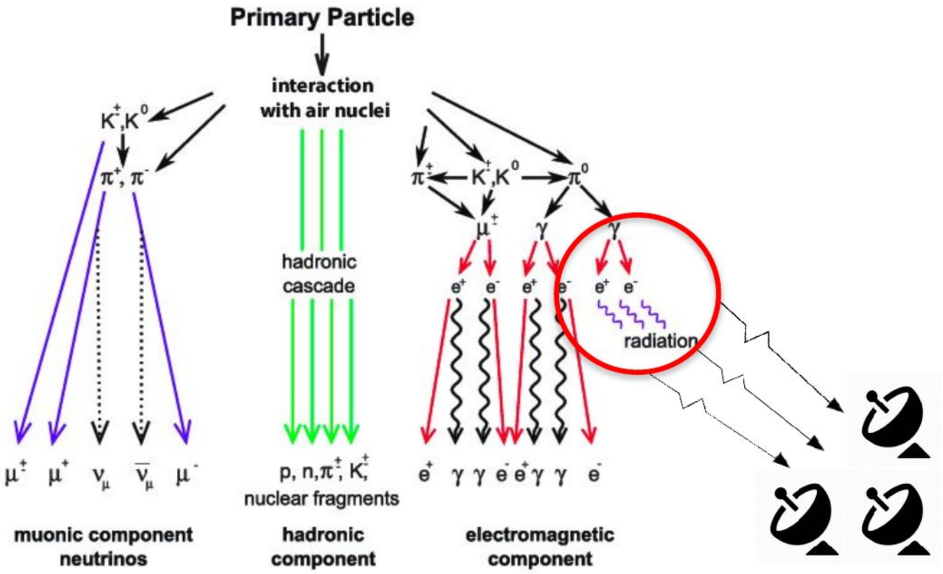
Generative Neural Networks for Simulating Radio Emission from Air Showers

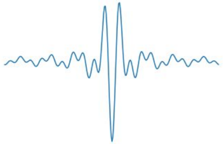
Pranav Sampathkumar[a1],
Tim Huege[a], Andreas Haungs[a], Ralph Engel[a]

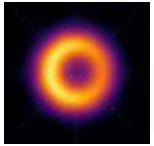
Workshop on Machine Learning for Analysis of High-Energy Cosmic Particles, University of Delaware
29/01/2025

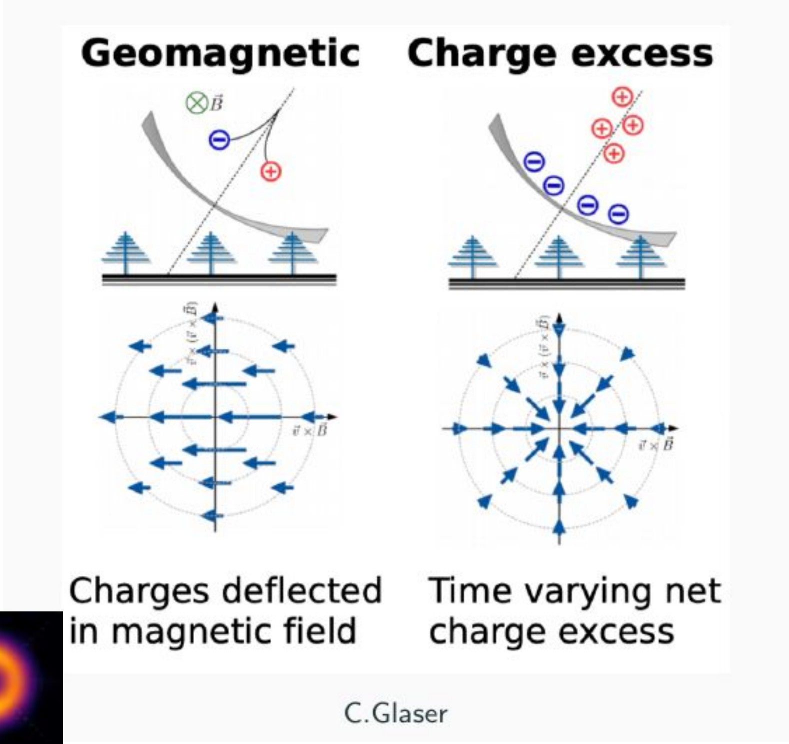
[1] pranav.sampathkumar@kit.edu
[a] Institute for Astroparticle Physics, Karlsruhe Institute of Technology

Radio Showers









Motivation:

- Analysis of data from radio arrays are heavily limited by the computational cost of CoREAS simulations
- There is a need for interpolation techniques which reduce the simulation cost in large arrays.

Our Work:

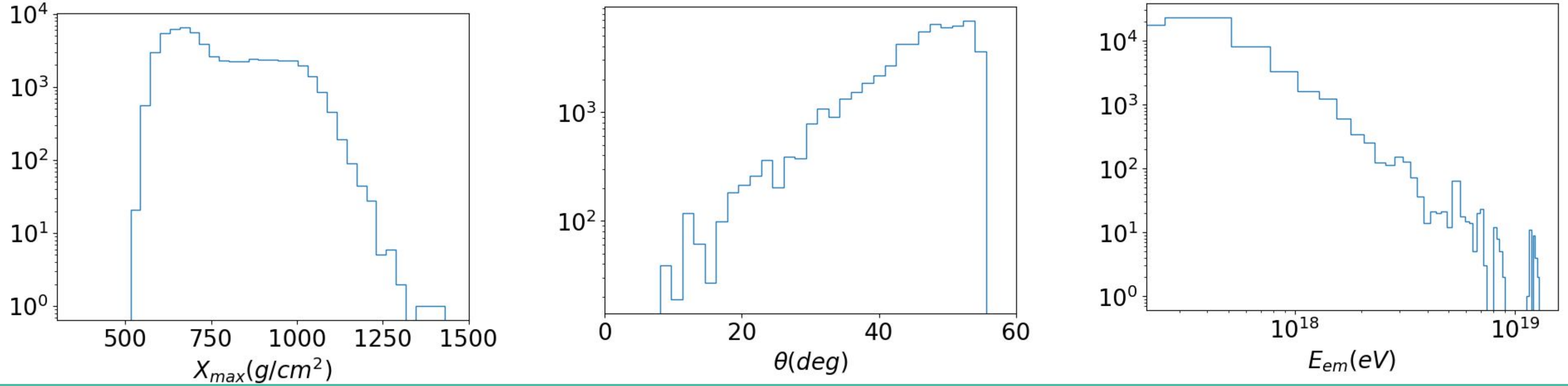
- We present a neural network which can generate pulses from shower parameters in the 30-80MHz range.
- The network can be used for X_{max} reconstruction.

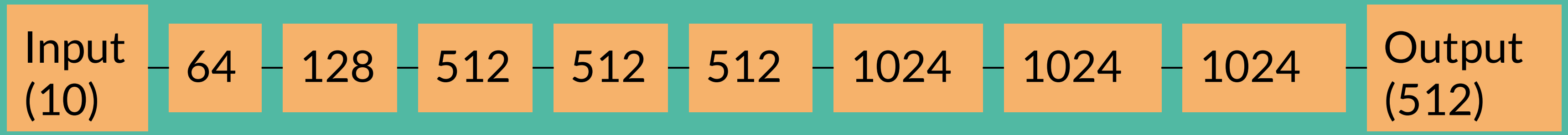
Training:

- We give as **input**,
  - Cos(Zenith Angle), Azimuthal angle
  - X_{max}, density at X_{max}, height at X_{max}
  - sin(geomagnetic_angle)
  - Electromagnetic Energy
  - Antenna position in shower coordinates
- We get as **output**,
  - Trace of length 256 time bins. (Shower plane - vB polarization)
  - Trace of length 256 time bins. (Shower plane - vvB polarization)

- Custom Loss Function:
  - We use a L1 norm loss, where the weaker vvB polarization is weighted more.
  - Regularization via weight decay during minimization (Adam)

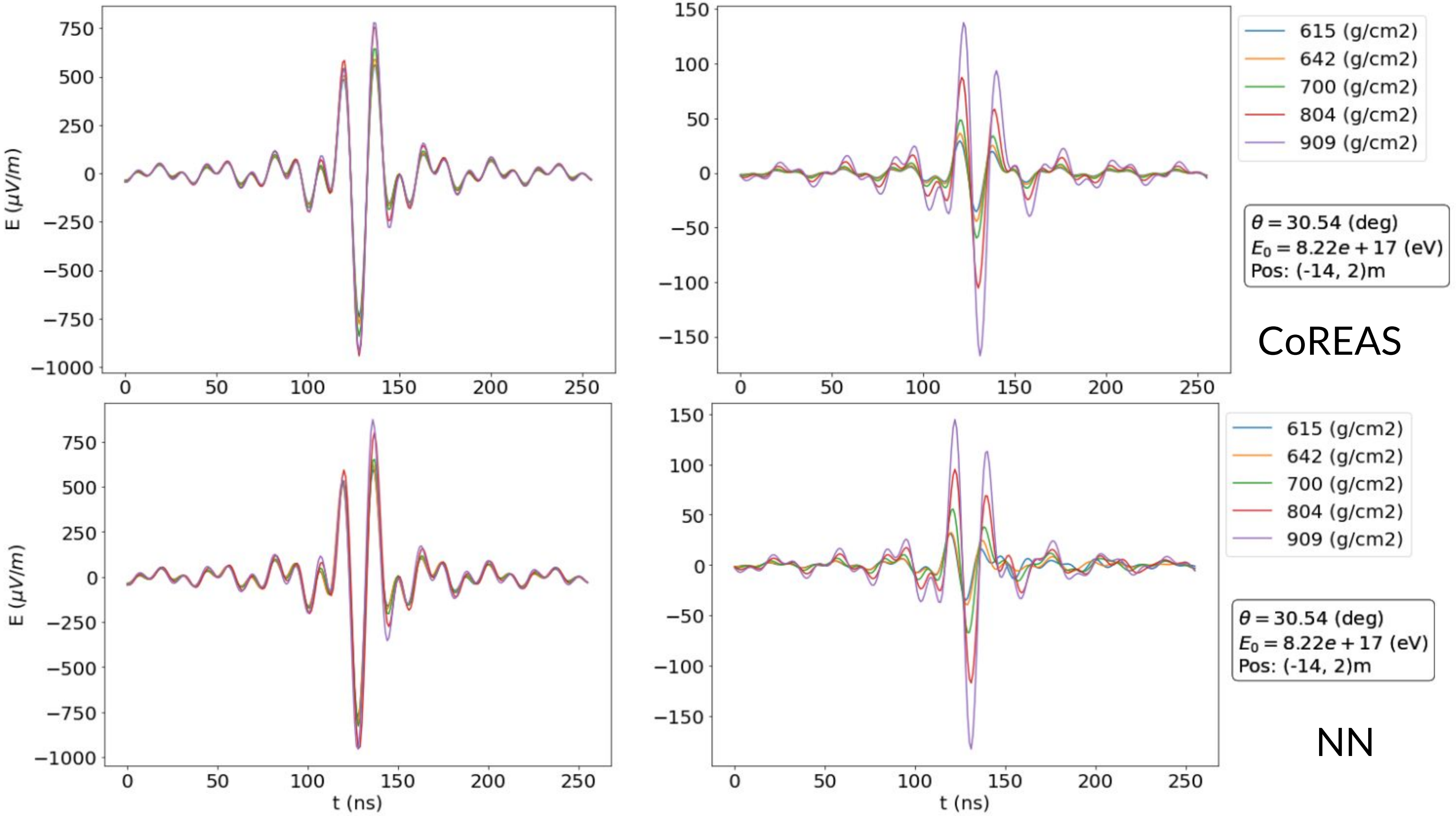
- Trained with the 2158 x 28 showers simulated for the AERA X_{max} analysis (Thank you, Auger MC Task!)
- Filter the pulses to 30-80MHz band.
- Train only with 70% (~42000) showers.
- For each shower calculate the radius where pulses are dominated by thinning and train within that radius.





Network:

- We use a deep fully connected network.
- The inputs are scaled to make all the parameters dimensionless and vary in similar ranges.
- The gradients are well in control, and we didn’t need skip connections for such a network.


E ($\mu V/m$)
t (ns)
615 (g/cm2)
642 (g/cm2)
700 (g/cm2)
804 (g/cm2)
909 (g/cm2)
$\theta = 30.54$ (deg)
$E_0 = 8.22e + 17$ (eV)
Pos: (-14, 2)m
CoREAS
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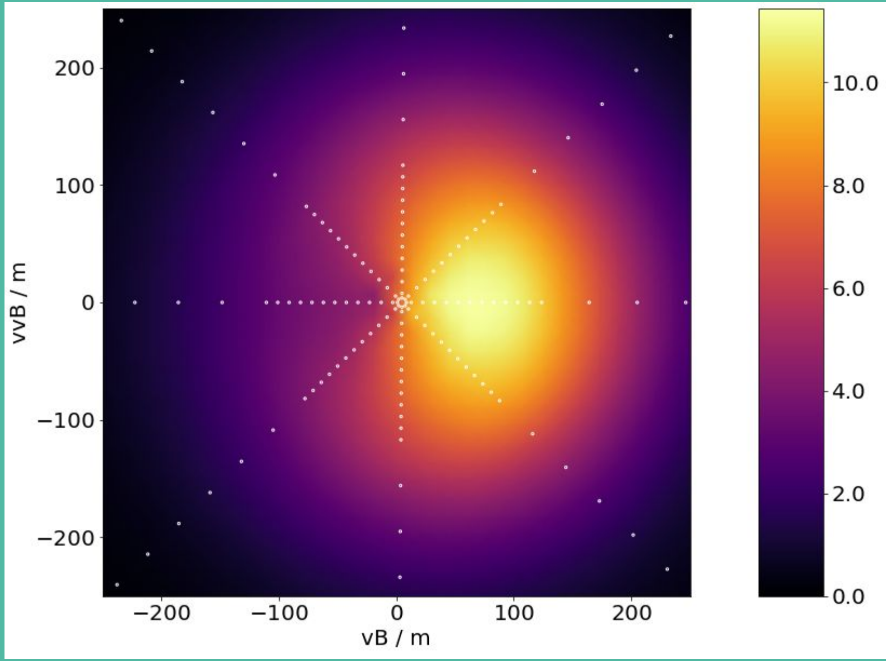
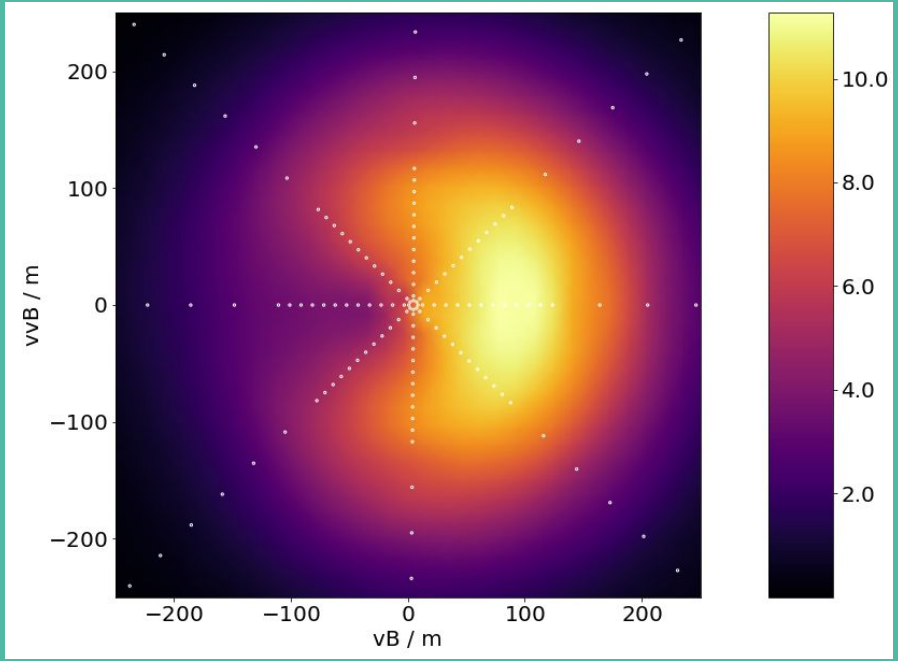
Pos: (-14, 2)m
NN

vB Polarization fluence (eV/m^2)

$\theta = 50.58$
$X_{max} = 693.61$
$E_0 = 3.15e + 17$

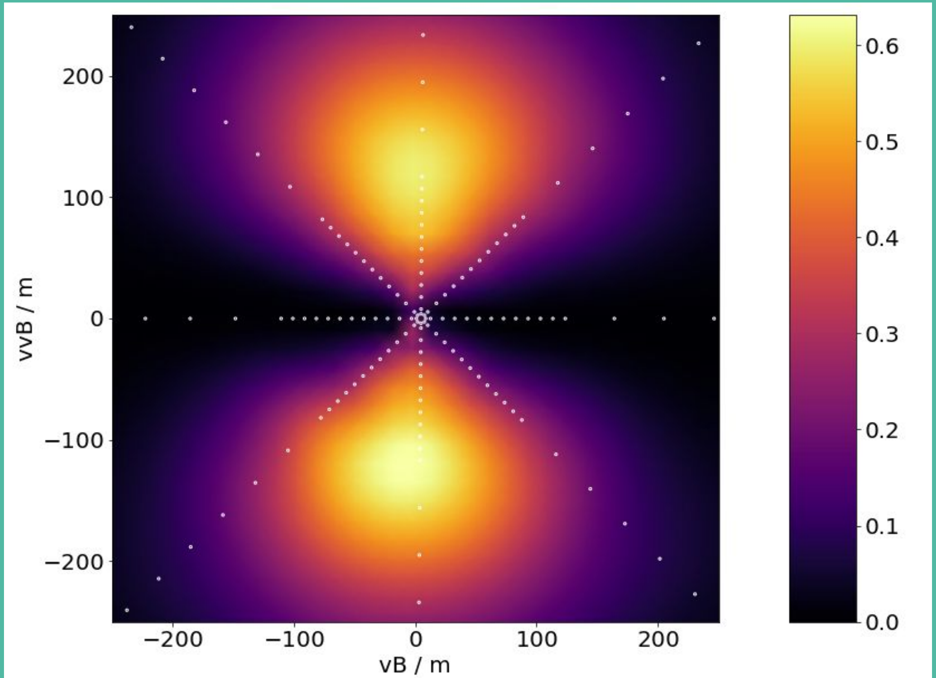


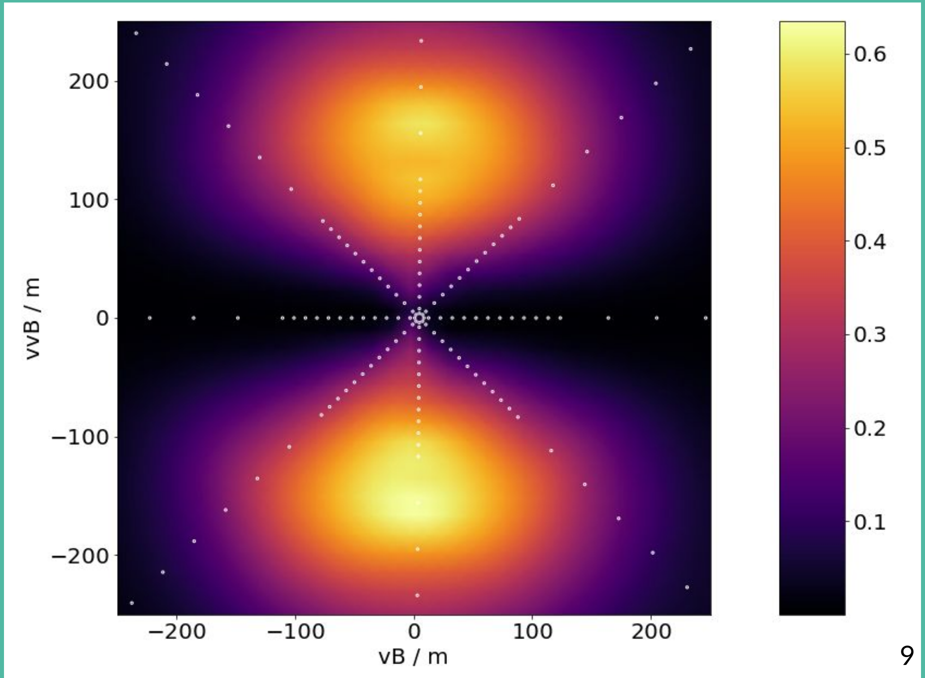


For the most common case in the training dataset, the fluences match reasonably well

vvB Polarization fluence (eV/m^2)

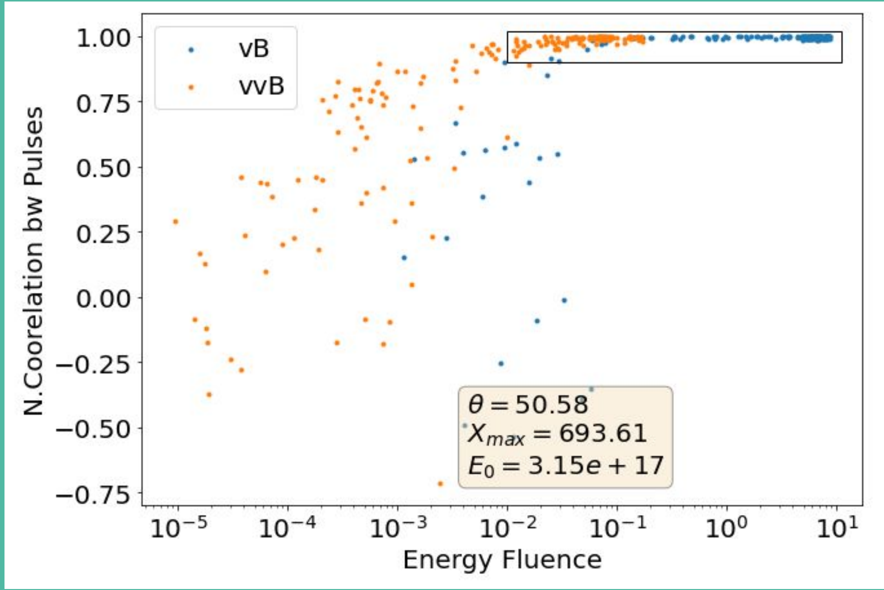
We see the same in the vvB polarization too.

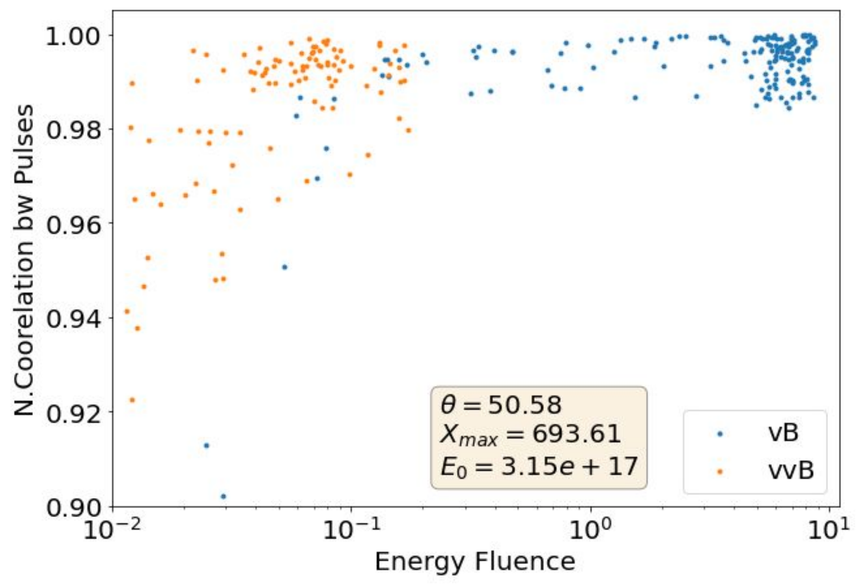




Normalized Correlation between Pulses.

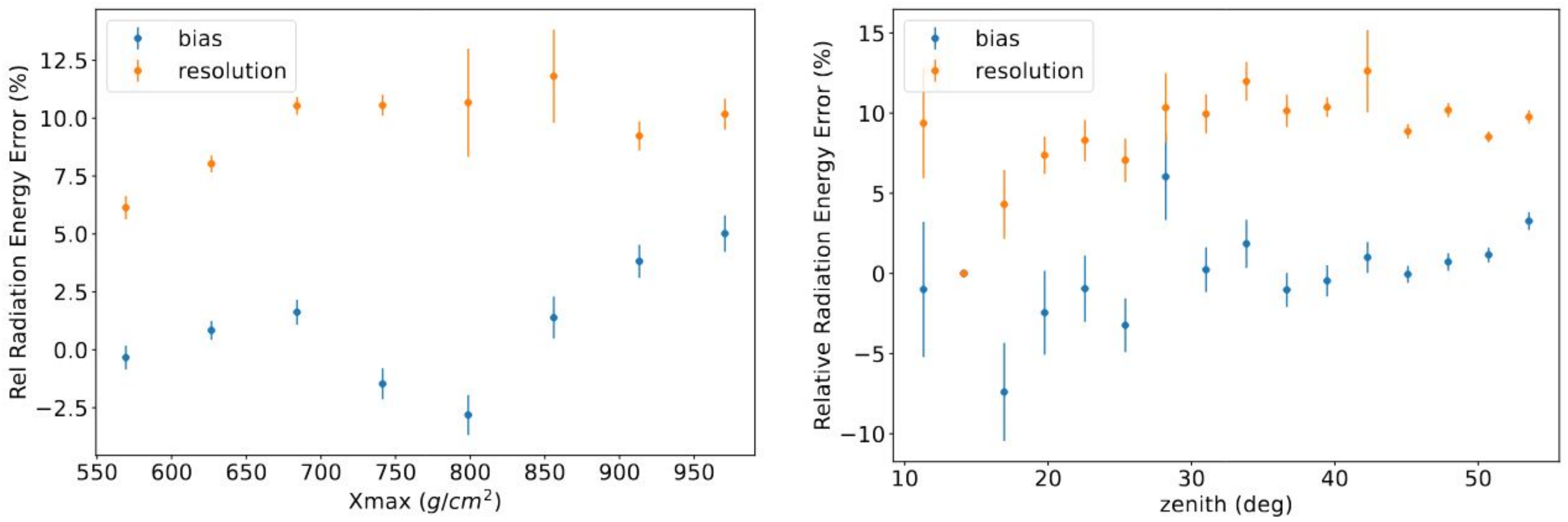
When we plot normalized correlation with respect to energy fluence of the pulse. The pulse correlation is very good for high fluences.



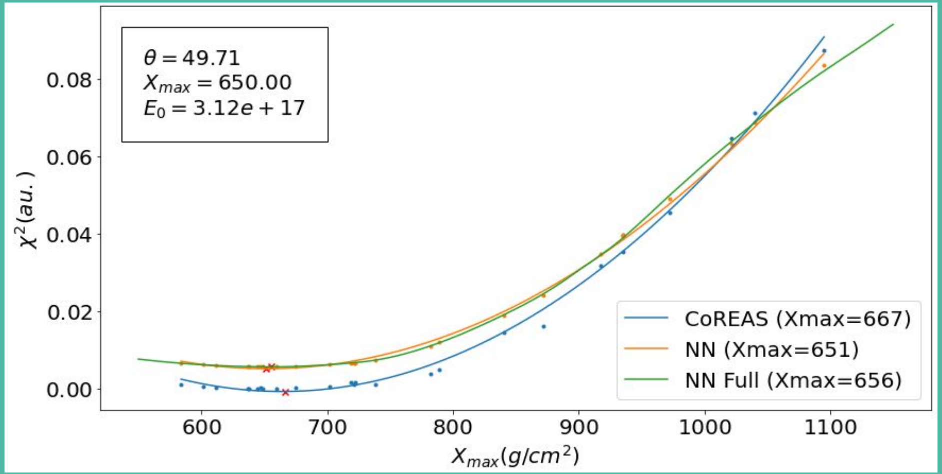


The plot on the right is a zoomed in version of the plot, and the fluences on the x-axis are the true fluences.

Error in Radiation Energy:



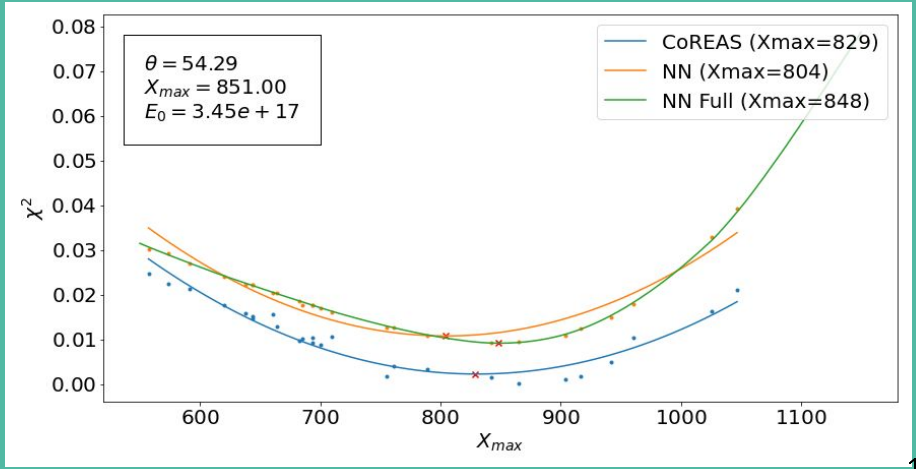
X_{max} reconstruction:



Using the same network for a simplistic χ^2 minimization procedure for X_{max} reconstruction.

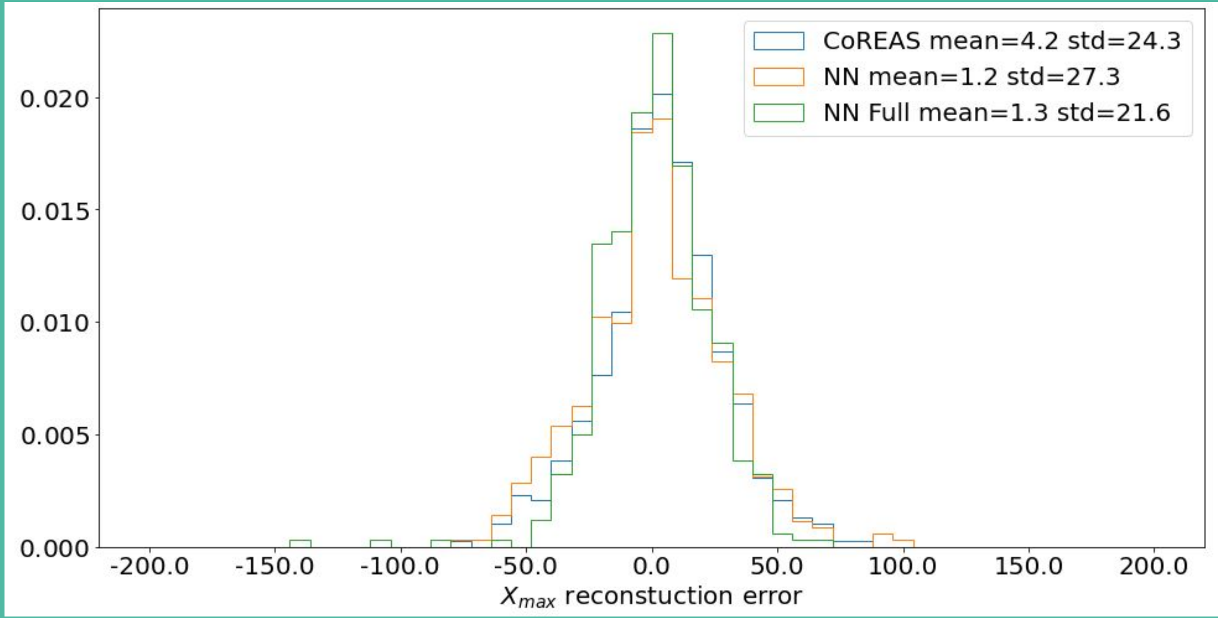
NN - The same shower parameters as the CoREAS simulation

NN Full - Scan the entire X_{max} range with a lot of simulations.



X_{max} reconstruction:

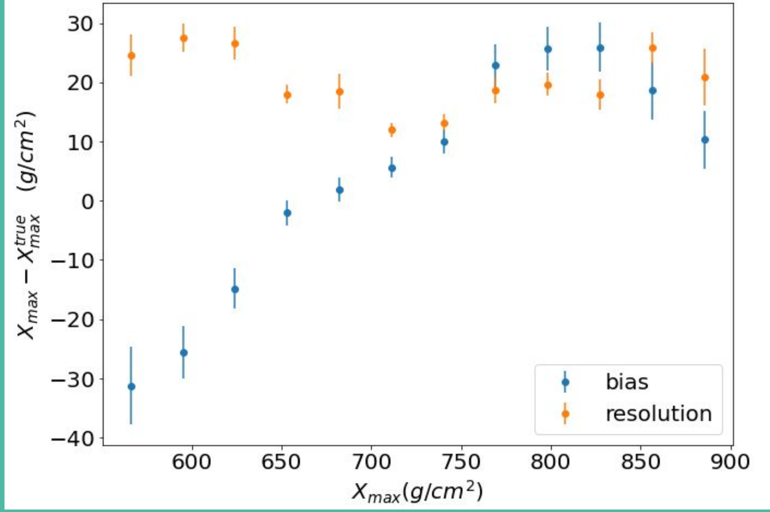
We can see that the X_{max} distribution is very similar between the reconstruction methods using the neural network and using the CoREAS simulations.



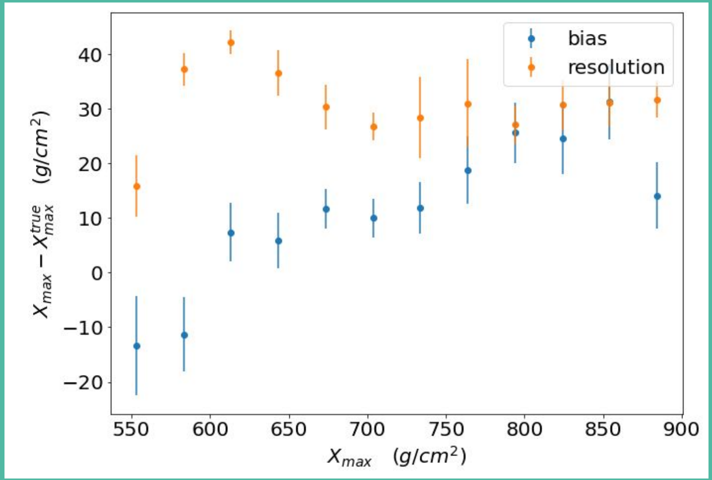
X_{max} reconstruction:

Comparing the X_{max} reconstruction resolution across various X_{max}

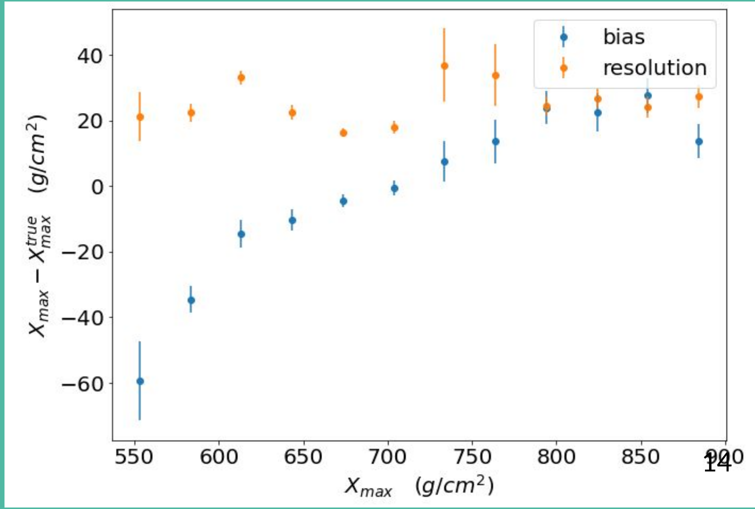
CoREAS



NN Full



NN



Results:

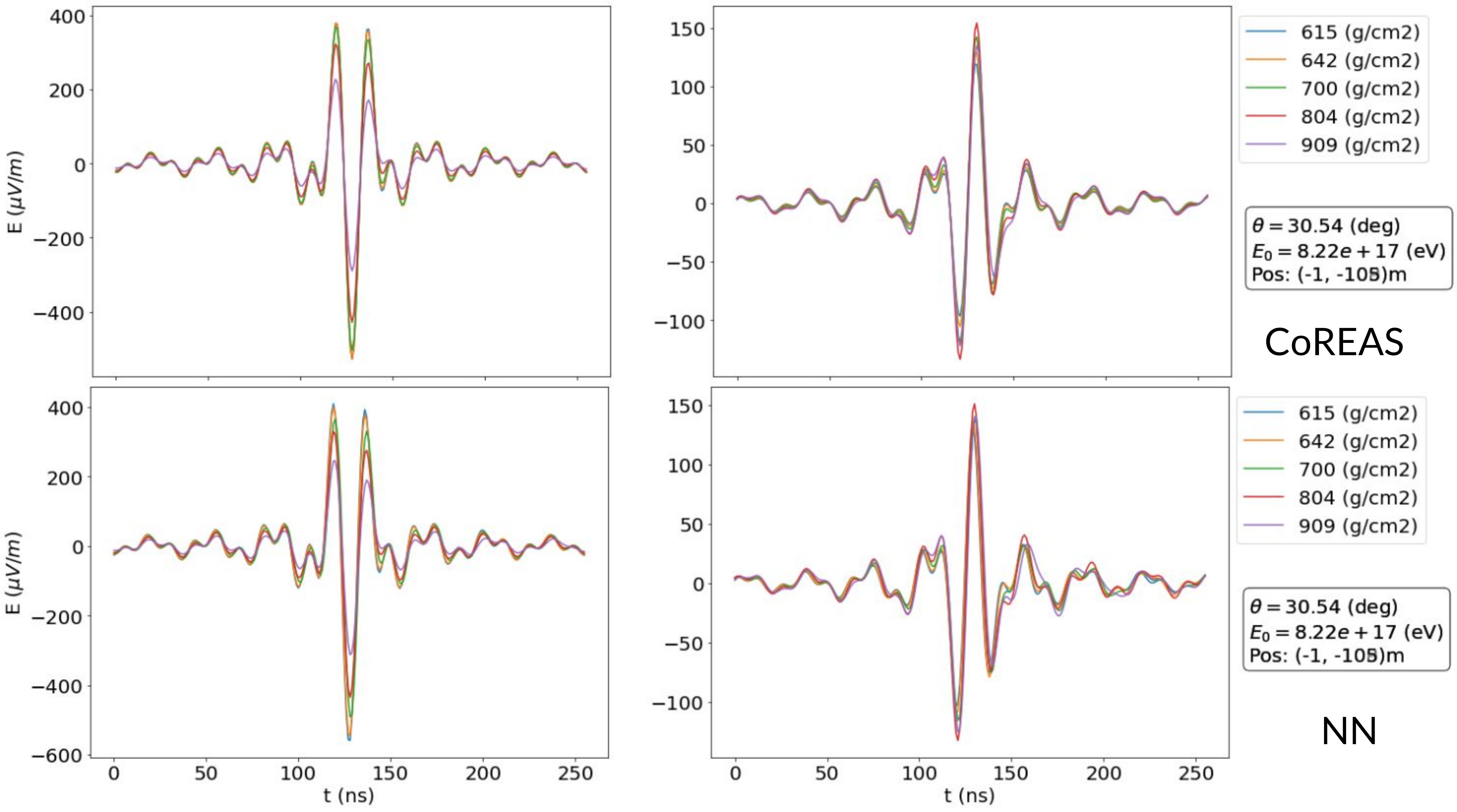
- The networks seems to perform reasonably well in the initial tests.
- High amplitude/High Fluence pulses are accurate.
- Total radiation energy is accurate within 10% for shallow showers.
- Total radiation energy is wrong in deeper showers.
- A quick X_{max} reconstruction is comparable with CoREAS using the network.
- ~100ms for simulating an entire star shape array, memory footprint of the model is ~20MB.

Todo:

- Do a X_{max} reconstruction along with the noise model. Similar to the AERA X_{max} Reconstruction pipeline. (PhysRevD.109.022002)
- Manuscript in preparation!

THANK YOU!

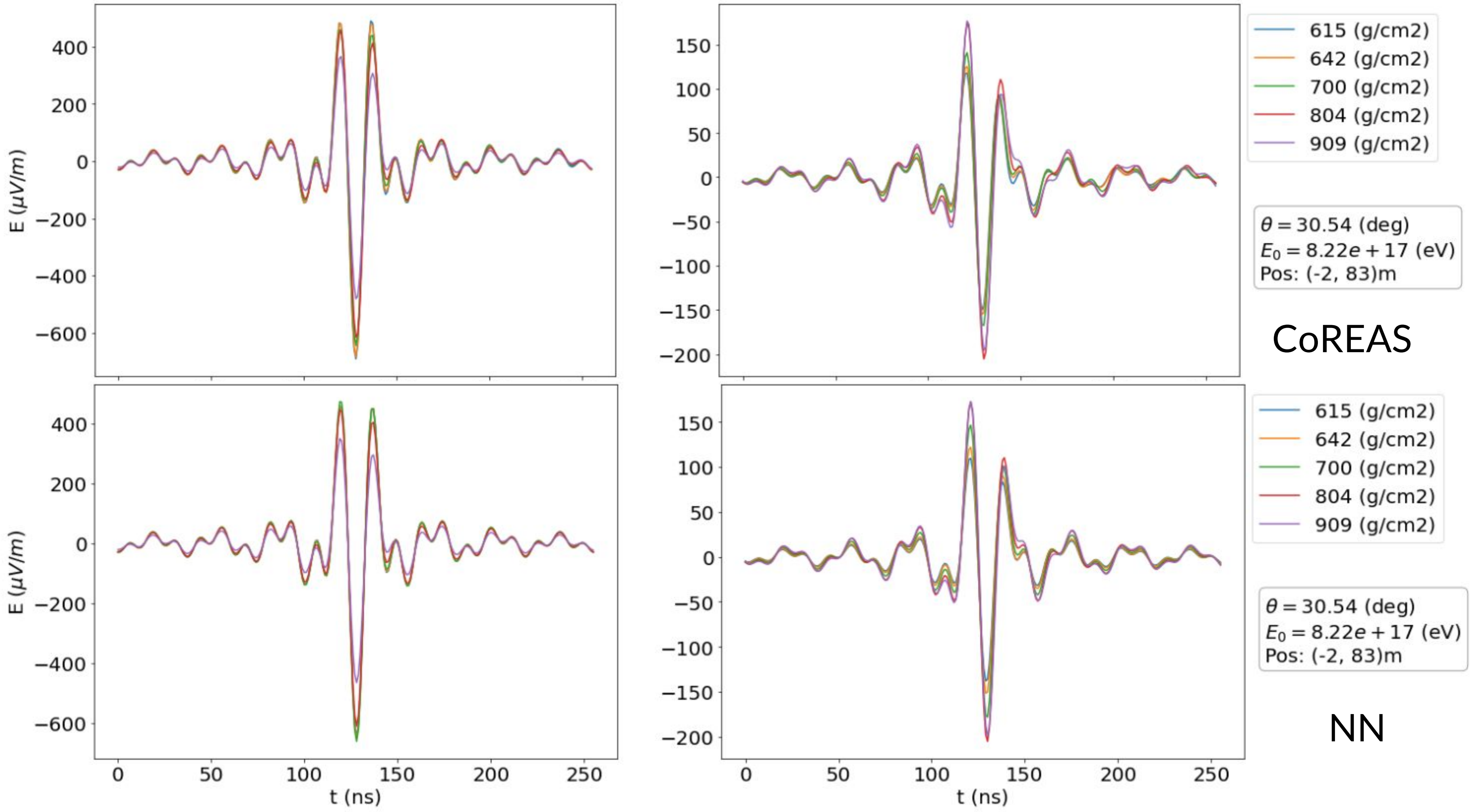
Backups



615 (g/cm2)
642 (g/cm2)
700 (g/cm2)
804 (g/cm2)
909 (g/cm2)
$\theta = 30.54$ (deg)
$E_0 = 8.22e+17$ (eV)
Pos: (-1, -105)m
E ($\mu V/m$)
t (ns)

CoREAS

NN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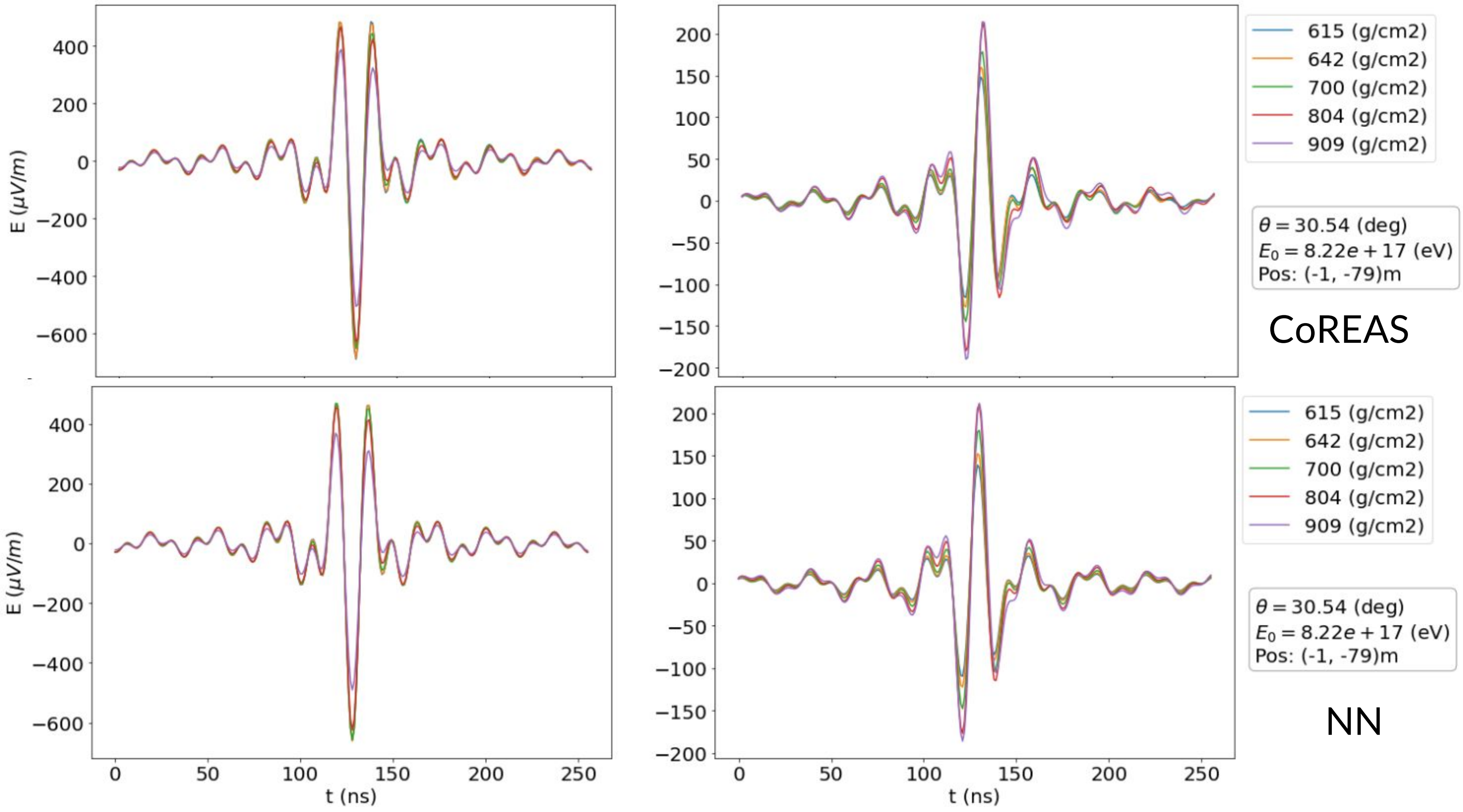
θ = 30.54 (deg)
E0 = 8.22e + 17 (eV)
Pos: (-2, 83)m
CoREAS
NN



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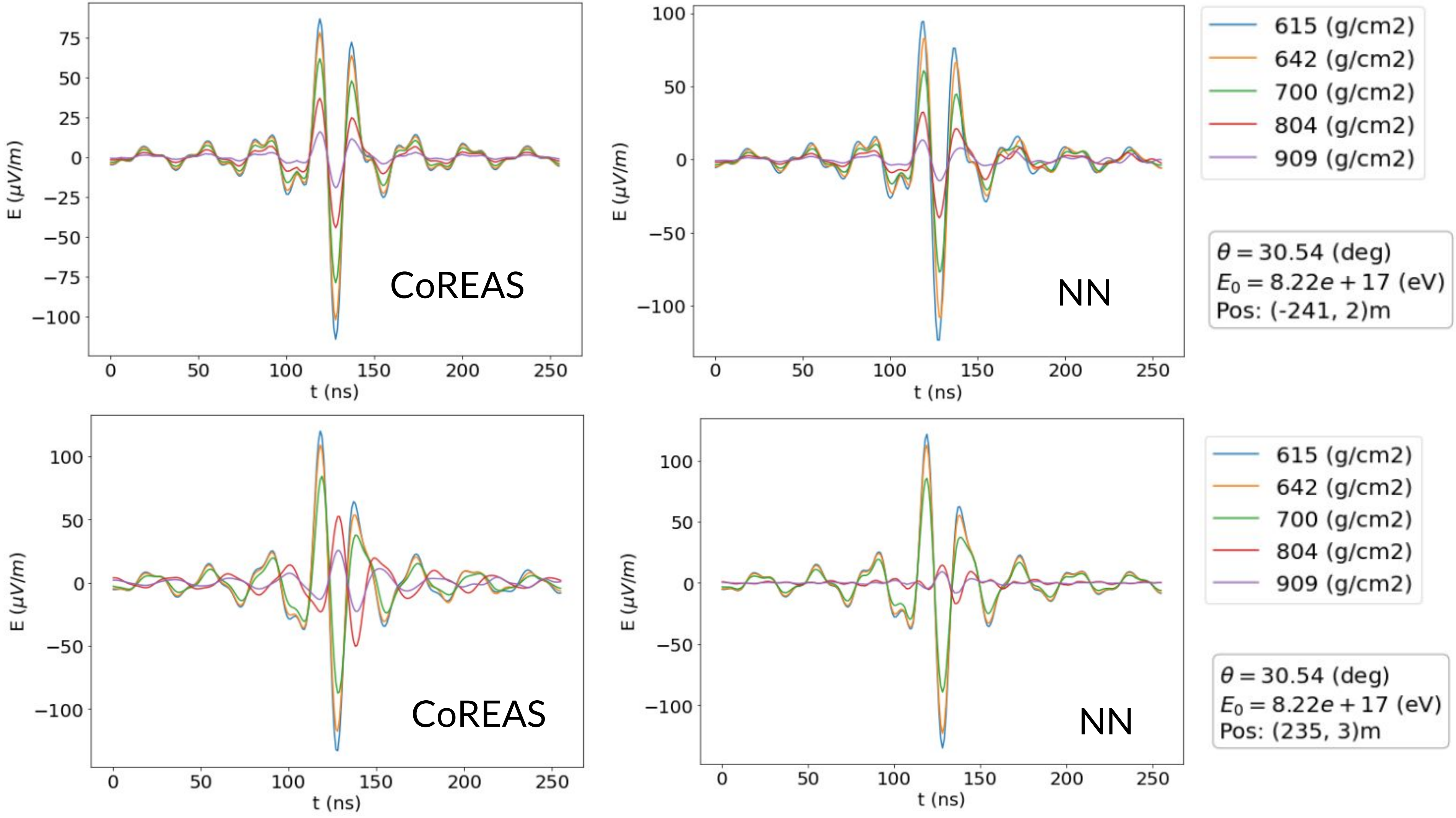
θ = 30.54 (deg)
E0 = 8.22e + 17 (eV)
Pos: (-1, -79)m
CoREAS
NN



CoREAS
NN
CoREAS
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Pos: (-241, 2)m
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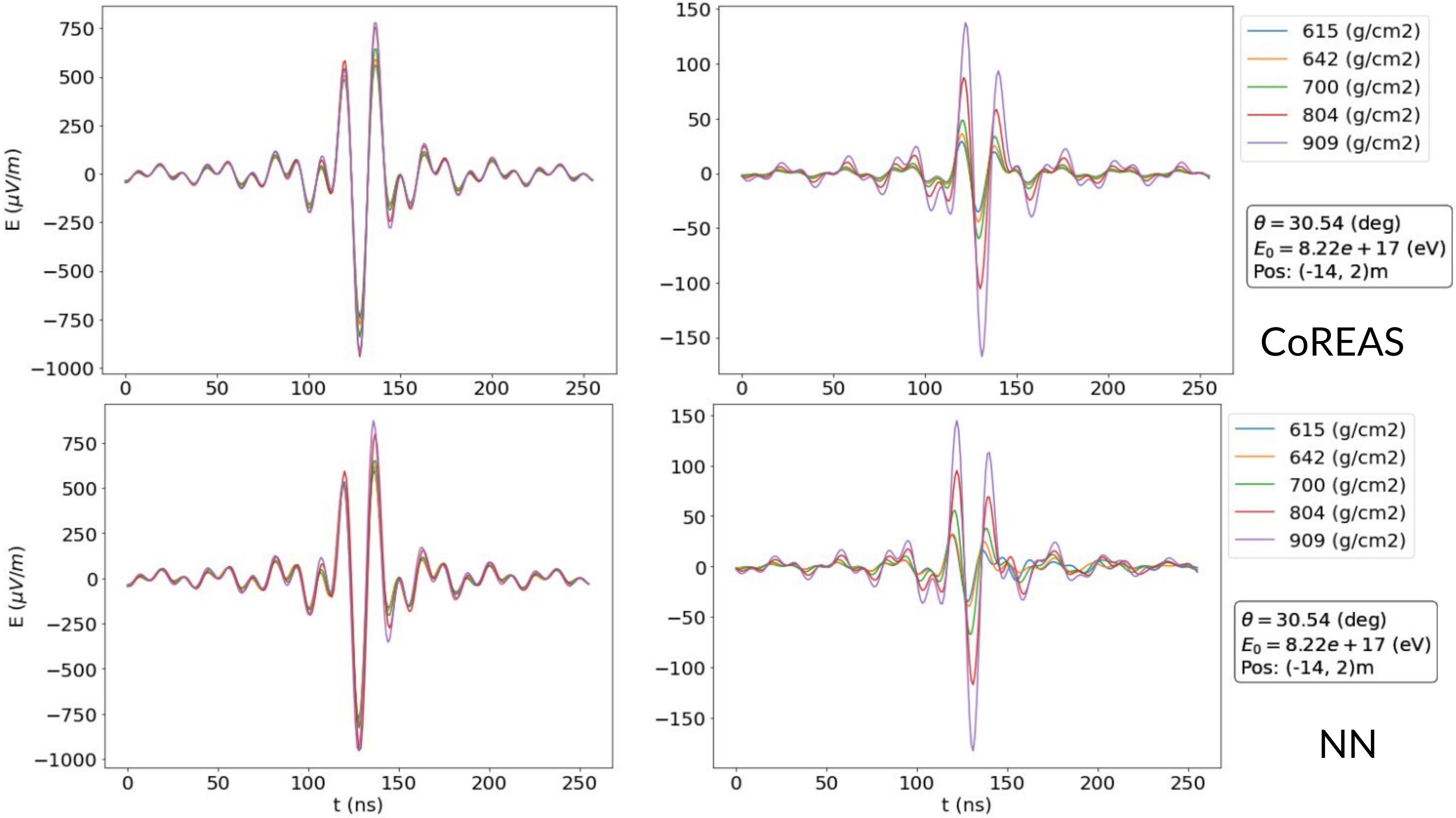
Pos: (235, 3)m



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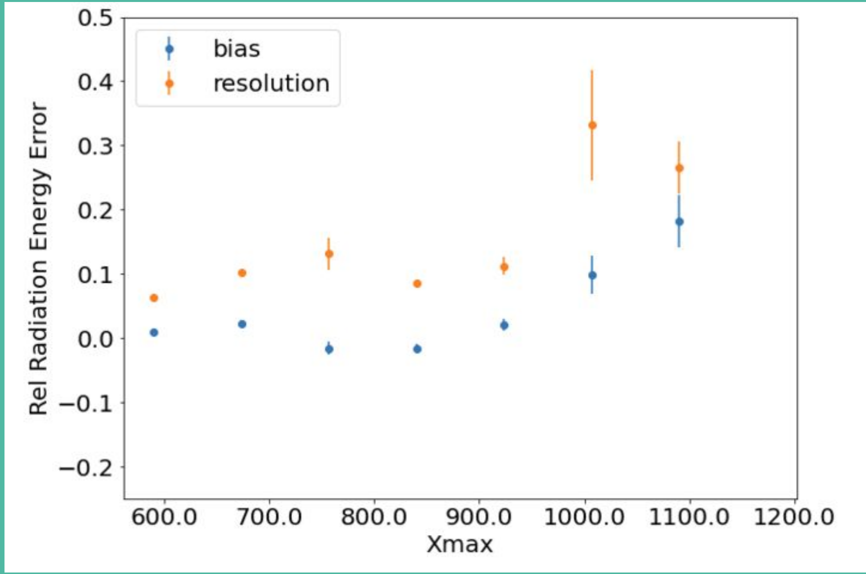
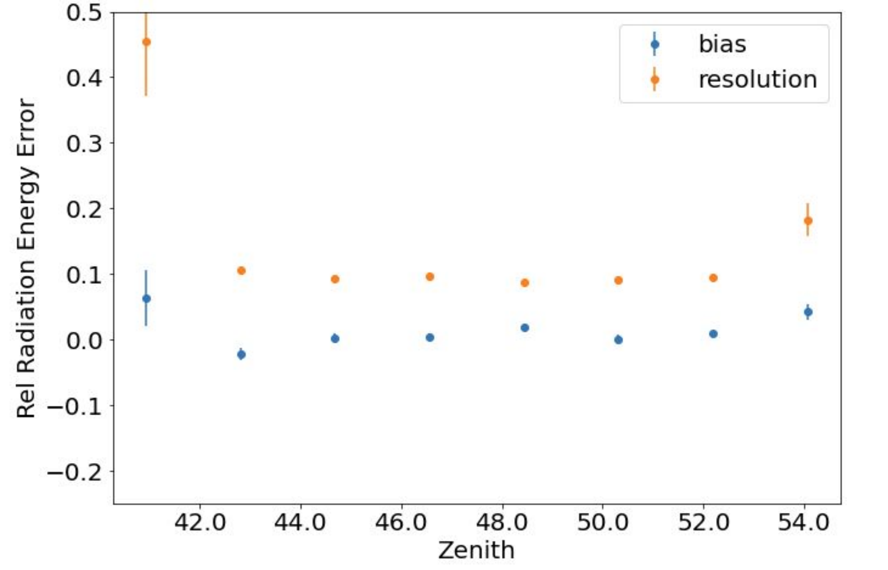
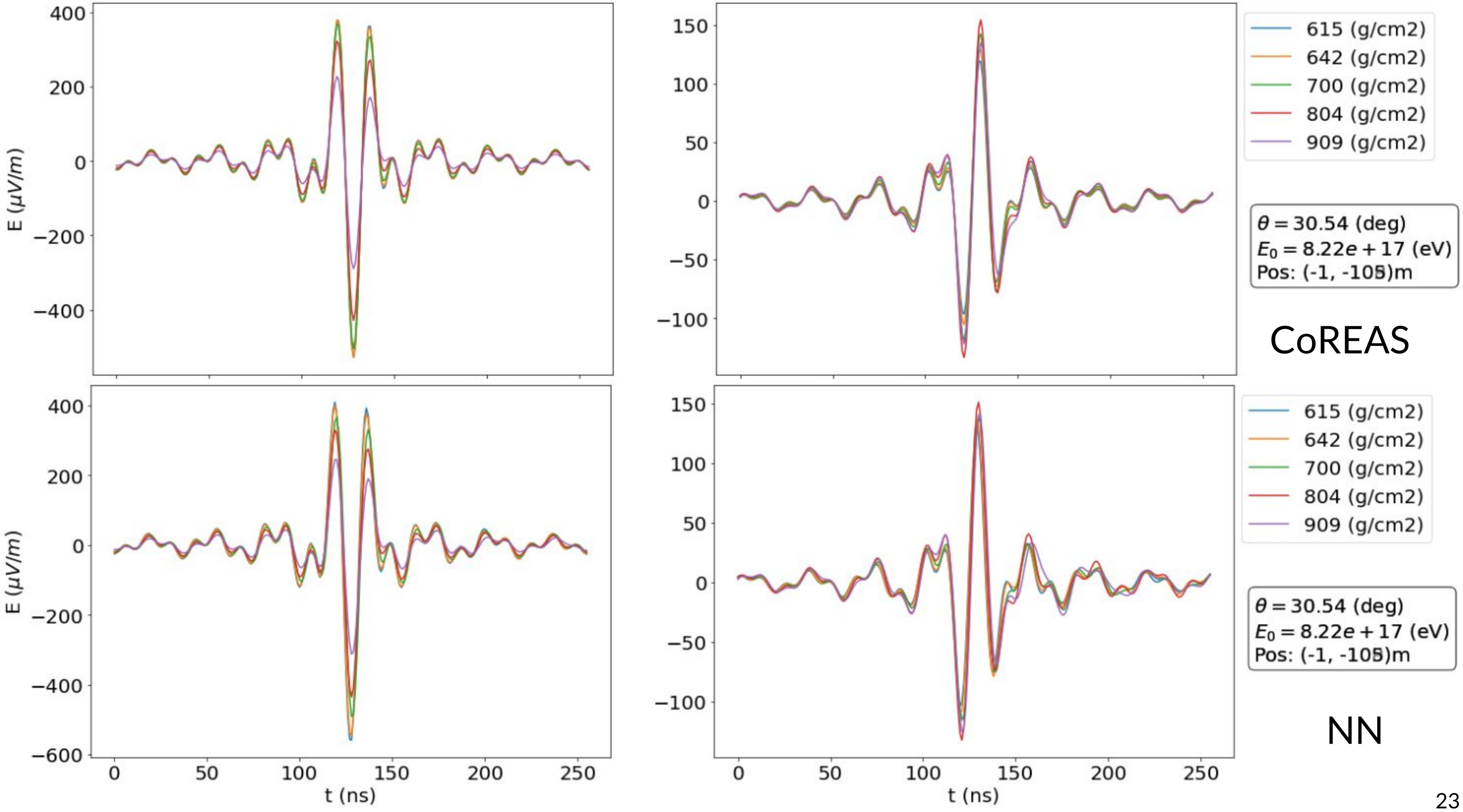

bias
resolution
Rel Radiation Energy Error
Xmax


bias
resolution
Rel Radiation Energy Error
Zenith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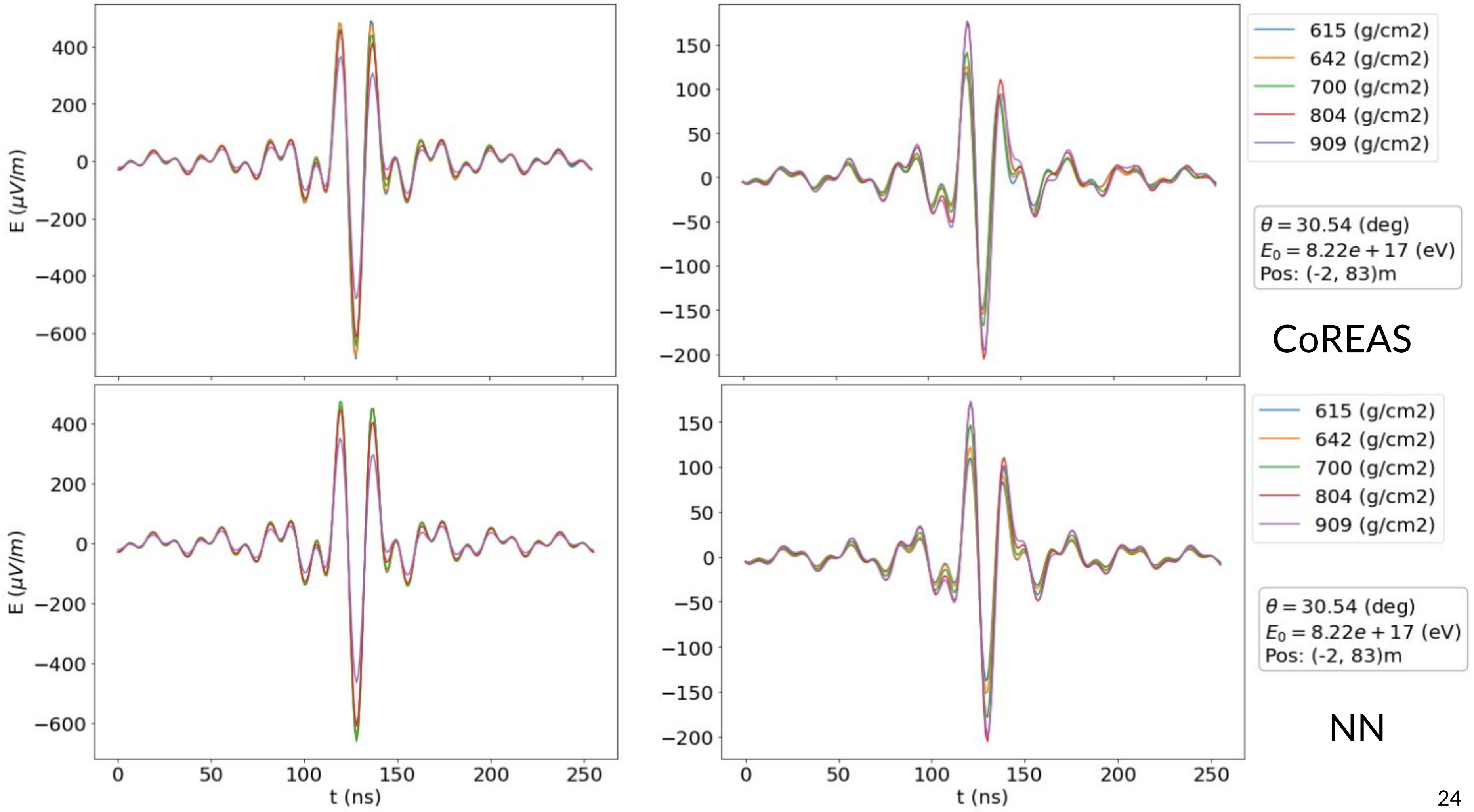
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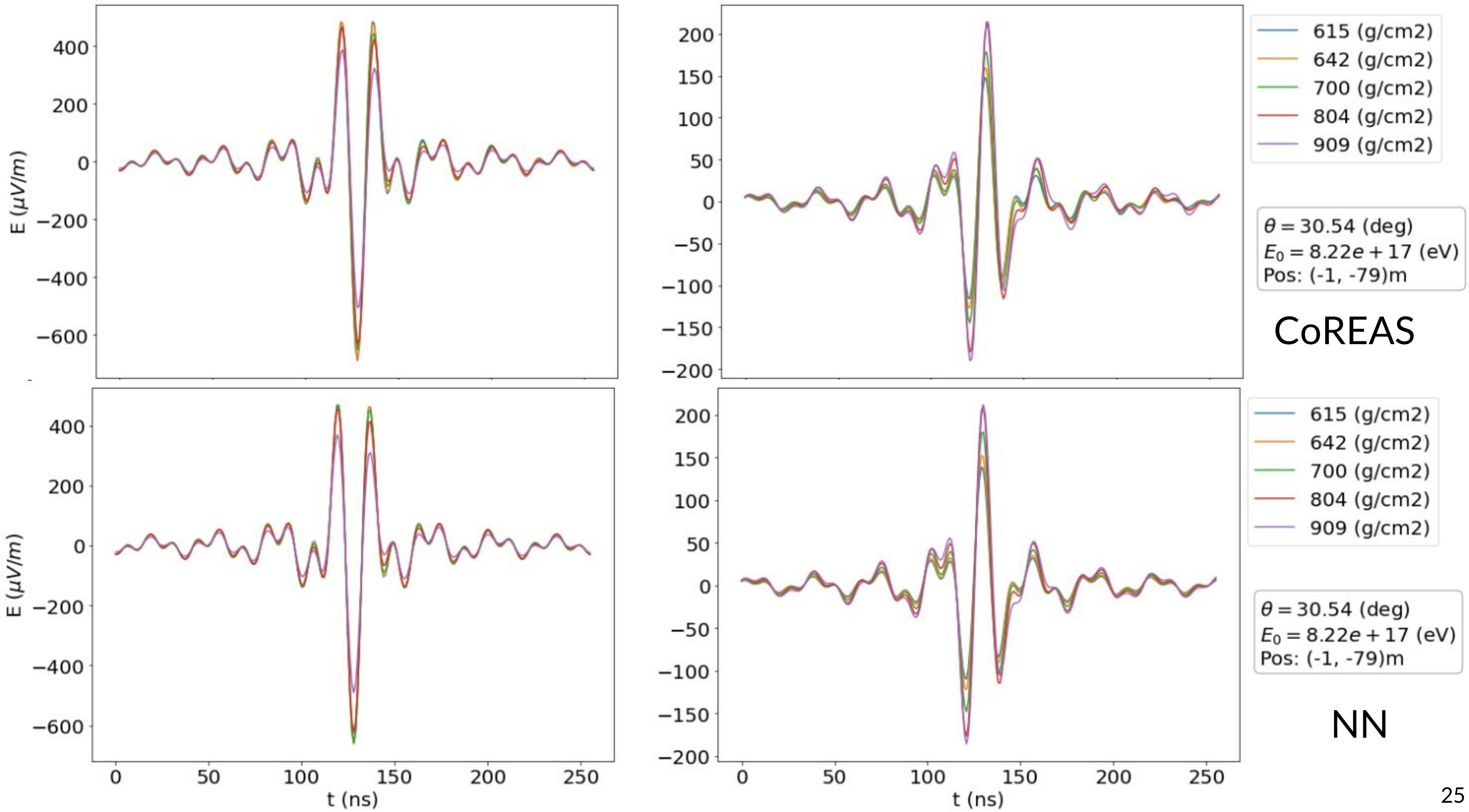
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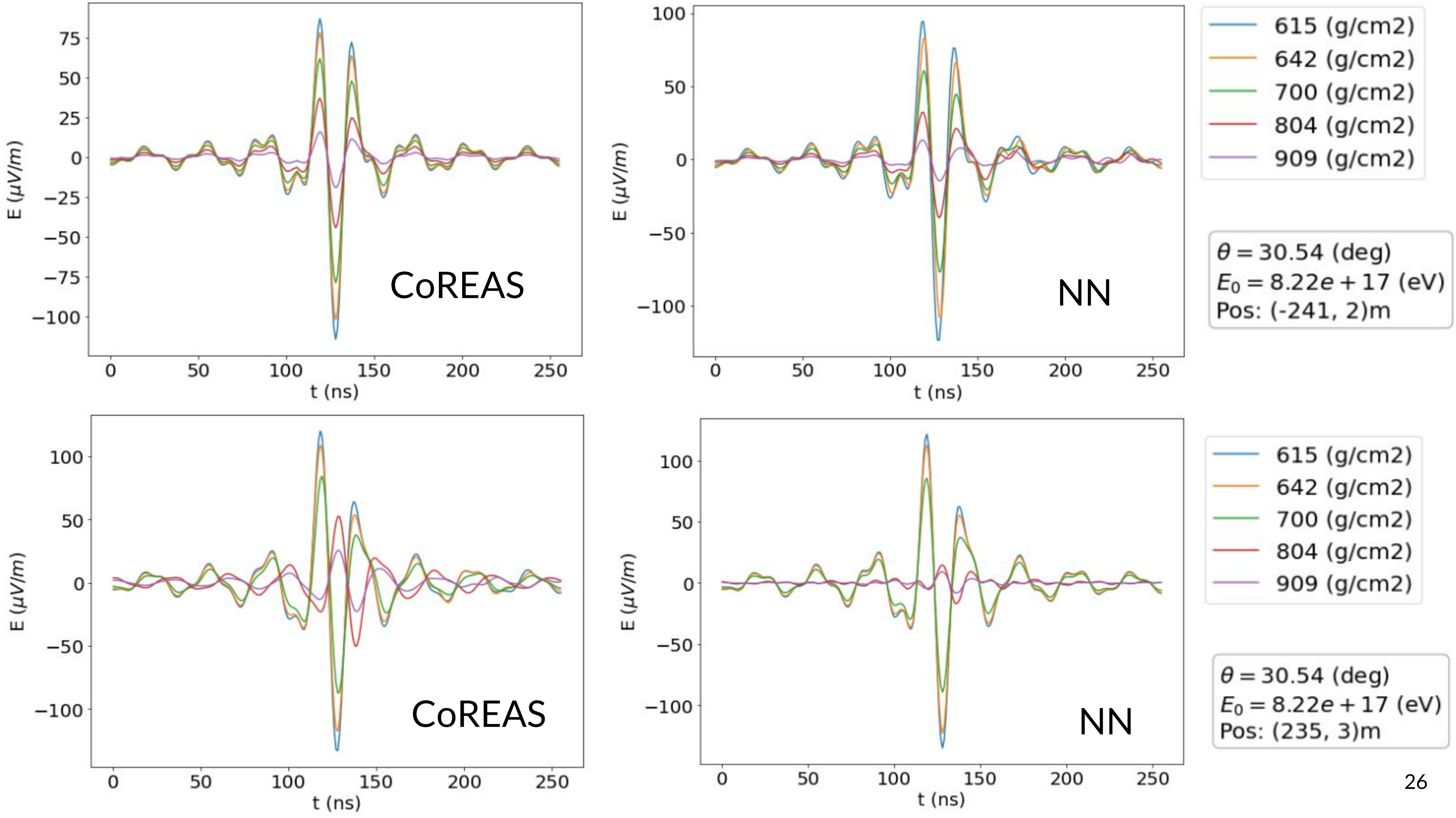
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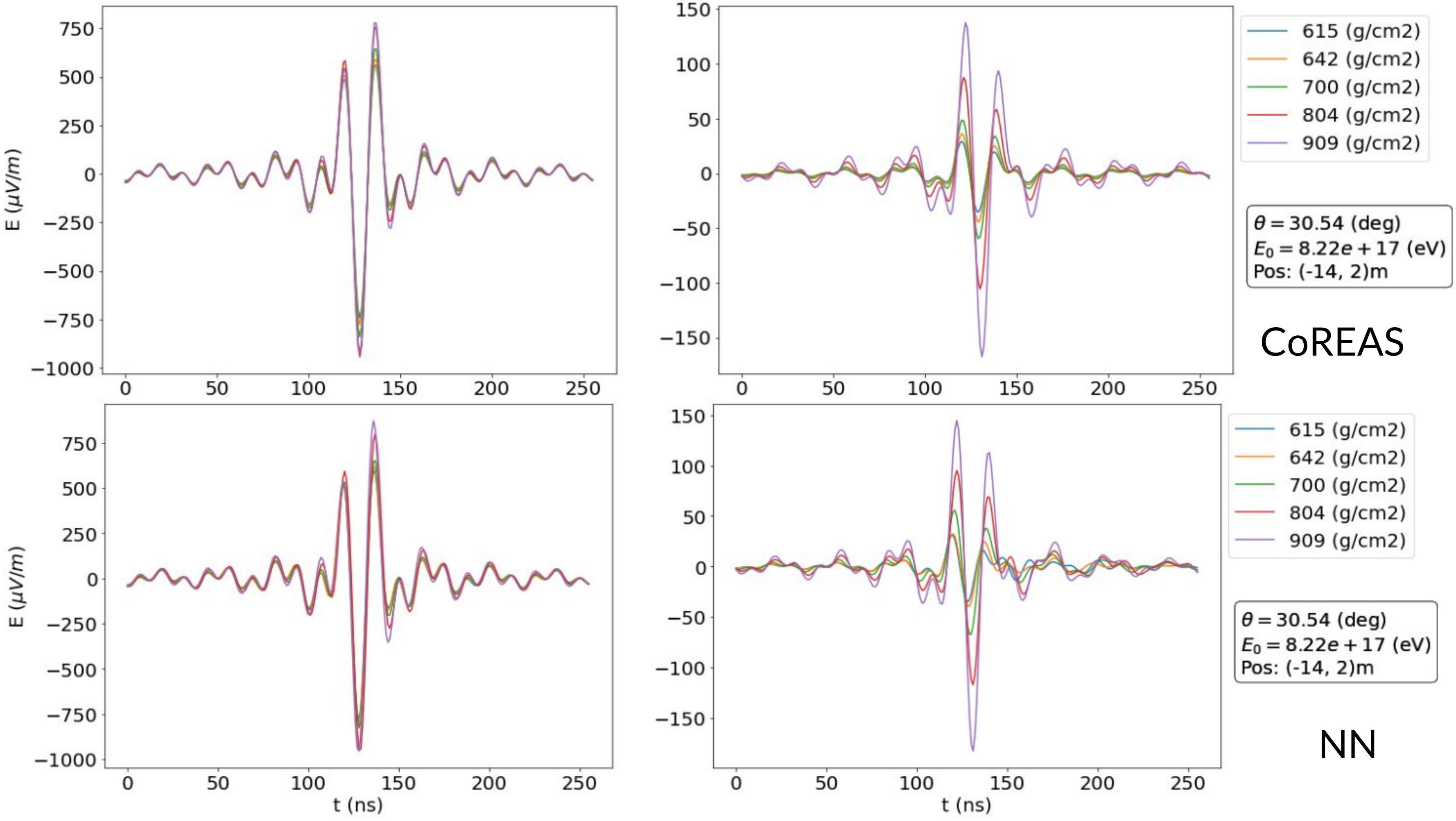

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