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Development of the MYTHEN III microstrip detector

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Outlook

- Principle of a photon counting detector
- MYTHEN II at the Material Science beamline at SLS
- Motivation for a new detector
- Characterisation of MYTHEN III
- Comparison of MYTHEN II & III
• Hybrid photon counting detectors for experiments at synchrotrons
  – Crystallography, powder diffraction, energy dispersive experiments, ...

• Development at PSI:
  – MYTHEN (strips)
  – EIGER (pixels)

• Strips for 1D applications:
  – Less channels per area, faster frames rates, smaller data throughput
  – Easier assembly, cheaper
  – Small pitch possible
  – Large angular coverage
Photon counting MYTHEN chip: one channel

- Count only photons with a signal above a set threshold
- Tune the gain, speed and shaping of the signal
- Tradeoff between noise and speed

*Vrf* and *VrfSh* change the feedback resistance in the PreAmp and Shaper, i.e. the gain and shaping time
MYTHEN II at the Material Science beamline at the Swiss Light Source (SLS)

• Single photon counting microstrip detector for time resolved powder diffraction
• In operation since 2007
• Covers 120° with two layers of 24 modules each, 30720 strips per layer
• Si-sensor: 320 μm thick, 8 mm long, 50 μm strip-pitch, 4 mdeg. per strip
• Gap of 0.17° between modules

• For standard settings in MYTHEN II:
  - 230 e- RMS noise
  - 8 keV minimum detectable energy
  - 170 ns dead time
  - 6 MHz maximum count rate
  - 80 % efficiency at ~2 MHz
New Features of MYTHEN III

- MYTHEN II is growing old (12 years)

New Features of MYTHEN III

- Faster readout of the chip: increase the frame rate
- Dual polarity: possibility to use e.g. high Z sensors
- Reduced noise: access lower energies
- Reduced threshold dispersion: more homogeneous response of strips
- Reduced dead time: higher count rates & photon flux
- Three comparators and gateable counters:
  - Energy-windowing, color imaging
  - pile-up detection
  - pump-probe with three timeslots

Two prototypes were tested MY 3.0.1 MY 3.0.2
The final chip is back right now MY 3.0
1. Do a threshold scan for energy calibration → **S-curve**
   
a) Scan the threshold in internal DAC units and measure the response to a defined photon energy

2. Fit the S-curve to find the inflection point

3. Map the inflection point in DAC units to the photon energy in keV

\[ \text{ENC: equivalent noise charge} \]
\[ N_s: \text{charge sharing between pixels} \]
\[ N_0: \text{number of photons at beam energy} \]
\[ E_0: \text{photon energy} \]
\[ E_t: \text{set threshold at half the photon energy} \]
1. Take S-curves at different energies
2. Fit the inflection point and the photon energy to get a calibration
3. Repeat for different settings in the preamplifier (Vrf) and shaper (VrfSh)
Threshold dispersion
Trimmed: 27 eV RMS (8e-)
Untrimmed: 438 eV RMS (122e-)
At high photon flux: several photons will arrive at the same time
  - Their signal will overlap
  - The preamplifier is blind to the 2\textsuperscript{nd} photon
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Rate Scan with pile-up detection

- At high photon flux: several photons will arrive at the same time
  - Their signal will overlap
  - The preamplifier is blind to the 2\textsuperscript{nd} photon
Rate Scan: why and how?

WHY:

- What is the dead time of the chip? → maximum photon flux?
- Paralizable counter model:

\[
\begin{align*}
M &= N \cdot \exp(- \tau \cdot \Phi) \\
\varepsilon &= \exp(- \tau \cdot \Phi)
\end{align*}
\]

HOW:

1. Place the detector in the direct beam
2. Use a set of filters to attenuate the beam and scan the intensity
3. Monitor the beam intensity and count the photons
   - Measure the efficiency
4. Fit the efficiency curve with the paralizable counter model to find the dead time
Rate Scan with pile-up detection

- Make use of the three thresholds to detect pile-up:
  - Put threshold A to $\frac{1}{2} \times$ photon energy: 1st photon
  - Put threshold B to $1\frac{1}{2} \times$ photon energy: 2nd photon
  - Put threshold C to $2\frac{1}{2} \times$ photon energy: 3rd photon

- Reach higher rate capabilities
MY3.0.2: Rate Scan with pile-up detection: measurement

### Standard settings

- **Counter A**
- **Counter B**
- **Counter C**
- **All counters**

### Fast settings

- $\chi^2 / \text{ndf}: 3700 / 63$
- Constant: $0.04143 \pm 0.001891$
- Slope: $-2.347 \times 10^{-8} \pm 3.327 \times 10^{-10}$

- $\chi^2 / \text{ndf}: 3553 / 63$
- Constant: $0.03979 \pm 0.001883$
- Slope: $-9.838 \times 10^{-9} \pm 3.192 \times 10^{-10}$
MY3.0.2: Rate Scan with pile-up detection: result

**Dead time**

<table>
<thead>
<tr>
<th>Setting</th>
<th>Dead Time [ns]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>78.5 ns</td>
</tr>
<tr>
<td>Fast</td>
<td>27.0 ns</td>
</tr>
<tr>
<td>Fast</td>
<td>23.5 ns</td>
</tr>
<tr>
<td>Fast</td>
<td>9.8 ns</td>
</tr>
</tbody>
</table>

**Maximum flux at 80% efficiency**

<table>
<thead>
<tr>
<th>Setting</th>
<th>Flux at 80% Efficiency [MHz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>3.2 MHz</td>
</tr>
<tr>
<td>Standard</td>
<td>9.4 MHz</td>
</tr>
<tr>
<td>Fast</td>
<td>11.3 MHz</td>
</tr>
<tr>
<td>Fast</td>
<td>26.8 MHz</td>
</tr>
</tbody>
</table>
• The deadtime increases with the gain
• The noise decreases with increasing gain & dead time

→ The slower the chip, the less noisy it is
Comparison of MYTHEN II & III

For „standard“ settings:

<table>
<thead>
<tr>
<th></th>
<th>MYTHEN II</th>
<th>MYTHEN III</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMS noise</td>
<td>230 e-</td>
<td>175 e-</td>
</tr>
<tr>
<td>Min. detectable energy</td>
<td>8 keV</td>
<td>6 keV</td>
</tr>
<tr>
<td>Dead time</td>
<td>170 ns</td>
<td>28 ns</td>
</tr>
<tr>
<td>Flux at 80% efficiency</td>
<td>2 MHz</td>
<td>9 MHz</td>
</tr>
<tr>
<td>Trimmed threshold dispersion</td>
<td>85 eV (~ 24 e-)</td>
<td>27 eV (~8 e-)</td>
</tr>
</tbody>
</table>

Improvement compared to MYTHEN II

MYTHEN III

- The new readout chip offers many improvements and new features
- The final chip is under test
- Module & detector design is done → production
- MYTHEN III will be installed in early 2020 at the Material Science beamline at SLS
My thanks go to

• SLS Detector Group
  Anna Bergamaschi, Rebecca Barten, Martin Brückner, Sabina Chiriotti, Roberto Dinapoli, Erik Fröjdh, Dominic Greiffenberg, Carlos Lopez-Cuenca, Markus Meyer, Davide Mezza, Aldo Mozzanica, Sophie Redford, Christian Ruder, Bernd Schmitt, Xintian Shi, Dhanya Thattil, Gemma Tinti, Seraphin Vetter and Jiaguo Zhang

• MS beamline
  Nicola Casati, Antonio Cervellino, Dominik Meister

Thank you very much for your attention!
BACK UP
MYTHEN III module

- Readout board: Read 1, 4, 8, 16 or 24 bits of each channel
- Data and control fibre, 10Gb:
  - Min. readout time: 320 ns
  - Max frame rate: 3 MHz
  - Standard readout time: 2.3 μs
  - Frame rate: 400 kHz
- Power
- Module HDI
- 10 chips:
  - 1280 strips per module
- Sensor
- 8 mm
- 6.4 cm

[Image of MYTHEN III module with annotations]
Power supply

Data fibres fully parallel readout

External power and control

Two rows of 24 modules with shifted gaps

Sensors: 2*30720 strips
Design of the MYTHEN III detector for MS

- Entrance window
- 120° coverage
- 2*24 Modules
Hybrid strip detector

SENSOR
Absorbs the radiation and directly converts it into electric charge

INTERCONNECTION
Transfer the signal from sensor to readout electronics

READOUT ELECTRONICS
Samples and digitizes the signal

DATA ACQUISITION SYSTEM
Transfers the information to the user

Parameters:
- Efficiency
- Spatial resolution
- Noise
- Dynamic range
- Speed
Photon counting MYTHEN III chip: one channel

- NEW: three comparators with adjustable thresholds
- NEW: three gateable 24-bit counters

*Vrf* and *VrfSh* change the feedback resistance in the PreAmp and Shaper, i.e. the gain and shaping time
Why do we need a new detector?

• MYTHEN II is in operation since 2007
  - at the end of its lifetime
  - Old electronics: replacement or repair is impossible

• Reach lower energies → reduce the noise
• Homogeneous response → reduce the threshold dispersion
• Increase the maximum photon flux → reduce the dead time
• Increase the frame rate → faster readout of the chip

• Playground for future pixel detectors
New Features of MYTHEN III

- **Dual polarity**: possibility to use e.g. high Z sensors
- **Reduced noise**: access lower energies
- **Reduced threshold dispersion**: more homogeneous response of strips
- **Reduced dead time**: higher count rates & photon flux
- **Three comparators and gateable counters**:
  - Energy-windowing, color imaging
  - pile-up detection
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▶ Two prototypes were tested **MY 3.0.1** **MY 3.0.2**
▶ The final chip is back right now **MY 3.0**
Basic calibration and gain scan

1. Take S-curves at different energies
2. Fit the inflection point and the photon energy to get a calibration
3. Repeat for different settings in the preamplifier (Vrf)
Trimming: threshold equalisation

Threshold dispersion
Trimmed: 27 eV RMS (8e-)
Untrimmed: 438 eV RMS (122e-)
## MYTHEN II parameters

<table>
<thead>
<tr>
<th>Settings</th>
<th>Gain (mV keV(^{-1}))</th>
<th>ENC (e(^{-}))</th>
<th>(2\Sigma) (keV)</th>
<th>(\tau_d) (ns)</th>
<th>(\Phi_{\text{max}}) (kHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>7.11 ± 0.13</td>
<td>230 ± 7</td>
<td>8.3 ± 0.2</td>
<td>170 ± 10</td>
<td>5900 ± 300</td>
</tr>
<tr>
<td></td>
<td>0.83 ± 0.02</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fast</td>
<td>5.55 ± 0.13</td>
<td>262 ± 7</td>
<td>9.4 ± 0.2</td>
<td>110 ± 10</td>
<td>9000 ± 900</td>
</tr>
<tr>
<td></td>
<td>0.94 ± 0.02</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High gain</td>
<td>9.19 ± 0.22</td>
<td>195 ± 7</td>
<td>7.0 ± 0.2</td>
<td>750 ± 50</td>
<td>1330 ± 90</td>
</tr>
<tr>
<td></td>
<td>0.70 ± 0.02</td>
<td></td>
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