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Comparison of Trigger and Data Acquisition Parameters for Future B Physics Experiments

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Abstract

A summary is given of the trigger and data acquisition parameters for a variety of proposed future B physics experiments at hadron accelerators.

Contribution to the Proceedings of the Workshop on B Physics at Hadron Accelerators, Snowmass, Colorado, June 21-July 2, 1993.

INTRODUCTION

The main task of the Trigger and Data Acquisition Working Group was to collect the global parameters of the Trigger/DA schemes envisaged by various approaches to future hadronic B physics, and to perform a zeroth order comparison of the overall performances. A few general comments are in order before presenting the detailed tables:

1- The numbers are presented as provided to the working group by representatives of the various collaborations. Due to the limited time, no in depth attempt was made to verify the validity of the quoted performance figures, nor to examine the technical implications and feasibility of any given scheme.

2- The level of reliability for the performance figures reported in the tables covers a wide range, due to the large variation in the procedures followed to derive the actual numbers. In order of decreasing reliability, sources of estimates were:

- extrapolations from data
- full detector and trigger simulation (with or without support from data)
- event generation (e.g. Pythia) plus smearing to simulate detector response
- educated guess
- performance goal, rather than actual projection

3- The exchange of ideas and information among workers with different backgrounds and experience was very constructive. As a result of the discussion some pre-conceptions were removed, triggering schemes and ideas were sharpened and the overall picture of triggering on B's in a high rate environment became clearer.

PERFORMANCE TABLES

The condensed picture of all the data that became available at the workshop is presented in Table 1. In spite of the large quantity of numbers appearing in the table, an even cursory examination of it allows us to identify some common trends and to make some general comments.

Starting from the top, the first well recognized fact is that all detectors, including the ones like SDC, GEM and ATLAS which were not designed having B physics in mind, are capable of addressing B -> J/ψ channels, by triggering on di-muons and possibly di-electrons. Even so, there are large differences in efficiency for the B-> J/ψ channels when going from collider to fixed target environments. These differences are due to the increased discriminating power of a lepton p_T cut in the fixed target mode because the transverse momenta characteristics of B decay products, typically around one or two GeV/c, are large compared to minimum bias interactions at fixed target energies, while the same is not true for collider energies. On the other hand, the B cross-sections are much larger at collider energies.

While everyone appears to be capable of developing a viable J/ψ trigger, the situation changes drastically for the other channels of interest (following the workshop's theme, one representative reaction for each of the unitarity angles, plus a generic b trigger addressing "all other B physics", were included in Table 1). As shown in the Table, only a few of the dedicated B detectors present capabilities for non-J/ψ modes or for an inclusive B trigger (it should be noted that, for the purpose of this document, CDF III and D0 III are being considered as dedicated B detectors since they represent the best effort of the collaborations to upgrade their detectors in order to address B physics). It is interesting to examine the similarities in the approaches of different detectors to the trigger sequence: effectively every setup plans for a Level 1 trigger based upon lepton and/or hadron p_T, with a notable difference for GÅJET that proposes the intriguing idea of impact parameter optical trigger. At Level 2, all the entries, with the exception of the high p_T non B-specific detectors, include the implementation of a multiple vertex and/or impact parameter trigger. All detectors also envisage a last level of selection performed in a Level 3 Processor Farm, although it should be noted that the Level 3 rejection factors reported in the Table are generally derived from the two sources of lowest reliability (i.e. educated guesses or simply design goals). Some special remark should also be made about the BCD approach. The BCD basic strategy is to require a 10^2 suppression at Level 1, no Level 2 and a further factor of 100 at Level 3. By their own admission, the BCD performance parameters provided by the proponents are design goals rather than simulation results. Moreover the realism of the goals - a 10^2 rejection at Level 1 with a modest 1 GeV/c p_T cut or a Level 3 accepting 10^6 events (= 500 Gbytes) per second - has been questioned. On the other side one should recognize the soundness of the basic philosophy of the BCD approach, stating that since B production at the SSC in collider mode represents 1% of the total cross-section it is wise to develop a trigger that is as loose as possible at the lower levels while trying to defer the selection to when the events can be fully analyzed.

Going back to the table entries, the brief descriptions of trigger choices also contain the rules for developing a generic B trigger; the two main approaches are:

1- presence of one (or more) high p_T lepton (possibly reinforced by a high p_T hadron) plus some sort of vertex/impact parameter trigger.

2- presence of several (two or more) high p_T hadrons, again combined with an indication of secondary vertices activity. The values of p_T threshold can be optimized to get the best acceptance for, e.g., the B -> $\pi\pi$ decay mode.

It is obvious that both of these approaches can be developed and run in parallel and in fact they end up providing similar acceptances for an inclusive B trigger , since the loss due to the semi-leptonic Branching Ratio in the first approach is offset by the need to impose higher p_T thresholds when a lepton is not present.

A few words about rates: rather than comparing luminosities, possibly a misleading quantity when comparing beam beam collisions with beam impinging on a heavy target, a better indication of how hard the detectors (and front end electronics) need to work is given by the list of Interaction Rates and Input Rates to Level 1. An Interaction Rate larger than the corresponding L1 Input Rate indicates a regime of more than one interaction per crossing (or per beam bucket on target), the ratio between the two giving the average number of interactions per crossing.

A more detailed discussion and comparison of the different strategies and their hardware implementations would be quite interesting, but goes far beyond the scope of the present document. It is worthwhile, nevertheless, to get a feeling for the relative complexity of the hardware by looking at the product, either at Level 1 or 2, of the Input Rate by the Latency. We have indicated in bold characters the cases where such a product exceeds 100% system occupancy, forcing therefore the need for pipelined and/or parallel processing, a fairly straightforward requirement at Level 1, but typically a rather complicated (and/or costly) proposition at Level 2. A few more comments can be made about some general features.

Concerning the performance requested from Level 1, one notices a very wide spread of values, ranging from a reduction of minimum bias of a factor 7 for COBEX up to 6000 for SDC and GEM. Much less spread is observed at Level 2 (ranging from 10 to 100), and even less at Level 3, where all detectors settle for rejections between 5 and 10 (with the exception of BCD). Combining all levels together, all detectors end up achieving global rejections contained in the relatively narrow range of 10^4 to 10^5, except for ATLAS (4 10^5) and COBEX, which envisages a global rejection of

10^3. This rather modest rejection, obviously chosen to minimize the loss of B events (first rule of triggering: there is no free lunch, any attempt to reject background will also entail a loss of signal), does not come without technical complications since it requires that data be logged at the rather ambitious rate of 300 Mbytes/sec (3 times higher than SDC but still lower than BCD).

Another important issue is whether the performances required by the various detectors represent a major jump with respect to what is being done routinely today. For this purpose we have collected (Table 2) the parameters relative to the best representatives of today's hadronic B physics: CDF, the most fertile producer of B hadro-production results to-date, and two examples of fixed target experiments, FNAL E771/P867, heavily based upon B-specific triggers, and E791, more of a charm than a B experiment, relying on the technique of an open trigger. The comparison between today and tomorrow is contained in Table 3, showing the growth of the most critical parameters going from CDF I to CDF III and from E771 to the SFT. While one can observe expected growths of fairly large factors in most entries, all of the extrapolations are rather reasonable, especially when the requirements of the B experiments are compared to the SSC high p_T detectors. The increase in the trigger efficiency for B->J/ψ modes needs some commenting; for CDF, a factor of 10 increase is achieved by increasing the acceptance of the microvertex detector and lowering the lepton trigger p_T threshold, while in the fixed target mode most of the gain comes from the increase in geometric acceptance typical of the SSC vs Tevatron environment for equal solid angle coverage. The Table shows how both Level 2 and 3 triggers will need to work at a much higher level of performance, which is nevertheless quite compatible even with today's technology. Finally, the projected increase in logging rates and data set volume ends up being within a factor of four of what has already been achieved by E791 (see Table 2).

FINAL COMPARISONS AND CONCLUSIONS

The major purpose of any triggering scheme is to maximize the number of signal events recorded on tape, while minimizing the background. From the information contained in Table 1 we have extracted and compiled the rates of B production vs. the rate at which B events are expected to be logged onto tape. Table 4 shows how, in spite of the large differences in B production rates, spanning over three orders of magnitude (or more than four if HERA-B is included) the logging rates for B events are contained within one order of magnitude (or two including HERA-B). This is a consequence of the by now well recognized effect of the larger acceptance and better triggerability of fixed target detectors, which start up with a disadvantage in terms of B cross-section

In conclusion, we have seen that dedicated B detectors are able to address at the trigger level the whole spectrum of B decays, as opposed to just collecting $B \rightarrow J/\psi$ events and that the appropriate trigger strategy is a combination of high p_T leptons, high p_T hadrons and vertex/impact parameter triggers. The performance required of the trigger/DA systems appears to be, with some possible exceptions, well within today's technology , or at most a mild extrapolation of it. Dedicated detectors should be able to log inclusive B events at the rate of up to a few hundred per second, or for rare decays of the type e.g. $B \rightarrow \pi\pi$, of a few tens per hour.

REFERENCES

The sources of information exploited to fill the summary tables were the following:

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D0 : R. Lipton, FNAL
SDC : J. Dorenbosch, SSCL
GEM : J. Dorenbosch, SSCL
BCD : K. MacDonald, Princeton University
COBEX : NIM A 333, 101, 1993
HERA-B : W. Hofmann and T. Lohse, Heidelberg Univ.
SFT: S. Conetti, University of Virginia
GAJET : S. Loucatos, Saclay
ATLAS : P. Eerola, CERN
LHB : F. Ferroni, Rome and S. Loucatos, Saclay
E771/P867: S. Conetti, University of Virginia
E791: M. Halling, FNAL and D. Summers, University of Mississippi

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Table 1: TRIGGER, DATA ACQUISITION, AND COMPUTING SUMMARY FOR FUTURE EXPERIMENTS

	CDF III	D0 III	SDC	GEM	BCD FULL	COBEX -LHC	HERA-B	SFT	GAJET	ATLAS	LHB
Trigger Eff: ΨK_S	2.5%† ee,$\mu\mu$	8% $\mu\mu$	0.1% ee,$\mu\mu$	0.1% ee,$\mu\mu$	14% ee,$\mu\mu$?	12% $\mu\mu$	40-50% ee,$\mu\mu$	56% ee,$\mu\mu$	24% ee,$\mu\mu$	?	32% ee, $\mu\mu$ or μ
$\pi\pi$	>4%	?	?	?	>2%	0.75%	?	45%	24%	0.3%	62% ?
$D_S K^-$	2%	?	?	?	>2%	?	?	40%	13%	?	?
Inclusive b	>0.5%	1.6%	?	?	>2%	?	?	≥20%	?	?	?
Luminosity	10^{32}	10^{32}	10^{33}	10^{33}	10^{32}	10^{32}	4.10^{33}	10^{33}	2.10^{33}	10^{33}	10^{33}
Int. Rate (MHz)	5	5	100	100	10	7	40	10	70	60	10
bbar per interaction	10^{-3}	10^{-3}	10^{-2}	10^{-2}	10^{-2}	7.10^{-3}	10^{-6}	$1.6.10^{-4}$	3.10^{-5}	10^{-2}	10^{-4}
Million Det. Channels	0.6	1	4 ?	?	2	0.6	0.5	0.65	1	10	1.2
L1	Pt had e,μ	μ 2μ	Pt had e,μ	Pt had e,μ	Pt e μ vertx	μ	2 lept mass	Pt had e,μ	Optl Pt Imp Si	Pt μ	SumEt Pt had e,μ
Latency (μs)	4	?	4	2	2	?	10	1	0.02(1)	2	0.2
Input (MHz)	2.5	2.5	60	60	10	7	10	10	40	40	10
Output (KHz)	100	10	10-100	10-100	N.A.	1000	10	50	400	100	100
L2	imp lept id mass photon	μ vertx	lept-id mass	lept-id mass	N.A.	μ Pt imp	lept id trk imp	vertx	Pt imp vertx ?	Trk Pt ee $\mu\mu$	Pt 2 had imp
Latency (μs)	20	?	10-50	2.10^5	N.A.	?	**1000**	10	**10-20**	**1000**	20
Output (KHz)	<1	0.5	1	1	100	30	1	5	3	1	5
L3 FARM (MIPS)	< 10^5	?	?	2.10^5	10^6	?	10^4	?	?	?	10^5
Output (Hz)	< 100	< 100	100	100	1000	5000	100	1000	300	<100	<500
OFFLINE Evnt Size (Kb)	< 220	190	1000	400	500	60	50	20	50	200	50
Raw Data-Set Size /yr (Tb)	< 220	< 190	1000	400	5000	3000	50	200	150	200 ?	250
CPU (MIPS)	< 70K	?	100K	400K?	2.10^6	?	10K	20K	?	?	10K
Rec. Data-Set Size/yr (Tb)	< 320	?	2000	200	5000	?	< 50	?	?	?	?

† 4% for $\mu\mu$ if CDF can trigger $\mu\mu$ up to $\eta = 3$.

Table 2: TRIGGER, DATA ACQUISITION, AND COMPUTING SUMMARY FOR EXISTING EXPERIMENTS

	CDF Ia	E771/P867	E791
b - modes and Trigger Efficiencies	ψK_S (0.3%; $\psi \to \mu\mu$,) B -> ψX (1%; $\psi \to \mu\mu$) B -> Xlν (0.05%)	B -> ψX (6% / 16%; $\psi \to \mu\mu$) B -> μX (4.5% / 13%)	ccbar (40%)
Interaction Rate (KHz)	300	3000 / 5000	40
bbar per interaction	10^{-3}	10^{-6}	10^{-6}
Detector Channels	80K	50K	24K
L0	N.A.	interaction in target	interaction
Input Rate (KHz)	N.A.	53000	530000
Output Rate (KHz)	300	3000 / 5000	40
L1	2μ, Pt >1.5 lept Pt >6	2μ, 1μ, Pt >0.8	Loose Et
Latency (ms)	3.5	0.6	
Output Rate (KHz)	2	N.N./1.5	20
L2	μ Trk match Pt	N.A. / vertex	N.A.
Latency (ms)	20	5	N.A.
Input Rate (KHz)	2	N.A. / 1.5	N.A.
L3 FARM	1000 MIPS	N.A.	N.A.
Input Rate (Hz)	15	N.A.	N.A.
Output Rate (Hz)	3	500 / 150	10 000
OFFLINE Event Size (Kb)	100	5	2.5
Raw Data-Set Size / year	1.5 Tb	1 month run	50 Tb
Raw Data-Set Size - Total	1.5 Tb	1 Tb	50 Tb
CPU Required (MIPS)	1100	1500 / 1500	10 000
Reconstrtd DataSet Size/yr	2.7 Tb	?	16 Tb

Table 3: Comparison of Present and Future Experiments

	CDF I -> CDF III	E771 -> SFT
Interaction rate (MHz)	.3 -> 5	3 -> 10
Channel count	$8x10^4$ -> $6x10^5$	$5x10^4$ -> $6x10^5$
J/psi trigger eff. (including geom. accept.)	0.3 % -> 2.5 (8) %	10 % -> 60 %
Level 2 Input (Hz)	$2x10^3$ -> 10^5	$1.5x10^3$ -> $5x10^4$
Level 3 Input (Hz)	15 -> 1000	0 -> 5000
Data set/year (Tbytes)	1.5 -> 200	10 -> 200

Table 4: Comparison of Event Rates

	bb / Sec Produced	EVENTS TO TAPE/SECOND				
		TOTAL(*)	B INCL.	ψK_S	$\pi\pi$	$D_S K$
CDF	$5x10^3$	<100	>25	$1.2x10^{-3}$ (3.8)	$1.6x10^{-3}$	$0.6x10^{-3}$
D0	$5x10^3$	<100	–	$3.8x10^{-3}$	–	–
SDC	10^6	100	–	$1.9x10^{-2}$	–	–
GEM	10^6	100	–	$1.9x10^{-2}$	–	–
BCD	10^5	1000	>2000(**)	$2.7x10^{-1}$	$1.6x10^{-2}$	$1.2x10^{-2}$
COBEX	$5x10^4$	5000	–	$5.8x10^{-2}$	$3x10^{-3}$	-
HERA-B	40	100	–	$4.1x10^{-4}$	–	–
SFT	$1.6x10^3$	1000	320	$1.9x10^{-2}$	$5.8x10^{-3}$	$3.8x10^{-3}$
GAJET	$2.1x10^3$	300	–	$1.0x10^{-2}$	$4.0x10^{-3}$	$1.6x10^{-3}$
ATLAS	$6x10^5$	<100	–	_	$2.0x10^{-2}$	-
LHB	10^3	<1000	–	$0.7x10^{-2}$	$5.0x10^{-3}$	-

(*) Signal + Background
(**) Note: the BCD figures are reported as given by the proponents. Obviously the B logging rate displayed here will have to be reduced in order to allow for the unknown rate due to irreducible backgrounds from minimum bias and charm events.