Time-of-Flight resolved neutron imaging from thermal to fast neutron energies at n_TOF EAR2

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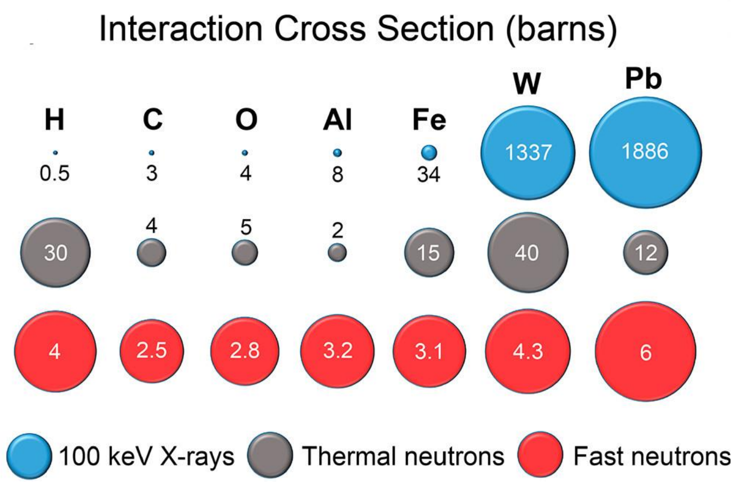
INTC-P-630

Neutron Imaging (NI) – a versatile tool

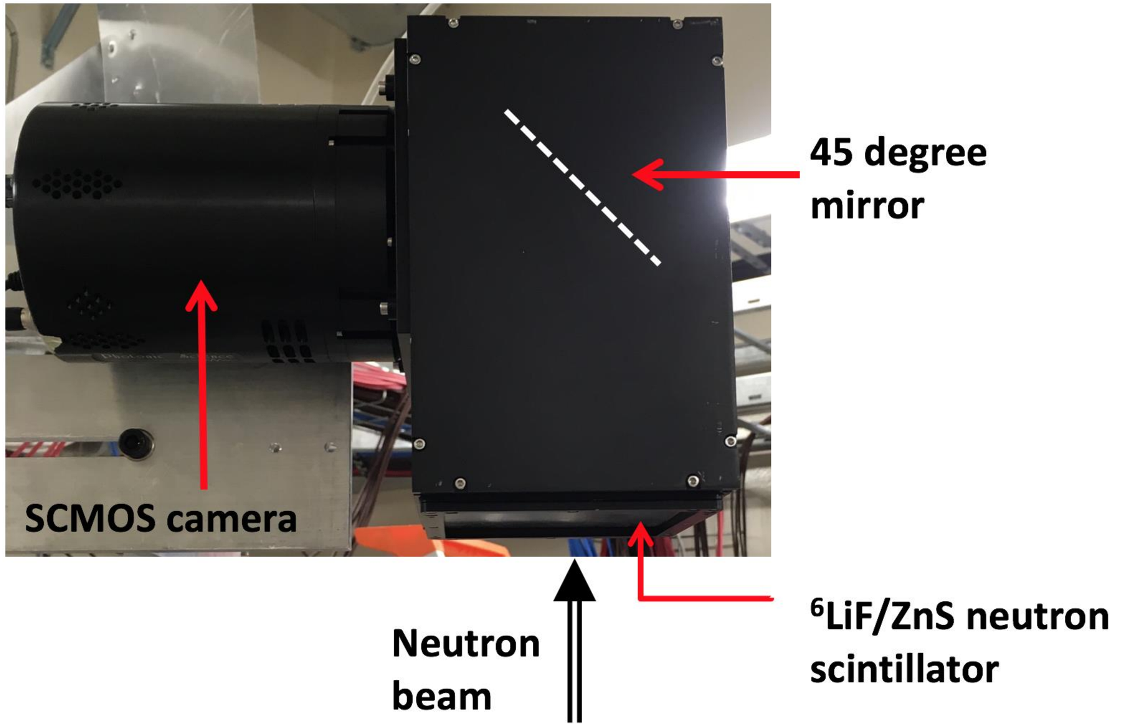
- **Non-destructive inspection method complementary to X-rays**
- **Plethora of applications (few examples):**
  - Energy research – fuel cells, batteries, catalysis, nuclear energy materials
  - Engineering materials – strains, stresses, textures and microstructures deep in metal components
  - Soft matter and biology – externally triggered transitions in soft matter, water uptake in plants
  - Magnetism and condensed matter – high density data storage materials, superconductivity
  - Archaeology, Palaeontology and Cultural heritage
  - Bulk material inspection (industrial application, slow dynamic processes)
- **Most NI facilities provide a cold-thermal neutron spectrum – epithermal and fast neutron imaging is still gaining momentum**
  - Smaller facilities can fill niches and help to develop the techniques and methods

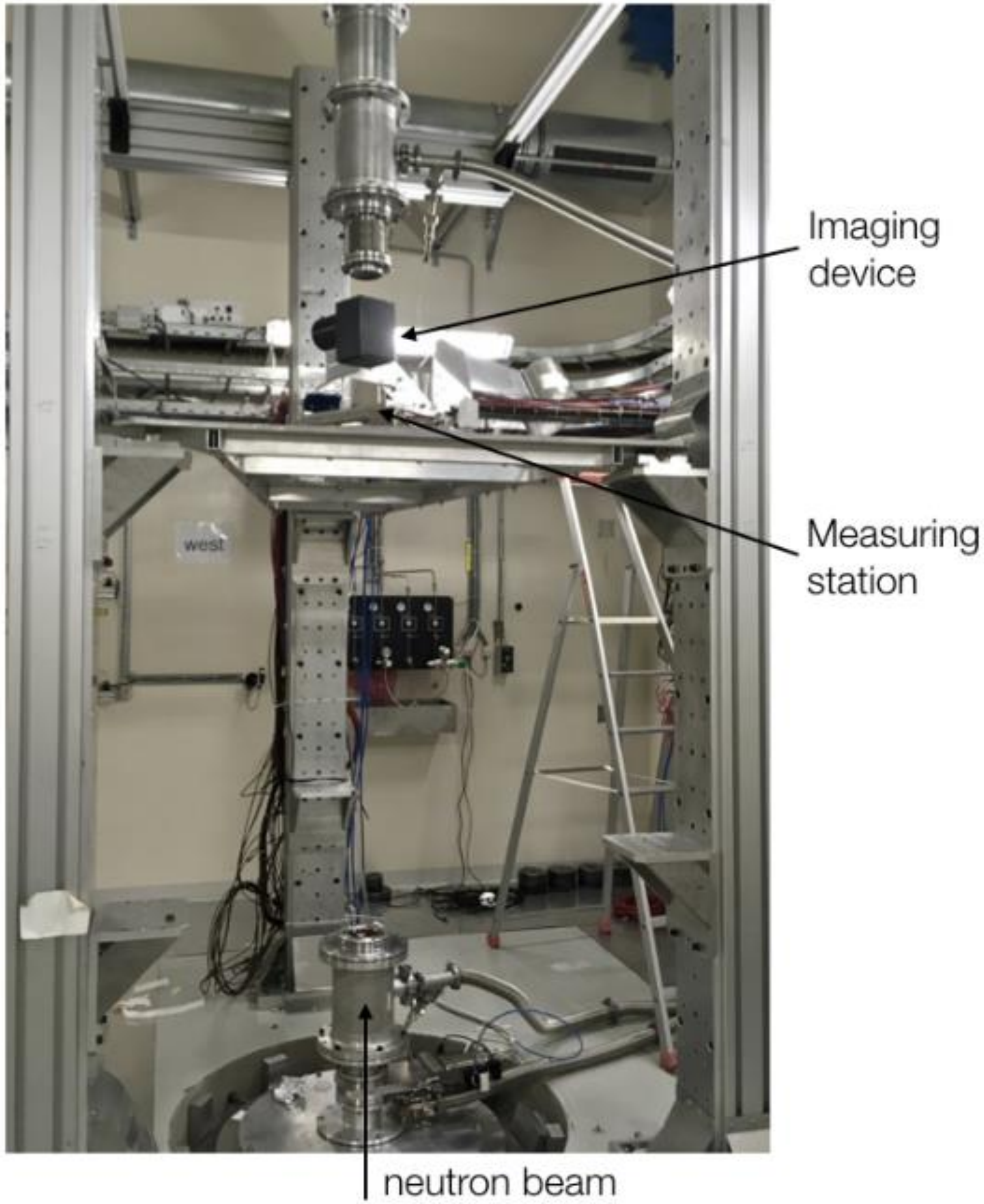


NI @ n_TOF (2015-2017)

Detection system from Photonic Science:

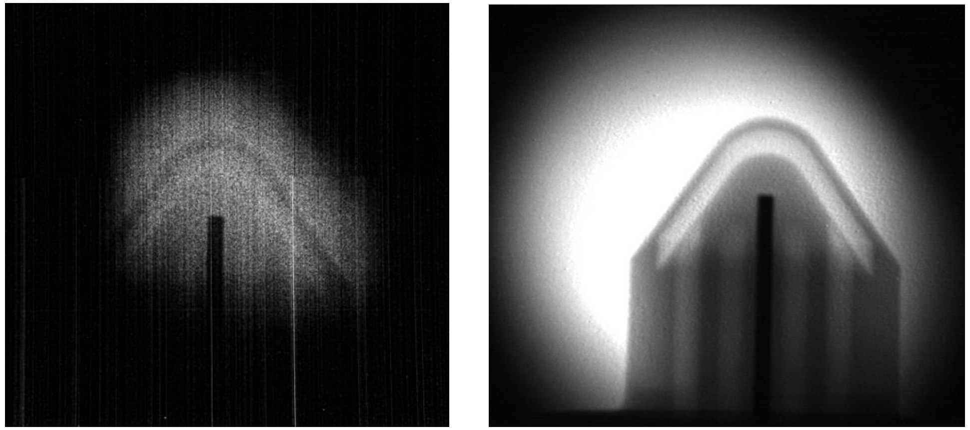
- ZnS/^{6}LiF based neutron scintillator (100×100 mm^2, 100 μm)
- Air-cooled SCMOS camera: 2k×2k @ ½ inch × ½ inch
- Auto mode or beam triggered



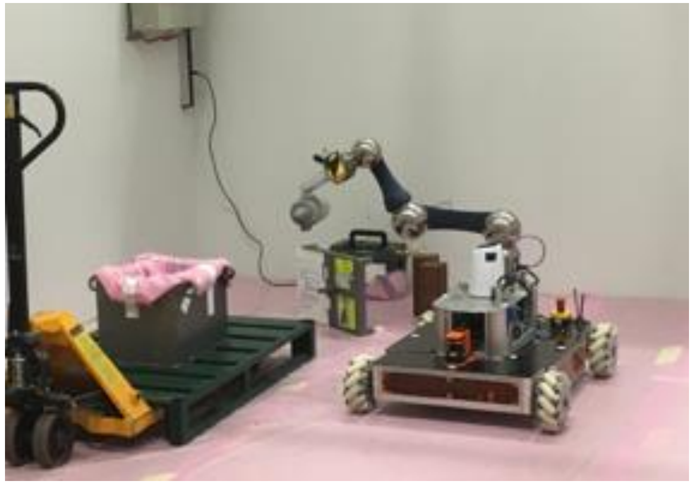


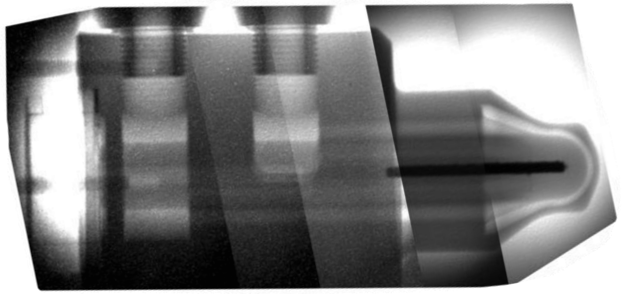
Imaging @ n_TOF (2015-2017) – results

- **Feasibility study:**
  - 2015 – small collimator
  - 2016 – big collimator

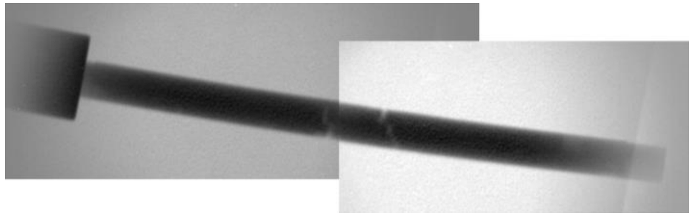


- **Measurement in 2017:**
  - Irradiated AD target (programme under SPSC)
  - Irradiated HRMT-27 rods (programme under SPSC)



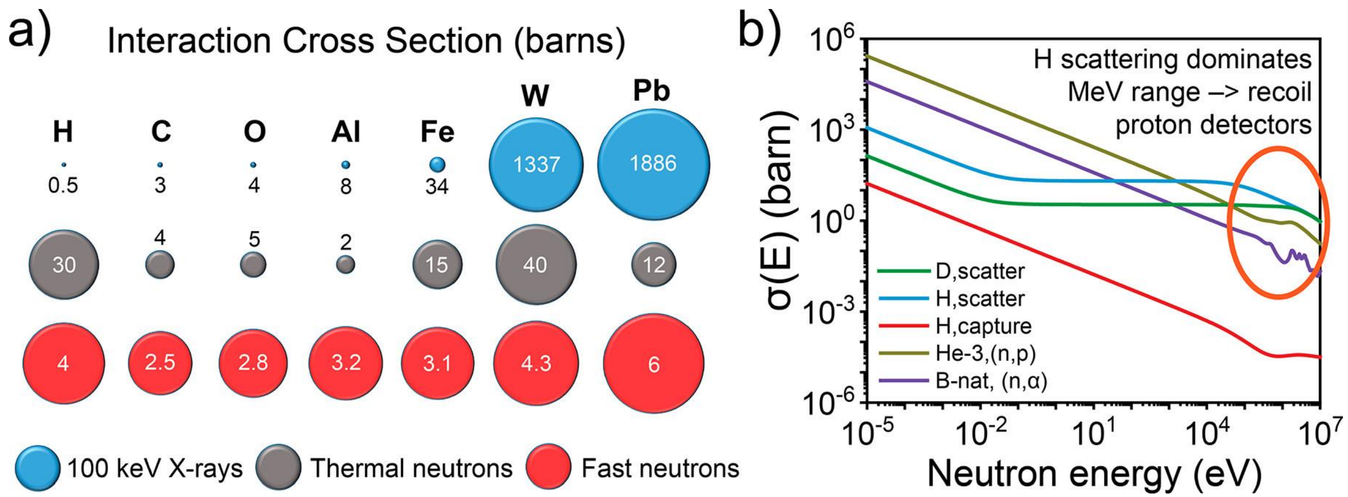


F. Mingrone et al., Instruments 2019, 3(2), 32



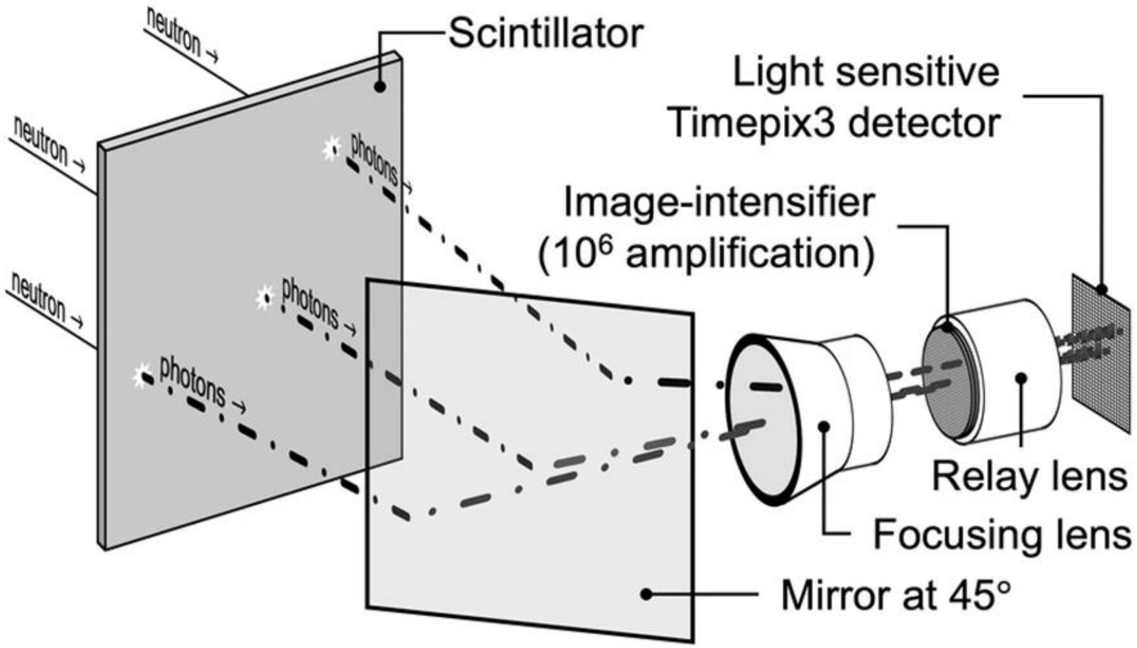
Conclusions in 2018

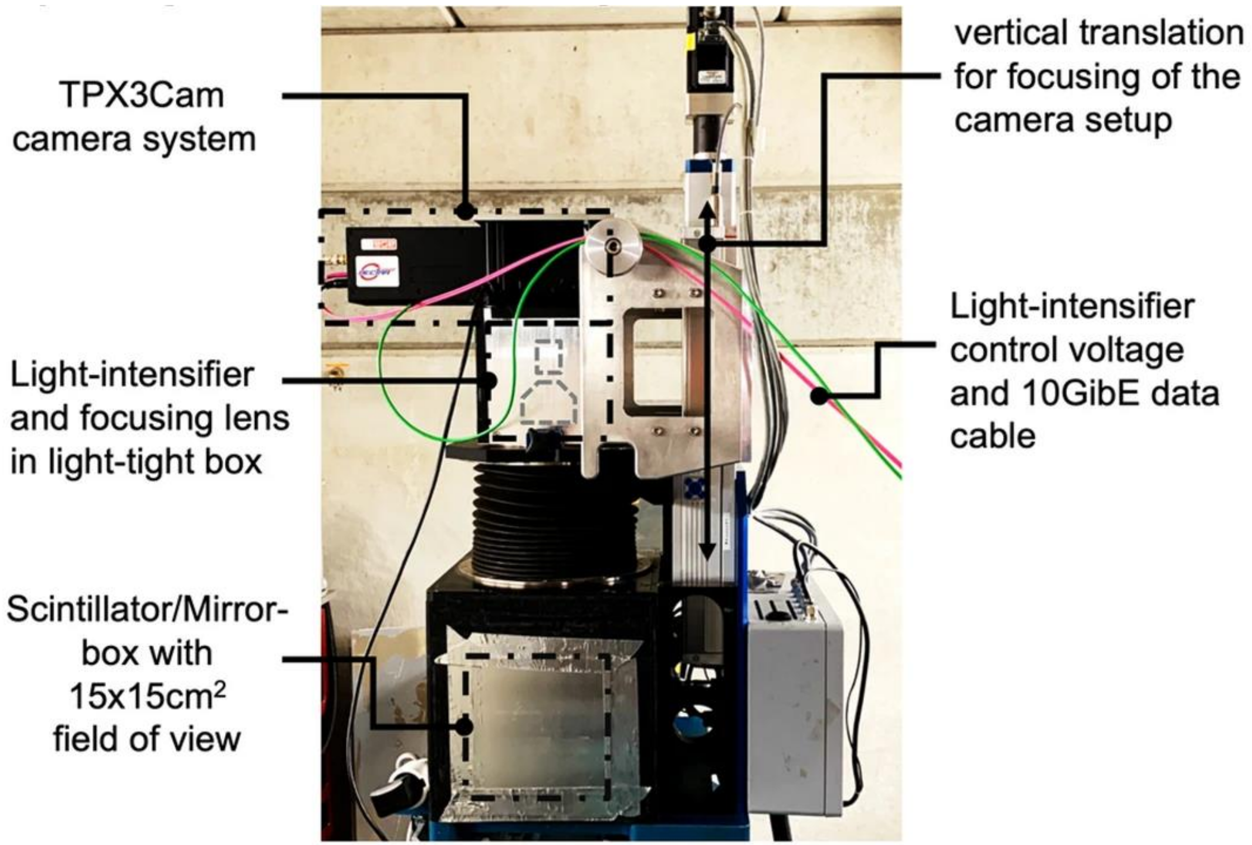
- **Neutron Imaging possible @ EAR2**
- **EAR2 not designed to be competitive with dedicated facilities (PSI, FRMII, ILL, …) (yet)**
  - EAR2 flux ~ 2×10^6 n/cm^2/s (> 10^7 n/cm^2/s @ PSI ICON/NEUTRA cold/thermal)
  - Spatial resolution (not fully characterized) – collimation system optimized for XS measurements
  - Full characterization of EAR2 wrt NI pending
- **… but EAR2 features:**
  - Neutrons from thermal to 100s MeV
  - No pulse overlap – „all in one“
  - Class A lab – radioactive sample handling is straight forward (no external transport for CERN samples)



Kyle M. McCall et al., ACS Nano 2020, 14, 11, 14686–14697

State-of-the-art TOF Neutron Imaging

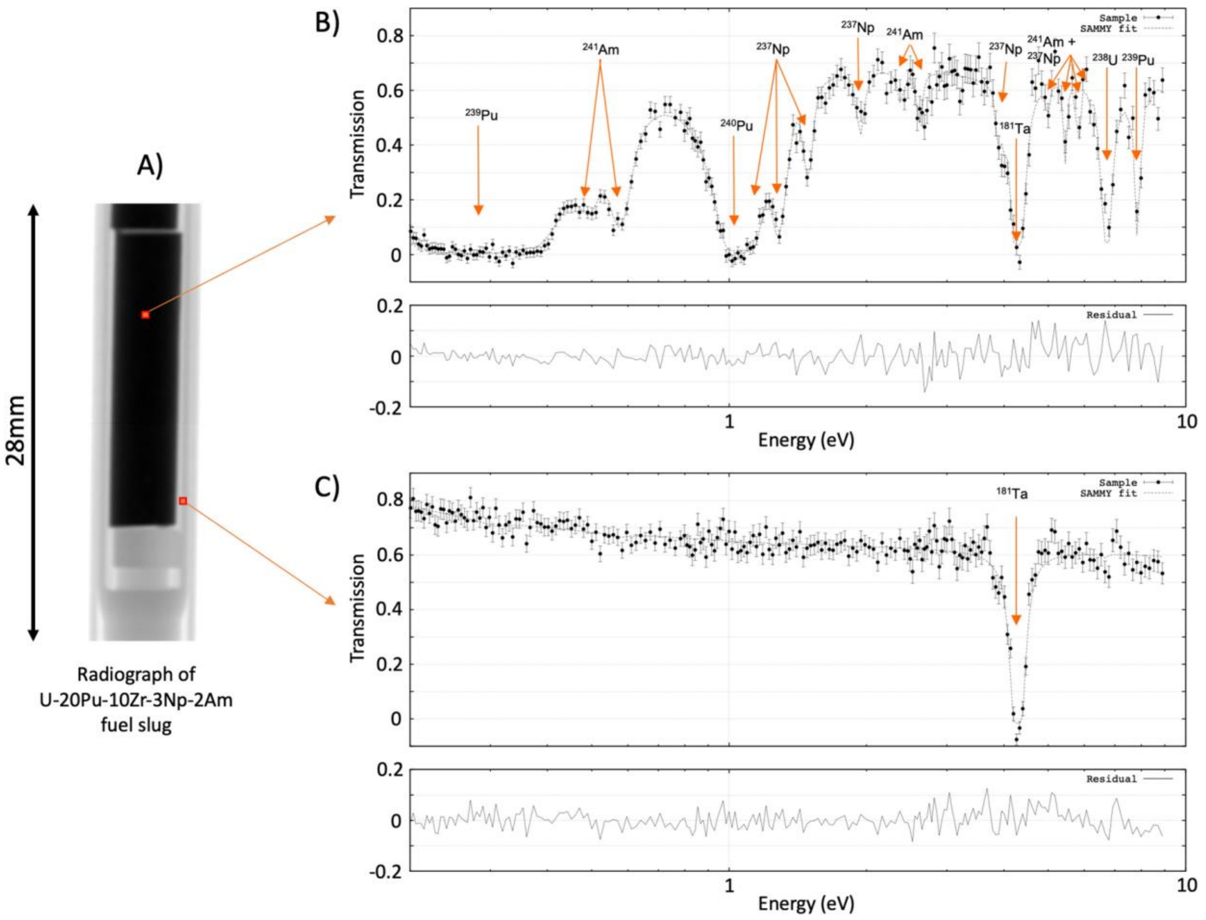


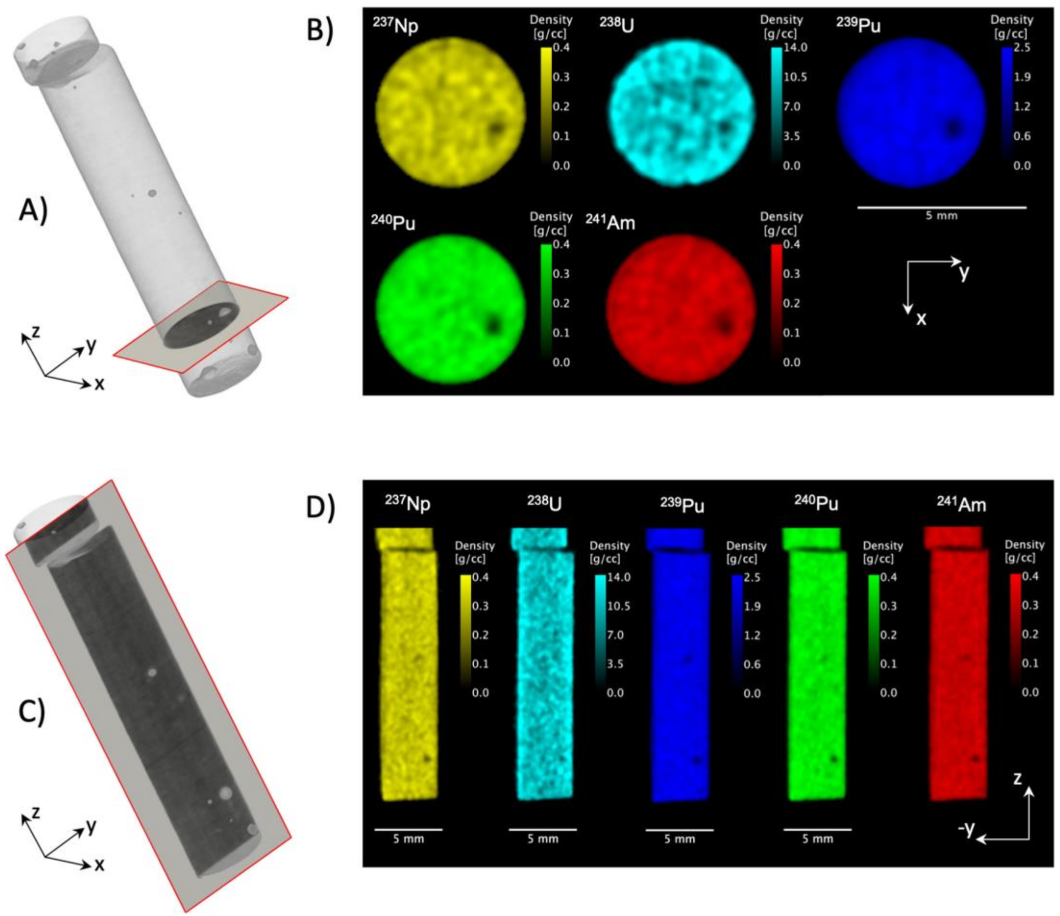


A. S. Losko et al., Sci Rep. 11, 21360 (2021): TOF cold NI setup @ BOA (PSI)

State-of-the-art TOF Neutron Imaging

Spent nuclear fuel slug: 3D isotope density distributions

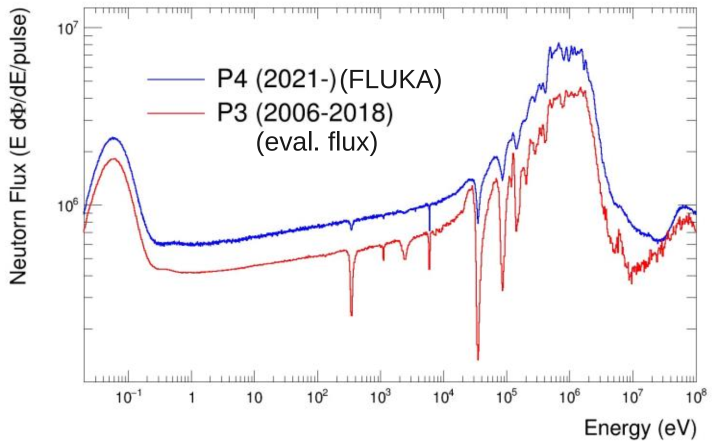




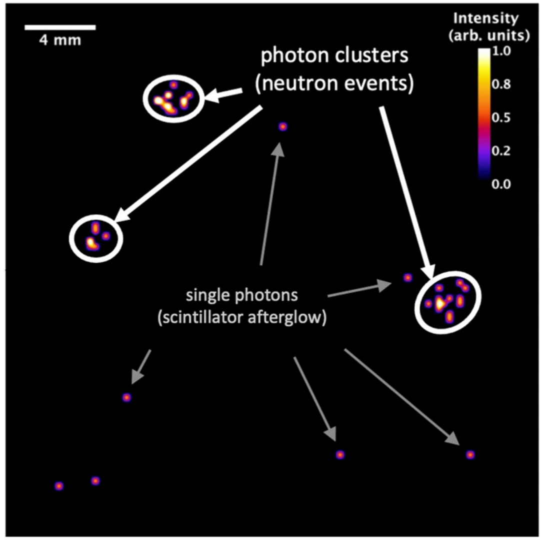
A. S. Losko et al., Sci Rep. 12, 6648 (2022): fast TOF NI @ LANSCE

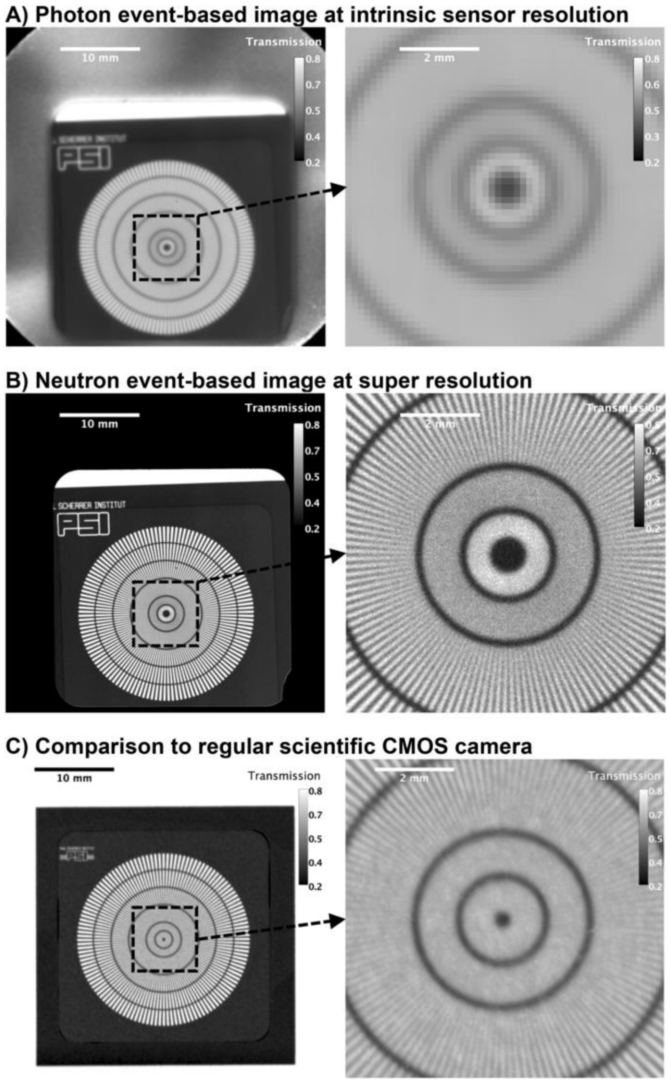
Restarting & extending NI activities: Potential

- **New spallation target → higher neutron flux**



- **Developements in the imaging community:**
  - Almost standardized and commercially available TOF cameras, i.e. TPX3CAM based on TimePix3 technology (1.6 ns time resolution, 500 MHz frame rate) → enables n/γ-discrimination
  - Novel fast neutron scintillators (multilayer, ZnS:Cu or semiconductor nanocrystals/Cu-perovskites)





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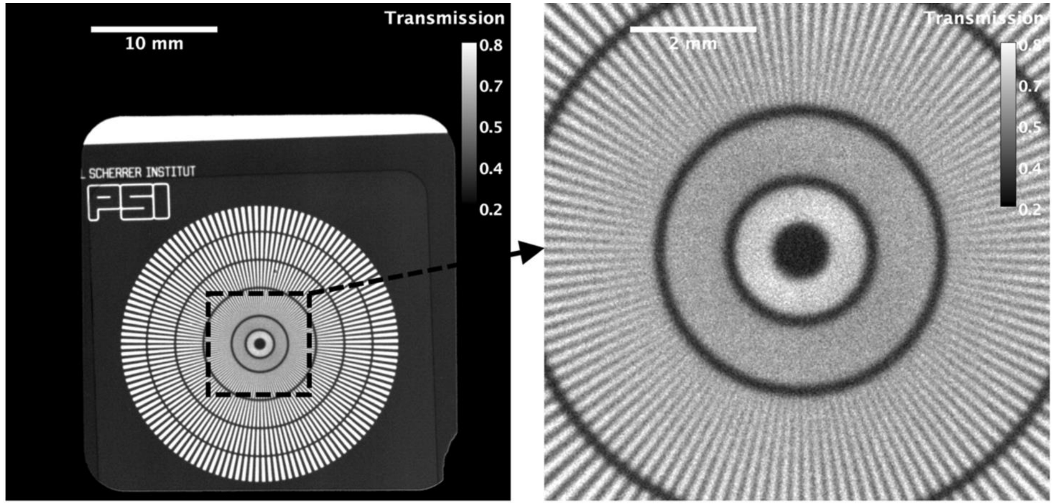
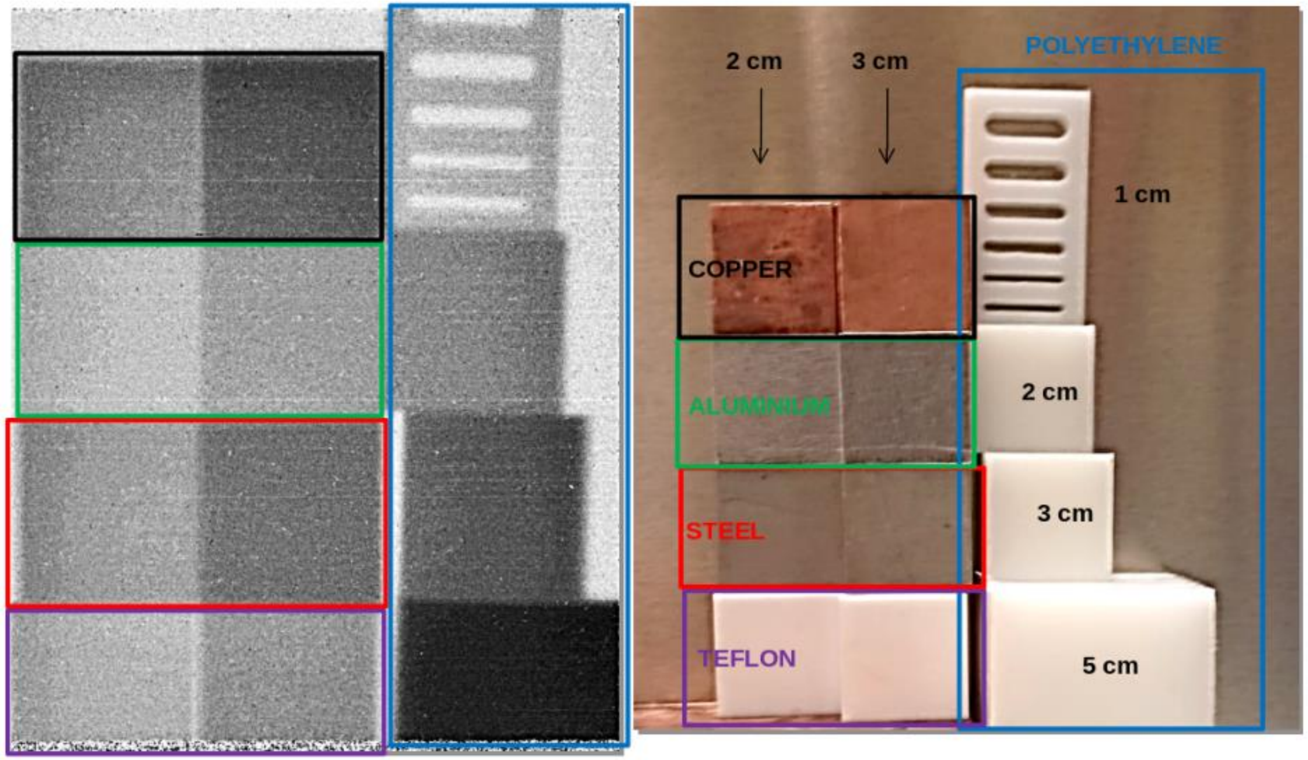
Aims with a TOF setup

- **Finalize the characterization of n_TOF EAR2:**
  - Flux & Profile: full field of view
  - Spatial resolution (Siemens stars, step wedges) over TOF





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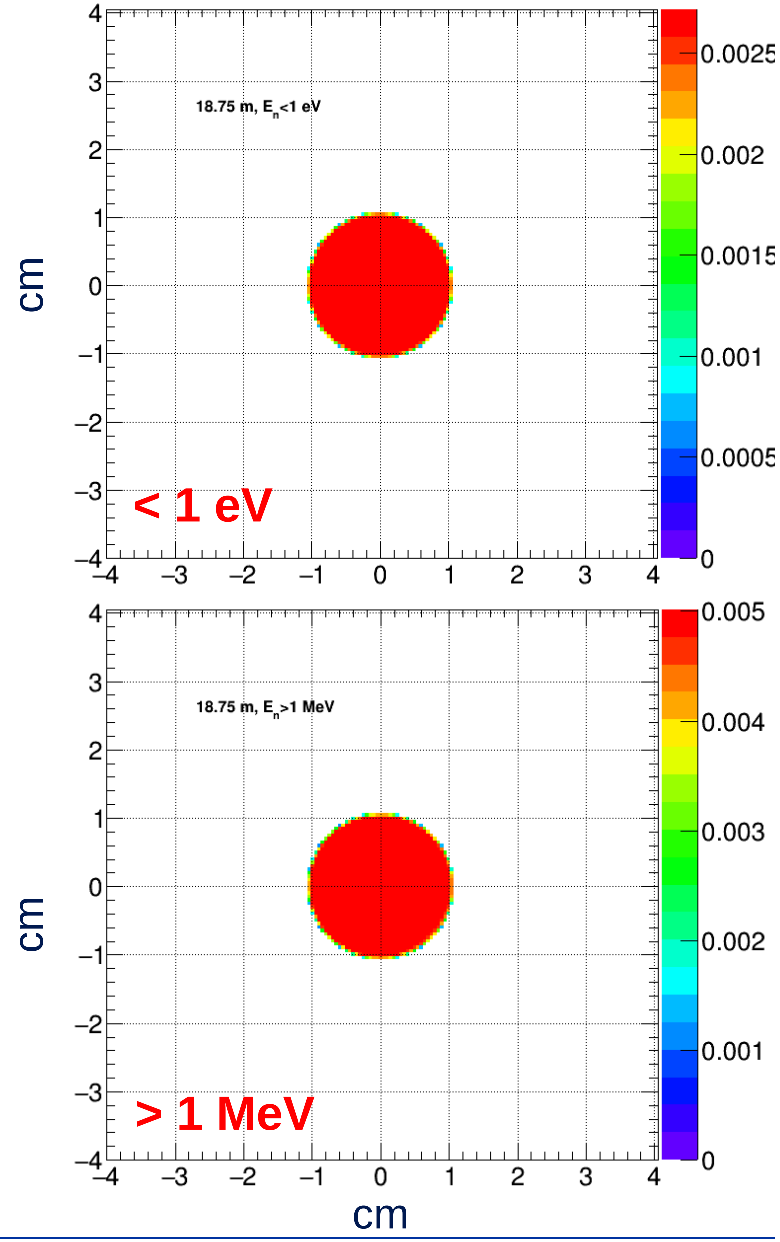

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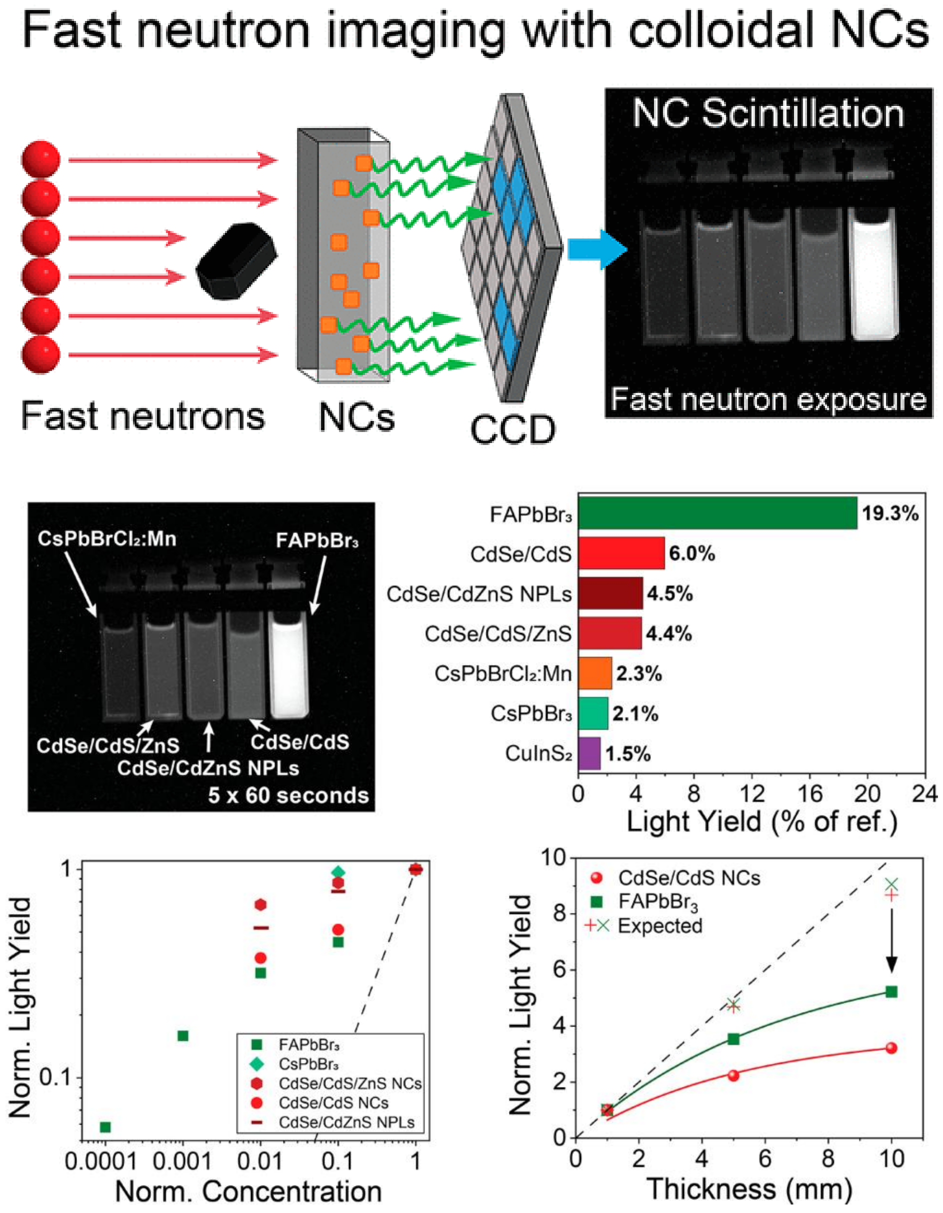
  - Characterization of efficiency, spatial resolution and light yield over the whole E_n range



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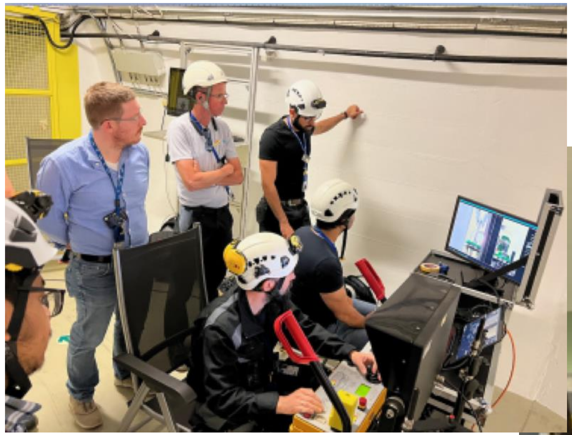
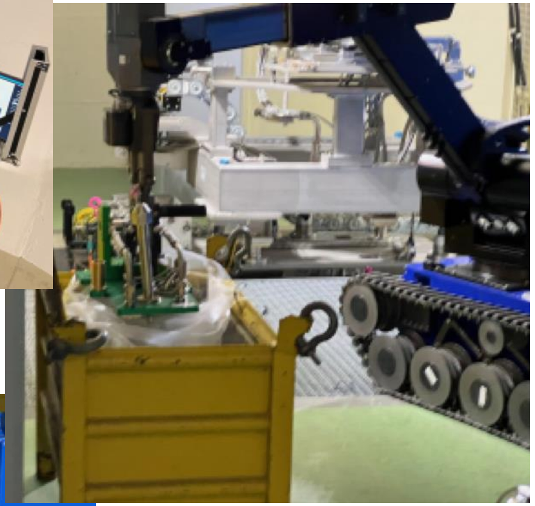
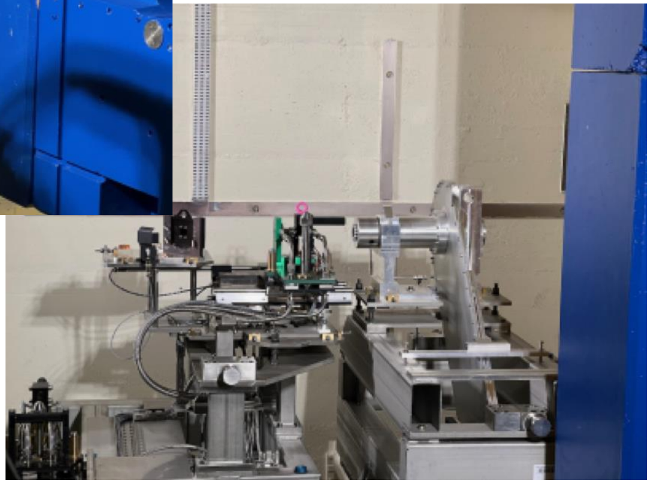
- **Application to CERN equipment:**
  - Irradiated AD target (successful swap 16-17th May) and Pb sample irradiated at HiRadMat







Conclusions & proton request

- **Full Characterization and extension of the EAR2 NI potential with TOF imaging**
- **Aiming to provide:**
  - Information for n_TOF (energy resolved, full beam profile measurements – neutrons and γ-rays)
  - Characterization of fast & slow neutron and γ–ray scintillators over a wide energy range
  - Application to samples relevant to CERN
- **Interested collaborateurs from 3 other NI facilities (PSI, FRM-II, CNA)**

Requested protons: **1.4×10^{18}**
Experimental Area: **EAR2**

Thank you for your attention

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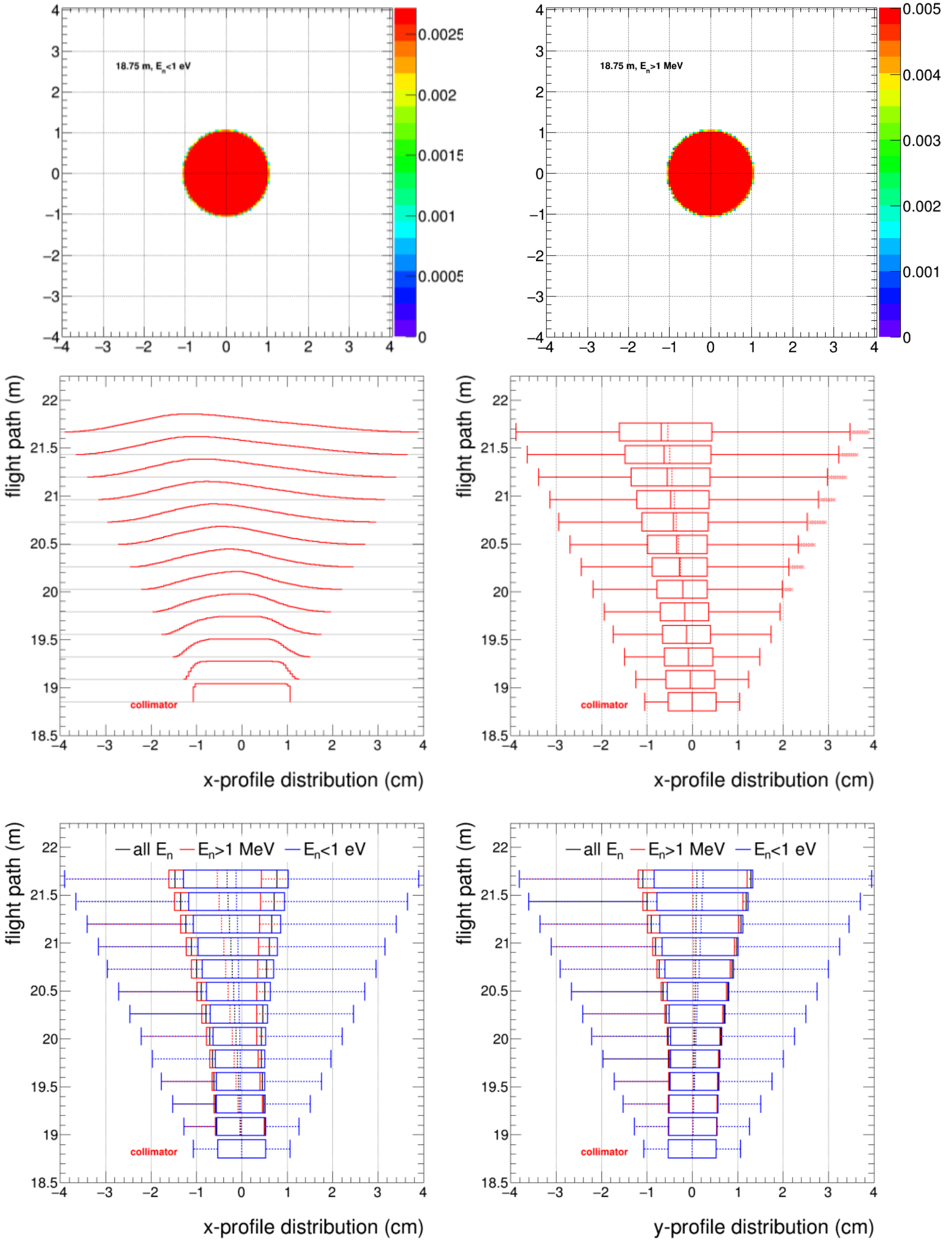

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