SAUNA III Detector Development

The design requirements for the SAUNA III radio-xenon measurement system pose several challenges for beta-gamma detector development.

To reach the specified system MDC using a detector of sensitivity comparable to SAUNA II, the xenon sample counted by the detector will need to be considerably larger. Increased electron energy straggling effects must be expected from the larger Xe sample and from the replacement of He by N_2 as carrier gas. Surface treatment for gas memory effect suppression coating may also degrade electron energy resolution. These effects must be countered mainly by improved scintillator cell design.

Other avenues of development for the SAUNA III beta-gamma detectors include suitable methods for coating of detector cells to avoid gas memory effects and methods to automatically detect and correct for changes in detector response functions over time.

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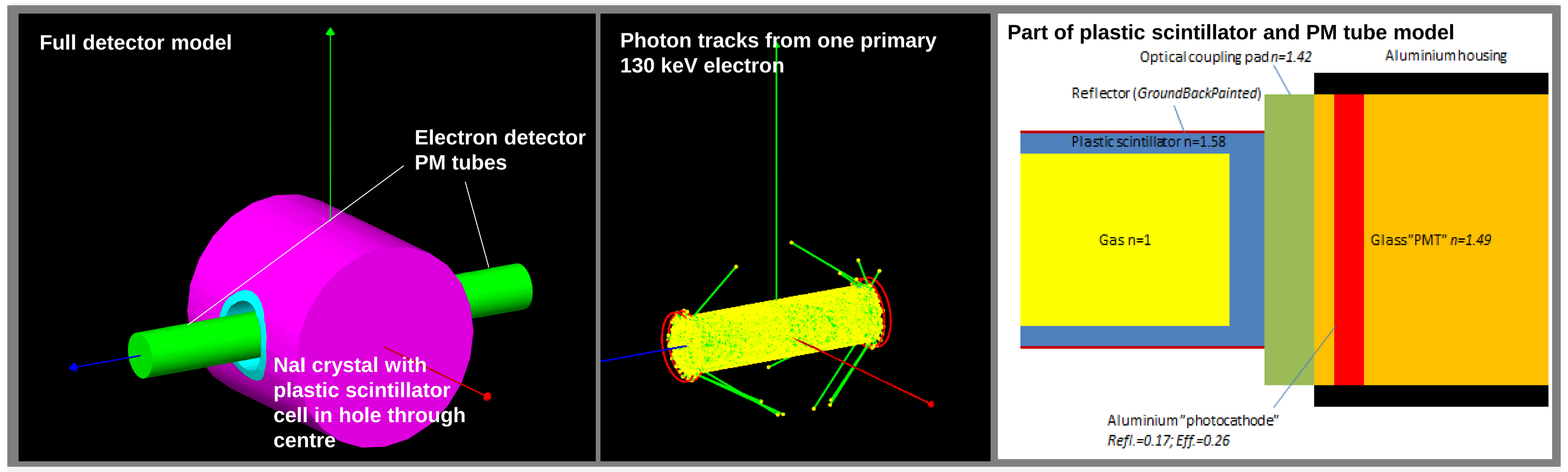
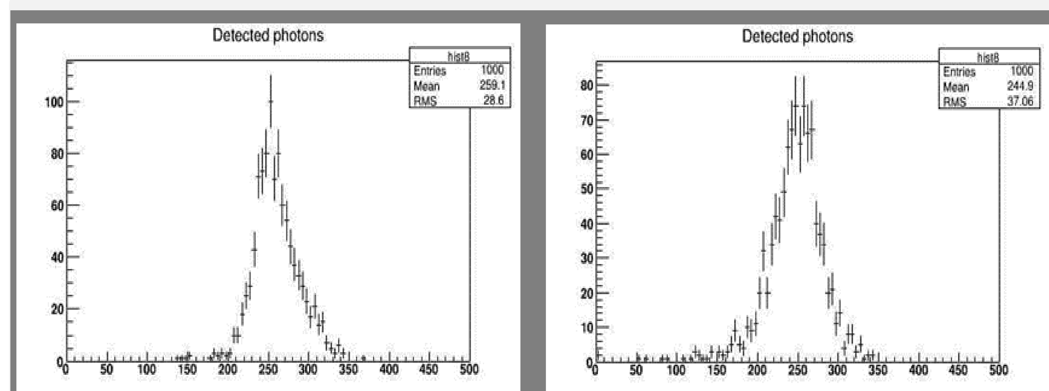


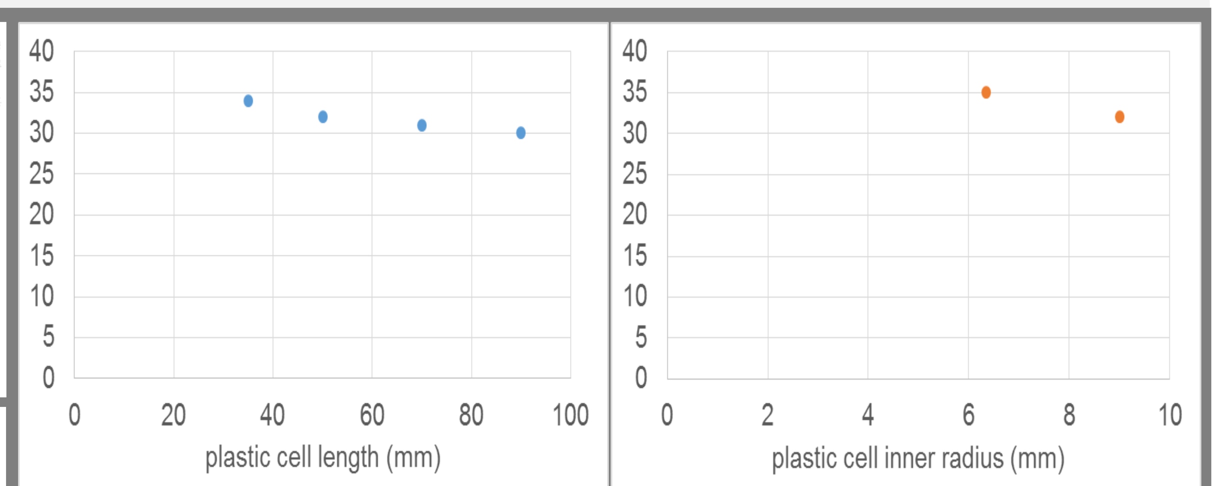
Monte Carlo model

To maintain the detector sensitivity despite the increased xenon volume and the change of carrier gas, a Geant4 application was developed to simulate the effects of plastic scintillator design variations. The main uncertainty is the modeling of optical surface properties. The qualitative and quantitative validity of the results will be tested by measurements on prototype components.



Deposited energy (keV) from 130 keV electrons to show energy straggling effects of Xe sample volume: 1 ml Xe (left) compared to 3 ml Xe (right)

The FWHM difference at 130 keV is 6 keV



Energy resolution (keV) for 130 keV electrons for plastic cell of 9 mm radius (left) and for plastic cell of 50 mm length (right)

Results of Monte Carlo simulations

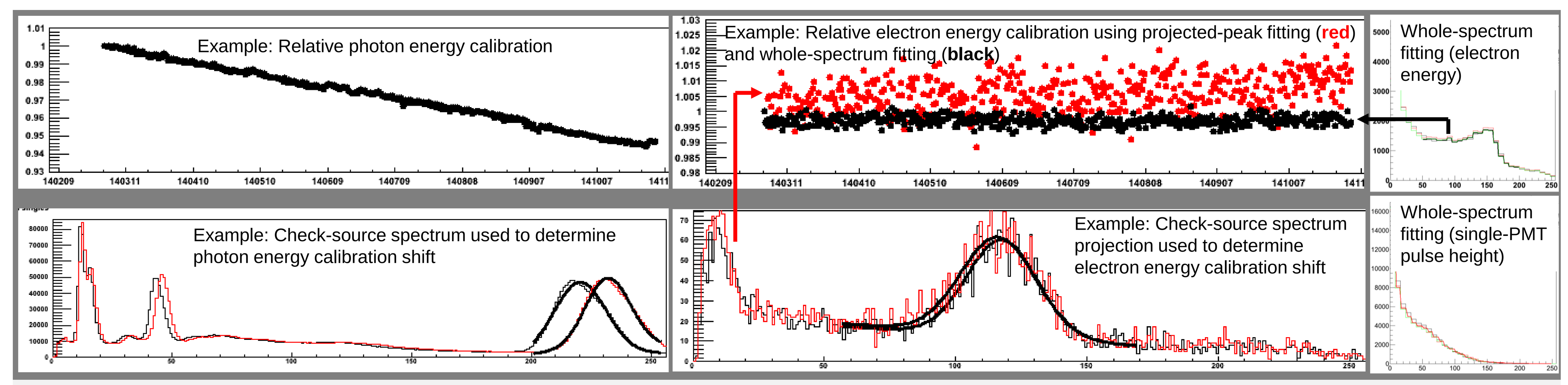
The negative electron resolution effects of larger sample size due to straggling (**illustrated above left**) and the replacement of He by N_2 as carrier gas can be countered by plastic scintillator cell geometry changes (**examples shown above right**) and lowering of the carrier gas pressure in the cell.
The Monte Carlo results suggest larger cell volumes. This also serve to reduce the fraction of sample residing in non-countable "dead volume", further improving the achievable MDA.

Plastic scintillator cell development and gas memory effect suppression

Beta detector cells will be manufactured from bulk scintillator material. Studies are on-going using different machining tools and methods for surface treatment, Test specimens show good performance with respect to energy resolution. The results from these studies will be used to manufacture beta detectors with the dimensions indicated by the Monte Carlo studies.

To prevent diffusion of radio-xenon into the plastic scintillator material of the beta detector ("memory effect"), a thin (about 100 nm) aluminium oxide barrier is applied to the plastic scintillator surface by means of Atomic Layer Deposition (ALD). [1]

A process has been developed to minimize the degradation in energy resolution caused by the ALD coating. The parameters explored include surface treatment (e.g. polishing) and surface activation prior to coating. With the optimized process, a degradation of less than 2 keV at 129 keV appears achievable.



Spectral stability over time

The current SAUNA detectors display a gradual drifting of spectral photon and electron energy-to-channel number response (**top left and center**). The effects can be corrected off-line using check-source spectra collected before and after each sample measurement (**bottom left and center**). Whole-spectrum fitting (**right**) is studied as an alternative to the current peak-fitting method of detecting small spectral shifts.
The SAUNA III detector will have energy calibration corrections automatically applied directly at the HV or signal-processing stage.

Conclusion

Detector resolution and sensitivity degradation due to increased Xe sample volume, change of carrier gas and gas memory effect suppression coating can be countered with appropriate scintillator cell design modifications. The SAUNA III detectors will also incorporate improvements in gas memory effect suppression and spectral stability.

[1] L. Bläckberg *et.al.*, "Memory effect, resolution, and efficiency measurements of an Al_2O_3 coated plastic scintillator used for radioxenon detection", Nuclear Instruments and Methods in Physics Research A 714 (2013) 128.

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