Machine Learning in HEP

Finding Higgs Boson

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Outline

1 Motivation: How do you find a needle in a haystack?

2 Find a concrete example for the needle: Higgs

3 How does the experiment work?

4 How the magnet works?

5 Machine Learning Vocabs

6 Machine Learning Examples:

7 Quantum Computers to save the day? (The challanges and outlooks)

8 Backups

Naively

```
while(1){
  stick_your_hand_in_the_haystack();

  vehemently_move_your_hand();
  if(needle_stick_in_hand){
    cout << "hurray I found the needle" << endl;
    return 0;
  }

 }
```

A better way?

```
get_a_magent();
use_the_magnet();
```

Magnet is Machine Learning

- Is it really a black box?
- But surely you don't know why it works.
- Not a rigorous algorithm
- There needs to be an invariant over some state that is related to our problem link to where I got this
- Boring, but that's what's awesome about Machine Learning

Large Amount of Data [1]

- It is costly to develop new algorithm
- Over abundance of data
- Hard and costly for humans to find the pattern

[1] [3]

Higgs Boson (naively) [2]

- Last elementary particle in the SM to be observed
- Mechanicsm that gives mass to massive elementary particles predicts its existence.
- But is it really necessary?

[2] [2]

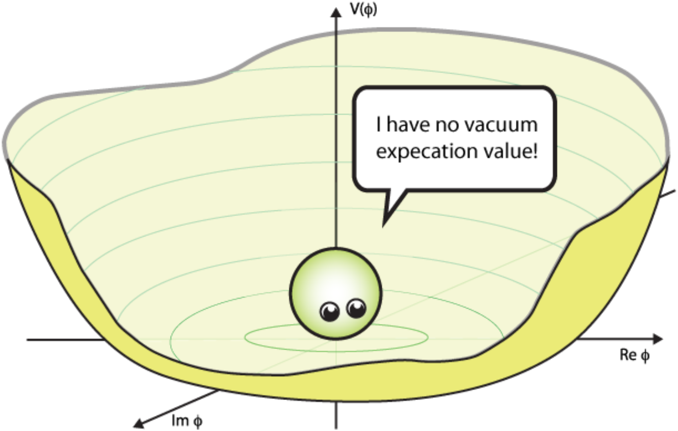
Higgs Boson (closely) [3]

- Unification of the electromagnetic and weak force
- Four force particles involved -> $W^{\pm}$, Z, and photon gauge bosons
- Threee of the four annexes three Bosons and "breaks" this symmetry
- What breaks it? Vacuum Expectation Value

[3] [5]

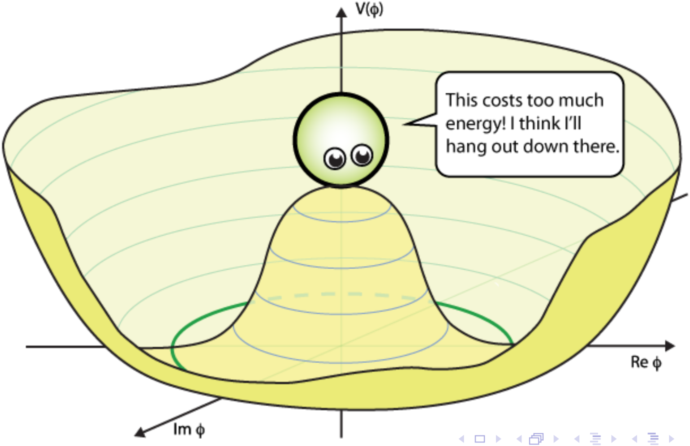
VEV [3]

- Whether $\phi = 0$
- Field vs. Potential



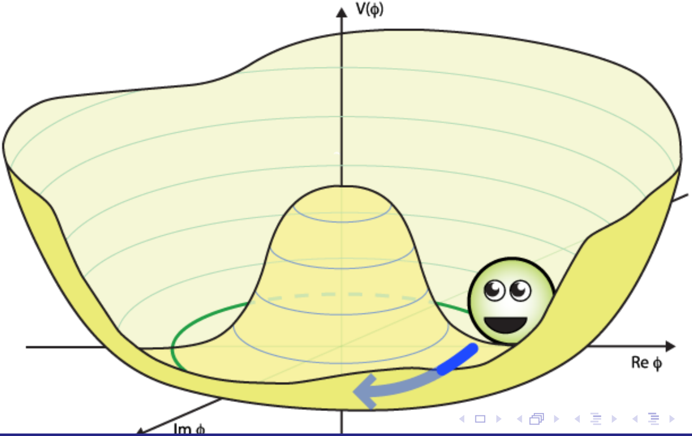
VEV [3]

- Higgs is special!
- Field is not zero when potential is lowest!



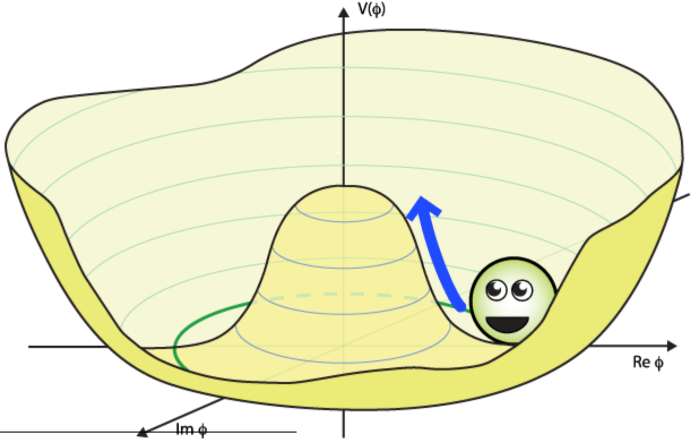
VEV [3]

- Breaks the rotation symmetry
- Similarily for electroweak symmetry
- One of the four Higgs obtains non-zero vev



Goldstone and Higgs Bosons [4]

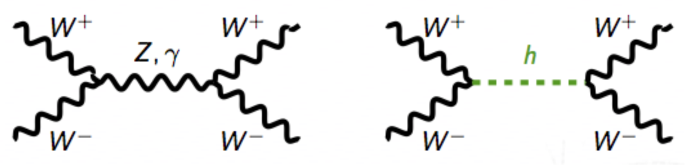
- Excitation in different direction -> different Bosons
- non-flat direction -> this boson has mass



[4] [5]

But you still did not tell me why [4]

- The Higgs is needed for the probability to work out if you don't change anything about the theory



What if you change the theory? [4]

- The theory becomes non-perturbative
- We need to introduce more internal virtual particles during a scattering process
- Too many possible ways for the intermediate process to be, too complex
- Meaning there are sub-particles that makes up W Bosons around TeV scale
- Did not see that in experiments
- Similar things could be explained with a much easier theory of Higgs, why not take that :)

What more do we know about the Higgs Boson [5]

- Know the rough range of mass
- General Consideration is for it to be smaller than ~ 1 TeV
- Electroweak Measurement says it is < 152 GeV
- LEP Collider says it shoud be > 114.4 GeV

[5] [4]

What haystack?

- what are the back ground noise?
- What are the information that we can get?

Challanges

- Why is it difficults

- describe how the experiment works and diverge to the machine learning part when we hit the obstacle of trying to find what we want to see

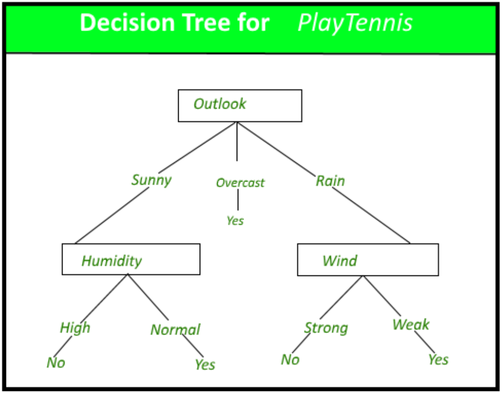
-mix the information about machine learning here.

BDT

Artificial Neural Networks

Decision Trees [1]

- Can be used to assign data to class



Boosted Decision Tree (BDT) [3]

- Convert weak to strong learner ?

Artificial Neural Networks

- Layers of nodes
- Weighted inputs and nonlinear transformation
- rectified linear unit (ReLU)
- Hidden Layers : Deep Learning

Optimizing the model

- Evaluating a cost for model
- Minimize the cost through evolution of model
- Backpropogation (chain rules)
- Stochastic Gradient Descent

- Higgs Boson 2012
- boosted decision tree
- small signals (invariant mass peaks) over large smoothly falling backgrounds

Little bit of physics behind it

-then the Higgs decays and couplings to the heavy W and Z gauge bosons, as well as the heavy third generation quarks (bottom and top) and tau leptons, have been observed by both ATLAS and CMS, and are consistent with the predictions of the SM at the current level of precision

What to look for

- observing Higgs decays and measuring its couplings to fermions outside the third generation
- decays to a pair of muons with oppotiste change (μ^+,μ^-)
- But this only occurs with small probablility 0.02% (other possibilities are Drell-Yan, top quark or W boson pairs production)
- dimuon invariant mass peak near 125 GeV, only a few GeV wide, determined by

the experimental muon momentum resolution. In contrast, the background events exhibit a smoothly falling mass spectrum in the search region from 110 to 160 GeV

Mentioned in paper

-The large amounts of data collected at colliders like the Large Electron-Positron collider (LEP) or the LHC, and at the intensity frontier, mean that the statistical errors on the collected data samples tend to get quite small, and often the systematic effects become important and even limiting. Experience shows that a large, often dominating amount of time in data analysis is spent on estimating and handling the systematic errors, after the express production of first, exploratory, results.

- scultping of variables , what does it mean?

Three Quaters of the Higgs Boson? [6]

- When we detected W and Z bosons, we have really detected the three quarters of Higgs Boson.
- W and Z Bosons absorbed them to become massive
- But force particles natrually appear in theory as massless
- A solution is to annex a massive particle: Higgs Mechanism
- Previously: Goldstone Bosons
- "The difference between massless force particles (like the photon and gluon) and massive force particles (like the W and Z) is the longitudinal degree of freedom."
- The Higgs breaks the electroweak symmetry for the weak charge that it had
- The vacuum expectation values allows the three to be eaten

[6] [5]

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