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by

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B Physics and CP Violation at UNK *

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Abstract

After discussing the prospects for B physics in the 1990's and the favorable position in which UNK will find itself in, I briefly review the present status of CP violation in the standard model and point out the importance of trying to verify experimentally the presence of CP violating effects in the B system. Four possible signals for CP violation in B decays are discussed involving, respectively, leptonic asymmetries, hadronic asymmetries, final state interactions and time dependent effects. Finally, I discuss rates, backgrounds and experimental strategies applicable to fixed target experiments at UNK and conclude that, with a dedicated effort, the goal of observing some of these CP violating effects in B decays is within reach.

1 B Physics in the 90's

In the coming decade B physics will be pursued in at least 5 distinct ways:

- In threshold machines ($e^+e^- \to \Upsilon(4s) \to B\bar{B}$) at DORIS, CESR and possibly at a new dedicated B factory
- At the Z^0 colliders ($e^+e^- \to Z^0 \to B\bar{B}$) soon to enter into operation in the United States (SLC) and in Europe (LEP)
- At the ep collider HERA ($ep \to B\bar{B}X$) being completed presently in Hamburg
- At a variety of hadron colliders ($p\bar{p}$ or $pp \to B\bar{B}X$) either already existing, like the CERN $Sp\bar{p}S$ and the Tevatron, or being proposed: the SSC in the United States, the LHC in Europe and UNK in the Soviet Union
- In fixed target machines ($pA \to B\bar{B}X$) in the United States (Tevatron) or in the Soviet Union (UNK)

Each of these machines has both advantages and disadvantages, concerning B physics. In general, hadronic machines are more efficient to produce B mesons than e^+e^- colliders. However, in electron colliders the signal to noise is much better. Furthermore, high

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energy hadronic colliders, although producing a prodigious amount of B mesons, have a considerably nastier environment than fixed target machines.

Threshold e^+e^- machines and Z^0 colliders produce about the same number of $b\bar{b}$ pairs, at a given luminosity, since the cross section for the $\Upsilon(4s)$ is roughly $\sigma(\Upsilon(4s)) \simeq 1nb$, while that for producing $b\bar{b}$ pairs at the Z^0 is $\sigma(Z^0 \to b\bar{b}) \simeq 5nb$. With a nominal luminosity $L = 10^{31} cm^{-2} sec^{-1}$, corresponding to the present performance of threshold machines and the expected performance of SLC and LEP, and using an experimental year of $10^7 sec$, one expects $10^5 - 5 \times 10^5 b\bar{b}$ pairs/year at the e^+e^- colliders. These numbers can be substantially increased at a dedicated B factory, operating with a luminosity of $10^{32} - 10^{33} cm^{-2} sec^{-1}$. However, to reach $10^8 b\bar{b}$ pairs per year - a number which we will see is crucial for CP violation effects - one will need a threshold B-factory with a luminosity of $10^{34} cm^{-2} sec^{-1}$. The production of $b\bar{b}$ pairs at HERA has a comparable cross section to that of the electron colliders: $\sigma(ep \to b\bar{b}X) \simeq 3nb$, with a fair fraction of the produced $B's$ being kinematically accessible. With an expected luminosity of $10^{31} cm^{-2} sec^{-1}$, the total number of $B's$ produced per year at HERA, although substantial, will be well below a million.

In hadronic machines the cross section for producing $b\bar{b}$ pairs is a rapidly growing function of $\sqrt{s}$. However, there exist considerable uncertainties in predicting this cross section, both at low energies, because of threshold effects, and at high energies, because one needs to know the value of the gluon structure function at small x [1]. Typically[1] one expects:

$$
\begin{aligned}
\sigma(b\bar{b}) &\simeq 10nb & \sqrt{s} &= 40GeV & &(Tevatron) \\
\sigma(b\bar{b}) &\simeq 100nb & \sqrt{s} &= 75GeV & &(UNK) \\
\sigma(b\bar{b}) &\simeq 2\mu b & \sqrt{s} &= 540GeV & &(Sp\bar{p}S) \\
\sigma(b\bar{b}) &\simeq 400\mu b & \sqrt{s} &= 40TeV & &(SSC)
\end{aligned} \tag{1}
$$

Even at the relative low energies of the fixed target machines, the cross sections are large enough so that the number of produced $B's$ exceeds the expectation of electron machines. A very reasonable estimate for a fixed target machine is to assume that there will be 10^6 interactions per second [2]. Then the above cross sections lead one to expect of the order of $3 \times 10^6 - 10^7$ B's produced per year at the Tevatron and of the order of $3 \times 10^7 - 10^8$ B's produced per year at UNK, where the larger figure takes into account a possible nuclear enhancement factor [3].

At the SSC, with an integrated luminosity of $10^{39} cm^{-2}$ per year, one expects an enormous amount of B's to be produced($\sim 4 \times 10^{11}$ per year). However, as discussed by Cox and Wagoner [3], the SSC environment will be considerably worse than that of a (multi)TeV fixed target machine, like the Tevatron or UNK. Because of the colliding mode, even at $\sqrt{s} = 40TeV$, the average longitudinal momentum of the B's will be less than that of a fixed target machine. With a smaller γ-factor, the actual decay distance of the B's decreases and the existence of a secondary vertex will be more difficult to find. Furthermore,

[1] At high energy, heavy quark production is dominated by gluon-gluon fusion

[2] This is the number assumed by experiment E 771 at Fermilab [2], which uses a thin W target and a proton beam with approximately 10^8 protons/sec.

[3] I shall return to this point later on

the expected charged particle multiplicity at the SSC will far exceed that at the Tevatron or at UNK, increasing the "confusion" factor in any given event.

The above considerations suggest that the Tevatron, as a fixed target machine, and especially UNK, operating at $E_{Lab} = 3TeV$, may be better machines for doing B physics, than either the electron or hadron colliders. In particular, the large rates at UNK ($10^7 - 10^8$ B's per year) suggest that this accelerator may well have the capability to explore CP violating phenomena in the B system. However, to do really B physics at UNK - or at the Tevatron - one must learn to reject the non trivial hadronic background. Indeed, the principal problem at fixed target machines is not the rate, but the unavoidable background. As shown in Table 1, in this respect, the e^+e^- colliders are considerably better off. I shall return to the crucial point of trying to cope with this background in the last section of this paper. Before doing this, however, I want to discuss some of the very exciting physics one may be able to do with $10^7 - 10^8$ B's/year.

Table 1: Signal/Background in various Machines

Machine	Signal/Background
$\Upsilon(4s)$	0.4
Z^0	0.15
Tevatron	$3 \times 10^{-7} - 10^{-6}$
UNK	$3 \times 10^{-6} - 10^{-5}$

2 CP Violation in the Standard Model

Up to now CP violating phenomena have only been seen in the Kaon system. The measured parameters are η_{+-} and η_{00}, which detail the ratio of the amplitudes of K_L and K_S to decay into charged or neutral pions, respectively:

$$\eta_{+-} = \frac{A(K_L \to \pi^+\pi^-)}{A(K_S \to \pi^+\pi^-)} \simeq \varepsilon + \varepsilon' \tag{2}$$

$$\eta_{00} = \frac{A(K_L \to \pi^0\pi^0)}{A(K_S \to \pi^0\pi^0)} \simeq \varepsilon - 2\varepsilon' \tag{3}$$

Experimentally, one knows that [4]:

$$|\eta_{+-}| \simeq |\eta_{00}| \simeq (2.27 \pm 0.02) \times 10^{-3} \tag{4}$$

Furthermore, very recently, the NA31 experiment at CERN has reported a preliminary value for $\frac{\varepsilon'}{\varepsilon}$, which differs statistically from zero [5]:

$$|\frac{\varepsilon'}{\varepsilon}| = (3.5 \pm 0.7 \pm 0.4 \pm 1.2) \times 10^{-3} \tag{5}$$

In the above, the first error is statistical, the second is an estimate of errors incurred in the Monte Carlo simulation of the experiment and the last is a systematic error.

The value in Eq(5) is in good agreement with the expectation of the standard model [6], where CP violation is attributed to a non zero phase in the quark mixing matrix. Indeed, a non zero value for ε' confirms the standard model presumption that there exist a $\Delta S = 1$

CP violating amplitude. The parameter ε, on the other hand, could have been purely due to some new $\Delta S = 2$ weak interaction. Now that ε' has been measured, however, it is very likely that ε itself arises as a second order effect, coming from the CP violating phase in the $\Delta S = 1$ amplitude.

In the standard model, once ε and ε' are measured to be nonvanishing, one expects that there should be CP violation also in the B system. These CP violating phenomena will be characterized both by an induced $\Delta B = 2$ interaction (the analog of the $\Delta S = 2$ parameter ε) and a direct $\Delta B = 1$ term. The induced $\Delta B = 2$ interaction is responsible for $B - \bar{B}$ mixing and leads to mass eigenstates which are not CP eigenstates. These mixing and CP violating phenomena are simply described by an effective Hamiltonian for the $B - \bar{B}$ system, which takes into account the fact that these states are unstable due to the weak interactions. One writes

$$H = M - \frac{i}{2}\Gamma \tag{6}$$

where the mass matrix M and the decay matrix Γ are Hermitian. CPT implies that the diagonal elements of H are equal, while the presence of non vanishing phases in M and Γ signify CP violation.

Diagonalizing the 2x2 Hamiltonian H:

$$H = \begin{vmatrix} m & M_{12} \\ M_{12}^* & m \end{vmatrix} - \frac{i}{2} \begin{vmatrix} \gamma & \Gamma_{12} \\ \Gamma_{12}^* & \gamma \end{vmatrix} \tag{7}$$

one obtains the eigenstates

$$|B_\pm\rangle = \frac{1}{[2(1+|\varepsilon|^2)]^{1/2}}[(1+\varepsilon)|B^0\rangle \pm (1-\varepsilon)|\bar{B}^0\rangle] \tag{8}$$

where

$$\frac{1+\varepsilon}{1-\varepsilon} = [\frac{M_{12} - \frac{i}{2}\Gamma_{12}}{M_{12}^* - \frac{i}{2}\Gamma_{12}^*}]^{1/2} \tag{9}$$

Clearly $\varepsilon \to 0$ if M_{12} and Γ_{12} are real, so that ε is a measure of $\Delta B = 2$ CP violation. The mass difference between the eigenstates $|B_+\rangle$ and $|B_-\rangle$ is just

$$\Delta m = m_+ - m_- = 2Re[(M_{12} - \frac{i}{2}\Gamma_{12})(M_{12}^* - \frac{i}{2}\Gamma_{12}^*)]^{1/2} \tag{10}$$

while the width difference is

$$\Delta\gamma = \gamma_+ - \gamma_- = -4Im[(M_{12} - \frac{i}{2}\Gamma_{12})(M_{12}^* - \frac{i}{2}\Gamma_{12}^*)]^{1/2} \tag{11}$$

These quantities reduce, in the CP conserving limit, simply to $2M_{12}$ and $2\Gamma_{12}$, respectively.

The above formalism for the $B - \bar{B}$ system is analogous to that in the Kaon system. However, in the standard model, there is a substantial difference between these systems, in that for the Kaon system $\Delta m \sim \Delta\gamma$, while for the B system $\Delta m >> \Delta\gamma$. The dominant graphs contributing to the mass and the decay mixing in the $B - \bar{B}$ system are shown in Fig 1. One easily sees from this figure that for the $B_q - \bar{B}_q$ system, with $q = d, s$,

$$\Delta m \sim m_t^2 |V_{tb} V_{tq}^*|^2 \tag{12}$$

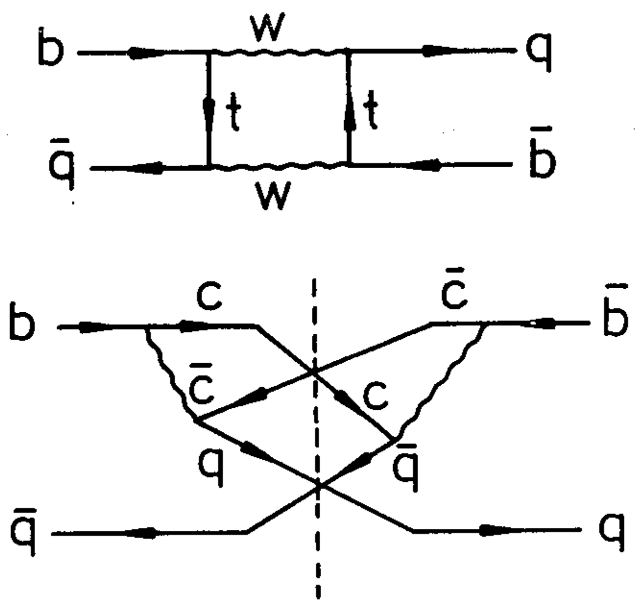

Figure 1: Mass and decay mixing in the $B - \bar{B}$ complex

while

$$\Delta\gamma \sim m_b^2 |V_{cb} V_{cq}^*|^2 \tag{13}$$

where V_{ij} are elements of the Kobayashi Maskawa mixing matrix. Since the Kobayashi Maskawa matrix elements in (12) and (13) are comparable, it follows that $\frac{\Delta\gamma}{\Delta m} \sim (\frac{mb}{mt})^2$ and thus this ratio is quite small. Furthermore, for the B's, because of the large phase space available, one expects that $\frac{\Delta\gamma}{\gamma} << 1$. Thus, in what follows, we shall neglect $\Delta\gamma$ altogether and take $\gamma_+ \simeq \gamma_- = \gamma$.

The CP mixing asymmetry, for the same reason, is very small. The relevant parameter is

$$|\frac{1+\varepsilon}{1-\varepsilon}|^2 \simeq 1 + Im\frac{\Gamma_{12}}{M_{12}} \tag{14}$$

This ratio differs from unity by an even smaller amount than $\frac{\Delta\gamma}{\Delta m}$, since for CP to be violated all quarks must be involved and no quarks can be degenerate in mass. Either by direct calculation, or by a simple physical argument [7], one deduces that

$$Im\frac{\Gamma_{12}}{M_{12}} \sim \begin{cases} \frac{m_c^2}{m_b^2}\frac{\Delta\gamma}{\Delta m} \sim \frac{m_c^2}{m_t^2} & B_d \\ \frac{m_c^2}{m_b^2}\frac{\Delta\gamma}{\Delta m} sin^2_{\theta_c} \sim \frac{m_c^2}{m_t^2} sin^2_{\theta_c} & B_s \end{cases} \tag{15}$$

The factor of $\frac{m_c^2}{m_b^2}$ above stands really for $\frac{(m_c^2 - m_u^2)}{m_b^2}$, corresponding to the fact that there should be no CP violation if $m_c = m_u$. For the B_s system, the graphs of Fig 1 do not involve any quarks of the first generation. Thus they cannot give rise to CP violation by themselves. Including some first generation contributions leads to the extra Cabibbo angle suppression, indicated in Eq(15).

With an appropriate phase convention, ε is essentially real and very small. From (14) one has

$$Re\varepsilon \simeq \frac{1}{4} Im \frac{\Gamma_{12}}{M_{12}} \sim \begin{cases} 2 \times 10^{-4} & B_d \\ 2 \times 10^{-5} & B_s \end{cases} \tag{16}$$

where the numerical values are typical numbers from detailed calculations in the literature [8], scaled to what appears now to be a more realistic value of $m_t, m_t \simeq 80GeV$. These numbers are one or two orders of magnitude below the equivalent ε parameter in the Kaon system, given in Eq(4). It would appear from this observation that the probability of detecting CP violating phenomena in the B system is hopeless. Fortunately, in the $B - \bar{B}$ complex the role of $\Delta B = 1$ and $\Delta B = 2$ CP violating phenomena are reversed, from that of the $\Delta S = 1$ and $\Delta S = 2$ analogues in the Kaon system. Although for the Kaon case, the $\Delta S = 2$ CP violating parameter ε is much greater than the $\Delta S = 1$ CP violating parameter ε', for the $B - \bar{B}$ system the reverse is true. So even though ε_d and ε_s are small, sizable CP violating phenomena exist, connected with $\Delta B = 1$ transitions.

To observe CP violating processes in $\Delta B = 1$ transitions requires that there should be interference between two amplitudes with different phases. This can occur in two circumstances. Either because of $B - \bar{B}$ mixing [9], or if there are final state interactions [10]. The important parameter in the case of mixing is the ratio of the mass difference to the total width γ:

$$x = \frac{\Delta m}{\gamma} \tag{17}$$

This can be seen as follows. The eigenstates $|B_\pm\rangle$ of Eq(8) have a simple time dependence

$$|B_\pm(t)\rangle = e^{-im_\pm t} e^{-\frac{1}{2}\gamma t} |B_\pm(0)\rangle \tag{18}$$

where I have taken $\gamma_+ = \gamma_- = \gamma$. Hence a state which started as a pure $|B^0\rangle$ evolves in time to a mixture of $|B^0\rangle$ and $|\bar{B}^0\rangle$. Neglecting the small $\Delta B = 2$ CP violating parameter ε, one has simply

$$|B_\pm\rangle = \frac{1}{\sqrt{2}}(|B^0\rangle \pm |\bar{B}^0\rangle) \tag{19}$$

Thus a state which originally started as a $|B^0\rangle$ evolves in time to the linear combination

$$|B^0(t)\rangle = f_+(t)|B^0\rangle + f_-(t)|\bar{B}^0\rangle \tag{20}$$

where

$$f_+(t) = e^{-imt} e^{-\frac{\gamma}{2}t} \cos\frac{\Delta m t}{2} \tag{21}$$

$$f_+(t) = i e^{-imt} e^{-\frac{\gamma}{2}t} \sin\frac{\Delta m t}{2} \tag{22}$$

with $m = \frac{1}{2}(m_+ + m_-)$. The linear superposition of both $|B^0\rangle$ and $|\bar{B}^0\rangle$ states will allow CP violating phenomena to manifest themselves. However, it is clear that the competition between Δm and γ will be a crucial factor in determining the magnitude of these CP violating effects.

3 CP violating signals in B decays

In this section I would like to briefly discuss four distinct manifestations of CP violation in B decays. Purely on the basis of standard model estimates, as we shall see, not all these phenomena are likely to be observed. Nevertheless, it is still worthwhile discussing even unprobable effects, since, if there is physics beyond the standard model, some of our estimates may be unnecessarily pessimistic.

3.1 Leptonic asymmetries

The idea of testing CP violation effects in heavy quark decays using leptonic asymmetries was suggested long ago by Okun Zakharov and Pontecorvo [11]. It uses the fact that, if there is $B-\bar{B}$ mixing, then it is possible for a B^0, or a $\bar{B}^0$, to decay into the "wrong" sign lepton. If there is CP violation in the theory, the ratio of decays into wrong sign leptons for a B^0 is not the same as that for a $\bar{B}^0$. One can readily calculate the Pais-Treiman ratios [12]:

$$r = \frac{\Gamma(B^O \to l^- X)}{\Gamma(B^0 \to l^+ X)} = |\frac{1-\varepsilon}{1+\varepsilon}|^2 \frac{x^2+y^2}{2+x^2-y^2} \tag{23}$$

$$\bar{r} = \frac{\Gamma(\bar{B}^O \to l^+ X)}{\Gamma(\bar{B}^0 \to l^- X)} = |\frac{1+\varepsilon}{1-\varepsilon}|^2 \frac{x^2+y^2}{2+x^2-y^2} \tag{24}$$

where x is given by Eq(17) and $y = \frac{\Delta\gamma}{2\gamma} \simeq 0$, in the standard model. Obviously $r \neq \bar{r}$ if $\varepsilon \neq 0$. However, since ε_d and ε_s are small in the standard model (cf Eq(16)), one expects a very tiny signal of CP violation, connected with leptonic decays.

Okun et al [11] suggested measuring the CP asymmetry between r and $\bar{r}$ by looking at the difference in same sign dileptons, arising from the production of $B^0\bar{B}^0$ pairs. One has

$$a = \frac{N(l^+l^+) - N(l^-l^-)}{N(l^+l^+) + N(l^-l^-)} = \frac{r-\bar{r}}{r+\bar{r}} \simeq -4Re\varepsilon \tag{25}$$

Unfortunately, although the number of same sign dileptons is expected to be large, the predictions for a which follow from Eq(16) are very dismal:

$$a \sim \begin{cases} 10^{-3} & B_d \\ 10^{-4} & B_s \end{cases} \tag{26}$$

Such small asymmetries require enormous numbers of $B\bar{B}$ pairs, for a statistically significant measurement. As an example, let us consider B_d decays. Using the recent ARGUS result on r_d [13]

$$r_d = 0.21 \pm 0.08 \pm 0.02 \tag{27}$$

implies

$$x_d = (\frac{\Delta m}{\gamma})_d = 0.73 \pm 0.18 \tag{28}$$

Hence the total number of same sign dileptons expected in B_d decays is

$$R = \frac{N(l^+l^+) + N(l^-l^-)}{N(l^+l^-)} = \frac{r+\bar{r}}{1+\bar{r}r} \simeq 0.4 \tag{29}$$

Since the leptonic branching ratio for B_d is about 10%, with 3×10^7 $B\bar{B}$ pairs, at UNK one expects a signal of roughly $10^5 l^+ l^+, l^- l^-$ pairs. However, if $a_d \simeq 10^{-3}$ then the asymmetry signal would amount to only 100 events, on a statistical background of 300 events.

In the standard model leptonic asymmetries are hopeless, unless one has at least $10^9 - 10^{10} B\bar{B}$ events. However, as I mentioned above, it is still reasonable to look at these asymmetries at UNK, as possible signs of physics beyond the standard model. Even then, one would have to be careful with drawing any conclusions from a possible positive signal, since there is considerable same sign dilepton background from B decays into charm.

3.2 Hadronic asymmetries

The idea here is again to use $B - \bar{B}$ mixing to get interference between two amplitudes with different CP phases. One needs for these purposes a hadronic final state f which occurs in both B^0 and $\bar{B}^0$ decays. The decay probability of a state $B^0(t)$, which at $t = 0$ was purely a B^0 state, into f need not agree with the decay probability of $\bar{B}^0(t)$ into $\bar{f}$, the CP conjugate state of f, if CP is not conserved. Even if f is a CP eigenstate ($\bar{f} = \pm f$), there can still be a difference in the decay probabilities. Furthermore $\Gamma(B^0(t) \to f)$ can differ from $\Gamma(\bar{B}^0(t) \to \bar{f})$, even if $\varepsilon = 0$. That is, the difference between these decay amplitudes can be a signal of pure $\Delta B = 1$ CP violation. Hence, these hadronic asymmetries are the analogue of ε' in the Kaon system.

The interesting asymmetry to consider is [14]

$$A_f = \frac{\Gamma(B^0(t) \to f) - \Gamma(\bar{B}^0(t) \to \bar{f})}{\Gamma(B^0(t) \to f) + \Gamma(\bar{B}^0(t) \to \bar{f})} = -\frac{2x \; Im\lambda_f}{2 + x^2 + x^2|\rho_f|^2} \tag{30}$$

In the above

$$\rho_f = \frac{A(\bar{B}^0 \to f)}{A(B^0 \to f)} \tag{31}$$

while

$$\lambda_f = \frac{1-\varepsilon}{1+\varepsilon}\rho_f \tag{32}$$

A number of comments are in order:

- The quantity $Im\lambda_f$ is reparametrization invariant. With an appropriate phase choice, ε can be made essentially real and, since $\varepsilon << 1$, then $Im\lambda_f \simeq Im\rho_f$.

- For the interesting case where f is a CP eigenstate and the weak decay process is dominated by just <u>one</u> amplitude, then [15] $|\rho_f| = 1$. In this case

$$A_f = -\frac{x}{1+x^2} Im\rho_f \tag{33}$$

  and the <u>asymmetry directly measures a combination of phases of the Kobayashi Maskawa matrix</u>. As we shall see these kind of asymmetries can be quite large.

- The asymmetry A_f vanishes either in the case of no mixing ($x \to 0$) or full mixing ($x \to \infty$). For B_d, the ARGUS result (28) puts one in almost an ideal situation, since $\frac{x_d}{1+x_d^2} \simeq 0.5$. For B_s, on the other hand, one can argue that [16]

$$x_s \simeq |\frac{V_{ts}}{V_{td}}|^2 x_d \sim \frac{x_d}{sin^2\theta_c} \tag{34}$$

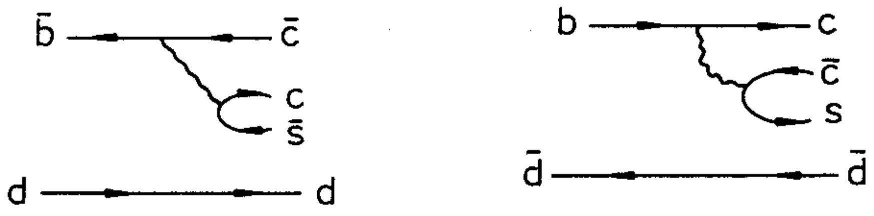

Figure 2: Diagrams contributing to $B_d \to \Psi K_s$ and $\bar{B}_d \to \Psi K_s$

Thus the asymmetry A_f for B_s decays is kinematically suppressed by the too large mixing! Furthermore, one can show [17] that $Im\lambda_f$ is suppressed by a further $sin^2\theta_c$ angle, for Cabibbo favored B_s decays [4]. Hence, it is sensible to focus only on B_d decays, when one wants to study this CP asymmetry.

As an illustration, I will focus on two examples of B_d decays where $f = \bar{f}$: $B_d \to \Psi K_s$ and $B_d \to p\bar{p}$. The relevant diagrams for these decays are shown in Figs 2 and 3. $Im\lambda_{\Psi K_s}$ and $Im\lambda_{p\bar{p}}$ can be easily computed from these diagrams. Since $|\rho_f| = 1$, these imaginary parts just measure the phase of a particular combination of Kobayashi Maskawa matrix elements. One finds

$$\lambda_{\Psi K_s} = [\frac{V_{cb}V^*_{cs}}{V^*_{cb}V_{cs}}][\frac{V^*_{tb}V_{td}}{V_{tb}V^*_{td}}] \to \frac{V_{td}}{V^*_{td}} \tag{35}$$

$$\lambda_{p\bar{p}} = [\frac{V_{ub}V^*_{ud}}{V^*_{ub}V_{ud}}][\frac{V^*_{tb}V_{td}}{V_{tb}V^*_{td}}] \to [\frac{V_{td}V_{ub}}{V^*_{td}V^*_{ub}}] \tag{36}$$

Here the first factor in both equations can be read off directly from the appropriate Feynman diagrams, while the second factor is the extra phase arising from the convention of taking ε_d to be purely real [18] [5]. The expressions on the right of Eqs (35) and (36) correspond to the parametrization of the Kobayashi Maskawa matrix [19], in which the only significant phases appear in V_{ub} and V_{td}. It is easy to check, however, that $Im\lambda_{p\bar{p}}$ is parametrization invariant. So is $Im\lambda_{\Psi K_s}$, if one remembers [20] that there are extra phases associated with $\bar{d}s \to K_s$ and $d\bar{s} \to K_s$.

Khoze and Uraltsev [21] and Donoghue, Nakada, Paschos and Wyler [22] have tried recently to estimate the phases entering in $Im\lambda_{\Psi K_s}$ and $Im\lambda_{p\bar{p}}$ [6]. They conclude that these phases can be quite large, so that one may well expect both $A_{\Psi K_s}$ and $A_{p\bar{p}}$ to be of the

[4] This suppression has the same origin as that appearing in Eq(15)

[5] More simply, this is just the phase of $\frac{1-\epsilon}{1+\epsilon}$

[6] These phases are also implicitly estimated in recent reanalyses of the Kobayashi Maskawa matrix, in light of the large $B - \bar{B}$ mixing observed [23].

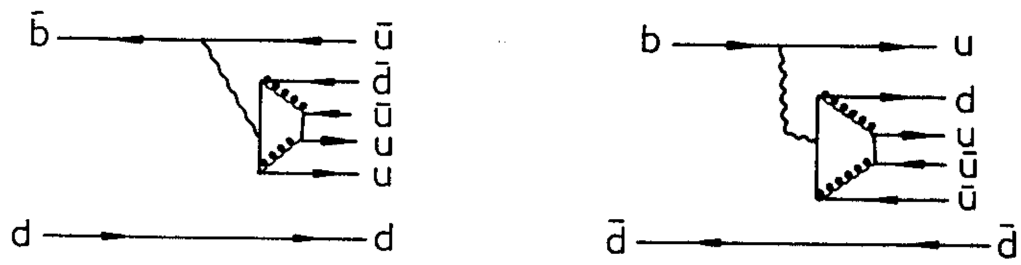

Figure 3: Diagrams contributing to $B_d \to p\bar{p}$ and $\bar{B}_d \to p\bar{p}$

order of 20%. To establish such a large asymmetry, at the 3σ level, requires only about 250 events. Since, for example, $B(B_d^0 \to \Psi K_s)B(\Psi \to \mu^+\mu^-) \simeq 5 \times 10^{-5}$, the number of $B\bar{B}$ events expected at UNK $(10^7 - 10^8)$ should be in the right range. Of course, one must also worry about detection efficiencies. The branching ratio $B_d \to p\bar{p}$ is not yet measured[7], but I would be surprised if it was much bigger than 10^{-5}. So again one will need about 10^8 B's to get a statistically significant sample. However, the signal here should be very clean [25].

3.3 CP violation due to final state interactions

CP violating effects can also occur if there is an interference between two amplitudes which have different weak CP violating phases and which, furthermore, are subject to different strong final state interactions [26]. If these conditions apply, it is possible to look for CP violating phenomena in the decay of charged B mesons. The relevant amplitudes, describing the decay of a B^- meson into a final state f and of a B^+ mesons into the conjugate state $\bar{f}$, read in this case:

$$A(B^- \to f) = |A_1|e^{i\delta_1}e^{i\phi_1} + |A_2|e^{i\delta_2}e^{i\phi_2} \tag{37}$$

$$A(B^+ \to \bar{f}) = |A_1|e^{i\delta_1}e^{-i\phi_1} + |A_2|e^{i\delta_2}e^{-i\phi_2} \tag{38}$$

Here $\delta_i(\phi_i)$ are, respectively, the strong and (weak) phases of the amplitudes A_i. The strong phase shifts are the same for particles and antiparticles. However, if CP is violated in the weak sector, so that there are some weak phases, these phases change sign as one passes from particle to antiparticle amplitudes.

One can construct an asymmetry

$$A_f{}^{+-} = \frac{\Gamma(B^- \to f) - \Gamma(B^+ \to \bar{f})}{\Gamma(B^- \to f) + \Gamma(B^+ \to \bar{f})}$$

[7] ARGUS has, however, measured the B_d^0 decay mode into $p\bar{p}\pi^+\pi^-$ [24]

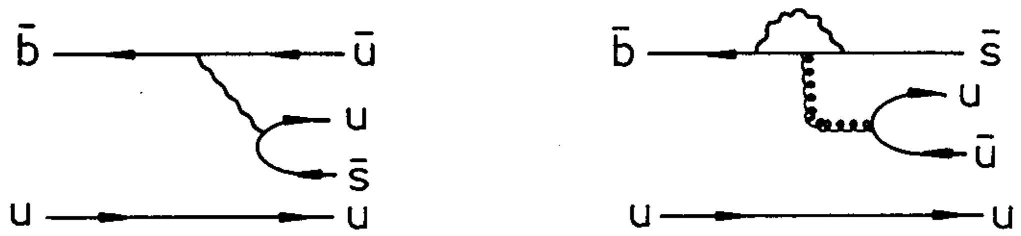

Figure 4: Amplitudes contributing to the process $B^+ \to K^+\rho$

$$= \frac{2|A_1||A_2|sin(\phi_1 - \phi_2)sin(\delta_1 - \delta_2)}{|A_1|^2 + |A_2|^2 + 2|A_1||A_2|cos(\phi_1 - \phi_2)cos(\delta_1 - \delta_2)} \tag{39}$$

where the second line follows from the definitions (37) and (38). It is clear from the above that there will be no asymmetry at all, unless both the weak CP phases , as well as the strong rescattering phases of A_1 and A_2, are different. Although it is difficult theoretically to prove that a sizeable asymmetry A_f^{+-} exists, experimentally the observation of this asymmetry is simpler. To establish the asymmetry requires comparing only the magnitude of the decay rates for $B^- \to f$ to that of $B^+ \to \bar{f}$. Such a comparison does not entail the extra tagging which is needed for the asymmetries A_f, discussed in the last subsection.

The asymmetries A_f^{+-} have been studied recently by Chau and Cheng [27] and I will briefly discuss, for illustrative purposes, an example taken from their work. The asymmetry I want to consider concerns the decay $B^{\pm} \to K^{\pm}\rho^0$. For the B^+ decays, the dominant amplitudes are shown in Fig 4. From this figure and the master equation (39), it is clear that the asymmetry $A_{K\rho}^{+-}$ will only be large if:

1. The magnitude of the Spectator decay amplitude is comparable to that of the $b - s$ Penguin graph:
$$|A_{Spectator}| \sim |A_{Penguin}| \tag{40}$$

2. The rescattering phase difference among these amplitudes is near $\frac{\pi}{2}$:
$$\delta_{Spectator} - \delta_{Penguin} \simeq \frac{\pi}{2} \tag{41}$$

3. The relative weak CP phase between these amplitudes is big.

Chau and Cheng [27] claim that all these three conditions are satisfied and obtain an extremely large asymmetry for this channel:

$$|A_{K\rho}^{+-}| \simeq 0.4 \tag{42}$$

It is difficult to judge the reliability of this result. Although the relative weak CP phase for these processes might be large, since it involves essentially the phase of V_{ub}, it is by no means clear to me that the conditions in Eqs(40) and (41) are satisfied. Furthermore, even granting that the asymmetry might be as large as (42), the rate for the processes $B^{\pm} \to K^{\pm}\rho$ is doubly Cabbibo suppressed. The Chau Cheng [27] estimate for this branching ratio of 10^{-5} would be great for UNK, but it seems a bit too generous for me.

Despite my negative attitude toward these kind of CP violating effects, it is obviously worthwhile to try to search for them at UNK. However, I emphasize that their observation will necessitate considerable theoretical analysis, before one can extract relevant information concerning the Kobayashi Maskawa matrix. This is not the case for the asymmetries discussed in the last subsection, where the experimental results are directly connected with the phases appearing in the KM matrix.

3.4 Time dependent CP violation effects

One of the great advantages of the high energy of UNK is that the produced B's are very time dilated. In fact, γ-factors of 0(100) will not be at all unusual. Since the B lifetime is near 10^{-12} sec, at UNK typical path lengths will be of order of a centimeter. Thus it should be possible to study the time development of B decays. As we shall see, the pattern of B decays as a function of time gives direct information about CP violation.

The existence of sizable $B - \bar{B}$ mixing causes the decay pattern of a state which was originally a B^0 not to follow an exponential form. For instance, it follows from Eqs(20) and (21) that the produced l^+'s from a beam of B's, which at $t = 0$ were B^0's, will have an oscillatory time dependence:

$$N^+(t) = N^+(0)e^{-\gamma t}[\frac{1 + cos\Delta mt}{2}] \tag{43}$$

The character of these oscillations depends crucially on $x = \frac{\Delta m}{\gamma}$. Fig 5 shows this behaviour for two values of x ($x = 0.75$ and $x = 15$), which should be appropriate for B_d and B_s decays, respectively. It is obvious from Fig 5 that departures from the usual $e^{-\gamma t}$ behaviour are clearly visible, in both cases. The above oscillatory behaviour disappears, if one does not energy select the produced B's. Without an energy selection, there is a superposition of different effective lifetimes $[\tau_{eff} = \tau_{\frac{1}{2}}(\frac{E}{m})]$ and the intricate pattern of Fig 5 is washed out. This is demonstrated explicitly in Fig 6, where the decay probability $N^+(t)$ is folded with the expected energy distribution of B's at UNK [28]. With a mild energy binning, however, one can partly recover the oscillatory behavior. An example of this is shown in Fig 7 [8].

Once the existence of B_s and B_d oscillations in space have been established experimentally, it should be feasible to look also for time dependent CP violating effects [29]. If one considers again processes which are accessible to both B^0 and $\bar{B}^0$, the CP violating effects will be governed by the function λ_f, defined in Eq(32). The time development is particularly simple if the state f is a CP eigenstate ($\bar{f} = \pm f$). In this case, the probability of obtaining a state f at a time t, from a beam which at $t = 0$ was pure B^0, is simply

$$N_f(t) = N_f(0)e^{-\gamma t}[1 - Im\lambda_f sin\Delta mt] \tag{44}$$

[8] For B_d decays, although no oscillations are visible, the convex shape of the l^+ distribution in space is a signal of $B_d - \bar{B}_d$ oscillations

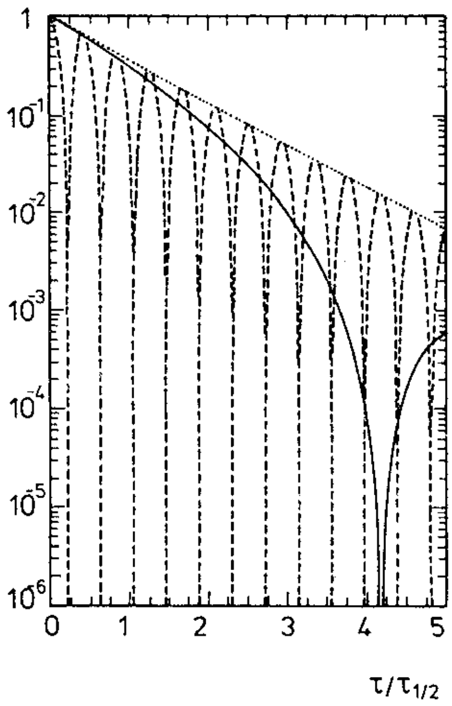

Figure 5: Behavior of $N^+(t)$ for $x = 0.75$ (solid line) and $x = 15$ (dotted line)

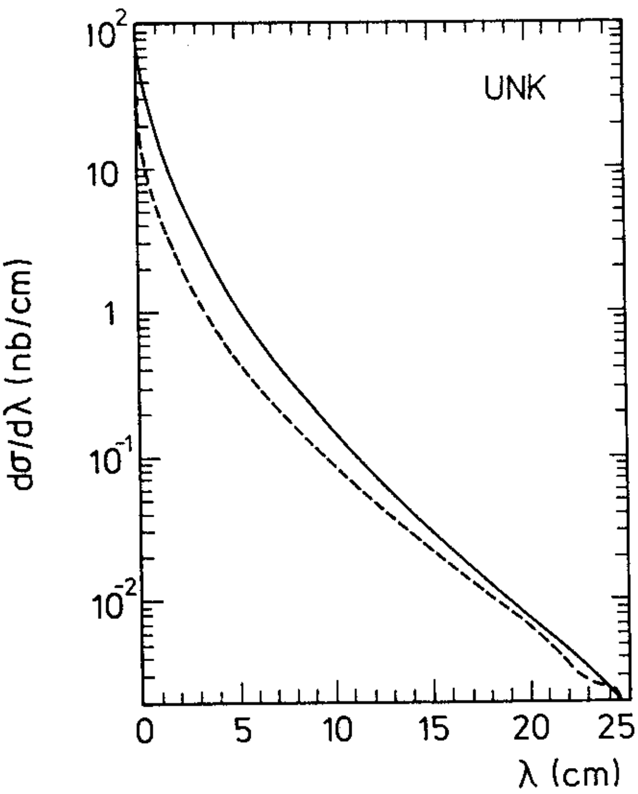

Figure 6: Distribution of l^+'s from B_d (solid line) and B_s (dashed line) decays at UNK energies, as a function of the decay distance in the lab.

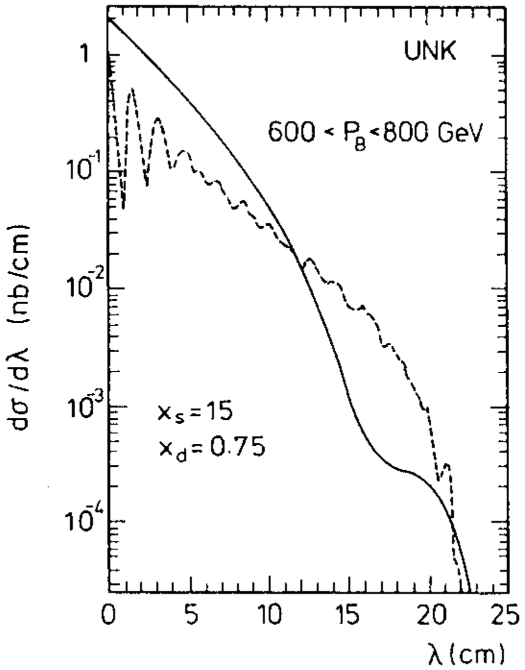

Figure 7: Distribution of l^+'s from B_d (solid line) and B_s (dashed line) decays at UNK energies, as a function of the decay distance in the lab, for produced B's in the interval $600 \leq P_B \leq 800 GeV$

Note that the observation of non exponential behavior is already a signal of CP violation! [29].

To see a time dependent CP violating effect, in contrast to the case of the asymmetry A_f, one would like to have a large mixing parameter: $x = \frac{\Delta m}{\gamma} >> 1$. If this is so, then the non exponential behavior of Eq(44) becomes rapidly visible. Of course, one would also like to have a large value for $Im\lambda_f$. This twin requirements are met by the Cabibbo suppressed decays of B_s. For instance, the decays $\bar{B}^0_s \to \rho^0 K_s$, $B^o_s \to \rho^0 K_s$, suggested by Khoze and Uraltsev [21], have as the relevant phase (in the Wolfenstein parametrization [19])

$$Im\lambda_{\rho K_s} \simeq Arg V^2_{ub} \tag{45}$$

which can be as large as 50%. However, probably the overall rate for $B^0_s \to \rho K_s$ is not much greater than 10^{-5} and the signal is not particularly distinctive. Thus the observation of this particular oscillating time dependence will be very difficult at UNK. But, other channels might be better, especially if they have a good signature. In principle, since these time dependent effects are additive, one could also try to use the sum of various states f, with the same CP properties, to enhance the effect [29].

4 Rates, backgrounds and experimental strategies

As I have indicated earlier, the principal problem of B physics at UNK - and at the Tevatron - will not really be the rate. Rather the question will be whether one will be able to achieve sufficient background suppression. In principle, the estimates for total B production given, which were based on 10^6 interactions/sec, can be increased by using either thicker targets or more intense proton beams [9]. However, although the signal goes up, so does the background, and really nothing is gained.

The important figure of merit for B physics in a fixed target machine is the ratio

$$R_B = \frac{\sigma(B\bar{B})}{\sigma_{in}(pp)} \tag{46}$$

of the B production cross section to the inelastic proton-proton cross section. Perturbative QCD estimates suggest that R_B increases by a factor of roughly 20 between Tevatron energies($\sqrt{s} = 40GeV$) and UNK energies ($\sqrt{s} = 75GeV$). The characteristics of the B signal at UNK, which emerge from the TWISTER program of Ingelman [31], are summarized in Table 2

Table 2: B signal at UNK

$\sqrt{s} = 75GeV$	$\sigma(B\bar{B}) = 190nb$
$q\bar{q} \to b\bar{b}$ 10%	$gg \to b\bar{b}$ 90%
$\sigma_{B_u^+} \sim \sigma_{B_u^-} \sim \sigma_{B_d} \sim \sigma_{\bar{B}_d} \sim 80nb$	$\sigma_{B_s} \sim \sigma_{\bar{B}_s} \sim 20nb$

Using these numbers and $\sigma_{in}(pp) \simeq 30mb$ yields $R_B \simeq 6 \times 10^{-6}$ for UNK, which typifies the signal to background problem. Actually, on heavy targets one may do slightly better, since it is likely that

$$\sigma_A(B\bar{B}) \simeq A\sigma(B\bar{B}) \tag{47}$$

In that case, since $\sigma(Ap) \simeq A^{0.72}\sigma(pp)$, one may gain a factor of $\sim A^{\frac{1}{4}}$:

$$R_B^{UNK} \simeq 6 \times 10^{-6} A^{\frac{1}{4}} \to 2 \times 10^{-5} \quad (for\ W) \tag{48}$$

So being a little optimistic, it is not unreasonable to expect that at UNK the real signal to background to face is of order 10^{-5}.

To do B physics at UNK one needs to devise triggers that can reject these 10^5 background events. Since one can write events on tape at a rate of 10-100/sec, operating at an interaction rate of 10^6 events/sec seems fine, if one can really trigger out the background events. Furthermore, to be able to perform the CP violation tests I discussed, it is necessary to be able to isolate the secondary vertex of B decays. Thus the target must be "active". These twin requirements of triggering and of having the ability of pinpointing the secondary vertex, have been strongly emphasized recently by Bjorken [32], in his comprehensive discussion of strategies for doing B physics at fixed target machines. Possible B triggers include [32]

- triggering on high P_T leptons ($P_T > 2GeV$)
- secondary vertex tags, along with some "front end" microvertex information
- triggering on $\Psi's$

[9] The use of hyperon beams to selectively increase B_s production, as discussed by Vorobyov [30] in this meeting, is also particularly interesting

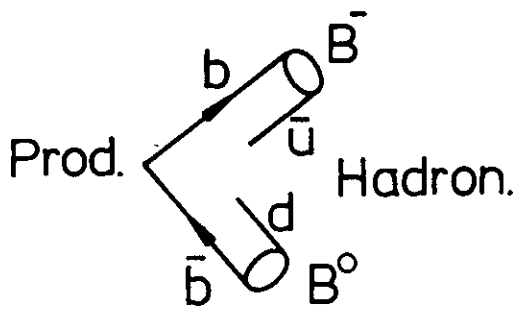

Figure 8: Charge correlation of produced B's

Some of these triggers will be tested soon by the WA82 experiment at CERN, which will use a secondary vertex tag, and by experiment E771 at Fermilab, where the Ψ trigger will be tried. The experience garnered by these efforts will be very valuable for planning experiments at UNK.

I want to discuss here briefly the Ψ trigger proposed in E771 since, in principle, this might be a very relevant trigger for CP violation. The idea of this trigger is to use the $\mu^+\mu^-$ from Ψ decay, in conjunction with information obtained from a front end silicon tracker. Direct Ψ production, which is significant, is rejected by asking that the $\mu^+\mu^-$ pair points to the Si tracker and not the interaction vertex. B meson final states can then be examined by studying the secondary vertex. In practice, the experiment will be more sensitive to decays of the type $B \to \Psi K^+\pi^-$, rather than to the more interesting mode $B \to \Psi K_s$, since the neutral K_s does not track. However, this latter mode is not hopeless. In the E771 proposal they estimate that they may collect as may as $10^3 B \to \Psi X$ decays, with a very minimal background of 10 events, from misreconstructed Ψ's.

The total number of $B \to \Psi K_s$ events which will be reconstructed by E771, will be a good gauge of how difficult it will be to look for CP violation in B decays. My guess is that E771 will be at least 2 orders of magnitude below the number of events needed to perform a statistically significant test of CP violation. Although the ΨK_s signal is roughly 10% of the total Ψ signal, the efficiency of picking out K_s's will probably not be better than 30%. However, to measure the asymmetry $A_{\Psi K_s}$ one needs to know if the decaying B was originally a B^0 or a $\bar{B}^0$. To determine this, perhaps the best hope is to try to establish the charge of the associated B. As shown schematically in Fig 8, an initial B^0 always will be accompanied by a B^-, not a B^+ [10]. The need to know whether in association to the ΨK_s a B^+ or a B^- is produced, implies looking for another secondary vertex. Assuming a 10% efficiency for this, will leave E771 with just a handful of tagged $B \to \Psi K_s$ events.

The factor of 20 increase of signal to background at UNK will help considerably. Still,

[10] Of course, 50% of the time there is no charged companion

unless one has detectors with very large angular coverage [32] to detect a second B decay vertex, one will be pushing very hard to get enough statistics to test $A_{\Psi K_s}$. Similar considerations apply for the time dependent CP violation signals, I discussed. Again one will need an extensive and fine spatial coverage to be able to both follow the signal and tag the initial state B. Care will be needed to select the best modes, not only from the point of view of rate, but also from that of their signature.

5 Concluding remarks

In reflecting on the possibility of doing B physics at UNK, three points became clear to me. I would like to conclude by listing these observations:

1. UNK will have the capability of studying very interesting phenomena in the B system, particularly the existence of CP violating transitions. Accurate measurements of certain hadronic asymmetries will directly provide information on the phase of the Kobayashi Maskawa matrix elements and ultimately test whether this is the source of CP violation.

2. UNK will benefit considerably from exploratory work, just now beginning, at lower energy fixed target facilities at CERN and Fermilab. These experiments are likely to identify what are the useful trigger strategies and they will help determine how active a target one really needs. Experiments at e^+e^- colliders may also help, by uncovering other interesting exclusive modes, with useful signatures.

3. To carry through a program, leading to the observation of CP violation in the B system, is going to be a very challenging task for UNK. This program cannot be done without

   - Clever triggering
   - Smart targets
   - Sophisticated data acquisition and analysis facilities

   Furthermore, if one wants to be successful, one needs to think about this from the very beginning.

Acknowledgments

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