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Deep Learning Applications - Aachen

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PIERRE AUGER OBSERVATORY

CMS

III. Physikalisches Institut A, Erdmann

- Deep Learning applications in Astroparticle and Particle Physics
  - CMS, Pierre Auger Collaboration
- VISPA Cluster, GPU extension

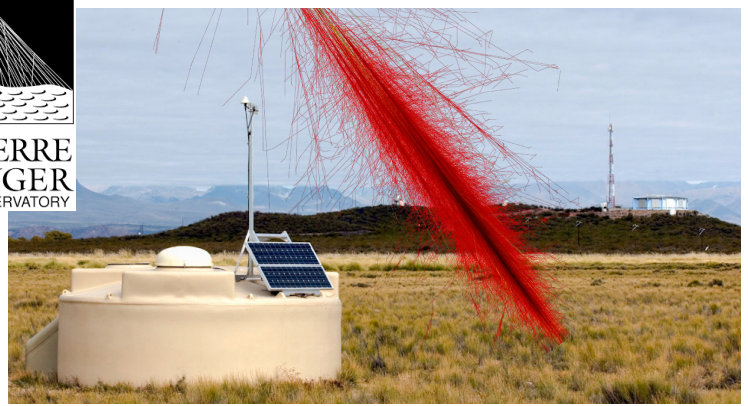
Pierre Auger Working Group

- Total energy calibration using radio emission of air showers
- Air shower reconstruction using Deep Learning
- Search for arrival directions of cosmic rays including galactic magnetic fields

CMS Working Group

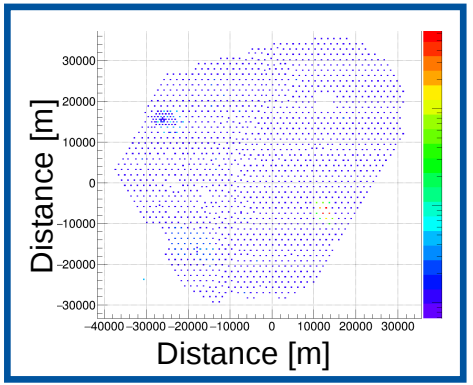
- Top quark and Higgs physics
- Event categorization into physics processes using Deep Learning
- Simulation of electromagnetic showers using generative models

Air Shower Reconstruction

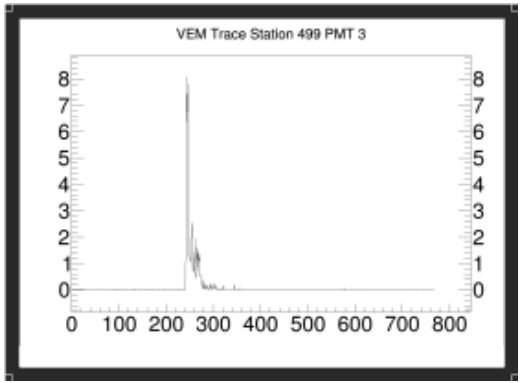


Pierre Auger Observatory

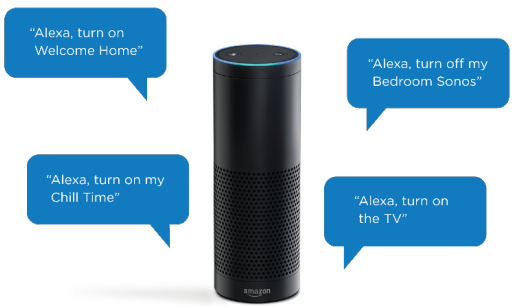
- Placed in Argentina
- Hybrid design
  - 1660 Water Cherenkov stations
  - 27 Fluorescence telescopes



Convolutional Networks

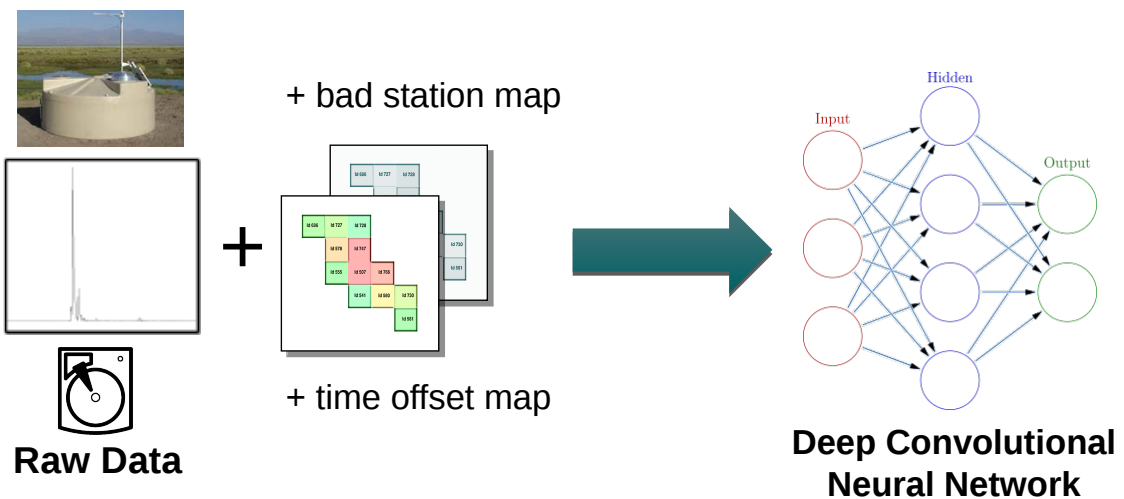


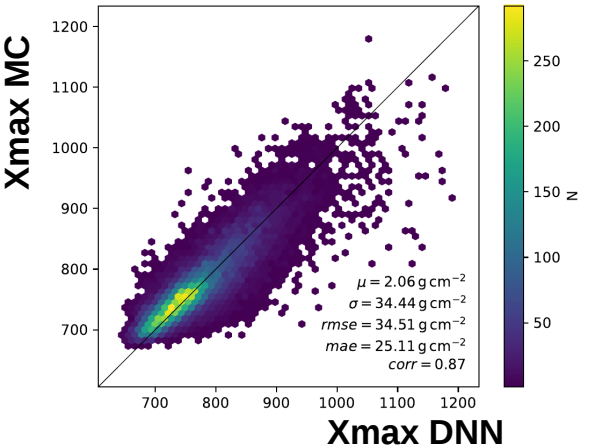
Recurrent Networks

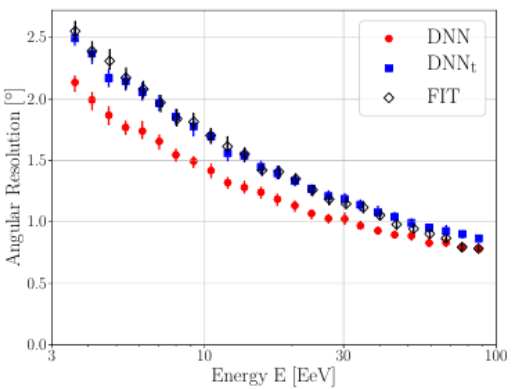


Air Shower Reconstruction

- Reconstruction of Air Showers
  - Geometry (shower axis, shower core)
  - Properties (energy, mass, Xmax)
- Train deep network on Monte Carlo Simulation
- **Crosscheck** using hybrid data







Erdmann, Glombitza, Walz - 10.1016/j.astropartphys.2017.10.006

Visualization of Deep Networks

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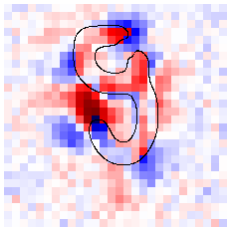
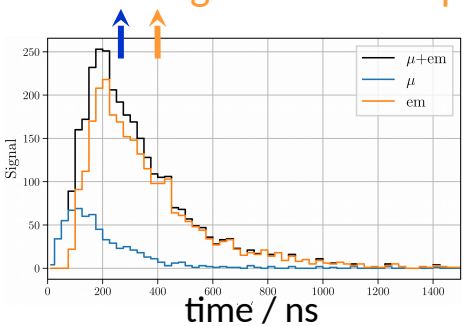
Erdmann, Eich, Glombitza

What makes a “9” a “9” for DNNs?

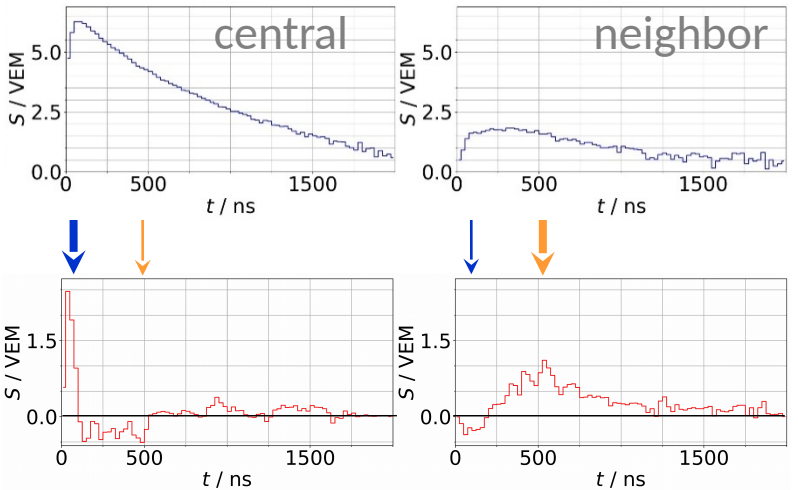


- Find patterns important for the reconstruction

1. Muons arrive first, then
2. Electromagnetic shower particles



1 event: raw signal traces of 2 detectors



Sensitivity to energy reconstruction

muons electromagnetic

Network learns physics aspects from data in 3h

Fitting Sources of Ultra-high Energy Cosmic Rays

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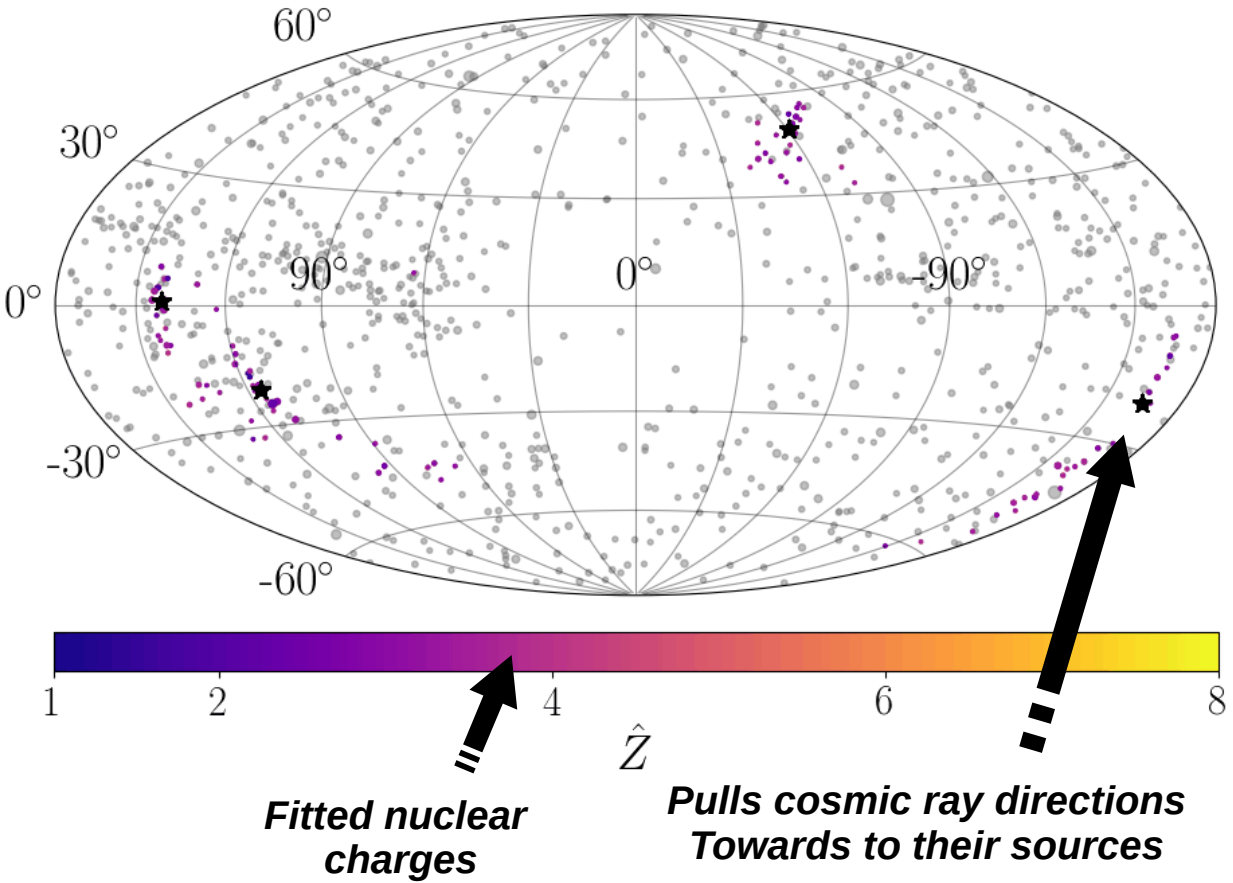
- **High dimensional fit** method to locate the origins of cosmic rays
- **Autonomous correction for uncertainties** in the deflection model of the Galactic magnetic field
- Simultaneously adapt O(1000) individual charges
- **Tensorflow** implementation



LHC: Coupling Top-Quark – Higgs

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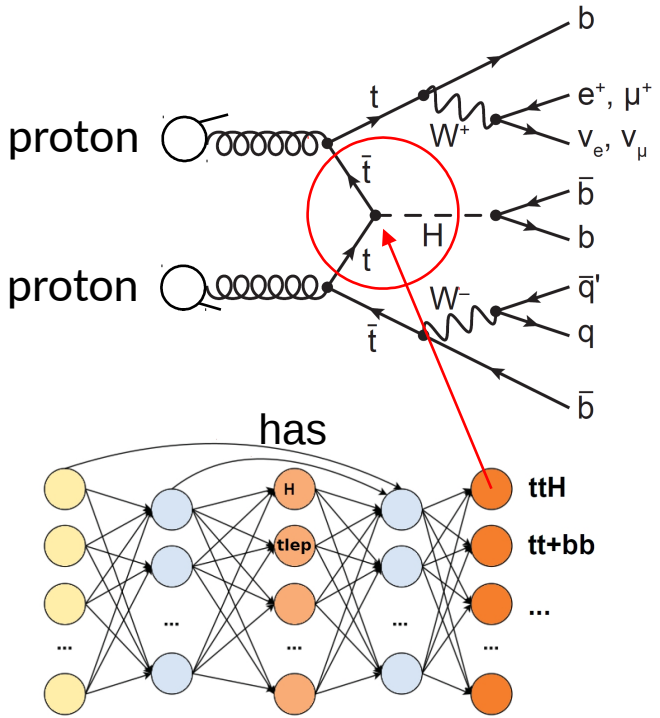
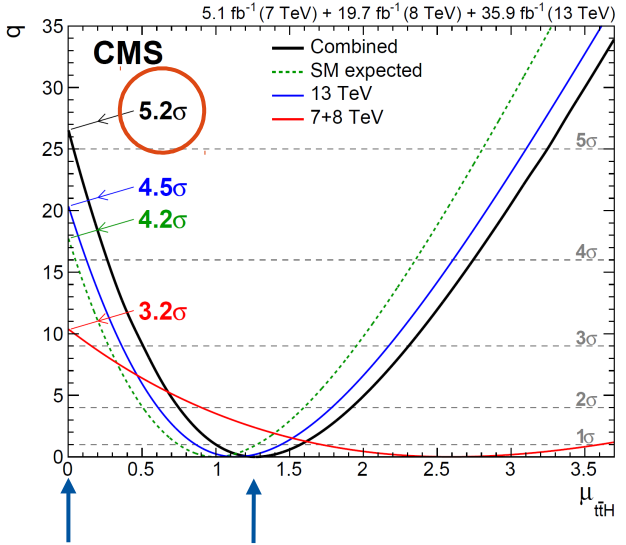
Classification of physics process for each event



Observation of ttH production

- H→ bb
- H→ WW
- H→ ZZ
- H→ γγ
- H→ ττ

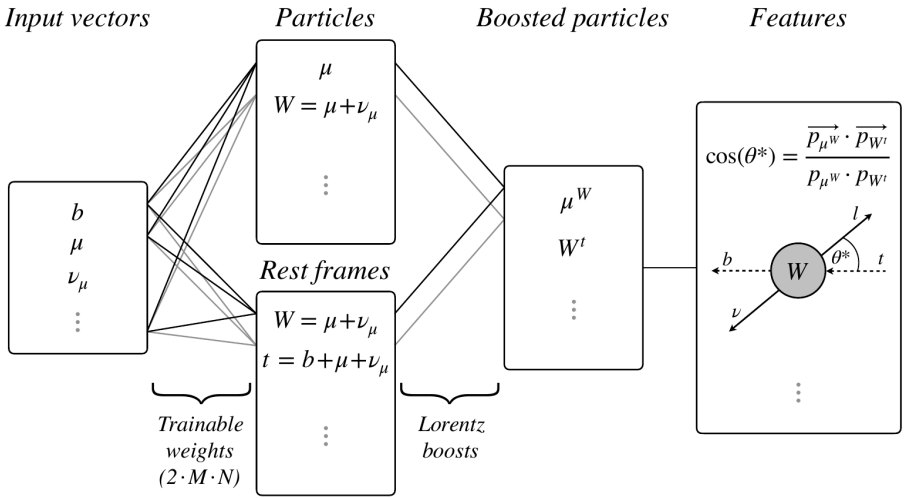


excluded: no coupling

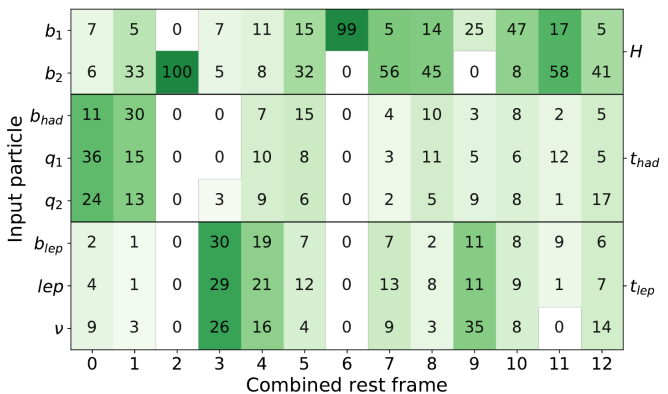
Measured signal close to Standard Model of particle physics (μ=1)

Physics-Inspired Feature Engineering

- Handcrafted high-level features might not exploit all information
- Neural networks struggle to learn high level features
- Extend networks with physics motivated symmetry → **Lorentz Boost Networks**
  - Allows for autonomous feature engineering
- Inspection of learned particle combinations allows crosschecks



Visualization of learned rest frames



Erdmann, Geiser, Rath, Rieger - https://arxiv.org/pdf/1812.09722.pdf

Generative Models for Fast Simulations

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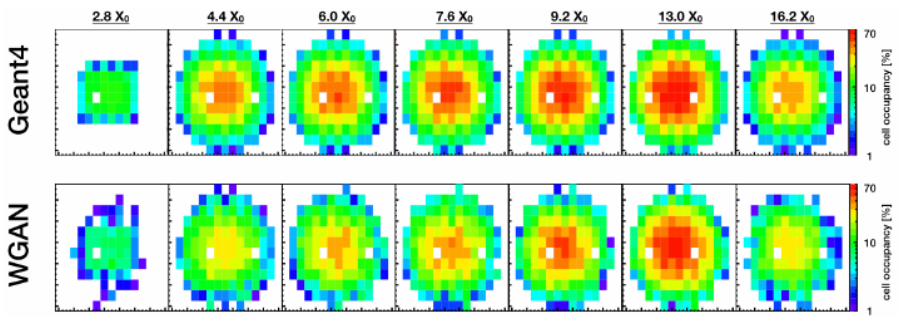
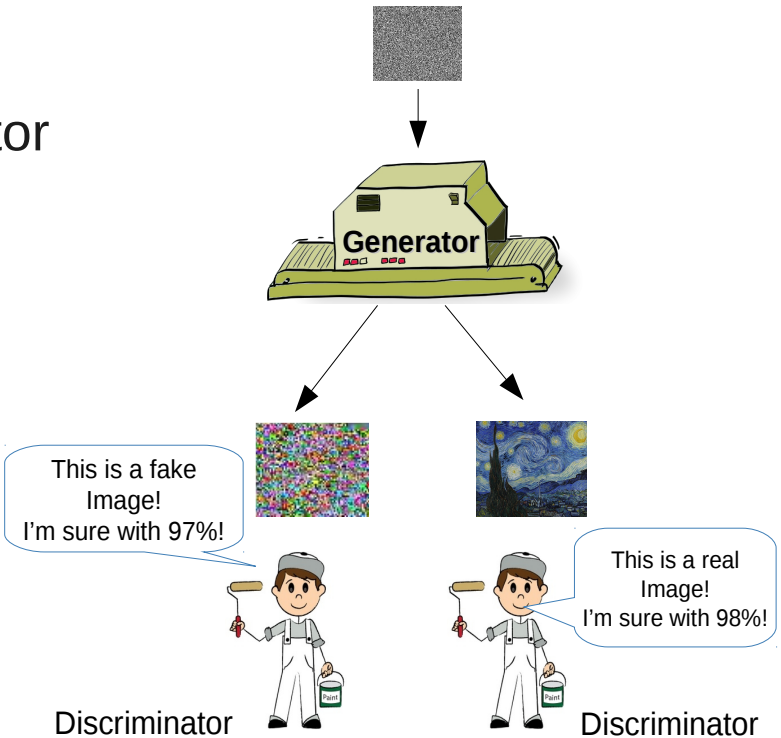
- Use Generative Adversarial Networks for simulations
  - Generator network generates new events
  - Discriminator rates quality of generated events
  - Discriminator feedback is used to train generator
- Replace time consuming physics simulations using GANs (speed-up of 10^3 – 10^5)



Erdmann, Glombitza, Quast, https://doi.org/10.1007/s41781-018-0019-7



The VISPA Project

HTTPS

VISPA

SSH

Software

Access via Web Browser

- ~ 100 active users
- Large updated software environment
  - Python, TensorFlow, ROOT etc.
- Physics specialized extensions

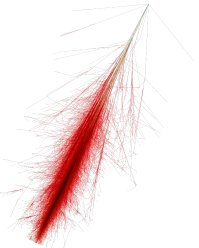
Cluster

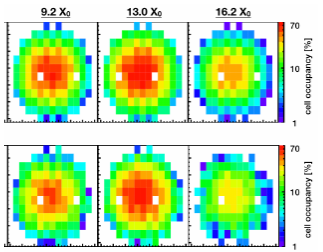
Working environment

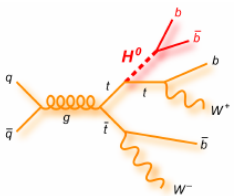
- 200 Cores
- 20 GPUs
- HTC Condor

Summary

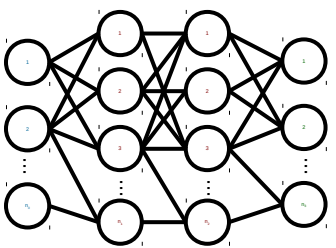
- Successful application of Deep Learning based algorithms at CMS and Auger
- Supervised Learning applications
  - Air Shower Reconstruction, Physics Events Characterization
- Unsupervised Learning applications
  - Simulation Refinement, Calorimeter Simulations







- Advanced Applications
  - Visualization of Deep Neural Networks
  - Interpretable feature engineering



- VISPA project
  - Deep Learning via web browser

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Deep Learning Applications - Aachen

Backup

Denoising of Air Shower Radio Signals

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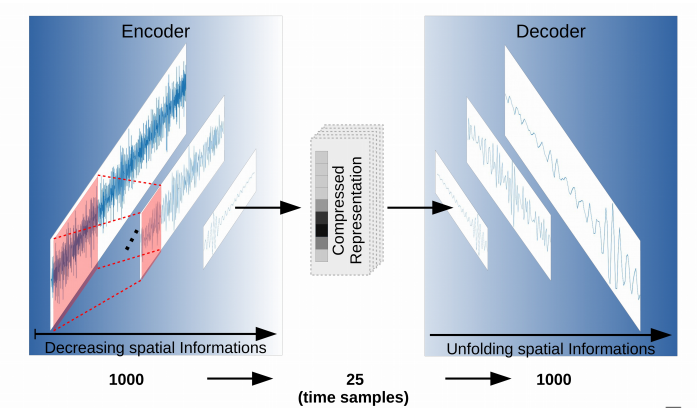
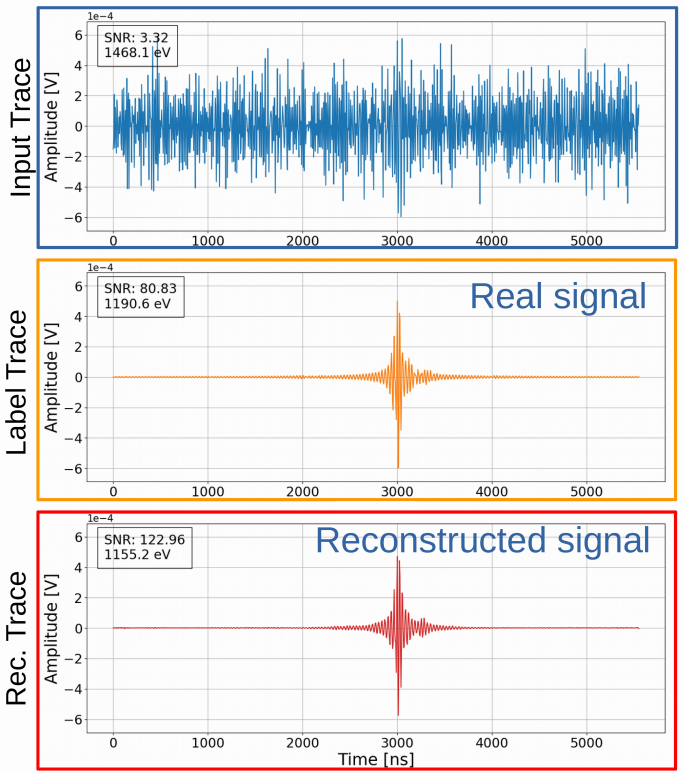
- Supervised trained Autoencoder
  - Network encodes only relevant information
- Remove noise of radio signals from cosmic ray induced air showers
- Signal energy and frequency spectrum approx. conserved





Erdmann, Schlüter, Smida - https://arxiv.org/pdf/1901.04079.pdf