A novel approach for fast scanning of nuclear emulsions with continuous motion of the microscope stage

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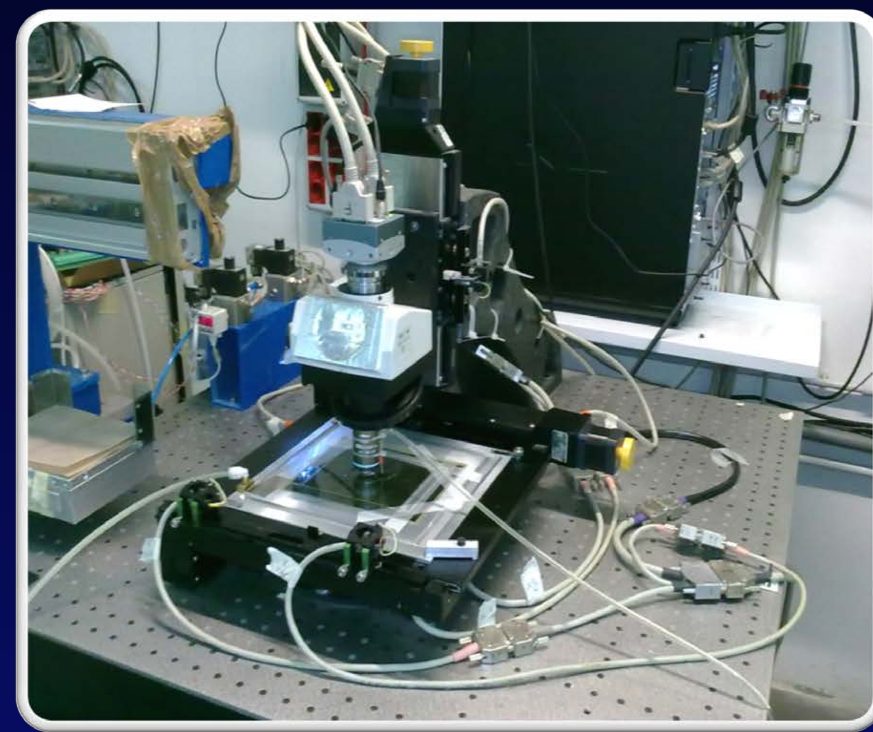
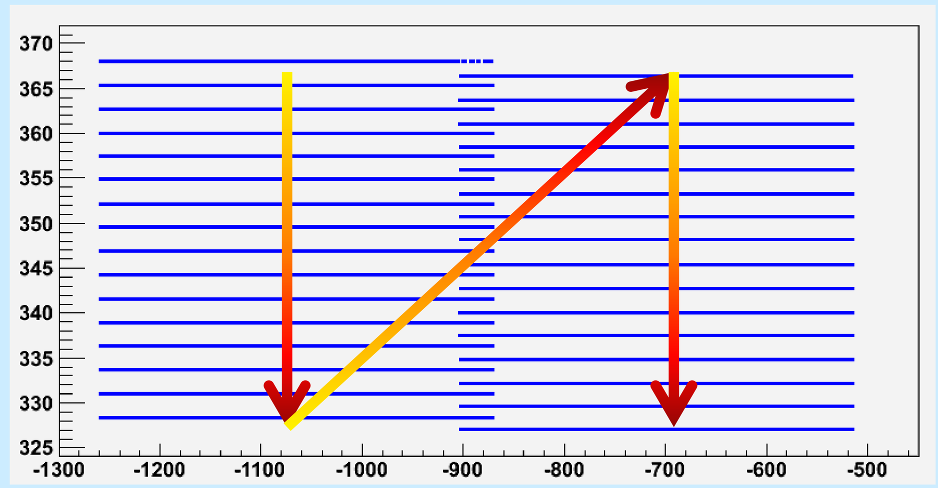
ABSTRACT

Nuclear emulsions have been used in particle physics experiments for many decades because of their unique spatial resolution. The use of nuclear emulsions as precise tracking detectors in large experiments has recently been made possible due to advances in the production of emulsion films and to the development of very fast automatic scanning devices. The present scanning speed of the European Scanning System (ESS), which has been developed within the OPERA Collaboration, is about 20 cm²/h. In addition to the scanning of OPERA films, the ESS is used for other applications with ever-growing demands for improved scanning speed, such as the muon radiography of volcanoes. In order to further increase the scanning speed of the ESS, we are testing a novel approach different from the standard stop-and-go motion of the microscope stage in the horizontal plane. Indeed we perform data acquisition with the stage moving at constant speed, using an objective lens with wide field of view. Unlike the implementation realized in Japan where the movement of objective lens and stage are synchronized to pile up images of the same view, in this approach only the stage is moving horizontally. Thus images at different depths are not fully overlapped and special care is needed in the reconstruction. This approach can give a substantial increase in the scanning speed, especially for thin emulsion layers and wide field of view. If special care is taken, the emulsion data quality can be as good as with the standard stop-and-go approach. This technique allows to double the scanning speed of the ESS, bringing it to 40 cm²/hour without any hardware modification.



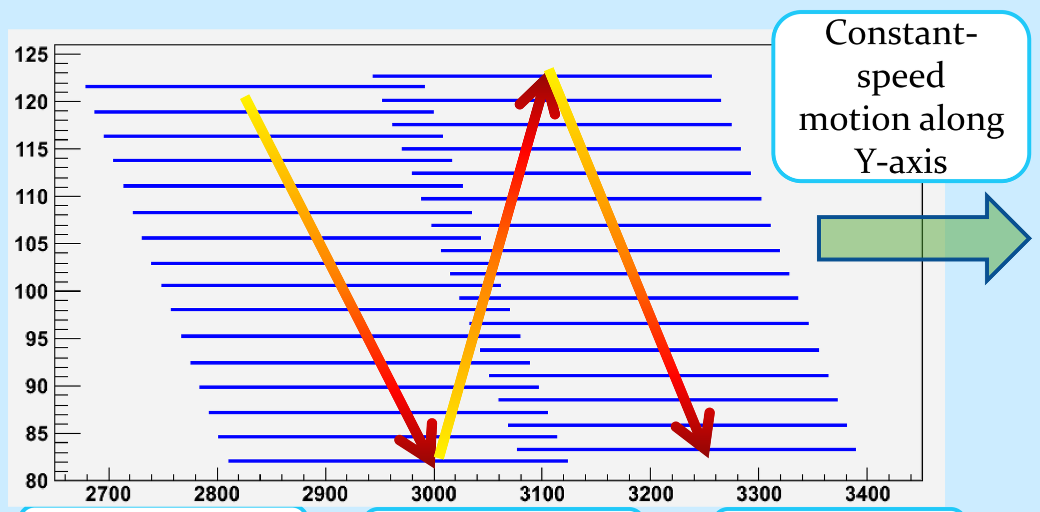
Standard 'Stop&Go' Motion



55 ms data acquisition + 95 ms back motion = 150 ms duty cycle

- Data acquisition is performed in movement along Z axis while X and Y axes are in rest
- For thin emulsions and large field of view movement to the next view can become a speed-limiting factor
- The ESS scanning speed is limited to 20-25 cm²/h

Continuous Motion



55 ms data acquisition + 25 ms back motion = 80 ms duty cycle

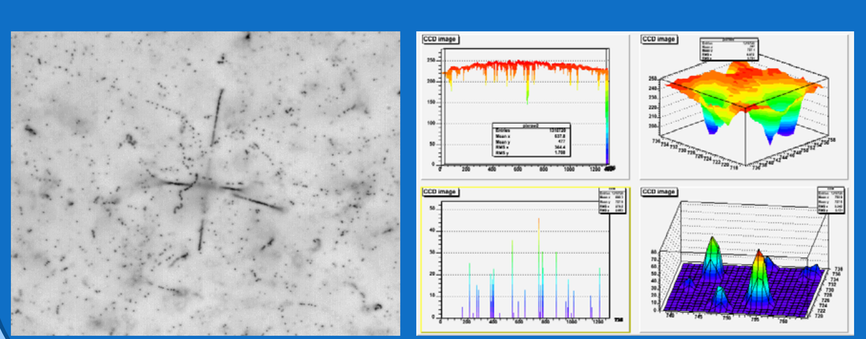
- Continuous cyclic motion in Z (80-90 ms/view)
- Continuous constant speed motion in Y (speed = 280 microns/80 ms = 3500 micron/s)
- Serpentine-like path in a horizontal plane
- Y-shift of consecutive frames is of 9 µm
- The ESS scanning speed increases to 40-45 cm²/h without any hardware modification

The Continuous Motion approach can give a significant benefit in scanning speed w.r.t. the standard Stop&Go approach especially if a scanning system is equipped with a fast high-resolution video camera or a very fast Z-motor (e.g. piezo-drive). Under these conditions the data acquisition cycle is usually much less than the time required to proceed to the next field of view in S&G mode. While in the Continuous mode acquisition is performed during simultaneous movement of stage along both Y and Z axes and hence the time required to move to the next view is not limited by the horizontal movement. But the Continuous mode requires more sophisticated processing since most of tracks will cross view boundaries as well as their clusters will appear at different positions within an image. Thus the processing must take into account effects of optical distortions, vibrations and views misalignment.

Processing Chain

Image Processing includes:

- Image Equalization
- Image Filtration
- Binarization
- Reconstruction of Clusters



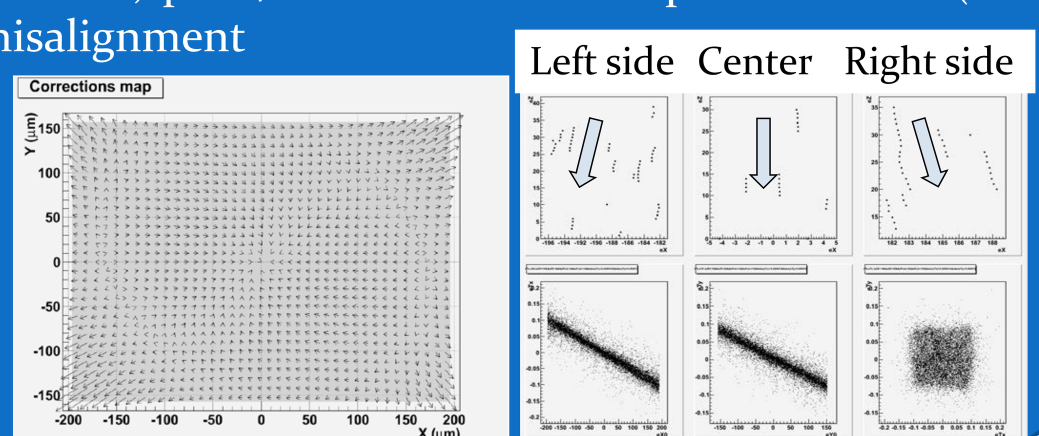
Higher scanning speed leads to a significant vibrations of a Z-axis optical group which results in a noticeable (few microns) displacement of images from their measured positions. This displacement can be eliminated by taking into account that the focal width of an objective is larger than the step between two consecutive frames and cluster shadows persist in neighboring images.

Since objective focal width is usually larger than the step between two consecutive frame, a silver grain will appear as several clusters belonging to consecutive frames. Taking that into account and having applied optical corrections and vibration compensation, it is possible to precisely reconstruct 3-dimentional grain's positions.

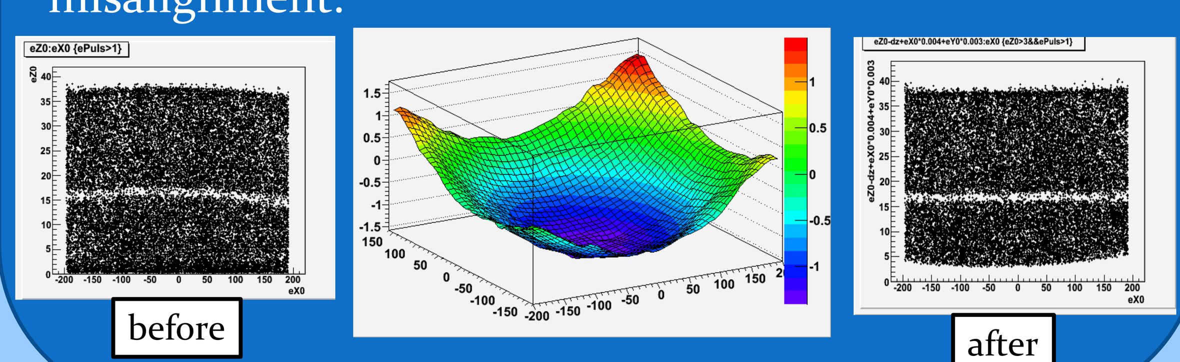
In order to estimate emulsion data quality a dedicated algorithm for microtracks reconstruction in emulsion has been designed. This algorithm uses both cluster and grain information in reconstruction. Studies showed that its efficiency in the S&G mode is about 95% for OPERA-like emulsions. The efficiency estimation for the Continuous mode is in progress, but preliminary tests show that it will be comparable.

Image Processing → Correction of Optical Distortions → Vibration Compensation → Correction of Field of View Curvature → Reconstruction of Grains → Alignment of Views → Reconstruction of Microtracks

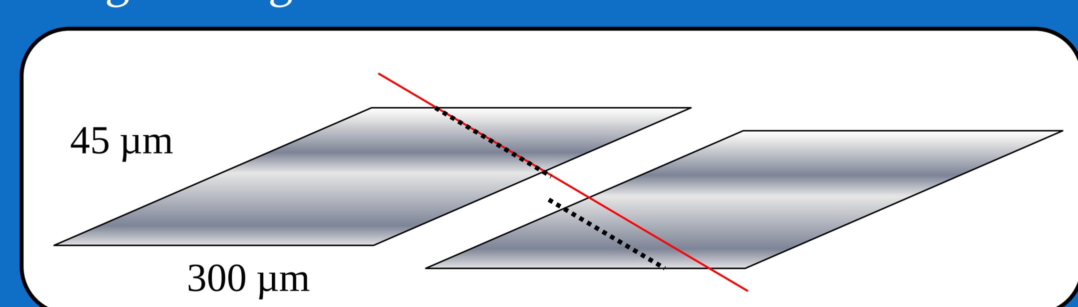
Optical distortions, present in any optical system, introduce a noticeable (few microns at edges) position-dependent error into measurement of a cluster position. This can be fixed by performing a dedicated measurement and generation of correction map which is later applied to every image. The resulting correction map automatically includes image distortion, camera rotation, pixel/micron error and optical centers (axes) misalignment



Field of view is not perfectly flat due to presence optical distortions. This will lead to a noticeable (few microns between clusters in the center and at edges) error in cluster Z-coordinate measurement. This can be fixed by performing a dedicated measurement and generation of correction matrix which is later applied to every cluster. The correction matrix accounts for focal plane curvature correction and small optical axes misalignment.



Unlike in Stop&Go Motion, boundaries between views in Continuous Motion are no longer vertical which means that the majority of mictotracks (even vertical ones) will cross them. Without applying views alignment such a microtrack will become broken at the boundary. The alignment is performed by matching 3D grain patterns in the overlapping volume of the neighboring views.



Breaking of a microtrack at view's boundary