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An integrated system for large scale scanning of nuclear emulsions

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ABSTRACT

The European Scanning System, developed to analyse nuclear emulsions at high speed, has been completed with the development of a high level software infrastructure to automate and support large-scale emulsion scanning. In one year, an average installation is capable of performing data-taking and online analysis on a total surface ranging from few m^2 to tens of m^2, acquiring many billions of tracks, corresponding to several TB. This paper focuses on the procedures that have been implemented and on their impact on physics measurements. The system proved robust, reliable, fault-tolerant and user-friendly, and seldom needs assistance. A dedicated relational Data Base system is the backbone of the whole infrastructure, storing data themselves and not only catalogues of data files, as in common practice, being a unique case in high-energy physics DAQ systems. The logical organisation of the system is described and a summary is given of the physics measurement that are readily available by automated processing.

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1. Introduction

The use of nuclear emulsions in modern high-energy Physics is motivated by their unique spatial resolution, allowing detection and discrimination of particle interactions and decay processes by topological signature. The nature of physics processes can thus be studied on an event-by-event basis. The tracking accuracy in emulsion is better than 1 μm, so that not only the final states of decays are measurable; it is often possible to measure and identify also intermediate products, such as the τ^- in $\nu_\tau + N \rightarrow \tau^- + X$; $\tau^- \rightarrow \mu^- \bar{\nu_\mu}\ \nu_\tau$, provided the flight length exceeds a few tens of micrometres. As a practical example, such ability was extensively used in the CHORUS experiment ([1–3]) to search for neutrino oscillations and yielded notable results in the study of neutrino-induced charm production and decay ([4–15]). Any automated system should then exploit this unique feature. At the same time, it should maximise the scanning speed to analyse vast regions of the emulsion-instrumented detector volume. This is required to provide high statistics searching for rare events with characteristic topologies.

Emulsion films are typically assembled in stacks. A single high-energy event may cross several stacks, whereas a single stack may contain hundreds or thousands of events, depending on the specific case. In each film a transparent plastic support (base) is coated on both sides with thin emulsion layers. In the case of the PEANUT ([20]) and OPERA ([21–23]) experiments, the films have transverse dimensions of $12.5 \times 10\ \mathrm{cm}^2$, with 200 μm thick base and two 44 μm thick sensitive layers.

Emulsions are often used in hybrid experiments ([1,20,21,24]) in combination with electronic detectors that provide timestamps for tracks and kinematical measurements (Fig. 1). The link between electronic signals and tracks in emulsion is not only an "a-posteriori" match done at analysis time, but it defines a logical relationship, e.g. it documents that a certain track was acquired after a hint from the electronic detectors. An electronic "target tracker" allows identifying the region where an event has occurred, thus minimising the volume to be scanned by microscopes. One or more electronic detectors may follow for diverse purposes. The information they provide is related to tracks measured in emulsion through the target tracker. This allows combining measurements in emulsion with information such as momentum reconstruction and particle identification, allowing event-by-event discrimination of the physics process, as shown in the example of Fig. 2: the impact parameter of all tracks at the primary vertex is below 9 μm; a muon is identified by correlating the information from a target tracker and a muon spectrometer; another track shows a decay kink 1.8 mm after the primary vertex; the impact parameter of the decay daughter with respect to the neutrino vertex is 270 μm, unambiguously defining the overall topology; kinematical information allows assessing that the decaying particle is a charmed meson produced in the neutrino interaction.

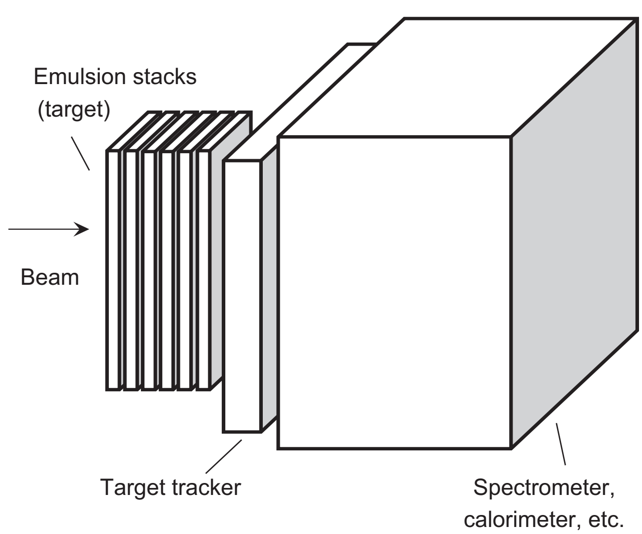

Fig. 1. Sketch of a hybrid emulsion experiment: the beam impinges on stacks of emulsion films possibly interleaved with a passive target, or acting as a target themselves. Electronic detectors provide complementary information.

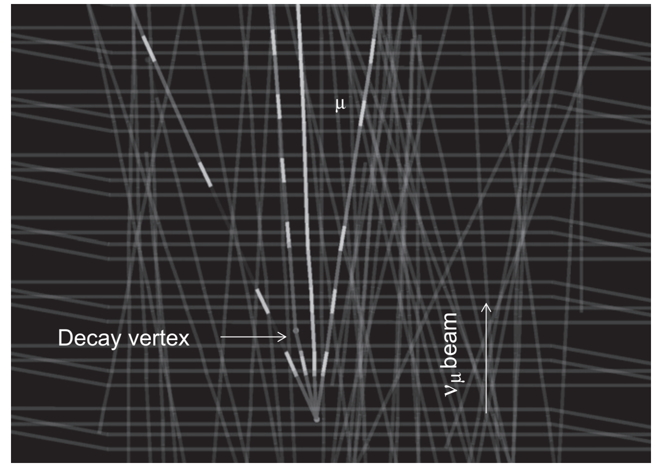

Fig. 2. Computer display of a neutrino-induced charm production event. The thin lines show sections ($1\ \mathrm{cm}^2$) of emulsion films, interleaved with lead plates. The neutrino beam is orthogonal to the films. The thick lines mark the tracks related to the event. One track shows a charm decay kink 1.8 mm after the primary vertex.

Sub-micrometric accuracy in data-taking is crucial for emulsion films exposed for several years: in the detector volume displayed in Fig. 2, about 10^7 tracks (not shown), mostly from ambient radioactivity (or from material in the detector itself, as in [25]), are recorded; thanks to the excellent spatial accuracy, event-related tracks can be reconstructed across the measured volume despite the huge background density.

The core of our system for automated analysis of nuclear emulsions is the European Scanning System (ESS) automated microscope. Its basic performances, i.e. its efficiency, speed and precision, have been described in [16–18]. A version optimised for high precision measurements has also been implemented ([19]). A typical scanning laboratory operates 4–10 automated microscopes and, when working at full speed, can measure several m^2 of emulsion surface per year. The film readout microscopes will not be described further in this paper, which instead focuses on the high-level software infrastructure that drives and uses them.

The system presented here runs a software set called SySal.NET, which is the evolution of a software approach ([26]) developed in the framework of the CHORUS experiment. It managed part of the statistics of the PEANUT experiment (approximately one year's data taking) and is now successfully used to locate and study OPERA events. It is also used in some additional activities such as muon radiography of volcanic edifices. Since its first data-taking tasks in 2004 to the present time, hardware and operating systems have been changing. Parallel and distributed computing was uncommon for emulsion scanning laboratories at the end of the 90's; the flexible, easy to maintain, fast performing infrastructure that has been developed for automated emulsion scanning has grown to progressively incorporate several event reconstruction and analysis tasks. Thanks to its flexibility, the infrastructure could in principle be used for any kind of distributed computing.

A system for mass data-taking must not only be stable, but also flexible and scalable: during the typical lifetime of an experiment,