Vincenzo Boccia

Update on NIT R&D and Data Takings

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Of Target

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Outline

- Overview of NIT related activities in Japan (January 2025 – March 2025)
- Current status on NIT sensitization, development and production
- Details from the data takings at Nagoya proton therapy center
- Conclusions and outlooks

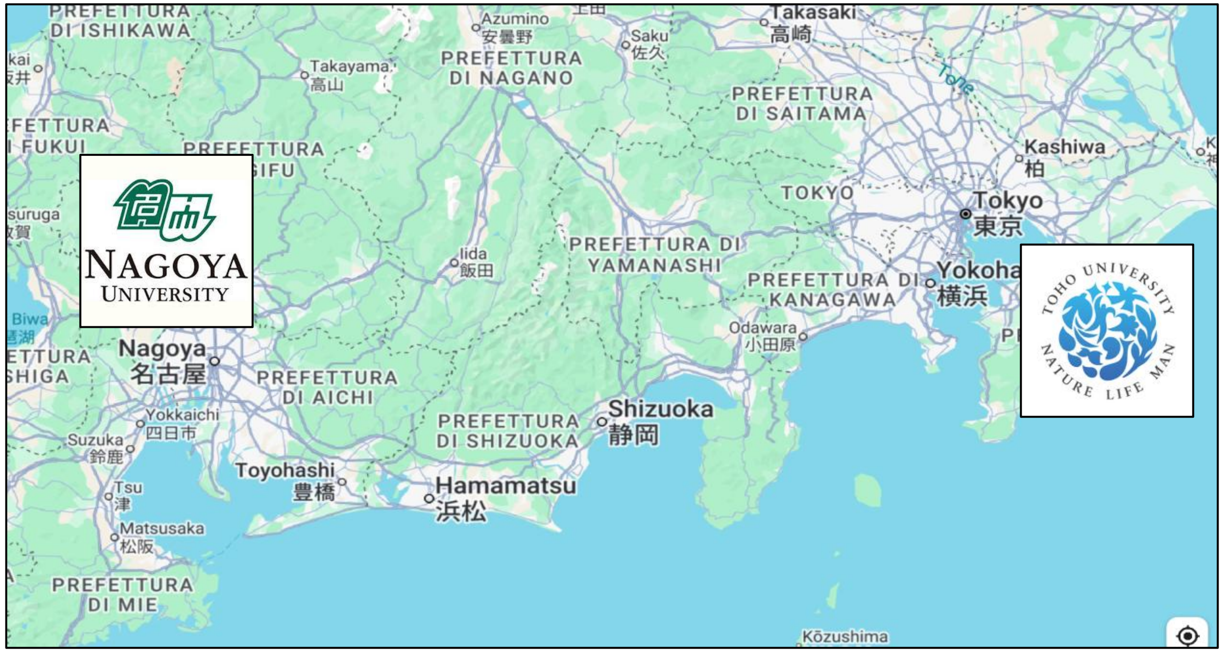
Overview of Activities in Japan

- Three data takings at the Nagoya proton therapy center (January – March 2025)

- Production of samples between Toho university (Narashino, near Tokyo) and Nagoya university

- Main improvements
  - New chemical development («reversal»)
  - Characterization of grain density as a function of proton energy
  - Successful usage of PMMA base (improved contrast and significant reduction of artifacts)

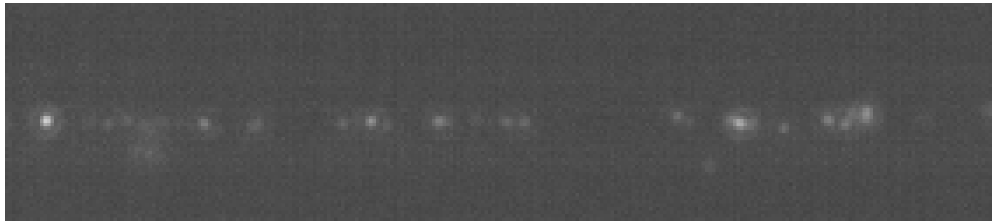
- Physics measurements
  - Target fragmentation with protons at 70 MeV (PS base and reversal development)
  - Target fragmentation with protons at 200 MeV (PMMA base, MAA and reversal developments)



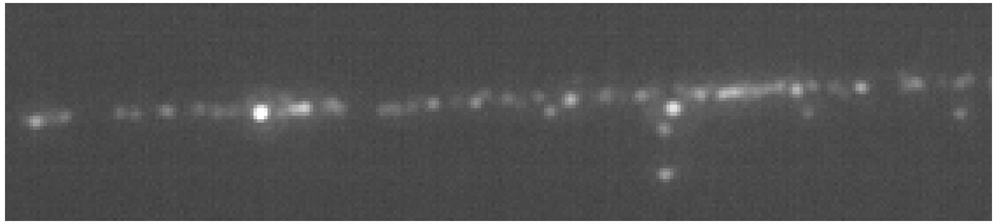
NIT Sensitization: Current Status

- Previous tests performed in LNGS had shown Triethanolamine (TEA) to be a promising candidate to increase crystal sensitivity in NIT emulsions
- The analysis of horizontal exposures to 290 MeV/n ^{12}C ions at HIMAC (T. Asada, T.Naka, December 2024) showed little to no increase in sensitivity for concentrations larger than 25 g/L of TEA
- Using larger concentrations is difficult because of changes in the mechanical properties of the emulsion gel

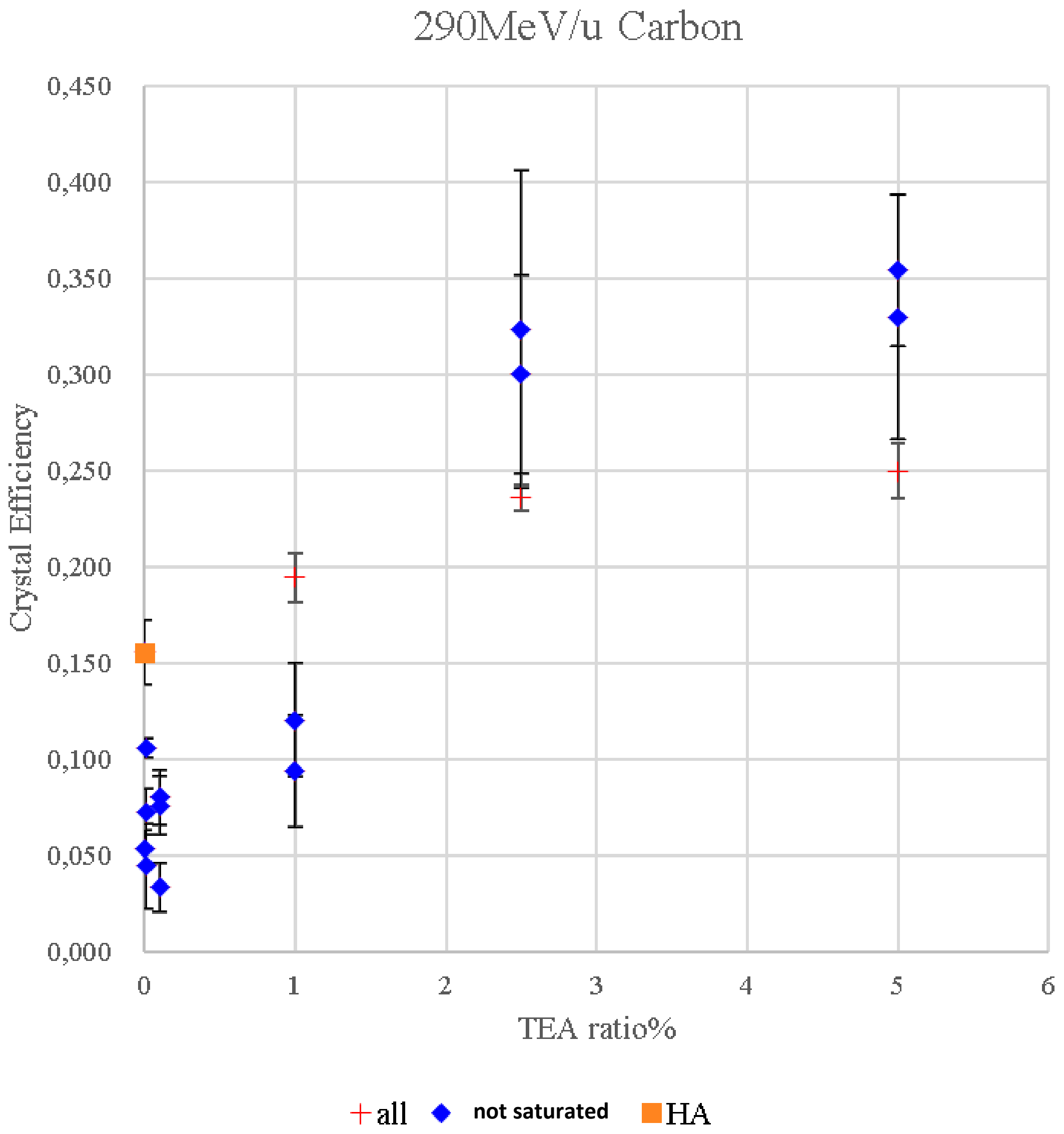
HA



TEA 2.5%



20 μm



Images and plot by T. Asada

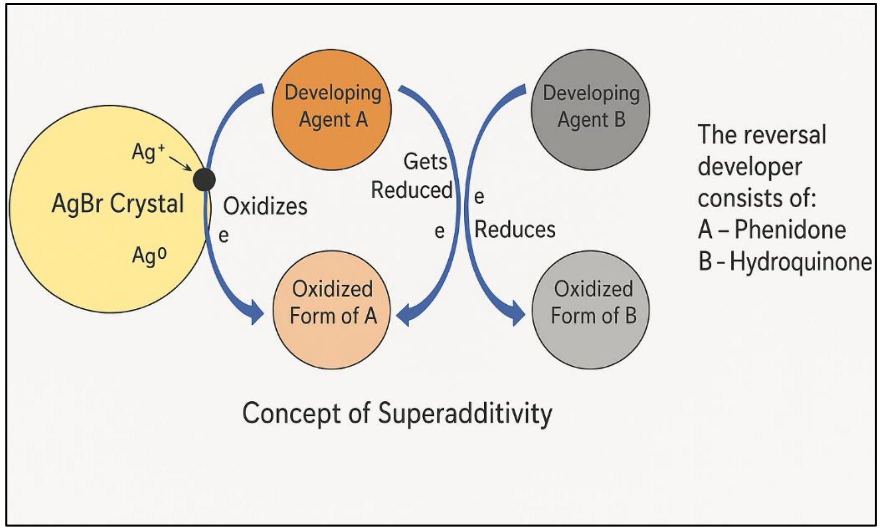
Reversal Development

- Standard NIT development is performed with the MAA developer, based on Metol and Ascorbic Acid
  - The main drawback of this developer is low brightness of the developed grains

- **Reversal development** has been designed to increase grain brightness
  - More aggressive development containing phenidone and hydroquinone, which melt the AgBr crystals to stimulate larger filament growth, resulting in a much larger brightness

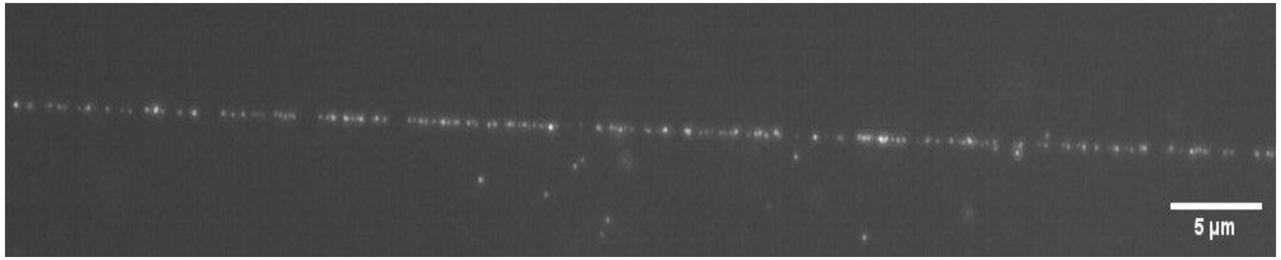
- Reversal was originally designed for 40 nm NIT (used for neutron measurements)

- At this time it has been tested and is being optimized for 70 nm NIT
  - One drawback: larger filaments exhibit weaker plasmon resonance!



Images by K. Someya

MAA

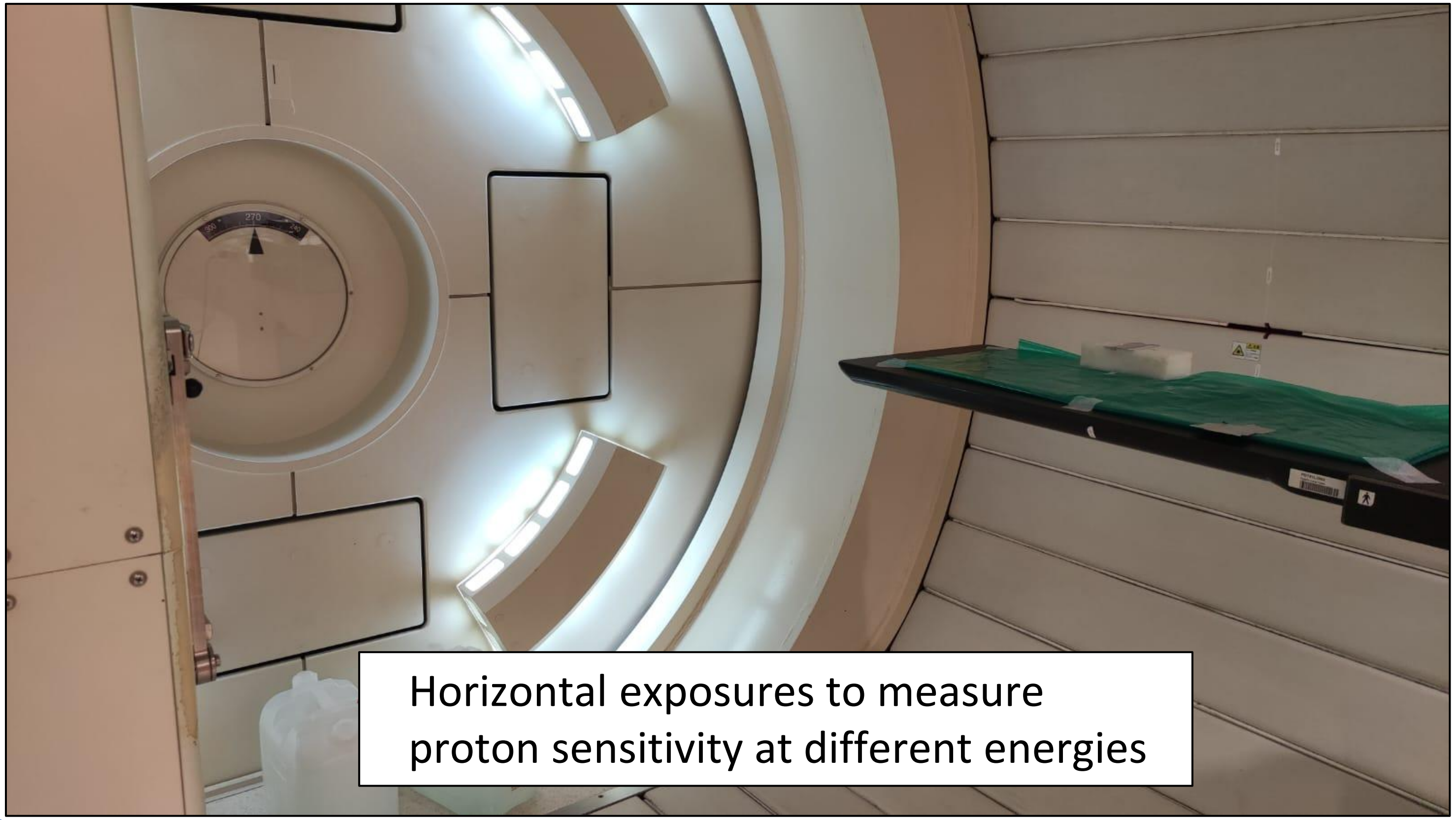


290 MeV/n Carbon ions

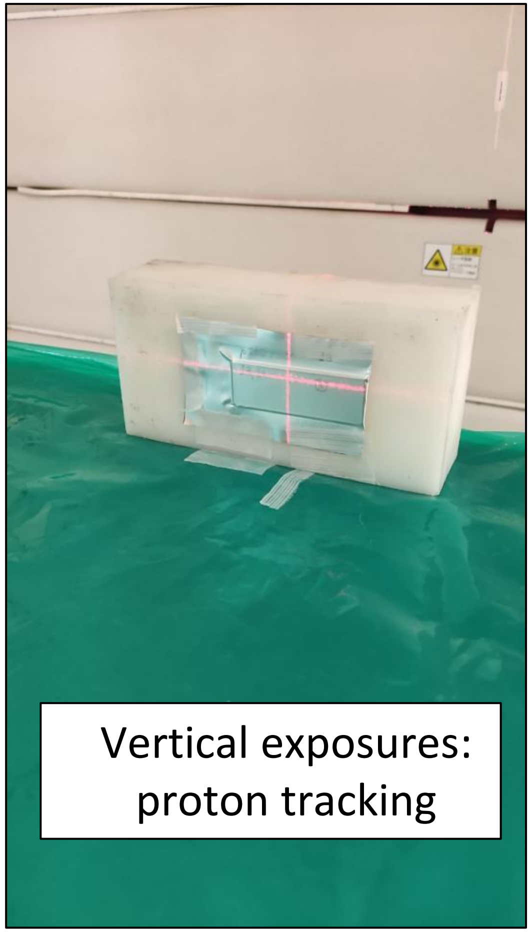
Reversal

First exposure at Nagoya Proton Therapy Center

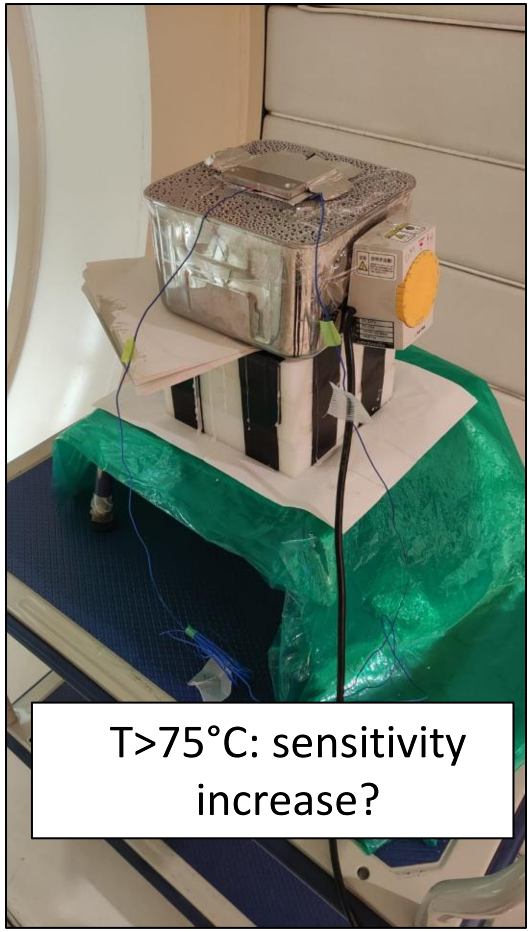
- Characterize NIT response to protons at different energies, when using 2.5% TEA and reversal development (completed)
- Test if sensitivity increases when emulsions are exposed at high temperatures (>75°, completed)
- Test proton tracking efficiency with vertical exposures (on-going)



Horizontal exposures to measure proton sensitivity at different energies

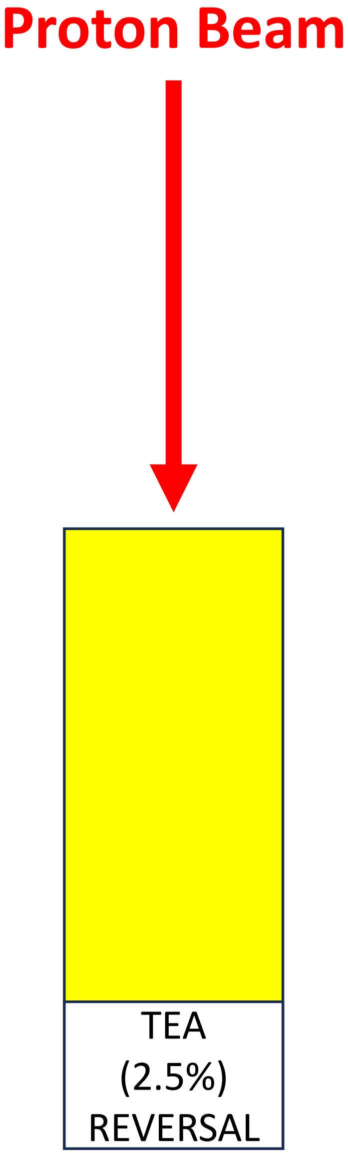


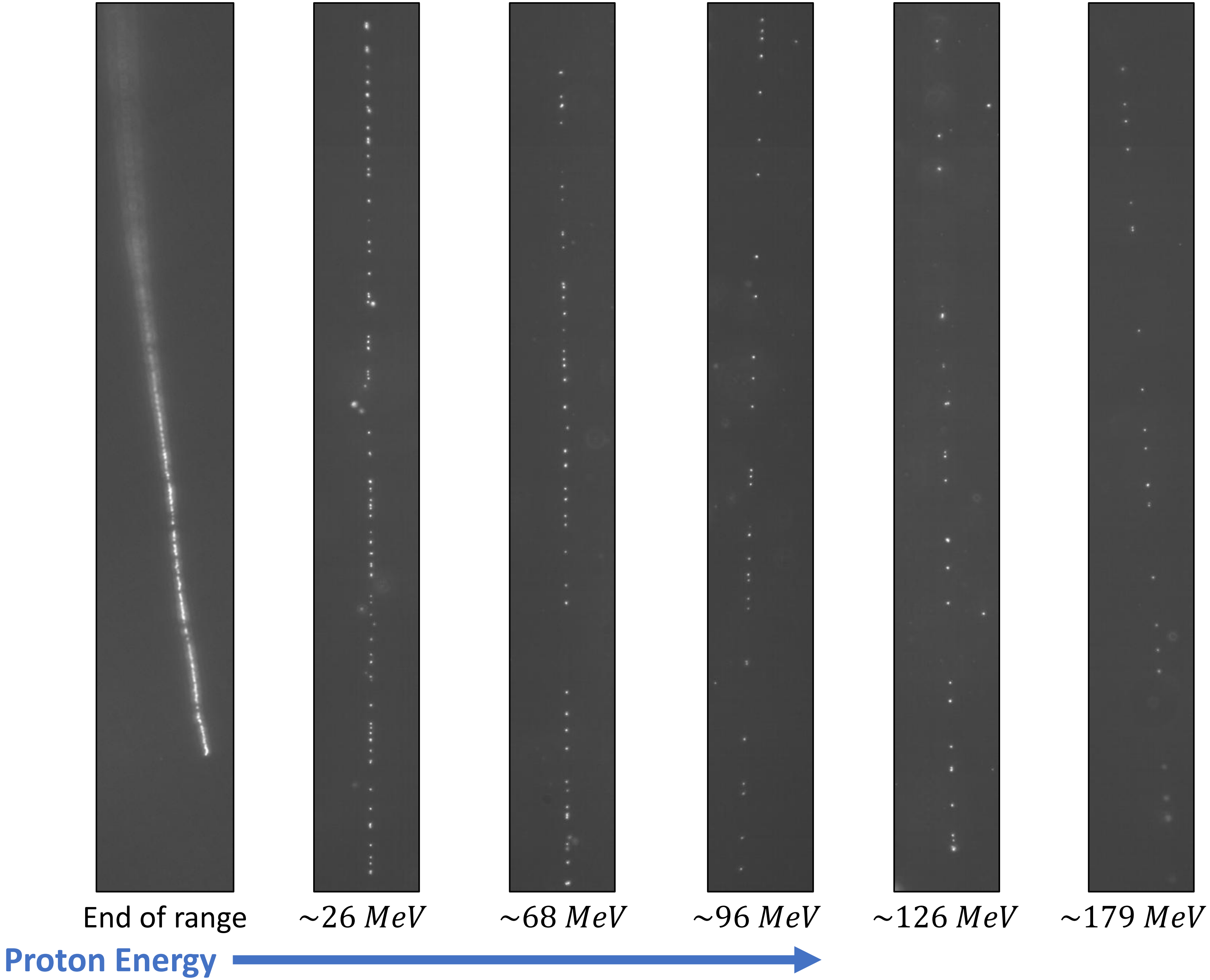
Vertical exposures: proton tracking



T>75°C: sensitivity increase?

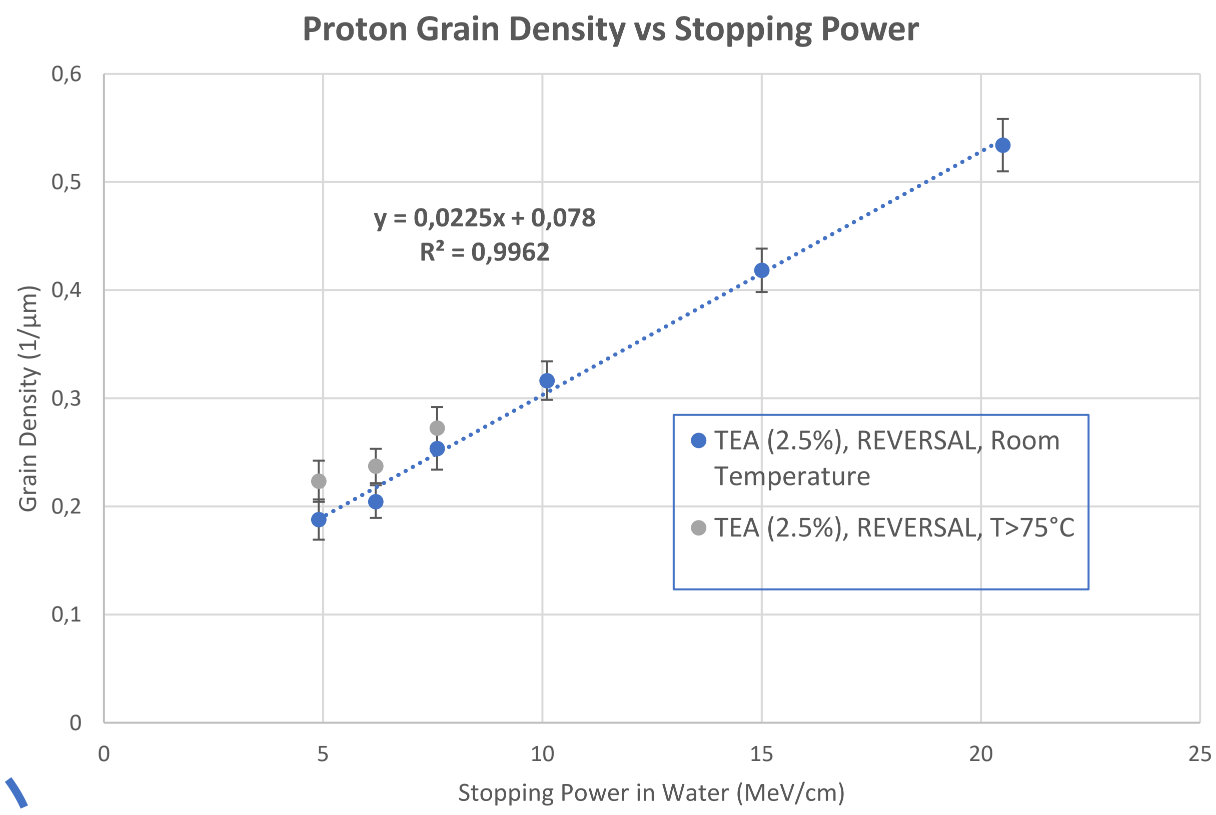
Results from Horizontal Exposures

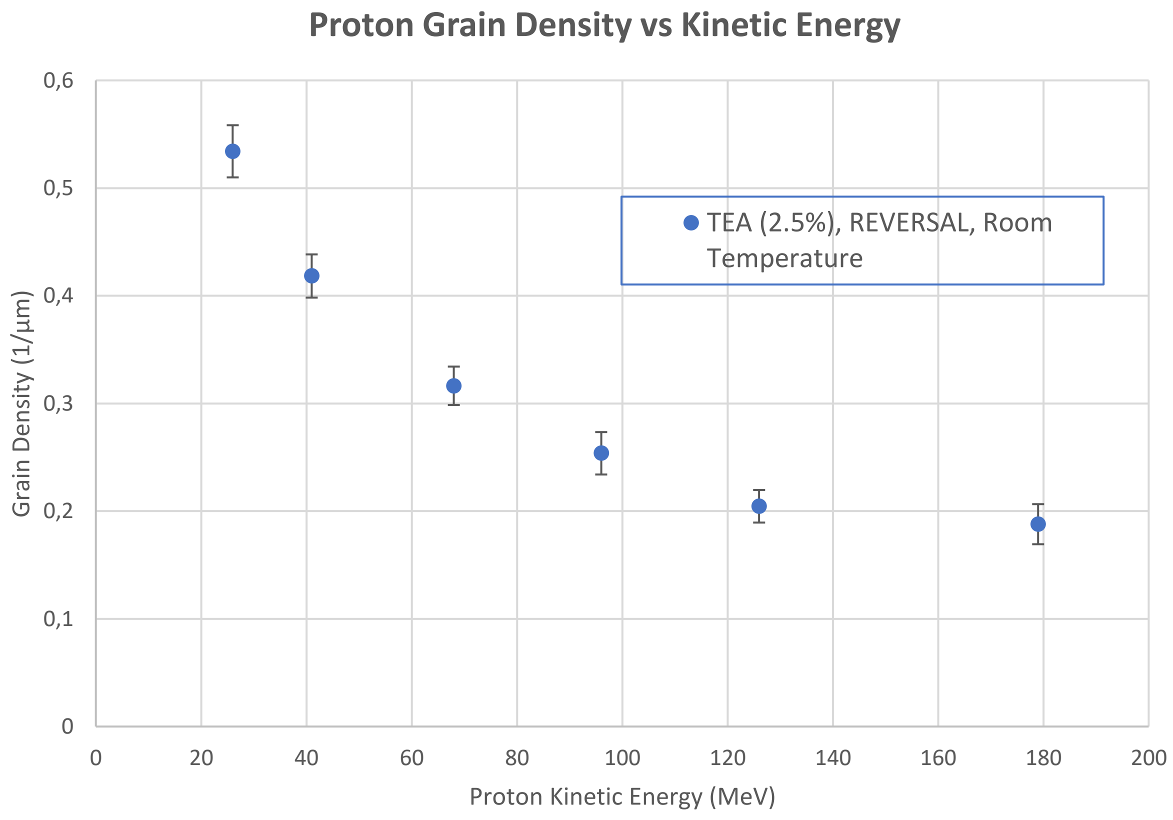




Grain Density Calibration

- Proton energy loss in the emulsion layer was simulated with Geant4
- Grain density was measured manually after choosing 10 proton tracks at different «depths», corresponding to different proton energies (the uncertainty on the energy has been neglected)
- Small sensitivity increase when the temperature is larger than 75°: not significant enough to justify the added complexity!
- Physics point of view: possible to identify protons and measure their energy (and separate them from helium tracks)





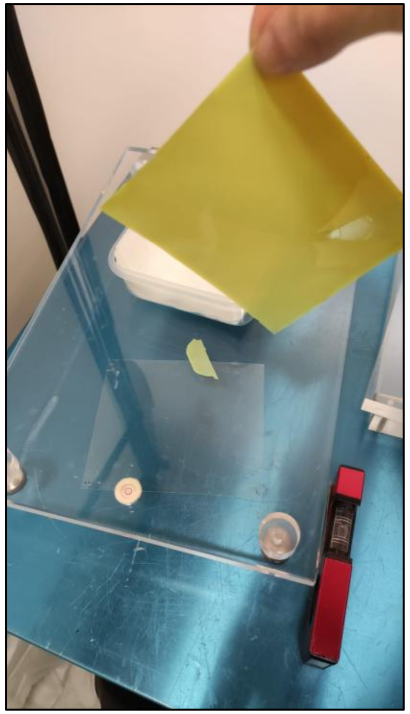
PMMA Pouring Tests

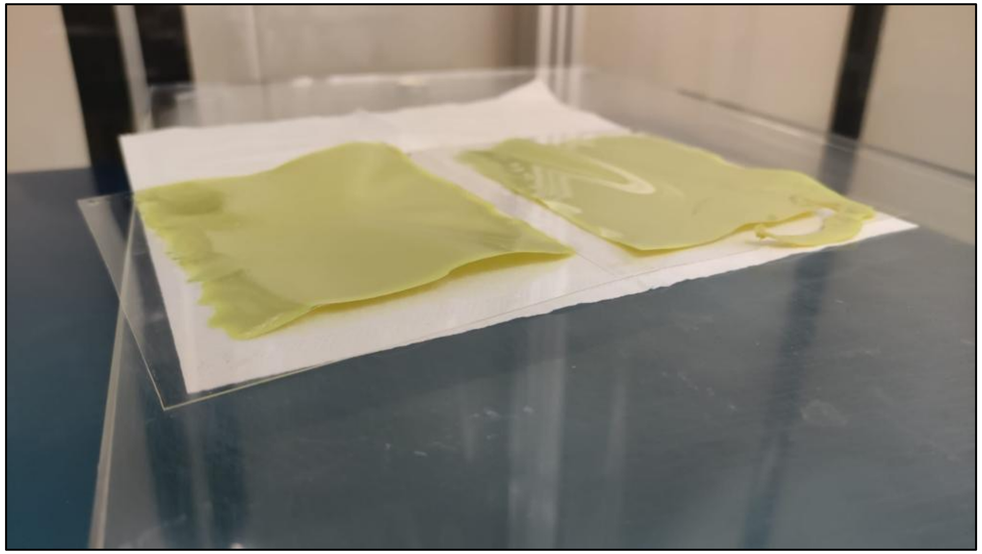
- In order to do pouring, it is necessary to treat the PMMA plastic with a corona discharge machine, before applying an Under Coat (UC)

- First, we tested pouring with a thin (200 μm) PMMA base in Nagoya and standard UC, with poor results: NIT detached from the plastic after removing the tape!

- A second test at Toho university has shown that the issue was low humidity (~ 40% in Nagoya vs ~65% in Toho)

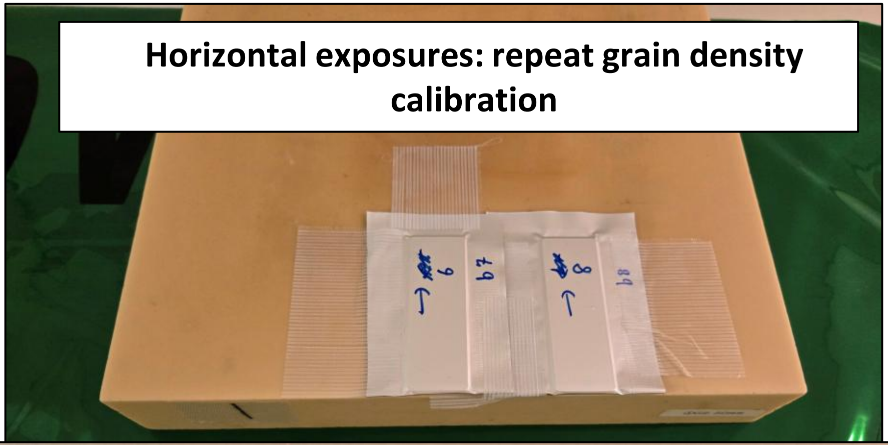
- The second pouring test was more successful but the samples detached from the plastic after the final protection coating



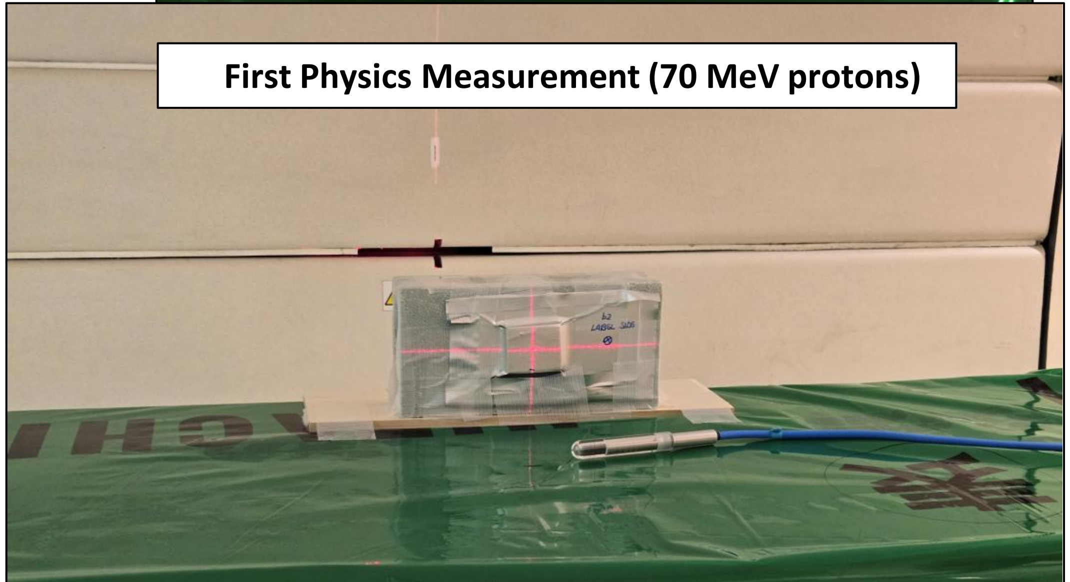


Second exposure

- Measure the primary proton density and the repeatability when close to zero Machine Units (down to 0.025 MU)
  - OPERA-like emulsion gel poured on slide glasses and exposed vertically
- Test the repeatability of the grain density calibration by using a different emulsion batch
- Test different development parameters
- Perform a first physics measurement in «conservative» conditions



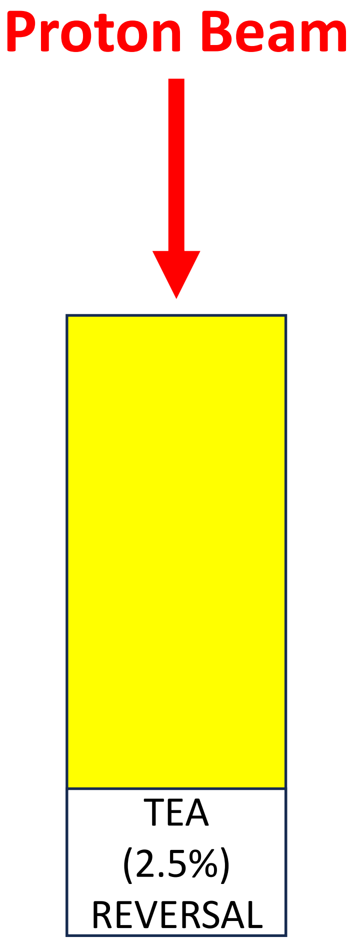
Horizontal exposures: repeat grain density calibration

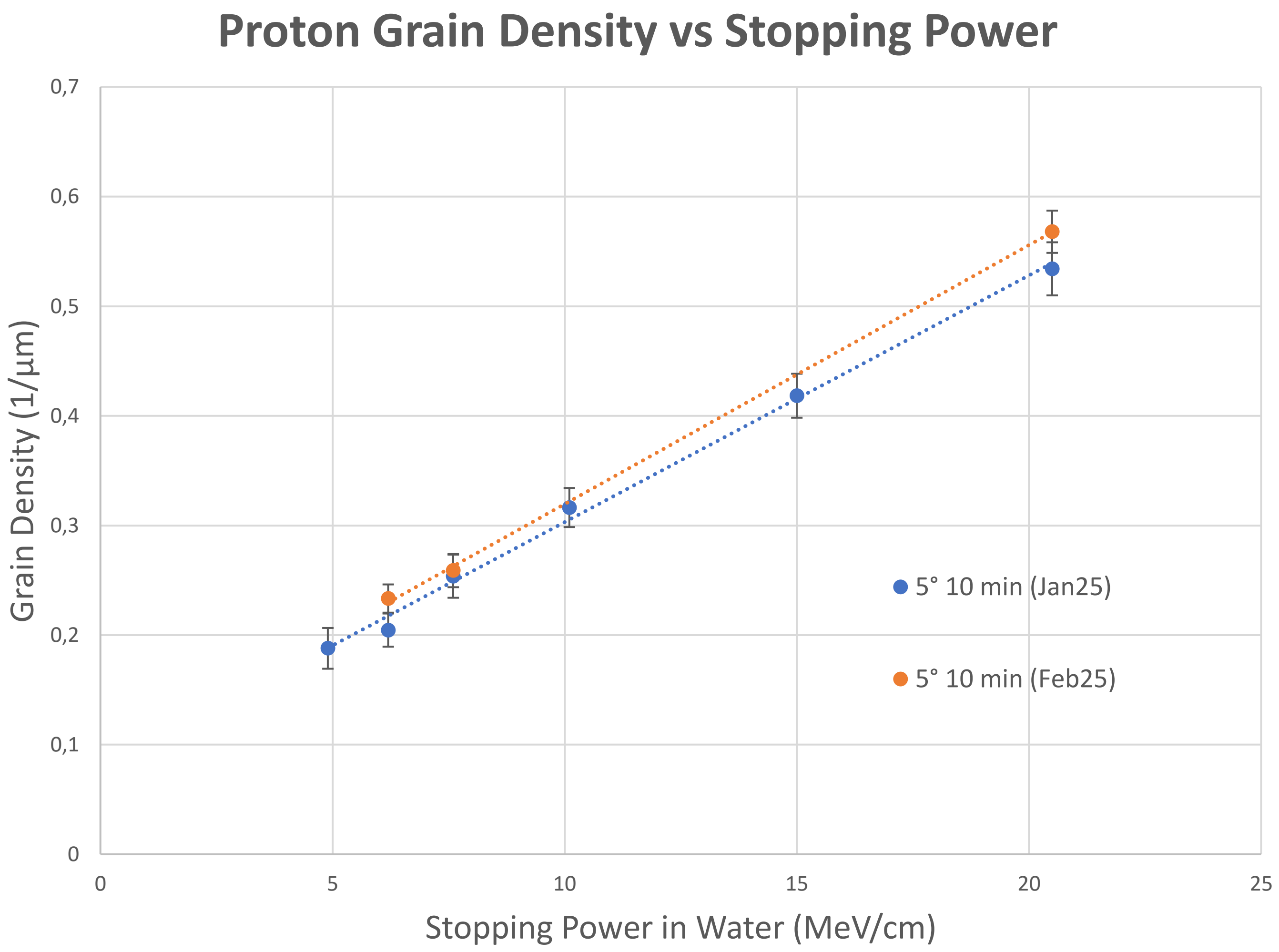


First Physics Measurement (70 MeV protons)

Grain Density Calibration repeatability

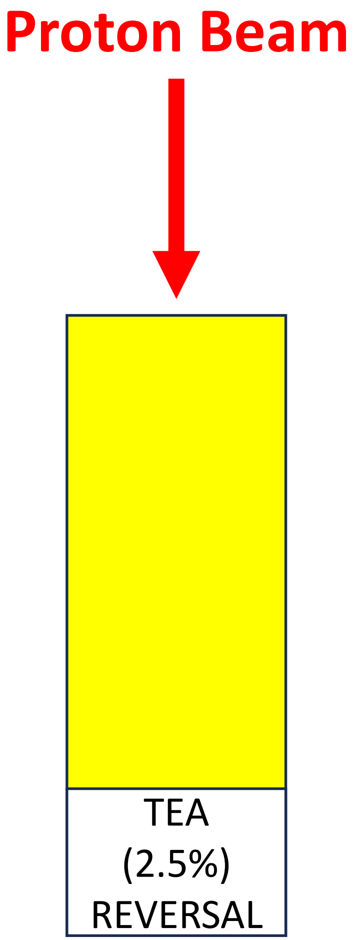
- The results of the second measurement were compatible with the previous one within the margin of error, demonstrating the robustness of this result

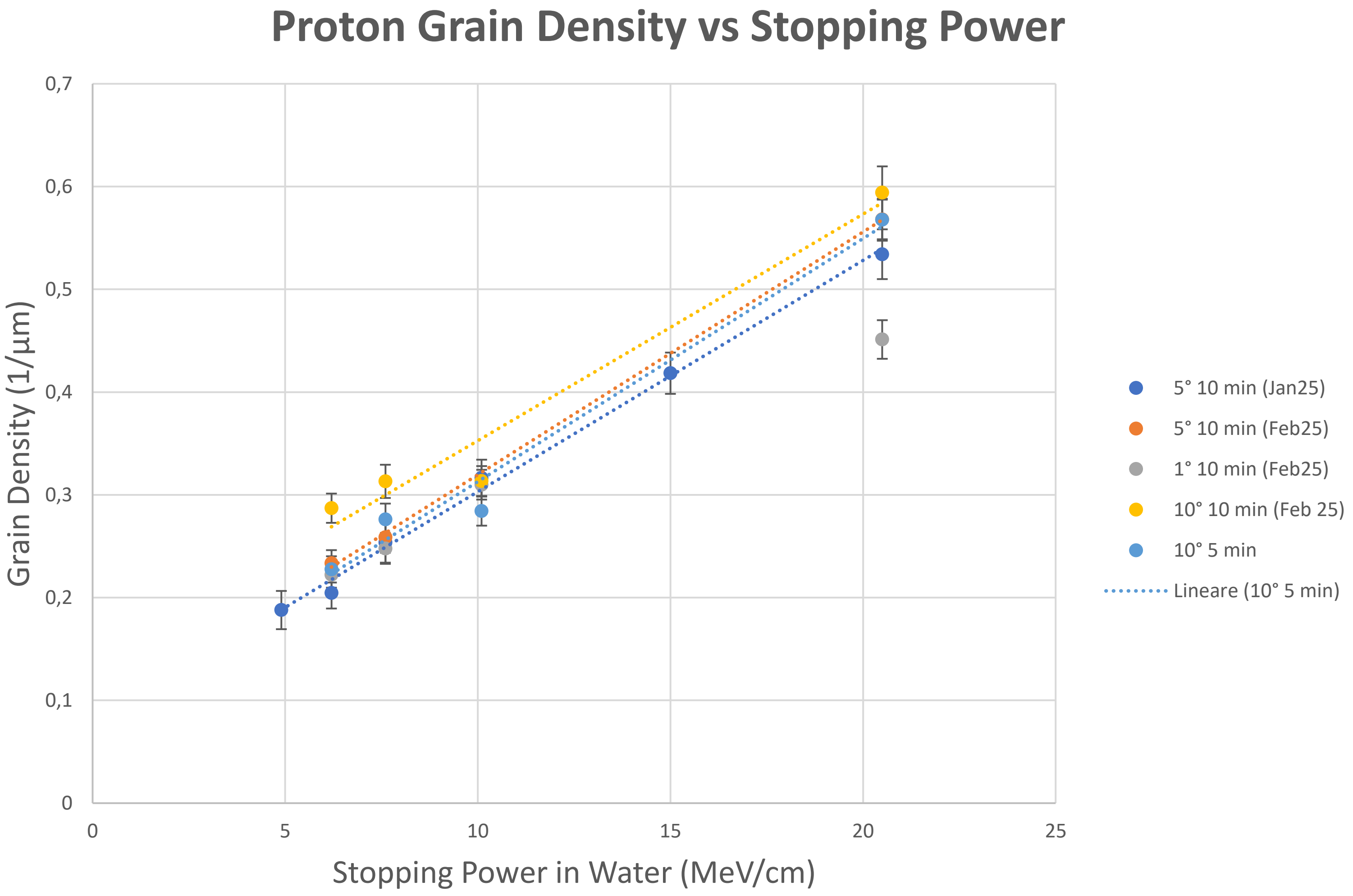




Tuning the development parameters

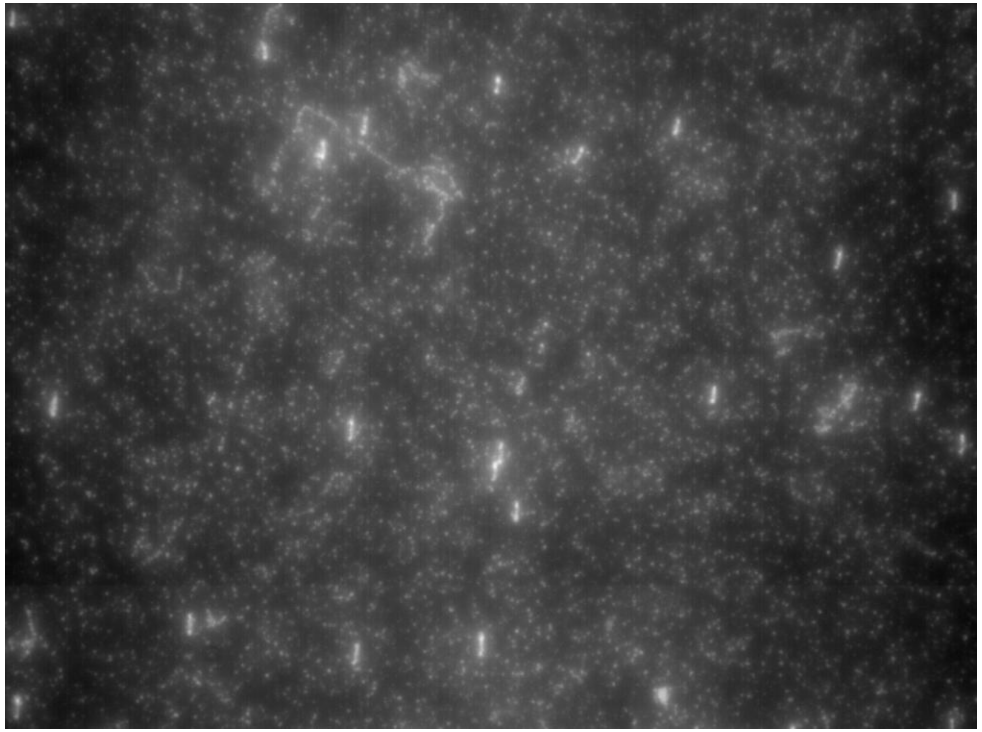
- Reversal development was tested with different temperatures and development times
- A small increase of grain density was observed when developing at 10° for 10 minutes. However this condition also led to an increase in fog density



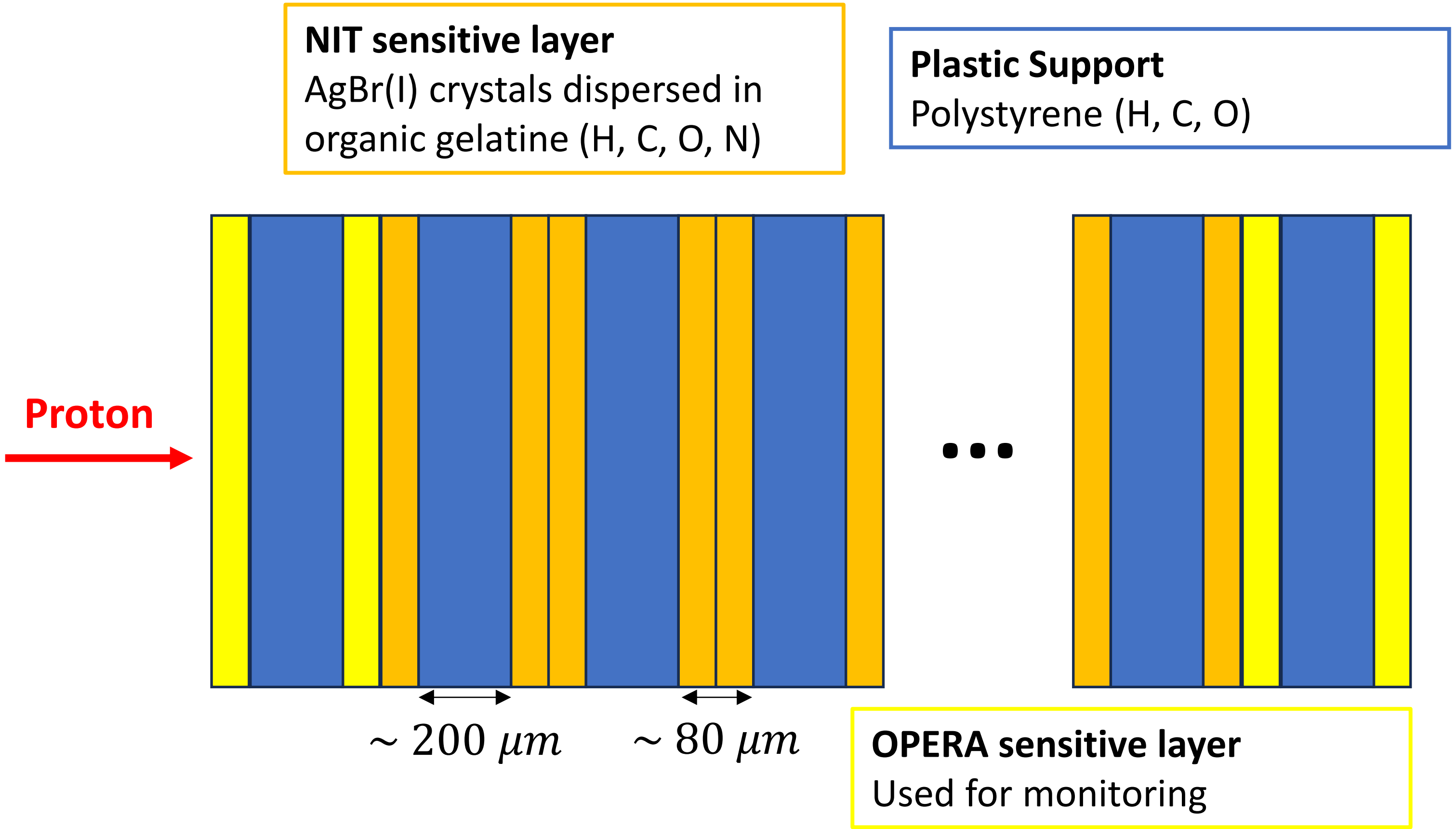


First Physics Measurement

- Because of the challenges in the production of samples on a PMMA base, the first brick was produced using PS (polystyrene) which showed better adhesion and developed with reversal (5°, 10 min)
- NIT emulsion layers were kept thin (35-40 microns) to reduce mechanical stress
- Using PS worsens contrast, making the identification of proton tracks at higher energies more difficult → first measurement performed at 70 MeV (measured density of $\sim 1.4 \times 10^5 cm^{-2}$)
- Sample area was $\sim 6 \times 3.5\ cm^2$. Assuming a sensitive area of $5 \times 2.5\ cm^2$, about 16.000 interactions are expected in the emulsion layers (18 NIT films in total)

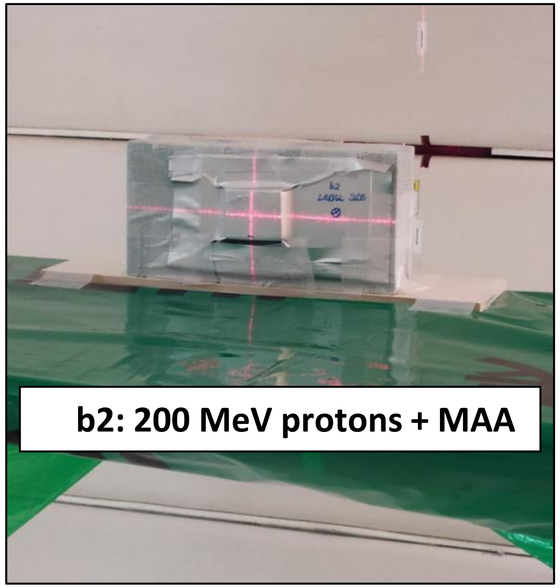


OPERA layer used as beam monitor

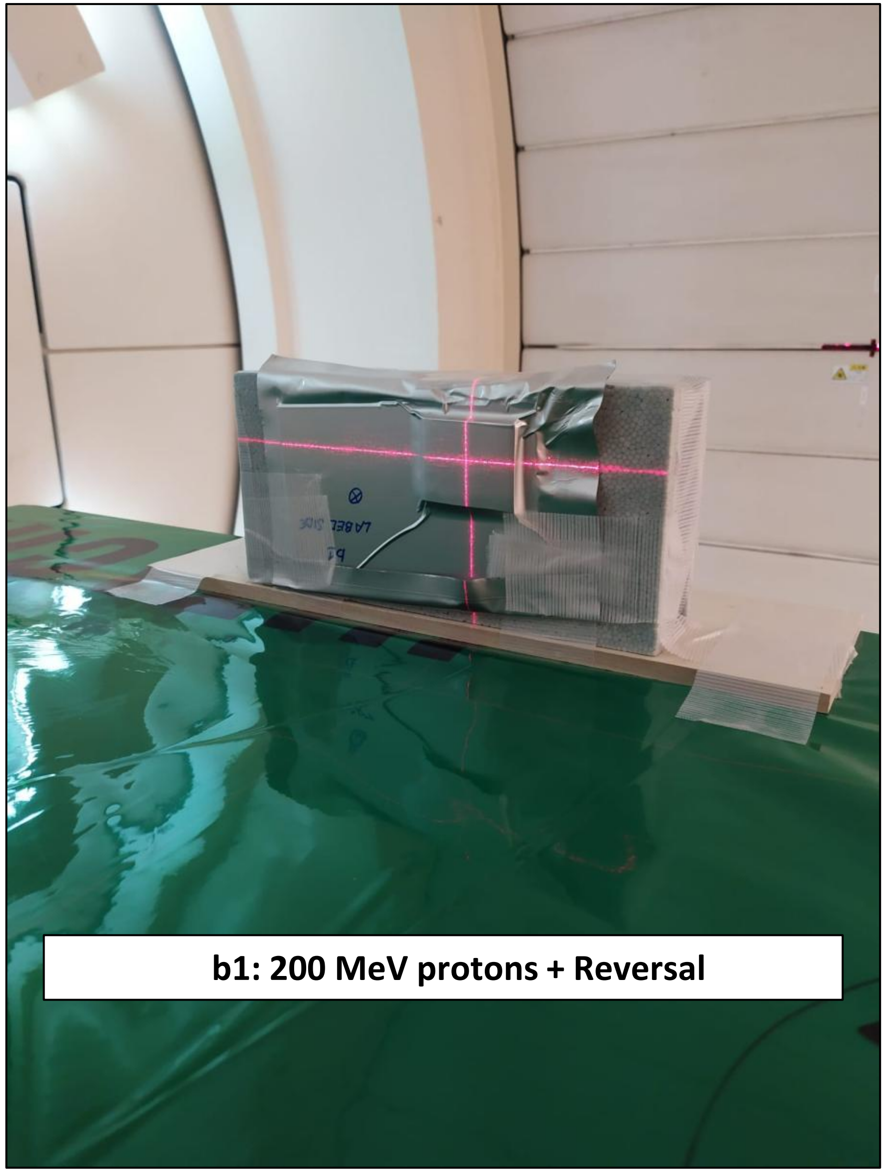


Final Exposure in Nagoya

- Several pouring tests were performed with PMMA: finally, the use of an UC solution containing Chromium lead to the first successful samples → possible to use PMMA
- While the increased brightness from reversal development is an improvement, its effect on plasmon analysis can reduce the reconstruction efficiency for tracks down to a few hundred nanometers → tuning of reversal development parameters
- Data takings performed with protons at 200 MeV



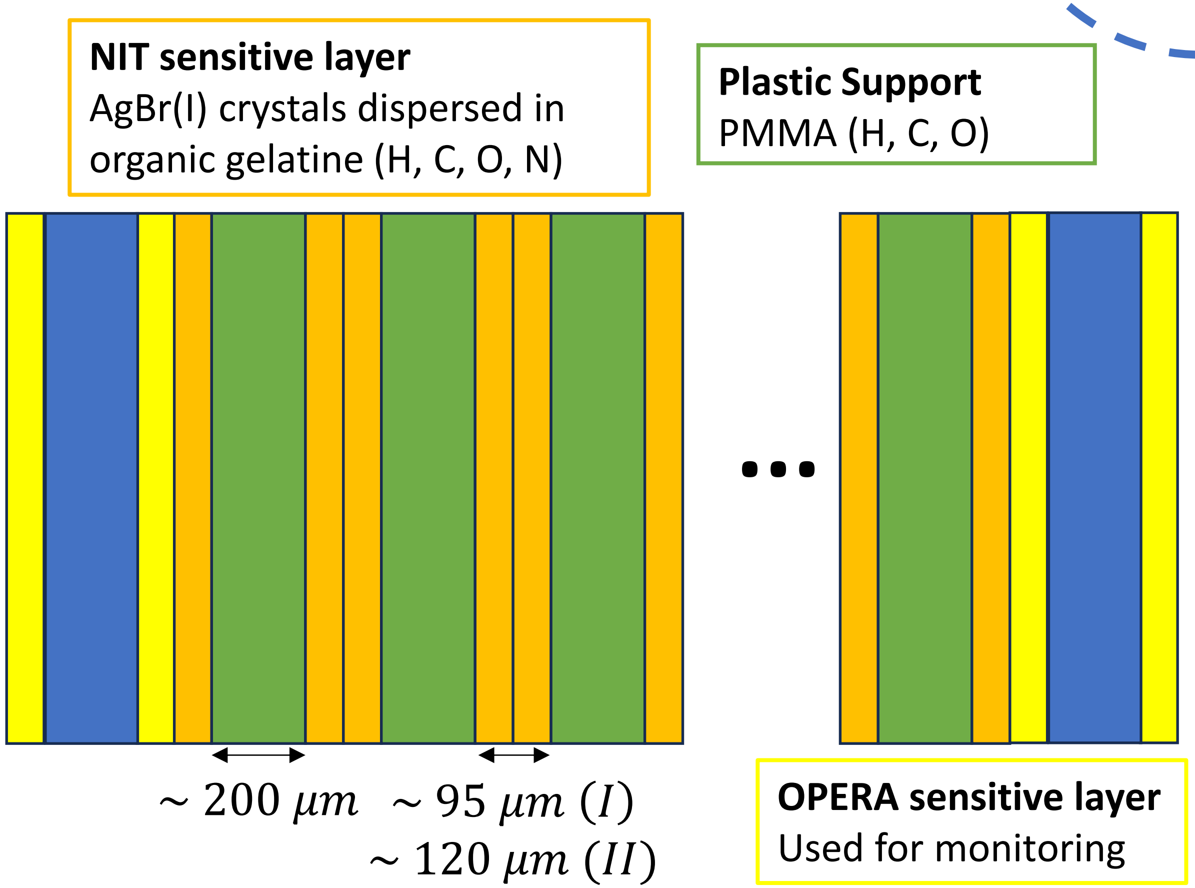
b2: 200 MeV protons + MAA

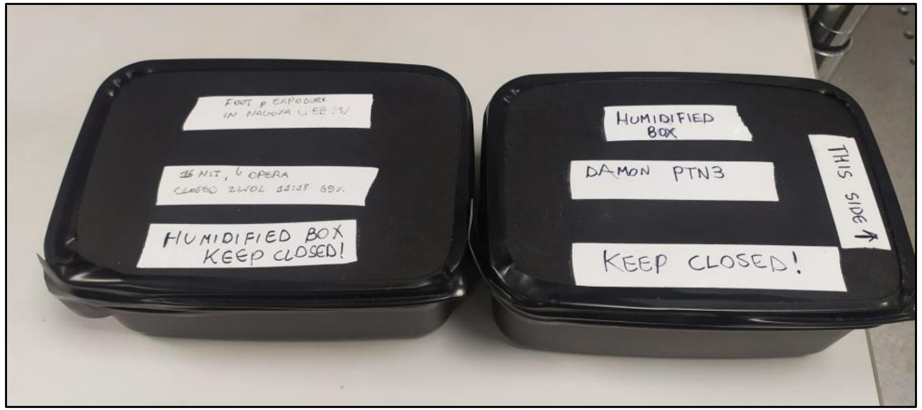


b1: 200 MeV protons + Reversal

Physics Measurements at 200 MeV

- For the final exposure (primary protons at 200 MeV), we produced two NIT bricks
  - The first brick (3 OPERA-PS + 12 NIT-PMMA + 3 OPERA-PS) has been developed with MAA and it has been exposed to $\sim 5 \times 10^5$ protons cm^{-2}. Its goal is to study the heavier fragments with the plasmon analysis, disregarding secondary protons (very faint with MAA). Unfortunately, about **half** of the films in this brick were damaged (detaching) immediately before development
  - The second brick (3 OPERA-PS + 20 NIT-PMMA + 3 OPERA-PS) has been developed with reversal and it has been exposed to $\sim 1 \times 10^5$ protons cm^{-2}. The higher grain brightness should enable the reconstruction of secondary protons
- All bricks were transported back to Italy in sealed boxes with a NaBr saturated solution to keep humidity stable





Visit at the Italian Embassy in Tokyo

- On February 28, we were invited to the Italian Embassy in Tokyo to present our research activities together with our Japanese colleagues
- The feedback was good, the embassy aims at supporting Italy-Japan collaborations

Conclusions

- We carried out several activities on NIT R&D in Japan (January 2025 – March 2025)

- Tests regarding sensitization, development and sample production (still on-going!)

- 3 bricks available for scanning and reconstruction
  - 70 MeV protons + reversal development (on PS base)
  - 200 MeV protons + MAA development (on PMMA base)
  - 200 MeV protons + reversal development (on PMMA base)

- More updates to follow!
  - CNAO 2024 samples are being developed today at LNGS

Thank you!

ありがとうございます！