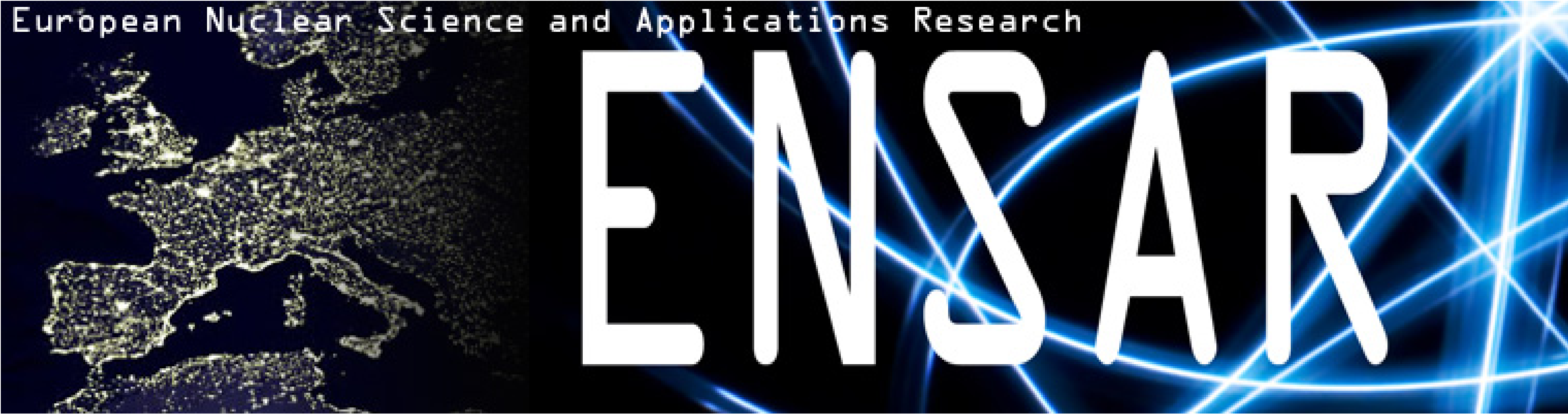


JRA 04: Innovative solutions for nuclear physics detectors: "From basic R&D to high performance detectors"

INDESYS **http://igfae.usc.es/~indesys**

Dolores Cortina
Universidad de Santiago de Compostela
Spain

Main Objectives

➢ Identify and investigate the properties of new scintillation materials and photo-sensors.

➢ Develop a detection principle adequate to the detection of high energy neutrons based on converter material plus subsequent charged-particle detection, with Resistive-Plate Chambers (RPCs) and the associated electronics.

➢ Investigate the implementation of these innovative solutions in real gamma and neutron detector devices.

➢ Study the impact of these detection technologies on applications to industry and society in general.

USC – IFJ PAN- CIEMAT-INFN Milano and Legnaro–JYFL- TuDA-FUL-GSI

Total Budget 500 k€

Task 1: USC
R&D on new and existing scintillation materials. Detectors coating and compacting (66% of JRA Budget)

- **Subtask 1:** (USC, CIEMAT,INFN-Milano, JYFL, IFJ PAN)

Study of new and existing inorganic scintillation materials with commercially available photo-sensors (LAAPD, SiPM, PM). Comparative study of the best commercial combination.

Characterization of organic scintillation materials to extend the neutron detection to lower energies. Investigate the use of LAAPD arrays and SiPM as photo-sensors of large volume liquid scintillation cells. Comparative study of the best commercial combination.

Test of new scintillation materials with neutrons, gammas and light charged particles with radioactive sources and dedicated irradiation at reference facilities (accelerators). Construction and tests of detector prototypes

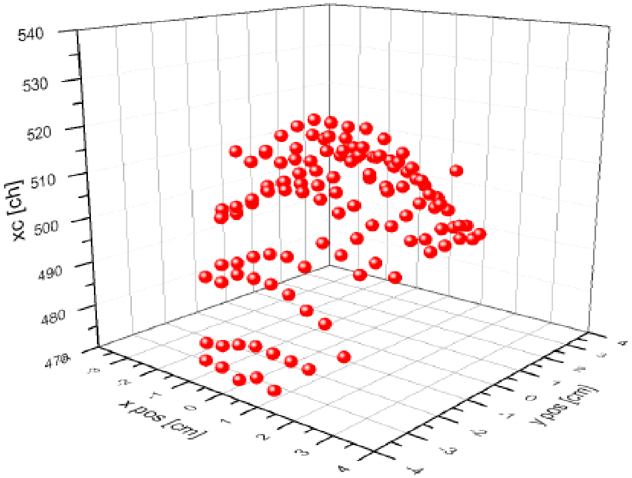
D-JRA04-1.1 **Report on characterization of organic and inorganic scintillators for neutron and gamma detection. Results of detector prototype tests** (month 46)

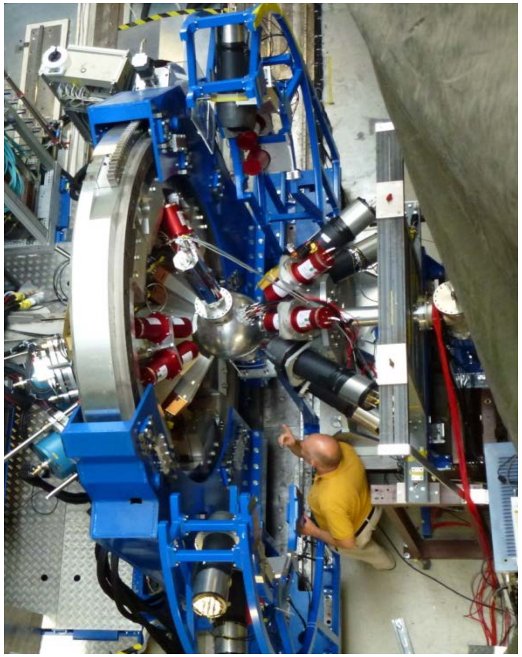
Characterization of new inorganic scintillators

Characterization of large volume detectors (3,5”x8”)

- Test of LaBr coupled to different PM R10233-100SEL PM
- Linearity of large volume detectors
- Voltage divider design LABRVD
- Response g-sources and high energy gammas (22.6MeV)
- Evaluation of detector efficiency (validation with simulation)
- Position sensitivity
- Use in g-detection arrays

A. Giaz et al., submitted to NIM
A. Giaz, abstract IEEE

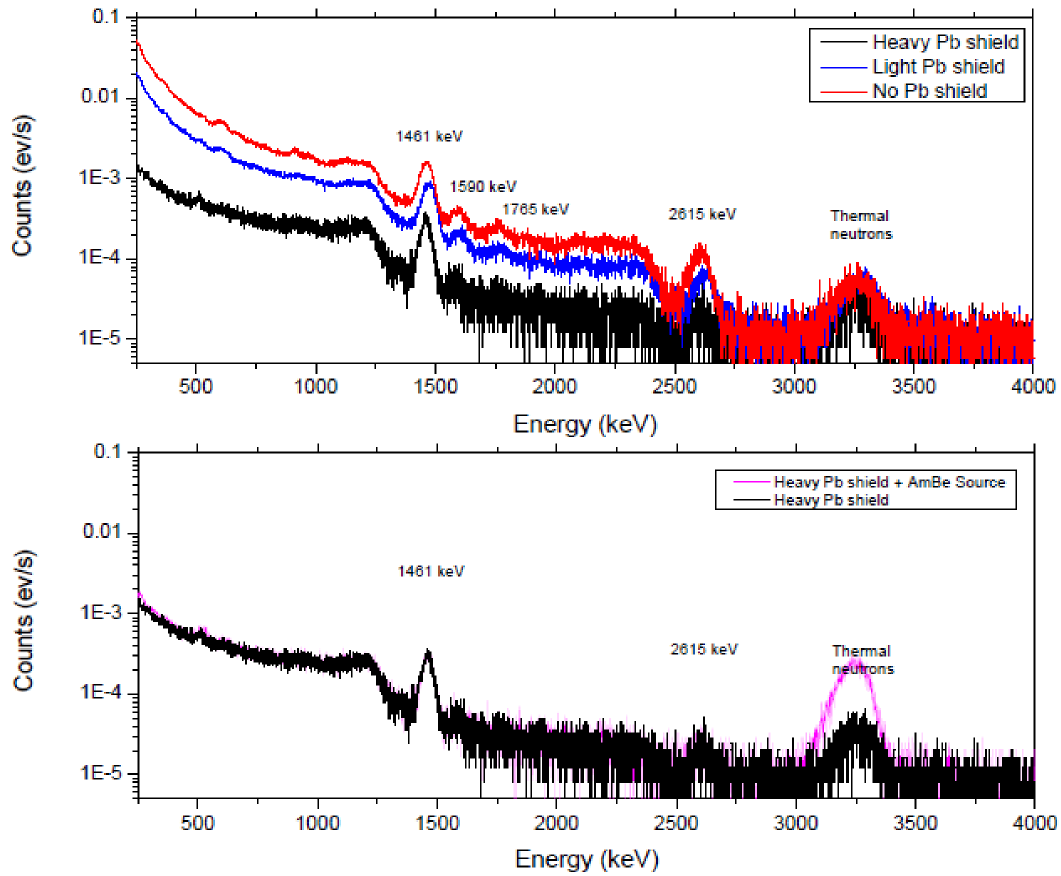




R&D PARIS detector

Characterization of new inorganic scintillators

Performances of a 1”x1” CLYC scintillator detector
E.Bizzarr et al.



CLYC scintillator (Cs_2LiYCl_6)

Study of the internal radiation

Response to fast and thermal neutrons

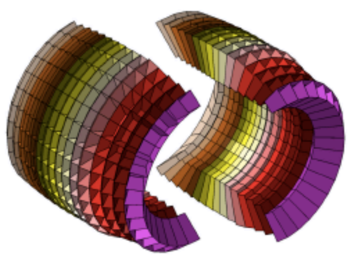
Characterization of new inorganic scintillators

Performant CsI(Tl) scintillators

FAIR/NUSTAR/R^{3}B/TDR CALIFA

Technical Report for the Design, Construction and Commissioning of The CALIFA Barrel: The R3B CALorimeter for In Flight detection of γ-rays and high energy charged pArticles

November 25, 2011



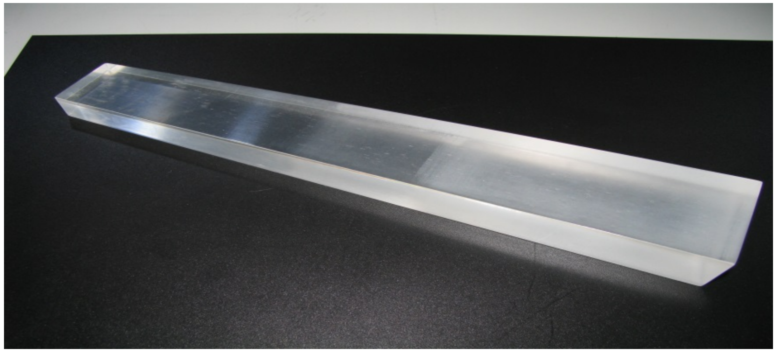
R^{3}B	Name	E-Mail
Project Leader/Spokesperson	Thomas Aumann	t.aumann@gsi.de
Deputy	Bjoern Jonson	bjn@fy.chalmers.se
Technical Coordinator	Roy Lemmon	roy.lemmon@stfc.ac.uk
Deputy	Olof Tengblad	olof@iem.cfmac.csic.es
Project Coordinator	Heiko Scheit	hscheit@ikp.tu-darmstadt.de
Contact Person at the FAIR site	Haik Simon	h.simon@gsi.de
CALIFA Convener	Dolores Cortina	d.cortina@usc.es
Deputy	Bo Jakobsson	bo.jakobsson@nuclear.lu.se

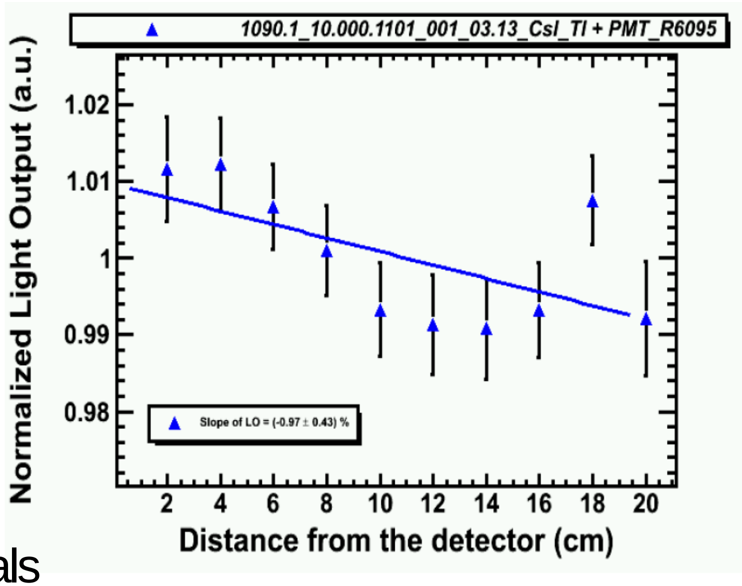
Inner radius	30 cm
N of crystals	1952
Crystal geometries	11
Av. Crystal Volume/ weight	285 000 cm^3/ 1300 kg

- **Long CsI(Tl) crystals**
- **Large Area Avalanche Photodiodes (LAAPD)**
- **Dedicated electronics**
- **Mechanical structure based on carbon fiber alveoli**

Characterization of new inorganic scintillators

Performant CsI(Tl) scintillators





NRE for development of finger-like CsI(Tl) scintillation crystals

Calorimetric hability → very large cristals

Spectroscopic hability →ΔE/E ~ 5 %@1 MeV (moving sources), very segmented

Extremely uniform in terms of dopant concentration homogeneity (0.06% and 0.12%.)

Extremely uniform in terms of light output (longitudinal interaction points N.U. < 5%) 1111

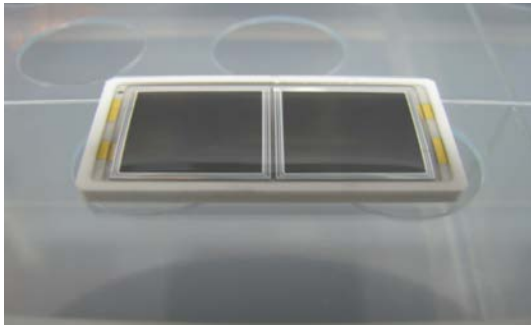
Very strict mechanical tolerances (50-100 μm)

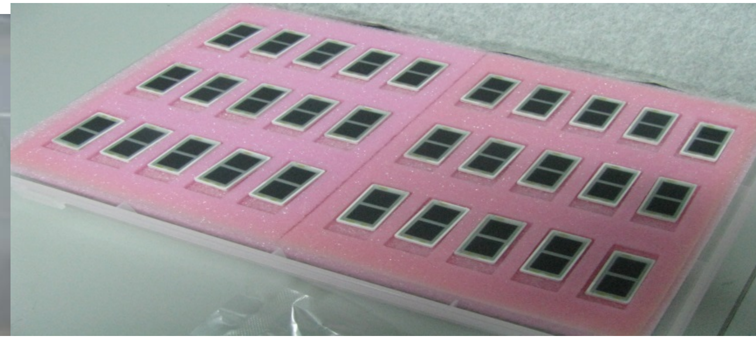
Optimization of the wrapping process (no light cross-talk, mechanical tolerance)

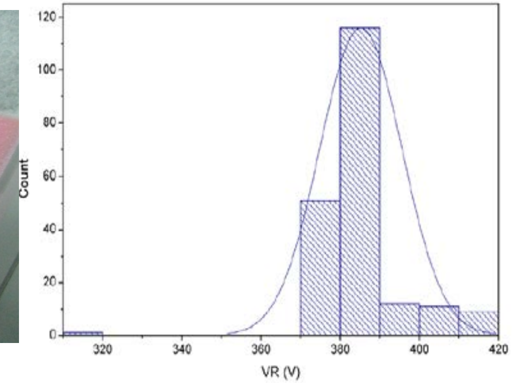
→ ready for mass production

R&D CALIFA Barrel

Characterization of new photosensors





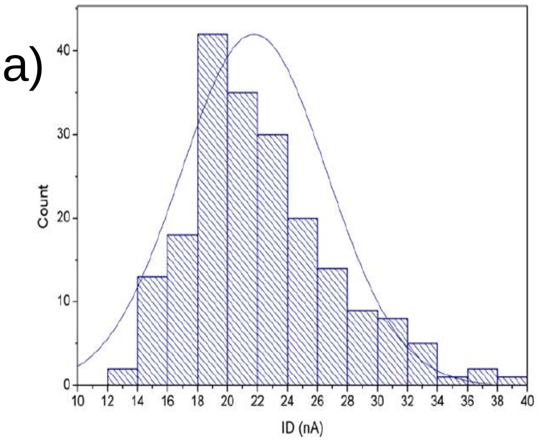


- Large Area Avalanche Photodiodes (10 x 20 mm^2 active area)

NRE for development of the ceramic mask (Hamamatsu)

Very low dark current, low Bias Voltage

From R&D to standard product → mass production



Performance tests of prototypes in laboratory and

Beam test :high energy gammas, high energy protons

Calibration Linearity

B. Pietras et al., NIM (2013) accepted

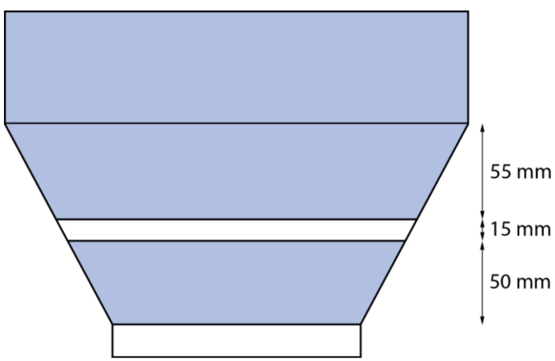
M. Gascón et al ., JINS (2013) submitted

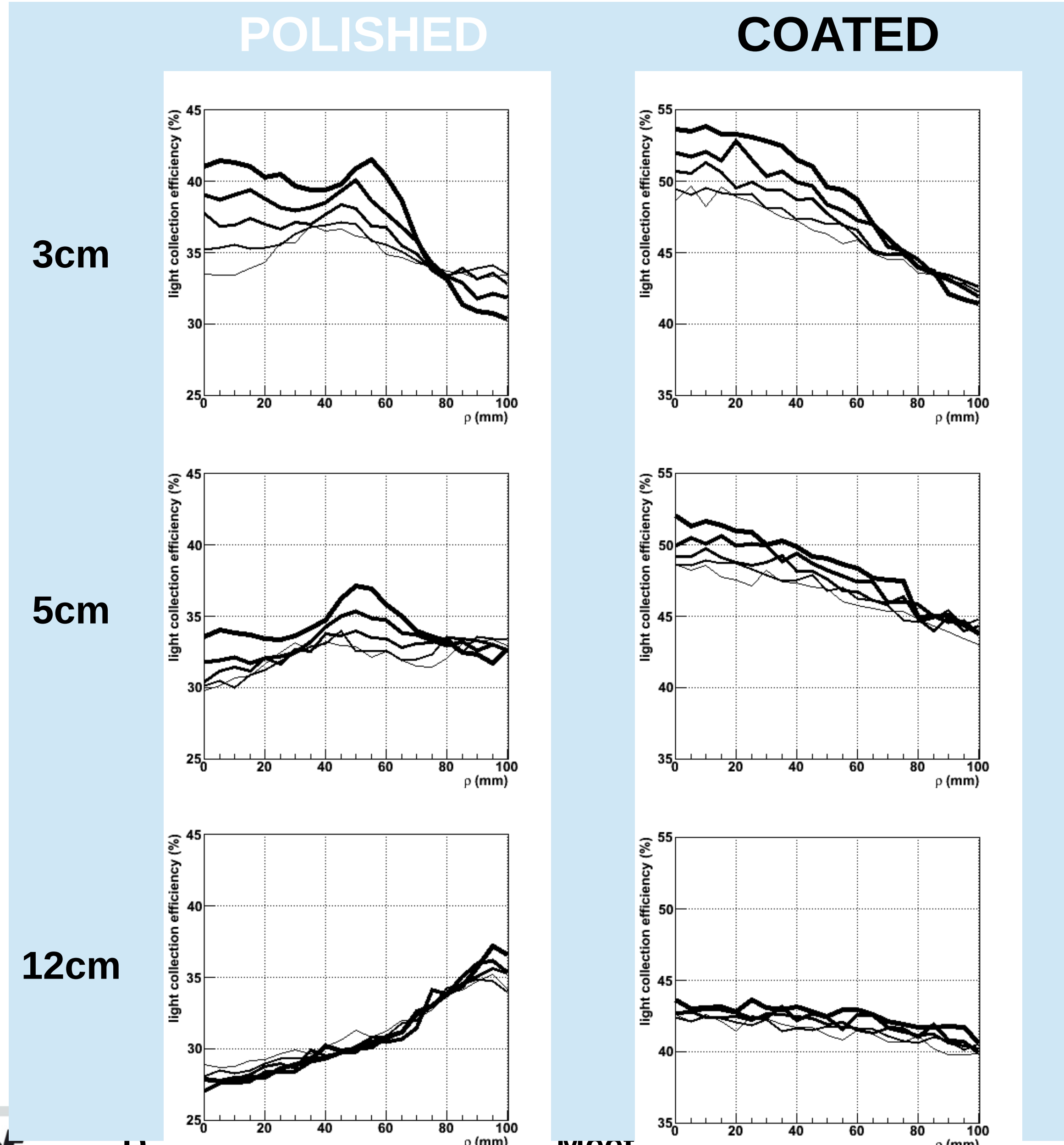
Characterisation of liquid organic scintillators

Validation of the optical transport simulations

Comparison to previous work for the design of a light guide.

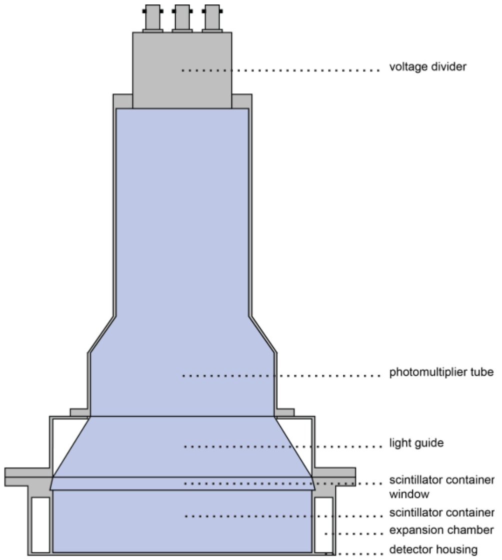
A 5 cm thick light guide offers an acceptable trade off between a high average value and uniformity in the light collection efficiency.



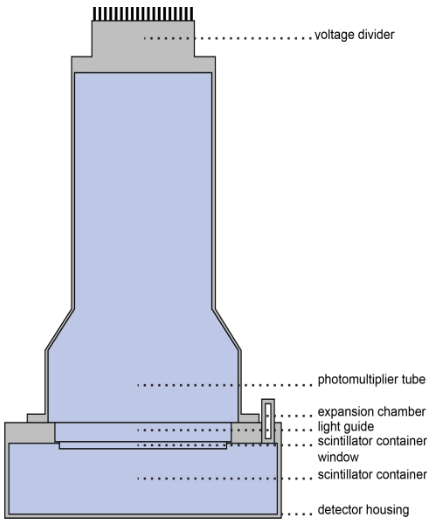


Performance of different detector concepts

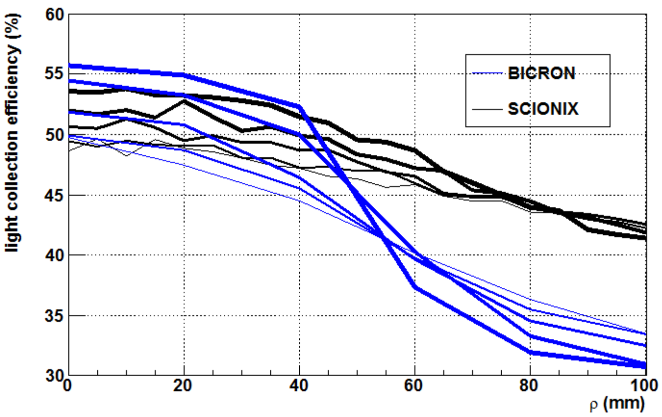
The most important part of the optical design focused in the design of the light guide, essential to get a uniform light collection efficiency.



CIEMAT/BICRON

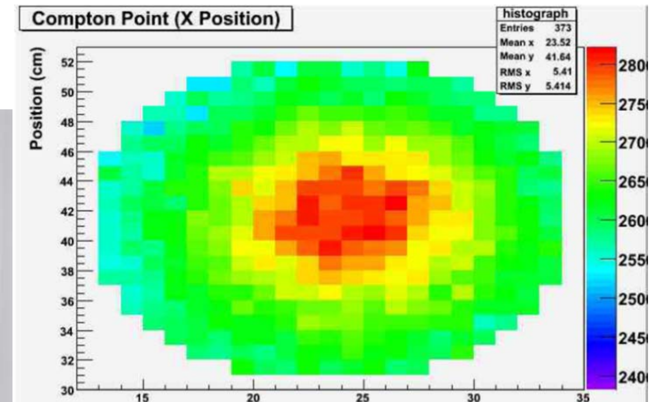


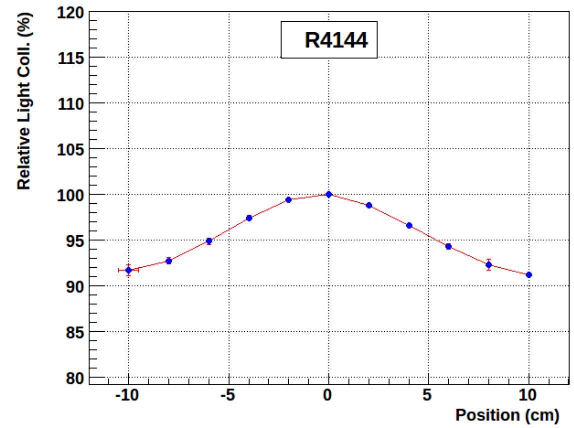
ELJEN



PMT and detector scanning system

We have set up a 2D scanning robot with sub-milimetric precision.
The system can scan the PMT photocathode with an led/laser (inside a black box) and a detector with a collimated γ-ray source.
Verification of the light transport simulations and characterisation of the detectors.



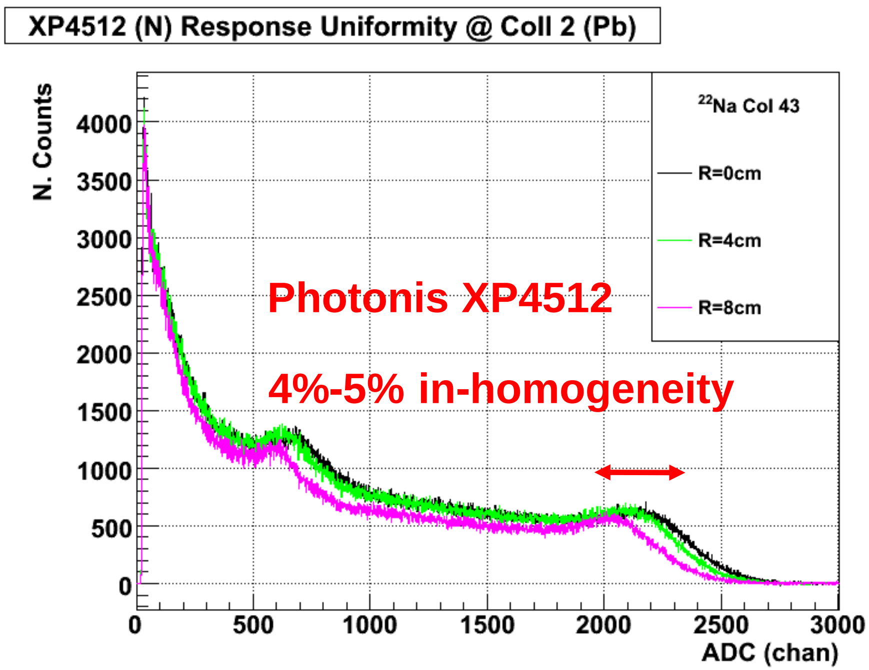


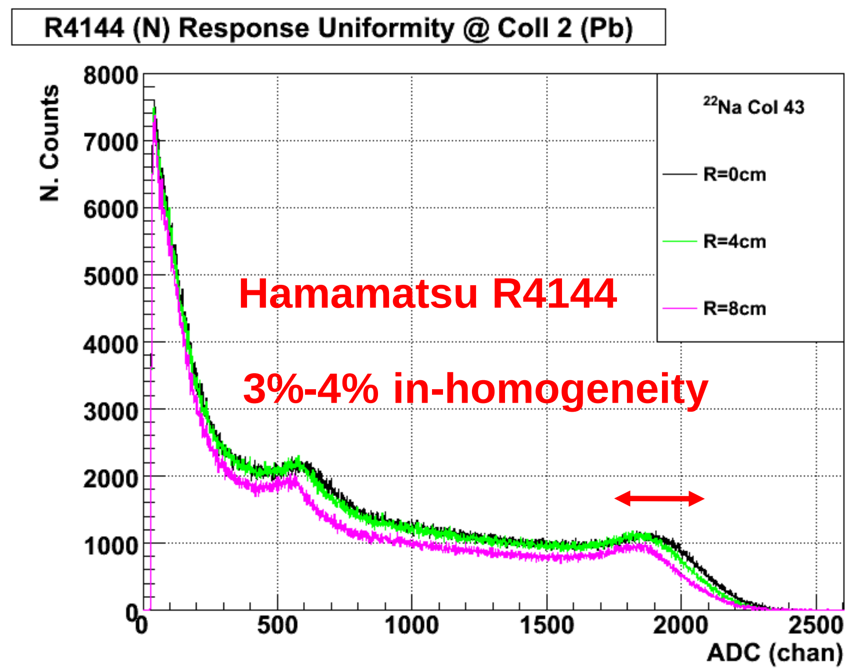
GOBIERNO DE ESPAÑA MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD

Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

The homogeneity of the light collection

Tests have been performed with a wide range of PMTs. T
he non-existent XP4512 shows the best overall performance.
The Hamamatsu R4144 seems to have a similar performance.
The tests were made with a 22Na source collimated with a 5 cm thick
Pb brick and a Φ=5mm hole.





Task 1:
R&D on new and existing scintillation materials. Detectors coating and compacting

➢Subtask 2: (IFJ PAN,CIEMAT,JYFL,USC,INFN Milano,GSI)

Characterization of light production, propagation and collection of new inorganic scintillation crystals to predict the response of these materials as standalone crystals or integrated in sophisticated devices. Implementation of a software tool able to define the best detector geometries.

Characterization of light production, propagation and collection of liquid scintillators. Determination of detector cell geometries in terms of light collection and compacting

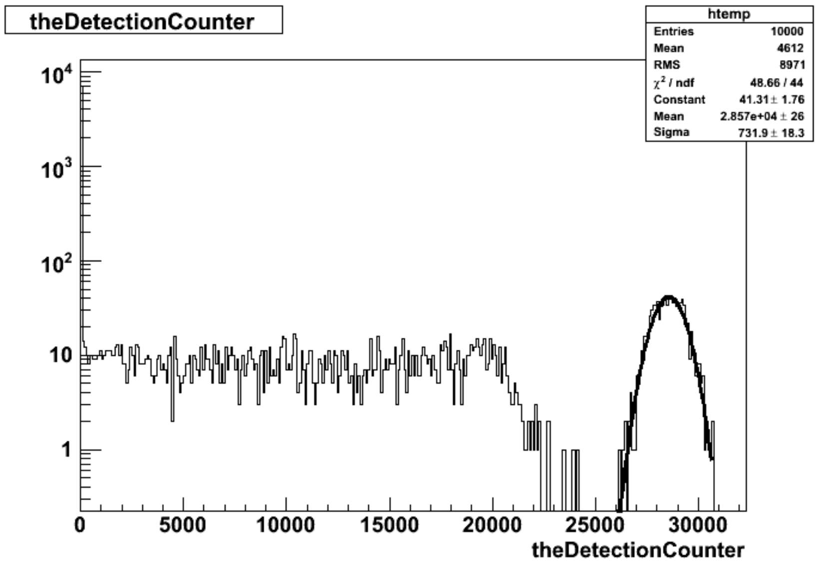
D-JRA04-1.2: Report on the light production, propagation and collection for both organic and inorganic scintillators (month. 36).

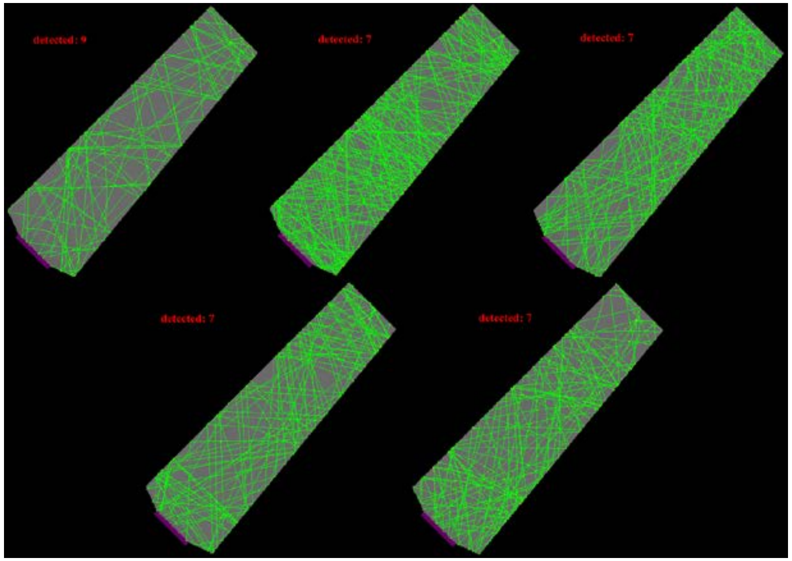
Scintillation Light characterization

Study of light properties in inorganic scintillator crystals with Geant4:

Detailed characterization of the optical processes (Unified model).

Results for different polished and diffuse surfaces, different parameters, evaluation of light ouptut in each case.





Application: determination of the shape of highly segmented detector

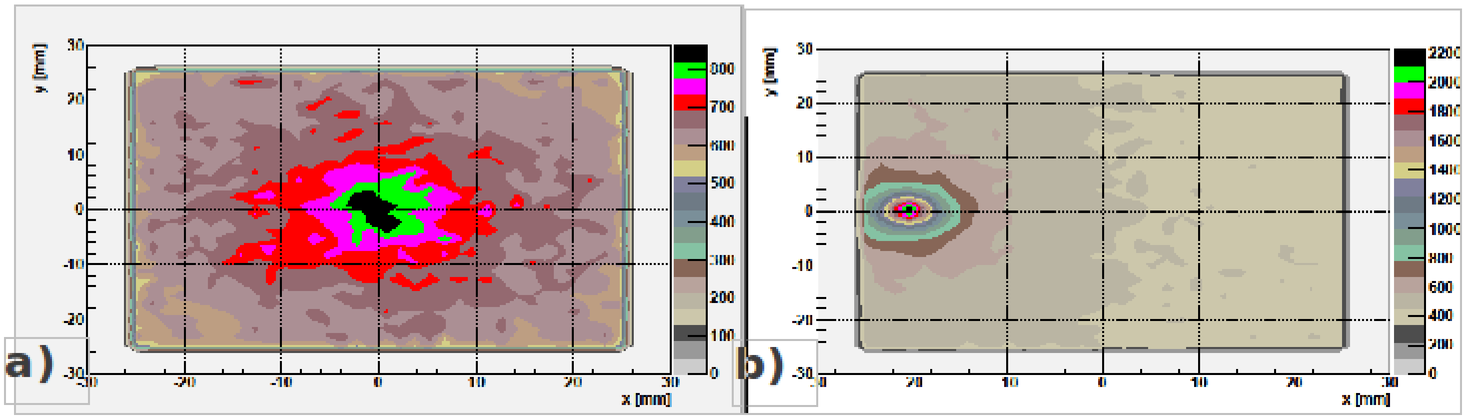
CALIFA @R3B

→experimental validation in the laboratory

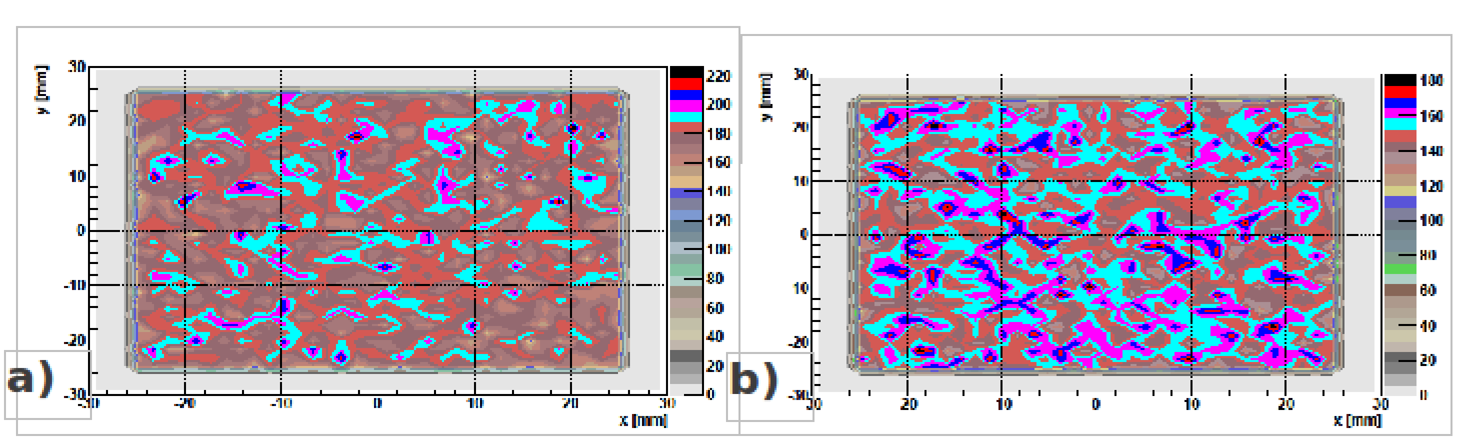
Scintillation Light characterization

Study of light properties in inorganic scintillator crystals with Geant4:

Cubic $LaBr_3$ crystal (2”x2”x2”)



phoswich detector $LaBr_3$ (2”x2”x2”) + NaI (2”x2”x6”)



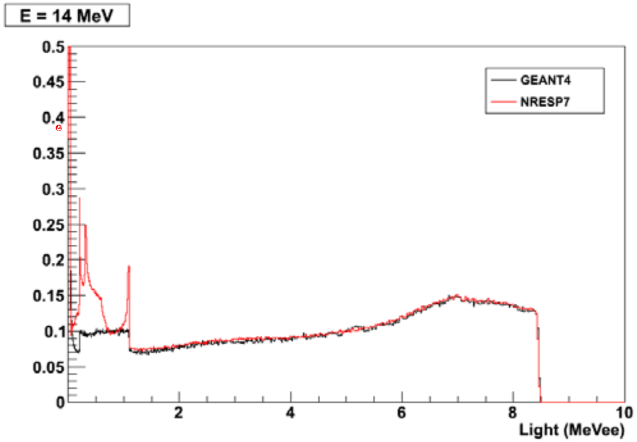
Scintillation Light characterization

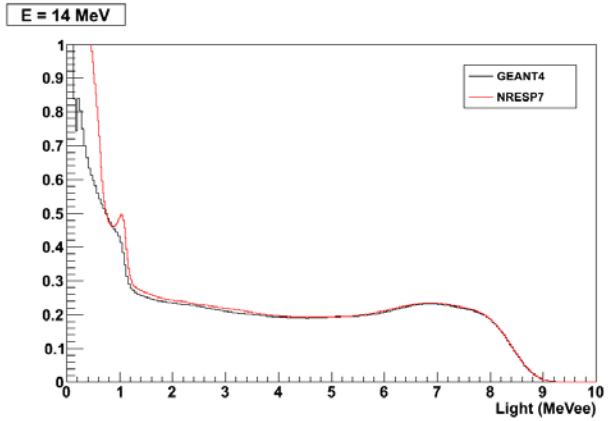
- **Modelling the light yield of (organic) scintillators**
- **Neutron interactions, Monte Carlo simulation of detectors and light output.**

Excellent agreement except in the low energy region of response functions for neutrons above 8 MeV due to (n,3α) reactions on carbon not implemented in GEANT4.

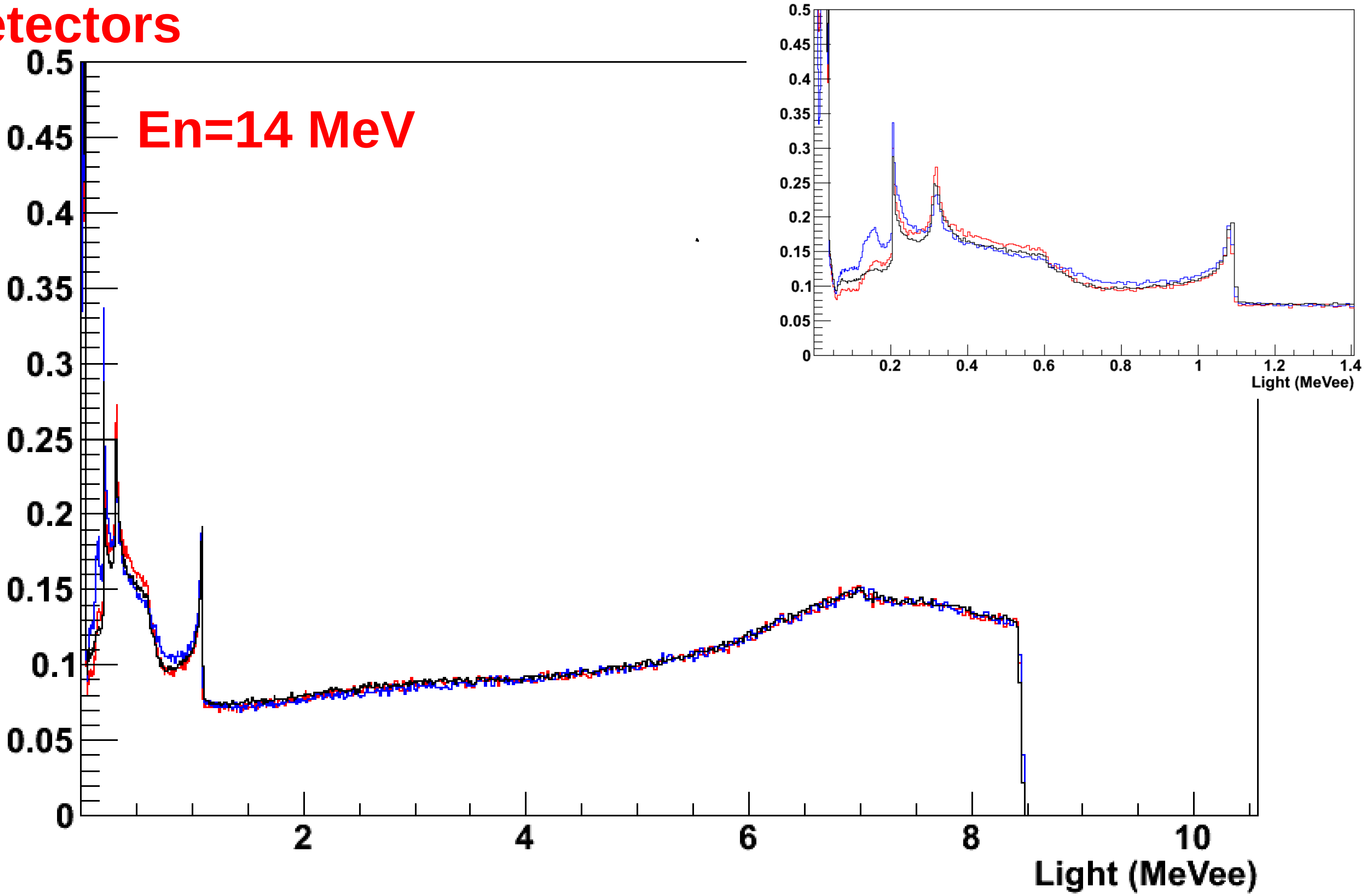
Table 3 Neutron reactions on carbon

reaction	Q-value MeV	threshold MeV	angular distribution used
$^{12}C(n,n)^{12}C$	-	-	non isotropic
$^{12}C(n,n')^{12}C^*$	-4.439	4.812	non isotropic
$^{12}C(n,\alpha)^{9}Be$	-5.71	6.19	non isotropic
$^{12}C(n,\alpha')^{9}Be^* \rightarrow n + {}^{8}Be \rightarrow 2\alpha$	-8.13	8.81	isotropic
$^{12}C(n,n')^{12}C^* \rightarrow$	-7.65	8.29	isotropic
$\alpha + {}^{8}Be \rightarrow 2\alpha$	-9.63	10.4	isotropic
	-10.80	11.7	"
	-11.80	12.8	"
	-12.70	13.8	"
$^{12}C(n,p)^{12}B$	-12.61	13.7	"
$^{12}C(n,d)^{11}B$	-13.73	14.9	"
$^{12}C(n,2n)^{11}C$	-18.72	20.3	not included
$^{12}C(n,pn)^{11}B$	-15.96	17.3	not included





Neutron interactions and Monte Carlo simulation of detectors



GOBIERNO DE ESPAÑA

MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD

Ciemat

Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

Task 1:
R&D on new and existing scintillation materials. Detectors coating and compacting

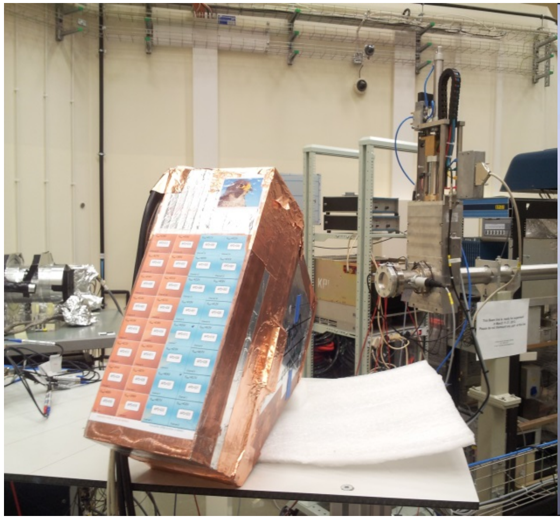
➢Subtask 3: (GSI, LNL, USC)

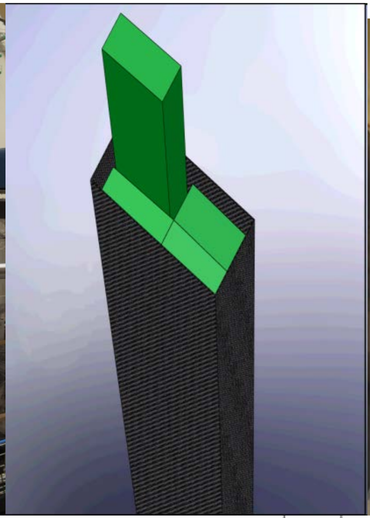
Application to new an existing scintillation materials.
Investigation of the performance of materials with both low photon and neutron interaction cross sections (i.e. carbon fiber) for detector housings.

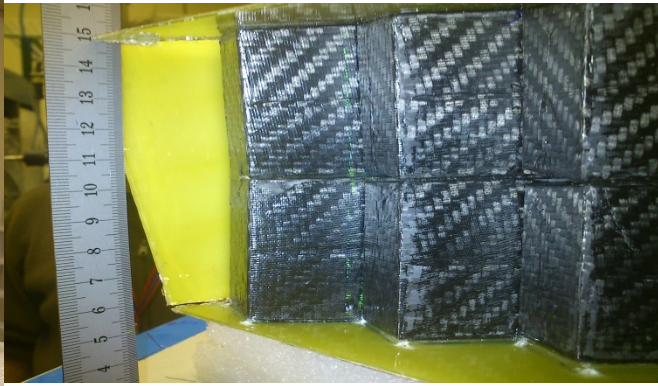
Application to germanium detectors. Development of minimal interacting passivating cover for Ge detectors

Evaluation of materials with low g and p interaction x-sections

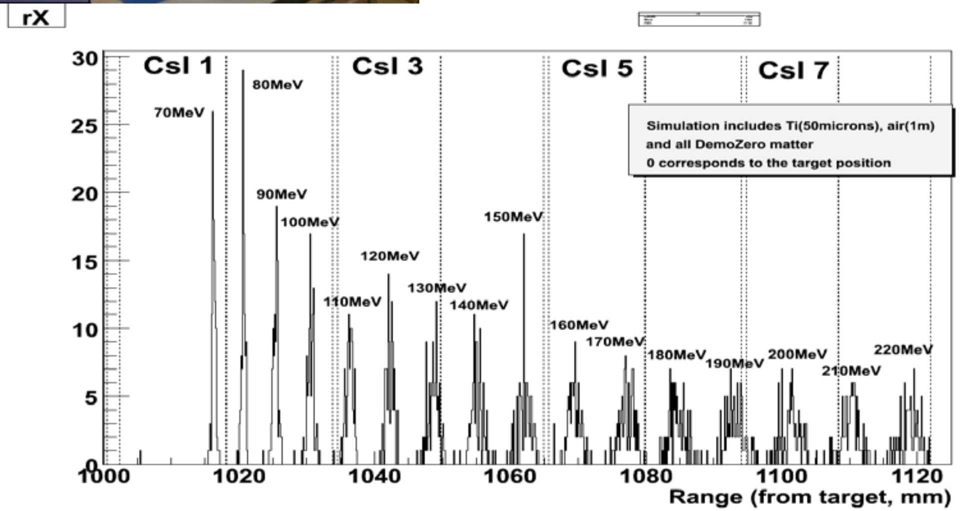
Experiment performed in Krakov medical accelerator. 70-180 MeV protons
→ in progress







Simulations performed to evaluate the efficiency reduction of a calorimeter structure based on thin Carbon fiber alveoli
→ CALIFA Barrerl TDR
http://www.fair-center.eu/



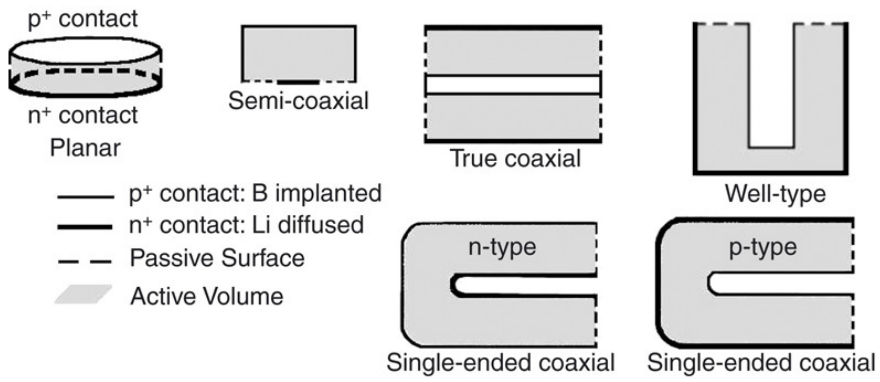
Experimental testing of carbon fibre alveoli thickness effect on proton scattering throughout crystal array.

R&D CALIFA Barrel

Development of new passivation techniques for HPGe detectors

We have studied in the last two years how to improve the passivation of the intrinsic surface of the HPGe detectors in order to increase their reliability and performance.

The intrinsic surface is the most critical part of any Ge detector as the full bias voltage is applied across the surface.



The intrinsic surface has to be electrically passive in order to avoid surface leakage currents when high voltage differences are applied. The passivation needs to have flat band conditions, to introduce no additional noise and has to be stable against thermal cycles.

Passivated surface layer in HPGe

The passivation technique has to be also applicable to the insulation in between segments.

Industrial processes:

- Sputtered layer of SiO_2
- Sputtered layer of amorphous Ge

Characterizations can be done in a Material Sciences Lab but the passivation has to be tested on a Ge detector, and we have acquired the R&D to make them in our lab.

Studied processes:

- Hydride-terminated Germanium Passivation
  We have obtain extremely good results with etch quenching through methanol but it is needed additional protection in order to be usefull in industrial processes. We are working on with good results.
- Sulfide Passivation
  We have done test of Sulfide Passivation on HPGe wafers. We have applied methods found in literature used in passivation of Ge for electronic applications. The quality of the passivating coatings is still not good for Ge detector standards.
- Deposition of oxides layers by liquid phase deposition (LPD) give successful results but can not be applied in industrial production of Ge detectors.
- Etching in a solution with acetic acids have been tested.
- Oxynitride (GeO_xN_y) passivations have passed the laboratory tests and we are starting to apply some of them to Ge detectors.

AGATA ADVANCED GAMMA TRACKING ARRAY

INFN Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Legnaro

Task 2: GSI
Development of a detection concept and prototypes for high-energy neutrons

- Subtask 1: (GSI, TUD,FUL)

Simulation of response functions from fast-neutron detector prototypes and full detector optimization with respect to efficiency, multi-hit capability, and converter implementation.

- Subtask 2:

Development, tests and optimization of Resistive-Plate-Chambers for the detection of fast neutrons including test measurements using electrons and neutrons, including a cost-effective electronic read-out scheme providing the excellent time resolution required (about 10.000 channels).

D-JRA04-2: Report describing the concept and proof-of-principle for a detection system for high-resolution measurement of fast neutrons. Report on detector prototype tests (month 48).

Neutron-detector developments

Development of full size prototypes:

- MRPCs with different converter materials and structure (FZD-Rossendorf, SINP Kolkata, LIP Coimbra)
- Scintillator-bar detector without converter material (GSI, TU Darmstadt)

Status: Full-size scintillator prototype has been constructed consisting of 200 sub-modules (250x5x5 cm3) in the final design (TU Darmstadt, GSI)

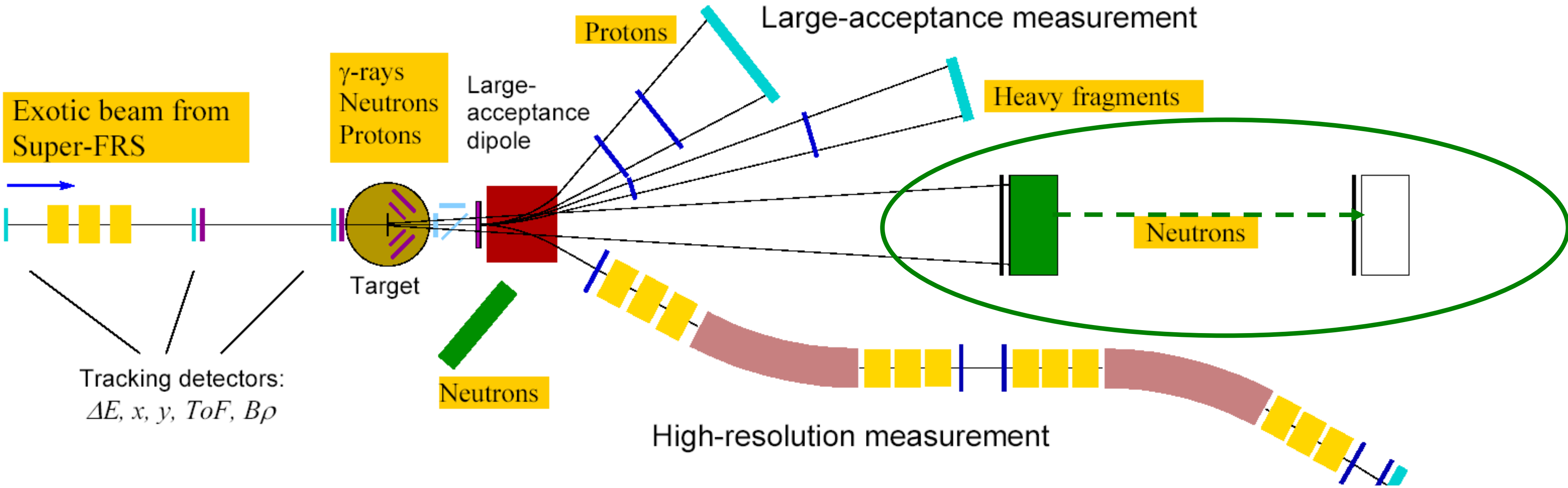
Prototype has been tested together with MRPCs with mono-energetic neutrons at different energies in Q4 2012 at GSI (all participants)

Simulation of complete detector:

- MRPC using glass as converter (Univ. Lisboa)
- Pure active detector from plastic scintillator (TU Darmstadt, GSI)
- Development of neutron tracking algorithms for NeuLAND

Status: NeuLAND Technical Design has been accomplished. NeuLAND will be based on a fully active scintillator detector which will provide excellent multi-neutron recognition and tracking capabilities

NeuLAND: High-Energy Neutron-Detection at R3B



NeuLAND design goals

- Acceptance 80 mrad @ 12 m distance: active area 200 cm x 200 cm
- >90% efficiency for 0.2-1.0 GeV neutrons
- Time resolution σ < 100 ps
- Multi-hit capability for up to 5 neutrons

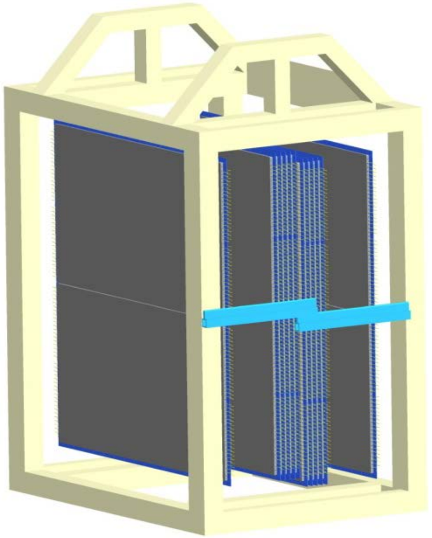
Example invariant-mass resolution: NeuLAND-target distance 35 m

ΔE ≈10 keV at 200 keV above the neutron threshold

NeuLAND detector design : two alternatives

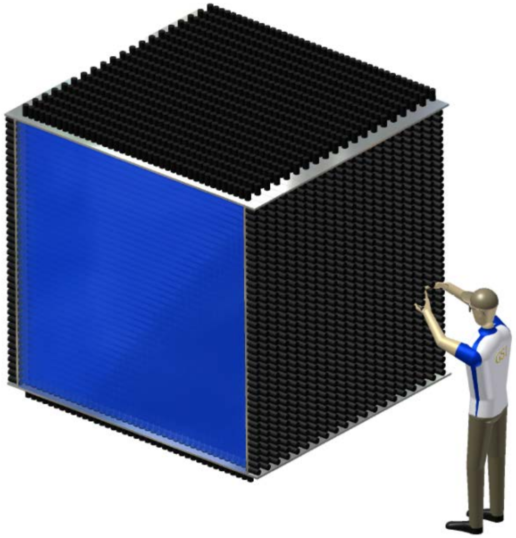
NeuLAND based on MRPC's:

- Alternating layers of passive converter material and Resistive Plate Chambers (RPC) for the detection of secondary particles
- Detector size 2*2*~1 m^3
- ~8.000 channels
- Mass 4 tons

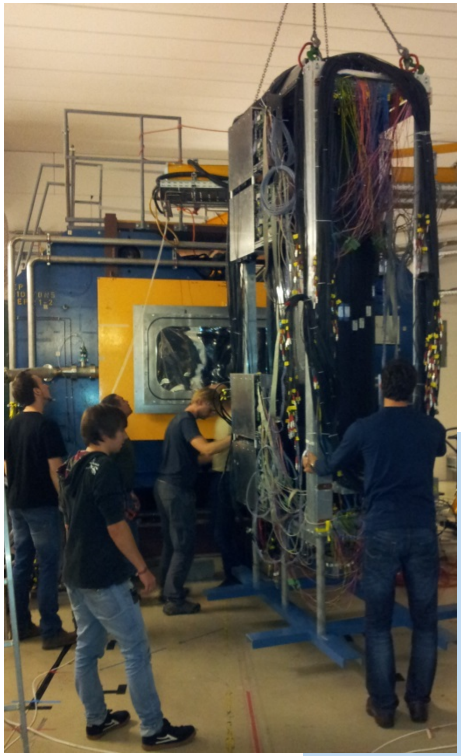


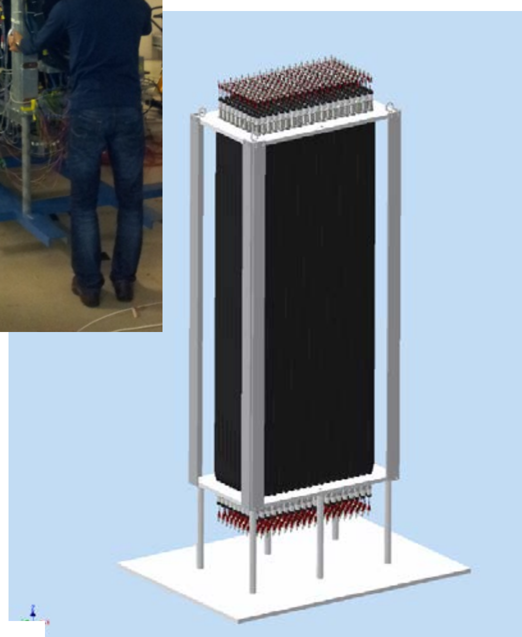
NeuLAND based on organic scintillator:

- Full active detector
- Bar structure read out from two sides by PMs/APDs
- Detector size 2*2*~2 m^3
- ~9.000 channels

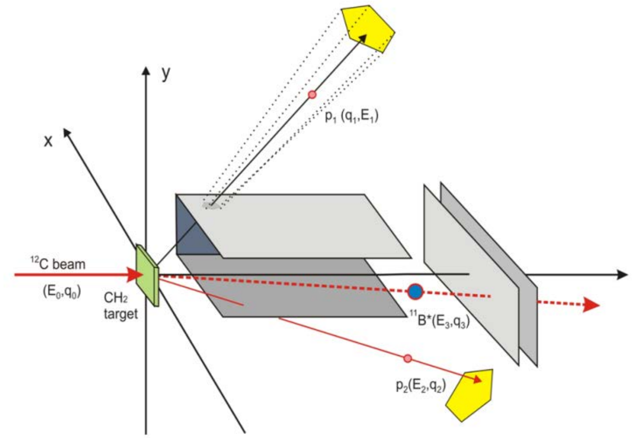


Test Experiment with high-energy neutrons performed in Nov 2012 at GSI





Production and tagging of mono-energetic neutrons from quasi-free d(p,2p)n reactions using deuteron beams at different energies

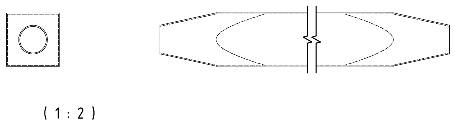


Prototype: 200 Modules, 400 PMs
10 x 20 modules
(50 x 200 cm2 face size, 1 m depth)
Status: Data analysis and detailed comparison to simulations in progress

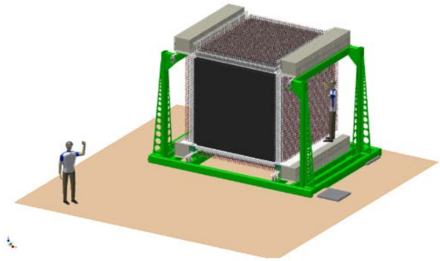
TECHNISCHE UNIVERSITÄT DARMSTADT

ENSAR

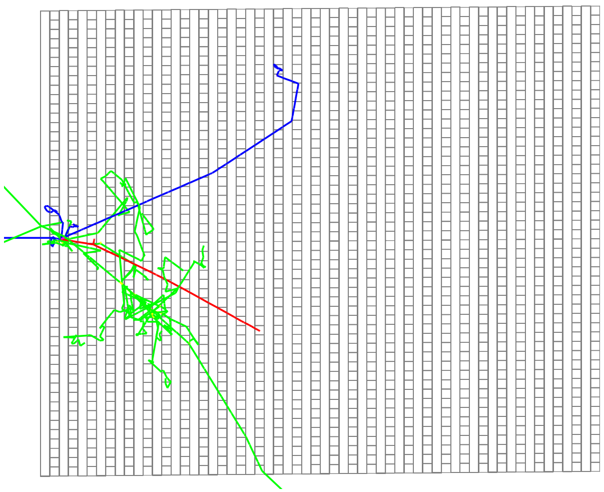
NeuLAND: final design and neutron tracking capabilities

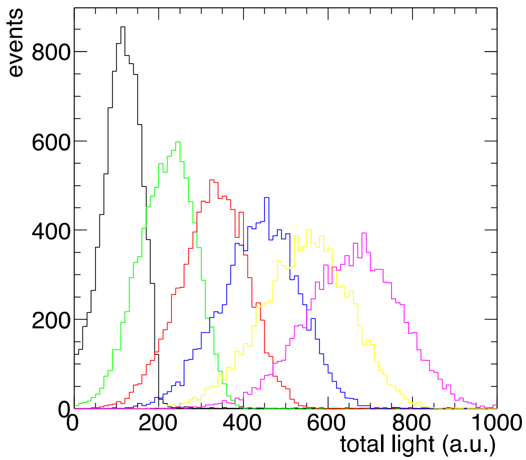


2.5x2.5x3 m3 active volume
3000 detector modules
6000 electronic channels
100 psec time resolution
1.5 cm position resolution



Calorimetric properties and high granularity are key for multi-neutron detection



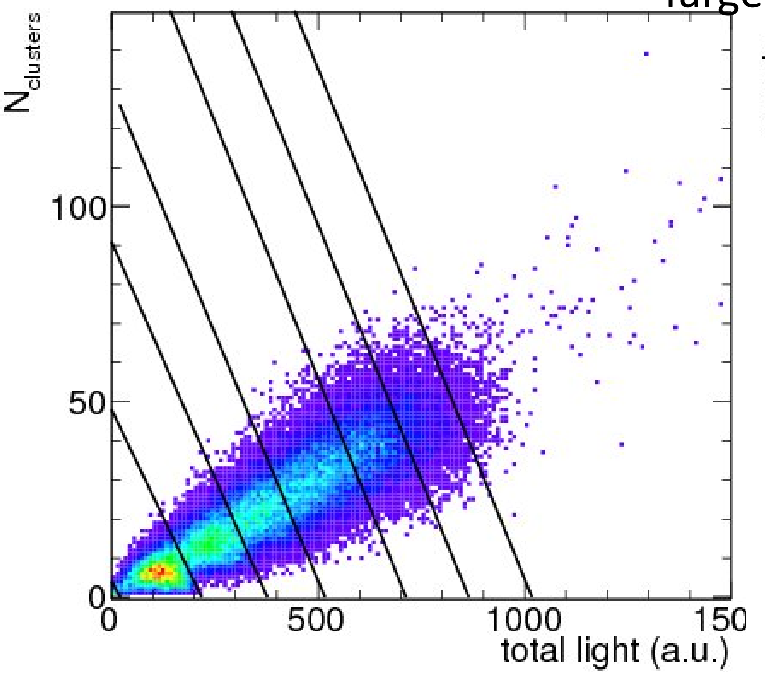


Simulations

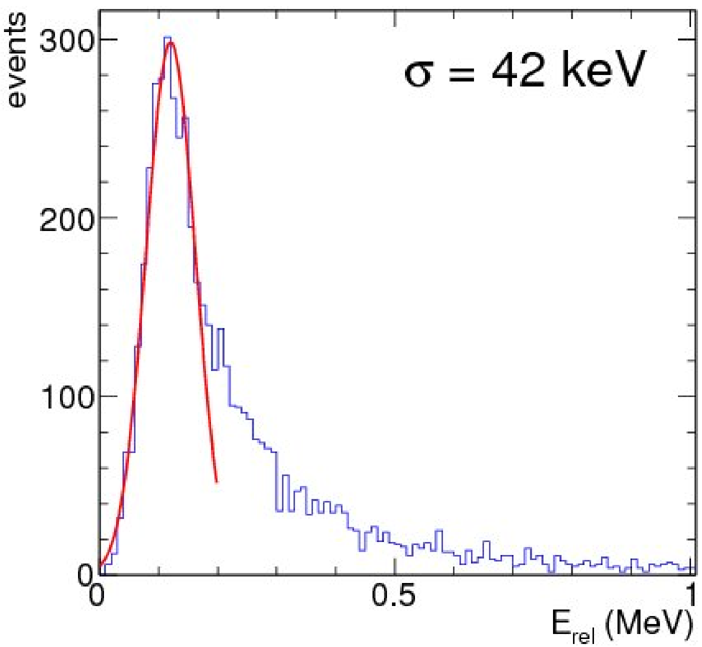
ENSAR Postdoc Dima Kresan (TU Darmstadt):

Simulation and development of tracking algorithms

60% efficiency for 4n detection at 600 AMeV with 10% contamination only



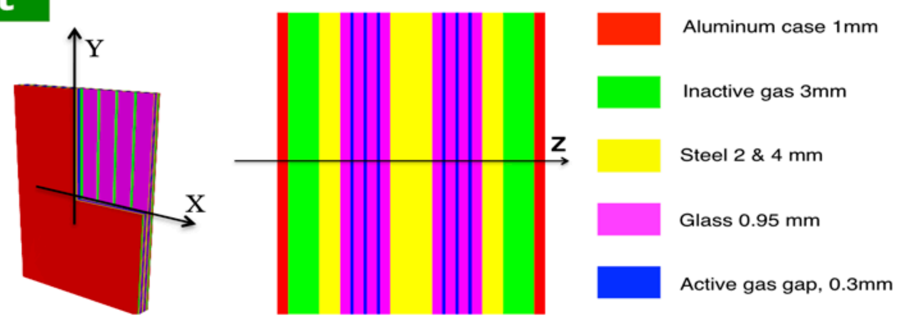
4n, 600 AMeV, 100 keV relative energy,
Target-detector distance 35 m

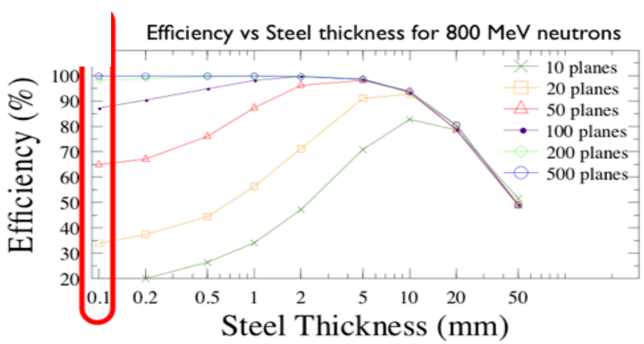


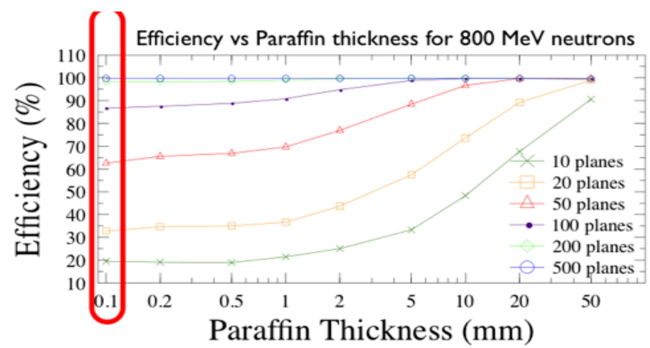
The RPC alternative

Develop a detection principle adequate to the detection of high energy neutrons based on converter material plus subsequent charged particle detection, with Resistive Plate Chambers (RPCs) and the associated electronics

The steel concept



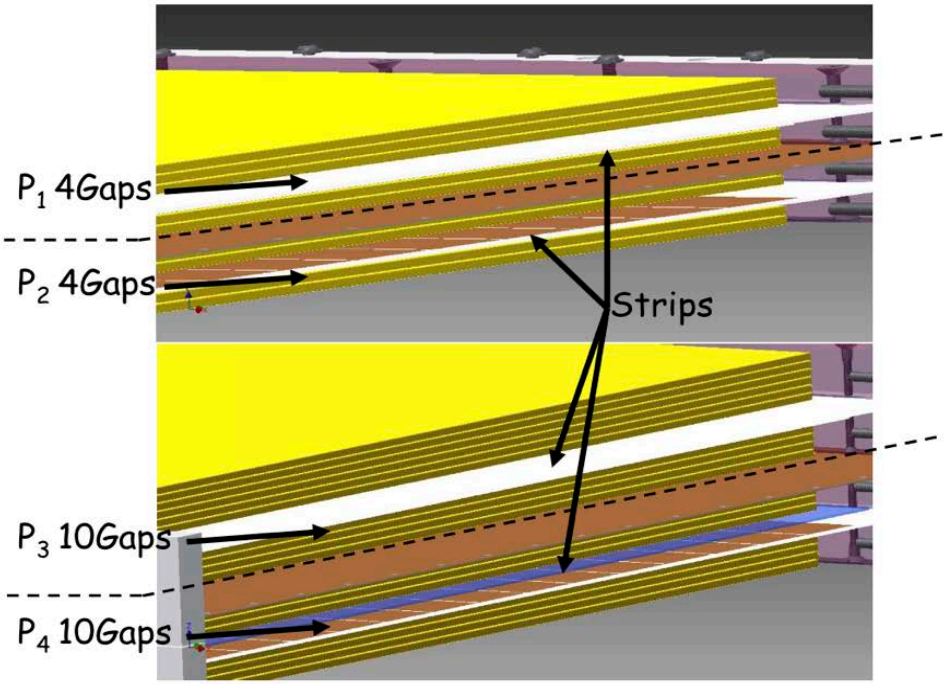


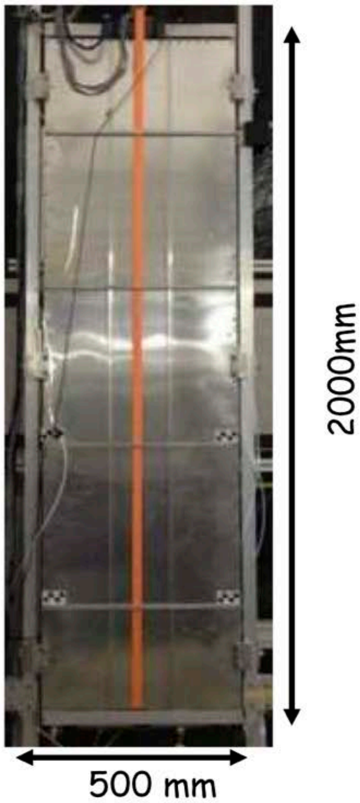


We concluded that the **glass could work also as a converter**

We defined a **new concept just with glass**

Prototype Construction at LIP-Coimbra





Prototype exposed to
Quasi-monoenergetic neutrons
during GSI experiment S406

Task 1: Summary

➢ Characterization of scintillators for neutron and gamma detection.

- Characterization of large volume LaBr3:Ce (INFN Mi, IFJ-PAN)
- Characterization of liquid organic scintillation (Ciemat)
- Development of LAAP and use with CsI(Tl) (USC)
- Irradiation tests of prototypes (INFN Mi, Ciemat, USC, JYFL, IFJ-PAN)

➢Study of light production, propagation and collection for scintillators:

GEANT 4: Light produced by gamma-ray in inorganic scintillation crystals (USC, INFN Mi)

Investigation of light propagation and collection employing APDs (GSI)

- Optimisation of the cell geometries for a better light collection in neutron detection (Ciemat, JYFL)

➢ Housing of hygroscopic scintillation materials with low interactive materials and minimal interacting passivating covers for Ge detectors :

- Carbon Fiber alveoli, study of minimal thickness and wrapping optimization (USC)
- Settig up procedures for mechanical lapping and chemical etching of HPGe crystals and characterisation. First tests coating deposition /growths (INFN-LNL)
- Investigation of procedures for mechanical and chemical treatment of Ge crystals (GSI)

Task 2: Summary

Development of full size prototypes 200*50 cm^2:

- MRPCs with different converter materials and structure (FZD-Rossendorf, SINP Kolkata, LIP Coimbra)
- Scintillator-bar detector without converter material (GSI Darmstadt, TU Darmstadt)
- Fast-timing readout electronics for all prototypes (TU Darmstadt)

Simulation of complete detector:

- MRPC incl. converter variation (Univ. Lisboa, FZD-Rossendorf)
- Scintillator variant (Univ. Cologne, GSI Darmstadt)

Beam tests for prototypes:

- Tests with single electrons at ELBE (FZD-Rossendorf)
- Testt using fast neutrons S406 at GSI (GSI Darmstadt, TU Darmstadt, Univ. Lisboa)

JRA 04 : Project Schedule

	1st year				2nd year				3rd year				4th year			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
T1: R&D on scintillation materials. Detector coating and compacting																
Study of inorganic/organic scintillators +photo-sensors																
Characterization of light production, propagation and collection																
Test of new scintillators/prototypes																
Detectors coating and housing for inorganic scintillators and Germanium detectord																
Report R&D on scintillation materials and detector prototype tests																D
Report R&D on light production, propagation and collection												D				
Report covers for Ge detectors and scintillators housing																D
T2: Detection for high-energy neutrons																
Simulation of detector concept																
Detector developments																
Report R&D and prototype detector test																D

- Project Progress without any major deviation from original plans