



THE UNIVERSITY *of* EDINBURGH
School of Physics
and Astronomy

Deep Learning & the Higgs Boson

Dr. Liza Mijović



Deep Learning & the Higgs Boson

Classification with Fully Connected and Adversarial Networks.

- **Lecture1: The Higgs boson and event classification:**

- Event classification with a fully connected neural network (NN) with Keras API.

- **Lecture2: Solving the background sculpting challenge:**

- Event classification with adversarial neural network (ANN).
 - Hands-on knowledge of manipulating neural networks in Tensorflow.

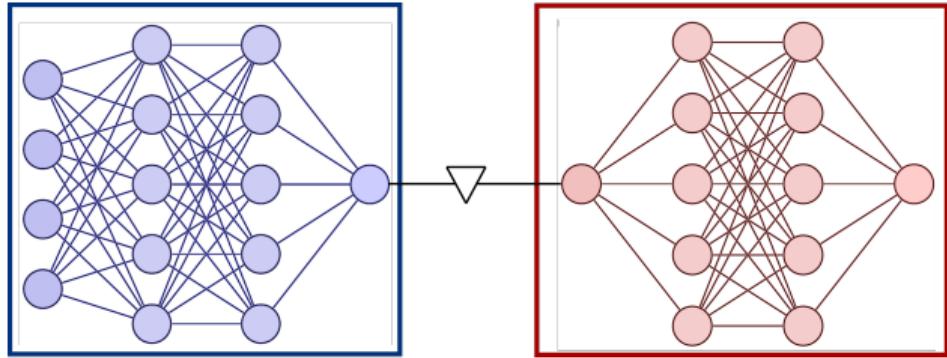
- **Lecture3: Putting it all together:**

- Compare ANN classification performance to the fully connected network.

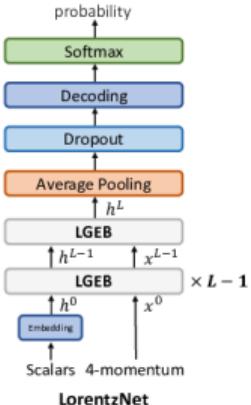
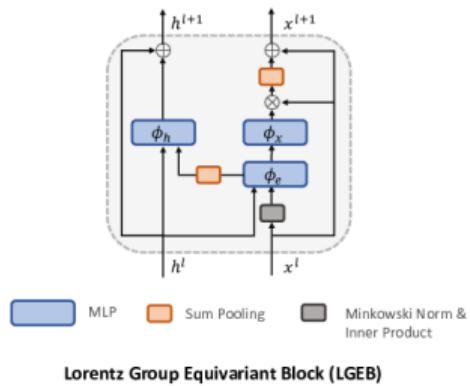


Why is this useful?

- Classification with Adversarial neural network: generic solution for removing bias.
- Good tool for your toolbox.



- Research at LHC: unique, big AI challenges.
- Bench-marking & collaboration.
- Image: [LorentzNet](#), Microsoft.



Lecture Schedule

10:30-12:00	Goldberger - Room M Mijovic - Room A	Gleyzer - Room M Liang - Room A Raj - Room B
	<i>Lunch - Rooms HG</i>	<i>Lunch - Rooms HG</i>
13:00-14:30	Gallinari - Room M Schultz - Room A Wei - Room B	Goldberger - Room M Mijovic - Room A
	<i>Short break</i>	<i>Short break</i>
14:45-16:15	Gleyzer - Room M Liang - Room A Raj - Room B	Gallinari - Room M Schultz - Room A Wei - Room B
	<i>Coffee break - Rooms HG</i>	<i>Coffee break - Rooms HG</i>
16:45-18:15	Goldberger - Room M Mijovic - Room A	Lampert - Room M Mahoney - Room A

Room A:

- **Lecture1: Mon Morning**
- **Lecture2: Mon Evening**
- **Lecture3: Tue Afternoon**

Please bring your laptop.

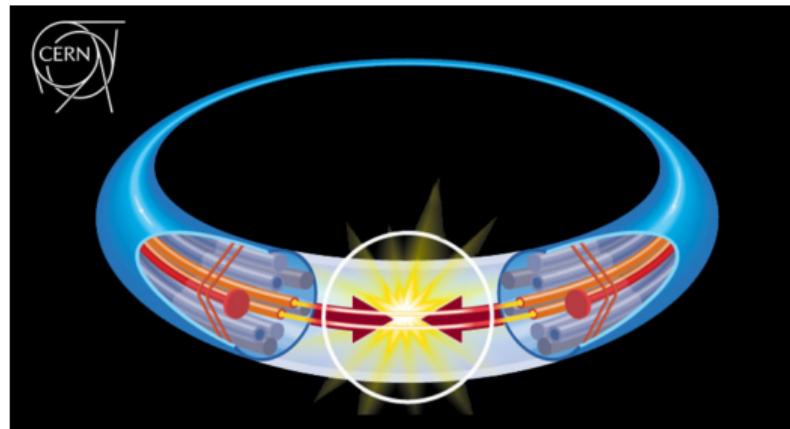
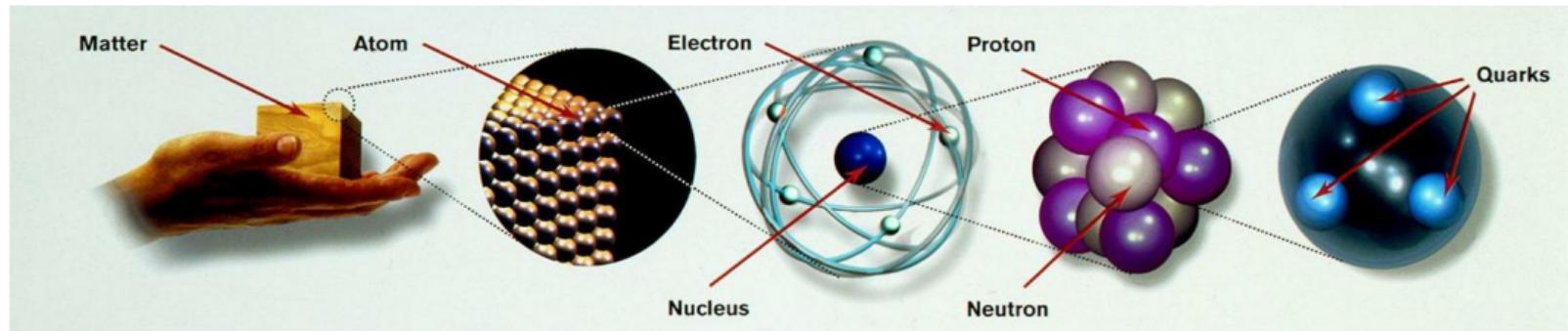
Lecture1:

Higgs boson & event classification:

event classification with a fully connected neural network (NN) with Keras API.



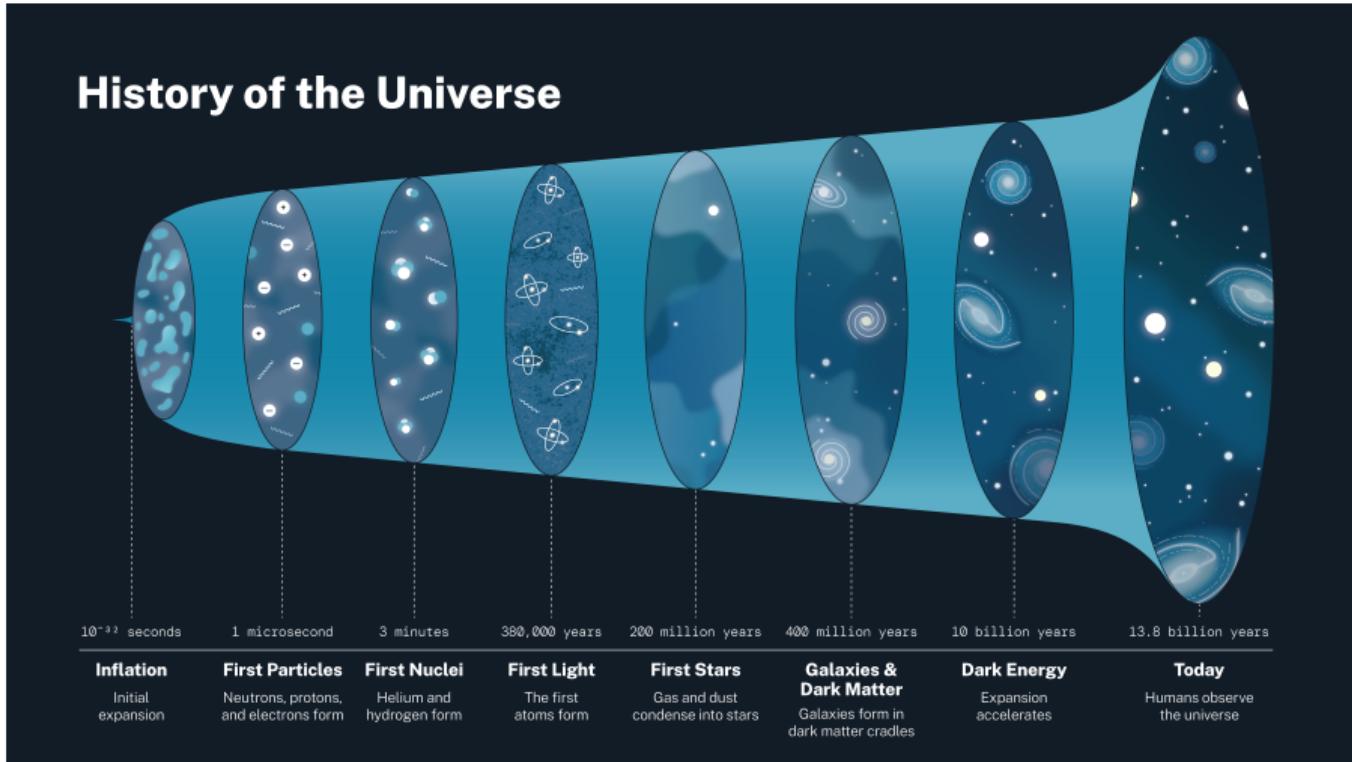
Fundamental Particles and Collisions



Large Hadron Collider (LHC):

- Collide protons.
- New particles: $E \sim mc^2$.
- Detector: snap-shot of collision.

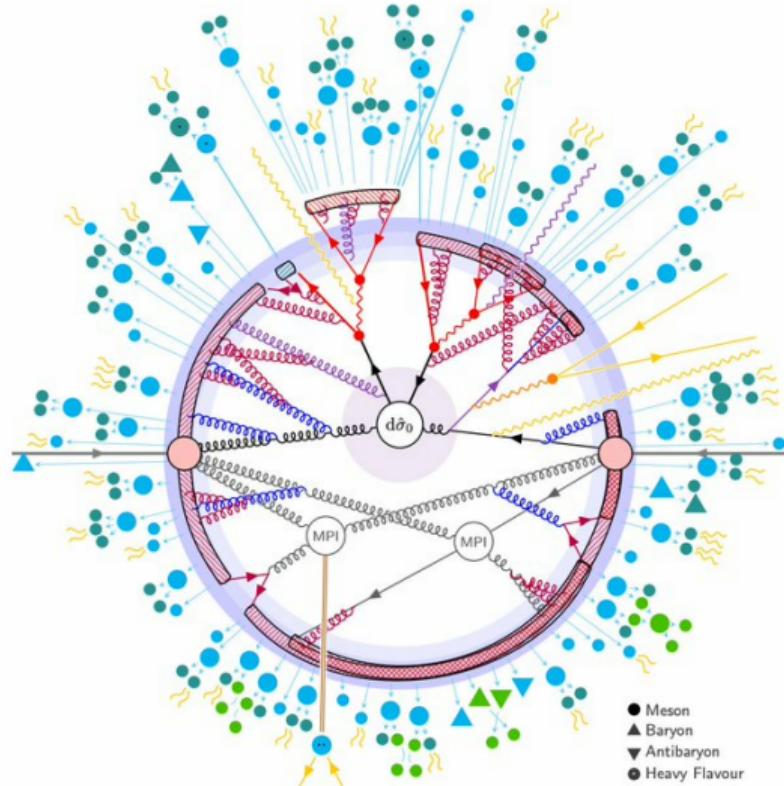
Why study particle collisions?



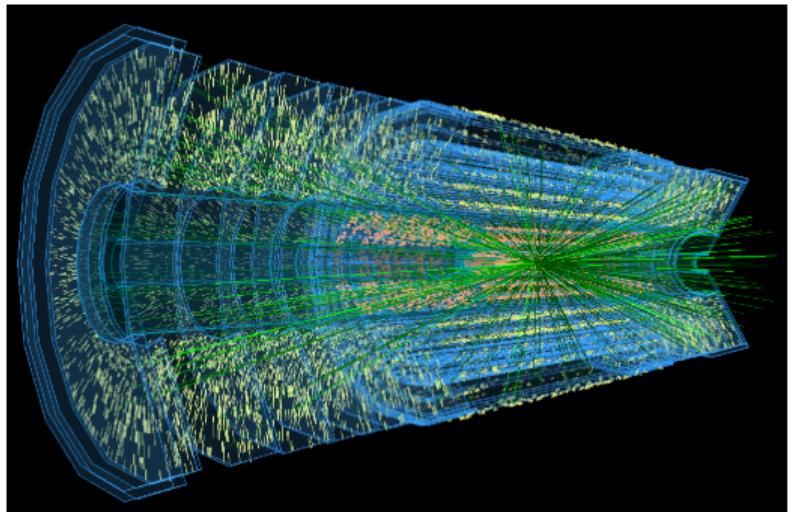
Cannot account for*: dark matter, cosmic inflation, matter/anti-matter asymmetry.

Image credit: NASA. *Additional observations we cannot account for are neutrino masses.

Challenge: Collisions are Complex



- ~ 1000 particles / collision.
- Figure: inner-tracker.
- 5B channels.



LHC Detectors



The Standard Model

THREE GENERATIONS OF MATTER INTERACTIONS/FORCE CARRIERS

(FERMIOS)			(BOSONS)		
QUARKS			SCALAR BOSONS		
Mass: 2.2* Charge: 2/3 Spin: 1/2			125,090 0 0		
Up  1,270 2/3 1/2			Gluon  0 0 1		
Down  4.7 -1/3 1/2			Higgs boson  0 0 1		
Charm  96 -1/3 1/2			Photon  0 0 1		
Top  172,500 2/3 1/2			Z boson  91,188 0 1		
Strange  4,180 -1/3 1/2			W boson  80,379 +/-1 1		
Bottom  0.511 -1 1/2			*All masses are given in MeV		
Electron  105.66 -1 1/2			Adapted from Quanta Magazine		
Muon  1,776.8 -1 1/2					
Tau  <0.00000012 0 1/2					
Electron neutrino  <0.00000012 0 1/2					
Muon neutrino  <0.00000012 0 1/2					
Tau neutrino  <0.00000012 0 1/2					

The Higgs boson

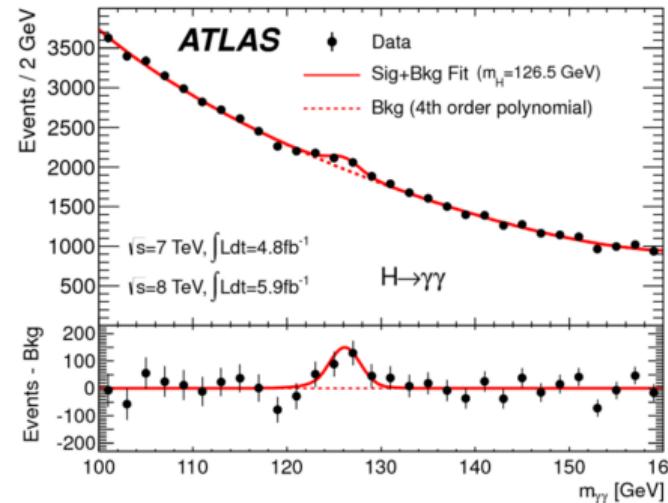
INTERACTIONS/FORCE CARRIERS (BOSONS)

GAUGE BOSONS (VECTOR BOSSONS)	SCALAR BOSSONS
0 0 1	125,090 0 0
 Gluon	 Higgs boson
0 0 1	
 Photon	
91,188 0 1	
 Z boson	
80,379 ± 1 1	
 W boson	

*All masses are given in MeV

Adapted from
Quanta Magazine

- 1964: R. Brout, F. Englert, P. Higgs: W, Z masses.
- 2012: Higgs boson observation, ATLAS & CMS



- 2013: Nobel prize to F. Englert & P. Higgs

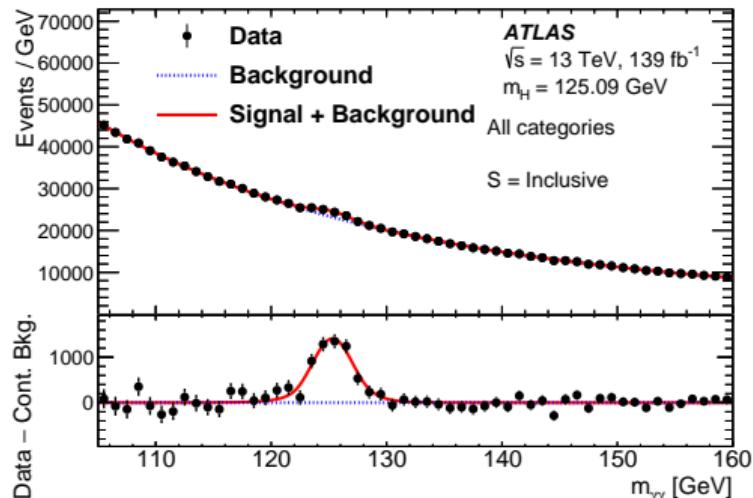
Our Challenge

Classification: separate

- **Signal** with Higgs boson.
- **Background** with no Higgs boson.

Approach:

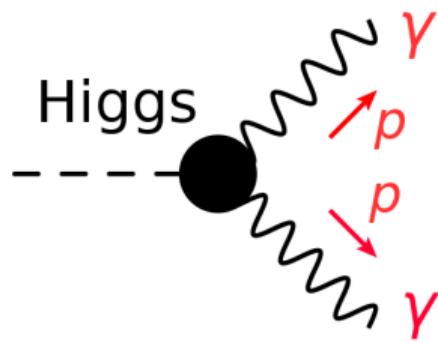
- use synthetic data.
- Introduce no bumps in the $m_{\gamma\gamma}$ distribution; these would hamper the background estimate.
⇒ evening lecture.



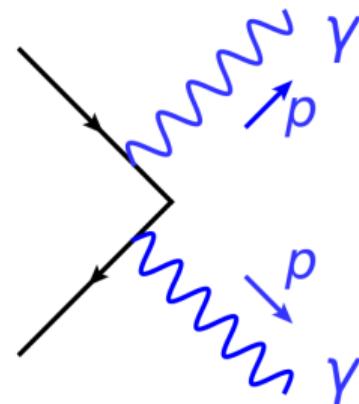
What is in the data?

Two photons (γ) per event, with momenta p .

Signal, label=1



Background, label=0



What is in the data?

Momenta p have two catches:

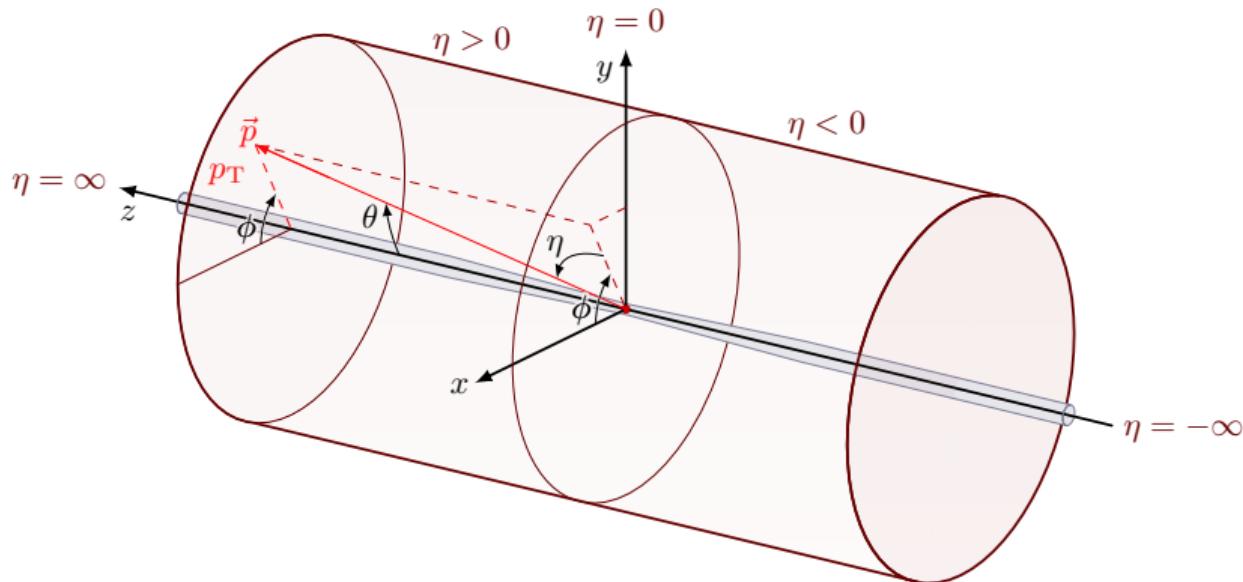
- (1) They are 4-dimensional (Lorentz) vectors.

1st photon	2nd photon	mass	S or B?
,pt_y1,eta_y1,phi_y1,e_y1,	pt_y2,eta_y2,phi_y2,e_y2	, myy, label	
0,62.2385,1.2206,2.02509,114.652,	58.7416,0.879753,-1.23967,82.9781,	122.464,0	
1,69.5362,-1.0435,-2.29563,110.958,	48.7077,-2.01968,1.48524,186.759,	125.308,1	

What is in the data?

Momenta p have two catches:

- (2) They are passed in cylindrical coordinates.



Hands-on work

Let's get set up!

- Download the data: <https://cern.ch/dl23data>
- Set up the environment: <https://cern.ch/dl23code>

Let's do some classification!

Using data_scaled_200k.csv try to classify signal vs background.

- Use Keras & fully connected deep neural network.
- Use photon momenta as (8) input features.
- Do not use myy as input feature.

Let's share results:

- <https://cern.ch/dl23lect1>
- Classification performance, eg ROC curve, accuracy etc.
- S and B myy distribution, for high discriminant scores (events likely to be S).

Extra



Example

