TIMEPIX3

First measurements and characterization of a hybrid pixel detector working in event driven mode

Erik Fröjdh\textsuperscript{1,2}, Michael Campbell\textsuperscript{2}, Massimiliano de Gaspari\textsuperscript{2}, Szymon Kulis\textsuperscript{2}, Xavier Llopart\textsuperscript{2}, Tuomas Poikela\textsuperscript{2,3}, Lukas Tlustos\textsuperscript{2,4}

1. Mid Sweden University
2. CERN
3. TUCS
4. University of Freiburg

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OUTLINE

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• Measurement setup
• Noise measurements
• Threshold spread
• Count rate performance
• Energy calibration in Photon Counting mode
  – Energy resolution
  – Threshold and gain dispersion
• Energy calibration in Time over Threshold mode
  – Energy resolution
  – Gain dispersion
• Time walk correction
• Time and energy measurements of cosmic particles
• 3d track reconstruction using depth of interaction information
### SPECIFICATIONS

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| **Measurement modes** | • Simultaneous 10 bit TOT and 18 bit TOA  
                       | • 18 bit TOA only  
                       | • 10 bit PC and 14 bit integral TOT |
| **Readout type**      | • Data driven  
                       | • Frame based (both modes with zero suppression) |
| **Dead time**         | >475 ns (pulse processing + packet transfer) |
| **Maximum count rate**| 85.3 Mhits / s |
| **Minimum time resolution** | 1.56 ns |
| **Power pulsing**     | Yes |
| **Minimum threshold** | ~500 e⁻ |
**Double column:**
- 2x256 pixels
- 64 super pixels

**Full Pixel Matrix:**
- 256x256 pixels
- 128 double columns
- 8192 VCOs (640MHz)
- 177 Mtransistors

**Active Periphery**

**Pad Extenders:**
- Removed if TSV

**Analog Front-End:**
- 13x55 μm²
- <25% pixel area

**IO Pad on digital area:**
- Careful shielding
- Pad is ½ of Timepix

**VCO (FTOA):**
- 9.6x20 μm²
- < 0.8% SP area

**Super Pixel (SP):**
- 2x4 pixels
- 110x220 μm²
MEASUREMENT SETUP

- Timepix3 mounted on CERN PCB
- 300um p-on-n Silicon sensor (ADVACAM)
- SPIDR Readout (NIKHEF)
  - Virtex 7 FPGA
  - 10 gigabit Ethernet link
  - Flexible and scalable firmware
  - Prototype built on evaluation board used but production version is under development
- Cu X-ray tube + radioactive sources
NOISE BEFORE AND AFTER BONDING

Before Bonding

- Mean: 51.4
- Sigma: 2.7

After Bonding

- Mean: 61.2
- Sigma: 3.4

Before Bonding

- Noise (e-)

After Bonding

- Noise (e-)

Pixels
THRESHOLD DISPERSION

![Graph showing threshold dispersion with peaks at 193e- RMS and 31e- RMS.](image-url)
THRESHOLD DISPERSION

After equalization

Note: color scale 5x more narrow
MAXIMUM COUNT RATE IN DATA DRIVEN MODE

Measurement limited by output bandwidth (8x160Mbps)
Maximum possible count rate is 85.33 Mhits/s with 8x640Mbps
ENERGY CALIBRATION IN PHOTON COUNTING MODE

- Energy calibration of each pixel in photon counting mode
- Measured using Pb-L fluorescence + Cu peak from the X-ray tube
- Fitted on the integral spectrum
- Threshold- and gain dispersion for each pixel

10.5 keV
712 eV

12.6 keV
820 eV

15.0 keV
1015 eV

Mean
FWHM
GAIN DISPERSION IN PHOTON COUNTING MODE

Mean: 10.5 e-
Sigma: 1.68%

Ikrum: 5
SINGLE PIXEL ENERGY RESOLUTION

Mean 559 eV FWHM
Sigma: 6.15 %
THRESHOLD DISPERSION IN PHOTON COUNTING MODE
ENERGY CALIBRATION: TIME-OVER-THRESHOLD

- Method published by J. Jakubek.
- Using only 3 peaks
- $^{109}$Cd and $^{241}$Am for linear range and $^{55}$Fe in the non linear range

$$M_{a,b,c,t,\mu,\sigma,A}(s) = G_{\mu,\sigma,A}(f_{a,b,c,t}^{-1}(s))$$

J. Jakubek, Precise energy calibration of pixel detector working in time-over-threshold mode
NIM-A Vol 633 Supplement 1 May 2011
ENERGY CALIBRATION: TIME-OVER-THRESHOLD

- TH ~ 1000e-
- Large spread in gain

Energy (keV) vs. ToT@40MHz
$^{241}\text{Am}$ PHOTOPEAK POSITION

Gain spread from calibration: 14.5%
ENERGY CALIBRATION: $^{241}\text{Am}$
ENERGY RESOLUTION FOR SINGLE PIXEL HITS USING FULL MATRIX

![Graph showing energy resolution for single pixel hits using full matrix. The graph displays a peak at 60 keV with a FWHM of 2.02 keV.](Image)
CALIBRATION VERIFICATION: $^{241}\text{Am}$

- "knee" for the surrogate is lower than Timepix1
- Need to fit on more points
- Better calibration will improve energy resolution

![Energy vs Counts Graph](graph)

- 3.76 keV FWHM
ENERGY RESOLUTION FOR SINGLE PIXEL HITS USING FULL MATRIX

Slightly worse energy resolution in the area with low gain but no big impact on overall energy resolution.
NOISE COUPLING WITH TIMING ON

- $^{109}$Cd (Ag XRF)
  - 22.1 keV
  - 24.9 keV
- FWHM: 1.92 keV
- FWHM: 2.44 keV
- Single pixel hits only
- Might impact lowest usable threshold for timing measurements
TIME WALK CORRECTION

• Using time and energy information it is possible to correct for time walk.
• We measure the time walk by taking the difference between the digital and the analog test
• The response of each pixel if fitted with an exponential function + constant
• From this we extract time walk and latency

• *Note: To optimize time measurements the chip should probably be run with different DAC settings than in this experiment*
TIME WALK CORRECTION

- $\exp(3.77 - 0.094x) + 9.1$
- $\exp(3.68 - 0.093x) + 8.64$
- $\exp(3.71 - 0.077x) + 8.75$

Pixel: (66, 97)
Pixel: (183, 48)
Pixel: (161, 107)
ENERGY AND TIME MEASUREMENTS WITH COSMIC PARTICLES

Integral frame ~ 72h
Bias 100V, Ikrum 5, **without** time walk correction
Bias 100V, Ikrum 5, **without** time walk correction
Bias 100V, Ikrum 5, with time walk correction
Bias 100V, Ikrum 5, with time walk correction

Note: Not to scale!
TRACKS WITH LOW BIAS VOLTAGE

Bias 20V, Ikrum 5, with time walk correction
CONCLUSIONS

• Noise after bonding is 61e-RMS
• Minimum threshold ~ 2 keV or 550 e-
• Energy resolution in PC mode is 712 eV at 10.5 keV
• Energy resolution for single pixel hits in ToT mode is 1.92 keV at 22 keV
• High gain spread observed in ToT mode but can be corrected with calibration
• Energy and time measurements of cosmic rays indicate that we can measure depth of interaction in the sensor using the drift time.
• Optimization of the timing resolution will require different settings compared to optimizing for energy resolution.

• Note: Measured for a single assembly only.