UNIVERSITÀ DEL SALENTO

Dipartimento di Matematica e Fisica "Ennio De Giorgi"

INFN

IstitutoNazionale di FisicaNucleare
SEZIONE DI LECCE

CEDAD
Centro di Datazione e Diagnostica

BoLAS-NEXT

F*lexible* ^{10} *B-based converter*
deposited by the ***laser ablation technique***

Preventivi 2022

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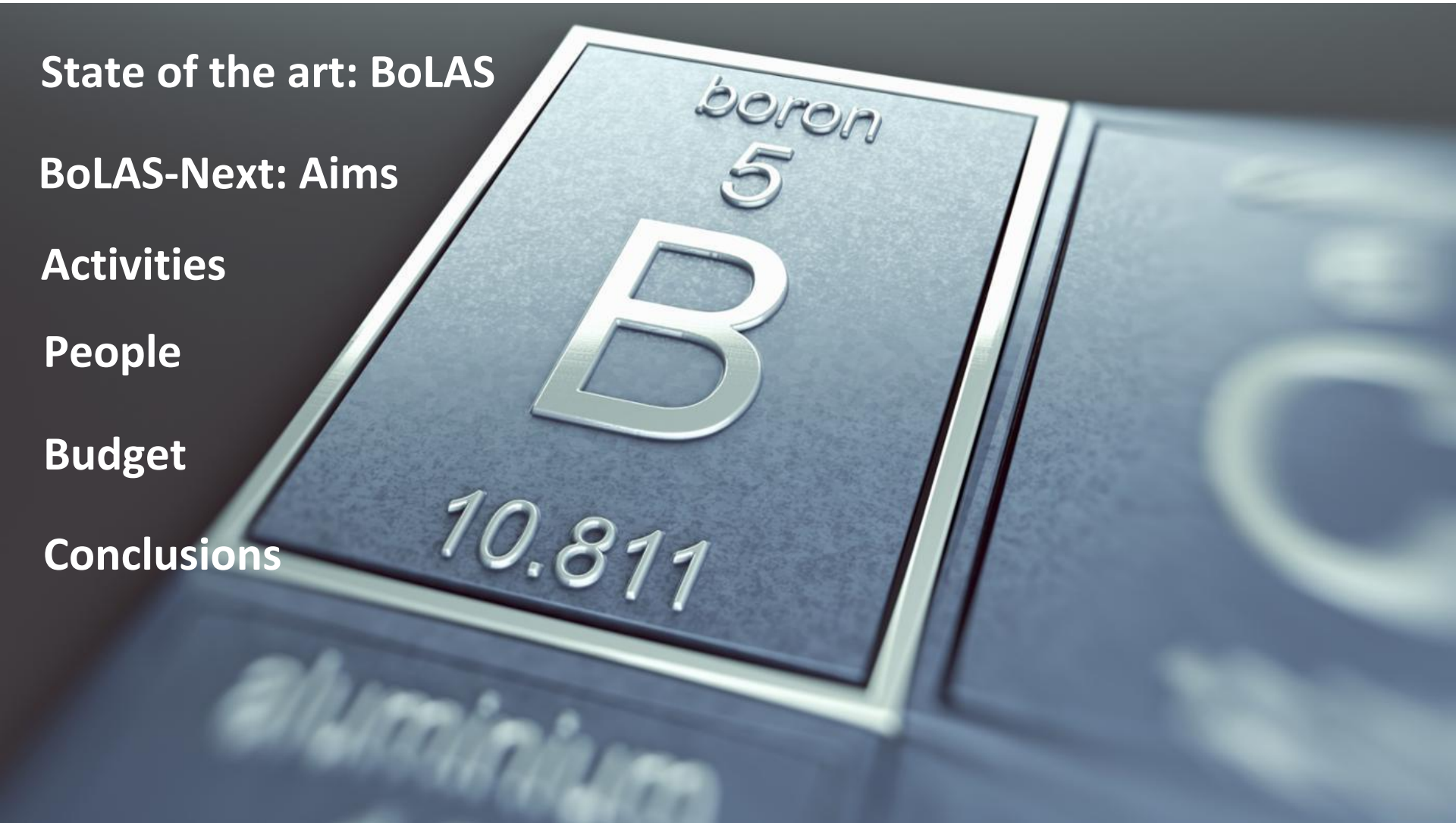
Outline



State of the art: BoLAS

BoLAS-Next: Aims

Activities

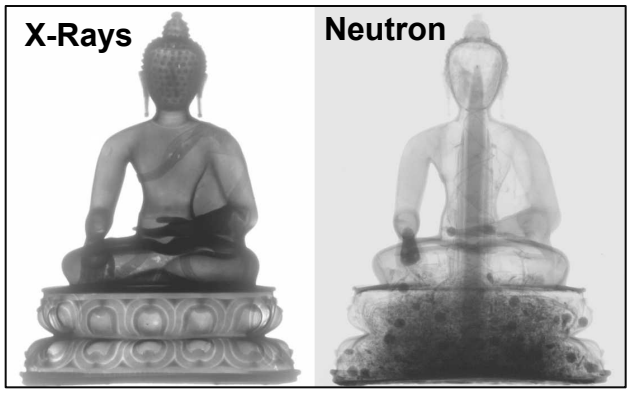
People

Budget

Conclusions

Introduction

INTEREST: Radiation portal monitors for home-land security and nuclear safeguards, workplace safety, cargo containers screening, material investigation based on neutron scattering, energy production and neutron monitoring in NPP, nuclear power instrumentation, cancer therapy, cultural heritage studies



Neutron detection: Neutrons are detected through nuclear reactions that result in prompt energetic charged particles such as protons, alphas, and so on

Two steps process

Neutron conversion + **Charged particles detection**

- **Semiconductor detectors**
- **Scintillators**
- **Gas detectors**

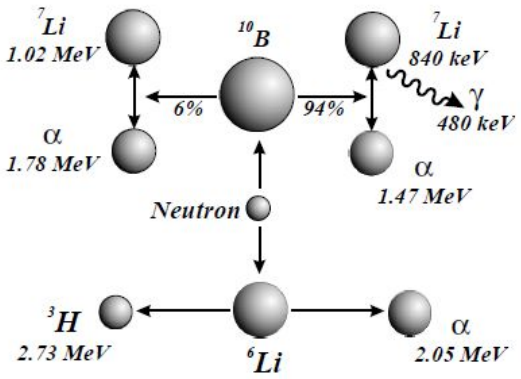
Introduction

Main neutron conversion reactions:

Reaction	Q value (MeV)	Products energy (MeV)	Cross section (b) @0.0253 eV
$^{3}He\ (n, p)\ ^{3}H$	0.764	$E_p = 0.573$ $E_T = 0.191$	σ = 5320
$^{6}Li\ (n, \alpha)\ ^{3}H$	4.78	$E_\alpha = 2.05$ $E_T = 2.73$	σ = 942
$^{10}B\ (n, \alpha)\ ^{7}Li$	2.792 (6%)	$E_\alpha = 1.78$ $E_{Li} = 1.01$	σ = 3842
$^{10}B\ (n, \alpha)\ ^{7}Li^{*}$	2.310 (94%)	$E_\alpha = 1.47$ $E_{Li} = 0.84$ $(E_\gamma = 0.48)$	

CRITERIA

- ✔ High conversion cross section
- ✔ High natural abundance (cheap)
- ✔ High Q
- ✔ Long products'range in the converter



Mc Gregor et al, NIMA, 2003

Introduction

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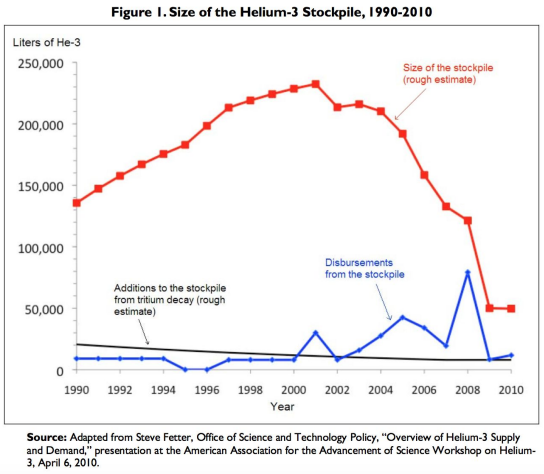
Problem:

^{3}He is running out



^{10}B based conversion

Deposition of **^{10}B enriched films** in order to realize a **flexible neutron converter**.

- ✔ **High neutron capture cross section**
- ✔ **Low cost/high natural isotopic abundance of ^{10}B (19.8 %)**

- ✔ **Shorter range of capture products (compared to ^{6}LiF)**
- ✔ **Gamma emissions from capture products**

The ideal technique should allow the deposition of films wit

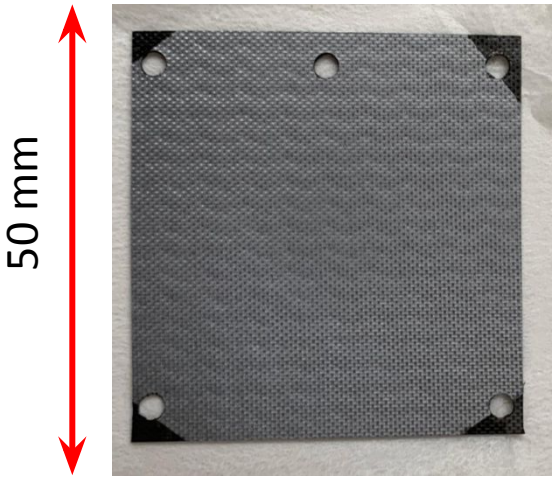
- ❑ **Low impurities (i.e. C and O) content** (high ^{10}B content)
- ❑ **Low residual mechanical stress and high adhesion;**

Pulsed **L**aser **D**eposition

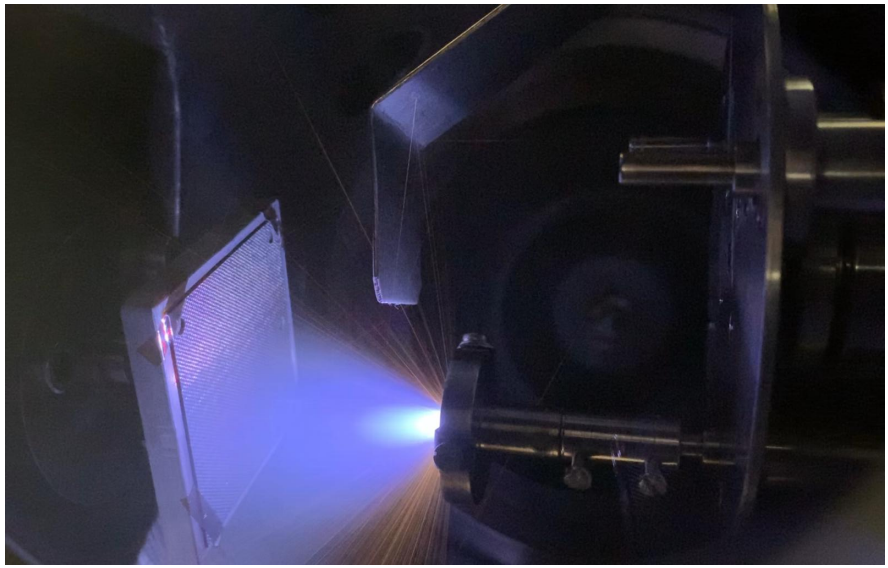
Bolas-NEXT : results

The expected results from BoLAS have been fully achieved:

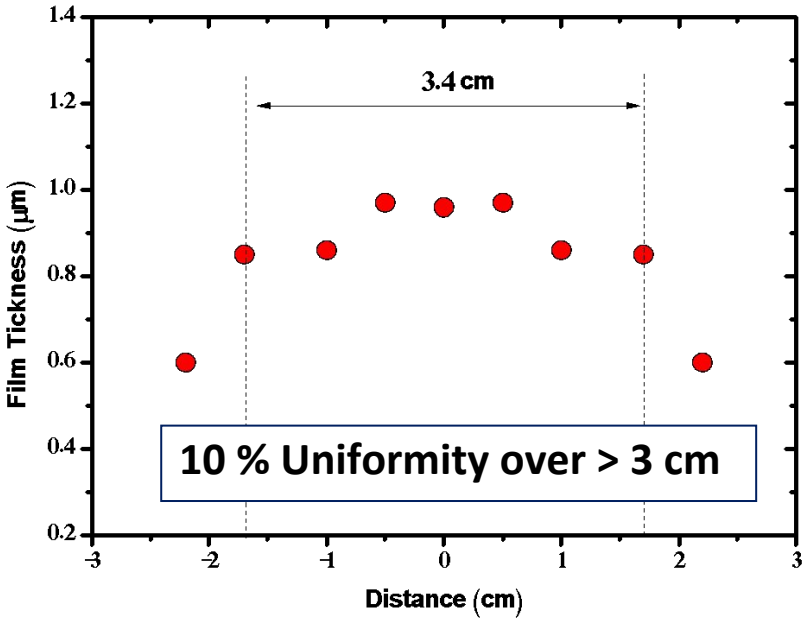
- ✔ **Deposition of pure B films with thickness in the 0.5-2 μm range**
- ✔ **Good films quality in term of morphology, adhesion, uniformity**
- ✔ **Deposition on different substrates can be carried out (@RT)**
- ✔ **Thermal neutron detection has been demonstrated**
- ✔ **Experiments in agreement with MC simulations**

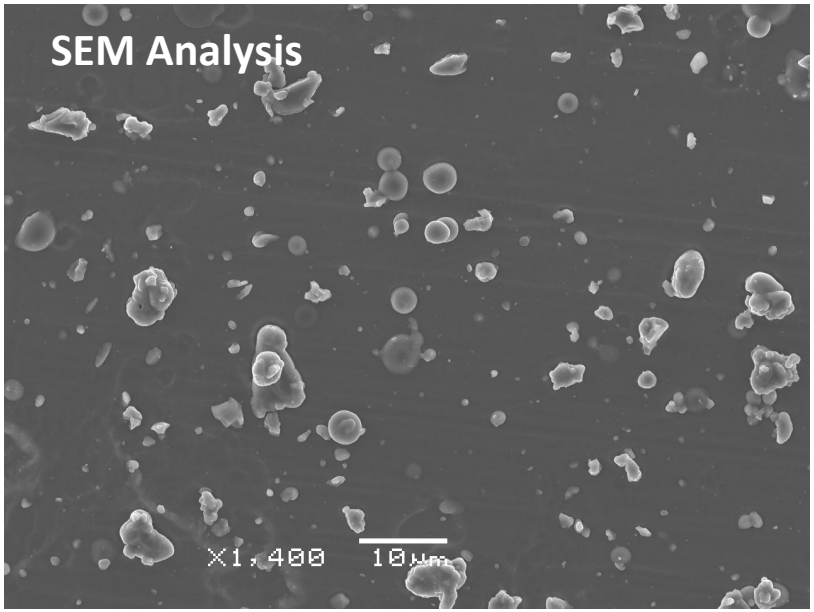


Carbon fiber substrate + B film

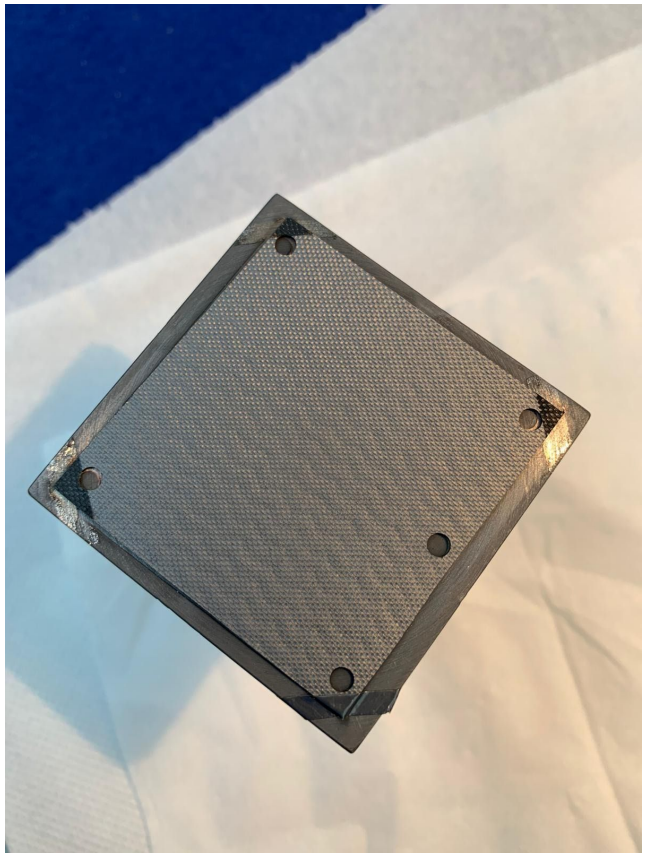


Bolas : Deposition of ^{10}B films - uniformity



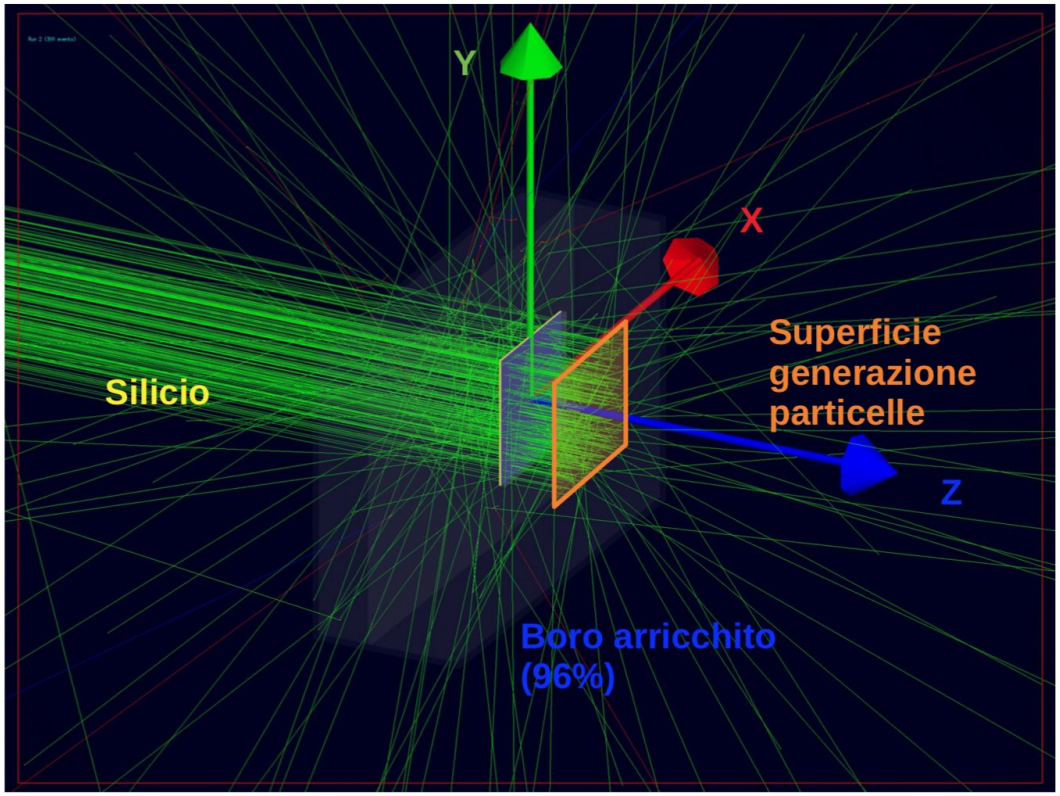


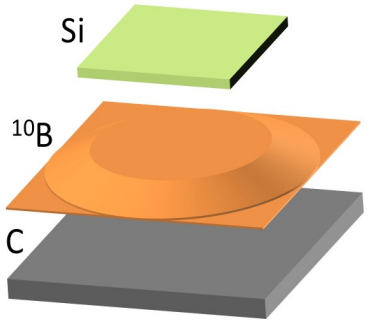
Good adhesion and film uniformity has been obtained also on **carbon fiber substrates**

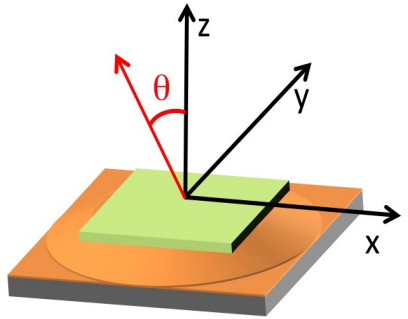


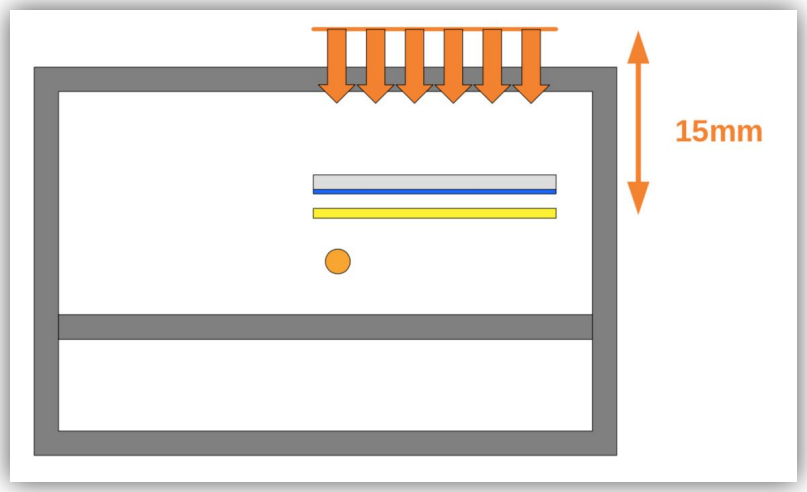
GEANT4 Montecarlo simulations

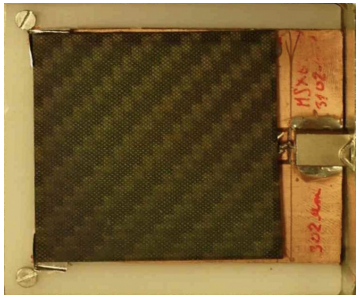
GEANT4 simulations: determination of optimal geometries



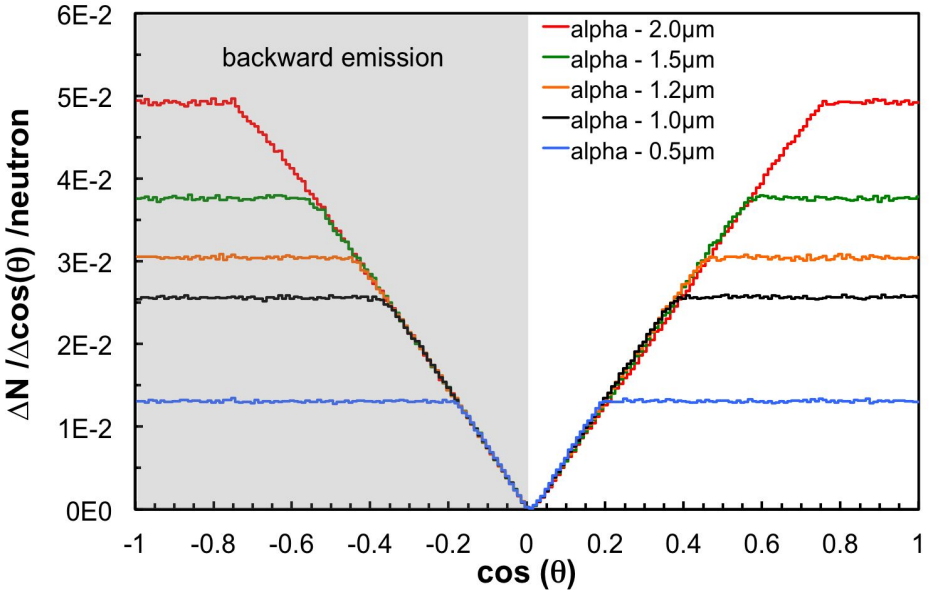


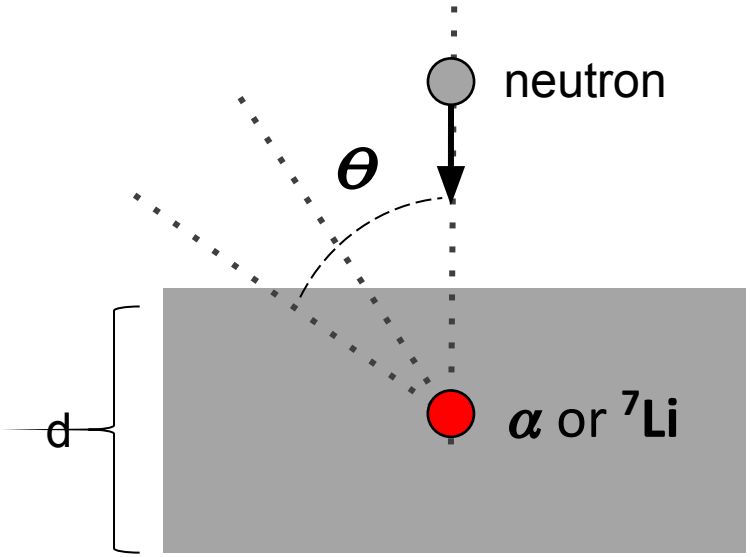




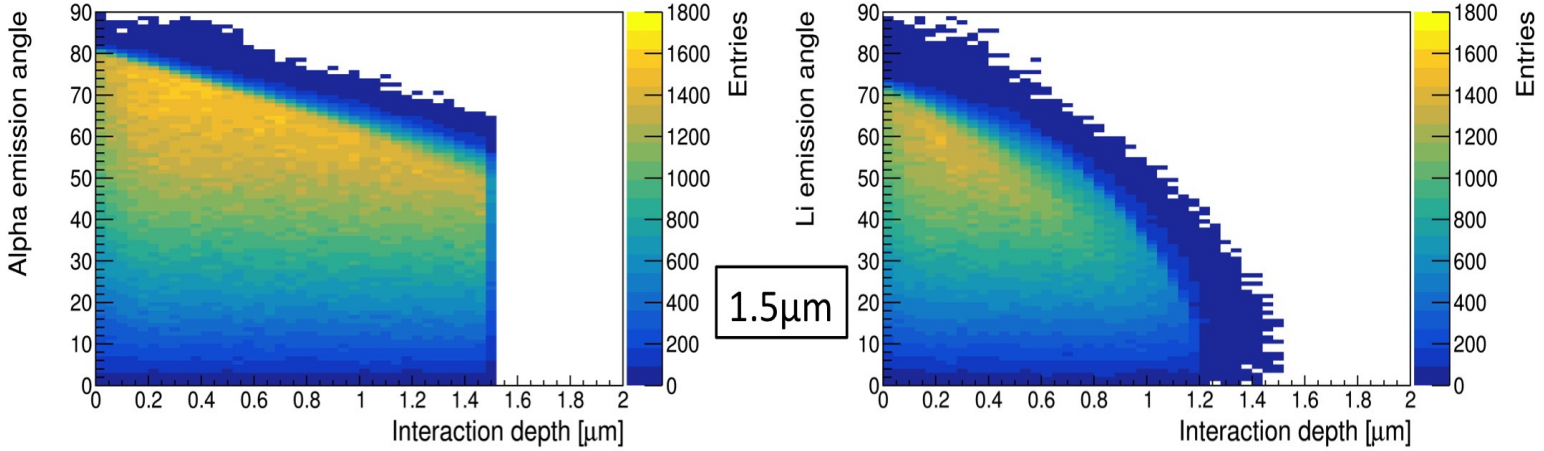


GEANT4 Montecarlo simulations: results



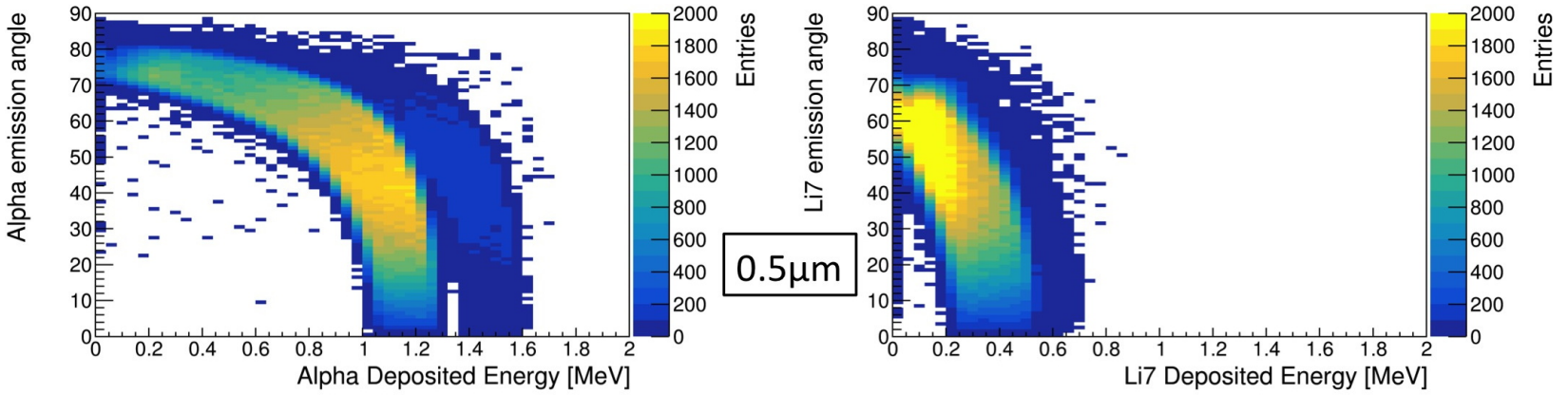


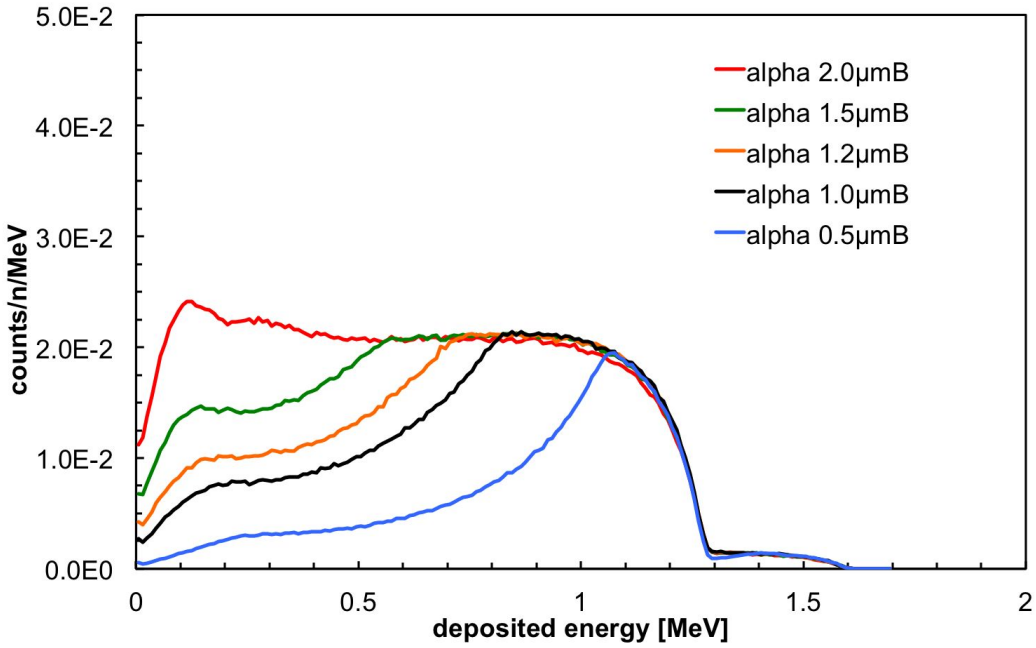
Distribution of the simulated z-direction cosine of α

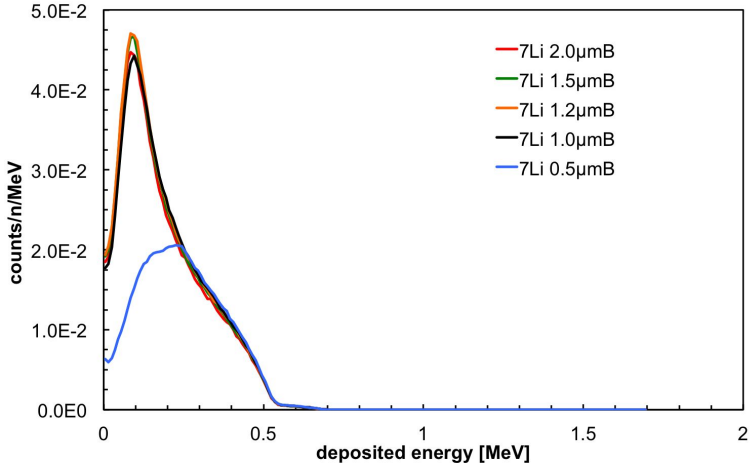


Number of α and ^{7}Li as a function of the interaction depth and of the emission angle, for the 1.5 μm converter

GEANT4 Montecarlo simulations: results







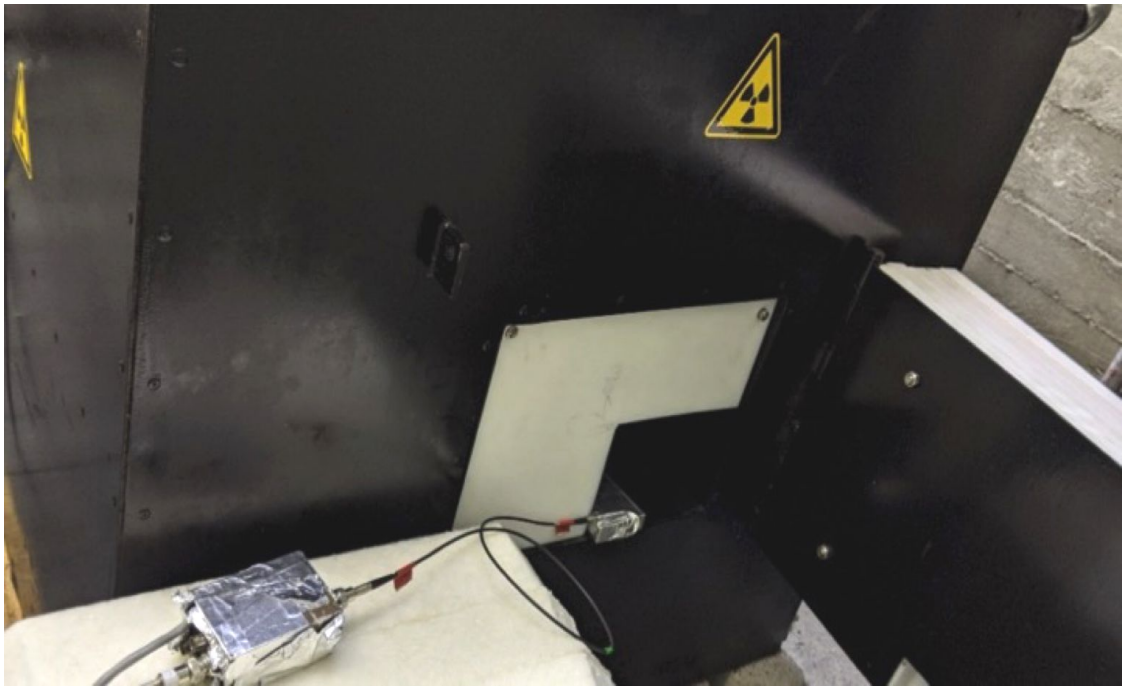
Simulation of the deposited energy spectrum of ^{7}Li and alphas for the five ^{10}B converter thicknesses.

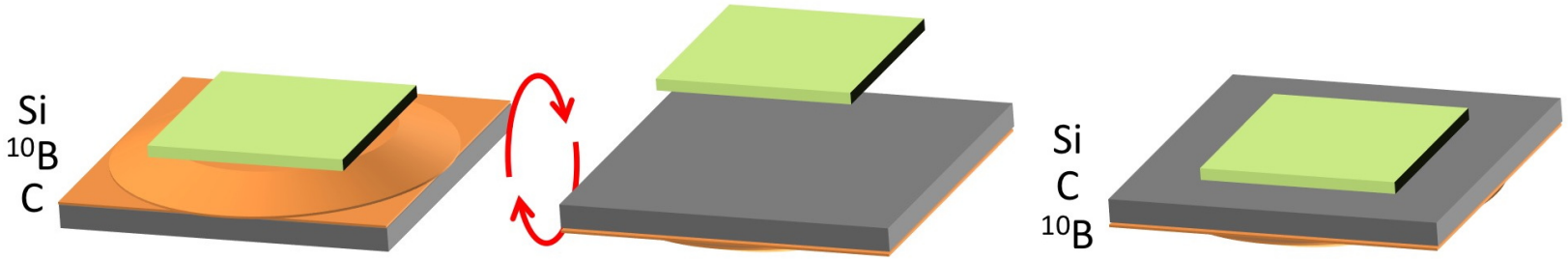
Neutron irradiation: Test set up@INFN-LNS

Neutron source: AmBe

Flux : 2.2 x10^6 n/s (4π)

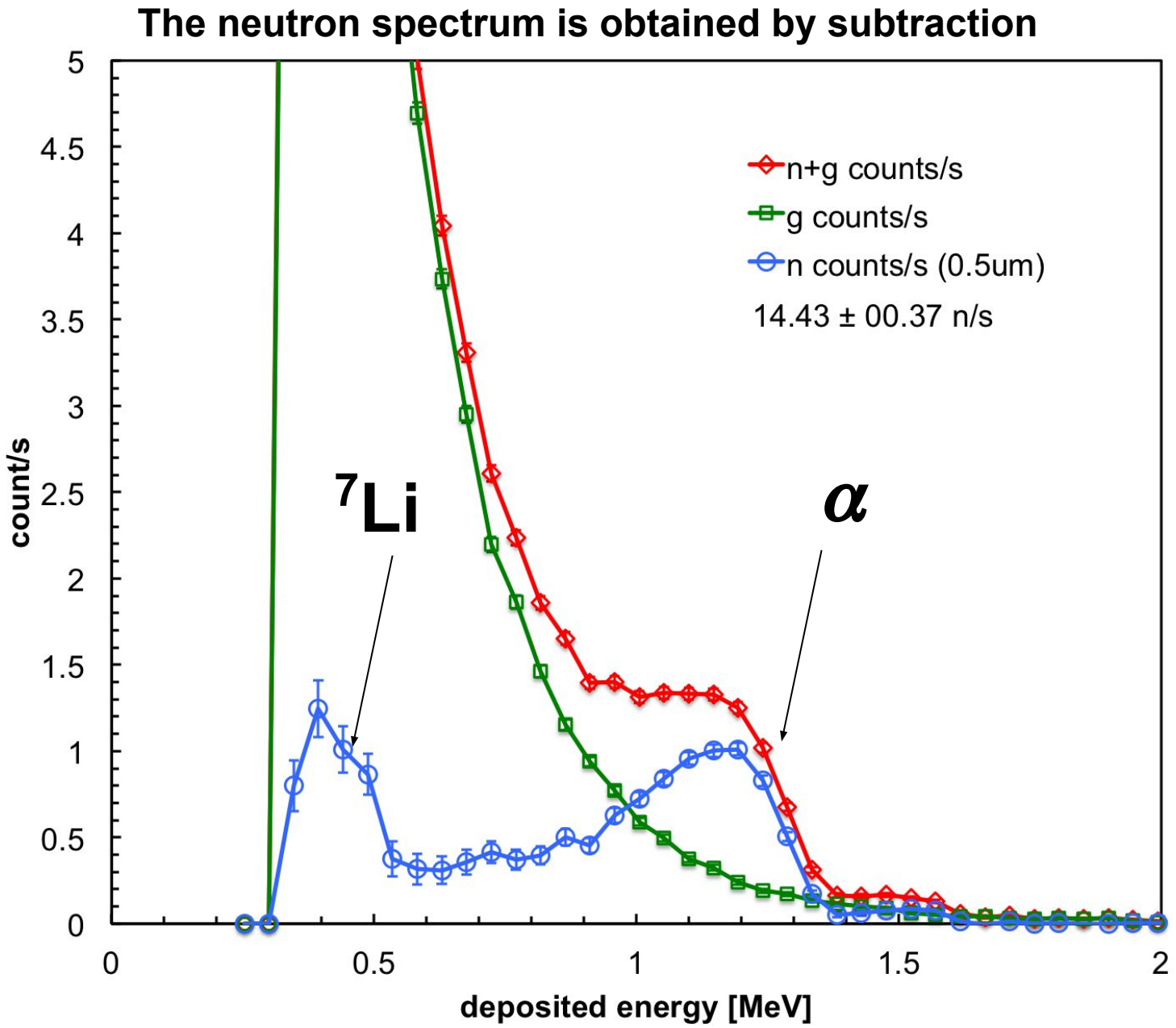
The source is surrounded by a first PE case and by 30 cm thick paraffin that slows down high energy neutrons (up to 10 MeV). The outer 5 cm of the shielding are made of borated paraffin stopping the vast majority of the outgoing thermalized neutrons



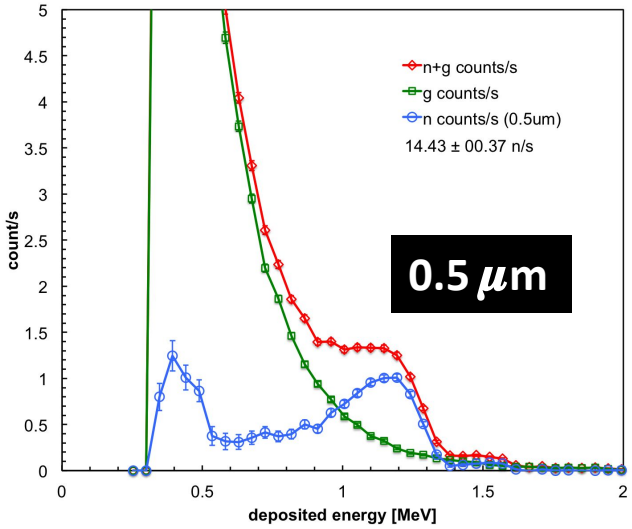


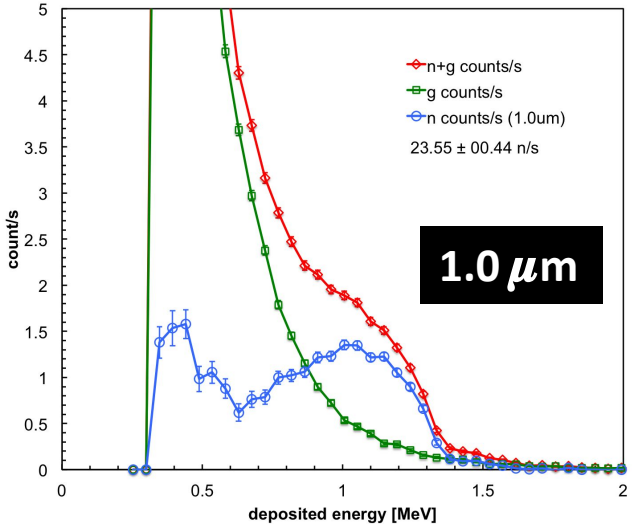
Gamma background substraction strategy

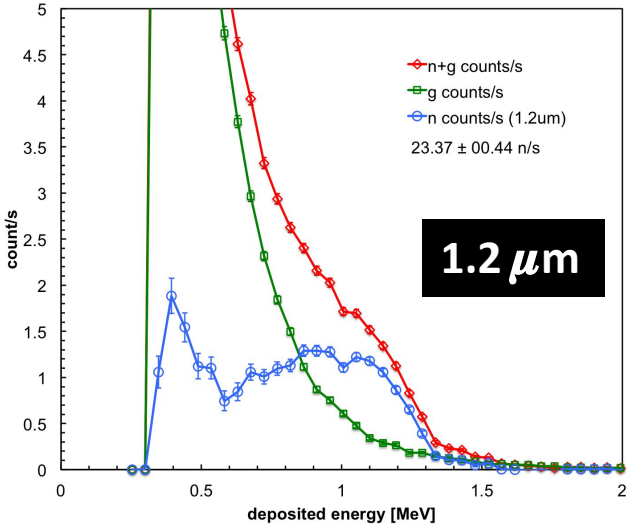
Neutron irradiation results

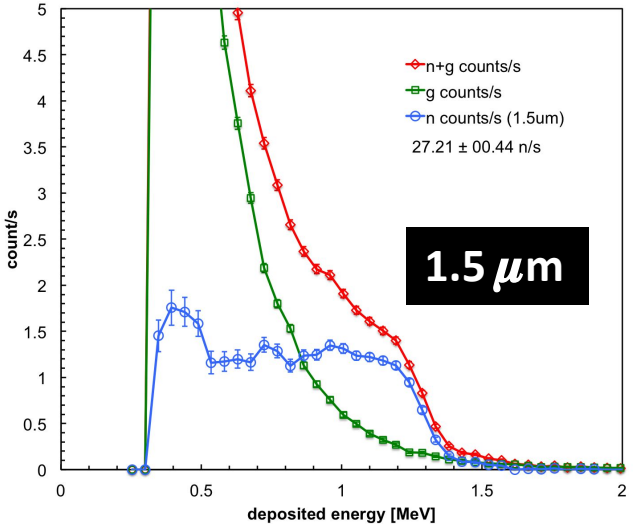


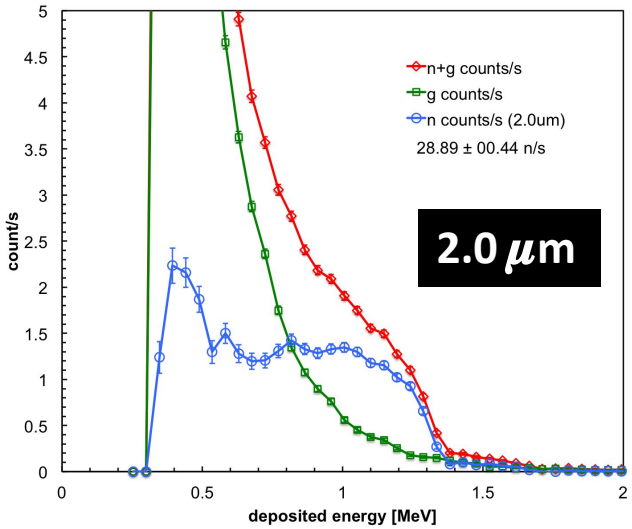
Neutron irradiation results



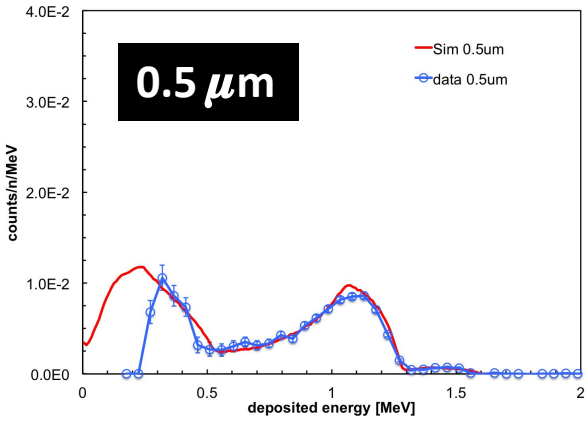


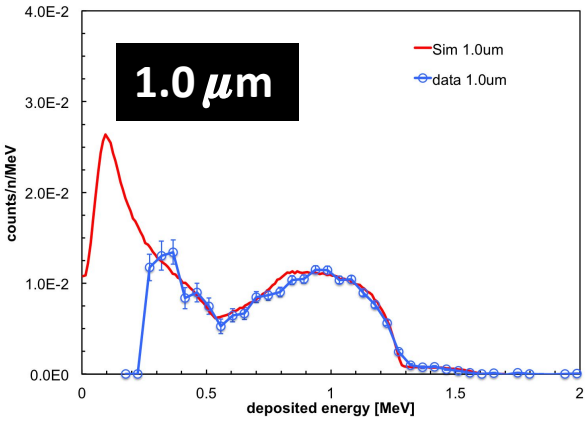


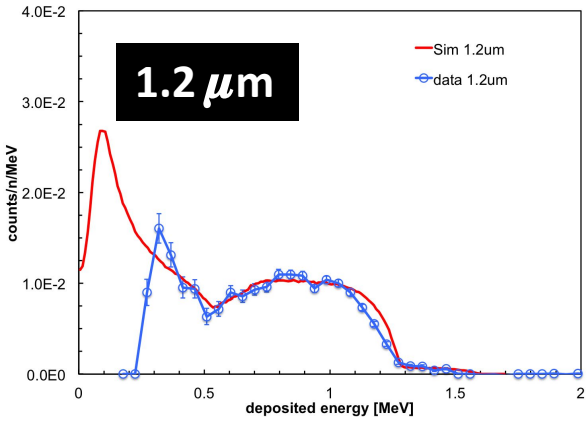


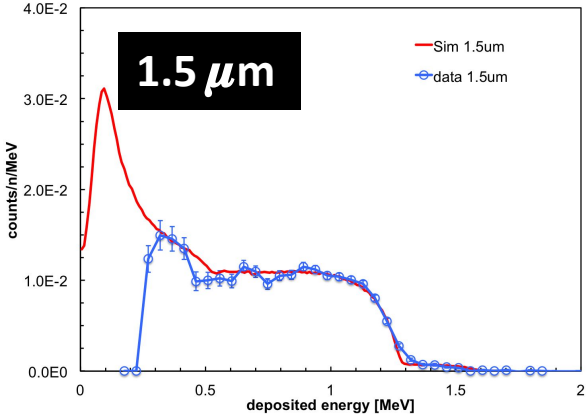


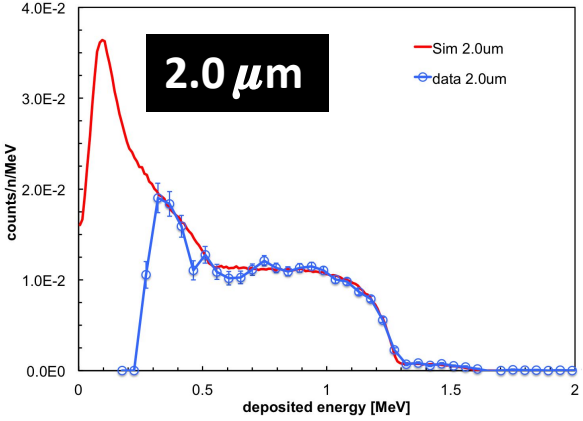
Neutron irradiation: comparison with simulation







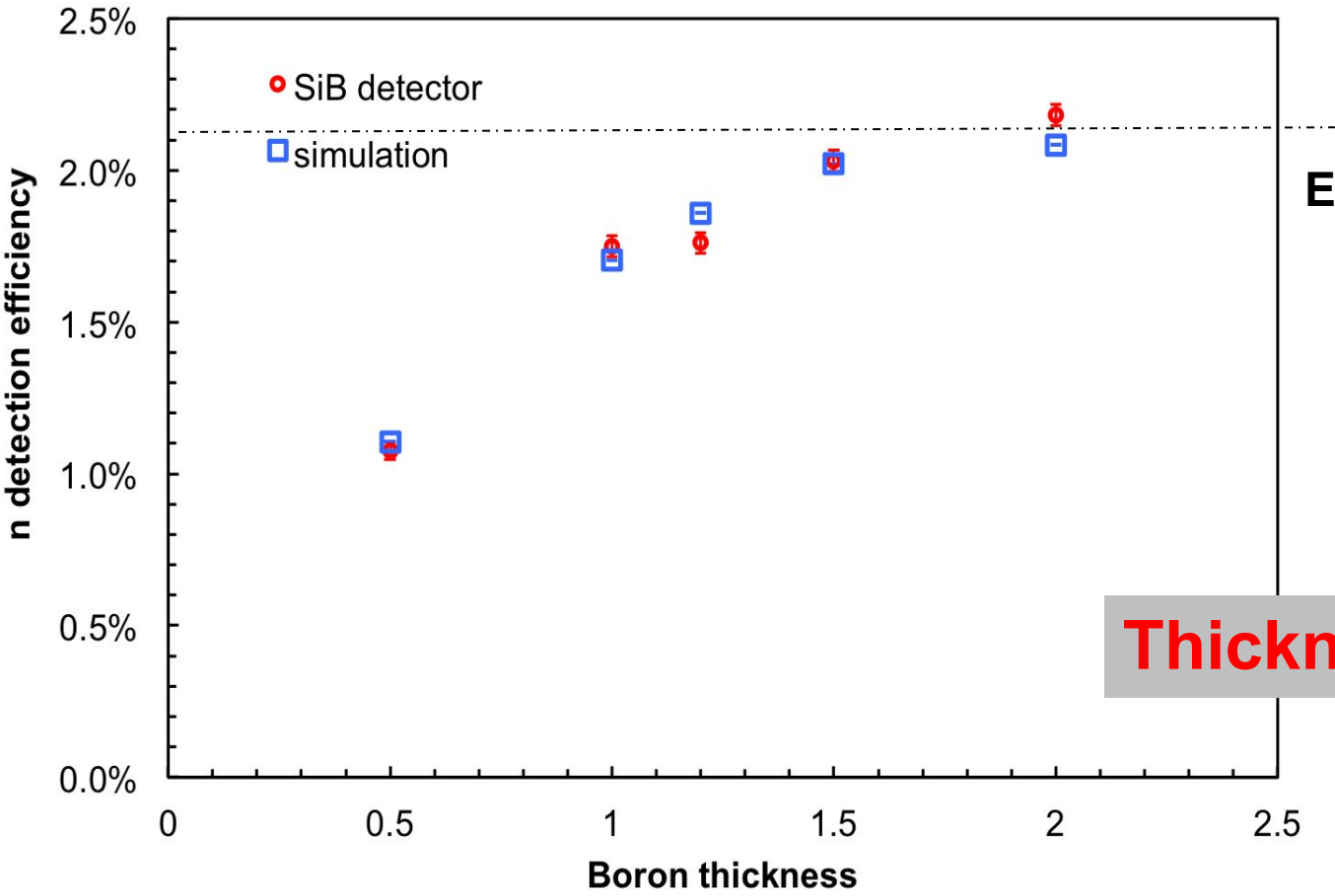




Very good agreement!

Detector efficiency

Detector efficiency was determined since the thermal n flux in the reference position was measured by means of an identical silicon detector featuring a 1.6 µm thick ^{6}LiF converter on carbon fiber, whose detection efficiency had been previously calibrated in a certified thermal neutron field



$\eta \simeq 2.2$ %

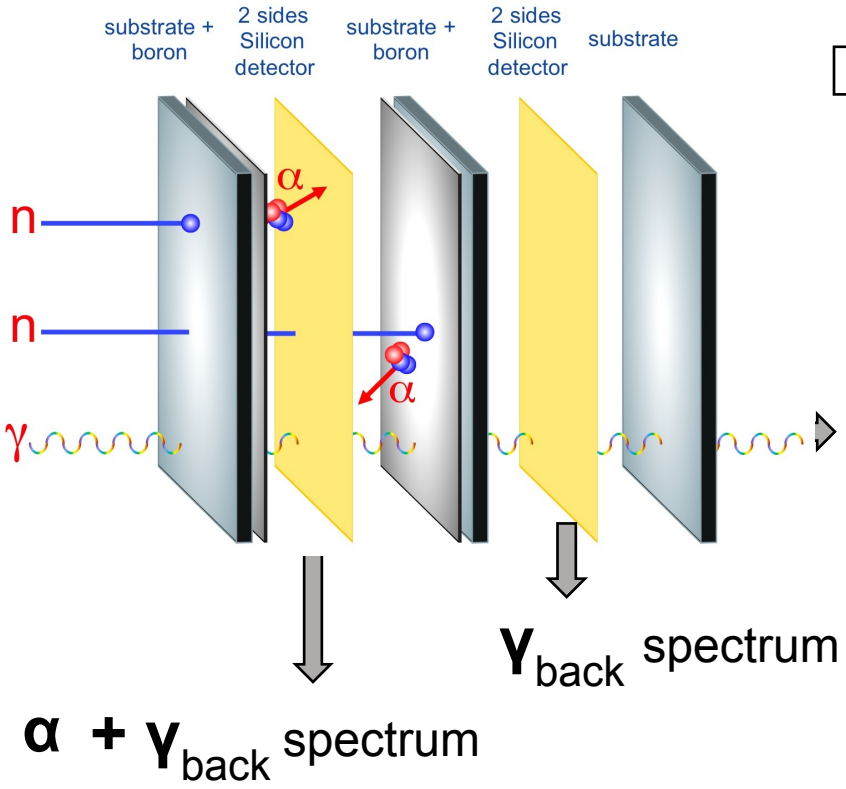
Estimated detection efficiency

Thickness ≃ 1.5 μm

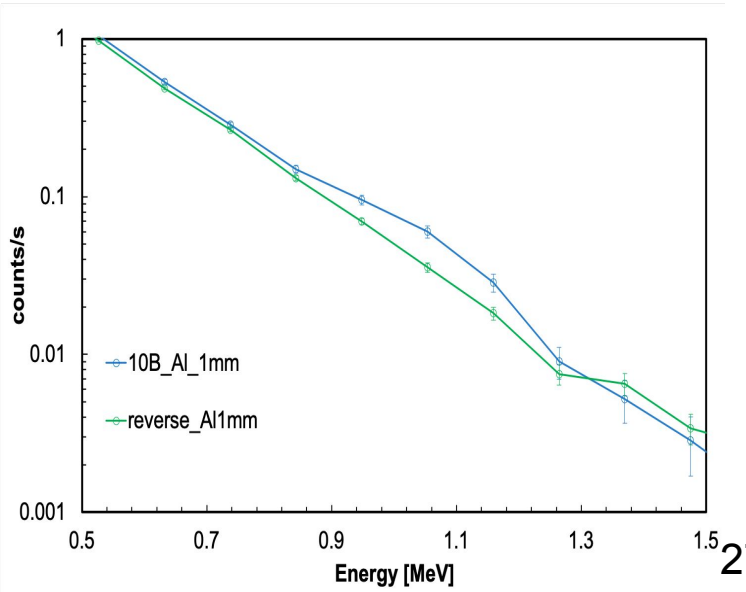
Bolas –NEXT: New geometries and devices

We propose a “sandwich” detection geometry:

- **Two identical substrates are used: with and without the conversion layer**
- **Two Si-detectors are simultaneously used to detect two energy spectra**
- **The final spectrum is obtained by subtraction**



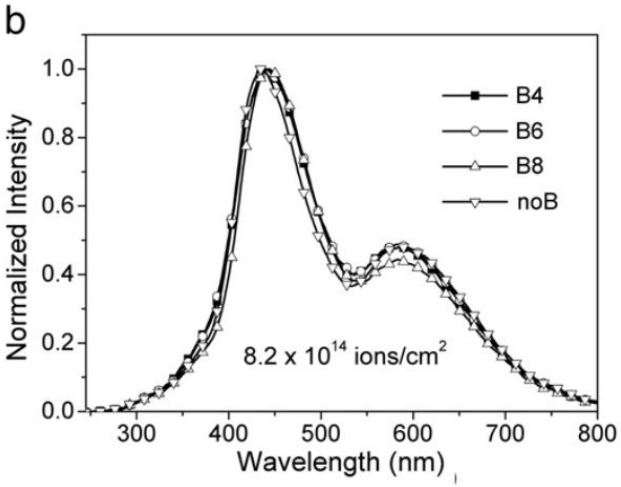
Prototype



Bolas –NEXT: New detectors

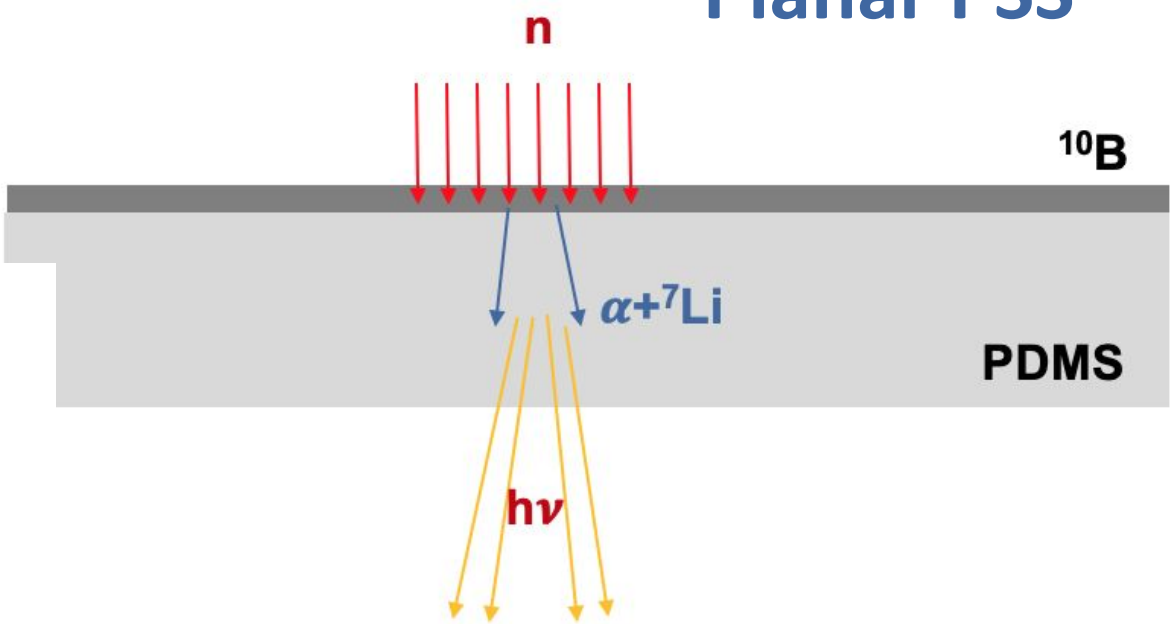
We propose the coupling between ^{10}B PLD grown films and plastic scintillators (PSS):

- **Higher rejection against**
- **Improved Efficiency**
- **Cost reduction**



IBIL spectrum of undoped and doped samples after 8.2×10^{14} ions/cm^2

Planar PSS



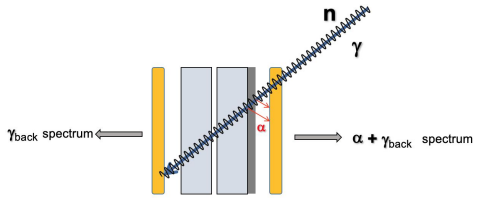
Scintillation Yield
$\simeq$ 6500 photons/particle (^{241}Am α)

Quaranta et al., Journal of Non-Crystalline Solids, 2011

^{10}B : project activities

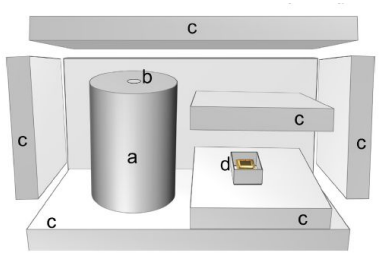
WP1

Development of new geometries with Si-Detectors comparison with ^{6}LiF



WP4

Tests of the detectors

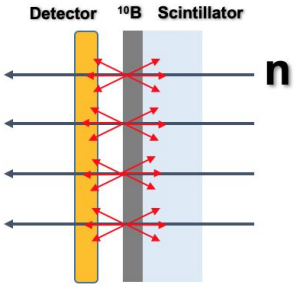


Find new/advanced geometries and configurations which allow to:

- ✔ Develop competitive devices
- ✔ Get rid of current limitations

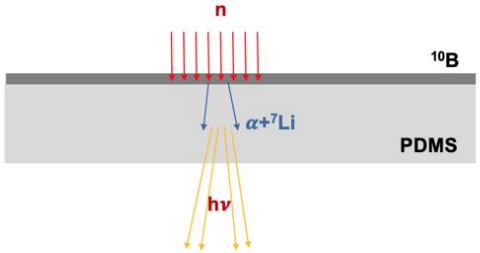
WP3

Hybrid Si/PDMS devices



WP2

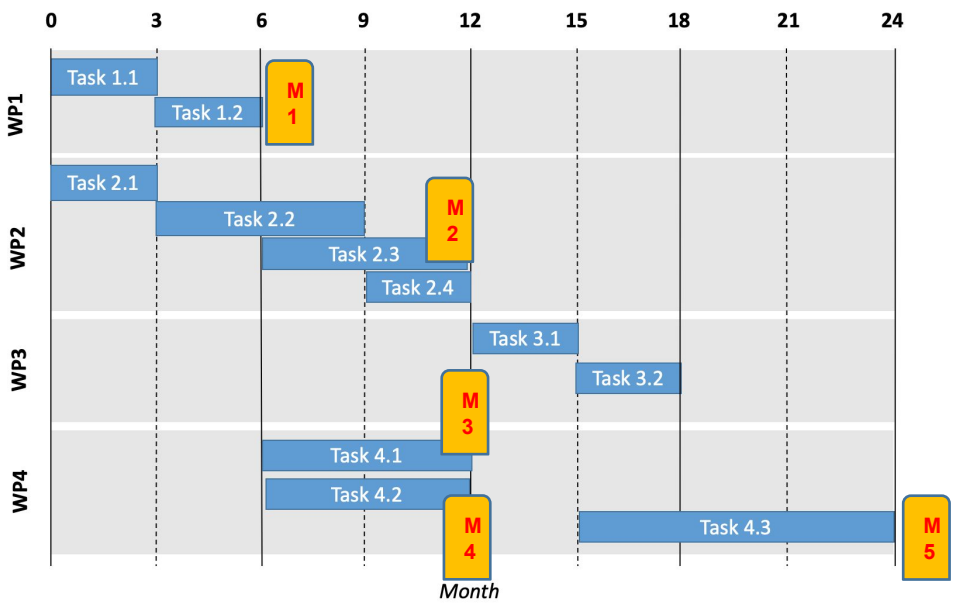
^{10}B deposition on plastic scintillators



SCHEDULE

***Table** : Organization of the project in four different work-programs (WPs) with indication of the main unit responsible of the activities with corresponding milestones, timing and expected results.*

Unit	Milestones	Time (months)
	WP1 - Development of new geometries with Si-Detectors, comparison with ^{6}LiF	
INFN-Le+LNS	1. Definition of deposition geometries, MC simulations	0-3
INFN-Le	2. Deposition and characterization of ^{10}B-enriched thin films	3-6
	Expected Results	
	• Definition of the proper geometries in terms of substrates, thickness and dimensions • Deposition of ^{10}B-enriched thin films with the proper thickness • Characterization of the deposited films by SEM/TEM/XRD/IBA methods	
	WP2 - ^{10}B deposition on plastic scintillators	
INFN-Le+TIFPA	3. Definition of geometries for ^{10}B enriched thin films deposited on PSS.	0-3
INFN-Le+TIFPA	4. Preparation and growth of the PSS substrates	3-9
INFN-Le	5. Determination of experimental condition for ^{10}B enriched thin films deposition	6-9
INFN-Le+TI FPA	6. Deposition and characterization of ^{10}B-enriched thin films	9-12
	Expected results	
	•Determination of the proper geometries of the PSS substrates and of the ^{10}B films •Determination of the experimental condition for PLD deposition (wavelength, fluence, geometry) •Characterization of the deposited structures including the scintillation properties of PSS	
	WP3 - Hybrid Si/PSS devices	
INFN-Le+TIFP Ar-LNS	7. Definition of the experimental set-up	12-15
INFN-Le	8. Deposition of the conversion layers on PSS and on CF/Al	15-18
	Expected results	
	•Definition of the experimental set-up and of the involved geometries • Growth of the conversion layers and preparation of the devices.	
	WP4 - Tests of the detectors	
INFN-Le+LNS	8. Set-up of the prototype and test of the double Si-based detector, comparison with ^{6}LiF	6-12
INFN-Le+TI FPA	9. Test of the PSS-based detector	6-12
INFN-Le+TIFP Ar-LNS	9. Test of the hybrid Si/PSS device	15-24
	Expected results	
	•Determination of the performance of the detectors •Validation of the proposed solutions •Assessment of the efficiency of the detectors	



M1. Set-up of the prototype

M2. Deposition of ^{10}B on PSS

M3. Test of the prototype/comparison with ^{6}LiF

M4. Test of the ^{10}B/PSS system

M5. Test of the hybrid devices

Bolas-Next : Paper

Thermal neutron conversion by high purity ^{10}B-enriched layers: PLD-growth, thickness-dependence and neutron-detection performances

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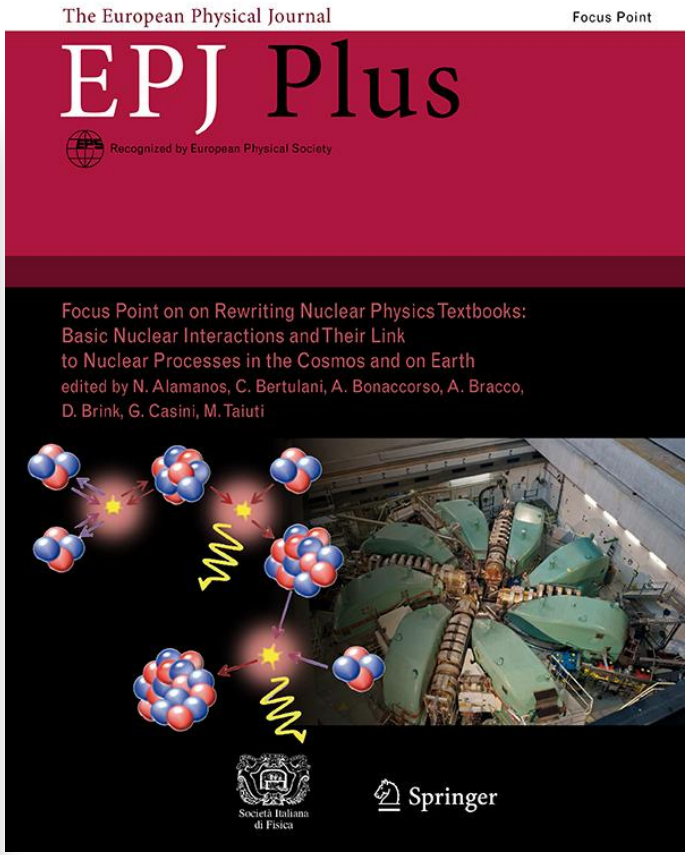
keywords: neutron detection, neutron converter, ^{3}He replacement, ^{10}B films, pulsed laser deposition, thickness dependence, silicon detectors, room temperature

Abstract

Neutron applications and detection are of paramount importance in industry, medicine, scientific research, homeland security, production of extreme UV optics and so on. Neutron detection requires a converter element that, as a result of its interaction with neutrons, produces reaction products (mainly charged particles) whose detection can be correlated with the source neutron flux/fields. Reduced availability and increased cost of the most used converter element, 3He, have triggered research efforts for alternative materials, proper deposition methods, and new detector architectures.10B converter is a valid alternative to 3He thanks to its high capture cross section for thermal neutrons and relatively high Q factor. In this paper we report on the room temperature Pulsed Laser Deposition (PLD) of high quality and uniform 10B films with the expected density, different thickness values (0.5, 1, 1.2, 1.5 and 2 μm) and uniform thickness over a circular area of about 30 mm in diameter. Additionally, they are adherent to the substrate with a negligible presence of contaminants. The conversion properties of such 10B coatings coupled to a Si solid state detector are studied upon exposure to a neutron flux from an Am-Be neutron source (2.2·106 n/s). The experimental results compared with spectra simulated by using a GEANT4 code, present a good agreement and efficiencies of the order of a few percent.



IF=3.2

Bolas-Next : Conferences

PLD-grown, isotopically enriched ^{10}B thin films for thermal neutron detection

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ANIMMA 2021 Prague, Czech Republic June 21-25, 2021

Plenary Talk 7th International Conference on **A**dvancements in **N**uclear **I**nstrumentation **M**easurement **M**ethods and their **A**pplications

Applied Nuclear Physics Conference 2021 September 12 – 17 Prague, Czech Republic

Amaduccì et al.- PERFORMANCES OF A COMPACT NEUTRON DETECTOR USING HIGH PURITY ^{10}B-ENRICHED PLD-GROWTH FILMS

Comunicazioni SIF

Provenzano et al. ***PLD deposition and characterization of 10B based conversion layers for thermal neutron detectors: results of the BoLAS-INFN experiment***

Marra et al. ***Coupling PLD-grown isotopically enriched boron with semiconductor and scintillator detectors***

Società Italiana di Fisica

ATTIVITA' SPERIMENTALI

TURNO DI MISURA A CATANIA-LNS (SETTEMBRE 2021)

Test del prototipo di rivelatore a «sandwich», irraggiamenti con sorgente AmBe, Simulazioni GEANT4-Montecarlo

TURNO DI MISURA A LECCE-LABORATORIO ACCELERATORE (13-15 LUGLIO)

Misure di ionoluminescenza da protoni su campioni di PSS

TURNO DI MISURA A LEGNARO

Test di rivelatori PSS a scintillazione

OUTCOME: Tesi di dottorato di ricerca

Chiara Provenzano-Dottorato in Ingegneria dei Materiali, Strutture e Nanotecnologie

Argomento: "Deposizione e caratterizzazione di film convertitori di ^{10}B, mediante PLD, per la realizzazione di un detector di neutroni termici in accoppiamento rivelatori al Si."

Marcella Marra-Dottorato in Fisica e Nanoscienze

Argomento: "Rivelatore di neutroni termici mediante film convertitori a base di ^{10}B accoppiati a scintillatori a base di polisilossano"

PEOPLE

INFN-Sezione di Lecce.

Gianluca QUARTA-PI
Anna Paola CARICATO
Lucio CALCAGNILE
Maurizio MARTINO
Antonio SERRA
Daniele MANNO
Massimo Corrado
Lucio Maruccio

INFN-TIFPA-Trento

Alberto QUARANTA
(Responsabile)

INFN-LNS (Dot. CSNV)

Paolo FINOCCHIARO

PEOPLE

INFN-LECCE			
Name	**Position**	**Role**	**FTE**
Gianluca QUARTA	Associate Professor	**Principal INvestigator**	0.5
Lucio CALCAGNILE	Full Professor		0.3
A.Paola CARICATO	Associate Professor		0.1
Daniela MANNO	Associate Professor		0.3
Maurizio MARTINO	Associate Professor		0.3
Antonio SERRA	Associate Professor		0.3
Lucio MARUCCIO	Technician		-
Massimo CORRADO	Technician		-
TOTAL			**1.8**

TOTAL:

TIFPA-INFN-TRENTO			
Name	**Position**	**Role**	**FTE**
Alberto QUARANTA	Full Professor	**Unit responsible**	0.4
Davide BRUNELLI	Associate Professor		0.2
Matteo FAVARO	Dottorando		0.4
Artem ARKHANGELSKIY	Dottorando		0.3
TOTAL			**1.3**

3.1 FTE

LNS-INFN-CATANIA			
Name	**Position**	**Role**	**FTE**
Paolo FINOCCHIARO	Dirigente tecnologo	**Unit responsible**	0.1
TOTAL			**0.1**

INFN-LECCE			
Item	**Cost**	**I year**	**II Year**
Hardware	Detector (Si Detector)	3.5 k€	-
	Detector electronics (Power supply, Preamp)	3.5 k€	-
	Total	**7.0 k€**	**-**
Consumables	He/Ne/Kr/F pure gas bottles for laser	8 k€	2 k€
	SEM/TEM/XRD/RAMAN (liquid nitrogen, consumables)	2 k€	2 k€
	Tandem consumable (targets, gases, pure materials)	3 k€	2 k€
	Pure materials for PLD (isotopically enriched materials, substrates)	5 k€	2 k€
	Scintillators, Fibers, supports	1 k€	1 k€
	Total	**19 k€**	**9 k€**
Travel expenses	2 pers. x 2 weeks (Catania) 2 pers x 2 weeks (Trento)	5.0 k€	5.0 k€
	Total	**5 k€**	**5 k€**
	TOTAL	**31 k€**	**14 k€**

TLNS-INFN-CATANIA			
Item	**Cost**	**I year**	**II Year**
Hardware	-	-	-
	Total	**-**	**-**
Consumables	Substrates, electonic components, glues, conductive glues, detector housing	1.0	1.0
	Total	**1.0**	**1.0**
Travel expenses	1 pers. x 1 weeks (Lecce) 1 pers x 1 weeks (Trento)	1.5 k€	1.5 k€
	Total	**1.5 k€**	**1.5 k€**
	TOTAL	**2.5 k€**	**2.5 k€**

TIFPA-INFN-TRENTO			
Item	**Cost**	**I year**	**II Year**
Hardware		-	-
	Total	**k€**	**k€**
Consumables	resins and raw materials for the production of scintillators, optics for luminescence measurements, reagents, and systems for the production of patterned structures of polymeric scintillators.	8.0 k€	5.0 k€
	Total	**8.0 k€**	**5.0 k€**
Travel expenses	2 pers. x 2 weeks (Catania) 2 pers x 2 weeks (Lecce)	4.0 k€	4.0 k€
	Total	**4.0 k€**	**4.0 k€**
	TOTAL	**12.0 k€**	**9.0 k€**

BUDGET: SUMMARY

Unit	YEAR	Hardware	Consumables	Travel expenses (k €)	
LECCE	I	7.0	19.0	5.0	
	II	-	9.0	5.0	
	Total	**7.0**	**28.0**	**10.0**	**45.0**
TRENTO	I	-	8.0	4.0	
	II	-	5.0	4.0	
	Total	-	**13.0**	**8.0**	**21.0**
CATANIA	I	-	1.0	1.5	
	II	-	1.0	1.5	
	Total	-	**2.0**	**3.0**	**5.0**
		7.0	**38.0**	**17.0**	**71.0**

UNIVERSITÀ DEL SALENTO

Dipartimento di Matematica e Fisica "Ennio De Giorgi"

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Thank you for your attention!

BoLAS-NEXT

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