Fast neutron micro-imaging by 2025?

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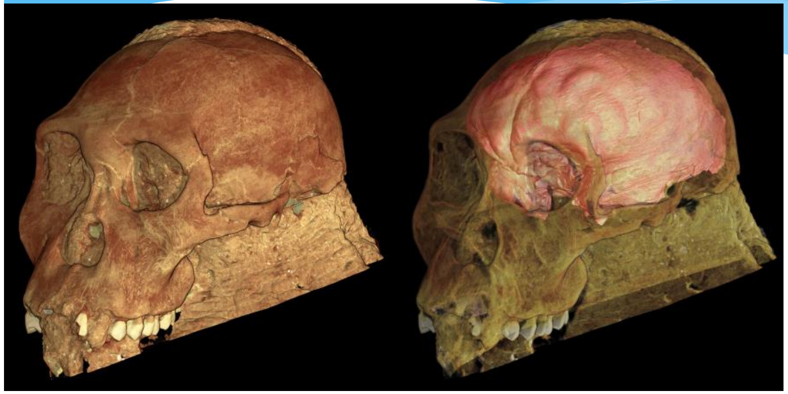
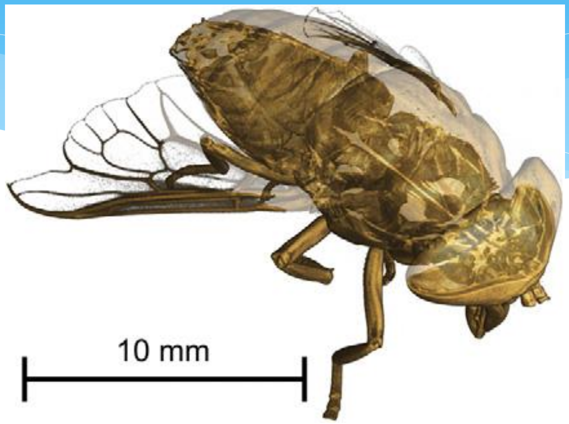
Nowadays μ-imaging techniques

X-ray μ-tomography



X-rays tomography of the skull of *Australopithecus* from an experiment at the **ID19 beamline @ ESRF**[1].

Thermal neutron μ-tomography



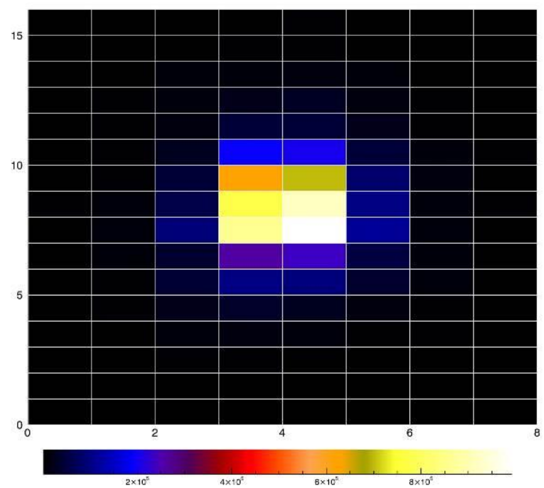
Neutron tomography of a horsefly taken at the **ICON beamline @PSI** [2]

What about micro-imaging with fast neutrons? Is high resolution fast neutron imaging a realistic proposition for a dedicated detector development effort in the next decade?

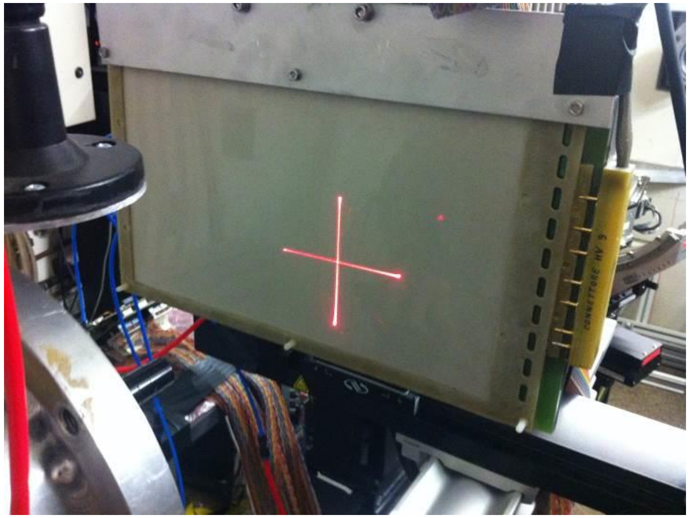
[1] ILL web site; [2] A.P. Kaestner et Al. NIM A 659 (2011) 387–393

Recent advances of fast neutron measurements with gaseuos detectors

* At the heart of any **neutron** detector is a suitable interaction mechanism to convert neutrons into a detectable charged particles.
  * For **Fast neutrons**: proton recoil in a **CH_2 converter**
* **Gaseous neutron detectors**
  * **Radiation harness is higher than silicon sensors (about 10^{13} neutrons)**
  * **Possibility to realize 3D cathodes in order to increase efficiency**
* The charged particle track reconstruction is usually assumed to be the fundamental limit for the achievable spatial resolution in such detectors.



Neutron beam profile reconstruction using pads with an area of 22 (x) mm x 13 (y) mm.

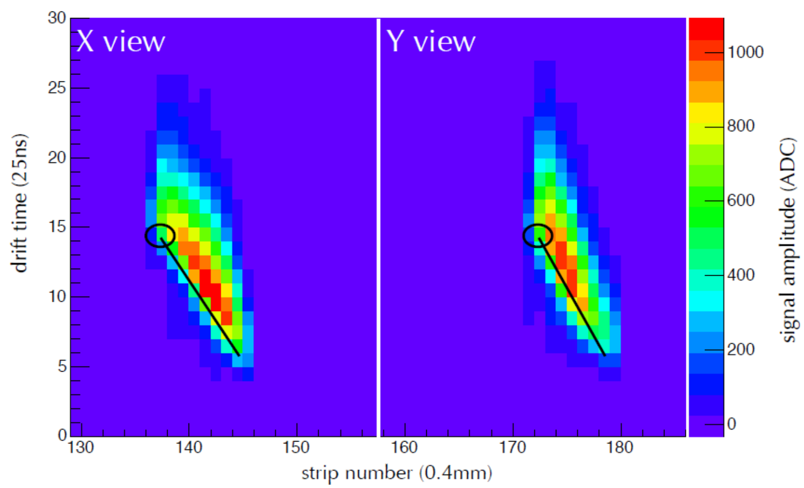


nGEM detector for the SPIDER experiment [3]. The CH_2 converter (white) is visible.

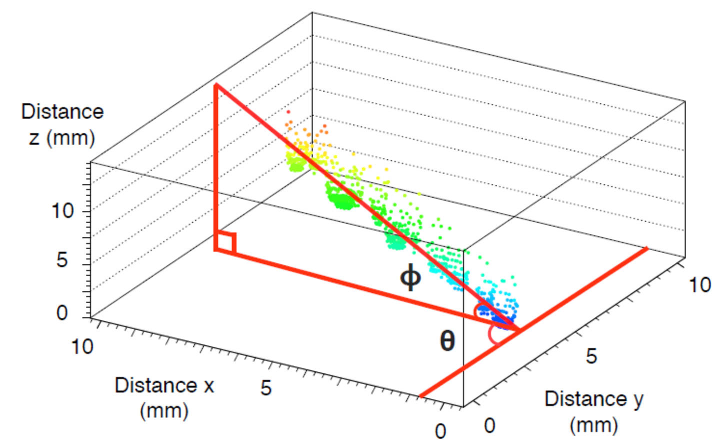
[3] A. Muraro et Al. NIM A 813 (2016) 147–152

Neutrons μ-imaging with a TPC-GEM based detector

- **TPC (Time projection chamber)** coupled to GEM readout are being developed for different applications including both HEP (e.g. Alice Experiment) and non-HEP (e.g. neutron physics or medical application)
- MicroPattern Gas Detectors (MPGD) nowadays detect neutrons at high rates (> MHz/cm^2), with a sub-mm space resolution and with a gamma background rejection <10^{-6}.



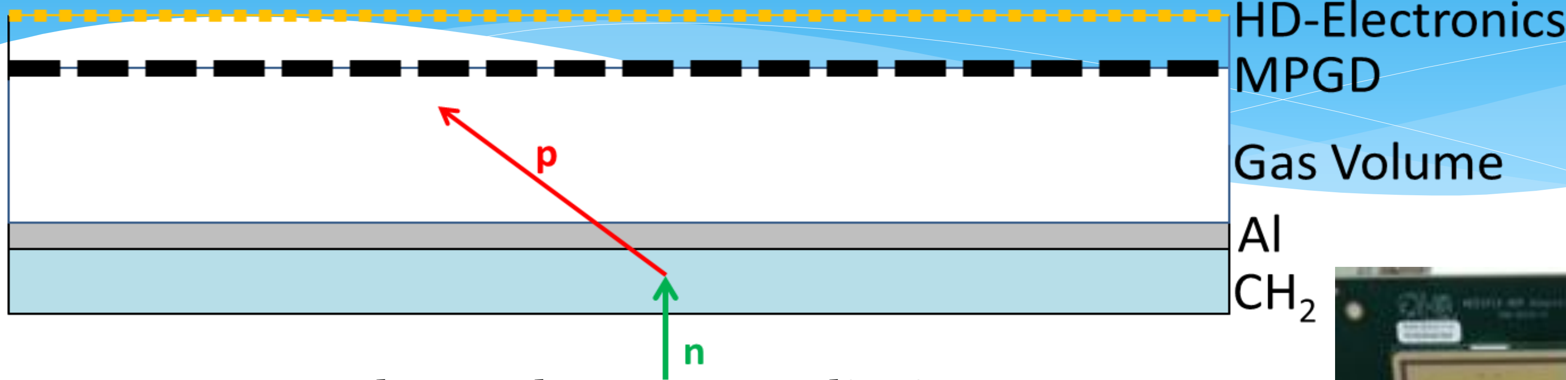
Alpha particle track reconstruction after neutron interaction in a **μ-TPC boron GEM detector**
Space resolution about 150 μm [4].
Front-end electronics: APV-25



Charged particle track reconstruction: **GEMPix detector**
Space resolution < 50 μm [5].
Front-end electronics: TimePix2

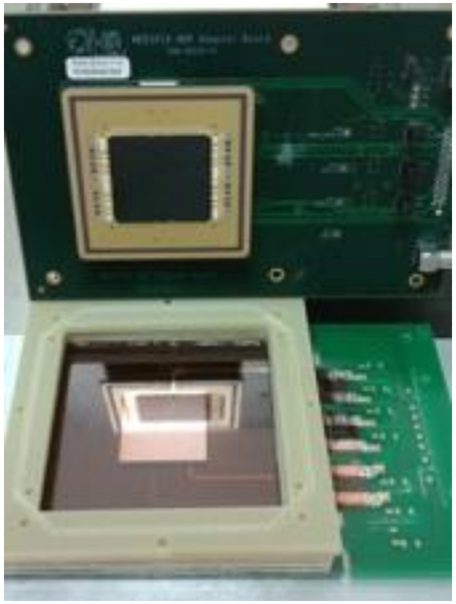
[4] D. Pfeiffer et Al. JINST 10 P04004 (2015)
[5] S.P. George et Al JINST 10 P11003 (2015)

Novel Technique: TPC-MPGD coupled to high definition electronics



Can we beat the present limit for the acheavable space resolution? Yes!

- Push Fast neutron detection intro the micrometer scale
- Detailed measurement of the proton track: spatial/time resolution improved substantially over state of art
- Micrometric measurement of fast neutron interaction point
- Ready to implement future read-out resolution advances (TimePix3 - wider active area - and beyond)



GEMPix detector: TripleGEM coupled to TimePix2 chip

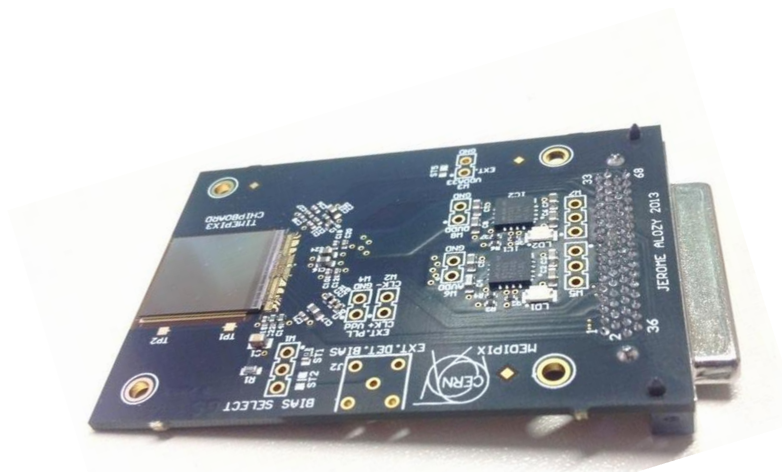
High Definition Electronics

Today: TimePix3

* Pixel matrix of 256 x 256 pixels (55 µm x 55 µm)
* Pixels are configurable:
  1) Time (TOA) AND Charge (TOT)
  2) Time (TOA)
  3) Event counting (PC) AND integral charge (iTOT)
* No external trigger needed
* Minimum threshold ~500e-
* > 35 Million transistors
* CMOS 0.13 µm
* Radiation hardness about 200 Mrad

Future

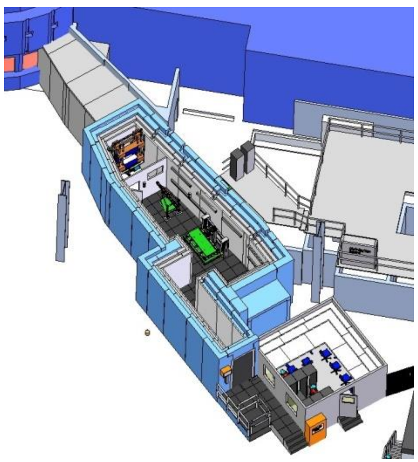
* Wider area
* Improved radiation hardess
* Lower power consuption
* ....



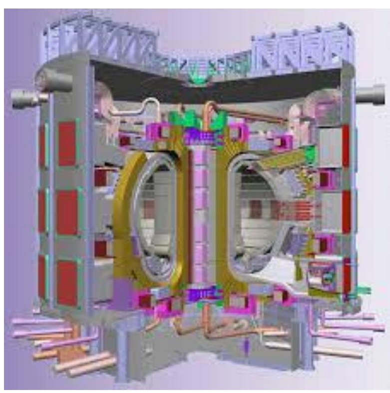
Today’s TimePix3 chip board

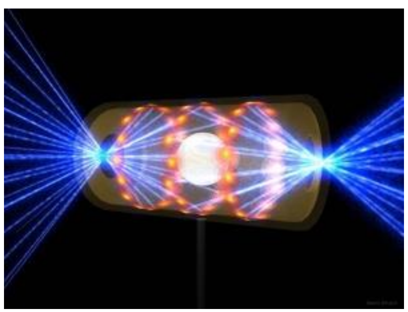
Possible foreseen applications

High rate and high resolution fast neutron μ-imaging detectors will find application at dedicated imaging beam-lines, at medical facilities and in fusion energy experiments



CHIPIR fast neutron irradiation beamline





Plasma-imaging in magnetic/inertial fusion energy experiments

Secondary neutron imaging in medical beam treatments

Conclusions

- Fast neutron detection with MPGD is performed using a suitable conversion mechanism
  - E.g. **Proton recoil in a CH_2 converter**
- The present limitation for **Fast neutron imaging** with **gaseous detectors** can be beated by precise measurement of the charged particle track resulting from neutron interaction
- **Time Projection Chamber (TPC)** fast neutron MPGD based detectors coupled to HD-electronics
  - Measurement of the full proton track
  - **Micrometric reconstruction** of the neutron interaction point
  - Ready to implement future read-out resolution advances (TimePix3 - wider active area - and beyond)
  - **High rate capability**
- Potential Impacts
  - Fast neutron imaging
  - Accurate monitoring of fast neutron beam-lines (e.g ChipIR – ISIS)
  - Plasma-imaging in magnetic/inertial fusion energy experiments
  - Secondary neutron imaging in medical beam treatments