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Improving the detection efficiency in nuclear emulsion trackers

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ABSTRACT

Nuclear emulsion films are a tracking device with unique space resolution. Their use in nowadays large-scale experiments relies on the availability of automated microscope operating at very high speed. In this paper we describe the features and the latest improvements of the European Scanning System, a last-generation automated microscope for emulsion scanning. In particular, we present a new method for the recovery of tracking inefficiencies. Stacks of double coated emulsion films have been exposed to a 10 GeV/c pion beam. Efficiencies as high as 98% have been achieved for minimum ionising particle tracks perpendicular to the emulsion films and of 93% for tracks with $\tan(\theta) \simeq 0.8$.

1. Introduction

Nuclear emulsions are among the earliest detectors of ionizing particles used in high-energy physics [1,2]. They have been recently used by the DONUT [3] and CHORUS [4,5] experiments as target and tracking detectors, exploiting their sub-micrometric position accuracy for the detection of short-lived particles, such as charmed hadrons and τ lepton. The use of nuclear emulsions has lead to the first direct observation of $\nu_\mu \rightarrow \nu_\tau$ oscillation by the OPERA experiment [6–11]. In OPERA, emulsion films interleaved with passive material in the so-called Emulsion Cloud Chamber (ECC) allow the observation of the τ decay topologies, as well as the measurement of charged particles by multiple Coulomb scattering, the identification and measurement of electromagnetic showers and electron/pion separation [12–14]. The revival of the nuclear emulsion technique is mainly due to the development of automated optical microscopes, allowing fast scanning and advanced real-time analysis of huge data sets. In this paper we report about improvements in the detection efficiency of the European Scanning System (ESS), which has been designed, made operational and jointly exploited with the contribution of several Scanning Laboratories in Europe [15–17].

2. Track reconstruction with the ESS

Nuclear emulsions are made of a gel with interspersed AgBr crystals deposited on a transparent plastic base. A particle crossing

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an emulsion layer ionises the medium along its path, leaving a *latent image*, i.e. a sequence of sensitized sites. After development, each site acts as a crystallisation centre for metallic Ag so that a sequence of aligned silver *grains* marks *the track*, i.e. the path of the ionizing particle in emulsion.

The developing time should be long enough to reduce completely those crystals with a latent image centre, but not so long that unexposed crystals are also developed. Crystals that are developed without containing a development centre constitute a source of background, known as *fog*.

In the OPERA emulsion films [18] a minimum ionising particle leaves about 30 grains in 100 μm, with linear size, after development, of about 0.6 μm. As shown on the right side of Fig. 1, these films feature a double-side structure, consisting of two 43 μm thick sensitive layers on a 205 μm thick plastic base.

The ESS was designed for the scanning of emulsions exposed to perpendicularly impinging particles. The design goals were high speed (20 cm^2/h, a factor of 20 faster than older scanning systems), sub-micron precision, high tracking efficiency and low instrumental background. The general structure of the system and the algorithms developed for image processing and particle tracking in single emulsion films, as well as the hardware and its performance, were described in detail elsewhere [19–22]. Its basic features are briefly recalled here.

By moving the focal plane of the objective lens through the whole emulsion thickness, tomographic images are taken at equally spaced depth levels for each field of view. Images are processed and analysed in order to identify aligned clusters of dark pixels (*grains*) produced by charged particles along their trajectories. Each emulsion layer is spanned by 16 images in steps of a few μm, accounting for the effective focal depth of the system.

A sequence of grains measured in a single emulsion layer is referred to as a *micro-track*. Micro-tracks are affected by three factors that can alter the original straight path of the ionising particle: shrinkage, linear distortion and parabolic distortion.

Shrinkage comes from the removal of unsensitized silver grains during the fixing stage of development. The emulsion layer, thus devoid of the silver halide, reduces its thickness during the drying process. Such shrinkage leads to a contraction perpendicular to the plane of the emulsion.

The linear distortion is due to the surface stress that causes relative displacement of emulsion layers parallel to the plane of the emulsion. The plane in contact with the support is not displaced while the plane of the free surface has maximum displacement.

The parabolic distortion is present if a stress arises at the support surface and no stress is applied externally. The simplest approximation is a linear decrease of the stress, which produces a constant gradient of the viscous shear.

The use of double-sided emulsions coated on a plastic support plate improves the angular resolution because the track direction can be defined by the two points near the support plate, which are practically free of distortion.

As shown in Fig. 1, double-side *base-tracks* are formed by connecting compatible micro-tracks across the plastic layer.

The full-volume reconstruction of particle tracks (*volume-tracks*) requires connecting base-tracks in several consecutive films in the ECC. In order to define a global reference system, a set of affine transformations in the coordinate space have to be computed to account for scanning data taken film by film in different reference frames and for possible deformations. The algorithms used for volume-track reconstruction is essentially based on finding and

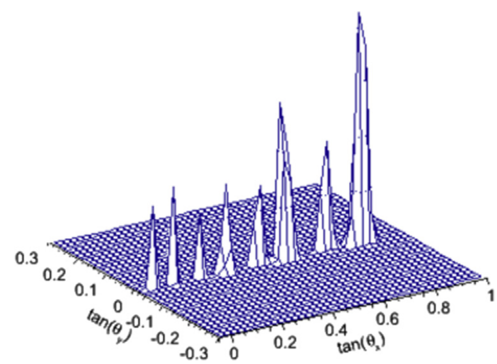

Fig. 2. Angular spectrum of the charged pion beam used for the test exposure. The beam tilt was along the *X* direction (being *XY* the plane perpendicular to the beam direction).

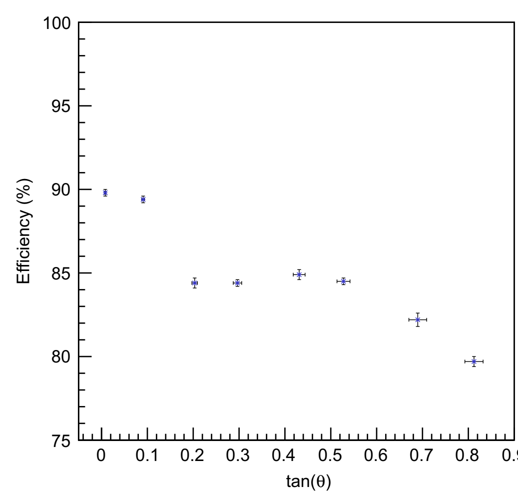

Fig. 3. Base-track efficiency as a function of tan (θ).

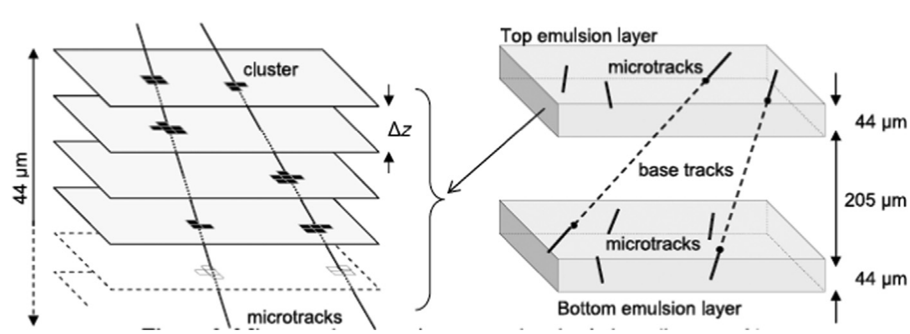

Fig. 1. Left: Micro-track reconstruction in one emulsion layer by combining clusters belonging to images at different levels. Right: micro-track connections across the plastic base to form base-tracks.