

# Laboratorio: Thermal Neutron Detectors

Paolo Finocchiaro



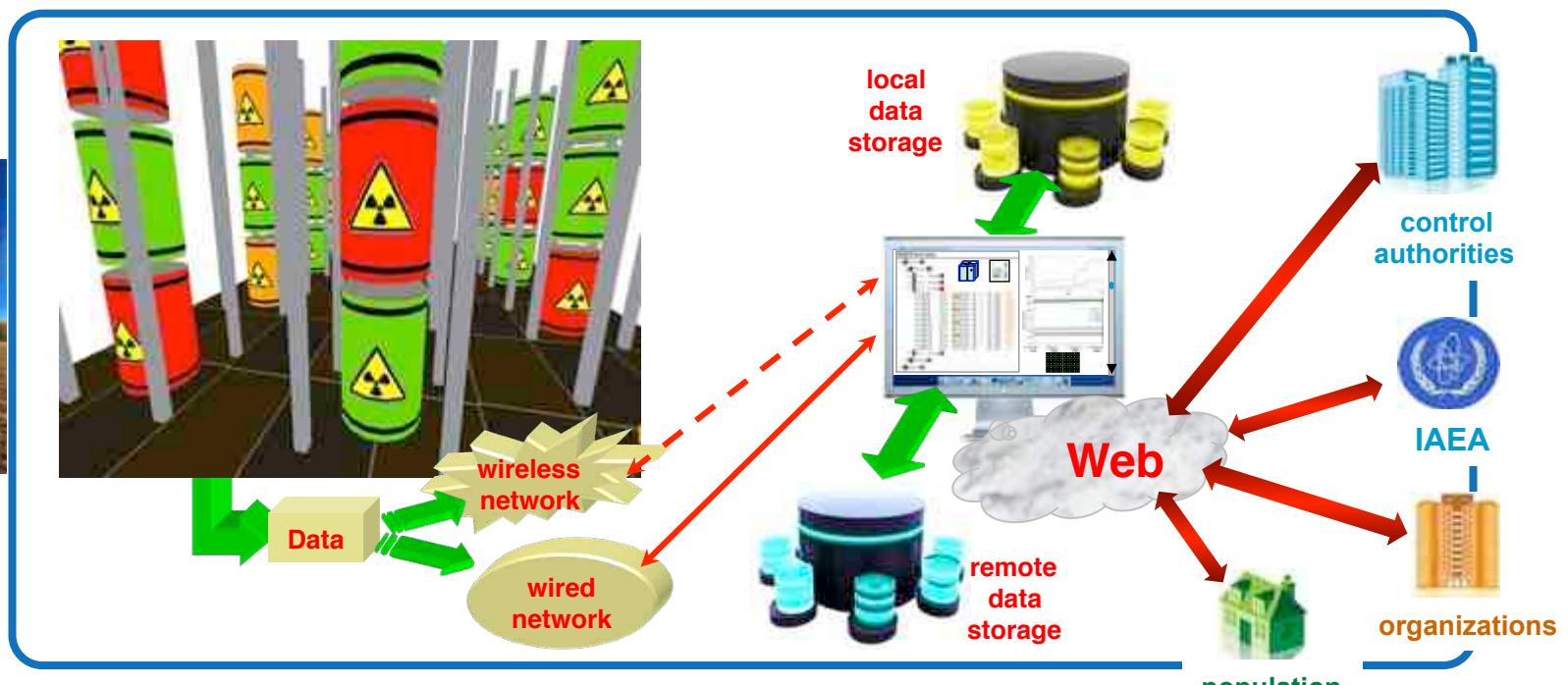
- Perchè?
- Come?
- Che cosa?

Abbiamo implementato una **soluzione a basso costo** per il monitoraggio puntuale di radwaste (radiazione gamma)

in collaborazione con **Ansaldo Nucleare**  
Detector Mesh for Nuclear Repositories



Lab fibre scintillanti

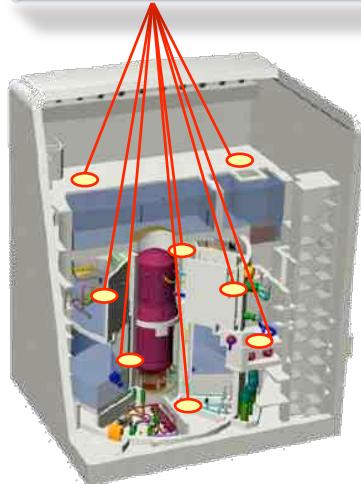


in collaborazione con **SOGIN**  
installato un prototipo in un deposito



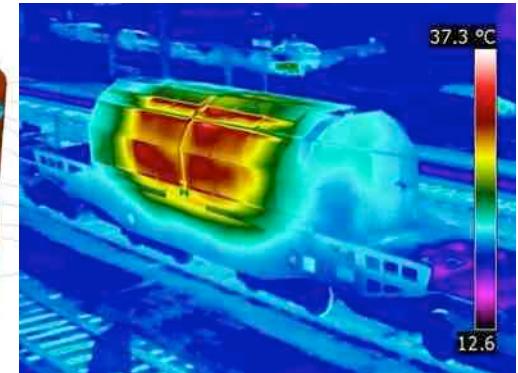
## nuovo obiettivo: rivelazione di neutroni

monitoraggio fuori dal core in reattori

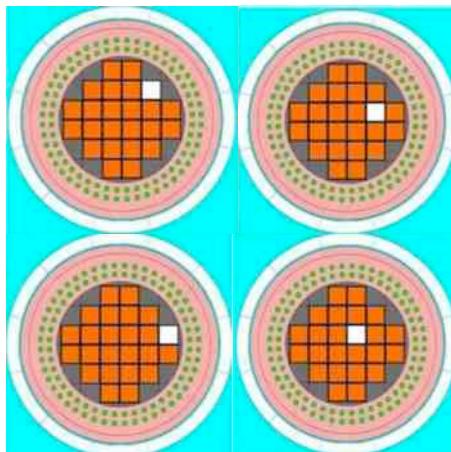


e perchè neutroni?

monitoraggio combustibile esaurito in loco e / o durante il trasporto



distrazione di elementi di combustibile da fusti



prevenzione contrabbando di combustibile nucleare

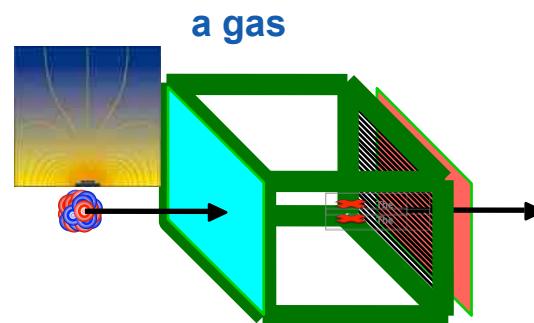


(P.Peerani, M.Galletta, Nuclear Engineering and Design 237 (2007) 94-99)

## rivelazione di radiazioni ionizzanti

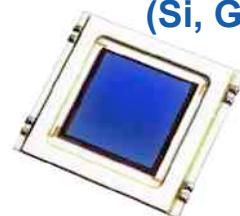


per interazione elettromagnetica



a gas

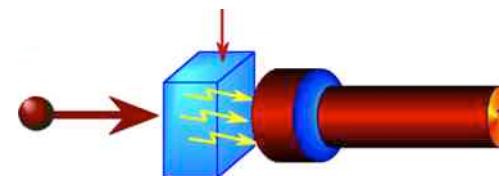
a semiconduttore  
(Si, Ge, ...)



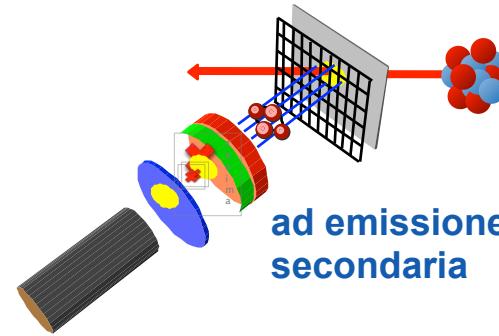
a diamante



a scintillazione



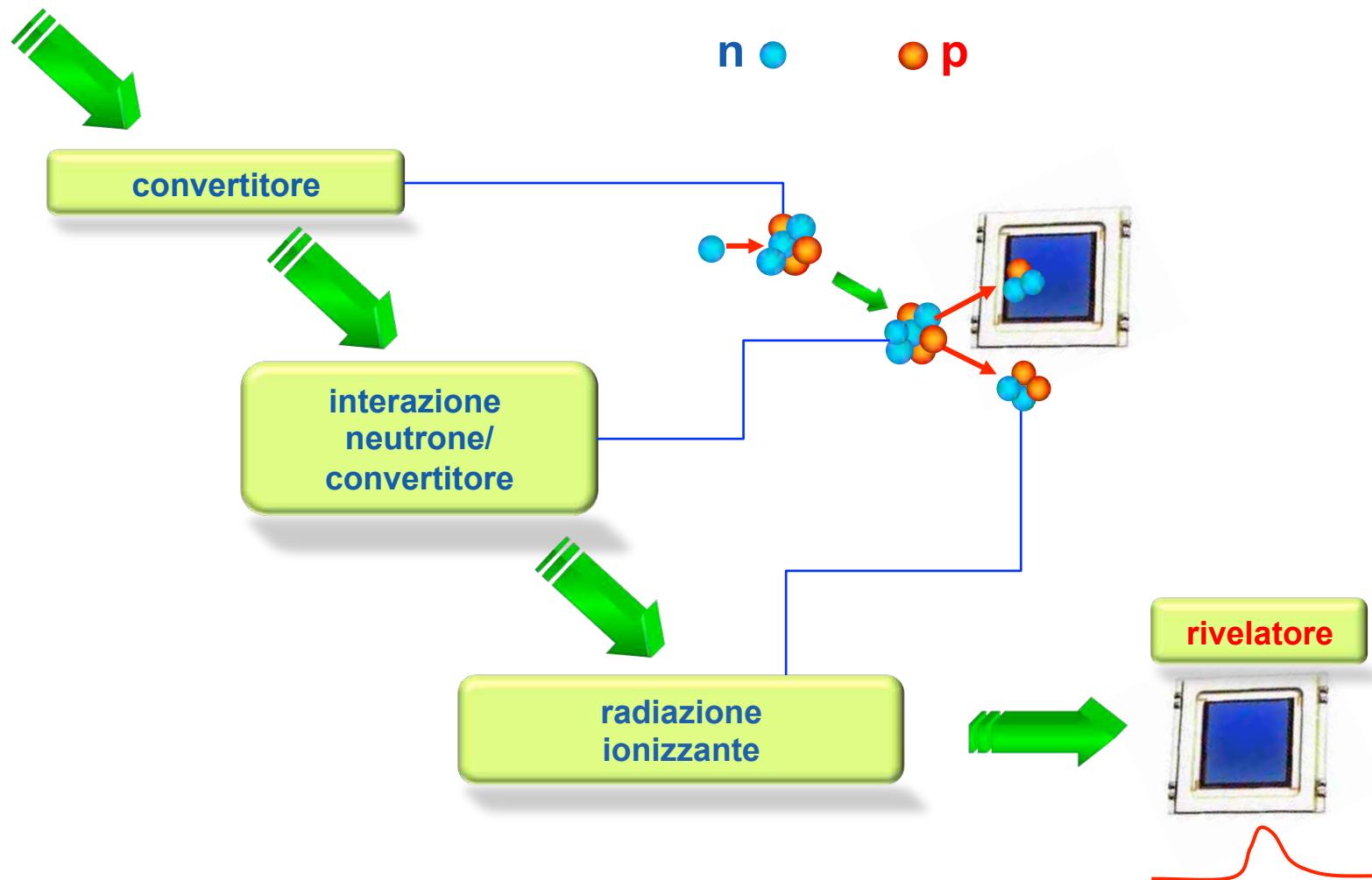
Cherenkov



ad emissione  
secondaria

altro...  
bolometri  
acustici  
....

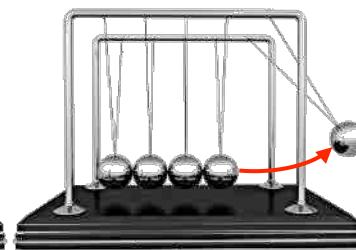
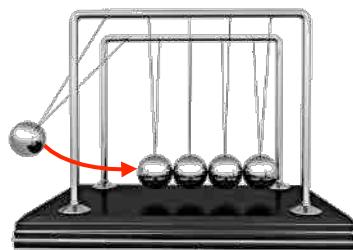
## il neutrone non ha carica elettrica



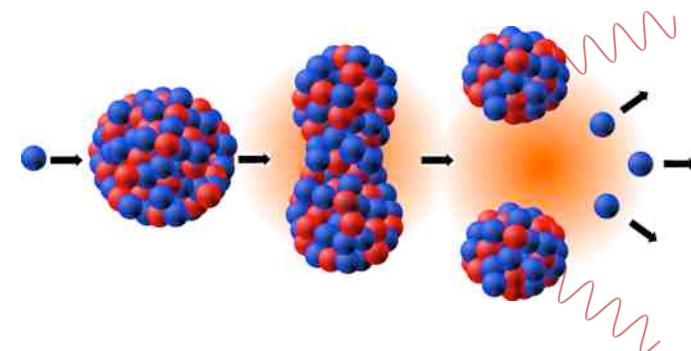
## interazione di neutrone



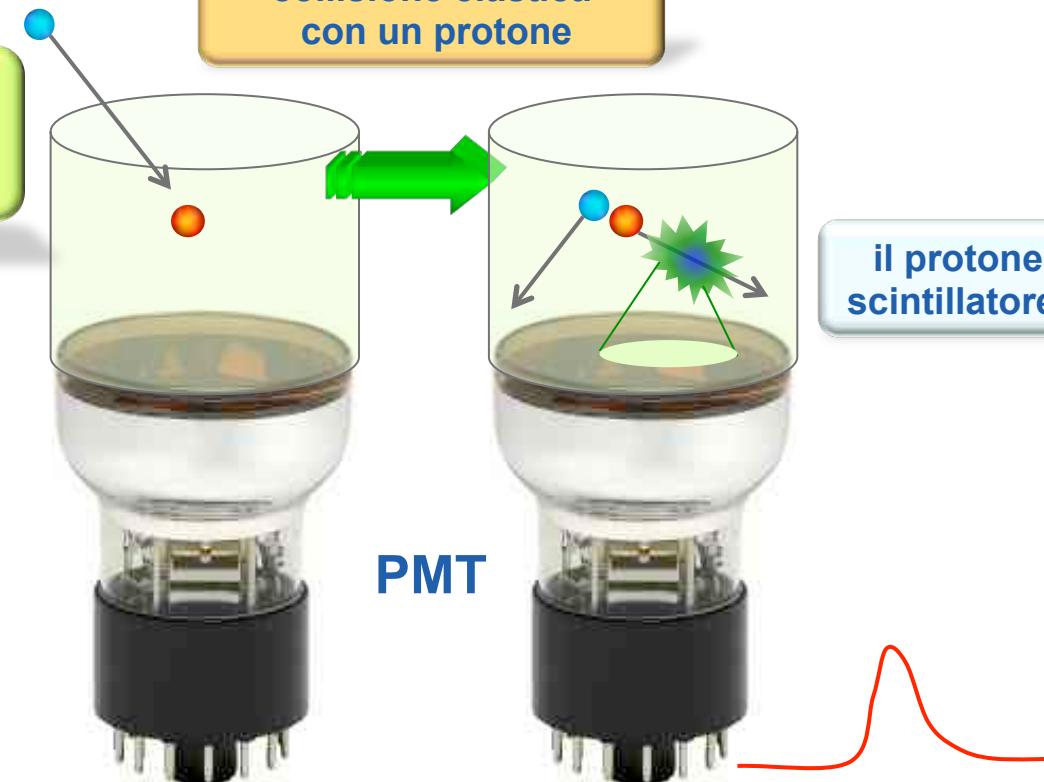
elastica



reazione

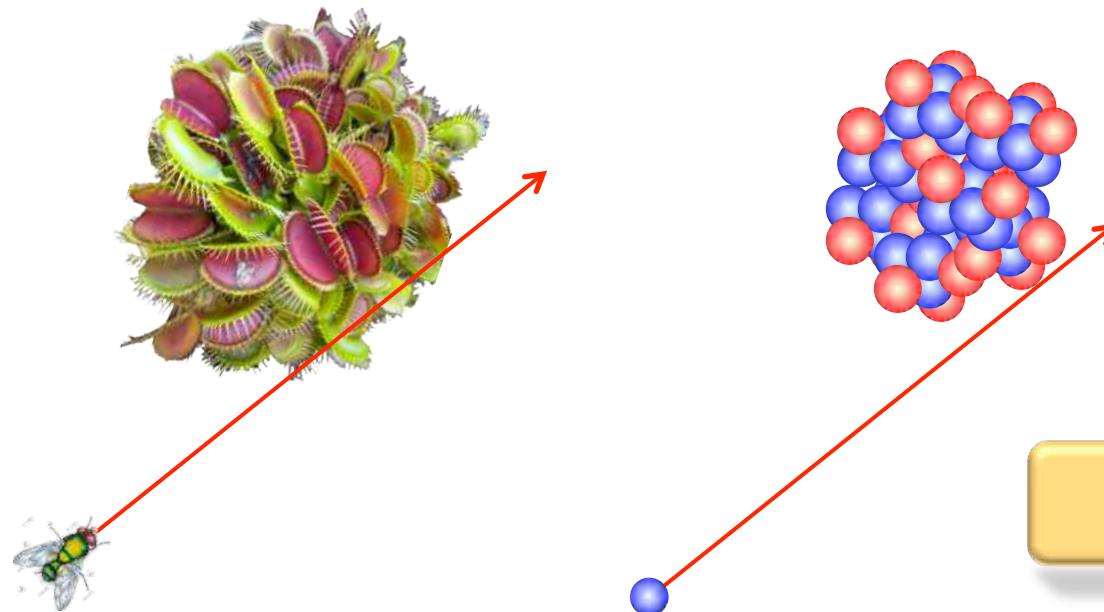
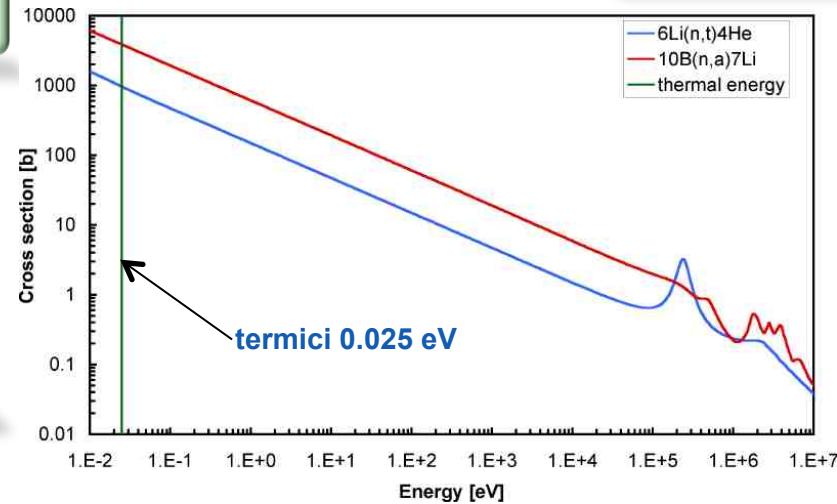
massimo trasferimento di energia:  
masse ugualimateriali leggeri per rallentare i  
neutroni (moderatori: paraffina, acqua)

## rivelazione di neutroni veloci

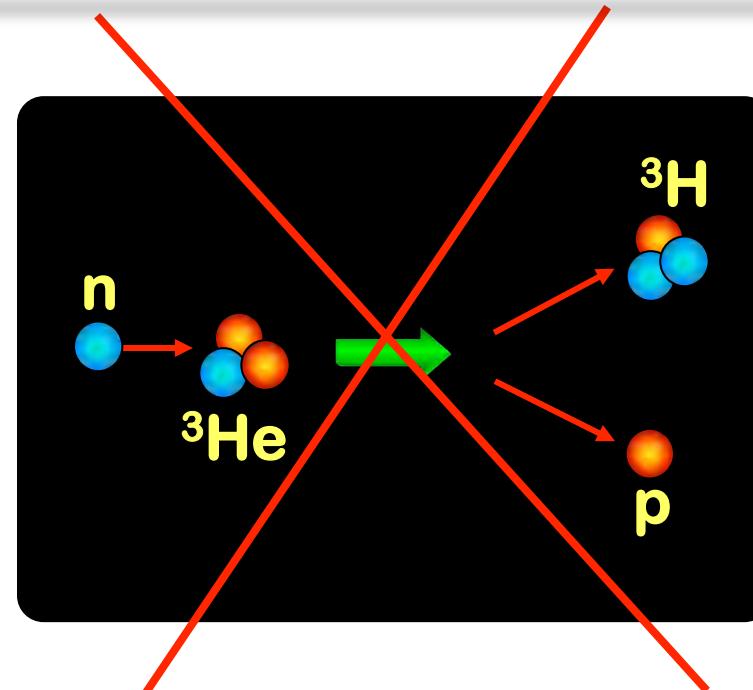
 $n$  $p$ collisione elastica  
con un protoneil neutrone entra nello  
scintillatore liquido  
(ricco di idrogeno)il protone si ferma nello  
scintillatore e produce luce

## rivelazione di neutroni lenti

sezione d'urto  $\approx$  proporzionale a  $1/v$   
maggiore il tempo di transito, maggiore la  
probabilità di cattura



grande sezione d'urto per  
neutroni lenti

**materiali per la conversione di neutroni:  ${}^3\text{He}$** 

$\sigma(0.025)$   
 $\approx 5330 \text{ b}$

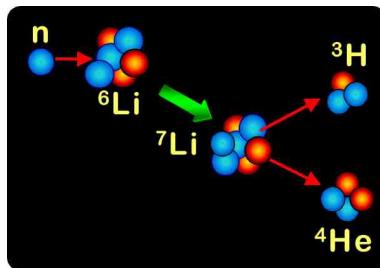
energia disponibile  
0.76 MeV  
niente gamma



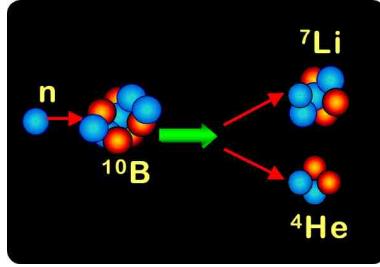
perfetto rivelatore a gas ma... carenza mondiale di  ${}^3\text{He}$



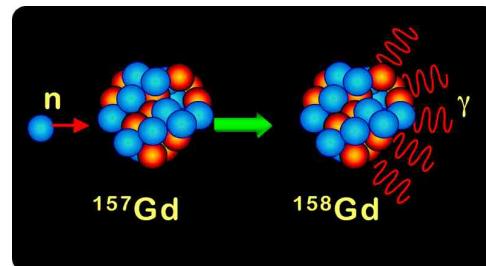
## materiali alternativi per la conversione di neutroni: quale?

 **$^6\text{Li}$** 

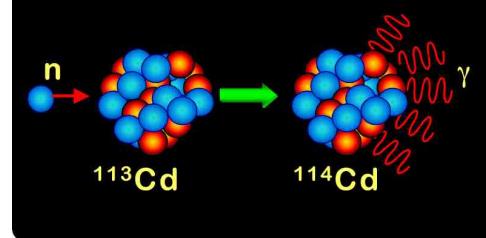
$\sigma(0.025)$   
 $\approx 940 \text{ b}$   
E disponibile  
4.78 MeV

 **$^{10}\text{B}$** 

$\sigma(0.025)$   
 $\approx 3840 \text{ b}$   
E disponibile  
2.79 MeV  
(e gamma)

 **$^{157}\text{Gd}$** 

$\sigma(0.025)$   
 $\approx 240 \text{ kb}$

 **$^{113}\text{Cd}$** 

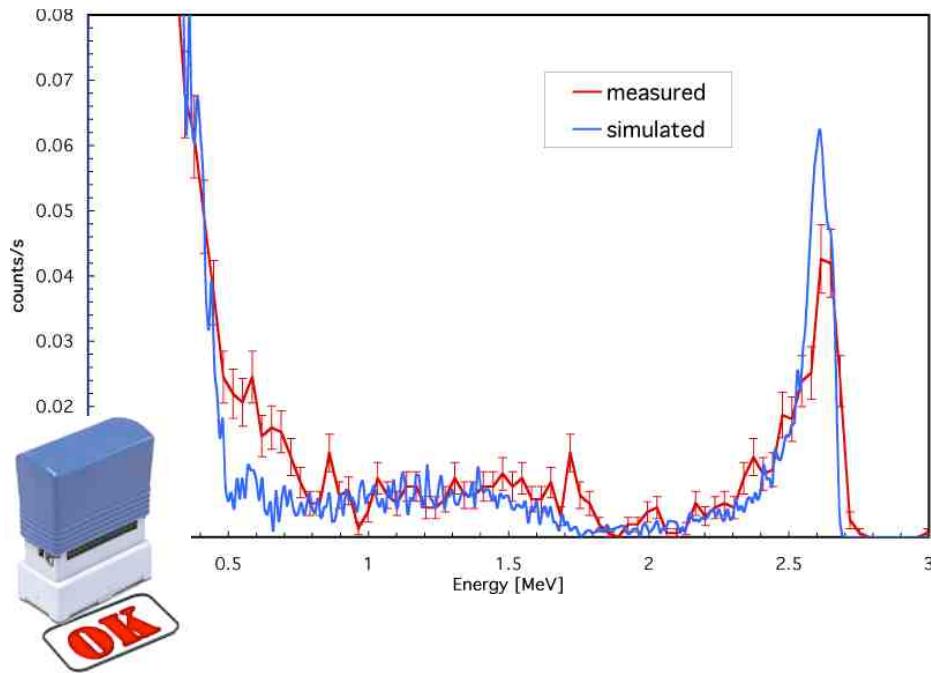
$\sigma(0.025)$   
 $\approx 20 \text{ kb}$

grande E disponibile  
ma in forma di gamma:  
difficile identificare neutroni

## <sup>3</sup>He-free Lithium-based NEutron Monitors con convertitore rimovibile

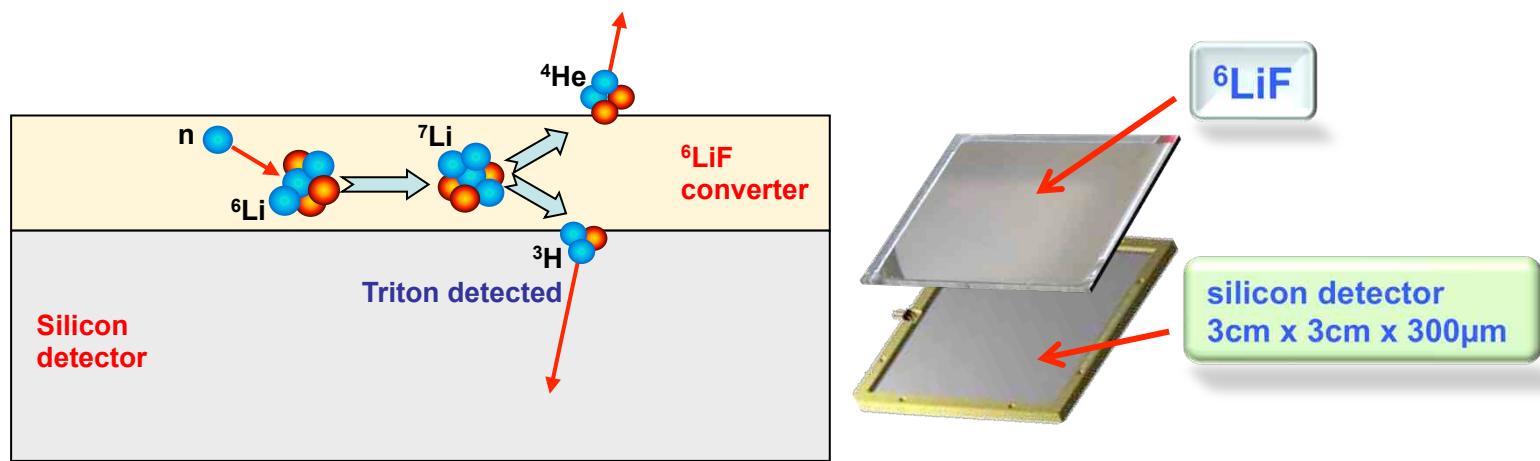
### produzione del convertitore di neutroni



Si detector +  $^{6}\text{LiF}$ : 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

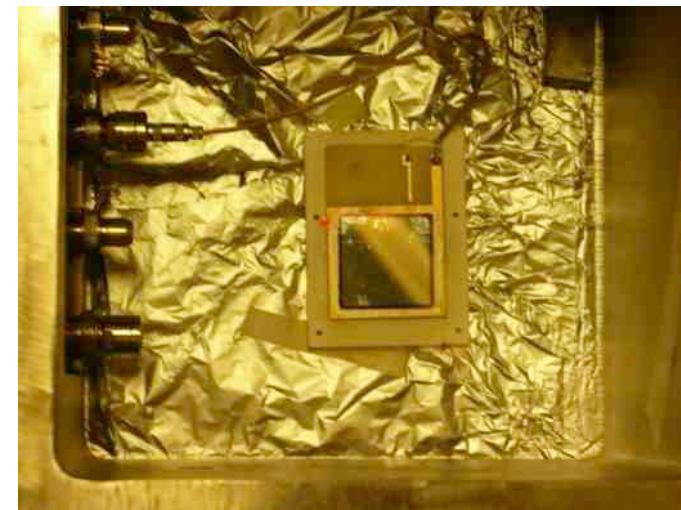
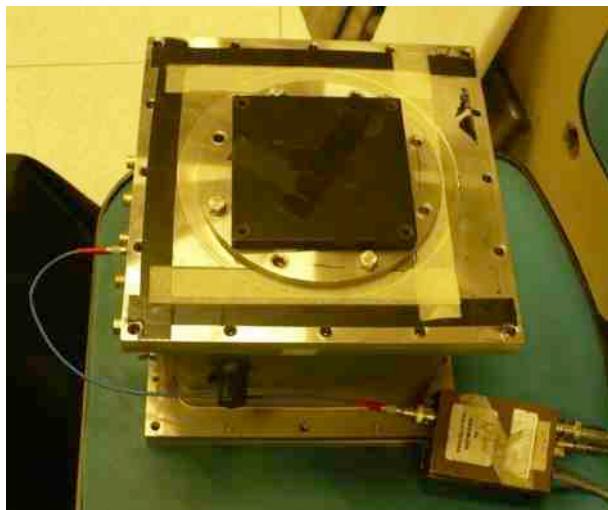


**3cm x 3cm silicon pad**



**+  $^{6}\text{LiF}$  converter**



**Neutron source, moderator, alpha source, detector box****Che cosa?**

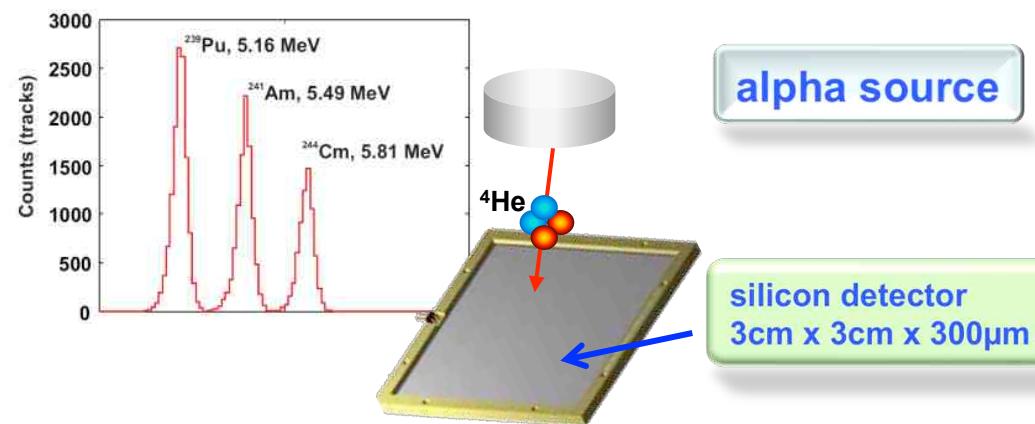
## Electronics



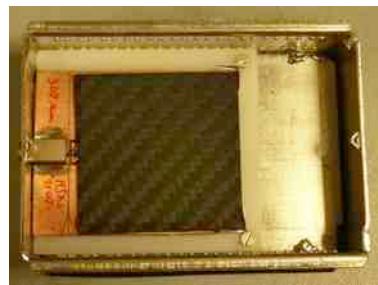
## Si detector calibration

Che cosa?

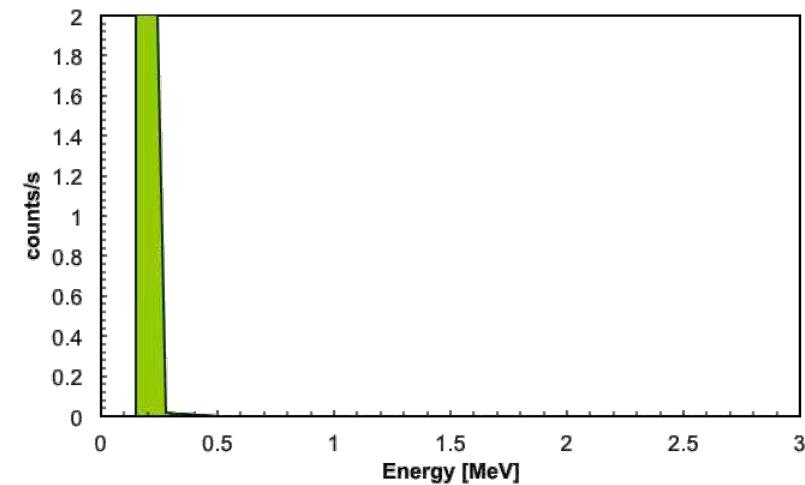
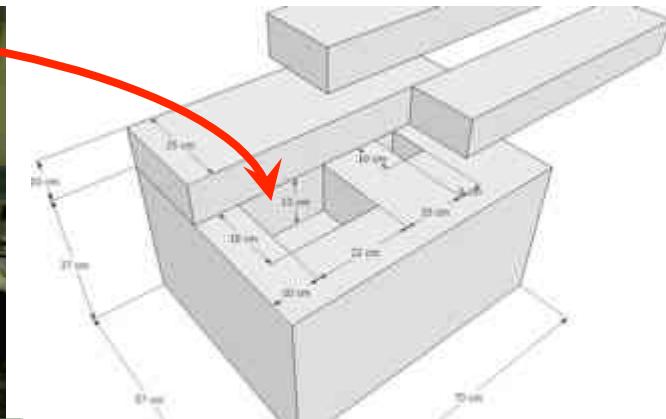
Isotopo	E alfa [keV]	B.R.	$\langle E \text{ alfa} \rangle$ KeV
239Pu	5156	71%	5147.84
	5144	17%	
	5105	12%	
241Am	5485	85%	5477.47
	5442	13%	
	5388	2%	
244Cm	5804	76%	5793.92
	5762	24%	



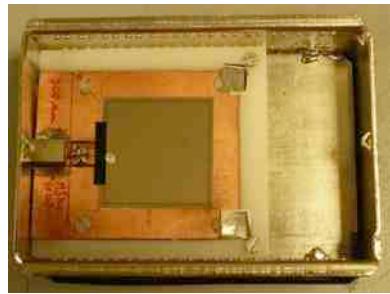
## measurement with converter without source

Si +  $^{6}\text{LiF}$ 

polyethylene to thermalize neutrons



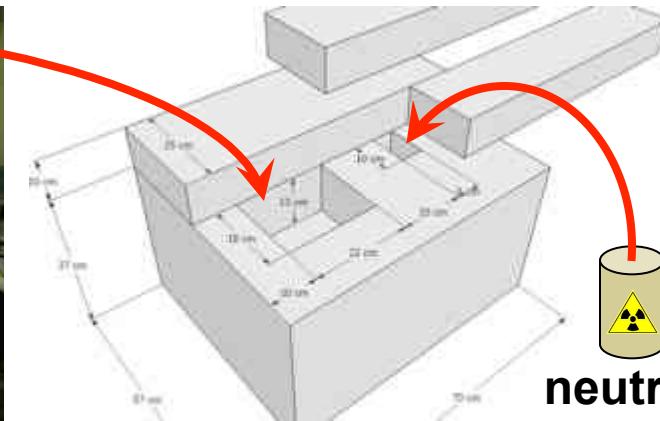
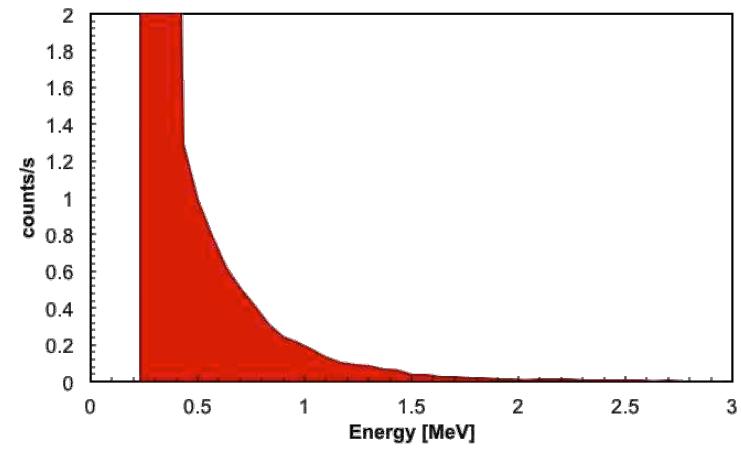
## measurement without converter



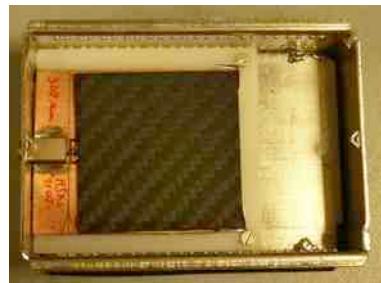
Si



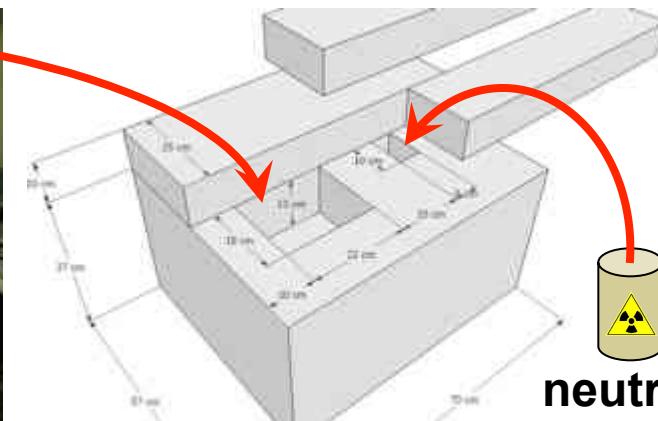
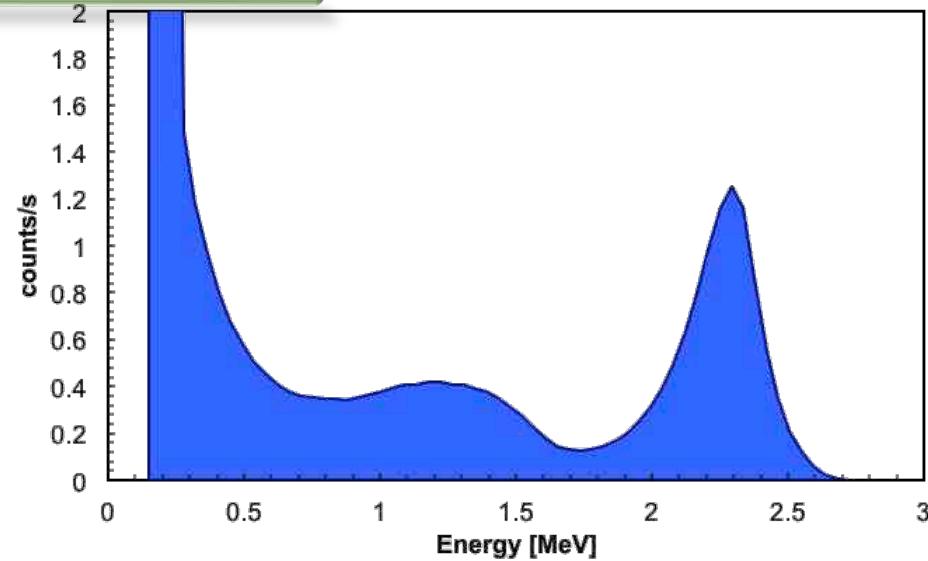
polyethylene to thermalize neutrons

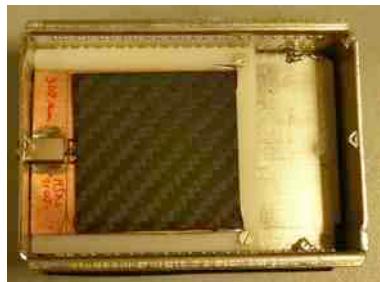
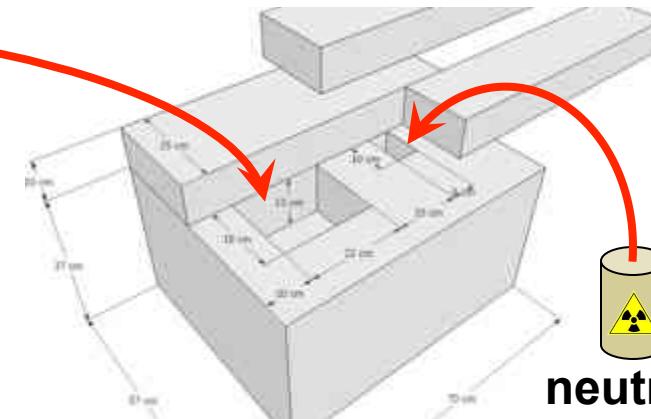
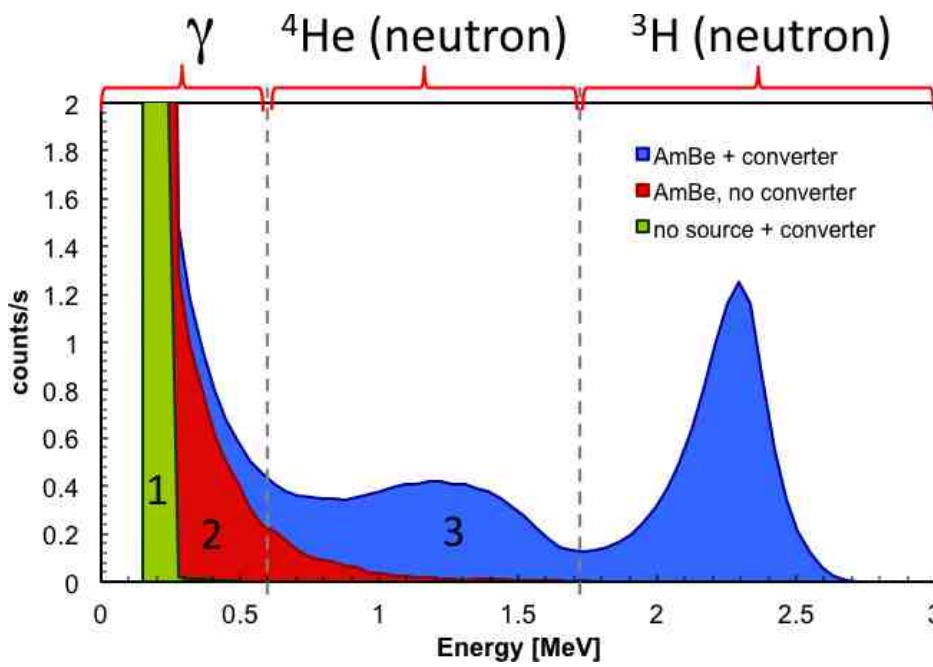
neutron  
source

## measurement with converter and source

Si +  ${}^6\text{LiF}$ 

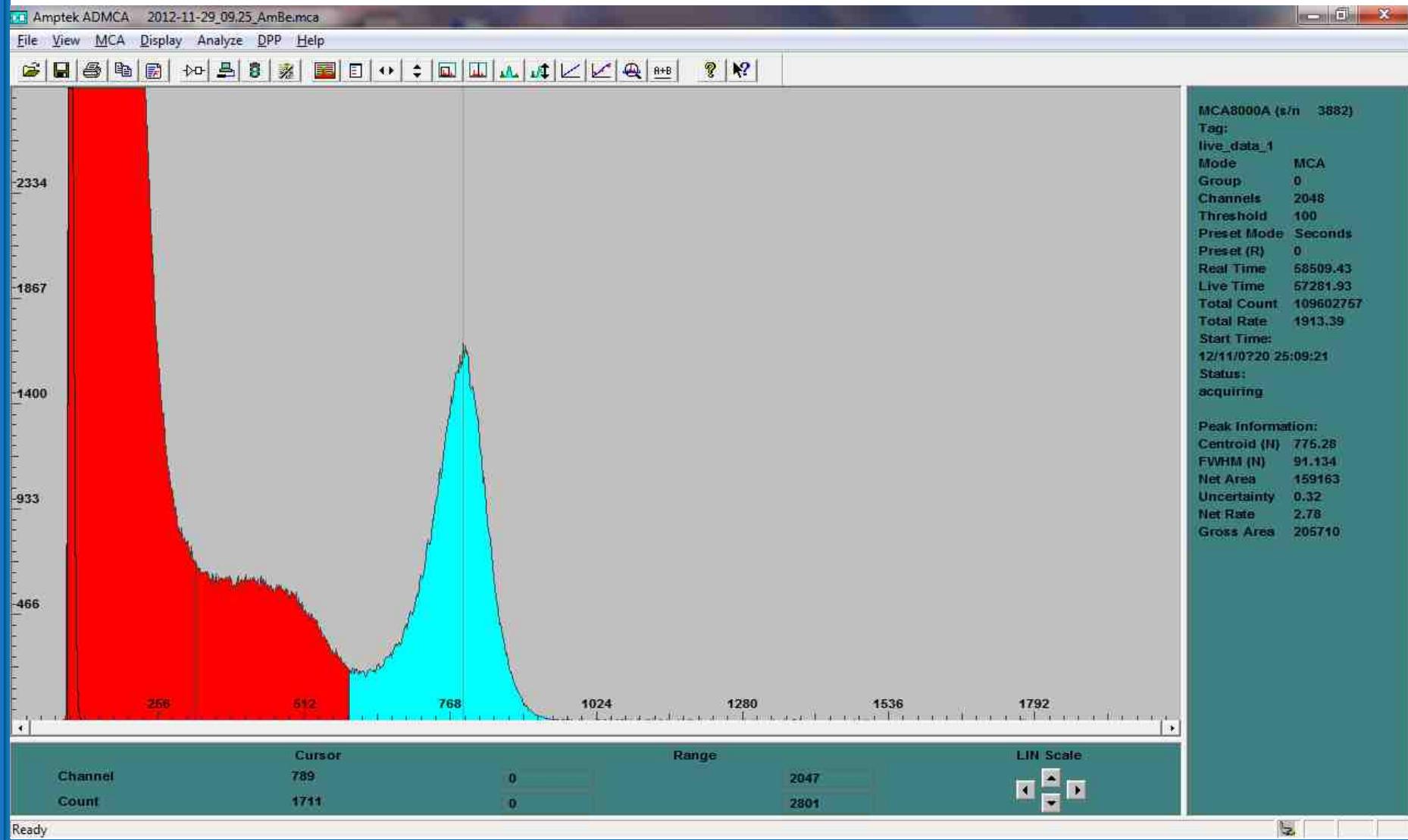
polyethylene to thermalize neutrons

neutron  
source

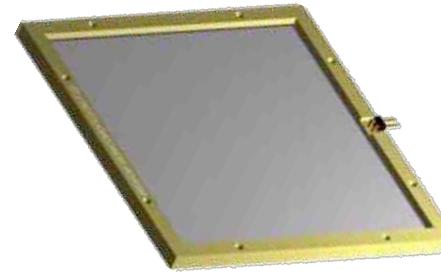
Si +  ${}^6\text{LiF}$ neutron  
source

PET moderator

## Multichannel analyzer screenshot



## **$^6\text{LiF}$ + solid state: benefits vs disadvantages**



**Silicon detector**

## **$^6\text{LiF}$ material: benefits vs disadvantages**



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

4.78 MeV kinetic energy

enrichment @95% € 7 / g

stable salt, easily evaporated

substrate: glass, Al, C,...

substrate thickness  $\geq 1\mu\text{m}$

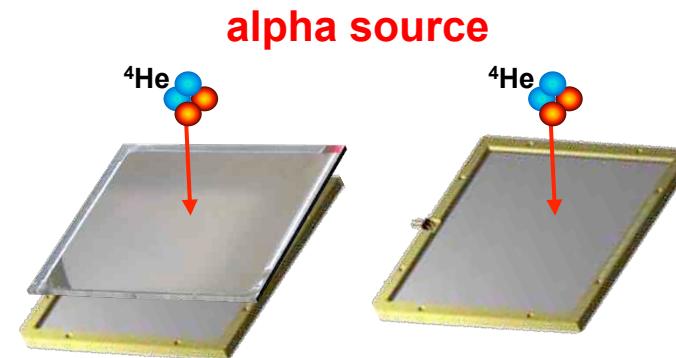
adherence: not quite relevant



not very high cross section

natural abundance: 7%

## $^{6}\text{LiF}$ layer thickness measurement

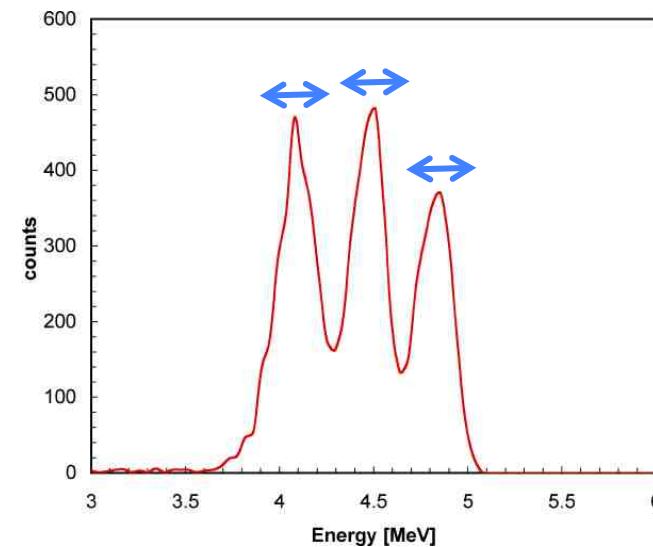


exploits the same detector

rough, simple, cheap:  
peak shift measurement

output in  $\mu\text{g}/\text{cm}^2$

precision and uniformity few %



## detector mechanical structure



robust, manageable

little non-detector material

stackable



large area = many detectors



but...  
promising larger size  
with scintillators

## operating features



vacuum compatible

low voltage

very stable

detector/converter box closed

easily assembled/disassembled

no physical/chemical agents  
on the converter

## outlook: application fields

- Nuclear physics research
- Homeland security
- Dosimetry
- Radwaste monitoring
- Spent fuel handling and storage monitoring
- Neutron beam science
- other...

## ongoing developments



scintillators: promising results coming soon



e adesso...  
in laboratorio!!!

