CMS Masterclass 2016 Documentation

Tiny URL for online documentation page: http://tinyurl.com/doc16cms.

External Links:
- **CMS WZH guide**
- **Masterclass Library**
- **CMS Masterclass website**
- **International Masterclasses**

CMS WZH Measurement

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The CMS WZH measurement is supported for International Masterclasses.

Languages supported: Chinese, Dutch, English, French, German, Hebrew, Hungarian, Italian, Japanese, Polish, Portuguese, Spanish, Turkish

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Description
- Students use event display of (mostly) leptonic decays to determine
  - lepton ID (electron, muon),
  - likely particle ID (W, Z, zoo, Higgs),
  - charge if W, using curvature of electron or muon tracks,
- Students use particle counts to find e:μ and W+:W- ratios.
- Students create mass plots. They find the mass of the Z boson and a possible Higgs signal but also other peaks in the mass plot to reveal additional particles.
- Students use the iSpy-webgl event display and the CMS Instrument for Masterclass Analysis (CIMA). Instructional screencasts are available.

Dataset: There are 3000 events from CMS, made up of W, Z, J/Ψ, upsilon, background, and a few Higgs (H) candidates. Only W, Z, H, and background are initially revealed to students; other particles are discovered by them and explained by

the mentor. "Background" events are dilepton events of invariant mass between 2-110 GeV. The events are divided into 30 sets of 100.

Requirements
for hardware and software

Online:
- Reliable, high-speed internet connection
- Up-to-date version of Firefox, Chrome, or Safari

Offline:
- Masterclass DVD 2016
- A browser that supports the FileReader API: Firefox 3.6+, Chrome 6+, Safari 6+, Opera 11.5+
- Spreadsheet (e.g. MS Excel, OpenOffice) may be needed
- Work out a system for data transfer from student level to institute level and then for transmission of results to moderators
- Note: Moderators cannot show institute mass plot results in the videoconference. The mentor should share the institute mass plot through shared desktop. (In the Fermilab-based masterclass, there is an Indico page for the videoconference and the mentor can upload material such as a mass plot by means of a modification key.)

Outline of the day
This is not a final schedule but an outline for most U.S. institutes.
- Arrival/Registration (~30 min)
- Cloud chamber, e/m apparatus, or other "gateway experience" apparatus setup for students to inspect
- Start and Ice-breaker activity (~30 min)
    - Students in small groups create 1-2 good questions about particle physics and/or LHC. Where practical, groups should be made of students from different schools.
- Mentor presentation
    - Template (~60 min, including Q&A)
- Tour of facilities/labs/cool stuff (~45 min)
- Analysis preparation (1-2 teachers facilitate; ~60 min, including Q&A)
    - Presentation (**template**)
    - **CMS data analysis slides**
    - Guided practice with discussion
- Lunch with a physicist (~60 min)
- Data Analysis (~90 min)
    - **Cheat sheet**
- Pre-conference (~30 min)
    - Students and mentor discuss meaning of analysis results.
    - Students and mentor discuss questions for other institutes.
    - Revisit questions from ice-breaker, discuss which to ask in video conference.
- Designated IT expert preps video connection.
- Videoconference (~30 min)
    - Greetings
    - Presentation of results
    - Discussion of results
    - Q&A
- Summing up and evaluation (~15 min)

- Student tasks:
    - Each pair of students analyzes a set of 100 events
    - For each event, distinguish between electron and muon decay and between W+, W-, Z candidate, Higgs candidate, and zoo.
    - Record into CIMA.
    - Be prepared to discuss in Masterclass Institute and in videoconference; prepare good questions.

Student procedure

It is important to carefully note the following:

1. **Mentors and tutors need to be familiar with CIMA** *in order to guide the students successfully.*
2. *The description below is for the current event display,* **iSpy-webgl**. *which works for both online and offline masterclasses. This version is recommended for the WZH-path masterclasses used in International Masterclasses.*
3. *The older* **iSpy-online** *is still recommended for the J/Psi-path masterclass and as a back-up for the WZH-path.*

Mentors should guide students to follow these procedures for the use of iSpy and CIMA:

- Pairs of students are assigned sets of 100 events to analyze in iSpy-online or iSpy-dvd.
- Event sets are found in the iSPy-webgl by choosing the folder icon (top left).
- A first window appears. If the data is to be taken from the internet, choose "Open file(s) from web" in this window. If the data is offline, choose the button under "Open local file(s)" and navigate to the file. Either way, a second window will open.
- In the second window, students first choose their event set (labelled masterclass_1, masterclass_2, etc.). The entire set of 100 events will then load into the browser. This may take some time.
- After the set of 100 events is loaded, a list of events in that set will appear on the left side of the window. The student chooses the first of these events and then the "load" button. This will open the first event.
- Students also open CIMA and then find their masterclass by date ("Choose your Masterclass") and then institute ("Choose your location"). They then choose the number of their event set ("Choose your group"): this is the same number as the event set in iSpy.
- **Notes on CIMA for students:**
    - **All institutes are strongly encouraged to use CIMA rather than a local spreadsheet.**
    - **There are two copies of CIMA for students:**
    - **Production version for students at https://www.i2u2.org/elab/cms/cima/index.php**
    - **backup/develoment copy at http://leptoquark.hep.nd.edu/sschoppmann/index.php.**
    - **Please use the production version of CIMA for your masterclass. It will have your date and your institute to choose from and will be at the URL for the masterclass videoconference inn which you will participate.** If needed, Google spreadsheets will be provided online in case of any problems with CIMA.
    - **CIMA is also linked at the CMS Library page at https://quarknet.i2u2.org/content/cms-wzh-path-measurement-2015 (scroll down to Data Analysis).**
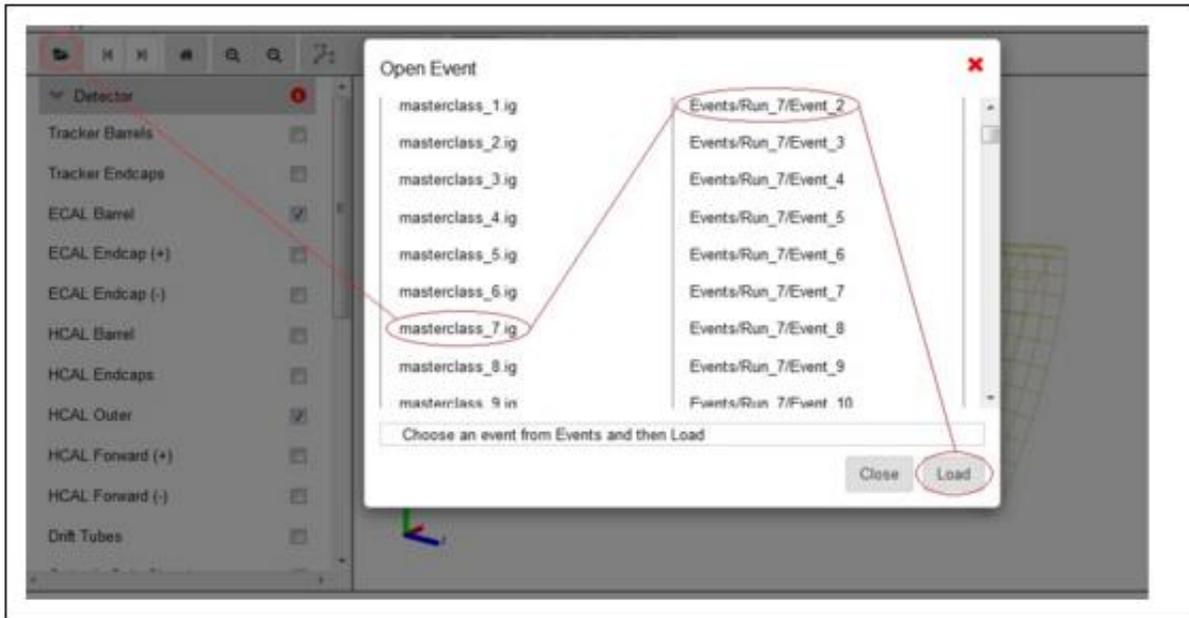
Open iSpy-webgl event display. To find the correct dataset, choose the file folder icon at the top left the choose events from the web or locally; when the "Open Event" box appears, find your dataset, choose the first event, and then choose the "Load" button.
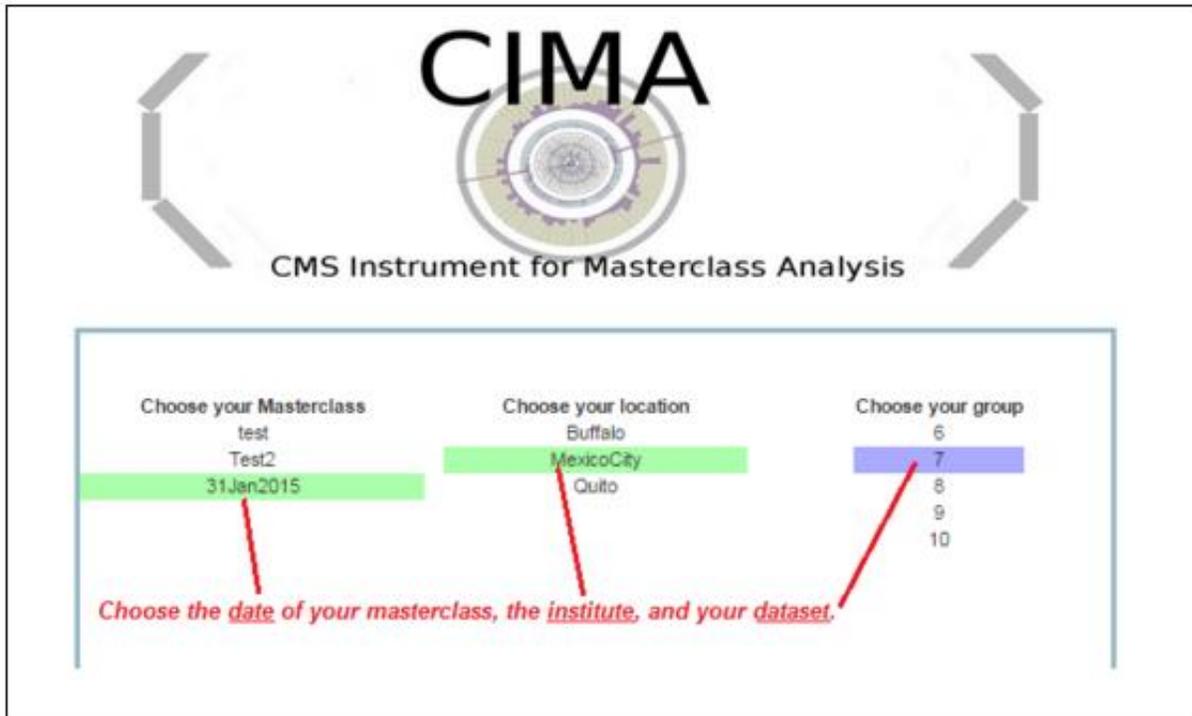
Open CIMA and find your dataset. First choose the date and then the location list appears. Choose your institute and then your set of events.

Students use event display of (mostly) leptonic decays to determine
- Lepton ID (electron, muon). This is to characterize the event, not individual particles.

- o If the event has one muon track (long, red) or two muon tracks (actually likely a muon-antimuon pair) it is a single muon event.
  - o If the event has one electron track (short, green) or two electron tracks (actually likely an electron-positron pair) is is a single electron event.
- Likely particle ID (W, Z, zoo, Higgs)
  - o W candidate appears as a single electron track or muon track and a missing Et vector (purplish track, possibly dashed, always transverse to beamline)
  - o Z candidate appears as 2 muons or 2 electrons; it is not always a Z. It may or may not have missing Et in the event.
  - o Some events will have multiple lepton tracks plus missing Et. The student can choose a track with the cursor and a window will appear with track information. The most important of these is transverse momentum, pt. This can be used to distinguish which tracks are important and which are low-energy background.
  - o Suspected Higgs (H); these are rare but noteworthy. Events show as
  - o H→ZZ: 2 electrons and 2 muons, or 4 electrons, or 4 muons.
  - o H→γγ: no electron tracks but 2 large energy deposits (seen as towers) in ECAL.
  - o Zoo events are "none of the above" but there can be interesting events among these.
- Charge if W, using curvature of electron or muon tracks. It helps to select the X-Y view and "orthographic mode" (the "flat cube" button), zoom in and to use a paper straight edge.
- Mass if Z or H candidate (taken from CIMA)
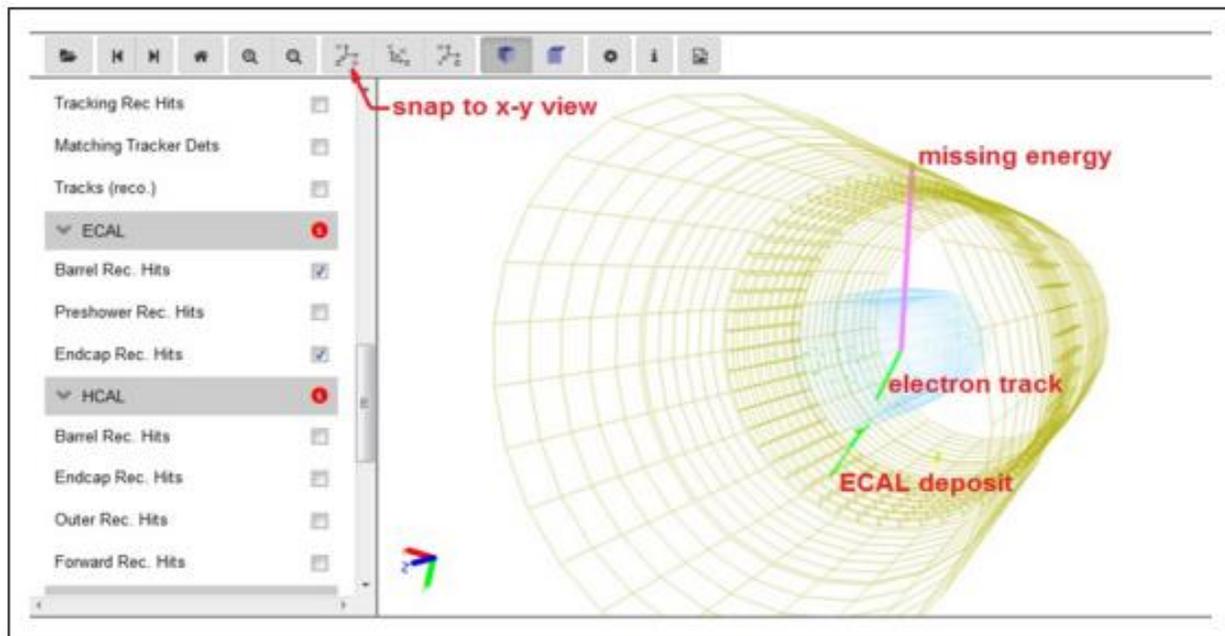
Adjust event settings to get x-y view for track curvature in case of W candidates.
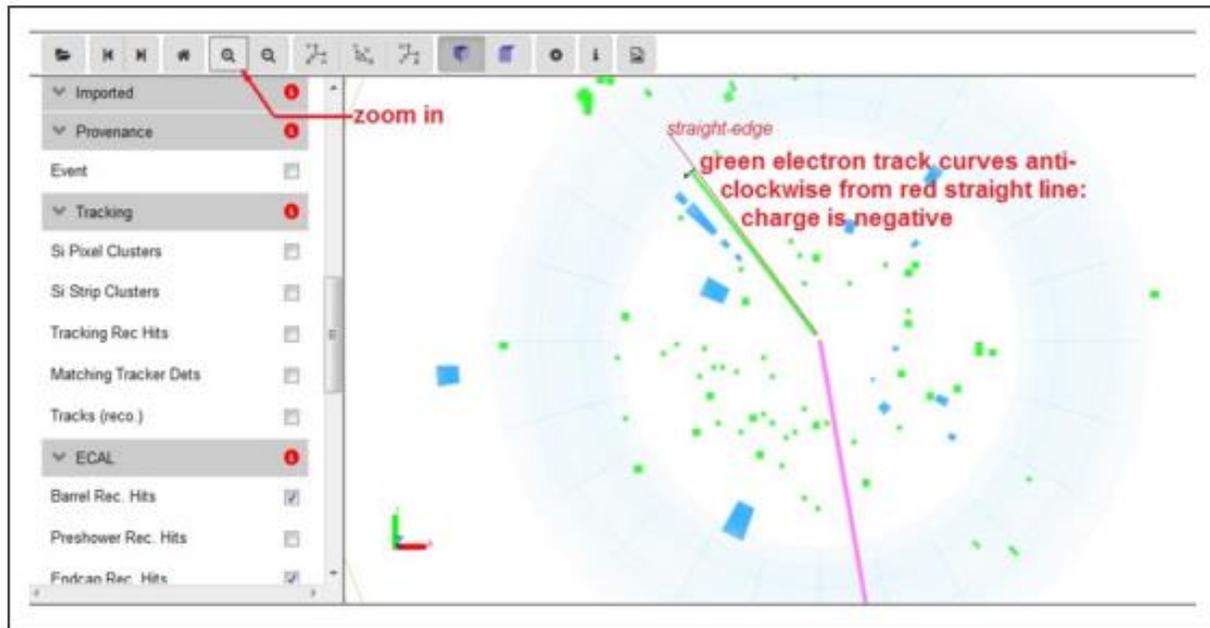
Candidate $W \to e^- + \text{anti-}v_e$.
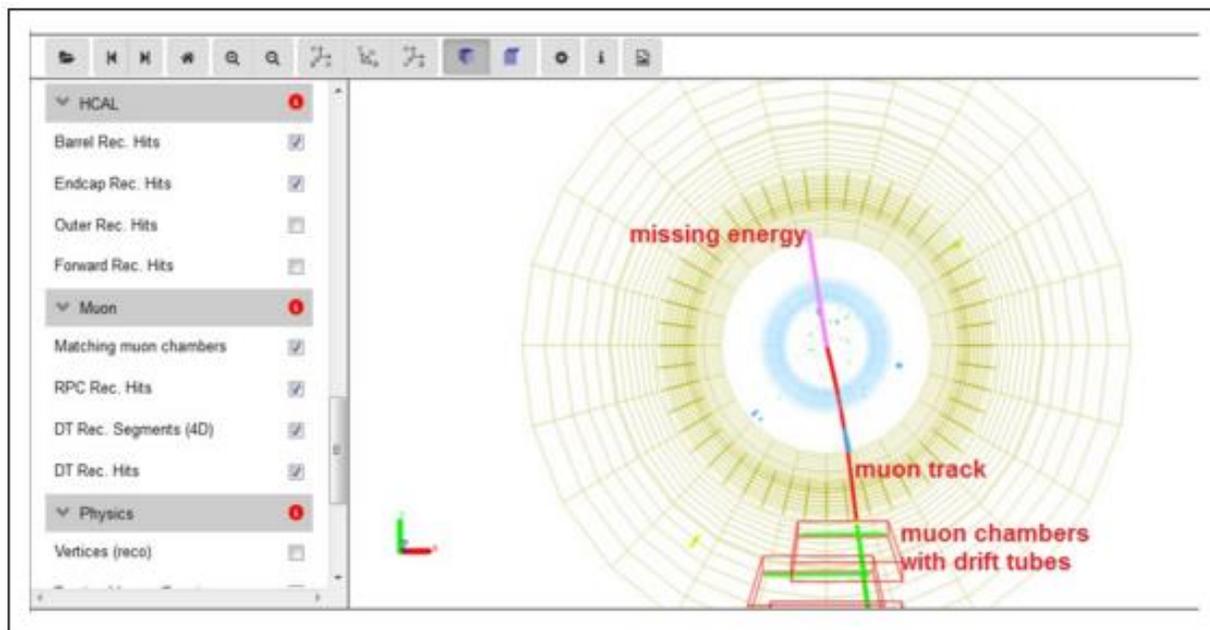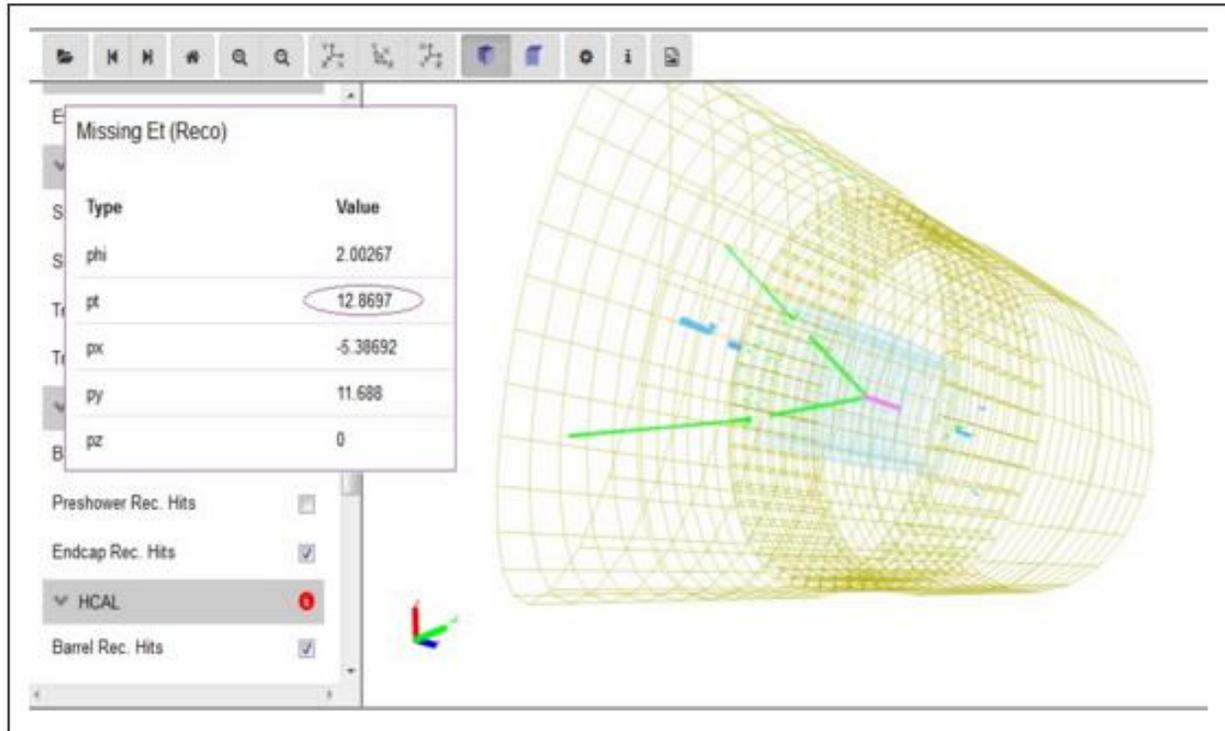
Candidate $W^+ \to \mu^+ + v_\mu$.

Candidate $Z \rightarrow e^+ + e^-$. Note the low value of missing Et, found by choosing the missing energy track. This gives some confidence that this is not a W event plus an aditional electron.

After a pair of students has found their "group" or dataset in CIMA, they will be sent to their Events Table. They will see checkboxes at the top to characterize each event. They should look at the corresponding event in iSpy-webgl (they can check the event numbers to be sure they do correspond) and determine which sort of event it is, following a few rules:

- Choose whether it is an electron or muon event under "final state".
- If the event is a Higgs or zoo candidate (under "special"), no final state is chosen.
- Choose the most likely parent particle under "primary" or "special". If it is a Z or Higgs candidate, a mass will appear. If it is a W or zoo, no mass will appear as we do not include these in the mass plot. If a W and a charge can be determined, choose either W+ or W-. Onlu choose W without a sign if the lepton track is so straight that a probable charge cannot be determined..
- Choose the Submit button. This puts the data below in a line corresponding to the Event Index number.
- In the case of an error, clicking the data line will erase it; you can then try it again.

Sample data entered into CIMA. These entries were made randomly and do not show any preferred results.

- When a mass is shown in the line for an event, the students should record it in the Mass Histogram. The student should:
    - Choose "Mass Histogram" at the top.
    - Zoom to get a good size for the massplot, if needed, using ctrl-minus (PC) or cmd-minus (Mac).
    - The numbers on the horizontal axis are the values of the middle of the bins of width 2 GeV. Select the bin by clicking. This will iterate the massplot up by one for that mass.
    - To remove an errant mass iteration, use ctrl-click (PC) or cmd-click (Mac) on the same number.
- Important note: *The Mass Histogram is attached to all groups in the same location. Thus when a student adds to or deletes from the Mass Histogram,the student is doing this for everyone at the masterclass institute. Thus students will see the Mass Histogram seem to change by itself. This is the normal result of other students working on it.*
- The total of number of events at each mass is then automatically transferred to the mass plot in the Results tab.
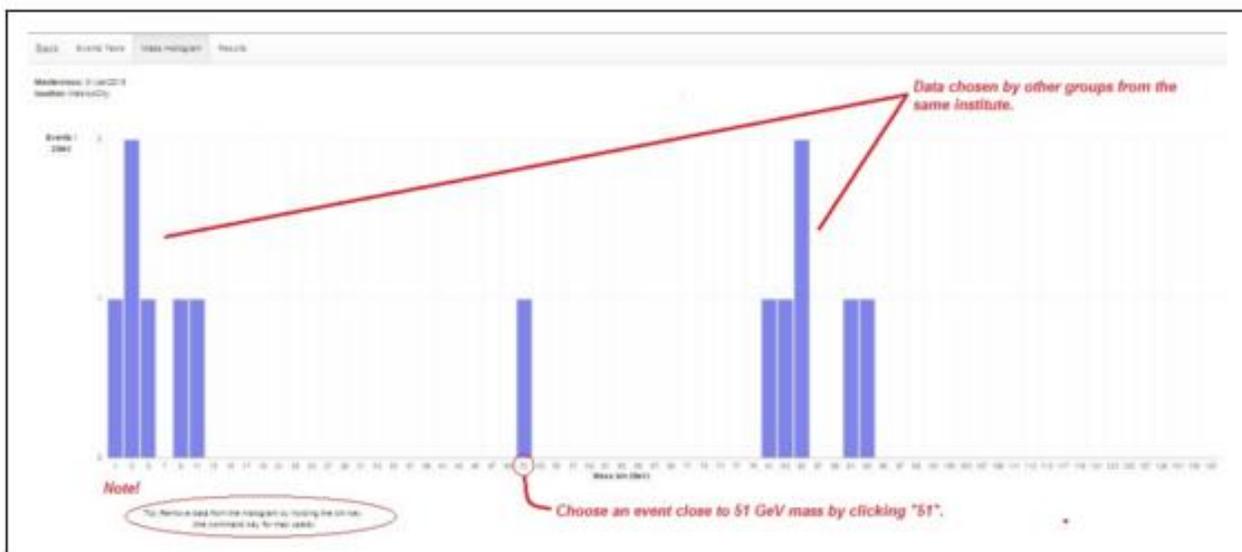
Enter masses the Mass Histogram for the entire institute (location). Refreshing will show any newly added masses.

Numerical results can be seen in the Results page for the institute (location).

Presentation of results

The mass plot and summary of results are automatically built in the institute (location) 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 cand, H cand, and zoo events plus the key ratios e:mu and W+:W-. The mentor should project the mass plot and the count/ratio results and discuss their signficance with students. The mentor should also help the students to generate questions for the videoconference or other later discussion.

For Fermilab-based videoconferences, the mentor should show the students the Mass Histogram and Results for another institute. Each institute is assigned another one to which they may ask one or two questions. In our example, Buffalo may ask questions of Mexico City and Mexico City may ask questions of Quito, etc.

Sample questions

In discussion, the moderator might ask students
- How many peaks are there in the mass plot?
- Where is the Z peak? What is the mass of the Z boson?
- What do the other peaks mean?
- Is there anything interesting in the 120-130 GeV range? What is it?
- What is the ratio of electrons to muons? Is it close to what we should expect?
- What is the W+:W- ratio? What should it be?
- In the videoconference, students might ask questions like

- Why are the widths or heights or numbers of peaks different from one Institute to the next?
- Why do different Institutes get different ratios? How did they identify electrons or muons or W candidates or Z candidates or zoo events? How did they measure charge for W candidates?
- Now that the Tevatron is shut down, what do you do at Fermilab?
- Is it boring at CERN when the LHC is not running?
- Why did you become a physicist?

...and better questions which only students can create.

Moderators

Fermilab-based moderators should refer to the **FNAL Masterclass 2016 Moderators page**.

All moderators should note the following:
As long as all groups use CIMA, moderators do not need to look for uploads from any of the masterclass institutes or make histograms on their own. There is one "Table" for each masterclass institute (location) participating in a single videoconference. Each institute has a Mass Histrogram and a Results page.

- Mass Histogram - students use "Events Tables" to record W or Z candidates, e or μ events, Higgs candidates, and "zoo" events. Choosing Z or Higgs candidates results in masses popping up, which students transfer into the Mass Histogram.
- Results - numbers of different types of particles are automatically transferred here; e:μ and W+:W- are calculated for the whole institute.

The moderators will access the Admin page of CIMA to view these and share them on Vidyo. They will also view and share the combined Mass Histogram and combined Results for all institutes participating in their videoconference.

To get to the appropriate places, **moderators only** should:
1. Go to the **CIMA Admin page**. There is also a **backup/development** copy.
2. Log in. The user name and password will be sent separately.
3. **Please do not touch anything above Manage Tables.**
4. Go to the part of the page under the Manage Tables heading. *To view the Results and Mass Histogram pages for one institute:* choose the date under Masterclasses and the institute under Table and then choose the Results button. *To view the combined Results and Mass Histogram for all institutes that day:* choose the date under Masterclasses but do not choose anything under Table and then go to the Results button.
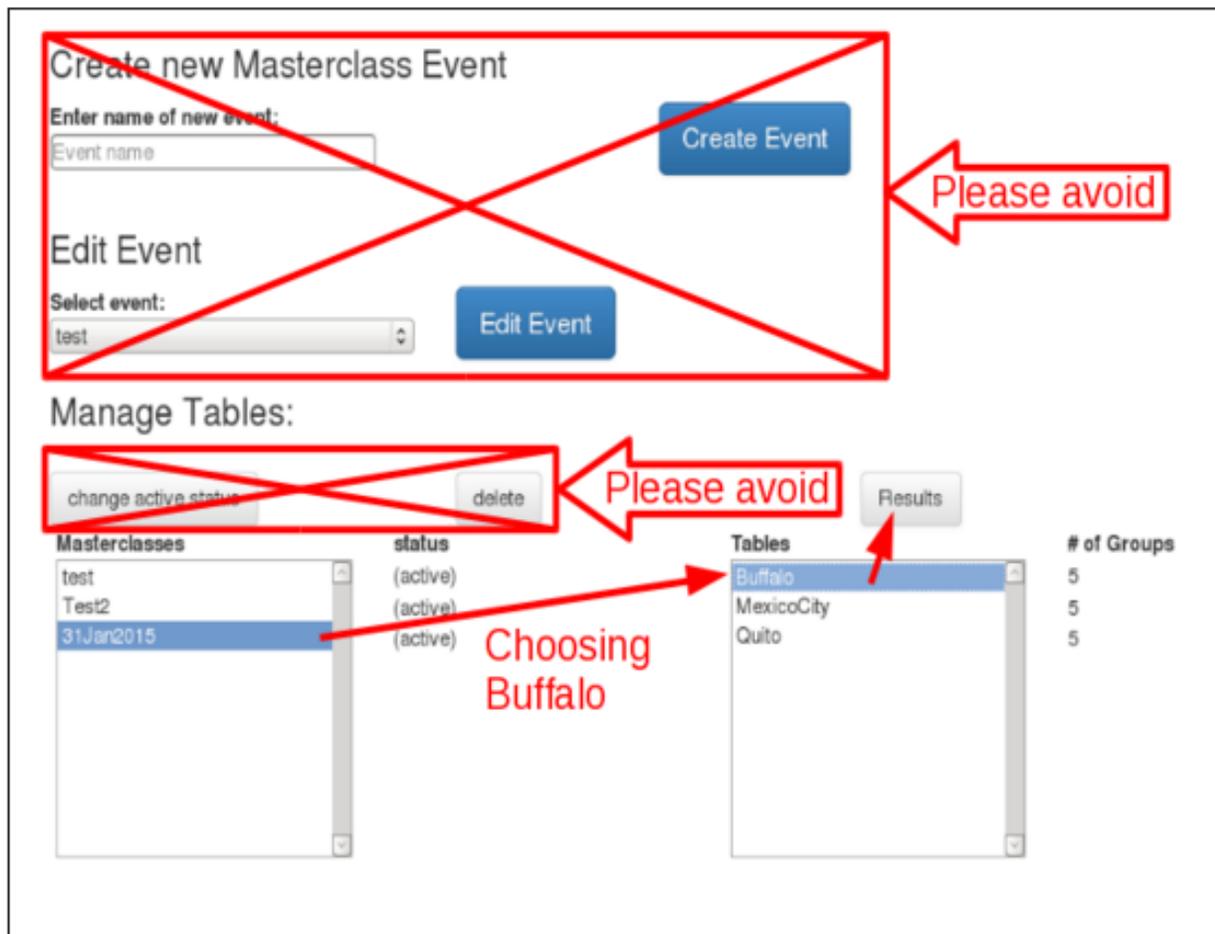
CIMA Admin page. This shows how to choose results for Buffalo on 27 January. To choose combined results for Buffalo, Mexico City, and Quito, choose the date but not a location under Tables.

Special feature!

As of 12 March 2015 we have very handy feature in the admin page of CIMA to help moderators handle swtiching between Institutes and combined Results. Here is how it works:

1. Go to the CIMA admin page and log in.
2. Immediately choose the "Results" button (as if you want to see the combined results).
3. You will indeed end up with the combined Results page. But at the top of the page there is a down arrow next to "All". Choose this.
4. A drop-down menu appears. This drop-down menu allows the admins to switch between single-location and combined results without going back to the admin page. This works for the mass histogram and the result summary.

You do not have to back up to the main menu to switch from one Institute to another. It works just as well on the Mass Histogram.

Moderators should discuss the results from each institute and the overall results with the students, making sure to stay within time constraints.
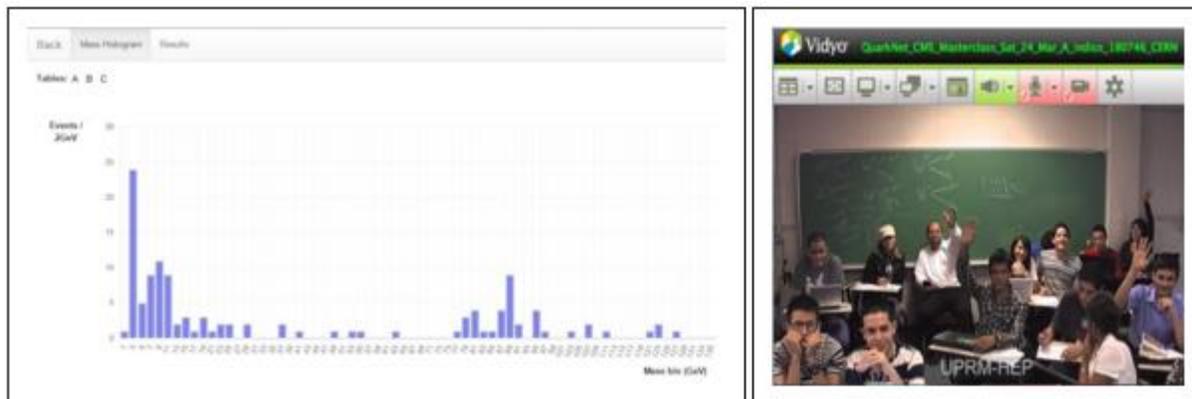
Sample combined Mass Histogram and a masterclass institute on Vidyo to discuss results.

If an institute does not use the online spreadsheet, the mentor for that institute should show their mass plot and results using Vidyo desktop sharing.

Material

for students and teachers:

- Classroom prep activities
    - Rolling with Rutherford at **https://quarknet.i2u2.org/data-portfolio/activity/rolling-rutherford**
    - Quark workbench at **https://quarknet.i2u2.org/data-portfolio/activity/quark-workbench**
    - Calculate the mass of the top quark from Tevatron data at **https://quarknet.i2u2.org/data-portfolio/activity/calculate-top-quark-mass**
    - Calculate the mass of the Z boson from LHC data at **https://quarknet.i2u2.org/data-portfolio/activity/calculate-z-mass**
- Aid in masterclass
    - Analysis presentation at **http://quarknet.i2u2.org/sites/default/files/cmsanalysis2016_v0.ppt**
    - CMS Masterclass "Cheat Sheet" at **http://quarknet.i2u2.org/sites/default/files/cmscheat_wzh16_v0.doc**

Low/No Bandwidth Supplement

In the case where bandwidth or connection to CIMA is a problem, please use these alternative steps:

- Use the **DVD version** if possible.
- Distribute the spreadsheet **mc2016dvd_students** to students. It is in the "more" folder of the DVD.
- Students should find their dataset in the Datasets tab. For each event they examine in iSpy-dvd, students should:
    - place a "1" (and *only* a "1") under electron or muon *only* if the event is a W- or Z-candidate.
    - place a "1" (and *only* a "1") under W+ cand, W- cand, W cand, or Z cand *only* if the event is a W- or Z-candidate.
    - place a "1" (and *only* a "1") under "zoo" if the event cannot be characterized.
    - place a "1" (and *only* a "1") under Higgs cand *only* if the event is a Higgs (diphoton or 4-lepton) candidate.

- If the student characterizes the event as a Z or Higgs candidate, a mass in GeV will appear in the rightmost column. The student should then go to the Results tab and place a "1" (and *only* a "1") above the mass (rounded to the nearest odd number) in the cell directly above the mass in row 33. If this cell is filled, the student goes to the next one up. The student then returns to the Datasets tab and continues to work.
- Once the data analysis has stopped, the student should find the total numbers of electrons, muons, W+, and W- from the bottom of their dataset and write these down. They should also write down the total non-zero number of events for each mass (with the mass) from the Resutls tabs. These numbers must be reported to the mentors. Students may use the **Data Report Form** found in the "more" folder of the DVD.
- A mentor or a teacher can then type in the totals in the **mc2016dvd_mentors** spreadsheet, found in the "more" folder of the DVD. The will create a combined e/µ, W+/W-, and mass plot for the whole institute.
- The results cannot be combined with the other masterclass institutes in a videoconference but they can be shared via the Vidyo desktop. Upon request, a Google version of the mentors spreadsheet can be made to make entering data much quicker. Send an e-mail to **kcecire@nd.edu** for this.