On the Possibility of Speeding-up Time Response of the D0 Calorimeter

Henryk Piekarz
Florida State University, Tallahassee, Fl32306

ABSTRACT

A proposal to increase by about a factor of 2 the ionization electron drift velocity in the D0 calorimeter by subcooling the liquid argon medium is presented. Further improvement of the signal processing using a multiple sampling method is also briefly discussed.

I. MOTIVATION

In the D0 liquid argon sampling calorimeter the 2.3 mm readout gap was selected as an optimal choice between the signal height requirement for the operation of the charge-sensitive front-end amplifier and the minimization of the electron/hadron response difference which depends in part on the absorber to readout gap ratio. With a typical electric field of 10 kV/cm the average ionization electron drift time in the D0 readout gap is in the range of 400 nsec thus inducing a signal at the amplifier input of about the same width. This signal width matches well the 396 nsec beam crossing time projected for Run II. For Run III, however, the projected instantaneous luminosity ranges up to 10^{33} and the rapid increase of multiple interactions requires to considerably shorten the beam crossing time. A current proposal for the TeV33 assumes operations with a 132 nsec beam crossing time. This implies that the calorimeter response time might be reduced as well to about the same time range in order to avoid excessive dead time and/or signal distortions due to pile-up. Those distortions will affect most strongly low P_T physics but adverse effects may be significant for high P_T physics with low production cross-section such as high Et jets, top quark, Higgs, and SUSY particles. The error of W mass determination may increase and the measurement of the missing E_T may be compromised. In addition to the above triggering on the low E_T jets may be strongly biased or even impossible.

II. EXPECTED PERFORMANCE OF THE D0 CALORIMETER AT SUBCOOLED LIQUID ARGON TEMPERATURE

The electronics noise is the main factor limiting liquid argon calorimeter signal sampling methods. A large fraction of this noise is due to parasitic capacitance of cable beteen the calorimeter cell and preamplifier input. In order to lower this noise an attempt is made at LHC to install the front-end preamplifiers inside the liquid argon/xenon calorimeters. With this technique, very satisfactory test results were obtained for both signal amplitude and timing resolution. This method, however, carries with it great difficulties in dealing with electronics located inside the cryostat. In the D0 liquid argon calorimeter the front electronics is located outside the calorimeter cryostats. With the average cable length of about 10 m, some 2000 pF of parasitic capacitance is added to the detector cell thus approximately doubling the electronic noise. Test have shown, however, that this noise level will allow for a satisfactory operation of the D0 calorimeter with bunch crossing time down to 396 nsec as expected for Run II.

Given this situation, further improvement of the D0 calorimeter performance with bunch crossing of 132 nsec may only be possible by reducing the ionization electron drift time in the readout gap which leads in turn to a shorter signal with higher pulse-height. The mobility of ionization electrons in the liquid argon is a function of both the electric field across the gap and the liquid medium temperature. Above some 10 kV/cm (which is a typical field applied in the D0 detector) the dependence of the electron drift time on the electric field is rather small (tends to form a plateau). In the argon medium a change from the liquid to solid phase occurs over some 16 K temperature range (from 92 K to 76 K). The electron mobility increases monotonically in this temperature range by about a factor of 4 [1] thus reducing the signal width in a 2.3 mm gap down to some 100 nsec.. Signals observed with a solid argon test cell [2] confirmed these expectations very well. However, as the D0 calorimeter has not been designed for the operation with the solid argon and any modifications are not practical due to its high complexity, a proposal is being considered to apply the subcooled liquid argon temperature of about 82 K. This will allow to reduce the electron drift time by a factor of 2. The signal width reduction will vary with the capacitance seen at the preamplifier input (cell plus cable). For the calorimeter EM sections (both central and end-cup), with average input capacitance of about 2000 pF, some 80% of the signal will be within first 200 nsec time interval. In the hadronic sections of the calorimeter the amplifier input capacitance spans up to 6000 pF allowing for only a moderate timing improvement. The EM calorimeter sections play a crucial role in defining the jet and particle triggers and they also account for most of the calorimeter readout channels.

In addition to improved timing, the collected charge also increases with lowering of the argon temperature, both due to decrease of the ionization electron scattering and increase of the argon density. Consequently the signal to noise ratio in all calorimeter sections will improve with respect to the current situation. This suggests that the signal sampling with 132 nsec time intervals may become feasible for most sections of D0 calorimeter. The signal width will be about a factor of two or so only longer than the sampling time so storing and digitizing signals for 2 or 3 consecutive beam crossings may be sufficient to provide the required data to determine the signal height, its timing and the level of underlying noise. Shortening of the signal by up to a factor of 2 may not require any major modifications to the front-end amplifiers, so the recently upgraded D0 calorimeter electronics can be used. The bench test of these amplifiers should be performed (using shorter input signals but of higher voltage height) to assess the extent of changes to be made.

Recently, considerable progress was made in processing signals from liquid argon/xenon ionization detectors [3] to be exposed to colliding beams with instantaneous luminosities of 10^{34} and above. In the LHC experiments the signal dwell time is generally longer than many bunch crossings. In addition to that, the event of interest may be identified by the trigger system only after a latency of several microseconds. This implies the necessity to store signals over this long period of time. An attractive solution to above problems is to sample the signal at the bunch crossing frequency and to digitize and record only a finite number of these samples (once the bunch crossing of interest has been identified). The samples are used to reconstruct the signal of interest and must provide for both the amplitude and its time origin. These requirements set a lower limit on the energy of the signal to be associated with the bunch crossing. In addition, the sampling pattern must not compromise the energy resolution of the calorimeter. The subcooling of the liquid argon medium at the D0 calorimeter would improve the detected signal and thus make it more feasible to apply the multiple sampling method. The method of recording the detector signal through the use of many samples over the waveform (as opposed to one sample at the peak of the waveform) has number of advantages particularly important at high luminosities. These include higher precision in reconstruction of both amplitude and timing as well as the ability to sense signal distortion due to occurence of the multiple interactions.

III. POSSIBLE ARRANGEMENT FOR SUBCOOLING THE LIQUID ARGON MEDIUM AT D0 CALORIMETER

In the case of the D0 calorimeter the arrangement of the LN_2 cooling loops is such that they not only cover the whole calorimeter structure but extend down to about 75% of the liquid argon level. At present this system operates with the liquid nitrogen source temperature of 82 K. Tests have shown that this allows to cool and regulate the liquid argon medium temperature in the D0 calorimeters down to 86 K. Consequently, by lowering the temperature of the LN_2 source to 78 K the temperature of 82 K for the liquid argon medium inside the calorimeter should be easily feasible. To change the LN_2 source temperature to a lower value, only a small modification (an installation of an inexpensive liquid nitrogen subcooling system) of the LN_2 cooling system outside the cryostat is required. The subcooling of the liquid argon medium in the D0 calorimeters should be preceded by tests with a small cryostat resambling the D0 calorimeter. These tests would allow to determine the required liquid nitrogen source temperature, the distribution and the stability of the subcooled temperatures within the calorimeter structure, etc.. These tests should also include the measurements of the signal height and shape from the beta cells (mimicing the D0 calorimeter cells) operating in the subcooled temperatures.

Selecting the working temperature at about 82 K has one disadvantage. In this range of temperatures the electron mobility changes by about 25% per deg. K. This implies that the temperature gradient through the calorimeter and stability of the temperature should be kept at the level of 0.5 K or better. Based on the current experience with the D0 calorimeter the temperature gradients and stability better than 0.5 K are feasible.

IV. CONCLUSIONS

Improvement of the performance of the D0 calorimeter might be obtained by just cooling the liquid argon medium down to 82 K. This would need to be followed by probably only a slight modification of the front-end amplifiers and small addition to the calorimeter cooling system. For further improvement that would make the D0 calorimeter truly immune to the problems induced by the multiple interactions at luminosity of 10^{33} and above, the digitized multiple sampling over the signal waveform should be considered as possible solution.

V. REFERENCES

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[3] *O.Benary et al., NI&M A349 (1994) 367*