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High precision measurements with nuclear emulsions using fast automated microscopes

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Abstract

We report on the development of an automated scanning system for nuclear emulsions aiming at very precise spatial and angular measurements. An accuracy of 0.06 μm in position was achieved with the emulsion films used for the measurement. An accuracy of 0.4 mrad was achieved for tracks penetrating orthogonally the emulsion films while an accuracy of 1 mrad was obtained for tracks inclined by about 300 mrad with respect to the perpendicular direction. This result shows unprecedented position and angular resolutions achieved by automated measurements.

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Keywords: Nuclear emulsions; Precision measurement; Automated measurement

1. Introduction

Nuclear emulsions have been largely used in high energy physics, leading to the discovery of new particles and to the measurement of their properties [1–4]. The high sensitivity and grain uniformity of nuclear emulsions make them capable of observing tracks of single particles with submicrometric space resolution and therefore they are especially suitable for the observation of short lived particles. The present use of the

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emulsion technique is linked to the impressive achievements in the development of automated scanning systems [5–8]. This allowed the design of a new generation of "hybrid" experiments [9–12], where nuclear emulsions are combined with electronic detectors.

The need for massive detectors has recently motivated the revival of the Emulsion Cloud Chamber (ECC) technique [13] for neutrino experiments aiming at the detection of the τ lepton [11,12]. The ECC consists of a sandwich structure made of thick metal plates (passive material) and thin emulsion layers (tracking device). This detector was successfully used in cosmic ray experiments, having the advantages of cost effectiveness and of particle identification capabilities. Most of the detector mass consists of metal plates, allowing for a substantial cost reduction (a few percent) compared with stacks of pure emulsions.

The use of metal plates in the ECC design prevents the recognition of short lived particles through the visual observation of their decay point, as done in experiments where only emulsion stacks are used as a target. This feature is replaced by the use of impact parameter techniques. For background rejection, one profits from better measurements of kinematical parameters through the showering and multiple Coulomb scattering measurements [14].

The intrinsic position resolution of the nuclear emulsions used is about $0.2/\sqrt{12}\,\mu\text{m}$, where $0.2\,\mu\text{m}$ is the diameter of the original AgBr crystal [15] for the used emulsions. The emulsion films used in this paper are made of two 44 μm thick layers stuck on both sides of a 210 μm plastic base. Given the level arm of 210 μm between the two layers, the intrinsic angular accuracy is about 0.4 mrad.

Automated scanning systems aimed at achieving a maximal scanning speed (now reaching $20\,\text{cm}^2/\text{h}$ [8]) are not focused on fully exploiting the intrinsic resolution of the nuclear emulsions. In this paper we report on the realization of an automated microscope aimed at achieving a high resolution, with a somewhat slower scanning speed (about $0.1\,\text{cm}^2/\text{h}$). This system is meant to scan a limited number of events for which a very high precision is needed. Therefore, the scanning speed should be measured per track rather than per unit surface. A speed per track of 270 tracks/h has been achieved. We also report on the development of a dedicated measurement procedure.

2. The automated microscope

The automated scanning system consists of a microscope equipped with a computer-controlled motorized stage, movable in all three directions, a dedicated optical system and a CCD camera, on top of an optical tube. For each field of view, several tomographic images of the emulsions are taken at equidistant depths by moving the focal plane across the emulsion thickness (Z direction). Images are grabbed and processed by a vision multi-processor board, hosted in the control PC together with the motor control board. Its design profits from the experience gained in the design of high speed microscopes developed in an R&D project in the framework of the OPERA experiment [8], with the addition of special features to enhance the precision of the measurements.

The mechanical stage is equipped with nano-step motors and optical encoders with a resolution of 0.1 μm for the horizontal axes. The stage allows to cover a range of 20 cm on the horizontal axes and 5 cm on the vertical one. A modified optical bench hosts the illumination system and it is equipped with a granite arm bearing on the Z stage and the optical system. The peculiar mechanical feature of this stage is the Z stage with optical encoders achieving the accuracy of 0.05 μm. The optical system includes a trinocular tube, mechanically assembled to fit the Z stage, and a magnification 50 oil-immersion objective with a working distance of 400 μm. The optical system is infinity-corrected and produces achromatic planar images through the whole thickness of the emulsion. A photograph of the system is shown in Fig. 1.

The image is formed on a CCD camera (Video Walls VWFT12I, type FTM12) capable of 30 frames per second with a sensor of 1024×1024 pixels and a size of $7.5 \times 7.5\,\text{mm}^2$. The resulting size of one microscope field of view is $150 \times 150\,\mu\text{m}^2$ yielding a pixel to micron conversion factor of $0.1477 \pm 0.0003\,\mu\text{m/pixel}$, a factor of