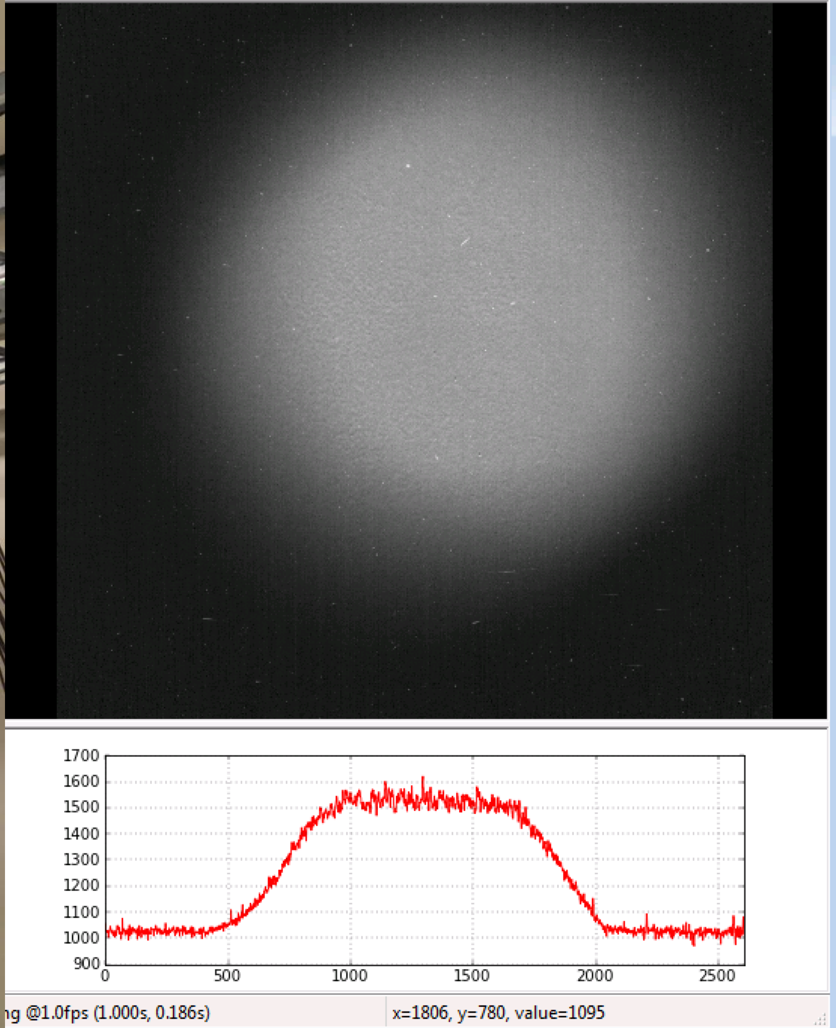

PROPOSAL FOR A NEUTRON IMAGING STATION AT n_TOF EAR2

F. Mingrone, M. Calviani, M. Barbagallo, E. Chiaveri, N. Colonna, L. Cosentino, P. Finocchiaro, A. Perillo-Marcone, V. Variale, V. Vlachoudis and the n_TOF Collaboration

55th INTC Meeting – CERN, 8 February 2017

Neutron Imaging

- Well developed radiography technique to inspect the inner part of an object
- Basic principles:
  - The peculiar interaction of neutron with matters allows them to penetrate thick-walled samples
  - The specific attenuation properties of the materials determines the intensity of the transmitted radiation
  - Complementary to X-rays radiography

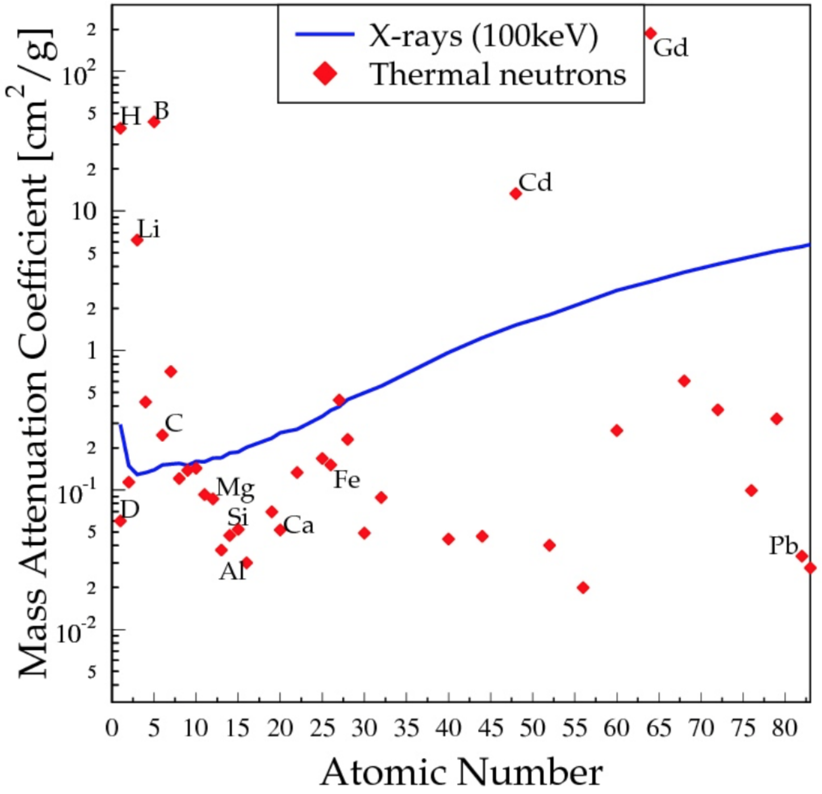

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Image obtained at the PSI NEUTRA facility

Neutron Imaging

- Different possibilities to exploit neutron imaging:
  - Single radiography or 3D tomography for rigid objects and stationary processes
  - Series of radiographs for dynamic processes
  - Advanced imaging techniques (e.g. energy-selective imaging methods, measuring techniques exploiting different neutron waves properties)
- Several facilities worldwide

Laboratory	Facility	Neutron source	Neutron spectra	Features
PSI - Switzerland	ICON	Spallation (SINQ)	Cold, monoenergetic	Micro-tomography Wavelength selective neutron imaging
	NEUTRA	Spallation (SINQ)	Thermal, monoenergetic	High-radioactive samples, optional X-ray tube
ORNL – USA	CG-1D	Reactor (HFIR)	Cold, polychromatic	Tomography
NIST – USA	Neutron Imaging Facility	Reactor (NBSR)	Thermal, monoenergetic	Tomography and dynamic processes

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CERN	**n_TOF EAR2**	**Spallation**	**Thermal, white**	**Single radiographs, high-radioactive samples**

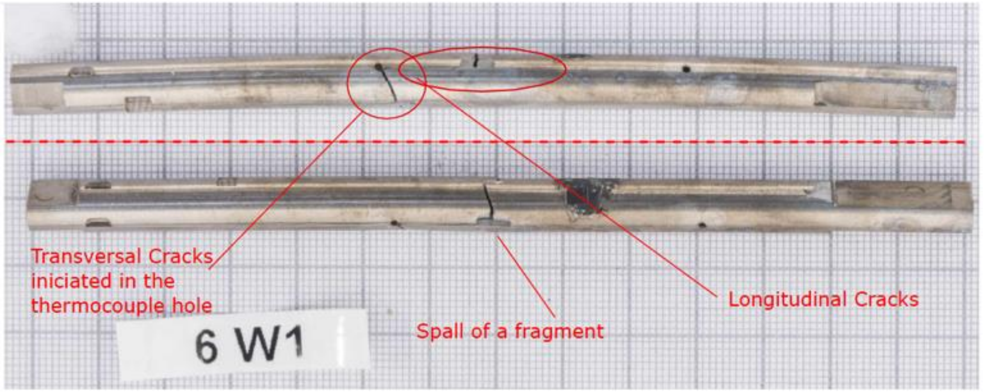
Technological motivation

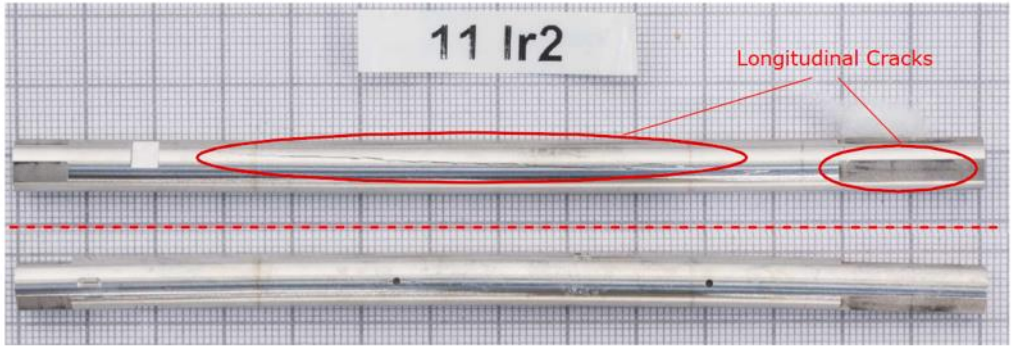
INSPECTION OF **HRMT27 RODS**

- HRMT27 experiment in 2015: high-Z material rods impacted with highly energetic beams to test their response to shock waves.
- Characteristics of the rods: 140/200 mm long, 8 mm diameter, high residual dose rate of hundreds of µs/h.
- Several cracks on the surface, both longitudinal and transversal

⇒ **Neutron imaging inspection to verify how surface cracks propagated towards the center of the rods**

(comparison with the X-rays scans already performed)





Technological motivation

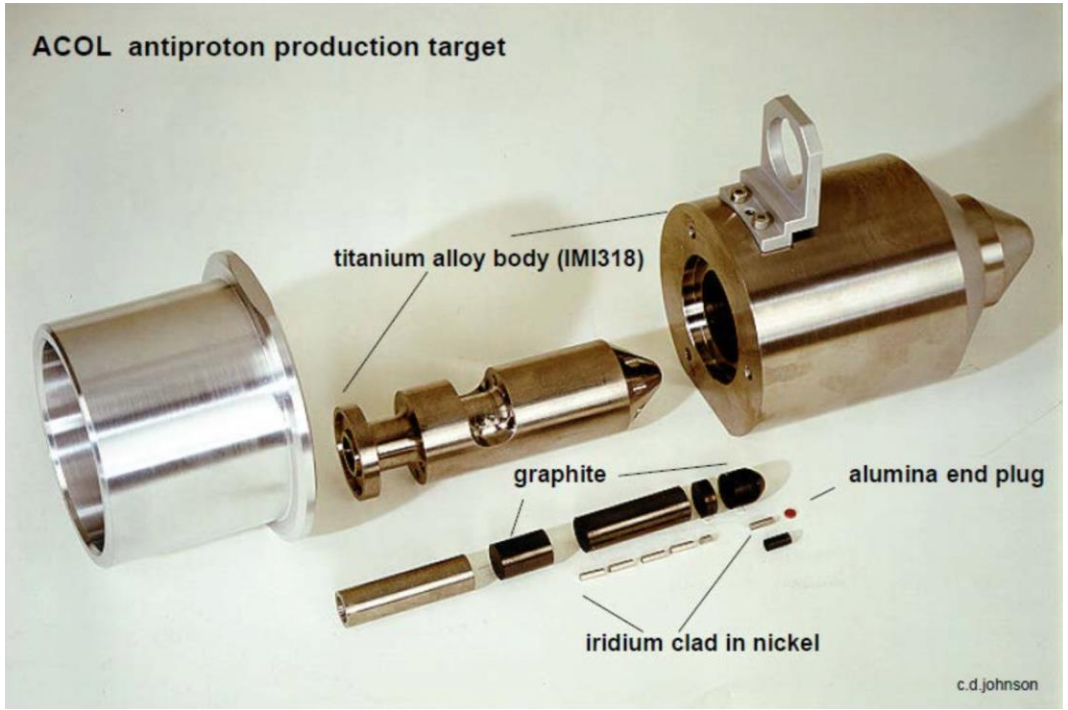
INSPECTION OF THE **AD TARGET**

- The antiprotons for the Antiproton Deceleration (AD) facility are created by collision of a 26 GeV/c momentum proton beam coming for the PS (Proton Synchrotron) with a high-Z target
- Main concept of the target design (unchanged since 1987):
  - Target core embedded in a graphite cylinder
  - Double-walled, water-cooled, titanium alloy container
- 2 major damaging concerns, resulting in a reduction of the p-target interaction and antiproton production (periodical replacement of the target)
  - Shock waves as a consequence of the sudden increase of temperature in the target material after each pulse
  - Radiation damage

Technological motivation

INSPECTION OF THE **AD TARGET**

- Iridium rod divided into 6 part (to reduce the dynamic stress):
  - Length: 5 or 10 mm
  - Diameter: 2 mm
- Highly radioactive (≈ 5 mSv @ 10 cm)
  - Target already in a stainless steel container
  - Possibility to have a fully- or semi-automated station
  - Safety procedures in cooperation with RP



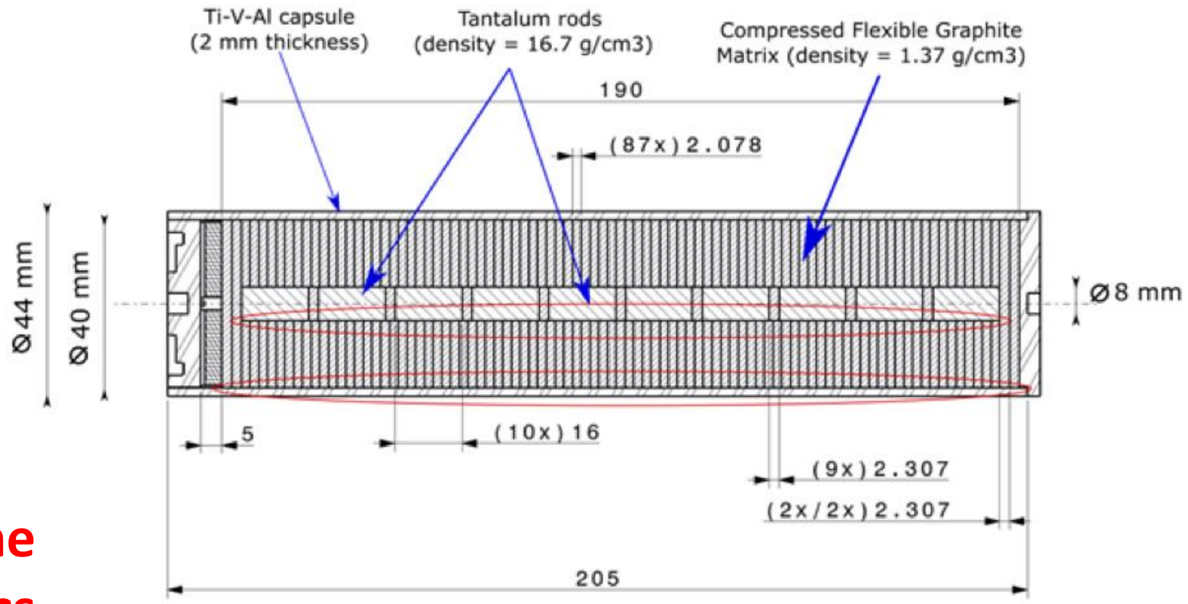
⇒ Neutron imaging inspection to check possible damages

(no easy mechanical inspections, opaque to X-rays)

Technological motivation

INSPECTION OF A **GRAPHITE EMBEDDED Ta ROD**

- Output of the HRMT27 experiment: Ta showed excellent properties (ductility and strength).
- New prototype: Ta bar fixed inside graphite discs and contained in a Ti6Al4V tube, to be irradiated at HiRadMat in 2017.



⇒ Neutron imaging inspection to evaluate the response of the discs

(low sensitivity of X-rays in the area between the Ta and the graphite discs)

Experimental technique

- Map of the attenuation of a neutron beam when transmitted through a sample.
- Two main parameters:

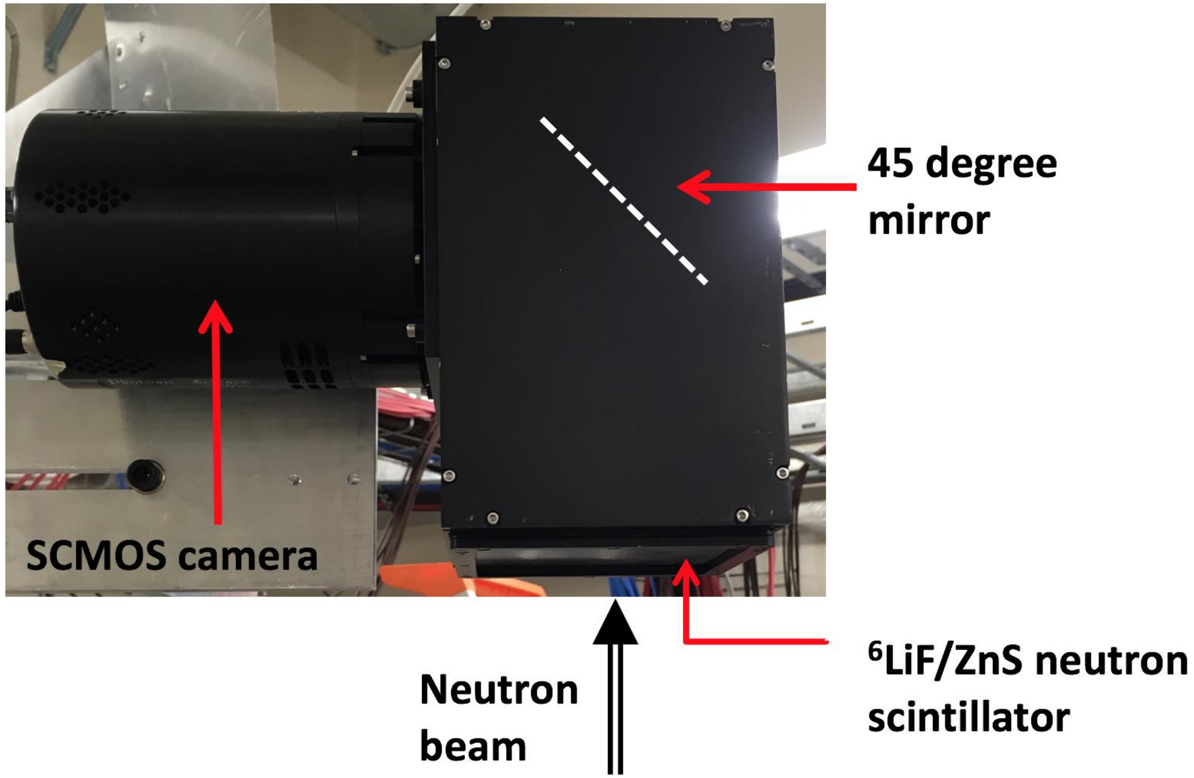
  Contrast. Depends on the beam intensity

  Spatial resolution. Depends on:

  - The beam divergence D/L, being D the size of collimator inlet aperture and L the distance between the inlet aperture and the point in the object to be analyzed
  - The distance l between the point in the object to be analyzed and the image detection plane.
  - The converter thickness and the distance between converter and detector
- @ n_TOF:
  - High intensity flux in EAR2
  - 2 fixed values of D, adjustable l and L
  - Optimized detector geometry

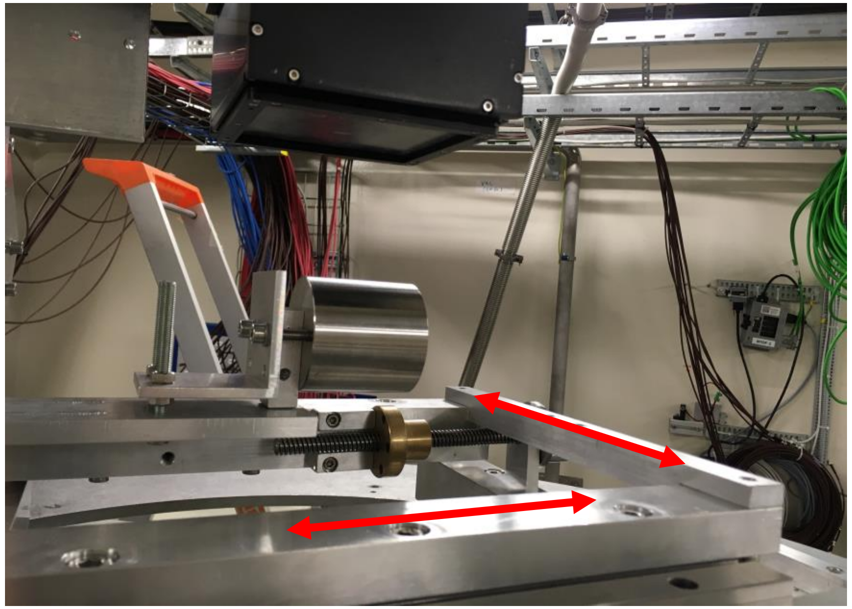
Experimental setup: neutron imaging detector

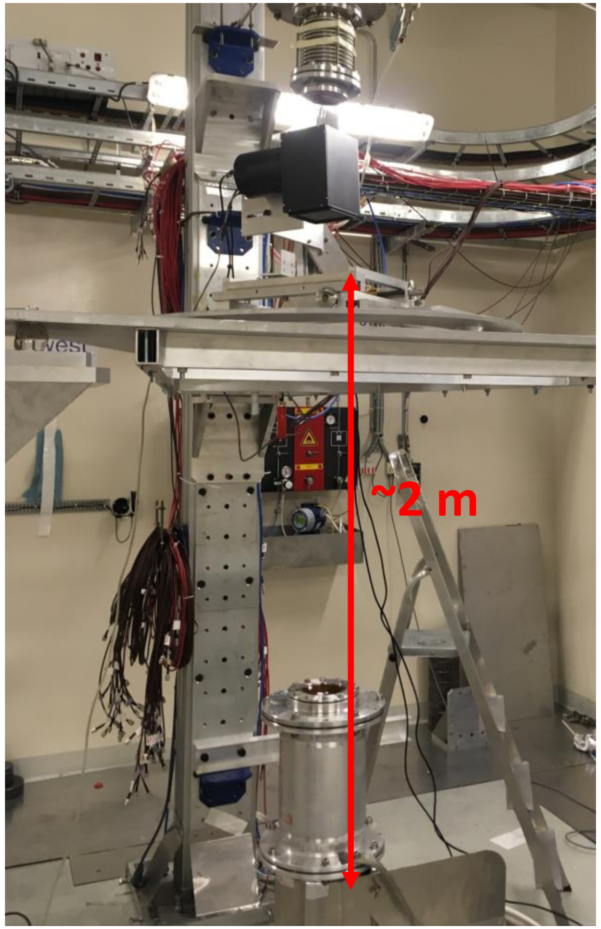
- Detection system from Photonic Science:
  - ZnS/^{6}LiF based neutron scintillator, active area of 100x100 mm^2, thickness ≈ 100 μm
  - 45 degree mirror to allow the positioning of the camera off-beam
  - Air-cooled SCMOS camera, 2048×2048 pixel for a 13.3×13.3 mm^2 active input area
  - Optical pixel resolution: 6.5 μm
- Remote control of the apparatus
- Possibility to externally trigger the camera with the PS trigger



Experimental setup: neutron imaging station

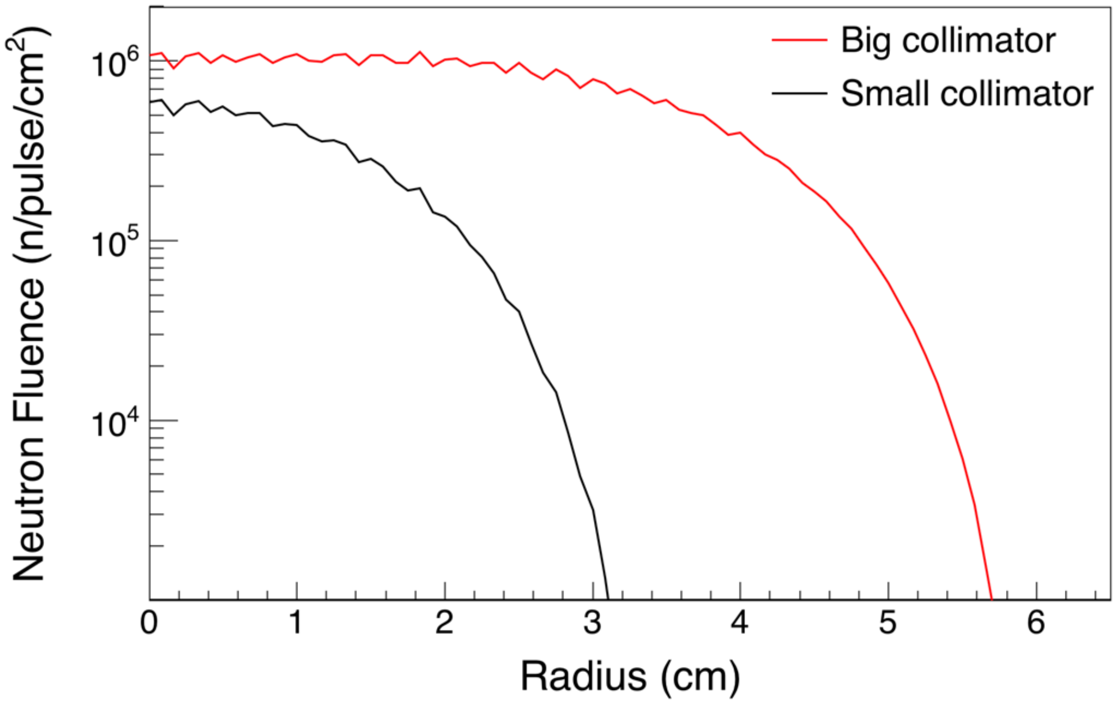
- Measuring station:
  - Height ≈ 220 cm from the floor
  - Sample-camera distance ≈ 5 cm
  - Able to host different sample, possibility to fine tune the sample position





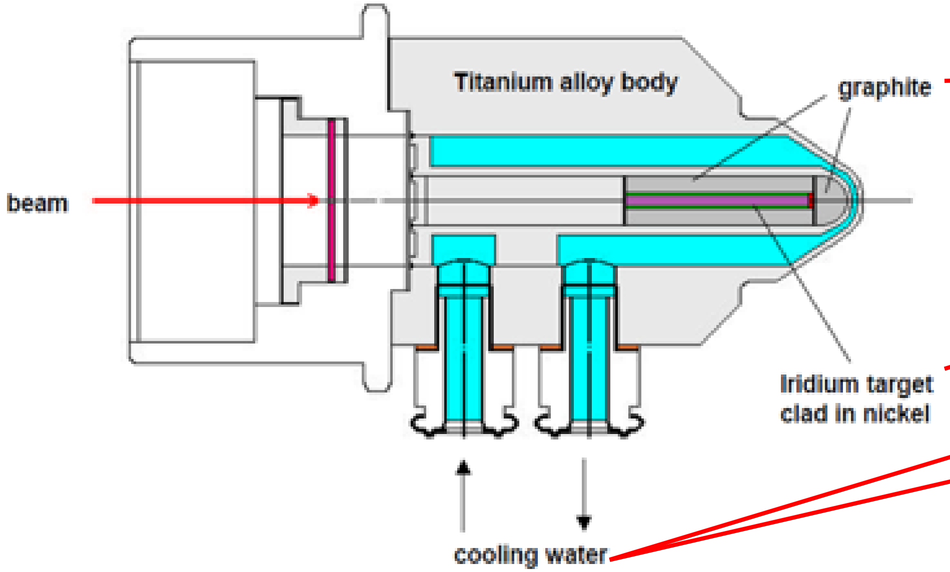
Experimental setup: neutron beam

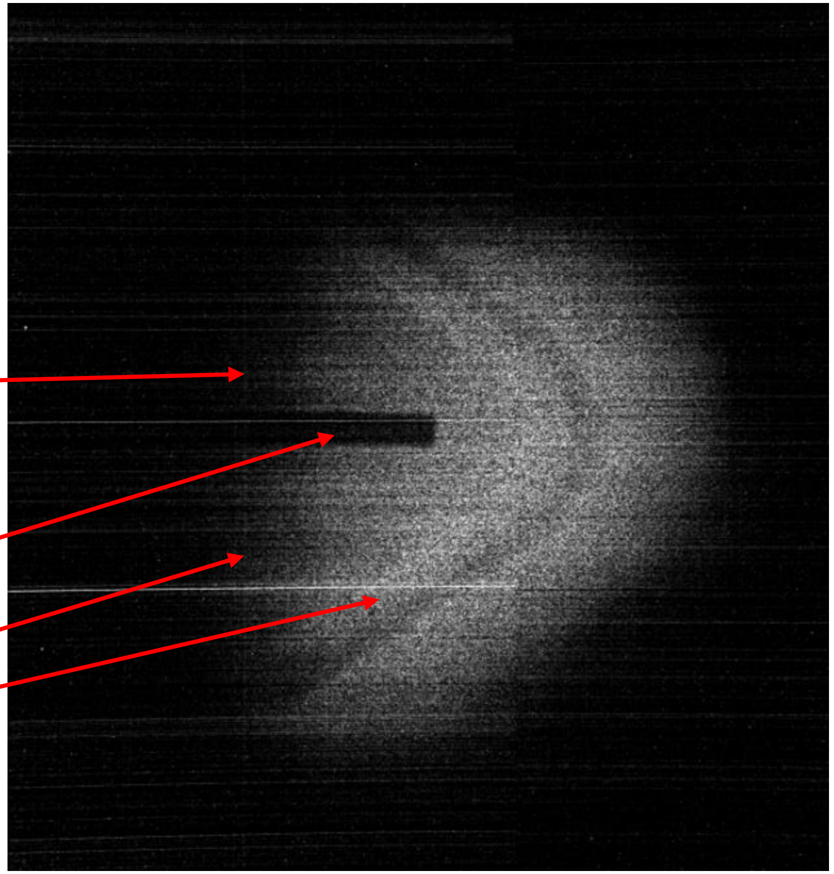
- n_TOF big collimator
  - 667 mm inner diameter
  - About 1×10^6 neutrons/cm^2/pulse (8×10^5 n/cm^2/s if 1 pulse every 1.2 seconds) @ thermal
  - Beam profile: 9 to 11 cm diameter
- n_TOF small collimator
  - 218 mm inner diameter
  - About 6×10^5 neutrons/cm^2/pulse (5×10^5 n/cm^2/s if 1 pulse every 1.2 seconds) @ thermal
  - Beam profile: 4 to 6 cm diameter



Feasibility: test of a neutron imaging station

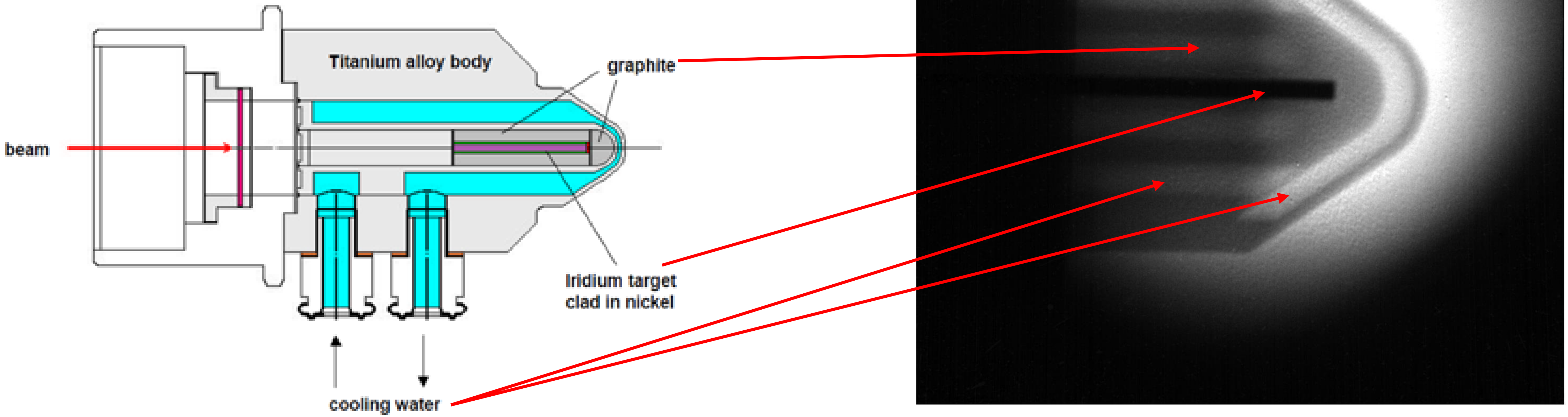
- Letter of Intent submitted to the INTC in 2015 (link)
- Test with a dummy AD target, 1000 frames (about 0h30 of measurement, about 2×10^{15} protons) – **2015, small collimator**





Feasibility: test of a neutron imaging station

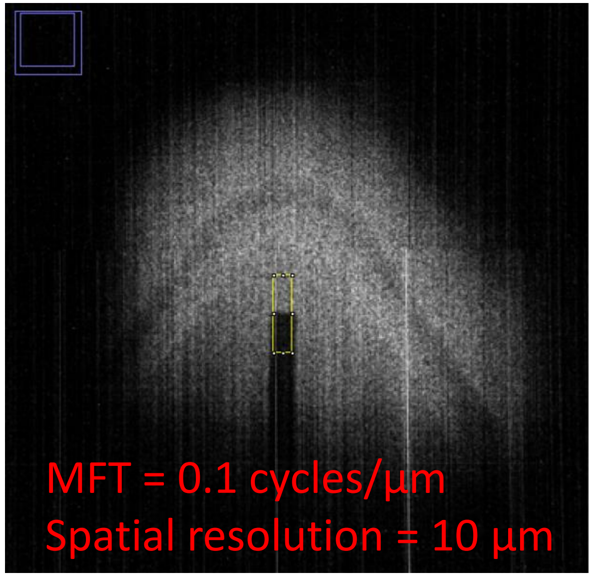
- Letter of Intent submitted to the INTC in 2015 (link)
- Test with a dummy AD target, 5000 frames (about 1h30 of measurement, about 6×10^{15} protons) – **2016, big collimator**

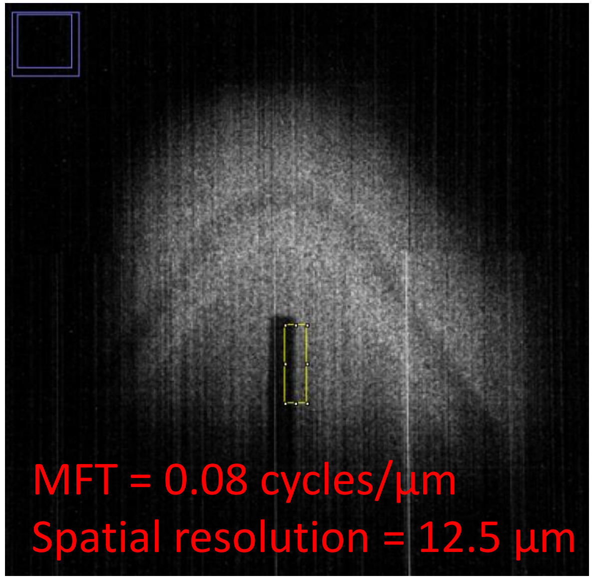


Feasibility: spatial resolution

- Analysis with the software ImageJ of the Modulation Transfer Function (MTF)
  - MTF is the spatial frequency response of an imaging system
  - For cameras it is measured in cycles per pixel (or per spatial unit if calibrated)
  - High spatial frequencies correspond to fine image detail. The more extended the response, the finer the detail, the sharper the image

SMALL COLLIMATOR





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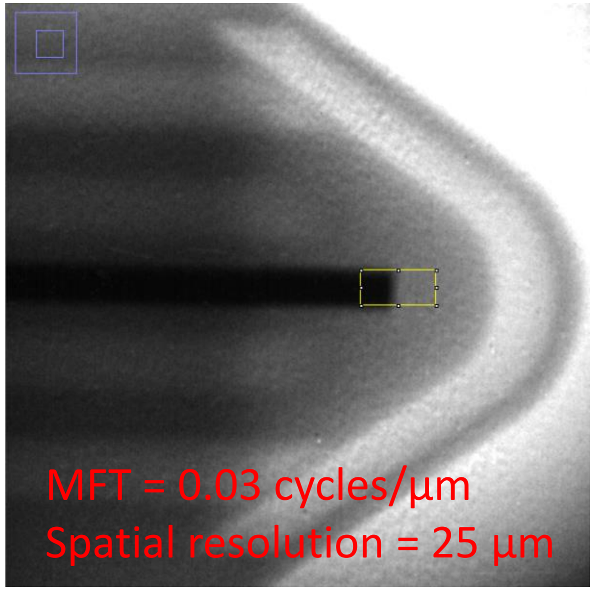
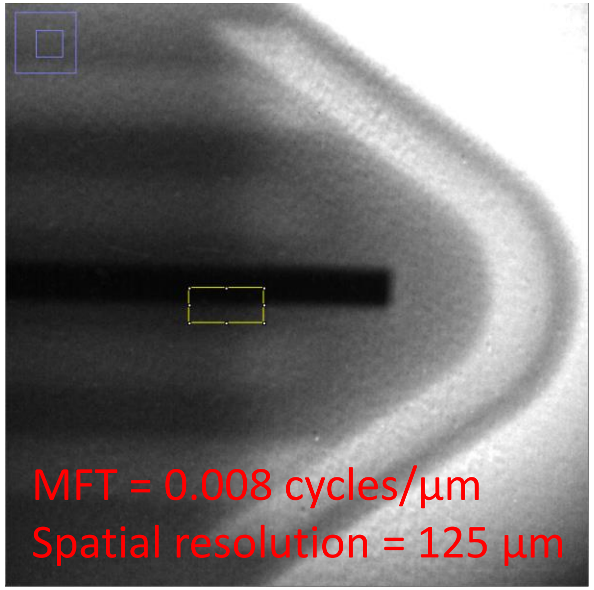
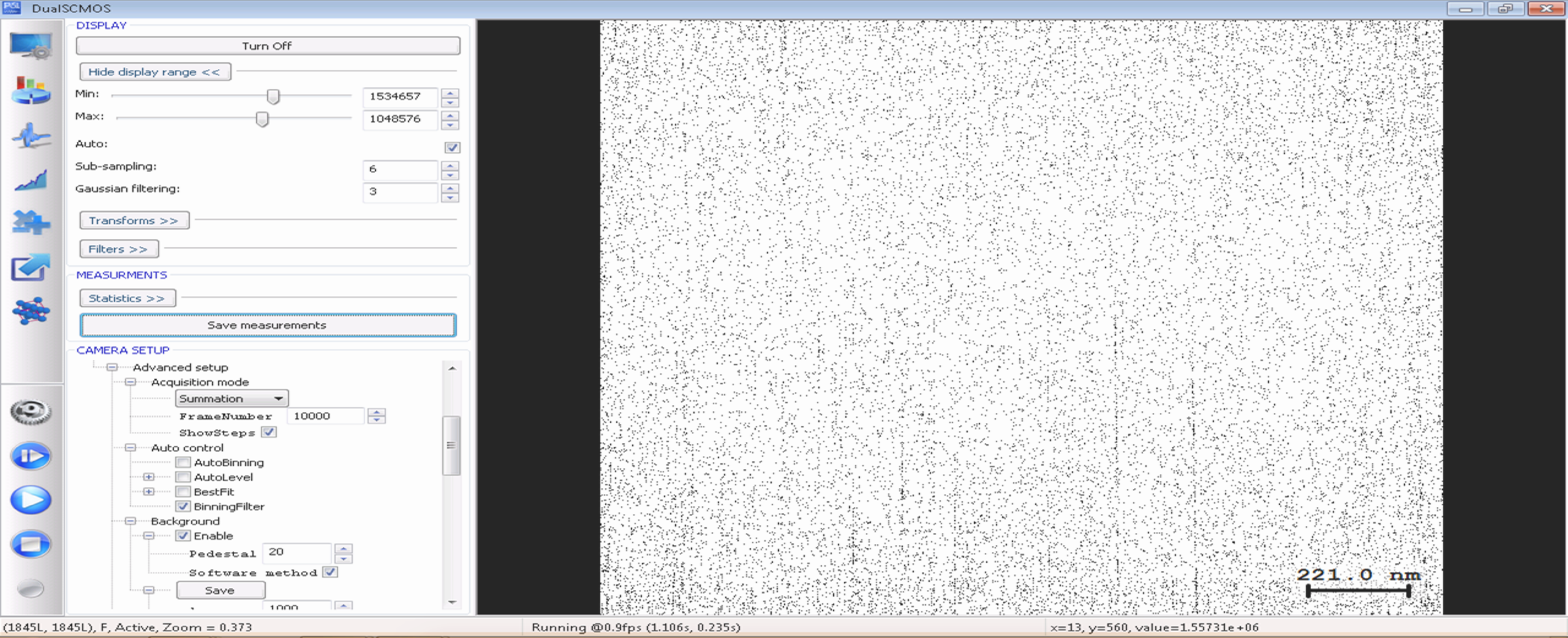
BIG COLLIMATOR





Summary and conclusions

- There is technological interest to exploit the neutron imaging non-destructive inspection to check for possible damages the internal structure of the antiproton AD source and different irradiated materials
- The feasibility of a neutron imaging station at n_TOF EAR2 has been successfully proved with 2 tests:
  - Small collimator (October 2015) – resolution of tens of µm
  - Big collimator (July 2016) – resolution of hundreds of µm
- 4-5 scans needed for the AD target, 3-4 scans needed for the HRMT27 rods. Each scan around 2×10^{16} protons + background images.
- Request of **1×10^{18} protons** with BIG collimator. To be keep in mind that off-beam operations would be needed (in total 1.5 weeks of measurement foreseen)



THANK YOU FOR YOUR ATTENTION

federica.mingrone@cern.ch

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