FRONTIERS

DEMONSTRATORS

Giulia Vannoni
Paris Centre for Cosmological Physics
Université de Paris

La physique des prix Nobel
Atelier en ligne, 12/12/2020

Erasmus+
This project is funded by the European Union.

Les scenarios pédagogiques

High Energy Physics

Search for the Z and Higgs Bosons

Study data from the Large Hadron Collider

How to accelerate particles

The ALICE Experiment at CERN

The Magnetic Field and its applications

Gravitational Wave Astronomy

Earthquake Interferometer

Gravitational Wave Noise Hunting

Finding Black Holes in a Chirp

EGO Control (Class)room

VIRGO Virtual Visits

Cosmic Ray Physics

Build your own cloud chamber

Study Cosmic Rays Using Data from School Detectors

Relativistic Muons and Time Dilation

Astrophysics / Cosmology

Discovering Alien Worlds

Black Holes in My School

Exploring the Sun: Does the Sun Rotate

Exploring the Sun: The Differential Rotation of the Sun

"Measuring the recessional velocity of distant galaxies": calculating the age of the Universe

General Physics

The Pendulum: From Cooking Spagetti to a Gravitational Wave Detector

Discovering and building a Michelson interferometer

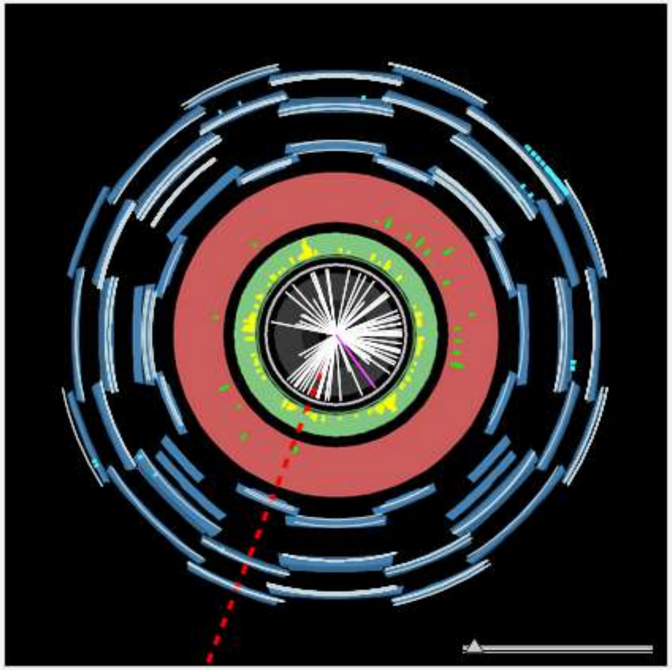
Mass- Energy Equivalence

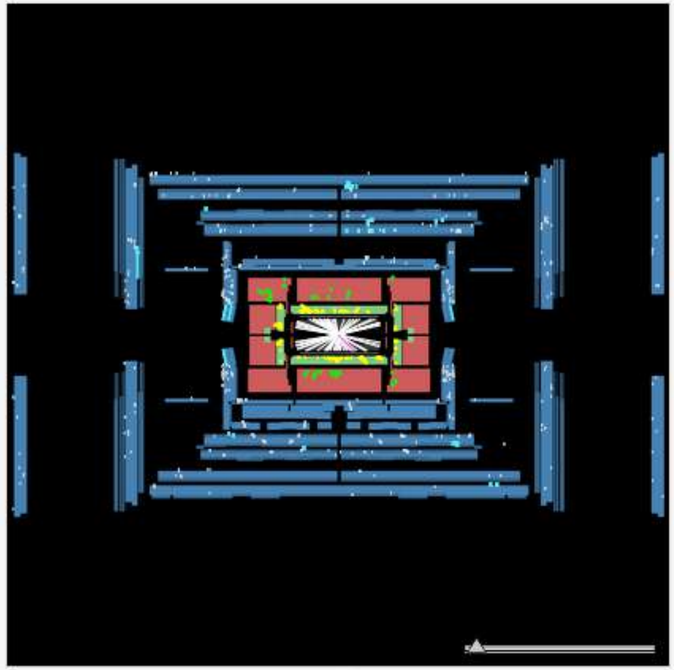
Sample of Demonstrators

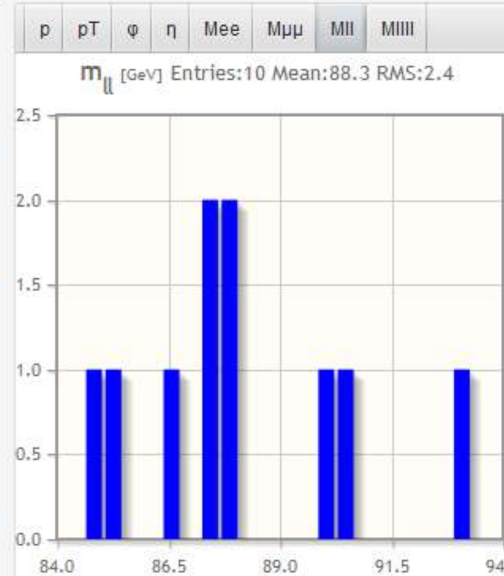
Discover the Z and Higgs bosons

by IASA

- Introduces students to CERN and high energy physics
- Allows students to study the elementary particles and perform simplified researcher work
- Uses real data from the ATLAS experiment
- Shows how a real cutting-edge science laboratory works







Event: 1/10 (1986314/178047) 2011-03-23
ETMiss: 12.43 GeV φ: -1.94 rad

Previous Event | Next Event | Insert Electron | Insert Muon | Delete Track | pT 1.0 GeV | Group_1 | event_01.xml

Track	+/-	p [GeV]	p_T [GeV]	φ [rad]	θ [rad]
Tracks_4	-	28.64	20.15	-0.934	-0.780
Tracks_5	+	4.77	1.03	2.632	0.219
Tracks_7	+	4.49	1.06	-0.580	-2.903
Tracks_8	+	67.67	42.39	1.922	2.465
Tracks_9	+	2.41	1.57	0.702	2.436
Tracks_10	+	6.91	3.39	-2.159	-0.514
Tracks_11	-	3.18	2.61	0.258	2.176
Tracks_13	+	3.93	3.49	-1.733	-2.049
Tracks_15	+	1.65	1.36	-1.842	-2.178
Tracks_16	-	7.45	3.57	0.951	2.643
Tracks_17	+	1.72	1.59	1.720	1.970
Tracks_18	-	2.21	1.67	-1.681	-0.856
Tracks_23	-	2.26	1.03	-1.498	-2.669
Tracks_24	+	1.65	1.63	-0.250	-1.440

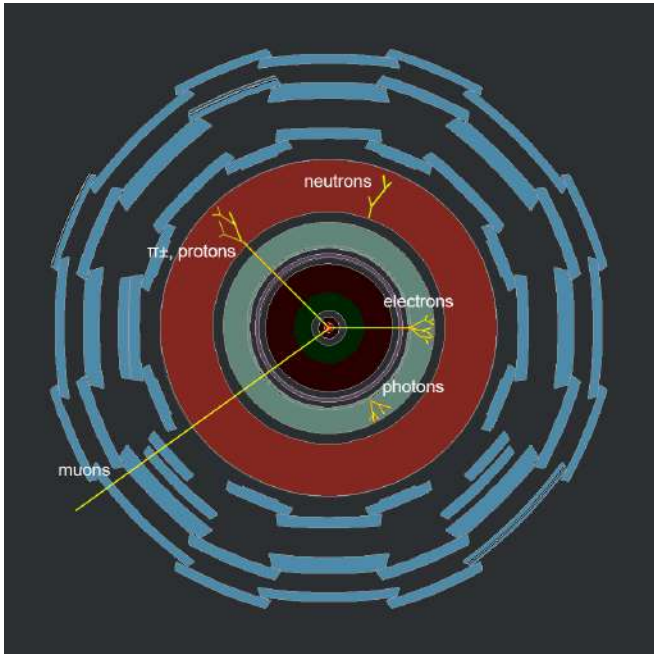
Event Name	ETMiss |	Track	p [GeV]	+/-	p_T [GeV]	φ [rad]	η [rad]	m_{ll} [GeV]	m_{llll} [GeV]	e/μ
event_01.xml / Gr	12.43	Tracks_4	28.64	-	20.15	-0.934	0.888	87.53		e
		Tracks_8	67.67	+	42.39	1.922	-1.044			e
event_02.xml / Gr	10.74	Tracks_0	50.79	+	40.44	0.001	-0.701	85.53		e
		Tracks_2	61.99	-	45.00	-3.109	-0.844			e
event_03.xml / Gr	35.94	Tracks_4	101.93	-	39.75	1.040	1.594	88.18		e
		Tracks_7	56.50	+	42.23	-1.924	0.801			e
event_04.xml / Gr	15.68	Tracks_2	138.78	+	34.08	-2.503	-2.082	84.83		e
		Tracks_20	90.59	-	45.74	0.769	-1.306			e
event_05.xml / Gr	4.23	Tracks_0	100.90	-	21.83	0.965	2.212	93.51		e
		Tracks_61	112.10	+	73.07	-2.628	0.992			e
event_06.xml / Gr	10.60	Tracks_4	36.65	-	36.16	-2.546	-0.164	90.54		μ
		Tracks_6	87.87	+	37.43	0.566	-1.498			μ
event_07.xml / Gr	29.73	Tracks_13	70.34	-	43.63	1.088	-1.057	87.58		μ
		Tracks_15	89.31	+	43.27	-1.892	-1.353			μ

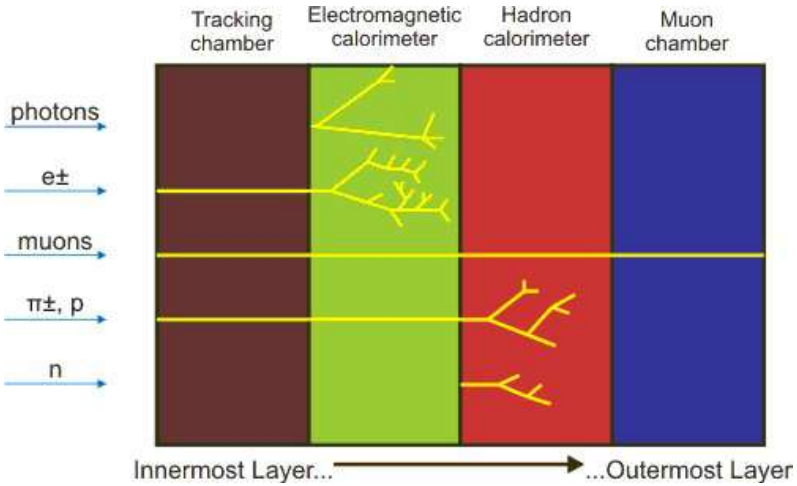
Exercise

- Students analyse 50 real events
- Determine which are signal and which are background events
- They select the tracks that belong to Z/Higgs boson leptonic decays (Z->ee, Z->μμ, H->4μ, H->2μ2e, H->4e)
- Mass histograms are created automatically based on their selection
- Based on the histogram they study and explain their findings about Z/Higgs mass

ATLAS

- Particle tracks appear as lines on the detectors
- The length of each track is determined by particle type
- Each particle leaves a trace only on specific detectors according to its type



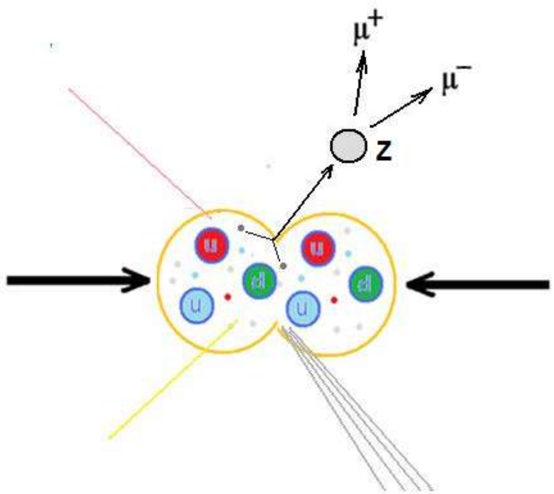


FRONTIERS

Laboratory Exercise

Detection and mass calculation of Z bosons

Selection criteria for real Events



- $Z \rightarrow \mu^- + \mu^+$ $Z \rightarrow e^- + e^+$
- 2 tracks, opposite charge, not diametrical
- Invariant mass 91,2 GeV
- Small missing energy ETMiss

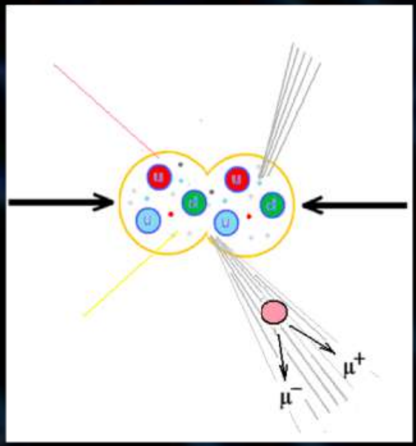
- Background events
- Leptons from quark decays are in jets
- Cosmic rays : diametrical tracks on both detector views
- Large missing energy ETMiss (because of neutrinos from W->l+ν)

World Wide Data Day
by IASA

- Introduction to high energy physics, structure of the atom, elementary particles
- FermiLab + HYPATIA
- *quarknet.org/content/lhc-world-wide-data-day-2018*
- Real data from the ATLAS experiment
- For high school students
- Videoconference with FermiLab and schools around the world

Particle production

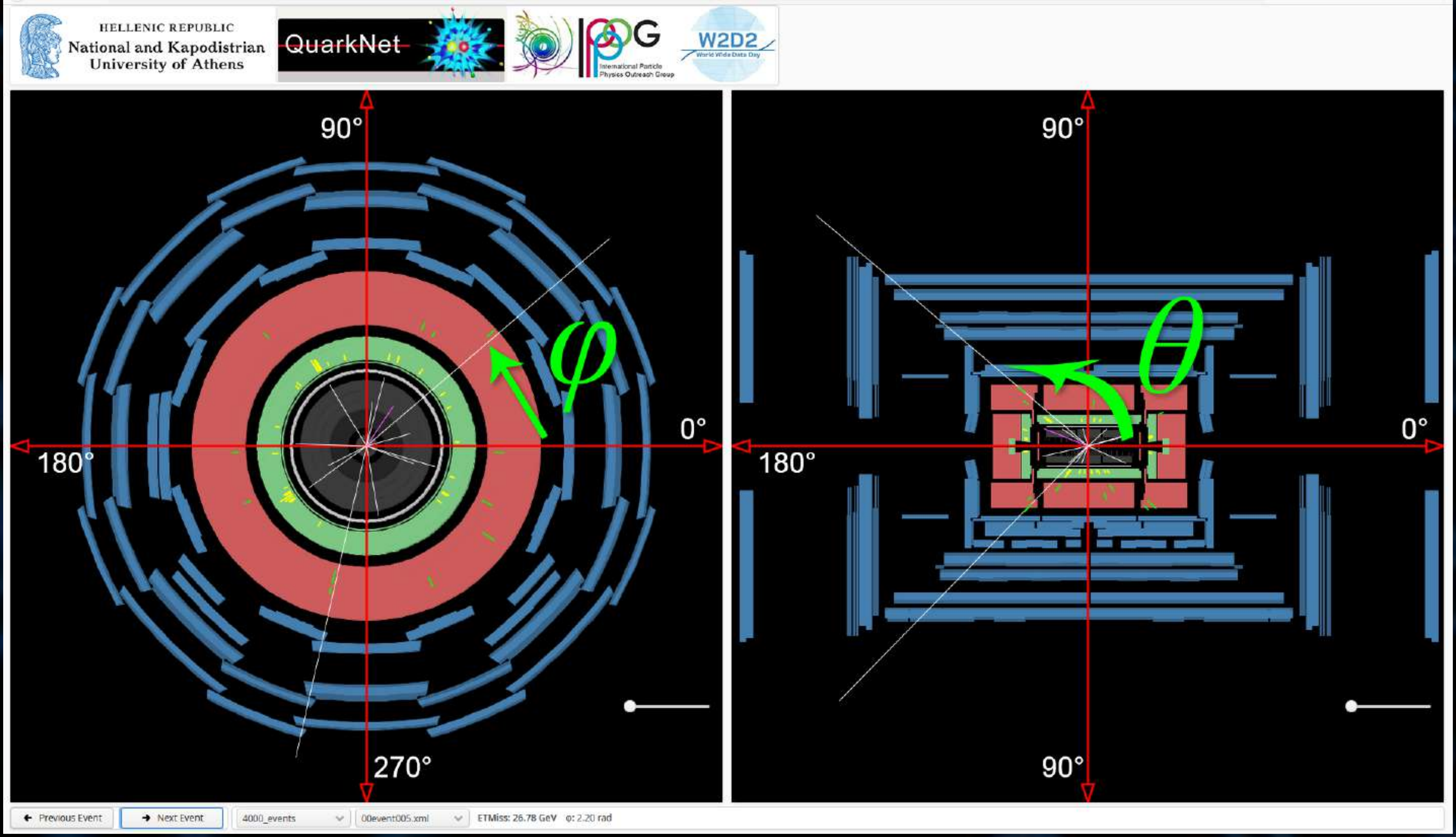
- New particles $E=mc^2$ (13 TeV → particles)
- Most are well known: background
- What we are looking for:
  - High mass particles
  - Unstable particles
  - Muon-antimuon pairs
  - Muon is like a "heavier" electron



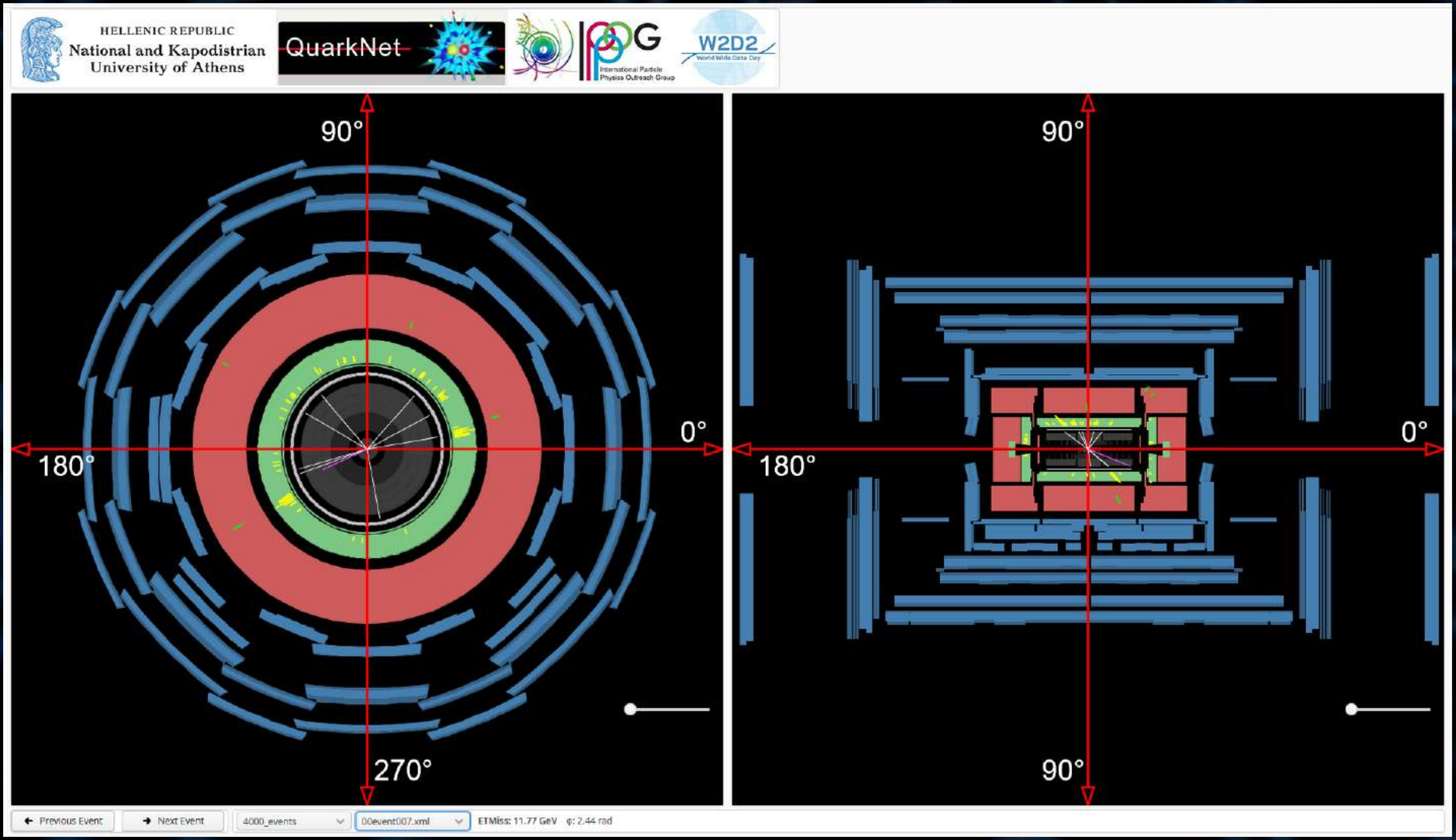
Measurement

- Each group of students analyses 50 evens
- Students measure the θ and ϕ angles of muons/antimuons and create histograms of them
- These are produced in particle colissions and are long tracks which reach in at least one view the blue muon detectors
- The entire class creates a collective histograms, looks for non-uniformities in the distributions and discusses their results with other schools
- The class joins the videoconference with Fermilab and explains their findings

Signal Event



Background Event

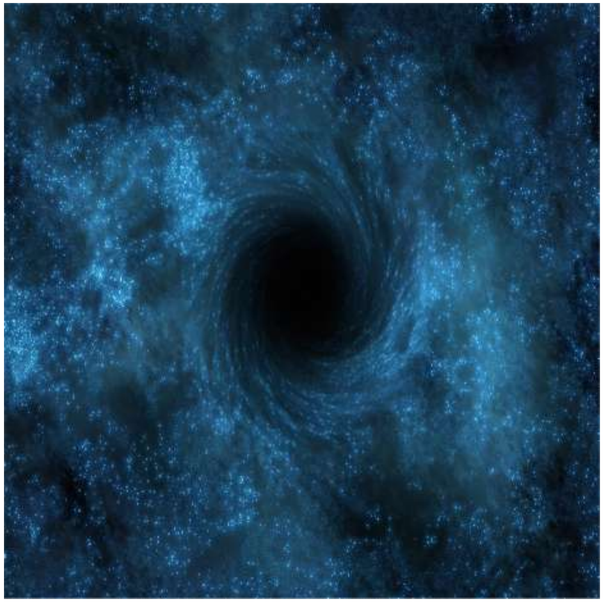


Demonstrator: Black Holes in My School

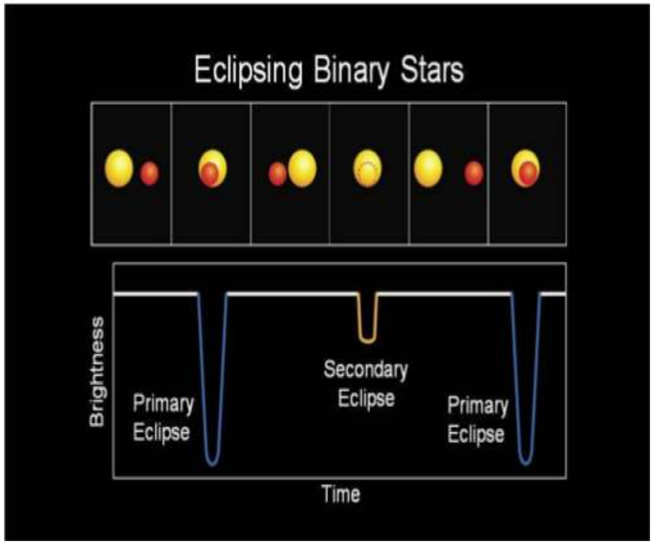
By NUCLIO

Short Description

How do we detect stellar mass black hole candidates?



To answer this question, learners are invited to explore real astronomical images of a binary system where there is a black hole candidate. They will build light curves of stars, analyze and interpret the data, and conclude if there is evidence towards a strong stellar black hole candidate or not. conclusions.



A specific image software will be introduced to analyze the images, as well as the basics of photometry. Students will build light curves for several stars and will have to find out which one belongs to a binary system. Then, from the orbit parameters that they determine, they can estimate the mass of the companion and argue if it is a really strong stellar black hole candidate.

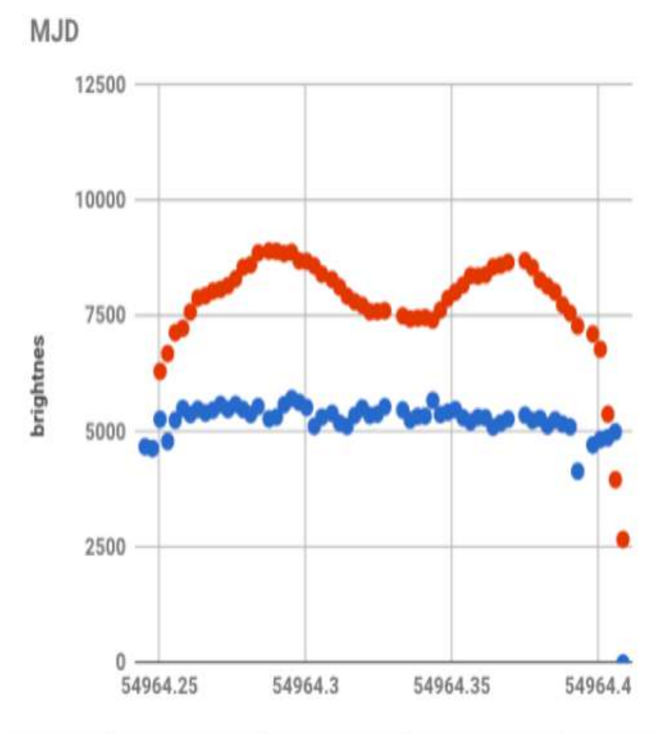
Demonstrator: Black Holes in My School

By NUCLIO

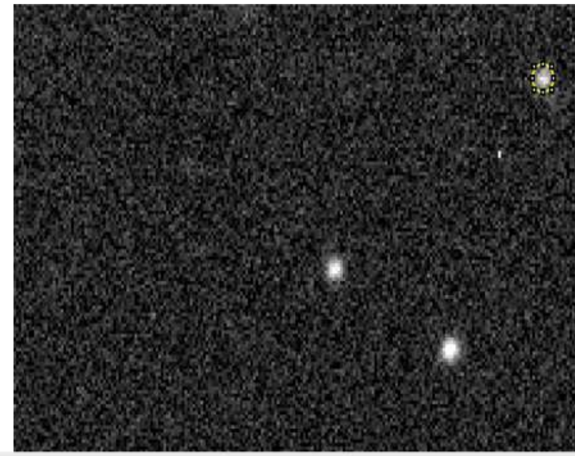
Goals

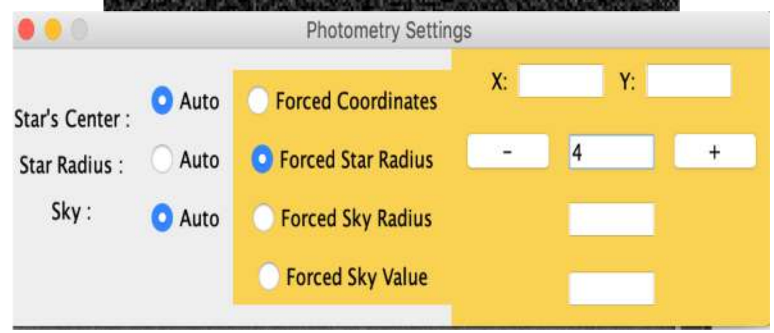
- Introduce students to black holes
- Introduce students to scientific research with real data
- Introduce students to image analysis techniques

Graph analysis



Software: SalsaJ





Age: 14-18

Curriculum: Kinematics & Mechanics, Graphs, The Universe

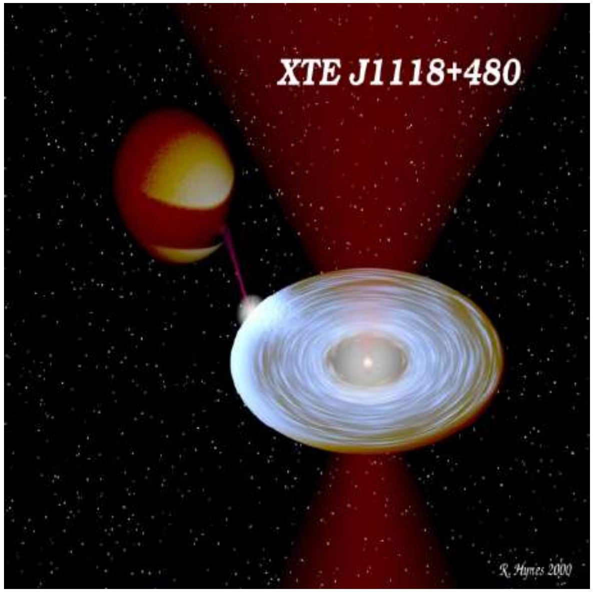
Demonstrator: Black Holes in My School

By NUCLIO

Learning Outcomes

Cognitive

- understand what scientists think black holes are;
- understand how astronomers use images to do research of distant objects;
- understand how astronomers detect stellar black hole candidates;
- use curriculum physics & mathematics to infer parameters of black holes.



Affective

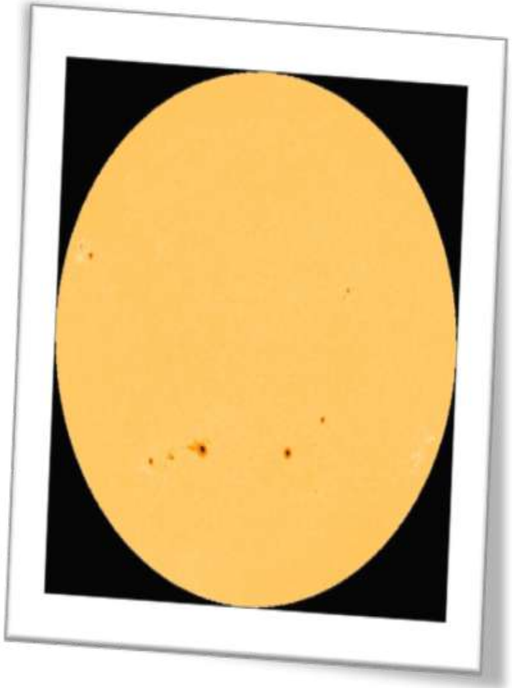
- thrilled for having made a scientific discovery;
- excited for having explored an exciting subject such as Black Holes;
- motivated to learn and investigate more;
- confident that they can use their knowledge in Physics and Maths in new situations;
- confident that they can do research.

Demonstrator: Exploring the Sun - Does the Sun rotate?

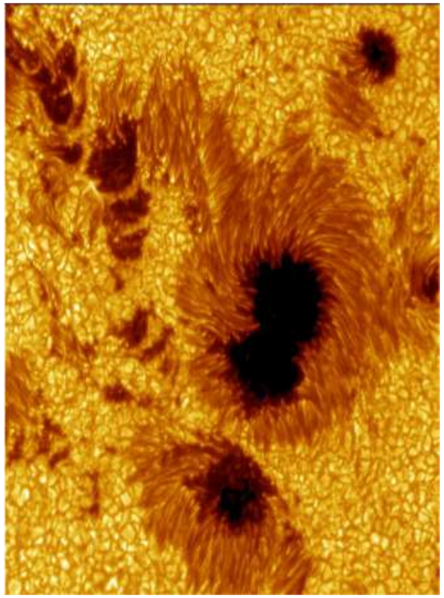
By NUCLIO

Short Description

Is it easy to prove (or disprove) that the Sun rotates?



To answer this question, learners are invited to explore solar images obtained with space observatories and learn to use astronomical image software. They will access scientific data archives, gather and analyze data, and present their conclusions.

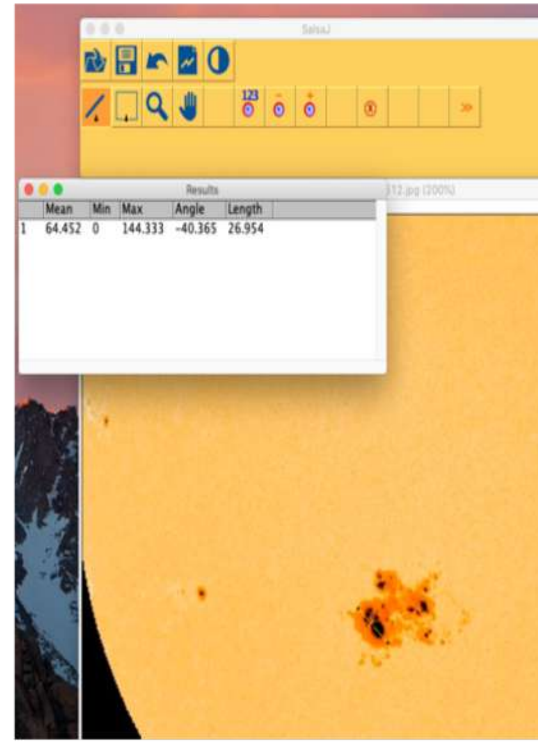


It might seem easy - time-sequential images of the sun when there are sunspots induce the viewer to conclude that the sun rotates.

But…. How do we know that sunspots are on the surface of the Sun and are not satellites revolving around the Sun? Learners will have to make an effort to overcome this dilemma - just like Galileo Galilei!

Demonstrator: Exploring the Sun - Does the Sun rotate?

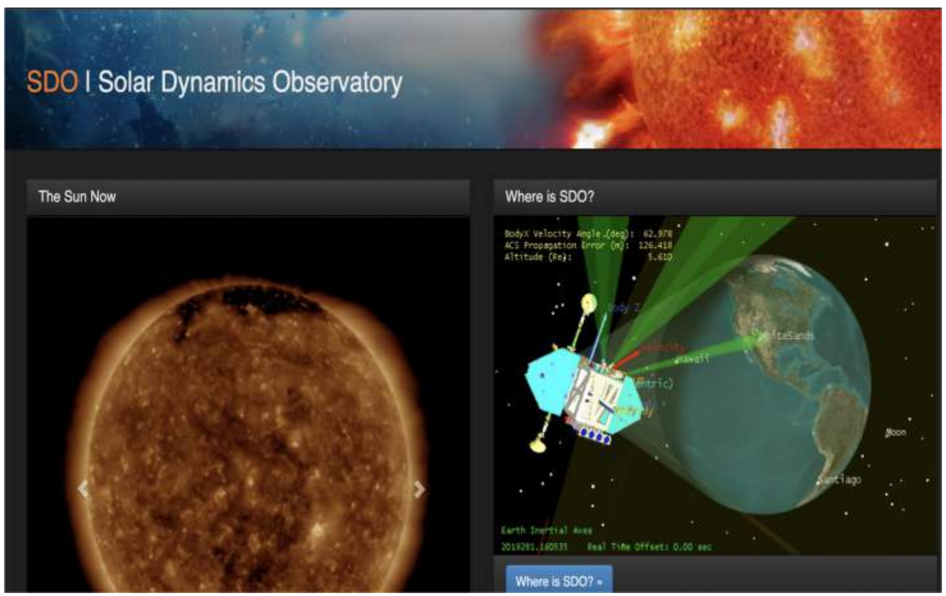
Software: SalsaJ



Goals

- Introduce students to real astronomical data
- Introduce students to real research
- Introduce students to image processing techniques

Scientific Data Archives



Age: 14-18

Curriculum: The Sun, our star

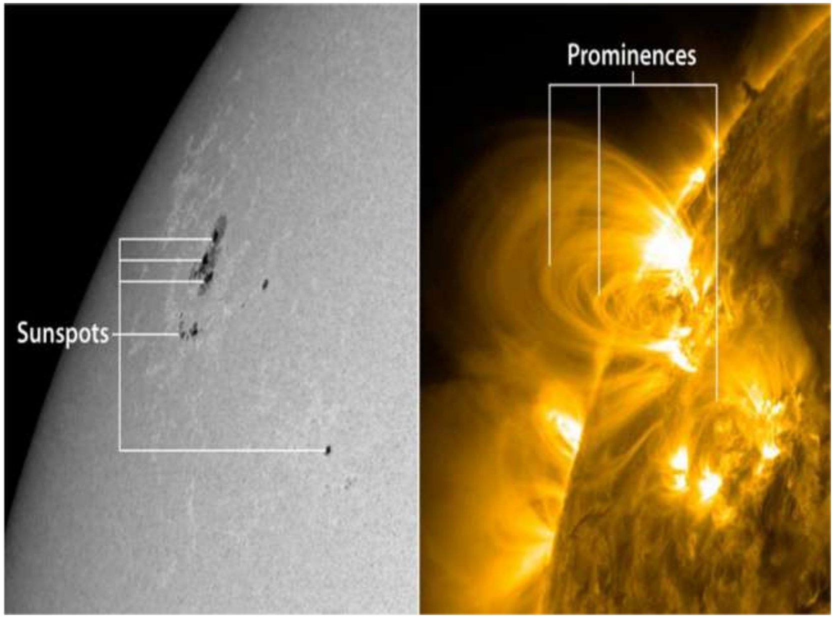
Demonstrator: Exploring the Sun - Does the Sun rotate?

Learning Outcomes

Cognitive

Students should:

- understand that the Sun is an active star;
- understand how astronomers use images to do research in solar physics;
- conclude that there is evidence that the Sun rotates around itself;
- recognize that sometimes the interpretation of the data analysis is not straightforward.



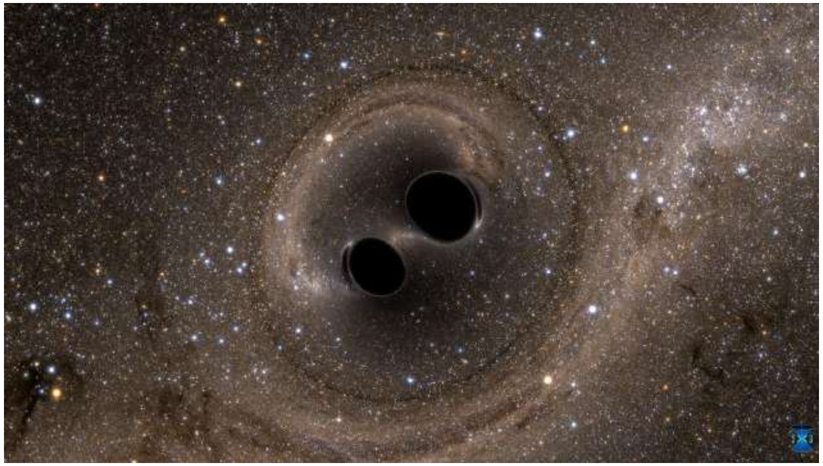
Affective

Students should be:

- thrilled for having made a scientific discovery;
- motivated to learn and investigate more;
- confident that they can do research.

Demonstrator: Finding black-holes in a chirp”: how to understand the first gravitational-wave detection

by
Paris Centre for Cosmological Physics



Frontiers has been funded within the framework of the European Union Erasmus+ programme

Metadata

Name of Demonstrator	**“Finding black-holes in a chirp”: how to understand the first gravitational-wave detection**
Short description	In this lesson you will be able to analyse the data of the first gravitational wave signal ever detected. You will retrace in your classroom the steps that lead to the Nobel Prize in Physics 2017 to the LIGO collaboration. You will also learn about General Relativity, black holes and binary systems.
Keywords	Physics; gravitational waves; black holes; general relativity
Target age group of students	16 - 18
Expected Duration	3 h
Connection with school curriculum	Astronomy, solving equations, plotting results.
Connection to research center/experiment	Ligo – Virgo collaborations

Frontiers has been funded within the framework of the European Union Erasmus+ programme

Description

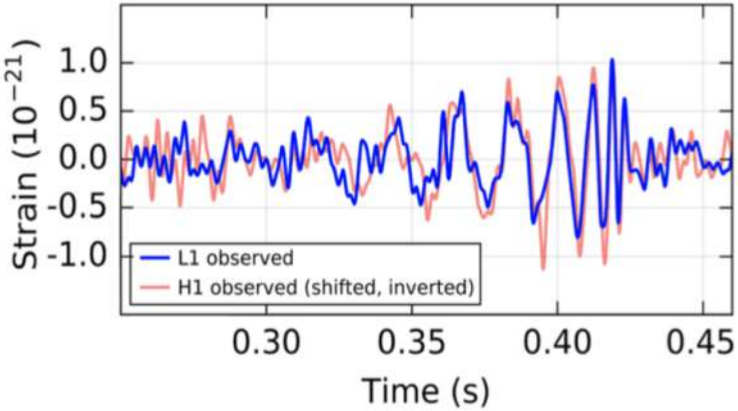
Calculating the source parameters for the first gravitational wave ever detected (GW150914).

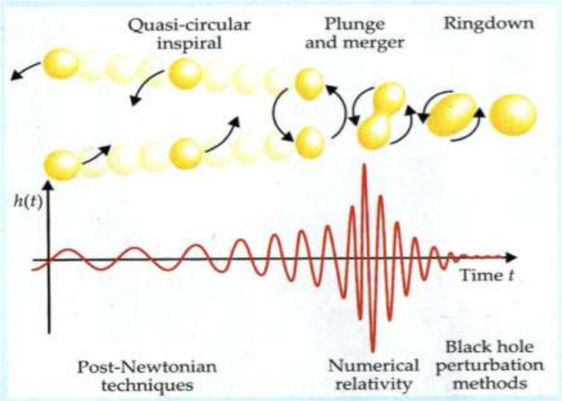
- Orientation phase: introduction to the concept of General Relativity's space-time and gravitational waves.
- Exploratory phase: How do we detect gravitational waves? What is the first gravitational-wave signal telling us? How can we understand what the source is and, specifically, that the source is a pair of black holes?
- From simple plots and basic formulae, students calculate the mass and the radius of the system that produced GW150914.
- Consolidation phase: Questions and insights, verbal and written reporting on the exercise.

Frontiers has been funded within the framework of the European Union Erasmus+ programme

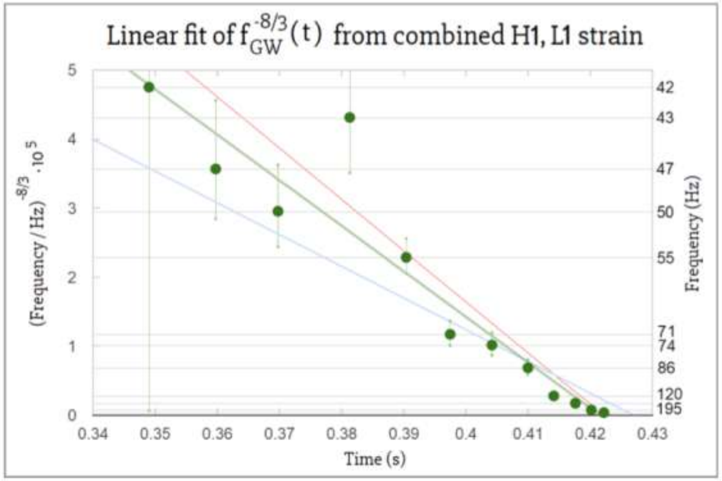
Description

A taste of the type of plots and level of mathematics present in the exercise.





GW150914 signal in the two LIGO detectors



$$\mathcal{M} = \left[\frac{5K}{(8\pi)^{8/3}}\right]^{3/5} \frac{c^3}{G}$$

Frontiers has been funded within the framework of the European Union Erasmus+ programme

Key features

- Basics on exiting research topics: black holes, gravitational waves, general relativity, GW detectors.
- Support of numerous and diverse media (videos, scientific papers, Wikipedia, scientific algorithms…).
- Exercise carried out with pen and paper calculation (but need to be able to read and interpret a scientific plot).

- Insight on the workings of big modern scientific collaborations: internationality and team work.
- Taste of how science is produced and communicated both within the scientific community and to the general public.

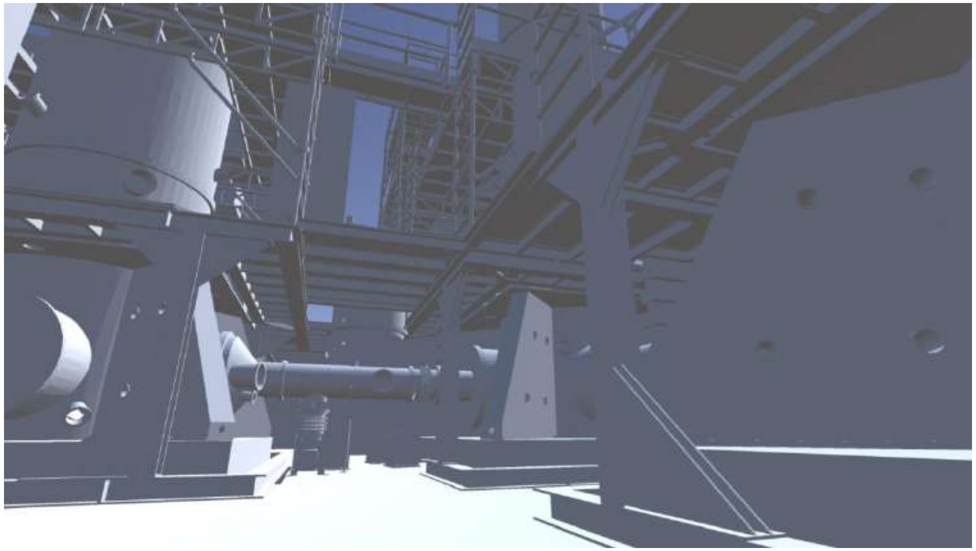
Frontiers has been funded within the framework of the European Union Erasmus+ programme

Virgo Virtual visit

by EGO

http://pub9.virgo.infn.it/WebGL/

You can also visit the inner part of the detector using our 3D virtual visit

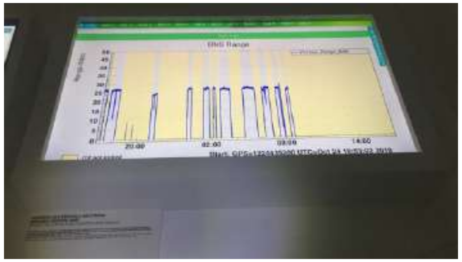


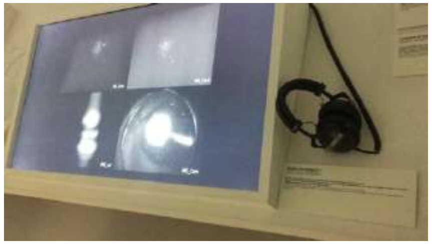
Control (class)room
by EGO

Whether you are detecting gravitational waves or measuring colliding particles, the control room is where all the magic happens !!

Control (class)room
by EGO

- Using simply a set of PCs or Raspberry PIs you can have all the data shown in the control room in your class !!





Now let's visit the real control room…