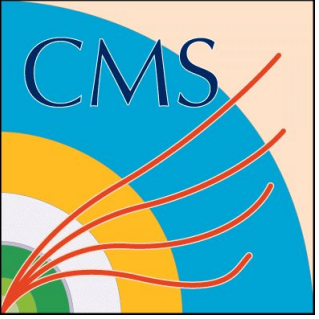


Imperial College London

CMS HZZ analysis exercise

IC Masterclass 2026

Ryan Schmitz, Daniel Winterbottom

Overview of the task

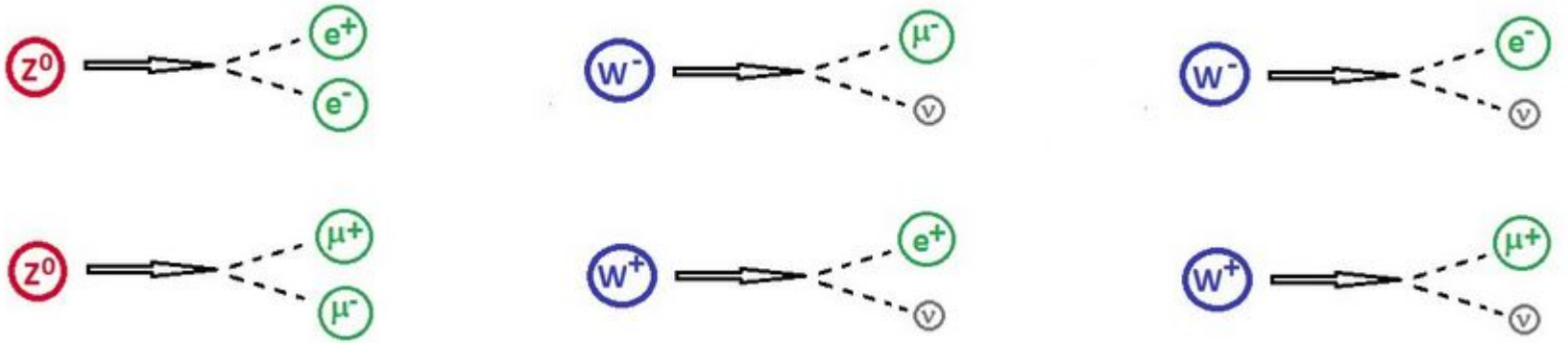
https://indico.global/event/18516/

- Your task today is to analyses some genuine LHC data collected by CMS
- You will look at event display and identify and study W, Z, and H boson events
- Then, you'll try to measure Z and H bosons in a Higgs decay,
- At the end of the session we will collect the results from everyone and analyse/discuss the collective results

W and Z boson decays

https://indico.global/event/18516/

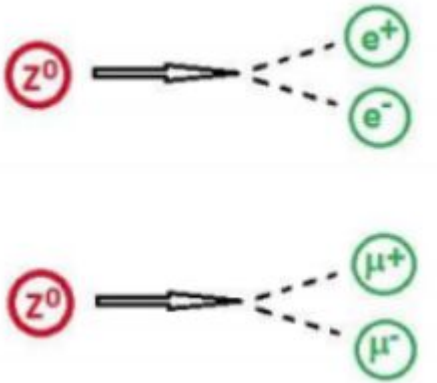
- W and Z bosons decay into particles called leptons
  - ➢ Electrons, muons, and neutrinos are all types of leptons
- Z boson has no charge and therefore decays into two leptons with opposite charge (e.g e^+ e^-)
- W boson has +1 or -1 charge and therefore decays into a single charged lepton (electron or muon) and a neutrino



H boson decays

https://indico.global/event/18516/

- Higgs bosons can decay into two Z bosons
- Z bosons subsequently decay into leptons (electron or muons) and therefore we get 4 leptons in the final state

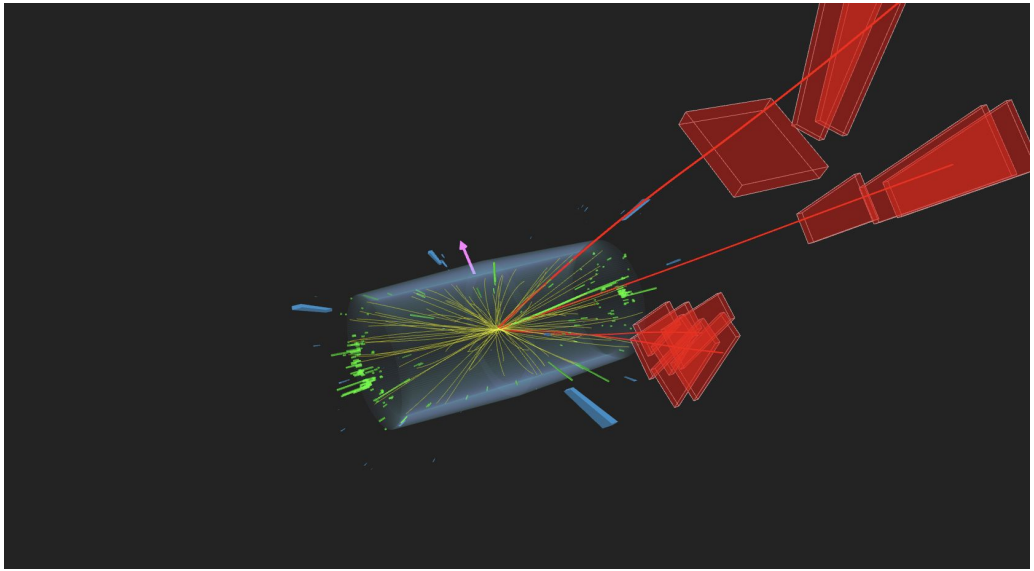


Event Displays

https://indico.global/event/18516/

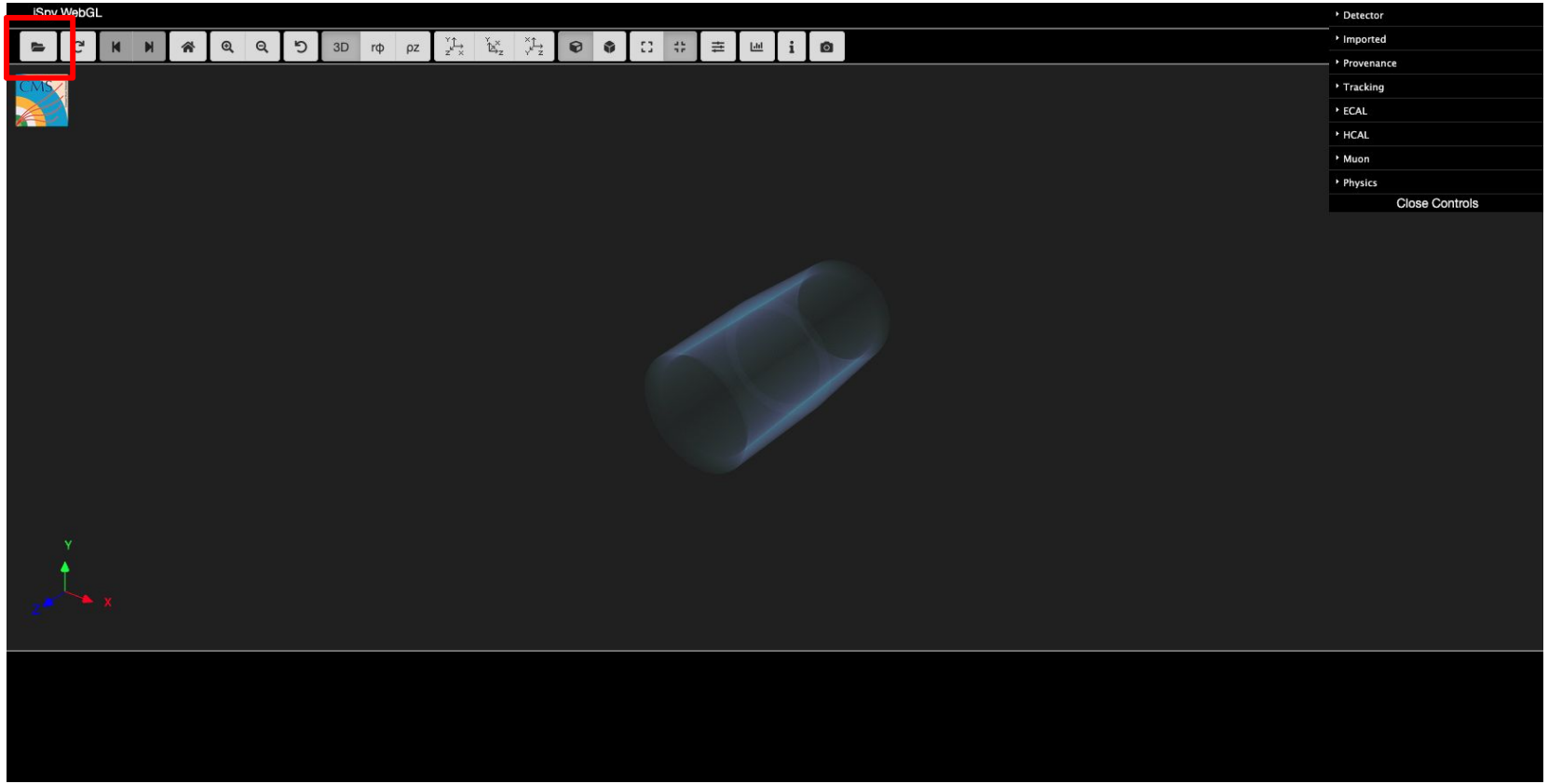
Let’s look at some real events

Navigate to https://tinyurl.com/ispycms



How to use the event display

https://indico.global/event/18516/



How to use the event display

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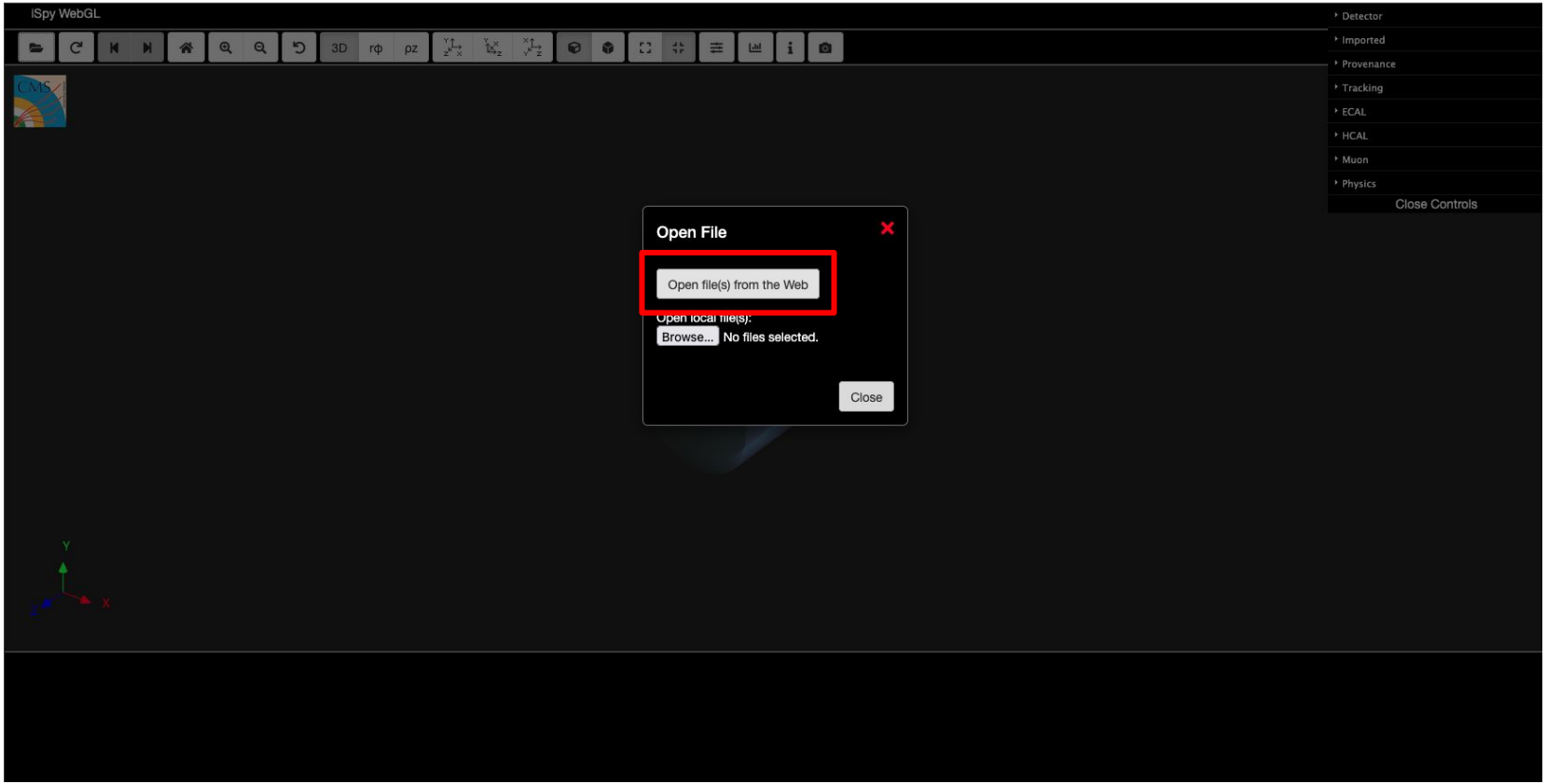

How to use the event display

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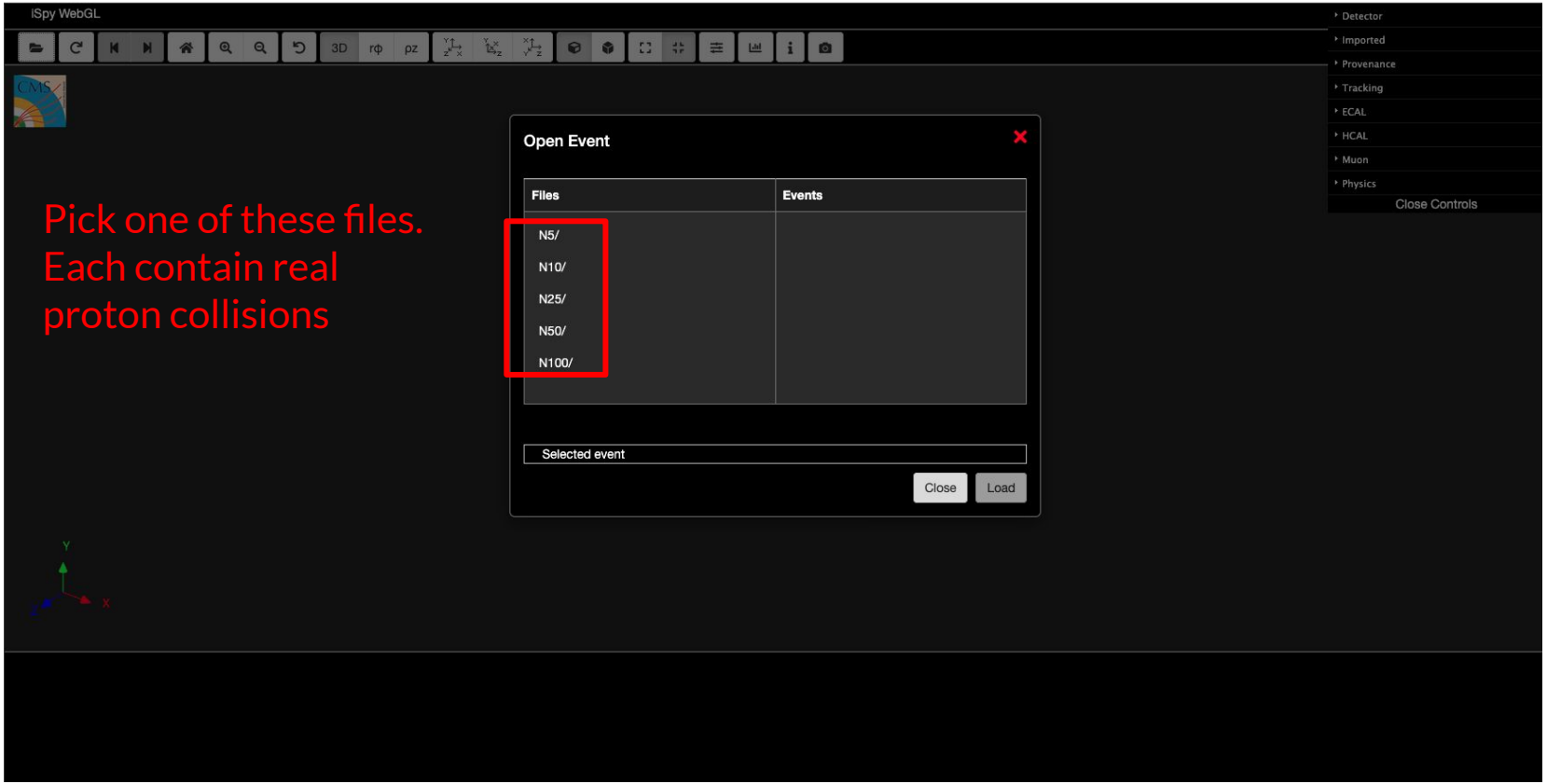

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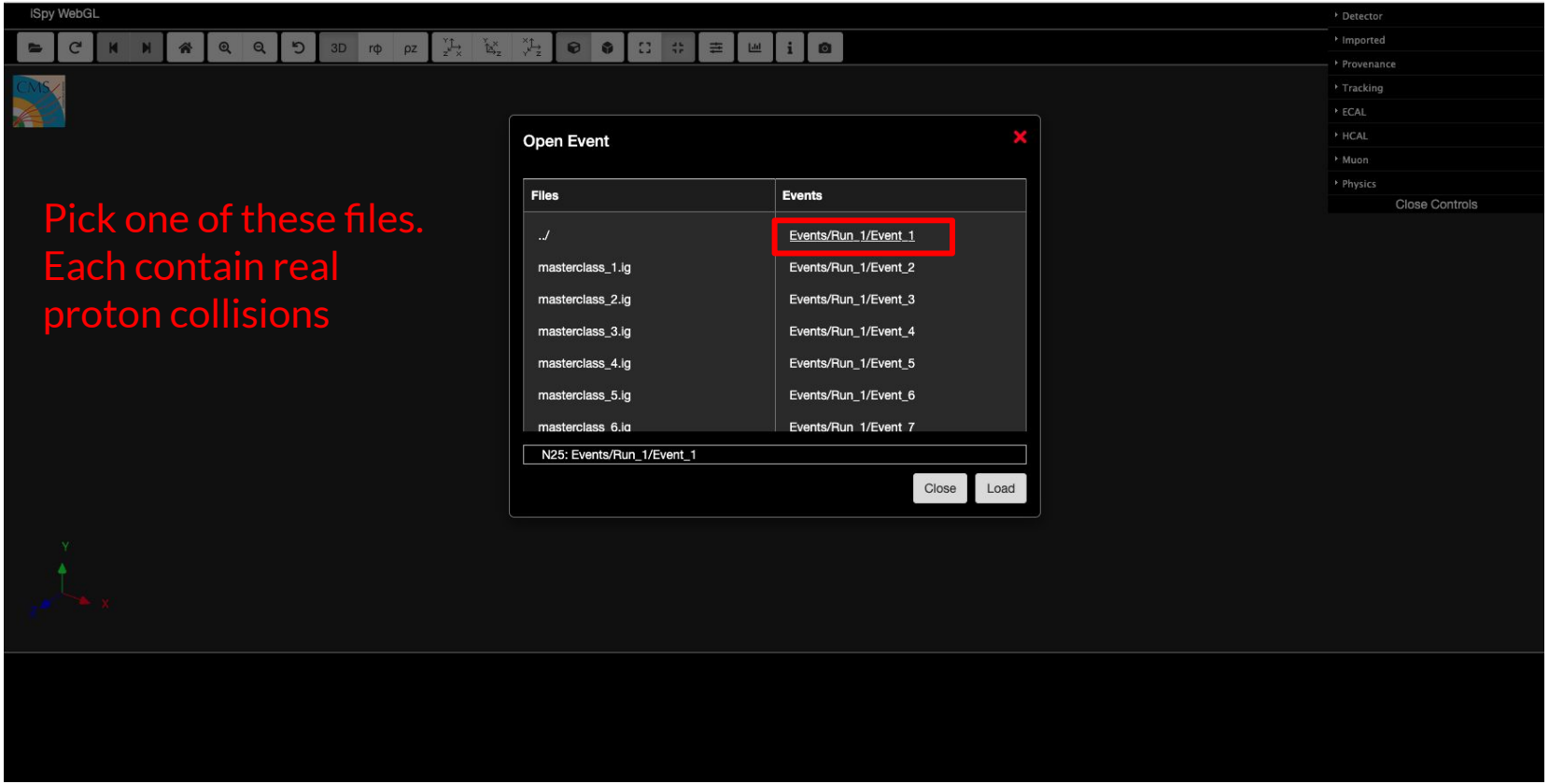

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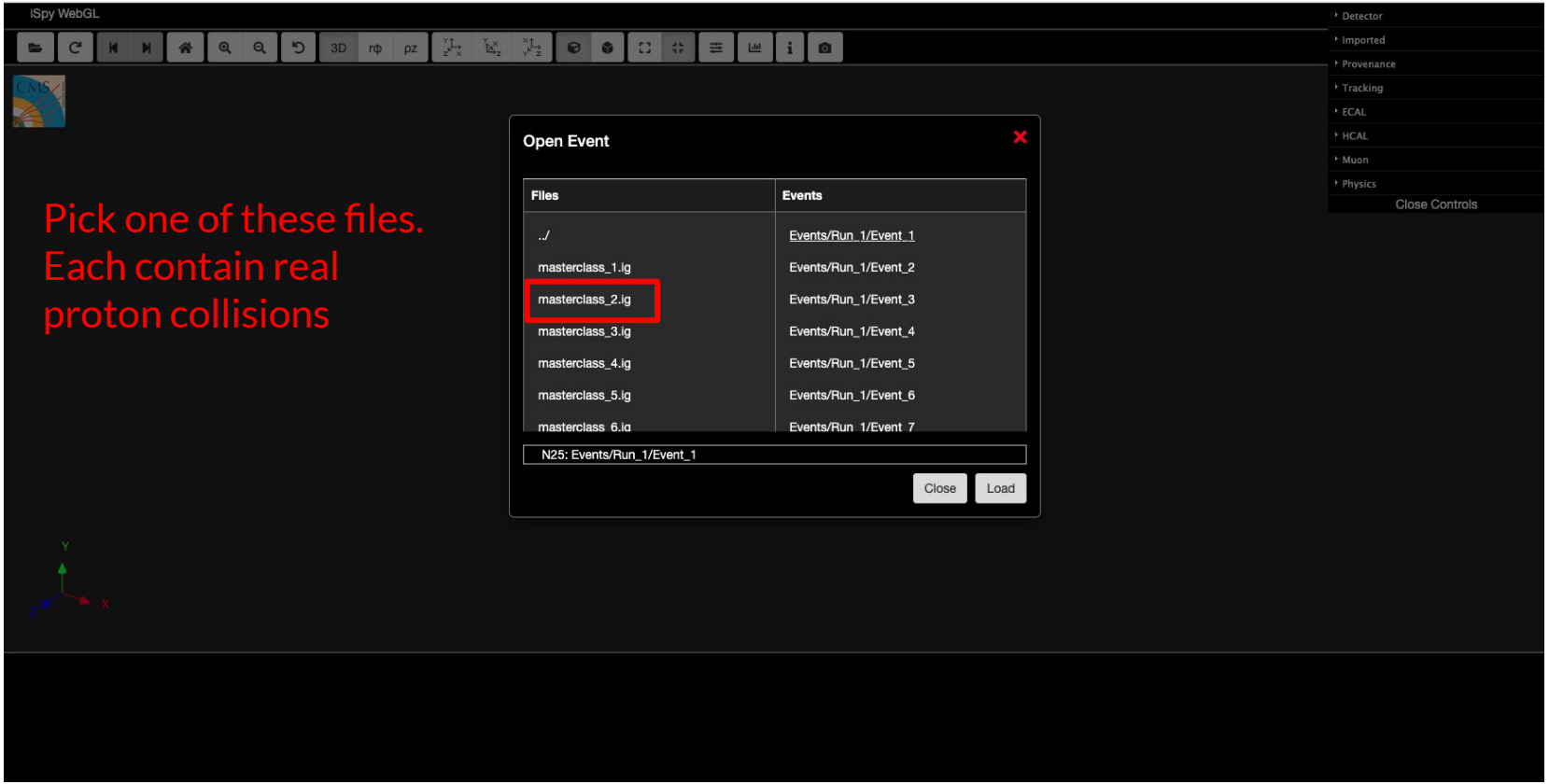

How to use the event display

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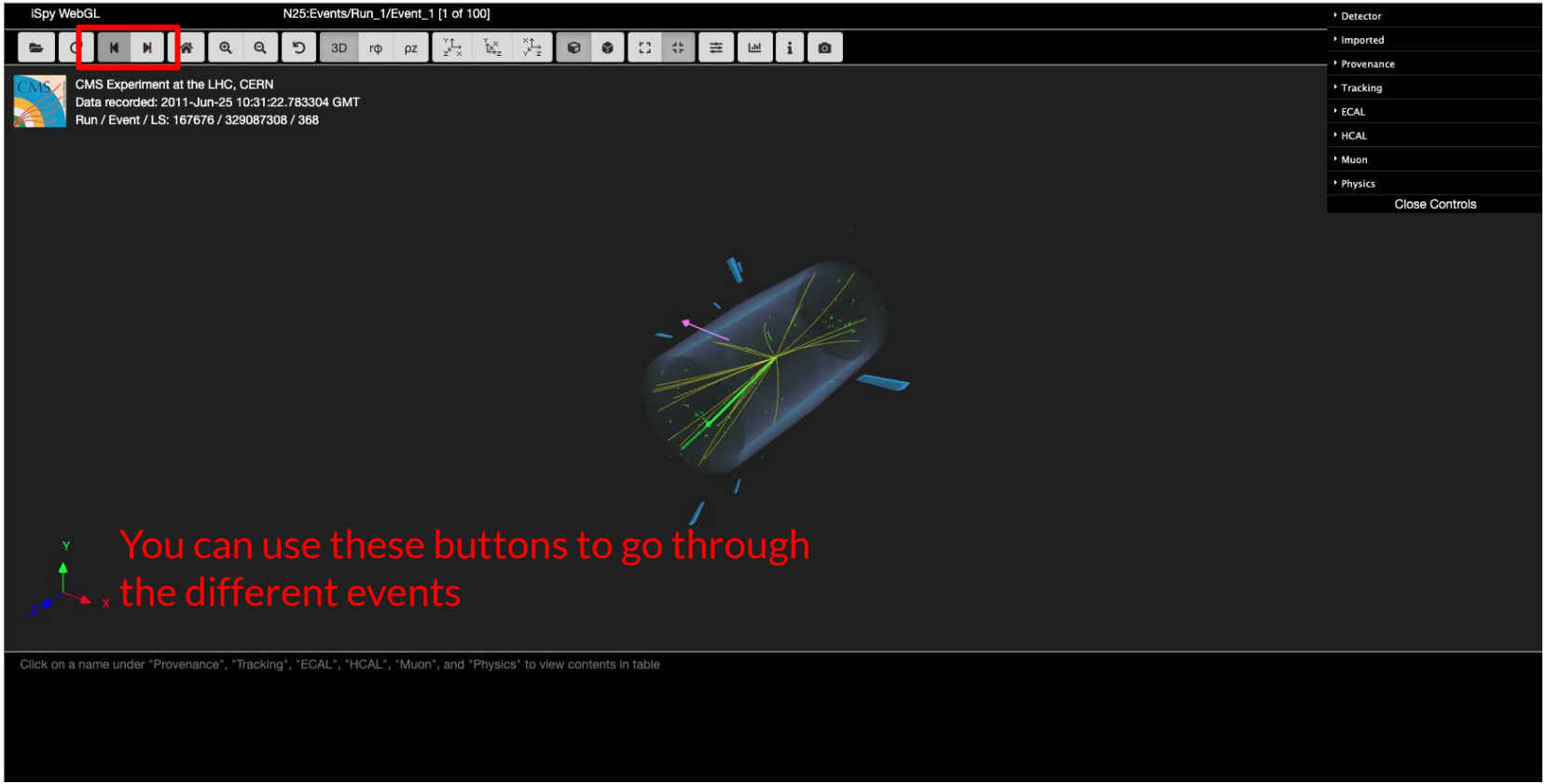
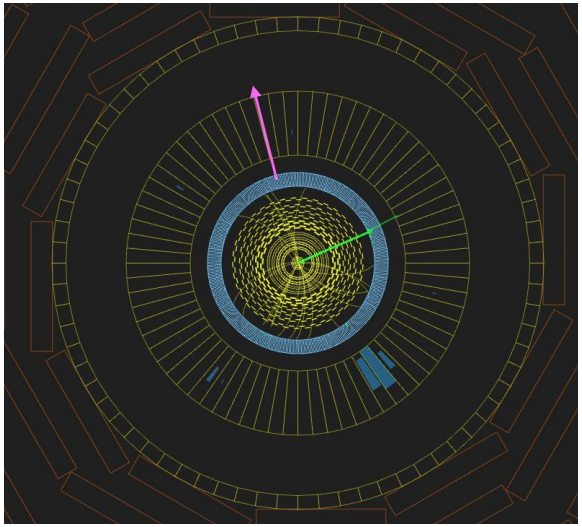


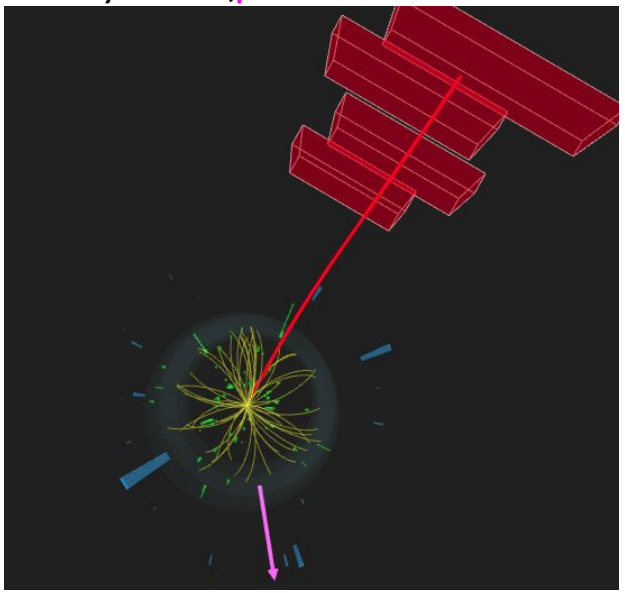
Identifying W bosons

https://indico.global/event/18516/

- Electrons identified as tracks in inner tracker pointing to deposits in the ECAL, muons are track in the inner tracker and muon system
- Electrons coloured green, Muons coloured red
- Neutrinos are undetected but missing momentum in the system (pink coloured thick straight line) indicates their presence



$W \rightarrow e\nu$

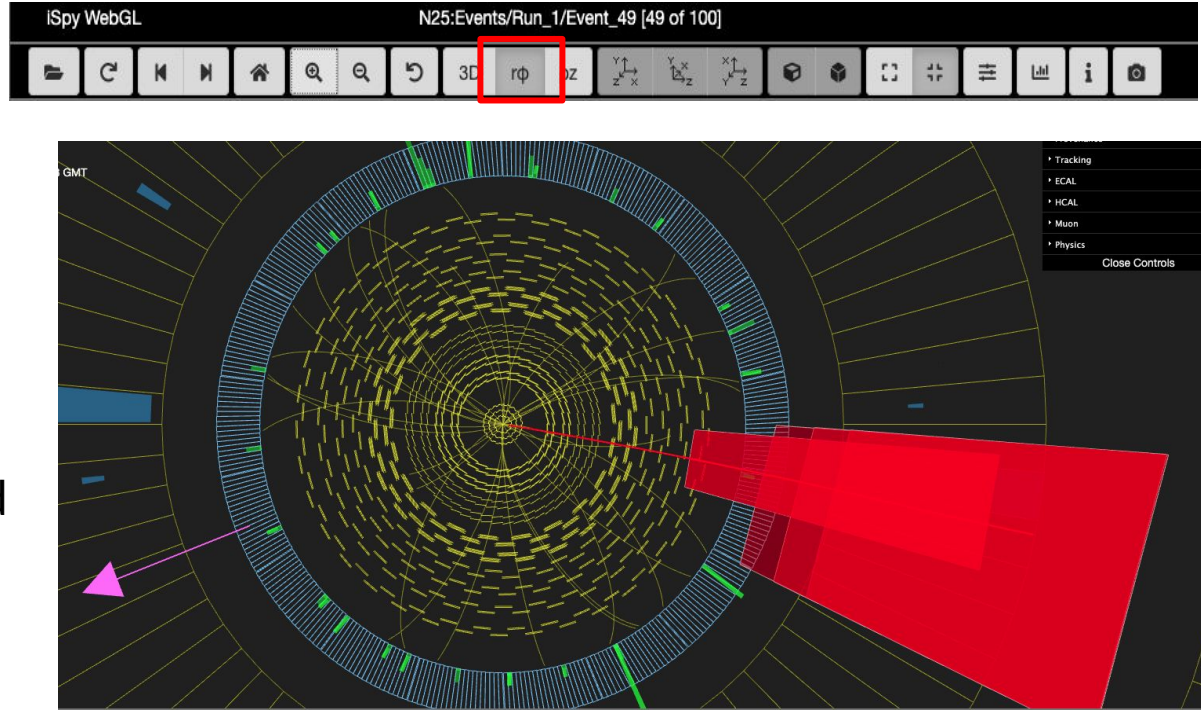


$W \rightarrow \mu\nu$

Measuring charges

https://indico.global/event/18516/

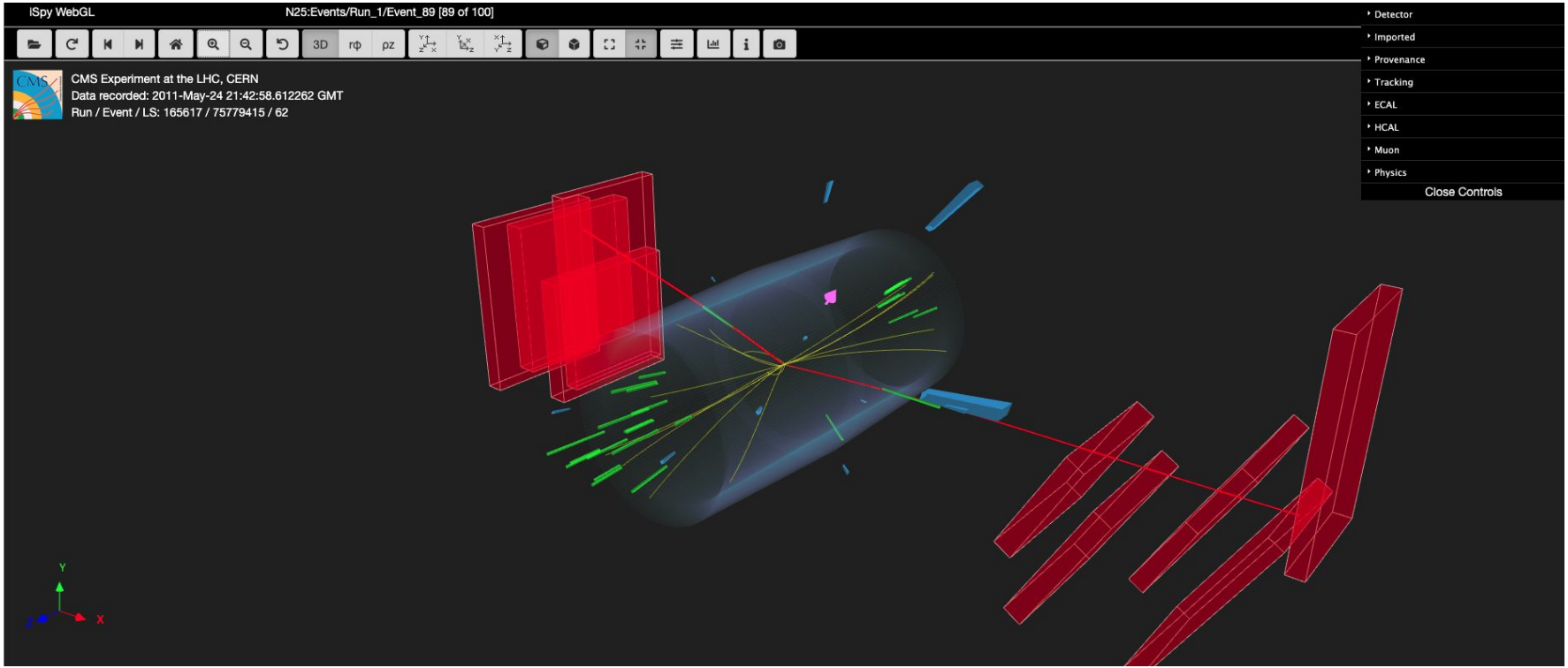
- Charged leptons bend in magnetic field
- The direction that they bend in depends on their charge
- **Positive** leptons will bend **clockwise**
- **Negative** leptons will bend **anti-clockwise**
- Select y-x view, zoom in to see curvature and then identify the charge



Identifying Z bosons

https://indico.global/event/18516/

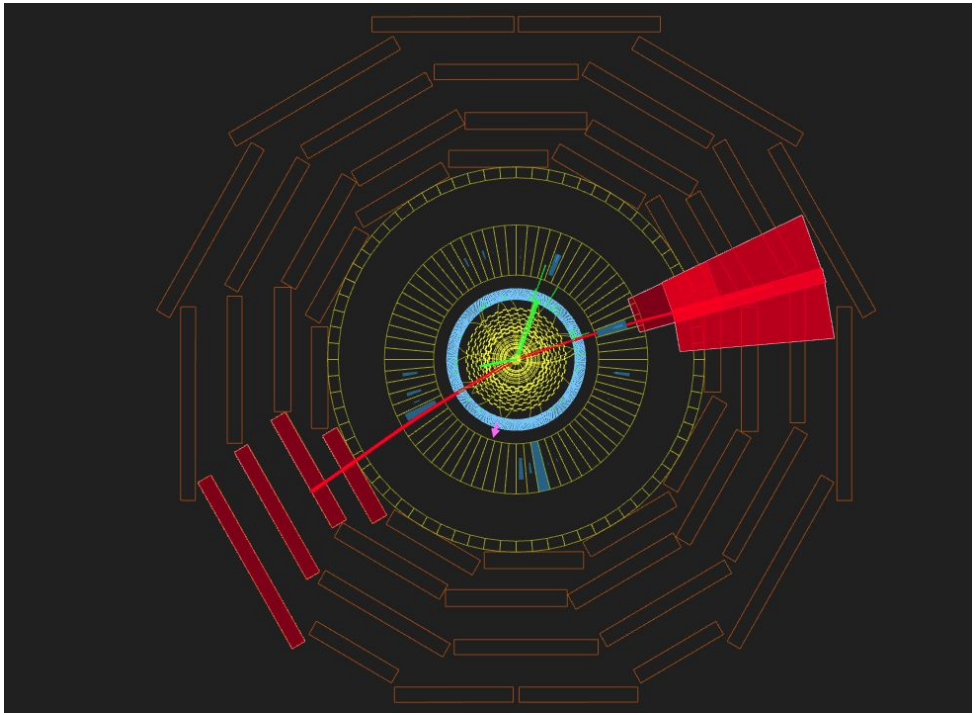
Z bosons decay into two oppositely charged electrons or muons



Identifying Higgs boson events

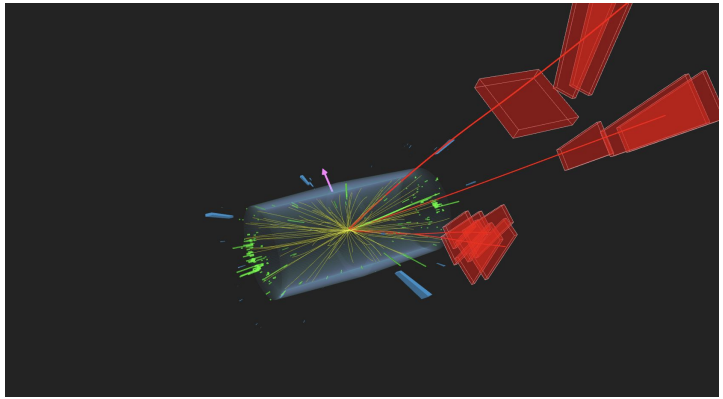
https://indico.global/event/18516/

- Higgs bosons can be identified by looking for 4 lepton events (4e, 4**μ**, or 2e2**μ**)



Let’s get started

- Follow the instructions in the slides to open your dataset
- Talk to a demonstrator if you have any issues - If you spot any events that are unclear/odd you can also discuss these with your demonstrators!
- You can also open this slides on: https://indico.global/event/18516/ under ‘Particle Physics Computer Exercise’
- In 15 minutes we’ll start analyzing some data from events like the ones you see here



https://tinyurl.com/ispycms

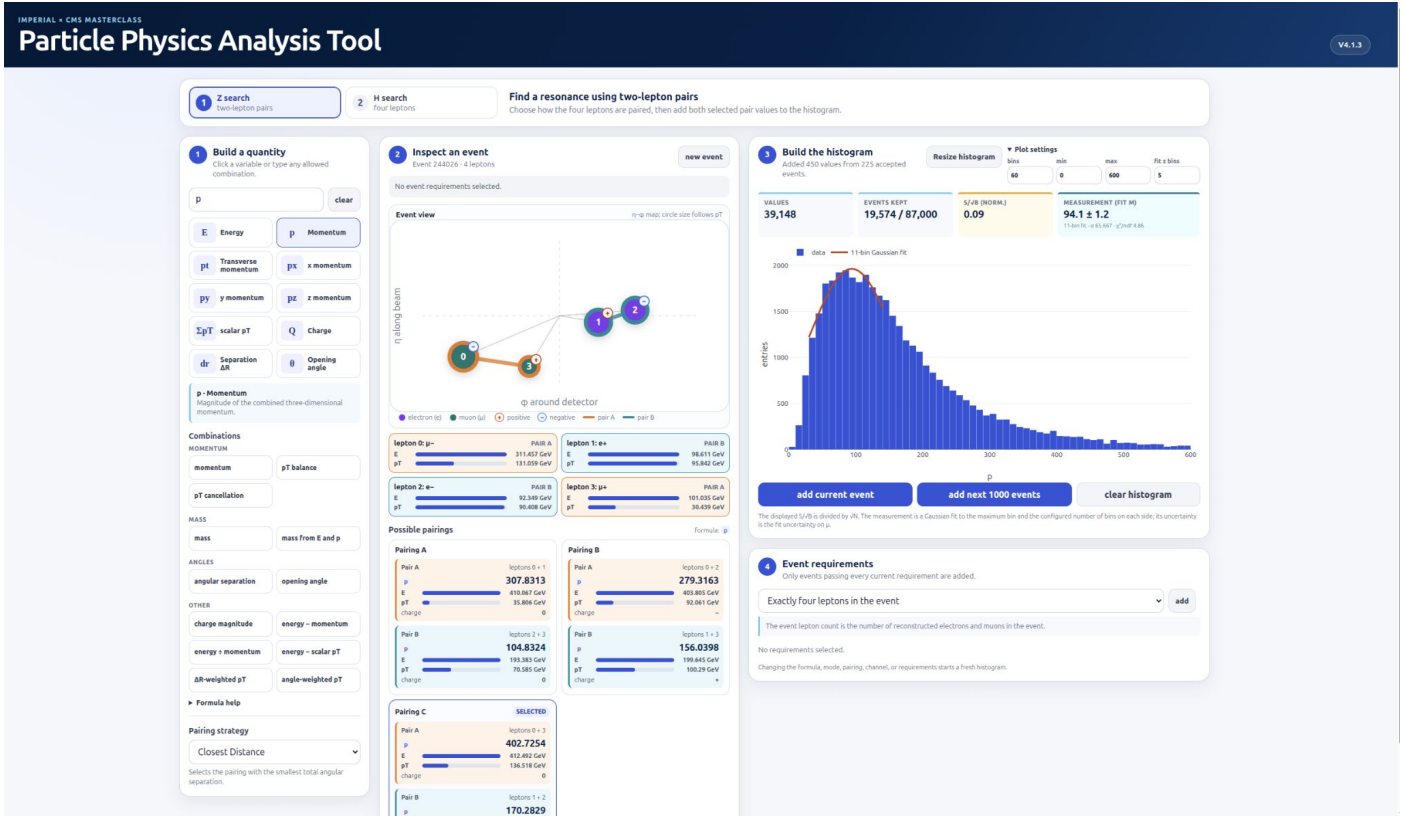
Analyzing data

https://www.hep.ph.ic.ac.uk/masterclass/

Now, let's analyze some data!

We'll use H->ZZ->4L data, which contains Higgs boson and Z boson decays

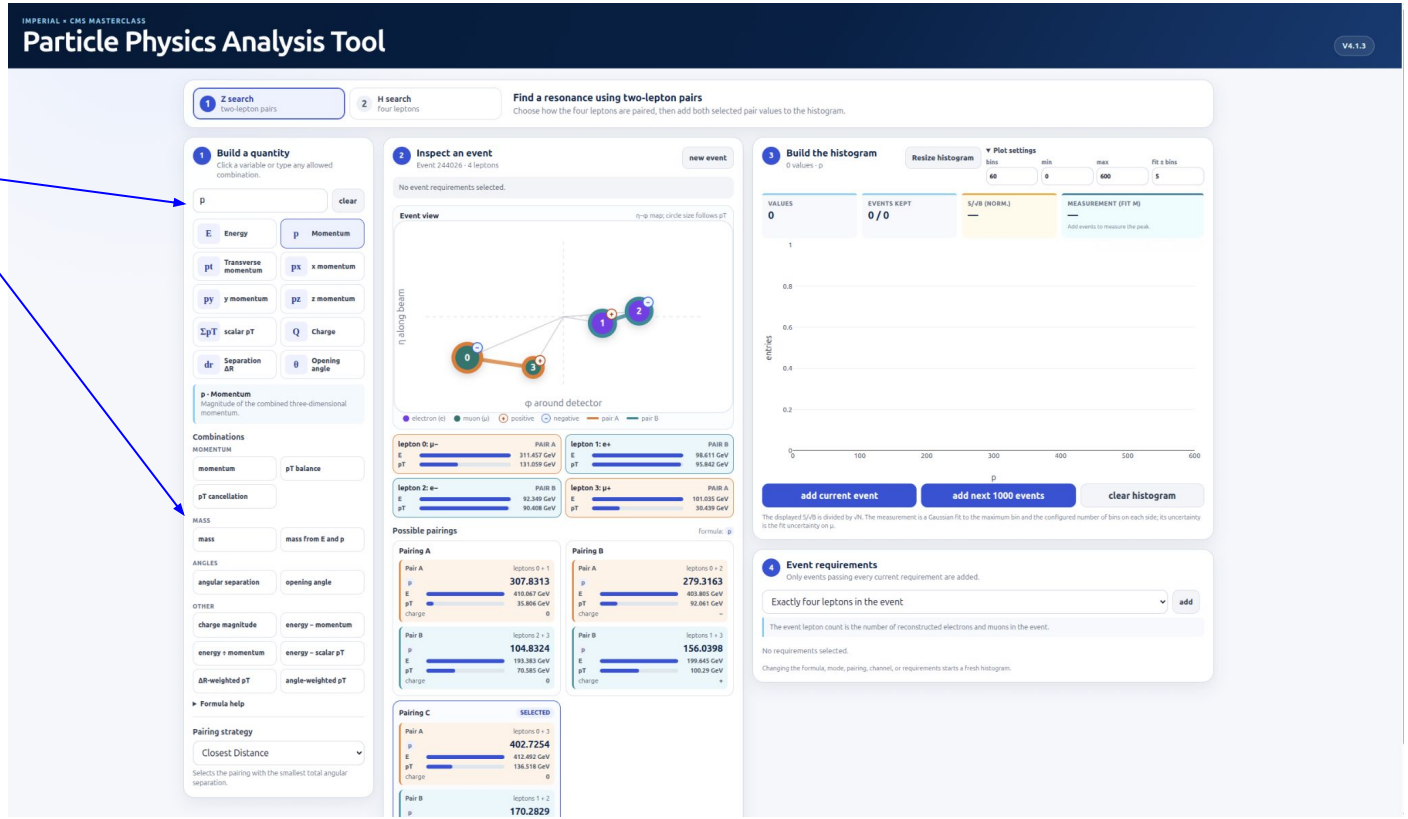
What can we learn about the H and Z by measuring their decay products?



Analysis Tool tutorial

https://www.hep.ph.ic.ac.uk/masterclass/

1. Choose a variable, mix of variables, or predefined combination you want to measure

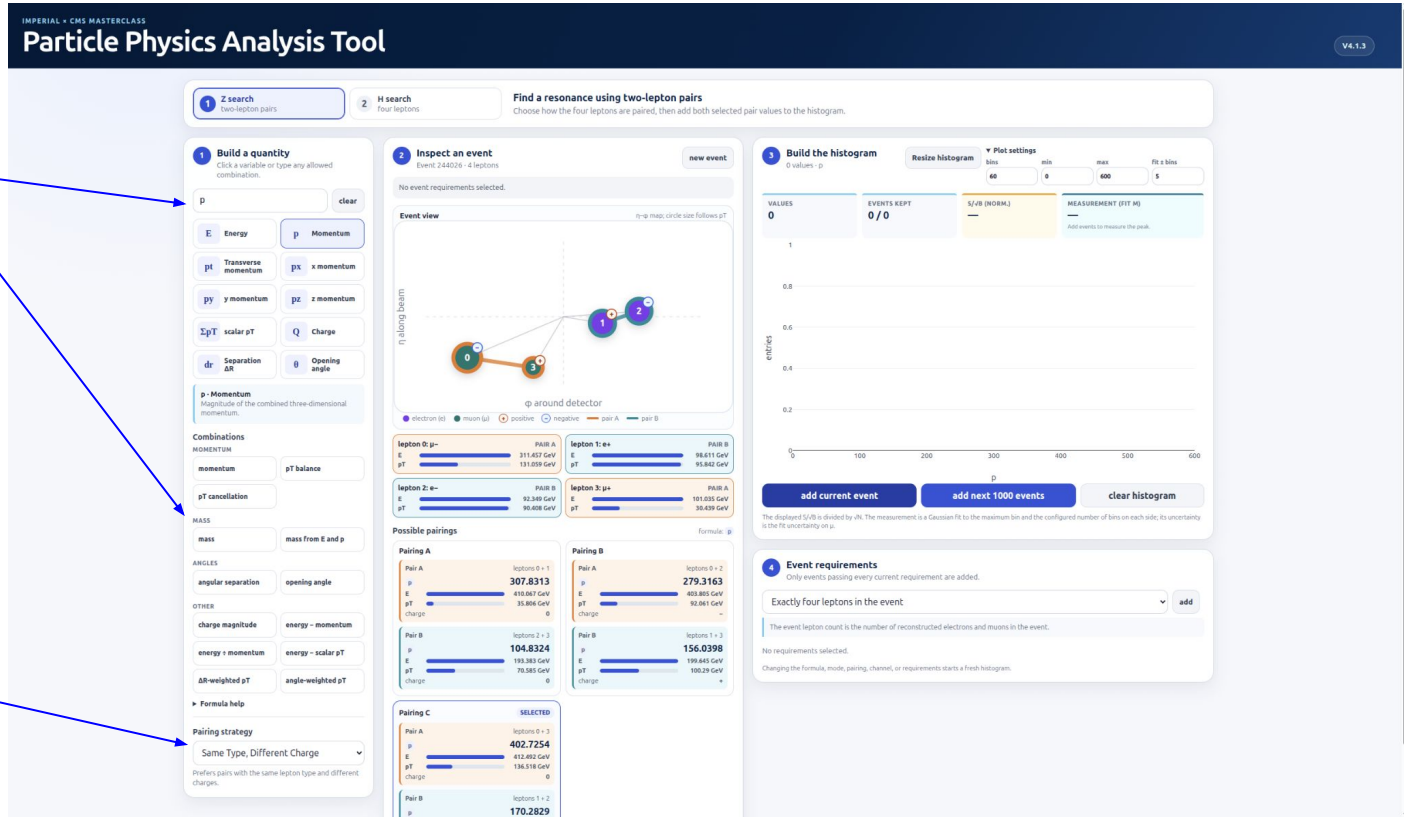


Analysis Tool tutorial

https://www.hep.ph.ic.ac.uk/masterclass/

1. Choose a variable, mix of variables, or predefined combination you want to measure

2. There are at least 4 leptons (electrons or muons) in this event, from 2 Z boson decays. Choose how you want to pair the leptons



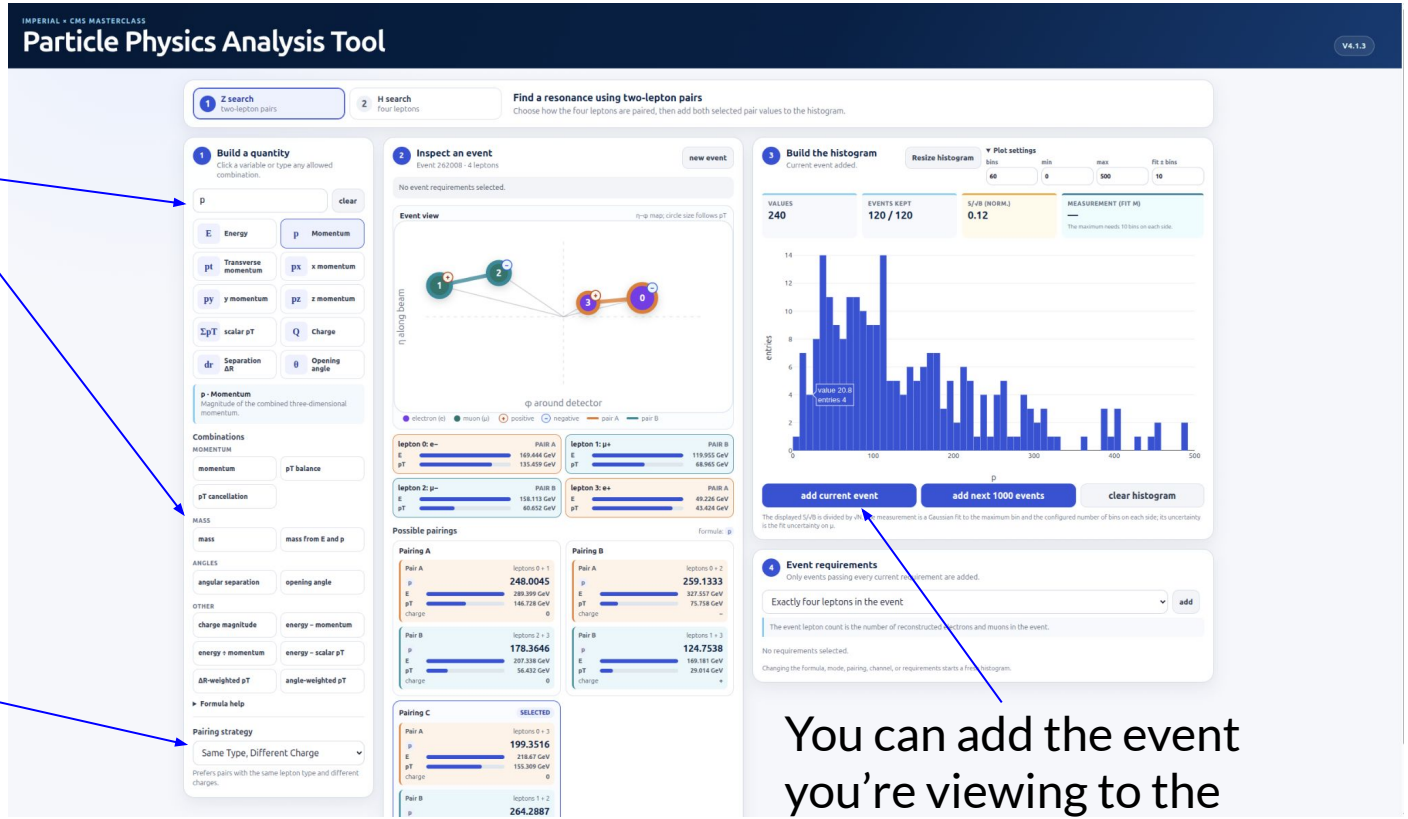
Analysis Tool tutorial

https://www.hep.ph.ic.ac.uk/masterclass/

1. Choose a variable, mix of variables, or predefined combination you want to measure

2. There are at least 4 leptons (electrons or muons) in this event, from 2 Z boson decays. Choose how you want to pair the leptons

3. Plot the data!



You can add the event you're viewing to the histogram here

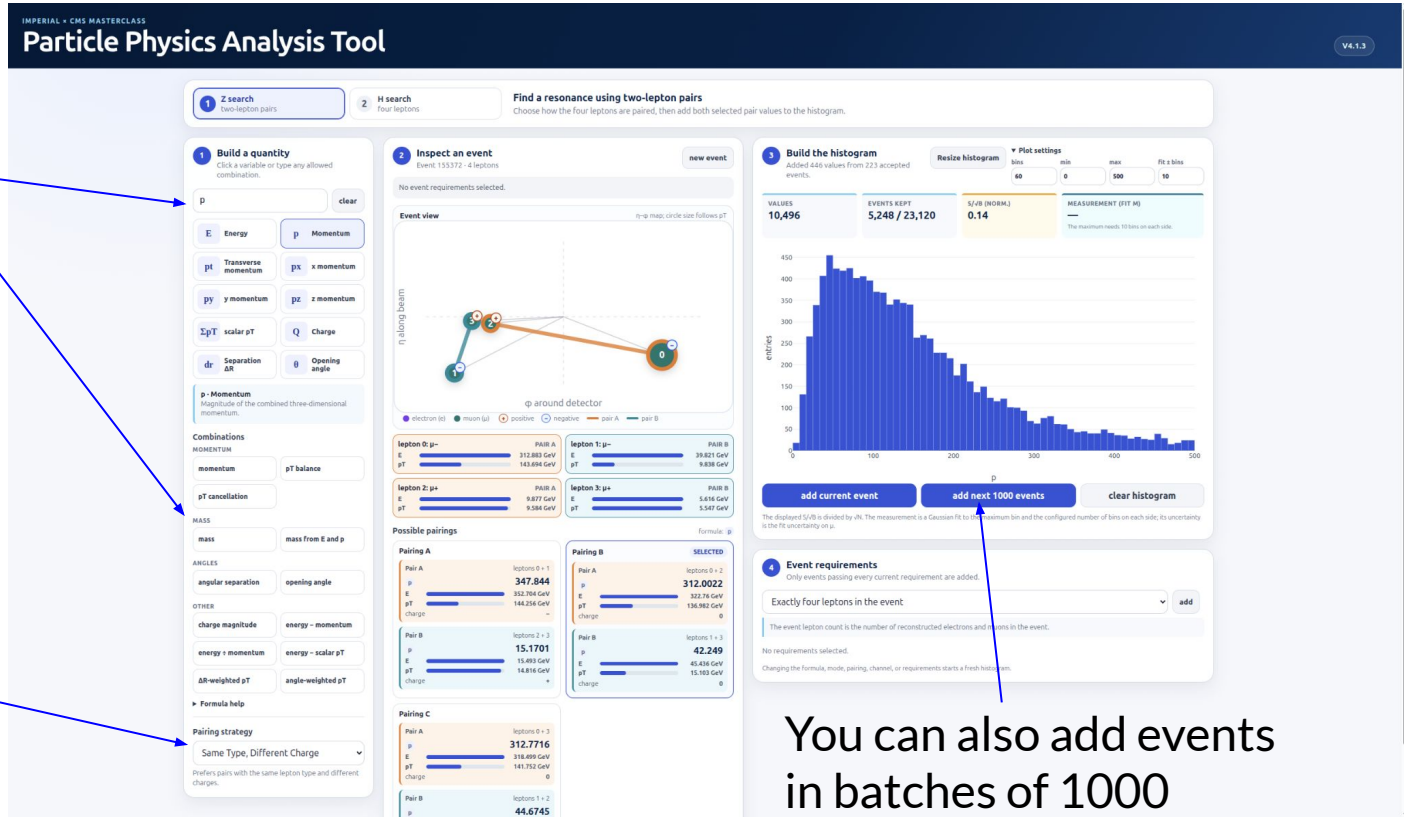
Analysis Tool tutorial

https://www.hep.ph.ic.ac.uk/masterclass/

1. Choose a variable, mix of variables, or predefined combination you want to measure

2. There are at least 4 leptons (electrons or muons) in this event, from 2 Z boson decays. Choose how you want to pair the leptons

3. Plot the data!

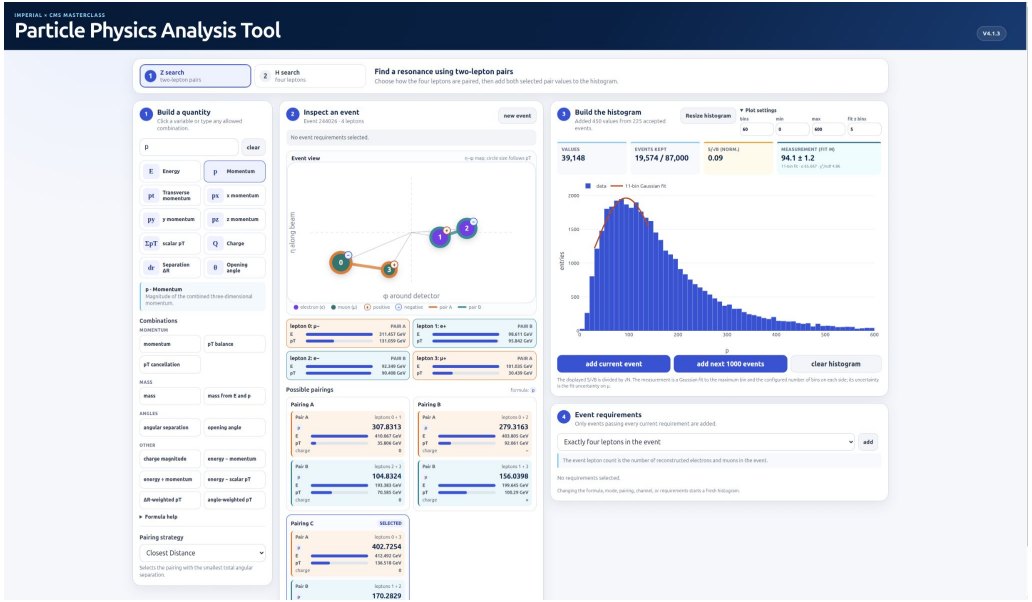


Let’s explore the data!

https://www.hep.ph.ic.ac.uk/masterclass/

Task #1: What can you learn about these events?

Try plotting different variables. Talk to your neighbors and helpers about what you found.



https://www.hep.ph.ic.ac.uk/masterclass/

Hint: Try plotting the mass of the dilepton pair

The **invariant mass** of the dilepton pair is calculated using the following, solving for m:

$$E^2=(mc^2)^2+(pc)^2$$

This tells us the amount of energy available in the decay.

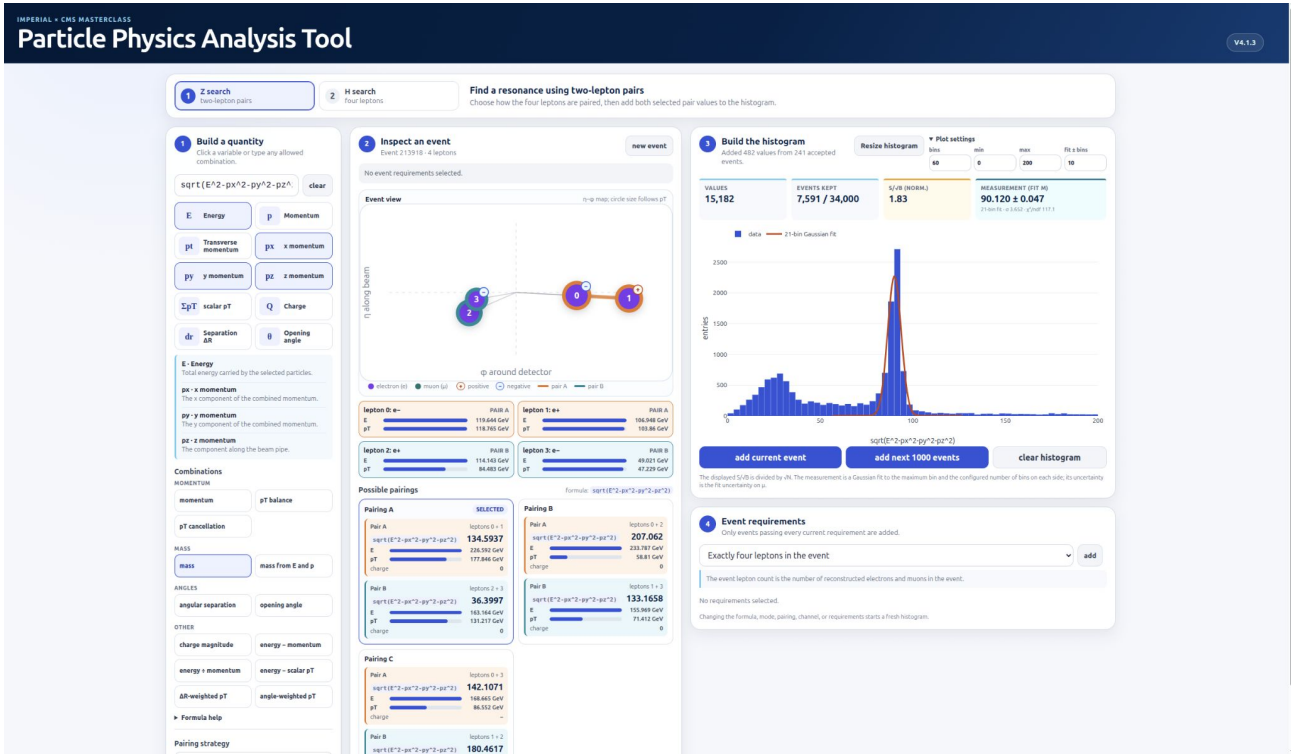
If you plot the mass, what can you learn about the Z boson?

How can we find the Z?

https://www.hep.ph.ic.ac.uk/masterclass/

If we plot the mass of our electron and muon pairs, we can see a peak!

This is a measurement of the energy before the decay– or, a measurement of the mass of the Z boson!



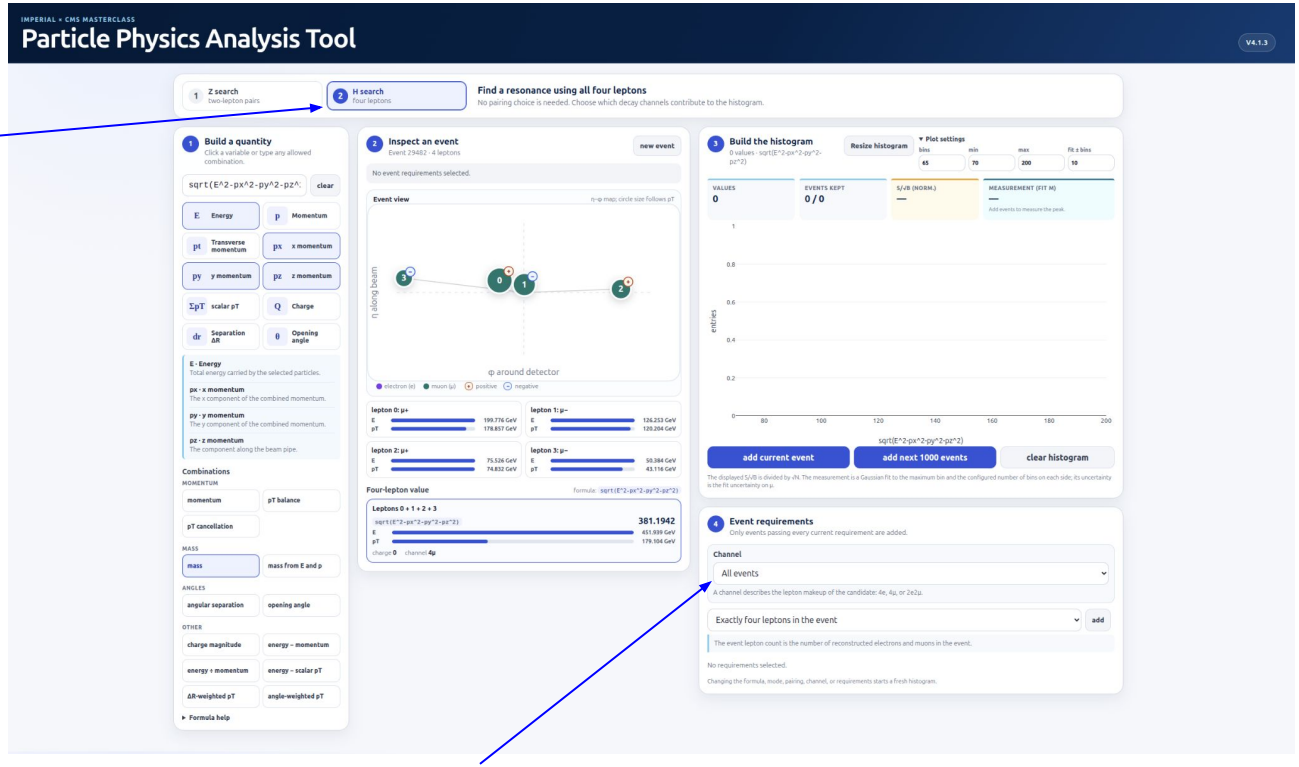
How can we find the H?

https://www.hep.ph.ic.ac.uk/masterclass/

Task #2: Now, let's try adding all the leptons in the event together

The event is H->ZZ->4L: a Higgs boson decay into two Z, and Z boson decays into 4L

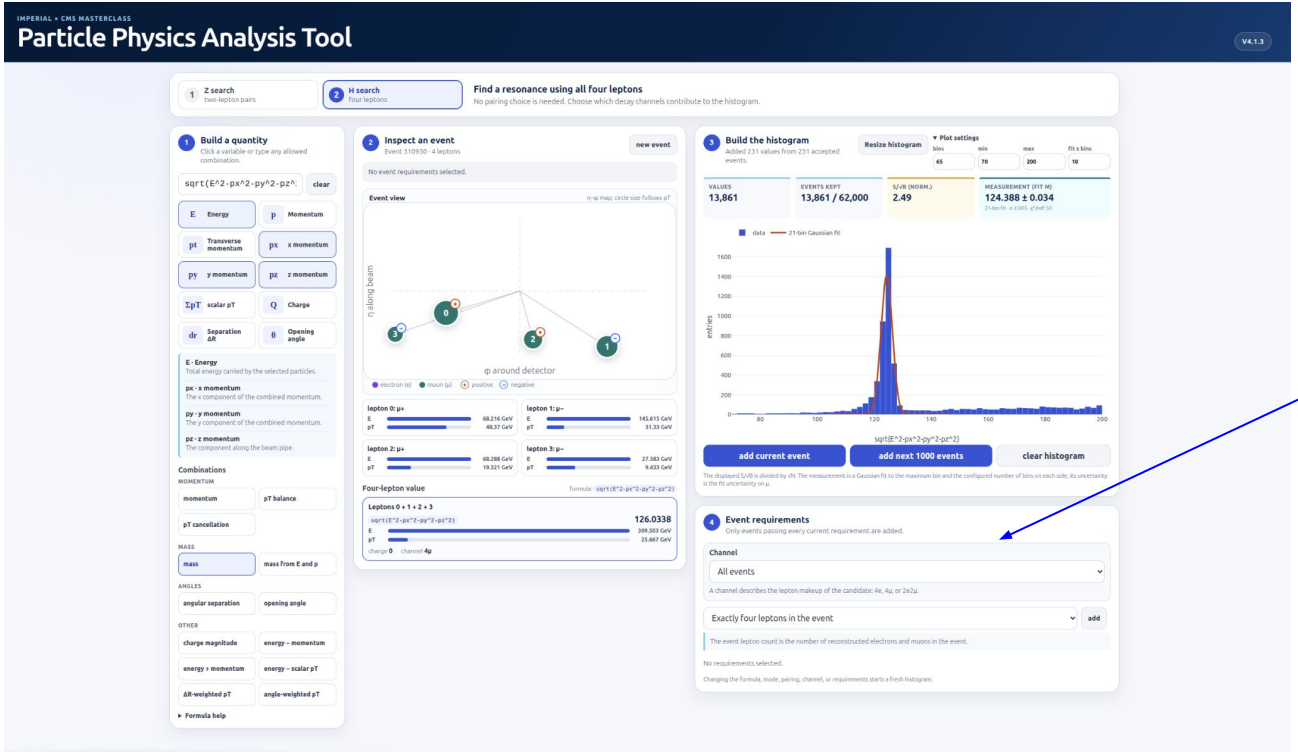
What will you find if you plot the mass of all leptons in the event? What does it tell you about the Higgs boson?



Question: Does the mass depend on the channel: whether the event contained electrons of muons?

Measuring the Higgs mass

https://www.hep.ph.ic.ac.uk/masterclass/



Final Task: How good a measurement can you make?

4. We can use event requirements to remove bad events and improve our precision

Try to improve your Z, H mass measurements by decreasing fit uncertainty (+/-)!

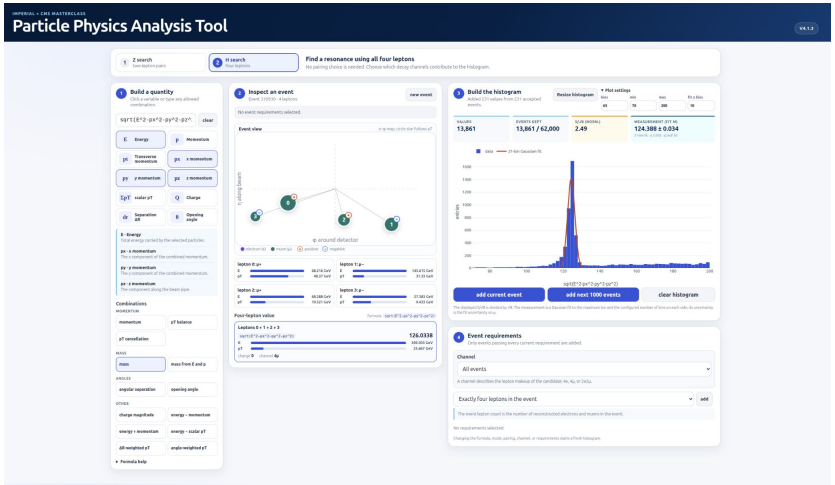
Explore!

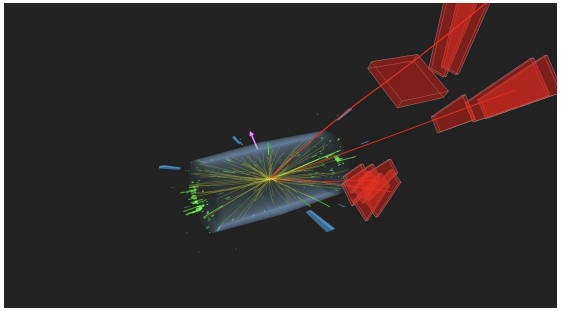
https://www.hep.ph.ic.ac.uk/masterclass/

Submit your best Z, H mass measurements and uncertainties in this form. We'll compile our results at the end to see how we did:

https://tinyurl.com/zhmass

https://tinyurl.com/ispycms





You're welcome to look at more event displays, plot new variables, and ask questions about what you see!