



# Ricerca delle particelle $W$ , $Z$ e $H$ con il rivelatore CMS: istruzioni

Massimo Casarsa

*Sezione INFN di Trieste*

Trieste, 13 e 24 febbraio 2023



**1**

Identificazione del tipo di evento rivelato:

- ▶ identificare **elettroni** e **muoni** e capire lo stato finale;
- ▶ individuare i candidati  $W^-$ ,  $W^+$ ,  $Z^0$  o  $H^0$ .

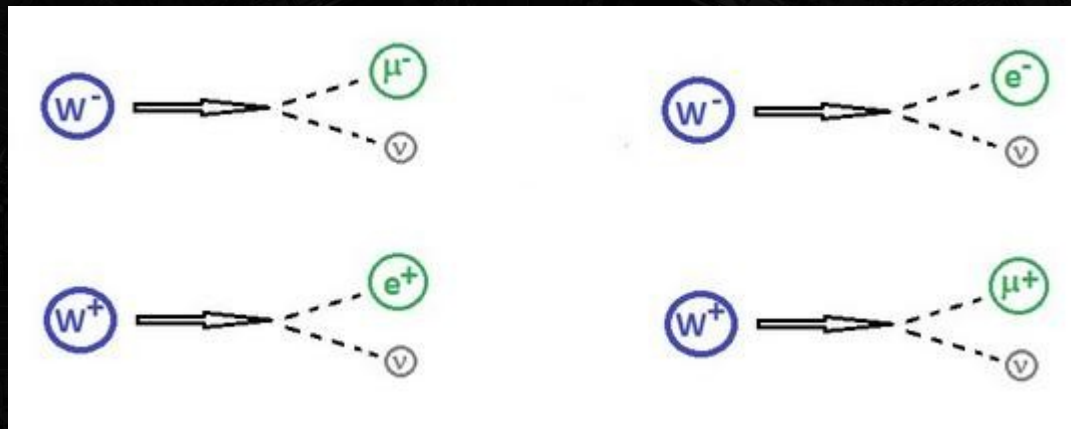
**2**

Misure da effettuare:

- ▶ nel caso dei candidati  $W^\pm$ :
  - ◆ distinguere i decadimenti delle  $W$  in elettroni da quelli in muoni e misurare il **rapporto  $e/\mu$** ;
  - ◆ distinguere  $W^+$  da  $W^-$  e misurare il **rapporto  $W^+/W^-$** ;
- ▶ nel caso di candidati  $Z^0$  e  $H^0$  (Neutral Particle):  
fare l'**istogramma di massa**.

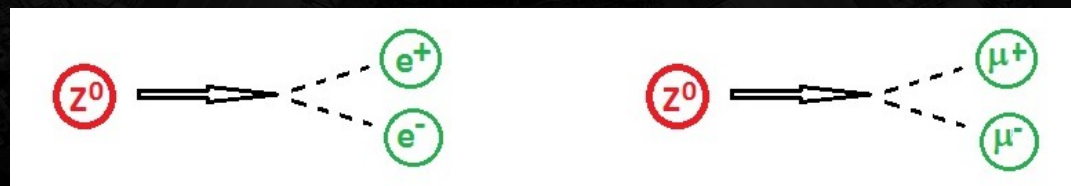
# Canali da cercare (I)

- I canali di decadimento di W, Z e H che voi cercherete sono:
  - ◆  $W^\pm \rightarrow e^\pm \nu_e$  (11%) e  $W^\pm \rightarrow \mu^\pm \nu_\mu$  (11%);



LHC produce  
circa 110000  
bosoni W l'ora

- ◆  $Z^0 \rightarrow e^+e^-$  (3%) e  $Z^0 \rightarrow \mu^+\mu^-$  (3%);

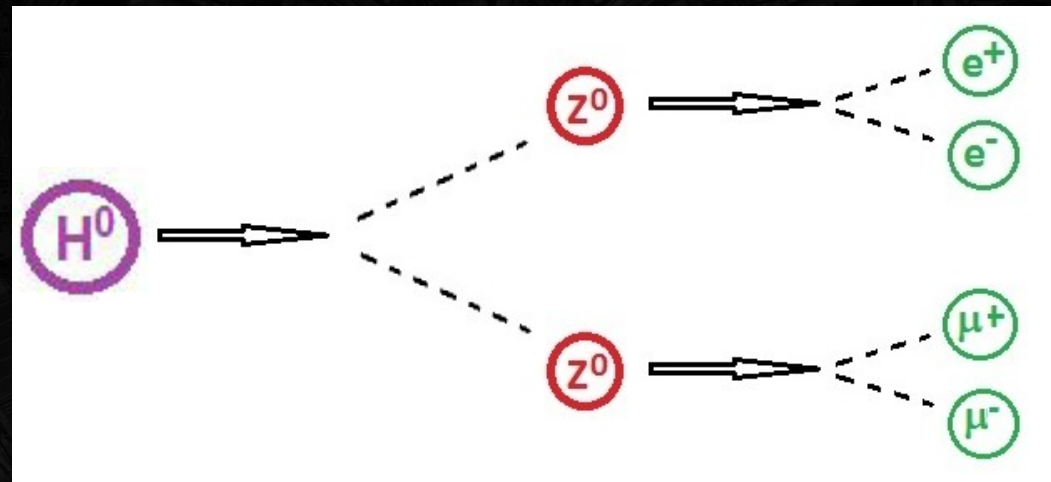


LHC produce  
circa 11000  
bosoni Z l'ora

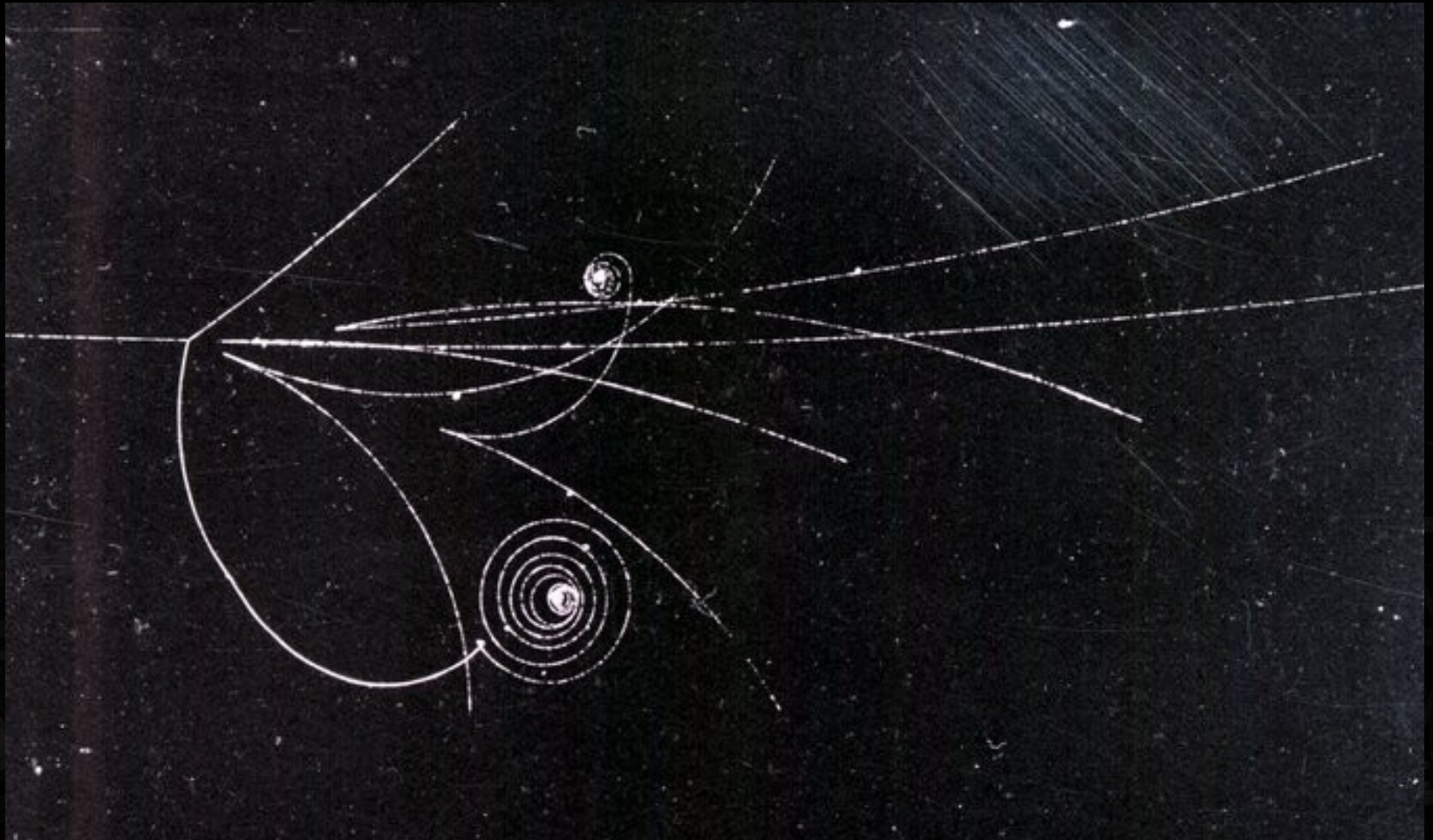
# Canali da cercare (II)

- ◆  $H^0 \rightarrow Z^0 Z^0 \rightarrow e^+ e^- e^+ e^-$  (0.003%),
- $H^0 \rightarrow Z^0 Z^0 \rightarrow \mu^+ \mu^- \mu^+ \mu^-$  (0.003%),
- $H^0 \rightarrow Z^0 Z^0 \rightarrow e^+ e^- \mu^+ \mu^-$  (0.006%).

LHC produce  
circa 2700  
bosoni H l'ora




- Il metodo di solito seguito consiste in:
  - ① individuare le caratteristiche peculiari del decadimento cercato, per esempio due elettroni di carica opposta;
  - ② stabilire a priori una serie di criteri oggettivi di selezione dei “candidati”, per esempio contare gli elettroni che hanno una certa carica;
  - ③ applicare sistematicamente tali criteri sull'insieme di eventi a disposizione.
  
- Due note:
  - ◆ Parliamo di “candidati” perché identifichiamo le  $Z^0$ ,  $W^\pm$  e  $H^0$  a partire dalle loro figlie, ma non è garantito che pigliamo sempre quelle giuste, in realtà scegliamo dei potenziali  $Z^0$ ,  $W^\pm$  o  $H^0$ .
  - ◆ 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.
  
- Una distinzione:
  - ◆ nel caso delle  $Z^0$  e  $H^0$  è possibile ricostruirne la massa a partire dalle masse e dai momenti misurati delle particelle figlie;
  - ◆ ciò non si può fare nel caso della  $W^\pm$  a causa del neutrino non rivelato.

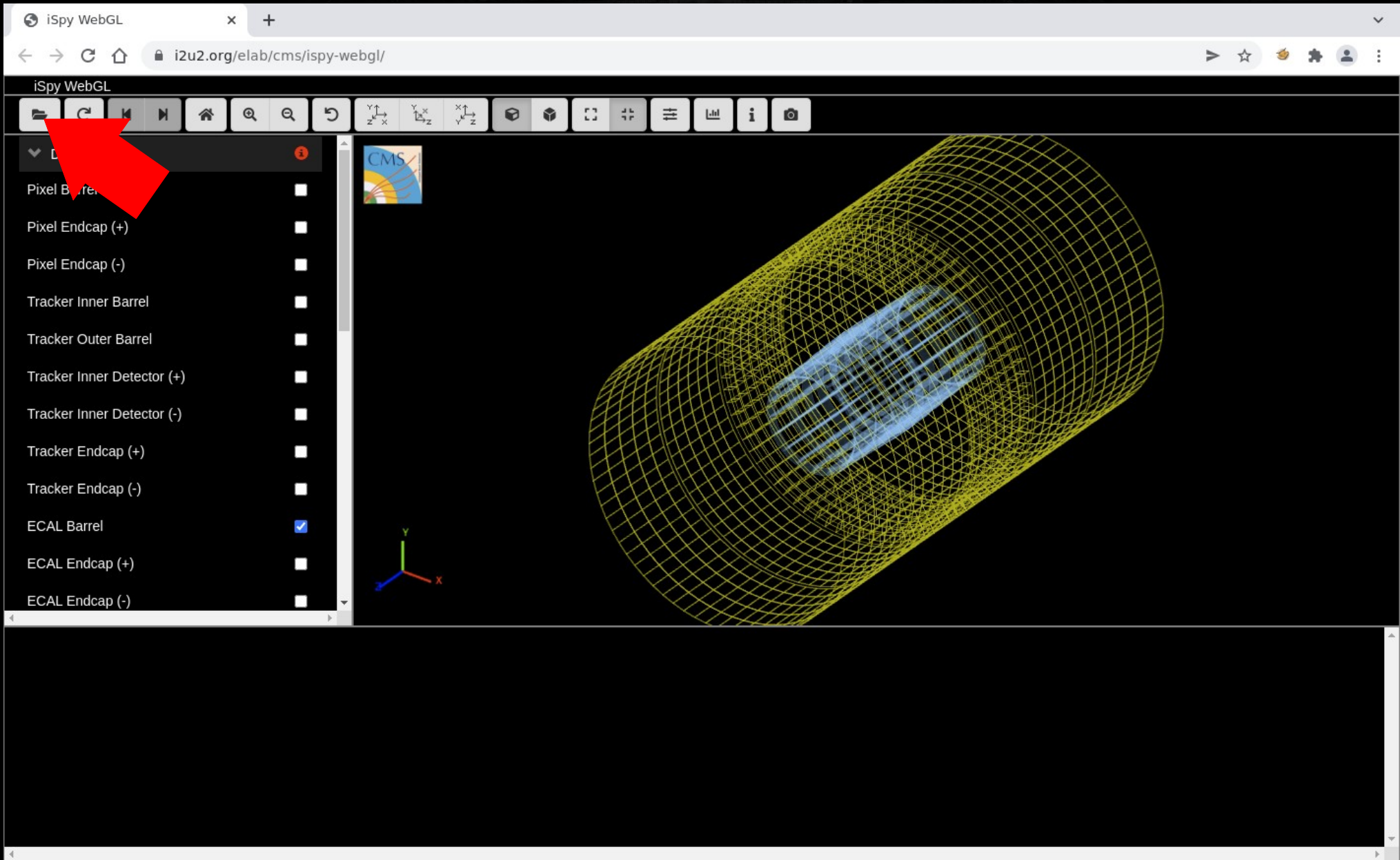


Fino alla fine degli anni '70 i fisici delle particelle eseguivano regolarmente analisi "visuali" simili alla vostra sulle fotografie scattate nelle camere a bolle.

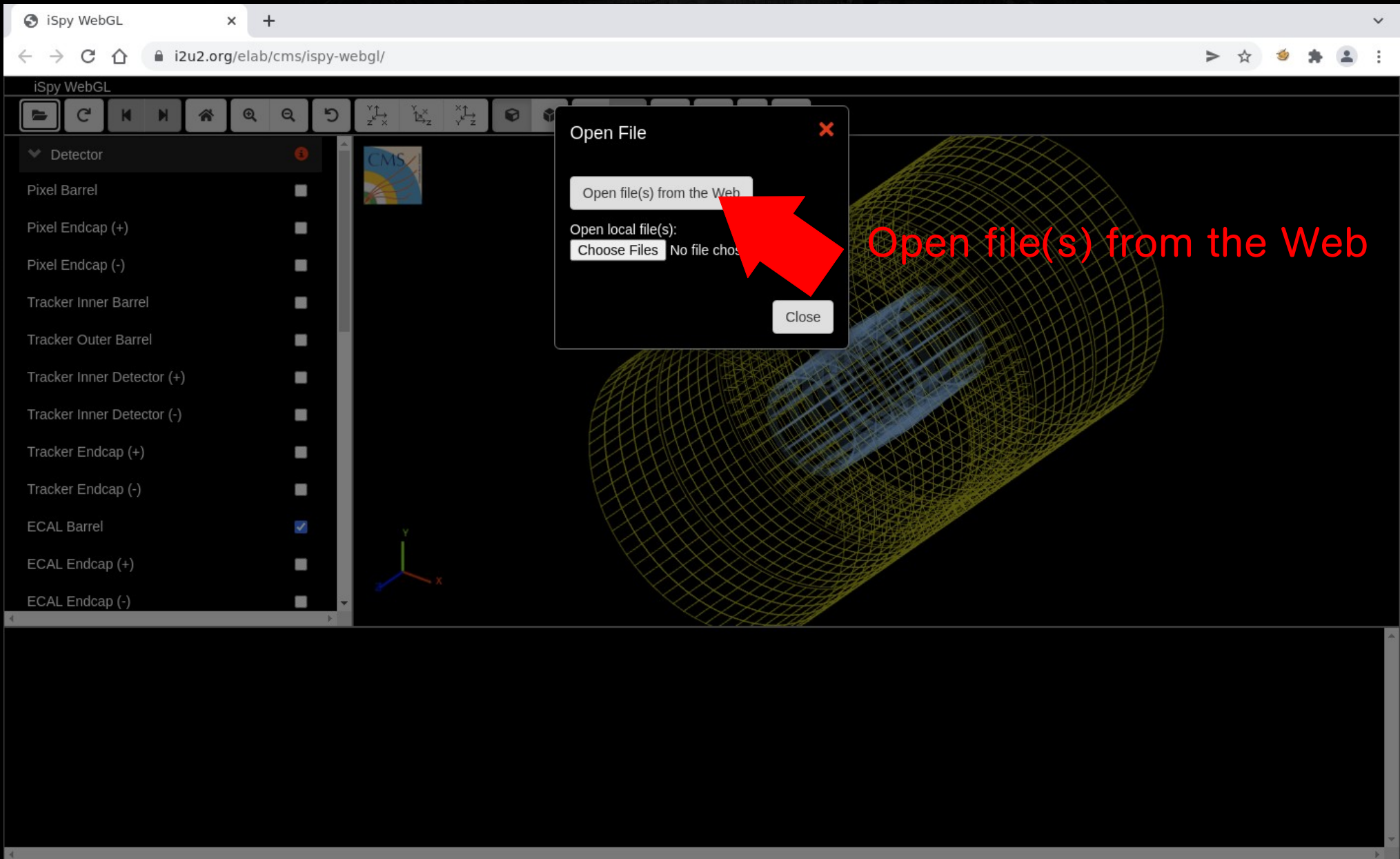
[l.infn.it/mc-ts](http://l.infn.it/mc-ts)

## Link utili:

- [Istruzioni](#)
  - **Strumenti per l'esercizio:**
    - display degli eventi: [iSpy Online \(backup\)](#);
    - tool per l'analisi: [CIMA](#).
- 







The screenshot shows a web browser window with the URL `i2u2.org/elab/cms/ispy-webgl/`. The browser title is "iSpy WebGL". The interface includes a toolbar with navigation and view controls, a left sidebar with a "Detector" panel, and a main 3D visualization area. The "Detector" panel lists components with checkboxes: Pixel Barrel, Pixel Endcap (+), Pixel Endcap (-), Tracker Inner Barrel, Tracker Outer Barrel, Tracker Inner Detector (+), Tracker Inner Detector (-), Tracker Endcap (+), Tracker Endcap (-), ECAL Barrel (checked), ECAL Endcap (+), and ECAL Endcap (-). The 3D view shows a wireframe model of a detector barrel. An "Open File" dialog box is overlaid on the 3D view, with a red arrow pointing to the "Open file(s) from the Web" button. The dialog also shows "Open local file(s):" with a "Choose Files" button and "No file chosen" text, and a "Close" button. The text "Open file(s) from the Web" is written in red on the right side of the 3D view.

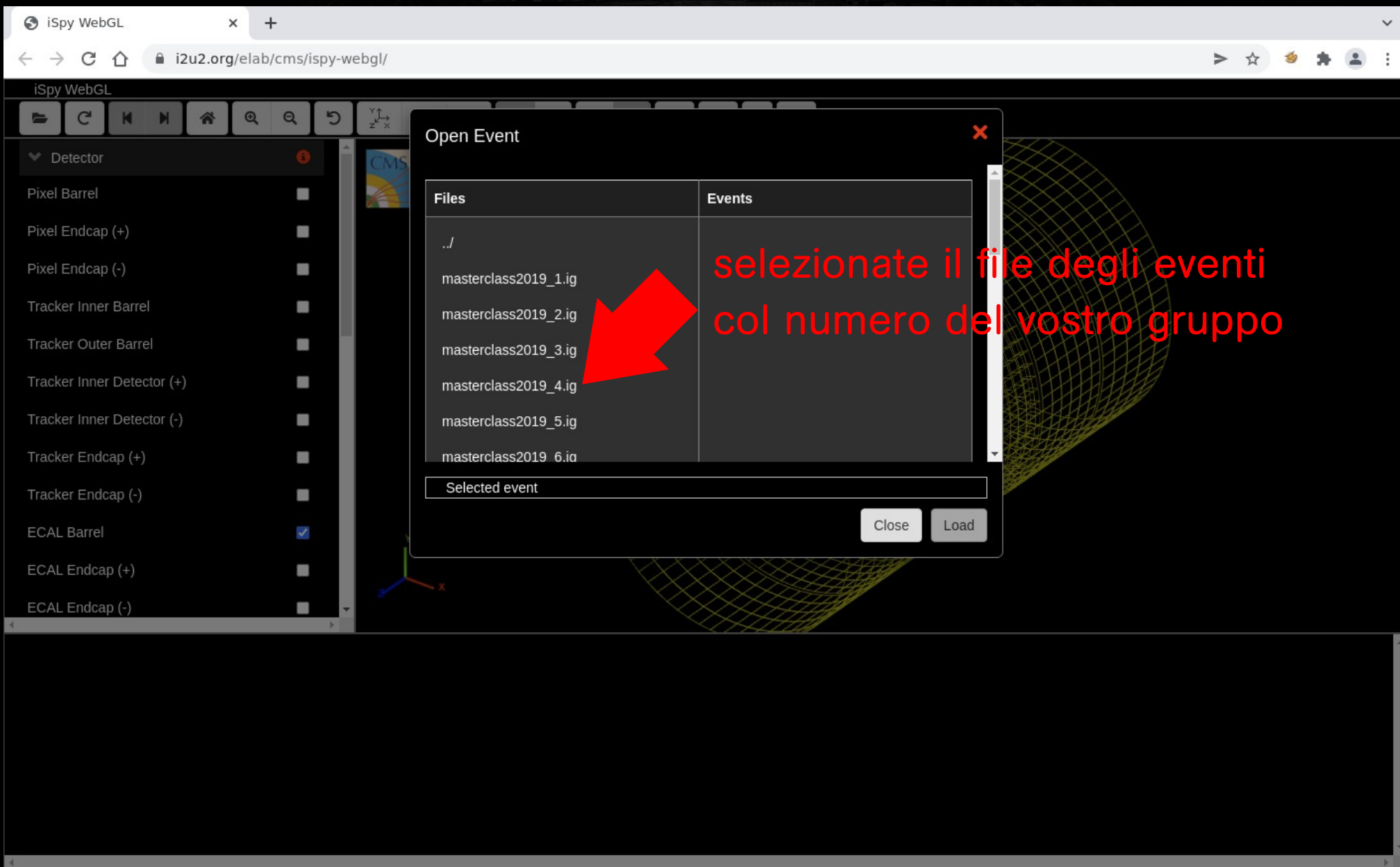


selezionate la cartella contenente il vostro campione di dati

Files	Events
N5/	
N10/	
N25/	
N50/	
N100/	

Selected event

Close Load



selezionate il file degli eventi col numero del vostro gruppo

Files	Events
..	
masterclass2019_1.ig	
masterclass2019_2.ig	
masterclass2019_3.ig	
masterclass2019_4.ig	
masterclass2019_5.ig	
masterclass2019_6.ig	

Selected event

Close Load

Open Event

Files	Events
../	Events/Run_25/Event_1
masterclass2019_1.ig	Events/Run_25/Event_2
masterclass2019_2.ig	Events/Run_25/Event_3
masterclass2019_3.ig	Events/Run_25/Event_4
masterclass2019_4.ig	Events/Run_25/Event_5
masterclass2019_5.ig	Events/Run_25/Event_6
masterclass2019_6.ig	Events/Run_25/Event_7

N25: Events/Run\_25/Event\_1

Close Load

selezionate il primo evento


caricatelo

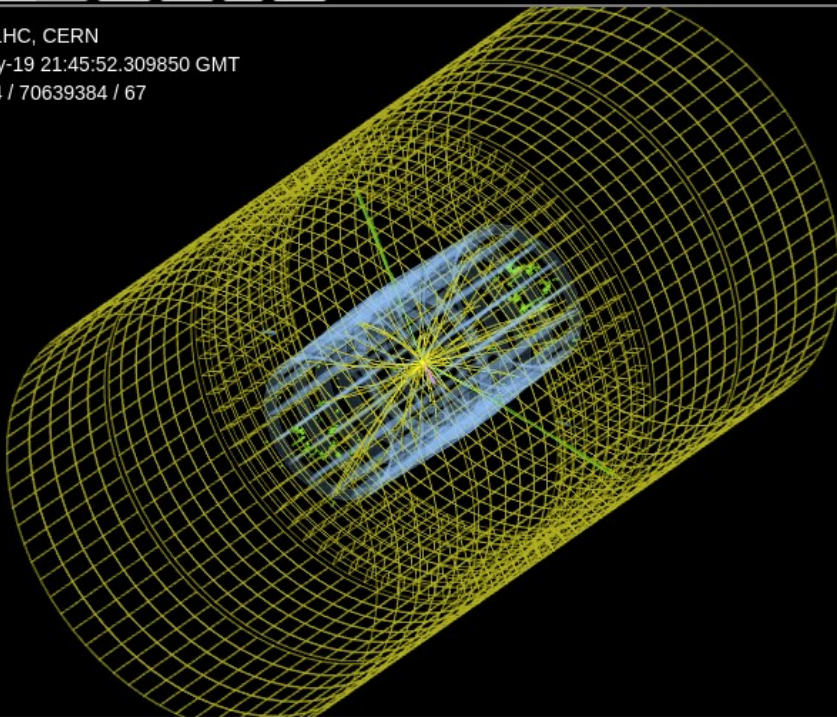
iSpy WebGL x +

i2u2.org/elab/cms/ispay-webgl/

iSpy WebGL N25:Events/Run\_25/Event\_1 [1 of 100]

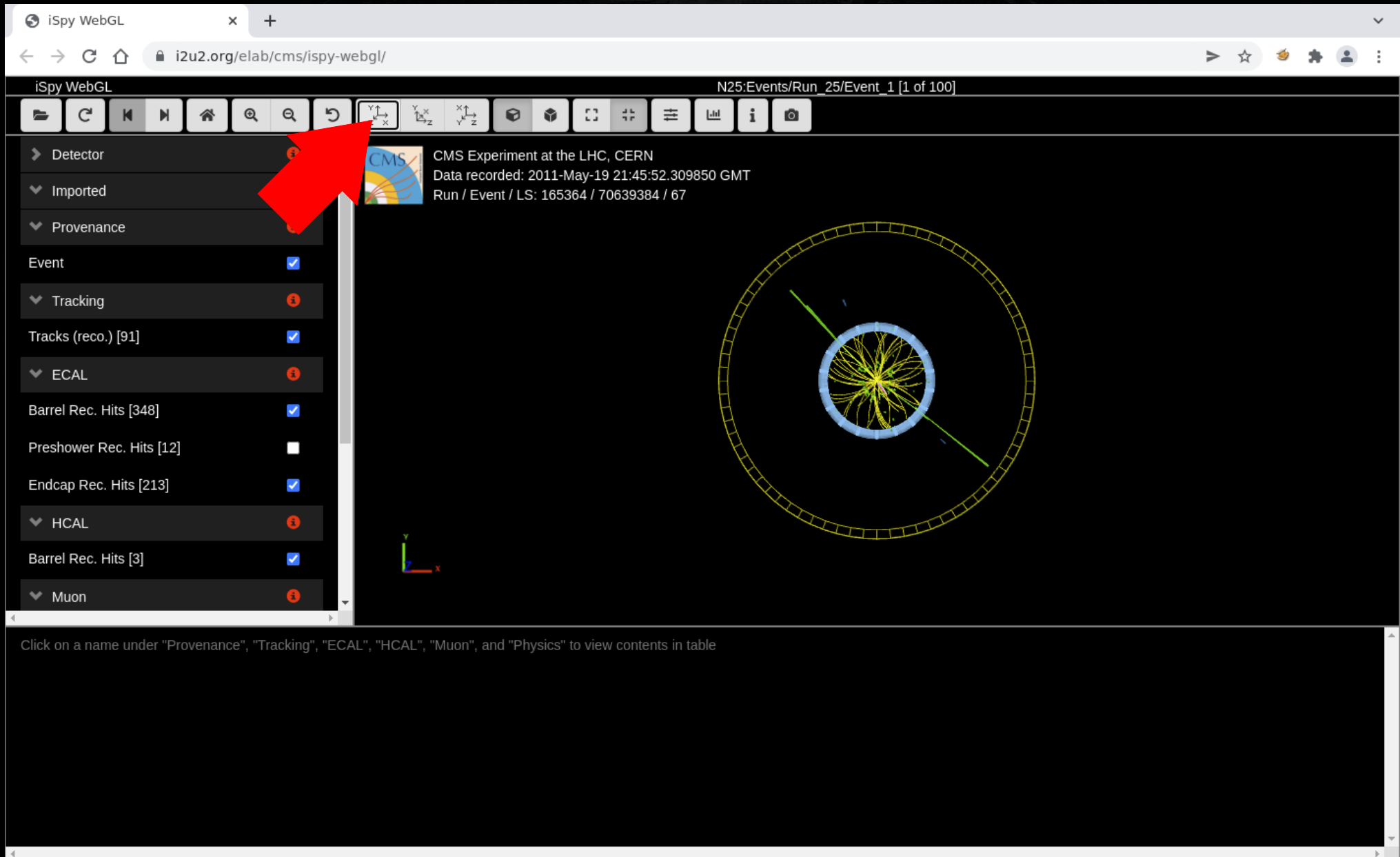
Detector ⓘ  
 Imported ⓘ  
 Provenance ⓘ  
 Event   
 Tracking ⓘ  
 Tracks (reco.) [91]   
 ECAL ⓘ  
 Barrel Rec. Hits [348]   
 Preshower Rec. Hits [12]   
 Endcap Rec. Hits [213]   
 HCAL ⓘ  
 Barrel Rec. Hits [3]   
 Muon ⓘ

 CMS Experiment at the LHC, CERN  
 Data recorded: 2011-May-19 21:45:52.309850 GMT  
 Run / Event / LS: 165364 / 70639384 / 67



Barrel Rec. Hits [3]   
 Muon ⓘ

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



The screenshot shows a web browser window displaying the iSpy WebGL interface. The browser address bar shows the URL `i2u2.org/elab/cms/ispay-webgl/`. The interface title is "iSpy WebGL" and the current view is "N25:Events/Run\_25/Event\_1 [1 of 100]".

The interface consists of a top toolbar with navigation and view controls, a left sidebar with a tree view of detector components, and a main 3D visualization area. A red arrow points to the CMS logo in the sidebar.

**Left Sidebar (Detector Tree):**

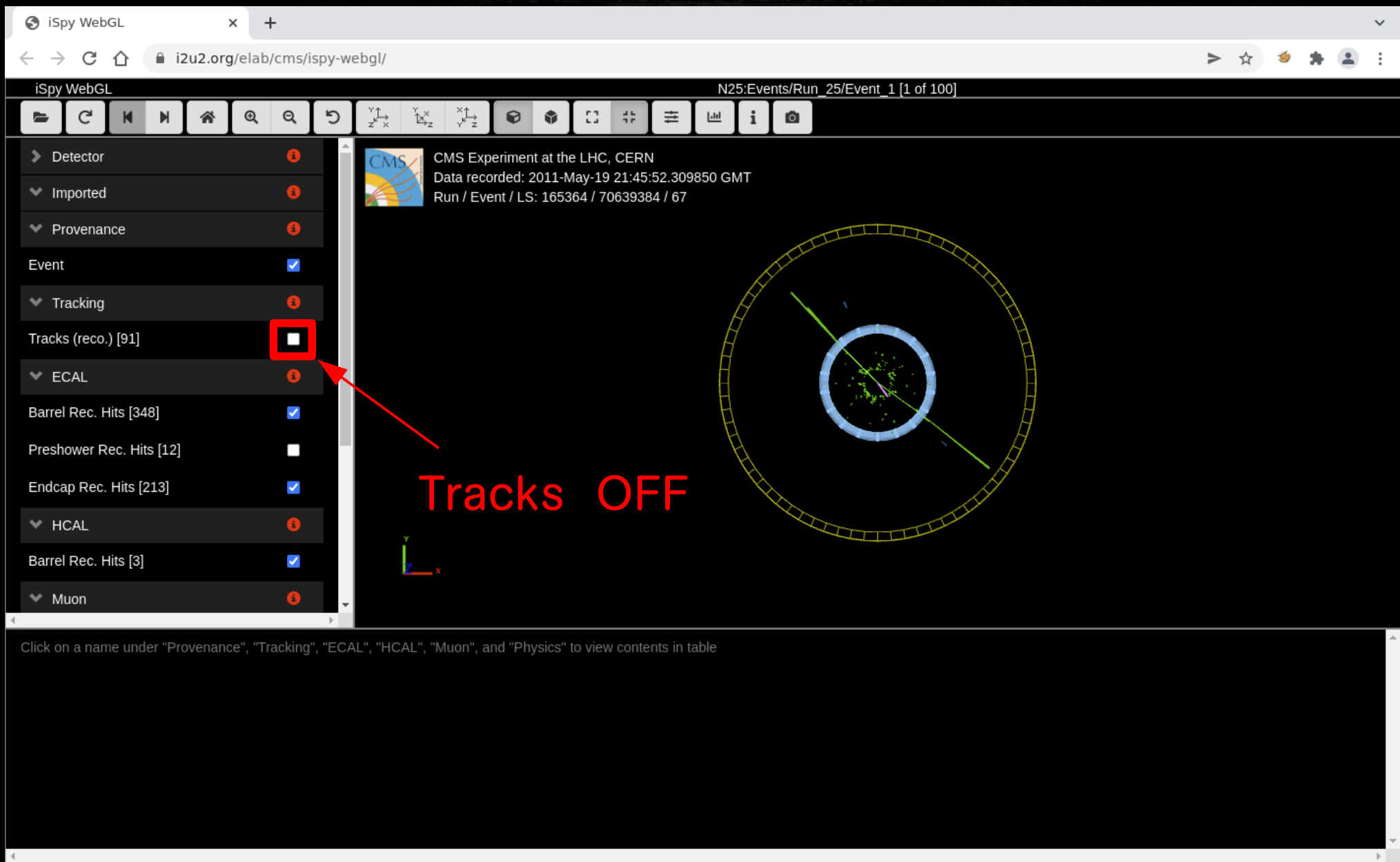
- Detector
- Imported
- Provenance
- Event
- Tracking  (3)
- Tracks (reco.) [91]
- ECAL  (3)
  - Barrel Rec. Hits [348]
  - Preshower Rec. Hits [12]
  - Endcap Rec. Hits [213]
- HCAL  (3)
  - Barrel Rec. Hits [3]
- Muon  (3)

**Main Visualization Area:**

Header: CMS Experiment at the LHC, CERN  
 Data recorded: 2011-May-19 21:45:52.309850 GMT  
 Run / Event / LS: 165364 / 70639384 / 67

The main area displays a 3D reconstruction of the CMS detector. It features a central blue circle representing the interaction region, surrounded by a yellow ring representing the detector's outer boundary. Numerous yellow lines radiate from the center, representing particle tracks. A green line is also visible, extending from the center towards the right. A small 3D coordinate system (x, y, z) is shown in the bottom left corner of the visualization area.

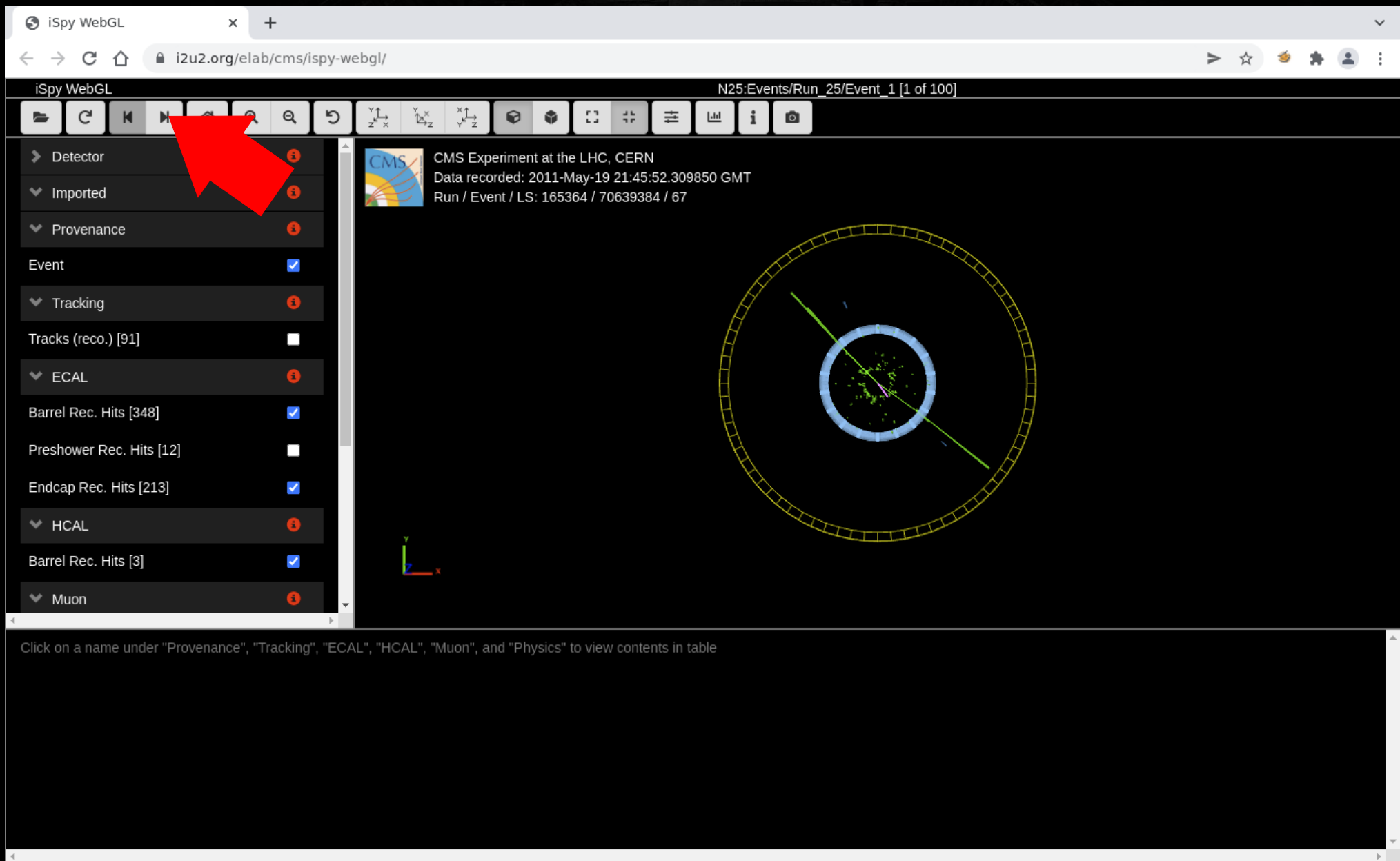
At the bottom of the interface, there is a text instruction: "Click on a name under 'Provenance', 'Tracking', 'ECAL', 'HCAL', 'Muon', and 'Physics' to view contents in table".



The screenshot shows the iSpy WebGL interface for the CMS Experiment at the LHC, CERN. The browser address bar shows the URL `i2u2.org/elab/cms/ispy-webgl/`. The interface includes a toolbar with navigation and visualization controls. On the left, a sidebar lists various detector components and their visibility status:

- Detector:
- Imported:
- Provenance:
- Event:
- Tracking:
- Tracks (reco.) [91]:  (highlighted with a red box and arrow)
- ECAL:
- Barrel Rec. Hits [348]:
- Preshower Rec. Hits [12]:
- Endcap Rec. Hits [213]:
- HCAL:
- Barrel Rec. Hits [3]:
- Muon:

The main visualization area displays a 3D detector model with a central event reconstruction. The text "Tracks OFF" is overlaid in red, indicating the current state of the tracking visualization. The interface also shows event information: "N25:Events/Run\_25/Event\_1 [1 of 100]", "Data recorded: 2011-May-19 21:45:52.309850 GMT", and "Run / Event / LS: 165364 / 70639384 / 67".



iSpy WebGL

N25:Events/Run\_25/Event\_1 [1 of 100]

Detector

Imported

Provenance

Event

Tracking

Tracks (reco.) [91]

ECAL

Barrel Rec. Hits [348]

Preshower Rec. Hits [12]

Endcap Rec. Hits [213]

HCAL

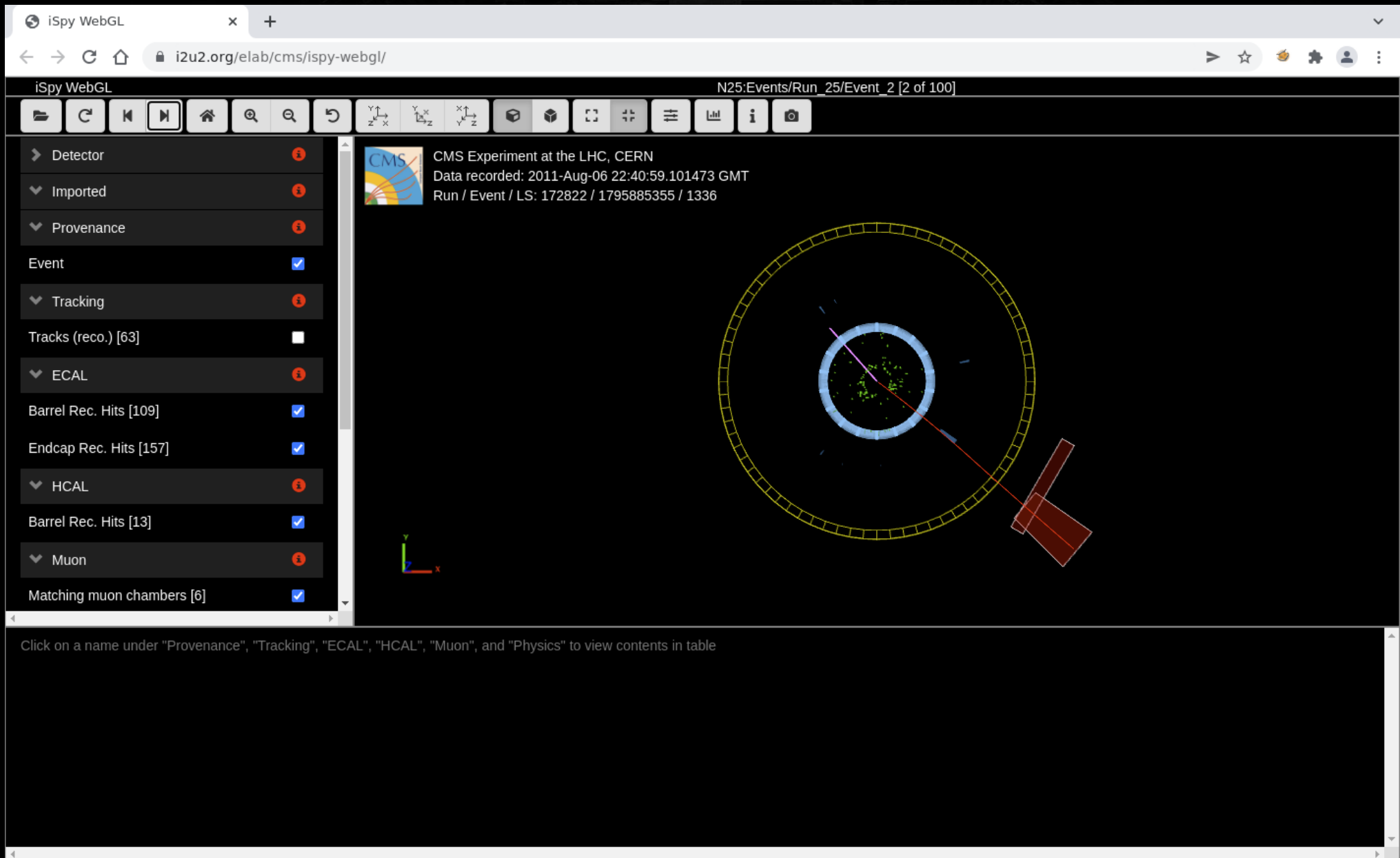
Barrel Rec. Hits [3]

Muon

CMS Experiment at the LHC, CERN  
Data recorded: 2011-May-19 21:45:52.309850 GMT  
Run / Event / LS: 165364 / 70639384 / 67

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





iSpy WebGL

i2u2.org/elab/cms/ispy-webgl/

N25:Events/Run\_25/Event\_2 [2 of 100]

Detector ⓘ

Imported ⓘ

Provenance ⓘ

Event

Tracking ⓘ

Tracks (reco.) [63]

ECAL ⓘ

Barrel Rec. Hits [109]

Endcap Rec. Hits [157]

HCAL ⓘ

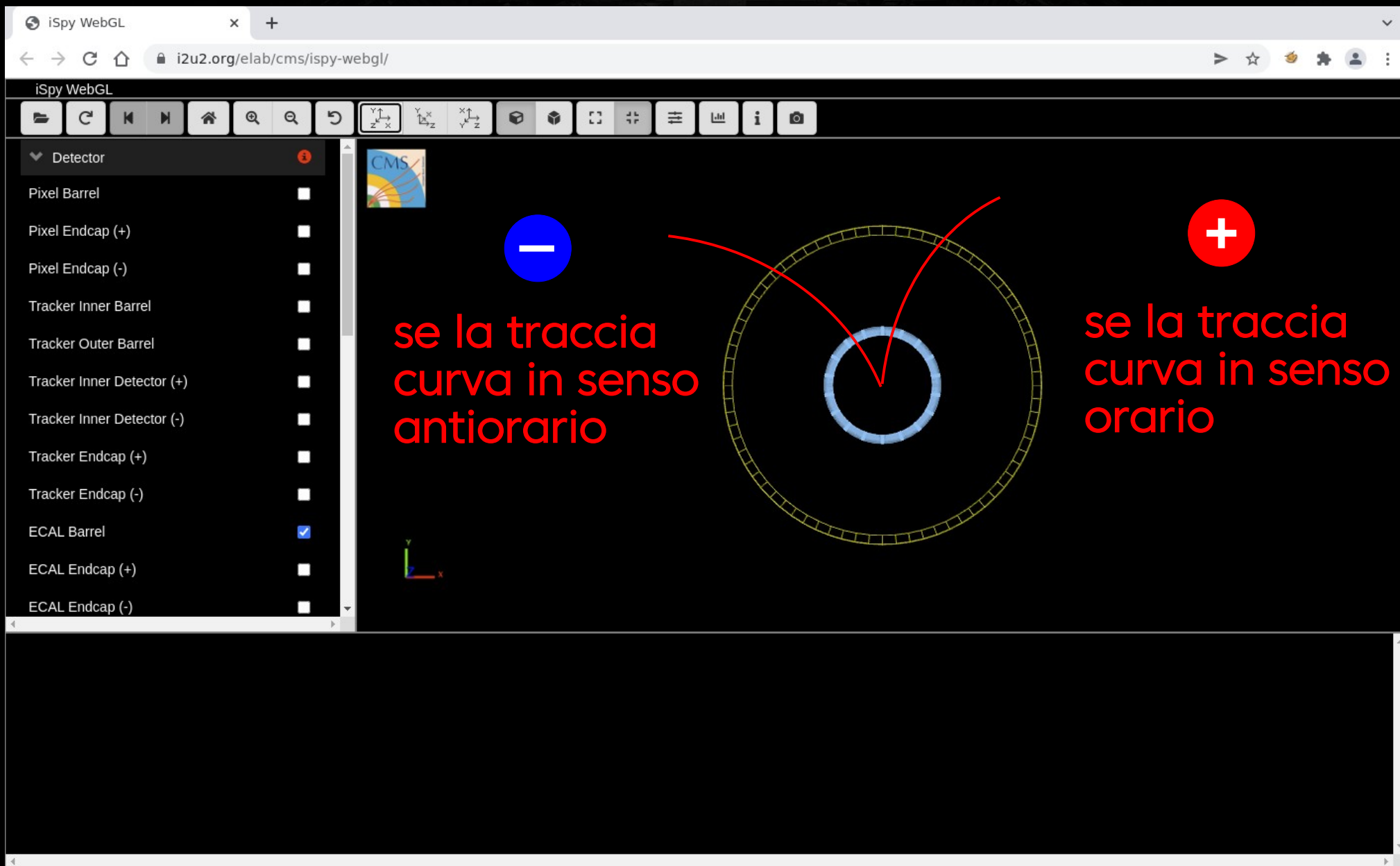
Barrel Rec. Hits [13]

Muon ⓘ

Matching muon chambers [6]

CMS Experiment at the LHC, CERN  
Data recorded: 2011-Aug-06 22:40:59.101473 GMT  
Run / Event / LS: 172822 / 1795885355 / 1336

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




The screenshot shows the iSpy WebGL interface for the CMS detector simulation. On the left, a sidebar lists detector components with checkboxes: Pixel Barrel, Pixel Endcap (+), Pixel Endcap (-), Tracker Inner Barrel, Tracker Outer Barrel, Tracker Inner Detector (+), Tracker Inner Detector (-), Tracker Endcap (+), Tracker Endcap (-), ECAL Barrel (checked), ECAL Endcap (+), and ECAL Endcap (-). The main view displays a top-down view of the detector with a blue track curving through the inner detector. A blue circle with a minus sign (-) is placed on the left side of the track, and a red circle with a plus sign (+) is on the right. Red arrows point from these circles to the track. Text annotations in red state: "se la traccia curva in senso antiorario" (if the track curves counter-clockwise) and "se la traccia curva in senso orario" (if the track curves clockwise). A CMS logo and a 3D coordinate system are also visible in the simulation area.

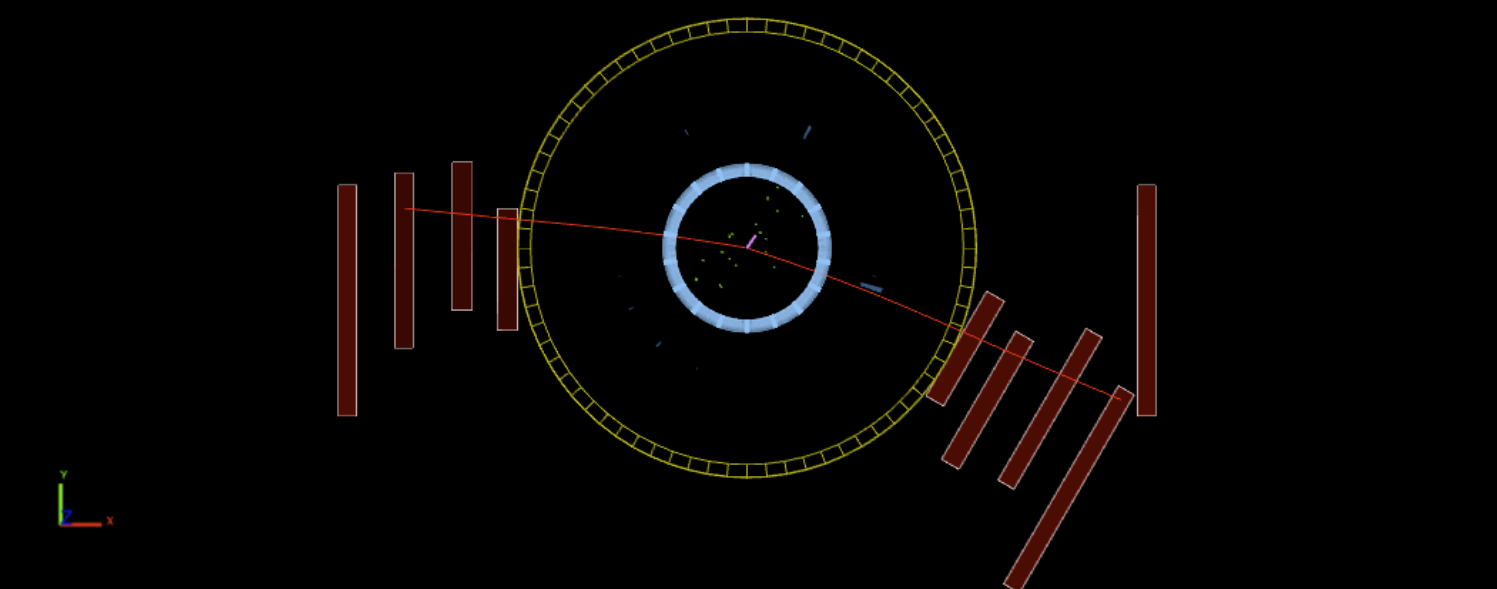
iSpy WebGL

i2u2.org/elab/cms/ispy-webgl/

N25:Events/Run\_25/Event\_67 [67 of 100]

Detector i  
 Imported i  
 Provenance i  
 Event   
 Tracking i  
 Tracks (reco.) [24]   
 ECAL i  
 Barrel Rec. Hits [23]   
 Endcap Rec. Hits [44]   
 HCAL i  
 Barrel Rec. Hits [13]   
 Forward Rec. Hits [1]   
 Muon i

 CMS Experiment at the LHC, CERN  
 Data recorded: 2011-May-24 21:42:58.612262 GMT  
 Run / Event / LS: 165617 / 75779415 / 62



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

iSpy WebGL

i2u2.org/elab/cms/ispy-webgl/

N25.Events/Run\_25/Event\_67 [67 of 100]

Detector

Imported

Provenance

Event

Tracking

Tracks (reco.) [24]

ECAL

Barrel Rec. Hits [23]

Endcap Rec. Hits [44]

HCAL

Barrel Rec. Hits [13]

Forward Rec. Hits [1]

Muon

CMS Experiment at the LHC, CERN  
Data recorded: 2011-May-24 21:42:58.612262 GMT  
Run / Event / LS: 165617 / 75779415 / 62

**clickare sulla prima particella**

Physics: Global Muons (Reco)

pt	charge	rp	phi	eta	E	px	py	pz	calo_energy
39.7394		0.00076542,0.000367432,0.0379889	-0.312266	-0.712338	50.244	37.8176	-12.2086	-30.7634	0
48.279		0.000765656,0.000366881,0.0380231	2.97032	-0.195625	49.2396	-47.5726	8.22874	-9.50493	0

iSpy WebGL

i2u2.org/elab/cms/ispy-webgl/

N25.Events/Run\_25/Event\_67 [67 of 100]

Detector

Imported

Provenance

Event

Tracking

Tracks (reco.) [24]

ECAL

Barrel Rec. Hits [23]

Endcap Rec. Hits [44]

HCAL

Barrel Rec. Hits [13]

Forward Rec. Hits [1]

Muon

CMS Experiment at the LHC, CERN  
Data recorded: 2011-May-24 21:42:58.612262 GMT  
Run / Event / LS: 165617 / 75779415 / 62

**clickare sulla seconda particella**

Physics: Global Muons (Reco)

pt	charge	rp	phi	eta	E	px	py	pz	calo_energy
39.7394		0.00076542,0.000367432,0.0379889	-0.312266	-0.712338	50.244	37.8176	-12.2086	-30.7634	0
48.279		0.000765656,0.000366881,0.0380231	2.97032	-0.195625	49.2396	-47.5726	8.22874	-9.50493	0

iSpy WebGL

i2u2.org/elab/cms/ispy-webgl/

N25.Events/Run\_25/Event\_67 [67 of 100]

Invariant mass ✕

90.33 GeV ← premere il tasto "m"

Close

Physics: Global Muons (Reco)

pt	charge	rp	phi	eta	E	px	py	pz	calo_energy
39.7394		0.00076542,0.000367432,0.0379889	-0.312266	-0.712338	50.244	37.8176	-12.2086	-30.7634	0
48.279		0.000765656,0.000366881,0.0380231	2.97032	-0.195625	49.2396	-47.5726	8.22874	-9.50493	0

iSpy WebGL

i2u2.org/elab/cms/ispy-webgl/

N25.Events/Run\_25/Event\_3 [3 of 100]

Detector

Imported

Provenance

Event

Tracking

Tracks (reco.) [139]

ECAL

Barrel Rec. Hits [428]

Preshower Rec. Hits [27]

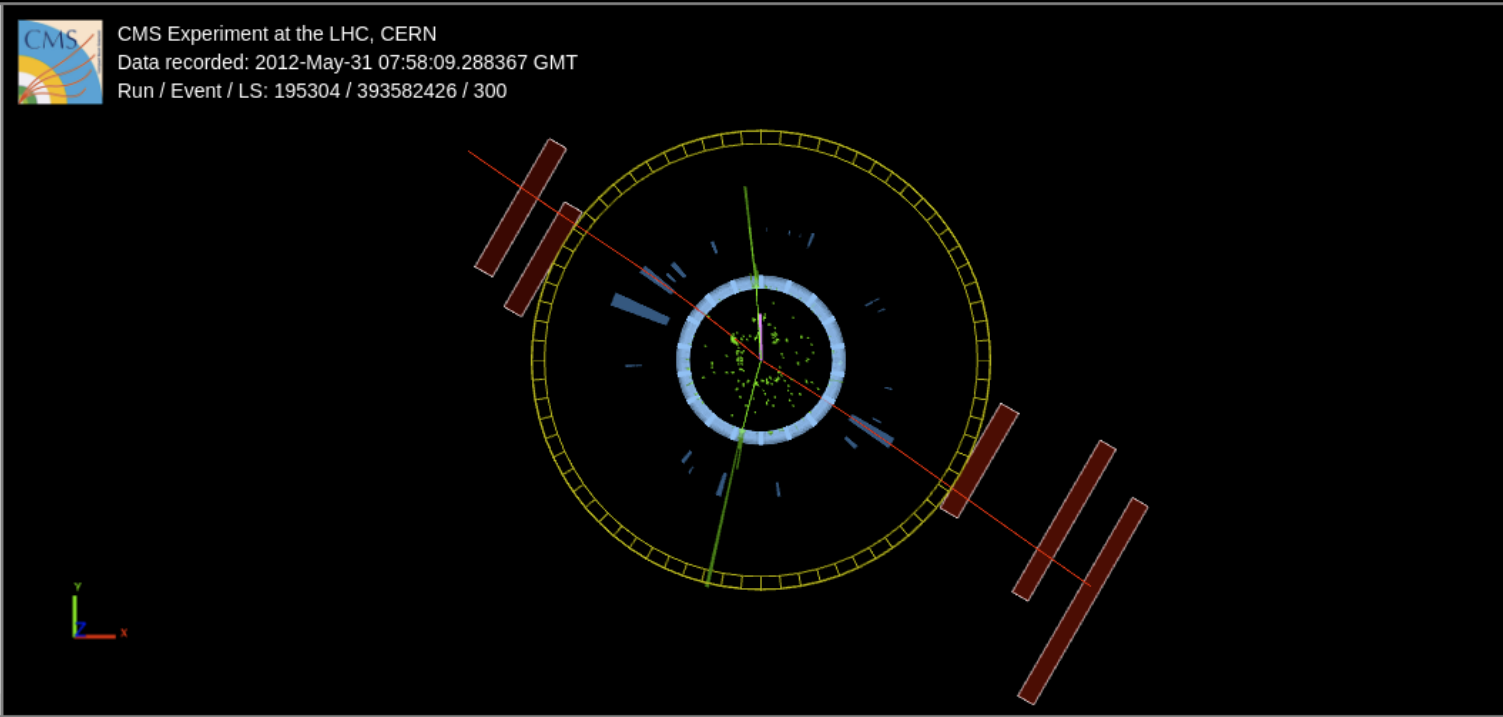
Endcap Rec. Hits [220]

SuperClusters [5]

HCAL

Barrel Rec. Hits [42]

CMS Experiment at the LHC, CERN  
Data recorded: 2012-May-31 07:58:09.288367 GMT  
Run / Event / LS: 195304 / 393582426 / 300



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

# Un evento con $2\mu$ e $2e$

iSpy WebGL | N25.Events/Run\_25/Event\_3 [3 of 100]

Invariant mass  
200.12 GeV

Close

massa  $\mu\mu ee$

Physics: Electron Tracks (GSF)

pt	eta	phi	charge	pos	dir
45.7356	0.981486	1.65224		0.000706333,0.00062298,-0.0264458	-3.72096,45.584,52.4511
45.0702	1.06903	-1.84763		0.000723635,0.000624808,-0.0264623	-12.3183,-43.3541,57.8973

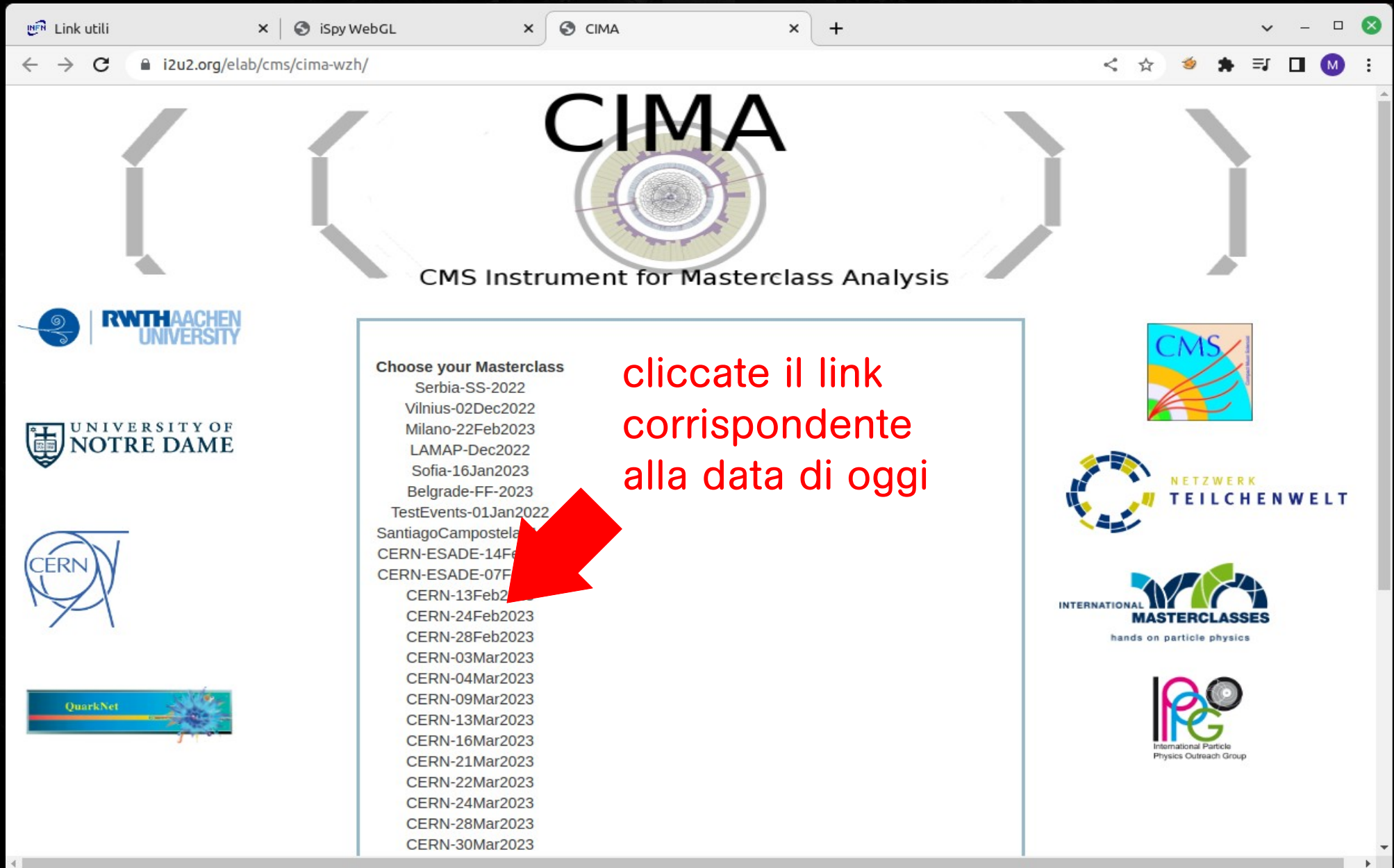


[l.infn.it/mc-ts](http://l.infn.it/mc-ts)

## Link utili:

- [Istruzioni](#)
- **Strumenti per l'esercizio:**
  - display degli eventi: [CIMA Online \(backup\)](#);
  - tool per l'analisi: [CIMA](#).

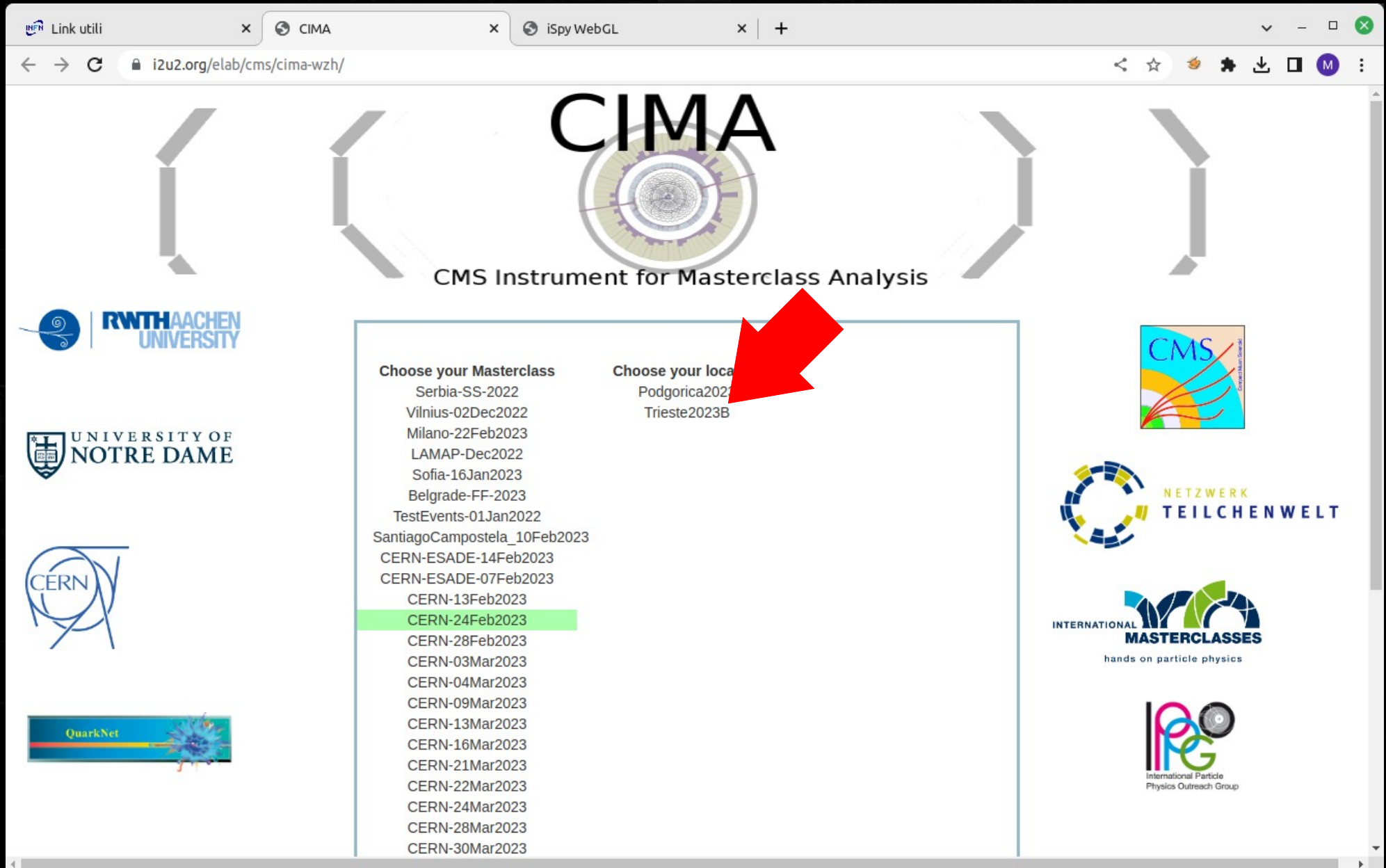




The screenshot shows a web browser window with the URL [i2u2.org/elab/cms/cima-wzh/](https://i2u2.org/elab/cms/cima-wzh/). The page features the CIMA logo and the text "CMS Instrument for Masterclass Analysis". A central list titled "Choose your Masterclass" contains the following entries:

- Serbia-SS-2022
- Vilnius-02Dec2022
- Milano-22Feb2023
- LAMAP-Dec2022
- Sofia-16Jan2023
- Belgrade-FF-2023
- TestEvents-01Jan2022
- SantiagoCampostela
- CERN-ESADE-14Feb2023
- CERN-ESADE-07Feb2023
- CERN-13Feb2023
- CERN-24Feb2023
- CERN-28Feb2023
- CERN-03Mar2023
- CERN-04Mar2023
- CERN-09Mar2023
- CERN-13Mar2023
- CERN-16Mar2023
- CERN-21Mar2023
- CERN-22Mar2023
- CERN-24Mar2023
- CERN-28Mar2023
- CERN-30Mar2023

A red arrow points to the "CERN-13Feb2023" entry. To the right of the list, red text reads: "cliccate il link corrispondente alla data di oggi". The page also includes logos for RWTH Aachen University, University of Notre Dame, CERN, QuarkNet, CMS, Netzwerk Teilchenwelt, International Masterclasses, and the International Particle Physics Outreach Group.



The screenshot shows a web browser window with the URL [i2u2.org/elab/cms/cima-wzh/](https://i2u2.org/elab/cms/cima-wzh/). The page features the CIMA logo and the text "CMS Instrument for Masterclass Analysis". A red arrow points to the "Choose your location" section, which lists "Podgorica2022" and "Trieste2023B". The "Choose your Masterclass" section lists various dates, with "CERN-24Feb2023" highlighted in green. The left sidebar contains logos for RWTH Aachen University, University of Notre Dame, CERN, and QuarkNet. The right sidebar contains logos for CMS, Netzwerk Teilchenwelt, International Masterclasses, and the International Particle Physics Outreach Group.

**Choose your Masterclass**

- Serbia-SS-2022
- Vilnius-02Dec2022
- Milano-22Feb2023
- LAMAP-Dec2022
- Sofia-16Jan2023
- Belgrade-FF-2023
- TestEvents-01Jan2022
- SantiagoCampostela\_10Feb2023
- CERN-ESADE-14Feb2023
- CERN-ESADE-07Feb2023
- CERN-13Feb2023
- CERN-24Feb2023**
- CERN-28Feb2023
- CERN-03Mar2023
- CERN-04Mar2023
- CERN-09Mar2023
- CERN-13Mar2023
- CERN-16Mar2023
- CERN-21Mar2023
- CERN-22Mar2023
- CERN-24Mar2023
- CERN-28Mar2023
- CERN-30Mar2023

**Choose your location**

- Podgorica2022
- Trieste2023B

# Selezionate il vostro dataset

**CIMA**  
CMS Instrument for Masterclass Analysis

aprite il link corrispondente al vostro dataset

Choose your Masterclass	Choose your location	Choose your time
Serbia-SS-2022	Podgorica2023	100.1
Vilnius-02Dec2022	<b>Trieste2023B</b>	100.11
Milano-22Feb2023		100.12
LAMAP-Dec2022		100.13
Sofia-16Jan2023		100.14
Belgrade-FF-2023		100.15
TestEvents-01Jan2022		100.16
SantiagoCampostela_10Feb2023		100.17
CERN-ESADE-14Feb2023		100.18
CERN-ESADE-07Feb2023		100.19
CERN-13Feb2023		100.2
<b>CERN-24Feb2023</b>		100.21
CERN-28Feb2023		100.22
CERN-03Mar2023		100.23
CERN-04Mar2023		100.24
CERN-09Mar2023		100.25
CERN-13Mar2023		100.3
CERN-16Mar2023		100.4
CERN-21Mar2023		100.5
CERN-22Mar2023		100.6
CERN-24Mar2023		100.7
CERN-28Mar2023		100.8
CERN-30Mar2023		100.9

iSpy WebGL x CIMA x +

← → ↻ 🏠 🔒 i2u2.org/elab/cms/cima-wzh/DataTable.php

Back Events Table (Group 25.25) Mass Histogram (Trieste2022A) Results (Trieste2022A) → Event Display

Masterclass: CERN-01Mar2022  
 Location: Trieste2022A  
 Group: 25.25

<p><b>Select Event</b></p> <p>Event index: <input type="text" value="1"/></p> <p>Event number: 25.25-1</p>	<p><b>Final State</b></p> <p><input type="radio"/> e v      <input type="radio"/> <math>\mu</math> v</p> <p><input type="radio"/> e e      <input type="radio"/> <math>\mu</math> <math>\mu</math></p> <p><input type="radio"/> 4e      <input type="radio"/> 4<math>\mu</math></p> <p><input type="radio"/> 2e 2<math>\mu</math></p>	<p><b>Primary State</b></p> <p>Charged Particle:</p> <p><input type="radio"/> W<sup>+</sup>    <input type="radio"/> W<sup>-</sup>    <input type="radio"/> W<math>\pm</math></p> <p><input type="radio"/> Neutral Particle (Z, H)</p> <p><input type="radio"/> Zoo</p>	<p><b>Enter Mass</b></p> <p><input type="text"/> GeV/c<sup>2</sup></p> <p><input type="button" value="Next"/></p>
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Event index	Event number	Final state	Primary state	Mass

Link utili | iSpy WebGL | CIMA

i2u2.org/elab/cms/cima-wzh/DataTable.php

Back | Events Table (Group 100.1) | Mass Histogram (Trieste2022) | Results (Trieste2022) | Event Display

Masterclass: CERN-07Mar2022  
 Location: Trieste2022  
 Group: 100.1

<b>Select Event</b> Event index: <input type="text" value="81"/> Event number: 100.1-81	<b>Final State</b> <input type="radio"/> e v <input type="radio"/> $\mu$ v <input type="radio"/> e e <input type="radio"/> $\mu$ $\mu$ <input type="radio"/> 4e <input type="radio"/> 4 $\mu$ <input type="radio"/> 2e 2 $\mu$	<b>Primary State</b> Charged Particle: <input type="radio"/> W+ <input type="radio"/> W- <input type="radio"/> W $\pm$ <input type="radio"/> Neutral Particle (Z, H) <input type="radio"/> Zoo	<b>Enter Mass</b> <input type="text"/> GeV/c <sup>2</sup> <input type="button" value="Next"/>
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Event index	Event number	Final state	Primary state	Mass
91080	100.1-80	$\mu\mu$	neutral	90.33
91079	100.1-79	$\mu\nu$	W+	
91078	100.1-78	$\mu\nu$	W $\pm$	
91077	100.1-77	$\mu\nu$	W-	
91076	100.1-76	e v	W-	
91075	100.1-75	$\mu\mu$	neutral	10.2
91074	100.1-74	e v	W-	
91073	100.1-73	$\mu\nu$	W-	
91072	100.1-72	4e	neutral	363.54
91071	100.1-71	e v	W-	
91070	100.1-70	2e	neutral	3.72
91069	100.1-69	$\mu\nu$	W+	
91068	100.1-68	$\mu\nu$	W+	
91067	100.1-67	2e 2 $\mu$	zoo	
91066	100.1-66	$\mu\mu$	neutral	6.18
91065	100.1-65	e v	W+	
91064	100.1-64		zoo	
91063	100.1-63	$\mu\nu$	W $\pm$	
91062	100.1-62	$\mu\nu$	W $\pm$	



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[Events Table \(Group 25.25\)](#)
[Mass Histogram \(Trieste2022A\)](#)
[Results \(Trieste2022A\)](#)
Event Display

Masterclass: CERN-01Mar2022  
 Location: Trieste2022A

**Events / 2GeV**

Mass bin (GeV)	Events
82	1

**stato finale con 2 particelle**

**Events / 6GeV**

Mass bin (GeV)	Events
195	1

**stato finale con 4 particelle**

Tip: Remove data from the histogram by holding the ctrl key (the command key for mac users)

- Nel campo “Enter mass”:
  - ◆ inserite solo numeri;
  - ◆ usate il . per separare le cifre decimali.