Did something ν just break the speed limit ?

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Chai-and-Why, Prithvi Theatre, Nov 6, 2011

Did something ν break the speed limit ?

1. What is the speed limit ?
2. How was the speed of light measured ?
3. What are these ν particles ?
4. How was their speed measured ?
5. So what ?
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Travelling at the speed of light

Speed of light: 299 792 km/s (about 3 lakh km/s) in vacuum

- Time to the sun: 8 minutes
- Time to the moon: 1 second
- Time to cross the earth: $\frac{1}{25}$ second
- Time to travel 1 foot: 1 nanosecond ($\frac{1}{1\ 000\ 000\ 000}$ second)

Nothing travels faster than the speed of light in vacuum !

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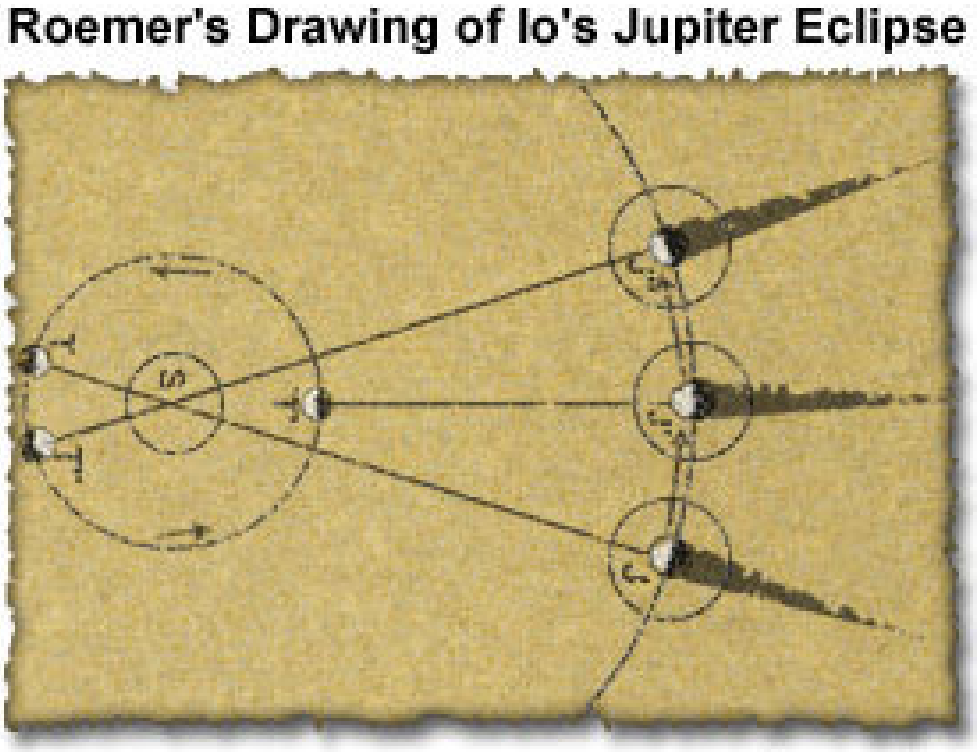
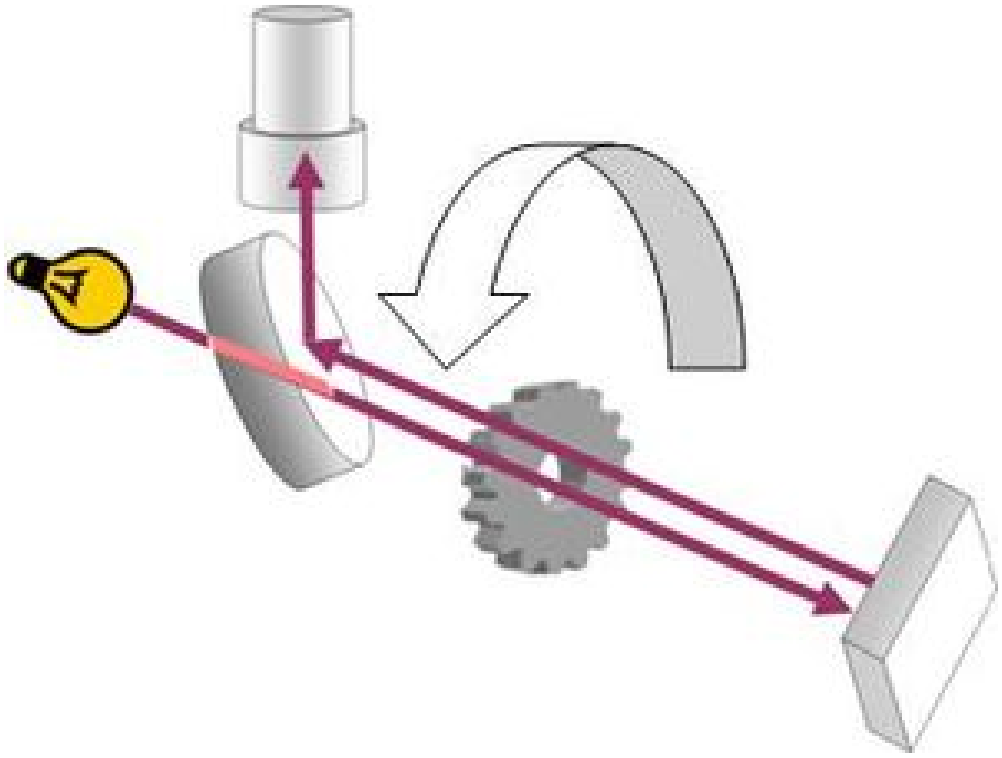
Eclipse of jupiter: Roemer 1676



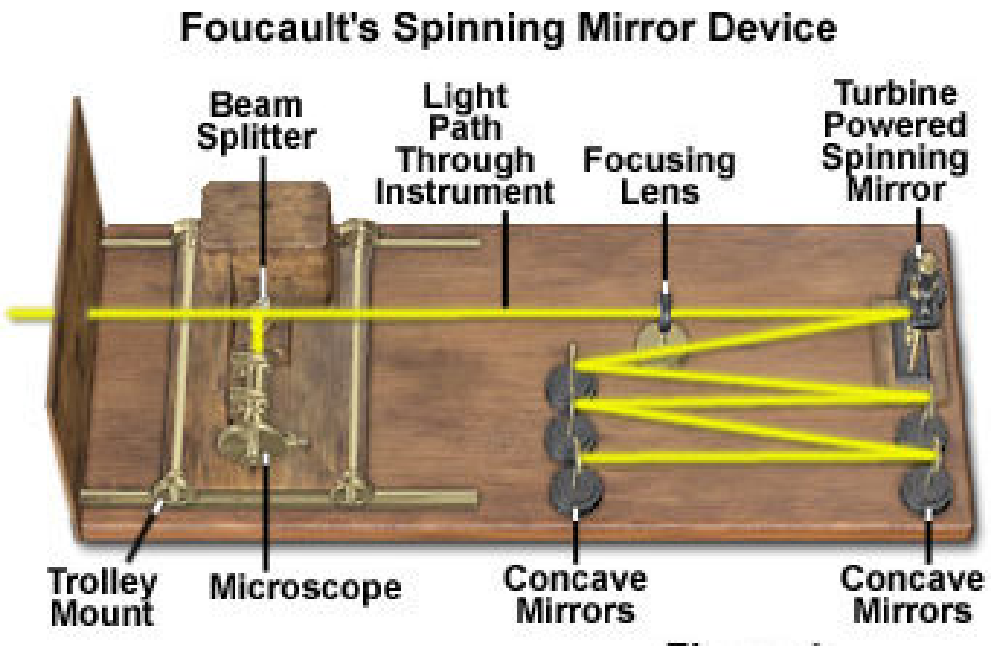
- When earth is closer to jupiter, eclipses happen earlier
- When earth is away, eclipses happen later
- Light takes 22 minutes to cross the earth's orbit

Cogwheel method: Fizeau 1849



- Mirror 8 km away
- Keep increasing the speed of cogwheel till
  Light enters from one gap, returns from the next
- Speed of light = distance / time

Rotating mirror method: Foucault 1850



- Many reflections, so the apparatus can be shorter
- Time measurement was the most difficult part
- Still 1% accuracy obtained !

Motion of earth and speed of light

Light on earth like a bullet fired on a train

- Speed of bullet on a train: faster when the bullet is fired in the same direction as the train
- We expect that the speed of light will be more when it is moving in the direction of the earth's motion

Speeds of the earth

- Spinning about its axis: 0.5 km/s
- Revolution about the sun: 30 km/s
- Solar system around the milky way: 250 km/s
- Milky way around other nearby galaxies: 300 km/s

Need to measure speed of light to an accuracy of $\sim$ 300 km/s (i.e. 0.1 %)

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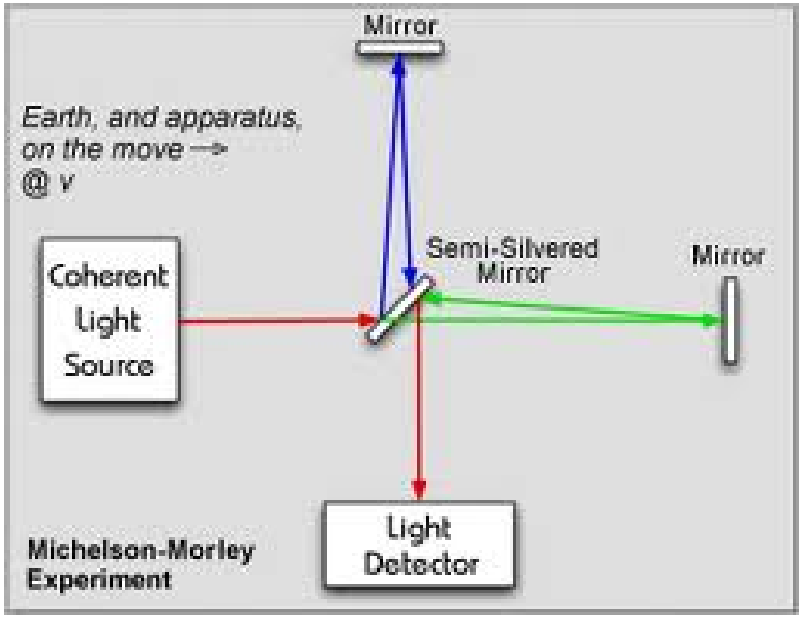
Michaelson-Morley experiment 1887



Shock of the century

- Speed of light along the earth's motion
  = Speed of light perpendicular to earth's motion
- A counter-intuitive result that revolutionised physics !

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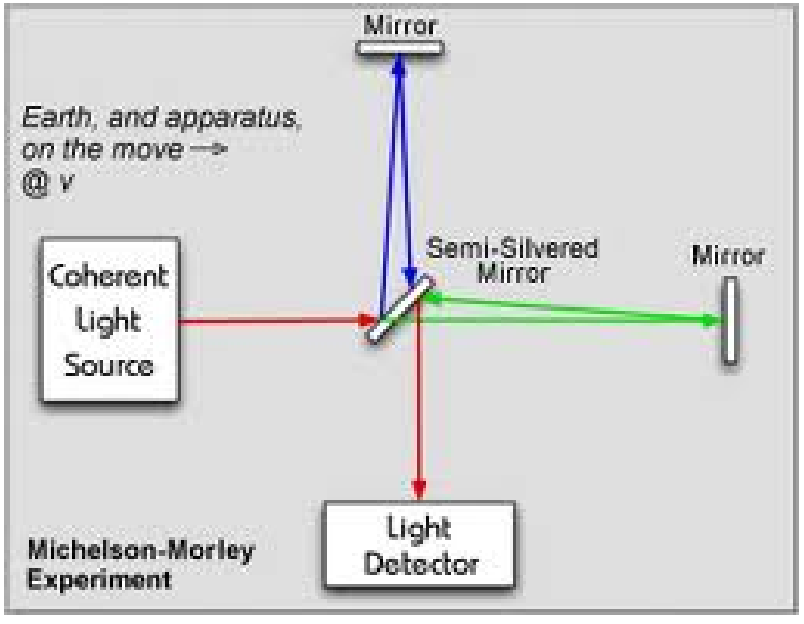

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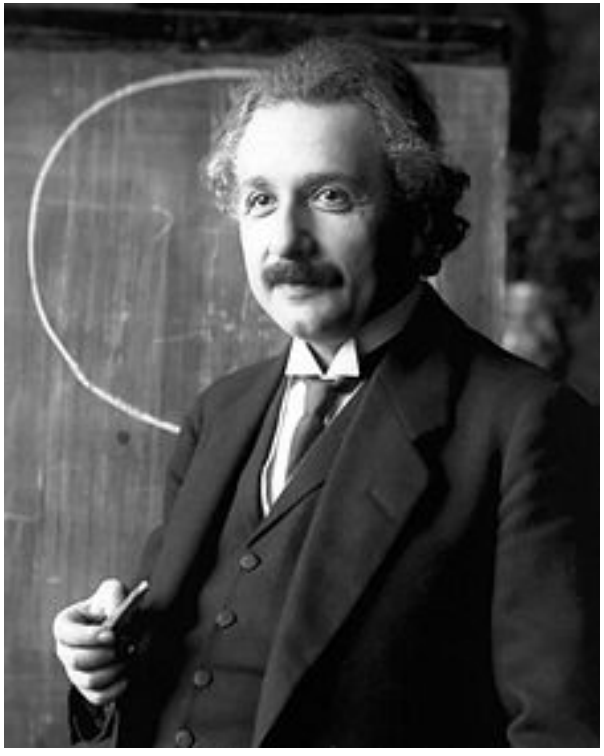
Special Theory of relativity: Einstein, 1905



- Speed of light in vacuum the same for everyone
- Distances not the same for everyone
- Time not the same for everyone
- Nothing can travel faster than the speed of light in vacuum

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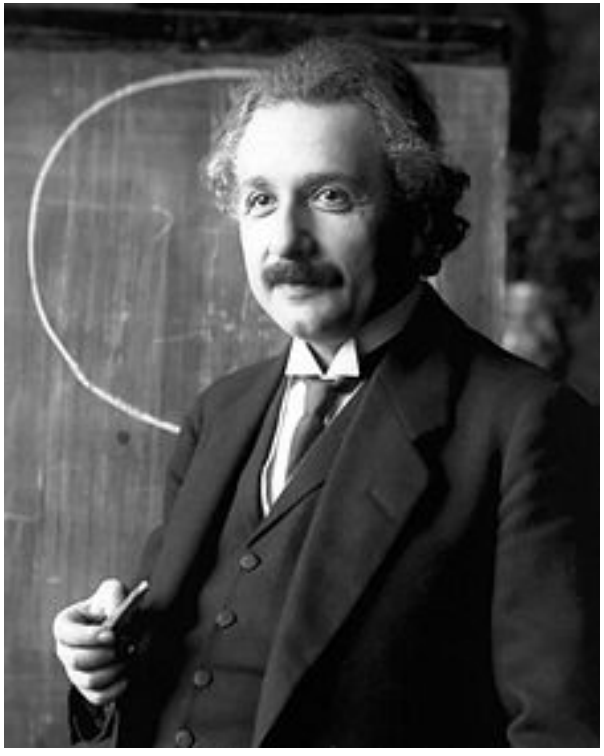

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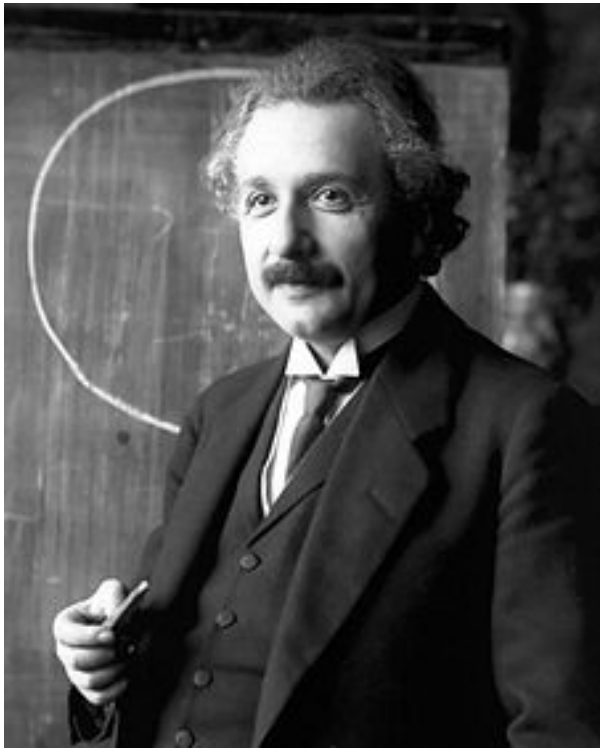

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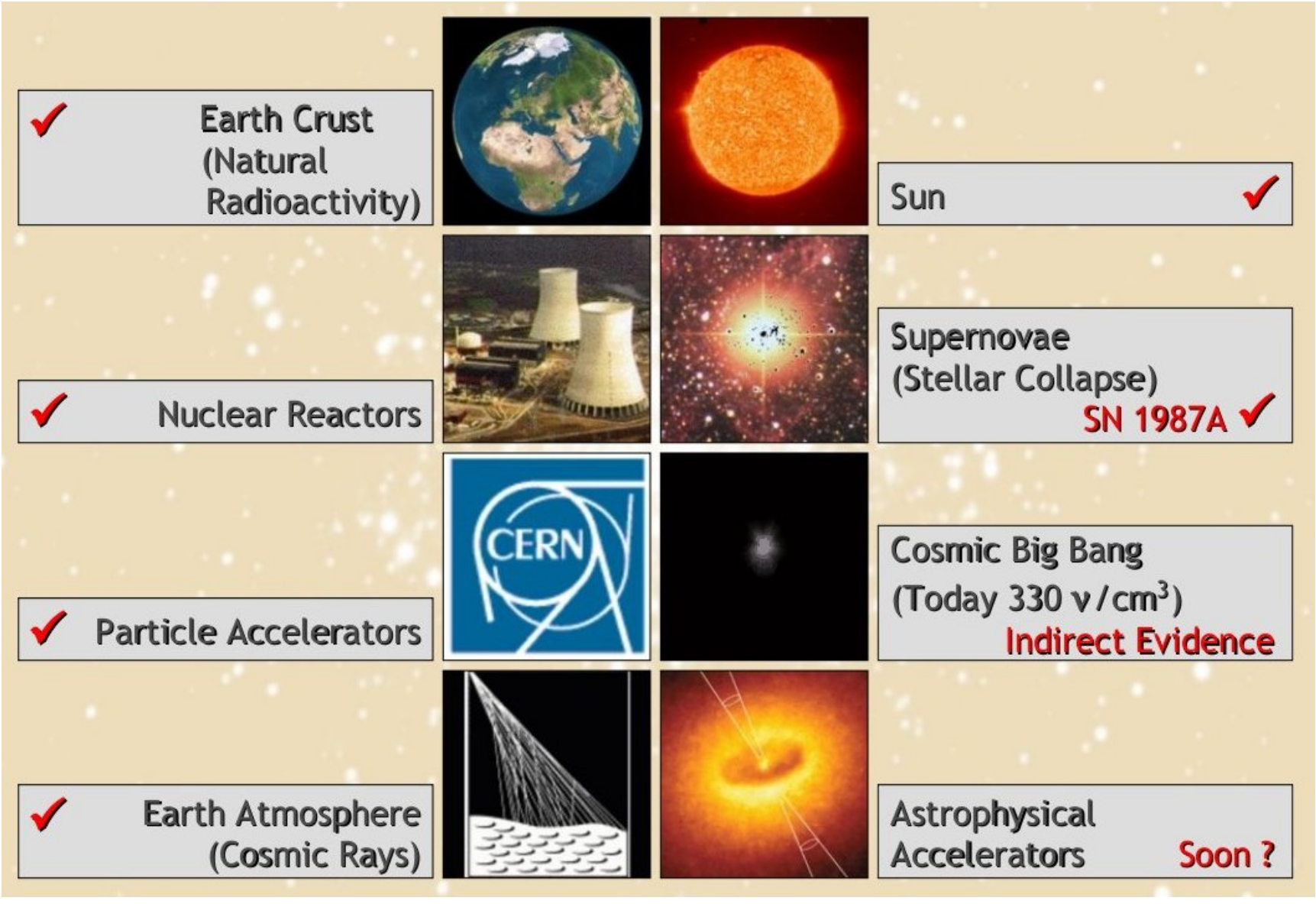
ν for neutrinos



The amazing neutrinos

- The lightest particles apart from photons
  (more than million times lighter than electron)
- The most weakly interacting particles
  (when 1 000 000 000 000 000 pass through an atom, only one interacts)
- Absorbed only rarely by matter: neutrinos from the sun will need lead shielding of the thickness of a light year to stop !
- Neutrino experiments need large detectors and a lot of patience...
- An accurate speed measurement was not possible yet.

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The OPERA experiment

Not designed to measure the speed of neutrinos !

- Neutrinos expected to move with the speed of light

What was the experiment designed for ?

- Three kinds of neutrinos:
  electron neutrino, muon neutrino, tau neutrino
- They can change their type while moving
- OPERA wanted to observe muon neutrinos going into tau neutrinos

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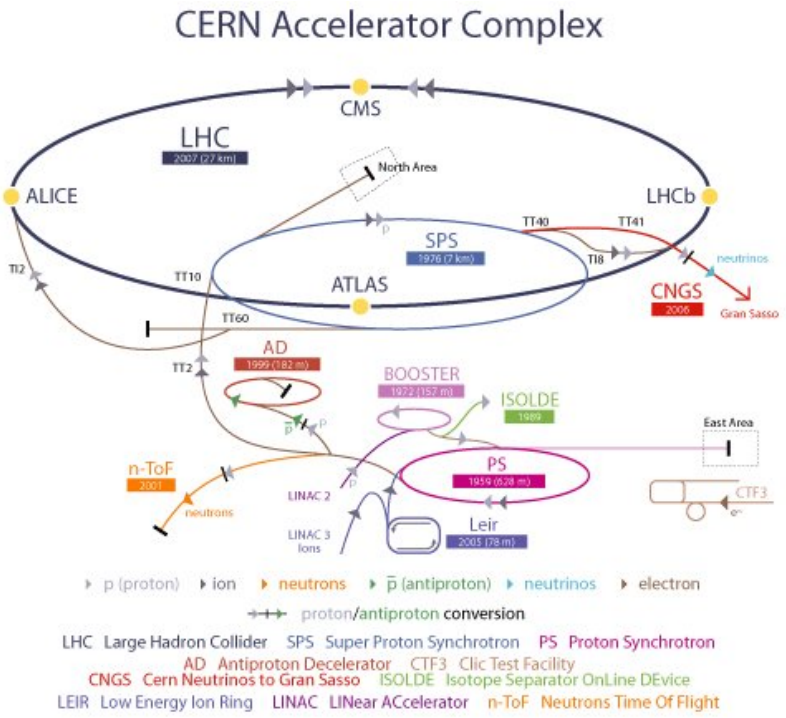
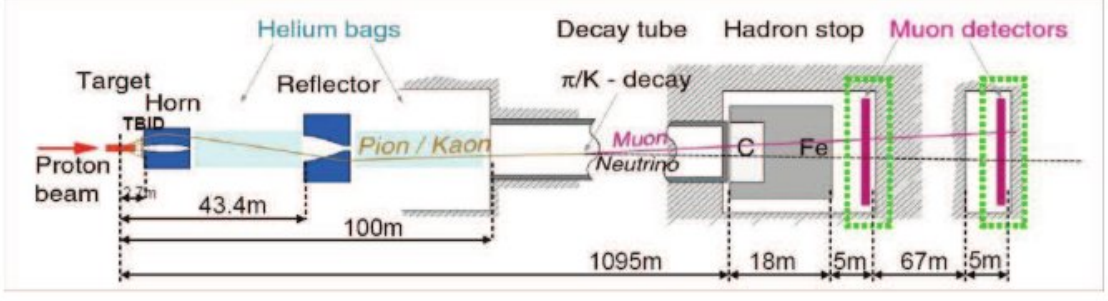
The looo...ooong baseline experiment

- From
  Geneva, Switzerland
  to
  Gran Sasso, Italy
- Distance 730 km through the earth
- Neutrinos pass through the earth, not along its surface

The source at CERN, Geneva

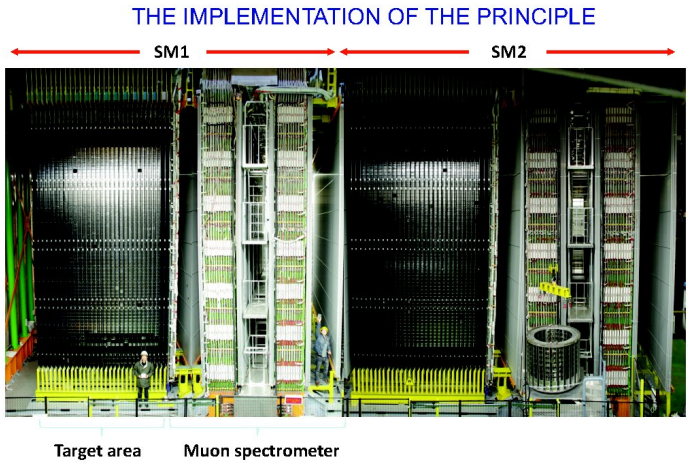


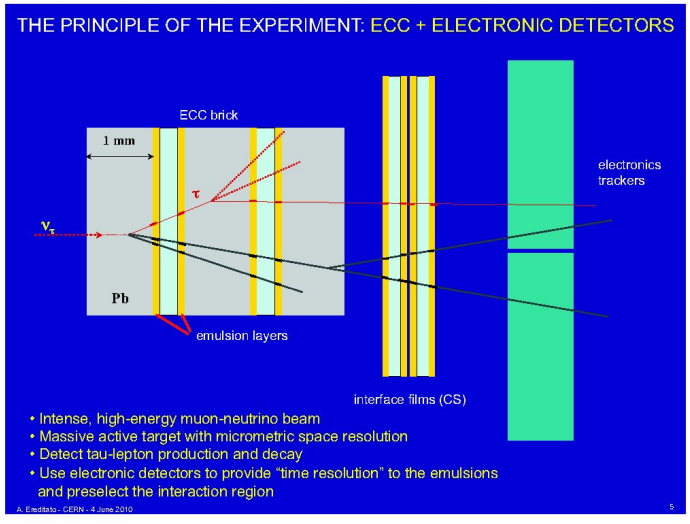
- A part of the proton beam is diverted to Gran Sasso before sending to the LHC ring



Beam animation

The detector at Gran Sasso





- Many layers of emulsion and scintillator detectors
- Neutrinos (rarely) interact and produce charged particles
- The detector can track the charged particles to identify neutrinos

Speed of neutrinos: schematic

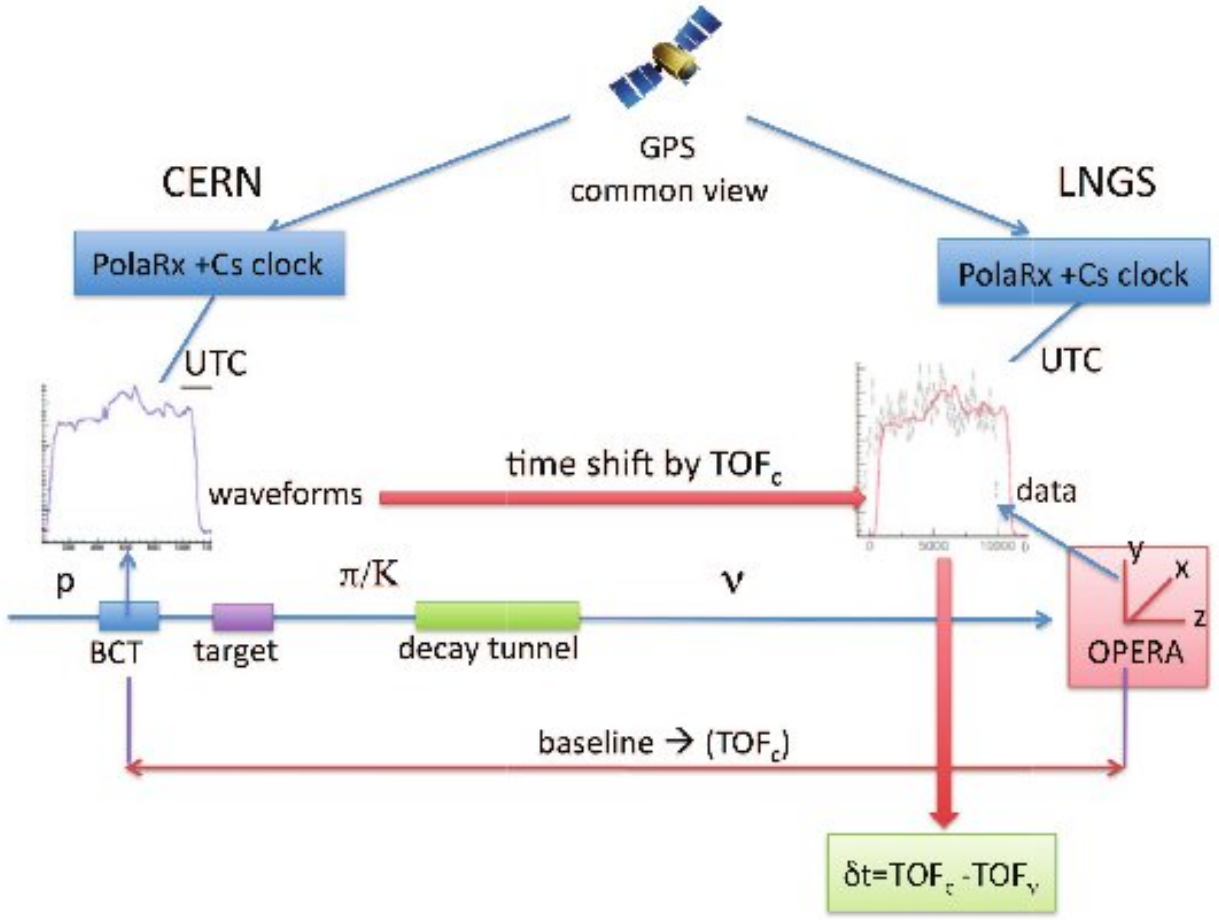


Fig. 5: Schematic of the time of flight measurement.

Distance measurement

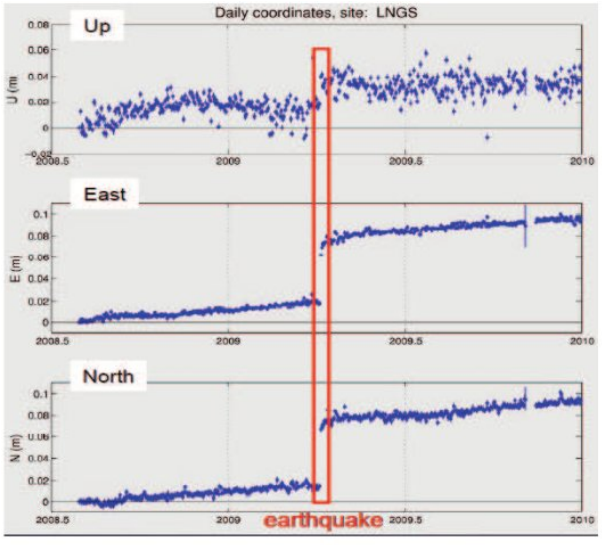
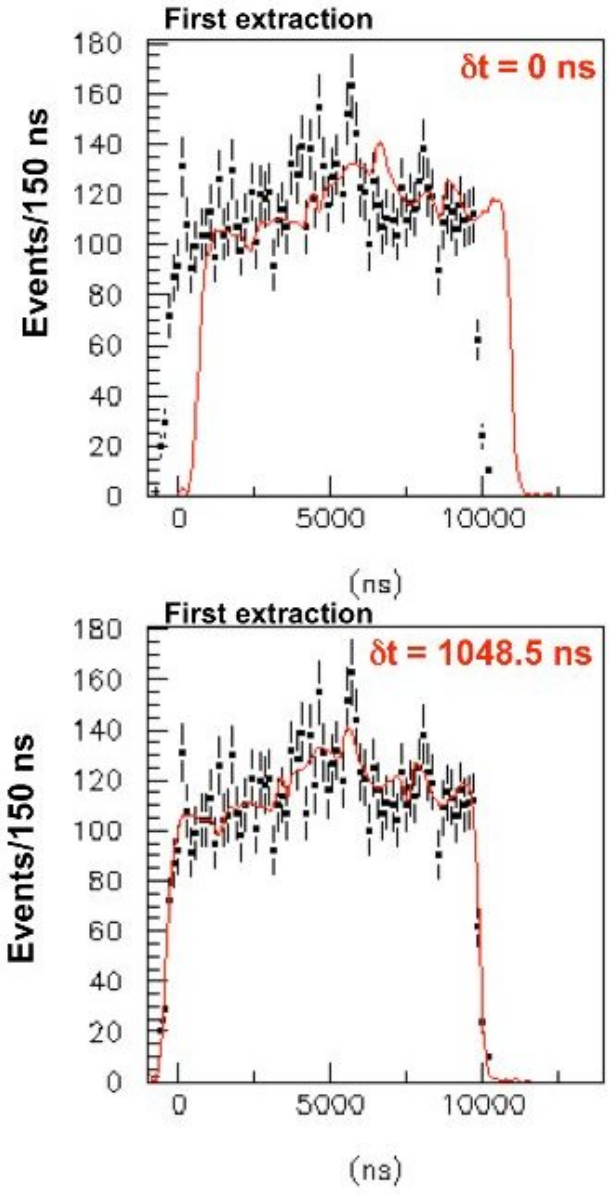


Fig. 7: Monitoring of the PolaRx2e GPS antenna position at LNGS, showing the slow earth crust drift and the fault displacement due to the 2009 earthquake in the L'Aquila region. Units for the horizontal (vertical) axis are years (meters).

- GPS system + surveying inside tunnel
- Accuracy of 20 cm (over 730 000 00 cm) and that too through the earth
- Even Gran Sasso earthquake detected by the GPS

Time measurement



- Universal Time Clock
- Special synchronization to take care of effects of time dilation by gravity and earth's motion
- Time difference between the average pulse at the source (red) and the average pulse at the detector (black data)

Speed of neutrinos: faster than light

- Speed of neutrinos: $v \approx 299\,800$ km/s $\quad (\pm 1$ km/s$)$
- Speed of light: $c = 299\,792$ km/s
- $v - c \approx 8$ km/s $\quad (\pm 1$ km/s$)$
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Why is this a big deal ?

- If true, this means that relativity is not entirely correct
- But relativity has been verified by numerous ways throughout the last 100 years
- A similar situation as after the Michaelson-Morley experiment
- Need to find a theory that will supersede Einstein's relativity, just like relativity superseded Newton's laws
- Exciting times ahead: years, maybe decades !
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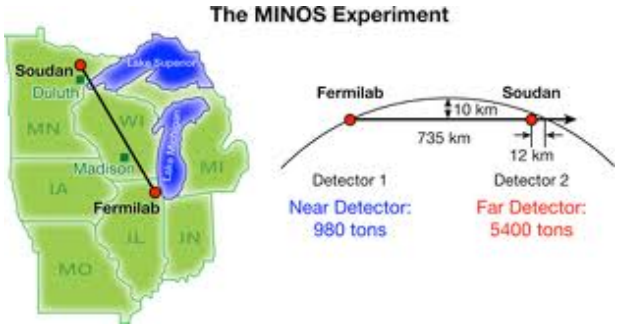
The scientific process begins

- Check and recheck all aspects of the experiment, try to find any source of error, even a tiny one
- Measure the speed of neutrinos at other independent experiments to confirm or rule out this result



- Start devising new theories to replace Einstein's :-)