

Exploitation of Research results In School practice

The project has been funded with support from the European Commission within ERASMUS+ Programme (grant agreement no. 2015-1-PL01-KA201-016622)

Elementary particles and fundamental forces - Upper secondary school -

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05.03.2018, Bucharest-Magurele

- 1 International collaborations, CERN, IFIN-HH, Masterclass
 - Educational resources - Masterclasses
 - Research laboratories
- 2 Introduction to elementary particle physics
 - Why particle physics?
 - The Standard Model of elementary particle physics
- 3 How do we measure?
 - Experimental work
 - Rutherford experiment
- 4 Practical exercise: LHCb masterclass
 - LHCb experiment
 - Measurement of the lifetime of the D^0 meson

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International Masterclasses

12th International Masterclasses 2016

Each year about 10.000 high school students in [47 countries](#) come to one of about 200 nearby universities or research centres for one day in order to unravel the mysteries of particle physics. Lectures from active scientists give insight in topics and methods of basic research at the fundaments of matter and forces, enabling the students to perform measurements on real data from particle physics experiments themselves. At the end of each day, like in an international research collaboration, the participants join in a video conference for discussion and combination of their results. See [here](#) for media coverage.



ALICE

Identification of elementary particles such as K_S^0 , Λ^0 and Ξ^- from data and the study of collisions proton - proton and Pb - Pb



Selection and identification of interaction bosons W^+ , W^- 'si Z^0 . Production of Higgs boson



Study of bosons production ratio W^+/W^-

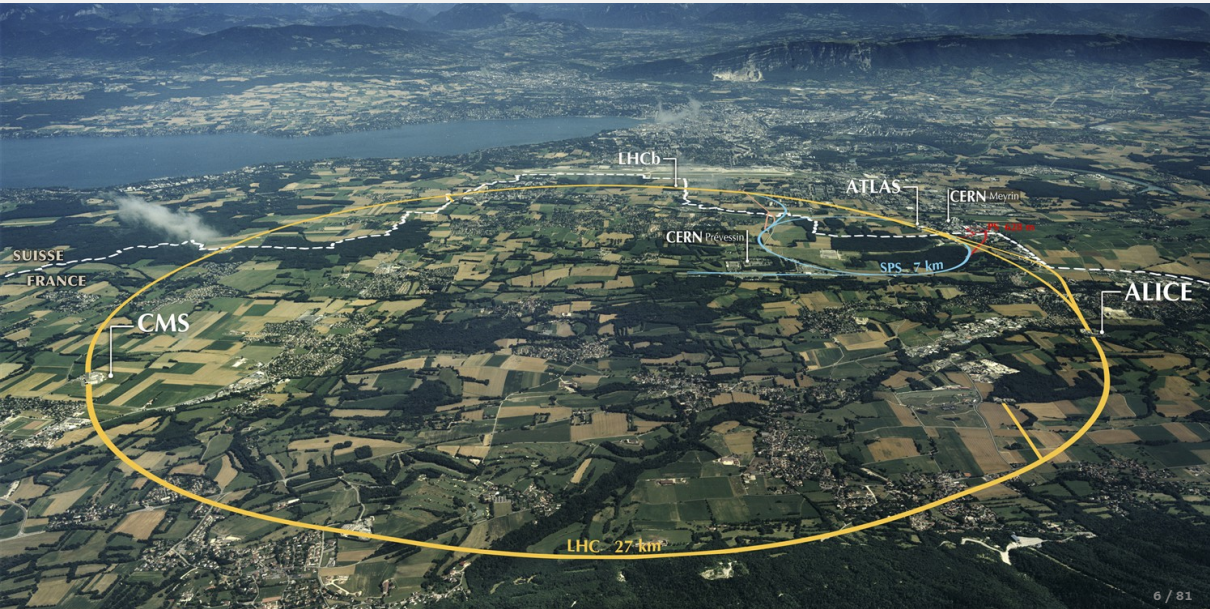


Measurement of the lifetime of the D^0 meson



Bucharest, 2013

What is Cern?



Reconstruction of Europe after two world wars, 1954
reconstruction through science



Reconstruction of Europe after two world wars, 1954 reconstruction through science

- The largest scientific laboratory
- 2300 staff, 1050 personal auxiliar, 11000 collaborators
- Budget (2012) 900 MEuro

Member state: Austria, Belgium, Bulgaria, Czech Republic, Denmark, Switzerland, Finland, France, Germany, Greece, Hungary, Israel, Italy, Holland, Norway, Poland, Portugal, Romania, Slovak Republic, Spain, Sweden, UK

Associated members: Cyprus, Serbia, Slovenia, Turkey

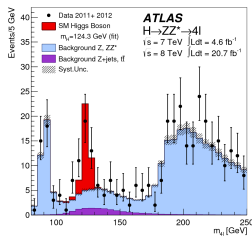
Observers: India, Japan, Russia, USA, EC, UNESCO



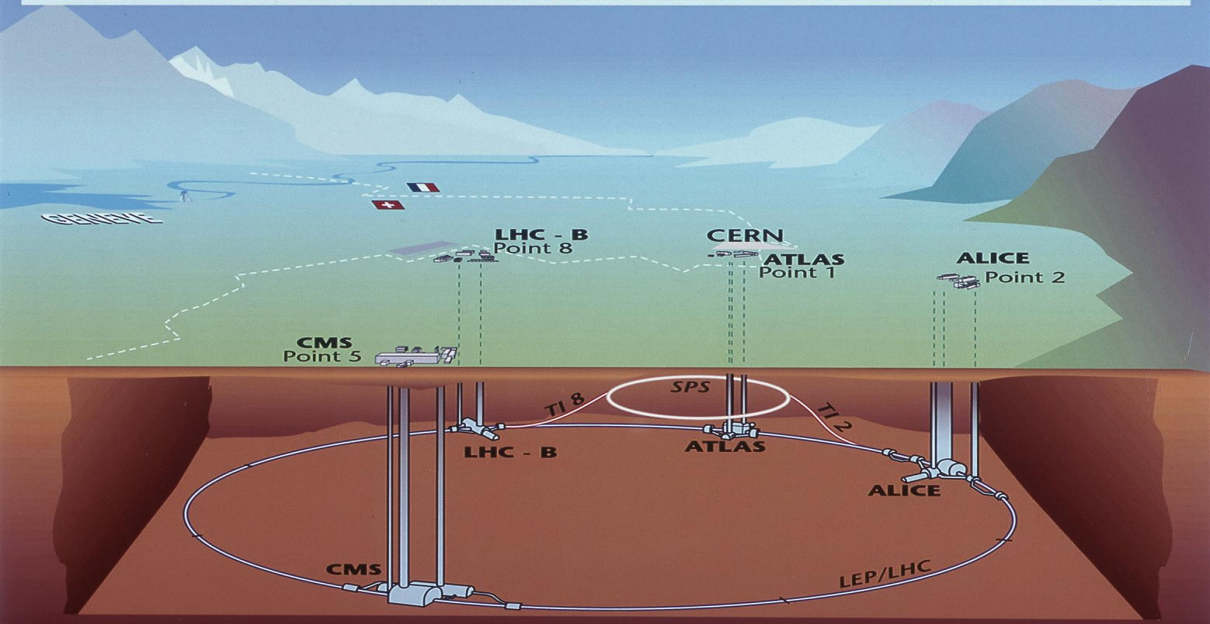
About CERN?

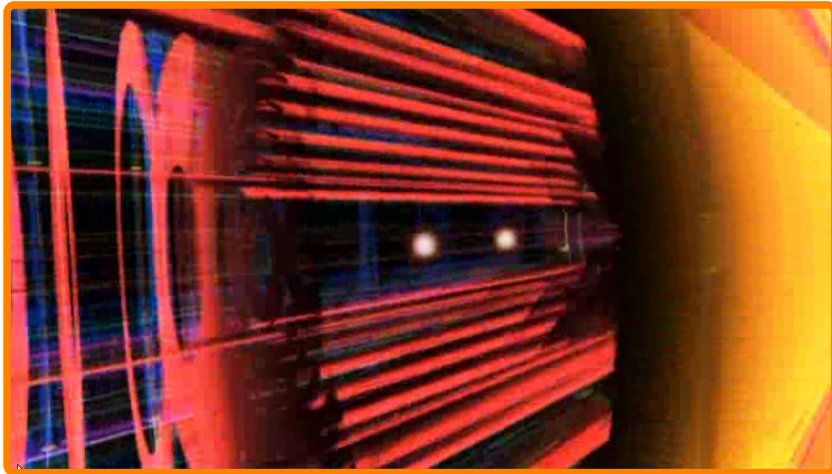


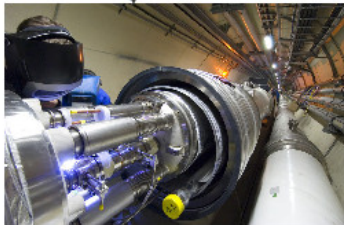
2012 Discovery of the Higgs boson



Overall view of the LHC experiments.



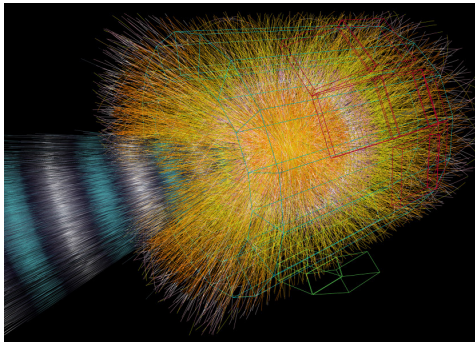




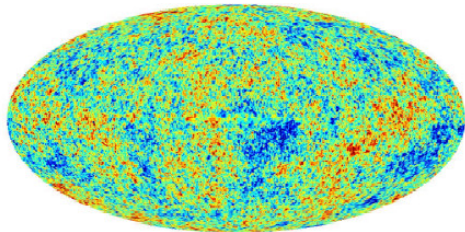
LHC

Super-Microscope

- the biggest "microscope", 27 km circumference, located 100 m underground
- the protons are accelerated to 6.55 TeV and the collisions have a rate of 40 millions per seconds
- the temperatures produced in the collisions are 100 000 higher than the ones in the centre of Sun
- the coolest place on Earth, 1.9 K (-271.3°C) (cooled with liquid nitrogen and helium)
- ultra-high vacuum, the pressure of 10^{-13} atm is 10 times lower than the one on the Moon
- the quantity of data processed is huge breaking record after records (LHCb sends data with a bandwidth equivalent to a phone company for a country of the size of Switzerland)



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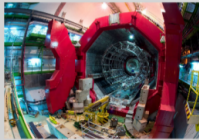
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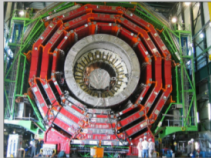
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Atlas



Alice



CMS



LHC-b

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Medical Application as an Example of Particle Physics Spin-off

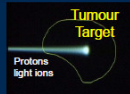
Combining Physics, ICT, Biology and Medicine to fight cancer



Accelerating particle beams
~30'000 accelerators worldwide
~17'000 used for medicine



Hadron Therapy



Leadership in Ion
Beam Therapy now
in Europe and
Japan

>70'000 patients treated worldwide (30 facilities)
>21'000 patients treated in Europe (9 facilities)



Detecting particles



Imaging

PET Scanner

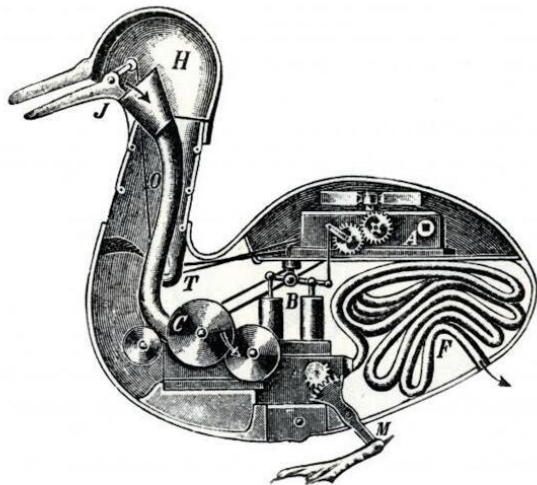
Clinical trial in Portugal
for new breast imaging
system (ClearPEM)



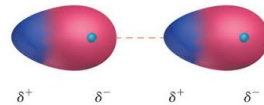
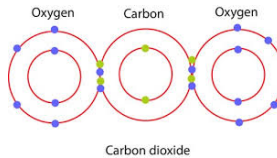
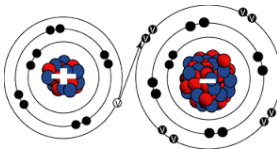
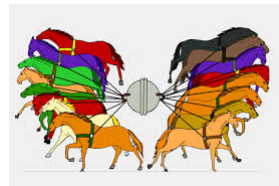
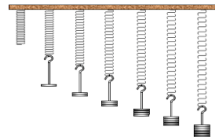
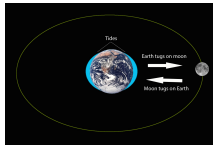
Brain Metabolism in Alzheimer's
Disease: PET Scan



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Types of forces in nature



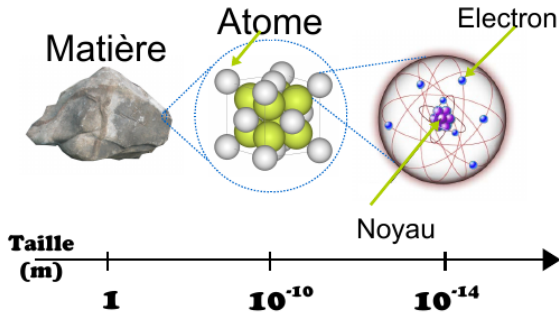


The first hypothesis about the inner structure of the nature are from antiquity times. Then the nature was formed by:

- four^a fundamental elements:
earth, air, water, fire
- atoms = non-divisible

The nature can be reduced to elementary units, identical and universal.

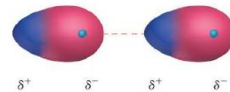
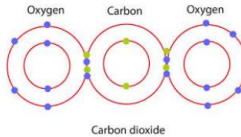
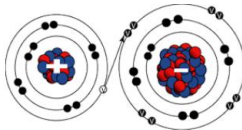
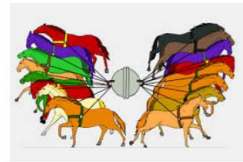
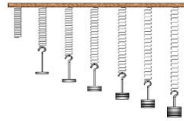
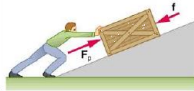
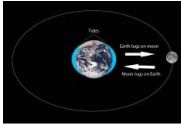
^aThe number varies accross cultures.



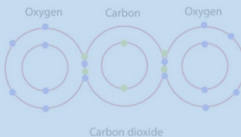
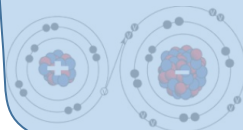
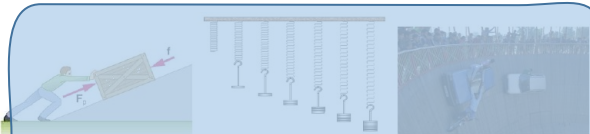
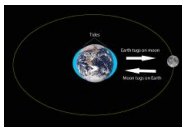
Z - atomic number
 A - mass number

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Types of forces in nature



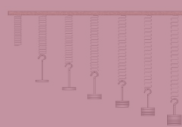
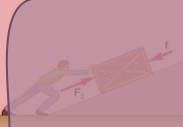
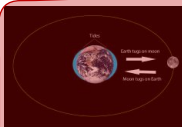
Types of forces in nature



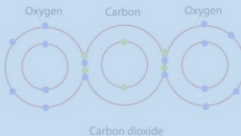
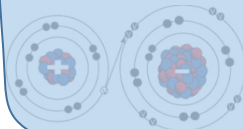
**Forța
electromagnetică**



Types of forces in nature

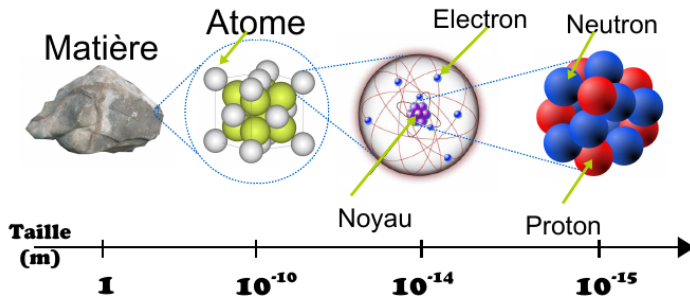


Forța gravitațională



Forța electromagnetică





The nucleus is 50.000 times smaller than the atom.

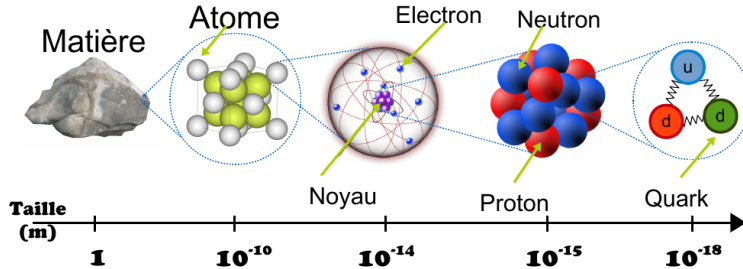
Kahoot!

Game PIN

Enter



The last level?



Quarks and leptons are the last level of division of the matter as we know it today.

Standard Model table

mass →	$\approx 2.3 \text{ MeV}/c^2$	$\approx 1.275 \text{ GeV}/c^2$	$\approx 173.07 \text{ GeV}/c^2$	0	$\approx 126 \text{ GeV}/c^2$
charge →	$2/3$	$2/3$	$2/3$	0	0
spin →	$1/2$	$1/2$	$1/2$	1	0
	u up	c charm	t top	g gluon	H Higgs boson
QUARKS	$\approx 4.8 \text{ MeV}/c^2$	$\approx 95 \text{ MeV}/c^2$	$\approx 4.18 \text{ GeV}/c^2$	0	
	$-1/3$	$-1/3$	$-1/3$	0	
	$1/2$	$1/2$	$1/2$	1	
	d down	s strange	b bottom	γ photon	
LEPTONS	$0.511 \text{ MeV}/c^2$	$105.7 \text{ MeV}/c^2$	$1.777 \text{ GeV}/c^2$	$91.2 \text{ GeV}/c^2$	
	-1	-1	-1	0	
	$1/2$	$1/2$	$1/2$	1	
	e electron	μ muon	τ tau	Z Z boson	
	$< 2.2 \text{ eV}/c^2$	$< 0.17 \text{ MeV}/c^2$	$< 15.5 \text{ MeV}/c^2$	$80.4 \text{ GeV}/c^2$	
	0	0	0	± 1	
	$1/2$	$1/2$	$1/2$	1	
	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W W boson	
				GAUGE BOSONS	

- Three types of particles: quarks, leptons, interaction bosons

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				GAUGE BOSONS	

- Three types of particles: **quarks**, **leptons**, **interaction bosons**
- Each particle has an anti-particle

Standard Model Table



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QUARKS						QUARKS
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Standard Model table

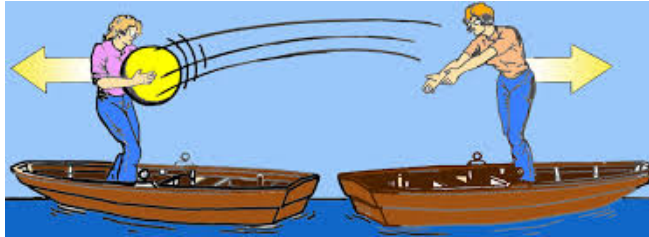
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				GAUGE BOSONS	

- Three types of particles: quarks, leptons, interaction bosons
- Each particle has an anti-particle
- Ordinary matter: *u*, *d* quarks and electrons

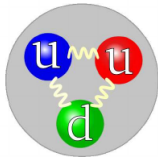
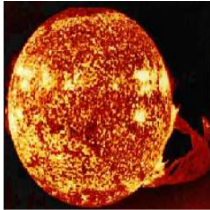
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				GAUGE BOSONS	

- Three types of particles: quarks, leptons, interaction bosons
- Each particle has an anti-particle
- Ordinary matter: u , d quarks and electrons
- Interaction bosons are "carriers" of forces: electromagnetic, strong, weak

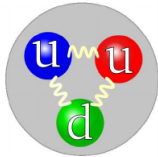
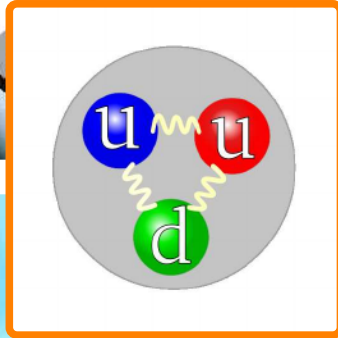
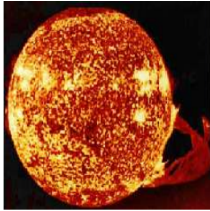


Forces act by exchange of interaction particles. The interaction particles are the photon, $W^\pm$ bosons, Z^0 boson, gluon, graviton. They all have different mass and behaviour.

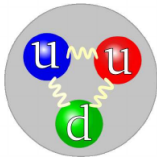
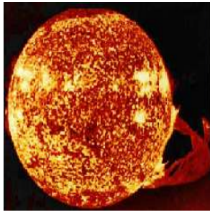


Types of forces

- gravitational force
 - graviton
- electromagnetic force
 - photon
- strong force
 - gluon
- weak force
 - W^+ , W^- , Z^0 bosons

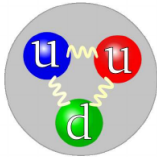
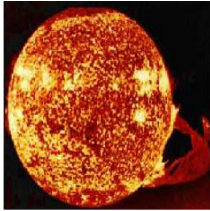


- strong force
 - gluon



- weak force
 - W^+ , W^- , Z^0 bosons

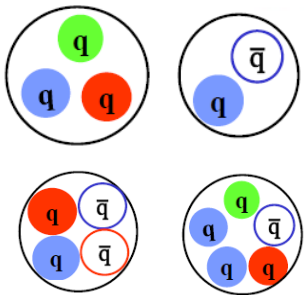




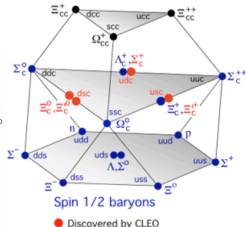
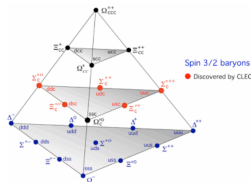
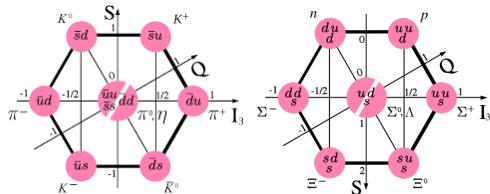
Types of forces

- gravitational force
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 - W^+ , W^- , Z^0 bosons

Composed particles



Combinations of quarks have entire (0, ± 1 , ± 2 ...) electric charge and they classify by the number of quarks in: mesons, barions, tetraquarks, pentaquarks.

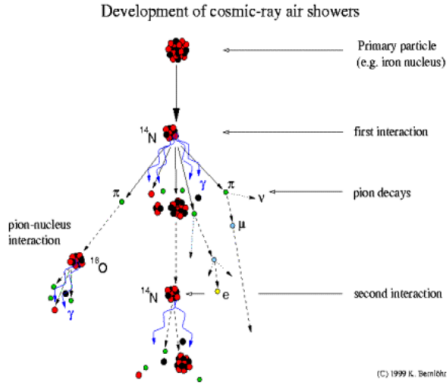


Quarks combinations obey certain well defined geometric laws.



Trivia (about particles):

- Particles live a finite time
- The life time varies with the type of force and the particle weight
- Protons and electrons are stable particles
- The neutron life time is about 10 min.



Trivia (about particles):

- Particles live a finite time
- The life time varies with the type of force and the particle weight
- Protons and electrons are stable particles
- The neutron life time is about 10 min.

- It offers answers about the structure of the matter
- It gives explanations to fundamental questions (symmetries, conservation laws, time - space, extra-dimensions, quantum interferences, dualities etc.)
- The theory has a beautiful structure: a small number of fundamental constituents, rigorous mathematical framework
- It connects microscopic world to the macroscopic world
- It is a truly global effort with thousands of researchers working together

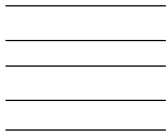
- 1 International collaborations, CERN, IFIN-HH, Masterclass
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Direct measurements



Indirect measurements



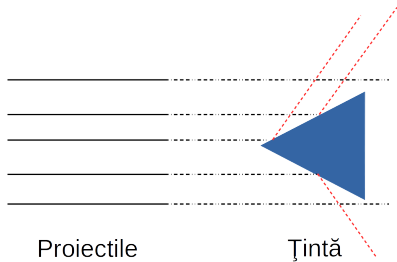


Proiectile

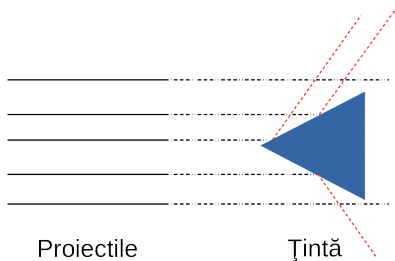


Țintă

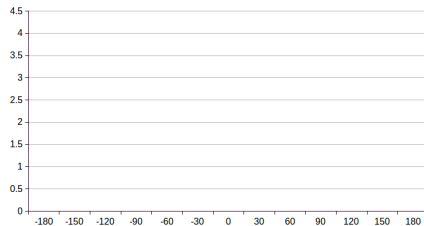
Through away balls to a solid brick.



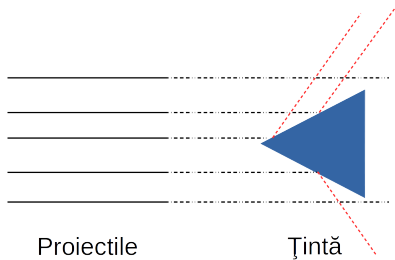
Through away balls to a solid brick.



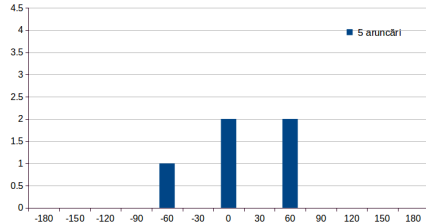
Through away balls to a solid brick.



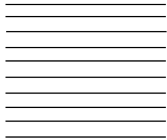
Measure the (angle) direction of the balls after collision.



Through away balls to a solid brick.



Measure the (angle) direction of the balls after collision.

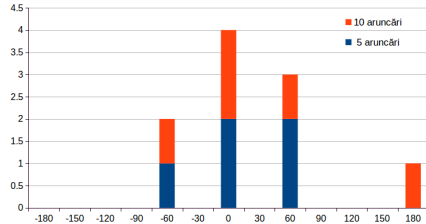


Proiectile

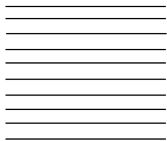


Țintă

Through away balls to a solid brick.



Measure the (angle) direction of the balls after collision.

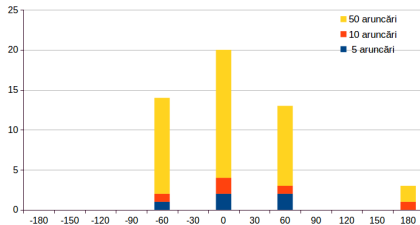


Proiectile



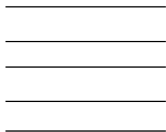
Țintă

Through away balls to a solid brick.



Measure the (angle) direction of the balls after collision.

Exercise



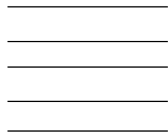
Proiectile



Țintă

Draw the histogram of the reflection
angles
that corresponds to the following figure.

Exercise



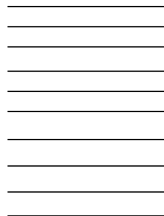
Proiectile



Țintă

Draw the histogram of the reflection
angles
that corresponds to the following figure.

Practical exercise



Proiectile



Țintă

Determine the distance between the balls
which form the target.

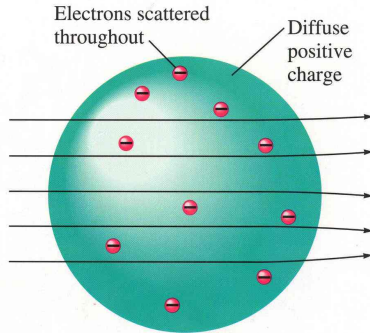
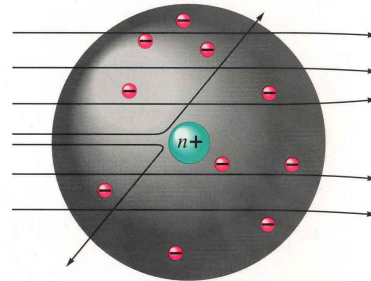
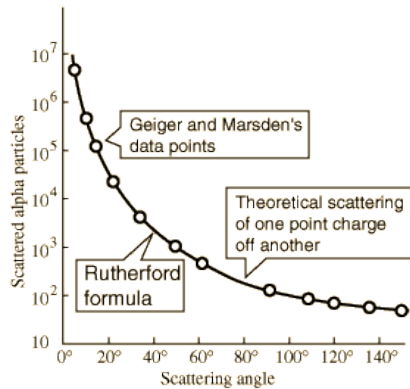
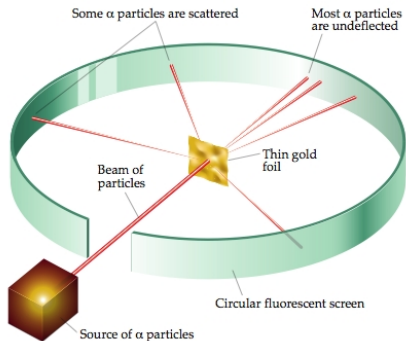


Figure : a) Pudding model



b) Orbital model

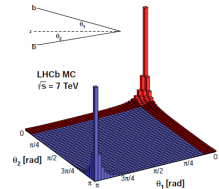
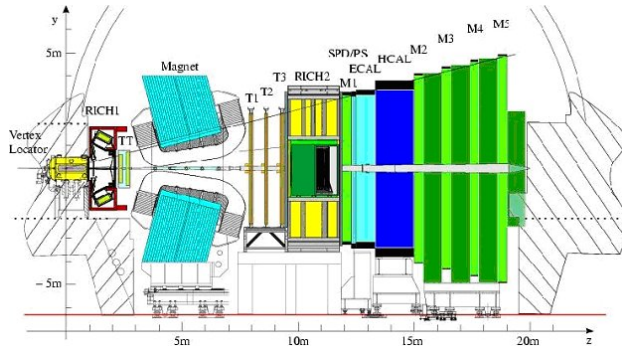
Rutherford experiment



Angular distributions $\frac{1}{\sin^4(\theta/2)}$

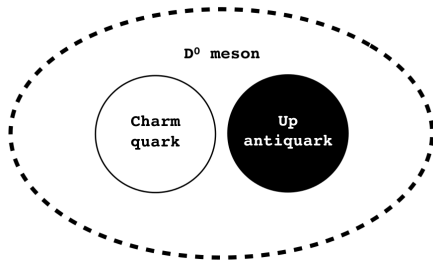
- There are four fundamental forces known in nature:
 - **gravitational**, **electromagnetic**, strong force and weak force
 - The forces that we encounter daily are only two
- The smallest particles we know are quarks and leptons
 - quarks: **up**, **down**, charm, strange, top, bottom + anti-particles
 - leptons: **electrons**, muons and tauons + neutrinos + anti-particles
 - interaction bosons: **photon**, gluon, $W^{\pm}$, Z^0 , graviton, Higgs
- Elementary particles have many characteristics different from the macroscopic bodies
 - Electrical charge, color, spin, partners/anti-matter ...
 - These properties are not perceptible at the macroscopic level
- Experiments in particle physics are collision type experiments

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The LHCb experiment search for New Physics, phenomena that are not predicted by the current Standard Model studying properties of b and c quarks.

Precision measurements and the study of rare decays will give new explanations on the asymmetry between matter and anti-matter from Universe.



- Mass : 1864 MeV
- Lifetime: $0.4101 \pm 0.0015 * 10^{-12}$ s
- What distance travels the D^0 particle in detector?
 $d = t * v = 3 * 10^{-4}$ meters or 0,3 mm ???
But the particle obeys relativistic laws, i.e. the particle lives longer in laboratory system, time is dilated:

$$t_L = t / \sqrt{(1 - v^2/c^2)}$$

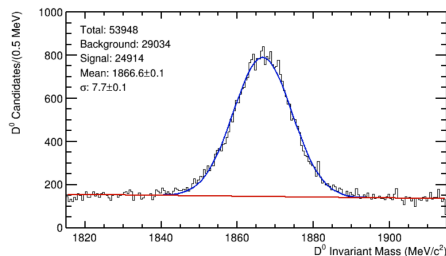
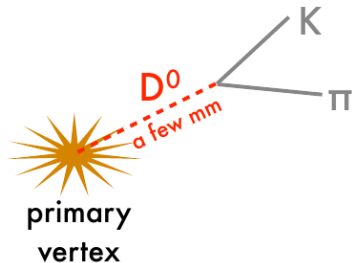
Recalculating, the particle travels ≈ 1 cm

The purpose of the exercises is:

- To illustrate how the decay events look like in the detector
- To perform the selection of D^0 candidates using the particle properties
- Extract the lifetime values by modelling (fitting) the signal
- To introduce the concept of systematic errors vs. statistical errors

D^0 meson decays according to the formula:

$$D^0 \rightarrow K^+ \pi^- \quad (\bar{D}^0 \rightarrow K^- \pi^+)$$

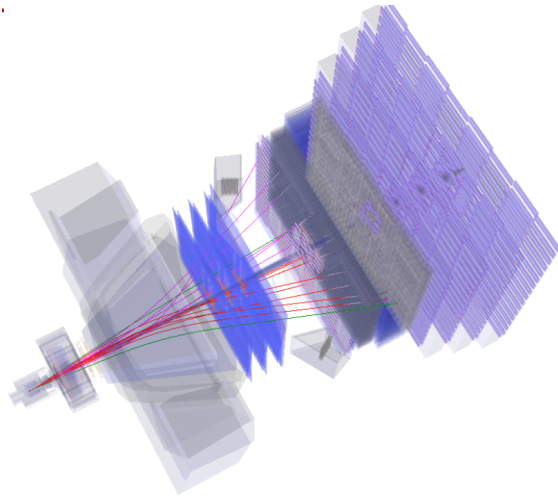


- The kaon and the pion are the "final state" particles that are measured (the energy and the momentum) in the detector
- The D^0 properties are inferred from the conservation laws:

$$M = \sqrt{E^2 - P^2 c^2}, \text{ unde } E = E_1 + E_2 \text{ 'si } \vec{P} = \vec{P}_1 + \vec{P}_2$$

Exercise I - Identification of D^0 and $\bar{D}^0$ candidates

- Open LHCb Masterclass application
- Visualise the tracks which belongs to the kaons and pions originating found in the events
- Look at 30 events and identify the tracks from D^0 candidates



Screen - exercise I



Eve Main Window

Event Control

Start
Combination 1

View

☒ Hide Geometry ☒ Transparency

Event manager
Event number: 7

Particle Info
Name: MeV/c²
Mass: MeV
q:
ch2:
px: MeV/c
py: MeV/c
pz: MeV/c

My Particles

Mass:

Histogram

Legend
K- —
K+ —
p- —
p+ —
pi- —
pi+ —
D0 —

Help

Zoom gives you closer look at collision

Click on the track to find out about particle properties

Carefully choose particles you want to save, because out of them you get a new mass which might not be right!

Add and Draw your results on histogram. Don't forget to save histogram when you finish!

View

☒ Hide Geometry ☒ Transparency

Event manager
Event number: 3

Particle Info
Name: p+
Mass: 139.57 MeV/c²
E: 5498.32 MeV
q: 1.00
ch2: 0.69
px: 125.11 MeV/c
py: 549.90 MeV/c
pz: 5458.96 MeV/c

My Particles
My particle to:
My particle: p+

Mass: 1021.14

Histogram

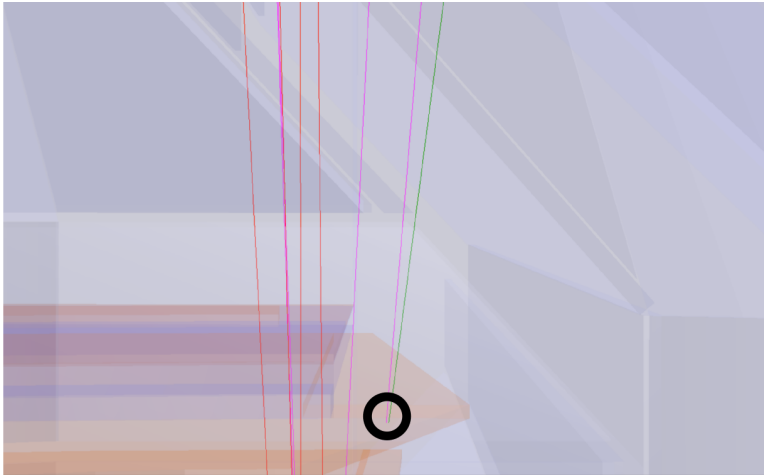
Hint shows you the hidden D0 and its children

Fullscreen shows the full view of UHCb detector and particle tracks

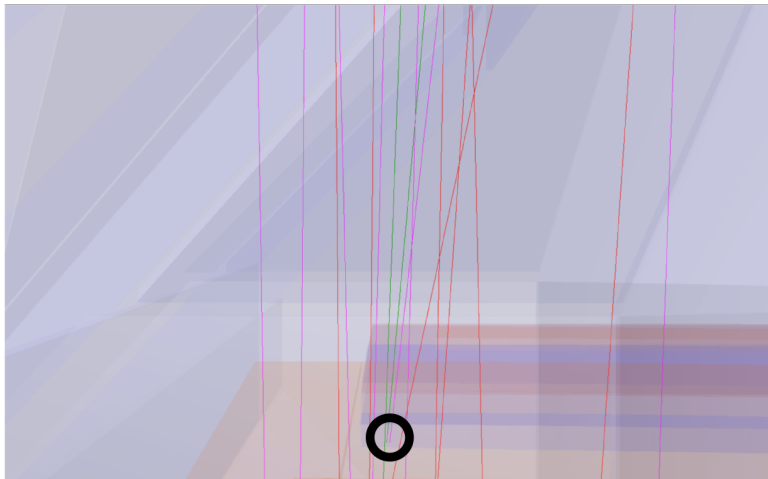
Transparent view gives you a better look at particle tracks and the UHCb detector

You can hide the geometry to see all the particle tracks.

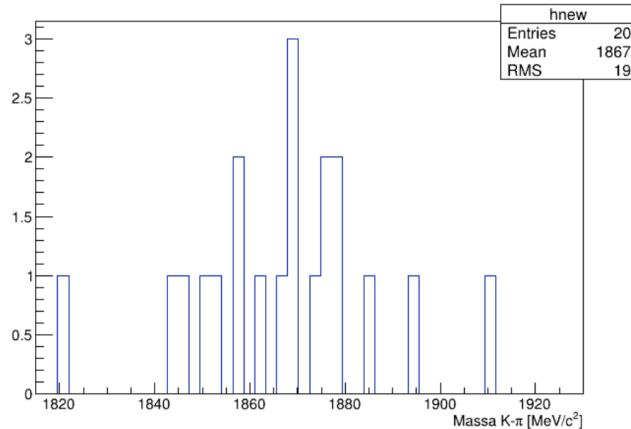
D^0 vertex - simple event



D^0 vertex- rich event



Mass plot for D^0



The result of the selection can be visualized in the mass diagram.

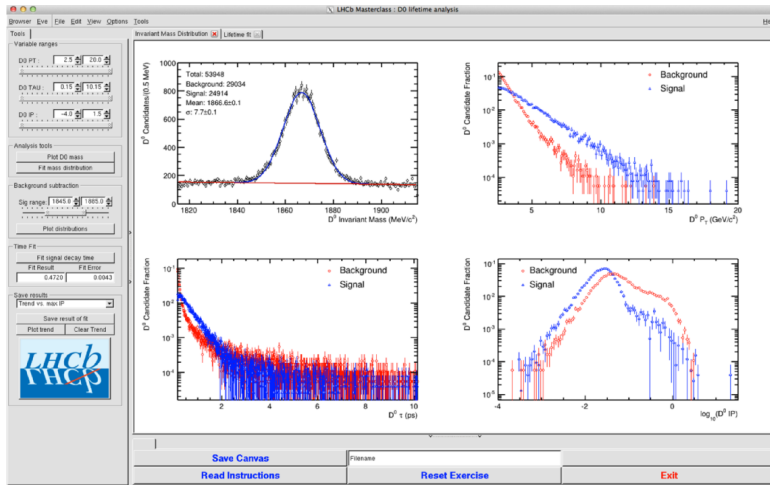
Exercise II

The measurement of the lifetime of D^0 particle with LHCb data from 2012 run

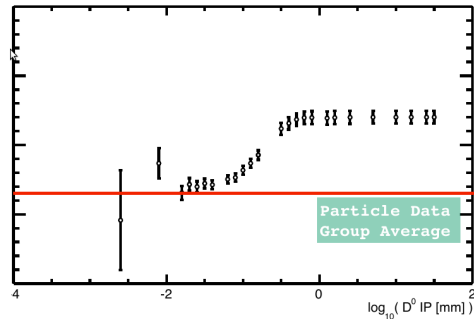
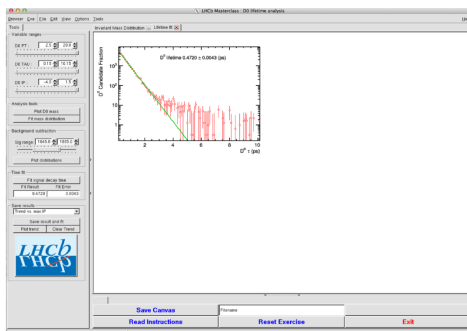
The next steps will be followed:

- monitor signal and background in different histograms types
- fit the mass distribution and the lifetime distribution
- study the lifetime as a function of impact parameter(IP)

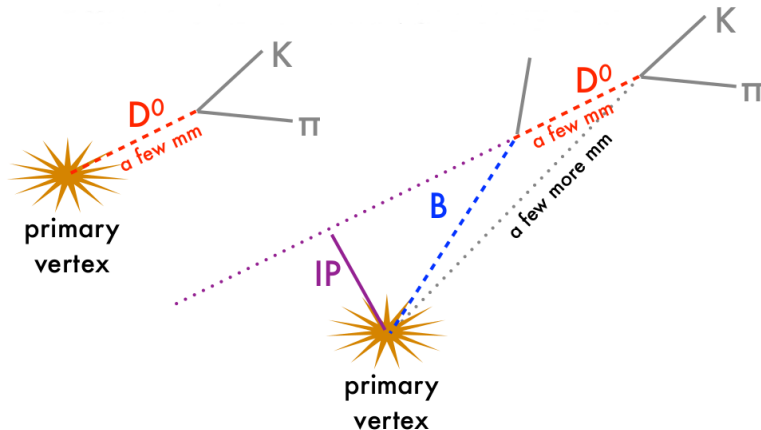
Signal vs. background distributions



Fitting the lifetime

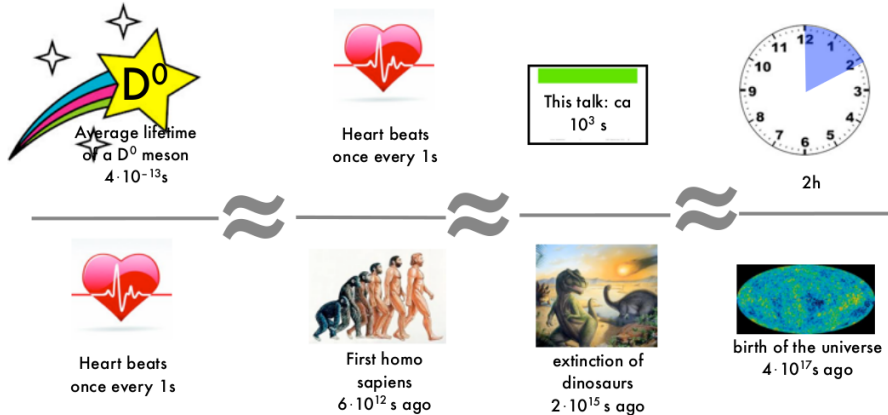


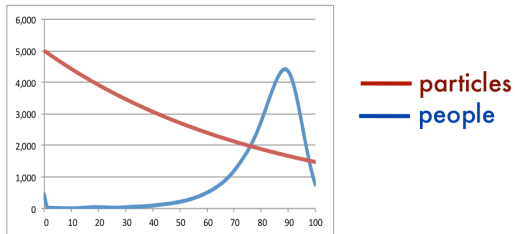
Secondary sources for D^0 candidates



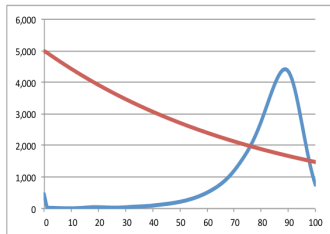
The decay of B ($B^+ \rightarrow D^0 \pi^+$) meson interfere with our measurement introducing systematic uncertainties.

Temporal scale



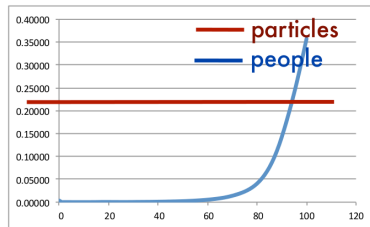


Comparison bewtween particle decay and human mortality

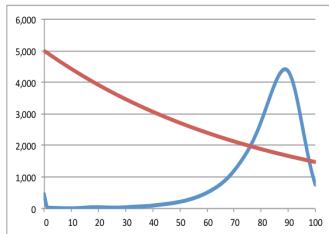


— particles
— people

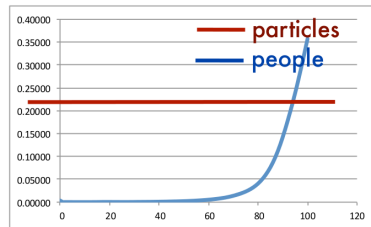
Comparison between particle decay and human mortality



Probability of decaying in time for particles and people



— particles
— people



Comparison between particle decay and human mortality

Probability of decaying in time for particles and people

- Particles decay, but don't age.
- The decay law of particles (exponential decay) is a direct consequence of this.

- A very small time have been measured
- This was possible due to the performances of LHCb detector, the high energies and the special relativity
- Particles don't age
- The result is important for present research topics

Kahoot!

Game PIN

Enter



- There four fundamental forces known in nature: gravitational, electromagnetic, strong and weak force
- The elementary particles are the quarks and the leptons (electrons, muons, tauon)
- Elementary particles have more properties than the electrical charge which influence the interaction they take part in (color, anti-partners, spin ...). These properties don't have a macroscopic manifestation
- The LHCb masterclass exercise give access to real data
- Modern physics is the result of cooperation on large scale and a succesfull scientist learns to communicate his research.

-  "Particle adventure" website (eng, fr, it) <http://particleadventure.org/>
-  Mobile phone application, Android and iPhone: LHSee
-  Video animation with LHC accelerator
<https://www.youtube.com/watch?v=pQhbhpU9Wrg>
www.youtube.com/watch?v=08x49b9tTNQ
-  Advanced data analysis for programming enthusiasts
particle-physics-playground.github.io
-  Resources proposed by the Quarknet
quarknet.i2u2.org

-  LHCb International Masterclass internet webpage
<http://lhcb-public.web.cern.ch/lhcb-public/en/LHCb-outreach/masterclasses/en/>.
-  Masterclass exercises - video www.youtube.com/watch?v=x2qJUbf2qUQ
-  Overview of LHCb experiment: www.youtube.com/watch?v=rsmBMuTFdkA,
lhcb-public.web.cern.ch/lhcb-public/.
-  International Masterclass programm physicsmasterclasses.org/.