HELNEM: Helium-3-free thermal neutron monitors

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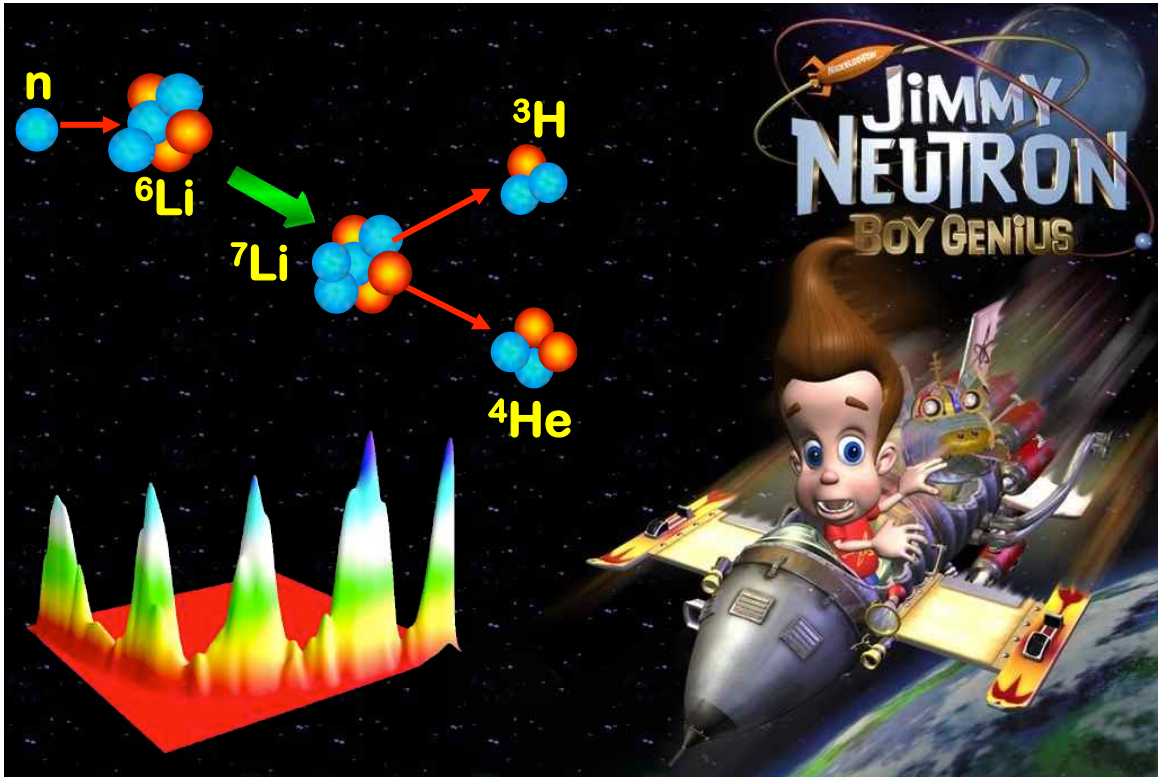
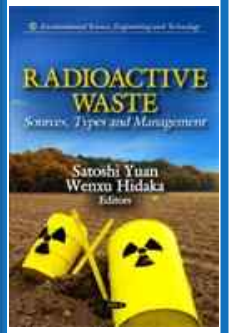


where did we start from?

radioactive waste in almost every country in the world

We implemented a low-cost solution for granular online radwaste monitoring (gamma rays)

in collaboration with Ansaldo Nucleare
Detector Mesh for Nuclear Repositories

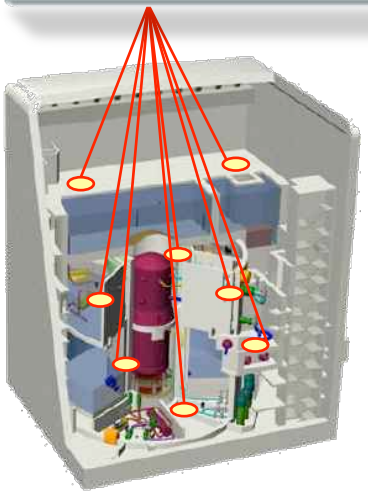


in collaboration with SOGIN
a prototype being installed in a storage site

Collaboration with JRC & Euratom: neutron detection

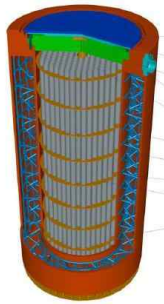
(INFN patent pending RM2013A000254)

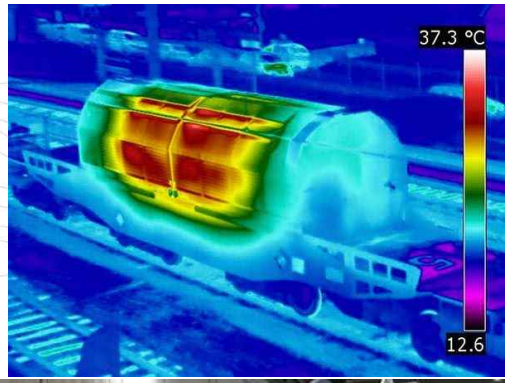
out-of-core monitoring in NPP

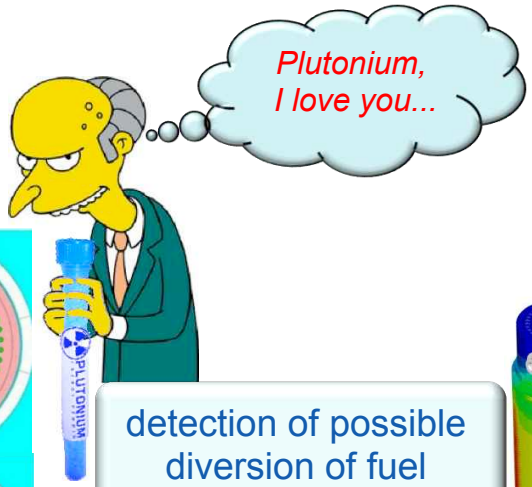


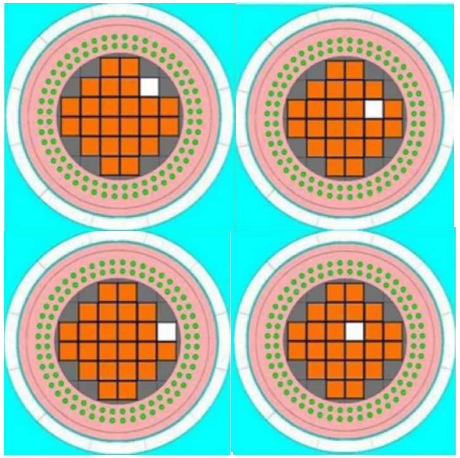
why neutrons?

spent fuel monitoring in place and/or during transportation

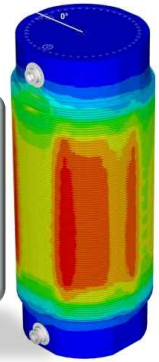






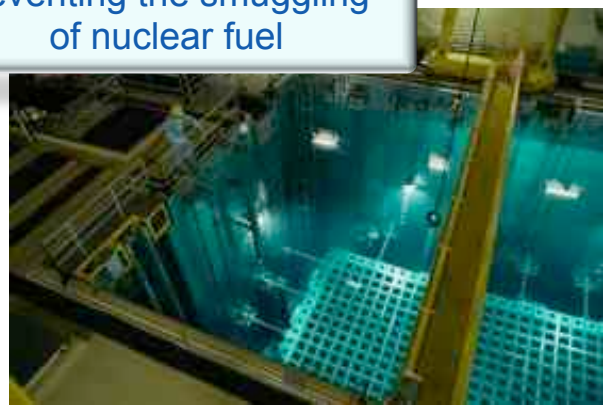


detection of possible diversion of fuel elements from Castor containers

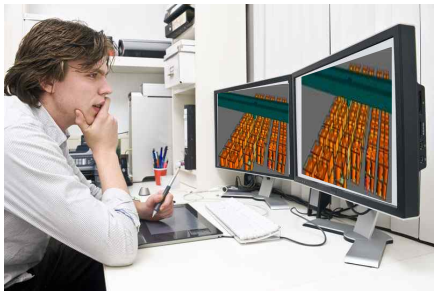


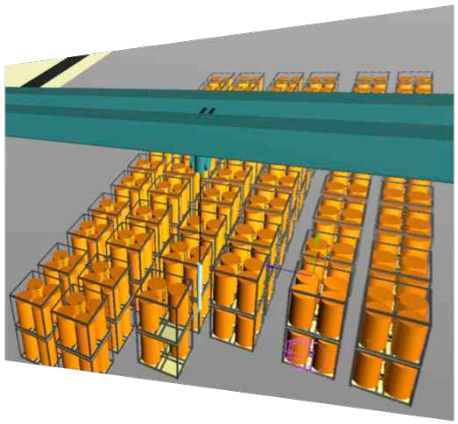
(P.Peerani, M.Galletta, Nuclear Engineering and Design 237 (2007) 94-99)

preventing the smuggling of nuclear fuel

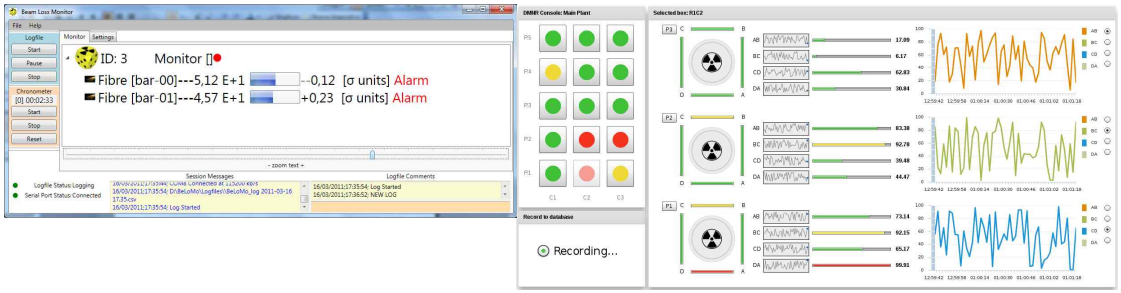


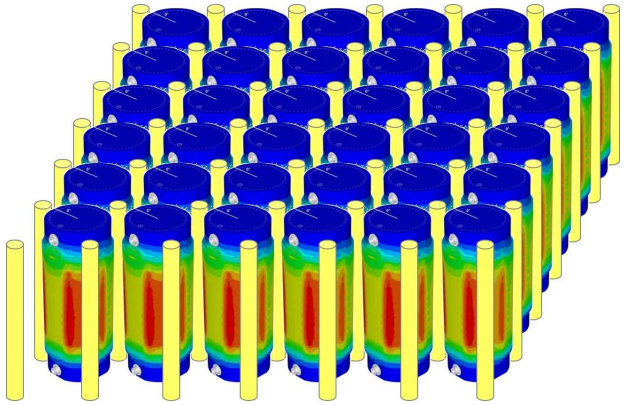
ensuring continuity of knowledge





current monitoring method: video camera

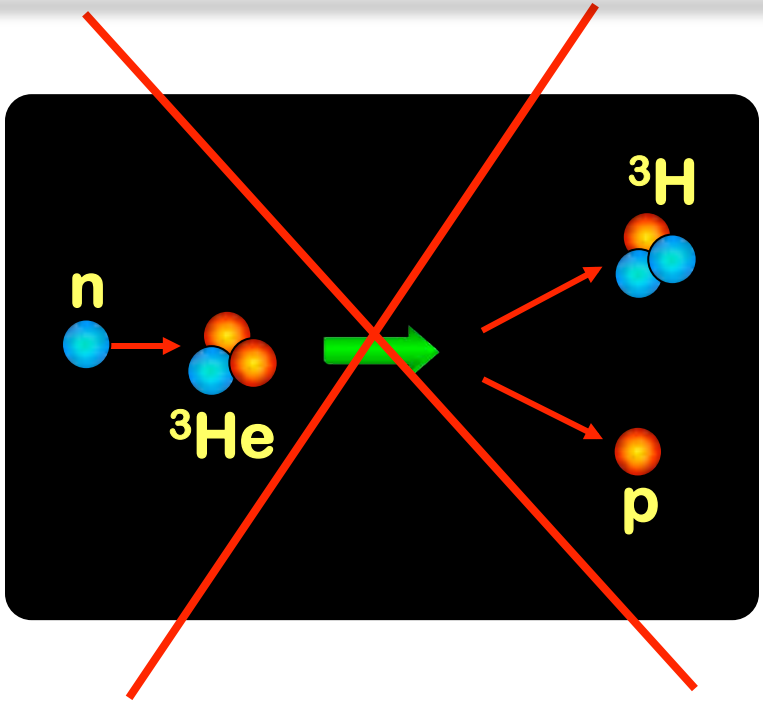




our idea: granular, real time, automatic

How?

materials for thermal neutron conversion: ^{3}He



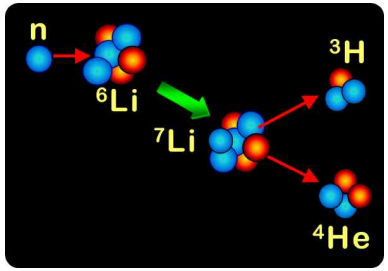
$\sigma(0.025) \approx 5330$ b

available energy
0.76 MeV
no gamma rays

perfect gas detector but... worldwide lack of ^{3}He

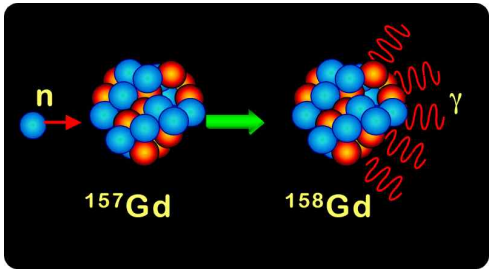
materials for thermal neutron conversion: which one?

^{6}Li



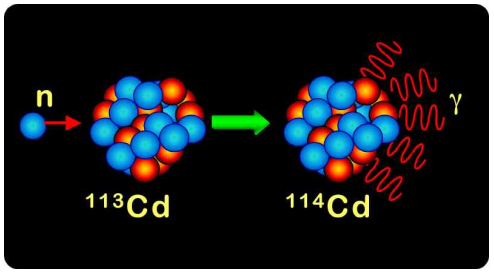
$\sigma(0.025)$
≈ 940 b
available E
4.78 MeV

^{157}Gd



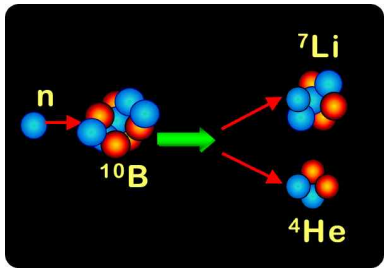
$\sigma(0.025)$
≈ 240 kb

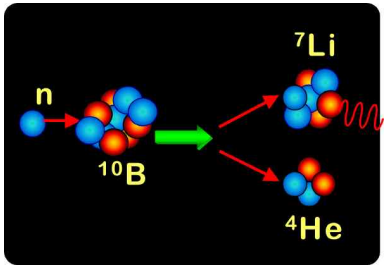
^{113}Cd



$\sigma(0.025)$
≈ 20 kb

^{10}B





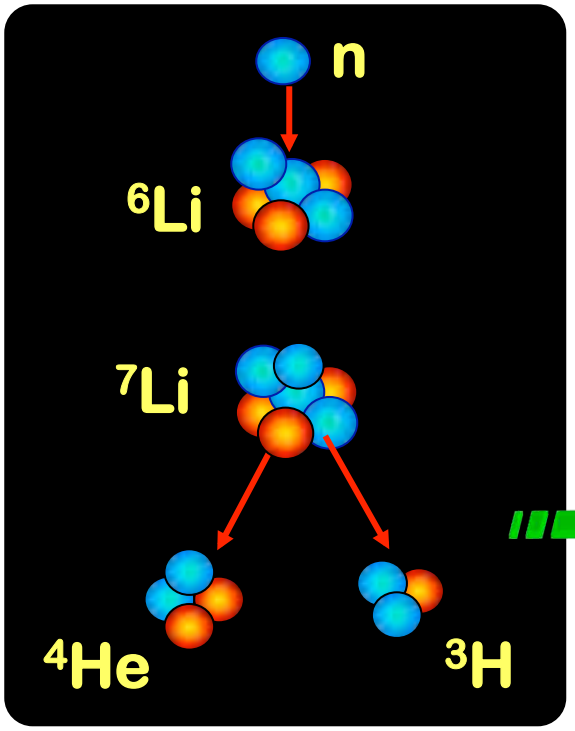
$\sigma(0.025)$
≈ 3840 b
available E
2.79 MeV
(and gamma rays)

large available E
but in form of gamma rays:
difficult neutron identification

physical process

^{6}Li – natural abundance: 7%

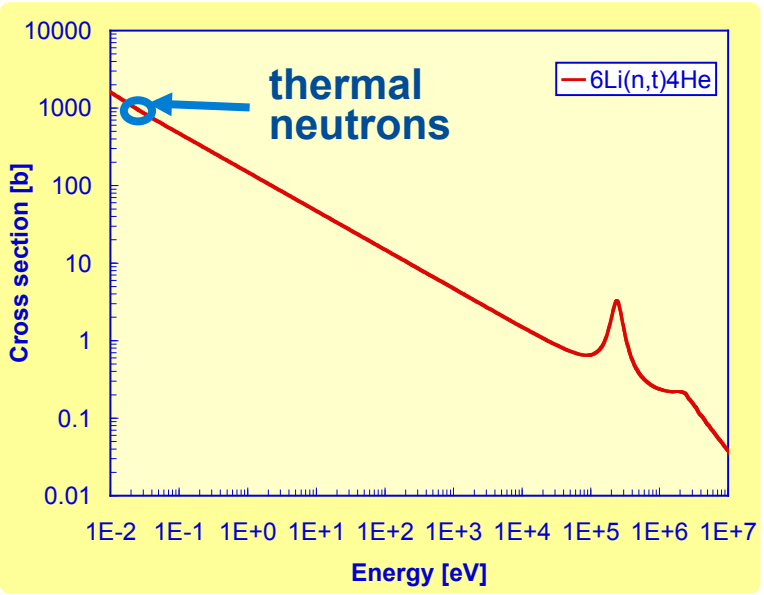
a ^{6}LiF converter captures a neutron...



2.05 MeV **2.73 MeV**

...and produces ^{4}He ed ^{3}H which can be detected

Cross section ≈ 940 b

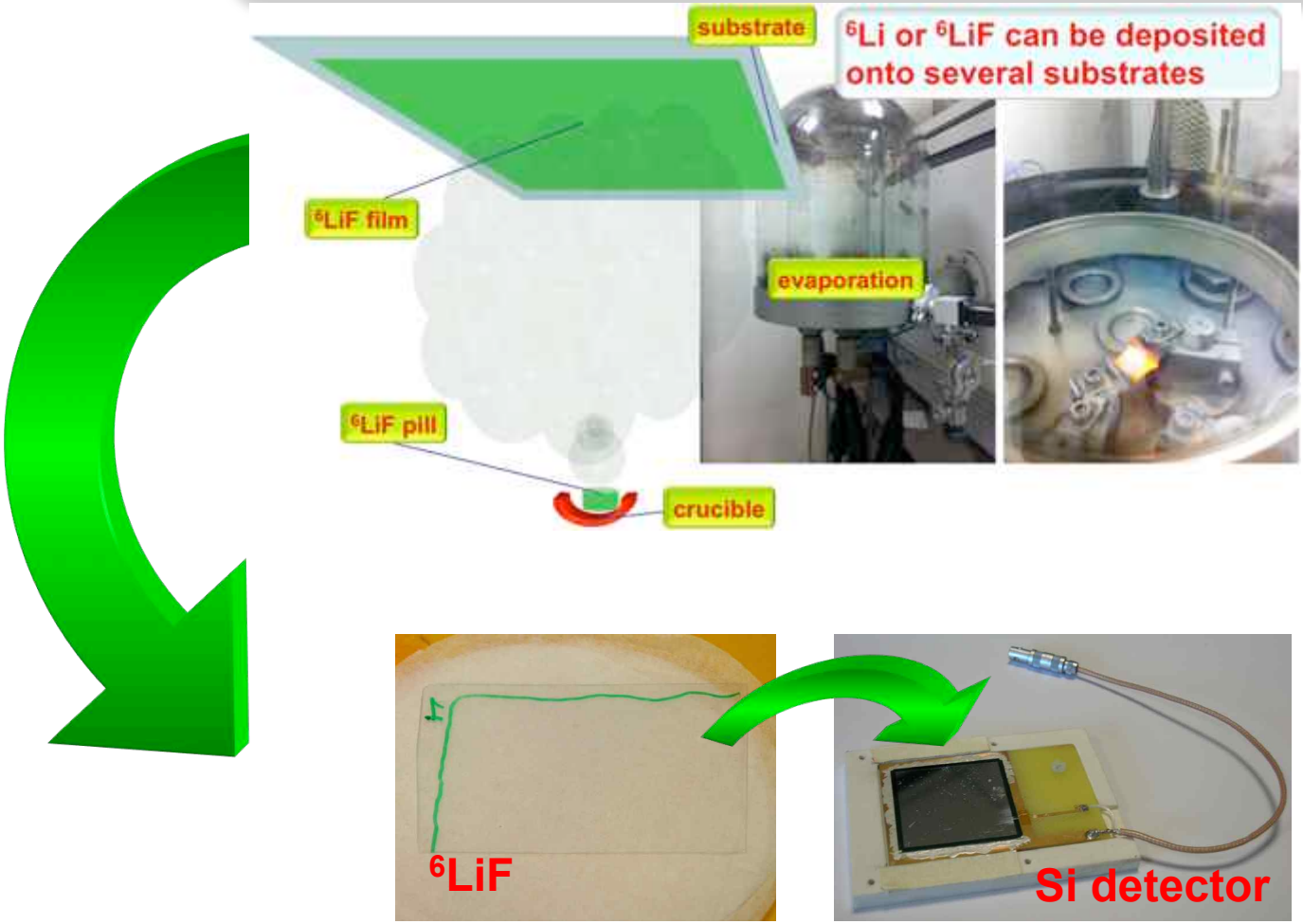


detection of ^{3}H and/or ^{4}He

how?

^{3}He-free Lithium-based NEutron Monitors

with removable converter

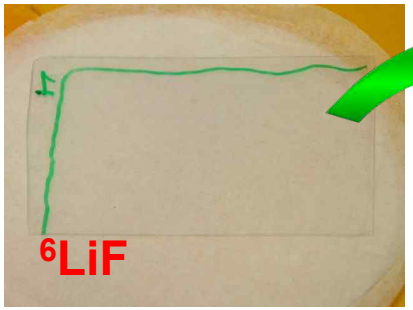


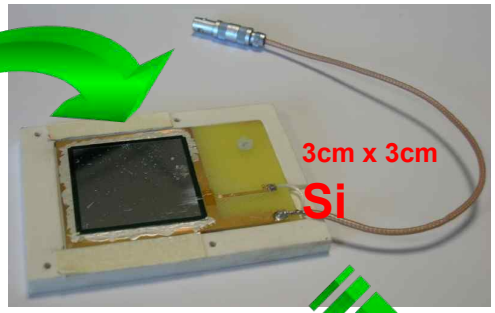
^{3}He-free Lithium-based NEutron Monitors

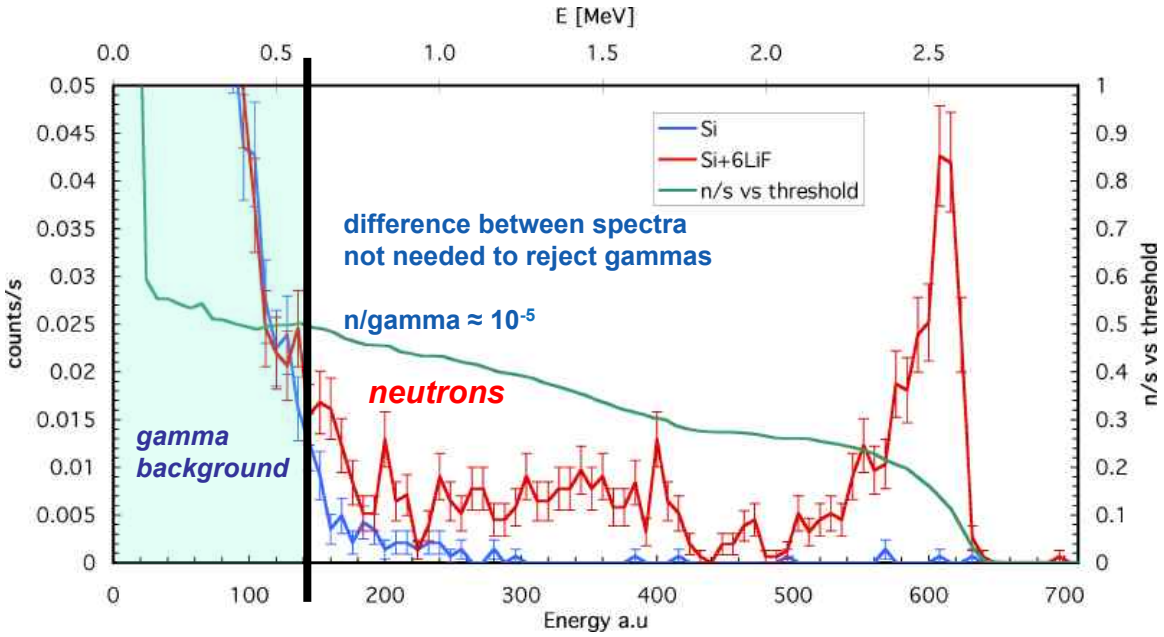
with removable converter

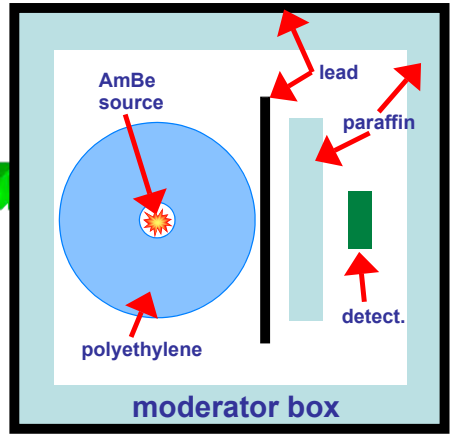
AmBe neutron source 5E4 n/s
thermal flux ≈ 4 n/s/cm^2

9cm^2 Si detector + ^{6}LiF(1.5μm)

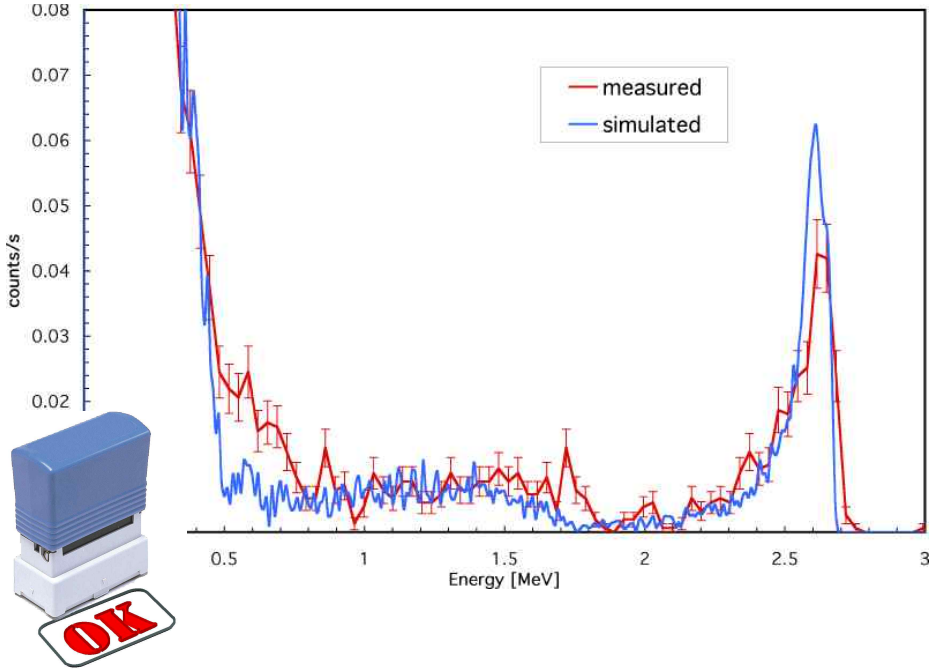








Si detector + ^{6}LiF: comparison with simulation



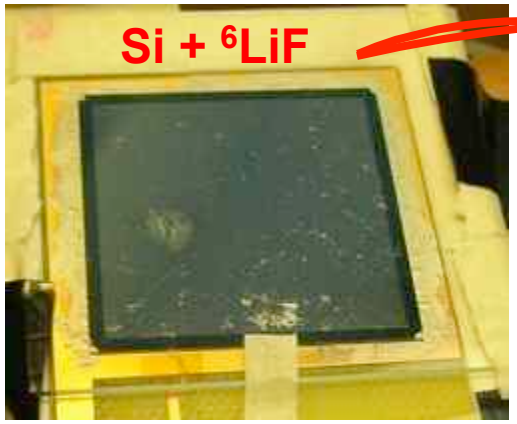
semi-quantitative GEANT4 simulation:

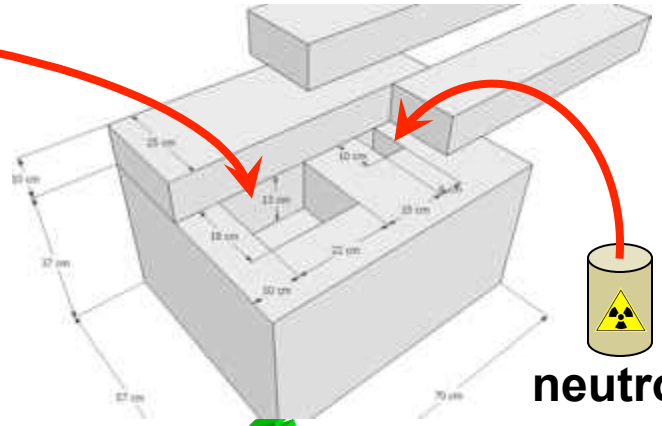
- ***neutrons: thermal***
- ***gamma: 60 keV***
- ***gamma: 662 keV***
- ***gamma: 1.2 MeV***
- ***gamma: 4 MeV***

- ***# alpha and tritium normalized to data***
- ***# gamma manually scaled***

quite encouraging data-simulation agreement (surprising?)

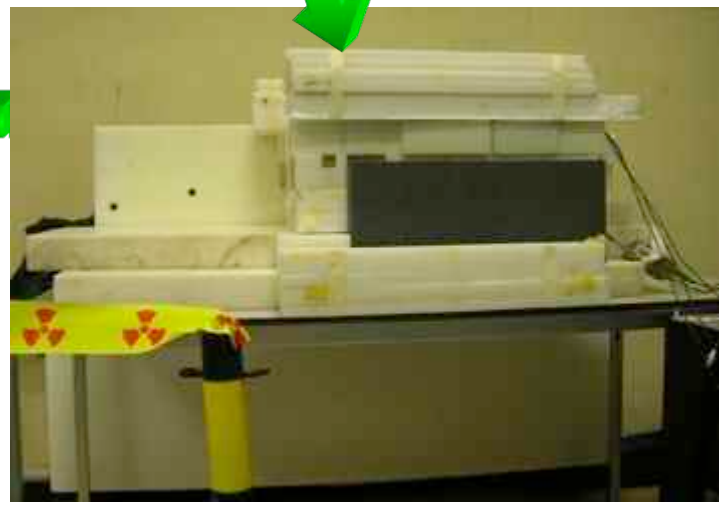
AmBe neutron source 1.6E6 n/s thermal flux ≈ 150 n/s/cm^2

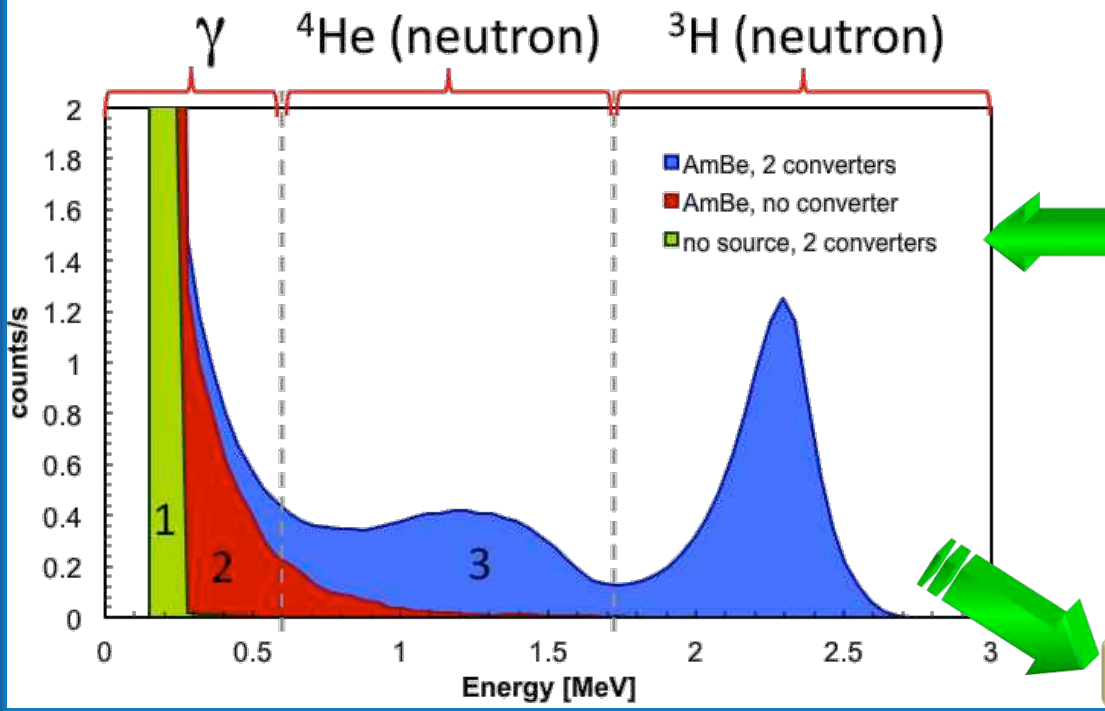




neutron source

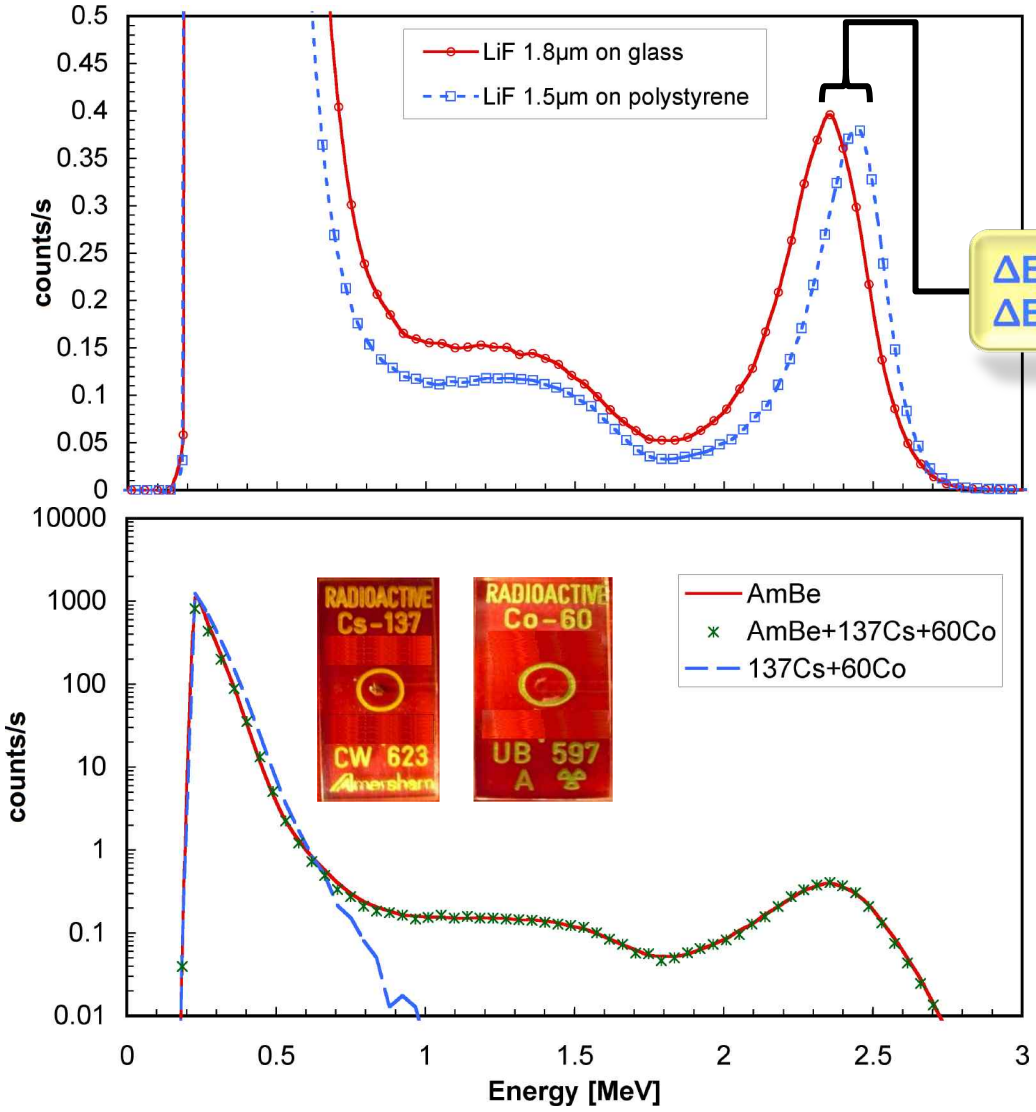
PET moderator





expected ≈ 4 cps measured 3.3

Si detector + ^{6}LiF



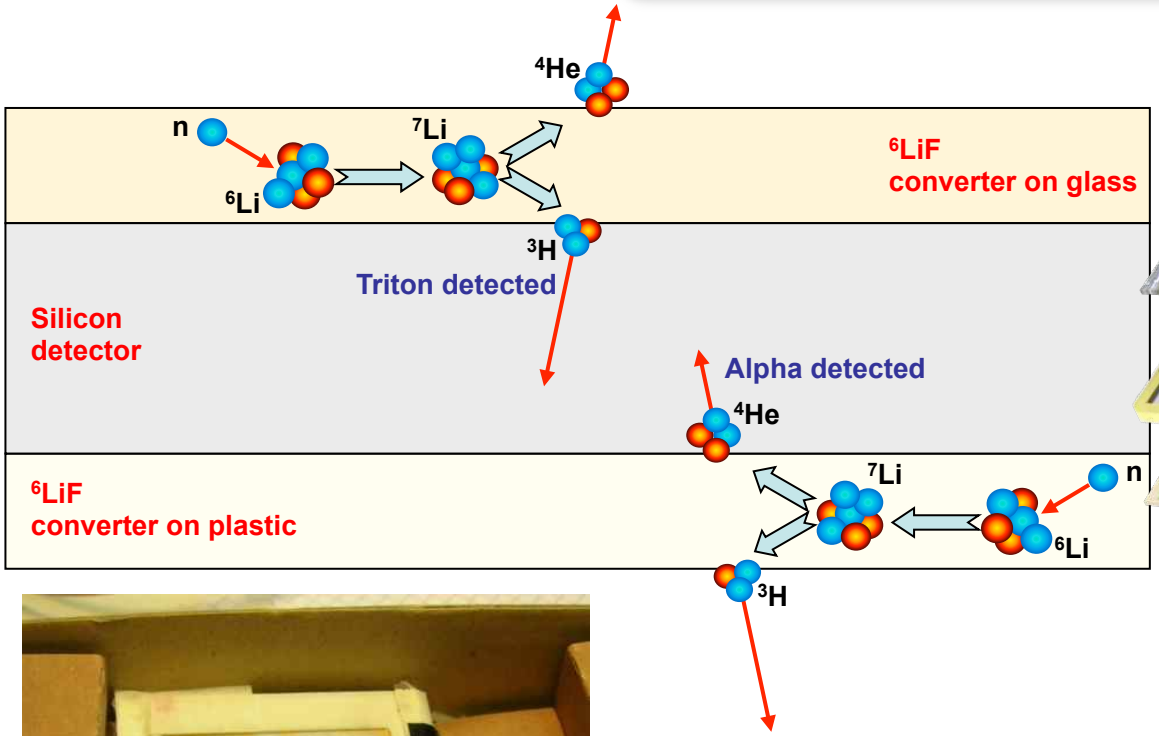
thickness: 1.8μm vs 1.5μm
20% more efficient

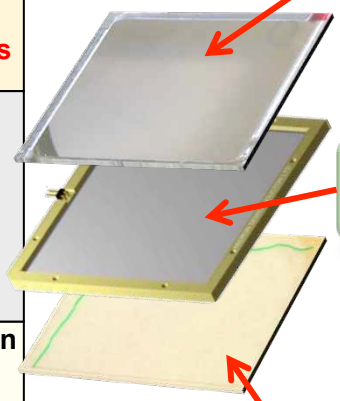
ΔE calculated: 195 keV
ΔE measured: 200 keV

optimal ^{6}LiF thickness 1.8μm

added 2 gamma sources
to test rejection (740 MBq)

Si detector + ^{6}LiF





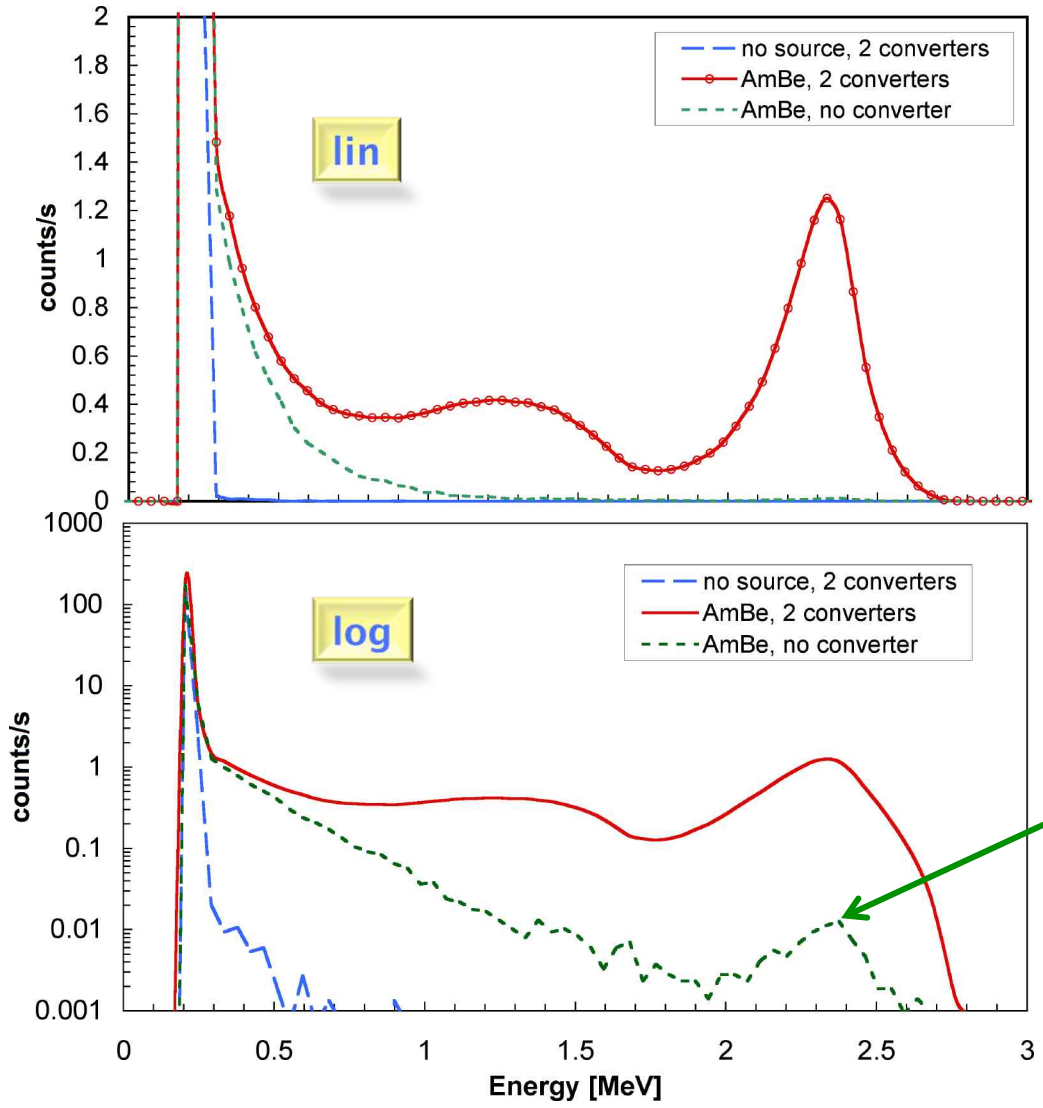
^{6}LiF on glass

double sided silicon
3cm x 3cm x 300μm

^{6}LiF on plastic

2 converters: double efficiency

Si detector + ^{6}LiF

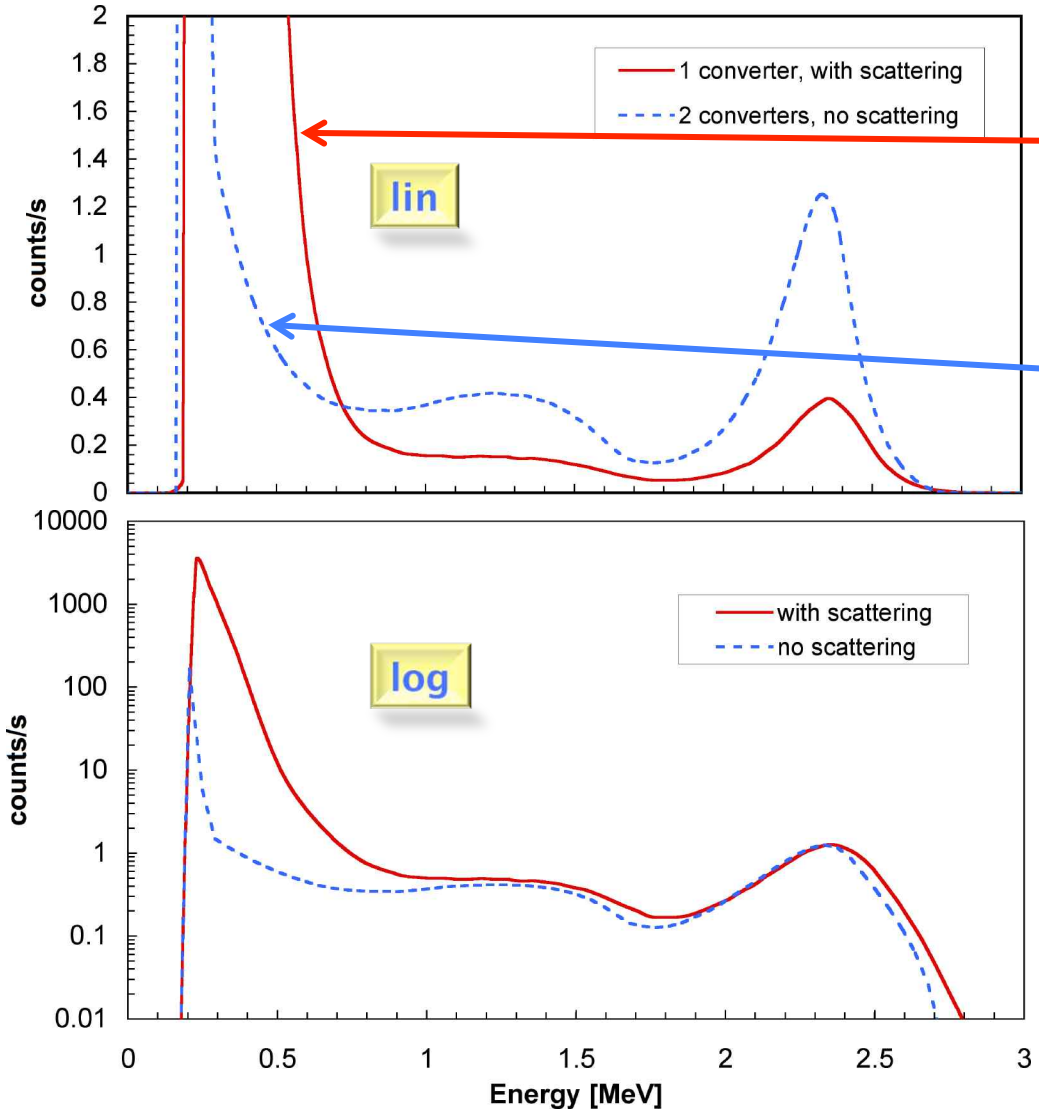


no source: background
2 converters: double efficiency (2%)
no converter: only gamma contribution

but... in log scale...

unexpected neutrons?
part of the ^{6}LiF migrated from the plastic substrate to the silicon face!

Si detector + ^{6}LiF



heavy material close to the detector:
higher energy gamma (scattering)

heavy material removed:
the gamma background is suppressed

same as before in log scale

advice:
no heavy material inside
the PET moderator

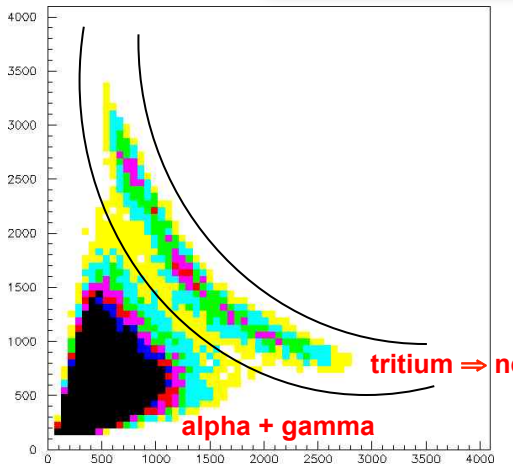
features

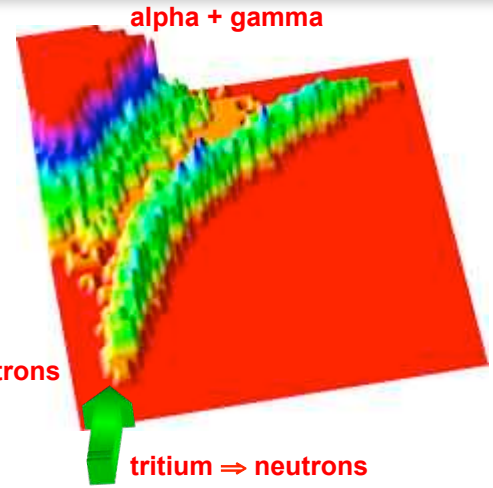
- mechanically simple and robust
- reasonably cheap
- commercial solid state detectors
- strips for position measurements
- simple use (no spectrum analysis or subtraction for gamma rejection)

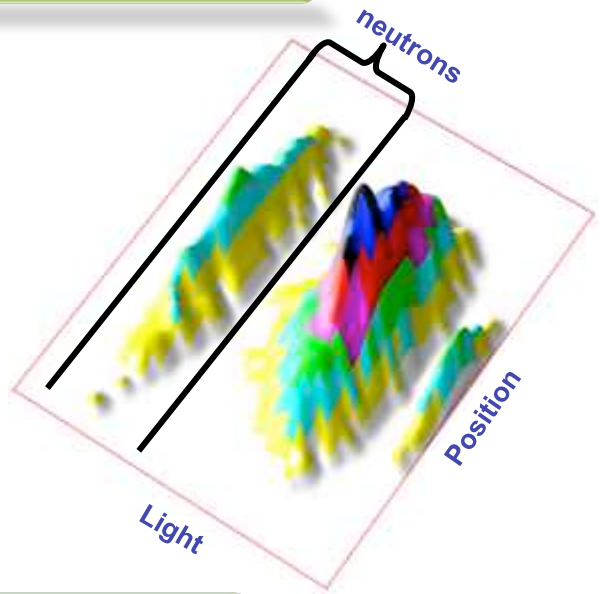
next steps

- ^{6}Li deposits over large area (A4?)
- better efficiency (up to 50%?)
- scintillators... → patent? YES

test with AmBe source: Scintillators + ^{6}LiF

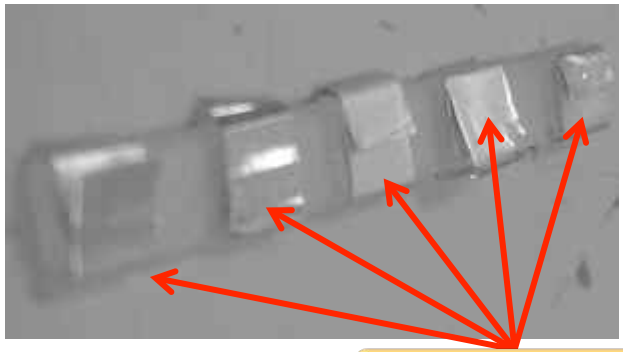




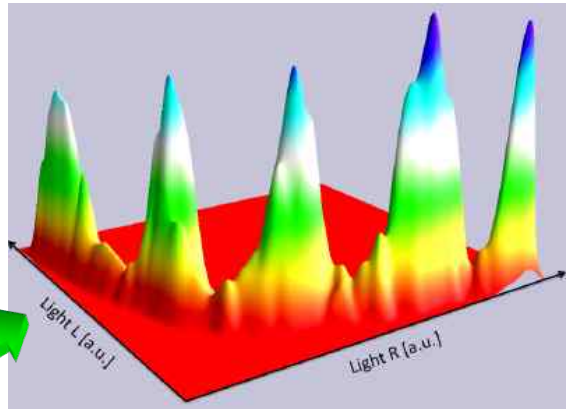


- good intrinsic efficiency
- position sensitive (Δx ≈ 1-2 mm)
- low cost
- many possible geometries and schemes

...and more to come

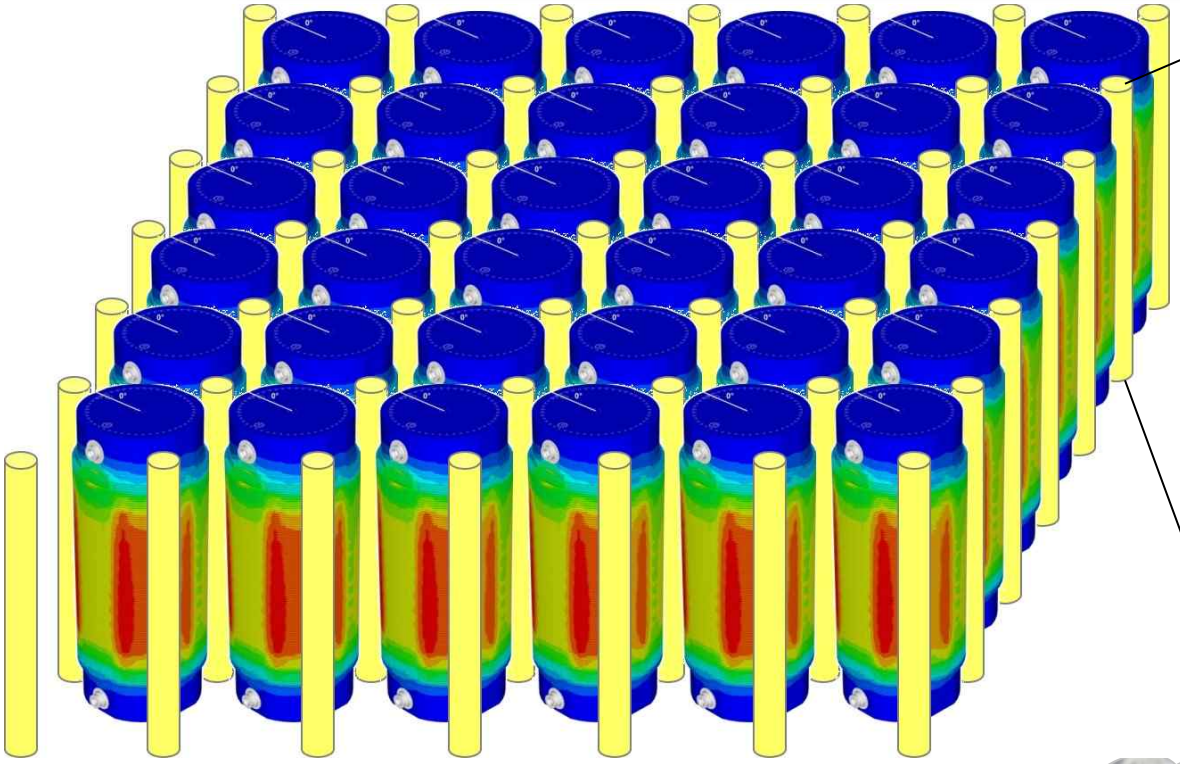


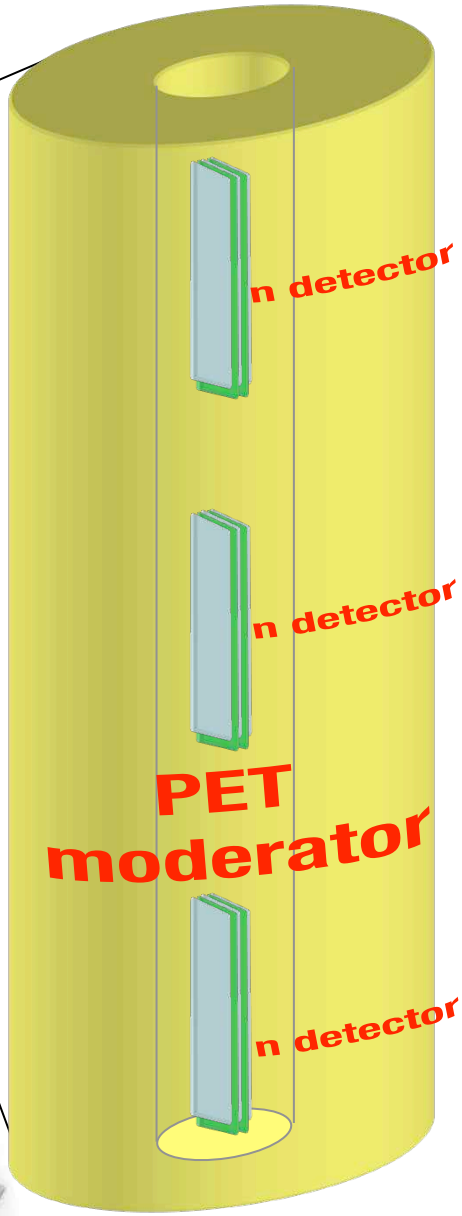
^{6}LiF converter



RM2013A000254

real-time castor storage monitoring





local
data
storage

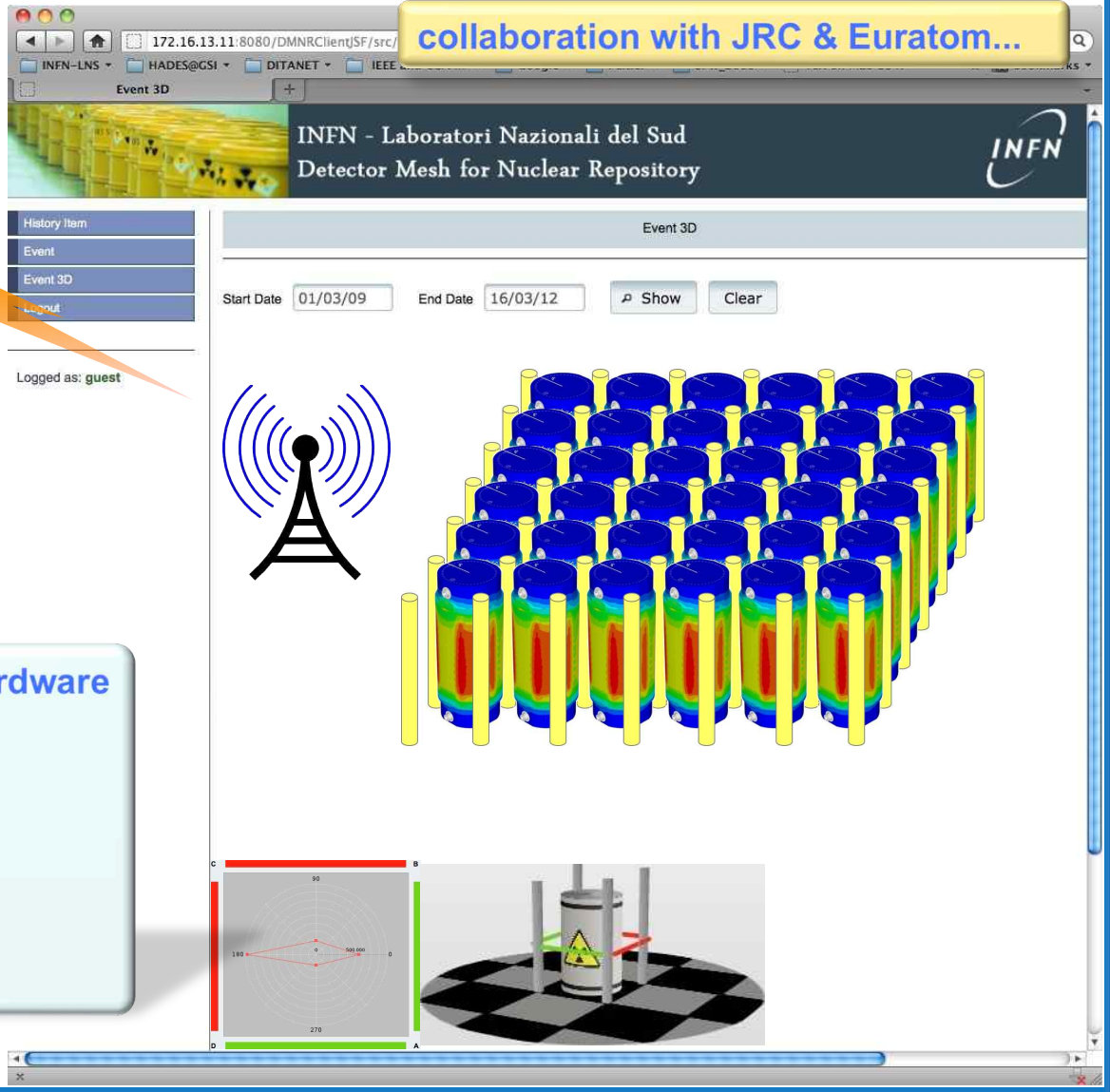
remote
data
storage

Web

real-time castor storage monitoring

wireless transmission

collaboration with JRC & Euratom...



easily integrated into the existing hardware and software architecture of DMNR:

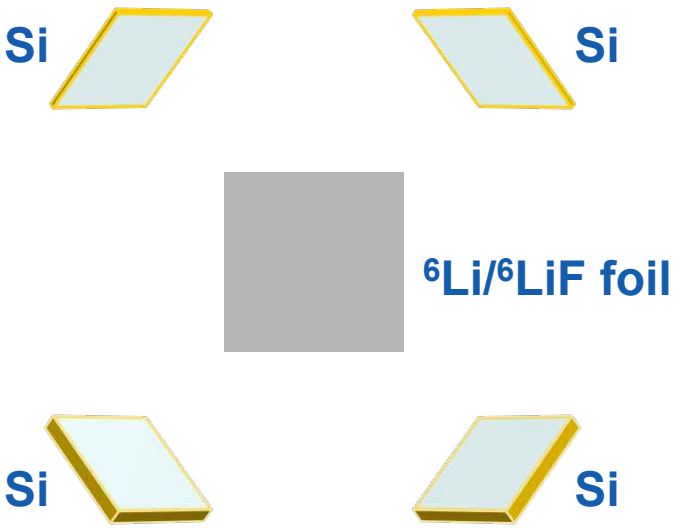
- electronics
- data acquisition
- system control
- data logging
- database handling
- Graphical User Interface

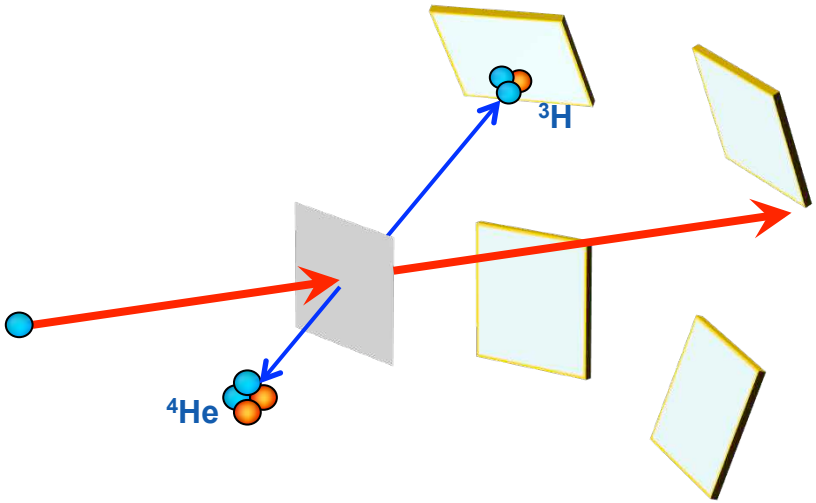
possible applications

- Nuclear physics research
- Homeland security (nuclear material smuggling)
- Dosimetry
- Radwaste monitoring
- Spent fuel handling and storage monitoring
- Search for nuclear material accidentally lost among scrap metal
- Material structure (with neutron beams)
- other...

SiMon2: neutron beam monitor for flux normalization

Si detector + $^{6}Li/^{6}LiF$

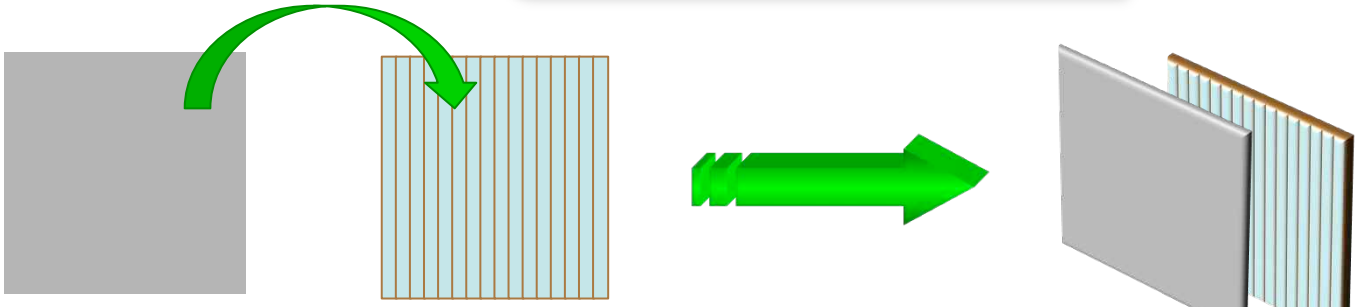




n-TOF collaboration @ CERN

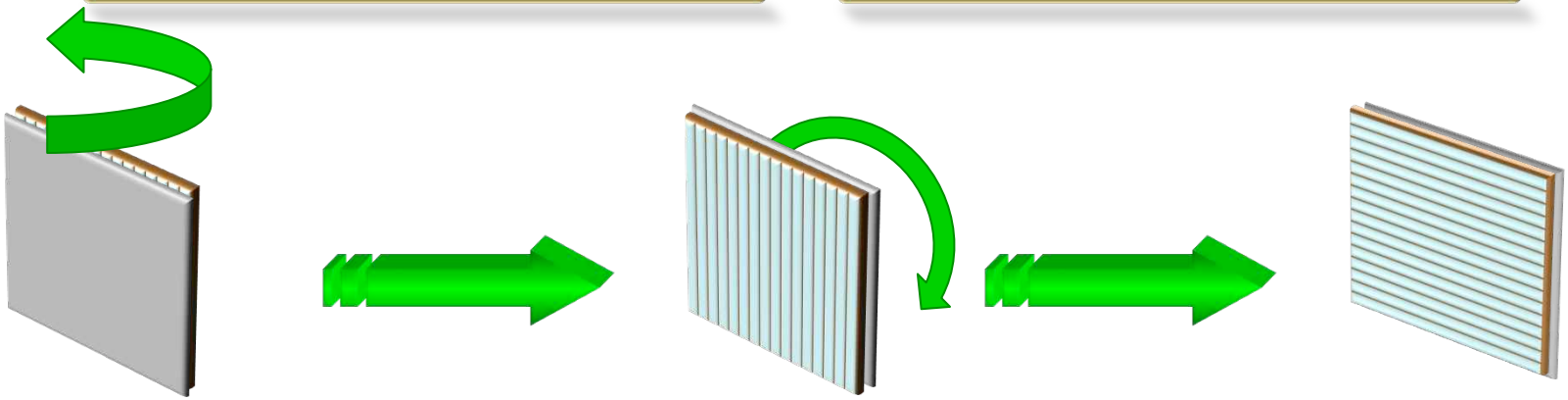
BeaMon: neutron beam characterization

Si detector + ^{6}Li/^{6}LiF



α-t forward-backward asymmetry

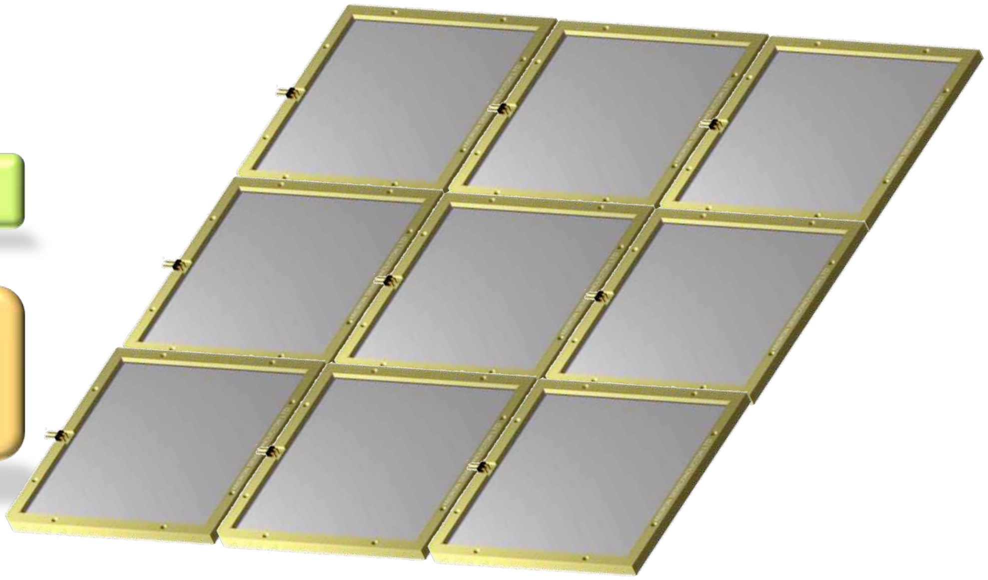
XY distribution



n-TOF collaboration @ CERN

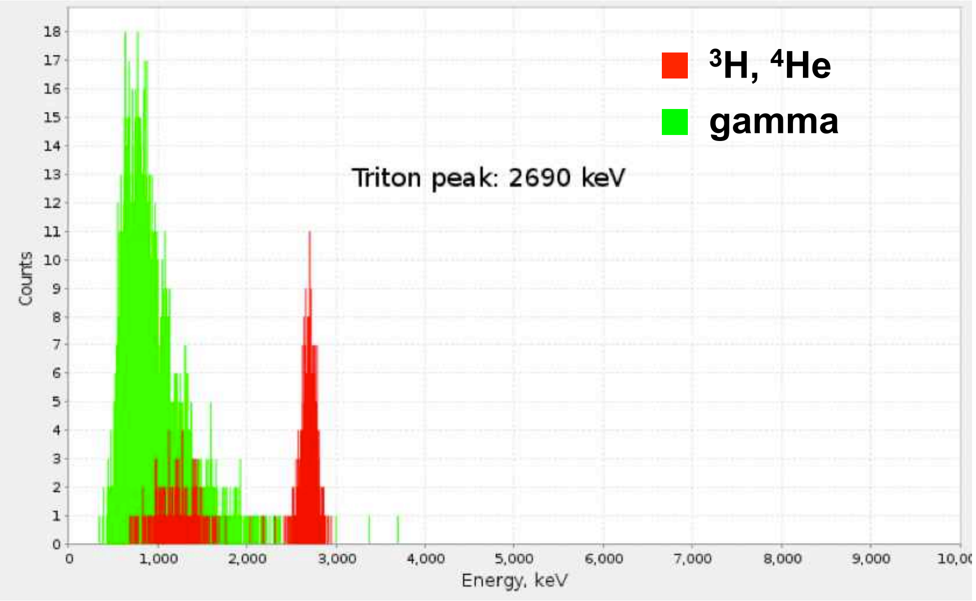
Ongoing ollaboration with JRC & Euratom:

large panels for neutron coincidence measurements
as possible ^{3}He panels replacement



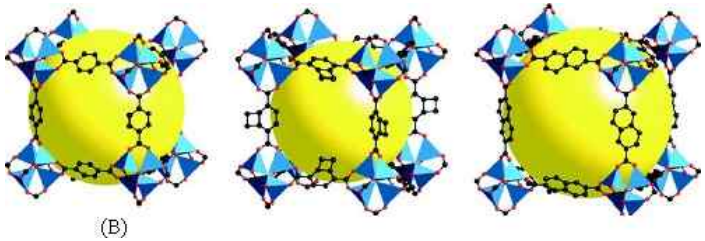
Last week's result from collaboration with CIVIDEC (Austria):

diamond detectors for thermal neutrons
outstanding results with the first test at a reactor

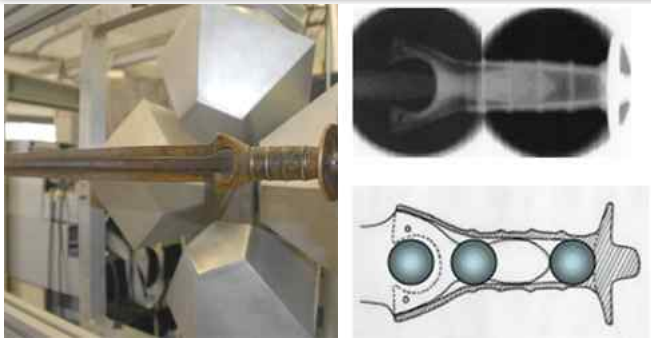


applications with neutron beams?

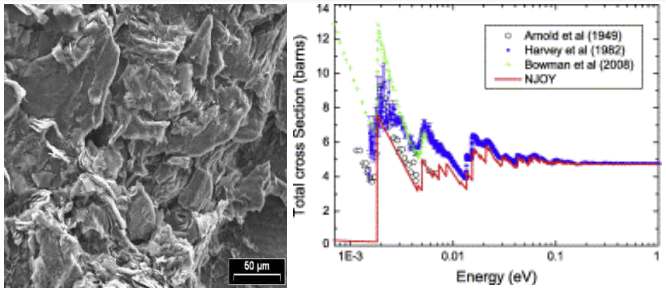
Time-of-Flight Neutron Diffraction (ToF- ND)
e.g.: University of Milan, inorganic stereochemistry



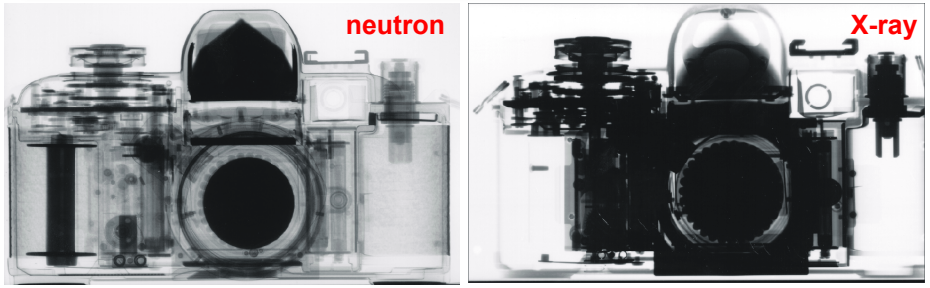
Neutron Resonance Capture Analysis
e.g.: Ancient Charm EU project
secrets of Bronze Age sword unveiled



Bragg Edge Transmission
e.g.: S.Petriw, J.Dawidowski, J.Santisteban,
Porosity effects on the neutron total cross section of graphite
Journal of Nuclear Materials 396 (2010)181-188



Neutron Radiography
e.g.: Institute of Atomic and Subatomic Physics - TU Wien



material analysis: composition and structure

compact neutron monitors?

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Thank you