Machine learning Project

Topic: Application of convolutional neural nets to identify jets at LHC

Shivam Verma
Research scholar, Dept. of physics
RKMVERI

Common terminology

Jets- A jet is a narrow cone of hadrons and other particles produced by the hadronization of a quark or gluon in a particle physics or heavy ion experiment.

Pseudorapidity(η) - It is a commonly used spatial coordinate describing the angle of a particle relative to the beam axis

Azimuthal angle (ϕ)- The angle measured orthogonally to the beam line.

Dataset Visualization

File Content

```
In [2]: ip = 'Data/JetDataset/jetImage_7_100p_30000_40000.h5'
        f = h5py.File(ip)
        print(list(f.keys()))

['jetConstituentList', 'jetFeatureNames', 'jetImage', 'jetImageECAL', 'jetImageHCAL', 'jets', 'particleFeatureName
s']
```

- 'jetImage' contains the image representation of the jets (vector representing each jet).
- 'jetImageECAL' and 'jetImageHCAL' are the ECAL- and HCAL-only equivalent images. not being used.
- 'jetConstituentList' is the list of particles cointained in the jet. For each particle, a list of relevant quantities is stored
- 'particleFeatureNames' is the list of the names corresponding to the quantities contained in 'jetConstituentList'
- 'jets' is the dataset that contains target.
- 'jetFeatureNames' is the list of the names corresponding to the quantities contained in 'jets'

Features

```
In [10]: featurenames = f.get('jetFeatureNames')
         print(featurenames[:])
```

```
[b'j_ptfrac' b'j_pt' b'j_eta' b'j_mass' b'j_tau1_b1' b'j_tau2_b1'
 b'j_tau3_b1' b'j_tau1_b2' b'j_tau2_b2' b'j_tau3_b2' b'j_tau32_b1'
 b'j_tau32_b2' b'j_zlogz' b'j_c1_b0' b'j_c1_b1' b'j_c1_b2' b'j_c2_b1'
 b'j_c2_b2' b'j_d2_b1' b'j_d2_b2' b'j_d2_a1_b1' b'j_d2_a1_b2' b'j_m2_b1'
 b'j_m2_b2' b'j_n2_b1' b'j_n2_b2' b'j_tau1_b1_mmdt' b'j_tau2_b1_mmdt'
 b'j_tau3_b1_mmdt' b'j_tau1_b2_mmdt' b'j_tau2_b2_mmdt' b'j_tau3_b2_mmdt'
 b'j_tau32_b1_mmdt' b'j_tau32_b2_mmdt' b'j_c1_b0_mmdt' b'j_c1_b1_mmdt'
 b'j_c1_b2_mmdt' b'j_c2_b1_mmdt' b'j_c2_b2_mmdt' b'j_d2_b1_mmdt'
 b'j_d2_b2_mmdt' b'j_d2_a1_b1_mmdt' b'j_d2_a1_b2_mmdt' b'j_m2_b1_mmdt'
 b'j_m2_b2_mmdt' b'j_n2_b1_mmdt' b'j_n2_b2_mmdt' b'j_mass_trim'
 b'j_mass_mmdt' b'j_mass_prun' b'j_mass_sdb2' b'j_mass_sdm1'
 b'j_multiplicity' b'j_g' b'j_q' b'j_w' b'j_z' b'j_t' b'j_undef']
```

A total of 53 features

Particle representaion in data

```
First five entries:
[1. 0. 0. 0. 0.]
[1. 0. 0. 0. 0.]
[0. 0. 0. 0. 1.]
[1. 0. 0. 0. 0.]
[0. 0. 0. 1. 0.]
Last 5 entries:
[0. 0. 1. 0. 0.]
[1. 0. 0. 0. 0.]
[0. 1. 0. 0. 0.]
[0. 1. 0. 0. 0.]
[1. 0. 0. 0. 0.]
```

- [1, 0, 0, 0, 0] for gluons
- [0, 1, 0, 0, 0] for quarks
- [0, 0, 1, 0, 0] for Ws
- [0, 0, 0, 1, 0] for Zs
- [0, 0, 0, 0, 1] for Tops

Each of them are represent a unique particle with unique signature

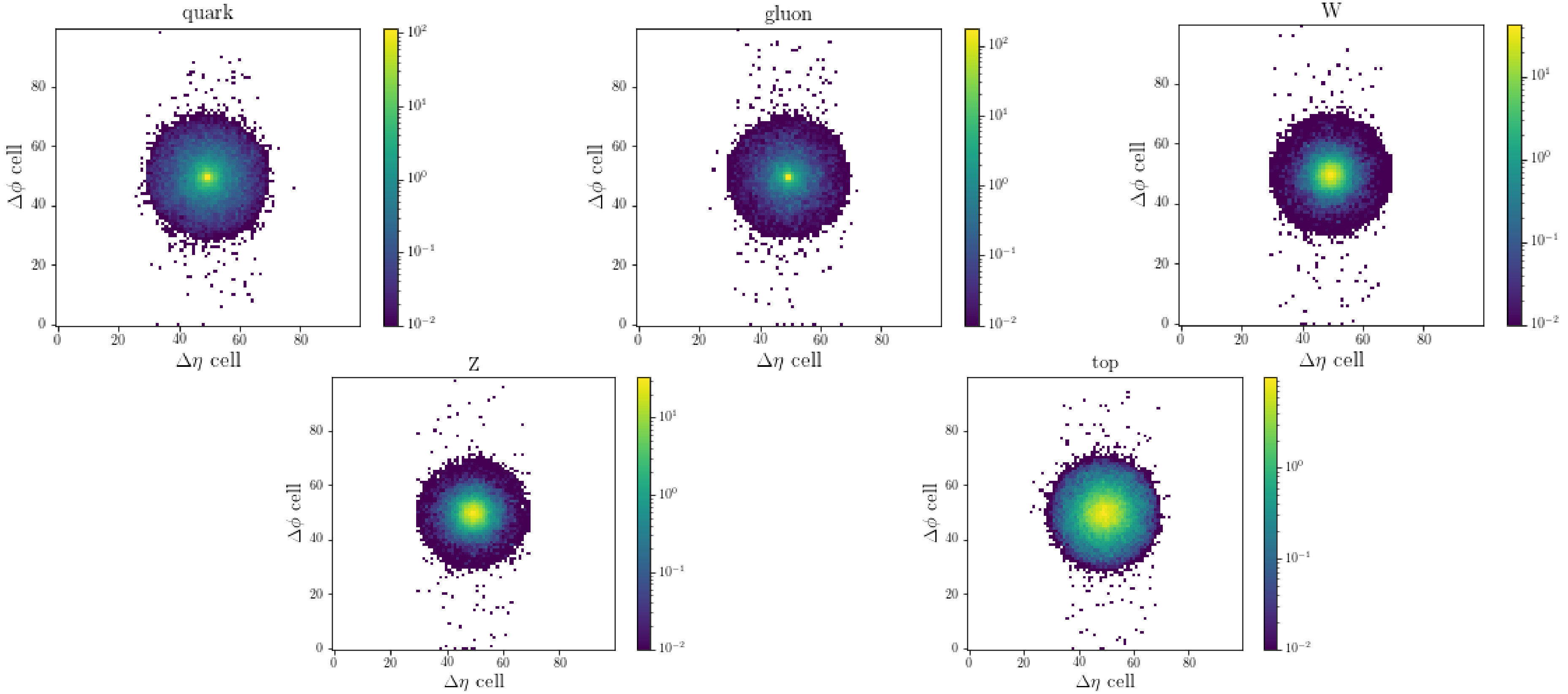
Image and target

```
print(target.shape, jetImage.shape)
```

```
Appending RKM_MLS_proj/Data/JetDataset/jetImage_7_100p_30000_40000.h5
Appending RKM_MLS_proj/Data/JetDataset/jetImage_7_100p_60000_70000.h5
Appending RKM_MLS_proj/Data/JetDataset/jetImage_7_100p_50000_60000.h5
Appending RKM_MLS_proj/Data/JetDataset/jetImage_7_100p_10000_20000.h5
Appending RKM_MLS_proj/Data/JetDataset/jetImage_7_100p_0_10000.h5
(50000, 5) (50000, 100, 100)
```

We can see that there are 50000 images, each of 100x100 size

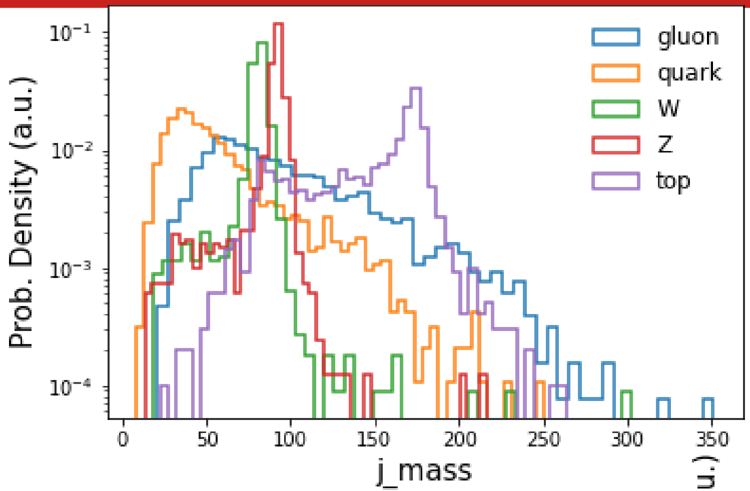
Image of particle jets in $\Delta\phi$ Vs $\Delta\eta$ plane

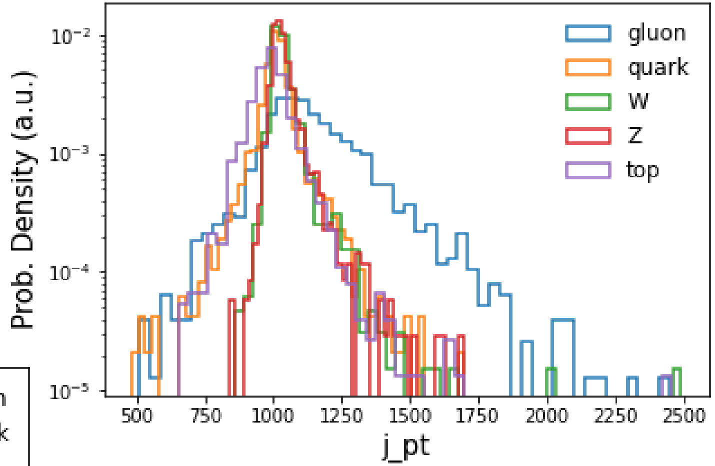


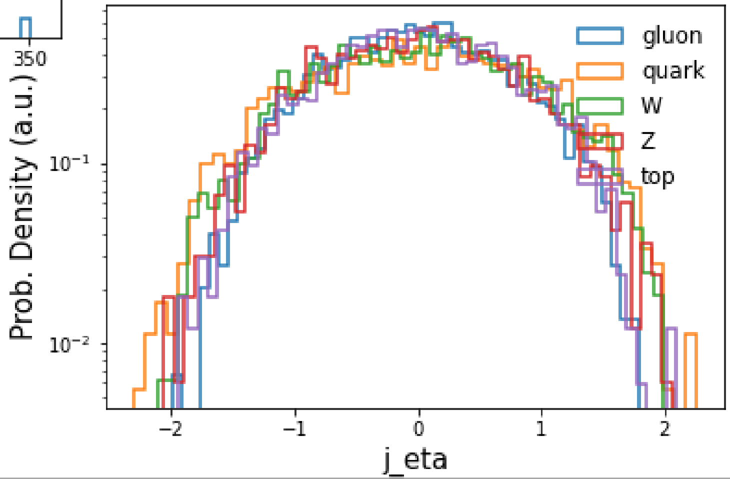
Average 100×100 images for the five jet classes. q (top left), g (top center), W (top right), Z (bottom left), and top jets (bottom right).

The temperature map represents the amount of pT collected in each cell of the image, measured in GeV and computed from the scalar sum of the pT of the particles pointing to each cell

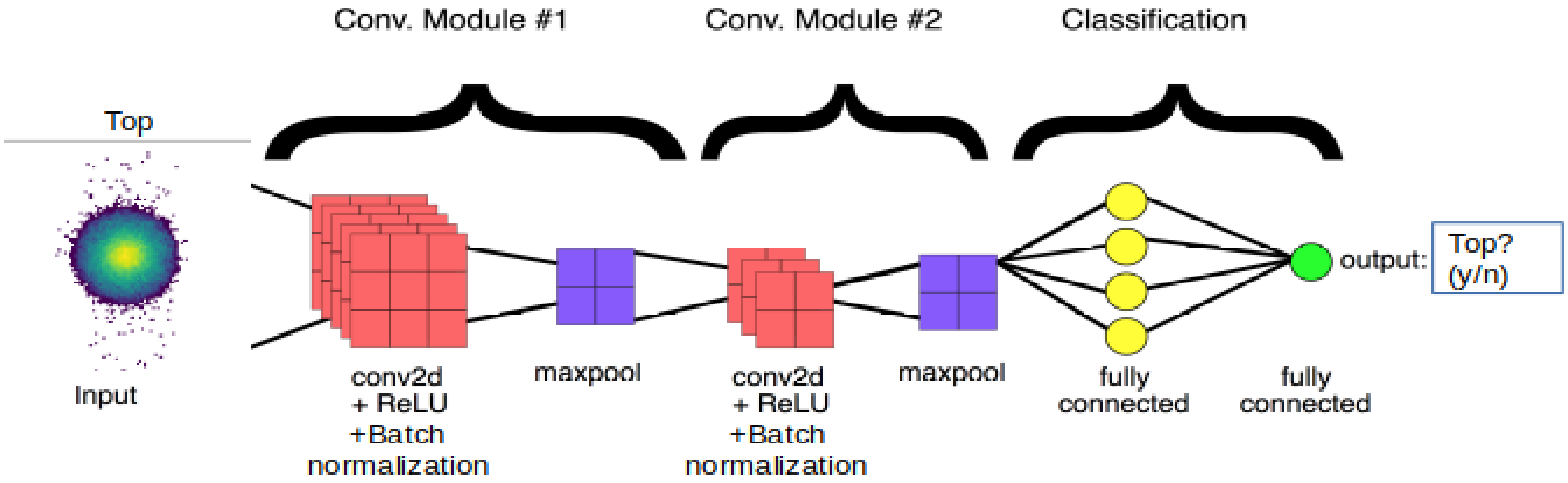
A few feature plots







Methodology for analysis



Convolutional filter

- The main ingredient of Convolutional neural network is a filter, i.e. a n x n' matrix to scan acoss the image matrix.
- The filter scans the image and performs a scalar product of each image patch while sliding through the whole image.
- This results into a new matrix of values, with different dimensionality.

0	3	5	6	2	4	5
7	4	7	3	6	3	4
9	1	2	1	9	6	0
9	2	1	1	7	3	5
8	0	4	7	6	8	0
8	3	4	5	5	3	4
7	9	4	6	5	2	6

4	-1	4
-2	2	-5
3	1	-6

3x4 - 5x1 + 6x4 +
-4x2 + 7x2 - 3x5 +
1x3 + 2x1 - 1x6 = 21

-8	21			

Source: GGI Lectures on ML by Maurizio pierini

Max pooling and padding

Max pooling: For a given image of m x m’ and a filter of size n x n’, scans the image and replaces each n x n’ patch with its maximum.

Padding:

- When the filter arrived at the edge, it might exceeds it (if m/n is not an integer).
- Padding can be of 2 types: **same**(the last entry is repeated) and **zero** (padded with 0 as the entry)

0	3	5	6	2	4	5
7	4	7	3	6	3	4
9	1	2	1	9	6	0
9	2	1	1	7	3	5
8	0	4	7	6	8	0
8	3	4	5	5	3	4
7	9	4	6	5	2	6

9	7	9	9	9
9	7	9	9	9
9	7	7	9	9
9	7	7	8	8
9	9	7	8	8

0	3	5	6	2	4	4
7	4	7	3	6	3	3
9	1	2	1	9	6	6
9	2	1	1	7	3	3
8	0	4	7	6	8	8
8	3	4	5	5	3	3
8	3	4	5	5	3	3

Same padding

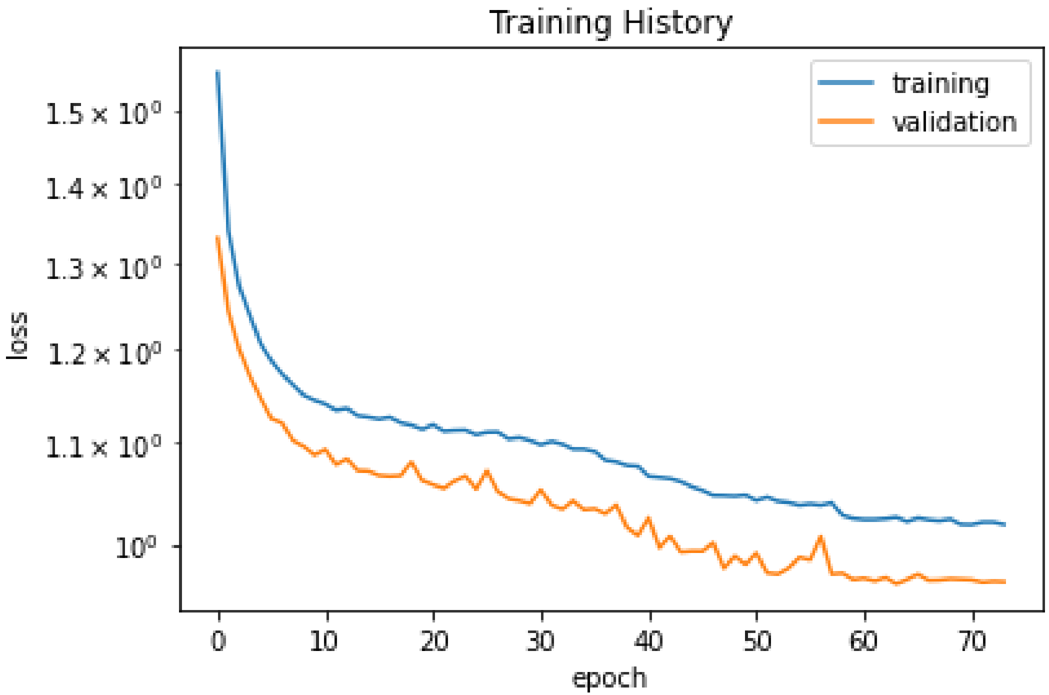
0	3	5	6	2	4	0
7	4	7	3	6	3	0
9	1	2	1	9	6	0
9	2	1	1	7	3	0
8	0	4	7	6	8	0
8	3	4	5	5	3	0
0	0	0	0	0	0	0

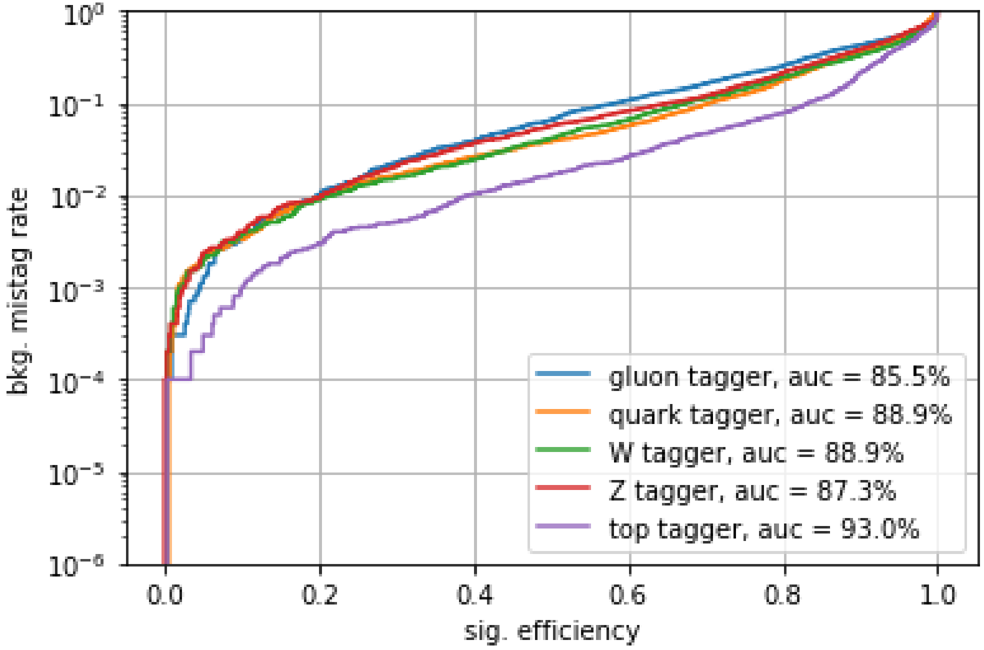
Zero padding

Model Summary

```
Model: "model"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
input_1 (InputLayer)         [(None, 100, 100, 1)]     0
_________________________________________________________________
conv2d (Conv2D)              (None, 100, 100, 10)      260
_________________________________________________________________
batch_normalization (BatchNo (None, 100, 100, 10)      40
_________________________________________________________________
activation (Activation)      (None, 100, 100, 10)      0
_________________________________________________________________
max_pooling2d (MaxPooling2D) (None, 20, 20, 10)        0
_________________________________________________________________
dropout (Dropout)            (None, 20, 20, 10)        0
_________________________________________________________________
conv2d_1 (Conv2D)            (None, 20, 20, 7)         637
_________________________________________________________________
batch_normalization_1 (Batch (None, 20, 20, 7)         28
_________________________________________________________________
activation_1 (Activation)    (None, 20, 20, 7)         0
_________________________________________________________________
max_pooling2d_1 (MaxPooling2 (None, 6, 6, 7)           0
_________________________________________________________________
dropout_1 (Dropout)          (None, 6, 6, 7)           0
_________________________________________________________________
flatten (Flatten)            (None, 252)               0
_________________________________________________________________
dense (Dense)                (None, 5)                 1265
_________________________________________________________________
dense_1 (Dense)              (None, 5)                 30
=================================================================
Total params: 2,260
Trainable params: 2,226
Non-trainable params: 34
_________________________________________________________________
```

Results


Training History
training
validation
loss
1.5×10^0
1.4×10^0
1.3×10^0
1.2×10^0
1.1×10^0
10^0
0 10 20 30 40 50 60 70
epoch


bkg. mistag rate
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
0.0 0.2 0.4 0.6 0.8 1.0
sig. efficiency
gluon tagger, auc = 85.5%
quark tagger, auc = 88.9%
W tagger, auc = 88.9%
Z tagger, auc = 87.3%
top tagger, auc = 93.0%