# Comparison of three different types of particle-track detectors

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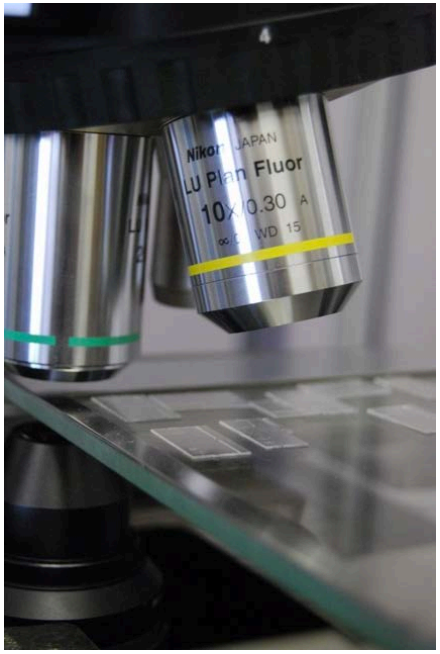
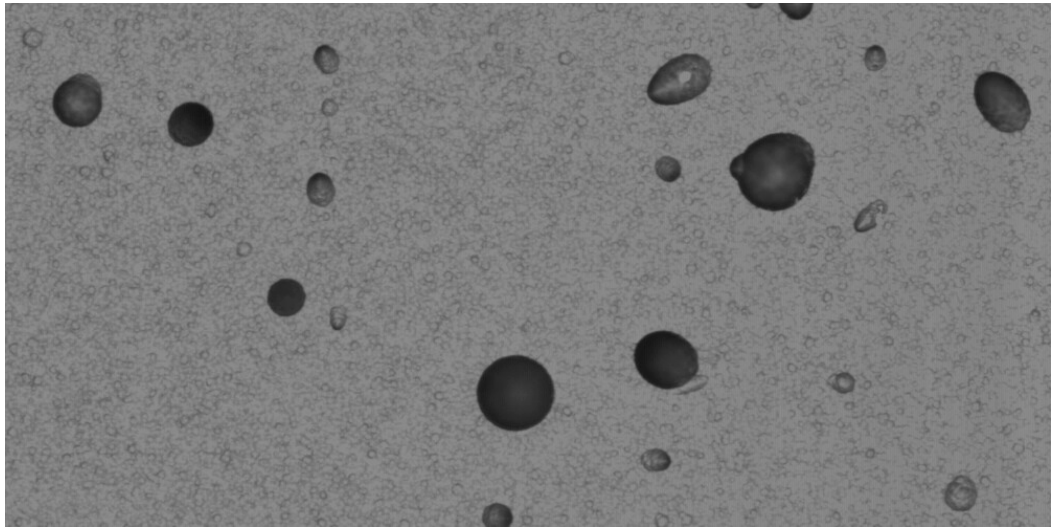
# Introduction

- information about individual particles (type, energy, direction…)
- detectors visualizing particle's track – plastic nuclear track detector (PNTD), nuclear track emulsion (NTE), Timepix, fluorescent nuclear track detector (FNTD) ...
- irradiation at HIMAC, various ions under different angles
- comparison of all three detectors on individual track basis
- properties of each method (duration of analysis process, detection efficiency, spatial resolution, spectroscopic properties)

# Plastic nuclear track detectors

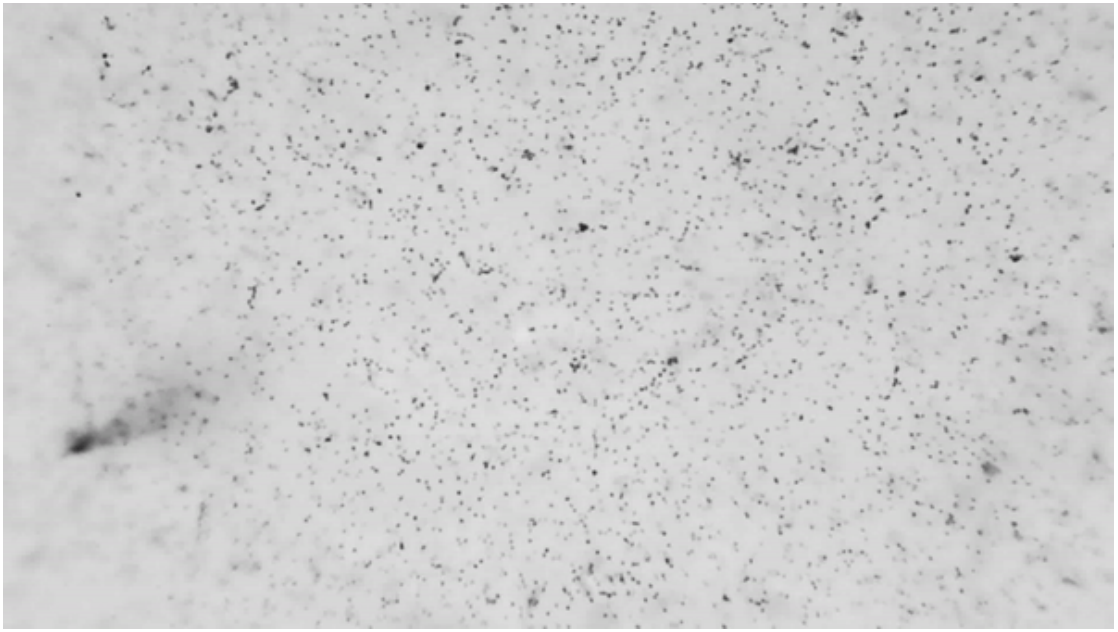
- latent track -> chemical etching -> optical microscope
- track parameters -> V -> LET of individual particles, incident angle
- Harzlas TD-1 (12 x 12 $mm^2$), etching 18h in 5N NaOH at 70$^oC$

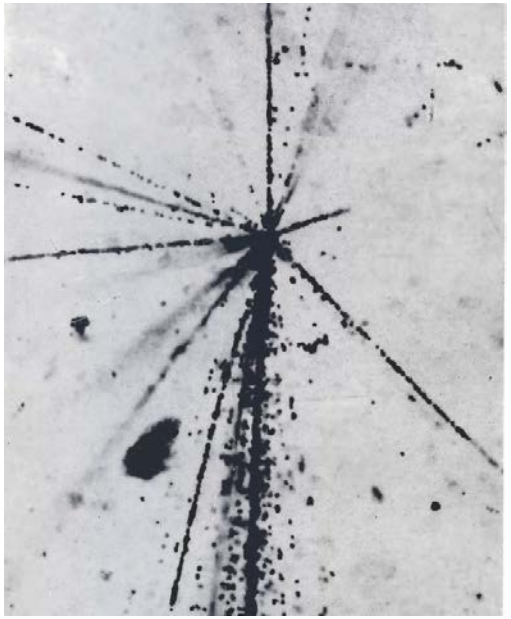


# Nuclear track emulsions

- high sensitive photographic film used for detection of 3D trajectory of charged particles
- latent image -> chemical development -> optical microscope



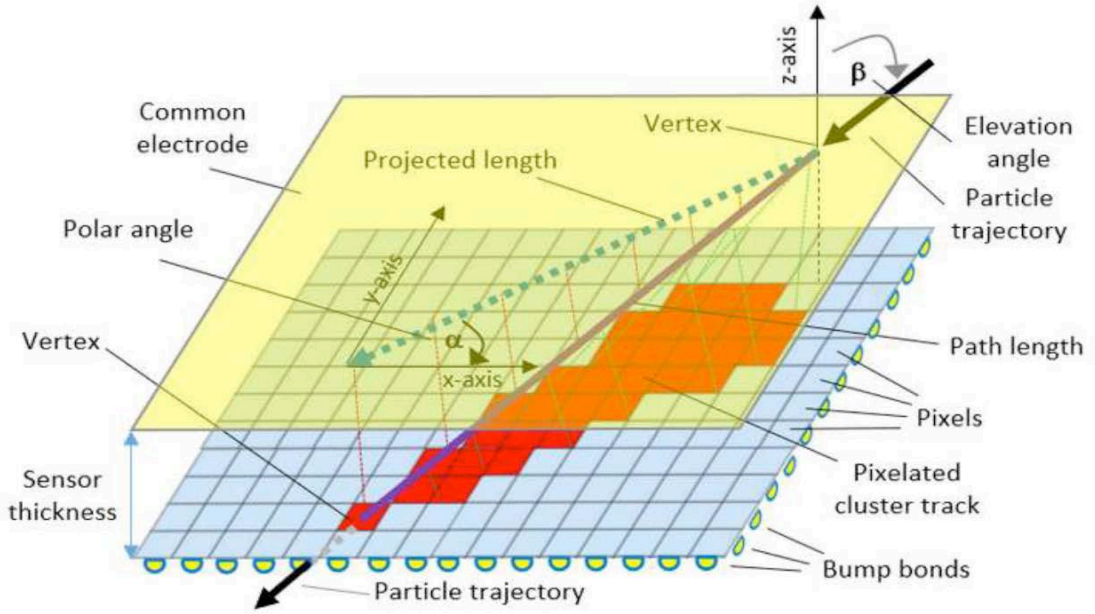


# Nuclear track emulsions

- BR-2 from Slavich Company (Pereslavl-Zalessky, Yaroslavl region, Russia)
- thickness 50 µm; 10 x 10 $mm^2$
- evaluation process: swelling 15 min, developer 15 min, bath 15 min, washing 15 min, fixer 30% 60 min, lowering of fixer concentration 110 min, washing 20 min, alcoholic drying 15 min, air drying
- sensitivity to alphas and heavier ions of all energies, protons from 0.1 – 4000 MeV, electrons, muons, charged pions…

# Timepix

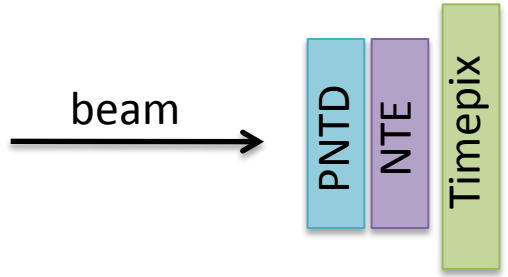
- semiconductor pixel detector, 256 x 256 pixels
- Timepix (Medipix 2), Si, 300 μm, 14 x 14 $mm^2$
- sensitive to X-rays, electrons, heavy charged particles
- clusters -> identification of particles, deposit energy, incident angle

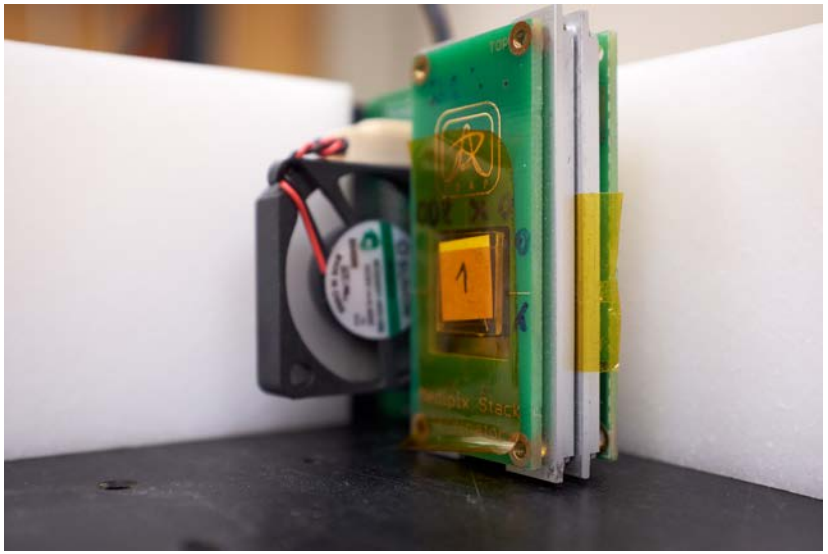



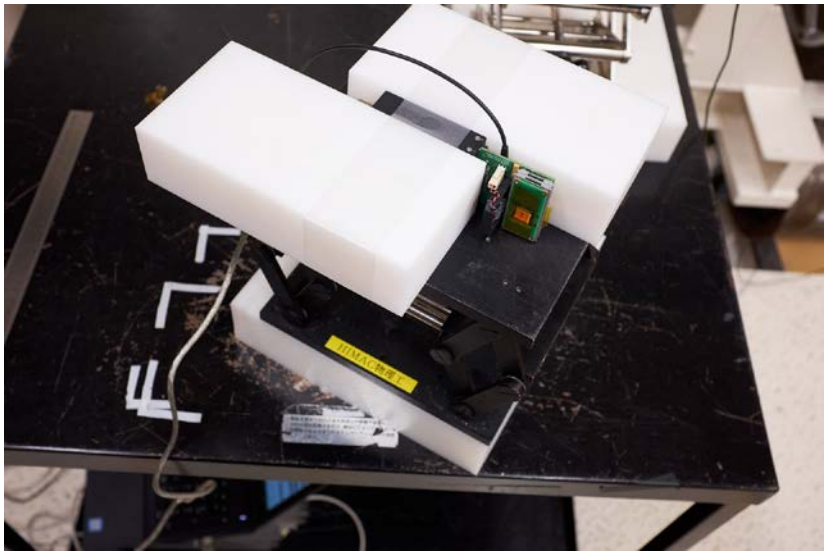

Granja et al., 2018; https://doi.org/10.1016/j.nima.2018.08.014

# Irradiation

- PNTD + NTE + Timepix
- HIMAC, January 2018
- Fe 500 MeV/u, Ne 400 MeV/u, O 400 MeV/u
- 2 angles (90 and 60 degree)

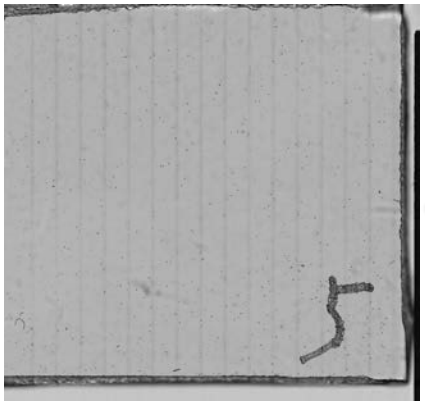


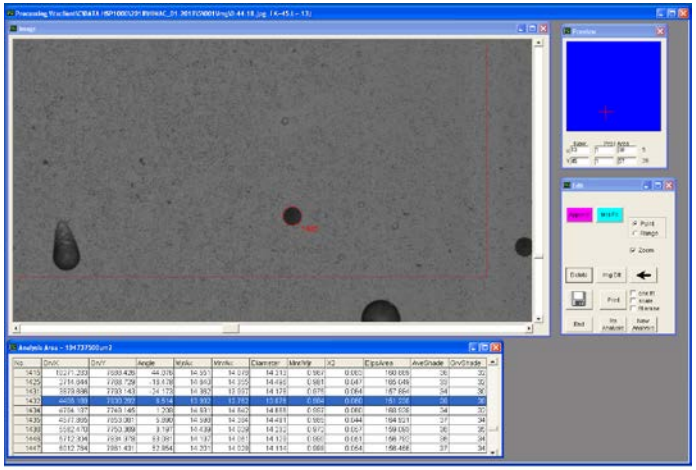





# Analysis – PNTD and NTE

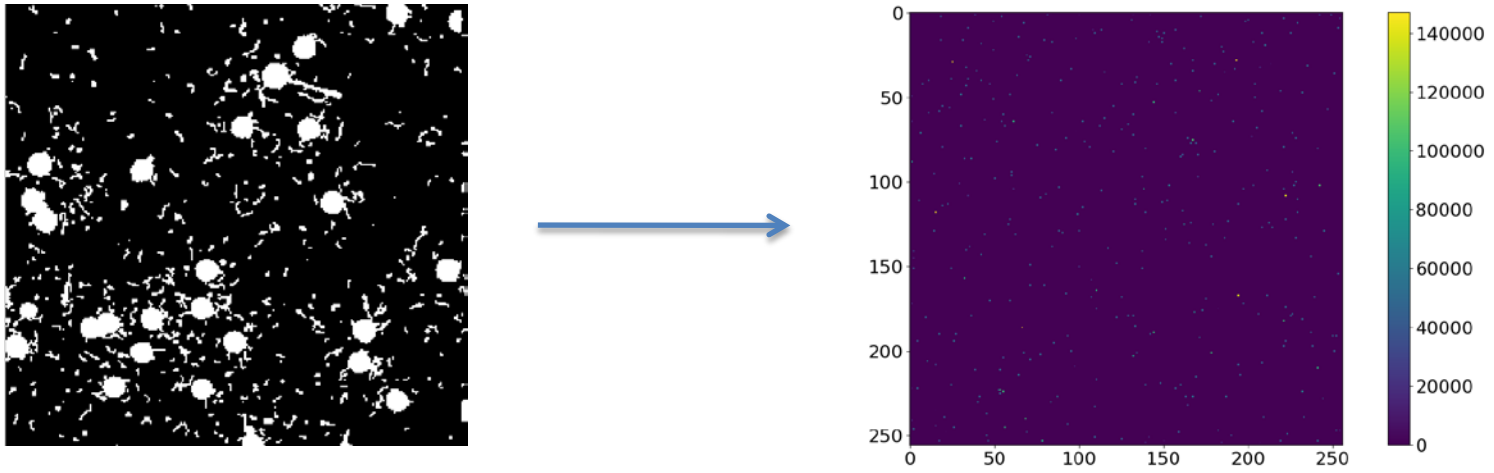
- High-speed microscope HSP-1000 (objective lens 20x)
- Software HspFit





# Analysis – Timepix

- Pixet
- ToT (Time-over-Threshold) mode
- frame acquisition time (50 ms for Fe; 100 ms for Ne and O)
- readout dead time about 20 ms



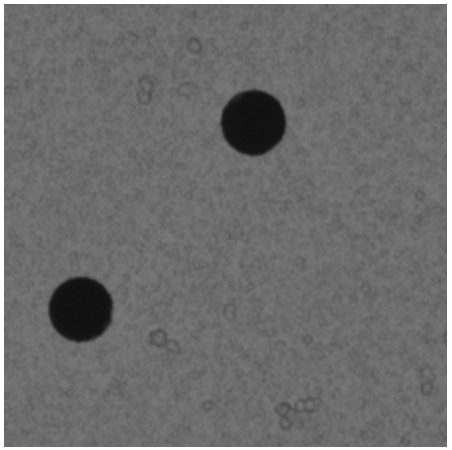
# Fe500

TED

NTE

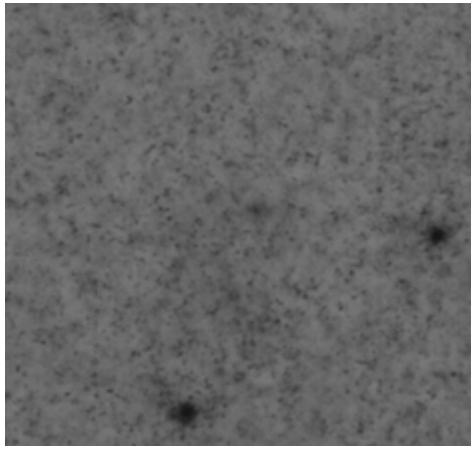
Timepix

90°



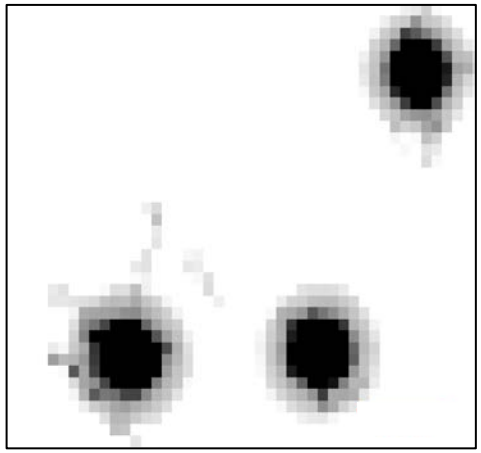
30 μm

about 26 μm



30 μm

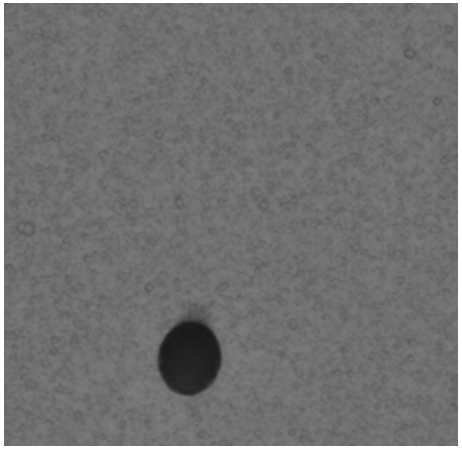
about 7 μm

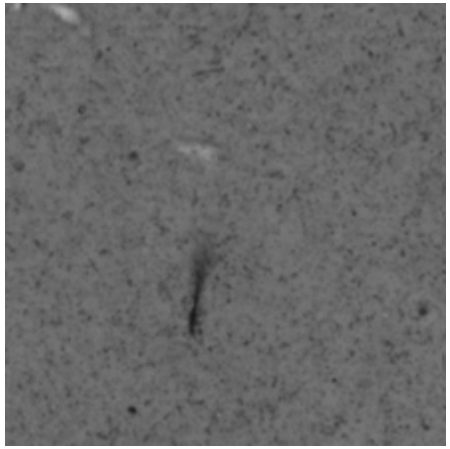


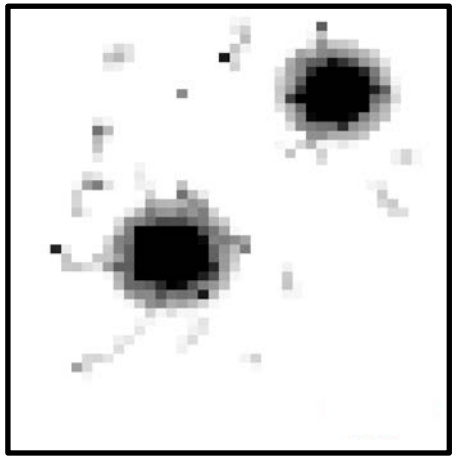
500 μm

about 600 μm

60°







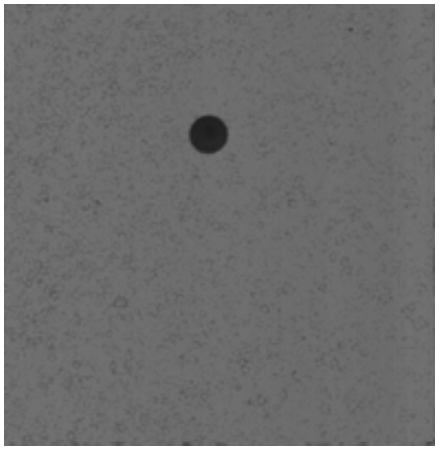
# Ne400

TED

NTE

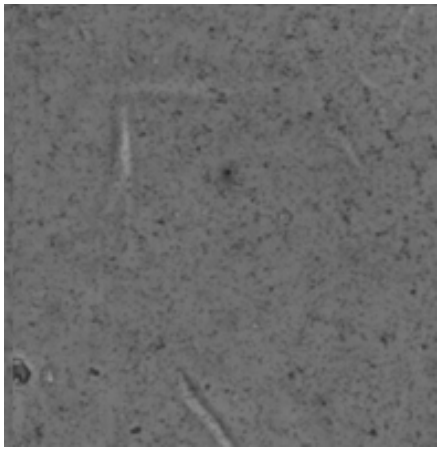
Timepix

90°



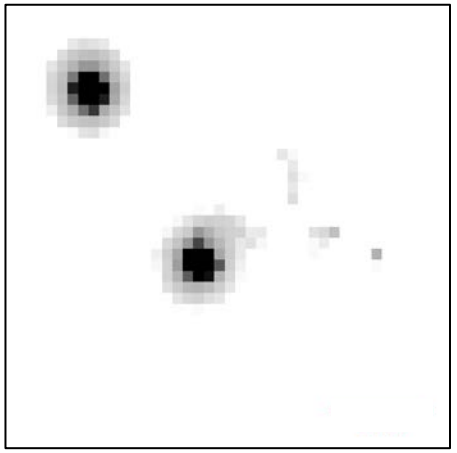
30 μm

about 15 μm



30 μm

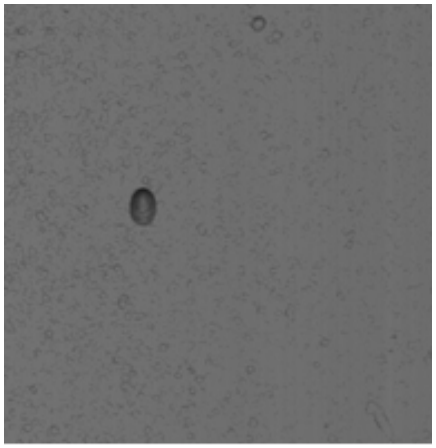
< 3 μm

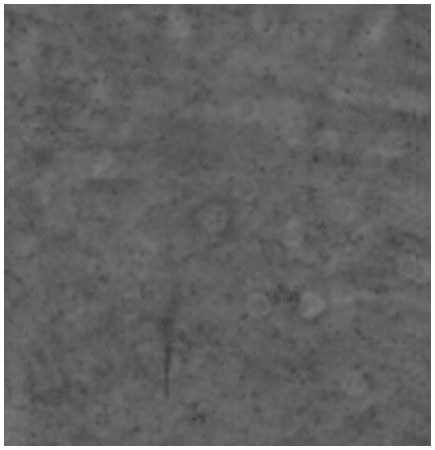


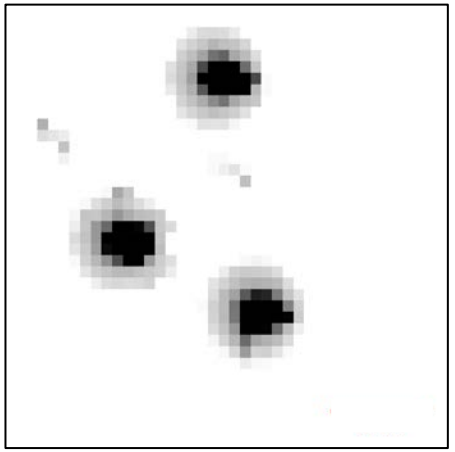
500 μm

about 440 μm

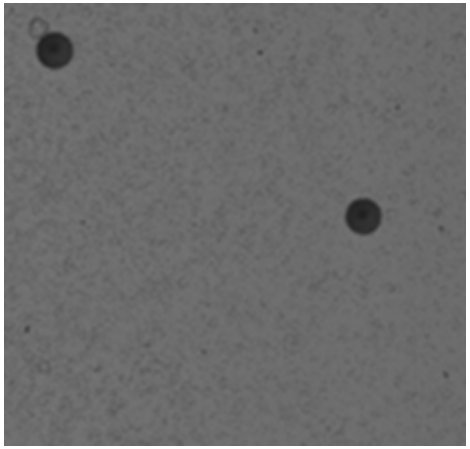
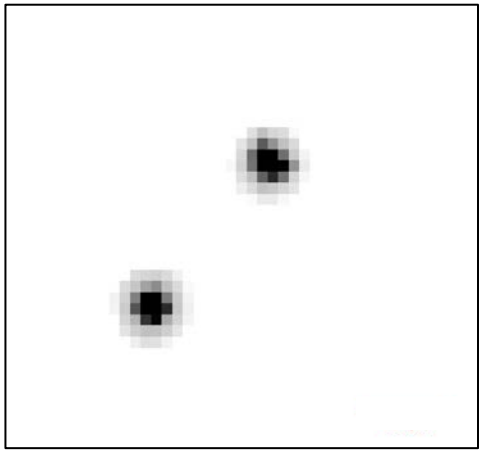
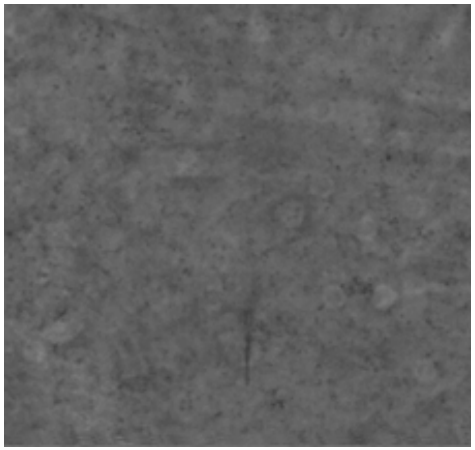
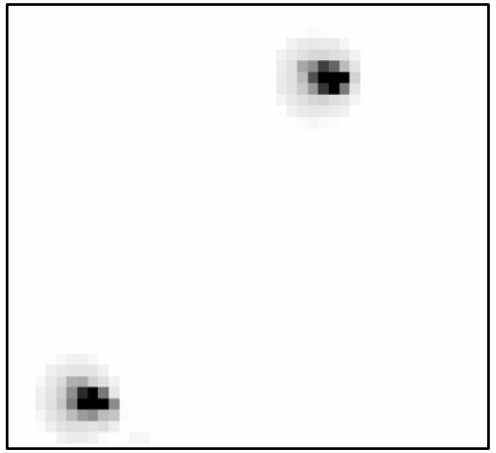
60°



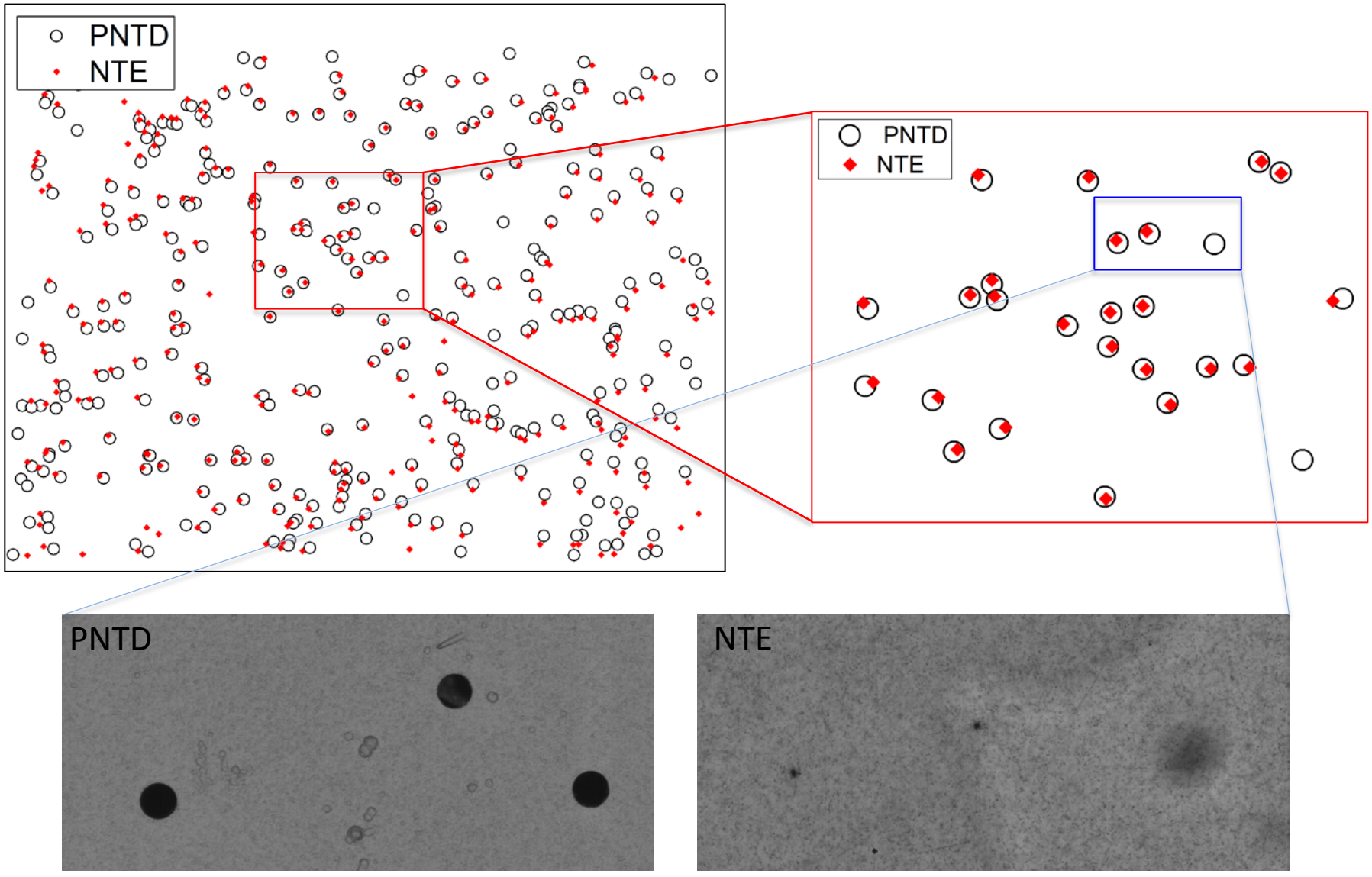




# O400

| | TED | NTE | Timepix |
|---|---|---|---|
| 90° |  30 µm about 14 µm | no tracks visible with HspFit 30 µm |  500 µm about 400 µm |
| 60° | no tracks |  |  |

# Results – PNTD and NTE



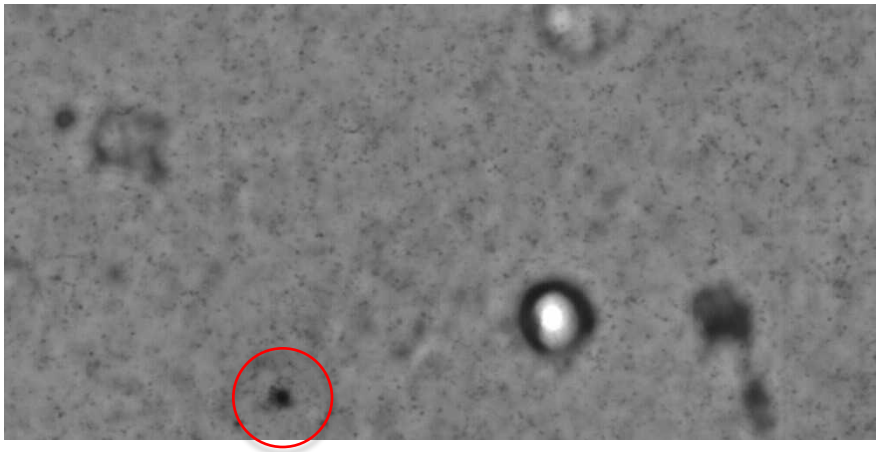
# Results – PNTD and NTE

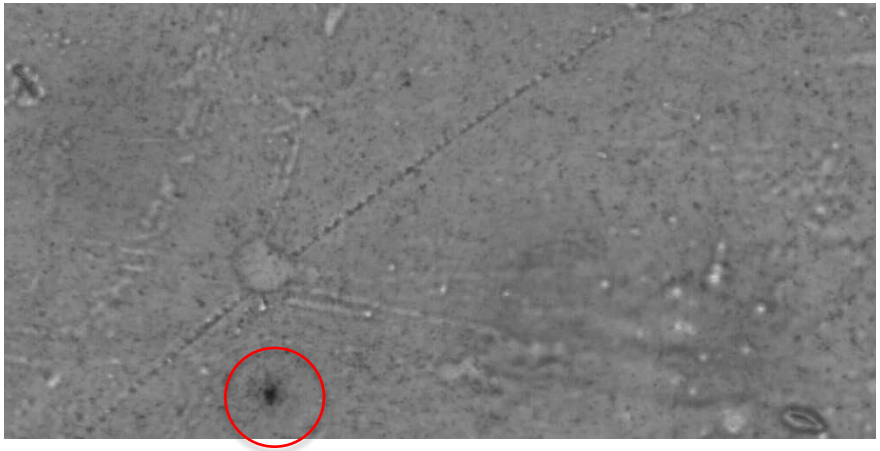
| Exposure | PNTD | NTE | matched | Efficiency (NTE) [%] | Area [$cm^2$] |
|---|---|---|---|---|---|
| Fe500, 90$^o$ | 318 | 301 | 283 | 89 | 0.7 |
| Fe500, 60$^o$ | 381 | 353 | 346 | 91 | 0.8 |

- defects
- nonuniform thickness
- low magnification of HSP-1000 for analysis of NTE

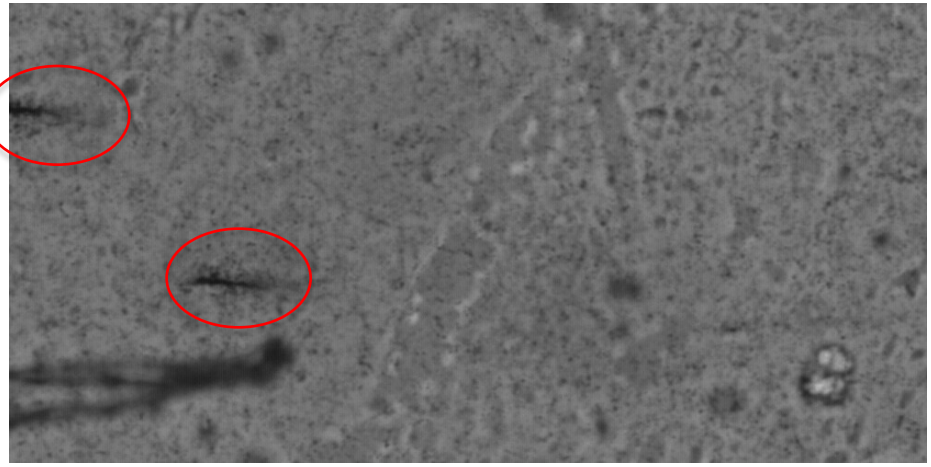
# Discussion

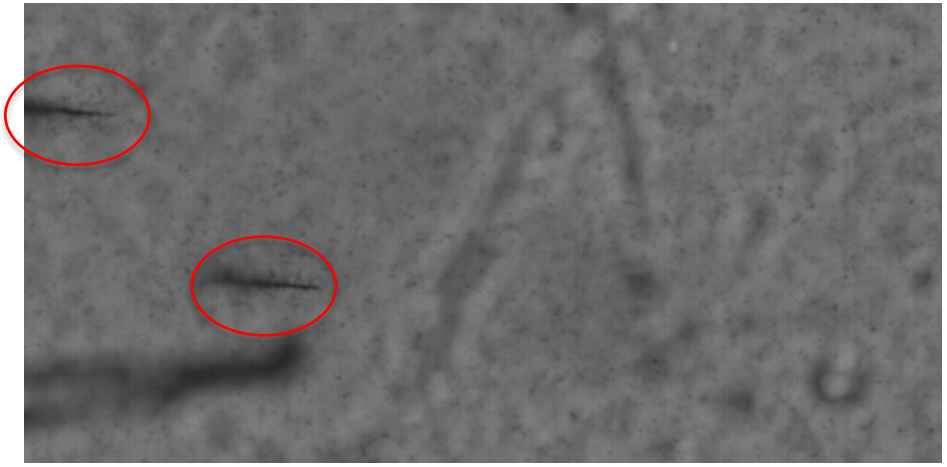
- analyses of tracks in various depths of NTE

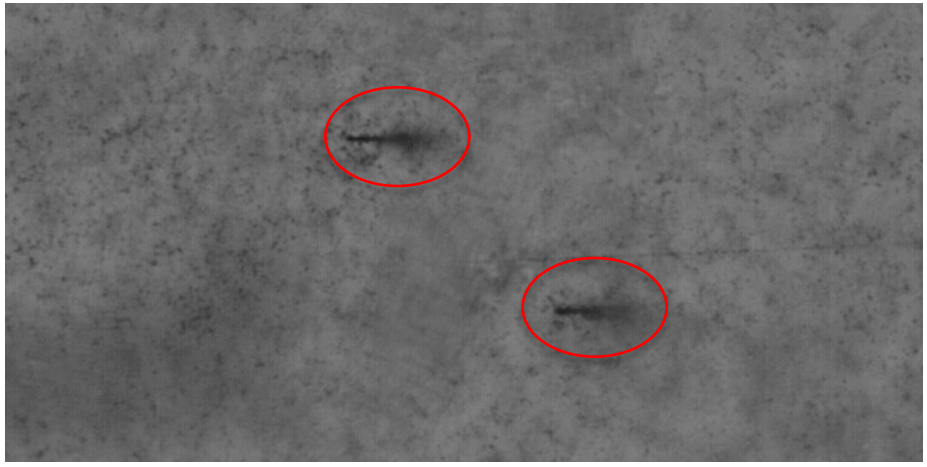


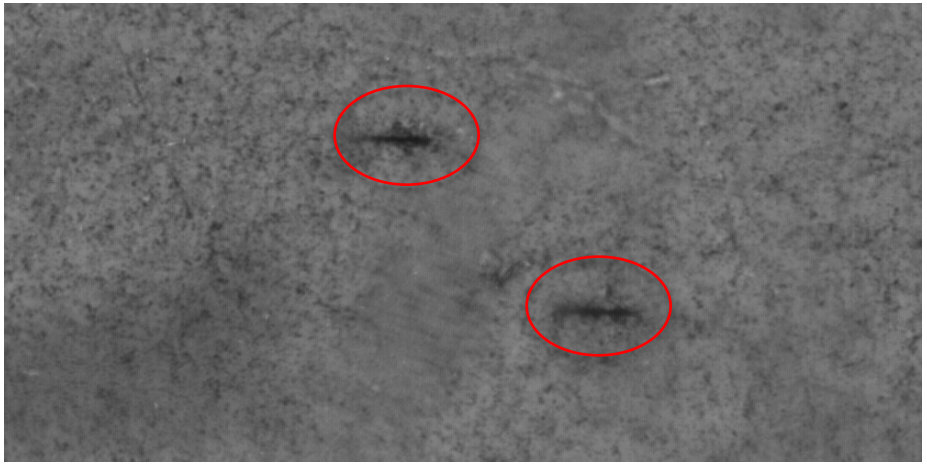


# Discussion



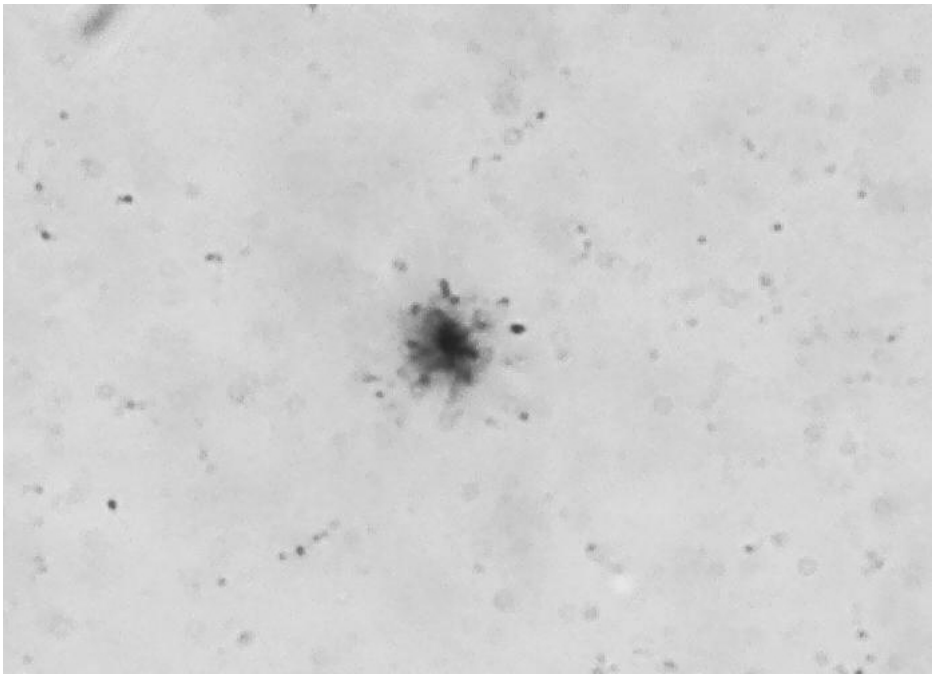


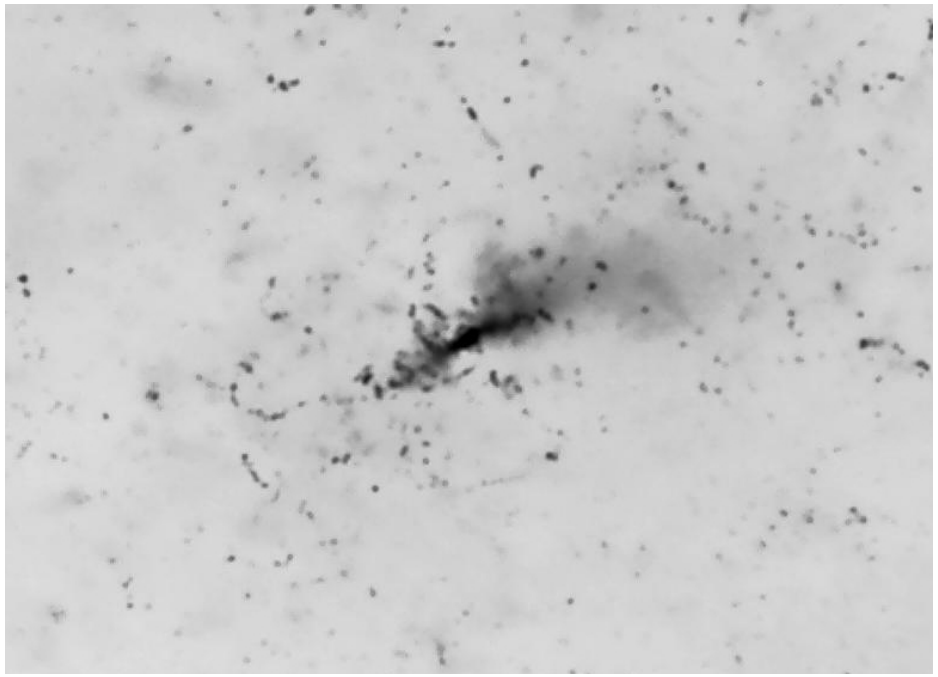




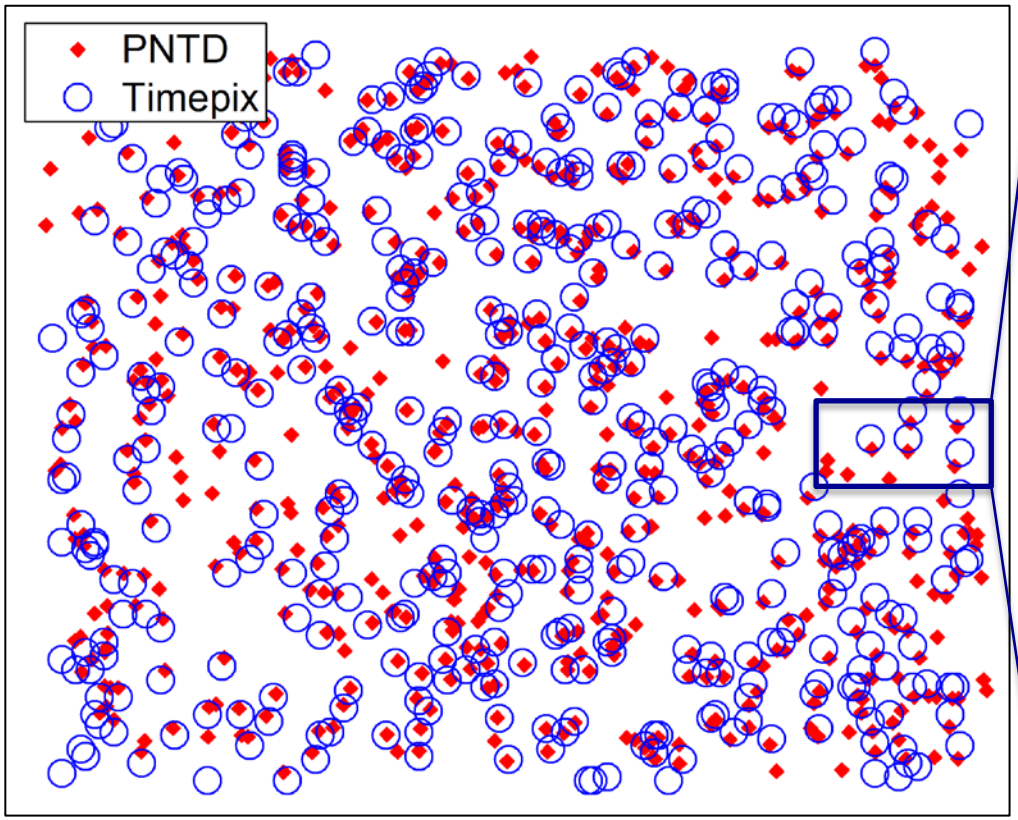
# Discussion

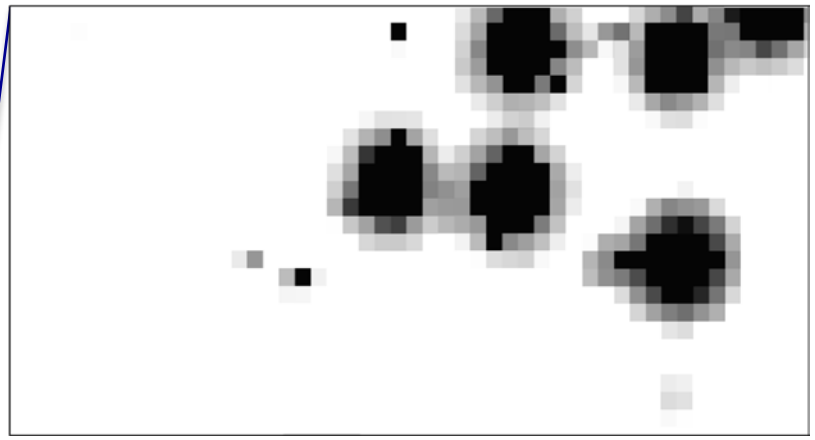
- microscope with higher magnification (objective lens 60x)

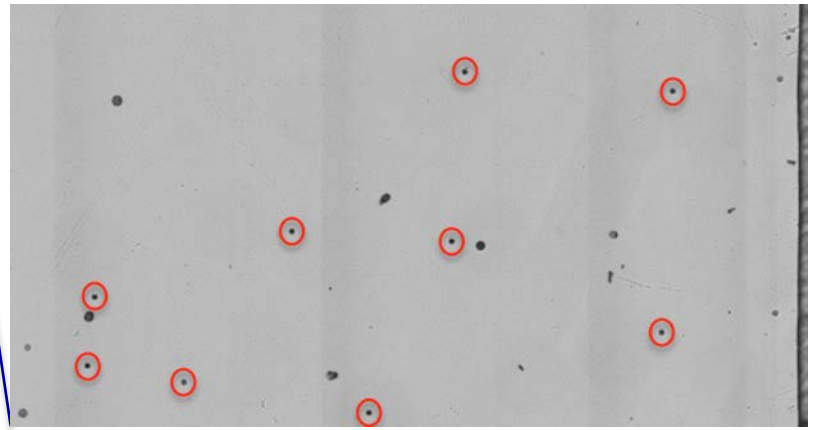




# Results – PNTD and Timepix





# Results – PNTD and Timepix

- less tracks in Timepix (deadtime, overlapping)
- uncertainties of tracks' coordinates about 100 μm (Timepix), larger dimensions of tracks
- difficult to match individual tracks

| Exposure | PNTD | Timepix | Efficiency (Timepix) [%] | Area [cm2] |
|---|---|---|---|---|
| Fe500, 90° | 490 | 172 | 35 | 1.1 |
| Fe500, 60° | 486 | 199 | 41 | 1.0 |
| Ne400, 90° | 660 | 477 | 72 | 1.3 |
| Ne400, 60° | 572 | 379 | 66 | 0.9 |
| O400, 90° | 805 | 524 | 65 | 1.3 |

# Results – PNTD and Timepix

- linear energy transfer, incident angle

| Ion, angle | $LET_{ref}$ [keV/μm] | $LET_{PNTD}$ [keV/μm] | $LET_{Timepix}$ [keV/μm] | $angle_{PNTD}$ |
|---|---|---|---|---|
| Fe500, 90° | 198 | 211 ± 7 | 80 ± 16 | 80 ± 2 |
| Fe500, 60° | 198 | 208 ± 10 | 88 ± 17 | 59 ± 2 |
| Ne400, 90° | 31 | 33 ± 1 | 29 ± 5 | 83 ± 2 |
| Ne400, 60° | 31 | 29 ± 2 | 35 ± 6 | 60 ± 2 |
| O400, 90° | 20 | 26 ± 2 | 22 ± 5 | 83 ± 2 |

# Summary

| PNTD | NTE | Timepix |
|---|---|---|
| nearly tissue-equivalent | 3D image of individual tracks; light sensitive | active device (provide time information) |
| about 250 USD (sheet of 30 x 30 cm) | about 4300 USD (1 $m^2$) | about 10 kEuro |
| chemical treatment (etching)<br>18 hours | chemical treatment<br>about 5 hours | - |
| optical microscope (scanning)<br>several minutes | optical microscope (scanning)<br>several minutes | - |
| data processing (semi-automatic analysis)<br>about 1-2 hours | data processing (manual)<br>several hours | data processing (automatic)<br>several minutes |

# Summary

| PNTD | NTE | Timepix |
|---|---|---|
| almost 100% efficiency for perpendicularly incident heavy ions | more than 90% detection efficiency for heavy ions (defects on the surface) | readout dead time (loss of some particles) |
| critical angle of detection | difficulties to analyze perpendicularly incident particles and particles with lower LET (low magnification of used system) | register particles coming from any direction |
| spatial resolution several μm | spatial resolution several tenths of μm | spatial resolution several tens of μm |
| detection of particles with LET above about 7 keV/μm | larger LET range of detection, but method of determination of LET needs to be develop; problems of uniformities within various batches | volcano effect |

# Future work

- upgrade of microscopes for analysis of NTE (HSP-1000 – lens with higher magnifications; KSM-1 – automatization of analysis)
- determination of LET in NTE
- study of volcano effect
- irradiation of detectors with lower fluence and for more angles

# Acknowledgement

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