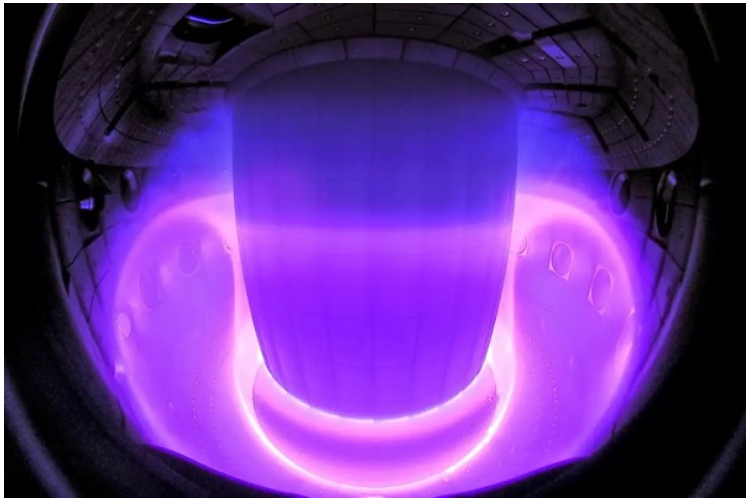
Synthesizing particle clustering in plasma using Neural Networks



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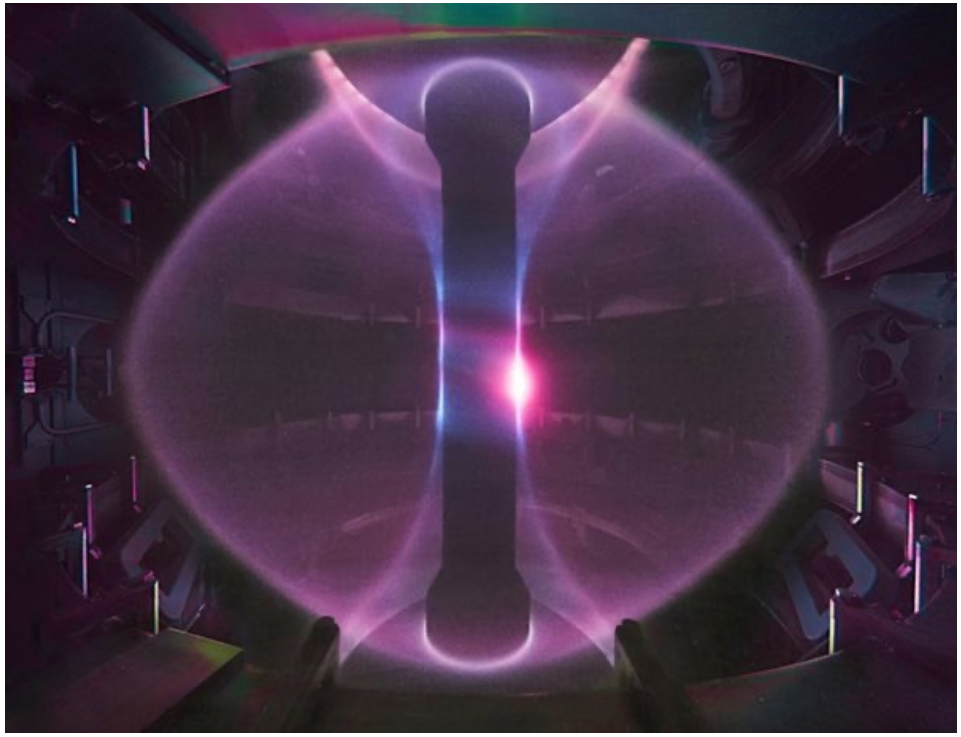
Motivation and outline

Confinement quality in fusion plasma is substantially affected by heavy particles.



Outline:

1. Model description

2. Simulation results

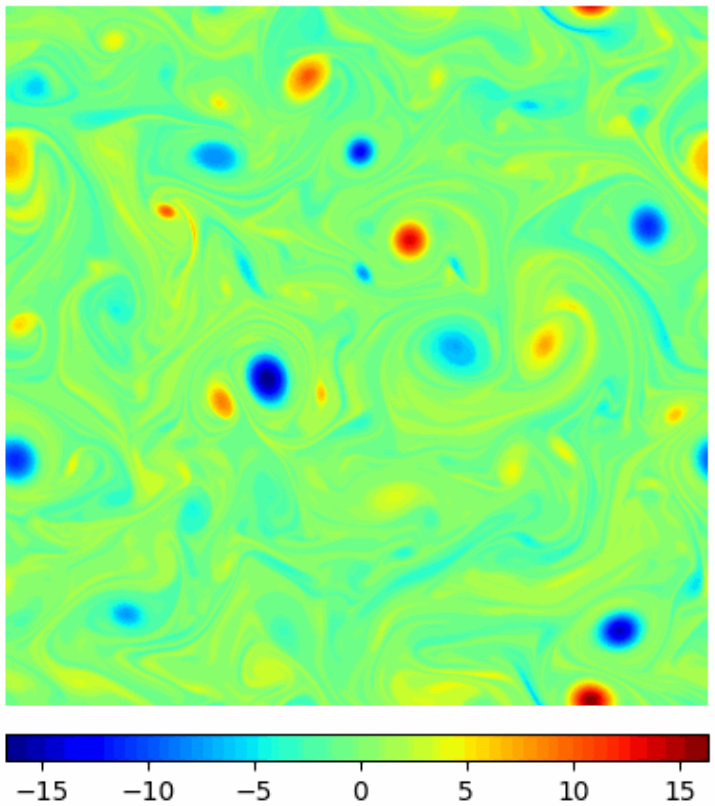
3. Synthesis of particle density using Neural Networks

Plasma Fluid Model

$$\left(\frac{\partial}{\partial t} - v\nabla^2\right)\nabla^2\phi = [\nabla^2\phi, \phi] + c(\phi - n),$$

$$\left(\frac{\partial}{\partial t} - D\nabla^2\right)n = [n, \phi] - \kappa\frac{\partial\phi}{\partial y} + c(\phi - n),$$

Not expensive



Particle Motion (10^4 particles)

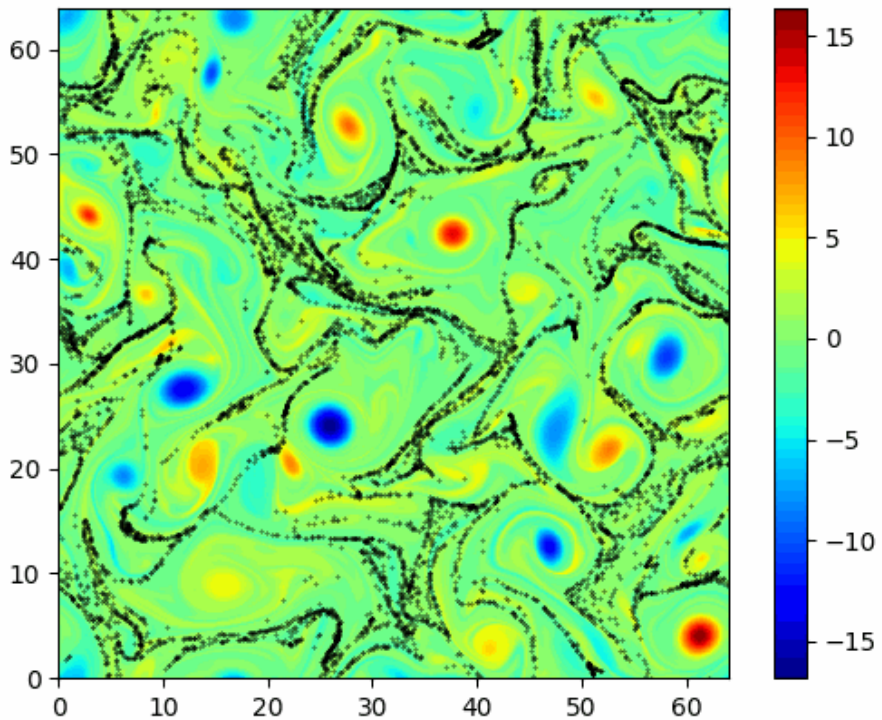
For position:

$$\frac{d\boldsymbol{x}_{imp,j}}{dt} = \boldsymbol{v}_{imp,j}$$

For velocity:

$$\frac{d\boldsymbol{v}_{imp,j}}{dt} = -\frac{\boldsymbol{v}_{imp,j} - \boldsymbol{u}_{imp,j}}{\tau_p}$$

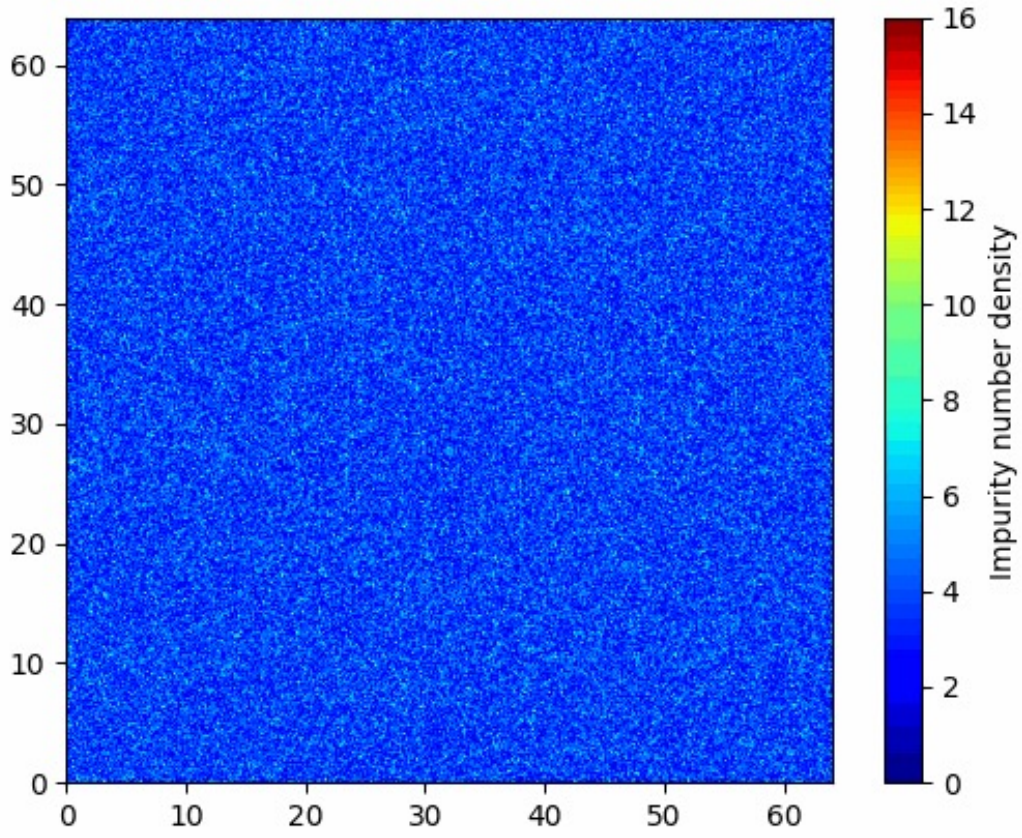
Not expensive



Particle density field (10^6 particles)

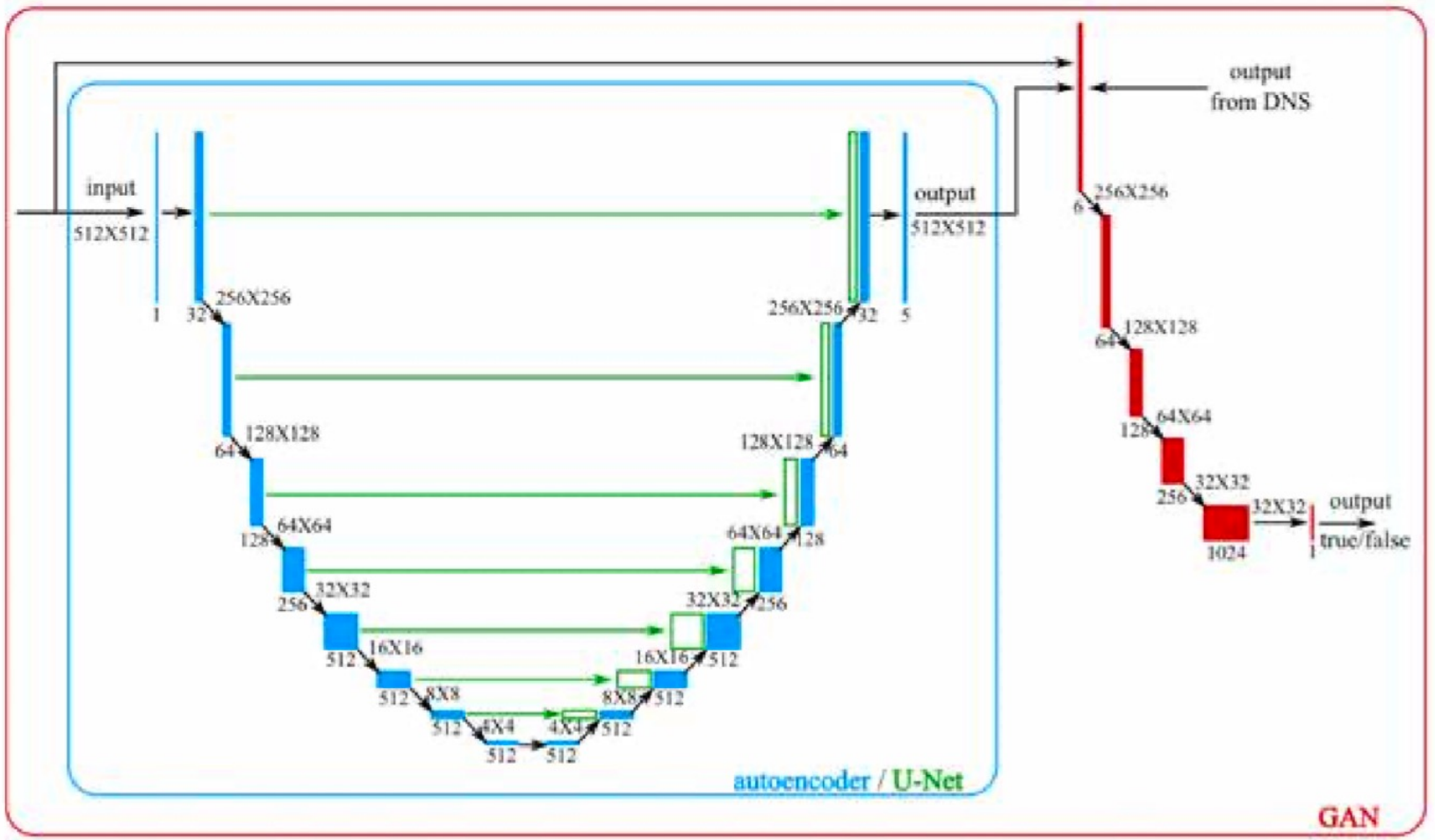
Increase the number particles from 10^4 to 10^6, and calculate the particle density.

very expensive!



Neural Networks for Synthesizing Particles Preferential Concentration

Simulating a million particles is costly. We will use Neural Networks to estimate density distribution.



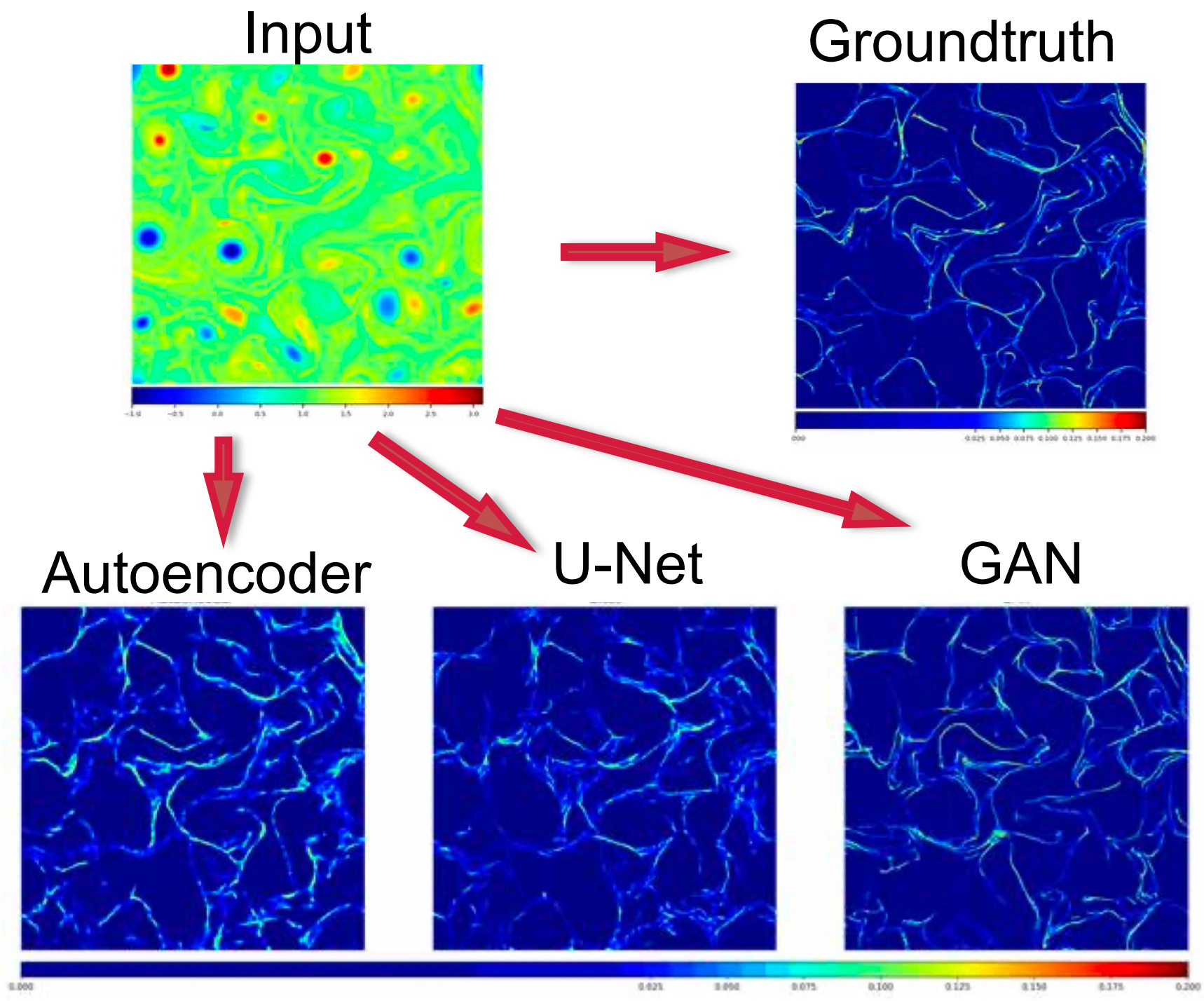
The goal is to input vorticity field (not costly) to predict the particle density (costly form DNS)

Autoencoder, U-Net and GAN

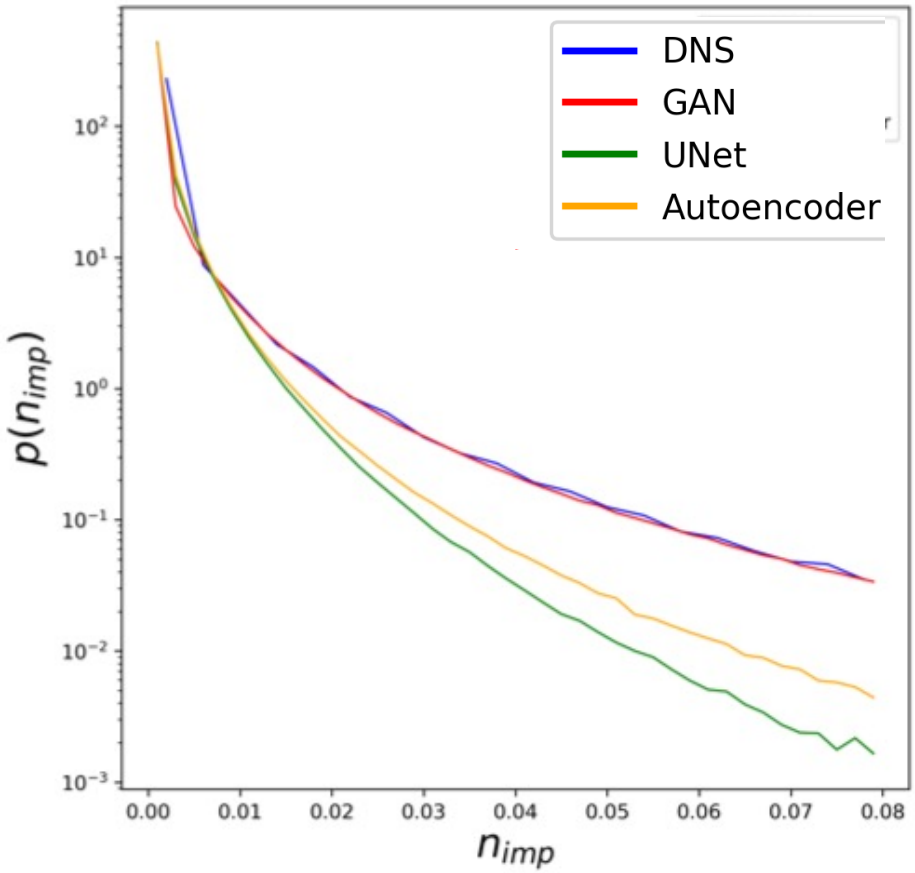
Autoencoder is composed of of an encoder that compresses the data, and a decoder that reconstructs the output from this compressed version.

U-Net is essentially an Autoencoder but with added skip connections. These connections facilitate non-sequential connections between layers which helps in the preservation of information throughout the network

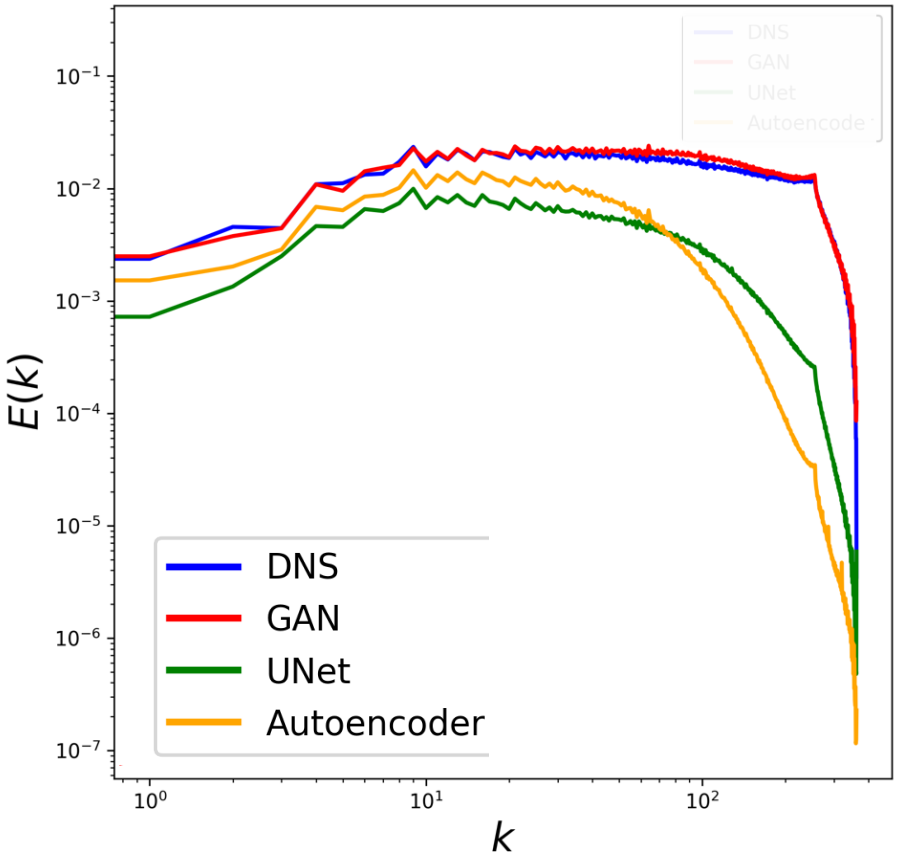
GAN (Generative Adversarial Network)consist of two neural networks, a Generator and a Discriminator, trained simultaneously through adversarial processes. The Generator attempts to produce synthetic data, while the Discriminator tries to distinguish between real and synthetic data. We use U-Net as the generator


Input
Groundtruth
Autoencoder
U-Net
GAN

PDF and Energy Spectra of Impurity Density (c =0.7, St = 1)



(a) PDFs of impurity density n_{imp}



(b) energy spectra

- GAN model excels in predicting the density distribution,
- GAN's energy spectrum is nearly identical to that of the DNS data.

Summary

- Simulating the flow is not costly
- Adding and tracking 10^6 particles is costly
- Neural Networks(Autoencoder, U-Net, GANs) are used for building surrogate model to reduce the cost.
- GANs outperform the other two.