Autoencoder-extended Conditional Invertible Neural Networks for Unfolding Signal Traces

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III. Physikalisches Institut A

RWTH AACHEN UNIVERSITY

Martin Erdmann, *Katharina Hafner*, Josina Schulte, Maximilian Straub
III. Physikalisches Institut A, RWTH Aachen University
katharina.hafner1@rwth-aachen.de
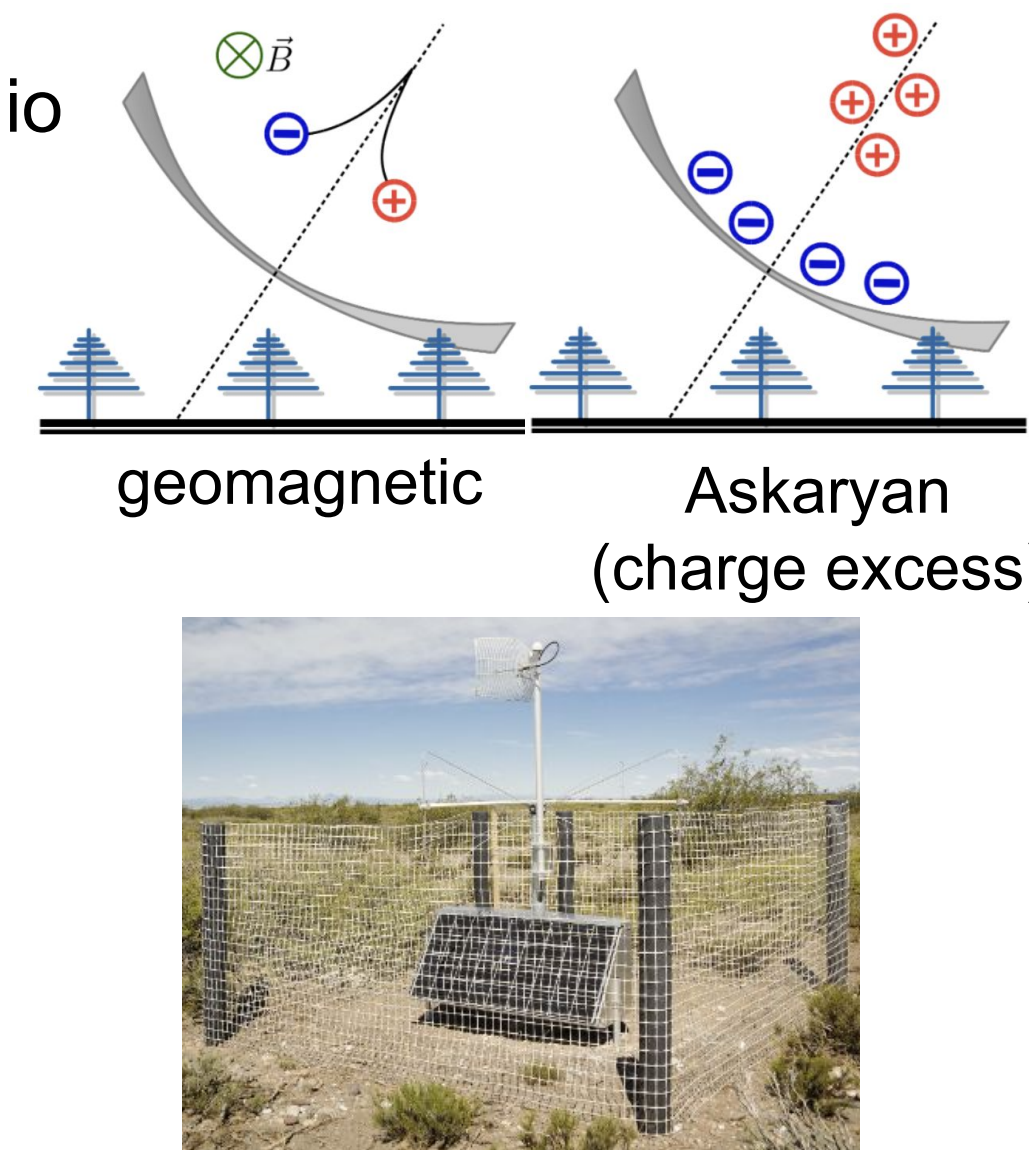
Radio Signals

- Ultra-high-energy cosmic rays induce extensive air showers which emit radio waves
- AERA is part of Pierre Auger Observatory and tests different antenna types

geomagnetic   Askaryan (charge excess)

Challenge
- Antennas measure two polarizations of 3D E-Field
- Existing techniques need arrival direction
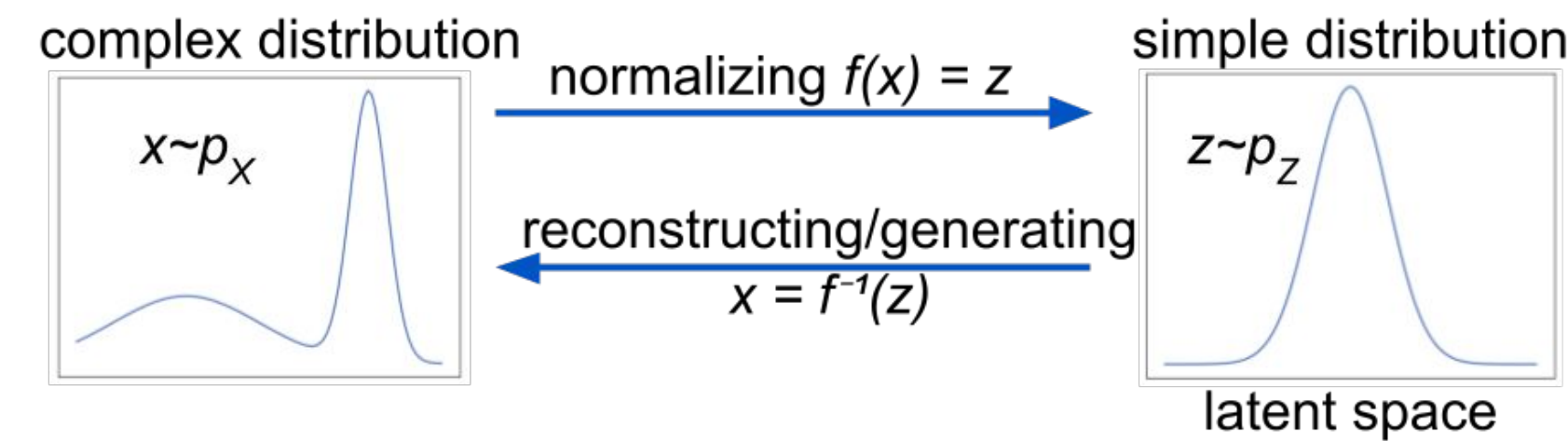 - Requires a measured radio signal from three stations

Task
- Reconstruct 3D E-Field from 2D antenna response:
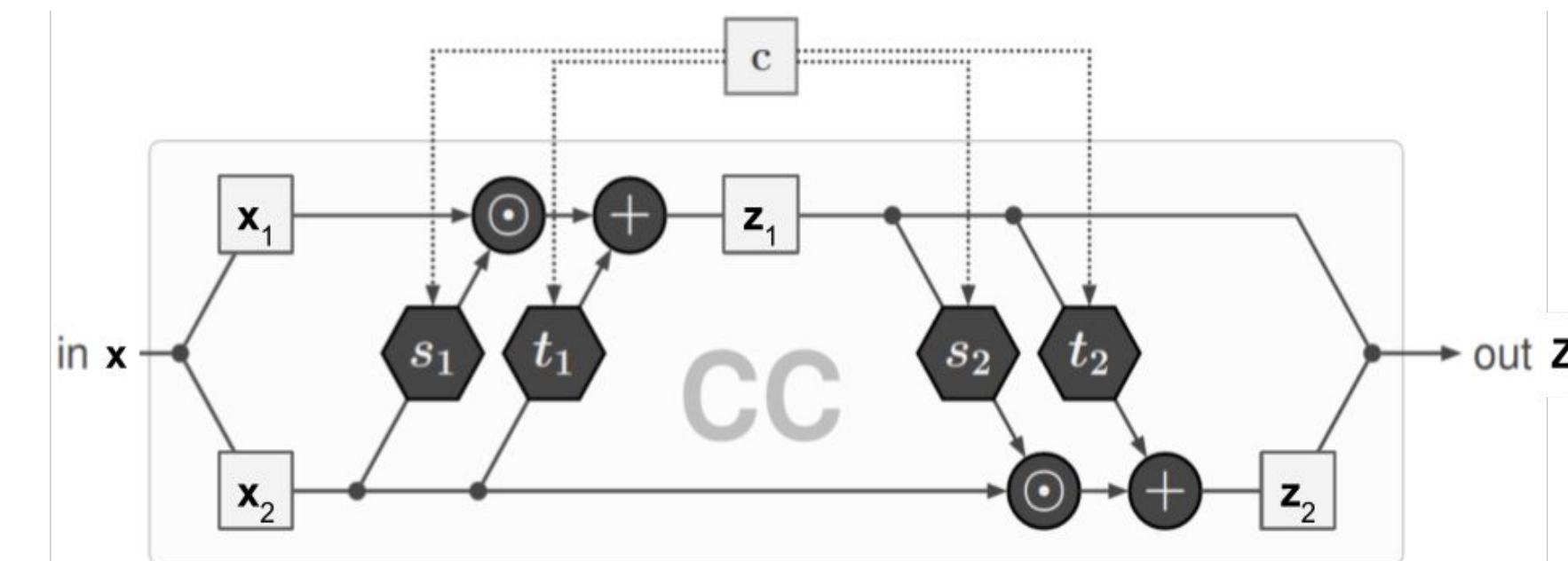 - Unfold detector effects, remove noise, recover third dimension

conditional Invertible Neural Networks

Normalizing Flow (arXiv:1908.09257)

complex distribution $x \sim p_X$

normalizing $f(x) = z$ →
← reconstructing/generating $x = f^{-1}(z)$

simple distribution $z \sim p_Z$

latent space

Reversible Block (arXiv:1907.02392)

in x → x_1, x_2 ... s_1 t_1 ... z_1 ... CC ... s_2 t_2 ... z_2 → out z

c

- Invertible architecture by design
- s and t are arbitrary functions/networks

Network Architecture

Autoencoder
- Reduce 128 time bins to 15 parameters
- Pretrained encoder used to preprocess condition

conditional Invertible Neural Network
- Reconstruct 3D E-Field from 2D measured voltage on reduced parameter space
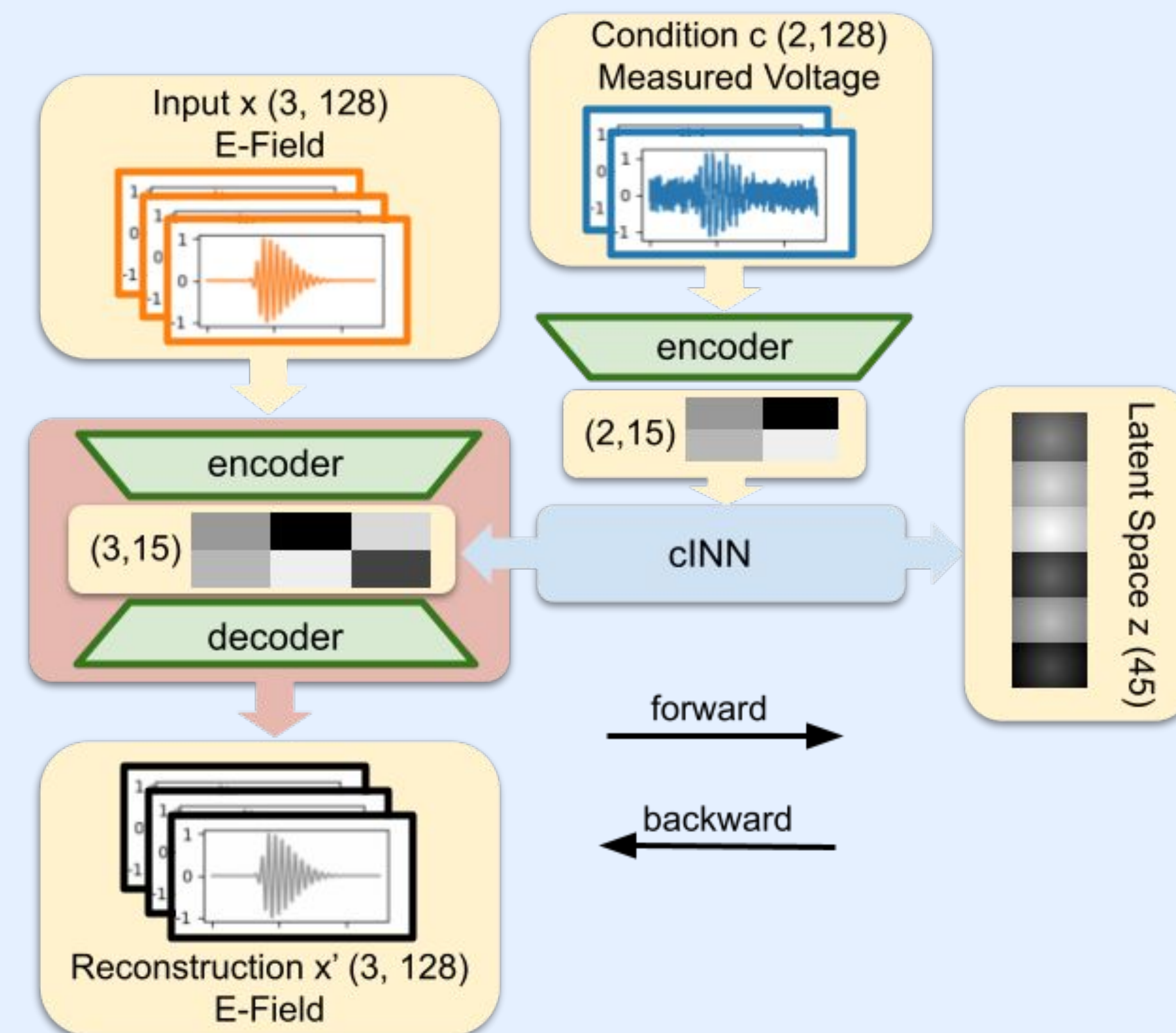
Training
- Encode 3D input and 2D condition and use cINN to map it to the latent space
- Whole network is trained in 20 min on a GPU
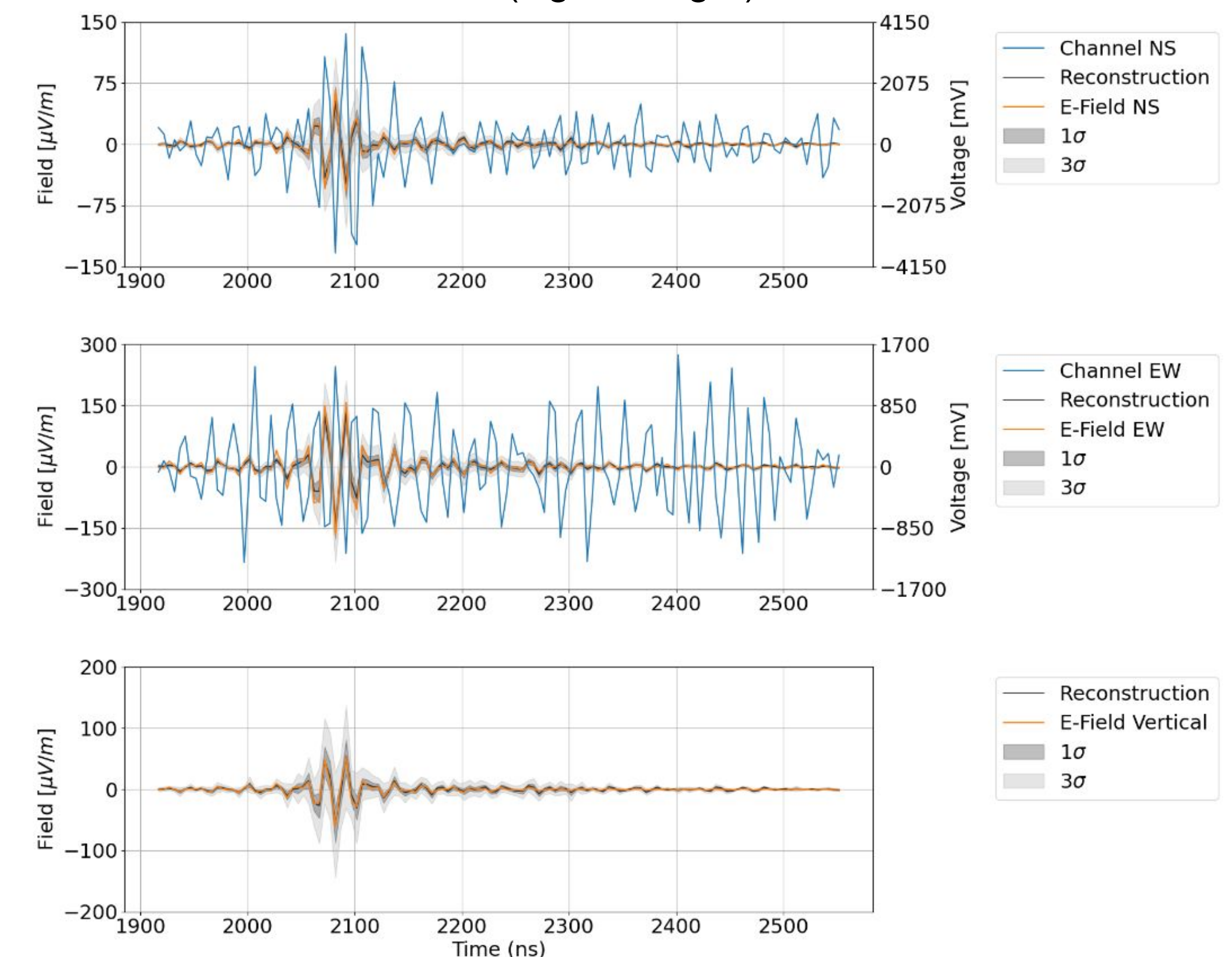
Evaluation
1. Encode condition and sample from latent space
2. Map it to 3x15 parameters
3. Decode parameters to reconstruct 3D E-Field

Repeat these steps multiple times to approximate p(x|c)

Input x (3, 128) E-Field

Condition c (2,128) Measured Voltage

encoder

(2,15)

encoder

(3,15)

cINN

Latent Space z (45)

decoder

forward →
← backward

Reconstruction x' (3, 128) E-Field

Reconstruction Quality

- Fast and reliable method using only <u>one</u> antenna station
- Deviation is below 10% (signal height)

Channel NS / Reconstruction / E-Field NS / 1σ / 3σ

Channel EW / Reconstruction / E-Field EW / 1σ / 3σ

Reconstruction / E-Field Vertical / 1σ / 3σ

→ Applicable to other signal trace problems