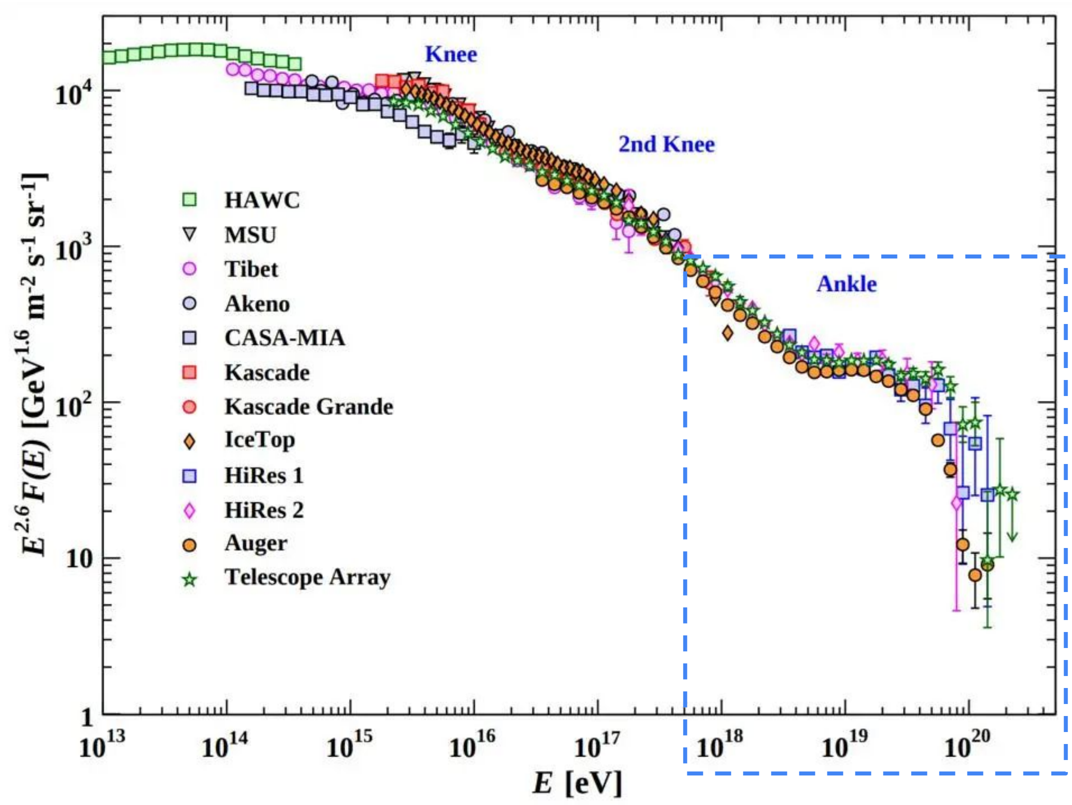
Energy and mass spectra of TA SD

Novosibirsk, 03.26

Cosmic Rays Spectrum



Mass and energy spectra of ultra high energy cosmic rays ($E > 10^{18}$ eV) is subject to active discussions

M. Tanabashi et al. (Particle Data Group), Phys. Rev. D, 2019

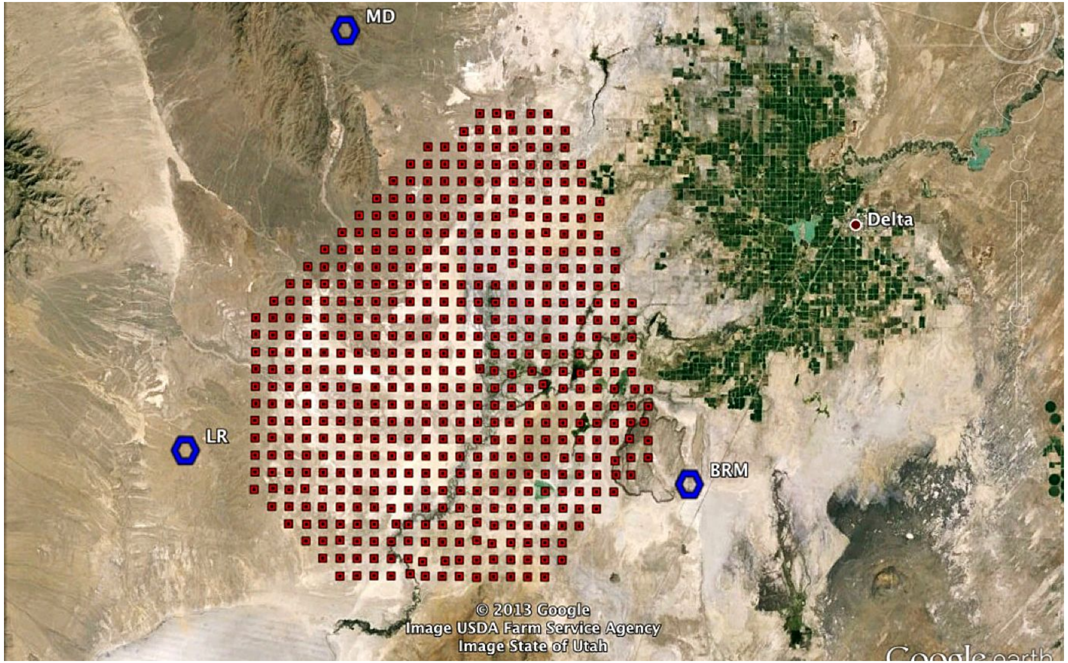
Outline

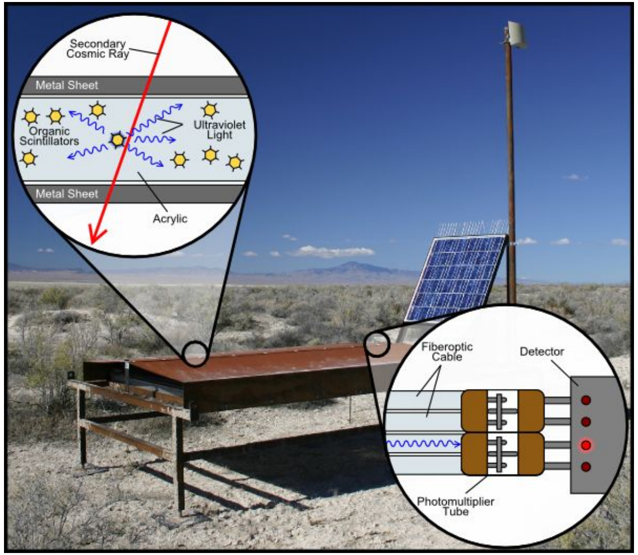
- Telescope Array experiment
- Neural network architecture
- Reliability of the neural network
- Mass-energy spectrum

Telescope Array experiment

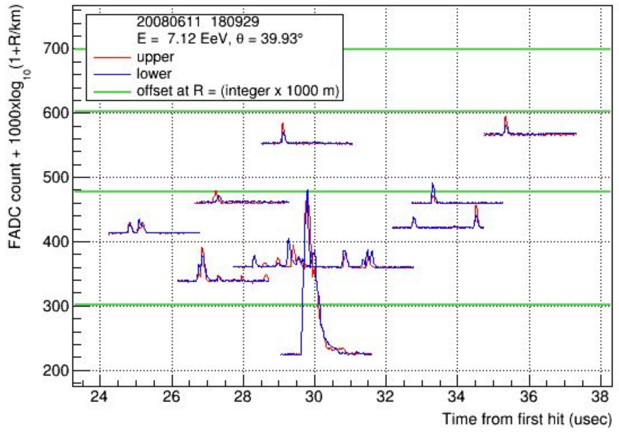
Telescope Array

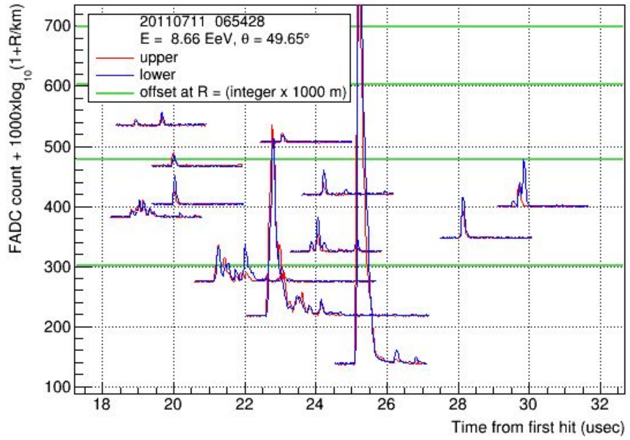
Largest cosmic ray observatory in Northern hemisphere
(700 km^2, 507 scintillator + 3 fluorescent stations)

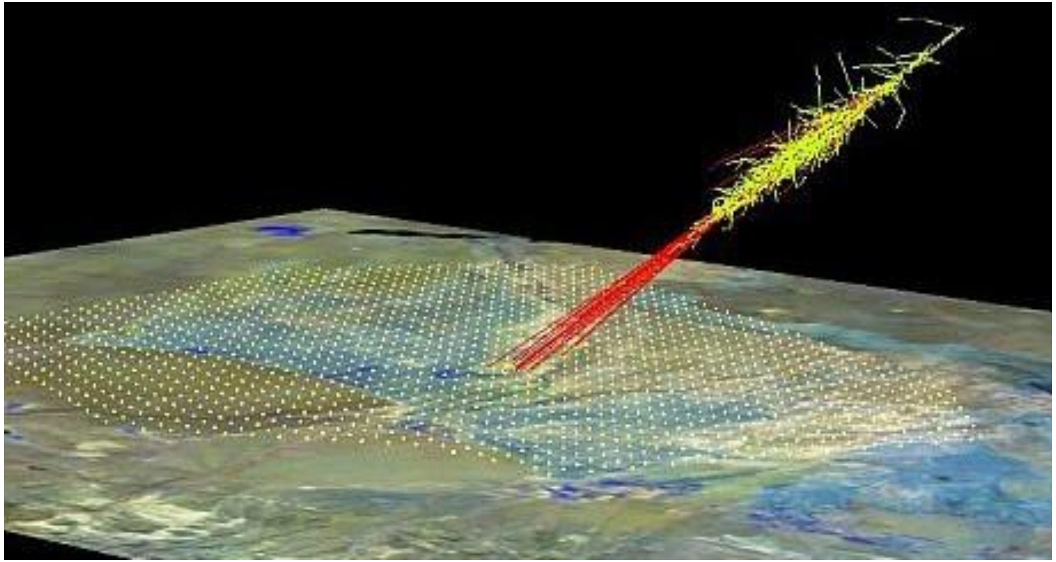




Telescope Array



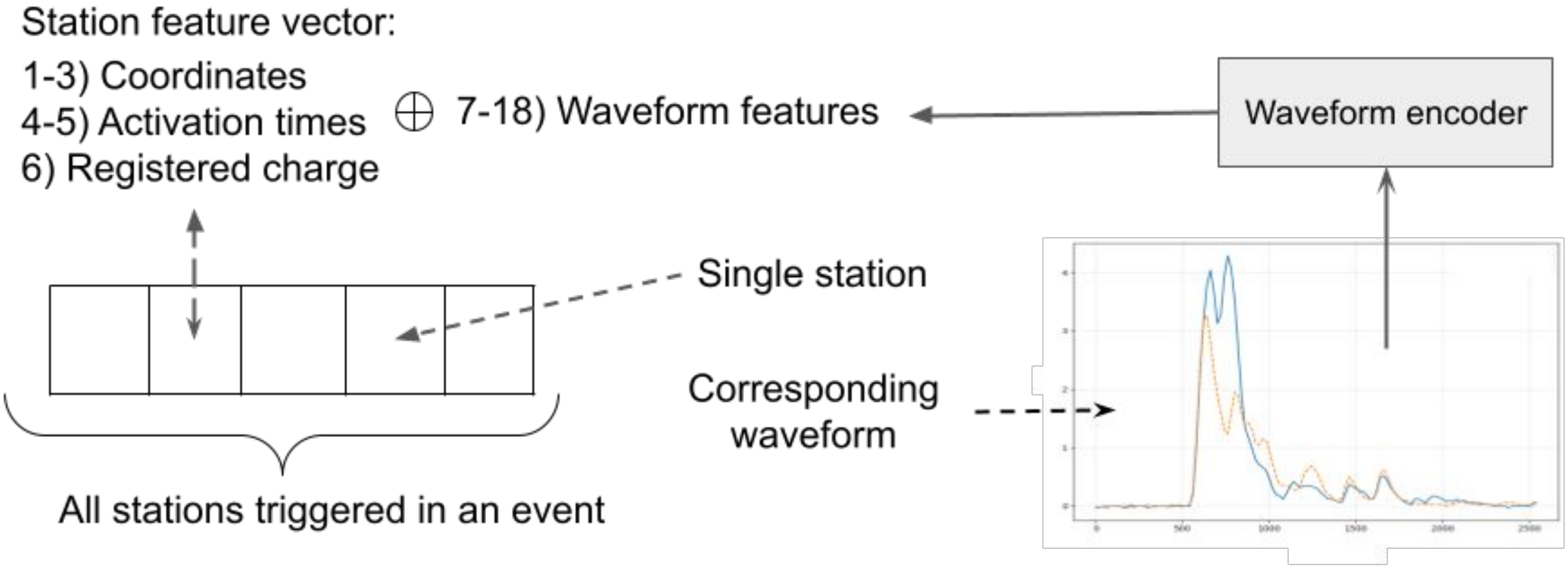




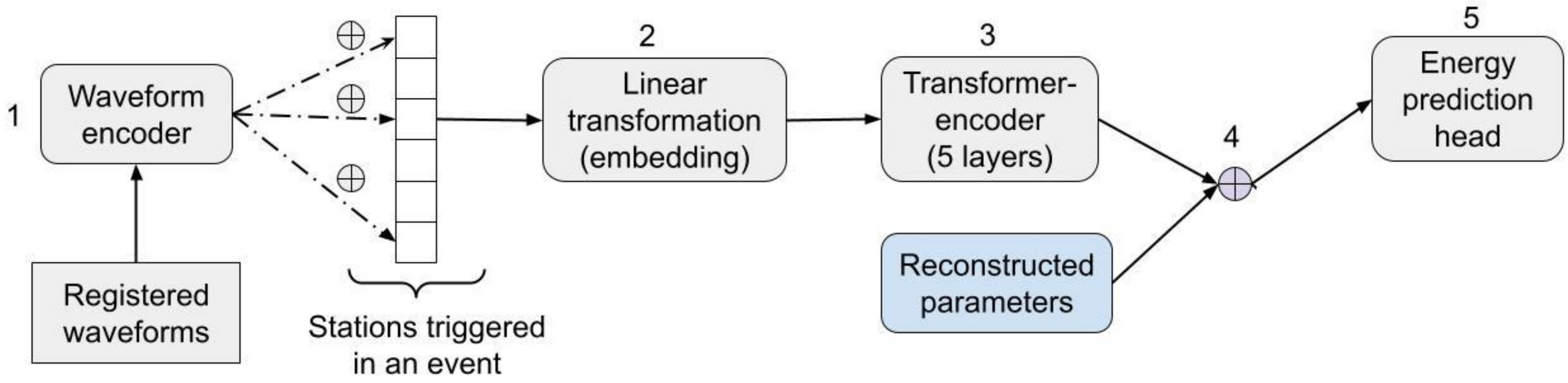
Neural network
and data representation

Data representation

Each events = set of activated stations

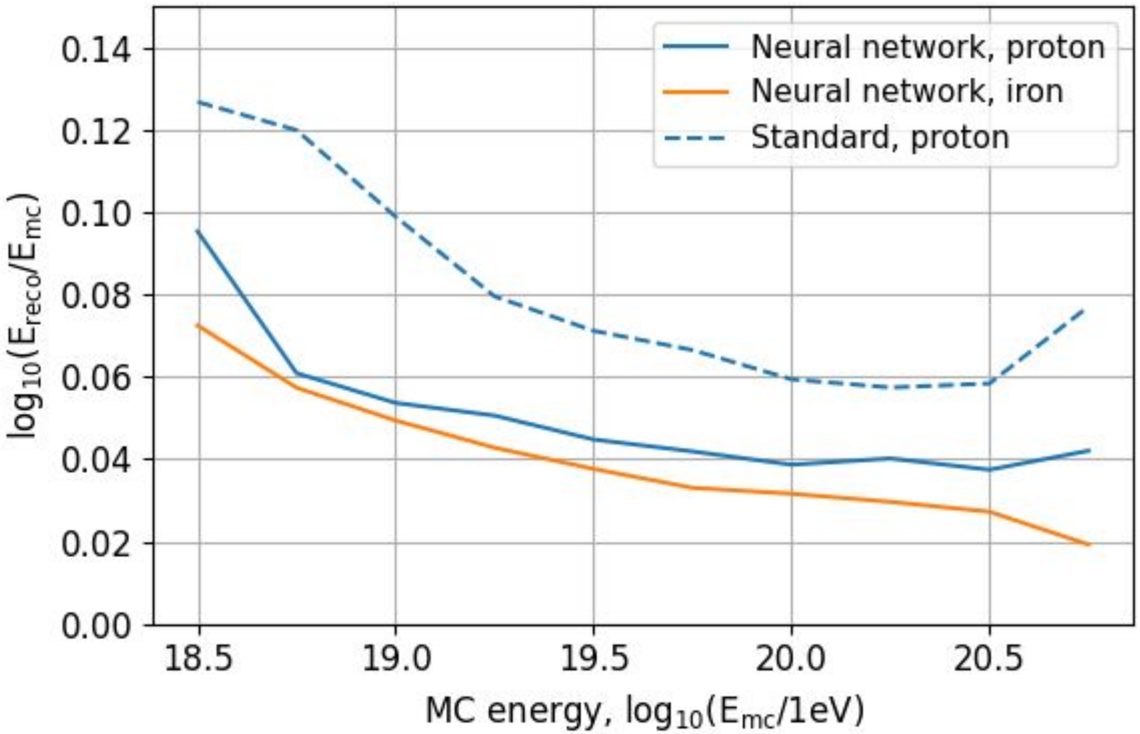


NN architecture



(1) Encode waveforms, concatenate with station properties (Q, t, r)
(2) Embed to higher dimensionality
(3) Pass through Transformer-Encoder
(4) Concatenate with algorithmically reconstructed parameters
(5) Predict Energy, Mass, Direction

Energy resolution, 68%



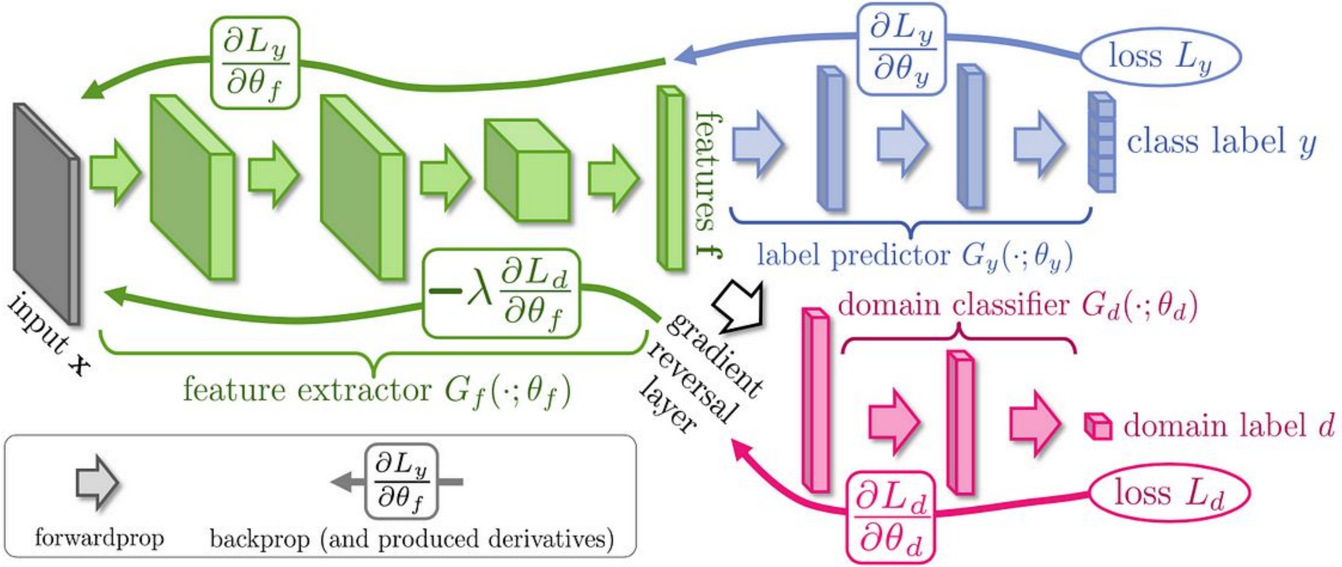
Neural network significantly improves energy resolution!

Reliability of the neural network

mitigating MC and real date differences

Domain adaptation

Digit recognition



Domain classifier

Gradient reversal:
Exclude domain-specific features

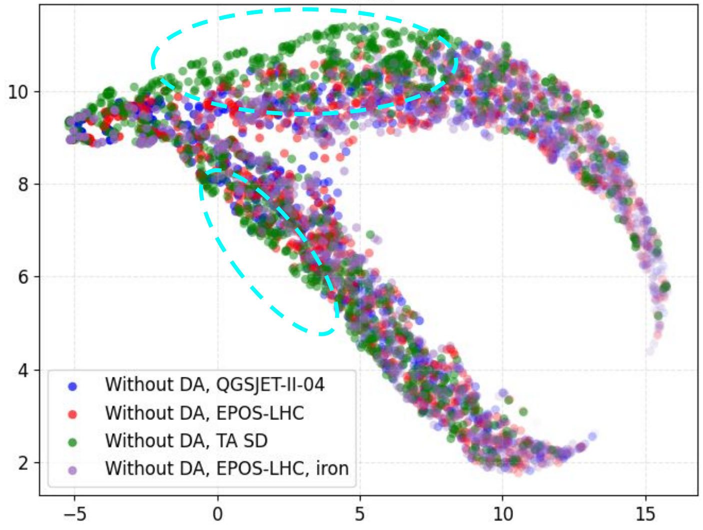
vs

Domain adaptation effect

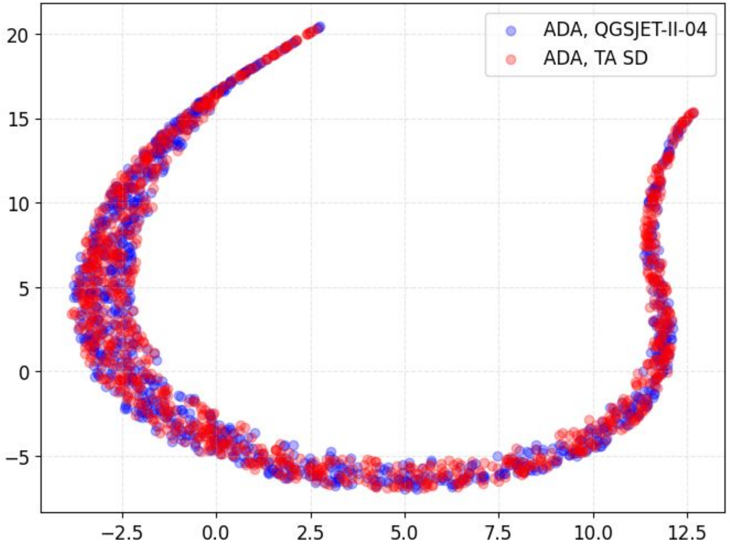
Comparison of feature distribution after the encoder

UMAP without DA

More transparent - lower energy (MC only)



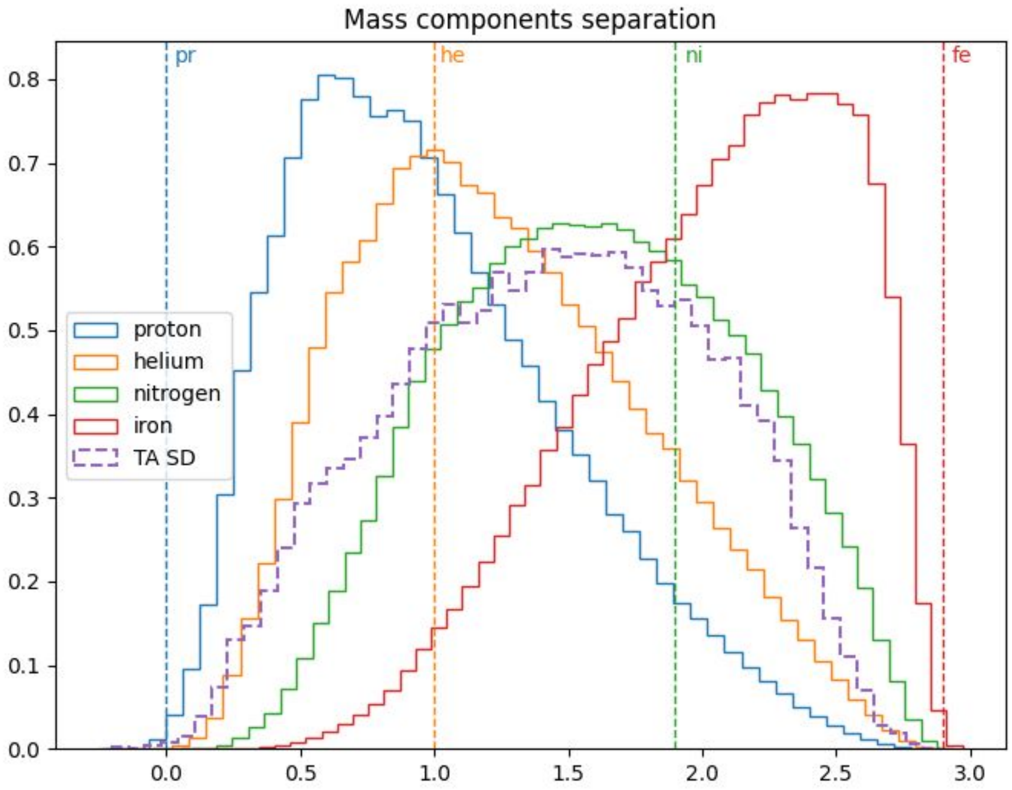
UMAP with DA



Domain Adaptation makes feature distributions close

Mass-energy spectra

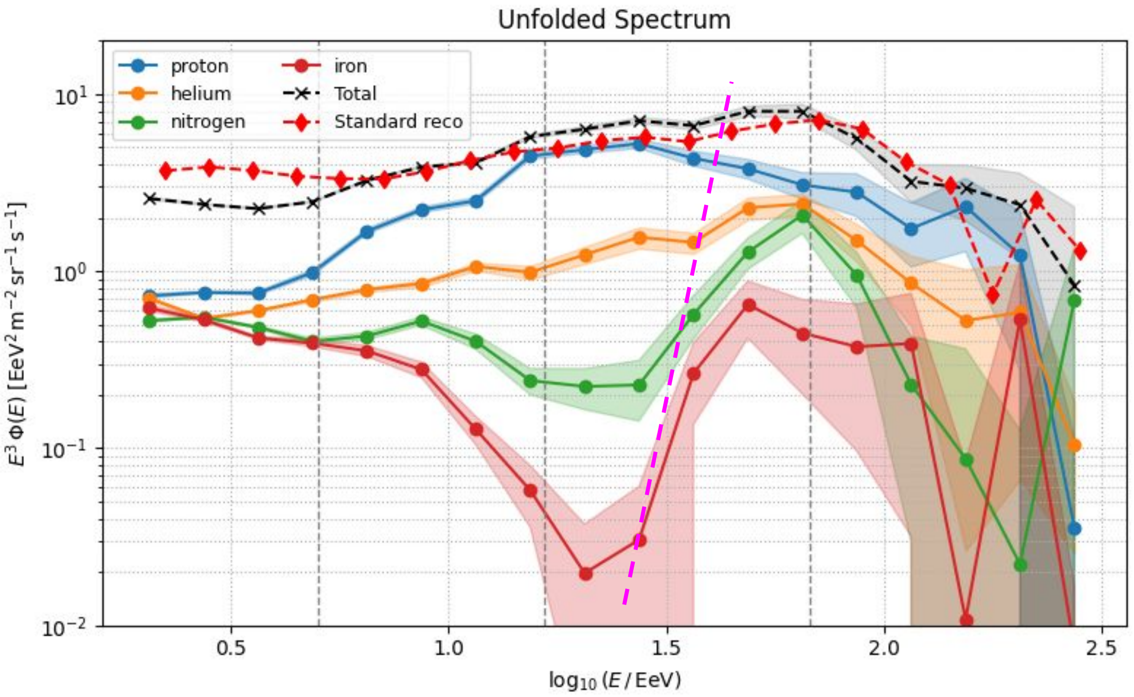
Mass resolution



Good separation between proton and iron.

This would have been impossible without NNs.

2D iterative mass-energy unfolding



Iterative unfolding:

1. Unfold energy spectrum
2. Unfold mass spectrum

Rapid increase of heavy nuclei at high energies

This might be a sign of local source

Conclusion

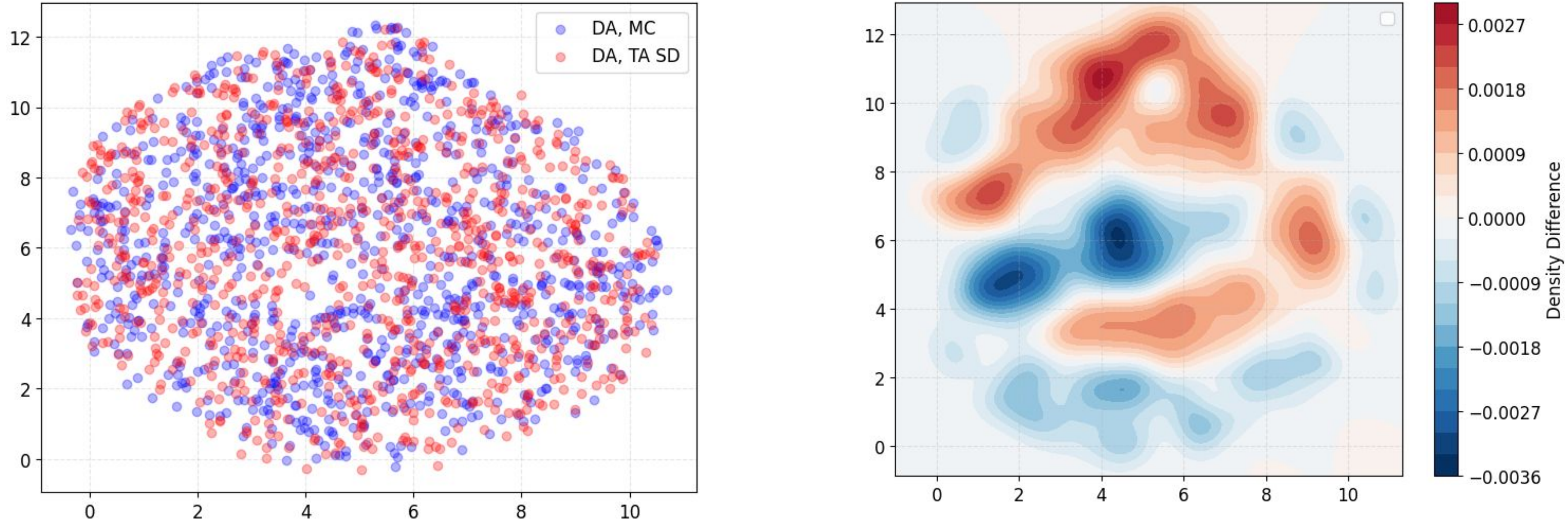
- Neural network improve energy resolution and allow for mass reconstruction
- Domain Adaptation is important for mitigating domain shift
- Mass-Energy spectra favours local source with intermediate mass spectrum

Appendix

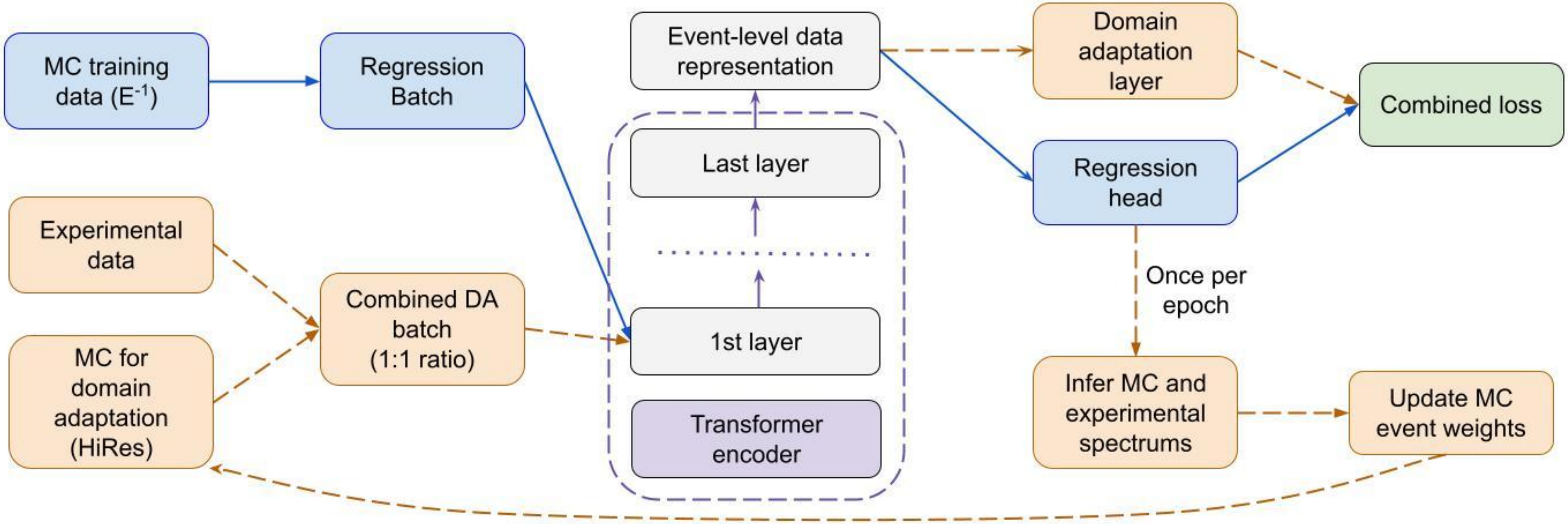
Full Domain Adaptation

- 4 cosmic ray prameries: proton, helium, nitrogen, iron
- Domain adaptation for mass, energy and arrival direction distributions.

UMAP for encoder features

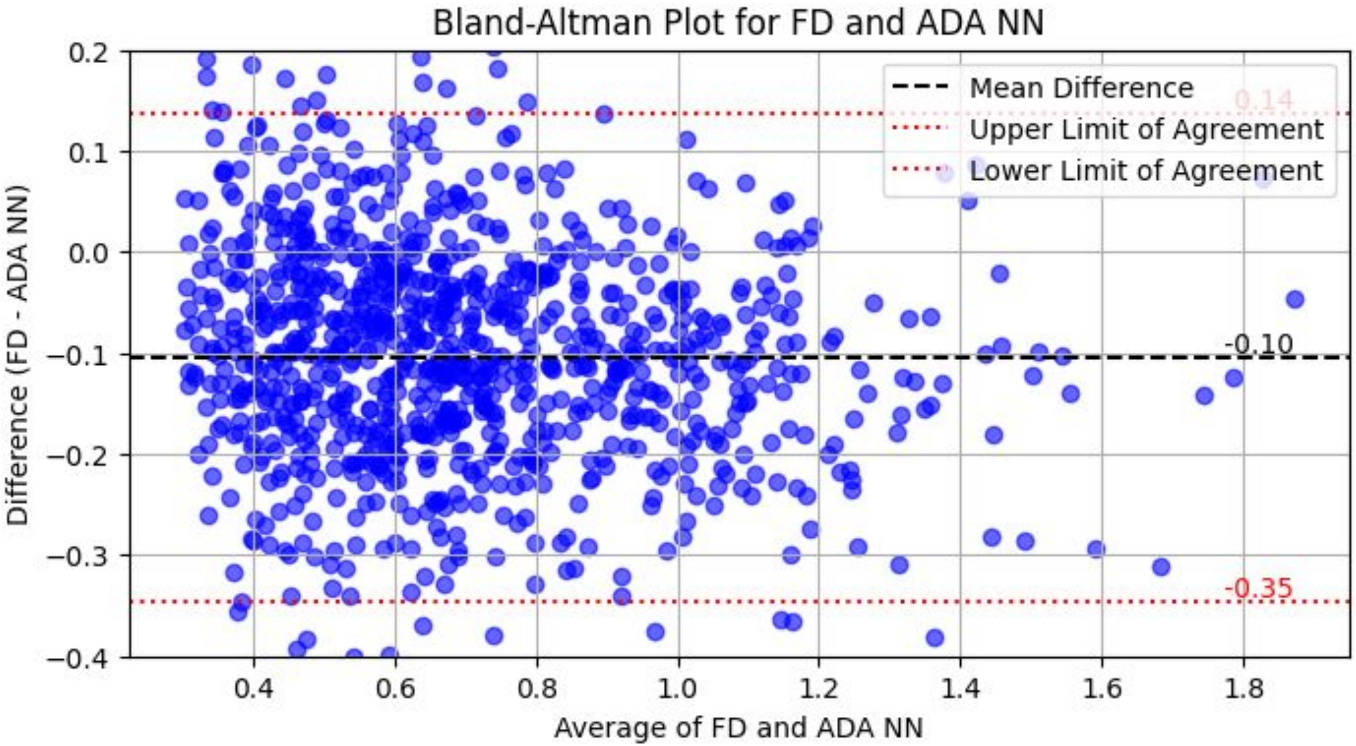


Data flow with Adaptive Domain Adaptation



find equilibrium point - iteratively reweight MC events so that during training the estimated MC and TA SD data spectra coincide.

SD/FD comparison



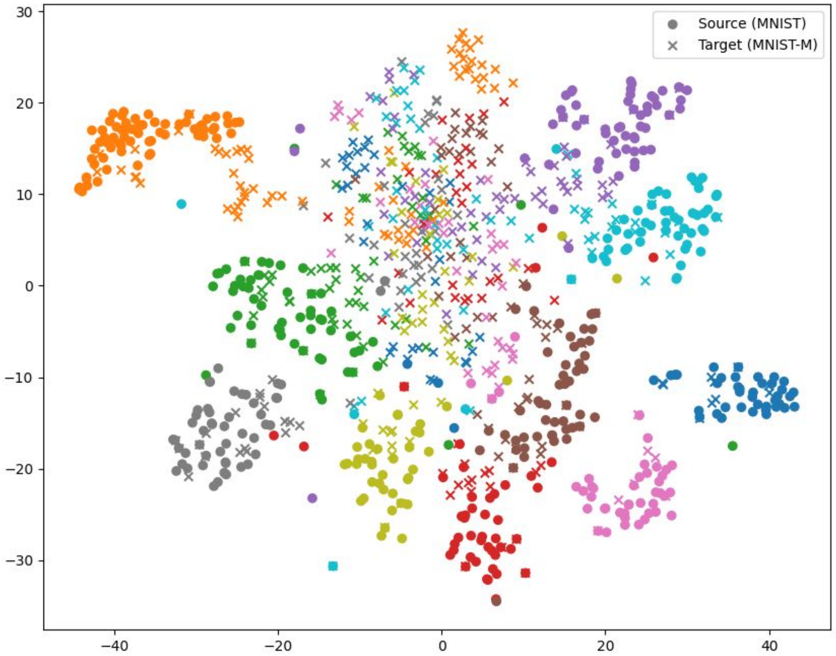
Good agreement with FD: residual variance 0.0075 (0.01 for standard reco)

Illustration of Domain Adaptation

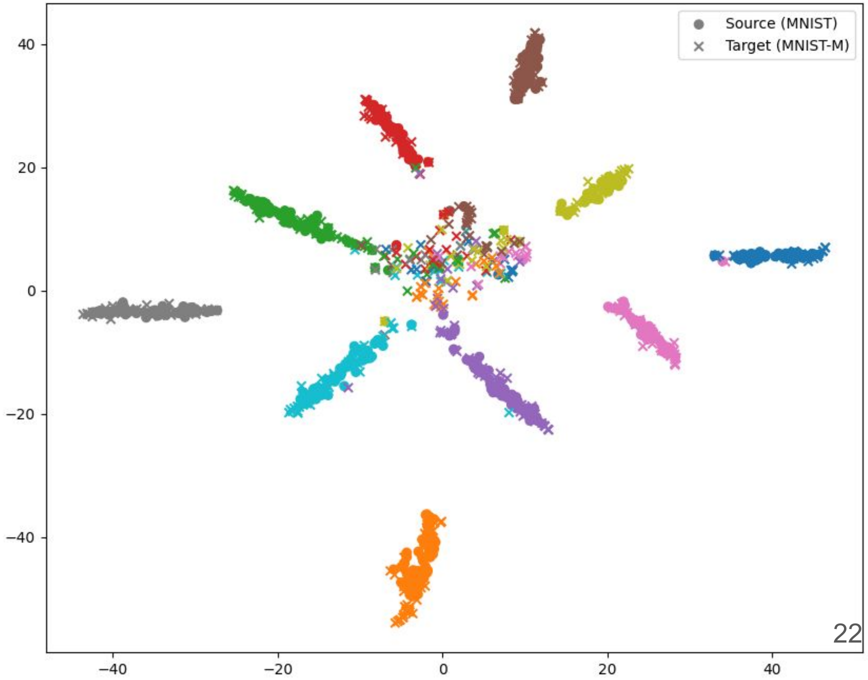
Accuracy of predictions on MNIST-M:

without DA: 57.5%, with DA:81.5, direct learning: 98.9%

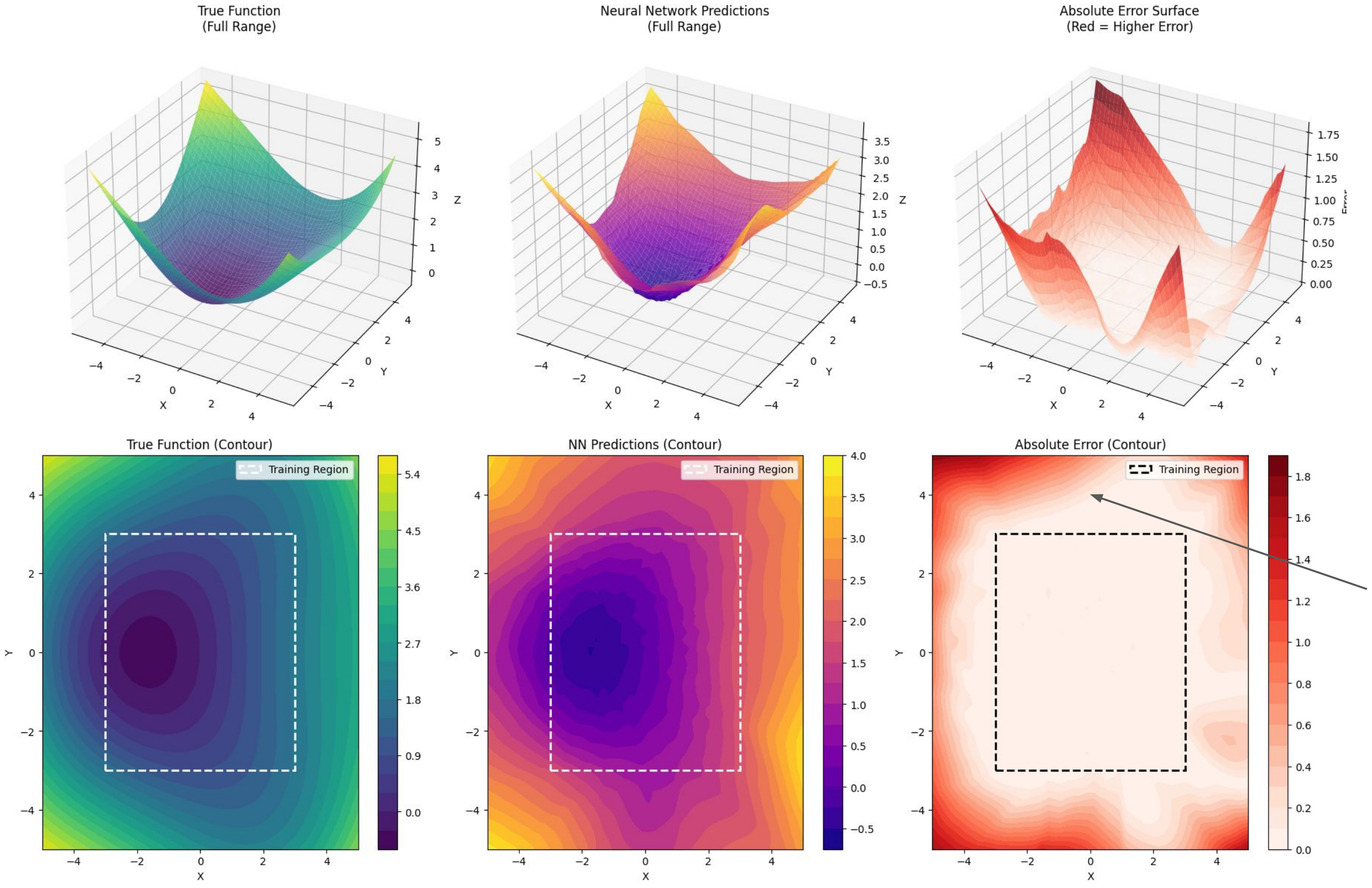
2D t-SNE without DA



2D t-SNE with DA



Why doing domain adaptation



NNs are bad at extrapolating

High uncontrollable errors outside the training phase space