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SECONDARY BEAM LINE PHASE SPACE MEASUREMENT AND MODELING AT LAMPF*

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Abstract

Hardware and software have been developed for precision on-line measurement and fitting of secondary beam line phase space parameters. A system consisting of three MWPC planes for measuring particle trajectories, in coincidence with a time-of-flight telescope and a range telescope for particle identification, has been interfaced to a computer. Software has been developed for on-line track reconstruction, application of experimental cuts, and fitting of two-dimensional phase space ellipses for each particle species. The measured distributions have been found to agree well with the predictions of the Monte Carlo program DECAY TURTLE. The fitted phase space ellipses are a useful input to optimisation routines, such as TRANSPORT, used to search for superior tunes. Application of this sytem to the LAMPF Stopped Muon Channel is described.

Introduction

A system has been developed to rapidly measure and analyze secondary beam phase space parameters. The traditional approach has been to measure a beam profile at one or two positions along the system and compare these data with the results of an optical calculation. The calculation is then the source of all other information about the beam transport. In large acceptance medium energy beam lines, geometric and chromatic aberrations, scattering and decay are often significant, and computer codes are required with accurate treatments of these effects. A simple first or second order matrix approach may not suffice to describe the system. The LAMPF Stopped Muon Channel, for example, is not adequately described by this method.

A superior approach utilizes measurement of charged particle tracks in sufficient detail to calculate all beam phase space parameters from the particle distributions. This can then be compared to a Monte Carlo model of the beam line which includes higher order optics, energy loss, decay, scattering and physical parameters such as slit and aperture geometry. Agreement between the model and data justify use of the code to infer beam parameters at other points in the beam line. Maximum benefit is achieved when the apparatus can analyze, display and fit beam phase projections in real-time, enabling comparison with the Monte Carlo code and providing input to conventional beam optimization programs. Such a system rapidly provides the physicist with the comprehensive information needed to tune the beam line while taking the data.

Apparatus

An apparatus employing three multiwire proportional chambers for measuring particle trajectories, in coincidence with a time-of-flight system and a range telescope for particle identification has been interfaced to a computer. On-line data acquisition and analysis provide the fitted beam phase space projections. The apparatus is a dedicated assembly and can be moved rapidly into any LAMPF secondary beam line.

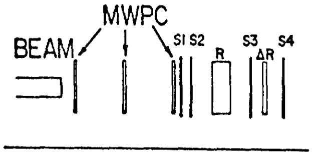

Fig. 1 - Schematic representation of the beam phase space measurement hardware.

Figure 1 is a schematic view of the apparatus. The three track chambers are proportional chambers with delay-line-readout[1], and an active area approximately 25 cm X 30 cm. They are arranged along the longitudinal beam coordinate over a distance of 1 meter. Generally, the apparatus is positioned at the end of the beam line and one of the chambers is positioned at the final focus.

Four plastic scintillation counters follow the chambers. They are used as a trigger telescope and in the particle identification system. In a secondary beam transporting several particle species, particle identification is accomplished by time-of-flight and range techniques. An upstream counter, with a suitable delay, or a timing signal synchronized with the LAMPF beam microstructure is used to stop a time-of-flight circuit. The start signal is provided by the counter telescope, with the timing set by the first counter S1.

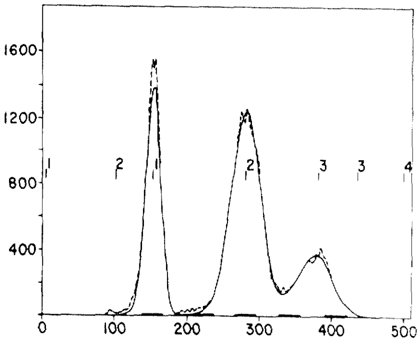

Fig. 2 - Raw time-of-flight spectrum from a development run in the LAMPF Stopped Muon Channel. The accelerator H^- beam was chopped with a 40 ns time structure. The chopper signal provided a stop pulse, and the counter telescope provided the start. The peaks represent, from left to right, the e^-, π^- and μ^- portions of the beam. The order of the peaks includes a wraparound due to the 40 ns chopper time. The solid curve is a fit to the data as described in the text. The large dashes are a background fit. The numbered cursor positions are the physicist's on-line definition of the centers and limits of the peaks.

A typical raw time-of-flight spectrum, from a development run with 40 ns chopped H^- beam, at the LAMPF Stopped Muon Channel is shown in Fig. 2. Particle separation for this momentum of 140 MeV/c is clean. An additional identification is provided by range requirements. Polyethylene absorber of thickness R is placed between S2 and S3, and a thinner slab, ΔR, is used between S3 and S4. The coincidence S1·S2·S3·S4 defines particles with range greater than the combined absorber thickness. The coincidence $S1 \cdot S2 \cdot S3 \cdot \overline{S4}$ defines particles with range between R and R + ΔR. The thickness R can be adjusted to select a particular particle type and ΔR varied to define a momentum range to be studied. All counter signals, timing and pulse height information are presented to the on-line computer through conventional CAMAC electronics.

Data-Acquisition and Analysis

The data is recorded and analyzed by a PDP-11/60 computer using the RSX-11 system. The data-acquisition tasks are organized under the LAMPF standard software

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"Q"[2]. The analysis involves track fitting, application of cuts on the tracks and other measured quantities and calculation of beam trajectory parameters at the specified position along the system. A separate routine displays histograms, as in Fig. 2, or two-dimensional phase space plots, as in Fig. 3.

An additional and crucial feature of the software is the ability to fit the histograms and scatter plots. Figure 2 is a time-of-flight spectrum in which the electron and pion peaks have been fitted to a Gaussian expression with a polynomial background under each peak. The physicist examines the raw distribution, and keys in the limits of the peaks and backgrounds. The fit is computed via a least squares algorithm, and added to the display. The technique used in fitting phase space projections is different. A fitted second moment matrix for the two-dimensional histograms is obtained by an iterative moment method using Gaussian weights[3]. It is a robust method that reduces the influence of the distribution tails. One-standard deviation and two-standard deviation ellipses are then calculated and displayed. Examples of these on-line fits can be seen in Fig. 3(a), (b), (c), and (d). The fitted ellipse parameters provide the physicist with the information needed for conventional beam ellipse matrix formulations[4]. The momentum phase space measurement is obtained from the time-of-flight spectrum, using the known channel length.

Application to the LAMPF Stopped Muon Channel

The apparatus has been used to measure the beam phase space in the East Branch of the LAMPF Stopped Muon Channel[5,6] for a 140 MeV/c π^- tune. Originally designed as a decay muon beam, the SMC contains a large number of elements in the central decay section. Data from this channel for a direct beam setting provides a stringent test of a Monte Carlo model. We have used the program DECAY TURTLE[7] to simulate the channel. Our calculation includes the full transport, all apertures and fringe fields, and particle decay. Fig. 3(e), (f), (g), and (h) are the results of the simulation displayed in the same phase space projections shown in the data, Fig. 3(a)-(d). The ellipse sizes and correlations are in good agreement. We note that the calculated distributions are fitted with the same two-dimensional Gaussian fitting routine used in the data analysis. This software has been added to the LAMPF version of DECAY TURTLE.

The Monte Carlo calculation is further checked by computing the pion flux from the known proton beam intensity, production target parameters and beam line acceptance as calculated by DECAY TURTLE. For the run used to gather the data in Fig. 2 and Fig. 3, the measured and calculated rates agree to within 15%.

Conclusions

An integrated system consisting of hardware and software has been developed to measure secondary beam line particle trajectories, to provide particle identification, and to reduce the data in real time to beam phase space distributions. These distributions are in good agreement with detailed Monte Carlo calculations of the particle transport. A description of the beam line is achieved with much greater detail than traditional ellipse methods. The system can be used to find improved tunes and to study high order effects. It has proven invaluable in providing information used in designing improvements to the LAMPF Stopped Muon Channel. We expect to extend this technique to extremely low momentum (30 MeV/c) "surface" muon beams in the near future.

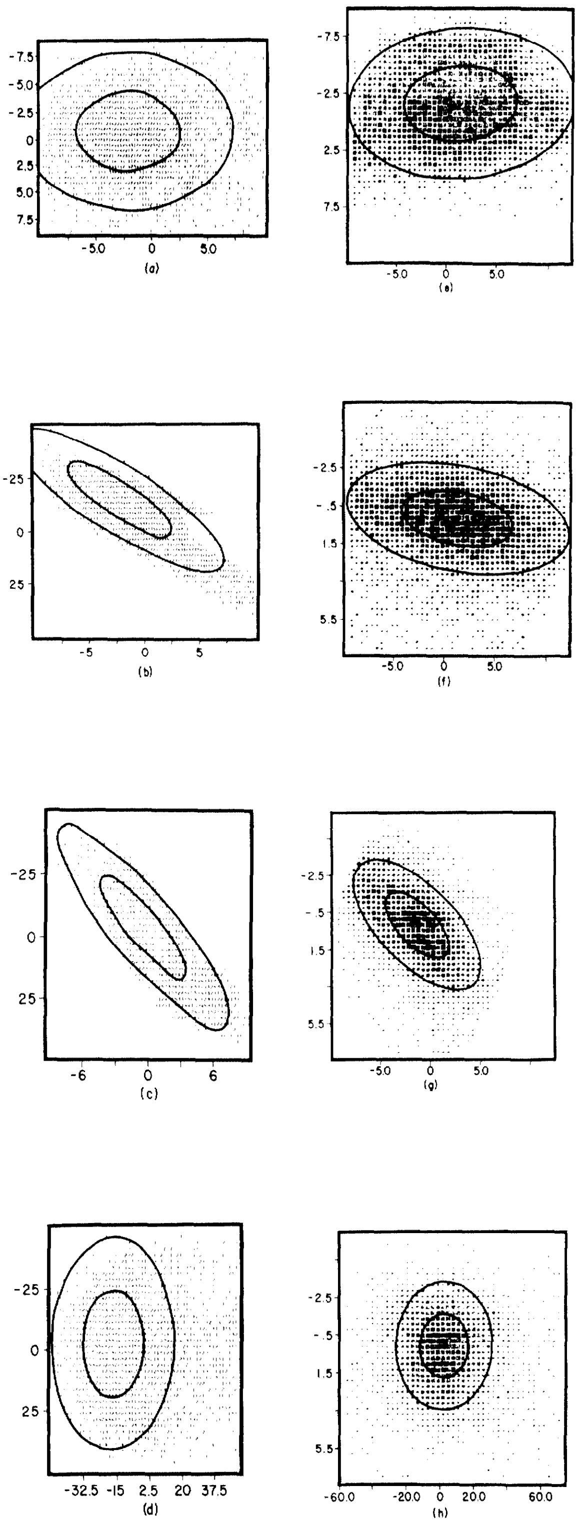

Fig. 3 - Measured and calculated beam phase space distributions. Fig. 3(a)-(d) are measured particle distributions. Fig. 3(e)-(h) are the corresponding simulations. All distributions are shown with fitted one σ and two σ beam ellipses as described in the text. The units are centimeters and .1 milliradian for Fig. 3(a)-(d) and centimeters and milliradians for Fig. 3(e)-(h).
Fig. 3(a) and 3(e) xy projection,
Fig. 3(b) and 3(f) $x\theta$ projection,
Fig. 3(c) and 3(g) $y\phi$ projection, and
Fig. e(d) and 3(h) $\theta\phi$ projection.

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