Neural Networks for inter-crystal scatter recovery in semi-monolithic PET detectors

Karol Brzezinski[1], Antonio J. González[2], José María Benlloch[2], and Gabriela Llosá[1]

1. Instituto de Física Corpuscular (IFIC), CSIC-UV, Spain.
2. Instituto de Instrumentación para Imagen Molecular (i3M), Centro mixto CSIC – Universitat Politècnica de València, Spain.

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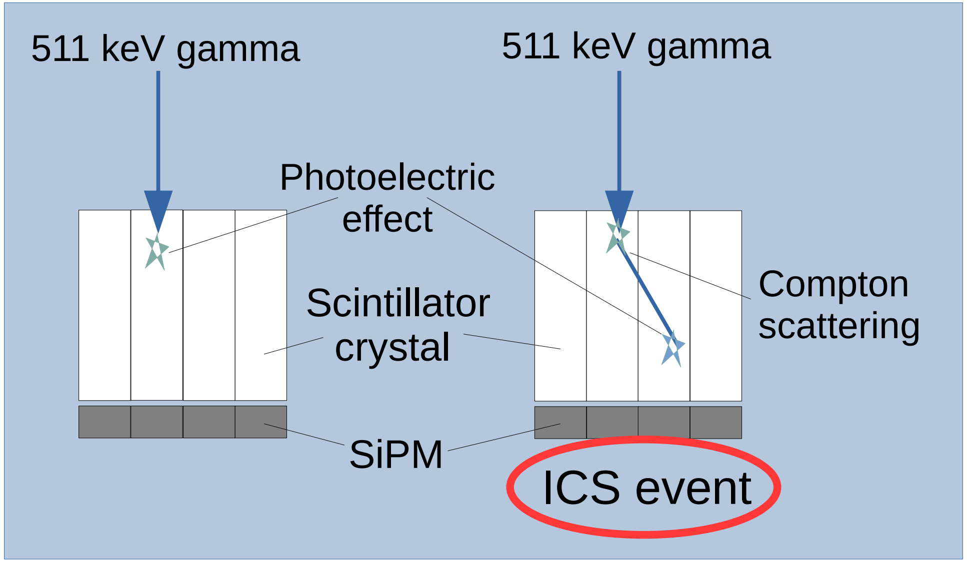
Overview

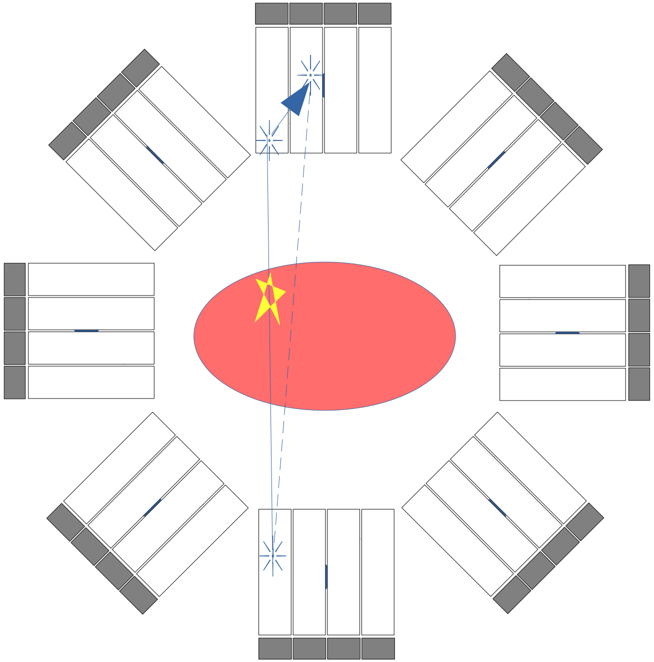
- Inter-crystal scatter (ICS) in positron emission tomography (PET)
- IMAS PET scanner
- Brain-dedicated 4D-PET scanner
- Neural network trained on 3D spatial and energy resolution
- Neural network trained on light distribution
- Conclusions

Inter-crystal scatter (ICS) in PET

PET scanner sensitivity may be improved by including ICS events

- ¤ Associated with multiple possible lines of response (LORs)
- ¤ Tend to degrade spatial resolution
- ¤ Various methods of ICS recovery have been developed





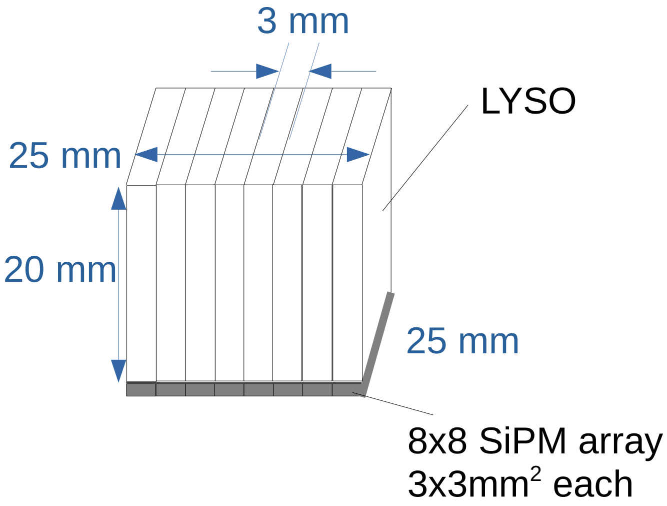
IMAS and 4D-PET scanners

PET scanners based on semi-monolithic LYSO crystals

- Developed by i3M (CSIC–UPV)
- Based on continuous LYSO crystals segmented in one direction into sections called slabs

Continuous	Pixelated
+Sensitivity +Spatial resolution +Depth of interaction (DOI)	+timing performance

Semi-monolithic
combine the benefits of pixelated and continuous configurations



IMAS Total-body scanner
(1 slab per SiPM row)

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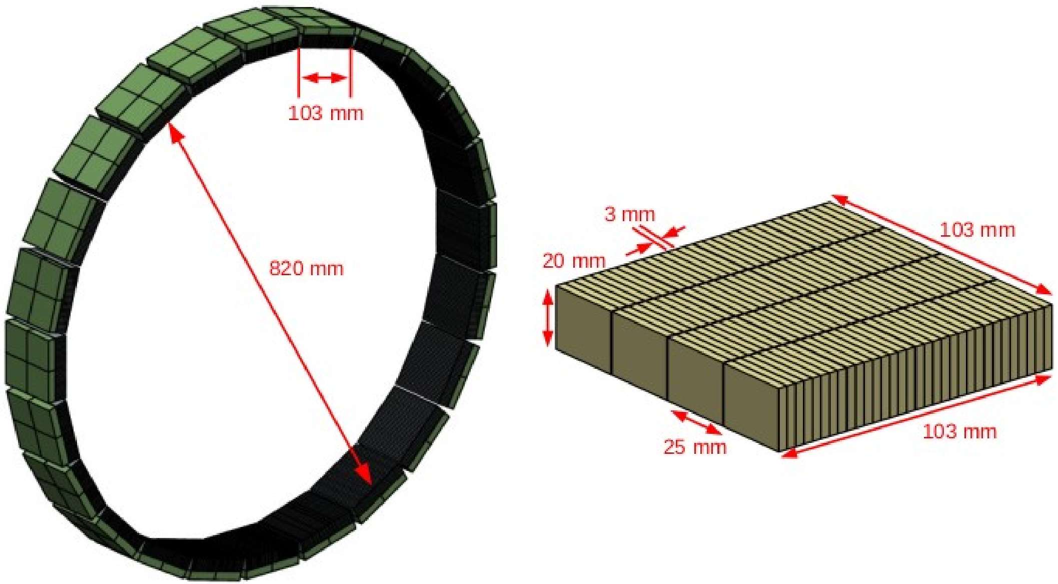

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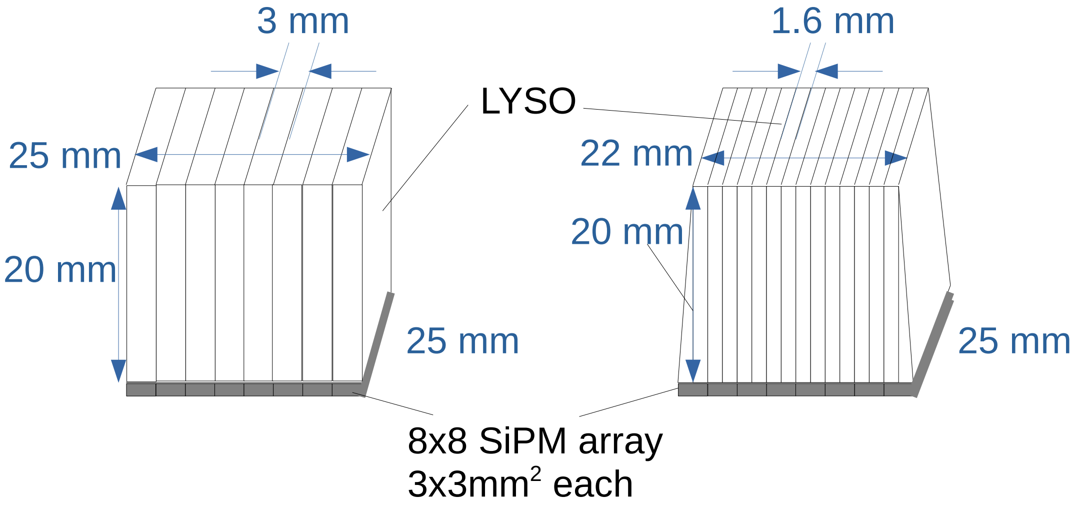
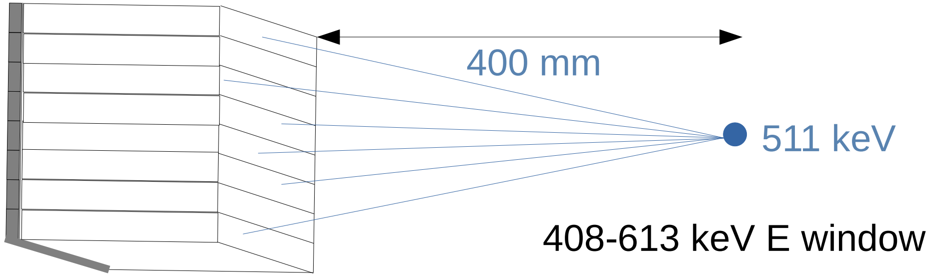


IMAS Total-body scanner (1 slab per SiPM row)

4D-PET brain scanner

IMAS simulations & ICS ordering via NN

GATE (Based on Geant4)



¤ Two models for spatial and energy blurring:
- ¤ Enhanced specular reflector (ESR)
- ¤ ESR + Retroreflector (RR)

Resolution	ESR	ESR + RR
DOI (FWHM)	3.4 mm	3.8 mm
Along slab (FWHM)	2.5 mm	2.9 mm
Energy (at 511 keV)	13%	10%

Only ICS events involving two slabs were considered for ordering

NN training features

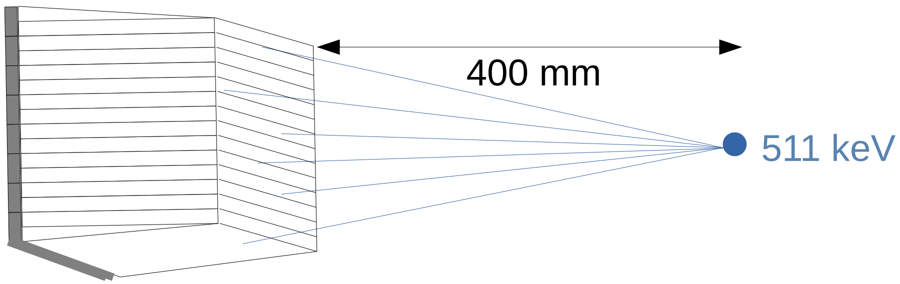
- ¤ DOI
- ¤ Deposited energy
- ¤ Position along slab
- ¤ Separation between slabs

NN architecture

- ¤ Python3 using Keras and Tensorflow
- ¤ Two hidden layers of 16 neurons each
- ¤ ‘ReLU’ activation function, input+hidden nodes
- ¤ ‘sigmoid’ activation function on output node
- ¤ ‘Adam’ optimizer
- ¤ ‘binary_crossentropy’ loss function

4D-PET simulations & ICS ordering via NN

GATE (Based on Geant4)



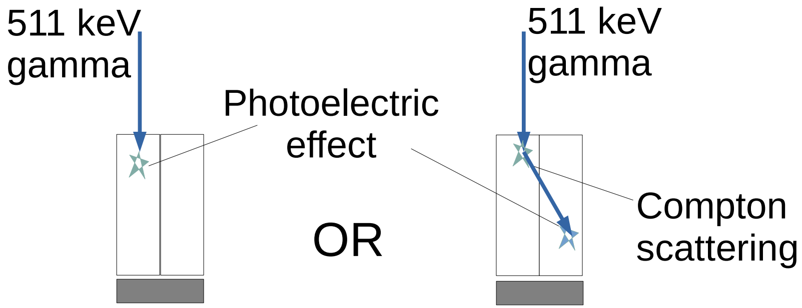
¤ Exact slab identification assumed

Resolution	
DOI (FWHM)	3.4 mm
Along slab (FWHM)	2.7 mm
Energy (at 511 keV)	10.2%

¤ ICS recovery: same NN as with IMAS

ICS in light sharing crystal pairs

Photoelectric or Compton scatter?

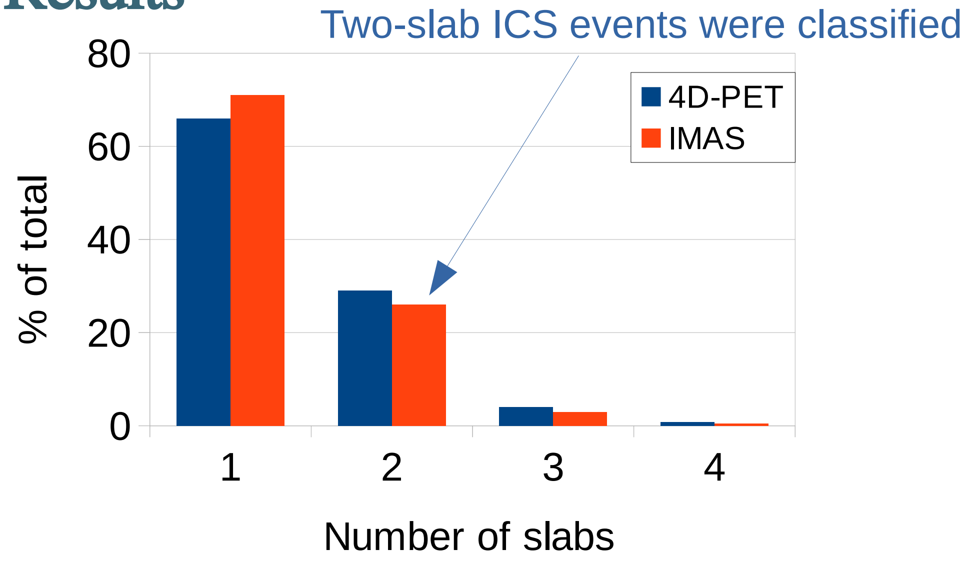


¤ Optical photon simulation (GATE)
- Slabs optically isolated using ESR
- BC-630 coupling to photosensor

¤ **NN trained on light distribution** in 8x8 SiPM (summed in both dimensions for 1x16 array)
- Input and one hidden layer: 16 neurons each

ICS ordering in IMAS & 4D-PET detectors

Results



¤ 26% (IMAS) and 29% (4D-PET) of all events are two-slab ICS events

Accuracy of ICS ordering (%)

Blurring model	IMAS	4D-PET
No blurring	79	80
ESR	73	73
ESR + RR	72	-

¤ Prior to image reconstruction, the NN assigns the correct LOR in ICS events with 72-73% accuracy.

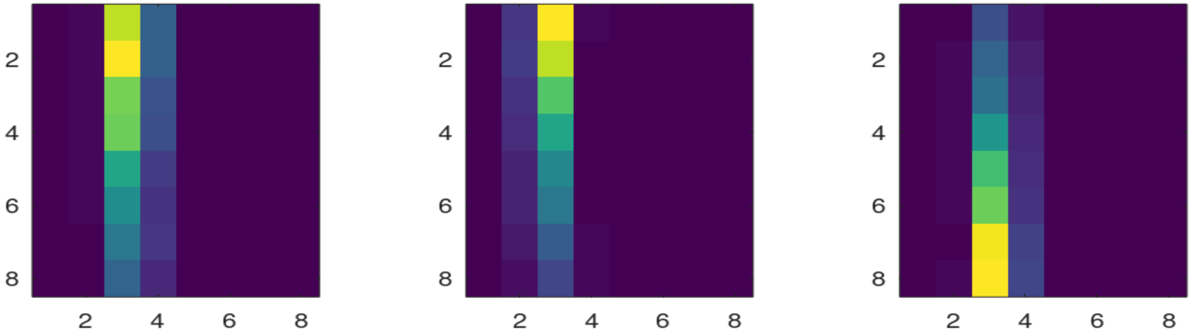
¤ Outperforms DOI method (~67%).

ICS in light-sharing crystal pairs in 4D-PET

Results

¤ NN trained on light distribution to identify PE vs ICS: Accuracy 98%

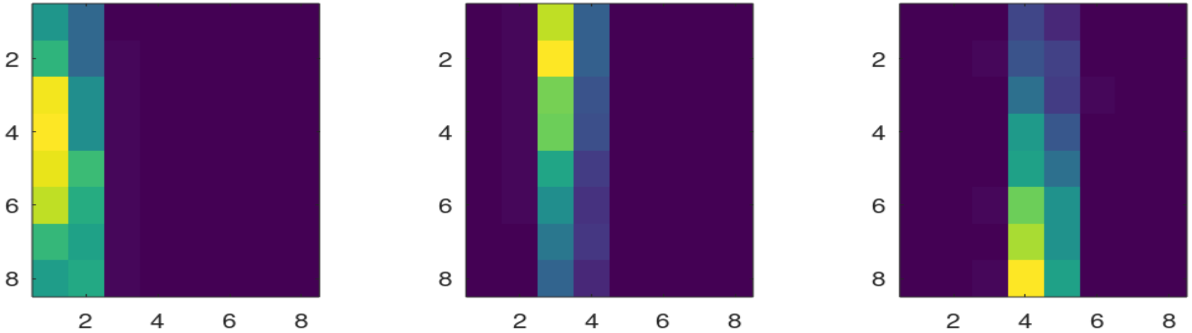
¤ Optical model still needs validation



Examples of light distribution for single-slab interactions

Future work

¤ Use the NN for predicting first event directly



Examples of light distribution for 2-slab interactions

Conclusions

¤ NNs are expected to have the ability of integrating Compton scattering kinematics, Klein–Nishina probabilities, optical photon transport and detector response for the benefit of ICS recovery in PET.

¤ NN trained on 3D spatial and energy information was developed to find primary event in ICS.

¤ NN was tested on simulation data from two PET detectors based on semimonolithic crystals.

¤ ICS ordering accuracy was 72-73% depending on the detector and blurring model used.

¤ Imaging studies in progress.

¤ A second NN is being developed for identifying ICS in light sharing detector pairs.

¤ An AI approach to ICS recovery has shown the potential for improved PET image quality, which may extend to enhancing diagnostic capabilities and patient outcomes.

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Thank you

karol.brzezinski@ific.uv.es