Design and Characterization of the VMM1 ASIC for Micropattern Gas Detectors

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VMM1 ASIC

The VMM1 ASIC is the first in a series of front-end read-out electronics designed for use with Micromegas and Thin Gap Chambers (TGCs) for ATLAS Upgrade. It features a range of gains and peaking times to allow use with other types of micropattern gas detectors as well. It incorporates several innovative features to allow operation in a fast trigger mode in the ATLAS Level 1 trigger as well as in a time projection mode (μ-TPC mode) for precision track reconstruction. The VMM1 also features smart token passing reading out only those channels above threshold and the first-order neighbors in order to reduce the bandwidth and increase the potential for new physics.

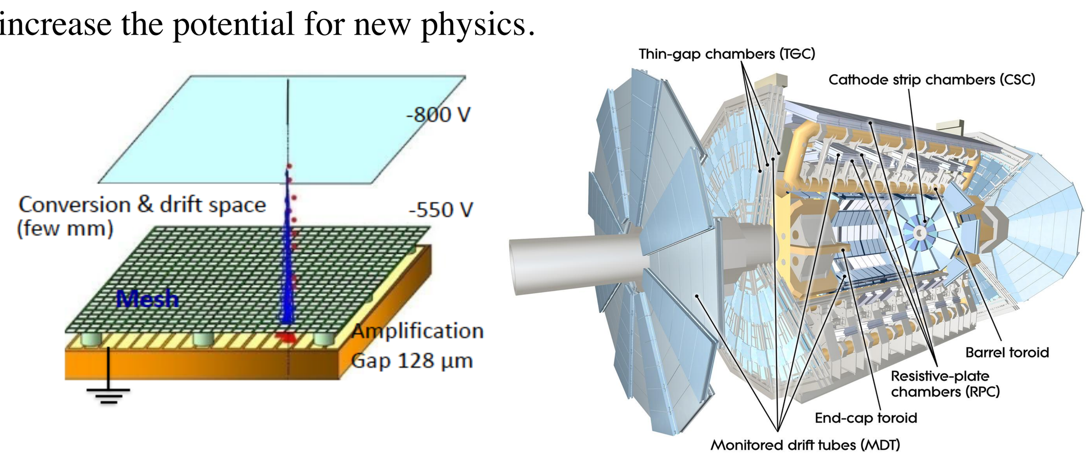

Figure 1: Left: Diagram of a Micromegas Detector slated for part of the New Small Wheel in the ATLAS Upgrade that will replace the Cathode Strip Chapmbers (CSCs) shown on the right. Right: The current ATLAS Detector.

VMM1 Design

The VMM1 ASIC was fabricated in a commercial 130 nm CMOS from IBM. It has 64 front-end channels each consisting of low noise charge amplifier (CA), shaper with baseline stabilizer (SA), a discriminator with trimmer (DSC), a peak- and time-detector (PD/TD), a time-to-amplitude converter (TAC), multiplexing with smart token, and direct Time-over-Threshold outputs (TOT) as shown in the figure below.

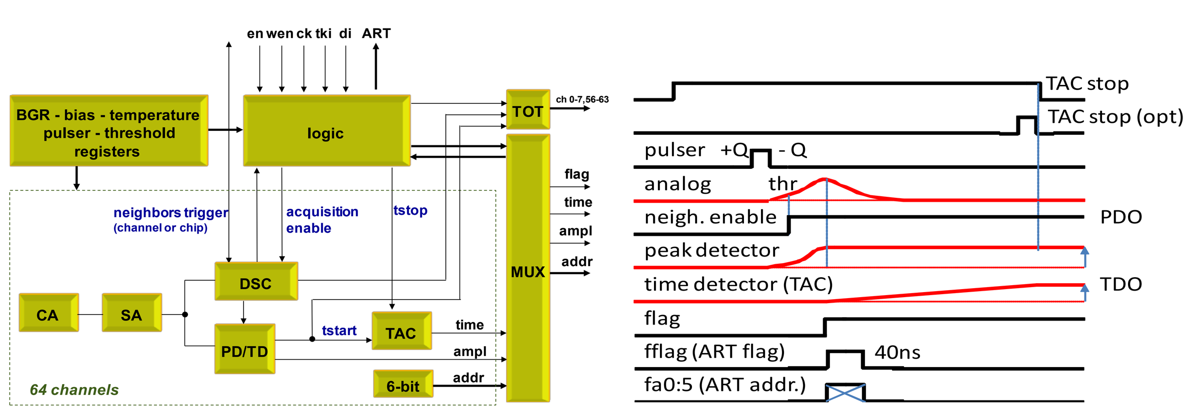

Figure 2: Left: VMM1 layout. Right: VMM1 Signal Acquisition.

Flexible Functionality of the VMM1

- ***Selectable Gain***
  - The nominal gain value has the option of 0.5, 1, 3, and 9 mV/fC to accommodate the needs of different applications.
- ***Selectable Peaking Time***
  - The Peaking Time or integration time can be selected from the following options: 25 ns, 50 ns, 100 ns, and 200 ns.
- ***Adjustable TAC slope***
  - The time-amplitude-conversion (TAC) slope can be adjusted according to 125 ns/V, 250 ns/V, 500 ns/V and 1μs/V.
- ***Neighbor Readout***
  - There is an option to read out the 2 neighboring channels of a channel with a signal over threshold. In the case the neighbor channel is read out by a neighboring VMM1, the information is passed to that ASIC and the neighbor channel signal is acquired.
- ***Smart Token Passing***
  - This feature allows only the signals above threshold to be read out reducing bandwidth requirements.
- ***Fast Trigger Readout***
  - The Address in Real Time (ART) reads out the address of the first channel with a signal hit for fast trigger applications.
- ***Timing Mode***
  - The Time-over-Threshold (ToT) and the Time-to-Peak (TtP) can be read out of the analogue monitor for the first and last eight channels.
- ***Threshold Trimming***
  - The threshold of each channel may be trimmed by approximately 15 mV in order to equalize channel-to-channel variation.
- ***Sub-Hysteresis***
  - The fast comparator introduces a hysteresis on the threshold of approximately ±10 mV. The Sub-Hysteresis counteracts this by

VMM1 ASIC flexible enough to work with several applications:
Micromegas (Micro-Mesh Gaseous Detector)
Thin Gap Chambers
Gas Electron Multiplier Detectors
in both precision tracking and fast trigger modes
with simulated charge resolution of ~5000 e^- at 25 ns and 200 pF
and timing resolution 1 ns at 1 V signal amplitude

VMM1 Features

Peak Amplitude

The peak detector measures the amplitude of the signal peak very precisely. The output amplitude, called the PDO (Peak Detector Output), measures the signal amplitude with a high degree of precision. For the case where nominal gain = 0.5 mV/fC and peaking time = 25 ns, and for an input signal of 600 fC the PDO rms is 0.26 mV.

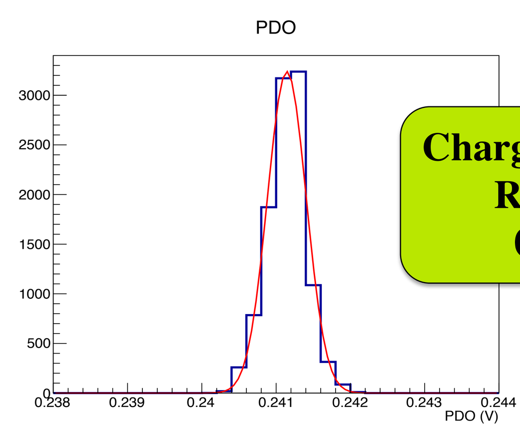

Figure 3: The peak detector output (PDO) with the gain set at 0.5 mV/fC and the peaking time at 25 ns. The noise is 0.26 mV.

There are 4 nominal values each for gain and peaking time. The combination of the configuration determines the real signal gain. The figure below shows the gain linearity for each of the gain settings (upper plot). The bottom plot shows the percentage of the linearity error or the percentage error from the expected value from the fit. The linearity error is of the order of less than 0.1%.

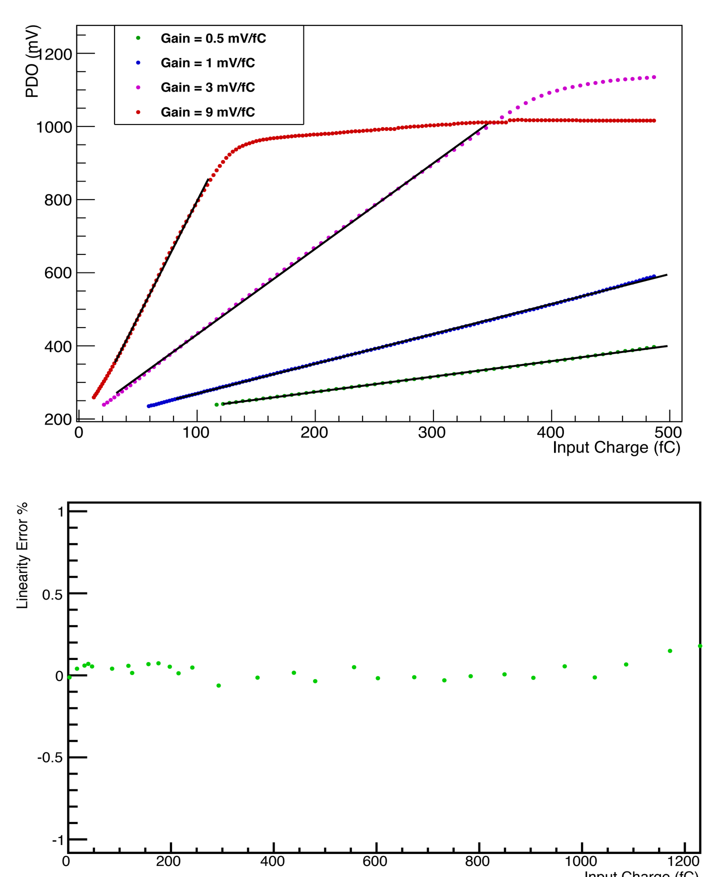

Figure 4: Top: PDO response as a function of input charge for each of the nominal gain settings and fits to extract measured gains. Bottom: The percentage linearity error or residual percentage of the PDO response with an external pulser taken at nominal gain of 1 mV/fC and peaking time of 50 ns.

Time Detection

The time is measured by charging a capacitor at a specific rate given by the Time-Amplitude-Conversion (TAC) slope from the time the peak is detected until the signal is read out as shown in Figure 2. The TAC slope has several settings to accommodate different applications depending on the signal integration time. In the figure below on the left the TDO response shows a timing resolution of 0.04 ns for nominal gain = 0.5 mV/fC, peaking time = 25 ns, and TAC = 125 ns/V.

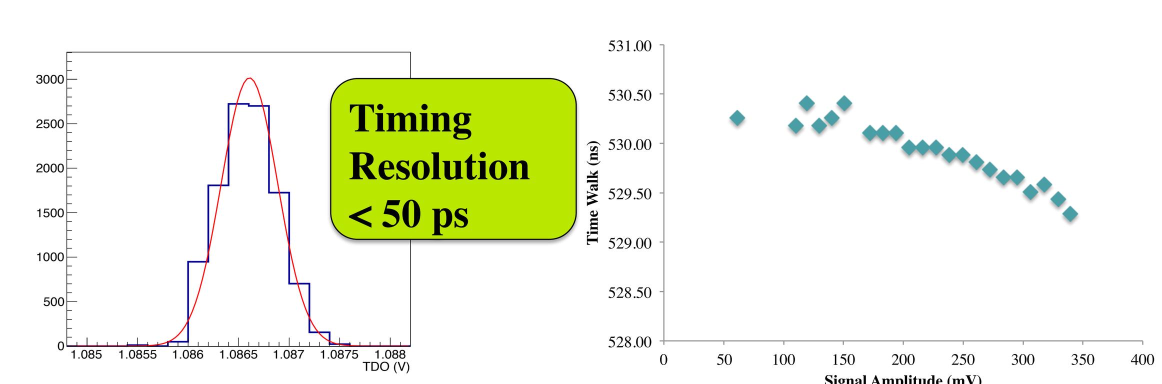

Figure 5: Left: Timing (TDO) resolution for gain = 0.5 mV/fC and peaking time = 25 ns, TAC = 125 ns/V. The resolution is 0.28 mV = 0.04 ns. Right: Time Walk at g=1, pT=25 ns shows approximately 1 ns variation over the range of signal amplitudes.

The time-walk measures the jitter of the time the peak is detected as the signal amplitude is varied. Ideally, the time is independent of the signal amplitude. In the figure on the right the time-walk is shown for the VMM1 and of the order of 1 ns.

Time Over Threshold & Time To Peak

The first version of the VMM has timing output on 16 channels. There are two modes of operation Time-over-Threshold (ToT) and Time-to-Peak (TtP).

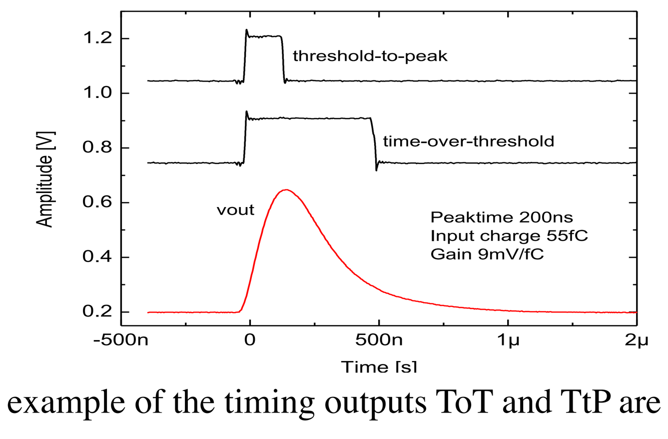

Figure 6: An example of the timing outputs ToT and TtP are shown for a signal pulse.

VMM1 Features

Threshold

The threshold inherently has some channel-to-channel variation. A threshold trim was included in the VMM1 design to equalize thresholds by allowing each individual channel to be trimmed by approximately 0-15 mV. The threshold was measured by varying the input amplitude and counting the percent of signals that were returned by the acquisition at each input amplitude resulting in an S-curve or turn-on curve. The mid-point of the turn-on gives the threshold for a particular channel. The figure below on the left shows the variation in the threshold channel by channel. The plot to the right demonstrates the range of the trim for 5 channels. In version 1 of the VMM the trim range is not sufficient to equalize all channels, but will be corrected in the second version.

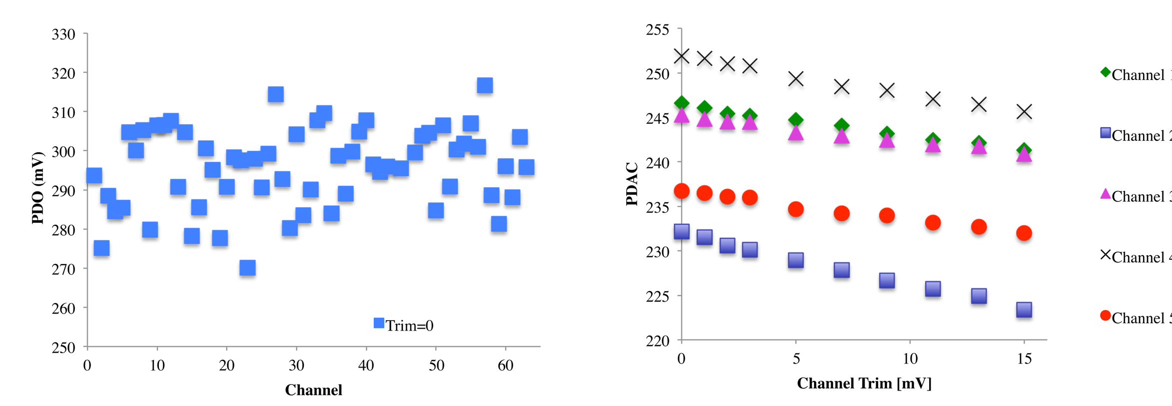

Figure 7: Left: Thresholds extracted from S-curve measurements versus channel number for the minimum trim setting equal to 0 mV. Right: The trim allowance is shown for each programmable trim setting for 5 channels.

Sub-Hysteresis

The fast comparator introduces a hysteresis, which effectively raises the minimum threshold by approximately 10 mV. The sub-hysteresis was introduced to compensate for this effect by moving the threshold level so that it triggers close to the baseline and resets after the peak is detected. See the diagram in Figure 8.

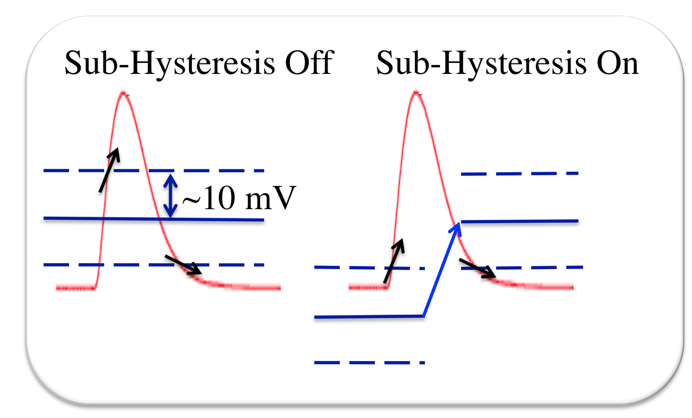

Figure 8: Diagram of the sub-hysteresis operation.

Figure 9 shows signal amplitude versus the input charge with and without the sub-hysteresis function for the lowest working threshold. Without the sub-hysteresis function the lowest threshold is at the baseline. With the sub-hysteresis function engaged, the threshold can be tuned down even further to a nominal threshold (not including the hysteresis) 9 mV below the baseline. The PDO is able to read out input amplitudes 56 fC smaller than without for gain = 0.5 mV/fC, peaking time = 25 ns, and input capacitance equal to 2.44 pF. The measurements show that for these conditions the VMM1 can measure signal amplitudes 11 mV smaller with the Sub-Hysteresis feature than without.

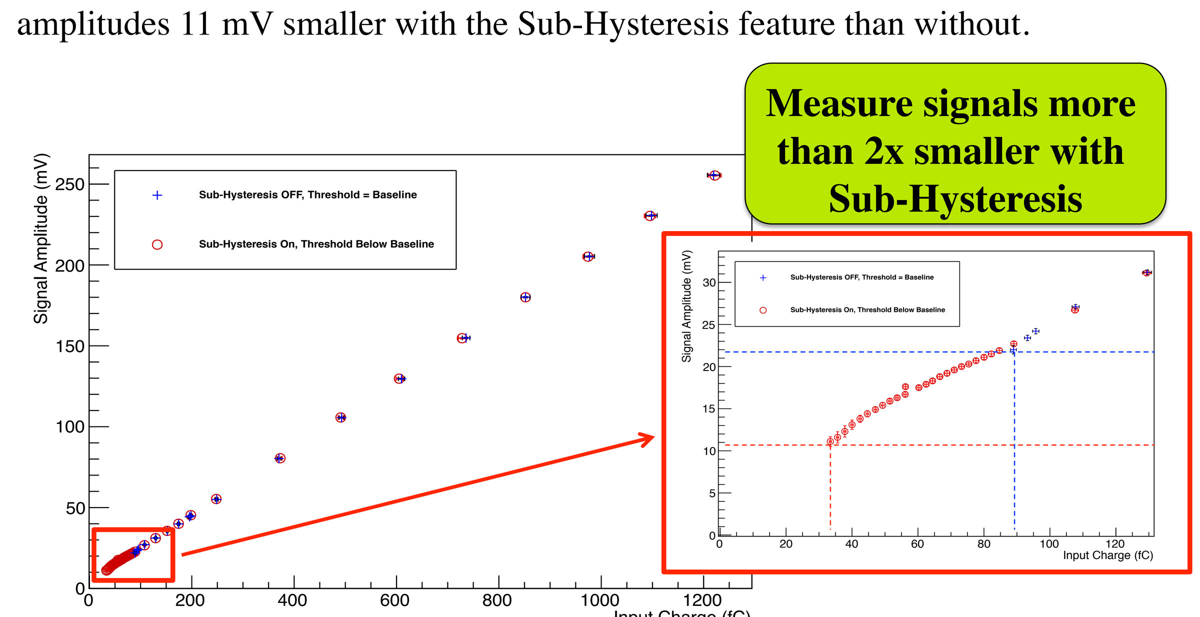

Figure 9: Left: The lowest threshold setting without the Sub-Hysteresis and the lowest threshold with the Sub-Hysteresis engaged is shown as a function of the input charge. Right: When the Sub-Hysteresis is on, the threshold can be set lower—below the baseline and much smaller charges can be read out.

Conclusion:

- **The first version of the VMM was very successful!**
- **charge resolution 0.26 mV at nominal gain = 0.5 mV/fC**
- **timing resolution < 50 ps for peaking time = 25 ns and TAC = 125 ns/V**
- **measure signals more than 2x smaller with Sub-Hysteresis feature**
- **VMM2 will improve upon the first edition and add new features such as digitization and more timing outputs**