Fast Timing: future prospects

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Fast timing: what is it?

- Devices/experiments that benefit from a timing resolution better than 50 ps ($\sigma$).

And at this moment **fast timing** is a hot topic

**why?**
the identification of rare events implies High luminosity accelerators.

- Pile-up of up to 200 collision events per bunch crossing at the upgraded LHC.
CMS event: the green towers indicate the energy of the photons

The tracking detectors can be used to assign charged tracks to individual vertices: but what about the photons?
So we need to build a pre-shower detector with precise timing just in front of calorimeter

N.B. need time resolution ($\sigma$) of 5-20 ps!

![Diagram of detector setup](image)

- Photo detector
- Cascade of electrons and photons
- Small scintillating crystals
- Silicon photomultiplier
- Incoming photon
• Time of Flight techniques can alleviate the pile-up problem, but:

• Current state of the art; ALICE TOF $\sim 75$ps (sigma)

• The goal of a calorimeter with 10 ps (sigma) TOF resolution is beyond the current state of the art
An example of excellent synergy between particle and medical physics:

yeast both needs exactly the same detector working with cutting edge performance
• Injection of a positron-emitting radionuclide (chemical substances such as glucose, carbon, or oxygen used naturally by the particular organ or tissue during its metabolic process).

• Emission and annihilation of the positron with an electron: production of two back-to-back 511 keV gammas.

• Detection of these gammas and find the position: construct line between these two space points.

• Construction of a 3D image from these lines.
So we have to create a 3-D image ... and that requires a detector that surrounds the patient - i.e. need a large detector with ultra-precise timing.

- TOF for rejecting background events (Compton scattering and random coincidences).
- TOF for improving image S/N
- Ultra-precise TOF gives direct 3D information
Current commercial TOF-PET has ~ 500ps CTR (10 cm)

State of the art (in our lab) ~ 250 ps FWHM (4 cm)

But to make a significant improvement one needs a FWHM of “100 ps”

i.e. 16 mm position resolution along line of flight
Can we approach this 100 ps limit?

- Concept of differential readout and the NINO asic (this asic was developed a decade ago as the ‘obvious solution’ for TOF arrays with MRPC: nowadays people are beginning to realise the importance of this development)

- Silicon photomultiplier
Differential or single-ended readout?

Basic schematic of all detectors

all signals in all detectors are due to the movement of charge between two readout electrodes. Equal and opposite signals are produced on these two electrodes and current flows through the external circuit.
Single-ended readout pumps spikes of current into common ground. The ground is the reference for all the discriminators.

Result: crosstalk and additional timing jitter.

Signal current flows through front-end and back to where it came from. No current injected into common ground.

Result: No crosstalk and no extra electronic jitter.
So our message is:
differential readout is essential to minimise
cross-talk and common mode noise (in the ground)
and is absolutely necessary for precise timing

So for fast timing: one needs
(a) fast differential amplifier/discriminator
  (i.e. the NINO)
(b) detectors that generate a differential signal
The best/only differential discriminator ASIC so far! 
The NINO
The Silicon photomultiplier

~ 4000 SPADs (single photon avalanche diode)

- operated in Geiger mode; thus single photon generates detectable signal
Where we were:

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2 times 4x4 crystal array of 3.1x3.1x15 mm³ each coupled to a monolithic SiPM array.

CTR ~ 350 ps FWHM

Bias Voltage = 73.6 V on both MPPCs
NINO Threshold =80 mV

22Na point source

CTR ~ 350 ps FWHM
Where we are now

4x4 discrete SiPM array with differential readout

FWHM=247.8 ps

FWHM=263.5 ps

FWHM=244.43 ps

FWHM=220.1 ps
Why not improve TOF resolution to 100 ps FWHM?

- The Crystals:
  - high light yield, fast, dense etc
  - but in general high refractive index (1.82 for LYSO) and difficult to get light out

- The SiPM
  - As shown previously - need differential detector.
  - Need to minimise dark count noise (we believe that we have the solution to that)

- The Readout electronics
  - Differential discriminator/amplifier such as NINO but needs improvement (we believe we will have a significant improvement in timing with a redesign)

also: we need funding for this project
Summary

In the last decade we have seen significant progress in the field of fast timing:

This is due to the MRPC, the NINO ASIC and Silicon PhotoMultipliers

Outlook:

Large TOF arrays with 20 ps time resolution with MRPCs

Pre-shower detectors with ultra-precise timing so that photons can be associated to the correct interaction point.

TOF-PET with better than 100 ps FWHM time resolution so that whole body scanners can be built with suitable sensitivity (screening of prostate and pancreas cancer).