Characterization of optical photon transport in Long Plastic Scintillators

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Abstract

Plastic scintillators have long been used in nuclear and particle physics experiments as cost-effective detectors [1]. The longer attenuation length for light transmission makes them ideal for applications requiring a larger field-of-view (FOV) [2]. The Jagiellonian PET (J-PET) collaboration has pioneered their use to build the first plastic scintillator-based PET scanner, which is composed of 50 cm long plastic scintillators [3,4]. With the successful demonstration of modules constructed based on J-PET technology in both medical [5,6] and fundamental physics [7,8,9,10], the collaboration now aims to construct standalone detection modules using even longer scintillators. Since light propagation in long plastic scintillators depends strongly on the interaction position and direction, it is required to perform a thorough study on scintillator light yield, light attenuation during the transport along the strip, variation in the time of detected photons, and how uniformly the light is collected [11]. Furthermore, the influence of surface reflectivity also plays a crucial role in shaping the detector response [12]. All these characteristic properties of the scintillator directly impact both the timing and spatial resolution [13], which are key parameters to optimize the overall performance, particularly when signals are read out only from the ends of the scintillator.

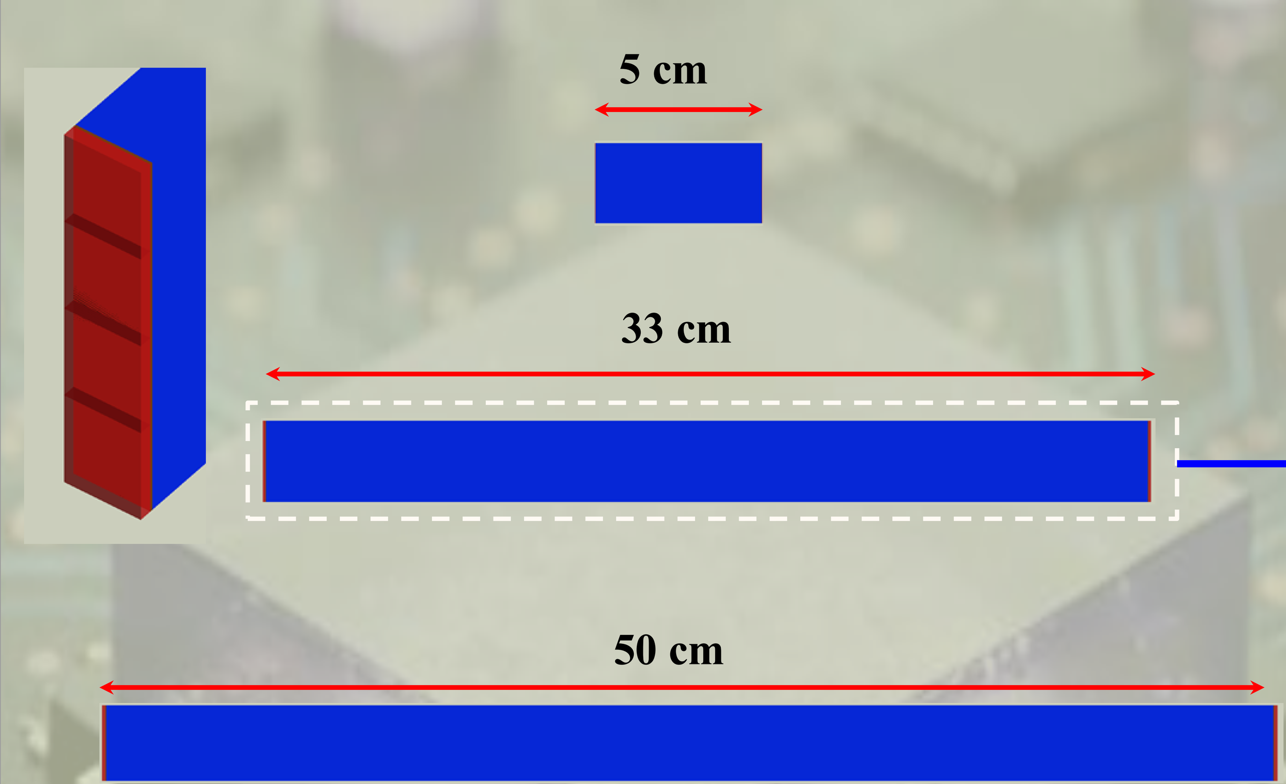
Geant4 simulation for optical transport in plastic scintillators

We developed a Monte-Carlo based simulation package in Geant4 for simulating optical-photon transport in plastic scintillators (**BC-404**) bars of different length. It models scintillation spectra, wavelength-dependent η and absorption, surface reflection (Vikuiti (~ 98.5%)) and optical-gel coupling to matrix of SiPMs sensors.

Scintillator properties[14,15]

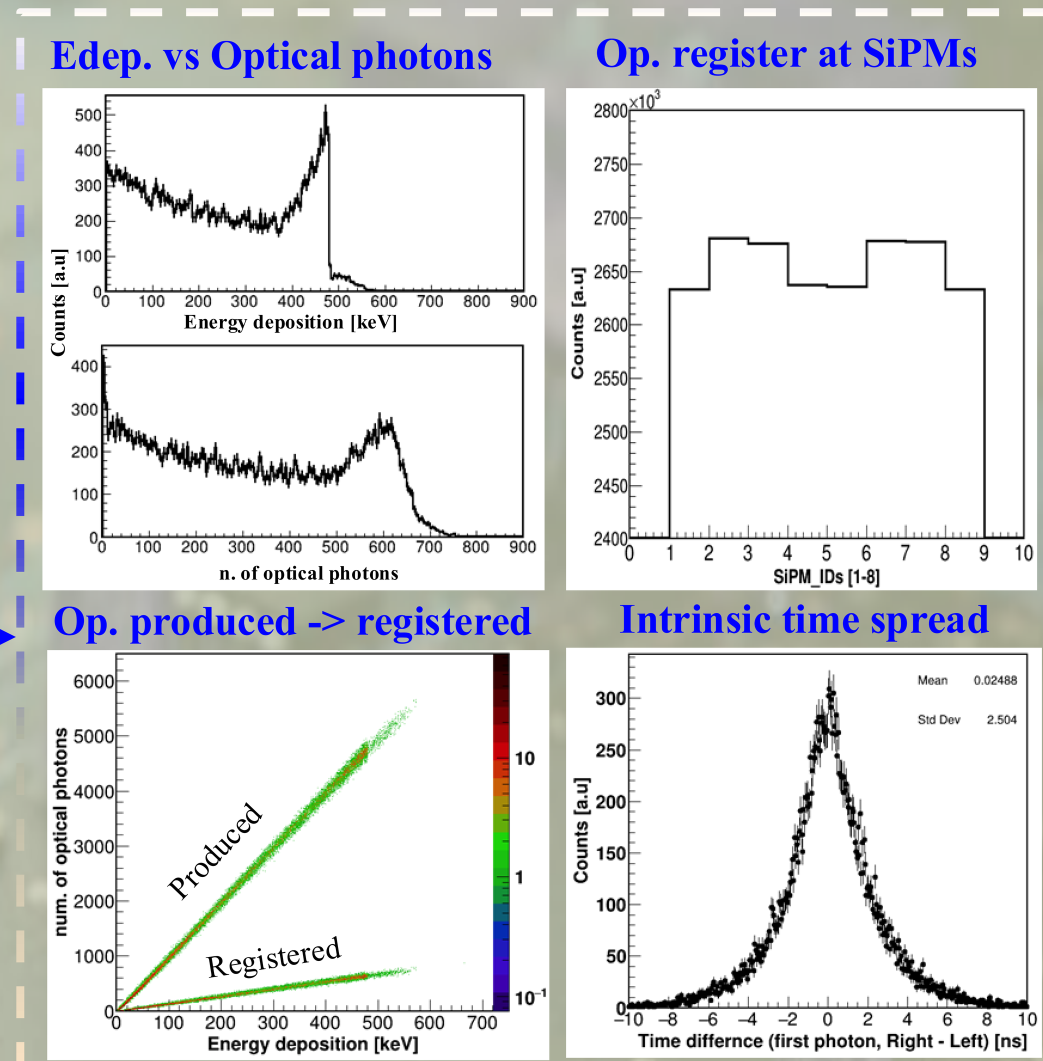
Name	Luxium Solution BC 404
BASE	Polyvinyltoluene
Detectors dimension (mm)	L x W x T (mm^3) 50x24x6; **330x24x6**; 550x24x6
Refractive index	~1.58
Rise time (ns)	0.7
Decay time (ns)	1.8
Wavelength of max. emission (nm)	~ 408 nm
Light attenuation length (cm)	140
Light output (n. of OpPhotons/MeV)	10,400
Birk constant	0.126/MeV

Scintillators of three different lengths



Optical gel thickness = 0.2 mm;

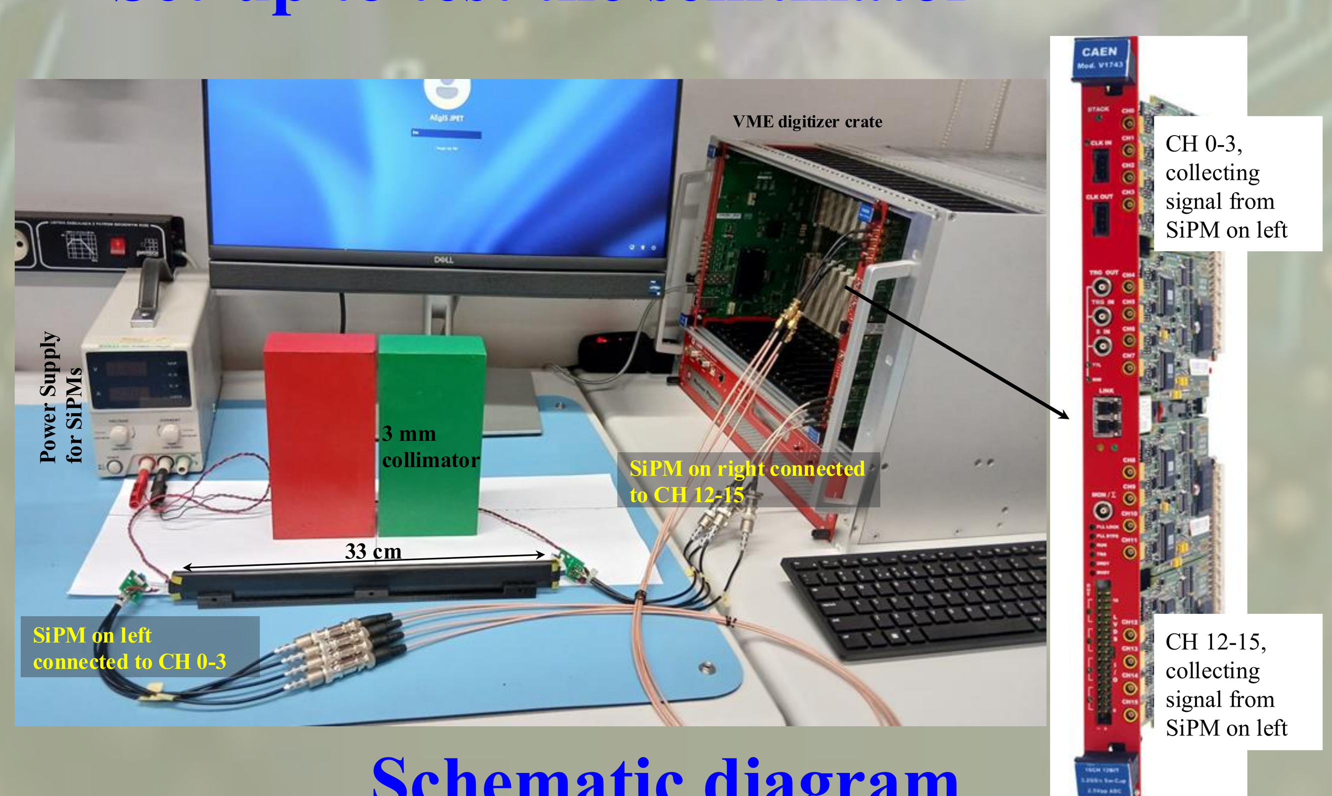
SiPMs sensor dimension = 1 x 6 x 6 mm^3



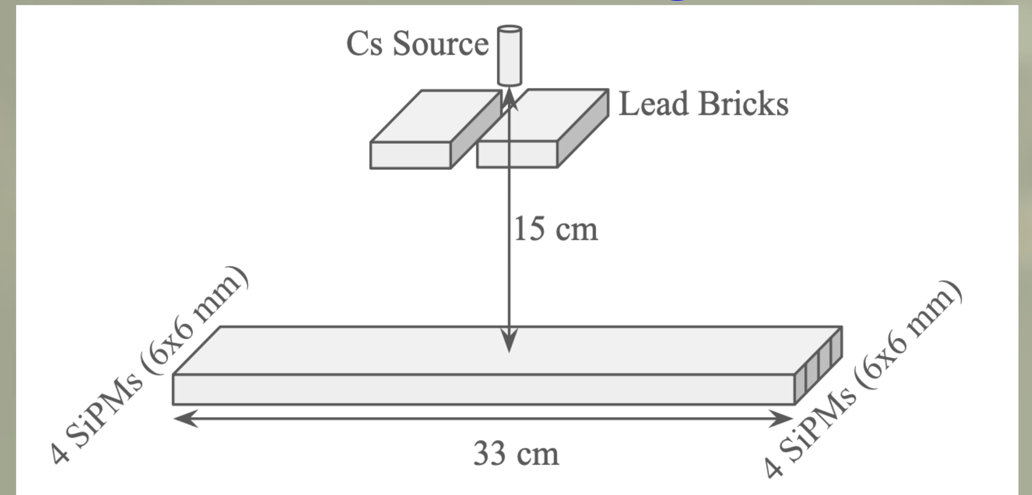
The developed package is capable of predicting several other important properties. Here, we present only a few spectra to illustrate the functioning of the transport procedure implemented in Geant4 [16].

Experimental data and comparison with simulations

Set-up to test the scintillator



Schematic diagram



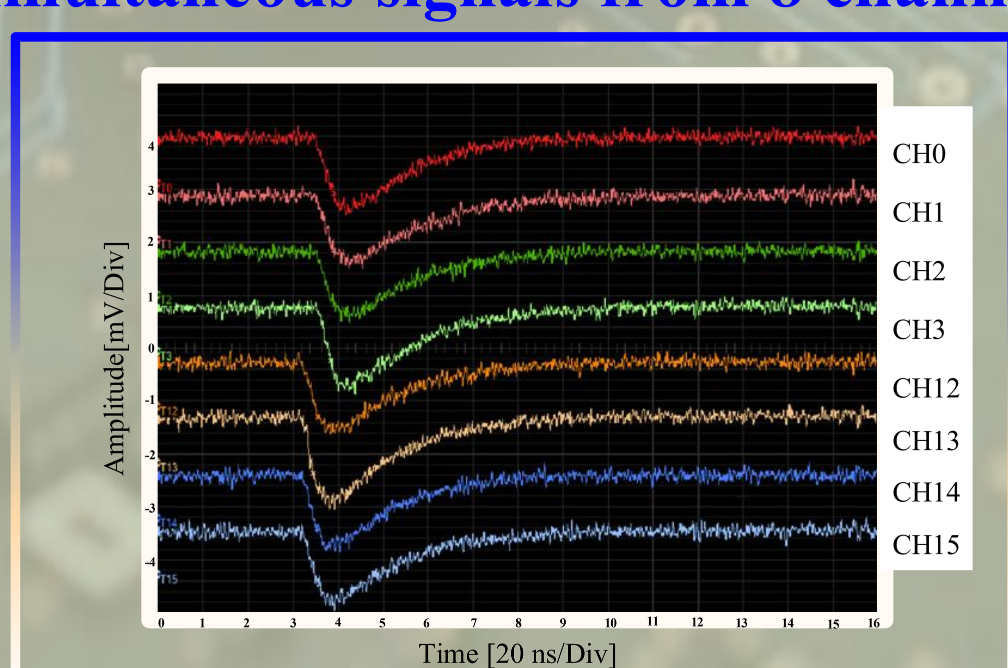
Scintillator wrappings

Vikuiti film wrapping is used as a highly reflective inner layer (~98.5% reflectivity) to maximize light collection from the scintillator.

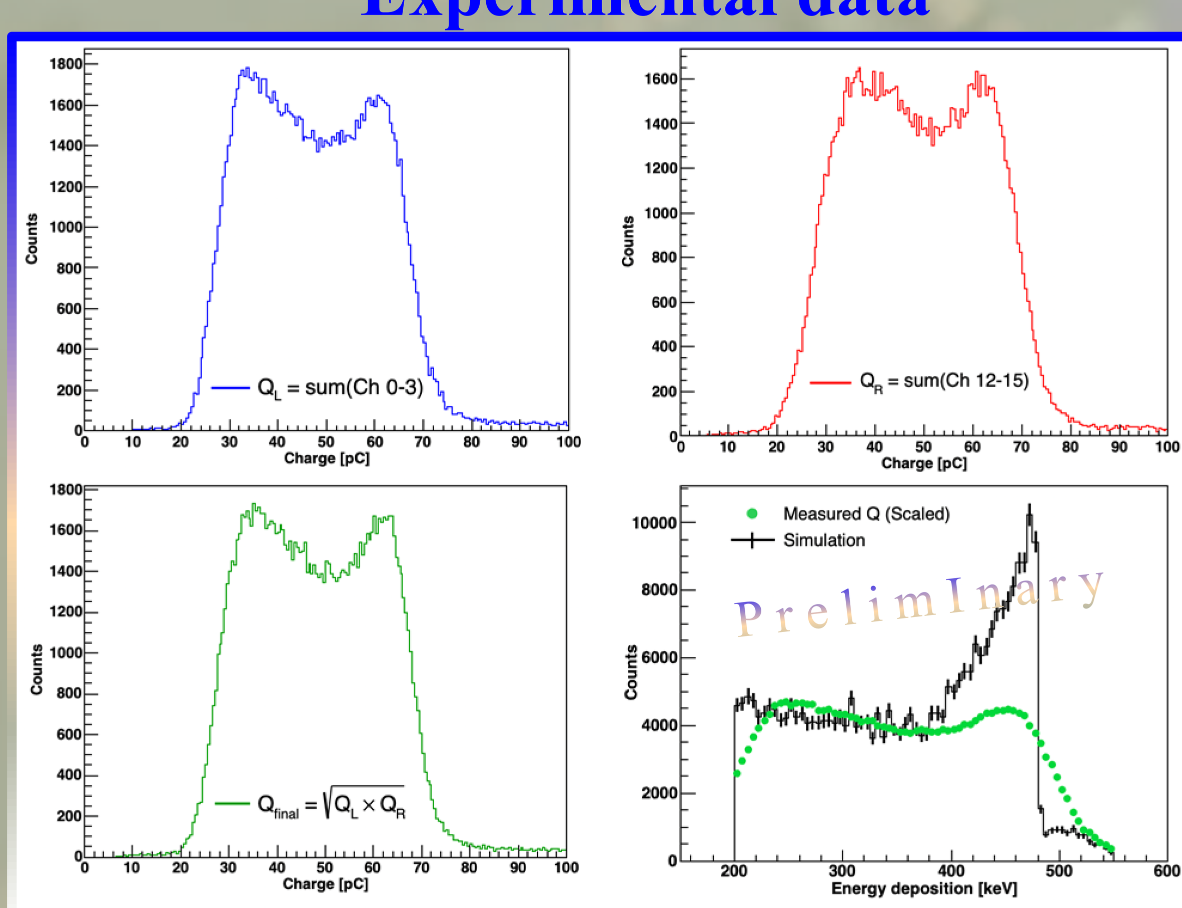
SiPM matrix cementing ensures efficient optical coupling between scintillator and SiPM, reducing losses due to air gaps.

Black paper (Tedlar) wrapping applied as an outer light-tight layer to block ambient light and prevent cross-talk.

Simultaneous signals from 8 channels



Experimental data



Summary

- ✓ A dedicated Monte-Carlo framework based on the Geant4 toolkit has been developed to simulate optical-photon transport in long plastic scintillators.
- ✓ The simulations incorporates detailed scintillator properties and accounts for various loss mechanisms, including photon transport inefficiencies and SiPM Photon Detection Efficiency (PDE).
- ✓ Preliminary comparisons between measured charge spectra (summed over SiPM matrices at both scintillator ends) and simulated non-smeared energy deposition spectra are presented.
- ✓ The ongoing validation with experimental data aims to extract essential parameters for the quantitative characterization of scintillators of different lengths.

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