MACHINE LEARNING IN JET PHYSICS

Sreedevi Narayana Varma

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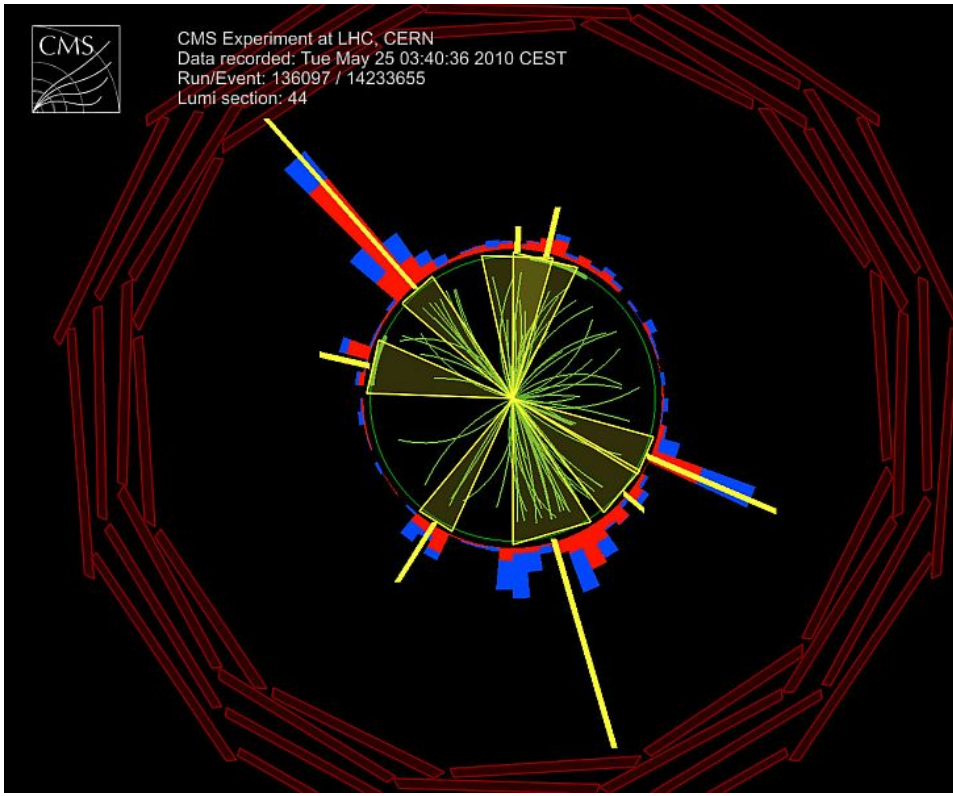
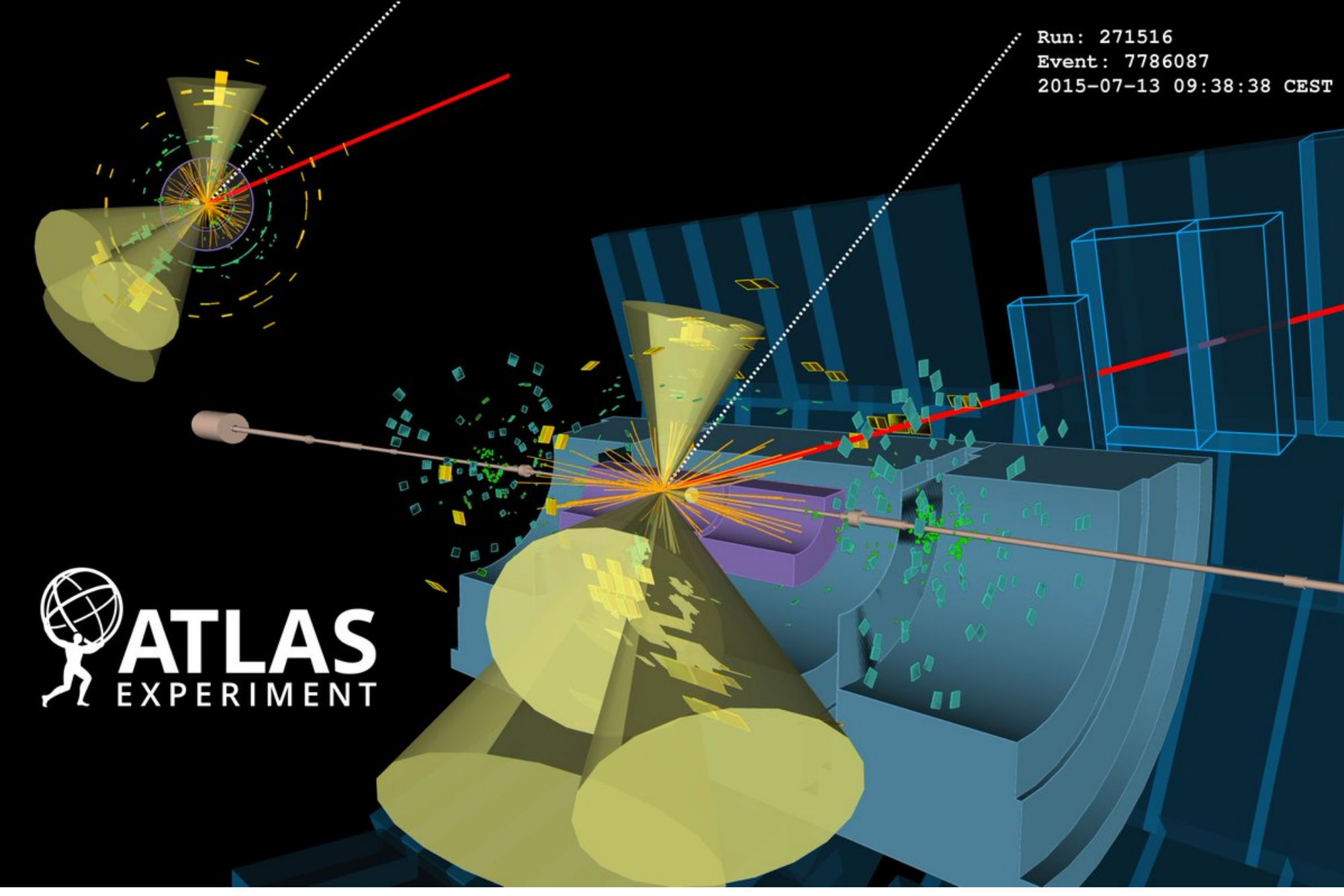
Content

Introduction

- Jets are collimated stream of particles produced by particle collisions.

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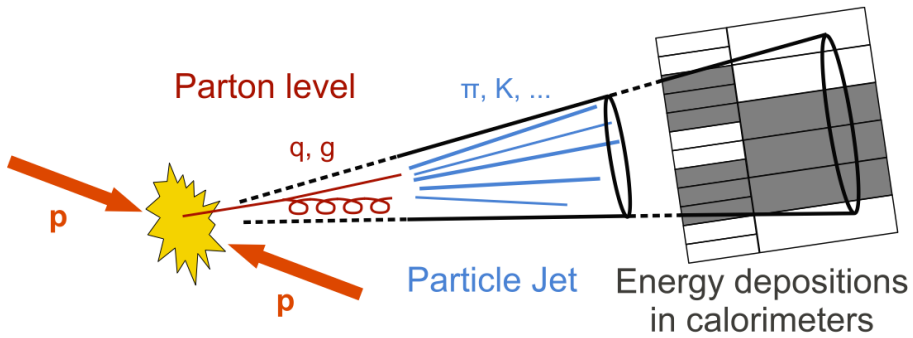
ATLAS
EXPERIMENT

1. Protons collide at high energies.
2. Quarks and gluons produced are hadronized.
3. The decay products are clustered into jets using algorithms.

Is the jet quark initiated or gluon initiated? 🤔



- In many searches for new physics signals at the LHC, jets are initiated by light-flavor quarks (u, d, s), while the jets background processes are initiated by gluons.

- We are currently working on,
  - Classification of quark and gluon initiated jets.
  - Bias between the event generators.
  - Bias between real and simulated data.

Quark/Gluon Jets

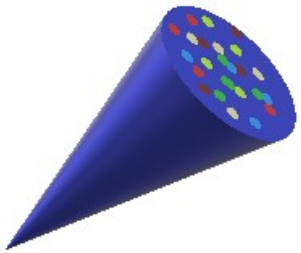


Figure: Quark jet

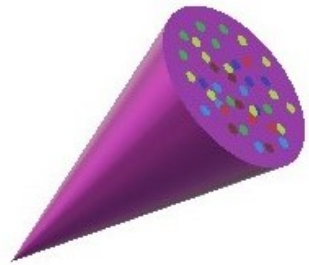


Figure: Gluon jet

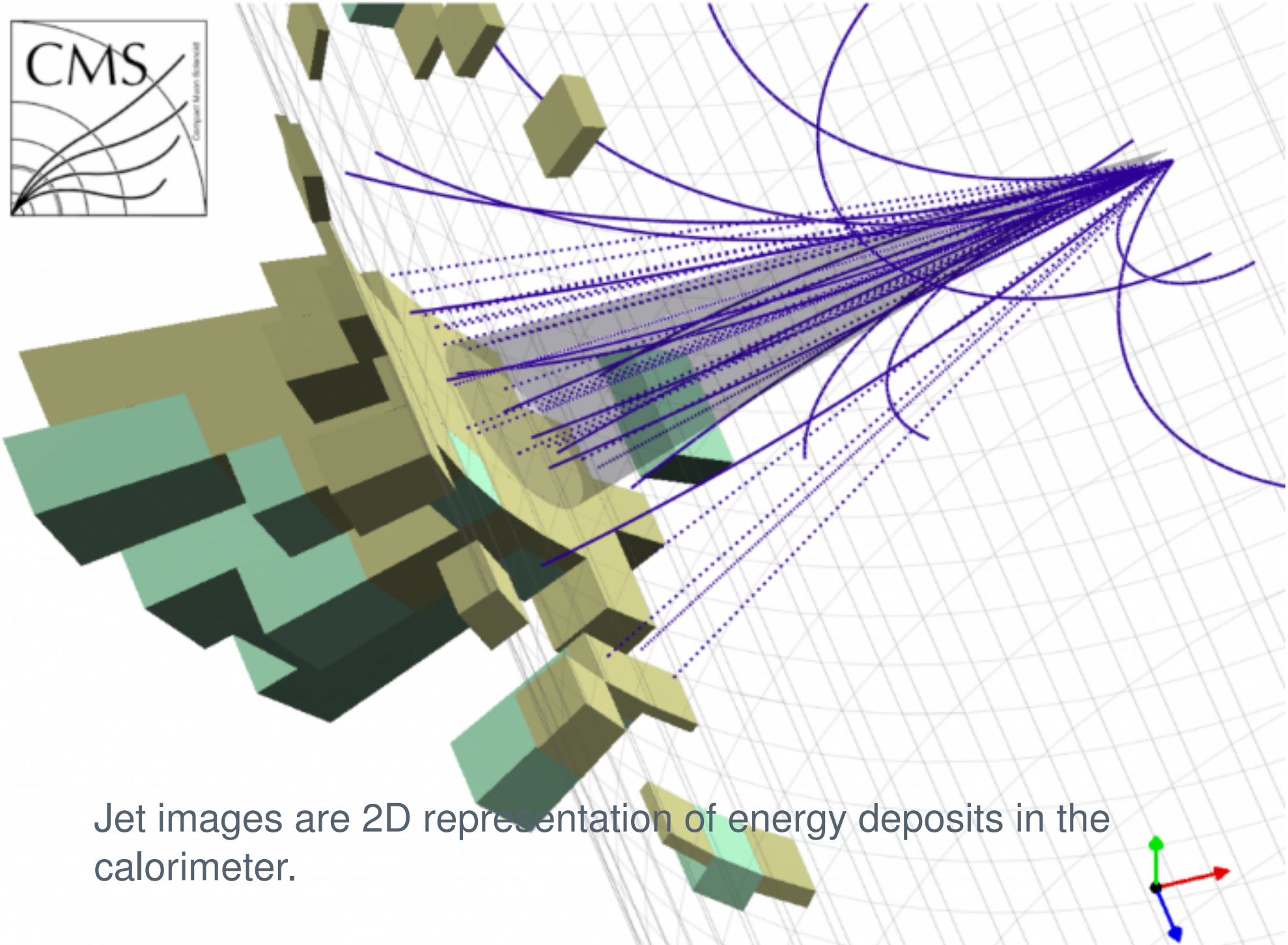
- Quark initiated jets are narrower

$$C_F = \frac{4}{3}$$

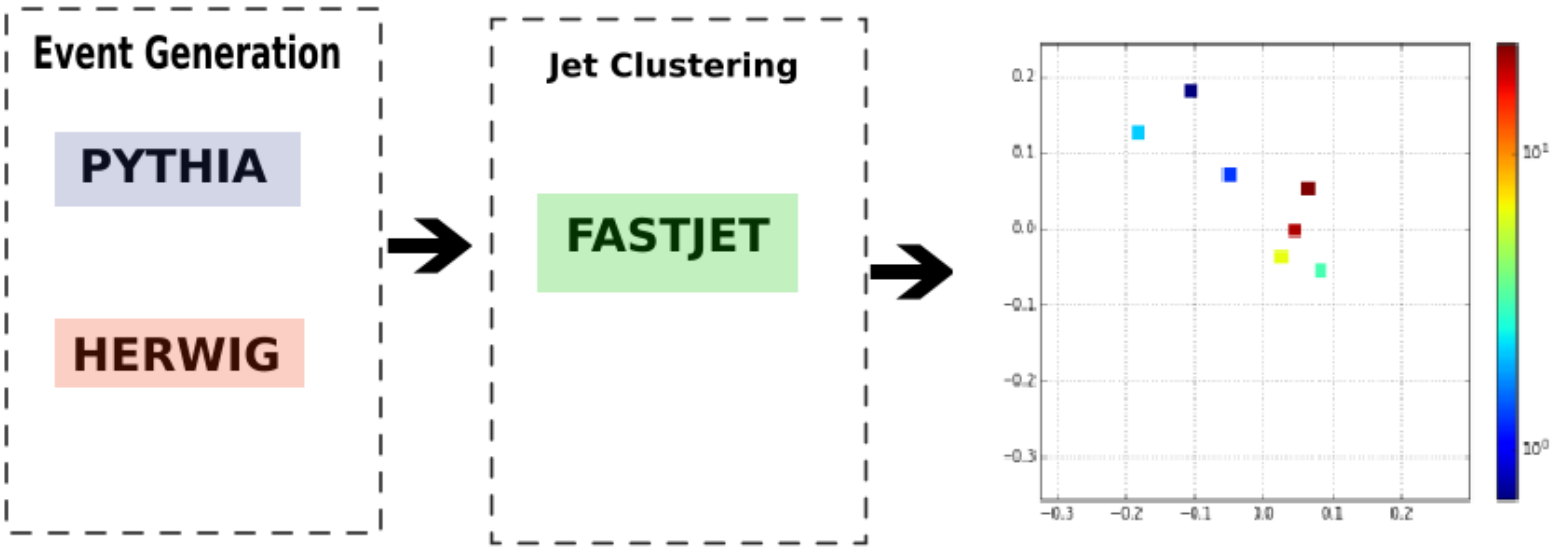
- Gluon initiated jets are more wide.

$$C_A = 3$$

B.R.Webber, Quark and Gluon Jets in Quantum Chromodynamics, Physica Scripta, vol 25, no 1B, p 198, 1982



Jet images are 2D representation of energy deposits in the calorimeter.


Event Generation
PYTHIA
HERWIG
Jet Clustering
FASTJET
0.2
0.1
0.0
−0.1
−0.2
−0.3
−0.3
−0.2
−0.1
0.0
0.1
0.2
10^1
10^0

Processes

- Quark-initiated jets
  - $qq \to qq$
  - $q\bar{q} \to q\bar{q}$
  - $gg \to q\bar{q}$
- Gluon- initiated jets
  - $gg \to gg$
  - $q\bar{q} \to gg$

P. T. Komiske, E. M. Metodiev, M. D. Schwartz, Deep learning in color: towards automated quark/gluon jet discrimination, arXiv:1612.01551 [hep-ph]

Parameters

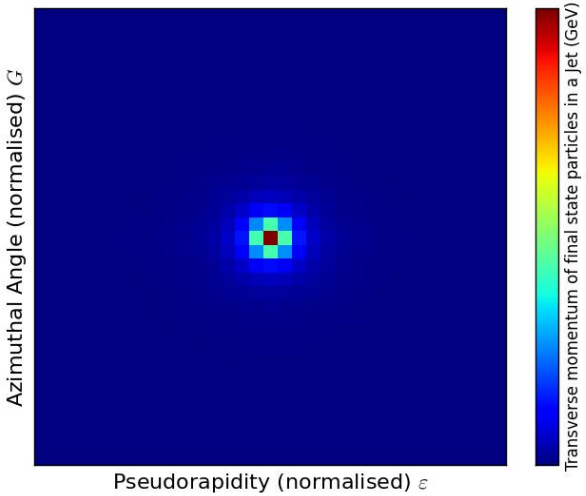
- Radius = 0.4
- Pseudorapidity $|\eta| < 2.5$
- Transverse momentum in ranges 100-110 GeV, 200-220 GeV, 500-550 GeV and 1000-1100 GeV.

P. T. Komiske, E. M. Metodiev, M. D. Schwartz, Deep learning in color: towards automated quark/gluon jet discrimination, arXiv:1612.01551 [hep-ph]

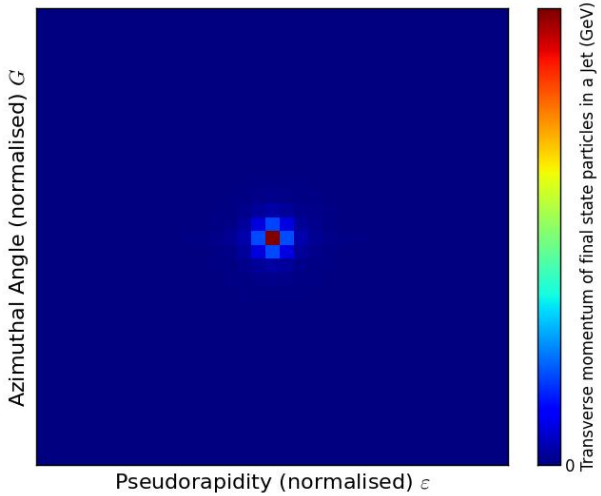
Preproccessing

1. Centering: The jet is rotated and boosted so that the central pixel is at $(0, 0)$.
2. Crop: Crop the image with $(\eta, \phi)\epsilon(-R, R)$.
3. Normalize: Total pixel intensity of the image is $\sum I_{ij} = 1$.
4. Zero-center: $I_{ij} \rightarrow I_{ij} - \mu_{ij}$, where μ_{ij} is the average of the training set.
5. Standardize: $I_{ij} \rightarrow I_{ij}/(\sigma_{ij} + r)$ where σ_{ij} is the standard deviation of the training set and $r = 10^{-5}$.

P. T. Komiske, E. M. Metodiev, M. D. Schwartz, Deep learning in color: towards automated quark/gluon jet discrimination, arXiv:1612.01551 [hep-ph]

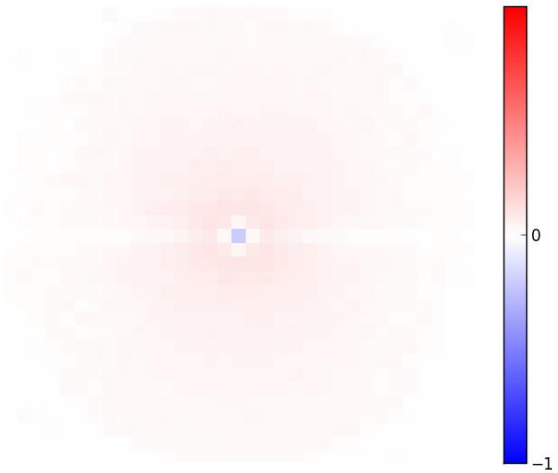


(a) Average gluon image before preprocessing steps 4-5

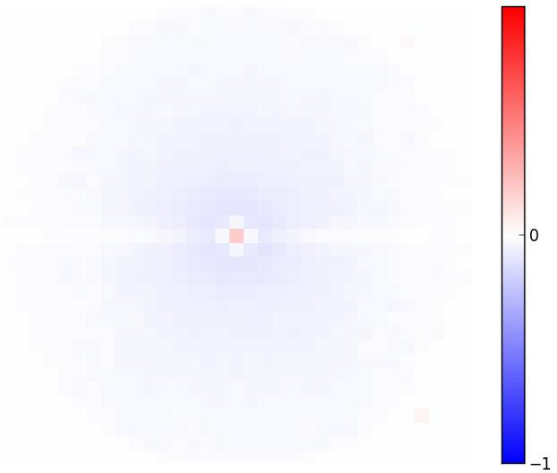


(b) Average quark image before preprocessing steps 4-5

Figure: Jet-Images



(a) Average gluon image after preprocessing



(b) Average quark image after preprocessing

Figure: Jet-Images

Convolutional Neural Networks

- Convolutional Neural Network (CNN) are neural networks for image recognition and image classification.
- CNN scans over the two dimensional pixel intensities of an RGB image.

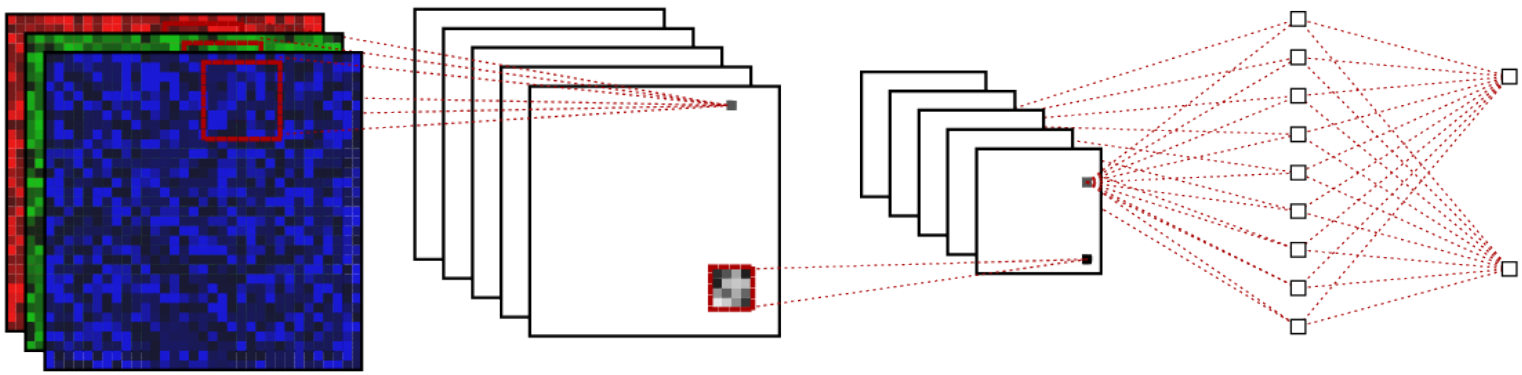


Figure: Convolutional Neural Network

P. T. Komiske, E. M. Metodiev, M. D. Schwartz, Deep learning in color: towards automated quark/gluon jet discrimination, arXiv:1612.01551 [hep-ph]

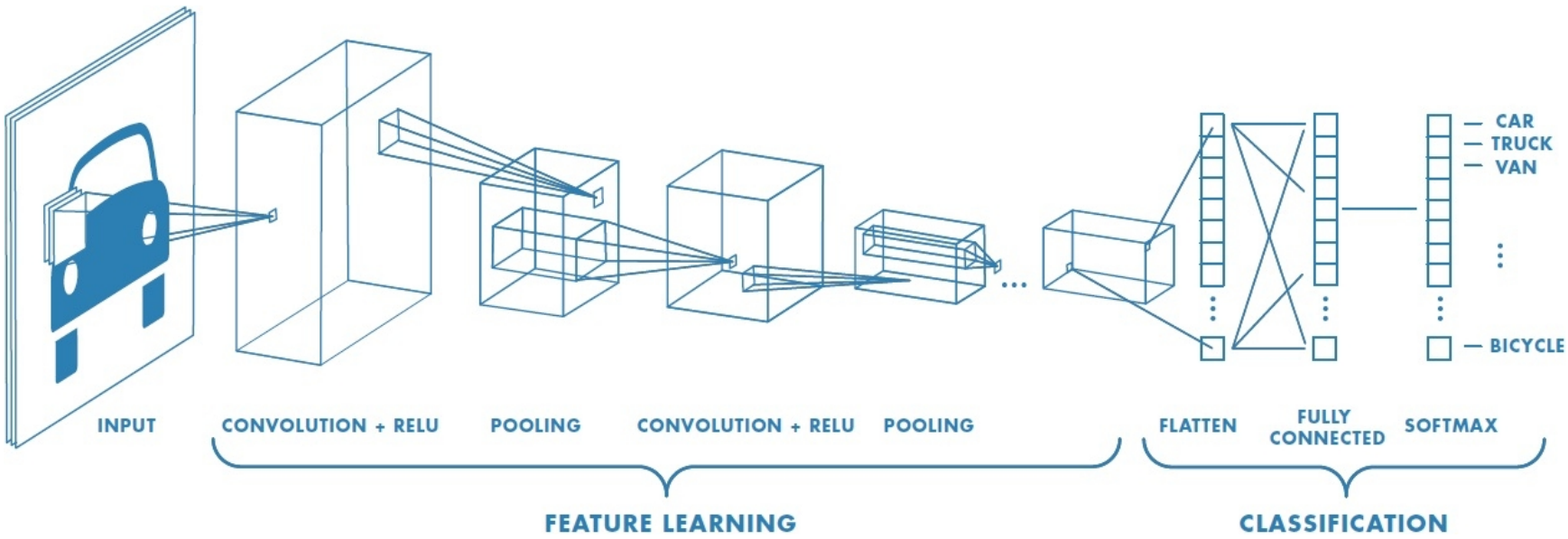


Figure: Components of a CNN

Deep Learning on Jet-Images

- Jet images of size 33×33.
- 3 convolutional layer and 2 fully connected layer.
- ReLU (Rectified Linear Unit) activation.

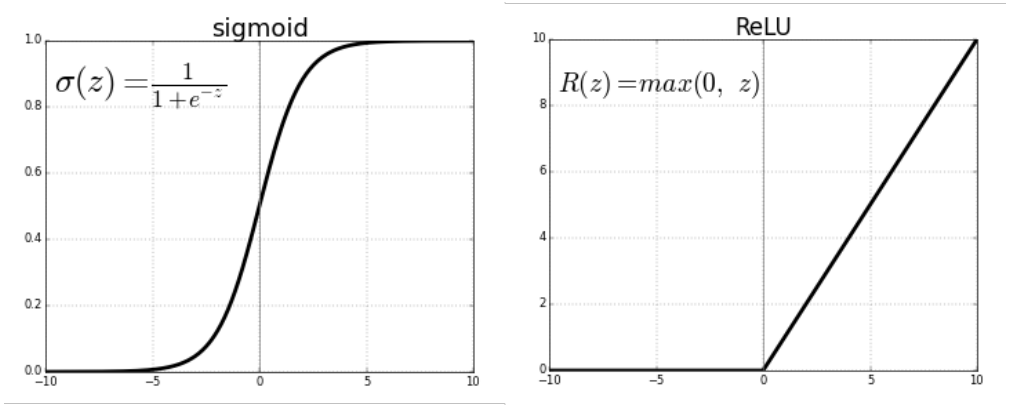


Figure: ReLU and Sigmoid activations

- Filters of size 8×8, $4 \times 4$and 4×4 are used.
- Maxpooling layers 2×2 is also applied to the CNN with a stride length of 2.
- The fully connected layer consists of 128 units.

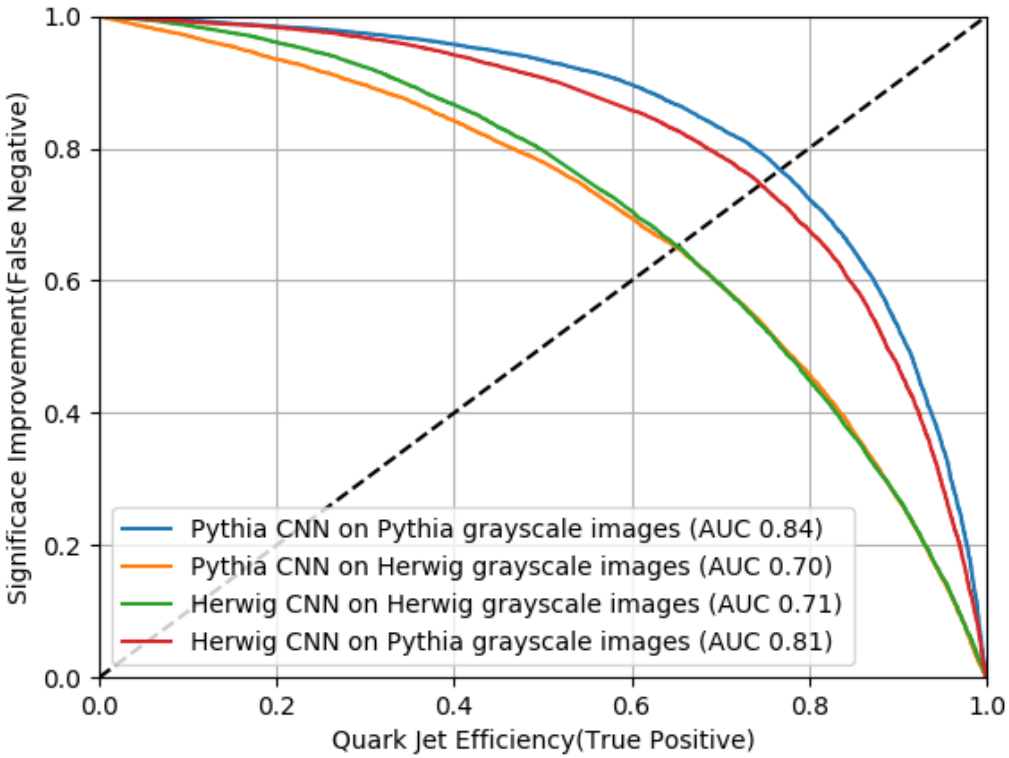
- The jet images produced are fed into the network as grayscale images.
- An additional information of charge is applied to improve the accuracy of the model.
- “Colour” images with colour channels,
  - RED = Transverse momentum of charge particles.
  - GREEN = Transverse momentum of neutral particles.
  - BLUE = Charge particle multiplicity.
- The “coloured” images are then trained.

P. T. Komiske, E. M. Metodiev, M. D. Schwartz, Deep learning in color: towards automated quark/gluon jet discrimination, arXiv:1612.01551 [hep-ph]

- CNN is trained on Tensorflow using NVIDIA GeForce 1080Ti GPU on Cuda 9.0 platform.
- The network is trained over 100 epochs with a learning rate α of 0.001.
- 180000 jet images are used for training, 20000 images for validation and 40000 images are used for testing.

Results and Future Works

- Pythia test images are better than Herwig test images.



Comparison of machine learning algorithms trained on Herwig and Pythia.

Domain Adversarial Neural Netwrok (DANN)

- Domain adversarial neural network is a new learning approach for data trained and tested on similar but different distributions.

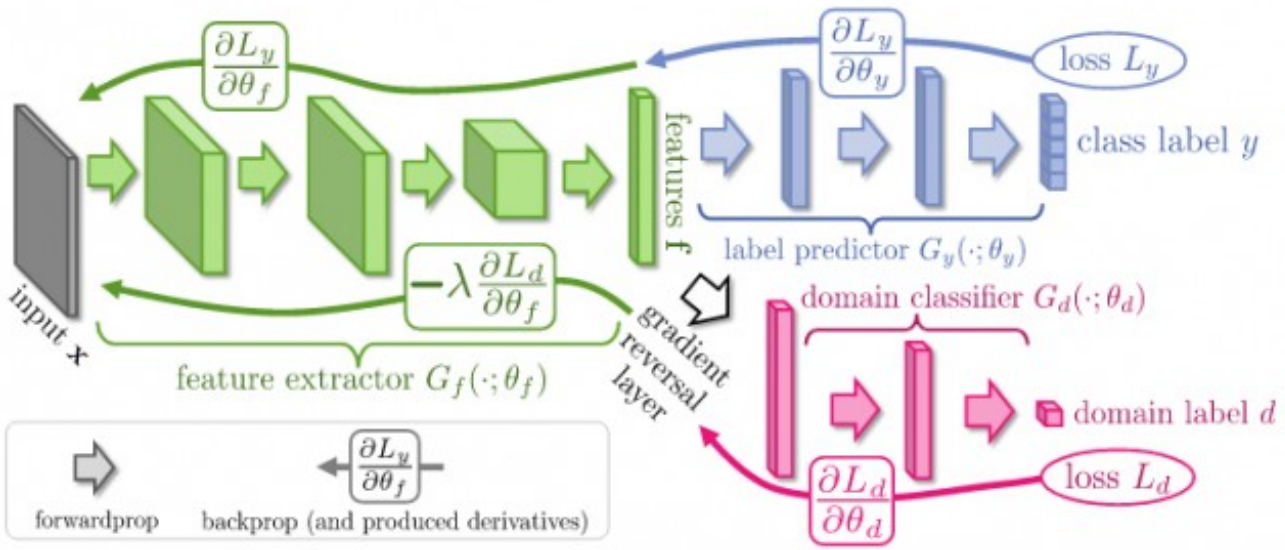
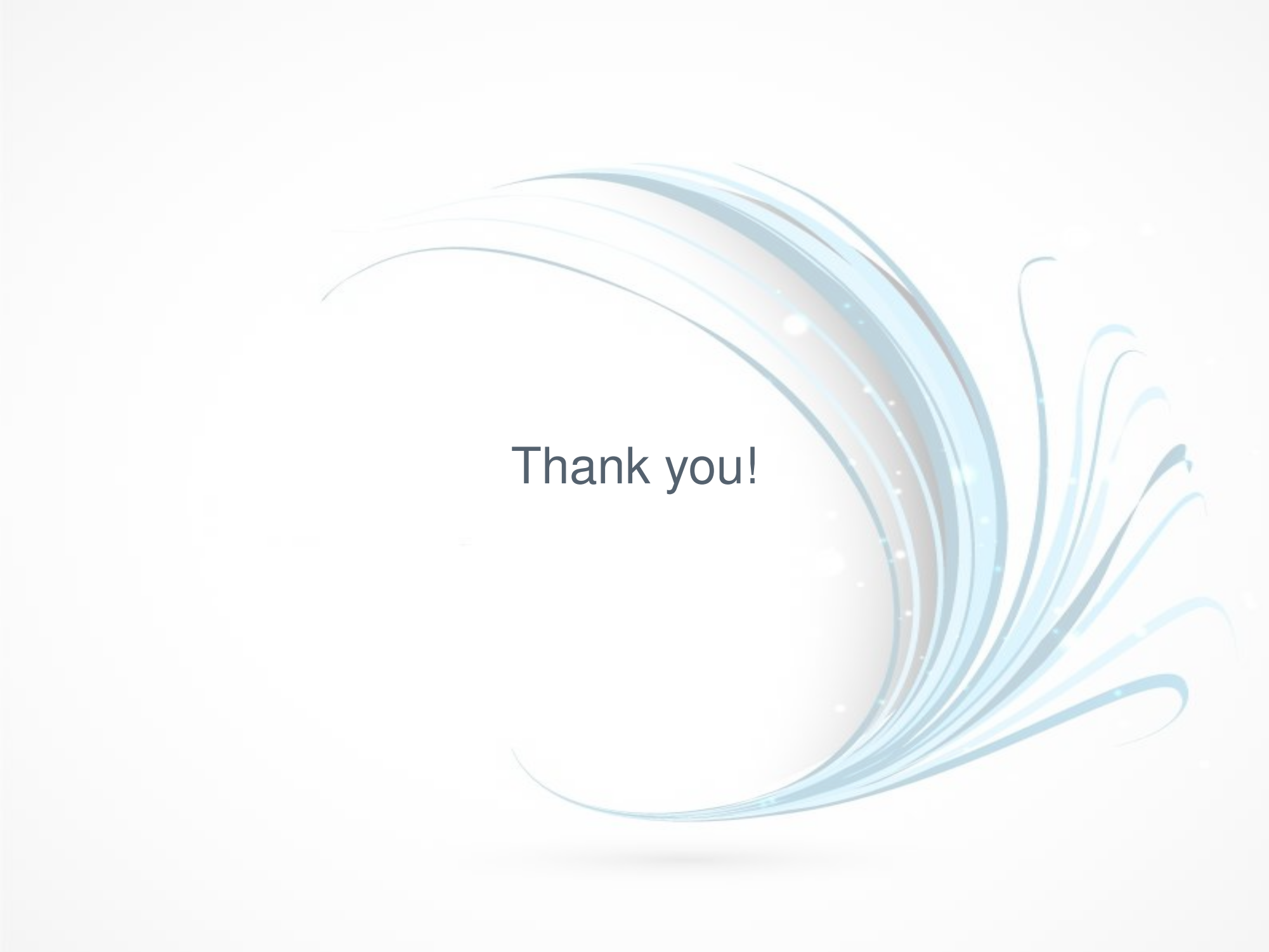


Figure: DANN architecture

Y. Ganin et al. , Domain-Adversarial Training of Neural Networks, arXiv:1505.07818 [stat]


Thank you!