ROOT Workshop Tutorial

ATLAS Open Data

Higgs Discovery

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Liverpool@CERN Summer School - 17/08/2021

Preparation

- Load Open Data kernel:
  - https://github.com/atlas-outreach-data-tools/notebooks-collection-opendata

ATLAS Open Data

notebooks-collection-opendata

A set of multiple notebooks using 8 TeV and 13 TeV ATLAS Open Data datasets

To execute in MyBinder: launch binder

Note: before starting running the code in the jupyter notebooks, click on the up right button "not trusted" in order to get "trusted" displayed. This should lead the JavaScript to be executed, that is useful to visualise interactive histograms. If that doesn't work, simply go to the top of the notebook, find the cell that contains the line of code `%jsroot` and comment out that.

For more, please go to: http://opendata.atlas.cern

@2021

Preparation

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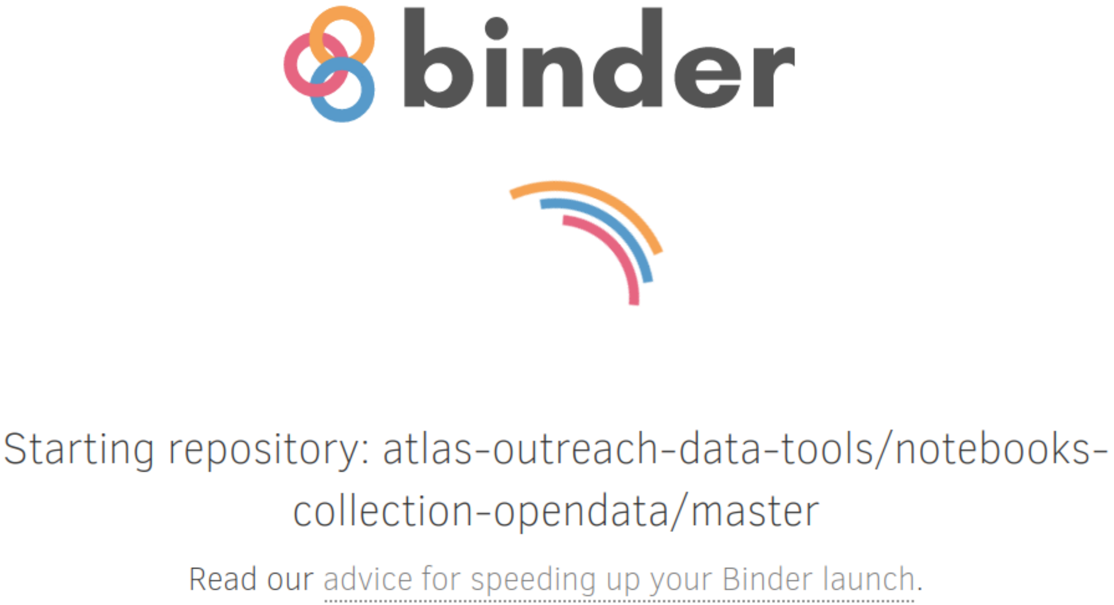
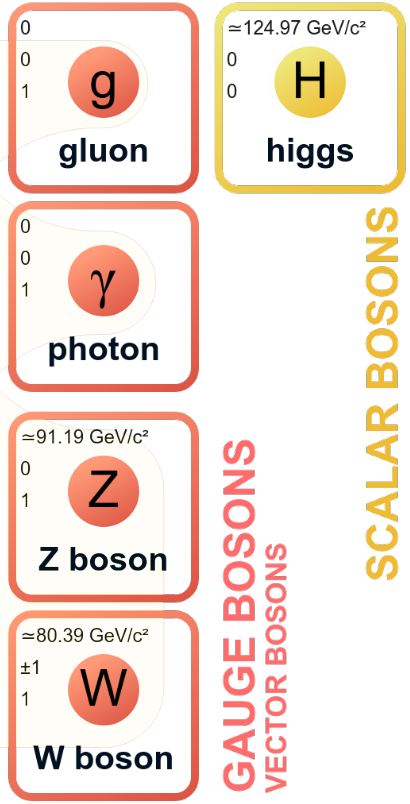
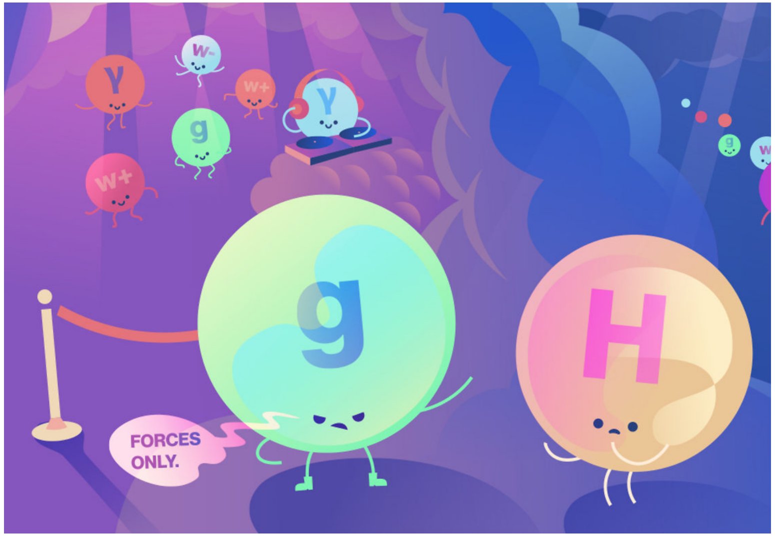


Flashback: What about the Higgs boson?

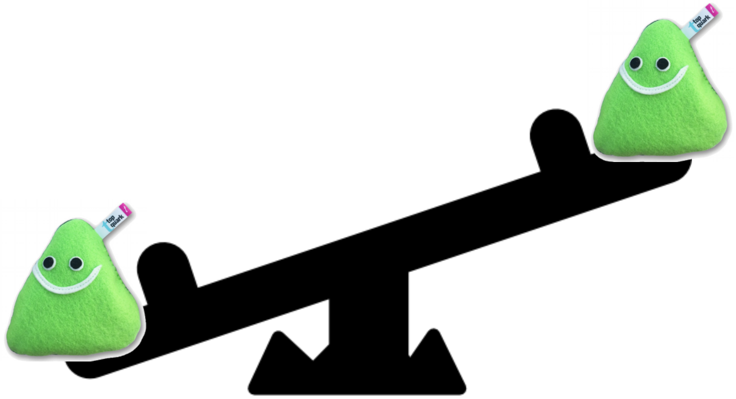


- Bosons in SM were presented yesterday. While most act as force mediators, Higgs stands on its own.
- Instead of mediating a force, the Higgs boson "grants mass" to all other particles.
  - How does this work?



Mass in quantum mechanics – Why do we need the Higgs?

- In Quantum Field Theory the mass of a particle is represented as its coupling with itself
- However, these terms would be non-symmetric in SM
  - We want our theory to be independent of shifts and rotations
- Solution: introduce self interactions via Higgs



Mass as an interaction with the Higgs field

- You can think of the Higgs field as a snowfield.
- The particles need to cross the field, but there's different ways to do so...

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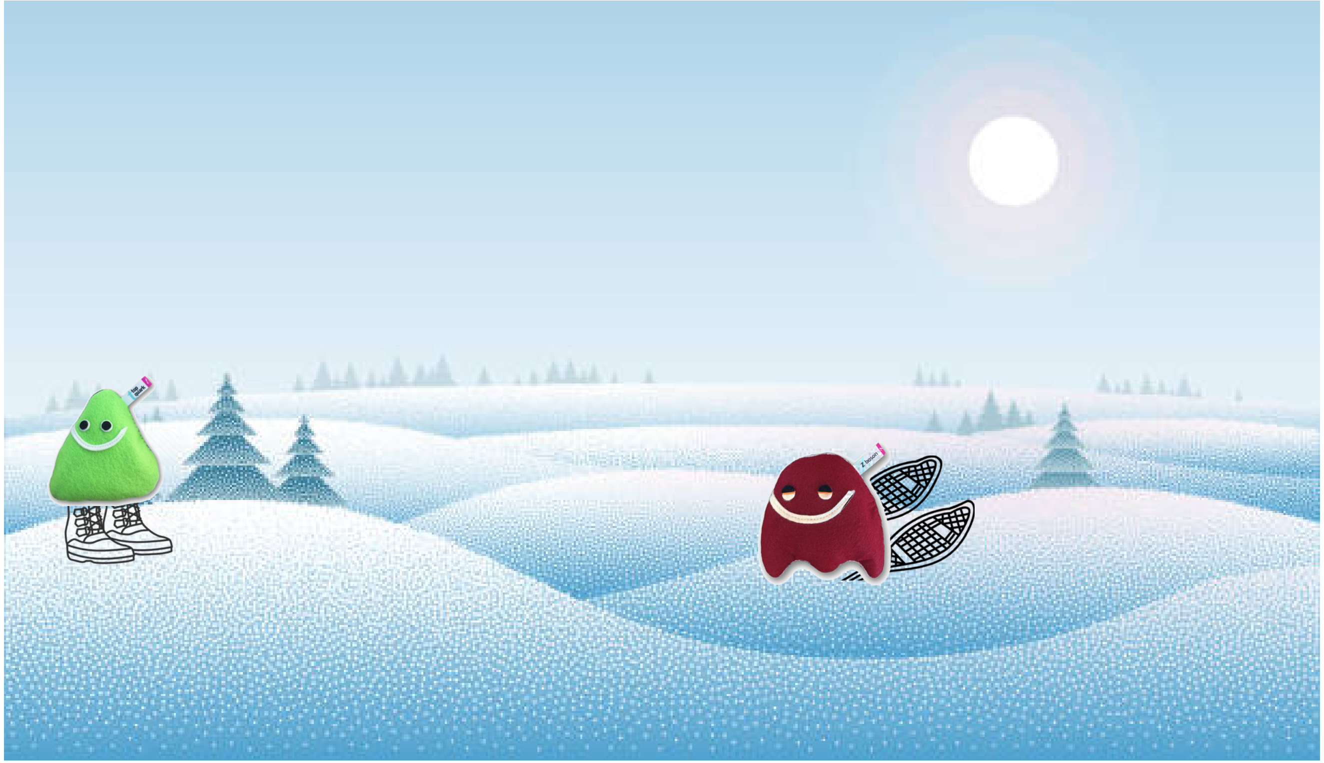

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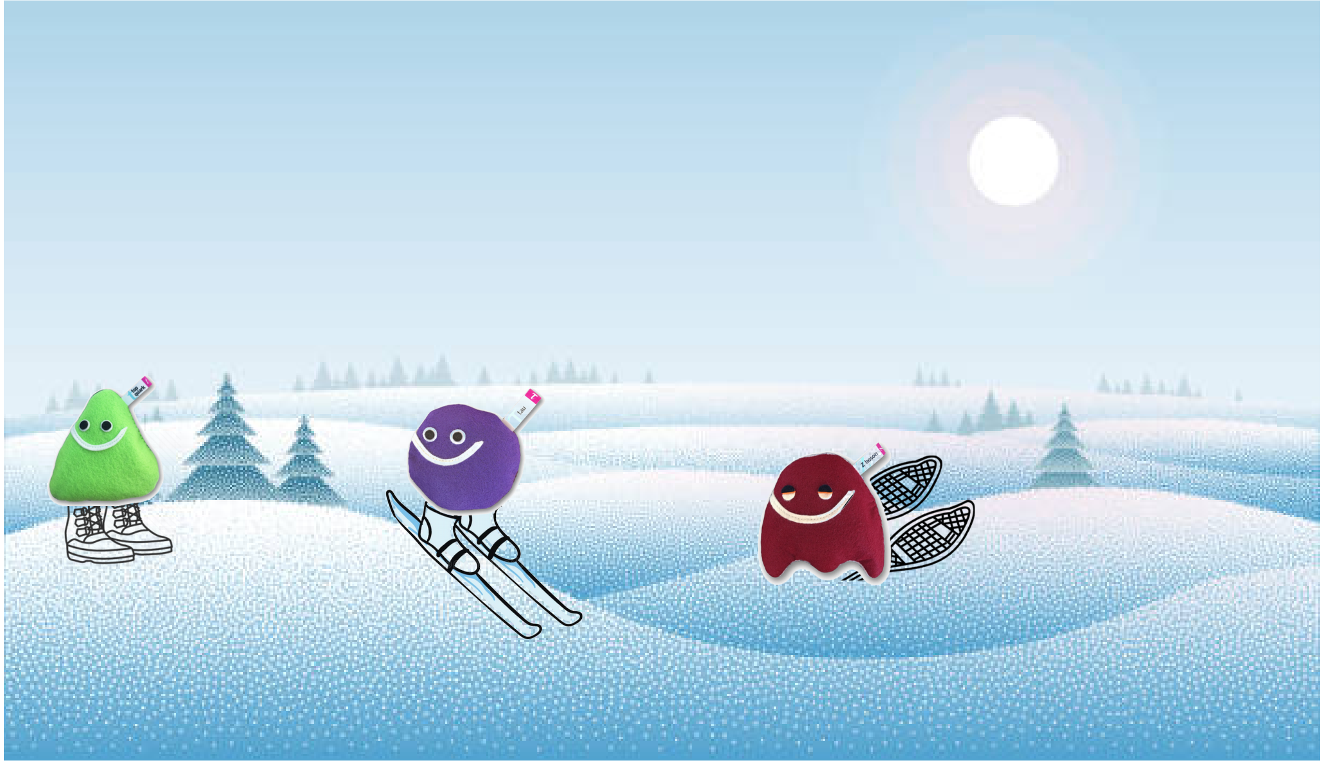

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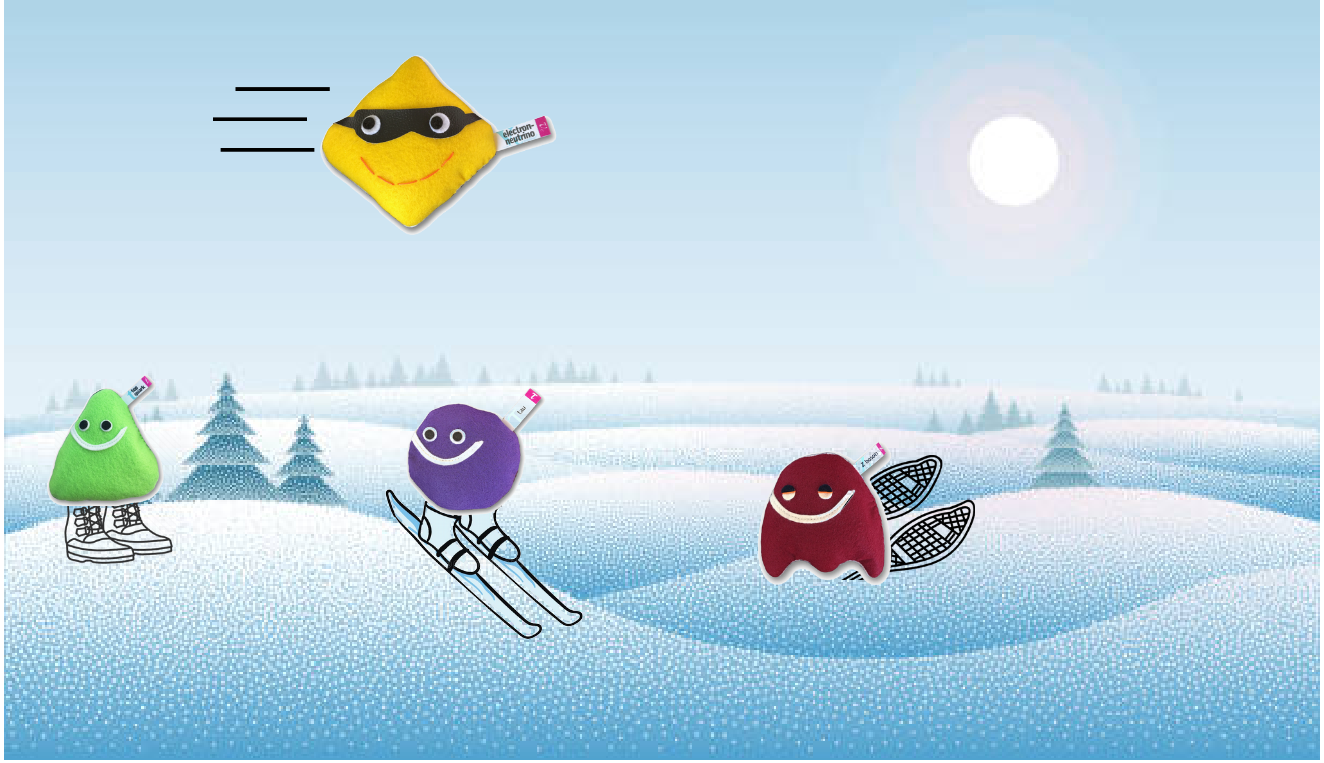
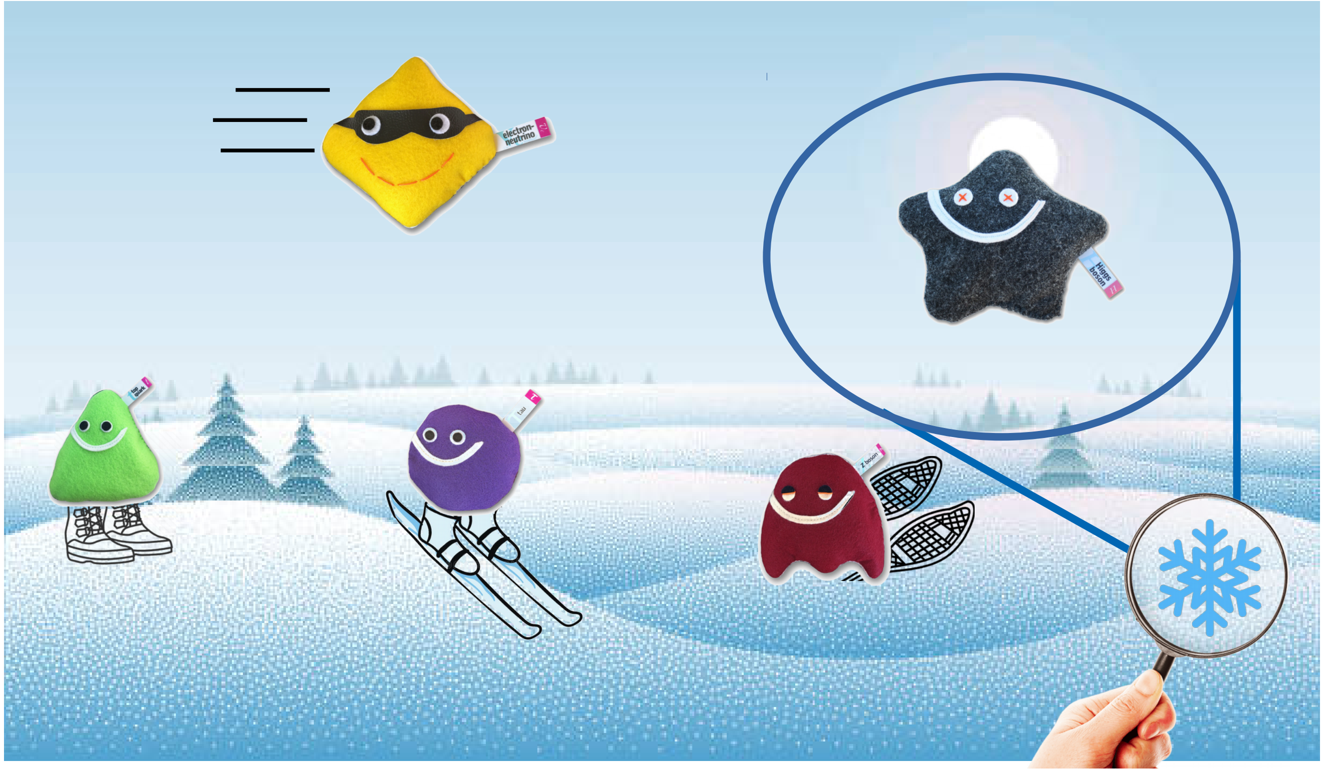


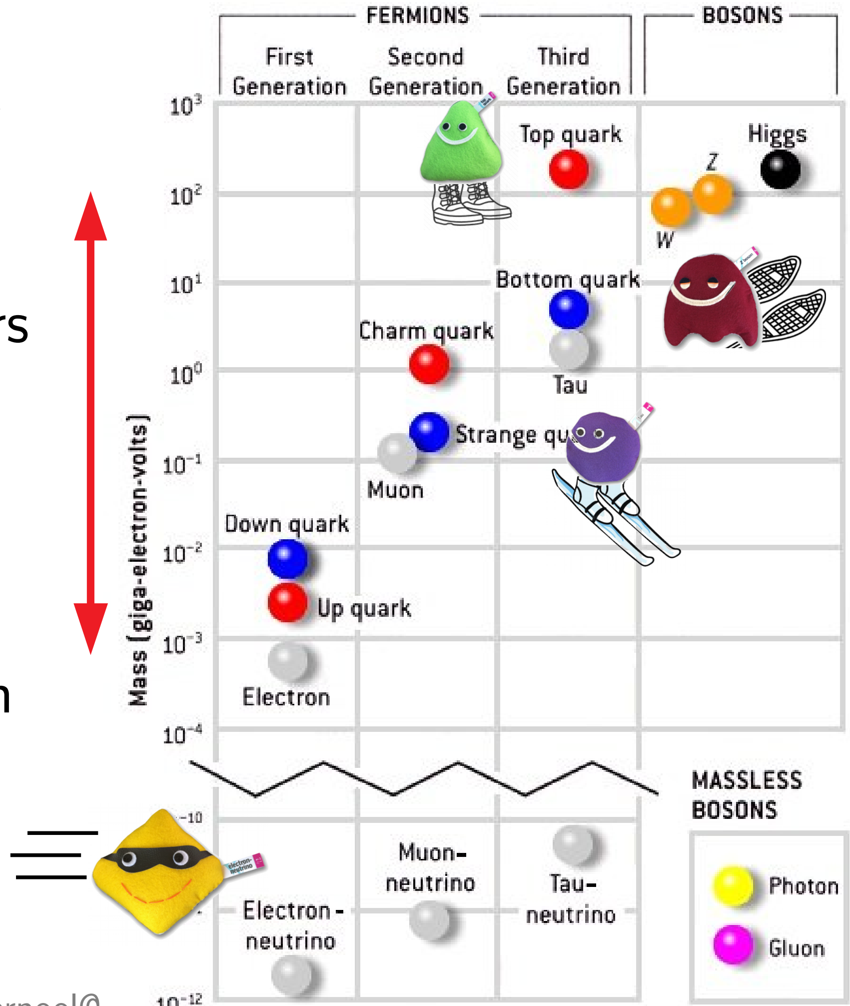
Mass as an interaction with the Higgs field

- You can think of the Higgs field as a snowfield.
- The particles need to cross the field, but there's different ways to do so…
- The snowflakes that make up this snowfield are the Higgs boson!



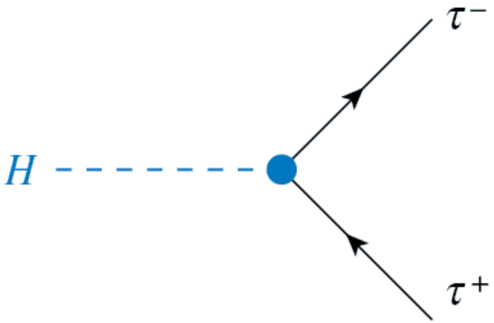
Mass as an interaction with the Higgs field

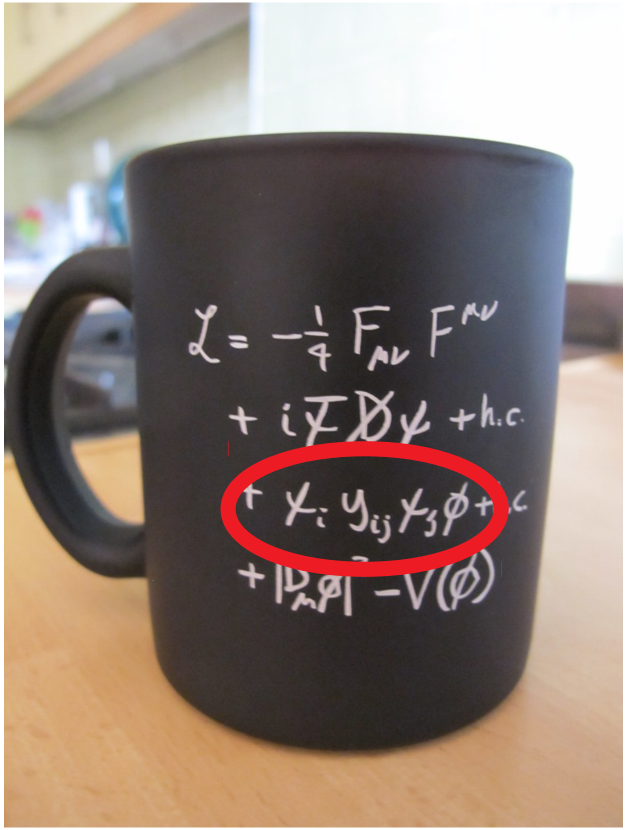
- The stronger these particles interact with the Higgs field/bosons, the higher their mass is.
- Note how mass range covers 5 orders of magnitude:
  - $M_{top} = 172$ GeV
  - $M_{ele} = 0.5$ MeV
  - Similar to comparing a bear with an ant!



The Universe in a mug

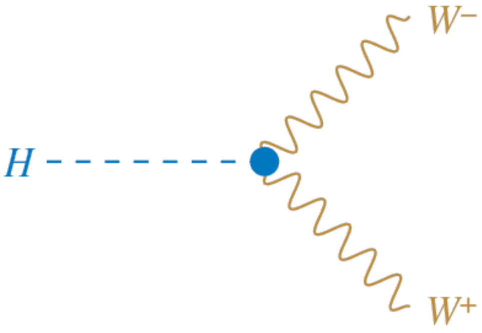
- Describes how matter particles couple to the Higgs field and gain mass.

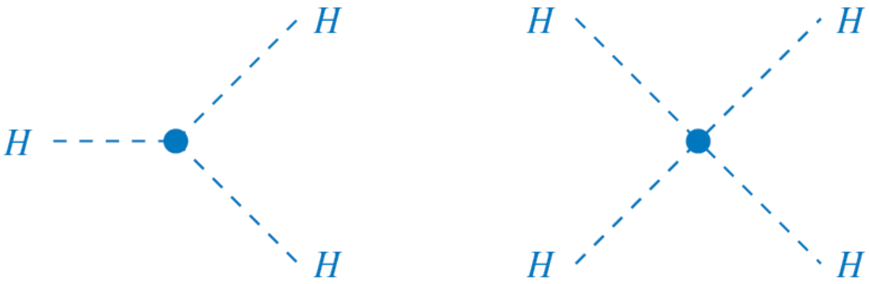


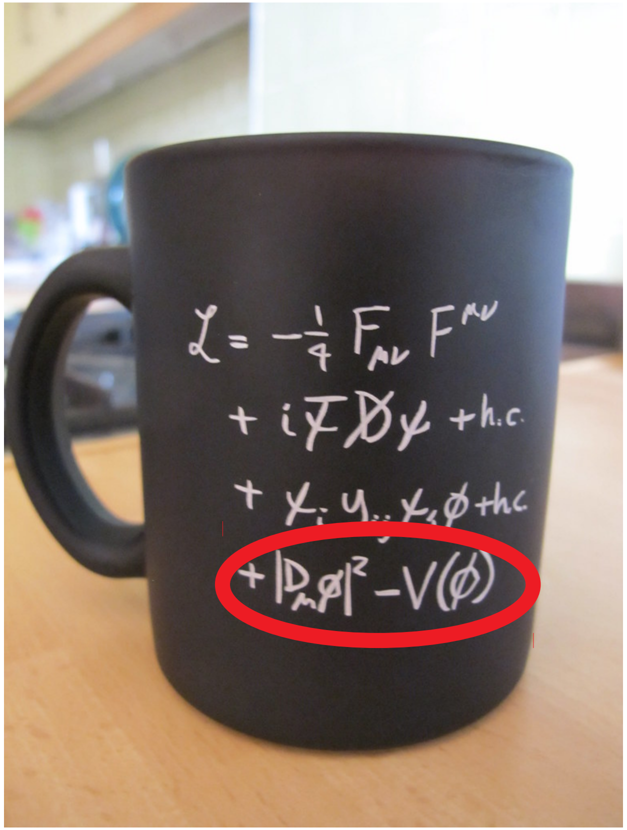


The Universe in a mug

- Describes the Higgs interactions with other bosons and itself.







But... how do we find the Higgs boson?

The Higgs discovery

- Particle physics discoveries depend on contrasting expectations and reality.

- If you expect X events for a given process and you find an excess, something must be causing those extra events!

- At LHC, an excess in the $\gamma\gamma$ channel was found, compatible with the Higgs boson predictions.

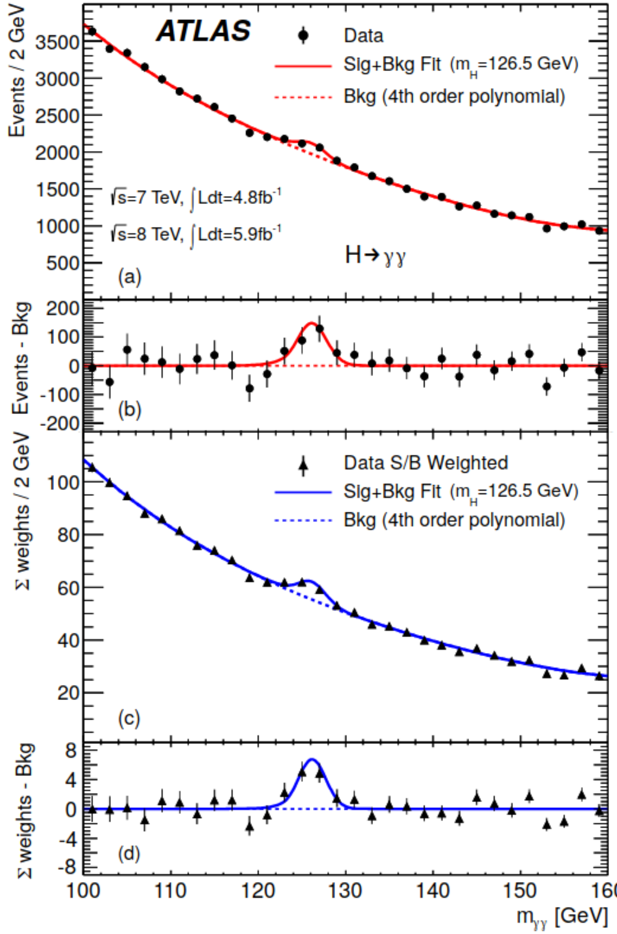
Summer

EXPECTATIONS

REALITY

The Higgs discovery

From: https://arxiv.org/abs/1207.7214



- Particle physics discoveries depend on contrasting expectations and **reality**.

- If you expect X events for a given process and you find an excess, something must be causing those extra events!

- At LHC, an excess in the $\gamma\gamma$ channel was found, compatible with the Higgs boson predictions.

ATLAS EXPERIMENT

The Higgs discovery

From: https://arxiv.org/abs/1207.7235

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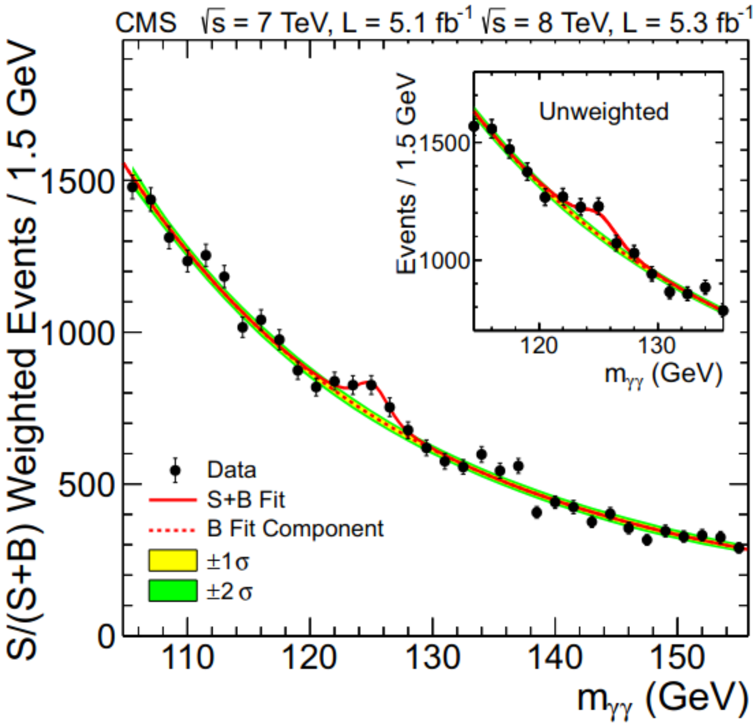
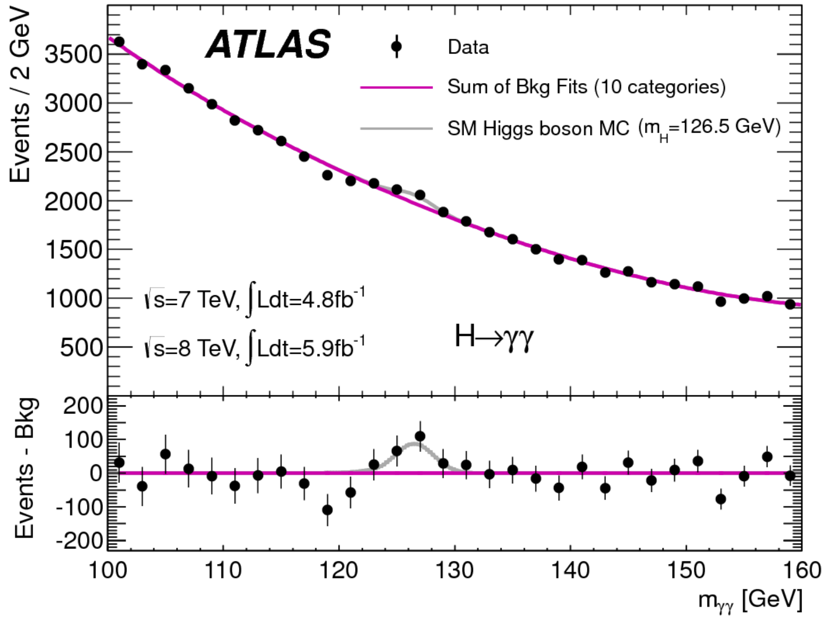
- If you expect X events for a given process and you find an excess, something must be causing those extra events!
- At LHC, an excess in the γγ channel was found, compatible with the Higgs boson predictions.



Particle discovery: background and signal

- Events observed at particle physics analysis are mainly divided into background and signal.
  - Background: events coming from processes you're not interested in.
  - Signal: events coming from the main process you want to study.

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/HIGG-2012-27/



Purple: events coming from background

Z, W, photons, electrons and many more can also decay into $\gamma\gamma$!

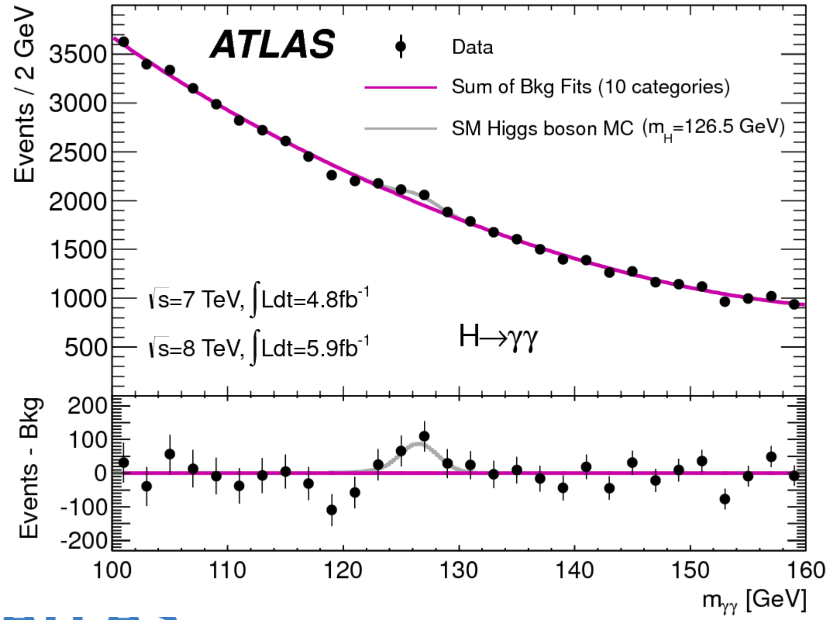
Grey: events coming from bkg+signal

May not look like much at first sight, but it's a ~300 events excess!

Particle discovery: background and signal

- Z, W, photons, electrons and many more can also decay into γγ!
  - How do we find excesses?
- When using photons, there's several things we can use to exclude non-relevant events:

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/HIGG-2012-27/



Photon ID: is our "photon" really a photon?

Photon momentum (p_T): the energy of our candidate.

Isolation: many particles are produced at LHC, we don't want our event to be contaminated!

Eta: the position of the photon in the detector.

When applying certain requirements (cuts) on these, we favour the appearance of signal events!

Back to programming!

Let's find the Higgs boson!

- Load Open Data kernel:
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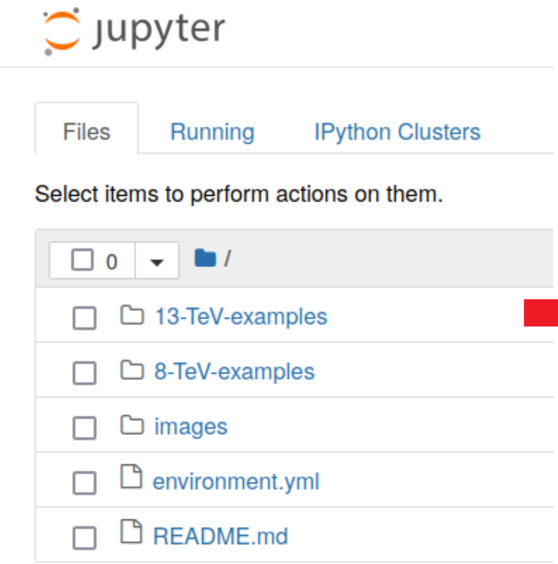

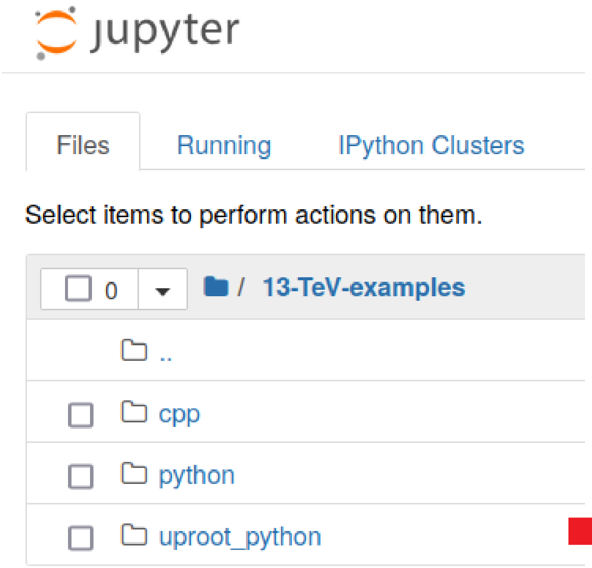

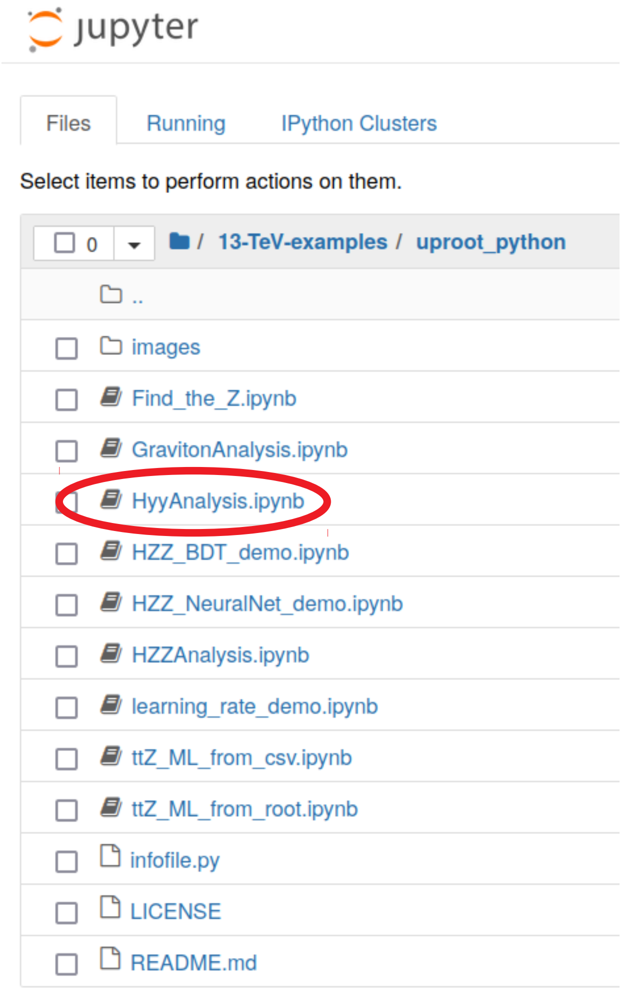

Let's find the Higgs boson!

- You will be taken to a jupyter notebook: interactive environment to run (python) code.
- Content is divided in cells, you can run a cell using the buttons on top of the page.
  - Content can be an image, text, code...
  - When running a cell that has no code it will skip to the next one. Code may take seconds, minutes, hours... depending on the function of the code.

Let's find the Higgs boson!

- Key parts of the code: lumi, fraction and data

Lumi, fraction, file path

General definitions of luminosity, fraction of data used, where to access the input files

```
lumi = 0.5 # fb-1 # data_A only
#lumi = 1.9 # fb-1 # data_B only
#lumi = 2.9 # fb-1 # data_C only
#lumi = 4.7 # fb-1 # data_D only
#lumi = 10 # fb-1 # data_A,data_B,data_C,data_D

fraction = 0.2 # reduce this is you want the code to run quicker

#tuple_path = "Input/GamGam/Data/" # local
tuple_path = "https://atlas-opendata.web.cern.ch/atlas-opendata/samples/2020/GamGam/Data/"
```

Samples

Samples to process

```
samples_list = ['data_A'] #'data_B','data_C','data_D' # add if you want more data
```

Lumi stands for luminosity, a quantity we use to account for how much data we collect.

Lumi needs to match the samples we use: when changing samples_list, we need to change lumi as well!

Let’s find the Higgs boson!

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```

Fraction represents the amount of data we want to use.

Fraction = 1.0 will use all data.
0.5 will use half of the data,
0.2 will use 20%, etc...

Samples

Samples to process

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Let's find the Higgs boson!

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Samples

Samples to process

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samples_list = ['data_A'] #'data_B','data_C','data_D' # add if you want more data
```

tuple_path tells the code where to look for the data.

Data is divided in different subsets (A to D), we can select which to use using samples_list

Remember to **change lumi accordingly**!

Let's find the Higgs boson!

- Key parts of the code: cuts

```
# Cut on photon reconstruction quality
# paper: "Photon candidates are required to pass identification crit
def cut_photon_reconstruction(photon_isTightID):
# isTightID==True means a photon identified as being well reconstruc
# want to keep events where True for both photons
# first photon is [0], 2nd photon is [1] etc
    return photon_isTightID[0]==True and photon_isTightID[1]==True

# Cut on Transverse momentum
# paper: "The leading (sub-leading) photon candidate is required to
def cut_photon_pt(photon_pt):
# want to keep events where photon_pt[0]>40000 MeV and photon_pt[1]>
    return photon_pt[0]>40000 and photon_pt[1]>30000

# Cut on energy isolation
# paper: "Photon candidates are required to have an isolation transv
def cut_isolation_et(photon_etcone20):
# want to keep events where isolation eT<4000 MeV
    return photon_etcone20[0]<4000 and photon_etcone20[1]<4000

# Cut on pseudorapidity in barrel/end-cap transition region
# paper: "excluding the calorimeter barrel/end-cap transition region
def cut_photon_eta_transition(photon_eta):
# want to keep events where modulus of photon_eta is outside the ran
    return (abs(photon_eta[0])>1.52 or abs(photon_eta[0])<1.37) and
```

Photon ID: is our "photon" really a photon?

Photon momentum (p_T): the energy of our candidate.

Isolation: many particles are produced at LHC, we don't want our event to be contaminated!

Eta: the position of the photon in the detector.

You can test the effects of lowering/removing these cuts!

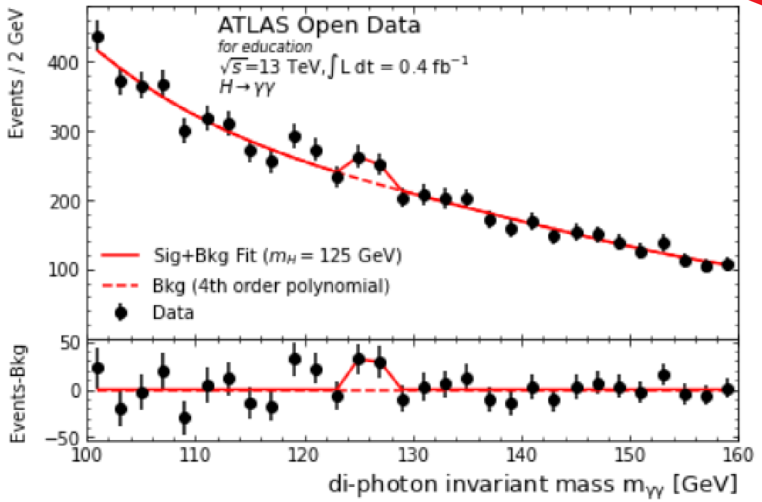
Let’s find the Higgs boson!

- Key parts of the code: running on data + plotting

```
start = time.time() # time at start of whole processing
data = get_data_from_files() # process all files
elapsed = time.time() - start # time after whole processing
print("Time taken: "+str(round(elapsed,1))+"s") # print total
```

Other lines only define variables/functions. This will actually run on data, so this will take the longest (depending on the value of fraction)

```
: plot_data(data)
```



This will plot the final result. plot_data is defined in the previous cell, no need to change that one!

Your turn!

- So far we've only repeated what was done in the original analysis, but there's things you can test:
  - What's the effect of the cuts?
  - What if you add more data?
- Many more analysis to test!