Why 6 milliseconds (3 maximum drift-times)

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August 19, 2006

Why record 3 drift-times?

For this note, 2 milliseconds is the maximum drift-time. The reason for the interval between 0 and 2 milliseconds is obvious. The ionization electrons from tracks from an event due to a beam-induced interaction will arrive at the sense-wires at some time between 0 and 2 milliseconds after the interaction depending on the distance of the track from the sense-wires. In general, however, the time of arrival relative to the spill-time of an electron at the sense wires is given by

time-of-arrival = time of entry of cosmic ray (relative to spill) +
length of time for ionization electron to drift to wire

(The cosmic ray itself is considered to take zero time to pass through the detector) Any segment (of a trajectory) for which the electron time-of-arrival is between 0 and 2 milliseconds could be considered part of a relevant (ie in-time) track.

To reconstruct the full trajectory of a particle inside the detector one needs to record times from -2 milliseconds to +4 milliseconds. The phrase *'full trajectory inside the detector'* is key. One can reconstruct *part* of the trajectory of any particle inside the detector if one only records from 0 to 2 milliseconds - but in this case some of the cosmic rays will appear, absent other information, as particles which materialize from within the body of the detector. It may also be useful to emphasize that while the full trajectory cannot be reconstructed without the full 6 milliseconds, extending the read-out time by as little as 0.1 milliseconds each side of the nominal should be sufficient to tag out of time cosmic rays.

Consider a muon which enters the detector near an anode (the sense-planes) 1.9 milliseconds *before* the beam-spill on a trajectory that crosses the full drift region to the HV cathode. The electrons from the section of track near the sense-planes will reach the wires before the beam spill (starting 1.9 milliseconds before the spill) and the signals these electrons produce are clearly associated with an out-of-time particle. As the muon moves away from the sense-wires towards the cathode, however, a point will be reached along the muon path beyond which the drifting electrons arrive at the wires *after* the beam spill and could be considered relevant. In this particular case, signals from electrons with drift time greater than 1.9 milliseconds, ie in the drift-region within 0.1 milliseconds of the cathode, will be recorded in the standard readout interval. These signals which actually correspond to a trajectory near the cathode would be interpreted (absent no other information) as a particle materializing in the body of the detector, starting (transversely) at the anode wires and moving a distance of 15 cms (0.1 milliseconds of drift) away.

Similarly, consider the electrons from a muon which enters the detector near the cathode (HV plane) 1.9 milliseconds after the beam-spill where the muon crosses the drift-volume to the anode (readout). The electrons drifting in from the muon point of entry (near the cathode) will reach the anode wires 3.9 milliseconds after the beam spill and these signals are, again, clearly associated with an out-of-time particle. Once, however, the track is close enough to the anode wires that the electrons take less than 0.1 milliseconds to reach the wires, the electrons will arrive in the valid time window. Thus if one only records signals during the nominal time, from 0 to 2 milliseconds, the muon trajectory near the anode will generate in-time signals which appear to be from a particle materializing in the body of the detector close to the cathode.

Suppose one wants to use the wires at the boundary of the detector to identify cosmic rays entering the detector, or more generally one wants to reconstruct the full trajectory of cosmic rays within the detector. The first case shows that one needs to start recording a full drift-time before the beam-spill; the second shows that one needs to keep recording for a full drift-time beyond the full drift-time associated with the spill.

It is also true that extending the recording interval at the beginning and the end from the nominal maximum drift by an amount of say 0.1 milliseconds will be sufficient to tag events as cosmic rays. The quantity 0.1 milliseconds is suggested as being large compared to timing uncertainties (few microseconds) but still small compared to the full-drift time.