I MøLLER FADC DAQ UPGRADE

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A Møller DAQ upgrade based on the JLab-built FADC has been in progress in 2009 and is nearly complete. It is part of the upgrade of the Møller polarimeter aimed at achieving a systematic error less than 1%.

A Application to Møller Polarimetry

The Hall A Møller polarimeter detects the two scattered electrons in two spectrometer arms. Each arm consists of 4 calorimeter blocks arranged in a column and a scintillator aperture counter positioned on the upstream side. When the upgrade is complete there will be 4 aperture counters per arm. The electrons are swept along the column by a dipole magnet so their positions depend on their energy. The HV on the PMTs are tuned to equalize the calorimeter outputs from all 4 blocks, allowing a common threshold to provide an efficient trigger. We hope to run at 50μA peak current and 5% duty cycle; this will reduce the uncertainty due to extrapolation from higher currents where the experiments run and the 2μA where Møller normally runs to keep target heating low. A higher speed DAQ is needed to accommodate maximum expected rates above the thresholds of 1 MHz per arm with a coincidence of 400 kHz. Since the FADC processes all the data and no samples are lost, it has the prospect of greatly reducing or even eliminating the deadtime, which historically was an important systematic error for Møller and which would potentially limit the high-peak-current application.

To first order the deadtime probability "ϵ" of one discriminator channel is $\epsilon = RT$ for a rate R and a discriminator width T (typically $T = 20$ nsec for the old DAQ). For the full DAQ the deadtime is a much more complex expression because several discriminator channels are involved and the rate is a mixture of singles-arm and coincidence Møller with different asymmetries and rates, as well as unpolarized background mainly from radiative Mott. Historically the systematic error due to ϵ was no better than $d\epsilon = 0.3\%$ at the low currents where the old DAQ ran. Note, the deadtime correction to the observed asymmetry A_{obs}, arriving at the physics asymmetry A_{phy} is:

$$A_{\text{phy}} \;=\; A_{\text{obs}}\,[1-\epsilon] \tag{1}$$

For the new DAQ we may hope that ϵ is very small or zero and that $d\epsilon \ll 1\%$. This will be demonstrated by showing how the observed rate and asymmetry varies with beam current.

With the old setup, the calorimeter signals arrive at an analog fan-out unit, the analog sums from the columns as well as the signals from the scintillation counters pass through discriminators, and various coincidence signals are formed with a Programmable Logic Unit (PLU). The coincidence rates are recorded with scalers and read out every helicity cycle at 30 Hz. Additionally, the raw signals are measured with ADC and TDC units, triggered by a selected combination of the pulses from the PLU. The first 3–10 of such events per helicity cycle were recorded, in order to make sure that the data are good, but without overloading the DAQ system. The Møller asymmetry can be measured only with the scalers, since the statistics of the ADC/TDC events is 100–1000 times shorter than needed for that. The "helicity triggers" contain additional information: scalers for a beam current monitor (BCM, VtoF), a 100 kHz pulser in order to measure the helicity window, encoders for the target positions etc. All the triggers contain the trigger info, the helicity state and the beginning of a helicity quad pattern (QRT), recorded via input registers.

One 16-channel FADC unit should be able to replace nearly all the electronics from the old setup. In addition, it would allow a reduction of the systematic errors by:

- measuring the asymmetries using all the event data;
- analyze the pile-up effects and compensate for them.
- reducing the deadtime correction and associated systematic error

The FADC implementation does the following

- Make logical signals when combination of the input signals exceed certain thresholds;
- Write out the FADC "event" data using a logical signal for the trigger with an adjustable prescaler, at a rate up to the maximum rate allowed by the existing FADC systems (160 kHz); the rate capability of the new FADC is expected to exceed 300 kHz.
- Makes internal scalers in the FADC unit counting the coincidence signal; the scalers are read out at every helicity cycle;
- The readout includes the "event triggers" (< 160 kHz) and the "helicity triggers" (30–2000 Hz). Both additionally contain the helicity bit and the QRT bit;

- The "helicity trigger" readout includes additional scalers/ADC for the BCM, pulser, BPM, encoders etc.

B Signal Processing Logic and DAQ Architecture

The input signals are typically -2 Volts and 40 nsec wide with a fall time of 5 nsec. Let P_i^j be the calorimeter PMT data for samples j and ADC input channel i, and let S_i^j be the scintillator data. The data are summed over 2 samples $j = 1, 2$ because the signals are aligned in time sufficiently well that they should peak within adjacent 4 nsec windows. We have set two programmable parameters: threshold$_1$ and threshold$_2$ in order to build logical combinations:

- **CL** $= \sum_{i=1,4} \sum_{j=1,2} P_i^j \ \geq$ threshold$_1$
- **CR** $= \sum_{i=5,8} \sum_{j=1,2} P_i^j \ \geq$ threshold$_1$
- **SL** $=$ ($\sum_{j=1,2} S_1 \geq$ threshold$_2$) .OR. ($\sum_{j=1,2} S_2 \geq$ threshold$_2$) .OR. ($\sum_{j=1,2} S_3 \geq$ threshold$_2$) .OR. ($\sum_{j=1,2} S_4 \geq$ threshold$_2$)
- **SR** $=$ ($\sum_{j=1,2} S_5 \geq$ threshold$_2$) .OR. ($\sum_{j=1,2} S_6 \geq$ threshold$_2$) .OR. ($\sum_{j=1,2} S_7 \geq$ threshold$_2$) .OR. ($\sum_{j=1,2} S_8 \geq$ threshold$_2$)

The triggers, which initiate a readout of the FADC raw data, are a mixture of the coincidence (CL.and.CR) and singles (CL, CR) with prescale factors from 1 to 2000. The FPGA produces a kind of a scaler, counting

- CL
- CR
- CL.AND.CR
- CL.AND.SL
- CR.AND.SR
- CL.AND.CR.AND.SL.AND.SR
- CL.AND.CR.AND.(SL.AND.SR delayed>100ns)

These scalers are read out by a separate trigger at the helicity cycle at 30Hz to 2kHz. In essence, the scalers are a deadtime-free integration of the data, integrated over the helicity period. A standard externally supplied helicity gate defines the integration time.

The DAQ is a standard CODA-based system using high-performance components for handling the high rates: a 64x VME crate, a 6100 VME cpu, Gigabit ethernet, and fast PC and disks.

C Status and Results

The new Møller DAQ was first put in the Hall in July 2009 and has been tested parasitically during the HAPPEX-3 and PVDIS experiments whenever a standard Møller polarimetry measurement was performed. The signals from the calorimeters are fanned out, with a copy going to the new DAQ while the old DAQ was preserved. The scintillators in the aperture were not yet available to the new DAQ. The rate capability was 20 MByte/sec to disk and can possibly be doubled in the future.

During the initial running, several small problems were noted which led to further testing of a copy of the FADC in the DAQ test lab and subsequent upgrades and bug-fixes for the FPGA firmware. At the moment, there are still a few mysteries which appear under certain running conditions and the FADC is under active development and testing. Nevertheless, for normal running conditions we have seen promising results. Fig 1 shows some typical snapshots of the FADC for calorimeter signals: voltage versus time. We integrate these pulses to obtain an energy deposition. Fig 2 shows the sum of the integrals of four calorimeter blocks in one spectrometer arm. Essentially this is the total energy deposited in the spectrometer. The data are reasonable and agree with the old DAQ. The rates are about 50% higher than for the old DAQ, but this is probably because the new DAQ does not yet use the aperture scintillator counters. This will be remedied during the January shutdown when we install new segmented scintillator counters. Fig 3 shows a 5% asymmetry from Møller scattering. This is slightly different (2% relative) to the old DAQ, again probably because of the aperture counters. We have taken some data with different beam currents and target thicknesses to begin studying the deadtime; preliminary results are encouraging.

As of this writing, there is much more work needed before the new DAQ is fully reliable and its advantages are demonstrated. During the January shutdown, pulser tests will be performed. The deadtime needs to be measured with higher precision. The new segmented scintillators from Syracuse University will be deployed. In addition, the GEANT Monte Carlo will be revived and used to study systematic effects such as acceptance and magnet misalignments. It might also be possible to simulate the deadtime of the system.

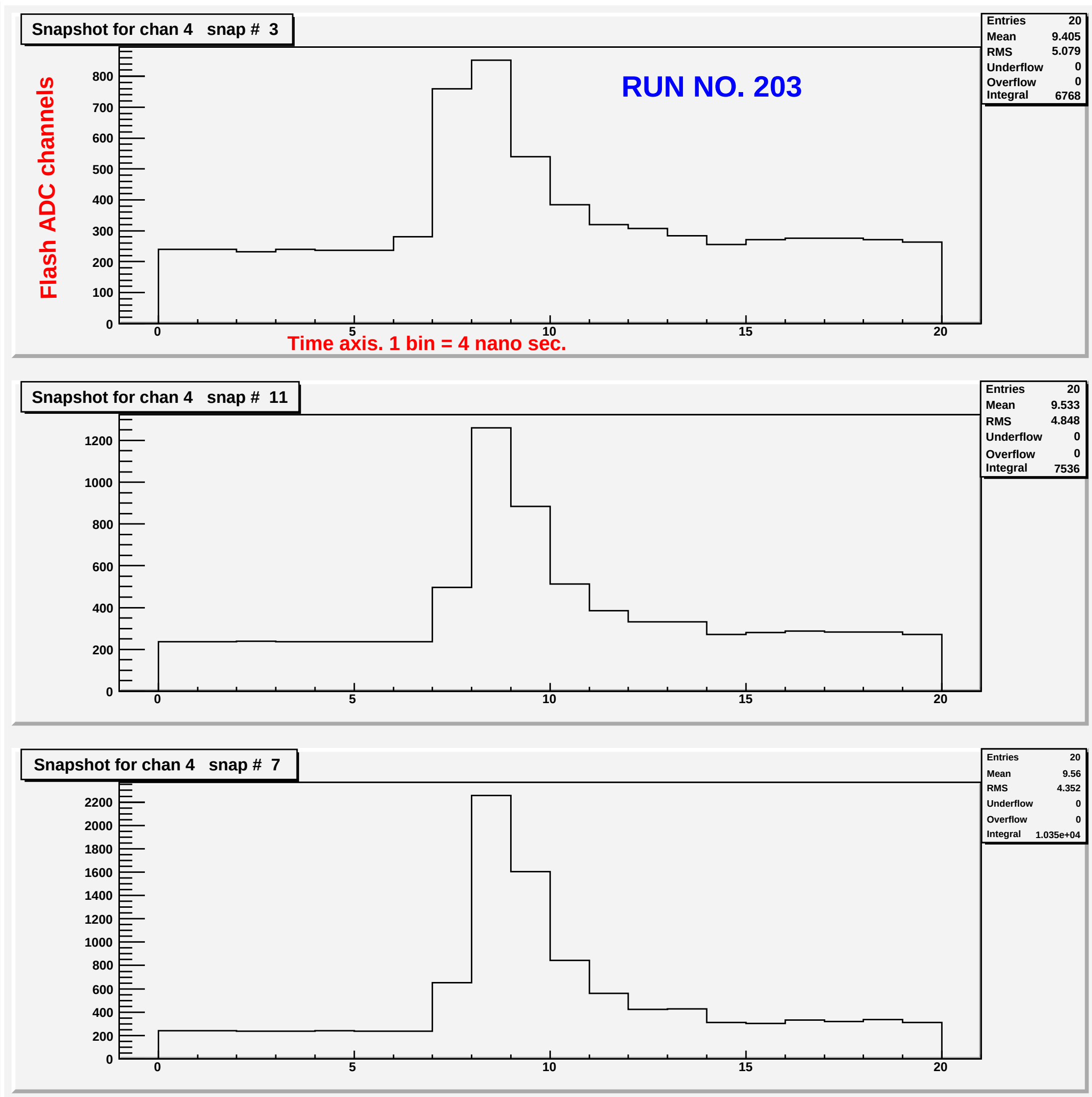

FIGURE 1. Typical pulses from the Møller calorimeter. Each snapshot shows the voltage versus time in the FADC.

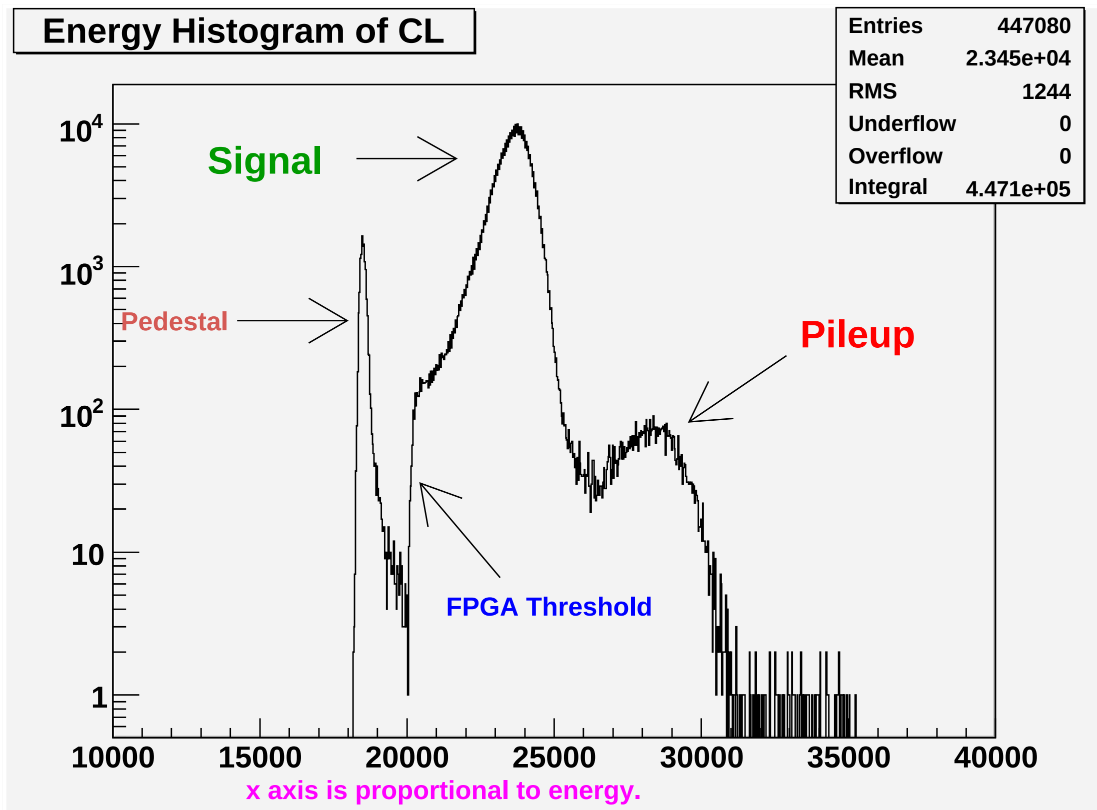

FIGURE 2. Integrated energy in one spectrometer from Møller calorimeters as processed by the FADC.

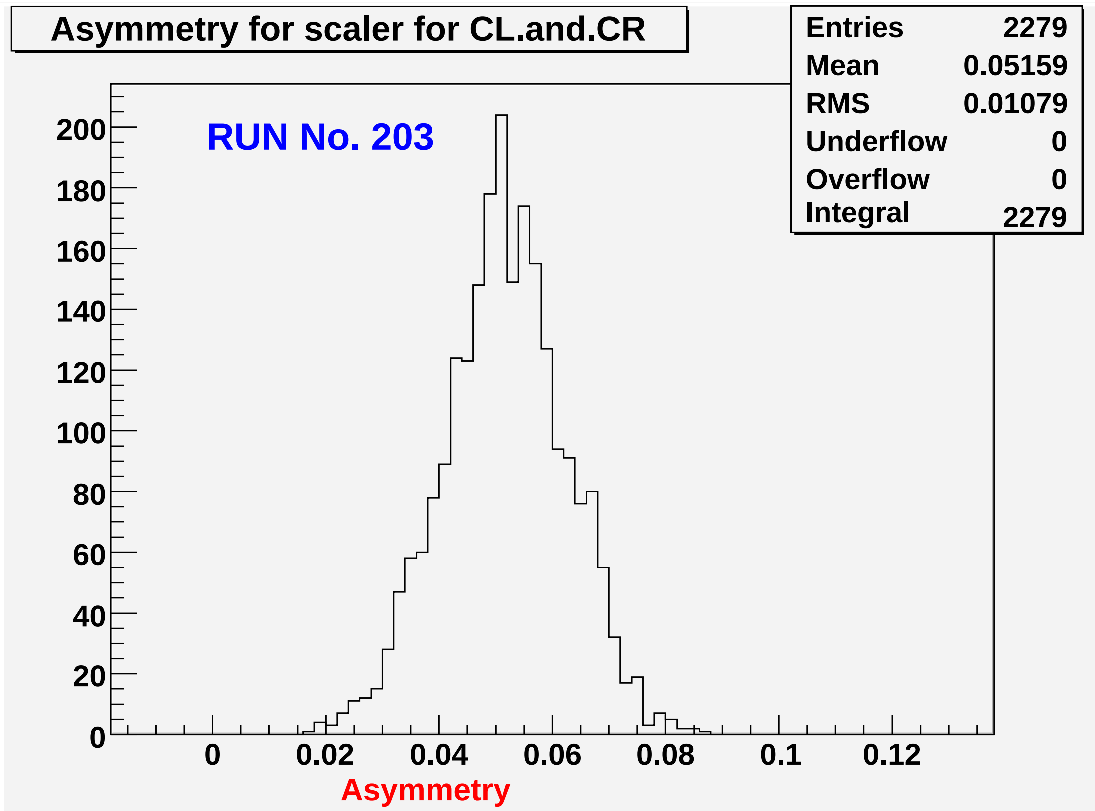

FIGURE 3. Møller asymmetry measured with on-board scalers in FADC. The 5% asymmetry is normal.