Year 1 Relativity: Seminar 2

Supernova and CERN

Jon Fenton & Mitesh Patel

- Today, a seminar of two halves :
  - More practice using space-time diagrams to help understand the time-ordering of events
  - The physics of a relativistic particle decay
    - In the Python miniproject you will look at a simulation using the physics from this part

- Credit:
  - 1%: seminar participation
  - 7.5%: Python mini-project; deadline 30th June (wk 9); more details at the end

Supernova!

- A star is about to explode in a supernova and a planet orbiting it must be evacuated. The starship Enterprise is sent to the planet to pick up some Imperial College Physics students on a field trip to observe the star's final stages

Spacetime diagram – planet

- Assuming the planet is not moving wrt the star, draw a spacetime diagram (ct, x) for the star/planet frame
- Add to your diagram the world lines for the star and the planet

Spacetime diagram – enterprise

- The Enterprise will fly by at a constant velocity (*v*<*c*) past the star and then the planet and beam up the students without stopping
- Add spacetime axes for the Enterprise frame (treat this as a problem with only one spatial dimension)

1. Setting up the diagram (recap)

- Assuming the planet is not moving wrt the star, draw a spacetime diagram (ct, x) for the star/planet frame
- Add to your diagram the world lines for the star and the planet
- The Enterprise flies at a constant velocity $v<c$ past the star and then the planet and beams up the students without stopping
- Add spacetime axes for the Enterprise frame
- Check results with your TA before you go on!

2. Adding events

- Now add labels for the following events:
  - (A) In the Enterprise frame, when the Enterprise arrives at the planet the star (not yet gone supernova) is at this spacetime point
  - (B) The Enterprise flies by the star
  - (C) Light from the supernova reaches the planet
  - (D) In the Enterprise frame, the planet is at this spacetime point when the supernova occurs
  - (E) The Enterprise arrives at the planet
  - (F) In the planet's frame, the planet is at this spacetime point when the supernova occurs
  - (G) In the Enterprise frame, the Enterprise is at this spacetime point when the supernova occurs
  - (H) Light from the supernova reaches the Enterprise
- Be ready to share a picture of your spacetime diagram in the Padlet before we come back together.

3. Time-order in the planet's frame

- Rank the following events in chronological order for an observer in the planet's frame
  - (1) A spectator on the planet sees the supernova
  - (2) The Enterprise arrives at the planet
  - (3) The star explodes in a supernova
  - (4) A spectator on the Enterprise sees the supernova

Add this to your Padlet post

4. Time-order in the Enterprise frame

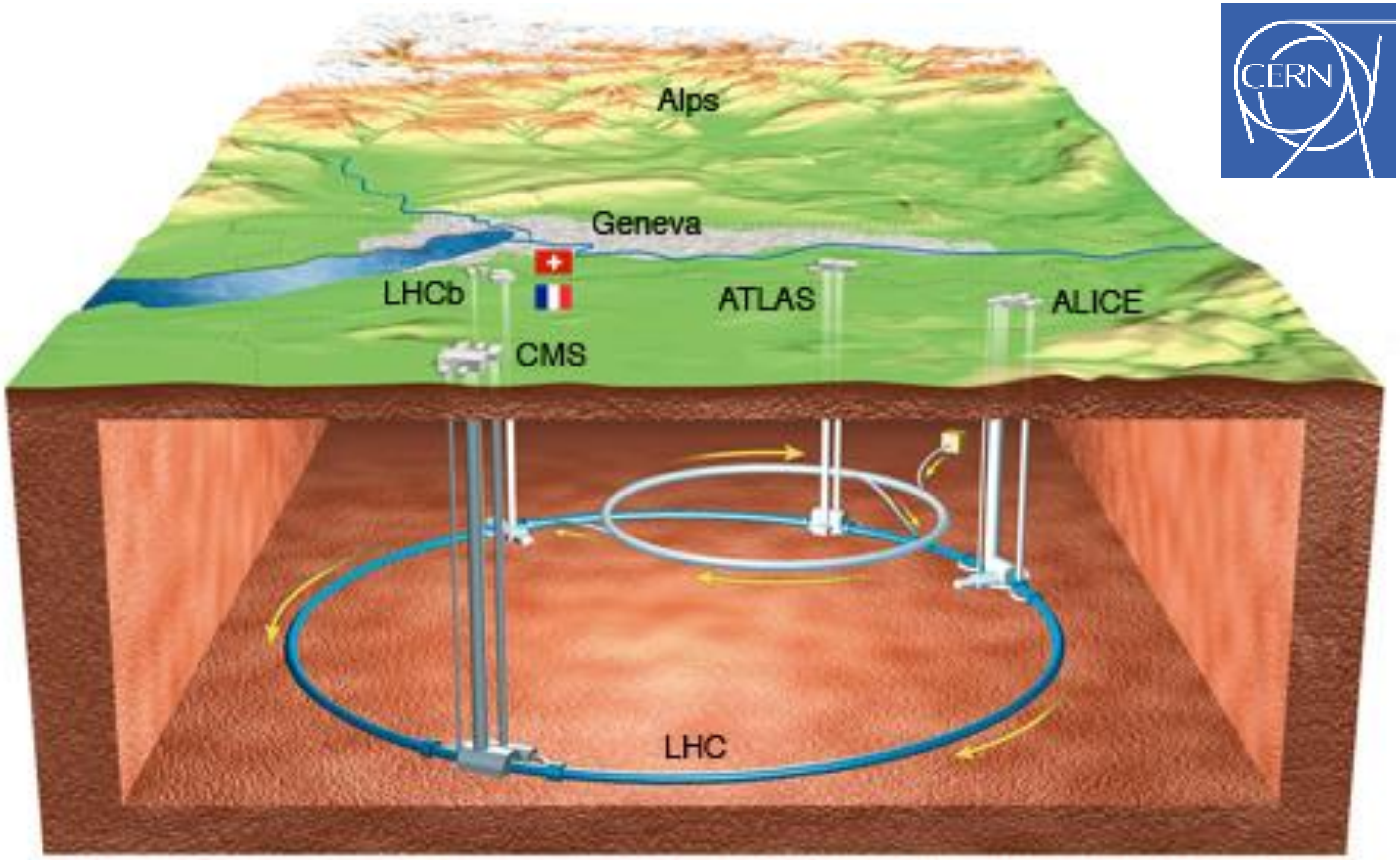
- Rank the following events in chronological order for an observer in the Enterprise frame
  - (1) A spectator on the planet sees the supernova
  - (2) The Enterprise arrives at the planet
  - (3) The star explodes in a supernova
  - (4) A spectator on the Enterprise sees the supernova

Compare to the time-order from the planet frame: does anything change?

5. Time-ordering

- In seminar 1, we found that the order depended on *v*
- Is a different time-order possible here too?

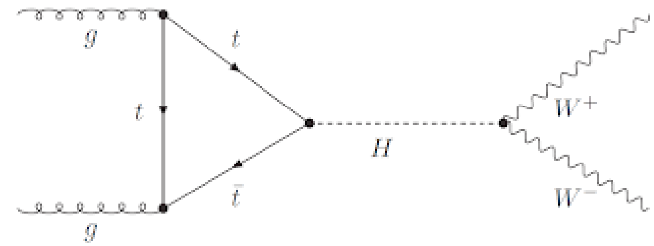
Part 2



A phone call from CERN

- As soon as you are back on Earth, you receive a phone call from CERN's Director General, Prof. Fabiola Gianotti

- Prof. Gianotti asks your group to help her compute the kinematics of the Higgs to W^+W^- decay that she will this afternoon present to an audience in CERN's main auditorium



Helping out the Director General

- The aim is to help the DG translate understanding of the decay in the rest-frame to the angular distribution in the lab-frame, which is what is measured by experiments

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6. Decay Kinematics

- For a two-body decay $A \rightarrow B+C$, draw a diagram of the decay in its rest frame and in the lab frame, assuming that the particle A is produced moving in the positive z direction in the lab-frame

7. Decay Kinematics

- Draw a diagram of the momentum vector of one of the decay products B or C in spherical coordinates
- Use your diagram to derive the cartesian 3-momentum components and and so **write-down the four-momentum** in terms of the angles θ, ϕ
  - If the decay products lie in the plane $x=0$, what must the value of ϕ be?
  - How is the momentum of the particle related to the energy of the particle?

- Post your diagram and a single set of answers from your group on the Padlet in 15mins and be ready to explain your understanding!

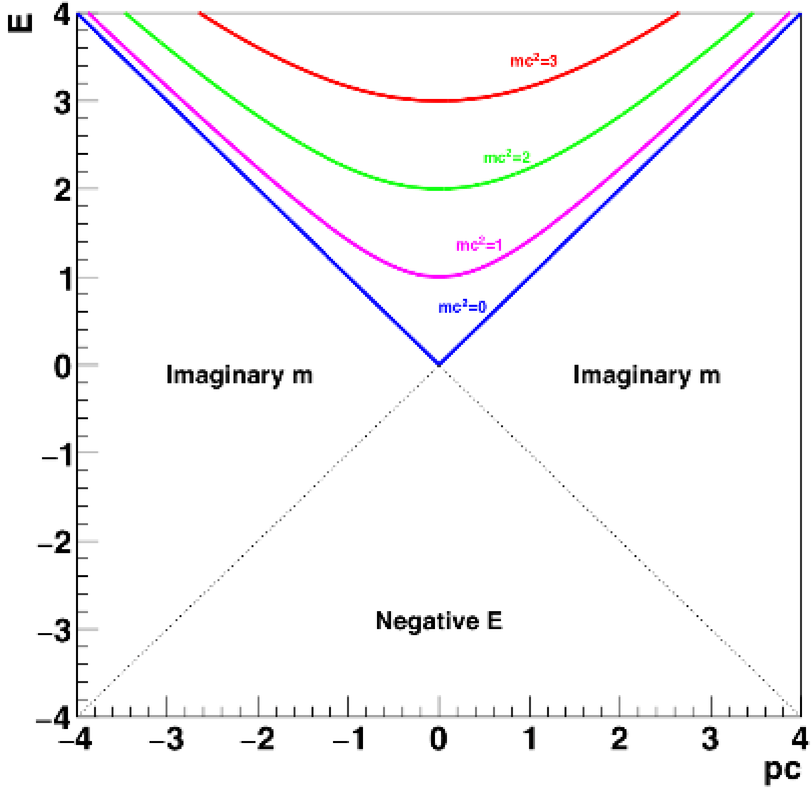
7. Decay Kinematics

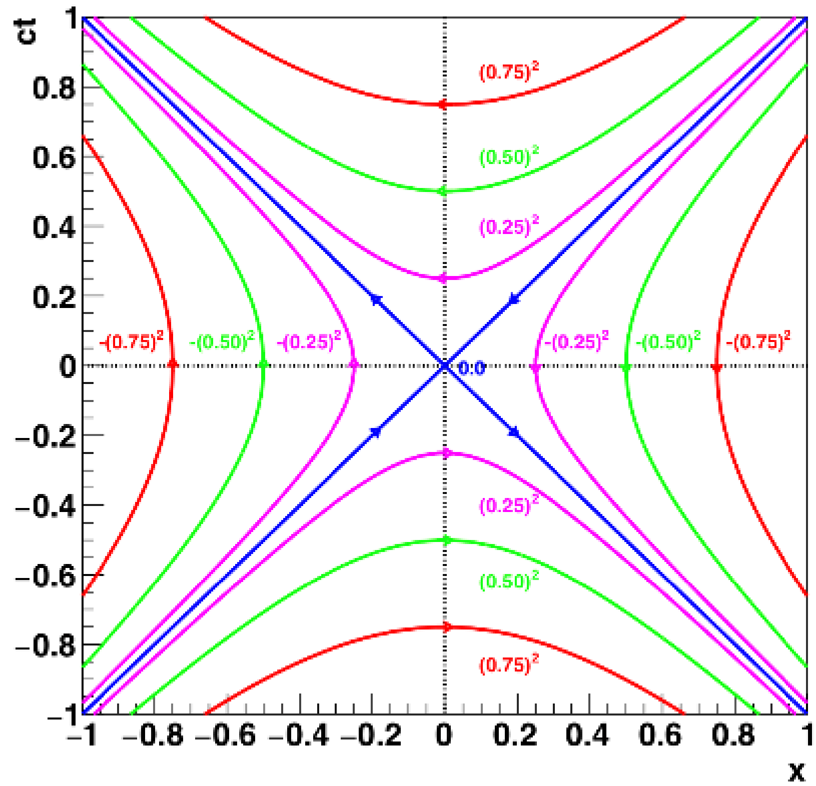
- Draw a diagram of the momentum vector of one of the decay products B or C in spherical coordinates
- Use your diagram to derive the cartesian 3-momentum components and and so **write-down the four-momentum** in terms of the angles θ, ϕ
  - If the decay products lie in the plane $x=0$, what must the value of ϕ be?
  - How is the momentum of the particle related to the energy of the particle? [NB: you can write the energy in terms of the masses, as shown in lecture 8]
- Post your diagram and a single set of answers from your group on the Padlet in 15mins and be ready to explain your understanding!

8. Decay Kinematics

- What values of E and p are expected in the lab frame after an arbitrary boost ***in the z-direction***?
- Sketch the allowed range of boosted values in the E, pc plane
- Contrast your sketch to what happens to spacetime position values after a boost
- Be ready to post your group's sketch on the Padlet in 15mins

Energy vs momentum





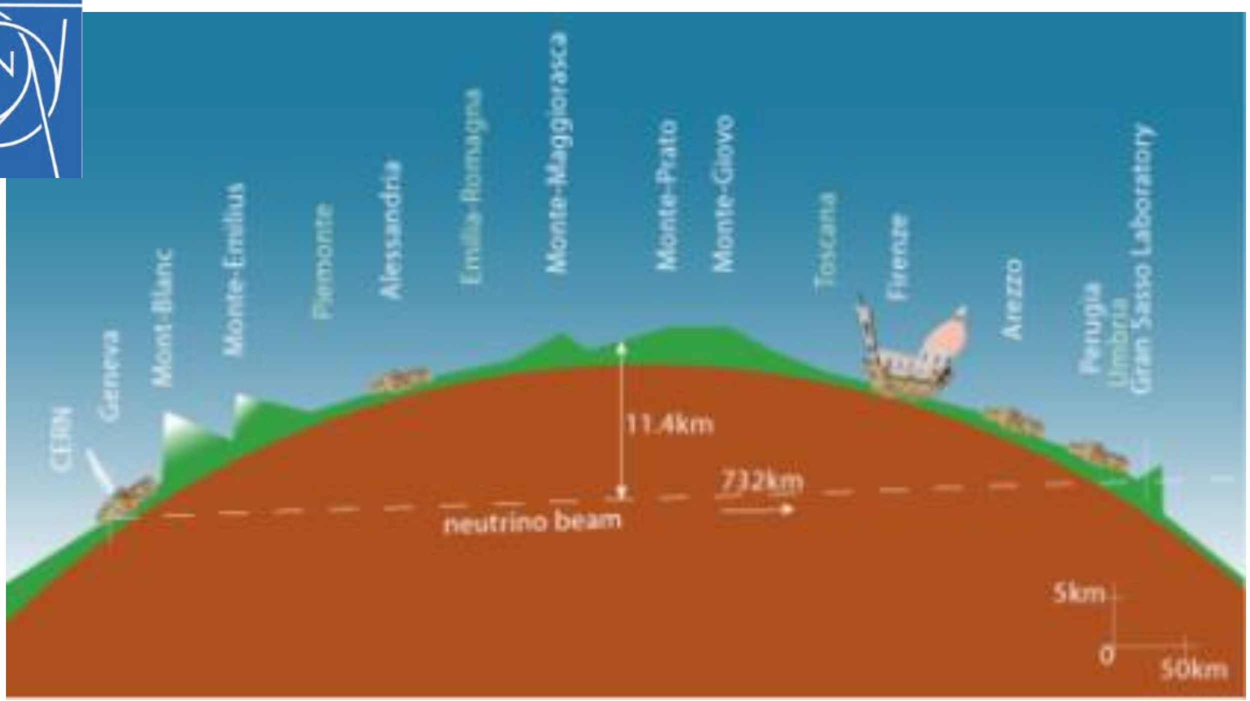
Only top quadrant is relevant as

E > 0 and m is real

A grateful Director General...

- Prof. Gianotti thanks you for your help and asks you to help debug a simulation used for CERN's neutrino physics programme...

  $p+p \rightarrow \pi, K \rightarrow \mu\nu$



Python mini-project

- Look on Blackboard for details of the task.
  The physics from this session will help
  - Do this on your own: it’s an individual not a group activity
  - 7.5% of module credit – graded, rather than just pass/fail
  - Submit on Blackboard by 2pm, Friday 30th June - week 9

Python mini-project

- Professional physicists often have to develop code. This has two stages:
  – Write the code ← A colleague has done this part for you!
  – Debug ← Your job is to do this bit!

  This should make the task a lot shorter!
- The exercise will much more closely mimic what we do professionally – what looks like sensible code may inadvertently have a (potentially subtle) mistake inside it
- Your colleague is a human being, so writes code that contains some errors! Note: every student will receive a different version of the code

Python mini-project

- You need to use your understanding of the principles that should apply to find any errors

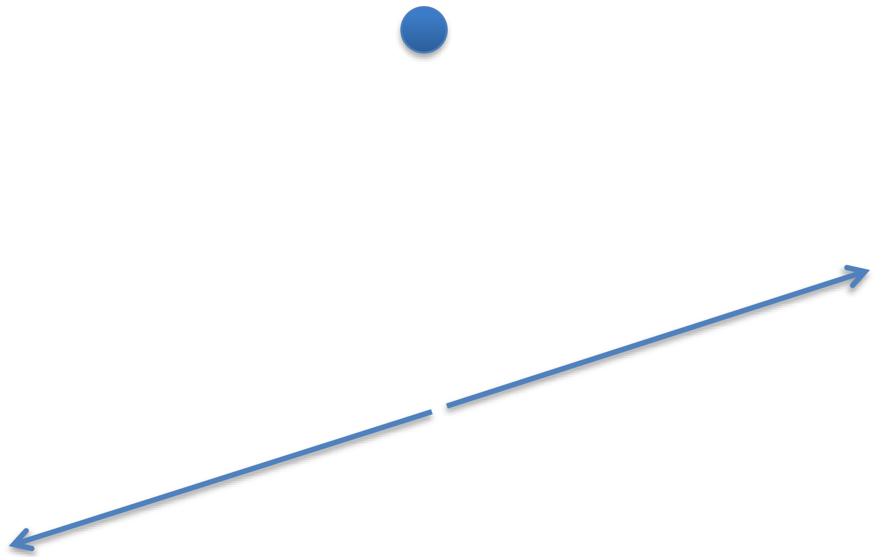
- Keep a note of the changes you make as you go along in the Jupyter notebook provided – this is what you will need to hand-in

- Where you’ve made a change, you should explain why what you’ve changed the code to is right with respect to the physics

Rest Frame

Before decay

a. Higgs



After decay

c. W^{-+}

b. W^{+-}

Lab Frame

Before decay

After decay