The E614 Detector Alignment

(Response to "Module Stack Misalignment" message)

V.I. Selivanov

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Writing in response on the R. Henderson's message "Module Stack Misalignment" from 14th February [1], I would like to propose the procedure to measure the misalignment. Detector calibration procedure and all cases of misalignment are described also.

1 Detector Geometry

E614 detector is assembled and fixed on the cradle. The detector is illuminating by a beam in order to reconstruct position of each sense wire in space. The U(V) position of each U(V)-wire relative to 1st wire in 1st U(V)-plane can be reconstructed by using a beam at a small angle θ between the beam direction and the orthogonal to the wire planes. Relative Z position of each wire can be reconstructed by applying the beam at $\theta \approx (45 - 60)°$ and azimuthal angle $\phi \approx 45°$. Coordinate system (U, V, Z) connected with the detector is used here. About 10^5 particles per wire are needed to reach the position accuracy about 10μ [2]. The random errors < 10μ in sense wire positions (not systematic inaccuracies) are unimportant. But deviation (2μ) of average distances in the assembly will cause the shift > $5 \cdot 10^{-4}$ of the δ parameter for example [3]. The needed total statistics for the precise detector calibration must be estimated. Obviously the reconstruction of the real wire positions in the coordinate system (U, V, Z) is the first needed step in order to carry out the E614 goals. Some attempts of the reconstruction were been done [2,4]. Let me suppose that we will be able to reconstruct the full geometry of the E614 detector (wire positions, shift and angle between planes, Z position of each plane) in the coordinate system (U, V, Z).

Any beam can be used for the measurement of the true wire positions. A high momentum beam is preferable because the average multiple scattering angle $\theta_0 \sim 1/(p \cdot \beta)$, where p is momentum of particle, β is the velocity. Pions with $p \approx 360$ MeV/c ($T_\pi \approx 230$ MeV, total intensity > 10^7 s^{-1}) from M11 beam line are most energetic particles at TRIUMF. The beam can be used at small angles θ between the beam and the Z axis for the reconstruction of the U (V) wire positions. The same beam can be used for the Z wire positions reconstruction at the $\theta \approx (45 - 60)°$ because the range of pion at T ≈ 230 MeV in G10 plate is more than 100 g/cm^2 (58 cm). This run on M11 beam line is an important and long time part of the experiment. We will have as result of the run the full information about the detector geometry.

The detector together with the cradle can be moved and installed into the E614 magnet after the M11 run. We must provide the detector geometry stability during its transportation and installation.

2 Detector – Muon Spin

The Z axis of the detector must be aligned to the beam axis or, more exactly saying, to the average direction of muon spin stopped in the Al–target. (Let me omit temporally the question about the alignment to the magnetic field). The measurement of the angle θ' between the Z axis of the detector and the average muon spin direction $<\mathbf{S}_\mu>$ can be done at B=0. Surface muon beam with $P_\mu \approx -1$ from M13 stops into the Al–target in center of the detector. Decaying positrons have the angle Michel distribution $N(\theta) = N_0(1 - P_\mu\xi\cdot\cos\theta)$ if $\theta' = 0$, where θ is the polar angle between the Z axis and vector $-<\mathbf{S}_\mu>$. If $\theta' \neq 0$ the angle Michel spectrum becomes a function of azimuthal angle ϕ. Let me quote a part of [3] further:
"We simulated Michel spectrum for $P_\mu = -1$ and $B = 0$ in polar coordinates with polar angle θ *and azimuthal angle* ϕ*. We have shown that fitting program can find the* ϕ *value with an accuracy better than 0.1mr for total statistics of* 10^8 *muon decays."*
The measurement of the angle θ' (or ϕ) requests B = 0. Really saying the muon spin direction must be saved during a time about 10 μs. Value of $B_\perp = 0.01$G will rotate the muon spin on ≈ 10mr in 10μs, therefore the component $B_\perp$ must be less than 0.001G. Another way is to measure the $B_\perp$ and $B_\parallel$ components with a needed precision and to introduce them into a fitting program. Time of muon depolarization is more than ≈ 30μs in a pure Al. The depolarization will cause inessential decreasing of the $(P_\mu\xi)$ value in the 10μs.

The suggested procedure allows also measuring of a "tilt" angle [1] because the "tilt" angle means that $\theta' \neq 0$ between Z axis of the assembly and the muon spin $<\mathbf{S}_\mu>$.

Next question is about a needed accuracy of the θ' angle measurement. Value of the $\theta' = 1$mr will decrease only the measured value of $(P_\mu\xi)$ from 1 to $1 - \cos\theta' \approx 1 - 5\cdot10^{-7}$ during the main experiment. The $\theta' = 1$mr will distort the $1/\cos\theta$ dependence also. This distortion is unimportant also according to [5].

3 Detector – Magnetic Field

Let me now to discuss the question about the misalignment between the Z axis and the Z′ axis of the magnetic field. The misalignment (if we do not know that) will distort the positron helixes. This distortion has been analyzed in [6]. I believe the misalignment angle $\theta' = 0.1$mr even will distort the positron helix sufficiently. More detailed estimations are needed to define the dependence between the θ' value and the positron reconstructed values of the $<\cos\theta_e>$ and $<p_e>$ because the shift of 10^{-4} of the $<\cos\theta_e>$ and $<p_e>$ will move the Michel parameters on ≈ 10^{-4} also. More detailed statistical simulation is needed also to estimate the requested statistics for the θ'measurement during the main experiment in order to input this angle into reconstructed values of θ_e and p_e. The misalignment angles θ_U and θ_V can be introduced in a fitting program as common fitted parameters for 10^5 (for example) fitted helixes in order to reduce a correlation between the $\theta_{U,V}$ and the helix parameters.

4 Control

Let me now to discuss methods of control all these alignments during the main experiment:

- Alignment control between the muon beam and the magnetic field could provide the muon TEC counter hard connected to the iron yoke. (Measurement of the muon beam position by the first PCs2 (or PCs4) is not so sensitive to beam shift because the chambers placed into strong magnetic field). Really saying it will be control between the beam and the iron yoke. Control of the alignment of the iron yoke relative to the magnetic field direction could be provided by optical methods. Requested accuracy of the control is not more than 1mr in order to do not shift the Michel parameters sufficiently. Influence of the 1mr misalignment on the fringe field depolarization must be simulated. Methods of the initial alignment between the muon spin $<\mathbf{S}_\mu>$ and the magnetic field were been discussed in [7].
- The initial alignment between the Z axis of the detector and the muon spin $<\mathbf{S}_\mu>$ has been discussed above. The requested accuracy is about 1mr. We can control the alignment by the muon beam directly only at B = 0. We can control the alignment by optical methods permanently as the alignment between the superconducting magnet (or/and the iron yoke) and the detector edge(s).
- Alignment between the Z axis of the detector and the Z′ axis of the magnetic field requests most accuracy. Direct measurement the angle θ′ is possible from the reconstructed values of the $<\cos\theta_e>$ and $<p_e>$ at sufficient statistics of the muon decays. Optical methods of the control are necessary of course. Connection between the detector and the magnetic field must be hard and stable during a run.

5 References

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6. Roman Tacik. Proposal for Determining the Relative Alignment of the E614 Detector and the Magnetic Field on an Event–by–Event Basis, message to E614Software@…, March 12, 1999.
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