Istituto Nazionale di Fisica Nucleare
SEZIONE DI TORINO

Principle of operation of an innovative new sensor for neutron detection based on resistive AC coupled LGADs

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Introduction

Neutron detection

Neutron detectors are not vertex detectors!

- Lower energies (typically below 10 MeV)
- Low rates and fluxes
- Should be photons insensitive

Neutrons need conversion into charged particles to be detected

- Recoil (high energies)
- Induced fission
- Nuclear capture by elements with A > 40 (passive)
- Nuclear capture by light elements

Classification	**Energy**
Cold	< 0.012 eV
Thermal	0.012 eV - 0.4 eV
Epithermal	0.4 eV – 0.01 MeV
Fast	0.01 MeV – 20 MeV
High Energy	> 20 MeV

Field of application: neutron imaging

Neutron Imaging is a radiographic non- destructive method.

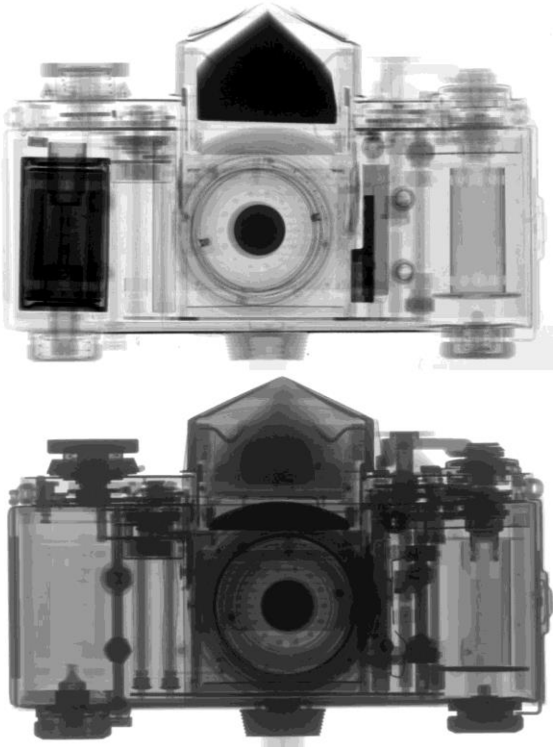
It exploits neutrons ability to penetrate materials with attenuation coefficients specific for each material (isotope).

In this field are employed

- cold or thermal neutrons beams
- Fluxes in the order of 10^5-10^9 n/(cm^{2}s)

Normally, images are shot using neutron cameras

- Maximum resolution ever achieved of circa 14 µm, normally around 100 µm
- Camera integration time is around 1-2 s



Xrays (top) and neutrons (bottom).
Image taken from PSI website.

How to detect thermal neutrons

Luca Menzio – INFN Torino

Given the high cross section, traditional methods to detect thermal neutrons rely on neutron capture and subsequential detection of secondary charged particles with scintillators or gases.

Excluding fissionable isotopes and materials which don't provide good neutron-photon discrimination, the main useful thermal capture reactions are

${}^{3}_{2}He + n \rightarrow {}^{3}_{1}H + p$	Q = 764 keV	5330 barn @ 25 meV
$\boxed{{}^{6}_{3}Li + n \rightarrow {}^{3}_{1}H + \alpha}$	Q = 4.78 MeV	940 barn @ 25 meV
${}^{10}_{3}B + n \rightarrow \alpha + {}^{7}_{3}Li$	Q = 2.79 MeV	3840 barn @ 25 meV
${}^{10}_{3}B + n \rightarrow \alpha + {}^{7}_{3}Li^{*}$	Q = 2.31 MeV	

- High Q-value, good photons rejection
- Solid compounds (i.e. LiF and LiI)
- Easy to enrich – relatively cheap

⇨ **Most employed with silicon devices**

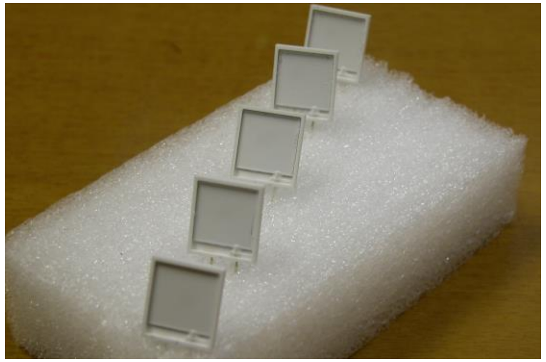
Neutron Detection with Silicon Sensors

Silicon detectors and ^{6}Li

At INFN LNF (Laboratori Nazionali di Frascati) Roberto Bedogni’s team is successfully using a LiF deposition technique to assemble silicon neutron detectors. It consists in:

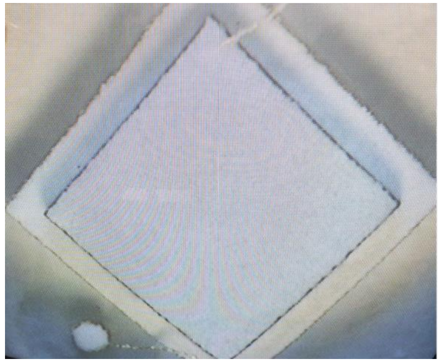
- Suspension with ^{6}LiF enriched powder
- Evaporation process

The method is quite simple, cheap and provides a good reproducibility



S3590-09 Hamamatsu Diode

Area 1 cm^2



SgLux UV photodiodes Silicon carbide

Area 7.2 mm^2

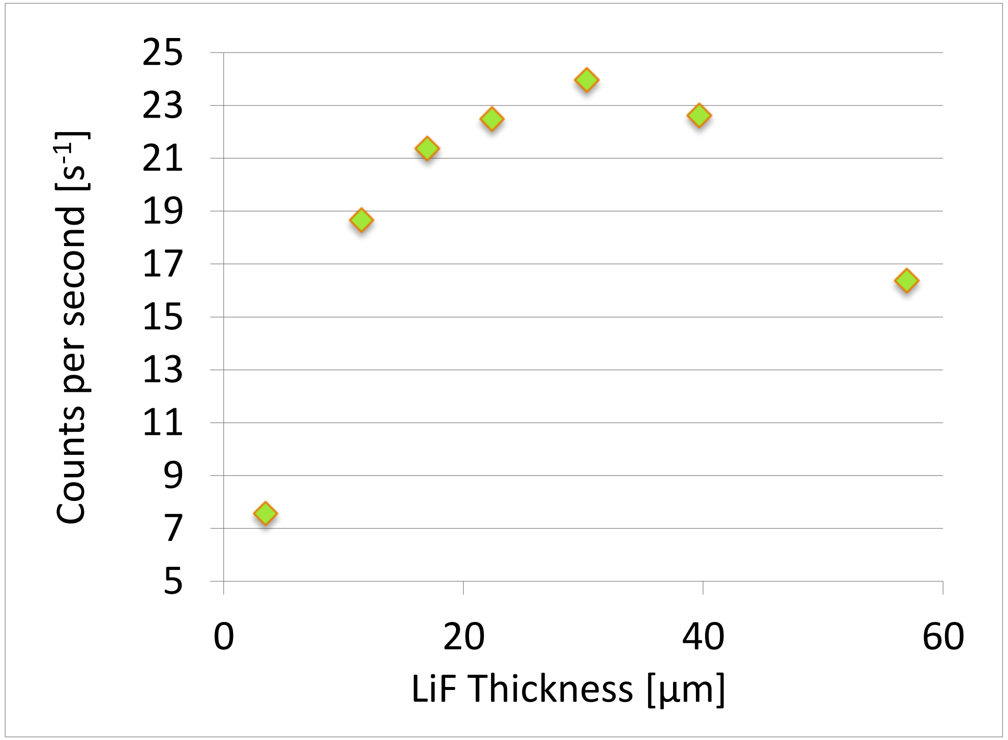
Diodes sensitive to neutrons

The detectors are assembled, wired and tested by the LNF group. The testing is carried out in the Hotnes facility.

Most recently, a set of diodes with ^{6}LiF deposit have been studied and produced for the NCT-WES project.

Both experimental and simulation results show that the maximum efficiency is achieved with **34 µm thick ^{6}LiF** deposition on the diode surface

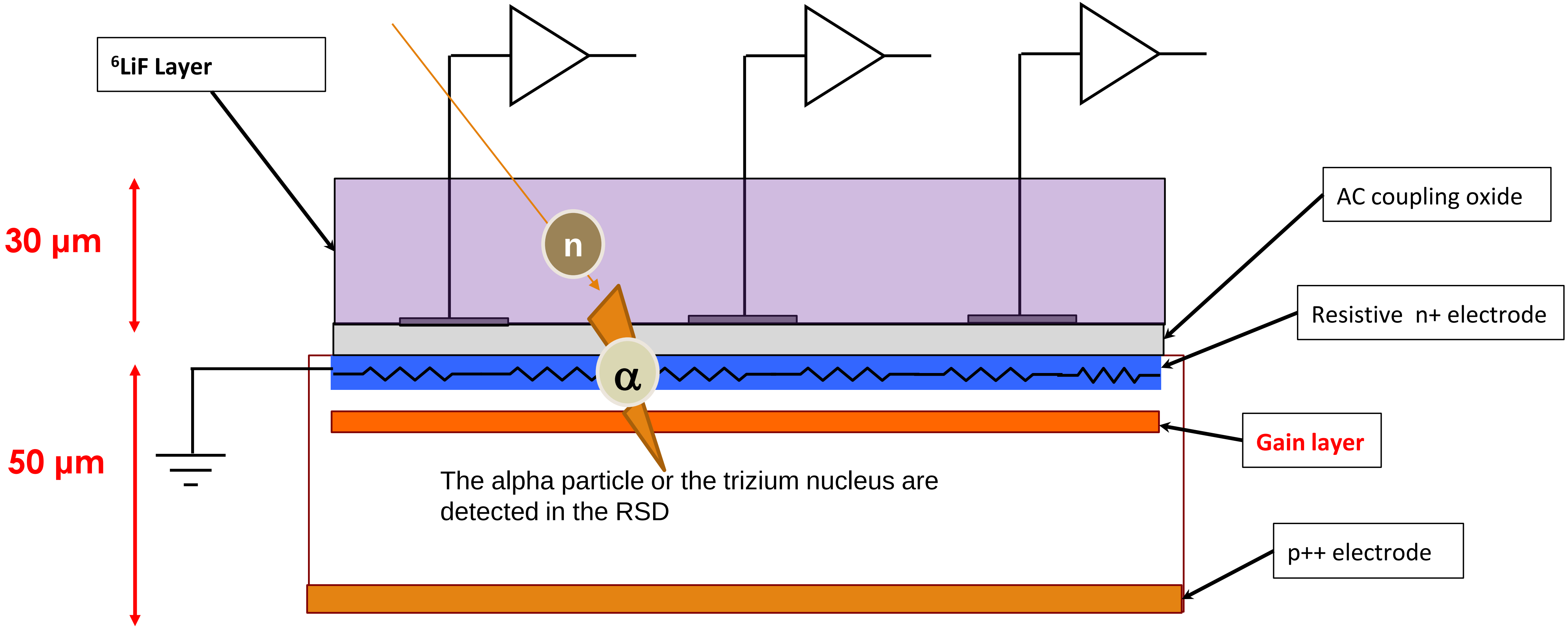
Extremely good for beam monitoring and neutron spectroscopy (inside Bonner Spheres), but not for position and time measurements.



Efficiency results obtained with a LiF coated detector in the Hotnes facility.

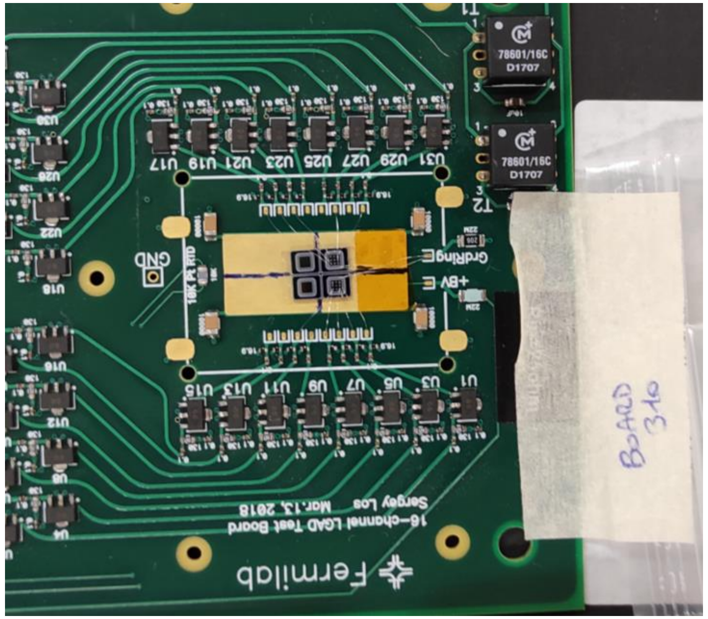
Our Project:
RSDs for neutron detection

Combining RSD with ^{6}LiF



The alpha particle or the trizium nucleus are detected in the RSD

AC-LGADs with LiF coating



AC-LGADs with LiF coating: an innovative neutron detector!

- Great timing performances, 40-50 ps
- Optimal spatial resolution, some µm for MIP protons
- LGAD multiplication provides optimal signal/noise
- Carbonated gain implant provides radiation resistance
- Intrinsic photon rejection
  - Photons with energy greater than 20 keV are very unlikely to generate signals in 55 µm thick sensors (1000 µm absorption length)
- Alphas are completely absorbed (15 µm range in silicon)

AC-LGADs with LiF in practice

For this first trial three different types of detectors were employed: 50-100, 100-200 and 200-500 FBK AC-LGADs.

Practically, coating these sensors proved difficult because of the many bonds.

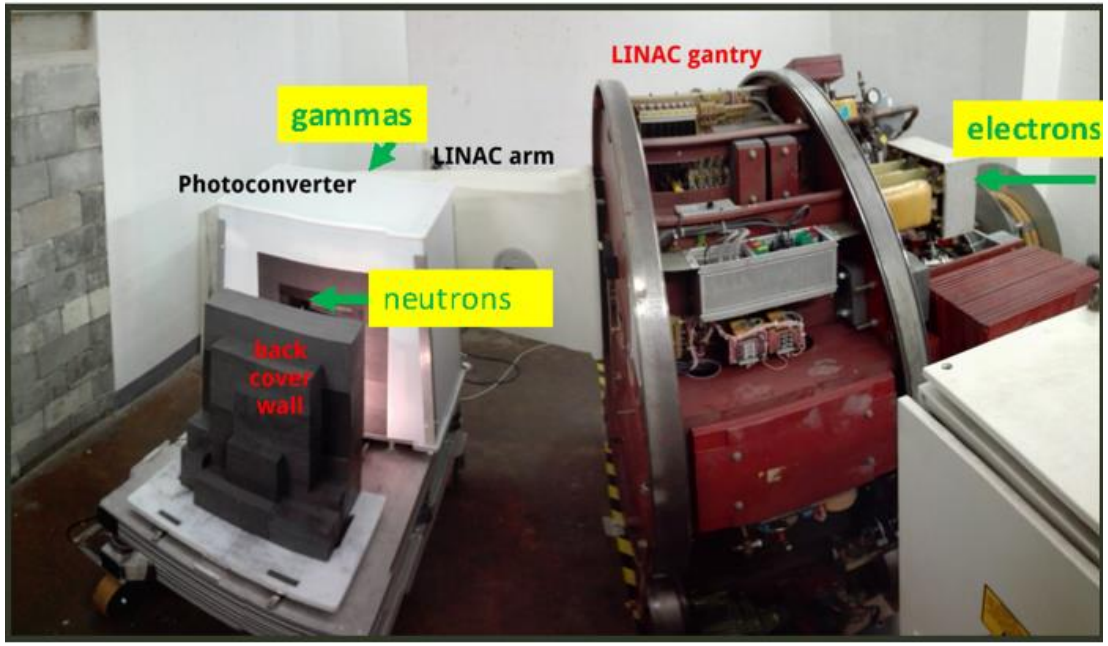
Therefore

- Bonded the sensors to a 16 channels FNAL board
- Glued 3D printed containment walls outside the bonds area
- Sent the boards to the Frascati Labs to do the ^{6}LiF deposition

Work in progress! We should receive them back by the end of June

Detector testing

Detectors will be tested in the Turin Thermal Neutron Source.



Based on the Elekta SL18 Precise Linac.

Accelerates electrons (up to 18 MeV) and can be operated in photon mode

A photoconverter provide a testing region with thermal neutrons

Maximum fluence rate:

$$\dot{\Phi}_{th} = (1.75 \pm 0.04\,)10^{6}\; n\; cm^{-2}\; s^{-1}$$

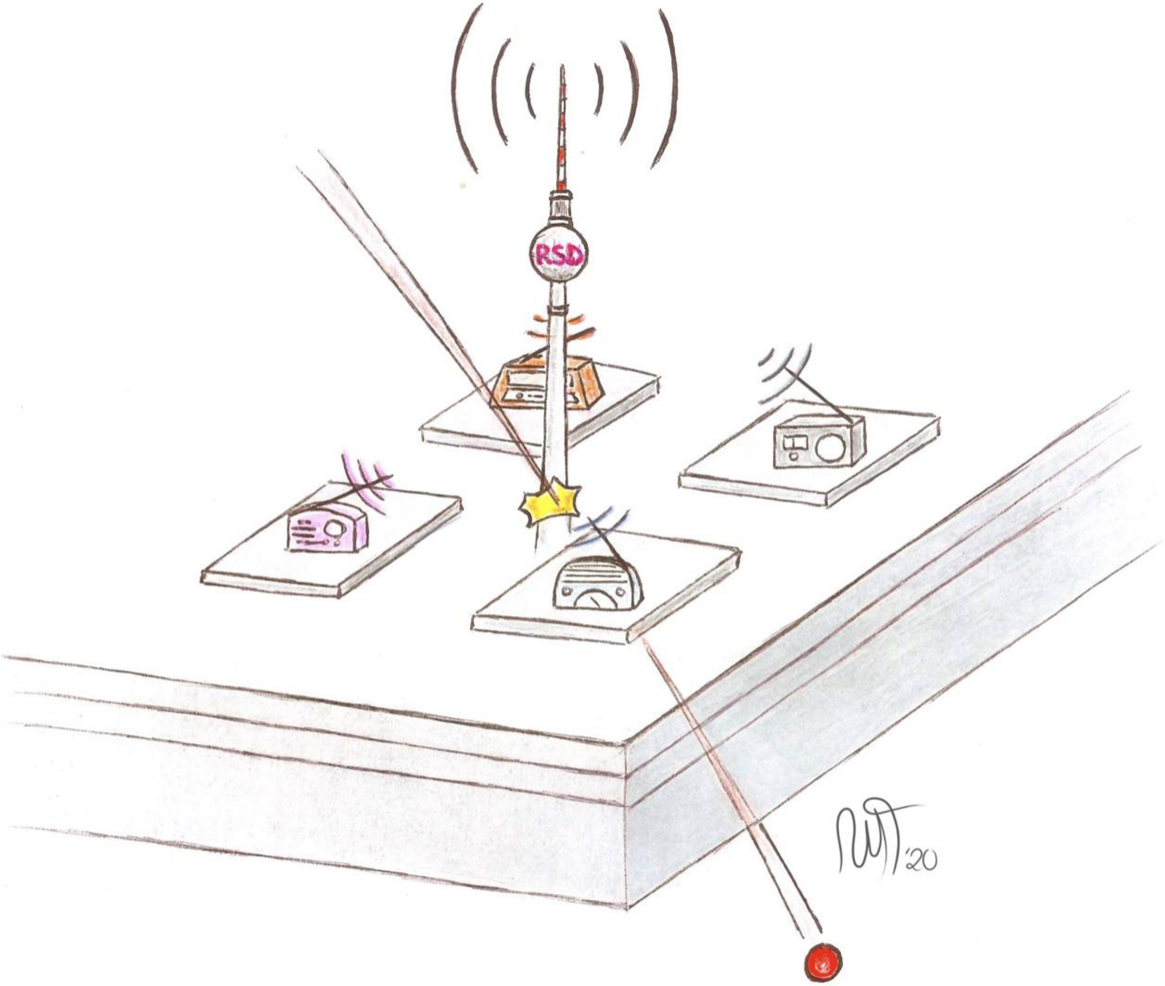
Conclusions

Our group is currently developing a method to detect thermal neutrons with the RSD devices, possibly for neutron imaging.

This detector would provide

- Good radiation resistance
- LGAD-like timing resolution
- Spatial resolution of few microns

First experimental tests are going to be carried out in the next future!



Thank you!

Special Thanks to

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- INFN - Gruppo V, UFSD and RSD projects
- INFN – FBK agreement on sensor production (convenzione INFN-FBK)
- Horizon 2020, grant UFSD669529
- Dipartimenti di Eccellenza, Univ. of Torino (ex L. 232/2016, art. 1, cc. 314, 337)
- Ministero della Ricerca, Italia , PRIN 2017, progetto 2017L2XKTJ – 4DinSiDe
- Ministero della Ricerca, Italia, FARE, R165xr8frt_fare

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- *A new active neutron detector*, R. Bedogni et al., Radiation Protection Dosimetry (2013)
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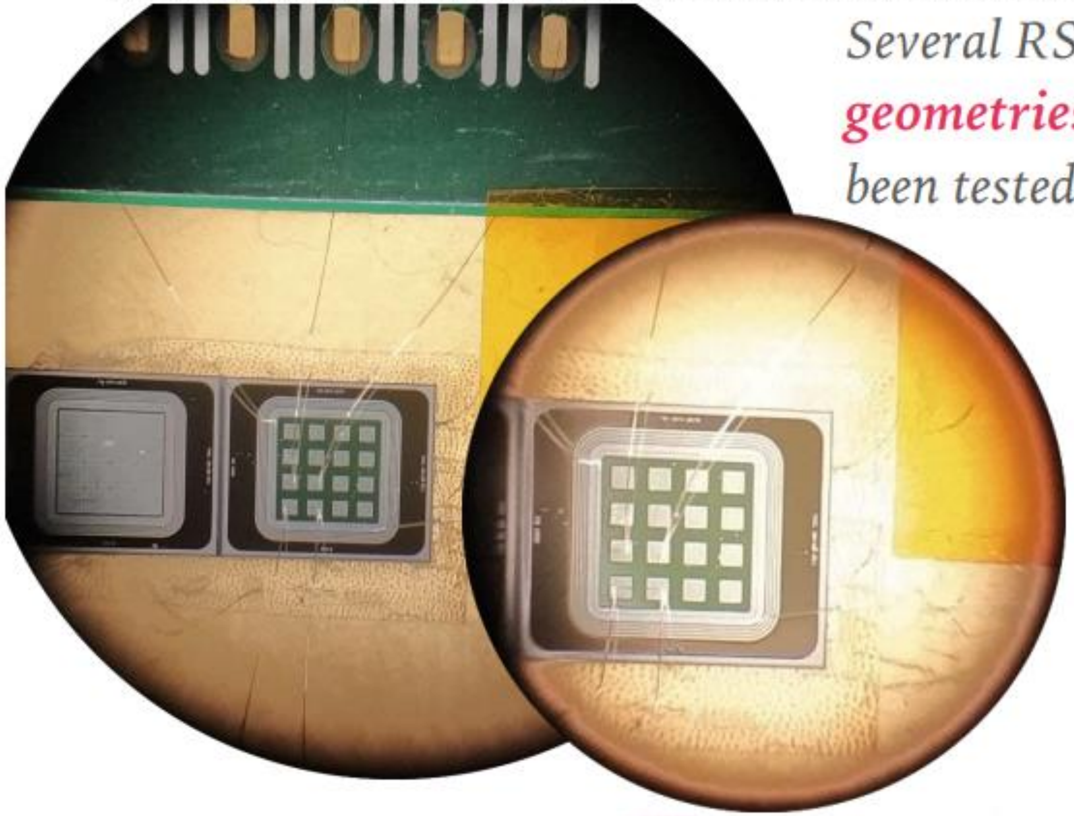
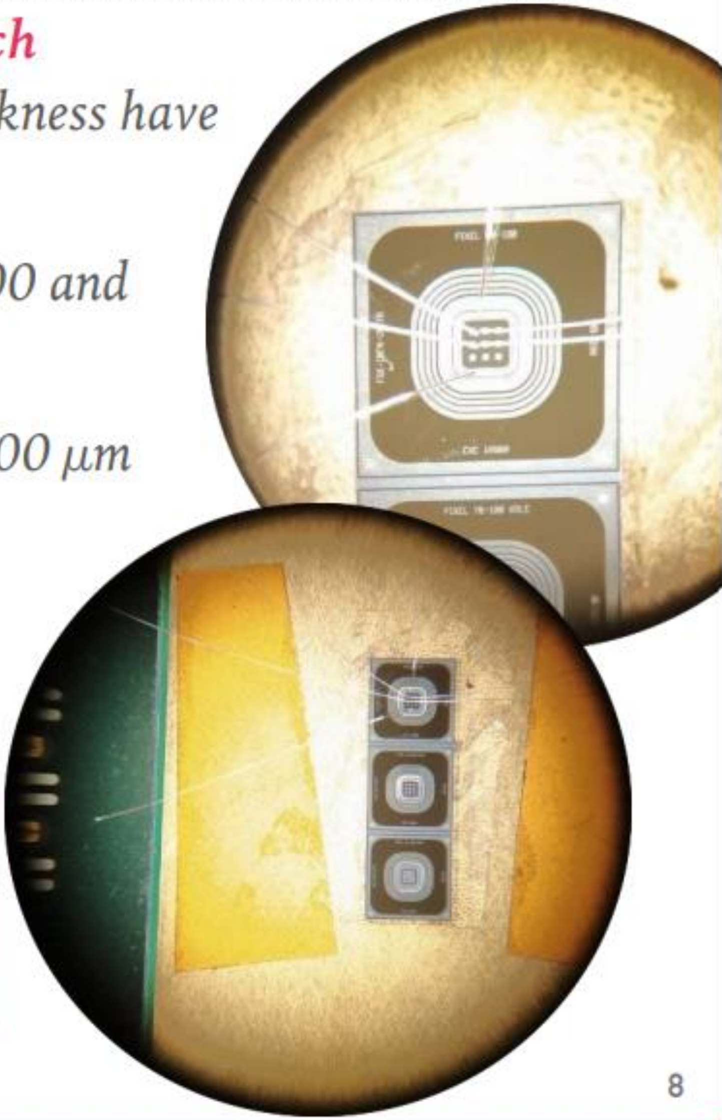
RSD DEVICES UNDER TEST



Several RSD matrices with ***different pad-pitch geometries*** *but same resistivity and oxide thickness have been tested*

Pitch dimensions range between 100 and 500 μm

Pads size ranges between 50 and 300 μm



50-100

70-100

100-200

150-200

150-300

200-300

200-500

300-500

SUMMARY OF 200-UM PITCH RSD TIMING RESOLUTION RESULTS

*Timing resolution results are **compatible with the best LGAD performances** obtained at the same gain*

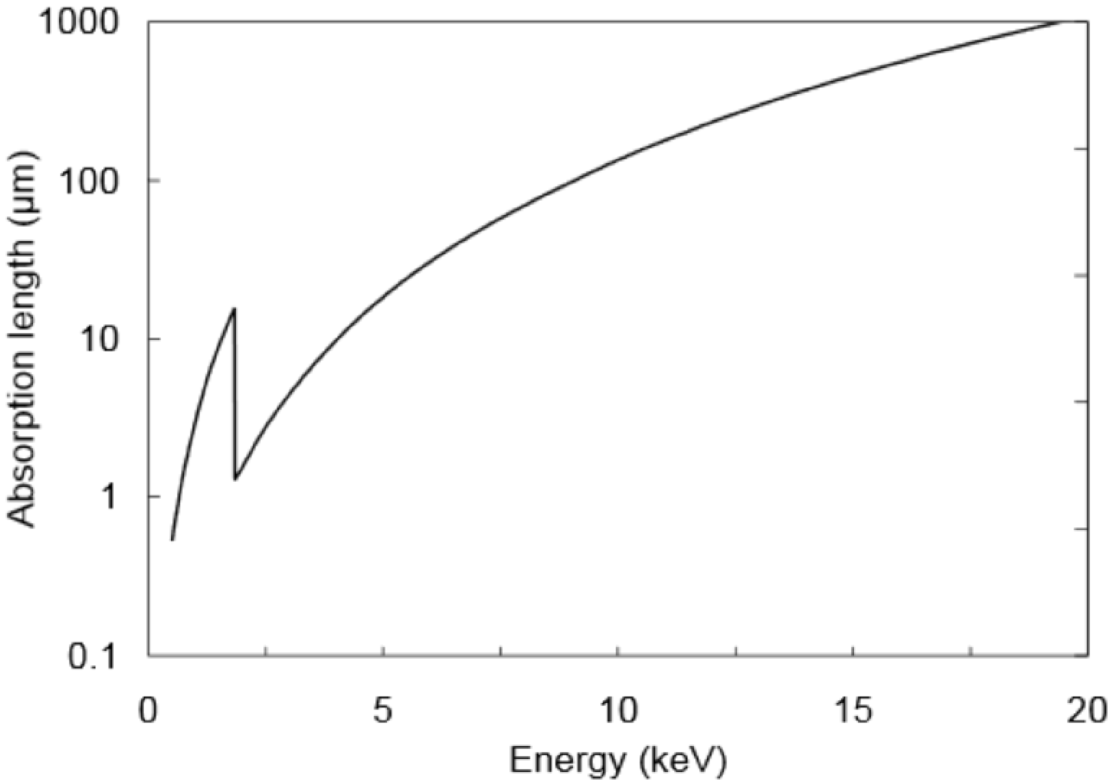
	single pad	3 pad	4 pad
100-200 laser	45 ps	-	22 ps
100-200 test beam	50 ps	44 ps	-
190-200 test beam	35 ps	42 ps	-

$$\sigma_t^2 = \sigma_{\mathrm{Jitter}}^2$$

$$\sigma_t^2 = \sigma_{\mathrm{Landau}}^2 + \sigma_{\mathrm{Jitter}}^2$$

Final analysis with amplitude-weighted average

Photon absorption length in silicon



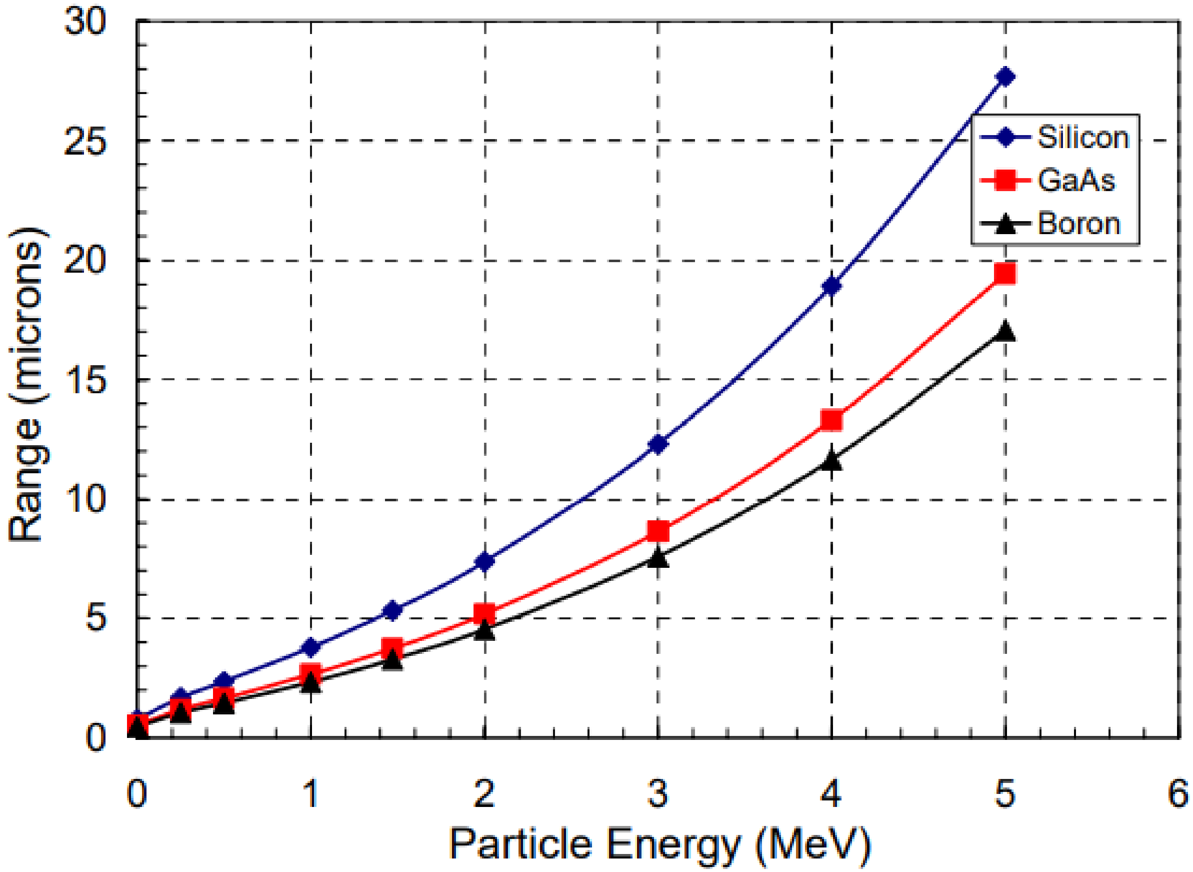


Figure 2 Range of alpha particles in Boron, Silicon and GaAs.

Thermal Neutron Detector Development

M. Costa INFN Torino

They should be:

- Active
- Low noise
- Minimal sensitivity to Photons
- Small dimension
- Able to measure rates 10^2 - 10^8 n cm^{-2} s^{-1} and resist an integrated Fluence ~10^{13} n cm^{-2}
- Cheap

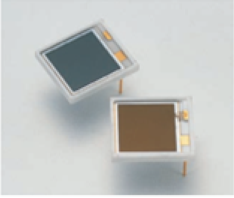
For absolute and punctual fluence rate measurement common silicon substrate devices like TNRD are suitable.
However long exposures or repetitive ones, force us to explore the use of more radiation resistant material → larger Energy gap semiconductor

➡ With this aim, Si-carbide (SiC) detectors have been studied

2 substrates have been considered

Si-TNRD

Based on:
S3590-09 HAMAMATSU diodes



Si-Carbide

Based on:
SgLux UV photodiodes
Active area: 0.05 – 7.6 mm^2

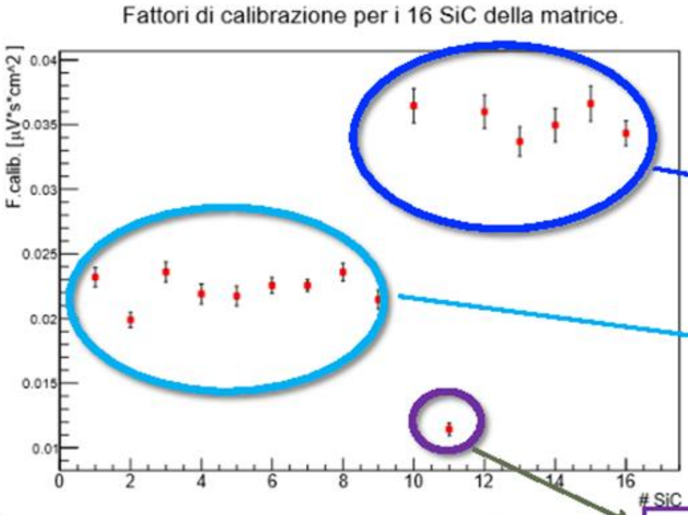
\+

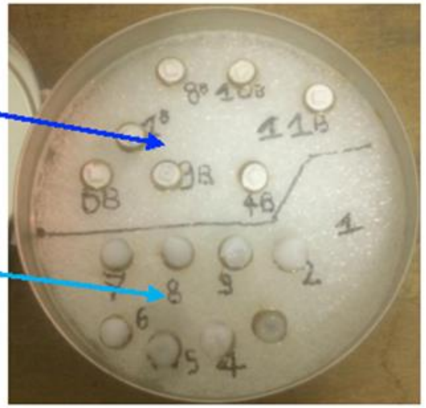
Appropriate radiator material

Detector Calibration and photon sensitivity

M. Costa INFN Torino

Calibration at ENEA Casaccia (RM) TRIGA Reactor (100kW – 1MW)
1 MW → (1.59 +- 0.03)10^6 $cm^{-2}s^{-1}$ (Thermal neutron)


Fattori di calibrazione per i 16 SiC della matrice.



2 different ^{6}LiF deposit recepies give different response sensitivity

irradiated to 5 x 10^{13} n $cm^{-2}s^{-1}$

Calibration accuracy 5-8%
being improved


CISAM (Pisa)

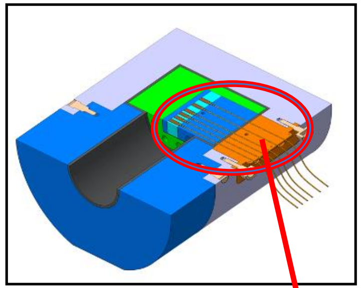
^{137}Cs and ^{60}Co sources

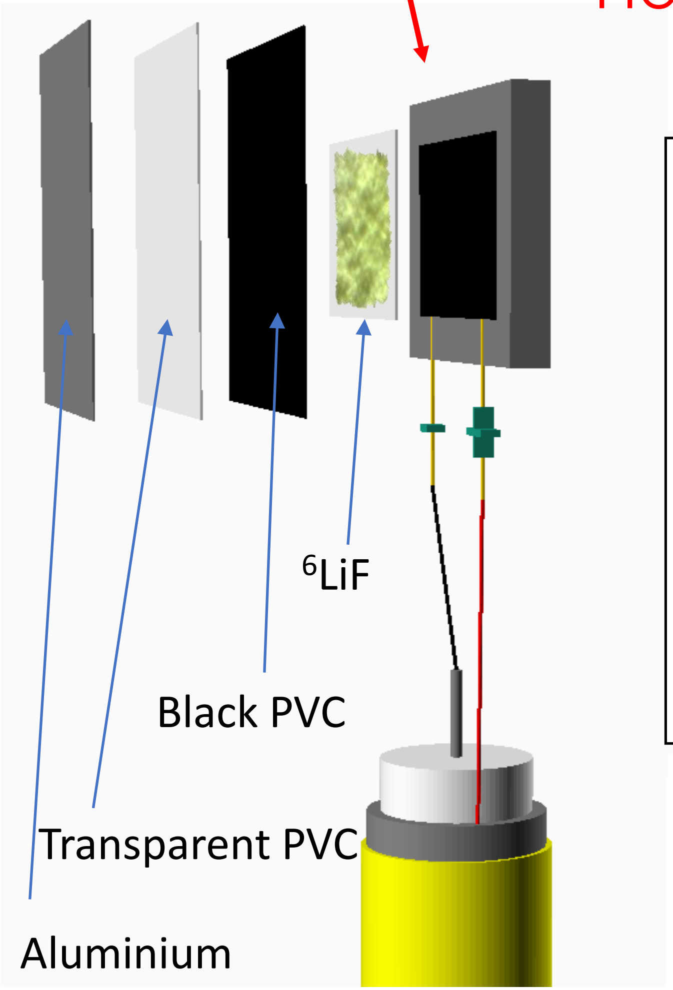
PHOTON SENSITIVITY
1 unit of thermal fluence rate (1 cm-2 s-1) produces a signal equivalent to 70 μGy/h of photon signal
Photon to neutron sensitivity ~10^{-4}

TNPD

(Thermal Neutron Pulse Detector)

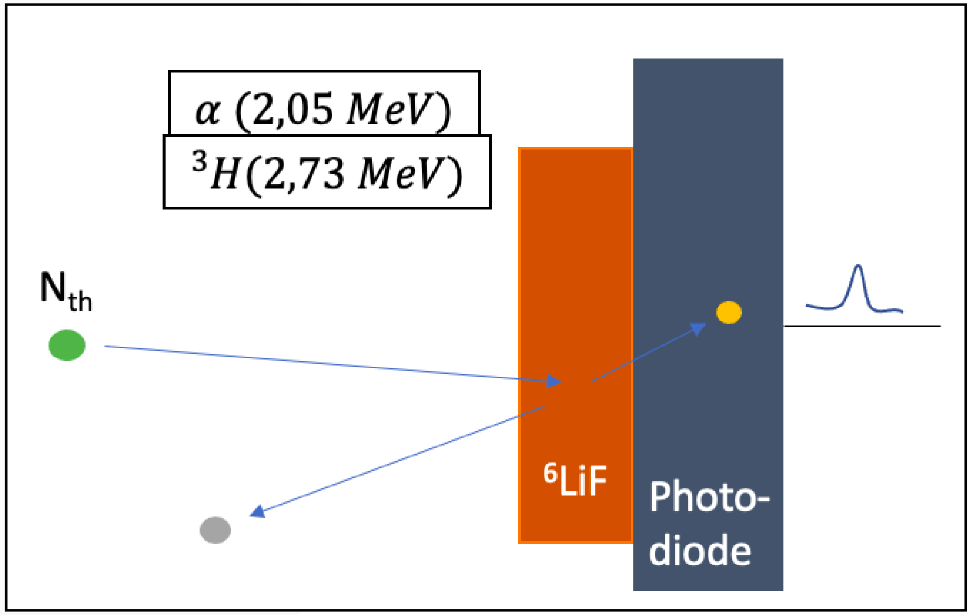
How do we measure thermal neutrons?





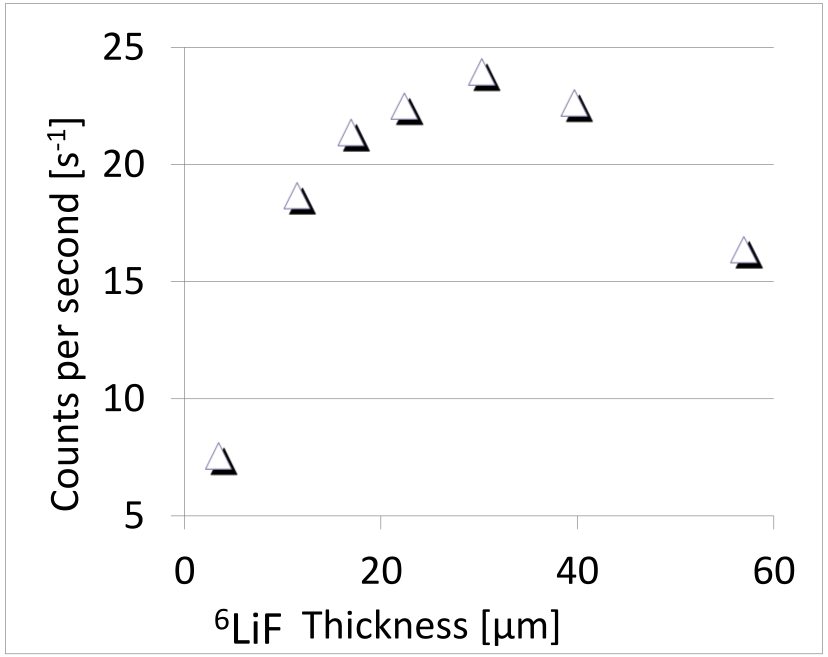
My work

1x1 cm^2 **S3590-09 Hamamatsu Photodiode**



My work

$$\sigma_{th(25meV)}\,[\,^6Li(n,\alpha)^3H] = 940\ b$$



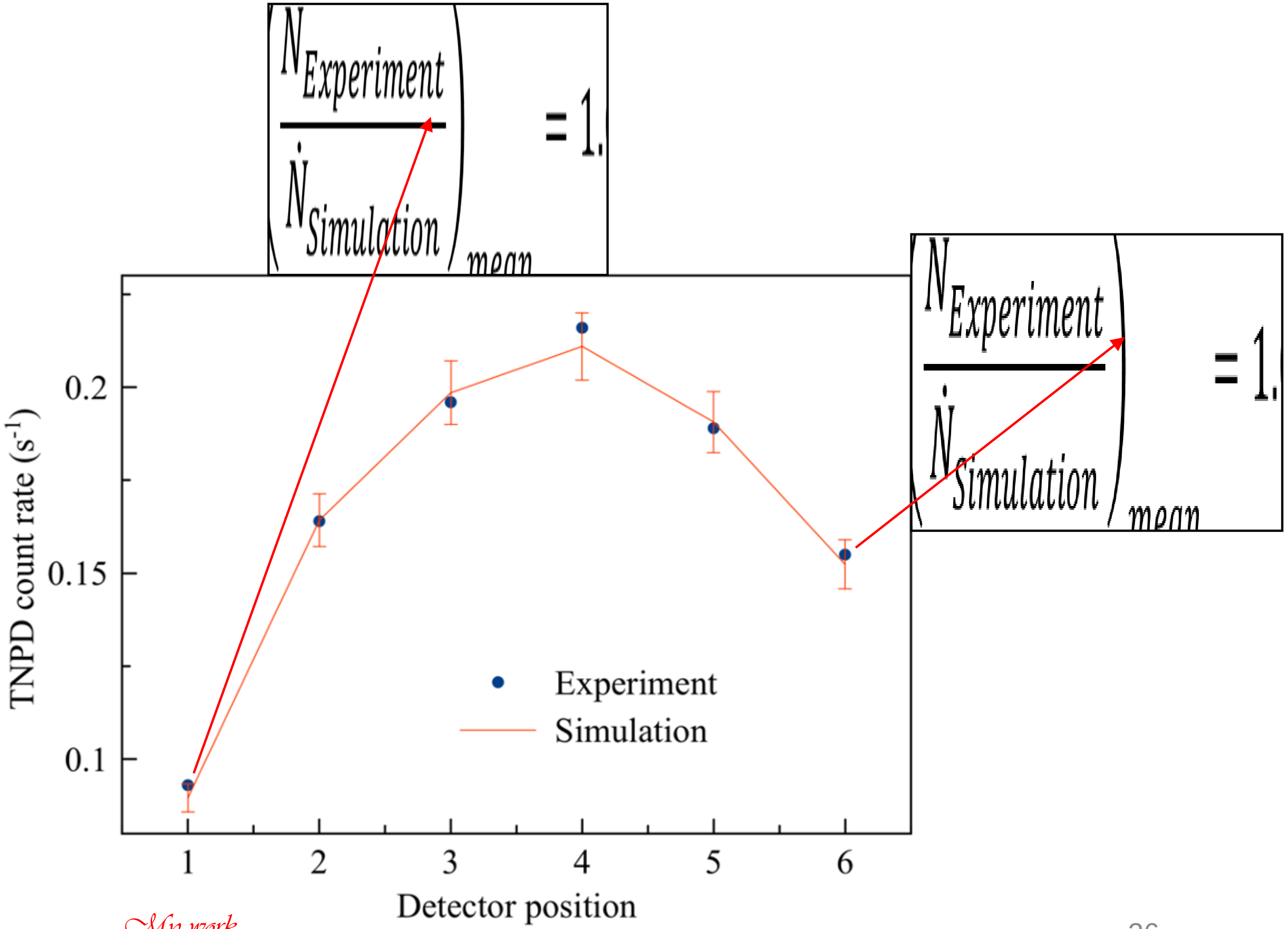
My work

Dedicated measure for the determination of the optimal **^{6}LiF thickness = 30 μm**

Absolute comparison between experiment and simulation

$$\dot{N}_{Simulation} = \varepsilon_{TNPD} \cdot \dot{N}_{{}^6Li(n,\alpha)^3H}$$

$$\left(\frac{\dot{N}_{Experiment}}{\dot{N}_{Simulation}}\right)_{mean} = 1.01 \pm 0.02$$



My work