Calorimeter Operations in RunII at DØ

Daniel Duggan

Florida State University, Tallahassee, FL.

Abstract. The operation and performance of the DØ calorimeter is presented. Calorimeter operation will be overviewed with specific focus on calibration techniques, hardware monitoring and stability, and overall data quality strategies.

1. Introduction

The DØ calorimeter is a hermetic liquid argon sampling calorimeter. It is housed in three separate crystostats, the central giving coverage of $|\eta| < 1.1$, and the entire calorimeter providing coverage of $|\eta| < 4.2$. The calorimeter was upgraded between RunI and RunII at Fermi National Laboratory, where it currently operates. Collisions are produced from the Tevatron using unpolarized proton and anti-proton beams with a center of mass energy of 1.96 TeV. The electronics were upgraded to optimize the system for the 396 ns bunch crossings and high instantaneous luminosities, which have exceeded $300 \times 10^{30}\ cm^{-2}s^{-1}$.

Although the electronics were upgraded, the crystostats have remained unchanged. In addition to original RunI calorimeter [1], both the Inner Cryostat Detector (ICD) and the preshower sytems are used in RunII for particle energy measurements. The ICD was installed to give additional coverage between cryostats, specifically in the region of $1.1 < |\eta| < 1.4$. The preshowers, both central and forward, were added to provide additional particle energy and position measurements as compensation for the added material in front of the calorimeter in RunII. More information about these systems can be found in Ref. [2].

2. Electronics

The DØ calorimeter is divided into four electromagnetic (EM) layers, four fine hadronic (FH) layers and up to three coarse hadronic (CH) layers to optimize the energy response for various types of particles. A schematic drawing of the entire calorimeter is shown in Fig. 1. The calorimeter uses a combination of metal absorbers and active liquid to accurately measure particles' energies that pass through it. Liquid argon (LAr) is the active sampling medium and the absorber layers, as well as the thicknesses, are listed in Table 1.

For the entire calorimeter, there are 47,364 active readout channels. All channels are finely segmented, 0.1×0.1 ($\Delta\eta \times \Delta\phi$), with increased segmentation for the maximal EM shower layer to 0.05×0.05. Up to 12 channels, or cells, form pseudo-projective towers in each $\eta - \phi$ position.

Each cell is comprised of a 2.3mm gap filled with LAr between an absorber plate and a G10 insulator board coated with an epoxy with high resistivity. Particles passing through the cell ionize the active medium and a potential of $\sim$2 kV creates a current of electrons towards the resistive pad with an average drift time of $\sim$450 ns. Copper pads etched into the board collect

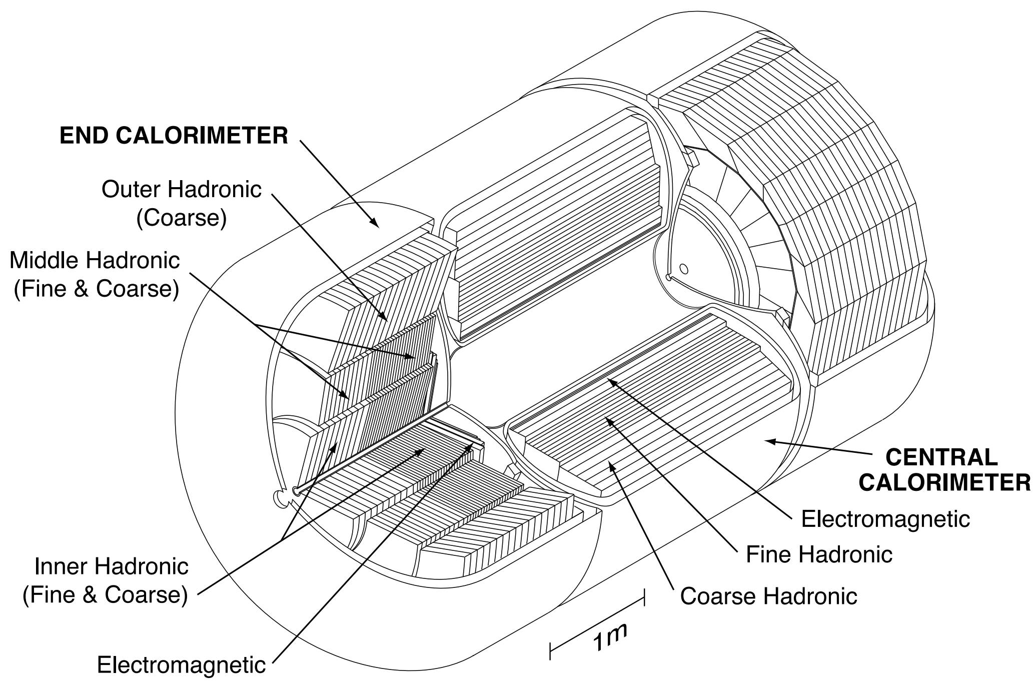

Figure 1. The three cryostat, hermetic liquid argon sampling calorimeter at DØ.

Table 1. Amount of material before each layer of the central (CC) and end cap (EC) calorimeters for the electromagnetic (EM), the fine hadronic (FH) and coarse hadronic (CH) layers. The thicknesses are listed in terms of radiation lengths (X_0) for the EM layers and in absorption lengths (λ_A) for the hadronic layers.

Layer	Region	Thickness	Material
EM	CC	2, 2, 7, 10	Uranium (3mm)
EM	EC	0.3, 3, 8, 9	Iron(1.4mm) + Uranium (4mm)
FH	CC	1.3, 1, 0.9	Uranium (6mm)
FH	EC	1.3, 1.2, 1.2, 1.2	Uranium (3mm)
CH	CC	3	Copper (46.5mm)
CH	EC	3, 3, 3	Iron (46.5mm)

the image charges produced, and pads are ganged together to form individual readout cells. Figure 2 shows a representation of the calorimeter cell design.

Once the charge is collected at the copper pads within the detector, they are sent via low impedance (30Ω) cables to the preamplification system. The preamplifiers are designed to match the cables' input impedance to prevent reflections in the signal. Fourteen types, or species, of preamplifiers are used to minimize cell-to-cell capacitance differences, which can be up to almost a factor of 10. This is done to create an integrated signal from the preamplification system that is independent of the input cells characteristics. This integrated signal is then sent to the Baseline Subtraction System.

The Baseline Subtraction (BLS) system receives the voltage signal from the preamplifier system and determines the energy deposited in each cell on an event-by-event basis. When the signal arrives to the BLS system, it is first intercepted from the Level 1 Calorimeter (L1Cal)

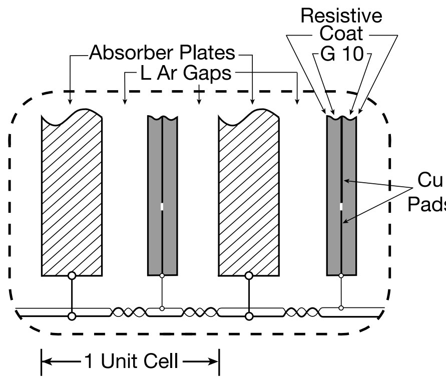

Figure 2. Schematic of a calorimeter cell.

trigger pick-off. The L1Cal sums the analog energy in towers of 0.2 × 0.2 ($\Delta\eta \times \Delta\phi$) for use in trigger decisions of event selection. The L1Cal was upgraded in 2006 to provide a more sophisticated trigger decision process [3]. The signal continues on to the signal shapers. The signal is shaped such that only the rising edge of the input signal is used in its energy estimation, which is approximately two thirds of the total signal. This is done because an integration of the entire signal is impossible given the timing constraints imposed by the Tevatron's 396 ns bunch crossings. The signal is then sampled at its newly shaped peak. In order to remove the remaining energy from previous events, the BLS system also samples the cell energy 396 ns before the peak of the signal. This excess energy is removed from the total measured signal energy and this modified signal energy is stored until a Level 2 accept is issued from the three-tiered trigger system. Due to the high volume of events processed and awaiting Level 2 decisions, Switched Capacitor Arrays (SCAs) are used for analog storage. The SCAs are also used for storage of signal information along the two calculated gain paths, ×1 and ×8. The use of two gain paths increases the dynamic range for the analog to digital conversion from 12 to 15 bit. The correct gain path is chosen by the BLS circuitry and once the event receives a Level 2 accept, it is sent to the Analog to Digital Converters.

The Analog to Digital Converters (ADCs) tranform the analog signal from the calorimeter cell into a digital energy value. It is here where signals are subject to a 2.5σ threshold in order to further suppress noise and minimum bias events. The ADC system also houses the timing and control operations of the entire calorimeter. It is synchronized to the accelerator clock and sends commands to the BLS system to regulate the signal and background sampling and subtraction. It also coordinates event processing among the ADCs and communications to the overall DØ detector framework. The digitized energy is sent to be used in event reconstruction.

3. Monitoring

Monitoring is an essential aspect to both efficient running and high quality calorimeter data. Monitoring is performed both online and offline for all parts of the system. This includes hardware readout of voltages, currents, temperatures as well as process statuses. Thousands of quantities are measured and monitored and if a problem does arise, alarms are connected to the data acquisition system to temporarily suspend data recording until the alarm status has been resolved. This is done to prevent bad quality data from being recorded. The hardware also contains failsafes so that no permanent damage would be done to the system due to malfunctions.

The monitoring also includes direct reconstruction of physics objects so that biases that are not observed as direct failures in the hardware can be possibly be seen in other ways. The reconstruction objects include missing transverse energy, as well as occupancy and energy, which

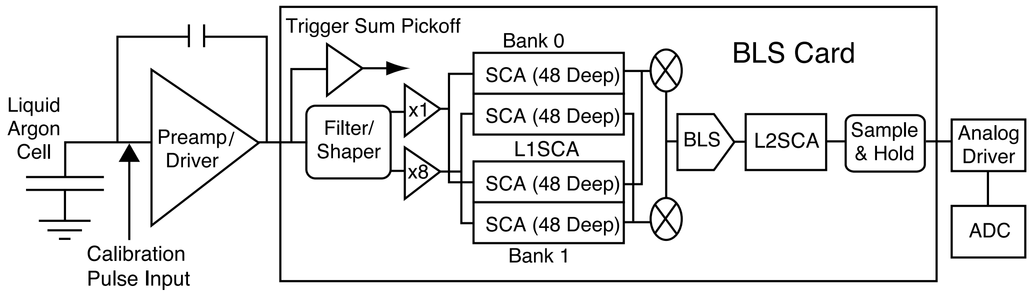

Figure 3. Schematic of the analog signal through the BLS circuitry using two independent gain paths.

are calculated at the cell and tower level. These quantities are reconstructed and monitored by a program that samples the data being recorded from the calorimeter. It has inline algorithms for both fast reconstruction of these objects and to search for signatures of failing hardware, unusually formed distributions and noise. Events containing any of these signatures are marked with data quality flags that used in the removal of bad events.

These tools are monitored by a trained shifter 24 hours a day, seven days a week in order to most efficiently address any potential problem that could arise with the calorimeter. Shifters have access to a large database of instructions, diagrams, and plots to aid in the proper identification and resolution of these problems. In addition to these resources, two pager carrying experts are available to answer and resolve any issues that are beyond the scope of the shifter.

Many times the information available for online quality criteria is not only used to help identify potential hardware failures, but they are also very sensitive to any noise that would possibly be introduced into the system. External noise has the potential to comprise good data, and extensive steps have been taken to remove it whenever it has appeared in the past. Safeguards were also developed to help prevent future instances, such as extensive grounding studies of the detector. Because of this proactive stance, the introduction of potential noise is unlikely. However, it is closely monitored and dedicated studies are performed to quickly identify and address whenever a candidate would arise. With constant monitoring and strict requirements on the these online hardware and physics readout values, we ensure the highest quality data and the most efficient running system possible.

4. Hardware Stability

Over 99.8% of the system is operational and performs optimally at all times. Almost all problems that do occur are well understood and thus the amount of downtime is minimized. However, access to a large part of the electronics systems is either restricted or, in some cases, not permitted. In these cases, efforts are made to migitate the downtime caused by these failures. As an example, it is advantageous to place the preamplification system within close proximity to the cryostat, but a power supply failure there results in a downtime of $8-10$ hours to access the area and repair the supply. In this case, redundant supplies are in place to be used in case of failures, thus avoiding extended periods without recording data for the affected section of the calorimeter.

Table 2 shows the most common hardware replacements for the calorimeter and maximum number of channels affected. As shown, most of the hardware replacements are in the BLS system. The BLS system is located directly under the detector in the collision hall, which means that access is restricted to times when there is no beam in the Tevatron. The replacement time itself is straightforward, and most often only single channels fail and have minimal impact on

Table 2. Listed are the most common hardware replacements for the calorimeter. The interval of time in between replacements is given as well as the maximum number of affected channels. This number is expressed as a fraction of all channels in the system, as shown in the last column.

Hardware	Interval (weeks)	Repair time (hours)	Channels affected	Fraction of system affected
BLS Daughtercard	1	0.5	12	0.00025
BLS Motherboard	4	0.5	48	0.001
BLS Power Supply	16	2	768 (1536)	0.014 (0.028)
Preamp Power Supply	12	8-10	4608	0.085

the quality of recorded data. Finally, it is worth noting that problems due to overall aging of the detector have been minimal over its lifespan. Only one channel was permanently disabled because of effects consistent with aging, corresponding to less than 2×10^{-3} % of the system.

5. Calibrations

5.1. Online Calibrations

To obtain the most precise data possible, the calorimeter itself must be well-calibrated. This calibration is done using both online and offline techniques. The online calibrations are performed in two ways. The first is a pedestal measurement for all channels, which is performed daily. Pedestal calibrations measure the average ADC counts per channel *without beam* for both gain paths. These values are used during event energy calculations as the pedestals are subtracted from the integrated signal, as well as being used in the 2.5σ noise suppression. The stability of the recorded pedestal values from previous ones are used as a cross check as fluctuating pedestals are a direct sign of hardware failure.

The other main online calibration is a pulser calibration, which measures the electronics energy response channel by channel. This calibration is performed weekly, and also immediately after any calorimeter hardware replacement. The pulser is connected to the preamplification system where it inserts a known amount of charge. This generated signal is processed and the measured and inserted charges are compared to determine the response of the system. The input charges are varied in order to validate the entire dynamic range of the channels. The electronics' response is fit with a linear function that characterizes the energy response over this range. The fit, along with any non-linear corrections derived for it, are combined into calibration coefficients and are calculated individually and applied channel by channel. Together these calibrations are very effective tools to maintain optimal precision in the calorimeter, to aid in the identification of under-performing hardware, to minimize any and all cell to cell response variations, and to maintain a very robust and stable system.

5.2. Offline Calibrations

The online calibrations ensure a uniform and well understood response from all channels over their entire dynamic range. Calibrations complimentary to these are the ones performed offline. One main offline calibration is the ϕ-intercalibration of the calorimeter. In the absence of mechanical detector effects, the calorimeter cell response is independent of the cell's position in ϕ as the beams from the Tevatron come unpolarized. Thus all cells would have a uniform response. However, variations in the detector's mechanical structure can bias this response. This calibration is done to account for these effects in order to regain this uniformity. This is done by calibrating all cells in rings of ϕ throughout the detector. This normalization is performed

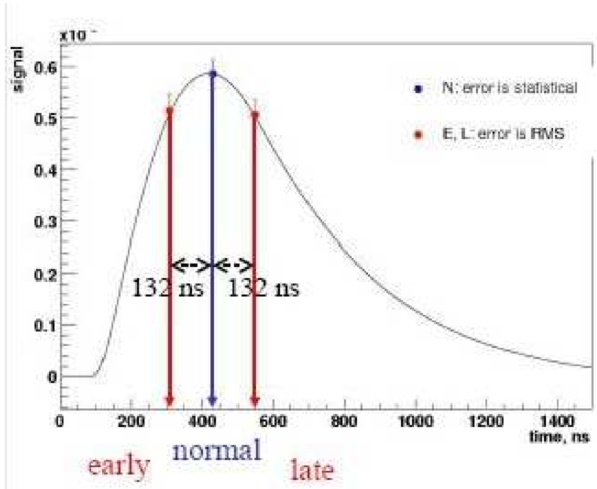

Figure 4. Triple timing studies use the information of the signal both before and after its peak. An optimal sampling point is one where the early sampling and the late sampling have the same values.

on data after all other calibrations have been taken into account. To obtain correction factors with very low uncertainty, these calibrations use ∼5-15 million events that have been recorded parasitically from normal data taking. The original study was performed in 2006 and is explained in greater detail in Ref. [4]. As an example of the results from this study, the uncertainties in the central calorimeter are approximately 0.7%. Cross checks are performed on these calibration constants approximately every six months. The found variations in these time periods are very small, indicating that the overall system is very stable.

Additional studies are also performed on the processed calorimeter data to verify the quality and stability of calibrations in place. One such study is the triple timing study. It was originally performed as an independent measure of the calibration technique listed previously and was found to yield consistent results. This study uses information of the signal before and after its shaped peak in the BLS system. Because the signal is sampled every 132 ns, it is possible to measure the signal value during the rise and fall of the distribution as well as at the peak. Figure 4 shows the nominal sampling point of the peak. This signal shape is symmetric about this point up to where the early and late samplings occur, thus a difference of these measured values would indicate an undermeasured signal value. The size of this difference is used to estimate how much of a bias is present in the BLS sampling procedure. This study is performed using ∼600,000 data events specially recorded to include this additional peak information. The study originally found that over 90% of all channels see less than a 0.5% percent diffence in these measured values. This procedure is repeated on the order of every six months as an independent verification of the sampling and timing stability of the BLS system and has found the system to be very stable with time with almost all channels showing variations on the order of 0.05%.

6. Conclusions

The DØ calorimeter has continued to perform efficiently and reliably throughout RunII at the Tevatron. It has maintained an efficiency greater that 90% over this entire period, and has seen improvement as RunII has progressed. Data quality is a top priority, and monitoring is performed online and offline for both hardware and reconstructed events to ensure the highest quality of recorded data, as well as preventative measures taken to counter potential noise problems. Online calibrations are performed as often as once a day for pedestal measurements and once a week for energy response measurements. These calibrations have helped to obtain a very stable system in which more than 99.8% of the system is at optimal performance. The problems that do occur typically affect less than 0.2% of all channels and are quickly fixed. The entire DØ collaboration looks forward much more high quality data and continued efficient running from the calorimeter throughout the entirety of RunII at the Tevatron.

Acknowledgments
We would like to extend our thanks to our DØ colleagues, as well as to Fermi National Laboratory for its continued support. I would also personally like to thank Walter Geist, Dean Schamberger, and George Ginther for all their help and guidance.

7. References

[1] S. Abachi *et al*, *Nucl. Instr. and Meth.* **A338**, 185 (1994).
[2] V.M. Abazov *et al*, *Nucl. Instr. and Meth.* **A565**, 463-537 (2006).
[3] M. Abolins *et al*, *Nucl. Instr. and Meth.* **A584/1**, 75-97 (2007).
[4] K. Peters, Proceedings of the 12^{th} Calorimetry in High Energy Physics Conference, AIP Conference Proceedings Volume 867, 17-24 (2006).