A Large Surface Neutron and Photon Detector for Civil Security Applications

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Frontier Detectors for Frontier Physics

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Motivation

- The security of ports and transportation is of utmost importance for the development of economy and the security of a nation
- Among the necessary actions to ensure the security of ports and borders, the inspection of cargo containers is one of the most time consuming and expensive procedure:

  over 9 million containers passed through Italian ports in 2008
- Potential threats are the smuggling of radioactive materials and in particular of special nuclear materials (SNM) such as highly enriched uranium (HEU) or weapon-grade plutonium
- New techniques for the inspections of cargo containers should be fast, allow the detection and identification of dangerous materials, and be non-invasive, to reduce the costs and shipping delays

We propose to use a large surface neutron detector based on plastic scintillator to identify the presence of fissile or fertile material inside a container

Existing Systems

- Active Interrogation Systems: use external radiation sources (neutrons or photons) to induce reactions as fission, photo-fission, nuclear resonance fluorescence, ...
  - Pro: high induced reaction rate results in high sensitivity
  - Con: safety issues in usage of radiation sources, dose limits in public areas, irradiation limits on inspected items (food, ..)

- Passive Systems: rely on detection of intrinsic radiation emitted by the material, such as neutrons from spontaneous fission or (α,n) reactions or characteristic photon lines
  - Pro: ideal for usage in public areas
  - Con: effectiveness depends on SNM type and presence of shields; low spontaneous fission rate of HEU requires large surface detectors

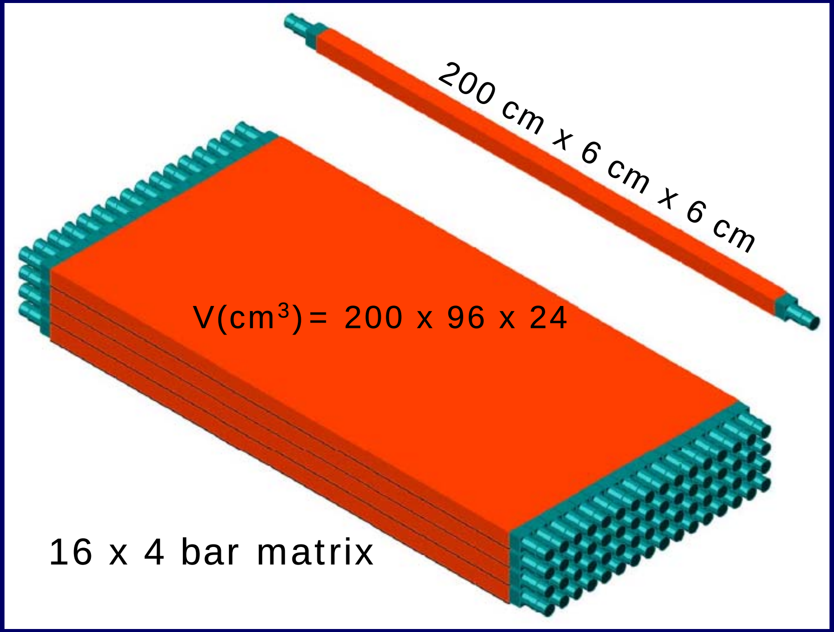
- Existing systems employ scintillators for gamma detection and ^{3}He tubes for neutron detection

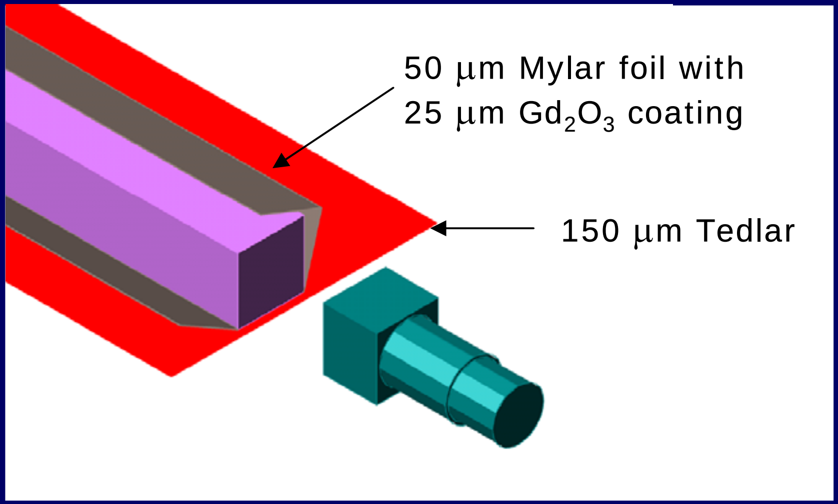
The proposed detector can be used both in passive and active systems for simultaneous detection of neutrons and photons with large acceptance

Detector Layout

- Matrix of plastic scintillator bars (16 x 4 bars of 200 cm x 6 cm x 6 cm)
- Bars wrapped in Mylar foils with Gadolinium coating for neutron capture
- 3 mm Lead foils between the scintillator planes to increase photon absorption
- Scintillator light read on both ends by 2” PMTs

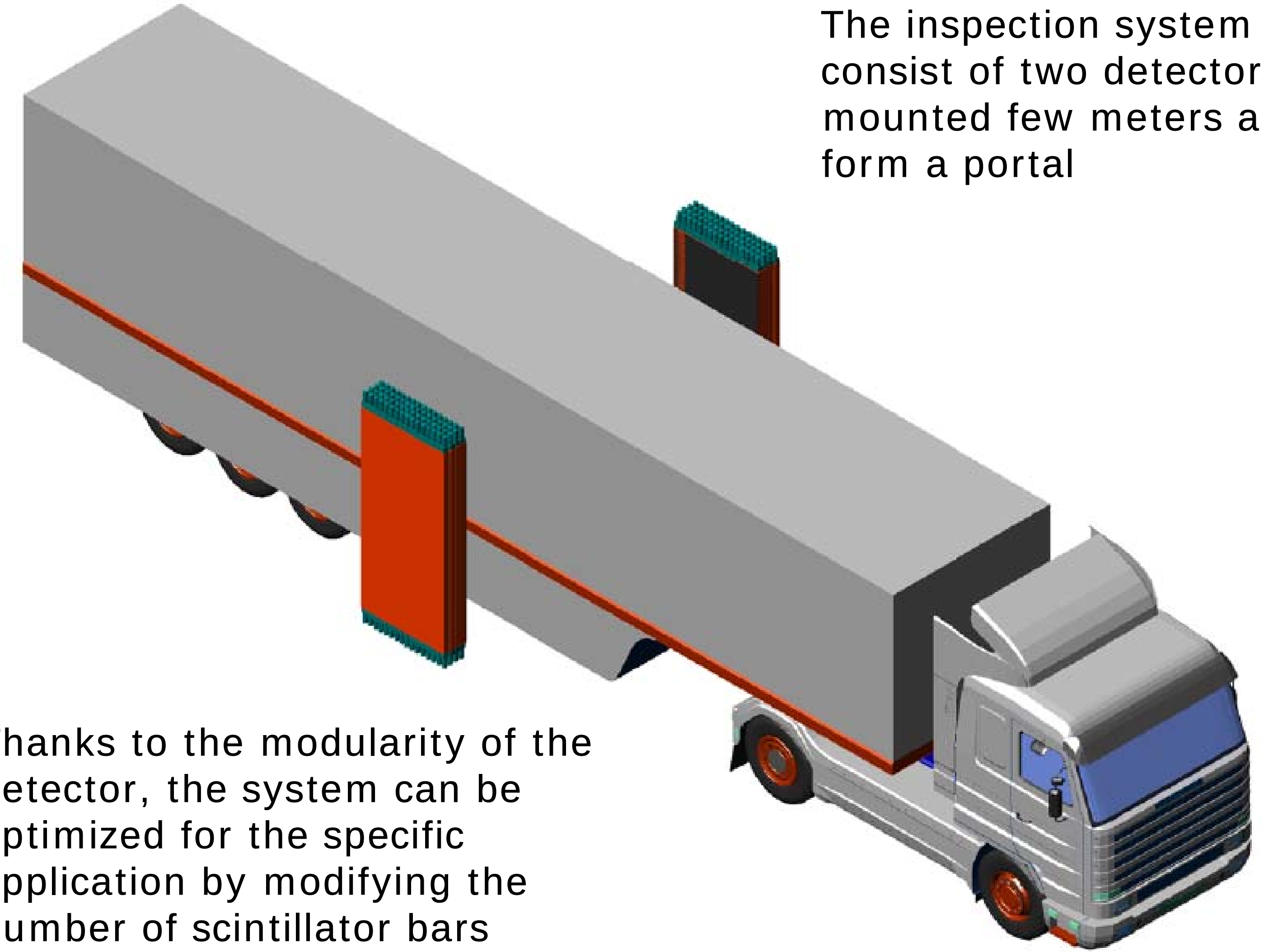
Total surface of ~ 2 m^2





Detector Layout

The inspection system will consist of two detectors mounted few meters a part to form a portal



Thanks to the modularity of the detector, the system can be optimized for the specific application by modifying the number of scintillator bars

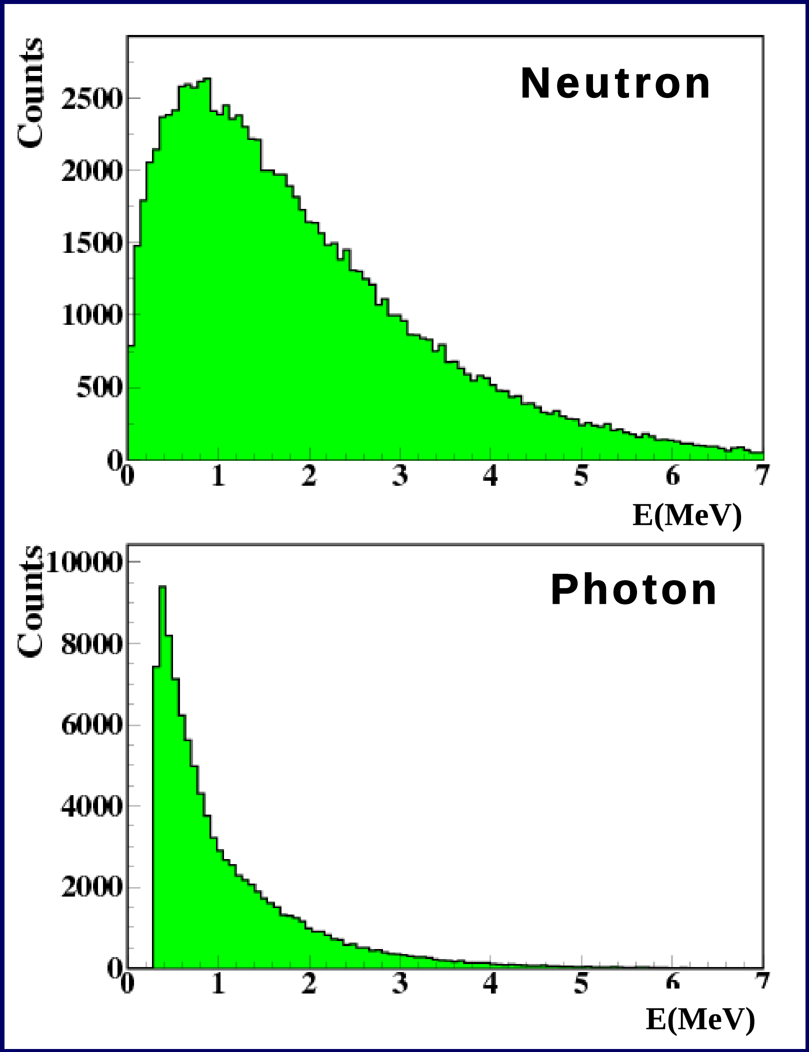
GEANT4 Simulation

Full simulations of detector response to neutrons and photons with GEANT4 (v.4.9.2)

Photon and neutron energy distribution generated according to typical fission spectra

Step-by-step tracking of particles through the detector

Simulations results were used to optimize the relevant parameters as the detector dimension, number of scintillator bars, gadolinium foils thickness, readout, ...



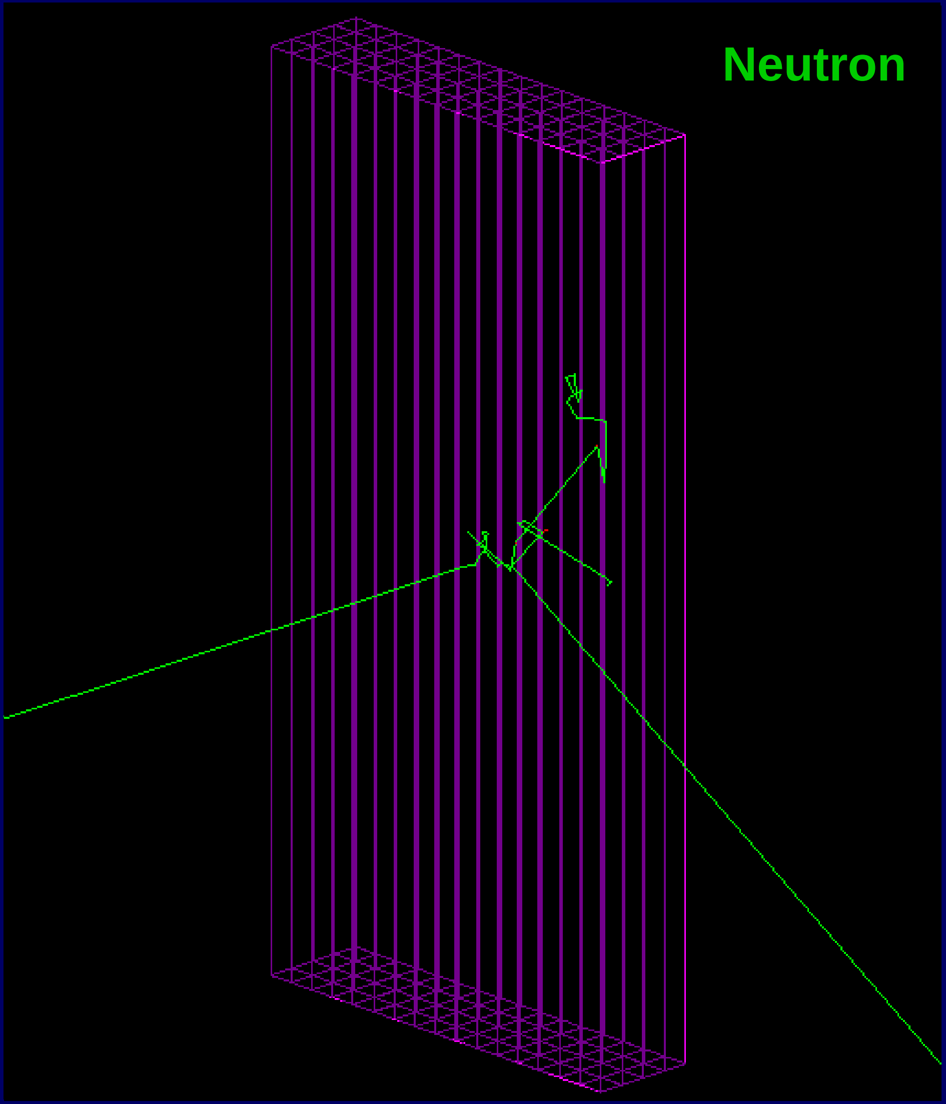
GEANT 4 Simulation

Photons:
interact primarily through Compton scattering

⇒ **few hits in the entire detector**

Neutrons:
scatter elastically on the hydrogen in the scintillators, till captured by the Gadolinium producing a photon cascade (total energy released ~ 8 MeV)

⇒ **several hits in the detector**

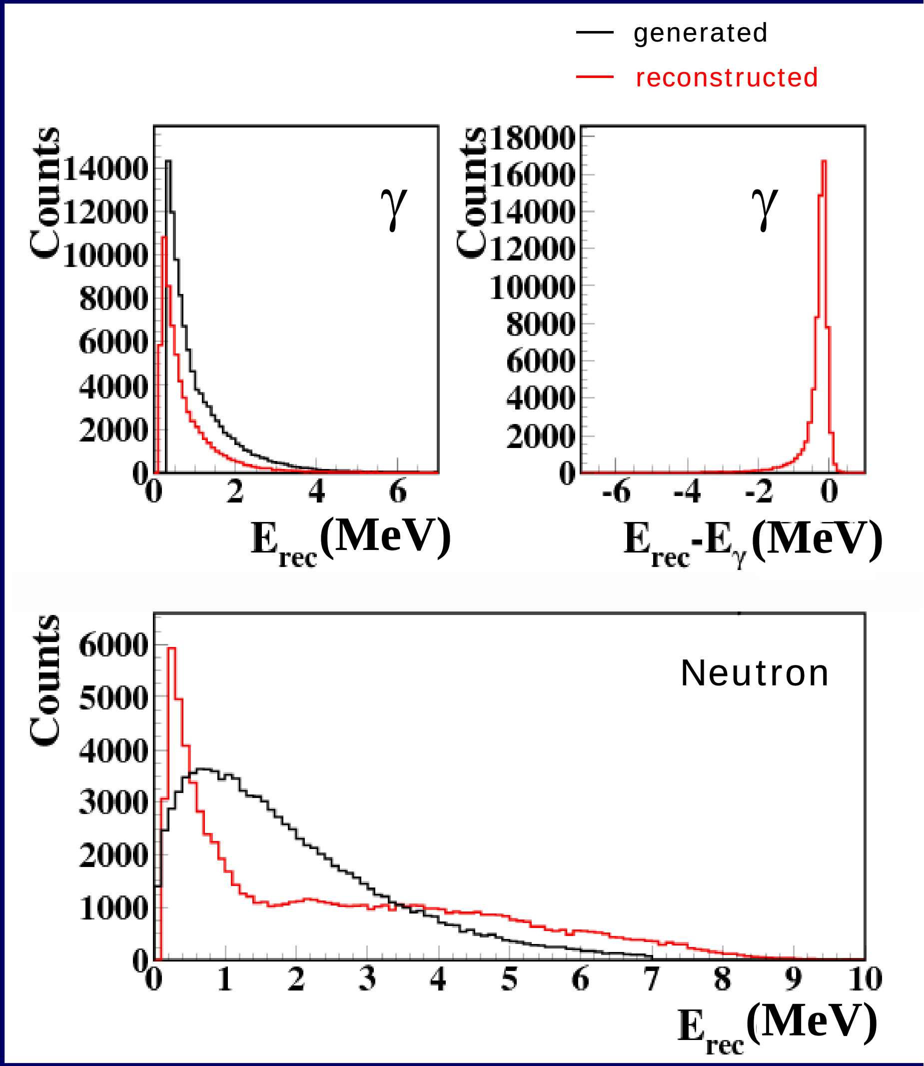


Detector Response

Simulations of scintillation light transmission and collection using effective parameters:

- scintillation light yield N=1600* optical photons/MeV
- attenuation length: λ=2* m
- light collection surface: 2" pmt
- QE = 15%

One hit in a bar is reconstructed if a signal greater than 4 p.e. is detected by both PMTs, corresponding to a 150keV threshold

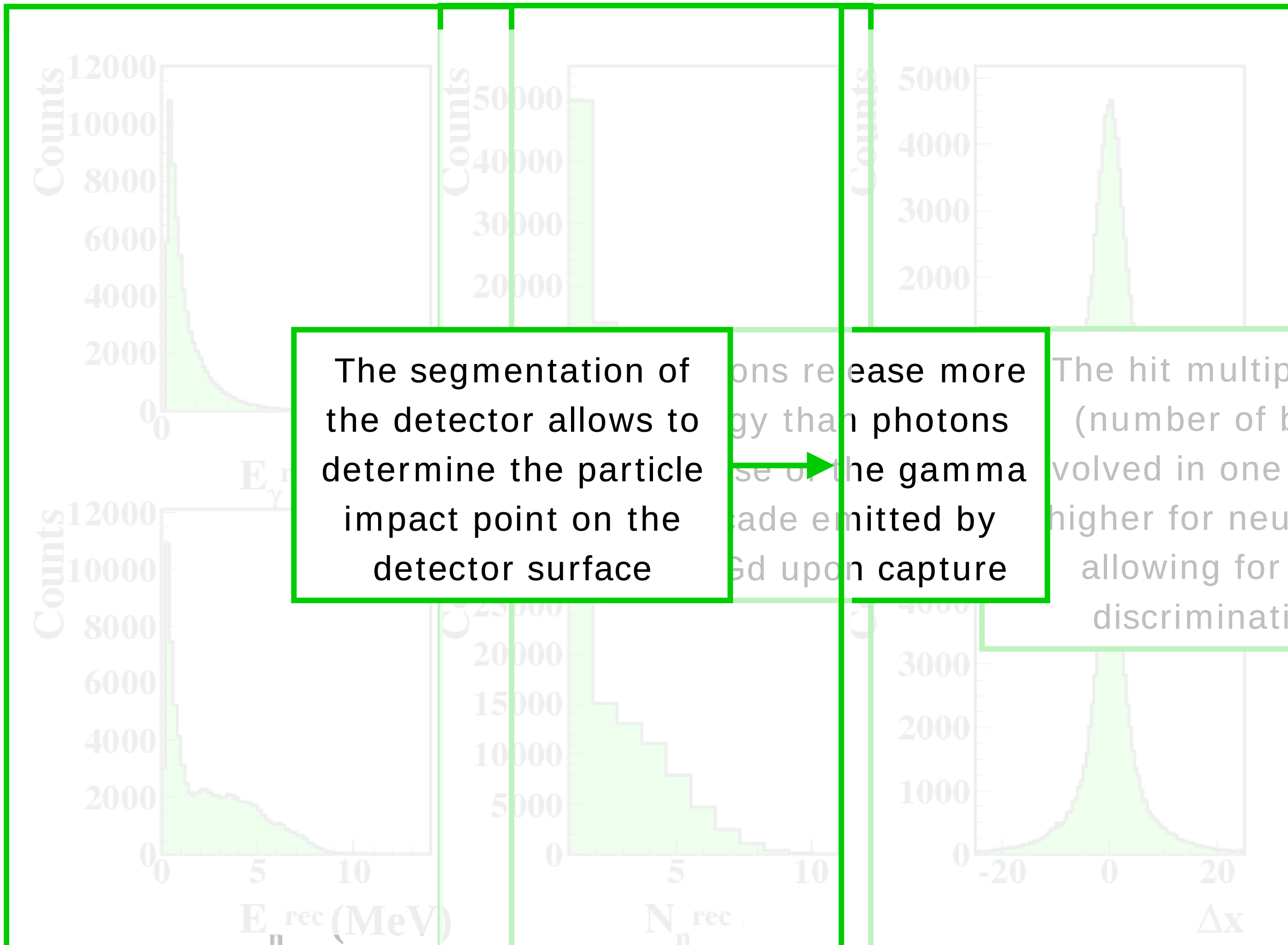


* very conservative values have been used in the assumption a first prototype may be built with low cost/low performance material

Detector Response

photons

neutrons



The segmentation of the detector allows to determine the particle impact point on the detector surface

ons release more
gy than photons
se of the gamma
ade emitted by
Gd upon capture

The hit multiplicity
(number of bars
volved in one event)
higher for neutrons
allowing for n/γ
discrimination

Detection Efficiency

The hit multiplicity allows to distinguish neutrons from photons

For example, requiring multiplicity Nhit>3, the detection efficiency for neutrons is 28% and for photons 0.17%, with a rejection factor of 165

The multiplicity cuts can be applied in the software analysis allowing to use the device both to detect neutrons and photons

Threshold (N_{phel})	N_{hit}	Eff_n (%)	Eff_γ (%)	R
4	> 0	87	66	1.3
4	> 1	55	16	3.4
4	> 2	41	2.1	20
4	> 3	28	0.17	165

Detection Efficiency

The hit multiplicity allows to distinguish neutrons from photon

For example, requiring multiplicity Nhit>3, the detection efficiency for neutrons is 28% and for photons 0.17%, with a rejection factor of 165

The multiplicity cuts can be applied in the software analysis allowing to use the device for simultaneous detection of neutrons and photons

The separation between neutrons and photons can be further increased inserting lead foils (3 mm) between the scintillator planes

Threshold (N_{phel})	N_{hit}	Eff_n (%)	Eff_γ (%)	R
4	> 0	85	44	1.9
4	> 1	53	7.6	7.0
4	> 2	34	0.69	49
4	> 3	19	0.04	475

GEANT4 Validation

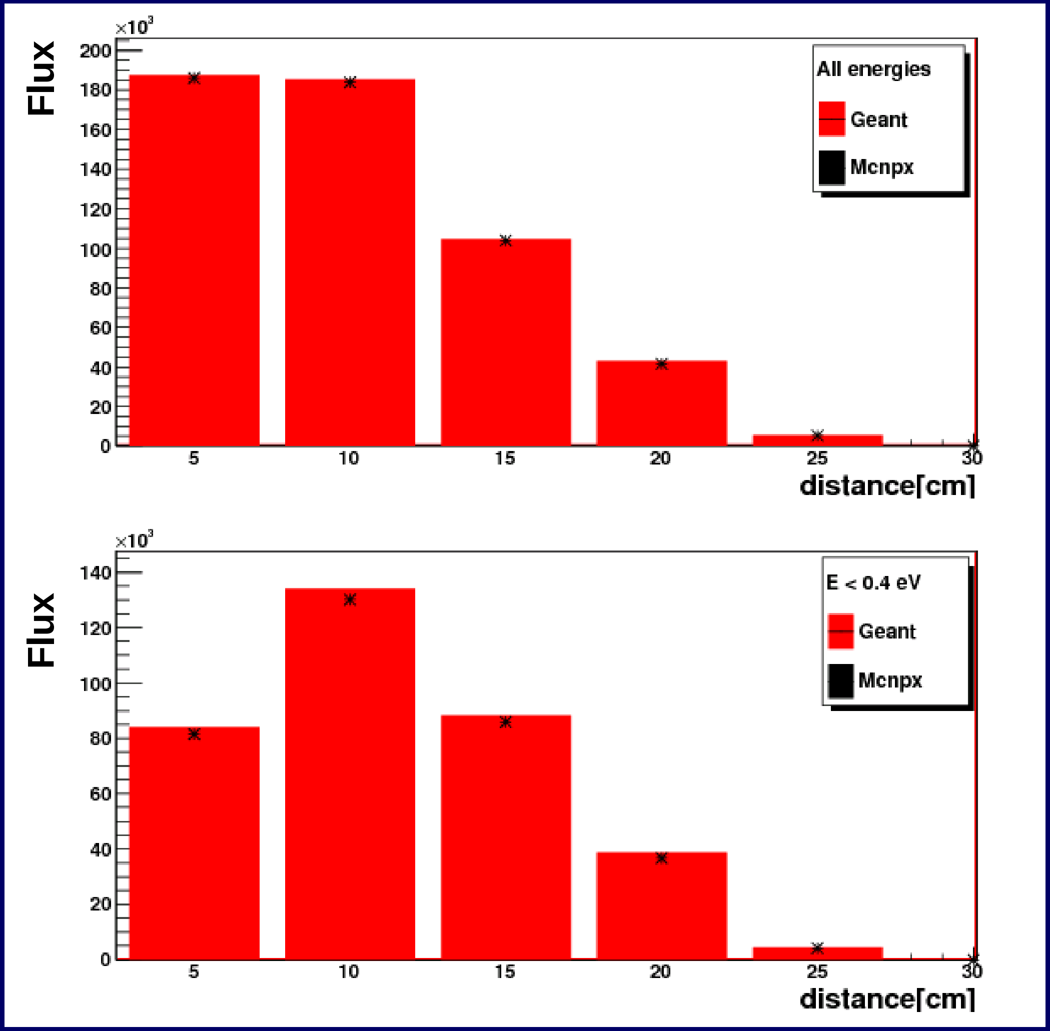
(F. Ambi, Università di Genova)

The results of GEANT4 simulations for neutron transport and interaction were tested by comparing with MCNPX

Transport and interaction of 1 MeV neutrons in plastic scintillator was simulated

Neutron flux and energy spectrum was evaluated on different surfaces in the scintillator volume

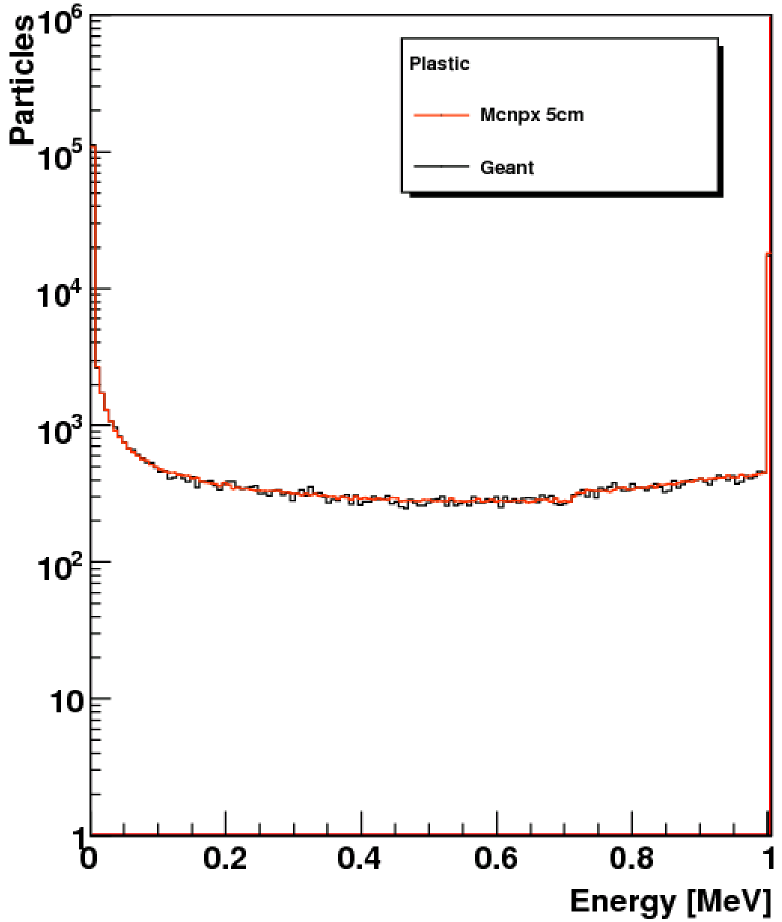
Good agreement between MCNPX and GEANT4 is found

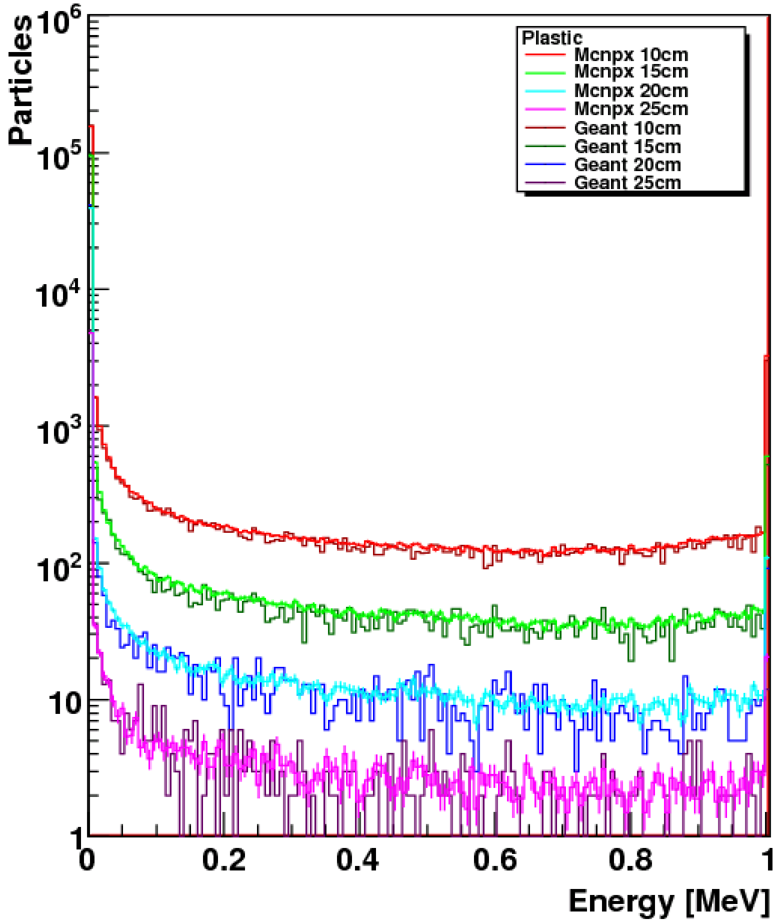


(F. Ambi, Università di Genova)

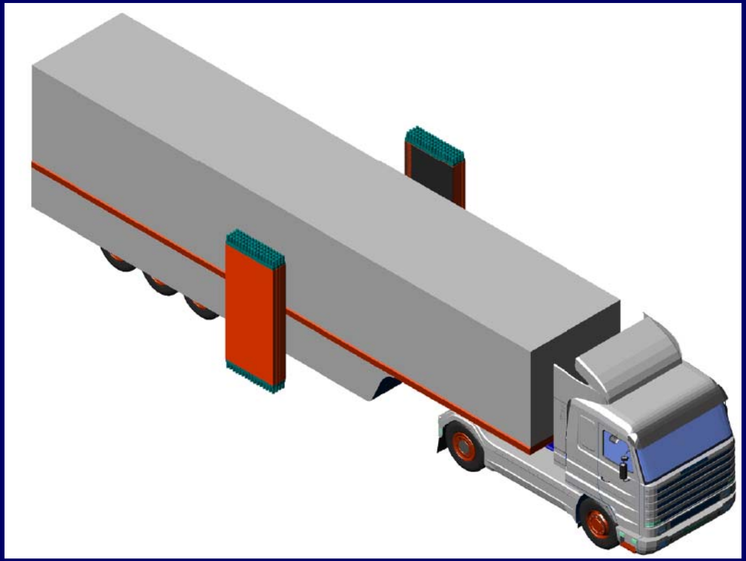
GEANT4 Validation

Good agreement between GEANT4 and MCNPX both in terms of integrated flux and energy spectrum





Applications



Detection of SNM by measuring neutron rates by spontaneous fission

two detectors located at 2 m from the source

1 Kg of Weapon-Grade Plutonium

⇒ 6.7×10^4 counts/min

10 Kg of Highly Enriched Uranium

⇒ 20 counts/min

Use of neutron/photon detector in active interrogation system

Bremsstrahlung Photons produced by a few MeV electron linac can induce photofission reactions.

Measure of induced photon and neutrons rate below and above fission threshold would allow the detection of fertile material

Background Sources

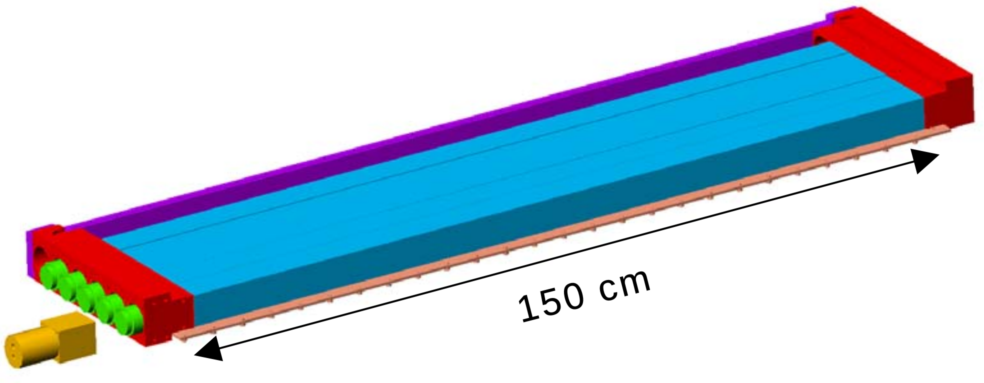
Cosmic rays: can be easily discriminated because of the **large deposited energy** (a charged particle crossing the plastic scintillator releases 2 MeV/cm) and **event topology** (a charge particle passing through the detector would create a hit in each bar along the path)

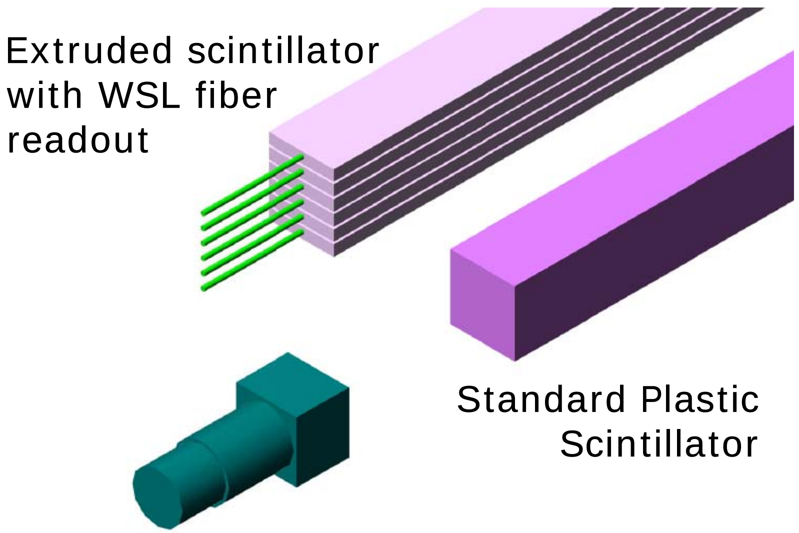
Spallation neutrons: neutrons produced by cosmic rays that interacts with the surrounding material.
Most problematic type of background since it is correlated with the presence of the container. Neutron/photon ratio can be used to reduce this contribution. Simulation of this background to provide a quantitative estimate of the resulting rate are in progress.

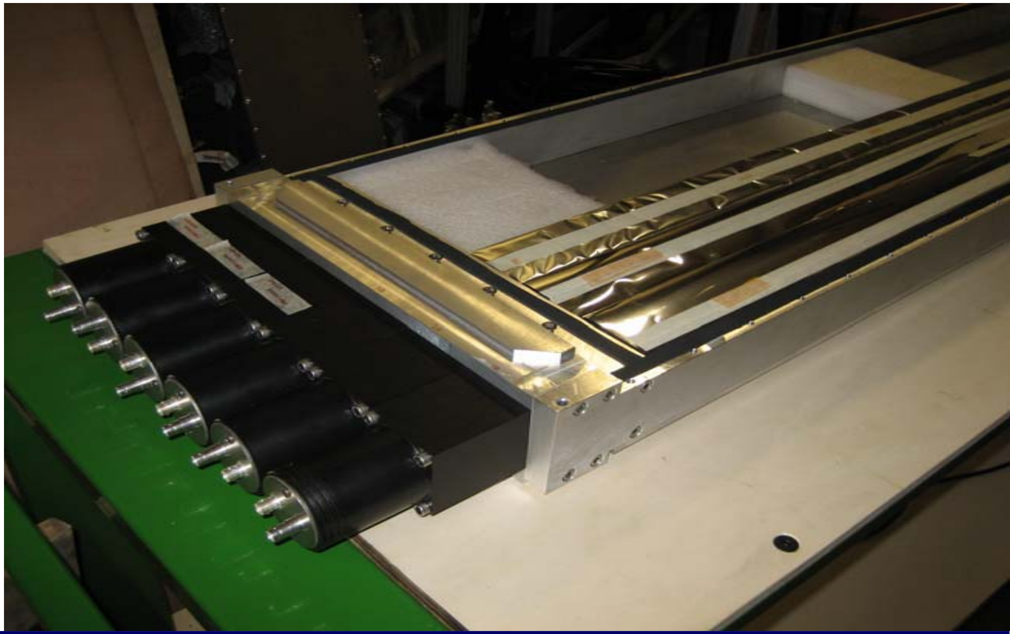
Environmental background: radiation emitted by other sources. Can be measured and subtracted from the final rate.

Detector Prototype

- Measurement of the response of a single bar
- Comparison of different plastic scintillator
- Measure of the detection efficiency as a function of the deposited energy
- Measure of environmental background rates



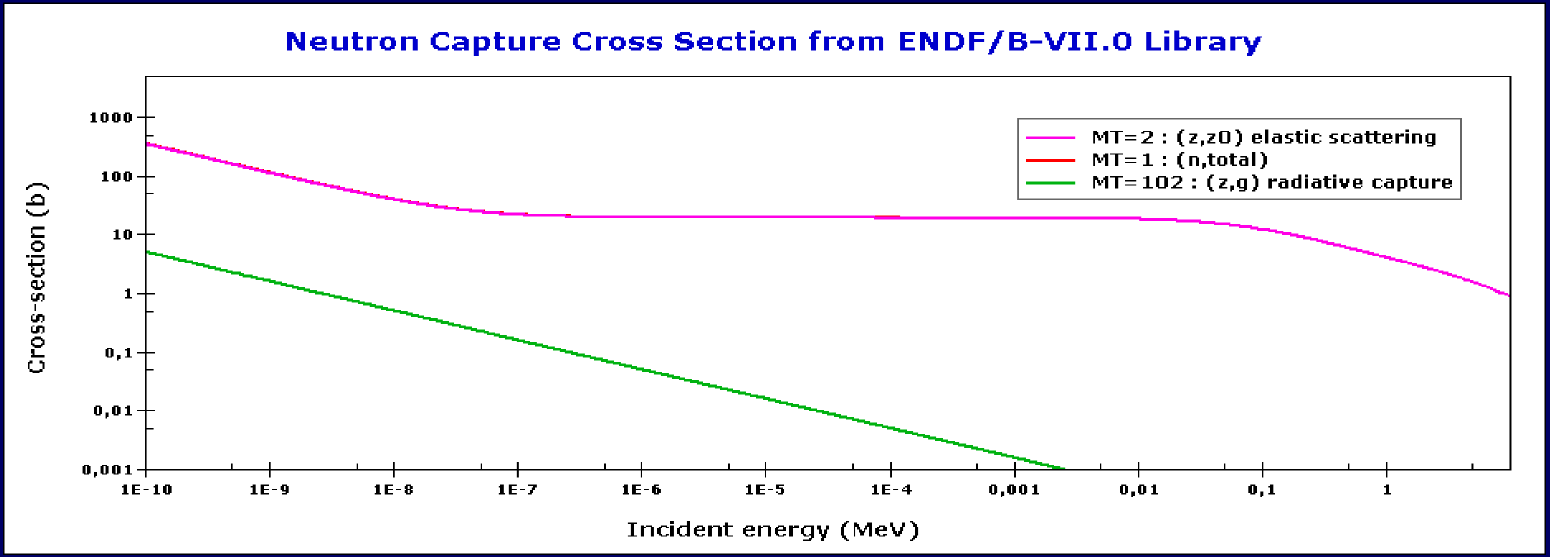


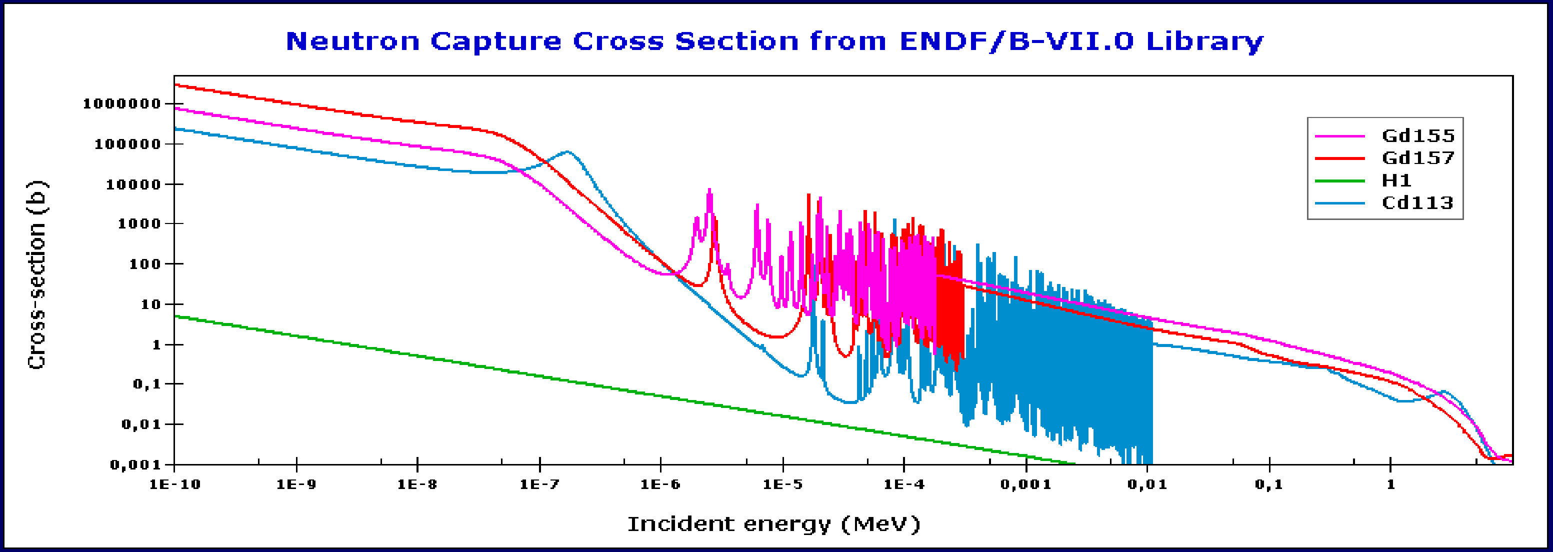


Summary

- We have developed the conceptual design of a large surface neutron and photon detector based on plastic scintillator to be used as radiation portal monitor
- The long experience with this technology from particle and nuclear physics application ensure the stability and reliance of this detector
- Simulations of the detector response show that high efficiency for simultaneous detection of photons and neutrons can be achieved
- Neutron/photon discrimination can be achieved at the level software analysis exploiting the different event topology
- First estimates of the expected rates indicate good sensitivity to the presence of SNMs with short time measurements (minutes)
- First prototype of the detector has been assembled and will be used for first measurements of the system response and validation of the simulation results

Neutron Cross Sections





Detector Response

The thickness of the Gadolinium Oxide coating was chosen based on the results of simulations

In the limit of 0 thickness, neutrons are captured by hydrogen with the emission of a 2.2 MeV photon