The P326 Gigatracker

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Abstract

P326 aims at measuring the very rare decay $K^+ \to \pi^+\nu\overline{\nu}$ at CERN. The beam spectrometer, named Gigatracker, has to provide precise position and time measurements on the beam particles at about 1 GHz rate. The material budget per station is minimized in order to preserve the beam quality and downstream measurements on the decay product π^+.

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1 P326 goal and strategy

Assuming a branching ratio [1] of 10^{-10}, a signal acceptance of about 10% and a signal-to-background ratio (S/B) of about 10, P326 aims to collect roughly 80 events $K^+ \to \pi^+\nu\overline{\nu}$ in two years of data taking. One P326-year corresponds to 100 days at 60% running efficiency and about 5×10^{12} kaon decays [2], at the SPS cycle consisting of a 4.8 s spill every 16.8 s.

Redundant measurements of the event kinematics and hermetic vetoes are necessary to achieve a sufficient background rejection. Roughly 92% of K^+ background decays ($K_{\mu2}, \pi^+\pi^0, \pi^+\pi^+\pi^-, \pi^+\pi^0\pi^0$), can be kinematically constrained by means of the squared missing mass, assuming the charged track is the π^+ track. The remaining 8% (K_{e3}, $K_{\mu3}$, $K_{\mu2}\gamma$, $\pi^+\pi^0\gamma$, K_{e4}, $K_{\mu4}$) are suppressed by particle ID and γ and μ vetoes.

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[1] A branching ratio of $(8.0 \pm 1.1) \times 10^{-11}$ is predicted in the Standard Model [1], a value of $1.47^{+1.30}_{-0.89} \times 10^{-10}$ has been measured by E949(BNL) [3].

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2 P326 layout and requirements on Gigatracker

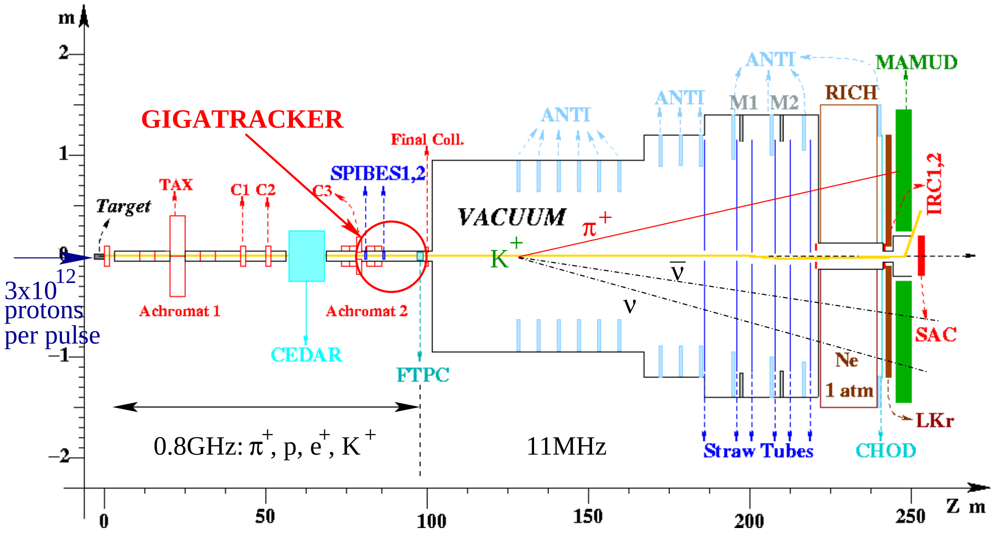

Fig. 1. P326 Layout. The expected rates on the detectors are about 1 GHz at the Gigatracker stations and about 11 MHz downstream of the final collimator.

The P326 hadron beam[2], with its narrow momentum band ($\frac{\sigma(p)}{p} \simeq 1\%$) centered at 75 GeV/c, has been designed to maximize the Kaon production rate and signal acceptance. Kaons with high energy, produced by high momentum (400 GeV/c) SPS-protons impinging on the P326 target (Fig. (1)), enhance acceptance, resolution and suppression of $\pi^+\pi^0$ background through a better photon detection efficiency. A disadvantage of this scheme is that pions and protons, that make up 60% and 20% of the beam rate, respectively, are not readily separated from kaons, which make up only 6% of the beam rate. Including the electron component of 14%, the total beam rate is estimated to be about 1 GHz.

The Gigatracker is located in the region of the second achromat (Fig. (2)), where the beam is displaced in the vertical axis. The time and momentum of the beam particle will be measured by the first two stations (pixel detectors), its direction by the second and the third stations. The average rate on the Gigatracker station ($36{\times}48\text{mm}^2$ area) is about 0.6 MHz/mm^2. The beam being slightly converging, the rate distribution is not uniform and reaches a peak value of 1.9 MHz/mm^2 in the center of the third station. Downstream of the final collimator and the fiducial region, the momentum and direction of the π^+ are measured by a double spectrometer and the event time is given by charged hodoscope counters. Due to the high rate, more than one track can be found in the Gigatracker[1] that matches the one of the π^+. Events with a wrongly matched track have, because of the beam divergence of about 100 μrad, an about 3.5 times worse missing mass resolution (Fig. (3)) than events

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[1] E.g. within a 500 ns coincidence window, at 1 GHz rate, there is a 40% probability to have more than one matching track in the Gigatracker.

with correctly matched tracks, thus spoiling the S/B. The matching of beam tracks and π^+ is performed in both space and time.

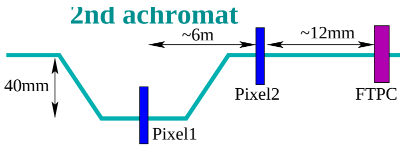

Fig. 2. Gigatracker layout

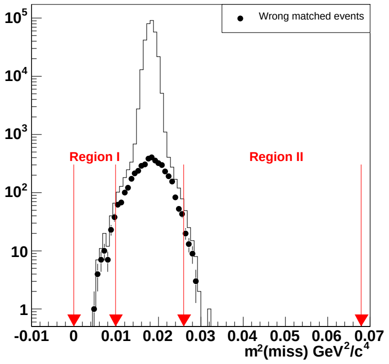

Fig. 3. m^2_{miss} in case of correct (line) and wrong (dots) track matching in the Gigatracker, for $K^+ \to \pi^+\pi^0$ events.

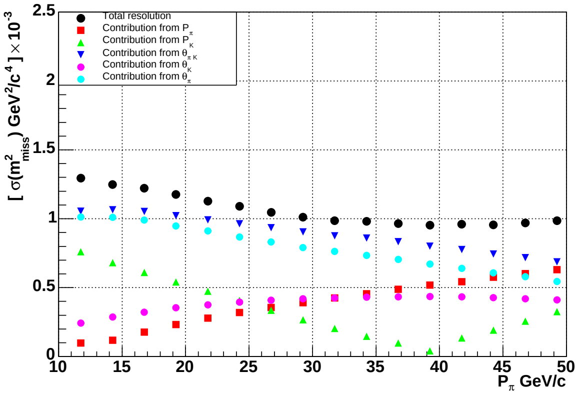

Fig. 4. Contributions to the m^2_{miss} resolution as a function of the π^+ momentum, obtained in an MC simulation assuming 0.4% X_0 per station and a pixel size of 300×300 μm².

Key requirements on the Gigatracker can be summarized as follows:
- The material budget per station must be $X/X_0 \ll 1\%$ to minimize multiple scattering.
- Track resolutions must be: $\frac{\sigma(p)}{p} \lesssim 0.4\%$; $\sigma(\theta) \lesssim 17$ μrad; $\sigma(t)_{track} \lesssim 120$ ps.
- A rate of 1GHz, which is not uniformly distributed, must be sustained.
- The detector should be ready for data taking in 2009.

In order to fulfill all these requirements, the first two stations will be equipped with hybrid silicon pixel detectors, a well known technique where the front-end chip, produced in CMOS technology, is bump-bondend on the silicon sensor. The third station will be a TPC with micromegas as amplification detector (FlashTPC): it is an improved version of the NA48/2-KABES detector where $0.13\% X_0$ and a spatial resolution of 70 μm have been obtained [5]. The FlashTPC has to sustain a rate per strip ten times higher than in NA48/2 while maintaining a spatial resolution of better than 90 μm.

3 Gigatracker pixel stations design

A sensor thickness of 200 μm has been chosen for the pixel detector, as a good compromise between the request for minimum material budget, fast charge

collection and a signal large enough for the electronics chain. The silicon on the chip side, being mostly a support, will be thinned down to $\lesssim 100\ \mu$m. In this way, the total amount of silicon can be kept below 0.32% X_0. The ALICE Silicon Pixel group has already produced silicon sensors of 200 μm thickness and bump-bonded them to front-end silicon chips from wafers thinned down to 150 μm [4]. Cooling and support will be performed by a single 125 μm thick carbon fibre structure, corresponding to about 0.06% X_0. The detector can be operated in vacuum, thus saving two mylar windows (100 μm, 0.0035% X_0 each) which would otherwise be needed to preserve the beam vacuum. The total material budget per station is about 0.4% X_0.
The contributions to $\sigma(m^2_{miss})$ due to the beam track momentum and angular resolutions are not crucial: a pixel size of 300 μm × 300 μm is adequate, corresponding to a spatial resolution of about 90 μm in both vertical and horizontal directions (Fig. (4)).

A dedicated ASIC chip is foreseen, which comprises the following main functional blocks: a fast amplifier and shaper, a low time-walk discriminator and a high resolution TDC. Both 0.25 μm and 0.13 μm CMOS submicron technology are under evaluation in terms of dimensions and power consumption of building blocks, density of components and noise performance. Two main architectures are under study: one TDC per pixel and one TDC per group of pixels. The design of the chip is determined by the high beam rate, the data transfer and the pixel grouping strategy. The inefficiency due to dead time must be kept below 2%.
The daily particle flux on a Gigatracker station will be about $9{\times}10^{12}$ particles/cm^2 on average and up to three times that value in the center. In the approximation of a π^+-only beam, the daily neutron-equivalent fluence in the center will be[3] about $2{\times}10^{12}$ 1-MeV n per cm^2. For comparison, this daily fluence approximately corresponds to the fluence that the Alice SPD pixels have to sustain in ten years [4]. The expected 100-days equivalent fluence is comparable to one year of operation for the innermost pixels in CMS [7].

Various options are under study for the sensor, the most accessible by 2009 being p$^+$ pixels on an n-type substrate, operated significantly over-depleted at a working point of 100-300 V, in order to obtain a fast charge collection within a few ns. Easy and precise replacement of detectors is foreseen, when the operating limits in terms of bias voltage or leakage currents are reached. The detectors can be replaced, without interrupting the normal data taking, during regular SPS machine development periods.
The total ionizing dose (TID) on the detectors, in 100 days, will be 2 Mrad in average. Radiation-hard designs, for example using enclosed transistors, in 0.25 μm CMOS technology have already shown to withstand doses of up to 30 Mrad [8].

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[3] Assuming a safety factor of two and a conversion factor[6] of 0.37.

4 Conclusions

Two pixel detector stations and a FlashTPC, the three stations being called Gigatracker, will measure the momentum ($\sigma(p)/p \lesssim 0.4\%$), direction ($\sigma(\theta) \lesssim 17\ \mu$rad) and time ($\sigma_{track} \lesssim 120$ ps) of beam particles for the proposed P326 experiment.

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