Recent Emulsion Technologies

A. Ariga

A. Einstein Center for Fundamental Physics, LHEP, University of Bern, Sidlerstrasse 5, 3012 Bern, Switzerland

Abstract. Emulsion technologies are very much developed in the last decade and still developing in both the emulsion gel and the data taking. Emulsion detectors are suitable for the neutrino experiments because they can distinguish all 3 flavors of neutrino. The OPERA experiment, a recent pillar in the emulsion experiments aiming at the first observation of the neutrino oscillation in CNGS beam in appearance mode, is running, showing the good capability to separate 3 flavor neutrino interactions. In this poster, the recent developments and prospects of the emulsions for the next generation experiments are reported.

Keywords: emulsion, neutrino, ECC, scanning
PACS: 14.60.Lm; 29.40.Rg

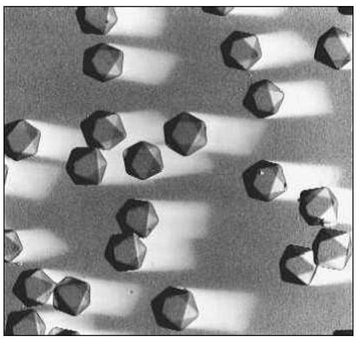

FIGURE 1. AgBr crystals used in the nuclear emulsions. The crystal diameter is 200nm.

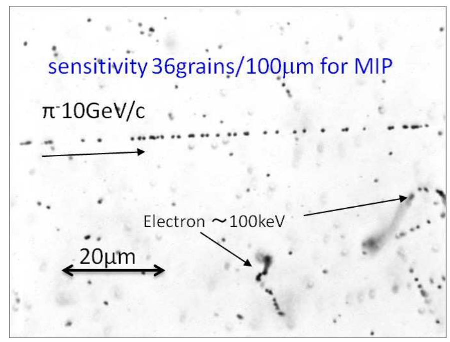

FIGURE 2. A view under the optical microscope.

EMULSION DETECTOR

Emulsion detector is a particle detector, which has an unrivaled position resolution.

The minimal detector unit is a silver bromide crystal with 200 *nm* diameter (Figure1), uniformly distributed in the gelatin layer. The silver bromide crystal is one of the semiconductors, which has 2.6eV band gap. When a charged particle passes through the crystal, the excited careers are diffused and trapped in a lattice defect on the surface of the crystal and then it gets ready to be photo-developed. The photo-developing process amplifies the signal by a factor $10^6 \sim 10^7$ and makes a bundle of the filament of a pure metal-silver. After the process, the signal becomes visible as a grain ($\sim 1 \mu m$) under the optical microscopes.

As shown in Figure 2, the trajectory of a charged particle is found as a sequence of the grains. With a typical emulsion tracker, like the one used for the OPERA experiment[1][2], a minimum ionizing particle leaves ~ 40 *grains*/100 *microns*, and the number of grains is proportional to the ionization loss of the particle. The deviation of each grain from the fitted line is measured as 50 *nm* (Figure 3).

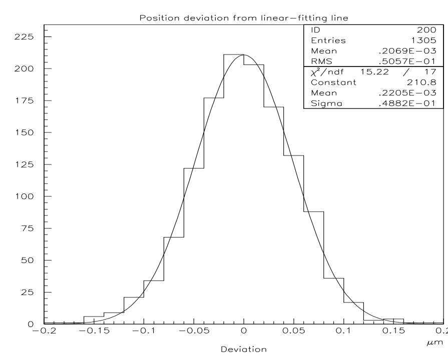

FIGURE 3. The deviation of each grain from the fitted line. Fitting is done using 40 μm ($\sim$14 grains). *RMS* is found as 50 *nm*.

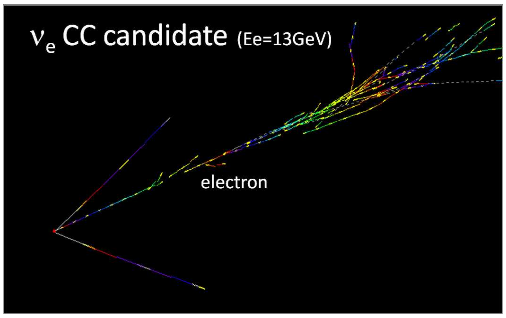

FIGURE 4. A ν_e CC candidate event. A electron from the ν interaction vertex makes a electromagnetic shower in an ECC brick (=10X_0).

OPERA EXPERIMENT

The OPERA experiment is a long-baseline neutrino experiment aiming for the observation of the flavor-mixing neutrino oscillation in the appearance mode[1]. It tries to observe $\nu_\mu \rightarrow \nu_\tau$ oscillation in CNGS beam[3].

The OPERA detector[4] is designed to detect all three flavors of neutrinos. It is realized as a hybrid detector with the emulsion trackers and the electronic detectors.

The emulsion trackers were employed to detect the ν_τ signal, because the lifetime of τ leptons created by the ν_τ charge current (CC) interaction is short ($c\tau = 87\mu m$). It requires a μm-scale resolution and a kilo-ton scale massive detector.

The main detector, so called Emulsion Cloud Chamber (ECC), consists of 57 layers of emulsion films ($125mm \times 100mm$) interleaved by 1mm lead plates. In total 150,000 ECCs, 1.25 kt are used. The total area of emulsion is $125,000m^2$, which is over 100 times bigger than the past biggest experiment, CHORUS[5].

The R&D and mass-production of the films were done by FUJI Film co. together with Nagoya university.

Each ECC is followed by the scintillation counters to trigger the read-out and localize neutrino interactions, and by the spectrometers to identify muons.

Detection of 3 flavors

An OPERA-type detector can detect all 3 flavors of neutrinos (ν_e, ν_τ, ν_μ). The observed candidate-events in OPERA are shown in Figure 4,5,6.

This type of detector has the highest spatial resolution amang the future large scale experiments. It is based on relatively conservative techniques, but it still has challenging points.

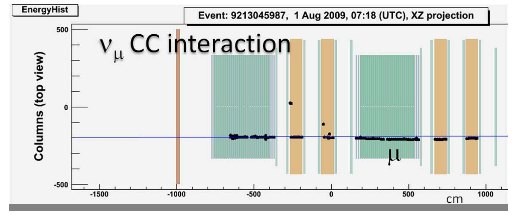

FIGURE 5. A ν_μ CC candidate event. A muon punches though the thick-dense detectors without a hadronic interaction.

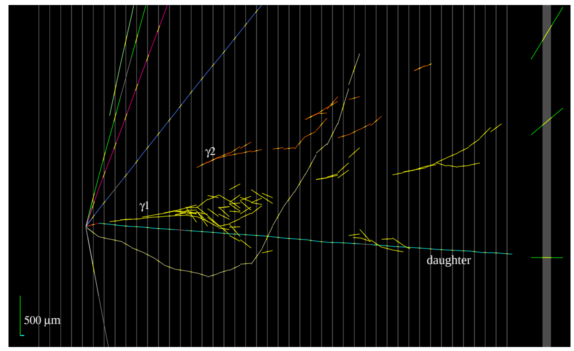

FIGURE 6. A ν_τ CC candidate event. A tau decays within a few mm from the primary vertex. This example is consistent with the decay topology and kinematics of $\tau^- \rightarrow \rho^- \nu_\tau \rightarrow \pi^- \gamma\gamma\nu_\tau$.

CHALLENGES FOR THE FUTURE EXPERIMENTS.

The OPERA-type detector is a simple solution for the far detector of Neutrino Factory or the others. It can detect the appearance of the wrong sign muons as the golden channel and also detect the ν_τ signal as the silver channel. The measurement of two channels will solve the degeneration in (θ_{13}, δ) space [7].

The challenging points are (1) Emulsion R&D and mass-production, (2) DAQ (=Scanning) speed, (3) Modular structure in a magnetic field to measure the particle charge. In following sections, the prospects for these points are described.

Emulsion R&D and mass-production

For Neutrino Factory, one needs the target mass bigger than 10 kt, which is several times bigger than the OPERA experiment. It is feasible to construct, if we do today.

However, a possible source of problem may come from the lack of commercial needs for the photograph business. The recent trend in this field is dramatically moving from the silver halide emulsions to the digital cameras. So far, FUJI Film co. keeps the production lines[1] for the conventional nuclear emulsions. It is not sure to have the lines available in 2025.

Recently two projects for the emulsion R&D have been launched. These are the attempts to be independent from the commercial needs for the photographic films. One is Innovative Nuclear Emulsion Technologies for fundamental science and applications (INET) project driven in the framework of the Scientific and Technological Cooperation Programme Switzerland-Russia. The other is the project in Nagoya university in Japan[2]. Although both projects have just started, they are already showing some nice results in the gel R&D. Those will be published soon.

GPGPU for next generation scanning

The expected number of events to be analyzed in the Neutrino Factory[3] is same or even smaller than that of the OPERA experiment. Analysis of emulsion can be reasonably handled. However, the higher scanning speed will simplify the analysis procedure and reduce the possible biases.

The raw data from the emulsion is huge, $\sim$ 5 TeraByte / $100cm^2$ is read out from a film as the minimum requirement[4]. The real time processing is mandatory.

The microscopes of the OPERA experiment [8][9] take 4 to 10 hours to scan the area of $100cm^2$. The scanning speed is limited by the real-time reconstruction of the tracks, which searches a sequence of grains in the emulsion. This requires a large computing power. Currently, it is done by the multi FPGAs, or a CPU with the sophisticated algorithms. The advantage of FPGA is that it can process a lot of data in parallel, however, only some simple algorithms can be implemented. On the other hand, the CPU can handle more complicated algorithms, but the computing power is limited.

Use of a GPGPU (General Purpose computing on Graphic Processing Unit) takes the benefit of the two. A GPGPU consists of several hundreds of the computing units, providing a possibility to process the complicated algorithms in parallel.

Recently an activity to test the feasibility started in Bern with NVIDIA GPGPUs. The results are promising. Potentially this solution can make the scanning speed $\sim 10\ times$ faster than current one with the same optics and cameras.

[1] Those are same production line as the other photographic films.
[2] Contact person : Mitsuhiro Nakamura, nakamura@flab.phys.nagoya-u.ac.jp
[3] In the case that one measures only the events with the wrong signed muons.
[4] In the OPERA experiment, 1 digit on the camera corresponds to $0.3\mu m$ for X and Y direction, $3\mu m$ for Z axis with a brightness of 256 bits. The resolution saturates with a higher magnitude at 0.1 μm/digit.

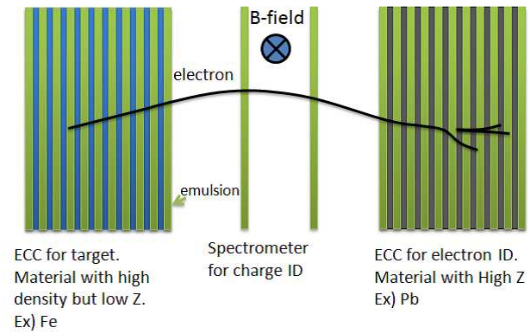

FIGURE 7. A possible module for electron charge identification.

Electron charge identification by emulsion

The charge identification is one of the key issues for the future neutrino experiments. The performance for the charge identification for pions by the emulsion modules with the magnet field is shown in the articles [10][11]. The experimental proof of the charge identification of electrons is being studied. A possible module structure is shown in Figure 7.

SUMMARY

The emulsion detector like the OPERA detector can detect 3 flavors of neutrinos. It has a potential to be a detector for the future neutrino experiments. The R&D activities are ongoing both on the hardware of the emulsion and on the readout.

REFERENCES

1. OPERA Collaboration, M. Guler et al., An appearance experiment to search for $\nu_\mu \rightarrow \nu_\tau$ oscillations in the CNGS beam, Experimental proposal, CERN/SPSC 2000-028.
2. T. Nakamura et al., NIM A 556 (2006) 80-86
3. CNGS project: http://proj-cngs.web.cern.ch/proj-cngs/
4. OPERA Collaboration, R. Acquafredda et. al., 2009 JINST 4 P04018
5. CHORUS Collab., Nucl. Instr. and Meth. A401 (1997), 7
6. OPERA collaboration, Phys. Lett. B 691 (2010) 138-145
7. Eur.Phys.J. C33 (2004) 243-260
8. K. Morishima and T. Nakano, JINST (2010) 5 P04011.
9. Nucl. Instr. and Meth. A 568 (2006) 578. etc.
10. C. Fukushima et al., Nucl. Instr. Meth. A 592 (2008) 56
11. ISS, T. Abe et al., JINST 4:T05001, 2009.