PHY654

Machine learning (ML) in particle physics

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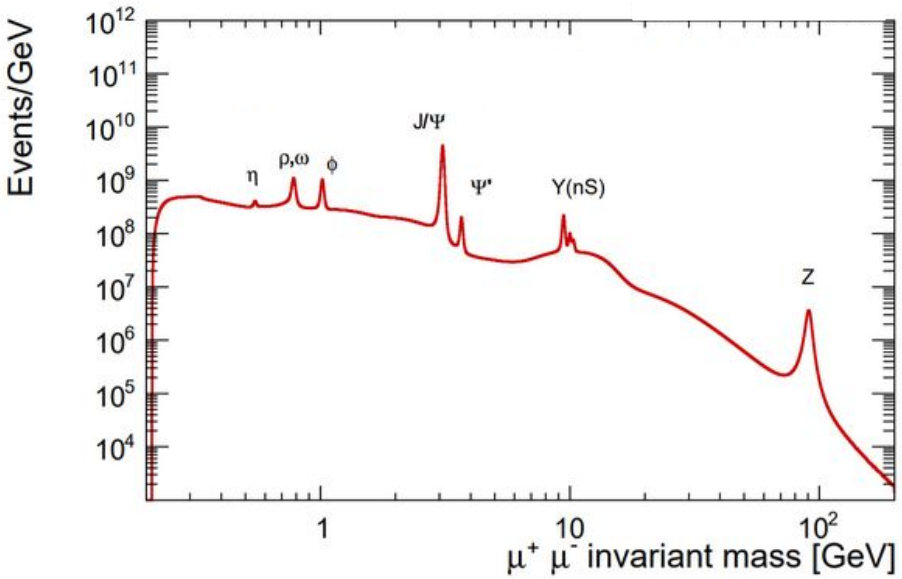
Invariant mass

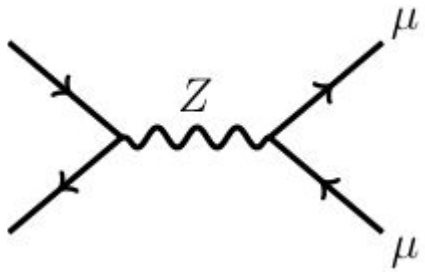
$$M = \sqrt{(E_1 + E_2)^2 - \|\mathbf{p}_1 + \mathbf{p}_2\|^2} = \sqrt{(E_1 + E_2)^2 - ((p_{1_x} + p_{2_z})^2 + (p_{1_y} + p_{2_y})^2 + (p_{1_z} + p_{2_z})^2)}$$



If invariant mass is calculated using two particles (here: 2 muons) that come from the decay of another particle (let's call it parent particle), we will get a value that is close to the mass of the parent particle.

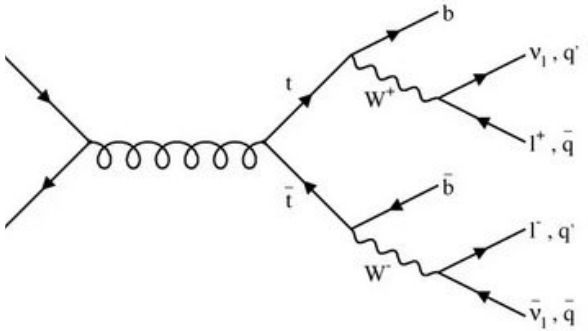
https://github.com/swagata87/IITKanpurPhy654/blob/main/invariant_mass.ipynb

Invariant mass can be useful feature for ML



y=1 class

Di-muon invariant mass will show a peak near Z mass (~91 GeV)



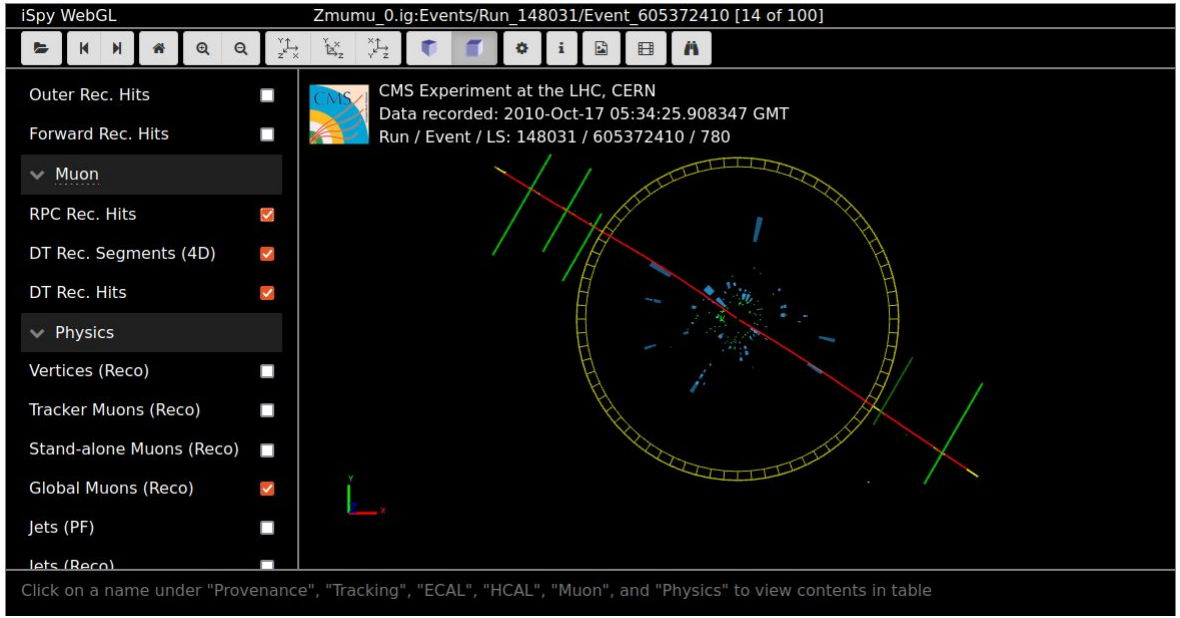
y=0 class

Even if two muons are found, their invariant mass is less likely to be around ~91 GeV

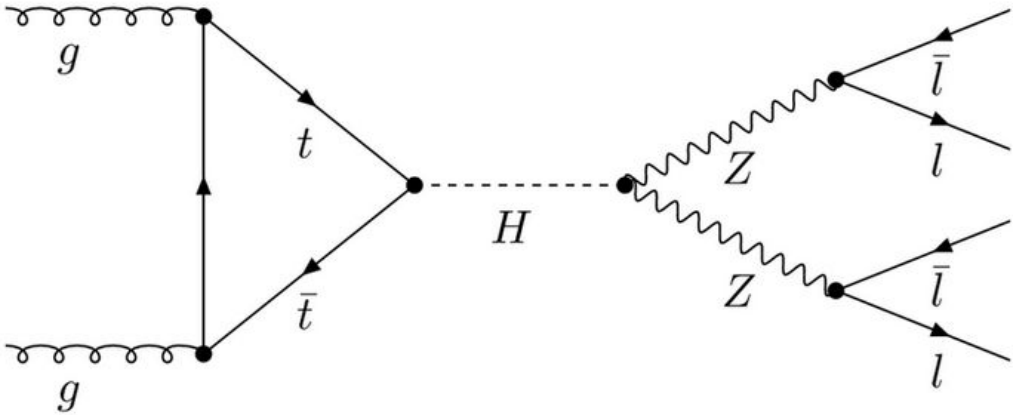
Event display

https://opendata.cern.ch/record/307

https://ispy-webgl-masterclass.web.cern.ch/

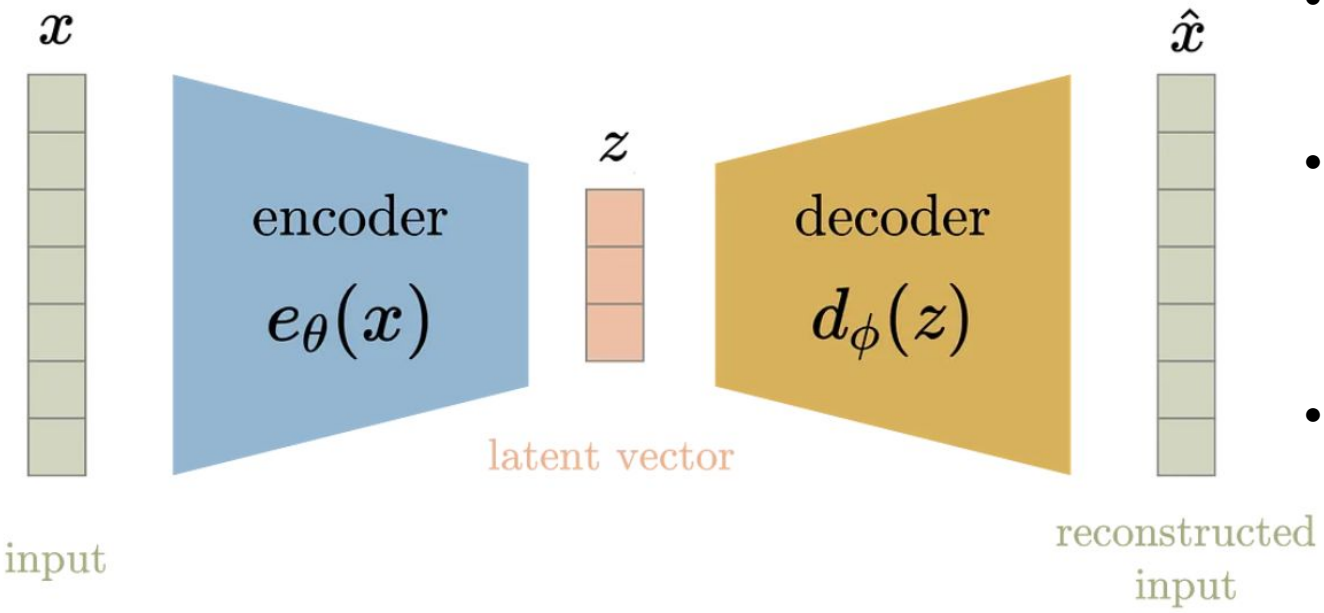


Invariant mass with >2 particles



https://github.com/swagata87/IITKanpurPhy654/blob/main/Higgs_discovery_4l_invMass.ipynb

Plain autoencoder

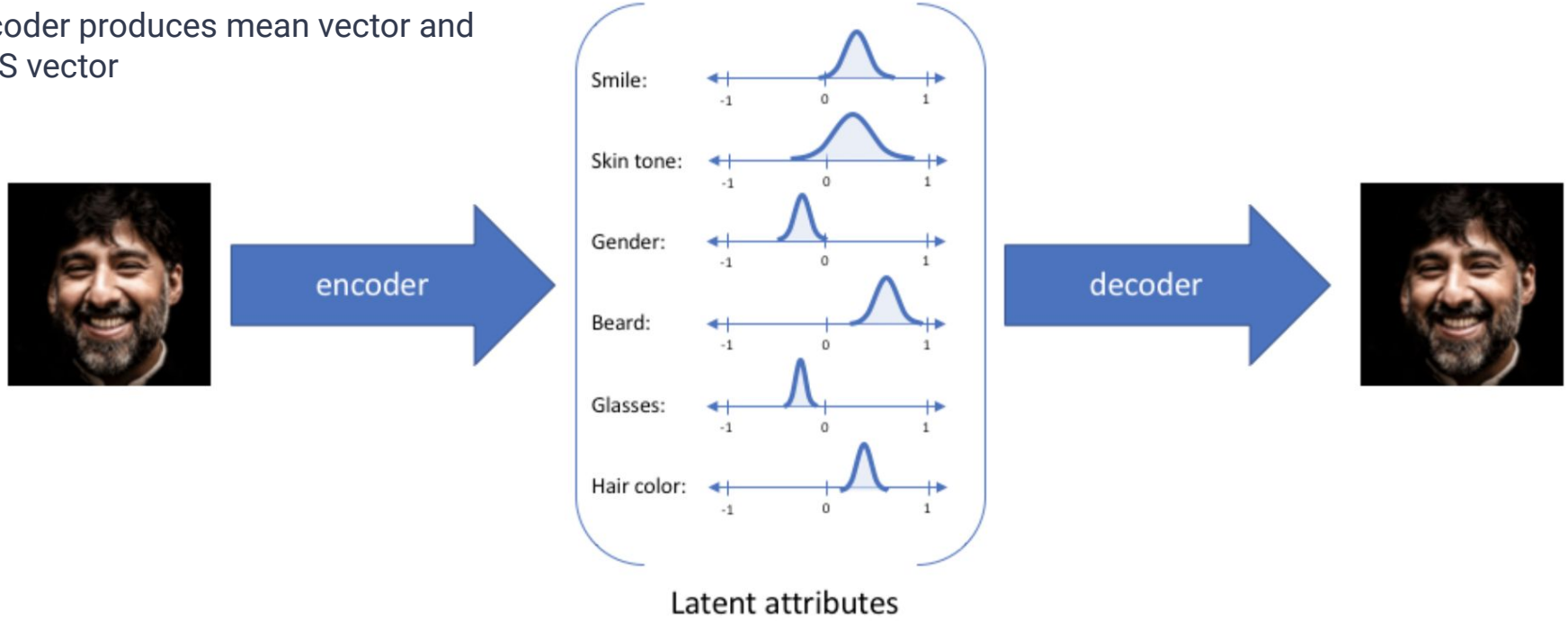


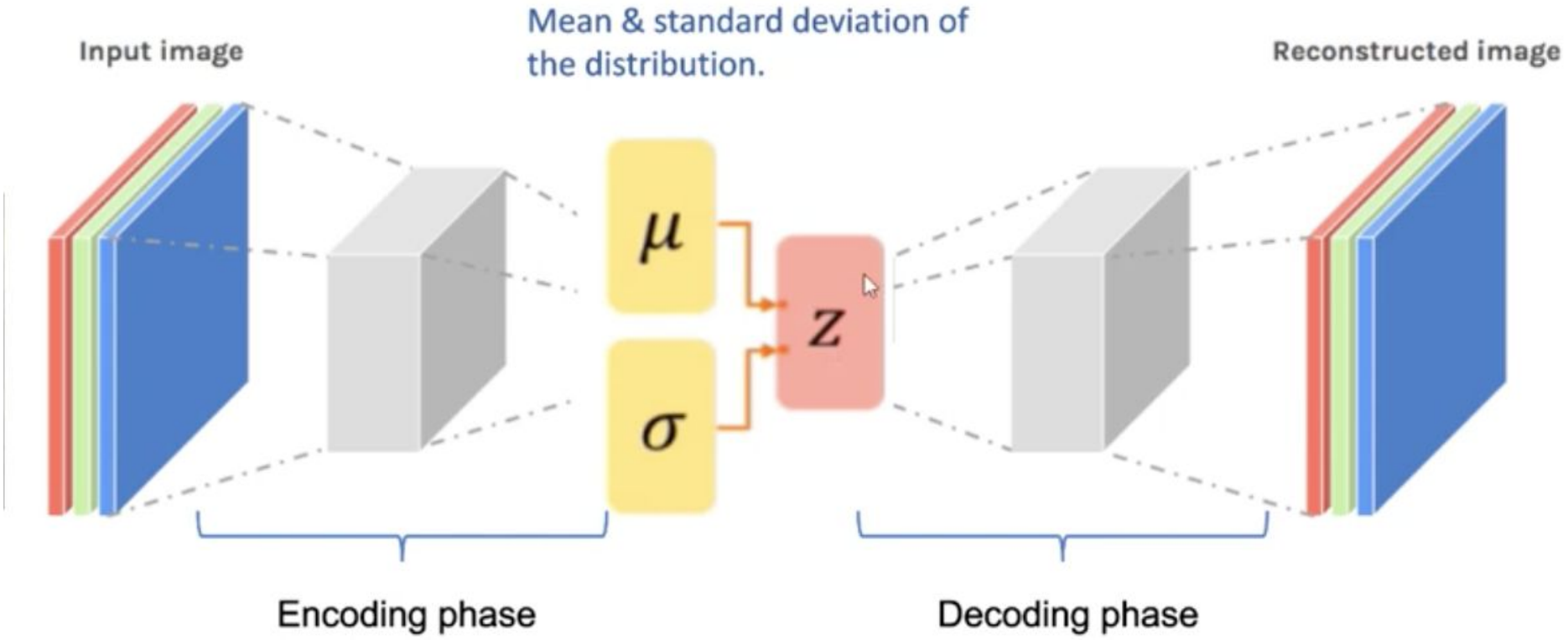
- We can use it to generate a compressed form of input in a latent space
- Picking a random latent variable will generate garbage output, i.e., the latent space lacks the generative capability
- Plain autoencoder is not a generative model

https://github.com/swagata87/IITKanpurPhy654/blob/main/autoEncoder.ipynb

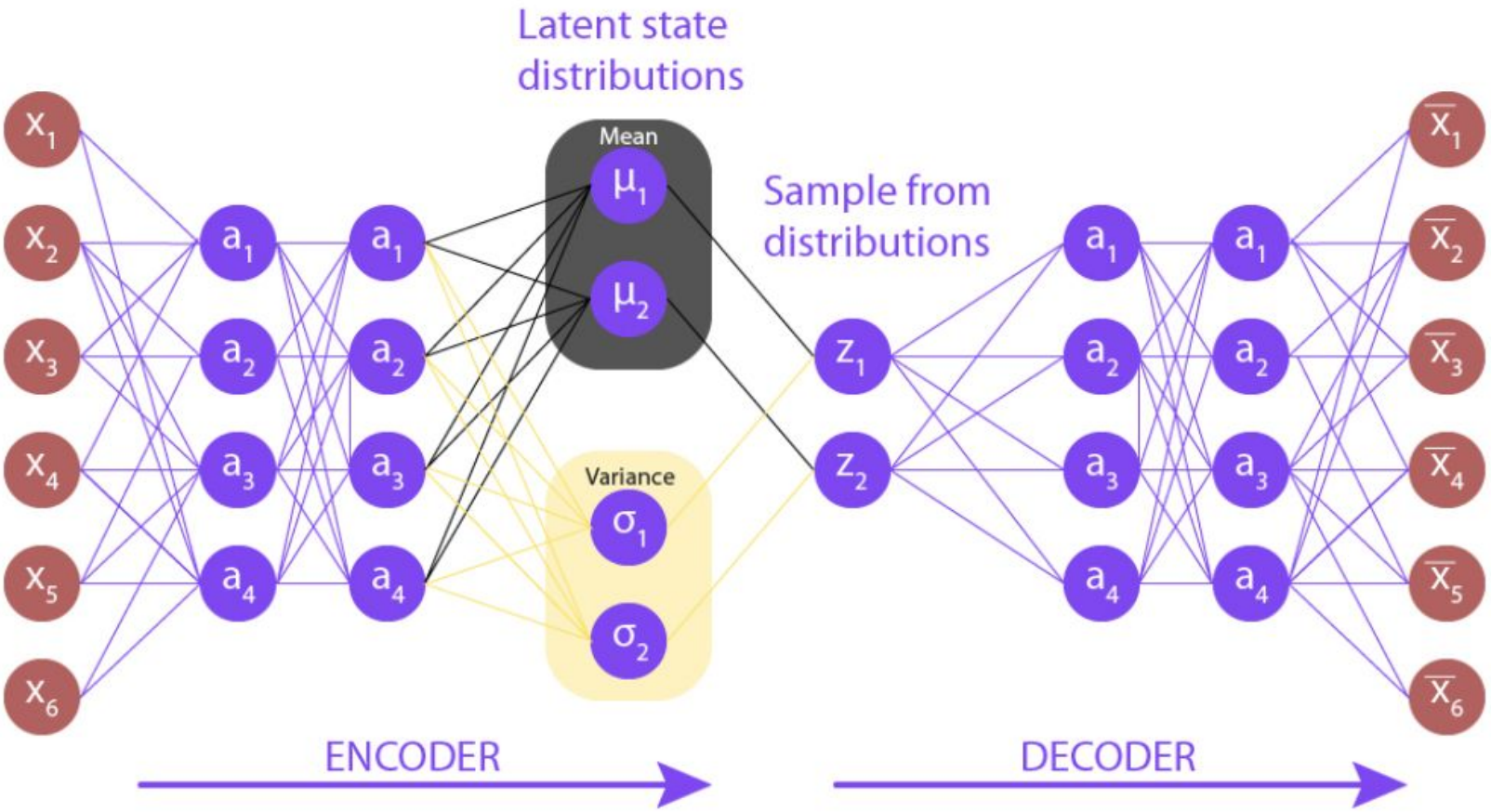
Variational Autoencoder

Encoder produces mean vector and RMS vector





https://arxiv.org/pdf/1312.6114


Latent state distributions
Mean
Variance
Sample from distributions
ENCODER
DECODER

```
inputs = keras.Input(shape=(original_dim,))
h = layers.Dense(intermediate_dim, activation='relu')(inputs)

mean = layers.Dense(latent_dim, activation='relu')(h)
log_var = layers.Dense(latent_dim, activation='relu')(h)
```

Variance can be a very small number close to 0. May lead to numerical instability during training. Use ‘log’ to avoid this issues; ‘log’ makes the range bigger. Stable training process be achieved.