

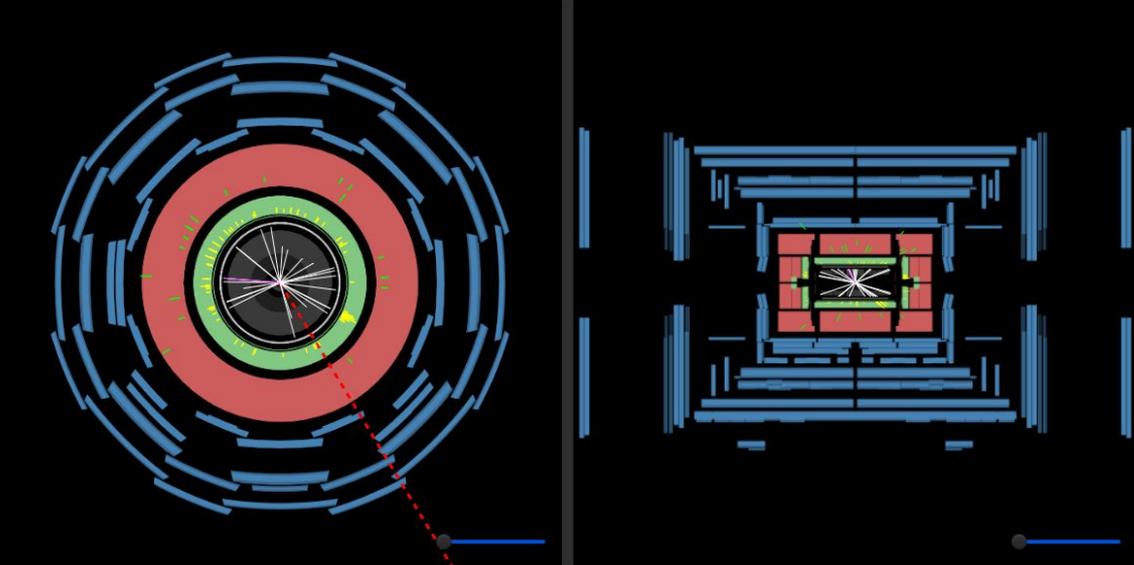
# HYPATIA Guide for BAMA

Big Analysis of Muons in ATLAS

05/02/22 SVHS

# Open the HYPATIA 4 site:

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$p$   $p_T$   $\phi$   $\eta$   $m_{ee}$   $m_{\mu\mu}$   $m_{ll}$   $m_{lll}$

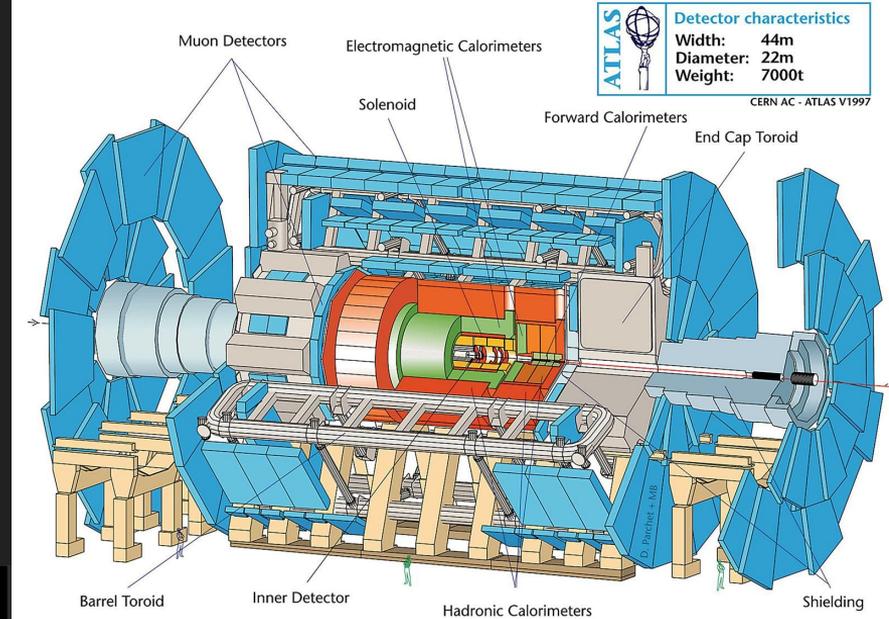
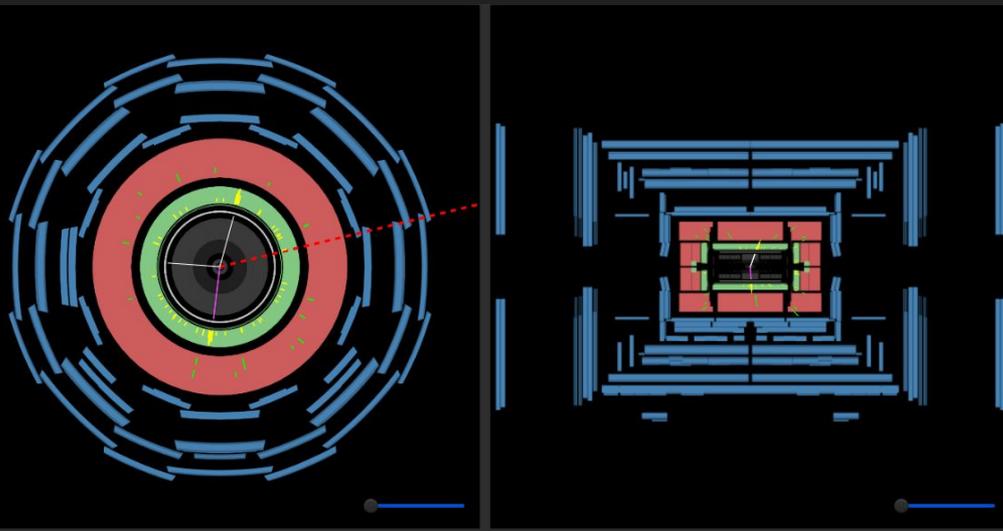
Event: 1/50 (899368/204796) 2012-06-11  
ETMiss: 30.54 GeV  $\phi$ : -1.02 rad

← Previous Event    → Next Event    + Insert Electron    + Insert Muon    - Delete Track     $p_T$  2 GeV    Group\_3A    event001...    Start

Track	+/-	p [GeV]	$p_T$ [GeV]	$\phi$ [rad]	$\theta$ [rad]
Tracks_4	-	2.87	2.51	3.06	2.07
Tracks_6	+	5.54	5.49	0.12	1.43
Tracks_19	-	3.38	3.05	3.06	2.01
Tracks_21	-	5.05	3.1	1.73	2.48
Tracks_25	-	29.65	17.68	-0.47	0.64
Tracks_27	+	54.45	35.96	-0.47	0.72
Tracks_59	+	5.94	3.13	-2.68	0.55
Tracks_71	-	4.14	2.59	-2.79	2.47

Event Name	ETMiss [GeV]	Track	+/-	p [GeV]	$p_T$ [GeV]	$\phi$ [rad]	$\eta$	$m_{ll}$ [GeV]	$m_{lll}$ [GeV]	e/ $\mu$
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Briefly, let's try to understand what we are looking at here. The HYPATIA site shows a representation of two different views of the ATLAS detector (below). The view on the left is a cross-section of the collider facing along the axis of the cylinder, i.e. along the path of the protons. On the right is a cross section as viewed perpendicular to the axis of the cylinder, more similar in angle to the drawing to the right.



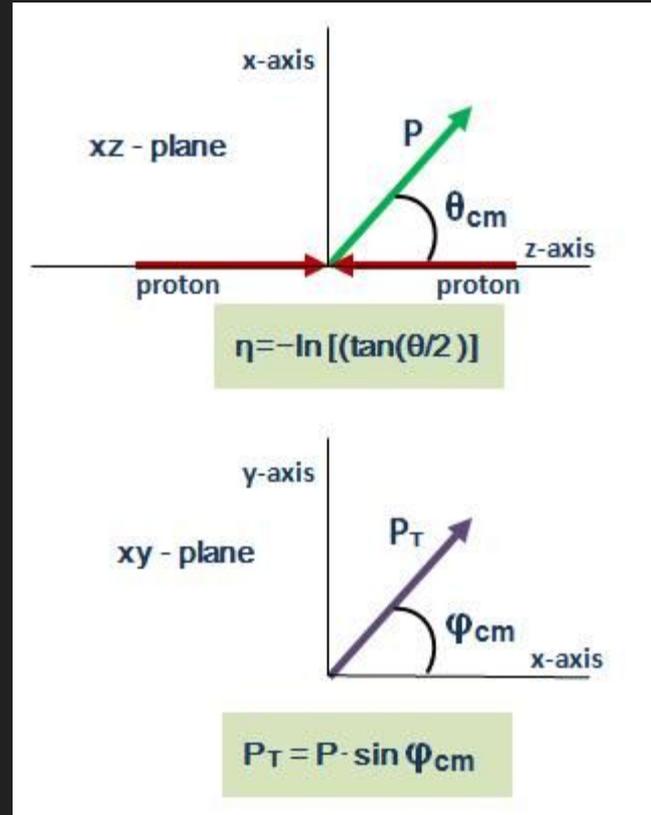
The values we want to extract are the  $m_{\parallel}$  values of muon pairs we find, that is, the invariant mass of the two-lepton system. These masses should correspond to the masses of the particles that decay to produce the muon pairs.

In our case,  $m_{\parallel}$  is calculated automatically for us in all our HYPATIA events. Here is a simple overview of some of the measurements used to calculate the  $m_{\parallel}$ :

The **pseudorapidity**  $\eta$  is a function of the polar angle of a given particle's momentum; it is thus a measure of the angle of the particle relative to the beam axis (z-axis).

The **transverse momentum**  $P_T$  is the component of momentum perpendicular to the beam axis (z-axis), with an **azimuthal angle**  $\varphi$ .

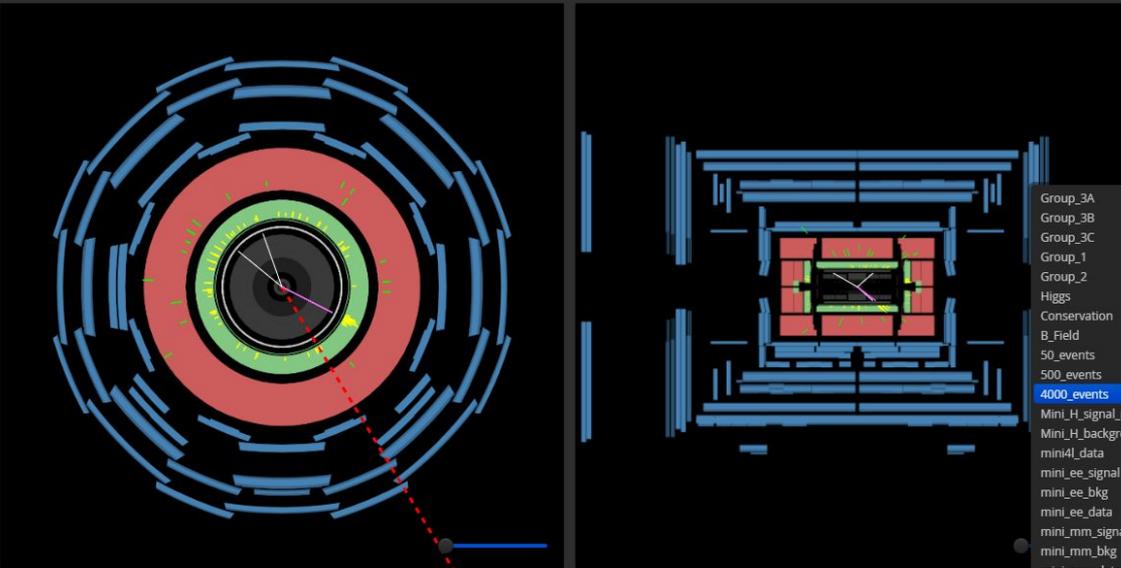
The measurements of these values from each lepton in a pair are used to calculate the dilepton invariant mass.





On the button to the right, click to open the menu and select the folder “4000 events.”

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Group\_3A  
Group\_3B  
Group\_3C  
Group\_1  
Group\_2  
Higgs  
Conservation  
B\_Field  
50\_events  
500\_events  
**4000\_events**  
Mini\_H\_signal\_new  
Mini\_H\_background\_new  
mini4l\_data  
mini\_ee\_signal  
mini\_ee\_bkg  
mini\_ee\_data  
mini\_mm\_signal  
mini\_mm\_bkg  
mini\_mm\_data

1/50 (899368/204796) 2012-06-11  
s: 30.54 GeV  $\phi$ : -1.02 rad

← Previous Event    → Next Event    + Insert Electron    + Insert Muon    - Delete Track     $p_T$  10 GeV    Group\_3A

Track	+/-	p [GeV]	$p_T$ [GeV]	$\phi$ [rad]	$\theta$ [rad]
Tracks_25	-	29.65	17.68	-0.47	0.64
Tracks_27	+	54.45	35.96	-0.47	0.72
Tracks_374	+	231.57	151.22	2.46	0.71
Tracks_375	-	268.22	132.88	1.91	2.62

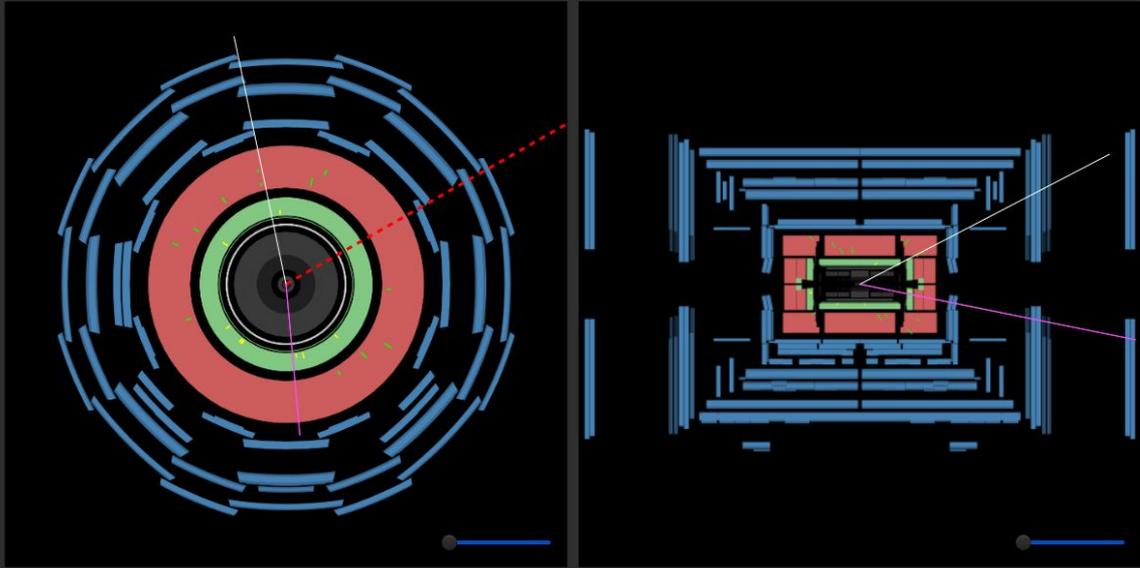
Event Name	ETMiss [GeV]	Track	+/-	p [GeV]	$p_T$ [GeV]	$\phi$ [rad]	$\eta$	$m_{ll}$ [GeV]	$m_{lll}$ [GeV]	e/ $\mu$
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1-20/24 01....    Start



Even further right, open this menu to select your starting event - scroll or click arrows to find events with the first two digits (##) as the number you've been assigned

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00event001.xml  
00event002.xml  
00event003.xml  
00event004.xml  
00event005.xml  
00event006.xml  
00event007.xml  
00event008.xml  
00event009.xml  
00event010.xml  
00event011.xml  
00event012.xml  
00event013.xml  
00event014.xml  
00event015.xml  
00event016.xml  
00event017.xml  
00event018.xml  
00event019.xml  
00event020.xml

641411/206497] 2012-07-06  
φ: 0.52 rad

← Previous Event    → Next Event    + Insert Electron    + Insert Muon    - Delete Track    pT 10 GeV 4000\_eve...    00event020.xml    Start

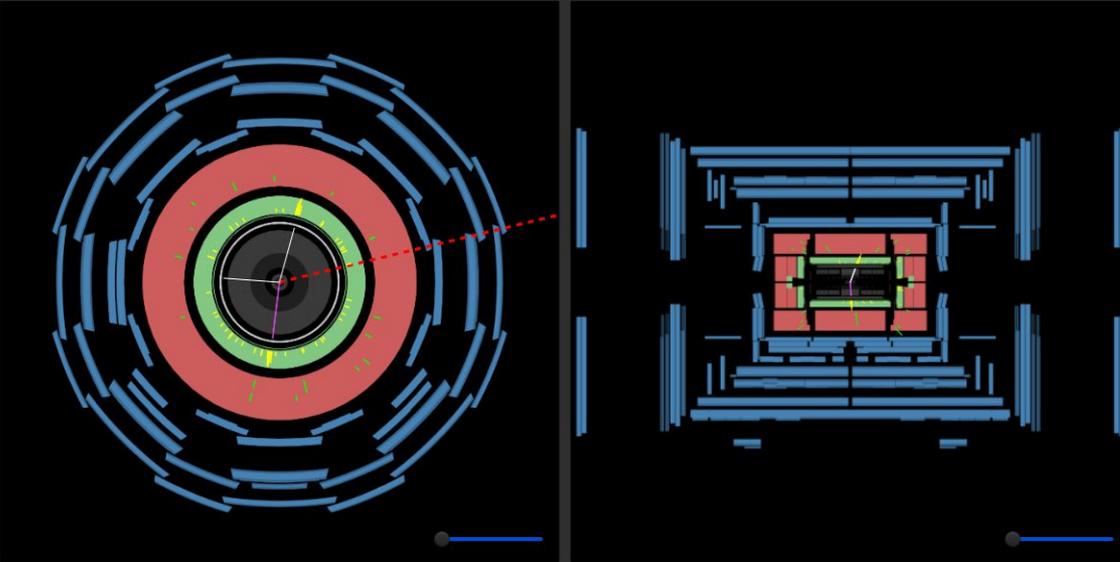
Track	+/-	p [GeV]	pT [GeV]	φ [rad]	θ [rad]	Event Name	ETMiss [GeV]	Track	+/-	p [GeV]	pT [GeV]	φ [rad]	η	m <sub>ll</sub> [GeV]	m <sub>llll</sub> [GeV]	e/μ
Tracks_0	-	216.96	42.63	-1.48	0.2											
Tracks_76	+	93.33	42.9	1.78	0.48											

A red arrow points to the '00event020.xml' entry in the event list.



Now we can begin going through the events.

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$p_T$   $\varphi$   $\eta$   $m_{ee}$   $m_{\mu\mu}$   $m_{ll}$   $m_{llll}$

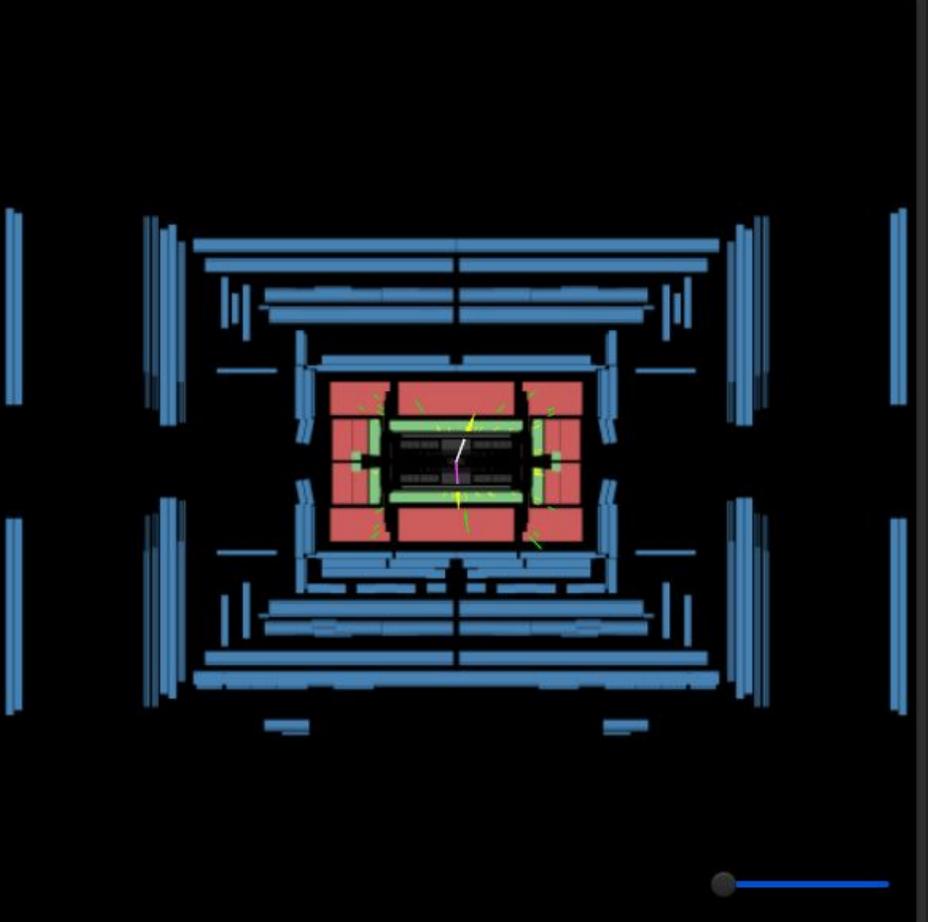
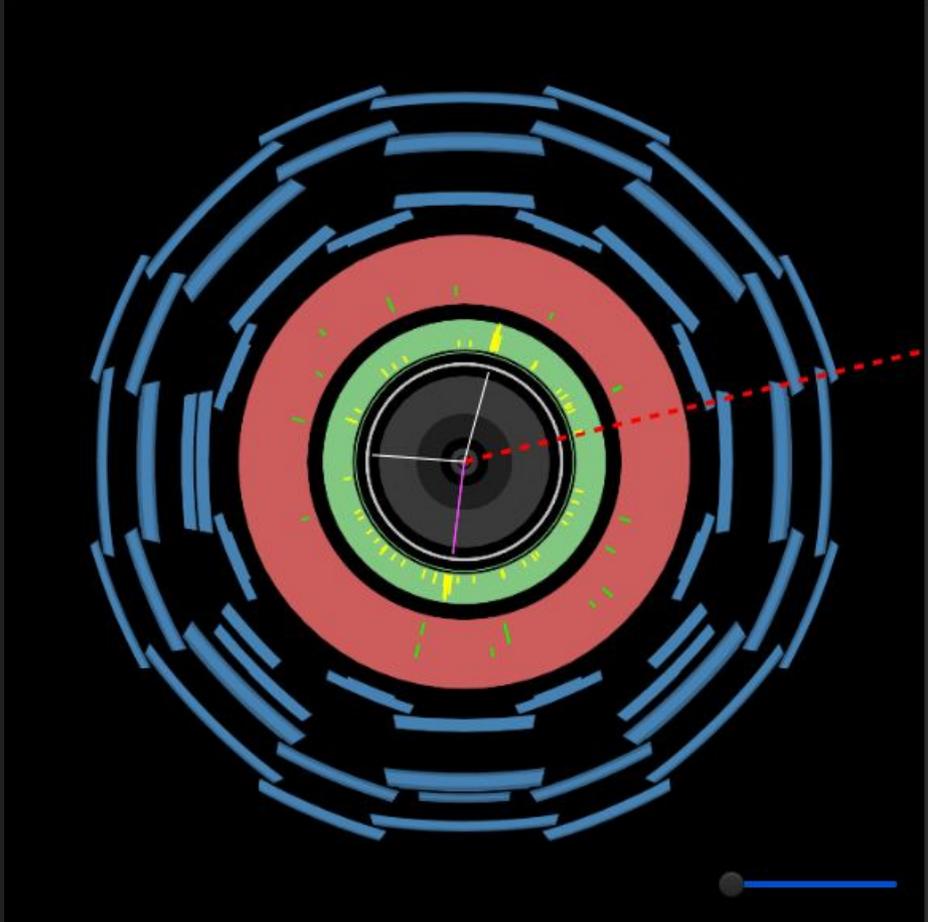
Event: 551/4000 (5512530/204796) 2012-06-11  
ETMiss: 17.08 GeV  $\varphi$ : 0.23 rad

← Previous Event   → Next Event   + Insert Electron   + Insert Muon   - Delete Track    $p_T$  10 GeV   4000\_eve...   11 event0...   Start

Track	+/-	p [GeV]	$p_T$ [GeV]	$\varphi$ [rad]	$\theta$ [rad]
Tracks_238	+	38.64	38.58	-1.69	1.51
Tracks_240	-	54.06	50.44	1.3	1.2
Tracks_319	+	152.15	143.54	3.07	1.23

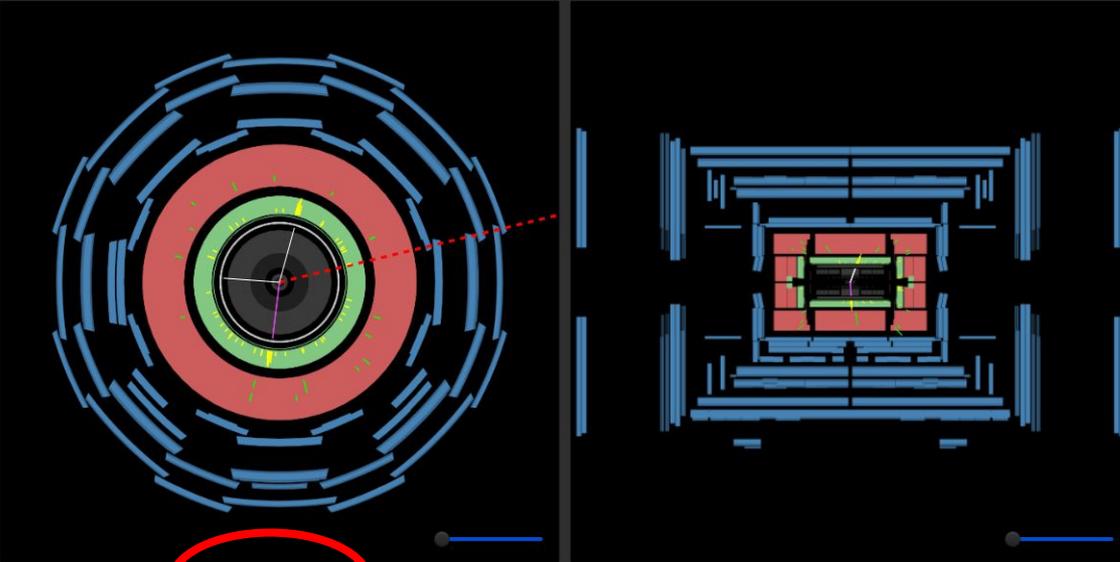
Event Name	ETMiss [GeV]	Track	+/-	p [GeV]	$p_T$ [GeV]	$\varphi$ [rad]	$\eta$	$m_{ll}$ [GeV]	$m_{llll}$ [GeV]	$e/\mu$
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The tracks (white/purple lines) we are looking for will penetrate the electromagnetic calorimeter (green section) of the detector. This event, for example, has no such tracks:



We go on to the next event by clicking “next event.”

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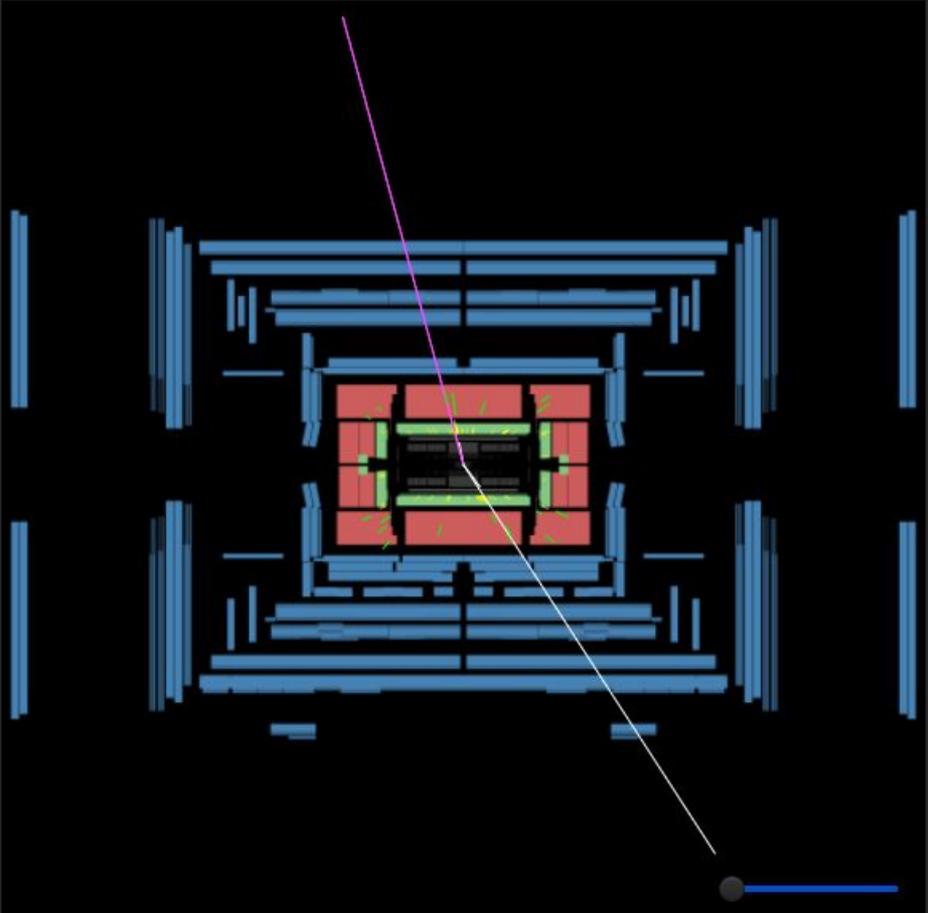
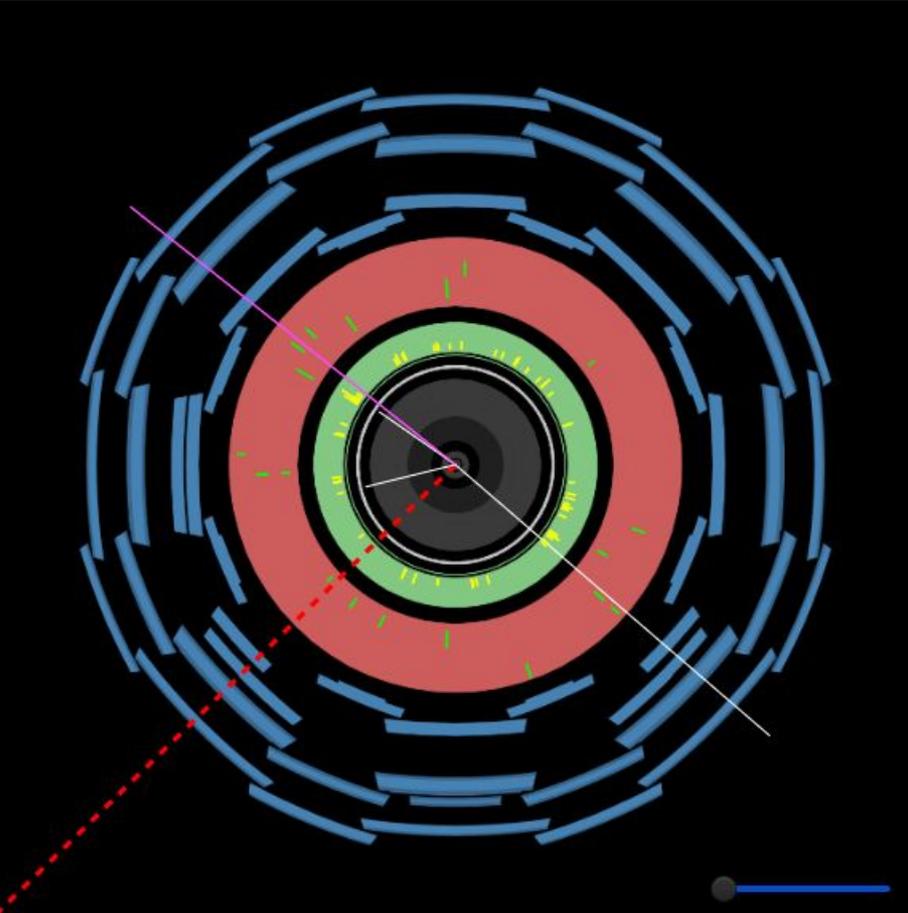
Event: 551/4000 (5512530/204796) 2012-06-11  
ETMiss: 17.08 GeV  $\phi$ : 0.23 rad

← Previous Event **→ Next Event** + Insert Electron + Insert Muon - Delete Track  $p_T$  10 GeV 4000\_eve... 11 event0... Start ≡

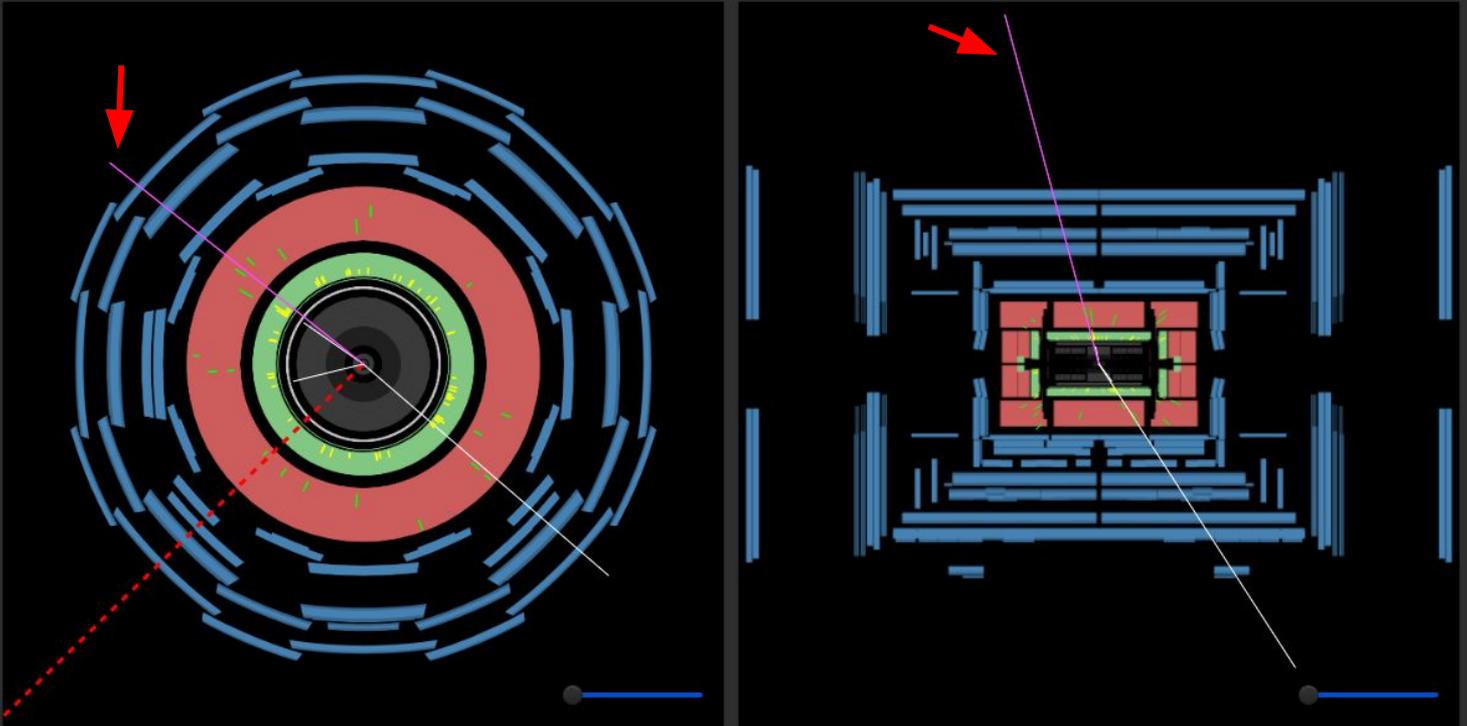
Track	Charge	$p$ [GeV]	$p_T$ [GeV]	$\phi$ [rad]	$\theta$ [rad]
Tracks_238	+	38.64	38.58	-1.69	1.51
Tracks_240	-	54.06	50.44	1.3	1.2
Tracks_319	+	152.15	143.54	3.07	1.23

Event Name	ETMiss [GeV]	Track	+/-	$p$ [GeV]	$p_T$ [GeV]	$\phi$ [rad]	$\eta$	$m_{ll}$ [GeV]	$m_{lll}$ [GeV]	$e/\mu$
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This event does have two trails penetrating through, and thus is of interest to us.



Note that the track highlighted in the lower left window will be purple in the upper display.



← Previous Event    → Next Event    + Insert Electron    + Insert Muon    - Delete Track    pT 10 GeV 4000\_eve... ▾

Track	+/-	p [GeV]	p <sub>T</sub> [GeV]	φ [rad]	θ [rad]	Event Name	ETMiss [GeV]	Track
Tracks_17	-	45.03	43.47	2.47	1.84			
Tracks_222	+	29.26	24.53	-0.71	0.99			
Tracks_239	-	10.66	10.47	2.54	1.76			
Tracks_362	+	18.28	14.62	-2.9	0.93			



Side note: The red dashed line and smaller colored lines on the displays aren't of concern to us in this exercise, so if they are distracting they can be turned off in the options menu:

The image shows the HYPATIA software interface. At the top, there is a histogram with a red dashed line and several smaller colored lines. Below the histogram, the event information is displayed: "Event: 747/4000 (11806857/206409) 2012-07-04" and "ETMiss: 4.66 GeV  $\phi$ : -1.43 rad". The main control panel includes a "Start" button and a menu icon (three horizontal lines) circled in red. A red arrow points from the menu icon to the "Options" menu item in the dropdown menu. The "Options" menu is open, showing various settings. A red arrow points from the "Options" menu item to the "Options" dialog box on the right. The "Options" dialog box has three sections: "Tracks", "ETMiss", and "Objects".

Event: 747/4000 (11806857/206409) 2012-07-04  
ETMiss: 4.66 GeV  $\phi$ : -1.43 rad

Start

Options

- Enable Light Mode
- Import Invariant Mass Table
- Append Invariant Mass Table
- Export Invariant Mass Table
- Clear Invariant Mass Table
- Show  $p$  Histogram
- Show  $p_T$  Histogram
- Show  $\phi$  Histogram
- Show  $\eta$  Histogram
- Show  $M_{ee}$  Histogram
- Show  $M_{\mu\mu}$  Histogram
- Show  $M_{\tau\tau}$  Histogram
- Show  $M_{\mu\tau}$  Histogram
- Show Curved Tracks
- Show Track Weight
- Show Axes
- Start Demo Mode
- Batch Process Events
- Options
- About HYPATIA

Options

Tracks

Color	Selected Track Color	Width
<input type="color" value="white"/>	<input type="color" value="magenta"/>	<input type="text" value="1"/>

ETMiss

Color	Width	Cut [GeV]
<input type="color" value="red"/>	<input type="text" value="3"/>	<input type="text" value="5"/>

Objects

<input checked="" type="checkbox"/> Hits	<input checked="" type="checkbox"/> Tiles	<input checked="" type="checkbox"/> RPC
<input checked="" type="checkbox"/> TGC	<input checked="" type="checkbox"/> MDT	<input checked="" type="checkbox"/> CSC
<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>

OK Cancel





Looking at the lower-right table, we can see that an  $m_{\mu\mu}$  (dilepton mass) value is calculated for each muon pair. These are the values we will record.

Event Name	ETMiss [GeV]	Track	+/-	p [GeV]	p <sub>T</sub> [GeV]	φ [rad]	η	$m_{\mu\mu}$ [GeV]	$m_{\mu\mu\mu\mu}$ [GeV]	e/μ
11event013.xml / 4000_events	15.953	Tracks_17	-	45.03	43.47	2.47	-0.27	71.70		μ
		Tracks_222	+	29.26	24.53	-0.71	0.61			μ
11event014.xml / 4000_events	17.703	Tracks_16	-	79.65	38.92	-1.45	1.34	97.30		μ
		Tracks_19	+	38.82	38.75	1.47	-0.06			μ
11event017.xml / 4000_events	13.572	Tracks_14	-	43.54	43.41	-2.62	0.08	87.70		μ
		Tracks_142	+	46.98	42.92	0.53	0.43			μ

The  $m_{\mu\mu}$  values can be copied from this table and pasted into your spreadsheet sections.

Event Name	ETMiss [GeV]	Track	+/-	p [GeV]	p <sub>T</sub> [GeV]	φ [rad]	η	$m_{\mu\mu}$ [GeV]	$m_{\mu\mu\mu\mu}$ [GeV]	e/μ
11event013.xml / 4000_events	15.953	Tracks_331	+	151.97	47.1	1.1	-1.84			μ
		Tracks_17	-	45.03	43.47	2.47	-0.27	71.70		μ
11event014.xml / 4000_events	17.703	Tracks_222	+	29.26	24.53	-0.71	0.61			μ
		Tracks_16	-	79.65	38.92	-1.45	1.34	97.30		μ
11event017.xml / 4000_events	13.572	Tracks_19	+	38.82	38.75	1.47	-0.06			μ
		Tracks_14	-	43.54	43.41	-2.62	0.08	87.70		μ
		Tracks_142	+	46.98	42.92	0.53	0.43			μ

A context menu is shown over the value 97.30 in the table above. The menu items are: Copy, Copy link to highlight, Search Google for "97.30", and Print... A red arrow points to the value 97.30.

On the right, you can click the “ $m_{\parallel}$ ” tab to view a histogram of your tabulated  $m_{\parallel}$  values.

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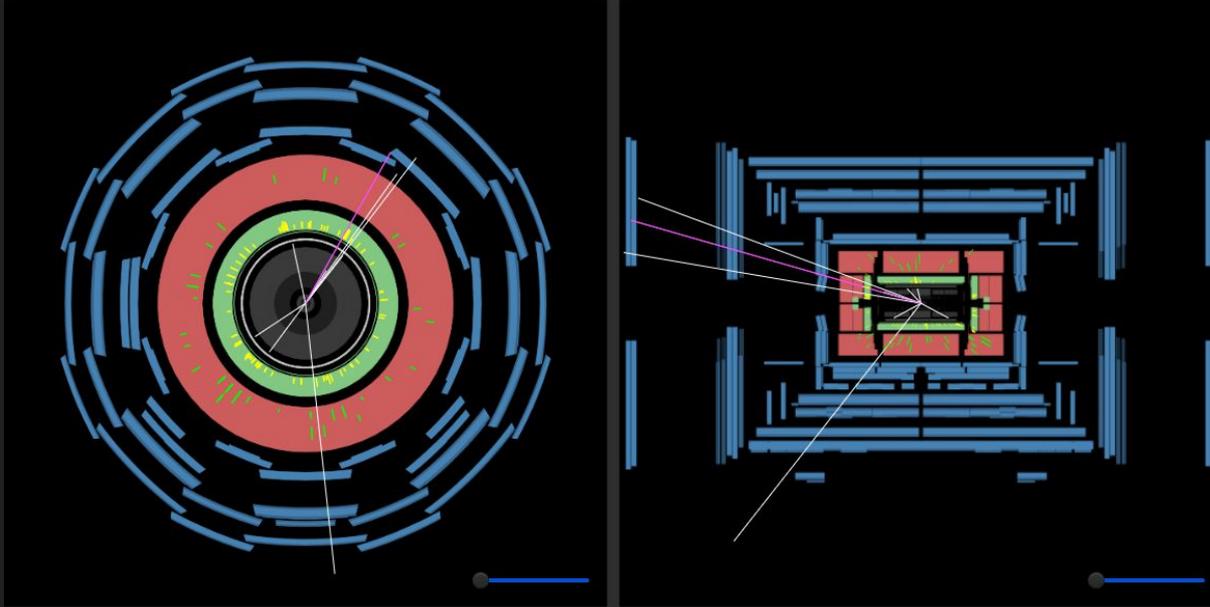
$m_{\parallel}$  [GeV] Events:9 Mean:71.8 RMS:37.9

Event: 11/4000 (2982185/206497) 2012-07-06  
ETMiss: 22.47 GeV  $\eta$ : 1.84 rad

← Previous Event    → Next Event    + Insert Electron    + Insert Muon    - Delete Track     $p_T$  10 GeV 4000\_eve...    11event0...    Start

Track	+/-	p [GeV]	$p_T$ [GeV]	$\phi$ [rad]	$\theta$ [rad]	Event Name	ETMiss [GeV]	Track	+/-	p [GeV]	$p_T$ [GeV]	$\phi$ [rad]	$\eta$	$m_{\parallel}$ [GeV]	$m_{\perp}$ [GeV]	e/ $\mu$
Tracks_40	-	76.39	24.32	0.59	0.32	11event022.xml / 4000_events	4.754	Tracks_5	-	275.74	59.31	-0.28	2.22	99.91		$\mu$
Tracks_298	+	72.47	23.5	0.72	0.33	11event025.xml / 4000_events	14.989	Tracks_397	+	152.56	89.99	-1.03	1.12			$\mu$
Tracks_299	+	99.22	20.31	-2.32	2.94	11event027.xml / 4000_events	21.854	Tracks_4	+	52.89	50.94	3.03	0.28	105.72		$\mu$
Tracks_314	-	117.78	24.39	-2.34	2.93	11event032.xml / 4000_events	22.472	Tracks_217	-	53.08	52.55	-0.06	-0.14			$\mu$
Tracks_509	-	1313.75	911.14	0.74	0.77			Tracks_13	-	143.17	46.43	-2.15	-1.79	88.67		$\mu$
Tracks_512	+	365.2	289.04	0.89	0.91			Tracks_32	+	93.16	41.23	1.08	-1.46			$\mu$
Tracks_514	+	44.12	41.58	-1	1.91			Tracks_40	-	76.39	24.32	0.59	1.81	3.00		$\mu$
Tracks_516	+	201.66	100	-2.4	2.62			Tracks_298	+	72.47	23.5	0.72	1.79			$\mu$

Very few events in the dataset will feature 4 muon tracks - in this case, add both pairs and record the  $m_{\mu\mu}$  masses as usual, but also record the  $m_{\mu\mu\mu\mu}$  mass of the entire quad-lepton system.



14event047.xml / 4000_events	4.655	Tracks_10	-	202.75	55.49	1.05	-1.97	8.49	88.31	$\mu$
		Tracks_11	+	46	15.96	0.92	-1.72			$\mu$
		Tracks_36	+	18.14	14.22	-1.46	-0.73	44.63		$\mu$
		Tracks_47	-	112.87	18.9	0.95	-2.47			$\mu$

Once you see the event selection reach the next double digit number (i.e. 11 -> 12), you have gone through the 50 events in your subset.

