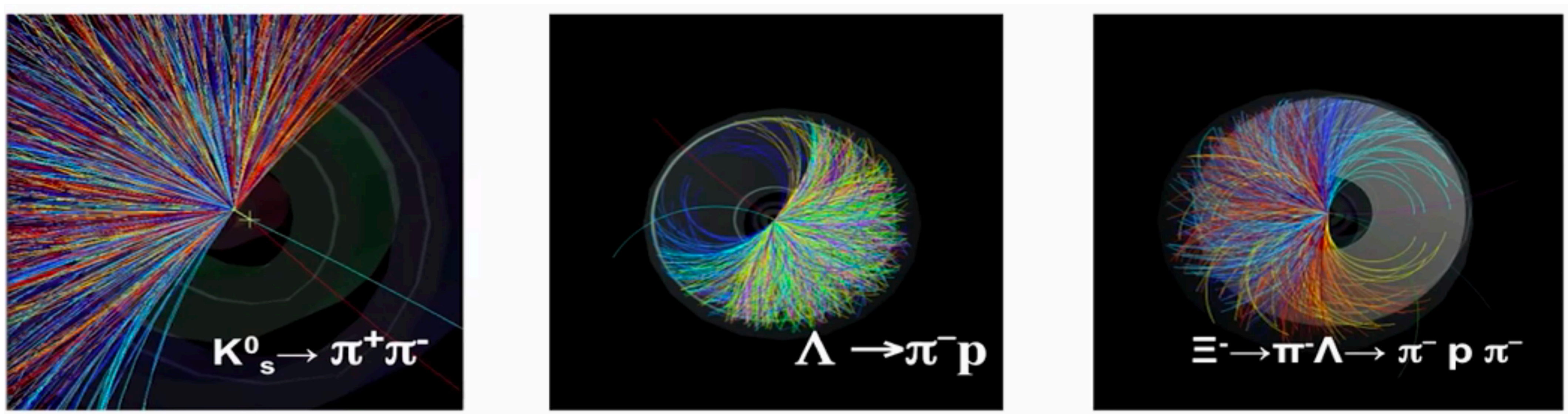
Looking for strange particles in ALICE

ALICE

Instituto de Ciencias Nucleares UNAM



1. Visually identification of V0s in p-p collisions
2. Large scale analysis: Find peak over background

Sushanta Tripathy, Antonio Ortiz

Introduction

- Particle physics: Study about the tiniest objects of nature

- Unit of energy: electron-volt (eV)

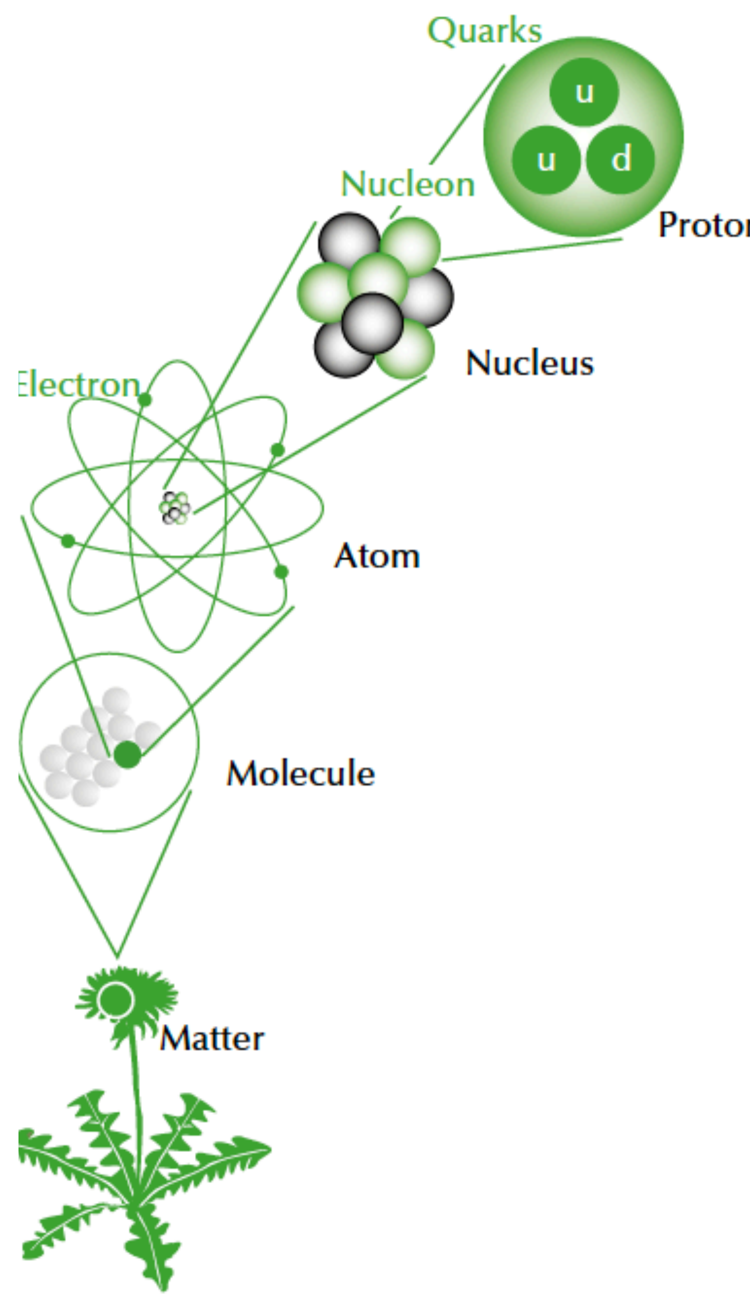
Large Hadron Collider at Geneva can reach up to **13 TeV** for proton-proton collisions

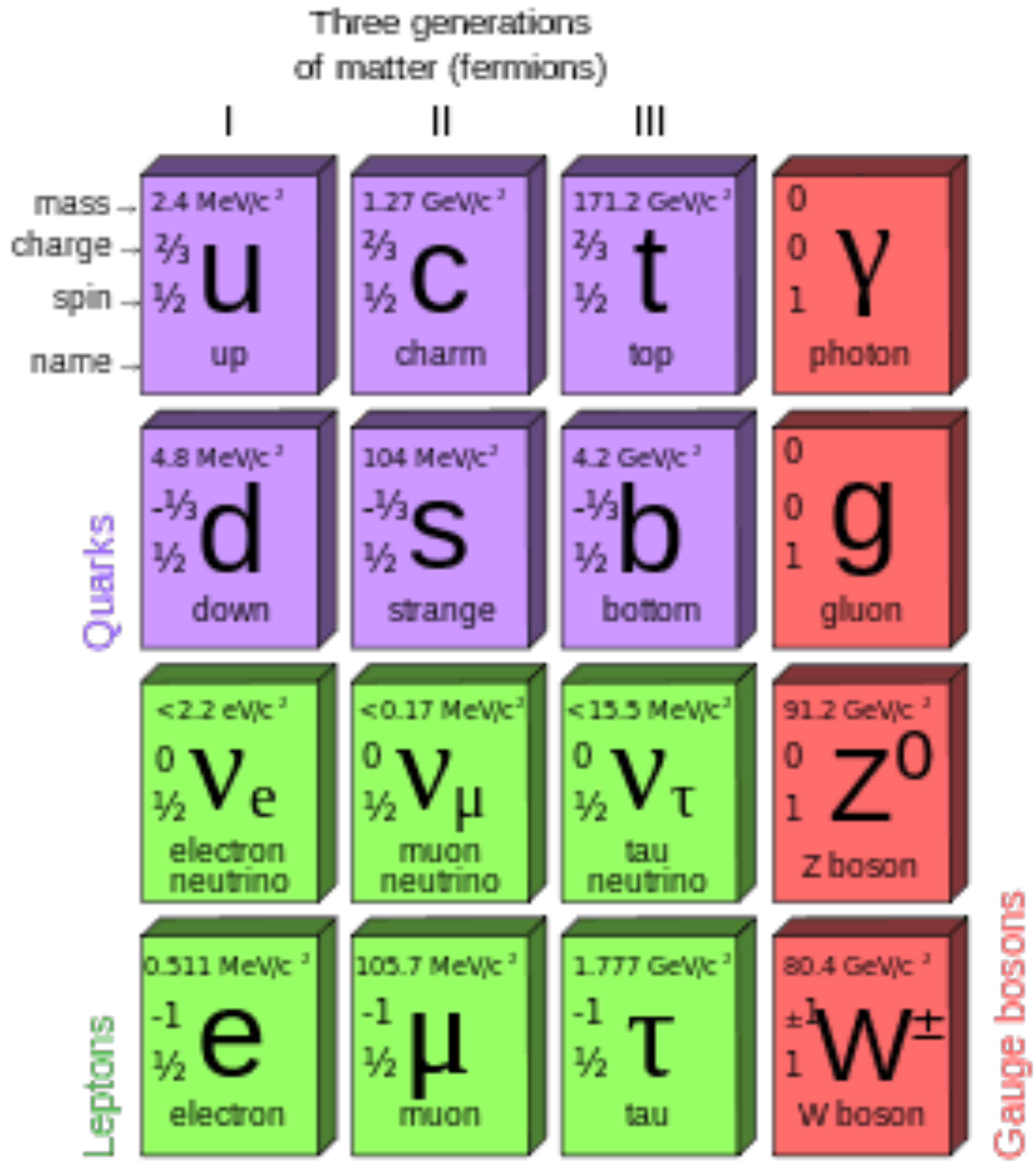
Einstein's special theory of relativity

No particle can move with a speed faster than the speed of light in vacuum; however, there is no limit to the energy a particle can attain.

- In high-energy accelerators, particles normally travel very close to the speed of light.

7 TeV protons travel at 99.9999991% speed of light at the LHC

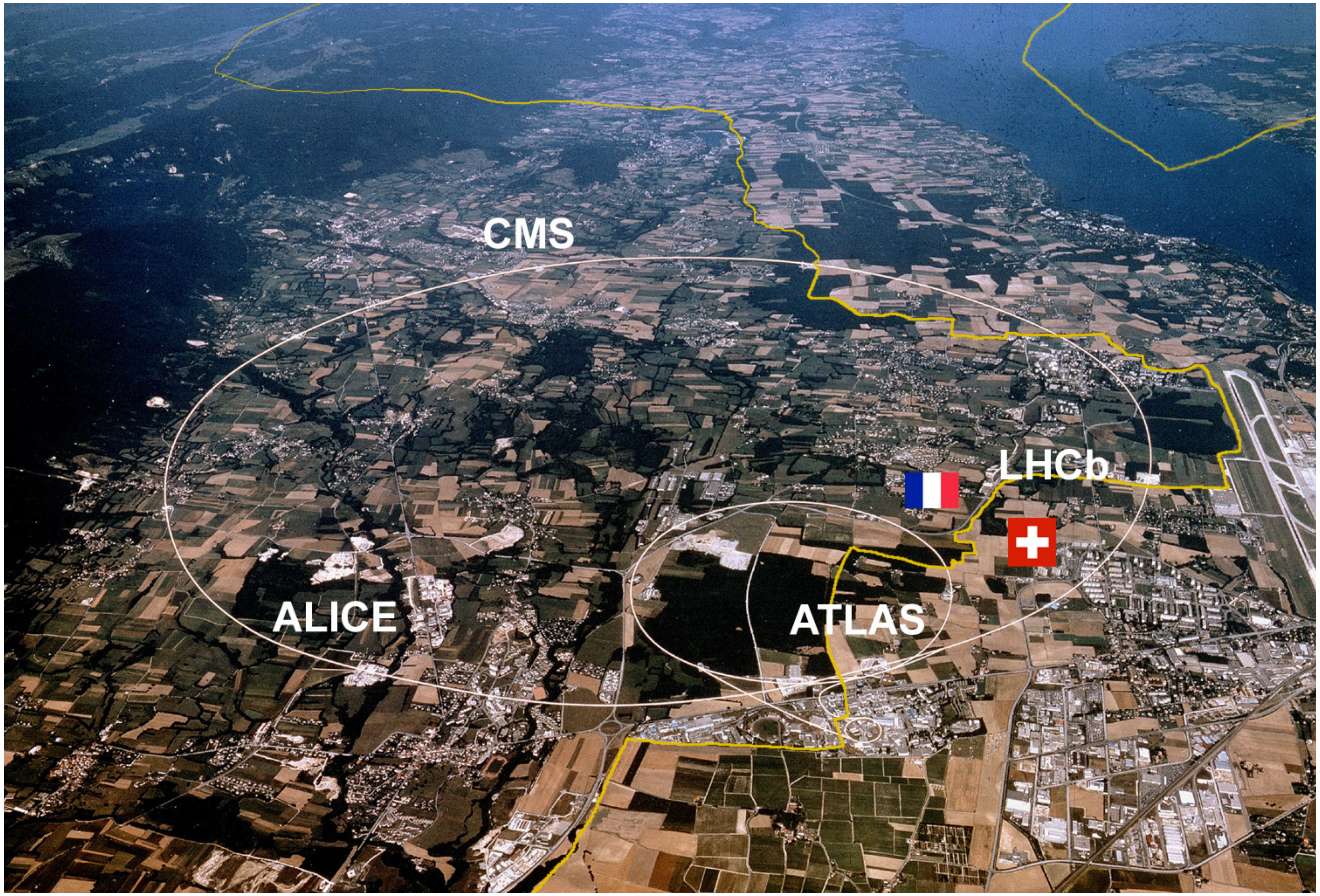




Three generations of matter (fermions)
I
II
III
mass
charge
spin
name
2.4 MeV/c²
⅔
½
u
up
1.27 GeV/c²
⅔
½
c
charm
171.2 GeV/c²
⅔
½
t
top
0
0
1
γ
photon
4.8 MeV/c²
-⅓
½
d
down
104 MeV/c²
-⅓
½
s
strange
4.2 GeV/c²
-⅓
½
b
bottom
0
0
1
g
gluon
<2.2 eV/c²
0
½
νe
electron neutrino
<0.17 MeV/c²
0
½
νμ
muon neutrino
<15.5 MeV/c²
0
½
ντ
tau neutrino
91.2 GeV/c²
0
1
Z0
Z boson
0.511 MeV/c²
-1
½
e
electron
105.7 MeV/c²
-1
½
μ
muon
1.777 GeV/c²
-1
½
τ
tau
80.4 GeV/c²
±1
1
W±
W boson
Quarks
Leptons
Gauge bosons

The Large Hadron Collider

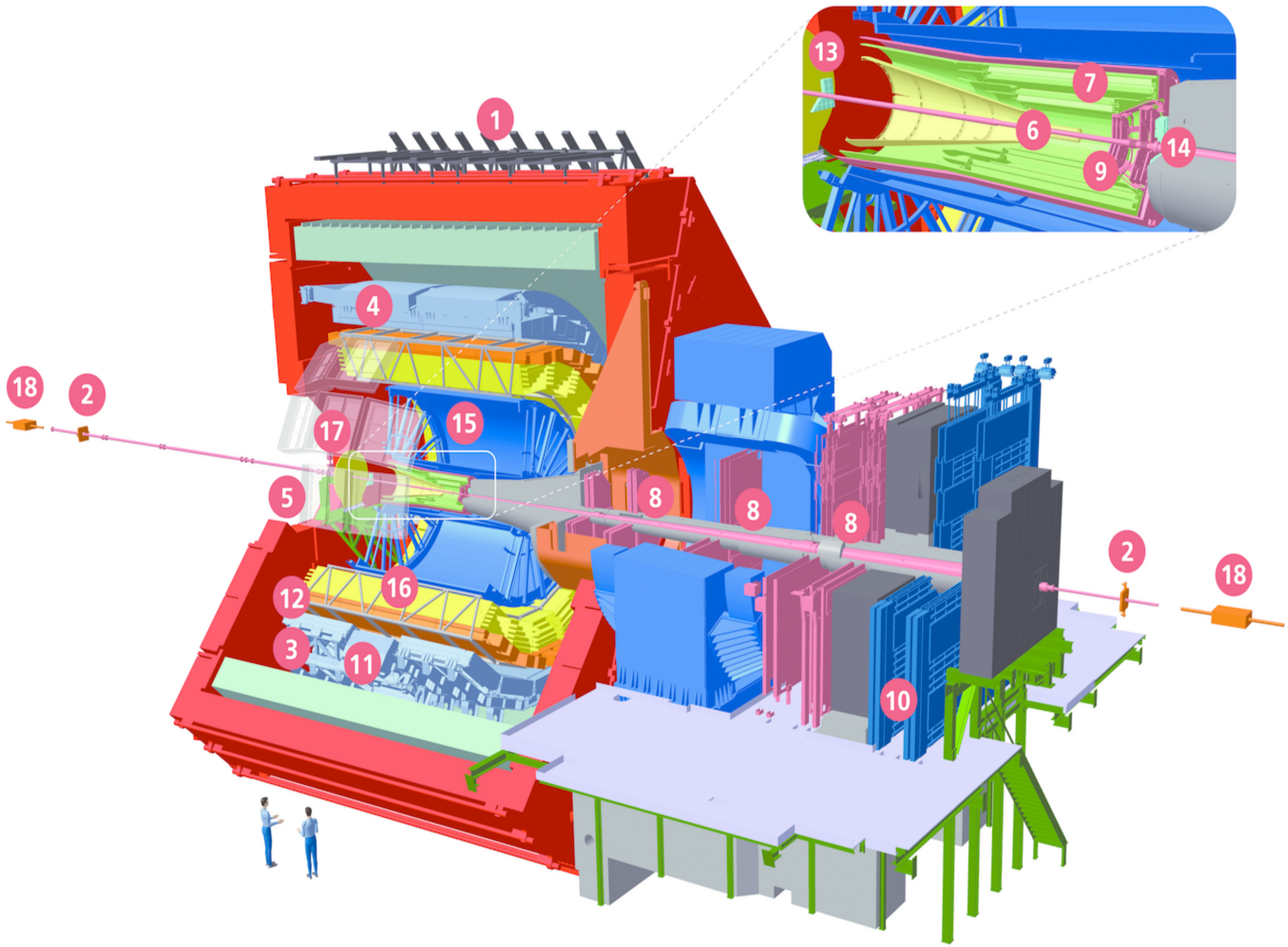
- Large due to its size (approximately 27 km in circumference)
- Hadron because it accelerates protons or ions, which are hadrons
- Collider because these particles form two beams travelling in opposite directions, which collide at four points where the two rings of the machine intersect



World's largest and most powerful particle accelerator

A Large Ion Collider Experiment (ALICE)

- The international collaboration includes more than 1800 members from about 174 institutes in about 42 countries.
- Size: 26m long, 16m high, 16m wide, Weight: 10,000 tonnes



1. **ACORDE** | ALICE Cosmic Rays Detector
2. **AD** | ALICE Diffractive Detector
3. **DCal** | Di-jet Calorimeter
4. **EMCal** | Electromagnetic Calorimeter
5. **HMPID** | High Momentum Particle Identification Detector
6. **ITS-IB** | Inner Tracking System - Inner Barrel
7. **ITS-OB** | Inner Tracking System - Outer Barrel
8. **MCH** | Muon Tracking Chambers
9. **MFT** | Muon Forward Tracker
10. **MID** | Muon Identifier
11. **PHOS / CPV** | Photon Spectrometer
12. **TOF** | Time Of Flight
13. **T0+A** | Tzero + A
14. **T0+C** | Tzero + C
15. **TPC** | Time Projection Chamber
16. **TRD** | Transition Radiation Detector
17. **V0+** | Vzero + Detector
18. **ZDC** | Zero Degree Calorimeter

Strange particles

In this masterclass we will be looking into neutral strange particles which decay (after a few mm or cm) into two oppositely charged particles. They make a shape of "V". Thus they are called as V0 particles.

$K^0_s \to \pi^+\pi^-$

$\tau = 0.89 \times 10^{-10}$ s
$c\tau = 3\times10^{10}$ cm $s^{-1} \times 8.9\times10^{-11}$ s
2.67 cm from the point of interaction

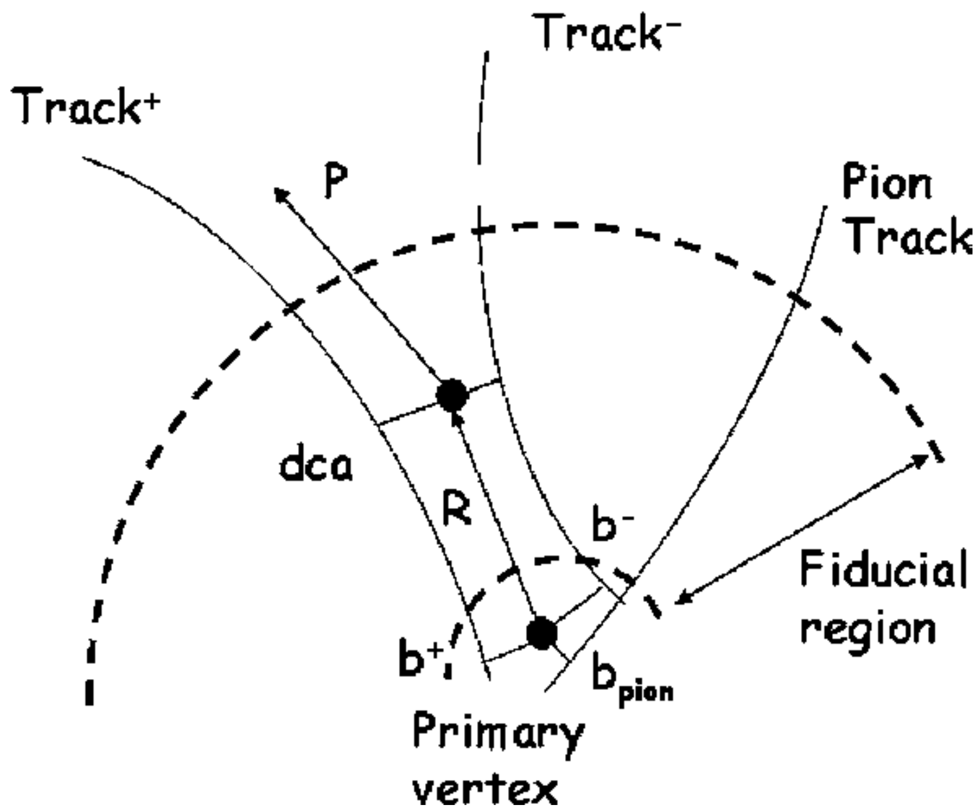
$\Lambda \to \pi^- p$

$\bar{\Lambda} \to \pi^+ \bar{p}$

$\tau = 2.6 \times 10^{-10}$ s
$c\tau = 3\times10^{10}$ cm $s^{-1} \times 2.6\times10^{-10}$ s
7.2 cm distance from the point of interaction

Weak decays : strangeness is not conserved

How do we identify V0?



$$P = Q.B.R$$

P - Particle momentum
Q - Electric charge
B - Magnetic field
R - radius of curvature

Invariant mass

1 - Decay daughter 1
2 - Decay daughter 2

$$m^2 = E^2 - p^2$$
$$= (E_1+E_2)^2 - (p_1+p_2)^2$$
$$= m_1{}^2+m_2{}^2 + 2E_1E_2 - 2p_1.p_2$$

Conservation Laws

Energy conservation ($E = E_1+E_2$)

Momentum conservation ($\mathbf{p} = \mathbf{p_1}+\mathbf{p_2}$)

Total energy: $E^2 = p^2c^2+m^2c^4$

Natural units, c = 1

$E^2 = p^2+m^2$

$E_1{}^2 = p_1{}^2+m_1{}^2$

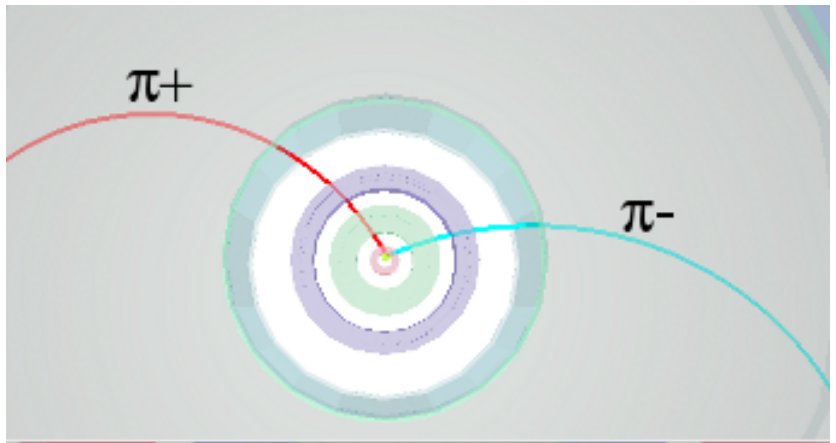
$E_2{}^2 = p_2{}^2+m_2{}^2$

We shall calculate the invariant mass of the mother particle from information of mass and momentum of the daughter particles (PID detectors)

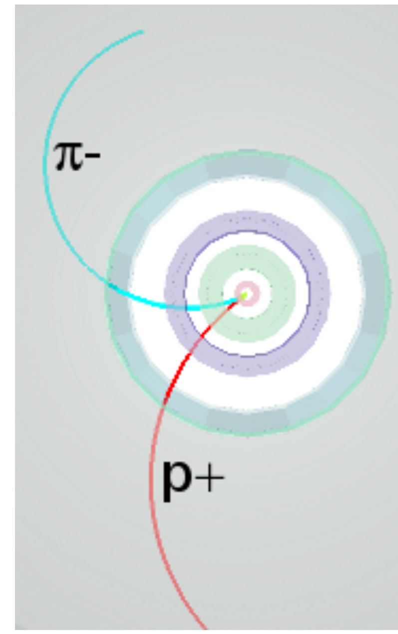
Instructions **(Exercise - 1)**

- In this exercise you will determine the number of strange particles in 15 pp collisions at collision energy of about 7 TeV.
- Each group will be assigned a different dataset to analyse which will have around 20 pp collisions (events) in each of them.
- See the topology and check if you can recognise the particle
- Invariant mass calculation (look for the mass table and if you find similar mass then select the particle and submit). If you can't recognise any of the particle, identify them as background.

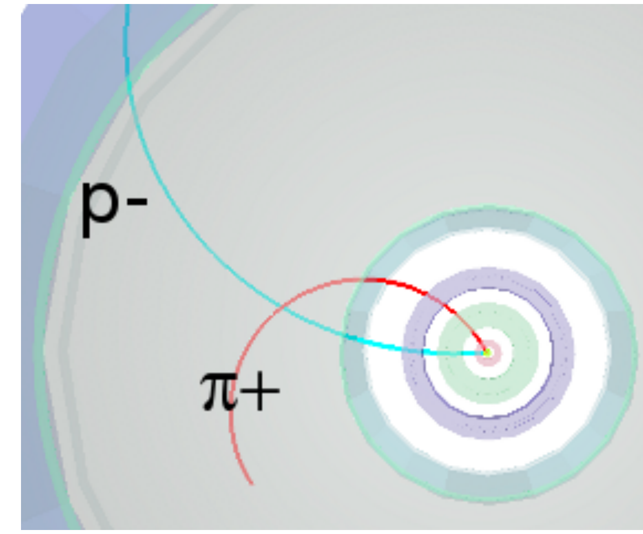
Decay patterns and mass table



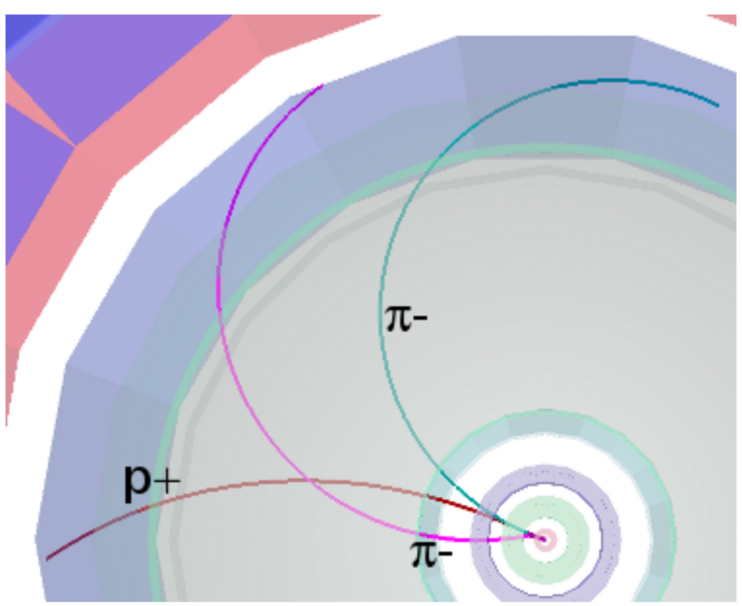
$K_S^0 \to \pi^+ + \pi^-$



$\Lambda \to \pi^- + p$



$\bar{\Lambda} \to \pi^+ + \bar{p}$

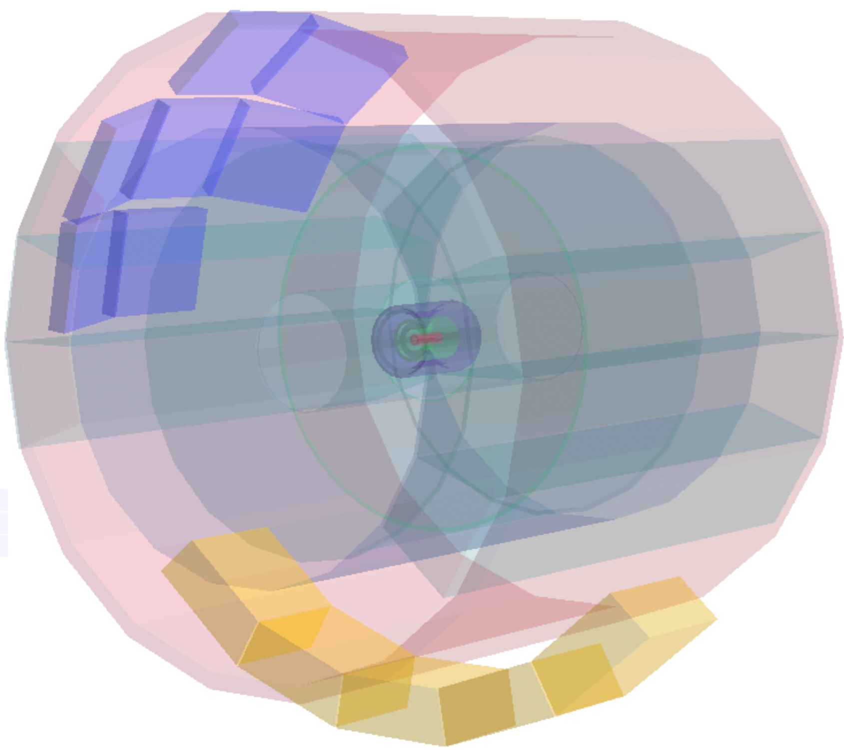


Ξ^-

Mass of the particles

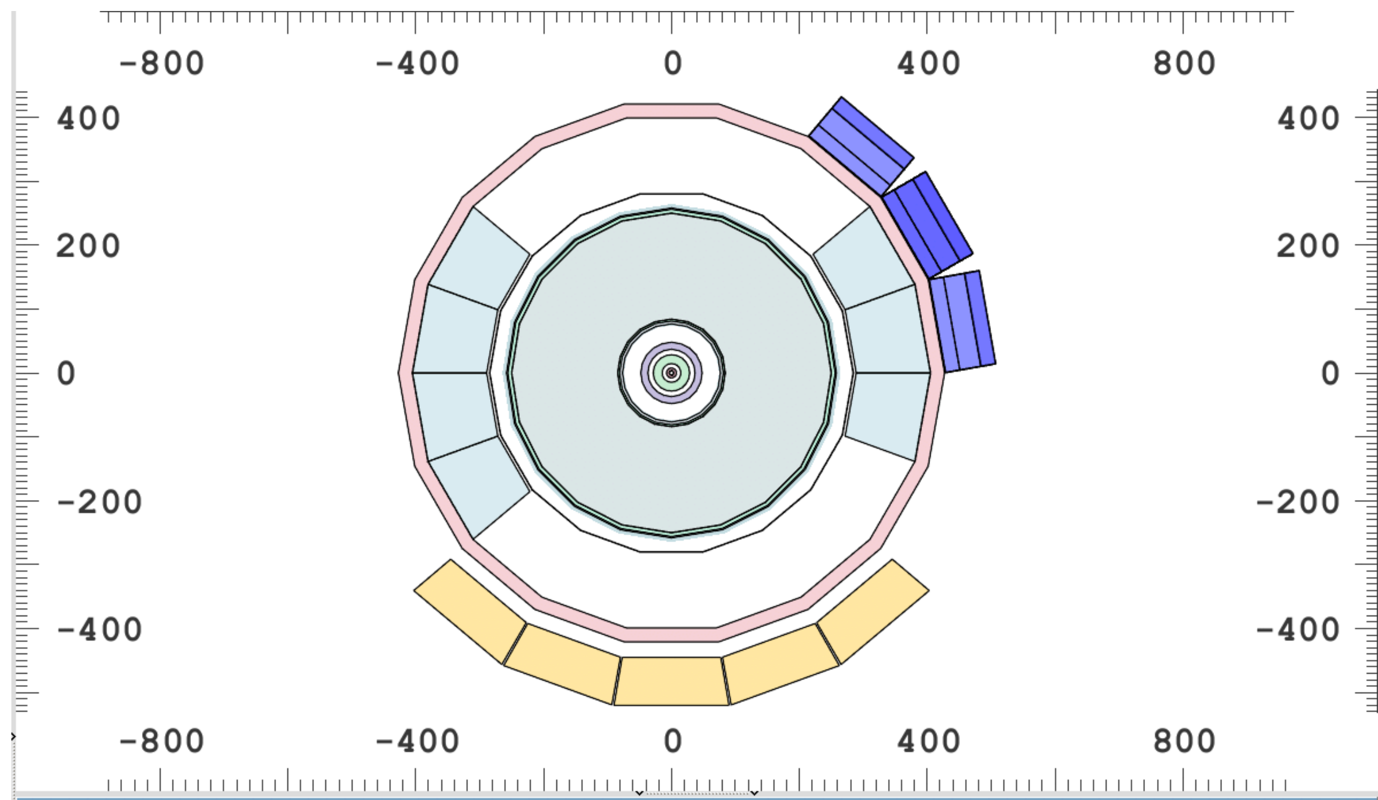
e-, e+	0.0005 GeV/c^2
π+, π-	0.139 GeV/c^2
Ks0	0.4976 GeV/c^2
p	0.9383 GeV/c^2
Λ	1.1157 GeV/c^2
Ξ	1.3217 GeV/c^2

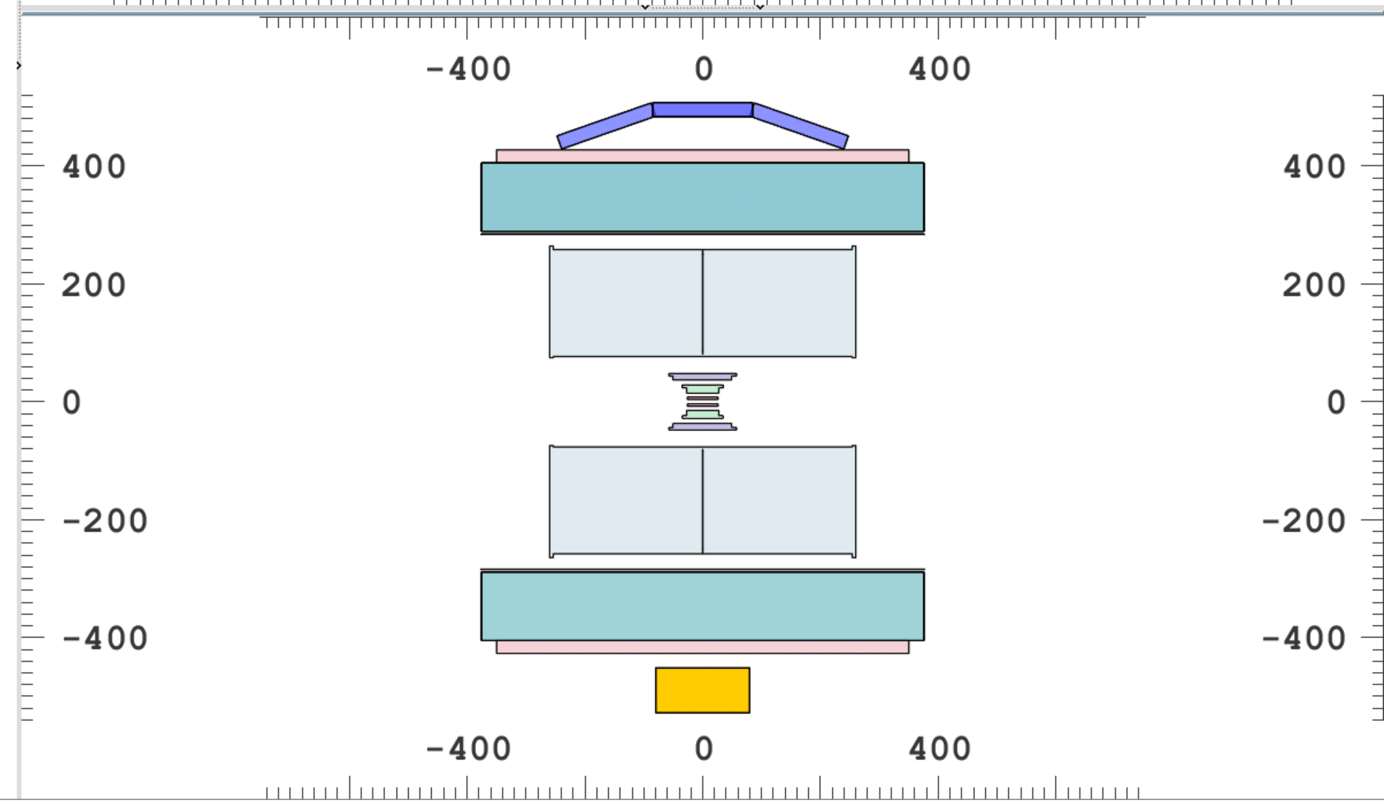
Instructions (Visual analysis)



3D view

Cross-sectional view

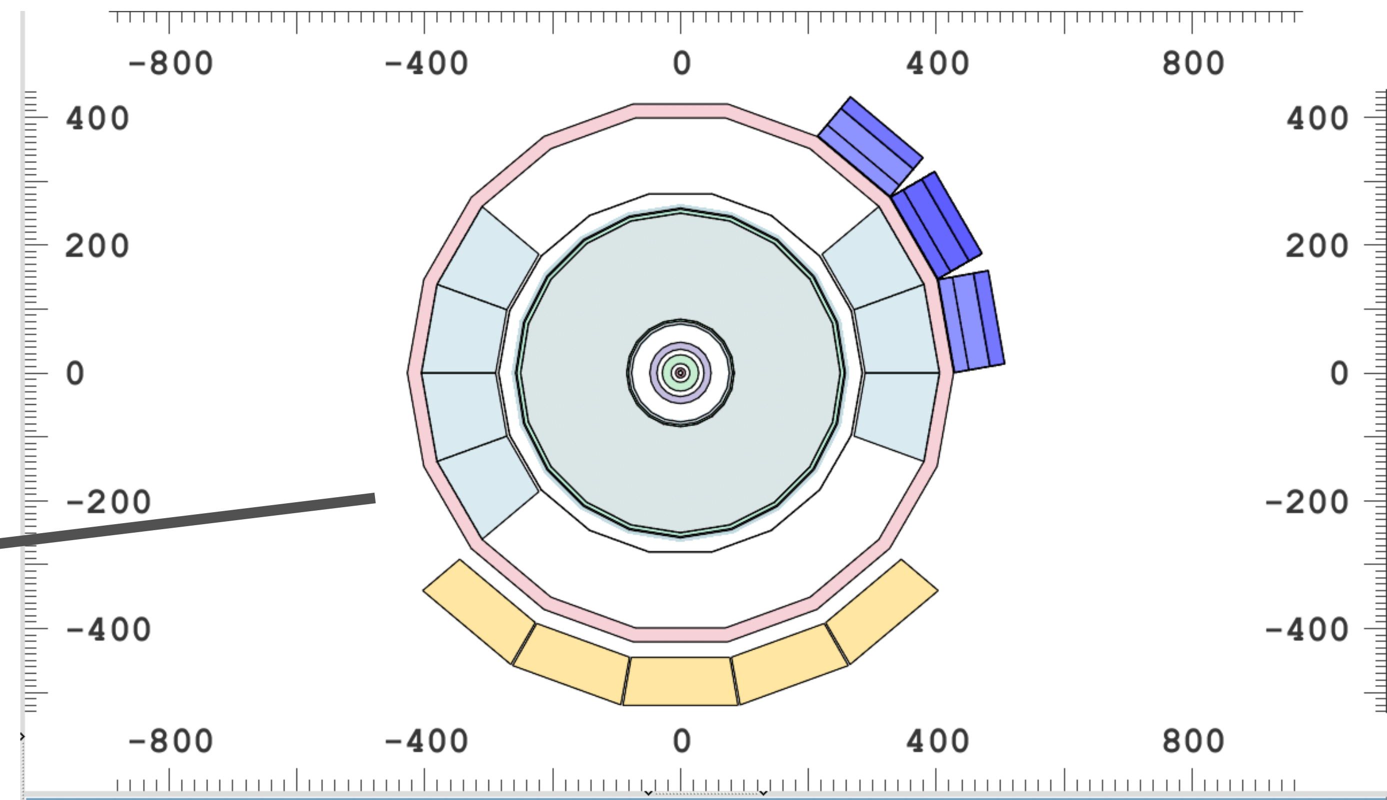


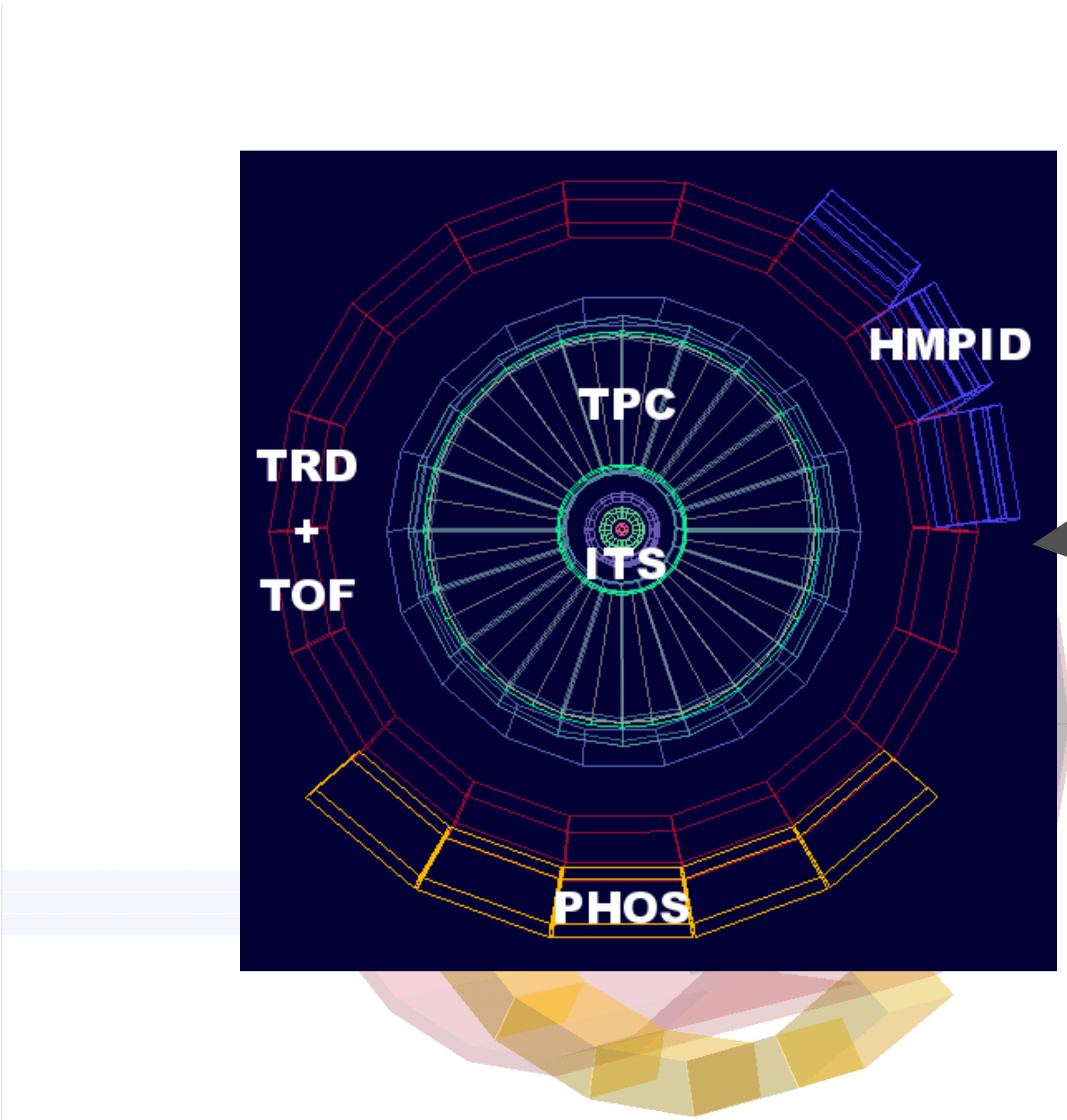


Longitudinal view

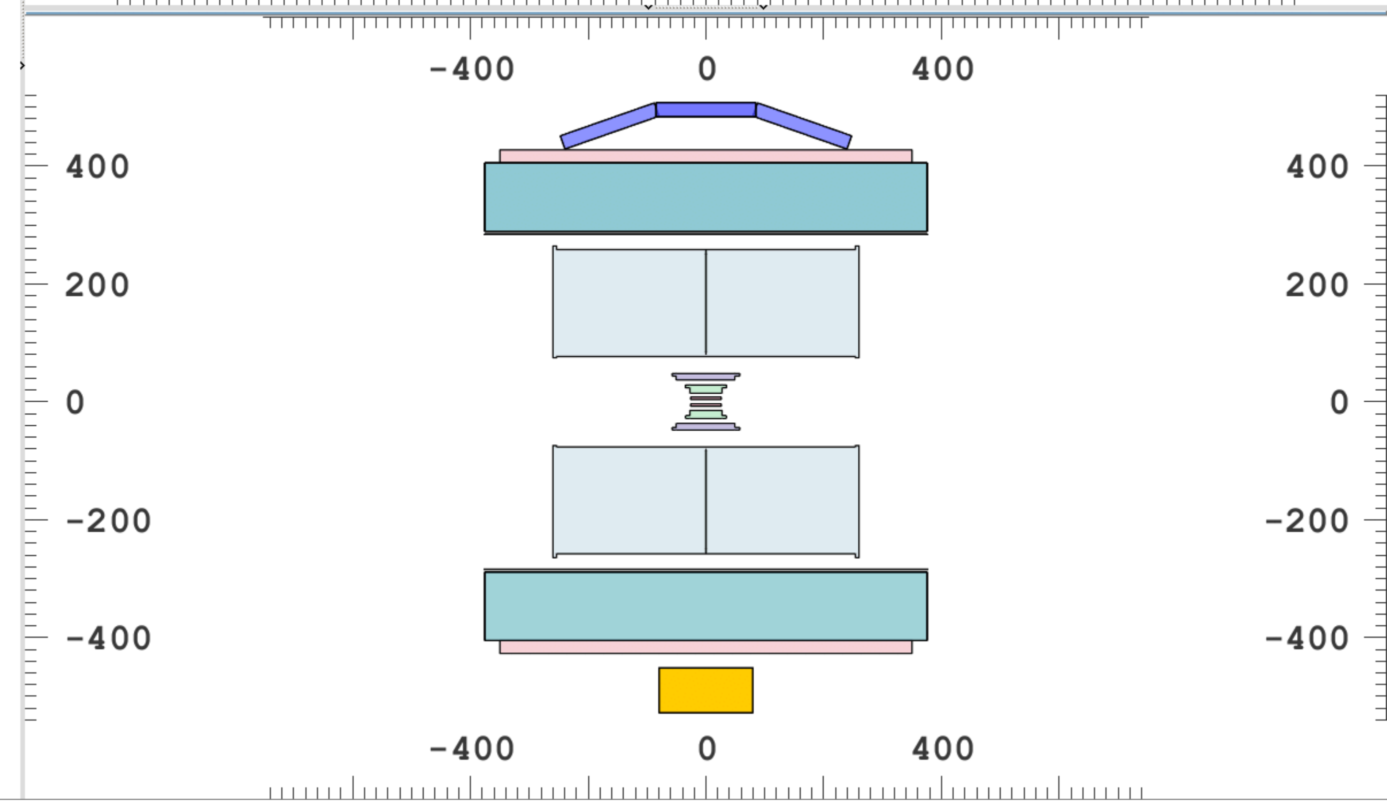
Instructions (Visual analysis)

Cross-sectional view



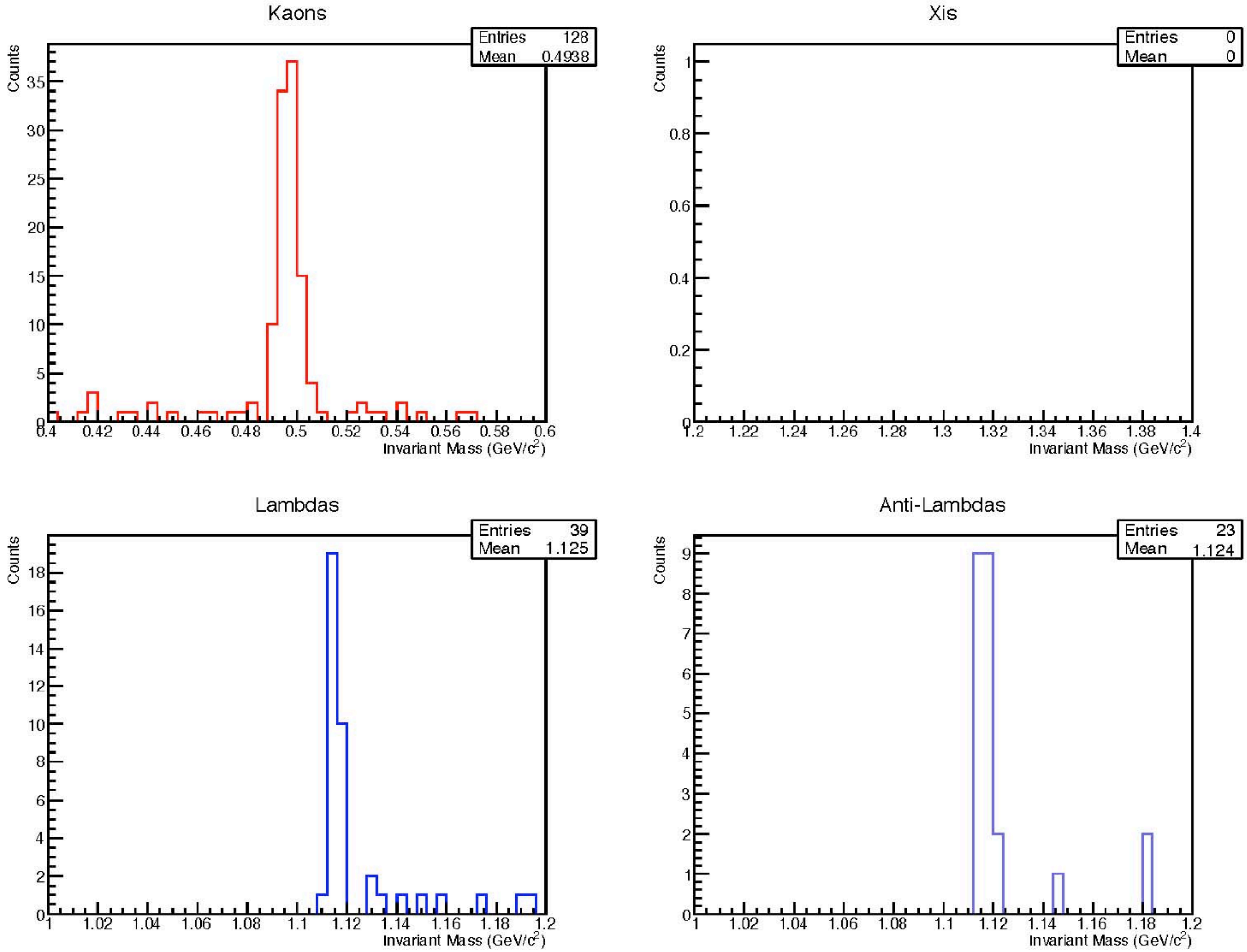


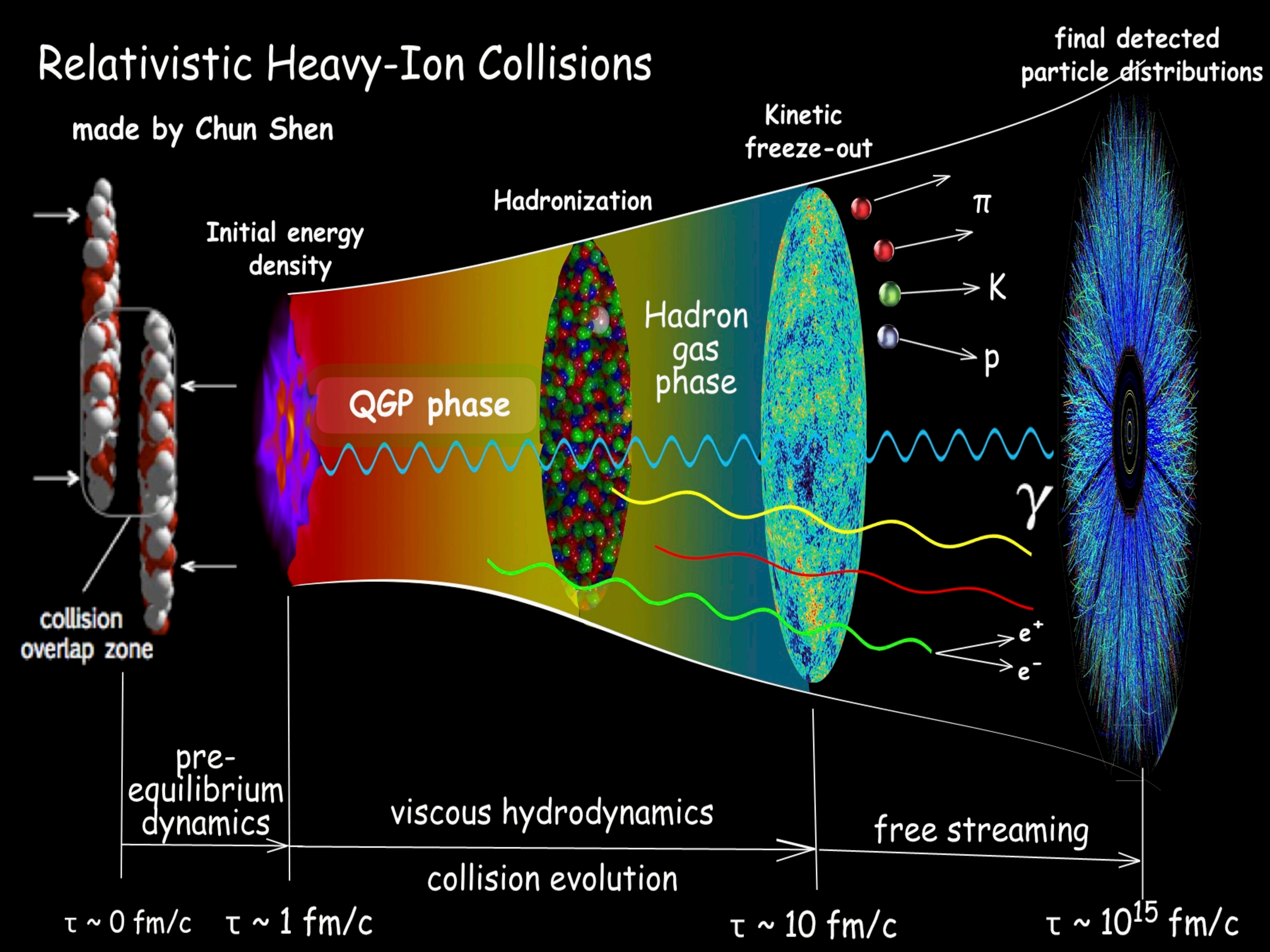
3D view



Longitudinal view

Results

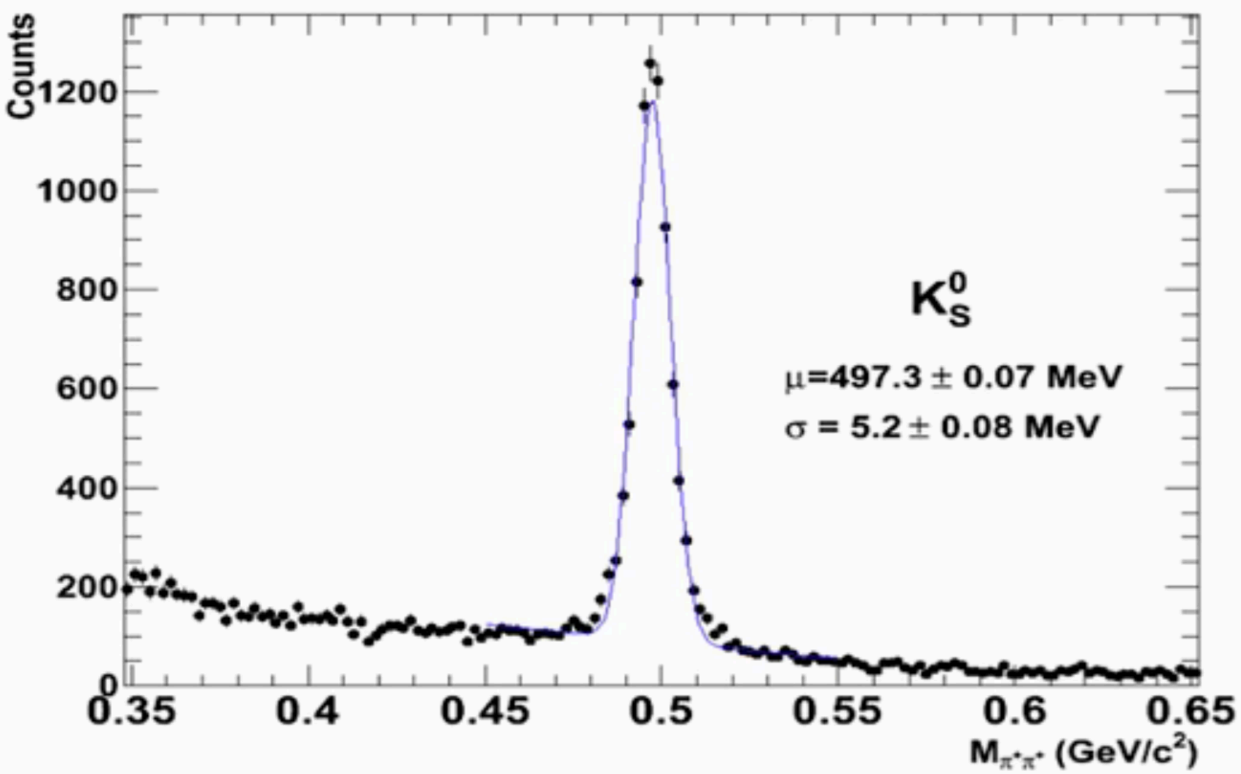

Kaons
Entries 128
Mean 0.4938
Counts
Invariant Mass (GeV/c²)
Xis
Entries 0
Mean 0
Counts
Invariant Mass (GeV/c²)
Lambdas
Entries 39
Mean 1.125
Counts
Invariant Mass (GeV/c²)
Anti-Lambdas
Entries 23
Mean 1.124
Counts
Invariant Mass (GeV/c²)

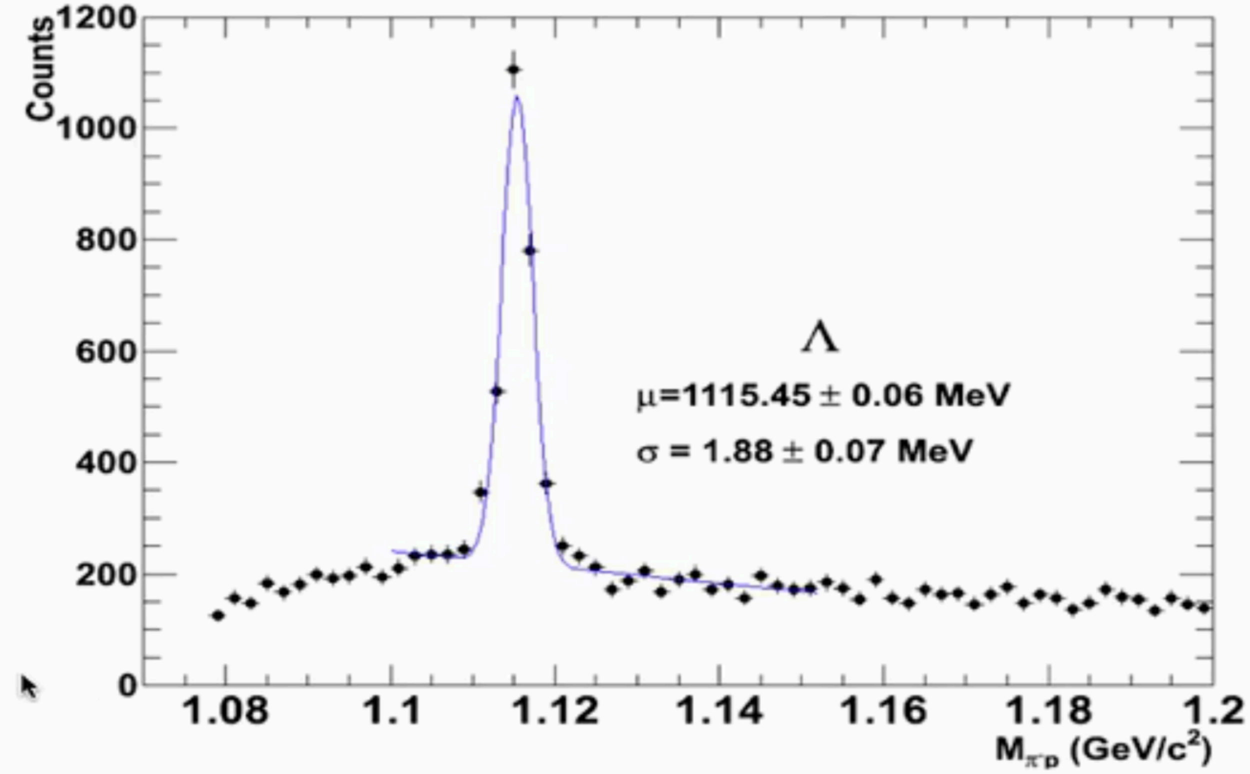

Relativistic Heavy-Ion Collisions
made by Chun Shen
final detected particle distributions
Kinetic freeze-out
Hadronization
Initial energy density
Hadron gas phase
QGP phase
π
K
p
γ
e+
e-
collision overlap zone
pre-equilibrium dynamics
viscous hydrodynamics
free streaming
collision evolution
τ ~ 0 fm/c
τ ~ 1 fm/c
τ ~ 10 fm/c
τ ~ 10^15 fm/c

Strangeness Enhancement in heavy-ion collisions

- Analysis large event samples from Pb-Pb collisions
- Find number of strange particles
- Calculate particle yields (number of particles per event)
- Calculate strangeness enhancement taking into account of particle yields in pp collisions

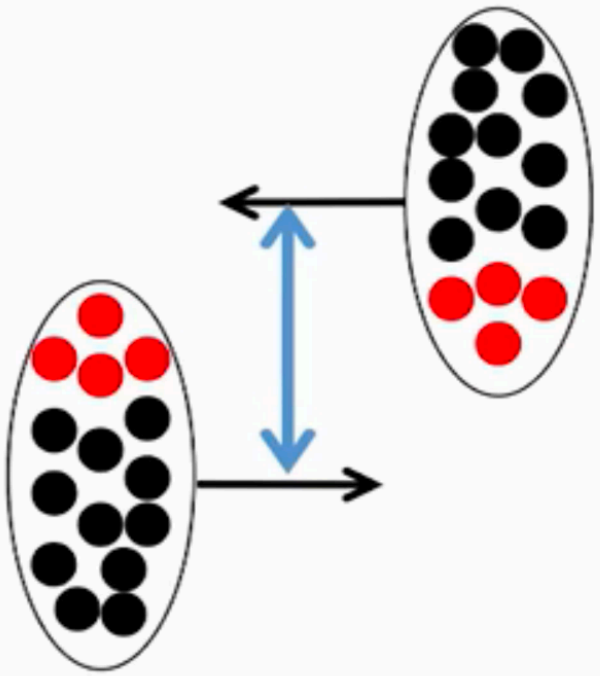
Invariant mass fitting



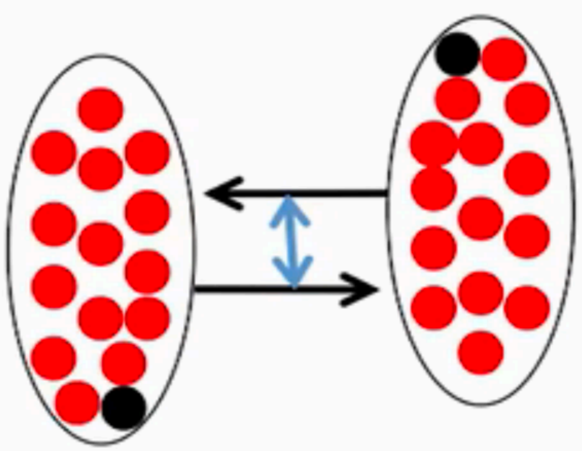


- Continuum : irreducible background due to random combinations of $\pi^+\pi^-$ or π^-p
- Fit curves to background (2nd degree polynomial) and peak (gaussian)
- Find number of K_s, Λ, anti-Λ after background subtraction

Geometry of Pb-Pb collisions



- Peripheral collision
  - Large distance between the centres of the nuclei
  - Small number of participants
  - Few charged particles produced (low multiplicity)



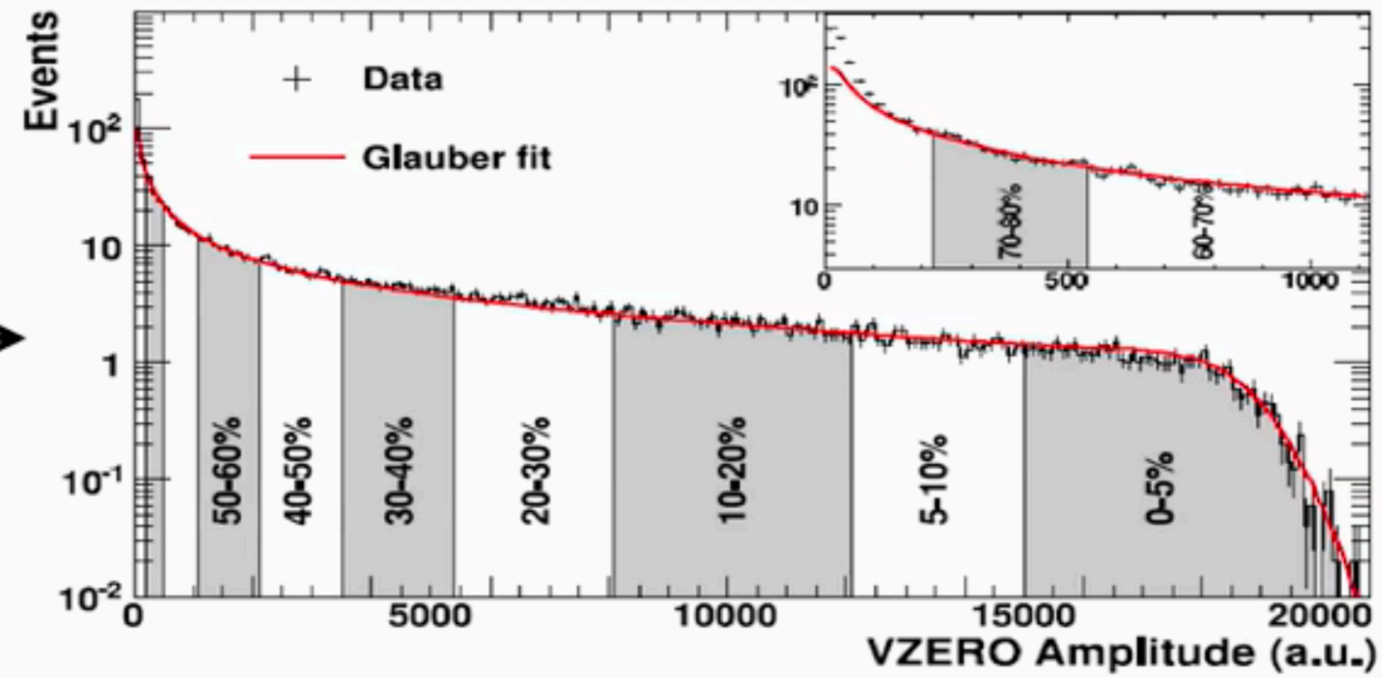
- Central collision
  - Small distance between the centres of the nuclei
  - Large number of participants
  - Many charged particles produced (high multiplicity)

In real life we can't measure the distances from the centre of two Pb nucleus but we find the centrality indirectly

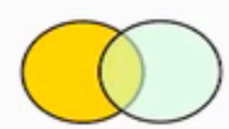
Geometry of Pb-Pb collisions

Distribution of the signal amplitude of V0 (plastic scintillators)

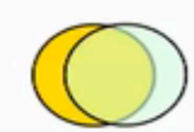
red line : described by model (Glauber)



Centrality	$dN_{ch}/d\eta$	$\langle N_{part} \rangle$	$(dN_{ch}/d\eta)/(\langle N_{part} \rangle/2)$
0%–5%	1601 ± 60	382.8 ± 3.1	8.4 ± 0.3
5%–10%	1294 ± 49	329.7 ± 4.6	7.9 ± 0.3
10%–20%	966 ± 37	260.5 ± 4.4	7.4 ± 0.3
20%–30%	649 ± 23	186.4 ± 3.9	7.0 ± 0.3
30%–40%	426 ± 15	128.9 ± 3.3	6.6 ± 0.3
40%–50%	261 ± 9	85.0 ± 2.6	6.1 ± 0.3
50%–60%	149 ± 6	52.8 ± 2.0	5.7 ± 0.3
60%–70%	76 ± 4	30.0 ± 1.3	5.1 ± 0.3
70%–80%	35 ± 2	15.8 ± 0.6	4.4 ± 0.4



peripheral collisions



central collisions

Yield calculation

Yield: number of particles produced per interaction

(measured particles/ events)

Efficiency: Measured particles/produced particles

(will be given to you)

Corrected yield: Measured particles/(Efficiency × events)

<u>For pp collisions</u>

K_S^0 yield = 0.25/interaction

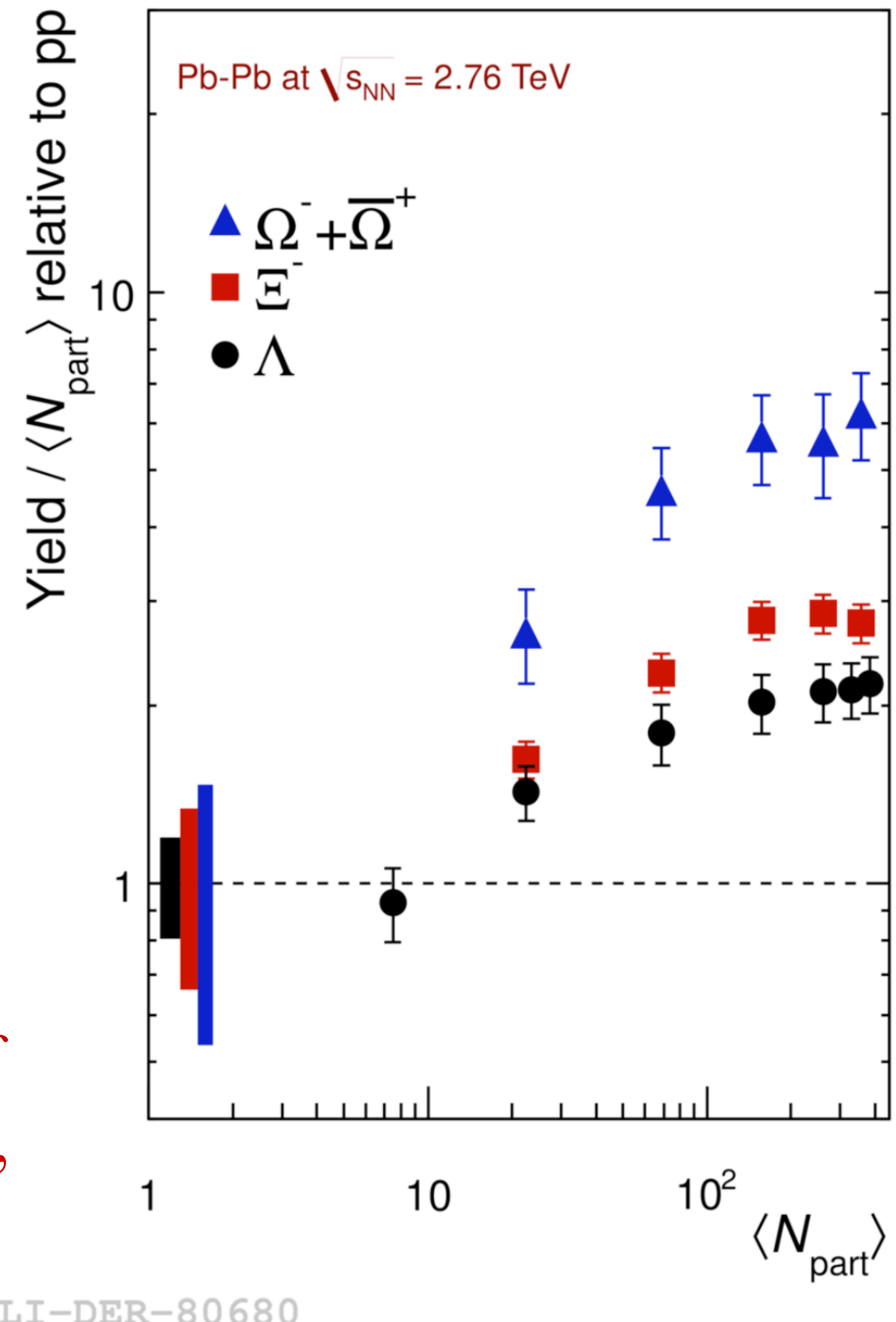
Λ Yield = 0.0617/interaction

$N_{part} = 2$

Strangeness Enhancement

- One of the signatures for the creation of QGP is the enhancement of strangeness.
- It was proposed in 1980, more than thirty years ago, as the first observable for quark gluon plasma.
- Twenty-five years ago, strangeness enhancement was observed in the fixed target ion experiments at the CERN Super Proton Synchrotron.
- Later on, strangeness enhancement was observed by experiments at the Relativistic Heavy Ion Collider at Brookhaven, near New York.

The particle yield normalised by the number of participating number of nucleons in the collisions, and divided by the same in pp collisions



Enhancement increases with the number of strange quarks (Ω has 3, *Ξ* has 2, Λ has 1 strange quarks)

***Instructions* (Exercise - 2)**

- In this exercise you will find the number of strange particles in the large scale events.

- Each group will be assigned a different centralities to analyse.

- Once you choose proper fitting range click on "Accept"

Starting point for fitting ranges:

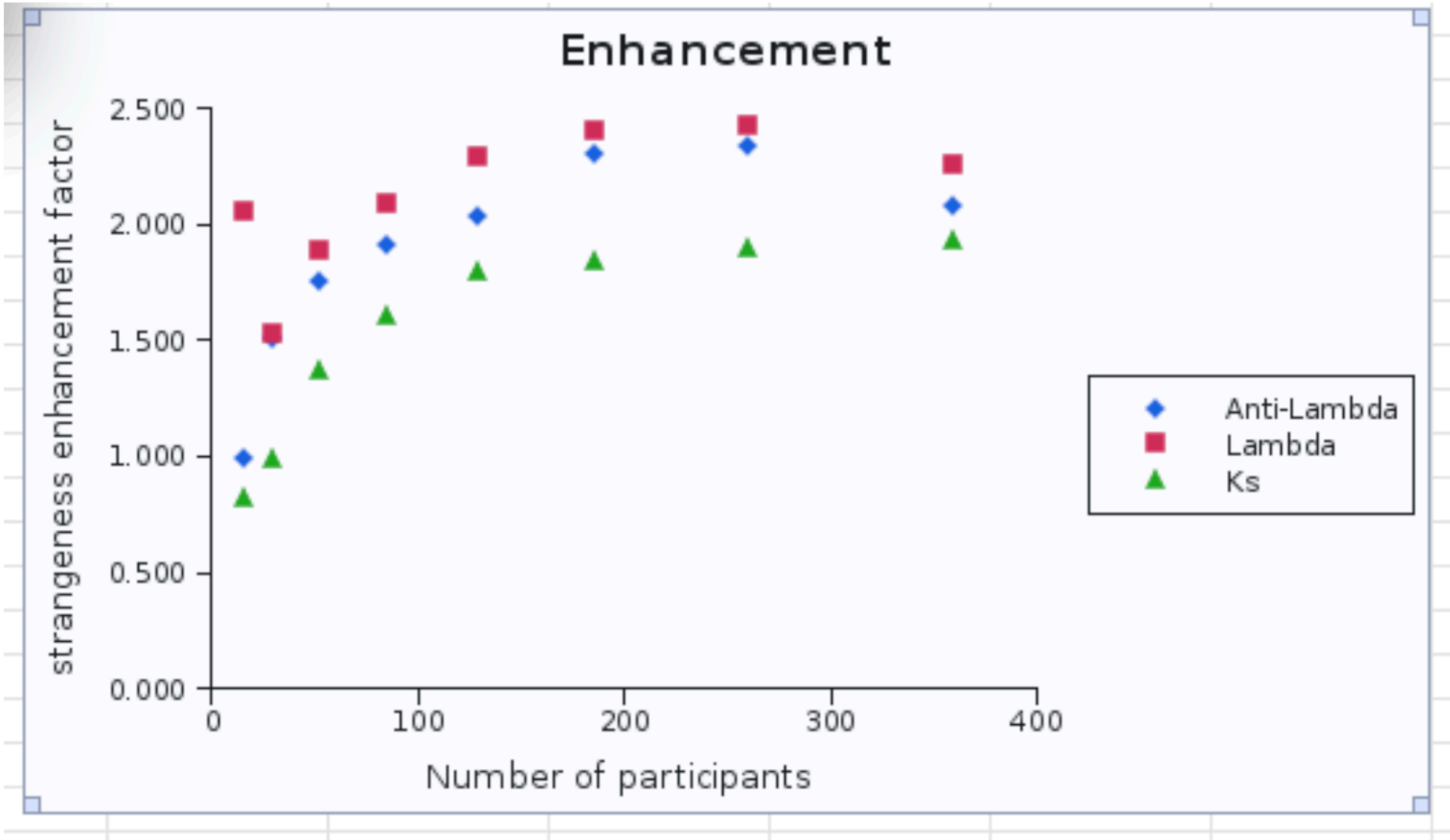
K_S^0: Background range (0.4-0.6), Signal range (0.45-0.54)

Λ: Background range (1.08-1.15), Signal range (1.11-1.13)

- Once you are done with all events, look at the Summary in the upper tab.

- At the end click on **Export** and save a file named **Exercise2_centrality_*.root** in the "**Documents**" folder in the desktop

Expected Results



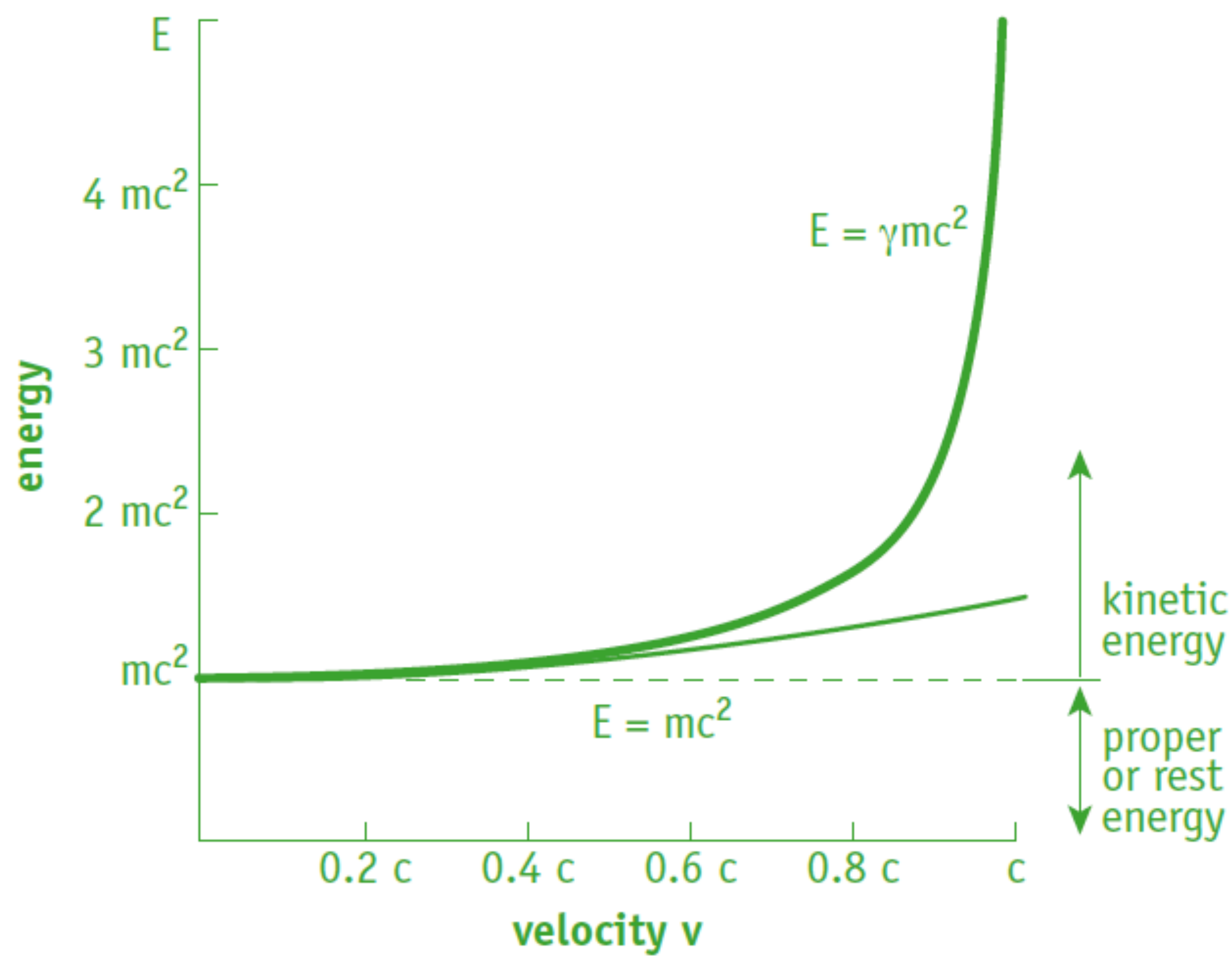
Questions

1. Why are the two tracks of each V0 curved in opposite directions?
2. Why is the radius of curvature of the proton bigger than that of the pion in Λ decays?
3. Why is that?
4. Why don’t you see the Λ or the K0 before their decay?
5. Why does the Λ not decay to two pions, like the K0?
6. Why does the invariant mass have a width and is not a delta-function?

Thank you for your attention

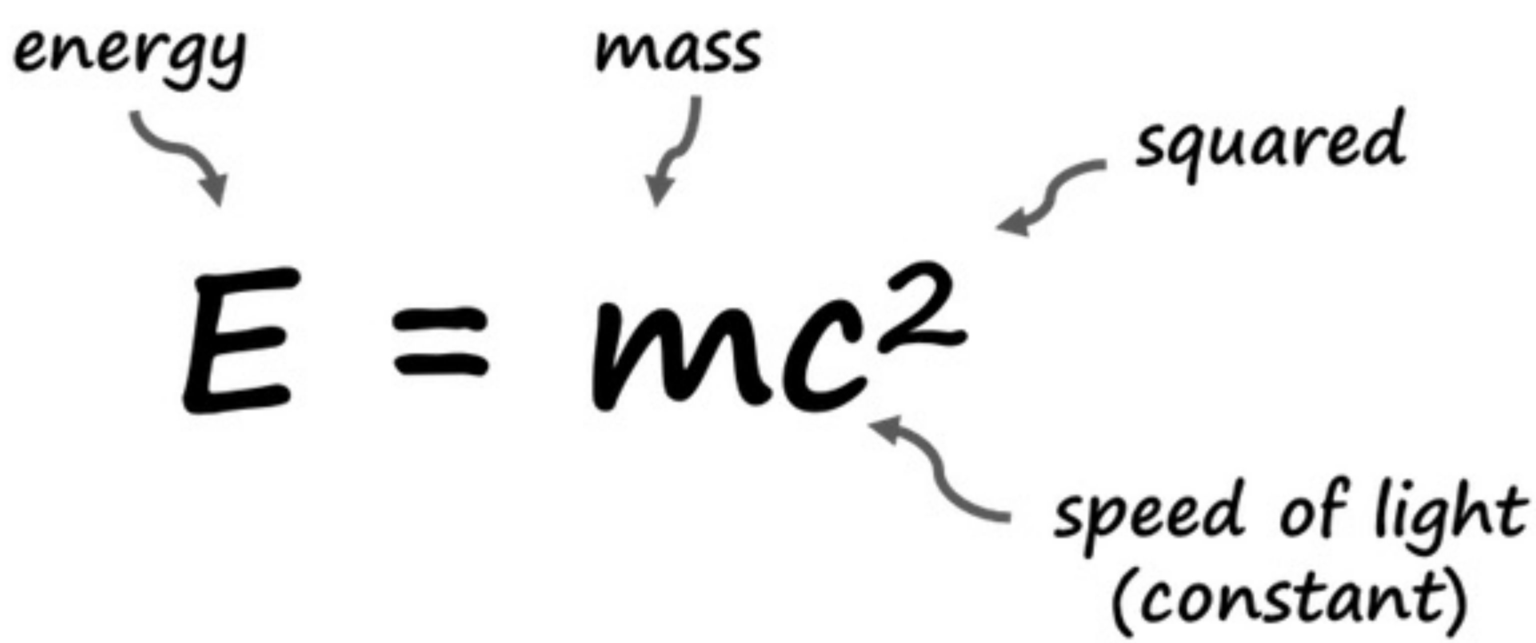
Back-up

The classical Newtonian relationship between speed and kinetic energy ($K = (1/2)mv^2$) only holds for speeds much lower than the speed of light. For particles moving close to the speed of light we need to use Einstein's equation from special relativity $K = (\gamma - 1)mc^2$ where c is the velocity of light (299 792 458 m/s), and γ is related to speed via $\gamma = 1/\sqrt{(1-\beta^2)}$; $\beta = v/c$ and m = mass of particle at rest.

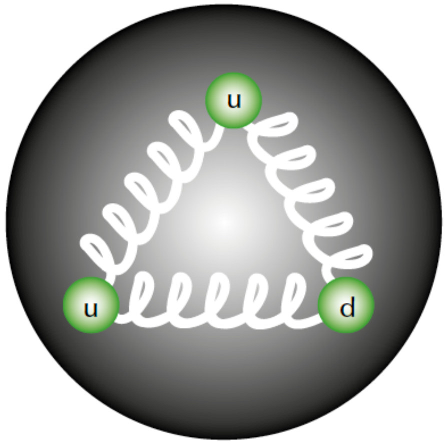


Energy and mass

- Energy and mass are two sides of the same coin
- Mass can transform into energy and vice versa in accordance with Einstein's famous equation ($E = mc^2$)
- At the LHC this transformation happens at each collision.



Fundamental forces of nature

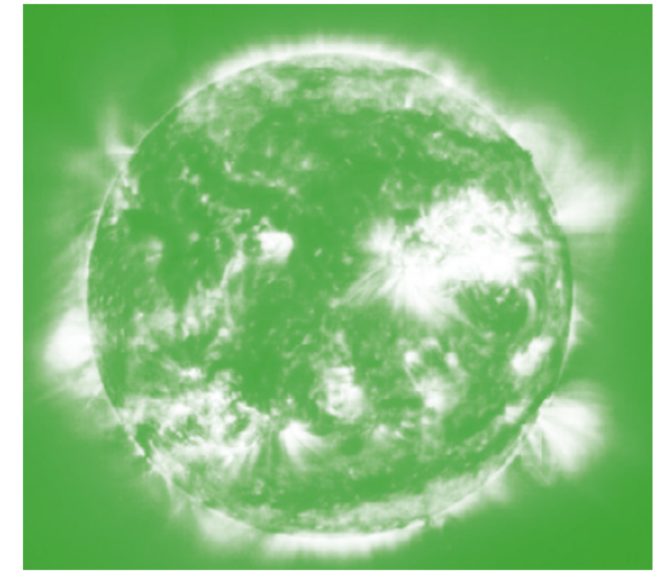


- **Strong Force:** Felt by quarks, Carried by gluons
  - Binds quarks together to make protons and neutrons
  - Binds protons and neutrons in nuclei
  - Particles that interact via the strong force are called hadrons

- **Electro-magnetic Force:** Felt by quarks and charged leptons, Carried by photons
  - Holds electrons to nuclei in atoms
  - Binds atoms into molecules
  - Responsible for the properties of solids, liquids and gases

Fundamental forces of nature

- **Weak Force:** Felt by quarks and leptons, Carried by intermediate vector bosons
  - Radioactivity and weak decay
  - Essential for nuclear reactions in centres of stars, where hydrogen is converted to helium (fusion)



- **Gravitational Force:** Felt by all particles, Carried by Graviton (not yet discovered)
  - In astronomical scale it binds matter in planets and stars, and holds stars together in galaxies

Why LHC is so special?

- Total cost: 3,11,63,64,78,249 INR (approx.)
- More than 10,000 scientists and Engineers from 100 countries
- Built by European Organization for Nuclear Research (CERN) in 1998-2008
- 27 km circumference and mean depth is around 100 m underground (Earth's crust provides good shielding for radiation)
- Reaches collision energies which has never been reached before in a lab (14 TeV). Energy concentration makes particle collisions so special. When you clap your hands, you do a 'collision' at an energy much higher than protons at the LHC, but much less concentrated, since it is distributed over the whole area of your hand. 😃

$$14 \times 10^{12} \times 1.602 \times 10^{-19} = 22.4 \times 10^{-7} \text{ joules.}$$

In absolute terms, these energies, if compared to the energies we deal with everyday, are not impressive. In fact, 1 TeV is about the energy of motion of a flying mosquito. What makes the LHC so extraordinary is that it squeezes energy into a space about a million million times smaller than a mosquito.

Main Goals of LHC

Our current understanding of the Universe is incomplete.

1. Origin of mass: Higgs field (Higgs boson), so called God Particle

2. Unified description of all the fundamental forces

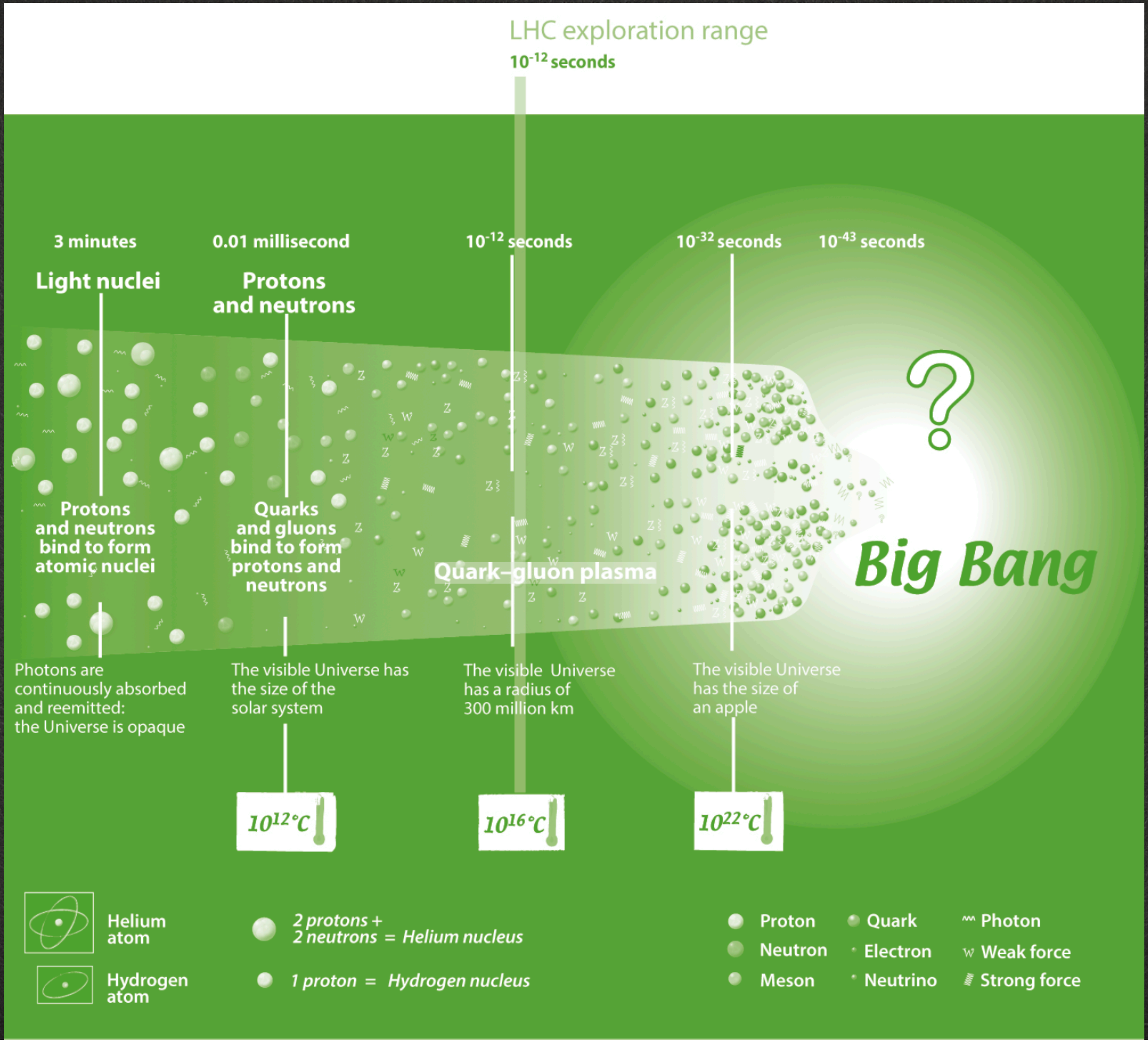
3. Dark matter (27%) and Dark energy (68%)

4. Mystery of antimatter: Matter-antimatter imbalance

5. Existence of Quark Gluon Plasma

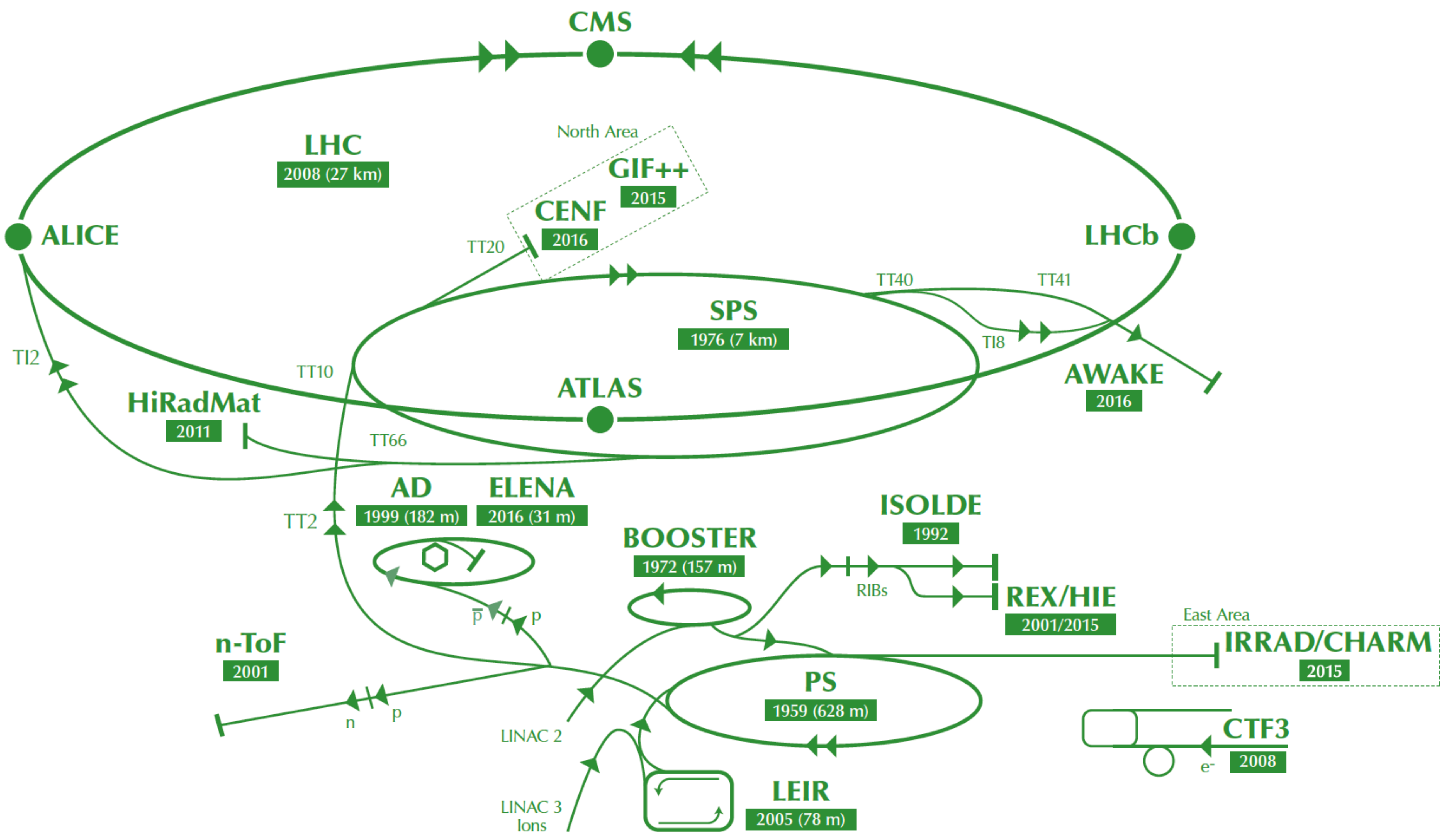
The energy density and temperature that are produced in the collisions at the LHC are similar to those that existed a few moments after the Big Bang.

In this way physicists hope to better understand how the Universe evolved.



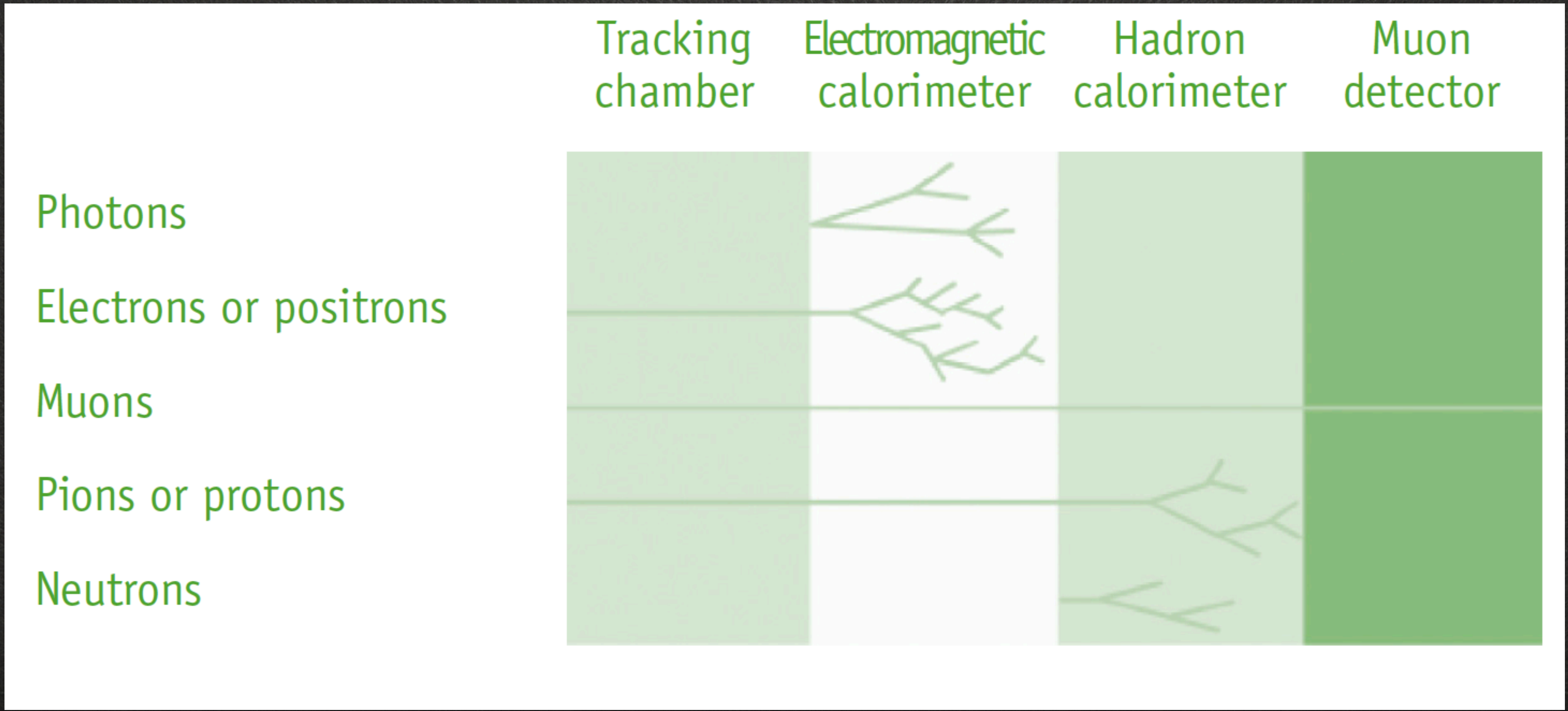
The CERN accelerator complex

- A succession of machines with increasingly higher energies
- Each machine injects the beam into the next one, which takes over to bring the beam to an even higher energy, and so on

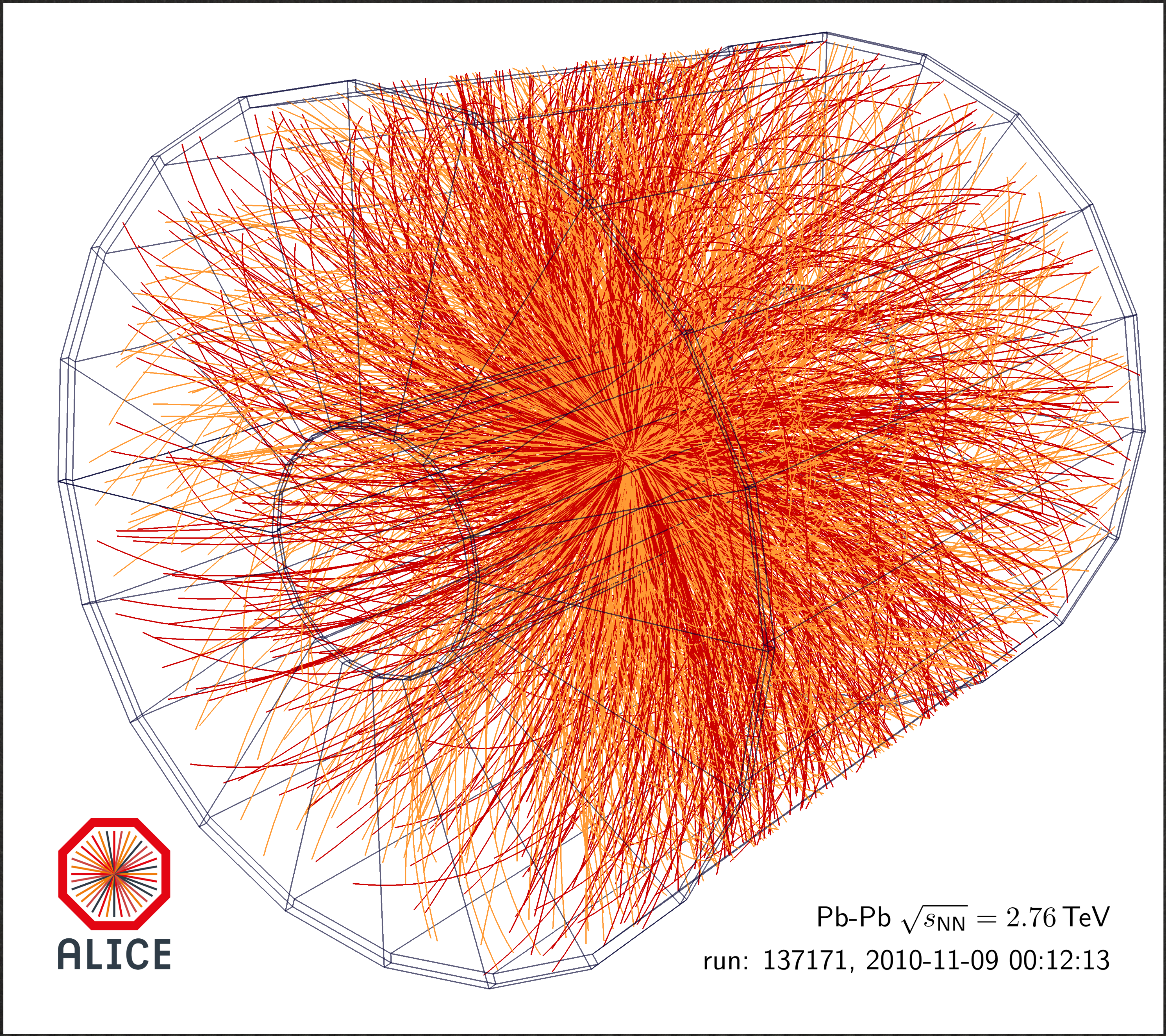


How do we see particles?

- Physicist’s goal is to count, track and characterise all the different particles that were produced in order to reconstruct the process in full.
- To know a particle's mass we need to know momentum and velocity simultaneously
- Magnetic field helps in bending the tracks and hence we know the momentum.



Event display from ALICE



Data Flow at the LHC

Total data flow for all the experiments at the LHC is around 50000000 GB per year, corresponding to a stack of about 10 million standard DVD packs, about 12km tall 😃

- *ATLAS produces about 1 GB/s*
- *CMS produces about 1 GB/s*
- *LHCb produces about 0.6 GB/s*
- *ALICE produces several GB/s during heavy-ion running*

Are the LHC collisions dangerous?

We, at the LHC, reach the highest ever collision possible in Earth!

1. Unprecedented energy collisions! (Cosmic rays 😃)

2. Mini Big bangs!! (Remember Mosquito 😃)

3. Black holes!! (Stephen Hawking says no issues at all 😃)

4. Radiation (Now this is a real and only issue which is unavoidable!)
Dosimeter is your friend and no harms till the allowed dosage

CERN research: Contribution to society

- World wide web (WWW) was invented at CERN by Tim Berners-Lee in 1989 (http://info.cern.ch/hypertext/WWW/TheProject.html)

World Wide Web

The WorldWideWeb (W3) is a wide-area hypermedia information retrieval initiative aiming to give universal access to a large universe of documents.

Everything there is online about W3 is linked directly or indirectly to this document, including an executive summary of the project, Mailing lists , Policy , November's W3 news , Frequently Asked Questions .

What's out there?
: Pointers to the world's online information, subjects , W3 servers, etc.

Help
: on the browser you are using

Software Products
: A list of W3 project components and their current state. (e.g. Line Mode ,X11 Viola , NeXTStep , Servers , Tools , Mail robot , Library)

Technical
: Details of protocols, formats, program internals etc

Bibliography
: Paper documentation on W3 and references.

People
: A list of some people involved in the project.

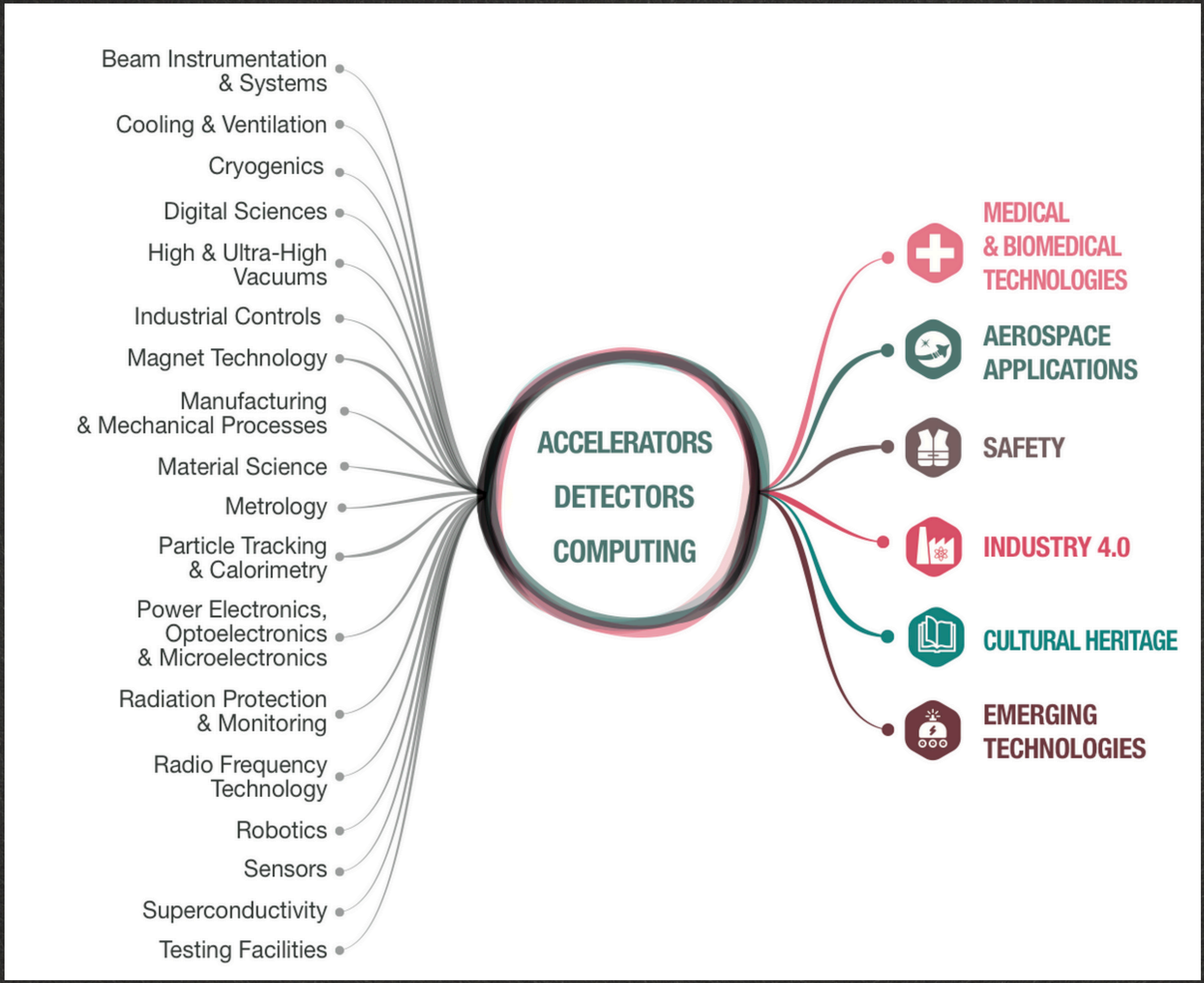
History
: A summary of the history of the project.

How can I help ?
: If you would like to support the web..

Getting code
: Getting the code by anonymous FTP , etc.

CERN research: Contribution to society

Advancing the frontiers of technology



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