Algorithms of B_d^0 Effective Mass Determination in Investigation of CP-Violation.

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New methods for calculation of a mass of J/Ψ and K_s^0 necessary for calculation of B-meson mass in a new approach to the measurement of CP-violation in B decays are presented. These methods have high speed of calculation and can be easily adapted for new conditions of experiment and can be applied for a set-up with complicated magnetic fields. This method reconstructs vertex coordinates and kinematic parameters concurrently and can be used for analysis of events with incomplete topology.

Introduction

A nontraditional approach in measuring the CP-violation in B-meson decays was suggested in [1],[2]. This approach can be realized in a fixed target experiment with a beam having a high level of intensity and allows to get 10^8 of B-mesons for energy 400 GeV/nucleon, during usual experiment time $10^7 s$, close to those produced at the planned B-factories [3]. At the UNK energy it is possible to achieve up to $10^9 - 10^{10}$ B's produced.

The set-up configuration

The set-up configuration is shown in fig. 1.

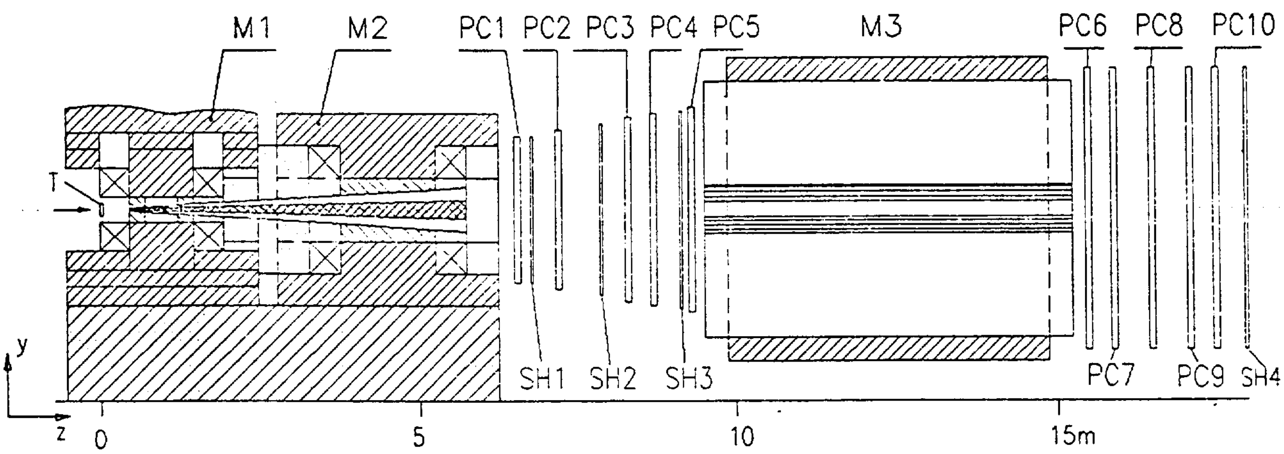

Figure 1: Scheme of the experimental set-up (the first stage). T - target, magnets: M1 - HYPERON, M2 - GOLIATH, M3 - toroidal, PC1-PC10 - proportional chambers, SH1-SH4 - scintillation hodoscopes.

The 450Gev/C proton beam with intensity of $10^{13}s^{-1}$ falls on the tungsten target with thickness of 0.1 times of the nuclear length. Two dipole magnets are placed sequentially behind the target along the beam axis 0Z: M1-the superconducting magnet HYPERON [4] with 1m pole length and integral magnet field of 7Tm and M2-the large aperture "warm" magnet GOLIATH with the pole length of 4m and integral magnet field of 4.5Tm. The gaps between the poles of both magnets are filled by a hadron absorber. The coordinates detectors of the μ's and K_s^0's spectrometers are placed directly downstream the magnets M1 and M2. The narrow gap proportional chambers(PC) which could be operated at high rates [5] are used for the charge particle tracking. The common PC1-PC5 are used in both spectrometers. These chambers have the 1mm wire spacing. The muon spectrometer contains 3 scintillation hodoscopes SH1-SH3. The signals from these hodoscopes are used for the triggering. The toroidal magnet M3 [6] is disposed behind PC1-PC5. The configuration described above was used in a special simulation program used GEANT [7] and PYTHIA [8]. This program was a base for elaboration and investigation of the methods for calculating parameters of events.

The precision of mass reconstruction of B_d^0

In investigation reaction mass of B_d^0 should be reconstructed by using invariant mass of decay products J/Ψ and K_s^0. The tracks of corresponding muons and pions $(\vec{X})$, $(\vec{Y})$ and physical characteristics of the experimental volume are the starting information for mass reconstructions of J/Ψ and K_s^0. The muon parameters are obtained using the coordinate data of hits in PC1-PC5. The central point of our problem is calculation of track's parameters in the vertex $(x_0,\ y_0,\ z_0)$. Let $\vec{R}$ is a vector of track's parameters that contain five elements, where $r_1 = x_0$, $r_2 = y_0$, r_3 and r_4 - gradients coefficients in the point $(x_0,\ y_0,\ z_0)$, r_5 -momentum value in the point $(x_0,\ y_0,\ z_0)$. The anlysis of possible methods for calculation $\vec{R}$ [9]-[13] of distinguished peculiarities shows, that the more convenient method is that from [9].

Let XYZ is a Cartesian coordinate system where axis 0Z is parallel to the beam and lies on the central axis of the set-up, axis 0Y is parallel to the vector of magnetic induction of the second magnet's field. From the system of ordinary differential equations that describe a motion of a particle in magnetic field one can get [12],[13]

$$\begin{cases} x = r_1 + r_3(z - z_0) + \frac{1}{r_5}A_1(z), \\ y = r_2 + r_4(z - z_0) + \frac{1}{r_5}A_2(z), \end{cases} \tag{1}$$

where $A_1(z) \equiv \int_{u=z_0}^{u=z}\int_{v=z_0}^{v=u} F(v)dvdu$, $A_2(z) \equiv \int_{u=z_0}^{u=z}\int_{v=z_0}^{v=u} G(v)dvdu$,
$F(z) \equiv \frac{f(x',y',B_x,B_y,B_z)}{1-E(r_5,z)/r_5}$, $G(z) \equiv \frac{g(x',y',B_x,B_y,B_z)}{1-E(r_5,z)/r_5}$, $E(r_5, z)$-function of energy losses,
$f(x',y',B_x,B_y,B_z) \equiv \frac{e}{c}(1 + x'^2 + y'^2)^{1/2}\left[y'B_z - (1 + x'^2)B_y + x'y'B_x\right]$,
$g(x',y',B_x,B_y,B_z) \equiv \frac{e}{c}(1 + x'^2 + y'^2)^{1/2}\left[(1 + y'^2)B_x - x'B_z - x'y'B_y\right]$. The $\vec{R}$ may be calculated by iterative method with each step using least square fit. A current value of $\vec{R}$ is a solution of the system of normal equations $[E^T \cdot D^{-1}(\vec{V}) \cdot E] \cdot \vec{R} = E^T \cdot D^{-1}(\vec{V}) \cdot \vec{V}^T$, where E - structure matrix of the system (1), $D(\vec{V})$ - covariation martix of a measuring $\vec{V}$, $\vec{V} \equiv \vec{X} \cup \vec{Y}$. The calculation value of $\vec{R}$ is used for making more precise $A_1(z)$ and $A_2(z)$, after that a new iteration is executed and so on until necessary precision of $\vec{R}$ will be reach.

At the first stage of the experiment, detectors dispose between magnets M1 and M2 will be used for calculation mass of J/Ψ. For this configuration the absence of information about track's curvature inside magnets M1 and M2 does not apply the method directly, additional information is required, may be coordinates of the decay vertex. The simulation experiment shows, that the substitution of the real vertex coordinates by coordinates x=0, y=0, z=0 (mean position of the decay vertex of J/Ψ) allows to calculate $\vec{R}$ (therefore, the mass of J/Ψ) without a noticeable loss of precision.

Let complete topology events of K_s^0 will be events when the both pions are passing through the both sets of the proportional chambers: before (PC1-PC5) and bihind (PC6-PC10) the magnet M3, incomplete topology events will be events when one of pions is detected only by the set (PC1-PC5). The next method may be used for complete events. On the first stage separately for each of pions $\vec{R}$ is calculated on the right boundary of the magnet M2 with using the method described above. On the second stage taking into account that the decay of K_s^0 is realised in the homogeneous field the parts of pion's momentum in decay vertex necessary for a mass calculation may be calculated as the parts in the point of intersection of track's projections on the plane XOZ.

For a part of the complete topology events and for the incomplete topology events (that form approximately one half of all events and could not be analysed in principal by the method described above) another method could be used. The analysis of all tracks of the decay particles when calculated concurently the vertex coordinates and all momenta is the main point of this method. For simplification of the calculation formulas the origin of the coordinates system is transferred on the right boundary of the magnet M2. Let $\vec{R}_i$, $\vec{V}_i$, $\vec{P}_i$ are vectors, where i - number of produced pion (i=1,2), r_{i1} - x-coordinate of a track of i-th pion for z=0, r_{i2} - y-coordinate of a track of i-th pion for z=0, r_{i3} r_{i4} - gradients in a point (r_{i1}, r_{i2}, 0), r_{i5} - momentum in a point (r_{i1}, r_{i2}, 0), v_1, v_2, v_3 - vertex coordinates of K_s^0 decay, p_{i1} - angle between axis 0Z and projection of the i-th pion's momentum on the plane X0Z, p_{i2} - angle between axis 0Z and projection of the i-th pion's momentum on the plane Y0Z, p_{i3} - momentum of the i-th pion. The $\vec{R}$ is expressed over the $\vec{V}$ and $\vec{P}$ for z=0.

$r_{i1} = v_1 - \frac{\hat{p}_{i3}}{0.3 \cdot H} \cdot [\cos p_{i1} - [1 - (v_3 \cdot \frac{0.3 \cdot H}{\hat{p}_{i3}} + \sin p_{i1})^2]^{1/2}]$,

$r_{i2} = v_2 - \tan p_{i2} \cdot \cos p_{i1} \cdot \frac{\hat{p}_{i3}}{0.3 \cdot h} \cdot [\arcsin (v_3 \cdot \frac{0.3 \cdot H}{\hat{p}_{i3}} + \sin p_{i1}) - p_{i1}]$,

$r_{i3} = \frac{v_3 + \sin p_{i1} \cdot \frac{\hat{p}_{i3}}{0.3 \cdot H}}{\frac{\hat{p}_{i3}}{0.3 \cdot H} \cdot [1 - (v_3 \cdot \frac{0.3 \cdot H}{\hat{p}_{i3}} + \sin p_{i1})^2]^{1/2}}$, $r_{i4} = \frac{\tan p_{i2} \cdot \cos p_{i1}}{\cdot [1 - (v_3 \cdot \frac{0.3 \cdot H}{\hat{p}_{i3}} + \sin p_{i1})^2]^{1/2}}$,

$r_{i5} = p_{i3}$, where H - value of the magnetic induction, $\hat{p}_{i3} \equiv p_{i3} \cdot [\frac{1 + \tan^2 p_{i1}}{1 + \tan^2 p_{i1} + \tan^2 p_{i2}}]^{1/2}$.

Let N_i - number of the registration coordinates of the i-th pion's track, then $\vec{V}$ and $\vec{P}$ may be calculated from the minimum of the function F

$F \equiv \sum_{i=1}^{2} \sum_{j=1}^{N_i} [[x_{ij} - (r_{i1} + r_{i3} \cdot z_j + \frac{A_{i1}(z_j))}{r_{i5}}]^2 + [y_{ij} - (r_{i2} + r_{i4} \cdot z_j + \frac{A_{i2}(z_j))}{r_{i5}}]^2]$.

Obviously, for some part of incomplete topology events (where the corresponding track is a straight line practically, because the momentum's module of the i-th pion is very large) only the value of the lower boundary of the $| r_{i5} |$ could be calculated in this method. More precision value of the r_{i5} could be calculated if coordinates of B_d^0 decay vertex and condition of complanarity of momenta K_s^0 and decay pions will be taken into account.

Calculated kinematic parameters J/Ψ and K_s^0 allow to calculate B_d^0 mass with precision need for the experiment's execution.

Conclusion

New methods for calculation of a mass of J/Ψ and K_s^0 necessary for determination of B_d^0 mass in a new approach to the measurement of CP-violation in B decays are presented. These methods have high speed of calculation and can be easily adapted for a new condition of experiment and can be applied for a set-up with complicated magnetic fields. A new method for analysis of K_s^0 events (incomplete topology case) is presented, this method reconstructs vertex coordinates and kinematic parameters of pions in K_s^0 decays concurrently. The precision of calculation of a mass B_d^0 - 117MeV, J/Ψ - 286MeV, K_s^0 (complete topology) - 9Mev, K_s^0 (incomplete topology) - 14MeV.

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References

[1] V.D. Kekelidze JINR, E2-88-460, Dubna(1988).

[2] A.N. Aleev et al. JINR, D1-89-614, Dubna(1989).

[3] T. Nakada (Editor), 90-02, PSI PR-90-08. Geneva(1990).

[4] I.A. Vetlitsky et al. ITEF-69, Moscow(1979).

[5] B.G. Zalikhanov et al. New Technology for Making Multiwire Chambers. Submitted to NIM.

[6] L. Anderson et ai. NIM, v.223(1984), p.26.

[7] R. Brun et al., GEANT3, CERN, DD/EE/84-1, Geneva(1987).

[8] H.-U. Bengtsson Comp. Phys. Commun.(1984), v.31, p.323.

[9] I.M. Ivanchenko, P.V. Moissenz, A.M. Rozhdestvensy In the book:"Proccedings of the VIII Work Meeting of the Neutrino Detector Set-Up IHEP-JINR". JINR, D1,2,13-88-90, Dubna(1988), p.197.

[10] I.M. Ivanchenko, P.V. Moissenz, In the book:"Proccedings of the VIII Work Meeting of the Neutrino Detector Set-Up IHEP-JINR". JINR, D1,2,13-88-90, Dubna(1988), p.187.

[11] V.P.Zhigunov, S.N. Sokolov PEPN(1982), v.13, p.1024.

[12] H. Wind NIM(1974), v.115, p.431.

[13] R. Brun NA4 Analysis Program. CERN, DD/EE/79-3,1979.