SAMPIC: a readout chip for fast timing detectors

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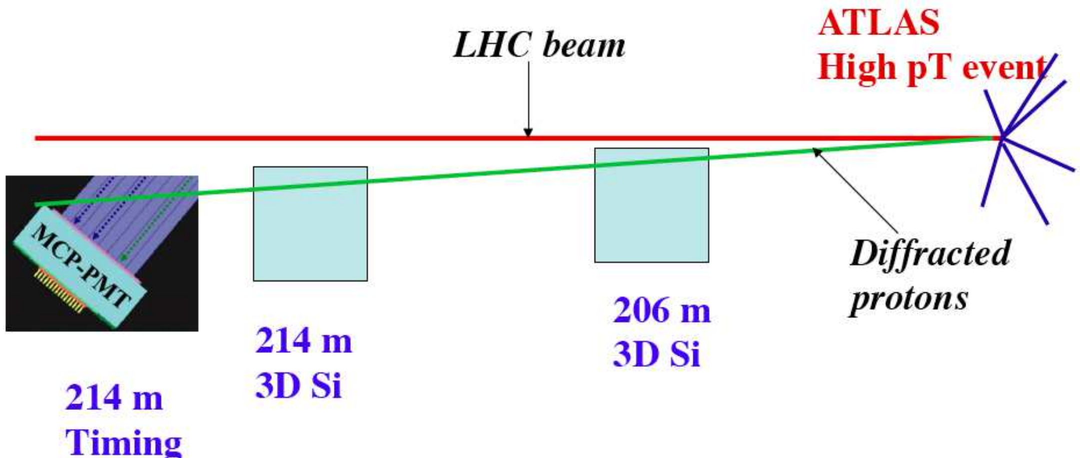
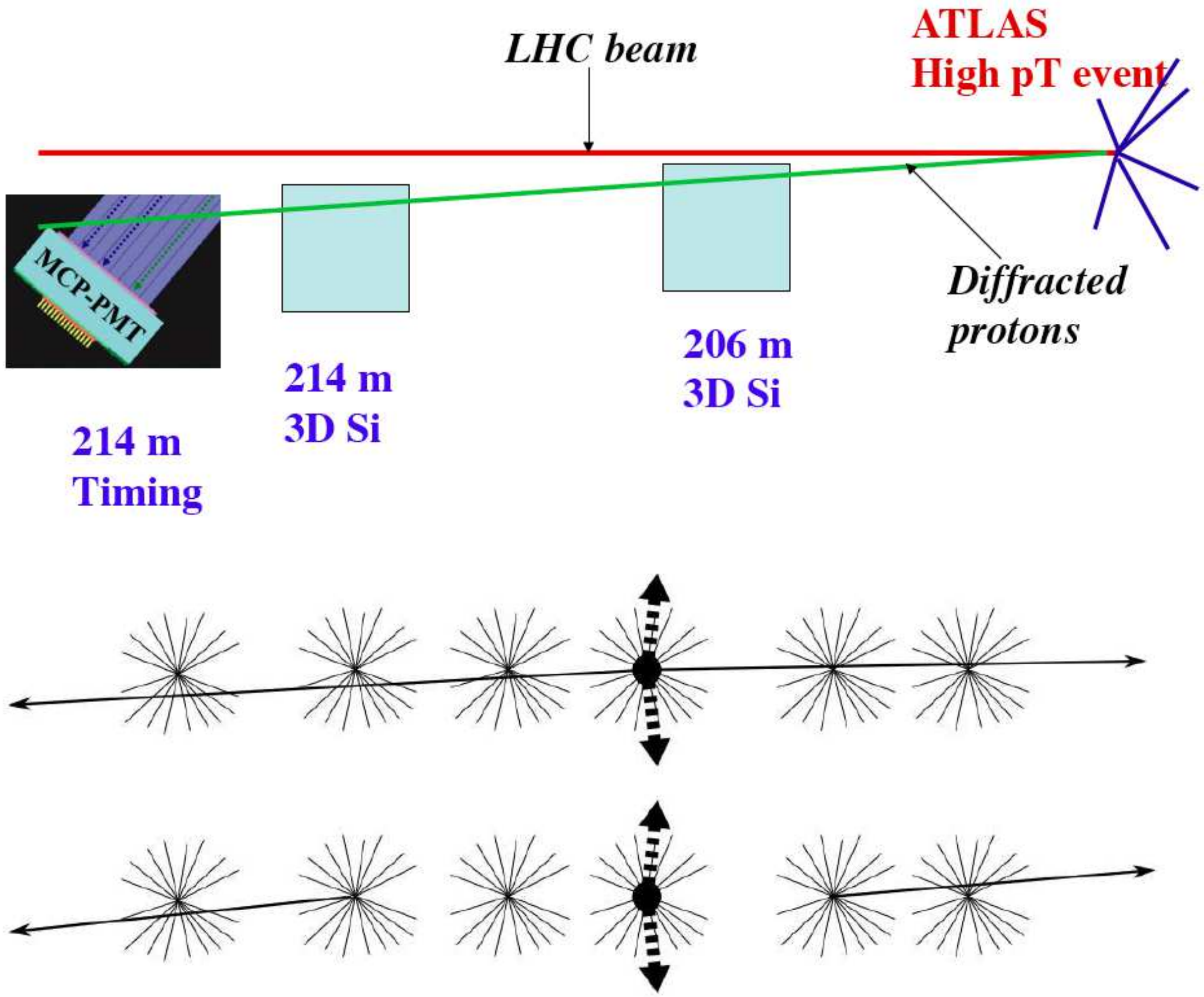
Contents:

- What is SAMPIC?
- Possible applications of timing detectors
- SAMPIC tests: electronics and with Si/diamond/quartz detectors



Introduction: Timing measurements in particle physics

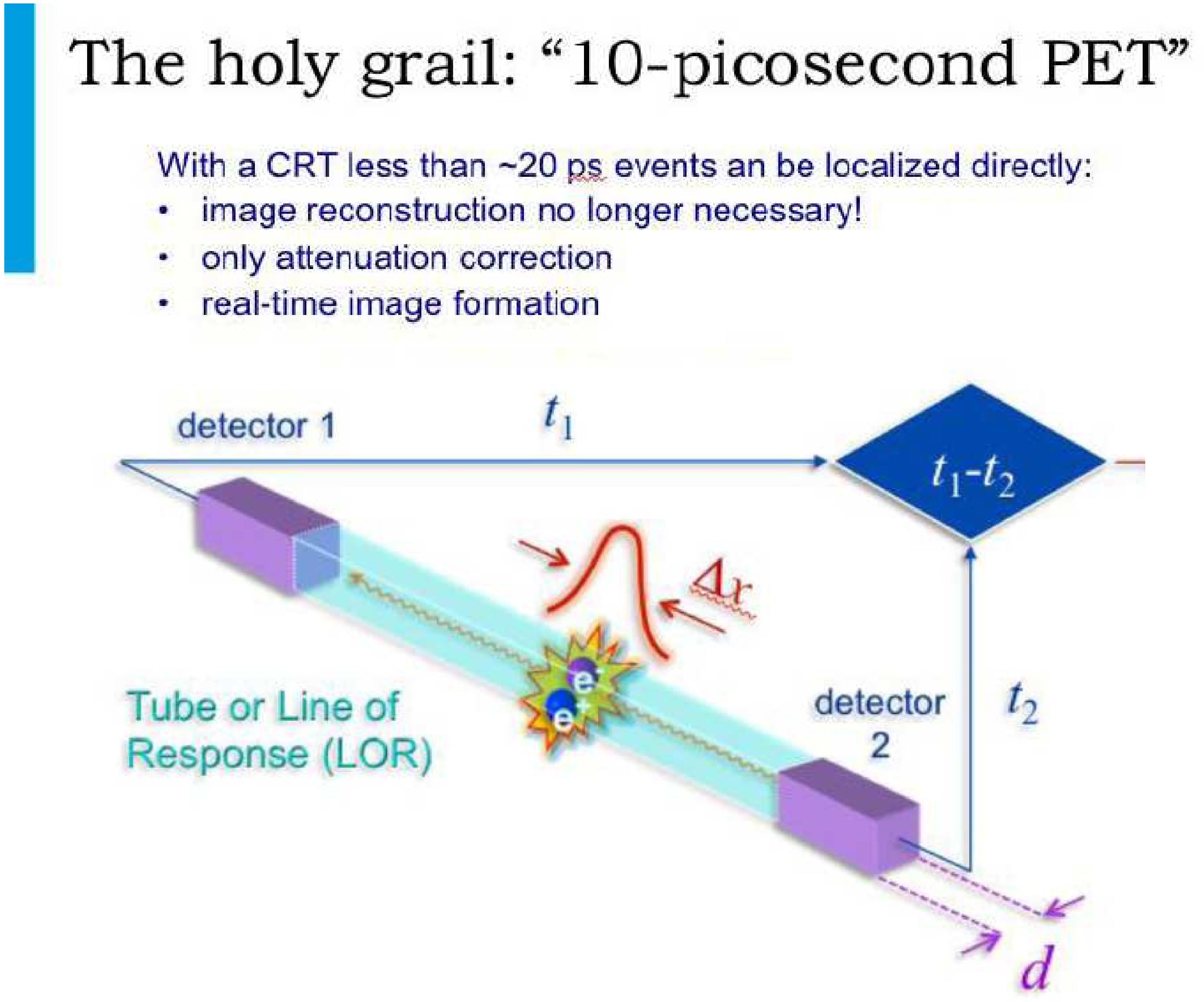
- Proton time-of-flight measurements at the LHC in ATLAS (AFP), and CMS/TOTEM (CT-PPS): $pp \to pXp$



- Determine if intact protons originate from main interaction in the events or from secondary ones (there are between 20-100 interactions per bunch crossing at the LHC)
- Ultimate goal of $\sim$5-10 ps resolution which means 1-2 mm in vertex position

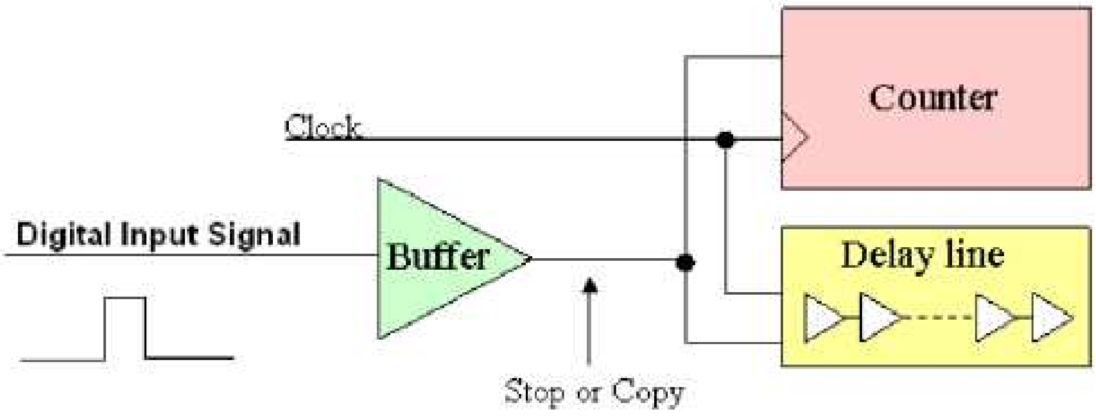
Introduction: Timing measurements in medical imaging

- SAMPIC: working well, to be tested with detectors in beam tests
- Many applications especially in PET imaging (Manjit Dosanjh)



Introduction: why a new chip to get precise timing?

- Before SAMPIC, the most performant Time to Digit Converters (TDCs) use digital counters and Delay Line Loops (DLLs)

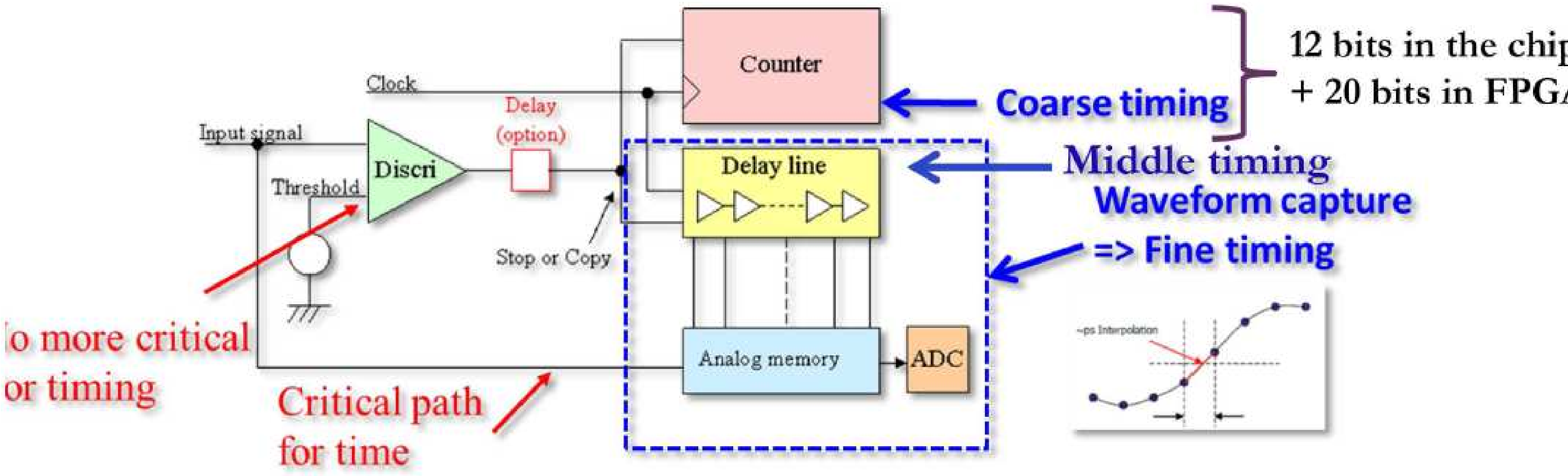


TDC Principle

- Timing resolution limited by the DLL step and with most advanced ASICS, we get $\sim$ 20 ps (new developments at CERN target 5 ps)
- A TDC needs a digital input signal: the analog input signal has to be transformed into a digital one with a discriminator which means that the timing resolution will be given by the quadratic sum of the discriminator and the TDC timing resolution

SAMPIC: Waveform based TDC

- SAMPIC acquires the full waveforme shape of a detector signal
  - Discriminator used only for triggering, not for timing: no jitter from it
  - All information is kept: possibility to use offline signal processing algorithms to improve timing resolution; can be used to obatin other signal characteristics as well (deposited charge...)
  - Important dead time per channel due to ADC conversion: about 1 μs, to be reduced to about a factor 10 in the next version
- SAMPIC is cheap ($\sim$ 10 Euros per channel) (compared to a few 1000 Euros for previous technologies), which means that it can be used in large scale detectors such as PETs...

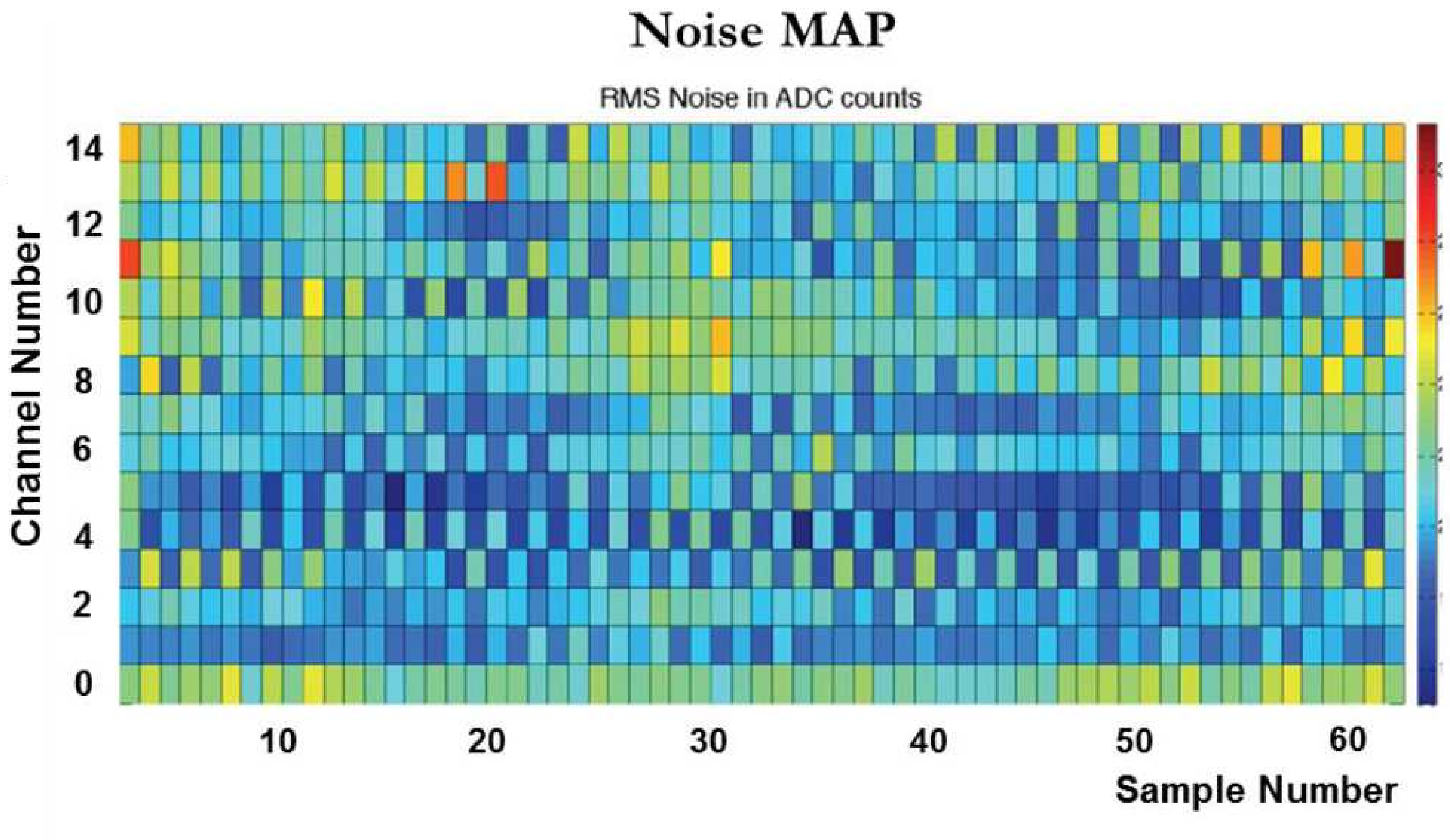


SAMPIC and its acquisition board

- Mezzanine board can host two SAMPICS: 32-channel system
- MCX connectors and UBS-Ethernet-Optic fiber readout
- 5V voltage supply, 1 Amp.

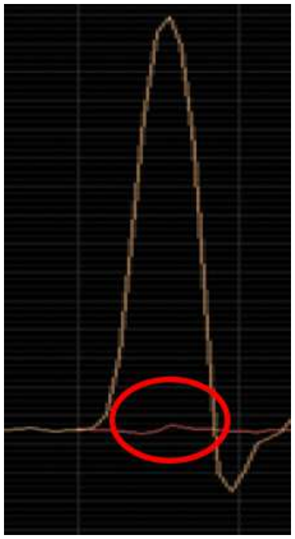
SAMPIC noise

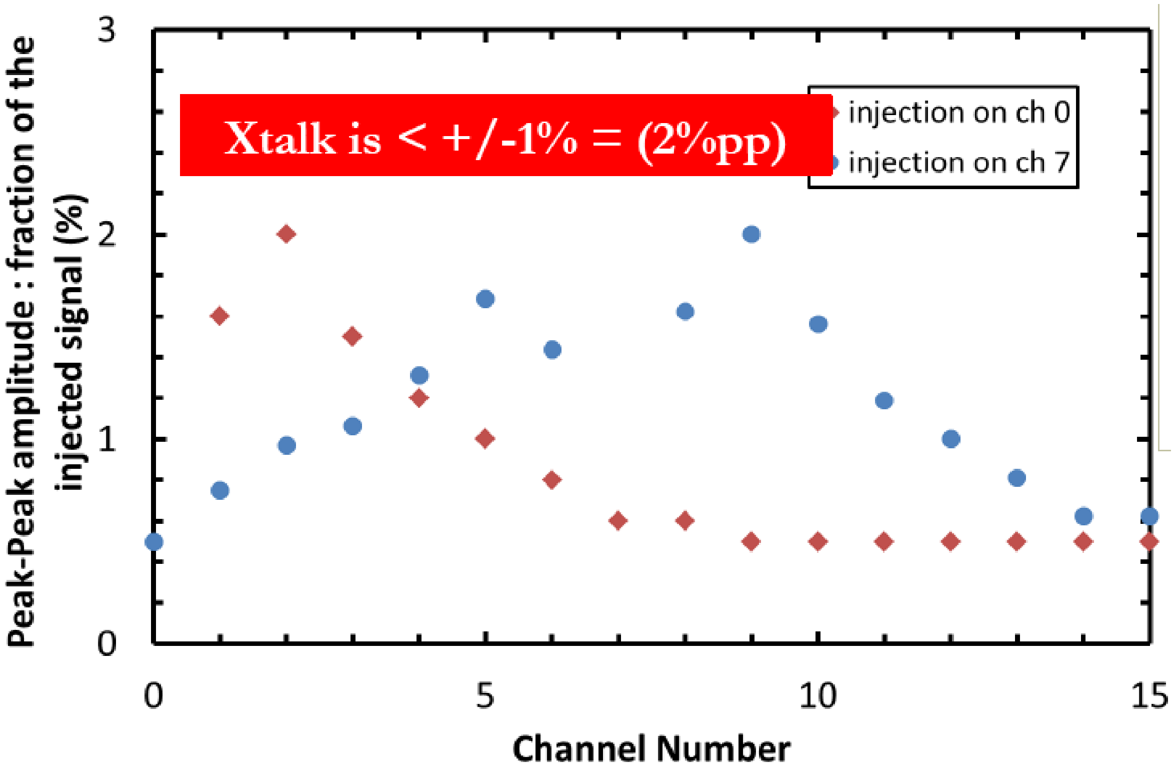
- Maximum signal size: 1V
- After corrections, average noise is 1 mV rms (noisiest cells are 1.5 mV rms), which means dynamic 10 bits rms



SAMPIC cross talk measurement

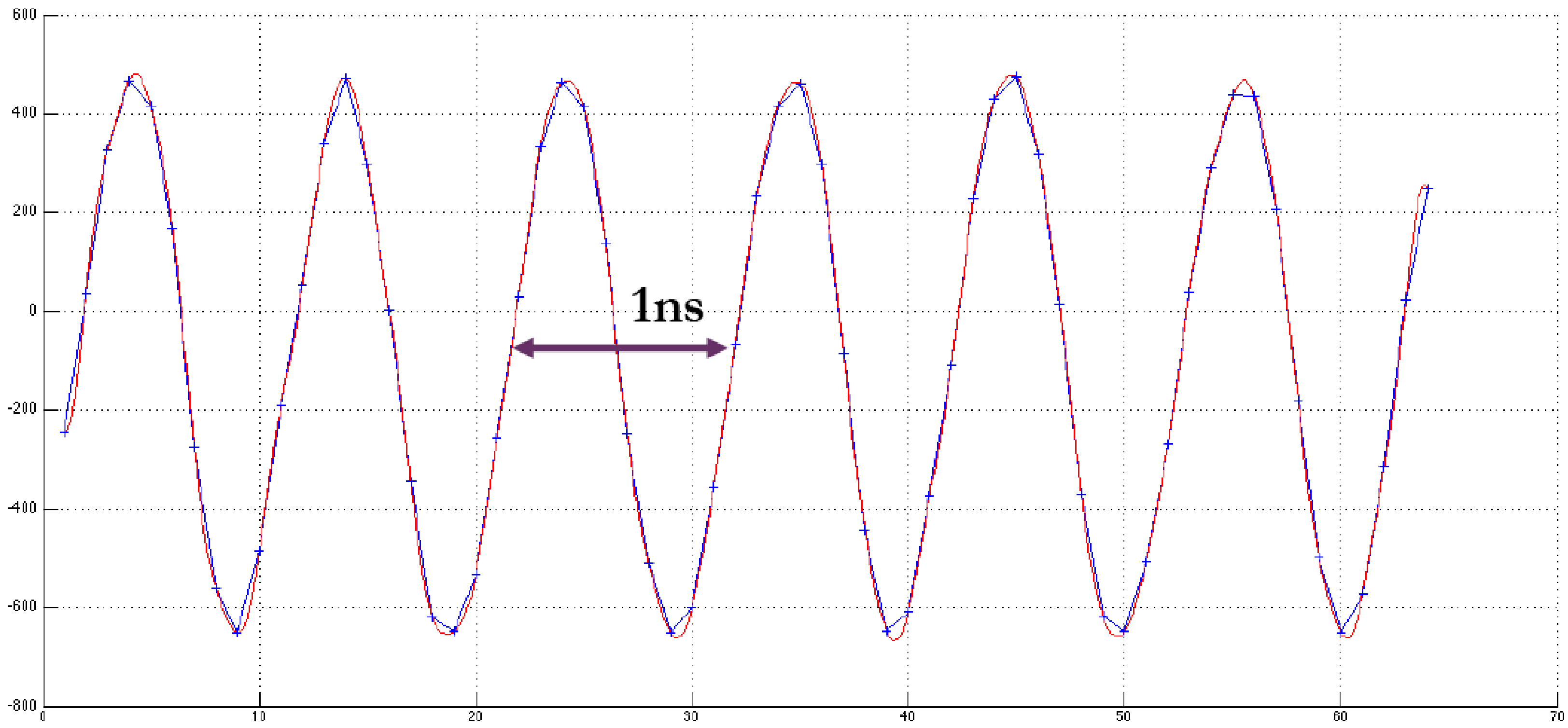
- Signal of 800 mV, 300 ps rise time injected on channel 0 or 7 of SAMPIC
- Signal measured on other channel
- Cross talk is less than 1%





Quality of sampling

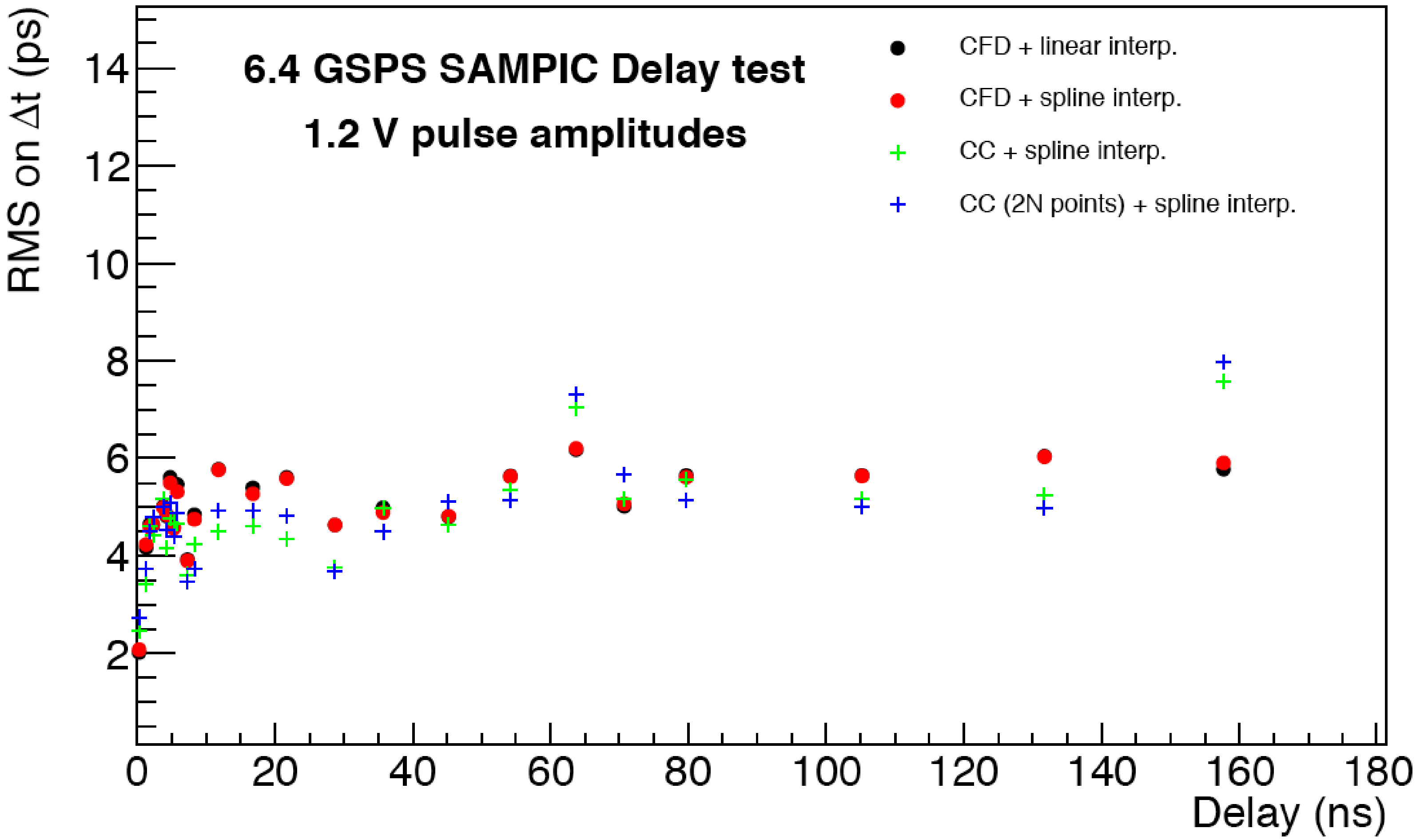
- Sample speed from 3 to 8.2 Gigasample per second on 16 channels (up to 10 GSPS on 8 channels)
- Already very good sampling quality: example of sampling of a sinus without corrections at 10 GSPS



Timing resolution vs delay

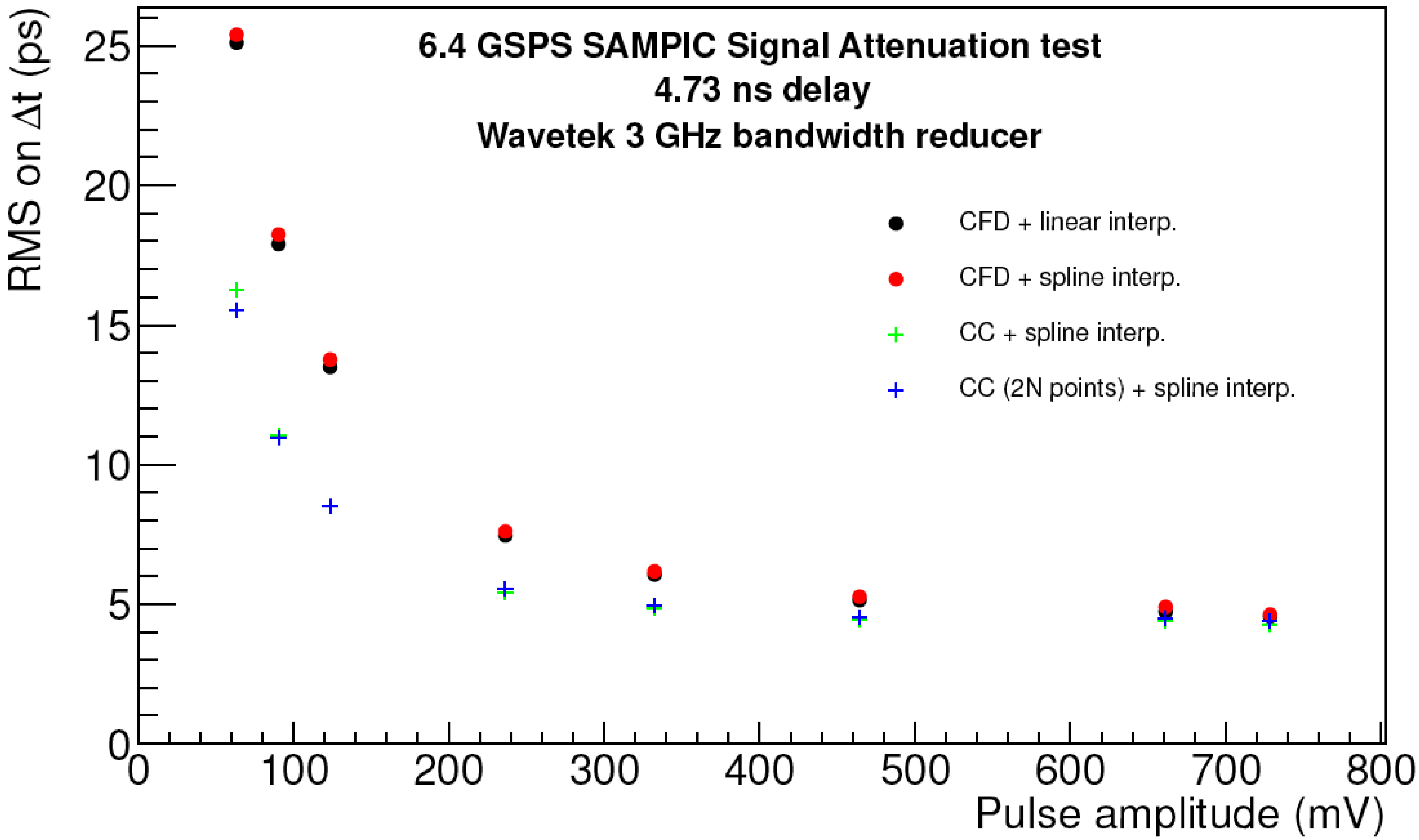
- Use two different channels of SAMPIC
- Send two times the same signal, one being delayed (delay box or longer cable)
- Measure the time difference and its RMS as a function of delay between 0 and μs
- check SAMPIC stability as a function of delay

Timing resolution vs delay



- Measure the RMS of the time difference between two pulses sent to SAMPIC vs delay using a pulse generator
- Different methods used: CFD (constant fraction discriminator), CC (cross correlation)
- Flat resolution of ∼5 ps vs delay: time resolution per channel of ∼3 ps

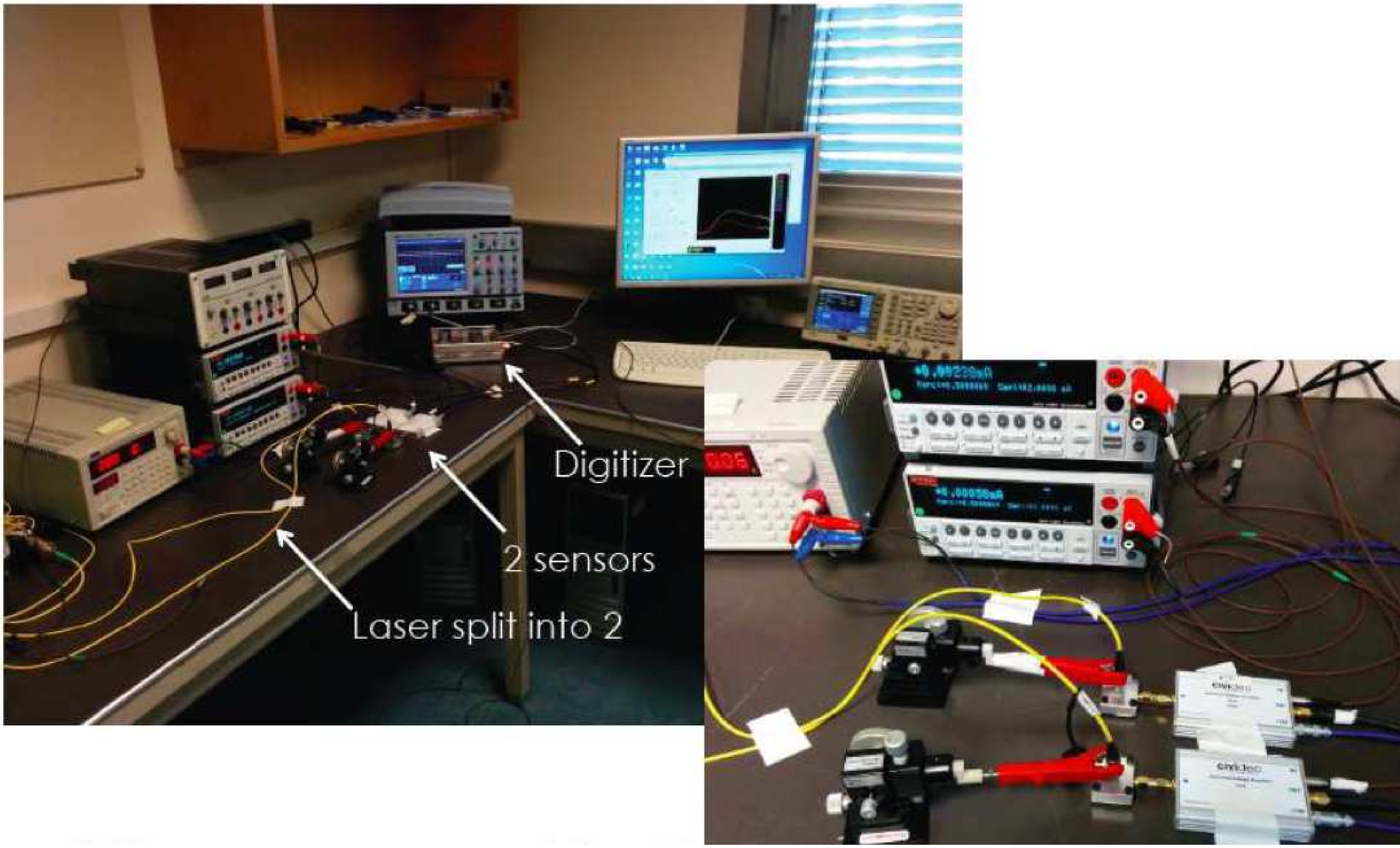
Timing resolution vs signal amplitude



- Measure the RMS of the time difference between two pulses sent to SAMPIC vs the pulse amplitude using a pulse generator
- Different methods used: CFD (constant fraction discriminator), CC (cross correlation)
- Best time resolution if the signal is above 450 mV

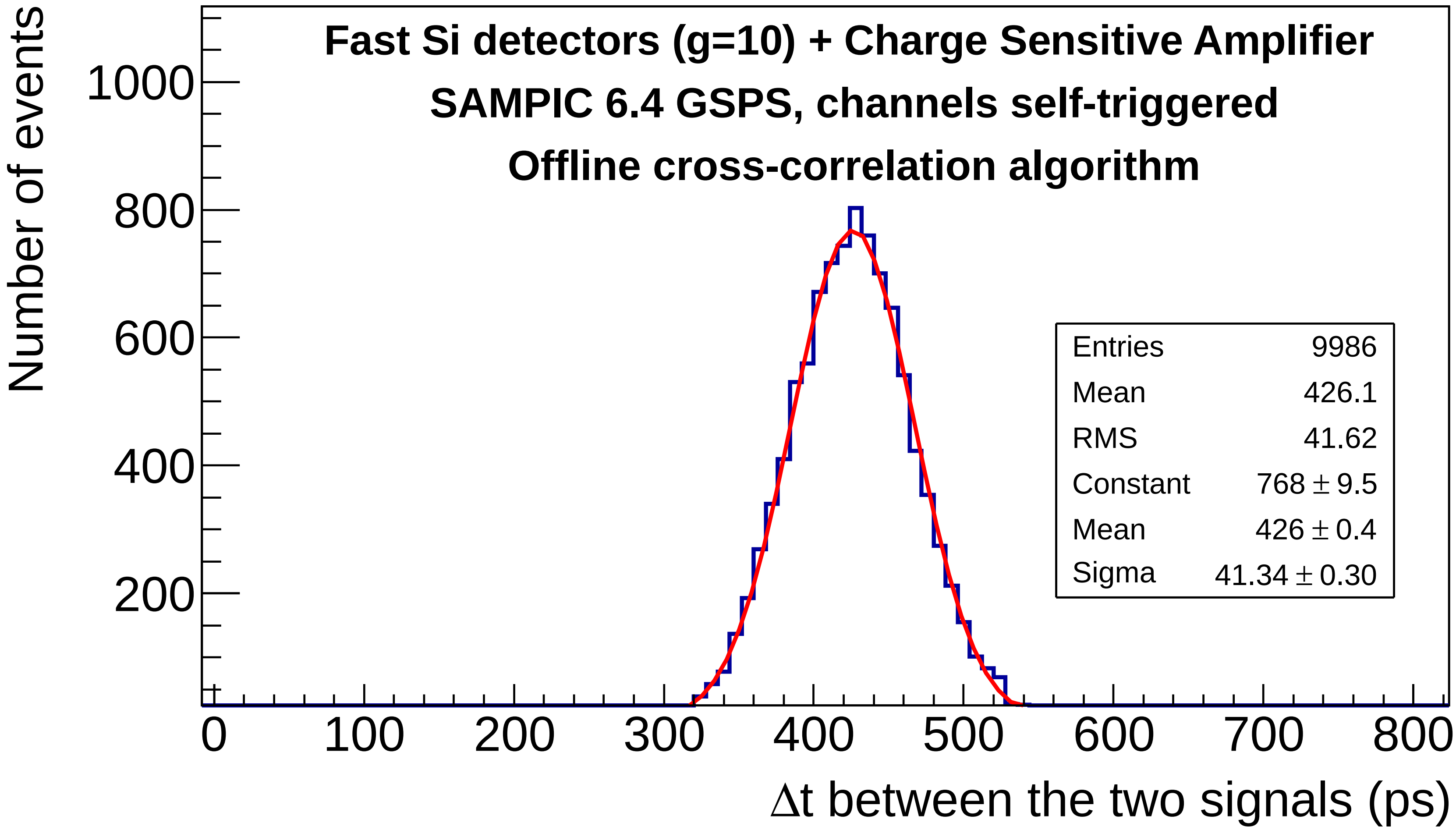
Time resolution using Si detectors

- Test setup using a laser signal splitted in 2 read out by fast Si detector
- Time difference and RMS measured by SAMPIC



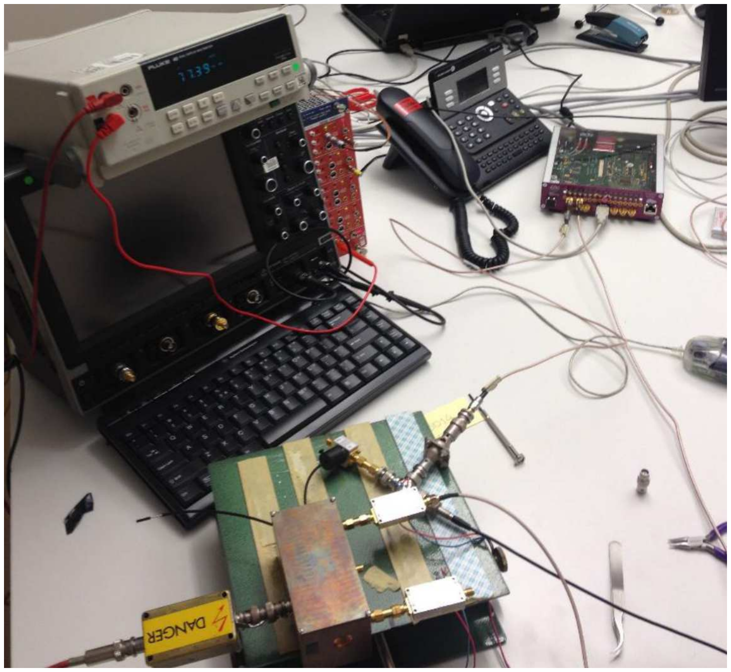
Time resolution using Si detectors

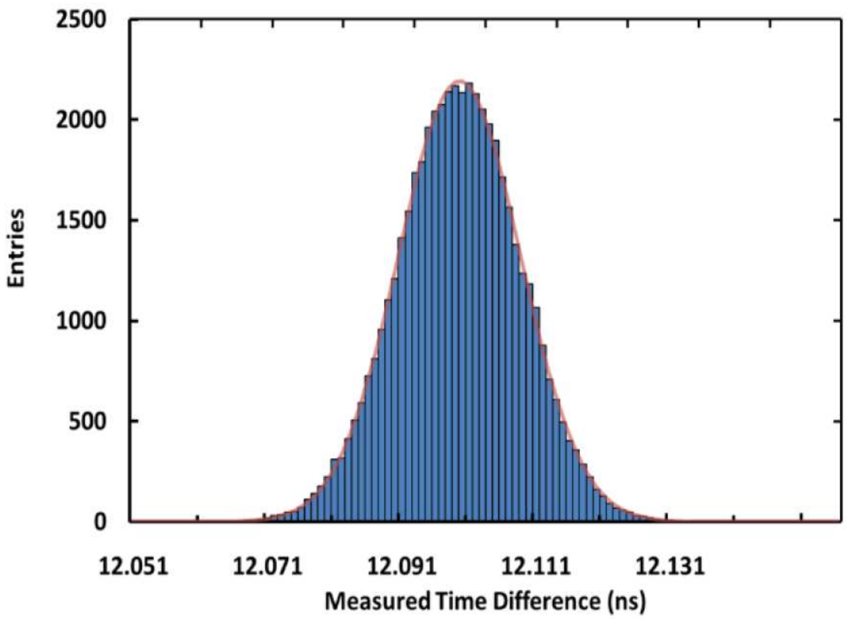
- Time resolution using sampic and fast Si detectors (Nicolo): measure the time difference between two channels
- Time reolution: (dominated by detector): $\sim$ 30 ps
- Results in beam tests for diamond detectrs: resolution of $\sim$80-90 ps because of the slower rise time of the signal (4.5 ns)



Time resolution using fast mesh APD detectors

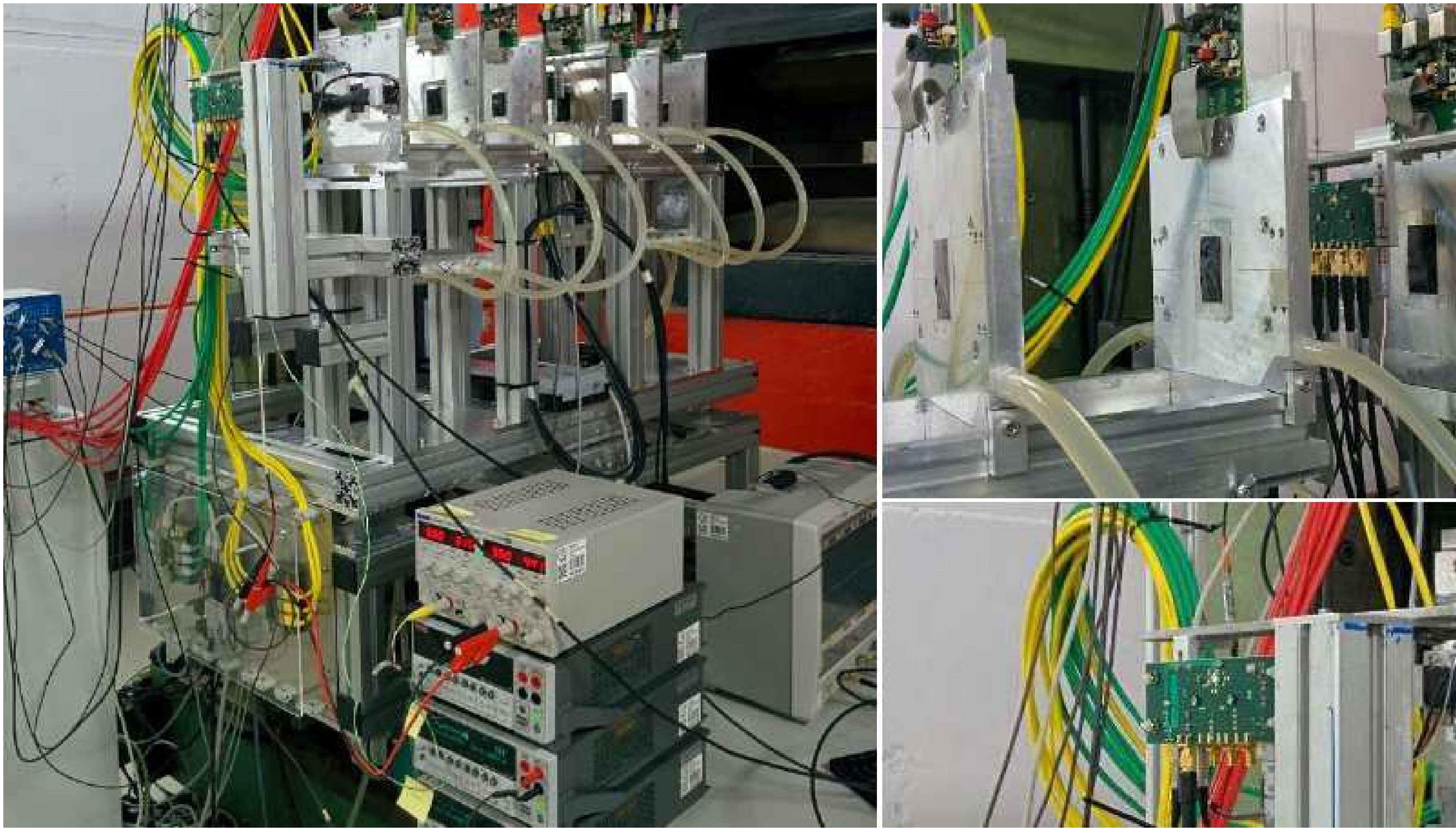
- Time resolution using sampic and fast mesh APD detectors: measure the time difference between two channels (one is the pulser and the other one the APD mesh output (Sebastian))
- Time reolution: (dominated by detector): $\sim$ 10 ps





Beam tests in TOTEM using diamond detectors (I)

- Beam tests performed at DESY and CERN by TOTEM using diamonds detectors and SAMPIC



Beam tests in TOTEM using diamond detectors (II)

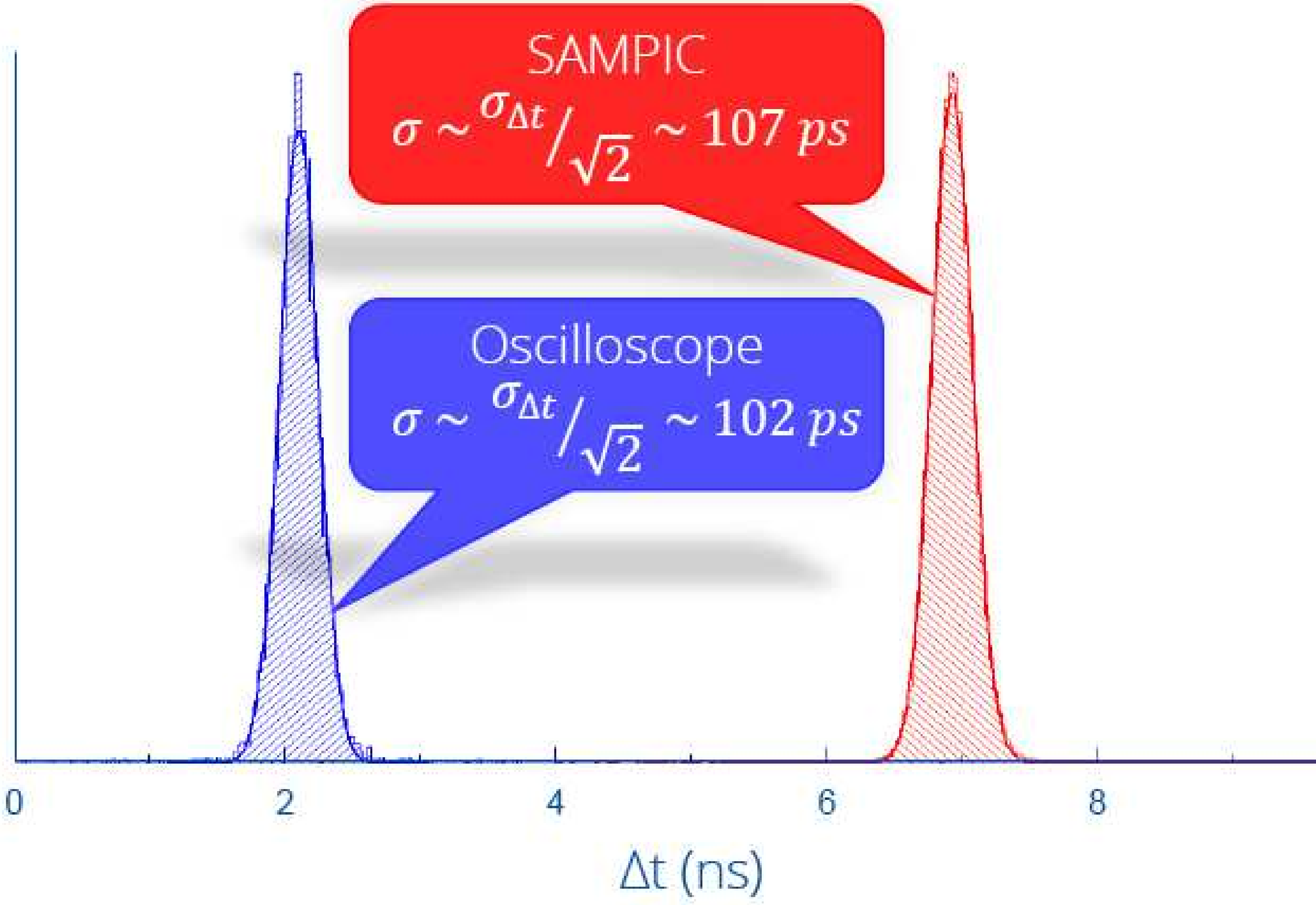
- Beam tests performed at DESY and CERN by TOTEM using diamonds detectors and SAMPIC

Agilent DSO 9254A
2.5 GHz bandwidth
10 Gs/s
8 bit
> 1000 samples
4 channels
Maximum rate ~100 Hz

SAMPIC
2.5 GHz bandwidth
10 Gs/s (used at 6.4 Gs/s)
11 bit
64 samples
16 channels
Maximum rate ~500 kHz

Beam tests in TOTEM using diamond detectors (III)

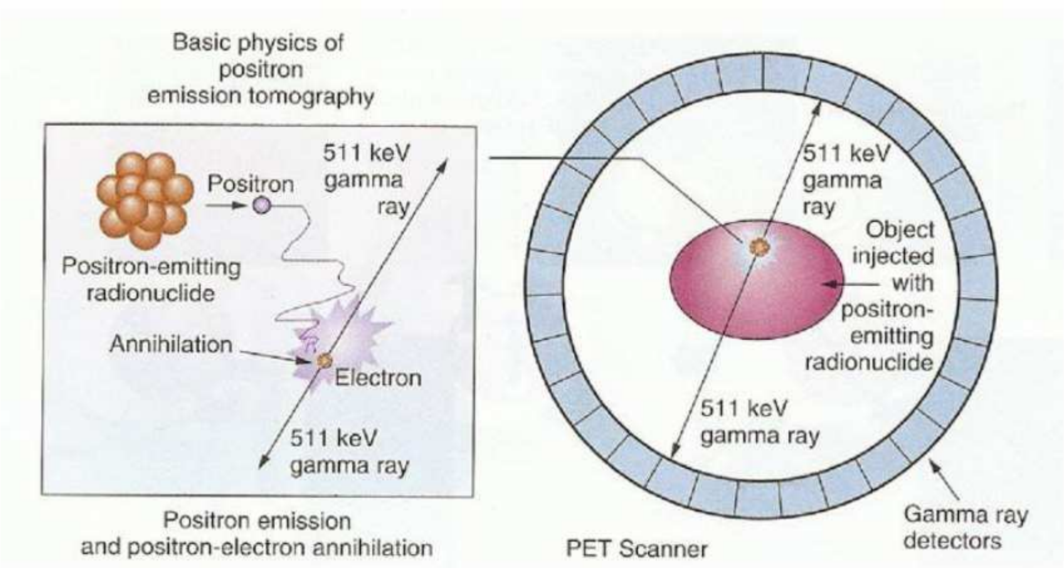
- Measure the resolution on the time difference between two channels

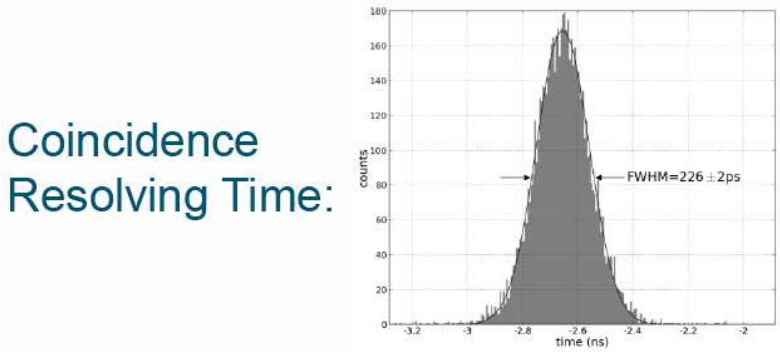


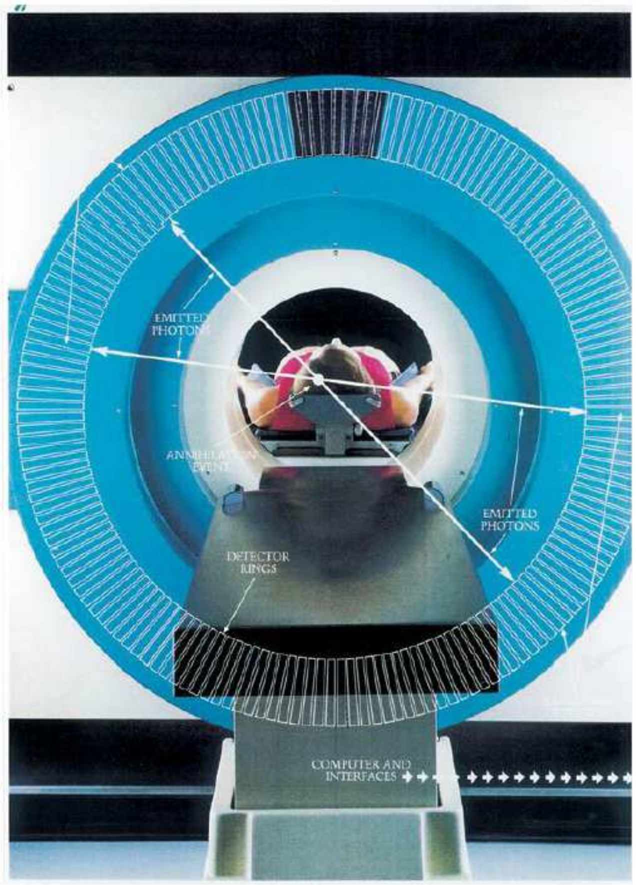
SAMPIC0 summary

		Unit
Technology	AMS CMOS 0.18µm	
Number of channels	16	
Power consumption	180 (1.8V supply)	mW
Discriminator noise	2	mV rms
SCA depth	64	Cells
Sampling Speed	<3-8.4 (10.2 for 8 channels only)	GSPS
Bandwidth	1.6	GHz
Range (Unipolar)	1	V
ADC resolution	8 to 11 (trade-off time/resolution)	bit
SCA noise	<1.3	mV rms
Dynamic range	9.6	Bit rms
Conversion time	0.2-1.6 (8bit-11bit)	µs
Readout time (can be probably be /2)	25 + 6.2/sample	ns
Time precision before correction	15	ps rms
Time precision after timing INL correction	< 5	ps rms

The future: Application: Timing measurements in Positron Emission Tomography







- The Holy grail: 10 picosecond PET (3 mm resolution)
- What seemed to be a dream a few years ago seems now to be closer to reality
- Other possible application in drone technology: fast decision taking and distance measurement using laser

Conclusion

- A self-triggered chip demonstrator has been designed and characterised: 1.6 GHz bandwidth, up to 10 GSPS, low noise (trigger and acquisition), $<$5 ps rms timing resolution
- Chip is usable for tests with detectors: tests started with quartz, diamond, Si detector together with ATLAS/CMS/Totem; intrinsic time resolution of $\sim$ 3 ps
- Work going on on DAQ sytem optimisation (firmware and software), second prototype including dead time improvement (ping-pong)
- Laser tests with Si detectors, Beam tests in common with CMS/Totem with diamond detectors
- SAMPIC can be used for many timing applications: PETs, cosmic applications... in detectors including many channels due to the low cost per channel