MYTHEN-III, a high performance, single photon counting strip detector

15th Pisa meeting on advanced detectors 22-28.05.2022
Why strips? *Chip designer’s view*

- Several applications in Photon Science (PS) are 1D do not require pixels
- 1D ASIC design less challenging
- Smaller ASIC required
- Simpler control/readout logic
- Less channels per area
  - Faster frame rate
  - Smaller data throughput
  - Resources much less critical
- Wire- instead of bump- bonding
  - Cheaper
  - Smaller pitches possible
  - Simpler
- Playground for new ideas
- Up-to-date ASICs required

Easier, cheaper, faster

X-Ray Powder Diffraction (XRPD)
MYTHEN I
(2001-2006)


MYTHEN II
(2007-present)


• Huge impact in 1D photon science, in particular XRPD
Mythen III for powder diffraction

• Same sensors as Mythen II: 1280 strips/module, 50 µm pitch, 8 mm length
• 120 degrees on two rows without gaps (24 x 2 modules)
  – 76 cm distance from diffractometer center
  – 4 mdeg intrinsic angular resolution
• Sensor material and characteristics can be changed (e.g. LGADs, HighZ)
### MY3 design specifications

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- Lower energies detectable
- Better fluorescence suppression
- Better flat field
- Higher fluxes
- Time resolved experiments
- Reliable calibration
- Use with High Z materials or LGADs
- New operational modes, new applications
The channel

Status register (3x6TB, 3x1Mask, 3 dummy)

TBs3  6

TBs2  6

TBs1  6

Vth1

Vth2

Vth3

Vrf

VrfSh

Vdc

Analog Pulsing

PULSING

EN1, EN2, EN3

POLARITY

Counting logic

Counter 1

Counter 2

Counter 3

ChSel1

ChSel2

ChSel3

serialIN, TBLoad, Control signals

Violet = backup material available

Control and readout logic

serialOUT

Violet = backup material available

Violet = backup material available

24x3 bits
Modes of operation

The chip can work in different modes of operation:

1. Normal counting mode
   a) My2 equivalent
   b) With energy windowing
   c) With multi-threshold rate correction
2. Pump-probe mode
3. Time over threshold
4. Interpolation mode
5. Improved performance in pulsed mode
6. Analog pulsing mode
7. Digital pulsing mode
8. Trim bits load mode
9. Chip status load
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Trivial
TRIMMING
Reduce threshold dispersion from 123 e⁻ untrimmed to < 6e⁻ trimmed
**Chip performance**

**TRIMMING**
Reduce threshold dispersion from 123 e- untrimmed to < 6e- trimmed

**TEMPERATURE STABILITY**
More pronounced in high-gain (slow) settings
Change in gain: \( \sim 0.3\% / ^\circ C \)
Mythen 2 mode configuration

- One comparator, one counter

- Maximum readout speed: 390 kHz in 8bit and dead-time free mode
- Time resolved experiments e.g. : In situ multilayer reacting foils
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Energy windowing configuration

• One comparator per counter, 3 thresholds, one Enable

➢ Selection of the characteristic line, synchrotron higher harmonic suppression
Energy windowing configuration

• One comparator per counter, 3 thresholds, one Enable

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Control and readout logic
Pump-Probe configuration

• One comparator, several counters with different enable (gate) windows
• Good timing control of gate signals (some ns)
• Stroboscopic measurements with up to 3 temporal counting slots

• Pumped-unpumped measurements with isolated/sliced bunch
Pump-Probe configuration

Very preliminary

![Graph showing counts vs. delay (ns)]
Pump-Probe configuration ✔

Very preliminary
**Time-over-threshold operation with int. oscillator**

- Two comparators, one generates clock. One counter: internally clocked if signal >Vth.

- Smaller rate corrections — less influenced by mismatches between channels

- ToT also possible clocking EN externally

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**Graphs and Diagrams**

- Single Photon Counting +2 X-rays
- Time over Threshold +15 clocks
- +3 X-rays

- Improvement of count rate capabilities
Time-over-threshold operation with int. oscillator

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  - less influenced by mismatches between channels

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**Two comparators, one generates clock. One counter: internally clocked if signal >Vth.**

**Improvement of count rate capabilities**

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**Single Photon Counting +2 X-rays**

**Time over Threshold +15 clocks**

**+3 X-rays**

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**Counting Efficiency (%)**

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**X-ray rate (kHz)**

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Roberto Dinapoli
Rate Capability: Pile-up tracking with 3 counters

- same as energy windowing

- One comparator per counter, one Enable

Vth1

Vth2

Vth3

Vrf

VrfSh

TBs1

TBs2

TBs3

Counter 1

Counter 2

Counter 3

Control and readout logic
Rate Capability: Pile-up tracking with 3 counters

- Rate scan with 3 thresholds to track pile-up
- Pile-up model: (paralyzable)

\[
\begin{align*}
\epsilon_1(\phi_0) &= e^{-\phi_0 \tau_d} \\
\epsilon_2(\phi_0) &= e^{-\phi_0 \tau_d} \cdot (1 - e^{-\phi_0 \tau_d}) \\
\epsilon_3(\phi_0) &= e^{-\phi_0 \tau_d} \cdot (1 - e^{-\phi_0 \tau_d}) \cdot (1 - e^{-\phi_0 \tau_d}) \\
\epsilon_{sum} &= \epsilon_1 + \epsilon_2 + \epsilon_3 > \epsilon_1.
\end{align*}
\]

- Model total efficiency as sum of 3 counters
- Fit with paralyzable model \(\rightarrow\) dead time \(\tau_d\) (1 to 3 counters)
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- Model total efficiency as sum of 3 counters
- Fit with paralyzable model \( \rightarrow \) dead time \( \tau_d \) (1 to 3 counters)
• Determine dead time and noise
  – If gain ↑: noise ↓ and dead time ↑

• Calculate rate per strip at 90% efficiency:
  – $\varepsilon_{\text{sum}} = \varepsilon_1 + \varepsilon_2 + \varepsilon_3$

Minimum achievable noise: 110 e- rms (not shown)
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<td>Slow</td>
<td>1.3 MHz</td>
<td>7.4 MHz</td>
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<tr>
<td>Medium</td>
<td>1.4 MHz</td>
<td>8.2 MHz</td>
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<td>Fast</td>
<td>3.5 MHz</td>
<td>20.9 MHz</td>
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→ Meets requirements for SLS 2

Minimum achievable noise: 110 e- rms (not shown)
Interpolation Mode

- Inter-strip communication between neighbors
- Redistribute counts: left, central, right counter
  - Virtually split strips → better resolution
• Imaging with 1D detectors: thin slit in front of detector, scan sample, 25 \( \mu \text{m} \) steps in vertical
• External pitch of star: 60 \( \mu \text{m} \), 2 mm diameter
• Imaging with 1D detectors: thin slit in front of detector, scan sample, 25 µm steps in vertical
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→ Impossible to resolve spikes (in horizontal) in normal mode
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• External pitch of star: 60 µm, 2 mm diameter
→ Impossible to resolve spikes (in horizontal) in normal mode
→ Distinguishable in interpolation mode!
→ More quantitative tests are ongoing
LGADs in photon science: low energy X-rays

- **Improve quantum efficiency**

  - Standard: $E > 1$ keV
  - Current: $E > 500$ eV
  - Goal: $E > 250$ eV

- **Increase SNR**
  - Low Gain Avalanche Detectors (LGADs)
  - Segmented avalanche photodiodes with limited gain, no dark counts
  - Timing not important for PS
  - Already proven with other detectors SNRx5
  - Ideal for soft X-ray single photon counters

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**Key Points**

- Protective metal
- Insensitive implant
- Sensitive volume
- $Q.E > 50\%$

**Diagram Notes**

- Soft X-ray vs. Hard X-ray
- Electron path

**Graph**

- Efficiency vs. Backplane thickness
- Energy levels: 250 eV, 500 eV, 700 eV, 1000 eV, 2000 eV

**Diagram**

- Pixelized iLGAD
- ASICS
- Al, p+, p−, p−

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**Conclusion**

- LGADs are ideal for soft X-ray single photon counters due to their high quantum efficiency and low noise characteristics.
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Inverse LGADs with MYTHEN

Very preliminary

Normalized counts vs. Threshold voltage [eV]

Dark frame subtracted
Inverse LGADs with MYTHEN

Normalized counts

Threshold voltage [eV]

Dark frame subtracted

Rough energy calibration

Threshold @ half counts (DACU)

Energy (eV)

beam_1500eV_1s
beam_1400eV_1s
beam_1300eV_1s
beam_1200eV_1s
beam_1100eV_1s
beam_1000eV_1s

Very preliminary
Mythen III status

- Full detector (120 degrees) currently installed at Material Science (SLS)
  - The detector runs flawless
  - First experiments ongoing
- Several modules installed as beam monitors (polarization, I0 monitor, position(?))
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- Time resolved
- Standard mode
- Pump-probe
- Energy windowing
- Rate correction
- Interpolation
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- Time over threshold
- Pulsed mode

15th Pisa Meeting
Acknowledgements

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- Dhanya Thattil
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...and many collaborators at the beamlines

SLS