

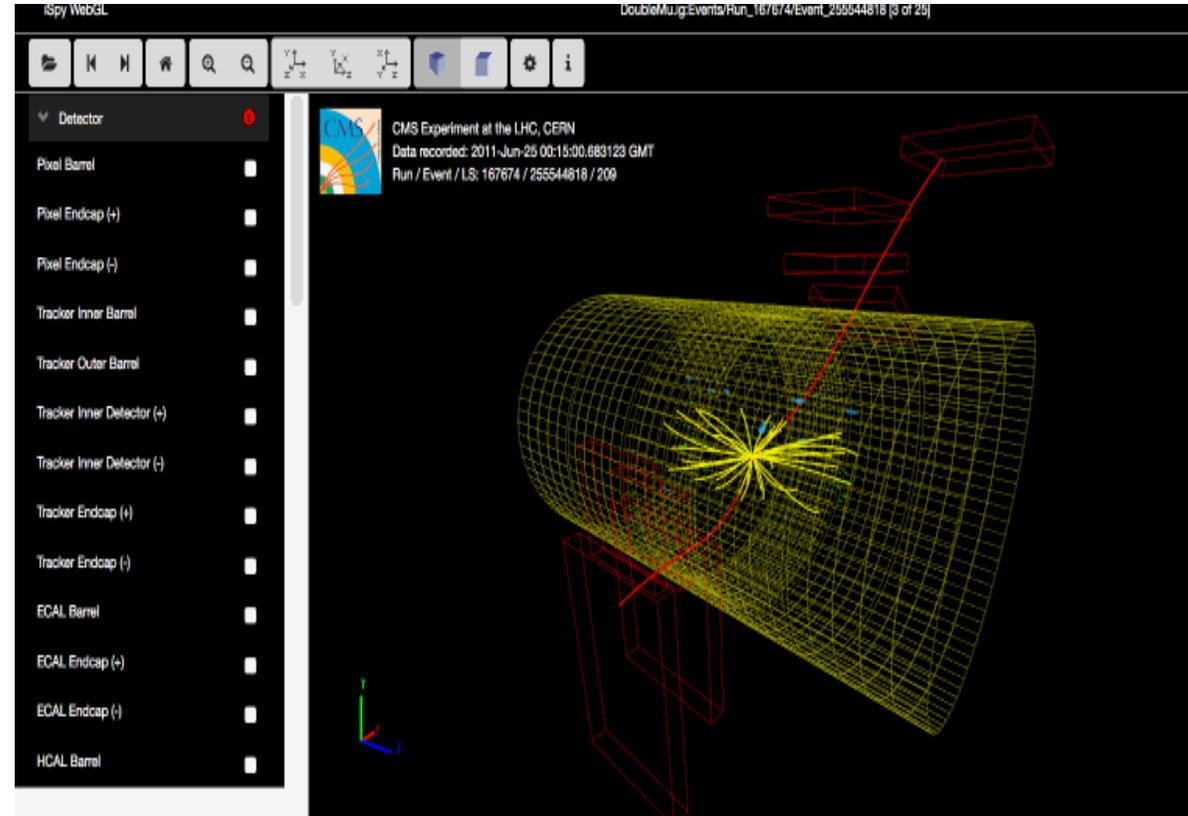


CMS Masterclass in Bulgaria



**INTERNATIONAL
MASTERCLASSES**
HANDS
ON PARTICLE
PHYSICS

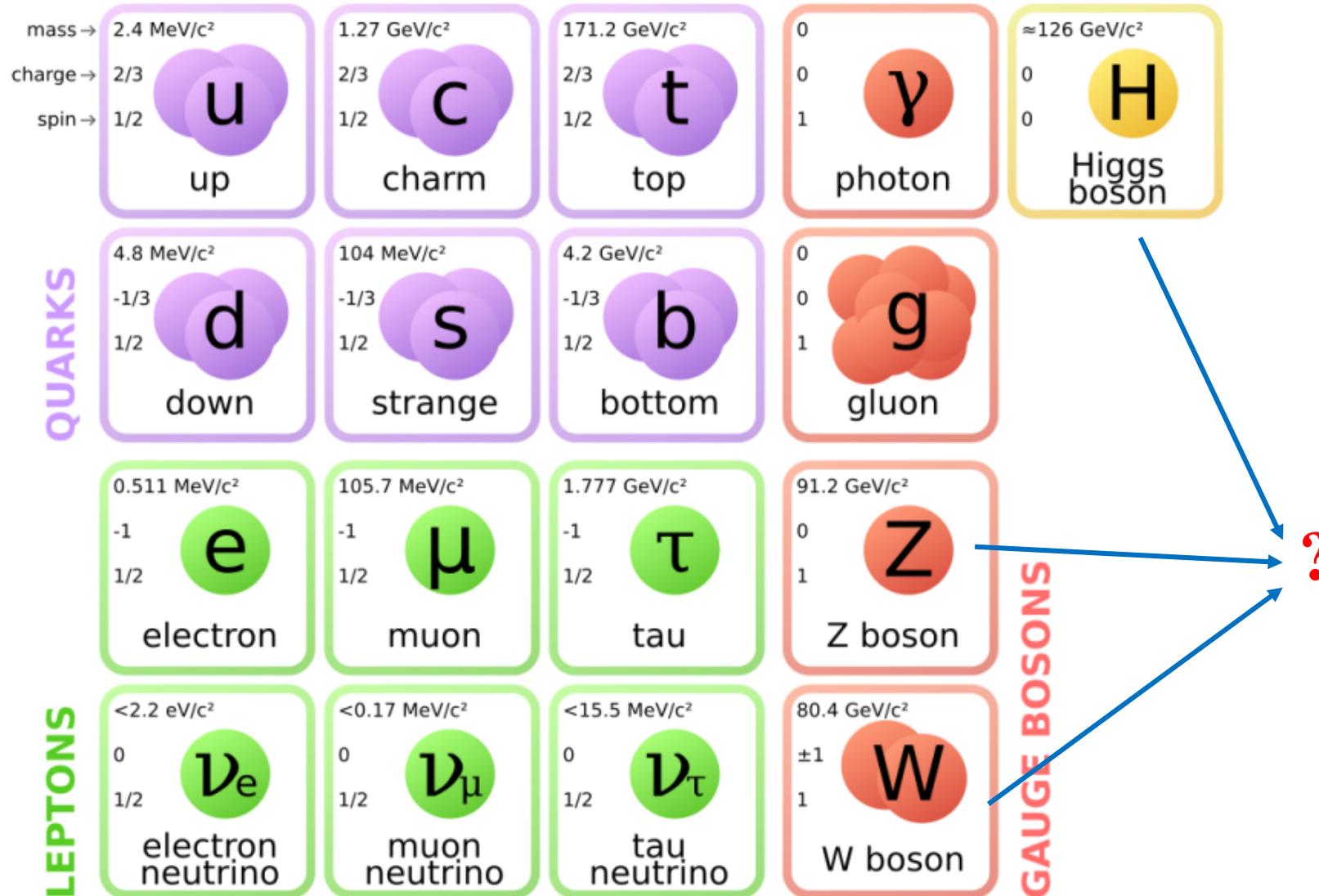
26.03.2018
от 10:00 до 18:00



Goals:

- to understand the scientific process of data analysis
- to do real measurements
- to understand what you find out (the meaning of measurement)
- where do these measurements play role in our Universe?

Standard Model of Elementary Particles



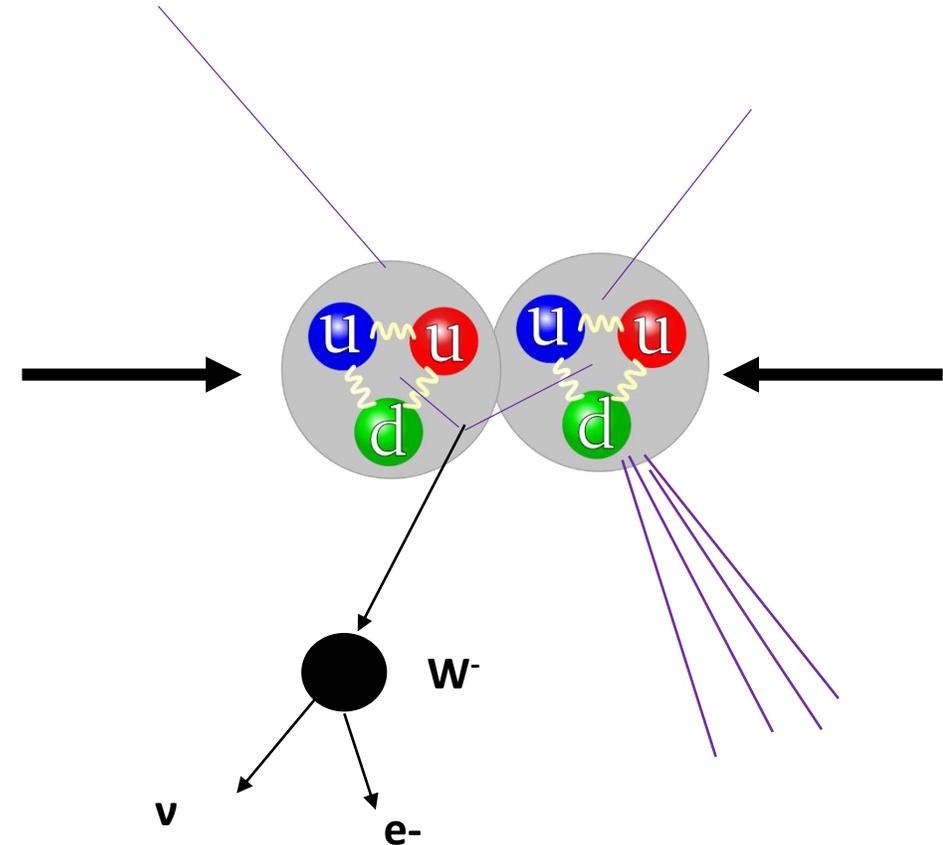
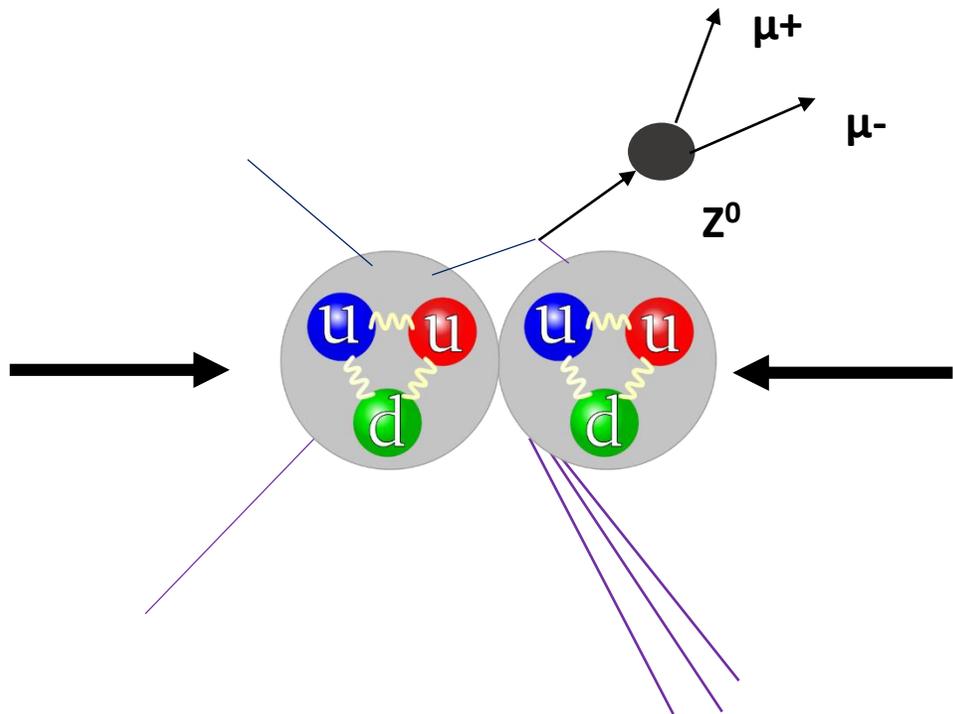
WZH measurement

You will study events with multiple signatures to:

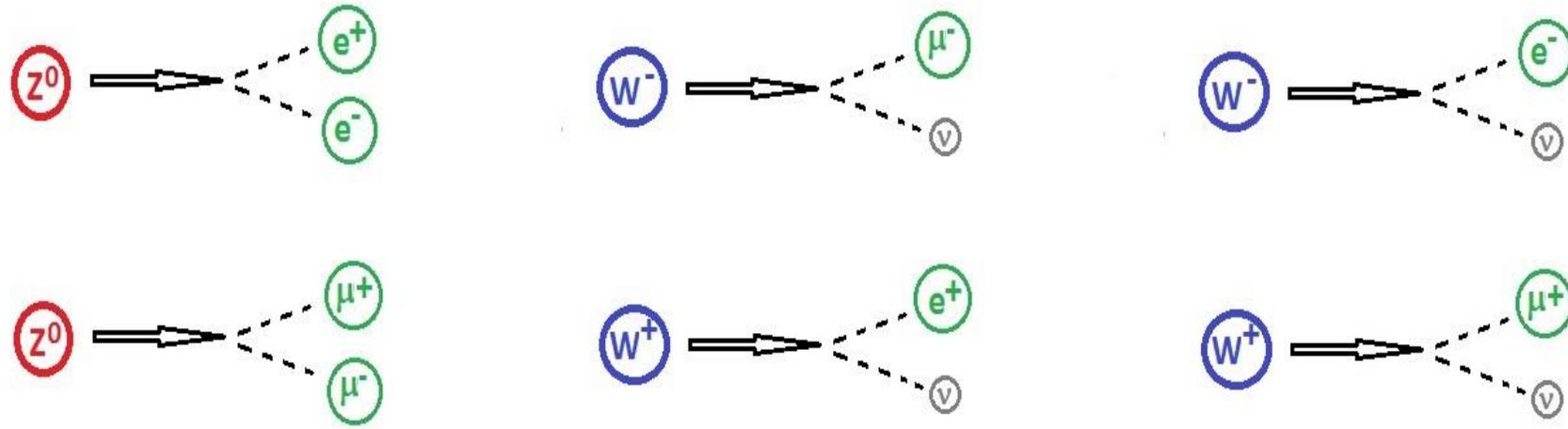
- ✓ determine which are the best candidates for W, Z, and Higgs bosons,
- ✓ distinguish W^+ from W^- candidates,
- ✓ distinguish decays into electrons from decays into muons,
- ✓ determine key ratios,
- ✓ and build a mass plot.

Unlike electromagnetic forces carried over long distances by massless photons, the weak force is carried by massive particles which restricts interactions to very tiny distances.

We are searching for the *mediators* of the *weak interaction*:
electrically charged W^\pm bosons & the neutral Z boson



Collisions of sufficient energy can create W and Z or other particles.



Because W and Z only travel a tiny distance before decaying, CMS does not “see” W and Z bosons directly.

CMS can detect: electrons and muons.

CMS can infer: neutrinos from “missing energy”

A Higgs boson has several possible decays.

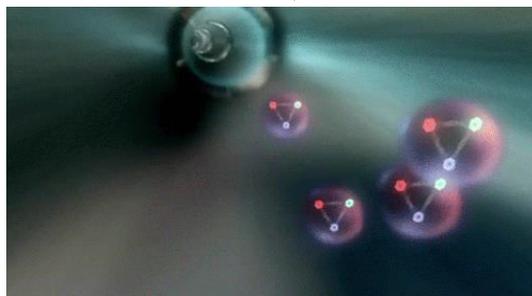
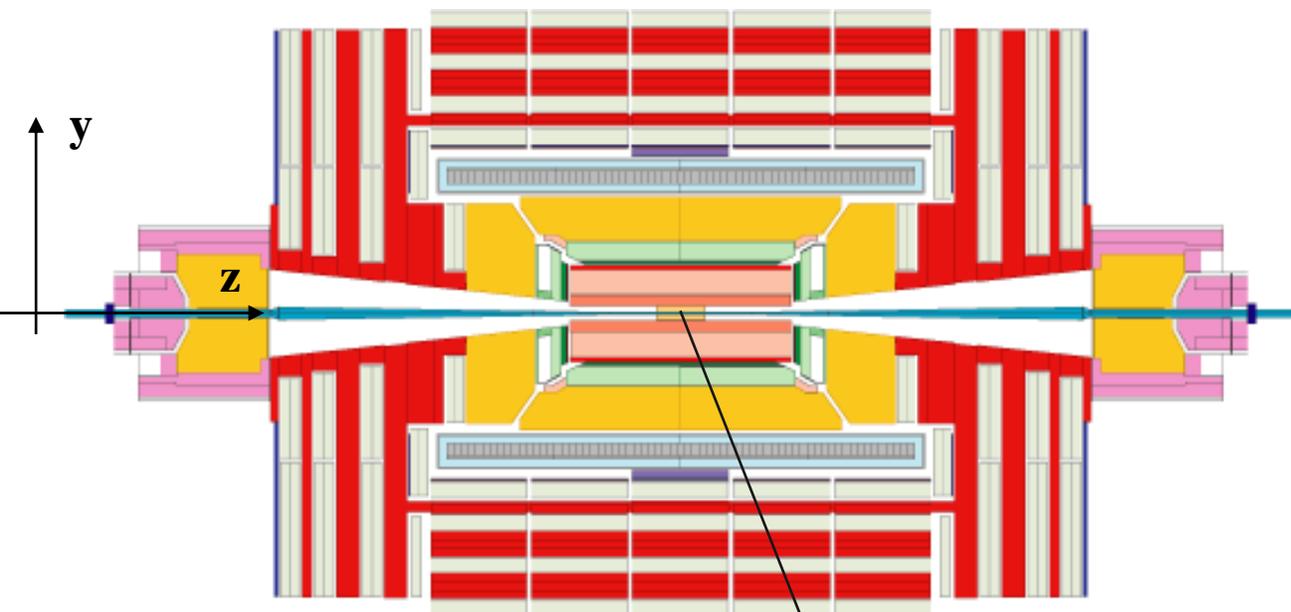
The two you might see are:

→ **Higgs boson decays to two Z bosons.**

→ **Higgs boson decays to two photons.**

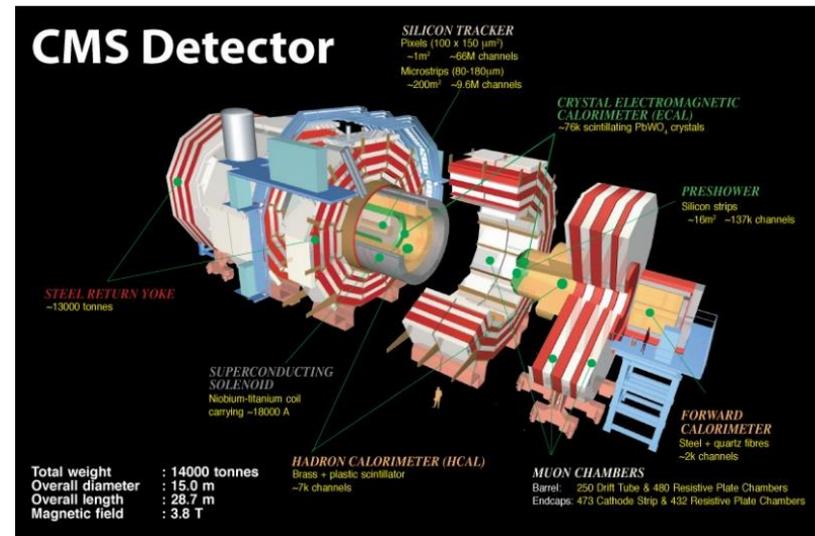
There are only a very few of either of these in your data.

Generic Design: Cylinders wrapped around the beam pipe

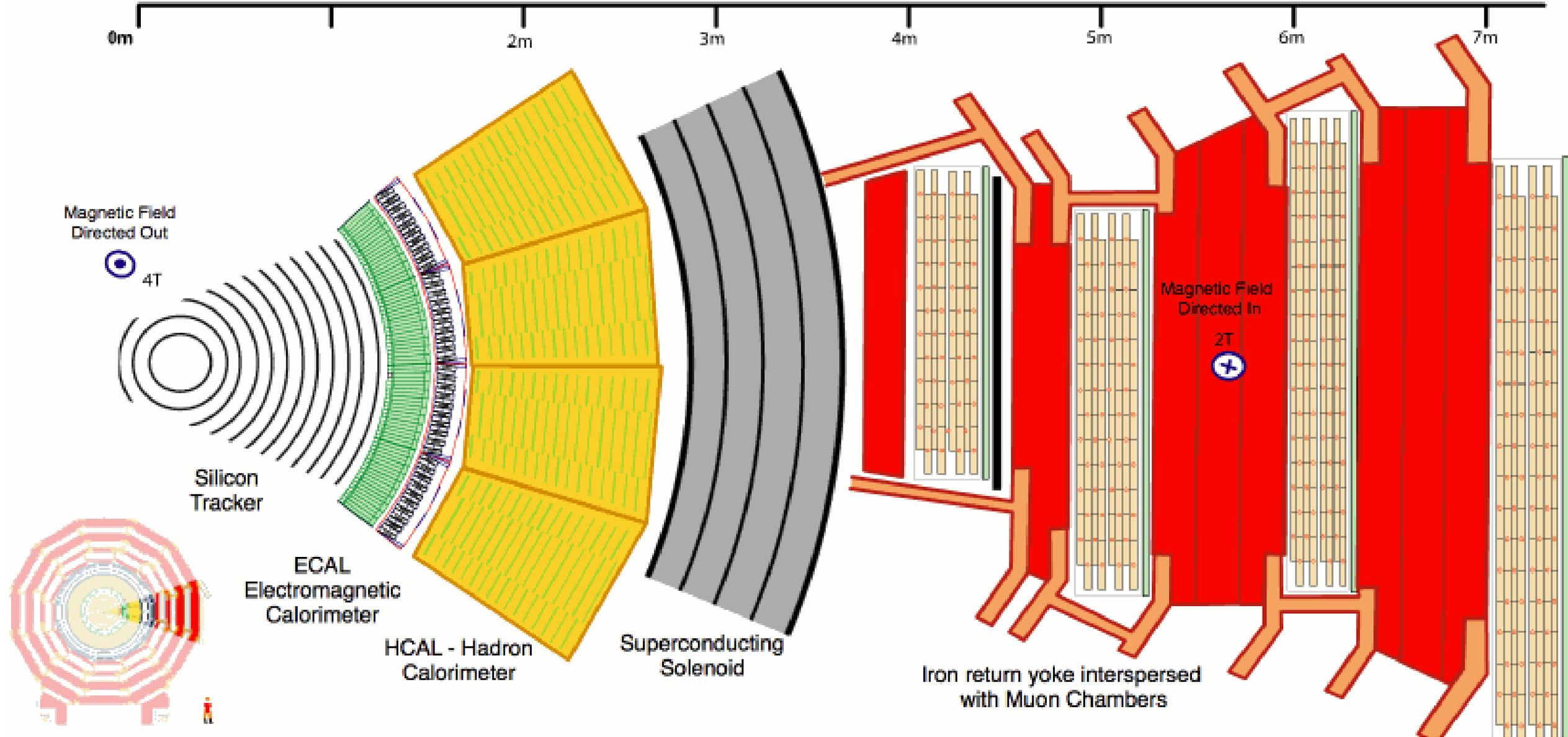


FROM INNER TO OUTER ...

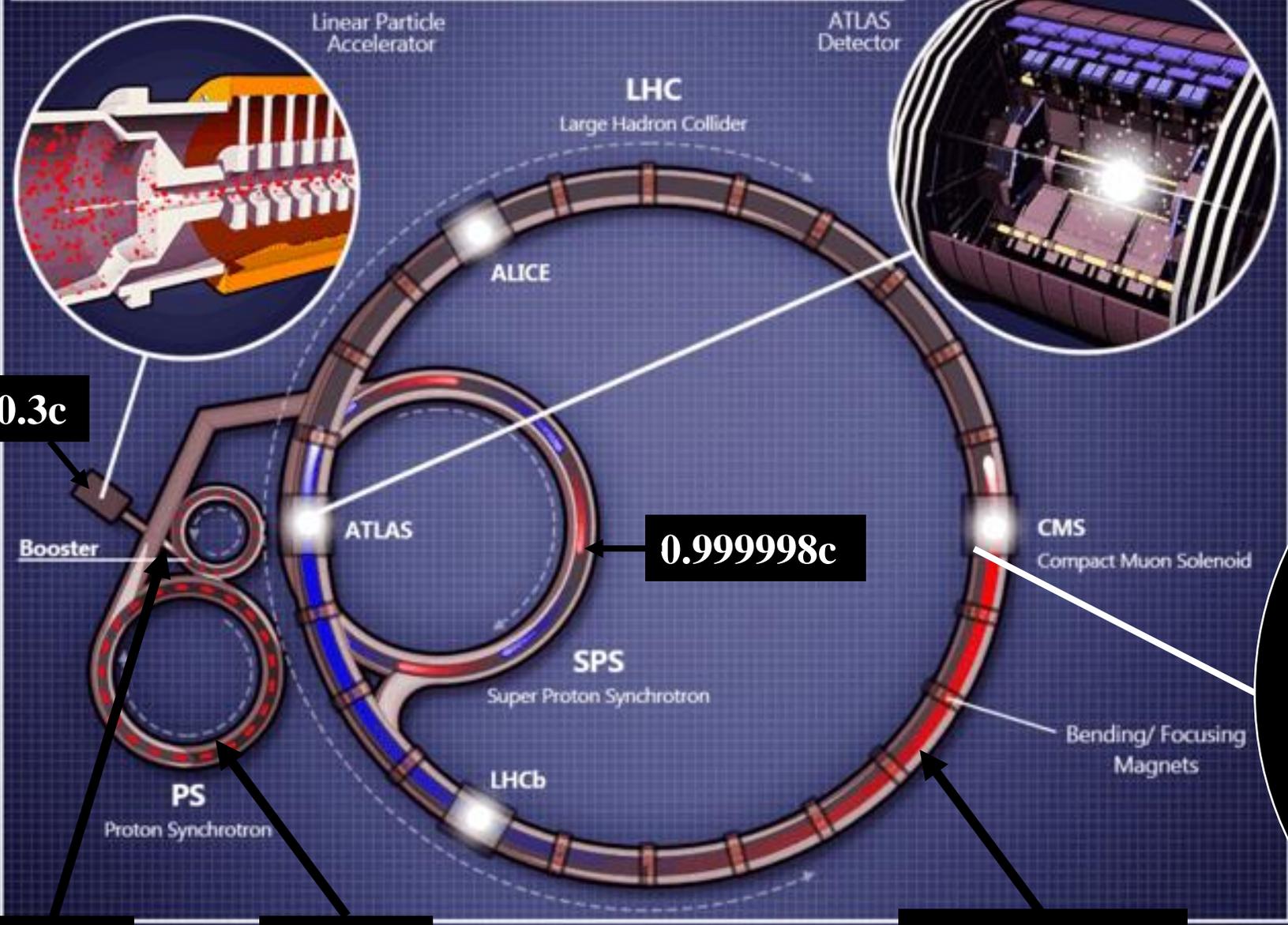
- tracking
- electromagnetic calorimeter
- hadron calorimeter
- magnet
- muon chamber



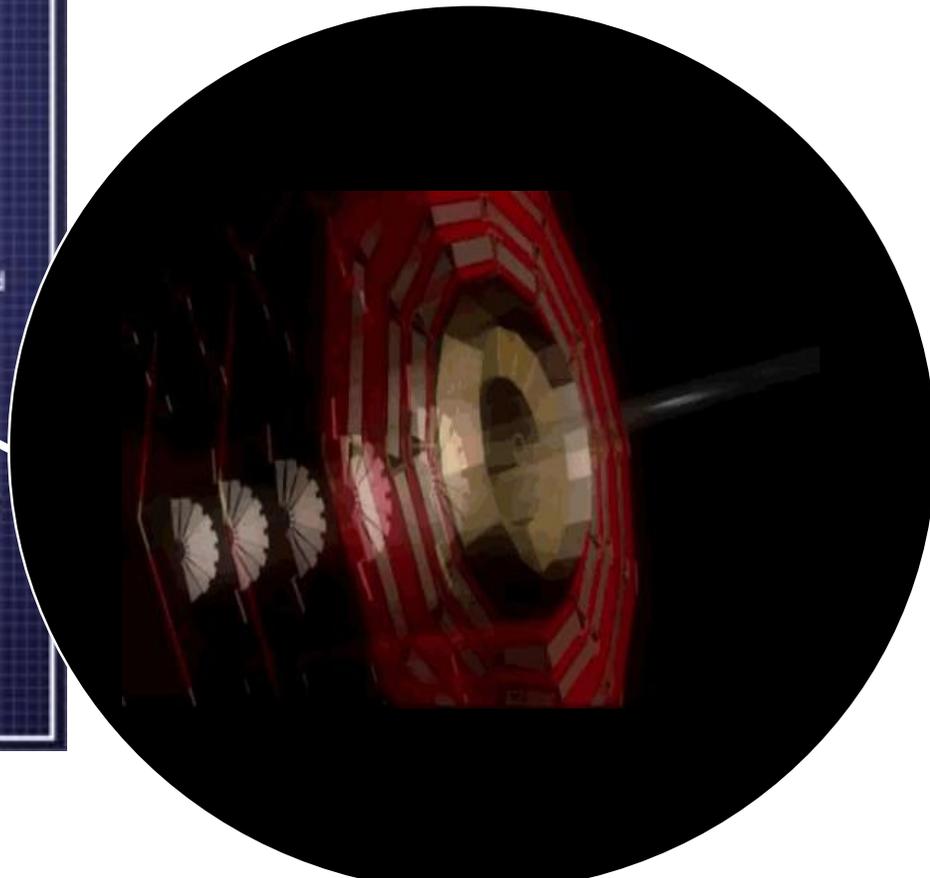
Transverse slice of the CMS Detector



CERN Particle Accelerator



LHC is buried ~100m below the surface near the Swiss-French border



0.3c

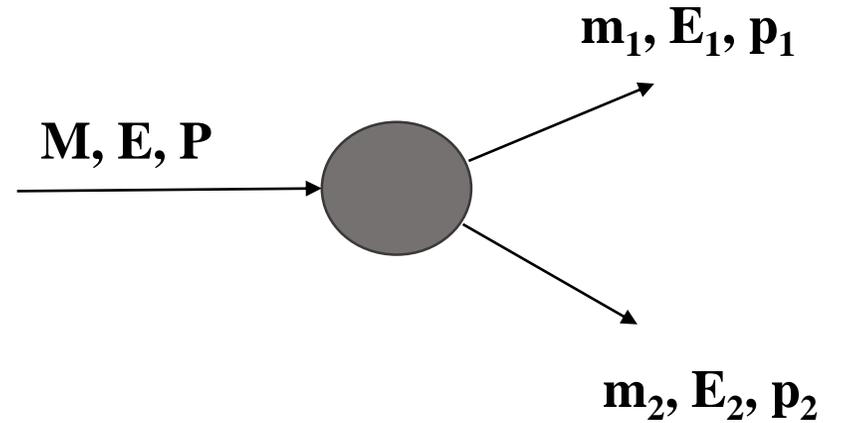
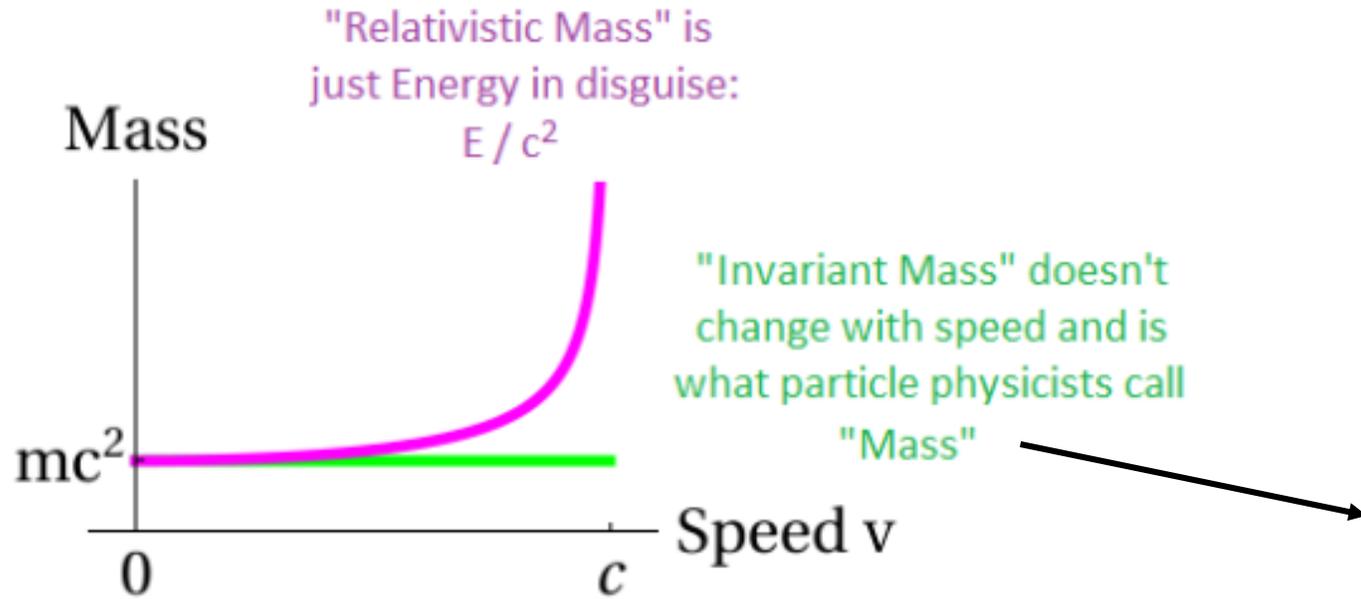
0.999998c

0.916c

0.9993c

0.999999991c

Conservation laws?



$$M^2 = m_1^2 + m_2^2 + 2(E_1 \cdot E_2 - p_1 \cdot p_2 \cos \alpha)$$

Energy and momentum for relativistic particles

(velocity v comparable to c)

Speed of light in vacuum $c = 2.99792 \times 10^8 \text{ m/s}$

Total energy: $E = mc^2 = \frac{m_0 c^2}{\sqrt{1 - (v/c)^2}}$ }
 m : relativistic mass
 m_0 : rest mass

iSpy-webgl and CIMA

Young 'scientists' tasks:

- 1) Each pair of young 'scientists' analyzes a set of 100 events

- 1) For each event, distinguish between electron and muon decay and between
 - a) W^+ or W^- candidate (recorded as "W" if charge cannot be determined),
 - b) NP (Z or other "neutral particle" candidate),
 - c) Higgs candidate,
 - d) zoo event (unusual and cannot be characterized).

- 3) Record into CIMA.

[Link to CIMA](#)

CIMA

CMS Instrument for Masterclass Analysis



Choose your Masterclass

- Imn/lk
- LasMatas-28Oct2017
- DürenJan2018
- Budapest-07Mar2018
- PracticeTables-IMC2018
- IDWGS-12Feb2018
- CERN-10Feb2018
- Roma-22Feb2018
- CERN-19Feb2018
- CERN-20Feb2018
- CERN-22Feb2018
- CERN-28Feb2018
- CERN-02Mar2018
- CERN-03Mar2018
- CERN-06Mar2018
- CERN-07Mar2018
- CERN-08Mar2018
- CERN-14Mar2018
- CERN-19Mar2018
- CERN-23Mar2018
- CERN-26Mar2018
- DürenFeb18
- DürenMärz18
- CERN-15March2018

Choose your location

- Belgrade2018A
- Lyon2018C
- NoviSad2018A
- Sofia2018A

Choose your group

- 21
- 22
- 23
- 24
- 25
- 26
- 27
- 28
- 29
- 30
- 31
- 32
- 33
- 34
- 35
- 36
- 37
- 38
- 39
- 40
- 41
- 42
- 43
- 44



**choose your group,
for example 29,
where the dataset is.**



hands on particle physics



The screenshot shows a web browser window with the URL <https://www.i2u2.org/elab/cms/cima/fillOut.php>. The browser's address bar and the top navigation menu are highlighted with red boxes. The navigation menu includes "Events Table (Group 34)", "Mass Histogram (Sofia2018A)", and "Results (Sofia2018A)". A red box also highlights an "Event Display" button in the top right corner. Below the navigation, the page content includes:

Masterclass: CERN-26Mar2018
Location: Sofia2018A
Group: 34

Instructions (also available as [screencast](#)):

- For each event, identify the final state and select a primary state candidate.
 - For Higgs or Zoo candidate, no final state is chosen
 - If you cannot decide between W+ and W-, choose W instead
- If you think the final state is a neutral particle (like a Z), but you don't know its exact type, select NP for "neutral particle." Find its mass from the Event Display and enter it.
- Once you have selected everything, click "Submit".

In case of an error, double clicking the data line will reload it; you can then try it again.

Select Event	final state	primary state candidate	NP Mass: <input type="text"/> GeV/c ²
Event index: <input type="text" value="1"/> Event number: 34-1	<input type="checkbox"/> Electron <input type="checkbox"/> Muon (μ)	<input type="checkbox"/> W- <input type="checkbox"/> NP <input type="checkbox"/> W+ <input type="checkbox"/> W	<input checked="" type="checkbox"/> Higgs <input type="checkbox"/> Zoo

Below the form, the following labels are present: Event index, Event number, Chosen Values, Mass.

[Link to CIMA Events Table, Mass Histogram and Results](https://www.i2u2.org/elab/cms/cima/index.php)

<https://www.i2u2.org/elab/cms/cima/index.php>

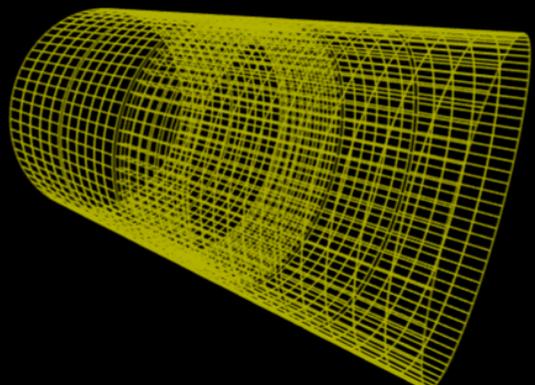
The screenshot shows the iSpy WebGL interface in a browser window. The URL is <https://www.i2u2.org/elab/cms/ispy-webgl/>. The interface features a 3D visualization of a detector component, which is a yellow wireframe cylinder. On the left side, there is a list of detector components with checkboxes:

- Detector
- Pixel Barrel
- Pixel Endcap (+)
- Pixel Endcap (-)
- Tracker Inner Barrel
- Tracker Outer Barrel
- Tracker Inner Detector (+)
- Tracker Inner Detector (-)
- Tracker Endcap (+)
- Tracker Endcap (-)
- ECAL Barrel
- ECAL Endcap (+)

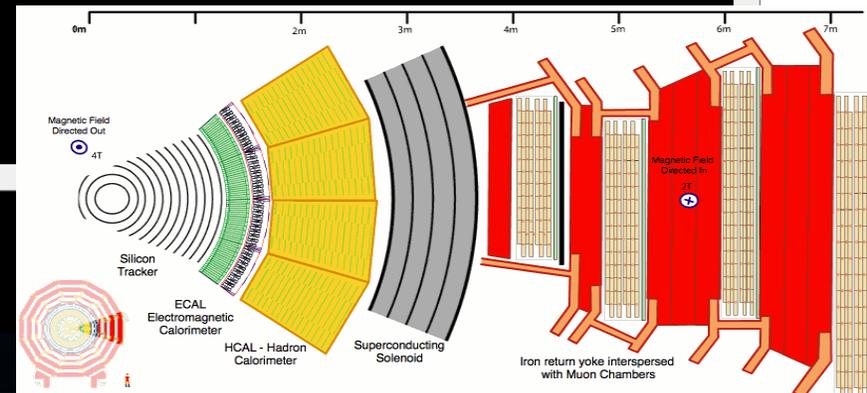
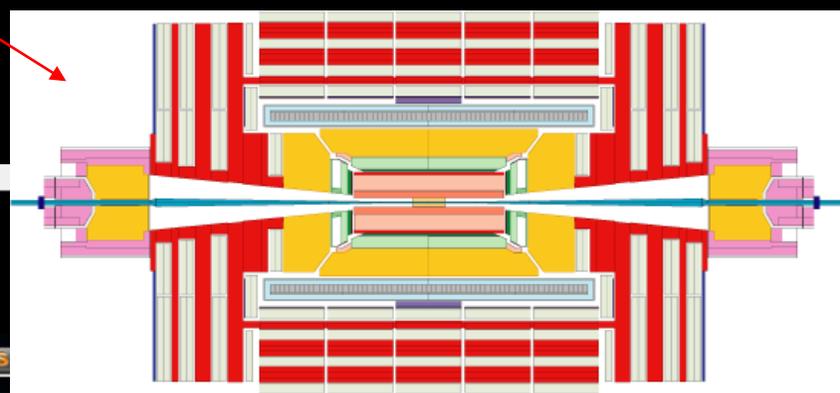
The bottom of the browser window shows the Windows taskbar with various application icons and the system clock displaying 5:01 PM.

iSpy WebGL

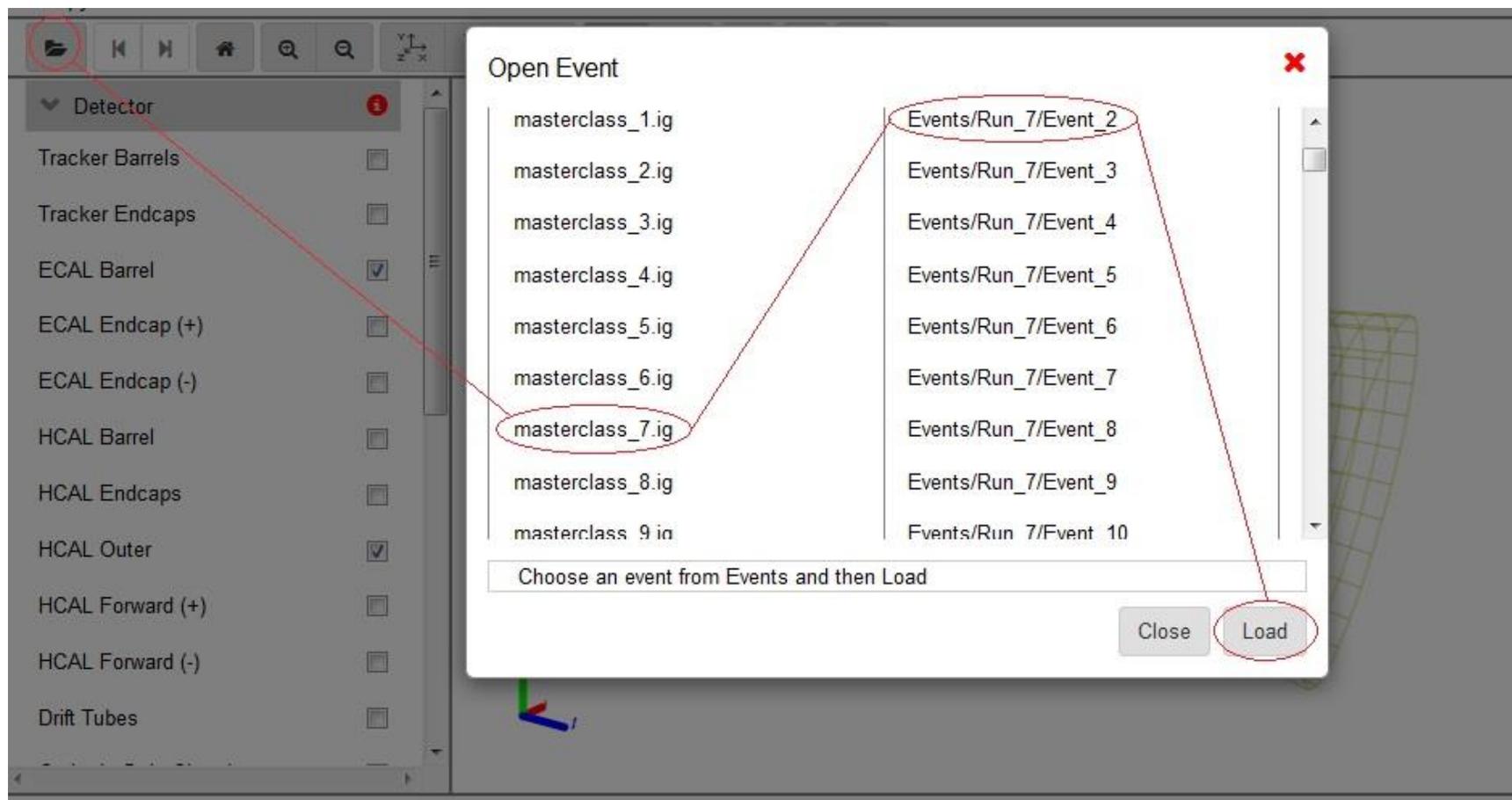
- Detector
 - Pixel Barrel
 - Pixel Endcap (+)
 - Pixel Endcap (-)
 - Tracker Inner Barrel
 - Tracker Outer Barrel
 - Tracker Inner Detector (+)
 - Tracker Inner Detector (-)
 - Tracker Endcap (+)
 - Tracker Endcap (-)
 - ECAL Barrel
 - ECAL Endcap (+)



iSpy

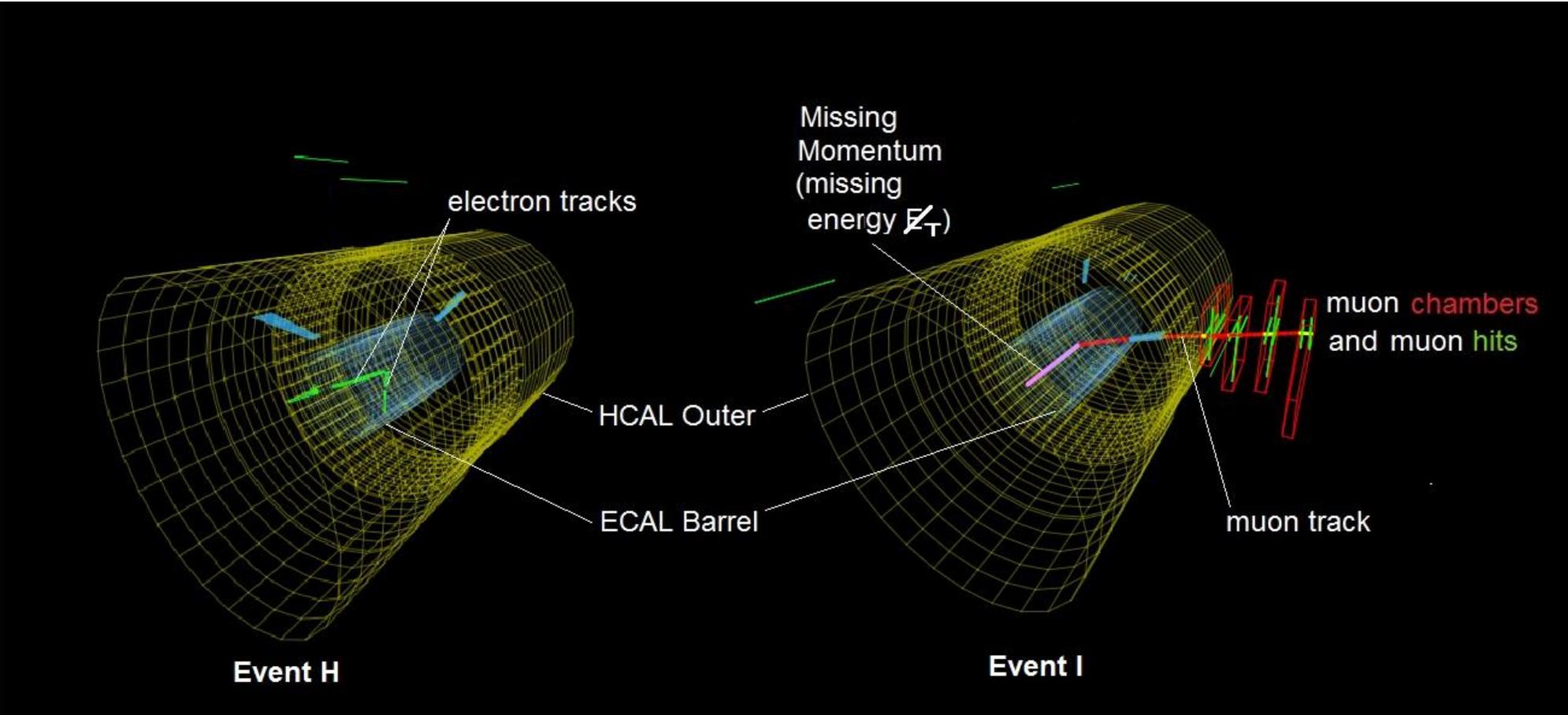


Find the correct data files in iSpy and CIMA



Elements of Events in iSpy-webgl

For each event, the beamline is along the common axis of the ECAL and HCAL wire-frame cylinders.
Which is the better W candidate? the better Z candidate?
In each event, where do the collision and particle decay occur?

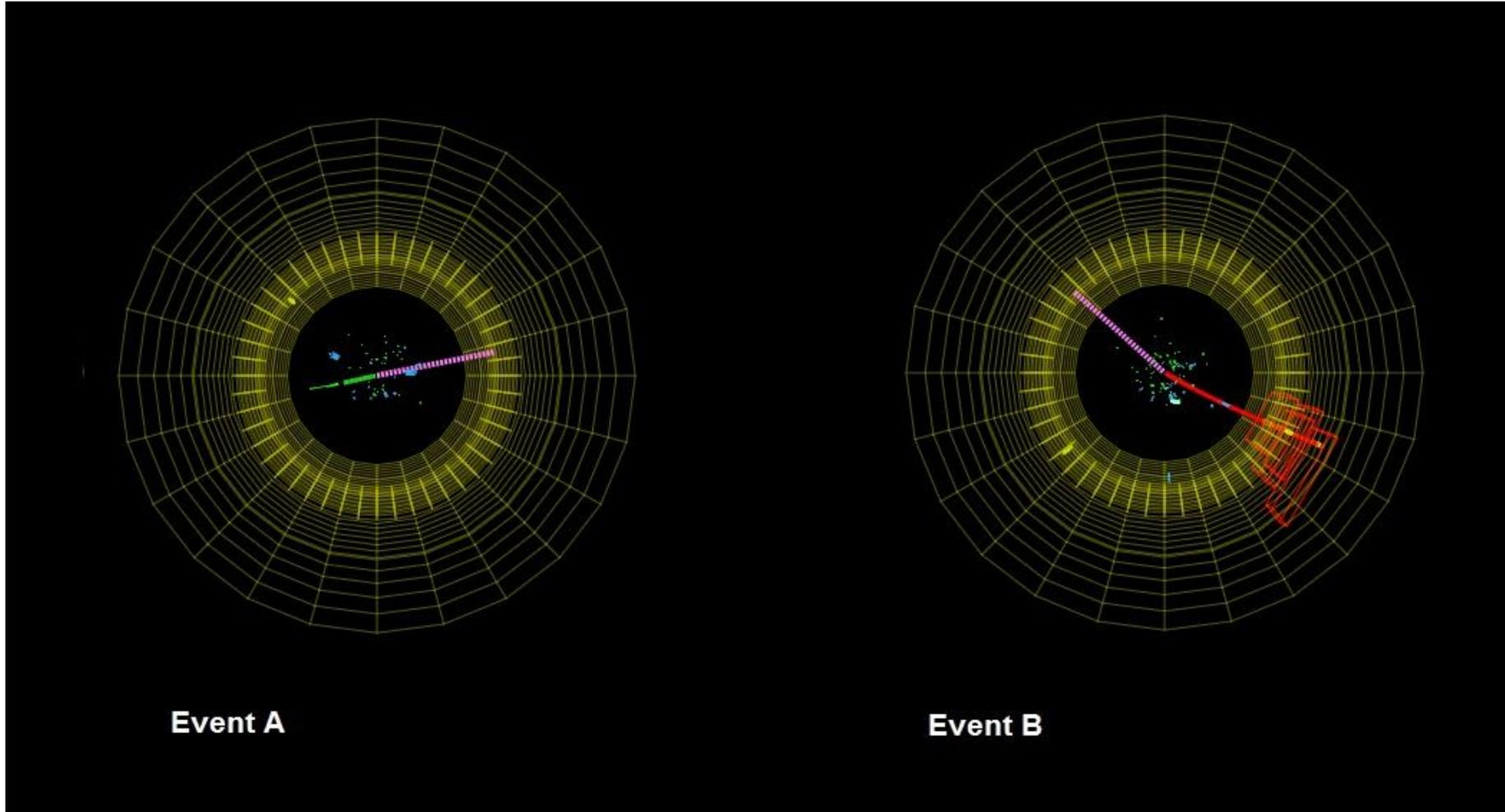


W boson candidate events

missing E_t = purple track = ν

green track = e^+/e^-

red track = μ^+/μ^-



? $W^+ \rightarrow \mu^+ \nu$ or $e^+ \nu$

? $W^- \rightarrow \mu^- \nu$ or $e^- \nu$

clockwise for positive charge or anticlockwise for negative

Z boson candidate events

missing E_t = purple track = ν

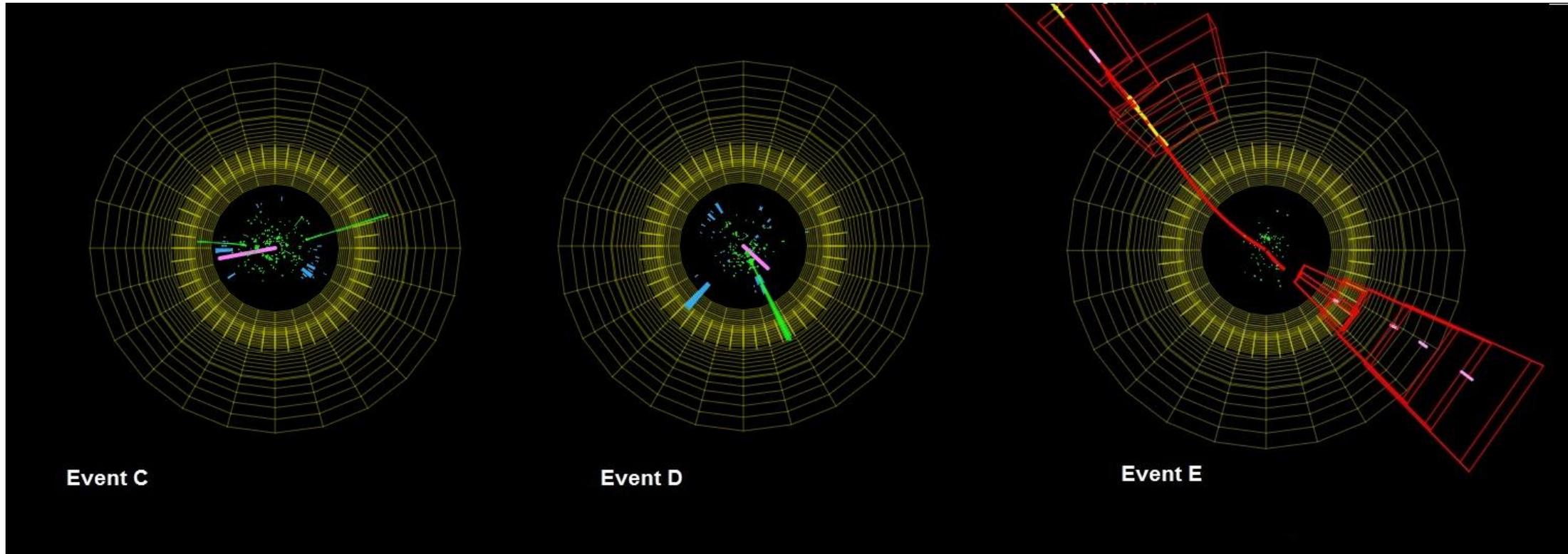
green track = e^+/e^-

red track = μ^+/μ^-

? $Z^0 \rightarrow \mu^+ \mu^-$

which event could be $W^\pm \rightarrow \mu^\pm \nu$ ($e^\pm \nu$)

? $Z^0 \rightarrow e^- e^+$



clockwise for positive charge or anticlockwise for negative

H boson candidate events

? $H \rightarrow Z Z \rightarrow \mu^+ \mu^- \mu^+ \mu^-$ or $(e^+ e^- e^+ e^-)$ or $(\mu^+ \mu^- e^+ e^-)$

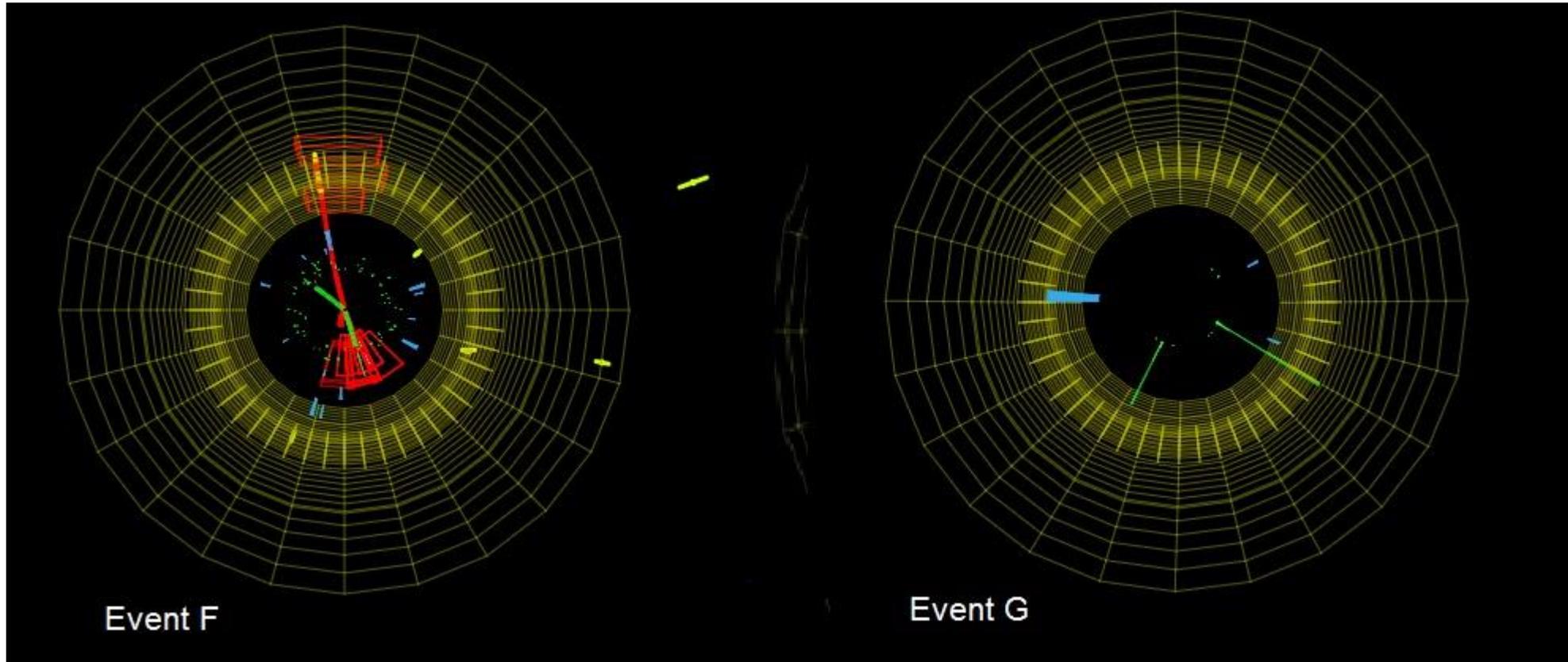
? $H \rightarrow \gamma \gamma$

missing E_t = purple track = ν

green track = e^+/e^-

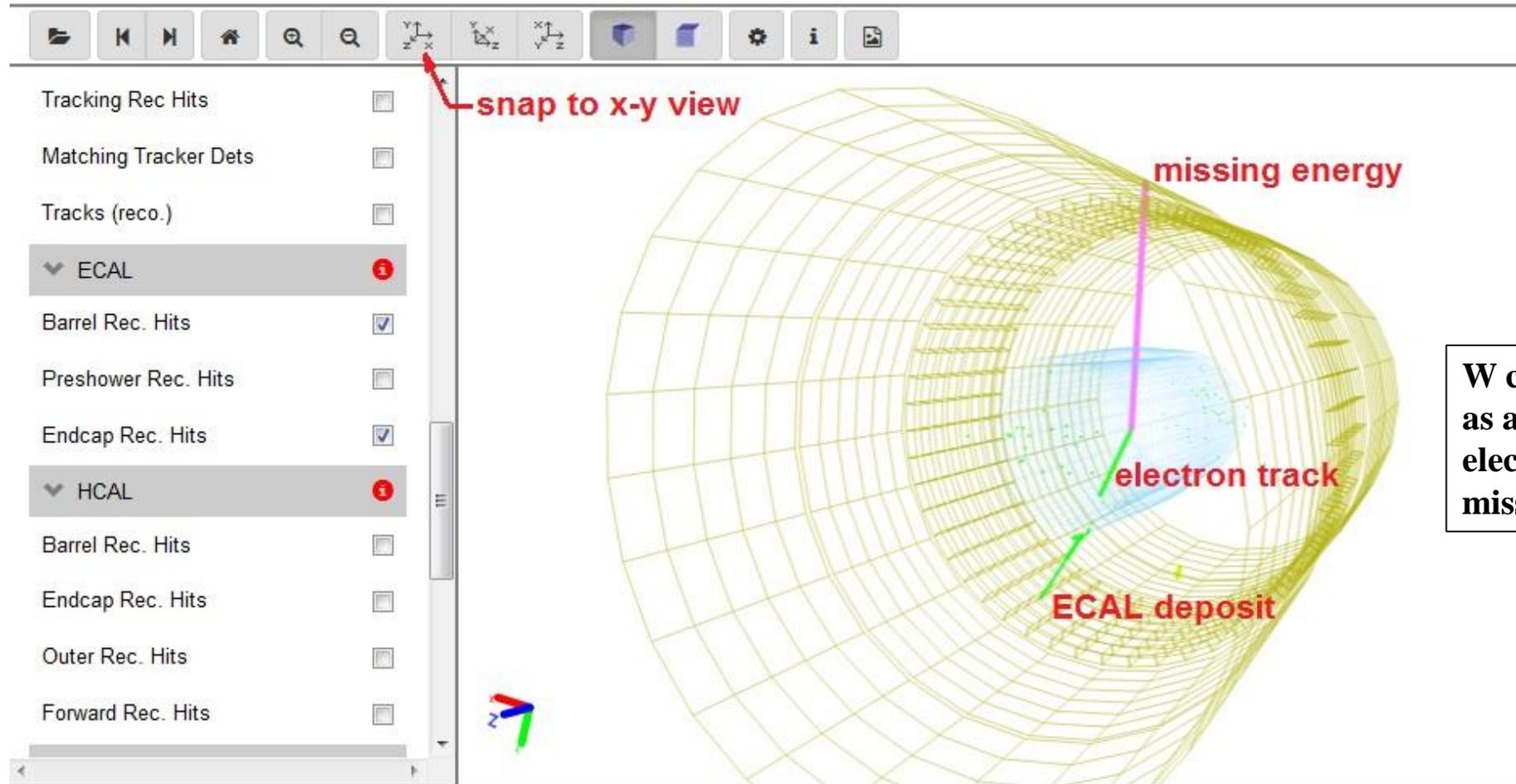
red track = μ^+/μ^-

green energy towers = γ



clockwise for positive charge or anticlockwise for negative

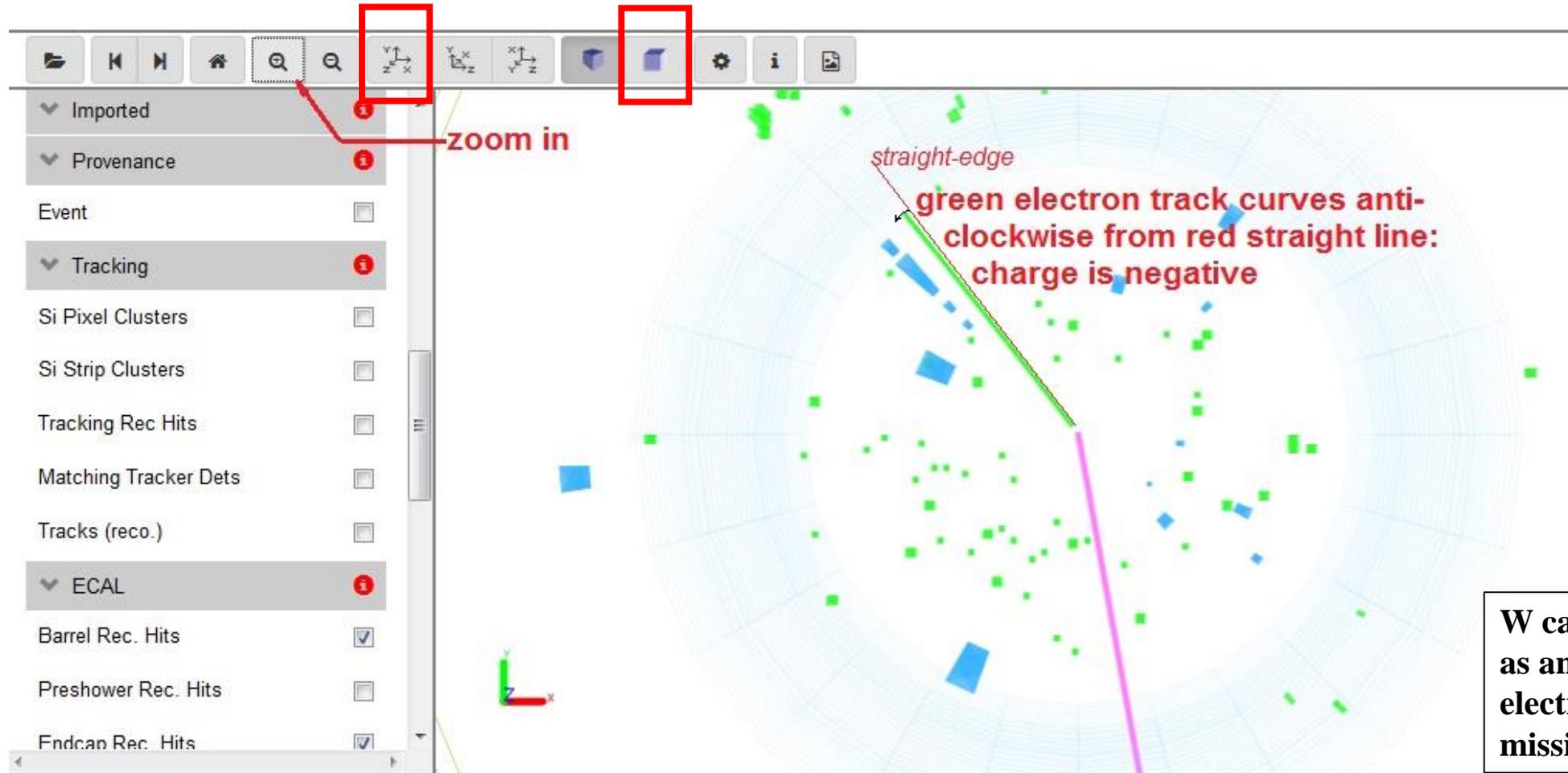
**Adjust event settings to get (x-y) view for track curvature (charge sign)
(in this case of W candidates)**



Lepton ID (identification), electrons and muons → to characterize the event, not individual particles !

Charge \rightarrow select (x-y) view
and "orthographic mode"

Candidate $W^- \rightarrow e^- \nu$



Fill in what kind of event you have just measured in the "Events Table" on CIMA

Masterclass: test

location: T6

Group: 6

Should look at the corresponding event in iSpy-webgl

Instructions (also available as [screencast](#)):

For each event, choose primary and final state. For Higgs or Zoo candidate, no final state is chosen. If you cannot decide between W^+ and W^- , choose W instead. If you have selected everything, click "Submit". If a mass shows up (for Z or Higgs), enter it by hand in the mass histogram after you clicked "Submit". In the case of an error, double clicking the data line will reload it; you can then try it again.

Event index:

Event number: 6-7

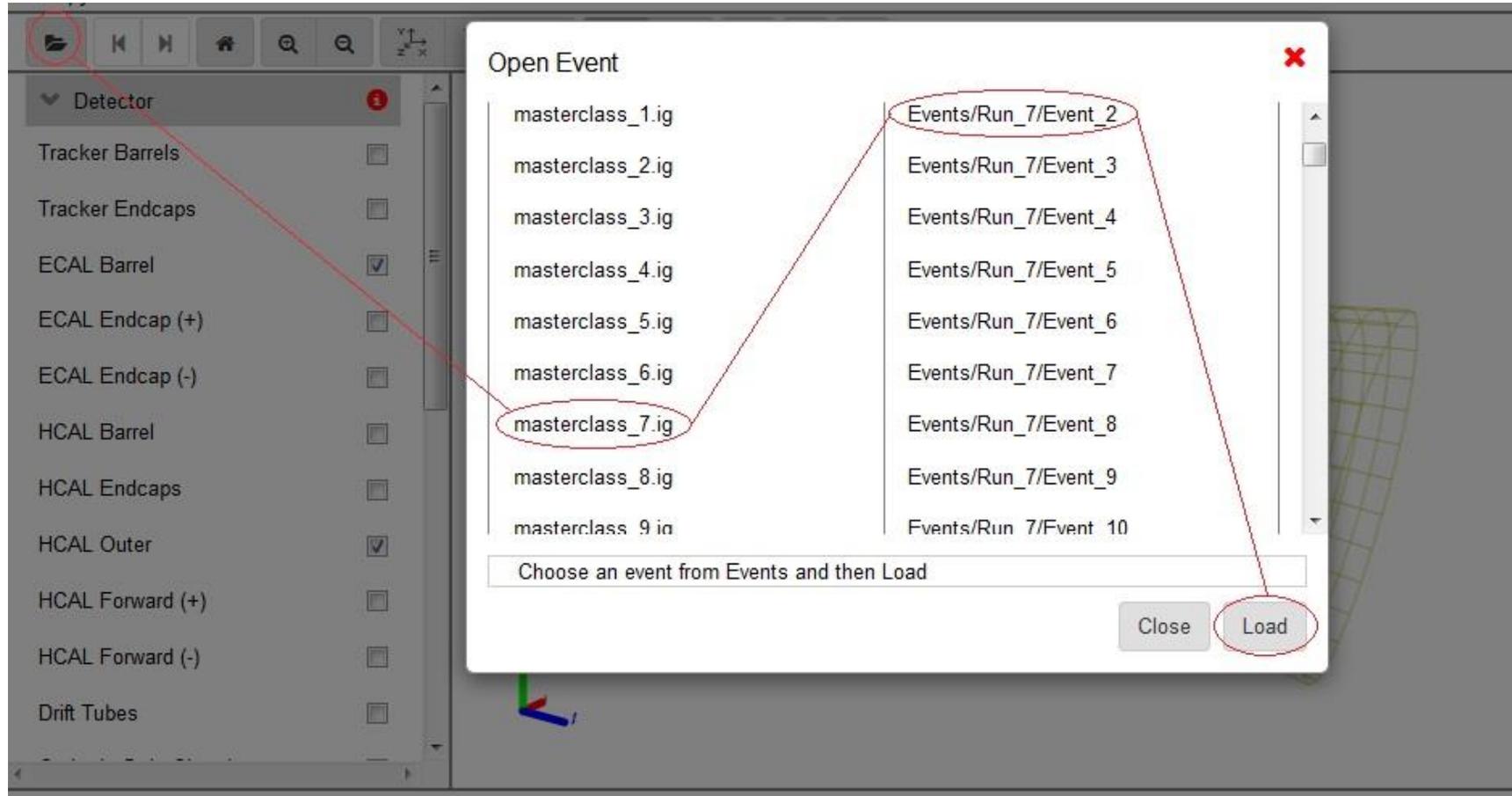
final state	primary	special
<input type="checkbox"/> Electron	<input type="checkbox"/> W^-	<input type="checkbox"/> Higgs
<input type="checkbox"/> Muon	<input type="checkbox"/> W^+	<input type="checkbox"/> Zoo
	<input type="checkbox"/> Z	
	<input type="checkbox"/> W	

Mass:

Event index	Event number	Chosen Values	Mass
6	6-6	e; W^-	
5	6-5	Z ;mu	124.444
4	6-4	H	8.609
3	6-3	Zoo	
2	6-2	mu; W^+	
1	6-1	e; Z	75.868

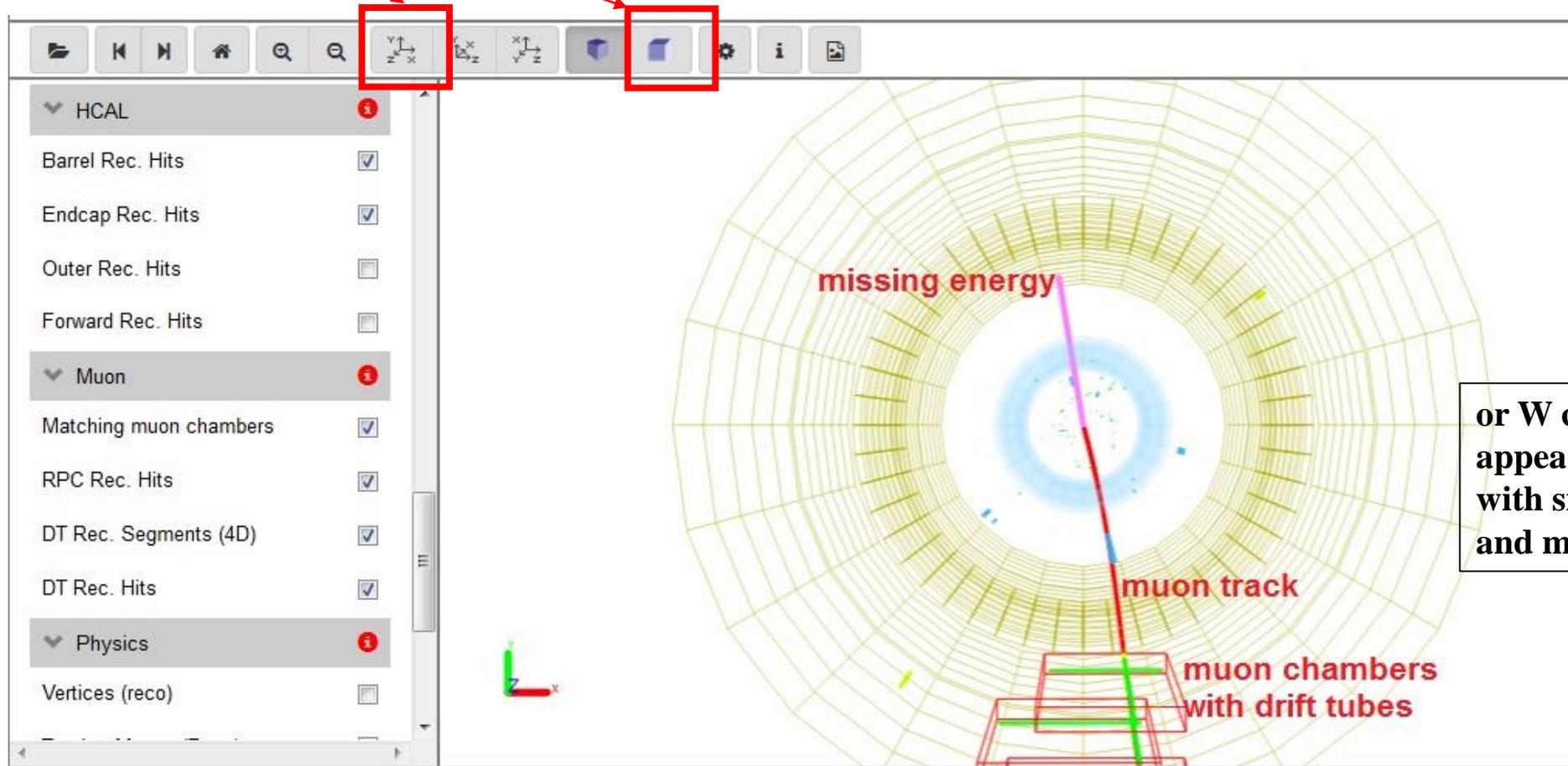
This table is just an example – you should not believe in everything written in it!

Then load next event



Charge → select (x-y) view and “orthographic mode”

Candidate $W^+ \rightarrow \mu^+ \nu$



or W candidate appears as an event with single muon track and missing E_t

Fill in what kind of event you have just measured in the "Events Table" on CIMA and then load next event

Masterclass: test
location: T6
Group: 6

Instructions (also available as [screencast](#)):
For each event, choose primary and final state. For Higgs or Zoo candidate, no final state is chosen. If you cannot decide between W+ and W-, choose W instead. If you have selected everything, click "Submit". If a mass shows up (for Z or Higgs), enter it by hand in the mass histogram after you clicked "Submit". In the case of an error, double clicking the data line will load it, you can then try it again.

Event index: Event number: 6-7

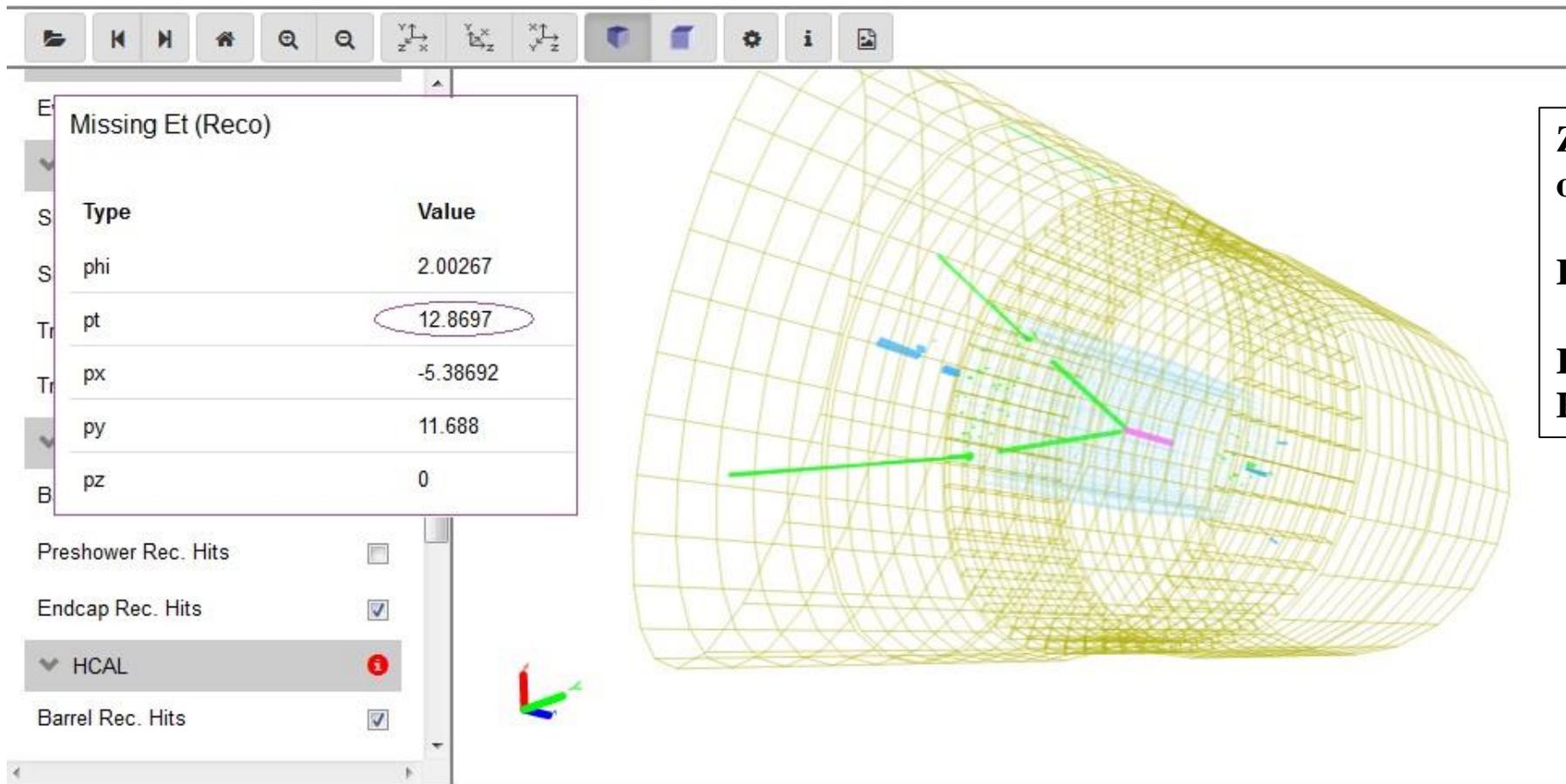
<input type="checkbox"/> Electron	<input type="checkbox"/> W-	<input type="checkbox"/> Z	<input type="checkbox"/> Higgs	Mass:
<input type="checkbox"/> Muon	<input type="checkbox"/> W+	<input type="checkbox"/> W	<input type="checkbox"/> Zoo	

Event index	Event number	Chosen Values	Mass
6	6-6	e;W-	
5	6-5	Z;mu	124.444
4	6-4	H	8.609
3	6-3	Zoo	
2	6-2	mu;W+	
1	6-1	e;Z	75.868

None of the events recognized as W, Z and H event

Candidate $Z \rightarrow e^- e^+$

N.B: Low value of missing energy track (missing Et) which gives you some confidence that this is not W event plus additional electron



Z candidates appear as 2 muons or 2 electrons.

It is not always a Z candidate!

It may or may not have missing Et in the event.

In case of W or Zoo – no mass will appear and do not include these in the mass plot.

In case of Higgs or Z, no final state is chosen but mass will appear.

Back Events Table (Group 6) Mass Histogram (T6) Results (T6)

Masterclass: test

location: T6

Group: 6

Instructions (also available as [screencast](#)):

For each event, choose primary and final state. For Higgs or Zoo candidate, no final state is chosen. If you cannot decide between W+ and W-, choose W instead. If you have selected everything, click "Submit". If a mass shows up (for Z or Higgs), enter it by hand in the mass histogram after you clicked "Submit". In the case of an error, double clicking the data line will reload it; you can then try it again.

Event index: Event number: 6-7

<input type="checkbox"/> Electron	<input type="checkbox"/> W-	<input type="checkbox"/> Z	<input type="checkbox"/> Higgs
<input type="checkbox"/> Muon	<input type="checkbox"/> W+	<input type="checkbox"/> W	<input type="checkbox"/> Zoo

Mass:

In case of an error, clicking the data line will erase

Event index	Event number	Chosen Values	Mass
6	6-6	e;W-	
5	6-5	Z;mu	124.444
4	6-4	H	8.609
3	6-3	Zoo	
2	6-2	mu;W+	
1	6-1	e;Z	75.868

In case of Higgs or Z, no final state is chosen but mass will appear

When a mass is shown in the line for an event, you should record it in the Mass Histogram (you will see the result of all your colleagues working on it)



The total number of events at each mass is automatically transferred to the mass plot of the Results tab!

Back Events Table Mass Histograms **Results**

Masterclass: 3 Jan2015
Location: Mexico

Group	Muon	Electron	W	W-	W+	Z	Higgs	Zoo	Total
1	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0
6	3	5	2	0	0	6	1	1	10
7	0	0	0	0	0	0	0	0	0
8	2	1	0	0	2	1	0	1	4
9	4	3	1	1	1	4	1	1	9
10	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0

Total:

Muon	Electron	W	W-	W+	Z	Higgs	Zoo	Sum	elmu	W+W-
9	9	3	1	3	11	2	3	23	1	3

Presentation of results

- The mass plot and summary of results are automatically built in the institute Mass Histogram and Results pages.
- The mass plot will show not only a Z peak but also peaks due to other particles.
- The results will show the numbers of electron, muon, W_+ , W_- , W (unknown charge), Z candidates, H candidates, and zoo events plus the key ratios **e:mu** and **$W_+:W_-$** .

