

Ricerca delle particelle W , Z e H con il rivelatore CMS

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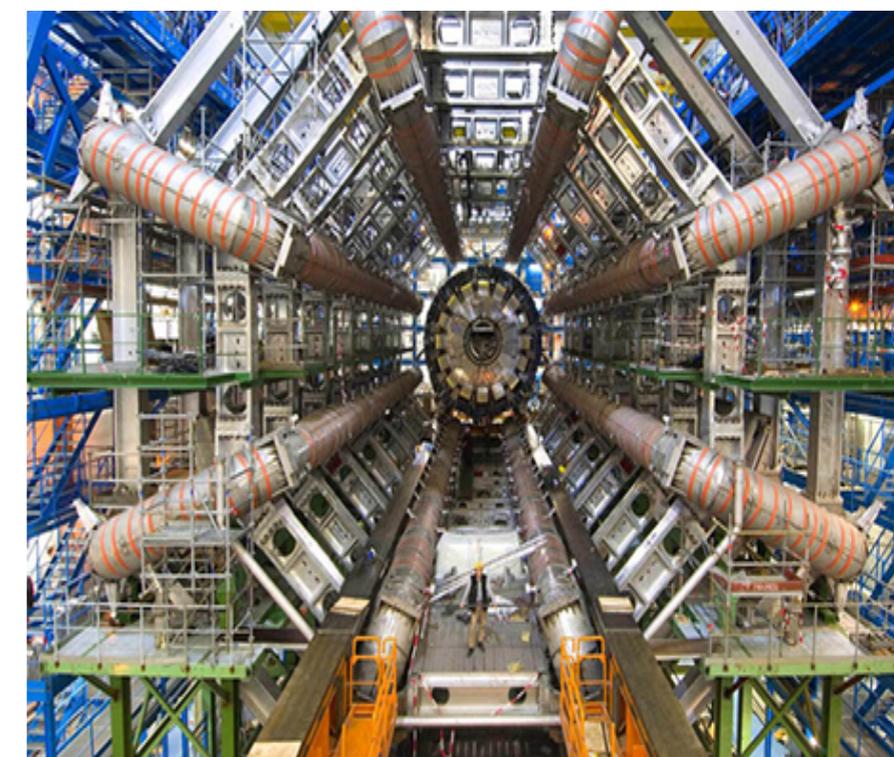
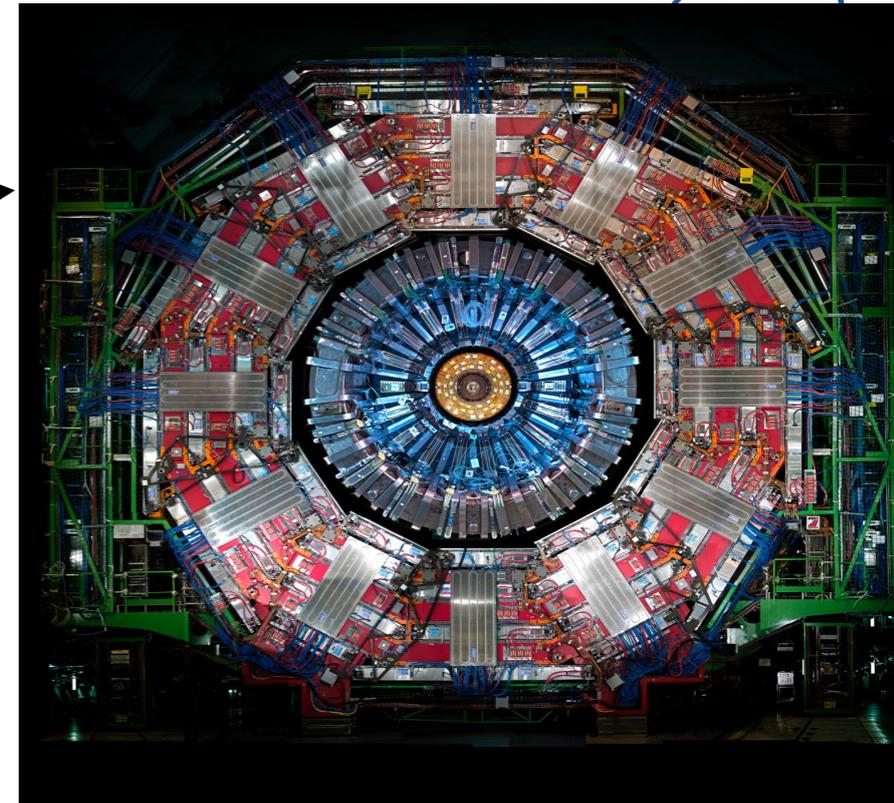
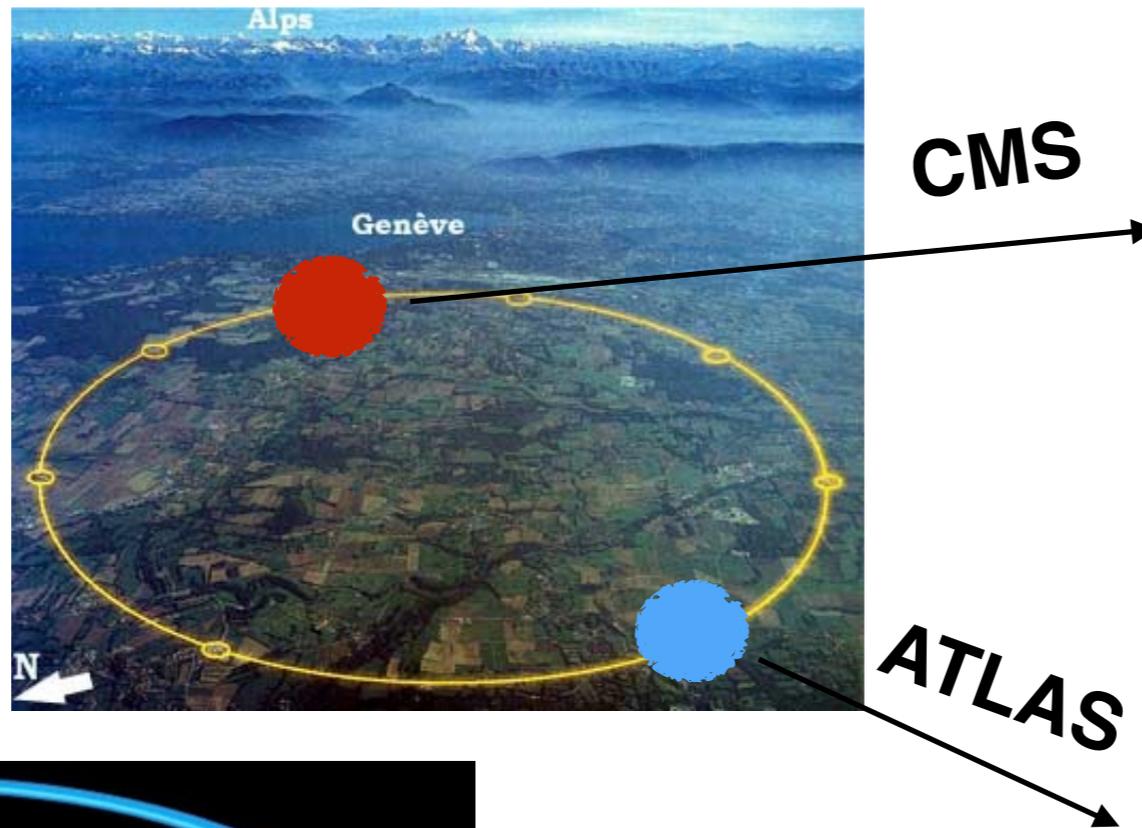
*Università di Trieste,
20-28 Febbraio 2018*

Il Large Hadron Collider (LHC)

visto dall'alto...

un anello sotterraneo di 30 Km al confine tra Francia e Svizzera

4 grandi esperimenti situati in quattro punti dell'anello



visto dal "basso"

I fisici accelerano dentro questo anello due "fasci" di protoni i protoni si scontrano in corrispondenza dei 4 grandi esperimenti

$$E = mc^2$$

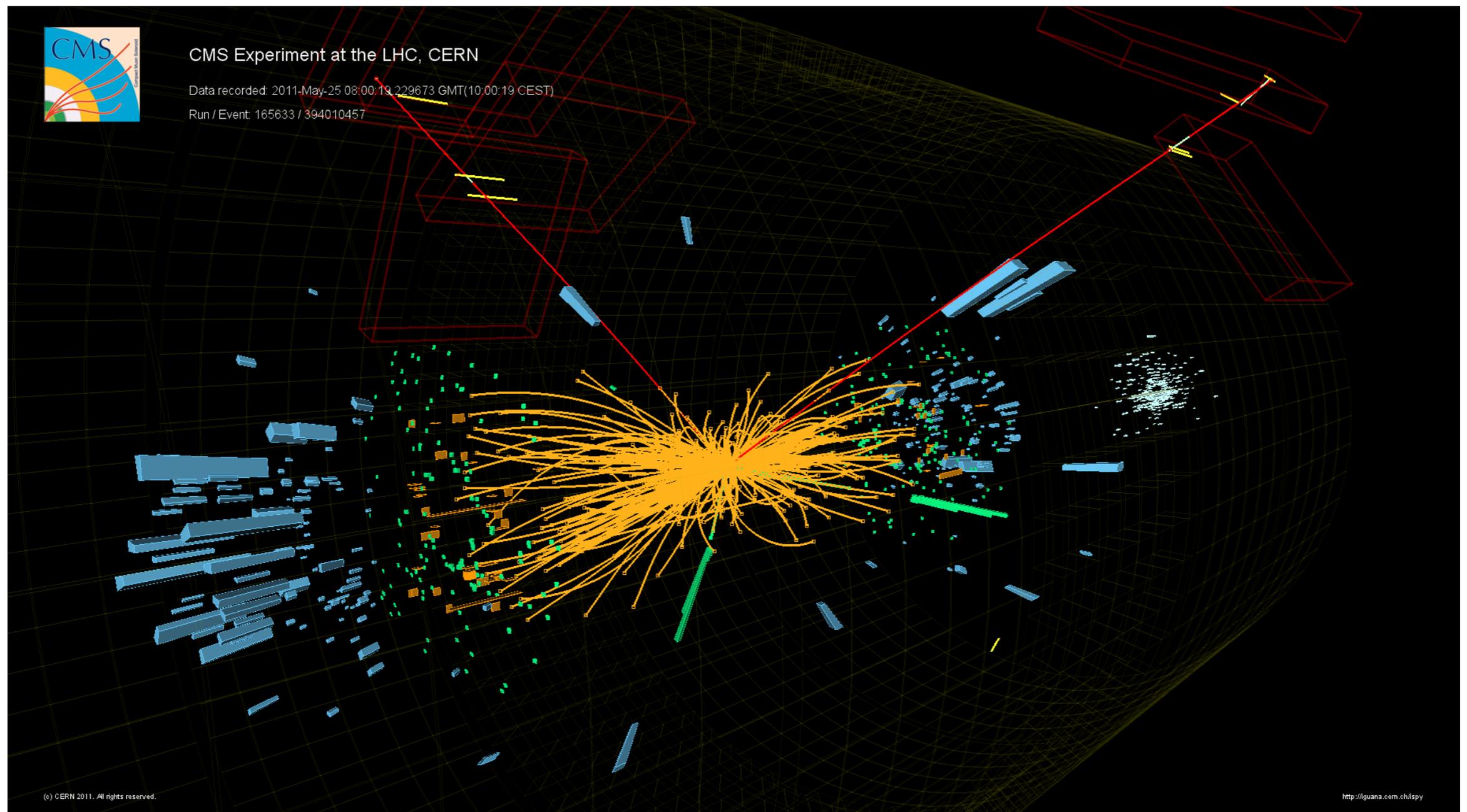
all'opera

velocita' dei protoni dentro l'anello:
99.999% c

dalla collisione si sprigiona una enorme quantità di energia che ci appare sotto forma di decine di particelle conosciute o sconosciute...

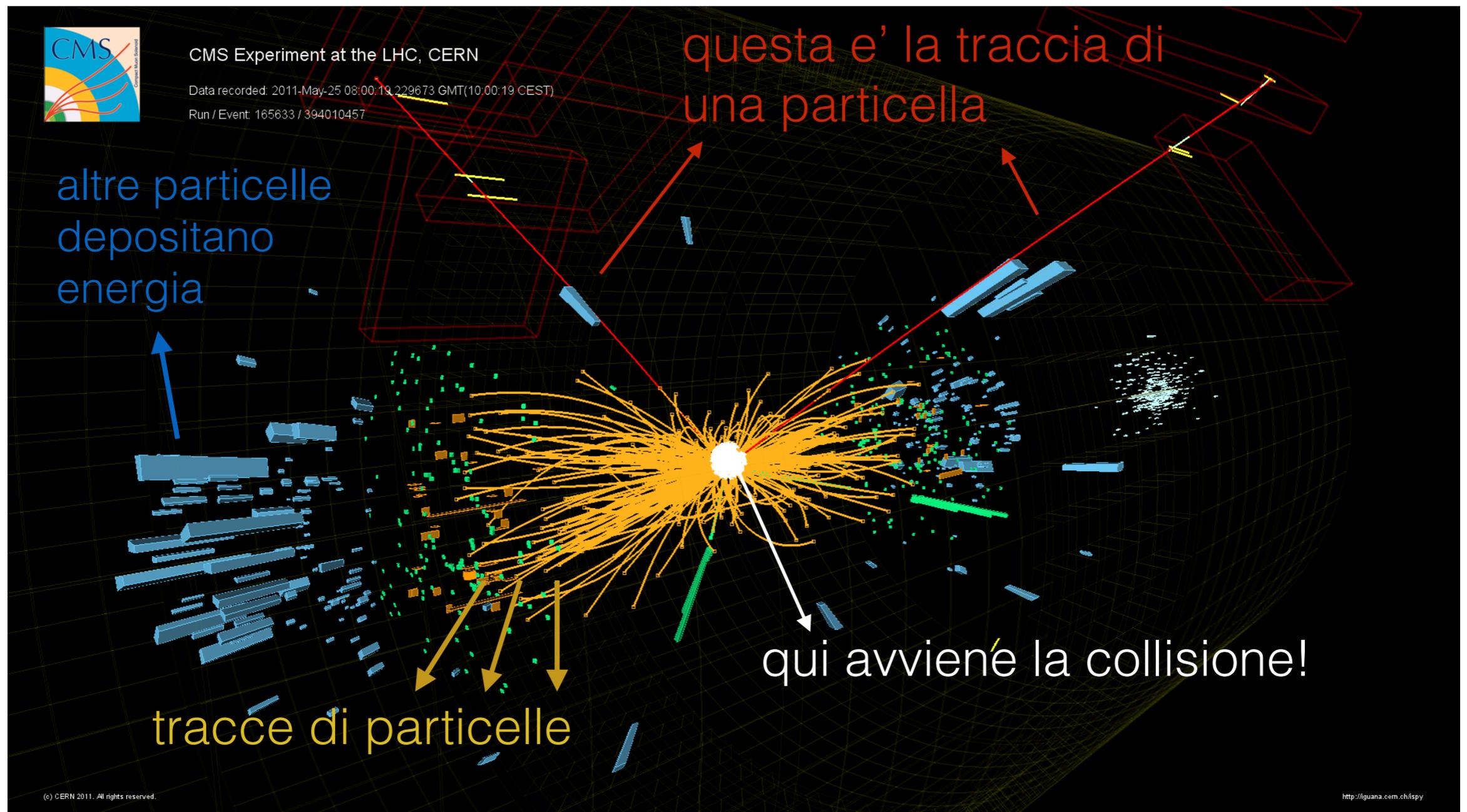
Cosa sono gli *Eventi* in CMS

L'esperimento CMS e' come una gigantesca macchina fotografica: ogni volta che i protoni collidono dentro LHC, CMS "fotografa" il risultato dello scontro: le particelle prodotte vengono poi catturate e misurate dagli apparati interni dell'esperimento



Cosa sono gli *Eventi* in CMS

L'esperimento CMS e' come una gigantesca macchina fotografica: ogni volta che i protoni collidono dentro LHC, CMS "fotografa" il risultato dello scontro: le particelle prodotte vengono poi catturate e misurate dagli apparati interni dell'esperimento



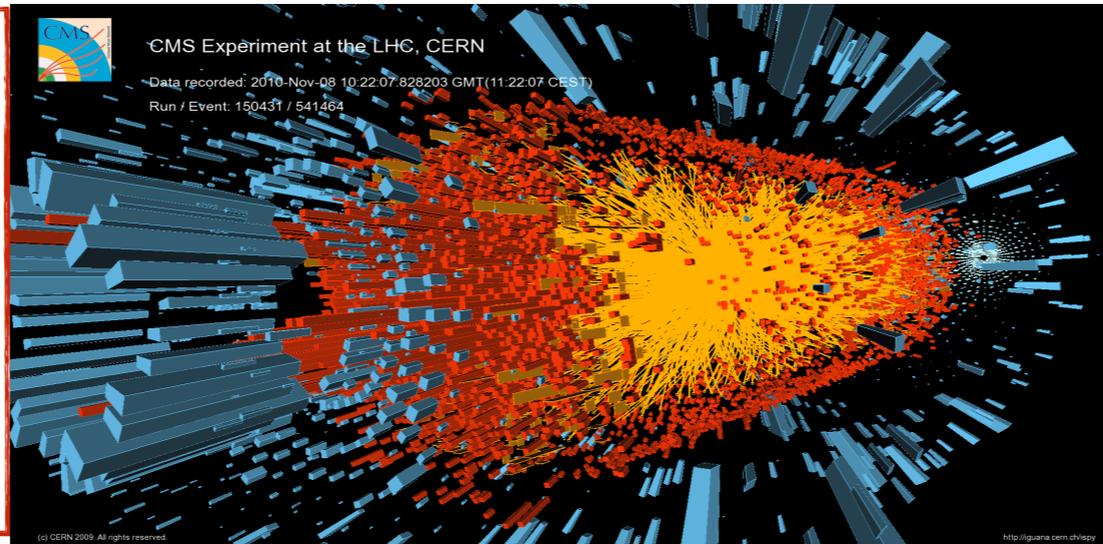
Questo e' un evento! ...ma quanti eventi ci sono? sono tutti interessanti?

L'esito delle collisioni dei fasci di protoni di LHC è casuale!

Non sappiamo cosa la Natura ci nasconde, ma potrebbe manifestarsi in eventi molto rari

100.000 milioni di protoni
"impacchettati" in $64 \mu\text{m}$

(1 milionesimo di metro,
pari allo spessore di un
capello umano!)



I pacchetti di protoni si
incrociano ogni 25 ns
(1 miliardesimo di
secondo)

spesso ci troviamo con
600 milioni di collisioni
al secondo

-> 600 milioni di eventi!

Quali eventi selezionare?

aka: come funziona la ricerca delle particelle in pratica:

(freccetta = decade)

particella madre → **particella figlia 1** + **particella figlia 2** + **particella figlia 3** + **particella figlia 4...**

(quella interessante,
pesante, un bosone ad
esempio)

(piu' leggera, piu' conosciuta,
un elettrone per esempio, che
sappiamo misurare)

(altre particelle leggere che
sappiamo misurare, neutrini,
muoni...)

Oggi avremo 100 eventi di CMS da analizzare: vogliamo tra tutti questi identificare i bosoni W^+ , W^- , Z , H tramite i loro decadimenti

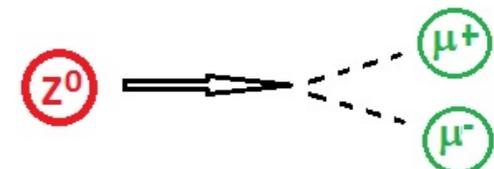
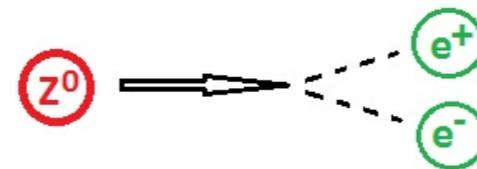
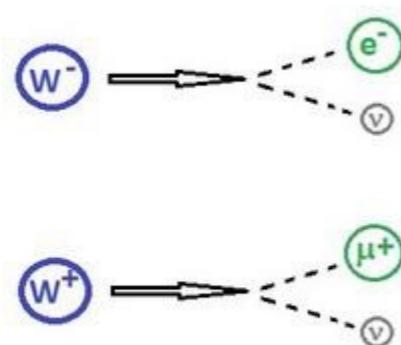
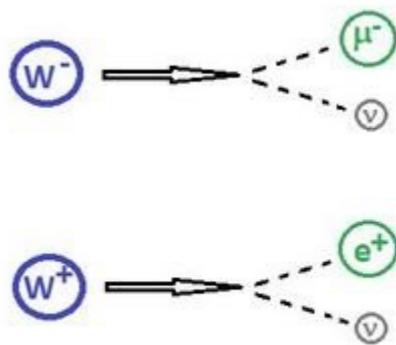
particella madre \longrightarrow particella figlia 1 + particella figlia 2 + particella figlia 3 + particella figlia 4...

vediamo in dettaglio cosa dovreste trovare:

1) decadimento del W

2) decadimento dello Z

schema



processo

$$W^+ \rightarrow e^+ \nu_e$$

$$W^- \rightarrow e^- \bar{\nu}_e$$

$$W^- \rightarrow \mu^- \bar{\nu}_\mu$$

$$W^+ \rightarrow \mu^+ \nu_\mu$$

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

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

quanto

11%

11%

3%

3%

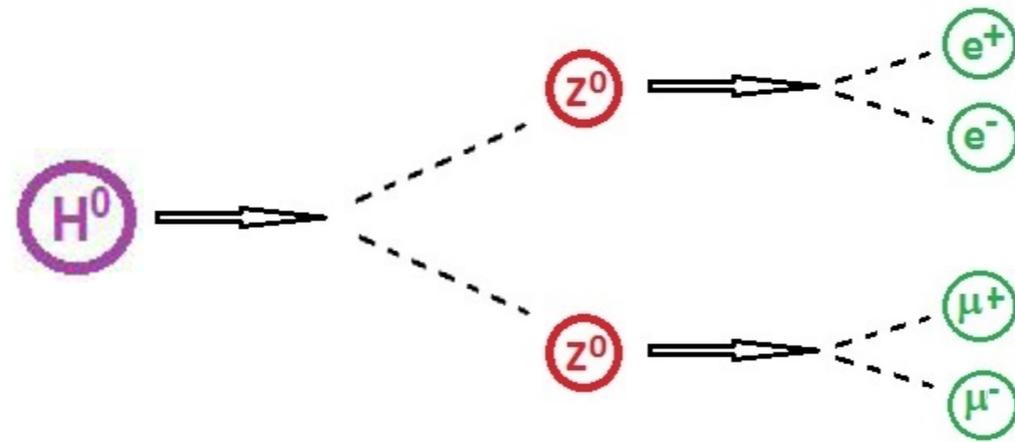
spesso?

3) decadimento del bosone di Higgs *coppie di bosoni Z*

$$H \rightarrow ZZ \rightarrow e^+e^-e^+e^-$$

$$H \rightarrow ZZ \rightarrow \mu^+\mu^-\mu^+\mu^-$$

$$H \rightarrow ZZ \rightarrow \mu^+\mu^-e^+e^-$$



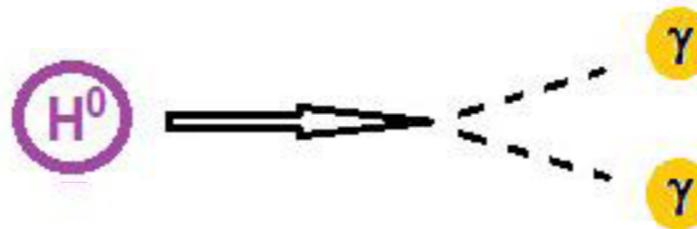
0.003%

0.003%

0.006%

3) decadimento del bosone di Higgs *coppie di fotoni*

$$H \rightarrow \gamma\gamma$$



0.3%

anche i fotoni sono bosoni!



ricerca dei *candidati*

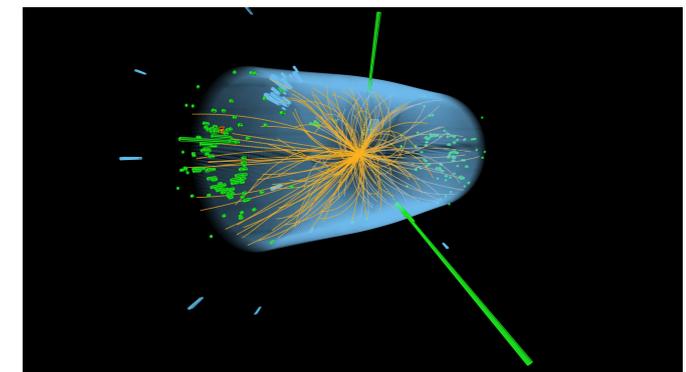
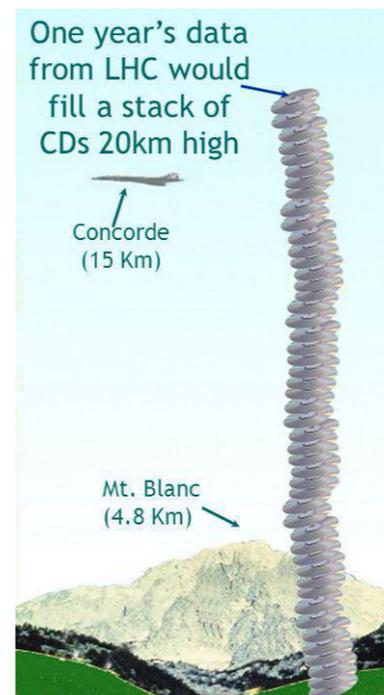
candidati: vogliamo identificare W/Z/H ma in realta' identifichiamo le particelle figlie, non e' garantito che prendiamo le figlie giuste!

come si fa?

- 1) individuare le caratteristiche del processo cercato **es. : due elettroni di carica opposta**
- 2) stabilire a priori un set di criteri oggettivi di selezione **es. : contare gli elettroni con carica +**
- 3) applicare questi criteri a tutti gli eventi disponibili **e' fondamentale non modificare i criteri!**

nella realtà

La ricerca che voi farete "a mano" su 100 eventi, in genere la si fa in modo computerizzato su miliardi di eventi, ma la procedura è la stessa!

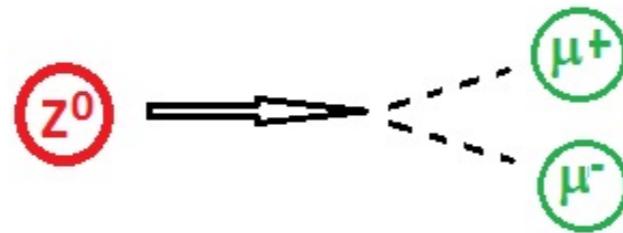


Le particelle instabili decadono immediatamente in particelle più leggere (particelle figlie) prima di poter essere rivelate.

Sfruttando le leggi di conservazione (impulso, energia, carica elettrica ...), è possibile determinare le caratteristiche e il tipo ("ricostruire") della particella instabile a partire dalle particelle figlie!



Un Esempio



carica dello $Z =$ somma cariche figlie:

$$Q = q_1 + q_2 = +1 - 1 = 0$$

impulso dello $Z =$ somma impulsi figlie

$$P = p_1 + p_2$$

massa della $Z =$...un po' piu' difficile

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

Leggi di Conservazione

carica iniziale = carica finale

impulso iniziale = impulso finale

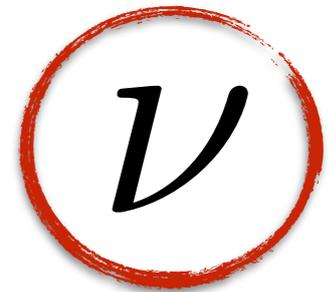
energia ("massa") iniziale = energia finale

Ricerca di Particelle II



carica iniziale = *carica* finale
impulso iniziale = *impulso* finale
energia ("massa") iniziale = *E* finale

**grandezze fisiche stato iniziale =
 grandezze fisiche stato finale**



FACT: about 65 million neutrinos pass through your thumbnail every second.
 Learn Something New Every Day LSNE.com

Aggiungiamo altre due grandezze, utili per misurare in particolare i **neutrini**

I neutrini sono elusivi: non lasciano tracce, non interagiscono e non hanno carica elettrica... **come identificarli?**
 Ci servirà per scoprire il $W \rightarrow e\nu$

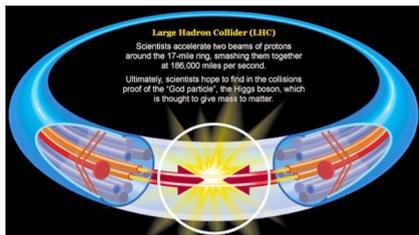
“energia mancante (missing energy)”

**stato iniziale
 prima**

conosco
 l'energia!



collisione



**stato finale
 dopo**

neutrino



energia
 mancante

particelle figlie prodotte

non conosco
 il momento/energia!

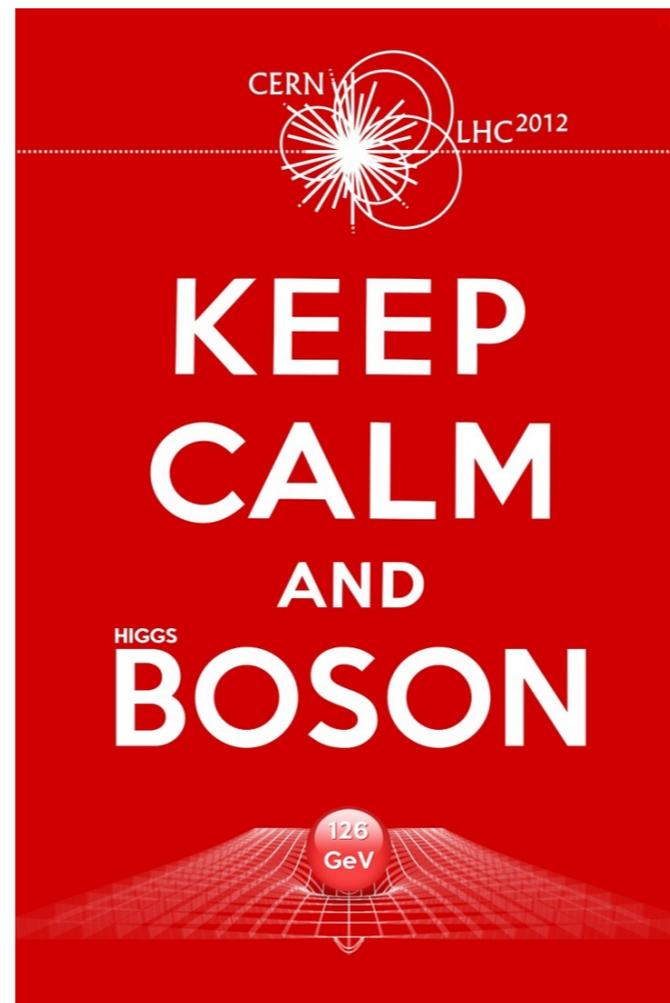
ma lo ricavo con
 $E_i = E_1 + E_2 + \dots$



ricavo quello mancante,
 che e' il neutrino!

Una Galleria di Eventi

Per finire... una carrellata di eventi W , Z , H
“visti” da CMS usando il programma che
utilizzerete oggi pomeriggio



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

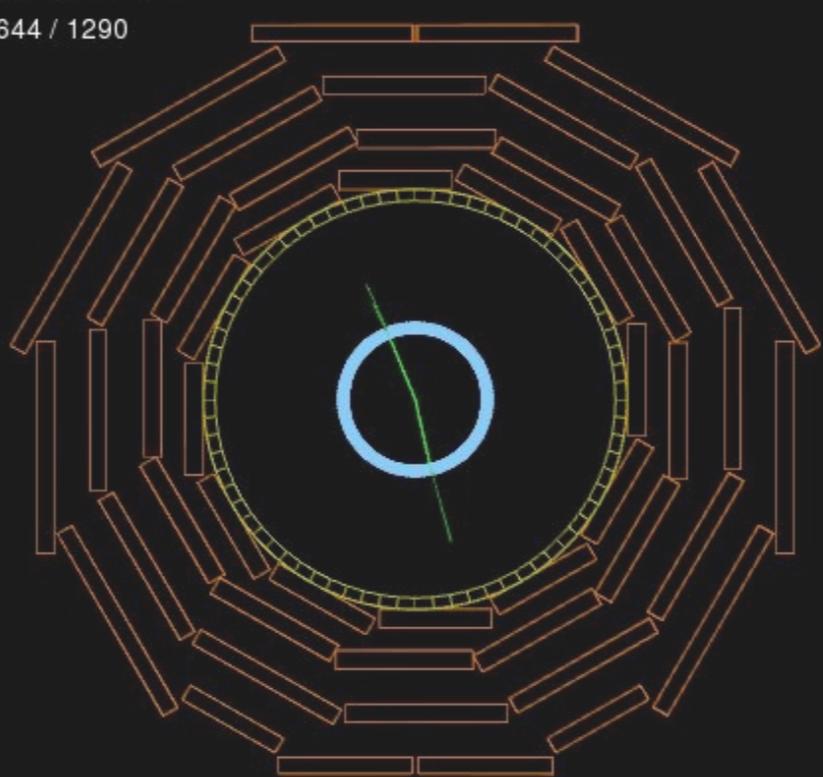
iSpy WebGL CIMA

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

iSpy WebGL masterclass_99.ig:Events/Run_99/Event_2 [2 of 100]

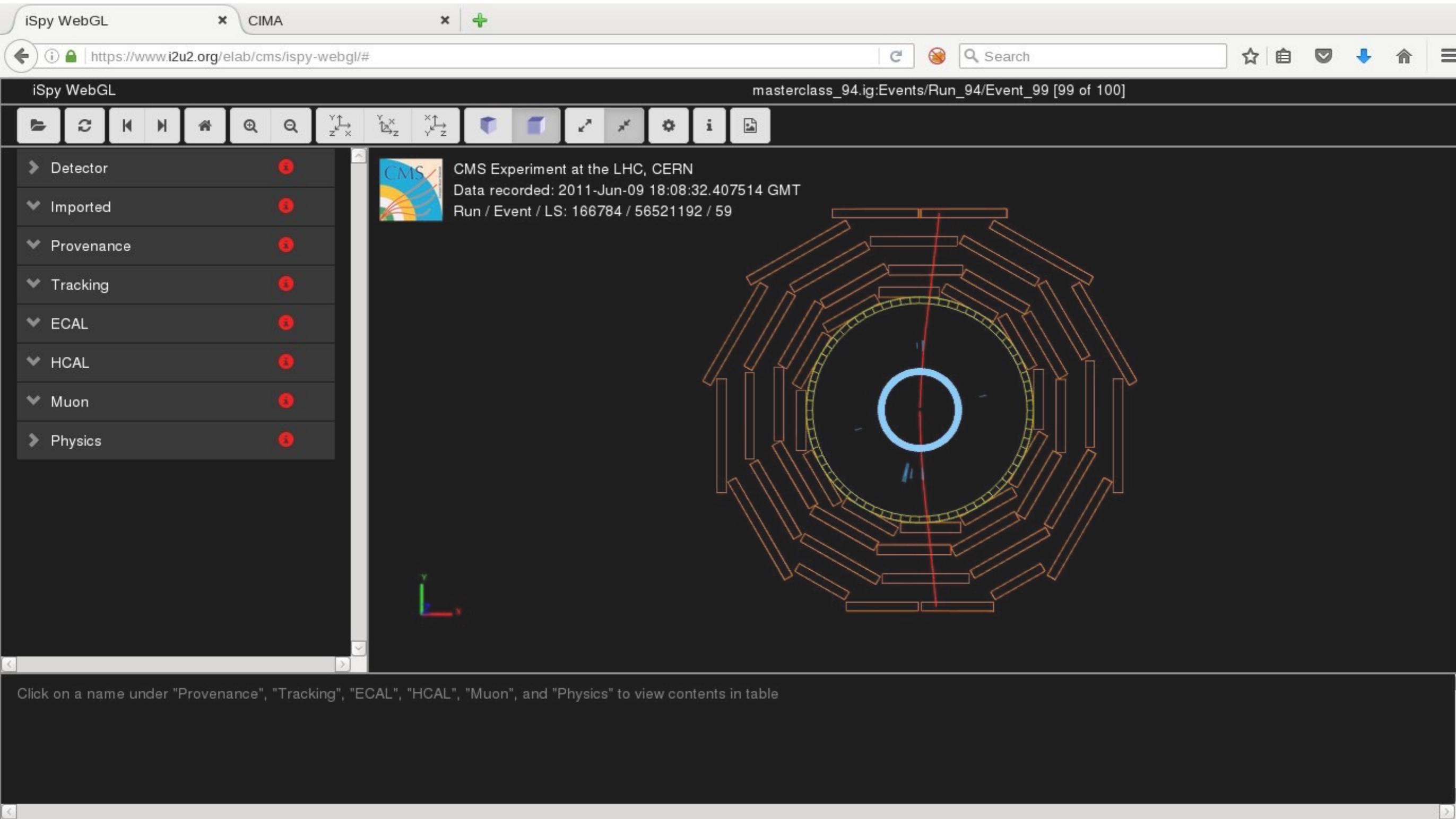
Detector Imported Provenance Tracking ECAL HCAL Muon Physics

CMS Experiment at the LHC, CERN
Data recorded: 2011-Jun-05 15:33:11.085209 GMT
Run / Event / LS: 166512 / 1457273644 / 1290



Click on a name under "Provenance", "Tracking", "ECAL", "HCAL", "Muon", and "Physics" to view contents in table

Candidato Candidato $Z \rightarrow \mu^+ \mu^-$



The screenshot shows a web browser window with the URL `https://www.i2u2.org/elab/cms/ispy-webgl/#`. The browser tabs are labeled "iSpy WebGL" and "CIMA". The page title is "iSpy WebGL" and the address bar shows "masterclass_94.ig:Events/Run_94/Event_99 [99 of 100]".

The interface includes a toolbar with navigation and interaction tools. On the left, a sidebar lists detector components: Detector, Imported, Provenance, Tracking, ECAL, HCAL, Muon, and Physics. Each item has a red information icon.

The main display area shows a 3D reconstruction of the CMS detector. A red line represents the Z boson decay path, and a blue circle highlights the muon pair production vertex. The detector is shown in a top-down view with a coordinate system (x, y, z) at the bottom left.

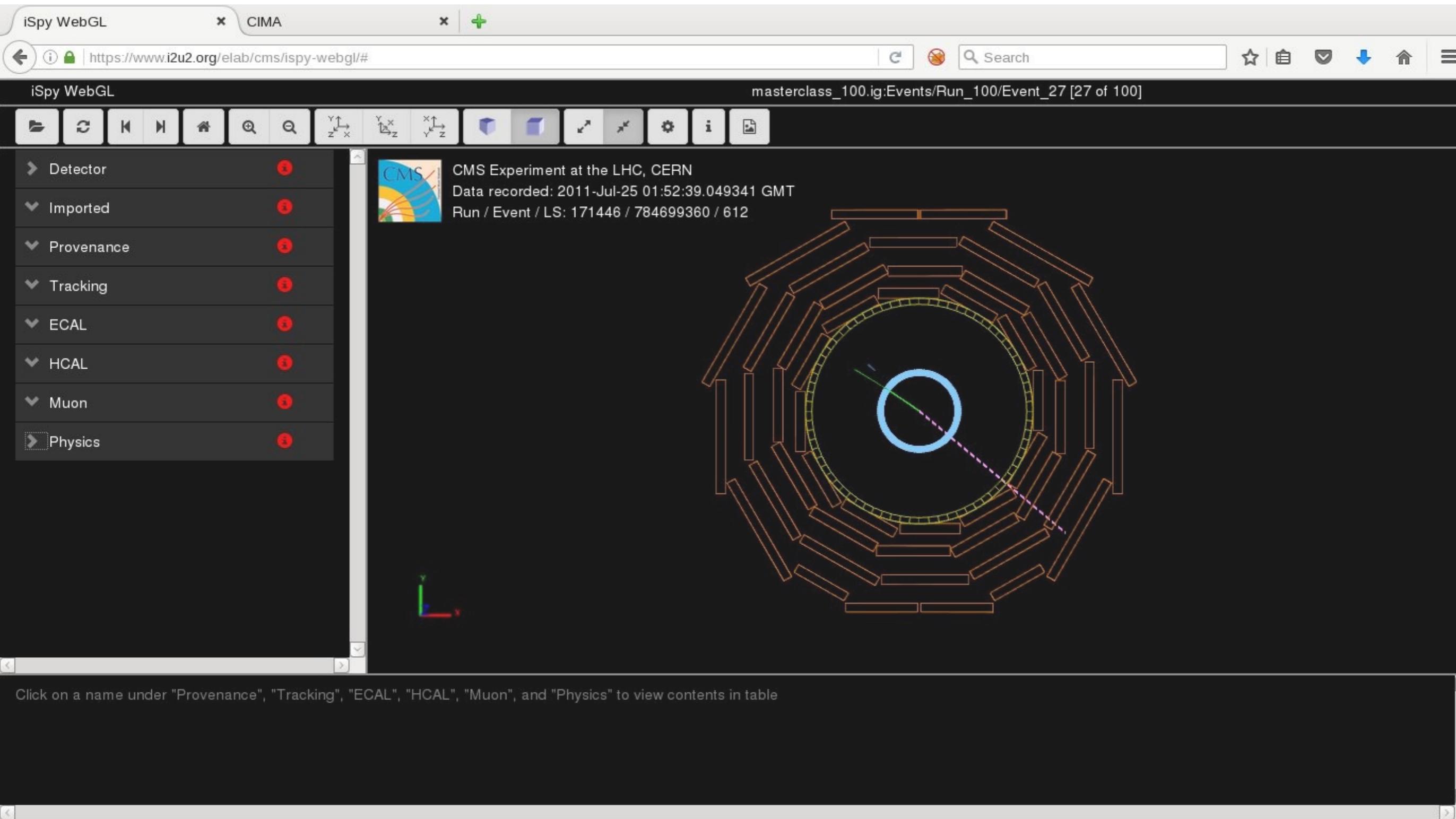
Metadata displayed in the top right of the main area:

- CMS Experiment at the LHC, CERN
- Data recorded: 2011-Jun-09 18:08:32.407514 GMT
- Run / Event / LS: 166784 / 56521192 / 59

A small 3D coordinate system is visible in the bottom left corner of the main display area.

Click on a name under "Provenance", "Tracking", "ECAL", "HCAL", "Muon", and "Physics" to view contents in table

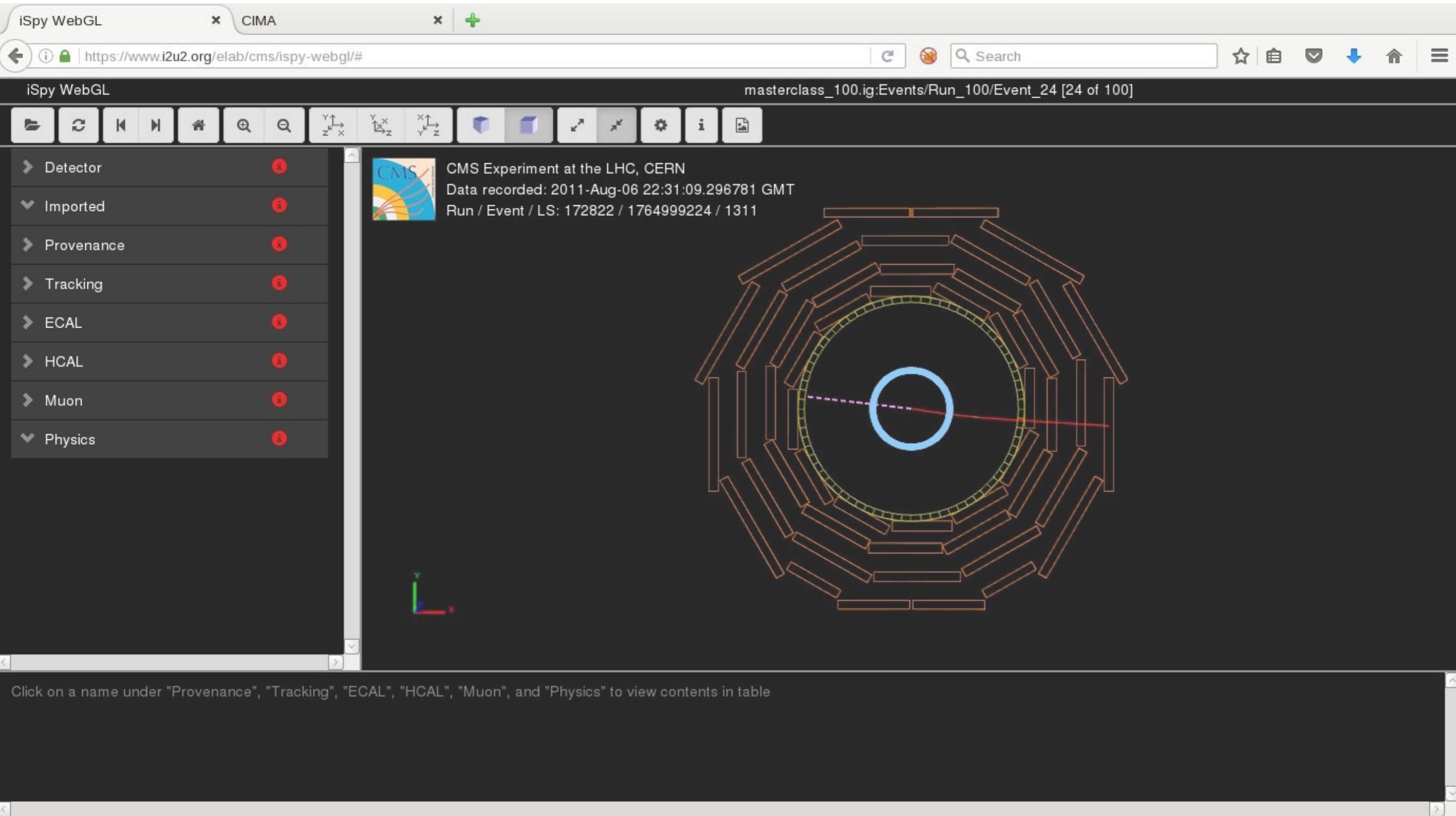
Candidato Candidato $W^+ \rightarrow e^+ \nu$



The screenshot shows a web browser window with the URL `https://www.i2u2.org/elab/cms/ispy-webgl/#`. The browser tabs are labeled "iSpy WebGL" and "CIMA". The address bar contains a search field and navigation icons. The main content area displays the iSpy WebGL interface for a CMS event. The top bar shows "iSpy WebGL" and "masterclass_100.ig:Events/Run_100/Event_27 [27 of 100]". Below this is a toolbar with various icons for navigation and interaction. On the left, a sidebar lists categories: Detector, Imported, Provenance, Tracking, ECAL, HCAL, Muon, and Physics, each with a red information icon. The main visualization area shows a top-down view of the CMS detector, a large octagonal structure with a central blue circle and a green line. A small 3D coordinate system is visible in the bottom left corner. A text box in the top left of the visualization area provides event details: "CMS Experiment at the LHC, CERN", "Data recorded: 2011-Jul-25 01:52:39.049341 GMT", and "Run / Event / LS: 171446 / 784699360 / 612".

Click on a name under "Provenance", "Tracking", "ECAL", "HCAL", "Muon", and "Physics" to view contents in table

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



The screenshot displays the iSpy WebGL interface for the CMS experiment. The browser address bar shows the URL <https://www.i2u2.org/elab/cms/ispy-webgl/#>. The page title is "iSpy WebGL" and the current event is identified as "masterclass_100.ig:Events/Run_100/Event_24 [24 of 100]".

The interface includes a navigation sidebar on the left with the following categories and counts:

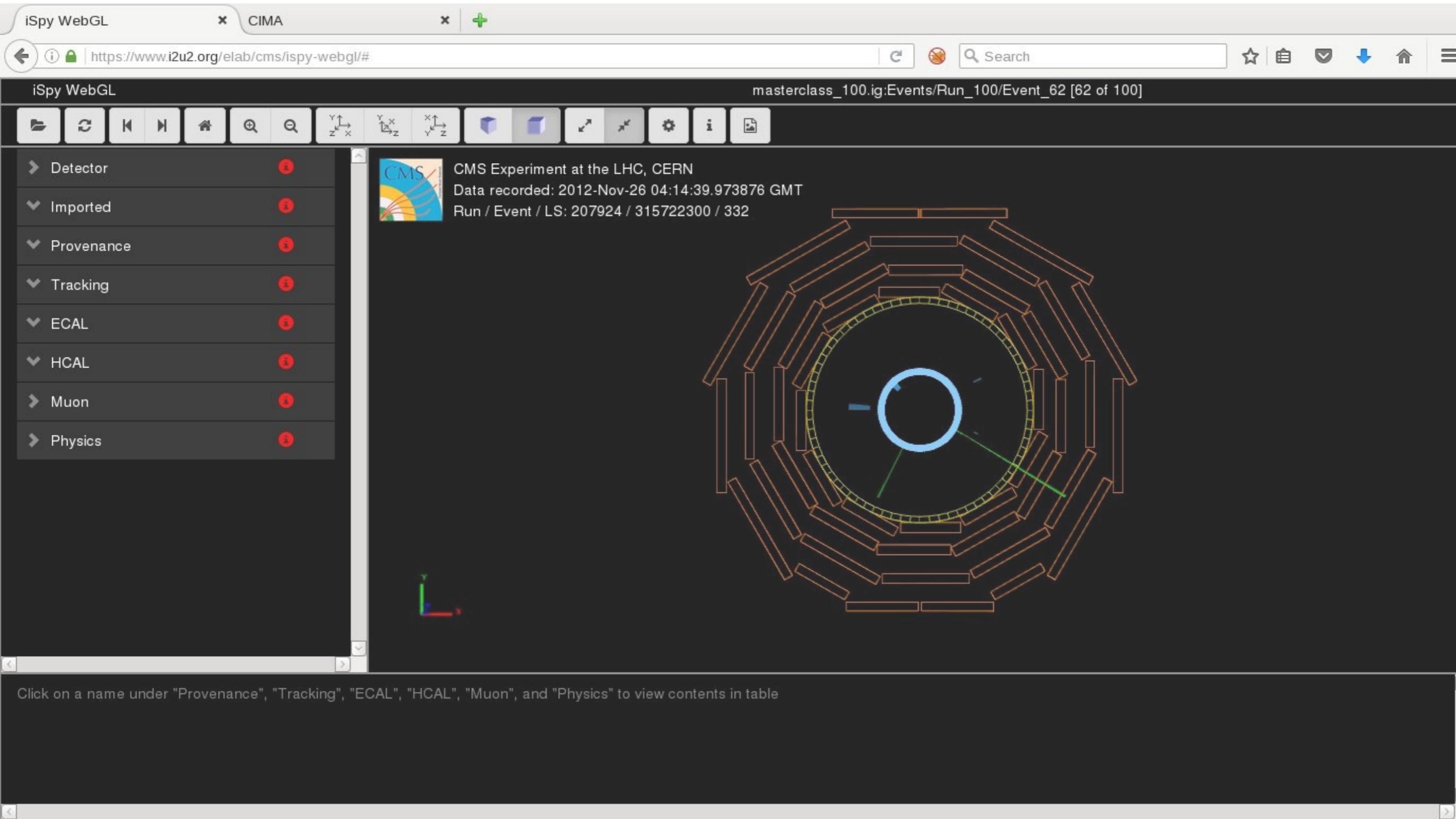
- Detector: 3
- Imported: 3
- Provenance: 3
- Tracking: 3
- ECAL: 3
- HCAL: 3
- Muon: 3
- Physics: 3

The main visualization area shows a 3D reconstruction of the CMS detector, which is a large cylindrical structure composed of many smaller components. A central blue circle represents the interaction point. A red line indicates the path of a muon, and a dashed purple line indicates the path of a neutrino. The event data is displayed in the top right corner:

CMS Experiment at the LHC, CERN
Data recorded: 2011-Aug-06 22:31:09.296781 GMT
Run / Event / LS: 172822 / 1764999224 / 1311

At the bottom of the interface, a message reads: "Click on a name under 'Provenance', 'Tracking', 'ECAL', 'HCAL', 'Muon', and 'Physics' to view contents in table".

Candidato $H \rightarrow \gamma\gamma$



The screenshot shows a web browser window with the URL `https://www.i2u2.org/elab/cms/ispy-webgl/#`. The browser tabs are labeled "iSpy WebGL" and "CIMA". The page title is "iSpy WebGL" and the address bar shows "masterclass_100.ig:Events/Run_100/Event_62 [62 of 100]".

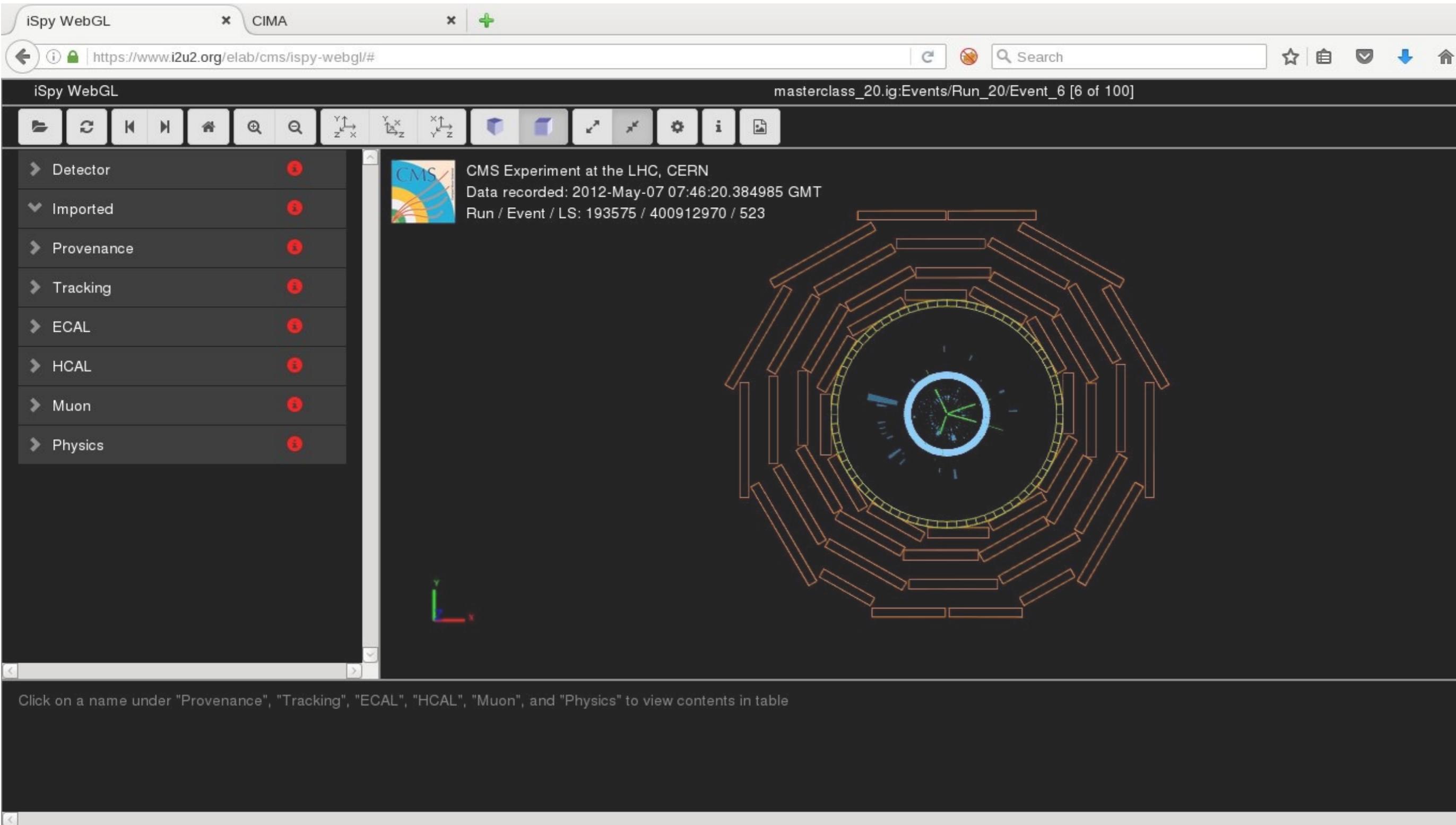
The interface includes a toolbar with navigation and interaction icons. On the left, a sidebar lists categories: Detector, Imported, Provenance, Tracking, ECAL, HCAL, Muon, and Physics, each with a red information icon. The main area displays a 3D visualization of the CMS detector, a large octagonal structure with a central blue circle and green lines. A small 3D coordinate system is visible in the bottom left of the main area.

Metadata information is displayed in the top left of the main area:

-  CMS Experiment at the LHC, CERN
- Data recorded: 2012-Nov-26 04:14:39.973876 GMT
- Run / Event / LS: 207924 / 315722300 / 332

A footer message reads: "Click on a name under 'Provenance', 'Tracking', 'ECAL', 'HCAL', 'Muon', and 'Physics' to view contents in table".

Candidato $H \rightarrow ZZ \rightarrow e^+e^-e^+e^-$



The screenshot shows a web browser window with the URL <https://www.i2u2.org/elab/cms/ispy-webgl/#>. The browser tabs are labeled "iSpy WebGL" and "CIMA". The page title is "iSpy WebGL" and the address bar shows "masterclass_20.ig:Events/Run_20/Event_6 [6 of 100]".

The interface includes a toolbar with various icons for navigation and visualization. On the left, there is a sidebar menu with the following items:

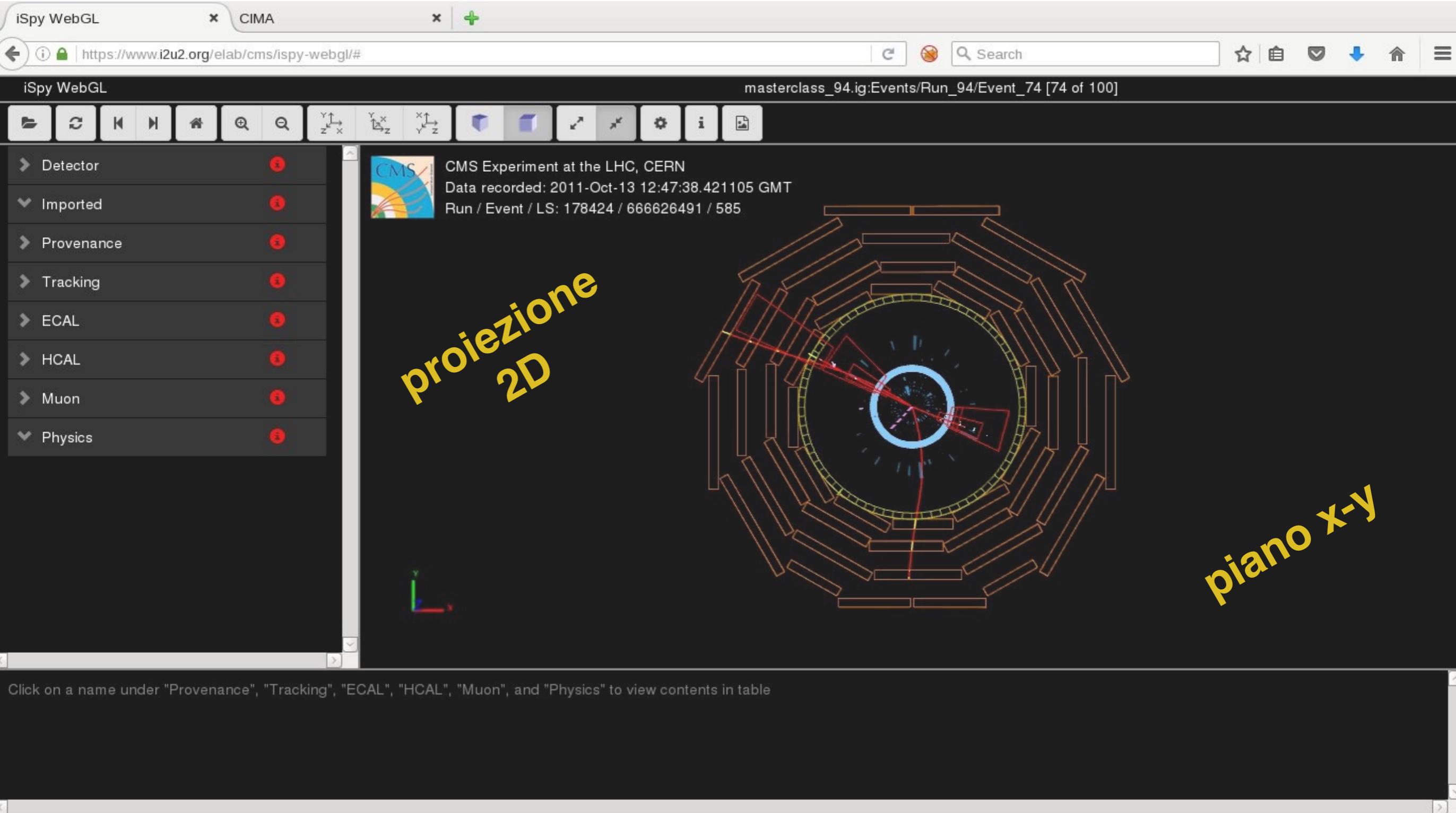
- Detector
- Imported
- Provenance
- Tracking
- ECAL
- HCAL
- Muon
- Physics

Each item in the sidebar has a red circular icon with a white 'i' next to it. The main content area displays a 3D visualization of the CMS detector, showing the central region with a blue circle and green lines, surrounded by the detector's structure. The text in the main area reads:

CMS Experiment at the LHC, CERN
Data recorded: 2012-May-07 07:46:20.384985 GMT
Run / Event / LS: 193575 / 400912970 / 523

At the bottom of the interface, there is a text instruction: "Click on a name under 'Provenance', 'Tracking', 'ECAL', 'HCAL', 'Muon', and 'Physics' to view contents in table".

Candidato $H \rightarrow ZZ \rightarrow \mu^+ \mu^- \mu^+ \mu^-$



iSpy WebGL CIMA

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

masterclass_94.ig:Events/Run_94/Event_74 [74 of 100]

Detector Imported Provenance Tracking ECAL HCAL Muon Physics

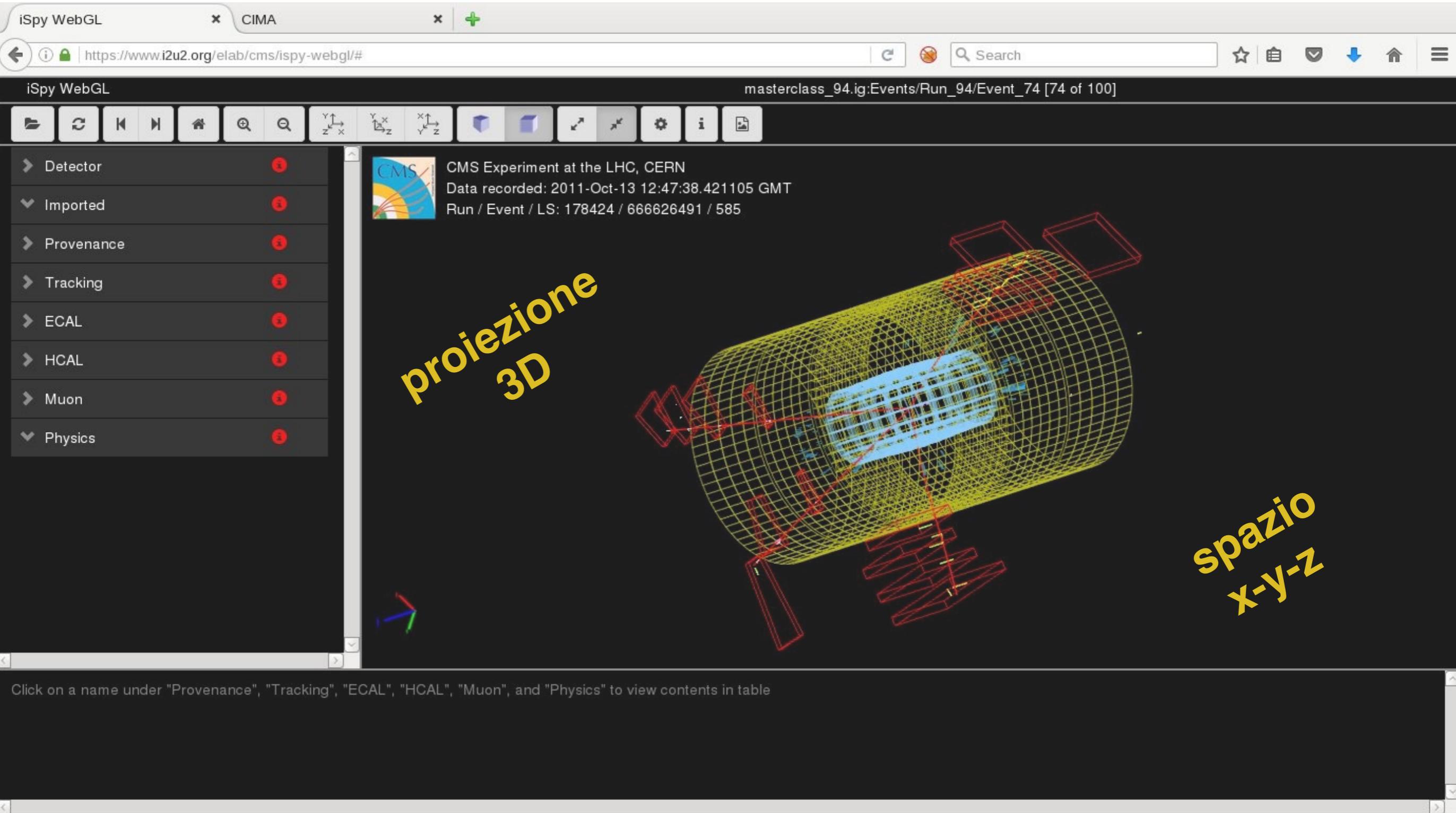
proiezione 2D

CMS Experiment at the LHC, CERN
Data recorded: 2011-Oct-13 12:47:38.421105 GMT
Run / Event / LS: 178424 / 666626491 / 585

piano x-y

Click on a name under "Provenance", "Tracking", "ECAL", "HCAL", "Muon", and "Physics" to view contents in table

Candidato $H \rightarrow ZZ \rightarrow \mu^+ \mu^- \mu^+ \mu^-$



iSpy WebGL CIMA

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

iSpy WebGL masterclass_94.ig:Events/Run_94/Event_74 [74 of 100]

Detector 3
Imported 3
Provenance 3
Tracking 3
ECAL 3
HCAL 3
Muon 3
Physics 3

CMS Experiment at the LHC, CERN
Data recorded: 2011-Oct-13 12:47:38.421105 GMT
Run / Event / LS: 178424 / 666626491 / 585

proiezione 3D

spazio x-y-z

Click on a name under "Provenance", "Tracking", "ECAL", "HCAL", "Muon", and "Physics" to view contents in table