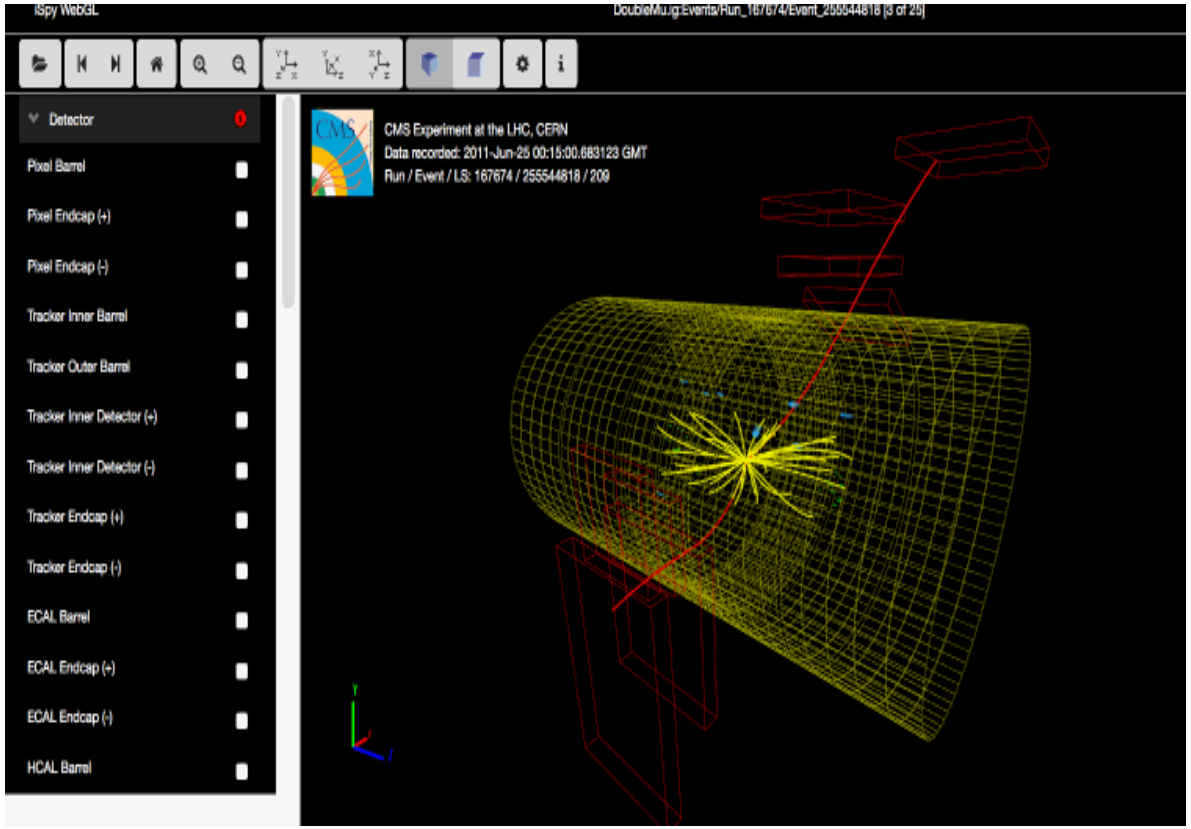
CMS Masterclass in Bulgaria

INTERNATIONAL MASTERCLASSES
hands on particle physics

International Particle Physics Outreach Group

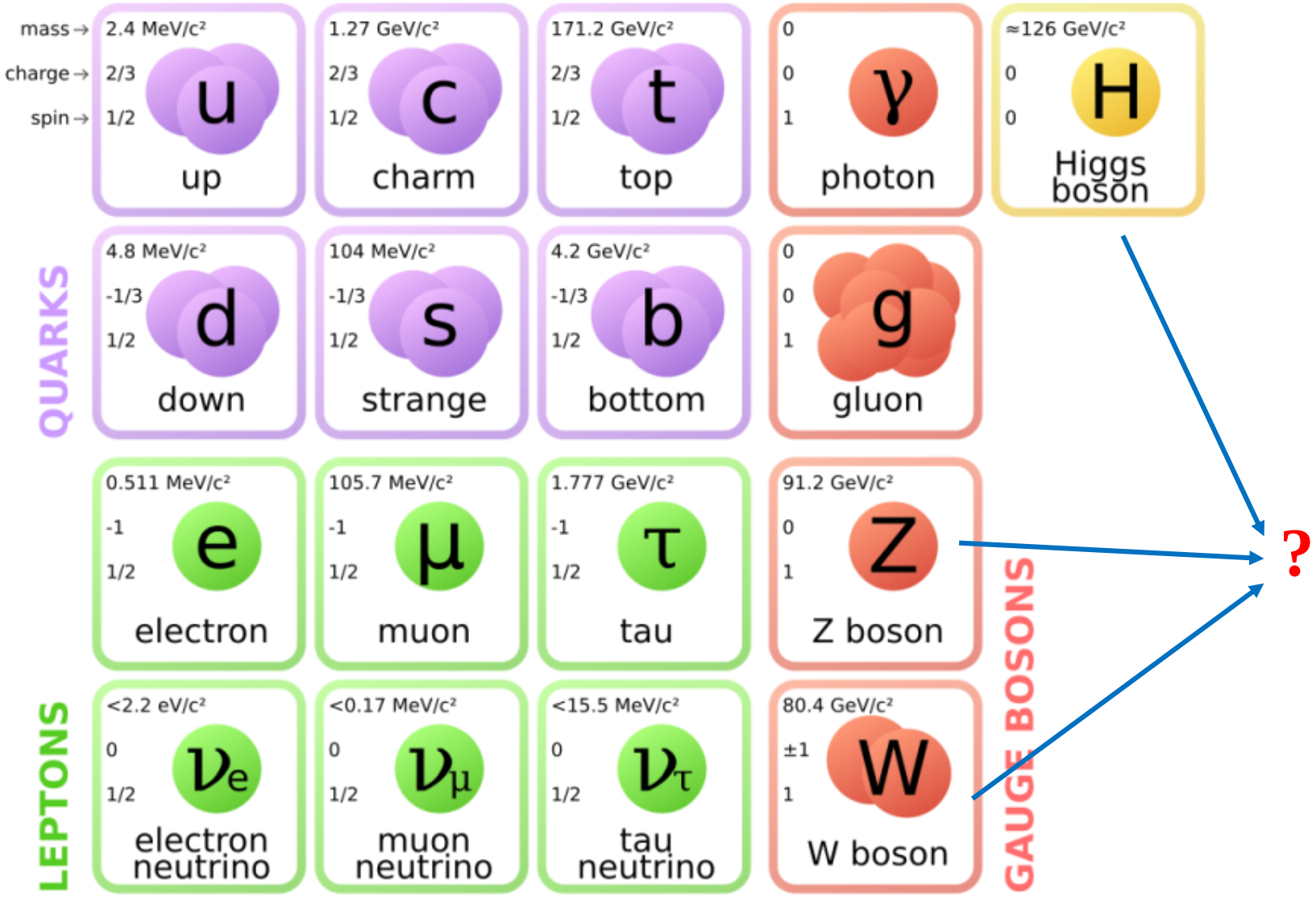
Open Schools for Open Societies



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



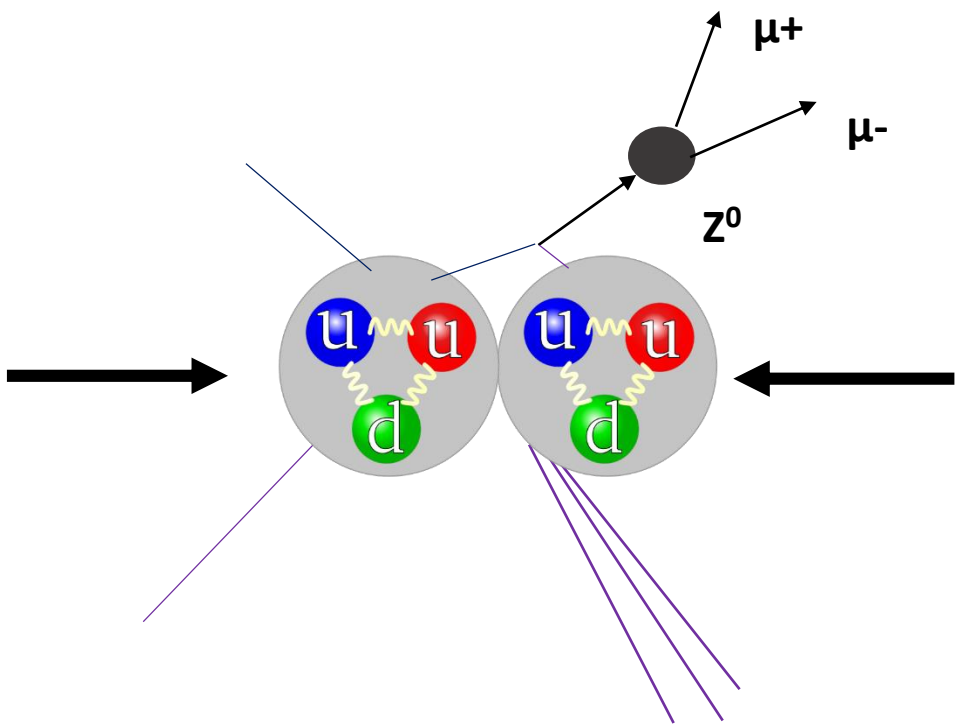
WZH measurement

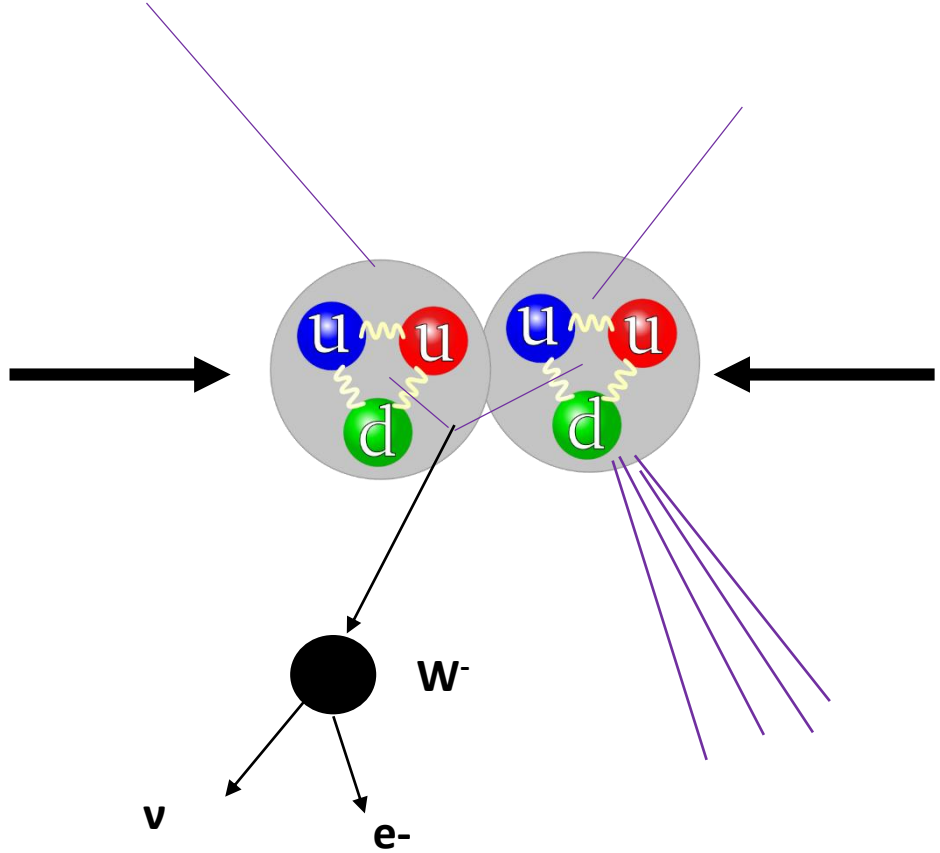
You will study events with multiple signatures to:

- ✓ **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.**

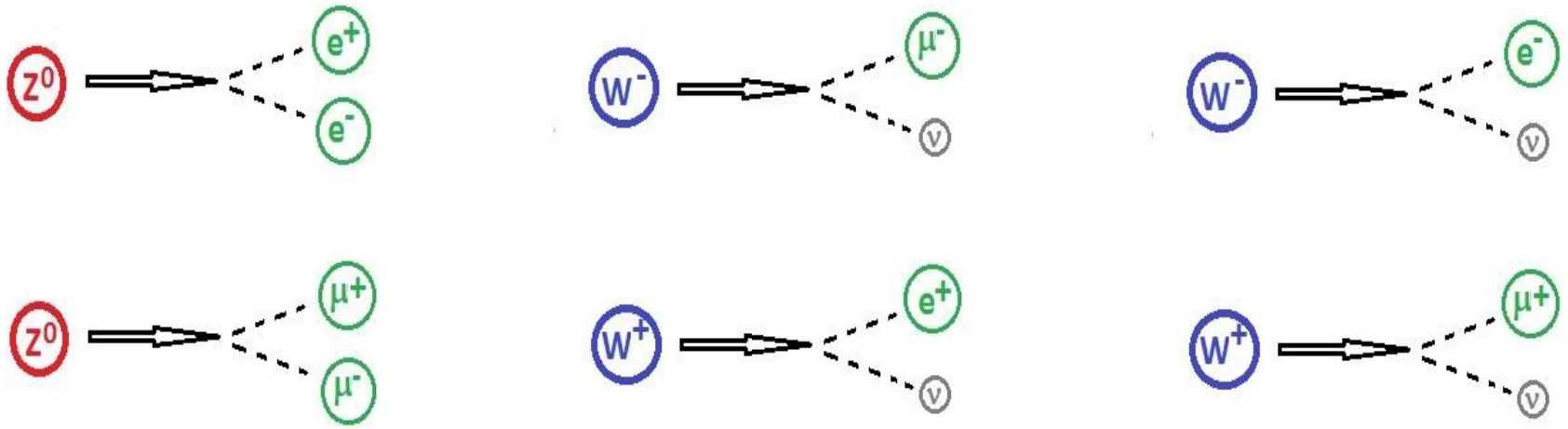
Unlike electromagnetic forces carried over long distances by massless photons, the weak force is carried by massive particles which restricts interactions to very tiny distances.

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"

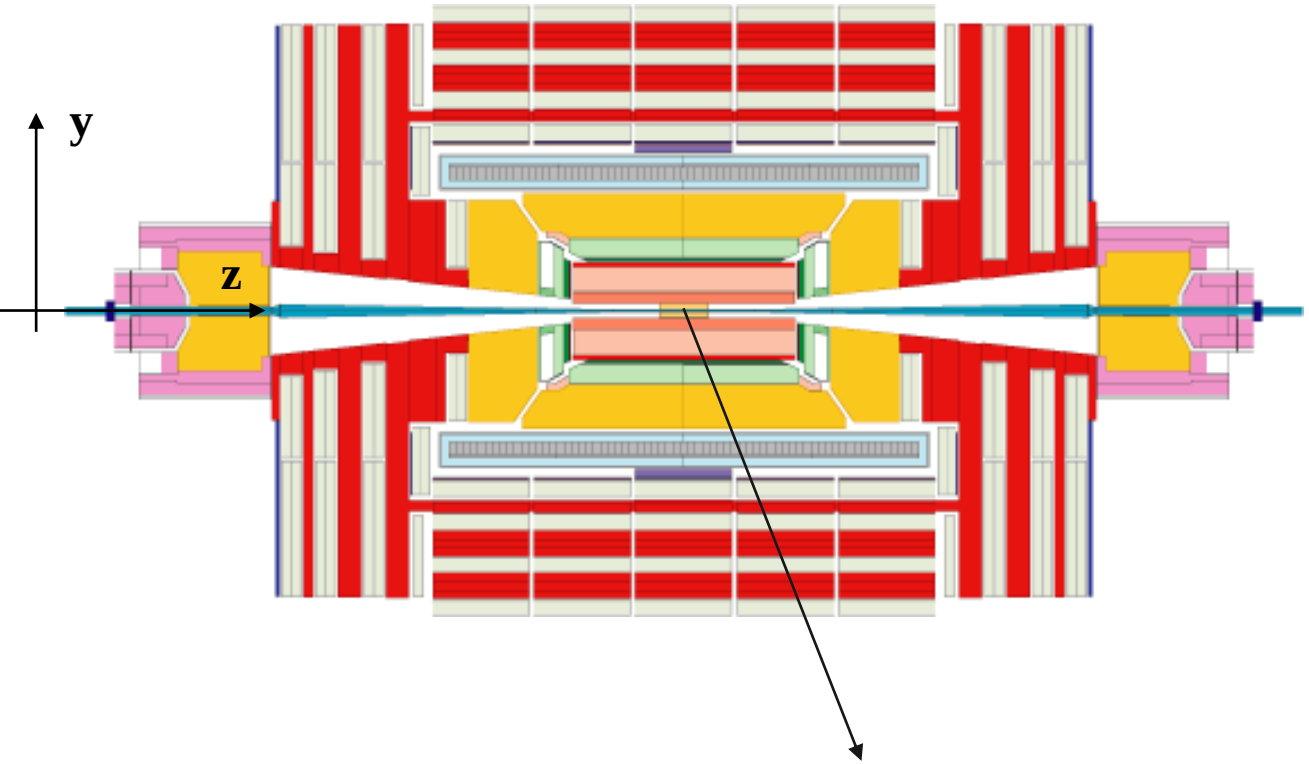
A Higgs boson has several possible decays.

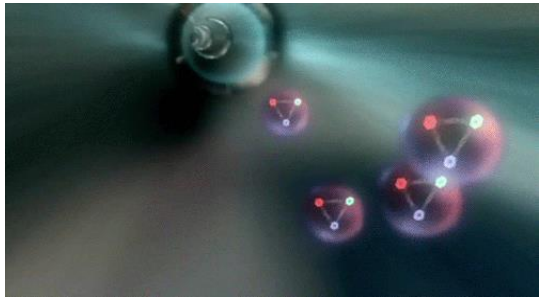
The two you might see are:

- → **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.

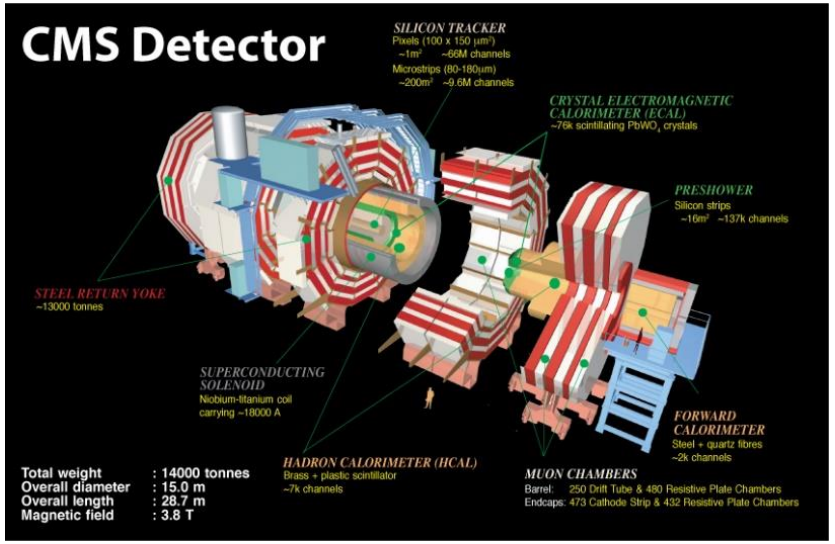
Generic Design: Cylinders wrapped around the beam pipe



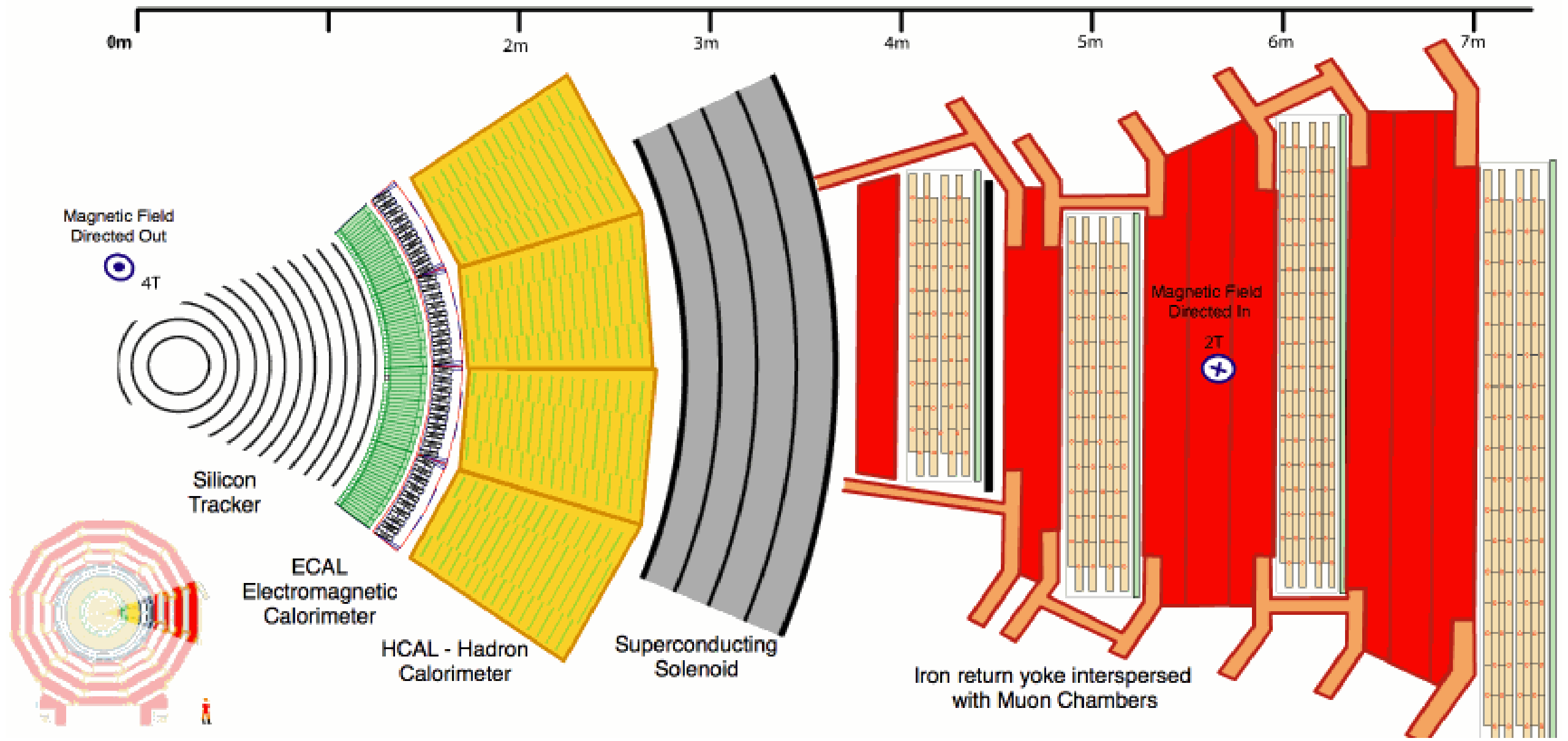


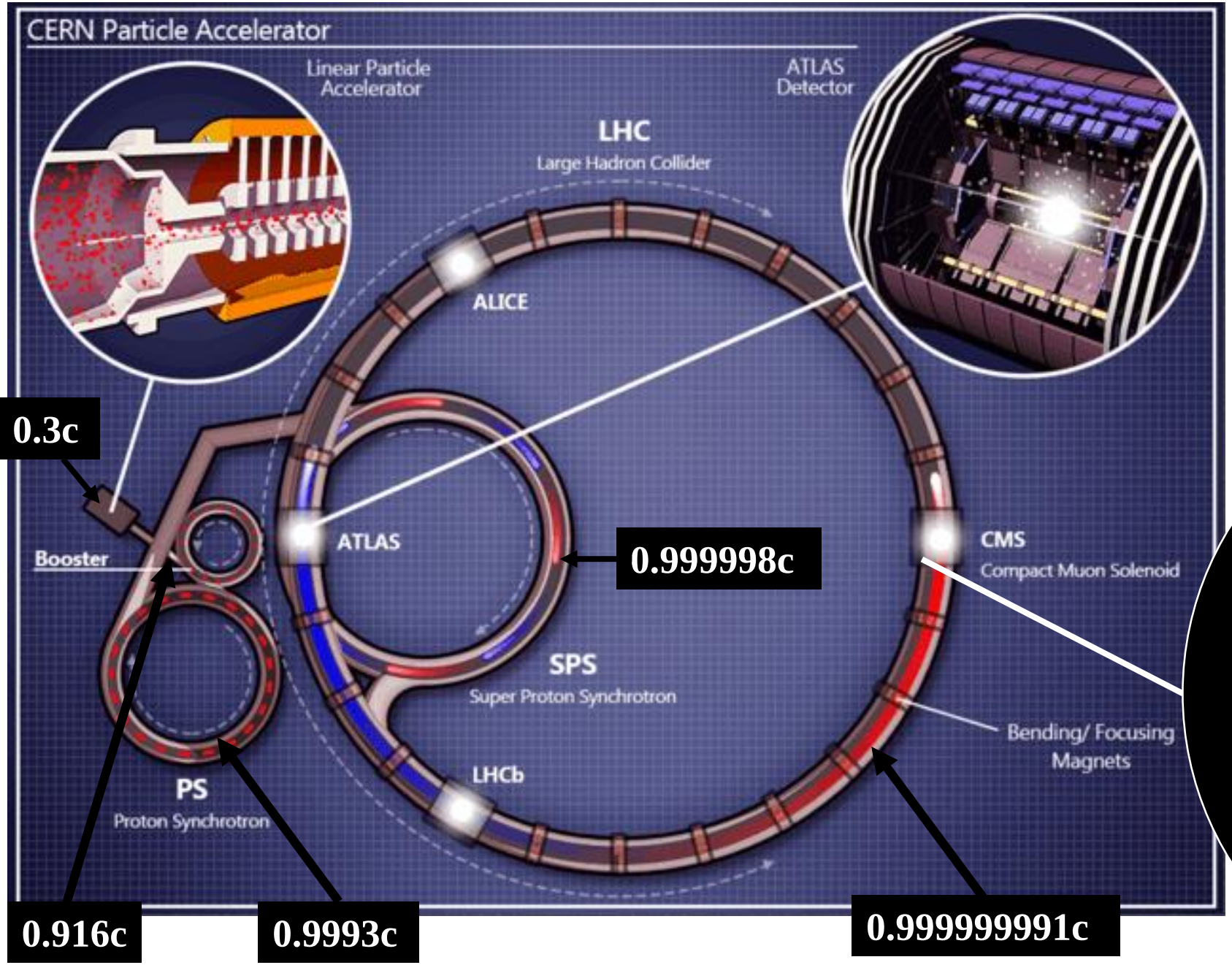
FROM INNER TO OUTER …

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

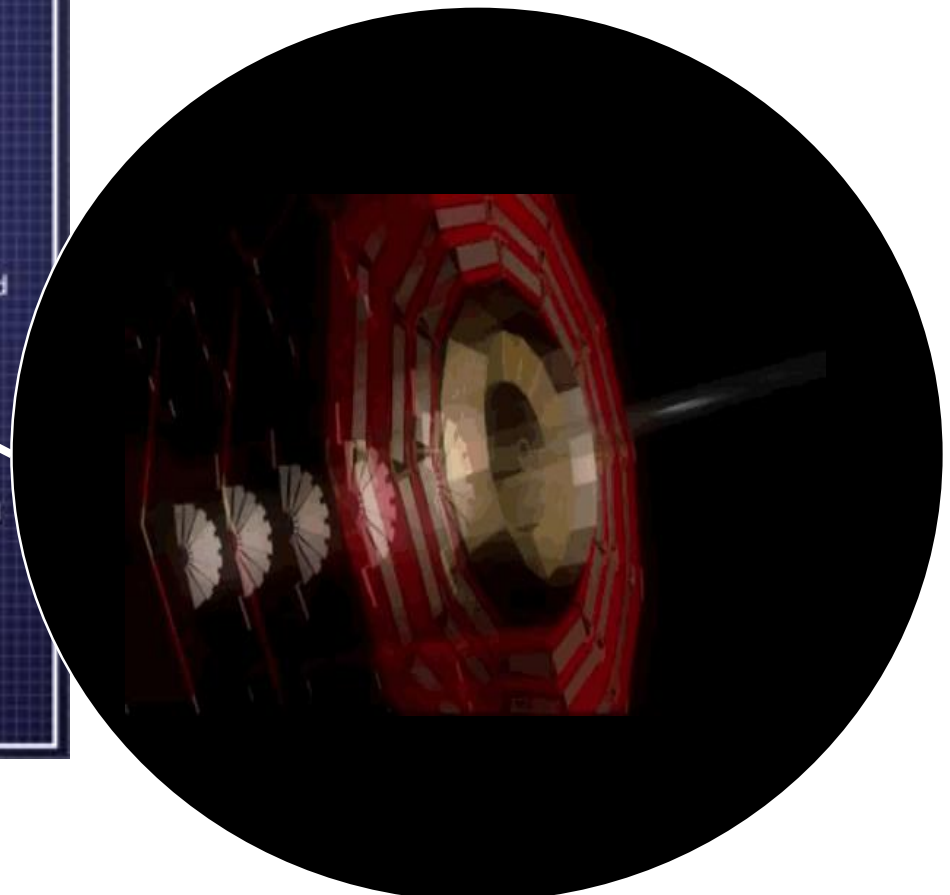


Transverse slice of the CMS Detector

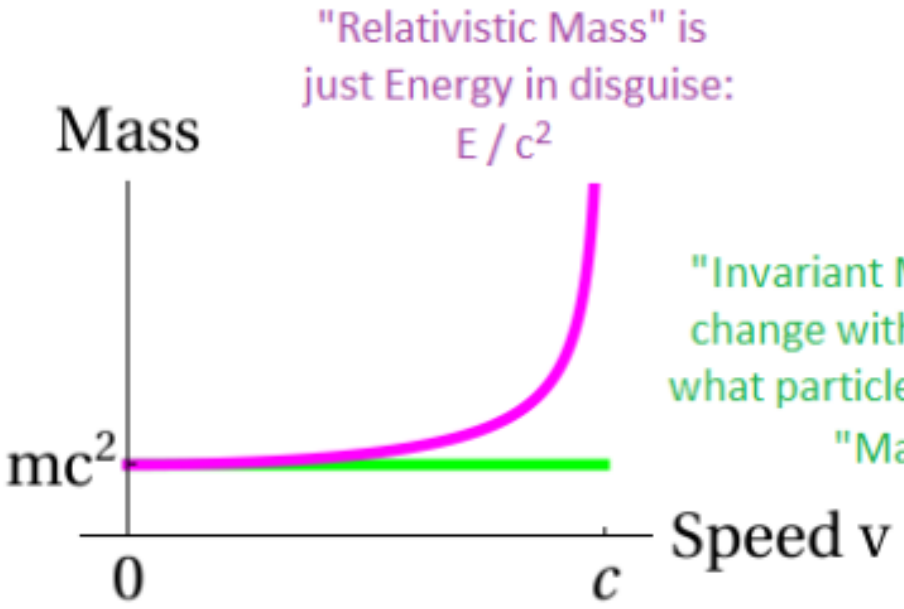




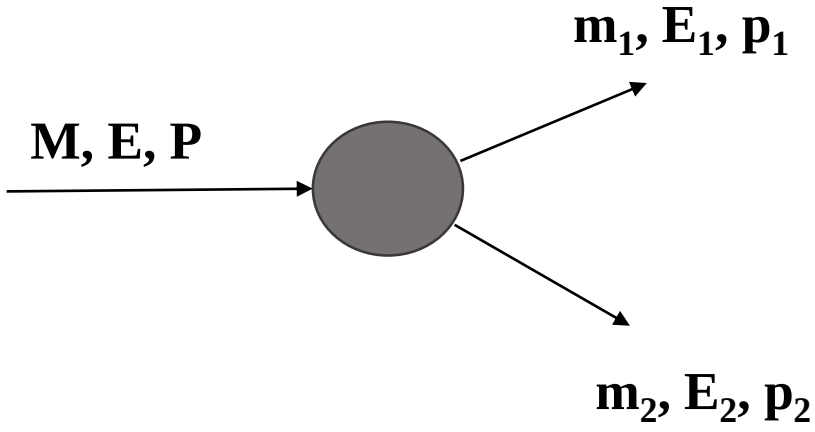
LHC is buried ~100m below the surface near the Swiss-French border



Conservation laws?



"Invariant Mass" doesn't change with speed and is what particle physicists call "Mass"



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

Energy and momentum for relativistic particles

(velocity v comparable to *c*)

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

Total energy: $E = mc^2 = \dfrac{m_0 c^2}{\sqrt{1-(v/c)^2}}$

***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.

CIMA

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

90%

Search

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Link to CIMA

CIMA

CMS Instrument for Masterclass Analysis

RWTH AACHEN UNIVERSITY

UNIVERSITY OF NOTRE DAME

CERN

QuarkNet

CMS

NETZWERK TEILCHENWELT

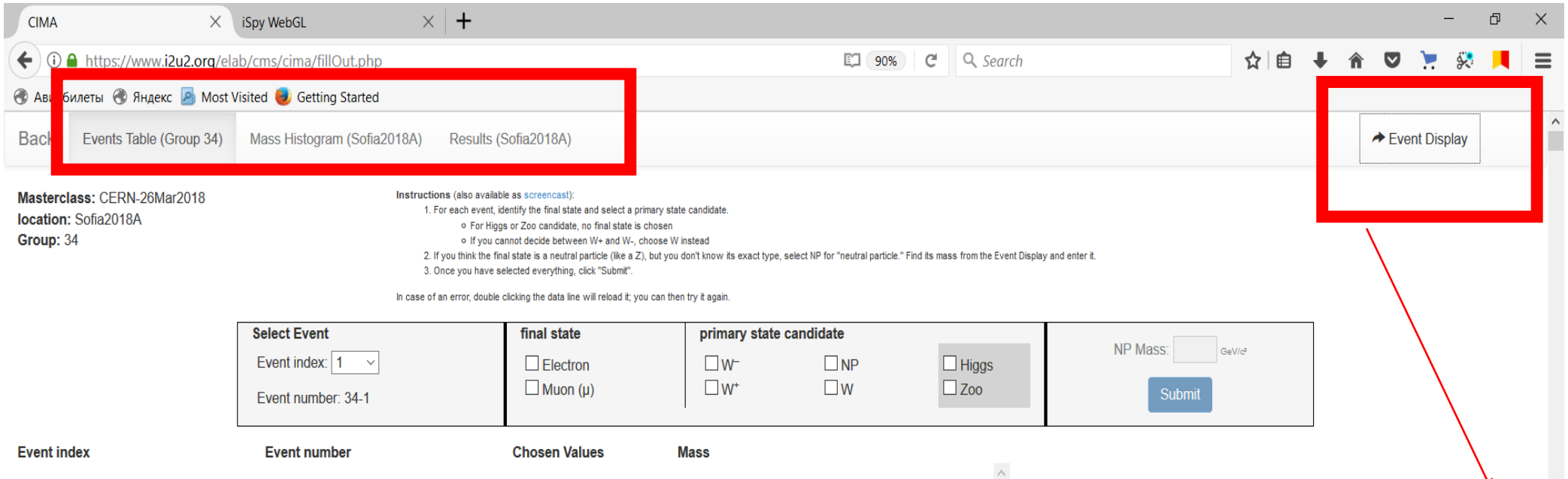
MASTERCLASSES

hands on particle physics

Choose your Masterclass	Choose your location	Choose your group
Imn/lk	Belgrade2018A	21
LasMatas-28Oct2017	Lyon2018C	22
DürenJan2018	NoviSad2018A	23
Budapest-07Mar2018	Sofia2018A	24
PracticeTables-IMC2018		25
IDWGS-12Feb2018		26
CERN-10Feb2018		27
Roma-22Feb2018		28
CERN-19Feb2018		29
CERN-20Feb2018		30
CERN-22Feb2018		31
CERN-28Feb2018		32
CERN-02Mar2018		33
CERN-03Mar2018		34
CERN-06Mar2018		35
CERN-07Mar2018		36
CERN-08Mar2018		37
CERN-14Mar2018		38
CERN-19Mar2018		39
CERN-23Mar2018		40
CERN-26Mar2018		41
DürenFeb18		42
DürenMärz18		43
CERN-15March2018		44

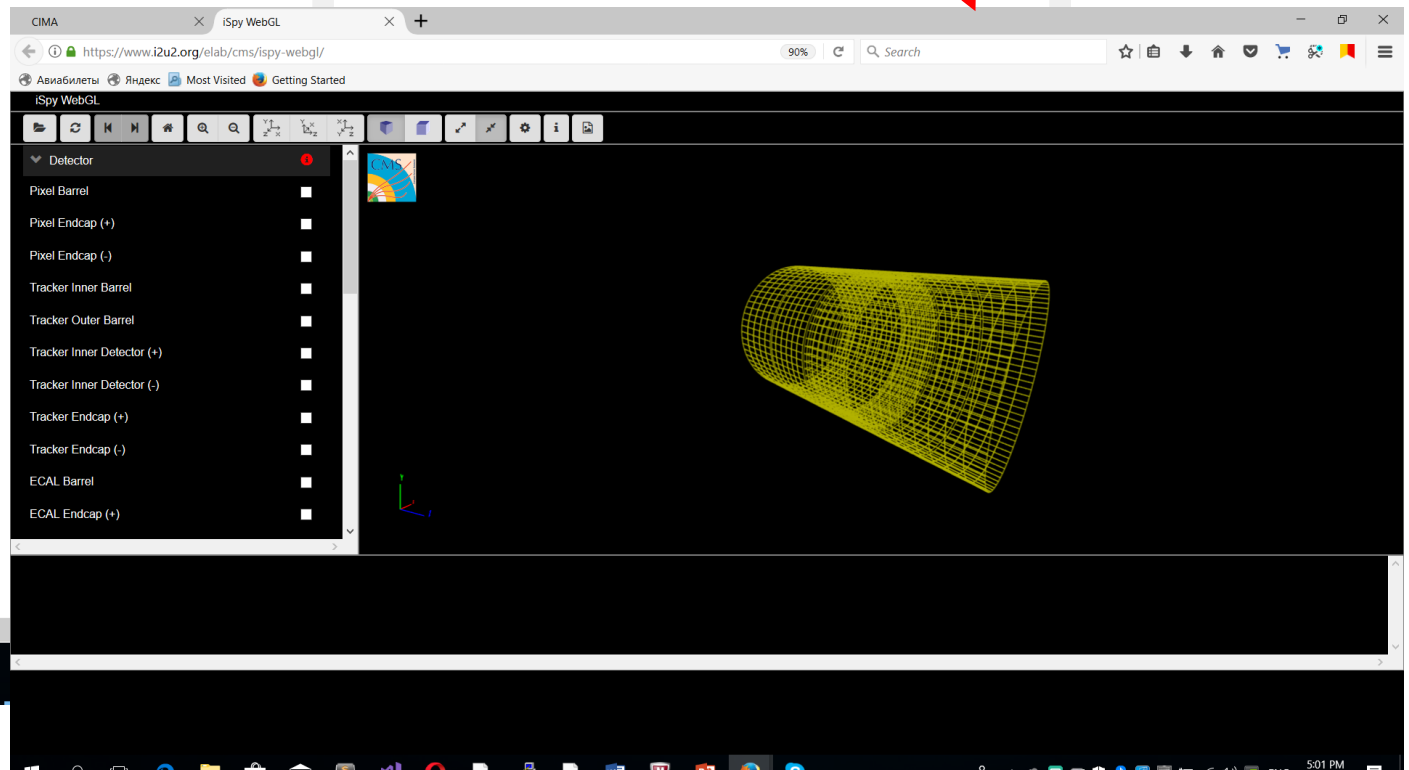
choose your group, for example 29, where the dataset is.

ENG 4:50 PM 3/22/2018



Link to CIMA Events Table, Mass Histogram and Results

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



CIMA

iSpy WebGL

https://www.i2u2.org/elab/cms/ispy-webgl/

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Search

Авиабилеты Яндекс Most Visited Getting Started

iSpy WebGL

Detector

Pixel Barrel

Pixel Endcap (+)

Pixel Endcap (-)

Tracker Inner Barrel

Tracker Outer Barrel

Tracker Inner Detector (+)

Tracker Inner Detector (-)

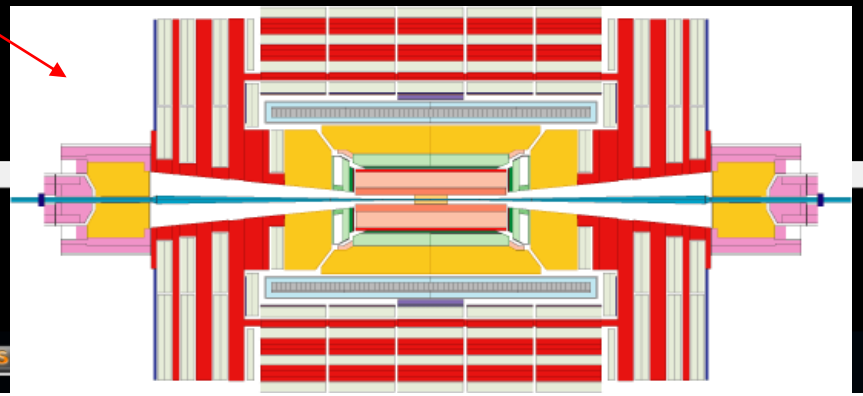
Tracker Endcap (+)

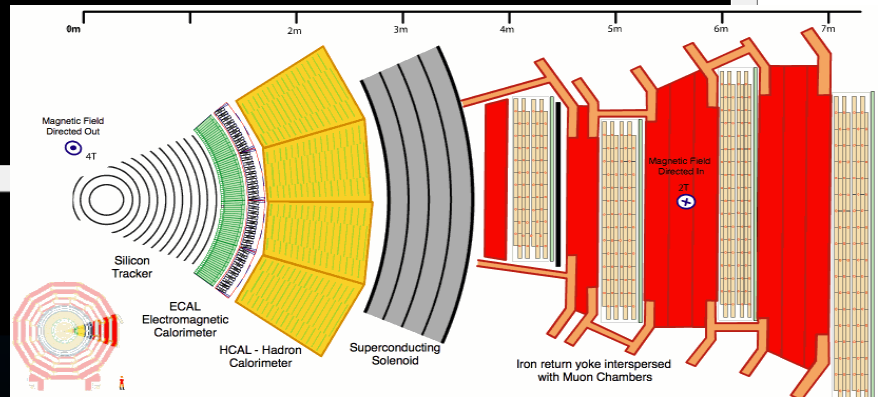
Tracker Endcap (-)

ECAL Barrel

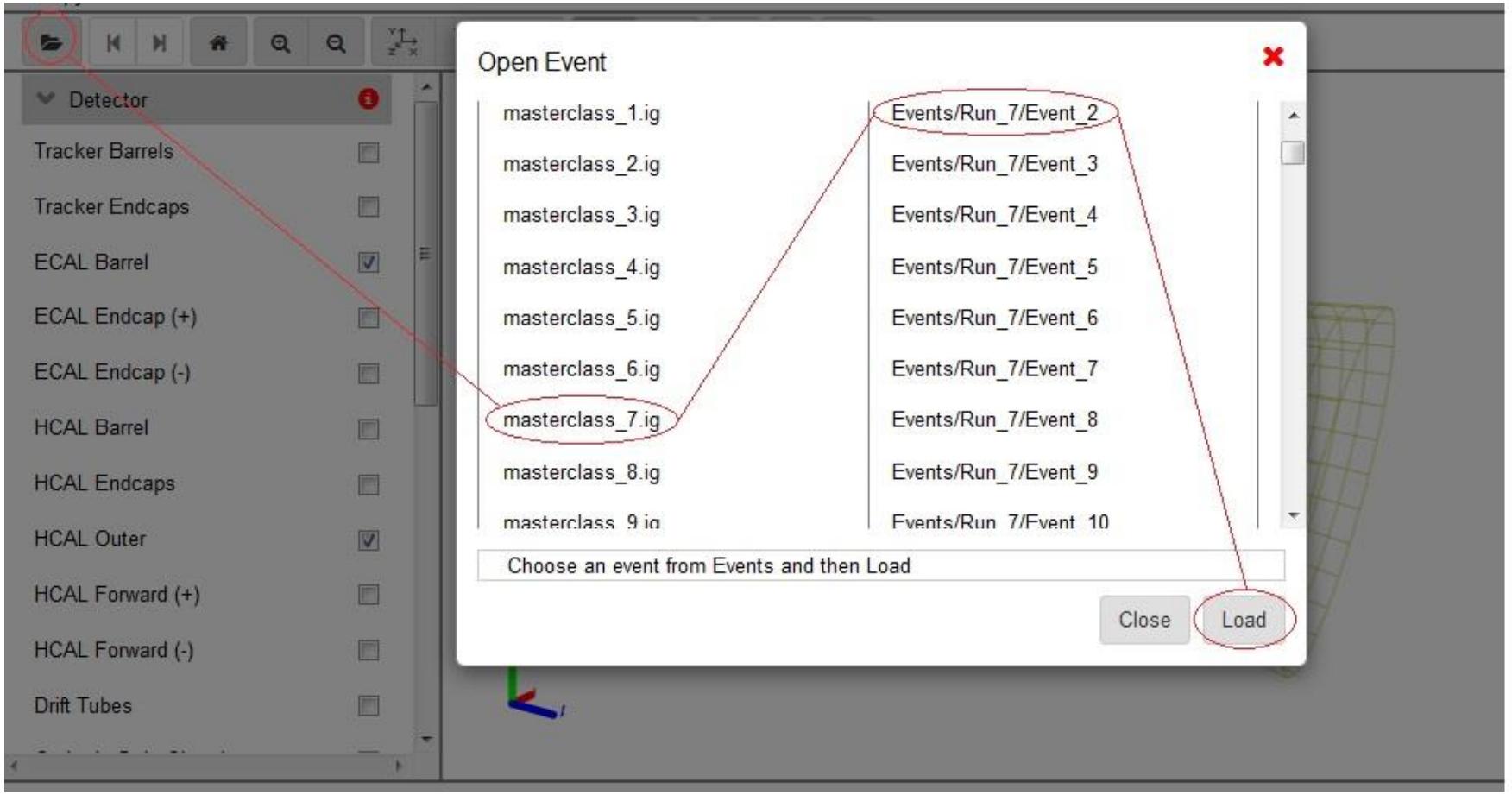
ECAL Endcap (+)

iSpy





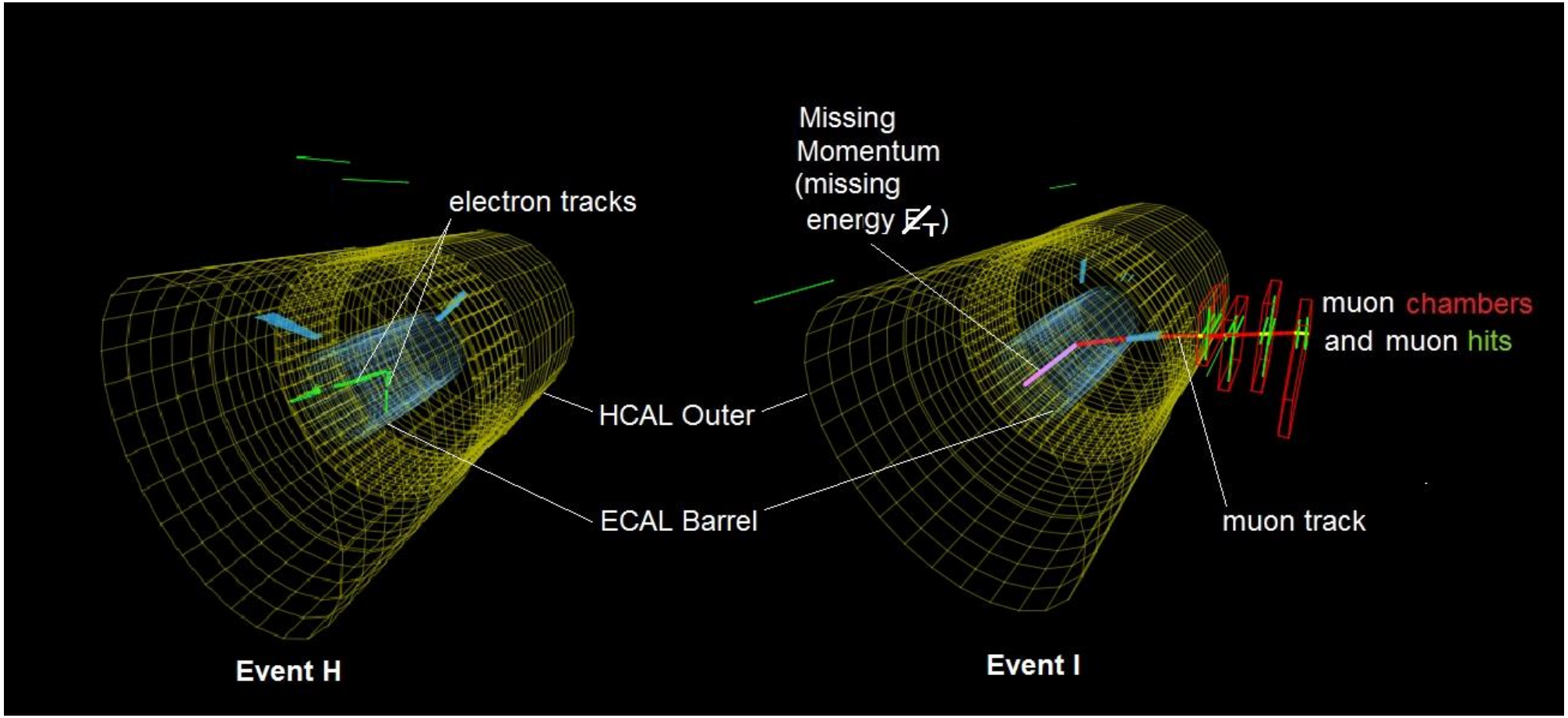
Find the correct data files in iSpy and CIMA



Thanks to https://quarknet.org/page/cms-masterclass-2016-documentation

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?

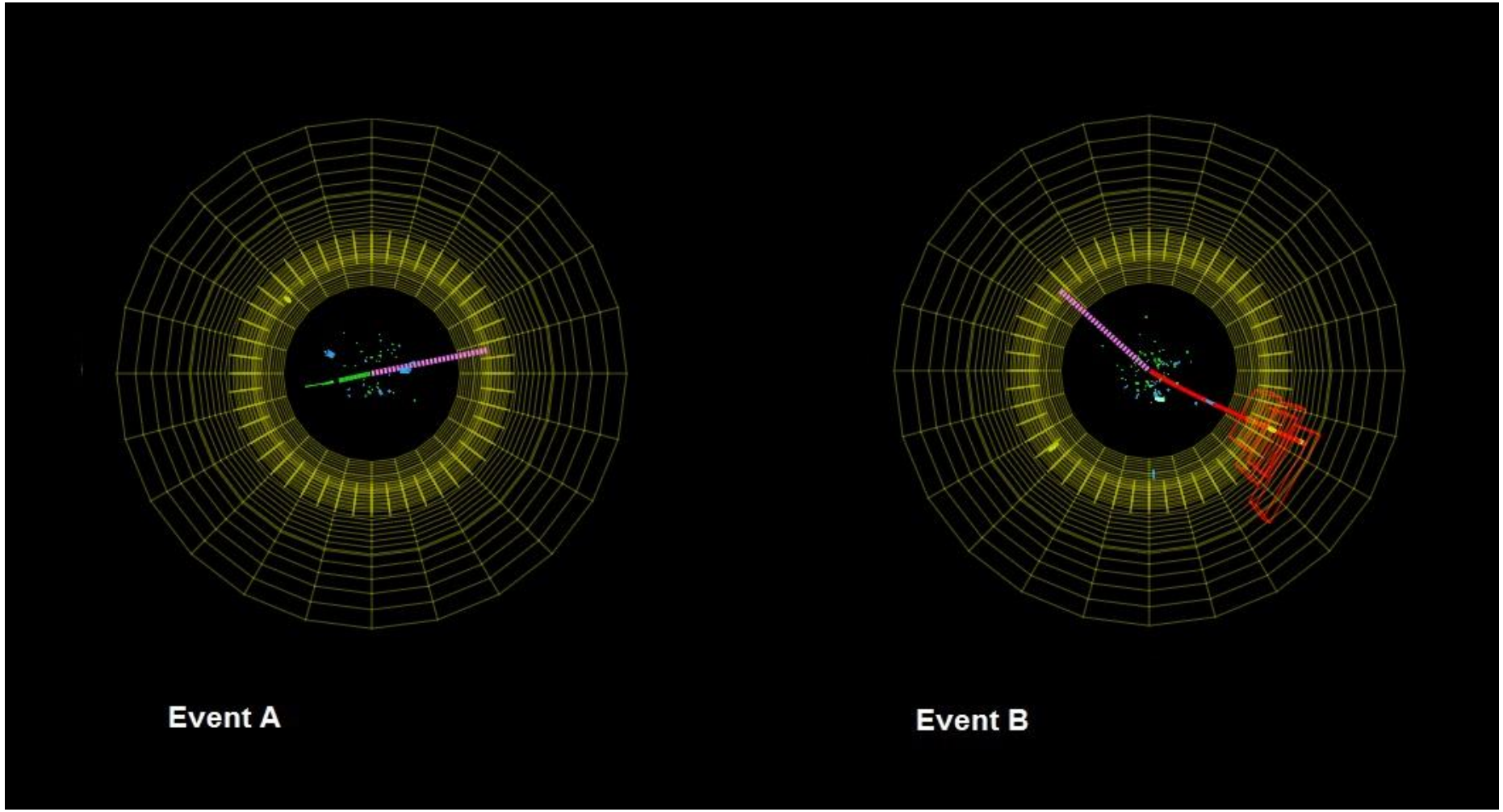


W boson candidate events

missing Et = 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 Et= purple track = ν

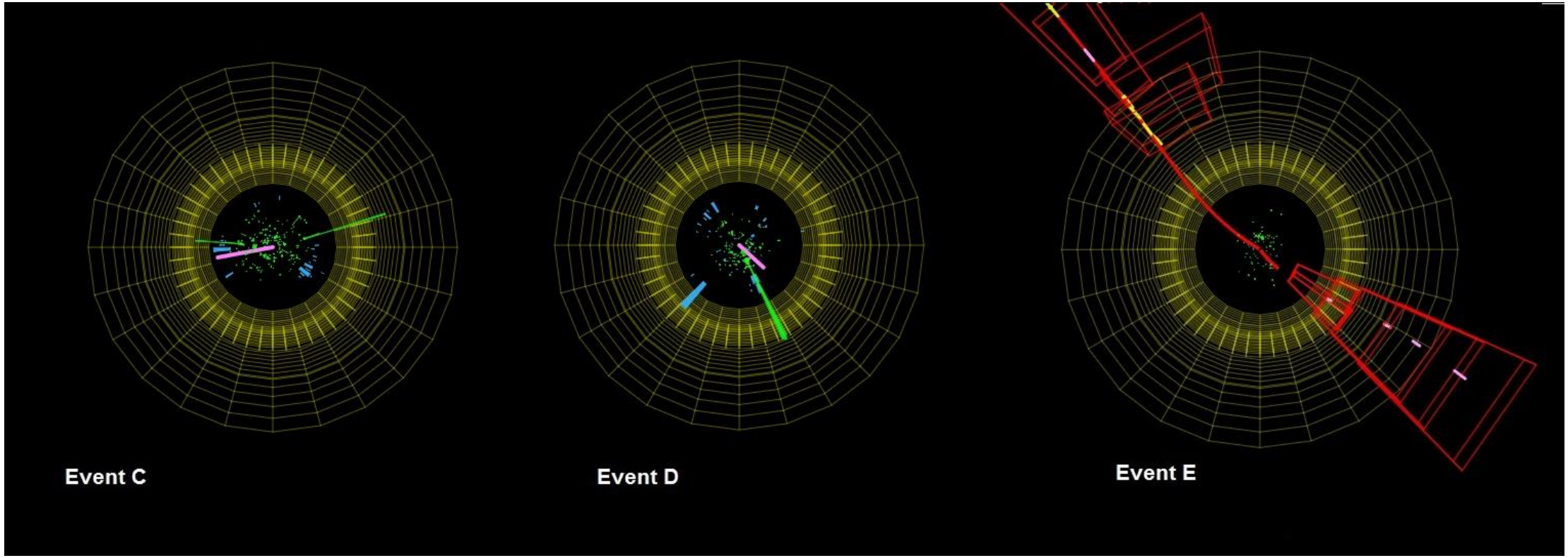
green track = e+/e-

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

missing Et= purple track = ν

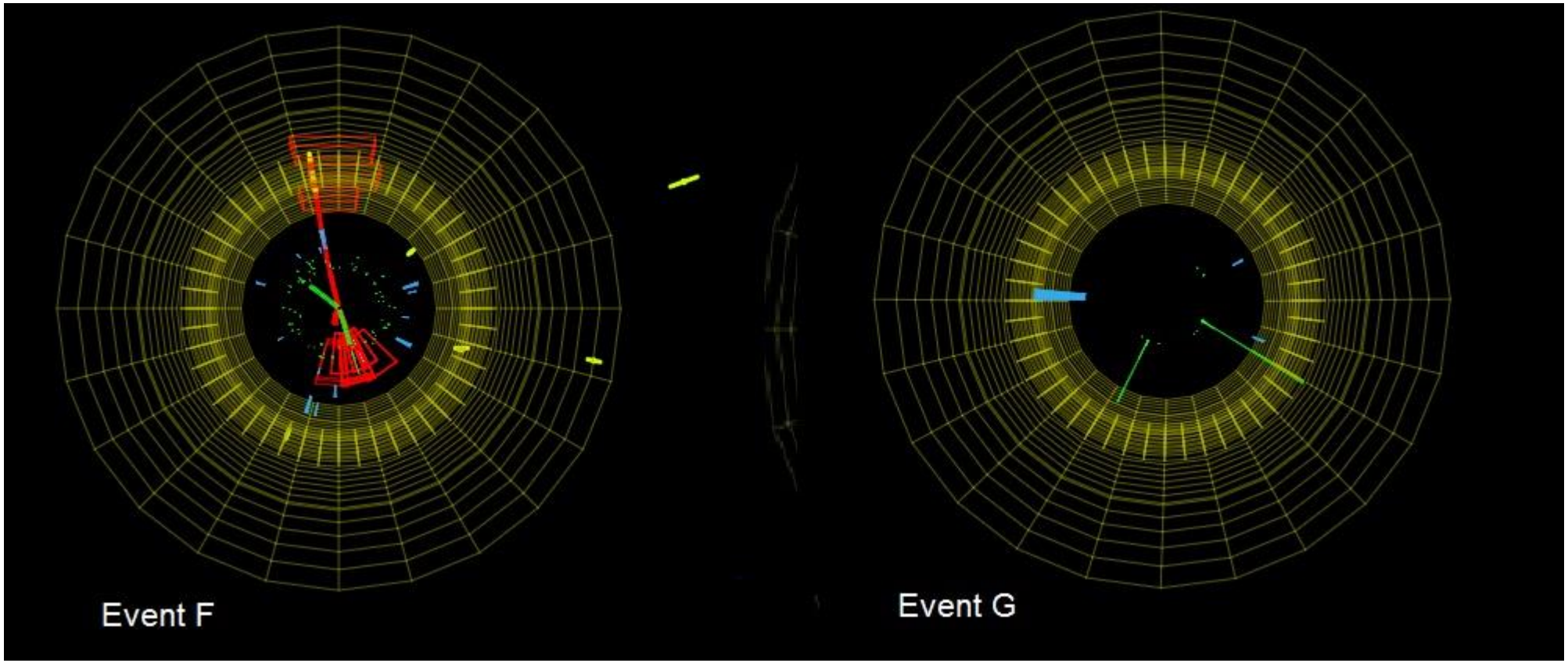
green track = e+/e-

red track = μ+/μ-

green energy towers = γ

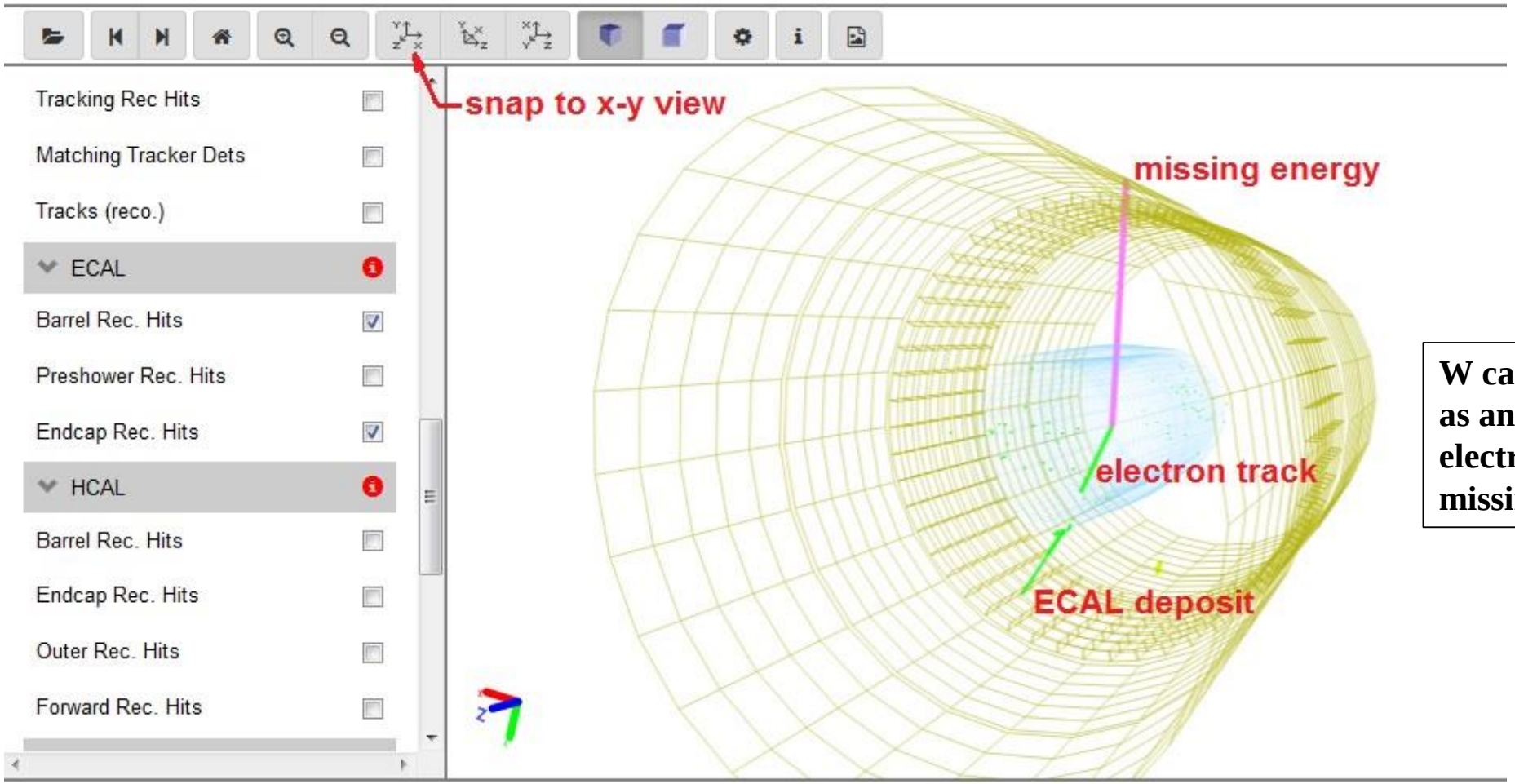
? H →Z Z →μ $^+$ μ$^-$ μ $^+$ μ$^-$ or (e$^+$ e$^-$ e$^+$ e$^-$) or (μ$^+$ μ$^-$ e$^+$ e$^-$)

? H → γ 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)



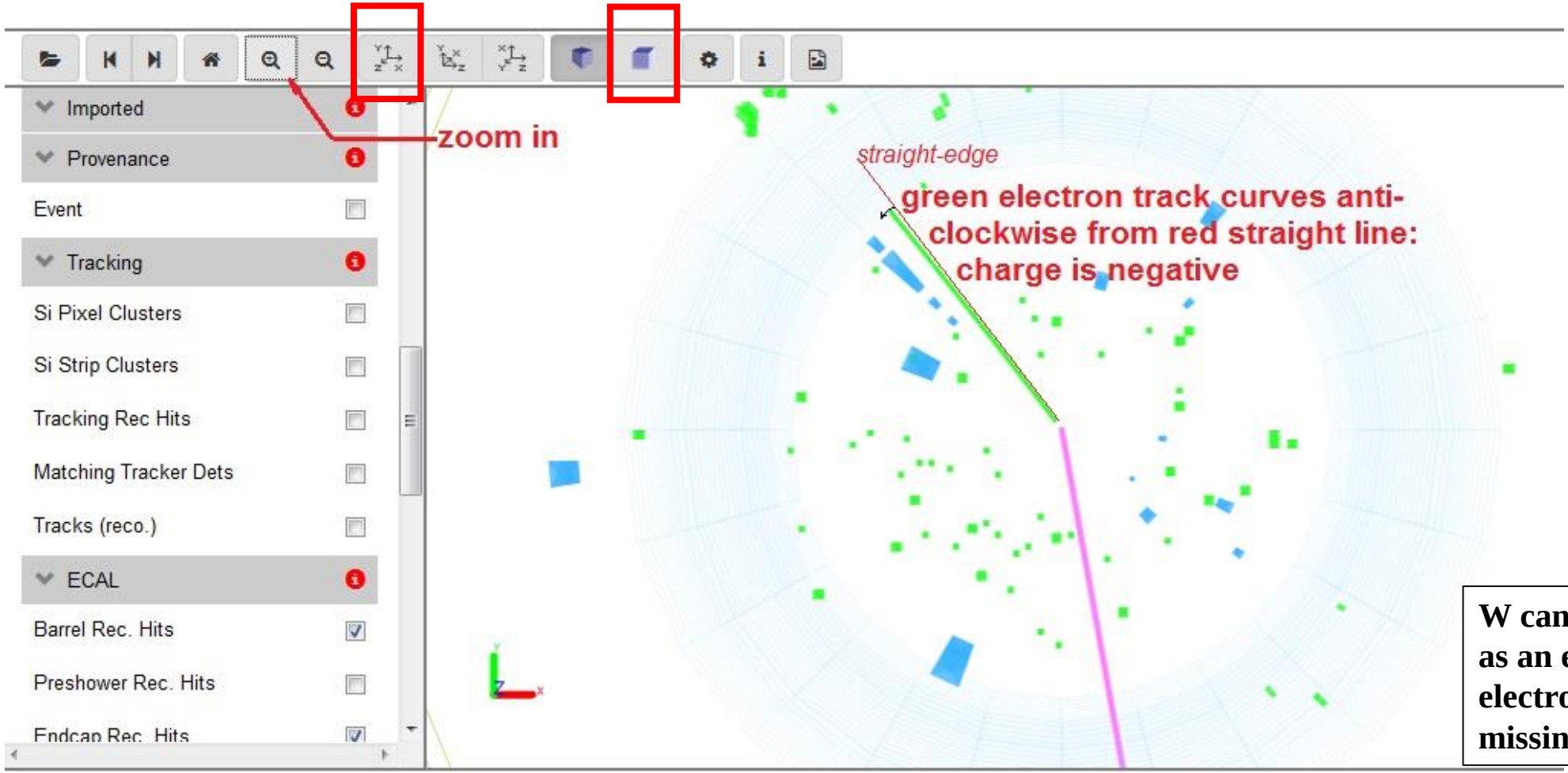
W candidate appears as an event with single electron track and missing Et

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

Thanks to https://quarknet.org/page/cms-masterclass-2016-documentation

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

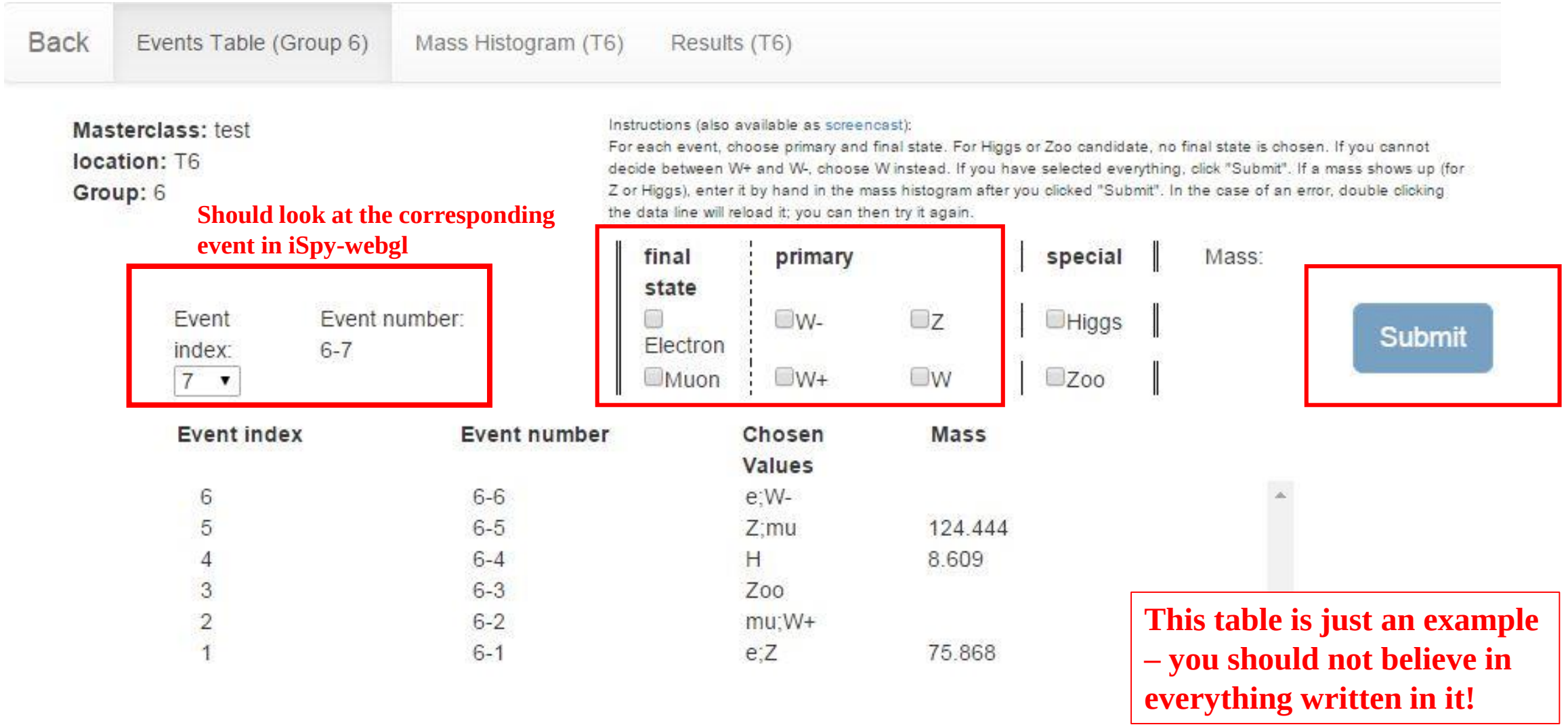
Candidate $W^- \rightarrow e^- \nu$



W candidate appears as an event with single electron track and missing Et

Thanks to https://quarknet.org/page/cms-masterclass-2016-documentation

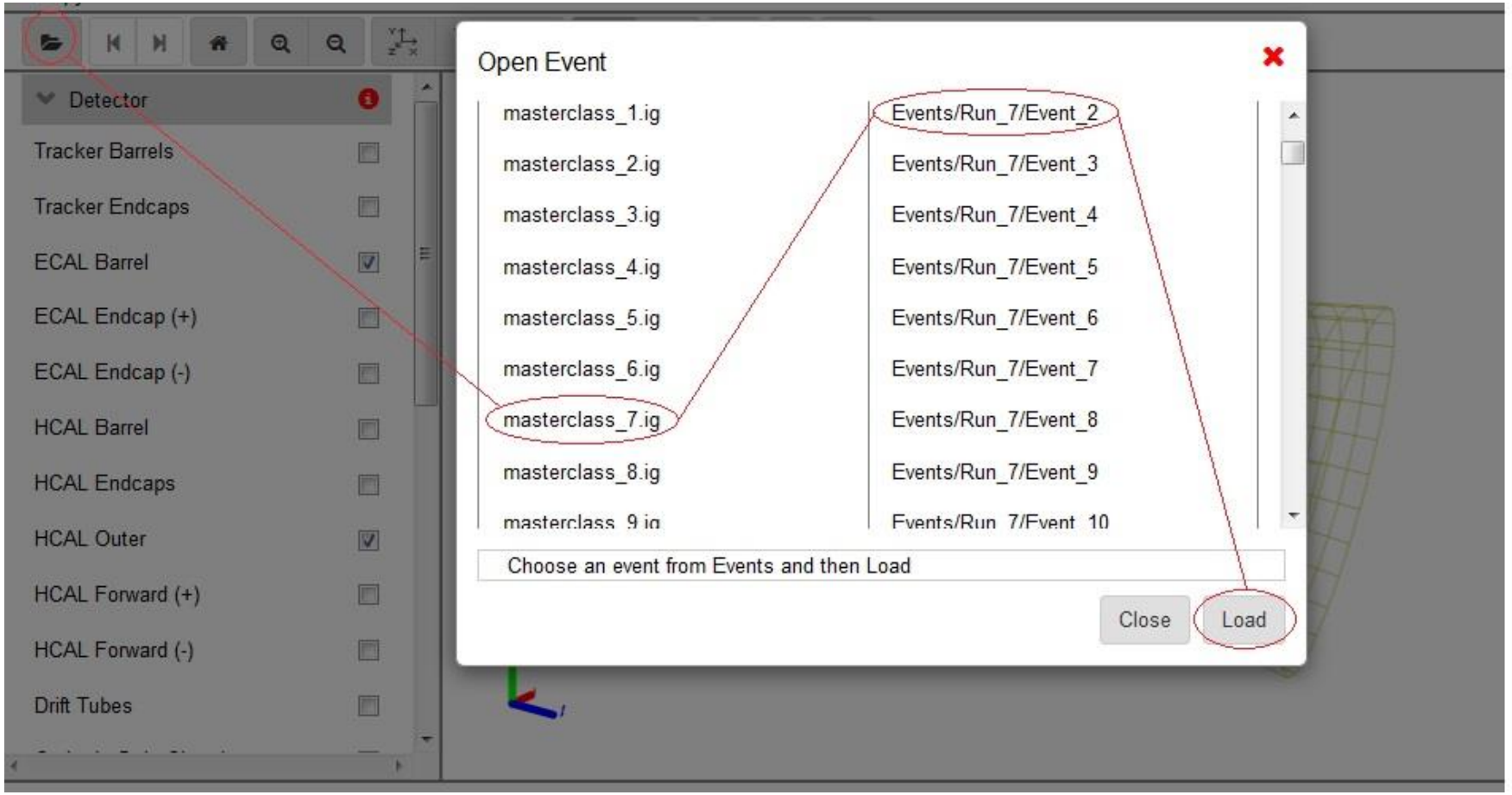
Fill in what kind of event you have just measured in the ‘’Events Table’’ on CIMA



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

Thanks to https://quarknet.org/page/cms-masterclass-2016-documentation

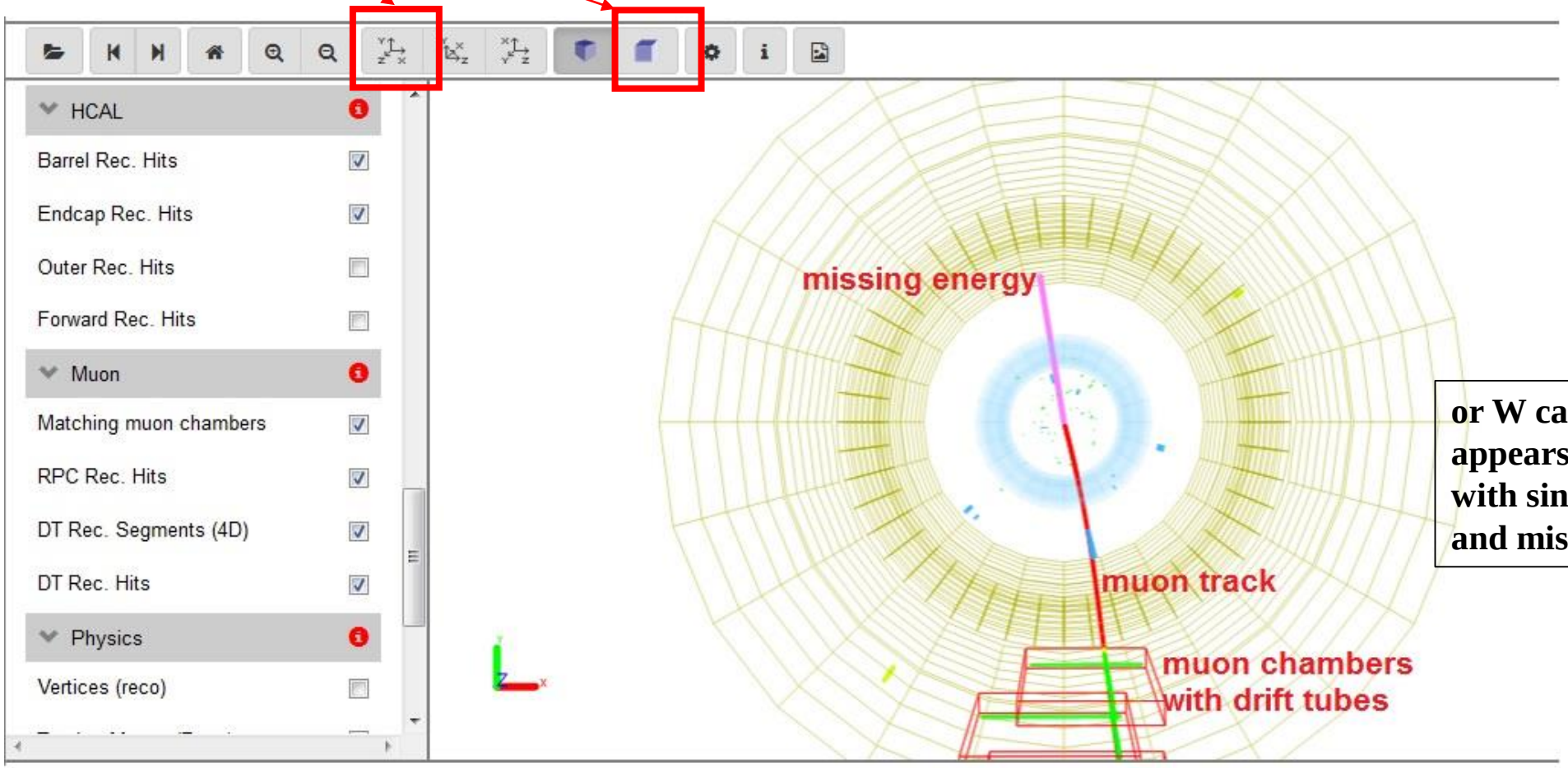
Then load next event



Thanks to https://quarknet.org/page/cms-masterclass-2016-documentation

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

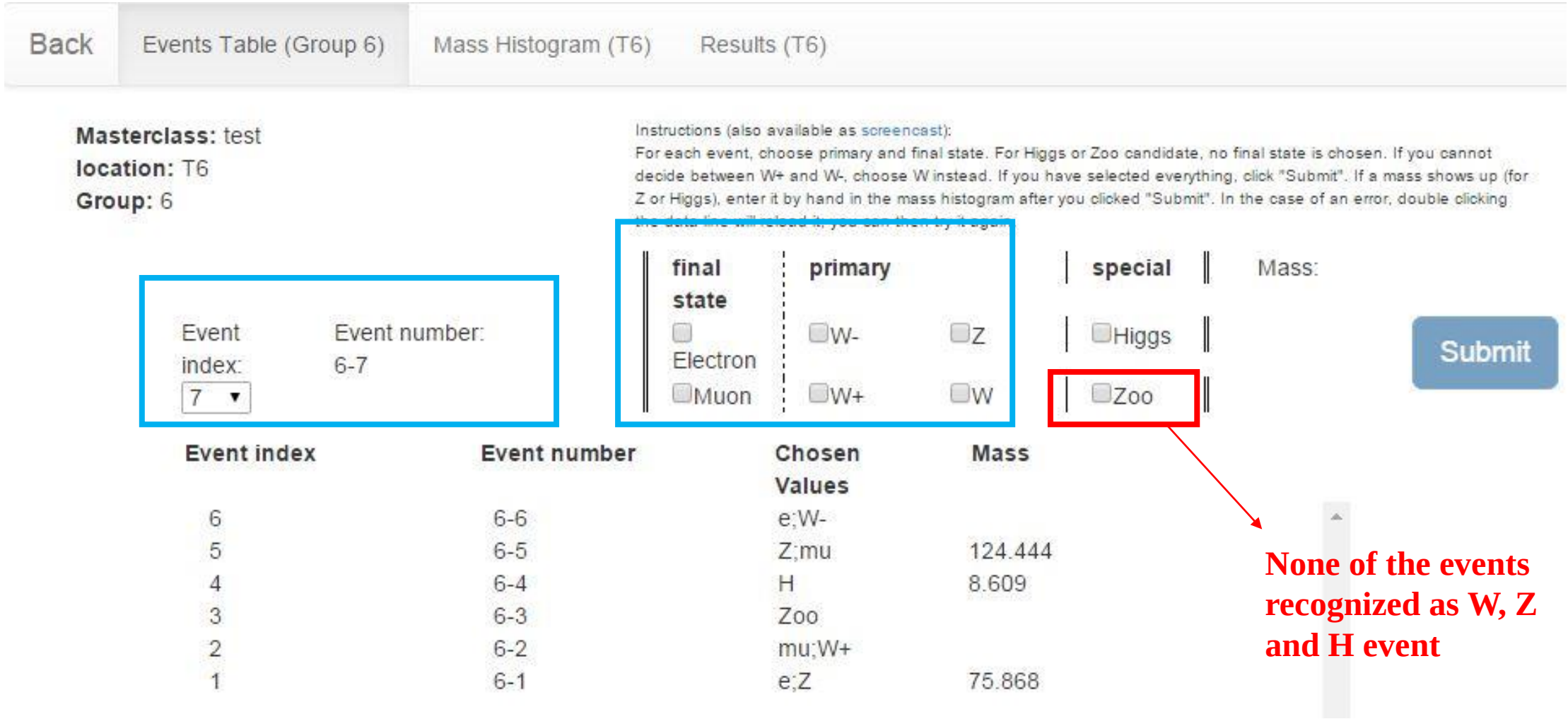
Charge → select (x-y) view and ‘’orthographic mode”



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

Thanks to https://quarknet.org/page/cms-masterclass-2016-documentation

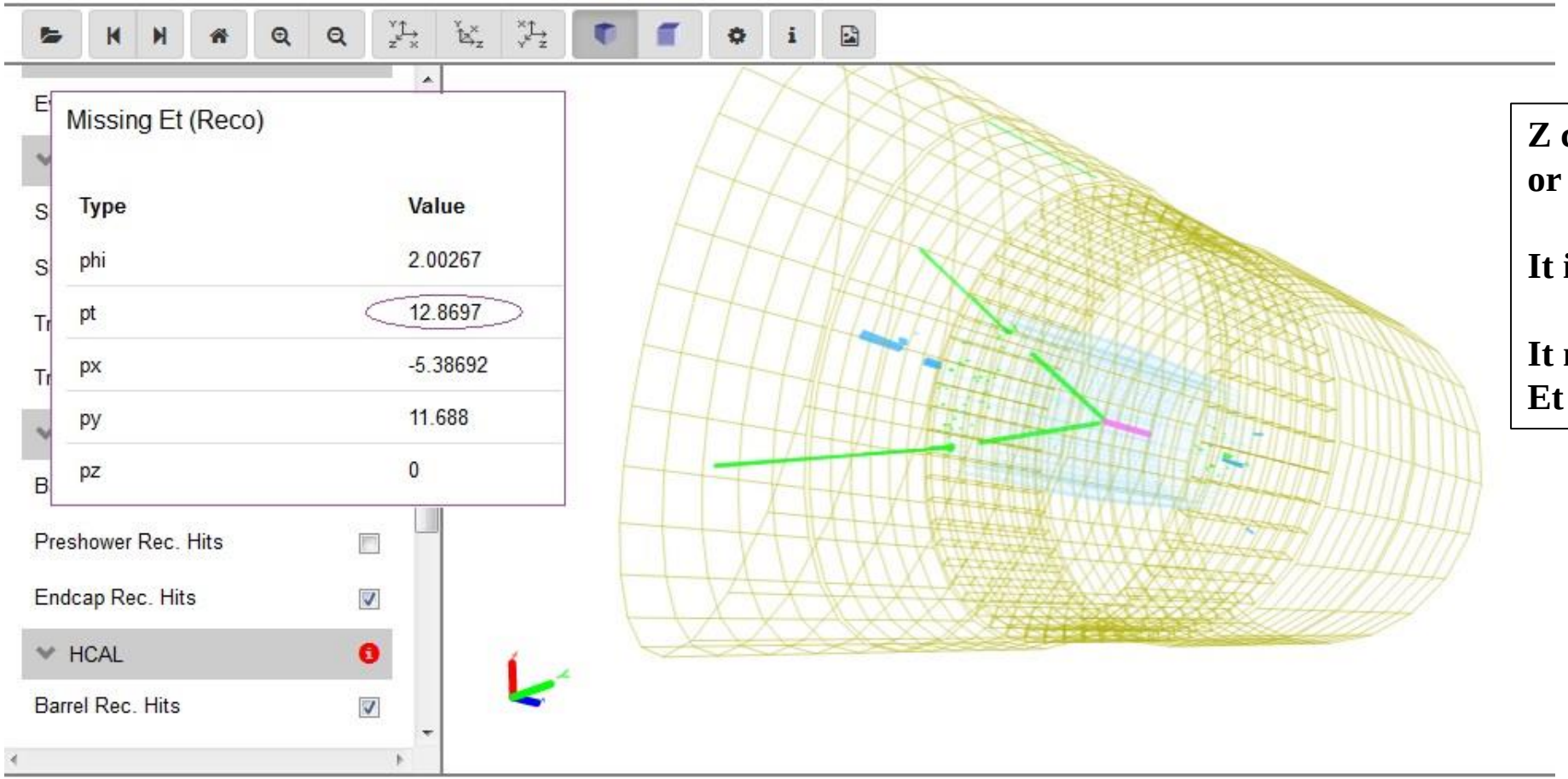
Fill in what kind of event you have just measured in the ‘’Events Table’’ on CIMA and then load next event



Thanks to https://quarknet.org/page/cms-masterclass-2016-documentation

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.

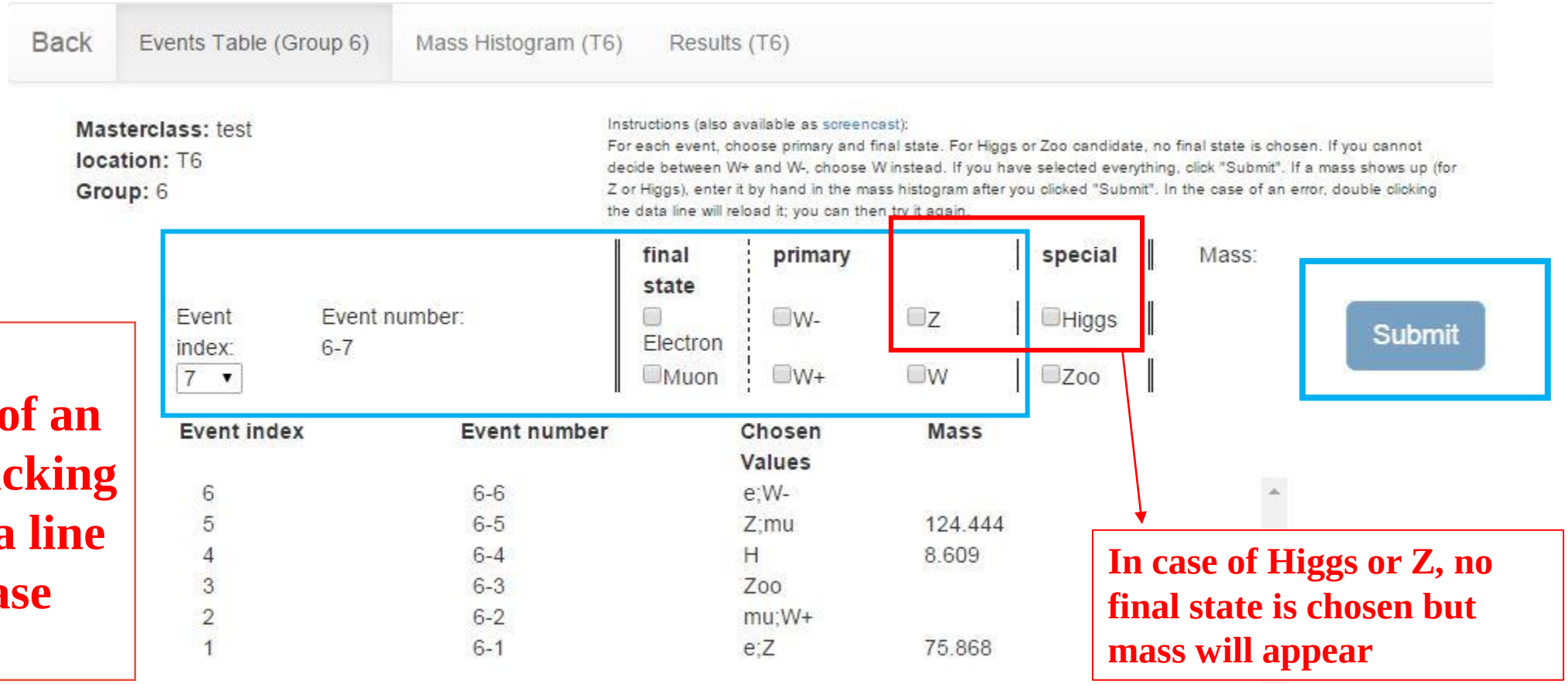
It is not always a Z candidate!

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

Thanks to https://quarknet.org/page/cms-masterclass-2016-documentation

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.



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

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 Histogra | Results

Masterclass: 3 Jan2015
location: Mexic

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	e/mu	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-.