GammaLearn: Deep Learning applied to the CTA data analysis

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for the GammaLearn team
IN2P3/IRFU Machine Learning workshop, 22/01/2020

- Gamma astronomy and the CTA
- Why DL for CTA data analysis ?
- Deep Multitask Learning
- γ-PhysNet performances
- Going further

Mikaël Jacquemont thesis

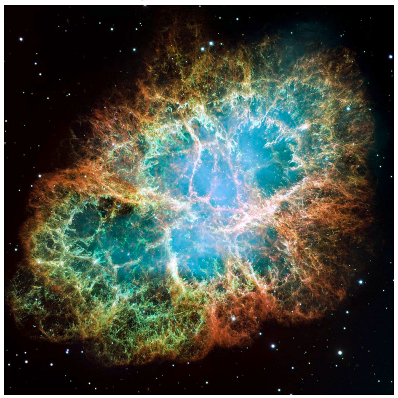
- Patrick Lambert
- Alexandre Benoit

- **Thomas Vuillaume**
- Gilles Maurin
- Giovanni Lamanna

*ASTERICS: european H2020 project

Gamma Astronomy

Supernova

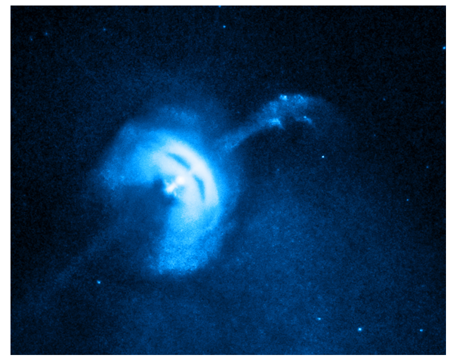


wikipedia

AGN

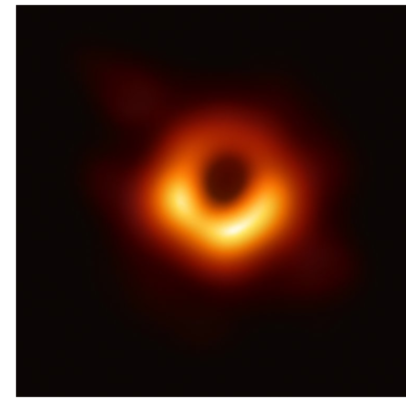
ESA/NASA

Pulsar



NASA

Black hole

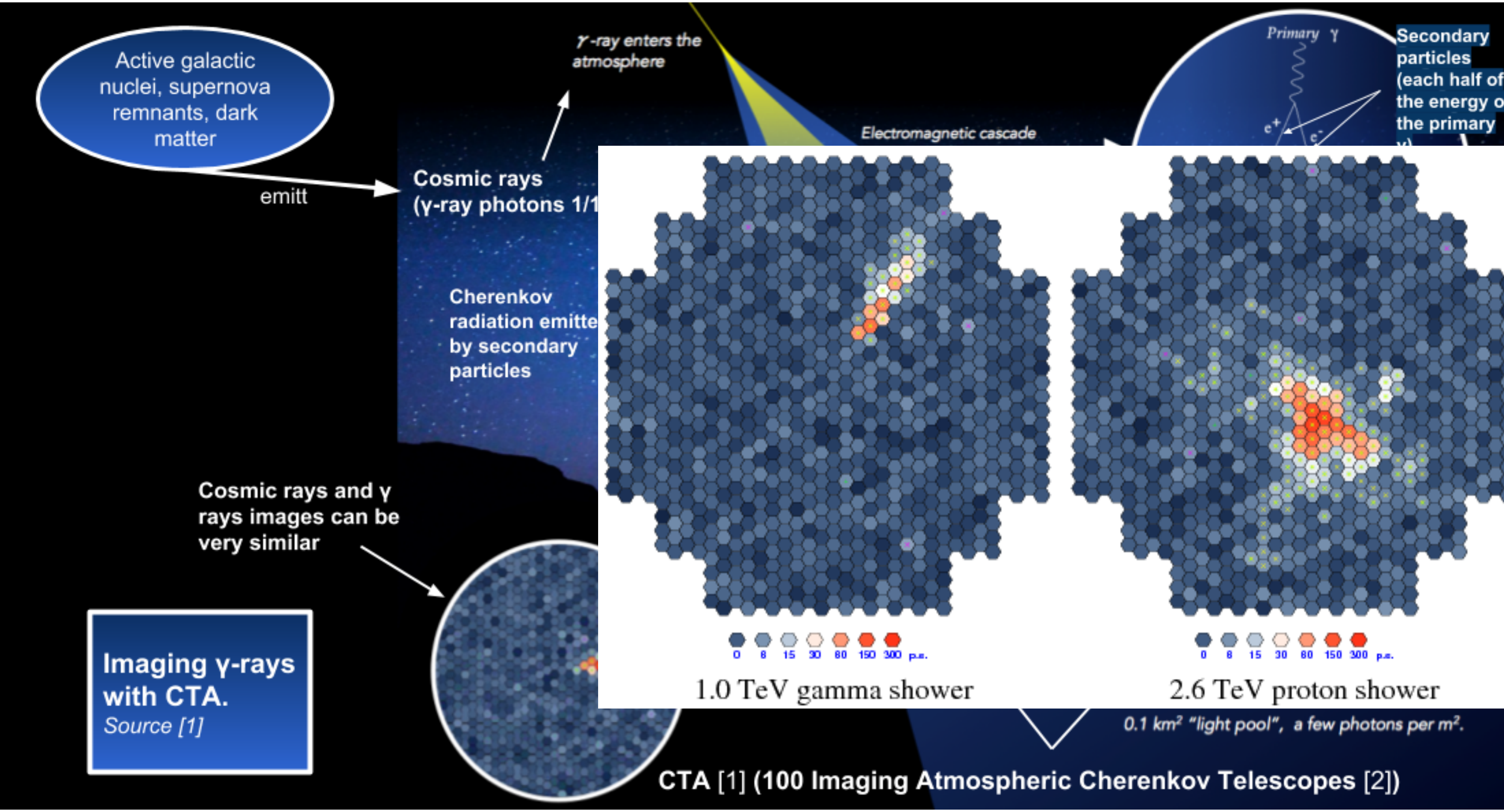


ESO

…

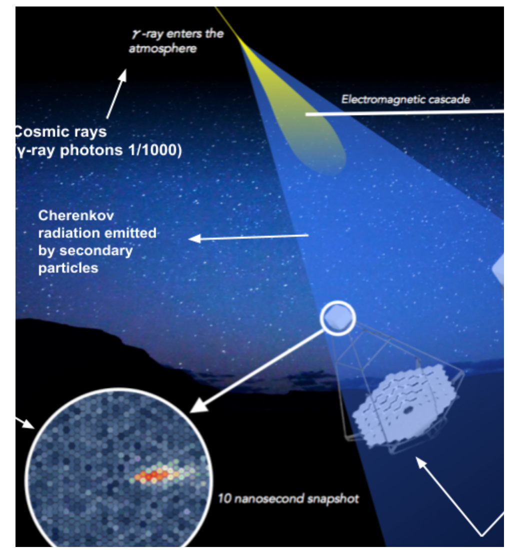
Gamma rays

Imaging gamma rays



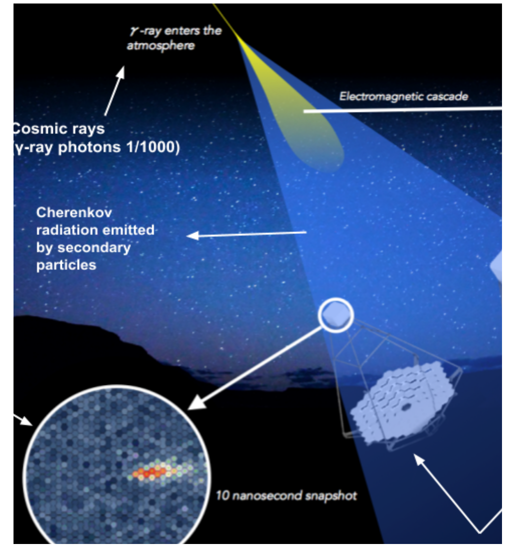
Data specificities

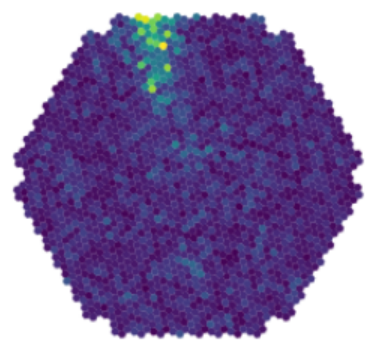
- Hexagonal pixels
- High SNR (~1/1000)
- Sequence of images (some ns)
  - ➢ Calibration
  - ➢ Integration



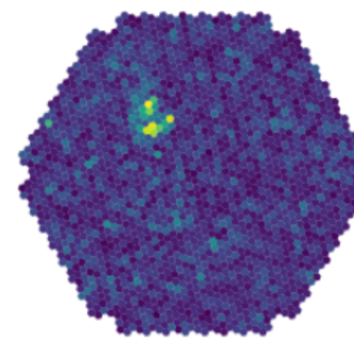
Strong interdependence

- Image shape and intensity
- Energy
- Arrival direction
- Impact point
- Particle type





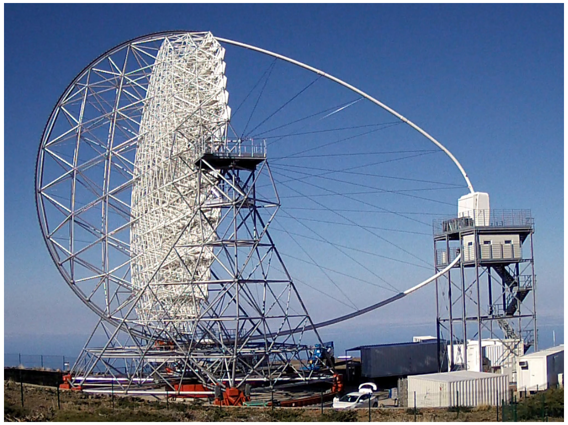
Gamma 7,3 TeV



Proton 27 GeV

Cherenkov Telescope Array (CTA)

- Next generation gamma astronomy observatory
- 2 sites (La Palma and Paranal)
- 108 telescopes
- First prototype on site: LST1
- 210 PB per year !



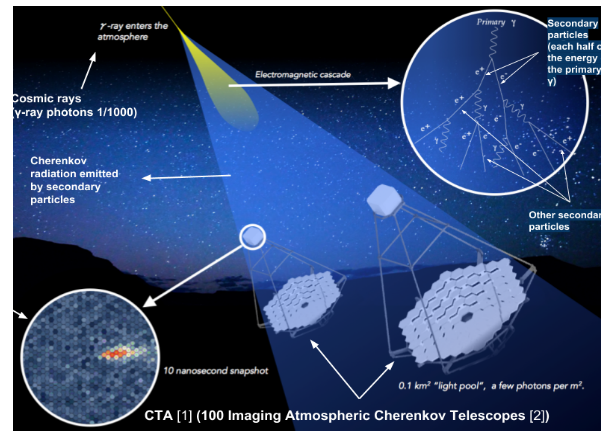
Credit: Gabriel Pérez Diaz, IAC, SMM

CTA data analysis

- Gamma / proton separation
- Energy and Direction reconstruction

Standard methods

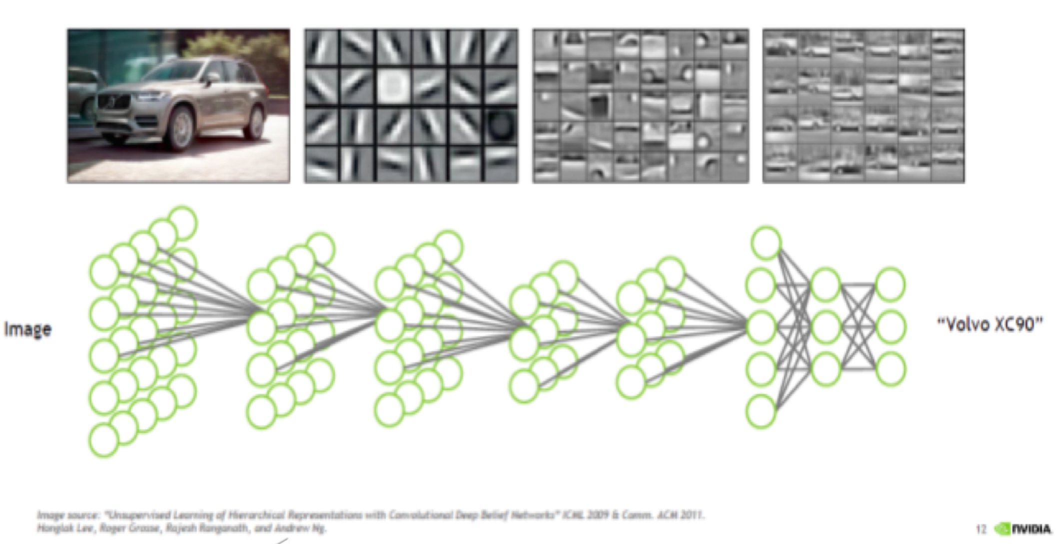
- Hillas + RF
- Impact / Model++

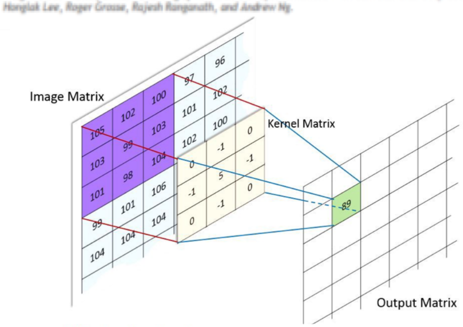


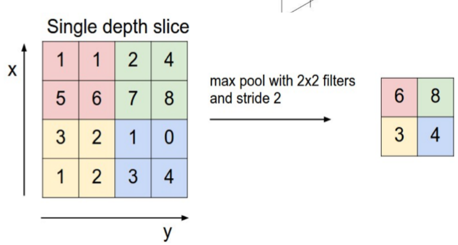
Why Deep Learning ?

- Potentially more performant
- Minimal images treatment before analysis
- Fast execution, thanks to GPUs

Convolution (and pooling): a key element of DL





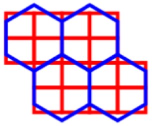


- Reducing the # of parameters
- (Locally) translation invariance
- Larger field of view
- Consideration of the context

Hexagonal pixels ?

Hexagonal pixels

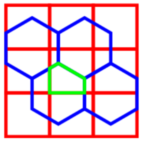
- Oversampling



(c) oversampling

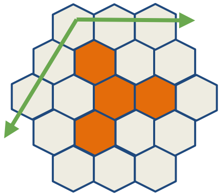
Credits: T. Holch et al.

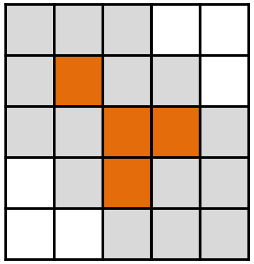
- Rebinning



- Image shifting + masked convolution

Axial addressing system





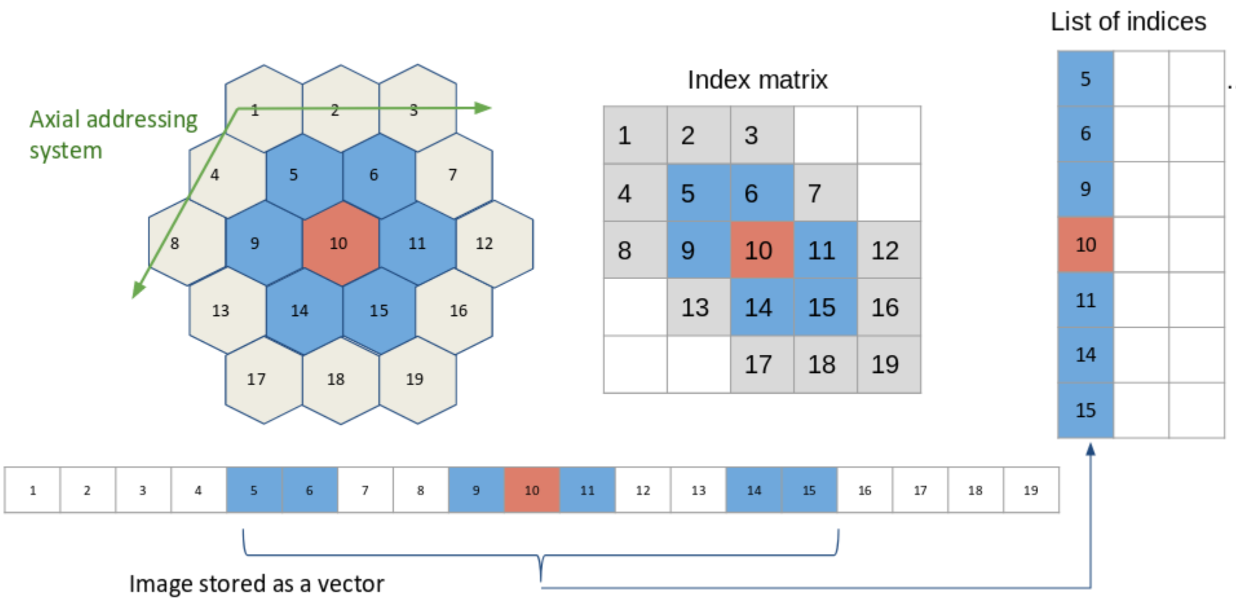
1	1	0
1	1	1
0	1	1

Convolution kernel mask

- ➢ Preprocessing
- ➢ Image distortion

IndexedConv

- GEMM for arbitrary lattices
  - ➢ im2col operation based on the list of pixel neighbors
- Hexagonal case



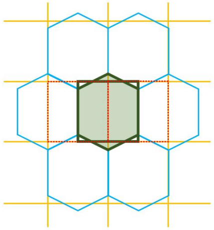
IndexedConv

CIFAR-10

Hexagonal kernels (i.c.)	Square kernels
88.51 ± 0.21	88.39 ± 0.48

AID

Hexagonal kernels (i.c.)	Square kernels
79.81 ± 0.73	79.85 ± 0.50



"Indexed operations for non-rectangular lattices applied to convolutional neural networks"
VISAPP 2019

Objectives

- Gamma / proton separation
- Gamma parameters reconstruction: energy and arrival direction

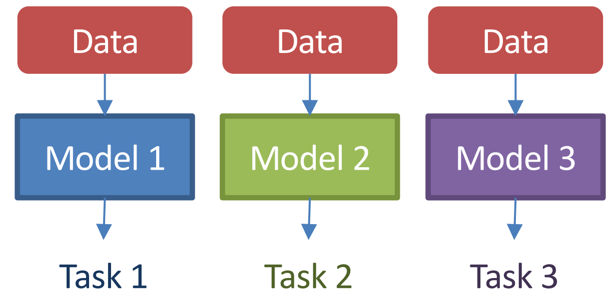
Challenges

- Data volume
- Camera and pixels shapes
- Parameters interdependence

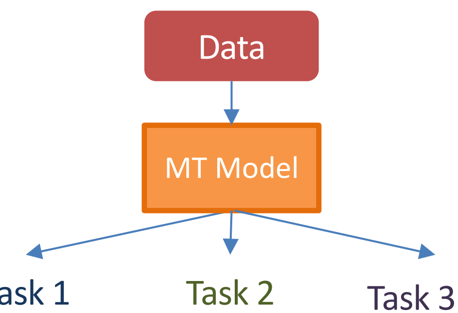
Multi-task problem

Deep Multi-task Learning

- Interests
  - Implicit data augmentation
  - Eavesdropping
  - Attention focusing
  - Representation bias
- Architecture
  - Hard parameter sharing
  - Soft parameter sharing
- Task balancing
  - Handcrafted
  - GradNorm
  - **Uncertainty estimation**
  - Multi-objective (Pareto)
  - Dynamic task prioritization



Single task learning

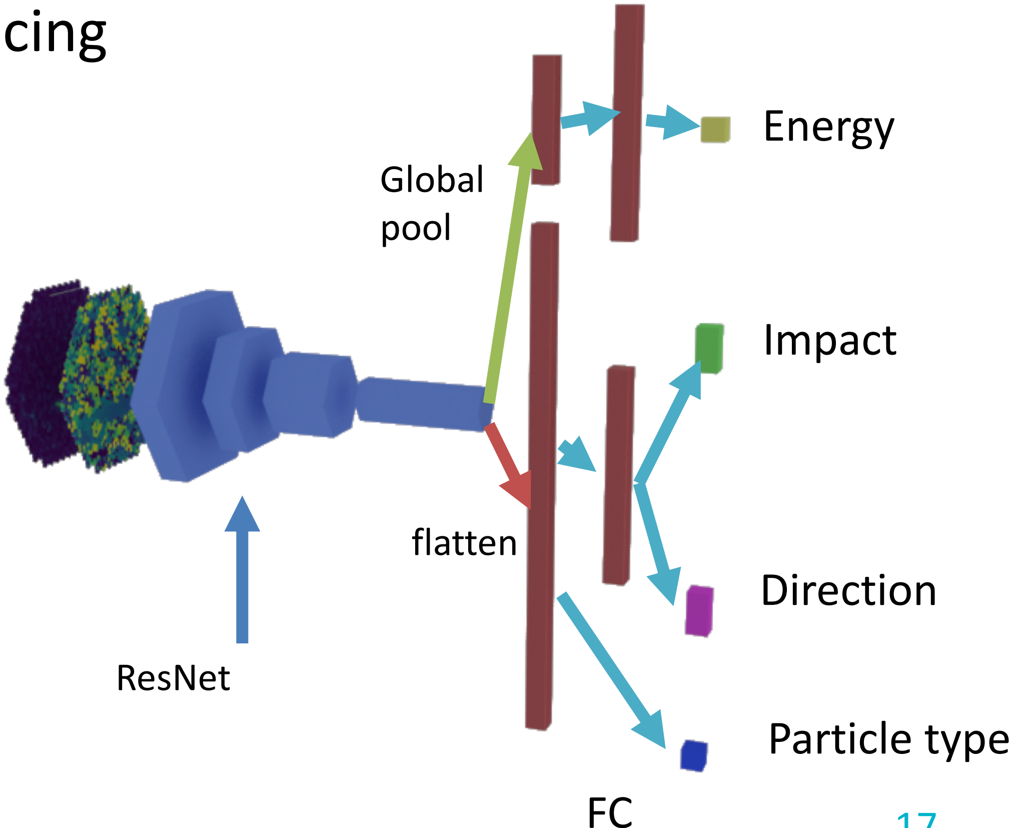


Multi-task learning

- Architectures for full event reconstruction
  - Gamma / proton separation
  - Energy
  - Direction
  - Impact point (auxiliary task)
- Focus on mono analysis for now
  - Interesting use-case
  - Preparation of the LST1 analysis
    - Aiming to apply on all telescope types
  - Incoming of real data
  - First step to the stereo analysis

γ-PhysNet

- Physically guided architecture
- IndexedConv
- Uncertainty balancing
- Conditional loss
- Gradient penalty



- Mono analysis with Deep MT Learning
- Deep Multi-task Learning is promising
- Very interesting results → consistent with template based analysis in H.E.S.S. but much (~1e3) faster

- Optimize γ-PhysNet
- Use these good results in mono for the stereo reconstruction
- Test on real data → adaptation needed
- Publication

Thank you for your attention

GammaLearner framework: https://gitlab.lapp.in2p3.fr/GammaLearn/GammaLearn

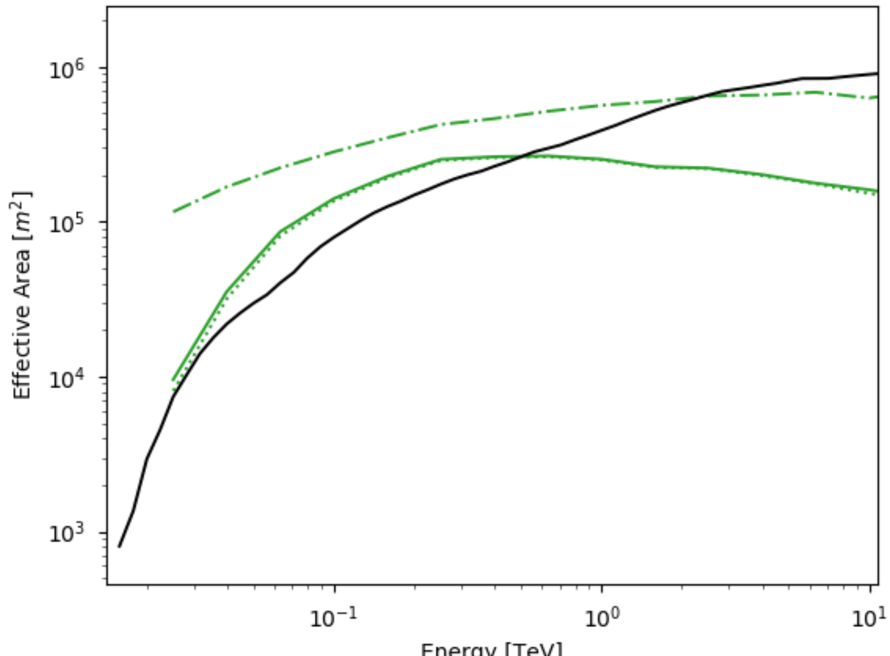
IndexedConv package: https://github.com/IndexedConv/IndexedConv

Ctaplot and Gammaboard: https://github.com/vuillaut/ctaplot

- Backup

Data

- LST4 monotrigger (gamma and proton events)
- Diffuse for training, point like for testing
- Calibrated and integrated images (625 k / 156 k)
- Mono analysis
- Cuts
  - Minimum amplitude 300
  - Leakage2 < 0,2
  - Result of cleaning



- Backup

--- γ-PhysNet
--- H.E.S.S. II mono loose cuts
--- H.E.S.S. II mono safe cuts