Event classification in Compton-Pair telescopes using Deep Learning Techniques

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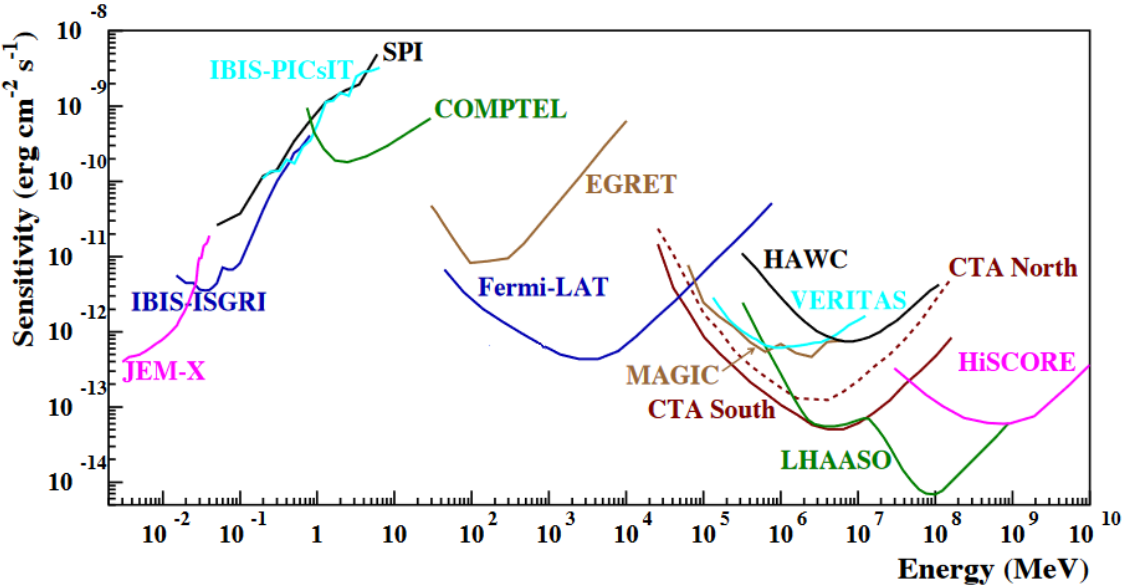
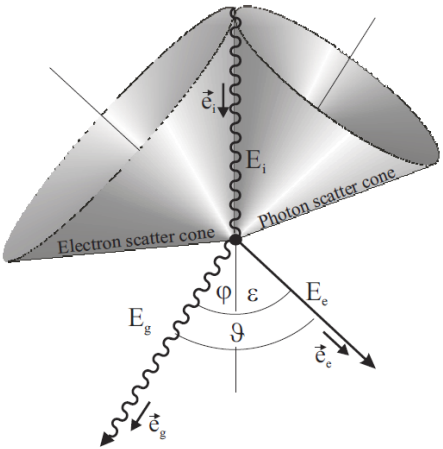
Sensitivity of past, current and future experiments



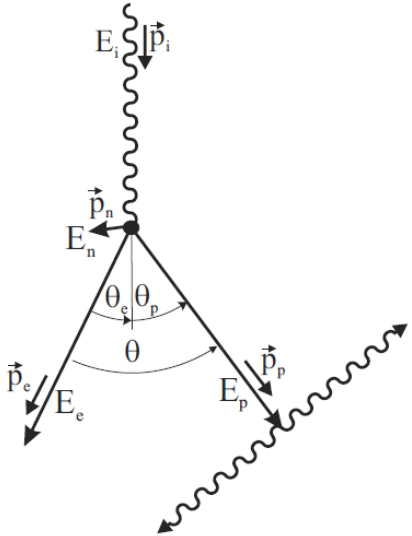
Adapted from Tatischeff et al: Proc.SPIE Int.Soc.Opt.Eng. 10699 (2018) 106992J

Detection Channels

Compton event



Pair event

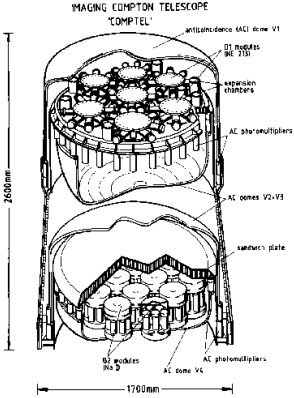


From: A.Zoglauer, First Light for the Next Generation of Compton and Pair Telescopes, Phd thesis 2005

Back in the days...

Compton Gamma Ray Observatory

COMPTEL (0.75-30 MeV)



EGRET (0.1-20 GeV)

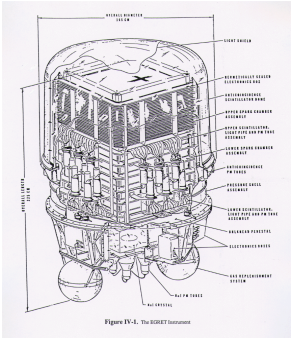
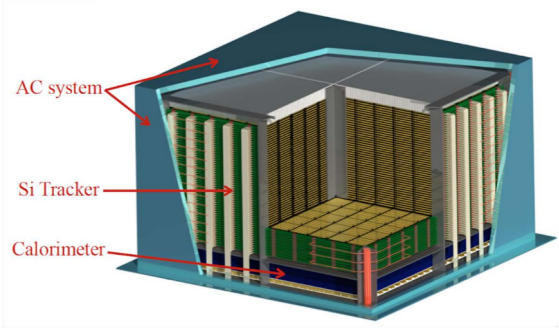


Figure IV-1. The EGRET Instrument

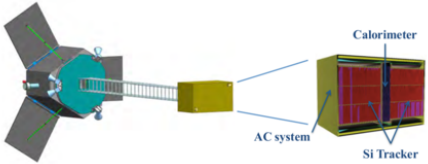
Image courtesy of NASA, Sketches from: NASA Research Announcement NRA 99-OSS-02

Design examples

e-ASTROGAM



as-ASTROGAM



From: The e-ASTROGAM Collaboration, De Angelis, A., Tatischeff, V. et al. Exp Astron (2017) 44: 25. arXiv:1611.02232

Convolutional Neural Nets for event categorization

Well proven concept, see for example:

- Nova [1]
- Microboone [2]
- Atlas [3]

Idea: Utilize the detector output to generate an image of the event.

For a Compton-Pair-Telescope like e-Astrogam or as-Astrogam:

Use the X- and Y-strips in 2-views!

[1] doi:10.1088/1748-0221/11/09/P09001
[2] arXiv:1808.07269
[3] Guest, Ann. Rev. Nucl. Part. Sci. 68, 161

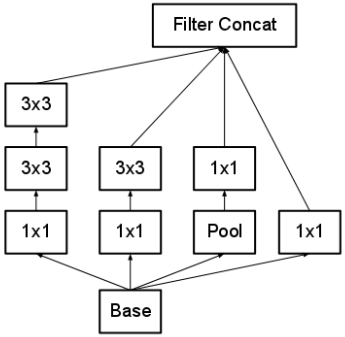
Example Images

Compton event with recoil electron at 5 MeV

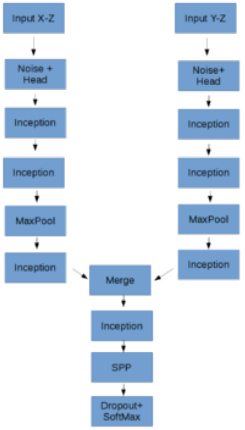
Pair event at 300 MeV

Generated with MEGAlib 2.99.10 (Zoglauer, New Astr. Rev. 50, 629) and custom python script. The e-Astrogam geometry was used for the simulations. The tracker has 56 layers with 3840 x- and y-strips.

Approach One: Tackle the task with complexity



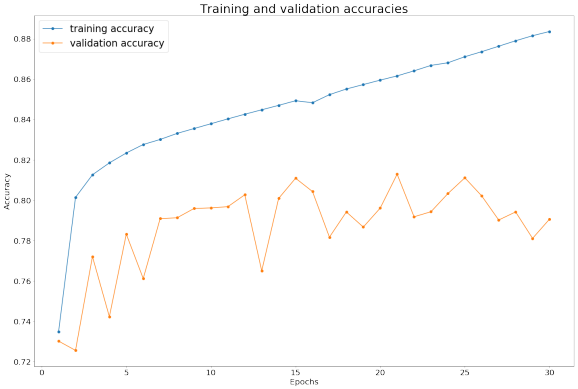
From: arxiv:1512.00567



- rebuild of Nova CNN categorizer
- Framework: Tensorflow + keras[4]
- updated modules to InceptionV3
- added Spatial Pyramid Pooling [5]
- other minor changes
- total of 6 million trainable parameters

[5] Abadi et al: Tensorflow ; Chollet: keras, https://github.com/fchollet/keras
[6] doi:10.1007/978-3-319-10578-9_23

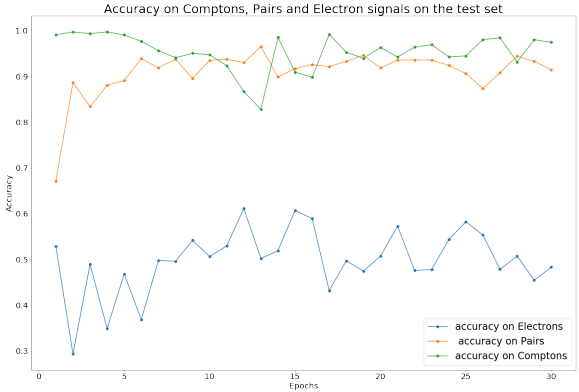
Results

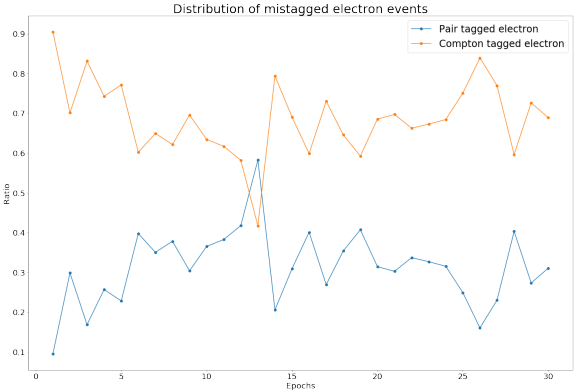


Training and validation losses and accuracies for 30 epochs training set of 1174500 samples and 20 per cent validation set

Training set and test set consisted of clean Compton and Pair events, i.e. the event started in the tracker, Comptons were completely absorbed.

Results

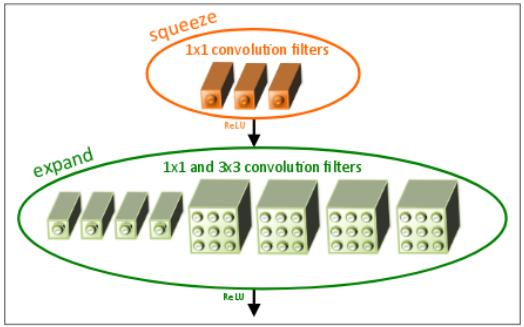




Class wise accuracy and distribution of the misstaged electron events on the test set. Most of the falsely categorized electron events are tagged as Compton event.

Result: The architecture provides powerful models for OFFLINE analysis but online categorization needs to work on smaller models.

Approach two: A more economic try



- Tries to shrink the intermediate output by applying Fire-Modules and pooling operations
- Reaches AlexNet performance with only a fraction of the size of AlexNet
- Was implemented on an FPGA-accelerated SoC [6]

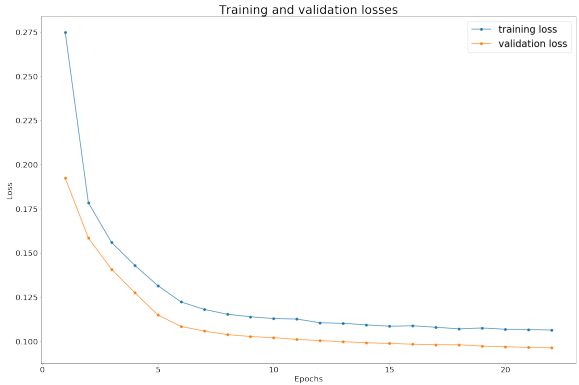
$\rightarrow$ allows implementation of lean and powerful architectures on limited memory

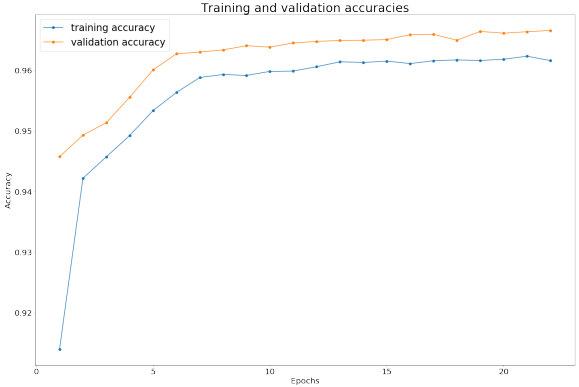
arxiv:1602.07360

Reduced classification task to Compton and Pair classification

[8] Gschwend, Zynqnet: An FPGA-Accelerated Embedded CNN, M.Th. ETH Zurich

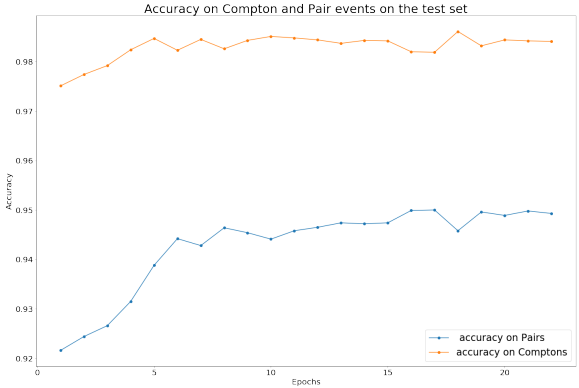
Results

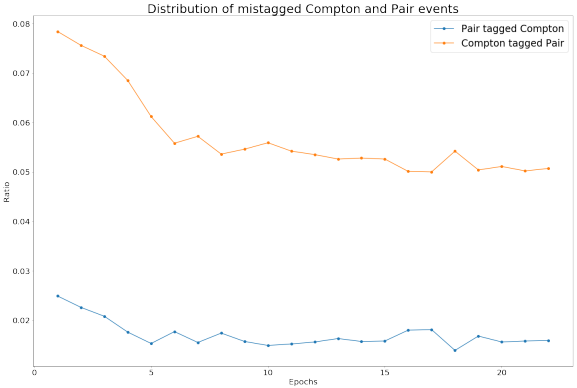




Loss and accuracy during training and validation. The training set contained 80000 samples, the validation set contained 25 per cent.

Results





True positive rate and false positive rate after each epoch evaluated on the test set.

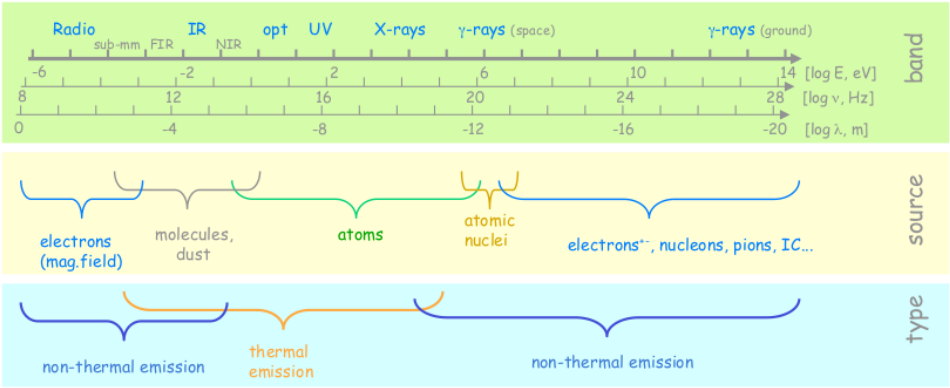
Result: A similar performance on the basic task is achieved as with the large architecture with a fraction of the model size. This make this model a candidate for implementation on space-worthy hardware.

Summary

- Compton-/Pair-Telescopes open a window into a very interesting and under investigated range of the electromagnetic spectrum
- Pixel wise deep learning approaches, especially CNNs, are a viable option with the investigated detector type.
- Clean Pair and Compton signatures are distinguished very well even on small scale models.
- Architectures can be envisioned for both on-ground and in-space data pipelines.

Thank you for listening

Back Up Slides



From: Diehl: Introduction to Astronomy with Radioactivity, arxiv:1007.2206

3D vs. Multiview-2D approach

Back-of-an-envelope calculation: e-Astrogam design consists of

- 56 layers with 3840 X- and 3840 Y-channels
- total image pixels: $8.3 \cdot 10^8$
- image size to process at least 0.77 GB (one color channel with 8bit integer)

Possible solution: coarsing.
BUT: most prob. pair opening angle scales with approx. $1/E$ [7]

More economic approach: generate two correlated views and preserve 3D information this way, e.g. X-Z and Y-Z views.

[7] Olsen, Phys.Rev. 131,406

Background Environment