International Particle
Physics Outreach Group

Belle II

Belle II Masterclass
March 26th, 2024

MASTERCLASS

Experimental method in High Energy Physics

INTERNATIONAL MASTERCLASSES
hands on particle physics

HOW DO WE CREATE PARTICLES?

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Consider a particle **X** with known mass m_X:

- We want to use the **equivalence of energy and mass**

$$E = m_X c^2$$

⟹ We must provide the energy E

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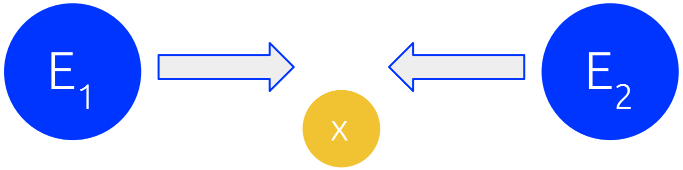

$$E \approx E_1 + E_2$$

<u>Transformation of energy into mass</u>

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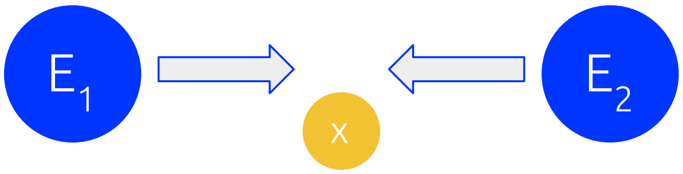
<u>Transformation of energy into mass</u>

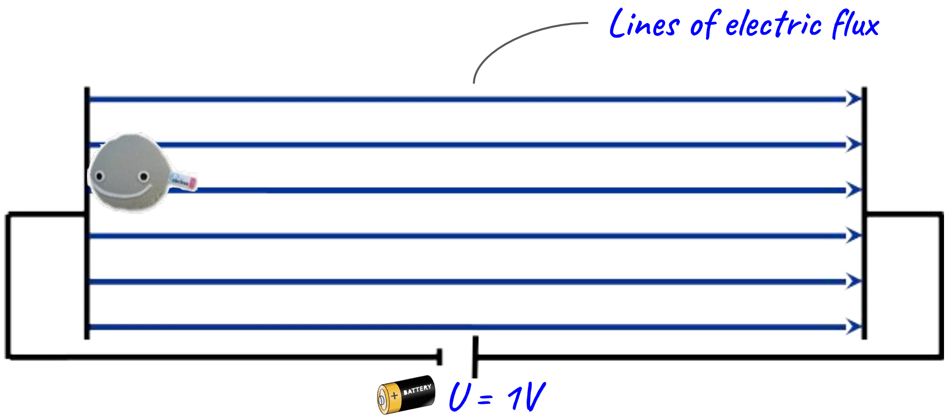
$\Longrightarrow$ Particles need to be **accelerated!**



PARTICLE ACCELERATION

PARTICLES ACCELERATION

- **A known principle to you:**
  when an electric field is generated, charged particles (like electrons) are accelerated along the flux lines



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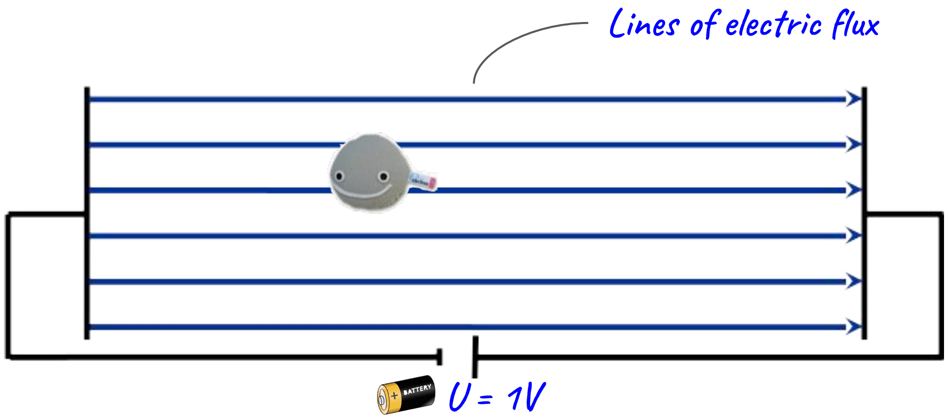

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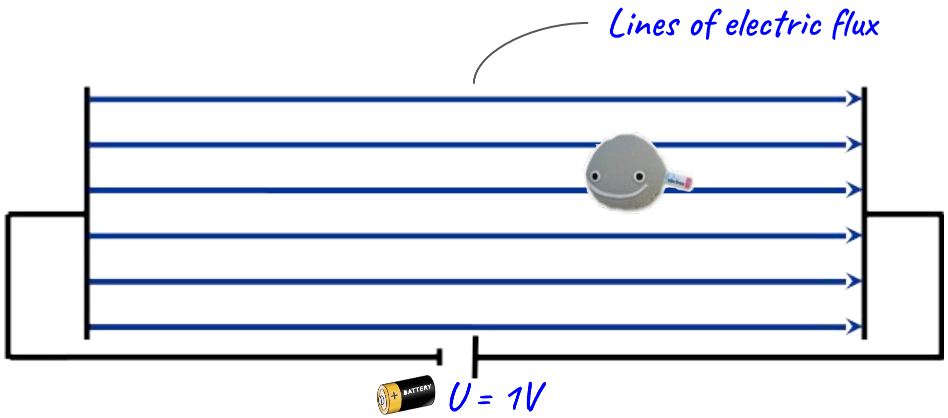
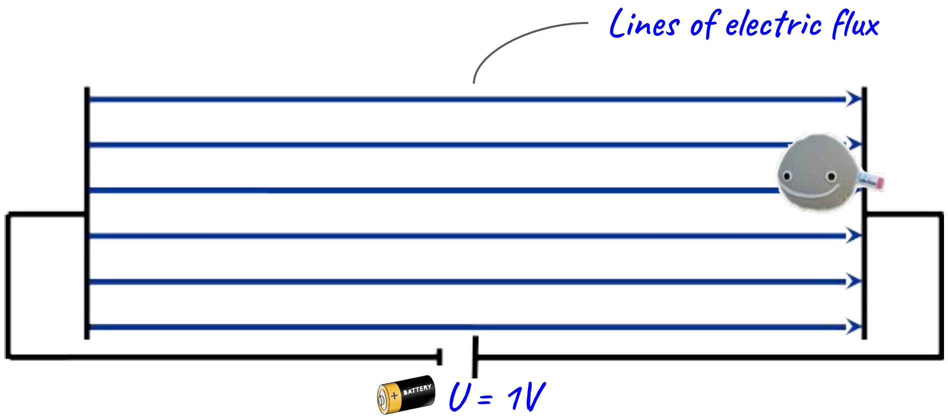


PARTICLES ACCELERATION

- Here we collected E = 1 eV



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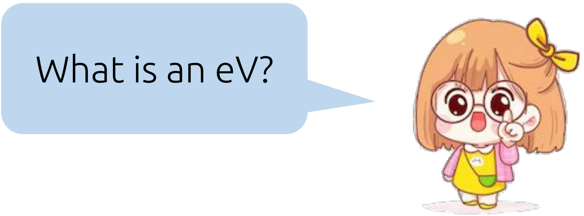

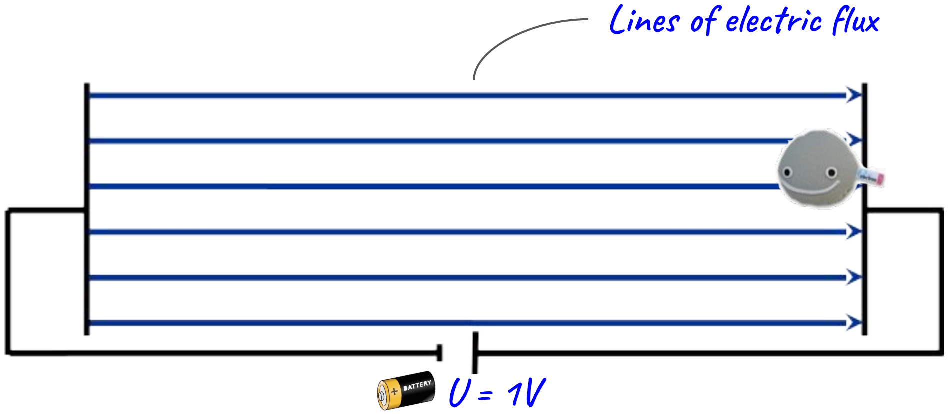

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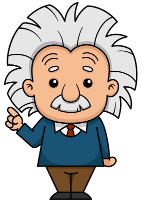
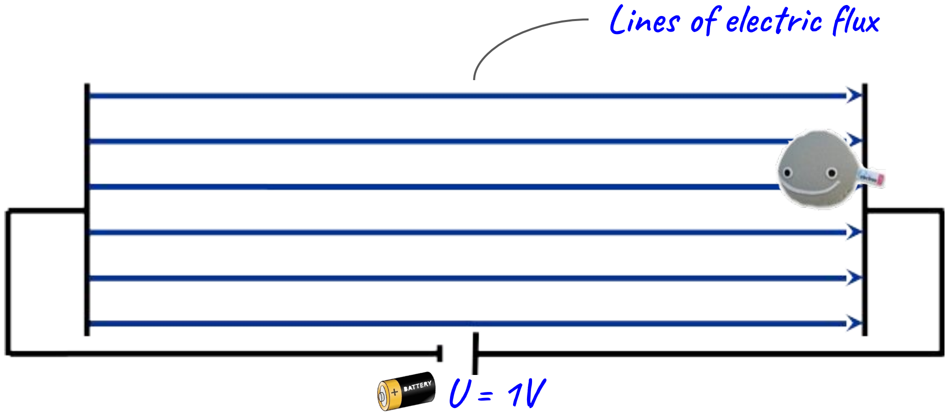
What is an eV?



It is the amount of kinetic energy gained by a **single electron** through an electric potential difference of **1V**



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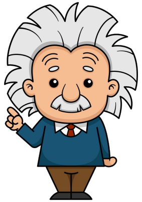

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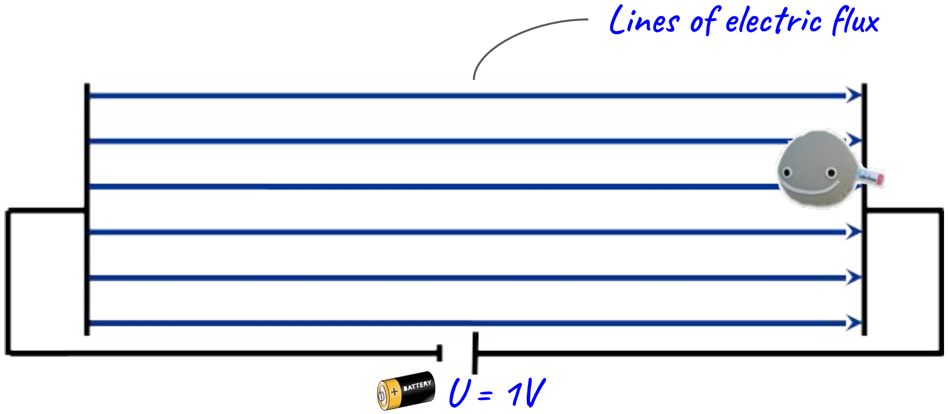
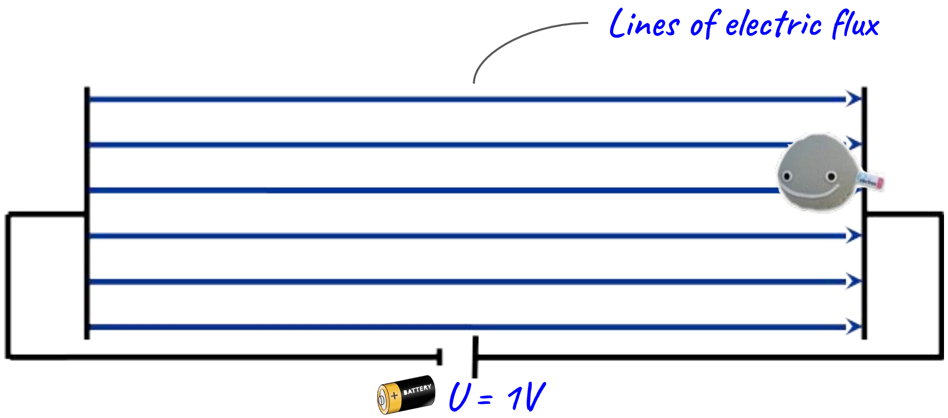
Then:
1 **keV** = **10^3** eV
1 **MeV** = **10^6** eV
1 **GeV** = **10^9** eV
1 **TeV** = **10^{12}** eV



PARTICLES ACCELERATION

- Here we collected E = 1 eV
- **How do we achieve more energy?**



PARTICLES ACCELERATION

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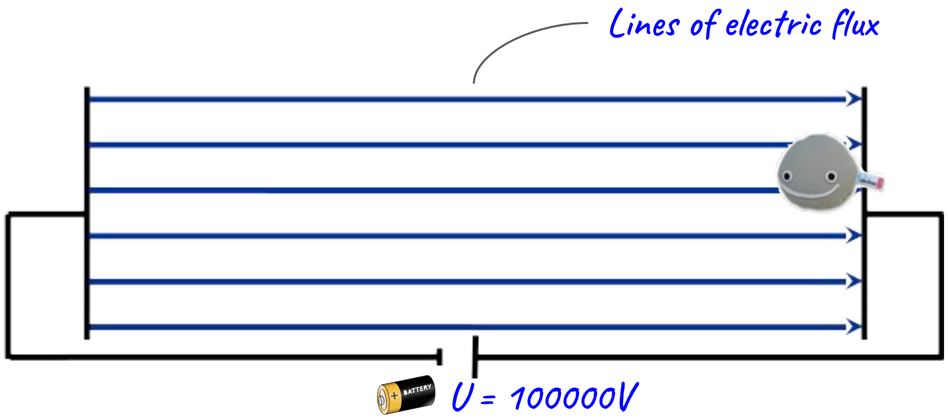

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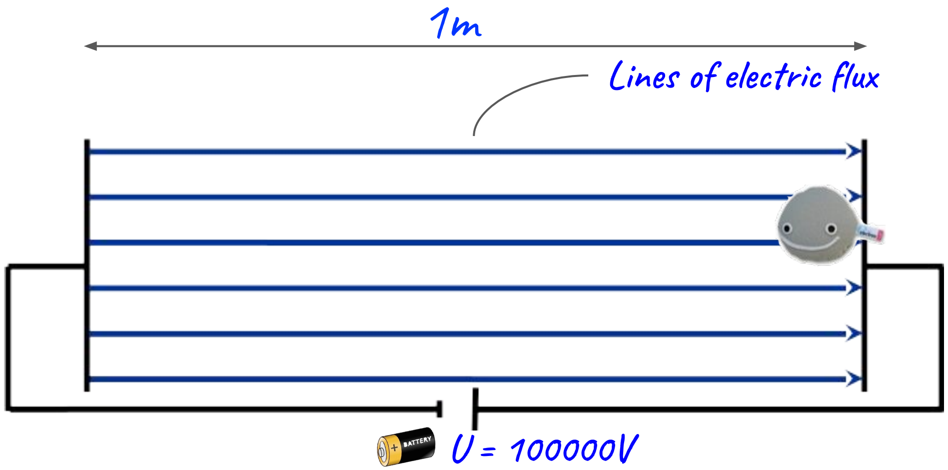
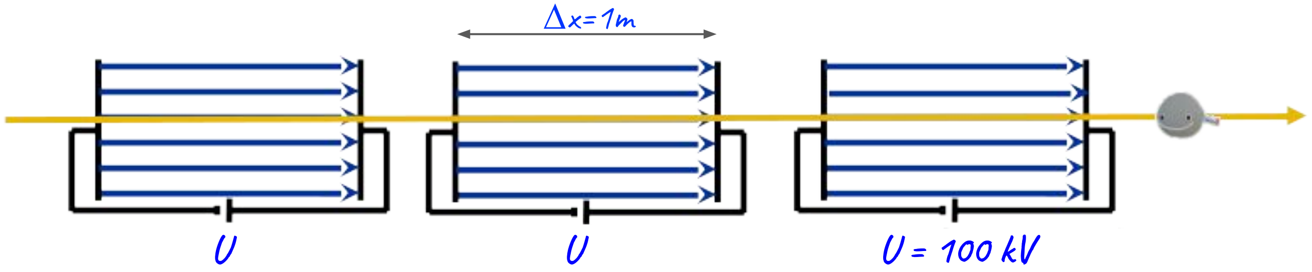
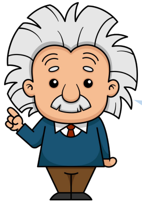


PARTICLES ACCELERATION

- We can put many of these cells behind each other





m_x = 11 GeV/c² = 11.000.000 keV/c²
How many cells do we need?

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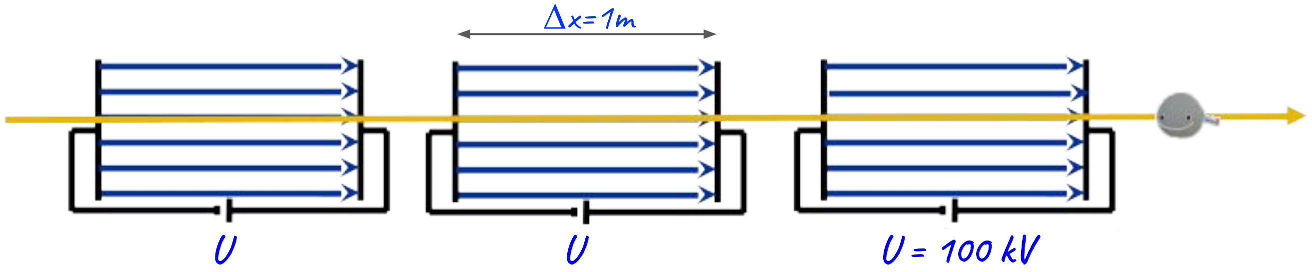

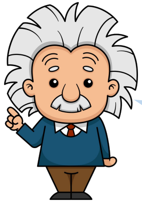

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needed energy

$E = m_x c^2$ = 11.000.000 keV

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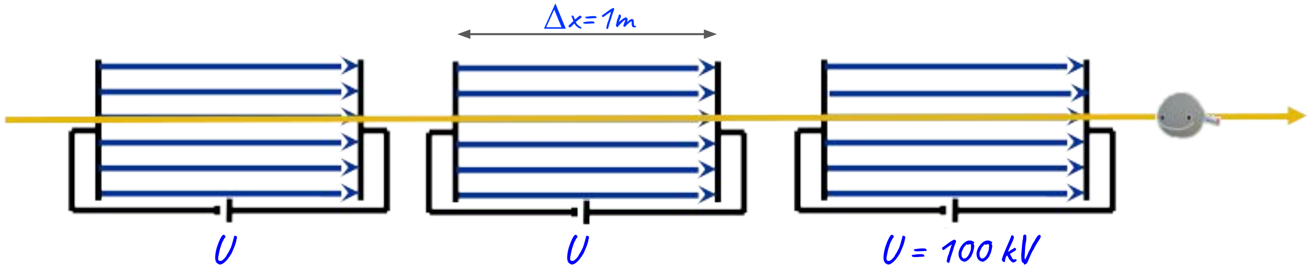

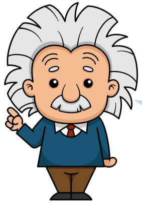

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E = $m_X c^2$ = 11.000.000 keV
N = E/ΔE = 110.000 cells

number of cells

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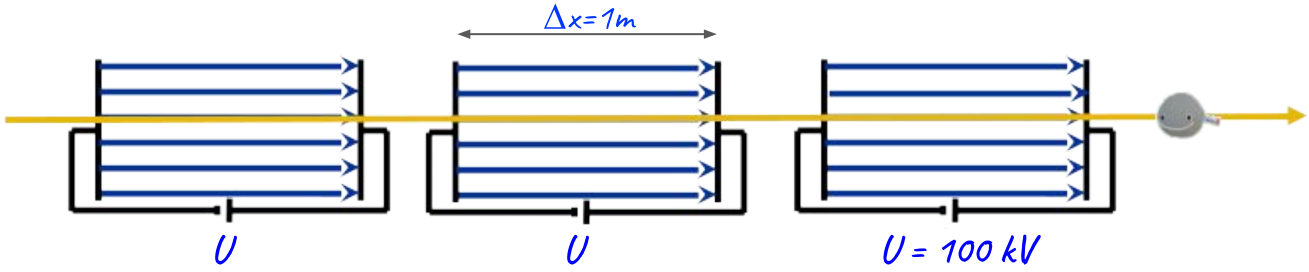

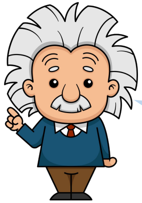

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L = NΔx = 110 km

lenght

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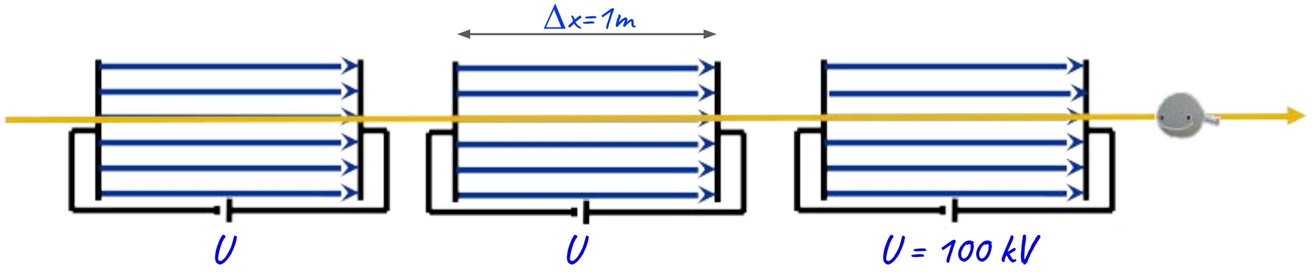

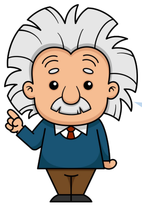

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High energies need extremely long accelerators!

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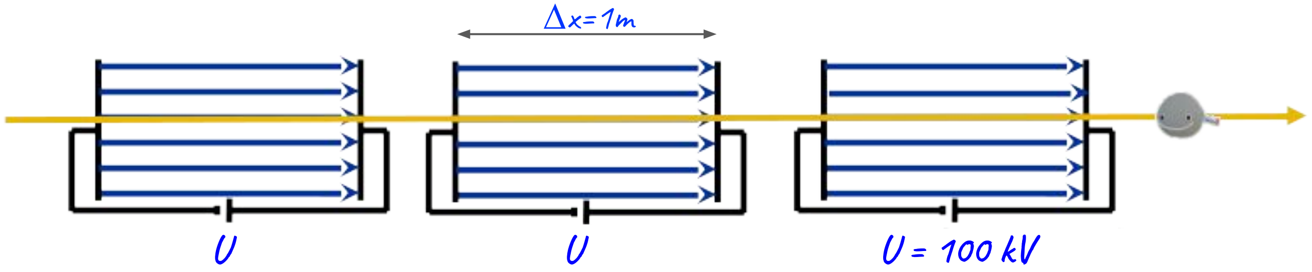

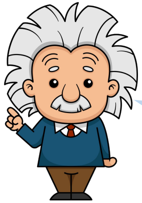

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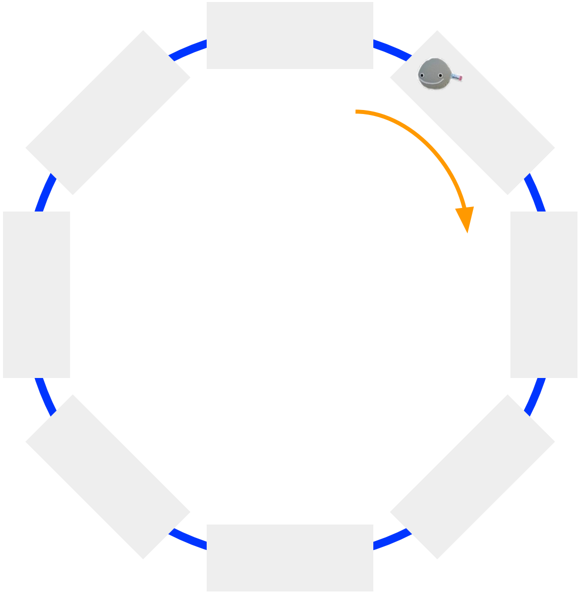
Better ideas?

CIRCULAR ACCELERATORS

Arrange the cells in a circle

→ They can be passed several times

But how do you force particles on a circular trajectory?



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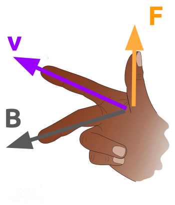
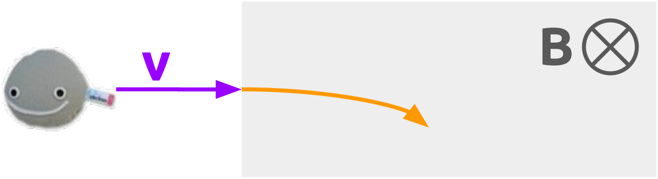
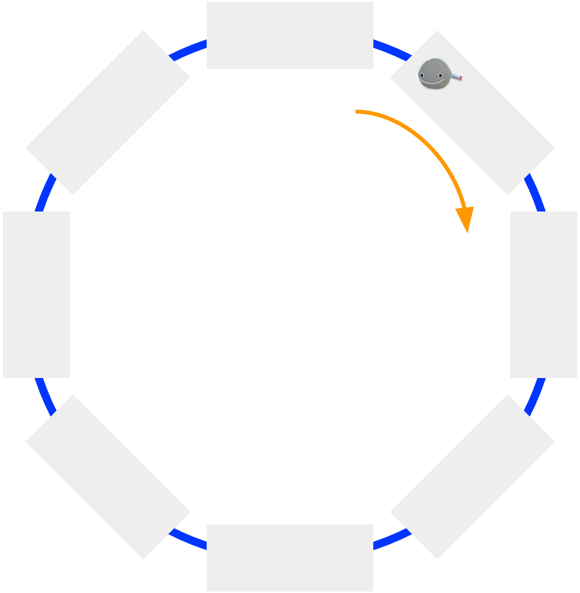
Lorentz force:

$$\mathbf{F} = q\mathbf{v}\times\mathbf{B}$$





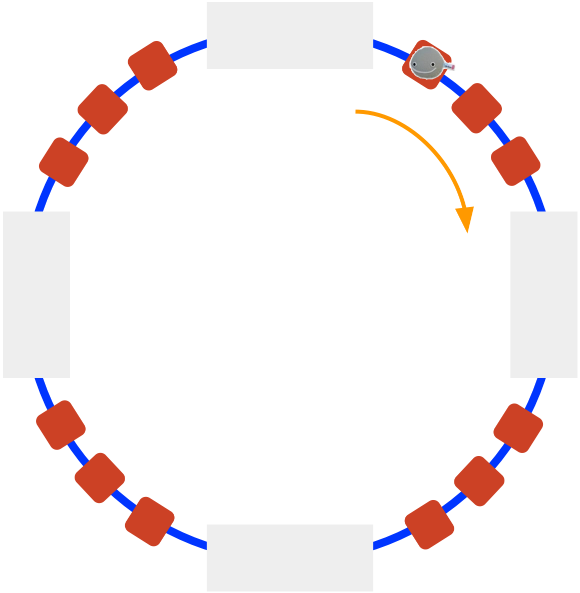


CIRCULAR ACCELERATORS

What happens in reality:

- straight passages to accelerate
- curved passages to redirect

Do you know any example of circular accelerators?



SUPERKEKB

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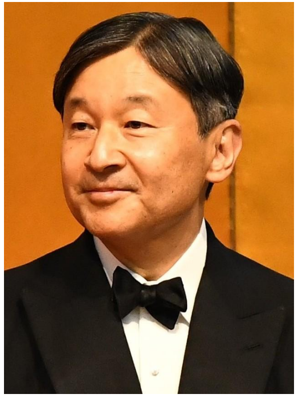
Naruhito, Japan's Emperor



Did you know that Japan consists of about **14000** islands?

Currently Japan is in the Reiwa era, which means "**Beautiful armony**"

If you are looking for chopsticks in Japan, you should ask for "**Hashi**"

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- Positrons and electrons are accelerated to 4 and 7 GeV, respectively
- Circumference of ~3 km

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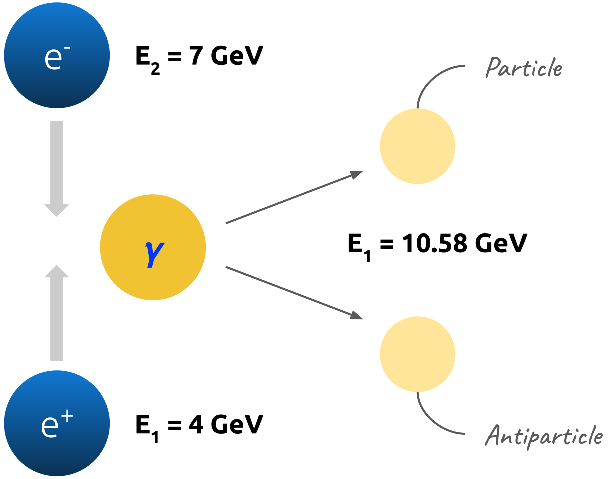
WHAT HAPPENS DURING A COLLISION?

WHICH PARTICLES DO WE SEE?



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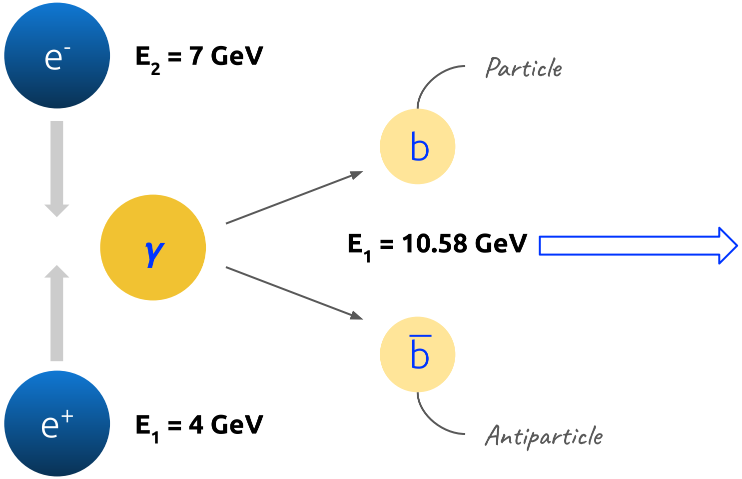

At this energy the production of $b\bar{b}$ pair is enhanced

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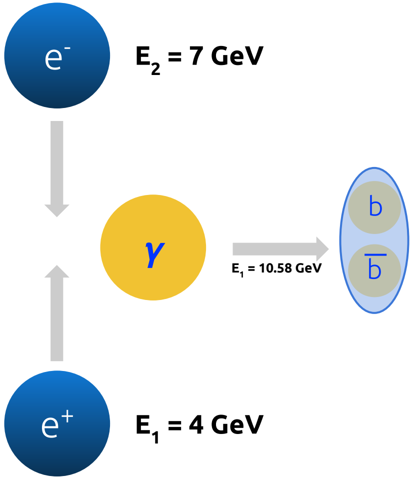

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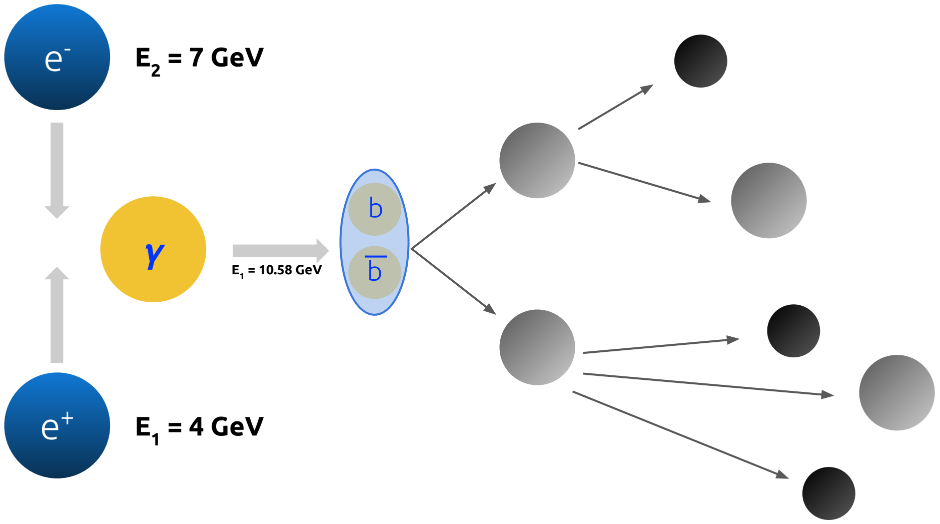

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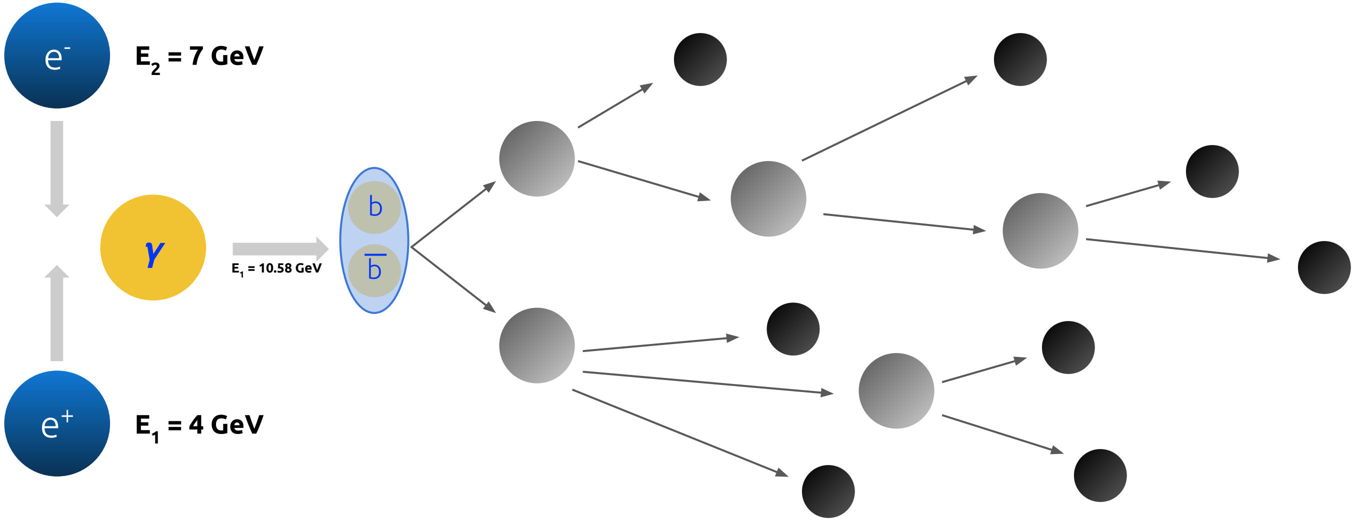

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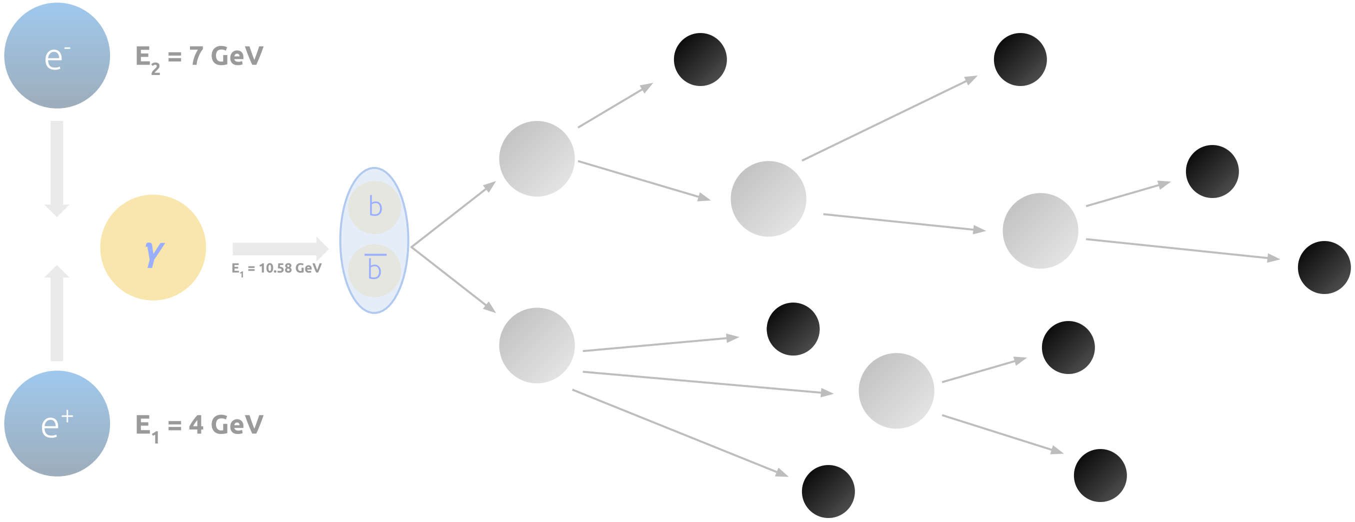
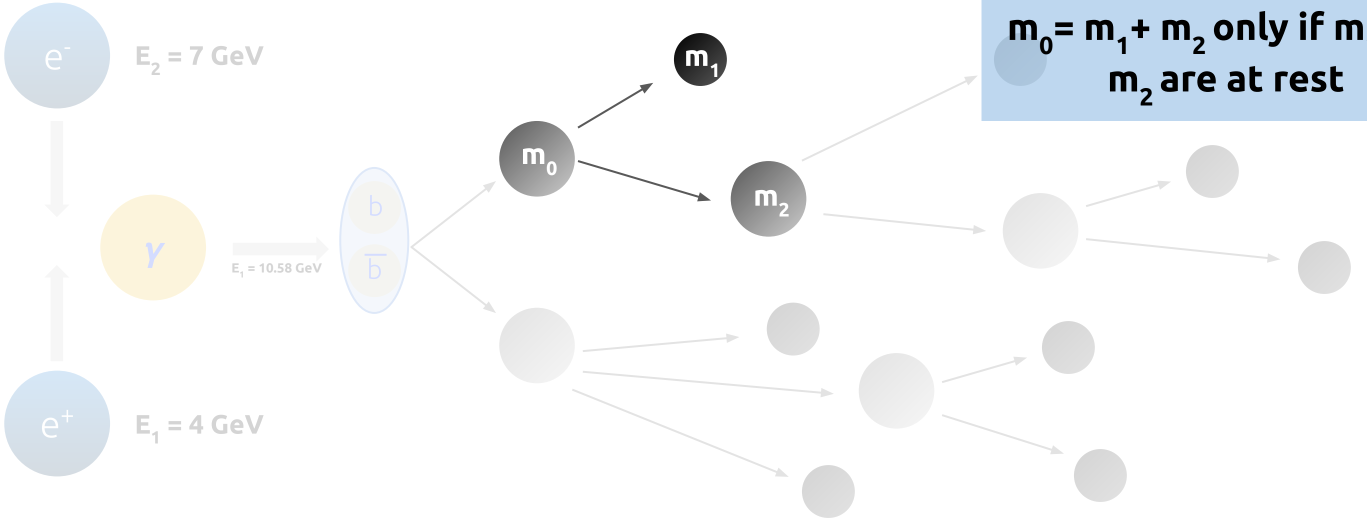


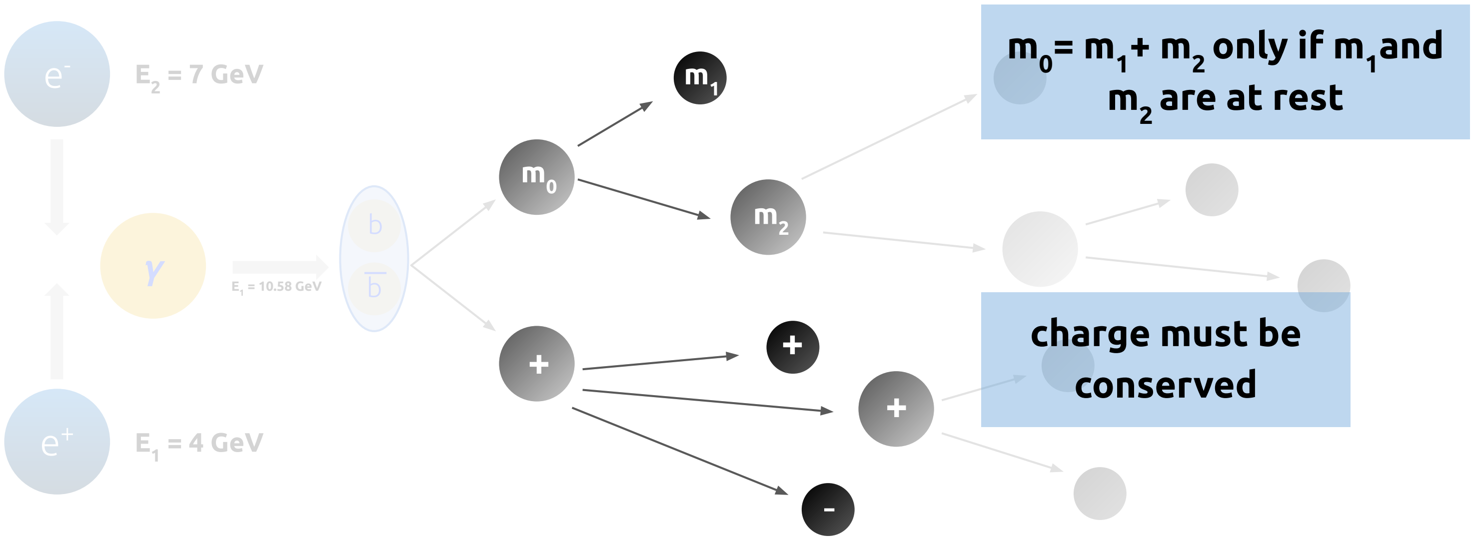
Long-lived particles!

PARTICLE DECAY: FEW RULES



$m_0 = m_1 + m_2$ only if m_1 and m_2 are at rest

PARTICLE DECAY: FEW RULES



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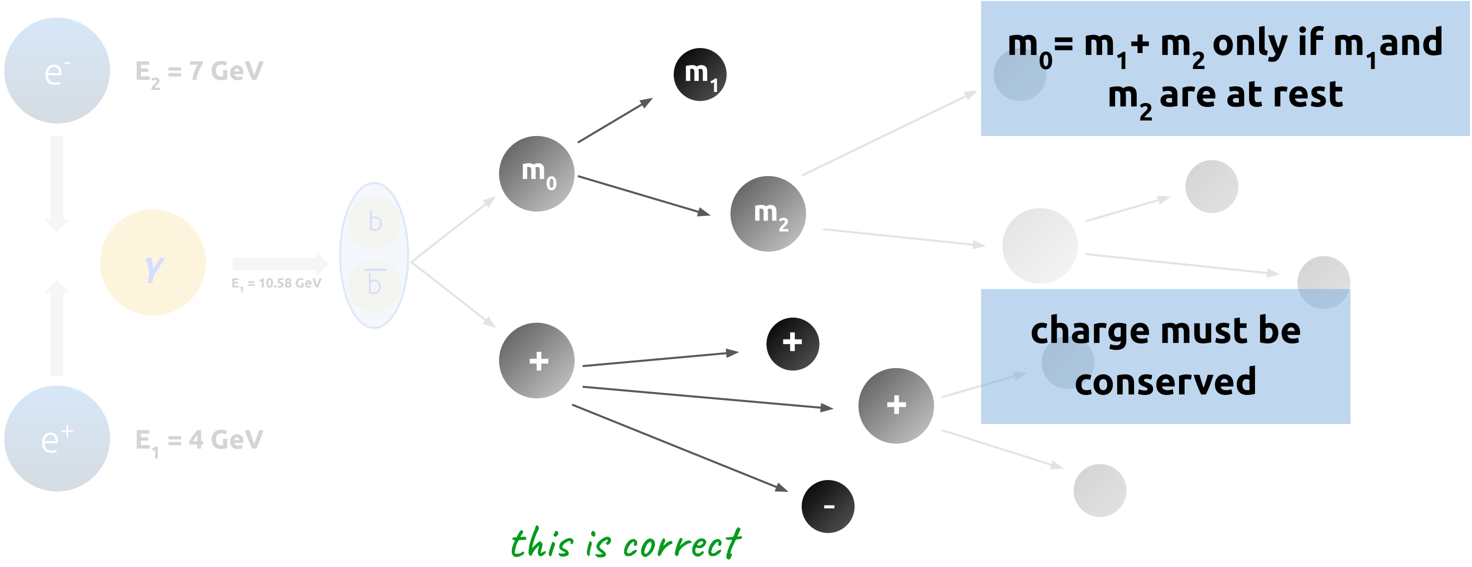

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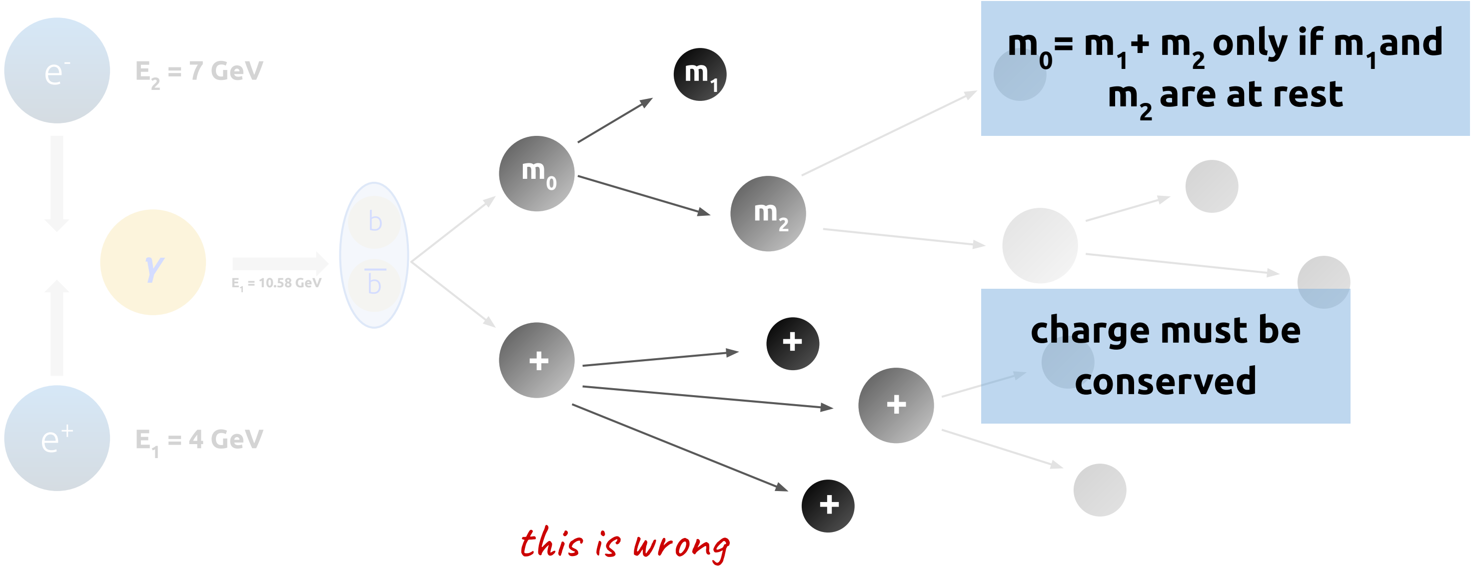

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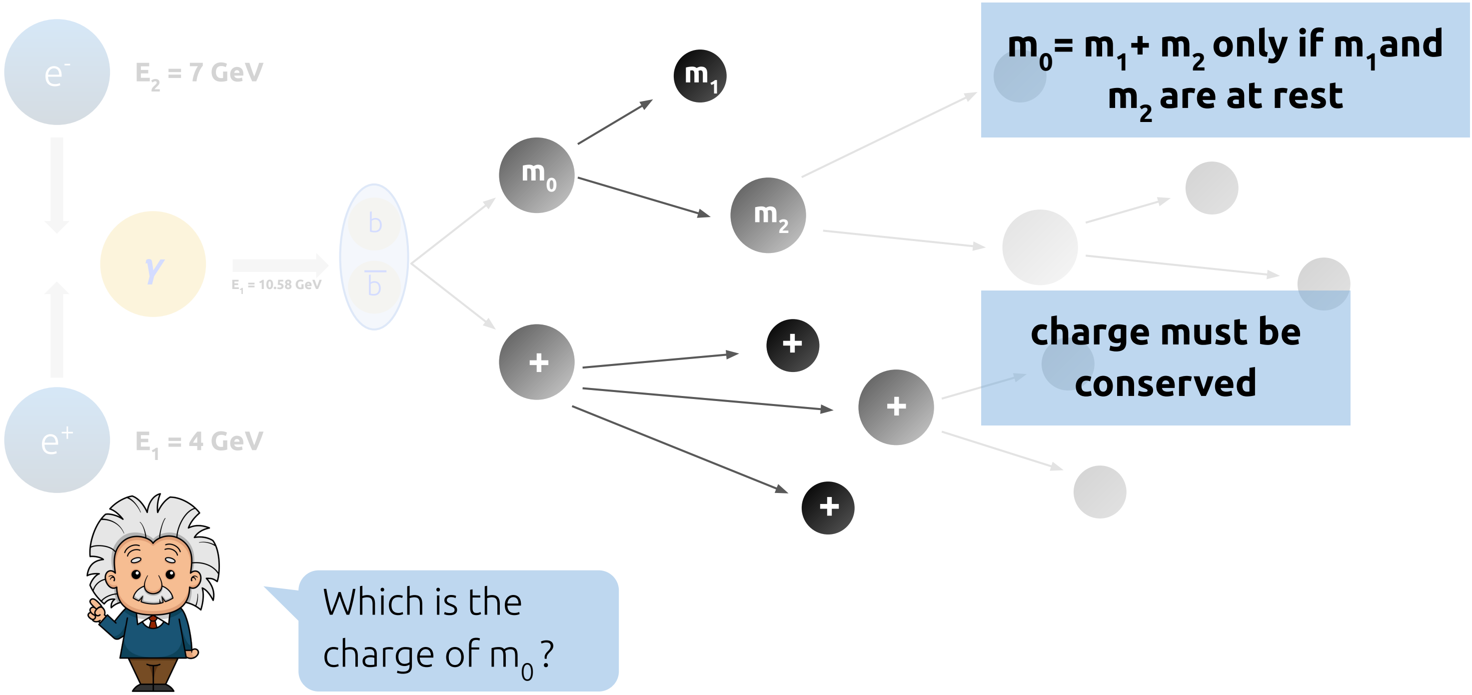

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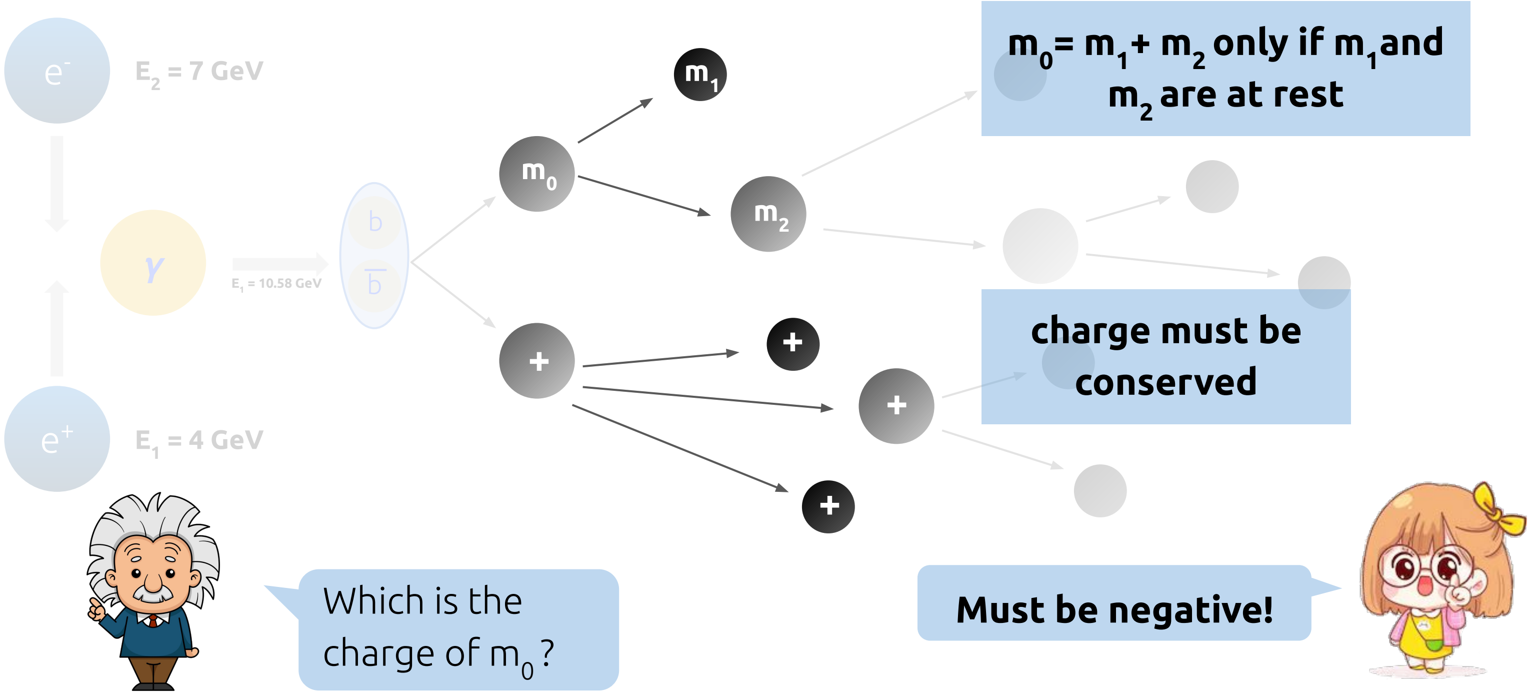


WHAT DO WE ACTUALLY SEE?

Imagine a car crash:

- wreckage is flying around and stops somewhere
  → **the car's velocity can be deduced**
  by the wreckage distance to the cars and their color

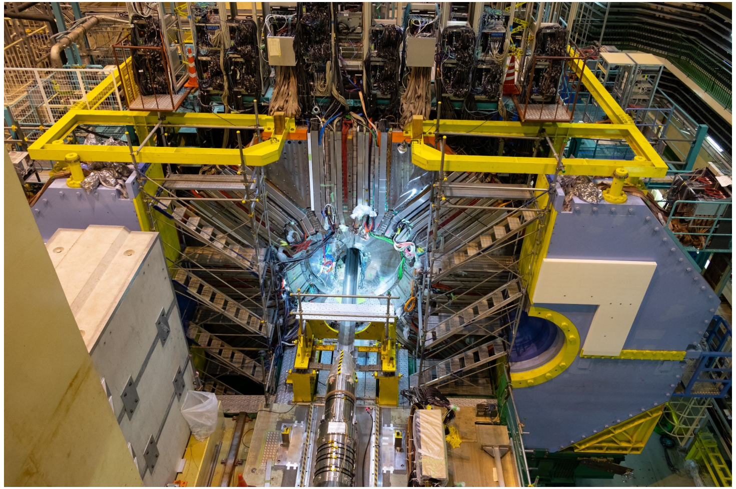
HOW DO WE SEE PARTICLES?

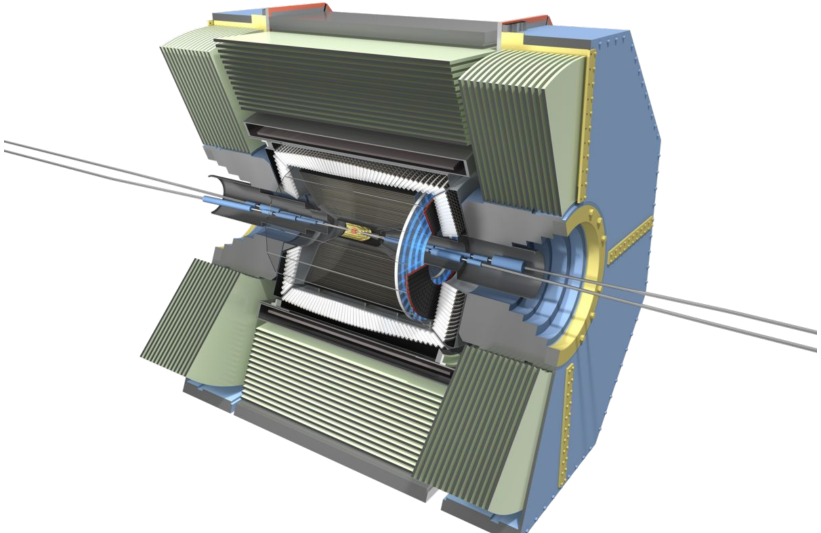
THE BELLE II DETECTOR

Build a detector around the collision point

We don’t see the particles literally

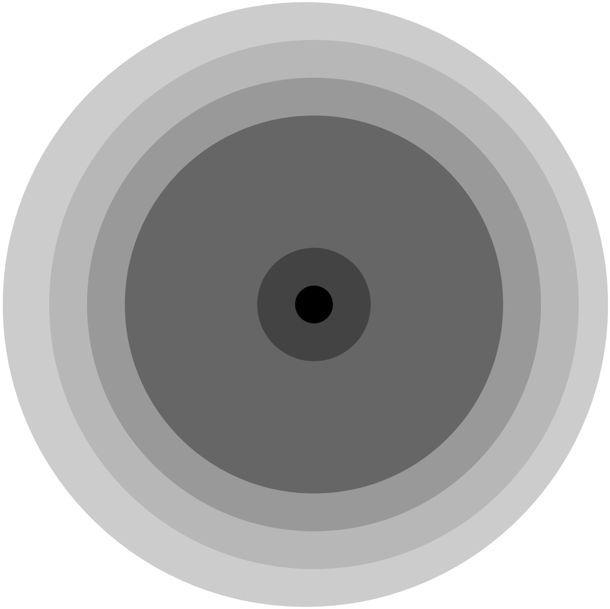
You need to reconstruct them from many small information pieces





THE BELLE II DETECTOR

Detector around the collision point: “Onion principle“



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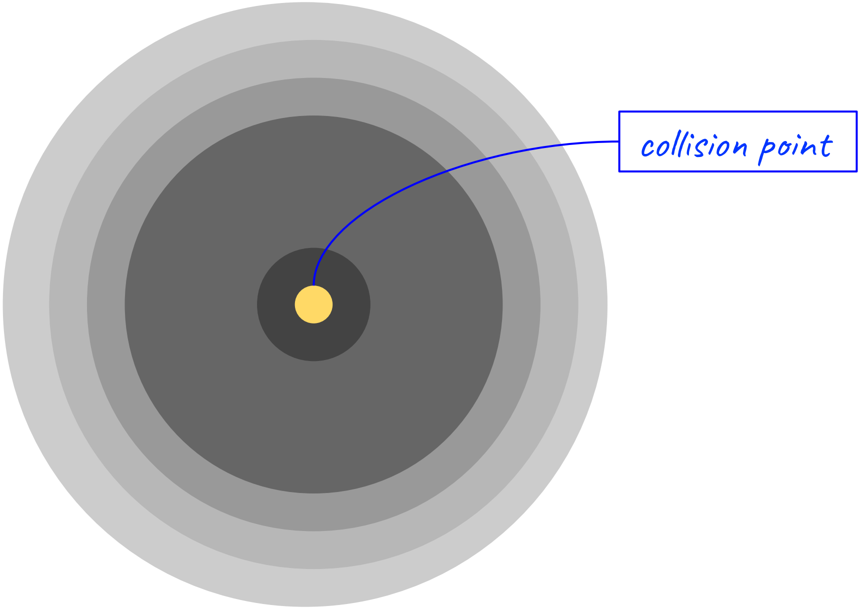

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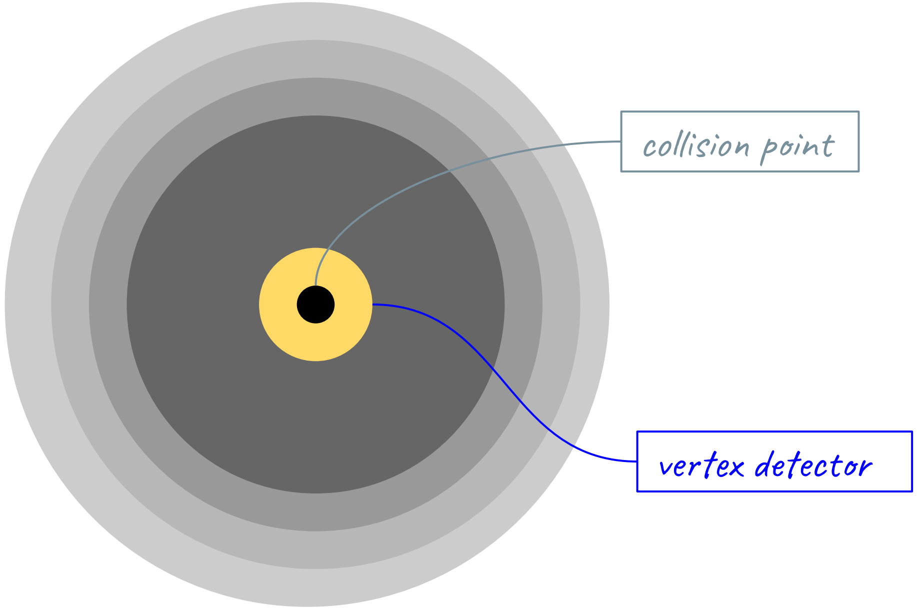

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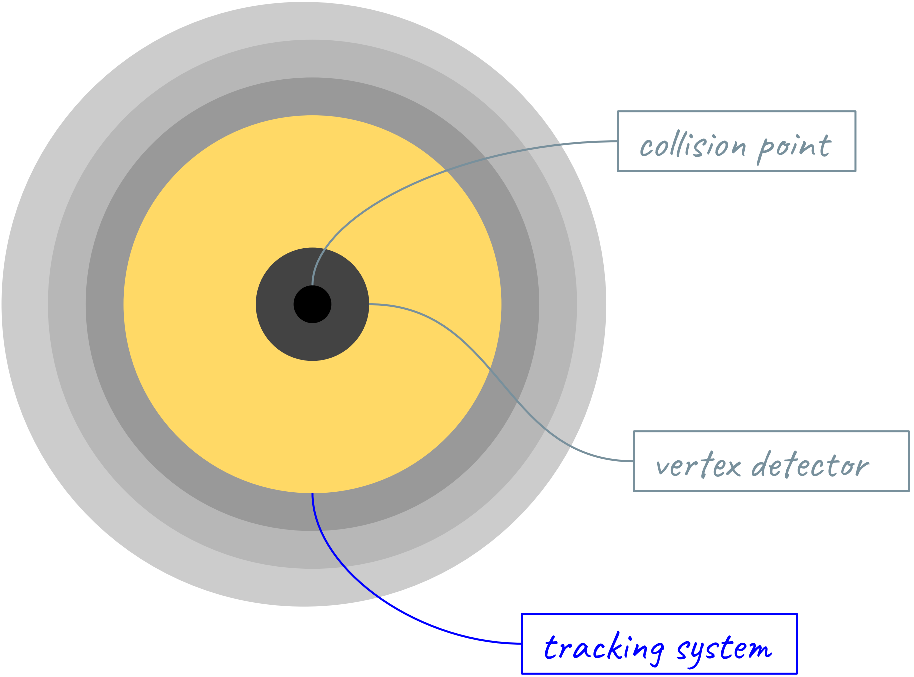
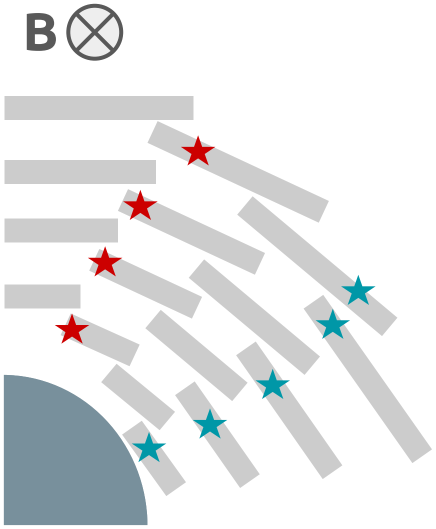
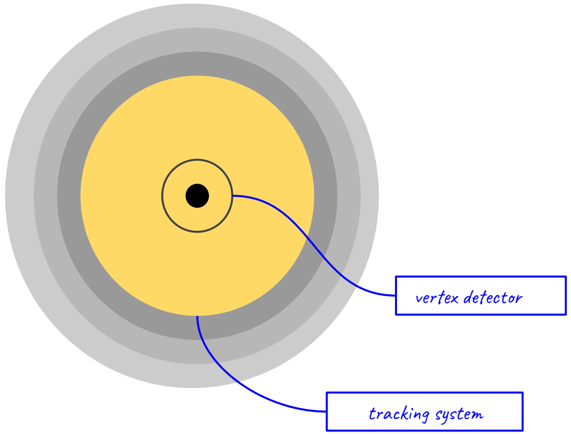


TRACKING SYSTEM





- charged particles cause electric signals

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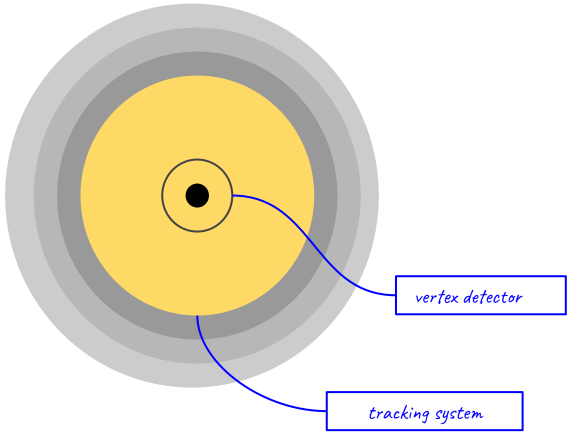
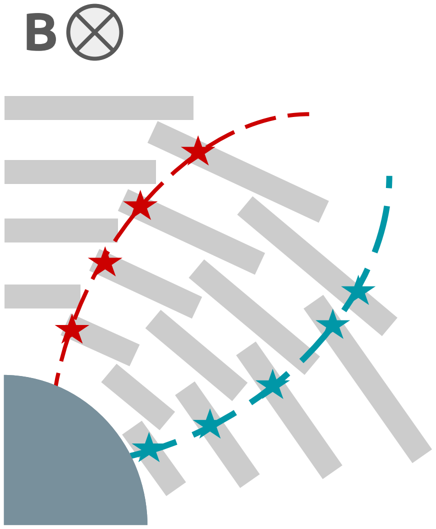
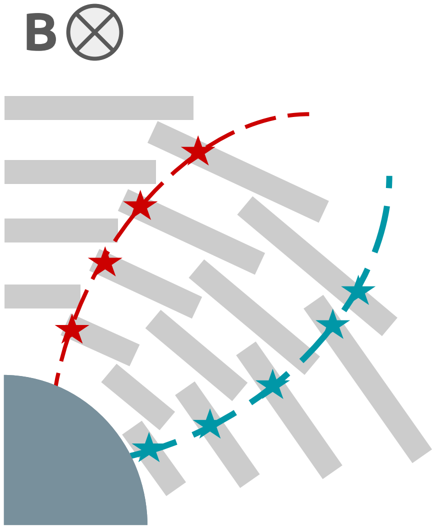
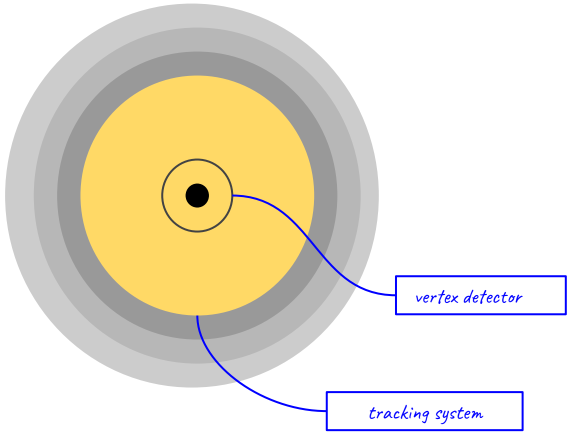




- charged particles cause electric signals
- from that, tracks can be reconstructed

TRACKING SYSTEM





- charged particles cause electric signals
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what's the charge of the red particle?

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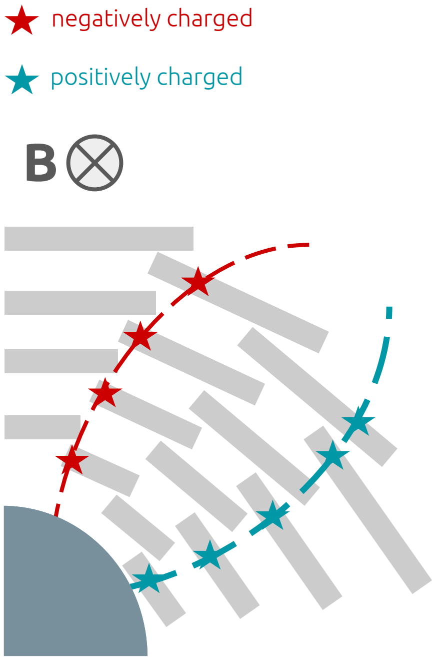

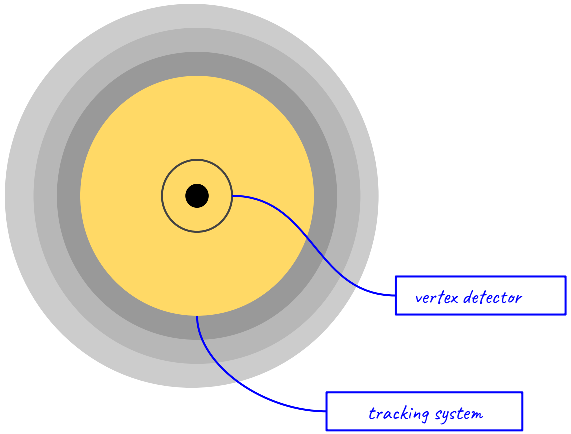

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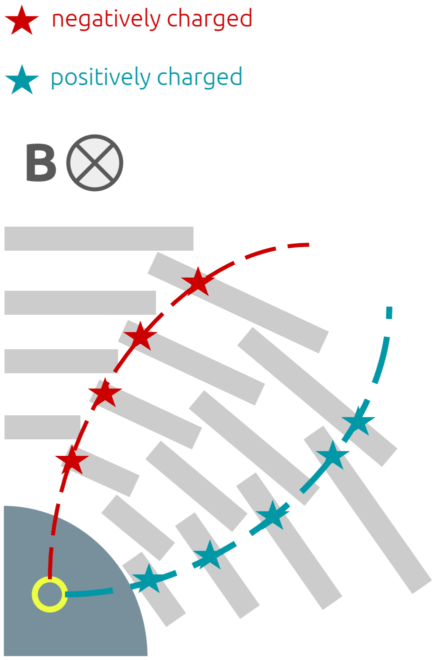
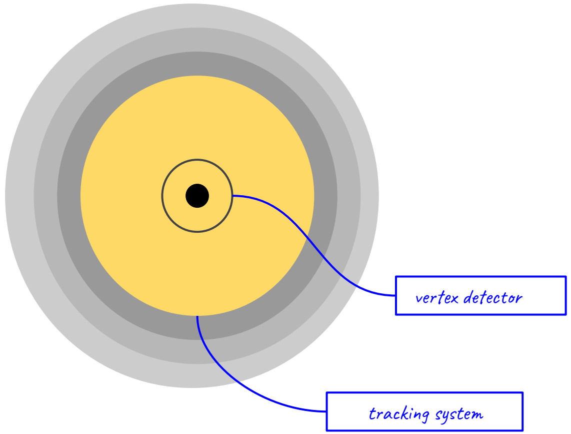
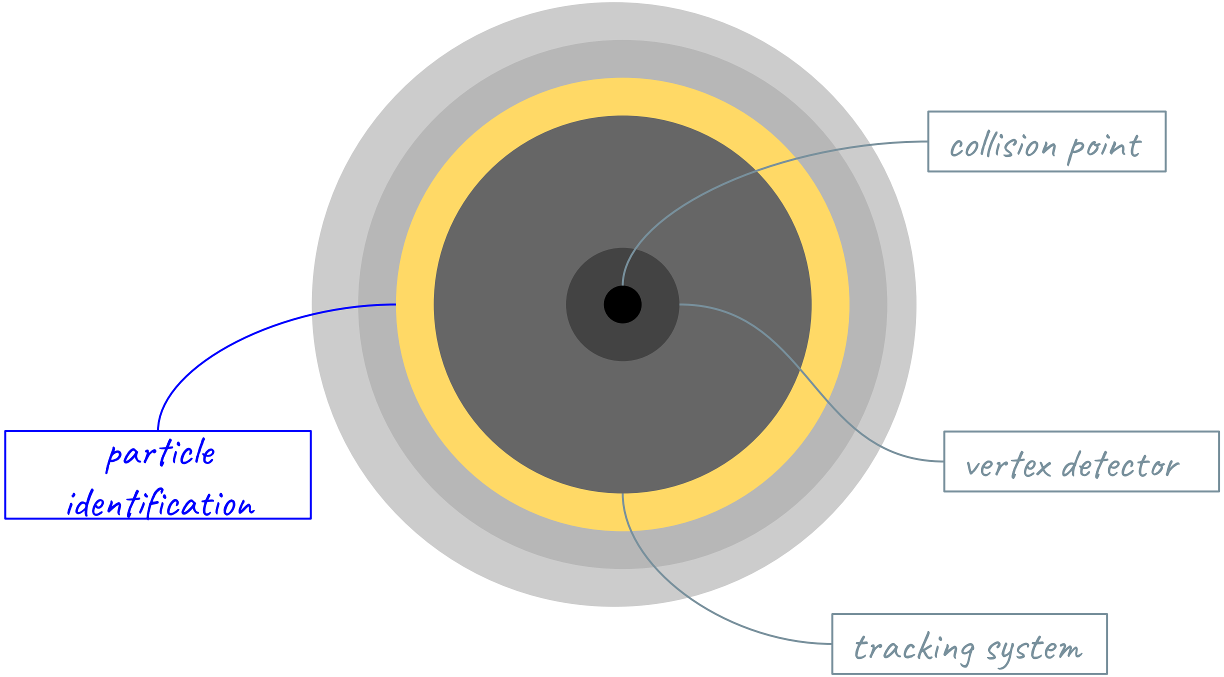




- charged particles cause electric signals
- from that, tracks can be reconstructed
- additionally, the vertex can be deduced

THE BELLE II DETECTOR

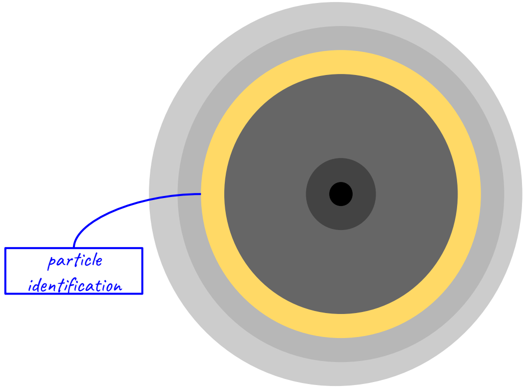
Detector around the collision point: “Onion principle“



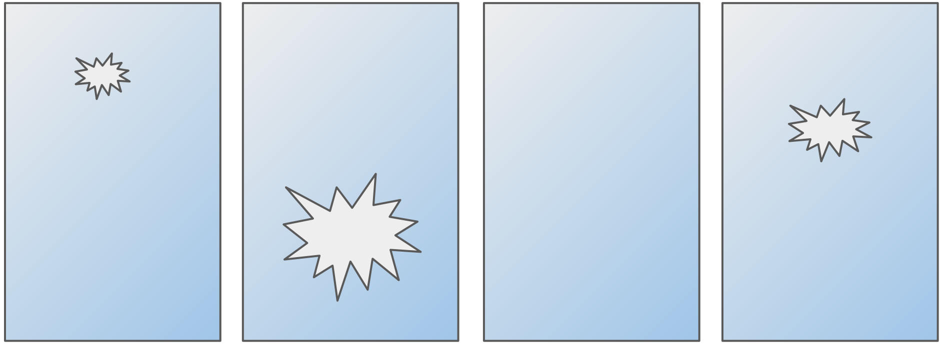
PARTICLE IDENTIFICATION

- particles have different masses
  → same velocity leads to different momenta:

p = mv



Example:
football, **tennis ball** , **golf ball** and **table tennis ball** hit a windows
<u>same velocity</u>, different damage:



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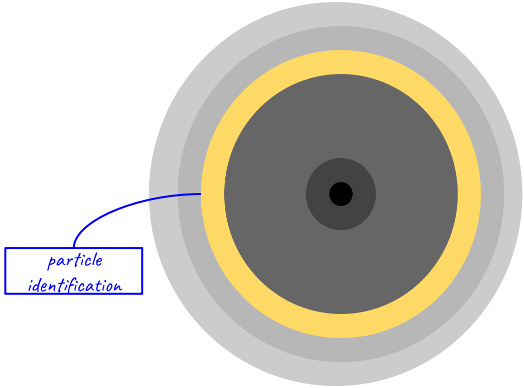

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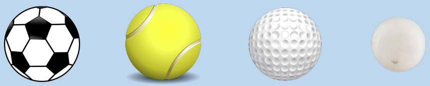

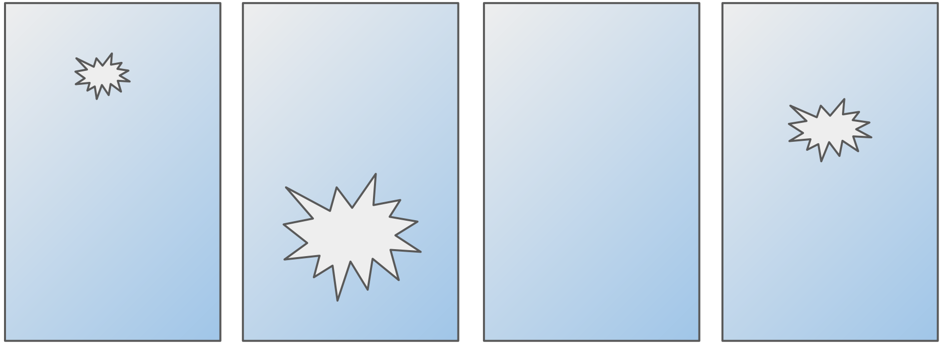

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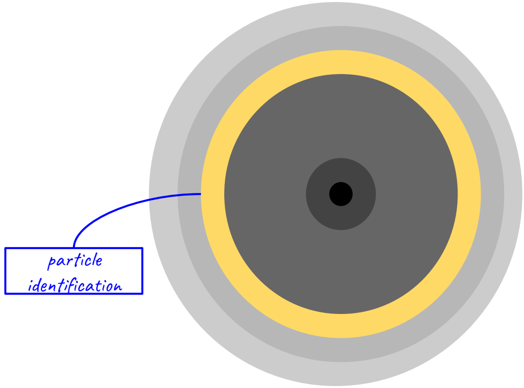

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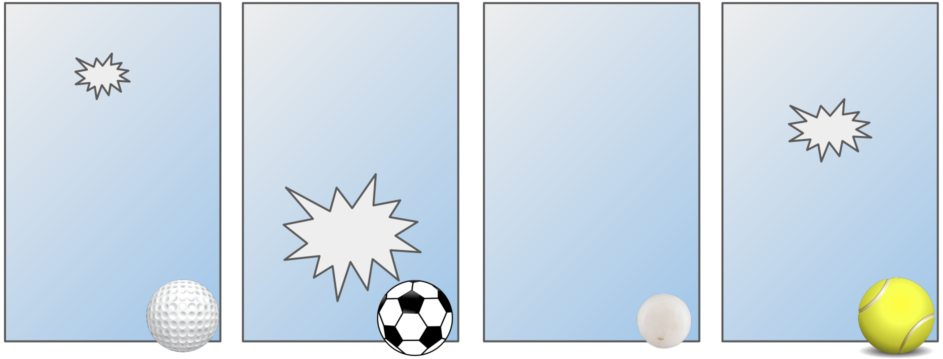

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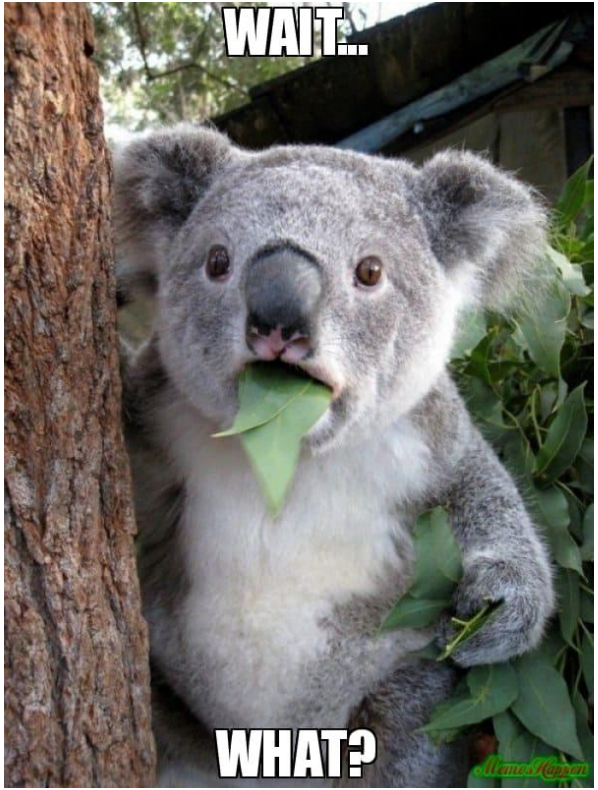

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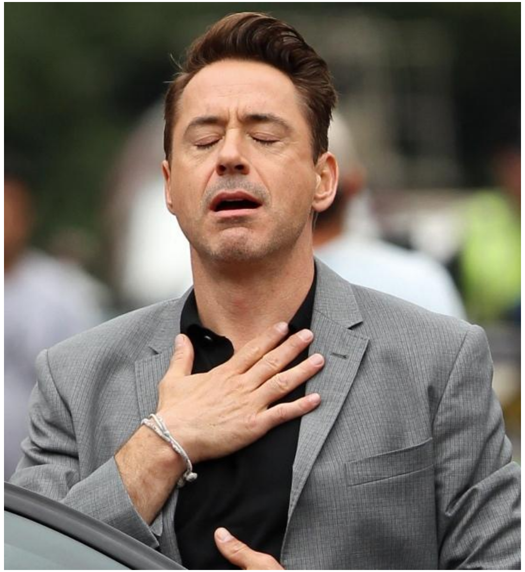

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speed of light in the medium

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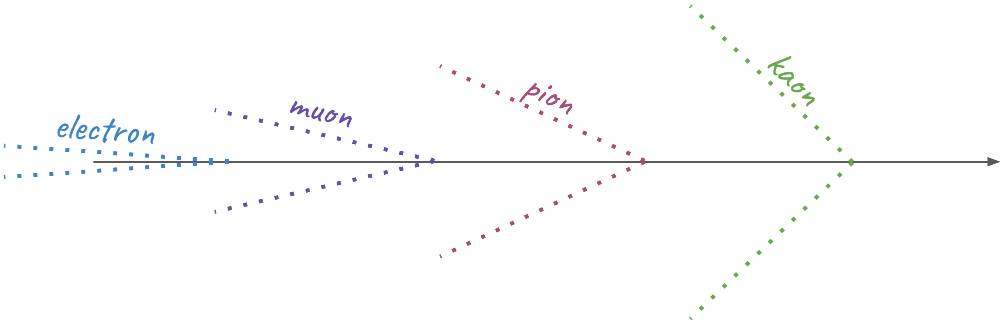
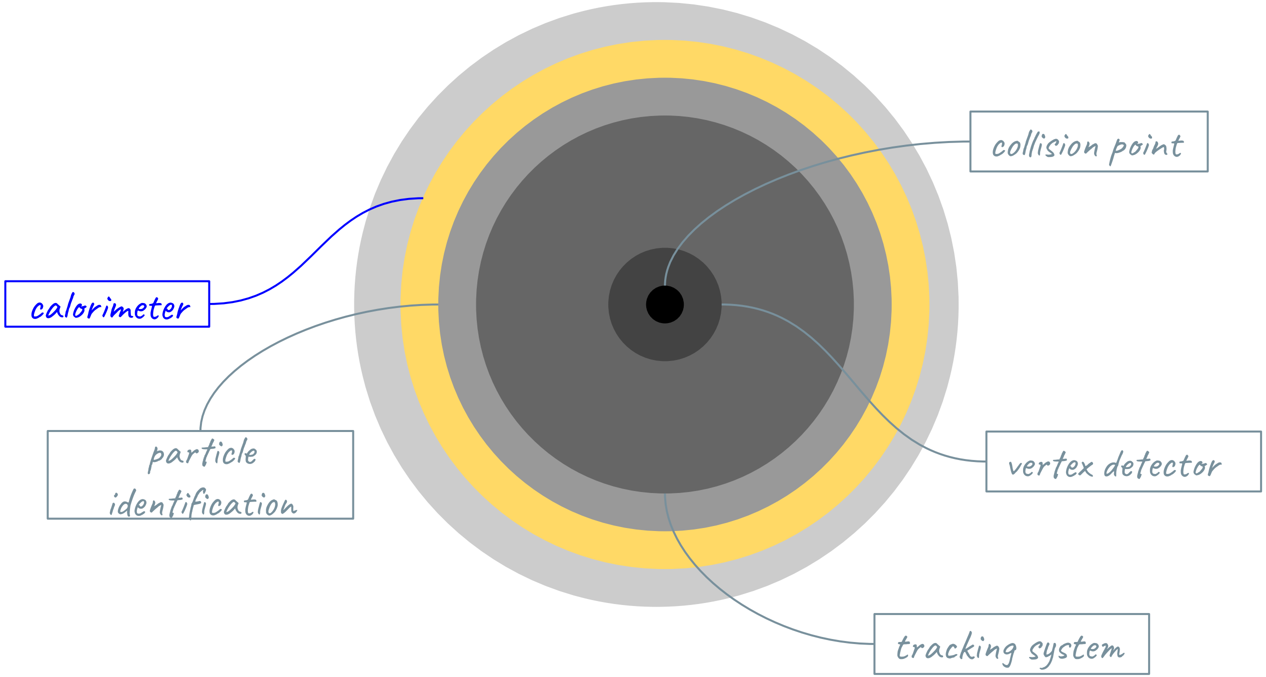


$$v = \frac{p}{m}$$

heavier particles are slower!

THE BELLE II DETECTOR

Detector around the collision point: “Onion principle“



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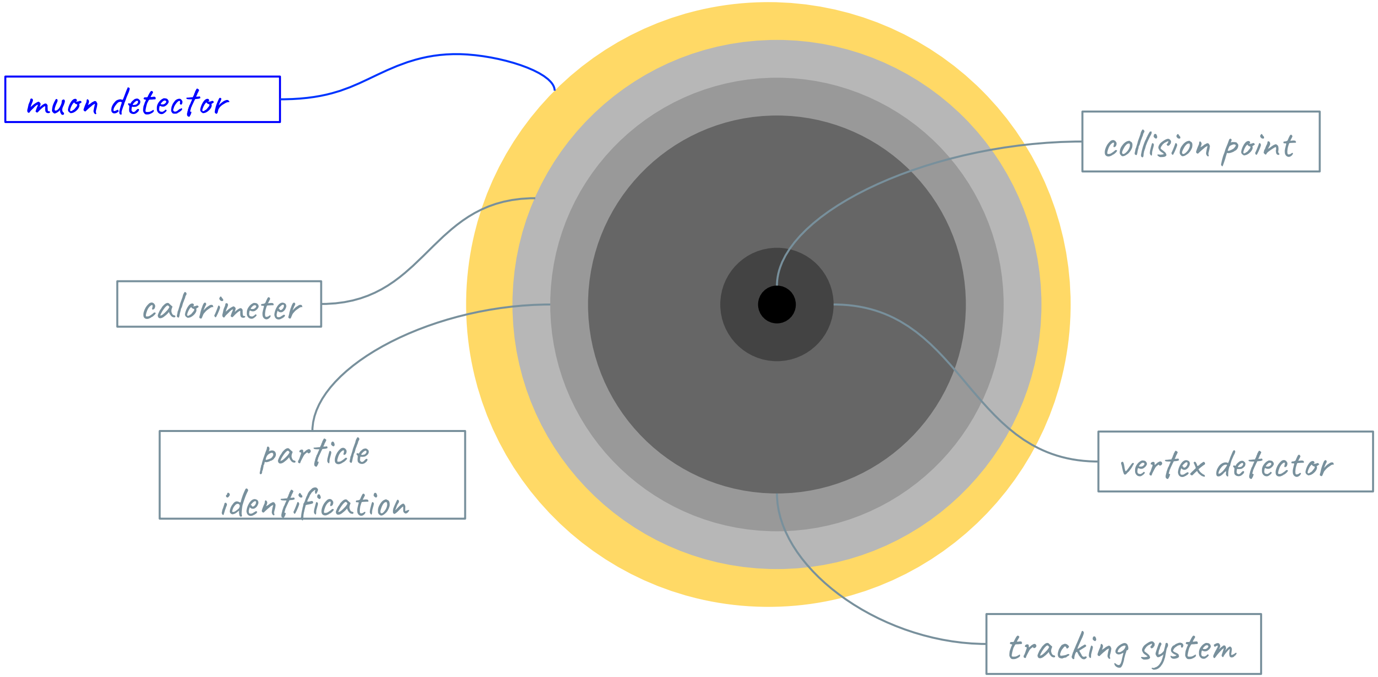
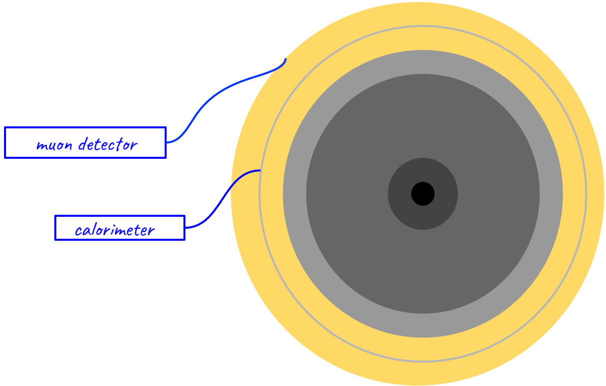
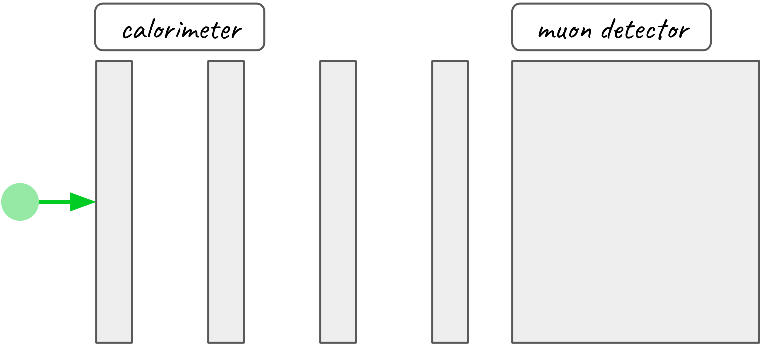


CALORIMETER

- **Calorimeter:**
  most particles deposit their whole energy…





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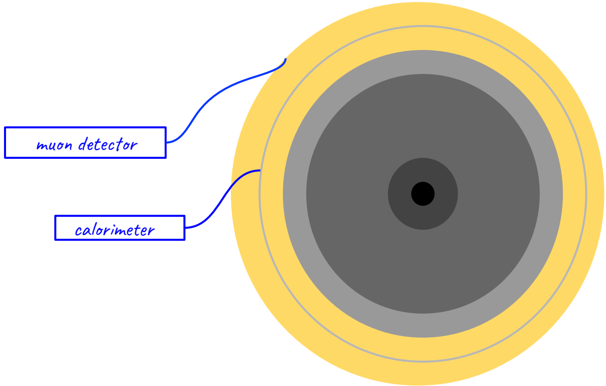
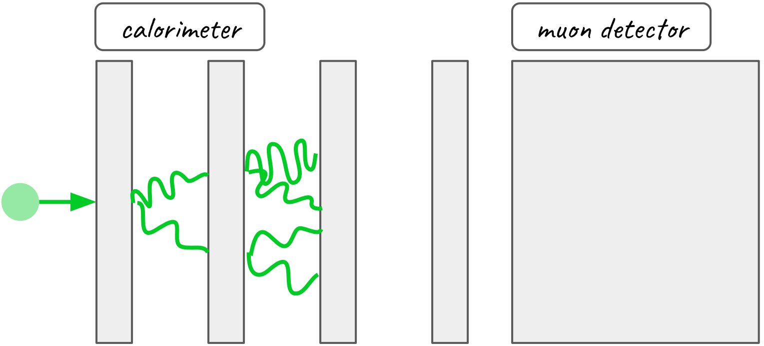
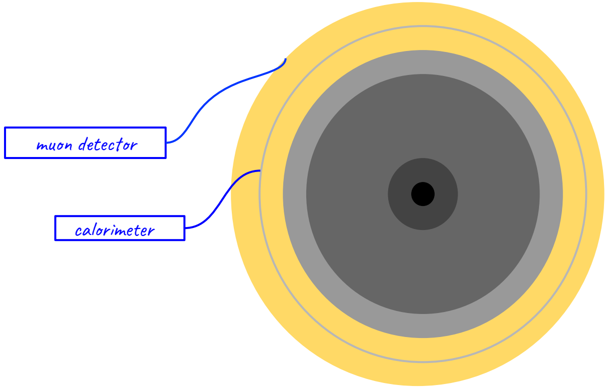
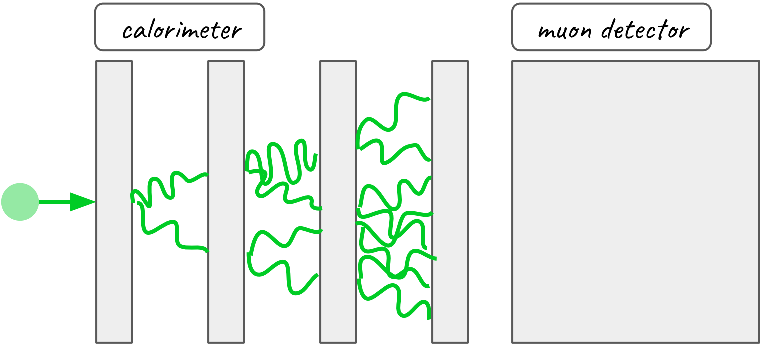




CALORIMETER

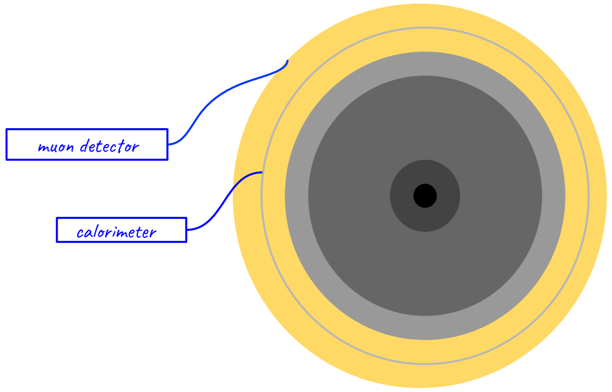
- **Calorimeter:**
  most particles deposit their whole energy…
  … and are stopped here

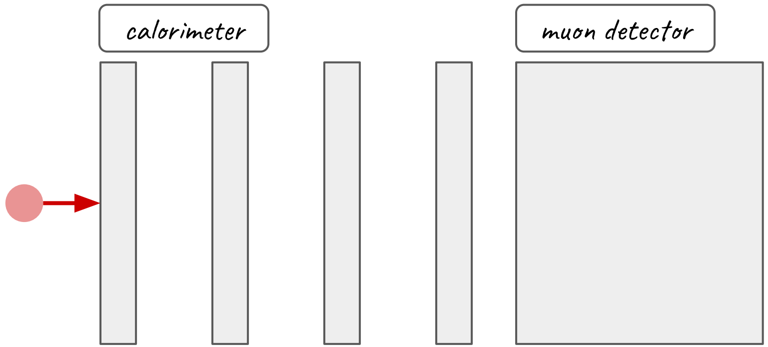




CALORIMETER AND MUON DETECTOR

- **Calorimeter:**
  most particles deposit their whole energy…
  … and are stopped here
- **Muon detector:**
  muons scarcely interact and leave the calorimeter





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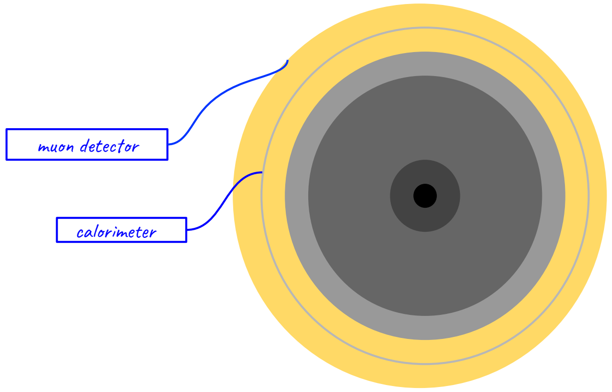

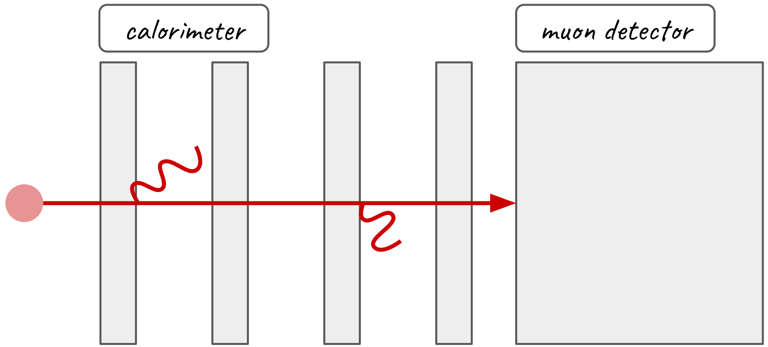

CALORIMETER AND MUON DETECTOR

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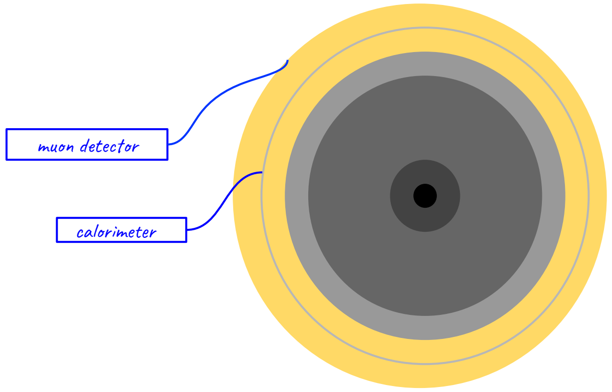
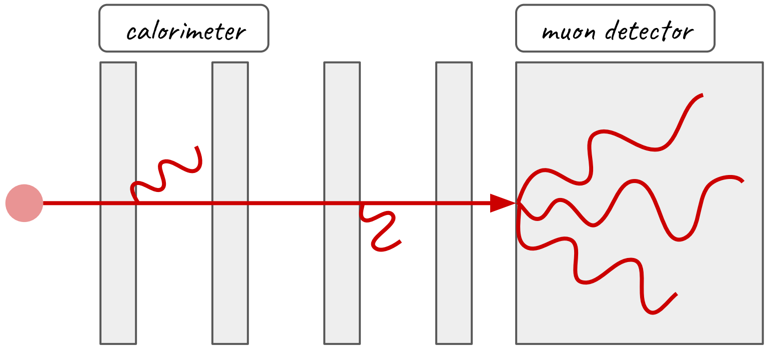
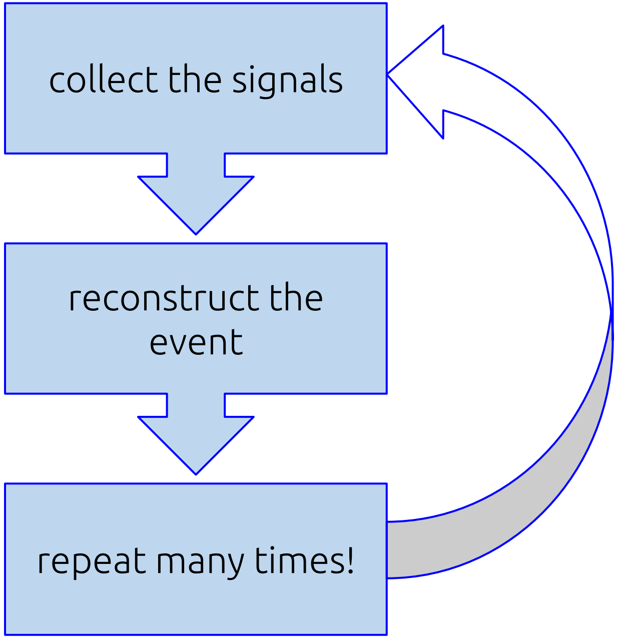
- **Muon detector:**
  muons scarcely interact and leave the calorimeter, they interact in the muon detector





WHAT'S NEXT?

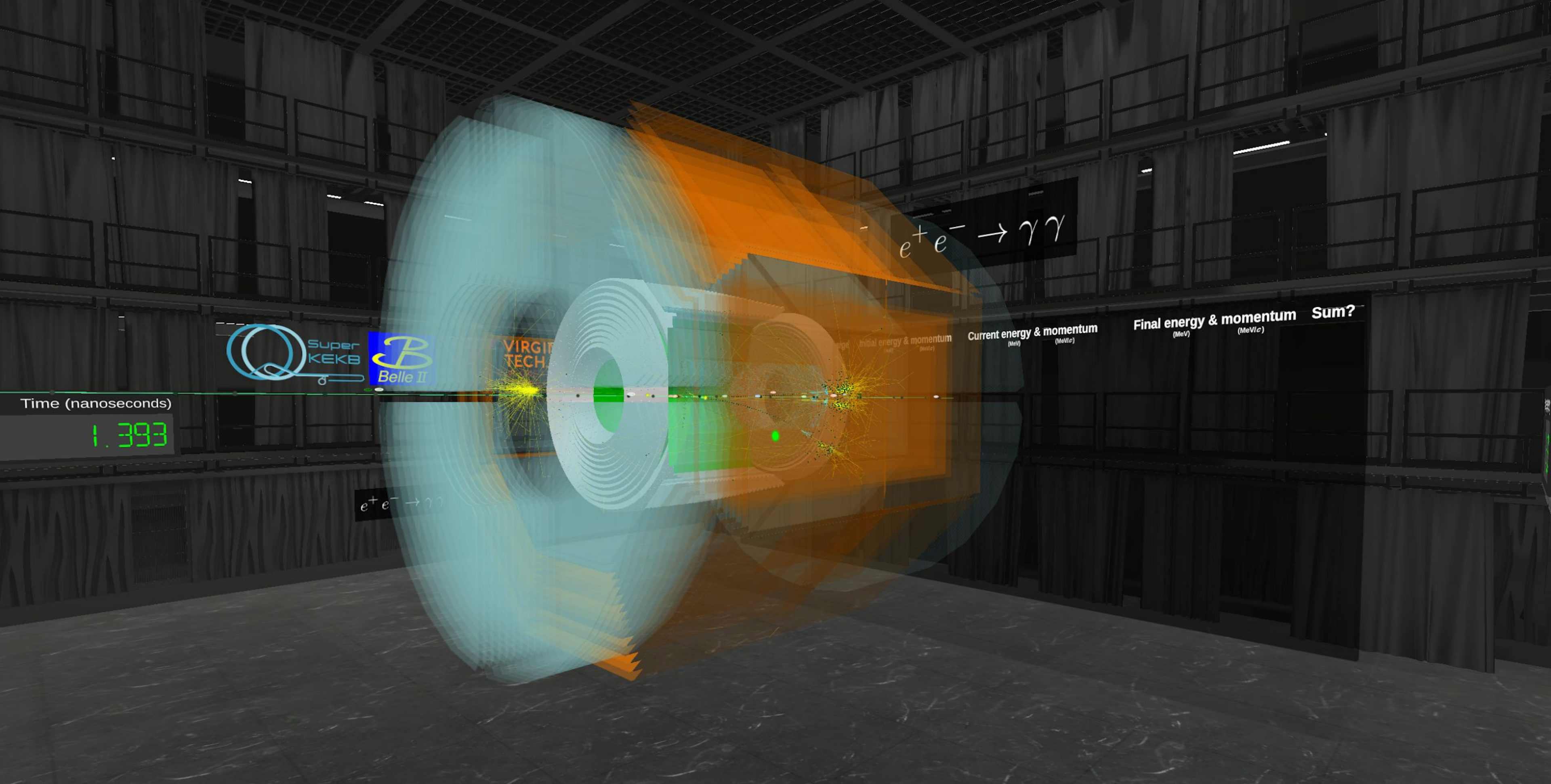


Why is not enough to just find one event?

- statistical fluctuations

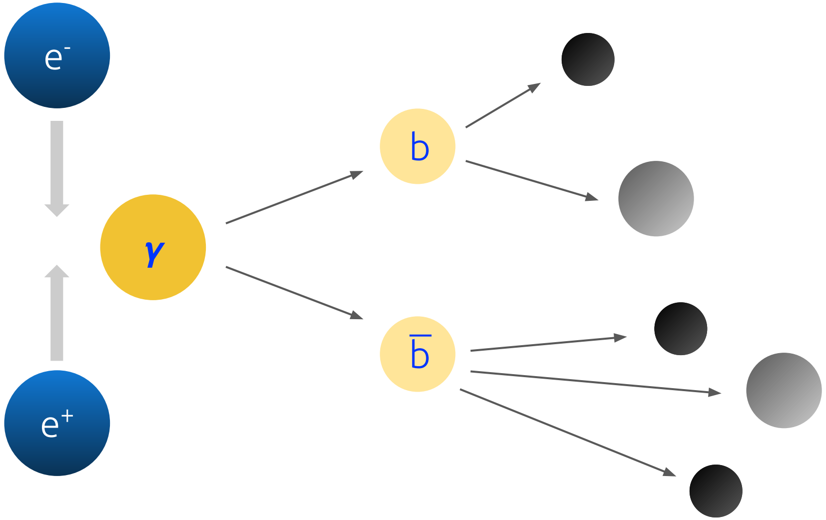
  → every measurement contains **uncertainties** and errors

  → the more individual measurements the smaller the overall uncertainty



Let's have a look to some events!

WHICH PARTICLES DO WE SEE?



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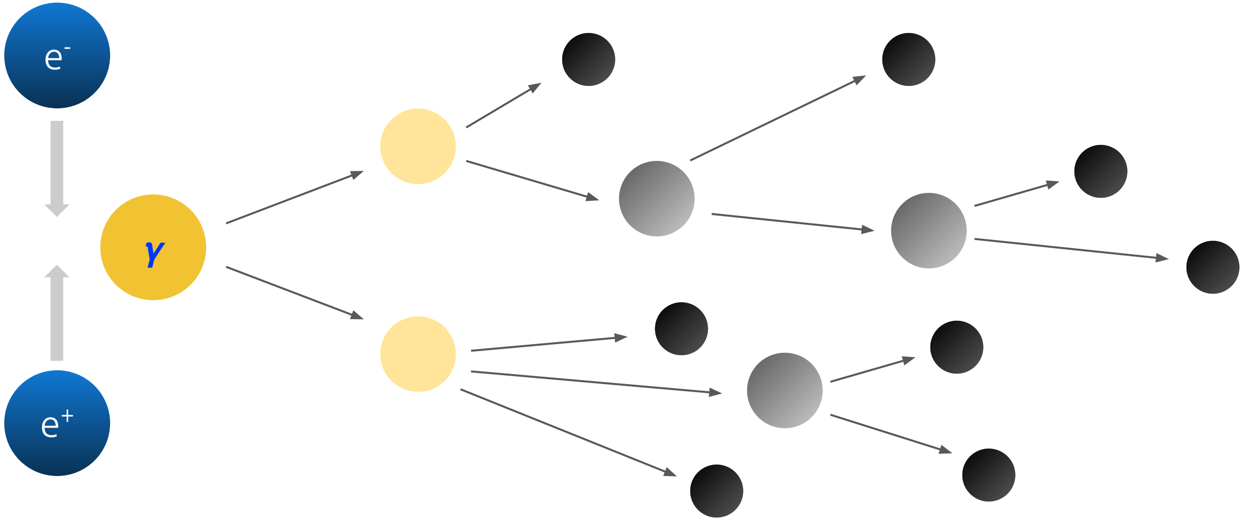

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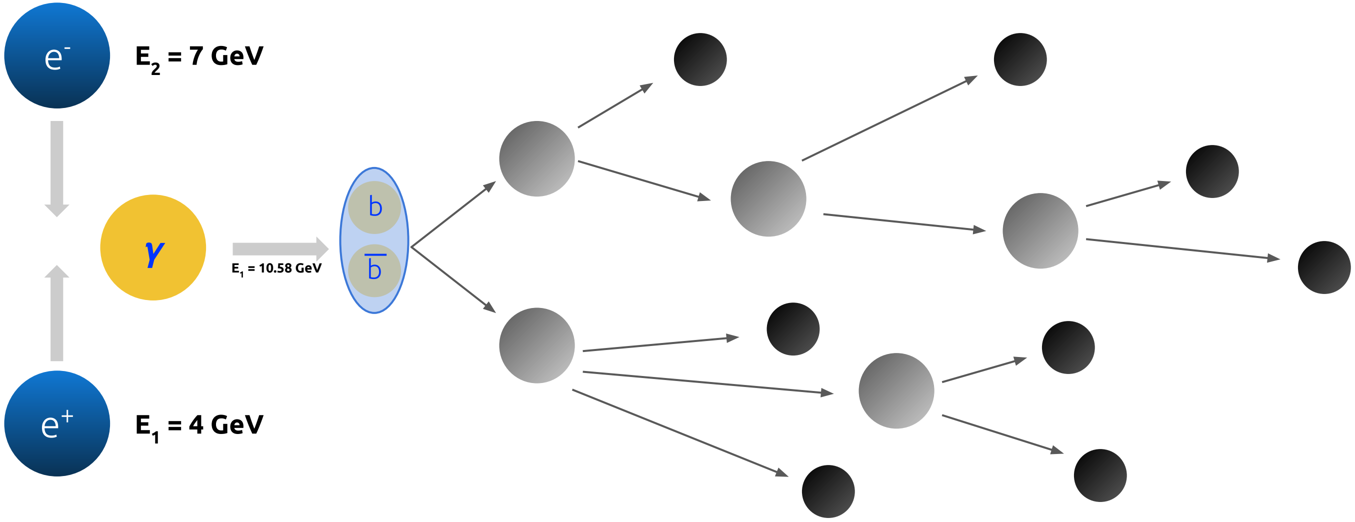

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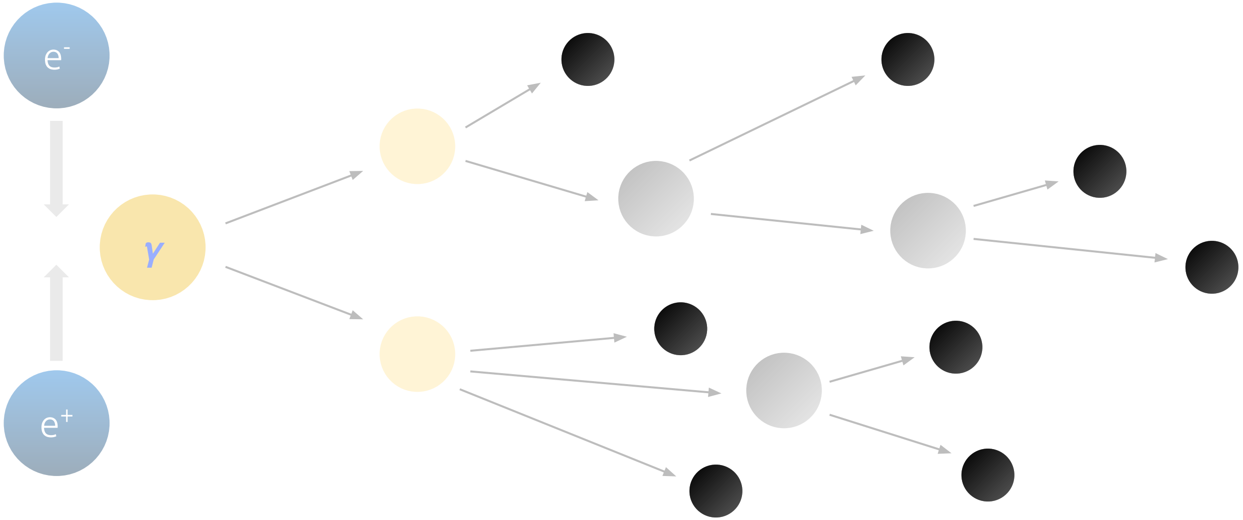
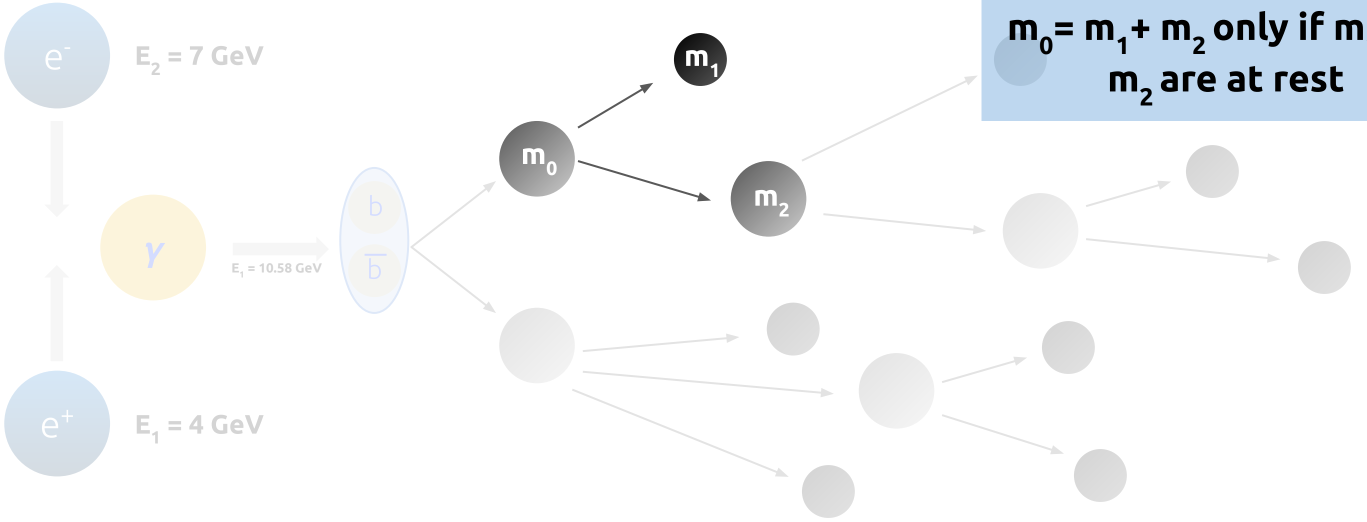


Long-lived particles!

PARTICLE DECAY: FEW RULES



$m_0 = m_1 + m_2$ only if m_1 and m_2 are at rest

PARTICLE IDENTIFICATION

- In reality we exploit the Cherenkov Effect:
  → charged particles can travel
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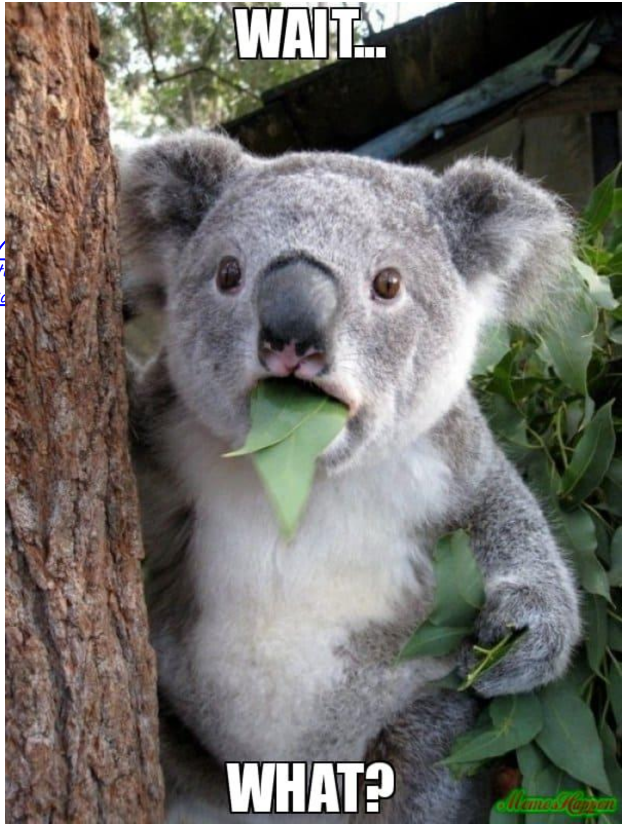

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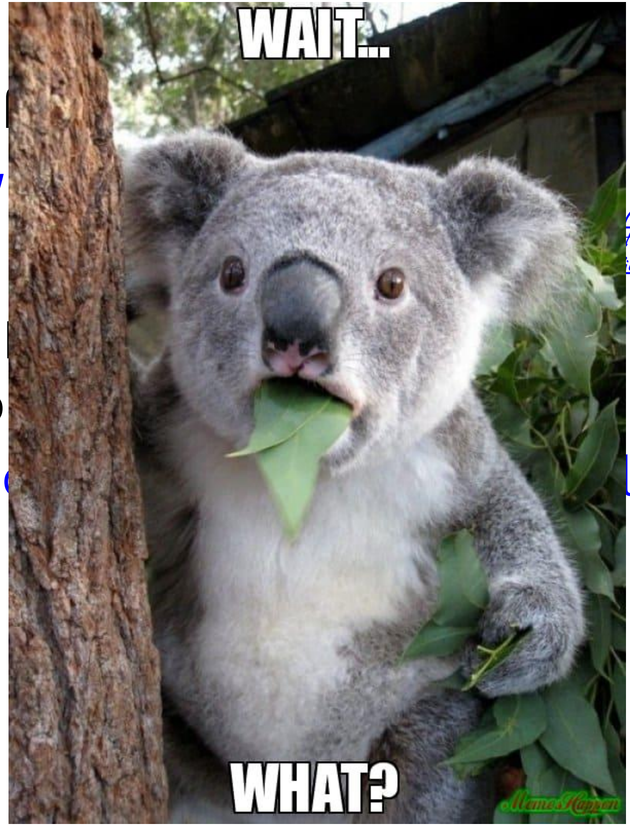

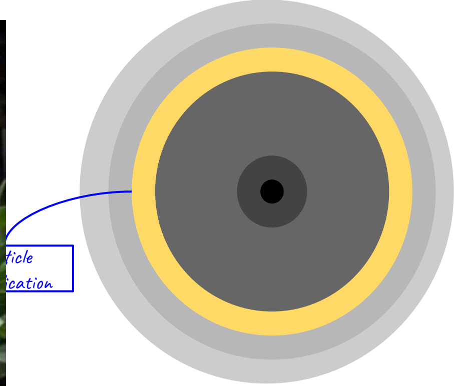

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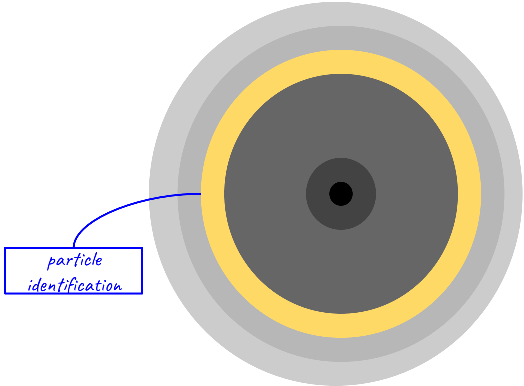

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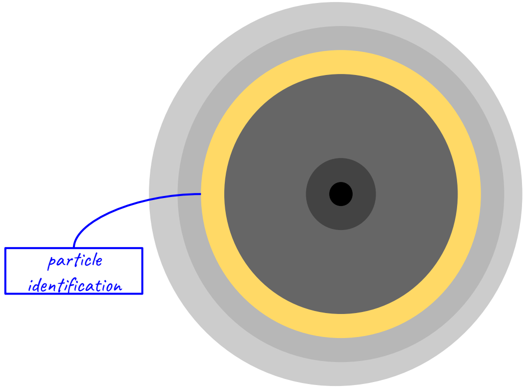

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refractive index of the medium

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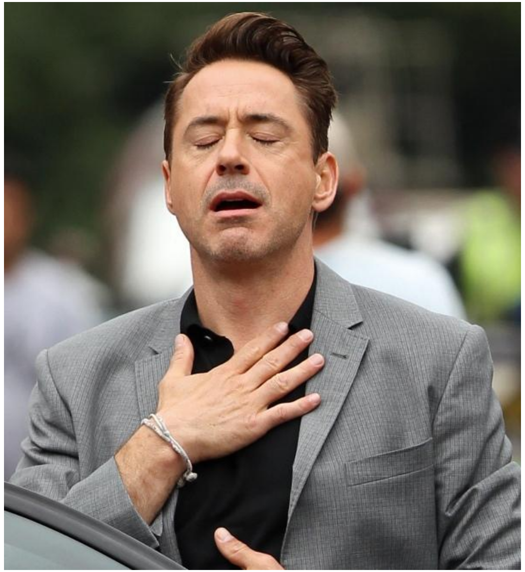

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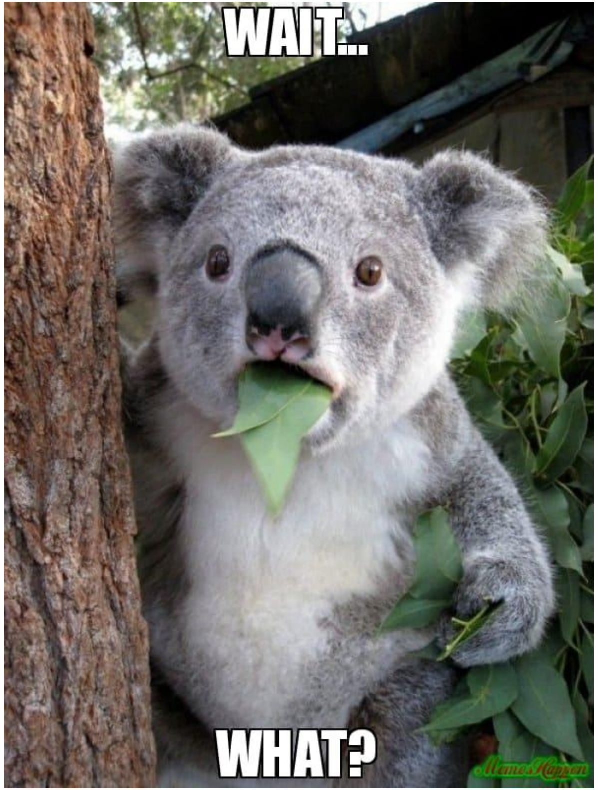

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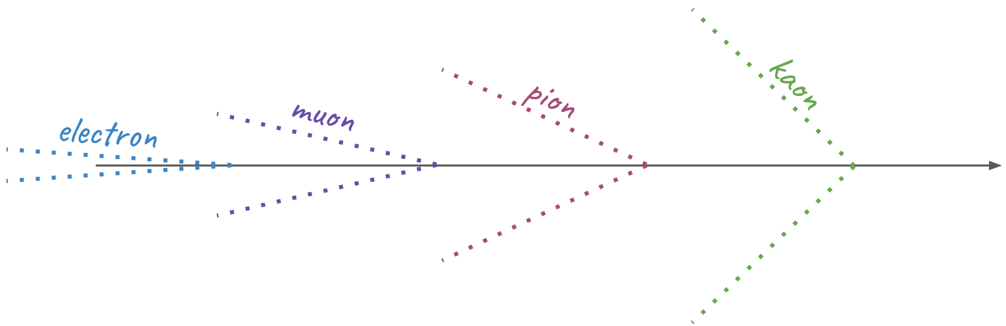

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