Search for optimal deep neural network architecture for gamma ray search at KASCADE

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Motivation

- Gamma astronomy enters PeV era
  - LHAASO detected PeV gammas[1].
  - Tibet detected diffuse sub-PeV gammas[2]
- KASCADE exposure comparable with LHAASO one at PeV energies → should contain gamma-rays in dataset
- Using DL with modern architectures[3]

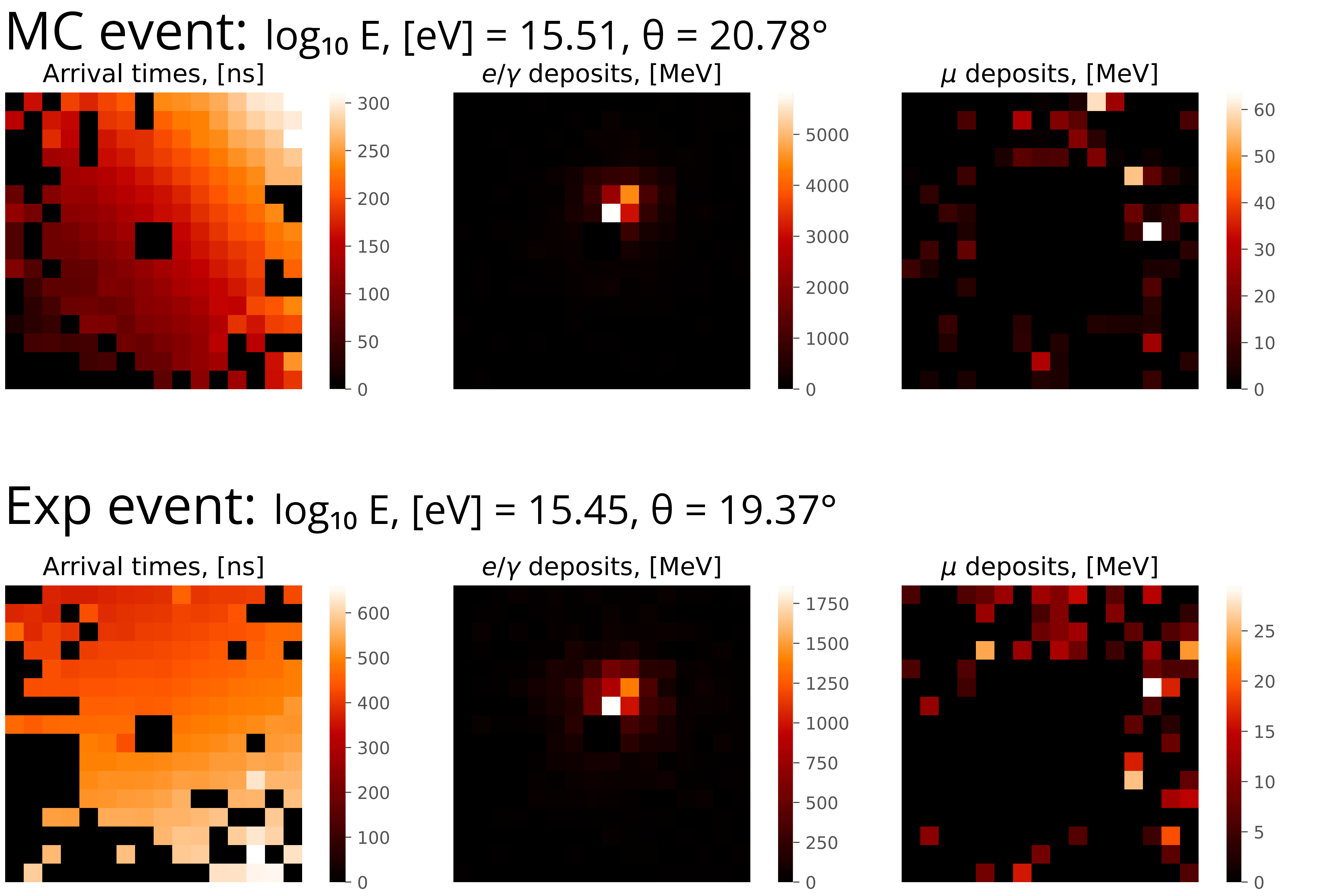
1. Cao, Z. et al (2021). Ultrahigh-energy photons up to 1.4 petaelectronvolts from 12 γ-ray Galactic sources. Nature, 594(7861), 33–36.
2. Amenomori, M. et al (2021). First Detection of sub-PeV Diffuse Gamma Rays from the Galactic Disk: Evidence for Ubiquitous Galactic Cosmic Rays beyond PeV Energies. Physical Review Letters, 126(14).
3. Jin, C. et al (2020). Classifying cosmic-ray proton and light groups in LHAASO-KM2A experiment with graph neural network *. Chinese Physics C, 44(6), 065002.

Data description

Event structure:

- 3 arrays, 16x16 shape
  - arrival times, [ns]
  - e/γ energy deposits, [MeV]
  - μ energy deposits, [MeV]

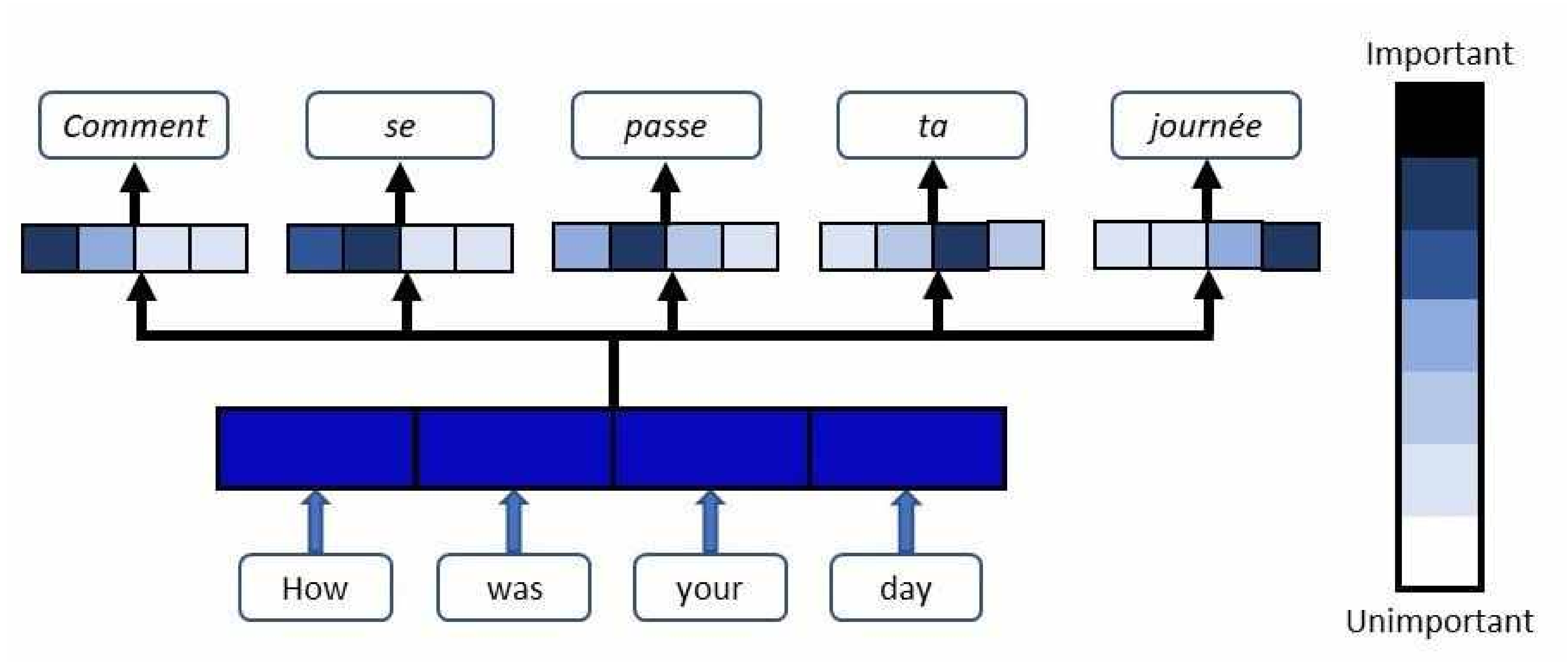
- reconstructed features
  - energy, zenith and azimuth angles of the primary particle
  - shower core position
  - electron and muon numbers
  - shower shape parameter



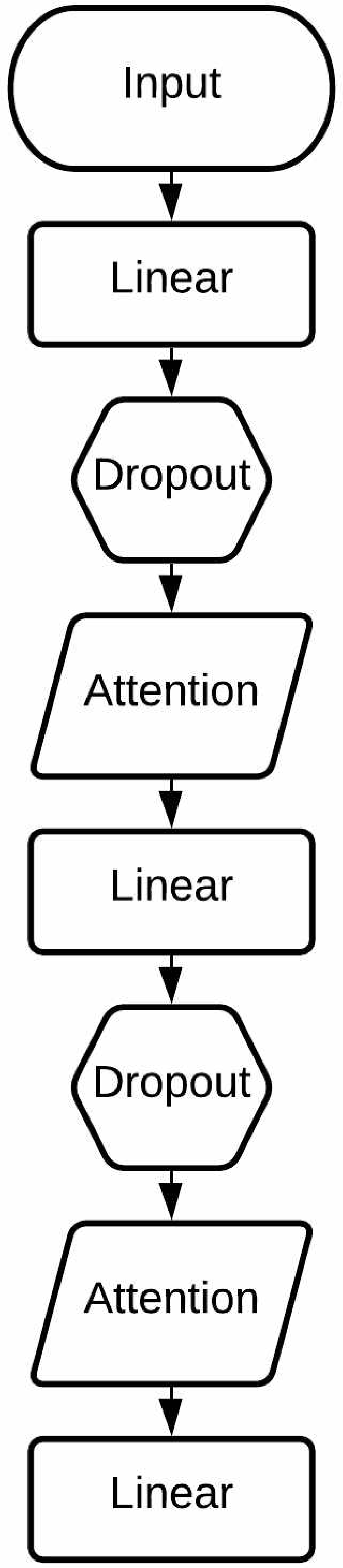
* Data are taken from KCDC: A.Haungs et al; Eur. Phys. J. C (2018) 78:741; “The KASCADE Cosmic ray Data Centre KCDC: granting open access to astroparticle physics research data”; (doi: 10.1140/epjc/s10052-018-6221-2)

Self-attention network (self-att)

- Uses revolutionary attention mechanism[1].



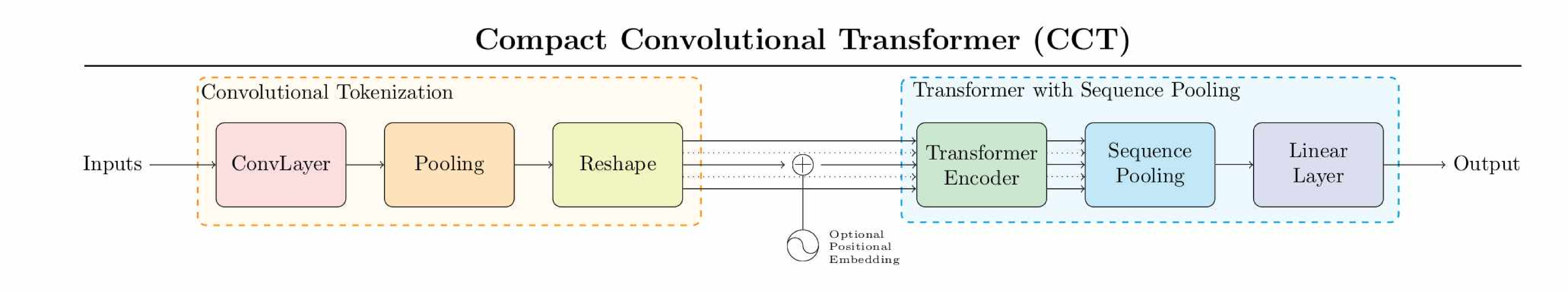
Attention principle schema

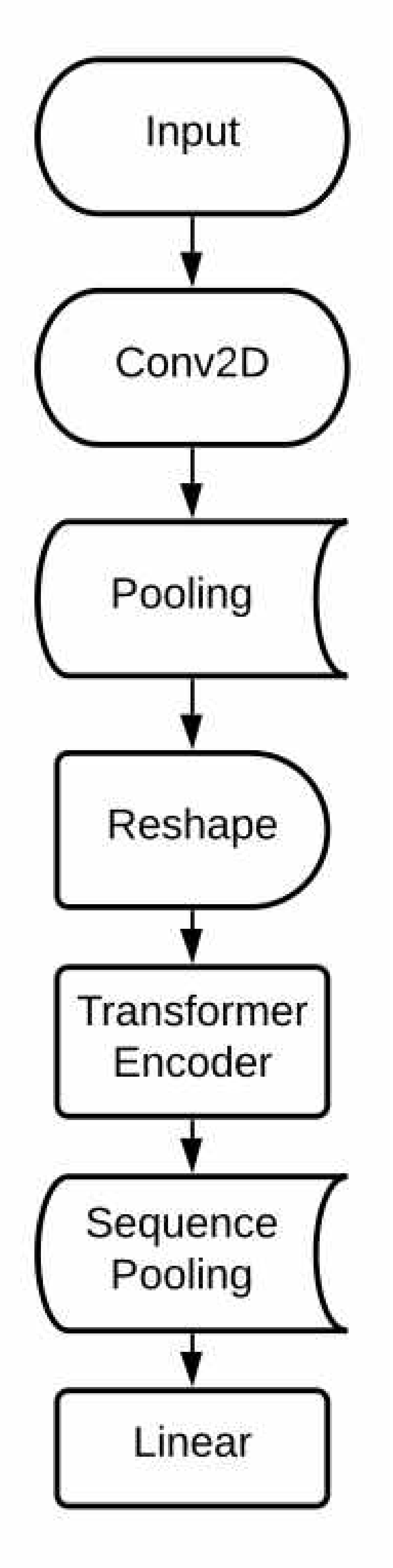


1. Vaswani, Ashish, et al. "Attention is all you need." Advances in neural information processing systems 30 (2017).

Compact Convolutional Transformer (CCT)

- Combines convolutions and attention mechanism.
- Outperforms Convolutional networks in classification tasks[1].

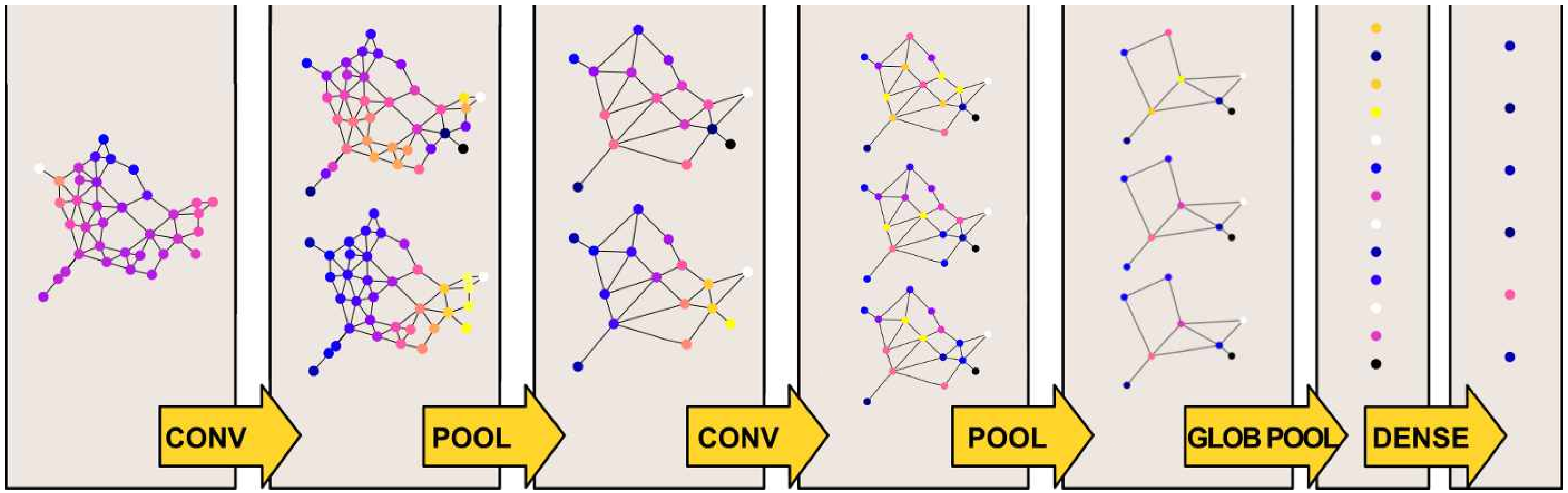




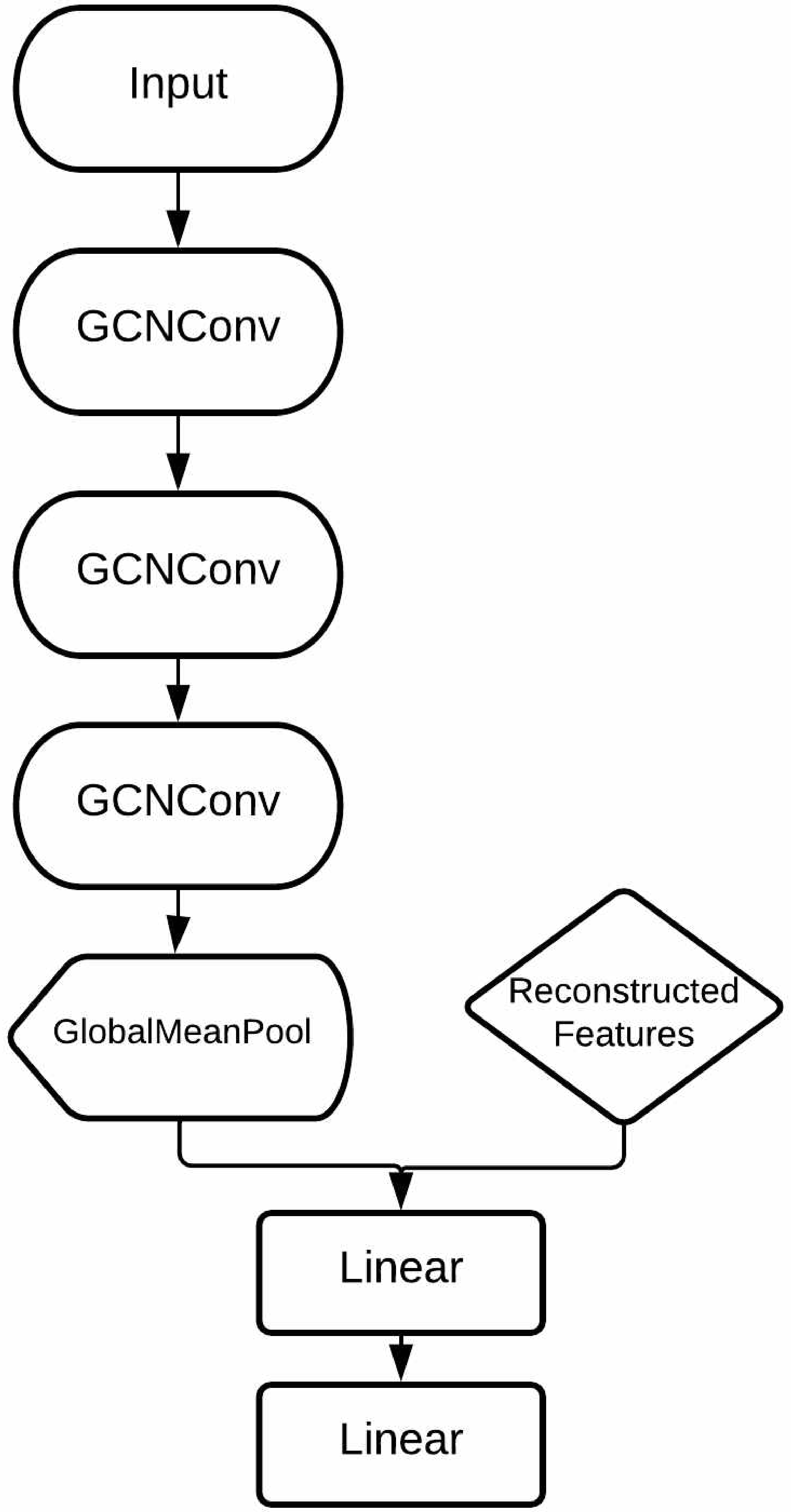
1. Hassani, A., Walton, S., Shah, N., Abuduweili, A., Li, J., & Shi, H. (2021). Escaping the Big Data Paradigm with Compact Transformers. arXiv.

Graph Convolutional Network (GCN)

- Successfully used for classifying cosmic rays at LHAASO[1].
- Takes irregularities into account.



Principle schema of GCN



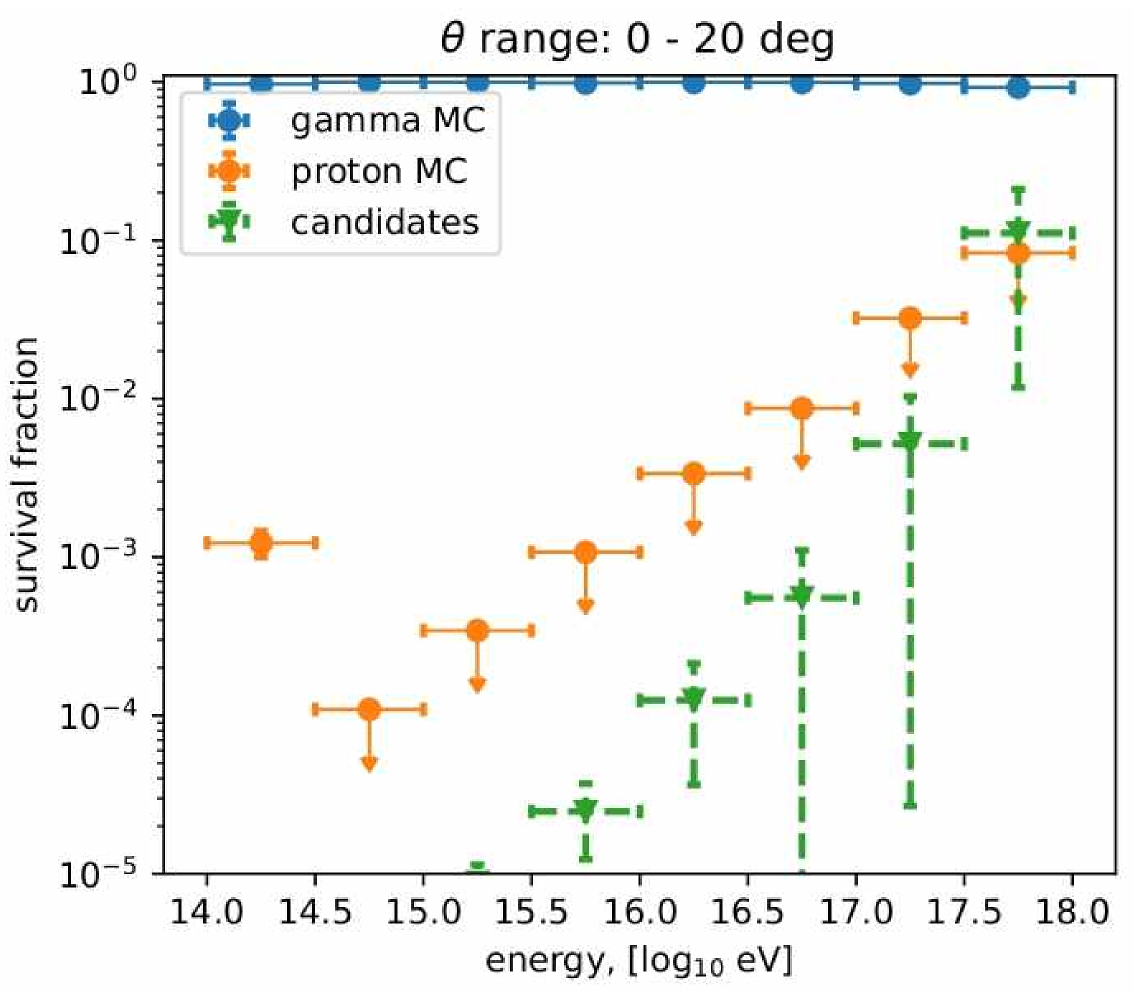
1. Jin, C. et al (2020). Classifying cosmic-ray proton and light groups in LHAASO-KM2A experiment with graph neural network *. Chinese Physics C, 44(6), 065002.

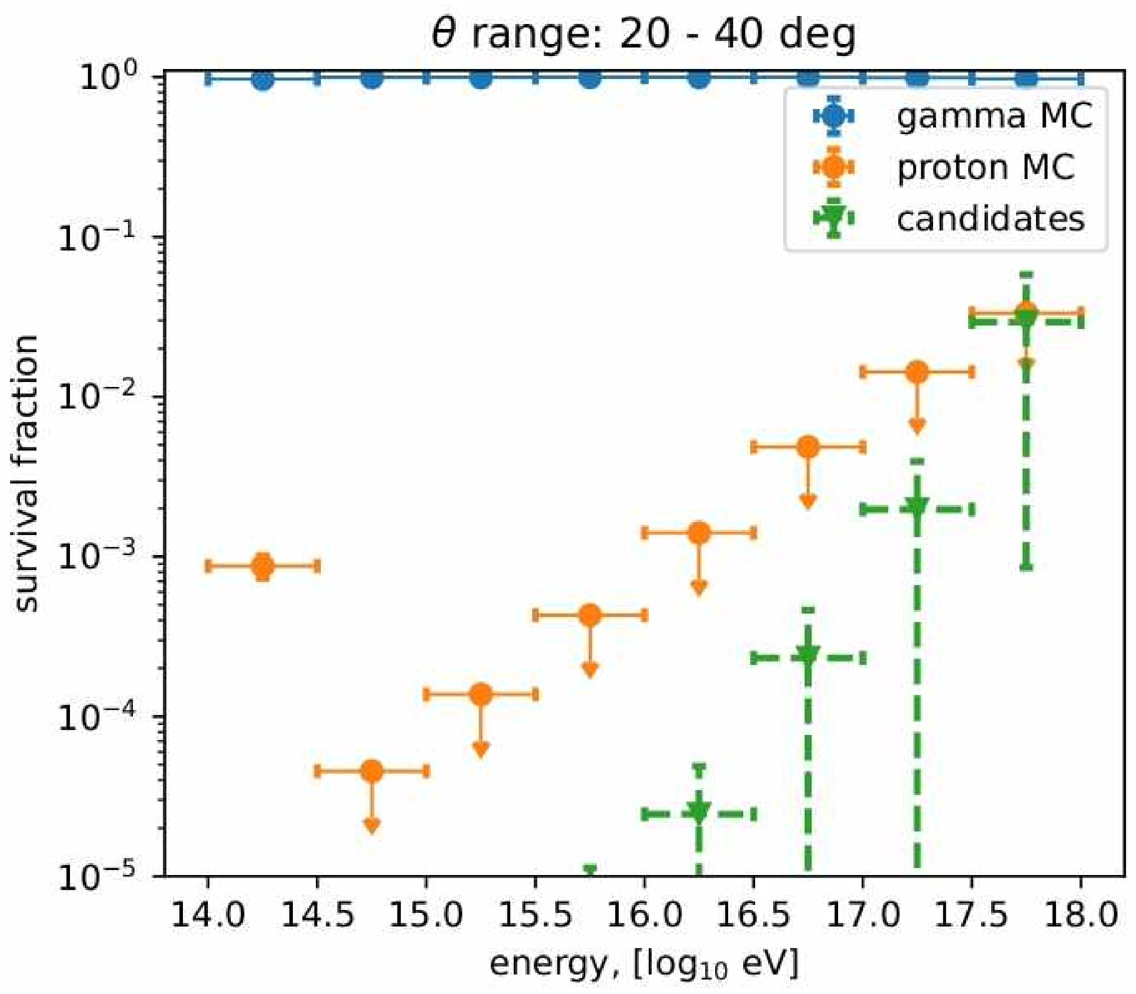
Models comparison

	Self-att	CCT	GCN
Input	e/γ + μ deposits, flatten to 1x512	e/γ + μ deposits, as an image 2x16x16	a graph: e/γ + μ deposits as nodes; edges btw stations + reconstructed features
Peculiarities	Attention	2D convolutions, Attention, Pooling	Graph Convolutions
Spatial invariance	Non-invariant	Partially invariant	Non-invariant
Number of parameters:	30 183	30 531	29 520

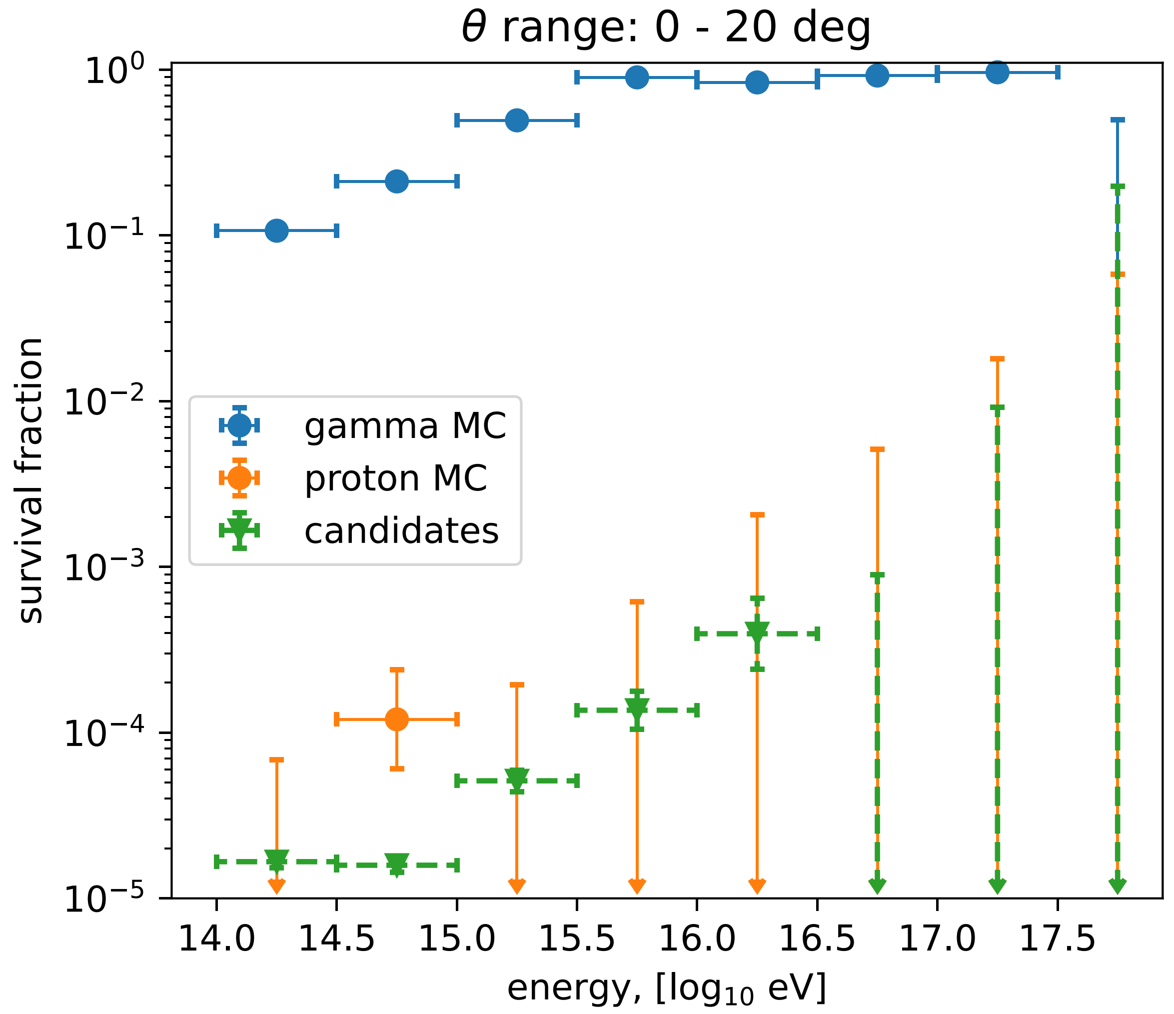
Preliminary results

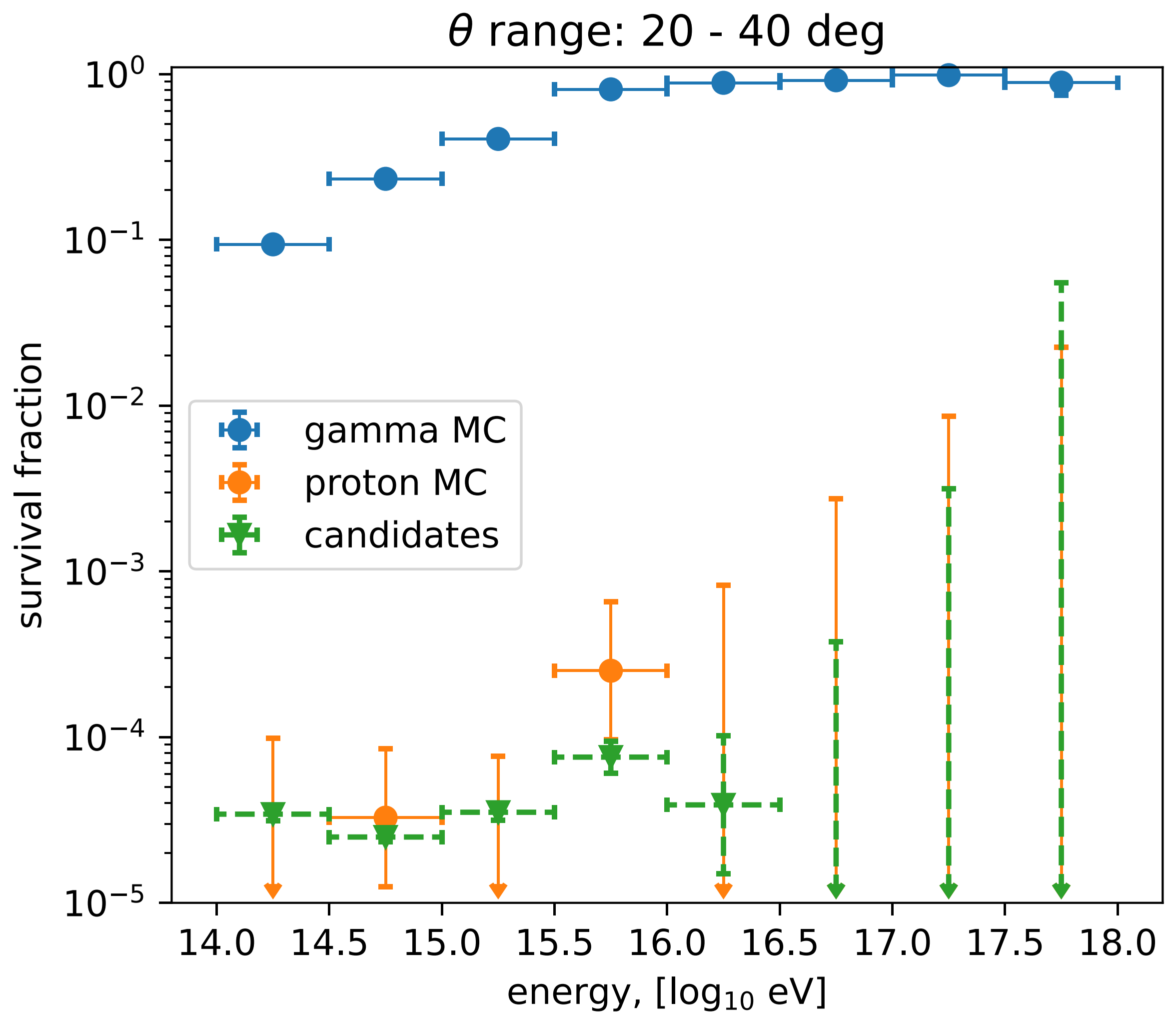
Self-att



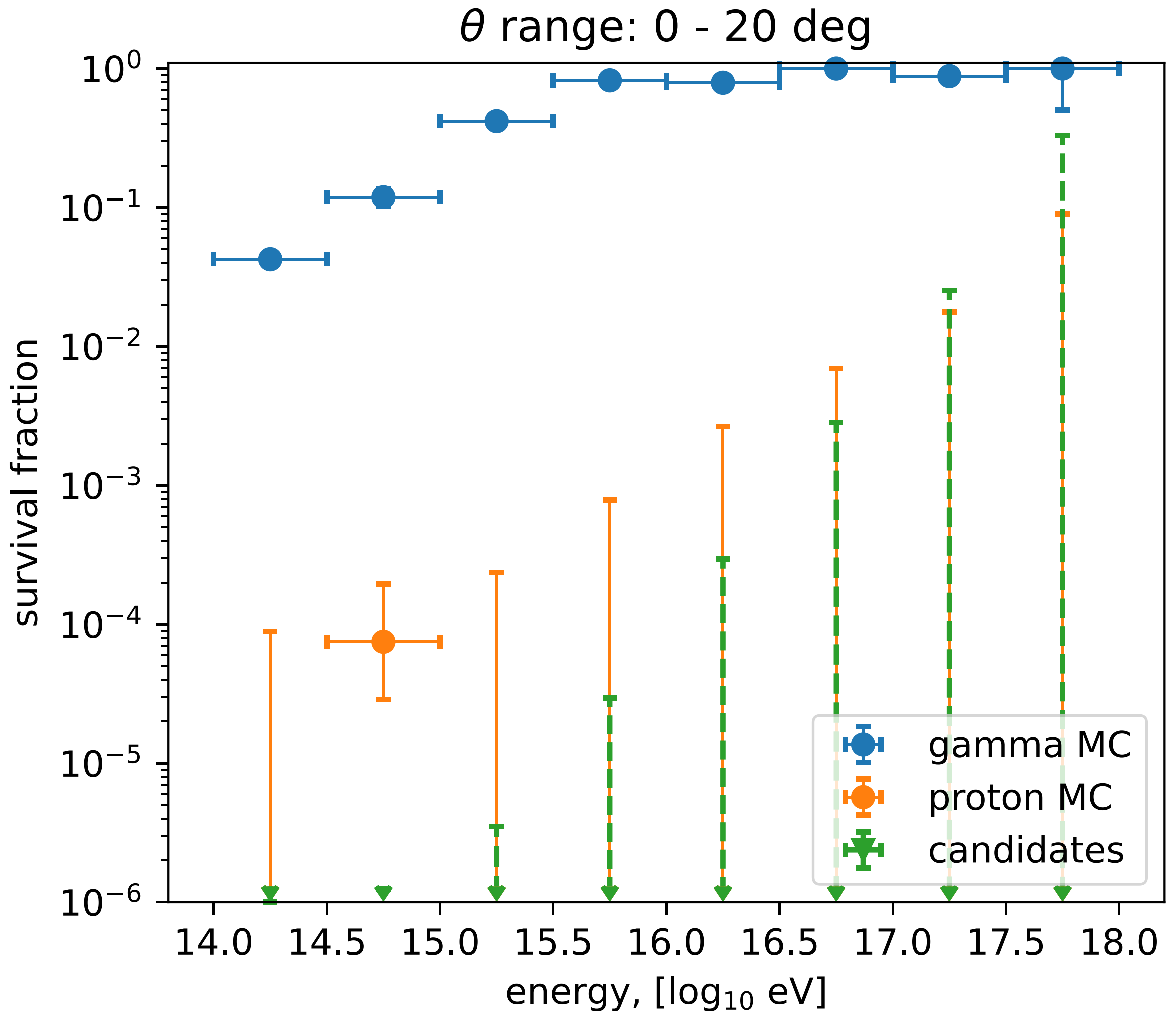


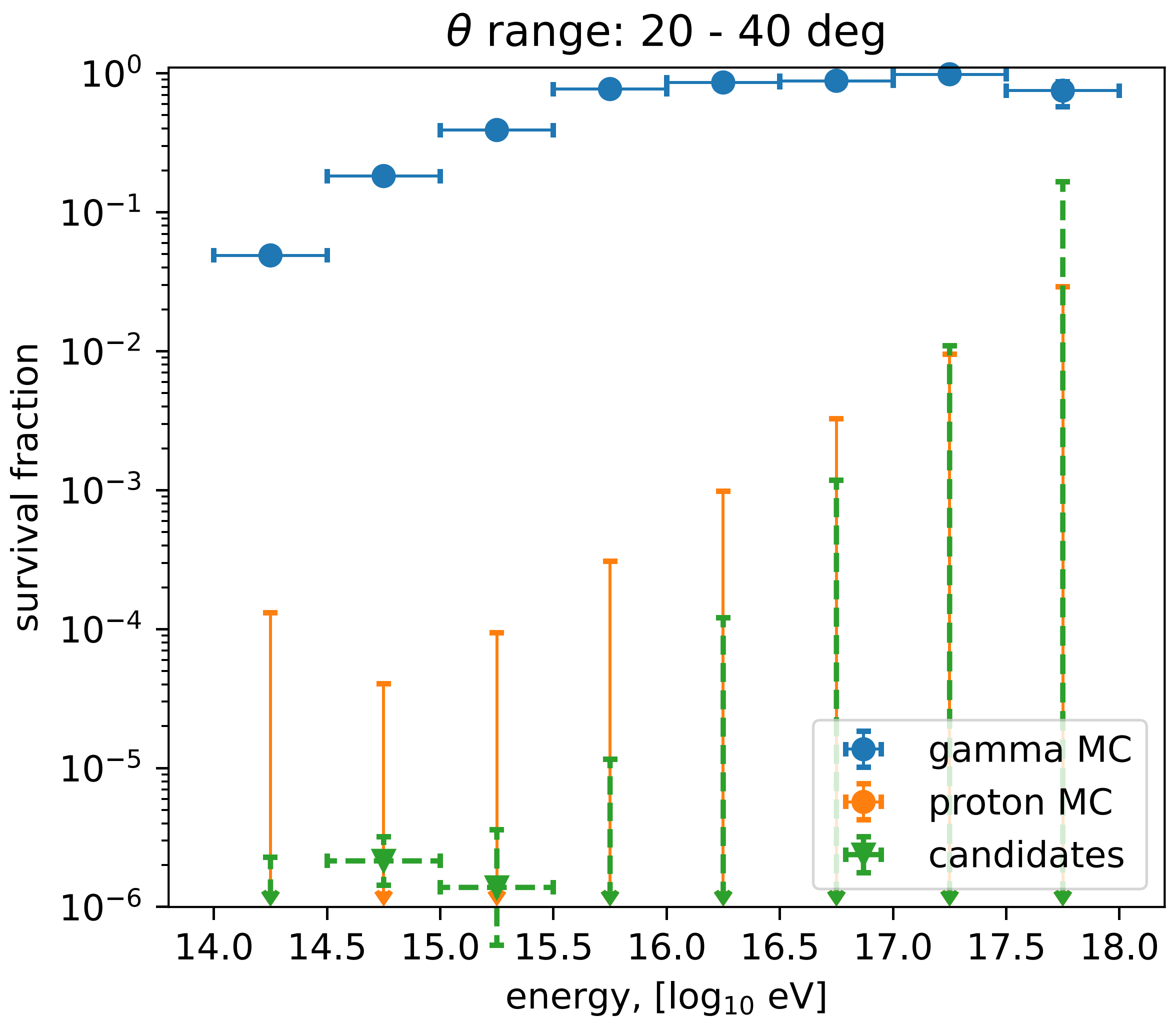
CCT





GCN





Conclusion

- We’ve developed a pipeline for gammas search at KASCADE data
- We’ve tested different architectures for gammas search at KASCADE
- We need more MC simulations
- Models has a good agreement btw experimental data and simulations

Future plans

- Improve a quality of the models
- Conduct an ablation study
- Use more MC simulations

Acknowledgments

This work was supported by the Russian Science Foundation (RSF)

Backup slides

Data details

MC Dataset structure

γ: QGS + EPOS + Sibyll
~90 000 events

p: QGS
~600 000 events

Experiment dataset

Unblind: 20%	Blind: 80%

~400 000 000 events in total