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Abstract

The stringent requirements on detector performances needed to complete an exhaustive study of CP violation in the B meson system are described. The BABAR detector designed to best meet these goals is presented with special emphasis on the innovative technologies used in the different subsystems. Recent results obtained with large scale prototypes have shown that design performances are quite likely to be achieved.

1 CP violation measurements and detector requirements

The detailed description of the CP violation study in the B meson system is outside the scope of this paper and can be found in these proceedings [1] and in [2]. Three conditions have to be fulfilled on the same event for its use in a CP violation measurement and lead to the following requirements:

Requirements for B spectroscopy

Most final states used to study CP violation present a combination of low branching fraction and potentially high background (e.g., $\pi^+\pi^-$, D^+D^-). The detector must then have:

- An excellent momentum and energy resolution
- A good acceptance in the forward region. This is made necessary by the large track density in this region induced by the machine boost.
- Track reconstruction down to p_t below 50 MeV/c. Many useful modes involve D^* which produce a low p_t pion in its decay.
- Powerful particle identification up to 4 GeV. The mode $B_d^0 \rightarrow K\pi$ forms the most dangerous background to the mode $B_d^0 \rightarrow \pi^+\pi^-$ and can have in addition a different CP asymmetry. The highest degree of separation at high momentum is thus required.

- 'No' material in front of the calorimeter. Many modes including low momentum π^0 and photons will be of great importance, for instance $B_d^0 \rightarrow \pi^+ \pi^- \pi^0$.
- K_L^0 detection capability. It will be very interesting to compare CP asymmetries obtained in the modes $J/\psi K_S^0$ and $J/\psi K_L^0$.

Requirements for B tagging

The most common methods used so far for B tagging are based on the lepton tagging and on the kaon tagging.

- Lepton identification down to 300 MeV/c. Recent studies [3] have shown that it is possible to separate soft secondary leptons coming from charm semileptonic decays from the primary leptons, produced in B semileptonic decays.
- Kaon Identification between 0.5 GeV/c and 2 GeV/c. This represents the momentum range for kaons coming from the $b \rightarrow c \rightarrow s$ chain. In these conditions, kaon and lepton tagging contribute equally to the overall tagging efficiency.

Requirement from Δz

- $\sigma_{\Delta z} \ll 250 \mu m$. The resolution must be a small fraction of the average distance between the two B vertices induced by the machine boost.
- Very transparent vertex detector. Since most particles have very low momentum, multiple scattering in the vertex detector plays a key role in the resolution.

2 The PEP-II Beauty Factory

The PEP-II beauty factory [4] is an asymmetric e^+e^- collider with a 9 GeV electron beam colliding with a 3 GeV positron beam. The design luminosity is $3 \cdot 10^{33} \text{ cm}^{-2}\text{s}^{-1}$, leading to 30 fb^{-1} per year. The very high currents in the machine (1 and 2 A in the high and low energy rings respectively) lead to the following issues:

Background control

- The commissioning detector. A special purpose background detector for PEP-II will enable a detailed understanding of PEP-II background during its commissioning and while BABAR is in construction. This initiative enhances significantly the probability of a fast BABAR turn-on in spring 1999.
- Pileup in the calorimeter. The background will induce about 1 MeV per μs in each calorimeter CsI crystal, making the reconstruction of low momenta photons more difficult.

- -Flexible and robust trigger Photoproduced hadrons from machine background will dominate the trigger rate. Multiplicity and p_t cuts are required in order to eliminate this source.

Radiation damage issues

Two subdetectors elements have to pay a special attention to radiation hardness problems:

- Radiation hard Silicon Electronics. These chips, mounted very close to the beam pipe, will receive 250 krad/year in the worst regions.
- Synthetic quartz for DIRC The very good optical transmission required for these quartz bars has been shown to be lost after exposure to a few kilorads for natural quartz. Synthetic quartz has therefore to be used.

The machine schedule

In June 1997, the first beams were stored in the PEP-II high energy ring and impressive results were already achieved : beam lifetime in excess of 6 hours, beam currents of 0.1 A, 1000 bunches in circulation. In October 1997, 0.3 A was obtained. The low energy ring will start its operation in April 1998 and the first collisions are expected in July 1998. A six month period is thus available for tuning the machine for high luminosity and low background before BABAR rolls on early 1999, with a good chance to start its operation with a high initial luminosity.

3 BABAR, an ambitious detector

The design of the BABAR detector has been based on the various requirements exposed above. The overall view of the BABAR detector can be seen on Fig. 1, with its five subsystems : Si vertex tracker, drift chamber, Detector of Internally Reflected Cerenkov light (DIRC), CsI calorimeter and Instrumented Flux Return (IFR).

3.1 The Si Vertex Tracker (SVT)

The SVT is a 5 layer double sided Si vertex detector with 50 and 100 μm pitch read out for both coordinates z and ϕ . The read out scheme is time over threshold, achieved with a custom-made rad hard low noise mixed analog/digital chip. The resolution is given by:

$$\sigma_z = 15\mu\text{m} + 50\mu/p_t; \sigma_\theta = 1.6\text{mrad}/p_t$$

The requirements for good acceptance in the forward region and for low p_t tracks led to the 5 layer design allowing an autonomous pattern recognition and tracking for p_t as low as 50 MeV/c and to the innovative arch design which allows to put all passive materials (support, electronics, cooling, cables) outside of the tracking acceptance (down to 350 mrad). An arch layer and a barrel layer have been exposed to test beam at CERN PS in August 1997 to measure their efficiency and resolution.

Figure 1: The BABAR detector

3.2 The Drift Chamber

The key feature of this chamber is low multiple scattering thru low-mass gas (80 % He-20% C₂H₆) and wires (Al). This allows a factor 2 improvement over previous similar chambers (e.g. CLEO-II) ¹. It will be segmented in 40 layers, both axial and stereo with a resolution given by :

$$\sigma_{p_t}/p_t = 0.21\% + 0.14\% p_t$$

A full length prototype has been built at SLAC and operated with cosmic rays. A 100 μ m cell resolution is achieved in the center of the cell, in agreement with expectation. A small chamber with similar cell structure has been run in a test beam at the CERN PS to study the dE/dx properties. Preliminary results indicate a 6.5% resolution, as expected.

3.3 The DIRC Imaging Cerenkov Counter

The DIRC is a Cerenkov counter where the light production and light transport functions are combined in the quartz bars. This elegant concept leads to several advantages : only passive material in the detector volume, small radial occupancy, small and uniform amount of material in front of the calorimeter, photodetectors and electronics located outside the detector volume leading to easy maintenance and operation, increase of number of photons

¹CLEO-III chamber will be very similar to BABAR's

in the forward region where it is most needed since tracks are more energetic in this domain. Although a novel concept, the DIRC is based on reliable techniques : quartz, water and photomultipliers tubes. The main challenge resides in the precise manufacturing and polishing of the 576 1.25m long quartz bars.

The expected performances of the DIRC are:

- N_γ between 20 (at $\theta = 20^\circ$) and 50 (at $\theta = 60^\circ$)
- $\sigma_{\theta_c} = 4 \text{ mrad}$ (at $\theta = 20^\circ$) and 2.5 mrad (at $\theta = 60^\circ$)
- π -K separation: $> 4 \sigma$ from 0.3 GeV/c (veto mode) up to 4 GeV/c.

The powerful technique of Cerenkov ring imaging will bring also bring the following benefits:

- (i) A useful $\mu - \pi$ separation exists below 700 MeV/c, quite complementary to the one provided by the Instrumented Flux Return, which is fully efficient above 800 MeV/c (see below).
- (ii) The possibility to reconstruct photons conversions in the latter part of the chamber and in the DIRC itself by seeing the rings generated by the electrons.
- (iii) The possibility to tag K decays in flight by observing rings for which the reconstructed θ_c will not lie on the normal (p, θ_c) curves.

Extensive tests of a large scale DIRC prototype have been carried out at the CERN PS in 1995 and 1996. They are described in detail in [5] in these proceedings [6]. The number of detected photons, the angular resolution and the light attenuation in the quartz bars have been found to be in good agreement with expectations. The π -proton separation at 5.4 GeV/c, equivalent to the π -K separation at 2.7 GeV/c - the momentum that would have pions produced in the decay $B_d^0 \rightarrow \pi^+ \pi^-$ at 20° (the worst case) - is 3.6σ as can be seen in Fig.2.

3.4 The CsI calorimeter

The calorimeter consists of 7000 $4.8 \times 4.8 \text{ cm}^2$ CsI crystals covering the barrel and the forward region. The design energy resolution is :

$$\sigma_E/E = 1\%/E^{1/4} + 1.2\%$$

which matches well the charged track momentum resolution and represents a significant improvement over CLEO-II CsI calorimeter, obtained through increased light output and lower noise electronics. This will allow a photon detection threshold as low as 20 MeV. The nominal resolution has been measured in a test beam at PSI [7] using a 5×5 crystal matrix.

Figure 2: π -p separation in the DIRC prototype at 5.4 GeV/c

3.5 The Instrumented Flux Return (IFR)

The Instrumented Flux Return consists of 19 layers of Resistive Plate Chambers (RPCs) inserted in the magnet return yoke. The iron thickness varies from 2 cm to 5 cm, allowing a muon detection threshold as low as 600 MeV/c, reaching full efficiency at 800 MeV/c. This low threshold is important for lepton tagging as explained above. All barrel RPCs have been installed in the BABAR magnet iron representing more than 1000 m². The noise rate is quite low, 0.1 Hz/cm².

The IFR fine granularity will also allow to tag K_L^0 and to measure their direction (not their energy) and thus to study the decay $B_d^0 \rightarrow J/\psi K_L^0$.

3.6 Software Issues

Given the very large data volumes to be collected by BABAR, it is very important to use state-of-the-art techniques in this area also to perform BABAR physics program in a satisfactory manner. BABAR has chosen to use a fully Object Oriented (OO) approach, with OO language (C++), on which the presently running reconstruction program is fully based, OO database as condition and event store, in conjunction with a hierarchical mass storage system (HPSS). It will use in the course of 1998 the OO GEANT4 simulation package. Although some risks are unavoidably attached to this strategy, it will clearly pay off in the long run, given the considerable potential brought by these new techniques.

4 Conclusion

The BABAR detector has been designed having the toughest requirements of CP violation physics in mind : excellent spectroscopy, particle identification over the largest possible domain, good vertex resolution. This, in conjunction, with the unusual environment of an high current asymmetric e^+e^- collider, lead to many innovative features which have been described in some details. All subsystems have exposed large scale prototypes to test beams, showing that the needed performances are quite likely to be met in BABAR.

BABAR and PEP-II schedules allow a 6-month period to tune the colliding beams in PEP-II with a dedicated commissioning detector while finishing BABAR construction. This important feature in addition to the very impressive start of PEP-II high energy ring gives a lot of confidence for a fast startup of BABAR in spring 1999.

References

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