Available online at www.sciencedirect.com
ScienceDirect
Nuclear Instruments and Methods in Physics Research A 568 (2006) 578–587
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.com/locate/nima

Hardware performance of a scanning system for high speed analysis of nuclear emulsions

L. Arrabito[a], E. Barbuto[b], C. Bozza[b], S. Buontempo[c], L. Consiglio[d], D. Coppola[c], M. Cozzi[d], J. Damet[e,1], N. D'Ambrosio[c], G. De Lellis[c], M. De Serio[f], F. Di Capua[c], D. Di Ferdinando[d], D. Di Marco[g,h], L.S. Esposito[h], G. Giacomelli[d], G. Grella[b], M. Hauger[i], F. Juget[i], I. Kreslo[e], M. Giorgini[d], M. Ieva[f], I. Laktineh[a], K. Manai[a], G. Mandrioli[d], A. Marotta[c], S. Manzoor[d], P. Migliozzi[c], P. Monacelli[g,h], M.T. Muciaccia[f], A. Pastore[f], L. Patrizii[d], C. Pistillo[c], M. Pozzato[d], P. Royole-Degieux[a], G. Romano[b], G. Rosa[j], N. Savvinov[e], A. Schembri[j], L. Scotto Lavina[c], S. Simone[f], M. Sioli[d], C. Sirignano[b], G. Sirri[d,*], G. Sorrentino[c], P. Strolin[c], V. Tioukov[c], T. Waelchli[e]

[a] *IPNL, IN2P3-CNRS, Université C. Bernard Lyon-1, 69622 Villeurbanne, France*
[b] *Dip. di Fisica dell'Università di Salerno and INFN, 84081 Baronissi (SA), Italy*
[c] *Dip. di Fisica dell'Università "Federico II" and INFN, 80126 Napoli, Italy*
[d] *Dip. di Fisica dell'Università di Bologna and INFN, 40127 Bologna, Italy*
[e] *Laboratory for High Energy Physics, University of Bern, 3012 Bern, Switzerland*
[f] *Dip. di Fisica dell'Università di Bari and INFN, 70126 Bari, Italy*
[g] *Dip. di Fisica dell'Università dell'Aquila and INFN, 67100 L'Aquila, Italy*
[h] *Laboratori Nazionali del Gran Sasso dell'INFN, 67010 Assergi (L'Aquila), Italy*
[i] *Institut de Physique, Université de Neuchâtel, 2000 Neuchâtel, Switzerland*
[j] *Dip. di Fisica dell'Università "La Sapienza" and INFN, 00185 Roma, Italy*

Received 20 March 2006; received in revised form 25 June 2006; accepted 28 June 2006
This paper is dedicated to the memory of our colleague N. Armenise
Available online 2 August 2006

Abstract

The use of nuclear emulsions in very large physics experiments is now possible thanks to the recent improvements in the industrial production of emulsions and to the development of fast automated microscopes. In this paper the hardware performances of the *European Scanning System* (ESS) are described. The ESS is a very fast automatic system developed for the mass scanning of the emulsions of the OPERA experiment, which requires microscopes with scanning speeds of ~20 cm^2/h in an emulsion volume of 44 μm thickness.

PACS: 29.40.Rg; 29.40.Gx

Keywords: Nuclear emulsions; Automatic scanning; Digital imaging; Microscopy; Neutrino oscillations; Elementary particles

1. Introduction

Nuclear emulsions record tracks of charged particles with an accuracy of less than 1 μm. Thanks to this feature, they were largely used in nuclear and particle physics experiments during the last century [1,2] and they are still

*Corresponding author. Tel.: +39 051 2095228; fax: +39 051 2095269.
E-mail address: gabriele.sirri@bo.infn.it (G. Sirri).
[1] Now at LAPP, IN2P3-CNRS and Universitè de Savoie, Annecy, France.

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doi:10.1016/j.nima.2006.06.072

successfully used nowadays, especially in experiments involving short-lived particles [3–5].

The amount of emulsions used in the early experiments was relatively small and the measurements were made manually. Significant improvements in the emulsion technique and the development of fast automated scanning systems during the last two decades [6–8] have made possible the use of nuclear emulsions in large scale experiments.

OPERA is a long baseline experiment [9] (located in the INFN Gran Sasso Underground Laboratories) which will use a hybrid detector to search for $\nu_\mu \rightarrow \nu_\tau$ oscillations in the parameter range suggested by atmospheric neutrino experiments [10–12]. The goal is to observe the appearance of τ leptons in a pure ν_μ beam produced at the CERN-SPS (the CNGS neutrino beam [13]). The τ leptons are identified through the direct detection of their decays that, at the CNGS energies, are at distances of $\sim$1 mm from the production point. Therefore, a high precision detector is needed. On the other hand, given the smallness of the neutrino oscillation probability and of the neutrino cross-section a very massive detector ($\mathcal{O}(kton)$) is mandatory. The Emulsion Cloud Chamber (ECC) [14], a sandwich of dense passive material (Pb) sheets, acting as target, interleaved with emulsion sheets, acting as high precision trackers, satisfies the need of both a large mass and a high precision tracking capability. The ECC technique has lead to the first observation of ν_τ interactions by the DONUT experiment [5].

The OPERA detector is a hybrid system consisting of electronic trackers, muon spectrometers and a massive lead-emulsion target segmented into ECC bricks, each with size $12.7 \times 10.2 \times 7.5\,\mathrm{cm}^3$ and consisting of 57 emulsion sheets interleaved with 1 mm lead plates. Emulsion sheets are made of two 44 μm thick films (including 1 μm insensitive protective layer) coated on both sides of a 205 μm thick plastic support [15].

Electronic detectors are used to identify the brick where the neutrino interaction occurred. The brick is then removed and two external emulsion sheets placed downstream of the brick (*changeable sheets*) are promptly detached and analyzed to confirm the interaction.

With the CNGS neutrino beam [13] at its nominal intensity, $\sim$30 neutrino selected interactions per day are expected. Therefore, $\sim$2000 emulsion sheets per day must be (partially) scanned in order to find the vertex and analyze the event. In total, $\sim 6000\,\mathrm{cm}^2$ per day ($\sim 200\,\mathrm{cm}^2$ per brick) have to be analyzed with a sub-micrometric precision per 5 years of data taking ($\gtrsim$30 000 neutrino interactions).

The need for a daily scanning of all neutrino interactions comes from the goal to analyze in "real" time the events and, for some decay topologies, remove other ECC bricks for a more refined kinematical analysis. Consequently, a very fast automatic scanning system is needed to cope with the daily analysis of the large number of emulsion sheets associated with neutrino interactions. In order to have a reasonable number of microscopes ($\sim$1 microscope/brick/day), the minimum required scanning speed is about $20\,\mathrm{cm}^2/\mathrm{h}$ per emulsion layer (44 μm thick). It corresponds to an increase in speed by more than one order of magnitude with respect to past systems [6,8].

For this purpose new automatic fast microscopes have been developed: the *European Scanning System* (ESS) [16,17] and the S-UTS in Japan [7].

In this paper the features and performances of the ESS hardware are discussed. High speed particle tracking for the ESS is described in Refs. [16,17], precision measurements in Ref. [18], alignments with cosmic ray muons in Ref. [19], items related to event analysis in Ref. [20].

2. The design of the ESS

The main components of the microscope shown in Fig. 1 are: (i) a high quality, rigid and vibration-free support table holding the components in a fixed position; (ii) a motor driven scanning stage for horizontal (XY) motion; (iii) a granite arm which acts as an optical stand; (iv) a motor driven stage mounted vertically (Z) on the granite arm for focusing; (v) optics; (vi) digital camera for image grabbing mounted on the vertical stage and connected with a vision processor; (vii) an illumination system located below the scanning table. The emulsion sheet is placed on a glass plate (emulsion holder) and its flatness is guaranteed by a vacuum system which holds the emulsion at a fixed position during the scanning.

By adjusting the focal plane of the objective, the whole 44 μm emulsion thickness is spanned and a sequence of 15 tomographic images of each field of view, taken at equally spaced depth levels, is obtained. Emulsion images are digitized, converted into a grey scale of 256 levels, sent to a vision processor board, hosted in the control workstation, and analyzed to recognize sequences of aligned grains (clusters of dark pixels of given shape and size). Some of these spots are track grains; others, in fact the majority, are spurious grains (*fog*), created in the emulsions by thermal

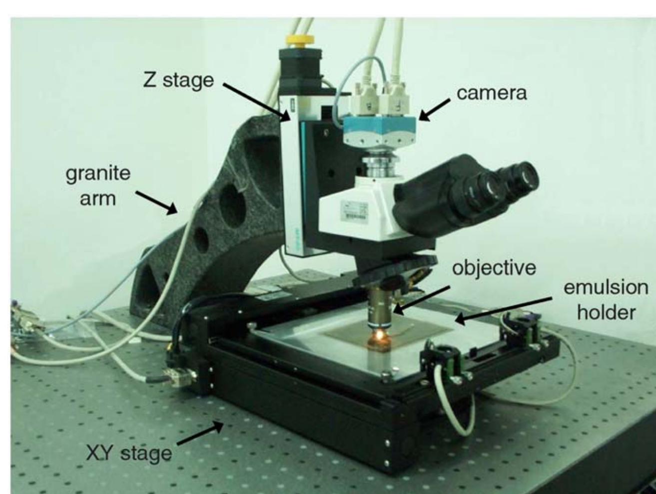

Fig. 1. A photograph of one of the microscopes of the European Scanning System.