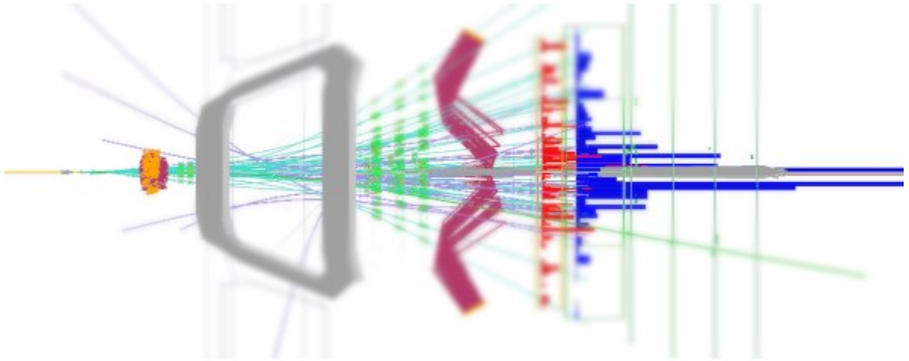

Introduction to the LHCb Masterclass exercise

David Hutchcroft

Liverpool Particle Physics Masterclass 2025

UNIVERSITY OF LIVERPOOL

Introduction

Here I will

- Briefly motivate why these exercises are interesting
- Explain what the LHCb detector is
- Explain the data format
- Give you some starting point for performing the exercises

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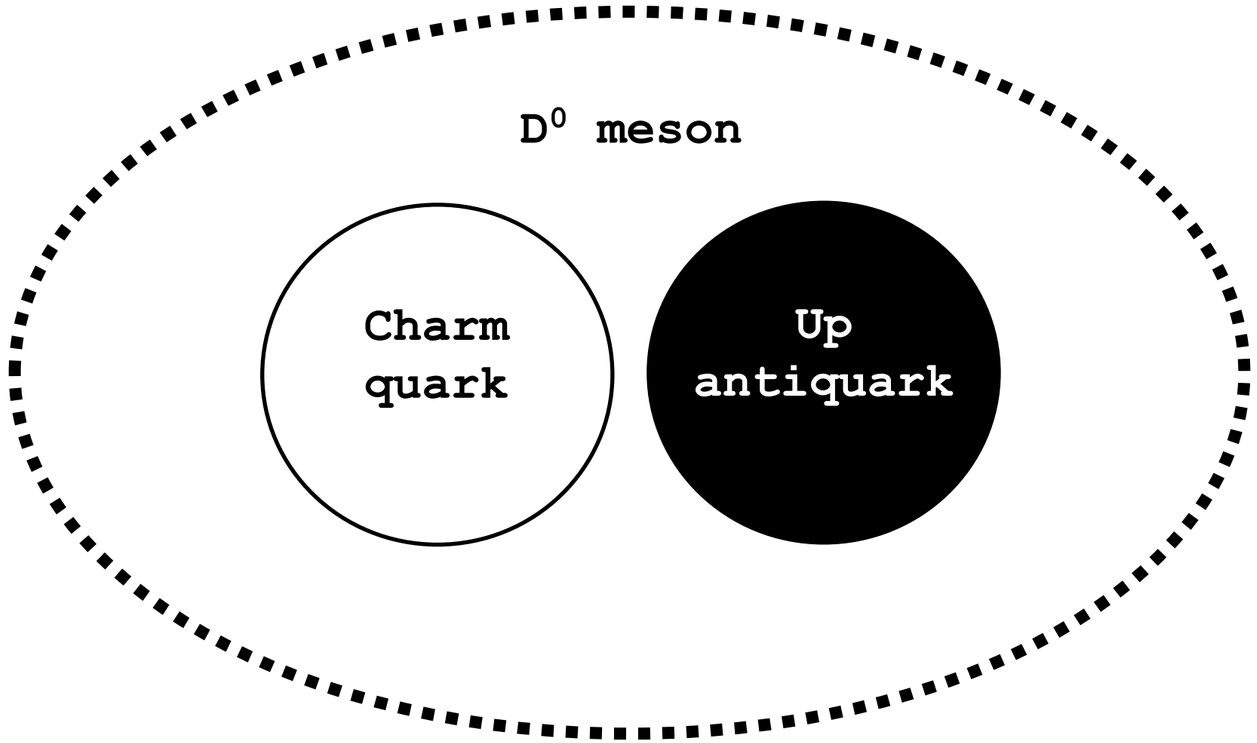
What will you be measuring today?



The object of this exercise is for you to measure the lifetime of a certain kind of particle found in nature:

The D^0 meson

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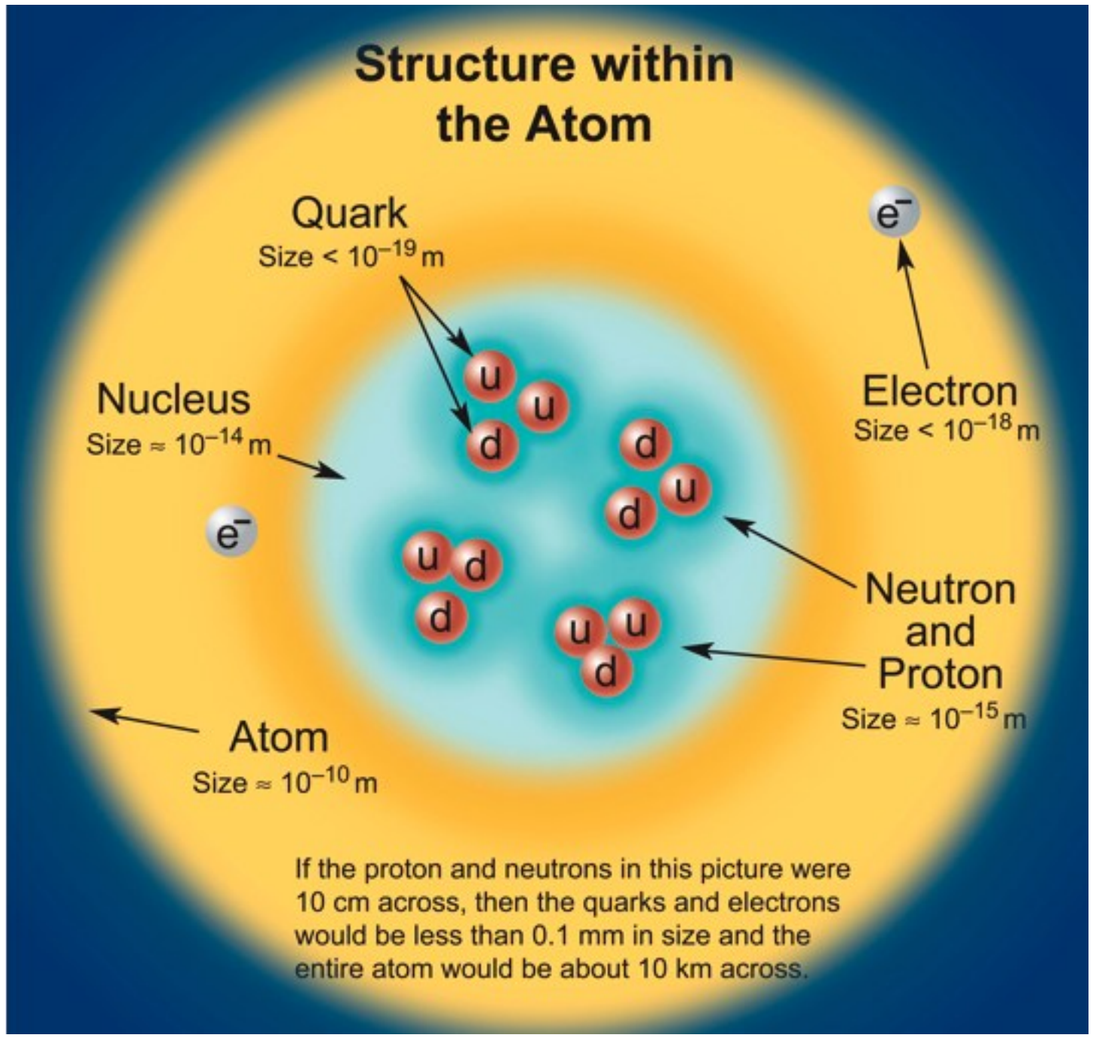
What kind of particles are there?

There are a small number of fundamental particles.



Quarks cluster into very small pairs or triplets

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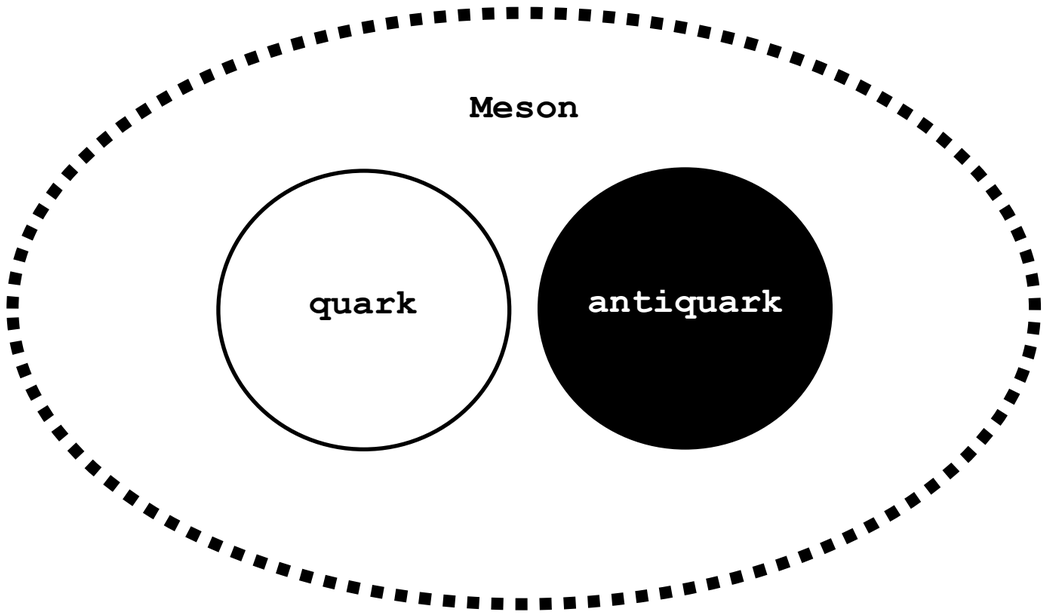
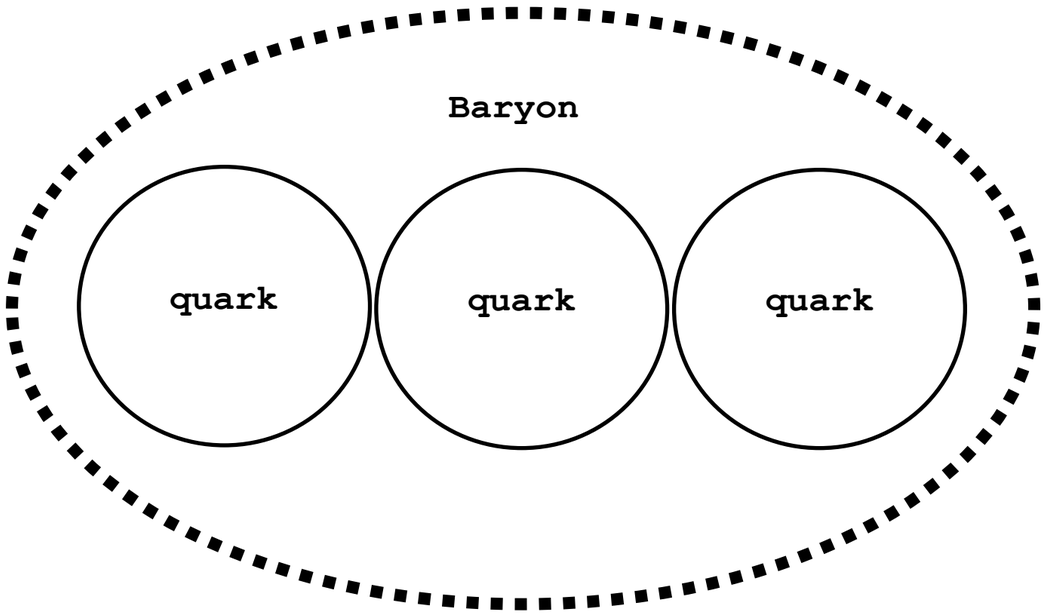
What do quarks form?





Two different kinds of combinations : quark-antiquark, or three (anti)quarks.

Antiparticles have opposite charges to the corresponding particles, otherwise they are supposed to interact in the same way. Most particles have a corresponding antiparticle (but sometimes a particle is its own antiparticle).

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What are some typical particle lifetimes?

Type	Name	Symbol	Energy (MeV)	Mean lifetime
Lepton	Electron / Positron	e^- / e^+	0.511	$> 4.6 \times 10^{26}$ years
	Muon / Antimuon	μ^- / μ^+	105.7	2.2×10^{-6} seconds
	Tau lepton / Antitau	τ^- / τ^+	1777	2.9×10^{-13} seconds
Meson	Neutral Pion	π^0	135	8.4×10^{-17} seconds
	Charged Pion	π^+ / π^-	139.6	2.6×10^{-8} seconds
Baryon	Proton / Antiproton	p^+ / p^-	938.2	$> 10^{29}$ years
	Neutron / Antineutron	$n / \bar{n}$	939.6	885.7 seconds
Boson	W boson	W^+ / W^-	80,400	10^{-25} seconds
	Z boson	Z^0	91,000	10^{-25} seconds

“Intermediate” decay lifetimes can be seen in particle detectors

Wikipedia: Almost all knowledge is here (some is even true)

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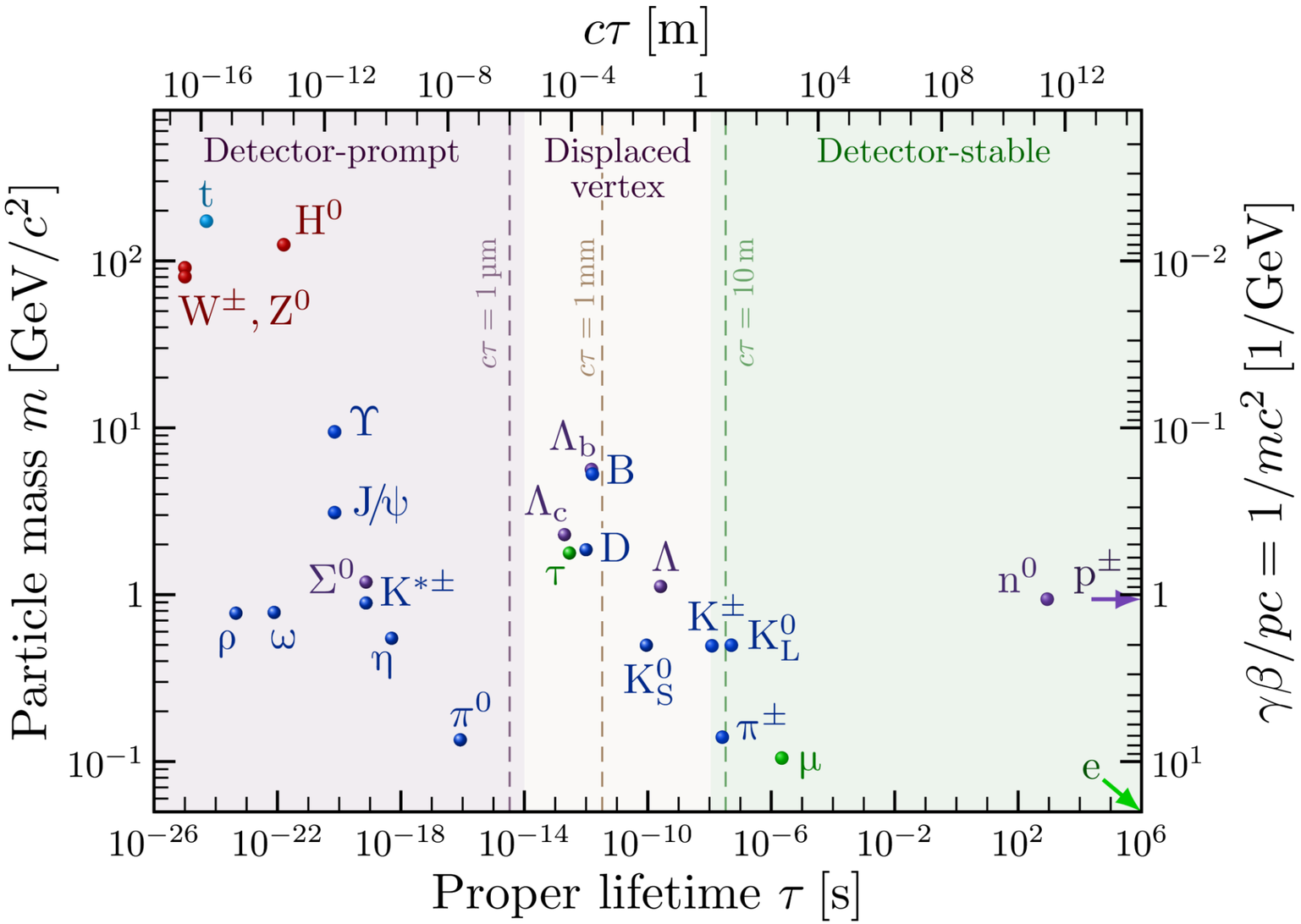
What can we detect?



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How do we measure a short lifetime?

As an example, consider a particle which lives 10^{-12} seconds

How far will it travel, on average, if it travels at the speed of light?

$$c = 3 \cdot 10^8 \text{ m/s}$$

It travels $3 \cdot 10^{-4}$m, or 0.3 mm

This is not very long! Luckily, the calculation is wrong; we forgot special relativity, which tells us that the particle lives longer because of time dilation

$$t' = \frac{t}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Typically, an LHC particle with a lifetime of 10^{-12} seconds will fly 1 cm... that is long enough that we can measure it!

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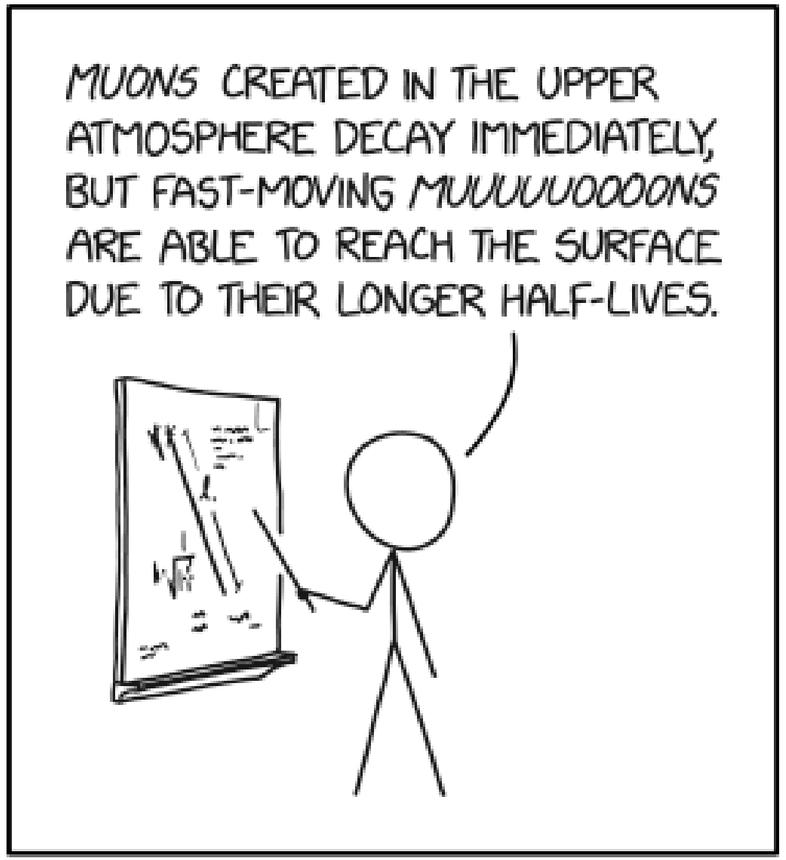
Cosmic rays

If you hold your hand out flat about 25 muons go through it every second

You can see the effects in our cloud chamber in the CTL atrium, the electrons knocked loose by the muons leave trails of droplets.

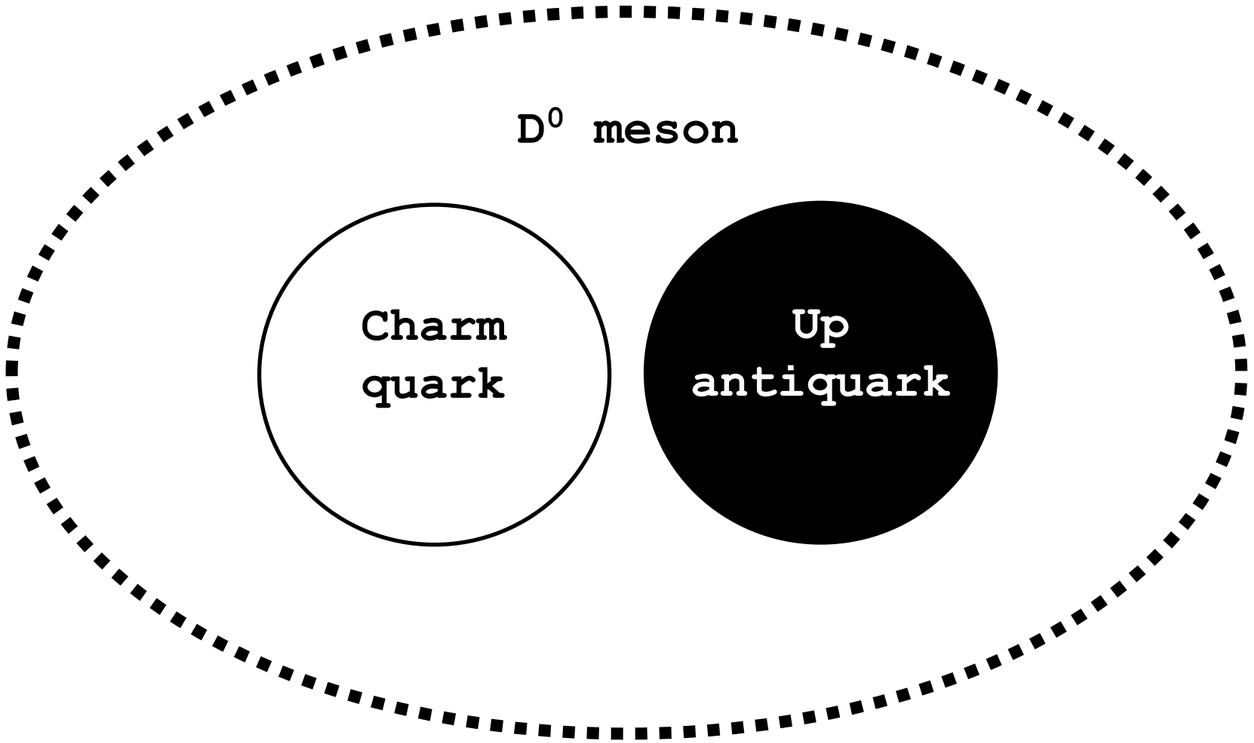


PHYSICS TIP: REMEMBER TO ADJUST YOUR PRONUNCIATIONS TO ACCOUNT FOR TIME DILATION.

Update: I've been banned from the physics department for the way I pronounce "Doppler effect."

https://xkcd.com/3043

So why is the D^0 special?



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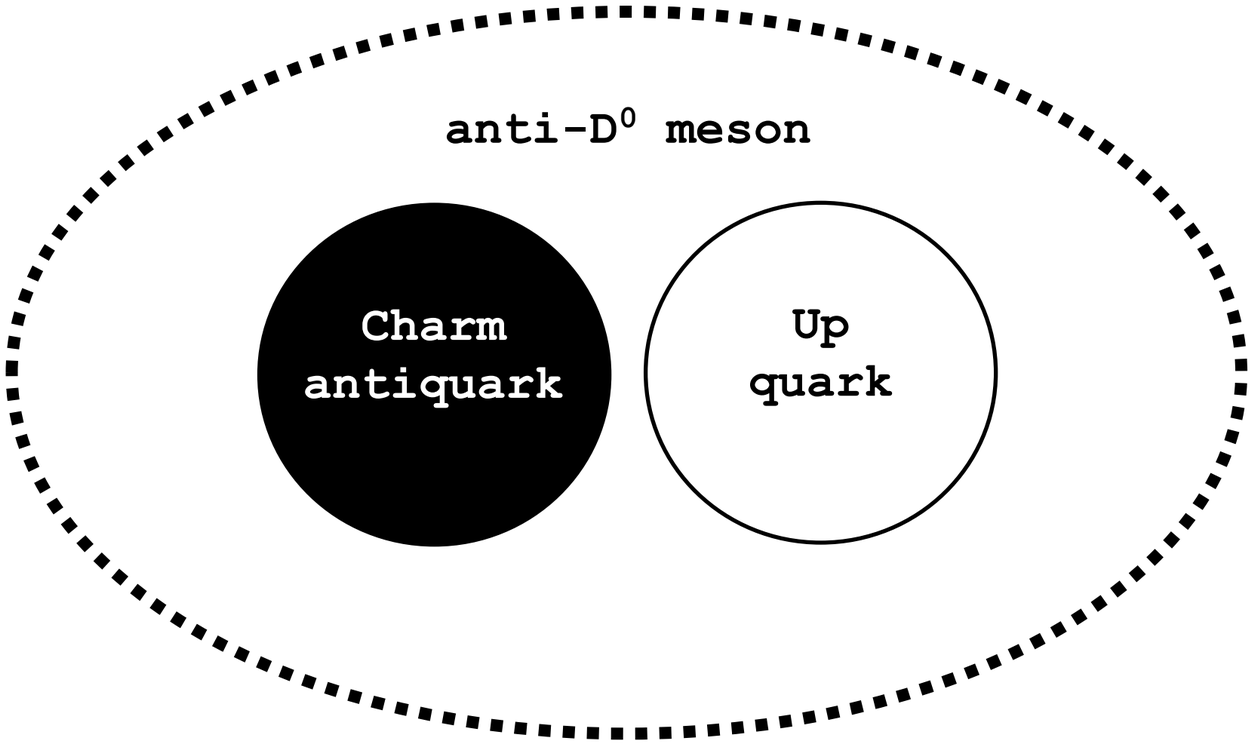
So why is the D^0 special?



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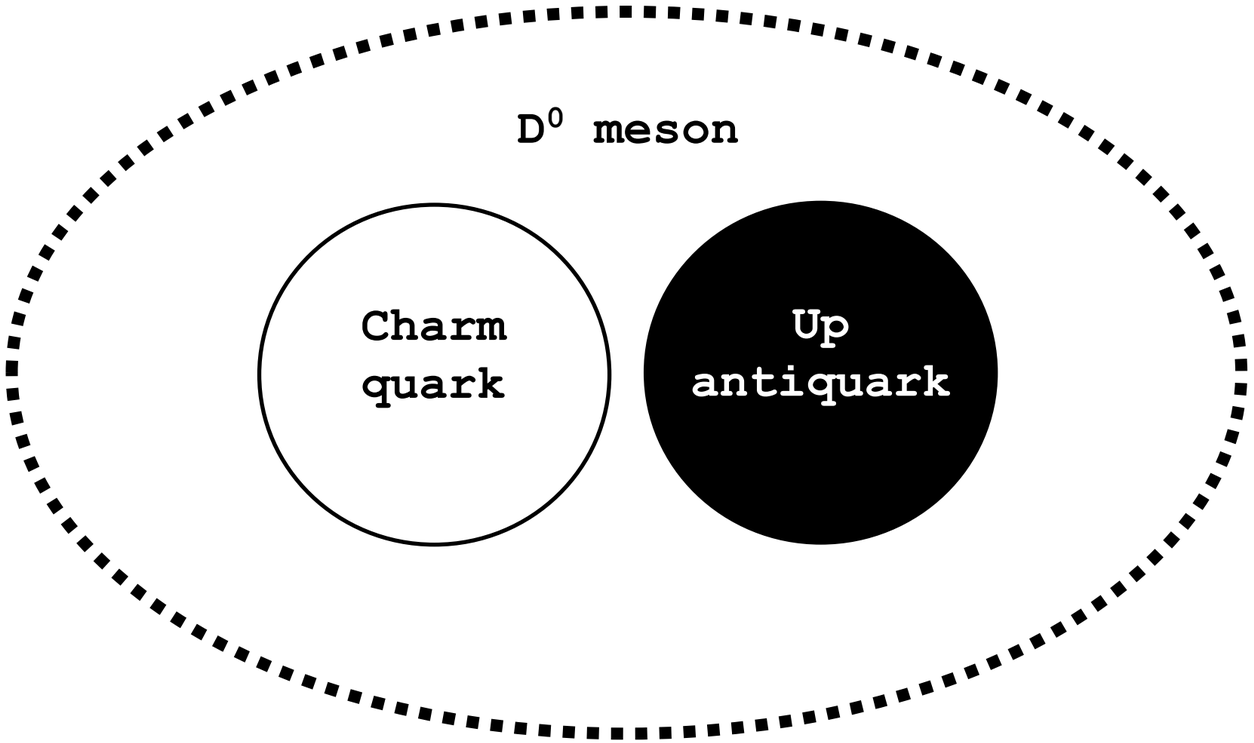
So why is the D^0 special?



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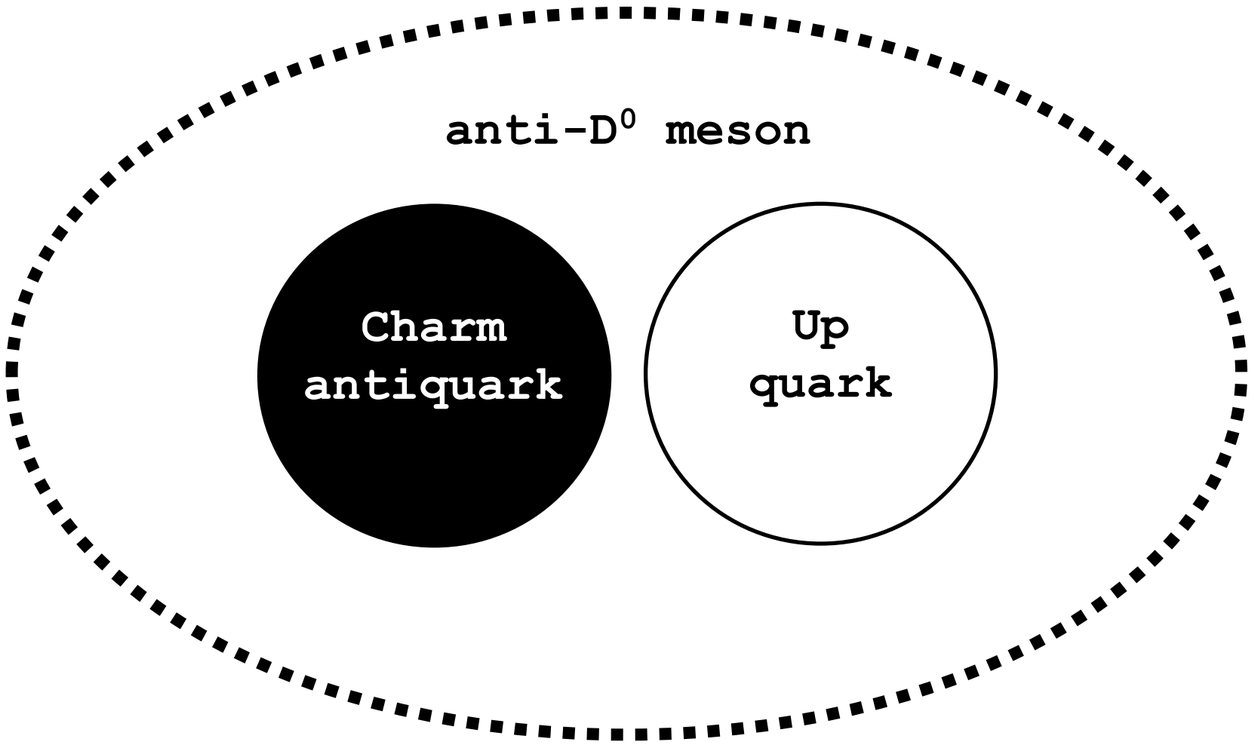
It oscillates!



The D^0 is a neutral particle : it can oscillate between matter and antimatter before decaying!

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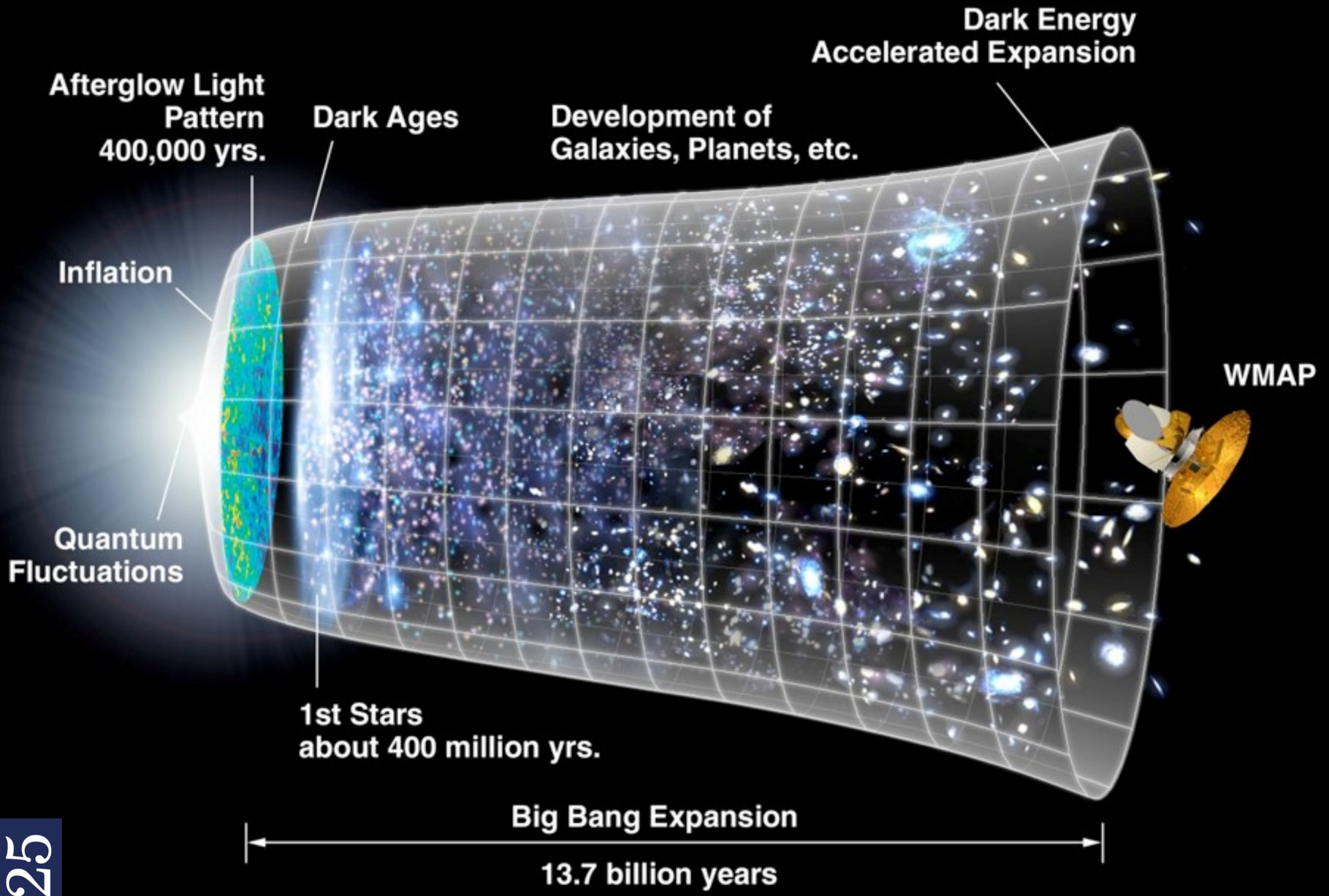
Why does antimatter matter?



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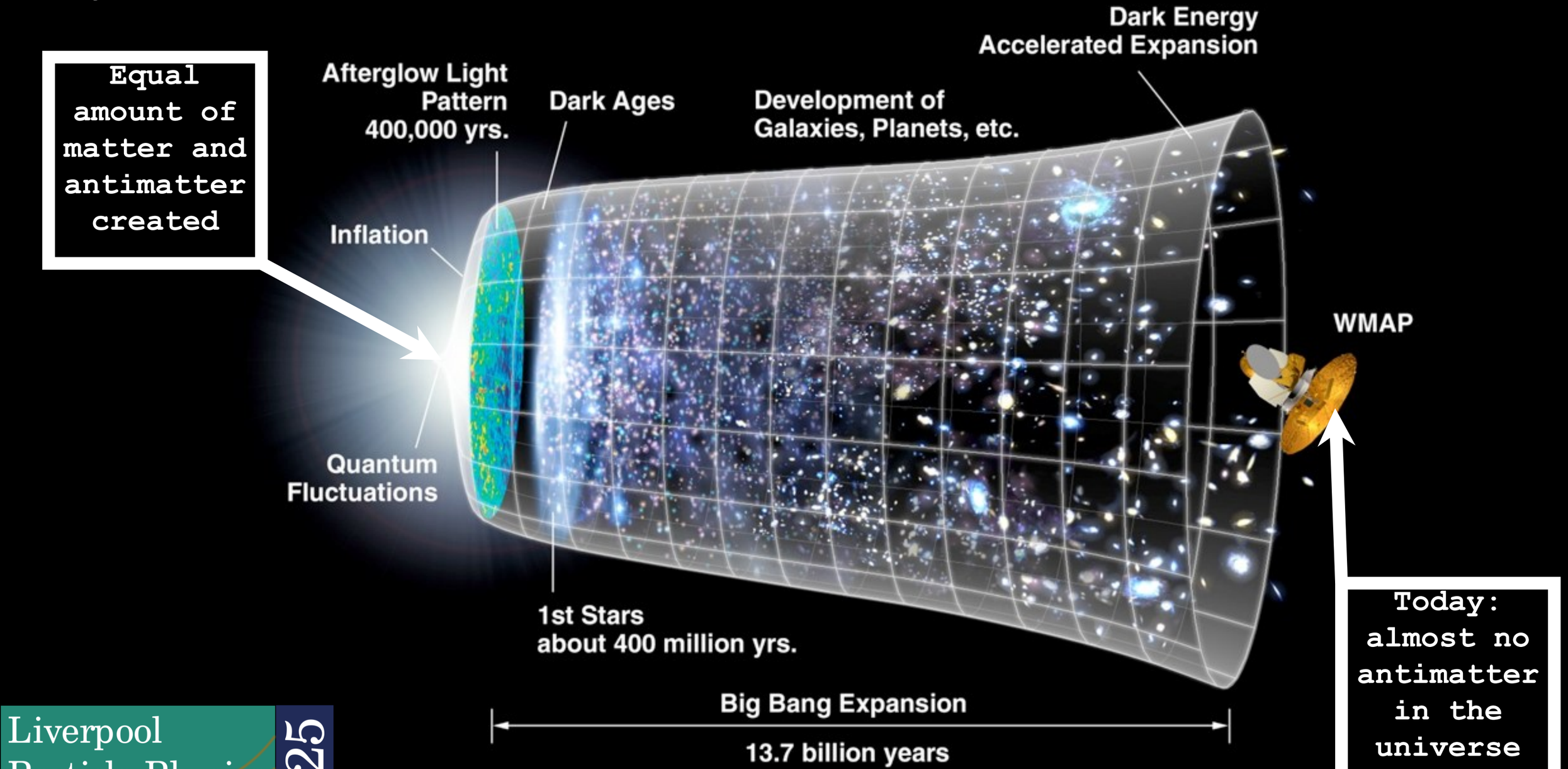
Why does antimatter matter?



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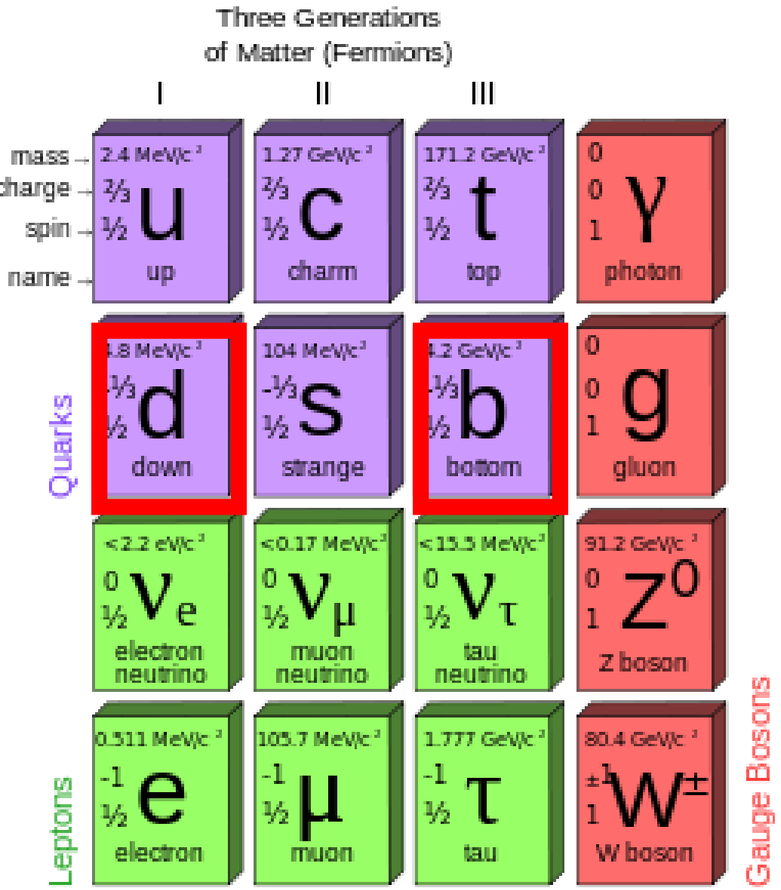
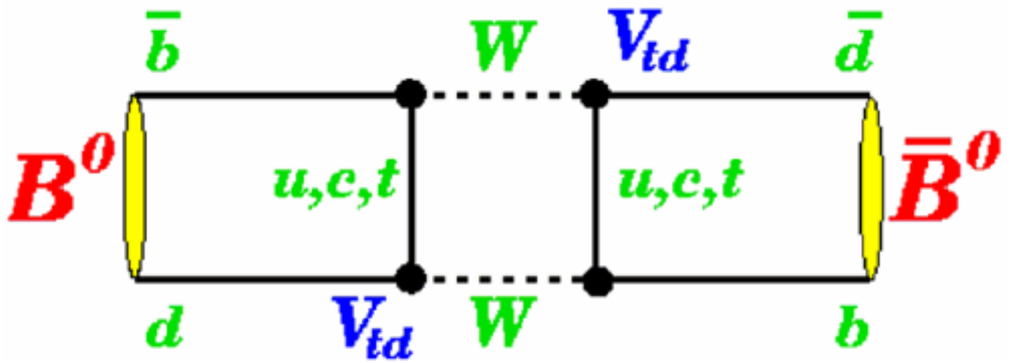
Why the D^0 and not another particle?



Neutral mesons can oscillate between matter and anti-matter as they propagate

Classic example is the B_d meson : measurement of B_d oscillations was an early indication of the top quark mass



Oscillations are interesting because they are sensitive to new particles appearing virtually inside the box diagram, which can be very much heavier than directly produced particles

LHCb's measurement of $D^0 \leftrightarrow \overline{D^0}$, first direct measurement of oscillations in flight
https://arxiv.org/pdf/1211.1230
Talk Measurement of D0 to anti-D0 mixing and CP violation in D0 to Kpi decays

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The object of the exercise

The purpose of this exercise is to

- Give you a look at the data coming out of the LHC
- Teach you about selecting particles in the LHC data
- Teach you about fitting functions to the data in order to measure the signal properties
- Teach you about uncertainties in measurements

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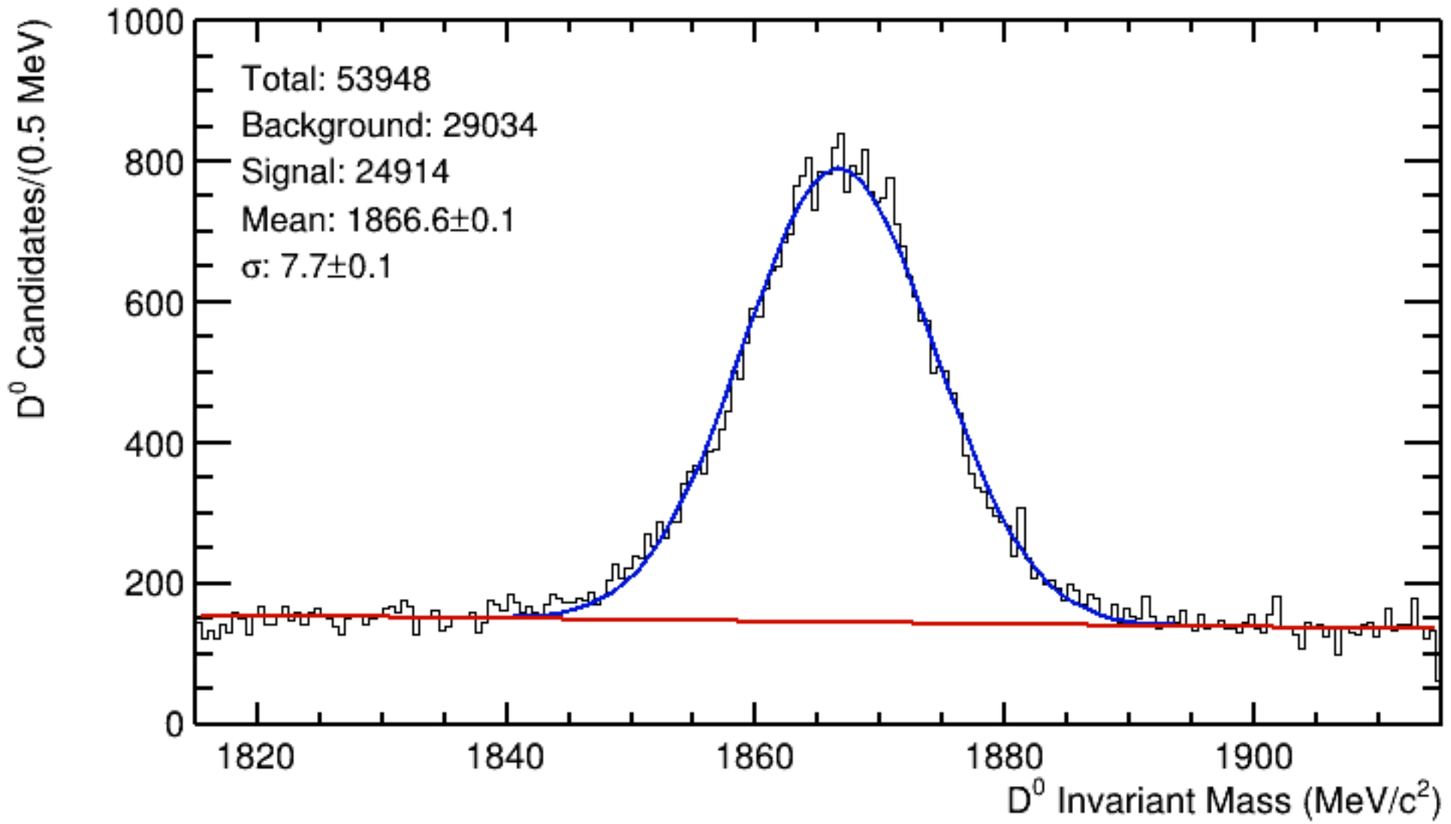
Data for exercise



Use the $D^0 \rightarrow K\pi$ events from 2012 data taking, starting mass distribution above.

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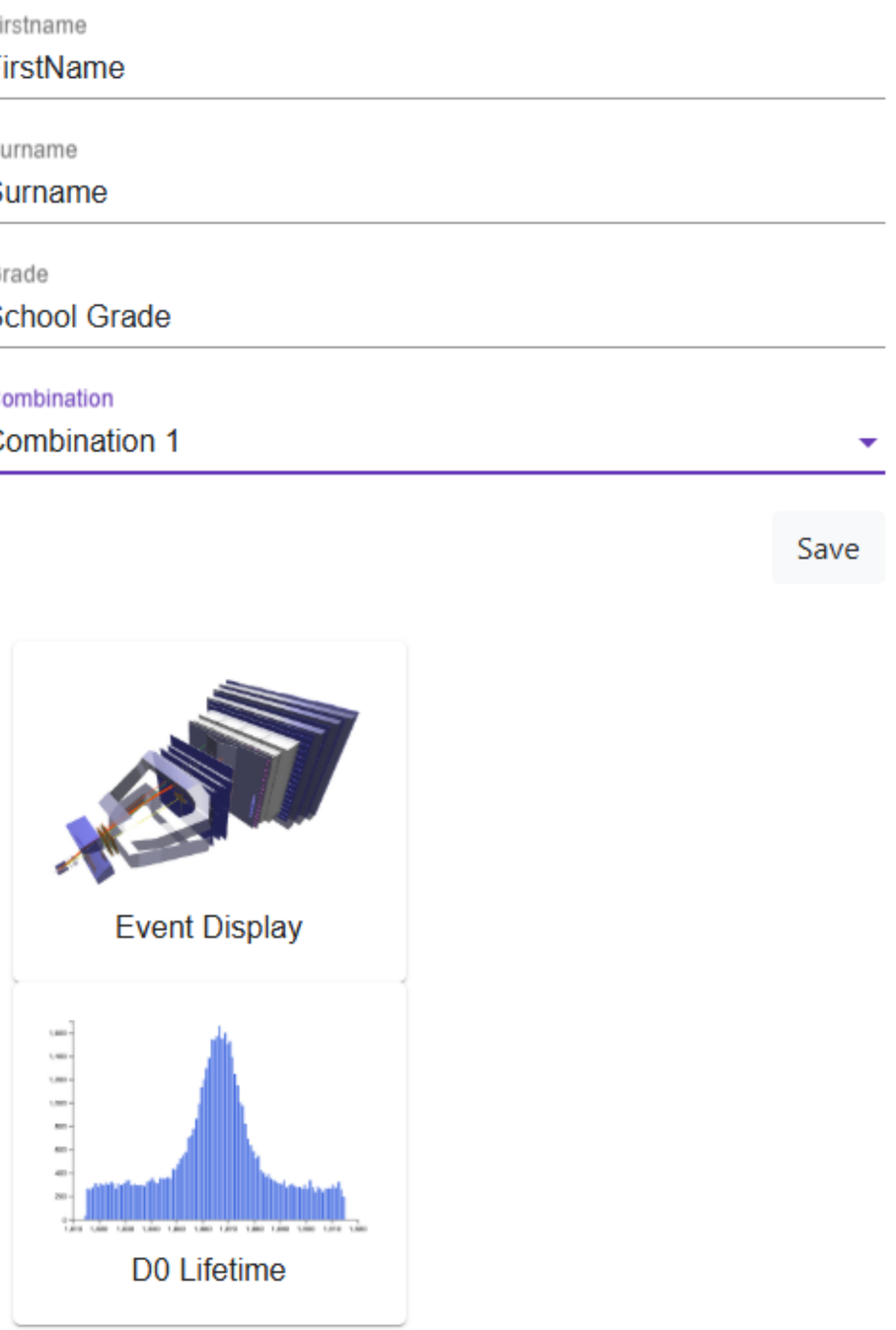
Sign in to the masterclass

Put your details here

There are 32 sets of D^0 to measure, you will each only do a couple of these

When the form is complete you can pick one of the options



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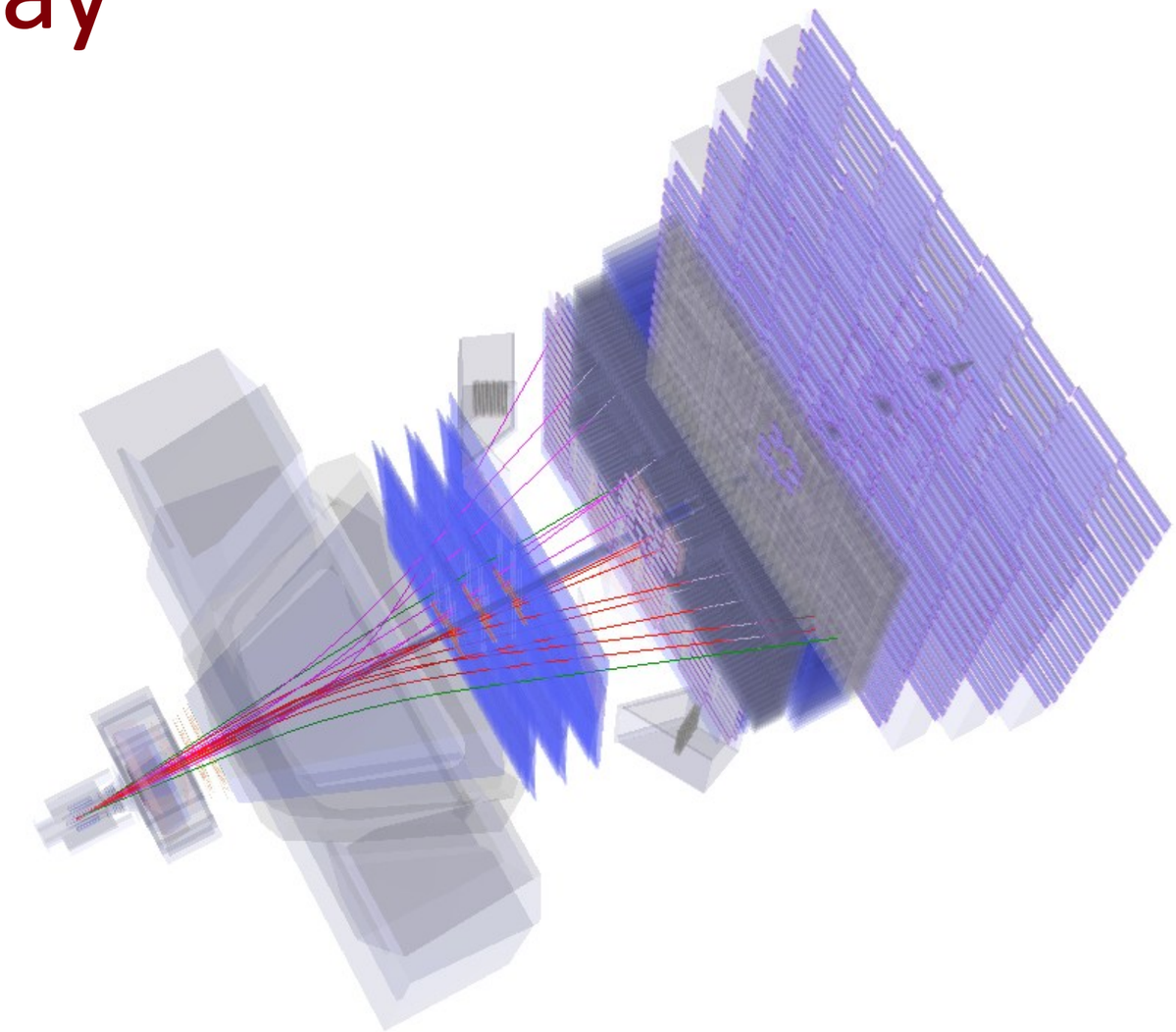
Event display



Because LHCb is a forward spectrometer with a dipole magnet, it is hard to do visual exercises looking at the full detector. We will zoom in around the interaction region for you to find displaced vertices.

The visual analysis framework

LHCb Masterclass

About
Language

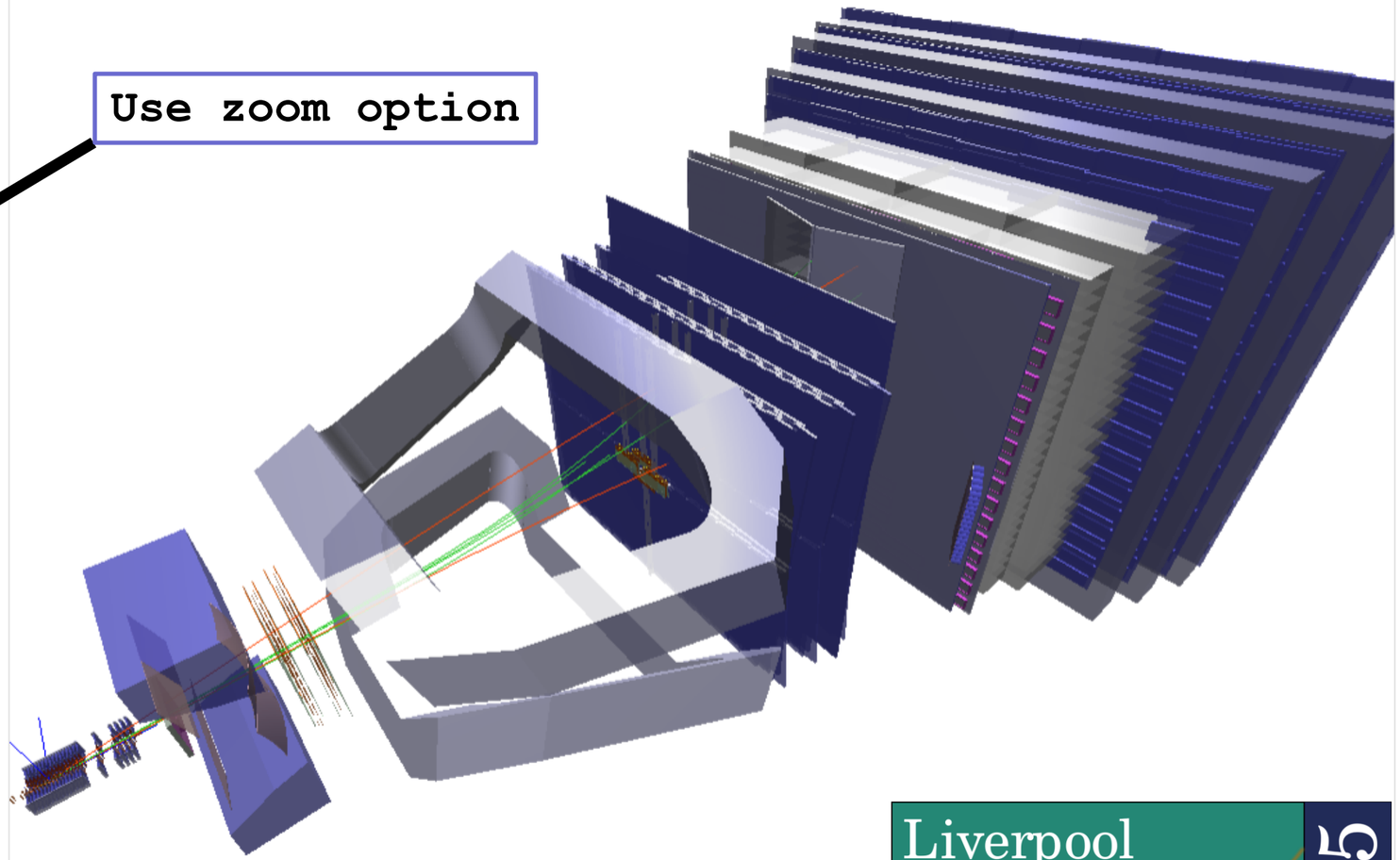
Event Display Exercise

Event handler
event_2_0.json
previous
next

View
Zoom
Detector
Help
View
Auto rotate

Legend
K^-
K^+
pi^+
pi^-
D^0

Use zoom option

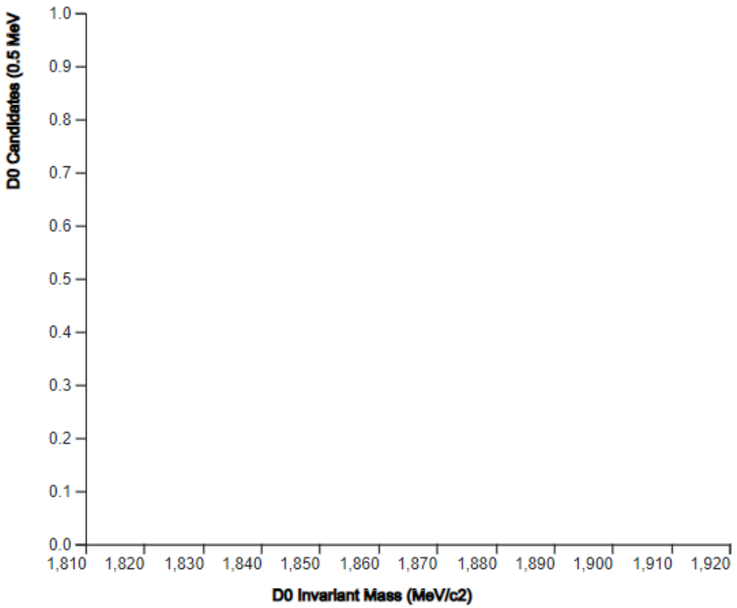


Particle information

E	MeV
chi2	
ipchi2	
mass	MeV/c^2
name	
ZFstM	

My particles

Mass
MeV/c^2
Add



v0.1

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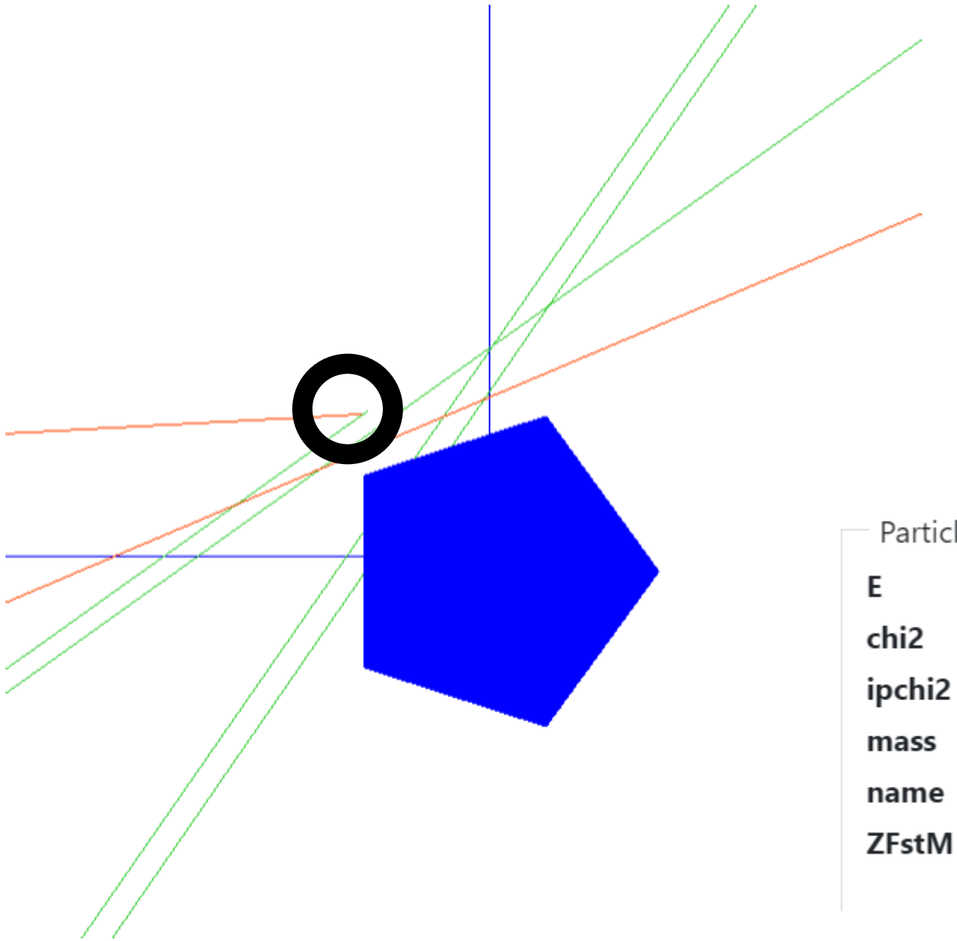
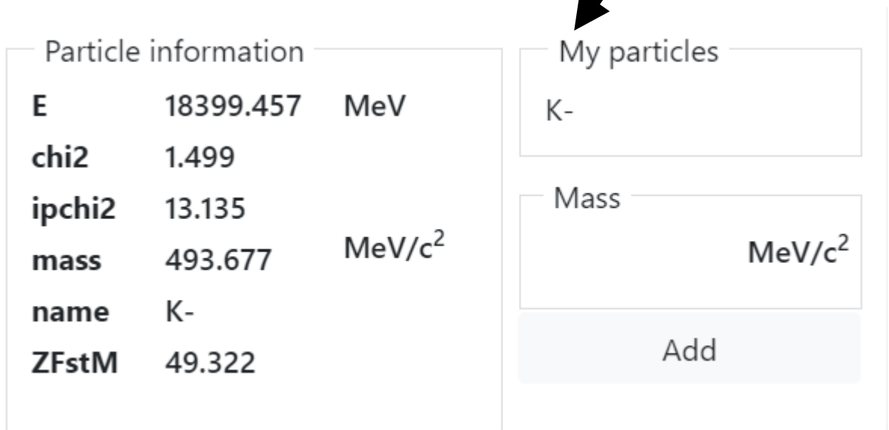
Pick a pion and kaon, starting not from the beam line



When selected, shown in "My particles"



Kaon selected here, also click pion then "Add"

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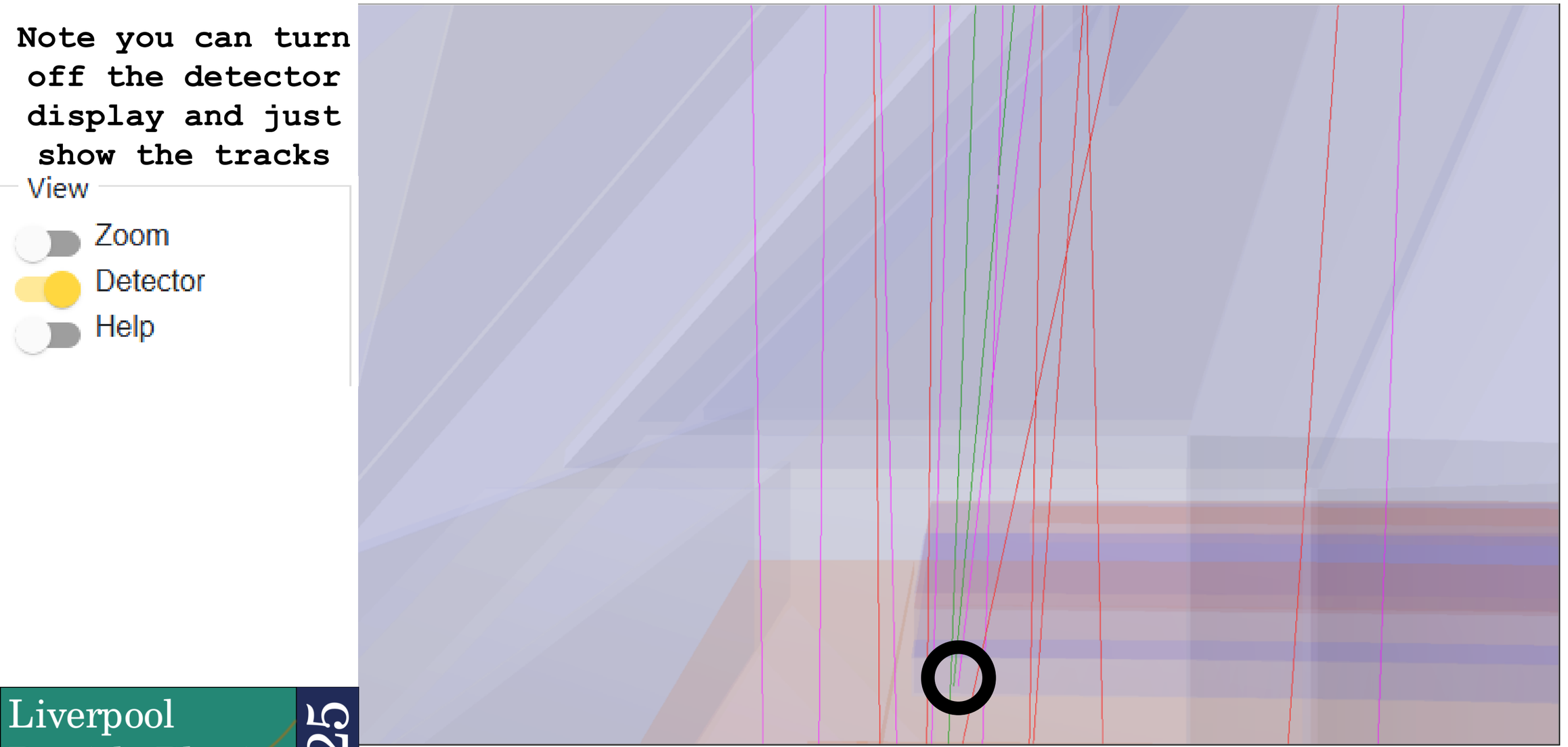
A “harder” event

Note you can turn off the detector display and just show the tracks



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Sign in to the masterclass

Firstname
FirstName

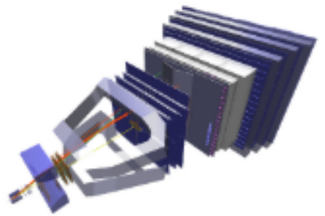
Surname
Surname

Grade
School Grade

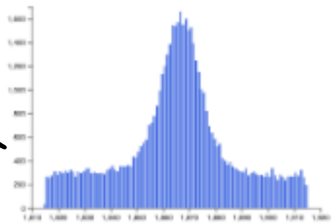
Combination
Combination 1

Save

The second part is to choose the D0 lifetime fitting option



Event Display



D0 Lifetime

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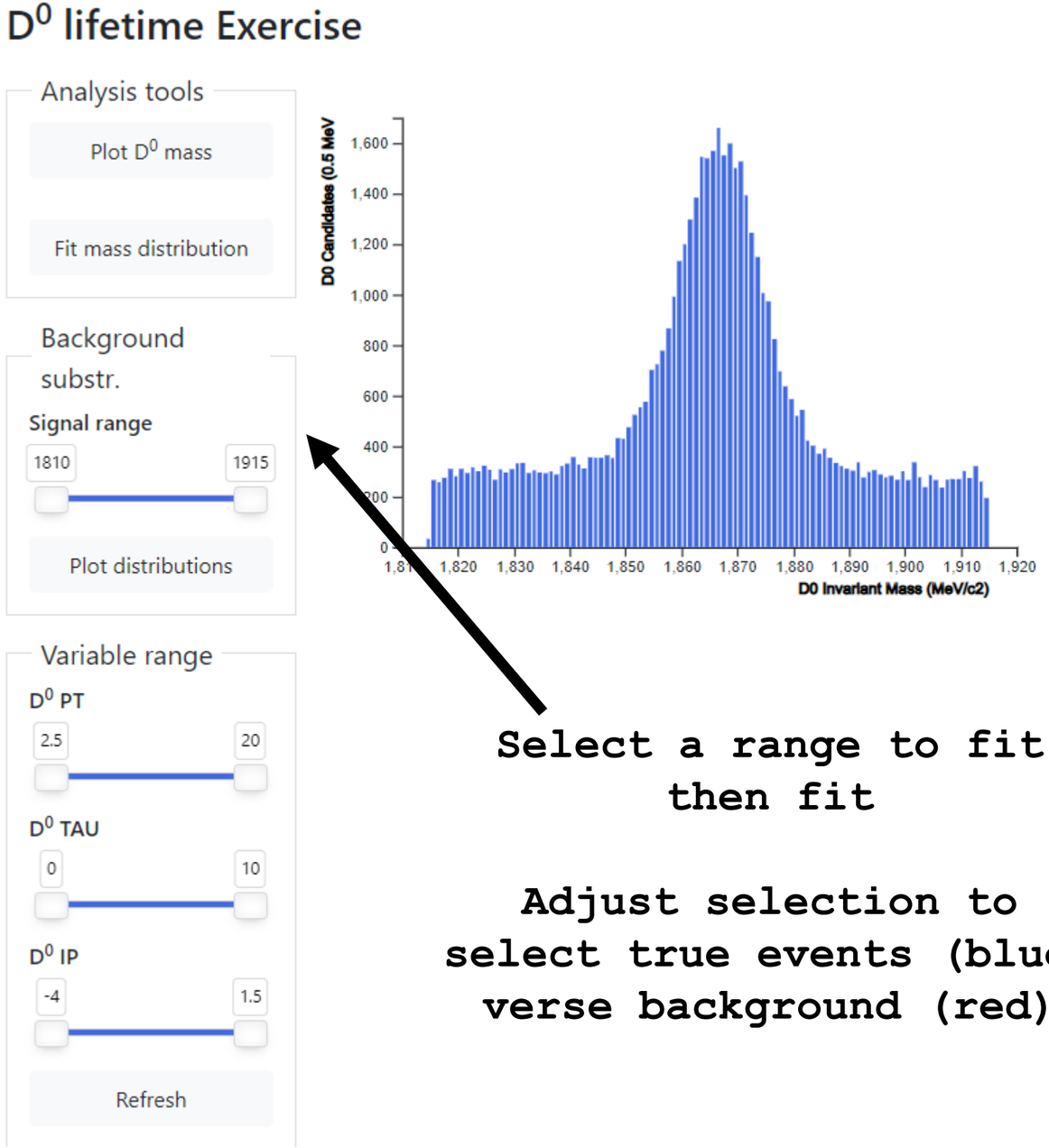
Fitting the lifetime

Once you finish looking for the events, you will get a bigger collection of data to use to measure the lifetime.



Select a range to fit then fit

Adjust selection to select true events (blue) verse background (red)

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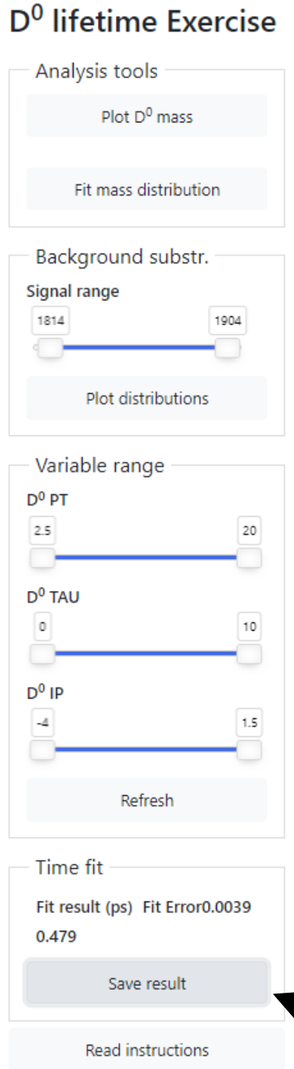
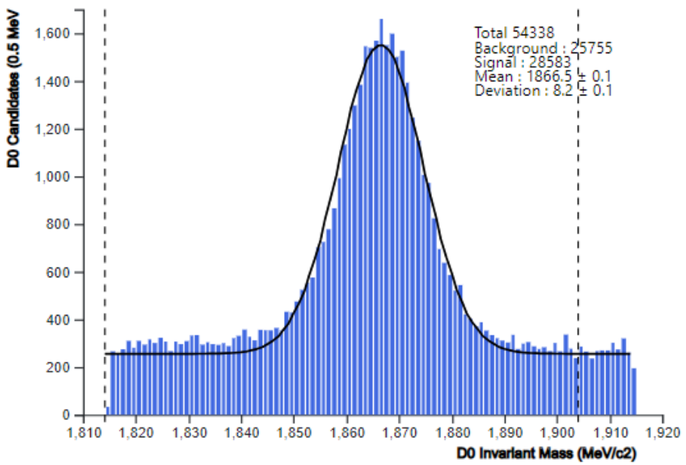
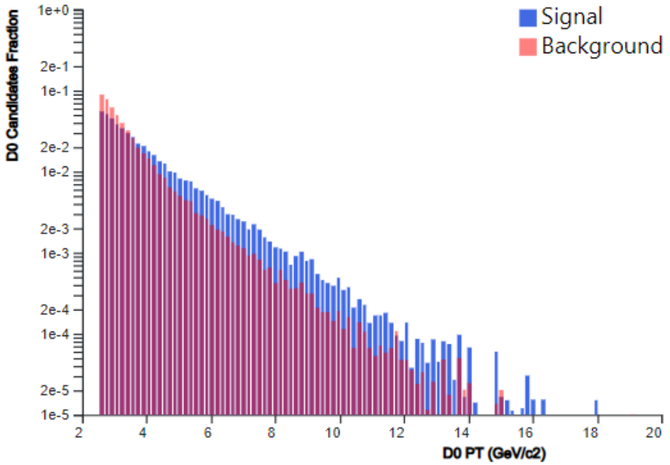
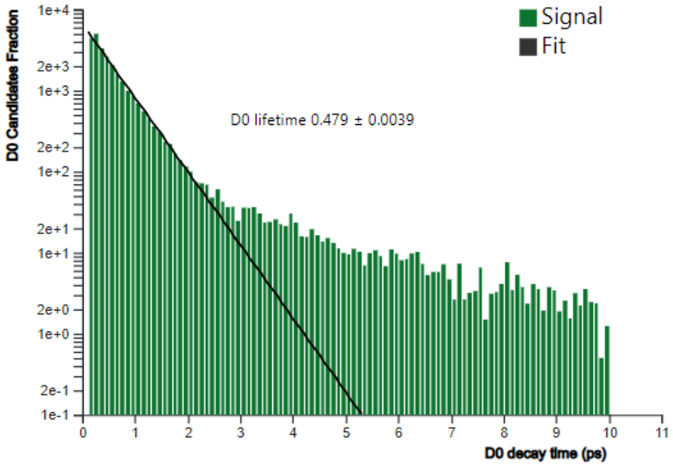
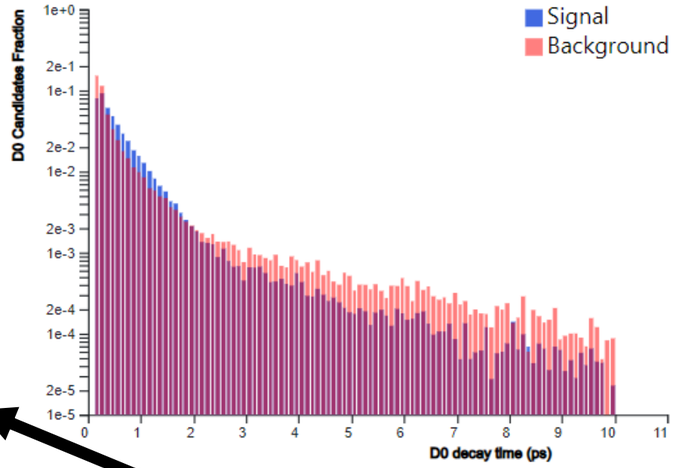
Plotting the distributions

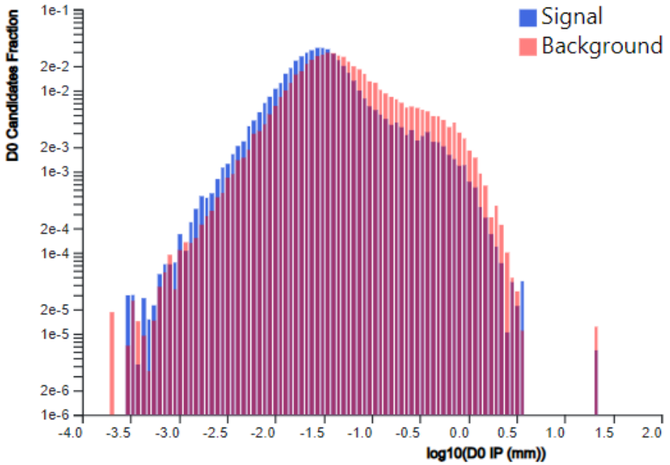












History of your value is here

Use save results button so see if you have improved with your changes

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