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BTeV: STRATEGY AND SENSITIVITY

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The next-generation experiments on Heavy Flavour Physics must be performed at the hadron colliders to exploit the superior production cross section and availability of all the species of b and c flavored hadrons. The particularly hostile environment of the hadron colliders, on the other hand, requires that new and adequate experimental tecniques be developed to face this extraordinary challenge. The BTeV experiment has developed the right experimental tools to perform this program with very high sensitivity and to extend our knowledge at the frontier of New Physics.

1 Introduction

In BTeV we believe that we have developed the right experimental techniques, both instrumentally and for physical analysis, to deeply probe the b and c Heavy Flavour sector well beyond the possibilities of the present generation of experiments. Our goal is to look for evidence of effects or inconsistencies brought in data by New Physics, and thus be in a unique position to determine properties of the New Physics that can only be found by seeing how it modifies CP violation and rare decays.

Indeed, any discovery at LHC could impact the Heavy Flavour sector, specifically in modifying diagrams containing loops that contribute to CP violation and rare decays. Should this physics not be discernable, it would place great restrictions upon it, thus making precision measurements incredibly important. A large number of papers (>100), discuss specific examples. We also want to understand connections between quark mixing and neutrino mixing. One possible link [1] within a SUSY GUT context predicts changes in specific CP violating angles. In the end, high precision measurements in the Heavy Flavour sector are and will be crucial and unavoidable for progress in our field, whatever the future scenario of particle physics turns out to be.

BTeV will perform this program in the forward region of the $p-\bar{p}$ collisions at the TEVATRON collider at Fermilab. The experiment is designed to fully exploit the superior potential of hadron colliders in terms of number of produced b-particles and, in particular, the advantages provided by working in the forward region at high rapidity. Here the high Lorentz boost, with which the $b-\bar{b}$ pairs are produced, drastically reduces multiple-scattering in the detector and the strong angular correlation between the two b-particles, dramatically enhances the flavour-tagging efficiency.

BTeV will be placed in the C0 experimental hall of the TEVATRON collider and is expected to start its data taking run in 2008-2009. The BTeV program has been already approved by the Fermilab PAC, its base-line cost has been successfully reviewed by Fermilab and, now, the experiment is waiting for funding from the U.S. Department of Energy.

2 Main experimental challenges

To fully exploit the enormous advantages of doing future Heavy Flavour Physics in the forward region of the hadron colliders, adequate strategies must be adopted to face the following experimental challenges (typical of a high-luminosity hadron-collider environment).

1. One has to isolate the b-signal from a large total rate: σ_{bb}/σ_{tot} 1/500 at the Tevatron energy;
2. Background from b-decays can overwhelm "rare" processes;
3. Large data rates are expected just from b-decays: 1 KHz within the acceptance;
4. Large particle rates cause radiation damage to the detectors and high photon multiplicities may obscure the signal in the EM calorimeter.

The BTeV approach [2,3] is characterized by the following key elements, which specifically address and resolve the previous experimental challenges.

1. High Precision silicon pixel vertex detector to provide excellent reconstruction of primary (interaction), secondary, and tertiary vertices [4];
2. First Level Trigger on detached vertices to select b-signals and reject background;
3. Excellent Particle & Lepton ID;

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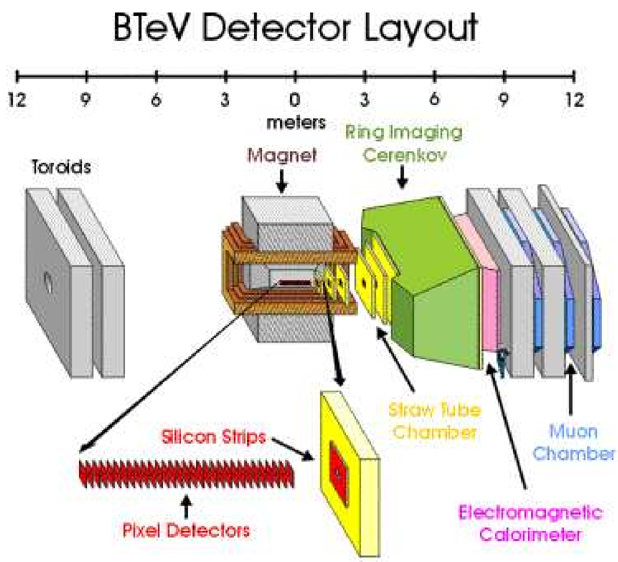

Figure 1. The BTeV detector.

4. Dead-timeless trigger and DAQ capable of writing KHz of events to tape;

5. $PbWO_4$ crystal calorimeter [5].

This approach is implemented through a suitable choice of detectors as illustrated in Fig. 1.

The experimental apparatus is designed around a pixel vertex detector which is placed inside the central dipole magnet centered on the interaction region. The pixel detector provides fast and precise hit information to the trigger processors that make a trigger decision on the evidence for decay vertices in the event. The forward tracking system consists of seven stations of straw tube chambers (in yellow) with silicon microstrip detectors (in red) in the innermost region, close to the beam pipe. Each station provides three coordinate measurements, X, along the horizontal direction, U and V, at $\pm 11^o$ around the vertical direction. The forward tracking system improves the momentum resolution of the tracks reconstructed by the vertex detector, allows for the reconstruction of the neutral Vees decaying downstream of the vertex detectors and measures with precision the trajectories of the tracks crossing the RICH detector (in green). At the end of the spectrometer are the EM calorimeter (in pink) and the muon detector, consisting of an array of three iron filters (in grey) and three stations of muon chambers (in blue). The first two iron blocks are magnetized with a toroidal field.

The apparatus is very compact and can be easily upgraded to cover the opposite hemisphere of rapidity. In the next section of this paper I will concentrate on the key element of the BTeV apparatus, the vertex trigger.

3 The BTeV vertex trigger

The BTeV vertex trigger can be viewed as the heart of the experiment. Every single crossing, at 7.6 MHz frequency, is analyzed to search for evidence of detached vertices. This is done by reconstructing the tracks from the collision, finding the primary interaction vertex, and then determining the number of tracks missing the primary vertex and having an impact parameter with a significance above a certain threshold value: $b/\sigma_b > n$, where b is the measured impact parameter and σ_b its corresponding error. All this is made possible by the unique features provided by the pixel vertex detector fully immersed in a magnetic field. The very low occupancy, together with the excellent spatial resolution and the intrinsically 3D coordinate information, makes the track reconstruction process very simple and practically free of fake track combinatorics. Thanks to the presence of the magnetic field, the track momenta can be simultaneously measured and the low momentum tracks disregarded. These tracks have large multiple scattering, which can cause false impact parameters leading to a poor background rejection in the trigger. Using our pixel prototype detectors in a test beam at Fermilab, we measured resolutions ranging from 4 to 10 μm, depending on the track crossing angle, and expect a fake tracks at the trigger level with a probability much lower than 1%. The proximity of the pixel planes to the beam line, 6 mm in our case, together with the pixel resolution, determines the impact parameters resolution and hence drives the trigger performance. The system of processors, used to run the trigger software, is based on a heavily pipelined and parallel architecture using inexpensive processing nodes optimized for specific tasks and sufficient memory to buffer the event data while calculations are carried out. The system employs about 3000 processors, DSPs & FPGAs, and ~1 Terabyte buffer memory.

There are several crucial advantages of using the detached vertex trigger at the first level. First of all, it allows us to select the most general class of b events without any bias toward particular final states. In particular, since it performs essentially the same selection that will be employed in the off-line analysis to isolate the signals, its effective efficiency, expressed as (number of reconstructed events) /(number of reconstructable events), turns out to be very high. It is worth noting that this ratio represents the figure of merit that counts in the end. Furthermore, the same trigger allows for an extensive charm physics program at very high sensitivity. The trigger algorithm, being completely programmable, can be configured in a variety of different ways. Unexpected situations, which could arise from the unknown characteristics of the extreme forward regions of the hadron colliders, can be easily handled thanks to this feature. The base-line algorithm has been developed to present an excellent robustness even in presence of more interactions per bunch crossing. At the BTeV nominal luminosity, $L = 2 \times 10^{32}$ cm^{-2}s^{-1}, two interactions on average are produced per bunch crossing, but the algorithm performance has been proven to remains unchanged by no more than 20%, up to 6 interactions per bunch crossing. Table 1 shows the simulated trigger efficiency with our base-line algorithm for a wide class of b-decays. The algorithm performance has been tuned to reject 99% of the Minimum Bias events.

Process	Eff.(%)
Minimum Bias	1
$B_s \to D_s K^-$	74
$B^o \to D^{*+}\rho^-$	64
$B^o \to \rho^o\pi^o$	56
$B^o \to J/\psi K_s$	50
$B^o \to J/\psi K^{*o}$	68
$B^- \to D^o K^-$	70
$B^- \to K_s\pi^-$	27
$B^o \to 2-body$ $(\pi^+\pi^-, K^+\pi^-, K^+K^-)$	63

Table 1. BTeV trigger efficiencies for a wide class of b-decays.

4 Physics reach of BTeV

The sensitivity of BTeV to the CP violating angles is summarized in Table 2 for a luminosity of 2×10^{32} cm^{-2}s^{-1} and 10^7 seconds of running time [6]. The performance is outstanding and covers all the spectrum of the important measurements. It worth noting that the sensitivity to the α-angle through $B^o \to \rho\pi$, as well as that to χ through $B_s \to J/\psi\eta^{(')}$, is amazing.

BTeV has an excellent reach in rare decays too, as shown in Table 3 together with the physics issue that each measurement addresses.

Precision studies of b decays can bring a wealth of information to bear on new physics, that probably will be crucial in sorting out anything seen at LHC. The BTeV data sample will be large enough to test different scenarios emerging from "New Physics" at the TeV energy scale. Table 4 shows the expected rates in BTeV for one year of running and in an e^+e^- B-factory operating at the Υ(4S) with a total accumulated sample of 500 fb^{-1}, about what is expected before BTeV begins running.

5 Conclusions

Heavy Flavour Physics is not only the ideal laboratory to investigate CP-violation and probe the Standard Model at an unprecedented level, but it is even more crucial in revealing which kind of New Physics is hidden in the data. The present generation experiments, BaBar & BELLE together with CDF, will produce a lot of very exciting results in the next few years. Starting in about 2008-2009, the high statistics results from BTeV and LHCb will take us to the next level, expanding our searches to a variety of other modes and fully engaging a major new player, Bs.

References

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Reaction	BR(10^{-6})	# of Events	S/B	Parameter	Error or (Value)
$B^o \to \pi\pi$	4.5	14,600	3	Asymmetry	0.030
$B_s \to D_s K^-$	300	7,500	7	γ - 2χ	8^o
$B^o \to J/\psi K_s$	445	168,000	10	$\sin(2\beta)$	0.017
$B_s \to D_s \pi^-$	3000	59,000	3	x_s	(75)
$B^- \to D^o(K^+\pi^-)K^-$	0.17	170	1		
$B^- \to D^o(K^+K^-)K^-$	1.1	1,000	>10	γ	13^o
$B^- \to K_s\pi^-$	12.1	4,600	1		theory errors
$B^o \to K^+\pi^-$	18.8	62,100	20	γ	$< 4^o$
$B^o \to \rho^+\pi^-$	28	5,400	4.1		
$B^o \to \rho^o\pi^o$	5	780	0.3	α	4^o
$B_s \to J/\psi\eta$	330	2,800	15		
$B_s \to J/\psi\eta'$	670	9,800	30	$\sin(2\chi)$	0.024

Table 2. BTeV physics reach on CKM parameters in 10^7 seconds.

Reaction	BR(10^{-6})	# of Events	S/B	Physics
$B^o \to K^{*o}\mu^+\mu^-$	1.5	2,530	11	polarization & rate
$B^- \to K^-\mu^+\mu^-$	0.4	1,470	3.2	rate
$B \to s\mu^+\mu^-$	5.7	4,140	0.13	rate: Wilson coefficents

Table 3. BTeV physics reach on rare decays in 10^7 seconds.

Mode	BTeV (10^7 s)			B-fact (500 fb^{-1})		
	Yield	Tagged	S/B	Yield	Tagged	S/B
$B_s \to J/\psi\eta^{(\prime)}$	12650	1645	>15	0		
$B^- \to \phi K^-$	11000	11000	>10	700	700	4
$B^o \to \phi K_s$	2000	200	5.2	250	75	4
$B^o \to K^{*o}\mu^+\mu^-$	2530	2530	11	50	50	3
$B_s \to \mu^+\mu^-$	6	0.7	>15	0		
$B^o \to \mu^+\mu^-$	1	0.1	>10	0		
$D^{*+} \to \pi^+ D^o(K^-\pi^+)$	10^8	10^8	large	8×10^5	8×10^5	large

Table 4. Sensitivities on new physics modes. Comparison of BTeV and B-factory yields on different time scales.