

Introduction to the LHCb masterclass exercise

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Introduction

You will all have received a printout with instructions for the workshop. 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

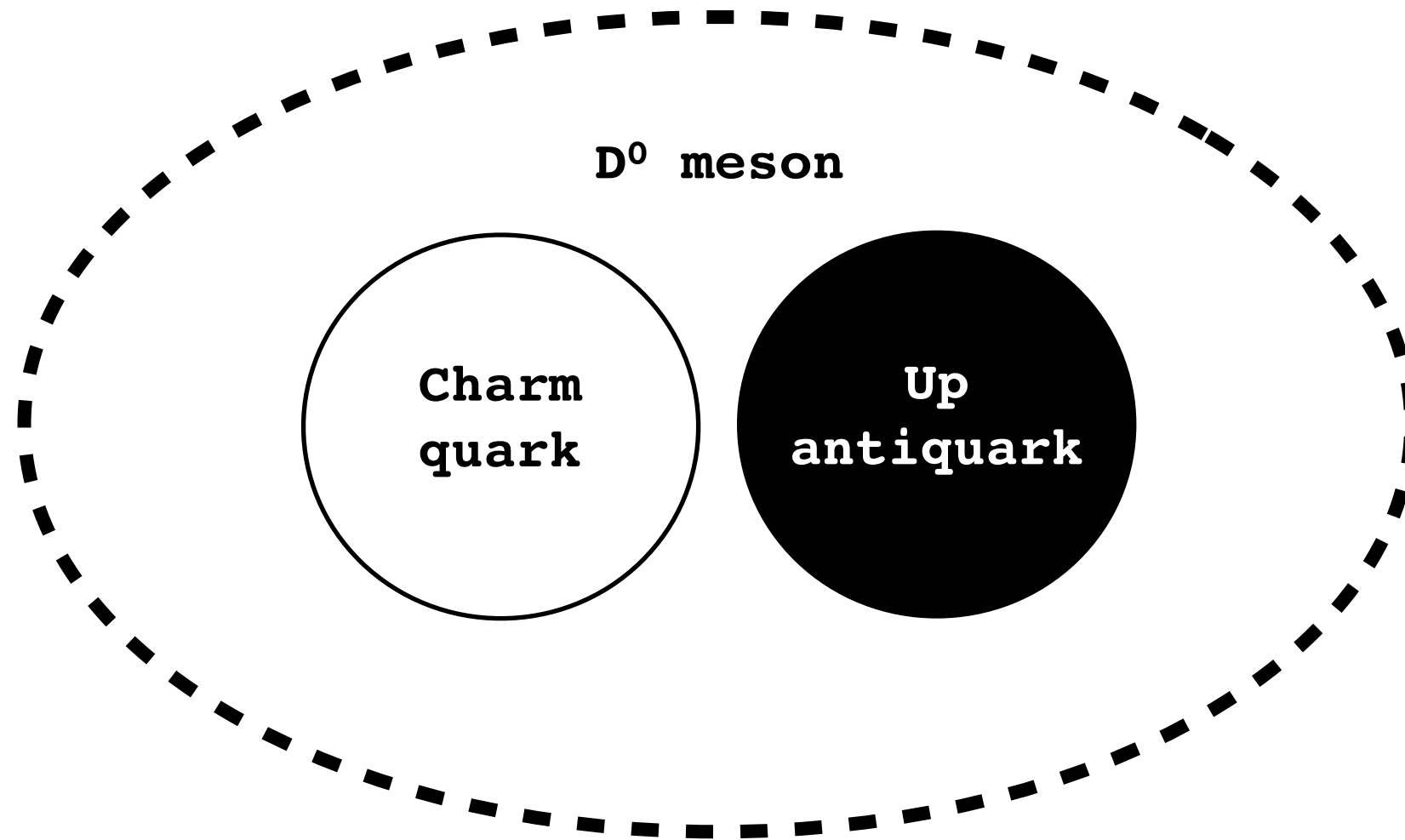
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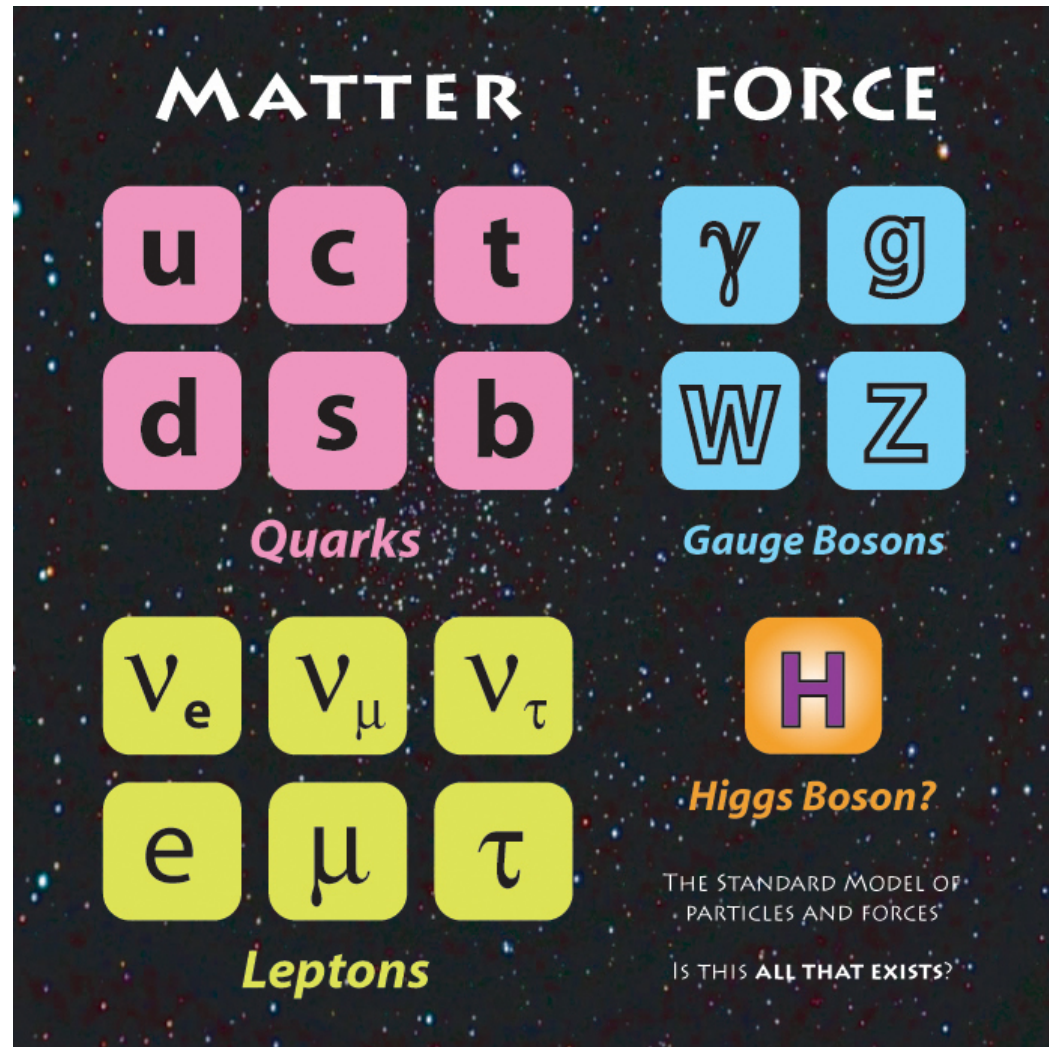
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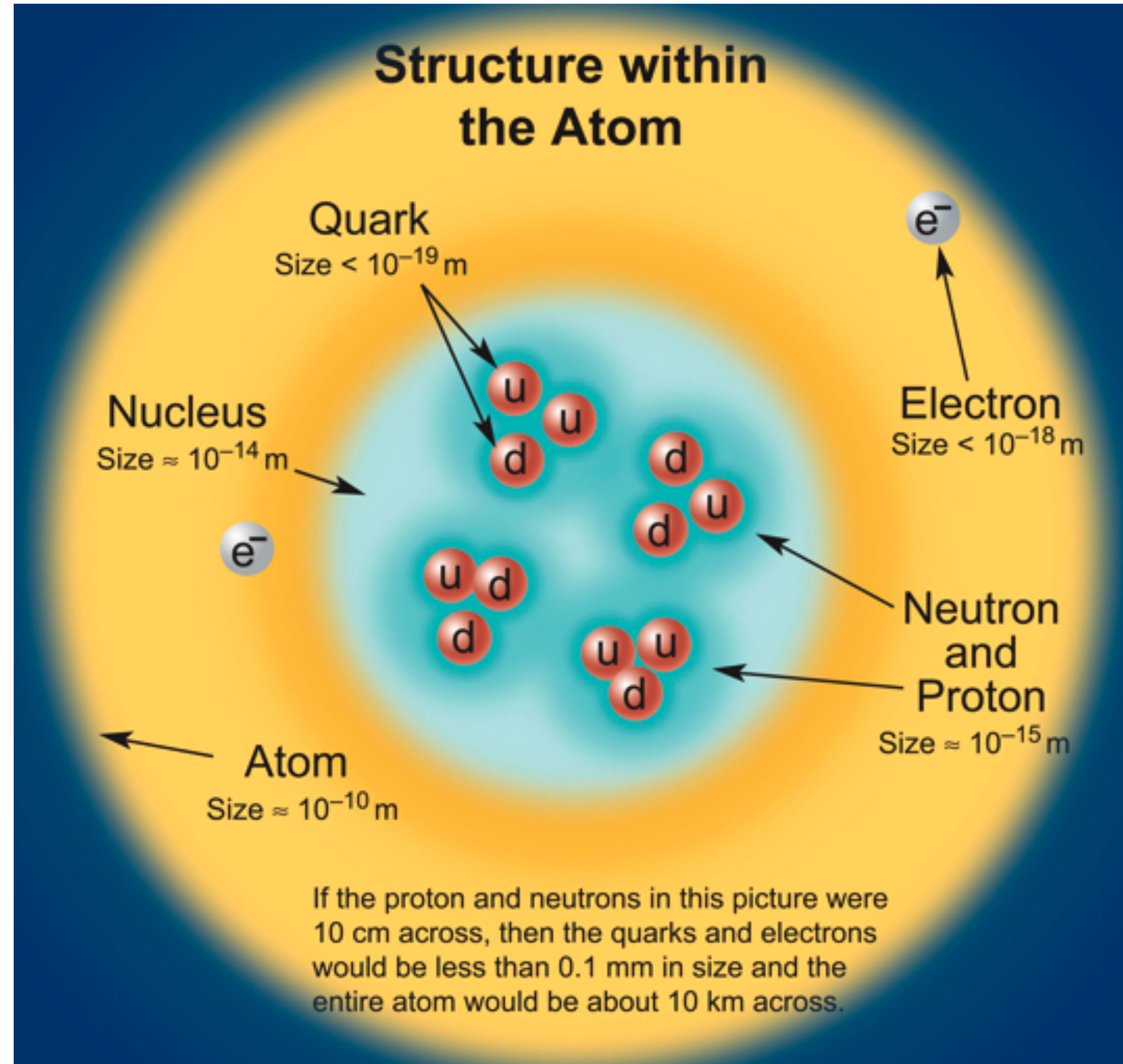
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What kind of particles are there?

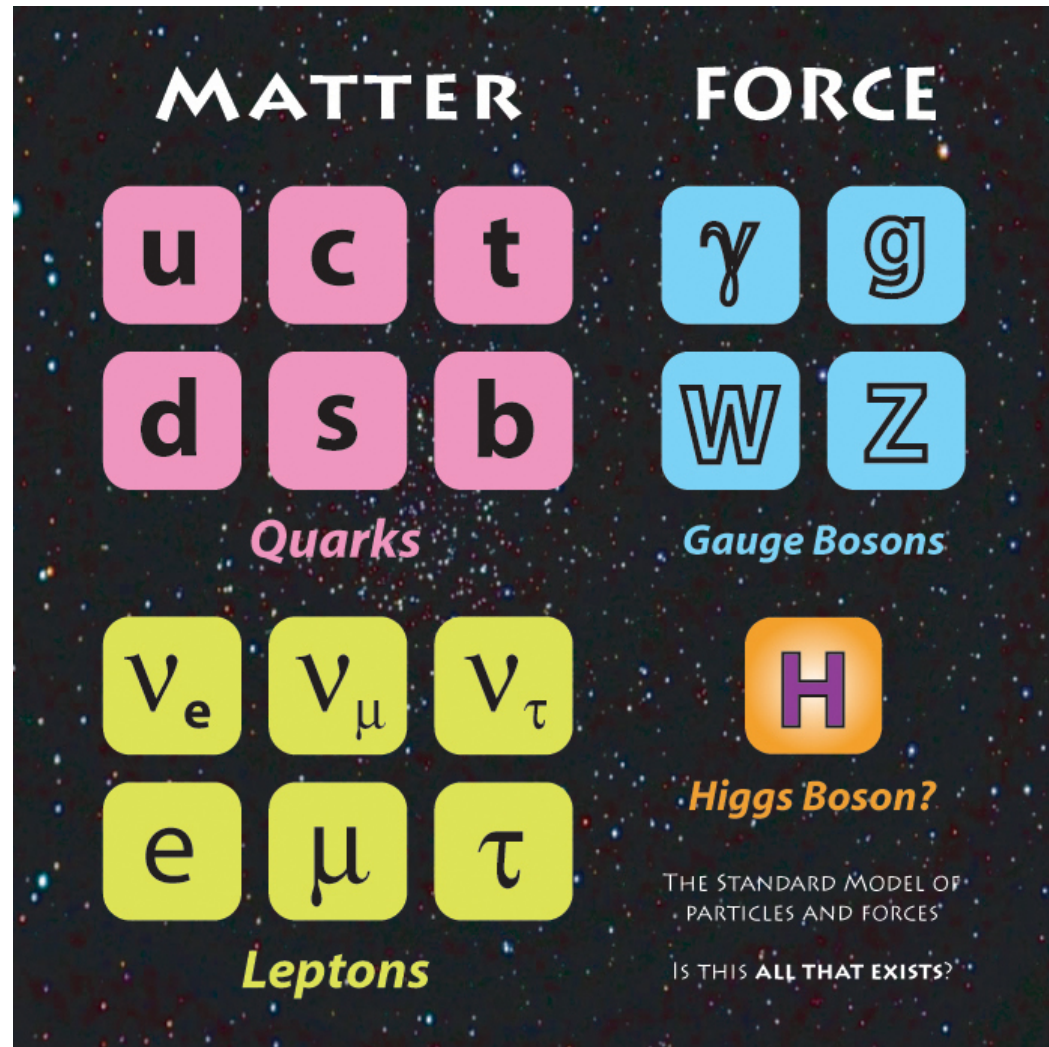


There are a small number
of fundamental particles.

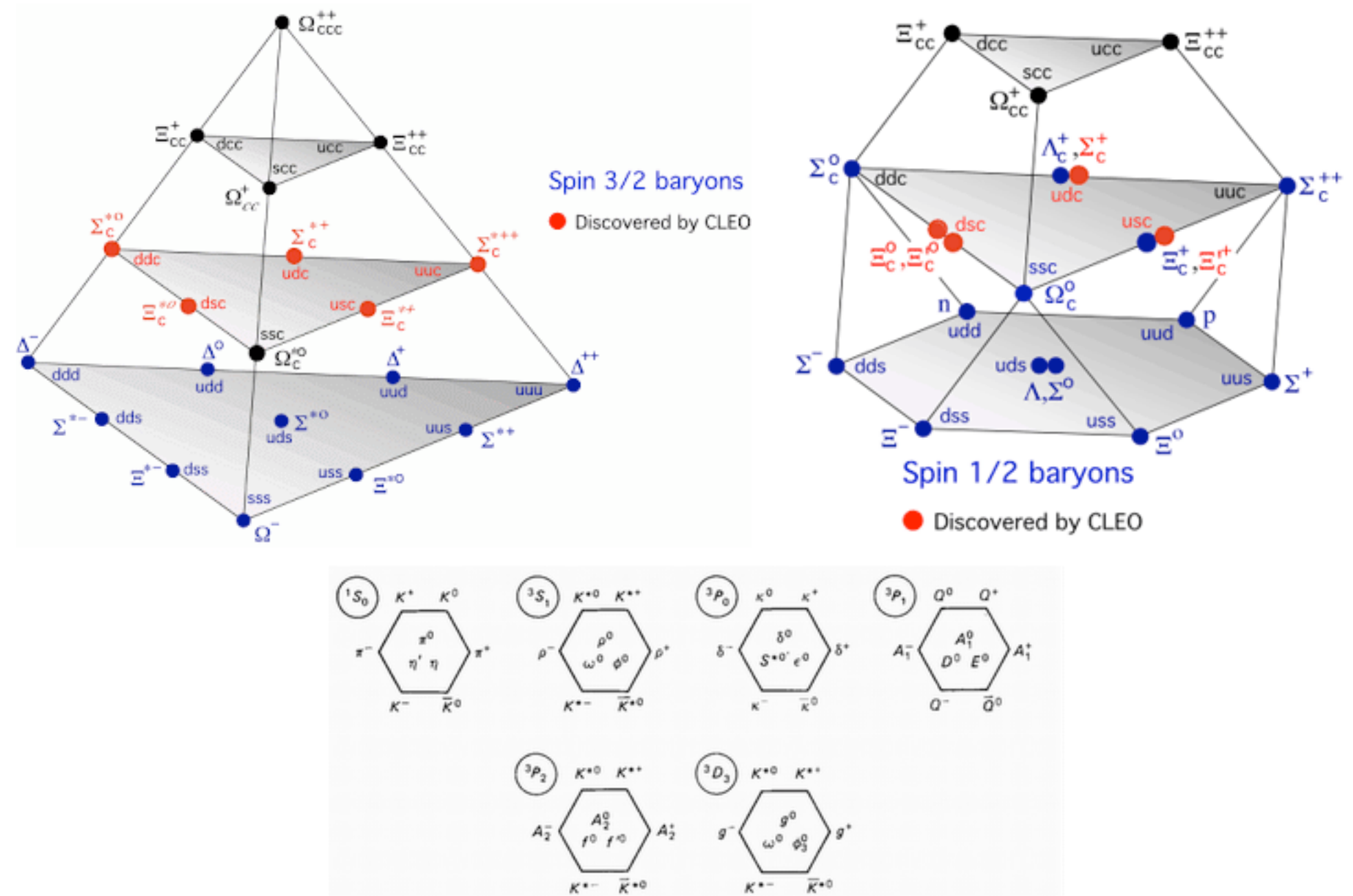
Smaller than atoms...



What kind of particles are there?

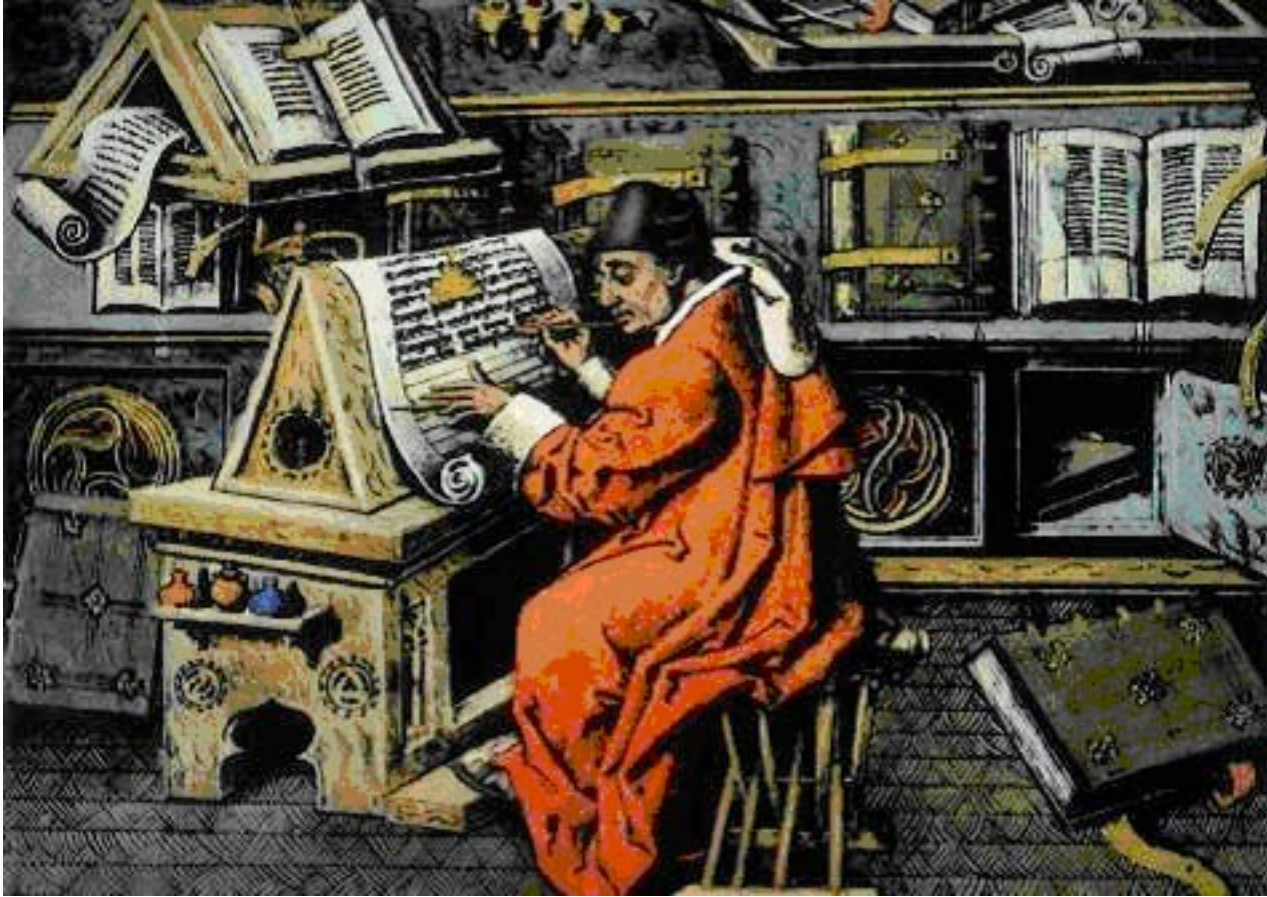


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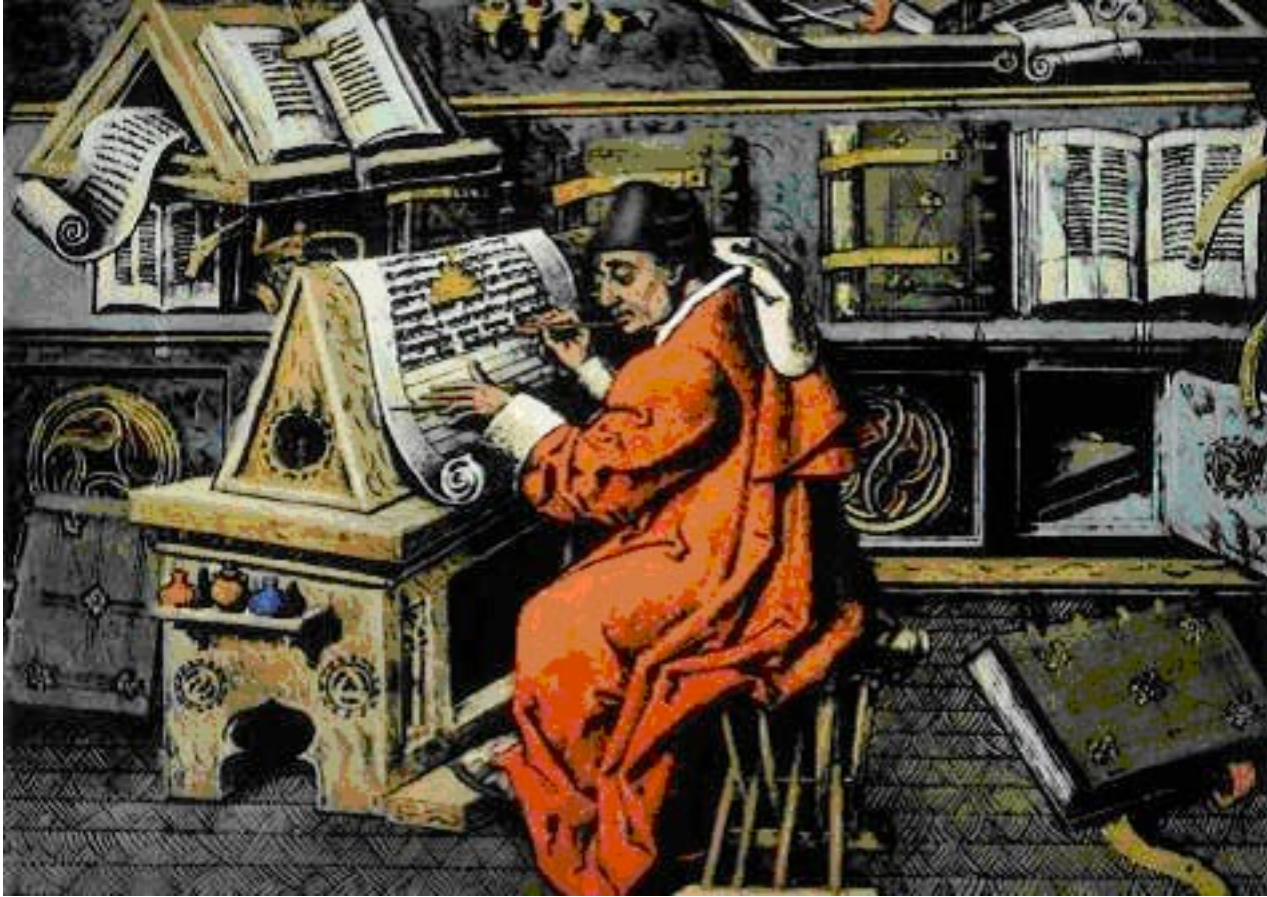
And a massive number of composite particles made up of quarks! The above is nowhere near the full list!

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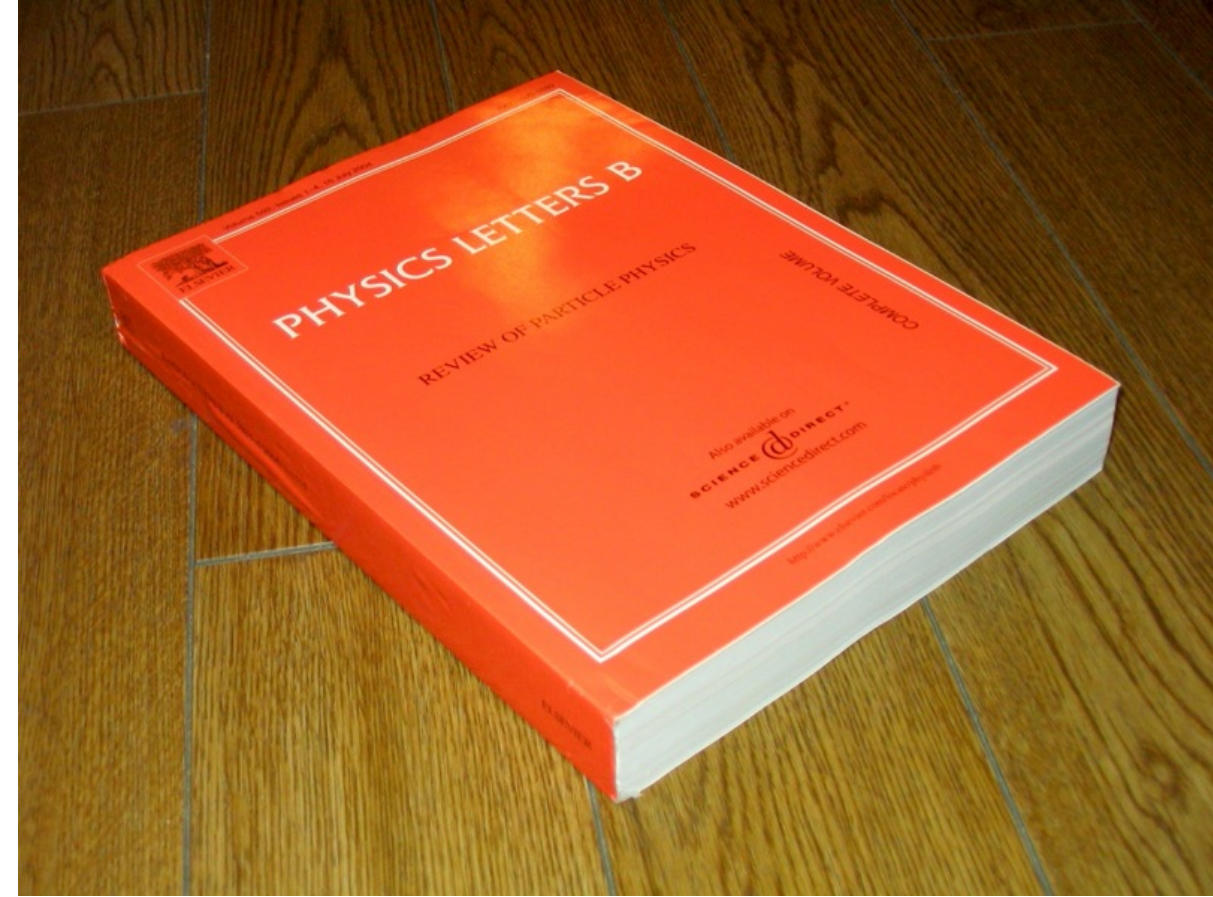


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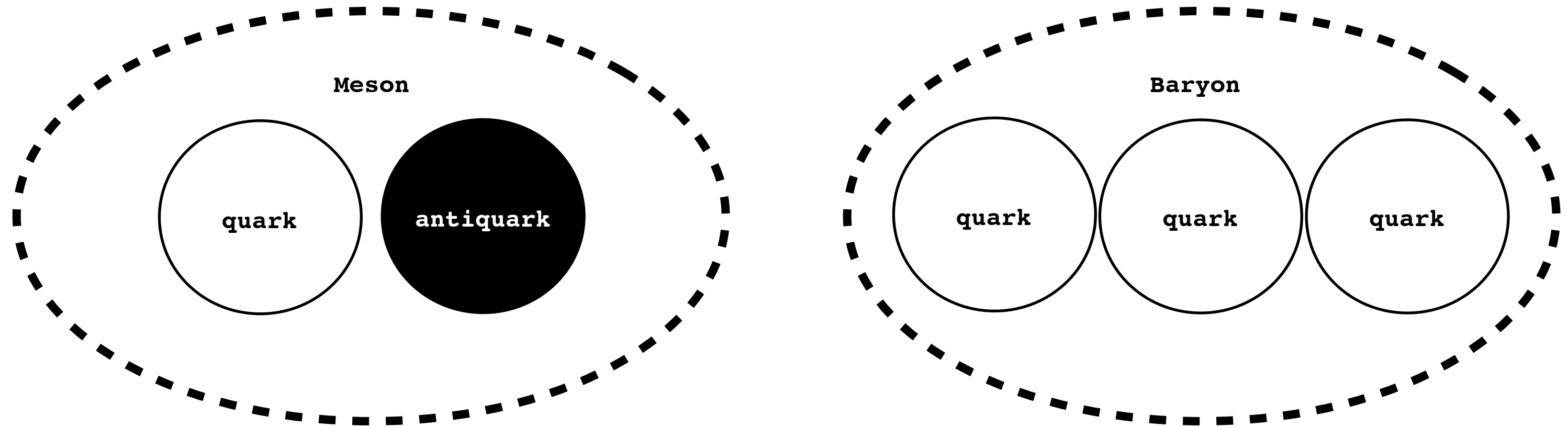


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We have the Particle Listings!

What do quarks form?



Two different kinds of combinations : quark-antiquark, or three (anti)quarks.
Antiparticles have opposite charges to the corresponding particles, but are otherwise supposed to interact in the same way. Most particles have a corresponding antiparticle (but sometimes a particle is its own antiparticle).

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
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A huge range of different lifetimes : you will be measuring a pretty short one...

How do we measure a short lifetime?

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

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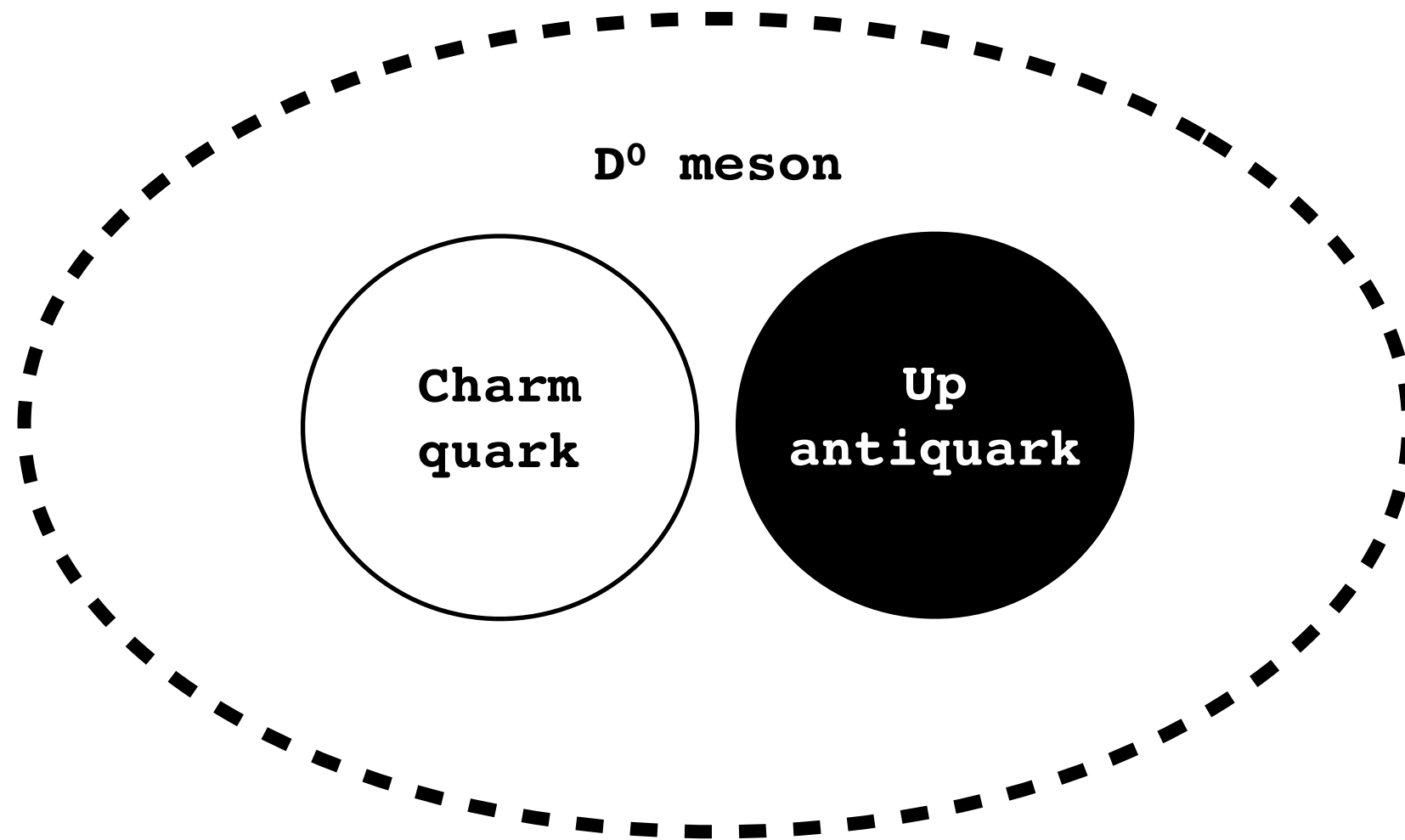
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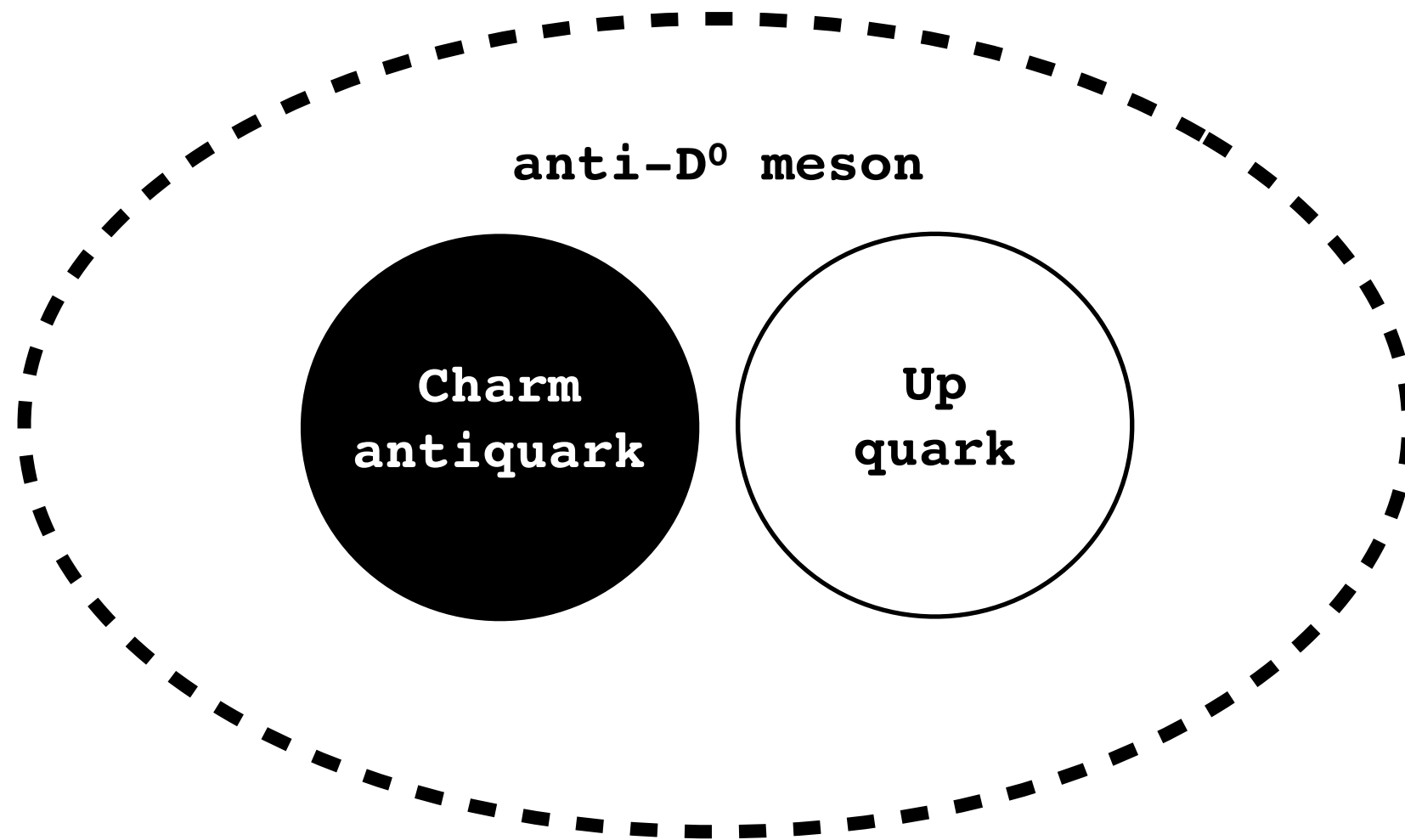
$$t' = t / \sqrt{1 - v^2/c^2}$$

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

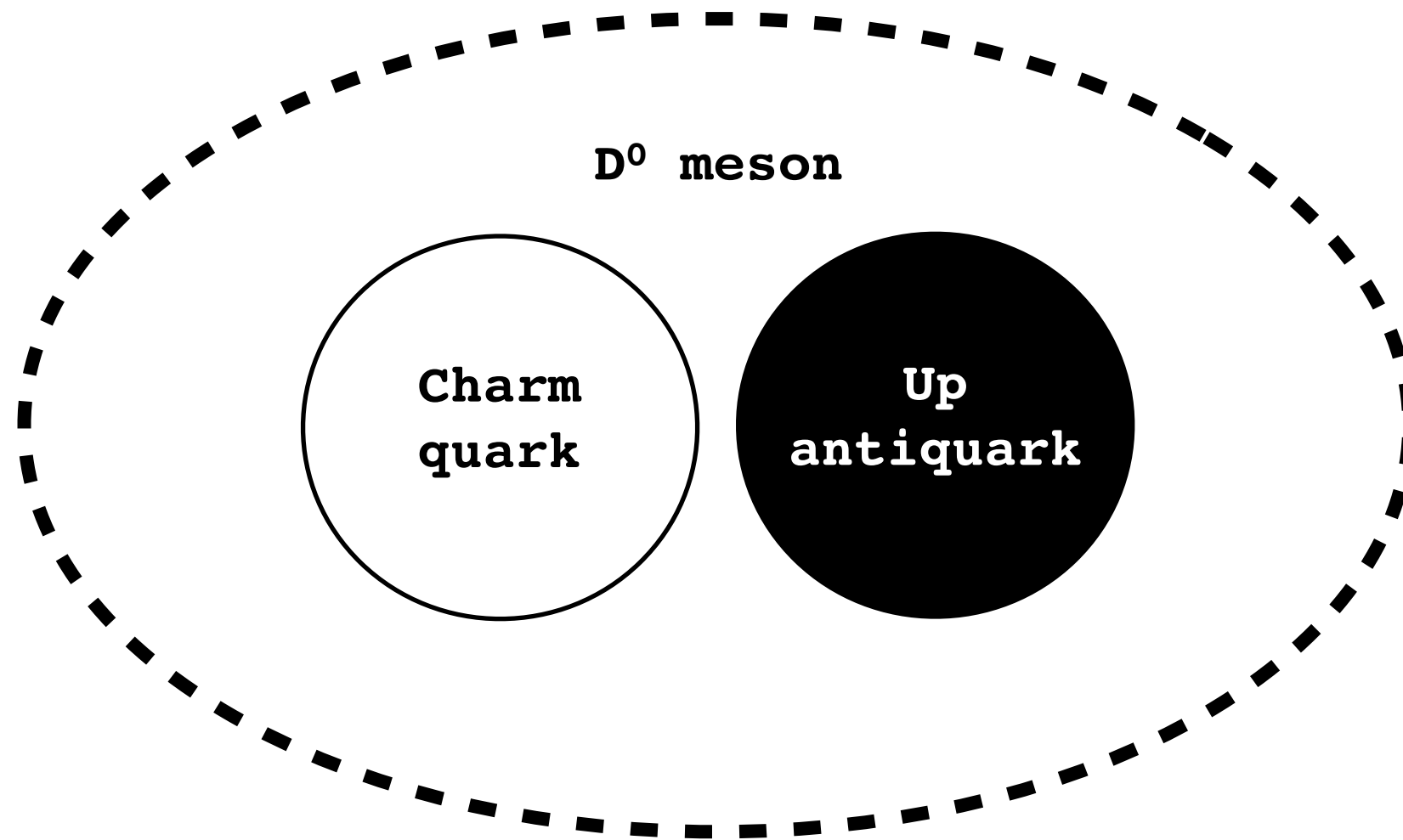
So why is the D^0 special?



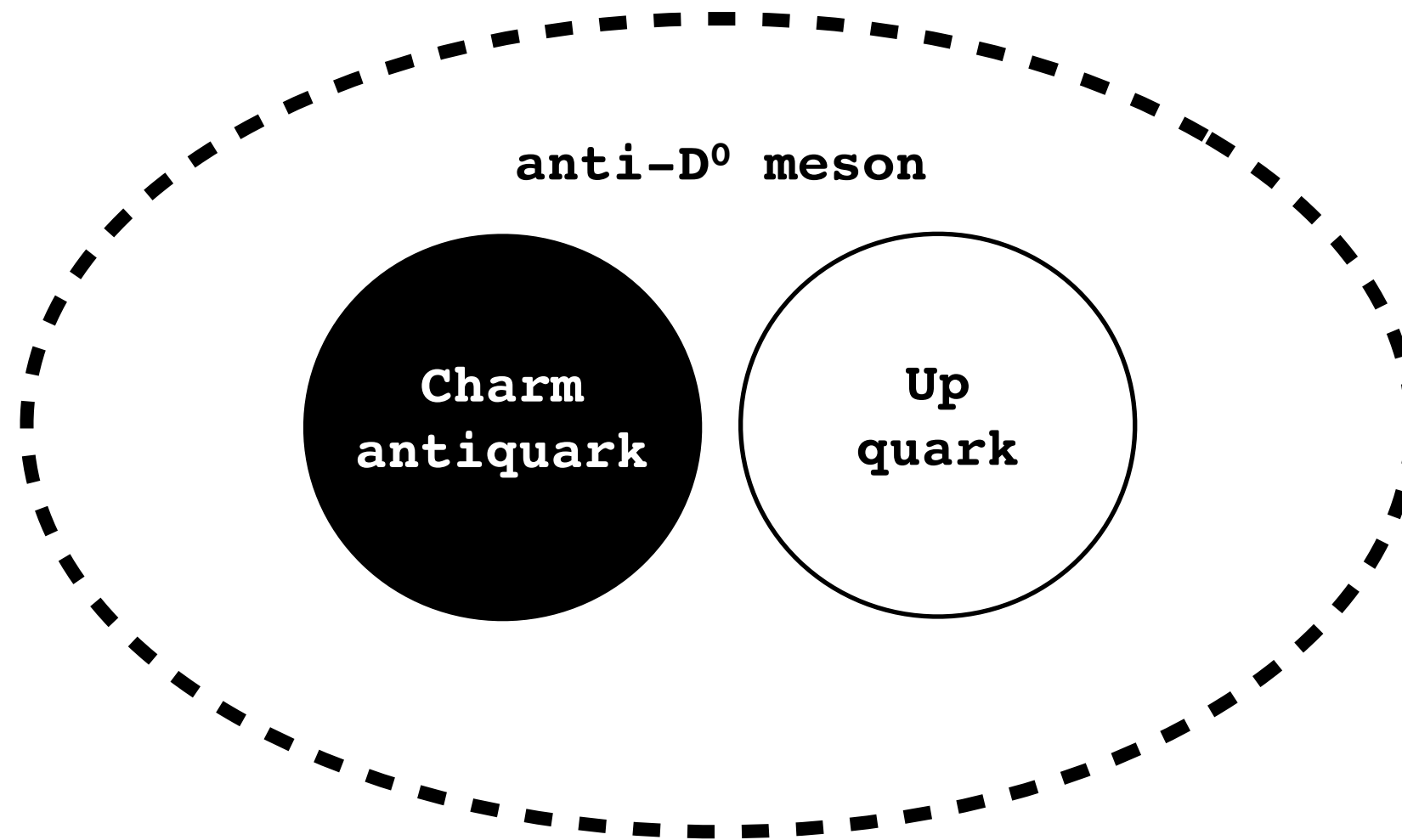
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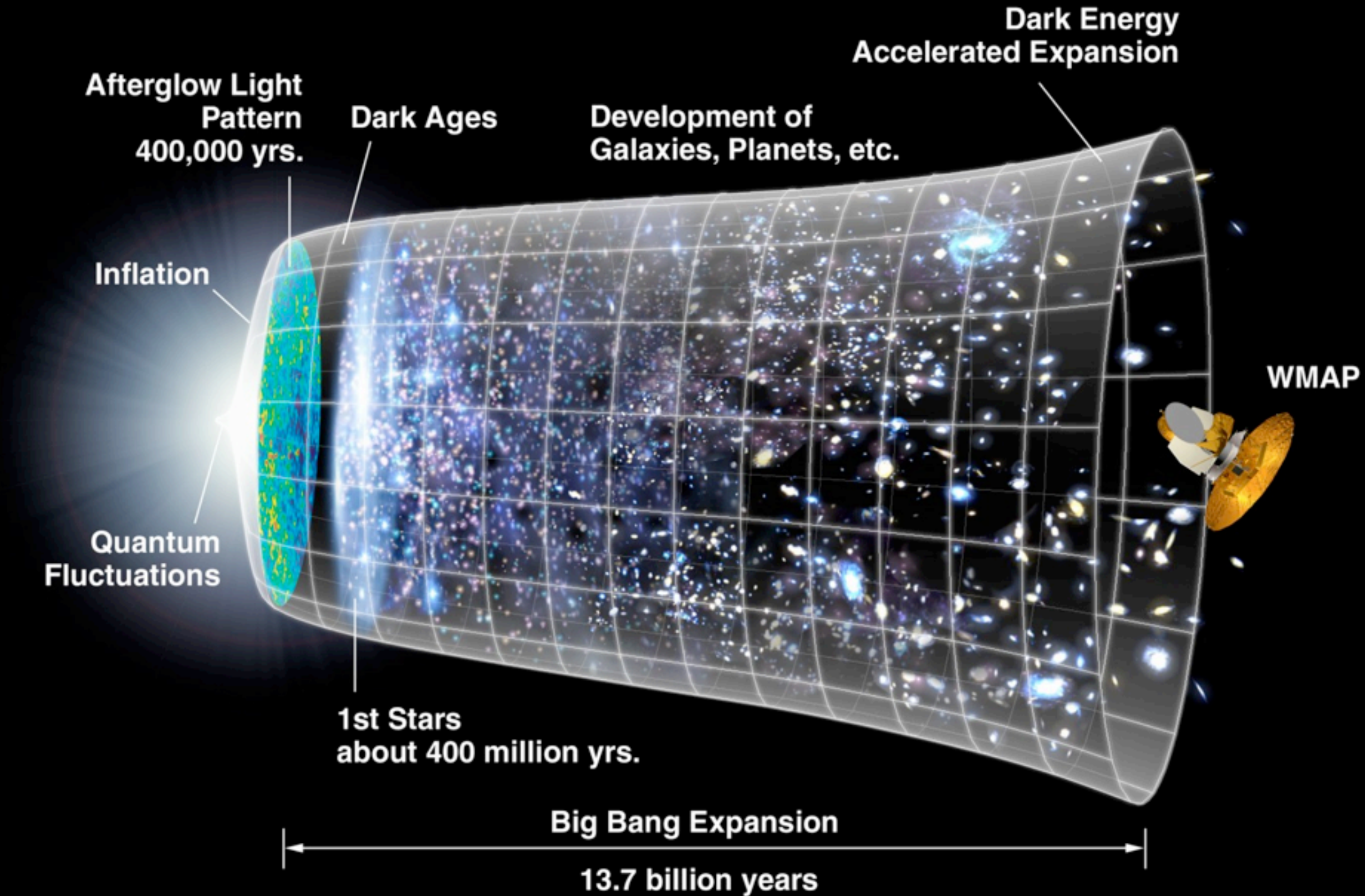


It oscillates!

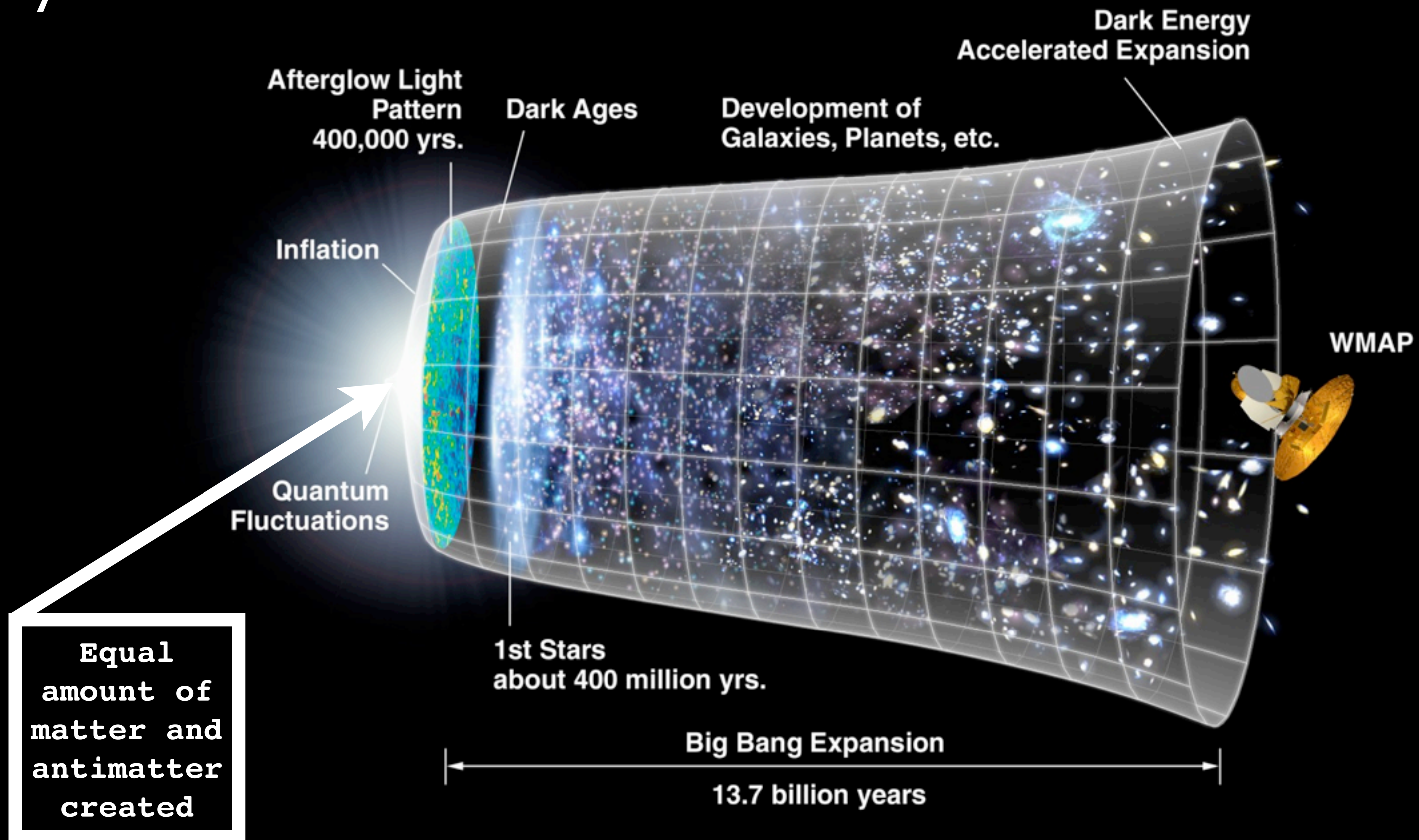


The D⁰ is a neutral particle : it can oscillate between matter and antimatter before decaying!

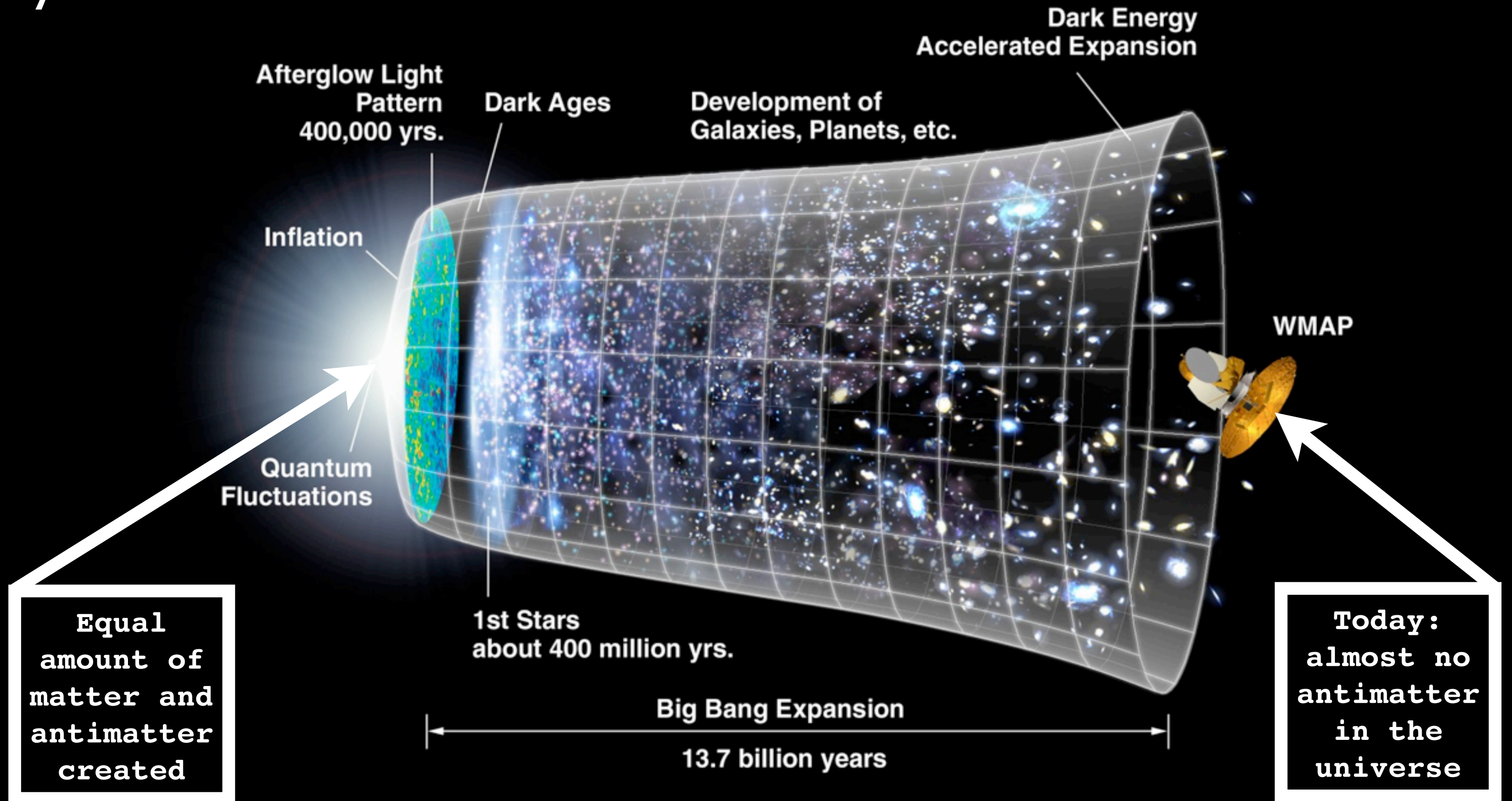
Why does antimatter matter?



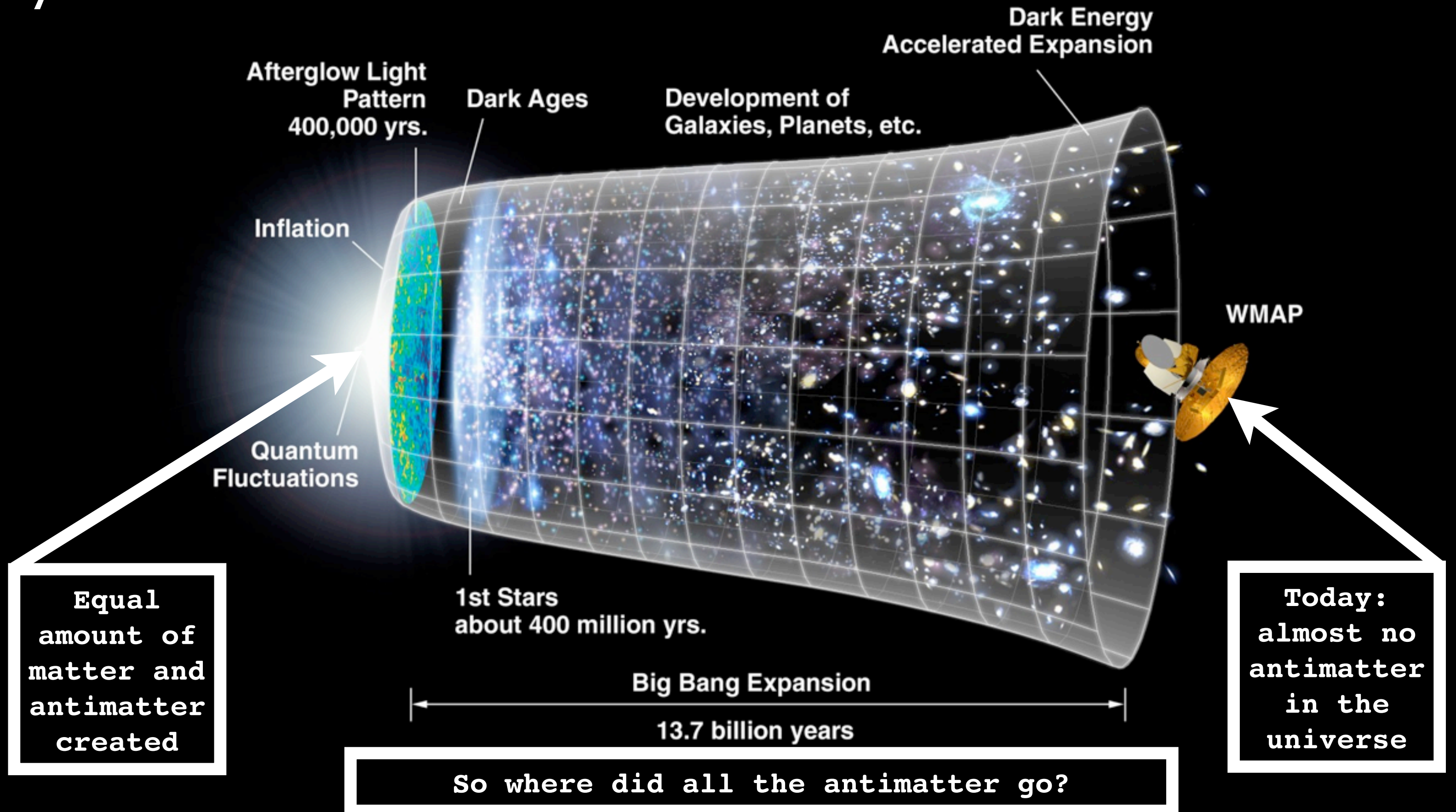
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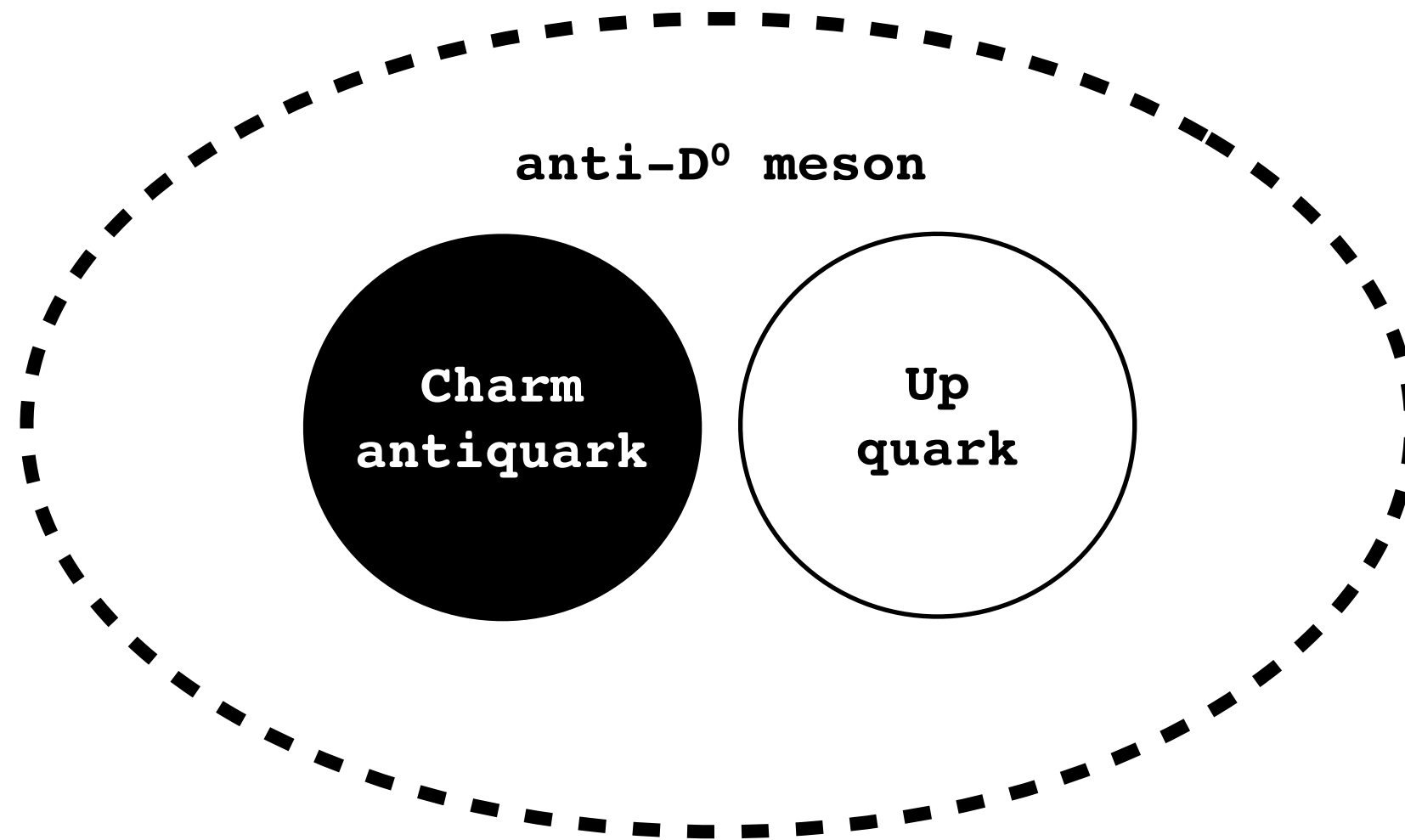
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Such particles can give us insight into small differences between matter and antimatter.

Why the D^0 and not another particle?

Three Generations of Matter (Fermions)

	I	II	III	
mass	2.4 MeV/c ²	1.27 GeV/c ²	171.2 GeV/c ²	0
charge	$\frac{2}{3}$	$\frac{2}{3}$	$\frac{2}{3}$	0
spin	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1
name	u up	c charm	t top	γ photon
	4.8 MeV/c ²	104 MeV/c ²	4.2 GeV/c ²	0
	$-\frac{1}{3}$	$-\frac{1}{3}$	$-\frac{1}{3}$	0
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Quarks	d down	s strange	b bottom	g gluon
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	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	Z⁰ Z boson
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Gauge Bosons

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

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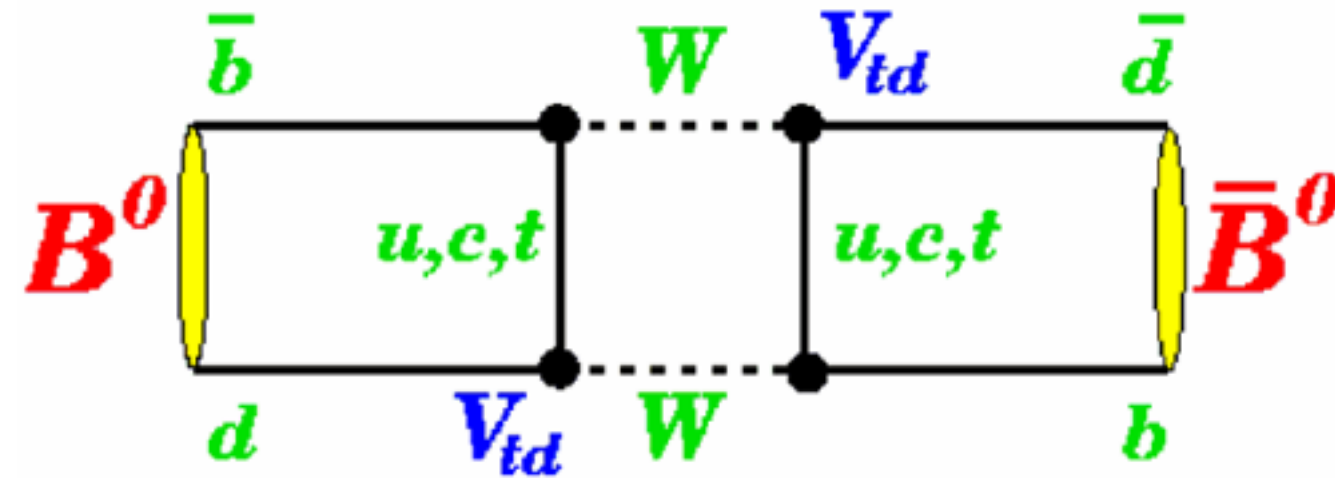
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Classic example is the B_d meson : measurement of B_d oscillations was an early indication of the top quark mass



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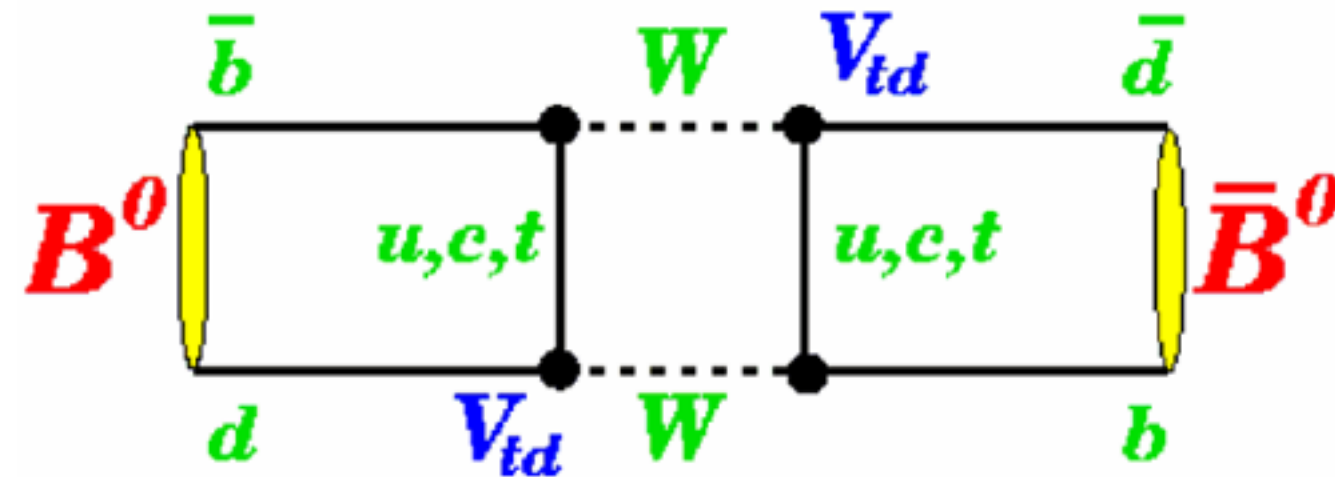
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Oscillations are interesting because they are sensitive to new particles appearing virtually inside the box diagram, which can be very much heavier than directly produced particles

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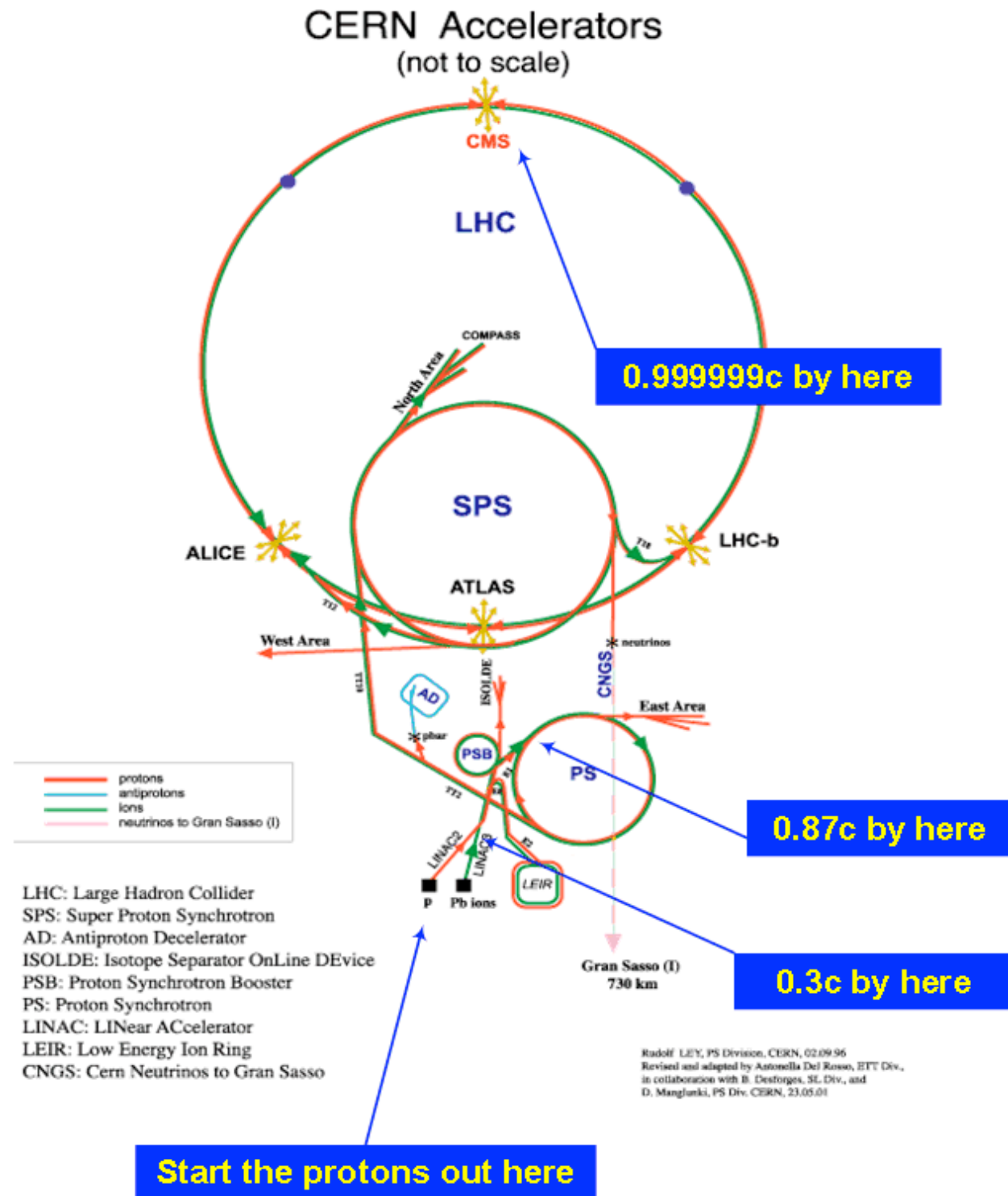
There are several different “down-type” mesons which oscillate : (ds) K^0 , (db) B_d , (sb) B_s

But only one up-type : the (cu) D^0 meson

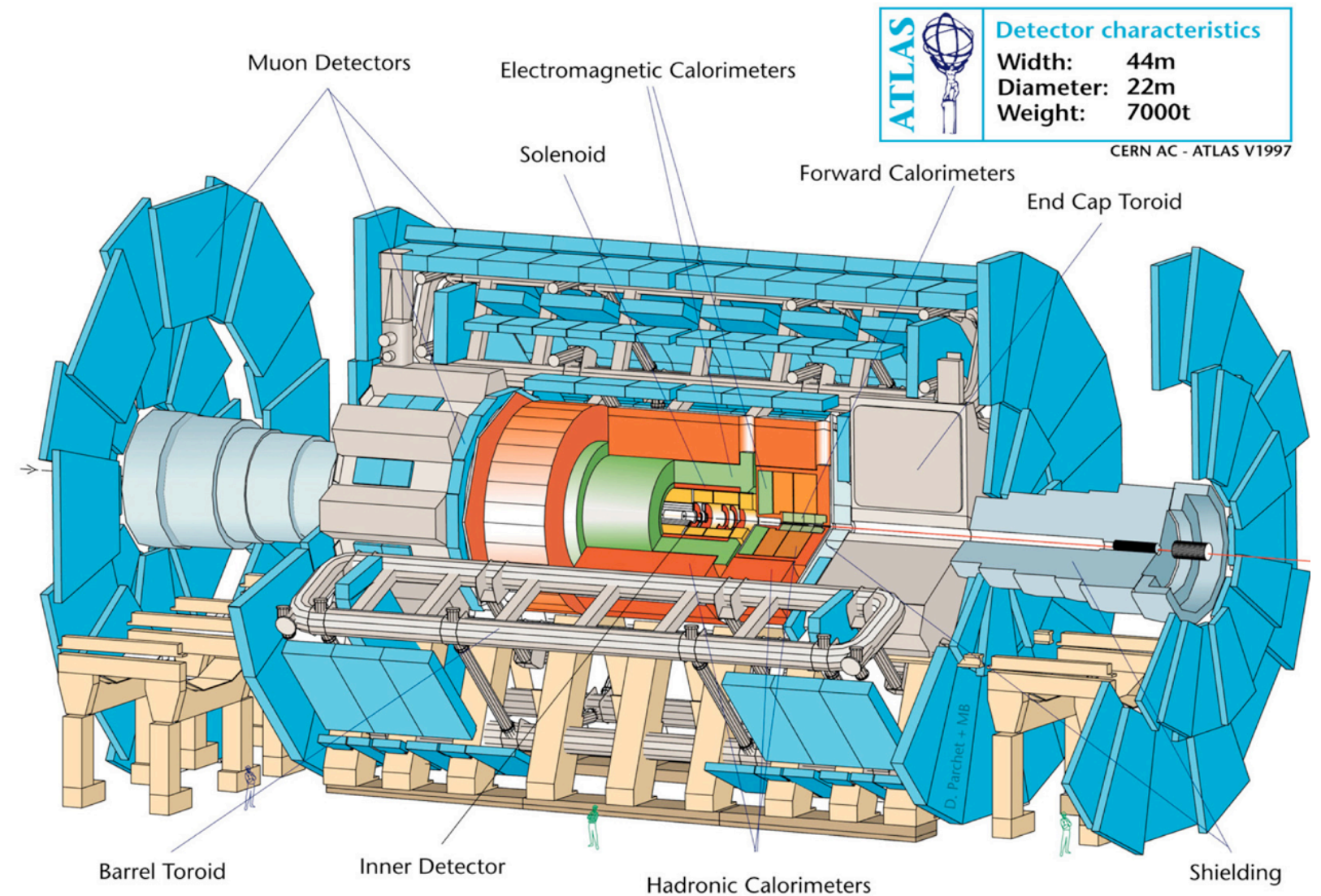
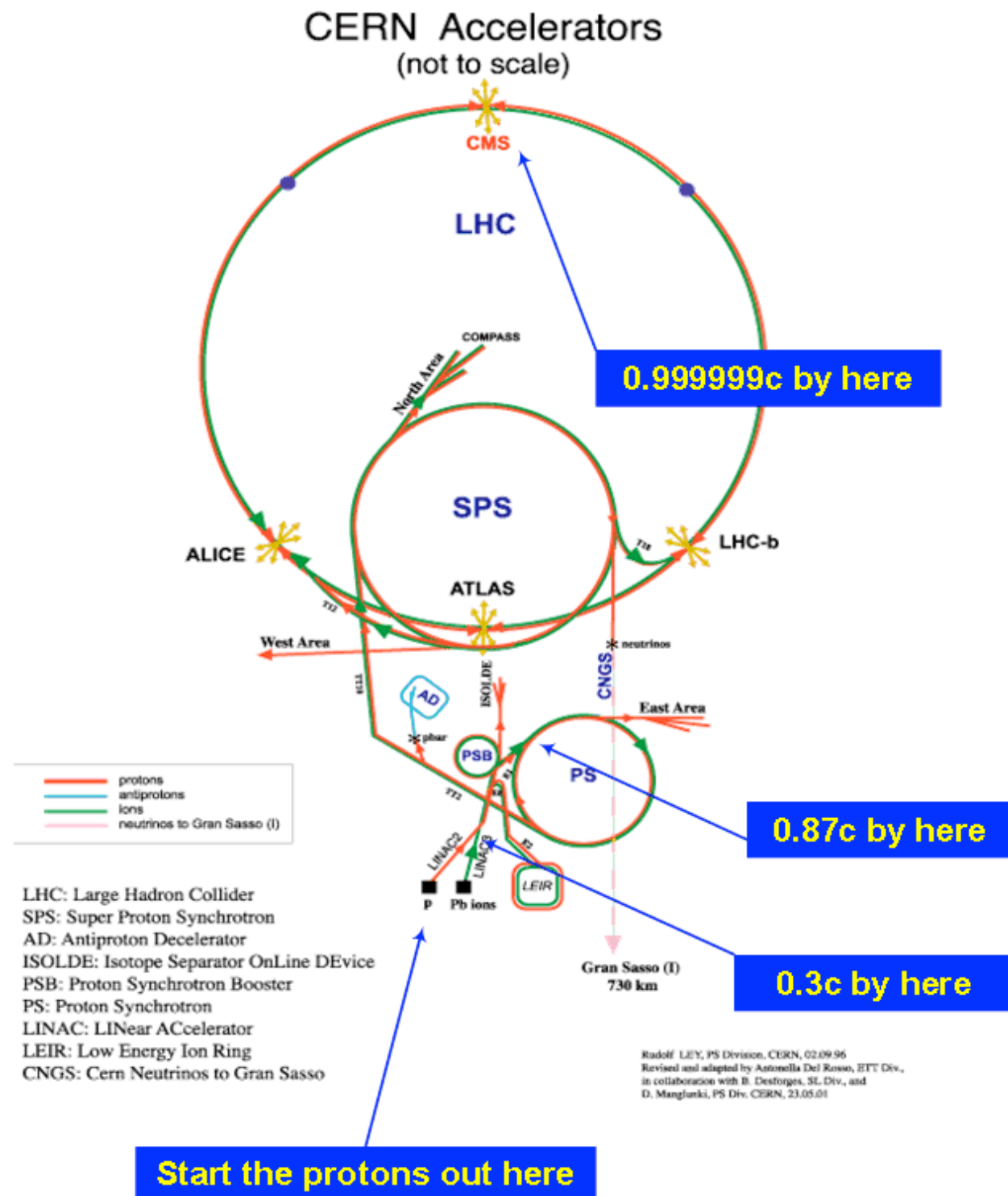
The top quark does not form mesons or baryons

This makes the D^0 a unique laboratory for studying matter-antimatter symmetry in the up-type quark sector

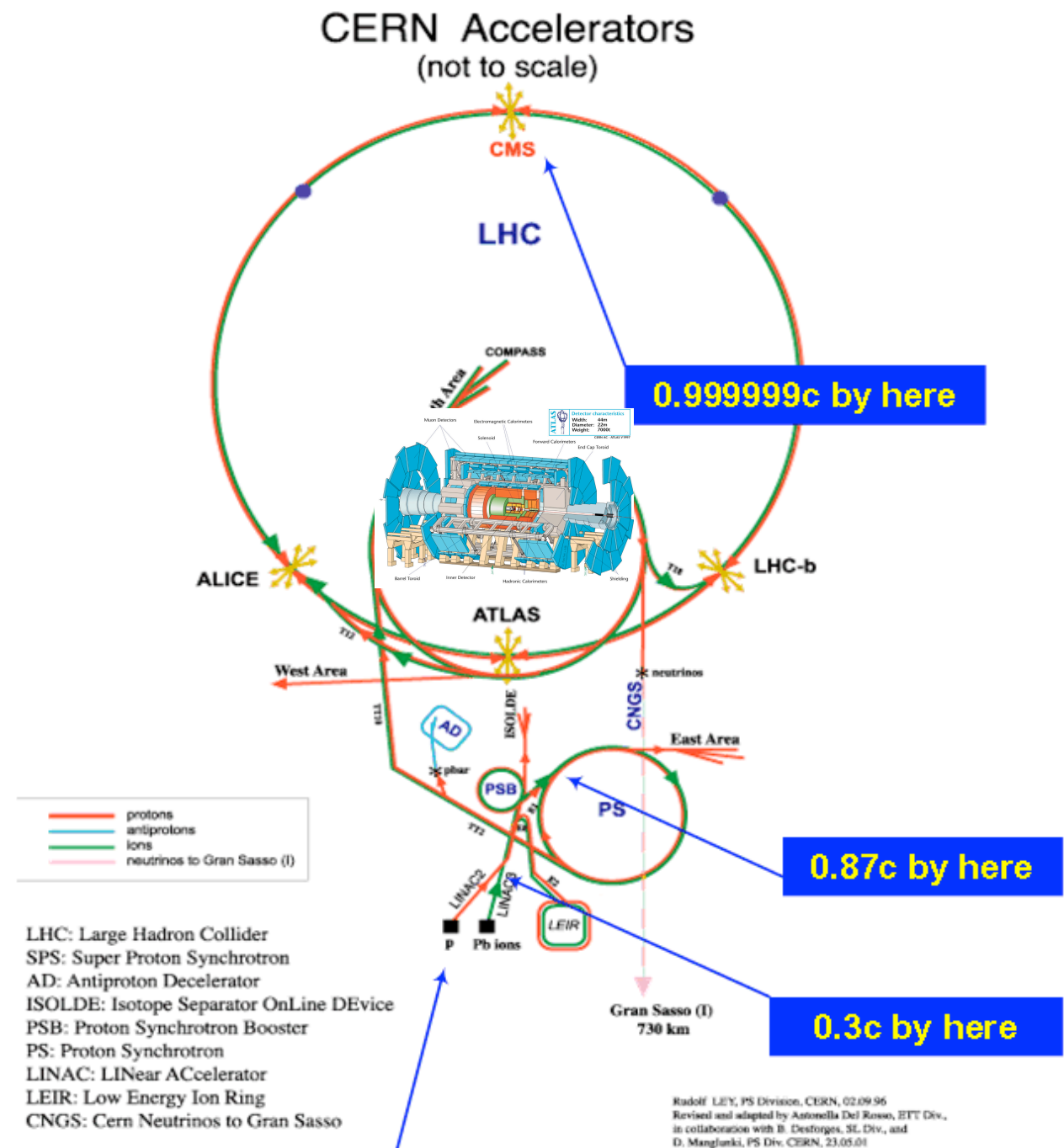
Large hadron collider @ CERN



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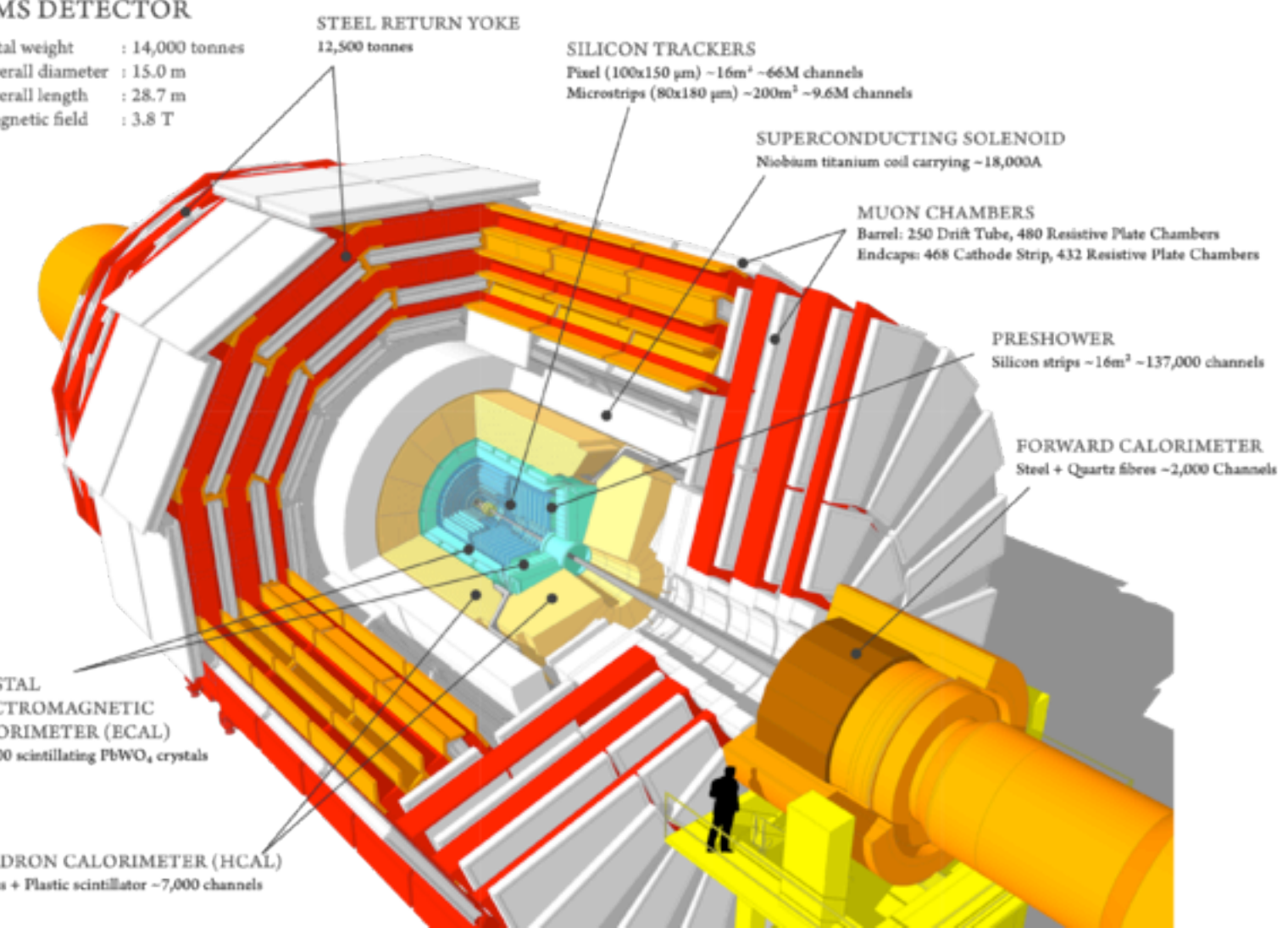


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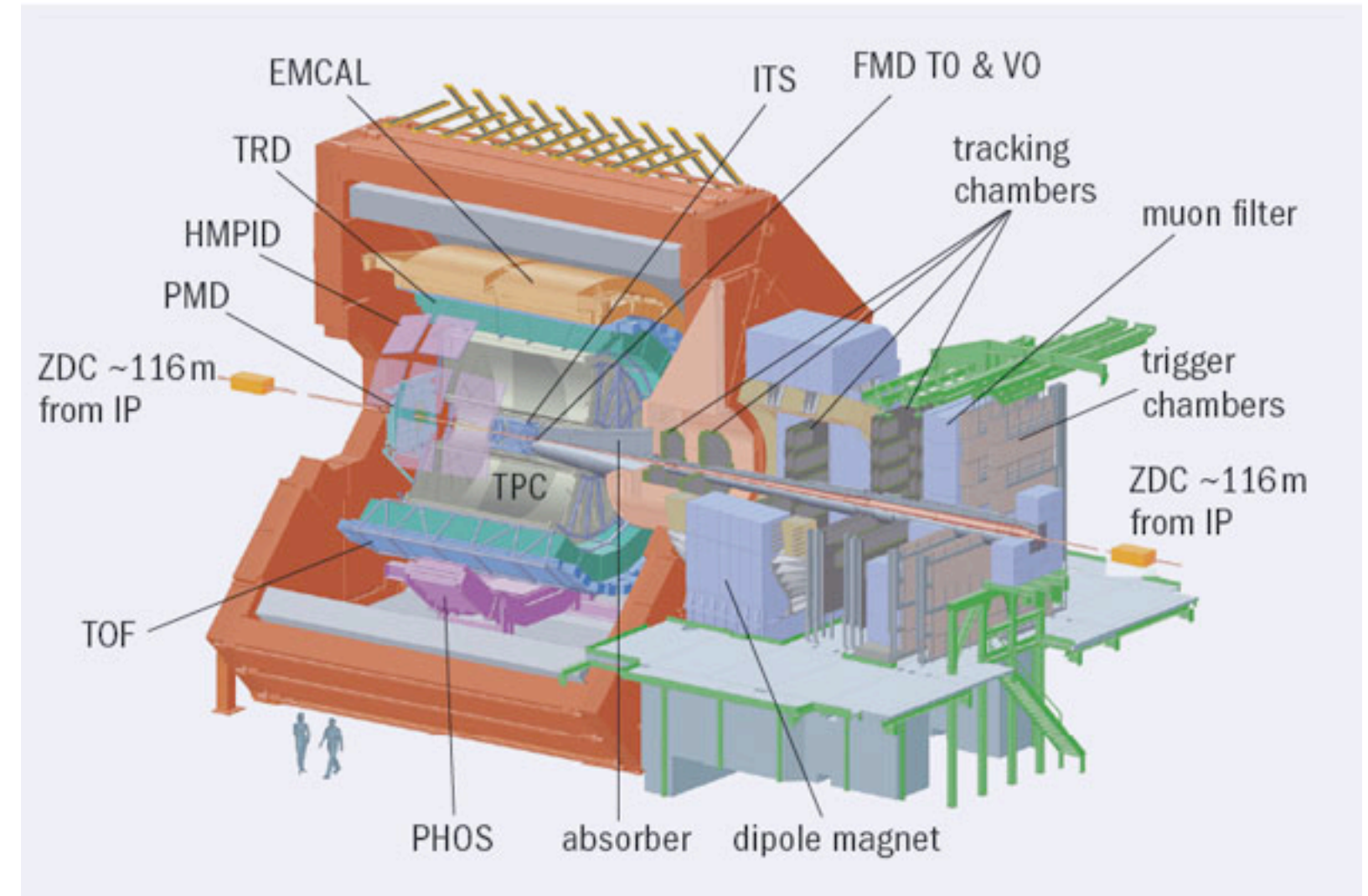
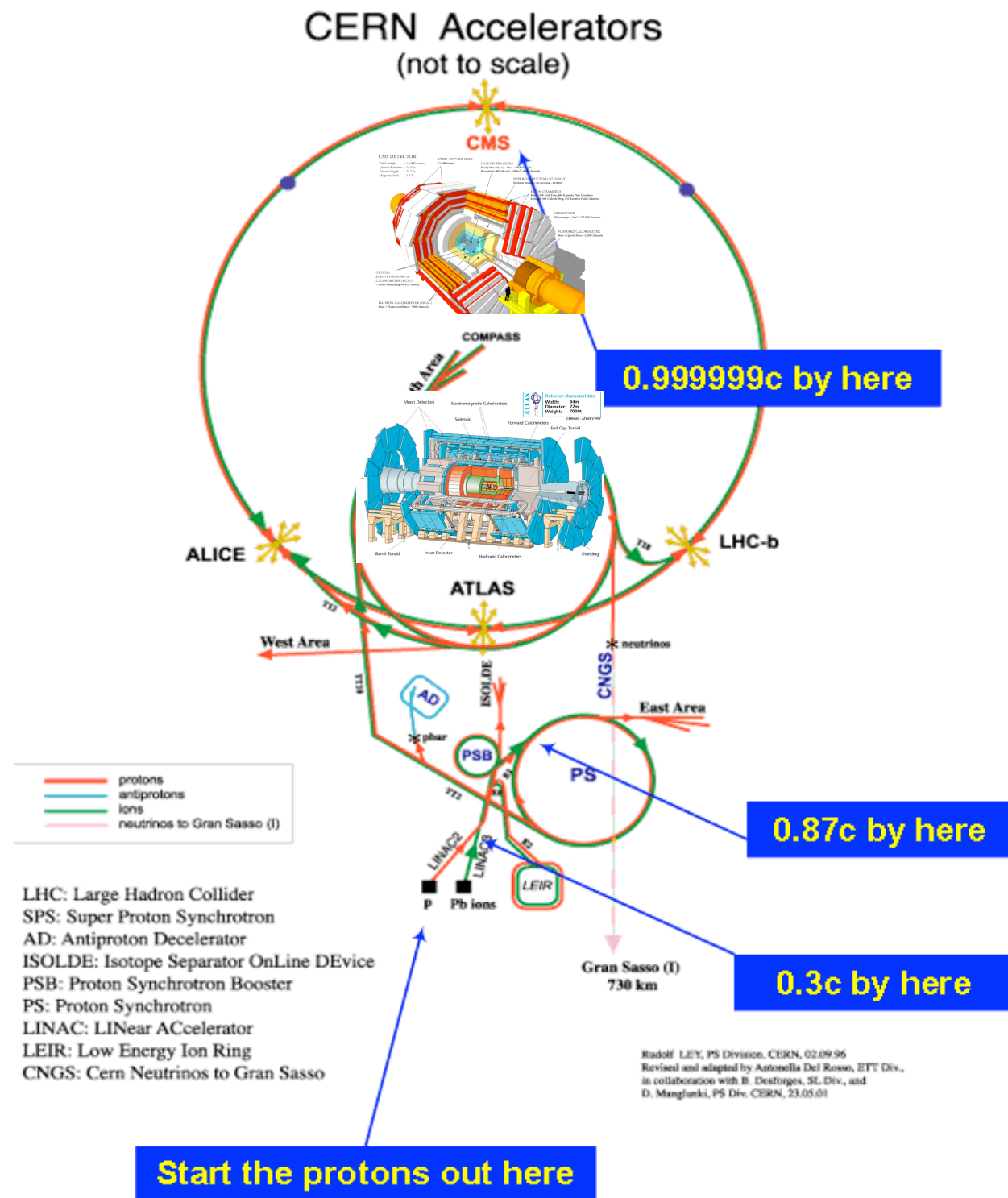


CMS DETECTOR

Total weight : 14,000 tonnes
 Overall diameter : 15.0 m
 Overall length : 28.7 m
 Magnetic field : 3.8 T

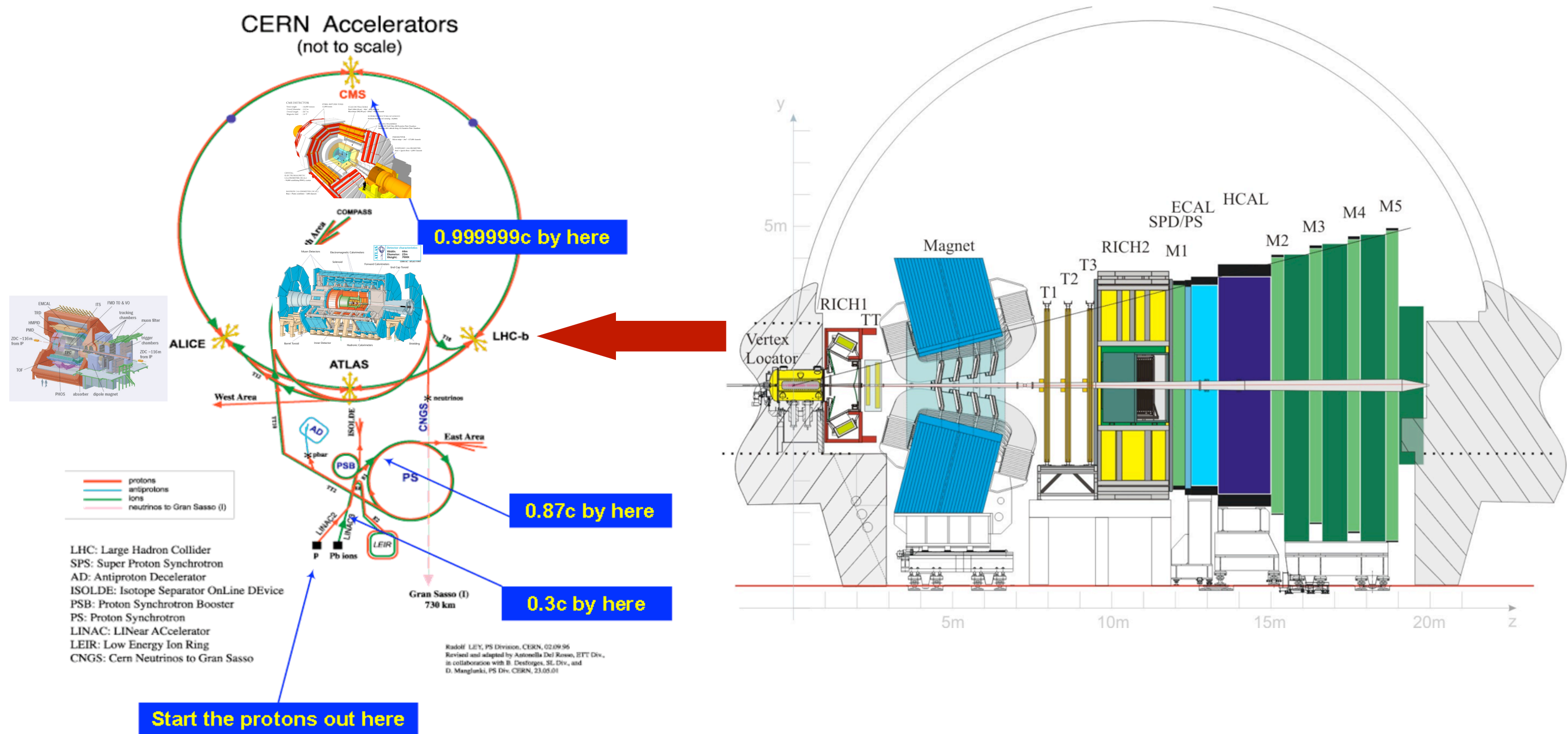


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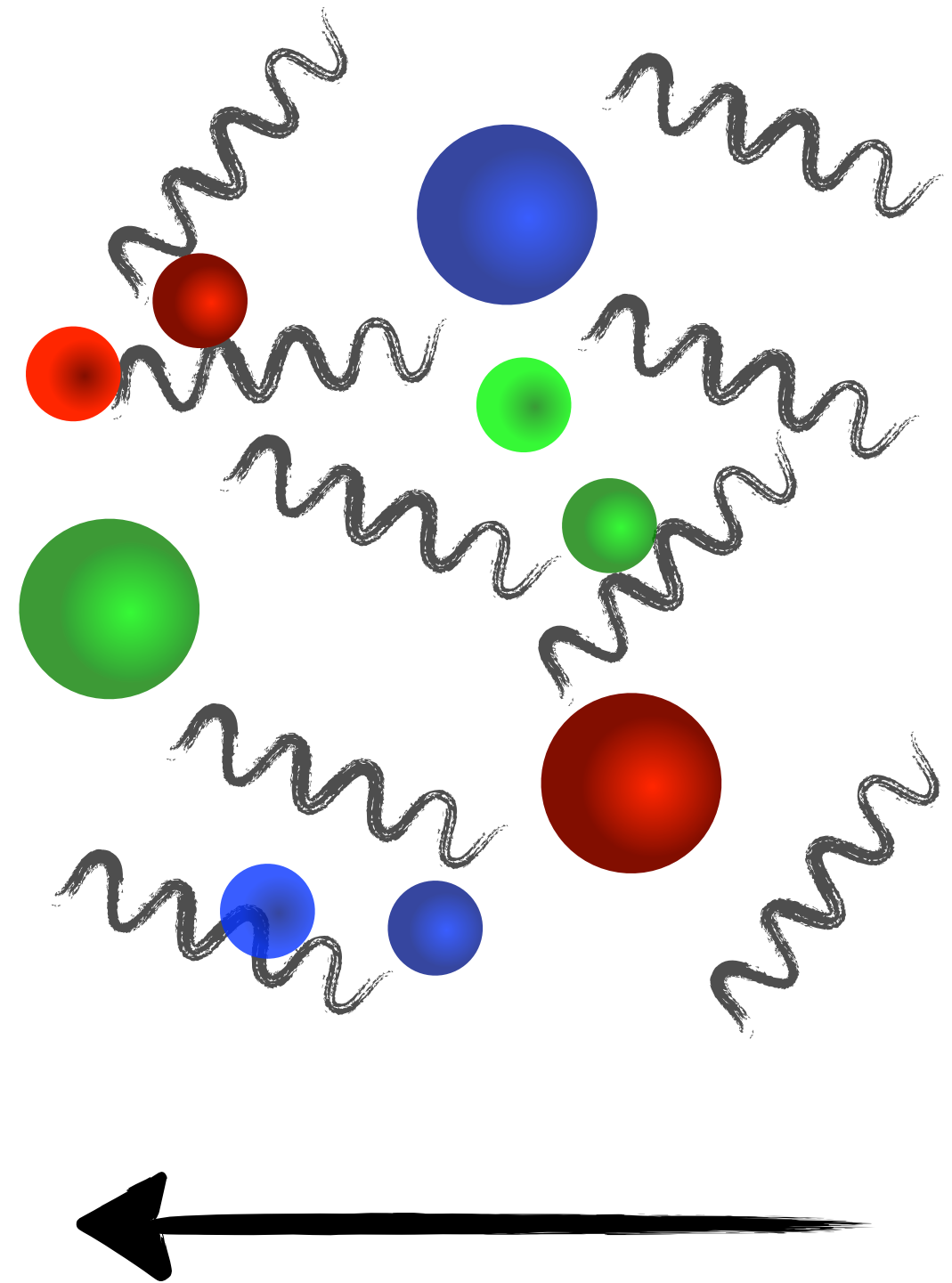
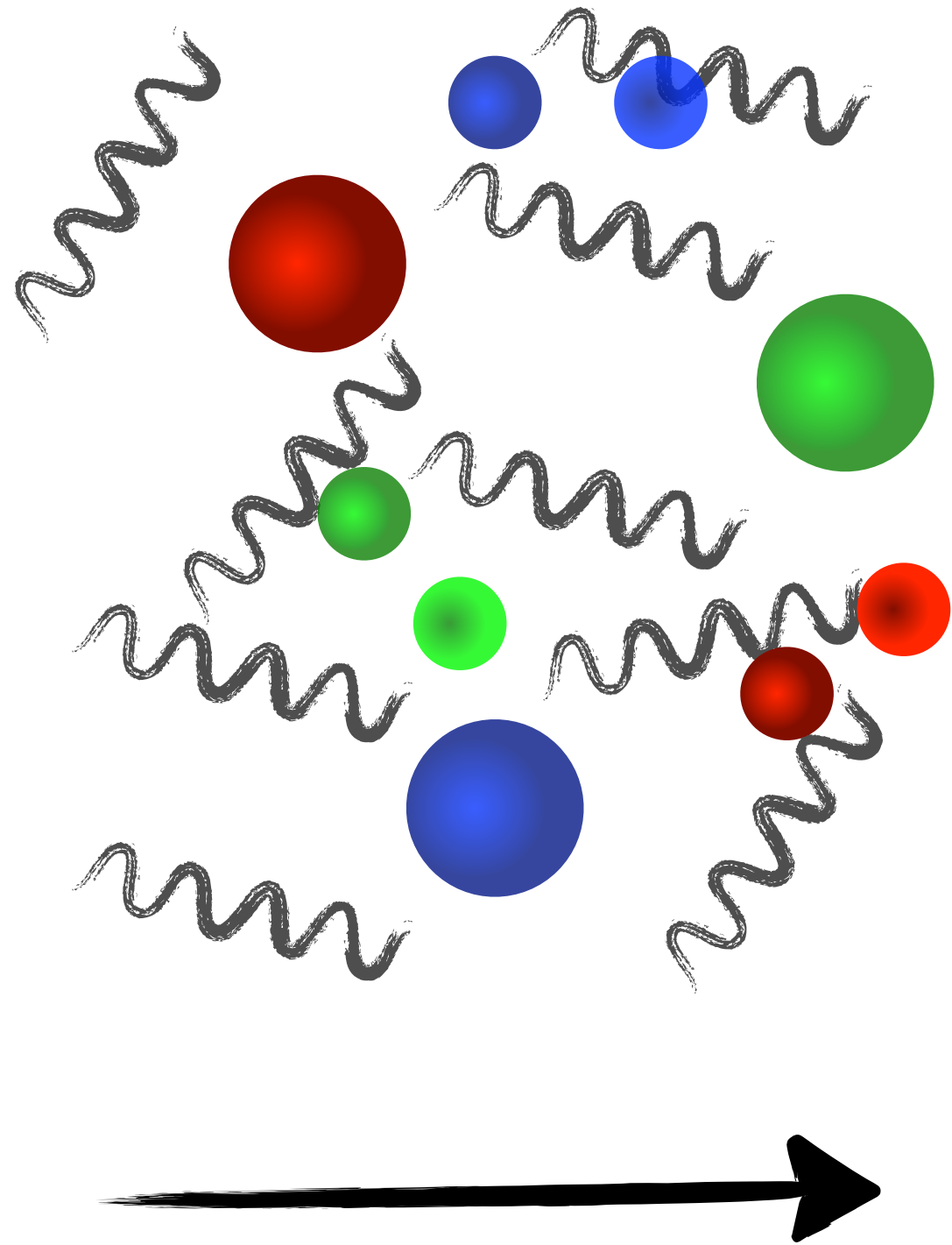


Radolf LEY, PS Division, CERN, 02.09.96
Revised and adapted by Antonella Del Rosso, ETT Div.,
in collaboration with B. Desforges, SL Div., and
D. Manglunki, PS Div. CERN, 23.05.01

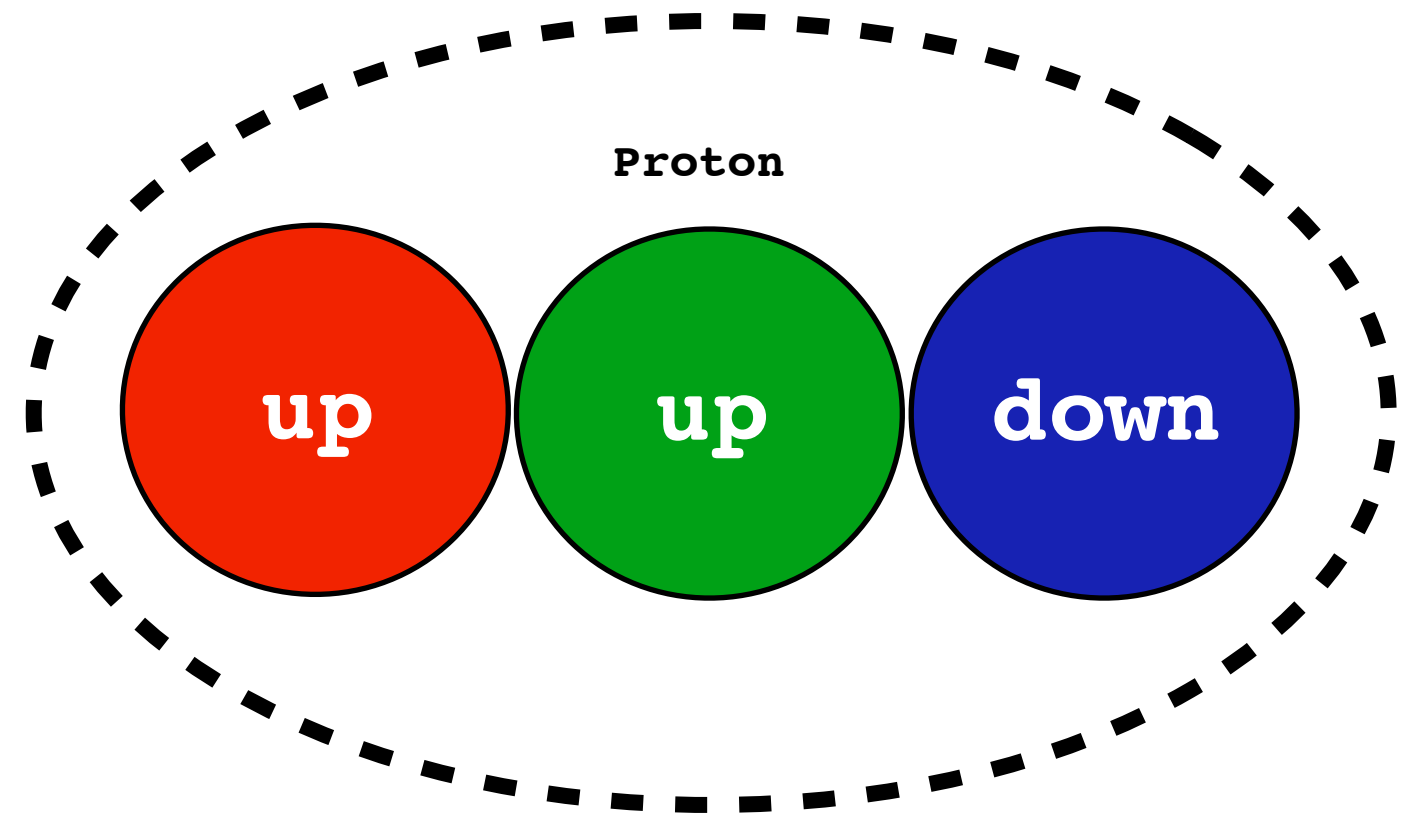
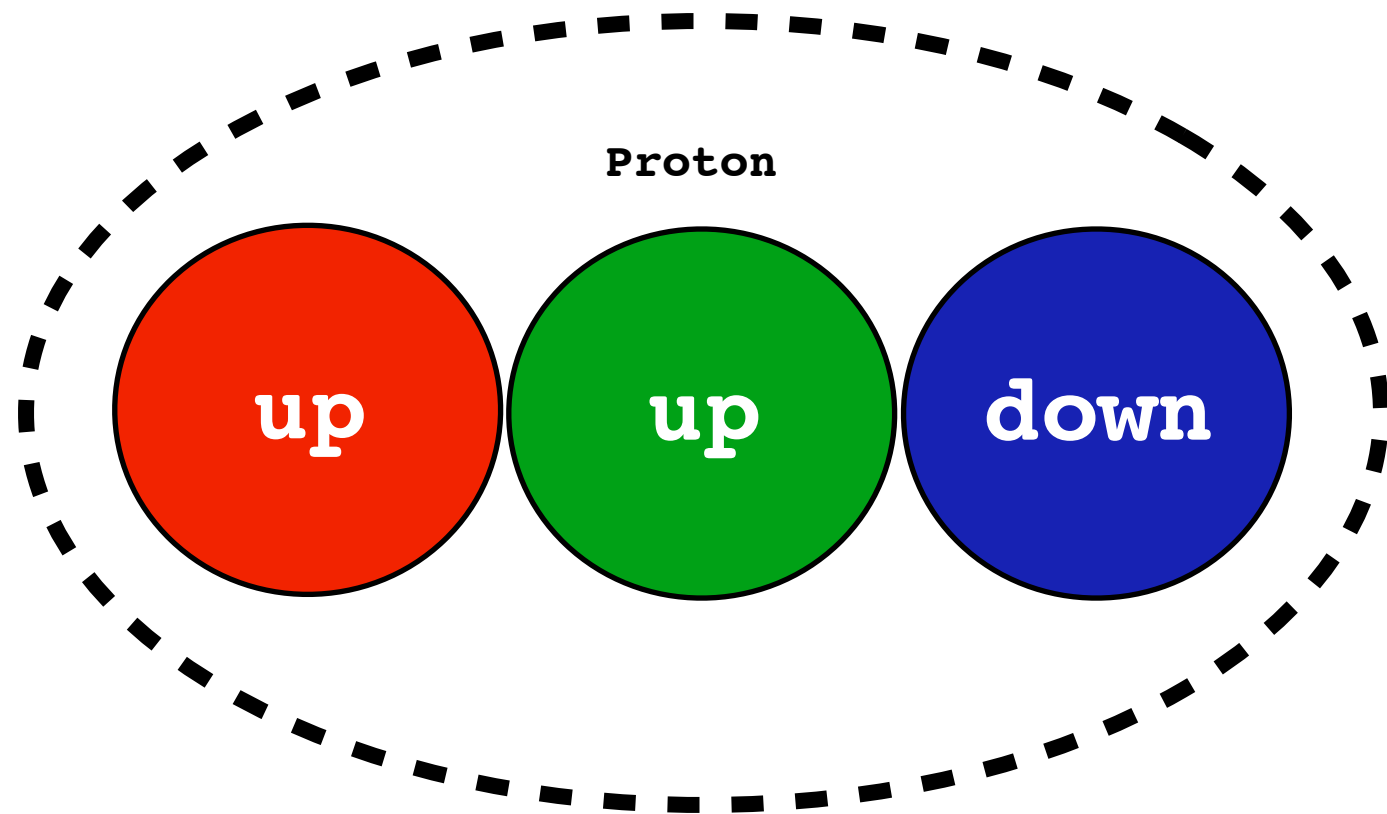
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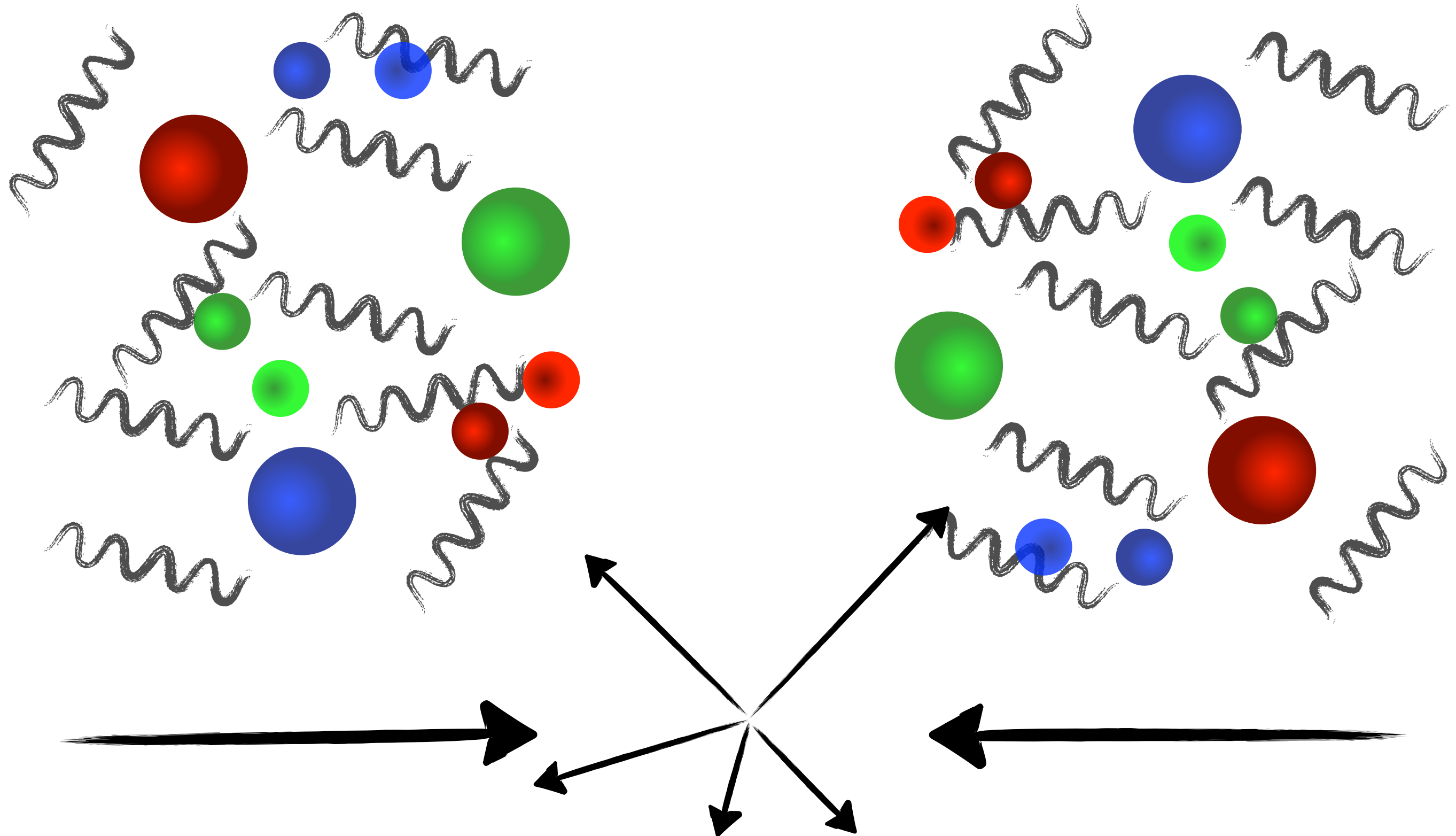
Protons colliding...



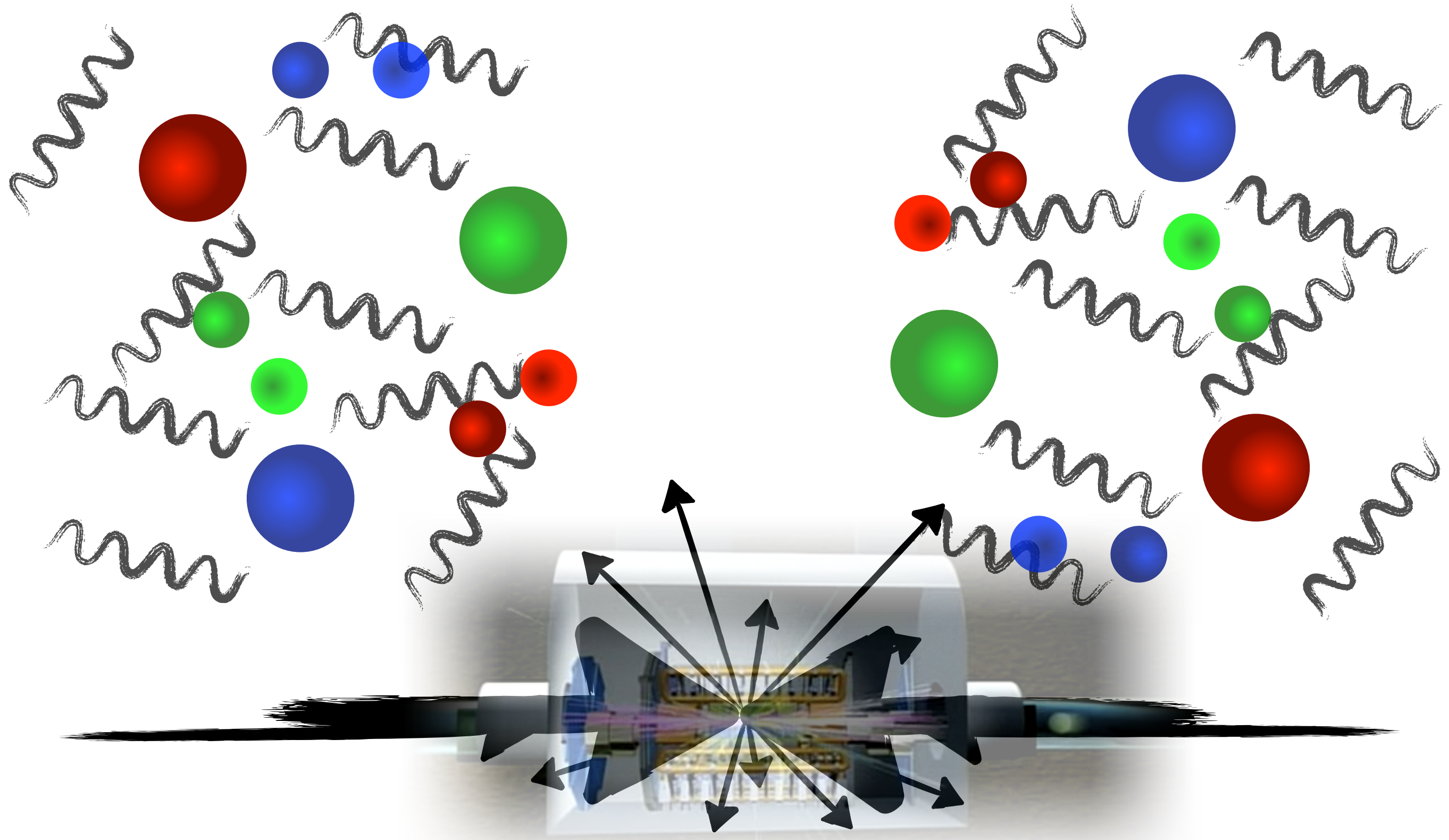
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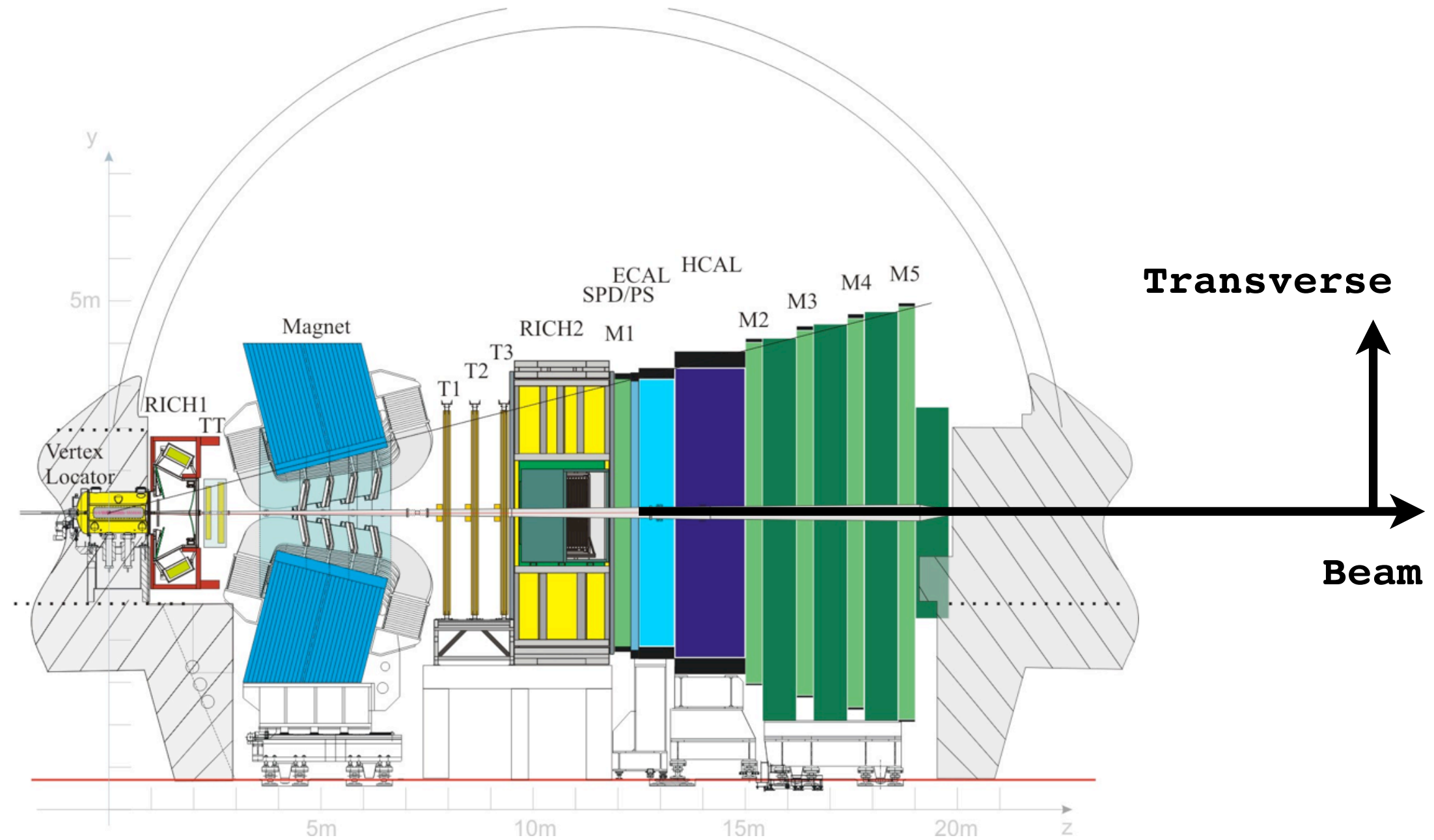
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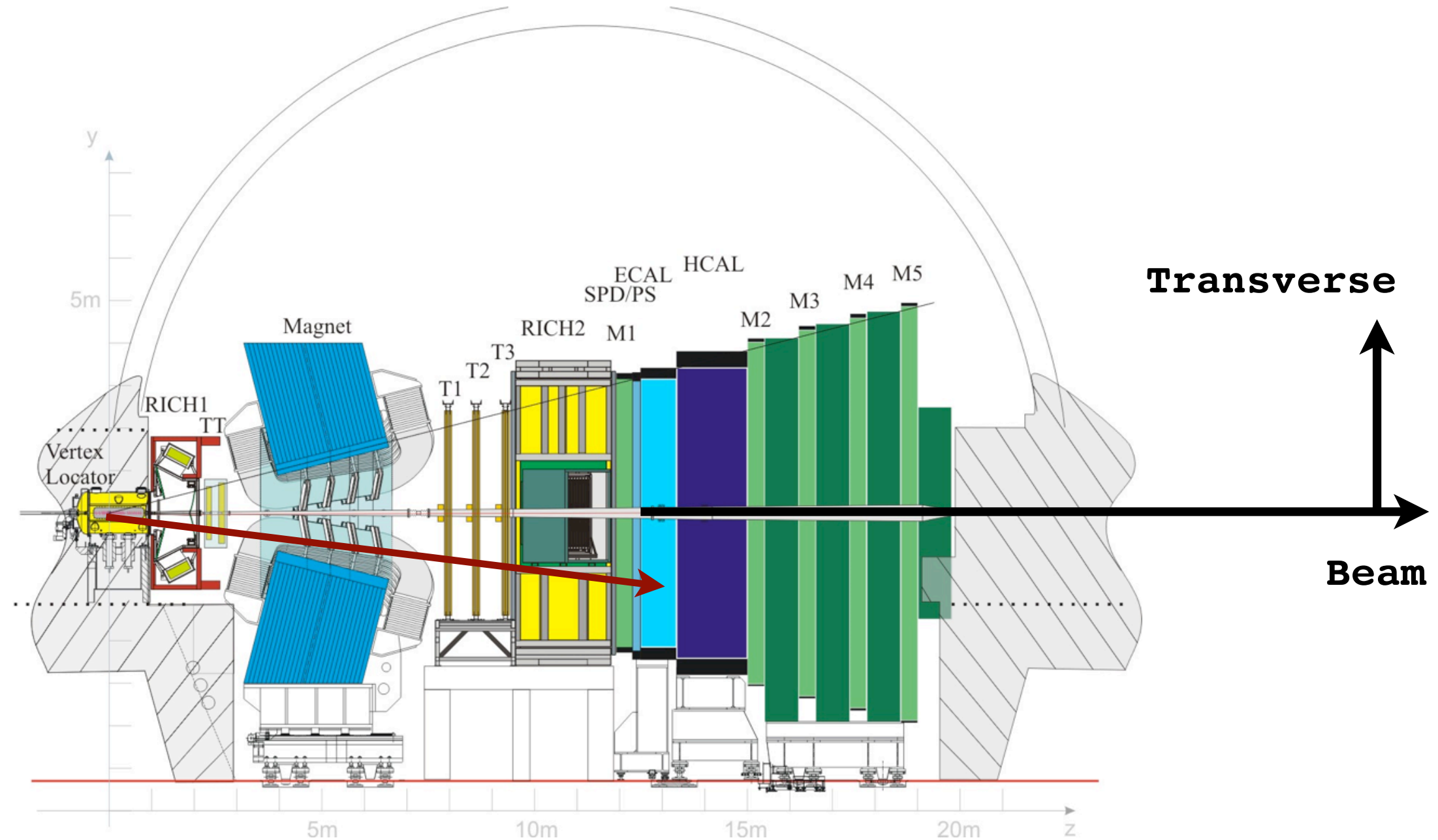
LHCb @ LHC



p_T = Transverse momentum
 E_T = Transverse energy

LHCb @ LHC

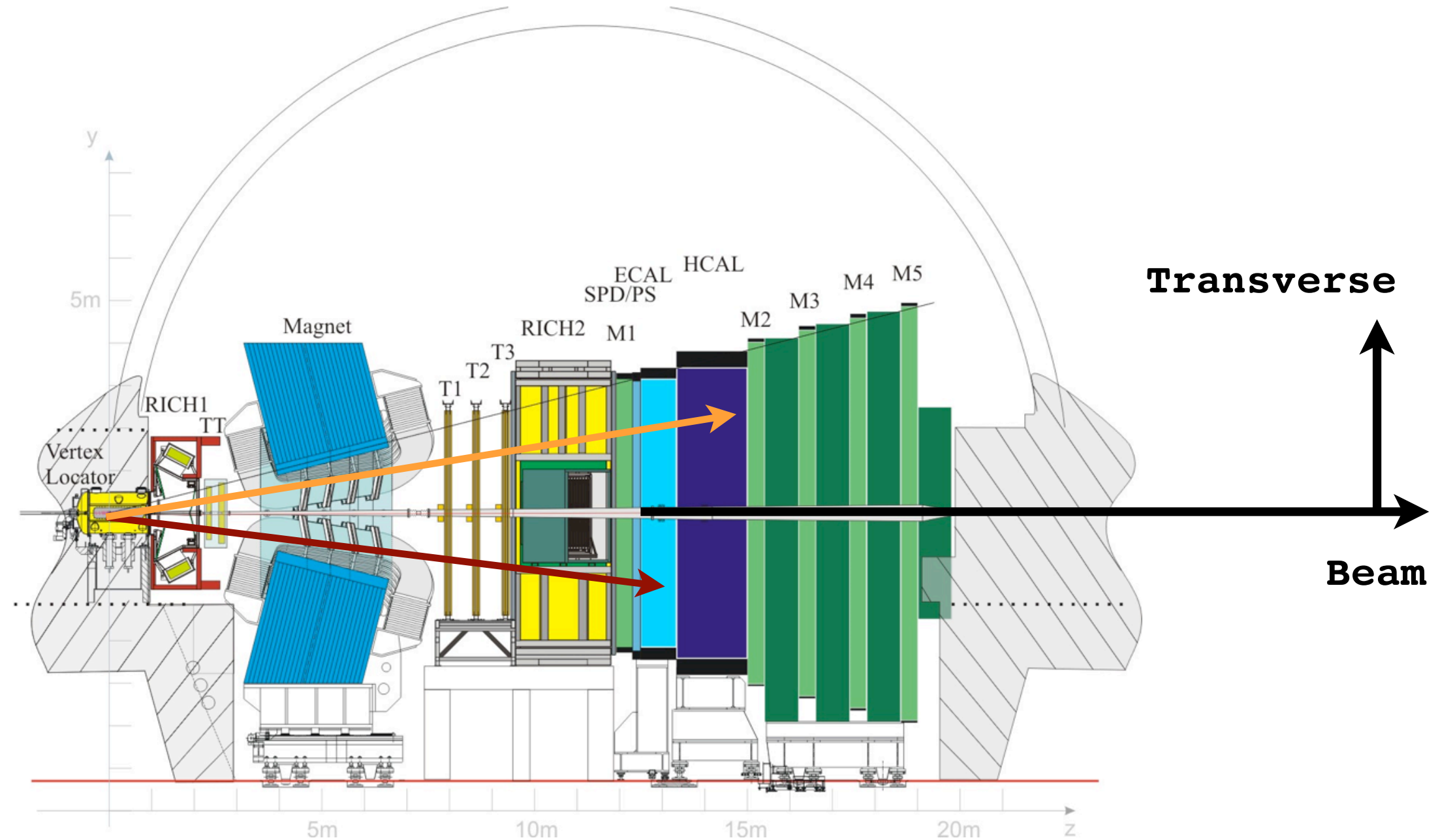
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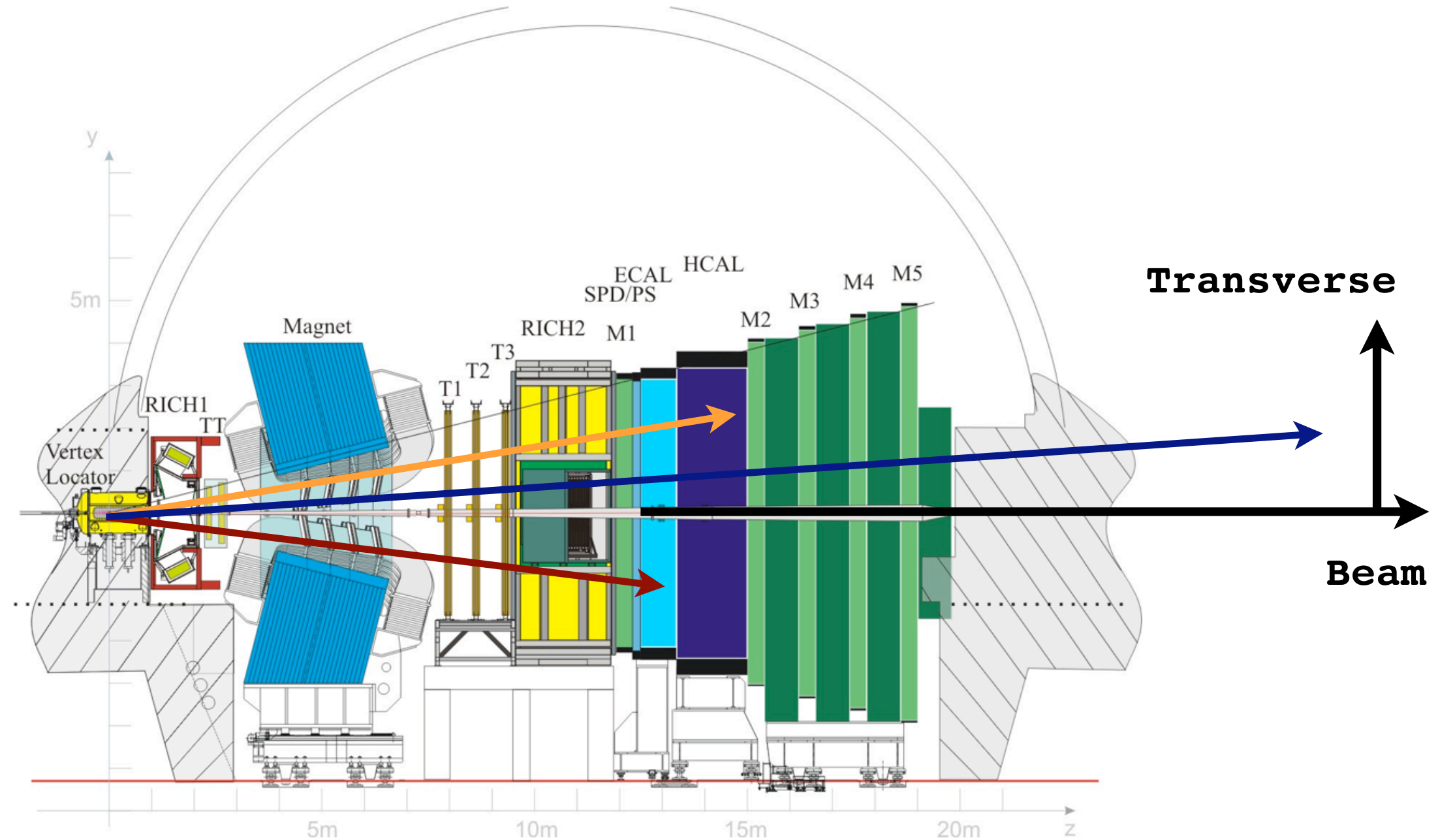
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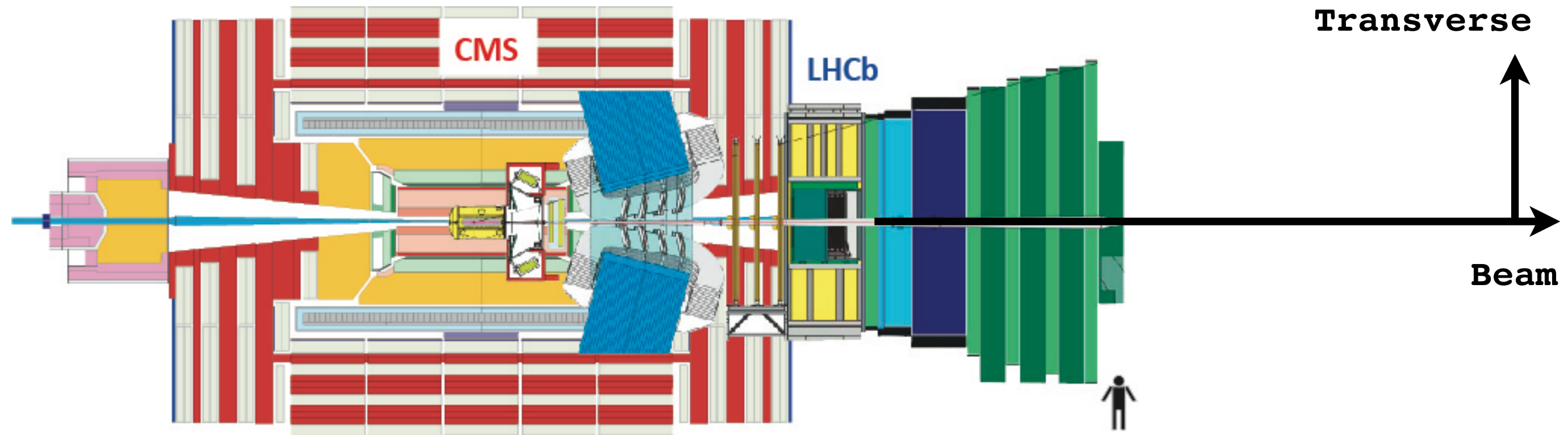
LHCb @ LHC

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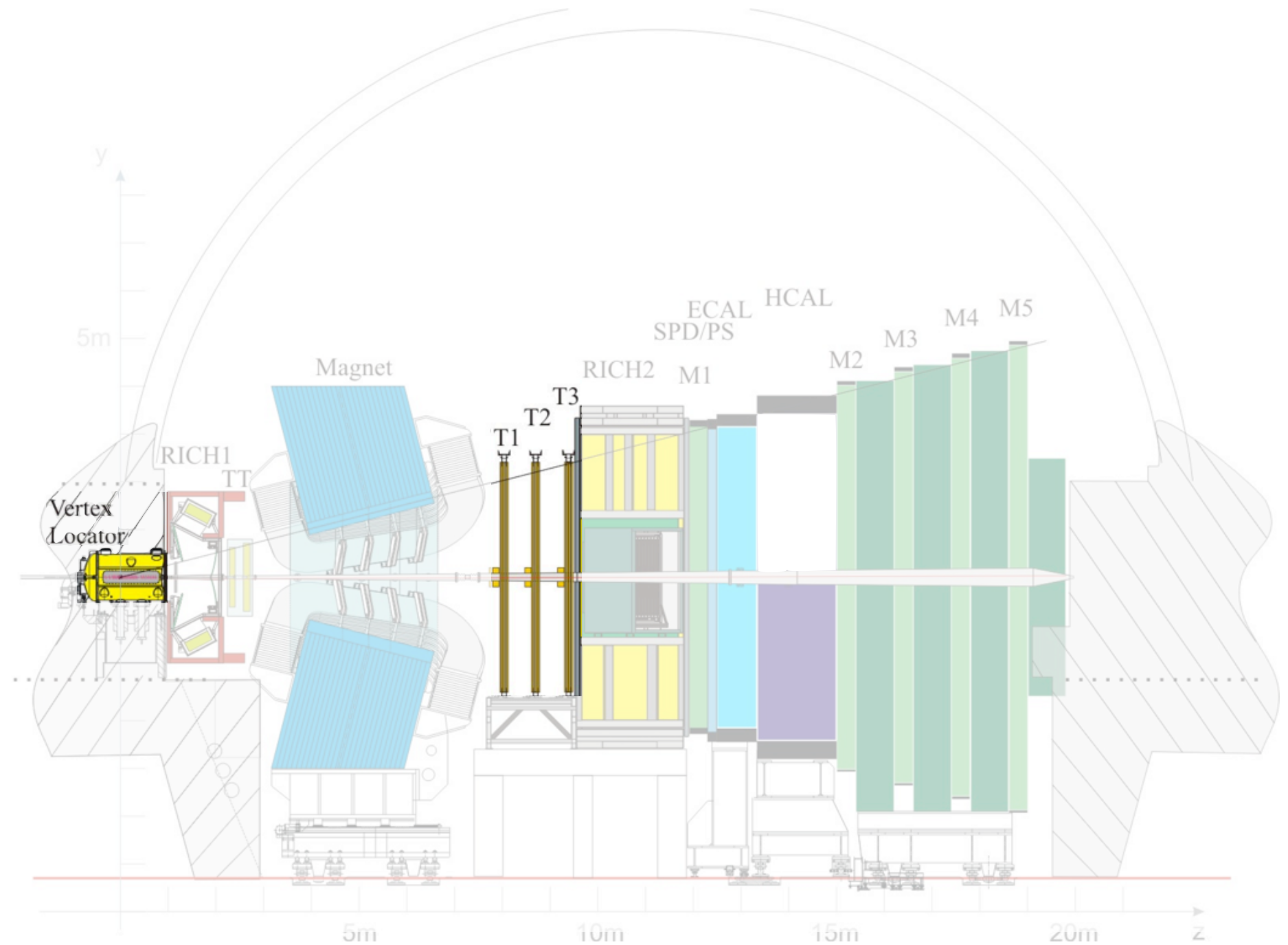
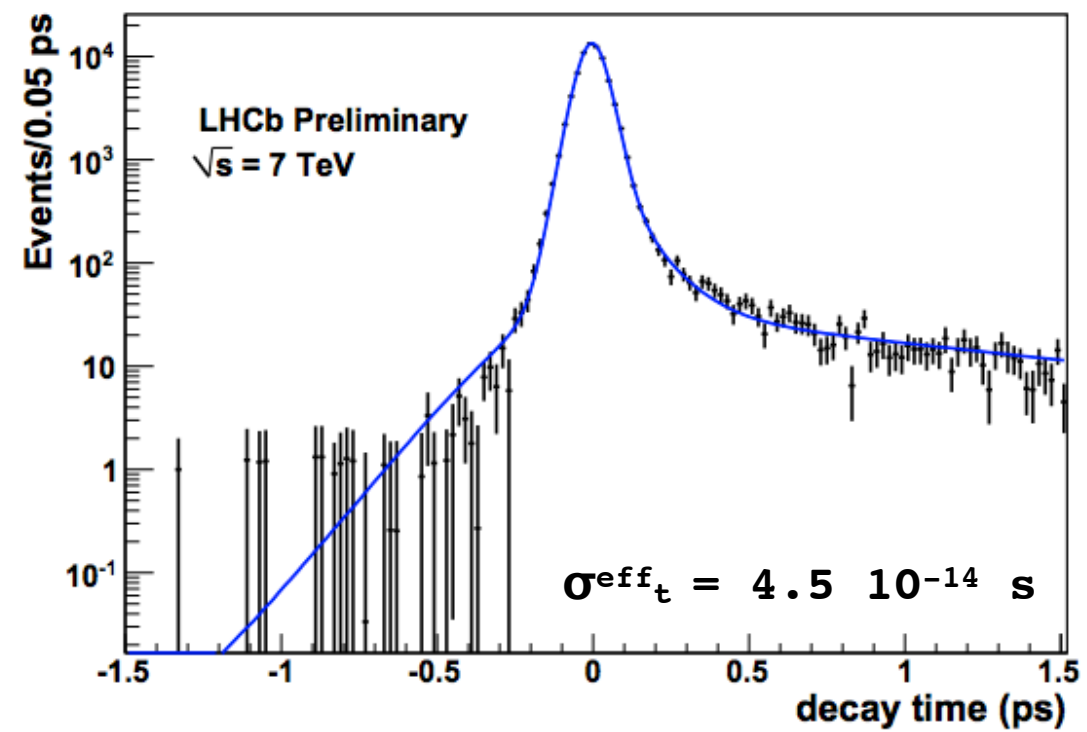
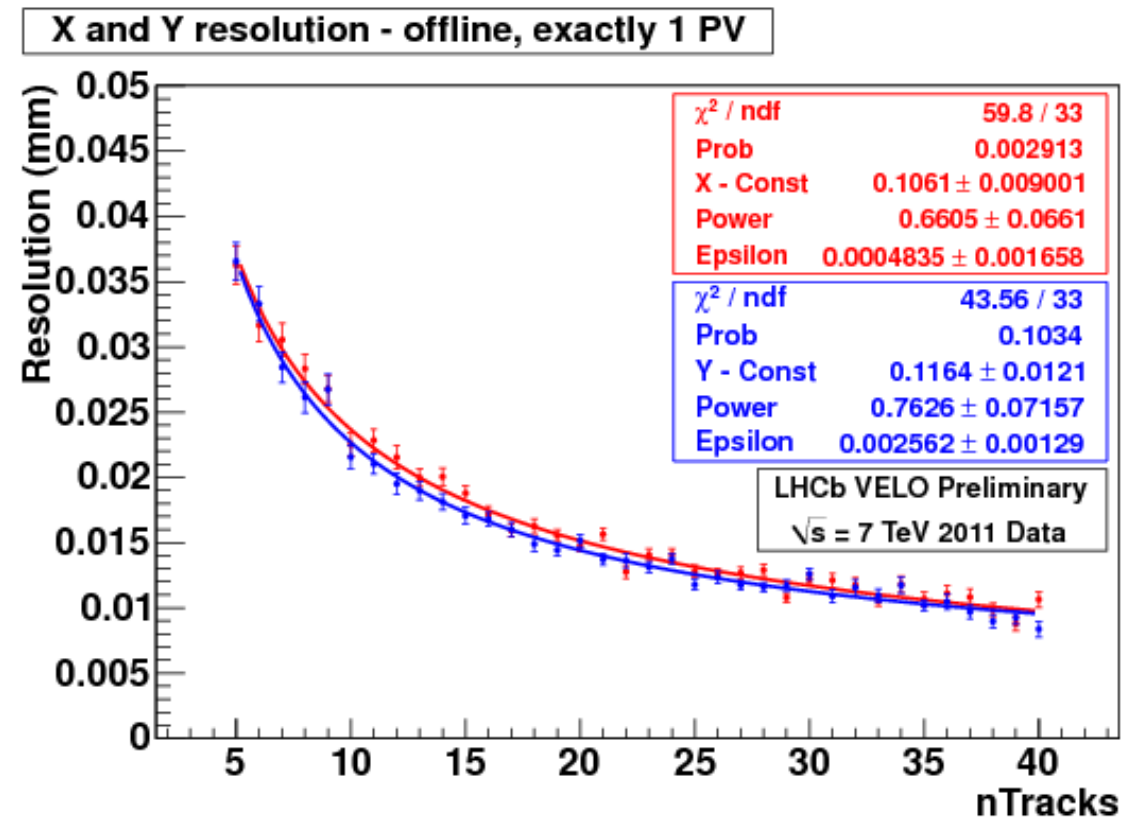
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LHCb and CMS geometries compared

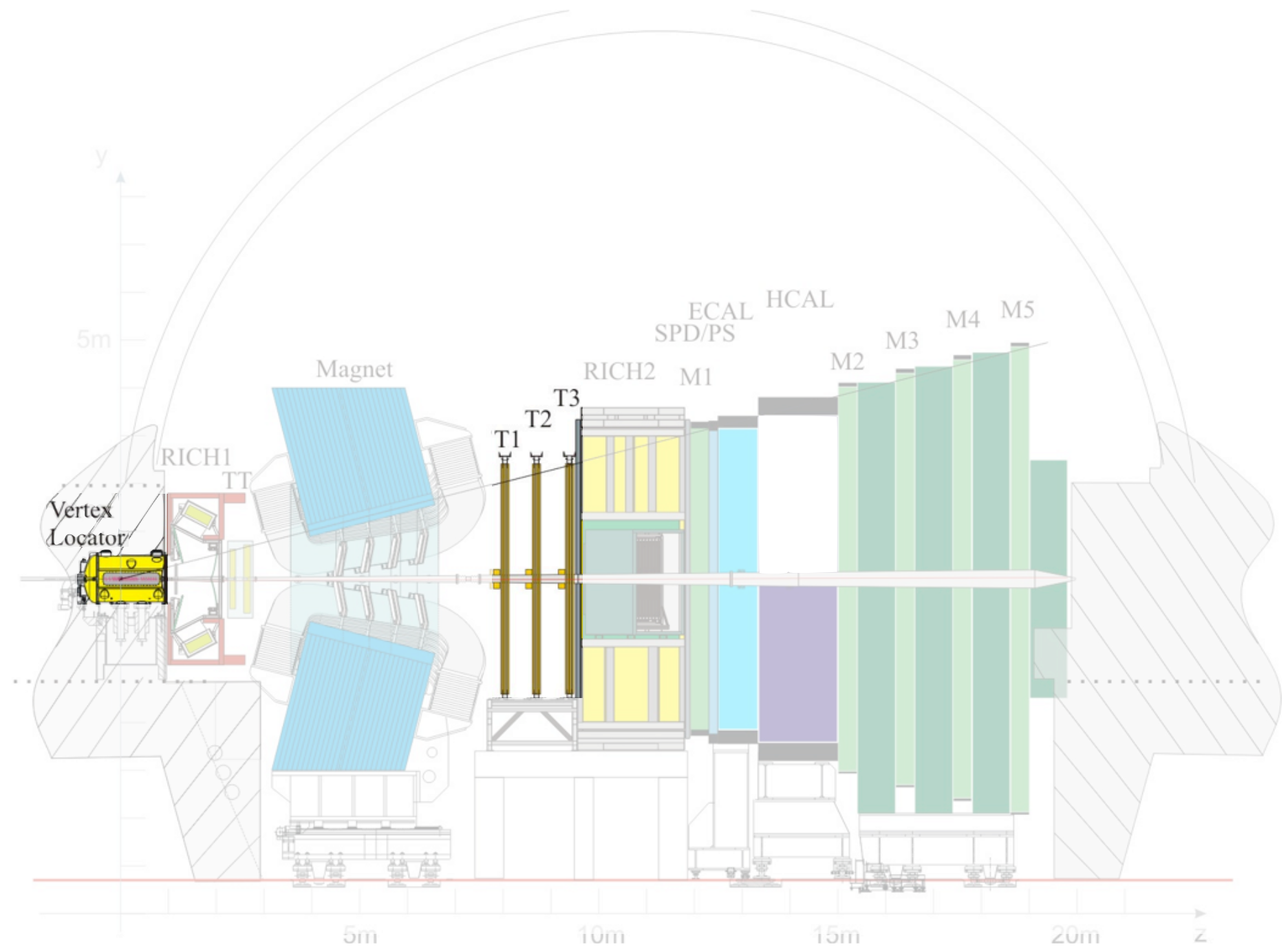
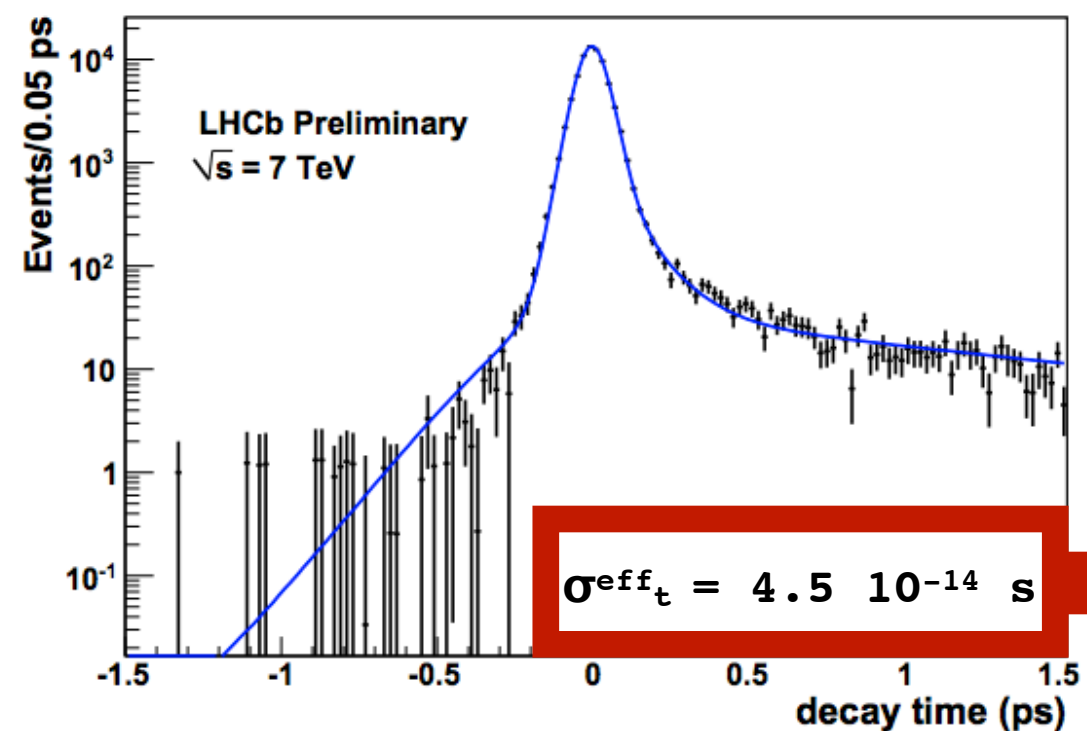
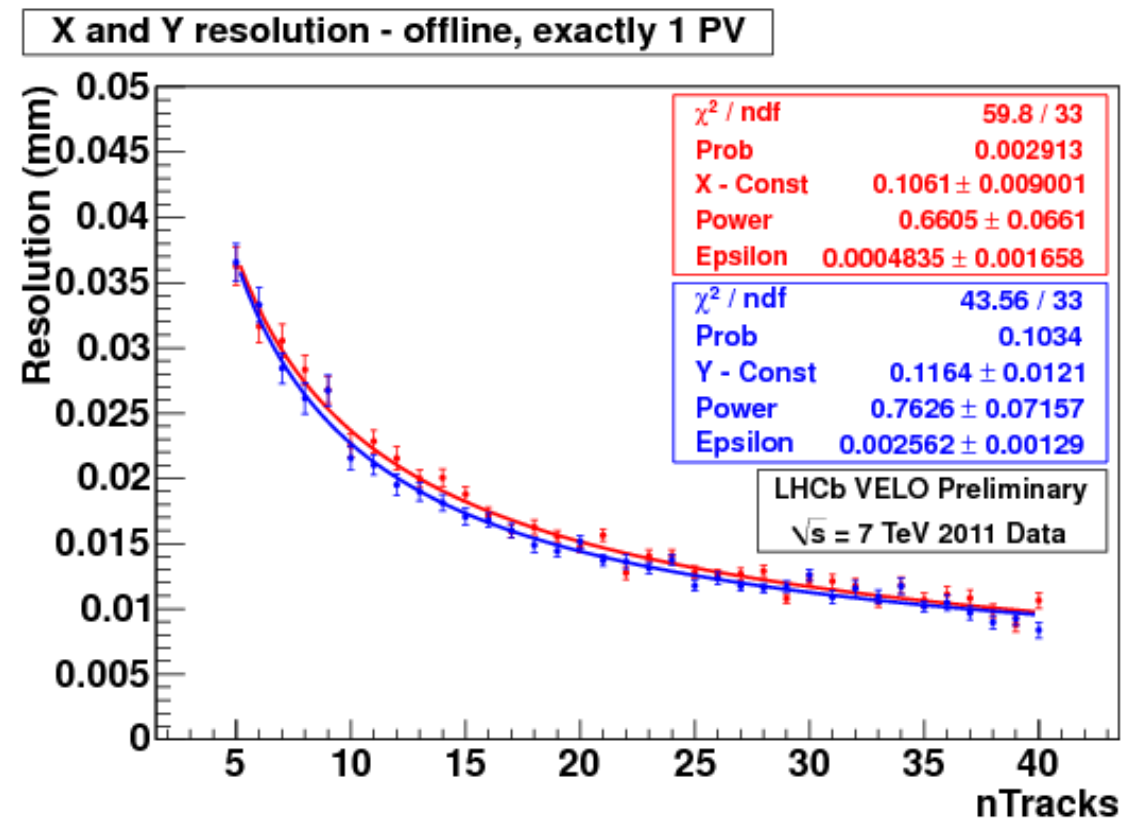


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LHCb performance



LHCb performance



We can measure lifetimes down to a few times $\sim 10^{-14}$ seconds...

Charm production @ LHC



10% of LHC interactions produce a charm hadron : LHCb has already collected more than 1 billion signal charm decays!

How sensitive is my measurement?

This is not an absolute rule but...

If you have no background and you have collected N signal events, then you can measure properties related to the signal production and decay (this includes the lifetime) with a relative precision of $(100/\sqrt{N})\%$

100	events means 10.0% precision
10000	events means 1.00% precision
1000000	events means 0.10% precision
100000000	events means 0.01% precision

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LHCb IS HERE

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LHCb IS HERE

Value (10^{-15} s)	EVTS	Document ID
$(41.01 \pm 0.15) \times 10^1$	OUR AVERAGE	
$409.6 \pm 1.1 \pm 1.5$	210k	LINK



WORLD PRECISION IS 0.35%

So we can't give you the full dataset to use!

The object of the exercise

The purpose of this exercise is to

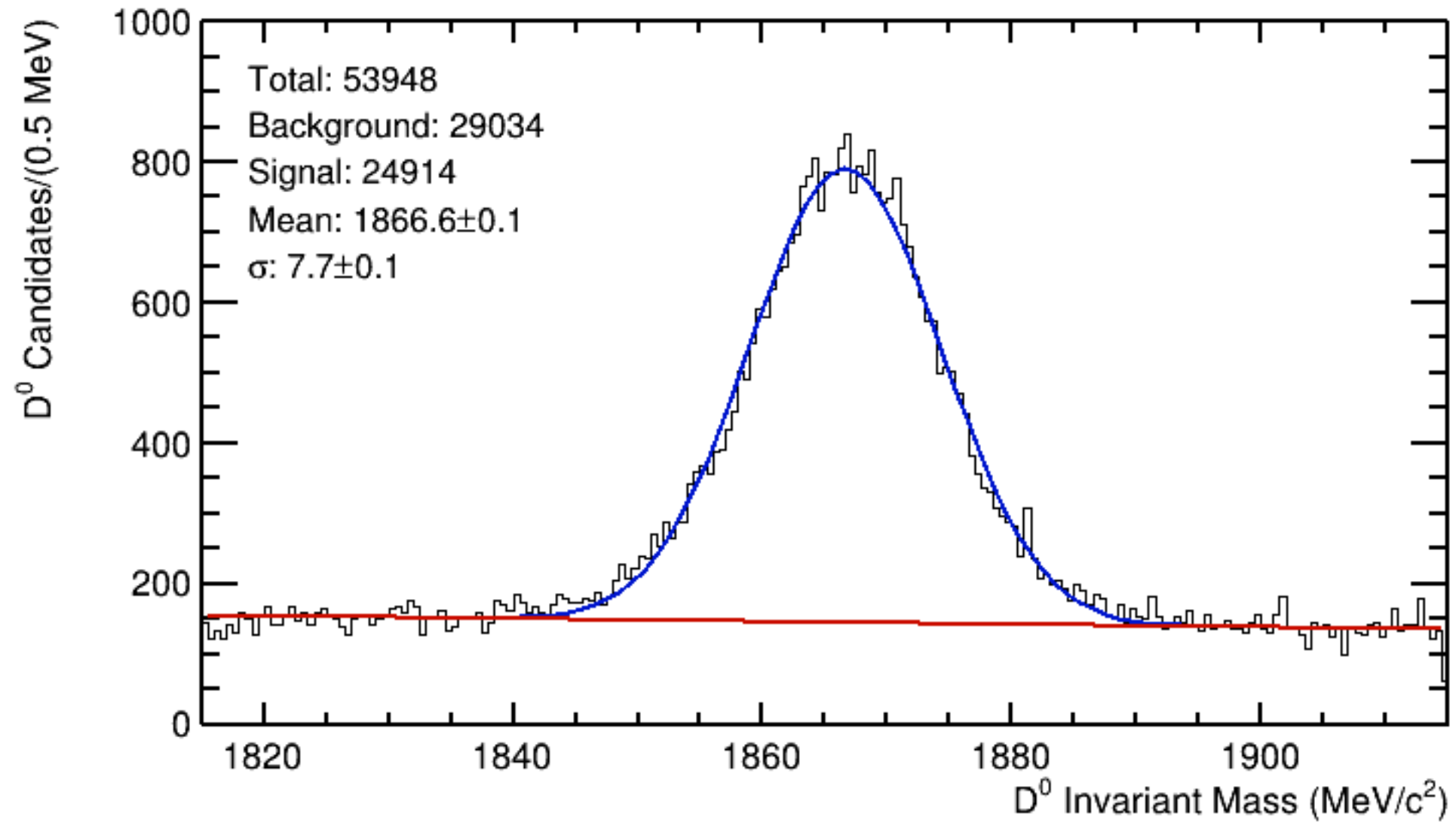
Give you a look at the data coming out of the LHC

Teach you about selecting particles in the LHC data

Teach you about fitting functions to the data in order to measure the signal properties

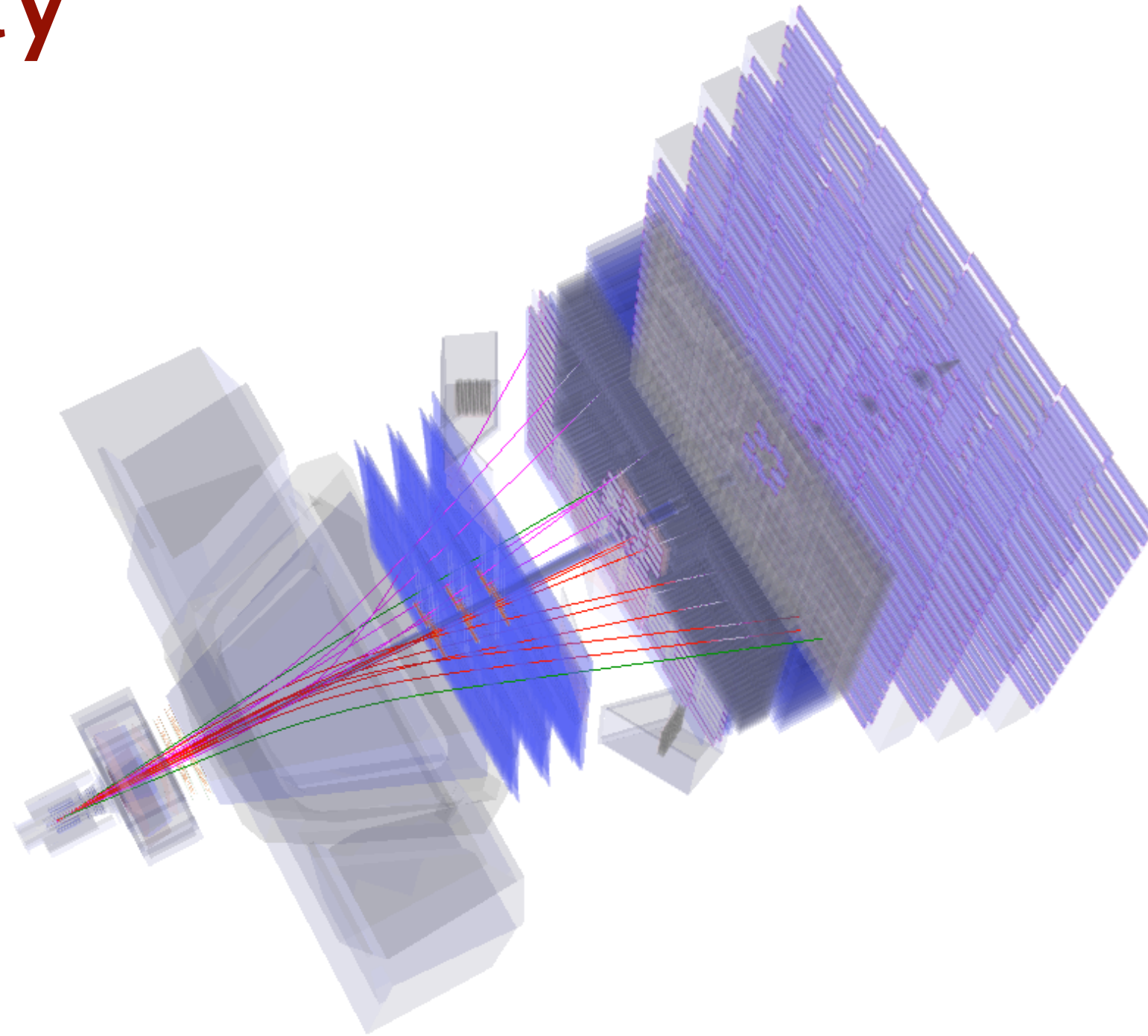
Teach you about systematic uncertainties in measurements

Data for exercise



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

Event display



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

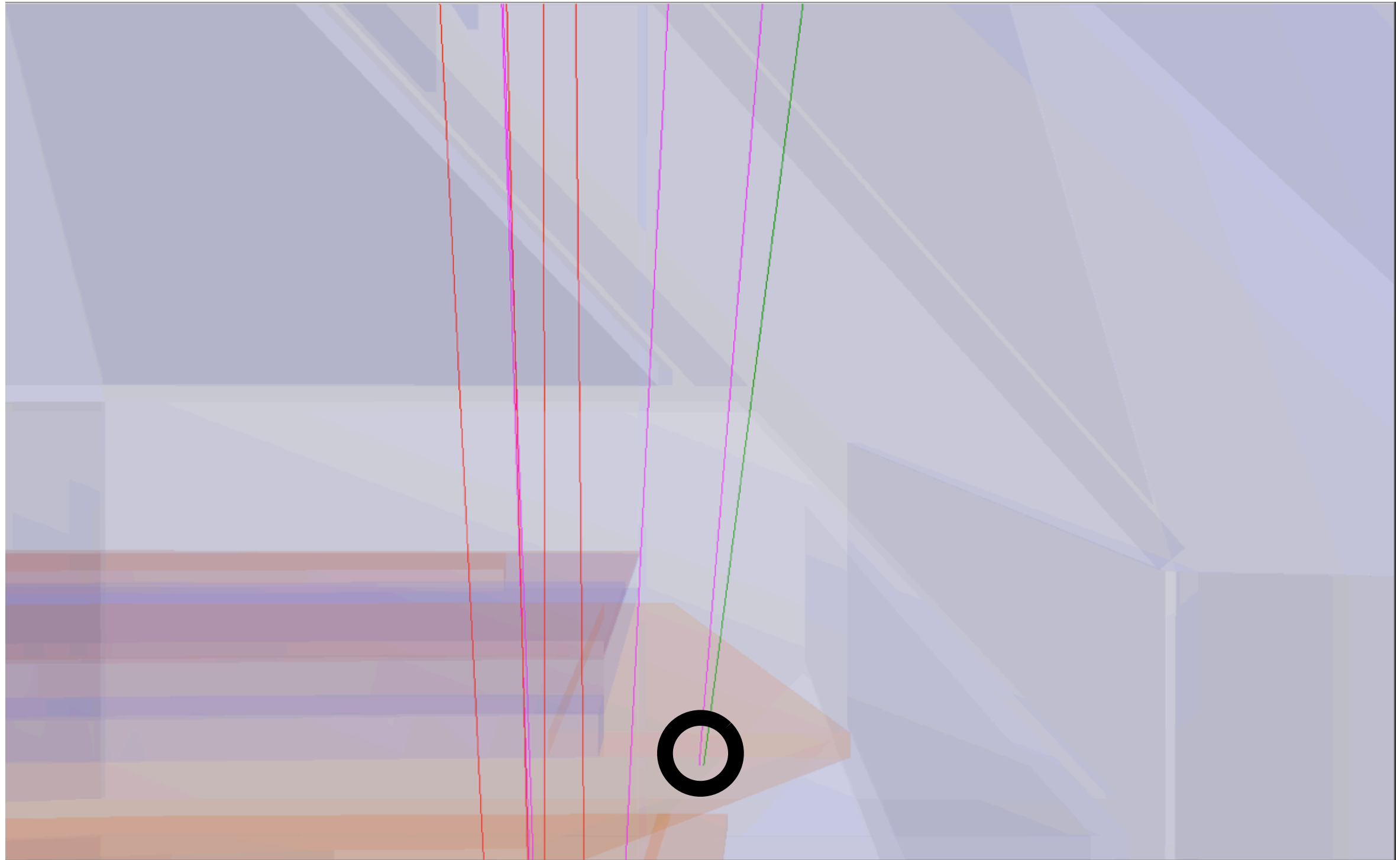
The visual analysis framework

The screenshot displays the 'Eve Main Window' interface, which is divided into several functional panels. On the left is the 'Event Control' sidebar, and the main area is titled 'Viewer 1 Help'. The 'Event Control' sidebar includes sections for 'Start' (with 'Combine 1' and 'Validate' buttons), 'View' (with zoom and pan icons and checkboxes for 'Hide Geometry' and 'Transparency'), 'Event manager' (showing 'Event number: 7' and navigation buttons), 'Particle Info' (a form for entering particle properties like Name, Mass, E, q, chi2, px, py, pz), 'My Particles' (with 'Calculate' and 'Delete' buttons), and 'Histogram' (with 'Add', 'Draw', and 'Save Histogram' buttons). A 'Legend' at the bottom left identifies particle types: K- (green), K+ (blue), pi- (red), pi+ (magenta), and D0 (black). The main 'Viewer 1 Help' area contains a 'View' panel with icons for zoom, pan, and a lightbulb (labeled 'Hint'), and checkboxes for 'Hide Geometry' and 'Transparency'. Below this is an 'Event manager' section showing 'Event number: 3' and navigation buttons. The 'Particle Info' section displays a table of properties for a selected particle (pi+):

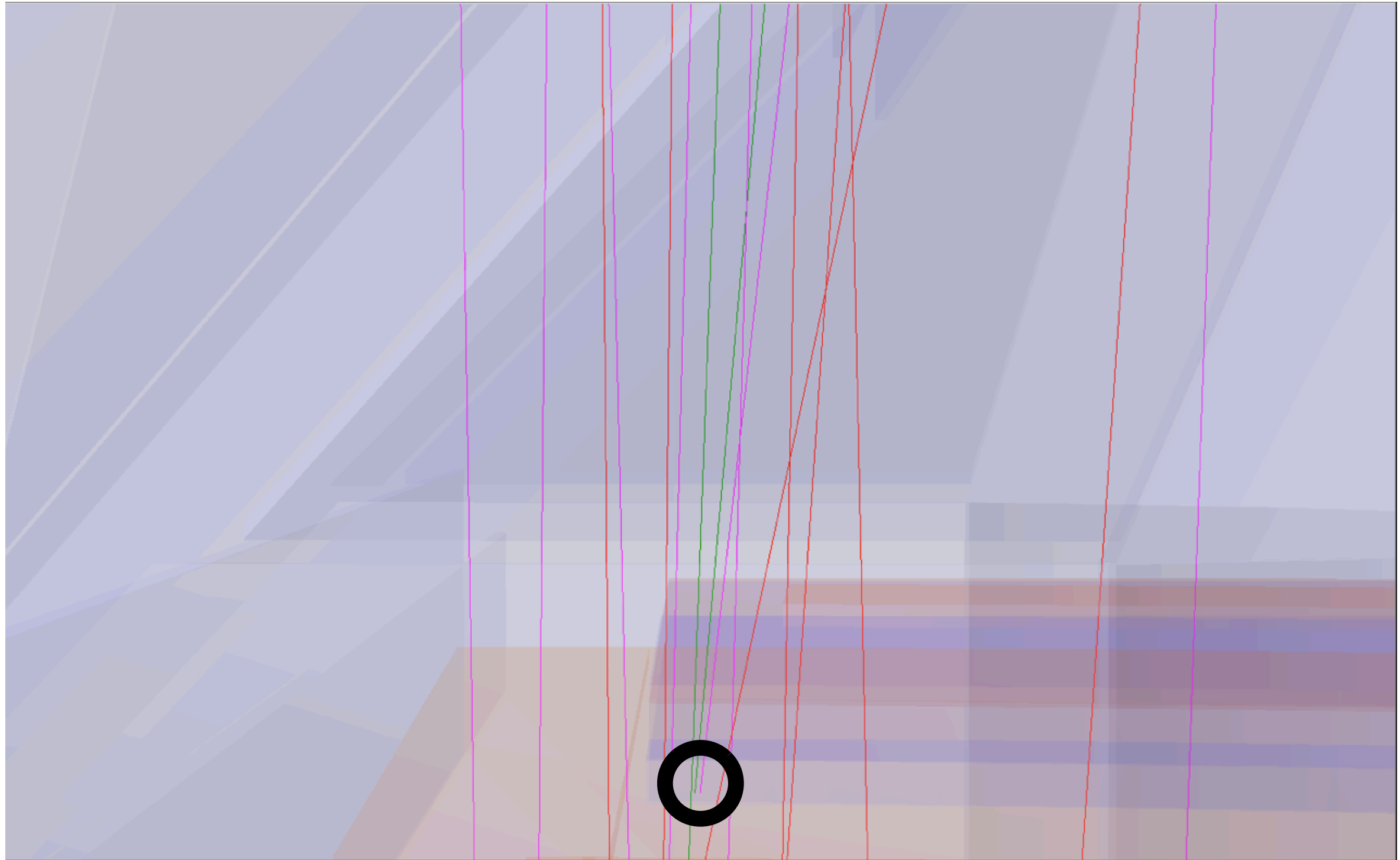
Name	Value	Unit
Mass	139.57	MeV/c ²
E	9498.92	MeV
q	1.00	
chi2	0.59	
px	-125.11	MeV/c
py	649.90	MeV/c
pz	9458.96	MeV/c

Below the table are 'Save Particle' and 'My Particles' sections. The 'My Particles' section shows 'My particle: K-' and 'My particle: pi+' with 'Calculate' and 'Delete' buttons, and a 'Mass' field with the value 1821.14. The 'Histogram' section has 'Add', 'Draw', and 'Save Histogram' buttons. The main viewing area shows particle tracks and the LHCb detector geometry. Annotations with leader lines explain various features: 'Zoom gives you closer look at collision' points to a zoomed-in track view; 'Click on the track to find out about particle properties' points to a track with a mouse cursor; 'Carefully choose particles you want to save, because out of them you get a new mass which might not be right!' points to the 'My Particles' section; 'Add and Draw your results on histogram. Don't forget to save histogram when you finish!' points to the 'Histogram' section; 'View' points to the 'View' panel; 'Hint shows you the hidden D0 and its children' points to a track view with a lightbulb icon; 'Fullscreen shows the full view of LHCb detector and particle tra' points to a 3D detector view; 'Transparent view gives you a better look at particle tracks and the LHCb detector' points to a transparent 3D detector view; and 'You can hide the geometry to see all the particle tracks.' points to a track view with 'Hide Geometry' checked.

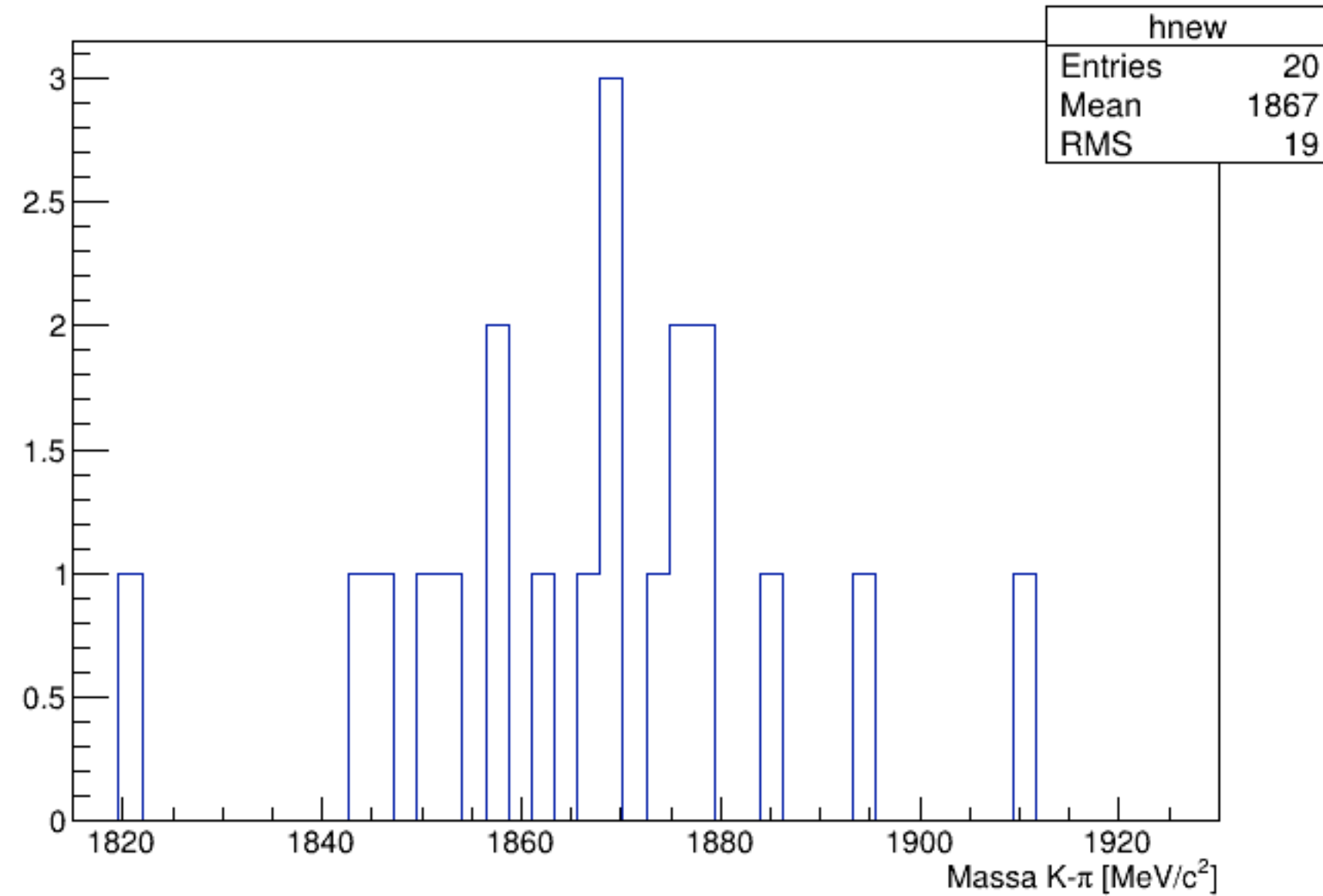
An “easy” event



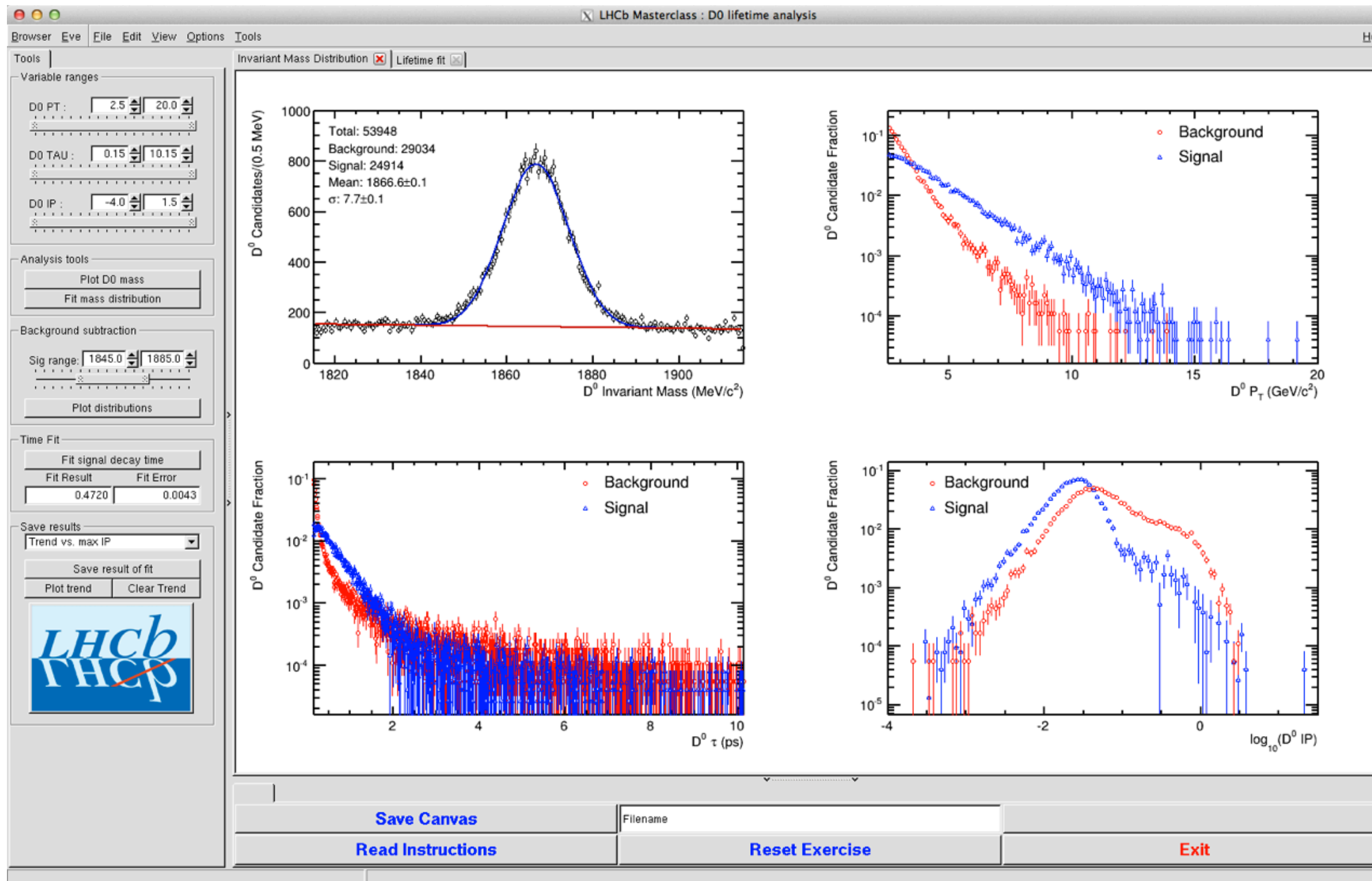
A “harder” event



An example histogram



Fitting the lifetime



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

Online instructions

The screenshot displays the 'LHCb Masterclass : D0 lifetime analysis' software interface. On the left, a sidebar contains various tool sections: 'Variable ranges' with sliders for D0 PT (2.5 to 20.0), D0 TAU (0.15 to 10.15), and D0 IP (-4.0 to 1.5); 'Analysis tools' with buttons for 'Plot D0 mass' and 'Fit mass distribution'; 'Background subtraction' with a 'Sig range' slider (1815.0 to 1915.0) and a 'Plot distributions' button; 'Time fit' with a 'Fit signal decay time' button and a table showing 'Fit Result' (0.0000) and 'Fit Error' (0.0000); and 'Save results' with a dropdown menu set to 'Trend vs. max IP' and buttons for 'Save result and fit', 'Plot trend', and 'Clear Trend'. The main window, titled 'Invariant Mass Distribution', is currently empty. An 'INSTRUCTIONS' dialog box is open in the center, providing a welcome message and a list of six steps for the exercise. The bottom of the interface features a control bar with buttons for 'Save Canvas', 'Read Instructions', 'Reset Exercise', and 'Exit', along with a 'Filename' input field.

INSTRUCTIONS

Welcome to the LHCb masterclass exercise on measuring the lifetime of the D0 meson.

The goal of this exercise is to measure the lifetime of the D0 meson, a fundamental particle made of a charm quark and an up anti-quark. In order to do so, you will first learn how to separate signal D0 mesons from backgrounds. Finally, you will compare your results to the values found by the Particle Data Group (<http://pdglive.lbl.gov>).

Step-by-step instructions :

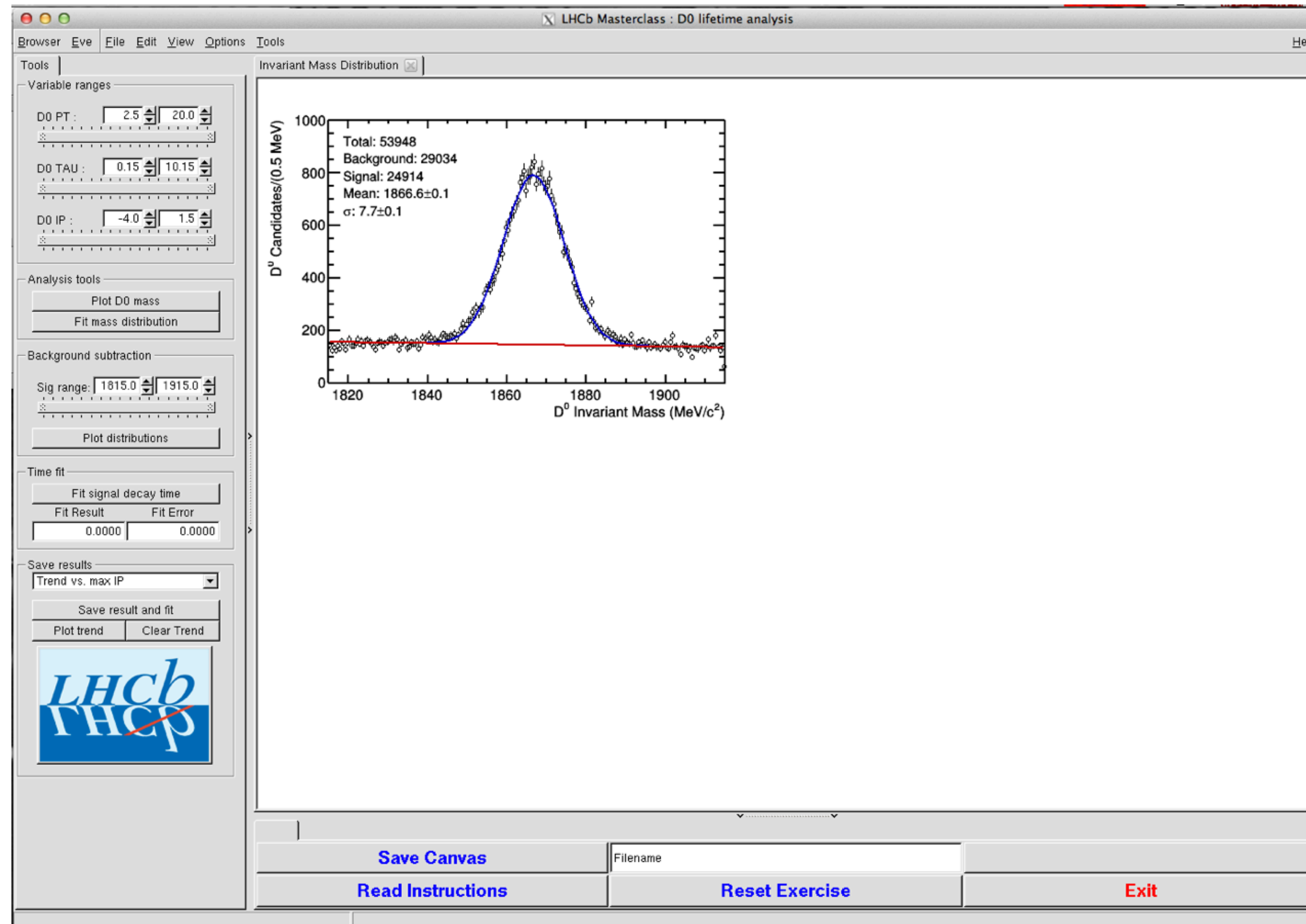
1. Plot the D0 mass distribution. The mass of the D0 is a fundamental variable which separates signal (the peaking structure in the middle) from the flat background.
2. Read the results of the fit and use them to determine the signal range. The function being fitted to the signal is a Gaussian, whose width, indicated by the greek letter sigma, is related to how far the signal extends from the mean (or most probable) value. In particular, an interval of ± 1 sigma around the mean value contains 68% of the signal, while ± 3 sigma contains 99.7% of the signal. Use the slider to set the signal range to be ± 3 sigma around the mean value.
3. Plot the variable distributions. You will see three further plots appearing, and in each one the blue points represent the distribution of the signal in that variable while the red points represent the distribution of the background. The plot is logarithmic in the Y axis, and each point represents the fraction of the total signal in that bin. Which regions of each variable contain mostly signal? Which contain mostly background?
4. Fit the lifetime distribution. Save the results of your fit and compare them to the PDG value. Do they agree?
5. Repeat step 4 but now varying the upper D0 log(IP) variable range from 1.5 to -2 in steps of 0.2. Do you notice a pattern?
6. Talk to a demonstrator about your results. Does the D0 lifetime with an log(IP) cut of -1.5 agree better or worse with the PDG than the lifetime with an log(IP) cut of 1.5?

OK

Save Canvas Filename Read Instructions Reset Exercise Exit

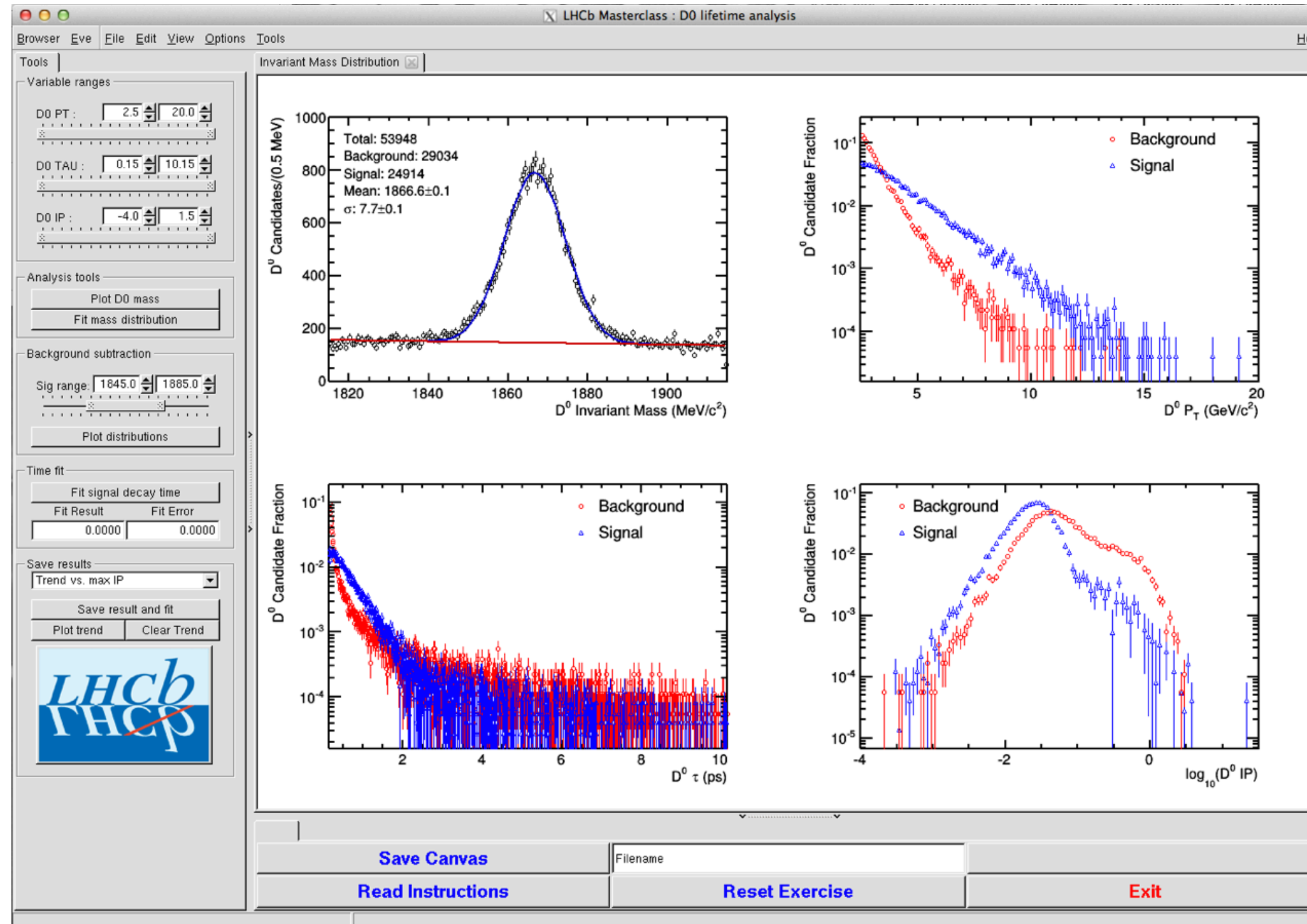
As with the event display, there are online instructions

Fitting the mass



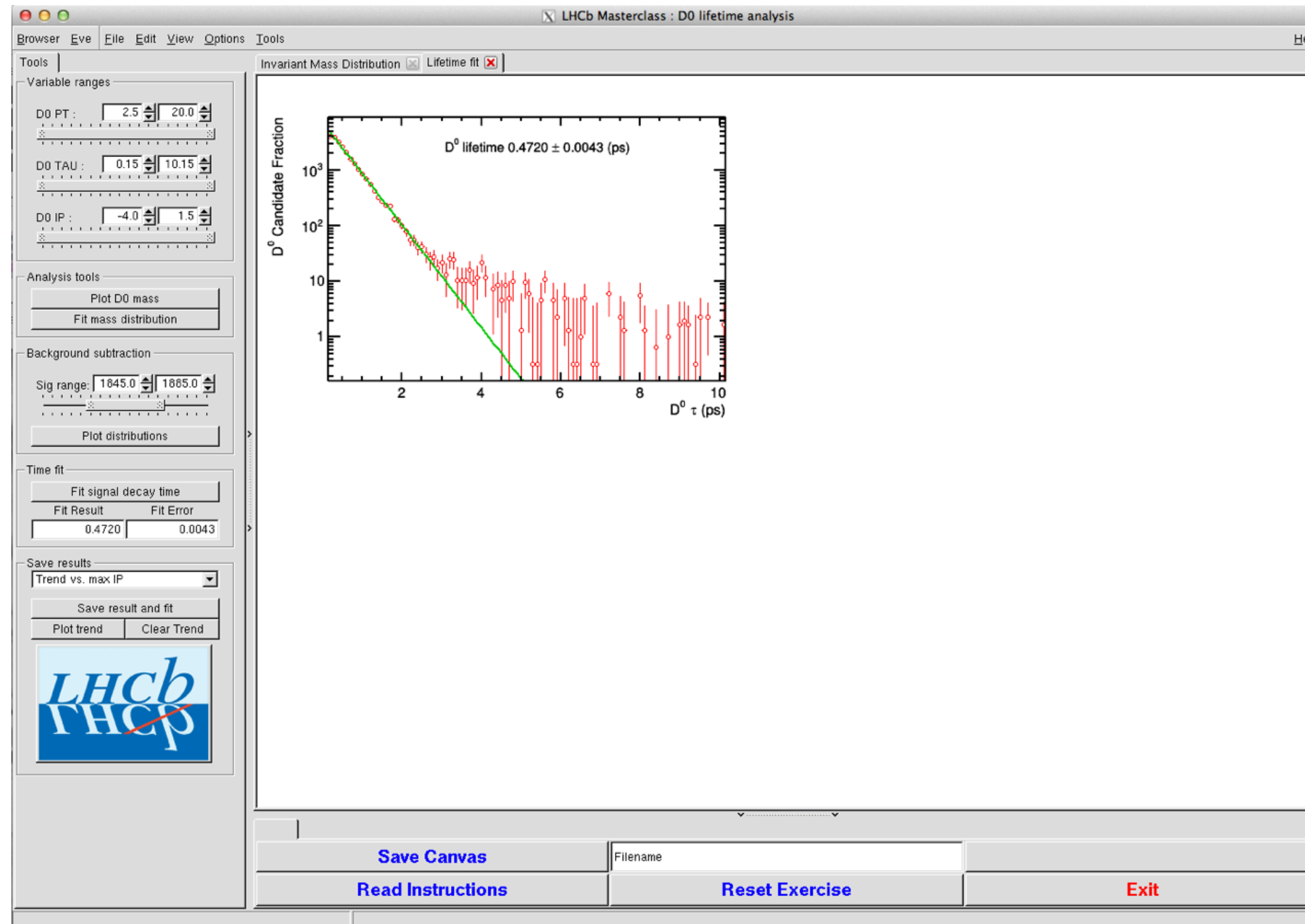
Your first task is to fit functions to signal and background

Plotting the distributions



Now use that fit to plot the distributions of background and signal events in the other physical parameters

Plotting the distributions



And fit the lifetime! Does your result agree with slide 51?