Characterization of 3D and planar Si diodes with different neutron converter materials

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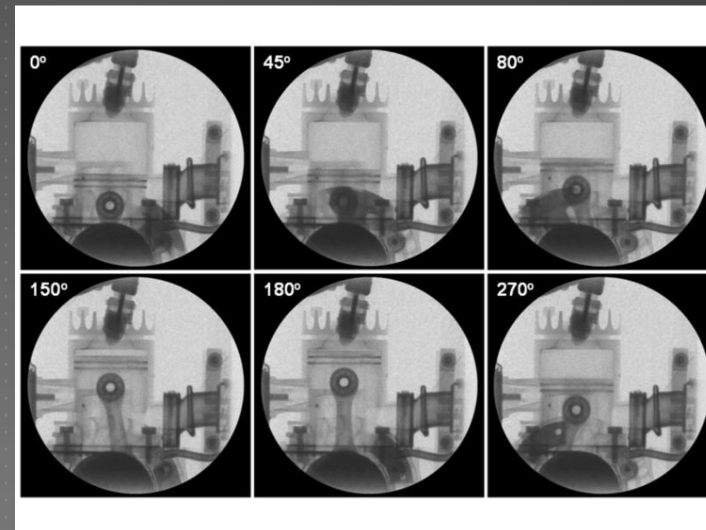
Outline

- Introduction: state of the art in neutron detector
- Neutron detectors:
  - 3D structures and their characterizations
  - Planar sensors and their characterizations
- New geometries under development for the next fabrication batch.
- Conclusions

Introduction

- Interest fields:
  - security, e.g. for detection of radioactive materials or explosives
  - medical imaging
  - high energy and nuclear physics
  - Etc.



- ^{3}H technology:
  - Low spatial resolution
  - High cost
  - High efficiency
  - High voltage required
  - ^{3}H in the world has dramatically decreased with a consequent increase of cost

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State of the art: Thermal Neutrons

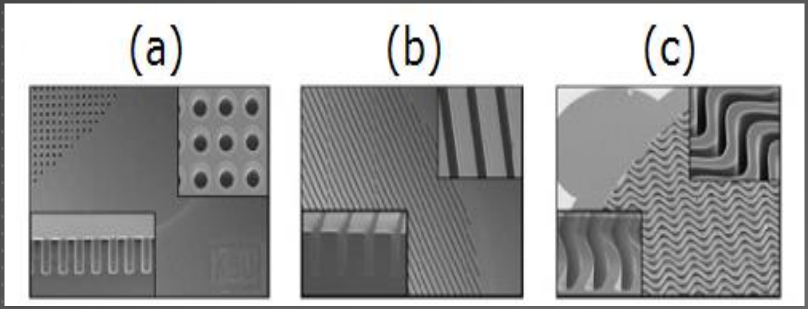
- Thermal energy per particle is about 0.025 eV.
- Considering ^{10}B converter:
  - 90% capture in 43µm
  - Path length reaction product 2-5 µm
- Absolute planar efficiency 3-4%

Material	Reaction products	σ[b]
^{10}B	α	3840
^{6}Li	3H+α	940
^{157}Gd	γ (low energy)	24000
^{113}Cd	γ (558.6 & 651.3keV)	20000

$$^{10}B + {}^{1}_{0}n \rightarrow \begin{cases} {}^{7}Li\ (at\ 1.015\ MeV) + \alpha\ at\ 1.77 MeV) \\ {}^{7}Li\ (at\ 0.840 MeV) + \alpha\ at\ 1.47 MeV) \end{cases}$$

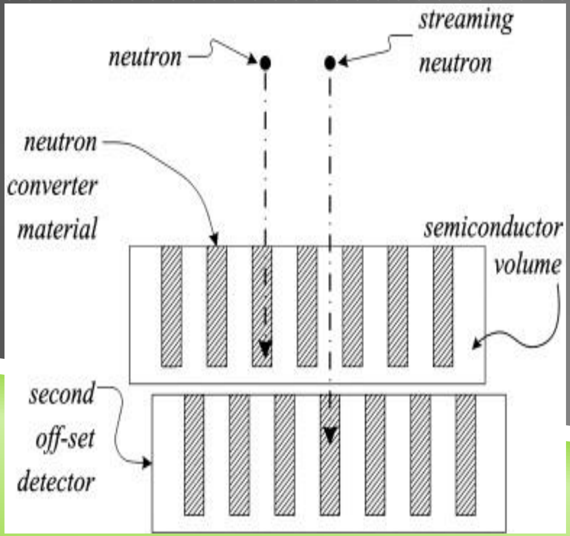
$$^{6}Li + {}^{1}_{0}n \rightarrow {}^{3}H\ (at\ 2.73\ MeV) + \alpha\ at\ \ 2.05\ MeV)$$

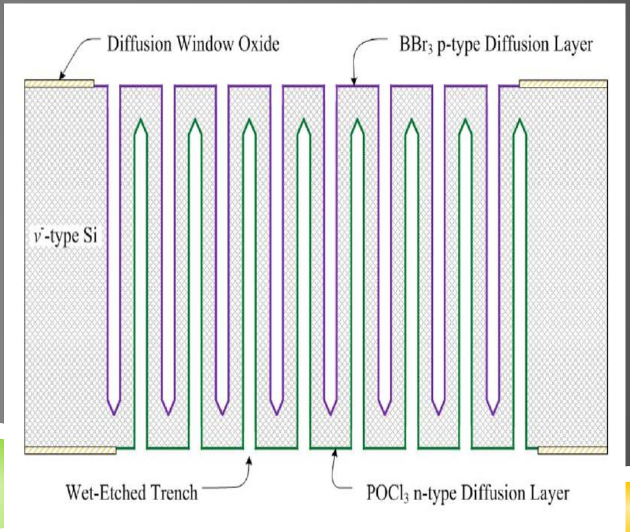
Kansas State University research



- Silicon Bulk 325um
- (a) hole 20 µm depth (~4%)
- (b,c) linear and sinusoidal trench 113/245 depth (up ~20%)

- New development under progress use double side technology





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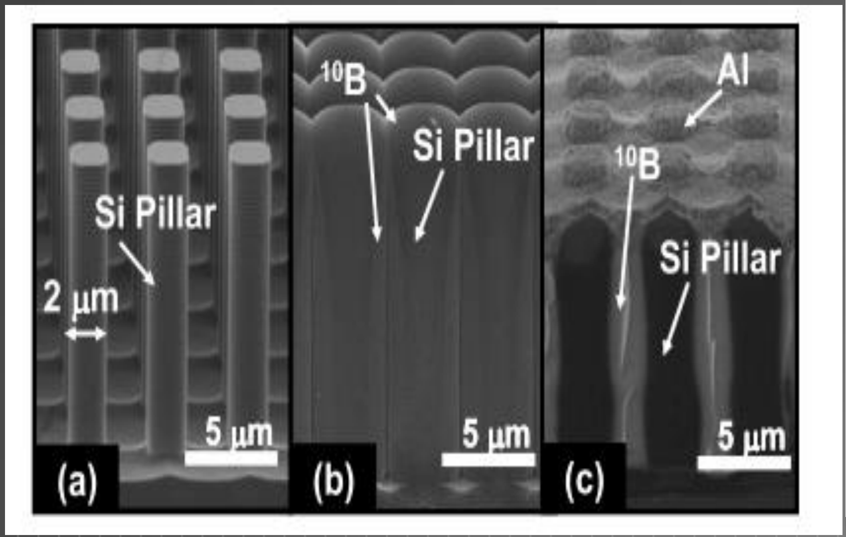
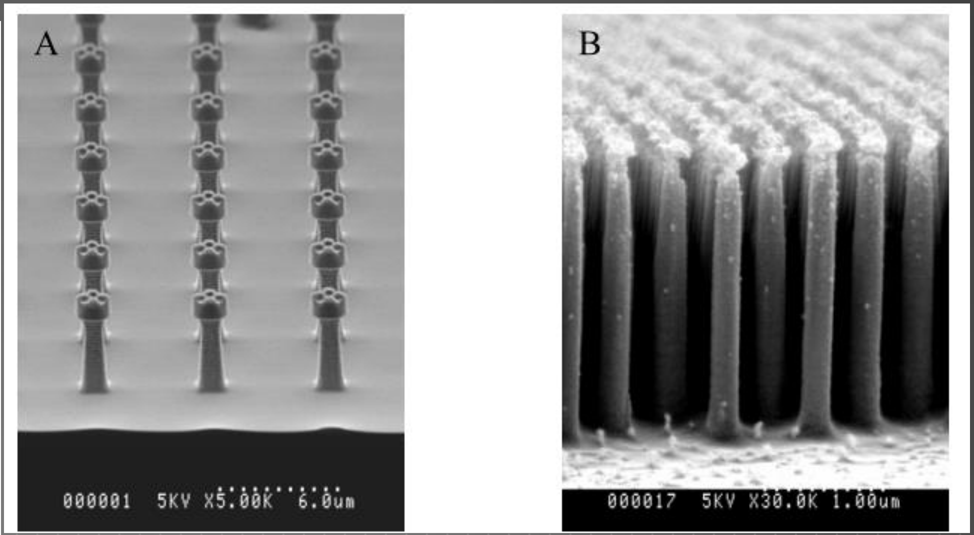
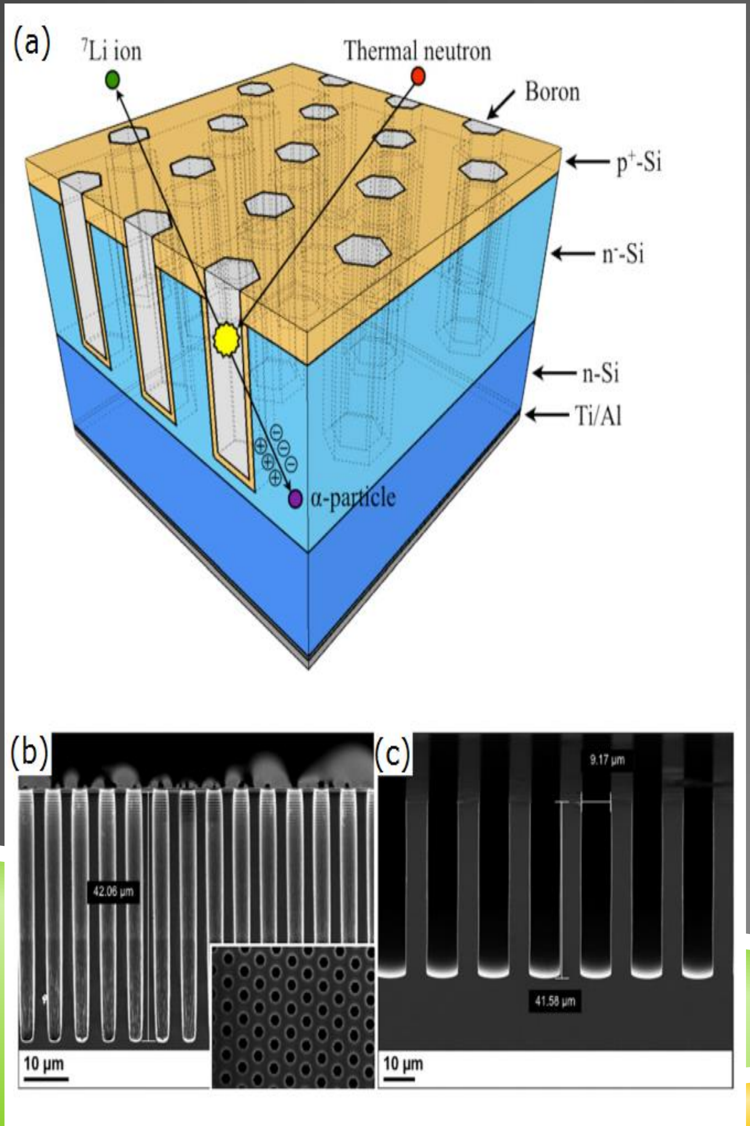
Lawrence Livermore National Laboratory solution



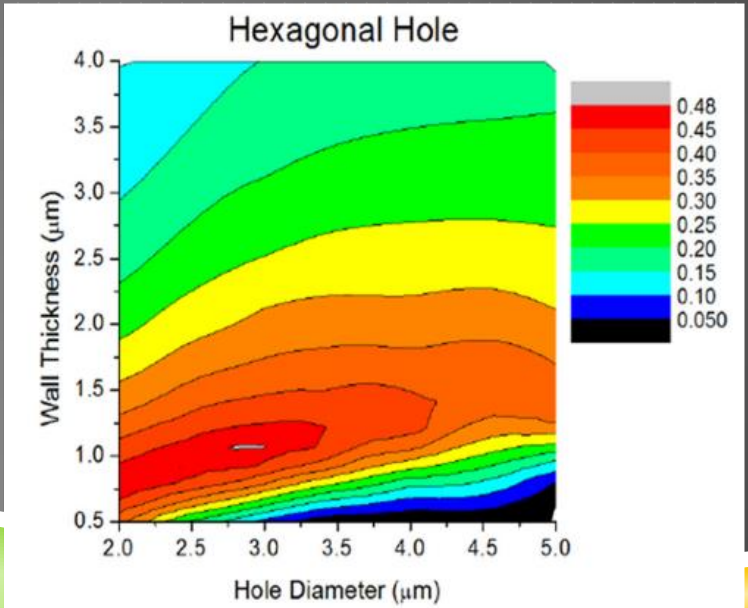


- It is composed of pillar etched from a planar sensor
- Pillar height 50µm predicted an efficiency of ~50%
- Simulation shows that with silicon pillar height 100 µm is it possible have efficiency ~90%

Rensselaer polytechnic Institute device



- Honeycomb array
- Geometry:
  - hole diameter: 2.8µm
  - Si wall width: 1µs
  - Aspect ratio of 40:1
- Efficiency ~26%



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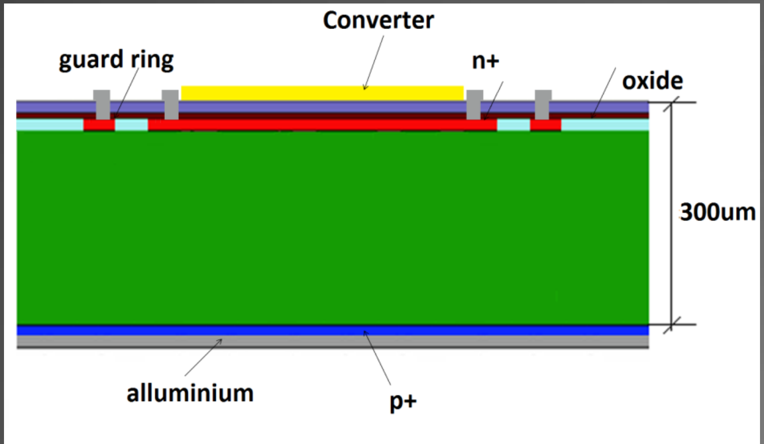
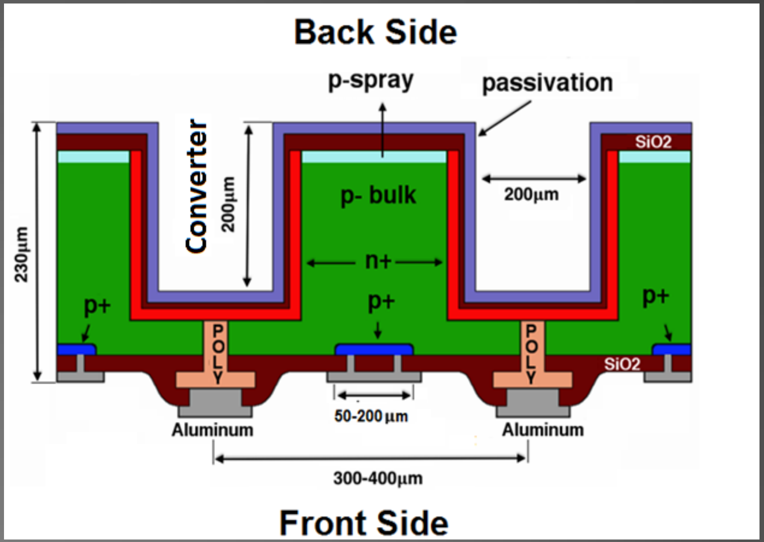
Hyde project



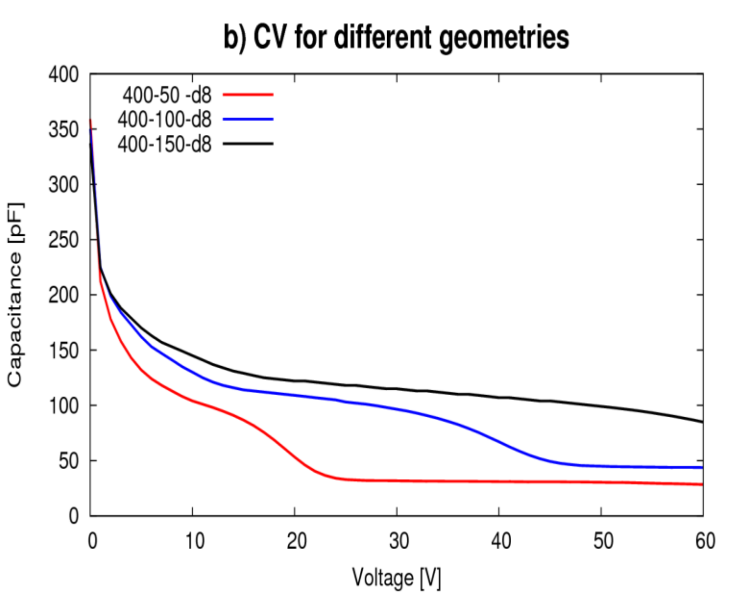


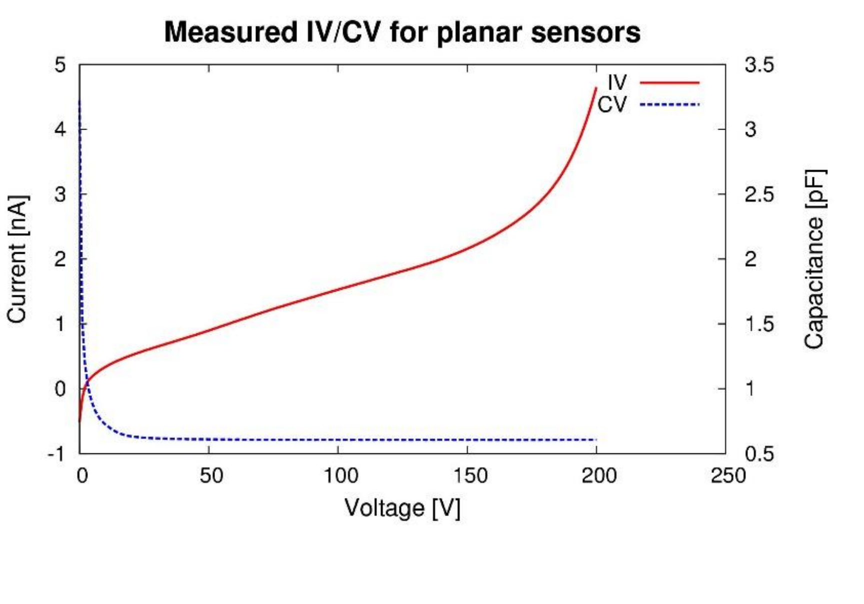
3D sensor schematic cross-section (not to scale), with values of the main geometrical parameters with all the contacts are on the front side.

Planar sensor with guard ring and sputtered converter on the top

Electrical characterization

- Room Temperature
- low leakage currents (a few nA/cm2)
- Measured performed with HP 4145





- Total depletion voltage:
- ~ 10V for 3D devices
- ~ 30V for planar devices

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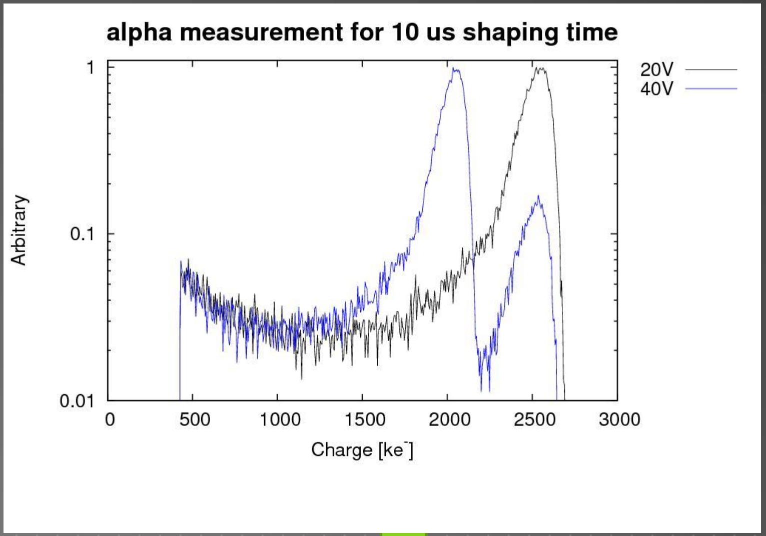
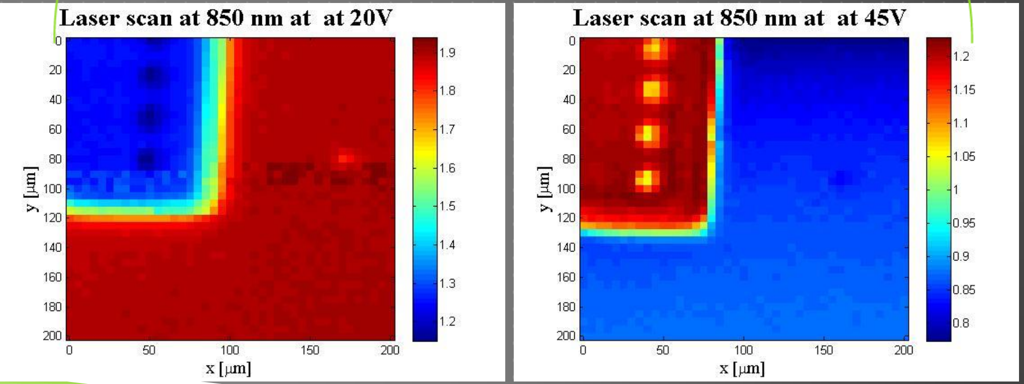
Functional characterization

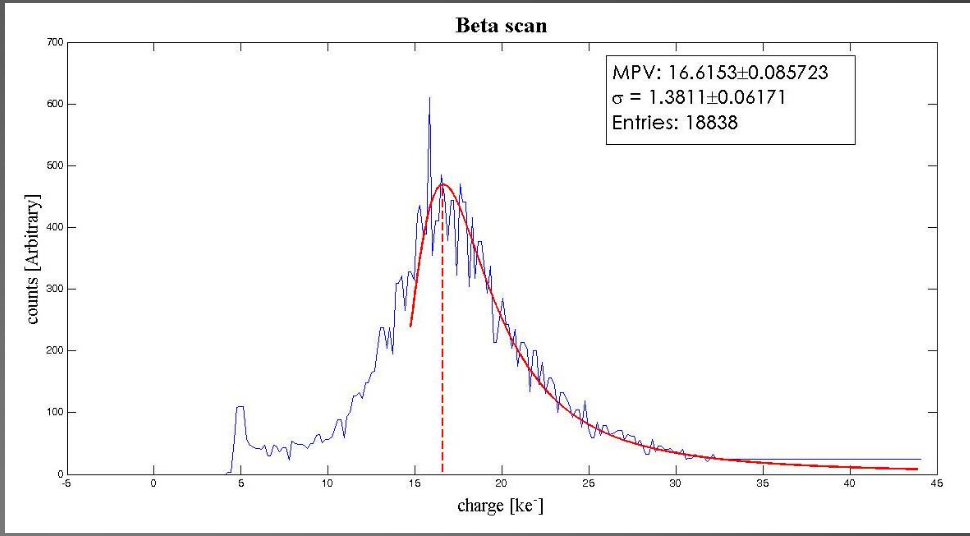
- Collected charge spectra obtained from 241 Am α particles impinging the 3D sensor from the back side at two bias voltages and two different peaking times
- Spectra scan (wavelength 850 nm) from the sensor back side performed at 4 µs peaking time and at two different voltages
- 400-100-d8 Geometry

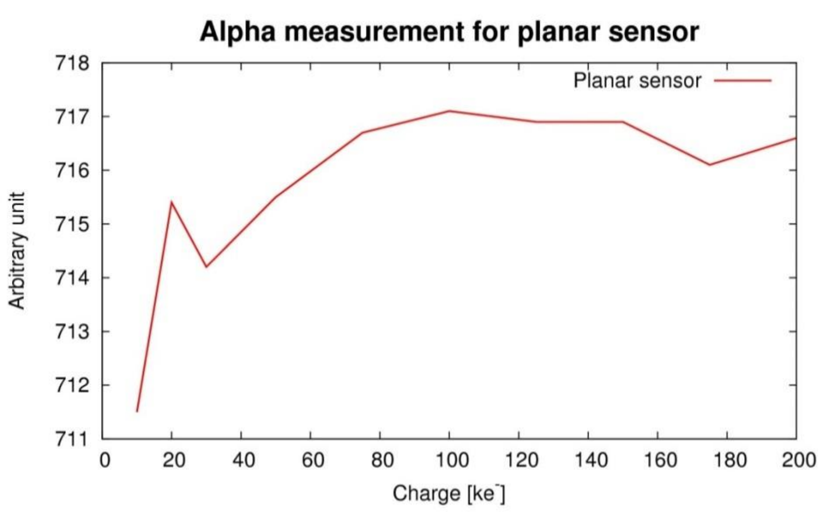




Electrical and functional characterization

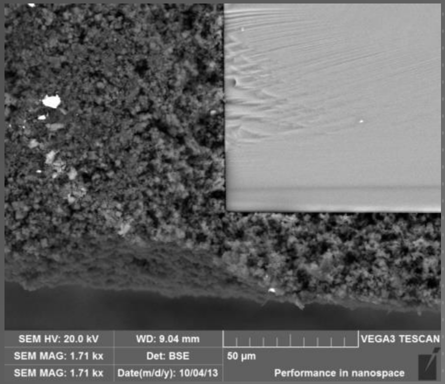
- Alpha and Beta source scan
- Tuning on beta setup not optimized





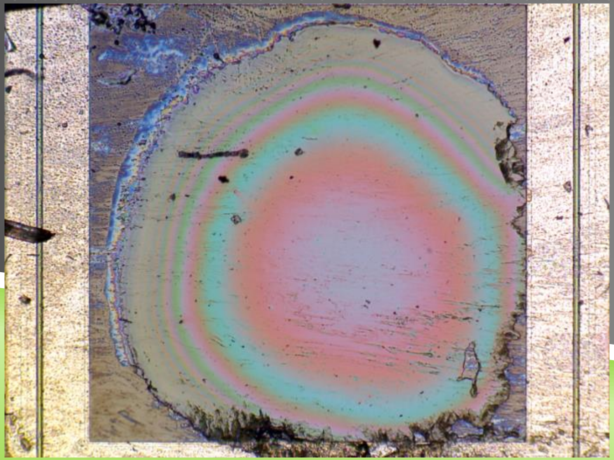
CONVERTER MATERIAL DEPOSITION

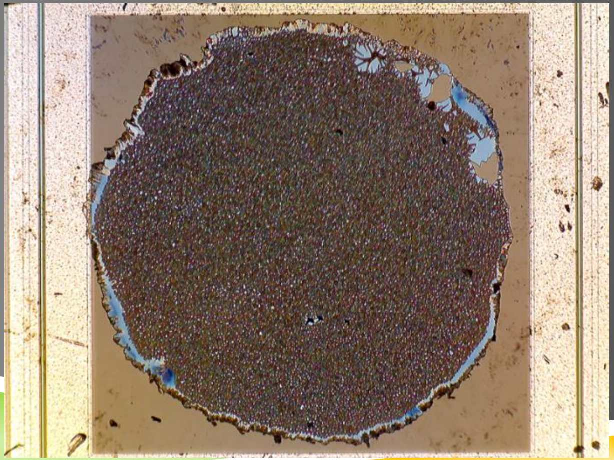
A SEM photograph of a cavity filled at the University of Prague with ^{6}LiF converter



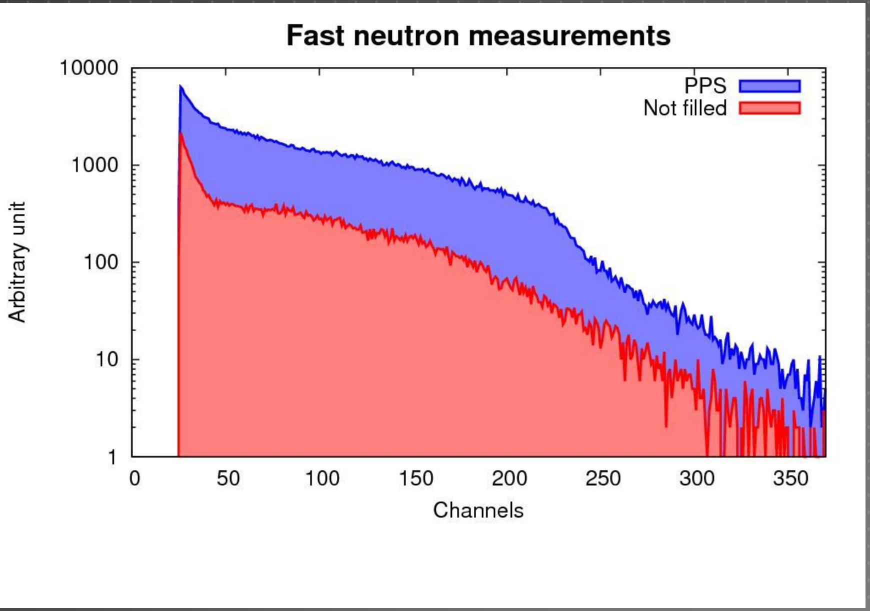
A SEM photograph of planar sensors with enriched Boron sputtered on the surface

- Optical microscopy images of spattered converter on planar sensors::





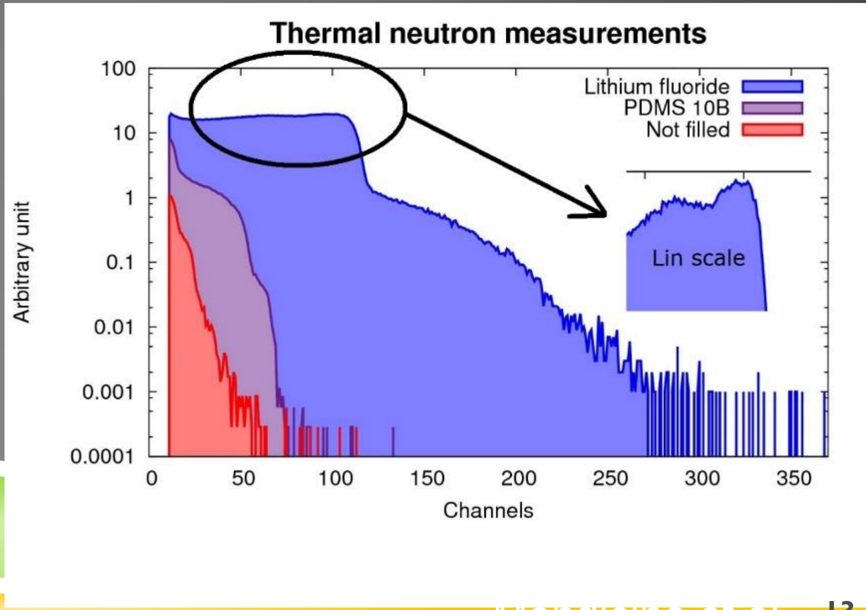
Hyde: Neutron measurements



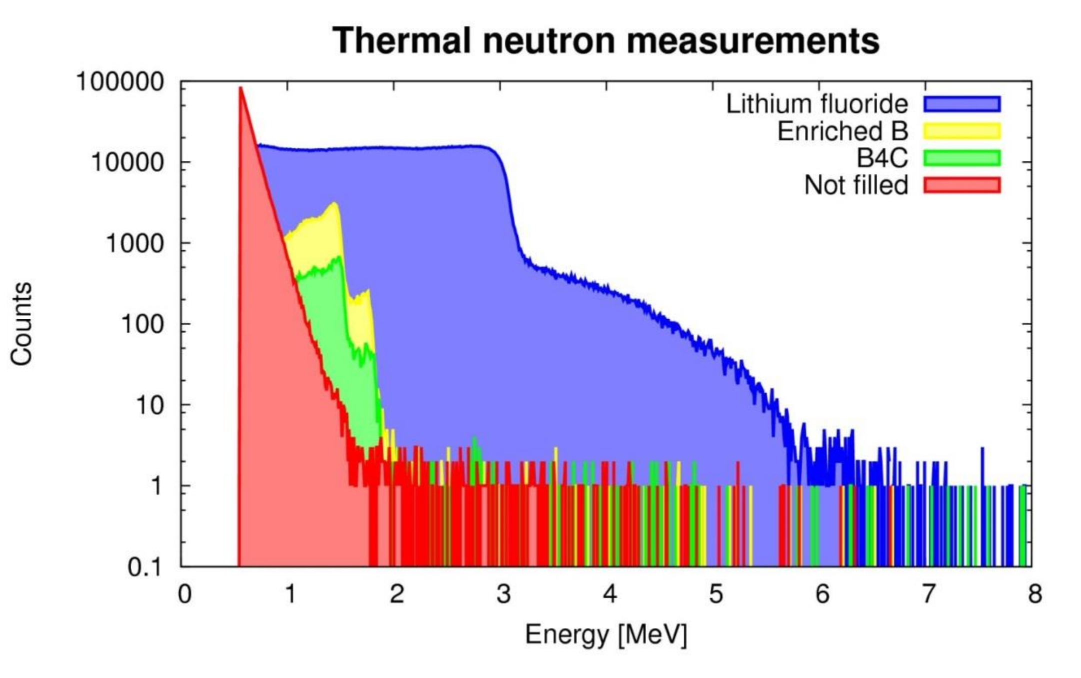
- Spectra obtained with different samples (V bias =10 V) in 20 minutes with a cyclotron ($^2H \rightarrow Be$) with a broad energy spectrum (up to 8 MeV) and fluxes exceeding 10^6 n/(cm^2 s)

- Spectra obtained with different samples with a collimated flux of thermal neutrons of about 1.5x10^7 n/(cm^2 s)

- V bias =10 V excepted for PDMS ^{10}B that was 3 V



Thermal neutron measurements (3D detector)



- Spectra obtained with different samples with a collimated flux of thermal neutrons of about 1×10^6 n/(cm^2 s) for 20 min on 3D sensors
- V_{bias} = 10V and shaping time of 4 µs
- Lithium fluoride filled sensor with higher efficiency

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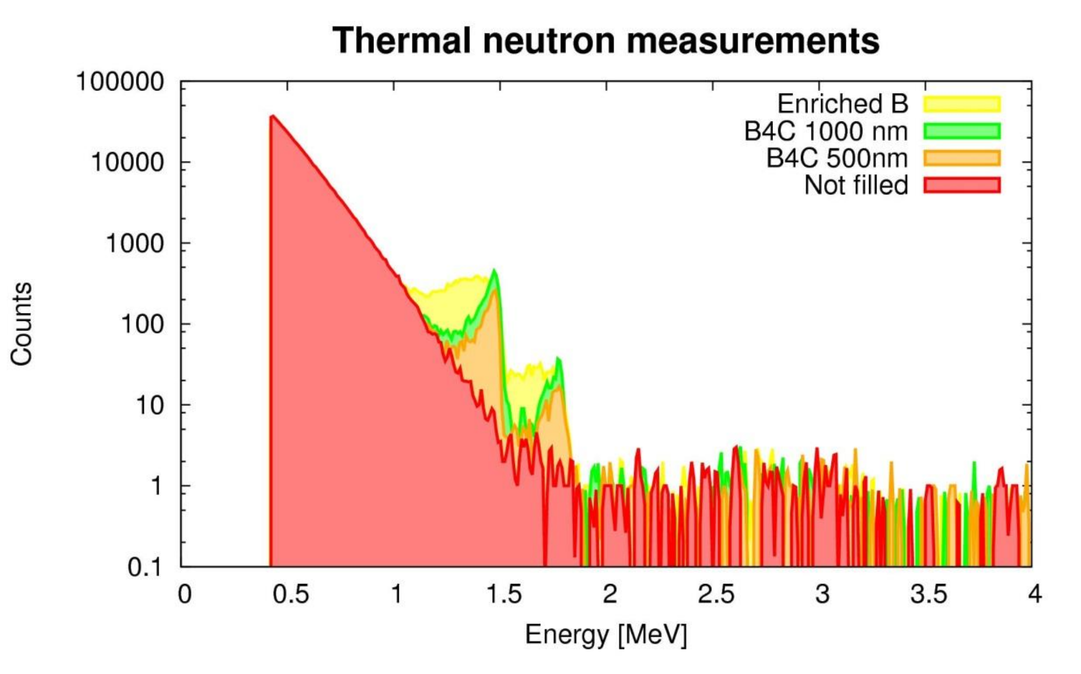
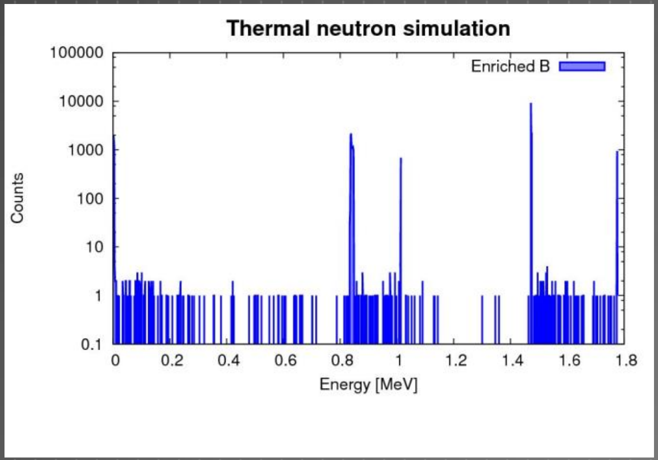
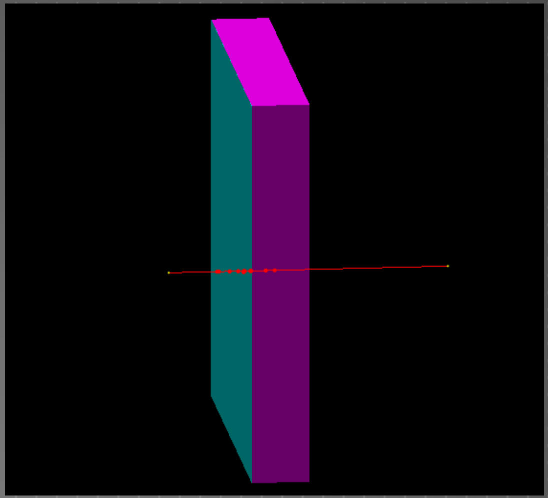
Thermal neutron measurements (Planar detector)



- Spectra obtained with different samples with a collimated flux of thermal neutrons of about $1x10^6$ n/(cm^2 s) for 1h on planar sensors
- V_{bias}= 200V and shaping time of 500ns
- Enriched boron coating with higher efficiency

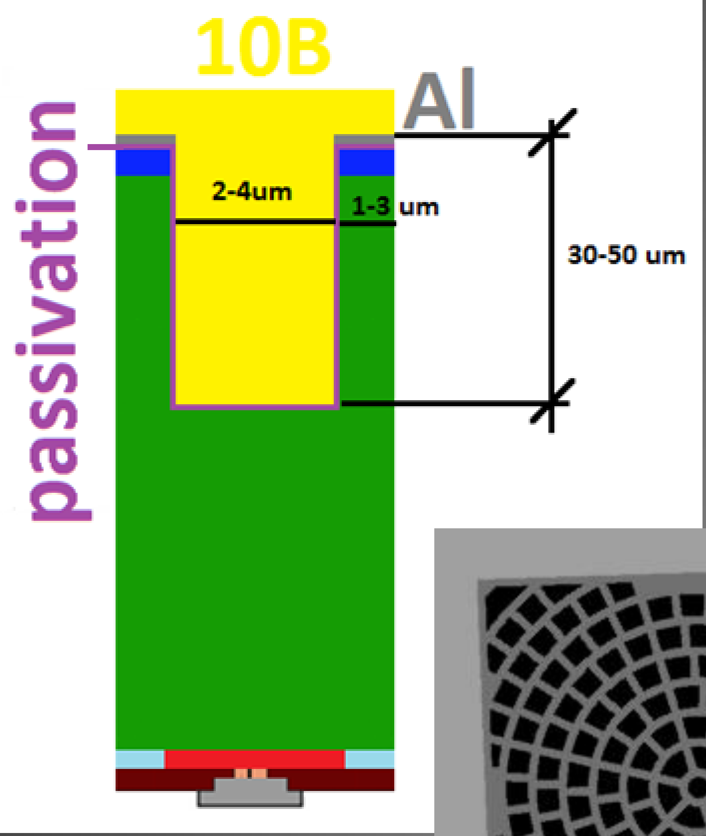
Thermal neutron simulation (Planar detector)

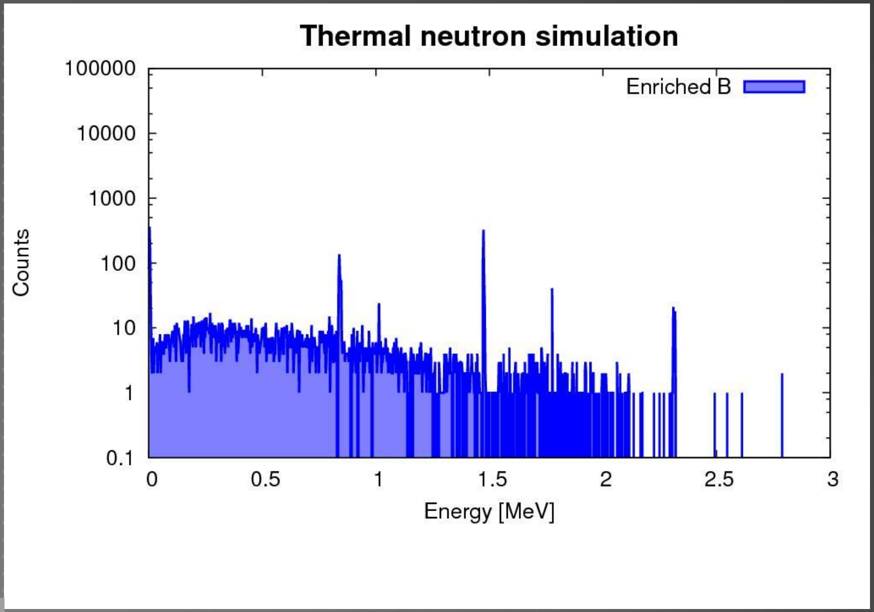


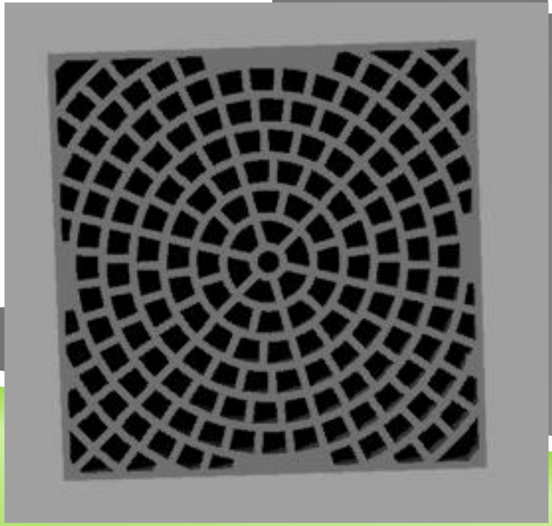


- Geant4 simulation for $6.3*10^5$ thermal Neutron
- QGSP_BERT_HP physics model and Geant4 10.01
- 10B wit purity 99% with a depth of 1000nm (3.86 % absolutely efficiency)

Thermal neutron simulation (new detector)







- Geant4 simulation for $14*10^3$ thermal Neutron
- QGSP_BERT_HP physics model and Geant4 10.01
- 10B wit purity 99% (29.251% absolutely efficiency)

Conclusions

- ✓ Silicon detectors for neutrons have been proposed and tested
- ✓ Preliminary results with thermal neutrons with sensors (both 3d and planar) coupled to 10B, B_4C and LiF have been reported
- ✓ In spite of largely non-optimized geometries, encouraging results were obtained
- ✓ Geant4 simulation shows an agreement on the relative efficiency of the detectors and allowed a new design concept to be validated
- ✓ A new batch of sensors will be fabricated at FBK in the next fe months

Acknowledgments

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Thank you for the attention!!