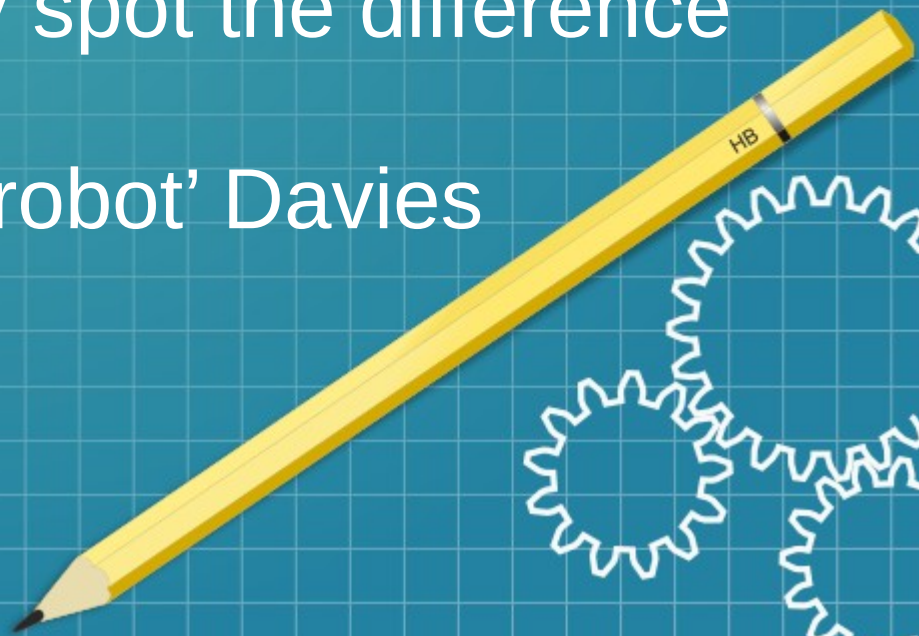
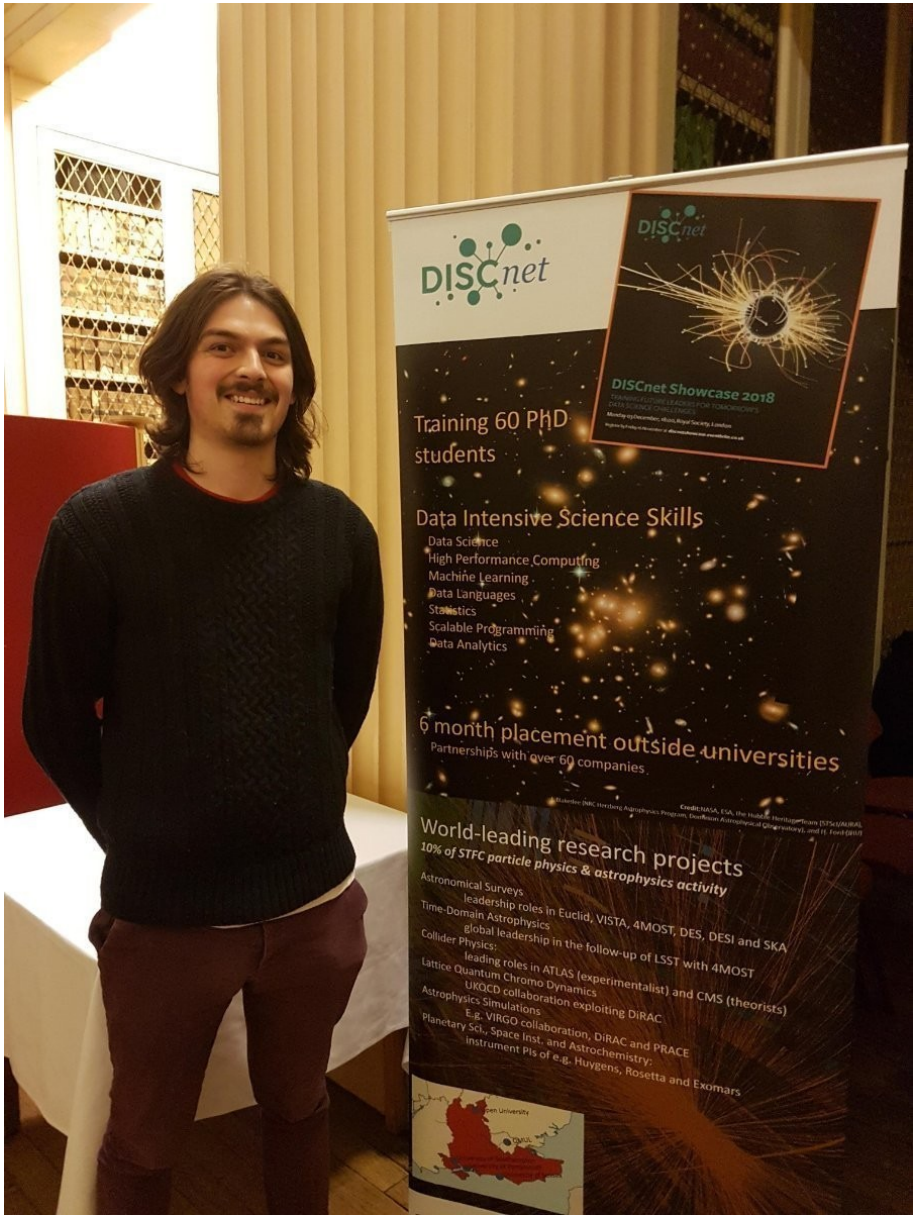
Artificial Intelligence and Dark Matter

Making the Terminator play spot the difference

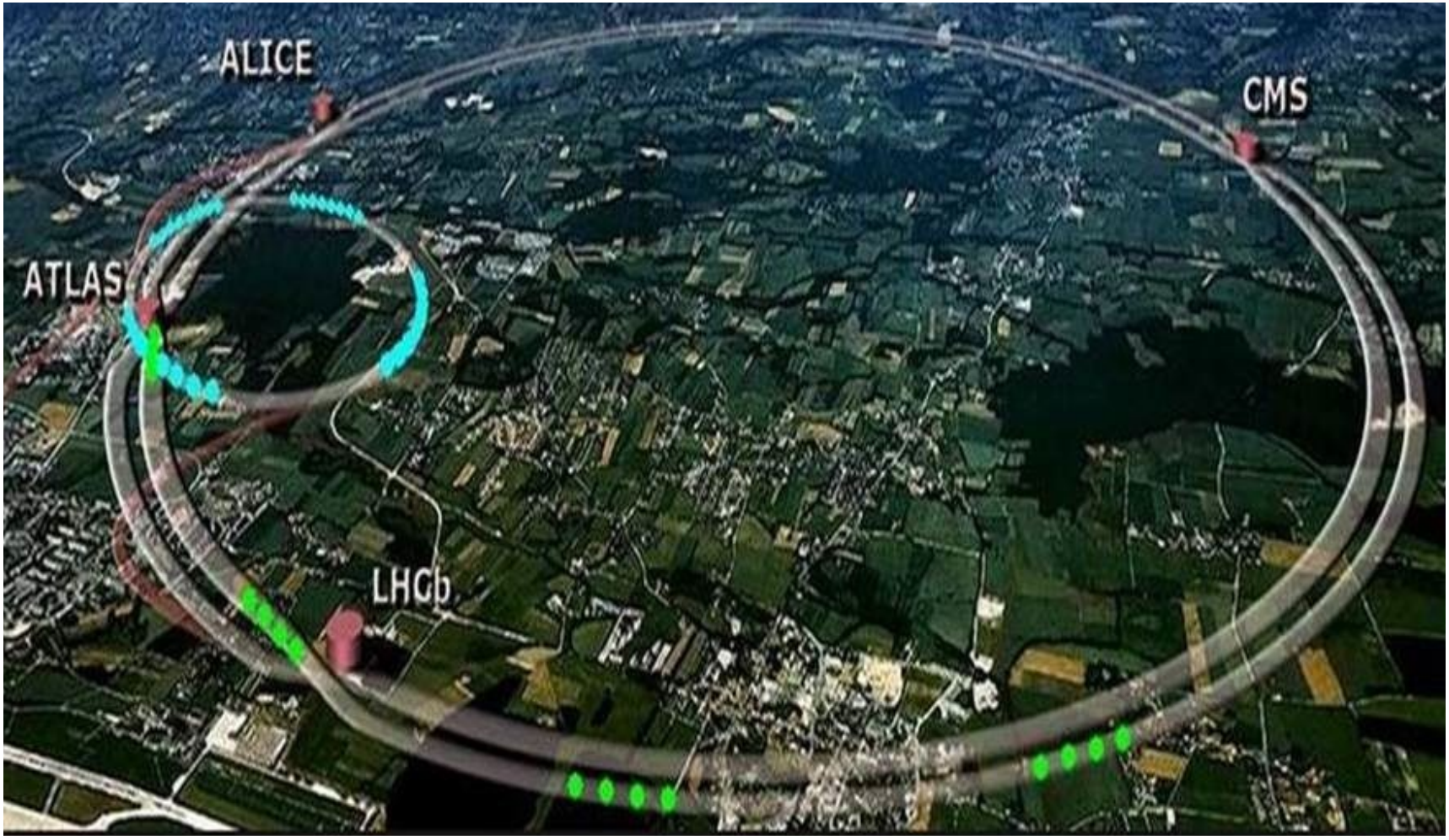
Joe ‘definitely not a robot’ Davies



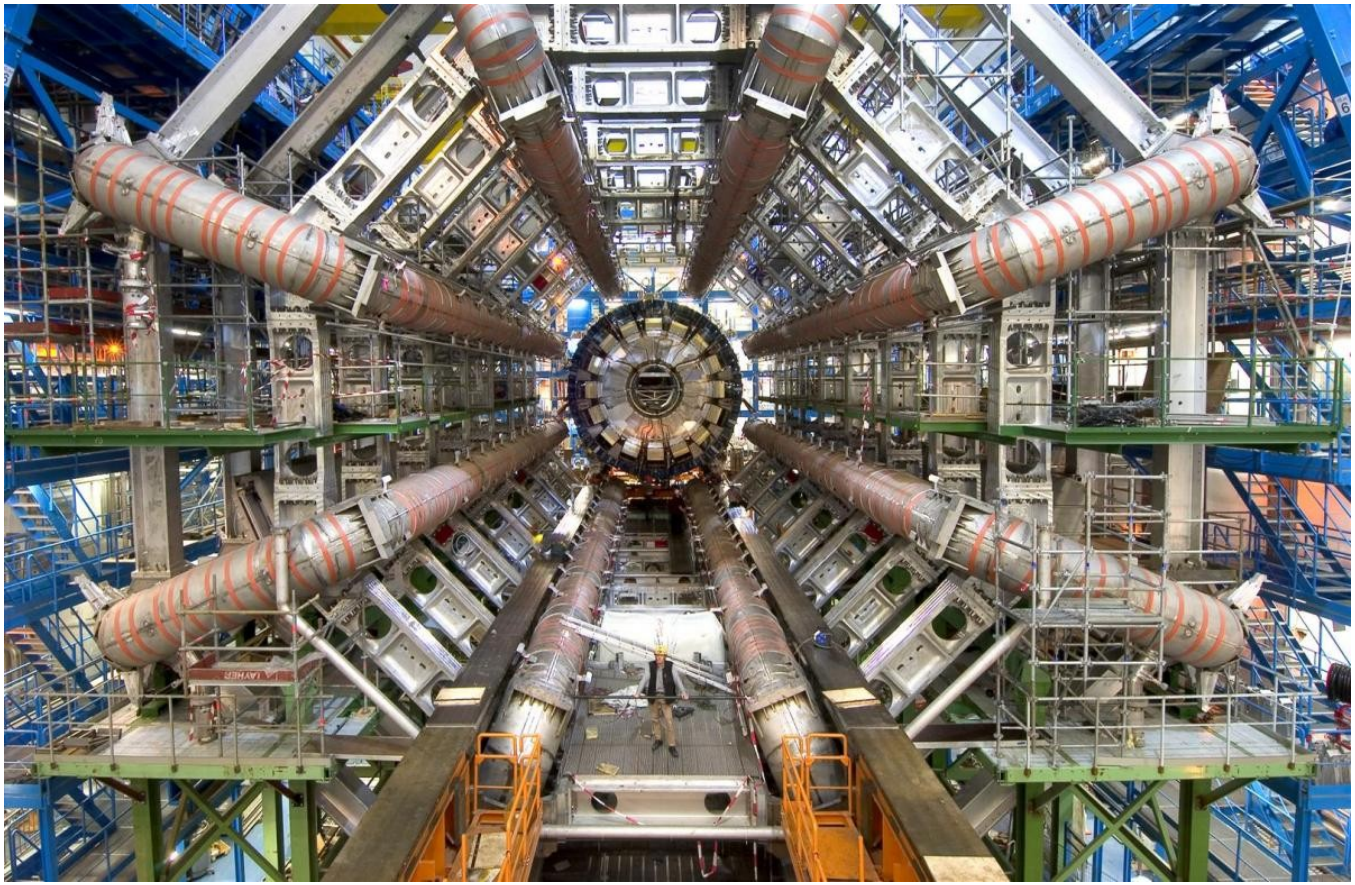
Introduction

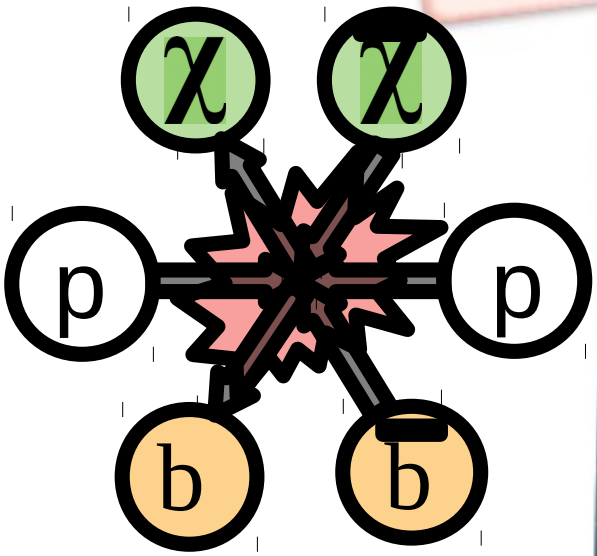


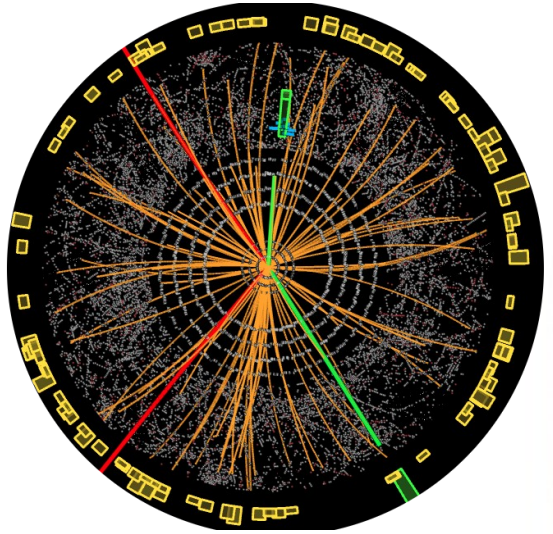
The Large Hadron Collider



The Search at ATLAS







The Dark Machines Group

- Group of academics and PhD students working on Dark Matter detection using Machine Learning
- QMUL works primarily on Anomaly Detection (AD)



Anomaly Detection

Anomaly Detection

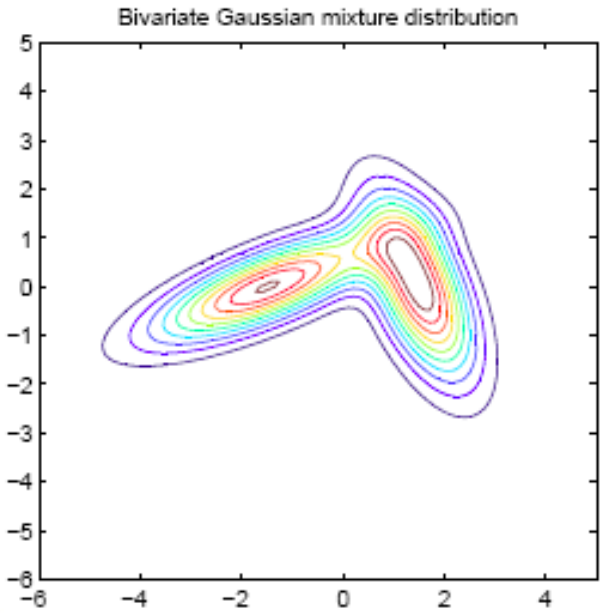
Anomaly Detection

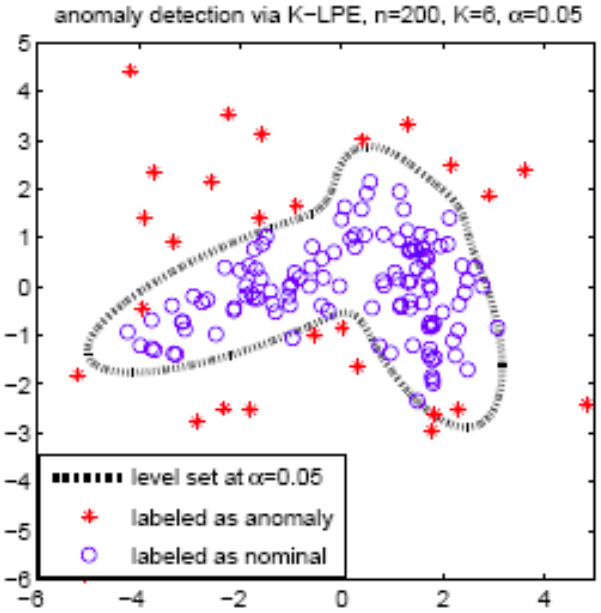
obj1	E1	pt1	eta1	phi1	obj2	E2	pt2	eta2	phi2	obj3	E3	pt3	eta3	phi3	obj4	E4
j	407492	393095	-0.266637	-2.68505	j	633731	283693	1.4419	-0.451286	j	269569	145318	1.22541	2.36482	j	138520
j	707690	390901	1.19577	-2.48665	j	165970	162374	-0.073124	0.558267	j	213806	88382.7	1.52776	0.769609	j	190327
j	484710	388499	0.669438	2.1595	j	466224	209644	1.43709	-1.48085	j	173345	159358	0.3921	0.722837	b	76508.9
j	913056	245434	-1.98767	0.978061	j	228497	202999	0.478876	-2.01883	j	153458	146721	-0.259158	-1.87386	j	126963
j	302325	294936	0.181659	3.03634	j	360228	251837	-0.8903	0.173217	j	203074	200825	0.149532	2.22357	j	359058
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
j	647782	316987	-1.33574	0.0408877	j	1.03028e+06	278691	1.98139	-2.63605	j	442513	190614	-1.48267	2.79699	j	353545
j	390920	325540	0.606702	0.269049	j	1.83279e+06	265269	2.62055	2.28375	j	197980	103625	1.25981	-1.96533	j	191427
j	1.04316e+06	309613	-1.88456	1.17333	j	809841	304875	1.63051	2.00532	b	403629	196592	1.34505	-1.43694	j	400995
j	450608	309967	-0.89566	-2.33551	j	216603	214715	0.0388365	0.642919	b	122718	106325	-0.535995	-2.88472	j	132238
j	715153	611756	-0.565908	1.03414	j	511507	314359	1.05445	-2.09756	j	555581	90541.5	-2.50039	-2.36606	j	83013.7

obj1	E1	pt1	eta1	phi1	obj2	E2	pt2	eta2	phi2	obj3	E3	pt3	eta3	phi3	obj4
j	1.11905e+06	1.09924e+06	0.150071	-1.34083	j	559871	165567	-1.88859	1.47369	j	226151	165330	-0.802848	2.94516	j
j	275612	245021	-0.469702	-2.83812	j	166684	143305	0.531173	2.26821	j	205771	103965	-1.30103	-0.295798	j
j	563988	312717	1.18657	-1.43681	j	1.34499e+06	250037	-2.36676	2.86416	j	184328	133523	-0.826793	1.13601	j
b	364748	274872	-0.761967	2.96886	j	636767	256438	1.55925	-2.528	b	186686	129489	0.906826	-0.737084	j
j	359307	342962	0.222528	-2.76879	j	1.03187e+06	201249	2.31779	0.180633	j	133718	103956	-0.715326	2.11942	j
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
j	544458	319749	-1.11093	0.350326	j	141426	133030	-0.339183	0.288143	j	131650	128141	-0.211974	3.04308	j
j	304548	296864	0.179741	-0.647328	j	181607	170330	-0.361503	0.820824	j	131605	126303	0.215301	0.0479811	j
j	694694	623764	-0.408878	1.48107	j	451083	415452	0.380902	0.699667	j	387672	255939	-0.970173	-0.776873	j
j	487901	372079	0.766972	-1.67763	j	387396	235274	1.07953	0.552393	j	194074	121355	1.04412	2.47628	j
j	529443	484368	-0.406192	0.762605	j	1.2478e+06	103019	3.18557	0.762635	j	105549	96556.7	0.425051	-2.57433	j

Anomaly Detection

- Used when looking for events or data that differ significantly from the general distribution
- Usually done using an Autoencoder which learns some background and attempts to replicate it





The Ill-Advised Code Demo

```
Model: "cnn"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
Input (InputLayer)           (None, 1, 14, 4)          0
_________________________________________________________________
conv_1 (Conv2D)              (None, 1, 14, 32)         544
_________________________________________________________________
max_pool (MaxPooling2D)      (None, 1, 7, 32)          0
_________________________________________________________________
conv_2 (Conv2D)              (None, 1, 7, 32)          4128
_________________________________________________________________
flatten_1 (Flatten)          (None, 224)               0
=================================================================
Total params: 4,672
Trainable params: 4,672
Non-trainable params: 0
_________________________________________________________________
Model: "encoder"
_____________________________________________________________________________________________
Layer (type)                 Output Shape              Param #     Connected to
=============================================================================================
Input (InputLayer)           (None, 1, 14, 4)          0
_____________________________________________________________________________________________
conv_1 (Conv2D)              (None, 1, 14, 32)         544         Input[0][0]
_____________________________________________________________________________________________
max_pool (MaxPooling2D)      (None, 1, 7, 32)          0           conv_1[0][0]
_____________________________________________________________________________________________
conv_2 (Conv2D)              (None, 1, 7, 32)          4128        max_pool[0][0]
_____________________________________________________________________________________________
flatten_1 (Flatten)          (None, 224)               0           conv_2[0][0]
_____________________________________________________________________________________________
dense_encoder_1 (Dense)      (None, 50)                11250       flatten_1[0][0]
_____________________________________________________________________________________________
dense_encoder_2 (Dense)      (None, 16)                816         dense_encoder_1[0][0]
_____________________________________________________________________________________________
z_mean (Dense)               (None, 4)                 68          dense_encoder_2[0][0]
_____________________________________________________________________________________________
z_var (Dense)                (None, 4)                 68          dense_encoder_2[0][0]
_____________________________________________________________________________________________
sampling (Lambda)            (None, 4)                 0           z_mean[0][0]
                                                                   z_var[0][0]
=============================================================================================
Total params: 16,874
Trainable params: 16,874
Non-trainable params: 0
_____________________________________________________________________________________________
Model: "decoder"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
decoder_input (InputLayer)   (None, 4)                 0
_________________________________________________________________
dense_decoder_1 (Dense)      (None, 56)                280
_________________________________________________________________
reshape_1 (Reshape)          (None, 1, 14, 4)          0
_________________________________________________________________
deconv_1 (Conv2DTranspose)   (None, 1, 14, 32)         544
_________________________________________________________________
deconv_2 (Conv2DTranspose)   (None, 1, 14, 20)         2580
_________________________________________________________________
decoder_output (Conv2DTransp (None, 1, 14, 4)          324
=================================================================
Total params: 3,728
Trainable params: 3,728
Non-trainable params: 0
_________________________________________________________________
Model: "vae"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
Input (InputLayer)           (None, 1, 14, 4)          0
_________________________________________________________________
encoder (Model)              [(None, 4), (None, 4), (N 16874
_________________________________________________________________
decoder (Model)              (None, 1, 14, 4)          3728
=================================================================
Total params: 20,602
Trainable params: 20,602
Non-trainable params: 0
```

```
Train on 192766 samples, validate on 192766 samples
Epoch 1/100
 - 18s - loss: 1911.5186 - kl_loss: 1682.3239 - recon_loss: 228.9868 - val_loss: 47.3007 - val_kl_loss: 1.6682 - v
al_recon_loss: 45.6170
Epoch 2/100
 - 17s - loss: 44.0986 - kl_loss: 1.6190 - recon_loss: 42.4739 - val_loss: 590457.9766 - val_kl_loss: 526147.8750
 - val_recon_loss: 64231.5352
Epoch 3/100
 - 17s - loss: 121814.1695 - kl_loss: 116571.5078 - recon_loss: 5236.7539 - val_loss: 38.9317 - val_kl_loss: 1.732
5 - val_recon_loss: 37.1863
Epoch 4/100
 - 17s - loss: 37.7864 - kl_loss: 1.6714 - recon_loss: 36.0981 - val_loss: 36.4631 - val_kl_loss: 1.6795 - val_rec
on_loss: 34.7718
Epoch 5/100
 - 17s - loss: 35.8215 - kl_loss: 1.6806 - recon_loss: 34.1281 - val_loss: 33.9626 - val_kl_loss: 1.7386 - val_rec
on_loss: 32.2137
Epoch 6/100
 - 17s - loss: 1777.8103 - kl_loss: 744.8854 - recon_loss: 1031.7015 - val_loss: 33.2147 - val_kl_loss: 1.8299 - v
al_recon_loss: 31.3746
Epoch 7/100
 - 13s - loss: 33.7194 - kl_loss: 1.8529 - recon_loss: 31.8570 - val_loss: 17696.6566 - val_kl_loss: 7021.7446 - v
al_recon_loss: 10662.0029
Epoch 8/100
 - 12s - loss: 694632.8472 - kl_loss: 335702.0000 - recon_loss: 358496.0000 - val_loss: 1024.0852 - val_kl_loss: 9
93.4492 - val_recon_loss: 30.6257
Epoch 9/100
 - 12s - loss: 89.4036 - kl_loss: 58.2211 - recon_loss: 31.1770 - val_loss: 31.4970 - val_kl_loss: 1.9480 - val_re
con_loss: 29.5390
Epoch 10/100
 - 12s - loss: 31.2938 - kl_loss: 1.9779 - recon_loss: 29.3026 - val_loss: 30.6659 - val_kl_loss: 2.0370 - val_rec
on_loss: 28.6194
Epoch 11/100
 - 12s - loss: 30.8430 - kl_loss: 2.0754 - recon_loss: 28.7551 - val_loss: 28.8196 - val_kl_loss: 2.2124 - val_rec
on_loss: 26.5989
Epoch 12/100
 - 12s - loss: 30.1142 - kl_loss: 2.2288 - recon_loss: 27.8747 - val_loss: 27.9302 - val_kl_loss: 2.2172 - val_rec
on_loss: 25.7049
Epoch 13/100
 - 12s - loss: 28.1635 - kl_loss: 2.3115 - recon_loss: 25.8434 - val_loss: 27.0528 - val_kl_loss: 2.2471 - val_rec
on_loss: 24.7982
Epoch 14/100
 - 11s - loss: 27.2132 - kl_loss: 2.2628 - recon_loss: 24.9439 - val_loss: 26.9261 - val_kl_loss: 2.2235 - val_rec
on_loss: 24.6948
Epoch 15/100
 - 11s - loss: 26.5497 - kl_loss: 2.3030 - recon_loss: 24.2381 - val_loss: 26.7589 - val_kl_loss: 2.3571 - val_rec
on_loss: 24.3936
Epoch 16/100
 - 11s - loss: 25.4426 - kl_loss: 2.2330 - recon_loss: 23.2022 - val_loss: 5108215579516110.0000 - val_kl_loss: 15
87176441643008.0000 - val recon loss: 3516769687830528.0000
```

Conclusion

- Artificial Intelligence is the newest tool in computational physics – it works!
- A lot of physics today is cutting edge software development
- There is immense creativity in the intersection between physics and computer science