Arrays of digital Silicon Photomultipliers
Intrinsic performance and Application to Scintillator Readout

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How to replace old-fashioned PMTs?

• Take the digital SiPM
  – 1 pixel

• Increase integration
  – 2 x 2 pixel on one chip

• Assemble arrays
  – 8 x 8 pixels on one PCB
Digital Photon Counting – The Concept

Intrinsically, the SiPM is a digital device: a single cell breaks down or not

**analog SiPM**

Summing all cell outputs leads to an analog output signal and limited performance

**digital SiPM (dSiPM)**

Integrated readout electronics is the key element to superior detector performance

- Number of photons
- Time-stamp
Digital silicon photomultiplier technology

The principle
Digital silicon photomultiplier technology

The principle
Digital silicon photomultiplier technology

*The principle*
Digital silicon photomultiplier technology

The principle
The digital SiPM array

Features

- 8 x 8 digital SiPMs (on 4 x 4 chips)
- 6400 diodes per pixel
- $\sim 11$ cm$^2$
- 4-side tiling possible

Inputs
- 1.8 V, 3.3 V, 30 V
- JTAG (test and configuration)
- 200 MHz reference clock
- External trigger input

Outputs
- 100 MHz serial data (photon count, timestamp)
- Event detect trigger
Measurement setup (1)

- dSiPM array
- Clock, Config, Data
- Coincidence detection
- FPGA board
- USB connection
- PC
Intrinsic timing performance

Timing jitter over full delay range: 44 ps FWHM

(44 ± 1) ps FWHM
Measurement setup (2)

dSiPM array → psec-laser → dSiPM array

Clock, Config, Data → FPGA board → Coincidence detection → FPGA board → Clock, Config, Data

USB connection → PC
Timing performance

Timing jitter over full delay range: 59 ps FWHM
Measurement setup (3)

- dSiPM array
- LYSO scintillator array
- Clock, Config, Data
- Coincidence detection
- USB connection
- PC
- FPGA board
- Clock, Config, Data
Scintillator readout

*Floodmap*

- LYSO array, 8 x 8 crystals, 4 mm x 4 mm pitch, 22 mm length
Scintillator readout

*Energy resolution*

12.1 % FWHM

- LYSO array, 8 x 8 crystals, 4 mm x 4 mm pitch, 22 mm length
- Saturation was corrected
Scintillator readout

*Energy resolution*

- LYSO array, 8 x 8 crystals, 4 mm x 4 mm pitch, 22 mm length
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Scintillator readout

Timing resolution

- LYSO array, 8 x 8 crystals, 4 mm x 4 mm pitch, 22 mm length
- Summed timing of all 8 x 8 crystals
- Timing mainly limited by photon statistics (CRT with 3x3x5 mm³ LYSO: 153 ps)
Scintillator readout

*Timing resolution*

Two sources 8.3 cm apart

\[ \Delta t = 570 \text{ ps} \]
\[ \cong 8.6 \text{ cm} \]
Small crystal readout

LYSO array, 30 x 30 crystals, 1 mm x 1 mm pitch, 10 mm length

Data analysis by P. Düppenbecker, see talk M03-4
Summary

- Arrays of 8 x 8 digital SiPMs operational
- Intrinsic timing resolution: 59 ps FWHM
- Performance with LYSO scintillator arrays
  - ~12 % FWHM energy resolution
  - 328 ps FWHM coincidence timing resolution
  - Mainly limited by number of detected photons
Next Steps

- Optimize the detection (crystal coupling, anti-reflection coating, fill-factor, …)

- Build detector modules

- Work together with partners to explore further applications
Talk N58-1 (Thu, Nov 4th, 8:00am, Ballroom G)

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