CDF/DOC/TRIGGER/CDFR/xxxx
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Firmware Specifications for a Level 1 $\phi \rightarrow K^+K^-$ Trigger

authors

1 Overview

A single Pulsar module will identify pairs of tracks consistent with the decay $\phi \rightarrow K^+K^-$ within a 180° azimuthal region of the detector. Input data will be provided by the SLAM modules on 12 fibers, each of which transmits the data from tracks found within a 15° azimuthal region. The data words associated with each track provide estimates of curvature, local azimuthal angle (φ) within a 1.25° region, as limited stereo information provided by the SLAM modules.

The ϕ-trigger is required to identify pairs of tracks that satisfy a set of criteria that has been determined to have a high efficiency for $\phi \rightarrow K^+K^-$ decays in the $B_s^0 \rightarrow D_s^-\pi^+$ decay chain, but which will have a low fake trigger rate at level 1. The logic is required to identify those pairs of tracks that satisfy the $\phi \rightarrow K^+K^-$ selection criteria from which three trigger decisions will be derived:

- at least one $\phi \rightarrow K^+K^-$ candidate
- > 1 $\phi \rightarrow K^+K^-$ candidate
- $\phi \rightarrow K^+K^-$ with an additional track within 90° in φ

with the possibility of automatically accepting or rejecting events containing too many vaid tracks to process in the limited time available.

2 Pulsar architecture

The Pulsar module will be used to perform the $\phi \rightarrow K^+K^-$ selection logic. Each Pulsar module will be assembled with four daughter-boards, that will receive data from SLAM modules over optical fibers. There are three Altera Apex 20K series FPGA's (part number EP20K400BC652-1XV on the Pulsar board through which data flows as shown in Figure 1. The track data will be provided on twelve fibers, each of which will carry data from a 15° azimuthal region of the detector. Therefore, each Pulsar will instrument 180° degress, and it will be necessary to have four identical such modules covering four 180° regions that overlap by 90° in order to identify ϕ-track correlations within 90°.

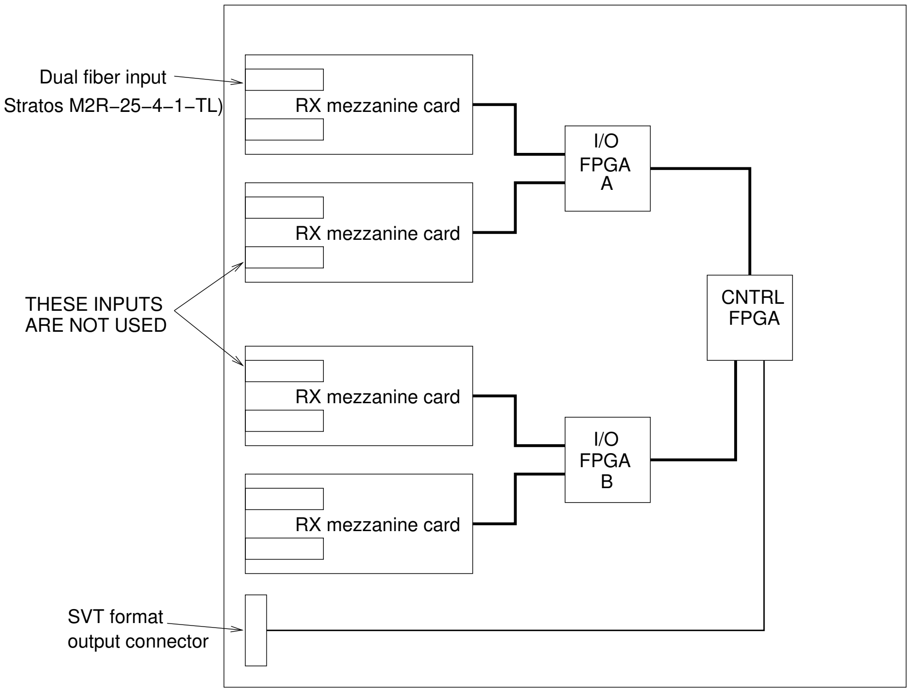

Figure 1: Data interconnects between FPGA's on the Pulsar module.

2.1 Data flow

The ϕ-trigger will identify pairs of tracks that satisfy a set of criteria described in Section 4. One of the criteria is that the pair of tracks be separated by no more than 25° in azimuth. Since each fiber provides data from a 15° region of the detector, this means that pairs only need to be identified using tracks that are recieved on adjacent fiber channels. Figure 2 shows the expected flow of data through the FPGA's that will allow all possible pairs to be identifed. The I/O FPGA's will each process four adjacent pairs of fibers, but will pass data from two of the fibers to the control FPGA, which will process three adjacent pairs of fibers.

2.2 Trigger output

The output trigger decision will be provided on the SVT connector which is accessible from the front-panel of the Pulsar module. This is driven by the control FPGA.

3 Input data

Track data provided on a single fiber in the form of 16 bit words clocked with a period of 16.5 ns. Data from a TLK1501 serializer/deserializer on each fiber channel is made available as a 16-bit bus along with clock, data valid and error signals. Data is to be latched on the rising edge of the clock pulse. Data on different fibers may not necessarily be aligned and clock signals on different fibers may be out of phase. For this reason, the high order bit in

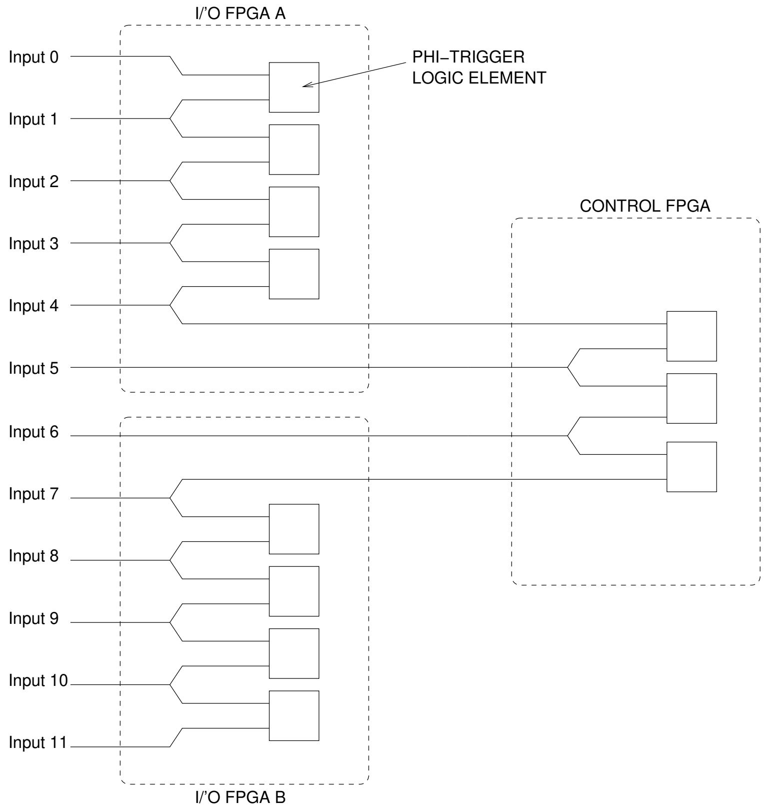

Figure 2: Data flow through the I/O and control FPGA's into the ϕ-trigger logic elements. The output decision from each logic element is not shown.

	15					0
Track 0	1	unused	SC	ST	phi	pT
Track 1	0	unused	SC	ST	phi	pT
Track 2	0	unused	SC	ST	phi	pT
Track 3	0	unused	SC	ST	phi	pT
Track 4	0	unused	SC	ST	phi	pT
Track 5	0	unused	SC	ST	phi	pT
Track 6	0	unused	SC	ST	phi	pT
Track 7	0	unused	SC	ST	phi	pT
Track 8	0	unused	SC	ST	phi	pT
Track 9	0	unused	SC	ST	phi	pT
Track 10	0	unused	SC	ST	phi	pT
Track 11	0	unused	SC	ST	phi	pT

Track 0	0	SLAM z information
Track 1	0	SLAM z information
Track 2	0	SLAM z information
Track 3	0	SLAM z information
Track 4	0	SLAM z information
Track 5	0	SLAM z information
Track 6	0	SLAM z information
Track 7	0	SLAM z information
Track 8	0	SLAM z information
Track 9	0	SLAM z information
Track 10	0	SLAM z information
Track 11	0	SLAM z information

Table 1: Format of the track data received on a single fiber. `pT` describes the track curvature, `phi` is the local azimuthal angle, `ST` is the short-track bit, `SC` indicates stereo confirmation.

the first track data word will be used to indicate the start of an event which will be used to synchronize a FIFO that buffers the input data.

3.1 Data format

The axial and stereo information for a given track will be transmitted in separate words according to the format shown in Table 1.

3.1.1 Azimuthal angle, φ_6

The track finder hardware identifies patterns of hits in the tracking chamber that are consistent with the expected trajectories of charged particles with transverse momentum greater than approximately 1.5 GeV/c. Tracks are identified in 288 separate azimuthal regions at the radius of the 6th superlayer of the trackign chamber. The global φ_6 of a track is determined by which fiber the track data is received, with 12 tracks transmitted per fiber in increasing ϕ_6 order.

Bits 8..10 of the axial track data words contain the local azimuthal position of the track within the 1.25° region φ_6. The absolute azimuthal angle of the track is then determined from the fiber number, i, the word index, j, and the three bits of local φ, p:

$$\varphi_6 = i \cdot (15^\circ) + j \cdot (1.25^\circ) + p \cdot (1.25^\circ/8). \quad (1)$$

3.1.2 Short tracks

Bit 11 will be 0 if the track was identified in all four axial superlayers of the tracking chamber. Tracks that exit the chamber at large polar angles can be identified with data from only three out of the four superlayers and will have the short track bit set to 1.

3.1.3 SLAM confirmation

The presence of tracks found by the axial track trigger system is confirmed by the presence of hits in the stereo superlayers. Bit 11 will be set to 1 for confirmed tracks, and will be zero otherwise.

3.1.4 Curvature (p_T)

Bits 0..6 contain the track curvature information. The value `0x7c` is used to represent a 1.25° region in which no track was found. Not all of the remaining possible values correspond to valid tracks. Since we will not analyse short tracks, the mapping of these values to the transverse momentum is only described for those tracks that have hits in four axial superlayers. Valid 4-layer track curvatures are stored as a 6-bit integers, with the mapping to transverse momentum for positive and negative tracks shown in Table 2. In this table, negatively charged tracks are indicated by negative values of p_T.

3.1.5 Azimuthal angle at the origin

The azimuthal angle φ_6 is measured at the radius of the 6th superlayer of the tracking chamber. The azimuthal angle at the origin is calculated as follows:

$$\begin{aligned} \varphi_0 &= \varphi_6 - \Delta\varphi \\ \Delta\varphi &= \arcsin\left(R_6 c / p_T\right) \end{aligned}$$

where $R_6 = 105.575$ cm and $c = 2.115939 \times 10^{-3}$ GeV/cm. Table 2 lists the $\Delta\varphi$ corrections associated with tracks based on their curvature index.

3.1.6 SLAM z-information

The SLAM module with not only confirm the presence of axial tracks using information from the stereo superlayers, but it will also provide some information about the polar angle of the track. This data is transmitted in the second set of 12 words on a given fiber in the same order as the axial track data. Although 15 bits are shown in Table 1, it is likely that fewer bits information will actually be provided. The idea is that the position in z at which a track exits the tracking chamber is divided up into n bins and a bit is set when a track exits the chamber in a given bin. More than one bit could be set for a given track if the exit bin is ambiguous.

Bits 6..0	p_T (GeV)	$\Delta\varphi$ (deg)	Bits 6..0	p_T (GeV)	$\Delta\varphi$ (deg)	Bits 6..0	p_T (GeV)	$\Delta\varphi$ (deg)
0x00	-1.52	-8.45	0x10	-3.04	-4.21	0x20	-6.19	-2.07
0x01	-1.57	-8.18	0x11	-3.14	-4.07	0x21	-6.62	-1.93
0x02	-1.63	-7.88	0x12	-3.25	-3.94	0x22	-7.11	-1.80
0x03	-1.68	-7.64	0x13	-3.37	-3.80	0x23	-7.68	-1.67
0x04	-1.74	-7.38	0x14	-3.49	-3.67	0x24	-8.34	-1.53
0x05	-1.81	-7.09	0x15	-3.62	-3.54	0x25	-9.14	-1.40
0x06	-1.88	-6.82	0x16	-3.76	-3.41	0x26	-10.10	-1.27
0x07	-1.95	-6.58	0x17	-3.92	-3.27	0x27	-12.29	-1.13
0x08	-2.04	-6.29	0x18	-4.09	-3.13	0x28	-12.80	-1.00
0x09	-2.13	-6.02	0x19	-4.26	-3.01	0x29	-14.77	-0.87
0x0a	-2.23	-5.75	0x1a	-4.46	-2.87	0x2a	-17.45	-0.73
0x0b	-2.34	-5.48	0x1b	-4.68	-2.74	0x2b	-21.33	-0.60
0x0c	-2.46	-5.21	0x1c	-4.92	-2.60	0x2c	-27.42	-0.47
0x0d	-2.59	-4.95	0x1d	-5.18	-2.47	0x2d	-38.40	-0.33
0x0e	-2.74	-4.67	0x1e	-5.48	-2.34	0x2e	-64.00	-0.20
0x0f	-2.91	-4.40	0x1f	-5.81	-2.20	0x2f	-192.00	-0.07

Bits 6..0	p_T (GeV)	$\Delta\varphi$ (deg)	Bits 6..0	p_T (GeV)	$\Delta\varphi$ (deg)	Bits 6..0	p_T (GeV)	$\Delta\varphi$ (deg)
0x30	192.00	0.07	0x40	5.81	2.20	0x50	2.91	4.40
0x31	64.00	0.20	0x41	5.48	2.34	0x51	2.74	4.68
0x32	38.40	0.33	0x42	5.18	2.47	0x52	2.59	4.95
0x33	27.42	0.47	0x43	4.92	2.60	0x53	2.46	5.21
0x34	21.33	0.60	0x44	4.68	2.74	0x54	2.34	5.48
0x35	17.45	0.74	0x45	4.46	2.81	0x55	2.23	5.75
0x36	14.77	0.87	0x46	4.26	3.01	0x56	2.13	6.02
0x37	12.80	1.00	0x47	4.09	3.13	0x57	2.04	6.29
0x38	11.29	1.13	0x48	3.92	3.27	0x58	1.95	6.58
0x39	10.10	1.27	0x49	3.76	3.41	0x59	1.88	6.82
0x3a	9.14	1.40	0x4a	3.62	3.54	0x5a	1.81	7.09
0x3b	8.34	1.53	0x4b	3.49	3.67	0x5b	1.74	7.38
0x3c	7.68	1.67	0x4c	3.37	3.80	0x5c	1.68	7.64
0x3d	7.11	1.80	0x4d	3.25	3.94	0x5d	1.63	7.88
0x3e	6.62	1.93	0x4e	3.49	4.08	0x5e	1.57	8.18
0x3f	6.19	2.07	0x4f	3.37	4.21	0x5f	1.52	8.45

Table 2: Table of p_T values corresponding to curvature index in axial track data words.

4 Track Pair Tests

The ϕ-trigger will identify pairs of tracks that have properties consistent with the topology and kinematics of the decay $\phi \to K^+K^-$. The *nominal* set of requirements that has been studied previously is:

- Two axial 4-layer tracks with $1.5 < p_T < 5$ GeV/c
- opposite charge
- confirmed by the presence of track segments in the stereo superlayers
- $2.5^\circ < \Delta\phi_6 < 25^\circ$
- $\Delta\phi_0 < 10^\circ$
- $m_T(\pi^+\pi^-) < 0.3$
- $|\Delta z_7| \lesssim 37$ cm

The constraints on the implementation of these tests in firmware using the Pulsar modules is described in this section.

4.1 Single Track Requirements

Some track data can be elliminated from those that are used to form $\phi \to K^+K^-$ candidates based on the following criteria:

- The data must correspond to a valid axial track: require the 7-bit p_T field to be strictly less than `0x60`.
- The axial track must have been found in four superlayers of the tracking chamber: require that bit 10 (short track bit) is zero.
- The axial track must have been confirmed by the presence of hits in the axial superlayers of the tracking chamber: require that bit 11 (stereo confirmation) is set to 1.
- The magnitude of the transverse momentum must be in the range $1.5 < p_T < 5$ GeV. A relaxed criteria would be simply $p_T < 6.19$ GeV which could be tested by checking bit 5 in the p_T bit field (see Table 2): if bit 5 is clear then $|p_T| < 6.19$ GeV.

4.2 Track Pair Requirements

The following criteria will be imposed on pairs of tracks.

- Opposite charge: the p_T bit-field for one track must be less than or equal to `0x2f` and the p_T bit-field for the other track must be greater than `0x2f`.

- Requirements on $\Delta\varphi_6$: tracks will be received in increasing φ_6 order which simplifies comparisons of relative φ_6. If j_0 and j_1 are the φ_6 indices of the two tracks, determined by their fiber number and word order, then the requirement that $2.5^\circ < \Delta\varphi_6 < 25^\circ$ is equivalent to the requirement that $1 < j_1 - j_0 < 20$ (see Equation 1).

- Requirement on $\Delta\varphi_0$: based on φ_6 and the p_T index of each track, φ_0 can be calculated and their difference will be required to satisfy $|\Delta\varphi_0| < 10^\circ$. Based on the p_T index, a signed 4-bit offset is calculated that is added to φ_6 to determine φ_0 for each track. Then, the signed comparison is performed to determine whether the pair satisfies $|\Delta\varphi_0| < 10^\circ$.

- Longitudinal exit point: both tracks must exit the chamber at the same point in z, identified by the result of a bitwise and of the "SLAM z information" for each track being non-zero.

- Transverse mass: an equivalent criteria can probably be arrived at by requiring that the maximum value of $\Delta\varphi_0$, described above, be a function of the scalar sum of the magnitudes of the transverse momentum of each track. *This has not yet been fully specified, but we expect that the sum of the p_T will address a multiplexer that will provide a 4-bit maximum $\Delta\varphi_0$ requirement.*

5 Global Trigger Logic

5.1 ϕ Multiplicity Trigger

The first exercise will be to identify pairs of tracks that are consistent with $\phi \to K^+K^-$ and output a trigger decision if there is at least one ϕ-candidate found, or if there are at least two *distinct* pairs that were found.

5.2 ϕ+track trigger

We would also like to identify the topology in which a $\phi \to K^+K^-$ is identified within 90° of a third track, which may have a higher momentum threshold requirement. *Still need to specify how this should work and suggest a possible implementation.*

6 Timing Requirements

The track data from one event is received in 396 ns. A trigger output decision is required within 990 ns of the first track word is delivered to the TLK1501 serializer/deserializer chip. Additional latency should be anticipated for the TLK1501 deserialization, alignment of data words common to the same event, and the output of a trigger signal in the correct $132ns$ clock cycle.