GammaLearn – Deep Learning applied to the Cherenkov Telescope Array data

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Today's menu

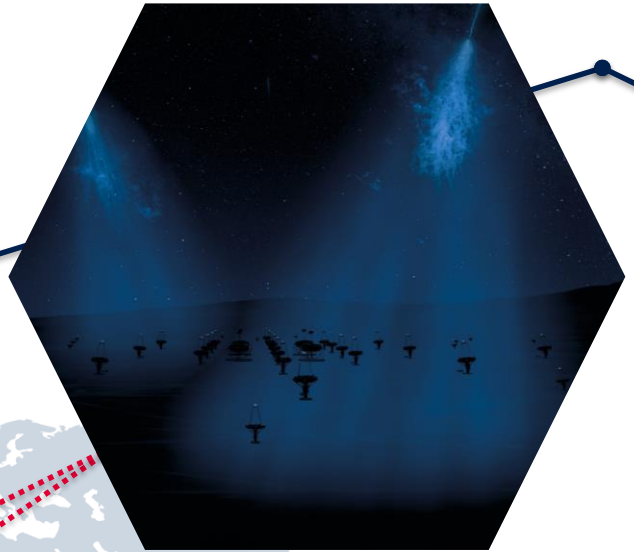
- Introduction on CTA
  - Science goals
  - Array and atmospheric showers
  - Data and processing
- Deep learning
  - Why deep learning for CTA data ?
- GammaLearn
  - A collaborative project
  - CTA specificities
  - Early results

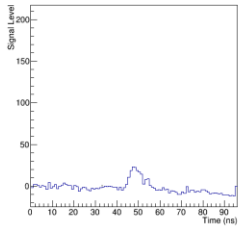
CTA introduction

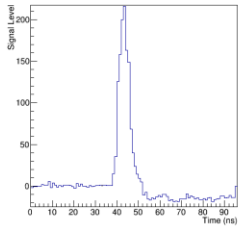
- Future ground-based telescope for gamma-ray astronomy (Imaging Atmospheric Cherenkov Telescope)
- Study the Very High Energy universe: cosmic ray origins, astrophysical phenomena, fundamental physics and cosmology
- > 1400 scientists and engineers in 31 countries
- Currently in pre-construction phase.

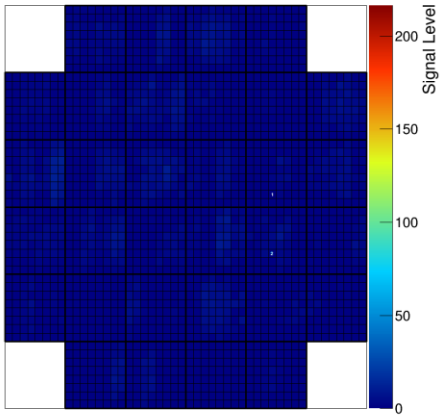
Cherenkov Telescope Array

Cherenkov Telescope Array





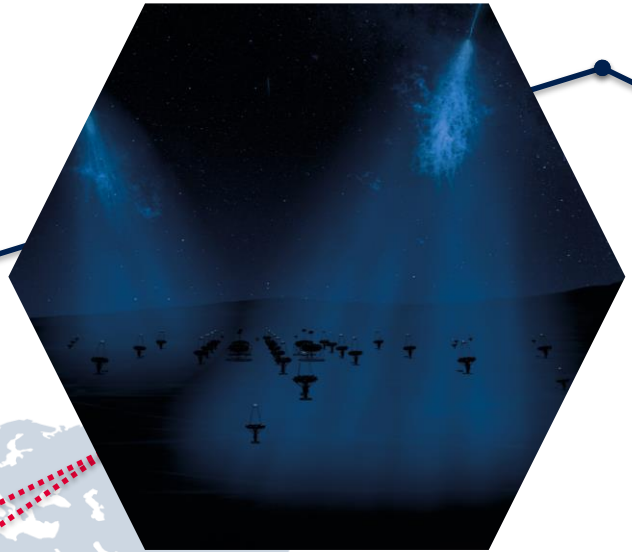




2048 pixels

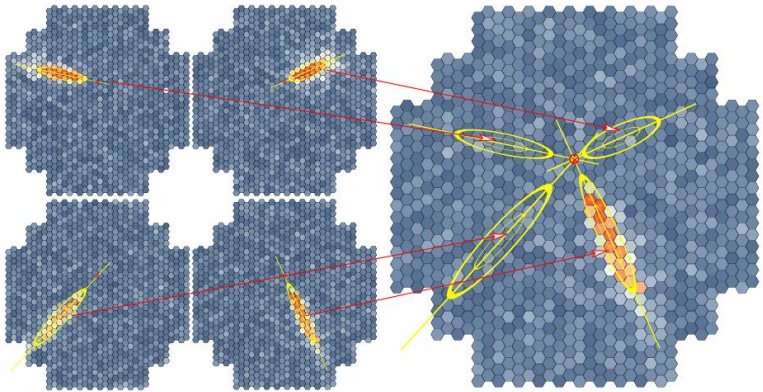
Credit: CTA GCT project

Cherenkov Telescope Array



La Palma,
Spain,
19 telescopes

Paranal,
Chile,
89 telescopes



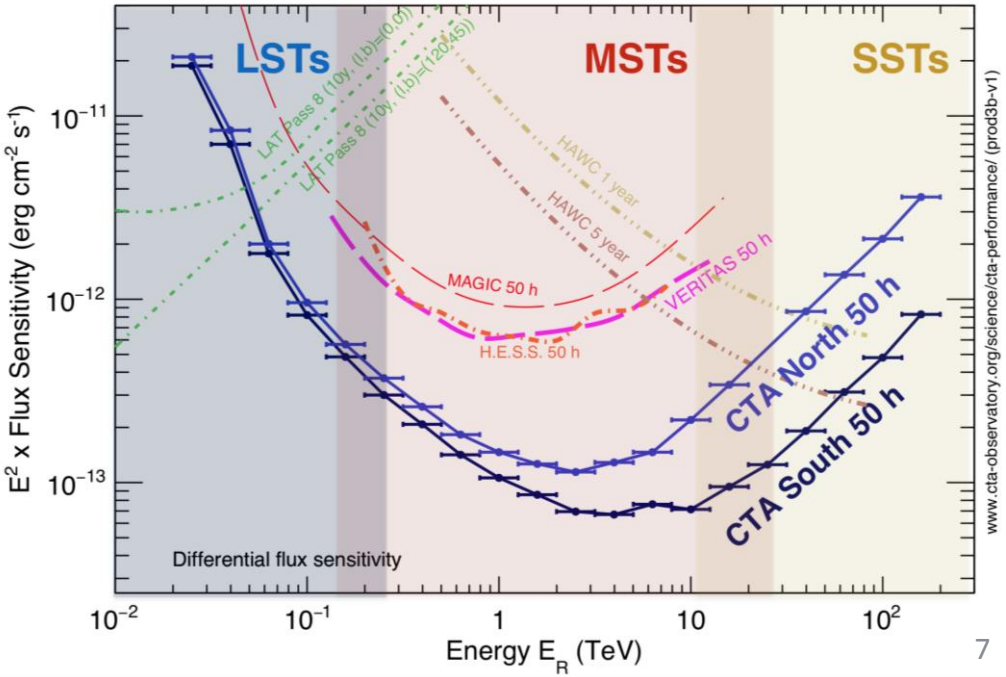
HESS figure (credit K. Bernlohr)

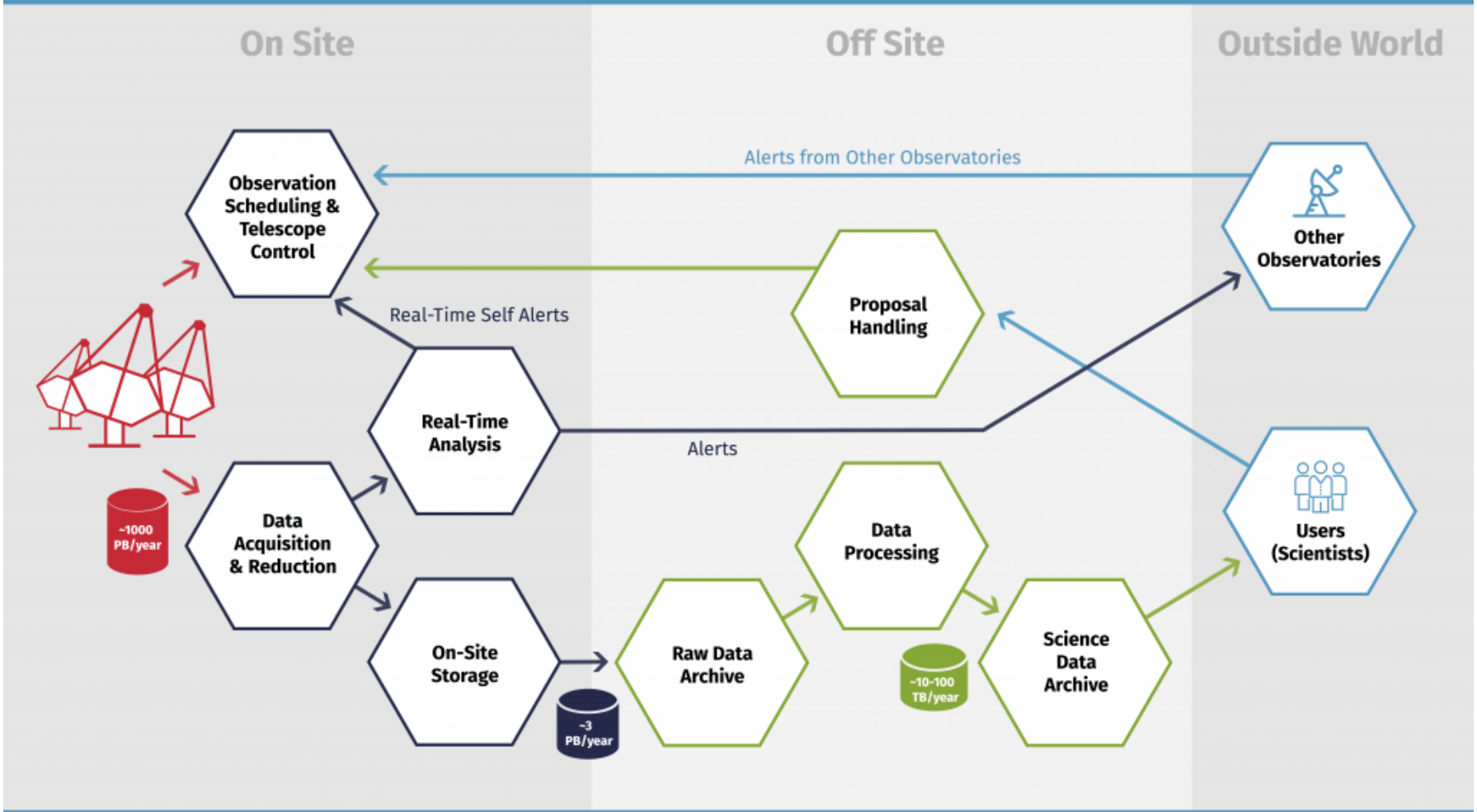
CTA sensitivity

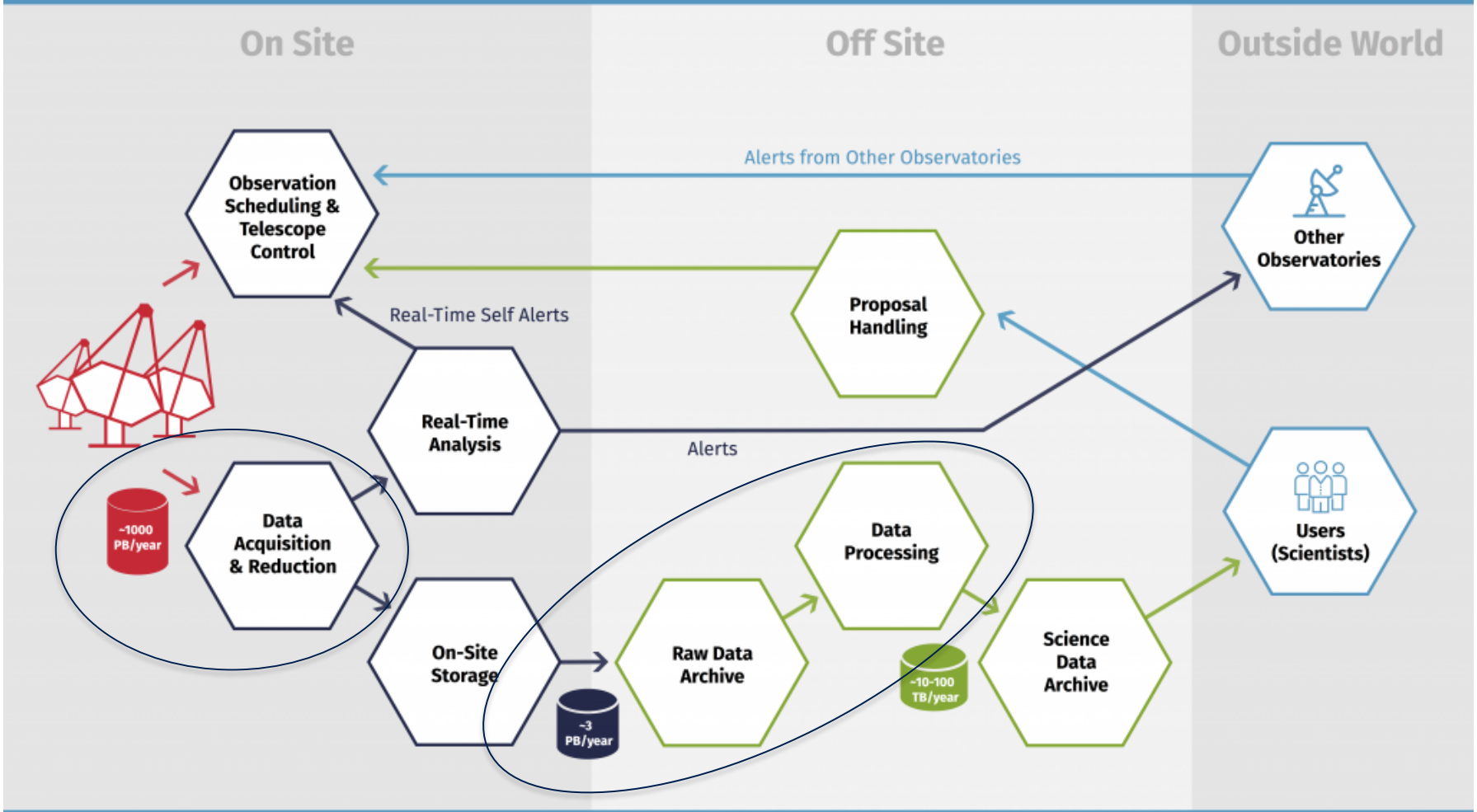
	LST	MST	SST
Mirror ⌀	**~23m**	**~11.5m**	**~4m**
FoV	~4.3deg	~7.5deg	~9deg

Increase of sensitivity
by factors 5 to 10
w.r.t existing facilities

Different telescopes sizes observe at different energies




On Site
Off Site
Outside World
Observation Scheduling & Telescope Control
Alerts from Other Observatories
Other Observatories
Proposal Handling
Real-Time Self Alerts
Real-Time Analysis
Alerts
~1000 PB/year
Data Acquisition & Reduction
Data Processing
Users (Scientists)
On-Site Storage
Raw Data Archive
Science Data Archive
~3 PB/year
~10-100 TB/year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Observation Scheduling & Telescope Control
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~1000 PB/year
Data Acquisition & Reduction
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Raw Data Archive
~10-100 TB/year
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~3 PB/year

Deep learning

- Machine learning (ML) is already being used in current Cherenkov telescope facilities
  - Energy reconstruction
  - Particle discrimination (classification)
  - E.g. random forests on pre-calculated features

- Deep learning (DL) aims at replacing the “pre-calculation” phase
  - Starting from raw images

A good choice for CTA data?

- DL requires training data
  - CTA data reconstruction is based on large simulations (= labelled data)

Offline processing

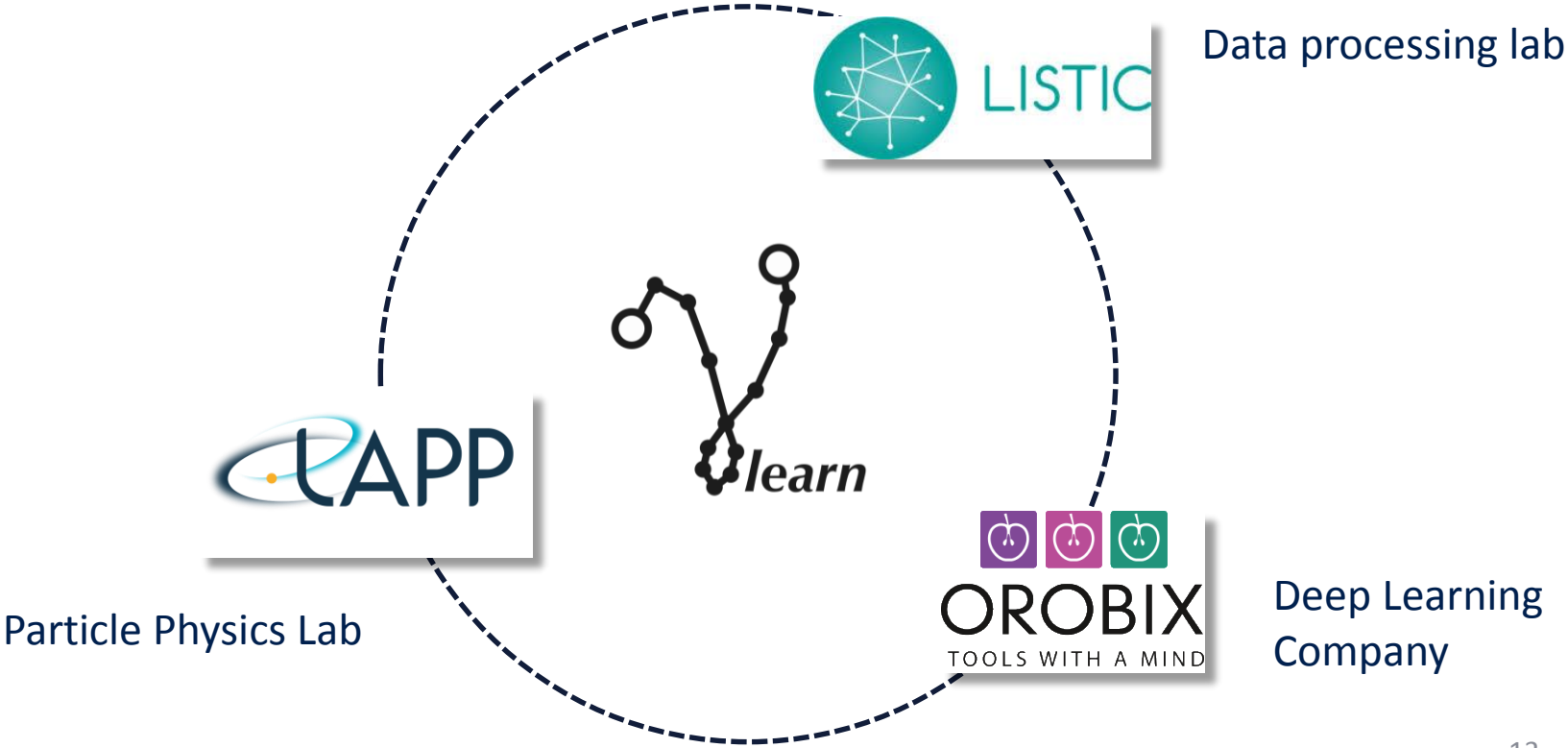
- DL approach is expected to improve the reconstruction, starting from raw information, without bias or modification
- DL could replace (and overcome) complex reconstruction algorithms

A good choice for CTA data?

Online processing

- Training can be done offline and predict quickly online
  - Event selection online for volume reduction before data transfer ?
  - 1 photon event (signal) for ~ 1000 hadronic events (background)

GammaLearn - a collaborative project



GammaLearn - objectives

- Reconstruct events physical parameters from raw images
  - Energy
  - Incoming direction
  - Particle type

- Improve particle discrimination
  - To improve CTA sensitivity
  - To reduce data volumes on-site before transfer

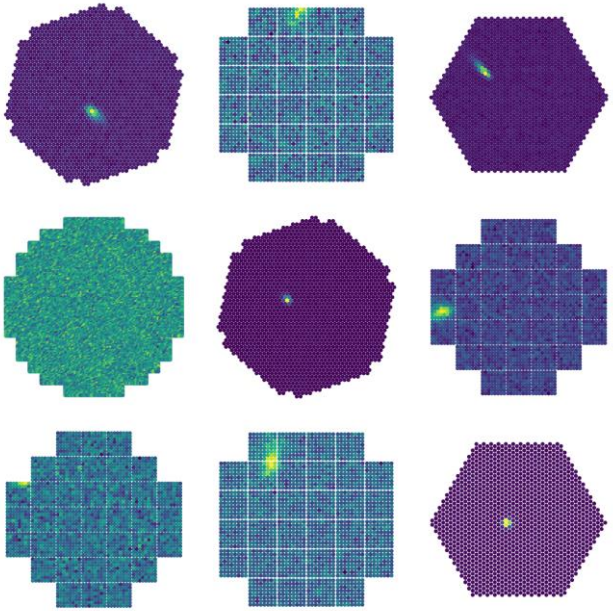
CTA specificities

CTA specificities to apply deep learning

- Non-standard images
- Stereoscopy

CTA specificities – images

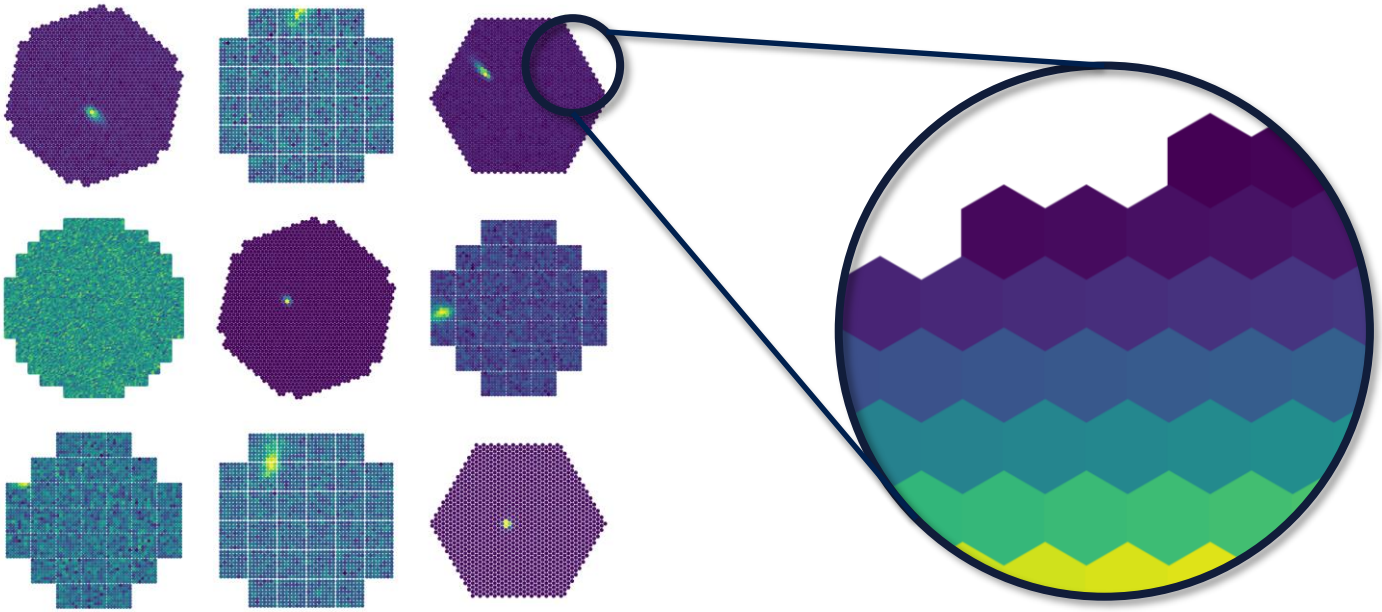
- Non-standard images shapes



- How to deal with images borders?

CTA specificities – images

- Non-standard images shape and hexagonal lattices



CTA specificities – images

- Non-standard images shape and hexagonal lattices

  - How to deal with pixels neighbours ?
    - Convolution
    - Pooling

Dealing with non standard images

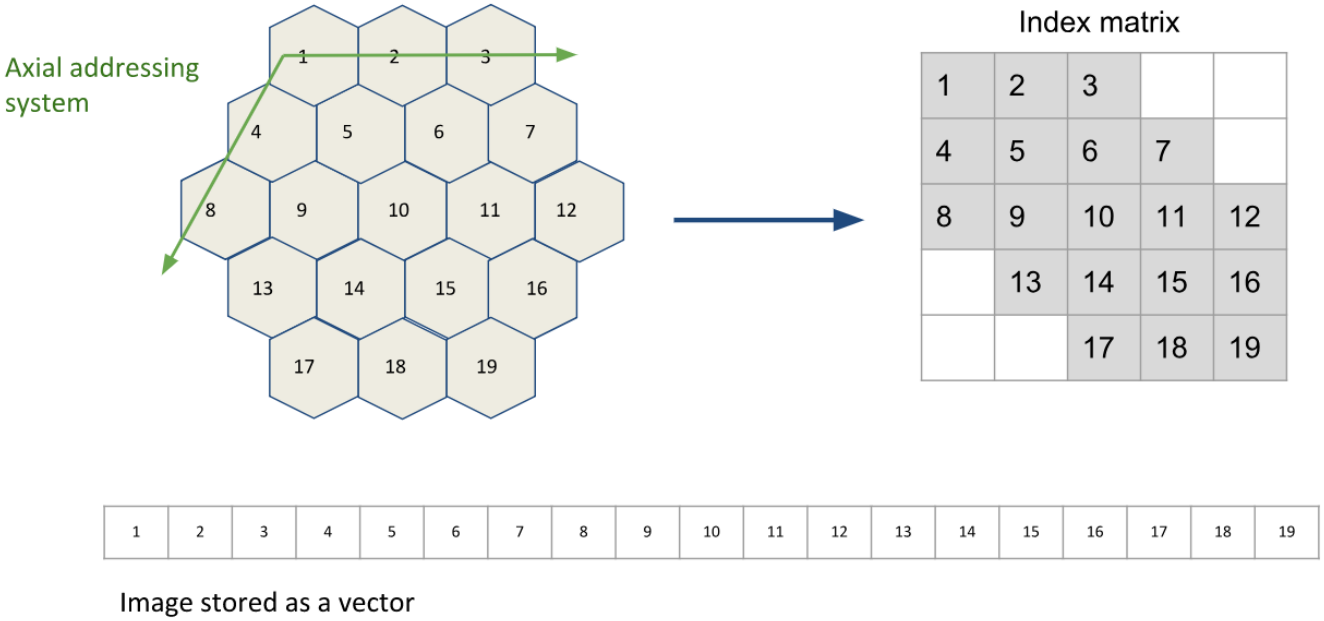
- Oversampling ?
  - Standard way to deal with this kind of problem
  - BUT it introduces:
    - CPU computation in production
    - Biases in already low-resolution images

Dealing with non standard images

- Oversampling ?
  - Standard way to deal with this kind of problem
  - BUT it introduces:
    - Some (heavy?) CPU computation in production
    - Biases in already low-resolution images

- ⇨ Re-define convolution and pooling !

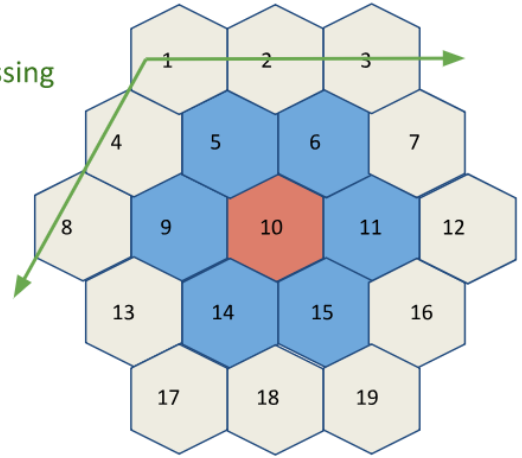
Dealing with non standard images



Pixel ordering is just a convention to build the index matrix

Dealing with non standard images

Axial addressing system



Convolution kernel

Index matrix

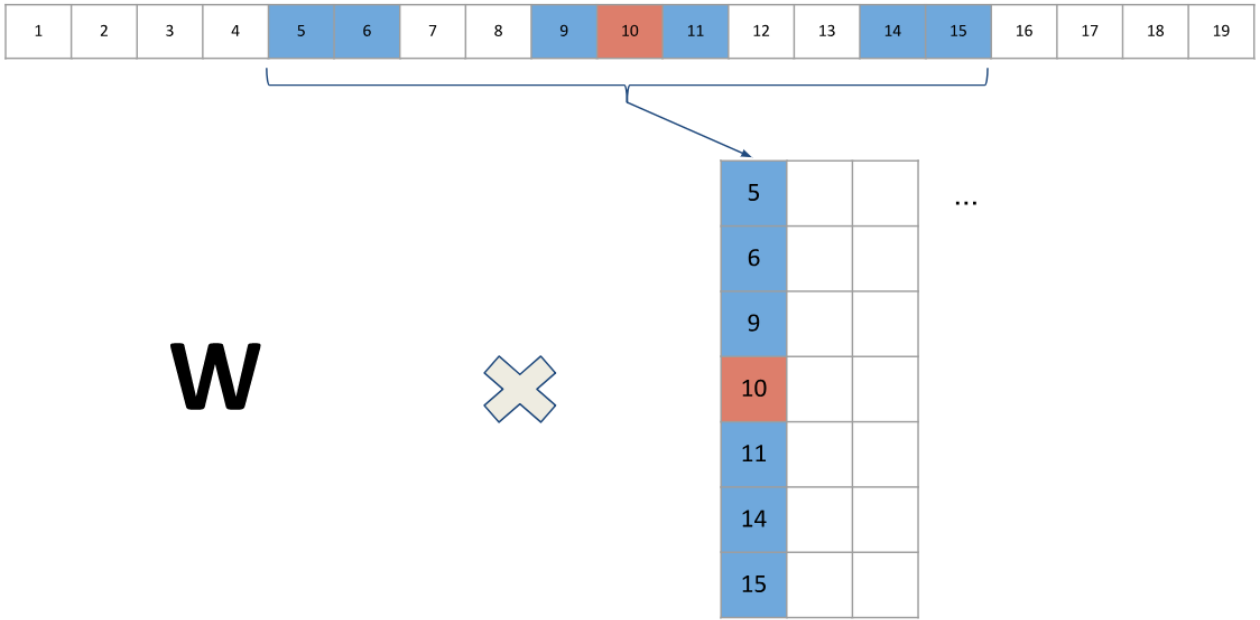
1	2	3		
4	5	6	7	
8	9	10	11	12
	13	14	15	16
		17	18	19

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19

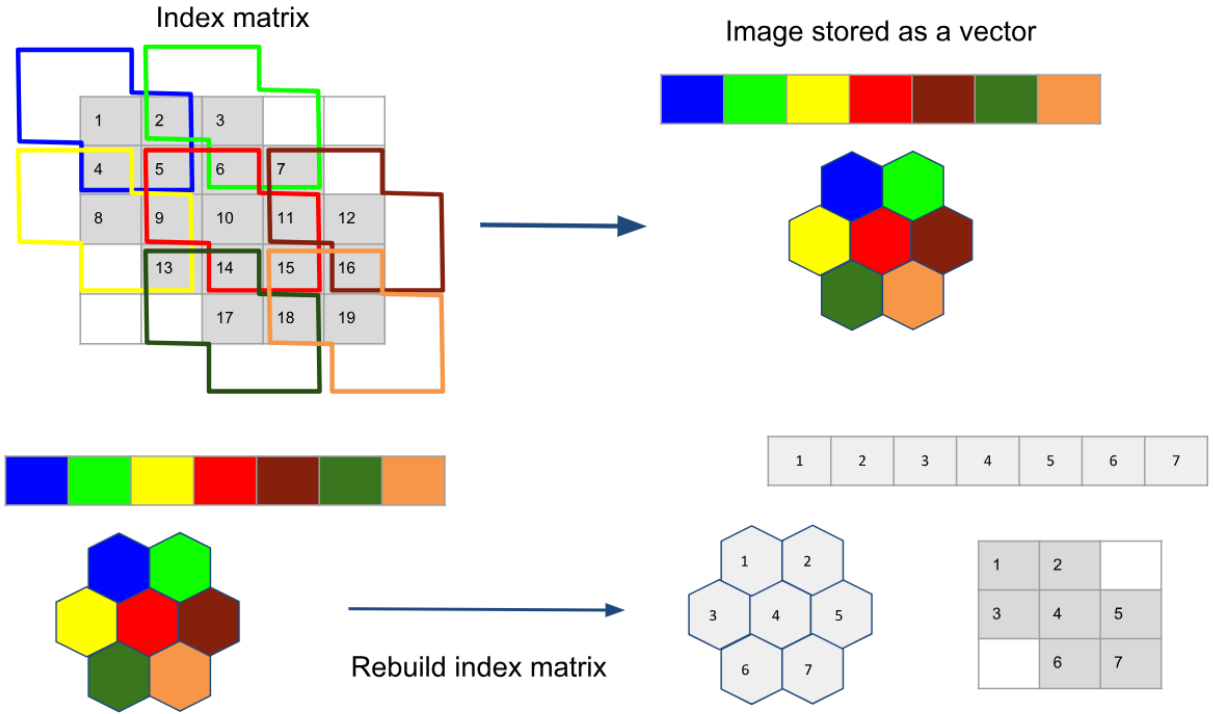
Image stored as a vector

Dealing with non standard images

Rebuild the image matrix and apply weights to compute the convolution



Dealing with non standard images



Pooling:

- Take the index matrix kernel to find the neighbours, then apply pooling

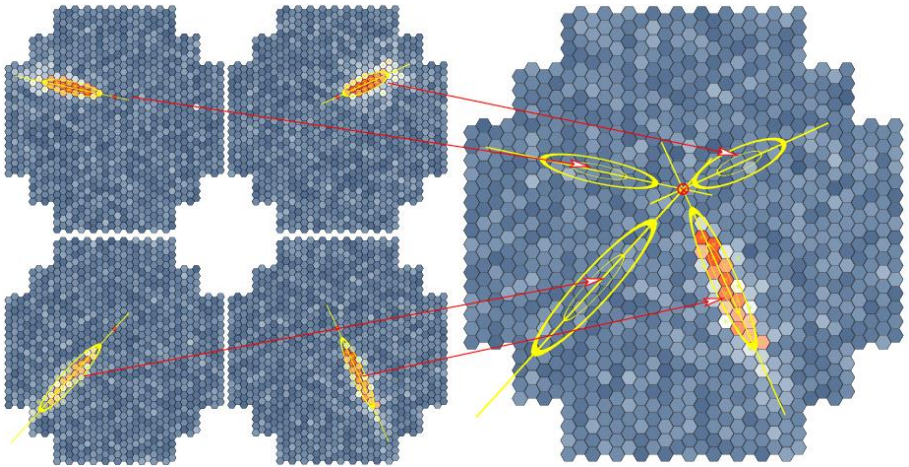
- Rebuild the index matrix with new neighbours

Indexed convolution & pooling

- The indexed convolution and pooling that we developed is
  - A simple and very generic solution
  - Can be applied to any non-standard image or detector as long as user knows its shape and can provide neighbours list
  - Build neighbours index matrix once for your detector and you can apply specific convolution and pooling

CTA specificities – stereoscopy

- Stereoscopy : combining several telescopes images at the heart of IACT performances

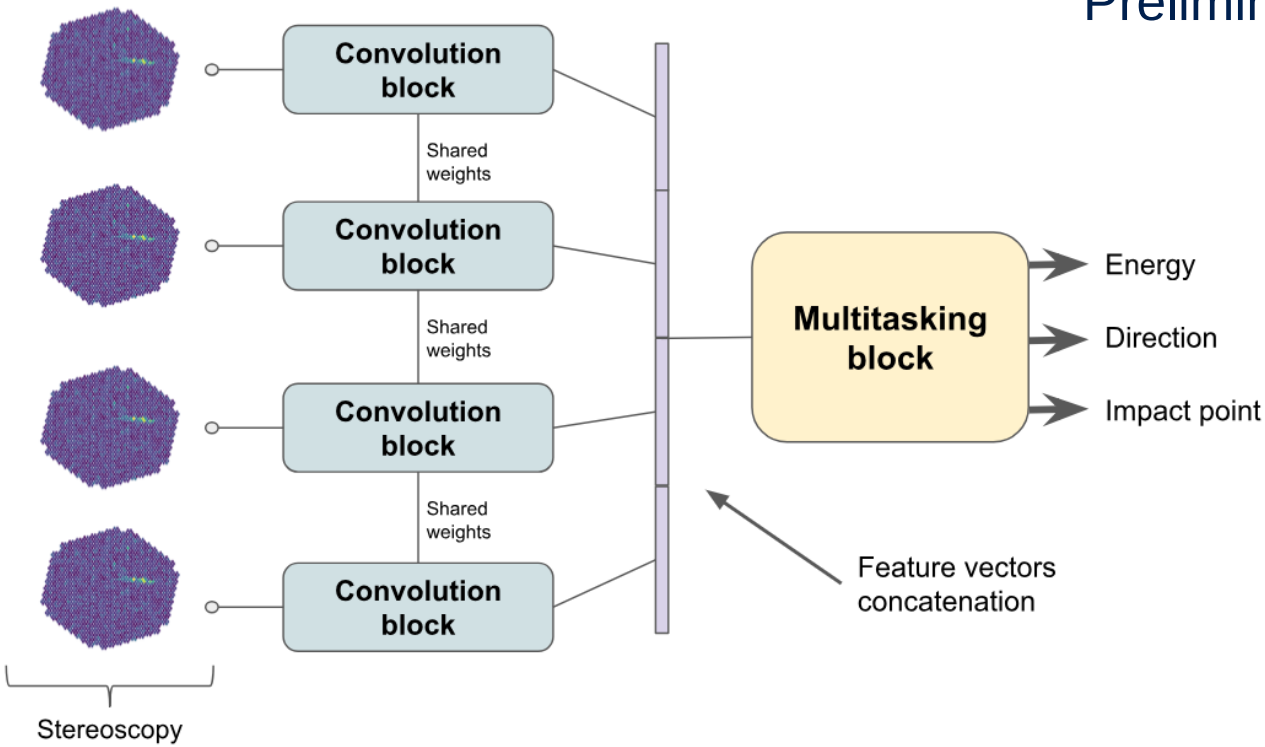


HESS figure (credit K. Bernlohr)

- Stacking images is not adapted to DL for CTA
  - Different camera shapes
  - Potentially tens of images to stack = loss of information
  - CTA envisages to provide full-waveform readout for each event.

CTA specificities - stereoscopy

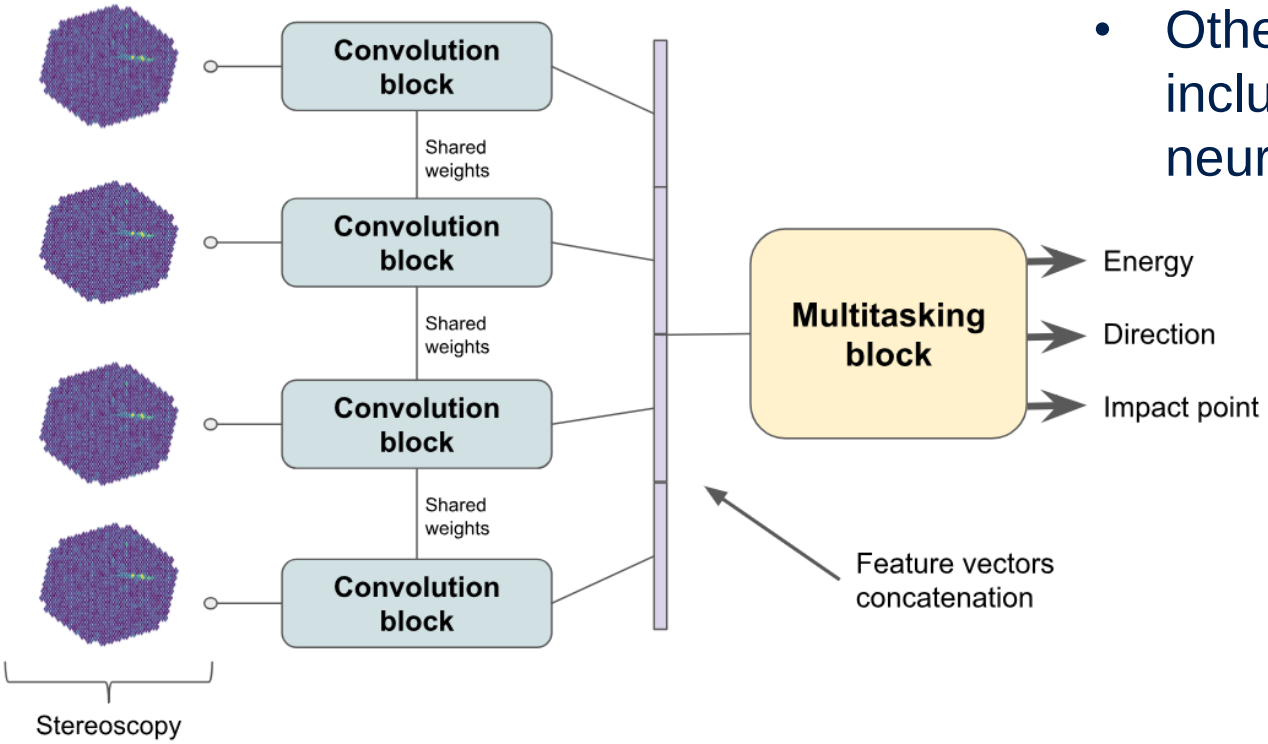
Preliminary architecture



CTA specificities - stereoscopy

Preliminary architecture

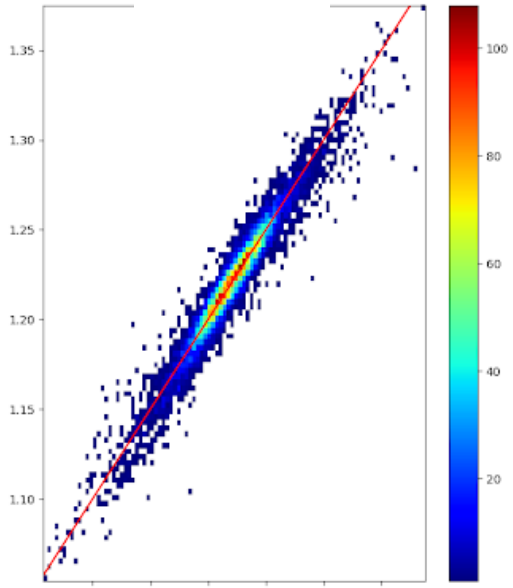
- Other architecture may include recurrent neural networks (RNN)



Preliminary results

Regression diffusion matrices

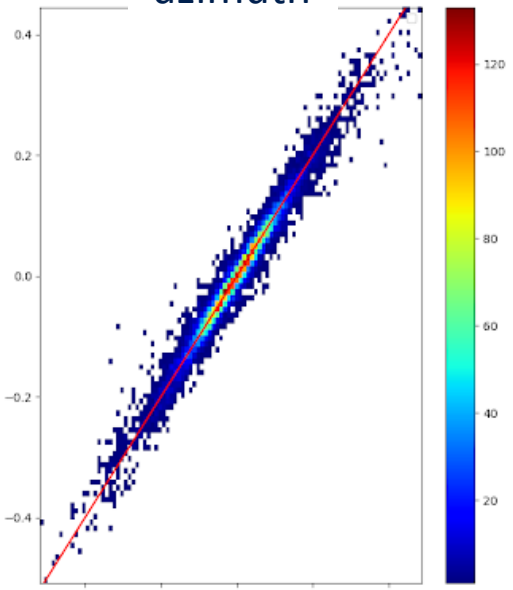
altitude



1.10 1.20 1.30

True position [rad]

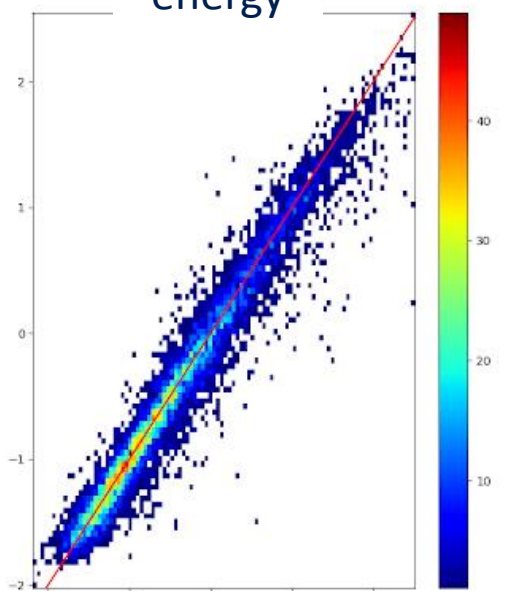
azimuth



-0.2 0 0.2

True position [rad]

energy

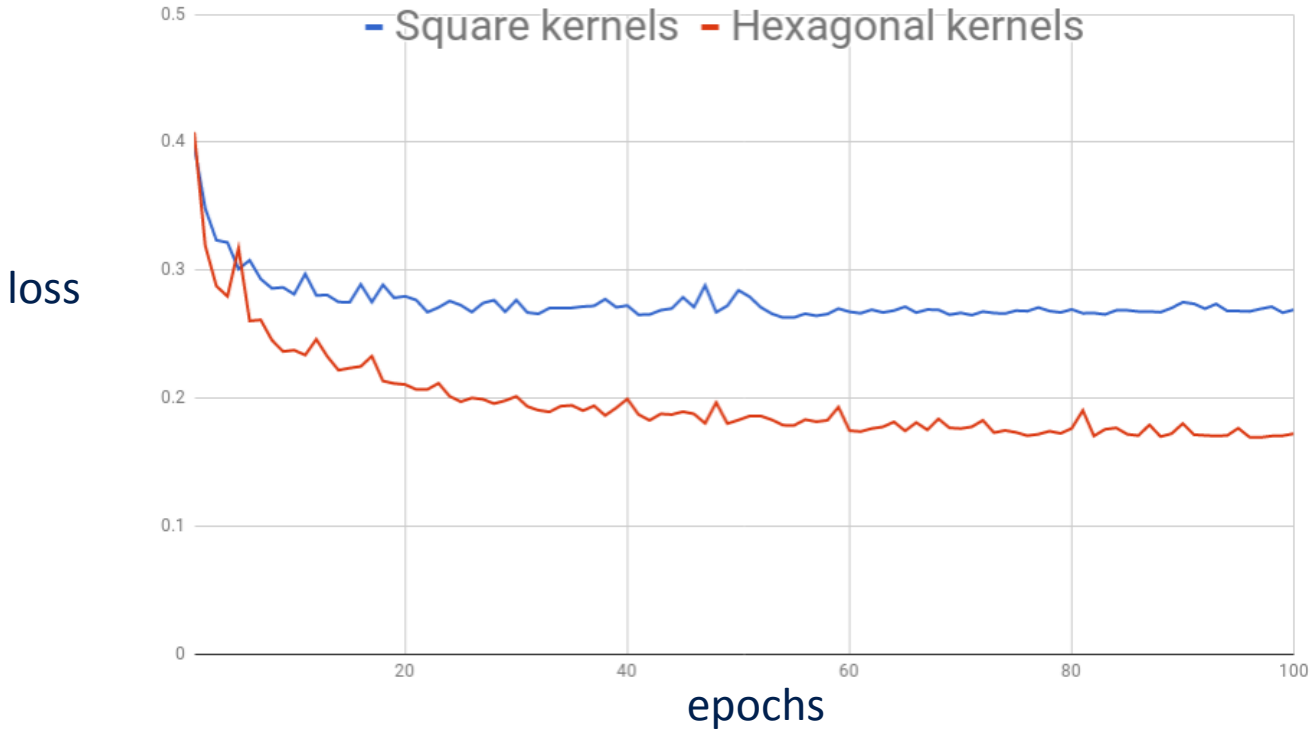


-1 0 1

True energy [log(E/TeV)]

Preliminary results

Comparison of the loss for regression task with hexagonal and standard kernels



Conclusion

- GammaLearn is a collaborative project between experts from CTA and deep learning
- Aiming at improving CTA performances thanks to DL techniques
- CTA specificities pushed us to develop generic solution to non-standard convolution kernel issue
  - Available as open-source code at https://lapp-gitlab.in2p3.fr/GammaLearn
- DL solution still under development

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