JUNIOR

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junior.aalto.fi

Missing particles Part 2

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Kuva: Pixabay

Today

- You'll analyze particle physics –related data by coding with Python in Jupyter notebook

- This is a two-part workshop:
  - We assume that you all have gone through Part 1: predata material of this workshop.
  - Today you'll go through part 2: Practical part (slides and coding activity)

Currents from Cern

- 12 years has gone since Higgs boson was found 2012.

- LHC-accelerator in Cern started its 3rd run July 2022 after a long maintenance and upgrade break.

- New research has been started in Cern (November 2023) which studies the possibility of ”dark photon” production in the decay of Higgs bosons in the detector.

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Standard model

https://home.cern/science/physics/standard-model

- Mathematical model, which describes:
  - Known elementary particles
  - Weak and strong interaction
  - Electromagnetic interaction

- Particles have different qualities (e.g. spin, electric charge, mass...)

- Qualities are studied by colliding particles in particle accelerator.

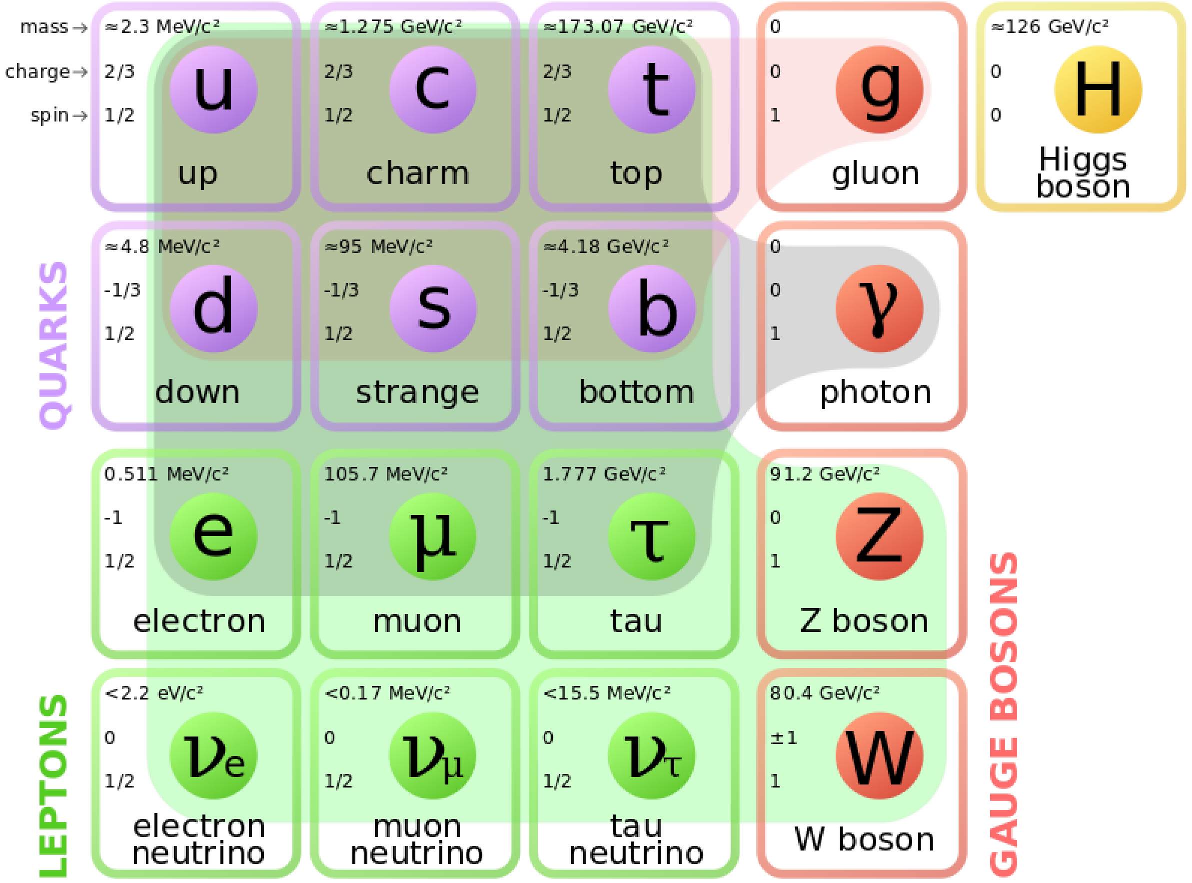

Figure:https://commons.wikimedia.org/wiki/File:Standard_Model_of_Elementary_Particles_modified_version.svg

Studying particle physics – Units (1/2)

Planck's constant: Natural constant, which combines units of frequency and energy together (E = hf)

$$\hbar = \frac{h}{2\pi}$$

$$= 1.055 * 10^{-34} Js$$

- **In the world of quantum physics basic laws of mechanics are not valid when mass changes to energy and vice versa. That is why units like meter and kilogram are not useful for particle physicists…**

- **Speed is approaching the speed of light, v ~ c**
- **Energy and momentum are much bigger than mass, E >> mc², p ~ E/c**

- **Commonly this presumption is made: $\hbar$ = c = 1**
  where c = speed of light and $\hbar$ = the reduced Planck's constant
  - **Change can be made, because the speed of light (in a vacuum) is a constant and its numeric value is dependent on selected unit of presentation.**
  - **Same change has an effect on the system at use, so that speed becomes dimensionless, it has no unit. That is why also units of momentum and energy changes:** $p = m * v \quad \rightarrow \quad p = m$
    $E = m * v^2 \quad \rightarrow \quad E = m$
- **With the presumption c = 1, several other formulas can be cleaned (e.g.** $E = mc^2 \rightarrow E = m$)

Studying particle physics – Units (2/2)

- Energy conservation laws apply. We can form quantity invariant mass (m_0) with the help of energies and momentums of particles.

$$m_0 = \sqrt{(E_1 + E_2)^2 - \|p_1 + p_2\|^2}$$

- When a particle splits (= ceases to exist), its mass before fission can be calculated from the energies and momentums of fission products. Reference frame, where energies and momentums were measured, do not have effect on the inferred value of mass. It is independent, invariant mass.

→ Invariant mass remains when a particle splits into new particles.

  - If it is calculated to daughter particles formed in a specific collision, an estimate is made which is close to the mass of mother particle.
  - If we calculate invariant mass to particles that are not related to each other, we get a value that does not describe anything, it is basically background noise.

- Energy, momentum and invariant mass are expressed in a common units of energy, electron volt (eV) = $1.602176634 \times 10^{-19}$ Joule

More information: https://profmattstrassler.com/articles-and-posts/particle-physics-basics/mass-energy-matter-etc/mass-and-energy/

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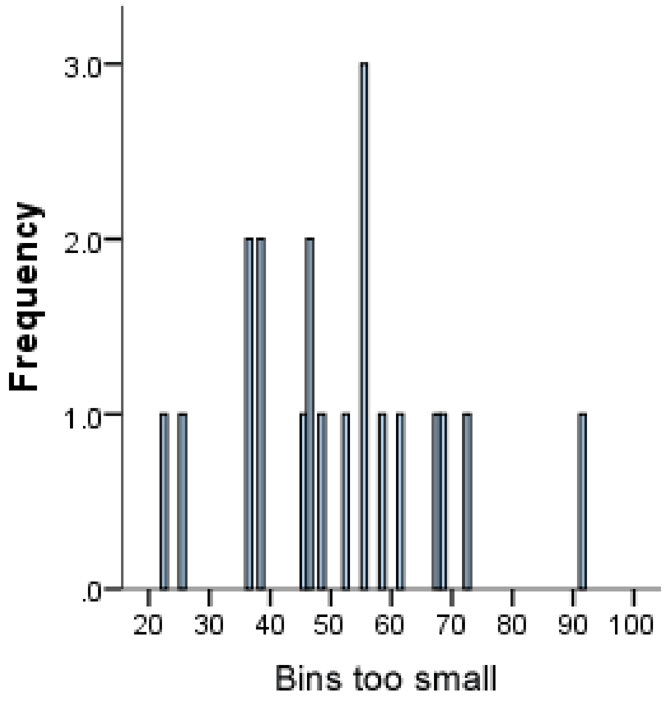
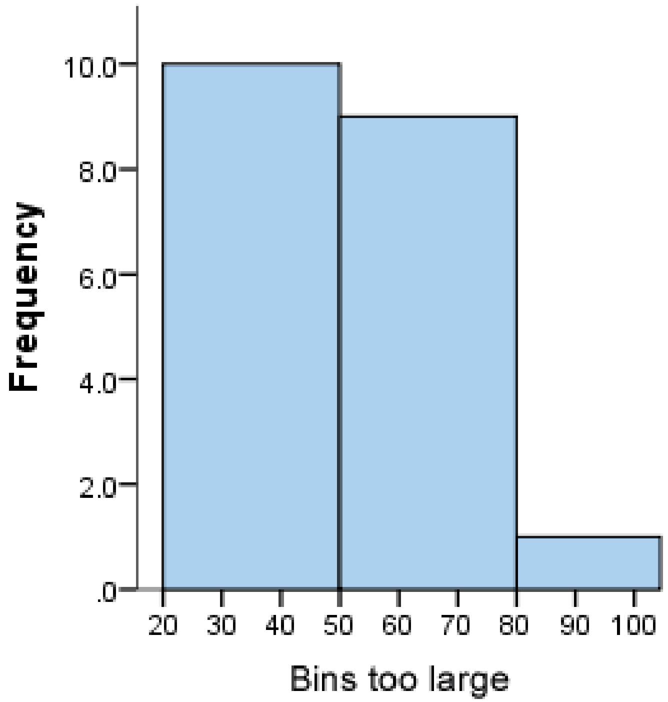
Example: Histograms with different amounts of data

Lets test, how the amount of data affects a histogram.

Run a code, which draws a histogram (4 times) with given amount of data from invariant masses of two large energy muons.

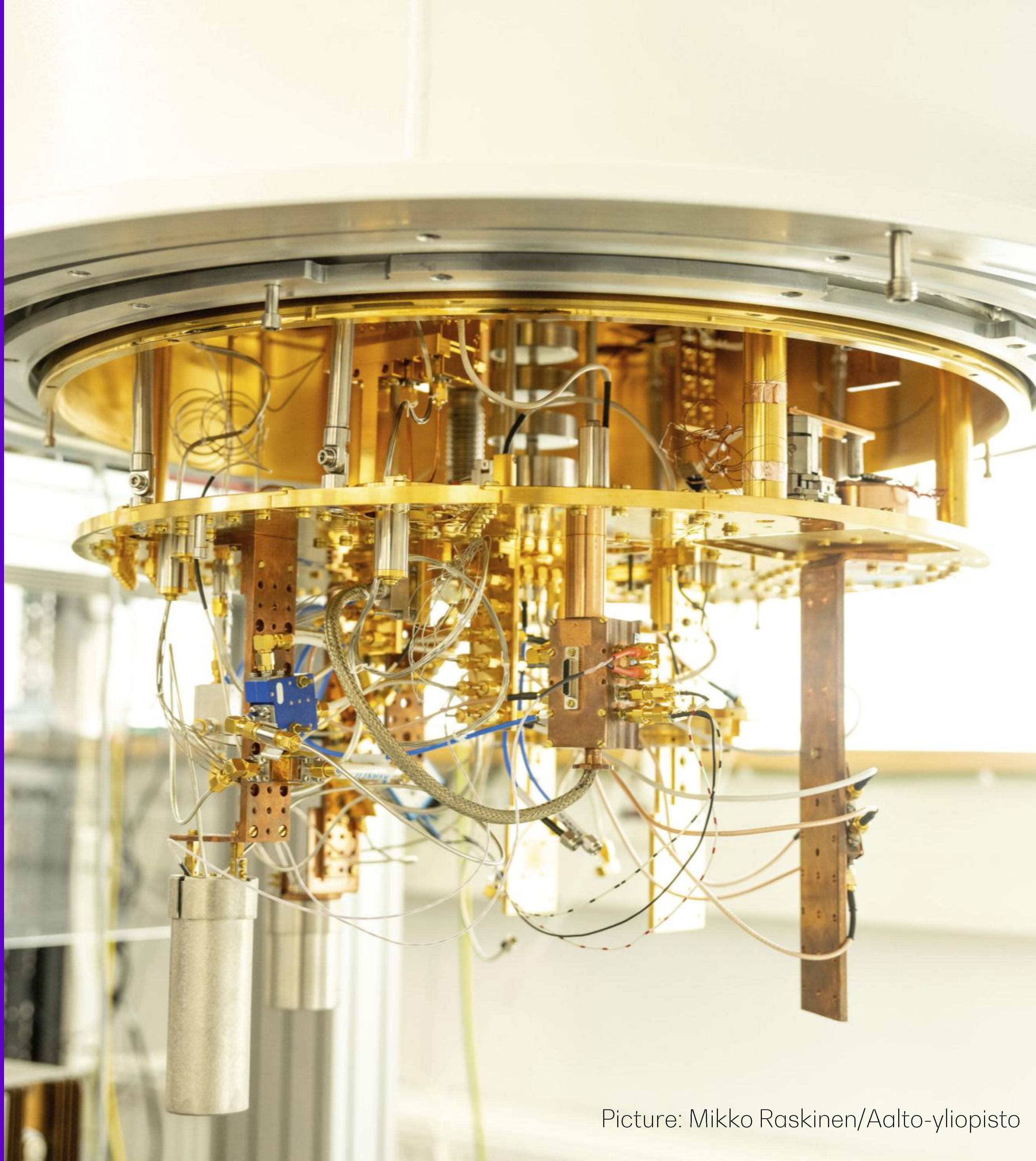
We'll start studying small numbers 0-20 and we'll grow the data amount little by little.





Research at Aalto University

- Researchers at Aalto University are developing a haloscope, which is a very sensitive quantum detector as a part of dark matter research in Dark Quantum –project.
- Centre for Quantum Engineering is part of Aalto University, and joins together theoretical, experimental, and applied knowledge.



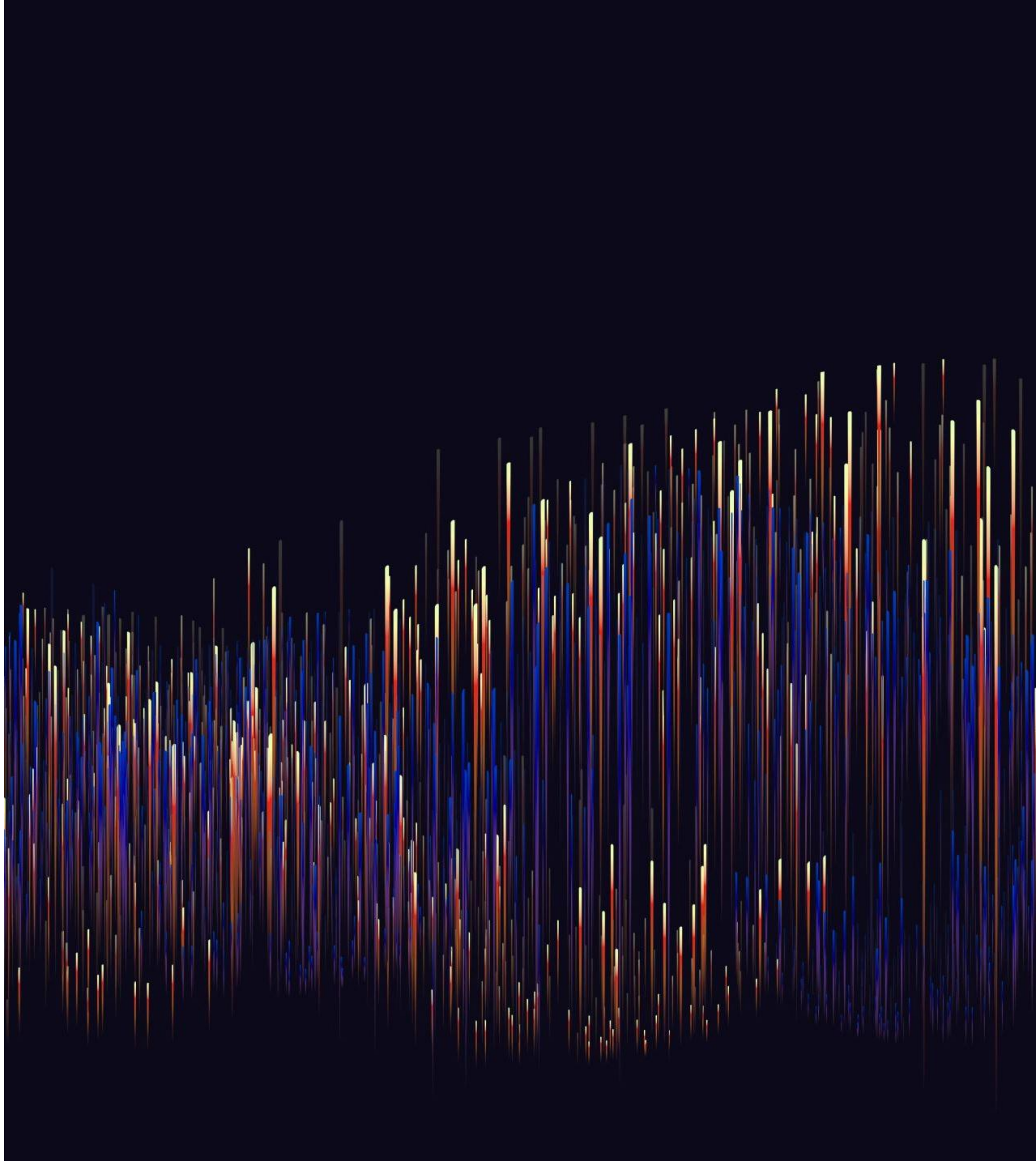
Picture: Mikko Raskinen/Aalto-yliopisto

Background for the exercise 1/2

Summer trainee at CERN has got a task to study research data measured by CMS during its runs during 2011.

Data consist of selected events, where particle accelerator has detected two muons.

According to earlier research, it is known that many particles can split into two muons and those particles can be indentified with the help of invariant mass.

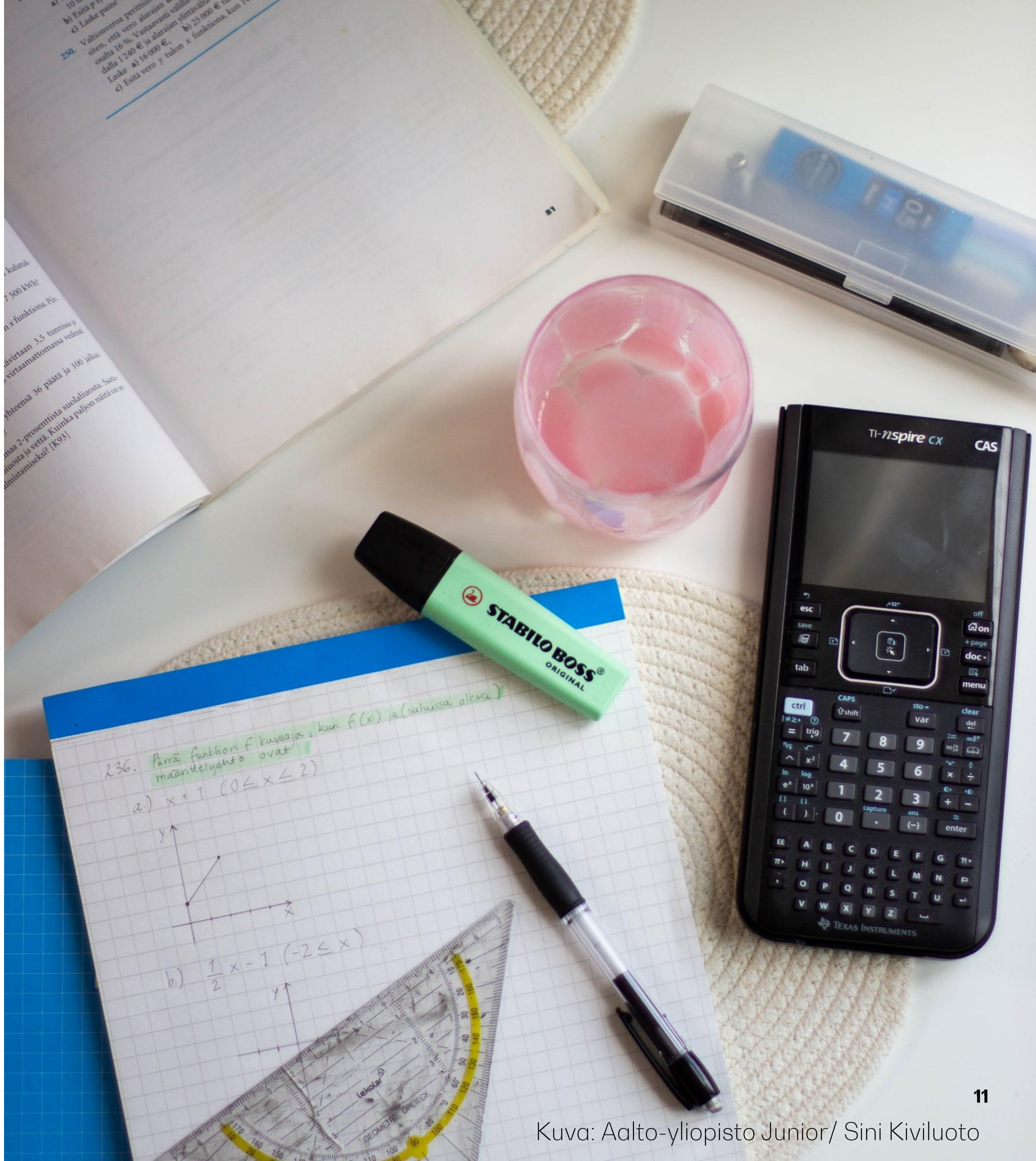


Background for the exercise 2/2

Busy summer trainee has forgotten to keep the measurement data in order.

Now he has got 6 files of CMS measurement data with odd names.

Each file contains measured values from two muons, which are potentially related to the splitting of some particle.

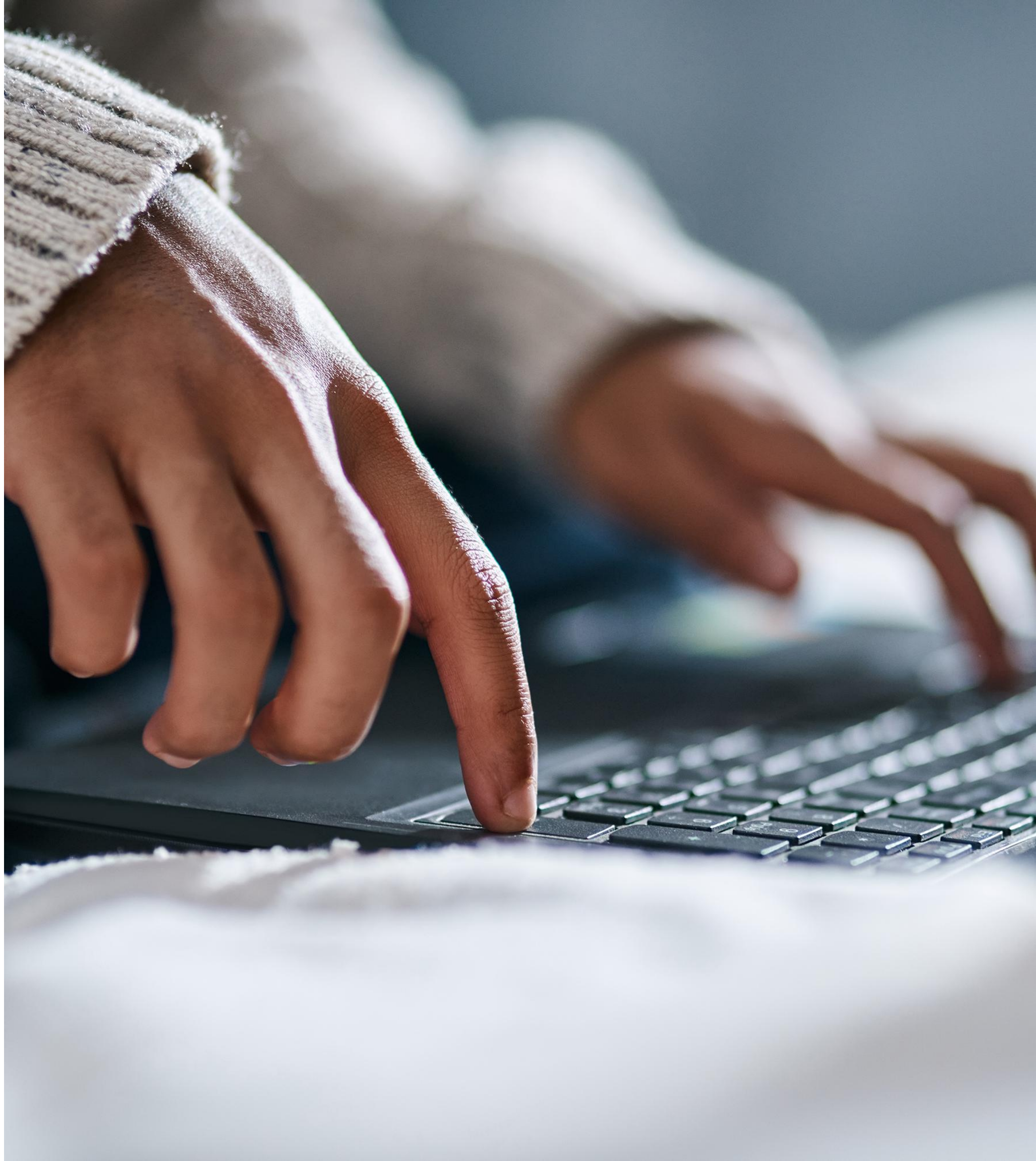


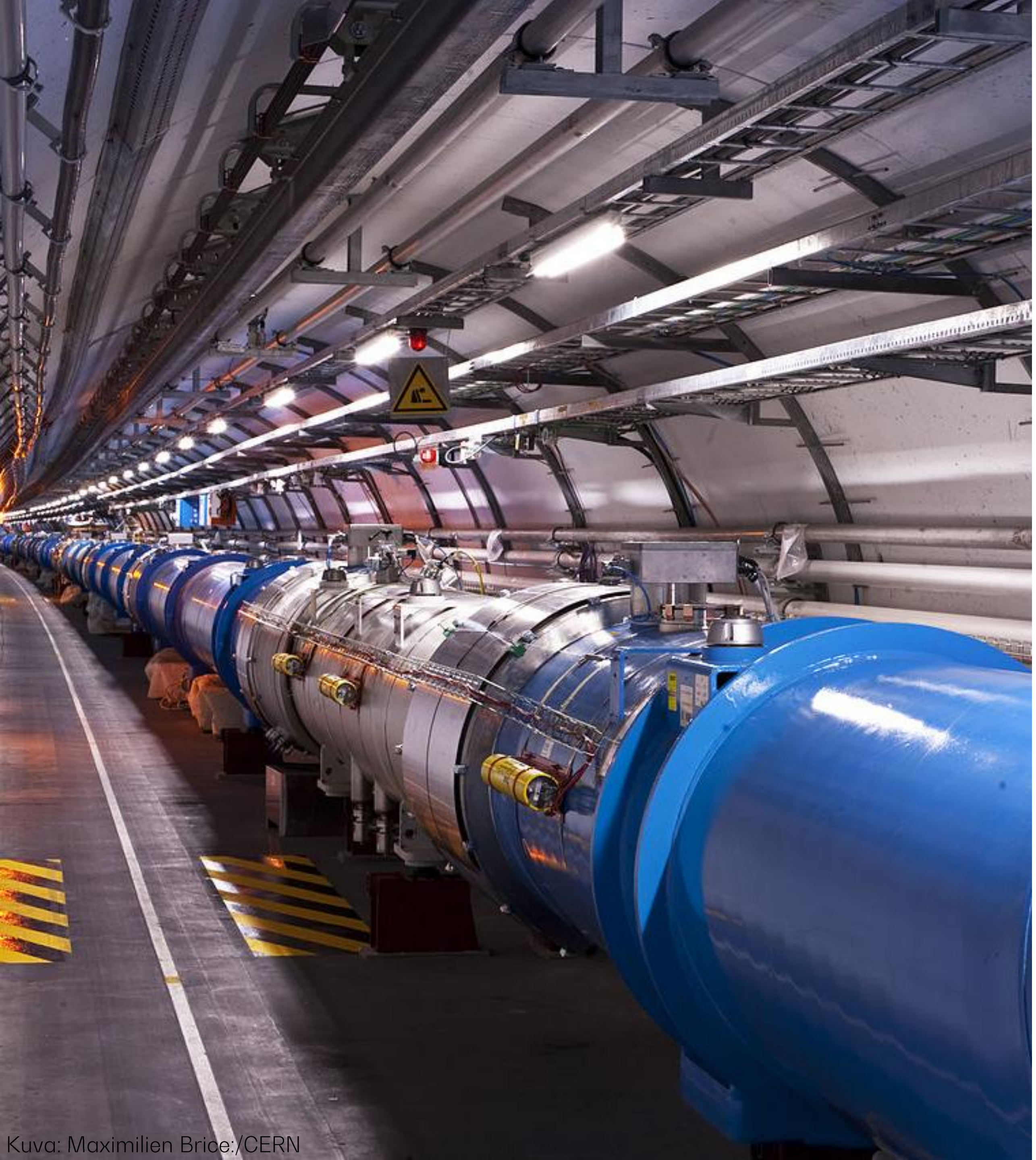
Kuva: Aalto-yliopisto Junior/ Sini Kiviluoto

Exercise for you

Summer trainee is asking for your help in studying the data in those files.

Hypothesis: Masses of the mother particles can be calculated with the help of the values of invariant masses. Particles split into two muons can be detected this way.




Kuva: Maximilien Brice:/CERN

Workflow

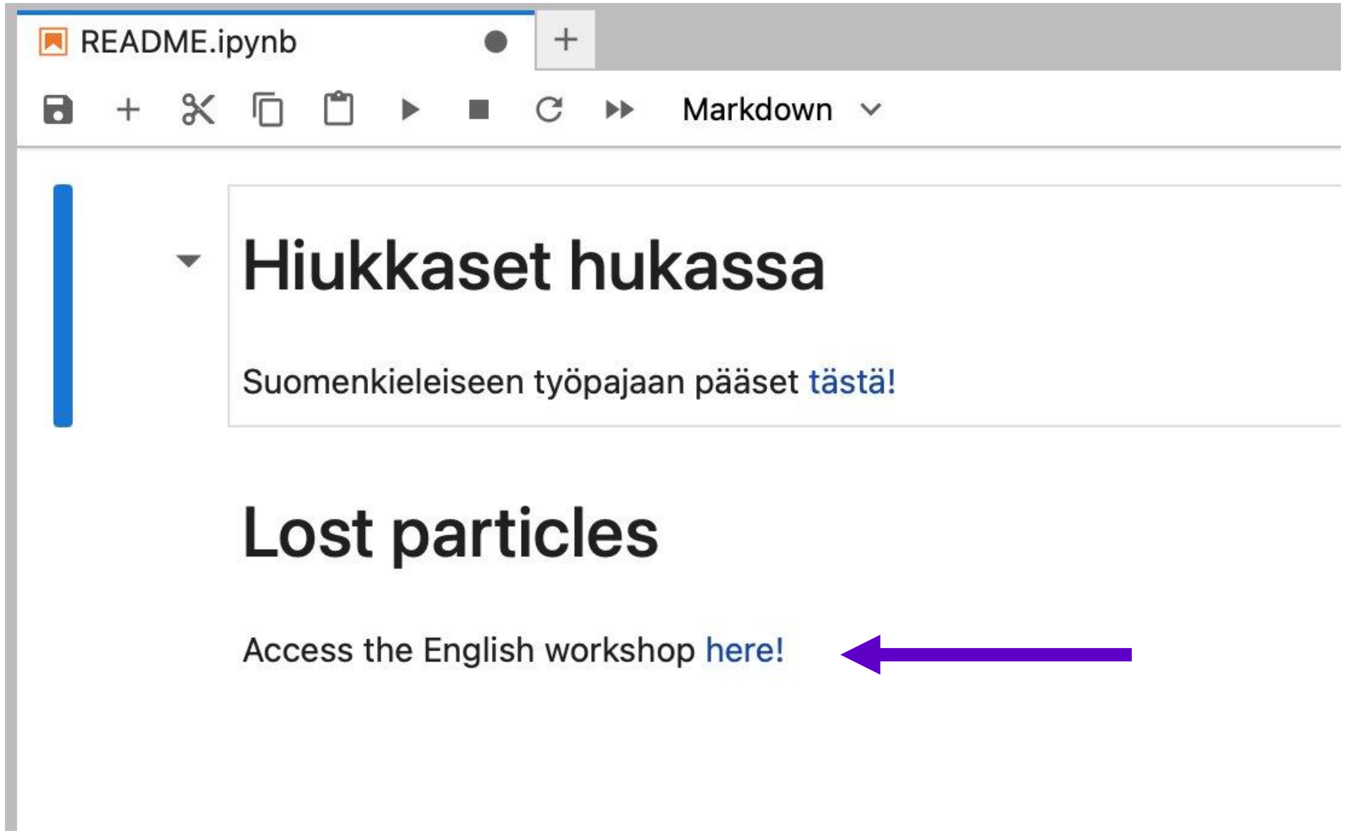
- Work is done in groups of 2-3 persons.
- Each group will get to analyze one spike data numbered from 1 to 6.
- Follow the instructions carefully and be bold to try to write your own code.

How to use Jupyter Notebook file

1. Follow instructions in order step by step.
2. The file is Jupyter Notebook -file, which combines normal text and code written in Python programming language.
3. Code and normal text are devided into blocks in this file.
4. You ”run” your code blocks pressing shift + enter.
5. Remember to advance step by step (Do not skip blocks!). Part of the code is dependent on code written to earlier block and if you skip one block, code does not work.
6. There are 6 different sets of spike data. 6 groups of students can do this work simultaneously. In the block ”Data analysing” choose right file to your group’s use.

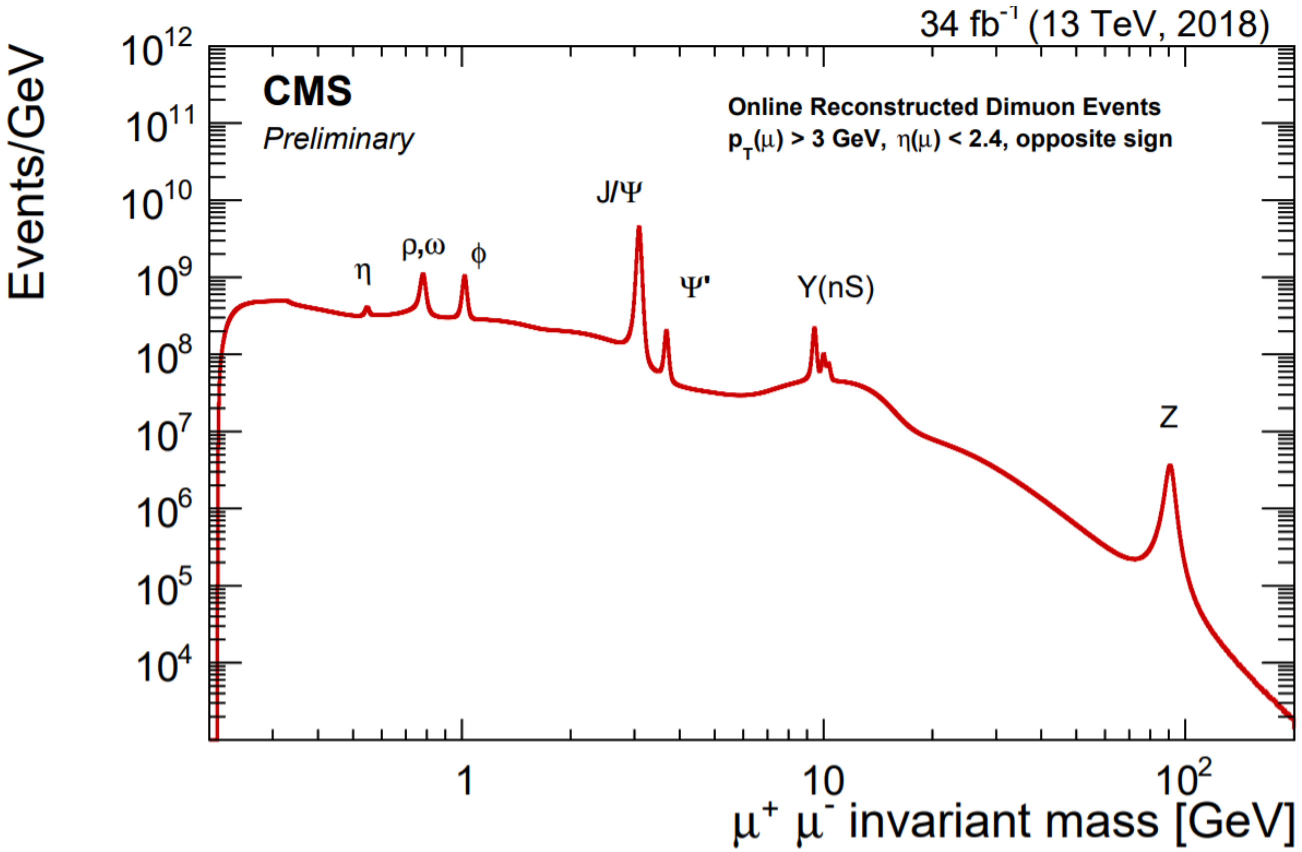
Start the work

1. **Open shared link: https://aaltojunior.github.io/Hiukkaset-Hukassa-Standalone/lab/index.html?path=notebooks/README.ipynb**
2. **Click text "here!" to open the English file.**



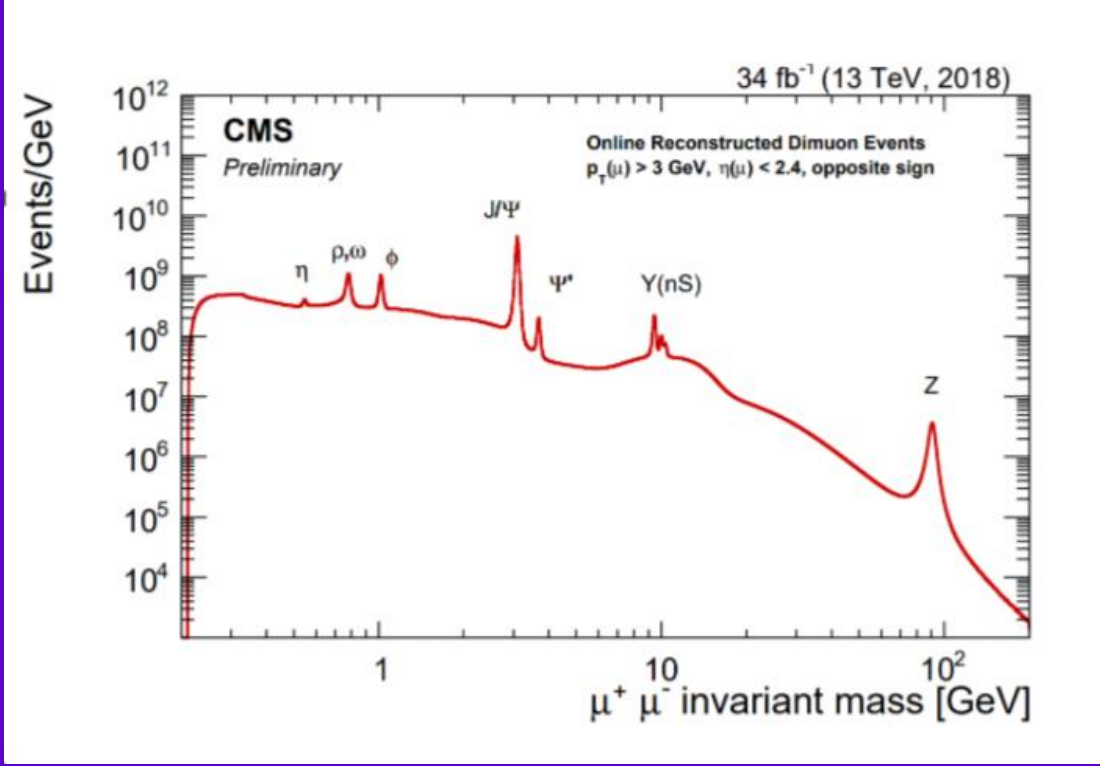
Conclusions

- *What advantage or use could this kind of analysis have?*
- *How are new particles found?*
- *Do you find from your new file some part that corresponds to spike data of your group?*
- *Could your spike data be part of this larger file?*



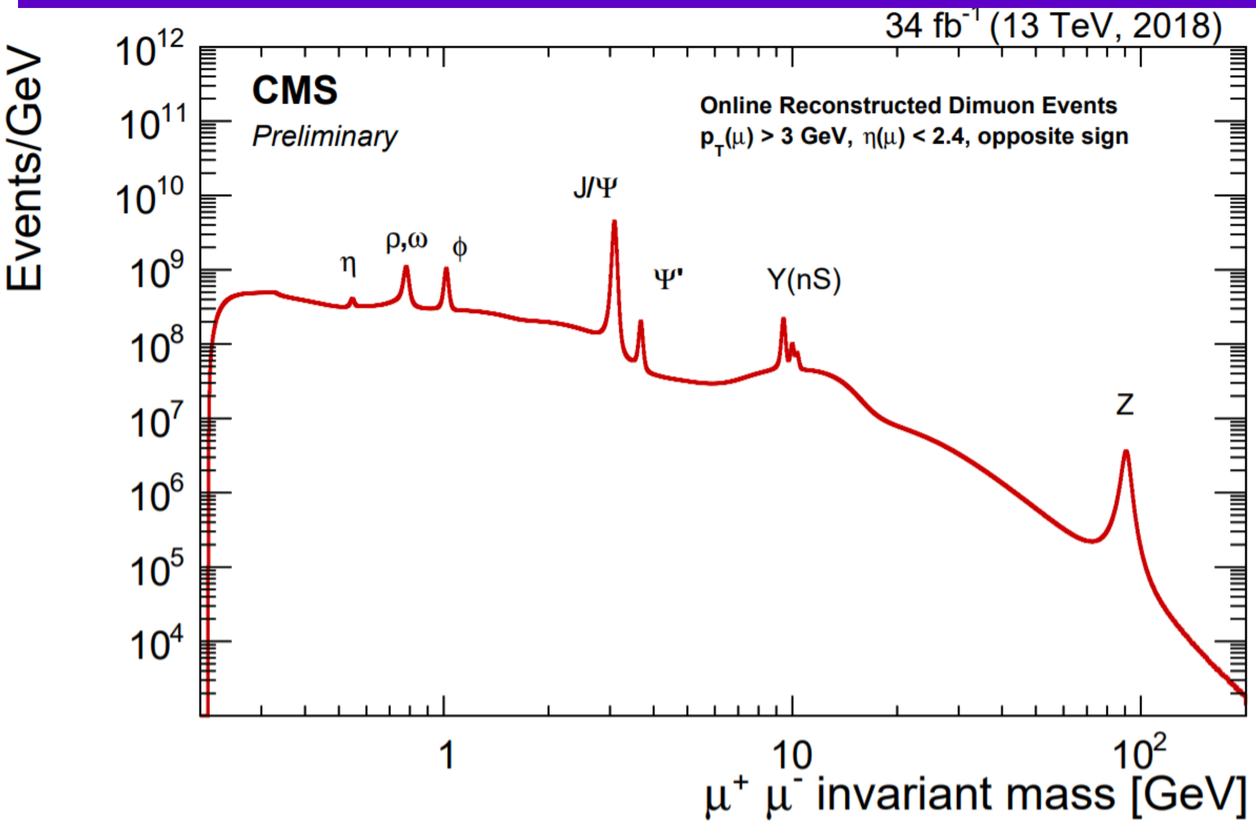
Conclusions

- The file you downloaded is from the real measurement data of CMS from the year 2011.
- File included only those events where two muons have been born.
- Data from two muons is interesting, because it can originate from the splitting of several different particles.
- In this figure, distribution of invariant masses of two muons is presented.
- Spikes of particles able to split into two muons are clearly visible in this distribution.
- In the real research, corresponding predictions are made by theoretical physic researchers, and based to these predictions, different spikes can be concluded to relate to specific type of a particle.



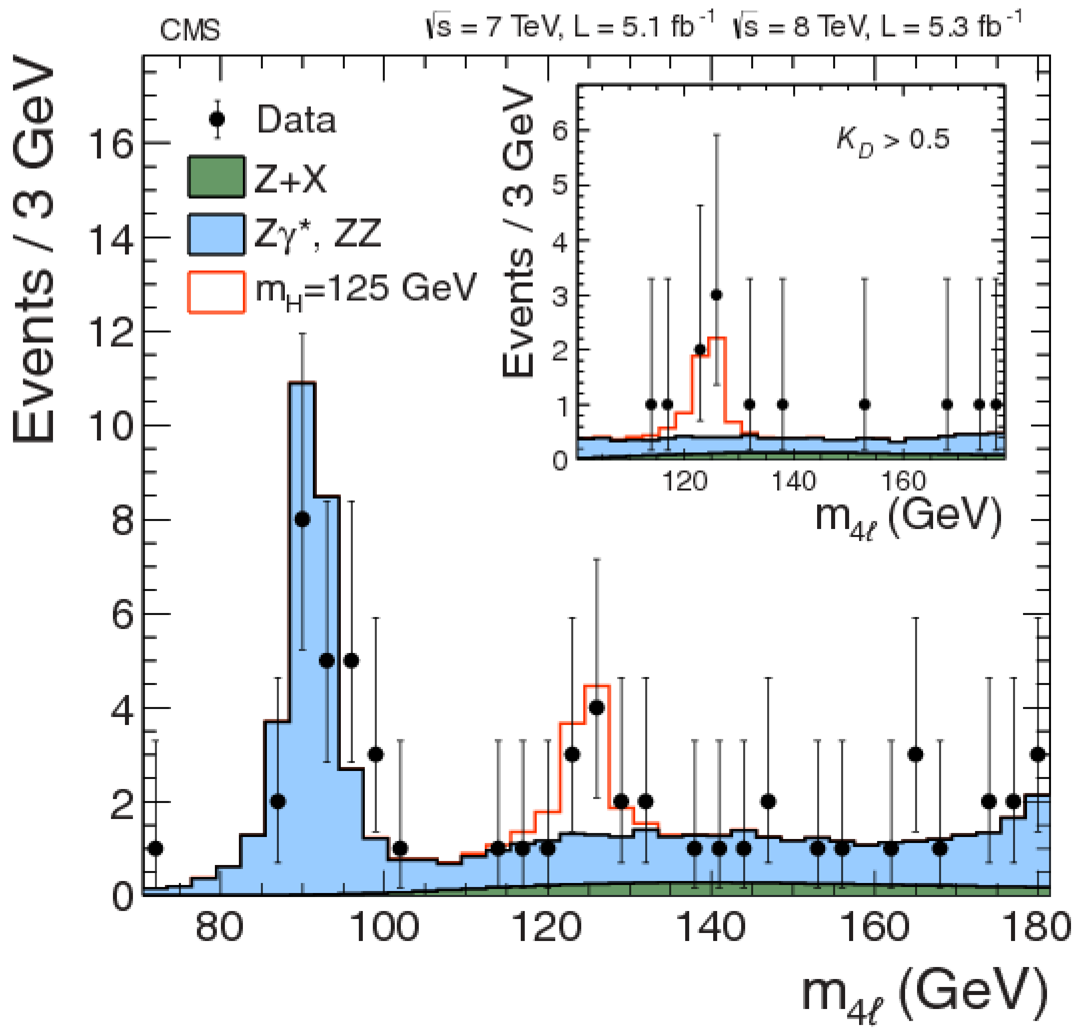
- *Does any of the spikes in the figure match to the spikes in spike data?*
- *If some of them match, which particle is that spike from?*

Hiukkanen	Massa [GeV]
η (eta)	0.548
ρ, (rho)	0.775
ω (omega)	0.782
φ (phi)	1.019
J/ψ (J/psi)	3.097
ψ' (psi)	3.686
Υ (ypsilon)	9.460
Z-bosoni	91.188



Finding the Higgs boson

- Based to the theory, hypothesis for the mass of Higgs boson and its daughter particles were set.
- Prediction was made after the hypothesis.
- Data was collected for years and LHC was running nearly 24 hours in a day.
- Results were compared to the prediction.
- Spike was detected for the value of one specific invariant mass, which is probably from the splitting of the Higgs boson (99.99% likelihood).



https://inspirehep.net/literature/1124338

Information about spike data

Table

Dataset	Particle	Range [GeV]	No. of events	max(E) [GeV]	min(E) [GeV]
piikkidata1	J/ψ (J/psii)	2.50001 - 3.59982	48223	249.377	2.66819
piikkidata2	Z-bosoni	70.0069 - 109.999	33177	1131.56	4.01271
piikkidata3	Υ (ypsilon)	9.00001 - 9.6999	19519	165.27	2.67178
piikkidata4	φ (fii)	0.90003 - 1.12998	7915	202.921	2.66267
piikkidata5	ρ, ω (rhoo, oomega)	0.650063 - 0.899988	8270	308.698	2.85848
piikkidata6	ψ′ (psii)	3.50017 - 3.89928	4106	221.887	2.57612

Materials of this workshop

Creator: Linda Hemmann

Sources:

https://github.com/AaltoJunior/Hiukkaset-Hukassa

A BRIEF INTRODUCTION TO PARTICLE PHYSICS by Nari Mistry, Laboratory for Elementary Particle Physics, Cornell University

https://www.classe.cornell.edu/rsrc/Home/Outreach/TeachingResources/Brief_Intro_to_HEP1.pdf

Editors

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