

Detector Components and Parameter Specifications for Achieving Target Accuracy

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1 Introduction

High-precision measurements require an integrated detector system where each component is optimized to minimize systematic uncertainties and maximize signal efficiency. To resolve an asymmetry at the level of 10^{-3} , the overall experimental setup must achieve a statistical precision better than 0.1–0.2%. This document outlines the required parameters for each detector element and explains the importance of the data they provide in the overall analysis.

2 Trigger Scintillators

2.1 Required Parameters

- **Time Resolution:** Better than 100 ps to ensure accurate timing of the beam particles and decay events.
- **Efficiency:** Above 99% to minimize missed triggers and ensure high event statistics.
- **Signal-to-Noise Ratio (SNR):** High SNR for clean pulse identification, reducing background from electronic noise.

2.2 Role and Impact

- **Event Timing:** Fast scintillators provide the initial trigger signal, ensuring that only relevant events (those with the proper timing) are recorded.

- **Background Rejection:** High efficiency and good SNR help reject noise and spurious signals, which is critical when aiming for sub-percent statistical precision.
- **Synchronization:** Precise timing is essential to correlate signals from other detectors (e.g., tracking and calorimetry) and to reconstruct event topology accurately.

3 Tracking Detectors

3.1 Required Parameters

- **Spatial Resolution:** On the order of $100\ \mu\text{m}$ or better to accurately reconstruct charged particle trajectories and decay vertices.
- **Timing Resolution:** A few nanoseconds to properly correlate tracks with trigger signals.
- **Efficiency:** Above 98% for track reconstruction to ensure minimal loss of charged particle information.
- **Multiple Scattering:** Minimal material budget to reduce scattering effects, which can degrade momentum resolution.

3.2 Role and Impact

- **Vertex Reconstruction:** High spatial resolution is critical for precisely determining the decay vertex of neutral kaons, which in turn improves the measurement of decay kinematics.
- **Momentum Measurement:** Accurate tracking directly affects the determination of particle momenta, an essential input for decay asymmetry studies.
- **Event Topology:** Detailed track information helps in discriminating signal events from background, enhancing overall data quality.

4 Spectrometer Magnet

4.1 Required Parameters

- **Magnetic Field Strength:** Typically in the range of 1–2 Tesla, depending on the momentum range of interest.

- **Field Uniformity:** Better than 1% across the tracking volume to ensure consistent momentum bending.
- **Stability:** High stability over time with precise calibration (relative uncertainty $< 0.1\%$) to avoid systematic shifts in momentum measurements.

4.2 Role and Impact

- **Momentum Analysis:** The bending of charged particle tracks in the magnetic field allows for the precise determination of momenta.
- **Charge Separation:** Accurate momentum and curvature measurements enable the discrimination between positively and negatively charged particles, which is essential for PID.
- **Systematic Control:** A well-calibrated and stable magnet minimizes systematic uncertainties in momentum reconstruction, directly impacting the resolution of the asymmetry measurement.

5 Particle Identification (PID)

5.1 Cherenkov Detectors

5.1.1 Required Parameters

- **Threshold Setting:** Optimized refractive index to differentiate electrons/positrons from pions and other charged particles.
- **Time Resolution:** On the order of 100 ps to provide fast PID information.
- **Efficiency:** High detection efficiency ($> 95\%$) for the particle species of interest.

5.1.2 Role and Impact

- **PID Accuracy:** Helps in the separation of electrons from hadrons, reducing misidentification and thus improving the purity of the sample.
- **Kinematic Reconstruction:** By accurately identifying particles, Cherenkov detectors assist in refining the momentum and energy reconstructions critical for asymmetry measurements.

5.2 Electromagnetic Calorimeter

5.2.1 Required Parameters

- **Energy Resolution:** Typically, $\Delta E/E \lesssim 5\%$ for the energy range of interest.
- **Spatial Resolution:** High segmentation (e.g., a cell size of a few centimeters) to accurately measure the shower position.
- **Linearity:** Good linearity over the operational energy range to allow precise energy calibration.

5.2.2 Role and Impact

- **Energy Measurement:** The calorimeter provides an independent measurement of the energy deposited by electromagnetic showers, crucial for cross-checking momentum measurements from tracking.
- **Particle Separation:** Combined with Cherenkov detectors, it enhances PID by distinguishing between electromagnetic and hadronic showers.
- **Systematic Reduction:** Accurate calorimetry reduces systematic uncertainties associated with energy scale and calibration, essential for achieving the desired precision.

6 Optional Muon Detector

6.1 Required Parameters

- **Absorber Thickness:** Typically a few tens of centimeters of iron to filter out non-muon backgrounds.
- **Detection Efficiency:** High efficiency (around 95% or higher) in identifying muons.
- **Timing Resolution:** Sufficient to correlate with other detector signals (few nanoseconds).

6.2 Role and Impact

- **Background Rejection:** The muon detector helps reject muon-induced background events, which might otherwise contaminate the signal sample.
- **Improved PID:** Provides an additional layer of particle identification, ensuring that only the relevant decay products are analyzed.
- **Data Quality:** Reducing background events directly improves the statistical precision and overall reliability of the asymmetry measurement.