Current Status of Measurements with NITs

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Outline

- Rundown of the **NIT Pilot Test** (Trento, February 2023)

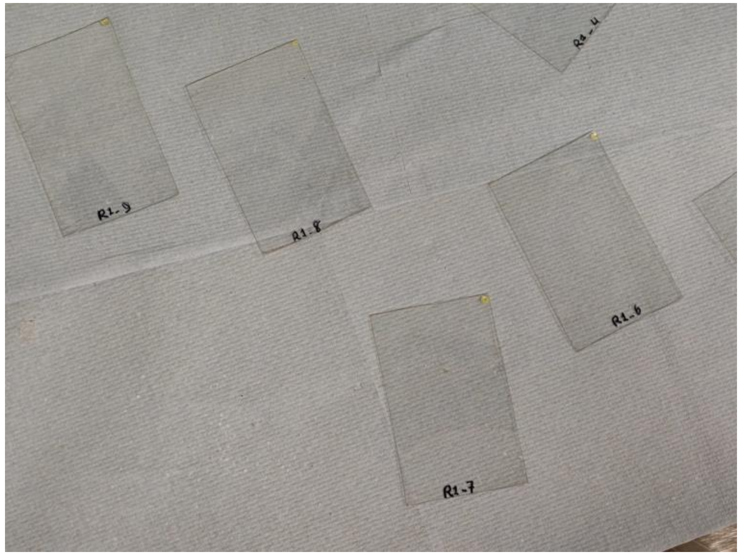
- Main challenges in the reconstruction for the Pilot Test data
  - Very Low sensitivity to protons
  - Image quality issues
  - Current status and first results

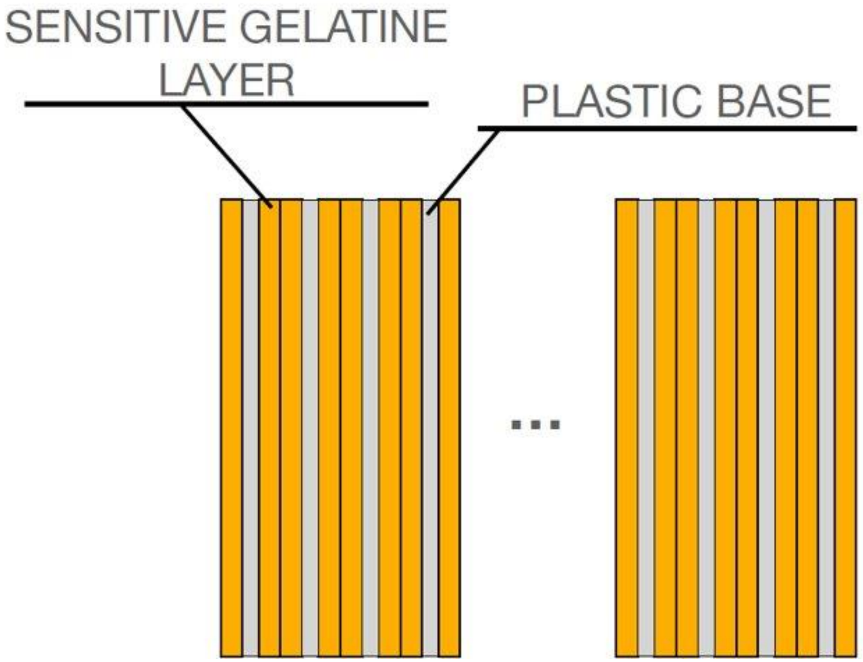
- Data taking at **CNAO** (November 2023)
  - Samples and brief exposure description

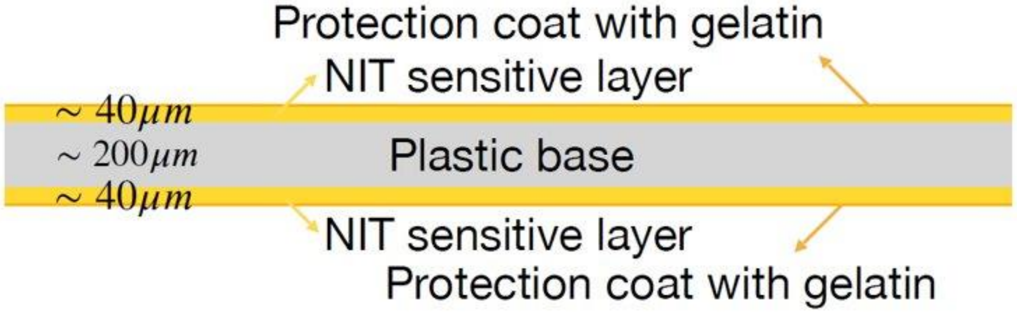
- Next steps

Direct Measurement of Target Fragmentation

- The goal of the project is the ***direct* measurement** of target fragments produced by a proton beam
- Nano Imaging Trackers (NIT) emulsions act both as target and tracking devices
- Each NIT film has two sensitive layers (40 µm thick) deposited on both sides of a plastic support (200 µm thick)

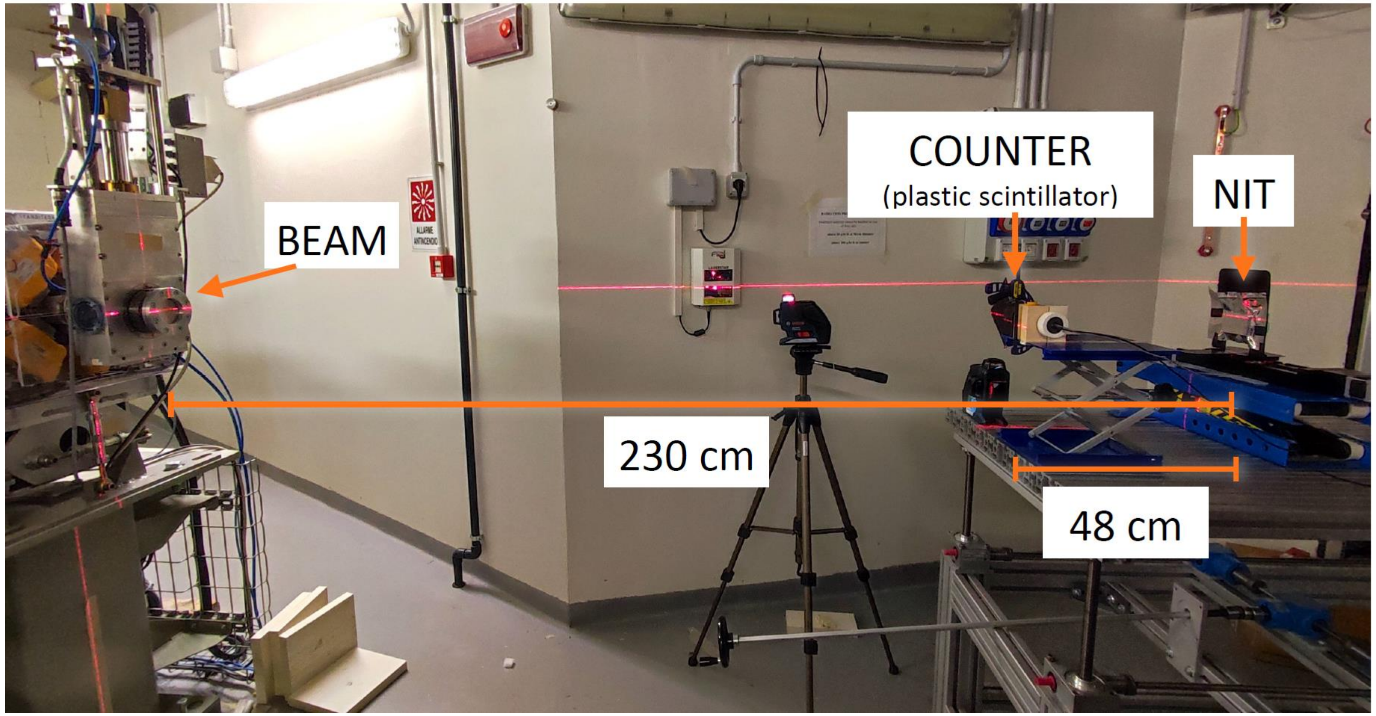


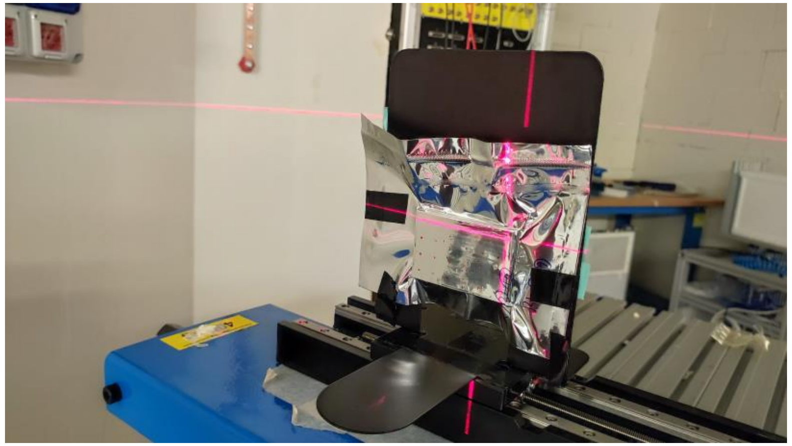




Data Taking in Trento (February 2023)

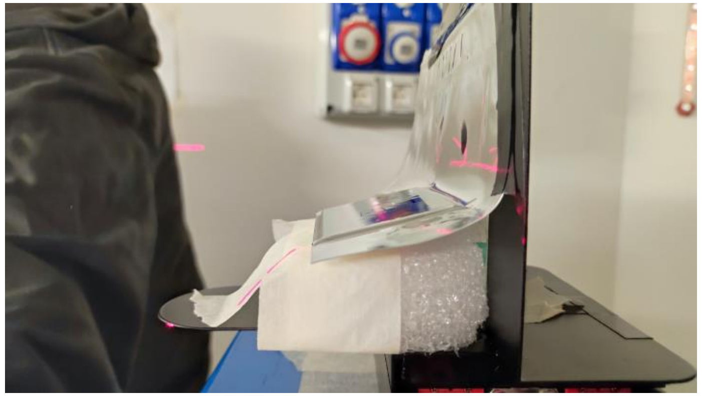
- 19 NIT films (~ 6.4x4 cm^2) for the brick, 1 film for sensitivity tests
- Fixed pencil beam @211 MeV (FWHM ~ 1.5 mm)
- 230 cm from beam exit window
- 6x4 grid for a uniform exposure of the NIT emulsions (about 11.000 protons per spot)





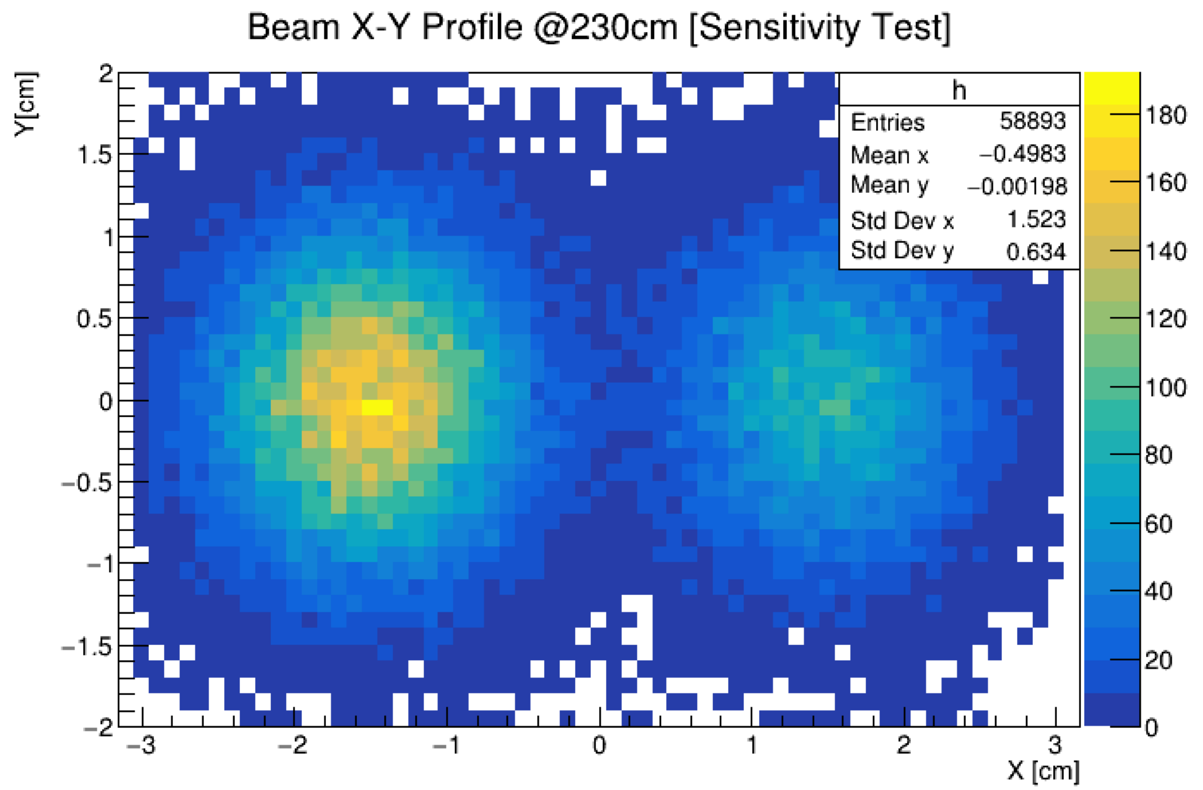
Brick Exposure

Sensitivity Test

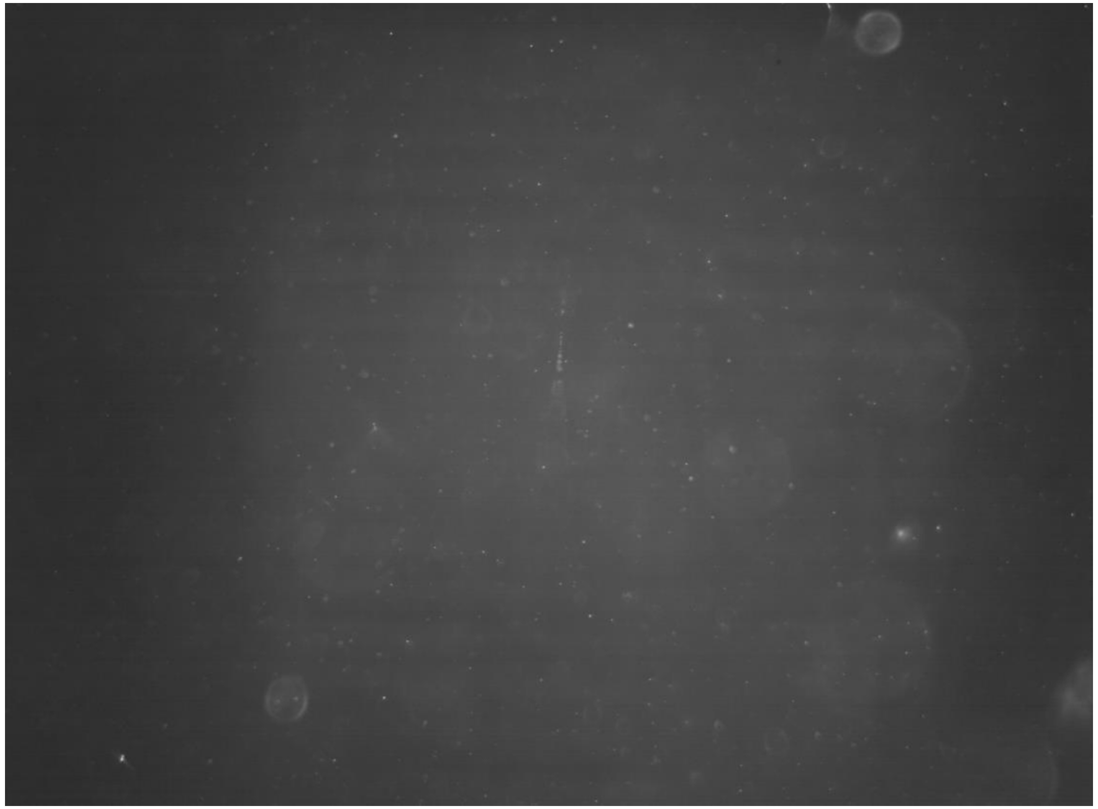


Sensitivity Issues: Test with Trento Data (1)

- The recorded sensitivity to primary protons (211 MeV) was extremely low
- The film was tilted by ~ 15° with respect to the beam direction so one expects approximately sin(15°)*(180)*0,12 ~ 6 protons per view (40x objective, 400x300 μm^2 views)



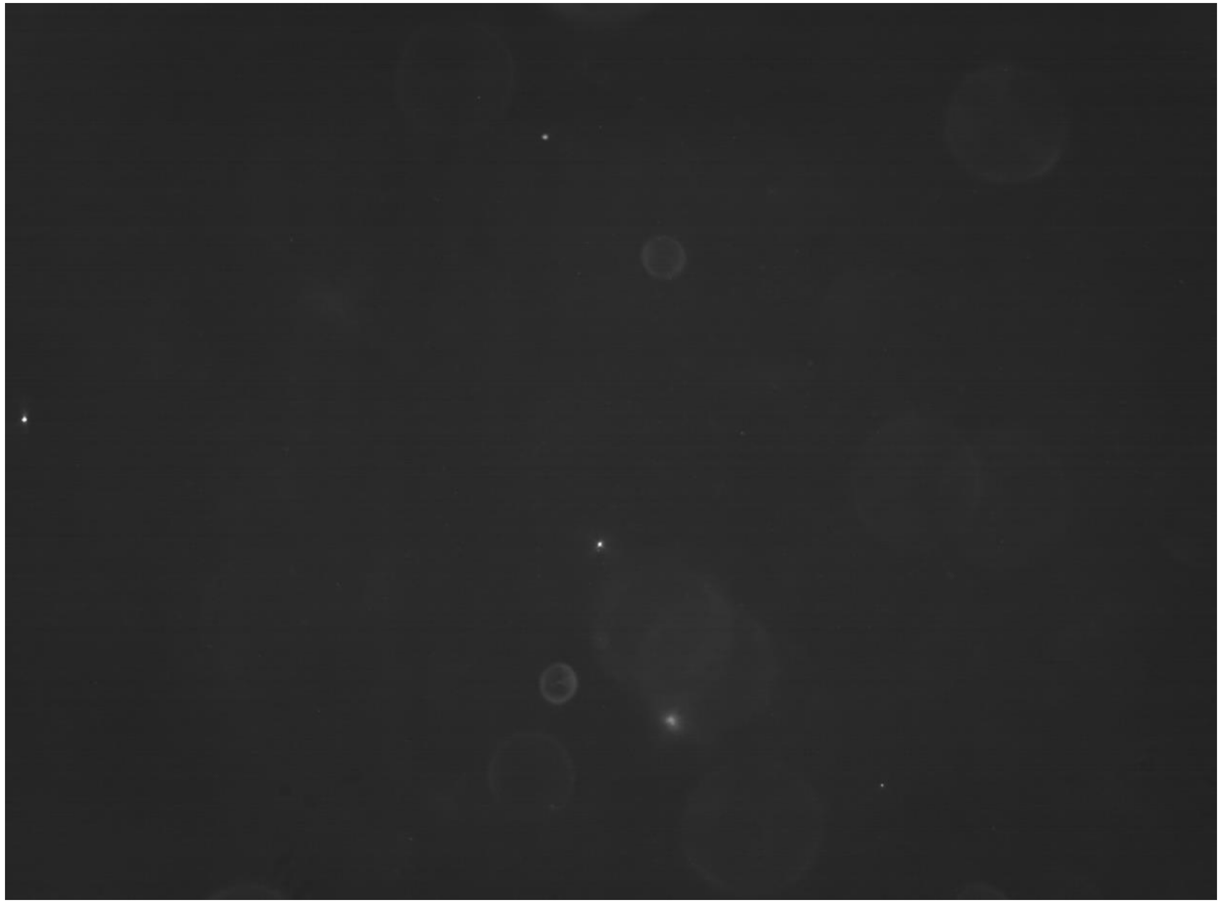
Simulated Beam Profile for Sensitivity Test

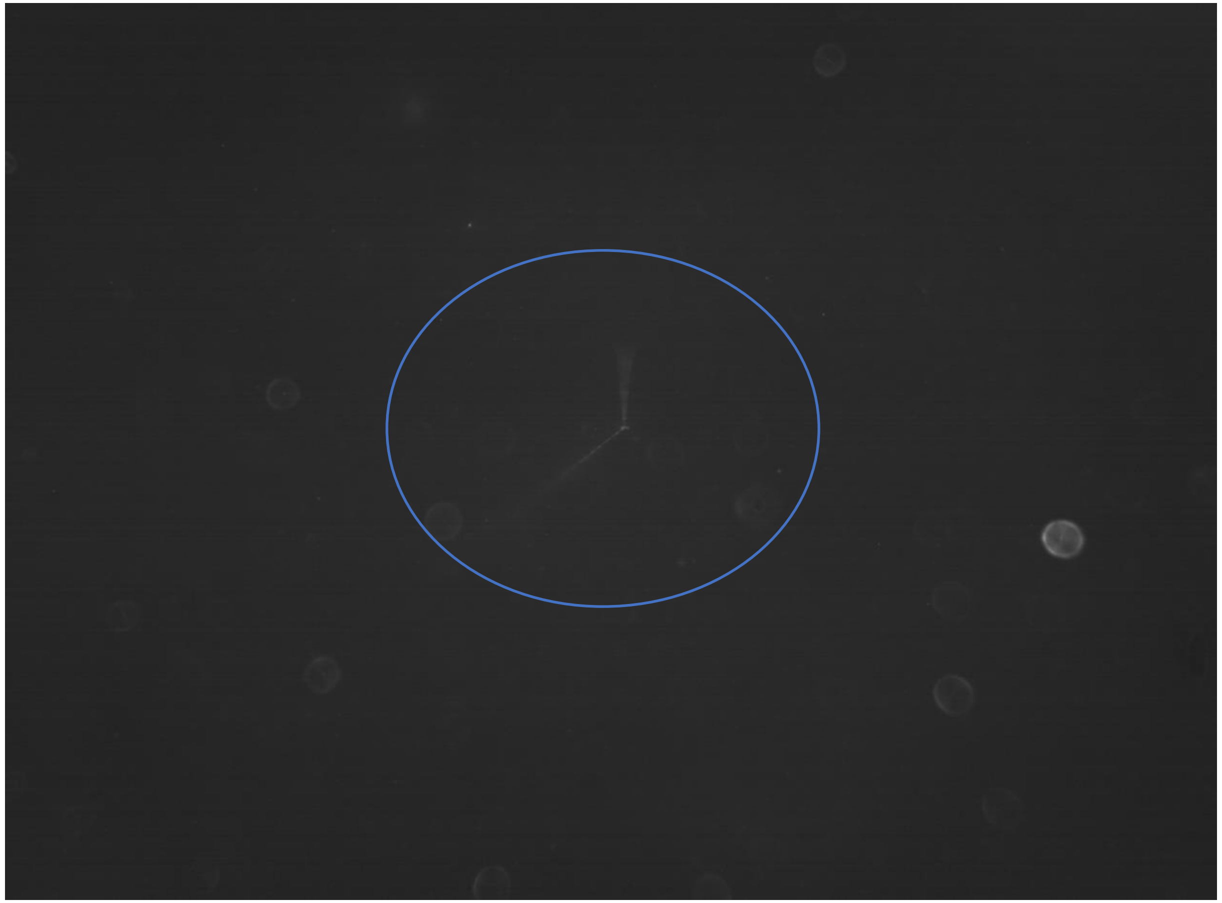


Most Views are Empty!

Sensitivity Issues: Test with Trento Data (2)

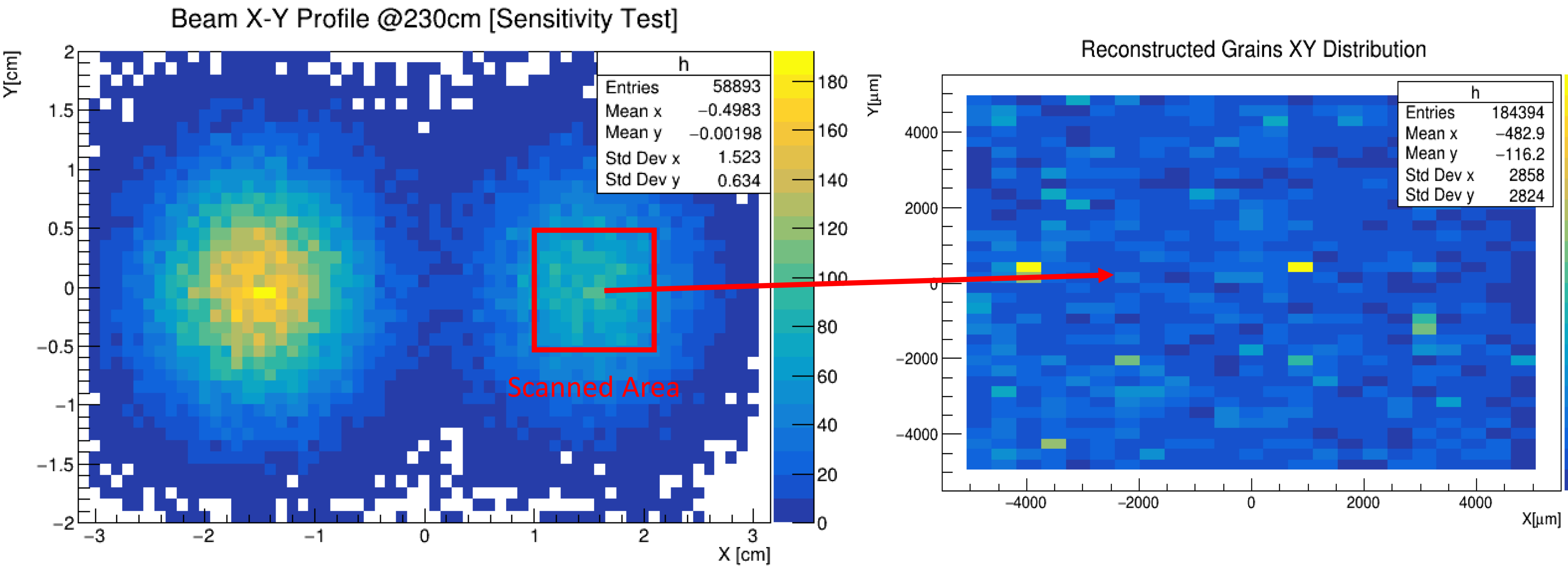
- Occasionally, some isolated tracks or even vertices can be found
- Most of the tracks are assumed to be environmental background, some could be secondaries from proton interactions





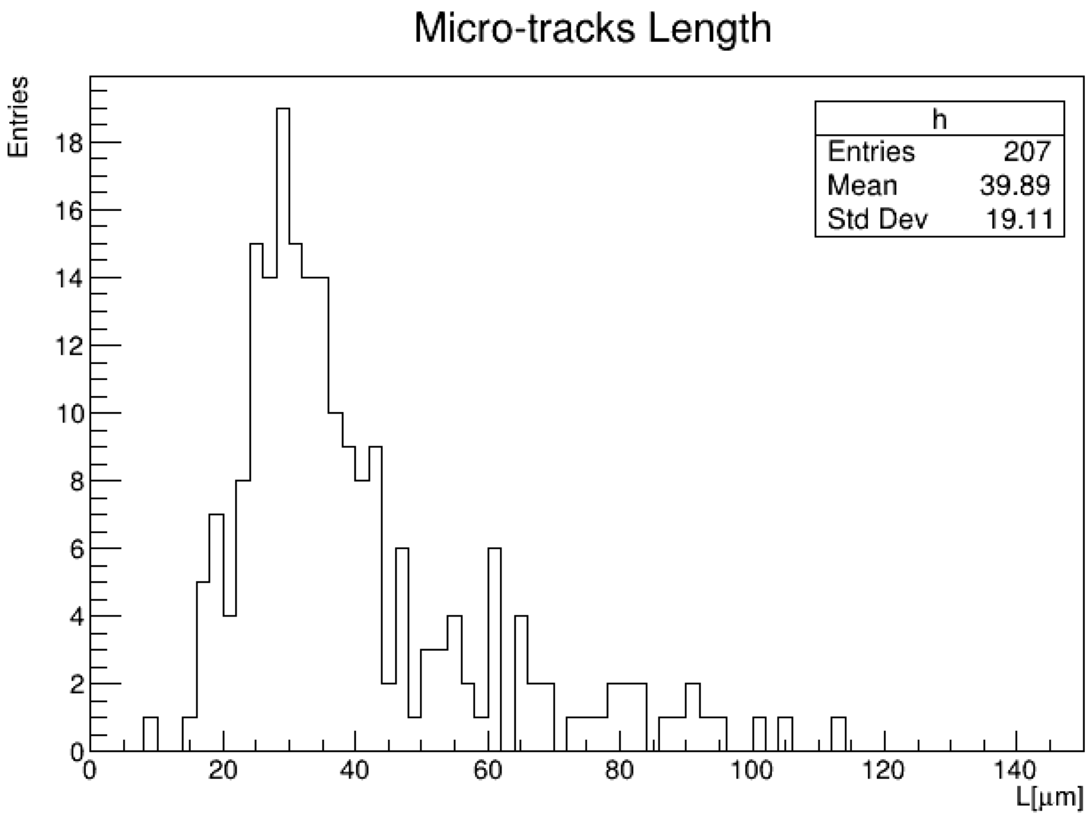
Sensitivity Issues: Scanning Results (1)

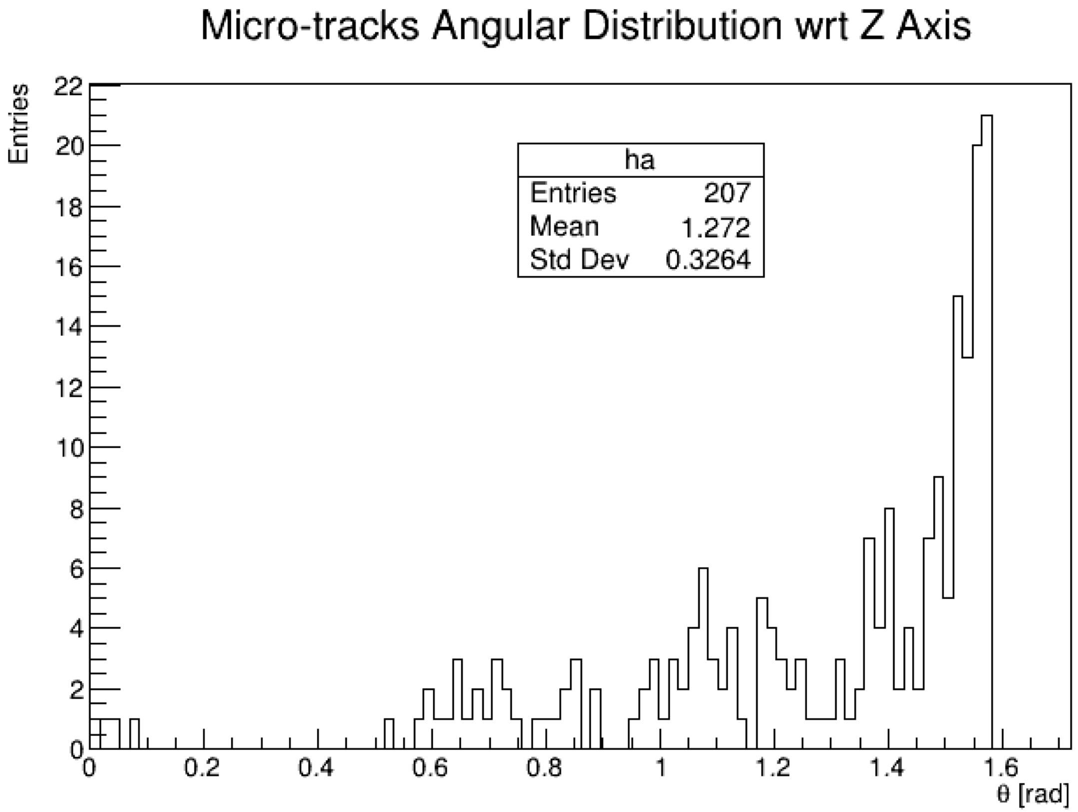
- Moreover, the emulsion film (R1-1) was partially damaged and it started to detach from the plastic support
- A 1 cm^2 area scan has been performed to confirm what the manual checks had shown
- The area was centered around the spot on the right of the emulsion surface



Sensitivity Issues: Scanning Results (2)

- After linking, the number of reconstructed tracks that could be identified as protons is about **200**!
- Moreover, the angular distribution and the track length distribution are not consistent with the ones expected from the exposure geometry





Sensitivity Issues: Discussion

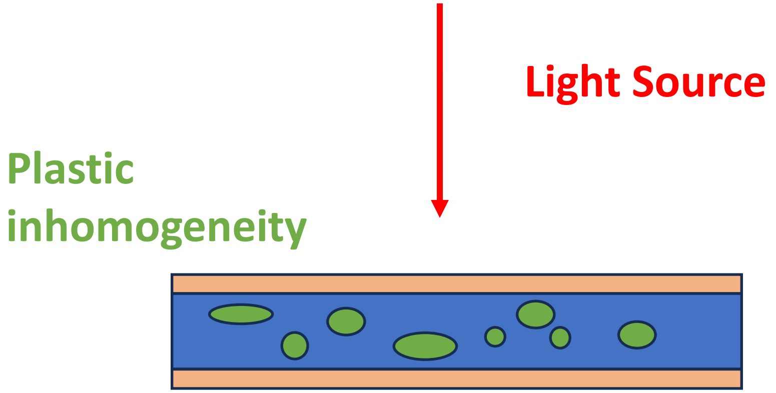
- Not possible to reconstruct primary protons' tracks: developed grains are too far away from each other!
- This is a significant liability for different reasons:
  - No possibility to follow protons up to the interaction vertex
  - Very hard to align adjacent emulsion films with pattern matching: each film is a stand-alone detector
  - Limited information about secondary protons
- A lower sensitivity to protons with respect to the OPERA-like nuclear emulsions is to be expected because of the **smaller crystal size** (70 nm vs 200 nm)

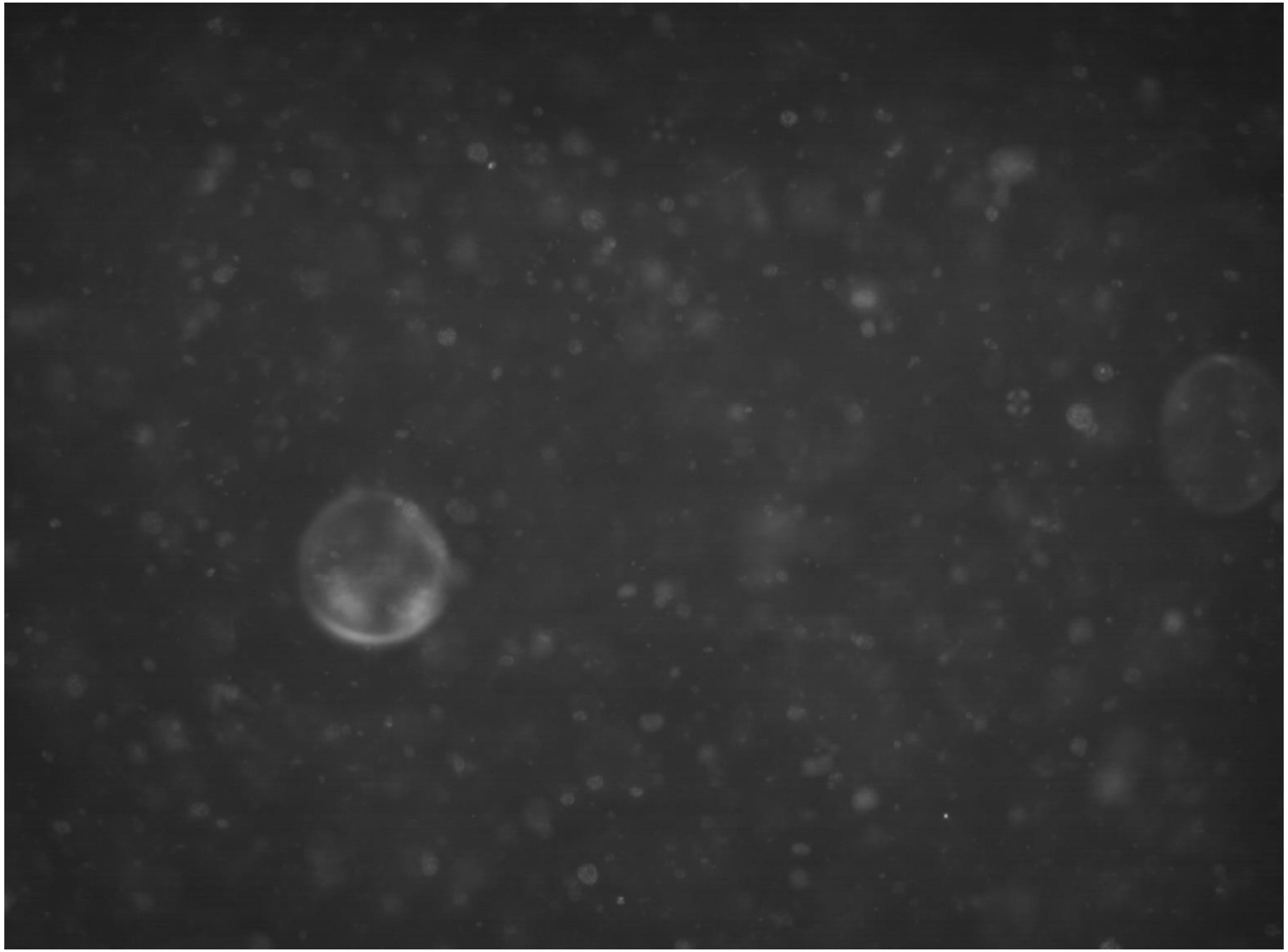
	OPERA-like	NIT
Crystal Size	200 nm	70 nm
Sensitization	Active sensitization (sulphur-plus-gold)	Passive Sensitization (HA)
Development	25 minutes at 20°C Physical solution development	10 minutes at 5°C MMA developer

- Can we improve the detector for future physics data takings?
  - Increase the crystal size with the trade-off of spatial resolution
  - Test OPERA-like sensitization with NIT emulsions
  - Follow-up measurements at CNAO (November 2023) to test sensitivity to protons @70 MeV

Contrast Issues (1)

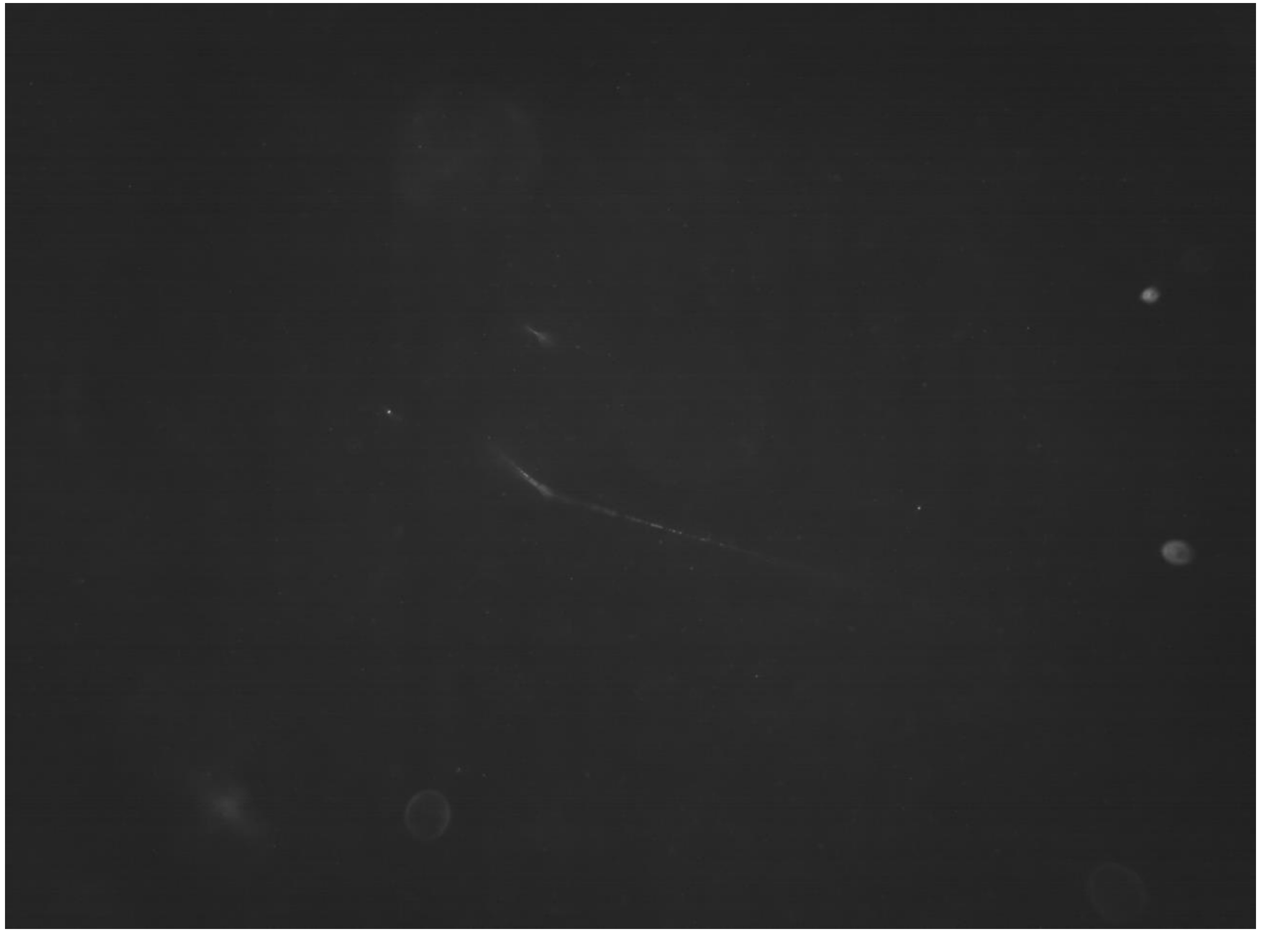
- Unwanted reflections from the plastic support degrade contrast
- Despite the sufficient working distance from the 40x objective, bottom side image quality is worse
- Moreover, automatic emulsion finding and surface following become harder when plastic contains a lot of fake clusters





Contrast Issues (2)

- For the time being, only single-side scanning has been implemented
- Started testing pouring emulsion on 170 μm thick cover glasses, but they are extremely frail



Example of top side view

Example of bottom side view

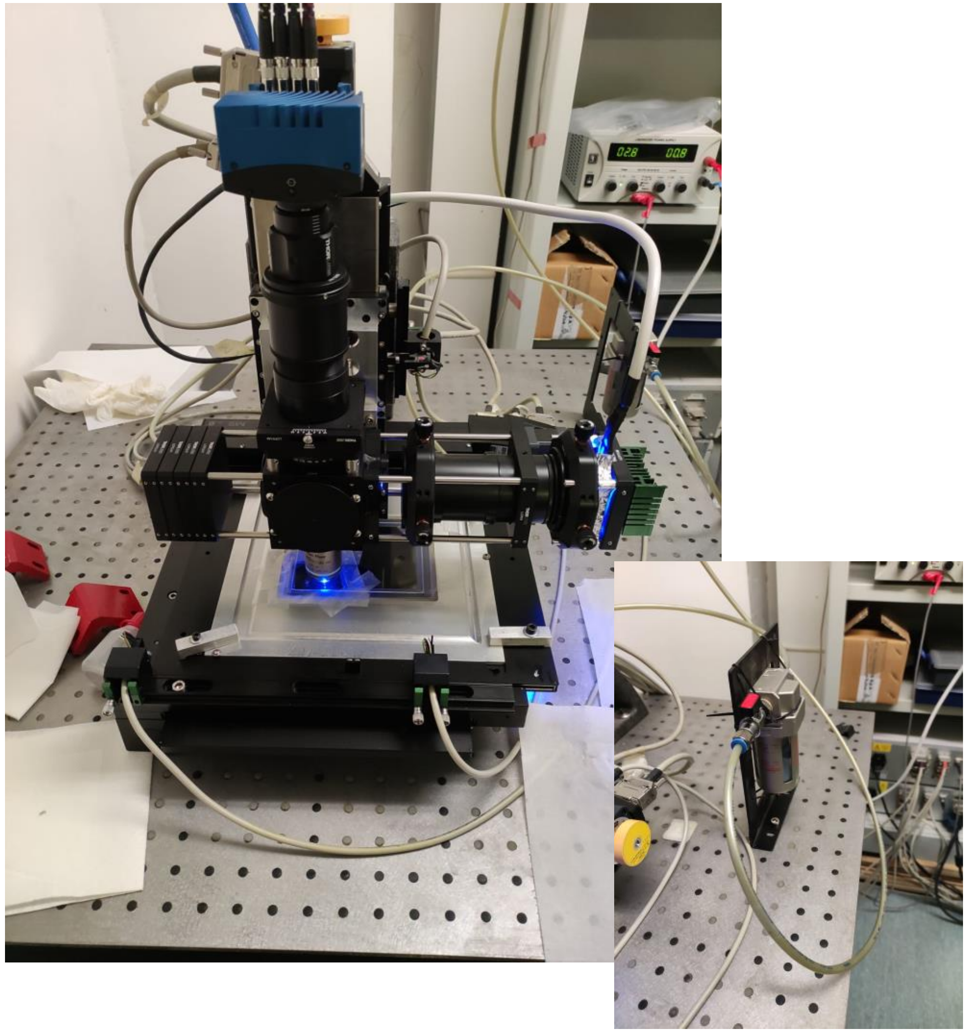
NIT Microscope Updates

- Microscope assembly completed (see more details in my last General Meeting presentation)

- New Microscope features:
  - Works with reflected light
  - 40x objective (NA=1.3)
  - Z step = 0.75 μm
  - Much better scanning speed compared to LNGS system
    - 15 cm^2 area of a single side requires about 5 hours
  - Larger working distance, possible to scan both sides
  - Blue light → plasmonic resonance

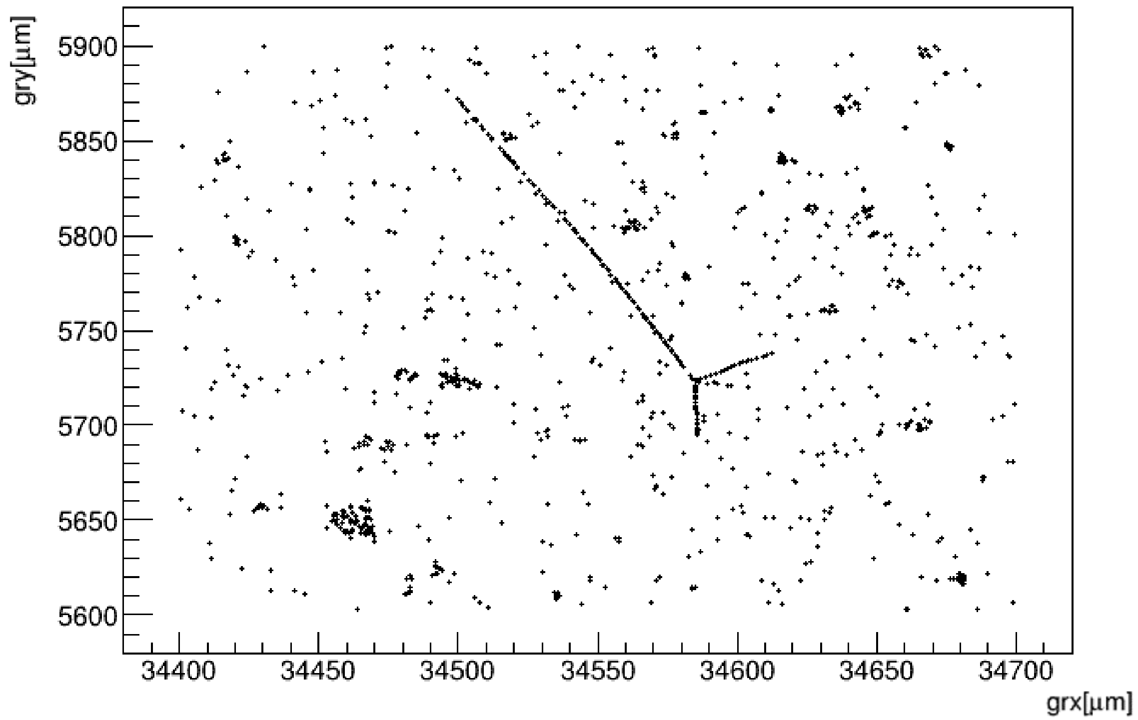
- With respect to the previous meeting:
  - Added vacuum to keep the films flat on the stage
    - Big improvement for emulsion surface finding during scanning as it helps make the lower oil layer more even
  - Performed stage leveling
  - Fixed light source position to have a uniform FOV

New FOOT microscope

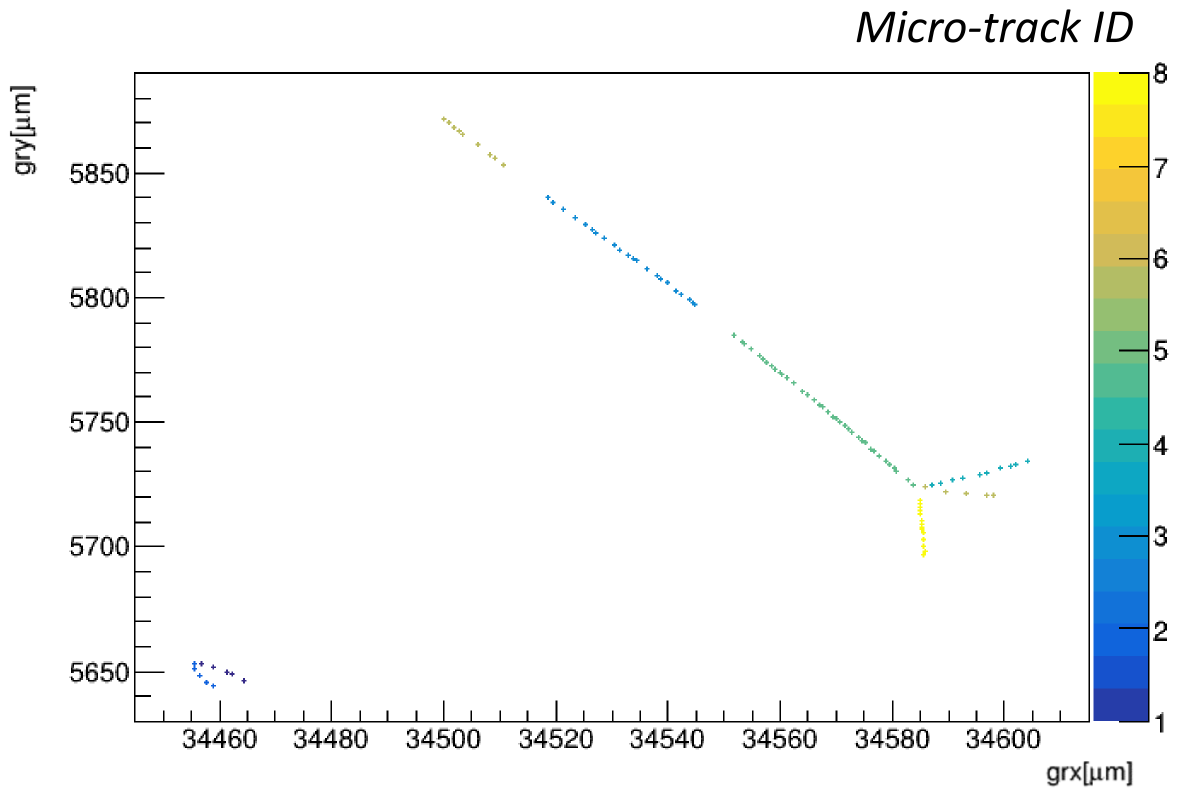


Processing Improvements (1)

- Two step linking procedure implemented to compensate the loss of grains due to low contrast
  - First linking step with shorter linking length (5 μm) to identify the background (fog)
  - Second linking step after fog removal to merge the MTs of surrounding views with larger angular acceptance but higher cut on the number of grains



MT + Fog Grains



First linking step + fog removal

Processing Improvements (2)

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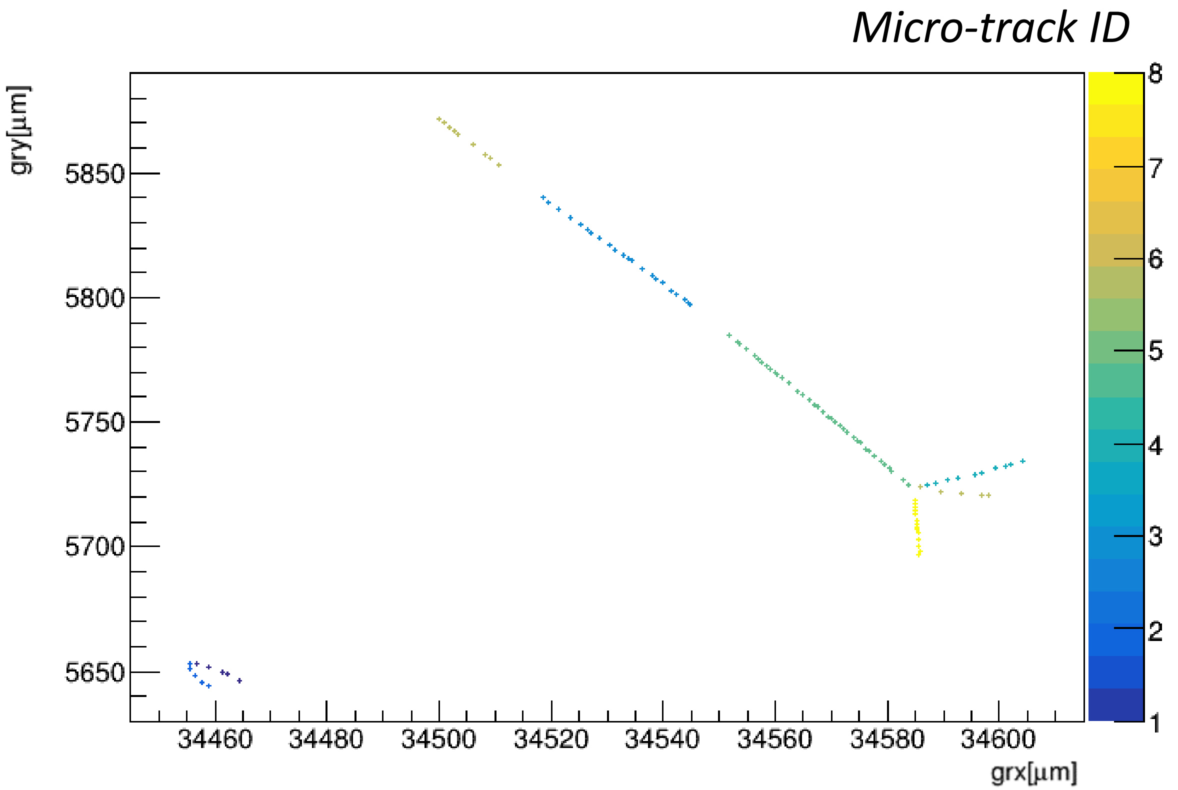
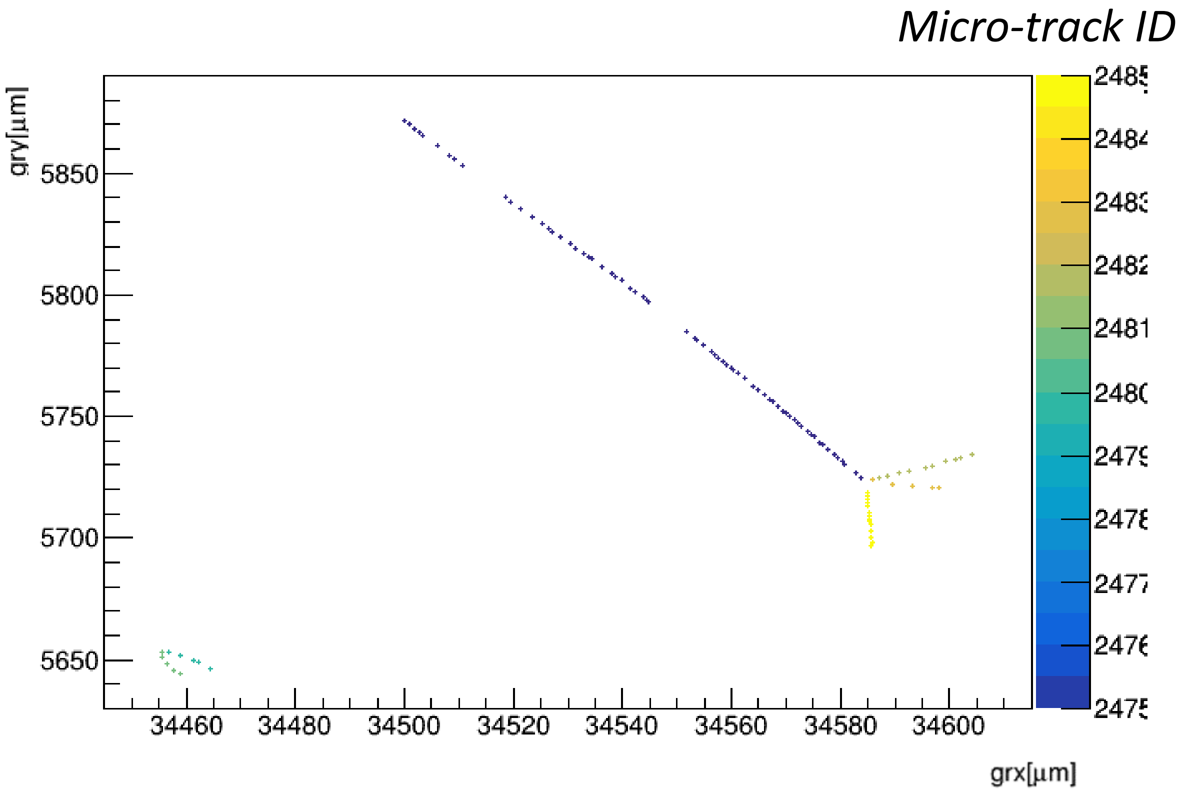


First linking step + fog removal



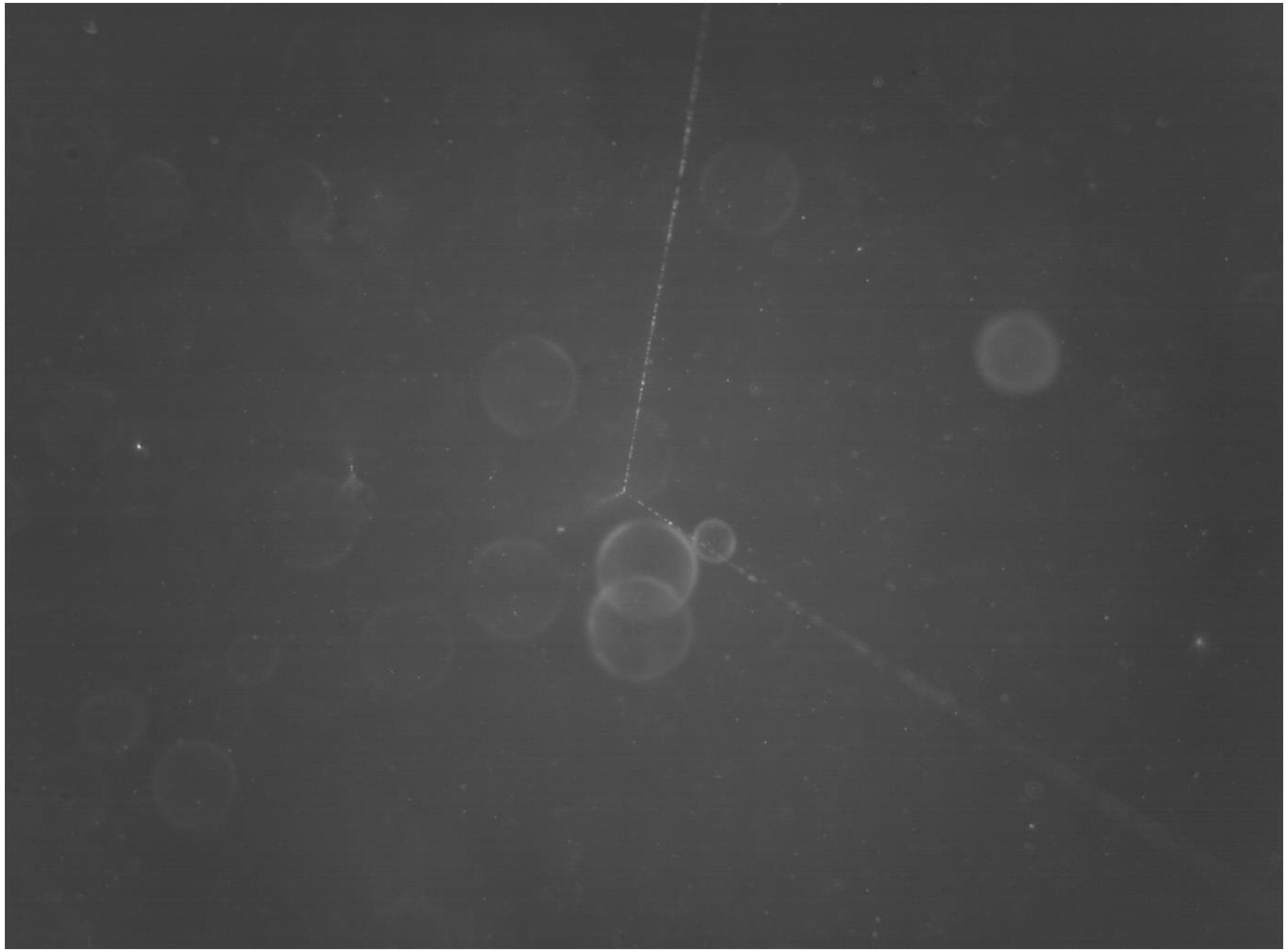
Final merge step + cut on number of grains (>=10)

Vertexing Strategy

- Ideally based on proton following but not possible for this data, so long secondary tracks are used instead

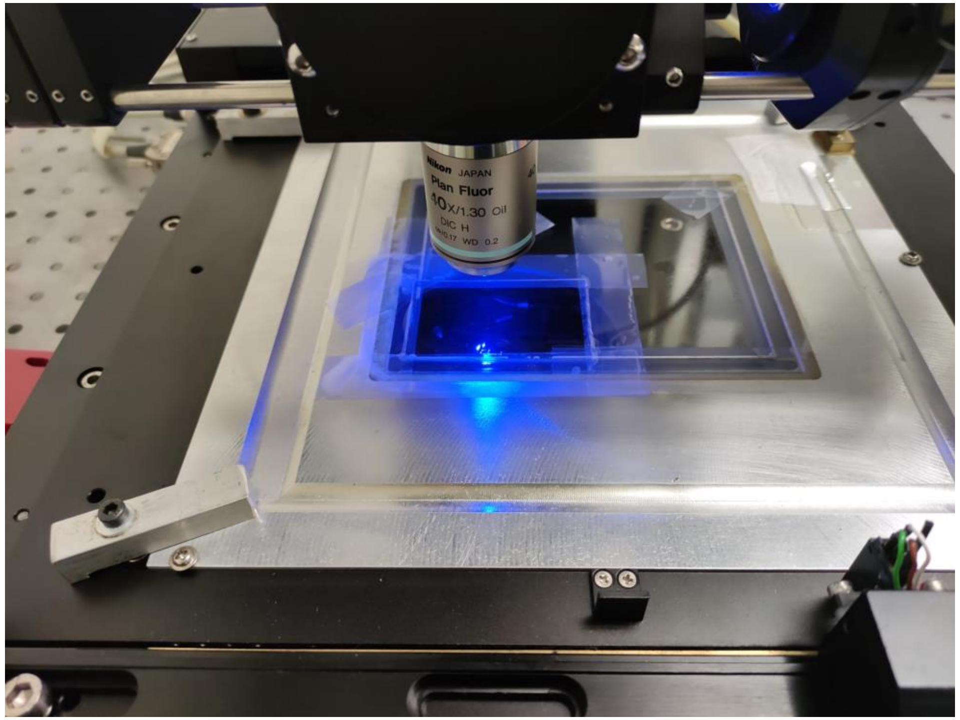
- Very low background expected
  - No cosmic MIPs
  - Only low energy protons
  - Environmental neutrons and radioactive nuclei (mainly Radon)

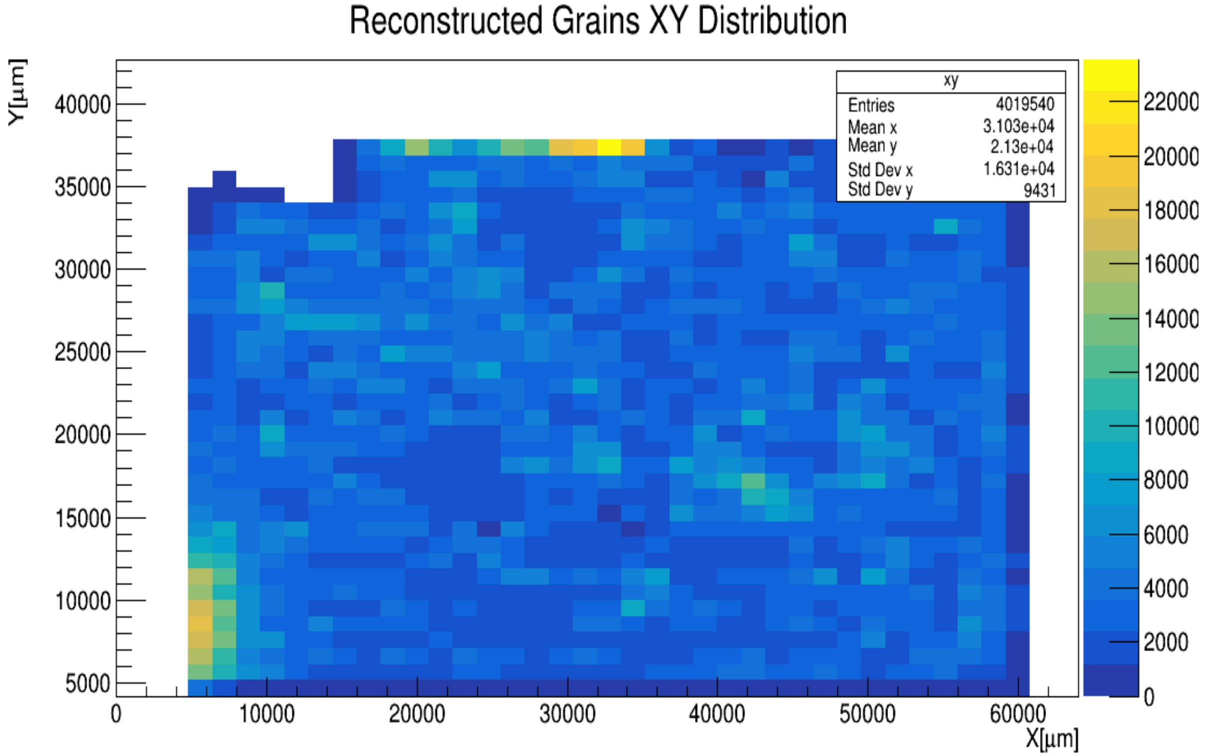
- Strategy
  1. Select long tracks after processing steps (minimum 25 grains + cut on grain density)
  2. Look for vertex candidates near the ends of these tracks
  3. Select only best vertex candidates (based on IP calculation)



First Large Area Scan

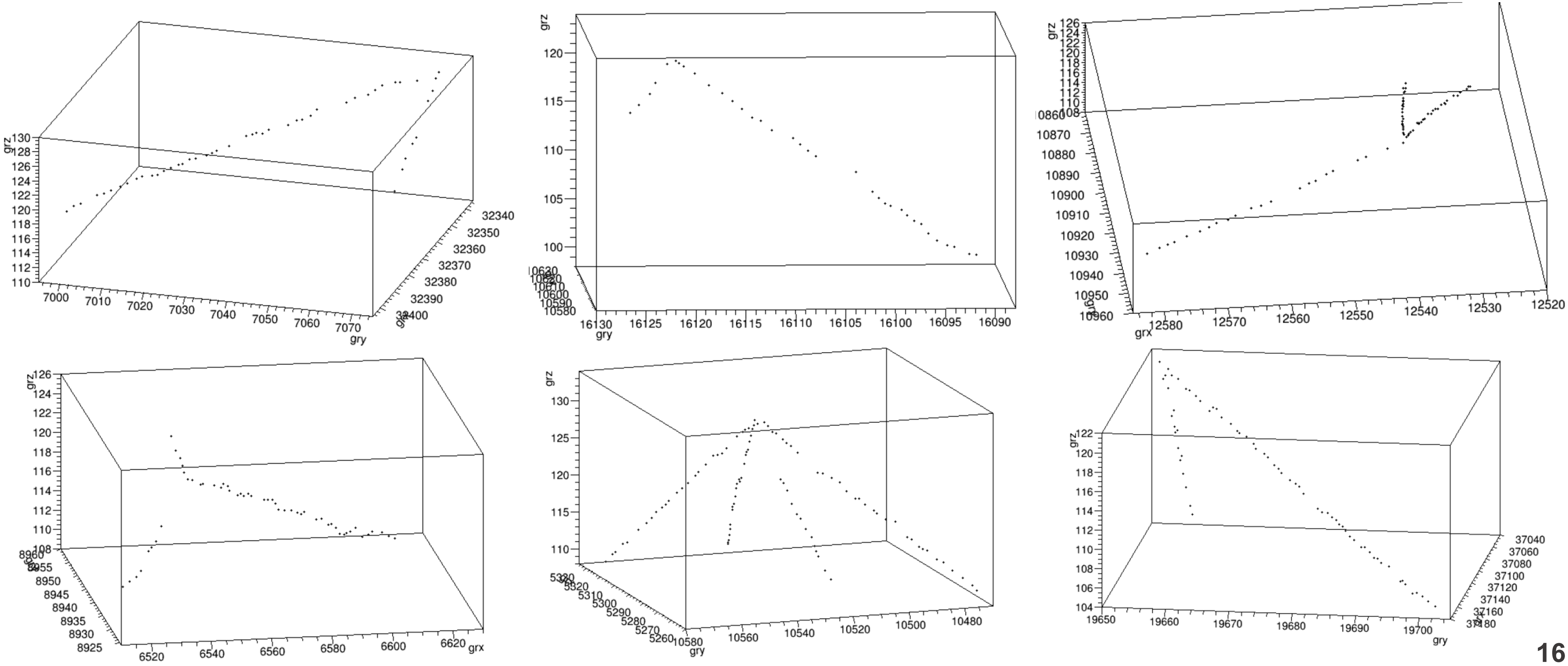
- Scanned ~ 15 cm^2 of the top side of R1-4 (scanning time ~ 5 hours)
- The reconstructed grains XY distribution shows only a small fraction of lost surface
- The higher density spot in the bottom left side is related to the higher incident proton density in the first spot of the exposure grid (~80.000 protons instead of 11.000)





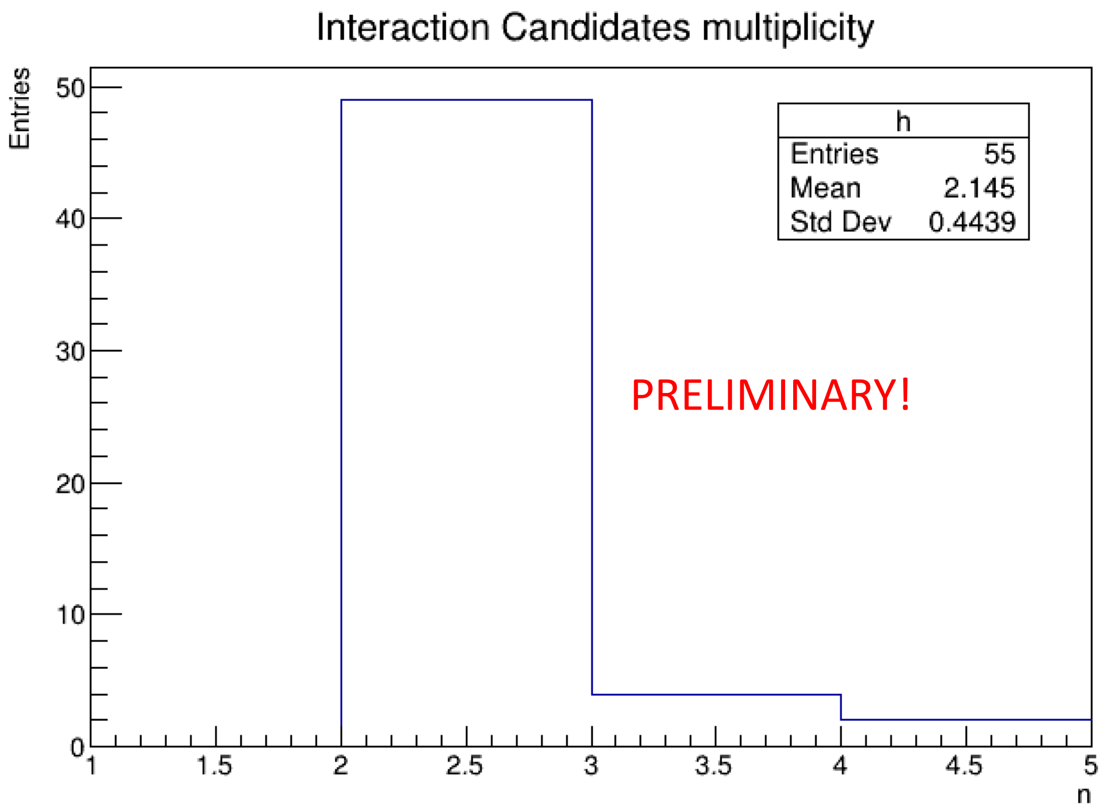
First Large Area Scan: Reconstructed Vertices (1)

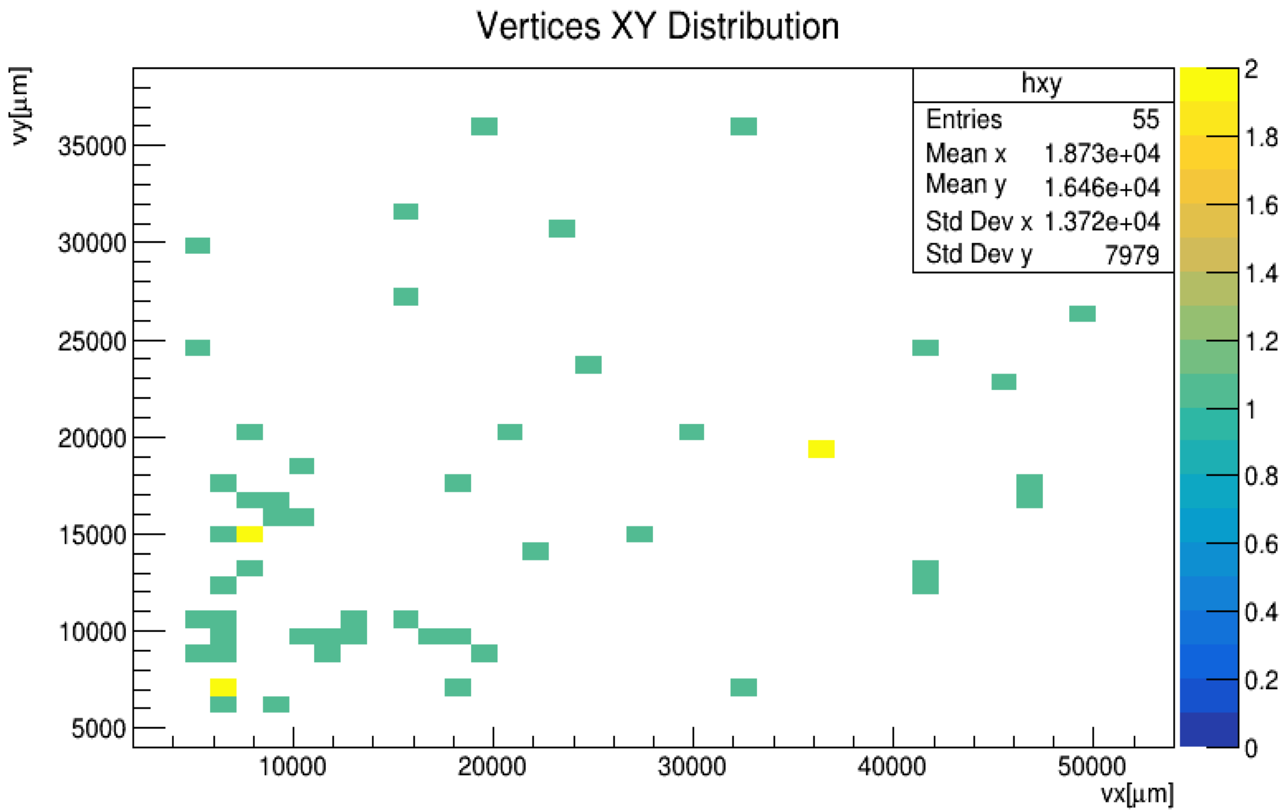
- The vertexing procedure yielded about 50 interaction candidates



First Large Area Scan: Reconstructed Vertices (2)

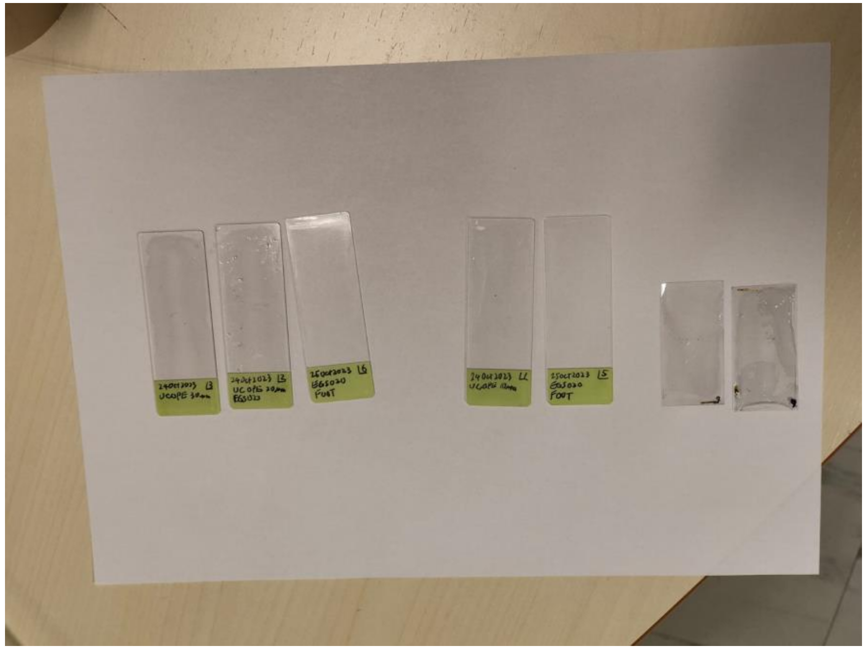
- The bottom left corner contains more vertices than the surrounding regions
- Most of the vertices are two-pronged but shorter tracks may be discarded during reconstruction
- In the future, a super-resolution microscope will be used to study these vertices in detail

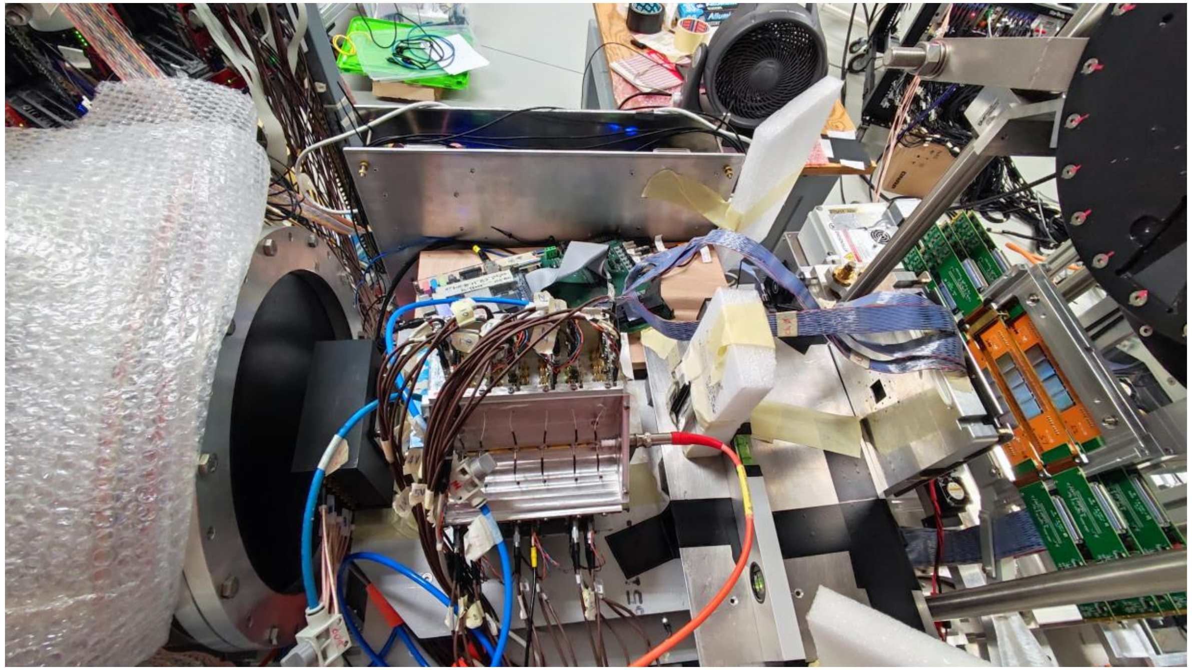




NIT Exposure at CNAO (November 2023)

- The samples exposed at CNAO are aimed at:
  - Testing NIT sensitivity to protons at 70 MeV (exposure with a single spot of 10^7 primaries)
  - Testing NIT-OPERA double coating and tracking with thin OPERA layers (exposure with a single spot with 10^5 primaries)
  - Mechanical test with double side pouring on 170 µm thick cover glasses
- For this purpose, NIT gel from two separate batches was poured on 2 mm thick slide-glasses
- The samples have been developed in LNGS and they need to be scanned (analysis on-going, more details will be given in future meetings)





Summary and Outlooks

- Challenges in Pilot Test data analysis
  - Sensitivity to protons
  - Unwanted reflections from the plastic support

- Latest developments and first results
  - Microscope and processing updates
  - First proton interaction vertices to be analyzed

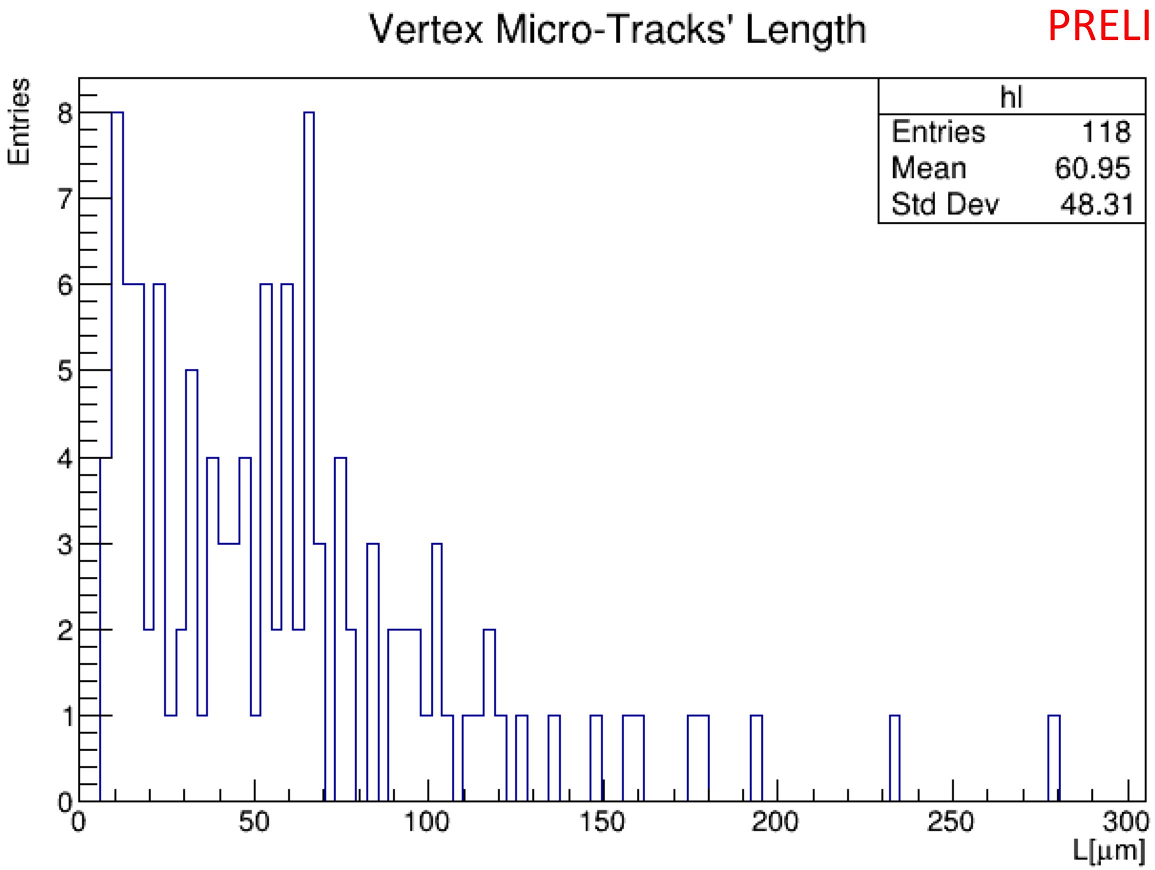
- Future steps
  - Systematic scanning of Trento emulsions
  - Comparisons with MC simulation and background evaluation
  - Analysis of CNAO 2023 data

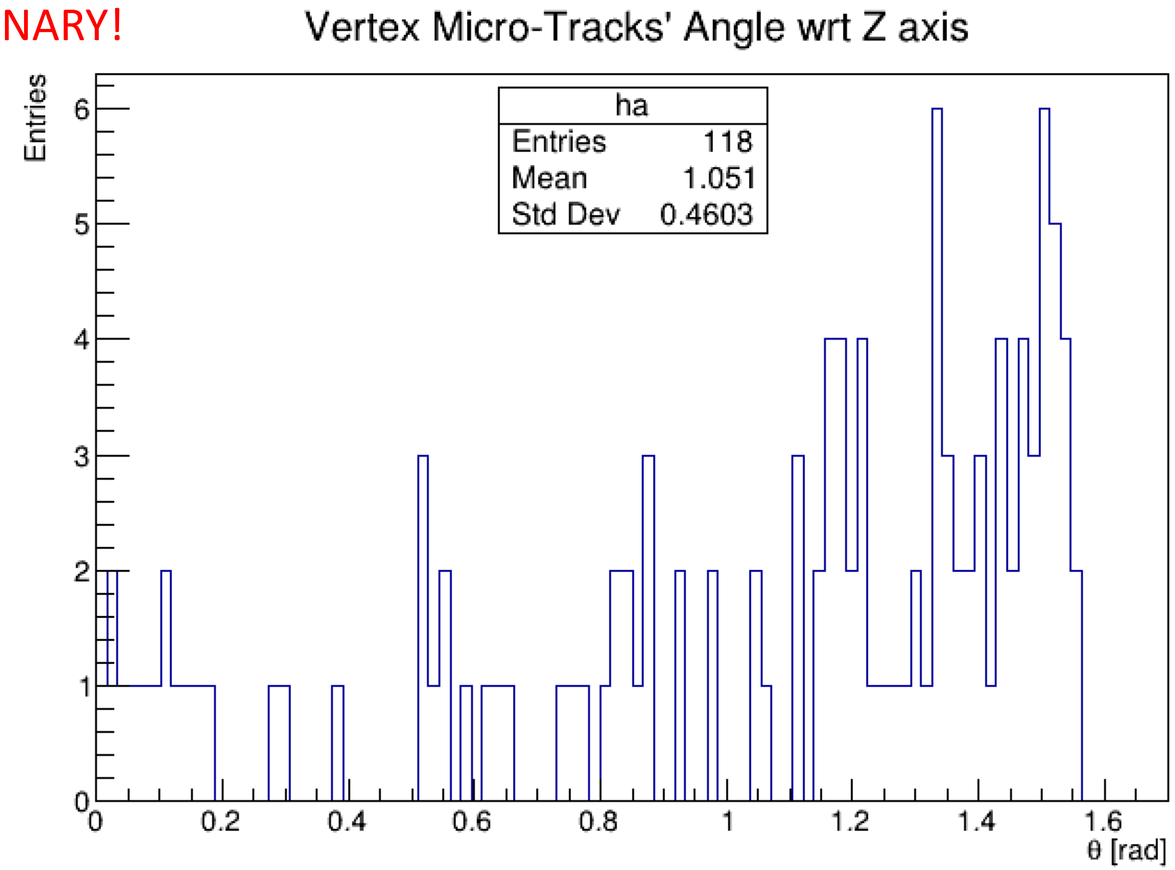
Back-up

First Large Area Scan: Reconstructed Vertices

- The track length distribution shows that very few tracks have length less than a few tens of microns
- There seems to be a peak of near-horizontal tracks → to be investigated
- The future scans will increase the statistics (by up to 36 times considering bottom and top sides!)

PRELIMINARY!





Higher Density Proton Spot

- A study of the track density in the bottom left corner of the scanned emulsion film can give us important clues about the maximum integrable track density with NIT films

- Despite the inability to reconstruct proton tracks, the secondaries from nuclear interactions are still visible