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

What will you be measuring today?

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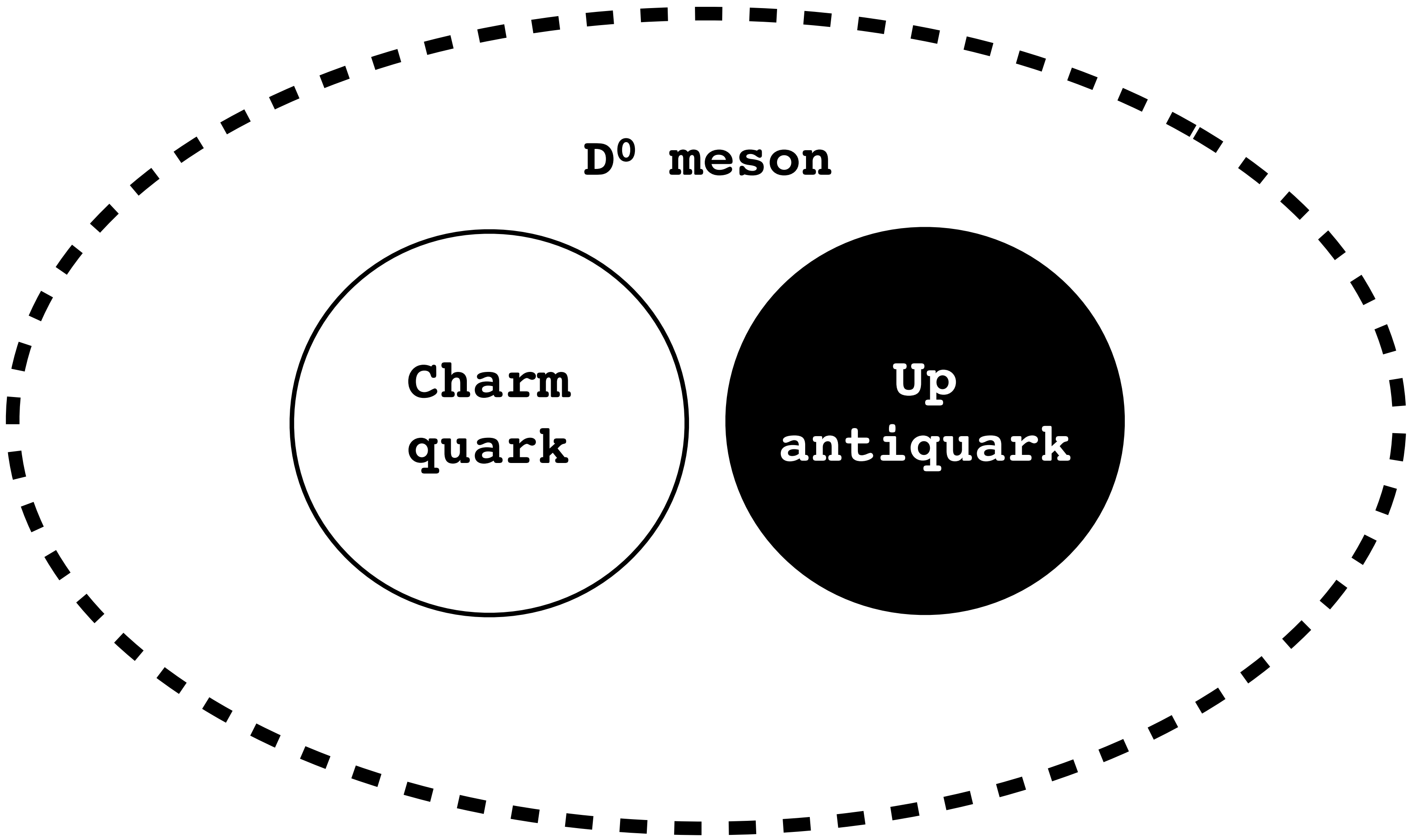

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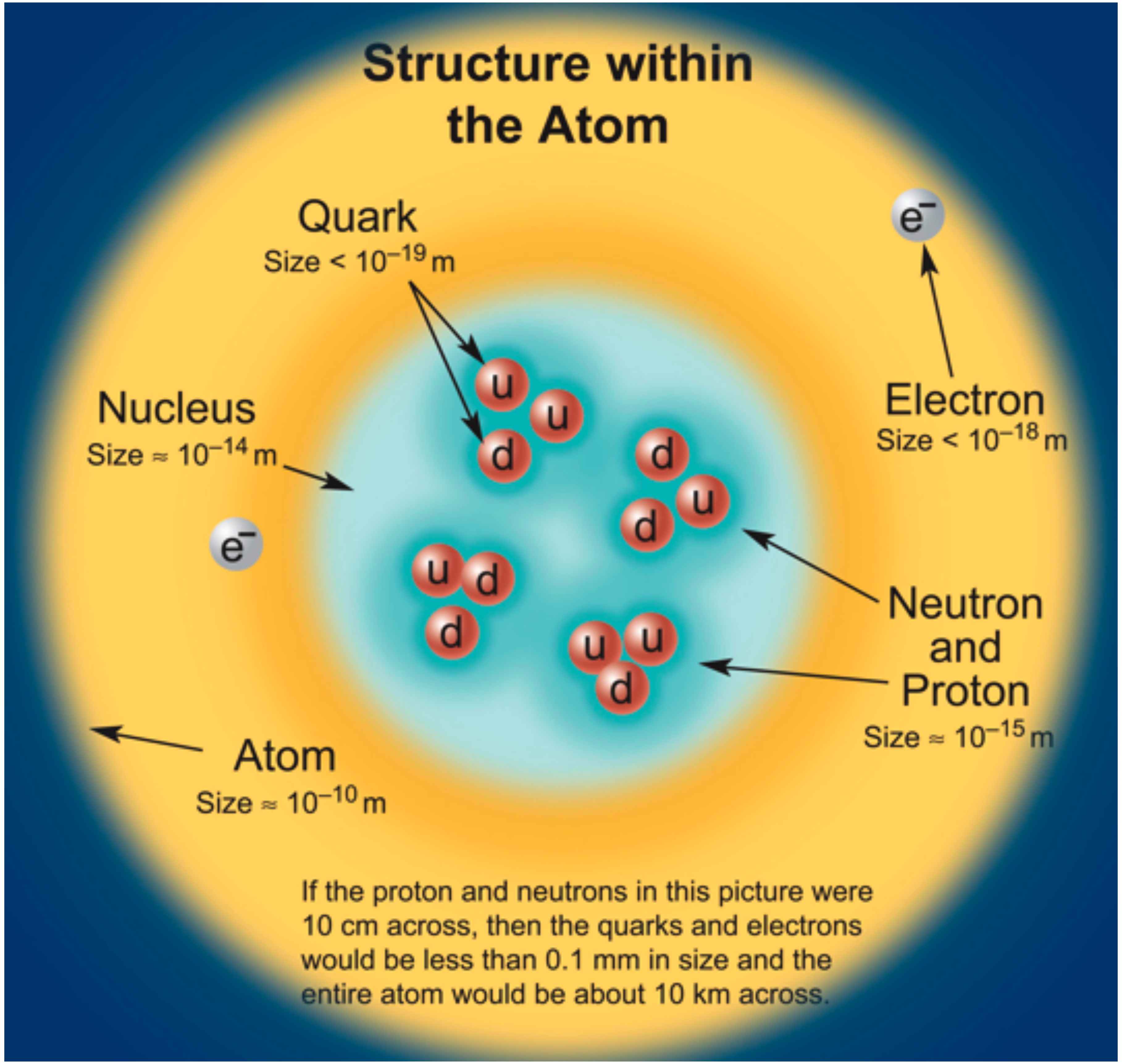
What kind of particles are there?

There are a small number of fundamental particles.

Smaller than atoms…



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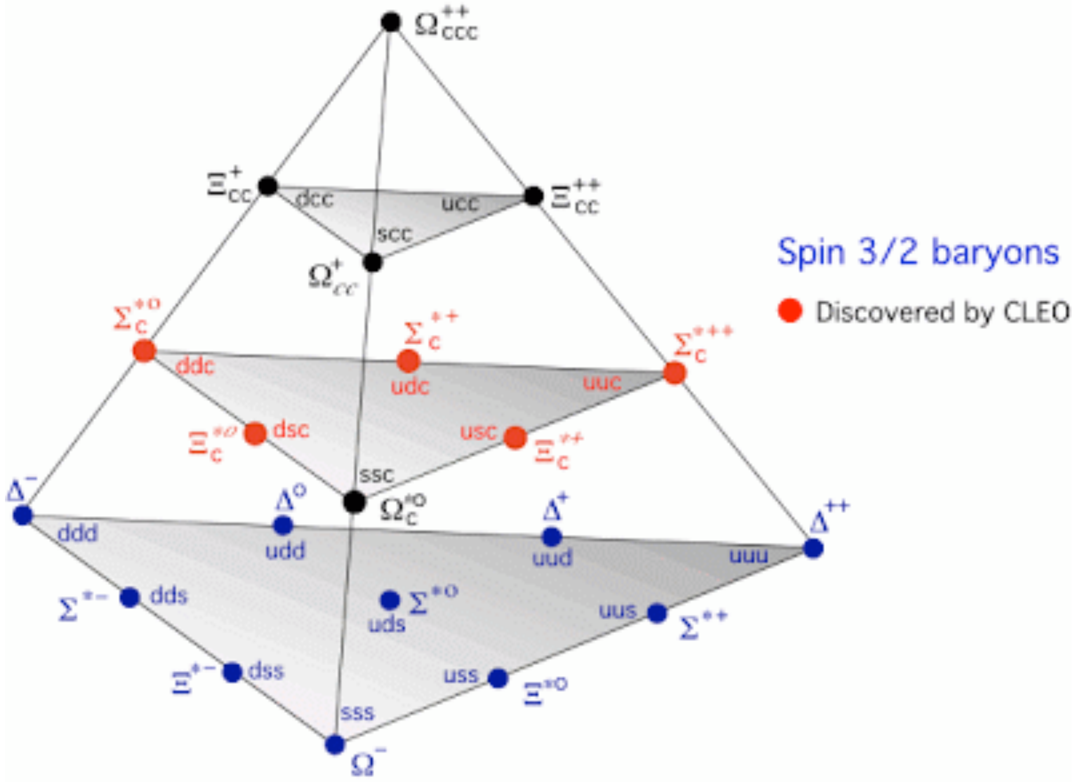

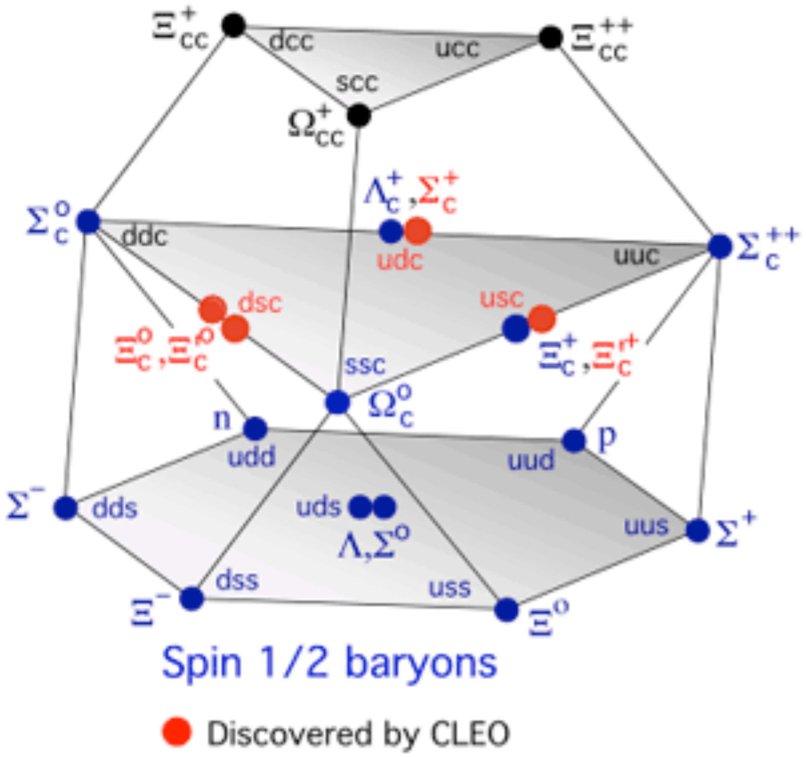

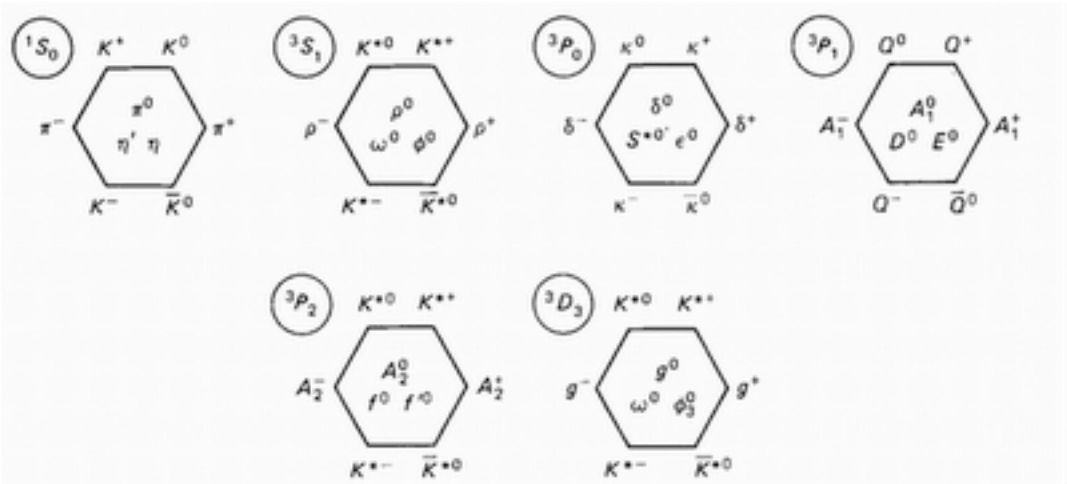

There are a small number of fundamental particles.

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

What kind of particles are there?

The monks had their bible...

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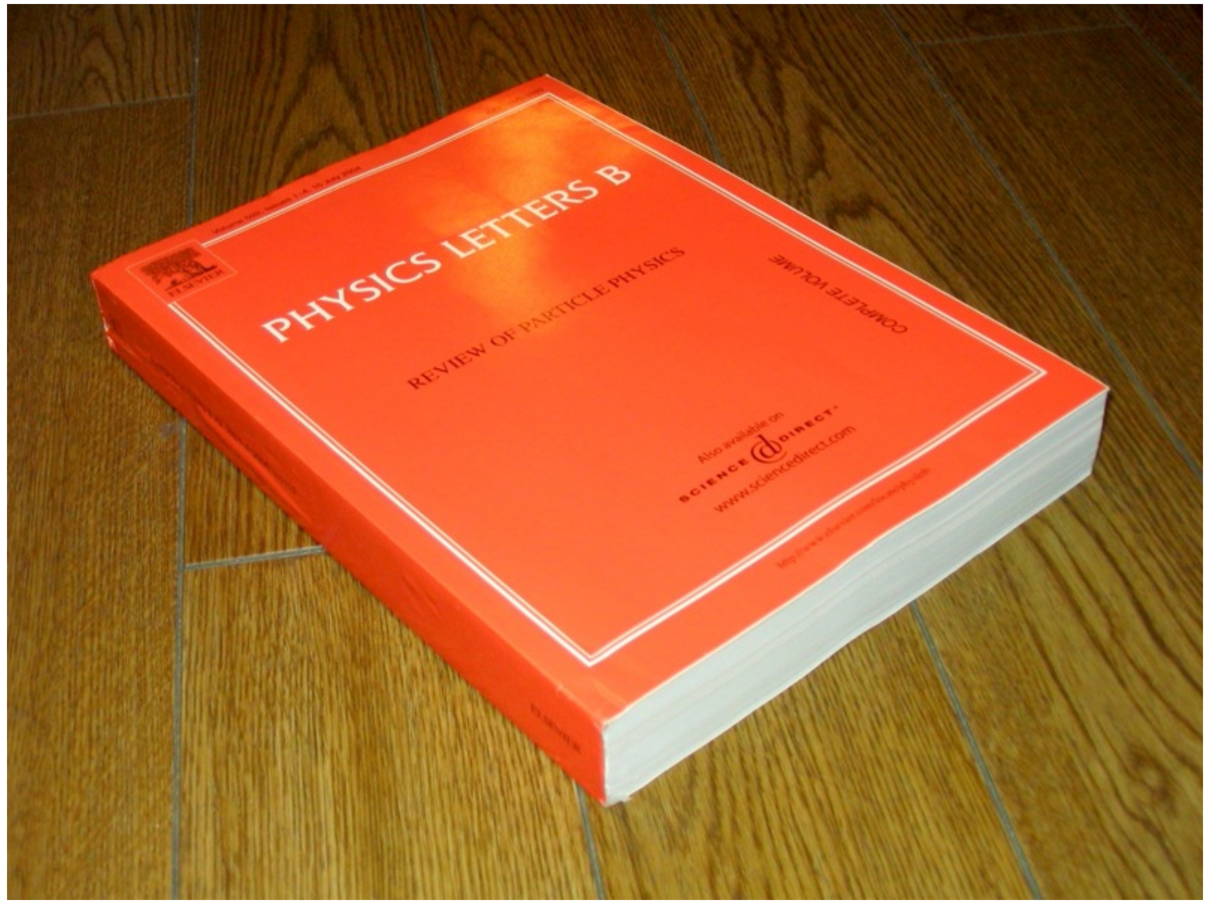
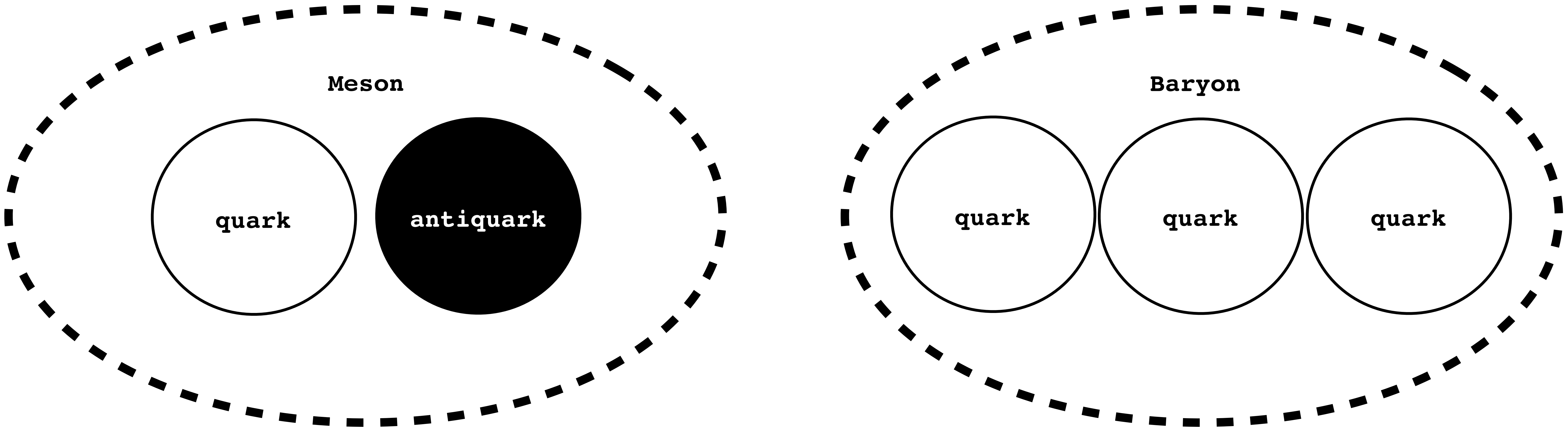


We have the Particle Listings!

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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Wikipedia : can't live with it, can't live without it...

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

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How do we measure a short lifetime?

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

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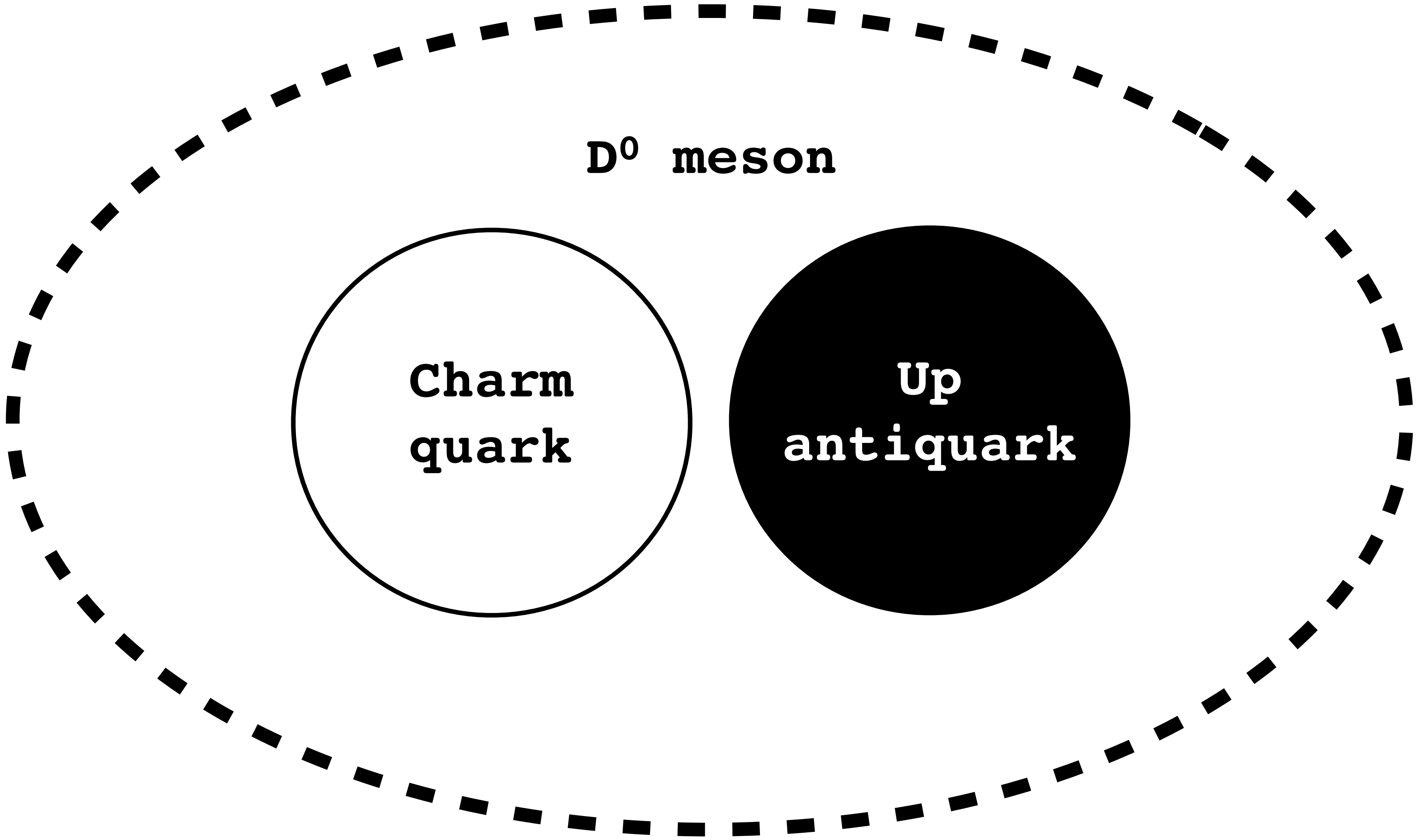
$t' = t/\sqrt{(1-v^2/c^2)}$

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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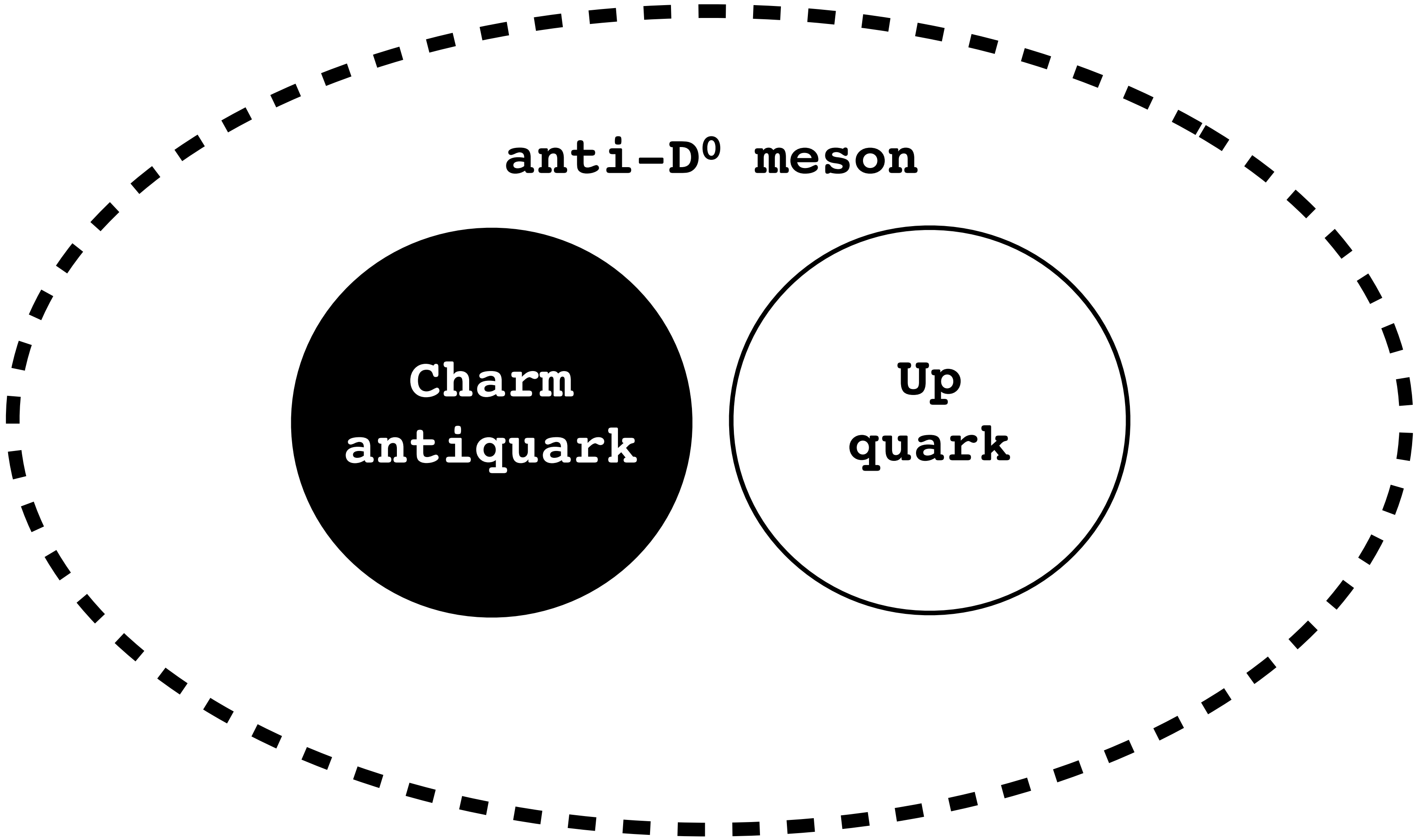

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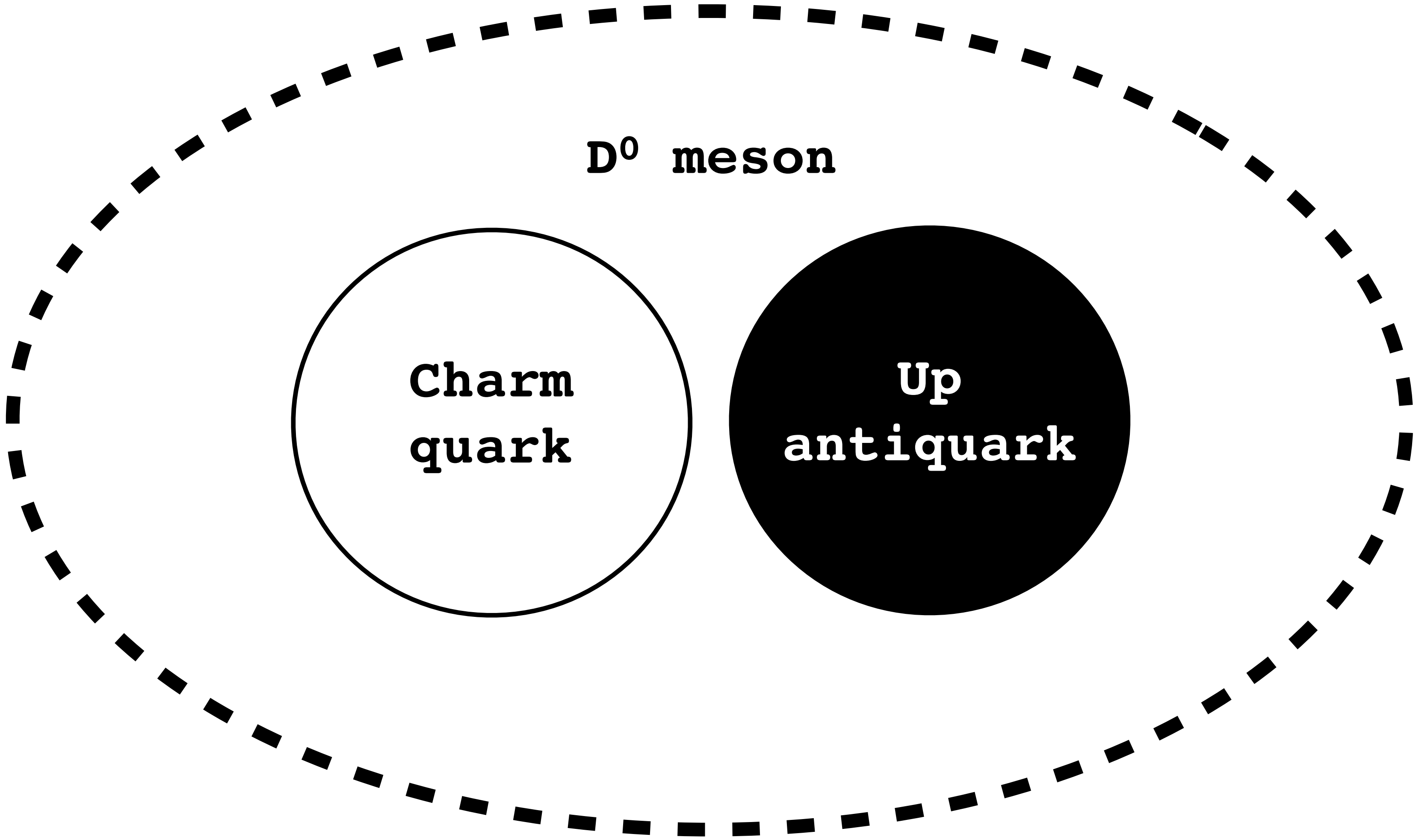
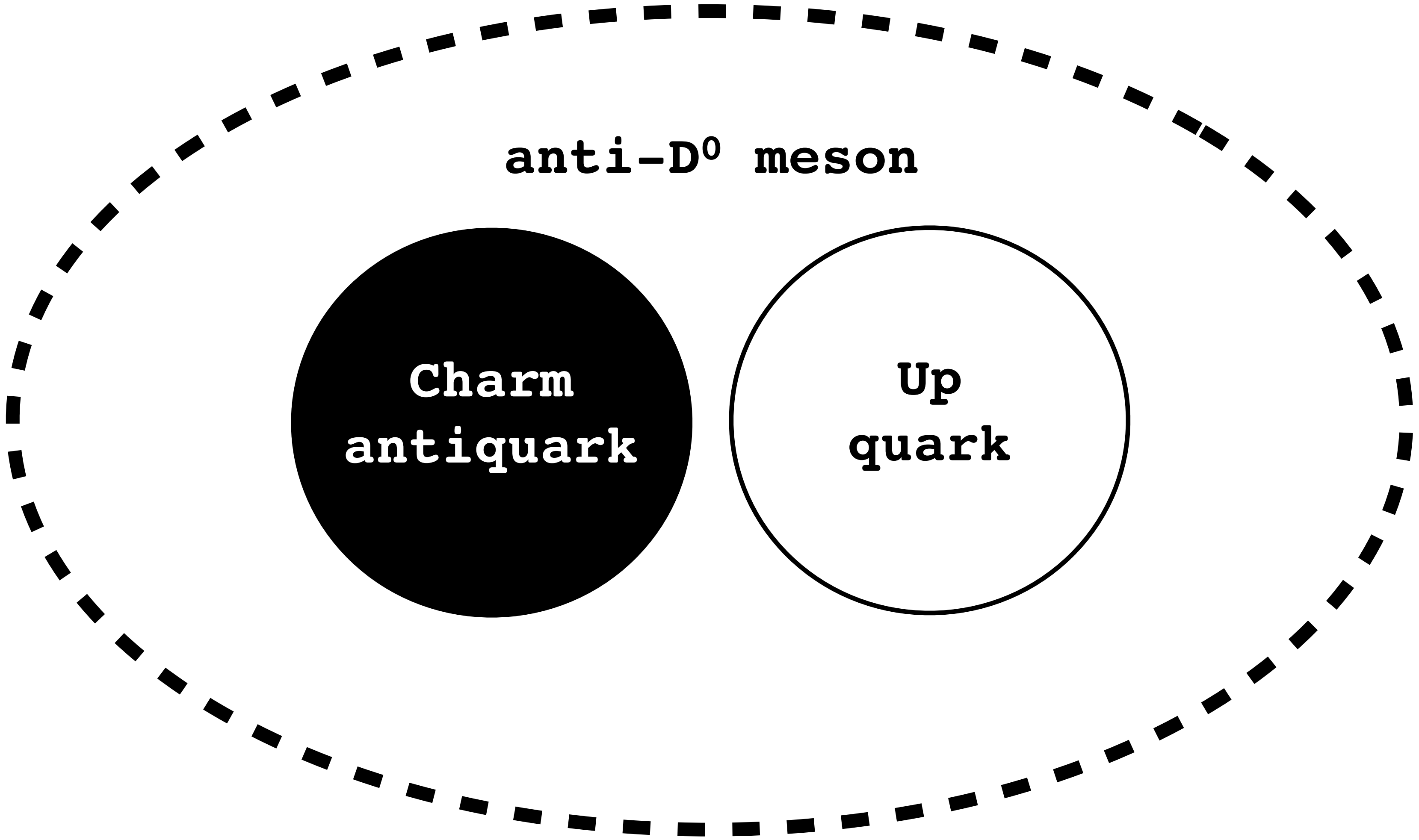
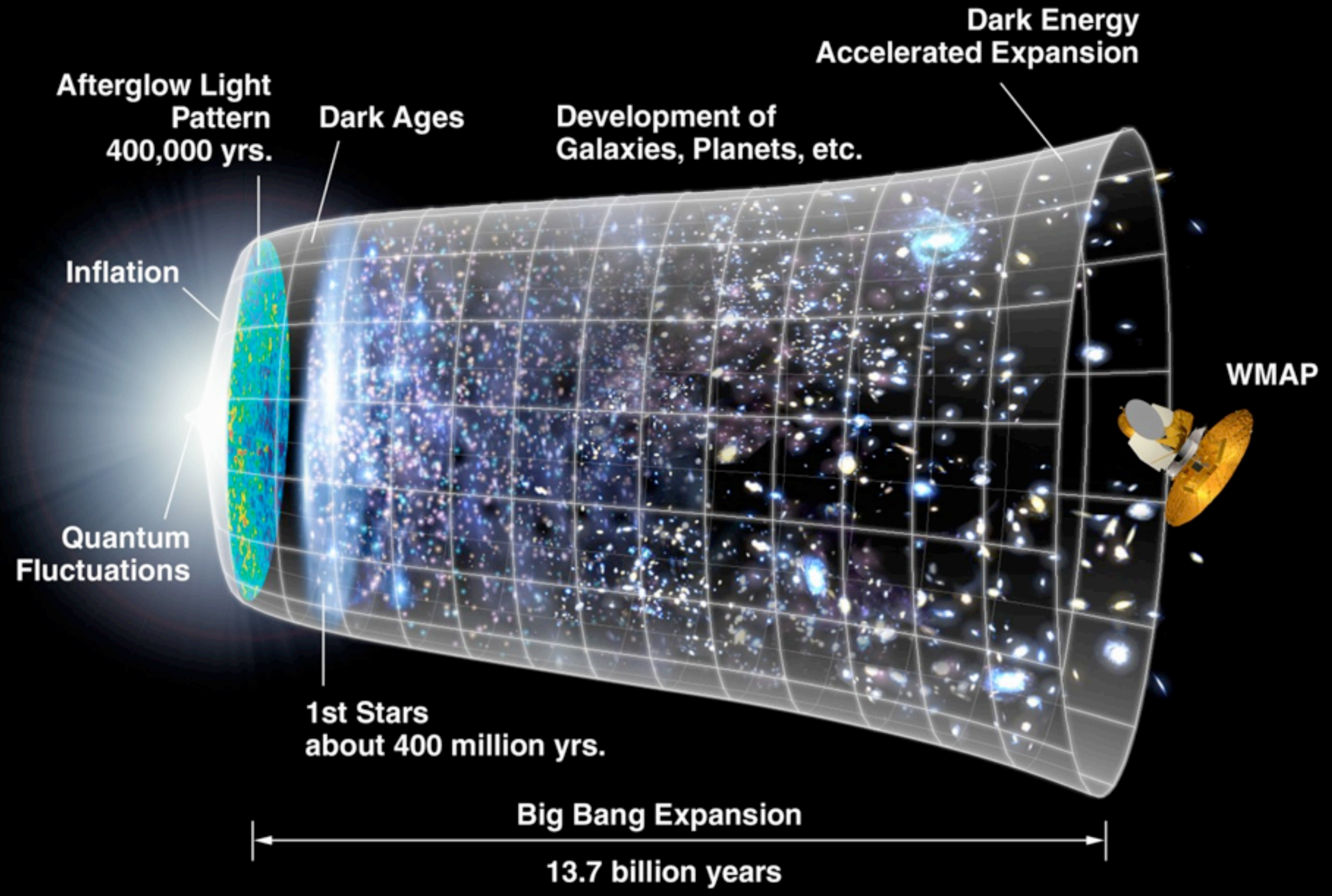


It oscillates!



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

Why does antimatter matter?



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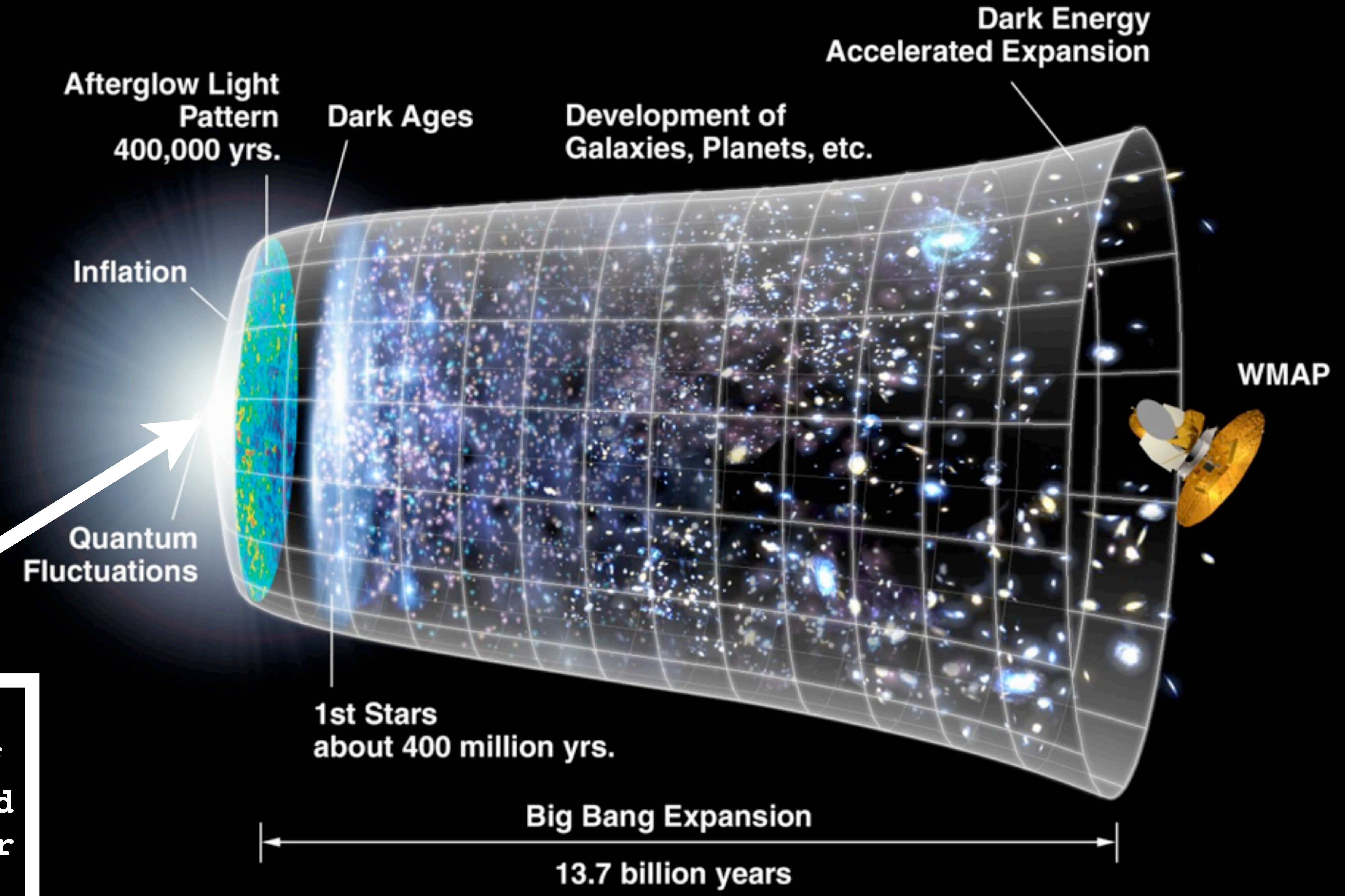

Equal amount of matter and antimatter created

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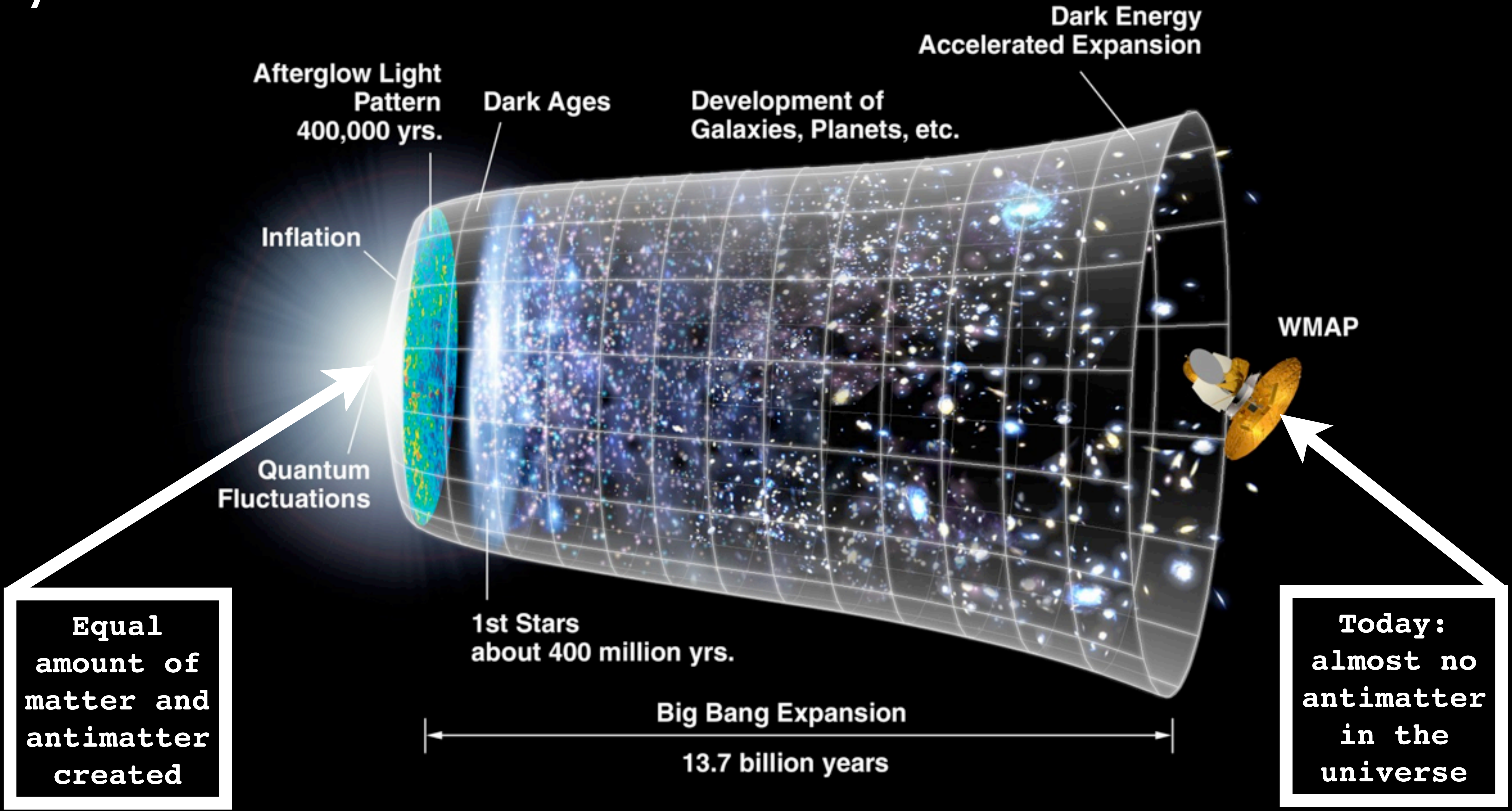

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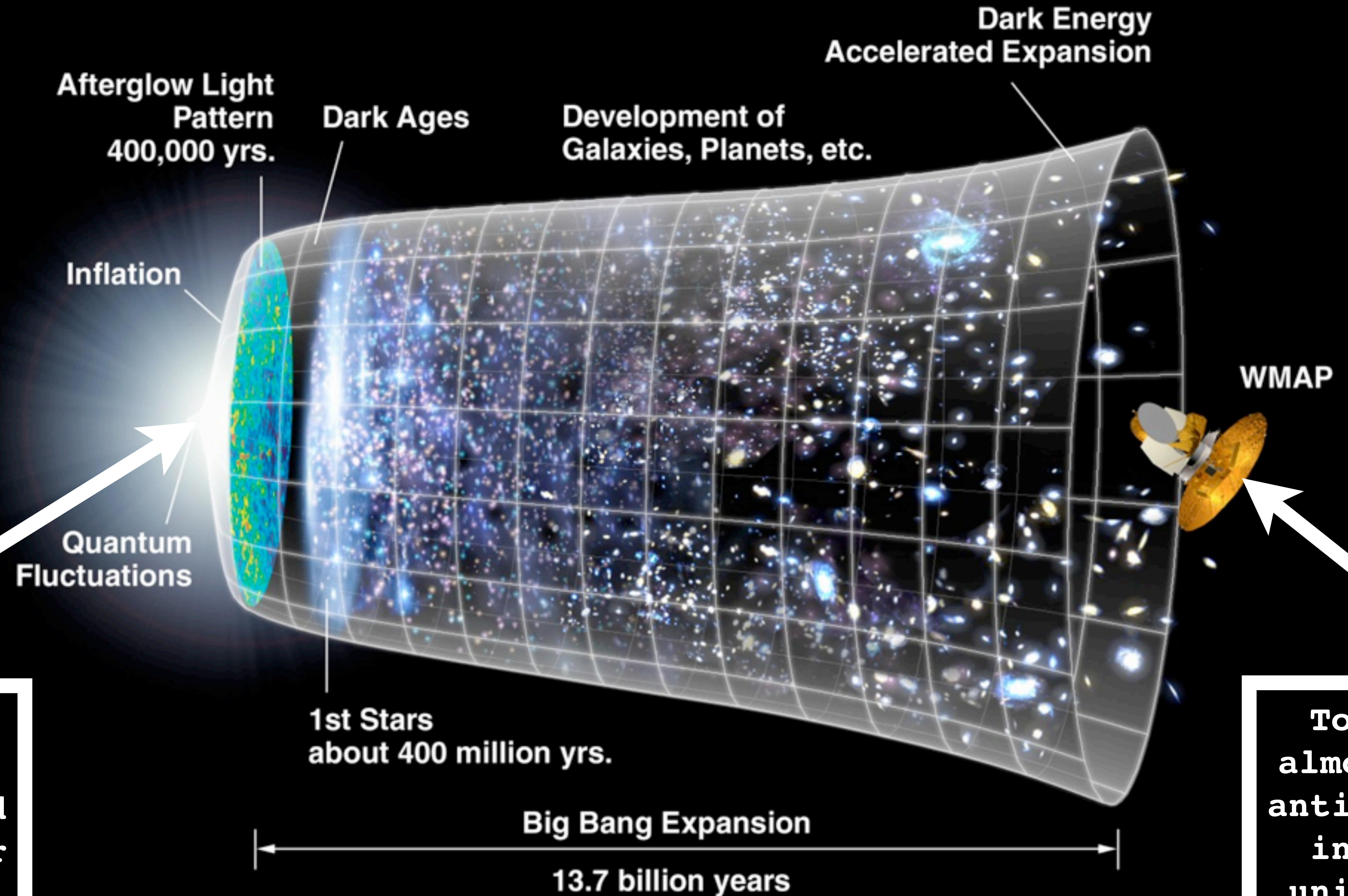
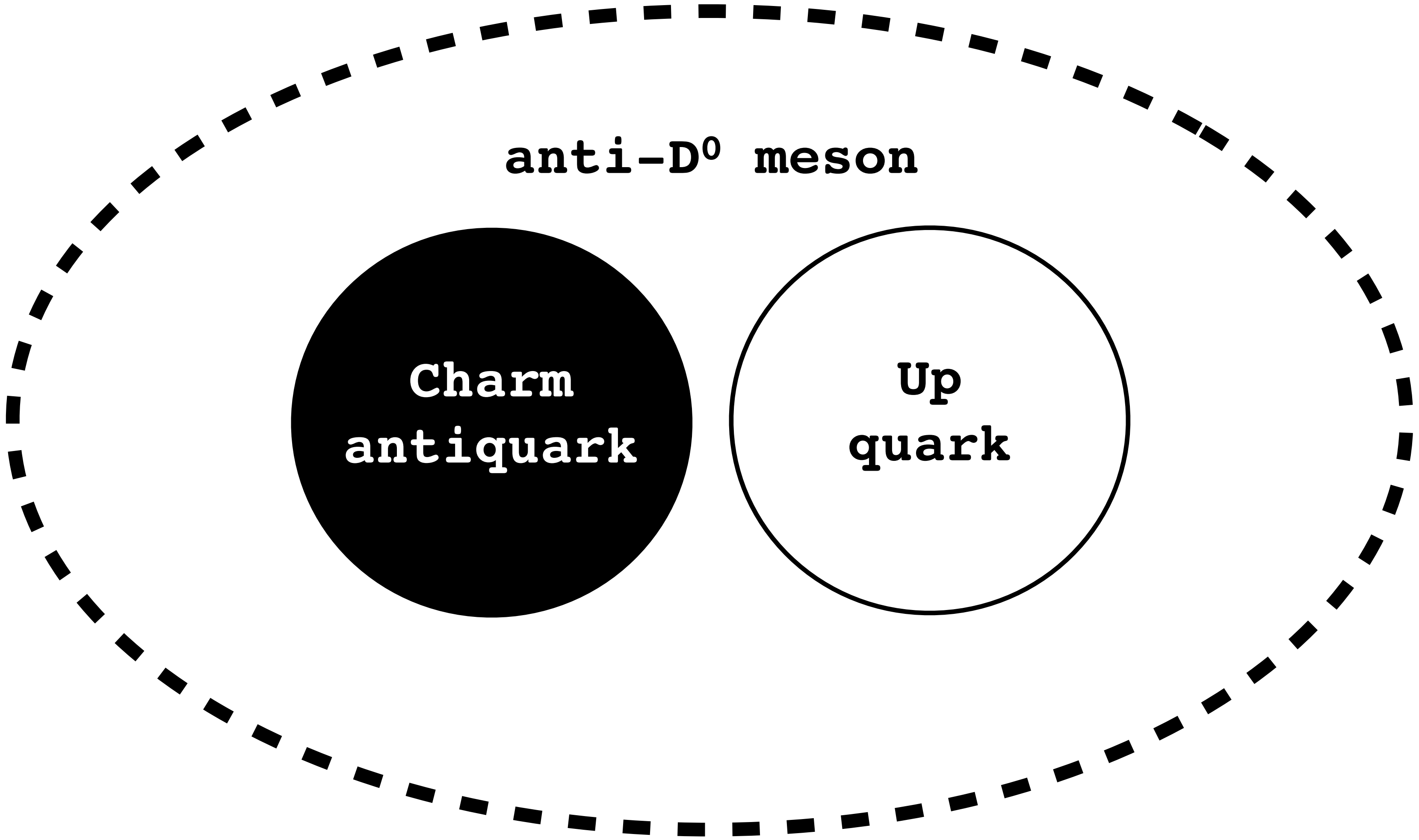


Equal amount of matter and antimatter created

Today: almost no antimatter in the universe

So where did all the antimatter go?

It oscillates!



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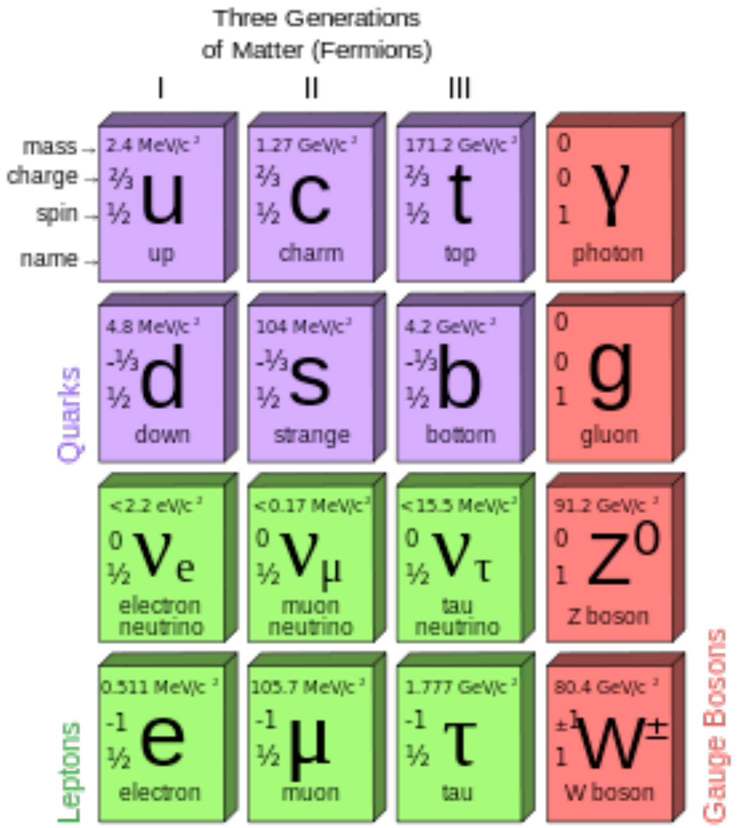
Such particles can give us insight into small differences between matter and antimatter.

Why the D^0 and not another particle?



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

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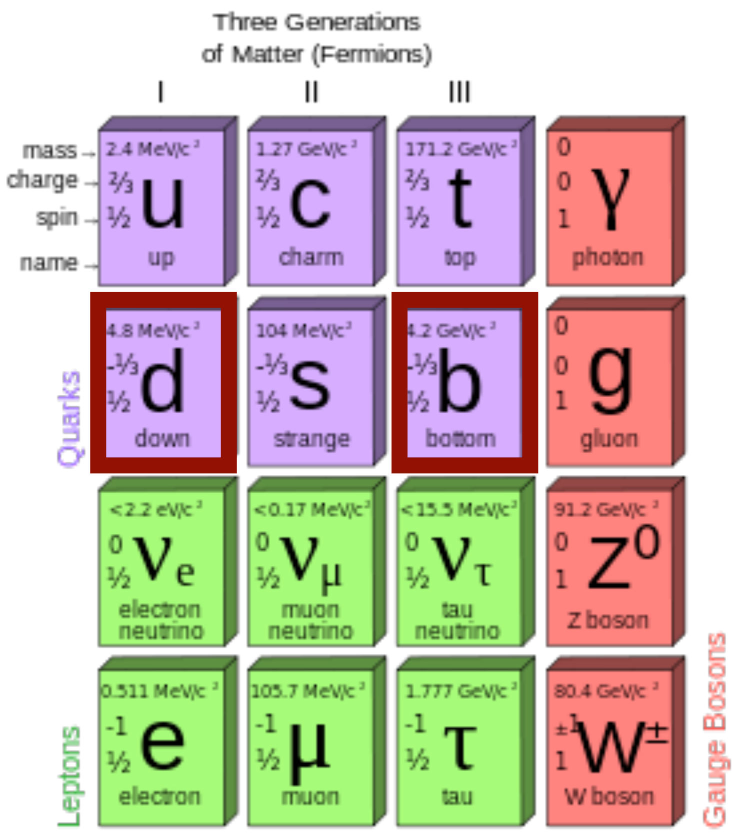
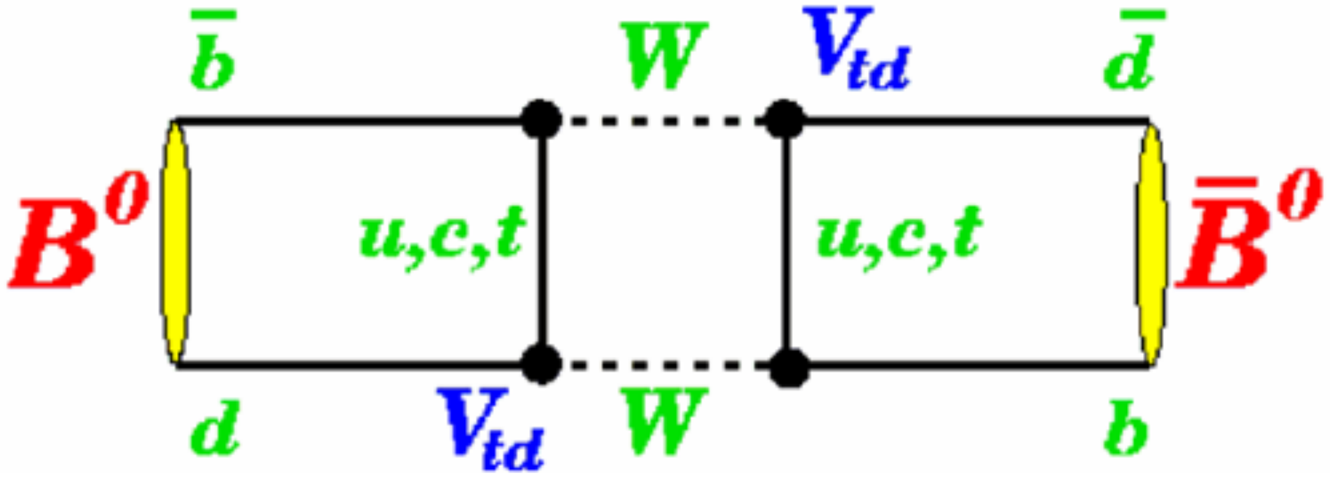


Neutral mesons can oscillate between matter and anti-matter as they propagate

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



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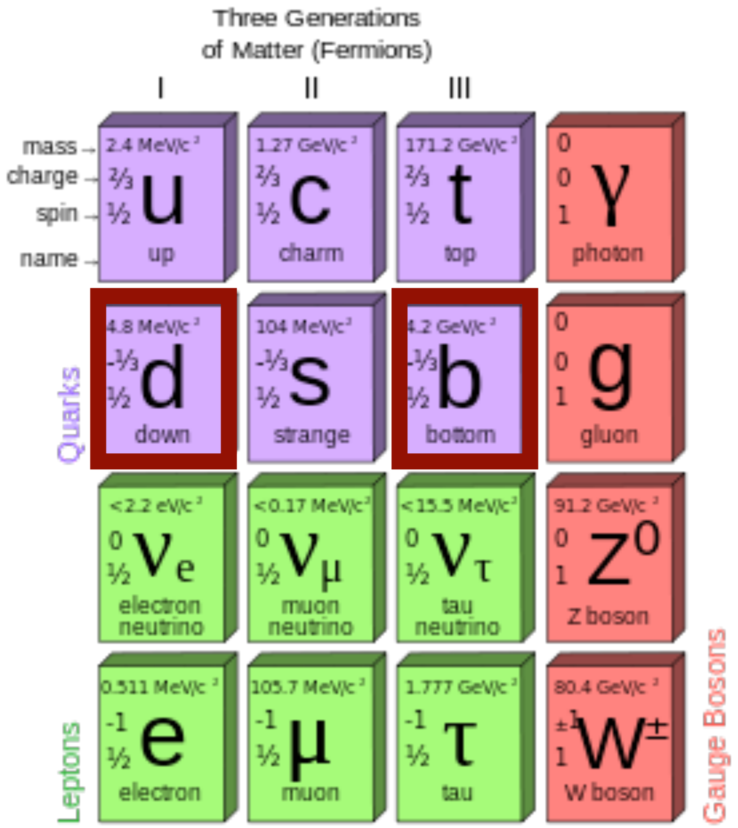

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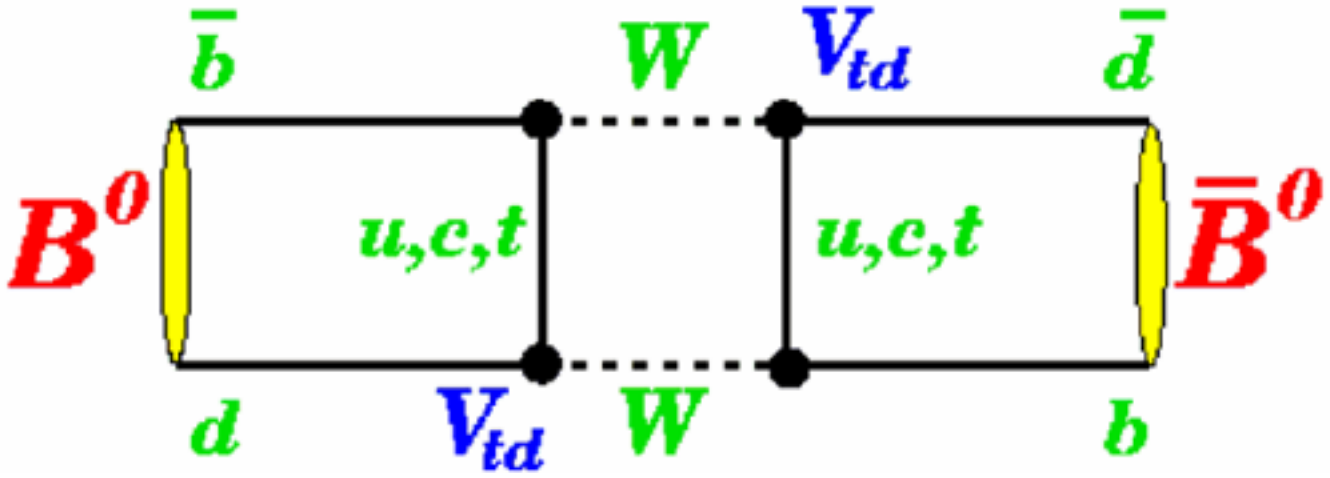

Oscillations are interesting because they are sensitive to new particles appearing virtually inside the box diagram, which can be very much heavier than directly produced particles

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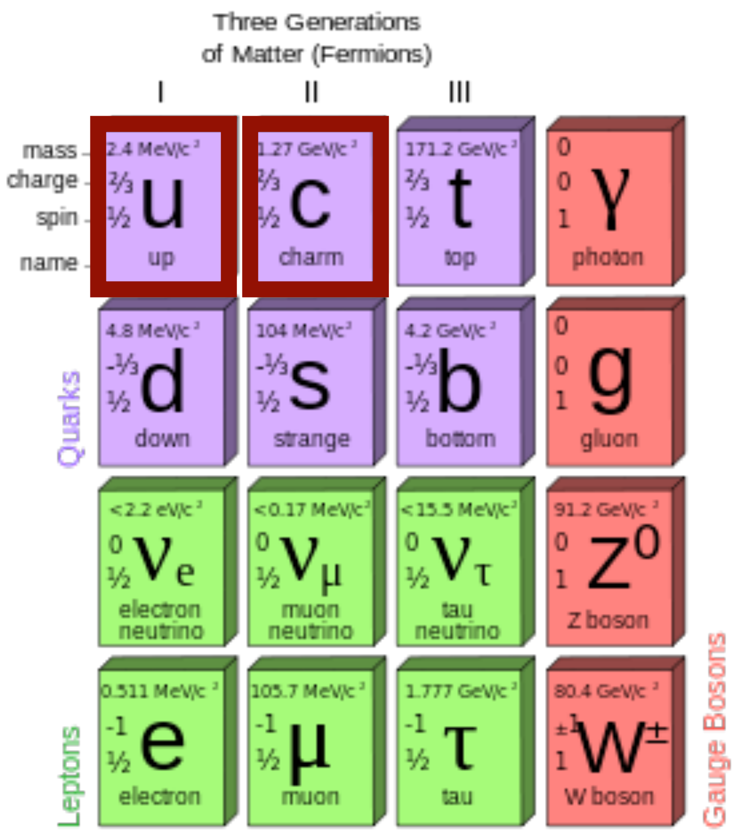


Neutral mesons can oscillate between matter and anti-matter as they propagate

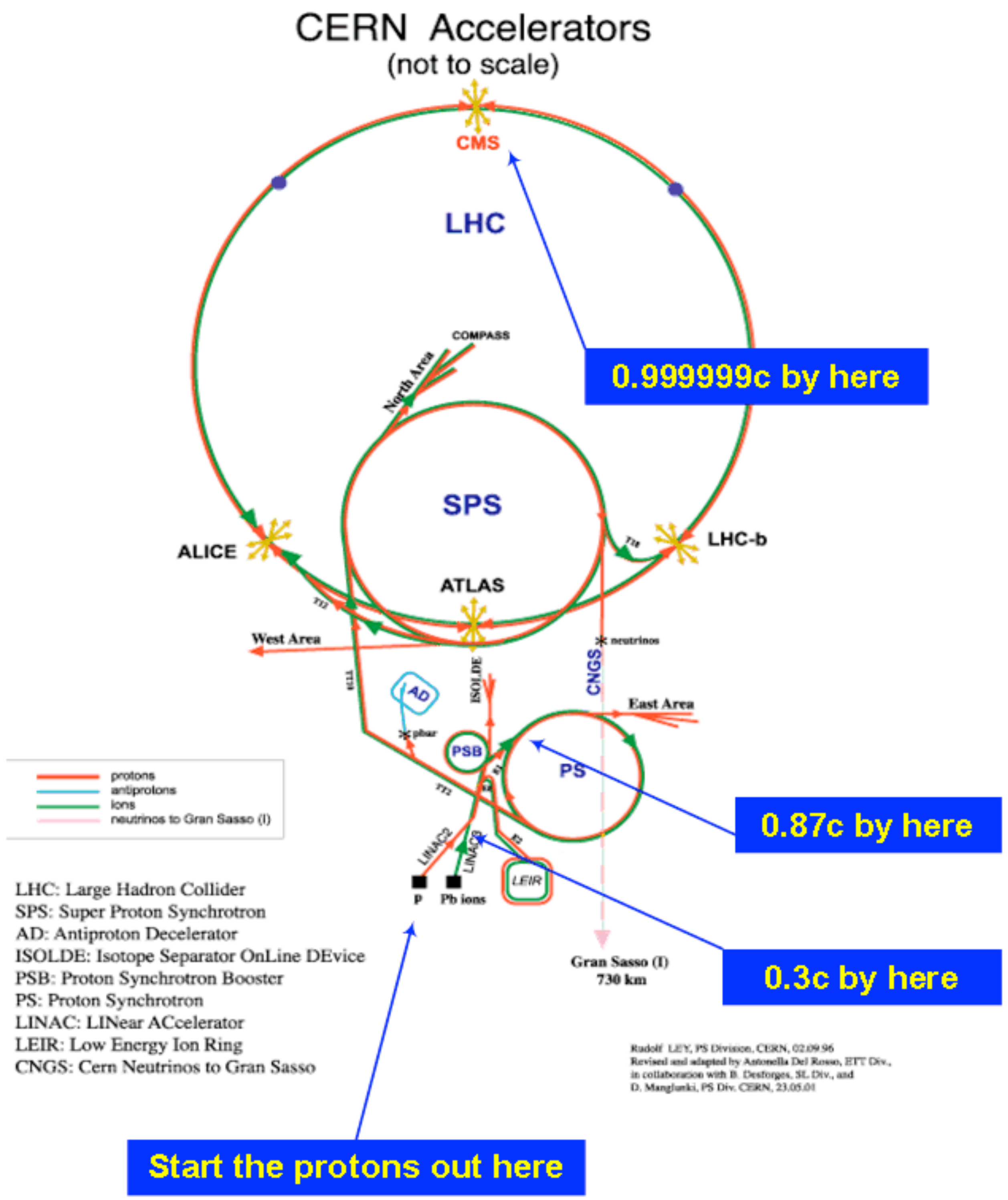
There are several different "down-type" mesons which oscillate : (ds) K^0, (db) B_d, (sb) B_s

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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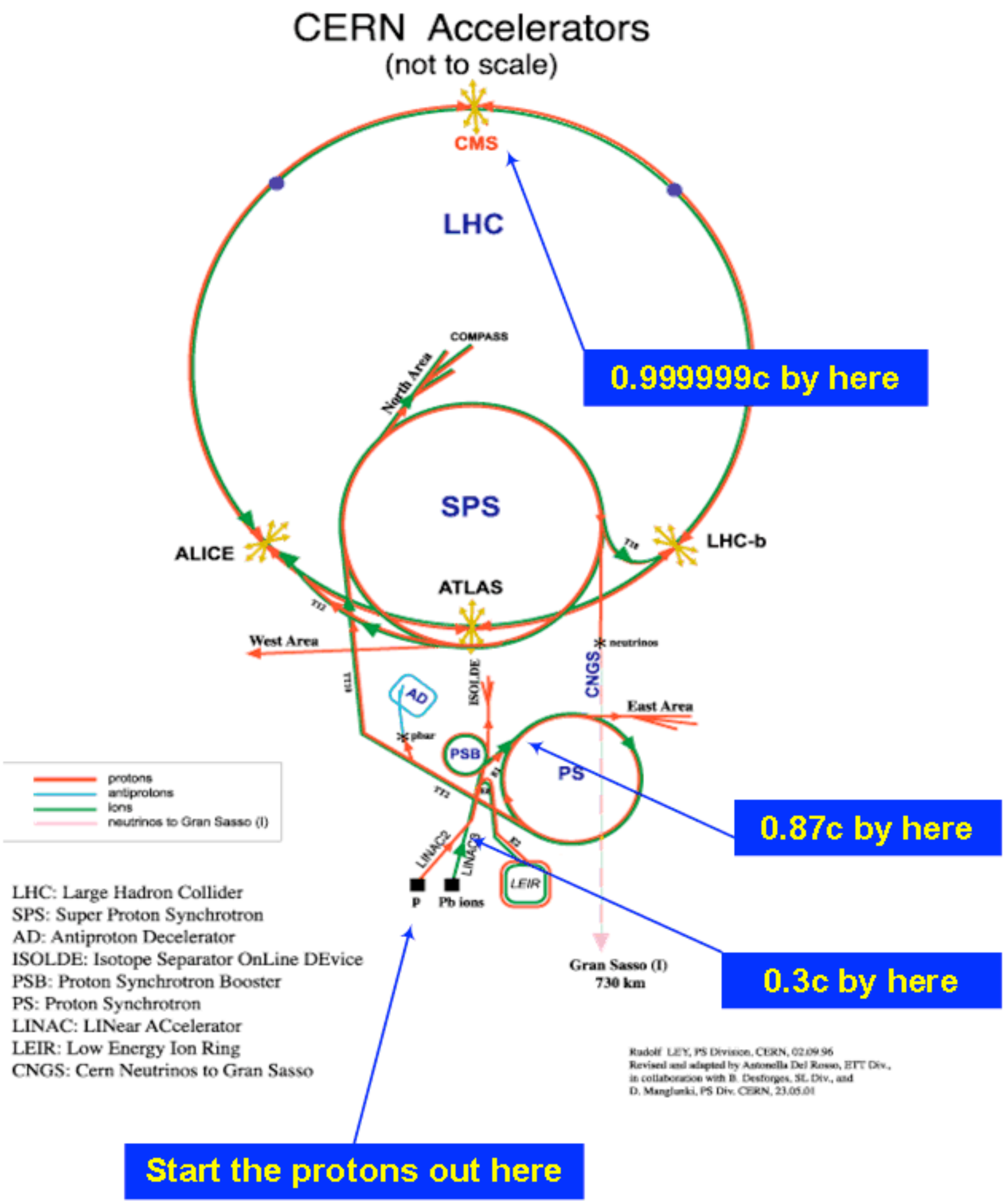

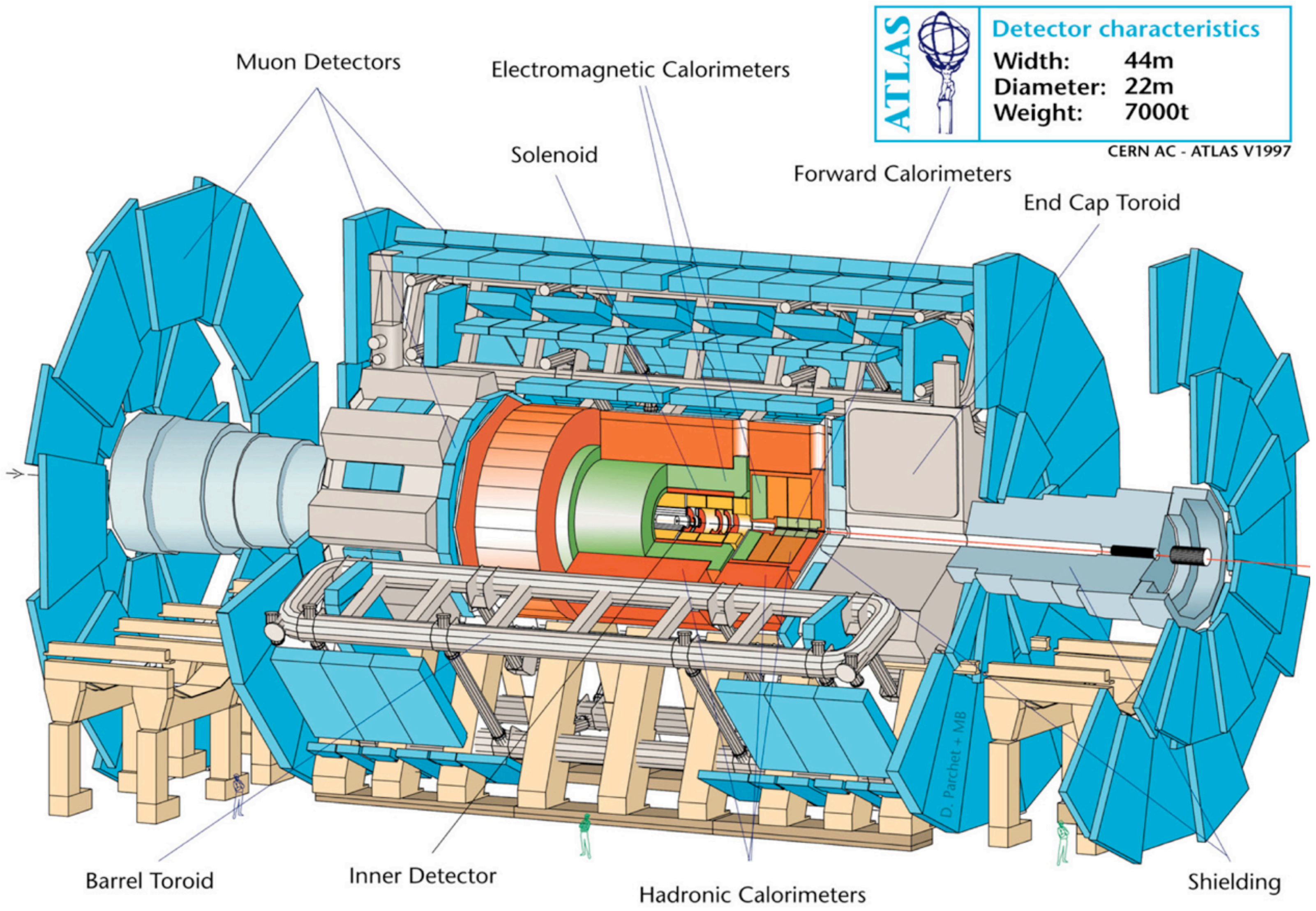

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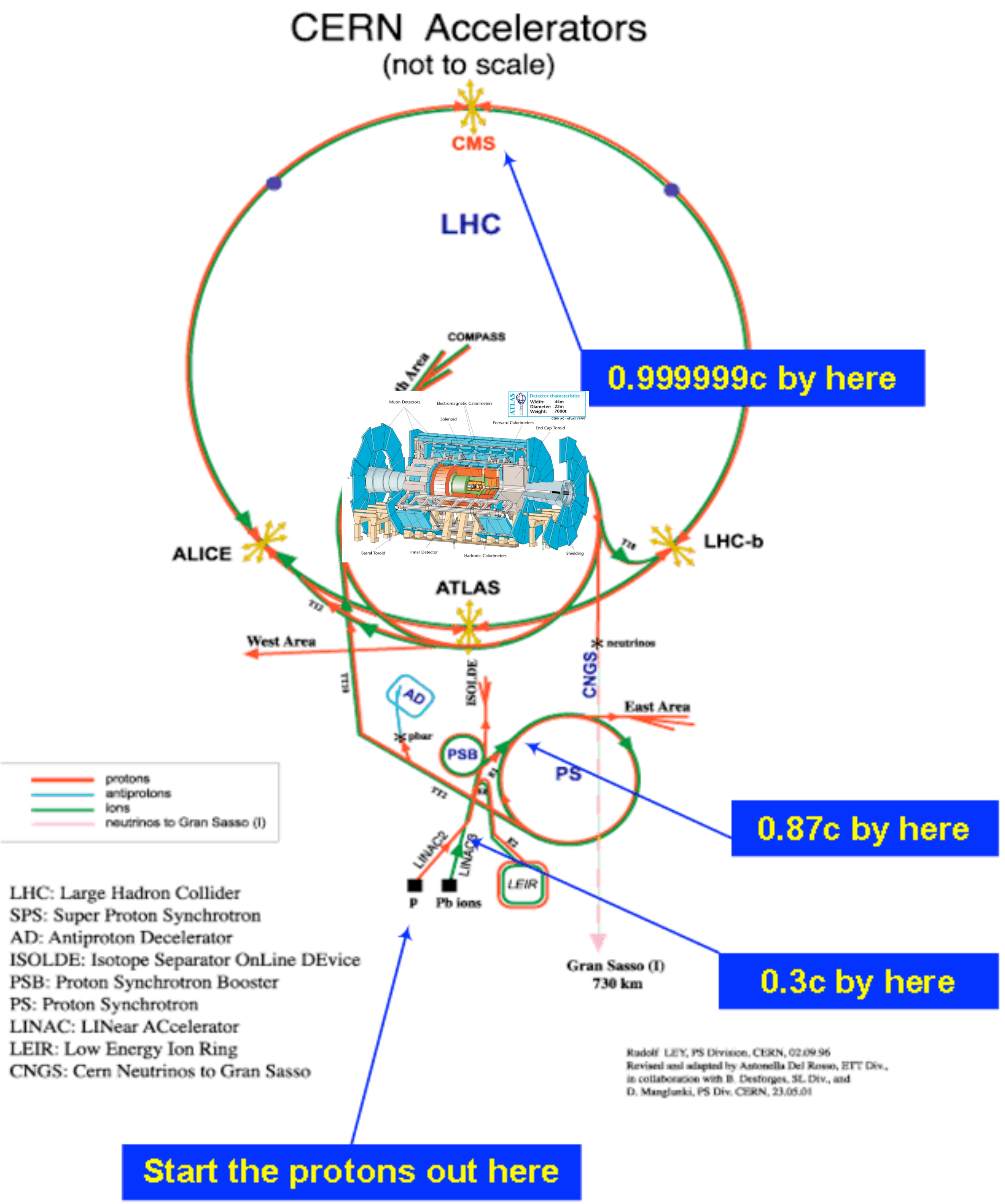

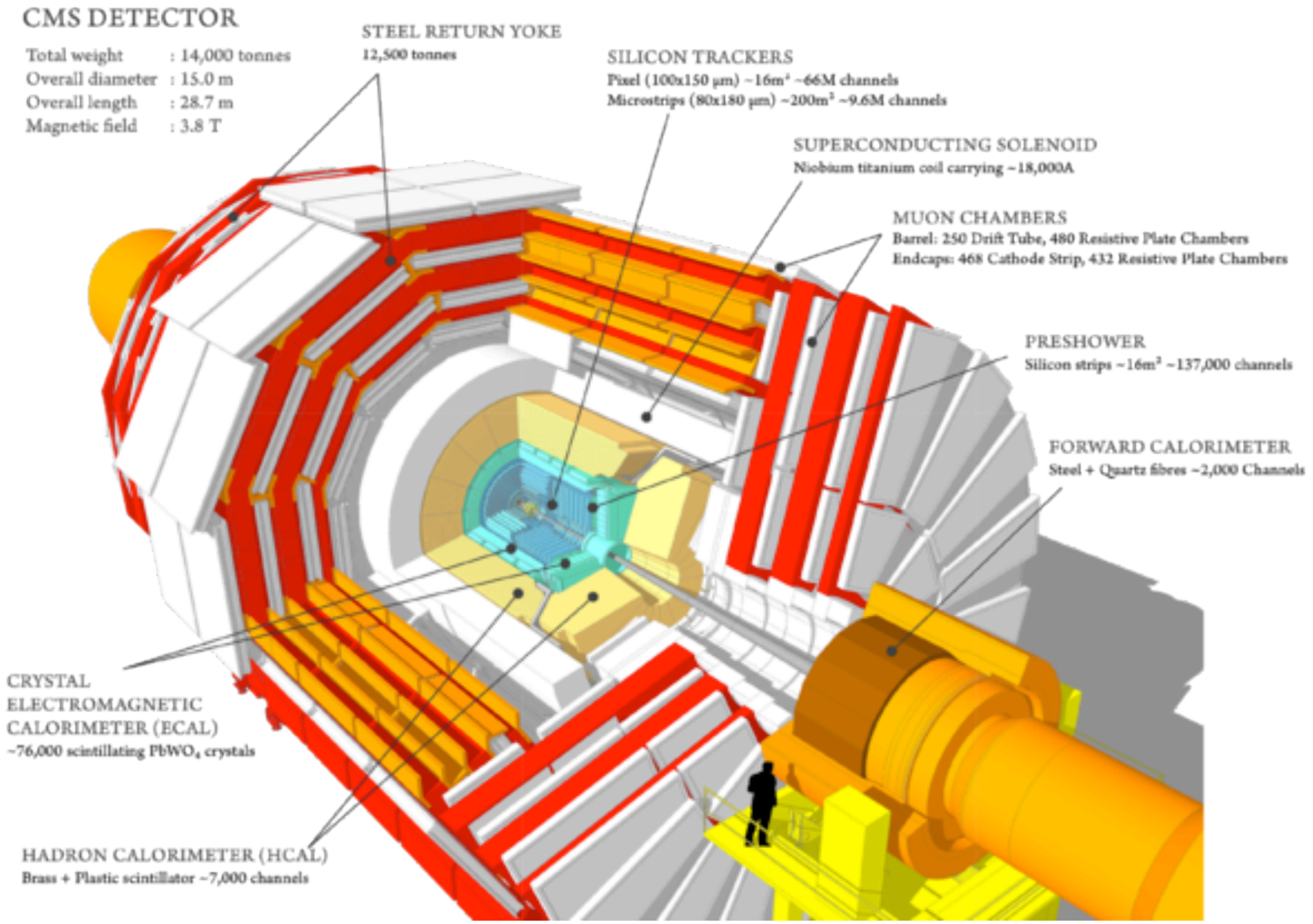

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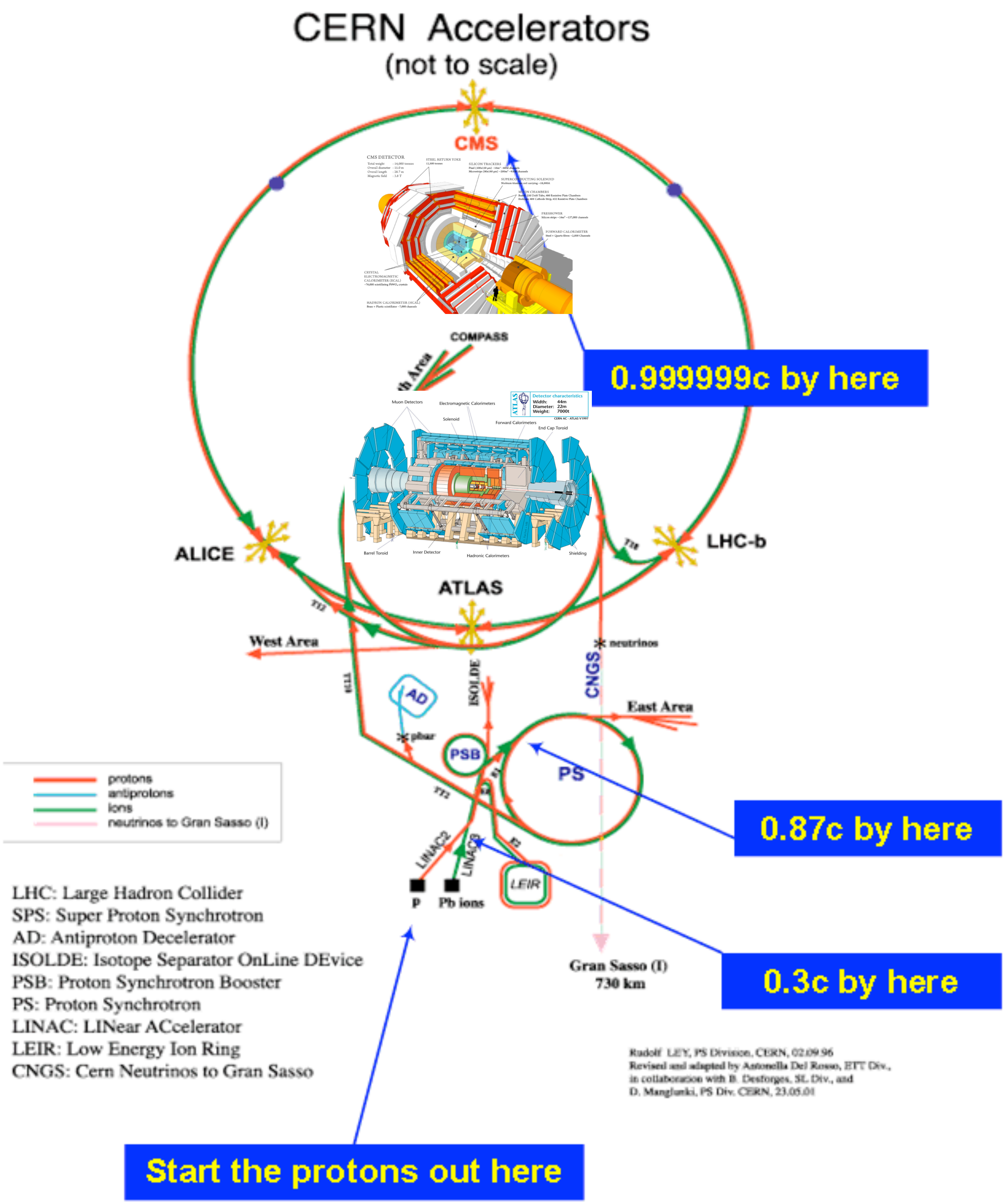

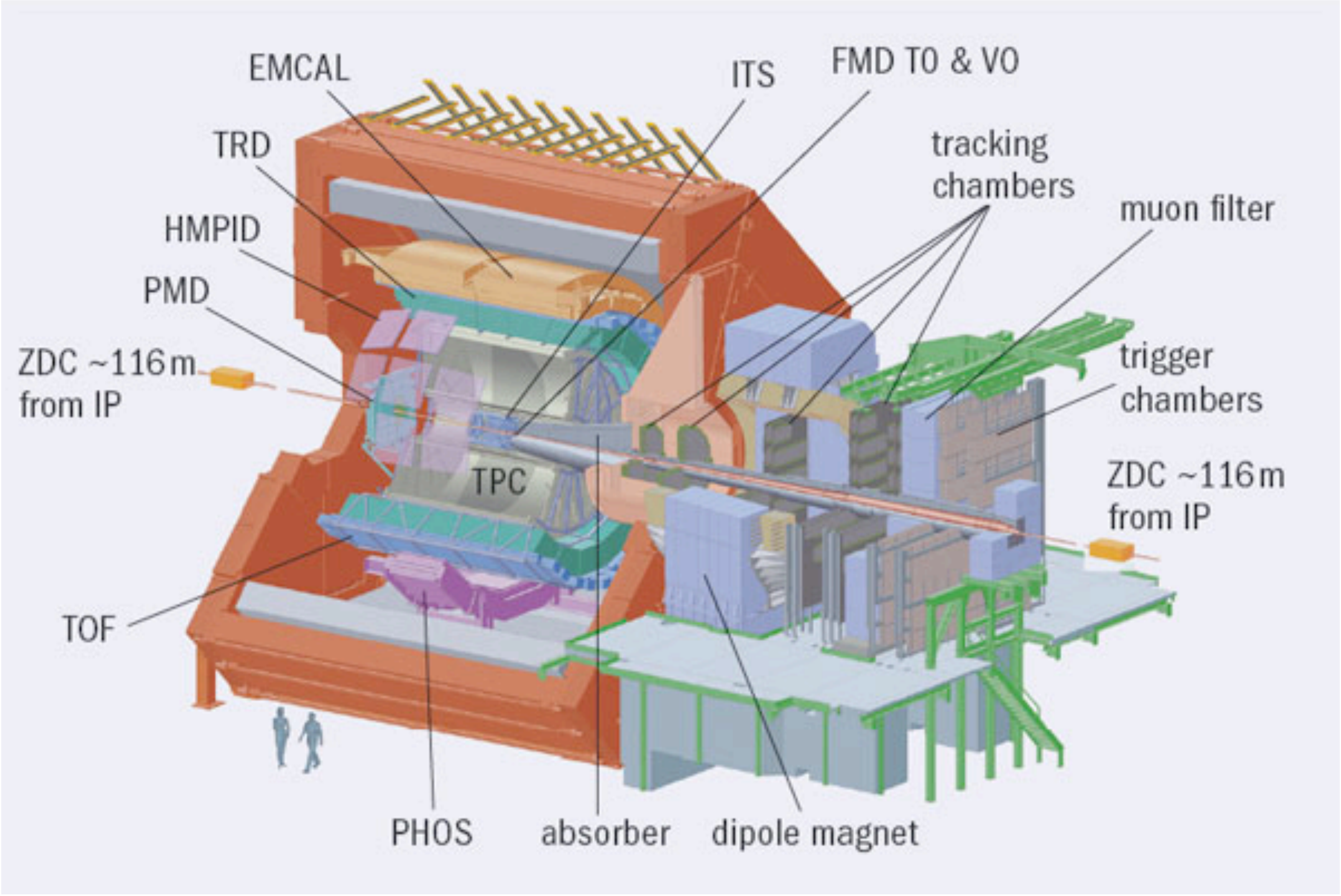

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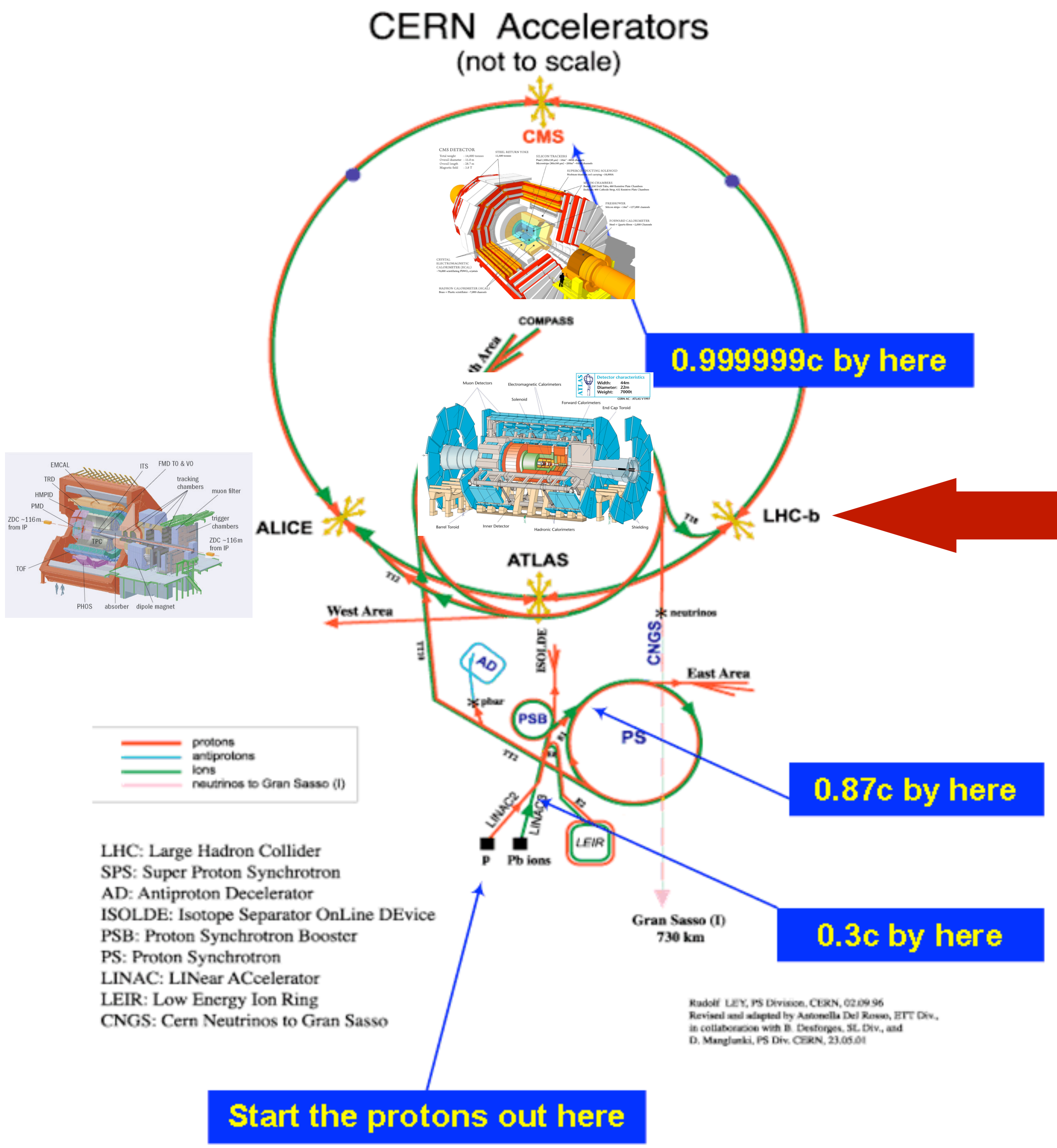
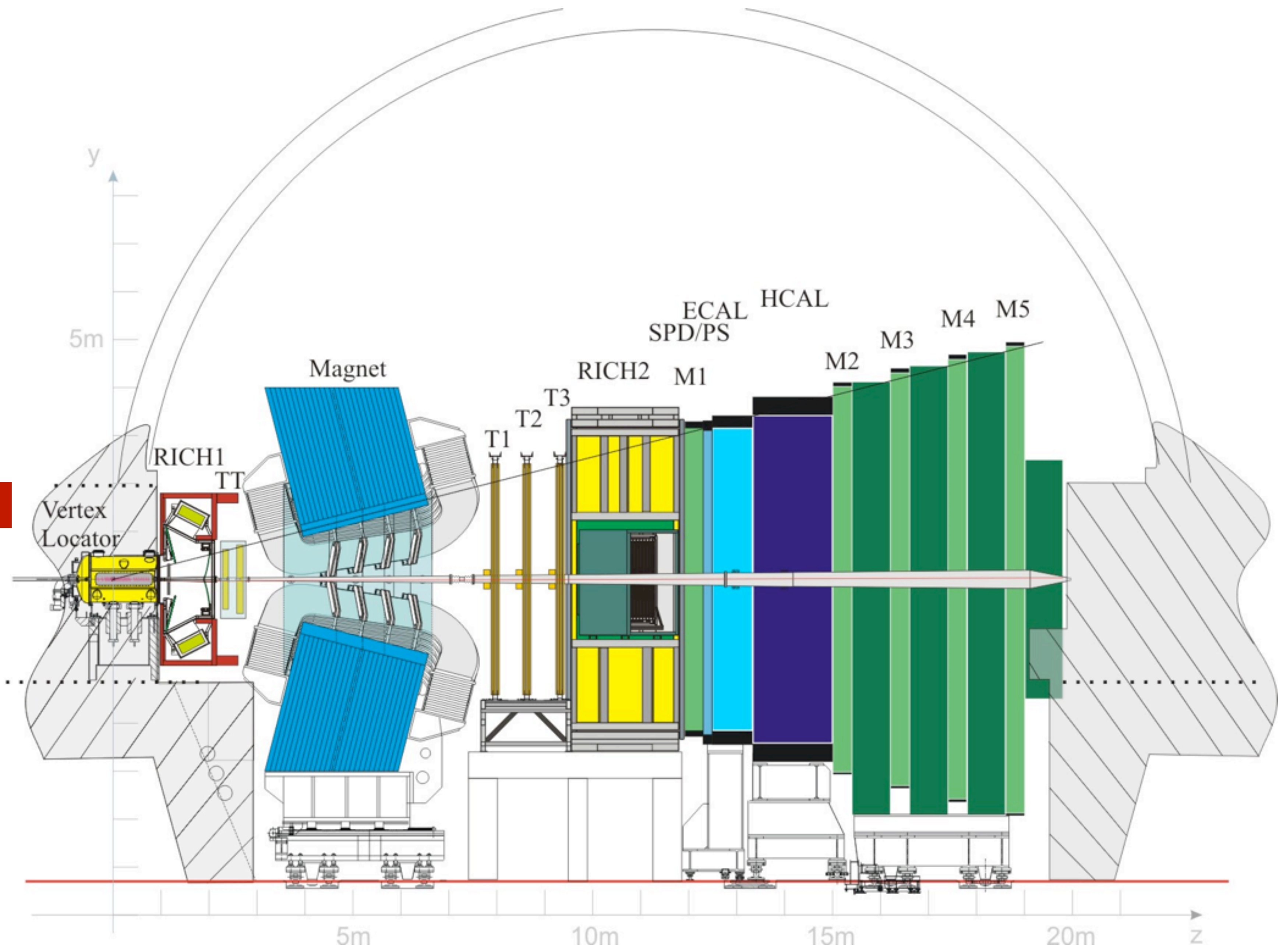
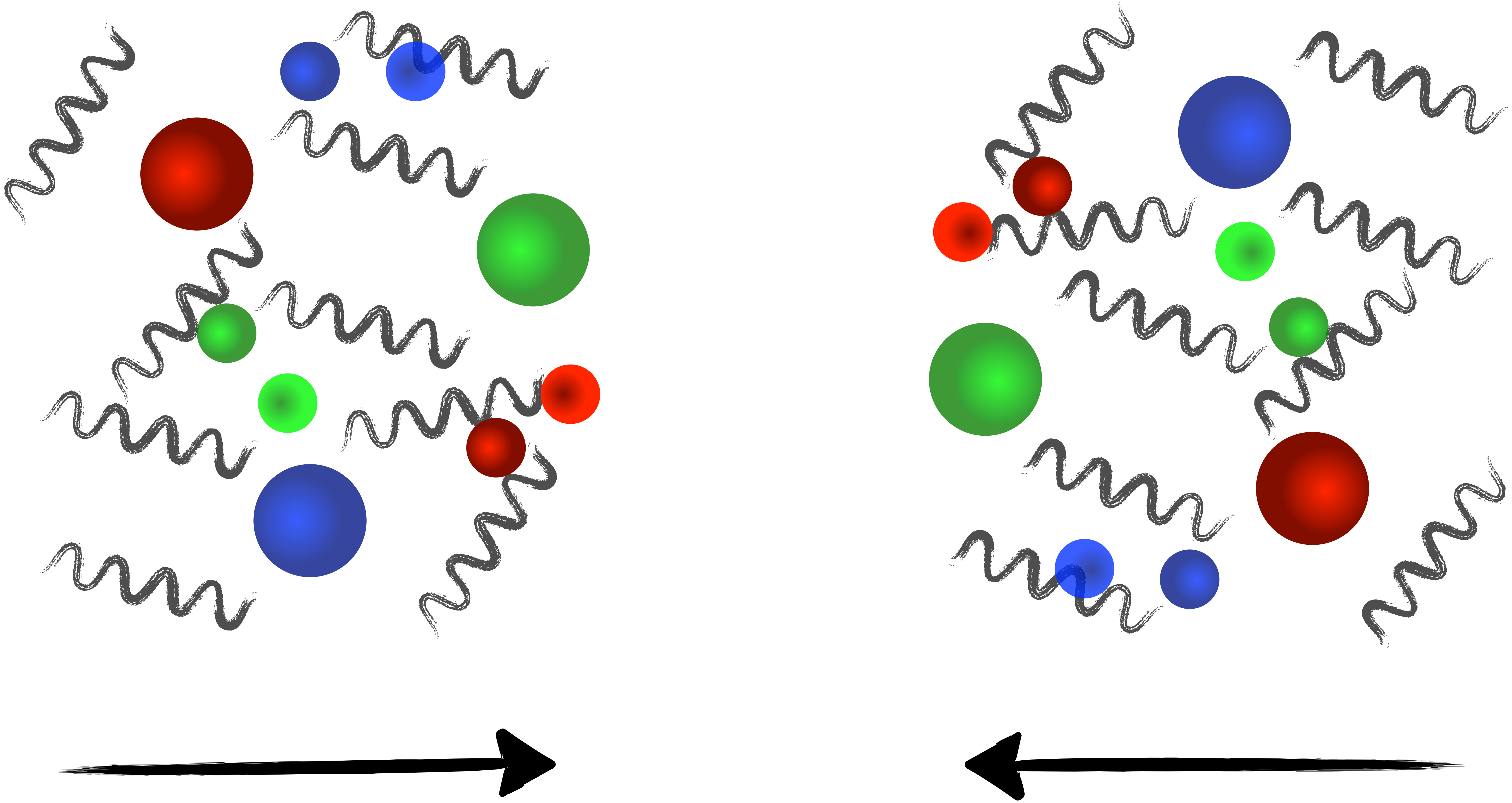




Protons colliding…



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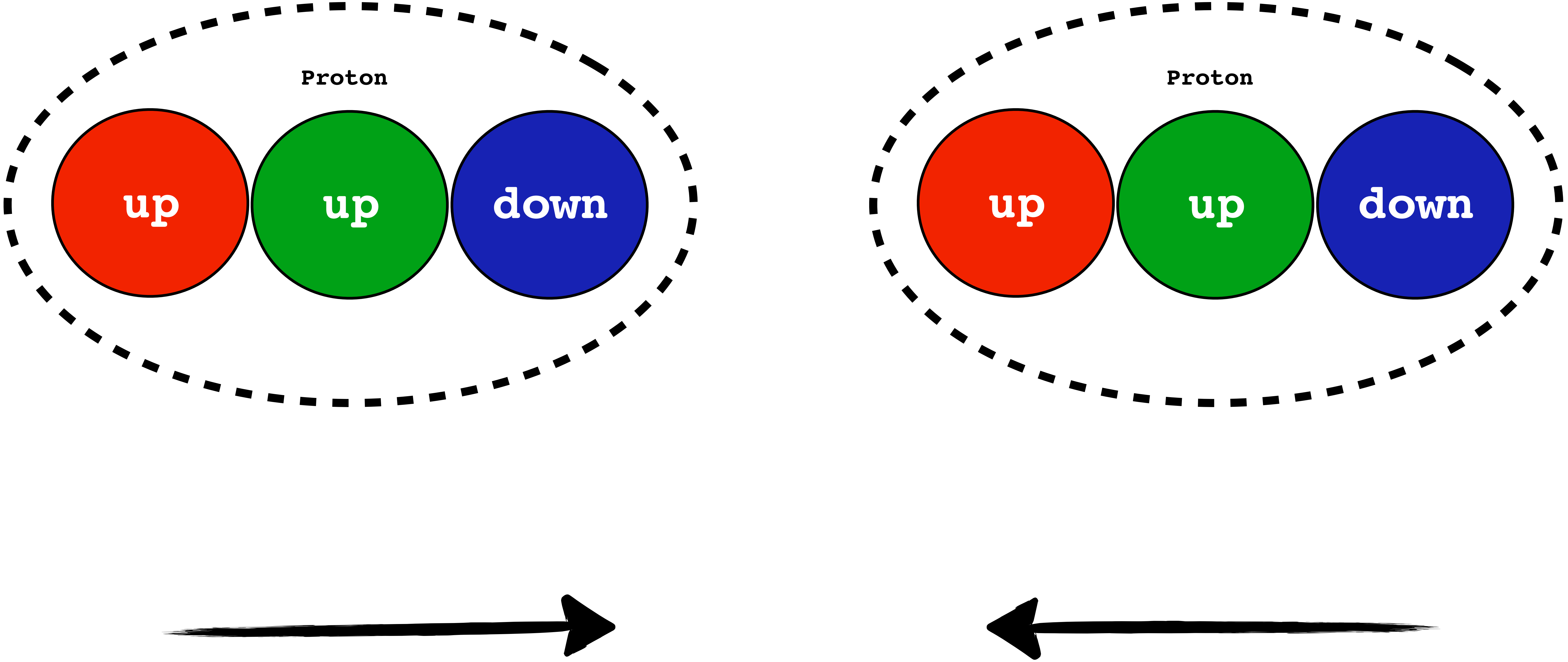

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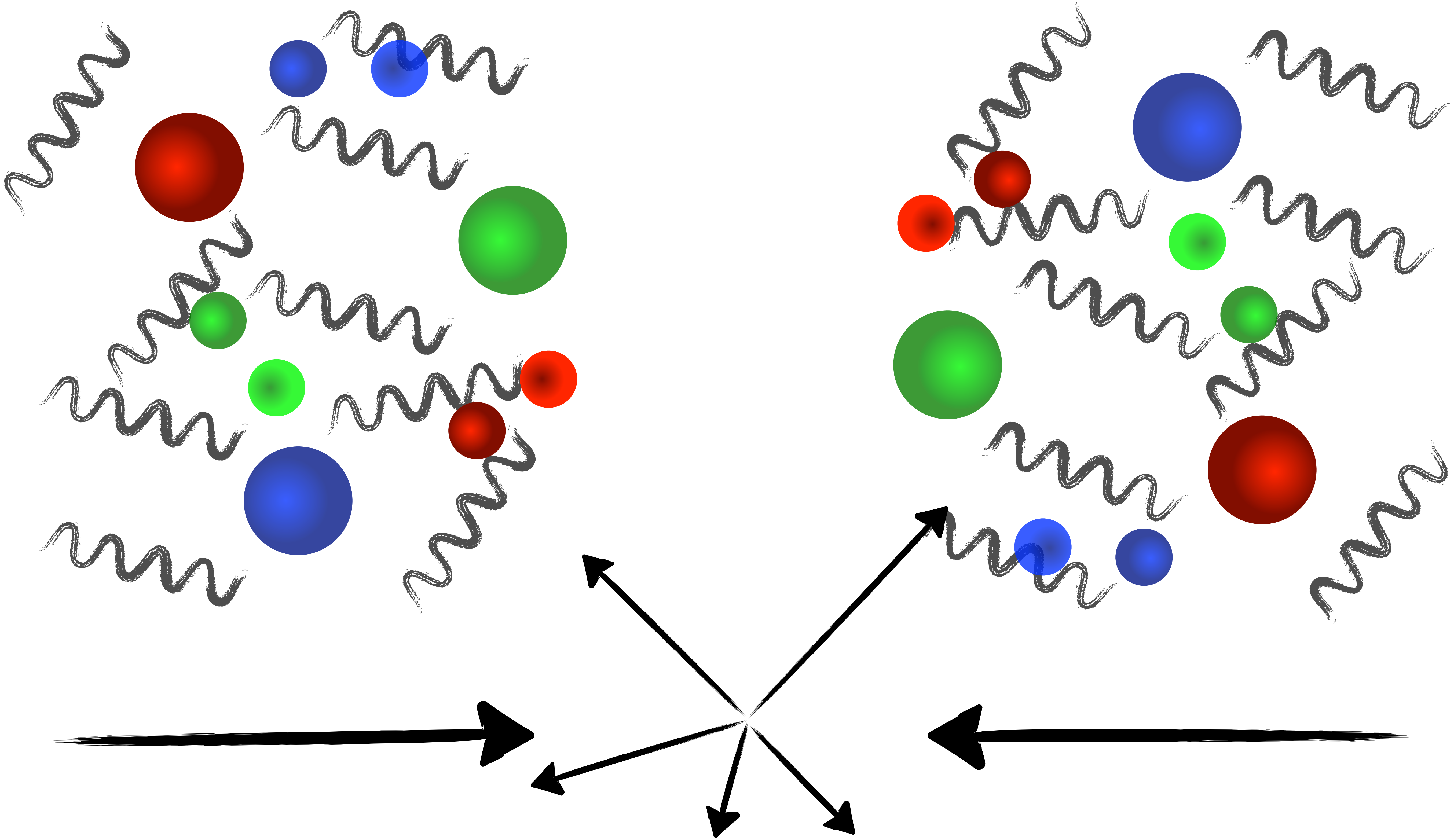

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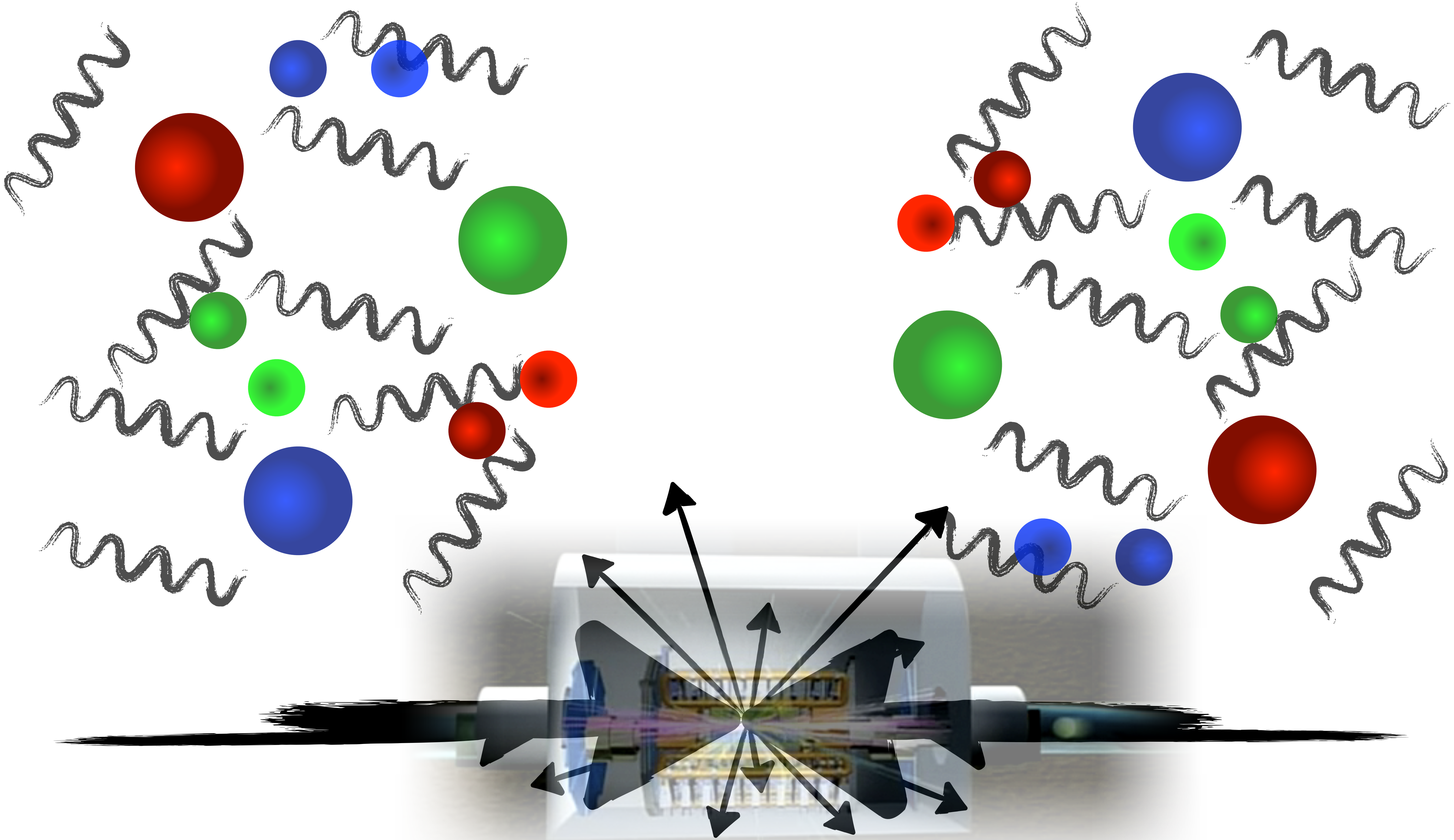
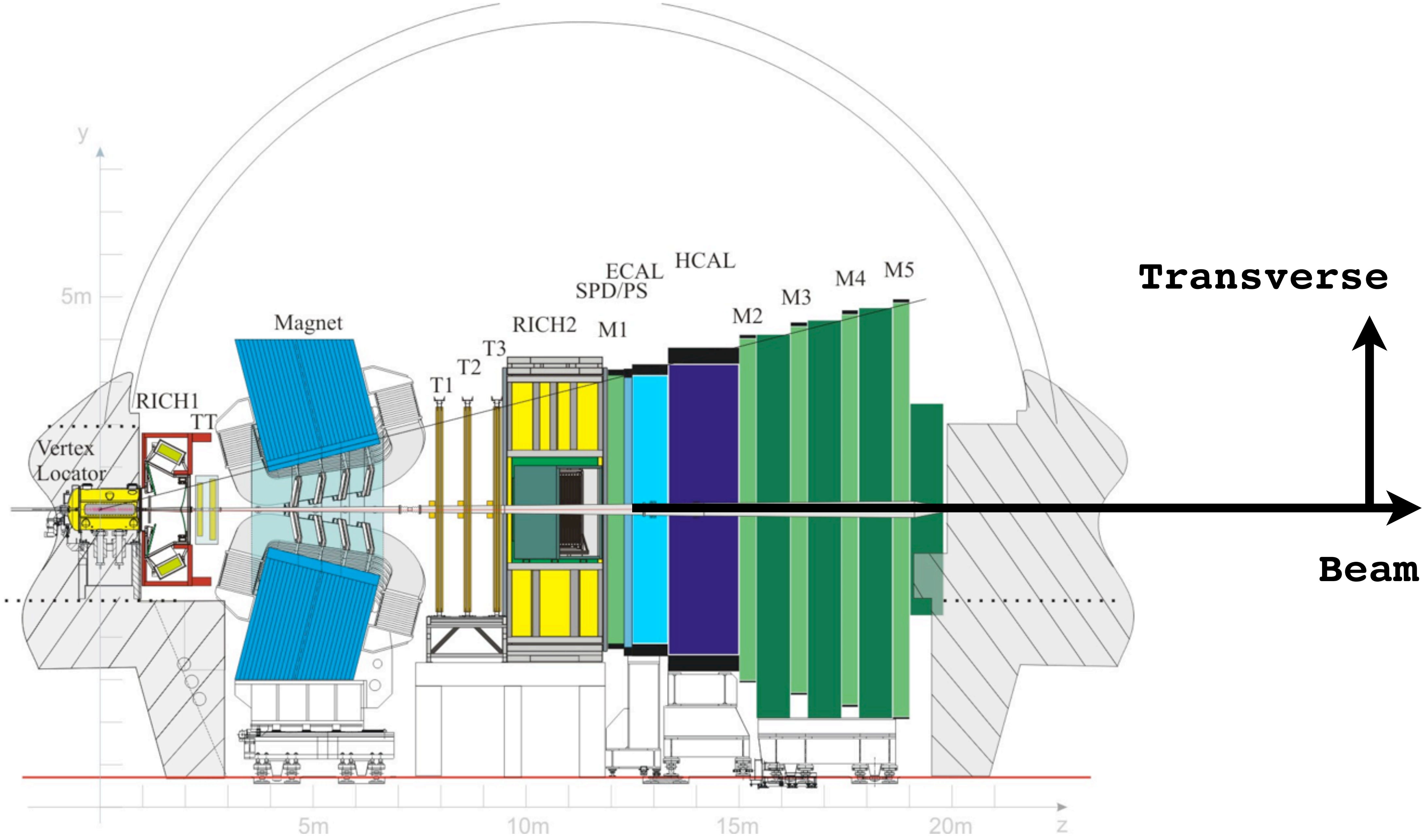


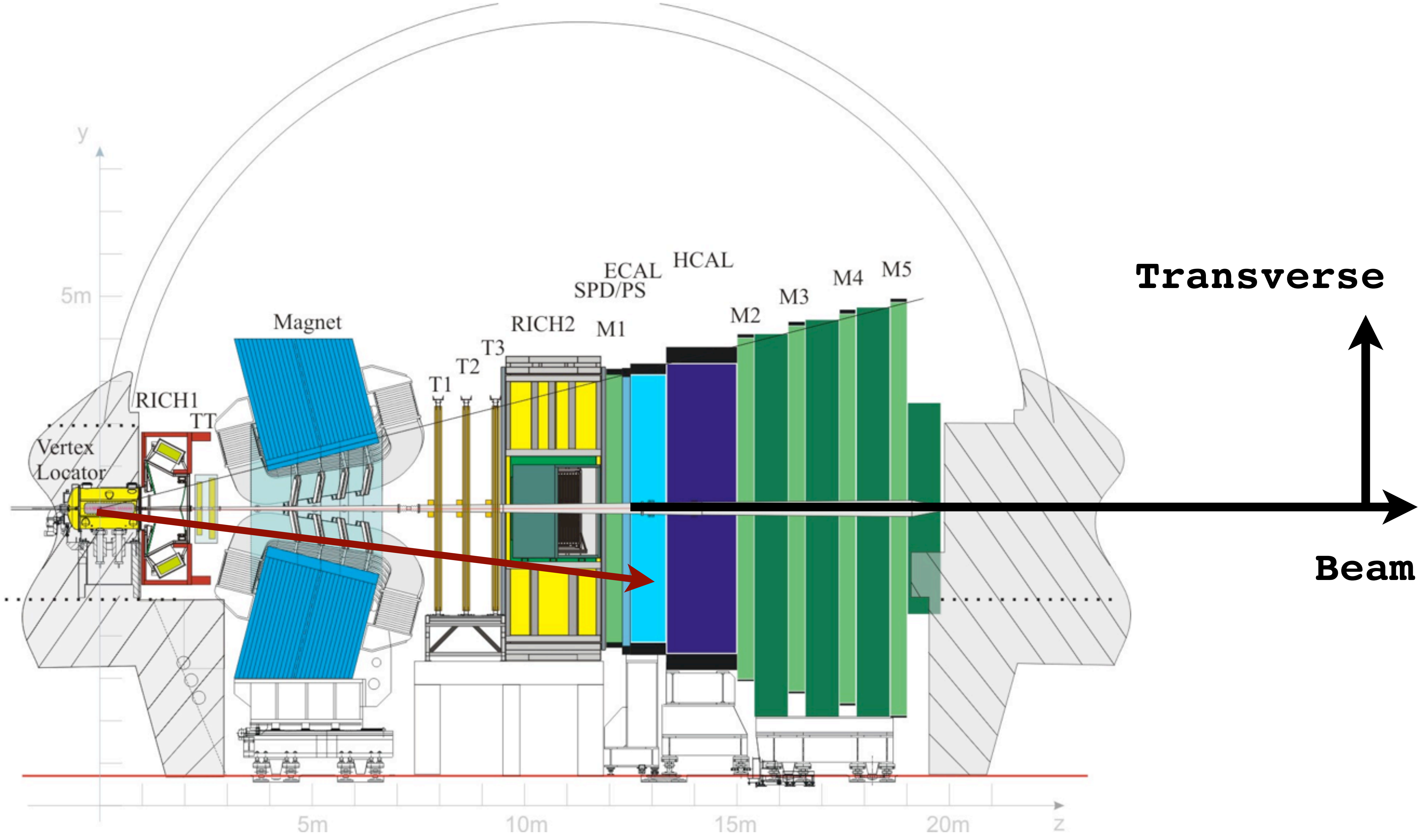
LHCb @ LHC



p_T = Transverse momentum
E_T = Transverse energy

LHCb @ LHC

- ➡ **ELECTRONS**
- ➡ **PHOTONS**



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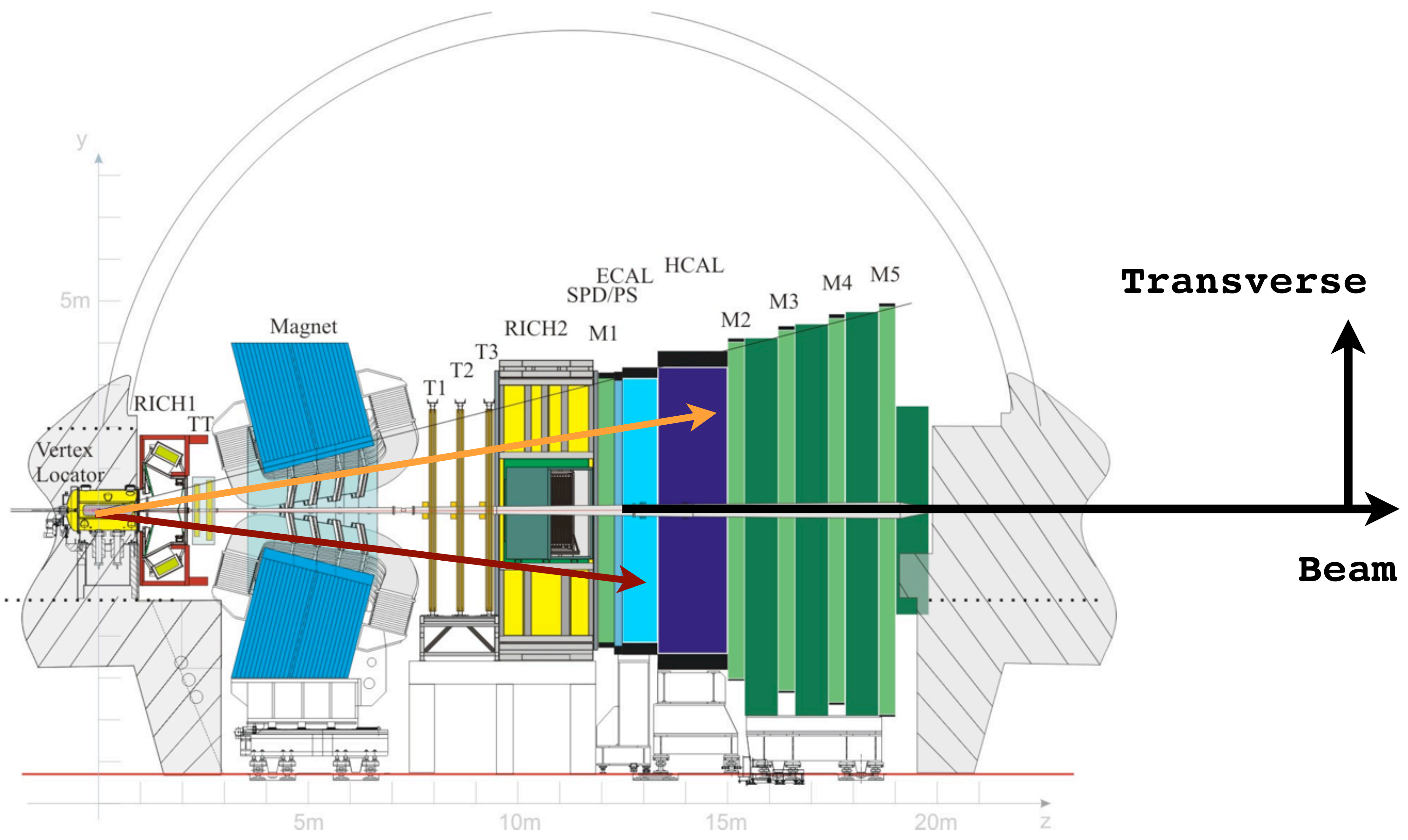

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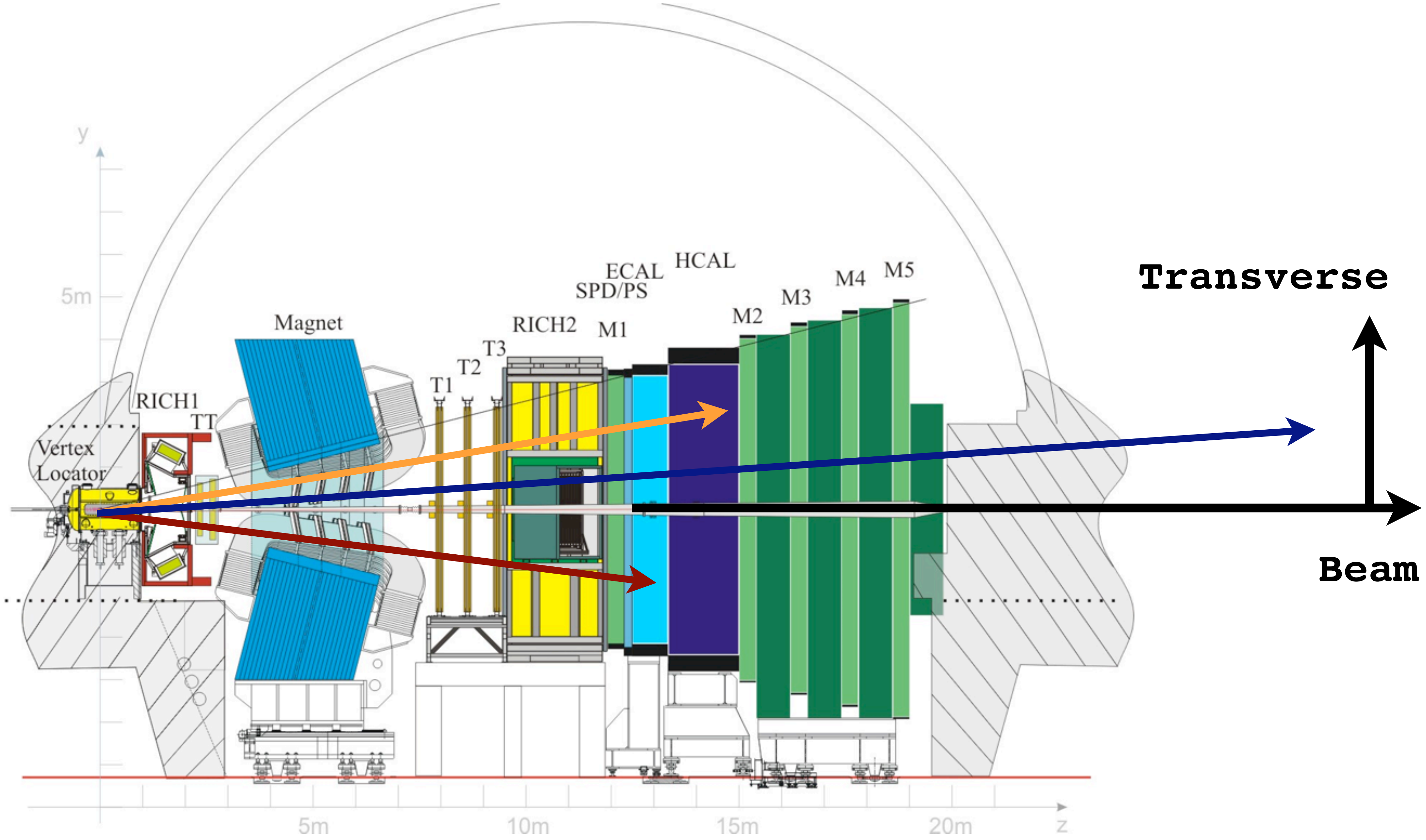

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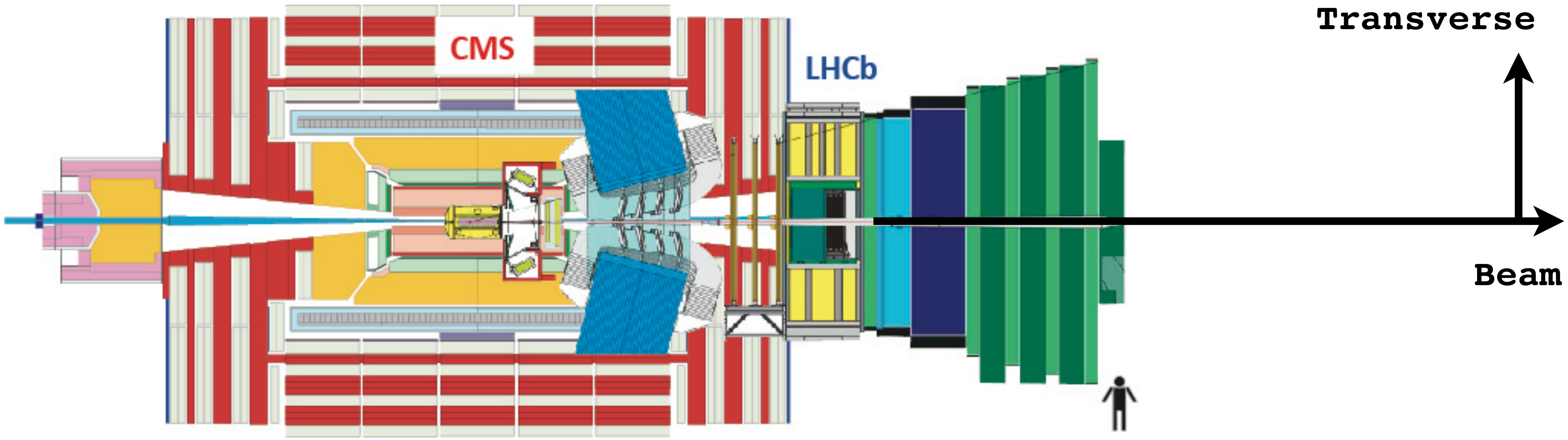
LHCb and CMS geometries compared



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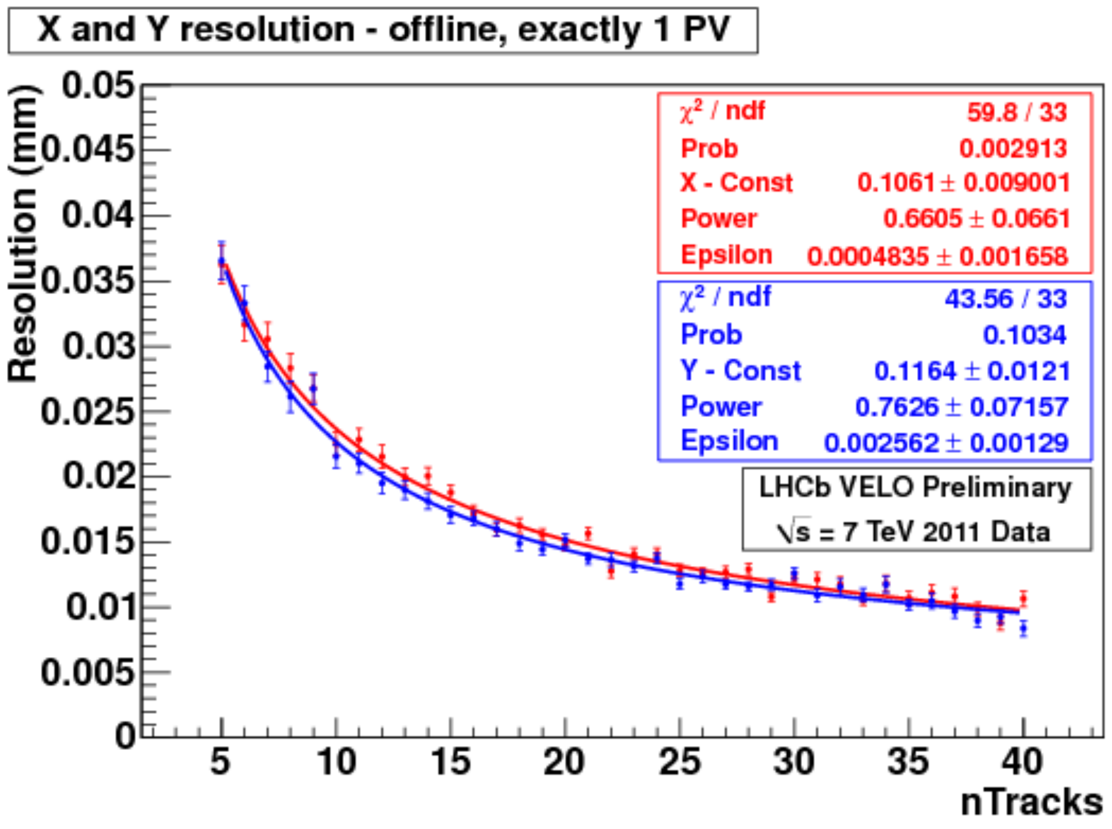
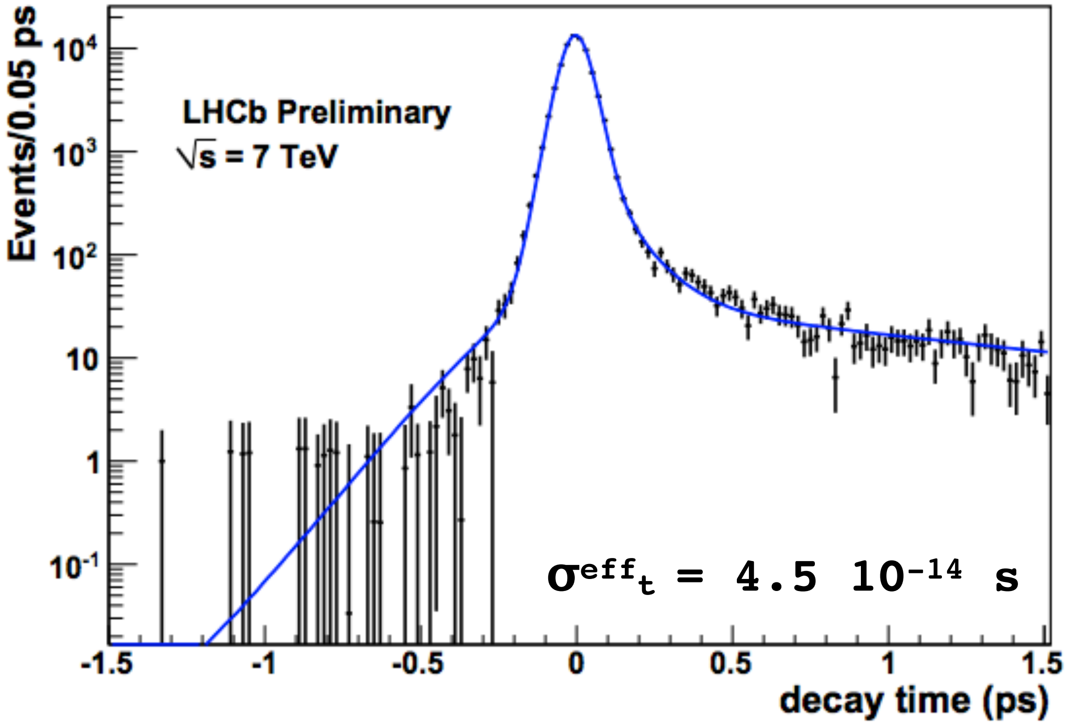
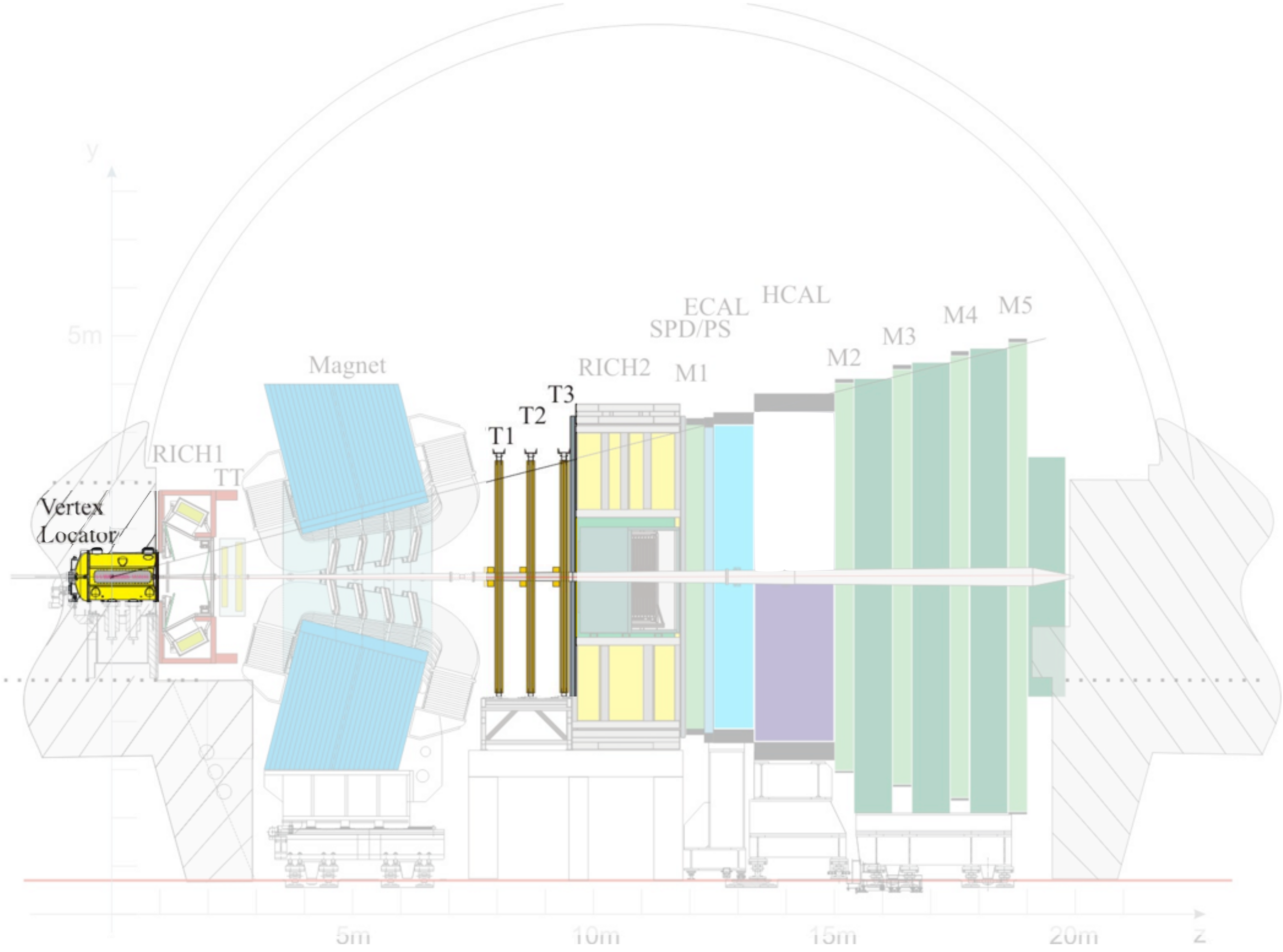
LHCb performance





$\sigma^{eff}_t = 4.5\ 10^{-14}$ s



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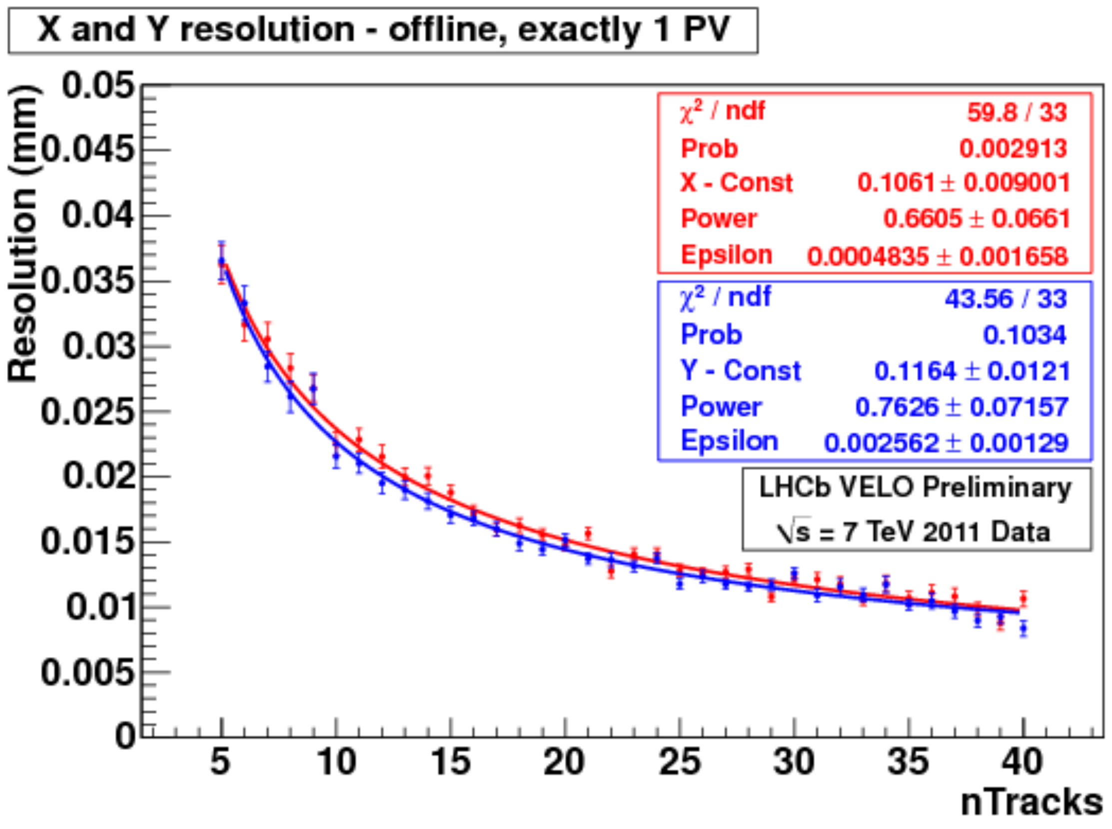

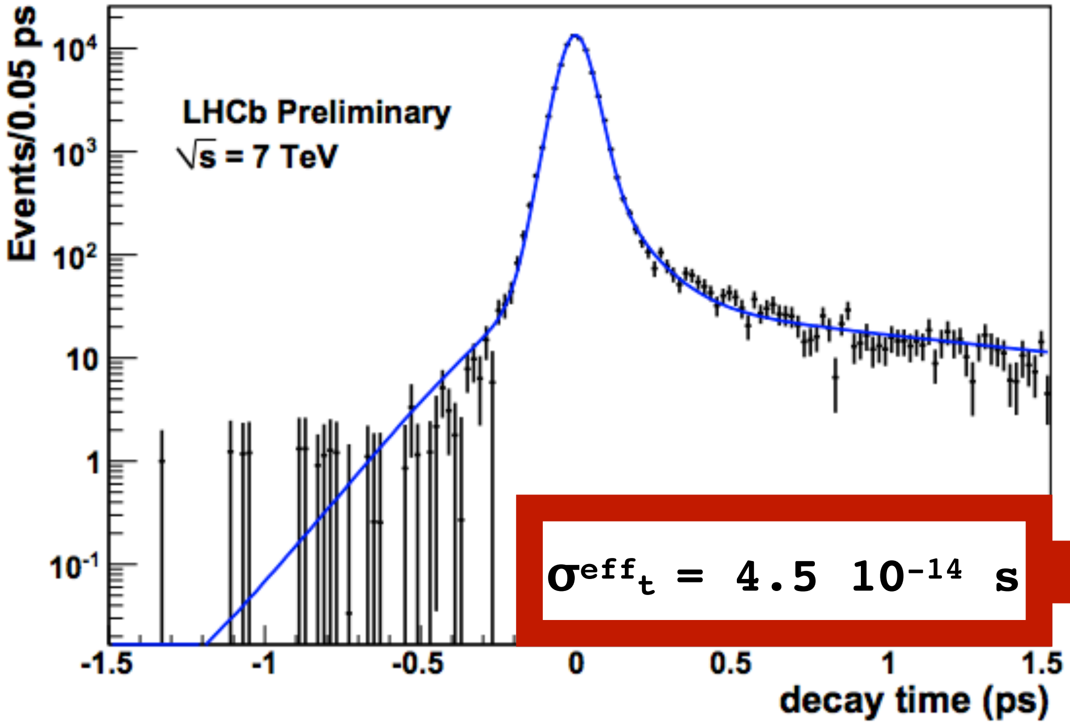

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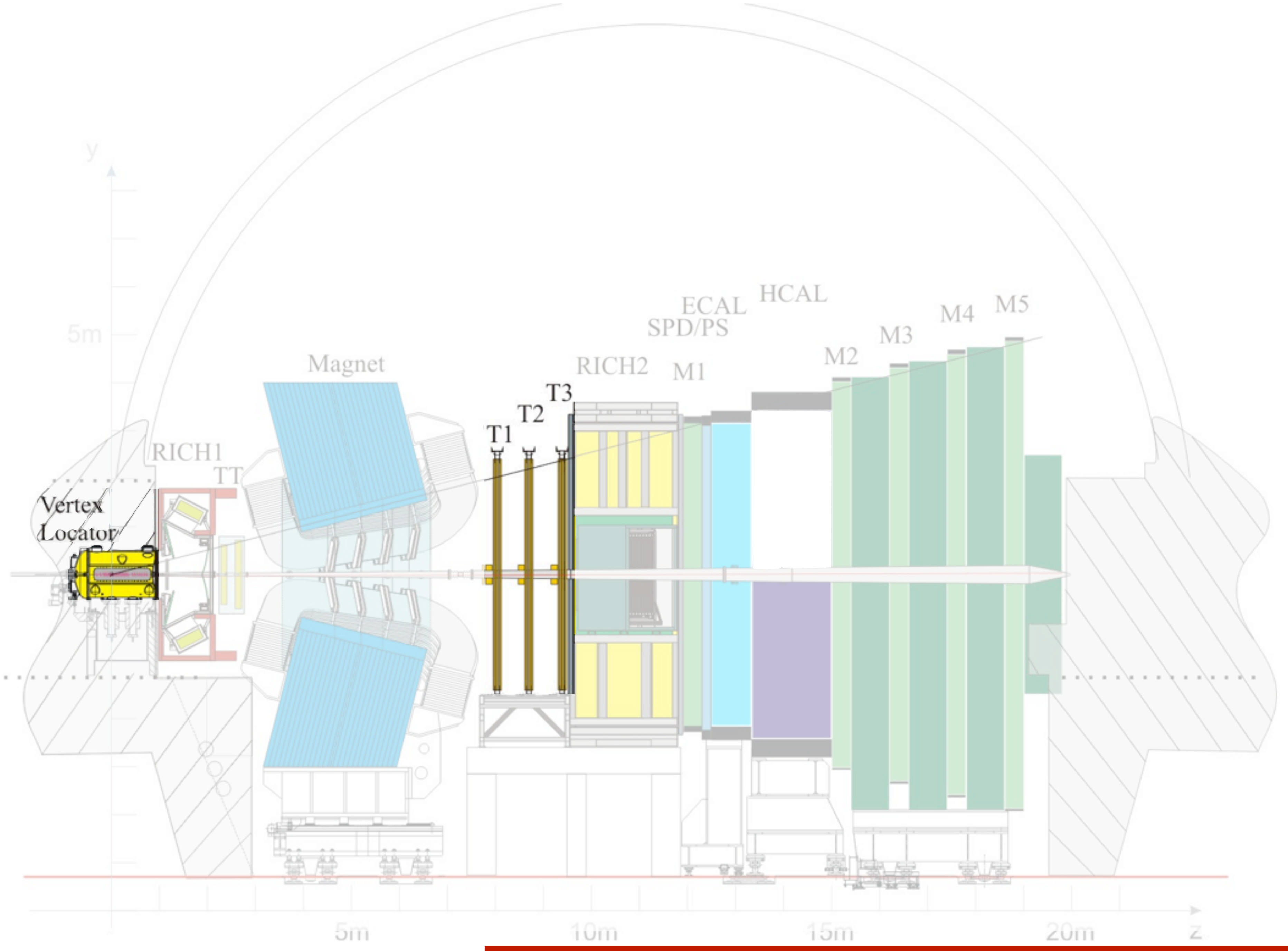

We can measure lifetimes down to a few times ~10^{-14} seconds...

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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100000000	**events means 0.01% precision**

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%

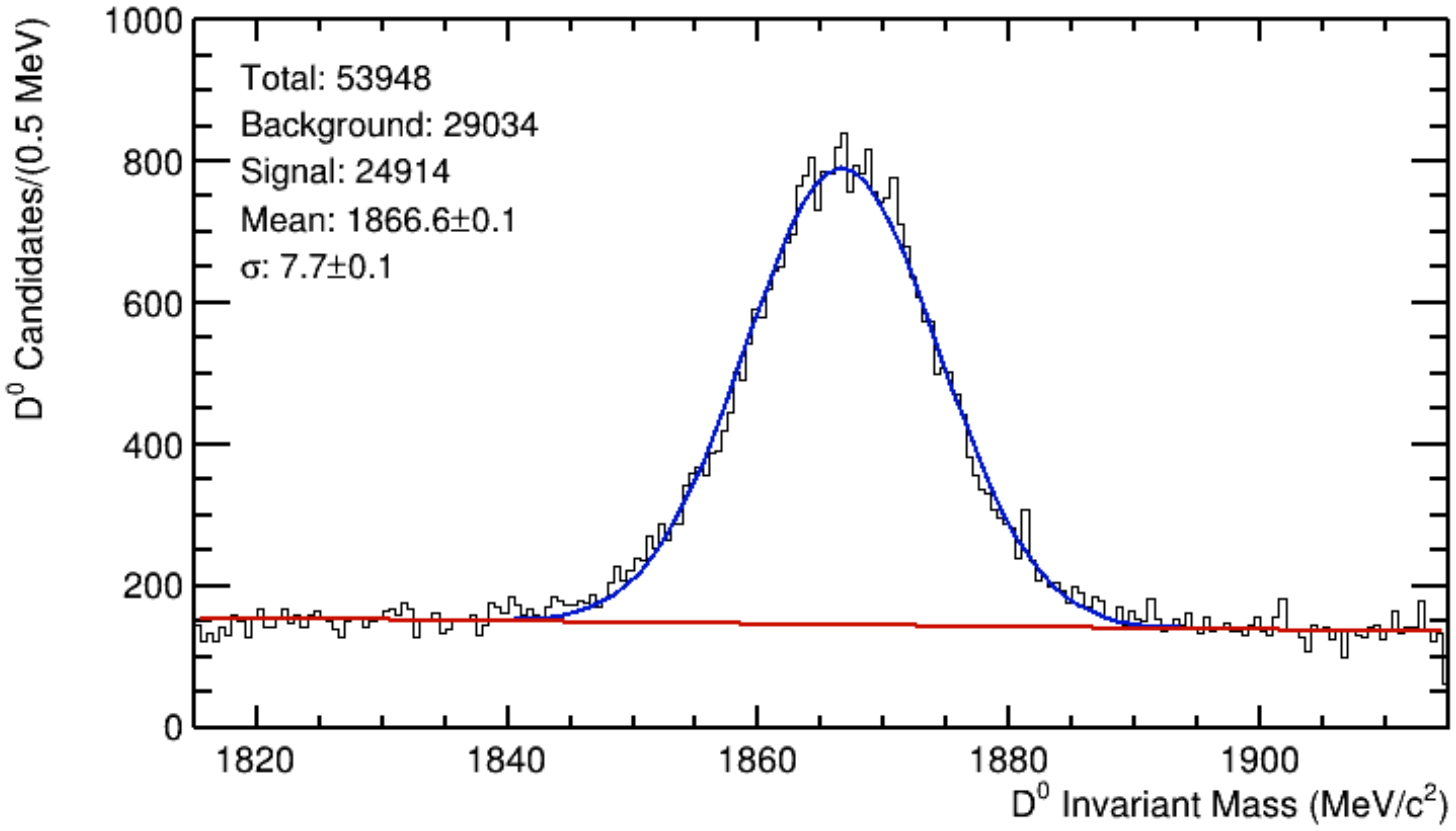
So we can't give you the full dataset to use!

The object of the exercise

The purpose of this exercise is to

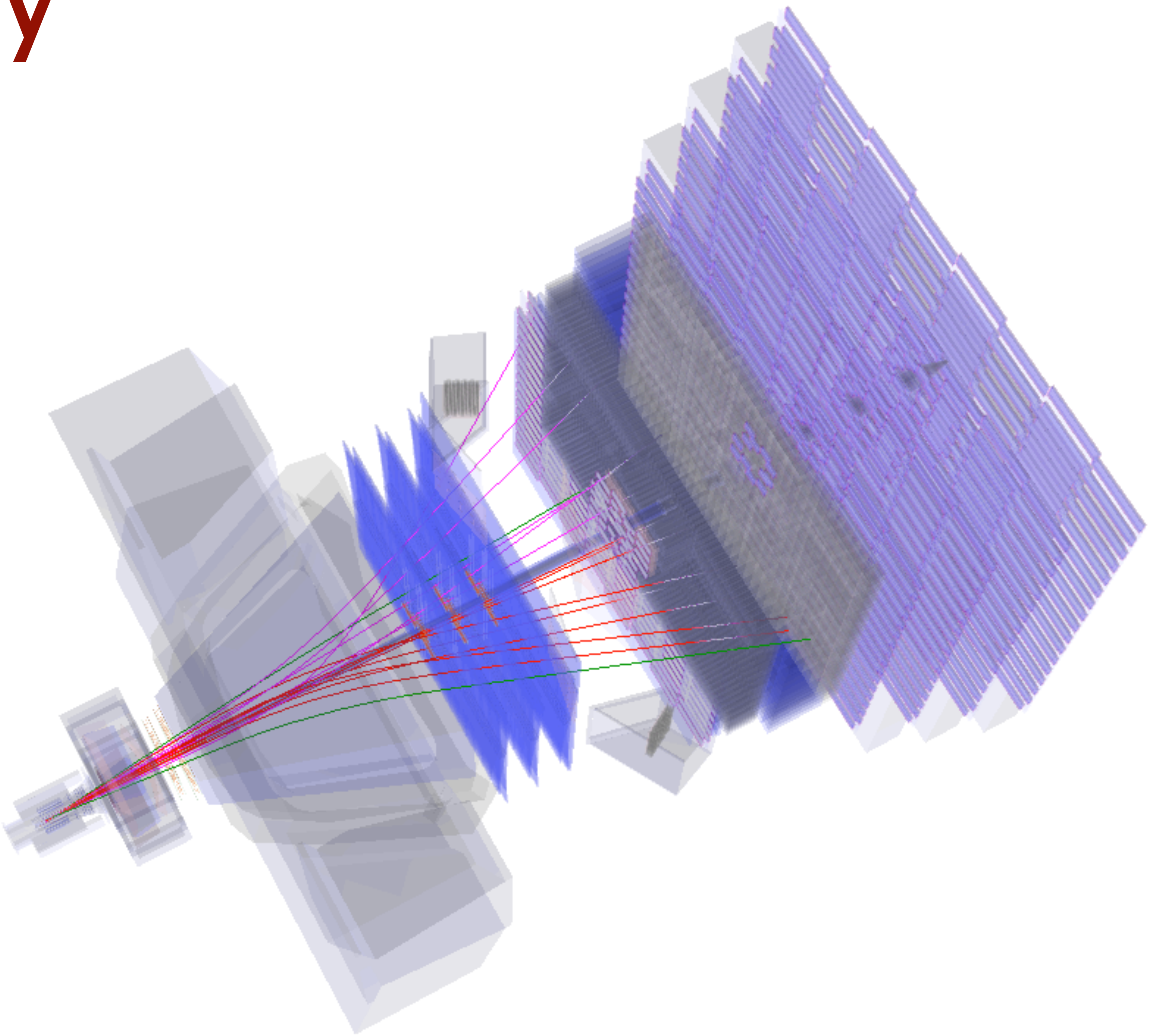
- Give you a look at the data coming out of the LHC
- Teach you about selecting particles in the LHC data
- Teach you about fitting functions to the data in order to measure the signal properties
- Teach you about systematic uncertainties in measurements

Data for exercise



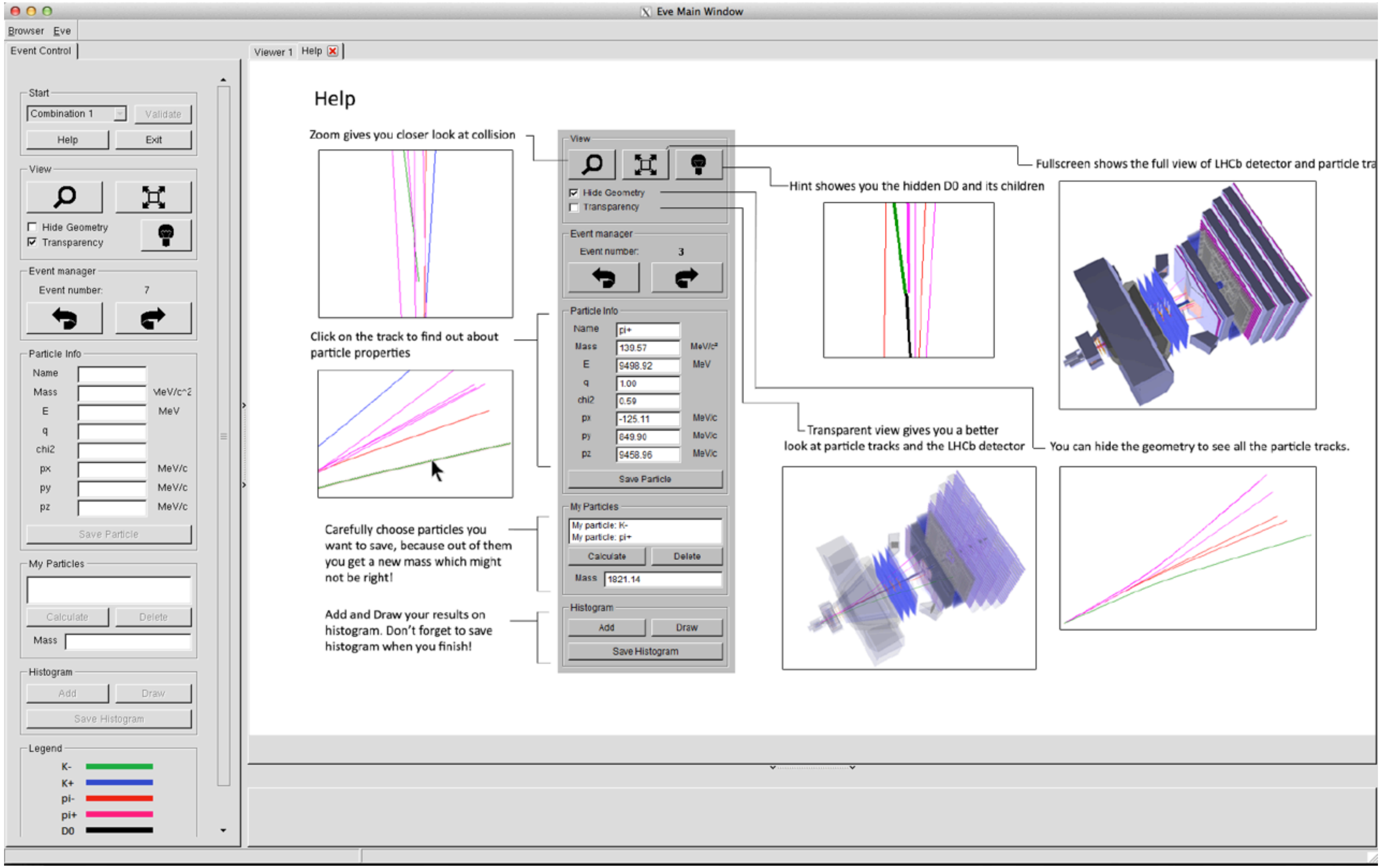
Use $D^0 \rightarrow K\pi$ events from 2012 datataking, starting mass distribution above.

Event display

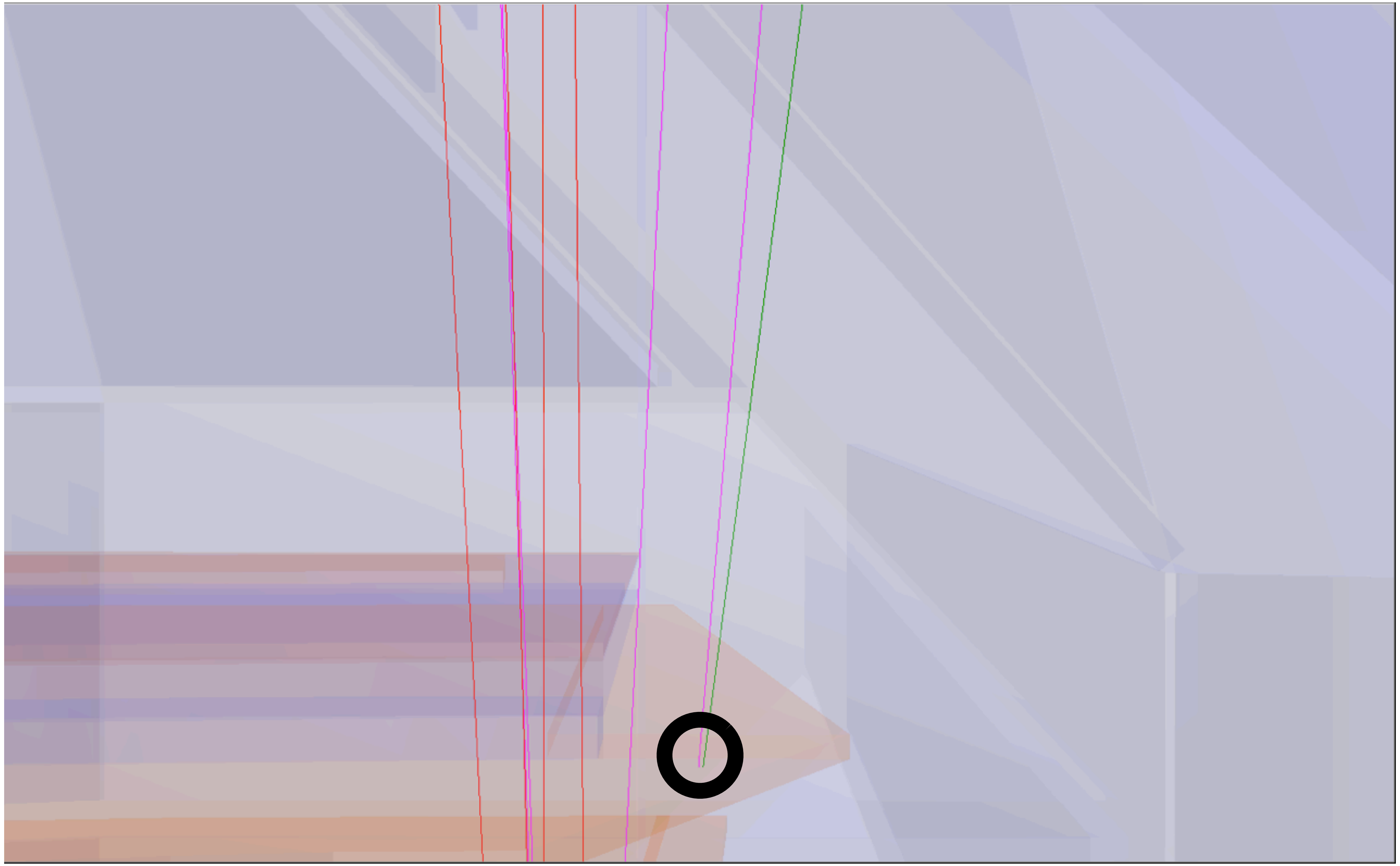


Because LHCb is a forward spectrometer with a dipole magnet, it is hard to do visual exercises looking at the full detector. Hence we zoom in around the interaction region for you to find displaced vertices.

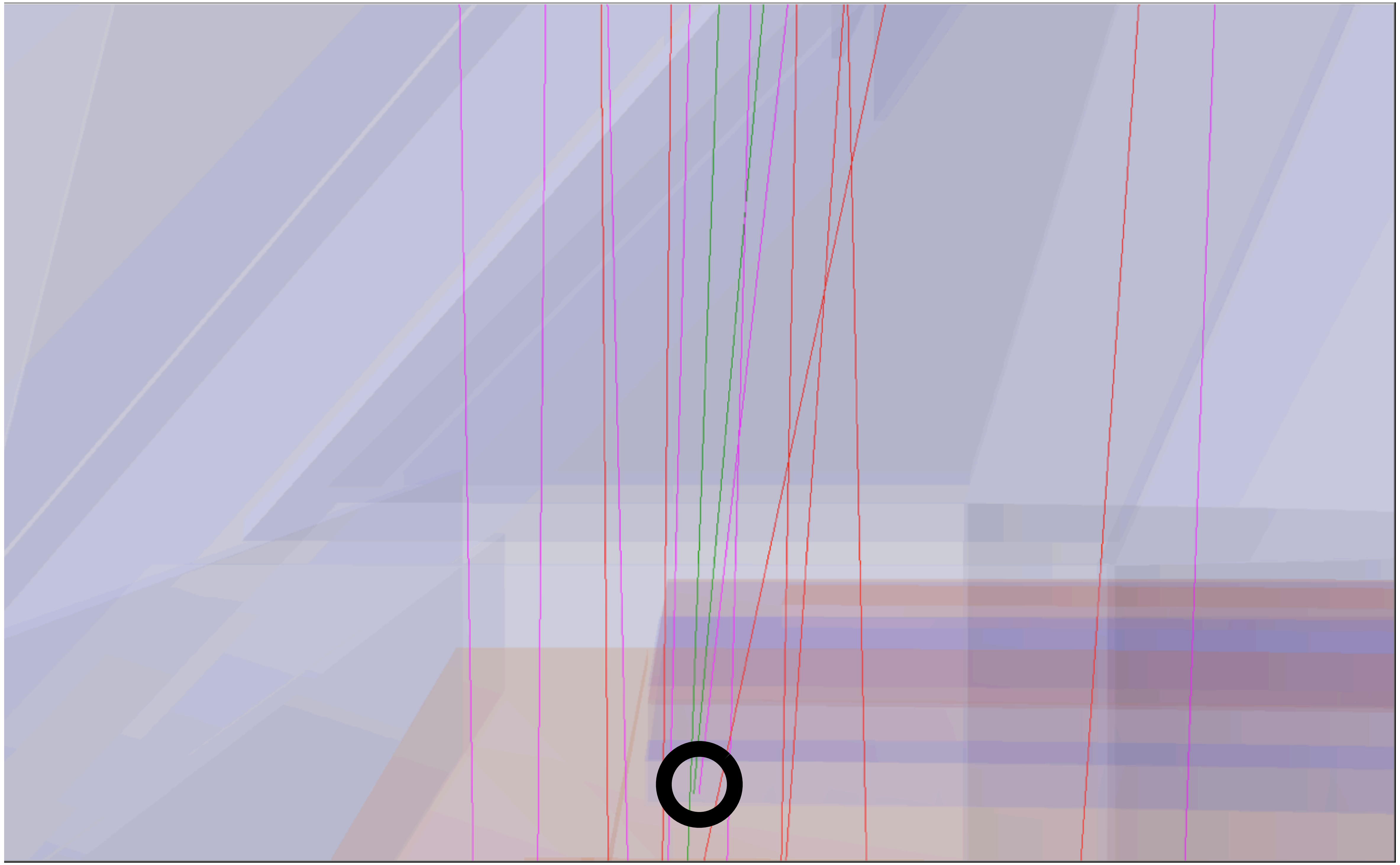
The visual analysis framework



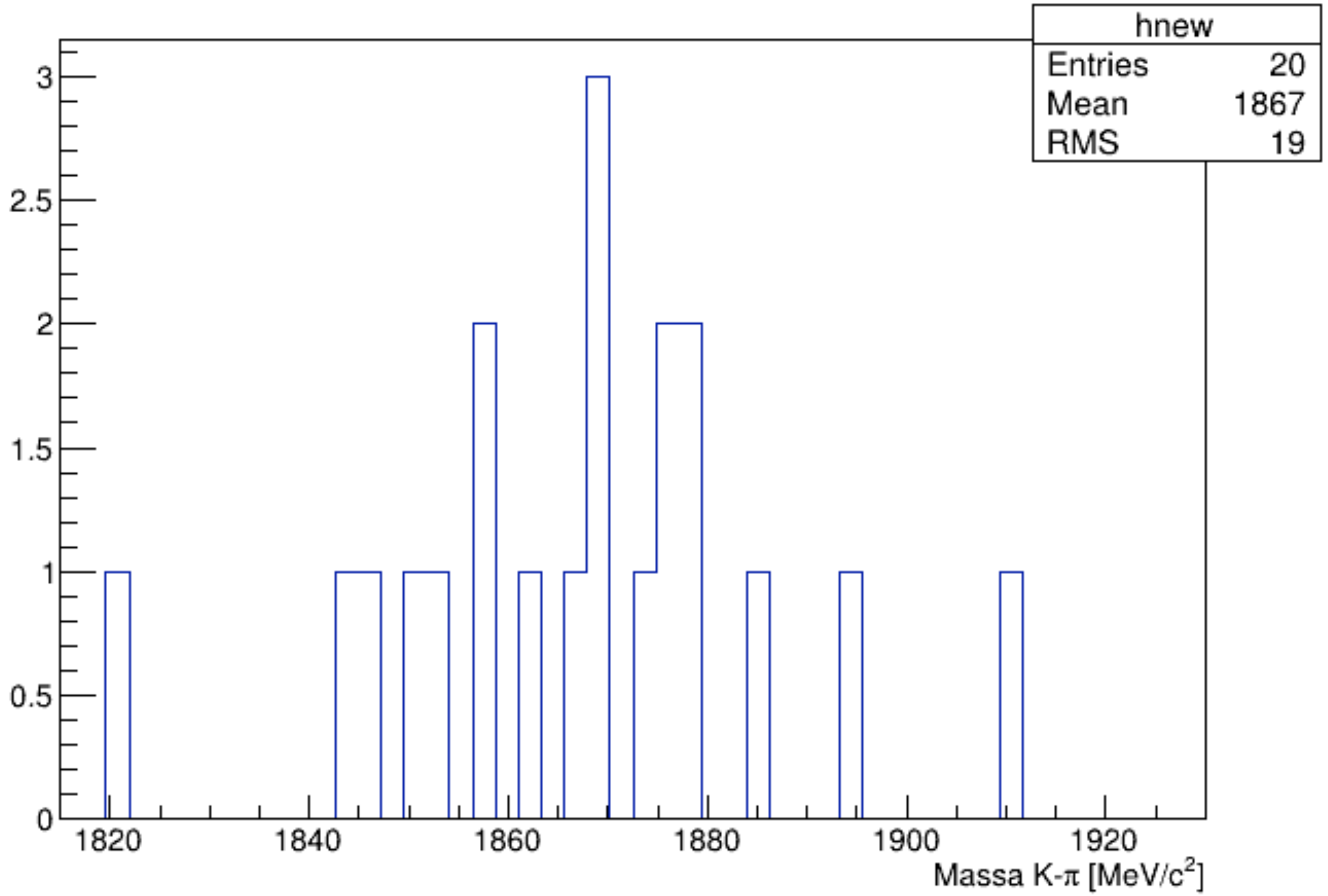
An “easy” event



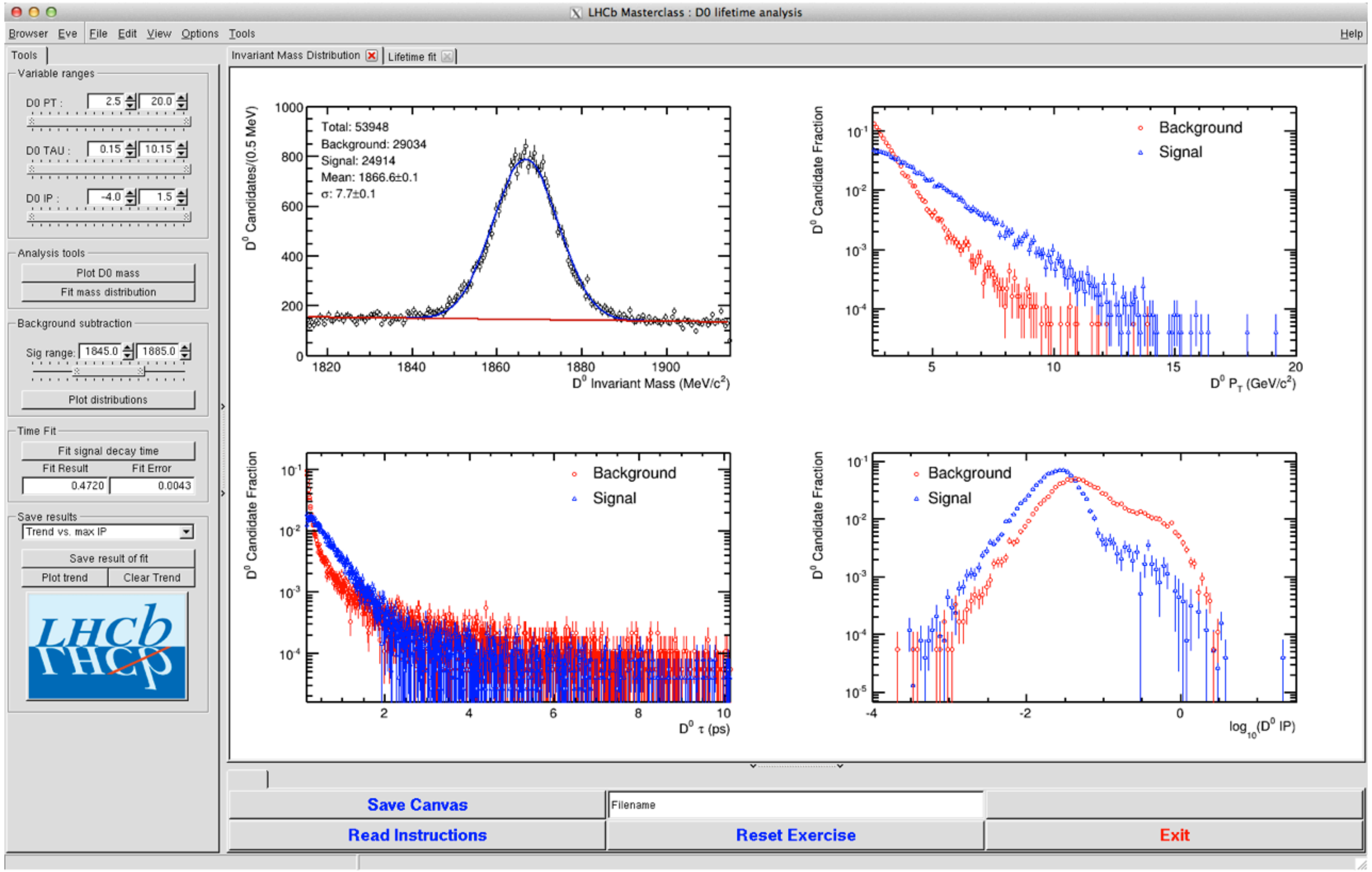
A "harder" event



An example histogram

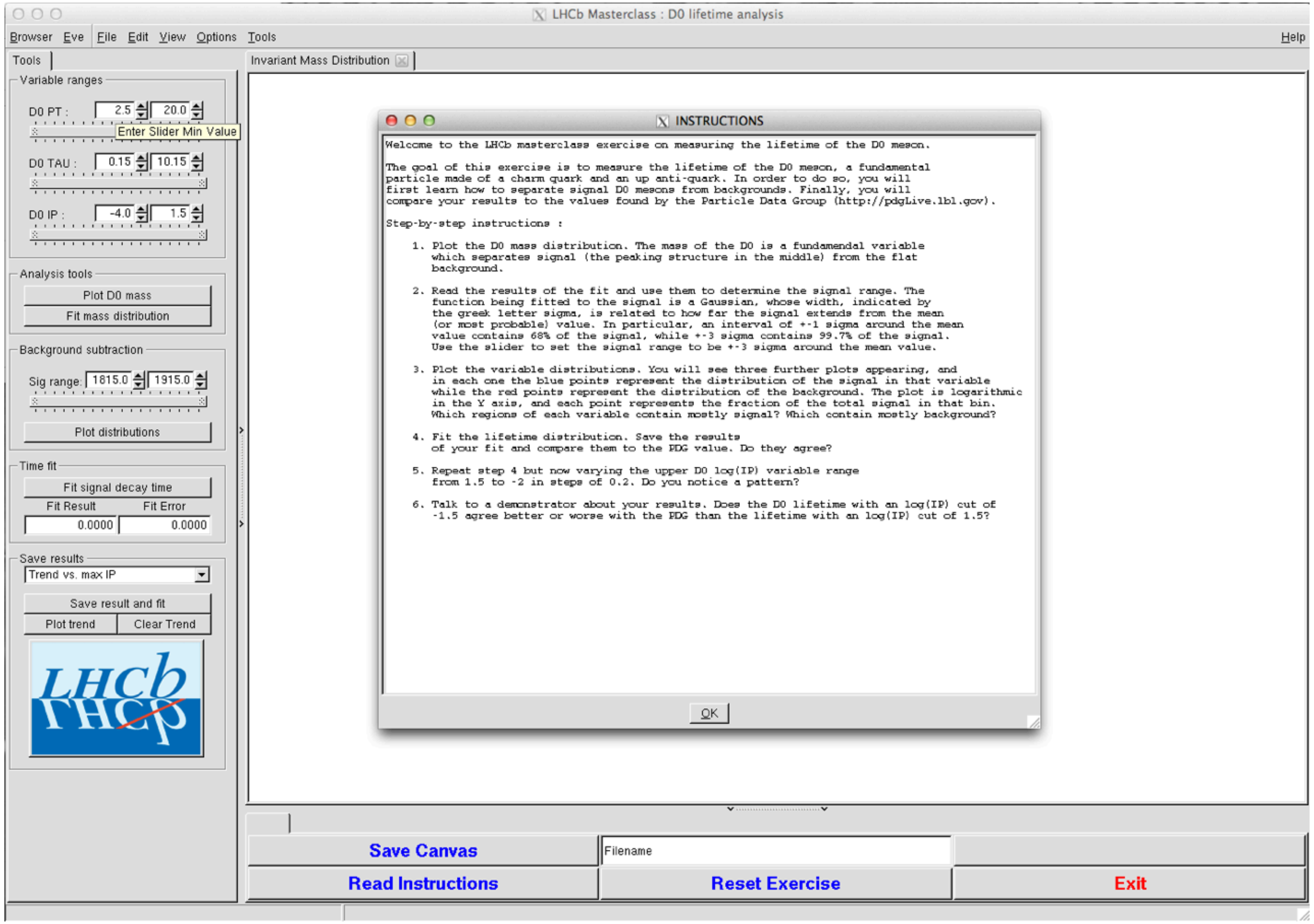


Fitting the lifetime



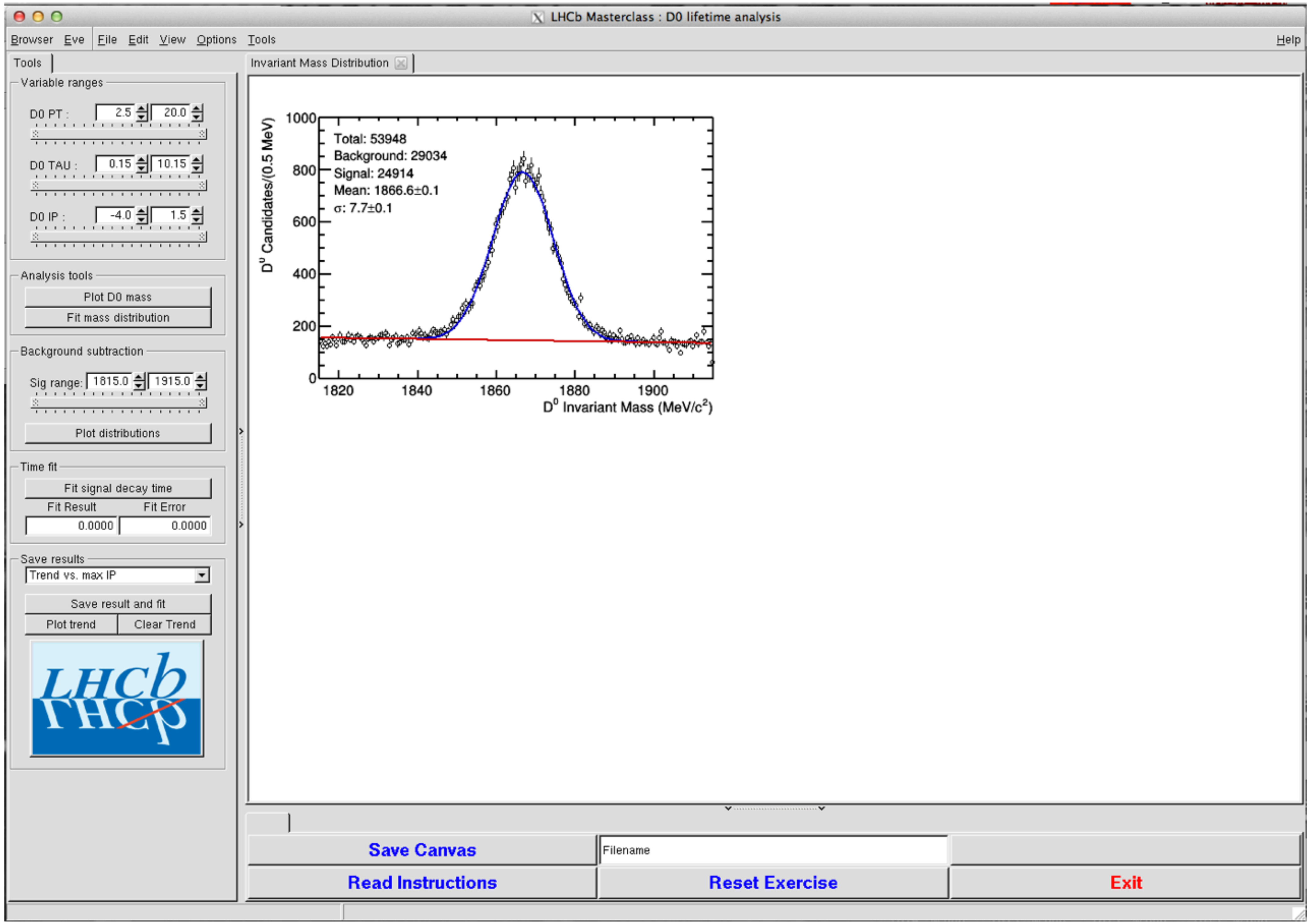
Once you finish looking for the events, you will get a bigger collection of data to use in order to measure the lifetime.

Online instructions



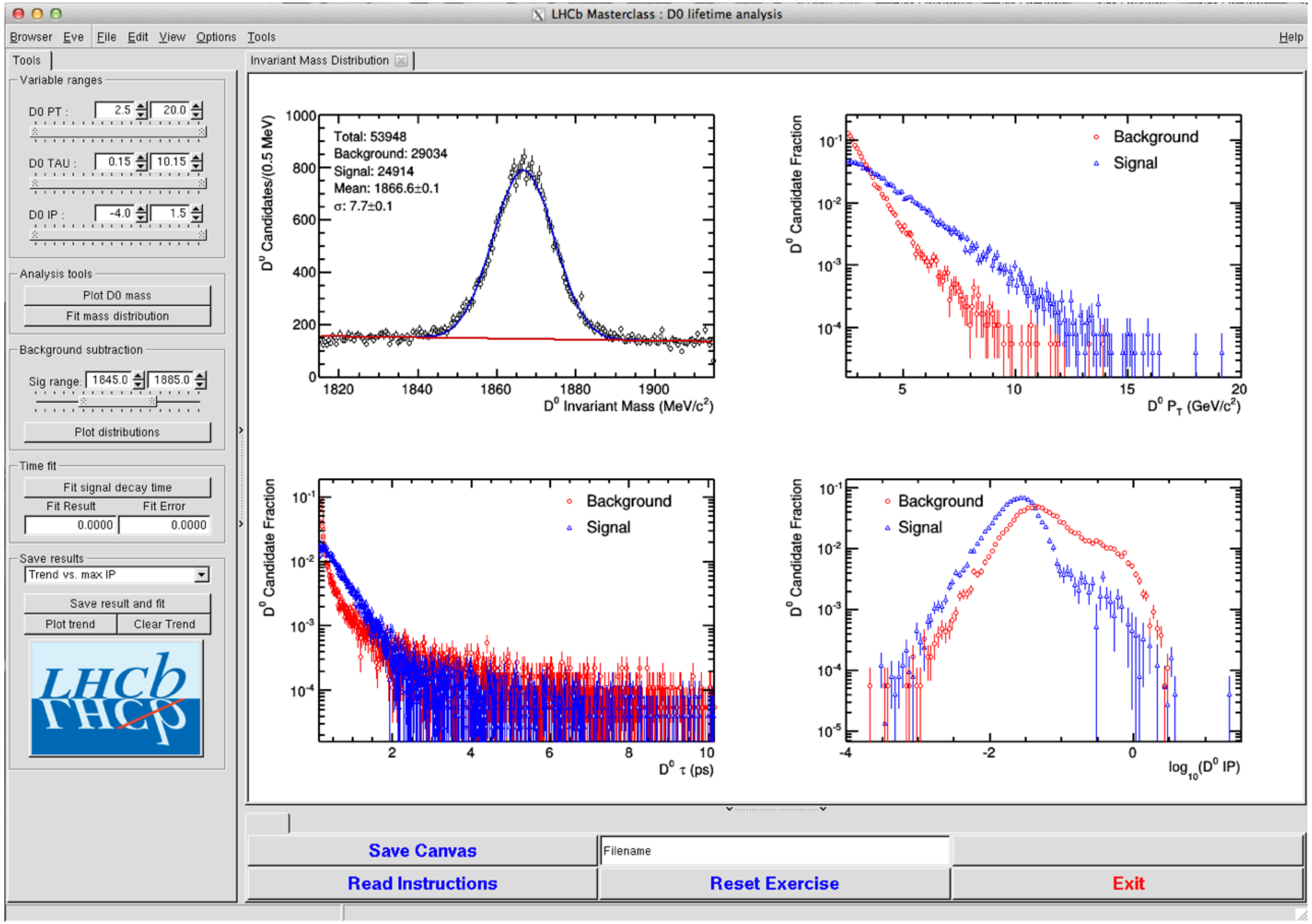
As with the event display, there are online instructions

Fitting the mass



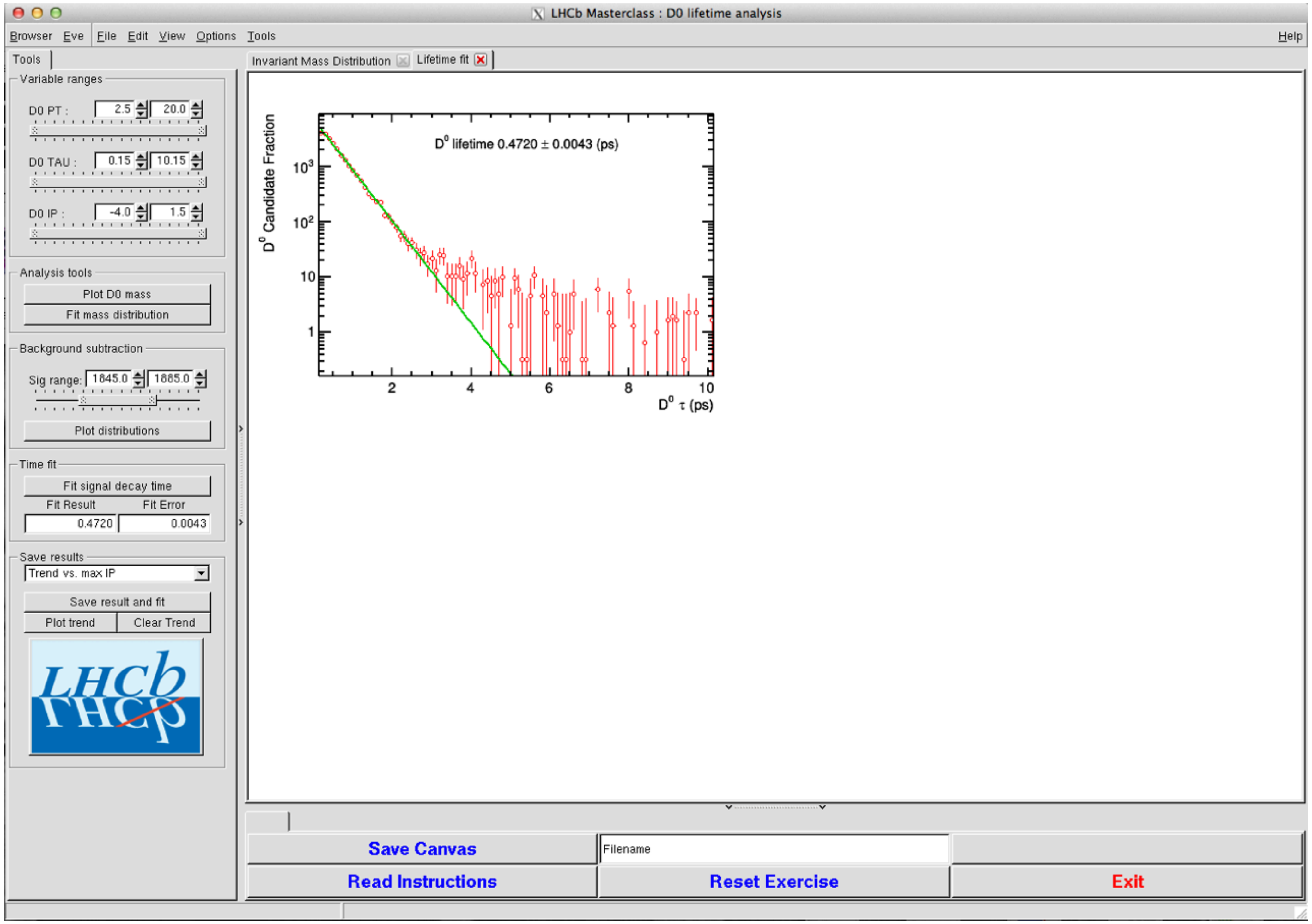
Your first task is to fit functions to signal and background

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?