MICE particle correlation to the ISIS 1RF Reference Signal

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MICE NOTE??
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1 Introduction

The MICE Scintillating Fibre Tracker [1] uses AFE-IIt boards from the D0 experiment, running a modified firmware. Charge collected from VLPC chips is integrated over a predefined integration window and any charge produced outside this window will be ignored by the electronics. Therefore for the tracker to operate efficiently it is crucial to align the integration window to particles in the MICE beam line. Furthermore to ensure all the light produced from a particle interaction is integrated by the tracker front end electronics an alive window will be applied to tracker readout triggers[1]. Only triggers arriving inside the alive window will be accepted by the electronics, all other triggers will be rejected.

To line up these windows to the particles in MICE the ISIS 1RF reference signal is used. This signal is synchronised to protons inside ISIS and by extension is also related particles inside MICE. The reference signal comes directly from the ISIS frequency law generator and is synchronised to particles in the ring using internal ISIS feedback loops. When ISIS is not operating the generator remains active and generates a dummy signal for other diagnostics, enabling operation even during ISIS shutdown.

The aim of this study was to correlate the arrival of particle triggers from the TOFs to the ISIS 1RF reference signal and estimate the impact of applying an alive window to triggers.

2 Methodology

To digitise the ISIS RF for an entire spill, without interfering with MICE running the data acquisition was done using a Tektronix DPO7000 oscilloscope located in the MICE Local Control Room (MLCR). The oscilloscope has sufficient internal memory to digitise 4 channels and 200MS/s for 20ms which enabled an entire spill to be recorded in a single shot. The 4 channels which were digitised include:

CH 1 ISIS 1RF Reference.

CH 2 Particle trigger request (TOF1)[2].

CH 3 TOF0 Hit.

CH 4 Spill Gate.

After each acquisition the oscilloscope saved the signals to disk in a text file (.csv). This allowed a simple root script to load and process the recorded signals in order to measure the frequency and delays.

[1] It is likely this veto will also be applied to all MICE trigger requests.

[2] Note that TOF1 is received as particle trigger request, which adds an additional (about 50ns) delay compared to the TOF0 hit.

The data for this simple study was initially taken during part of the December run of 2011. It was noticed that there was a mistake made in the oscilloscope configuration and the data was retaken for a wider range of beams during the March 2012 run. For the March run only 5ms of data was recorded, but at an increased sample rate of 500MS/s. During the oscilloscope recording MICE runs 3601-3611 were also taken.

3 ISIS RF Frequency

During acceleration the ISIS RF frequency increases to match the proton revolution rate as the particles are accelerated from 70MeV to 800MeV. The frequency of the ISIS RF was determined by fitting a sine function to each period of the wave and then averaging over 10 cycles. The frequency over an entire ISIS spill can be seen in Figure 1.

The time of interest for MICE is limited to when the target is in beam and the spill gate is open, Figure 2 shows the frequency over this time. For the single station test a gate of 3.026ms was used which caused a total frequency shift of 168kHz (5.4%). For later steps of MICE containing RF cavities the spill gate may be reduced to 1ms, which will reduce the frequency shift to around 17KHz(0.6%), which is barely noticeable.

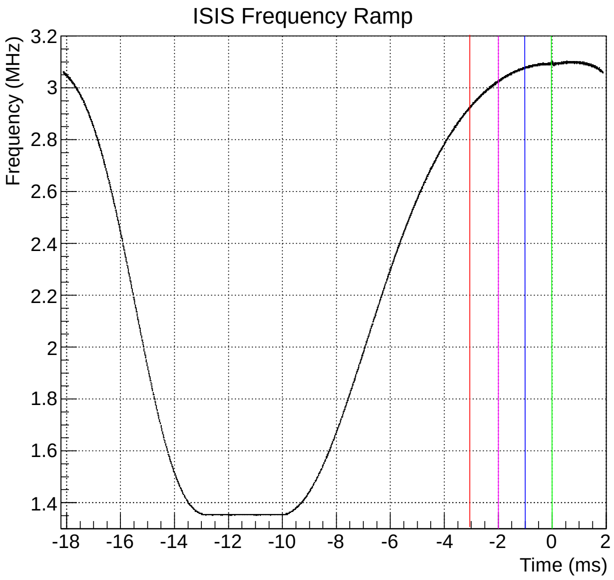

Figure 1: Plot of the frequency of the ISIS 1RF reference signal across an entire spill. The oscilloscope was triggered at the end of the spill gate so that ISIS injection occurs at -10ms and extraction occurs at 0ms. The frequency was averaged over 10 periods to reduce the noise.

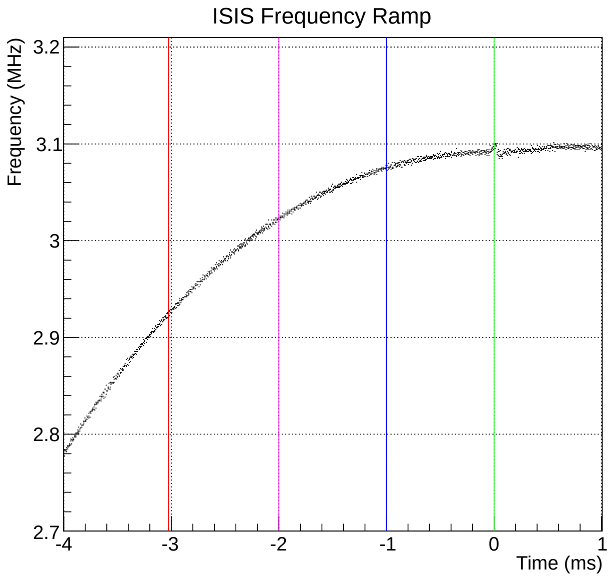

Figure 2: Same as figure 1 but the X Axis is limited to the MICE spill gate.

4 Trigger Correlation

The next part of the exercise was to correlate the triggers to the ISIS RF. For this the ROOT script looked for rising edges from the trigger signal. Once the rising edges had been found the script then located the previous RF edge and measured the delay. Figure 3 shows an example for a single trigger.

The delay from the ISIS RF is shown in Figure 4. The hits from TOF1 arrived at around 320ns (0°). To prevent the distribution of triggers being split, the x-axis was set to 200-524ns and triggers falling below this had 324ns added to bring them into the correct range for the plot.

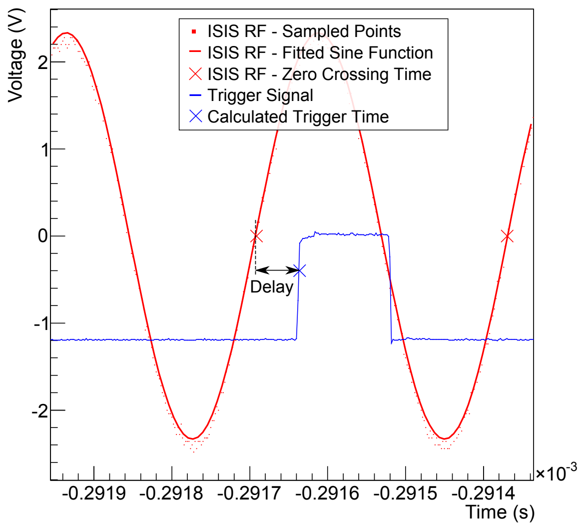

Figure 3: Image of the ISIS RF with a fitted sine wave and the zero crossing highlighted. Additionally a particle trigger from TOF1 is overlaid to demonstrate the delay. The trigger signal is an inverted NIM output as there were no other spare outputs from the appropriate fan-out.

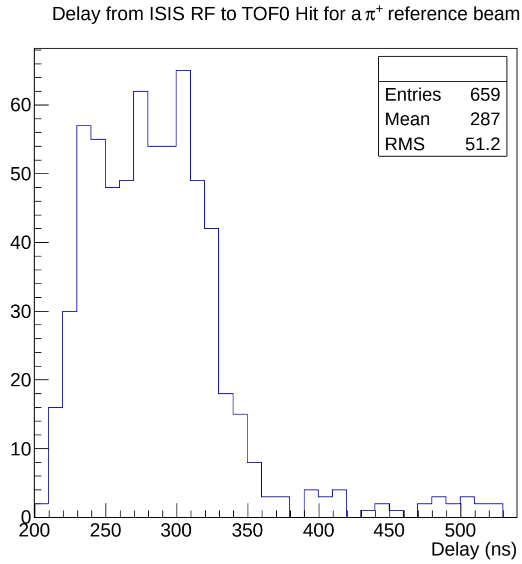

Figure 4: Delay from RF edge to TOF0 hit for a 272MeV/c π^+ reference beam.

This study was done for a range of muon and pion beams. The beams all used a 29mm proton absorber and the momentum at D2 was recorded. During running the decay solenoid was not operational and significantly reduced the muon beam rate. It was apparent during analysis that the low rate caused a large percentage of noise hits. To minimise these effects a coincidence cut was made which required a hit in TOF0 300-50ns before the particle trigger request was seen from TOF1. For each run around 20 oscilloscope traces were stored to disk.

The results from TOF0 can be seen in figure 5. The pion beams showed a high rate and the majority of triggers falling between 200 and 350ns. Once a cut was made the overall number of particles dropped significantly due to losses in the beam line but the fraction of particles falling within a gate increased. The final (anti-cut) plot shows the rejected data, which is made up of a large number of particles which did not reach TOF1 and a large number of background hits (outside the 200-250ns) range. For the muon beams a large excess of hits was noticed around 400ns, these hits were correlated to the ISIS RF, but not seen in TOF1 and are rejected by the cut. It is likely these hits are due to protons triggering TOF0 (due to insufficient proton absorber), but were not transported through the final quadrupole triplet.

The same process was repeated for TOF1 and the results are shown in figure 6. The majority of hits occurred between 280 and 420ns. This is shifted from the TOF0 result by a combination of the particle time of flight and the trigger generation time. For the muon beam without the coincidence cut it is difficult to see a correlation, especially in the low momentum beam. After the coincidence cut it becomes clearer that the majority of particles are arriving with similar time to the pion beams. The anti-coincidence cut shows noise which is uncorrelated to the ISIS RF.

5 Veto Efficiency

The final part of this study was to apply an alive window to the triggers recorded and calculate the fraction of accepted triggers. The number of accepted triggers was found by looping over all the

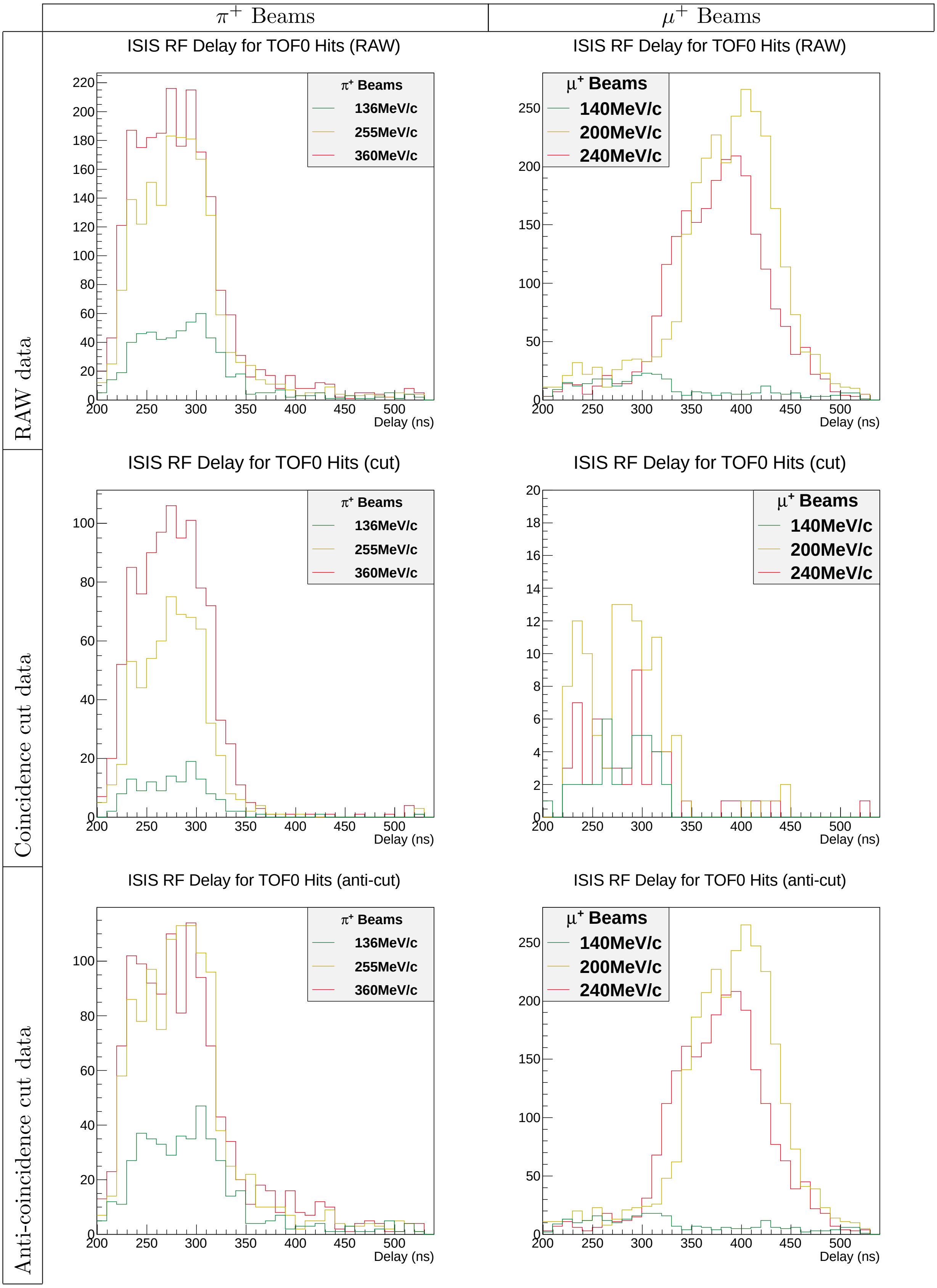

Figure 5: Delay from RF edge to TOF0 hit for a range of beams. A coincidence cut is made with TOF1, requiring a hit within 300ns after a hit in TOF0. This has the effect of reducing background from particles which do not traverse the beam line. The hits in the low momentum muon beams appear to be dominated by protons, caused by a lack of sufficient proton absorber.

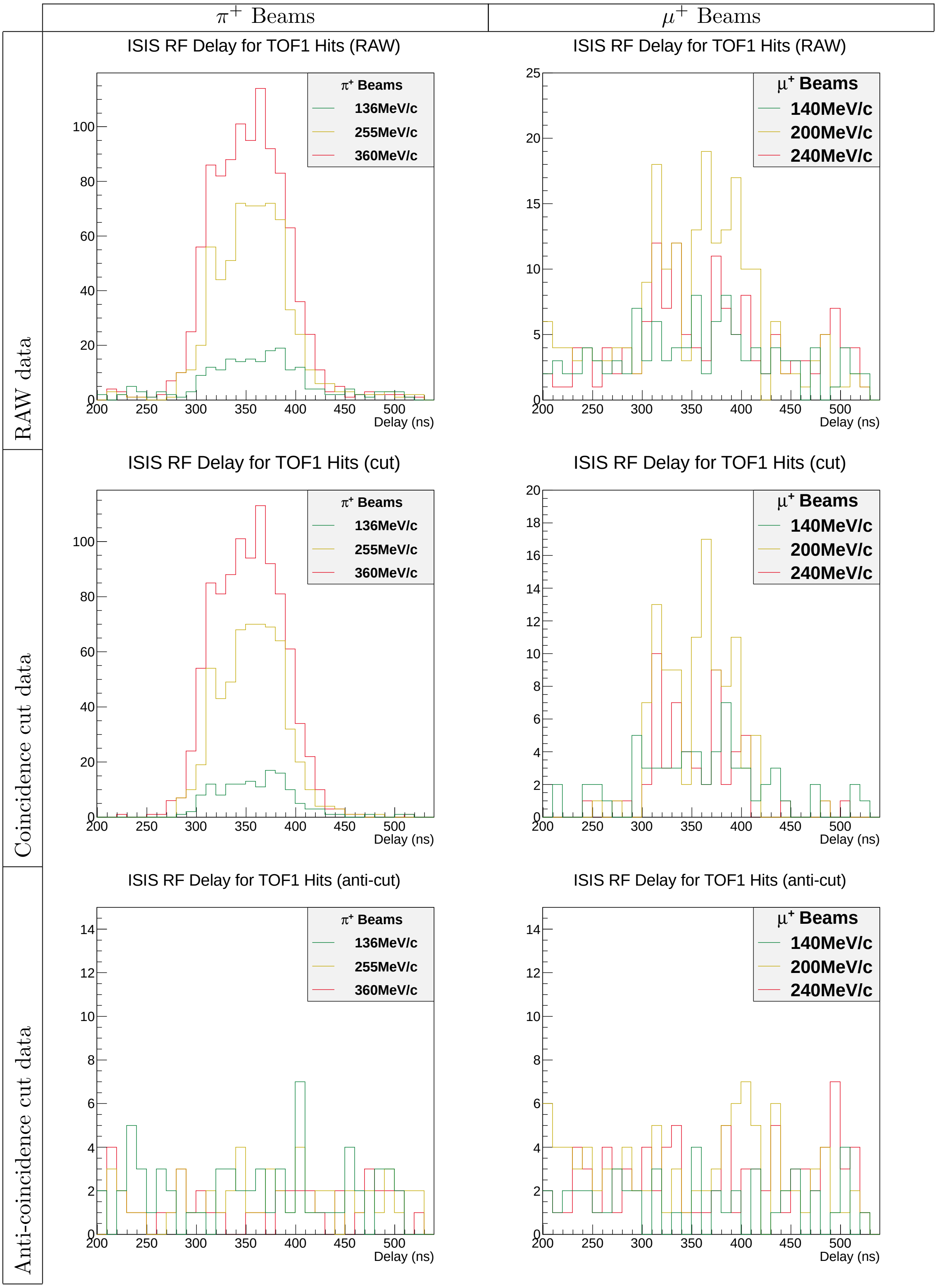

Figure 6: Delay from RF edge to TOF1 trigger for a range of beams. A coincidence cut is made with TOF1, requiring a hit within 300ns after a hit in TOF0. This has the effect of reducing background from particles which do not traverse the beam line. The coincidence cut data shows clear bunch of particles following the RF edge. The anti-coincidence cut data shows background noise hits.

recorded triggers and counting the number of triggers which met the criteria in equation 1:

$$a_c - \frac{a_w}{2} < t_d < a_c + \frac{a_w}{2} \tag{1}$$

Where a_c is the center of the alive window, a_w is the alive window width and t_d is the trigger delay as measured previously. If a trigger did not meet the above criteria it was counted as a rejected trigger. To study the effect of changing the width of the alive window, a_w was scanned and the number of rejected triggers was minimised by adjusting a_c.

The results for the three pion beams are shown in figure 7, the muon beams were not investigated due to a lack of statistics. In the 136MeV/c π^+ the low signal to noise ratio caused a substantial drop in the accepted triggers and this effect was reduced with a coincidence cut identical to in section4. For $a_w < 100$ns the number of accepted triggers drops almost linearly as the window cuts into the peak of the histogram. For $a_w > 120$ns the fraction of accepted triggers begins to flatten and reduce the gains for increasing the window width. For the perfectly aligned window of width 120ns over 90% of coincident triggers will be accepted.

To assess how sensitive the window is to misalignment the plots in figure 7 also have the accepted fraction of triggers if the window was shifted by 10ns from the optimal value. A 10ns misalignment was chosen as a worst case practical scenario. The digital delay units used for generating the alive window can be configured with sub-ns resolution [2]. And using the config-db a setting can be made for every beam. In this case a 120ns alive window will accept at least 88% of coincident triggers.

At the moment the maximum width of the alive window (a_w) is limited by a combination of the integration window ($\tilde{2}$00ns) and the shifting ISIS RF frequency. For a spill gate width of 3ms, the ISIS RF introduces a 5.4% shift. The transmission length to the hall and back is around 600ns, making the jitter relative to the RF around 30ns.

6 Conclusion

The 1RF reference signal from ISIS has been digitised and recorded to disk with particle triggers from TOF0 and TOF1. This study has found a good correlation between particle triggers in MICE and the ISIS 1RF reference signal. Finally an alive window has been applied to the data which found that for a window width of 120ns over 90% of triggers at TOF1 coincident with TOF0 will be accepted.

References

[1] M. Ellis and all, "The design, construction and performance of the MICE scintillating fibre trackers," *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* **659** (2011), no. 1, 136 – 153.

[2] "T560 4-channel compact digital delay and pulse generator." Highland Technology data sheet `http://www.highlandtechnology.com/DSS/T560DS.shtml`.

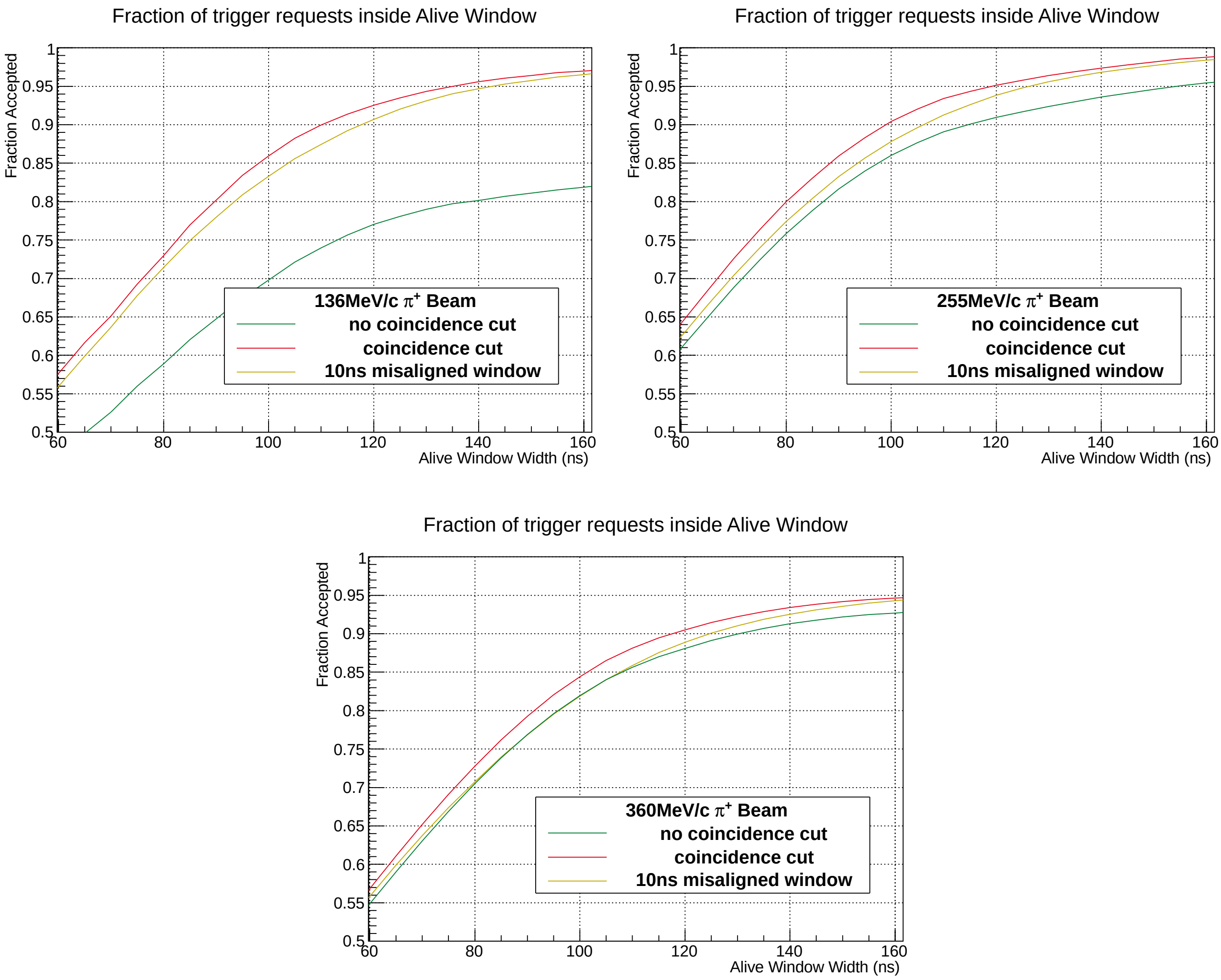

Figure 7: The fraction of accepted triggers for alive window widths spanning from 60 to 160ns for different pion beams at TOF1. The green line represents fraction of total triggers within the window. The red line represents the fraction of triggers which saw a coincidence 300-50ns before in TOF1. The yellow line is identical to the red, except a_c is shifted by 10ns from the optimal value.