WHO CAN RUN FASTER THAN LIGHT?

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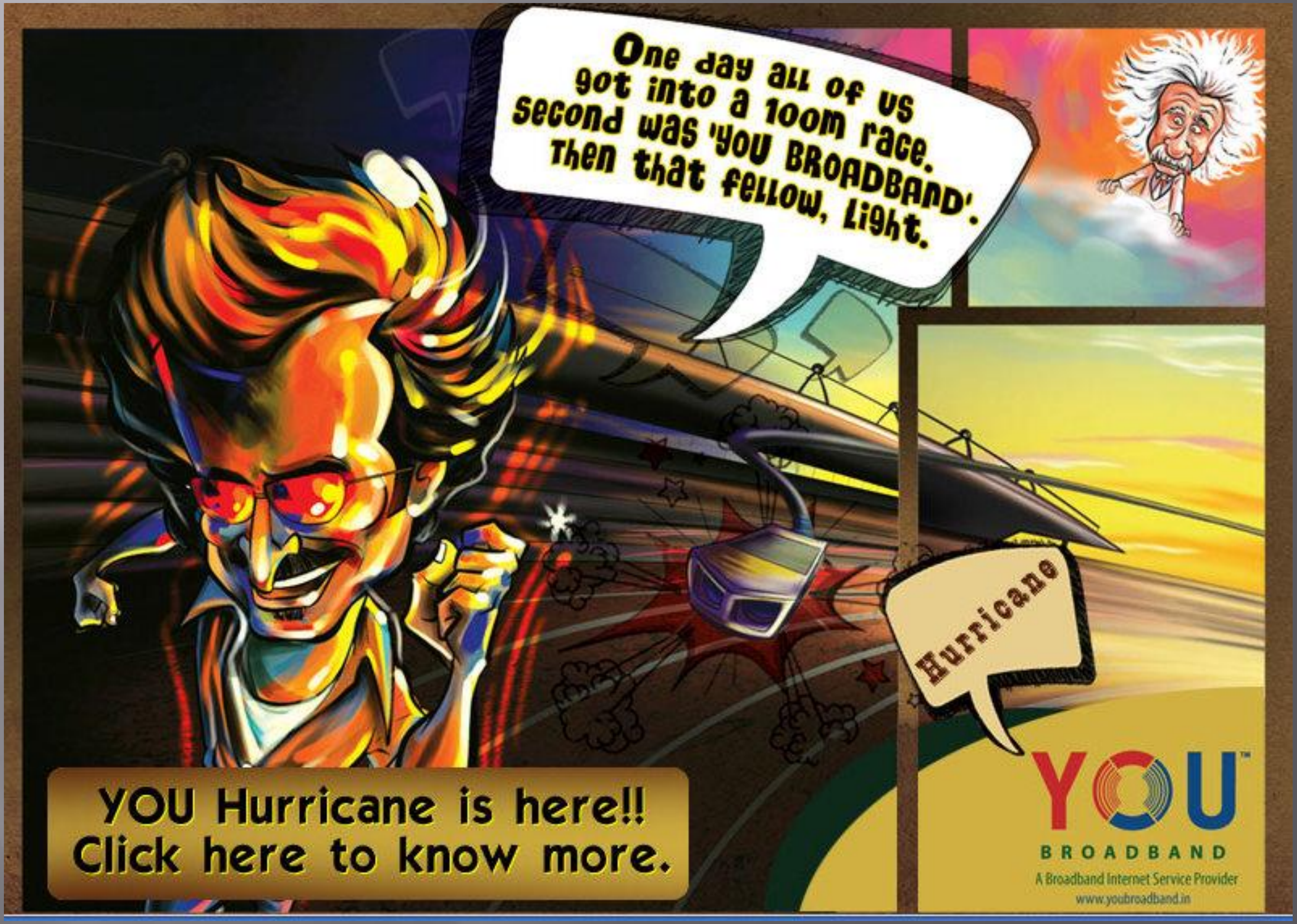
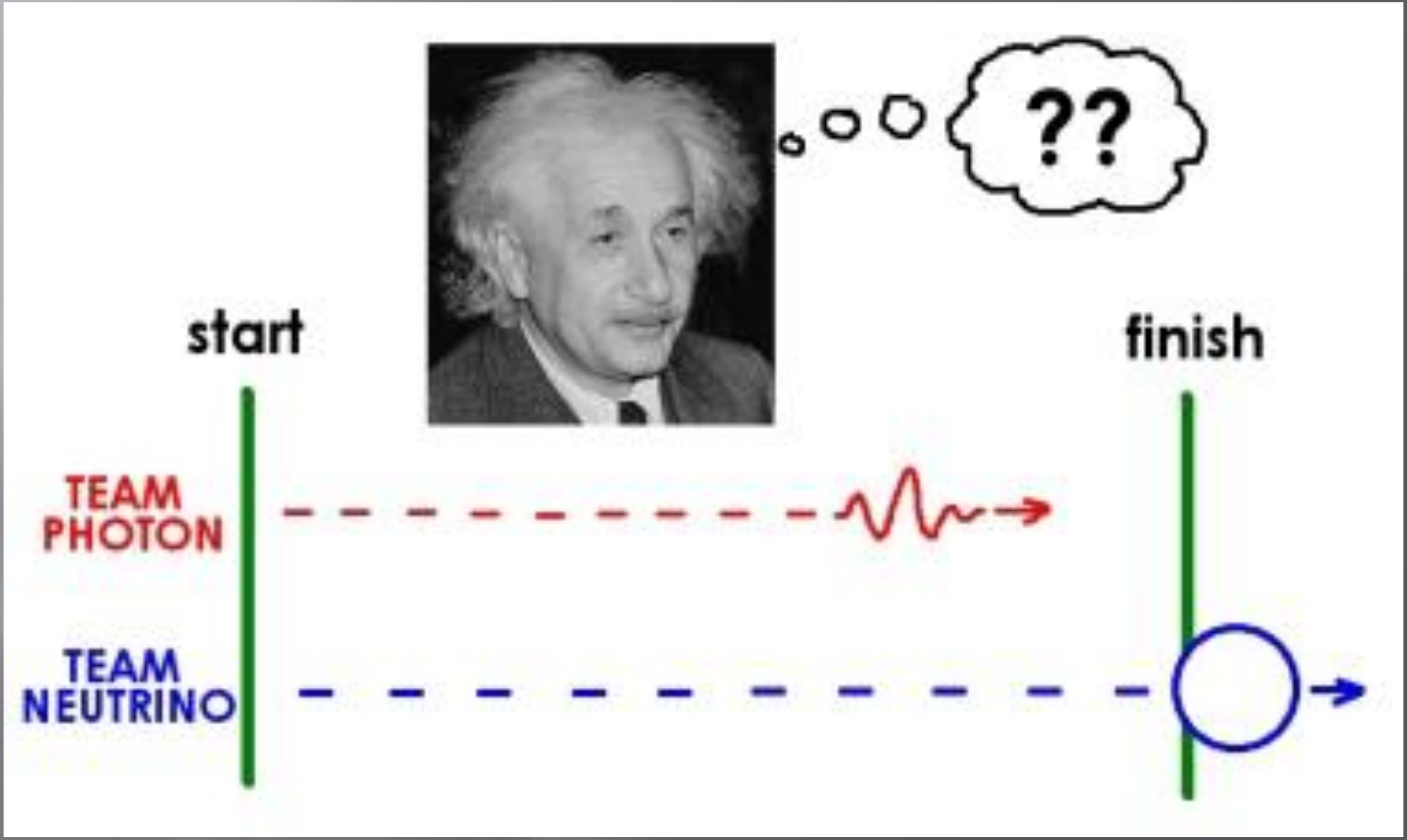
No; I did not mean *RK*…



This is the race



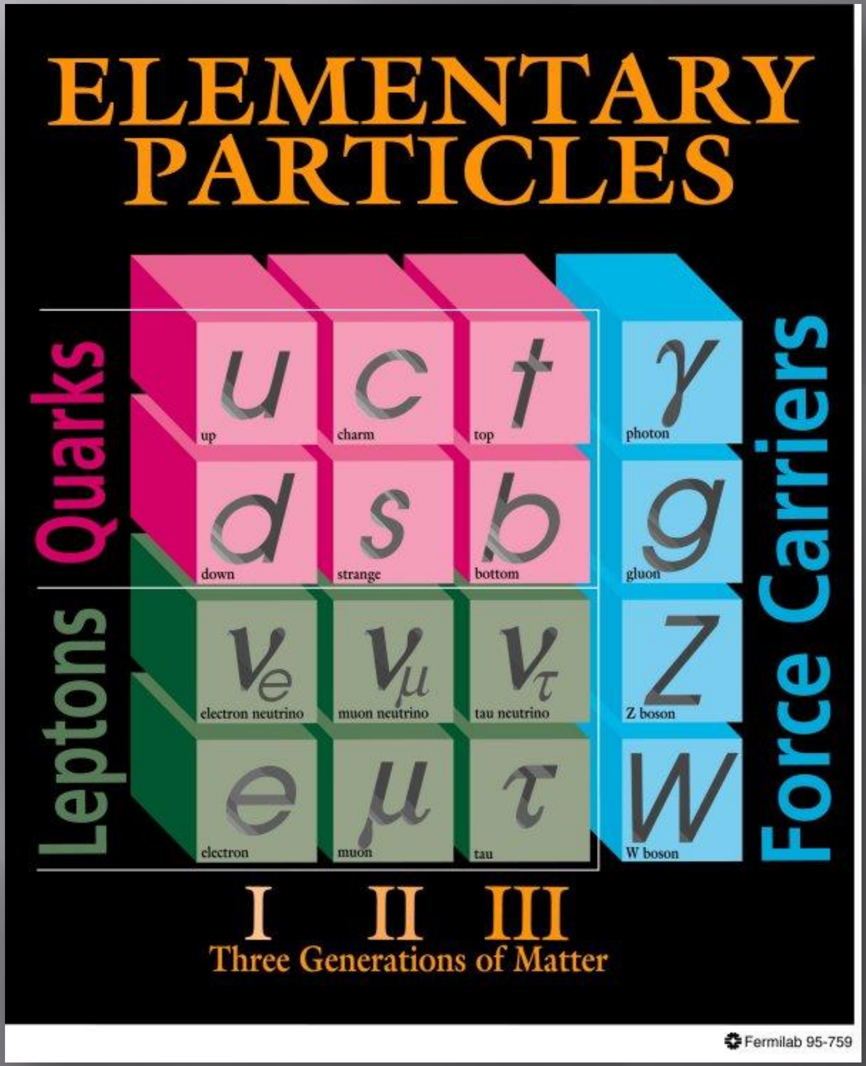
Einstein's theory of relativity

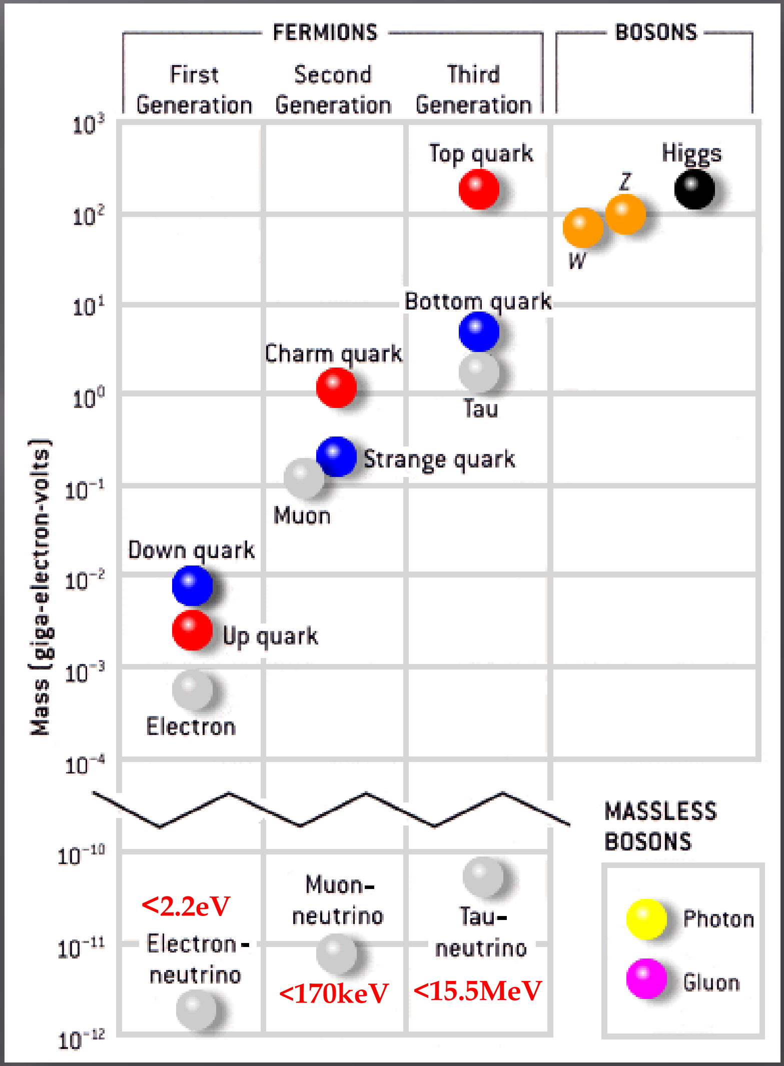
- Faster the objects travel relative to each other, slower the time passes for one object when observed from the other.
- If the objects travel at the speed of light, time appears to stand still for the observed object.
- The theory of relativity is required whenever we study objects that are either:
  - moving in a strong gravitational field
  - moving near the speed of light
- In everyday life on Earth, neither of these is true. Nonetheless, its effects can still be important when extremely high precision is needed:
  - For example: Global Positioning System (GPS)
- Constancy of the speed of light

First measurement of c

- Greek astronomers believed that the speed of light was effectively infinite.
- One of Galileo's more unsuccessful experiments was his attempt to quantify the speed of light, by using distant lanterns with shutters in 1600.
- Speed of light was first truly measured by Olaf Roemer in 1676.
- Time elapsed between eclipses of Jupiter with its moons became shorter as the Earth moved closer to Jupiter and became longer as the Earth and Jupiter drew farther apart.
- This behaviour could be accounted for by a finite speed of light.
- He calculated that the speed of light was something like 2.14×10^8 meters per second.
- This measurement, considering its antiquity, method of measurement, and 17th century uncertainty in exactly how far Jupiter was from the Earth, is surprisingly accurate.
- The modern value of c is 2.99792458×10^8 meters per second.
- Laser interferometers are used to very precisely measure speeds and distances.

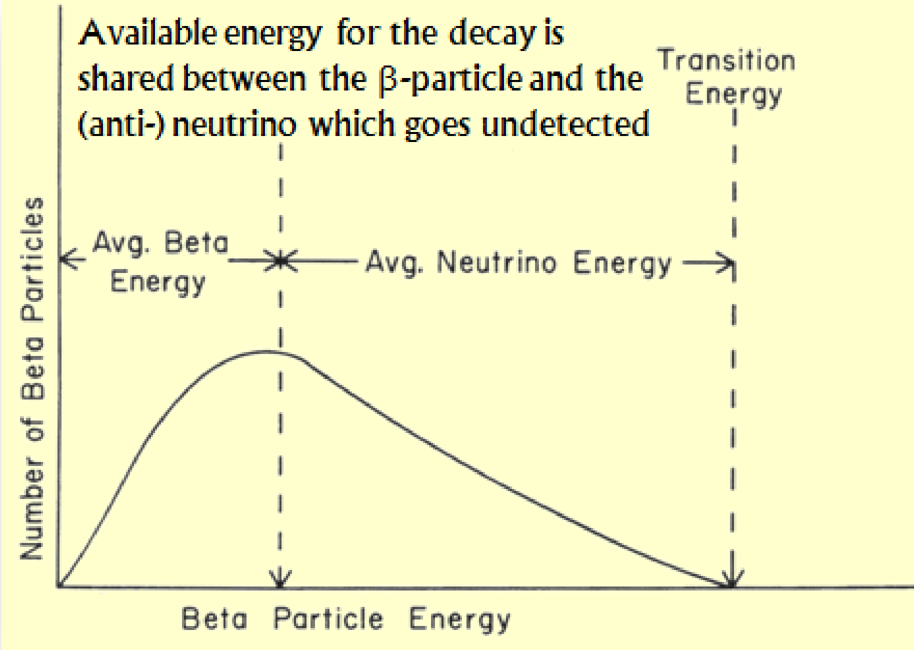
Standard model of particle physics





Neutrino (ν)

- Proposed by Wolfgang Pauli in 1930 to explain beta decay.
- Named by Enrico Fermi in 1931.
- Discovered by F.Reines and C.L.Cowan in 1956.
- Created during the Big Bang, Supernova, in the Sun, from cosmic rays, in nuclear reactors, in particle accelerators etc.
- Interactions involving neutrinos are mediated by the weak force.



$$n \rightarrow p + e^{-} + \bar{\nu}$$

$$p \rightarrow n + e^{+} + \nu$$

$$4p \rightarrow \alpha + 2e^{+} + 2\nu_e + 25MeV$$

$$\pi^{+} \rightarrow \mu^{+} + \nu_{\mu} \rightarrow e^{+} + \bar{\nu}_{\mu} + \nu_e + \nu_{\mu}$$

Unique features of neutrinos

The second most abundant particles in the universe

- Cosmic microwave background photons: 400 / cm^3
- Cosmic microwave background neutrinos: 330 / cm^3

The lightest massive particles

- A million times lighter than the electron
- No direct mass measurement yet

The most weakly interacting particles

- Invisible: do not interact with light
- Stopping radiation with lead shielding:
  - Stopping α, β, γ radiation: 50 cm
  - Stopping neutrinos from the Sun: several light years !

Neutrino oscillations

- It is now known that neutrinos of one flavour oscillate to those of another flavour.
- The oscillation mechanism is possible only if the neutrinos are massive.
- Neutrino experiments are setting the stage for extension of Standard Model itself.
- Massive neutrinos have ramifications on nuclear physics, astro physics cosmology, geo physics apart from particle physics

- Electron and muon neutrinos (ν_e and ν_μ) are the flavour eigen states. They are super positions of the mass eigen states (ν_1 and ν_2)

$$\nu_e = \nu_1 \cos\theta + \nu_2 \sin\theta$$
$$\nu_\mu = -\nu_1 \sin\theta + \nu_2 \cos\theta$$

- If at t = 0, an eigen state $\nu(0) = \nu_e$, then any time t

$$\nu(t) = \nu_1 e^{-iE_1 t} \cos\theta + \nu_2 e^{-iE_2 t} \sin\theta$$

- Then the oscillation probability is

$$P(\nu_e \to \nu_f; L) = \sin^2 2\theta \sin^2 1.27 \Delta m^2 L/E$$

- And the oscillation length is

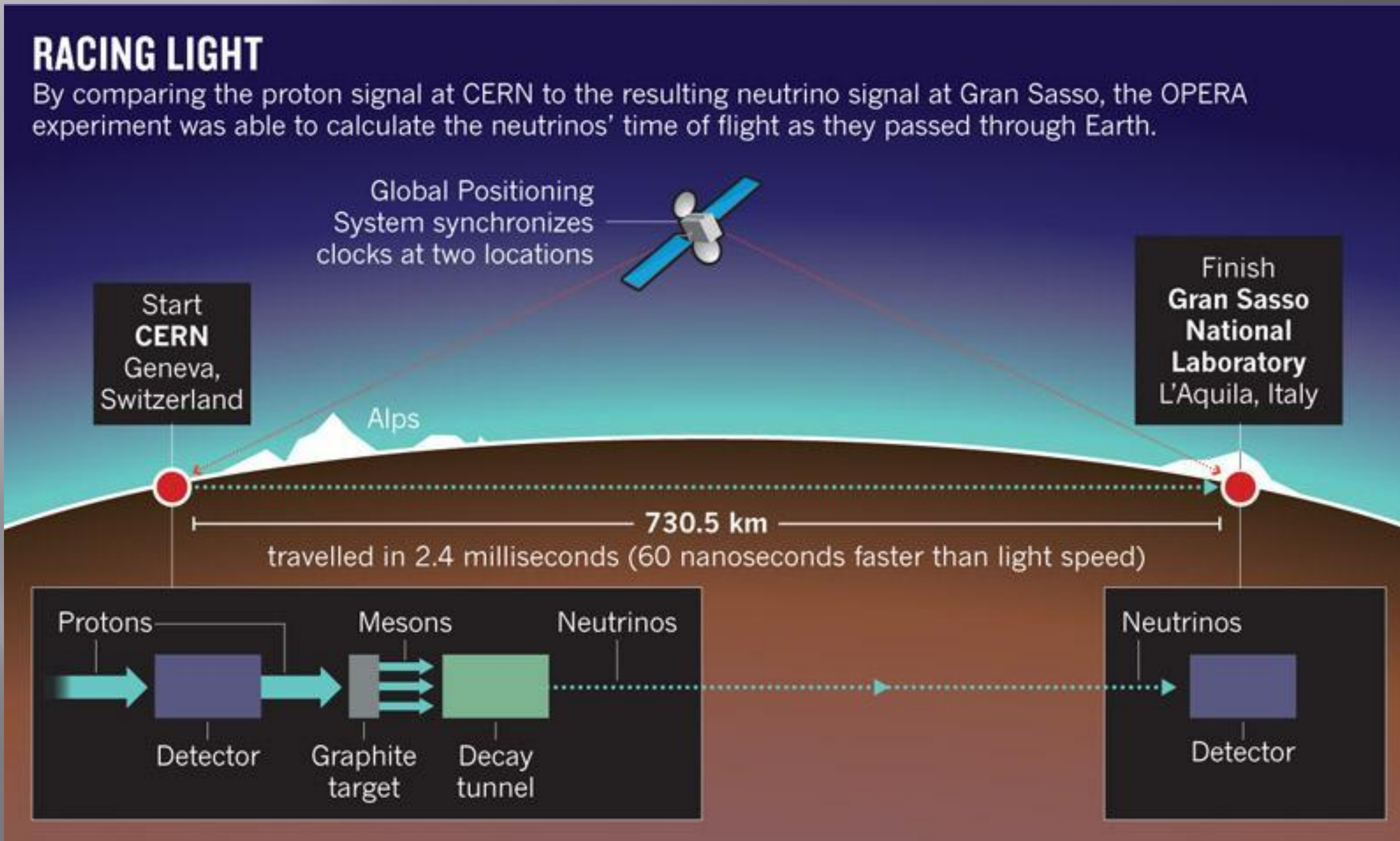
$$\lambda = 2.47 m (E/MeV)(eV^2/\Delta m^2)$$

Gran Sasso National Laboratory

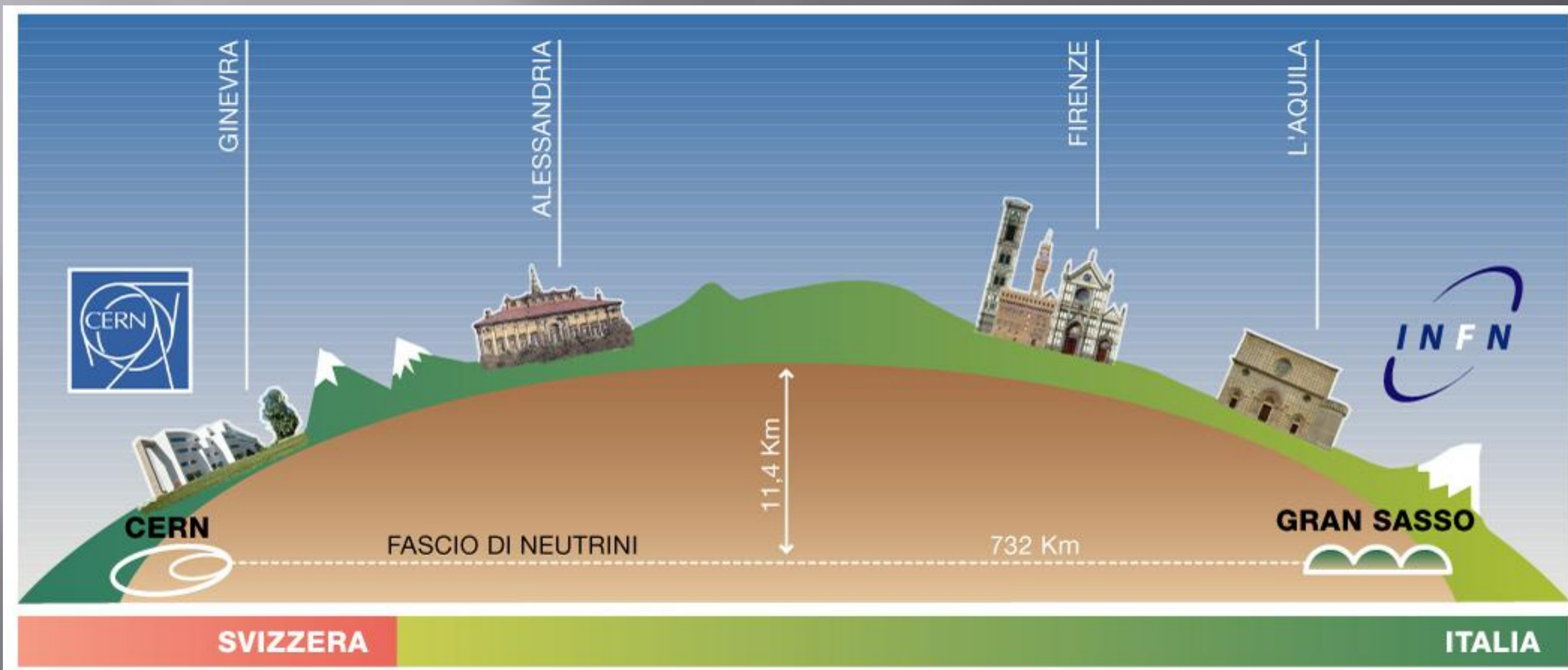
The OPERA detector

Oscillation Project with Emulsion (T)racking Apparatus

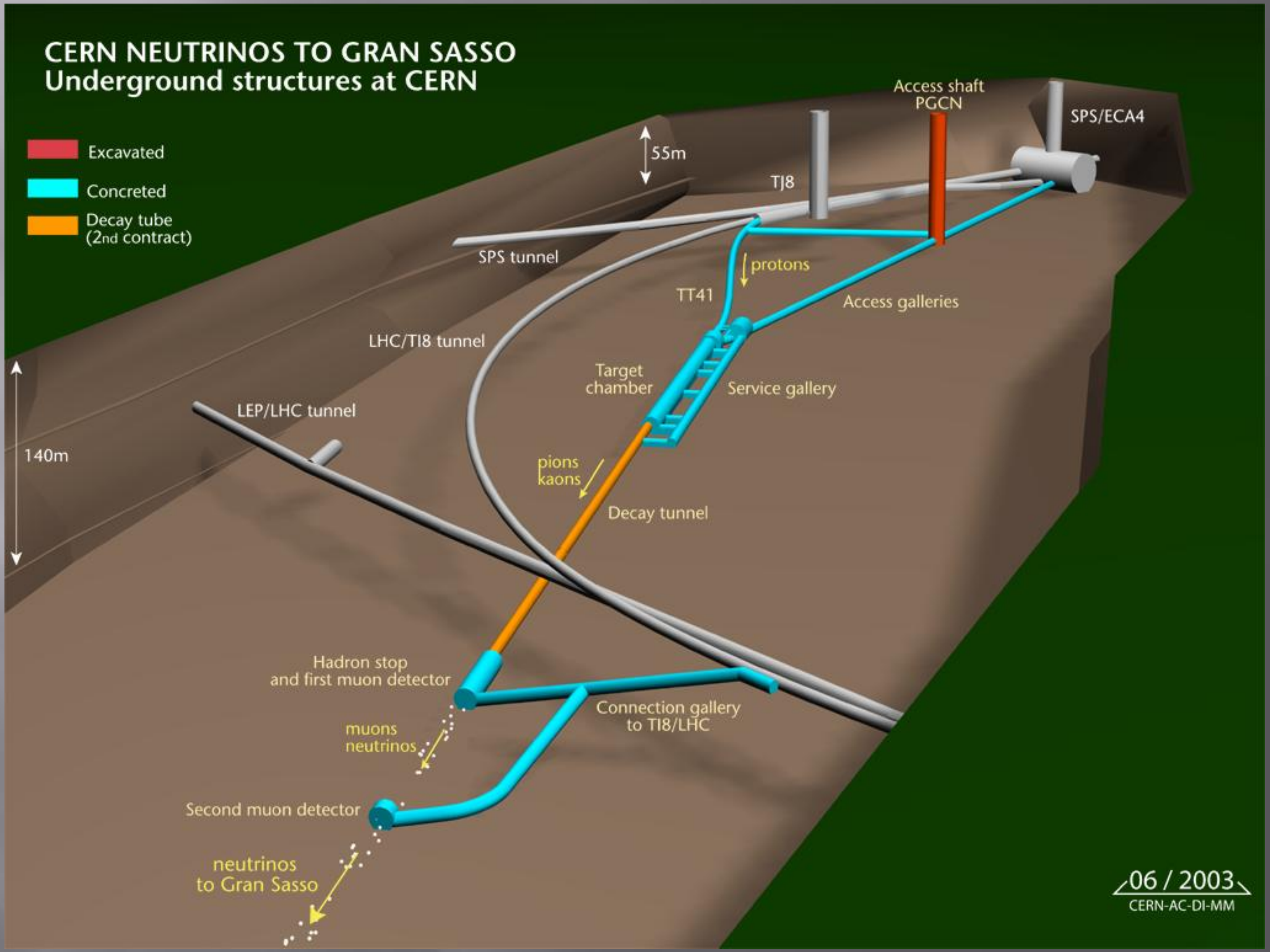
The experiment



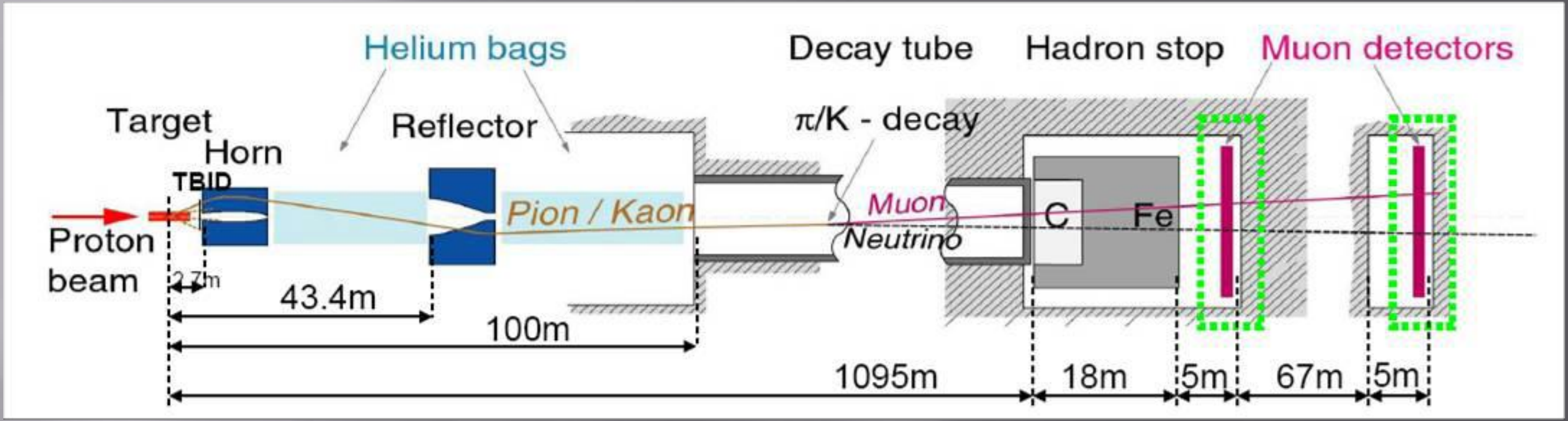
Long journey of neutrinos



An artistic view of the layout



Layout of the CNGS beam line



- Baseline: 731.278km (measured with a precision of 20cm, geodesy campaign, GPS bench marks)
- 400GeV/c from SPS on graphite neutrino production target (average ν energy 17GeV)

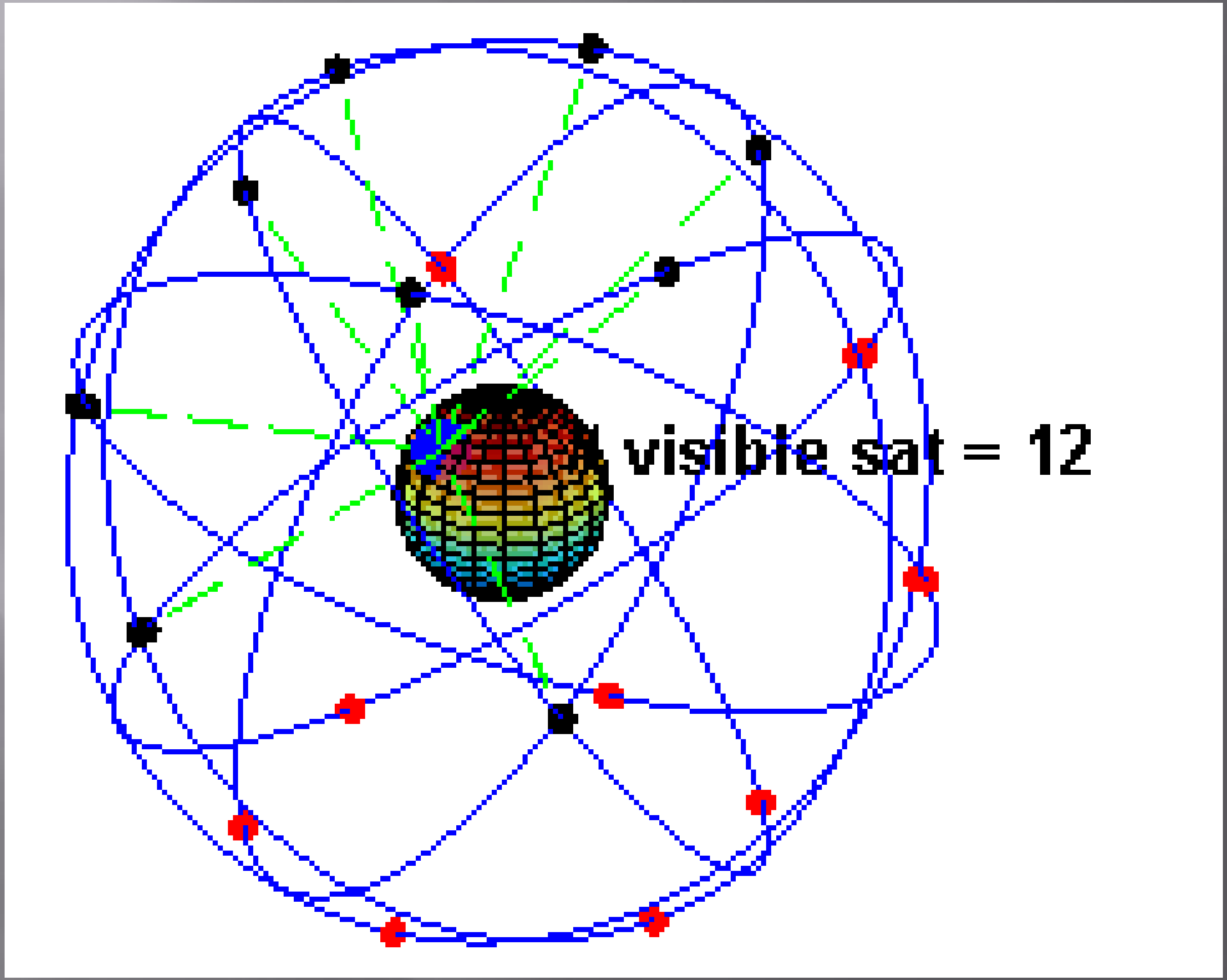
Basic concept of GPS

- GPS receiver calculates its position by precisely timing the signals sent by GPS satellites high above the Earth.
- Each satellite continually transmits information that include:
  - the time the information was transmitted
  - precise orbital information
- The receiver determines the transit time of each message and computes the distance to each satellite.
- These distances along with the satellites' locations are used to compute the position of the receiver.
- Three satellites might seem enough to solve for position since space has three dimensions and a position near the Earth's surface can be assumed.
- Even a very small clock error multiplied by the very large speed of light — the speed at which satellite signals propagate — results in a large positional error.
- So, GPS receivers use four or more satellites to solve for both the receiver's location and time.
- The very accurately computed time is not used by most of the GPS applications, which use only the location.
- Some specialized GPS applications do use the time; these include time transfer, traffic signal timing, and synchronization of cell phone base stations.
- GPS time is accurate to about 14 nanoseconds

GPS applications

- Surveying and mapping, on land, at sea and from the air.
  - The applications are of relatively high accuracy.
  - Positioning in both the stationary and moving mode.
  - Land, sea and air navigation, including enroute as well as precision navigation, cargo monitoring, vehicle tracking, etc.
- Search and rescue operations, including collision avoidance and rendezvous functions.
- Spacecraft operations.
- Military applications.
- Recreational uses, on land, at sea and in the air.
- Other specialised uses, such as time transfer, altitude determination, automatic operation.

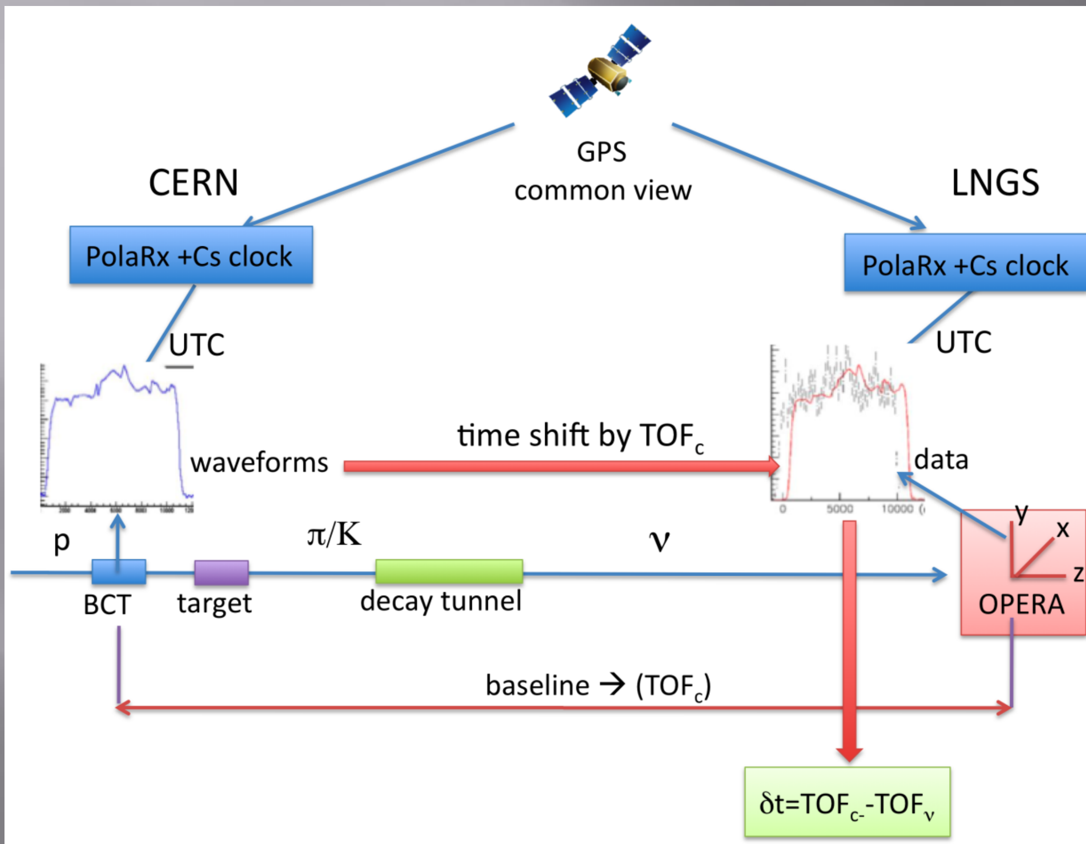
GPS constellation

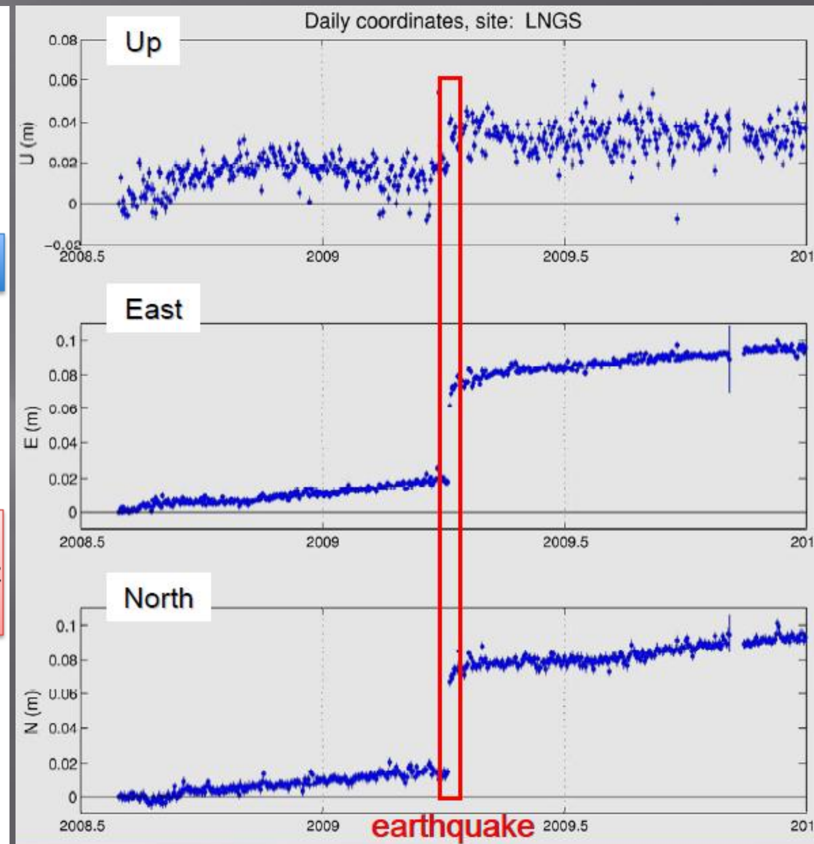


Geodesy for distance measurement

- Geodesy ("division of the Earth") is primarily concerned with positioning within the temporally varying gravity field.
- In surveying and mapping, two general types of coordinate systems are used in the plane:
  - Plano-polar, in which points in a plane are defined by a distance *s* from a specified point along a ray having a specified direction α with respect to a base line or axis;
  - Rectangular, points are defined by distances from two perpendicular axes called *x* and *y*. It is geodetic practice—contrary to the mathematical convention—to let the *x* axis point to the North and the *y* axis to the East.
- Point positioning is the determination of the coordinates of a point on land, at sea, or in space with respect to a coordinate system. Point position is solved by computation from measurements linking the known positions of terrestrial or extraterrestrial points with the unknown terrestrial position.

Precise time & distance measurement





Earthquake April 2009, displacement 7cm

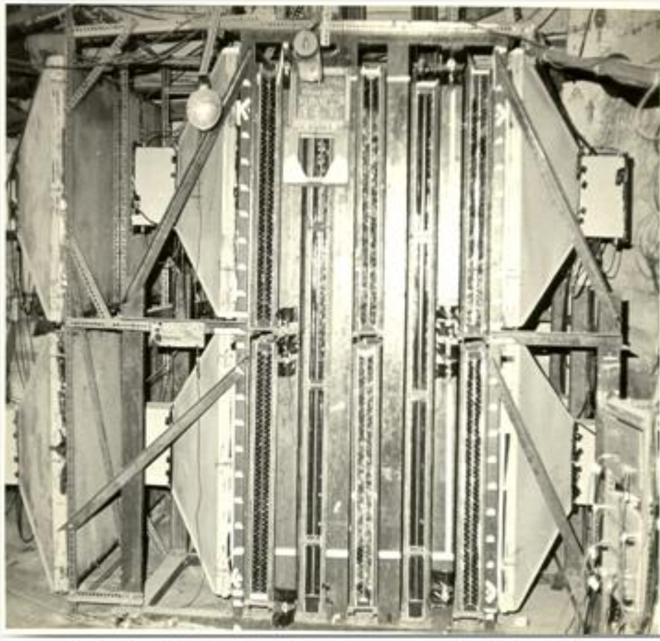
Summary of the observations

- Data recorded during 2009-2011, 10^{20} protons, 15223 ν events
- Early arrival time w.r.t. light: 57.8ns
- Relative difference of ν_μ w.r.t. light, (v-c)/c: 2.37
- Long bunch time structure: 10.5μs (separated by 50ms, total cycle is 6s long)
- Reconfirmed results at single interaction level using short-bunch time-structure
- Short-bunch time-structure: Four bunches, 3ns long, separated by 524ns, 4×10^{16} protons, 36 ν events
- Possible flaws in the experiment:
  - The first one is linked to the oscillator used to produce the events time-stamps in between the GPS synchronizations.
  - The second point is related to the connection of the optical fiber bringing the external GPS signal to the OPERA master clock.
  - These two issues can modify the neutrino time of flight in opposite directions
- More studies in progress by OPERA as well as its competitors.

If Einstein is proved wrong…

Legacy of underground physics in India

Atmospheric neutrino detector
at Kolar Gold Fields –1965



DETECTION OF MUONS PRODUCED BY COSMIC RAY NEUTRINO DEEP UNDERGROUND

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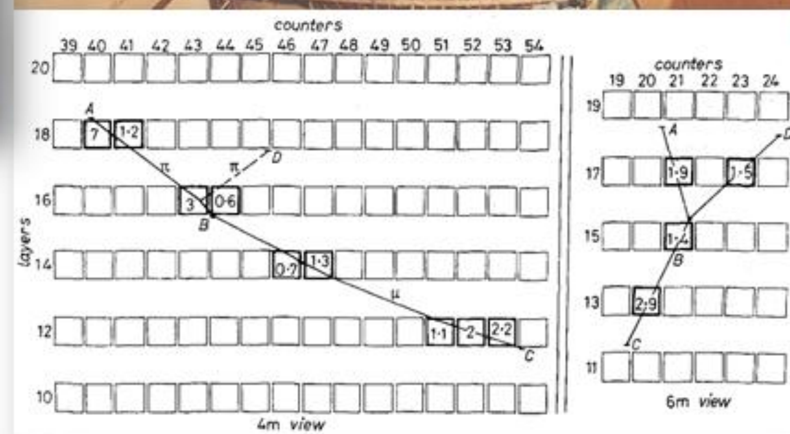
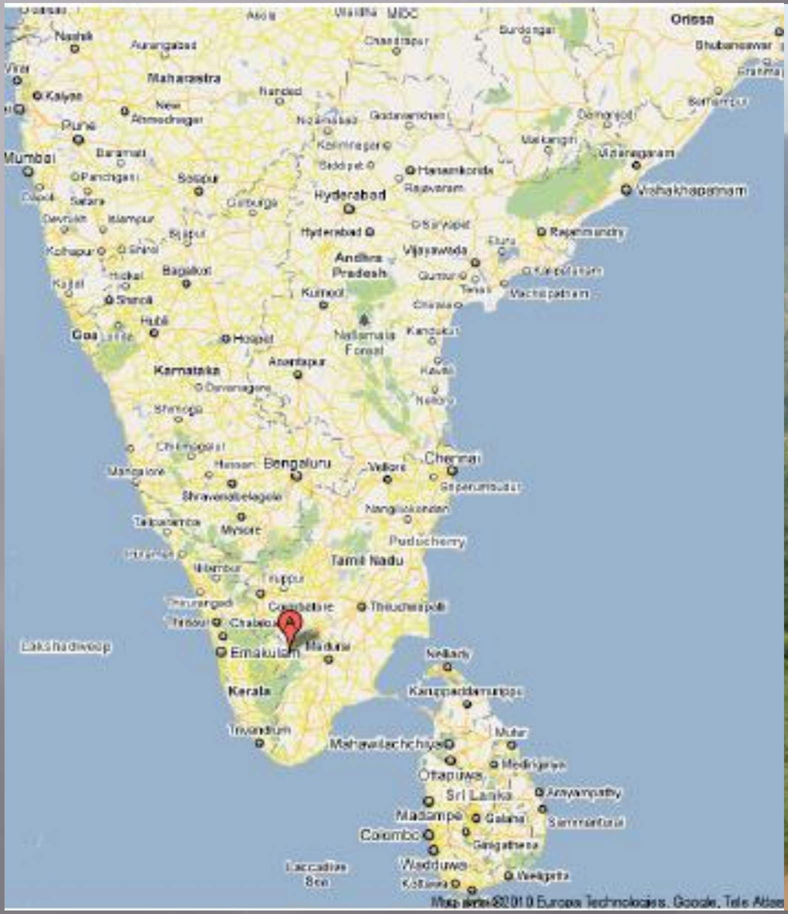
Received 12 July 1965



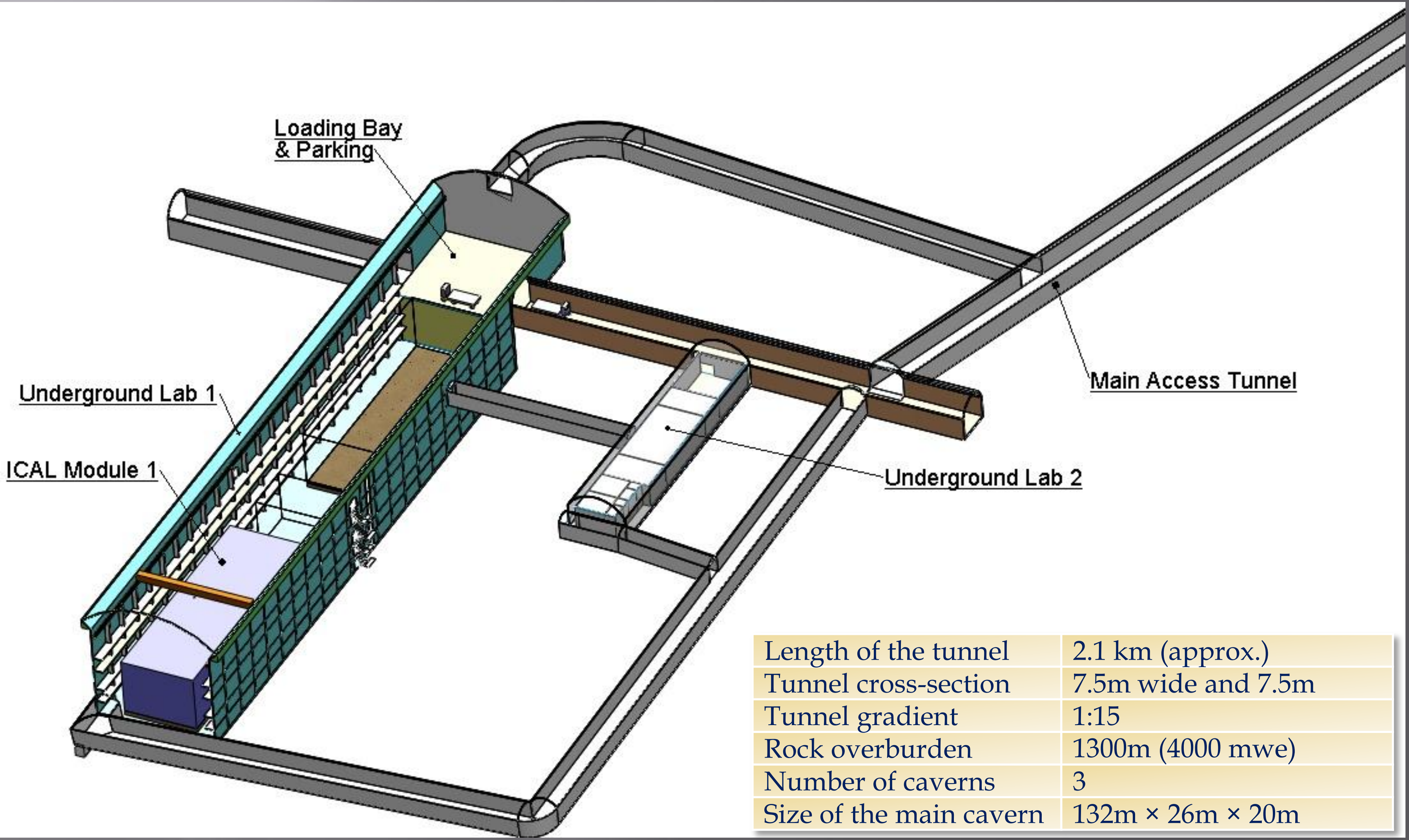
Proton decay experiments

INO experimet

Location: 9°58′ North; 77°16′ East, 110km from Madurai (South India)

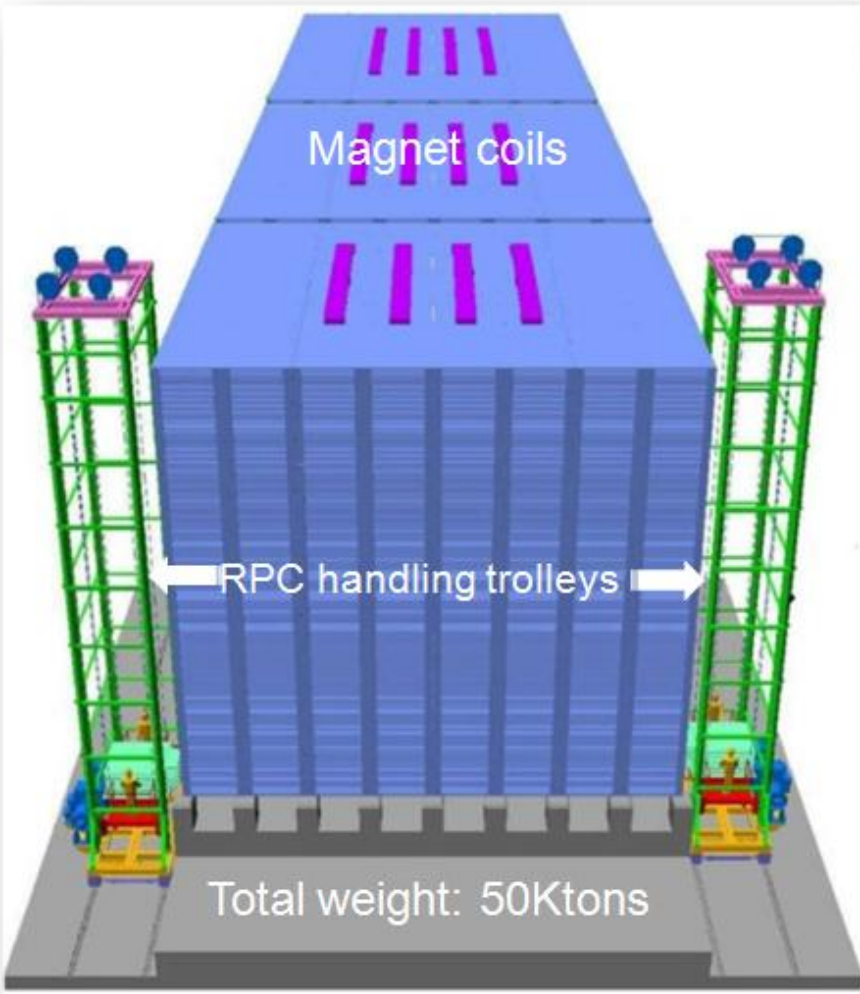


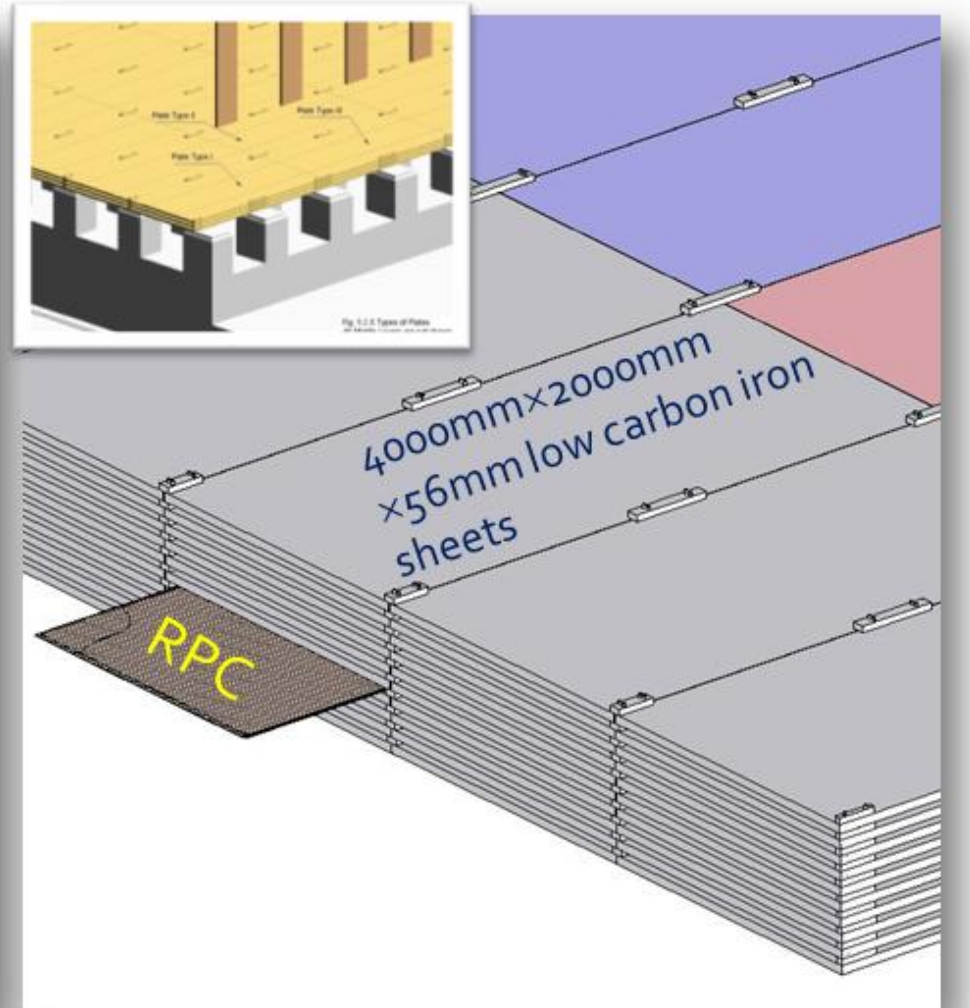
Schematic of the underground labs



Length of the tunnel	2.1 km (approx.)
Tunnel cross-section	7.5m wide and 7.5m
Tunnel gradient	1:15
Rock overburden	1300m (4000 mwe)
Number of caverns	3
Size of the main cavern	132m × 26m × 20m

ICAL detector and construction

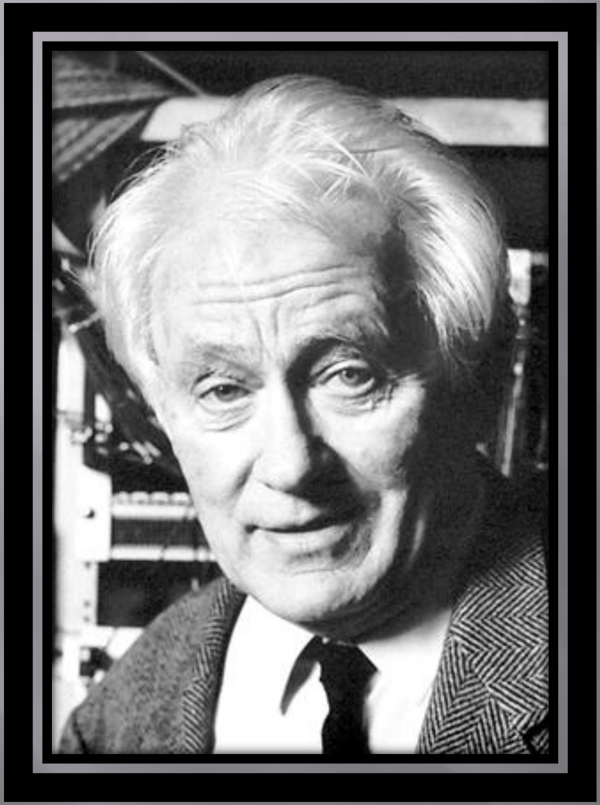




Factsheet of ICAL detector

No. of modules	3
Module dimensions	16m × 16m × 14.5m
Detector dimensions	48.4m × 16m × 14.5m
No. of layers	150
Iron plate thickness	56mm
Gap for RPC trays	40mm
Magnetic field	1.3Tesla
RPC dimensions	1,950mm × 1,840mm × 24mm
Readout strip pitch	3 0mm
No. of RPCs/Road/Layer	8
No. of Roads/Layer/Module	8
No. of RPC units/Layer	192
No. of RPC units	28,800 (97,505m^2)
No. of readout strips	3,686,400

Science and Instrumentation



Georges Charpak (1924–2010)

The Nobel Prize in Physics 1992 was awarded to Georges Charpak "for his invention and development of particle detectors, in particular the multi-wire proportional chamber".

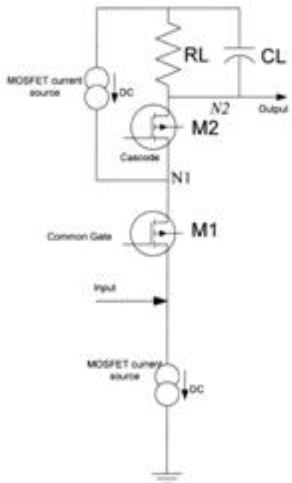
"The discoveries of the W and Z bosons at CERN, the charm quark at SLAC and Brookhaven and the top quark at Fermilab would not have been possible without this type of detector, and current research in high energy physics continues to depend on these devices".

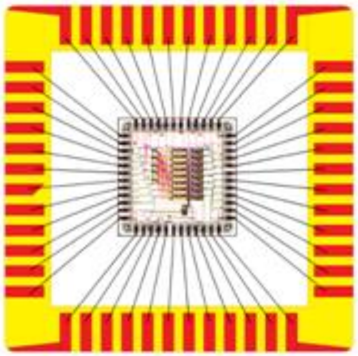
State-of-the-art technologies for ICAL

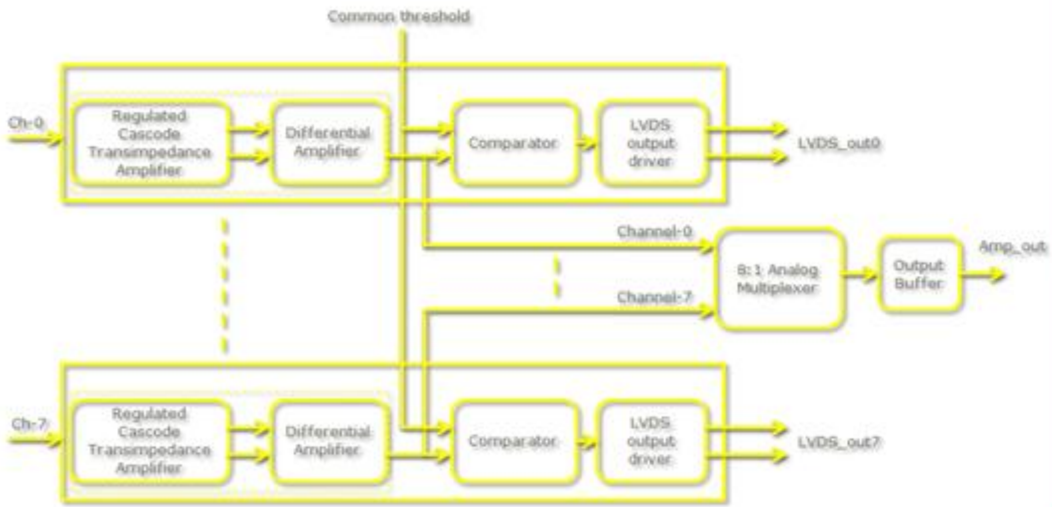
- Ultra high speed ASIC based front-end circuits
- FPGA based signal processing systems
- High time resolution time-to-digital converters
  - ASIC based
  - FPGA based
- Very high sampling waveform digitizers, flash ADCs
- Highly complex *trigger* architectures and systems
- Novel architectures for data networks and highways
- Software for high speed data acquisition, visualization and web serving etc.
- Efficient encapsulated power supply systems
- Slow control and monitoring systems

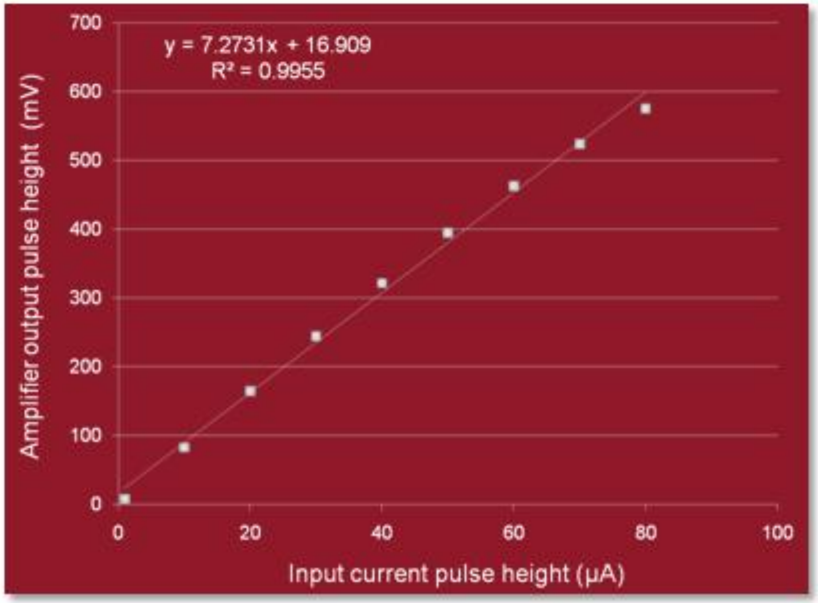
High speed ASIC amplifier

- Process: AMSc35b4c3 (0.35um CMOS)
- Input dynamic range:18fC – 1.36pC
- Input impedance: 45Ω @350MHz
- Amplifier gain: 8mV/μA
- 3-dB Bandwidth: 274MHz
- Rise time: 1.2ns
- Comparator's sensitivity: 2mV
- LVDS drive: 4mA
- Power per channel: < 20mW
- Package: CLCC48(48-pin)
- Chip area: $13mm^2$

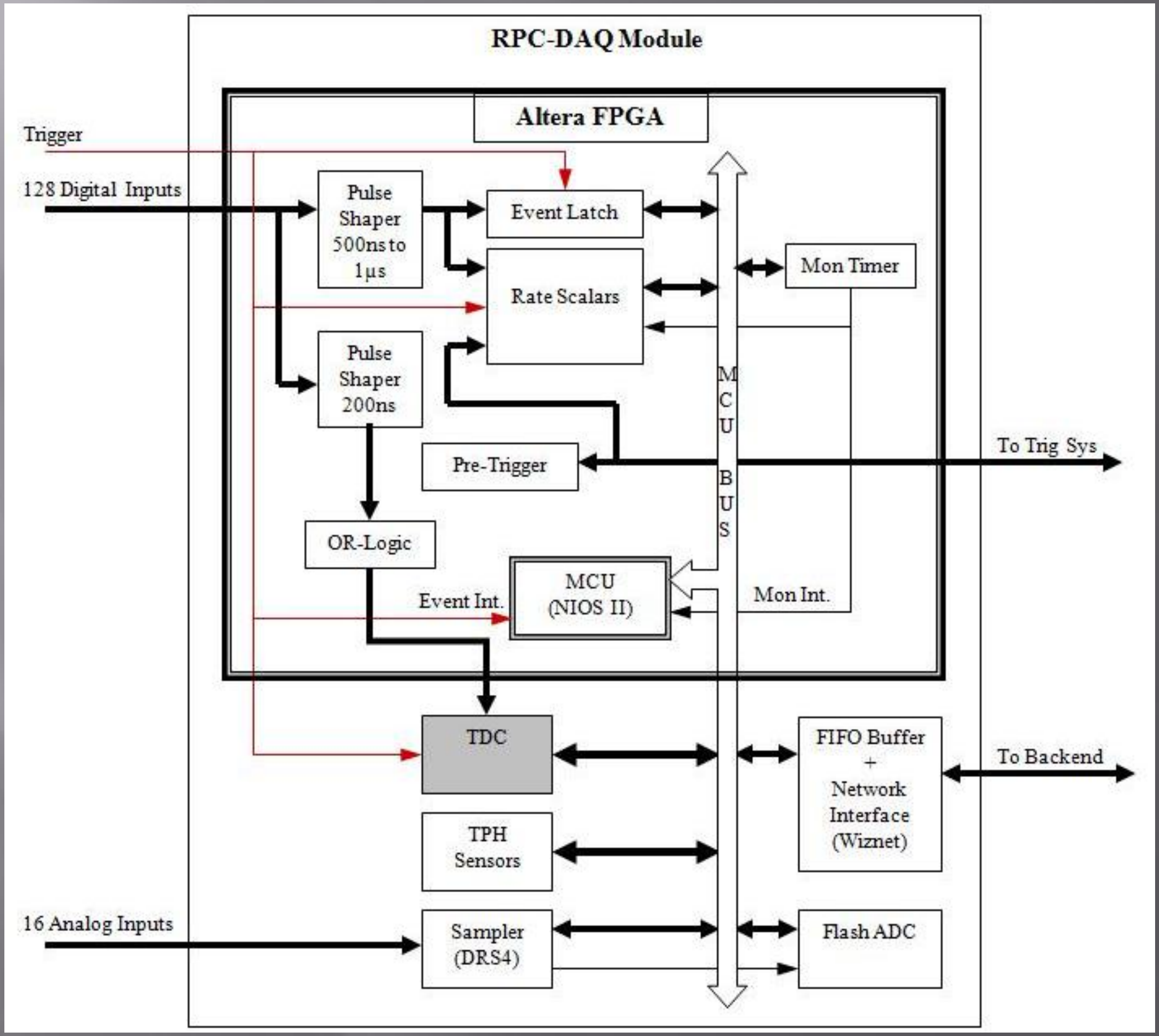






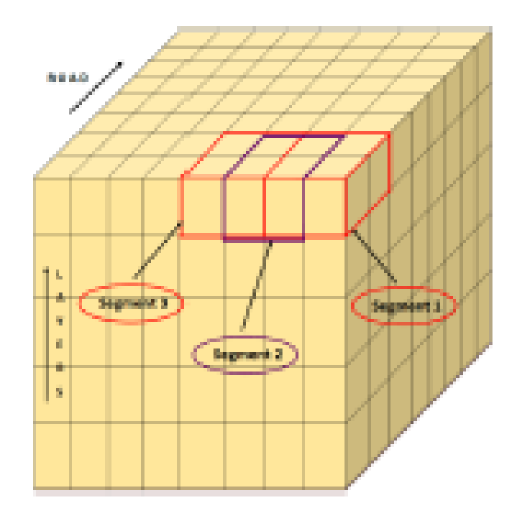


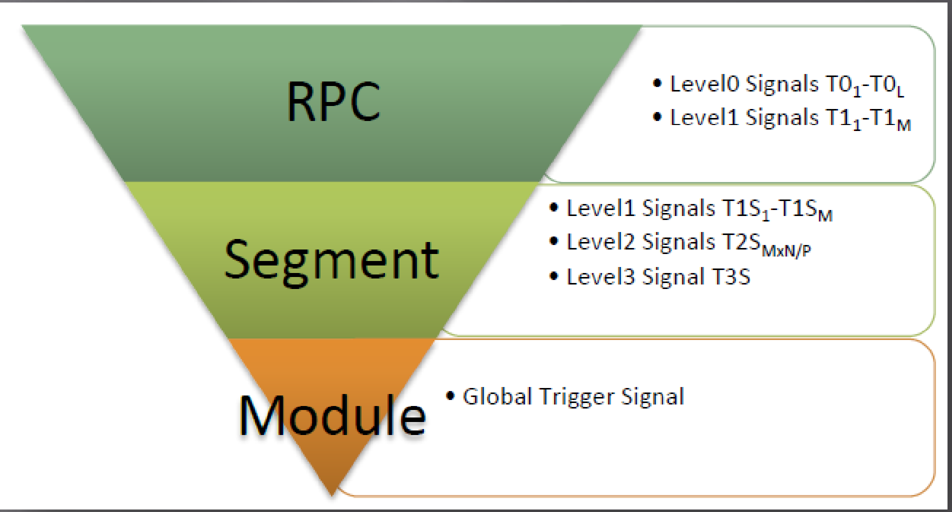
FPGA based signal processing



ICAL trigger system

- *Physicist's mind* decoded!
- *Insitu* trigger generation
- Autonomous; shares data bus with readout system
- Distributed architecture
- For ICAL, trigger system is based only on topology of the event; no other measurement data is used
- Huge bank of combinatorial circuits
- Programmability is the game, FPGAs, ASICs are the players





Software requirements

- RPC-DAQ controller firmware
- Backend online DAQ system
- Local and remote shift consoles
- Data packing and archival
- Event and monitor display panels
- Event data quality monitors
- Slow control and monitor consoles
- Database standards
- Data analysis and presentation software standards
- Operating System and development platforms

Career opportunities in INO

http://www.ino.tifr.res.in

- Research Scholars
  - Applicants must have a minimum qualification of M.Sc. degree in Physics or B.E./B.Tech. degree in any one of Electronics, E & CE, Instrumentation and Electrical Engineering subjects with strong motivation for and proficiency in Physics.
  - The selected candidates will be enrolled as Ph.D. students of the Homi Bhabha National Institute (HBNI), a Deemed to be University, with constituent institutions that include BARC, HRI, IGCAR, IMSc, SINP and VECC.
  - They will take up 1 year course work at TIFR, Mumbai in both theoretical and experimental high energy physics and necessary foundation courses specially designed to train people to be good experimental physicists.
  - Successful candidates after the course work will be attached to Ph.D. guides at various collaborating institutions for a Ph. D. degree in Physics on the basis of their INO related work.
- Career opportunities for bright engineers in Electronics, Instrumentation, Computer Science, Information technology, Civil, Mechanical and Electrical engineers

Career opportunities in TIFR

http://www.tifr.res.in

- Visiting Students' Research Programme (VSRP)
  - Physics/Chemistry :
    Pre-final year students of M.Sc./B.E./B.Tech.
  - Biology:
    Pre-final year students of M.Sc./B.E./B.Tech. Students doing M.Pharm., Medicine/Engineering will be also be considered.
  - Mathematics:
    Pre-final and final year students of M.A./M.Sc./M-Stat./B.Tech. Exceptionally bright pre-final and final year students of B.Sc./B.Stat./B.Math. will also be considered.
  - Computer & Systems Sciences:
    Pre-final year students of B.E./B.Tech./M.Sc./M.C.A./M.E./M.Tech.
- Research opportunities for exceptionally talented and strongly motivated students
  - TIFR is India's premier institution for advanced research in fundamental sciences. The Institute runs a graduate programme leading to the award of Ph.D. degree, as well as M.Sc. and Integrated Ph.D. in certain subjects.
  - The Graduate Programme at TIFR is classified into the following Subjects - Mathematics, Physics, Chemistry, Biology, Computer & Systems Sciences and Science Education.
- Career opportunities for bright engineers in Electronics, Instrumentation, Computer Science, Information technology, Civil, Mechanical and Electrical engineers

THANK YOU