PLOTTING LHC DISCOVERY
TEACHER NOTES

Note: This exercise is for educational purposes only; any combination of results from these data is not valid for research.

DESCRIPTION
Students and teachers benefit from analyzing similar data when experiments announce discoveries. They use data from the "re-discovery" of a known particle to construct a plot. Students then examine features of the plot and attempt to describe features of a well-understood particle. They then can examine plots from any announcements and do the same for the new particles.

NATIONAL SCIENCE EDUCATION STANDARDS
Content Standard A, Science as Inquiry:
- As a result of activities in grades 9-12, all students should develop:
  - Abilities necessary to do scientific inquiry.

Content Standard G, History and Nature of Science:
- As a result of activities in grades 9-12, all students should develop an understanding of:
  - Nature of scientific knowledge.

OTHER EDUCATION STANDARDS
Next Generation Science Standards, Scientific and Engineering Practices:
- We consider eight practices to be essential elements of the K-12 science and engineering curriculum:
  4. Analyzing and interpreting data
  5. Engaging in argument from evidence

IB Physics:
- Uncertainty and error
- Particle Physics

OCR A-level (Advancing) Physics
- Physics in Practice/Quality of Measurement
- Field and Particle Physics/Fundamental Particles

ENDURING UNDERSTANDINGS
- Discoveries can occur when observations differ significantly from explanations provided by models.
- Particle physicists have stringent definitions of evidence.

LEARNING OBJECTIVES
As a result of this activity, students will be able to:
- Indicate signal and background in a plot.
- Find a peak in a histogram.
- Discuss the significance of the discovery and its nature in particle physics.

PRIOR KNOWLEDGE
Students must be able to plot and interpret a graph from data. It is helpful but not required that students have a working understanding of:
- Mass, energy and momentum units as used by particle physicists
- Histograms

BACKGROUND MATERIAL

The links below provide useful background material.

Detectors at the LHC:

- http://aliceinfo.cern.ch/Public/Welcome.html
- http://atlas.ch
- http://cms.cern.ch
- http://lhcb-public.web.cern.ch/lhcb-public/

How particles are produced and detected:

- http://leptoquark.hep.nd.edu/~kcecire/LHCdiscovery/JpsiCMS.ppt

Histograms, useful units:

- http://quarknet.fnal.gov/toolkits/new/histograms.html
- http://quarknet.fnal.gov/toolkits/ati/whatgevs.html
- http://leptoquark.hep.nd.edu/~kcecire/zweb/mcz_home.html

PART 1: PLOT OF A KNOWN PARTICLE

Students plot data collected in 2010 by the CMS detector. The result will yield the mass of a well-understood particle: the J/Ψ. The students also discuss the results.

When CMS detects a decaying J/Ψ particle, it also detects other things that mimic this decay. These other things are called "background events." There is no way to tell if any particular event is from a decaying J/Ψ or from the background. Only many, many observations will provide enough statistics to allow the mass of the J/Ψ to appear in the plot. The student plot shows the background as a dashed line. Students should ignore this line as they make their plot; the teacher will discuss it with them after they are finished.

Students should discuss their results in small groups with these points as possible prompts:

- Where is the peak of your plot? What does it represent?
- Why is there a distribution around the peak?
- Where does the data plotted match the dashed "background model" and where does it differ?
- How many events at the peak of your plot do you think are there because of the background?

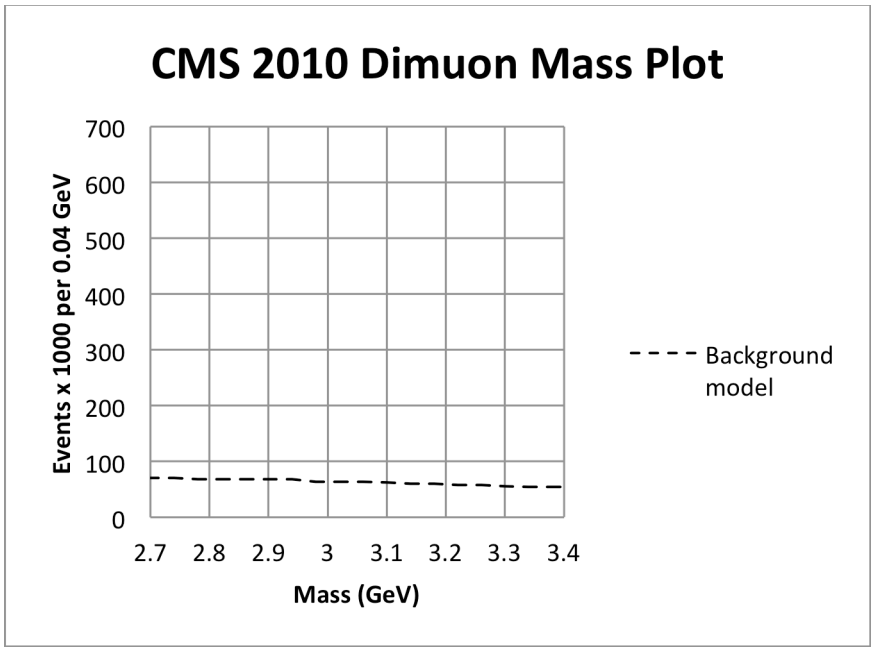
At this point, 1–3 groups can present their plots and conclusions, with questions from fellow students.

The teacher should sum up, taking care to remind students of the following:

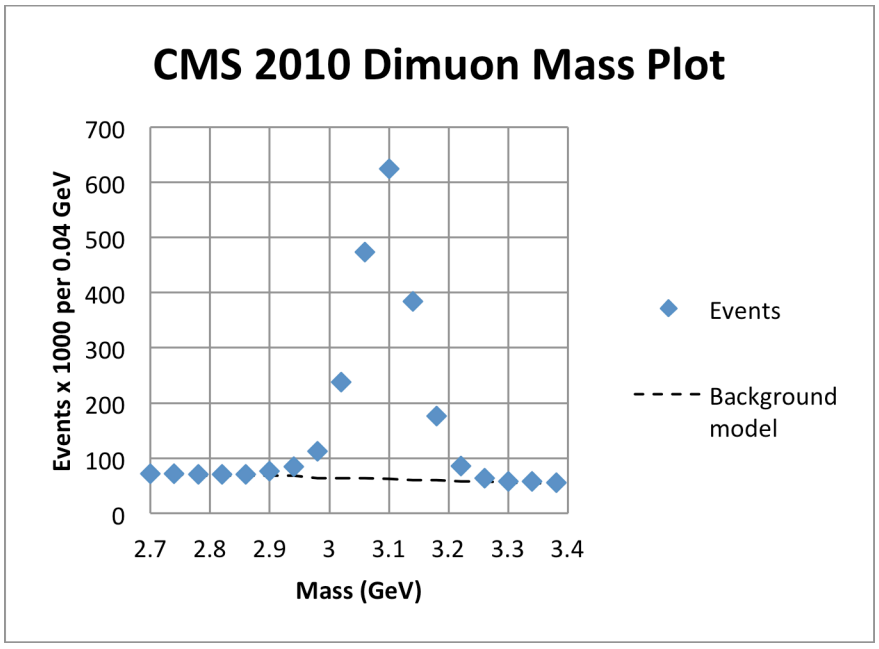
- No single dimuon event is distinguishable as J/Ψ or background; the signal is found in the number of events, not in specific events.
- A bump does not guarantee a particle discovery: it has to be high enough above background to show statistical significance, and it must persist after all attempts to explain it away.

CMS 2010 Dimuon Data and Plot:

Mass (GeV)	Events x 1000 per 0.04 GeV
2.7	72
2.74	72
2.78	70
2.82	70
2.86	70
2.9	76
2.94	84
2.98	112
3.02	238
3.06	474
3.1	624
3.14	384
3.18	176
3.22	86
3.26	64
3.3	58
3.34	58
3.38	56



Blank graph for student use, including background model. A larger version is in the student handout.



Expected result from student plot.

Plot reference: https://twiki.cern.ch/twiki/pub/CMSPublic/PhysicsResultsMUO/JPsi40pb-1_endcap.pdf

PART 2: INTERPRETATION OF DISCOVERY PLOT

After the discussion of the student plots in Part 1, students investigate recent public plots that indicate discovery. Students seek and discuss features that they believe are significant. The teacher should provide the context for the plot and then might add questions like the following:

- Is the bump easy or difficult to distinguish?
- What is the mass at the peak, if you can find one?
- How is this plot different from the one that you made earlier? How is it similar?

At the time of a discovery, IPPOG, QuarkNet, or a similar group will provide discovery plots and context for teachers. A set of plots that can be used as of December 2012 is available in slides at: http://leptoquark.hep.nd.edu/~kcecire/LHCfellows/data/LHCDiscovery.pptx.

ASSESSMENT

Students can be assessed on:

- Quality of their plots
- Interpretation
- Discussion

A written report may be useful.

PLOTTING LHC DISCOVERY

INTERPRET THE LATEST FROM LHC.

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TO THE STUDENT ANALYSIS TEAM:

You have been given this assignment because a possible new discovery has been announced by CERN from the Large Hadron Collider (LHC). You will analyze a mass plot from previous, well-understood results and then interpret the new result. Along the way, you will explore:

- Mass plots
- Significance of a result

Analysis: Part 1.

In the first part of your analysis, you have data that can show the "re-discovery" of the J/Ψ meson.

Mass (GeV)	Events x 1000 per 0.04 GeV
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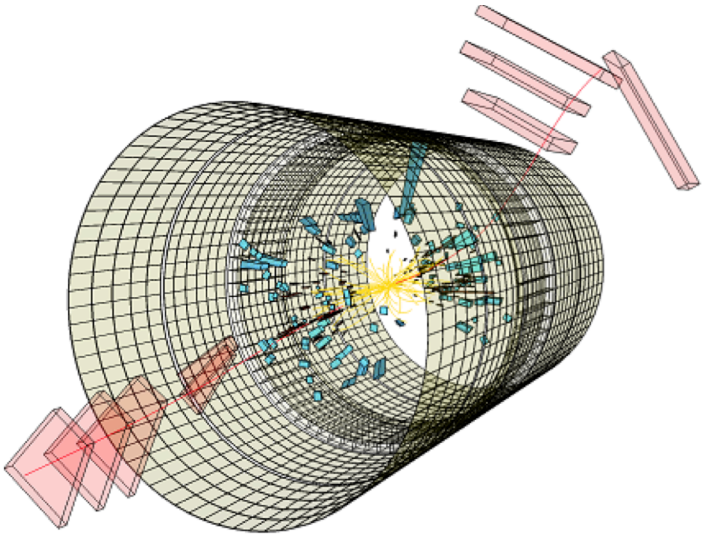
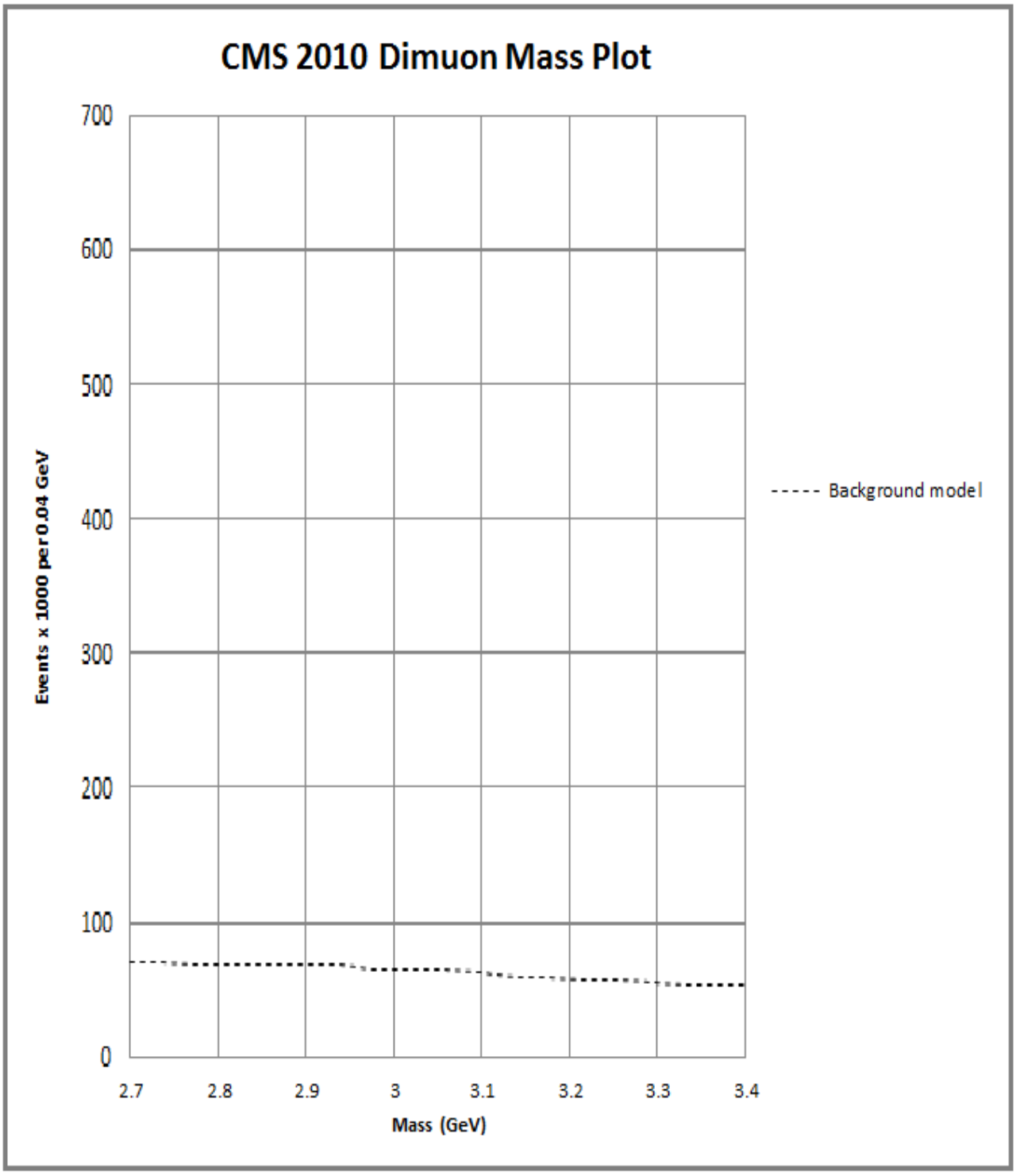


This image shows a "dimuon" event in the CMS detector. The two red tracks indicate a muon and an antimuon. The pink boxes outlined in black indicate parts of the CMS muon system that indicated the passage of these muons. The parent particle existed at the vertex of the tracks before it decayed into the observed muons.

Graph the data on the space provided on the next page.



Plot your graph here and then form a group for discussion.

After you have made your plot, get together with 1–3 other students to discuss your results. Here are a few points of discussion you may use:

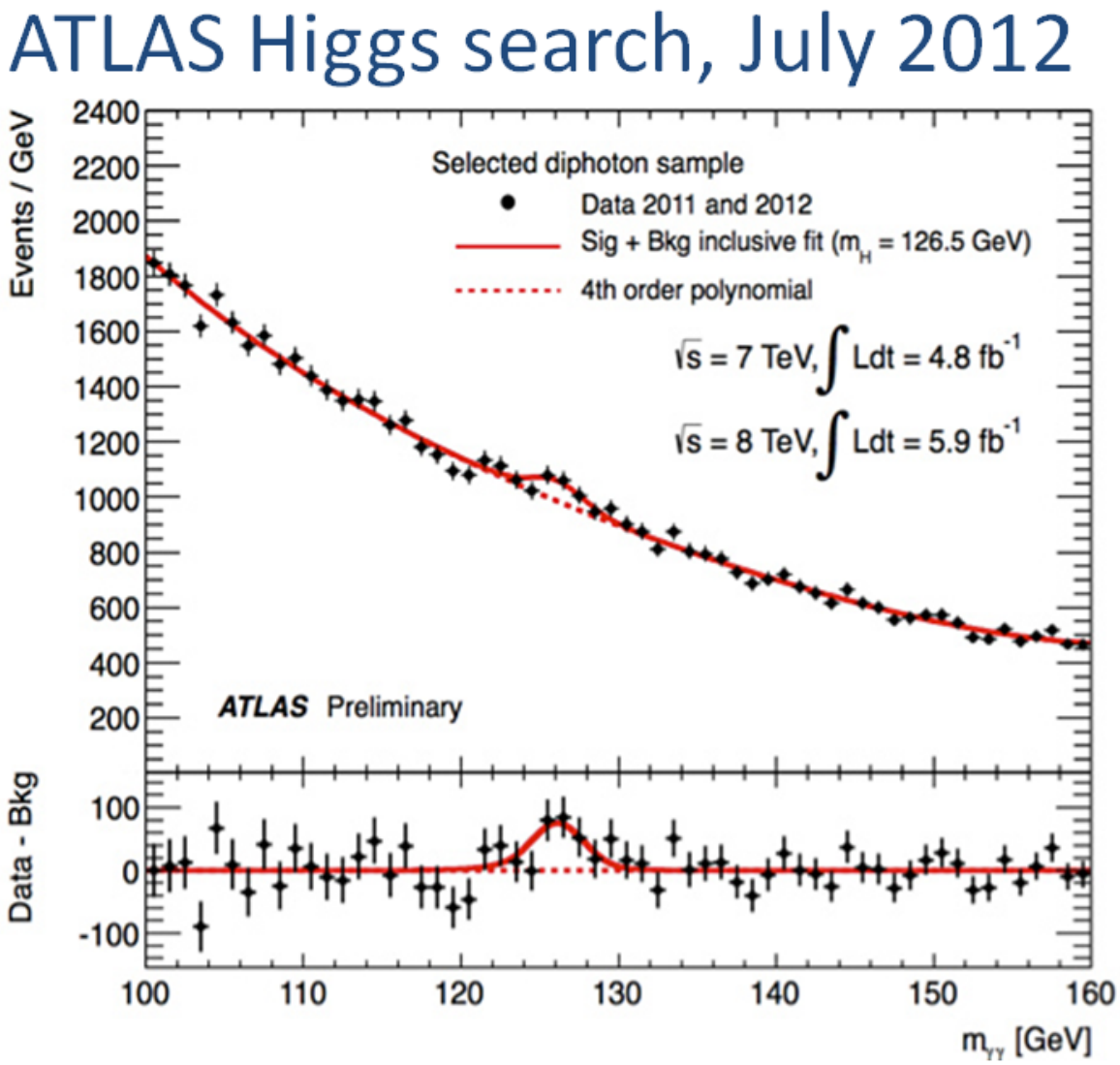
- Where is the peak of the plot? What does it represent?
- What is the mass of the J/Ψ meson? Why is there a distribution around that value?
- Where does the data you plotted match the dashed line and where does it differ?
- How many events at the peak of your plot do you think are there because of the background?

Discuss your conclusions with your teacher.

Analysis: Part 2.
You will receive a recent discovery plot. Use what you learned in Part 1 to identify:

- The mass value of the peak.
- Where the signal rises above background to form a peak or "bump."
- The meaning and significance of the peak.

Discuss your conclusions with your teacher.



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