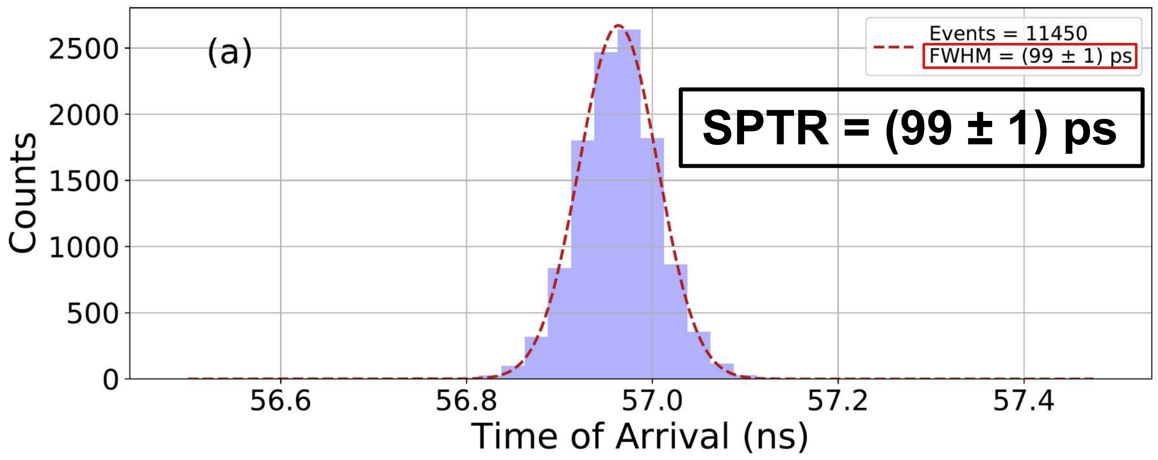


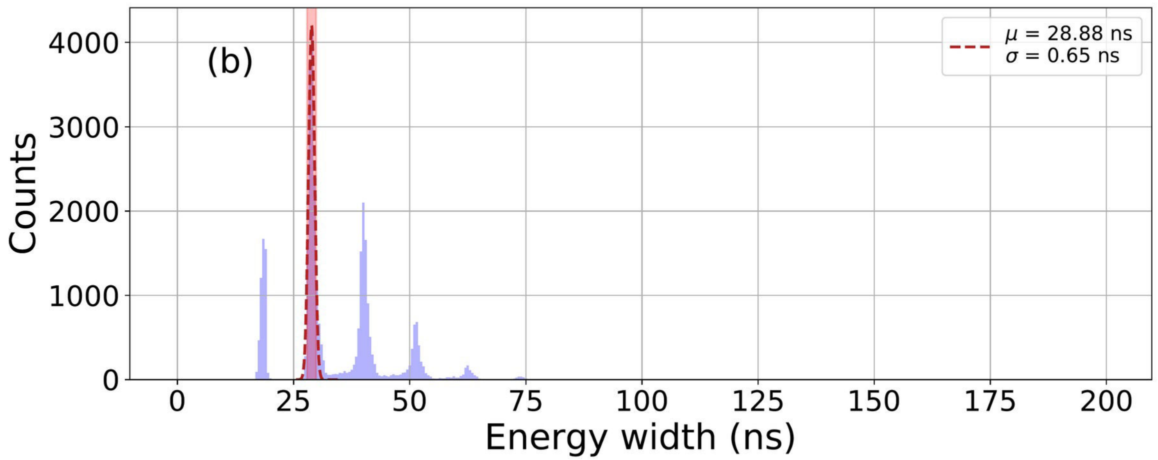
- **Laser**: Pulsed Diode Laser (PiLAS) at 405 nm (jitter < 3 ps, pulse width ~ 28 ps FWHM). Set at a repetition rate of 100 kHz and tuned at a intensity level of the 50%.
- **Oscilloscope**: Agilent MS09254A (2.5 GHz, 20 GSa/s, 10 bits ADC).
- In both measurements, the acquisition was triggered by the laser trigger signal.

FastIC+ performance – SPTR analog vs digital results

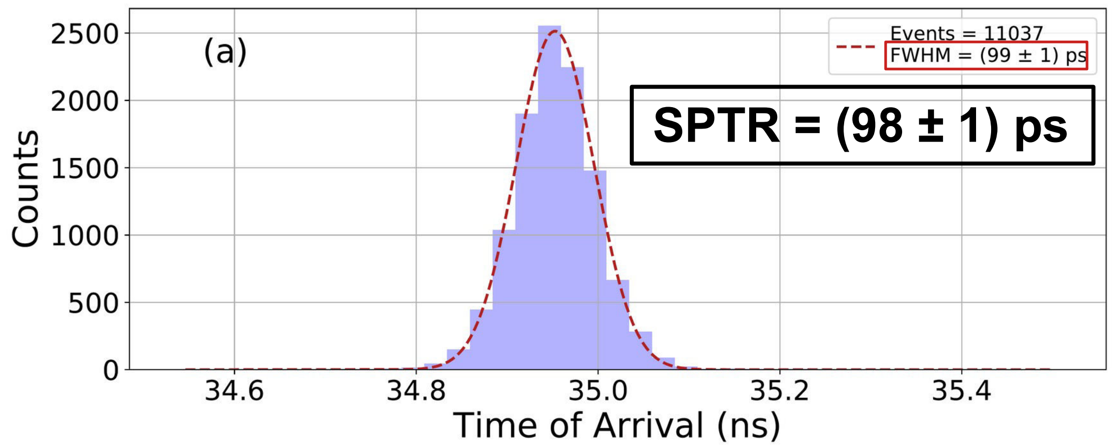
- **SiPM:** FBK NUV-HD-MT LFv2 3x3 mm^2 50 µm SPAD
- **Over-Voltage:** ~15 V

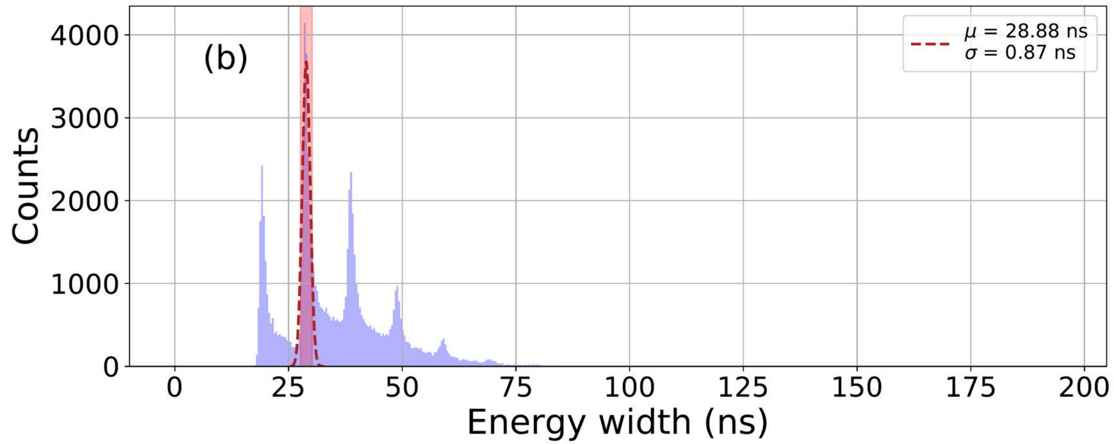
ANALOG MEASUREMENTS



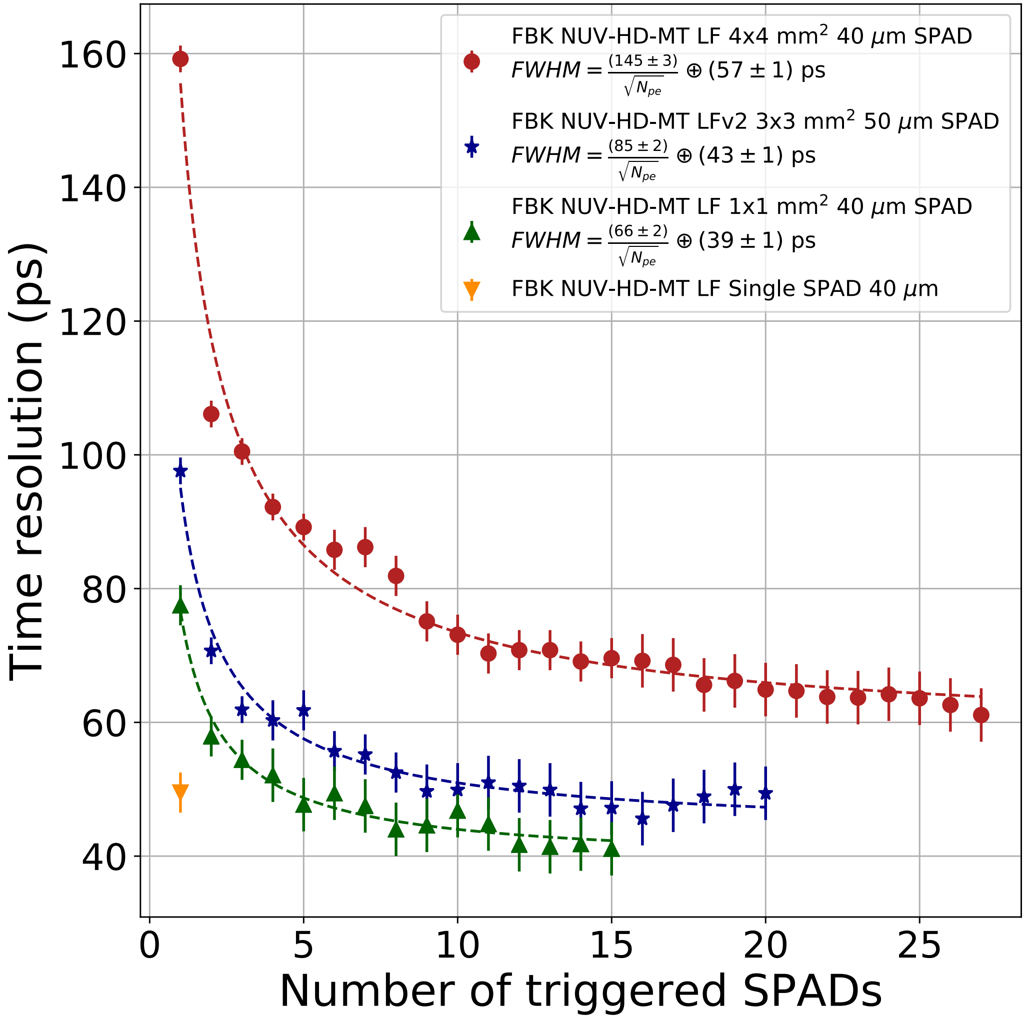


DIGITAL MEASUREMENTS



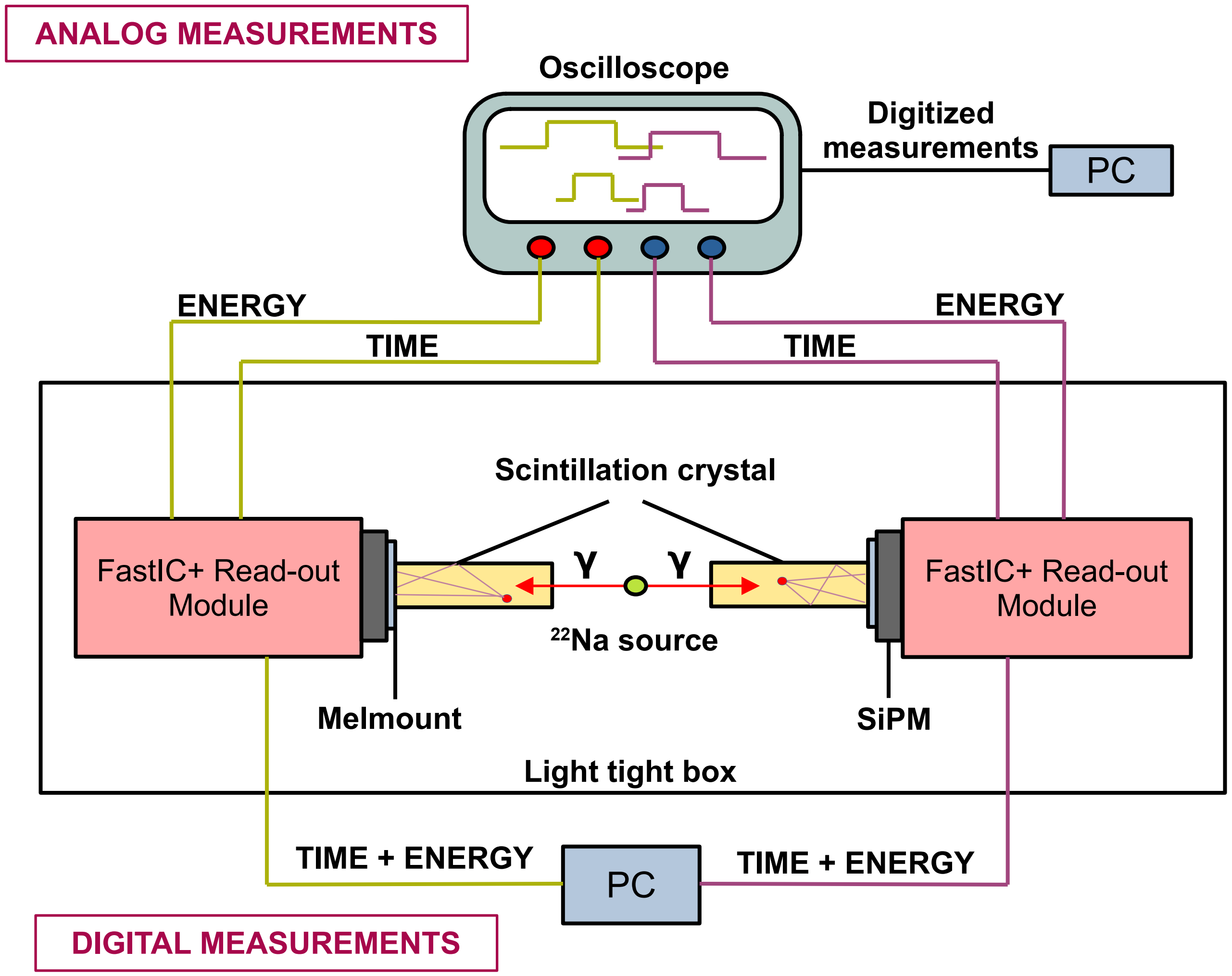


FastIC+ performance – System's jitter FastIC+ TDC



- Data fitted to $\Delta T(N_{p.e.}) = 2\sqrt{2\ln(2)} \cdot \sqrt{\frac{\sigma_{PJ}^2}{N_{p.e.}} + \sigma_{syst.}^2}$
- Time resolution improves as the number of triggered SPADs increases.
- Differences between sensors can be attributed to the sensors themselves
- All measurements were performed in identical conditions (same set-up + same TDC)
- **FastIC+ TDC jitter is low enough to resolve precise time measurements.**

FastIC+ CTR performance - set-up

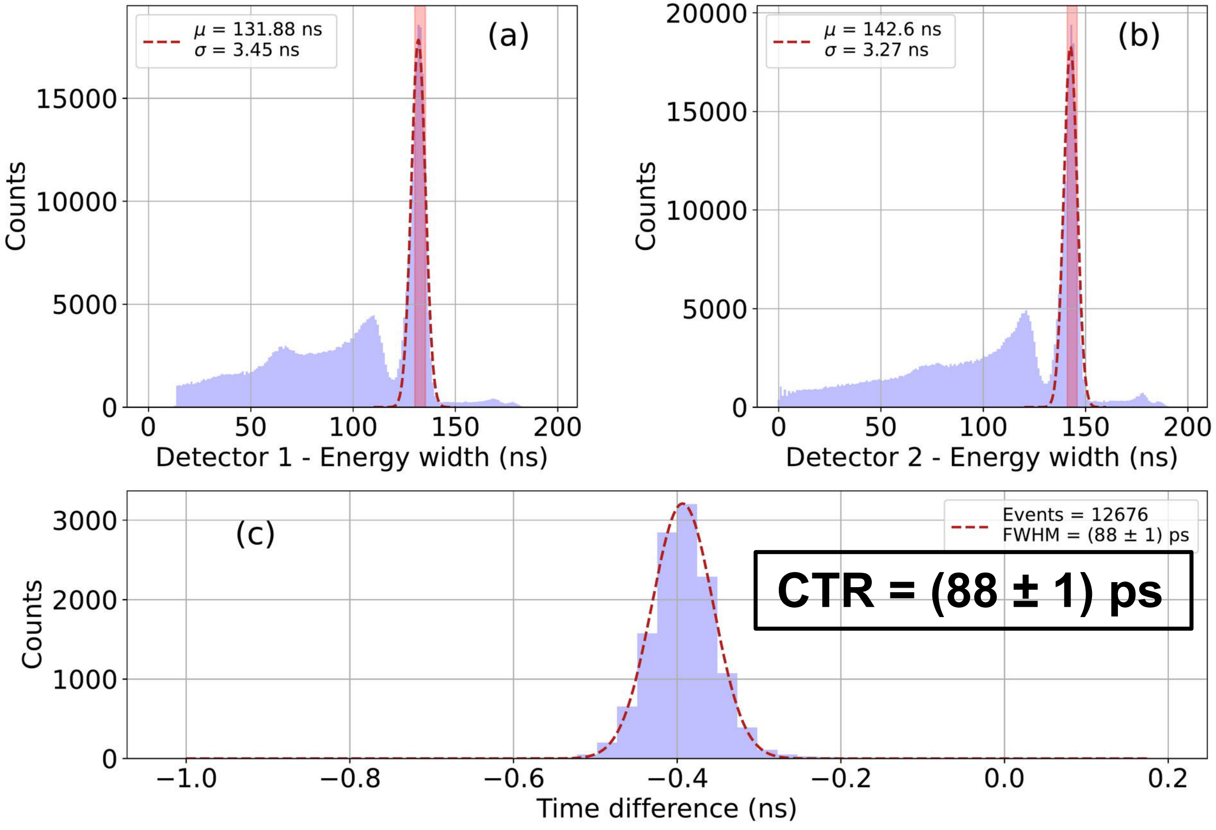


- **Radioactive source**: ^{22}Na, 330 kBq (2018).
- **Oscilloscope:** Agilent MS09254A (2.5 GHz, 20 GSa/s, 10 bits ADC).
- Oscilloscope coincidence windows was set to 25 ns.
- Cargille Melmount (n = 1.582 at 588 nm) was used to optically couple the crystals with the SiPMs.
- Internal trigger was used for both measurements. The threshold was set high to minimize high dark count interference.

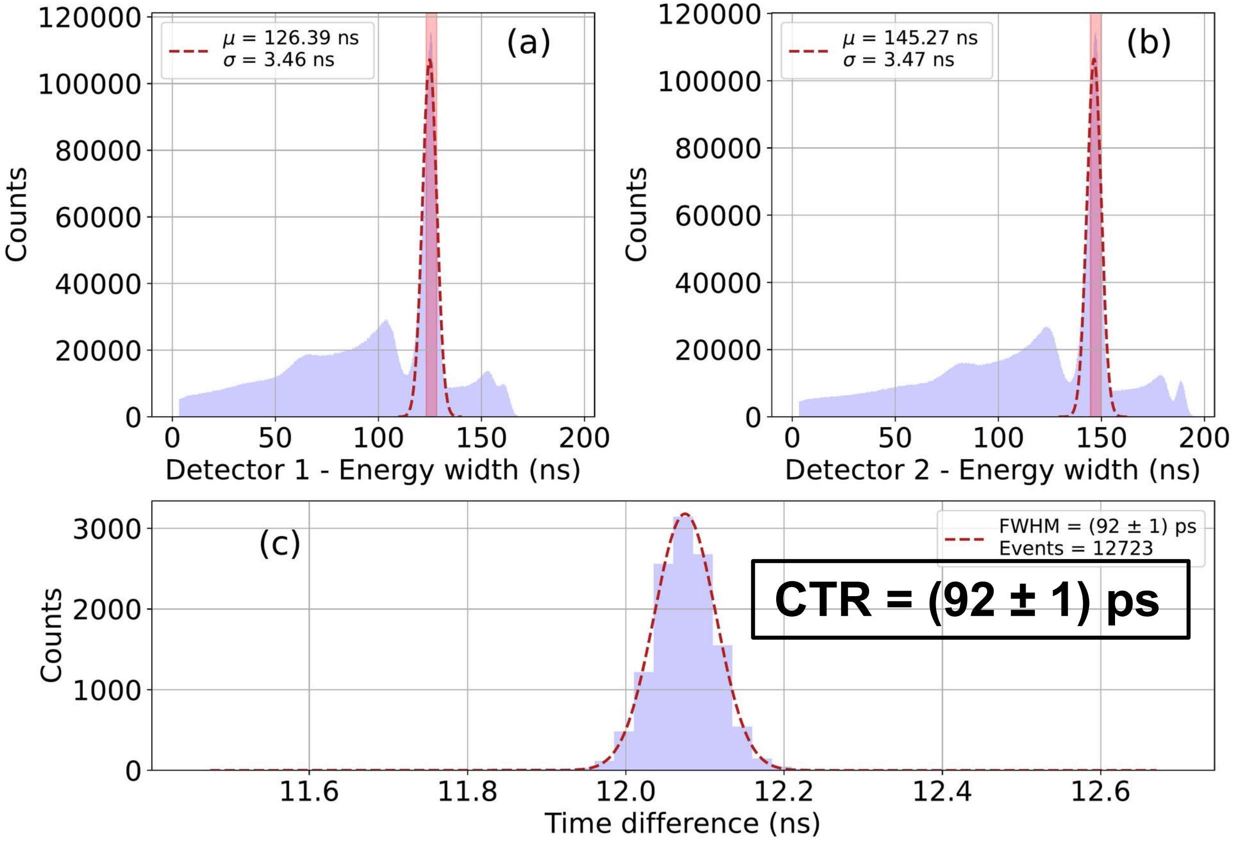
FastIC+ CTR performance – Analog vs digital

- **SiPM:** FBK NUV-HD-MT LFv2 3x3 M0 mm^2 50 µm SPAD
- **Over-Voltage:** ~10 V
- **Crystal**: LYSO:CeCa (Taiwan Applied Crystals) – 2x2x3 mm^3

ANALOG MEASUREMENTS

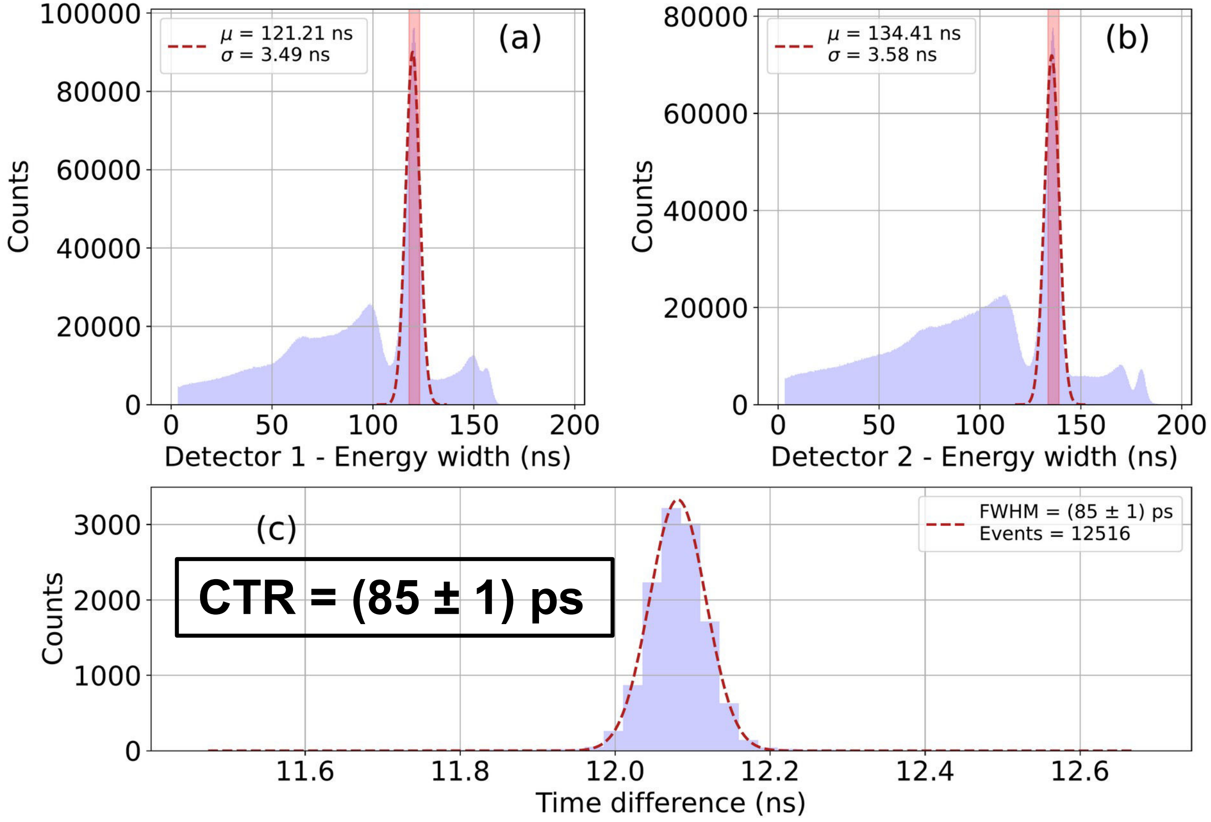


DIGITAL MEASUREMENTS



FastIC+ Digital CTR performance – Best results

- **SiPM:** FBK NUV-HD-MT LFv2 M0 3x3 mm^2 50 µm SPAD
- **Over-Voltage:** ~10 V
- **Crystal**: Fast-LGSO (Oxide Corporation) – 2x2x3 mm^3



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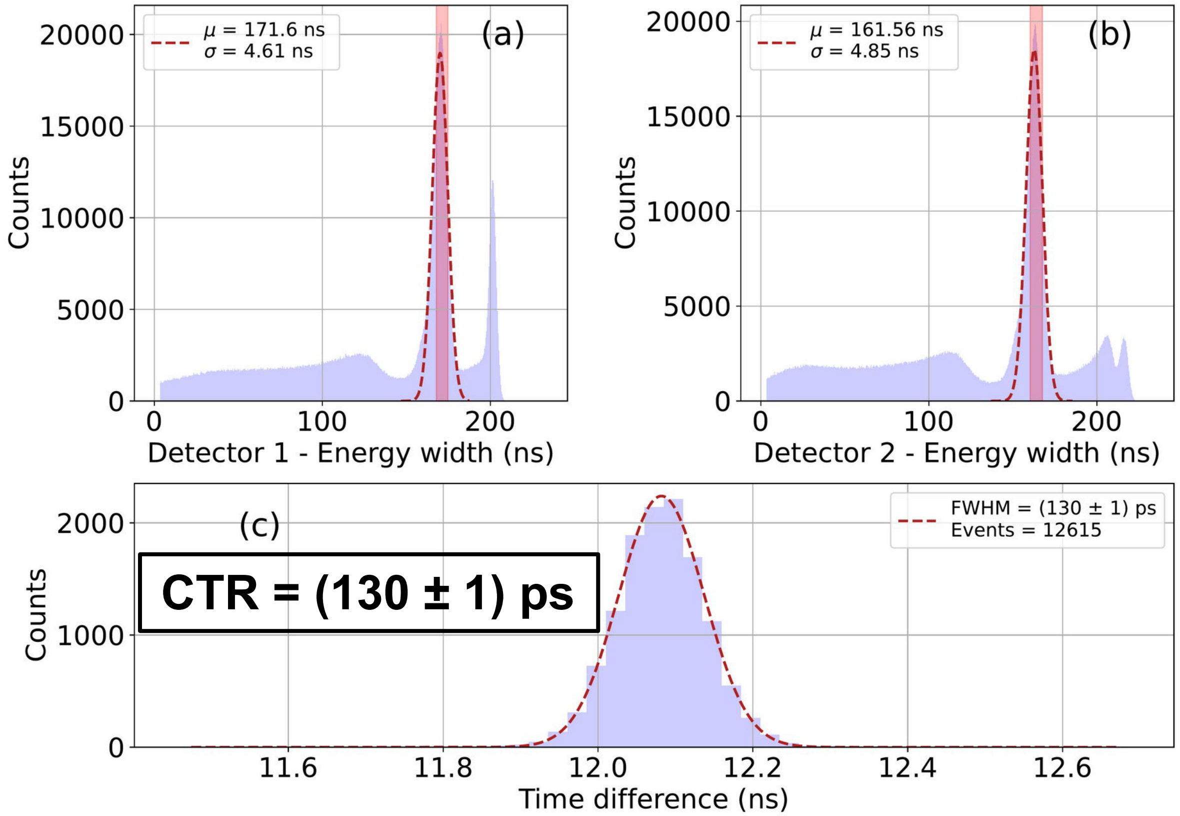
FastIC+ Digital CTR performance – Best results

- **SiPM:** FBK NUV-HD-MT LF 4x4 M0 mm^2 40 µm SPAD
- **Over-Voltage:** ~10 V
- **Crystal**: LYSO:CeCa (Taiwan Applied Crystals) – 2.8x2.8x20 mm^3



Comparison with other fast-timing electronics

ASIC	Power (mW/ch)	Crystal [mm^3]	SiPM [mm^2]	DAQ	CTR (ps FWHM)
HF readout [1]	143	LYSO [3x3x20]	Broadcom NUV-MT [3.8x3.8]	Oscilloscope + IC	95
Radioroc [2]	3.3	LYSO [3x3x20]	Broadcom NUV-MT [4x4]	Oscilloscope	127
TOFPET2c [3]	8	LYSO [3x3x19]	Broadcom NUV-MT [3.8x3.8]	**TDC**	157
FastIC [4]	12	LSO [3.13x3.13x20]	FBK NUV-HD MT LFv2 M0 [3.12x3.2]	Oscilloscope	127
FastIC+	12.5	LYSO [2.8x2.8x20]	FBK NUV-HD MT LF M0 [4x4]	**TDC**	130

[1] Nadig. V et al, Timing advances of commercial divalent-ion co-doped LYSO:Ce and SiPMs in sub-100 ps time-of-flight positron emission tomography, 2023.

[2] Saleem. T et al, Study experimental time resolution limits of recent ASICs at Weeroc with different SiPMs and scintillators, 2023.

[3] Nadig. V et al, Timing advances of commercial divalent-ion co-doped LYSO:Ce and SiPMs in sub-100 ps time-of-flight positron emission tomography, 2023.

[4] A. Mariscal-Castilla. Toward sub-100 ps ToF-PET systems employing the FastIC ASIC with analog SiPMs, 2024.

Conclusions

- **FastIC+** is a **highly configurable ASIC** with a **multi-channel front-end and internal digitization**, adaptable to large ToF-PET scanners.
- The **TDC implementation shows no significant degradation** compared to analog results:
  - **SPTR**: 3x3 mm^2 SiPM – 98 ps (Analog) vs 99 ps (Digital)
  - **CTR**: 3x3 mm^2 SiPM + LYSO 2x2x3 mm^3 crystal – 88 ps (Analog) vs 92 ps (Digital)
- To the best of our knowledge, this is **the first ASIC with on-chip digitization to achieve < 100 ps CTR**, reported for multiple crystals. It also achieves < 140 ps for long crystals.
- It is currently being tested in various ToF-PET applications, including array systems, BGO crystals and double-sided readout for long crystals.
- FastIC+ is also suitable for other fast-timing applications, such as mass spectrometry.

Thanks a lot for your attention!