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

Massimo Casarsa

Sezione INFN di Trieste

Trieste, 13 e 24 febbraio 2023

Analisi dei dati

❶

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.

❷

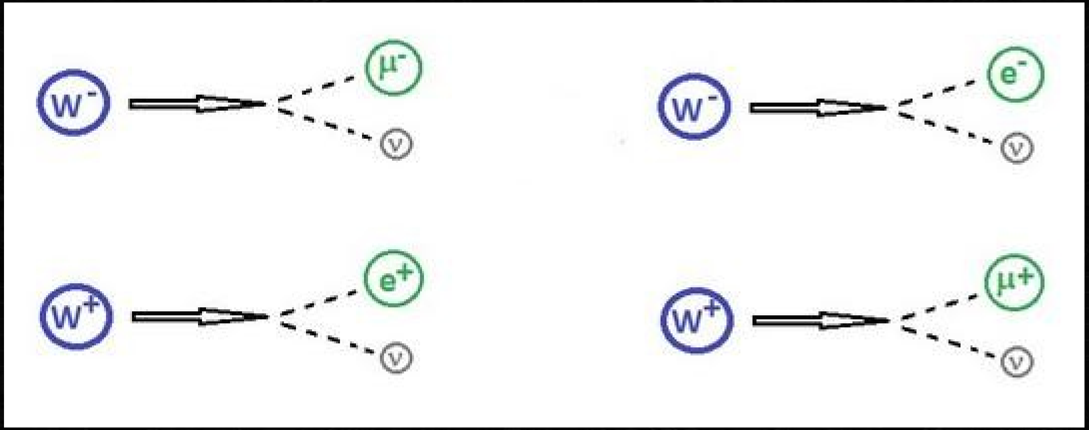
Misure da effettuare:

- nel caso dei candidati $W^\pm$:
  - distinguere i decadimenti delle W in elettroni da quelli in muoni e misurare il rapporto e/μ;
  - 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 1100000 bosoni W l'ora



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

LHC produce circa 110000 bosoni Z l'ora

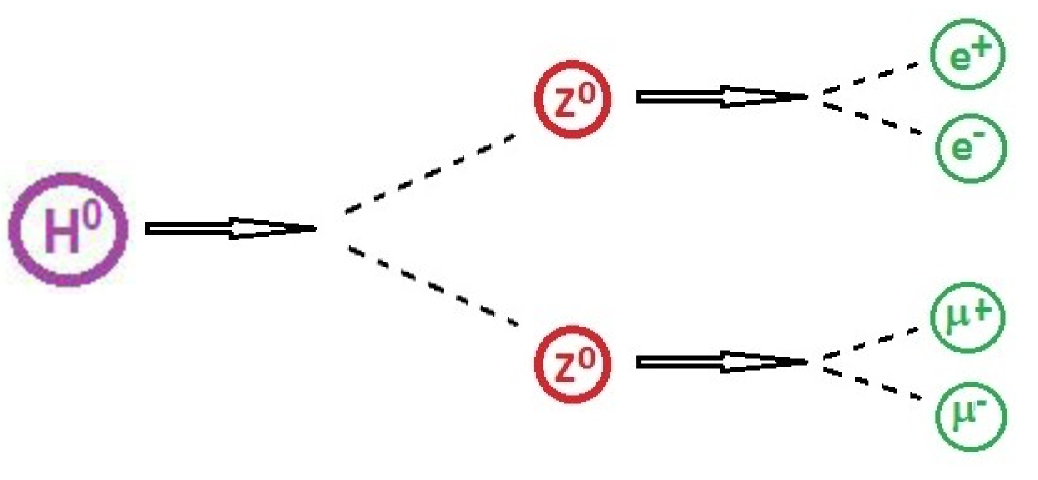
Canali da cercare (II)

- $H^0 \rightarrow Z^0Z^0 \rightarrow e^+e^-e^+e^-$ (0.003%),

  $H^0 \rightarrow Z^0Z^0 \rightarrow \mu^+\mu^-\mu^+\mu^-$ (0.003%),

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

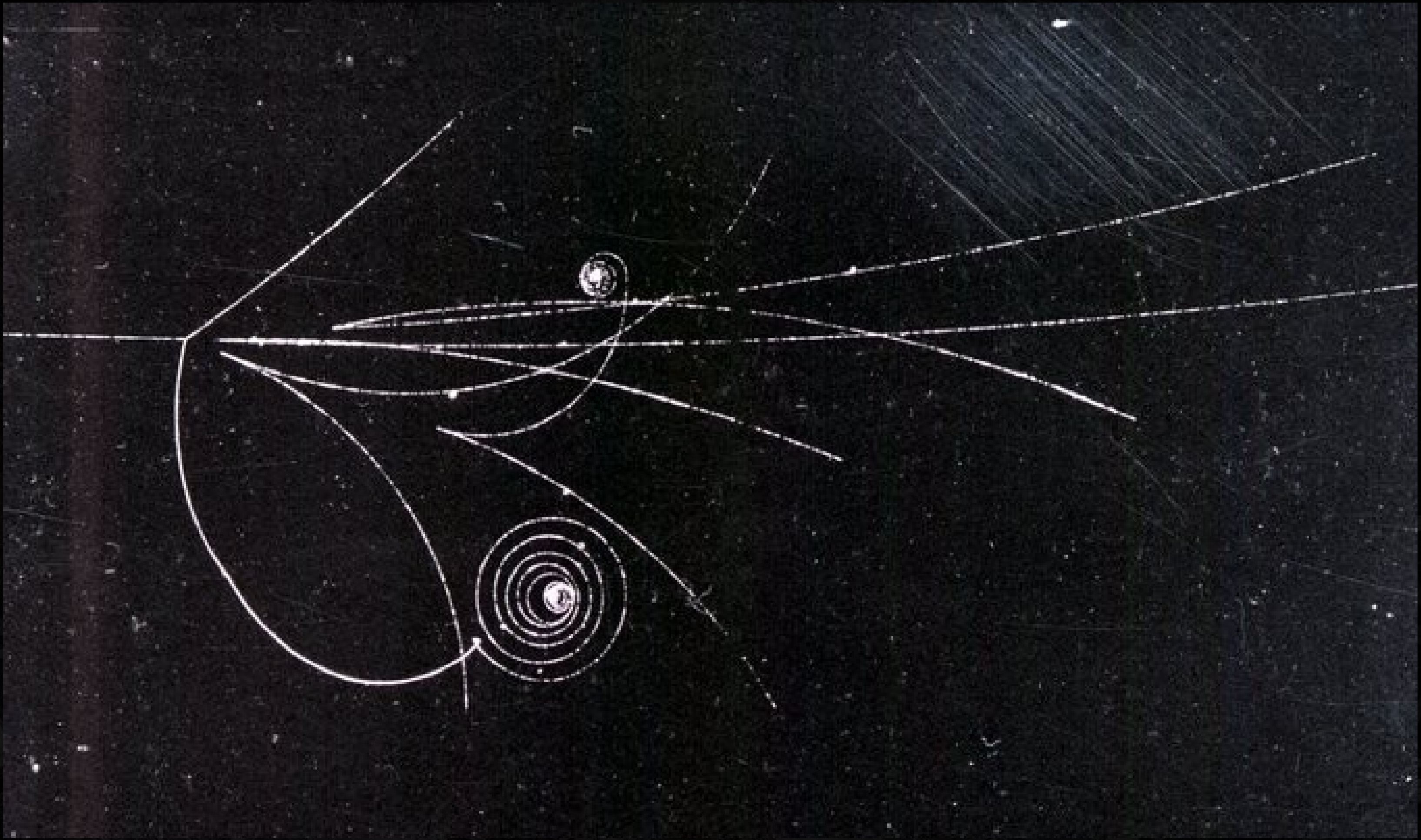
LHC produce
circa 2700
bosoni H l'ora



Metodologia della ricerca

- Il metodo di solito seguito consiste in:
  - ❶ individuare le caratteristiche peculiari del decadimento cercato, per esempio due elettroni di carica opposta;
  - ❷ stabilire a priori una serie di criteri oggettivi di selezione dei “candidati”, per esempio contare gli elettroni che hanno una certa carica;
  - ❸ 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.

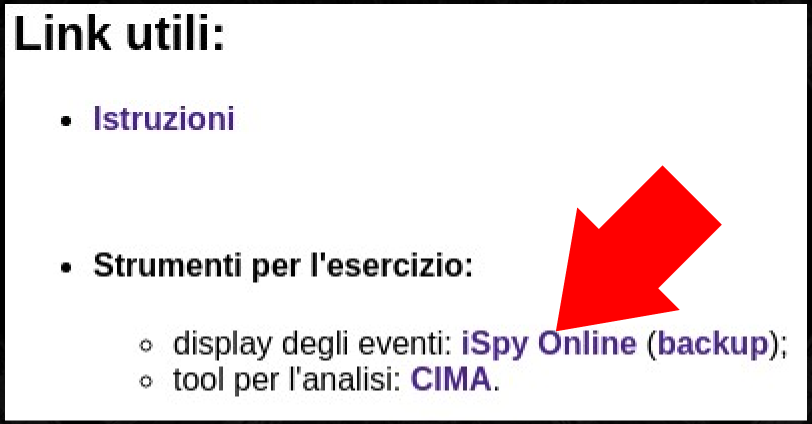
Flashback



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

Apriamo l'event display

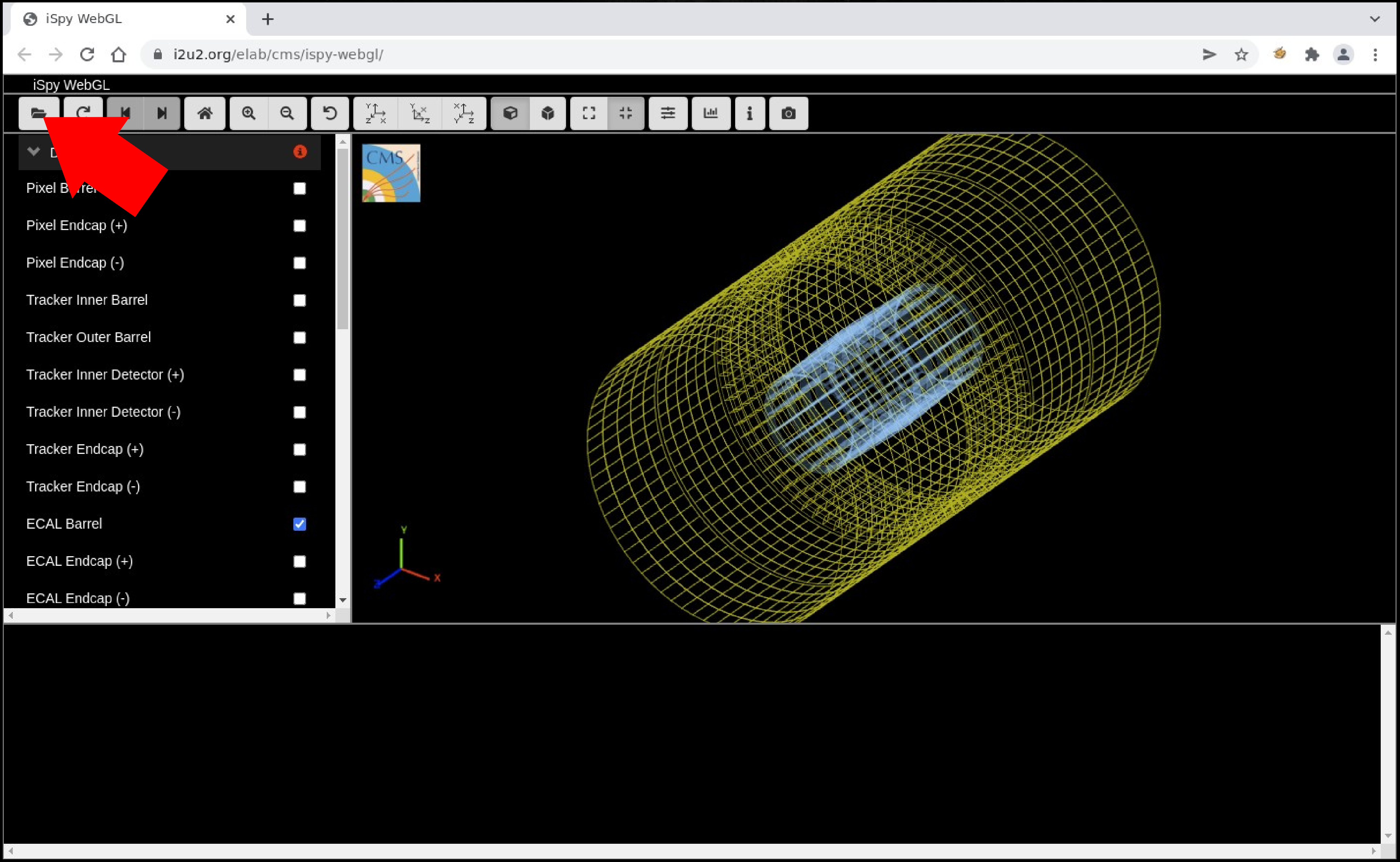
l.infn.it/mc-ts



Link utili:

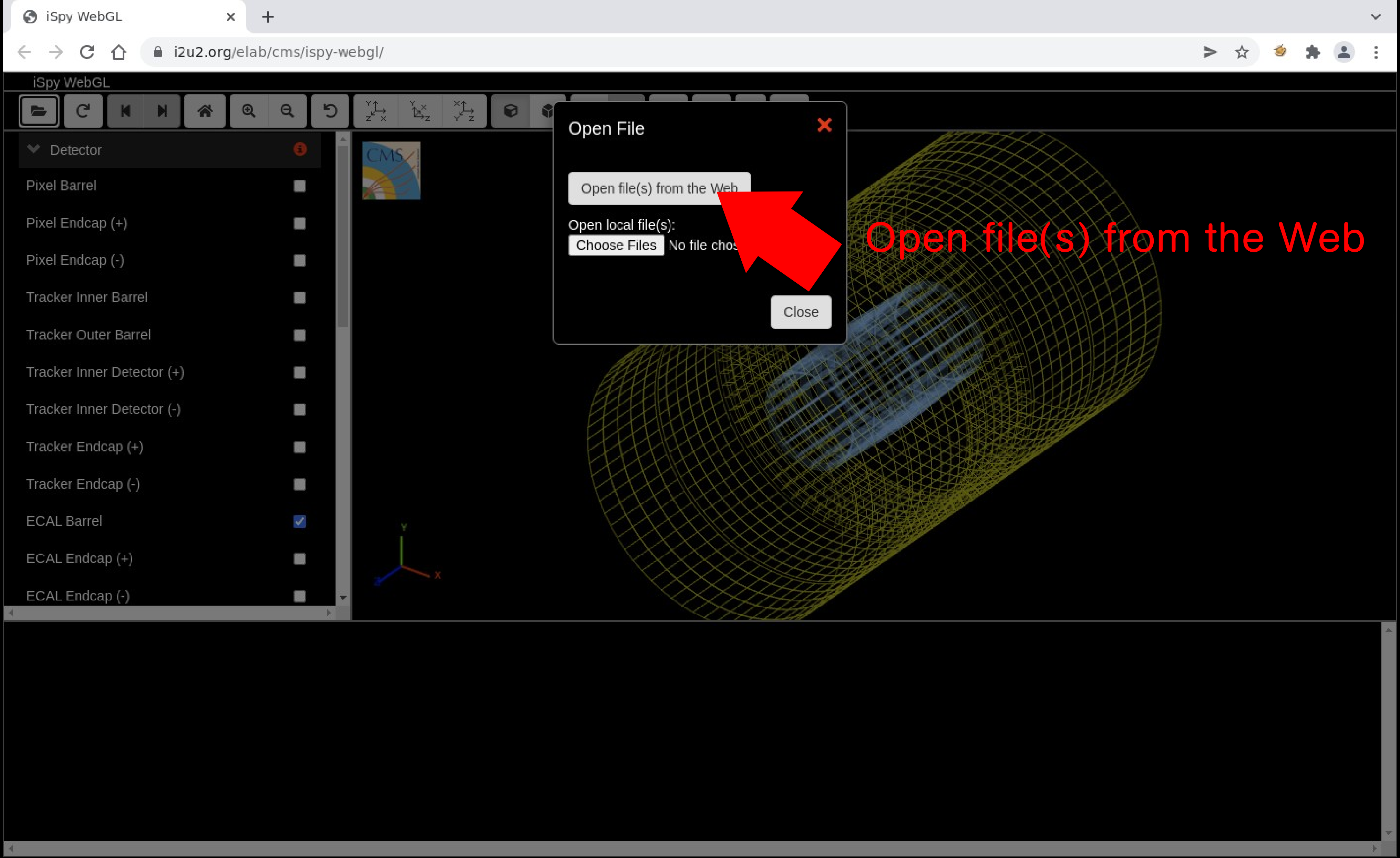
- Istruzioni
- **Strumenti per l'esercizio:**
  - display degli eventi: iSpy Online (backup);
  - tool per l'analisi: CIMA.

Caricamento degli eventi (I)


iSpy WebGL
i2u2.org/elab/cms/ispy-webgl/
iSpy WebGL
CMS
Y
X
Z

- Pixel B rel ☐
- Pixel Endcap (+) ☐
- Pixel Endcap (-) ☐
- Tracker Inner Barrel ☐
- Tracker Outer Barrel ☐
- Tracker Inner Detector (+) ☐
- Tracker Inner Detector (-) ☐
- Tracker Endcap (+) ☐
- Tracker Endcap (-) ☐
- ECAL Barrel ☑
- ECAL Endcap (+) ☐
- ECAL Endcap (-) ☐

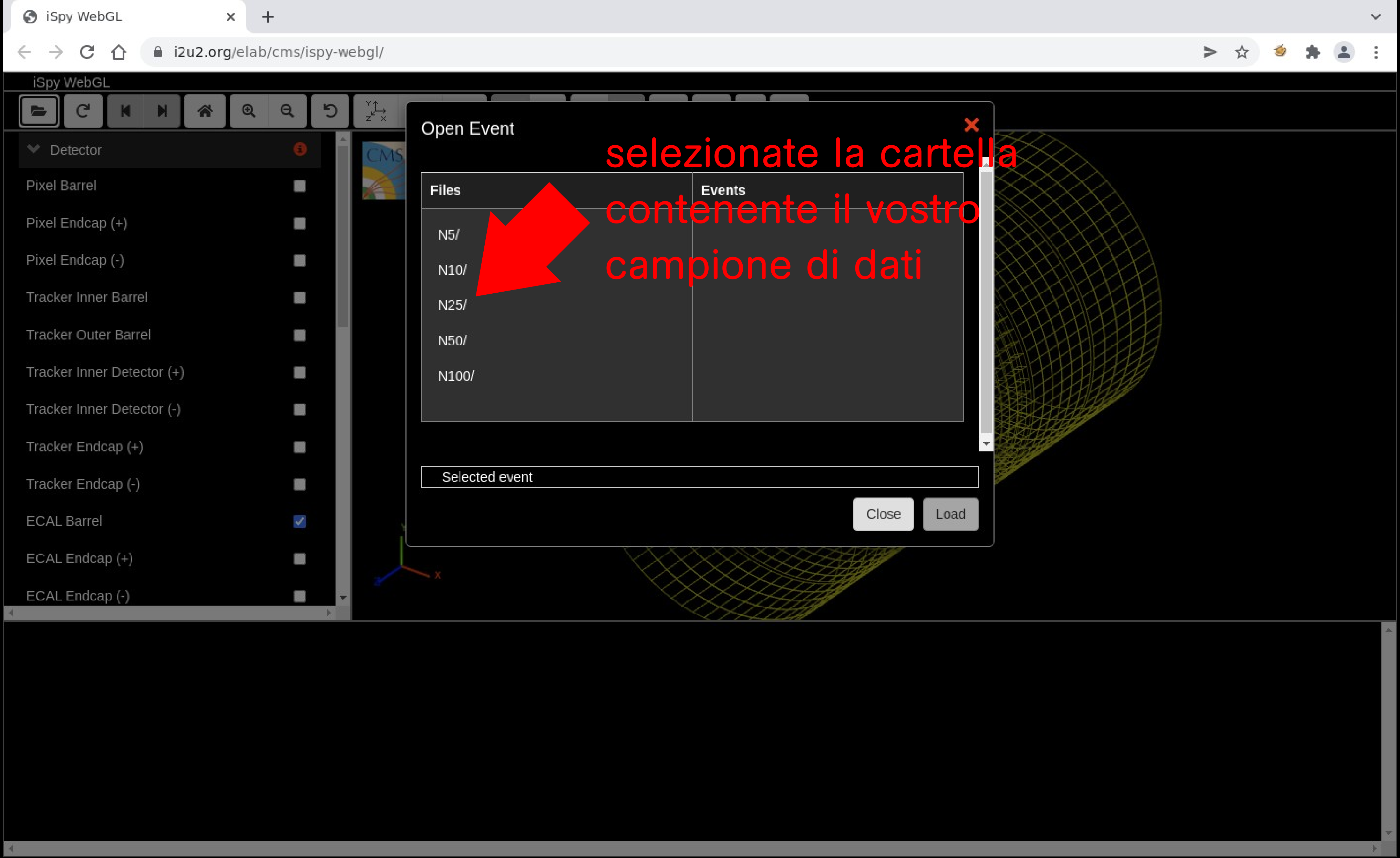
Caricamento degli eventi (II)



iSpy WebGL
i2u2.org/elab/cms/ispy-webgl/
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 (+) ☐
ECAL Endcap (-) ☐
CMS
Open File
Open file(s) from the Web
Open local file(s):
Choose Files
No file chos
Close
Y
X

Open file(s) from the Web

Caricamento degli eventi (III)


iSpy WebGL
i2u2.org/elab/cms/ispy-webgl/
iSpy WebGL
Detector
CMS
Open Event
Close
Load

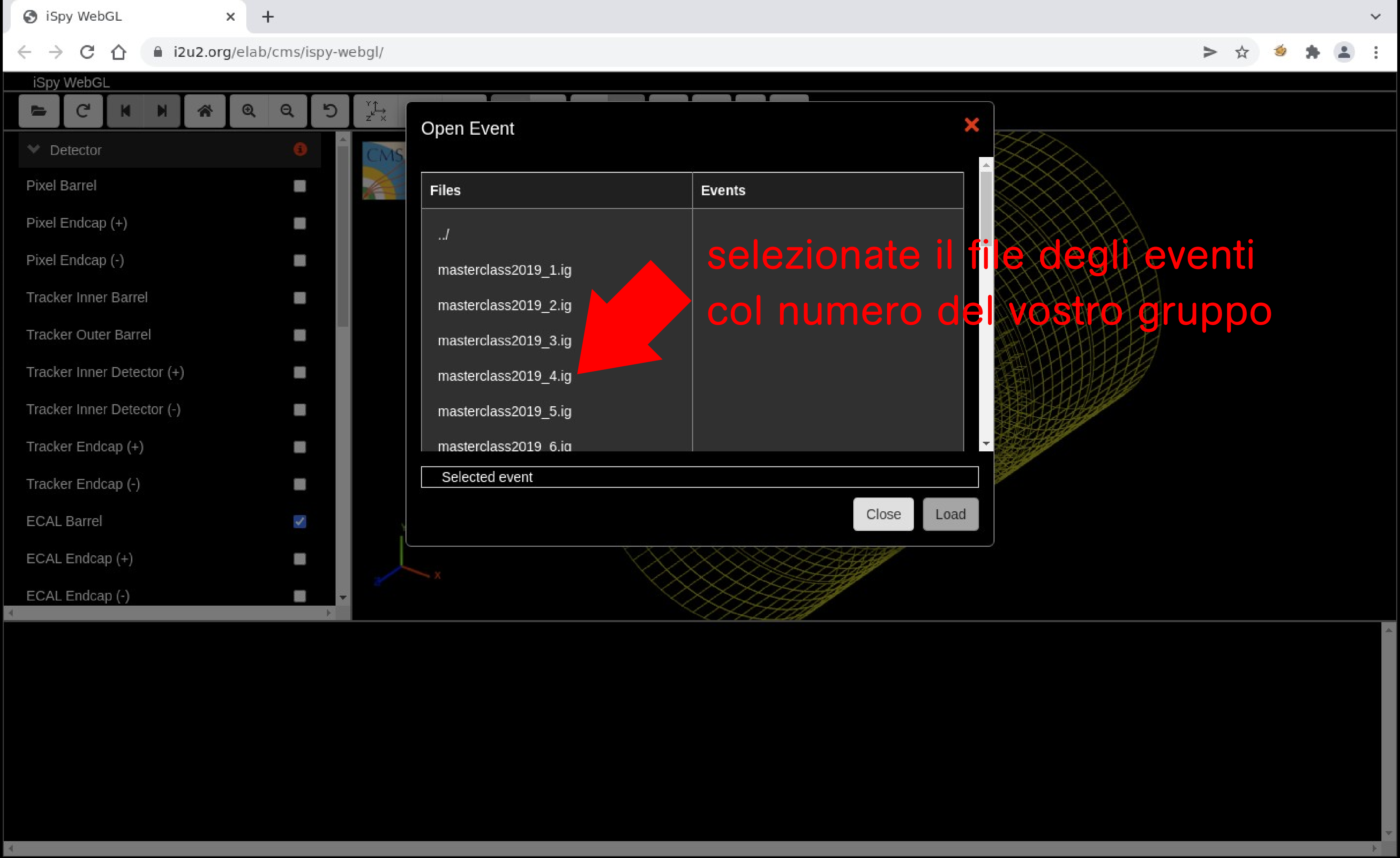
- Pixel Barrel ☐
- Pixel Endcap (+) ☐
- Pixel Endcap (-) ☐
- Tracker Inner Barrel ☐
- Tracker Outer Barrel ☐
- Tracker Inner Detector (+) ☐
- Tracker Inner Detector (-) ☐
- Tracker Endcap (+) ☐
- Tracker Endcap (-) ☐
- ECAL Barrel ☑
- ECAL Endcap (+) ☐
- ECAL Endcap (-) ☐

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

Selected event

selezionate la cartella contenente il vostro campione di dati

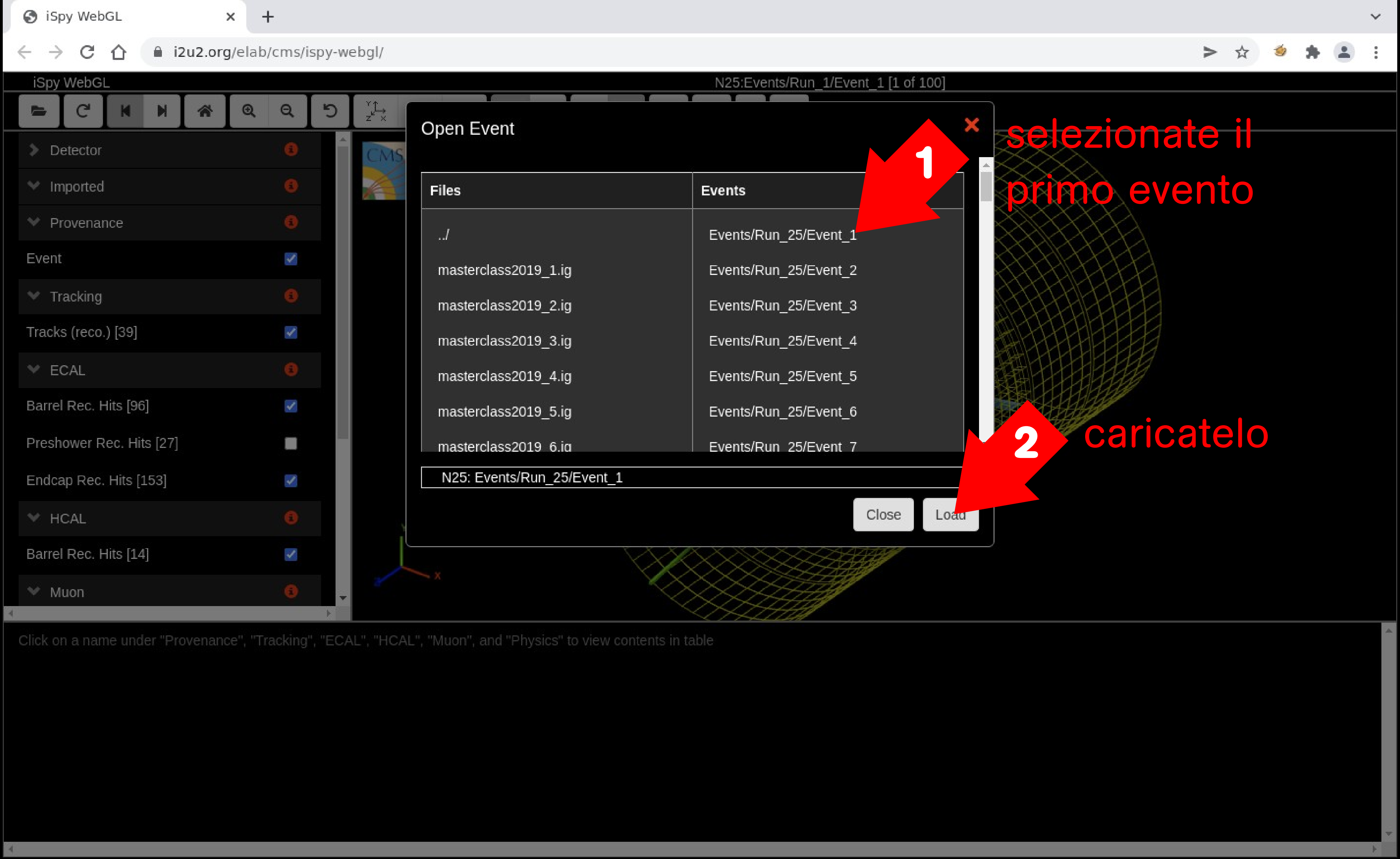
Caricamento degli eventi (IV)



iSpy WebGL
i2u2.org/elab/cms/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 (+) ☐
ECAL Endcap (-) ☐
Open Event
Files
Events
../
masterclass2019_1.ig
masterclass2019_2.ig
masterclass2019_3.ig
masterclass2019_4.ig
masterclass2019_5.ig
masterclass2019_6.ig
Selected event
Close
Load

selezionate il file degli eventi col numero del vostro gruppo

Caricamento degli eventi (V)



iSpy WebGL
i2u2.org/elab/cms/ispy-webgl/
iSpy WebGL
N25:Events/Run_1/Event_1 [1 of 100]
Detector
Imported
Provenance
Event ☑
Tracking
Tracks (reco.) [39] ☑
ECAL
Barrel Rec. Hits [96] ☑
Preshower Rec. Hits [27] ☐
Endcap Rec. Hits [153] ☑
HCAL
Barrel Rec. Hits [14] ☑
Muon
Open Event
Close
Load

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

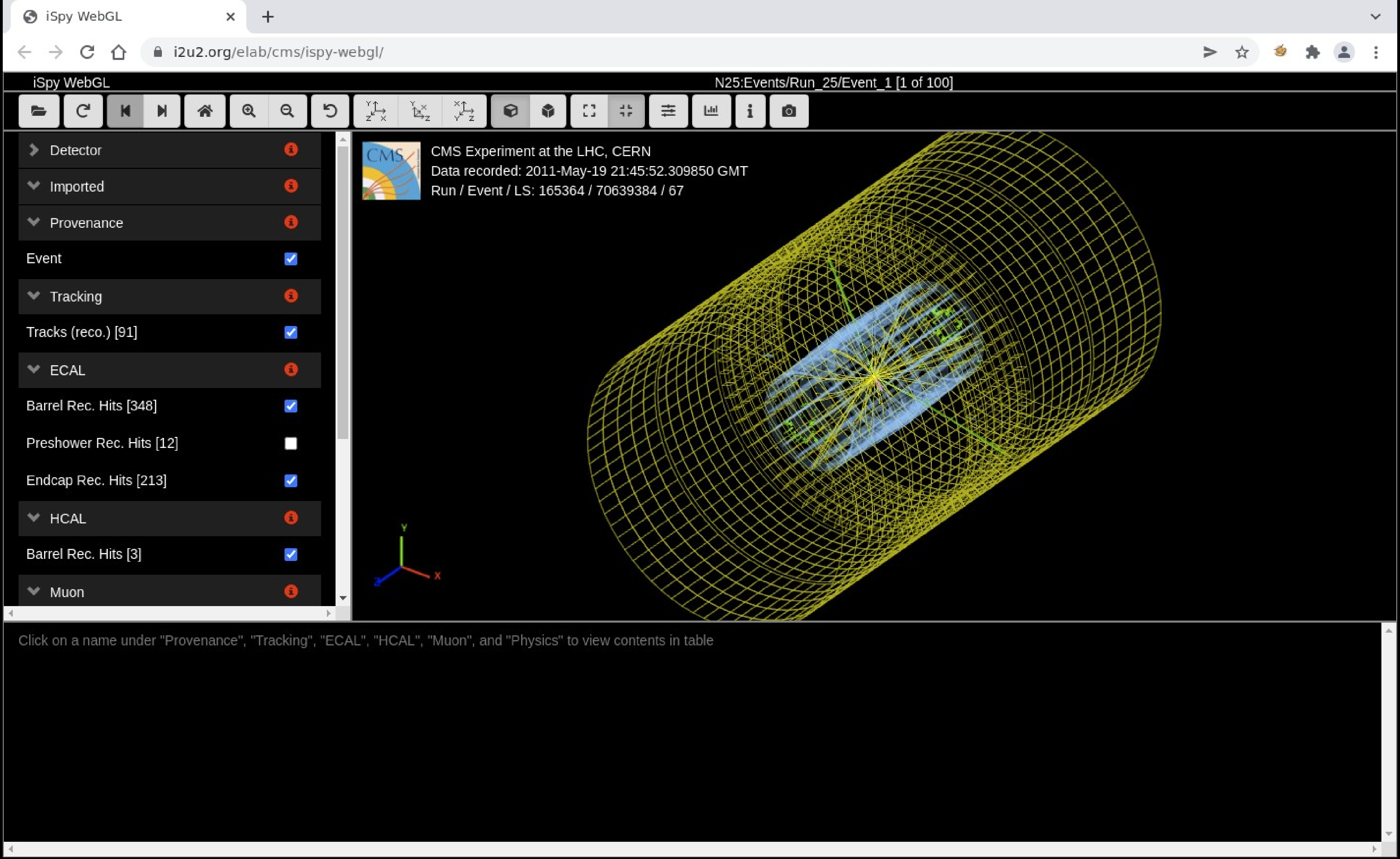
N25: Events/Run_25/Event_1

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

1 selezionate il primo evento

2 caricatelo

Il primo evento


iSpy WebGL
i2u2.org/elab/cms/ispy-webgl/
iSpy WebGL
Y
X

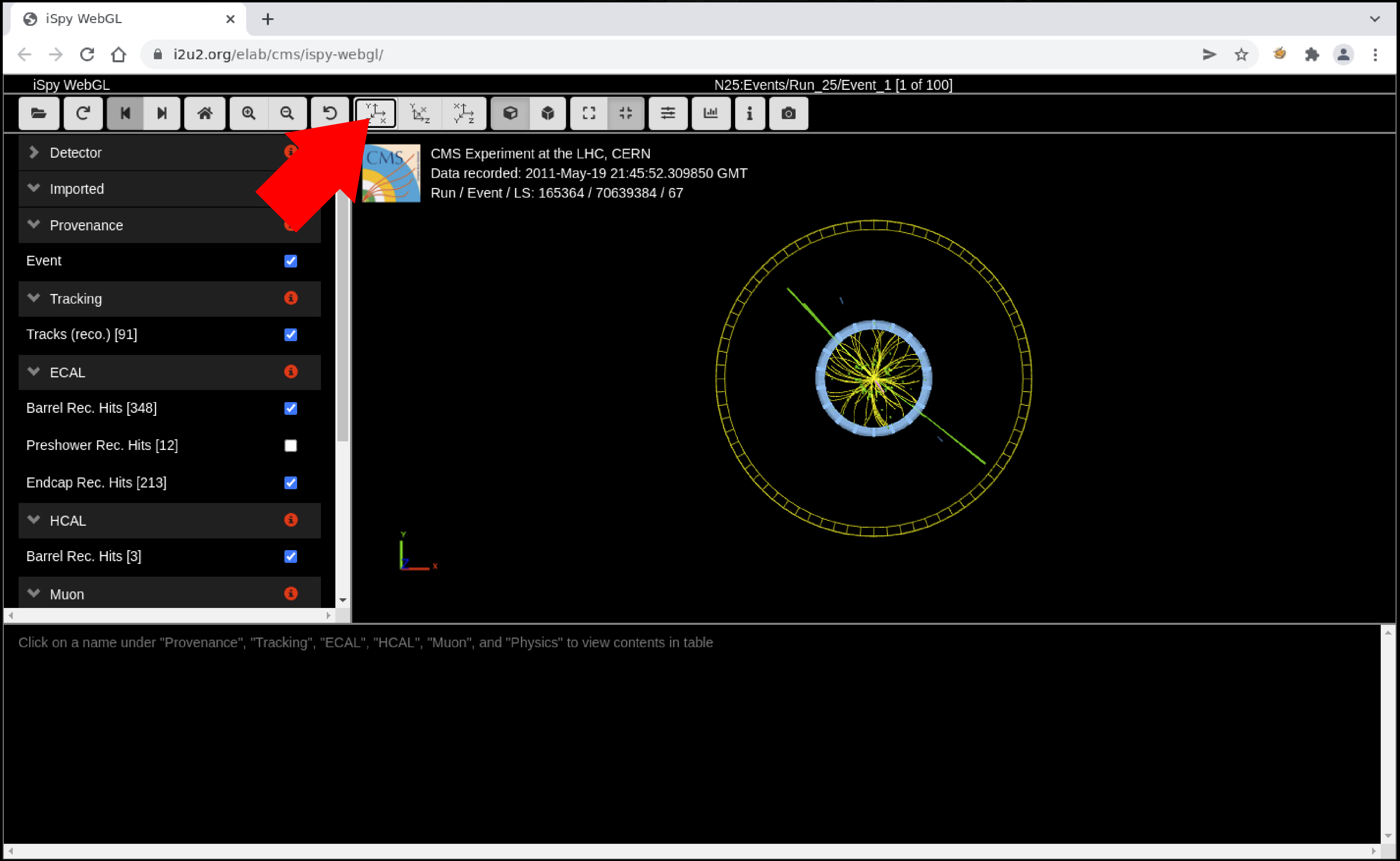
N25:Events/Run_25/Event_1 [1 of 100]

- 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

View frontale



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

iSpy WebGL

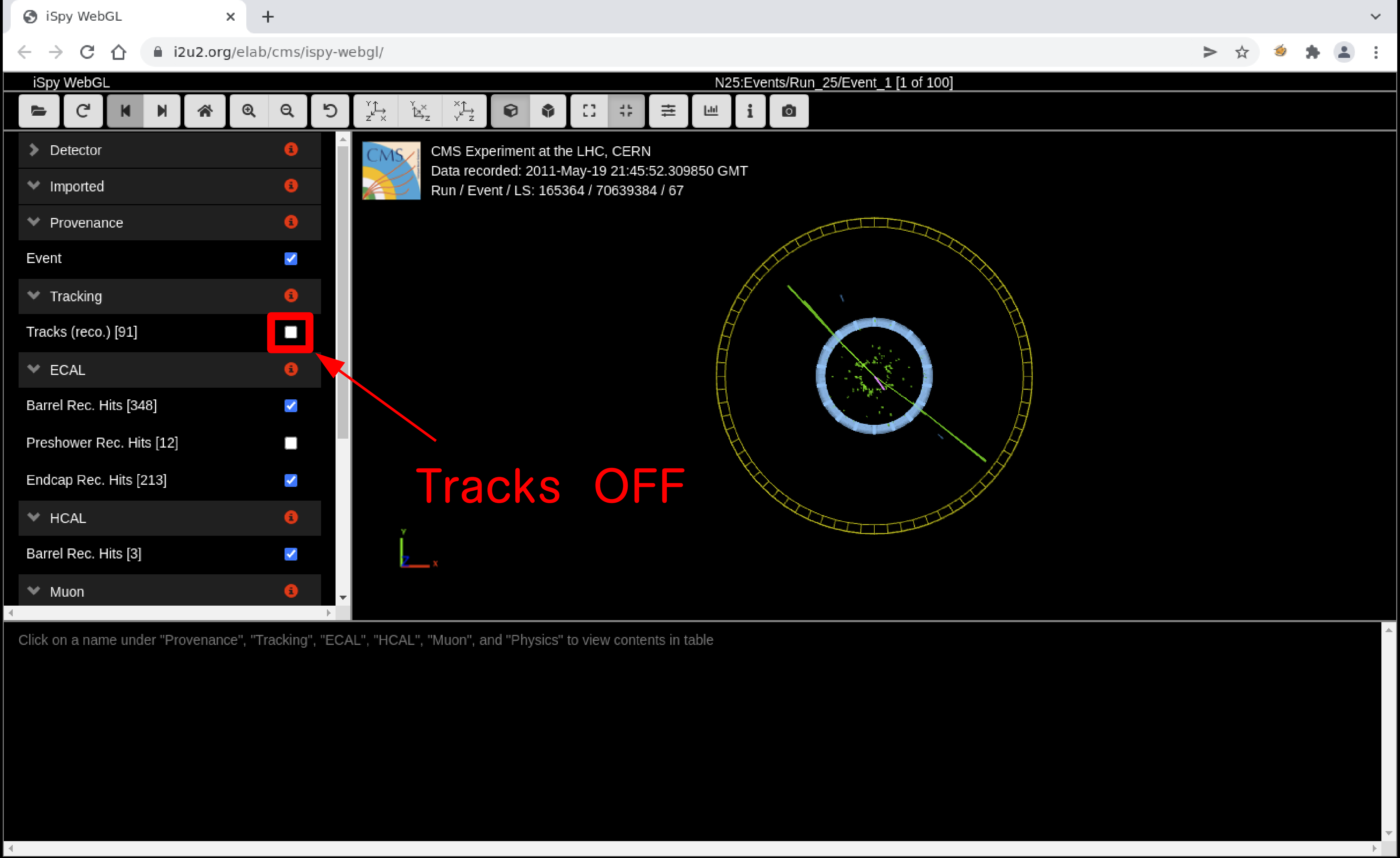
N25:Events/Run_25/Event_1 [1 of 100]

- 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

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

Spegniamo le tracce


iSpy WebGL
i2u2.org/elab/cms/ispy-webgl/
iSpy WebGL
N25:Events/Run_25/Event_1 [1 of 100]
CMS

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] ☑

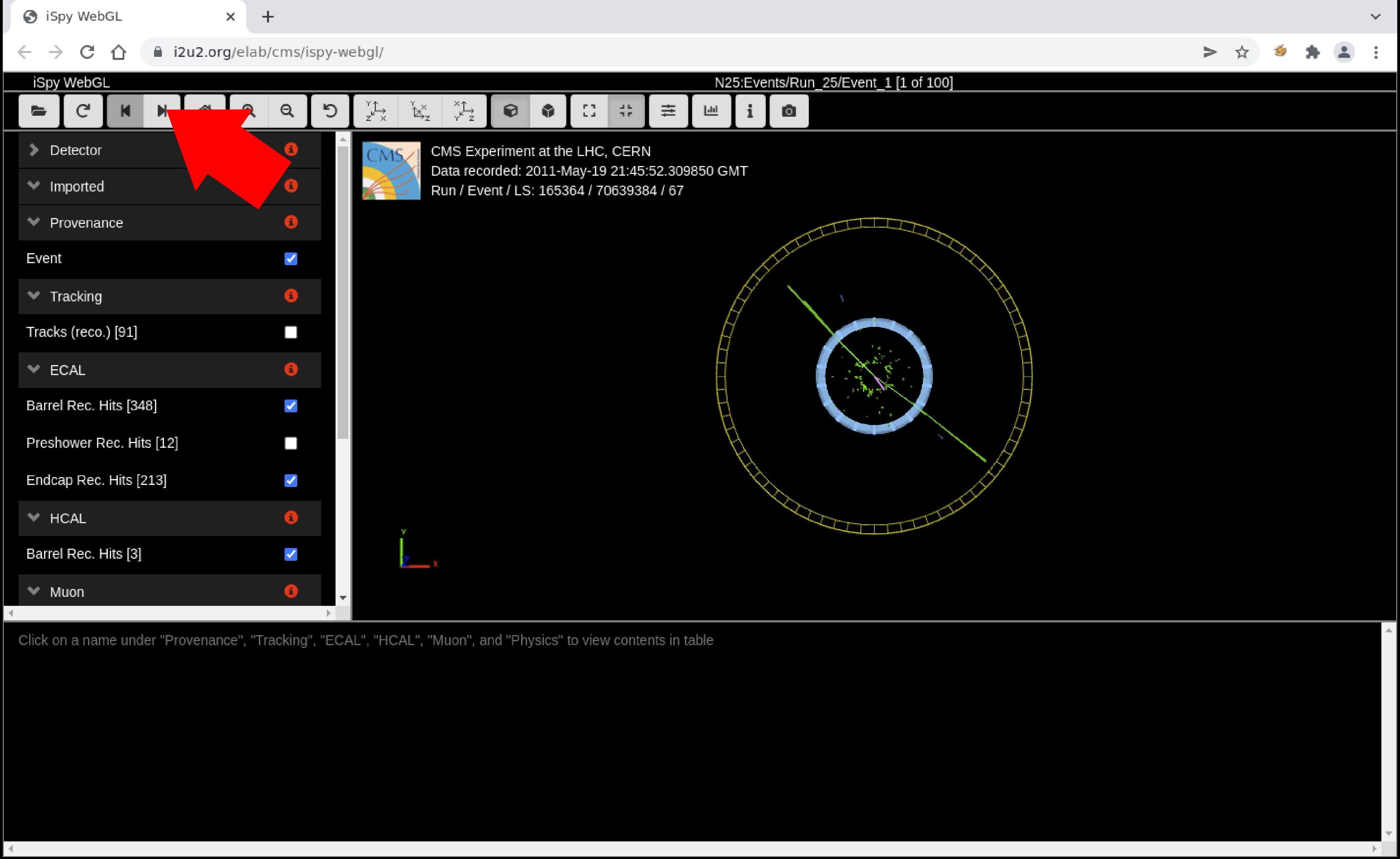
Muon

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

Tracks OFF

Evento successivo (I)


iSpy WebGL
i2u2.org/elab/cms/ispy-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

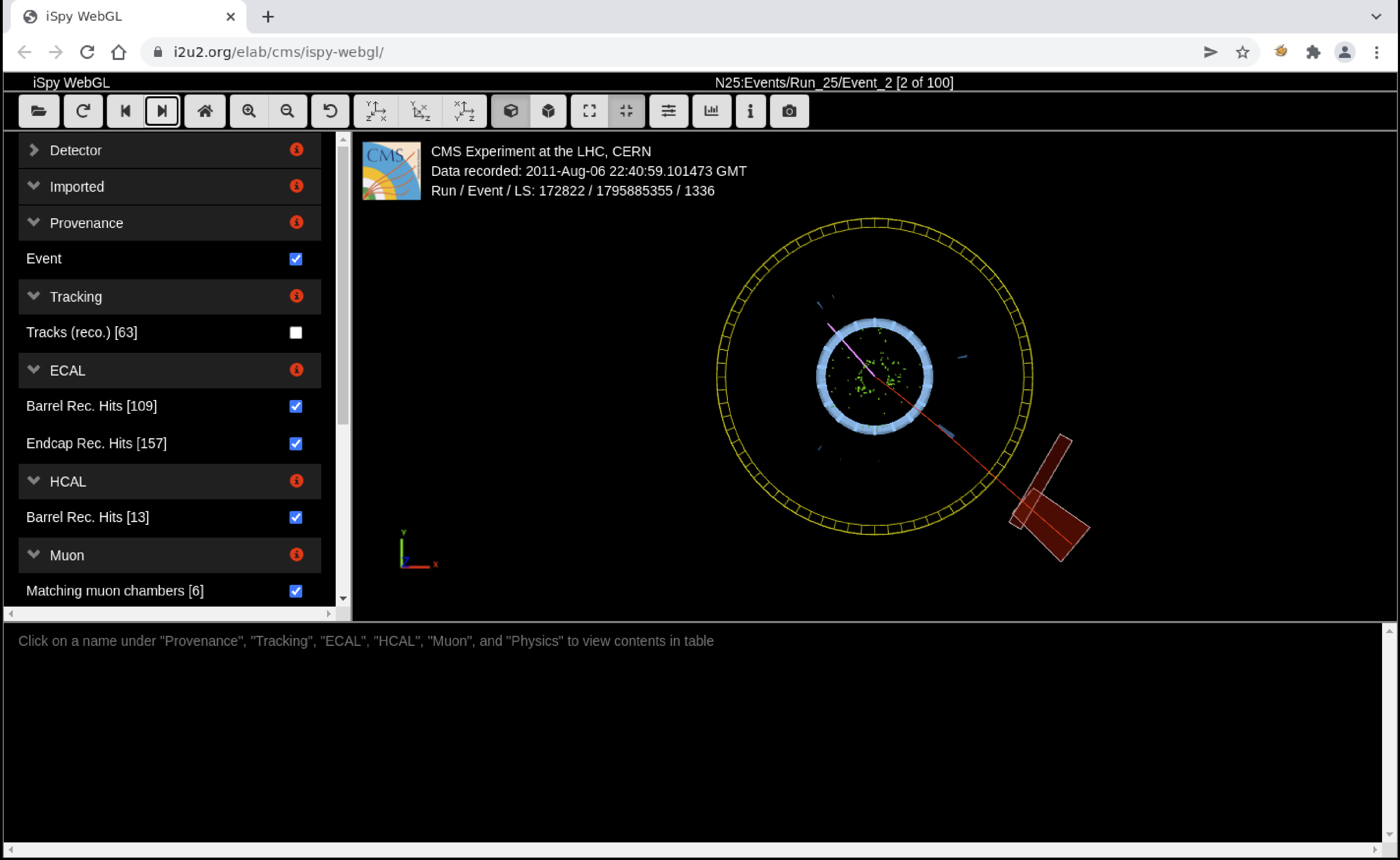
Barrel Rec. Hits [3] ☑

Muon

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

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

Evento successivo (II)



iSpy WebGL

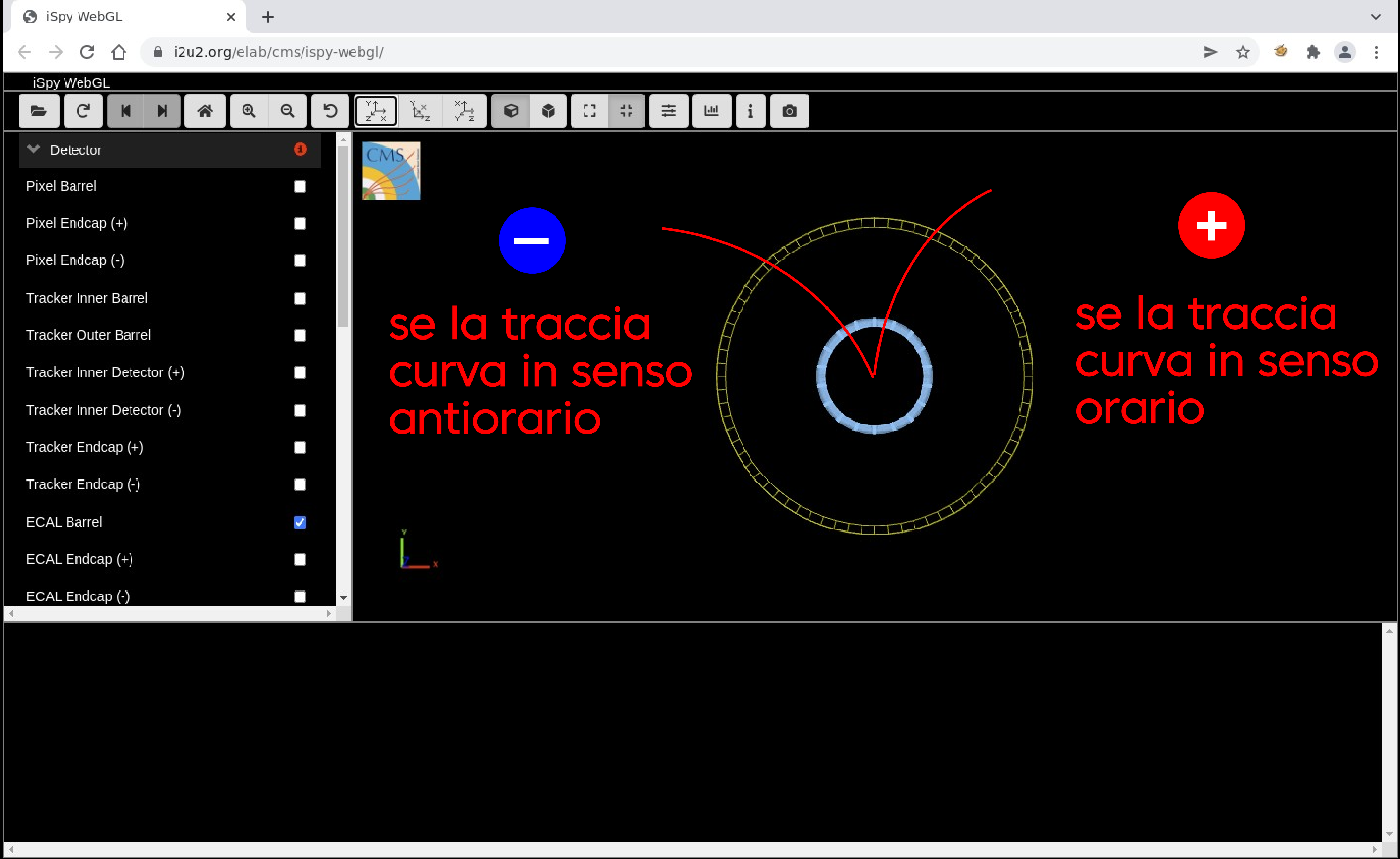
N25:Events/Run_25/Event_2 [2 of 100]

- 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

Determinazione della carica + o -


iSpy WebGL
i2u2.org/elab/cms/ispy-webgl/
iSpy WebGL
Detector
CMS
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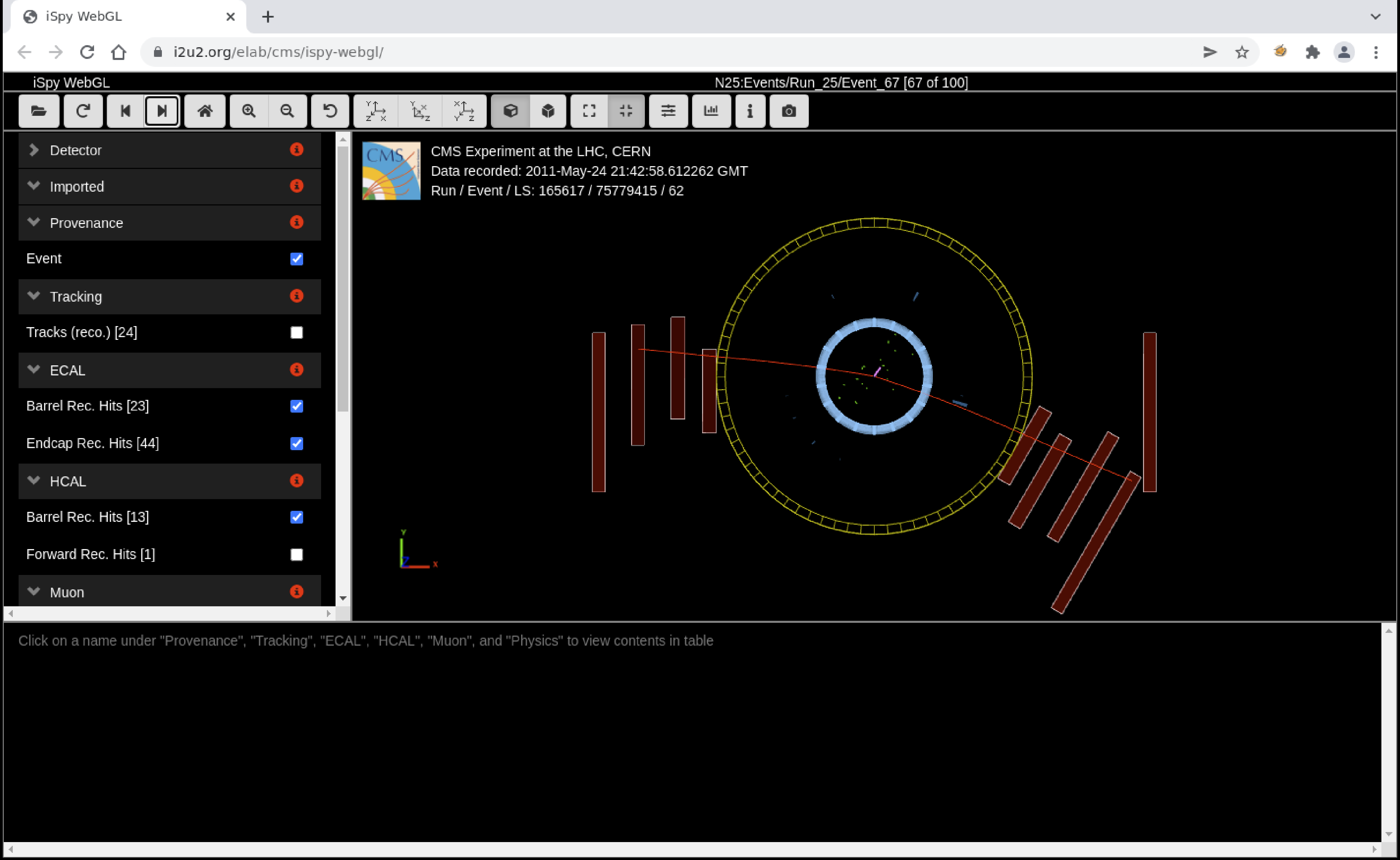
x

- 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 (+) ☐
- ECAL Endcap (-) ☐

se la traccia curva in senso antiorario

se la traccia curva in senso orario

Calcolo della massa invatiante



iSpy WebGL

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

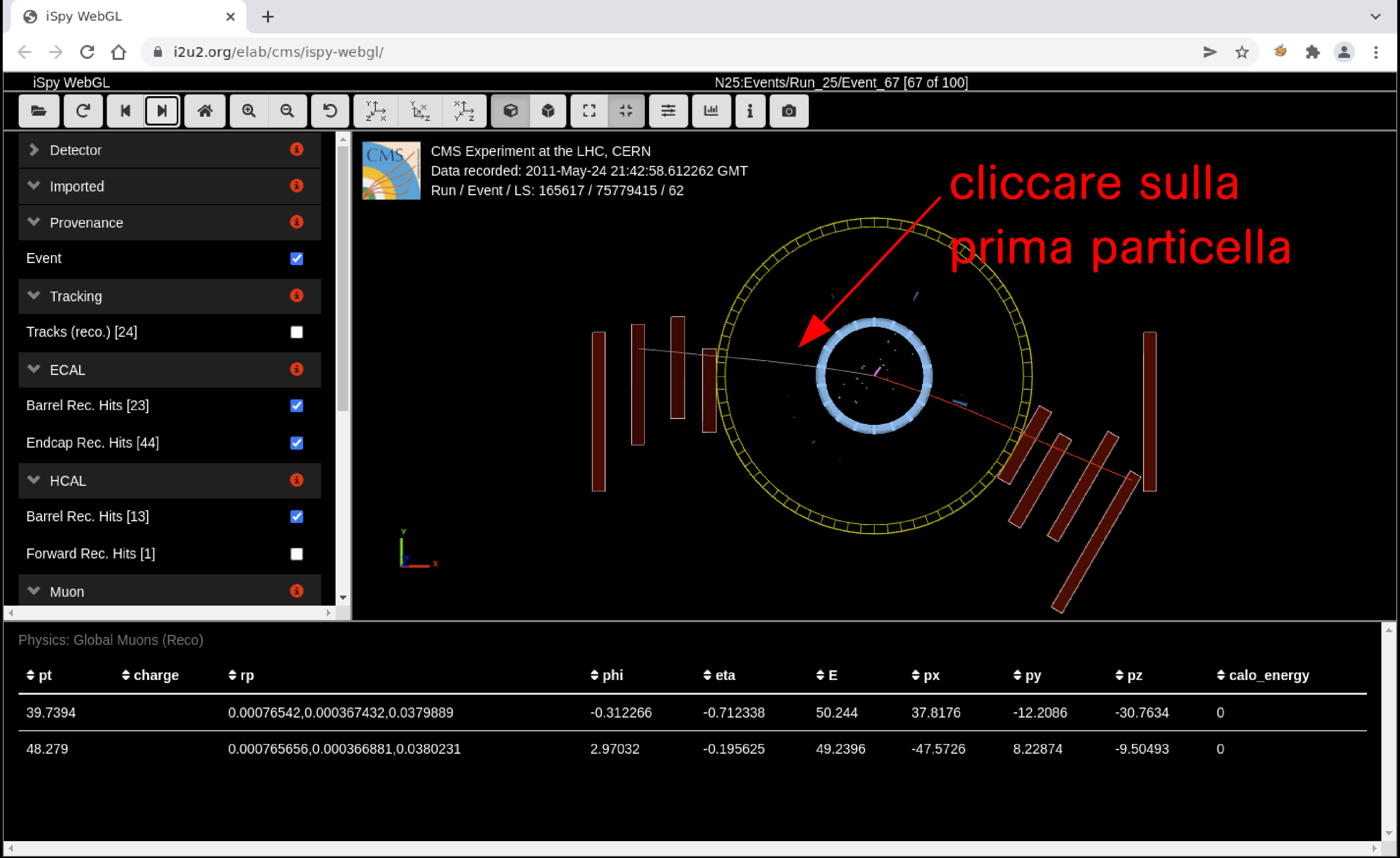
N25:Events/Run_25/Event_67 [67 of 100]

- 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

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

Calcolo della massa invatiante


iSpy WebGL
i2u2.org/elab/cms/ispy-webgl/
iSpy WebGL
N25:Events/Run_25/Event_67 [67 of 100]
Detector
Imported
Provenance
Tracking
ECAL
HCAL
Muon
CMS
y
x

Event ☑

Tracks (reco.) [24] ☐

Barrel Rec. Hits [23] ☑

Endcap Rec. Hits [44] ☑

Barrel Rec. Hits [13] ☑

Forward Rec. Hits [1] ☐

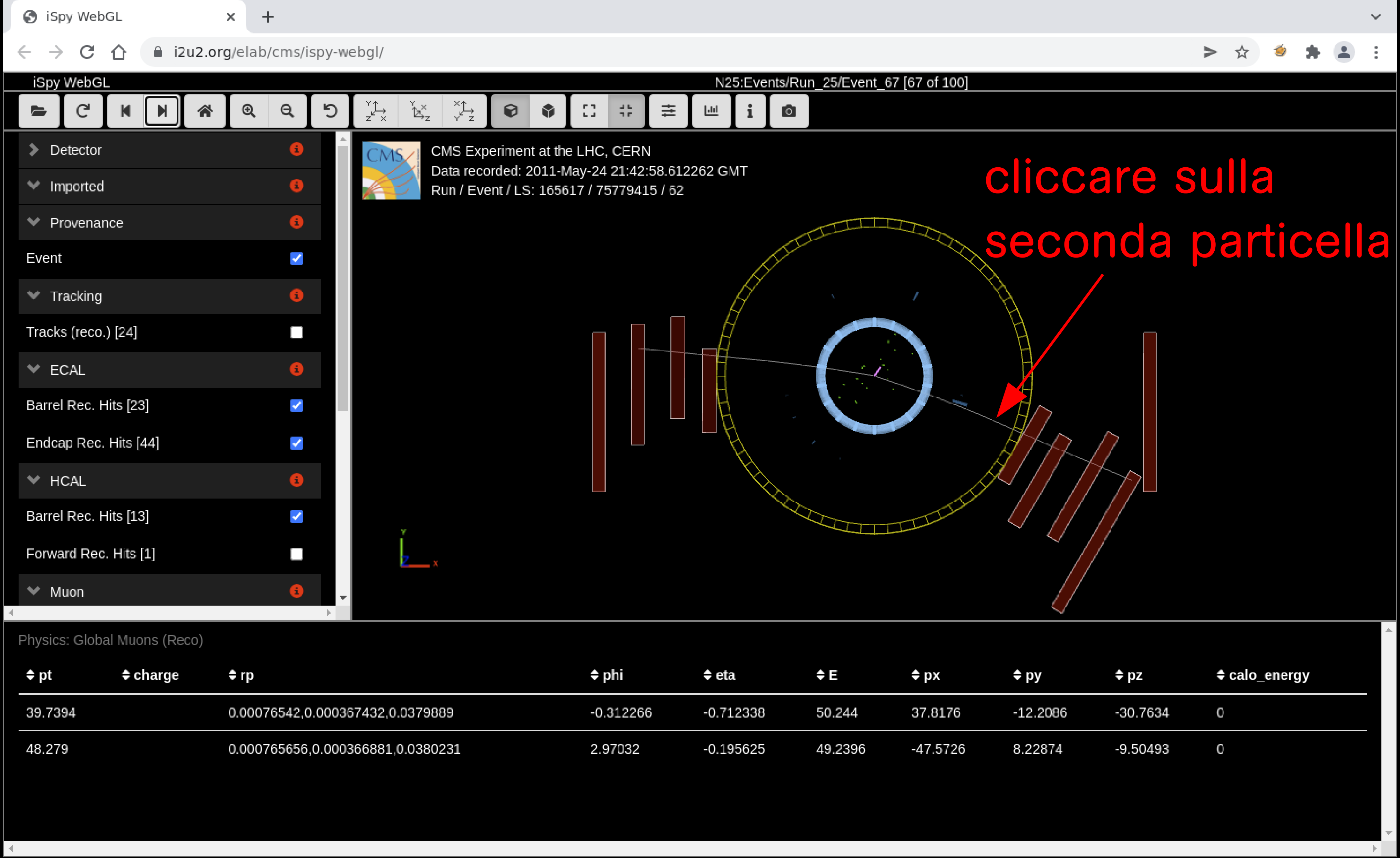
CMS Experiment at the LHC, CERN
Data recorded: 2011-May-24 21:42:58.612262 GMT
Run / Event / LS: 165617 / 75779415 / 62

cliccare 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

Calcolo della massa invatiante


iSpy WebGL
i2u2.org/elab/cms/ispy-webgl/
iSpy WebGL
N25:Events/Run_25/Event_67 [67 of 100]
Y
X

- 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

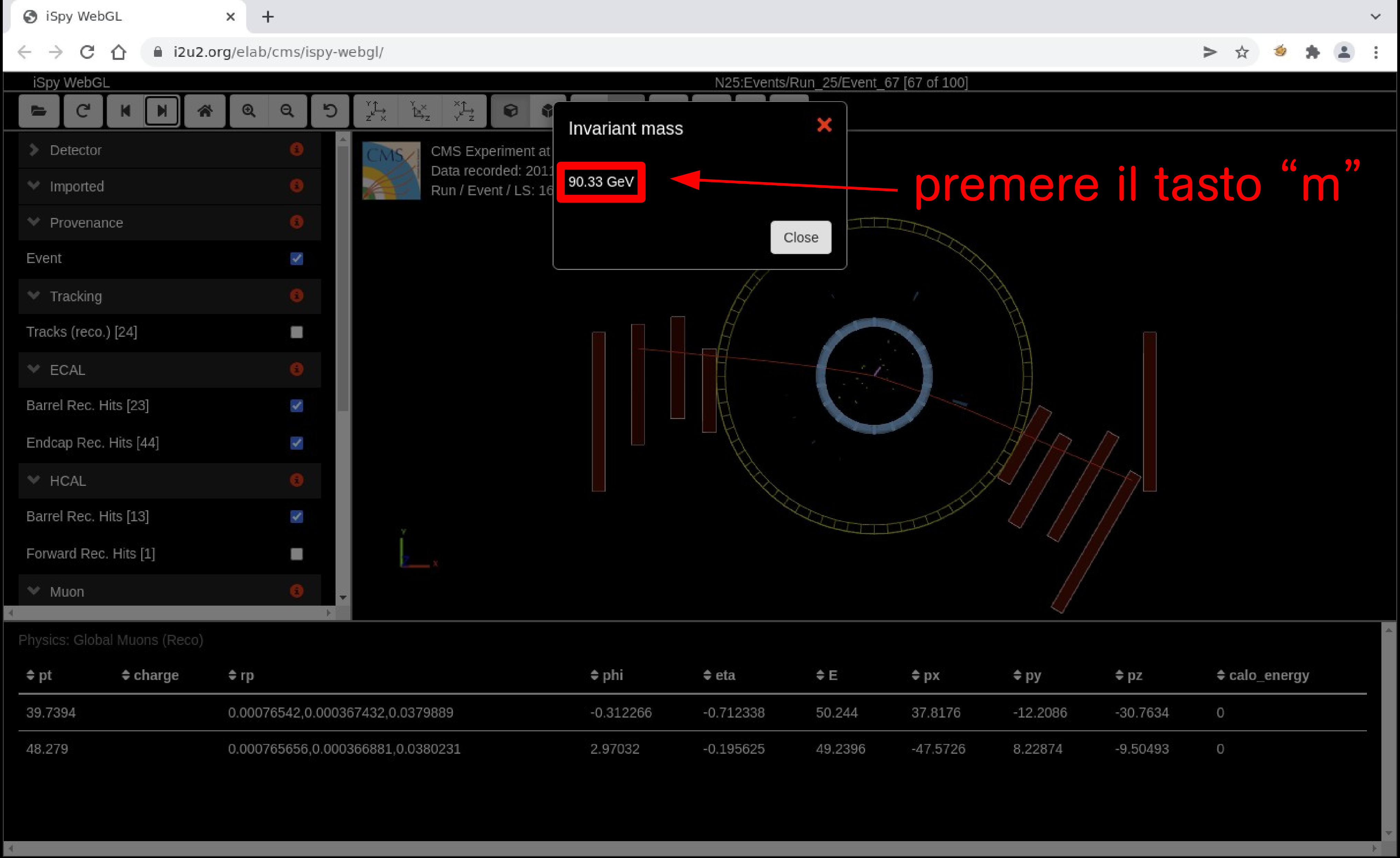
CMS Experiment at the LHC, CERN
Data recorded: 2011-May-24 21:42:58.612262 GMT
Run / Event / LS: 165617 / 75779415 / 62

cliccare 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

Calcolo della massa invatiante



iSpy WebGL
i2u2.org/elab/cms/ispy-webgl/
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
Data recorded: 2011
Run / Event / LS: 16

Invariant mass

90.33 GeV

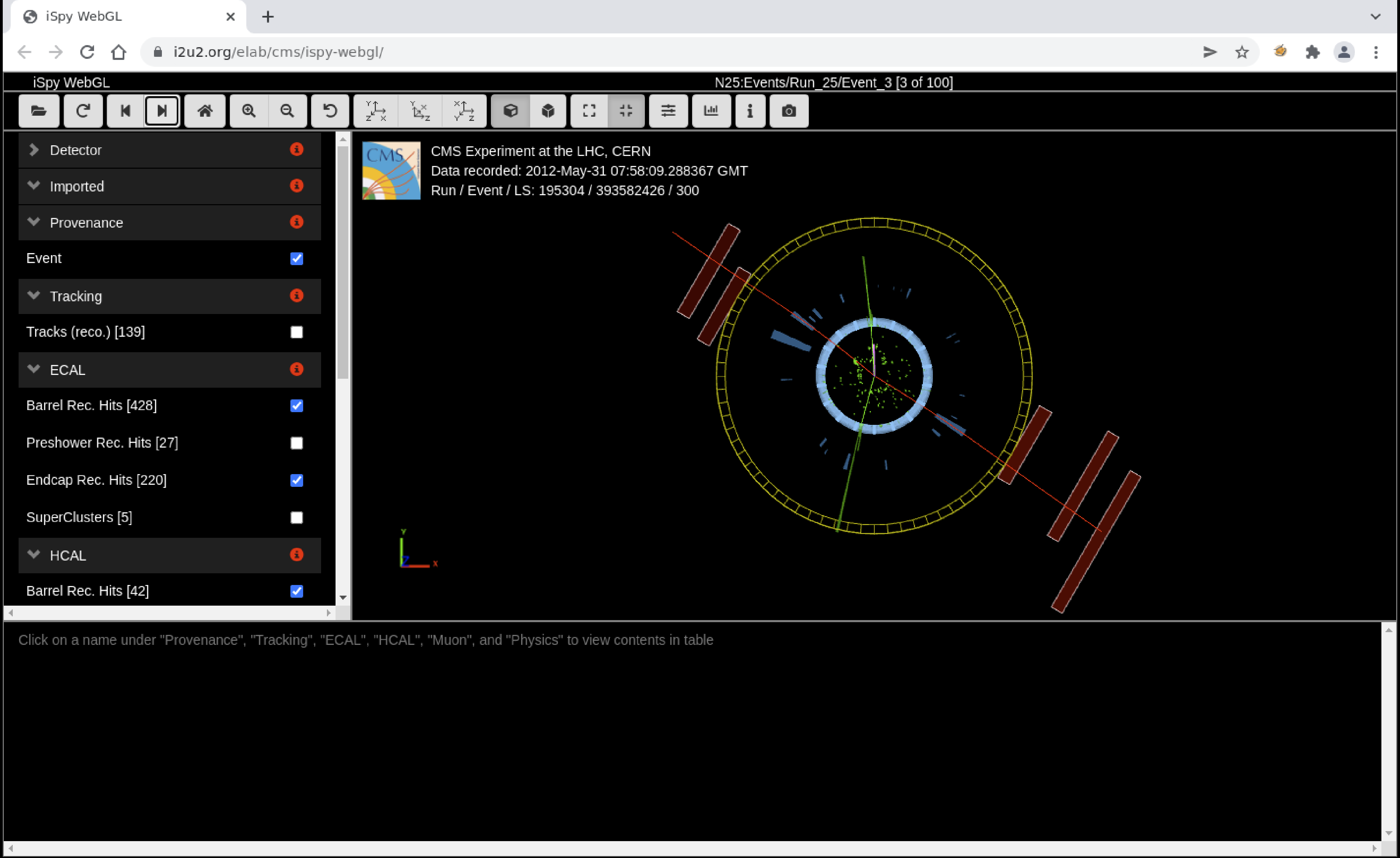
Close

premere il tasto “m”

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

Un evento con 2μ e 2e


iSpy WebGL
i2u2.org/elab/cms/ispy-webgl/
iSpy WebGL
N25:Events/Run_25/Event_3 [3 of 100]
Detector
Imported
Provenance
Tracking
ECAL
HCAL
CMS

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

Event ☑

Tracks (reco.) [139] ☐

Barrel Rec. Hits [428] ☑

Preshower Rec. Hits [27] ☐

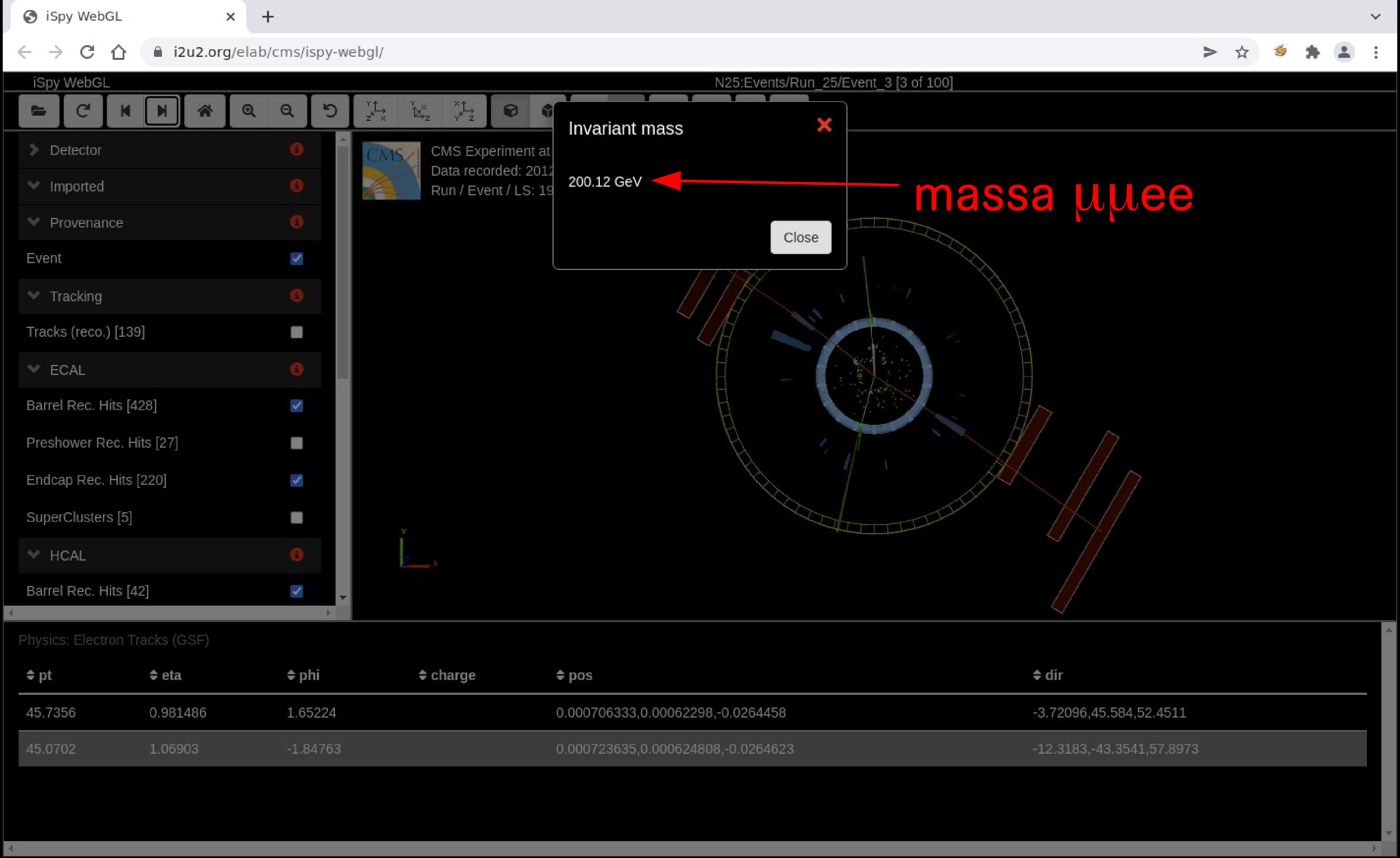
Endcap Rec. Hits [220] ☑

SuperClusters [5] ☐

Barrel Rec. Hits [42] ☑

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

Un evento con 2μ e 2e


iSpy WebGL
i2u2.org/elab/cms/ispy-webgl/
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
Data recorded: 2012
Run / Event / LS: 19
Close

Invariant mass

200.12 GeV

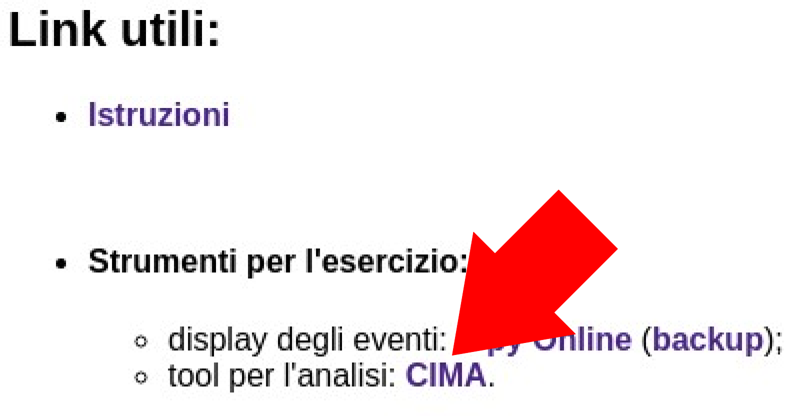
massa μμee

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

Apriamo CIMA

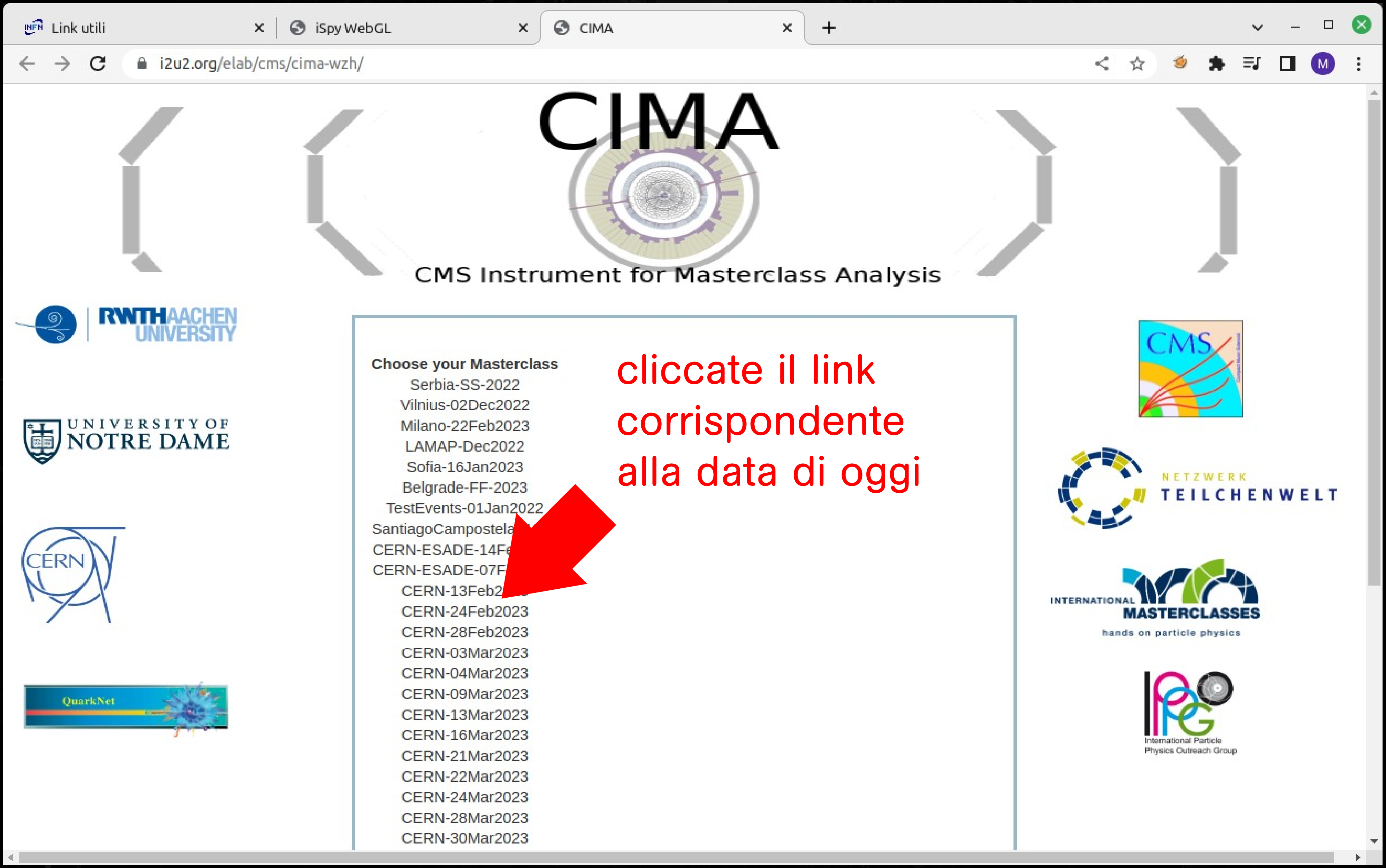
l.infn.it/mc-ts



Link utili:

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

Selezionate la Masterclass di oggi


Link utili
iSpy WebGL
CIMA
i2u2.org/elab/cms/cima-wzh/
RWTH AACHEN UNIVERSITY
UNIVERSITY OF NOTRE DAME
CERN
QuarkNet
CMS
NETZWERK TEILCHENWELT
INTERNATIONAL MASTERCLASSES
hands on particle physics
IPPOG
International Particle Physics Outreach Group

CIMA

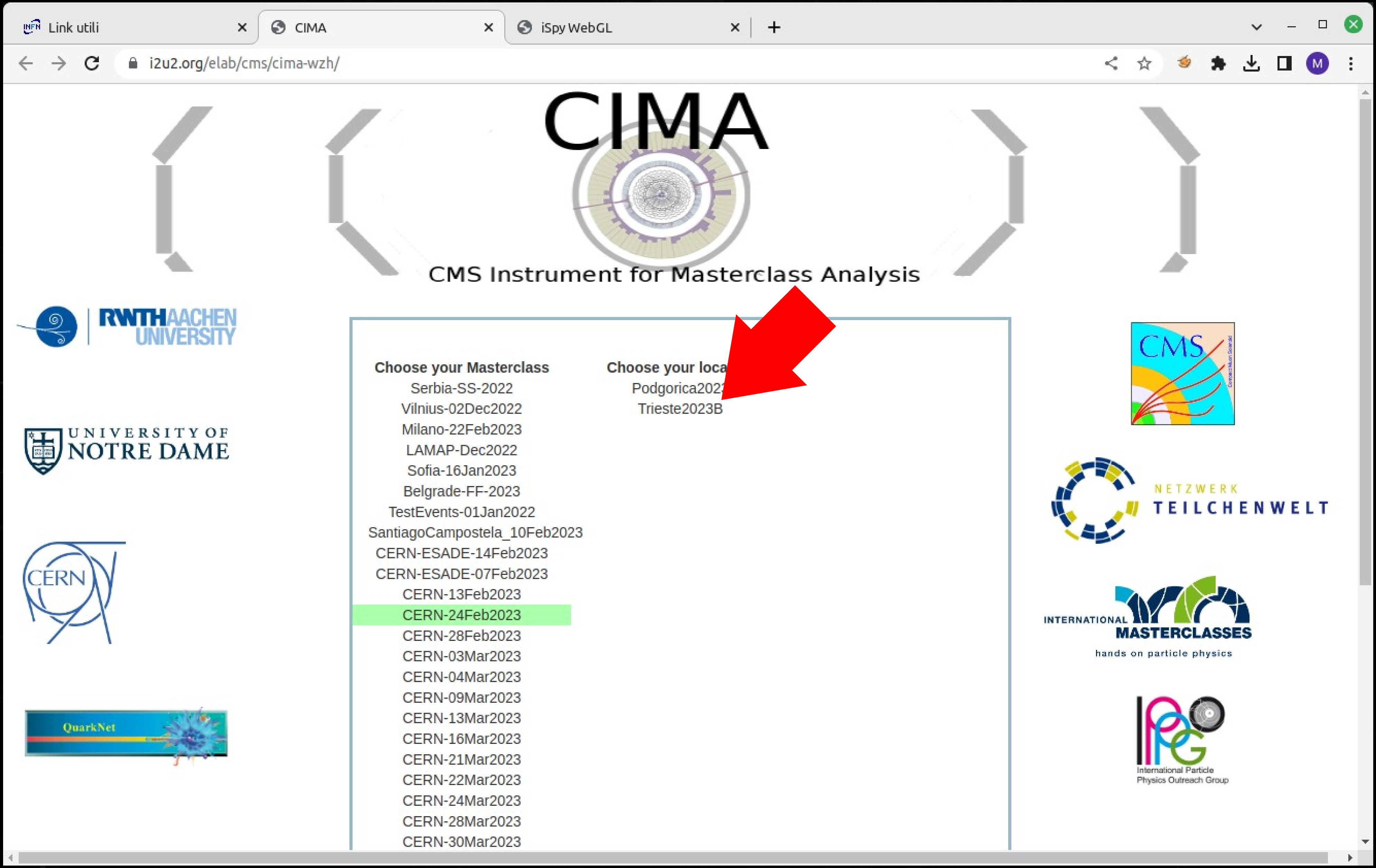
CMS Instrument for Masterclass Analysis

Choose your Masterclass

Serbia-SS-2022
Vilnius-02Dec2022
Milano-22Feb2023
LAMAP-Dec2022
Sofia-16Jan2023
Belgrade-FF-2023
TestEvents-01Jan2022
SantiagoCompostela
CERN-ESADE-14Fe
CERN-ESADE-07F
CERN-13Feb2
CERN-24Feb2023
CERN-28Feb2023
CERN-03Mar2023
CERN-04Mar2023
CERN-09Mar2023
CERN-13Mar2023
CERN-16Mar2023
CERN-21Mar2023
CERN-22Mar2023
CERN-24Mar2023
CERN-28Mar2023
CERN-30Mar2023

cliccate il link corrispondente alla data di oggi

Selezionate la nostra località



CIMA

CMS Instrument for Masterclass Analysis

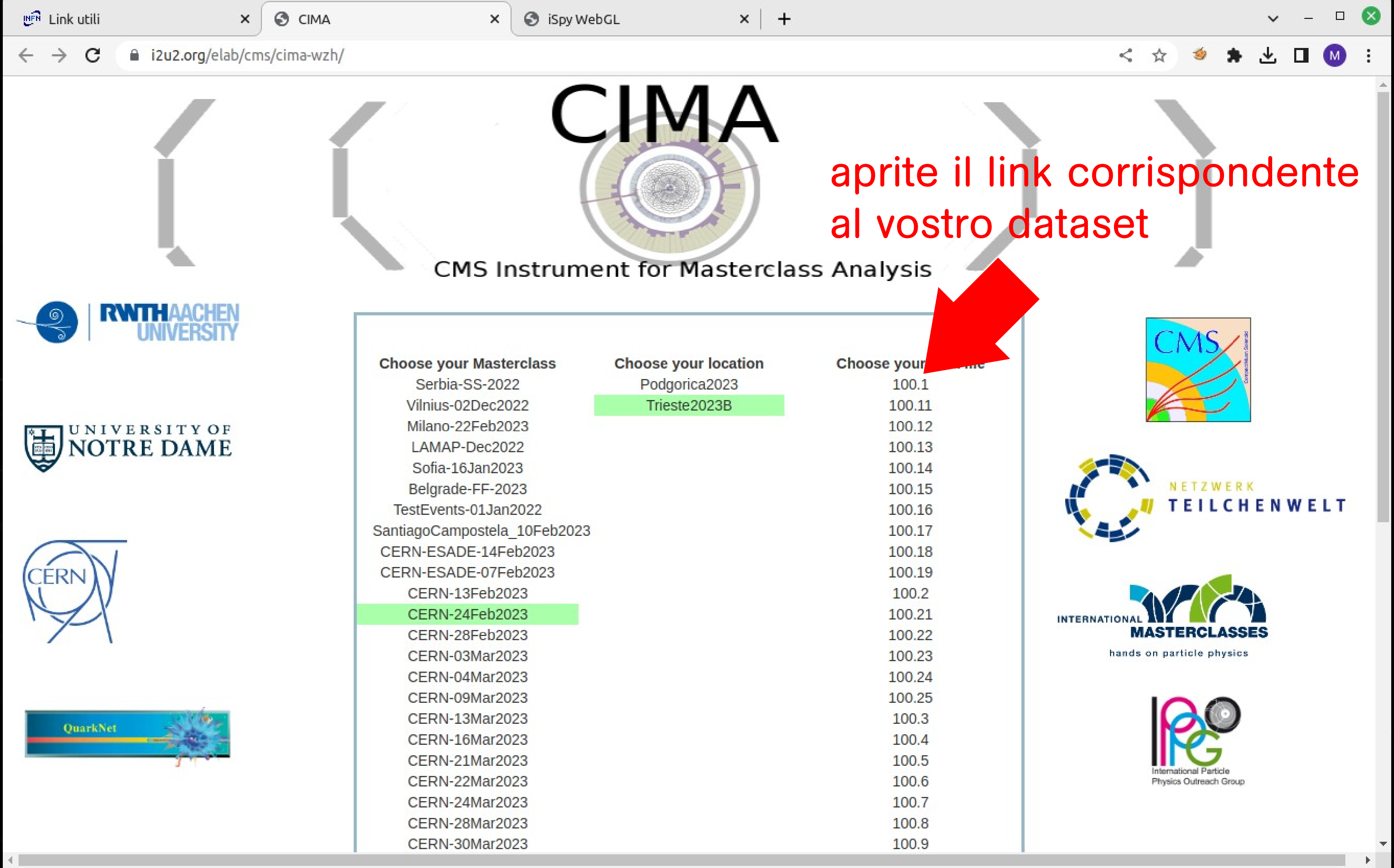
Choose your Masterclass

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 loca

Podgorica202
Trieste2023B

Selezionate il vostro dataset



CIMA

CMS Instrument for Masterclass Analysis

aprite il link corrispondente al vostro dataset

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
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- CERN-13Mar2023
- CERN-16Mar2023
- CERN-21Mar2023
- CERN-22Mar2023
- CERN-24Mar2023
- CERN-28Mar2023
- CERN-30Mar2023

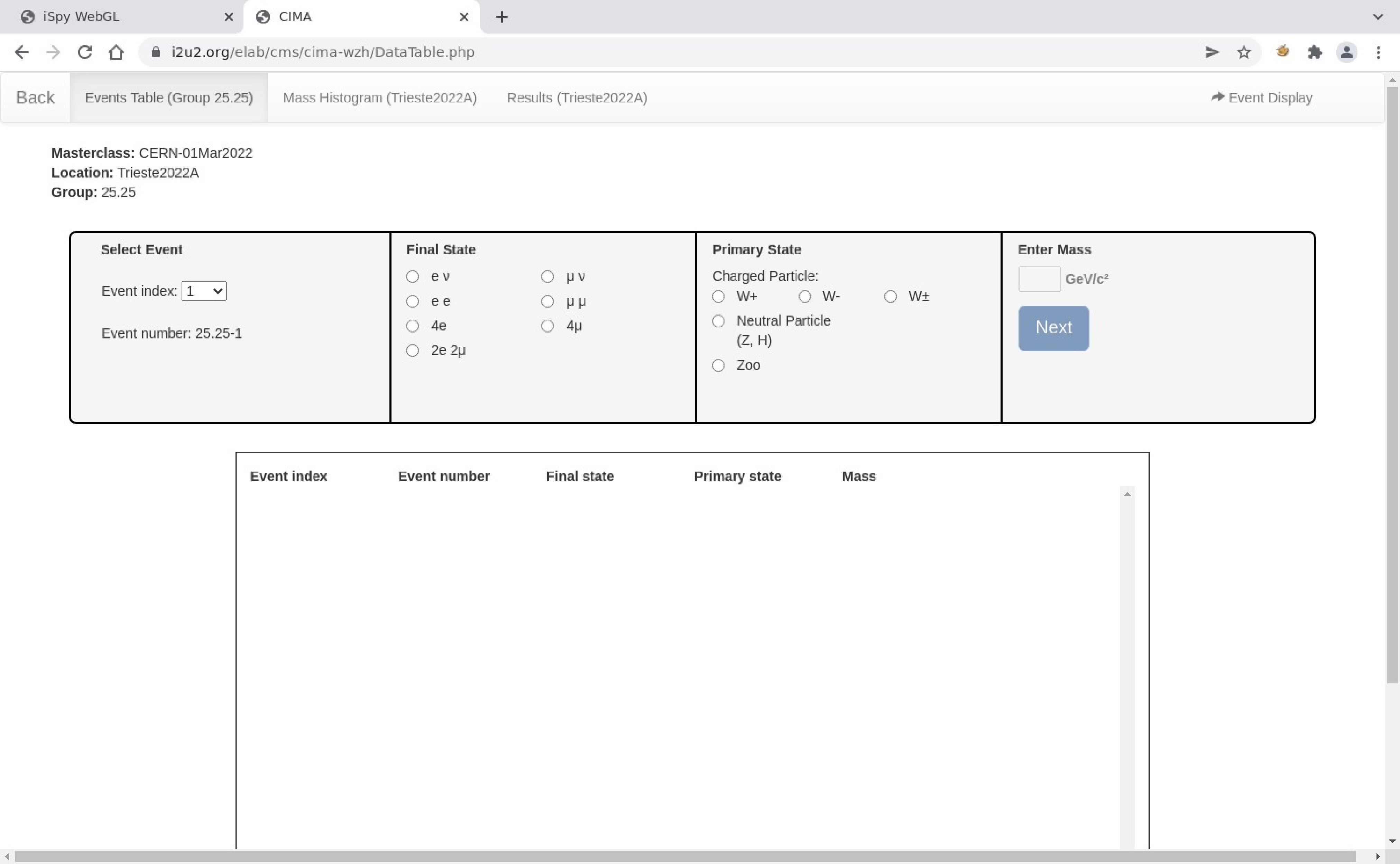
Choose your location

- Podgorica2023
- Trieste2023B

Choose your

- 100.1
- 100.11
- 100.12
- 100.13
- 100.14
- 100.15
- 100.16
- 100.17
- 100.18
- 100.19
- 100.2
- 100.21
- 100.22
- 100.23
- 100.24
- 100.25
- 100.3
- 100.4
- 100.5
- 100.6
- 100.7
- 100.8
- 100.9

Tabella degli eventi



iSpy WebGL
CIMA
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

Select Event

Event index: 1

Event number: 25.25-1

Final State

○ e ν ○ μ ν
○ e e ○ μ μ
○ 4e ○ 4μ
○ 2e 2μ

Primary State

Charged Particle:
○ W+ ○ W- ○ W±
○ Neutral Particle (Z, H)
○ Zoo

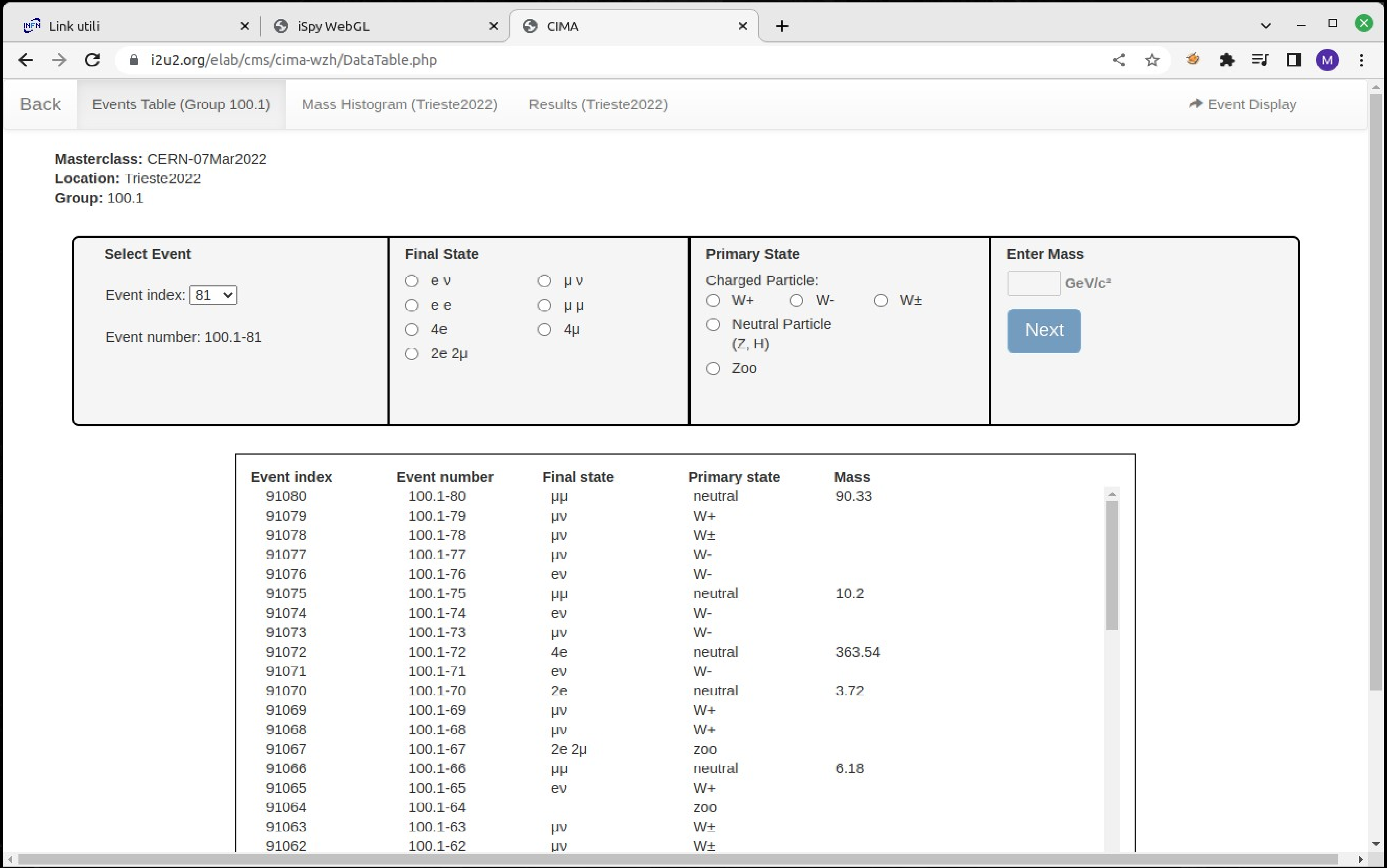
Enter Mass

GeV/c²

Next

Event index	Event number	Final state	Primary state	Mass

Tabella degli eventi


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

Select Event

Event index: 81

Event number: 100.1-81

Final State

- ○ e ν
- ○ μ ν
- ○ e e
- ○ μ μ
- ○ 4e
- ○ 4μ
- ○ 2e 2μ

Primary State

Charged Particle:
- ○ W+
- ○ W-
- ○ W±
- ○ Neutral Particle (Z, H)
- ○ Zoo

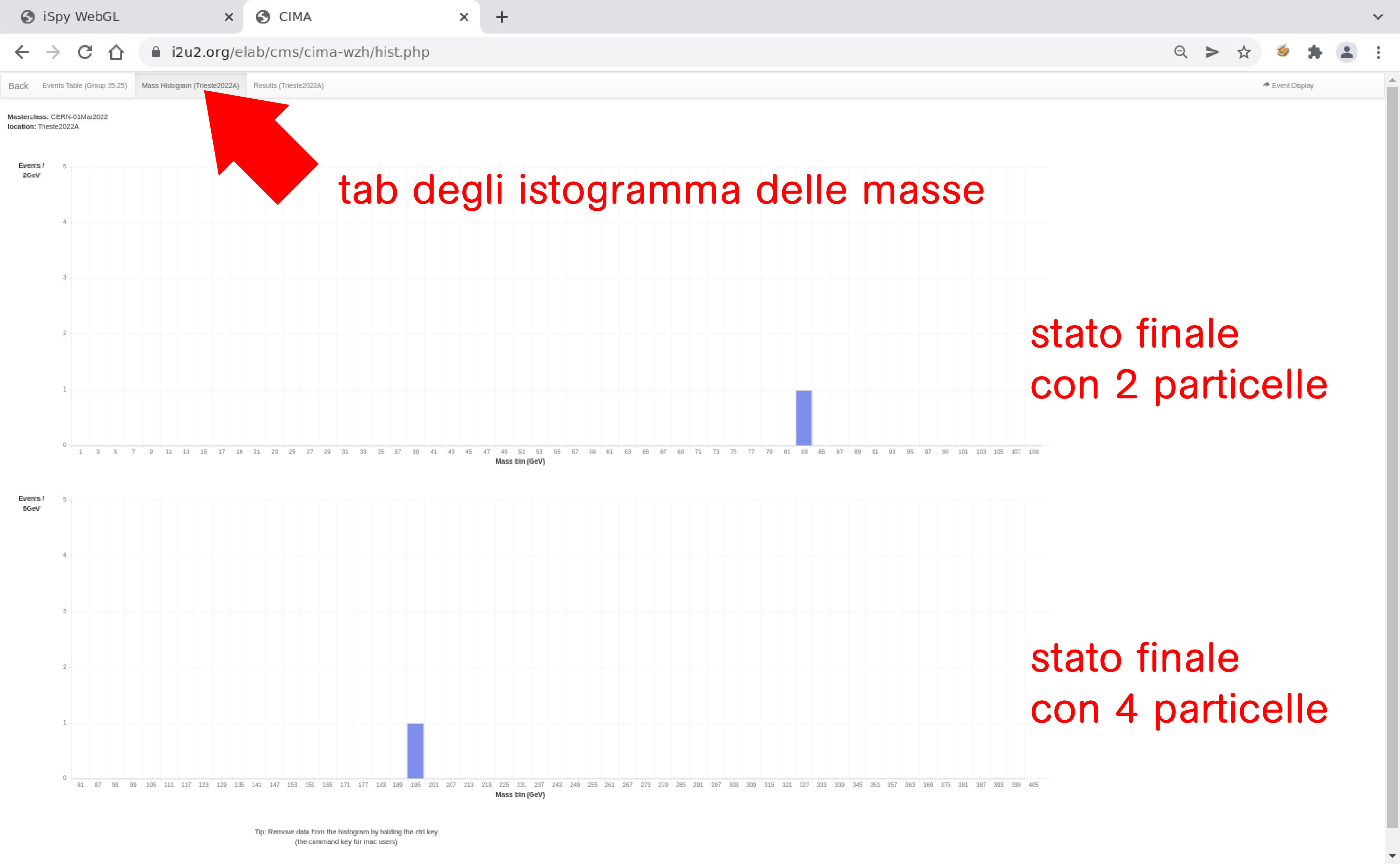
Enter Mass

GeV/c²

Next

Event index	Event number	Final state	Primary state	Mass
91080	100.1-80	μμ	neutral	90.33
91079	100.1-79	μν	W+	
91078	100.1-78	μν	W±	
91077	100.1-77	μν	W-	
91076	100.1-76	eν	W-	
91075	100.1-75	μμ	neutral	10.2
91074	100.1-74	eν	W-	
91073	100.1-73	μν	W-	
91072	100.1-72	4e	neutral	363.54
91071	100.1-71	eν	W-	
91070	100.1-70	2e	neutral	3.72
91069	100.1-69	μν	W+	
91068	100.1-68	μν	W+	
91067	100.1-67	2e 2μ	zoo	
91066	100.1-66	μμ	neutral	6.18
91065	100.1-65	eν	W+	
91064	100.1-64		zoo	
91063	100.1-63	μν	W±	
91062	100.1-62	μν	W±	

Istogrammi delle masse


iSpy WebGL
CIMA
i2u2.org/elab/cms/cima-wzh/hist.php
Back
Events Table (Group 25.25)
Mass Histogram (Trieste2022A)
Results (Trieste2022A)
Event Display
Events / 2GeV
Mass bin (GeV)
Events / 6GeV
Mass bin (GeV)

Masterclass: CERN-01Mar2022
location: Trieste2022A

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

tab degli istogramma delle masse

stato finale
con 2 particelle

stato finale
con 4 particelle

Raccomandazioni finali

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