UNIVERSITY OF OXFORD

ATLAS EXPERIMENT

Intro to finding Z & Higgs bosons

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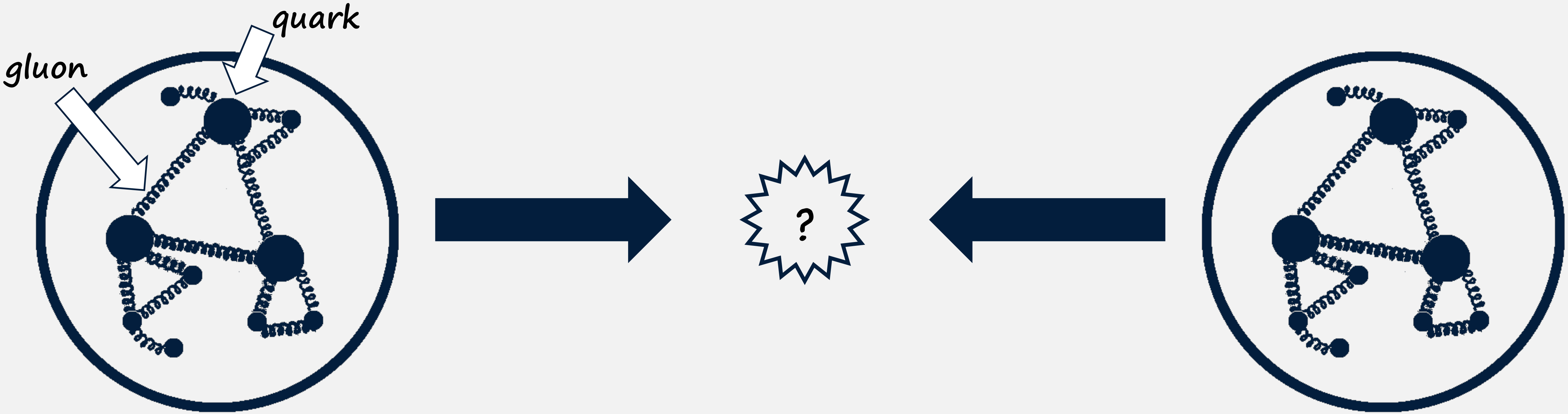
(artwork c/o Siyuan Yan - Oxford)

Protons colliding at the LHC are made of **quarks** and **gluons** – these interact to create new particles



In the following notebooks will be searching for two of these: the Z^0 and Higgs bosons

The Z^0 boson

- Exchanges the **weak nuclear force,** along with the W^+ and W^- bosons
  - This is the force responsible for radioactive decay
- It is similar to a ‘heavy photon’, except it can also interact with neutral particles e.g. neutrinos
- Unlike the photon, the Z^0 boson is:
  - Heavy: Mass = 91 GeV
  - Short-lived: Lifetime = 3×10^{-25} s

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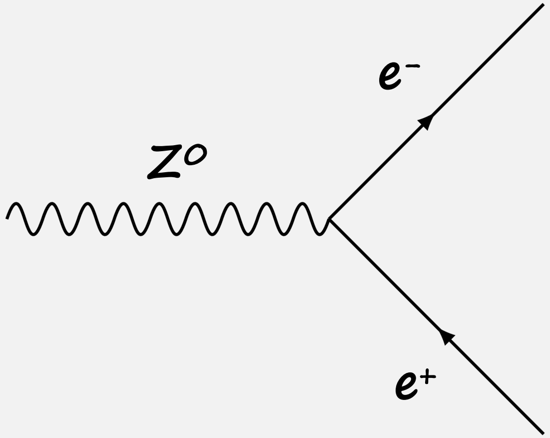
Q: How do we find a particle that decays in 0.0000000000000000000000003 seconds?
A: By looking at what it leaves behind!

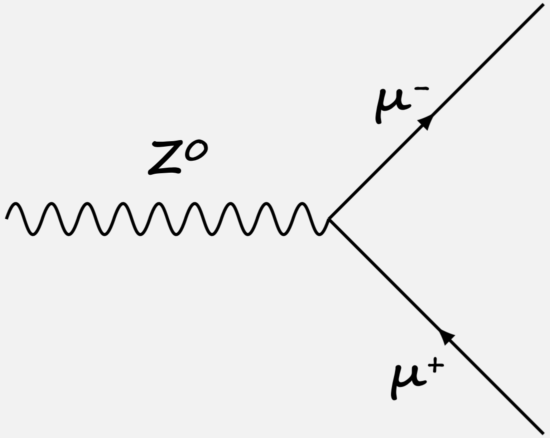
Z^0 Decays

The two easiest Z^0 decays to see in ATLAS are:

Electron-positron pair



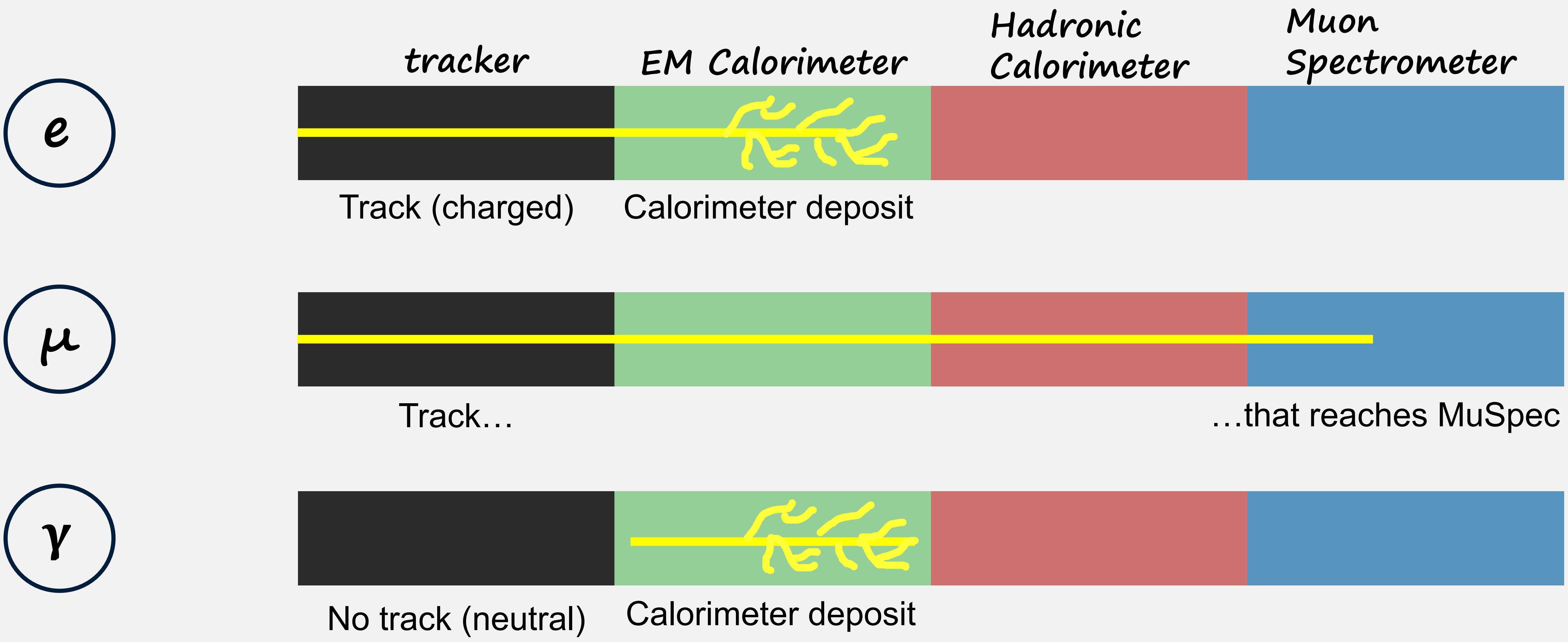
Muon-antimuon pair



Both decay products are stable enough to see in the ATLAS detector

Particle Identification - Signal

We can identify a particle based on the set of signals it leaves in ATLAS



HOWEVER, other interactions can make our ‘signal events’ difficult to spot

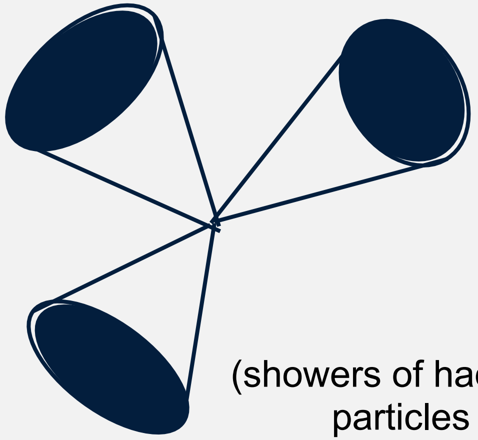
Background Events

- When protons collide, all sorts of particles can be created, not just Higgs and Z
- Some of these can have similar decay products as our signal events

W boson

Top quark

Jets

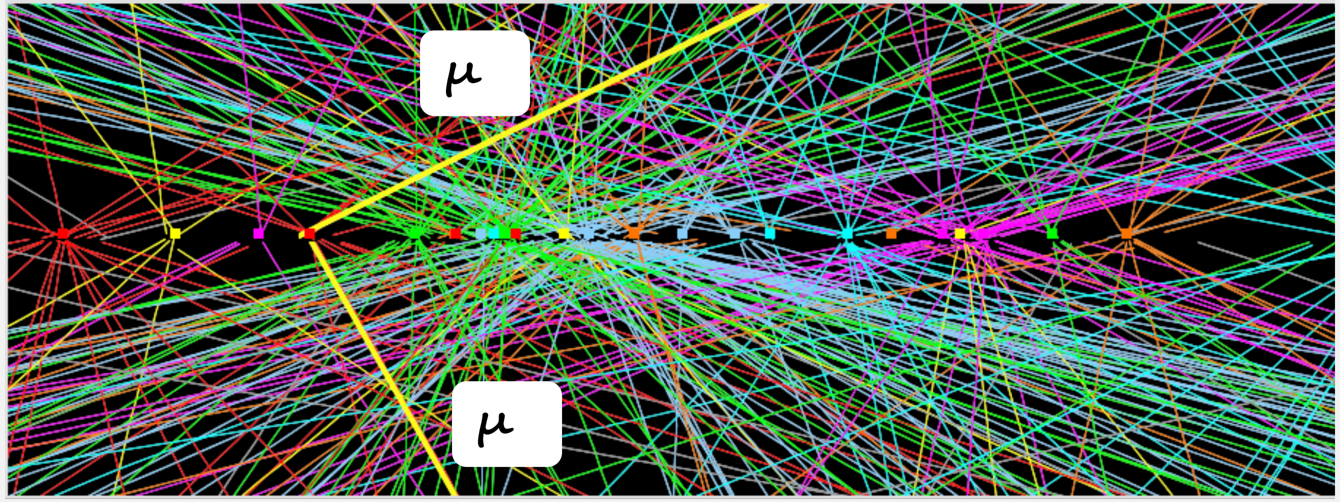


(showers of hadronic particles which interact via the strong force)

HOWEVER, other interactions can make our 'signal events' difficult to spot

Pile-up

- The LHC collides protons in 'bunches' of 100000000000 (1.1×10^{11}) every 25 ns
- Uninteresting events take place at the same time as something interesting

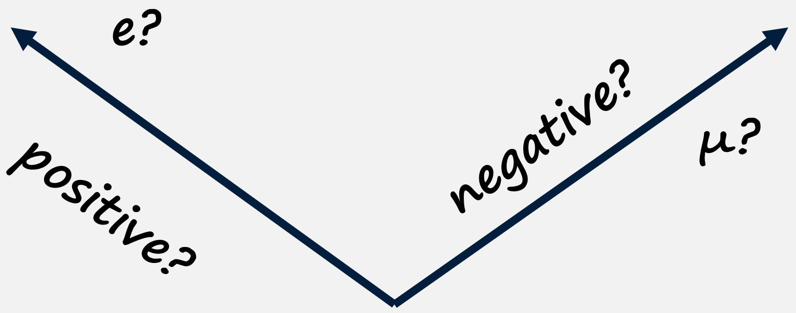


HOWEVER, other interactions can make our 'signal events' difficult to spot

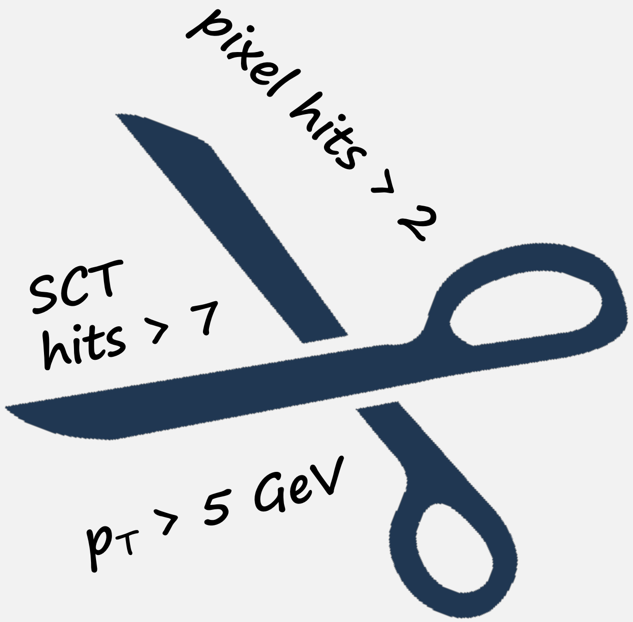
What can we do?

1. Look carefully for the correct **final state**

- Two oppositely charged electrons or muons



2. Apply **cuts**: Filters aiming to reduce background



The Higgs boson

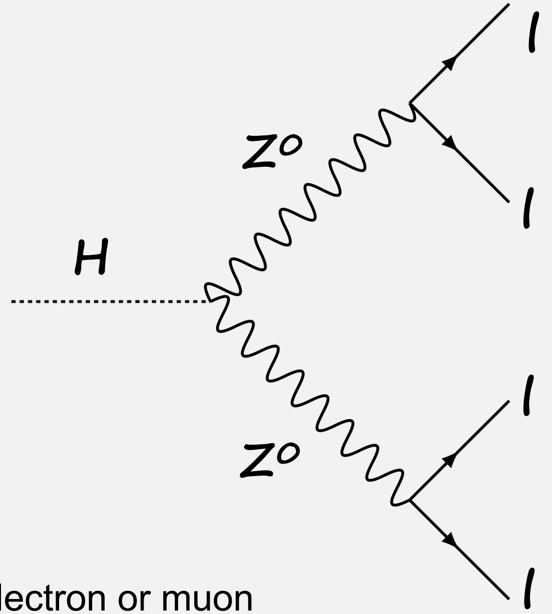
- Final Standard Model particle to be discovered, in 2012 by ATLAS and CMS
- Couples to other particles to give them mass
- Very heavy: Mass = 125 GeV

Identify Higgs events: Same game as before – via decays

Higgs Decays

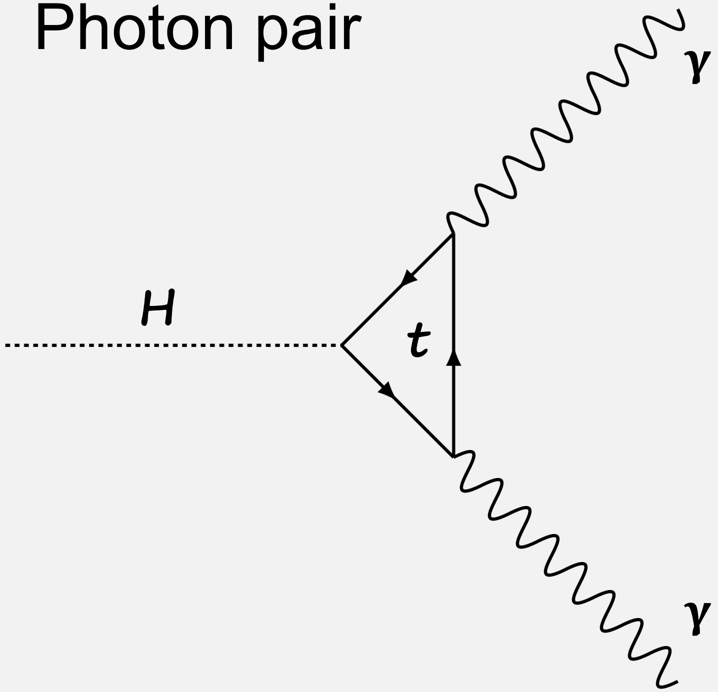
The two easiest Higgs decays to see in ATLAS are:

ZZ pair → 4 leptons*



*electron or muon

Photon pair



Other decays e.g. H → bb are more common but also harder to spot – backgrounds!

We've found our leptons, but how do we know they've come from the Z of the Higgs?

→ **Invariant mass** is a unique fingerprint for each particle!

You may be familiar with:

$$E = mc^2$$

A more complete version is...

$$E = \sqrt{(\underbrace{\boldsymbol{p}}_{\text{momentum}} \cdot c)^2 + (\overbrace{m_0}^{\text{invariant mass}} \cdot c^2)^2}$$

$$E = \sqrt{(\boldsymbol{p} \cdot c)^2 + (m_0 \cdot c^2)^2}$$

Rearranged... →

$$m_0 = \sqrt{(\frac{E}{c^2})^2 - (\frac{\boldsymbol{p}}{c})^2}$$

- Invariant mass is **conserved** → total m_0 of the decay products is the same as the particle which has decayed
- To reconstruct e.g. the Z^0 mass:
  1. Sum the energy (E) of the decay leptons (measured in ECAL or muon spectrometer)
  2. Sum the momentum (**p**) of the decay leptons (tracker)
  3. Put results into formula above

In practice, we have coding tools to help with this – continue the notebook to find out more!

Your turn!