Study for Direct Measurement of Target Fragmentation

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The idea

- The main experimental difficulty for a direct measurement of target fragmentation induced by a proton beam is the short range of produced fragments (≤100 μm)
- In usual configurations, so short fragments do not exit the target: we propose to use the Emulsion Cloud Chamber (ECC) technique, in a configuration where the target and the tracking device coincide
- We will use a novel kind of nuclear emulsion, called Nano Imaging Tracker (NIT), with grains at the nanometric scale that allows us to detect path lengths shorter than 100 nm

References:
- Asada, T. et al. The development of a super-fine-grained nuclear emulsion. Prog. Theor. Exp. Phys. 6, (2017)
- Alexandrov, A. et al. Super-resolution high-speed optical microscopy for fully automated readout of metallic nanoparticles. Sci. Reports 10, 18773 (2020)

The project has been proposed for a PRIN (March 2022) by three research units: Bari, Naples, INFN (LNGS)

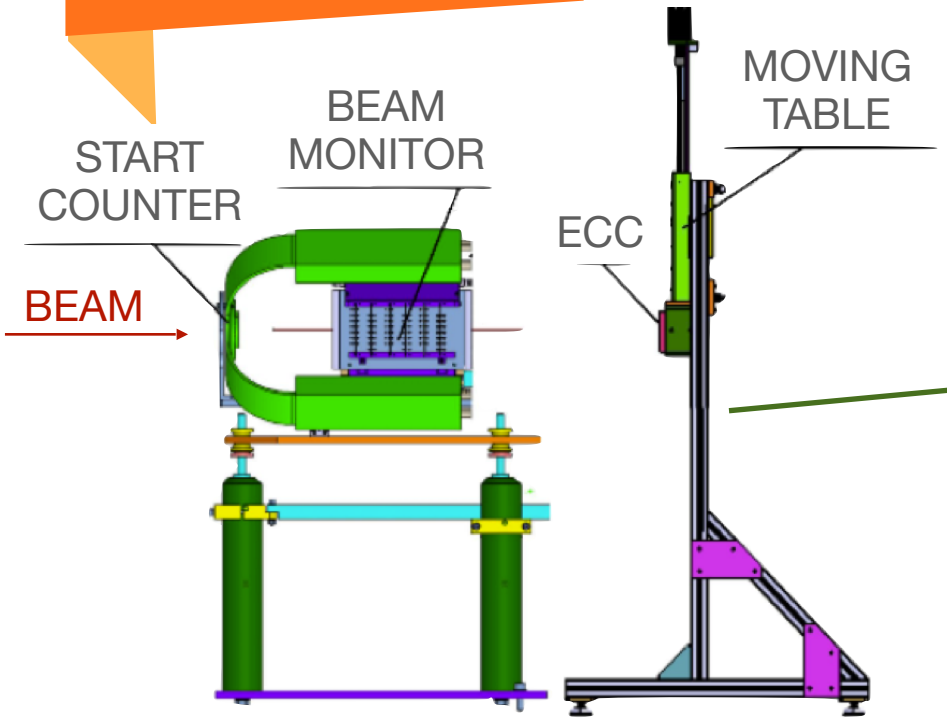
Pilot run at TIFPA

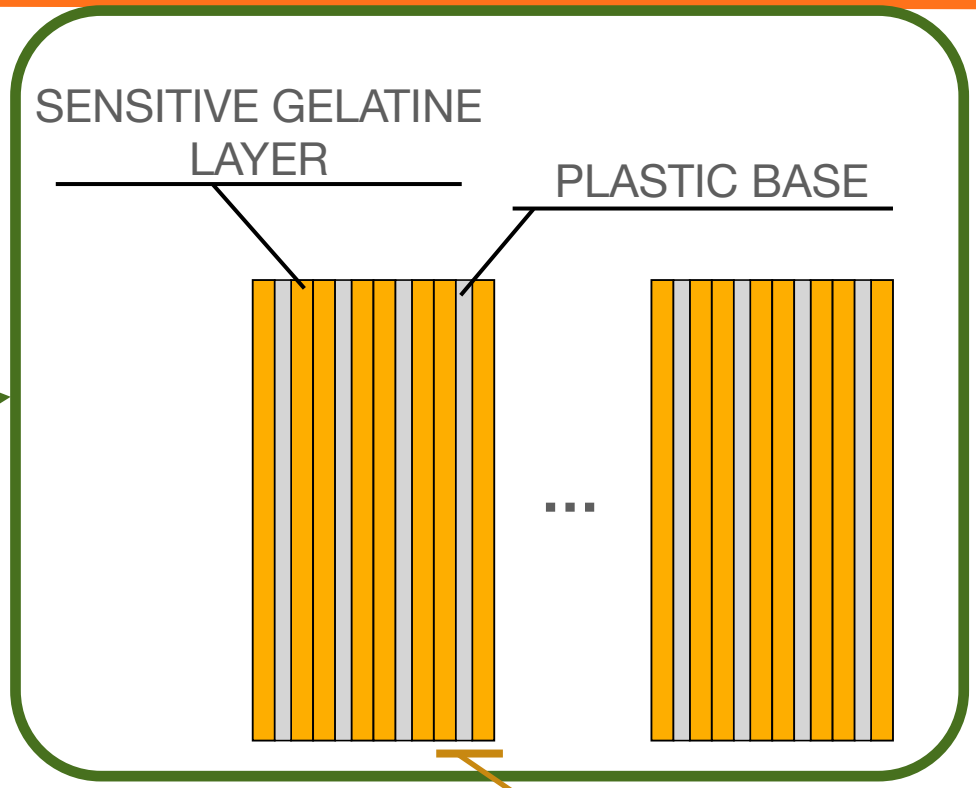
- Two lines can be used for NIT exposure:
  - physics line: a fixed pencil beam is available with energies between 70 and 228 MeV, with FWHM ~1 mm
  - biology line: a dual-ring double scattering system has been designed to produce to produce irradiation fields of two sizes (i.e. 6 and 16cm diameter) starting from a fix pencil beam at 148MeV.
- A slot was available in December, but it was not possible to produce NITs in time. A new slot will be found in 2023

References:

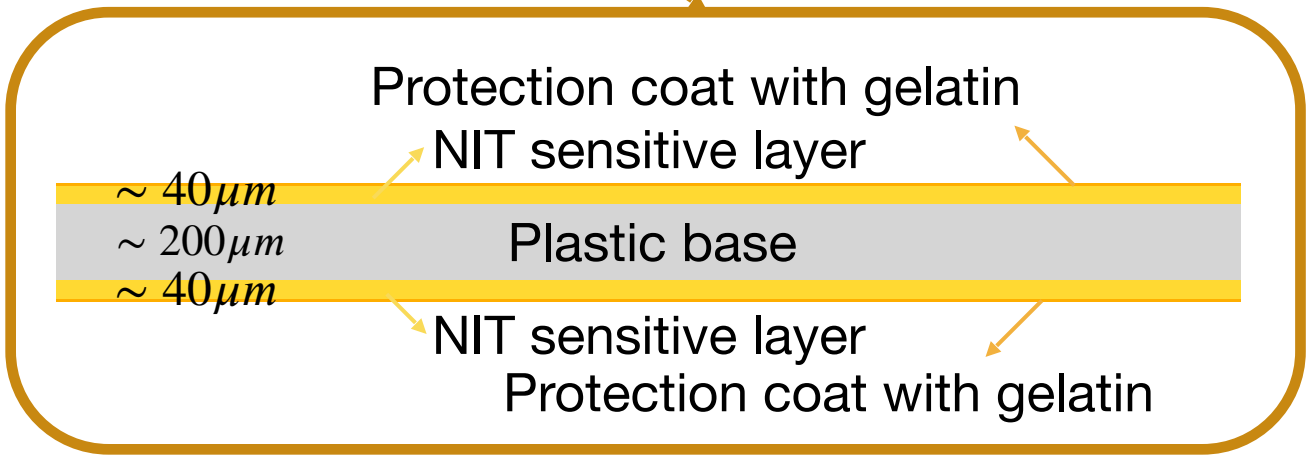
- Tomasino F. at al, A new facility for proton radiobiology at the Trento proton therapy centre: Design and implementation
- Tomasino F. at al, Proton beam characterization in the experimental room of the Trento Proton Therapy facility

Experimental set-up





- Feasibility studies at LNGS: usually NIT are made with 2 mm COP base → too thick for our purposes!
- Another possibility: 200μm plastic base
  - ➡ New MC simulation (previous one was with 70-50-70 μm
  - ➡ 200μm plastic bases not available at LNGS: shipped from Nagoya University



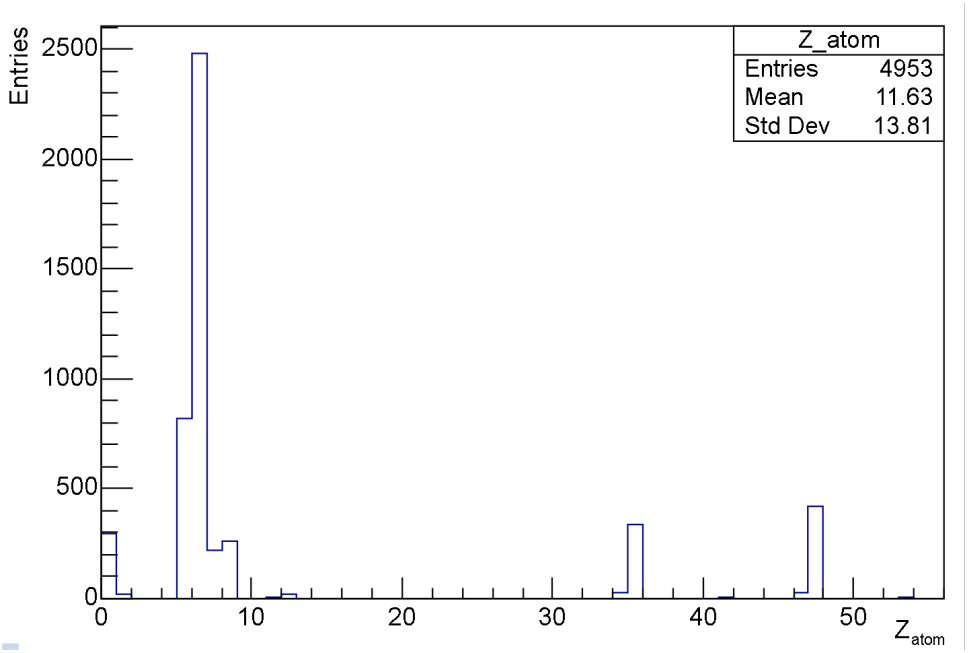
MC simulation

- New MC Simulation performed with Fluka using the new NIT gel and base thicknesses:
  - 10^5 protons @ 200 MeV
    Rectangular beam $2.5 cm^2$
  - 100 NIT: $40 \mu m \cdot 2$ sensitive gel layers, $200 \mu m$ plastic base, $(10 \times 12) cm^2$ area
  - Transportation threshold 10keV

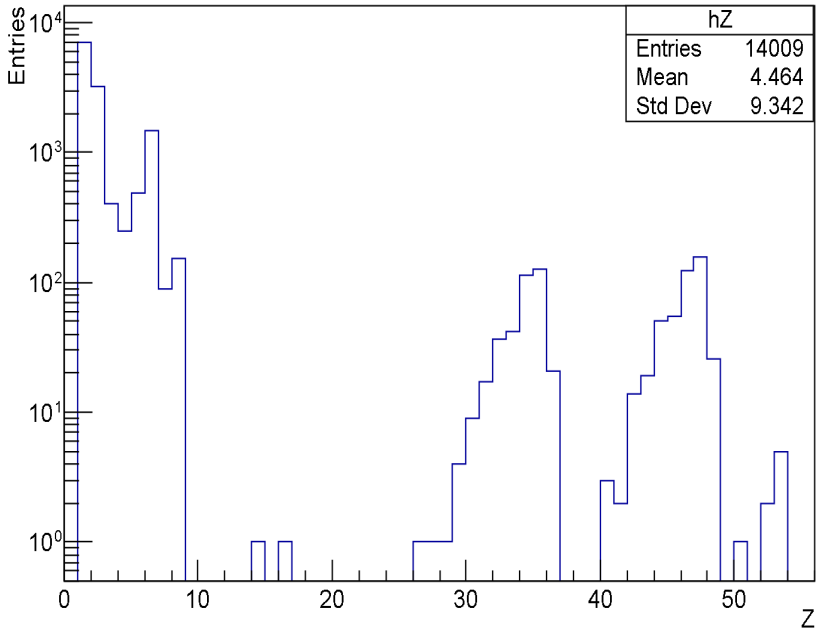
- Cross checks on-going using the software TOPAS

MC simulation

Charge of nuclei on which a proton interaction occurred



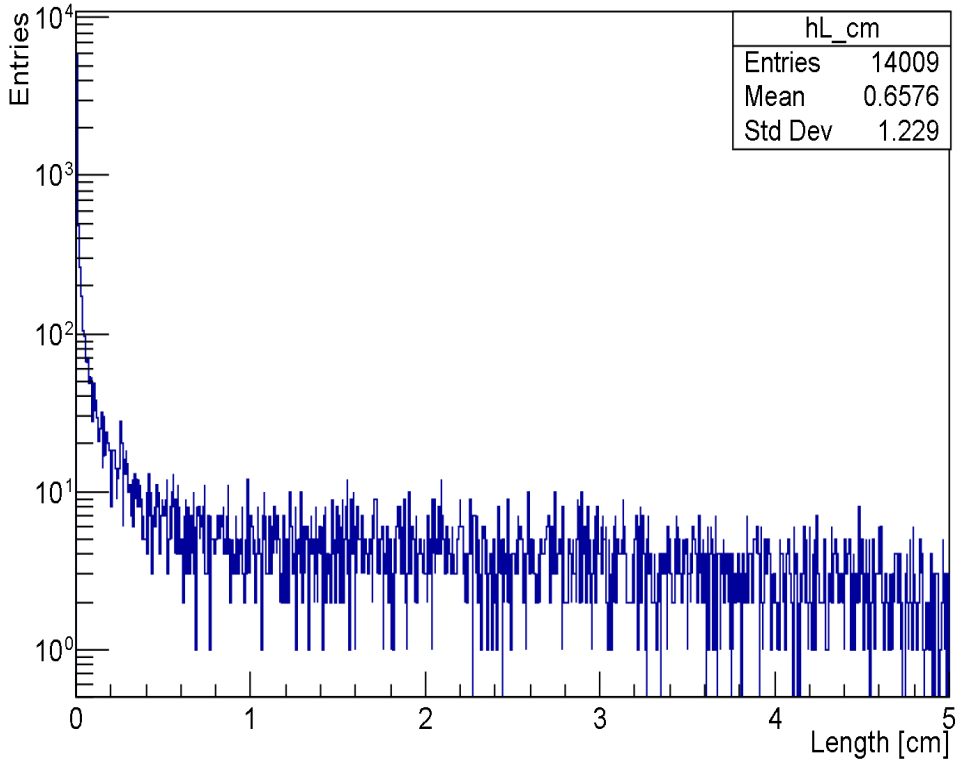
Fragments' charge after a proton interaction, including residual atoms traveling at least 200 nm

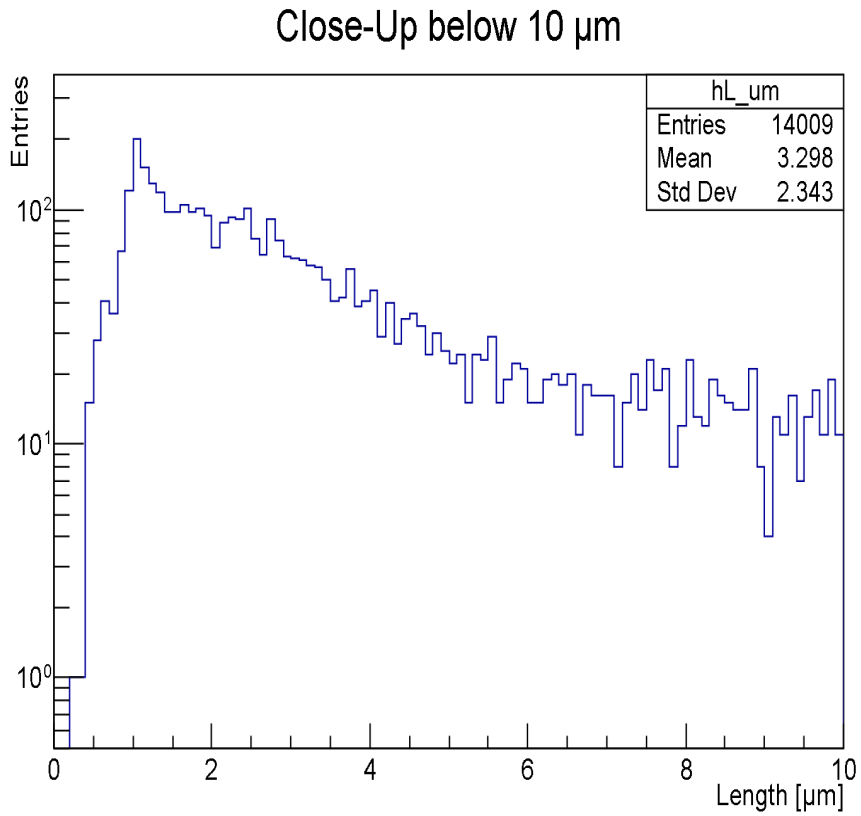


- ~4,6% of beam protons interact in the detector:
  - 38% in emulsion gel (C, O, H, N, Ag, Br…);
  - 62% in the plastic base $(C_8H_8)_n$
- ~83% interactions on nuclei ≠ Ag, Br

Monte Carlo simulation: fragments' track length

- Typical energies of fragments, of the order of MeV, make them travel at least 300-500 nm.
- At least 13% of fragments exit the ECC: possible second section with 1mm Lead passive material (30 layers) and standard nuclear emulsions to track long tracks and measure MCS and range

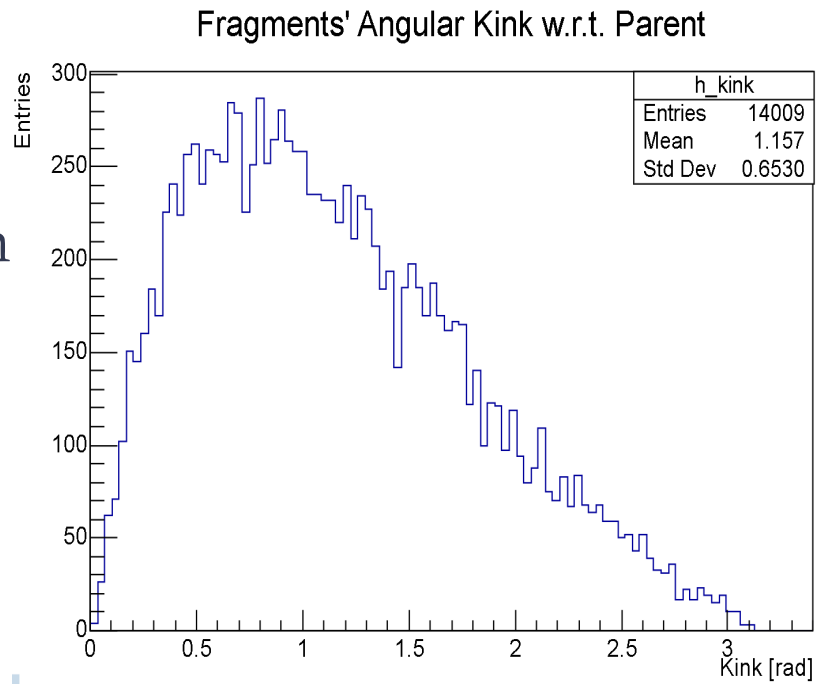


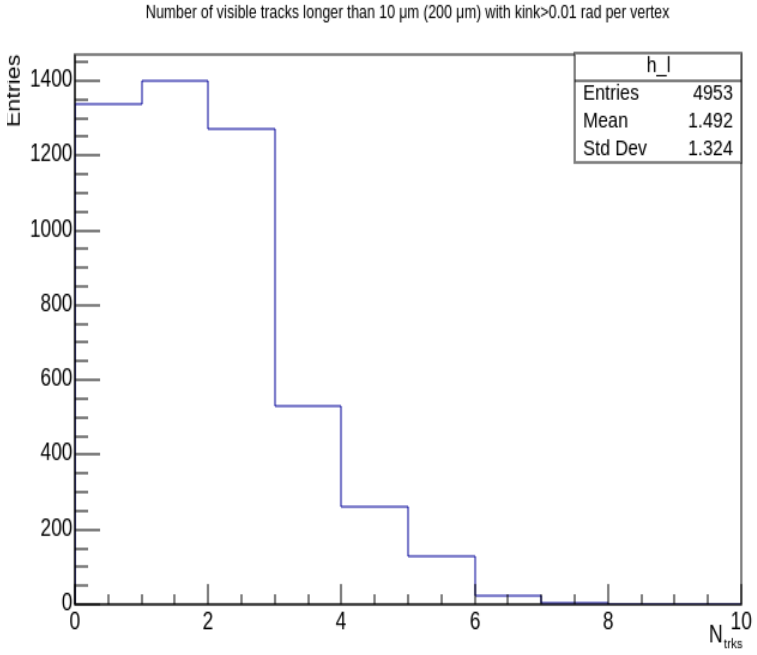


Monte Carlo simulation: conditions for vertices reconstruction

A vertex is reconstructed if one of the following occur:

- at least one visible track is longer than 10 μm (200 μm if it starts in plastic support) and has a kink larger than 0.01 rad with respect to parent
- at least two charged tracks begin in the emulsion gel and at least one is longer than 10 μm

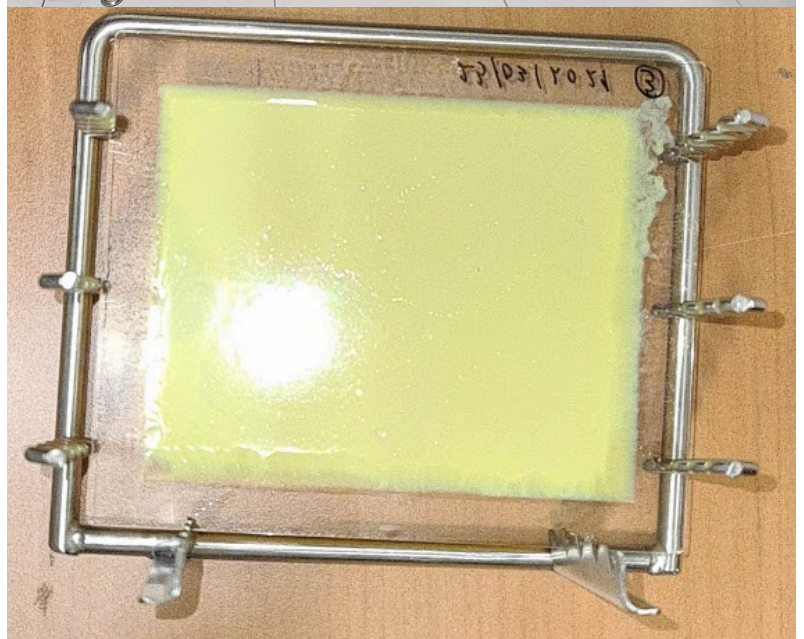




at least 70% of interactions can be reconstructed

Pilot run

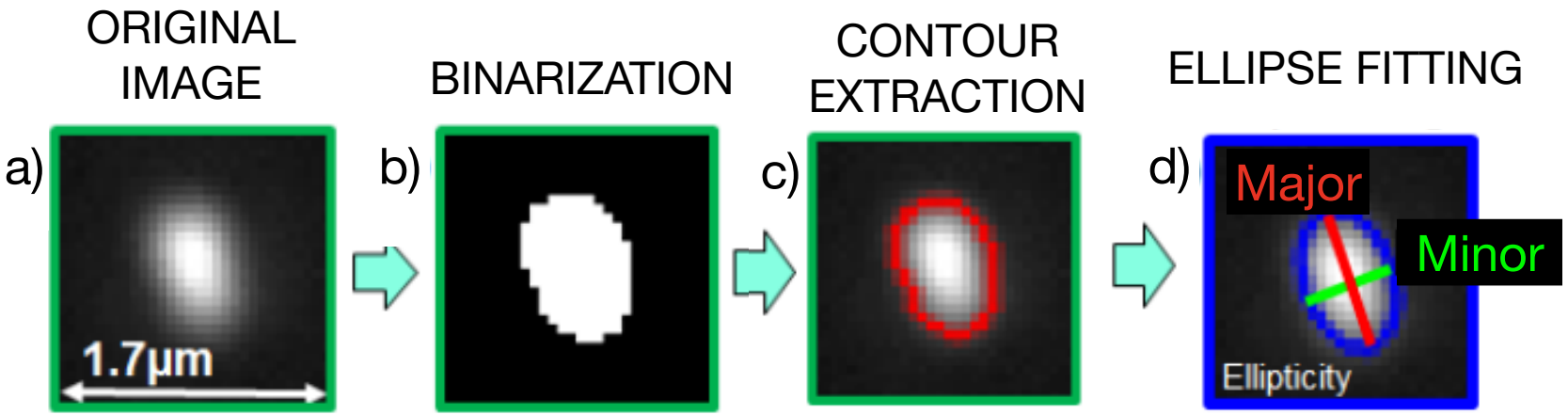
- Production of 20 NIT $(10 \times 12) cm^2$ will be started as soon as plastic bases arrive from Japan (already shipped)
- The beam will impinge on a larger area (wrt MC simulation) to account for the smaller number of NITs
- Tests for microscopy read-out will be carried out in Naples

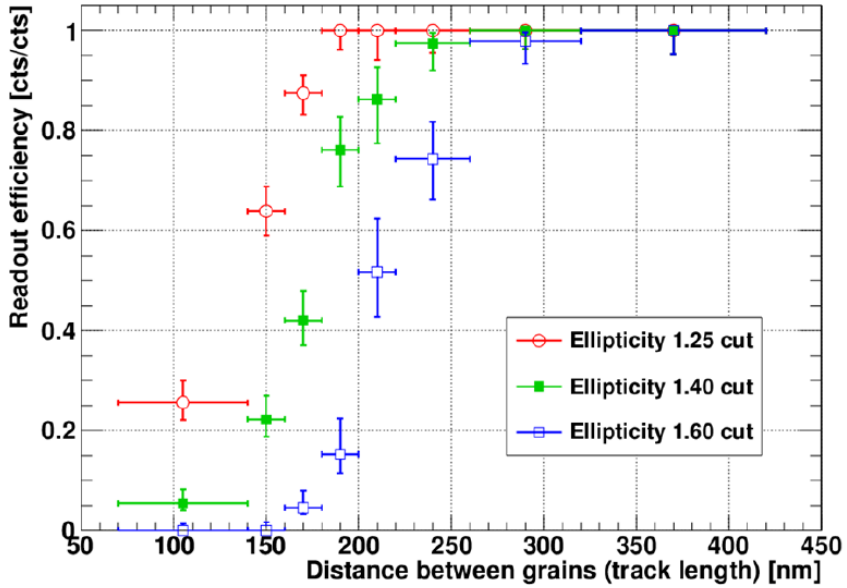


NIT Read-out I

The NIT readout has been developed within the NEWSdm experiment for dark matter search and consists of **two** steps.

1) Read-out with "normal" optical microscopes: an ellipticity cut defines tracks candidate → in NEWSdm performed at Nagoya University

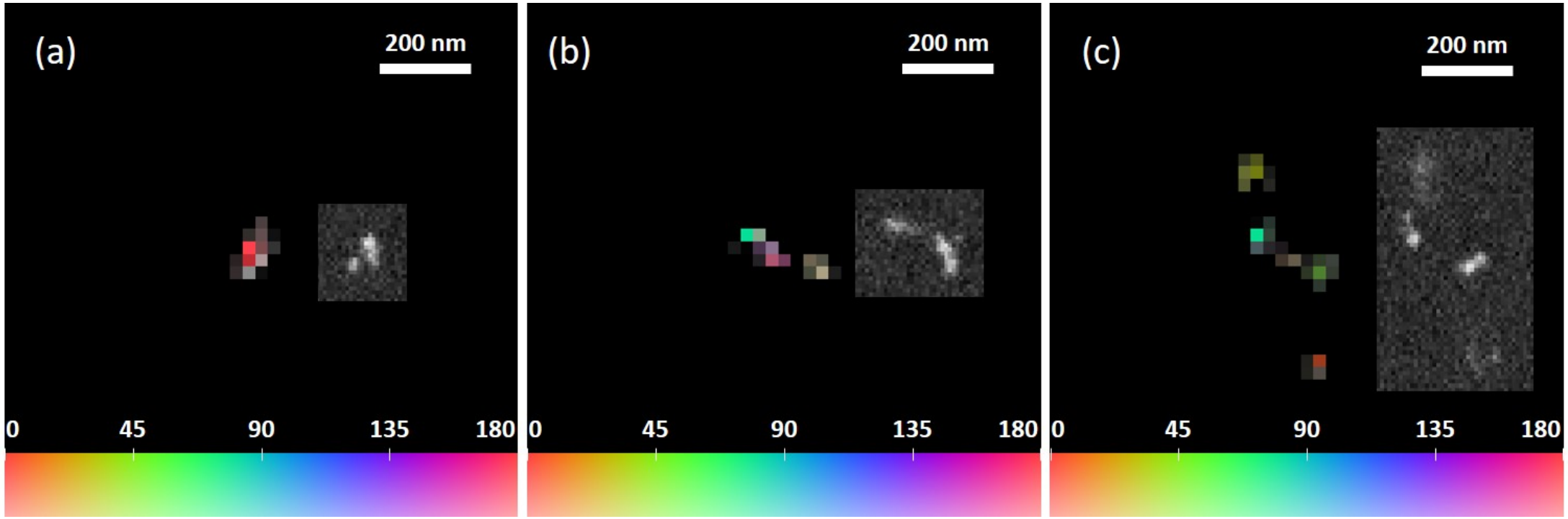




A pilot run is needed to tune our "normal" microscopes for NIT read-out

NIT Read-out II

2) In the second phase all candidates are analyzed in Naples with a super resolution optical microscopy exploiting the Localized Surface Plasmon Resonance (LSPR) phenomenon



"Plasmon analysis": barycentre shift analysis, color analysis, super-resolution imaging

Conclusions

- Nano Imaging Trackers (NIT) allows us to set an experiment with 100 nm threshold for tracks reconstruction: the direct measurement of target fragmentation due to proton beam seems feasible

- Pilot run will be performed at TIFPA with 20 NIT in 2023
  - New MC simulation
  - NIT production forseen at LNGS
  - Tests on NIT read-out to be performed in Naples

THANK YOU!