

Neutrini Superluminali rivoluzione o miraggio ?

Caffe' scienza: 15 novembre 2011
Libreria Assaggi, Roma
Paolo Lipari
INFN, Universita' Roma ,La Sapienza

23 settembre. Seminario al CERN
di Dario Autiero (IPN Lyon) per la collaborazione OPERA.

*Measurement of the neutrino velocity with
the OPERA detector in the CNGS beam*

Riportato un risultato sorprendente
Con conseguenze potenzialmente rivoluzionarie

I Neutrini sembrano muoversi
Piu' veloci della luce !!?

Grandissimo interesse:

Tra gli scienziati
[molto scetticismo, ma anche molta discussione!]

nei MEDIA, nel pubblico in generale

Google

Superluminal neutrinos

Circa 500.000 risultati

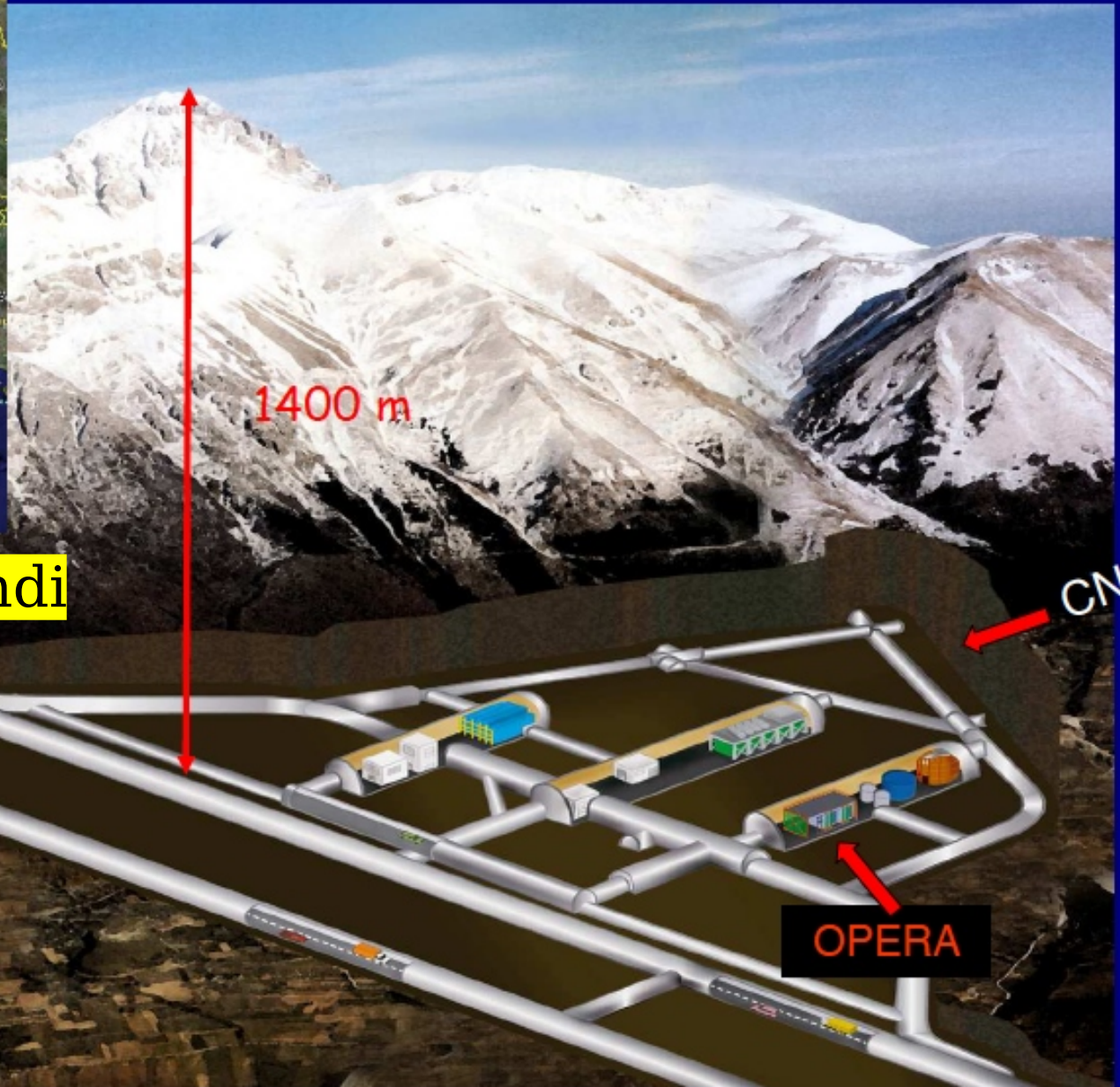
Google

Opera neutrinos

Circa 962.000 risultati

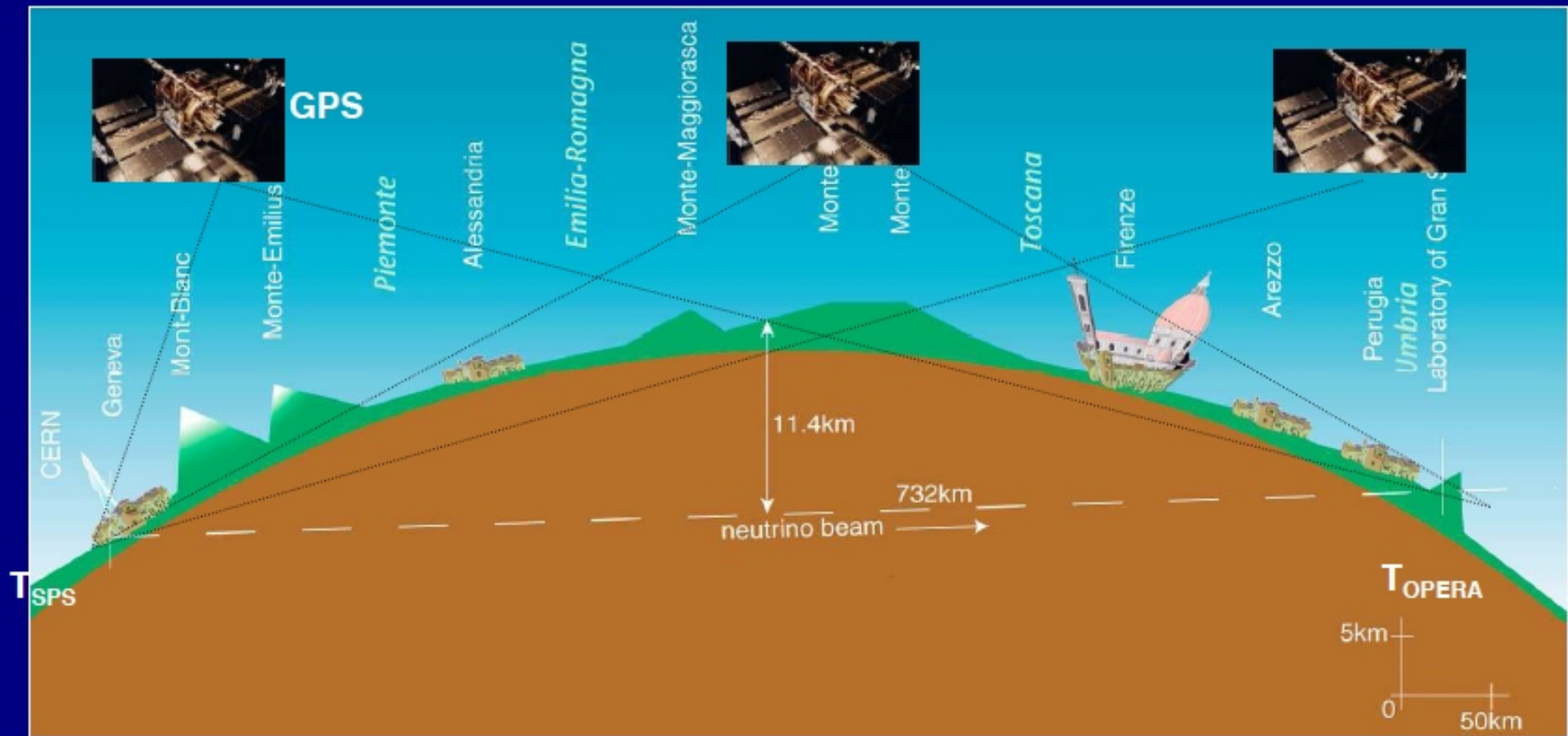
In continua crescita ...

The LNGS underground physics laboratory



Time=2.43 milli secondi

CNGS events selection



SPAZIO

TEMPO

Nulla di piu' fondamentale
(e di piu' sottile e profondo)

$$\text{velocita}' = \frac{\text{spazio}}{\text{tempo}}$$

Misura dello SPAZIO

Quanto bene si puo' misurare

La distanza tra due punti ? A, B

Misura il TEMPO

Differenza tra due tempi:

Neutrino parte da A, t1

Arriva a B, t2

Evento A:
'creazione' del neutrino

$$t_A \quad \vec{x}_A$$

$p + \text{nucleo} \rightarrow \text{molte particelle}(p, n, \pi^+, \pi^-, \dots)$

$$\pi^+ \rightarrow \nu_\mu + \mu^+$$

Evento B:
'interazione' del neutrino

$$t_B \quad \vec{x}_B$$

$\nu_\mu + \text{nucleo} \rightarrow \mu^- + \text{altre particelle}$

$$\Delta t = t_{\text{fotone}} - t_{\text{neutrino}} = 60.7 \text{ nanosecondi}$$

1 nanosecondo = 1 miliardesimo di secondo

$$\Delta t = 60.7 \pm 6.9 \text{ (stat)} \pm 7.4 \text{ (sistematico)} \text{ nanosecondi}$$

$$\Delta t = t_{\text{fotone}} - t_{\text{neutrino}} = 60.7 \text{ nanosecondi}$$

1 nanosecondo = 1 miliardesimo di secondo

$$\Delta t = 60.7 \pm 6.9 \text{ (stat)} \pm 7.4 \text{ (sistematico)} \text{ nanosecondi}$$

$$\Delta t \times c = 18 \text{ metri}$$

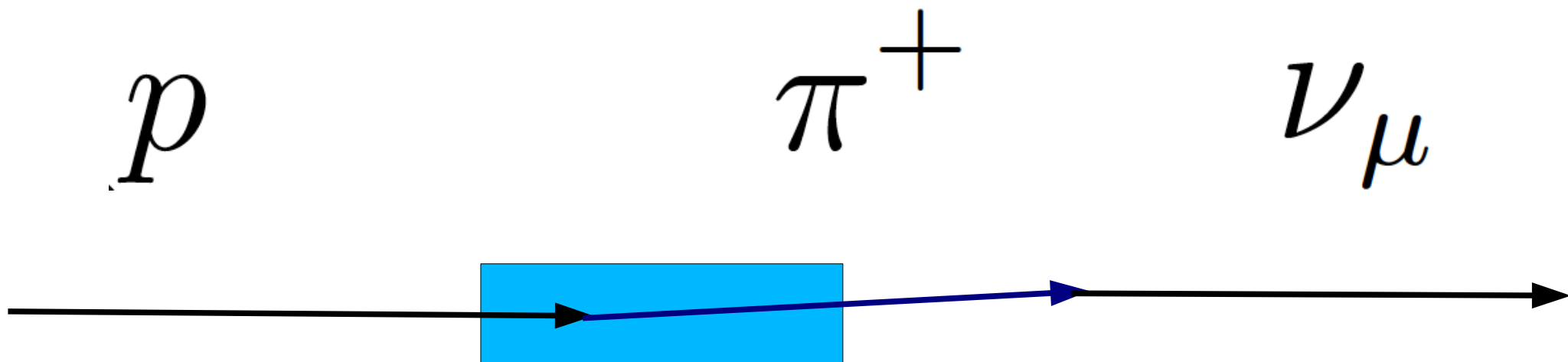
$$\Delta t = t_{\text{fotone}} - t_{\text{neutrino}} = 60.7 \text{ nanosecondi}$$

1 nanosecondo = 1 miliardesimo di secondo

$$\Delta t = 60.7 \pm 6.9 \text{ (stat)} \pm 7.4 \text{ (sistematico)} \text{ nanosecondi}$$

25 milionesimi

$$v_{\text{neutrino}} = v_{\text{luce}} \times [1 + 0.000025]$$

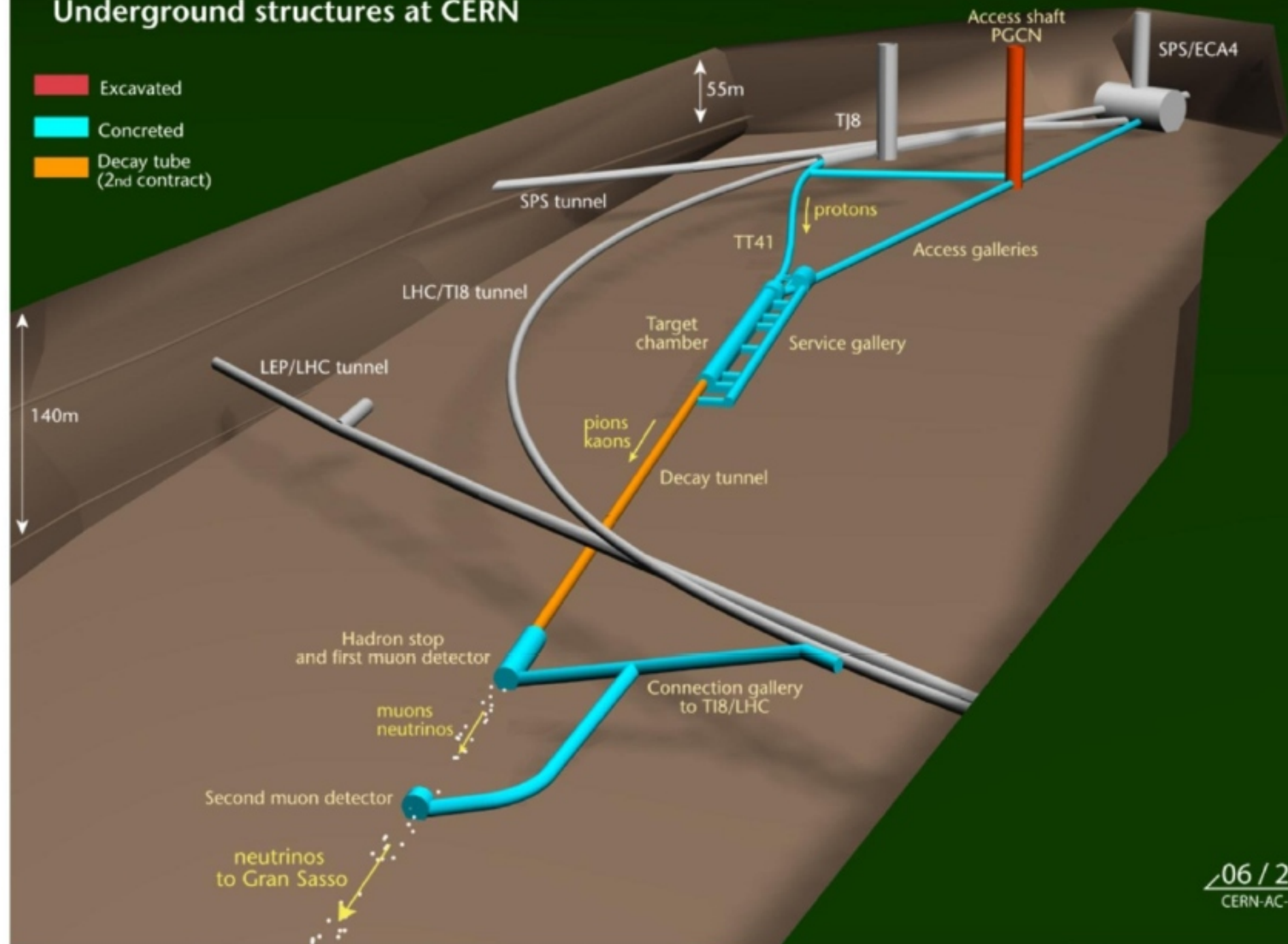


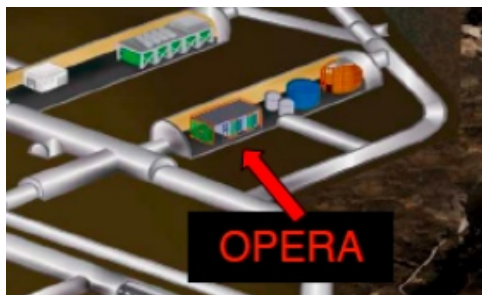
Passaggio di un protone
in un punto noto

CERN NEUTRINOS TO GRAN SASSO

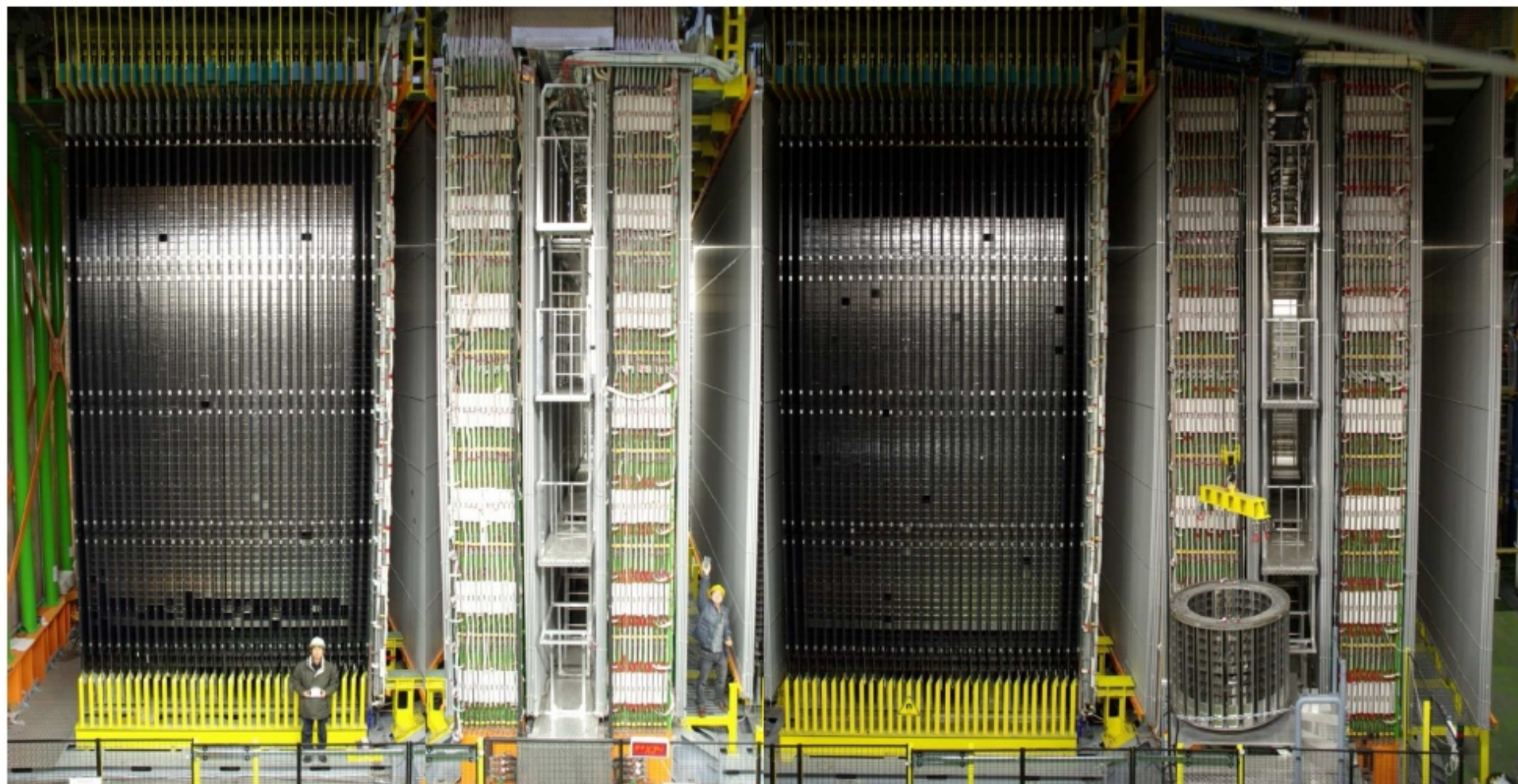
Underground structures at CERN

- Excavated
- Concreted
- Decay tube (2nd contract)





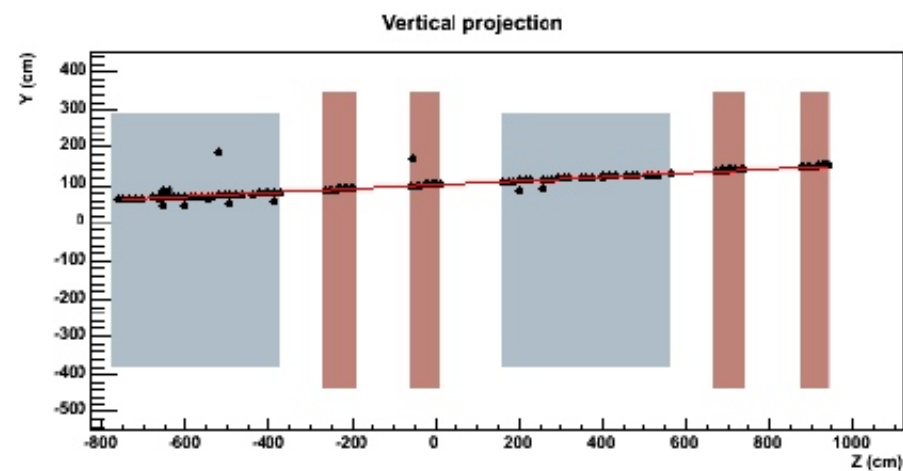
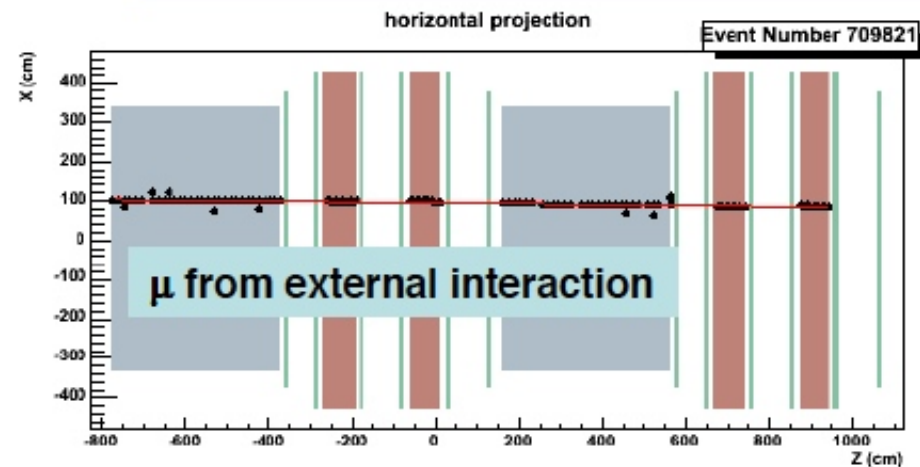
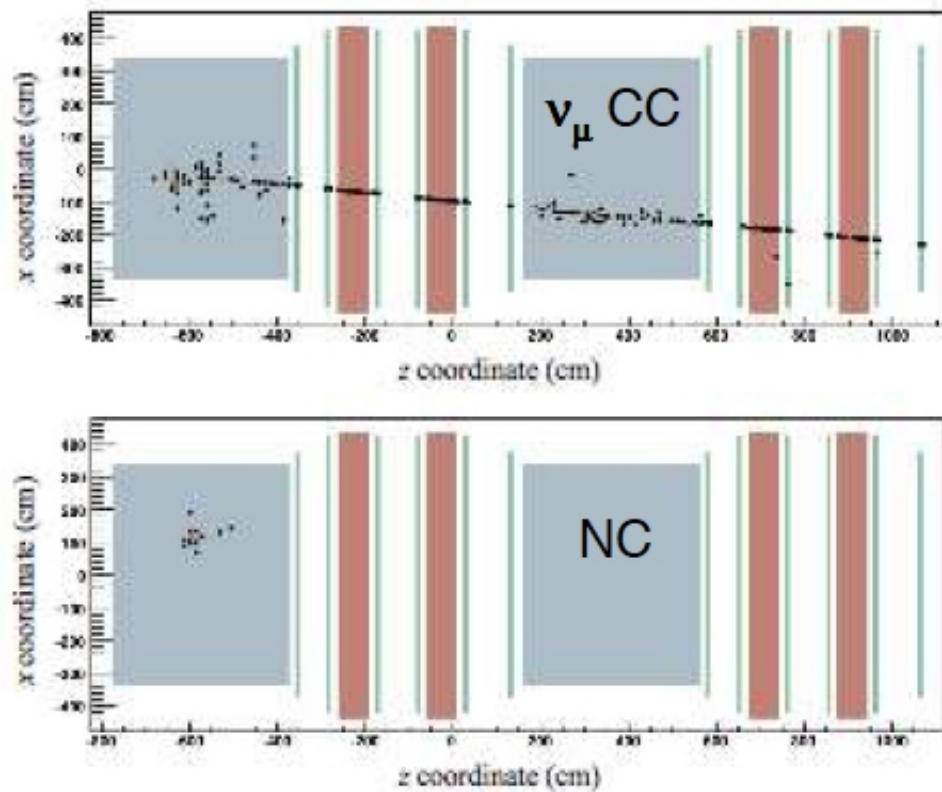
← SM1 → ← SM2 →



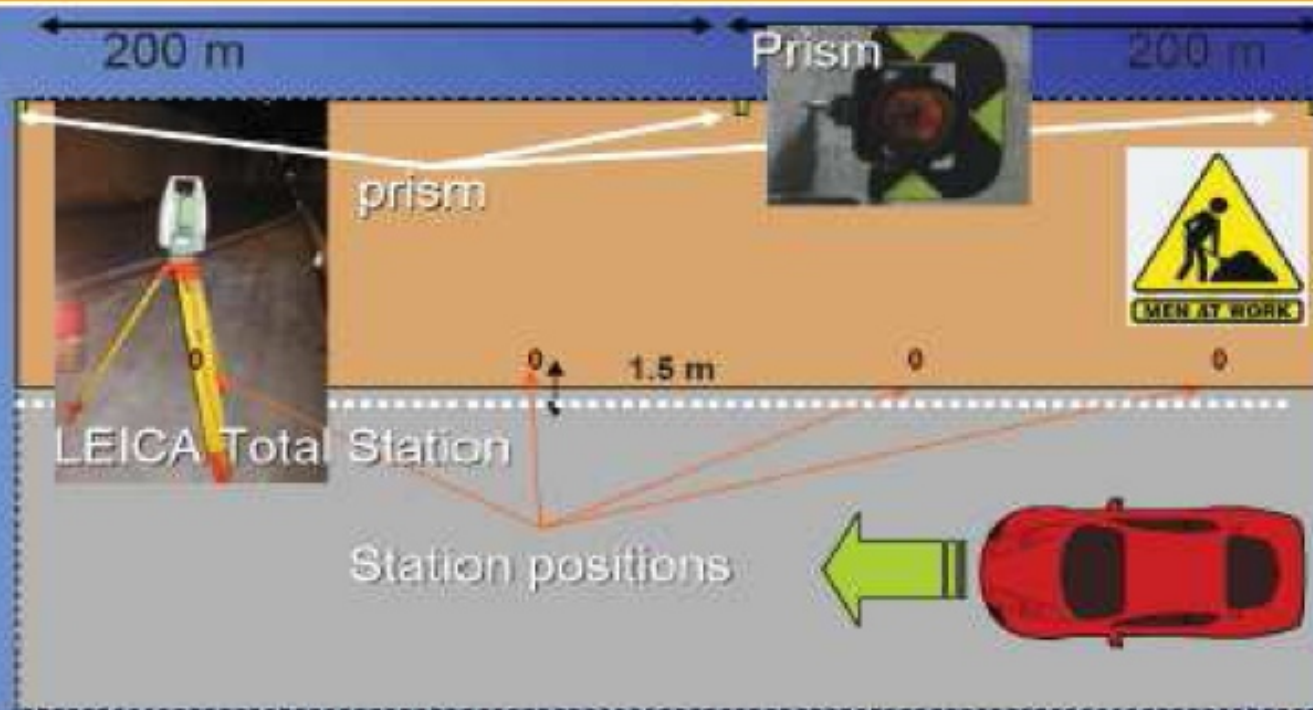
Target area

Muon spectrometer

“INTERNAL” and “EXTERNAL” OPERA EVENTS



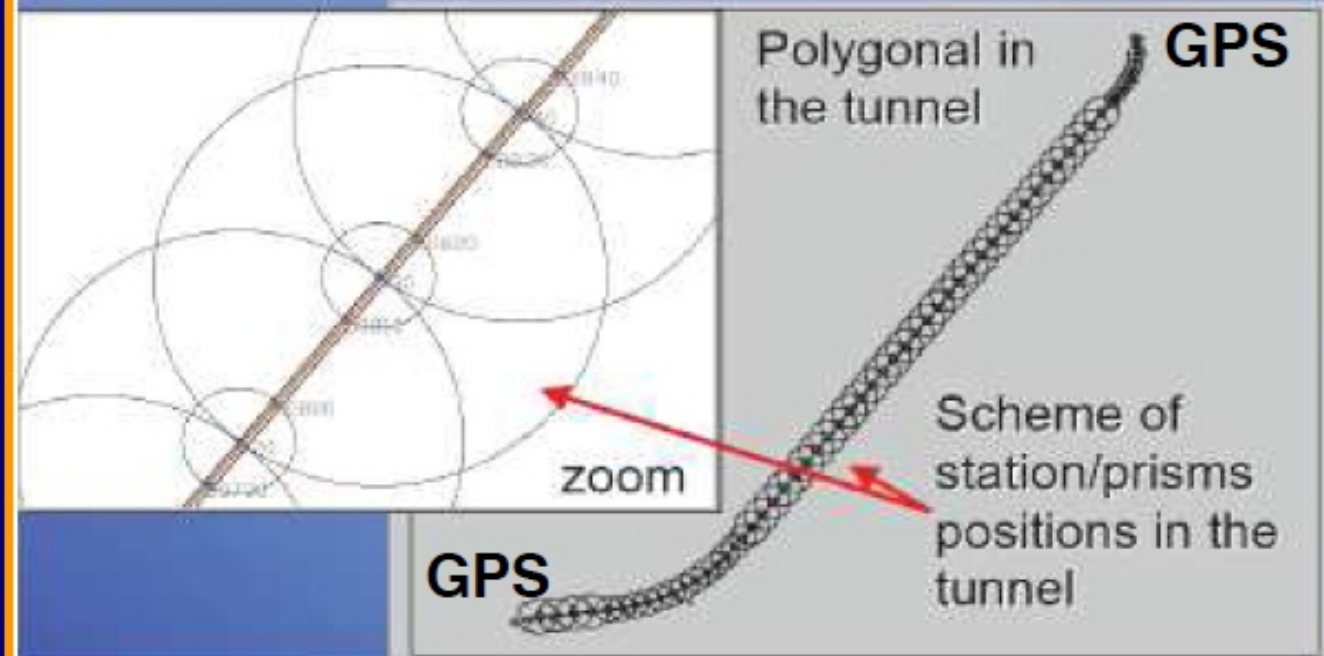
Geodesy at LNGS



Dedicated measurements
at LNGS: July-Sept. 2010
(Rome Sapienza
Geodesy group)

2 new GPS benchmarks
on each side of the 10 km
highway tunnel

GPS measurements
ported underground to
OPERA



Combination with CERN geodesy

CERN –LNGS measurements (different periods) combined in the ETRF2000 European Global system, accounting for earth dynamics (collaboration with CERN survey group)

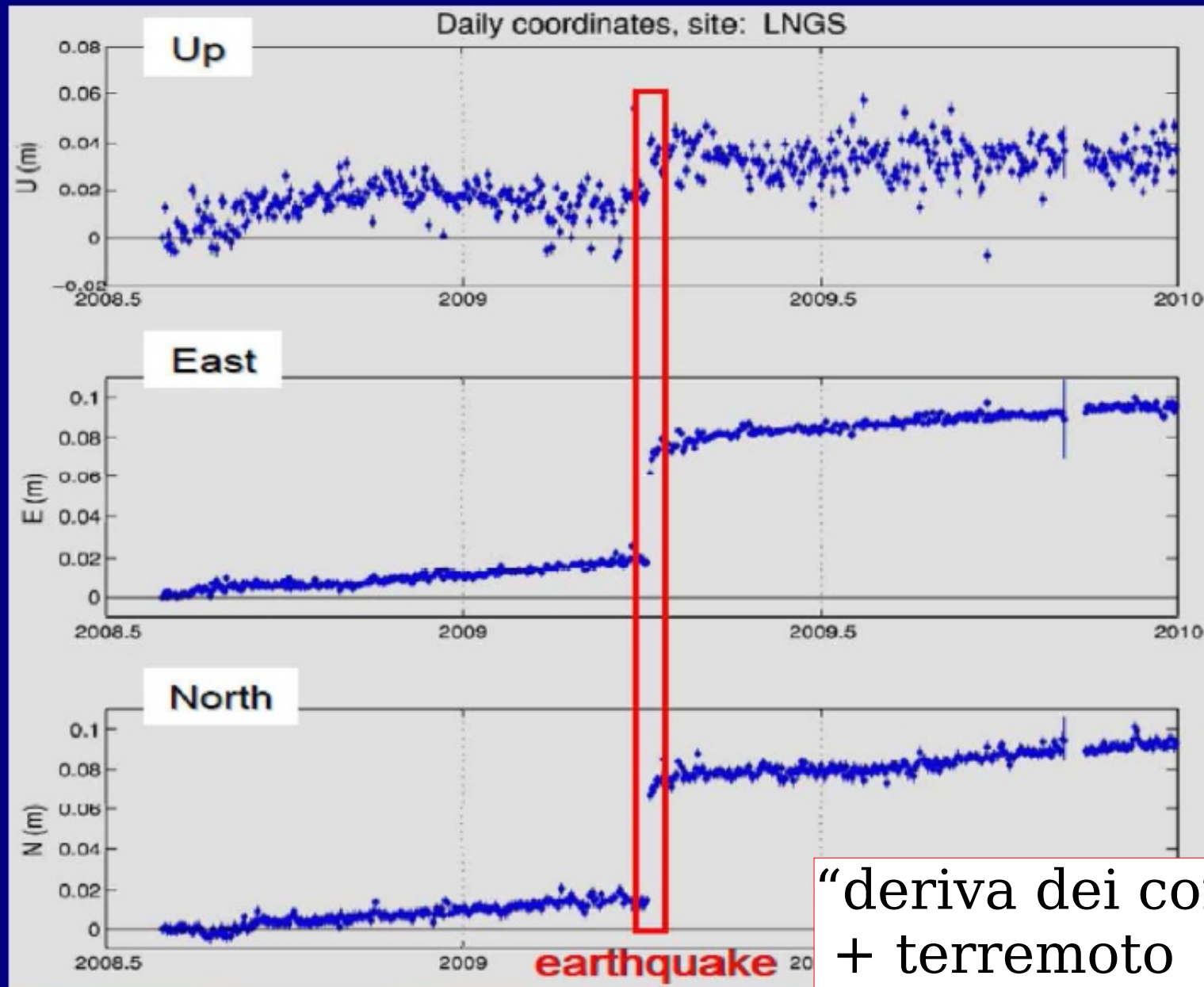
Benchmark	X (m)	Y (m)	Z (m)
GPS1	4579518.745	1108193.650	4285874.215
GPS2	4579537.618	1108238.881	4285843.959
GPS3	4585824.371	1102829.275	4280651.125
GPS4	4585839.629	1102751.612	4280651.236

LNGS benchmarks
in ETRF2000

20 centimetri di errore nello spazio!

**Resulting distance (BCT – OPERA reference frame)
(731278.0 ± 0.2) m**

LNGS position monitoring



“deriva dei continenti”
+ terremoto

Monitor continent drift and important geological events (e.g. 2009 earthquake)

GPS common-view mode

Standard GPS operation:

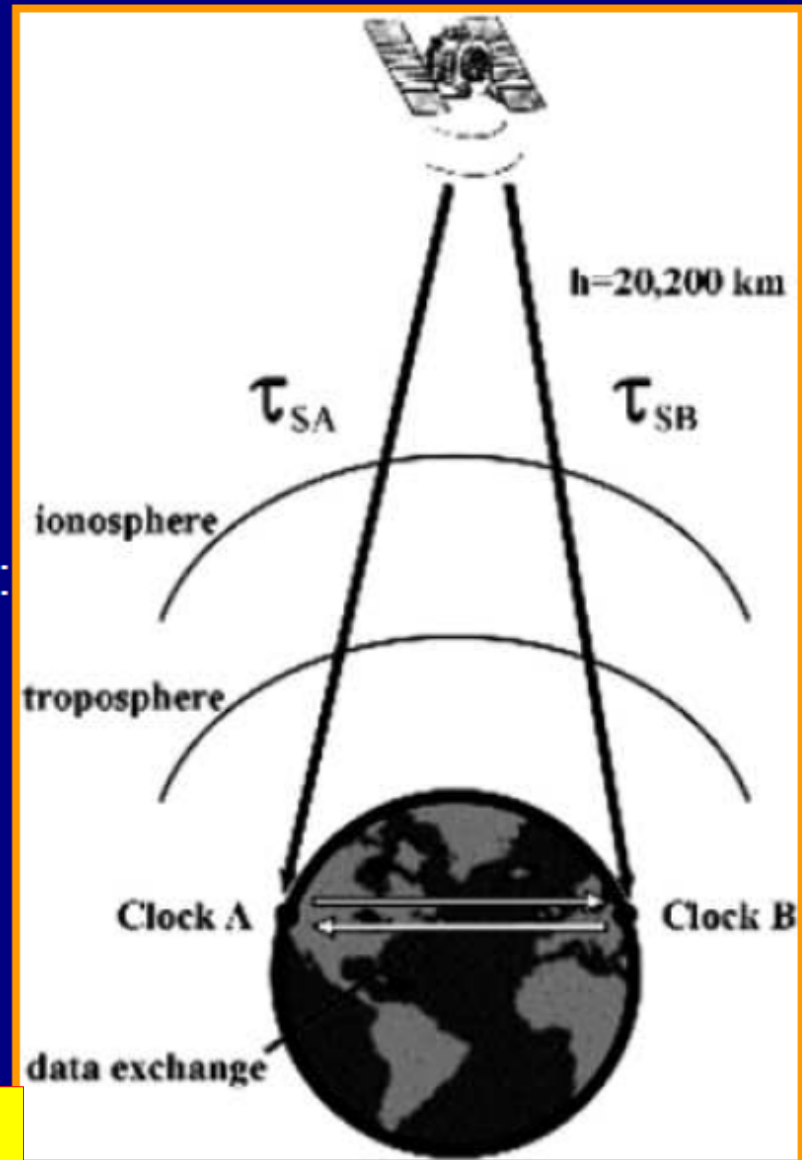
resolves x, y, z, t with ≥ 4 satellite observations

Common-view mode (the same satellite for the two sites, for each comparison):

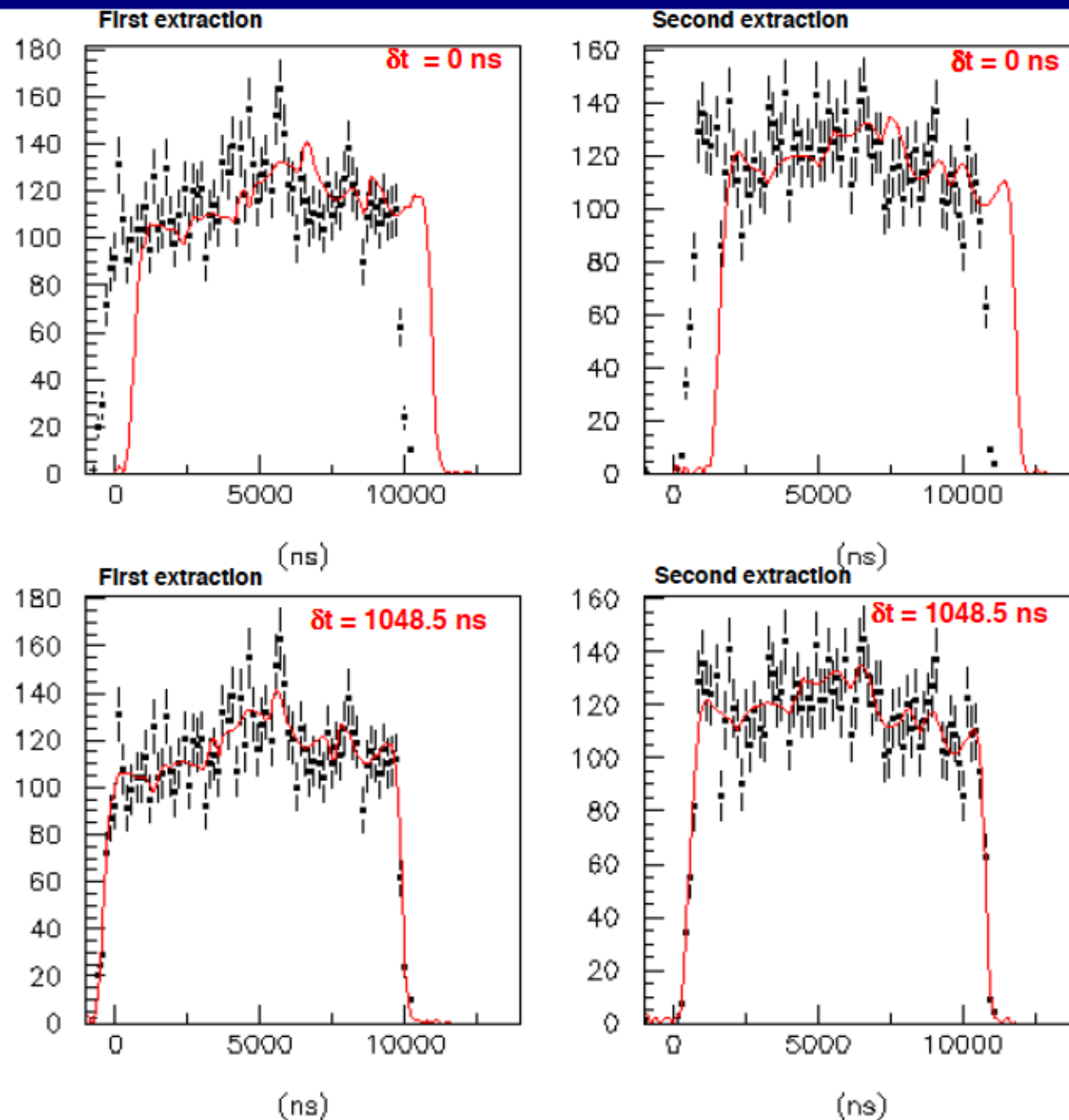
x, y, z known from former dedicated measurements:
determine time differences of local clocks (both sites) w.r.t. the satellite, by offline data exchange

$730 \text{ km} \ll 20000 \text{ km}$ (satellite height) $\rightarrow$ similar paths in ionosphere

Sincronizzare due orologi
in due punti diversi dello spazio



Data vs PDF: before and after likelihood result



(BLIND) $\delta t = \text{TOF}_c - \text{TOF}_v =$
(1048.5 $\pm$ 6.9) ns (stat)

$\chi^2 / \text{ndof} :$

first extraction: 1.06
second extraction: 1.12

Nonostante la grande significativita delle misure riportate qui e la stabilita' dell'analisi, il grande impatto potenziale di questo risultati motiva la continuazione dei nostri studi per identificare possibili effetti sistematici

Non facciamo tentativi di interpretazione teorica o fenomenologica di questi risultati

- Despite the large significance of the measurement reported here and the stability of the analysis, the potentially great impact of the result motivates the continuation of our studies in order to identify any still unknown systematic effect.
- We do not attempt any theoretical or phenomenological interpretation of the results.

SE [se!] i neutrini

si muovono piu' veloci della luce

Cosa vuole dire per la fisica?

Cosa cambia della nostra comprensione
del mondo ?

SE [se!] i neutrini

si muovono piu' veloci della luce

Risultato cosi' sorprendente e dalle
conseguenze cosi' ampie e profonde
che deve essere ancora considerato come
una prima indicazione da confermare!

Discussione scientifica molto intensa:

1. Measurement of the neutrino velocity with the OPERA detector in the CNGS beam.

OPERA Collaboration (T. Adam *et al.*). Sep 2011. 24 pp.

e-Print: **arXiv:1109.4897 [hep-ex]**

[References](#) | [BibTeX](#) | [LaTeX\(US\)](#) | [LaTeX\(EU\)](#) | [Harvmac](#) | [EndNote](#)
[Abstract](#) and [Postscript](#) and [PDF](#) from arXiv.org
[Interactions.org article](#)

Detailed record - Similar records - Cited by 139 records

'PREPRINT' online sull'argomento: > 100

[lavori che non hanno ancora
passato il processo di “peer review” per essere
accettati su una rivista scientifica.]

Diverse “classi” di lavori:

1. Articoli che ipotizzano/cercano di dimostrare l'esistenza di un qualche errore nell'analisi di OPERA
2. Discussioni su cosa questo risultato potrebbe implicare
“Quale e' il “PREZZO” da pagare per I neutrino super-luminali ?”
3. Speculazioni su possibili soluzioni
4. Lavori che cercano di mostrare che il risultato di OPERA “deve” essere un errore perche' (in uno schema concettuale molto generale) Prevede altri fenomeni non osservati.

SuperNova SN 1987A (23 febbraio 1987)

(prima "A" supernova osservata nel 1987)

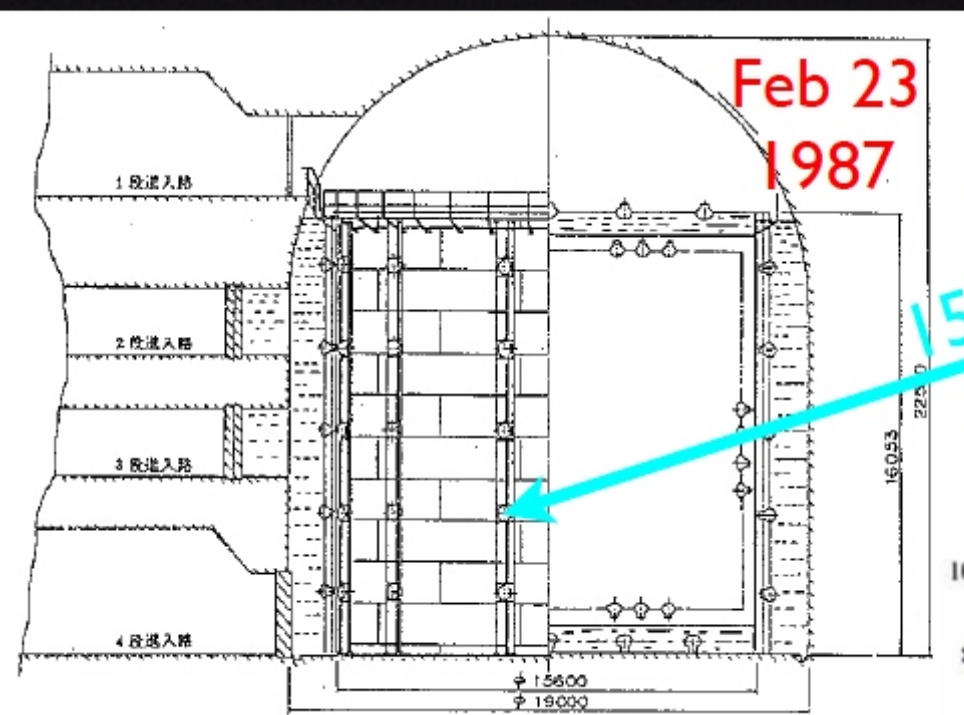


Misura di grandissima precisione
della velocita' del neutrino ottenuta in
circostanze straordinarie nel 1987.

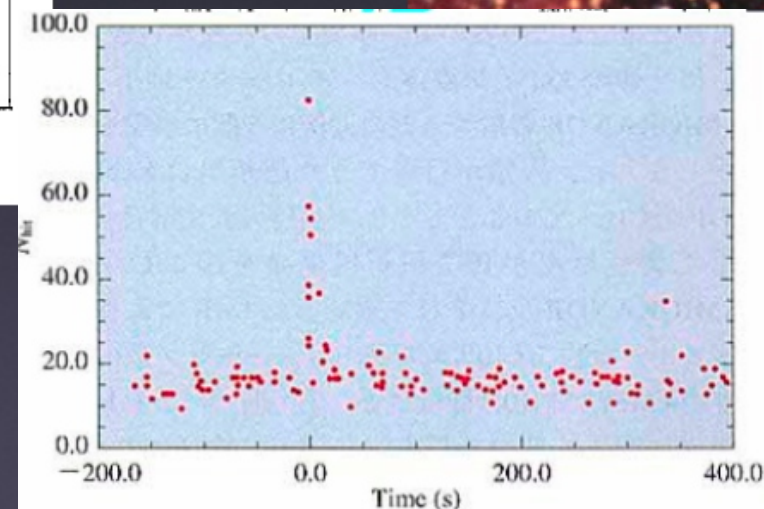
SuperNova nella Grande Nube di Magellano
(una galassia-nana satellite della Via Lattea)
[La supernova piu' vicina dall'epoca dell'invenzione
del telescopio]

Esplosione di una stella ad una distanza di
160,000 anni luce dalla Terra.

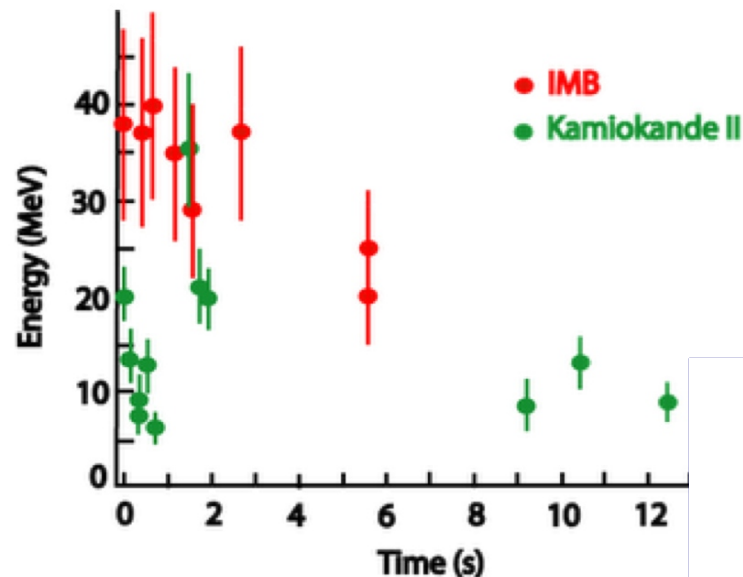
Osservati i neutrini emessi dalla
“protostella di neutroni” formata dal collasso
Gravitazionale della stella madre



150,000 years



Segnale dei neutrini

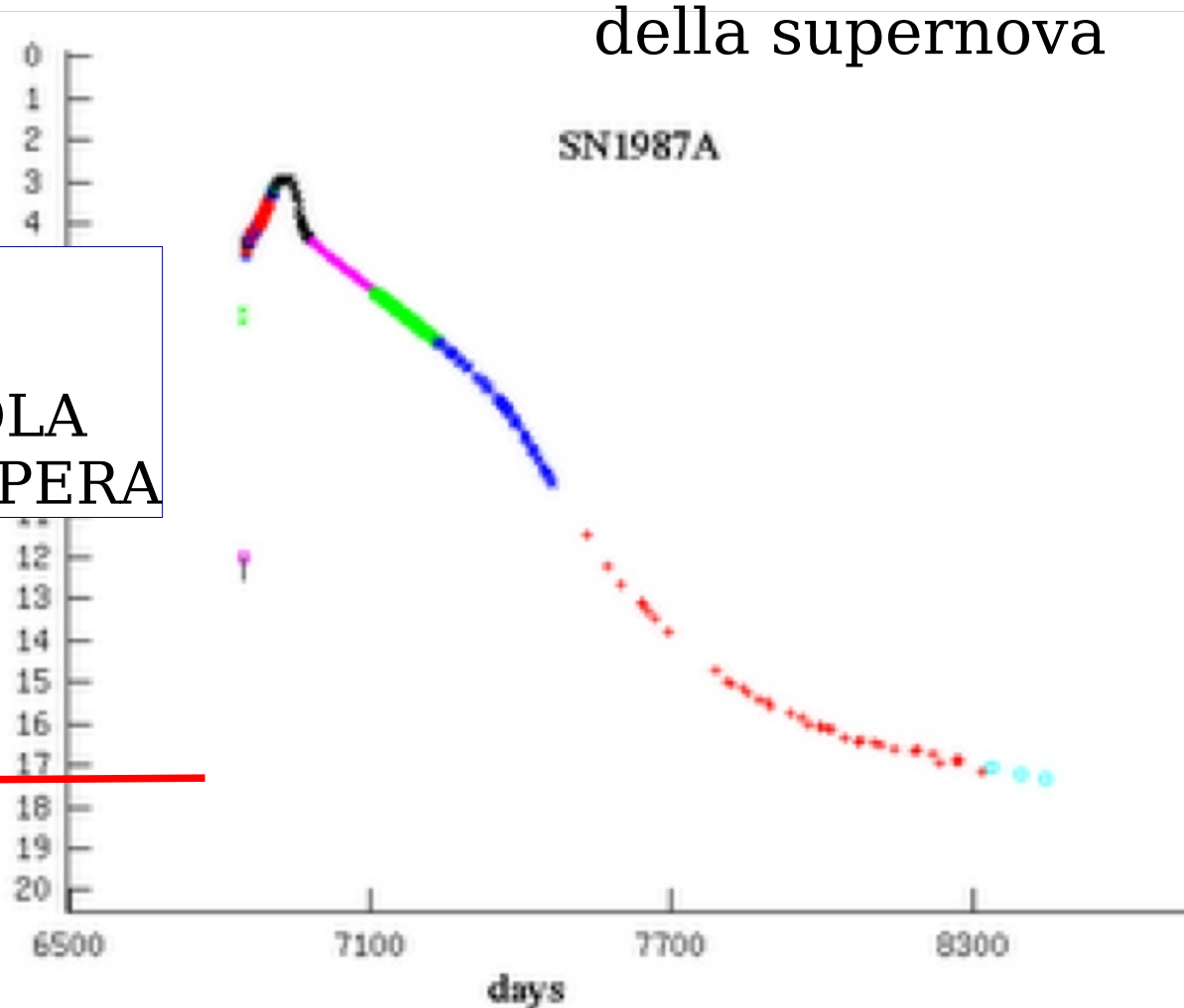


Ritardo della luce
rispetto ai neutrini
al massimo qualche ora

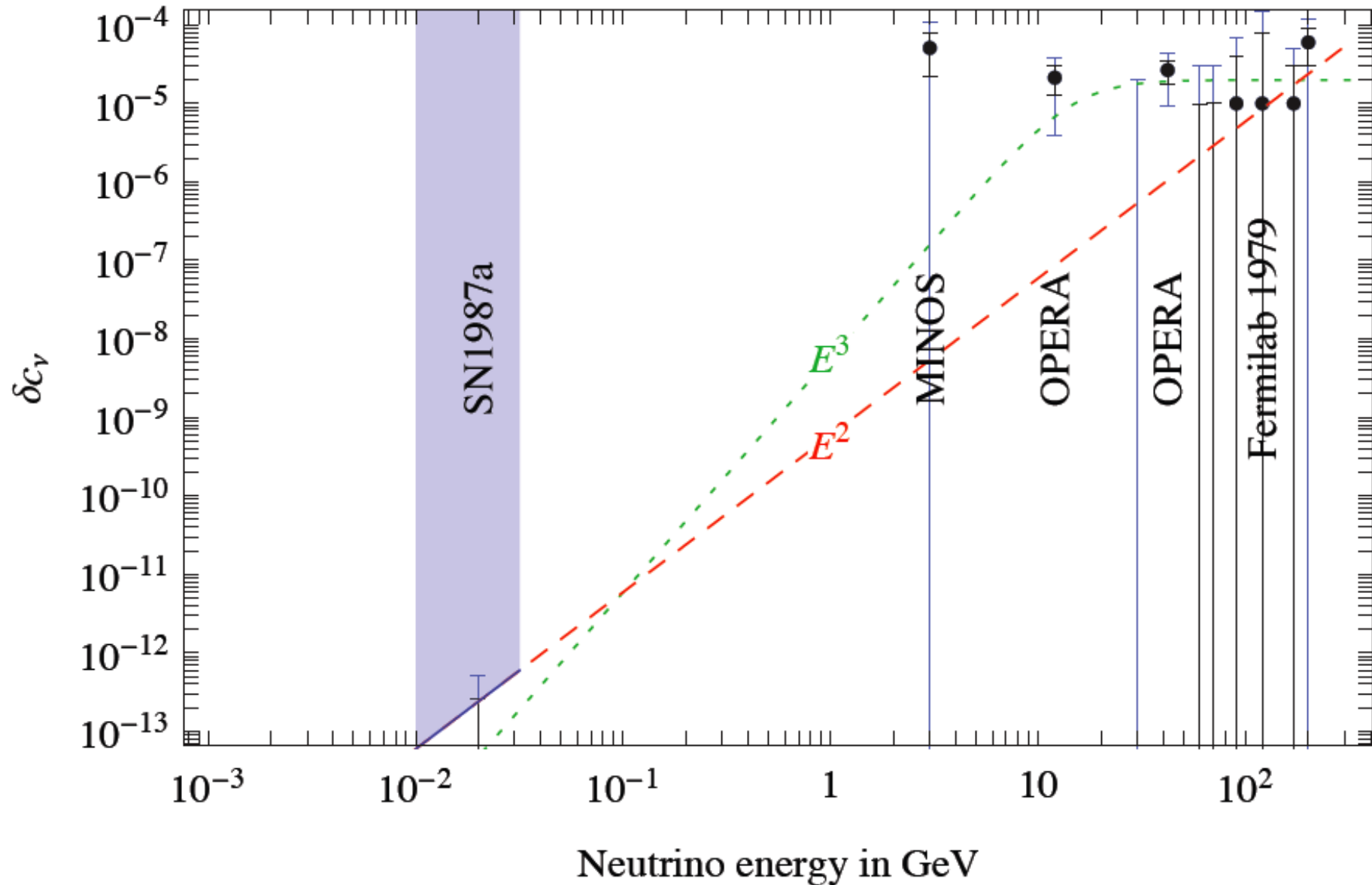
“Curva di luce”
della supernova

Neutrini
con energia
MILLE VOLTE piu' PICCOLA
di quella dei neutrini di OPERA

Pre-collapse star



La velocita' del neutrino
Deve dipendere dalla sua energia !



Velocità della Luce c

Velocità Limite c_0

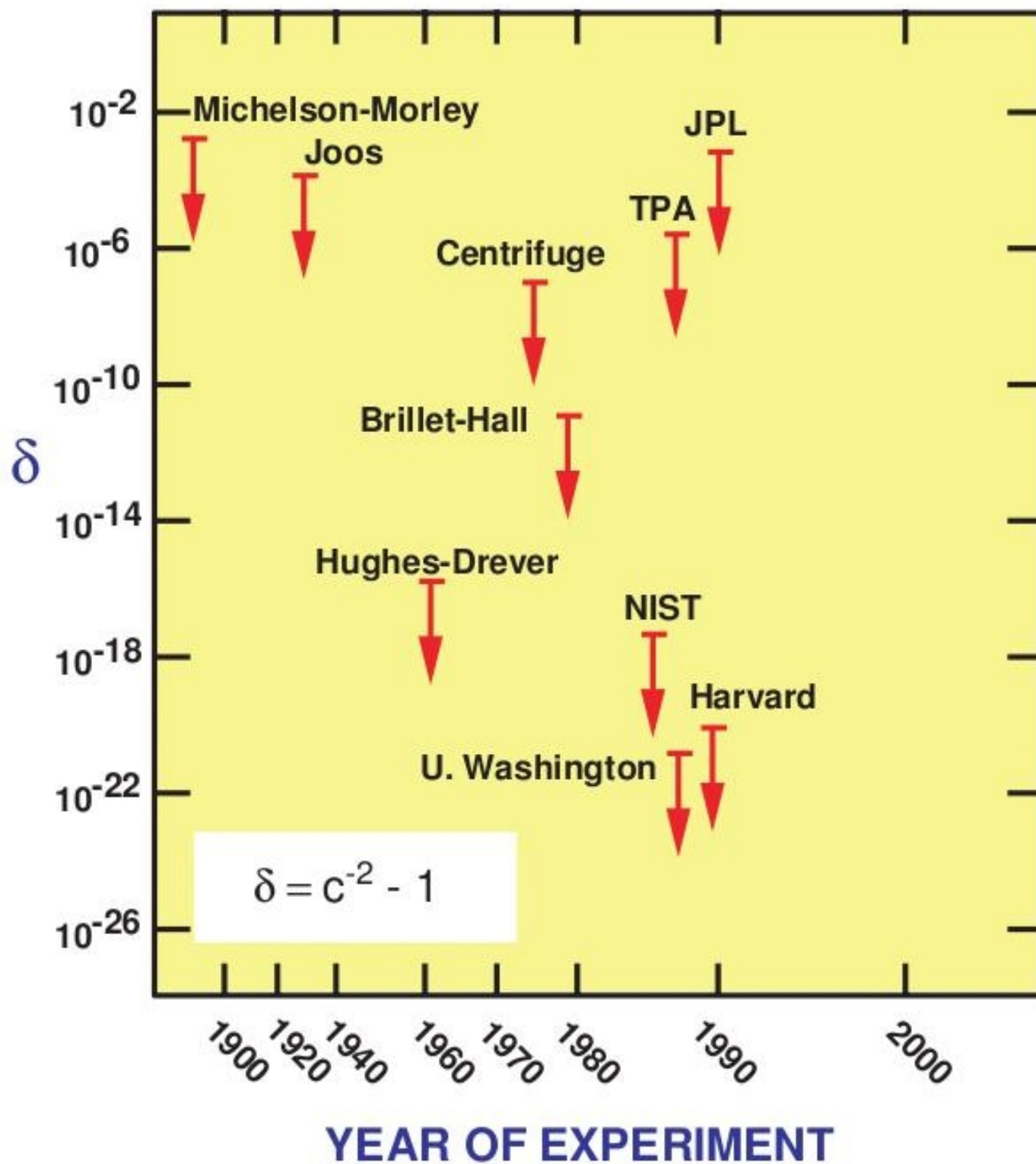
Velocità della Luce c

Velocità Limite c_0

$$c = c_0 \quad [?]$$

Velocità della luce
E la velocità limite
Differiscono per una
Quantità molto piccola

$$\delta = \left(\frac{c_0}{c} \right)^2 - 1$$

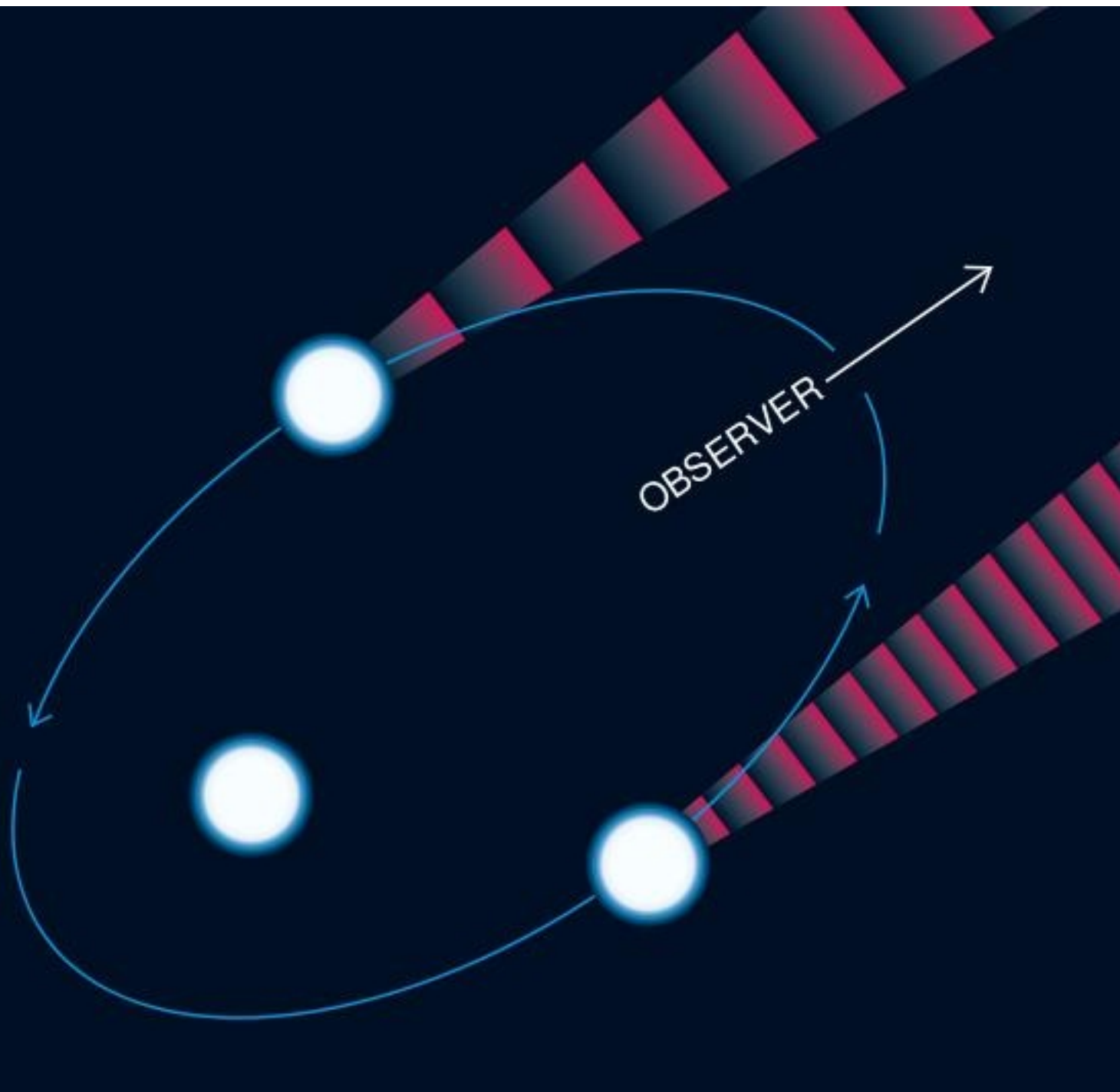


Velocità di uno “scontro frontale”

$$v \oplus u = \frac{v + u}{1 + \frac{v u}{c_0^2}}$$

$$c_0 \oplus u = c_0$$

a



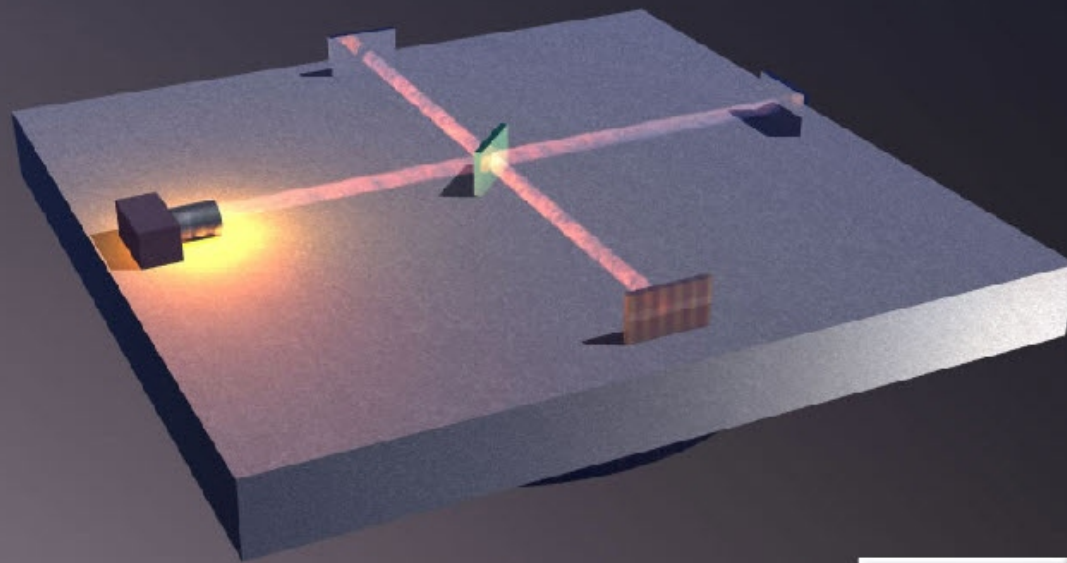


A.A. Michelson
1852 - 1931



E.W. Morley
1838 - 1923

Michelson-Morley Experiment



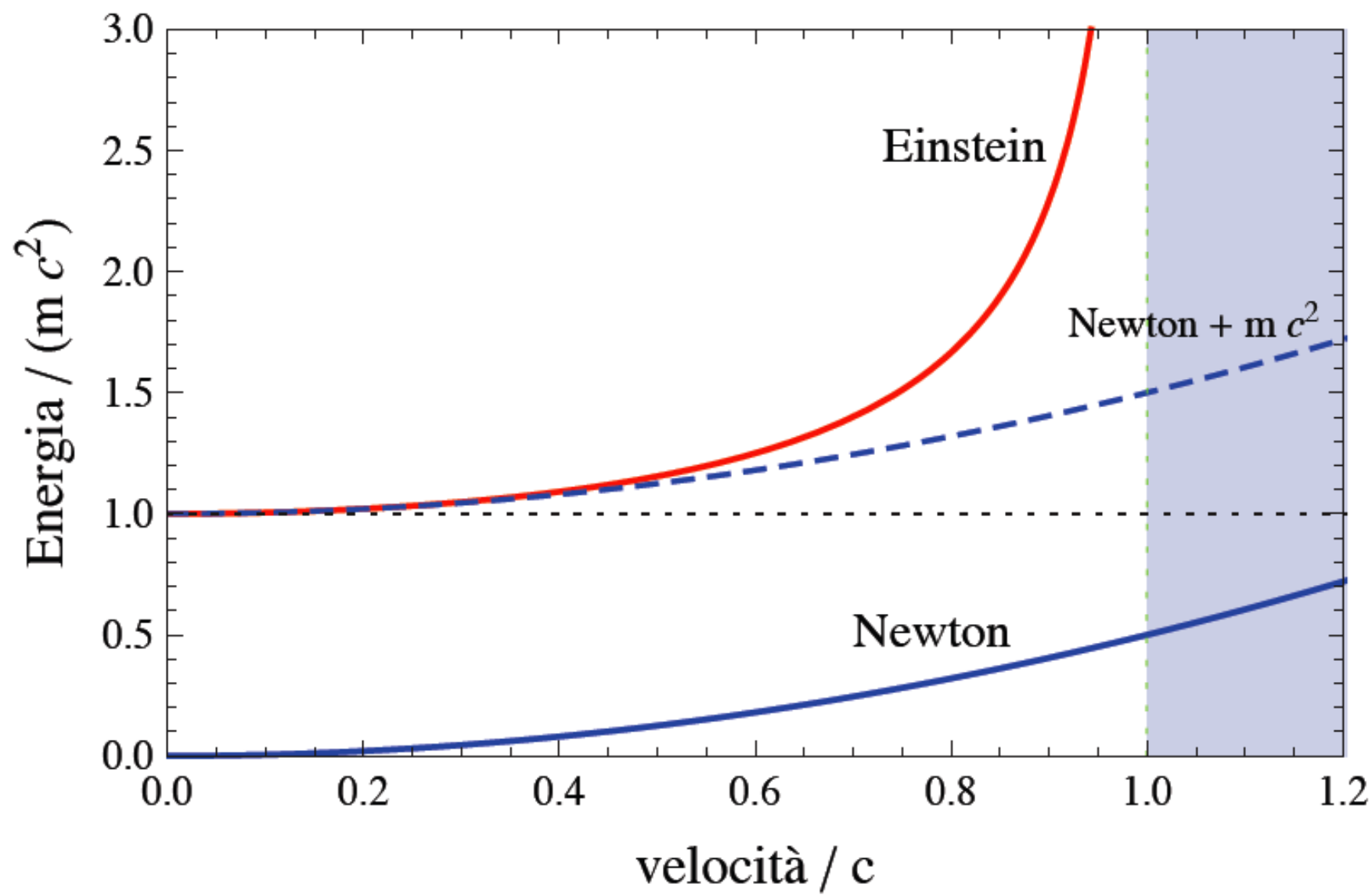
Start

$$E_{\text{particella in quiete}} = m c_0^2$$

$$E_{\text{particella in moto}} = \frac{m c_0^2}{\sqrt{1 - v^2 / c_0^2}}$$

$$E \rightarrow \infty$$

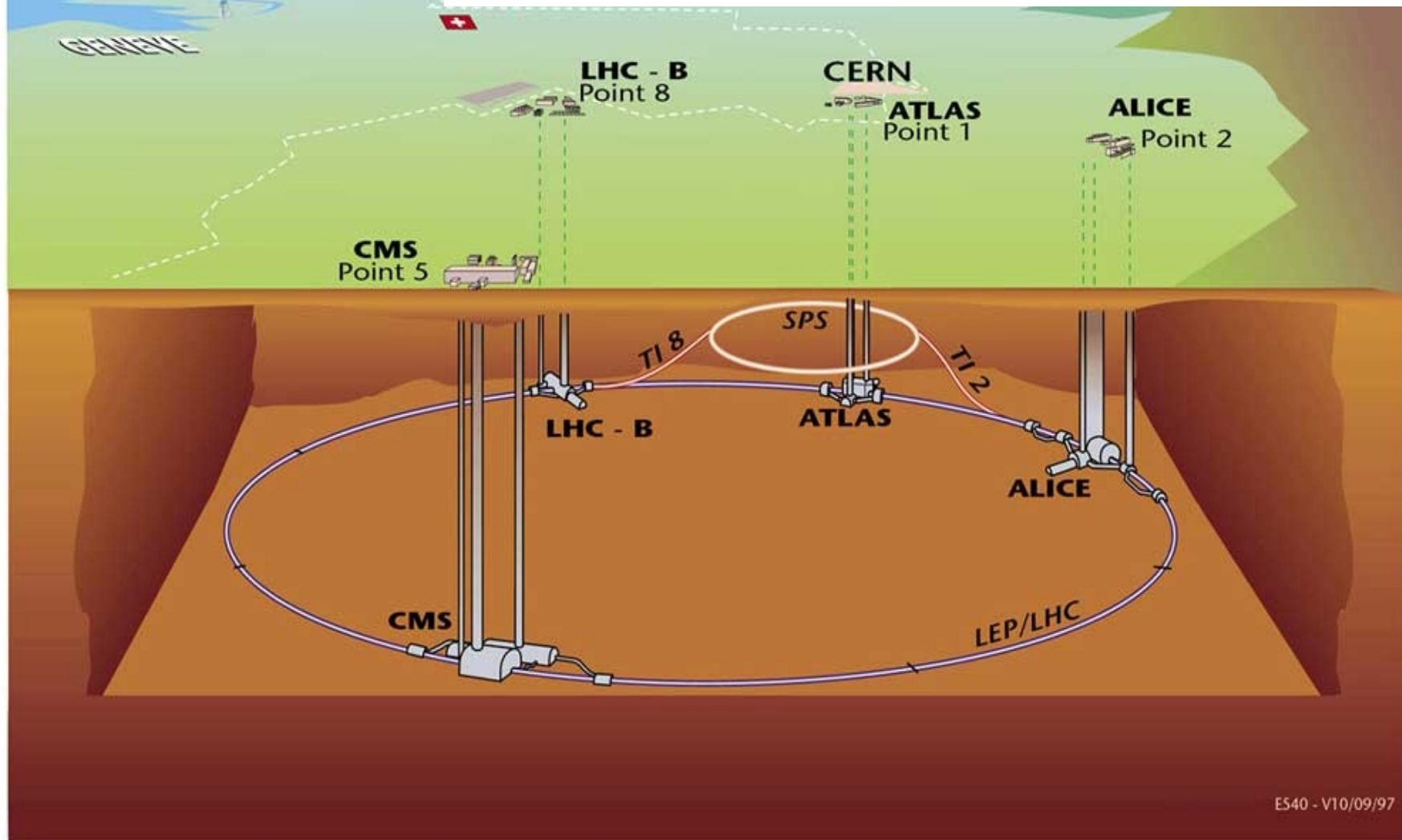
$$v \rightarrow c_0$$



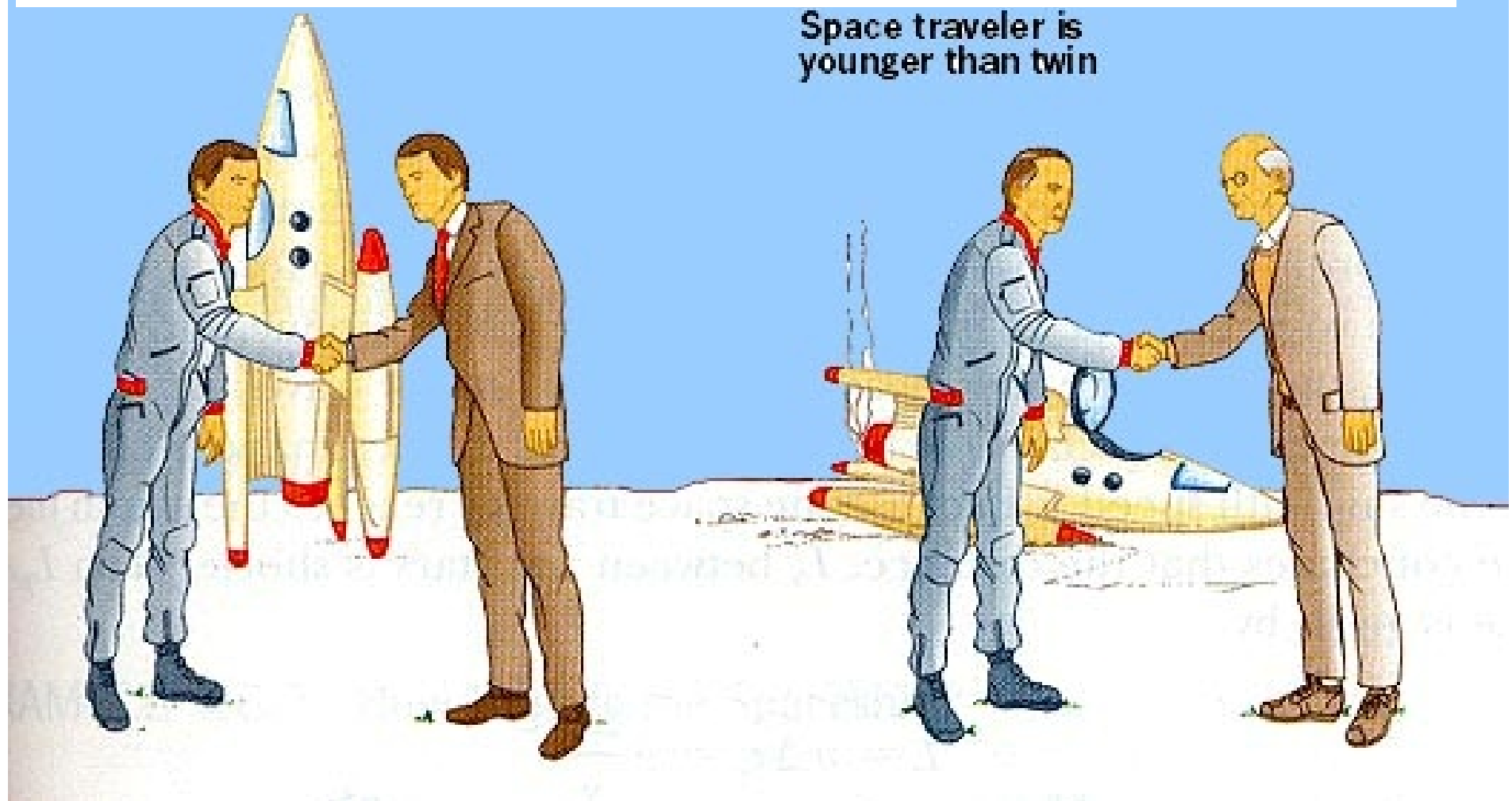
$$E_{\text{particella in moto}} = \frac{m c_0^2}{\sqrt{1 - v^2 / c_0^2}}$$

Overall view of the LHC experiments.

$$\frac{v_{\text{proton}}}{c} = 0.9999999991$$



“Paradosso” dei Gemelli



$$\Delta t = t_{\text{gemello fermo}} \left(1 - \sqrt{1 - v^2/c_0^2} \right)$$

Clifford Will

“Was Einstein right? Testing Relativity at the centenary”

On the 100th anniversary of the introduction of special relativity one might ask “what is there to test”. Special relativity is so thoroughly integrated into the fabric of modern physics that its validity is rarely challenged, except by cranks and crackpots.

Clifford Will

“Was Einstein right? Testing Relativity at the centenary”

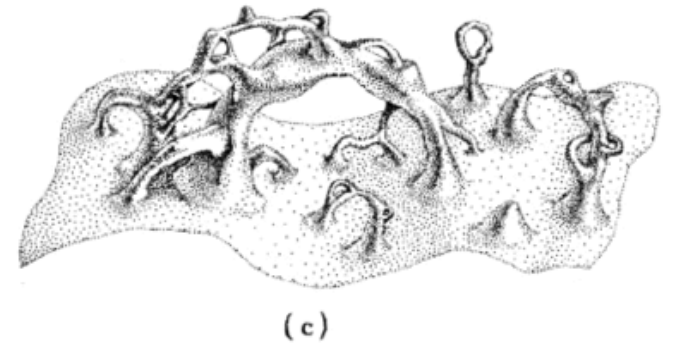
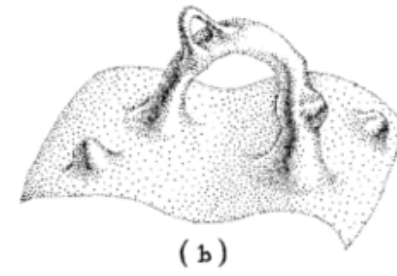
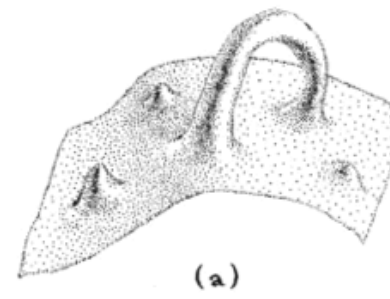
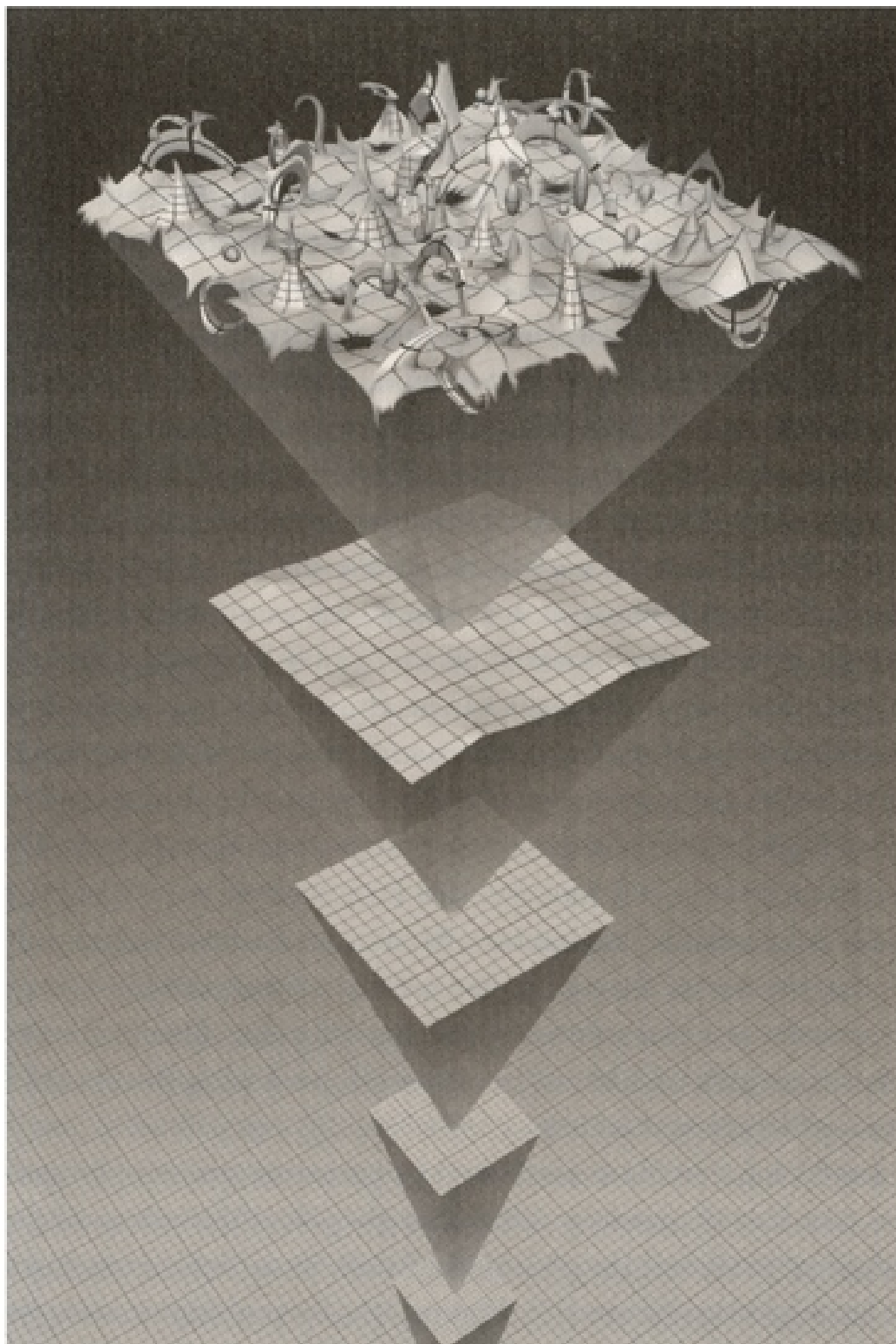
On the 100th anniversary of the introduction of special relativity one might ask “what is there to test”. Special relativity is so thoroughly integrated into the fabric of modern physics that its validity is rarely challenged, except by cranks and crackpots.

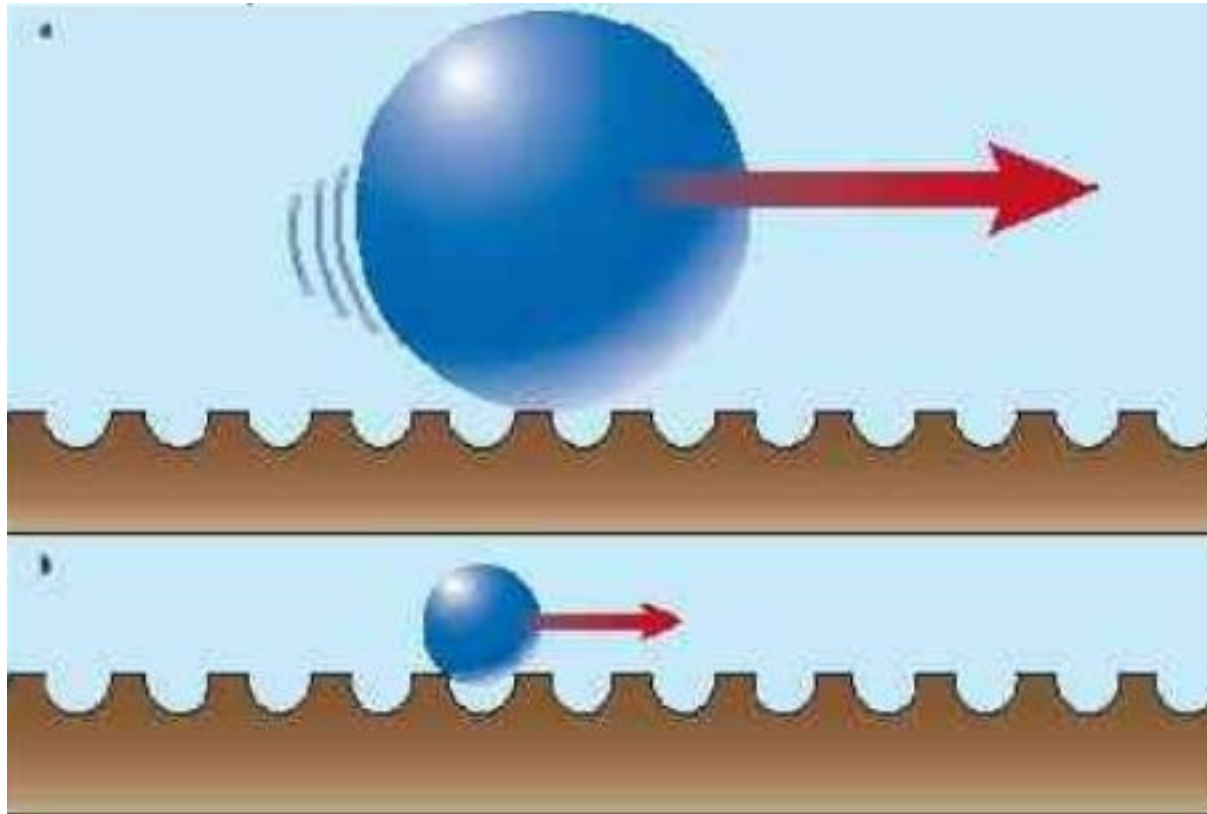
It is ironic then, that during the past several years, a vigorous theoretical and experimental effort has been launched, on an international scale, to find violations of special relativity.

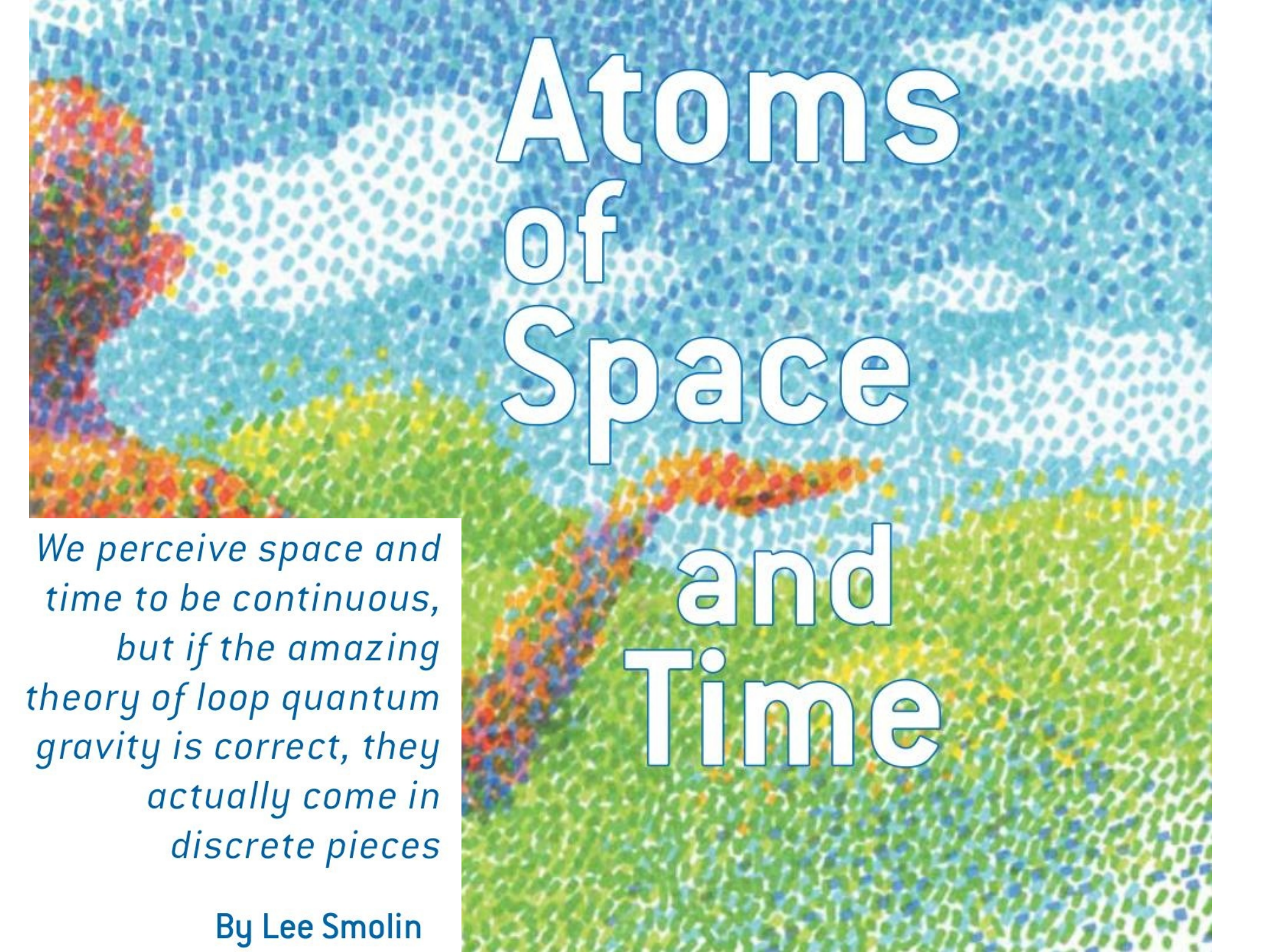
The motivations of these efforts is not a desire to repudiate Einstein, but to look for evidence of new physics “beyond Einstein” such as violations of Lorentz invariance that might result from certain models of quantum gravity.

“Gravità Quantistica”

“Dimensioni–Extra”



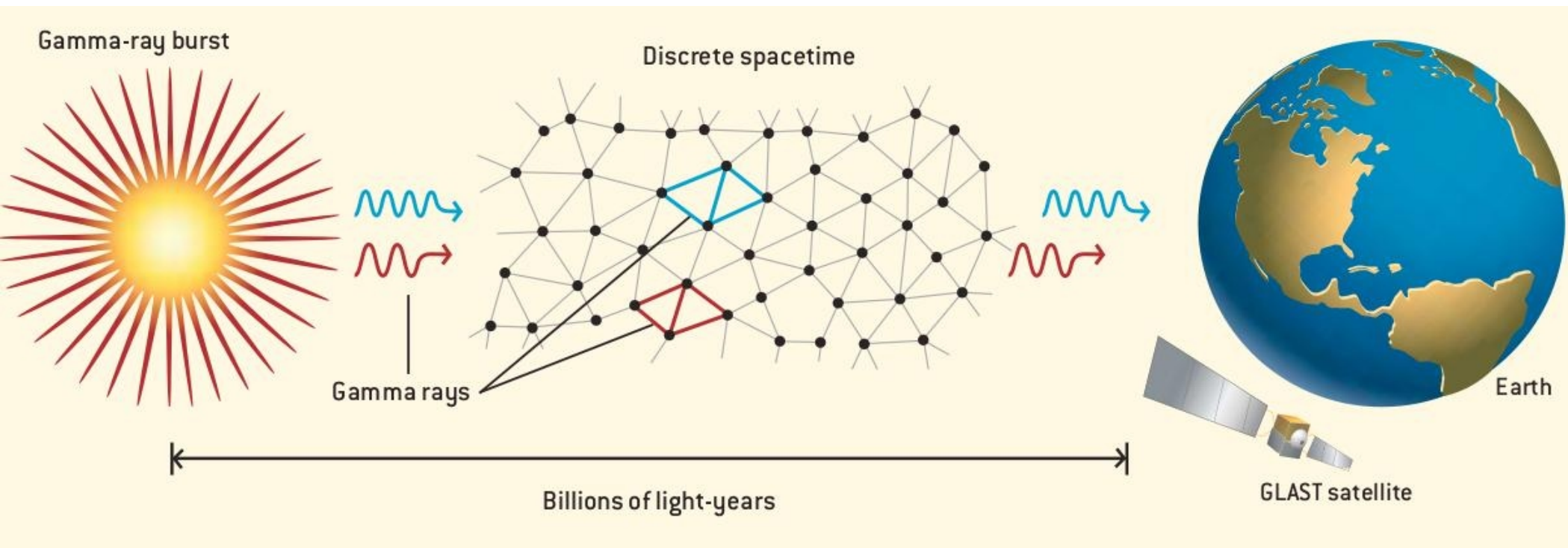




Atoms of Space and Time

*We perceive space and
time to be continuous,
but if the amazing
theory of loop quantum
gravity is correct, they
actually come in
discrete pieces*

By Lee Smolin

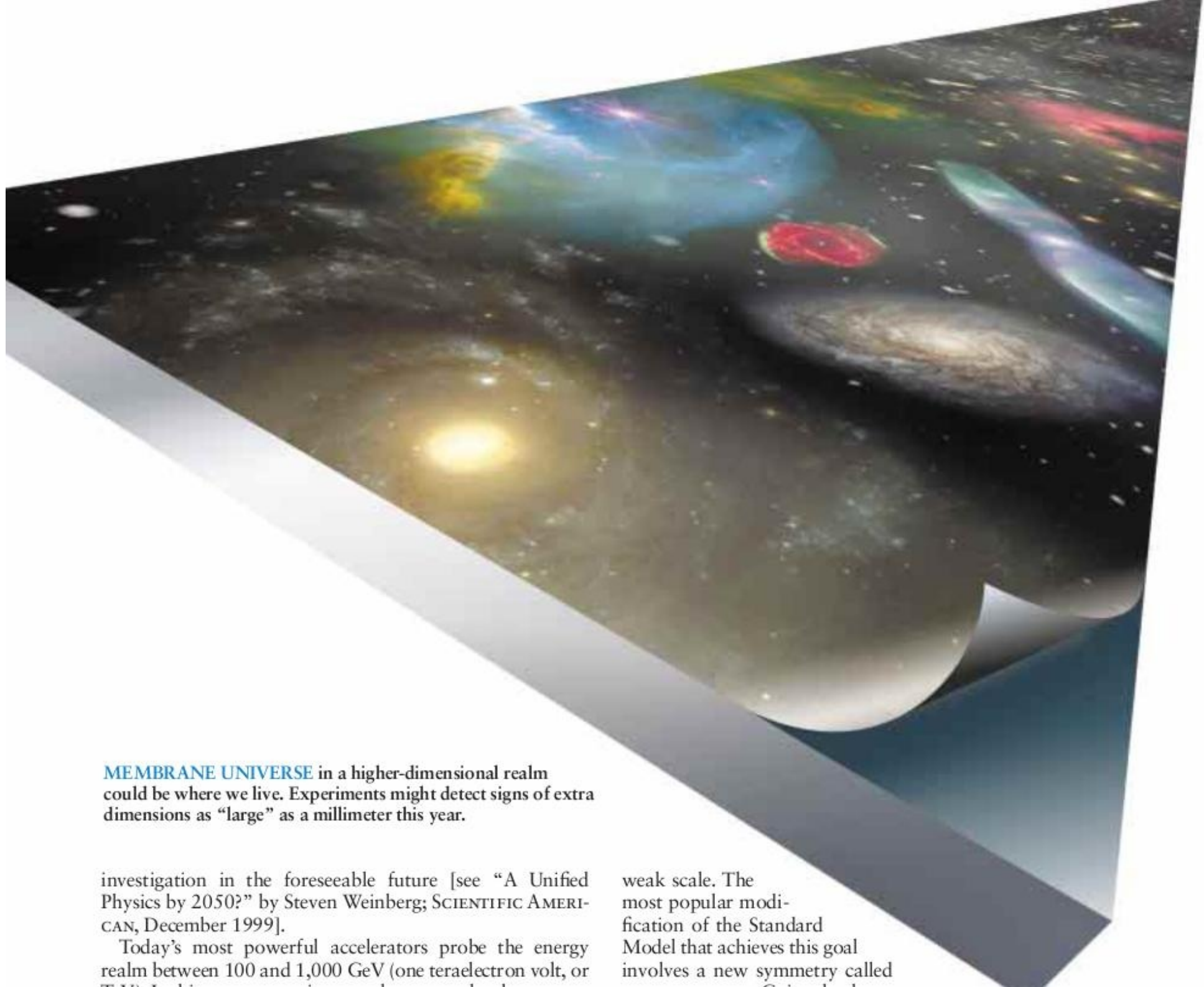


The Universe's **UNSEEN DIMENSIONS**

The visible universe could lie on a membrane floating within a higher-dimensional space. The extra dimensions would help unify the forces of nature and could contain parallel universes

by Nima Arkani-Hamed, Savas Dimopoulos and Georgi Dvali

Scientific American August 2000.

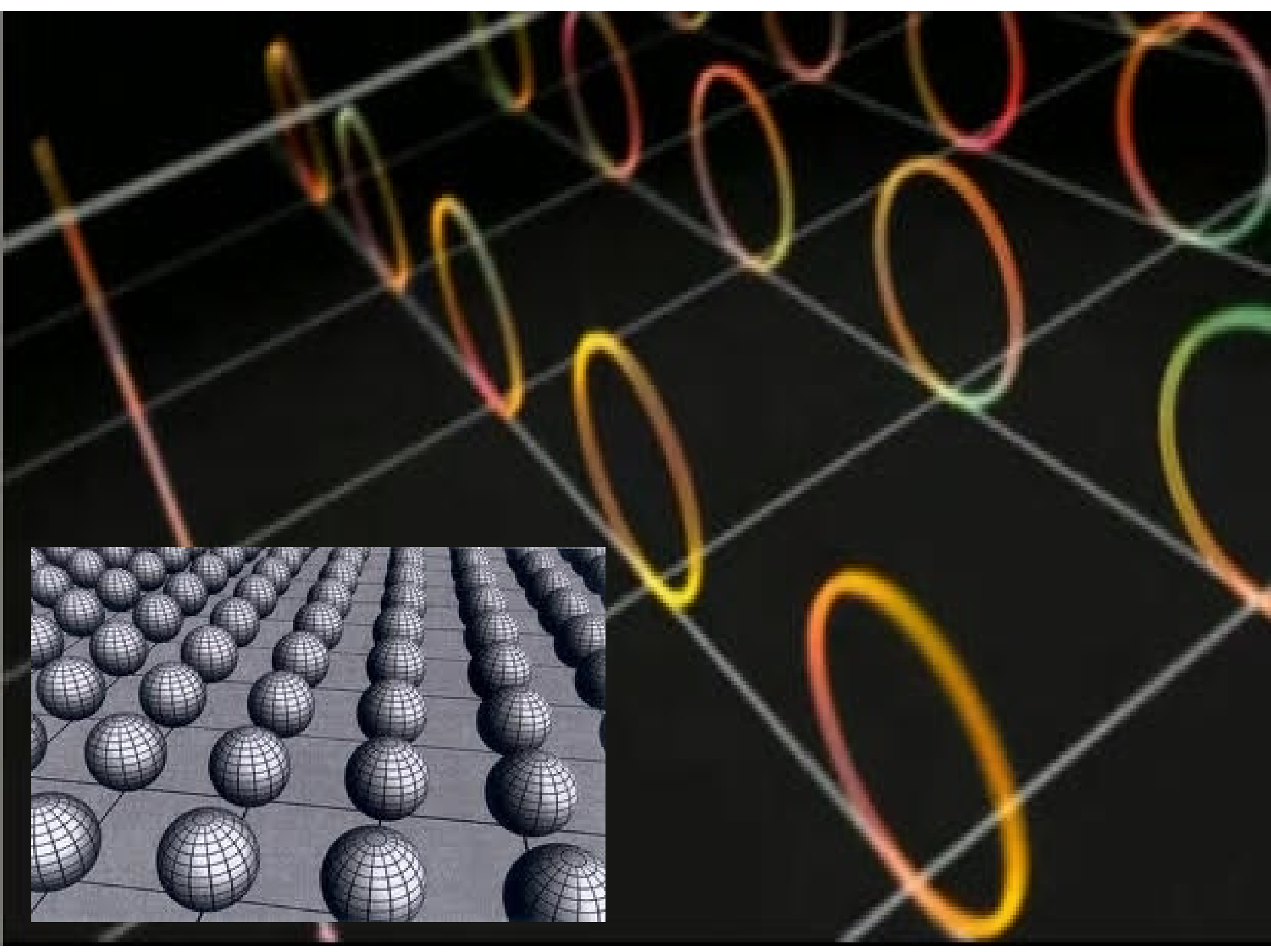


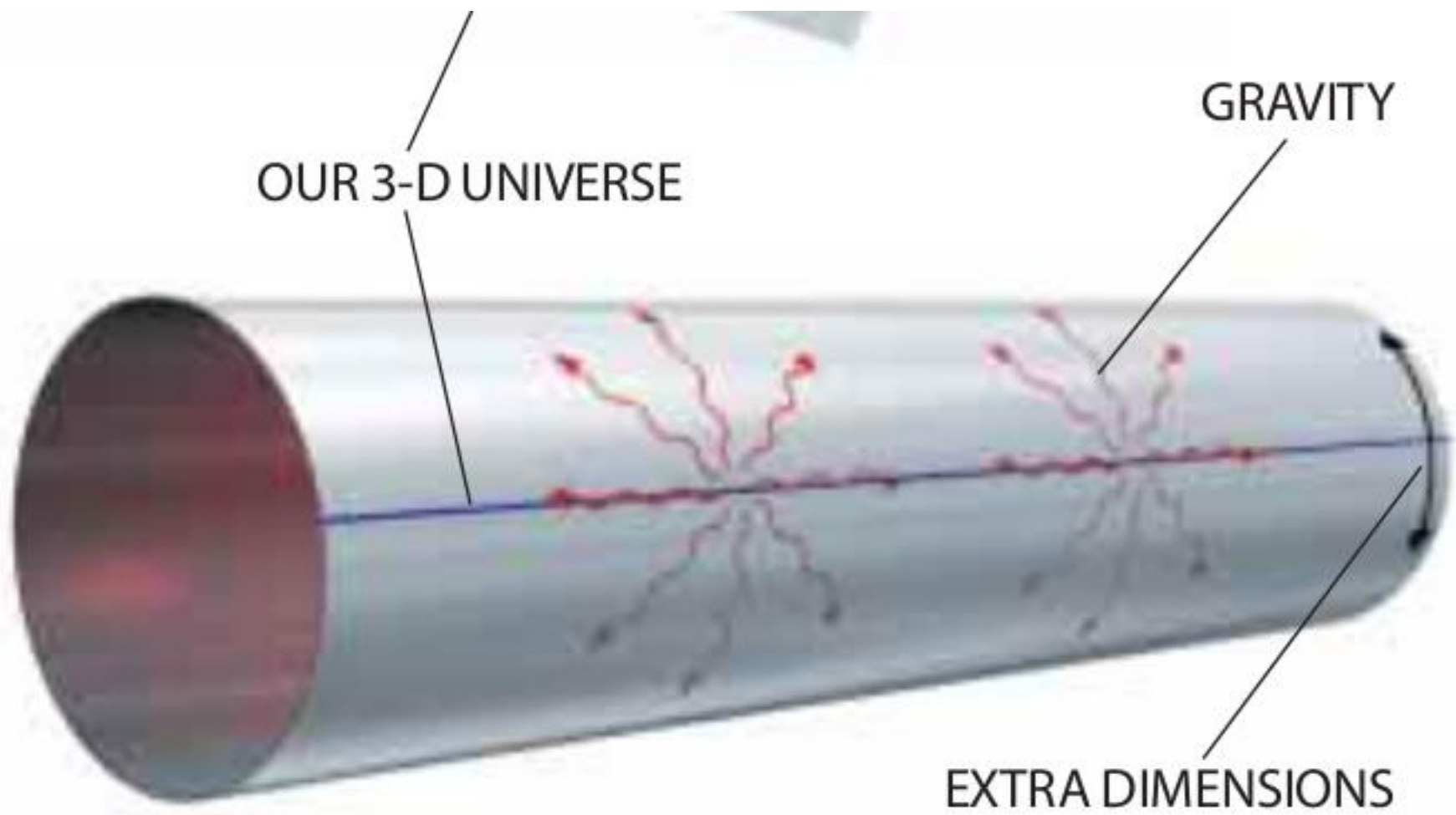
MEMBRANE UNIVERSE in a higher-dimensional realm could be where we live. Experiments might detect signs of extra dimensions as “large” as a millimeter this year.

investigation in the foreseeable future [see “A Unified Physics by 2050?” by Steven Weinberg; *SCIENTIFIC AMERICAN*, December 1999].

Today’s most powerful accelerators probe the energy realm between 100 and 1,000 GeV (one teraelectron volt, or 10^{12} eV). In this energy range, the Standard Model of particle physics

works well. The most popular modification of the Standard Model that achieves this goal involves a new symmetry called *Gauge* symmetry.





“Scorciatoia” attraverso le altre dimensioni.





Antonino Zichichi
[press release 22nd september]

If MINOS were to confirm OPERA's find, the consequences would be enormous. "If you give up the speed of light, then the construction of special relativity falls down," says Antonino Zichichi, a theoretical physicist and emeritus professor at the University of Bologna, Italy. Zichichi speculates that the "superluminal" neutrinos detected by OPERA could be slipping through extra dimensions in space, as predicted by theories such as string theory.

Shortcuts in extra dimensions and neutrino physics

Heinrich Päs (Alabama), Sandip Pakvasa (Hawaii), Thomas J. Weiler (Vanderbilt)

(Submitted on 20 Nov 2006)

We discuss the possibility of sterile neutrinos taking shortcuts in extra dimensions, and the consequences for neutrino oscillations. This effect influences the active–sterile neutrino mixing and provides a possibility to accommodate the LSND evidence for neutrino oscillations together with bounds from accelerator and reactor experiments. We briefly comment on causality in such schemes.

Neutrino time travel

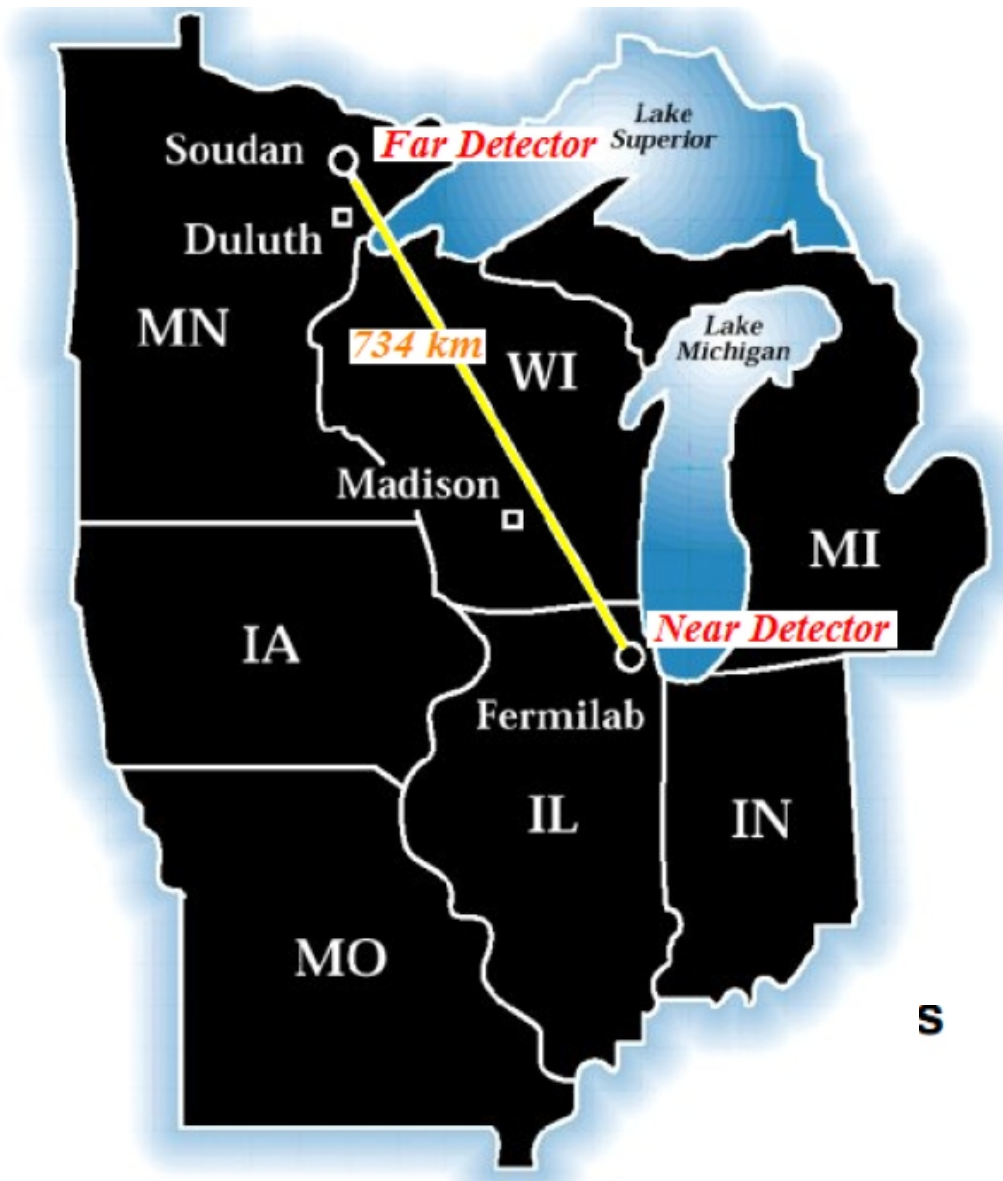
James Dent, Heinrich Päs, Sandip Pakvasa, Thomas J. Weiler

(Submitted on 12 Oct 2007 (v1), last revised 9 Dec 2007 (this version, v2))

We discuss causality properties of extra–dimensional theories allowing for effectively superluminal bulk shortcuts. Such shortcuts for sterile neutrinos have been discussed as a solution to the puzzling LSND and as a sub–category of asymmetrically warped extra dimensions may allow for time travel in extra dimensional bulk. In principle sterile neutrinos can be manipulated in a way to test the chronology protection conjecture experimentally.

Not surprisingly
Tom Weiler has been interviewed
Extensively in the media

VERIFICHE SPERIMENTALI



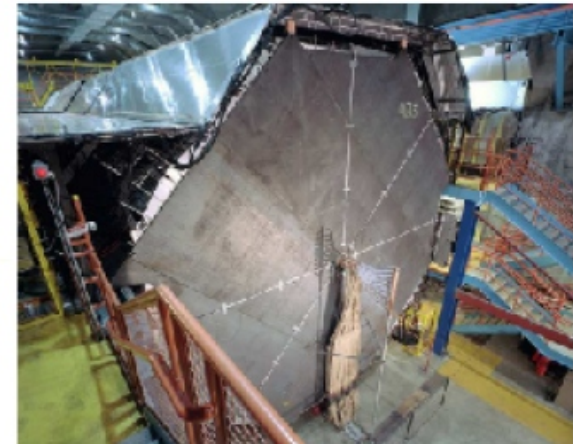
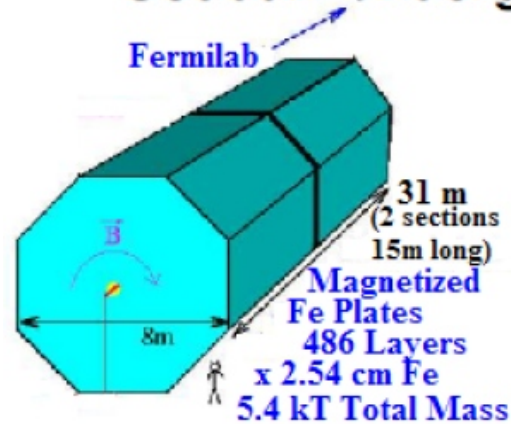
FermiLab to
MINOS

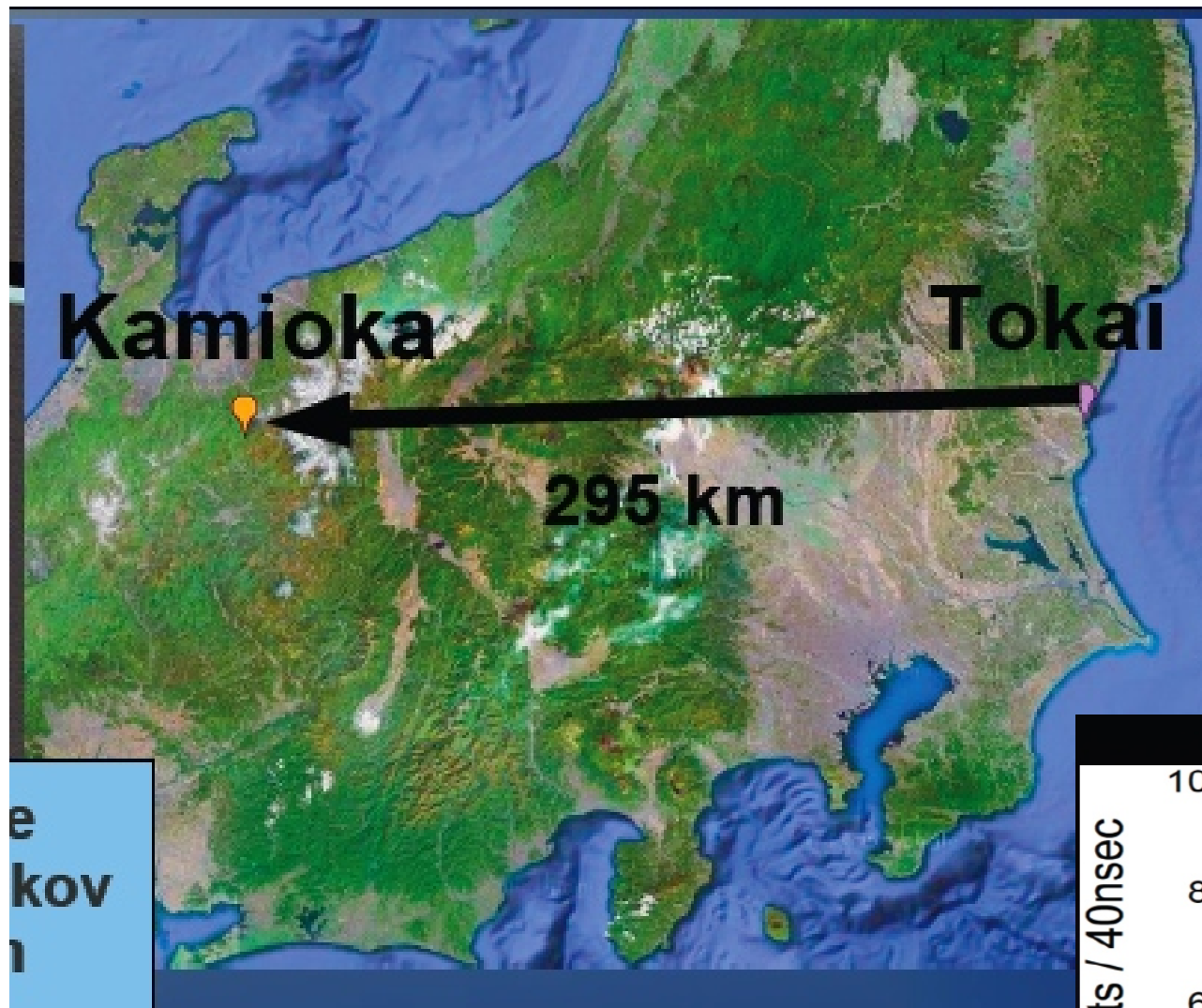
(734 Km)

$\langle E_{\nu} \rangle = 3 \text{ GeV}$

S

Soudan Underground Lab, Minnesota

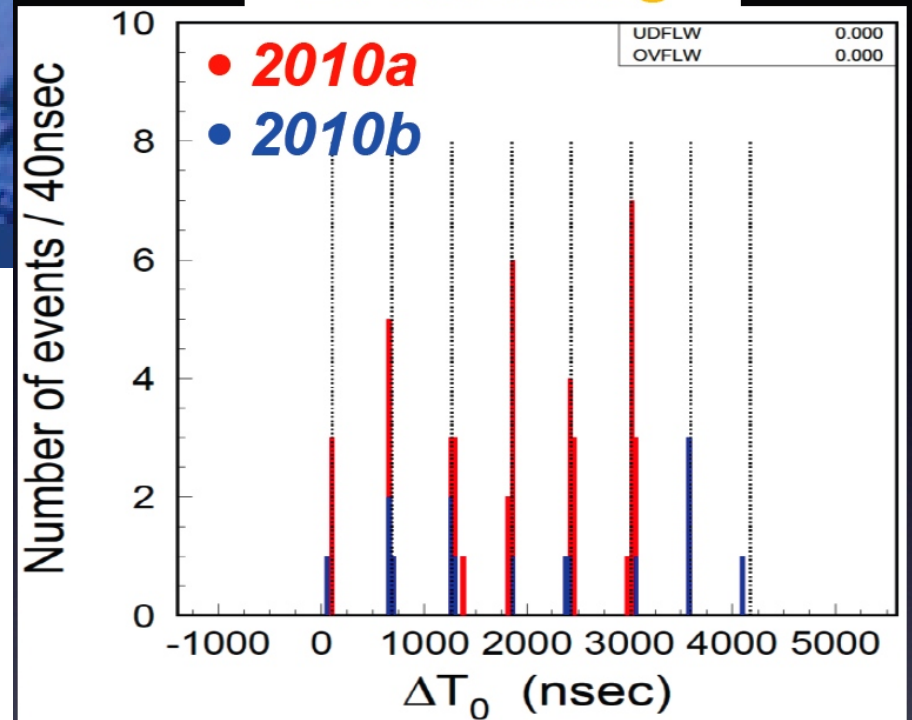




T2K neutrino beam

[very attractive
“bunch structure”]

Event timing



Fascio di neutrini CERN – Gran Sasso :

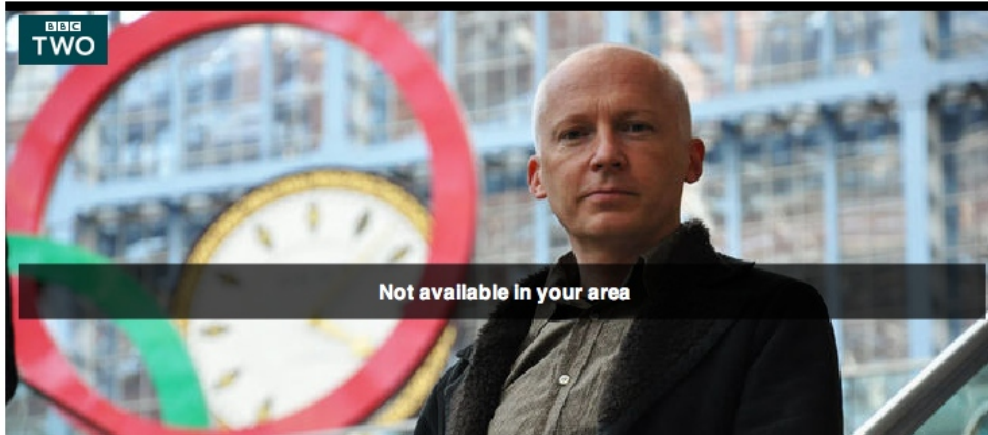
- [1] La misura verra' fatta da altri esperimenti
[Borexino, Icarus]
[La strumentazione per la misura di precisione
Del tempo e' gia' stata finanziata]
- [2] Nuovo fascio di neutrino pusato.
[stretti impulsi (5 ns)]

Ma intensita' piu' bassa.

La storia dei neutrini superluminali
E' importante per la percezione della
Scienza nella nostra societa'

BBC : Programma di 60 minuti (diverse volte in tarda serata)

Faster Than the Speed of Light?



Faster than the Speed of light ?

Nel settembre del 2011, un gruppo internazionale di scienziati ha fatto una straordinaria dichiarazione - hanno rivelato particelle che sembrano viaggiare piu' veloci della luce. E' una dichiarazione che contraddice piu' di cento anni di ortodossia scientifica.

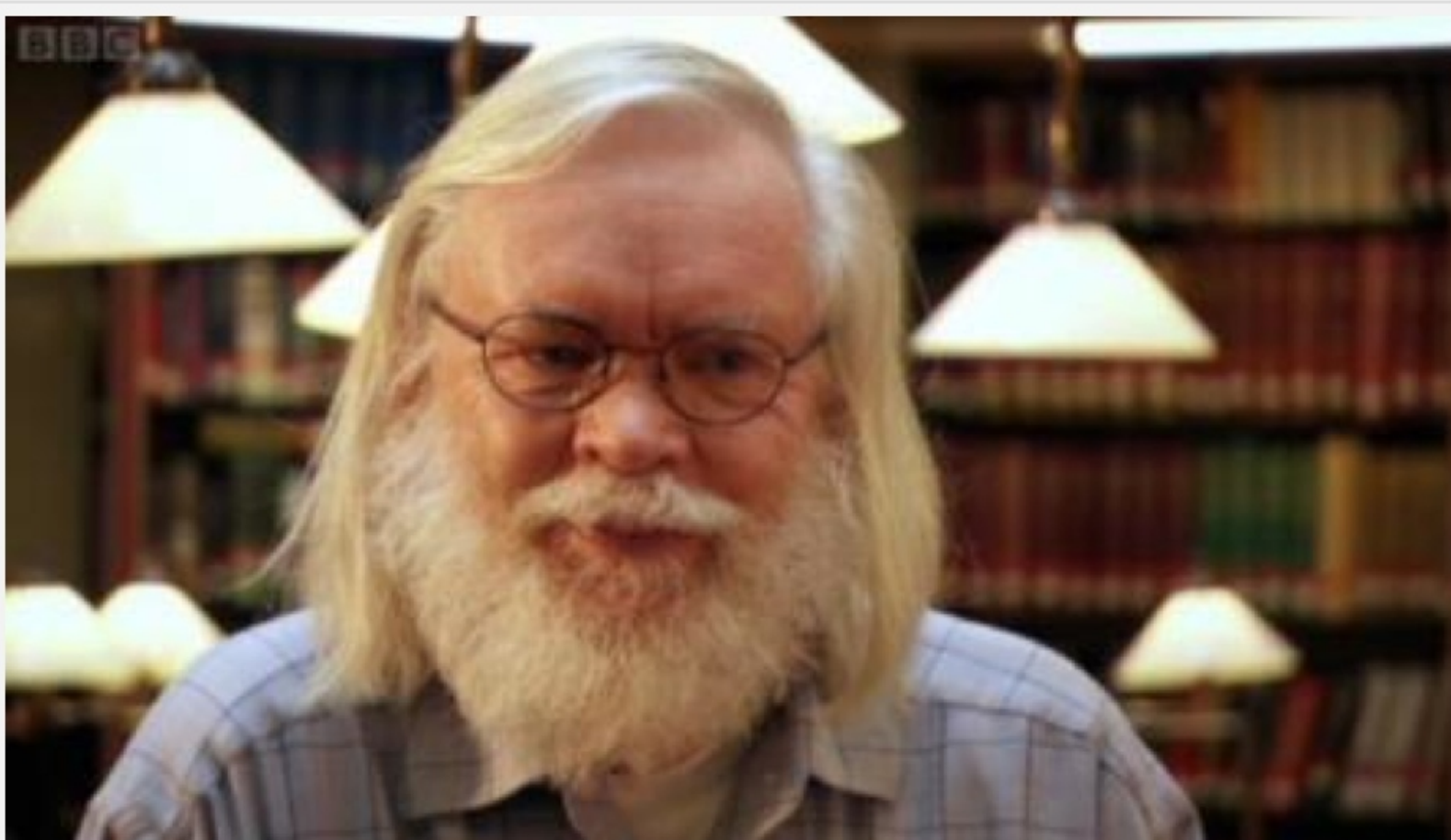
All'improvviso si parla di ogni tipo di concetto bizzarro, dal viaggio nel tempo, agli universi paralleli'.

Cosa sta avvenendo? Saremo un giorno capaci di viaggiare nel passato o persino in un altro universo?

In this film, Professor Marcus du Sautoy explores one of the most dramatic scientific announcements for a generation. In clear, simple language he tells the story of the science we thought we knew, how it is being challenged, and why it matters.



Si puo' quasi sentire fisicamente il brivido che passa attraverso tutta la comunita' scientifica quando un risultato cosi' strano esce fuori. Tutti ne parlano. E' questo il momento per l'emergere di una nuova grande teoria che spiega tutti i misteri che ancora pervadono la fisica, o semplicemente c'e' stato un errore nella misura?



John Ellis

John Ellis: "If the speed of light turned out not to be absolute, we would just have to tear up all the textbooks and start all over again. On the other hand it would be nice if it were true."

?!

Le doute scientifique, une attitude exemplaire

Edito du Monde | Le Monde

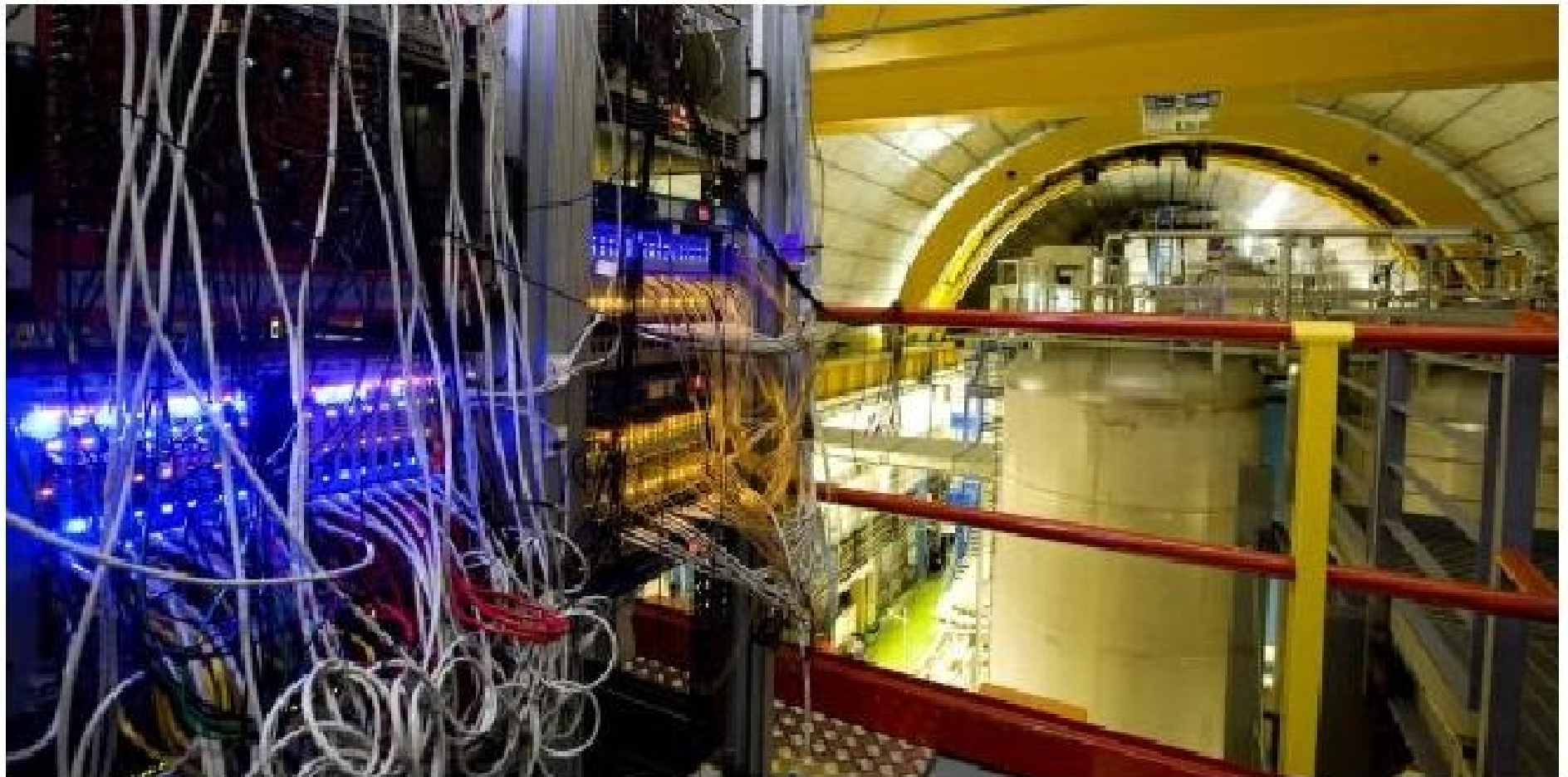
Le Monde: 24/settembre/2011

Il dubbio scientifico

Abonnez-vous
15 € / mois

50

Una attitudine che e' un buon esempio



C'est une belle leçon de morale que viennent d'administrer les chercheurs du CNRS et du CERN, l'organisation européenne pour la recherche nucléaire, qui est aussi le plus grand laboratoire de physique du monde. Après avoir découvert, dans le cadre d'une expérience baptisée "Opera", que des particules pouvaient voyager plus vite que la lumière, l'équipe de physiciens a passé six mois à tenter de trouver une faille à cette découverte. L'enjeu est de taille : si les résultats de ces travaux sont confirmés, ils mettront à bas la théorie classique de la relativité restreinte d'Albert Einstein, loi centrale de la physique depuis 1905.

E' una bella lezione di etica quella che hanno impartito i ricercatori del CNRS e del CERN, l'organizzazione europea per la ricerca nucleare, che e' anche il piu' grande laboratorio di fisica del mondo.

Dopo avere scoperto, nel quadro di un esperimento chiamato OPERA, che delle particelle potrebbero viaggiare piu' veloci della luce, hanno passato piu' di sei mesi a cercare di trovare un errore in questo risultato.

La posta in gioco e' alta: se i risultati di questo lavoro saranno confermati, metteranno in questione la teoria della relativita' di Albert Einstein, la legge centrale della fisica dal 1905.

Lo scetticismo come antidoto all'arroganza

Amenés à mettre en doute la validité d'un principe cardinal de la physique, ils offrent ainsi à la communauté scientifique tous les moyens de mettre à son tour en doute, méthodiquement, le fruit de leurs travaux. Ils s'exposent, volontairement, à la critique de leurs pairs. Au cours de ce processus, qui pourra être orageux, les arguments des uns et des autres seront entendus ; de nouvelles expériences seront sans doute menées ou imaginées, pour trancher la question. Peu à peu se dégagera un consensus, et la science en sortira plus forte, ouvrant ou non la voie à de nouvelles théories capables de mieux décrire les lois de la nature. Les "neutrinos supraluminiques" - nom de ces particules fondamentales furtives - du laboratoire souterrain de Gran Sasso, en Italie, où ont eu lieu les mesures de la vitesse de leur propagation, seront peut-être à l'origine d'une nouvelle aventure pour la science. Dans l'immédiat, ils sont surtout le symbole de la soif de savoir des communautés scientifiques, et de leur volonté de se libérer des convenances sociales, idéologiques ou économiques. Du scepticisme comme antidote à l'arrogance.

Spinti a mettere in dubbio la validita' di un principio cardine della fisica, offrono alla comunita' scientifica tutti mezzi per mettere, a loro volta, in dubbio, metodicamente il frutto del loro lavoro. Si espongono, volontariamente, alla critica dei loro pari. Nel corso di questo processo, che potra' essere tempestoso, gli argomenti degli uni e degli altri saranno ascoltati: delle nuove esperienze saranno certamente condotte o immaginate per chiarire il problema.

Poco a poco si sviluppera' un consenso, e la scienza ne uscirà piu' forte, sia che apra oppure no la via a nuove teorie capaci di descrivere meglio le leggi della natura.

I neutrini superluminali, [...] saranno forse all'origine di una nuova avventura per la scienza.

Nell'immediato, sono soprattutto il simbolo della sete di sapere delle comunita' scientifiche, e della loro volonta' di liberarsi delle convenzioni sociali, ideologiche o economiche,

dello scetticismo come antidoto all'arroganza.

Editorial of New Scientist [28 September 2011]

Accompanying article:

“Superluminal neutrinos point to new physical reality”

History is moving at light speed

Scientific revolution or not, the neutrinos that seem to travel faster than light have captured people's imagination

It has been a while since the last proper scientific revolution. Our generation has never experienced a rethink of the kind that quantum theory and relativity provoked.

The media went to town on the story. Many scientists expressed discomfort over what they felt sure would be exposed as an embarrassing mistake, not least because it lacks a good explanation. Yet, as they trotted out the old mantra about extraordinary claims requiring extraordinary evidence, many others must have felt a shiver of excitement that a new chapter of physics may have opened at long last.

Let's hope it has. And even if it was a mistake, there's no reason to be uncomfortable or embarrassed. We should celebrate the fact that so many people have had the chance to witness science in action. We are in a new era - of science as a spectator sport. Extraordinary results are now being debated in public before scientists have even got a grip on what they mean.

Osservazioni finali

- [1] Nessun errore e' stato (ancora ?)
Trovato nell'analisi di OPERA.
La “anomalia” e' ancora in vita.
- [2] La “ANOMALIA di OPERA”
Verra' testata sperimentalmente
- [3] Le implicazioni di una conferma dell'effetto
Sarebbero veramente STRAORDINARIE
- [4] La discussione scientifica intorno
A questi risultati e' concettualmente molto interessante.