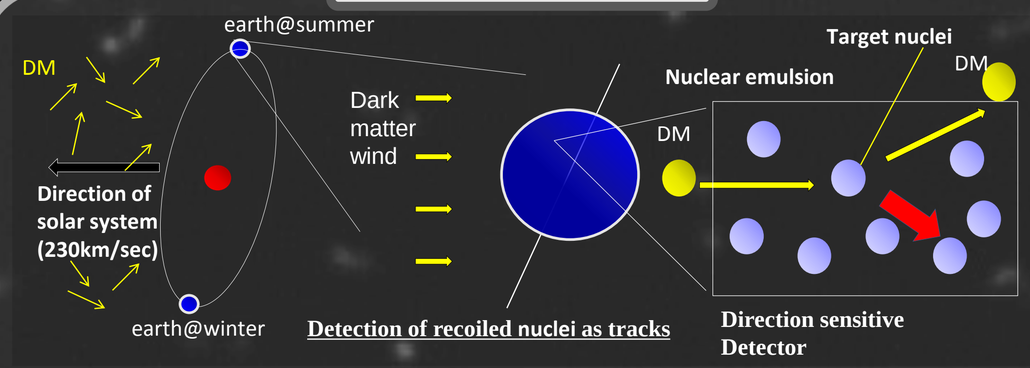
Development of a super-resolution optical microscope for directional Dark Matter search experiment

Andrey Alexandrov (INFN-Napoli) on behalf of the NEWS collaboration
E-mail: andrey.alexandrov@na.infn.it

ABSTRACT

The Dark Matter (DM) existence is one of the most open and discussed questions nowadays. The best candidates are so-called Weakly Interactive Massive Particles (WIMPs) with mass ranging from few GeV to a few TeV that interact with ordinary matter with cross sections typical or smaller than that of the weak processes. The motion of the Sun inside the galaxy causes an anisotropy in direction of WIMP-induced nuclear recoils, and, as it has never been observed, its evidence would unambiguously prove the existence of WIMP particles as DM constituents, which makes the directional DM search an extremely interesting and important issue from the point of view of fundamental science. Nuclear emulsion is a perfect choice for a detector for directional DM search because of its high density and the best position accuracy. The track length of recoil nuclei in emulsion is of the order of 100 nm, making the resolution of conventional optical microscopes insufficient to resolve them. Here we report about the R&D on a super-resolution optical microscope to be used in a future directional DM search experiment with nuclear emulsion as a detector media. The microscope will be fully automatic, will use novel image acquisition and analysis techniques, will achieve the spatial resolution of the order of few tens of nm and will be capable of reconstructing recoil tracks with the length of at least 100 nm with high angular resolution.

DIRECTIONAL SIGNATURE



How long is the recoil in emulsion?

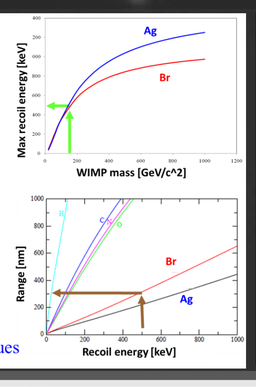
WIMP velocity < 800 km/sec

Take e.g. M_{WIMP} ~ 150 GeV/c²

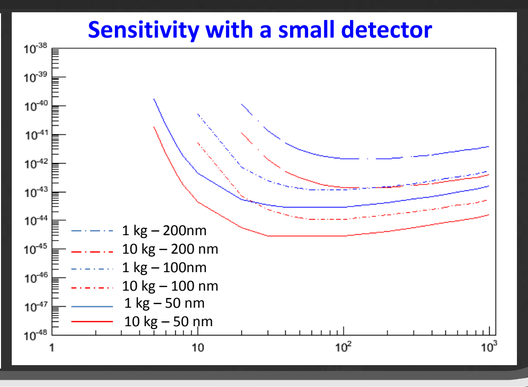
Recoil energy < 500 keV

Br range < 300 nm

Nano-grains and improved detection techniques

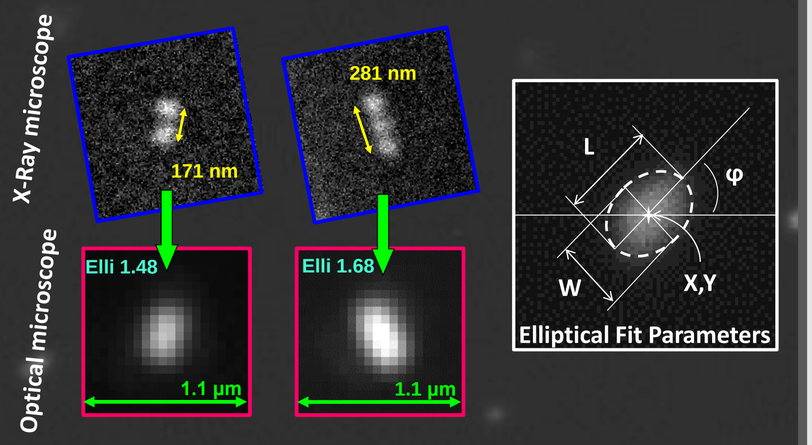


Sensitivity with a small detector

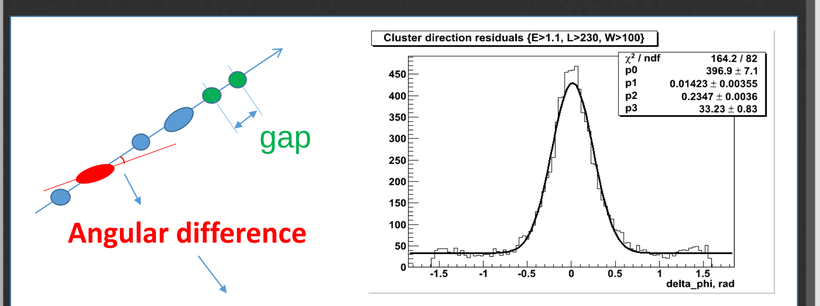


ELLIPTICITY ANALYSIS

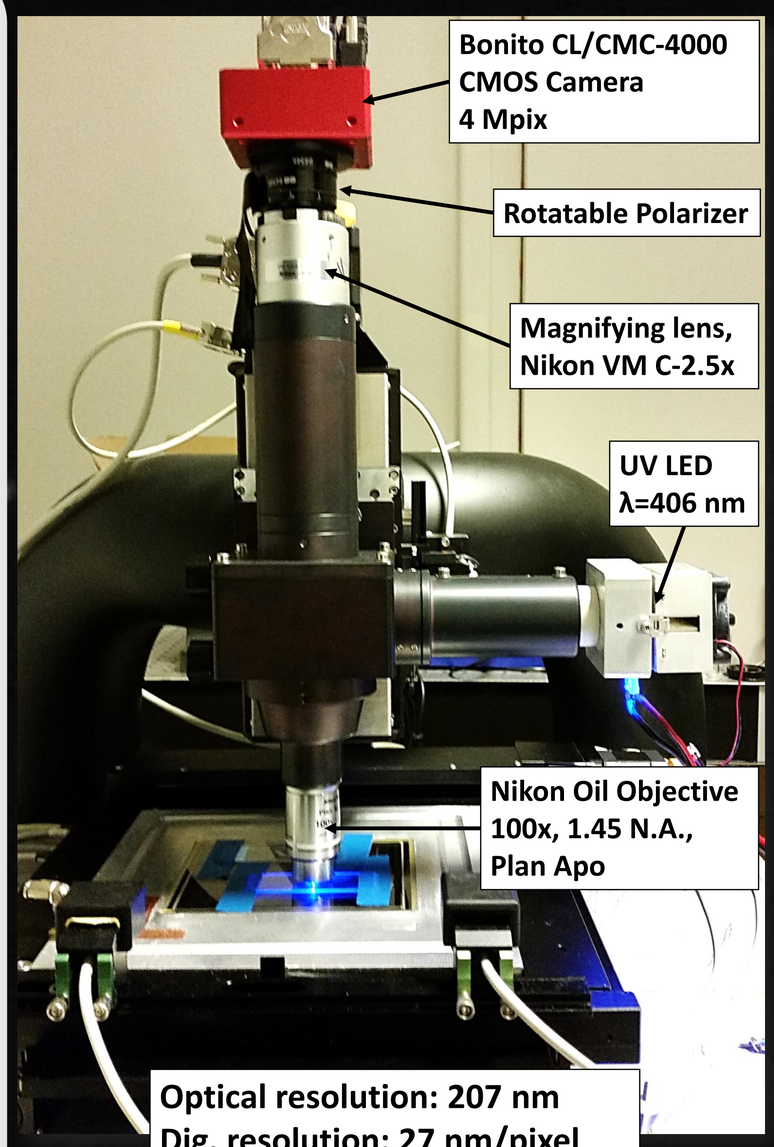
- The sequence of several grains making a track of a few hundred nm appears as a single cluster
- A cluster made of several grains tends to have an elliptical shape with the major axis coincident with the direction of the trajectory
- A cluster produced by a single grain tends to have a spherical shape



- With cluster ellipticity analysis it is possible to locate sub-resolution tracks and determine their direction



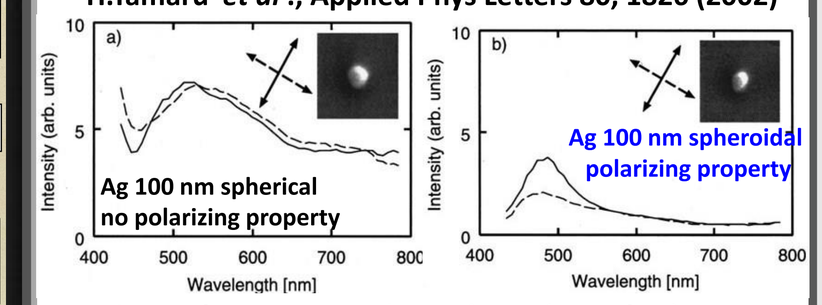
Angular resolution = 235 mrad = 13°



Optical resolution: 207 nm
Dig. resolution: 27 nm/pixel
View Size: 65 x 48 µm

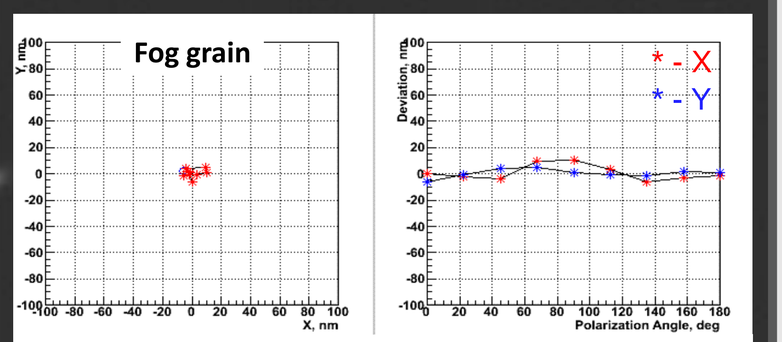
POLARIZATION ANALYSIS

H.Tamaru *et al*., Applied Phys Letters 80, 1826 (2002)

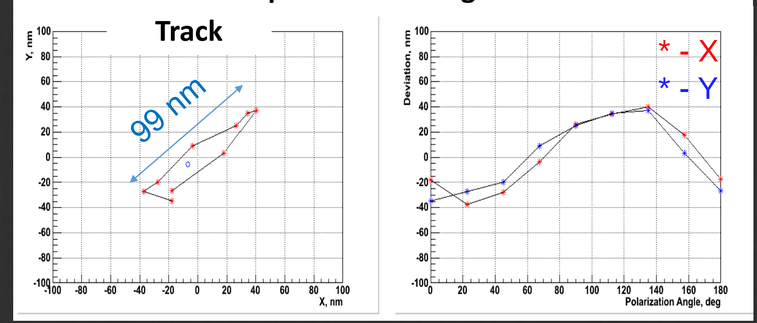


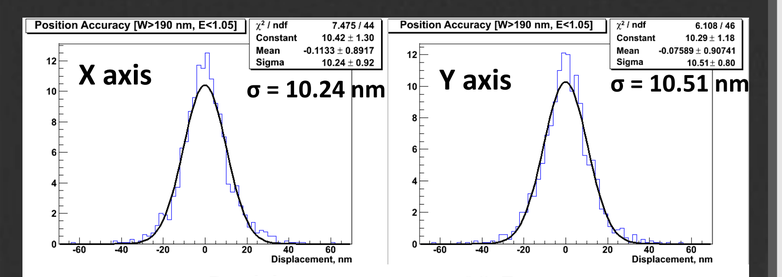
Scattering spectrum depends on the grain shape

- Silver grains in emulsion are nanoparticles
- Grains tend to have spheroidal shape
- The reflected light is polarized
- Polarization angle depends on grain orientation
- Grain orientation is random
- With the analysis of the reflected light polarization it is possible to isolate individual grains
- With polarization analysis reconstruction of tracks with the length of 100 nm becomes possible
- Additional studies are in progress to push recoil length limit to below 100 nm



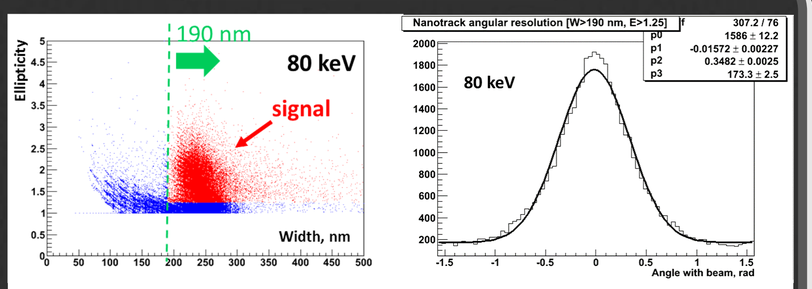
Displacement of the cluster mass center with change of polarization angle



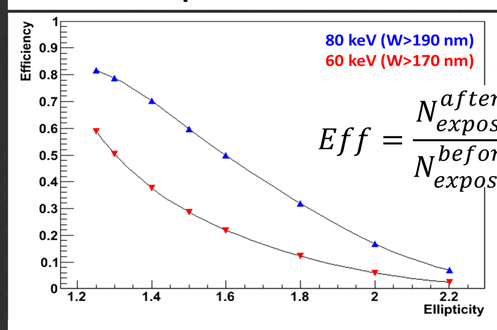


Position accuracy = 10.5 nm

TEST WITH C-ION BEAM



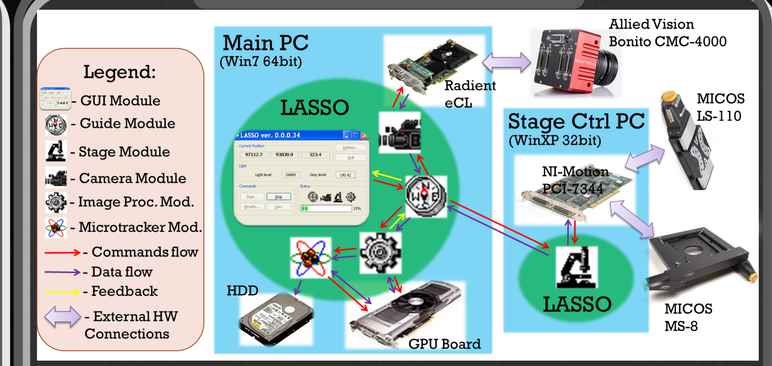
Sample irradiated with 80 keV Carbon ions



$$Eff = \frac{N^{after\ cut}_{exposed\ area} - N^{after\ cut}_{mask\ area}}{N^{before\ cut}_{exposed\ area} - N^{before\ cut}_{mask\ area}}$$

Ellipticity cut efficiency

SCANNING SYSTEM



- The microscope operation, DAQ and analysis is performed by the LASSO (Large Angle Scanning System, A. Alexandrov et al., 2014 JINST 9 C02034)
- Implemented a dedicated module to perform a 3D track reconstruction and ellipticity analysis
- Work on integration of a rotatable polarizer and implementation of a module for polarization analysis is in progress

13th Pisa Meeting on Advanced Detectors, La Biodola, Isola d'Elba (Italy), May 24 - 30, 2015