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The Beam Shower Counters for Run II

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1 Introduction

This document describes the design and configuration of the Beam Shower Counters (BSC) for Run II. The BSC will detect particles traveling in either direction from the Interaction Point (IP) at very small angles relative to the beam-pipe.
The BSC will be used to study single diffractive (SD) and double-pomeron exchange (DPE) processes, which are characterized by forward rapidity gaps. An almost ideal Rapidity Gap Tagger (RGT) at the trigger level can be implemented with a set of BSC around the beam pipe at several locations along the $\bar{p}$ and p directions covering the pseudorapidity region $5.5 < |\eta| < 7.5$. This RGT will reject most of the non-diffractive and multiple interaction events, while retaining almost all the diffractive events.
In addition to their use in the forward physics program, these detectors can provide a measurement of beam losses from the Tevatron as well as collision rates.
A schematic layout of all the forward detectors is shown in Figure 1. Additional information can be found in Ref. [1, 2]. In the following, we will focus on the description of the BSC and on the electronics for their readout.

2 The Detectors

The proposed RGT can be realized by a BSC system consisting of four stations on the West (see Figure 1) and three on the East side of the IP. The East side (p-direction) is symmetric to the West, except that it has no warm straight section in a location corresponding to that on the West side. Therefore, only three BSC stations can be installed on the East side. All stations are located along the beam-pipe, at increasing distances from the IP as one goes from BSC-1 to BSC-4 (see Figure 1). BSC-1, 2 and 3 consist of two stations each, positioned symmetrically with respect to the IP, whereas BSC-4 consists of a single station on the West side.
Stations are made up of two scintillation counters (see Figure 2), except for the BSC-1 (see Figure 3) stations, which have four counters. The BSC-1 are preceeded by a $3/8''$ thick lead plate to convert γ's. The scintillator material is SCSN-81 for all the counters and has thickness of $1/4''$ for the two BSC-1 stations, and of $3/8''$ for the other five stations. Each counter is viewed by its own PMT: therefore the entire system consists of 18 signal channels, 10 from the West and 8 from the East.
The BSC can detect particles either directly from the interaction region or by the showers produced by these particles by hitting the beam-pipe and/or magnet walls.
BSC 2, 3 and 4 consist of $6'' \times 6''$ scintillator plates with a hole in the center to accommodate the beam pipe. Each of these BSC are made of two halves and are positioned so as to 'hug' the beam pipe.
The two BSC-1's are circular with a $4\frac{3}{4}''$ outer diameter and a $2\frac{3}{4}''$ hole, and are made of four quadrants. These counters will also be used as "beam loss" monitors for the accelerator Beams Division. At the BSC-1 location the beam pipe has a diameter of $2\frac{1}{2}''$, which can comfortably fit into the $2\frac{3}{4}''$ diameter hole of the BSC-1 assemblies. This BSC configuration covers approximately the range $5.5 < |\eta| < 7.5$.

2.1 Photomultiplier Tubes and High Voltage

Beam Shower Counters BSC–2, BSC–3 and BSC–4 use RCA PMTs (Mod. 8575) with a base resistor divider of $\sim 2M\Omega$. The base circuit, shown in Figure 4, draws approximately 0.9 mA at 1800 Volts. The maximum allowed voltage for these PMTs is 2400 Volts.

Beam Shower Counters BSC–1 use Hamamatsu PMTs (Mod. 4125) with a resistor divider of $\sim 6M\Omega$ (~ 0.26 mA at 1500 Volts). The maximum allowed voltage for the Mod. 4125 PMTs is 1800 Volts.
Due to the high current draw of the BSC–2, BSC–3 and BSC–4 base the High Voltage will be supplied to all the PMTs by a CAEN SY527 crate equipped with CAEN modules Mod. A938N. Each A938N module has 24 channels with a maximum current supply of 1.2 mA per channel.
The total number of HV channels for all the forward detectors is 60 (see Table 1). To supply all voltages, three CAEN A938N modules are required. In Table 2 and in Table 3 we list the PMTs and the approximate voltage settings required for equal response to MIPs, for Mod. 8575 and Mod. 4125 PMTs, respectively. These settings were obtained by using a ^{90}Sr source and measuring the pulse height with an oscilloscope.

3 Data Acquisition

The data acquisition crate for the BSC stations resides on the first floor of the B0 building. The signals from the BSC PMTs travel approximately 100 meters to the DAQ crate through RG-58 cables, resulting in a factor of ~ 5 attenuation of their amplitude [1]. The attenuated signal is still large enough for our needs as we can adjust the PMT gain and the trigger thresholds. The 10+8 BSC channels are brought to the DAQ crate and read out by two ADMEM [3] boards. The signals arrive into the ADMEM board about 500 nsec after being generated at the BSC. We propose to map the counters into the ADMEM input channels as shown in Table 4 (see also Figure 5). The ADMEM will provide 7 trigger outputs, one for each BSC station. The seven trigger cables from the two ADMEM boards are directed to two 'patch panels', where the outgoing trigger bits are combined into two trigger cables and sent directly to PreFRED, where we set the two trigger bits (BSC-W and BSC-E). From the PreFRED, the trigger signals go to FRED and then on to the TSI, where the final L1 decision is made.
In order to identify tracks traveling close to the beam-pipe, we use the coincidence of the output signals from the PMTs on each side of the IP. First, we combine the trigger signals from the individual stations in the ADMEM

[1] The attenuation of a signal (100 MHz) through RG58/U cable is 0.135 dB/m.

board, and then we combine the triggers from the BSC stations in the Pre-FRED where we determine the trigger bits for the East and West BSC coincidences (BSC-E and BSC-W).

4 Beam Loss & Collision Rate: Requirements

In addition to the studies for forward physics, we will also monitor collision rates and beam losses at B0. Typically, there will be 36 proton bunches and 36 anti-proton bunches in the Tevatron. We will refer to a "bunch-by-bunch" measurement as the rate given at each crossing by a specific bunch-bunch interaction. "Total rate" is the rate summed over all bunches. Both these measurements are averaged over many bunch crossings.
The Beam Division is interested in beam losses and collision rates (see Tables 5 and 6) at a rate of approximately 1-2 Hz.

5 Beam Loss & Collision Rate: Measurement

The BSC-1 counters will be used to monitor Tevatron beam losses and measure collision rates.
We refer to the signals from BSC-1 as "Out-of-Time" for particles hitting the counters ~ 20 nsec **before** the interaction time (due to beam losses), and as "In-Time" for particles coming from a $p\overline{p}$ interaction and hitting the counters ~ 20 nsec **after** the interaction time (collision rate and diffractive physics measurements). Figure 6 shows a schematic diagram of the electronics and timing of these signals. The signals from BSC–1 [2] go to a transition board of one ADMEM board (labeled "BSC" in Figure 5), which provides one analog and two discriminated outputs. The analog signal goes to the ADMEM board, where it is digitized and used for diffractive physics.
The discriminated outputs [3] are used to measure beam losses and collision

[2] We have determined that after traveling 225 ft through an RG-58 cable, the signals from BSC-1 from a Minimum Ionizing Particle (MIP) have a triangular shape with a width at the base of approximately 10 nsec.

[3] We use a modified version of the CLC transition board which provides ECL output signals through discriminators with a *Time–over–threshold* output. This scheme ensures short ($\approx$10 nsec) output pulses.

rates. They are directed through a second transition board [4] to a Tevatron-dedicated 6U VME crate for "Beam Loss" and "Collision Rate" measurements (see Figure 7 and Figure 8). For timing purposes, the earlier signal due to beam losses is delayed by about 40 nsec. A Dual Port Memory (LeCroy Mod. 1190) receives the information serially and sends it to the crate controller (Motorola, MVME–2301), which determines collision rates and beam losses (see Figure 9) both as a "total rate" and on a bunch-by-bunch basis.

6 Cables and Signals

The signals from the BSC and from the RPS detectors must be timed so that they arrive together at an ADMEM module, since the analog-to-digital conversion is simultaneous for all channels of a module. Table 7 lists the Time-of-Flight (in nsec) from the IP for a particle to arrive at the location of the detector in question, the lengths (in ft) of the signal cables that are needed in order to synchronize the signals, and the number and type of the cable.
Table 8 lists the cable lengths and characteristics of all the high voltage and signal cables. The HV power supply crate (1RR06C) as well as the VME crate (1RR27E) for the signal read-out are located in the first floor. In order to provide a ground loop interruption, the HV cable ground is connected to the PMT signal ground through a 1 kΩ resistor.

7 Conclusions

We present an outline of the Beam Shower Counters as installed and instrumented for Run II. In addition to the studies of hard diffraction and very forward physics, the BSC will also provide beam loss and collision rate measurements.

8 Acknowledgments

We would like to thank Mike Lindgren for his precious suggestions and help in many circumstances, Gary Drake and Charlie Nelson for their insights and

[4] This is a *standard* CLC transition board.

help with their invaluable knowledge of the readout electronics, and Steve Hahn for many discussions which helped understanding the detector and its subtleties. We are indebted to the CLC group for accomodating the forward detector electronics in the CLC crate, and for many discussions which helped finalize the readout.

References

[1] "Further Studies in Hard Diffraction and Very Forward Physics", CDF Notes 4591, 5138 and 5248 and references therein;

[2] http://rock16.rockefeller.edu/~michgall/fd/forward_detectors.html

[3] Specification for ADC/Memory Module (ADMEM) – Dec. 1998; see http://www–ppd.fnal.gov/ett_www/CDF_docs/Admem.htm .

Detector	Channels	Voltage (V)	Current (mA)
MP (inner)	12	700	0.8
MP (outer)	24	700	0.2
BSC1	8	1500	0.3
BSC2, BSC3, BSC4	10	1800	0.9
RPS (Trigger)	3	1500	0.4
RPS (MCPMT)	3	2000	0.5

Table 1: High Voltage channels of forward detectors (total of 60). MP=MiniPlug, RPS=Roman Pot Spectrometer.

Detector	List No.	Serial No.	Volts	Comments
BSC2W–1	47	C11772	1630	to Moscow (Nov.99)
BSC2W–2	50	C09808	1650	to FNAL (Jan. 00)
BSC3W–1	19	C09286	1560	to FNAL (Jan. 00)
BSC3W–2	39	J47920	1560	to Moscow (Nov.99)
BSC4W–1	49	J38038	1680	to FNAL (Jan. 00)
BSC4W–2	48	C09178	1680	to FNAL (Jan. 00)
BSC2E–1	6	P52121	1640	to FNAL (Jan. 00)
BSC2E–2	38	H40430	1650	to FNAL (Jan. 00)
BSC3E–1	43	C11777	1760	to FNAL (Jan. 00)
BSC3E–2	33	C09810	1660	to FNAL (Jan. 00)
N/A	7	U12378	1420	
N/A	18	U02492	1480	to FNAL (Jan. 00)
N/A	20	C07262	2020	to FNAL (Jan. 00)
N/A	23	N/A (glass bottom)	2080	to FNAL (Jan. 00)
N/A	25	C09285	2030	
N/A	46	V53845	1700	to FNAL (Jan. 00)

Table 2: Comparative tests of RCA, Mod. 8575 PMTs. The table gives the voltage settings for a -30 mV peak signal (at similar rate), when the trigger threshold is set at –20 mV.

Detector	Number	Serial No.	Volts	Comments
BSC1W–1	BSC1-02	CX2985	1640	to FNAL (Jan. 00)
BSC1W–2	BSC1-01	ZA7176	1400	to FNAL (Jan. 00)
BSC1W–3	BSC1-03	ZA7183	1400	to FNAL (Jan. 00)
BSC1W–4	BSC1-04	ZA8103	1350	to FNAL (Jan. 00)
BSC1E–1	BSC1-05	ZA7764	1300	to FNAL (Jan. 00)
BSC1E–2	BSC1-06	ZA7195	1470	to FNAL (Jan. 00)
BSC1E–3	BSC1-08	ZA8102	1400	to FNAL (Jan. 00)
BSC1E–4	BSC1-07	ZA7175	1530	to FNAL (Jan. 00)
N/A	BSC1-09	CX3189	1540	
N/A	BSC1-10	CX2967	1540	
N/A	BSC1-11	ZA7767	1240	
N/A	BSC1-12	ZA8105	1300	

Table 3: Comparative test of the Hamamatsu Mod. R4125 PMTs. For the updated operating voltage settings of these counters see Ref. [2].

	BSC Station	ADMEM Input Channel	ADMEM Trigger Output
ADMEM 1	BSC–1 East	0–3	0
	BSC–1 West	4–7	1
	BSC–2 East	8–9	2
	BSC–2 West	12–13	3
ADMEM 2	BSC–3 East	0–1	0
	BSC–3 West	4–5	1
	BSC–4 West	8-9	2
	RPS	12-14	3

Table 4: Mapping of the signals from the BSC stations and from the Roman Pot Spectrometer (RPS) trigger counters into two ADMEM boards, and the corresponding output trigger signals. The seven BSC and one RPS trigger outputs are directed to a PreFRED board.

Index	Bunch Crossing
0	Sum
1	P1×A25
2	P2×A26
3	P3×A27
4	P4×A28
5	P5×A29
6	P6×A30
7	P7×A31
8	P8×A32
9	P9×A33
10	P10×A34
11	P11×A35
12	P12×A36
13	P13×A1
14	P14×A2
15	P15×A3
16	P16×A4
17	P17×A5
18	P18×A6
19	P19×A7
20	P20×A8
21	P21×A9
22	P22×A10
23	P23×A11
24	P24×A12
25	P25×A13
26	P26×A14
27	P27×A15
28	P28×A16
29	P29×A17
30	P30×A18
31	P31×A19
32	P32×A20
33	P33×A21
34	P34×A22
35	P35×A23
36	P36×A24

Table 5: Numbering of bunch crossings for collision rate measurements. There are 36 proton (P) bunches and 36 anti-proton (A) bunches.

Index	Proton Bunch	Anti-proton Bunch
0	Sum	Sum
1	P1	A1
2	P2	A2
3	P3	A3
4	P4	A4
5	P5	A5
6	P6	A6
7	P7	A7
8	P8	A8
...	...	...
36	P36	A36

Table 6: Numbering of bunch crossings for beam loss measurements.

Detector Channel	Distance (m)	ToF (nsec)	Cable to FE crate (ft)	Type
BSC–1 (E and W)	6.4	21	225	RG–58
BSC–2 (E and W)	23.2	77	190	RG–58
BSC–3 (E and W)	31.6	105	375	RG–58
BSC–4 (W only)	56.4	185	320	RG–58
RP1,RP2,RP3	57	188	315	RG–58

Table 7: Length of the signal cables (RG–58) required for the various detectors to reach the front-end VME crate. The crate is located in the first floor of the B0 building. Distance and Time of Flight (ToF) are from the Interaction Point to the location of the counters. The attenuation of a signal (100 MHz) through RG58/U cable is 0.135 dB/m. For a cable of 100 meters, the attenuation is 13.5 dB, or a factor of ~ 5.

Loc. 1	Location 2	Conn.1/Conn.2	Qty	Length (ft)	Cable Type
1RR06C	BSC-1/MP (West/6.4 m)	SHV/SHV	26	140	RG-58 Red
1RR06C	BSC-2 (West/23.2 m)	SHV/SHV	2	145	RG-58 Red
1RR06C	BSC-3 (West/31.6 m)	SHV/SHV	3	180	RG-58 Red
1RR06C	BSC-4 (West/56.4 m)	SHV/SHV	2	260	RG-58 Red
1RR06C	RPots (West/57 m)	SHV/SHV	7	270	RG-58 Red
1RR06C	BSC-1/MP (East/6.4 m)	SHV/SHV	26	205	RG-58 Red
1RR06C	BSC-2 (East/23.2 m)	SHV/SHV	2	210	RG-58 Red
1RR06C	BSC-3 (East/31.6 m)	SHV/SHV	3	245	RG-58 Red
1RR27E	MP (W-E/6.4 m)	Amphenol/Lemo	40	180	RG-58 Green
1RR27E	BSC-1 (W-E/6.4 m)	Amphenol/Lemo	12	225	RG-58 Green
1RR27E	BSC-2 (W-E/23.2 m)	Amphenol/BNC	6	190	RG-58 Green
1RR27E	BSC-3 (W-E/31.6 m)	Amphenol/BNC	6	372	RG-58 Green
1RR27E	BSC-4 (West/56.4 m)	Amphenol/BNC	3	320	RG-58 Green
1RR27E	RPots (West/57 m)	Amphenol/Lemo	6	315	RG-58 Green
CH(West)	6U/Tunnel (West/57 m)	10168-6000EC(3M)	1	150	Mod. 3644B/68 (by 3M)
CH(West)	6U/Tunnel (West/57 m)	10126-6000EC(3M)	6	150	Mod. 90101/26 (by 3M)
1RR27E	2nd floor (L1 crate)	FCN-235D020-G/E (by Fujitsu)	2	65	L1 Trigger
1RR18D	2nd floor (L1 crate)	FCN-235D020-G/E (by Fujitsu)	3	65	L1 Trigger

Table 8: Length and number of the signal (RG–58 Green) and High Voltage (RG–58 Red) cables required for the forward detectors. Crate location: (1) VME crate (1RR27E and 1RR18D) and HV crate (1RR06C) on 1st floor, (2) VME crate on West Side of Collision Hall (CH). Connectors: (1) Lemo: Kings 1075–2; (2) Amphenol: Mod. 901-9870; (3) BNC: Kings KC 59–500; (4) SHV: Kings 1705–2

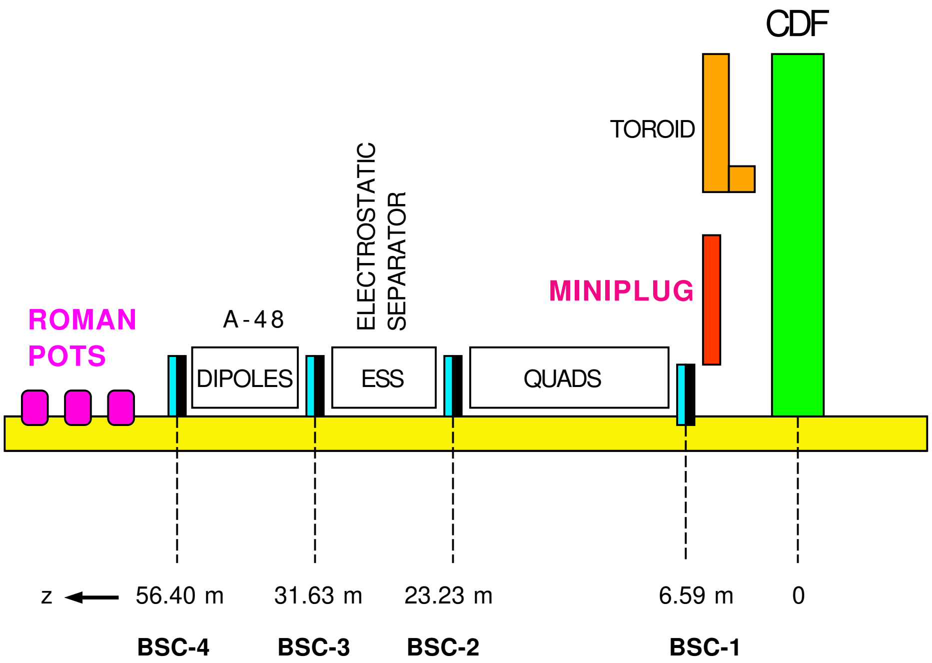

Figure 1: Location of the forward detectors along the $\bar{p}$ direction on the west side of the CDF central detector (not to scale). On the east side, only the first three BSC stations will be installed, as there is no room for BSC-4.

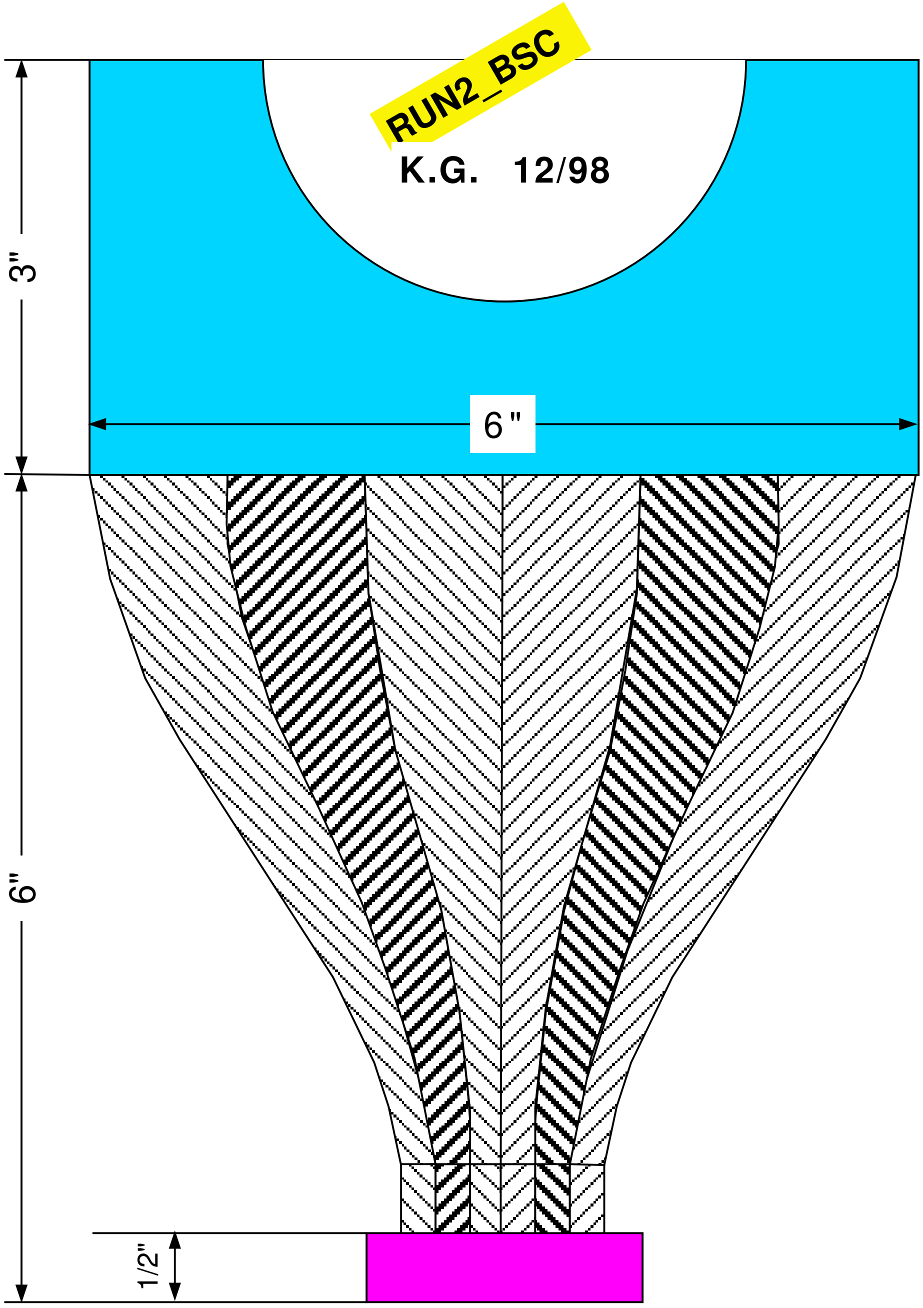

Figure 2: Schematic drawing of one half of the beam shower counters BSC–2, BSC–3, BSC–4.

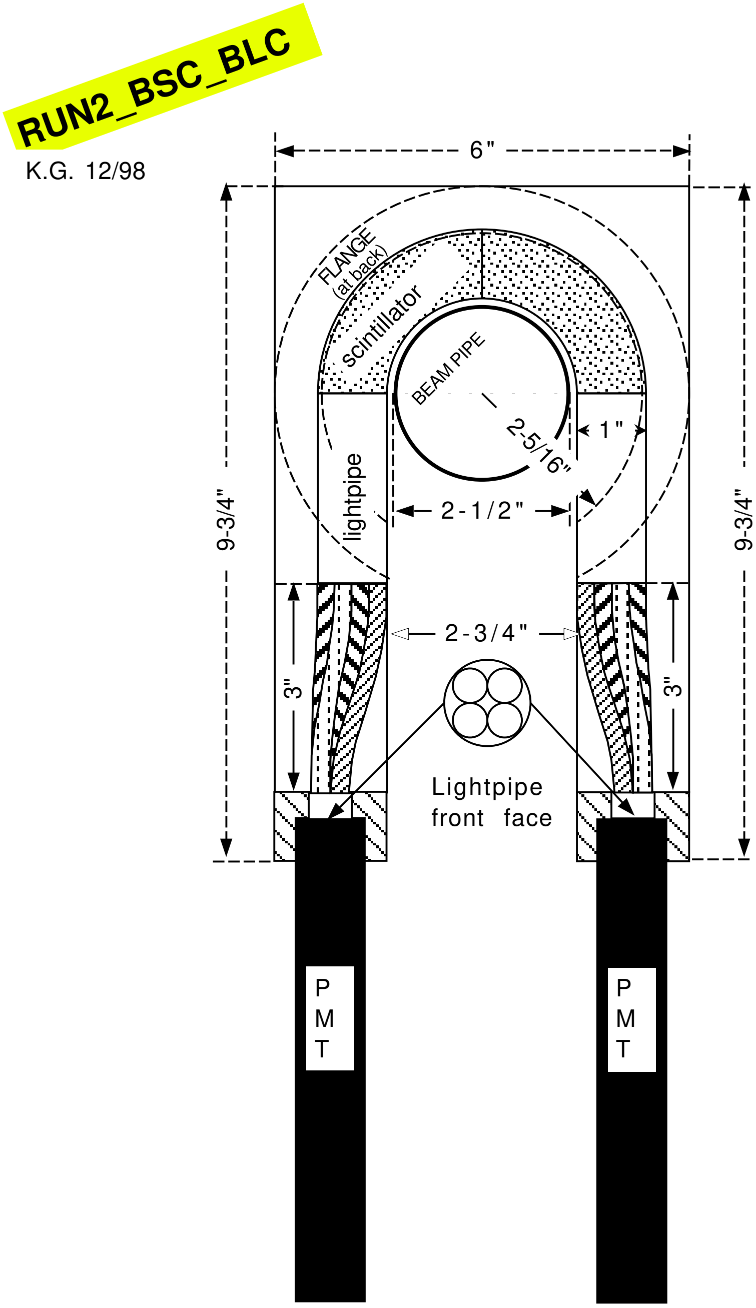

Figure 3: Schematic drawing of one half of the beam shower counters BSC–1.

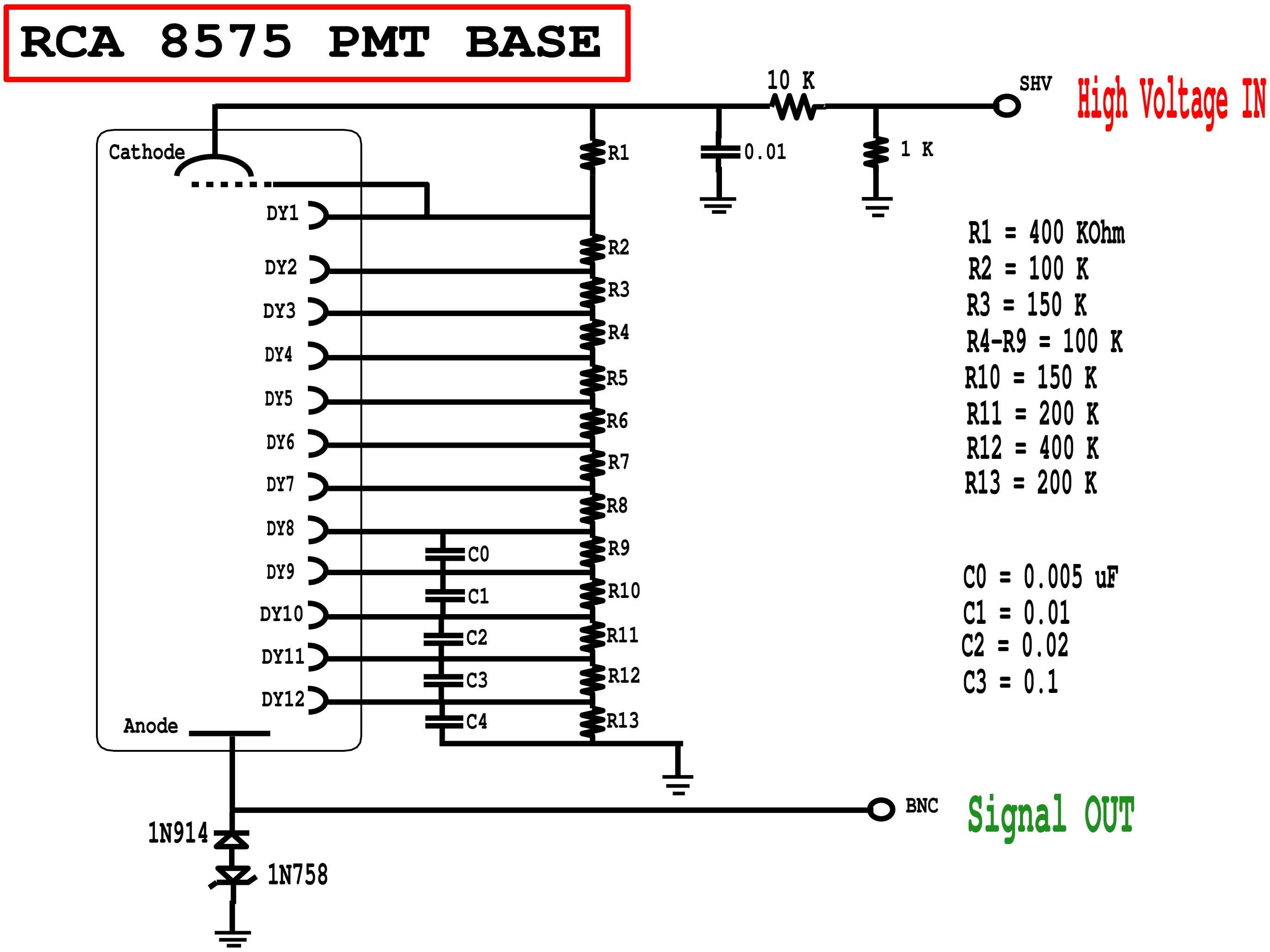

Figure 4: Schematic drawing of the RCA 8575 PMT base used for BSC-2, BSC-3 and BSC-4.

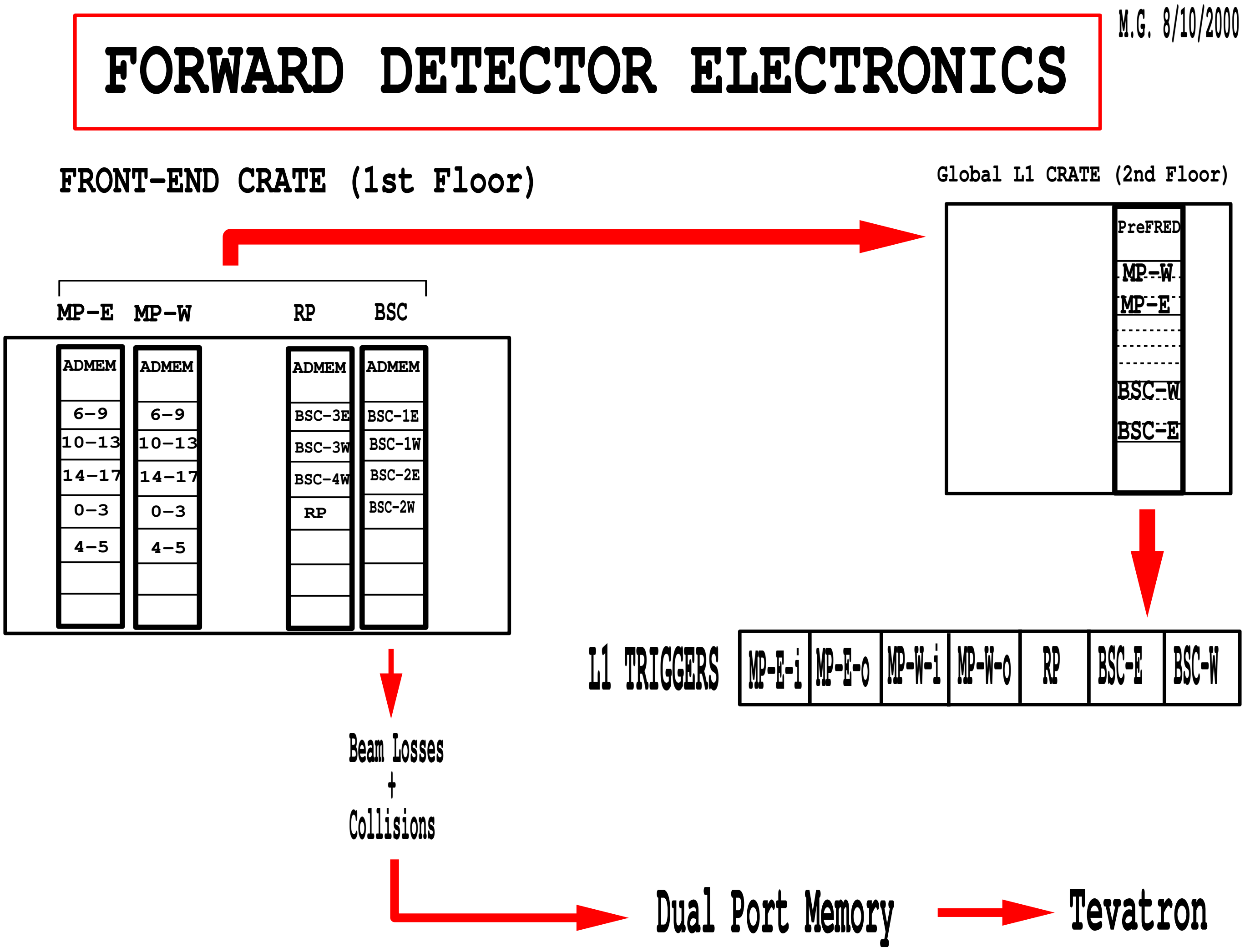

Figure 5: Forward detector electronics layout indicating the signal flow and the modules, channels and trigger outputs employed.

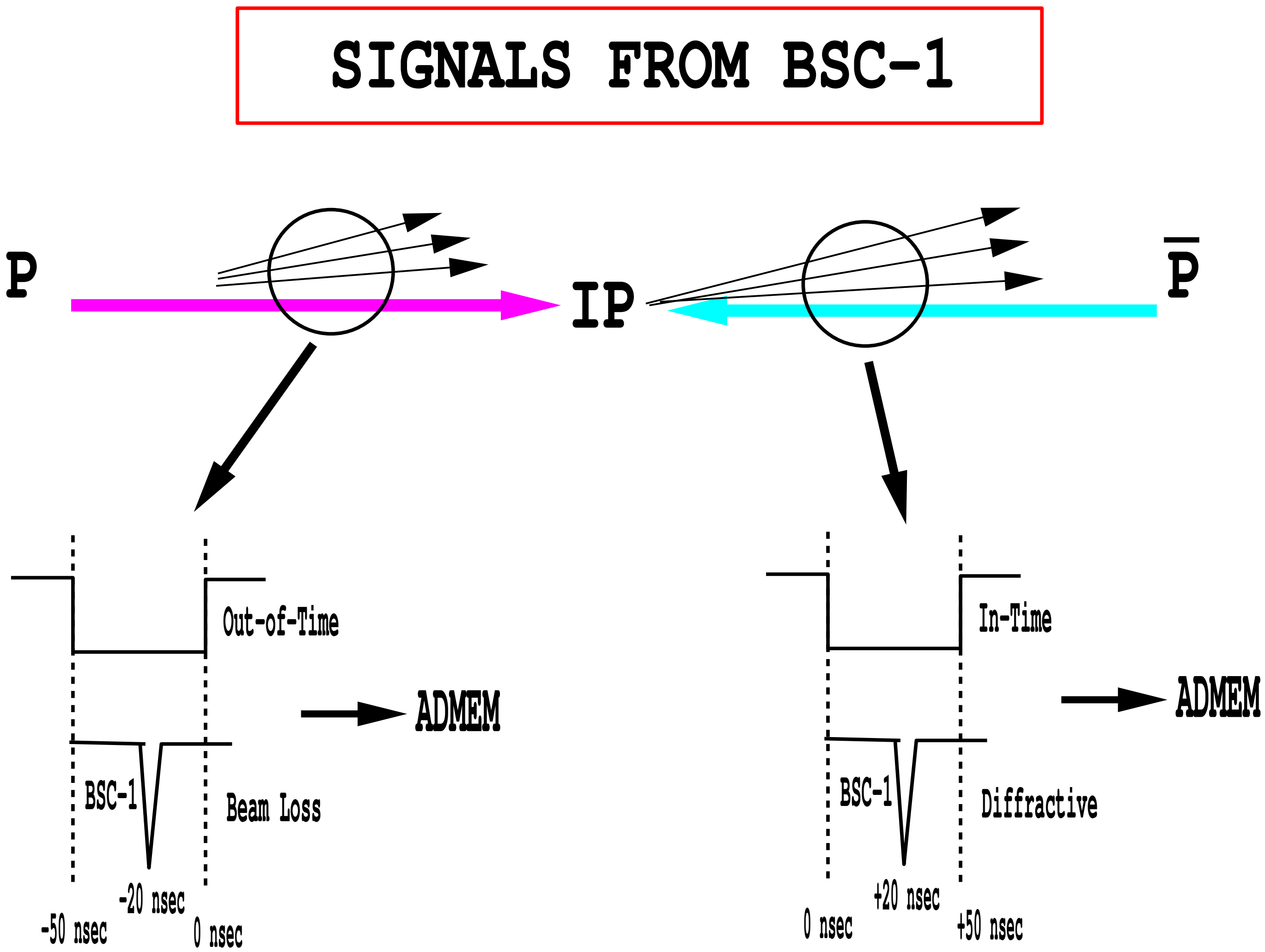

Figure 6: Beam losses are measured by properly selecting a gate ("Out–of–Time") for signals arriving before the interaction time; for collision rates and diffractive triggers an "In–Time" gate is selected.

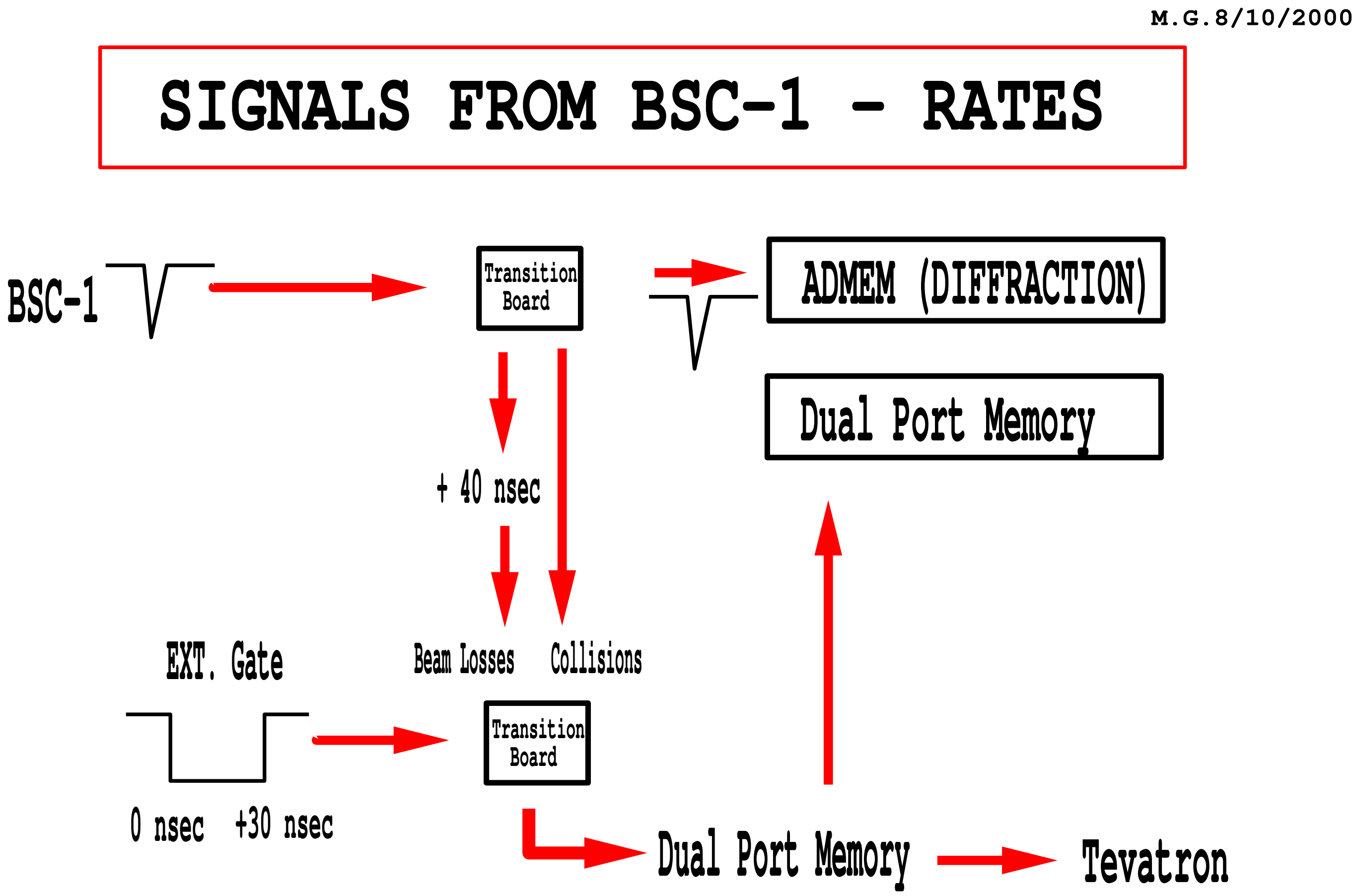

Figure 7: Signals from BSC–1 are directed to a transition board, which provides one analog and two discriminated outputs. The analog output is directed to an ADMEM module and is used for the diffractive trigger. The discriminator outputs are sent to a second transition board for monitoring beam losses (BLM) and collision rates (BCM). The signal to measure beam losses is delayed by 40 nsec, and gated with the "In–Time" clock.

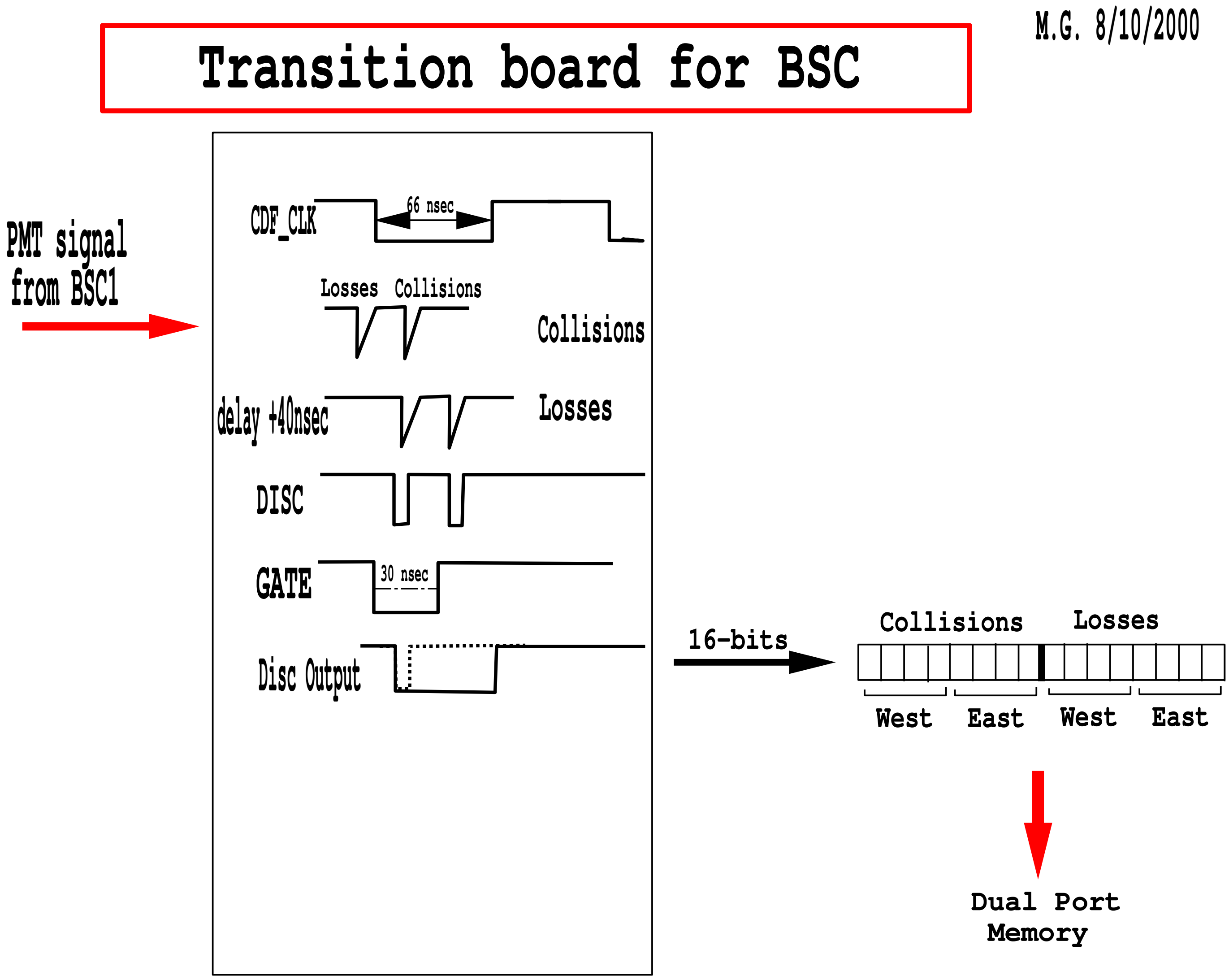

Figure 8: Schematic functioning of the transition boards for measuring beam losses and collision rates. The signal to measure beam losses is delayed by 40 nsec. Both signals discriminated and then 'gated' with the "In–Time" bunch crossing gate. A 16-bit output is sent to the Dual Port Memory.

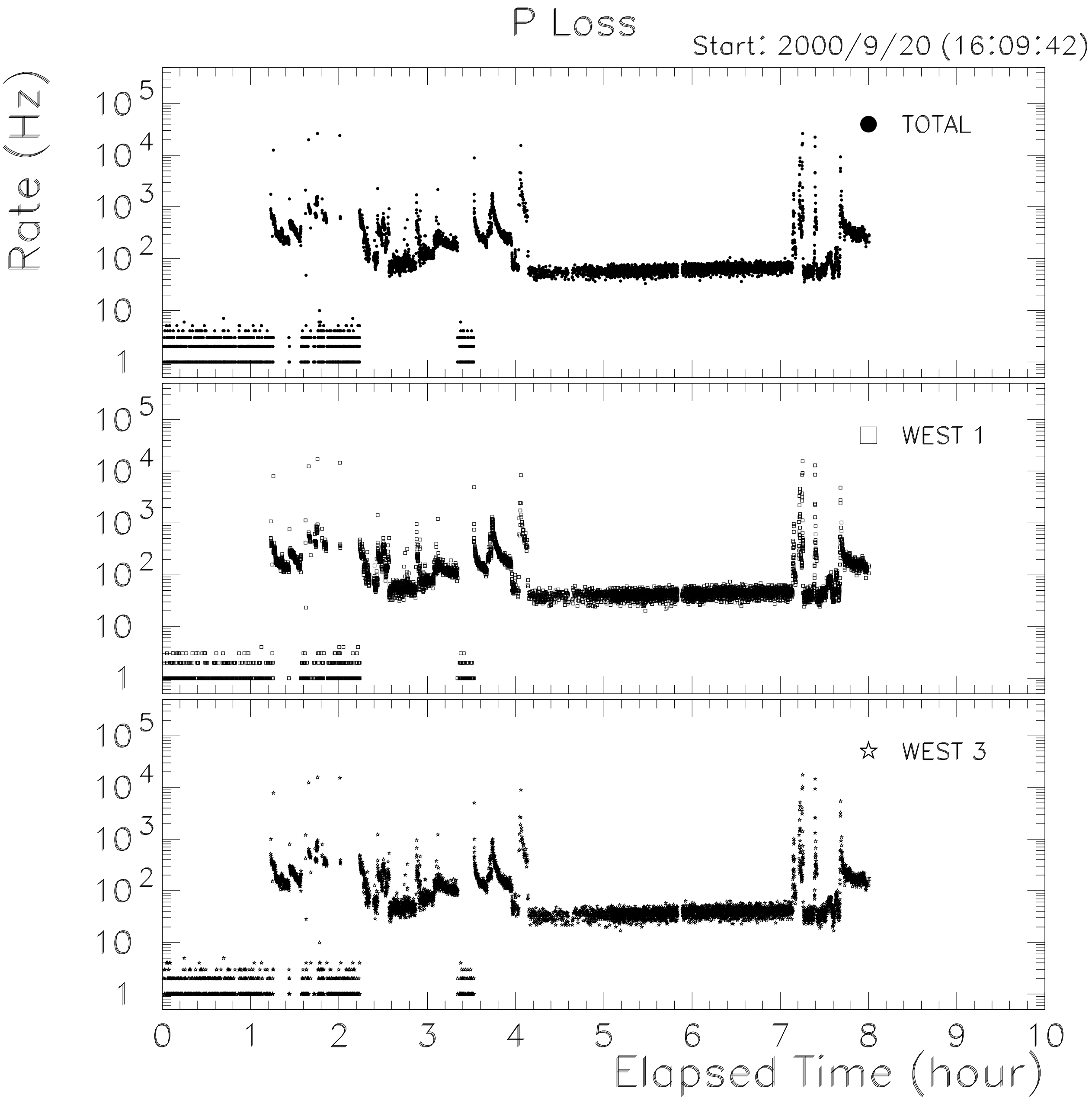

Figure 9: Rates of Beam Shower Counters BSC-1 (counters #1 and #3 West) during a proton store in September 2000.