Neural Networks approach to event reconstruction for the GAPS experiment

Nadir Marcelli on behalf of the GAPS collaboration
A complete list of authors can be found in `https://gaps1.astro.ucla.edu/gaps/authors/`

nadir.marcelli@roma2.infn.it

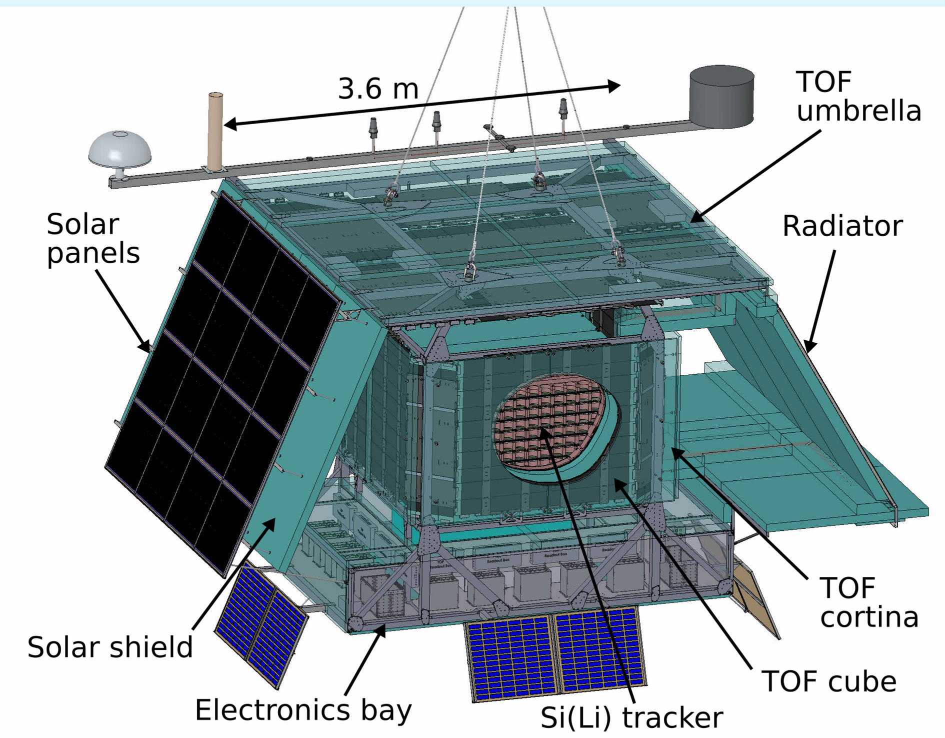
Introduction

- Dark matter (DM) constitutes $\sim$ 26% of energy budget of the Universe, but its fundamental nature is still unknown:
  - DM evidence came only by gravitational observation, it barely interacts with ordinary baryonic matter and radiation
  - Appealing candidates for DM particles are weakly interacting massive particles (WIMPs)
- Indirect searches for DM aim at detecting the signatures of possible annihilations or decays of DM particles in the fluxes of cosmic rays (CRs)
- Because of the kinematics of the antinuclei formation, DM-produced cosmic antideuterons below few GeV/n is predicted to be several orders of magnitude above the astrophysical background [1]

The GAPS experiment

The General Antiparticle Spectrometer (GAPS) is a balloon-borne experiment, scheduled for a first flight in the austral summer 2022/2023:

- Designed to measure low energy ($<$ 0.25 GeV/n) cosmic antinuclei [2]
- The apparatus consists of a Time-of-Flight (ToF) system surrounding a Si(Li) tracker [3]
- Detection technique based on the formation and decay of exotic atoms
- Antinucleus annihilation topology reconstructed with a custom algorithm [4, 5]
- Data analysis is performed on simulated data which is "digitized" to mimic realistic instrument measurements



A schematic view of the GAPS detector.

Energy deposition reconstruction

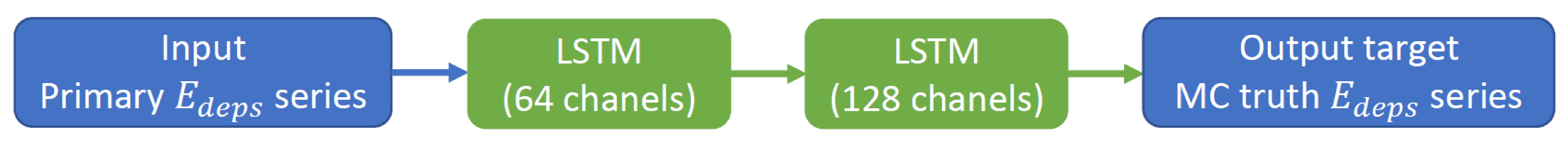
In some cases, reconstructed primary energy present an excess with respect to Monte Carlo truth.
This excess results from a combination of two effects:

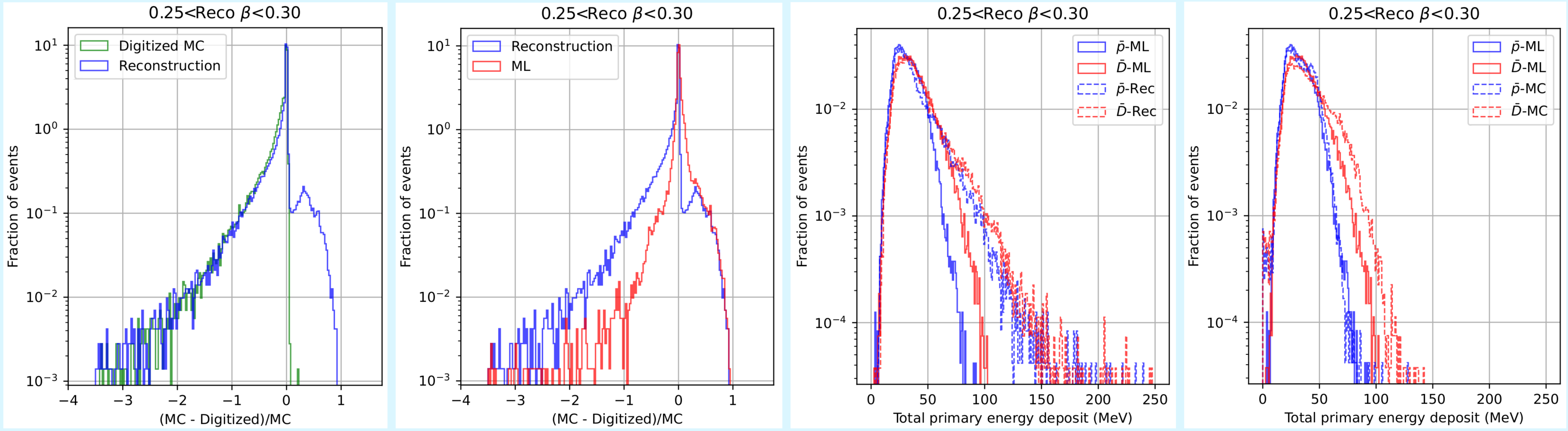
- The primary antinucleus annihilates in a detector and the produced secondaries release energy in the same volume
- Secondary particles can cross a volume already crossed by the primary in a time scale smaller than the integration time of the detector

The Neural Network architecture

The primary energy deposition is one of the most relevant quantities for particle identification and to treat the energy excess observed, a Recurrent Neural Network known as Long Short Term Memory (LSTM) [6] was used:

- It can easily manage variable length input/output sequences
- It can extract information by the order of the input sequence





First panel: Residuals between MC and digitized primary energy depositions associated with the primary according to MC (green histogram) and to reconstruction algorithm (blue histogram). **Second panel**: Residuals between total MC and digitized primary energy depositions associated with the primary according to reconstruction algorithm before and after applying the ML correction (blue and red histograms respectively). **Third panel**: Total energy distribution of all digitized (dashed histogram) and ML corrected (solid histogram) primary energy deposits. **Fourth panel**: Comparison between the total primary energy distributions of all MC (dashed histogram) and ML corrected (solid histogram) primary deposits.

Conclusions

- A clear reduction of the energy excess can be observed with the ML output
- The mean absolute error (MAE) of the NN predictions are $\bar{p}_{MAE} = 0.63$ MeV and $\bar{D}_{MAE} = 0.69$ MeV
- ML corrected total energy deposit has the potential to significantly benefit $\bar{p}$ and $\bar{D}$ identification analysis

References

[1] Fiorenza Donato, Nicolao Fornengo, and Pierre Salati. Antideuterons as a signature of supersymmetric dark matter. *Phys. Rev. D*, 62:043003, Jul 2000.

[2] M. Xiao et al. In search of cosmic-ray antinuclei from dark matter with the GAPS experiment. *This conference PoS*, 2021.

[3] S. Quinn et al. The GAPS instrument: A large area time of flight and high resolution exotic atom spectrometer for cosmic antinuclei. *This conference PoS*, 2021.

[4] R. Munini et al. The antinucleus annihilation reconstruction algorithm of the GAPS experiment. *Submitted on Astroparticle Physics*, 2021.

[5] A. Tiberio et al. Reconstruction of antinucleus-annihilation events in the GAPS experiment. *This conference PoS*, 2021.

[6] S. Hochreiter et al. Long short-term memory. *Neural computation*, 9:1735–80, 12 1997.