

# Elementary Particle Physics

## Microcosmos

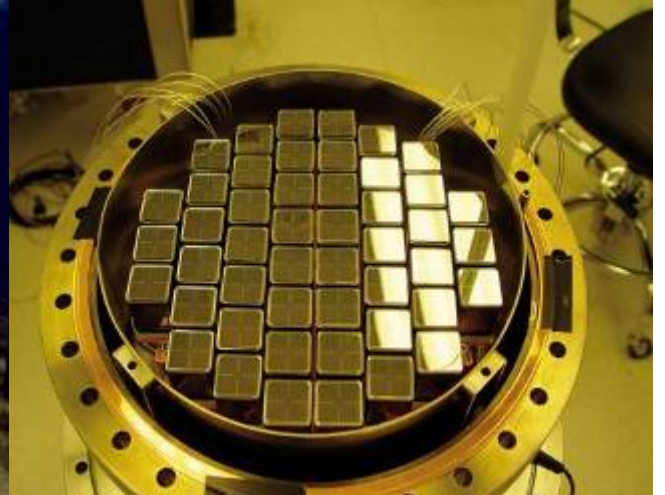
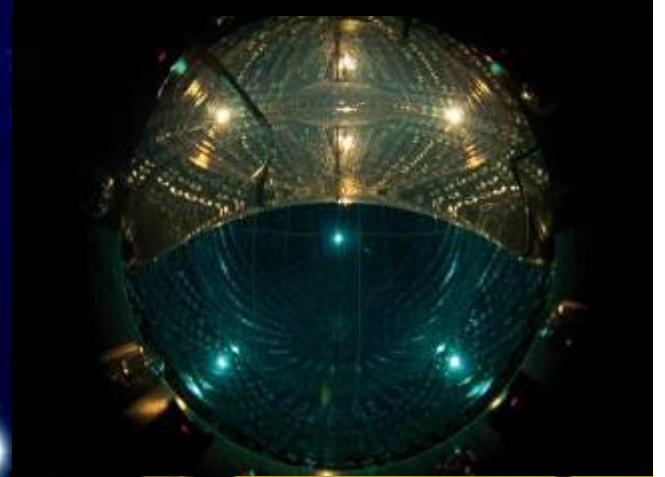
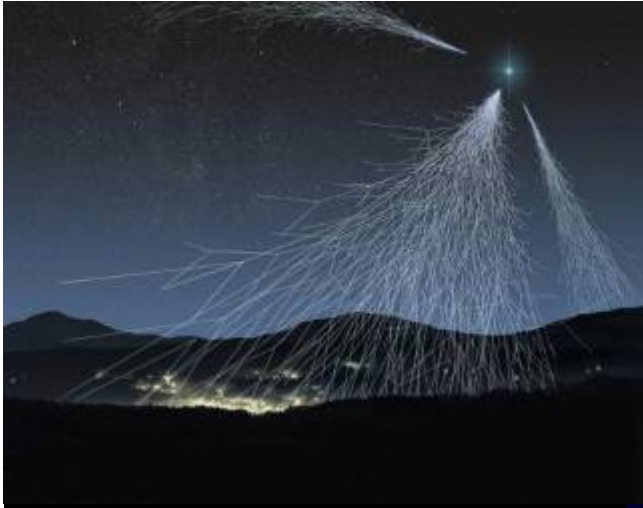
- I. Quantum world
- II. CERN: *past & present*
- III. *Particle physics matters!*
- IV. **Astroparticle physics**

Frank Linde  
Nikhef & UvA  
+31-205925001  
f.linde@nikhef.nl

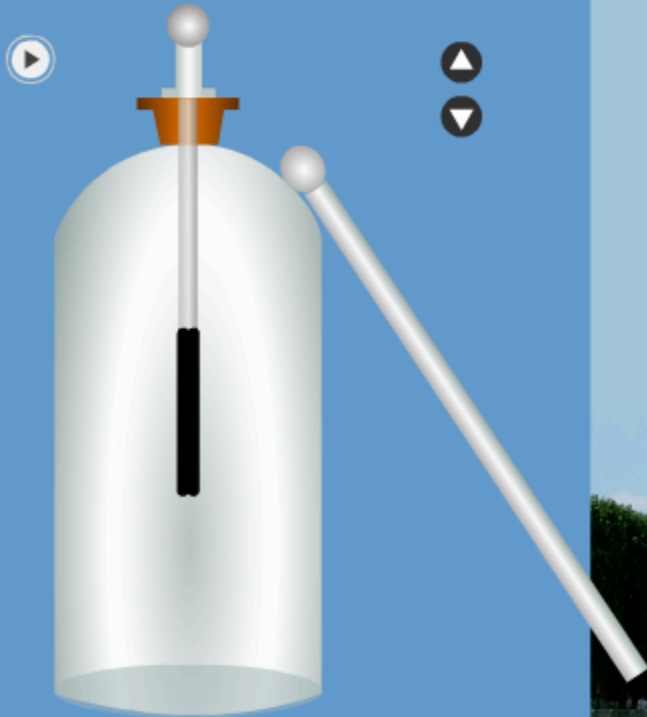


*cosmic rays  
photons  
neutrino's  
gravitational waves  
dark matter*

*Messengers from outer space!*



# Cosmic Rays



Remco Brantjes (NIKHEF)



# Cosmic Rays

## MUON

$\mu$



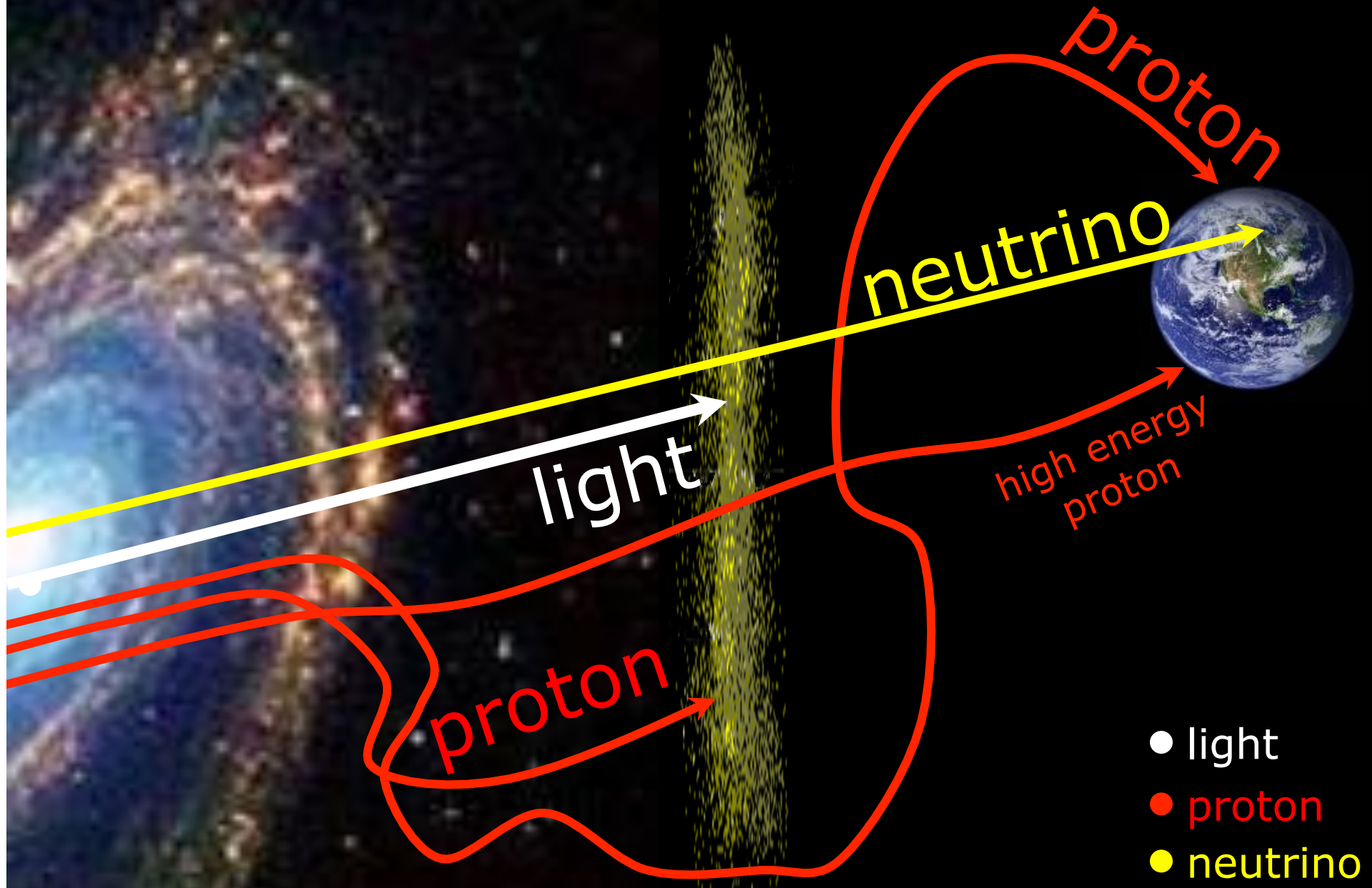
The **MUON** is a short-lived, heavier version of the electron. It has the same negative charge, but is 200 times more massive than the electron.



GLUON PHOTON NEUTRINO TACHYON ELECTRON UP QUARK DOWN QUARK TAU NEUTRINO MUON UP QUARK  
NEUTRON DOWN QUARK TAU GLUON **MUON** NEUTRINO TACHYON ELECTRON UP QUARK DOWN QUARK  
NEUTRINO MUON UP QUARK PROTON NEUTRON DOWN QUARK TAU GLUON PHOTON NEUTRINO TACHYON  
UP QUARK DOWN QUARK TAU NEUTRINO TACHYON ELECTRON UP QUARK DOWN QUARK TAU GLUON  
NEUTRON DOWN QUARK TAU NEUTRINO TACHYON ELECTRON UP QUARK DOWN QUARK TAU GLUON  
DOWN QUARK TAU GLUON PHOTON NEUTRINO TACHYON ELECTRON UP QUARK DOWN QUARK TAU NEU  
UP QUARK PROTON NEUTRON DOWN QUARK TAU GLUON PHOTON NEUTRINO TACHYON ELECTRON UP

*The* **PARTICLE ZOO**

# Origin of cosmic rays?



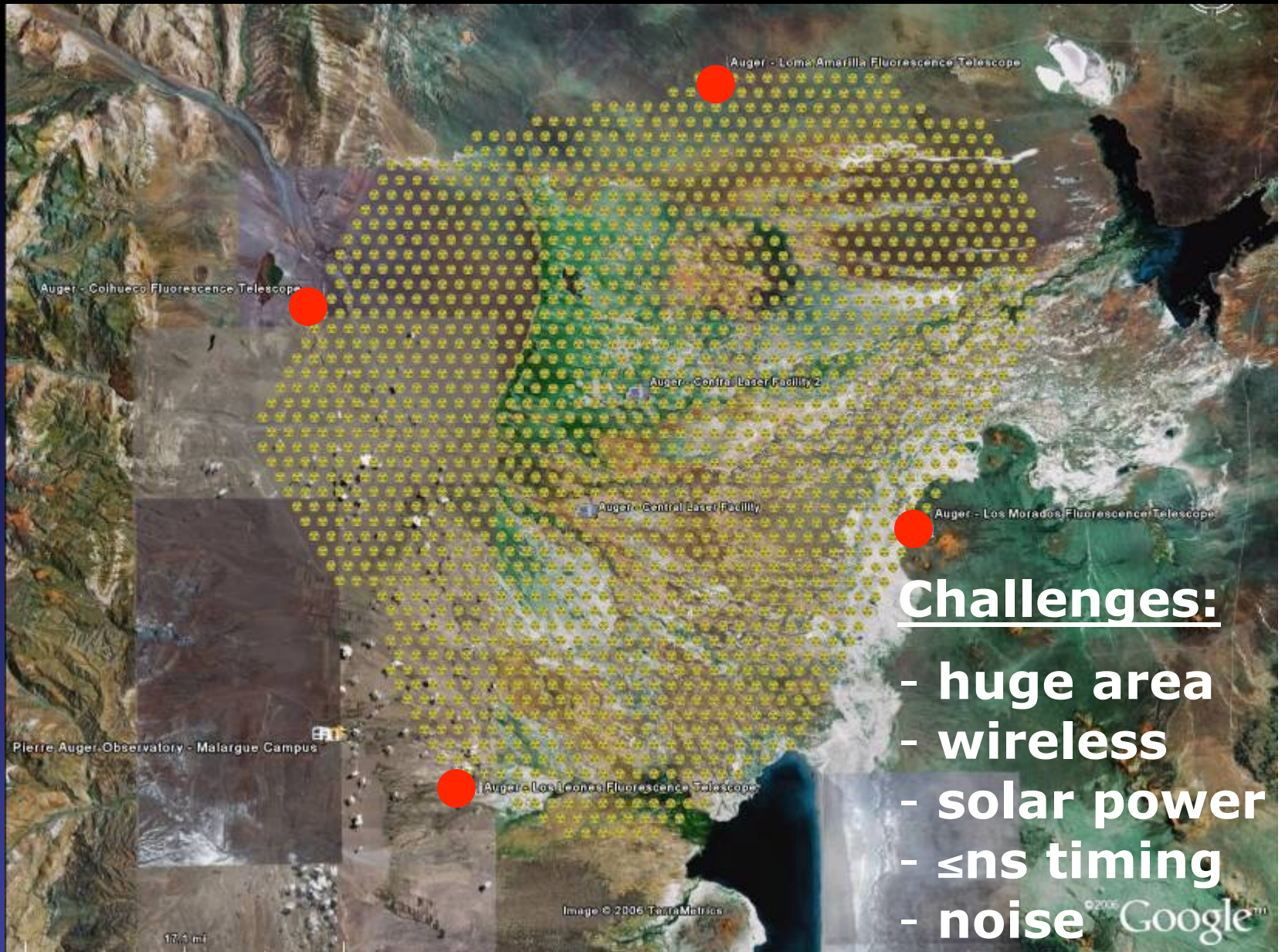
# Cosmic Rays

*AUGER* cosmic ray observatory



# **AUGER** cosmic ray observatory

## Cosmic Rays



### Challenges:

- huge area
- wireless
- solar power
- $\leq$ ns timing
- noise



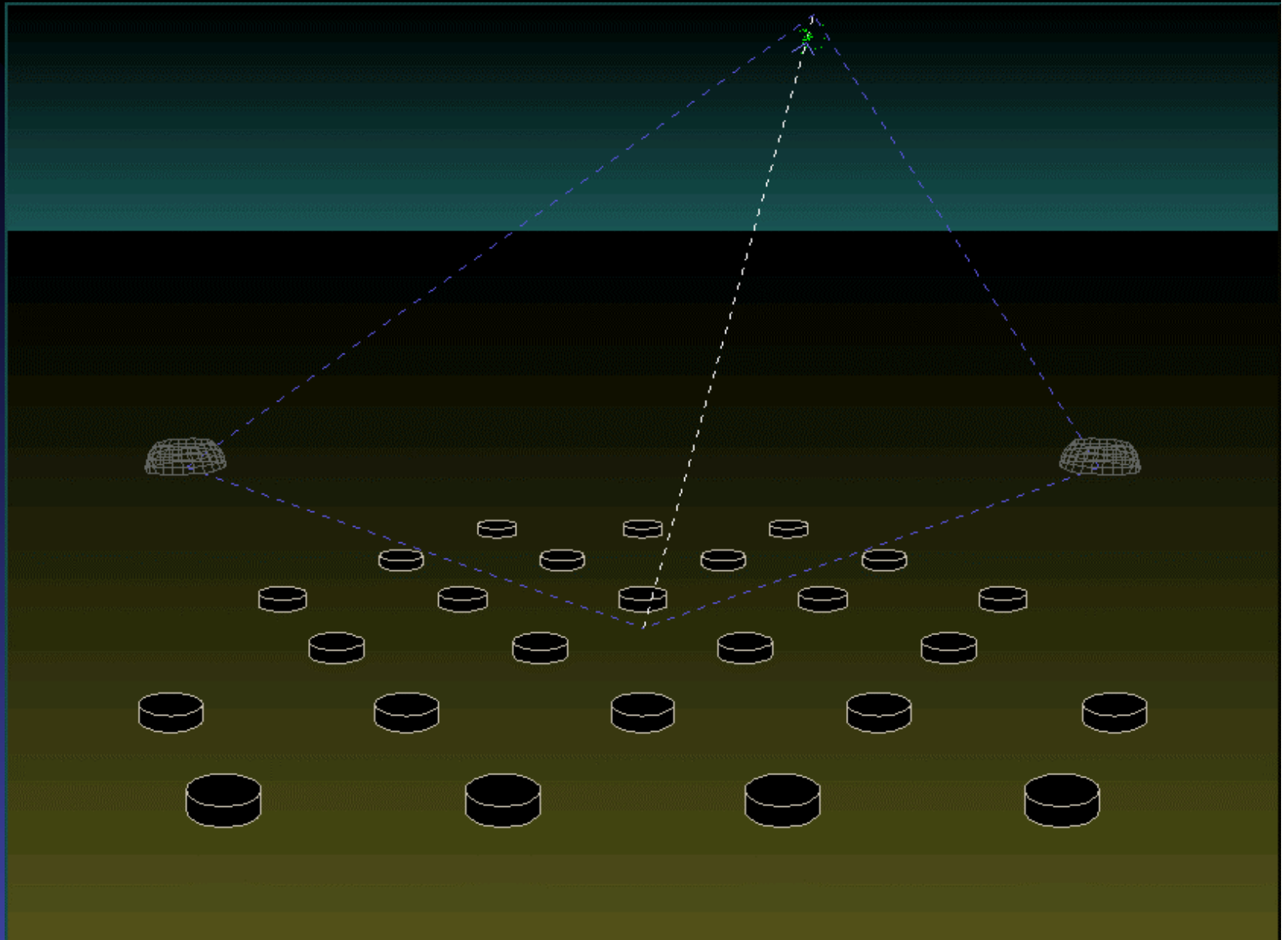
# *AUGER* cosmic ray observatory

## Cosmic Rays

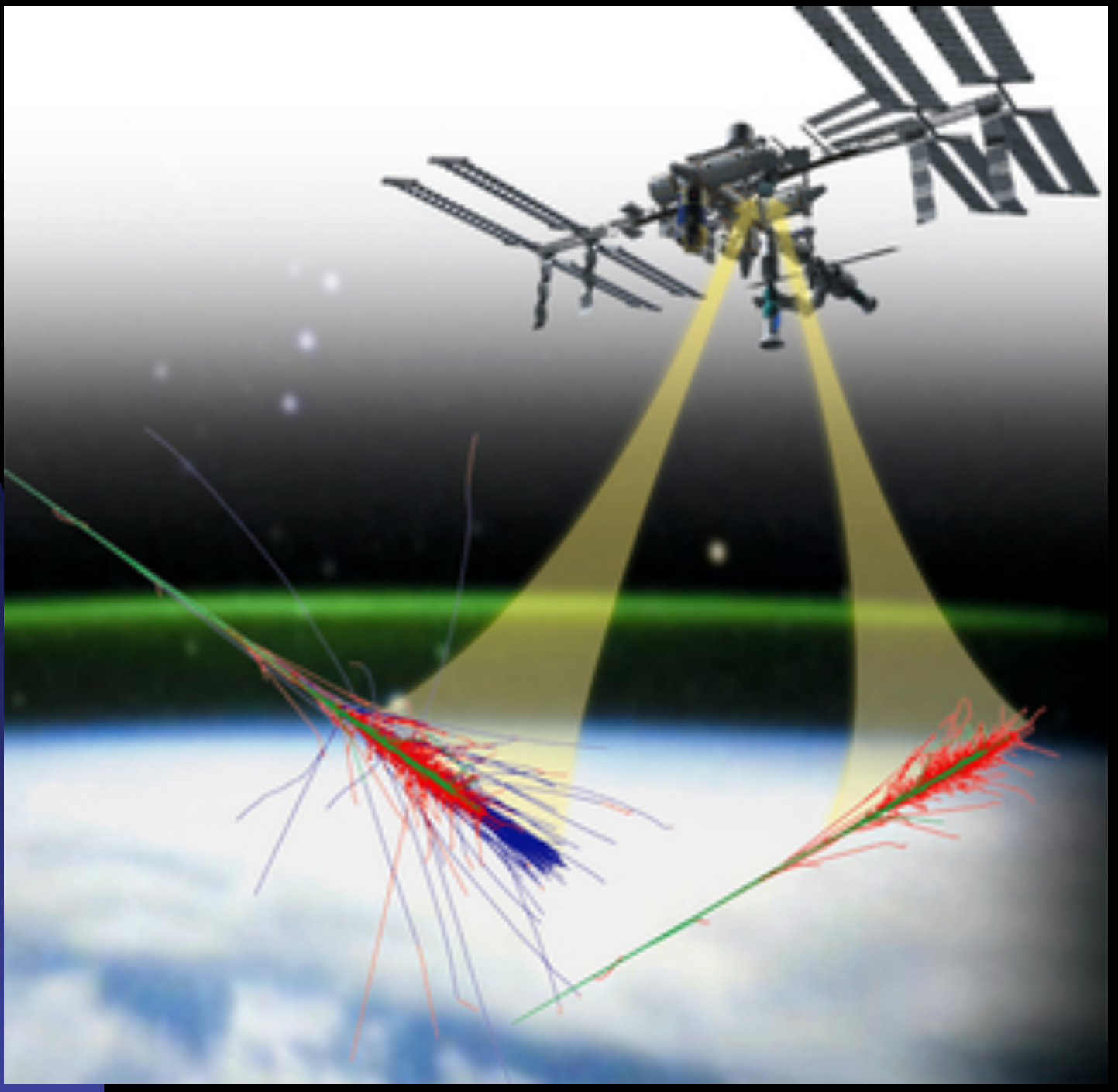


# *AUGER* cosmic ray observatory

## Cosmic Rays

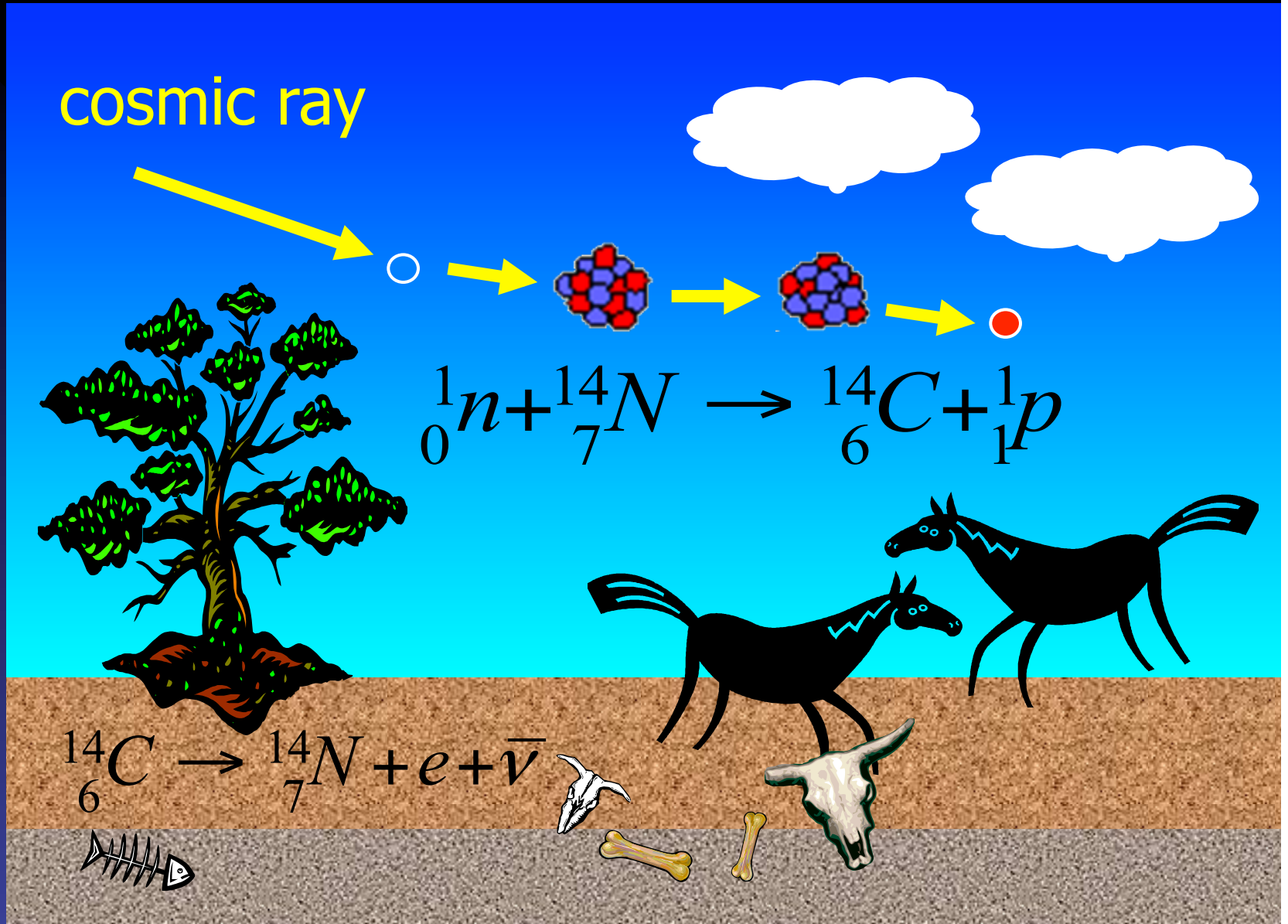


# Cosmic Rays



# Radiocarbon dating

## Cosmic Rays

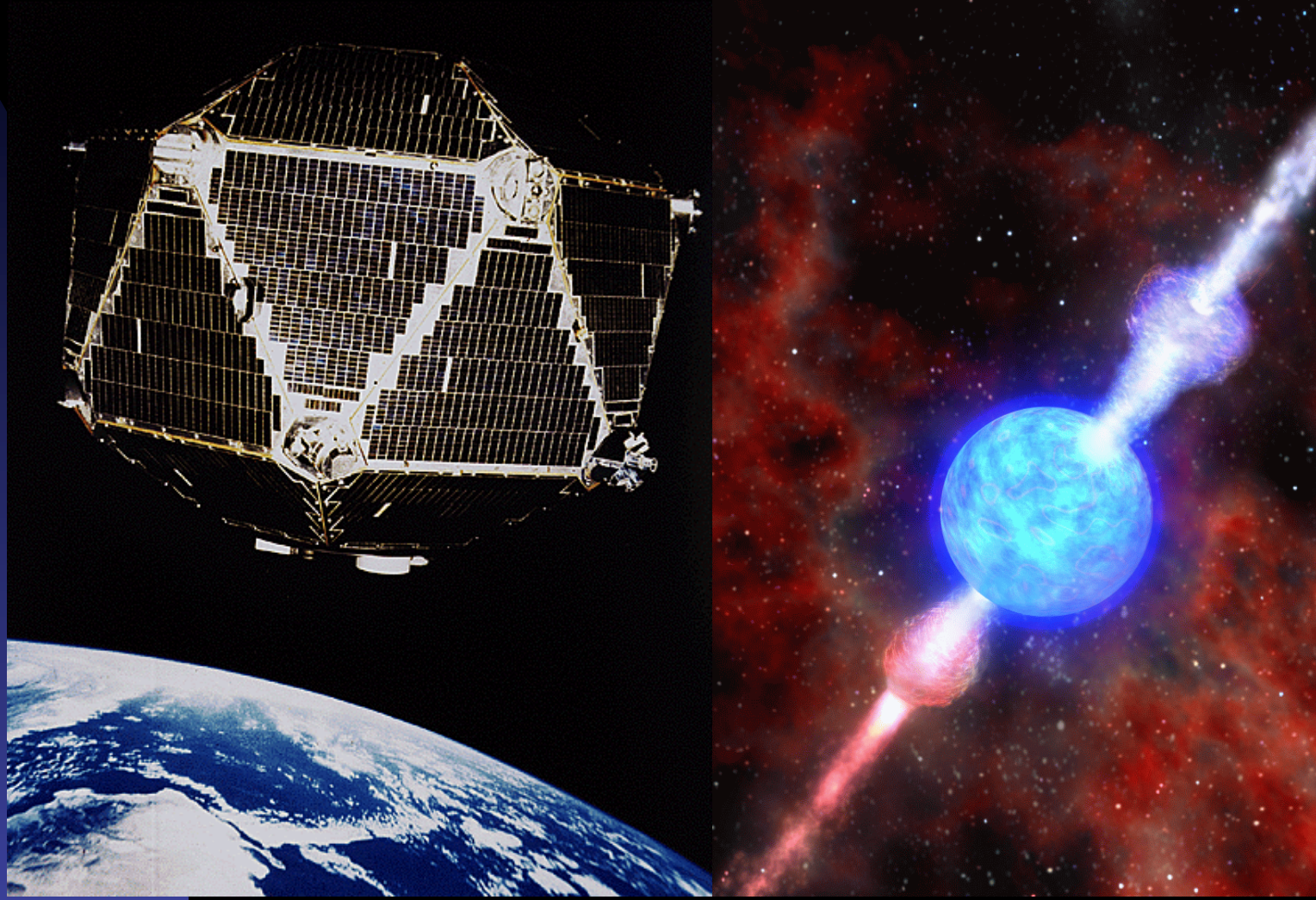


# Thunderstorms & lightning

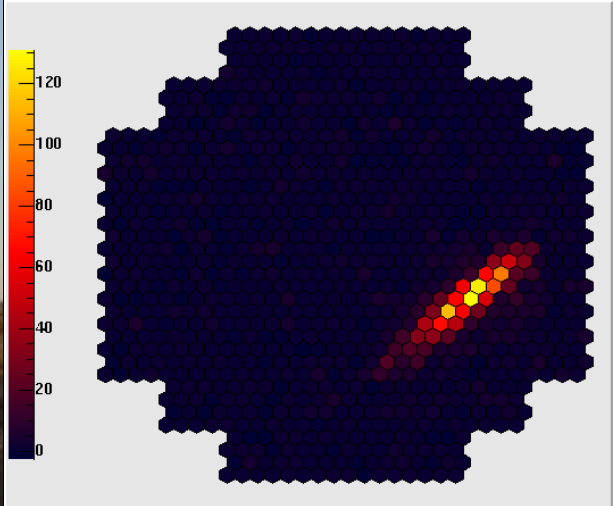
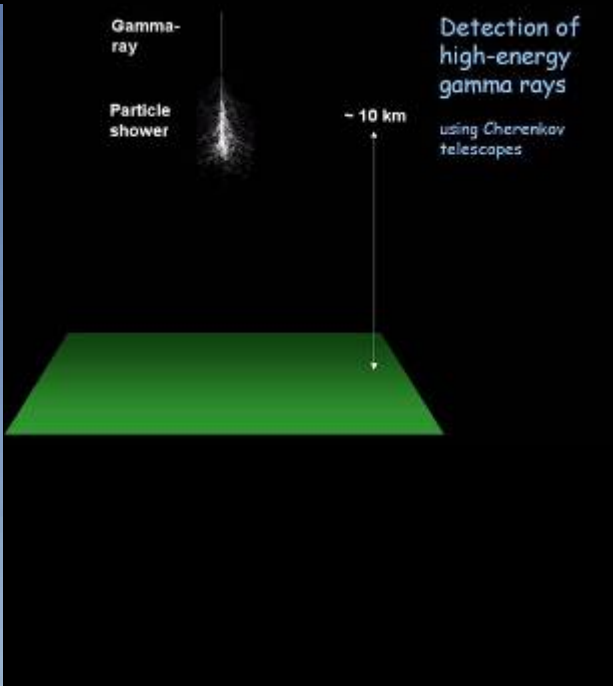
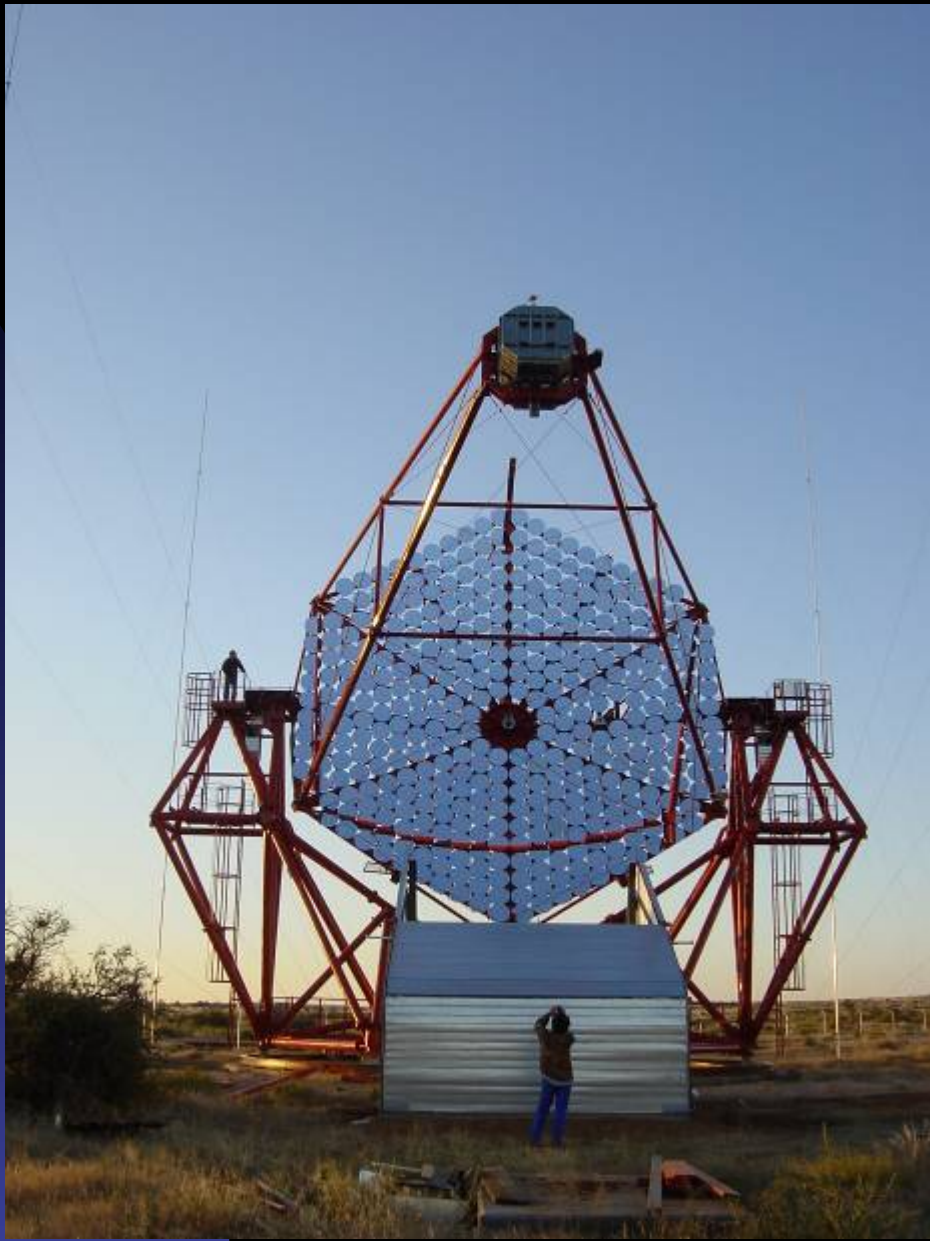
Cosmic Rays



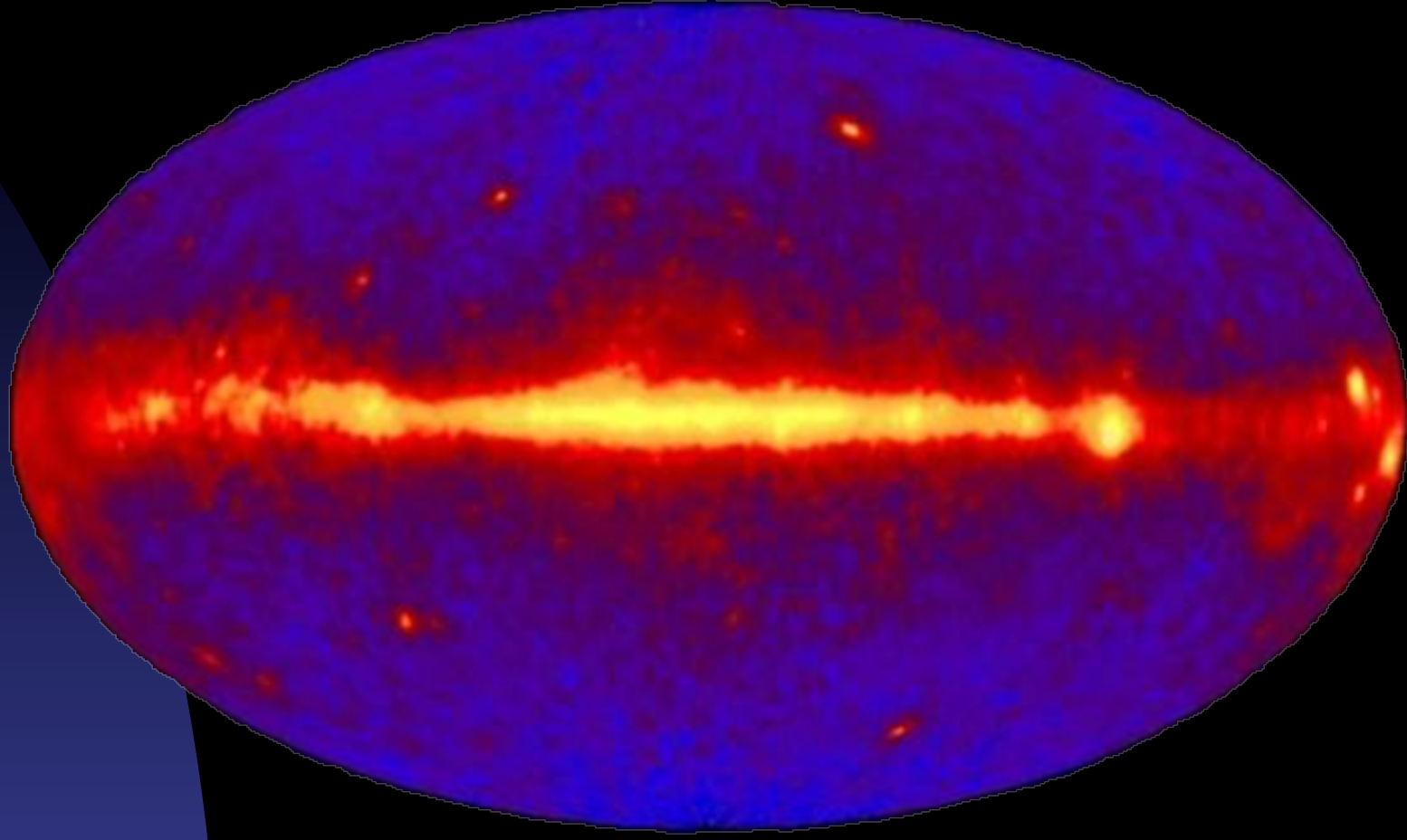
# Photons *high energy*



# Photons *high energy*



Photons *high energy*

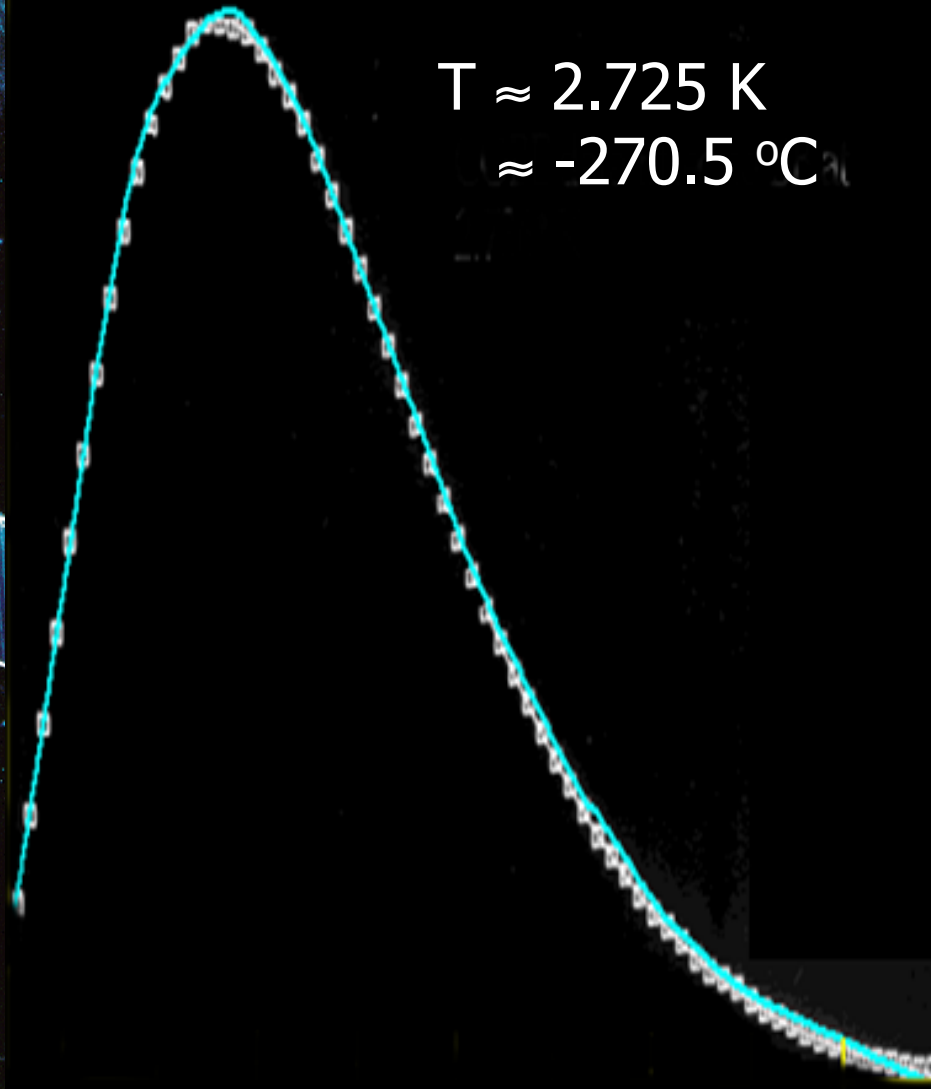




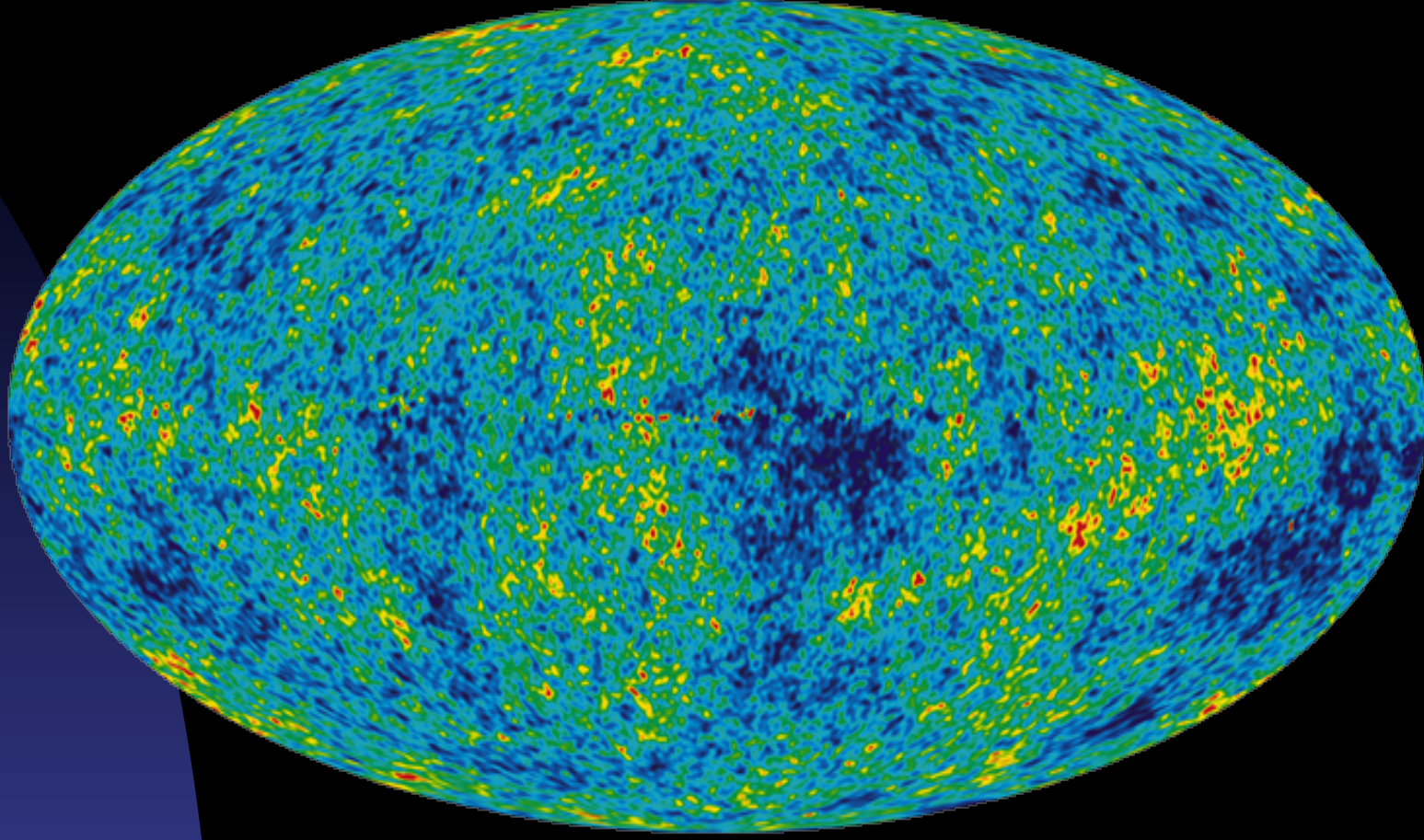
# Photons *low energy*



# Photons *low energy*

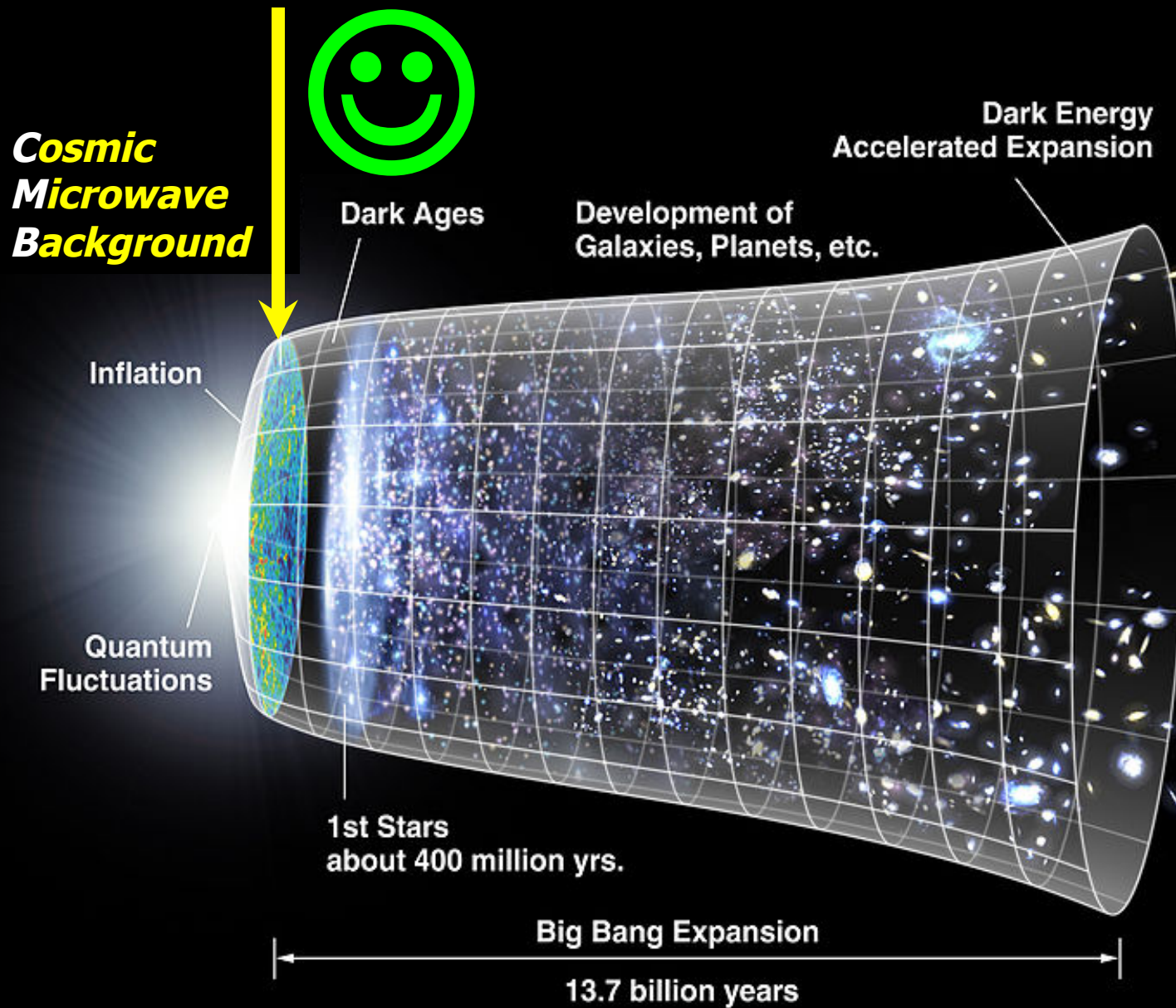


Photons *low energy*



# Photons *low energy*

“picture” from a few 100,000 years “old” Universe!



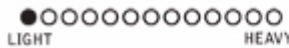
# Neutrino's

## ELECTRON-NEUTRINO

$\nu_e$



The **ELECTRON-NEUTRINO** wears a bandit's mask because he likes to steal away energy and is notoriously difficult to detect. Traveling close to the speed of light, he is the most pervasive form of matter in the universe.



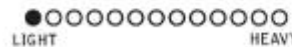
GLUON PHOTON NEUTRINO TACHYON ELECTRON UP QUARK  
NEUTRON DOWN QUARK TAU GLUON **ELECTRON-NEUTRINO**  
NEUTRINO MUON UP QUARK PROTON NEUTRON DOWN QUARK  
The **PARTICLE ZOO**

## MUON-NEUTRINO

$\nu_\mu$



Like its first-generation sibling lepton the electron-neutrino, the **MUON-NEUTRINO** is extremely difficult to detect (hence the bandit's mask). Discovered in 1962, it is emitted in the decay of



GLUON PHOTON NEUTRINO TACHYON ELECTRON UP QUARK  
NEUTRON DOWN QUARK TAU GLUON **MUON-NEUTRINO**  
NEUTRINO MUON UP QUARK PROTON NEUTRON DOWN QUARK  
The **PARTICLE ZOO**

## TAU-NEUTRINO

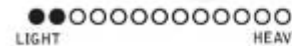
$\nu_\tau$



Like its sibling leptons the electron-neutrino and muon-neutrino, this cheeky little devil, the **TAU-NEUTRINO**, is extremely difficult to detect (hence the bandit's mask). Discovered in 2000, it is about 100 times heavier than a muon-neutrino.

*Wool felt with poly fill for minimum mass.*

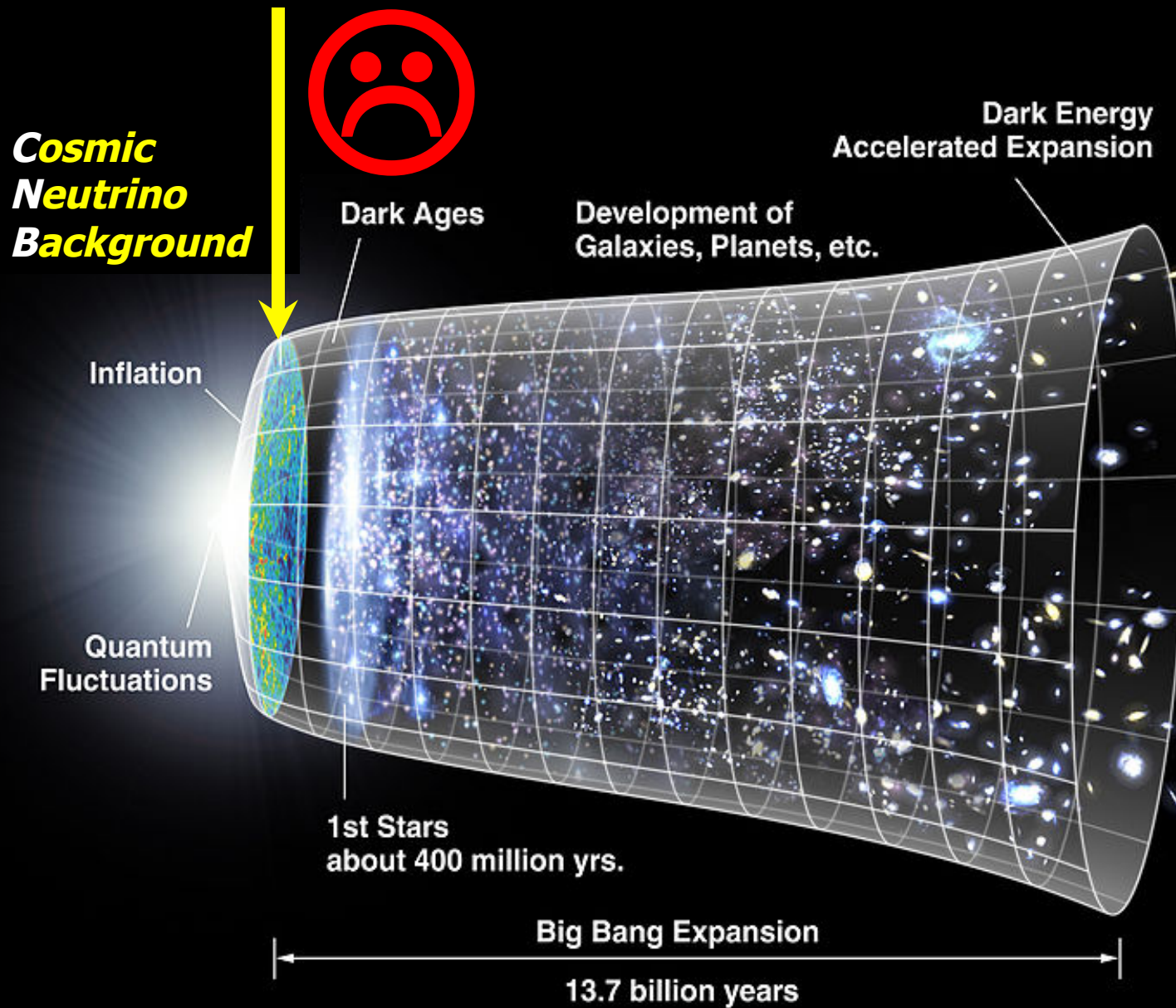
**\$10.49** PLUS SHIPPING

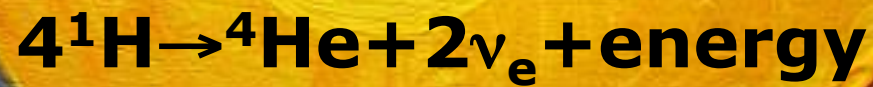


GLUON PHOTON NEUTRINO TACHYON ELECTRON UP QUARK DOWN QUARK TAU NEUTRINO MUON UP QUARK  
NEUTRON DOWN QUARK TAU GLUON **TAU-NEUTRINO** TACHYON ELECTRON UP QUARK DOWN QUARK  
NEUTRINO MUON UP QUARK PROTON NEUTRON DOWN QUARK TAU NEUTRINO TACHYON  
The **PARTICLE ZOO**

# Photons *low energy*

“dreaming” of a few seconds “old” Universe!





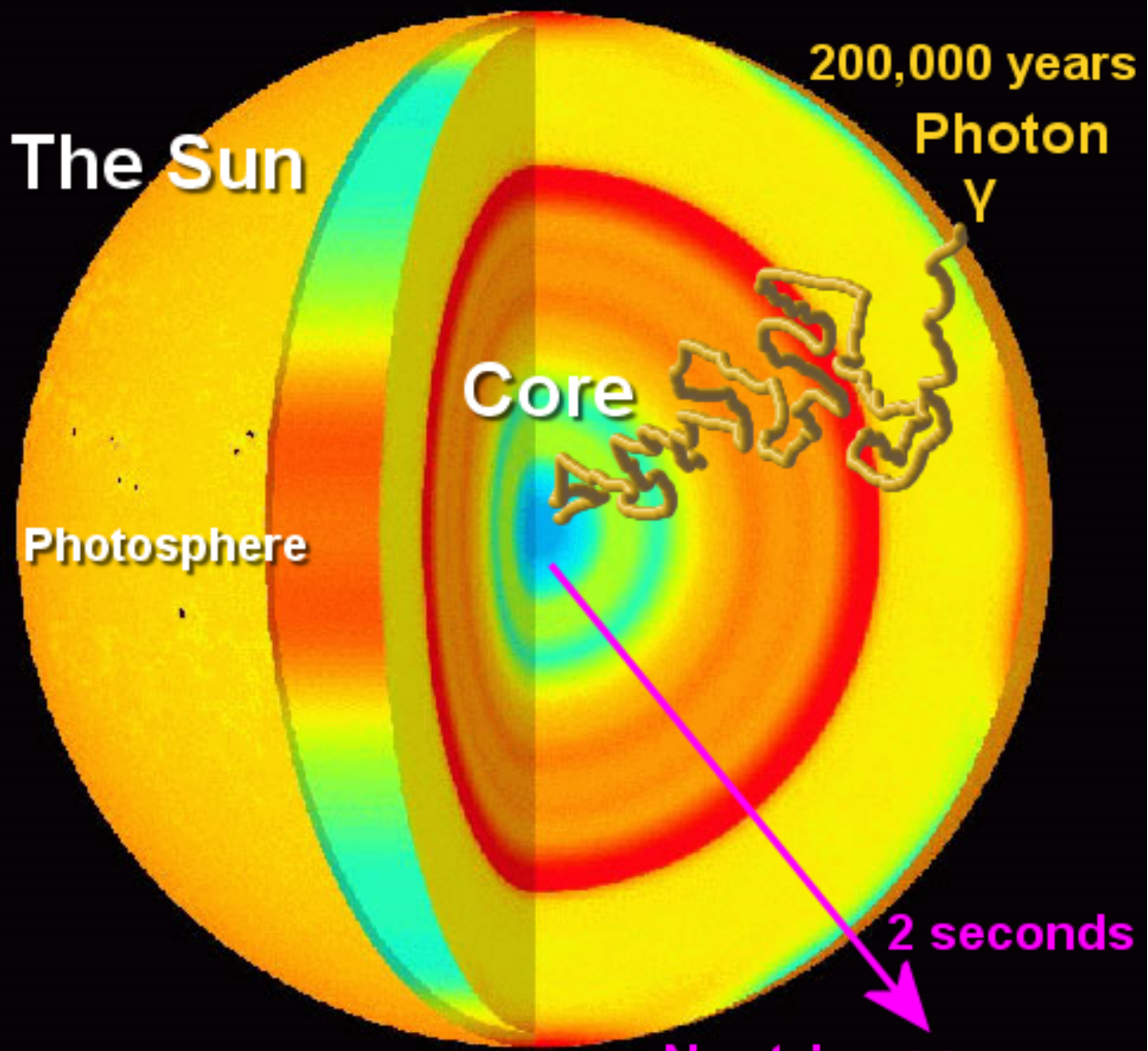
*are*

*$\nu$ 's*

*rare?*

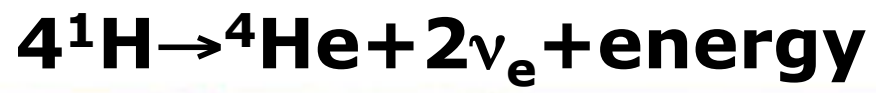
# Neutrino's low energy

Photons take a long and tortuous path

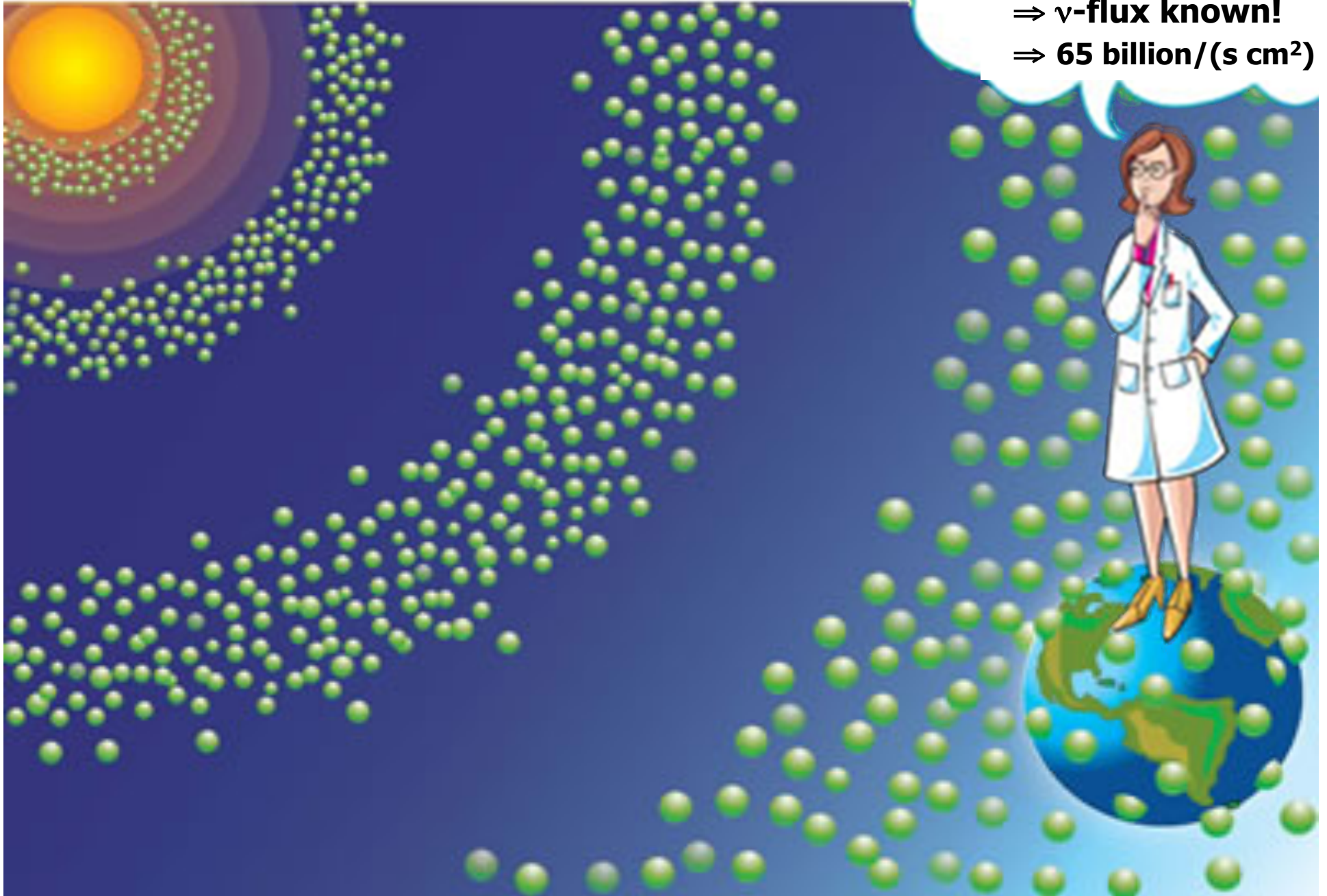


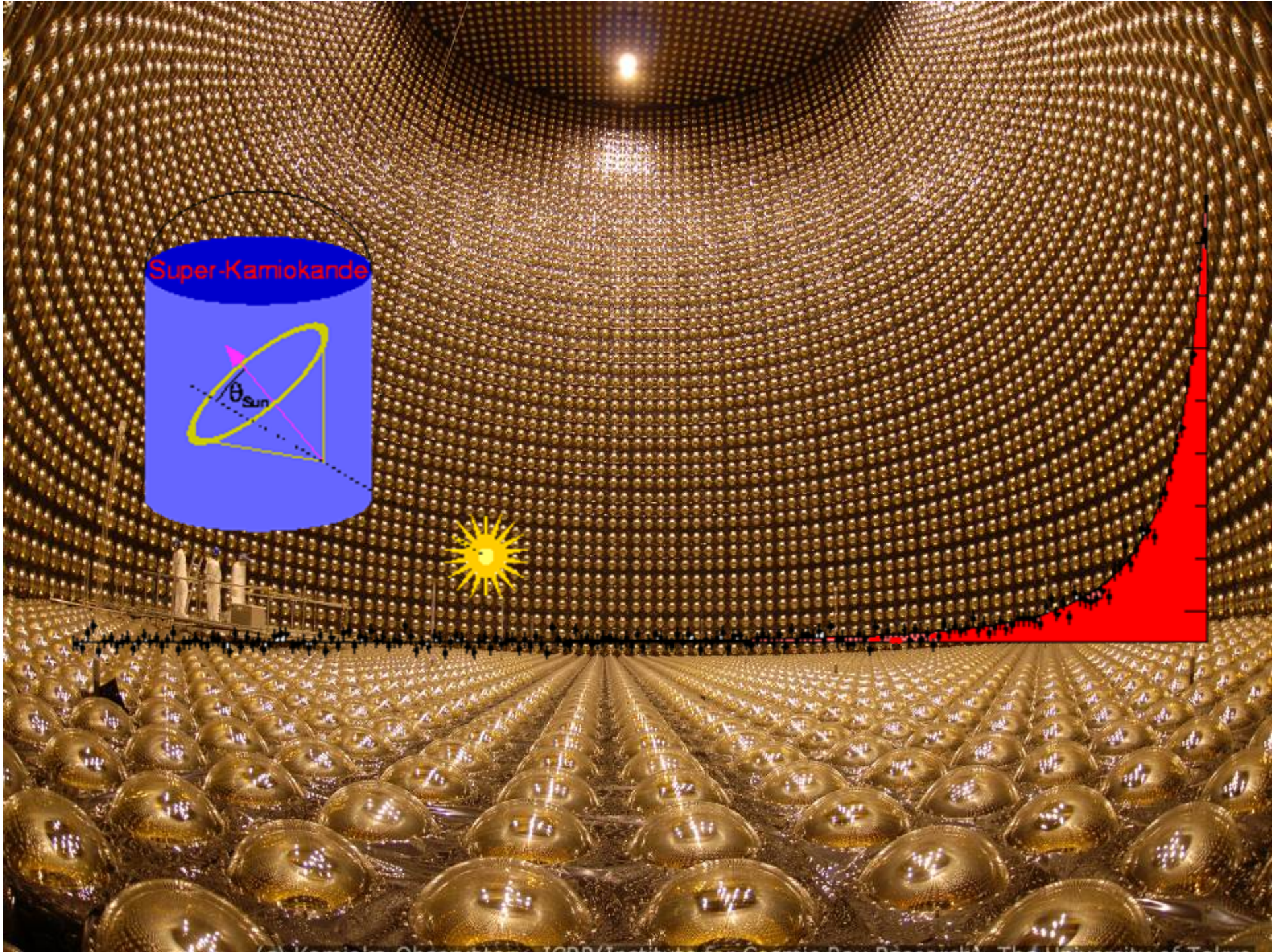
Neutrinos zip through quickly



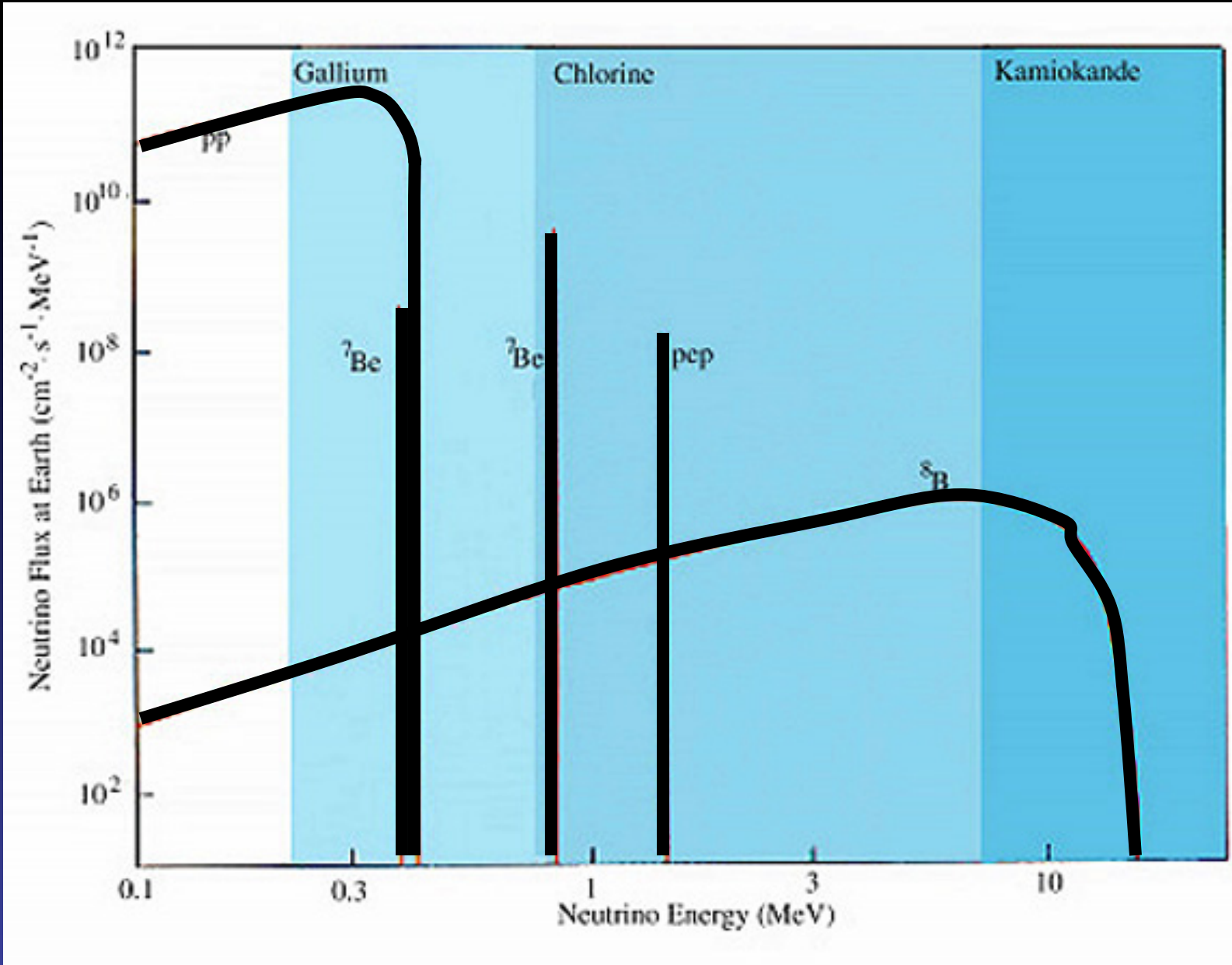


On Earth:  
**1400 W/m<sup>2</sup>**  
⇒  **$\nu$ -flux known!**  
⇒ **65 billion/(s cm<sup>2</sup>)**

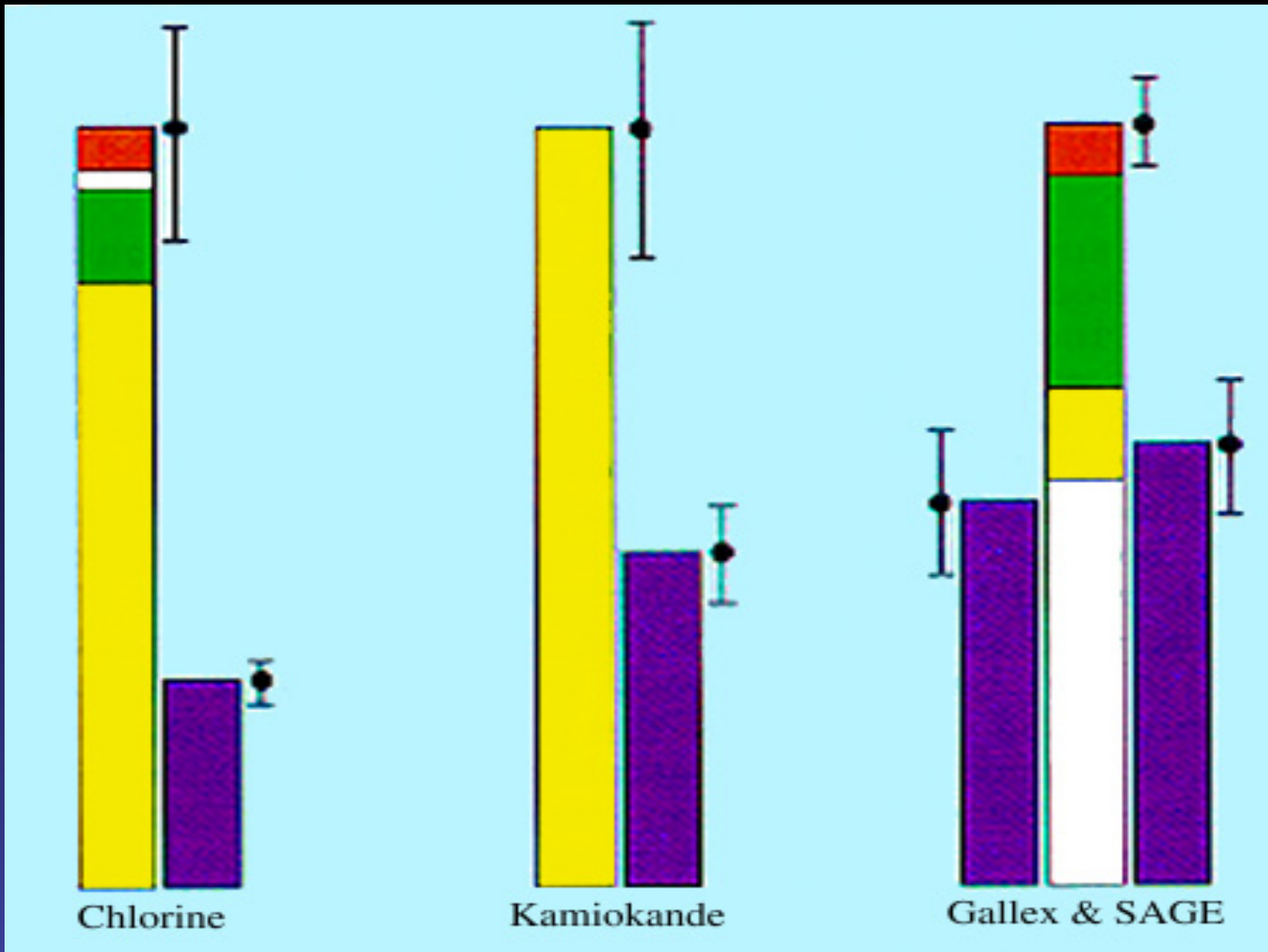


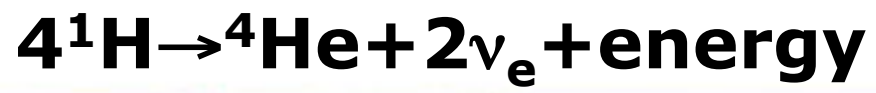


# Neutrino's low energy

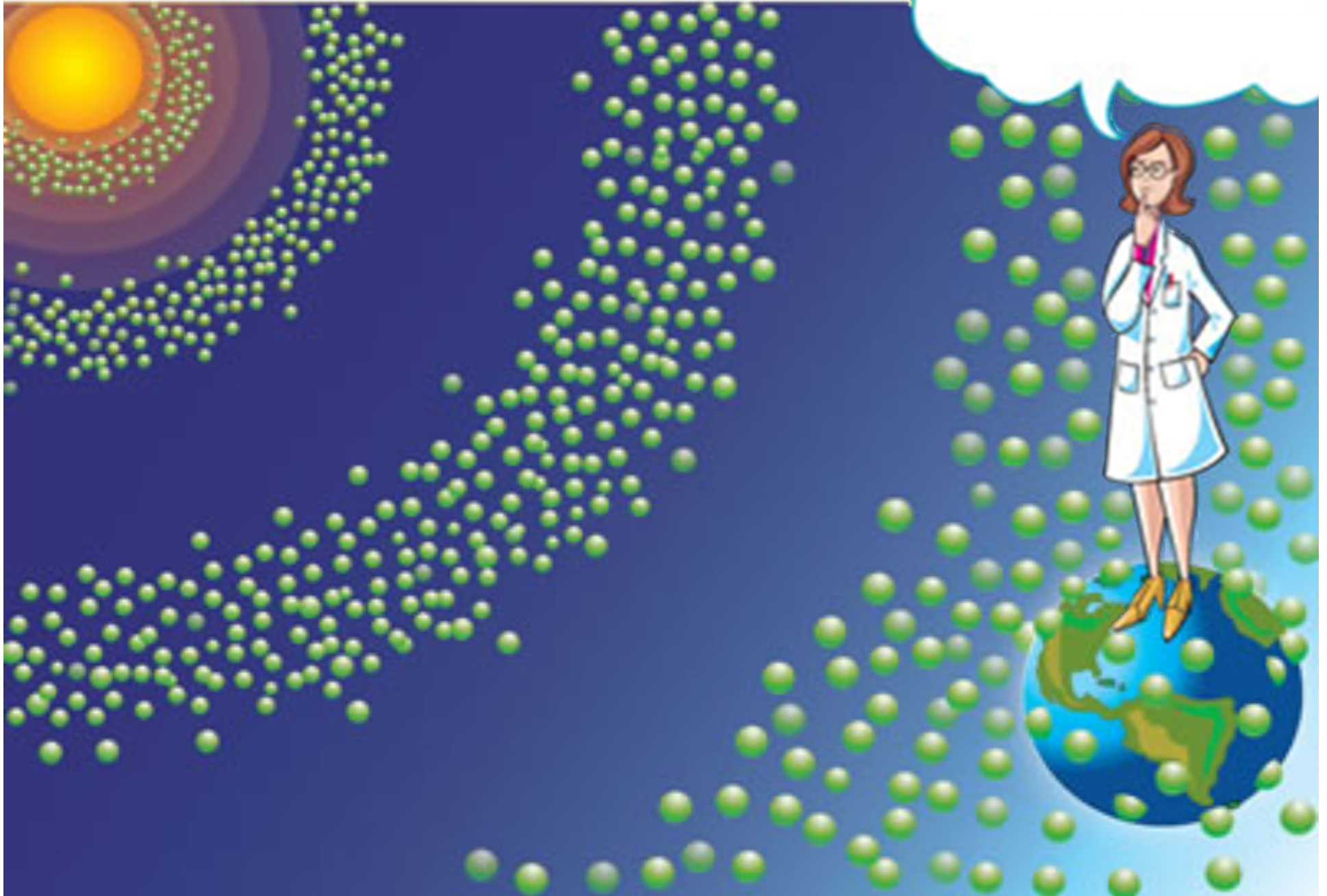


# Neutrino's *low energy*





To few neutrino's  
observed ????????

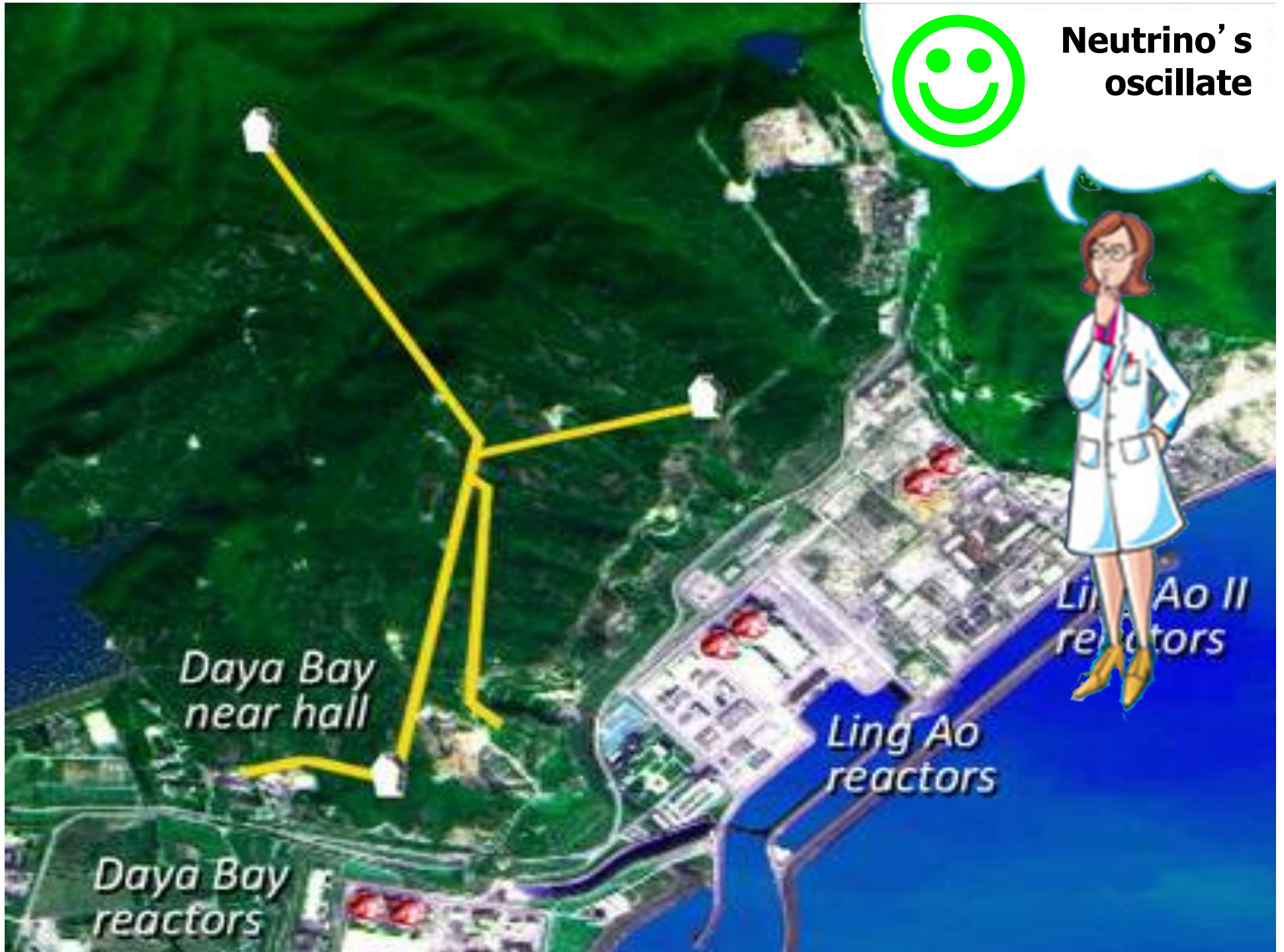


# Neutrino “oscillations”





Neutrino's  
oscillate



***supernova SN1987A neutrino's***














***supernova SN1987A neutrino's***



# Intermezzo I begin

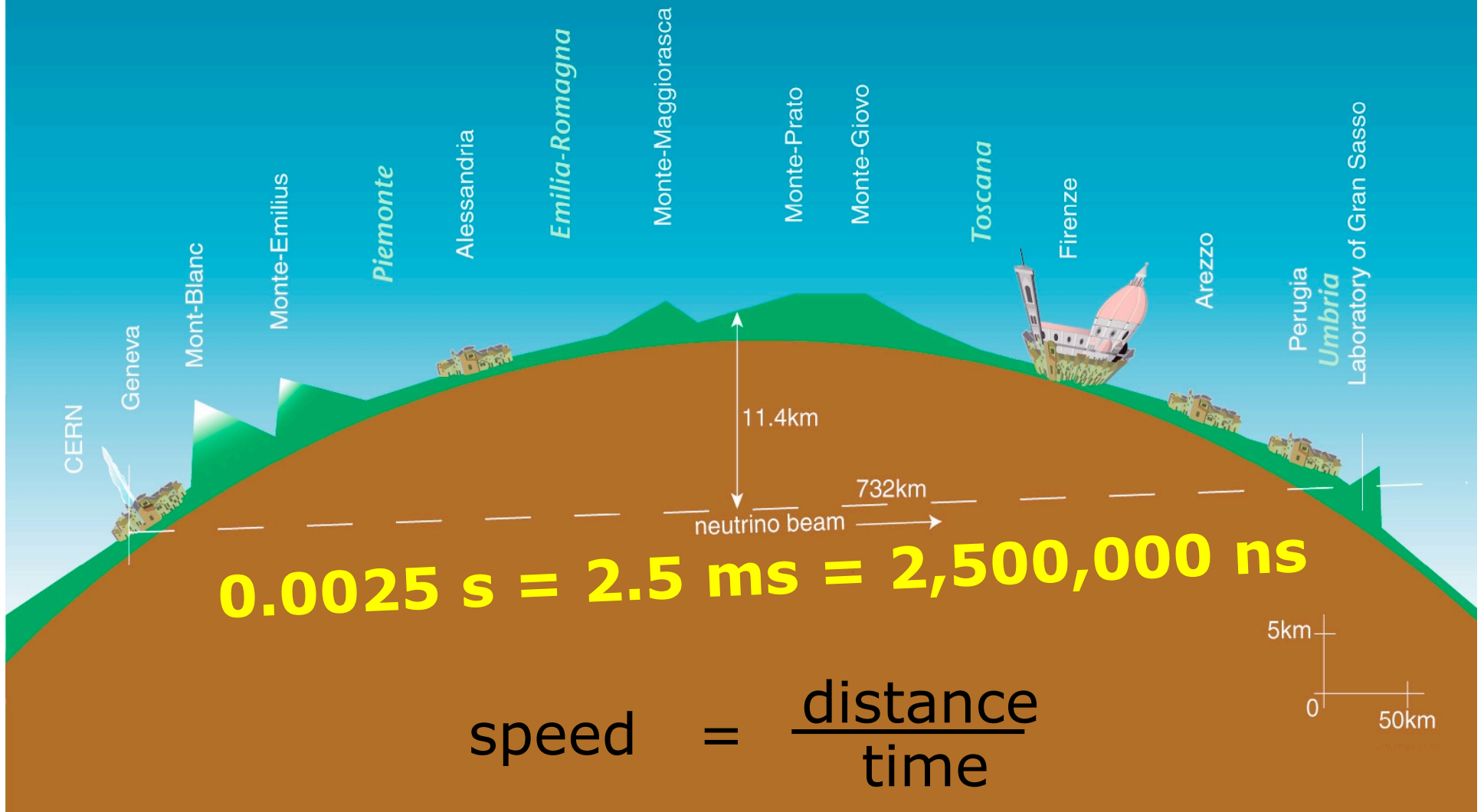
## *neutrino speed*

Massa Lading	Gevoelg voor:	Elektronische interactie Zwakke interactie Sterke interactie Gravitatie
 u	 c	 t
 d	 s	 b
 $V_e$ e	 $V_\mu$ $\mu$	 $V_\tau$ $\tau$

Feynman Diagrams (1984)

# CNGS

## *CERN Neutrino's to Gran Sasso*



# CERN



SUISSE  
FRANCE

CMS

LHCb



ATLAS

CERN Main Ring



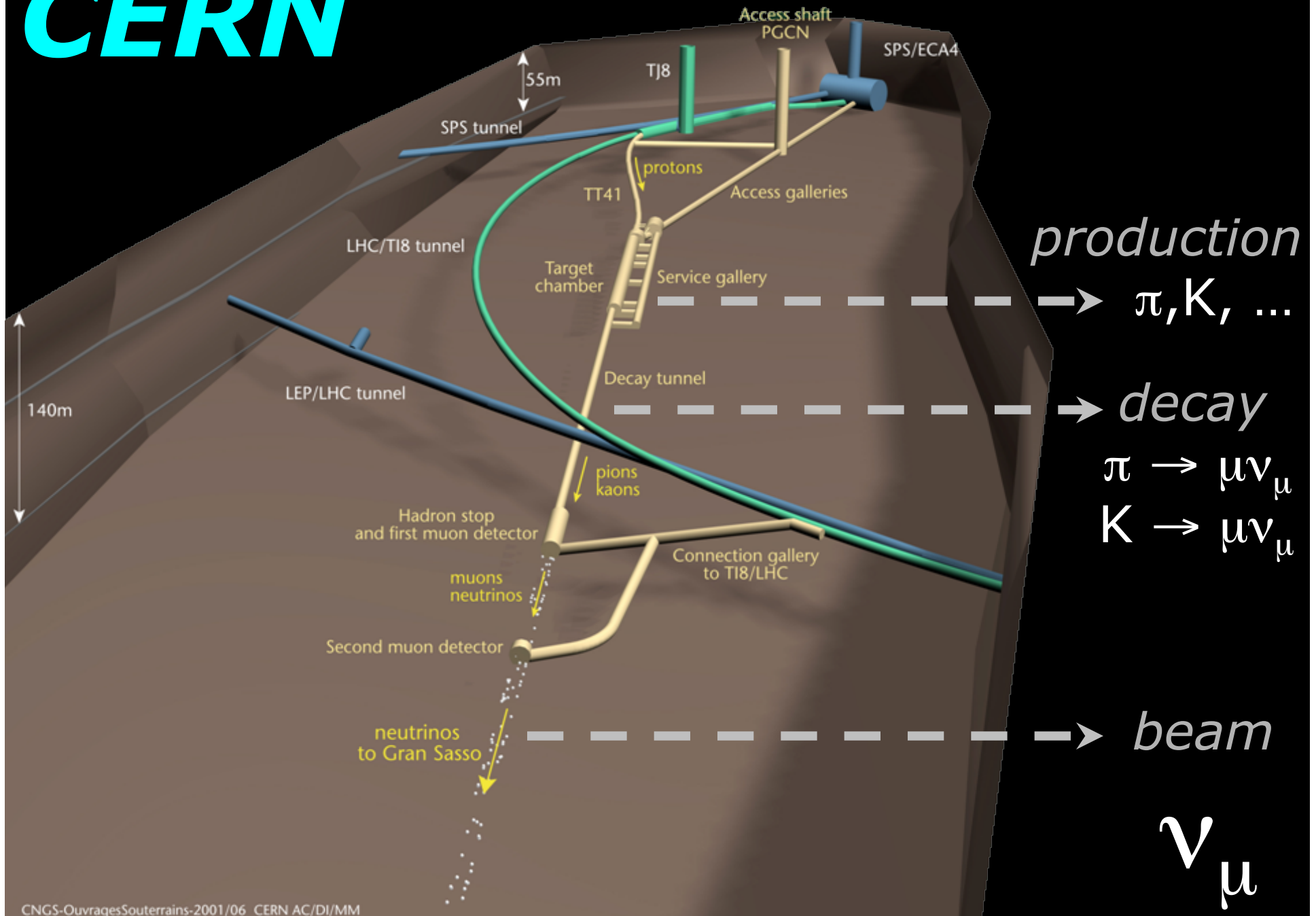
SPS 7 km

CERN Pre-Injector

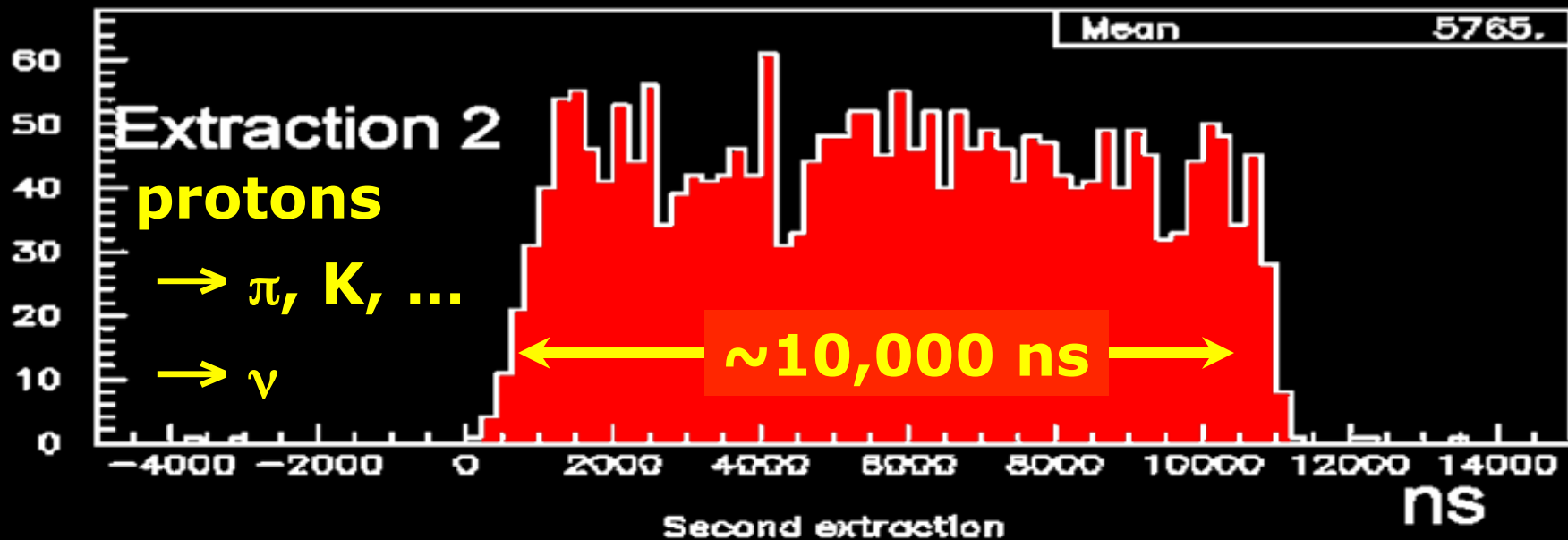
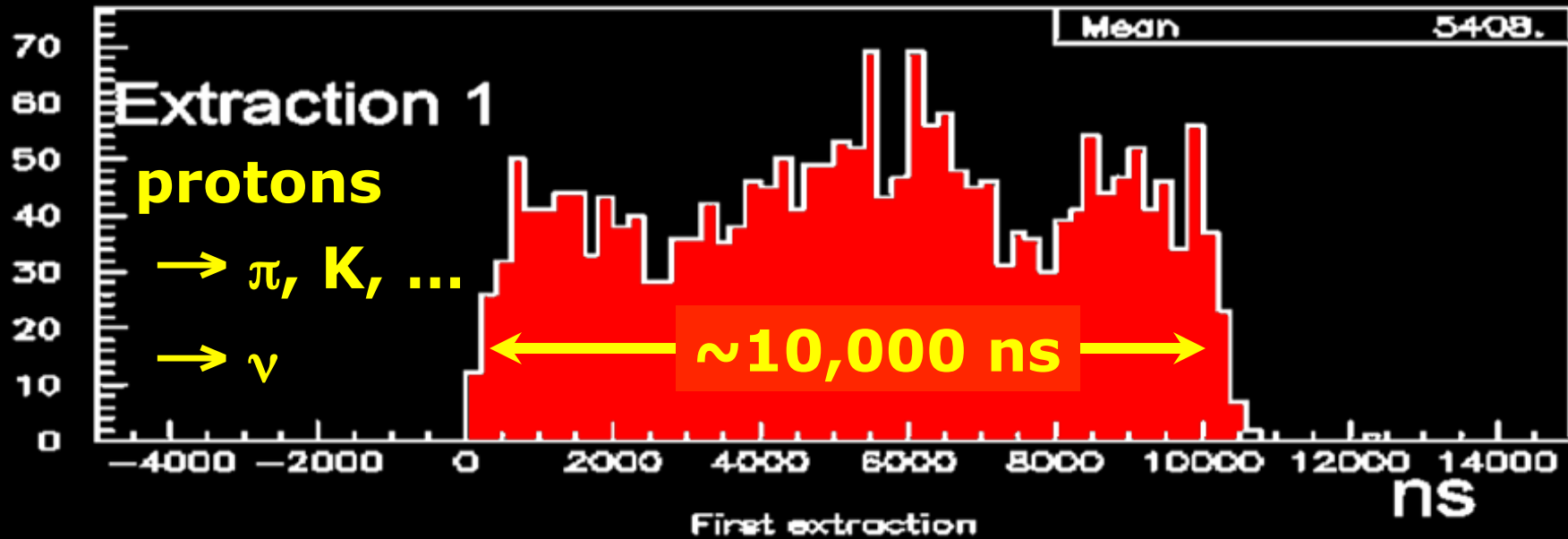
ALICE

LHC 27 km

# CERN



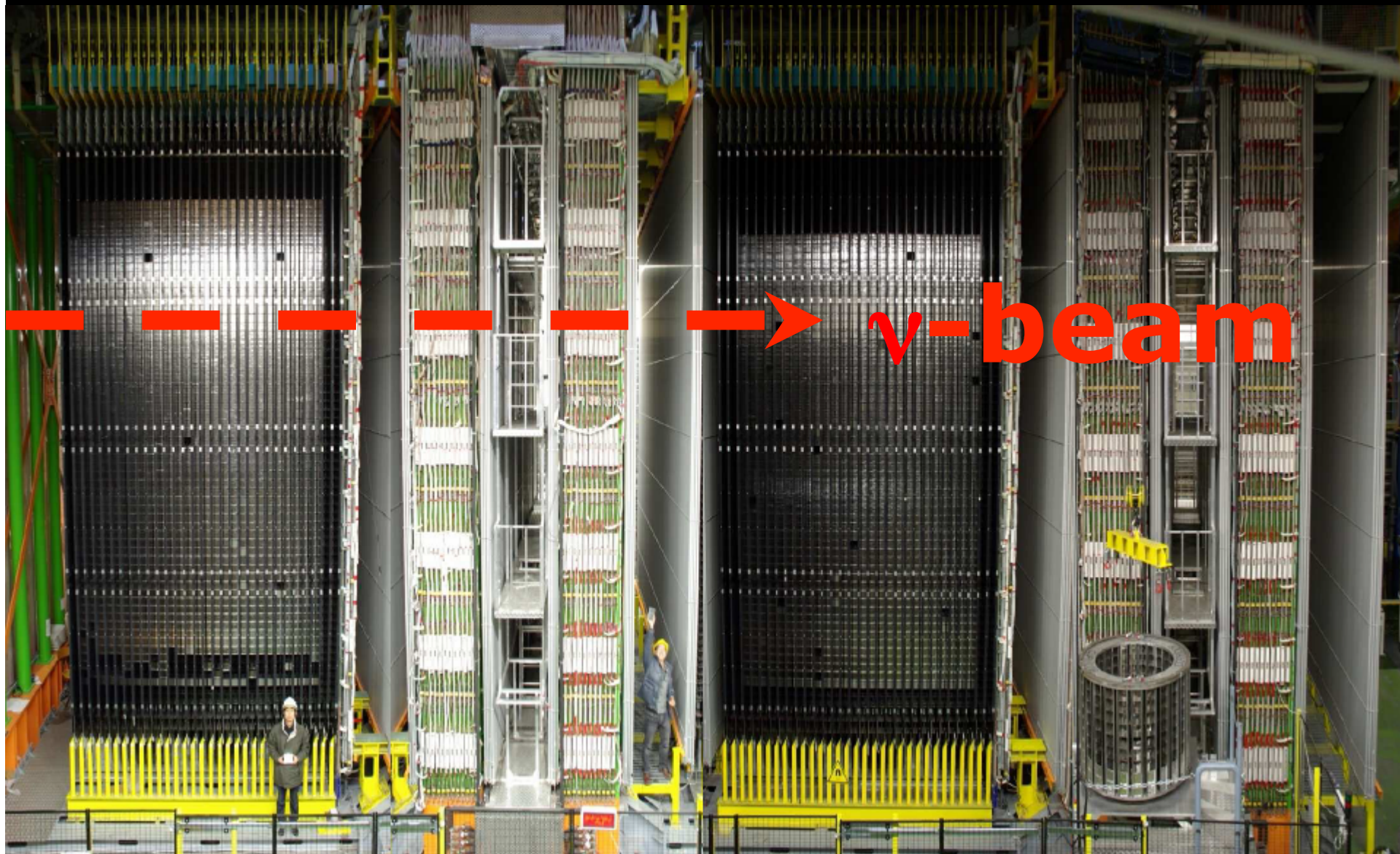
# Time profile “ $\nu$ -pulse” at CERN



# **LNGS:** *Laboratori Nazionali del Gran Sasso*

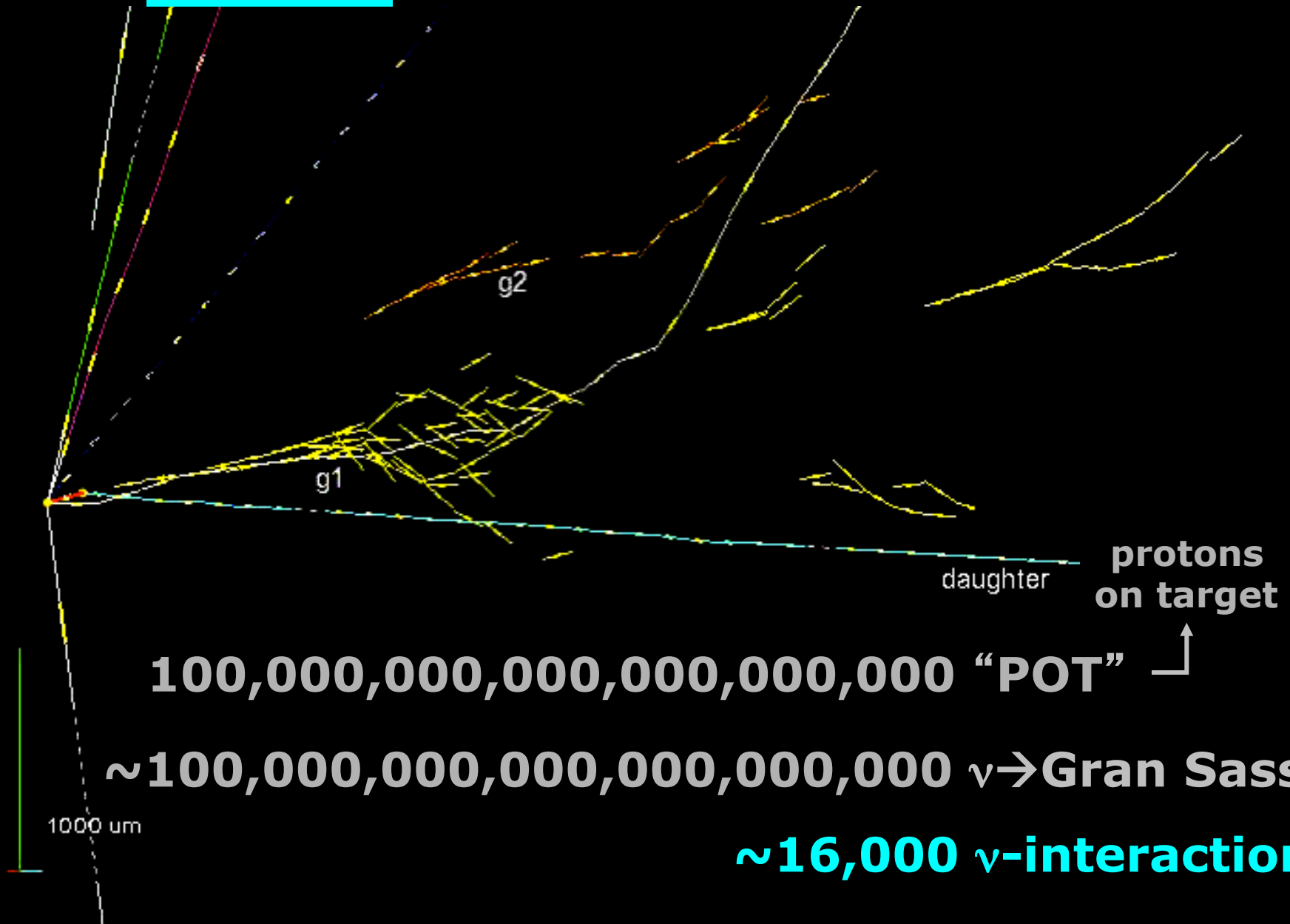


# ***OPERA** detector*

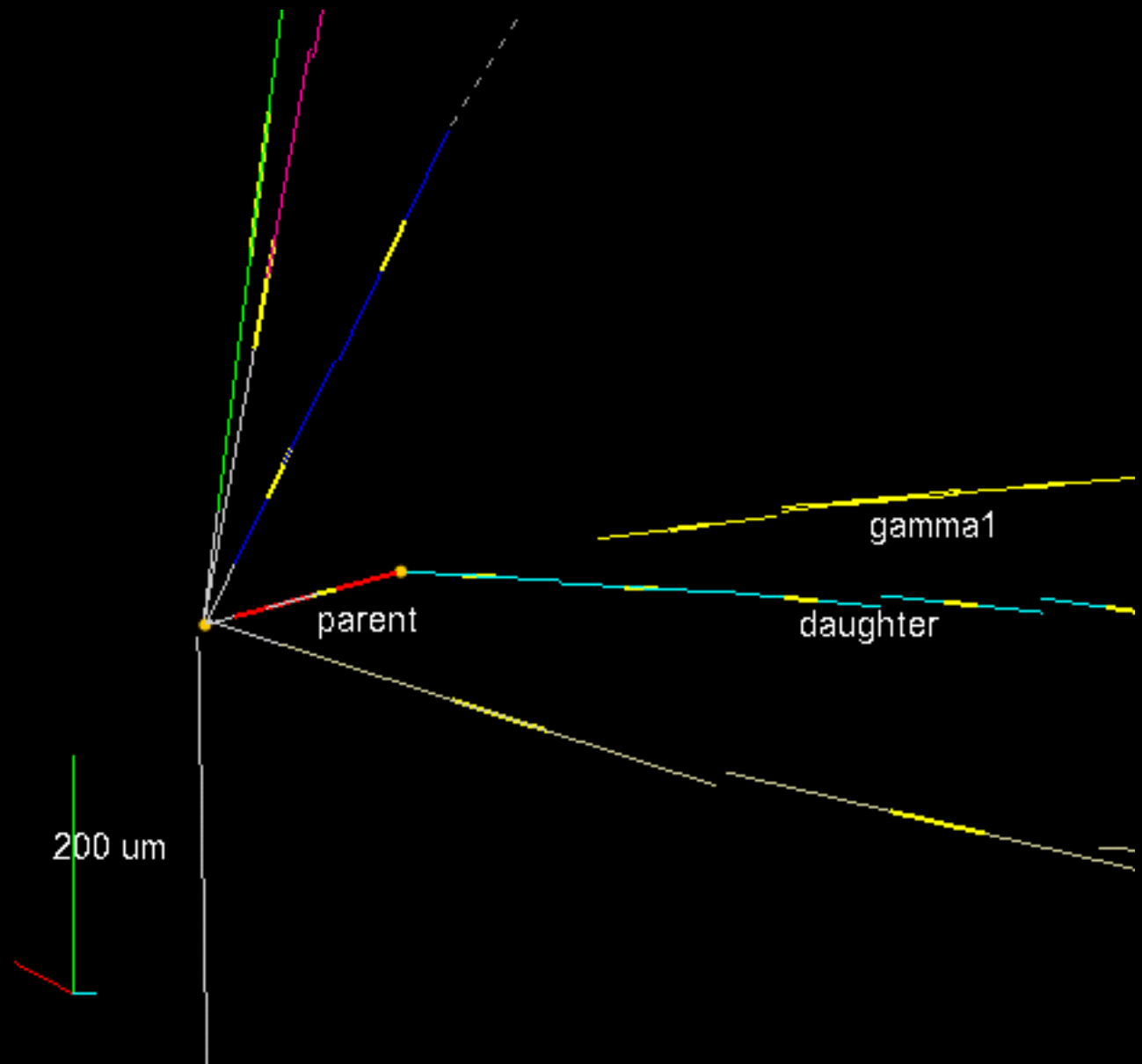




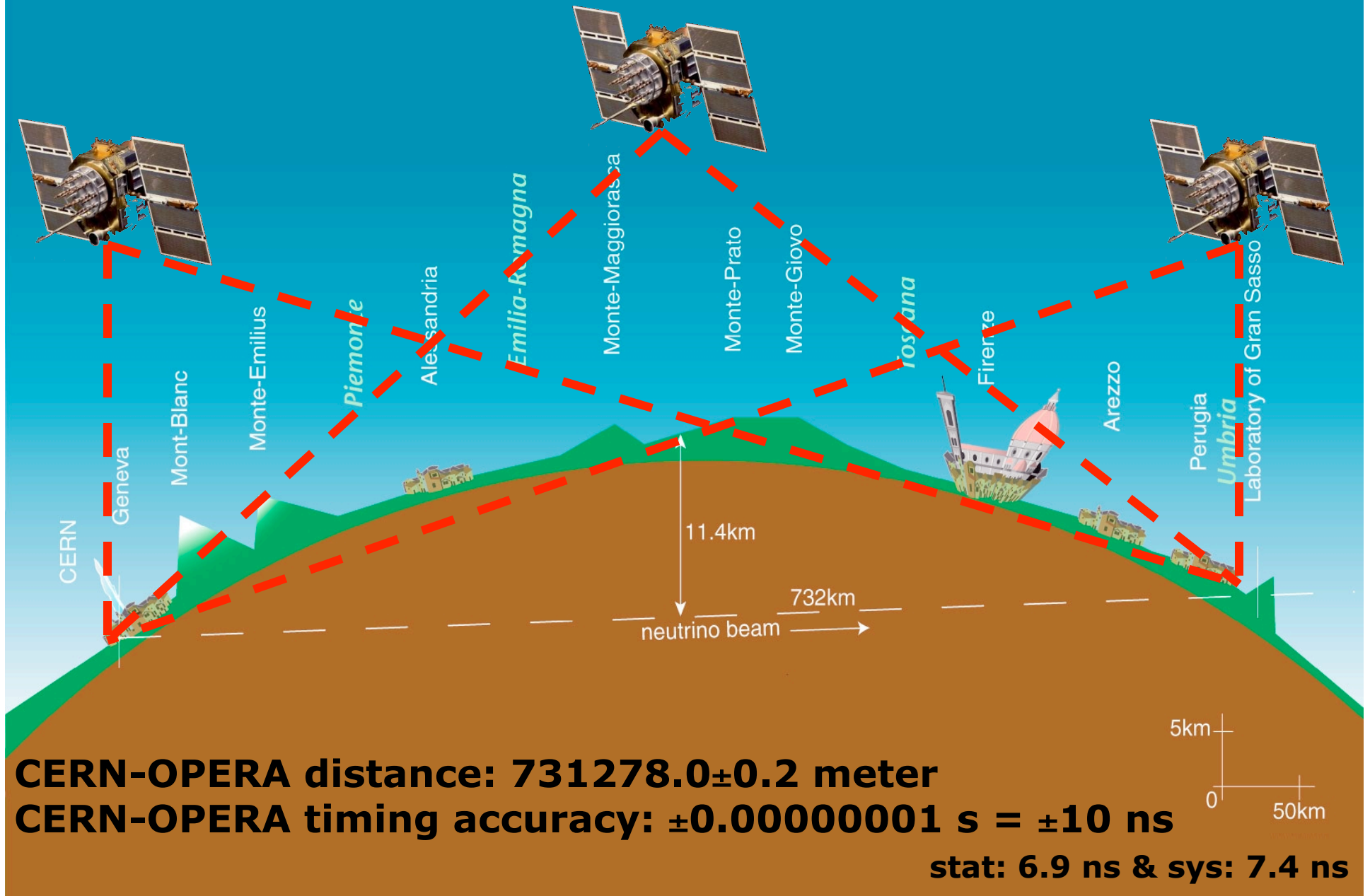
# The OPERA event



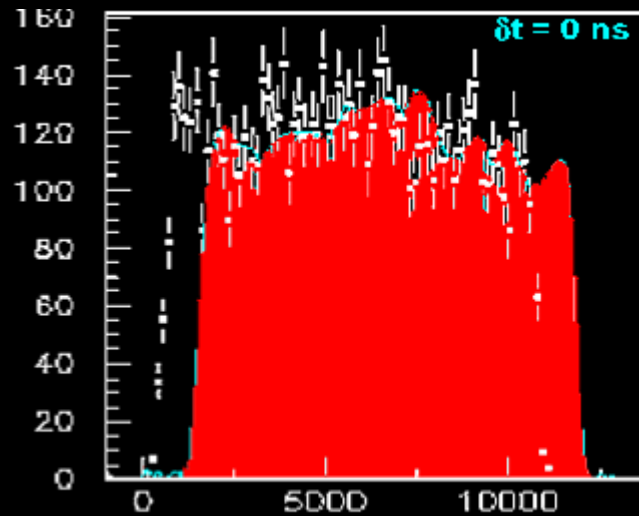
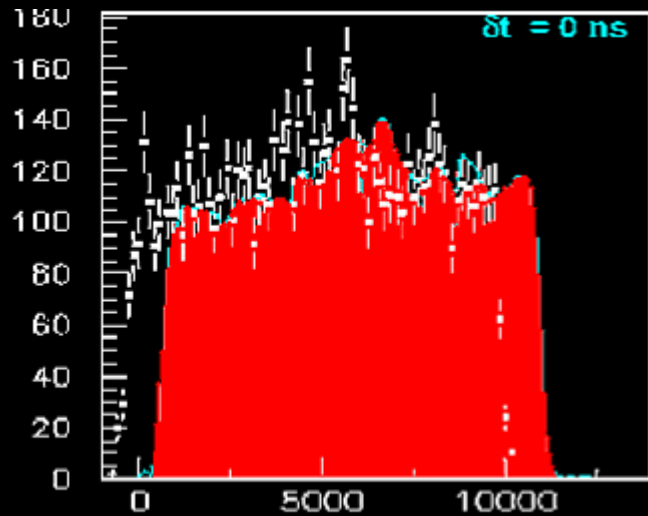
# The OPERA event



# The measurement



# *The result*



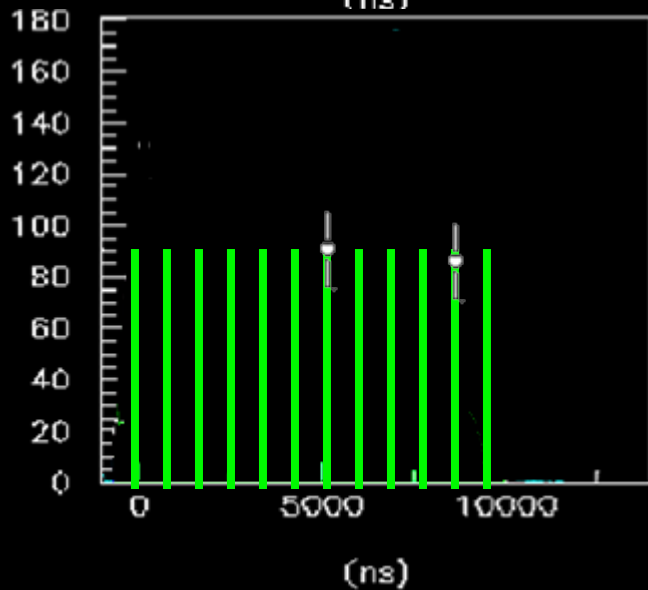
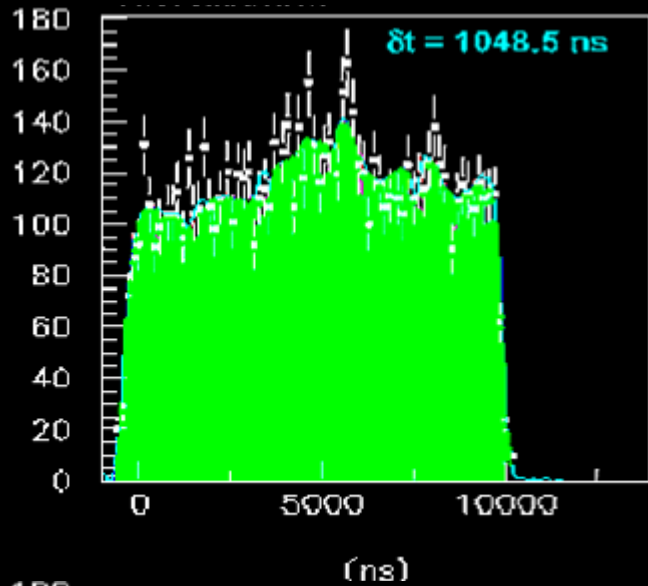
compare  
measured  
&  
predicted  
spectra

shift

corrections

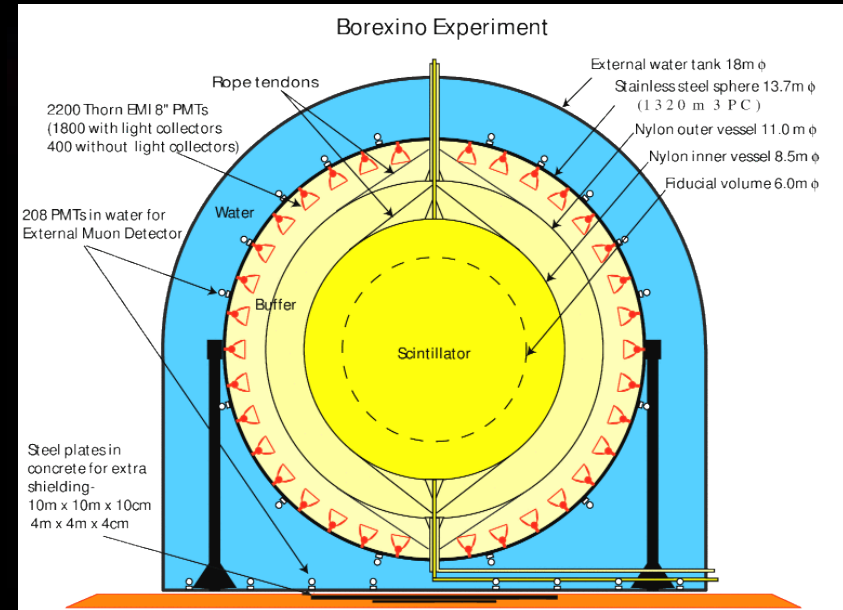
$\nu$   $60 \pm 10$  ns  
faster than  
light!

# Follow-up measurements



**BOREXINO**

**ICARUS**

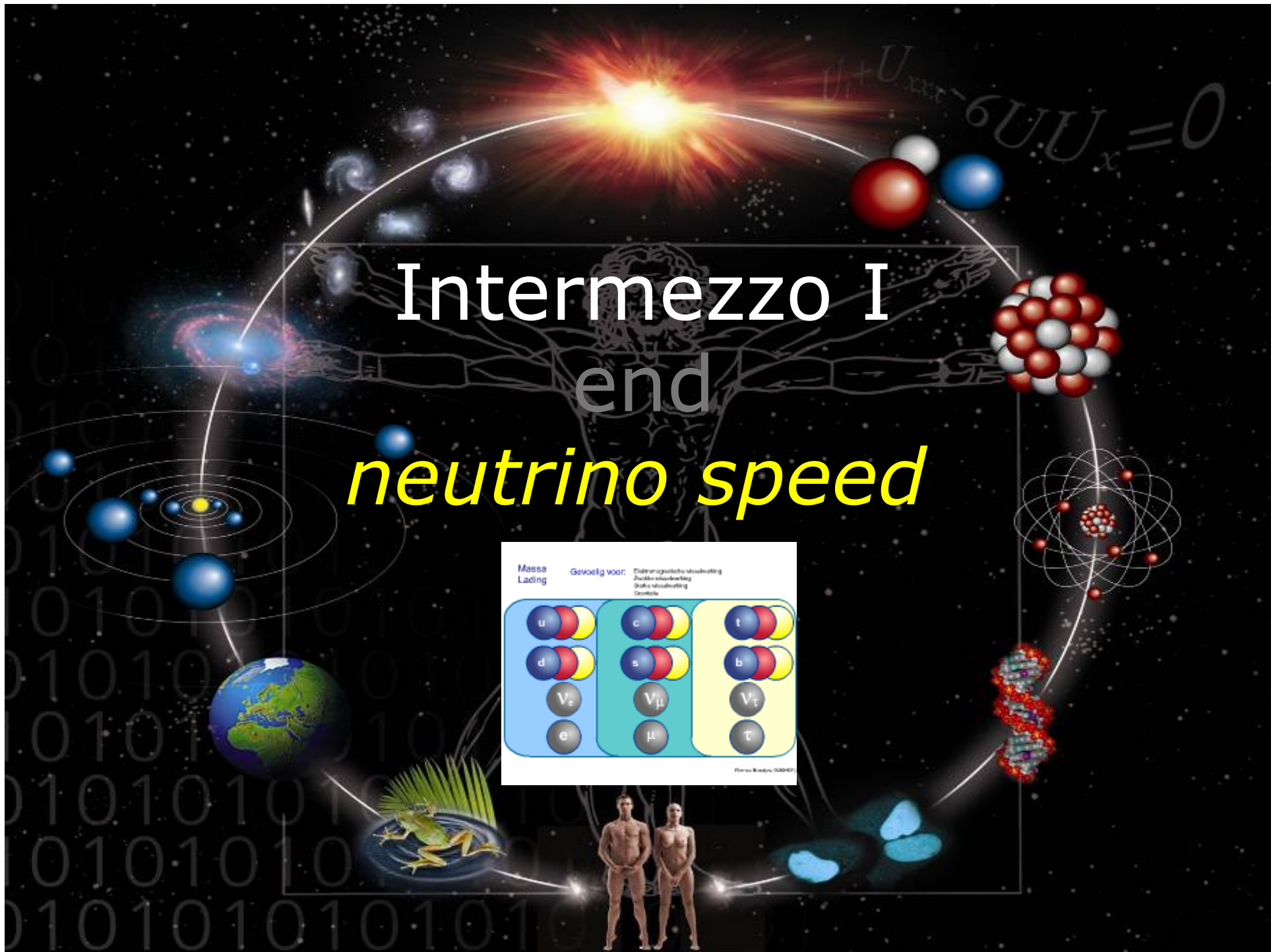


Implication: *cause*  $\leftrightarrow$  *consequence*

# Intermezzo I end *neutrino speed*

Massa Lading	Gevoelg voor:	Elektronische interactie Zwakke interactie Sterke interactie Gravitate
u		
d		
$V_e$		
e		
c		
s		
$V_\mu$		
$\mu$		
t		
b		
$V_\tau$		
$\tau$		

Feynman Diagrams (1984)



# Intermezzo II

## begin

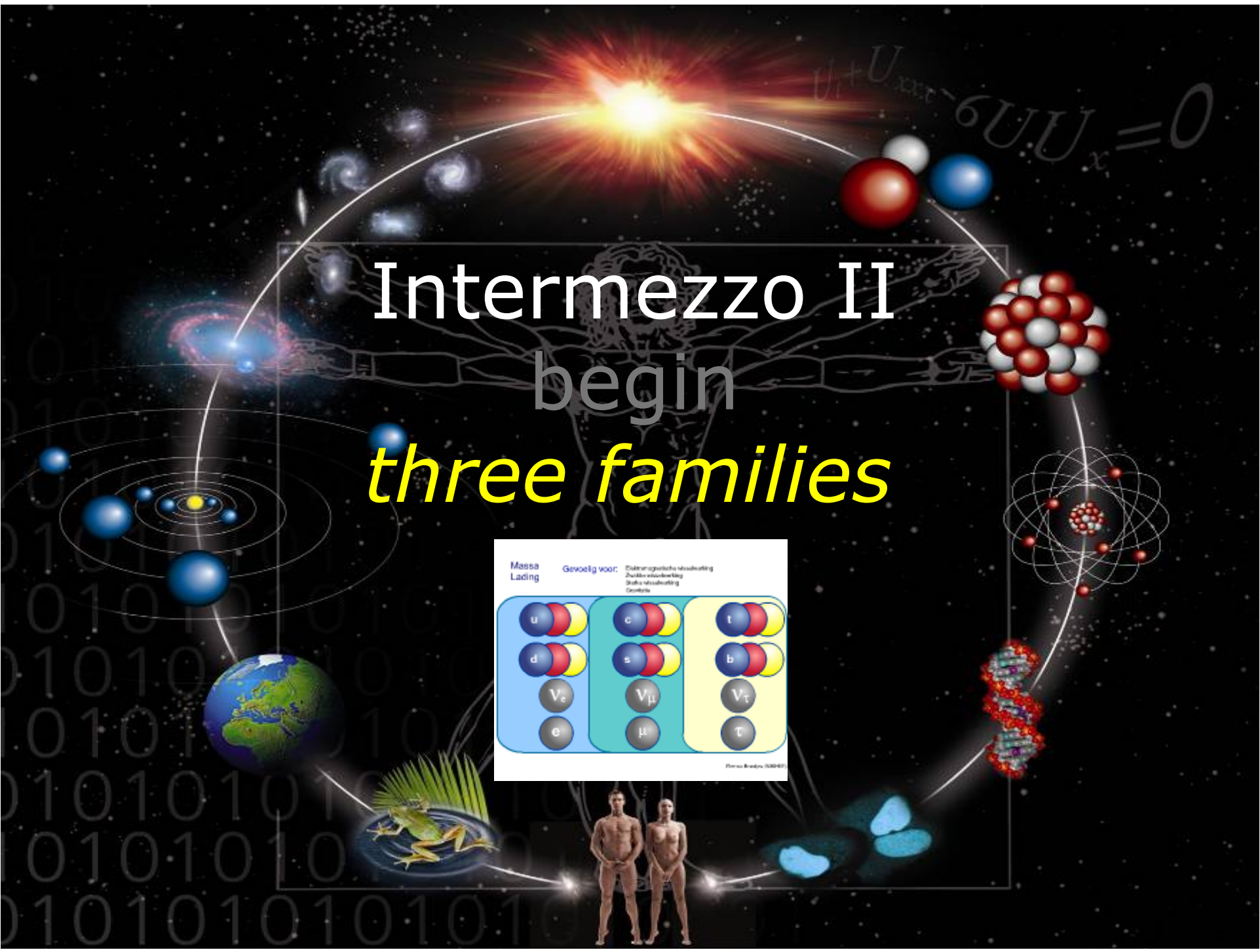
### *three families*

Massa Lading	Gevoelg voor:	Elektronische interactie Zwakke interactie Sterke interactie Gravitatie
u		
d		
$V_e$		
e		
c		
s		
$V_\mu$		
$\mu$		
t		
b		
$V_\tau$		
$\tau$		

Feynman (1984)

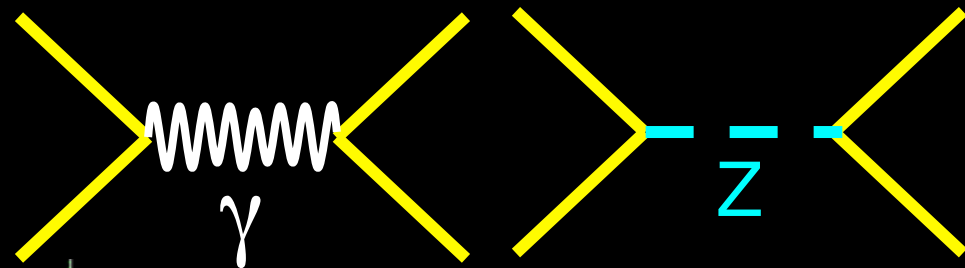
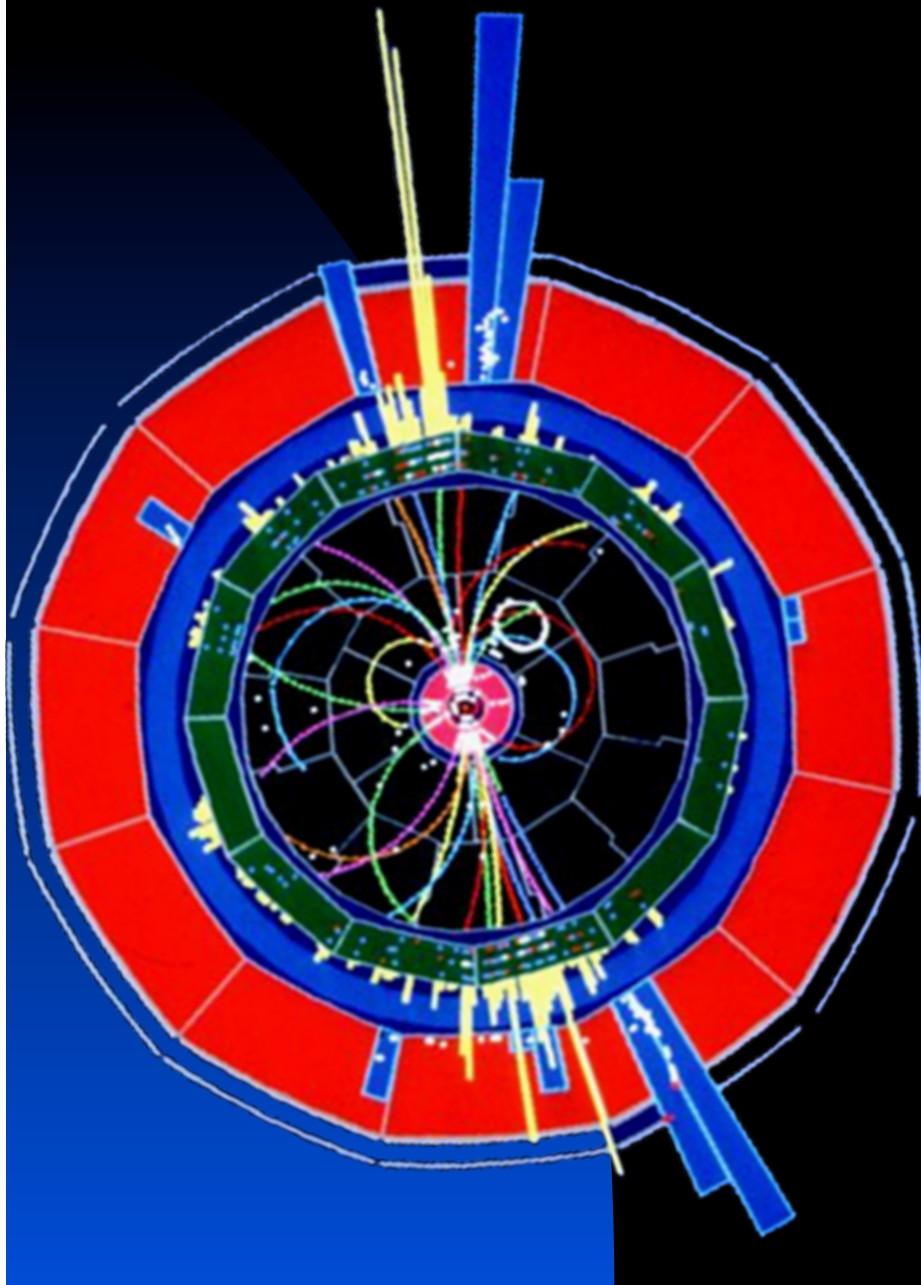


$$U_1 + U_{ext} - 6U_2 U_x = 0$$



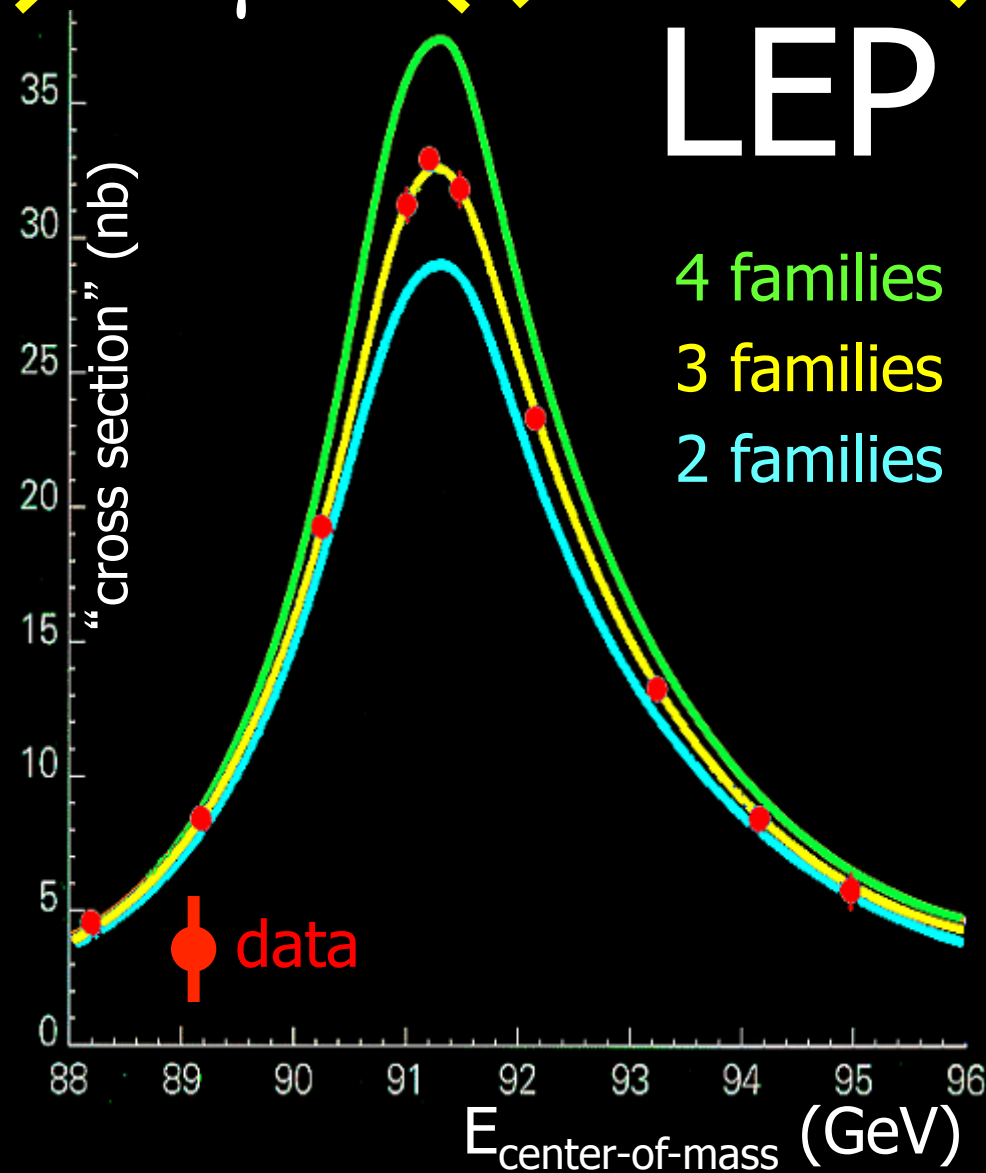


$e^+e^- \rightarrow$  quark antiquark  
production rate

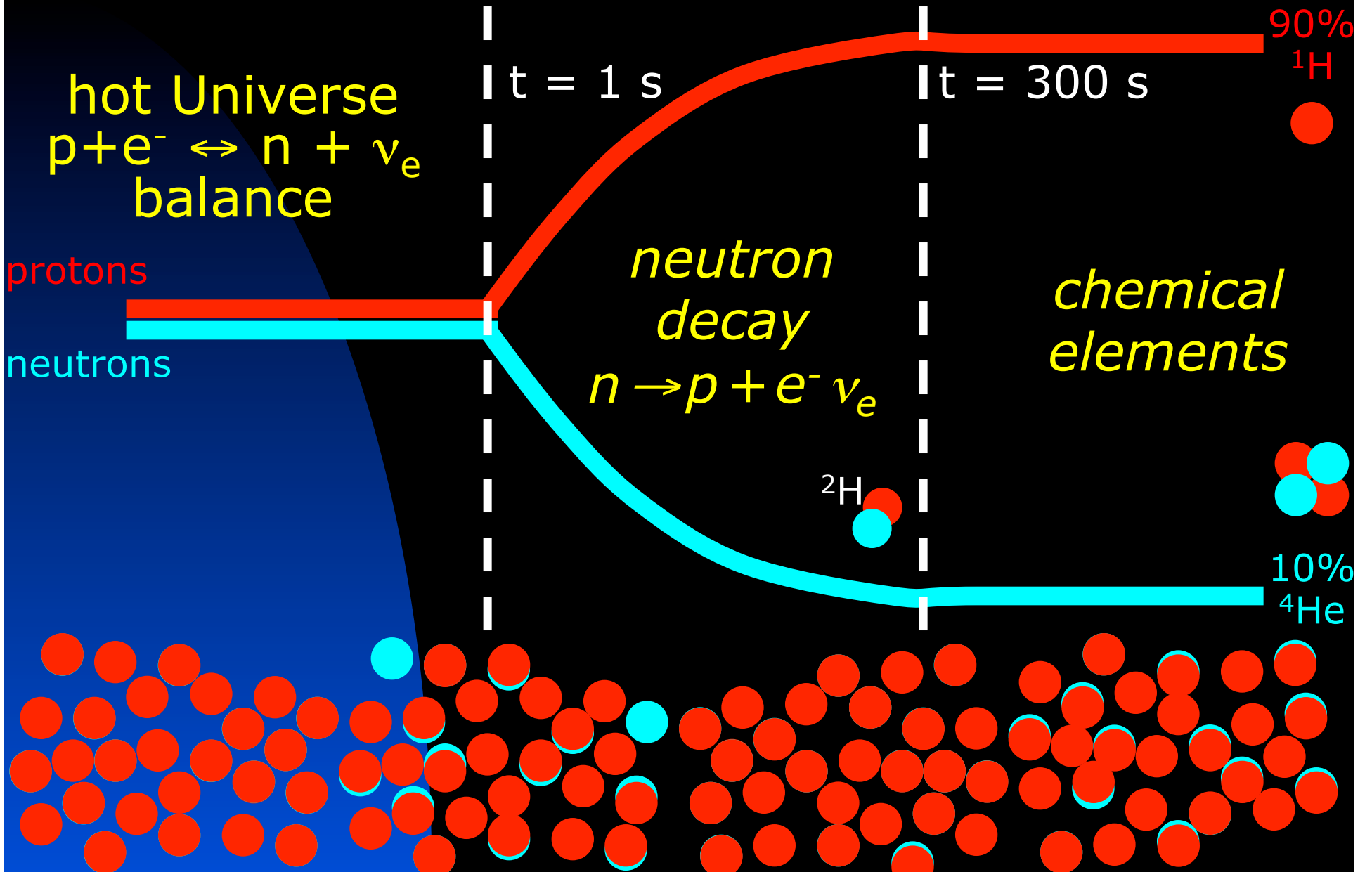


# LEP

4 families  
3 families  
2 families

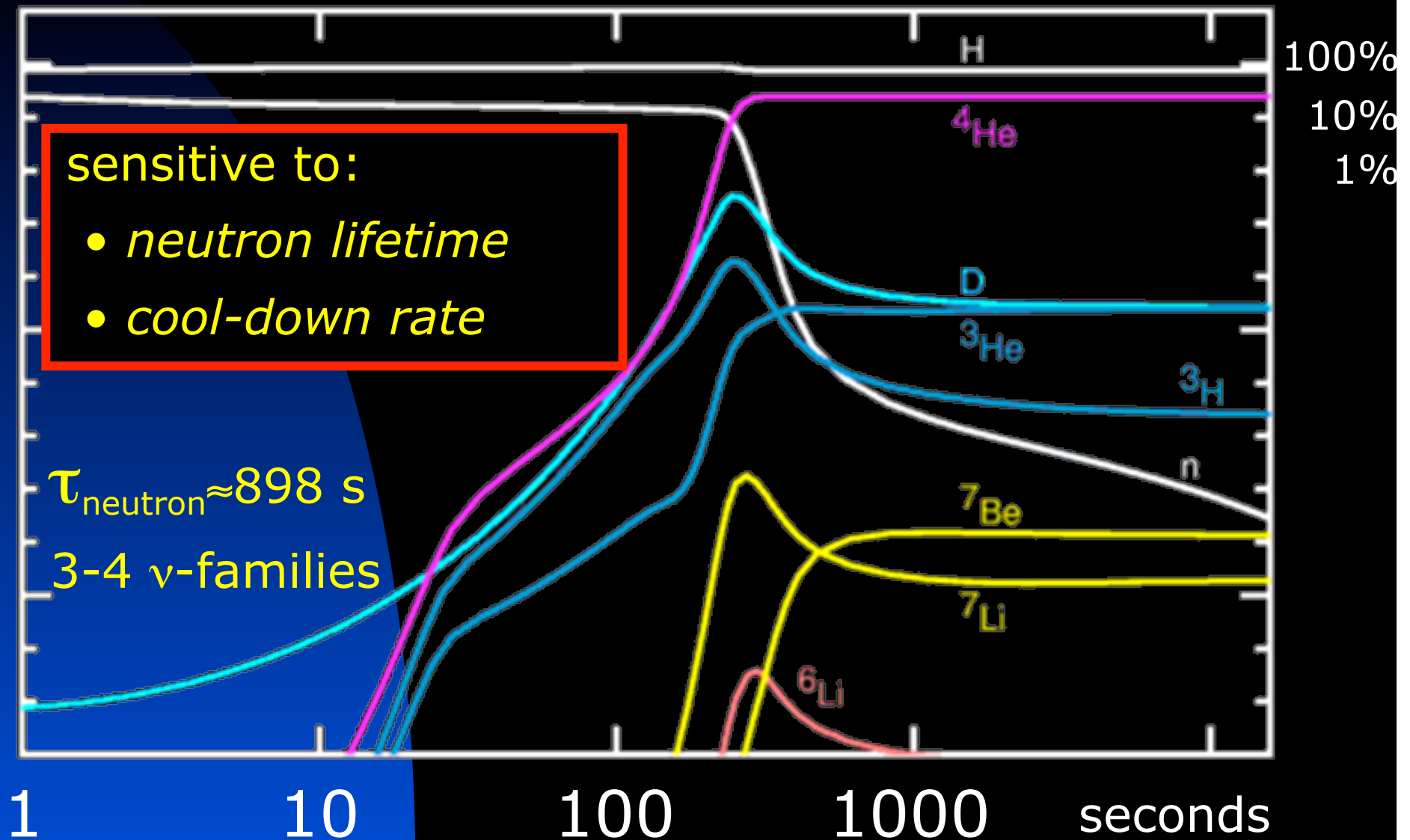


# hydrogen/helium ratio



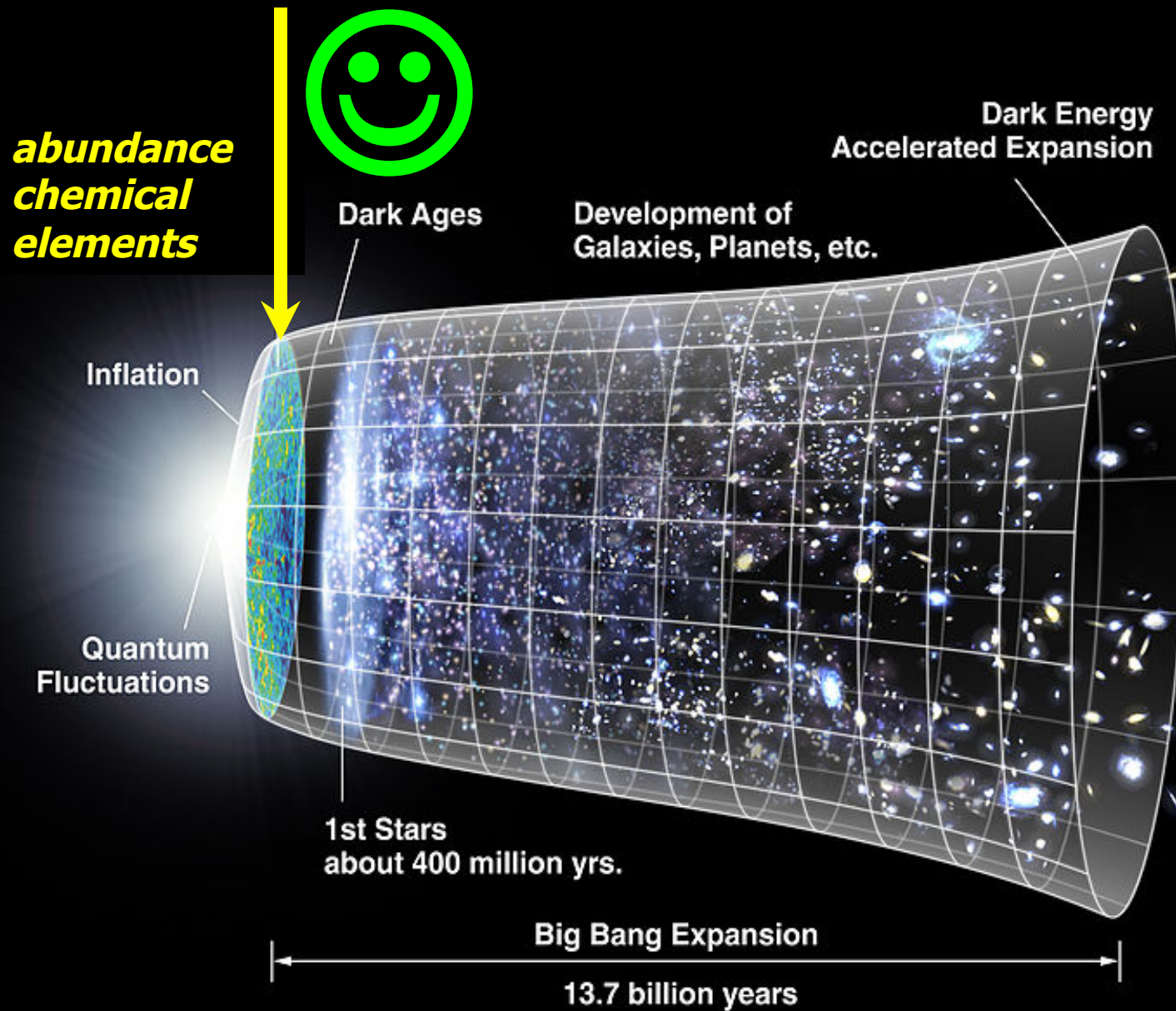
# Mass ratio chemical elements

Gamov, Alpher & Herman (1948)



# Neutrino's

“imprint” from a few minutes “old” Universe!



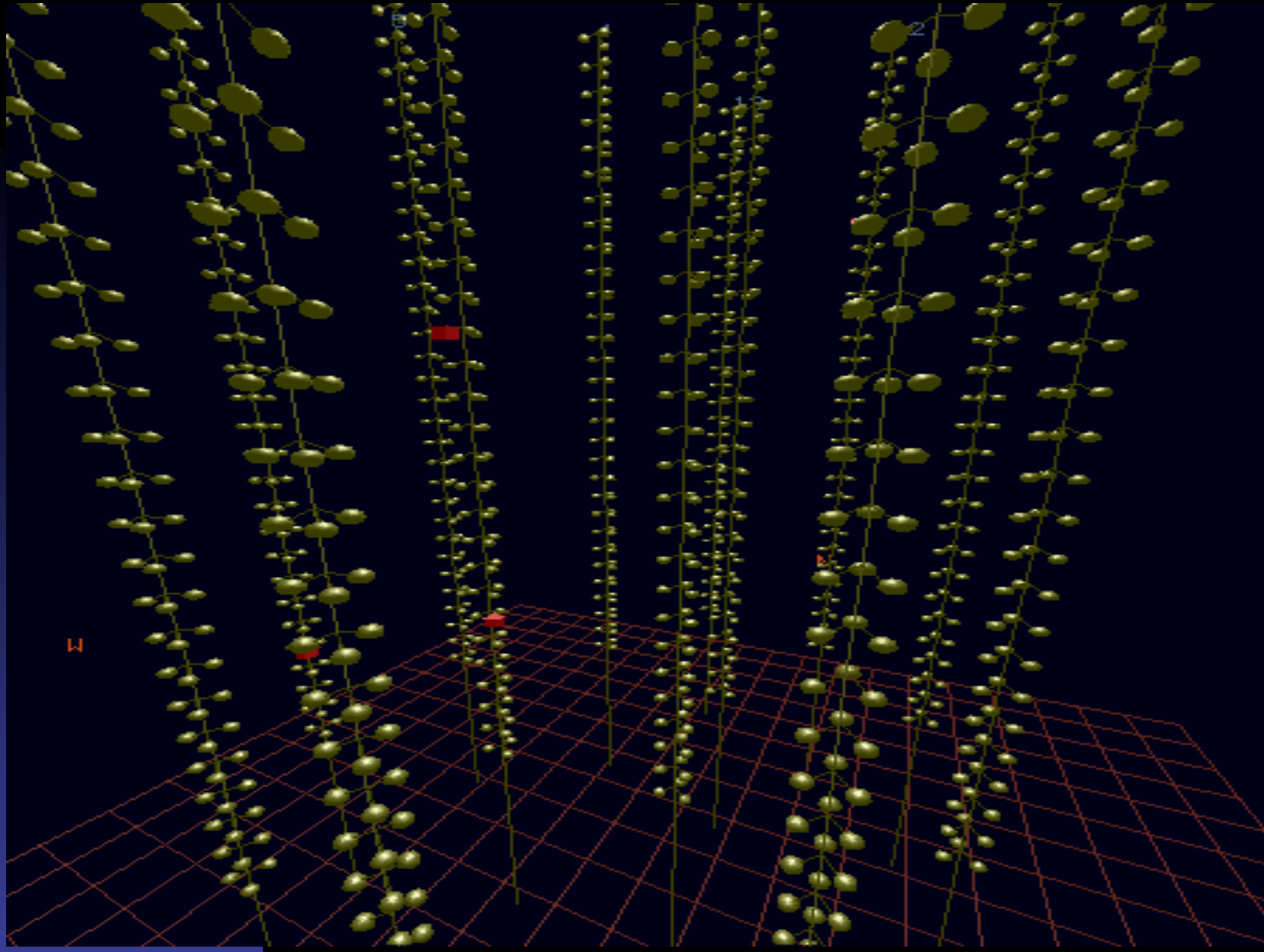
# Intermezzo II end *three families*

Massa Lading	Gevoelg voor:	Elektronische interactie Zwakke interactie Sterke interactie Gravitatie
u		Elektronische interactie
d		Zwakke interactie
$V_e$		Sterke interactie
e		Gravitatie
c		Elektronische interactie
s		Zwakke interactie
$V_\mu$		Sterke interactie
$\mu$		Gravitatie
t		Elektronische interactie
b		Zwakke interactie
$V_\tau$		Sterke interactie
$\tau$		Gravitatie

Feynman (1984)



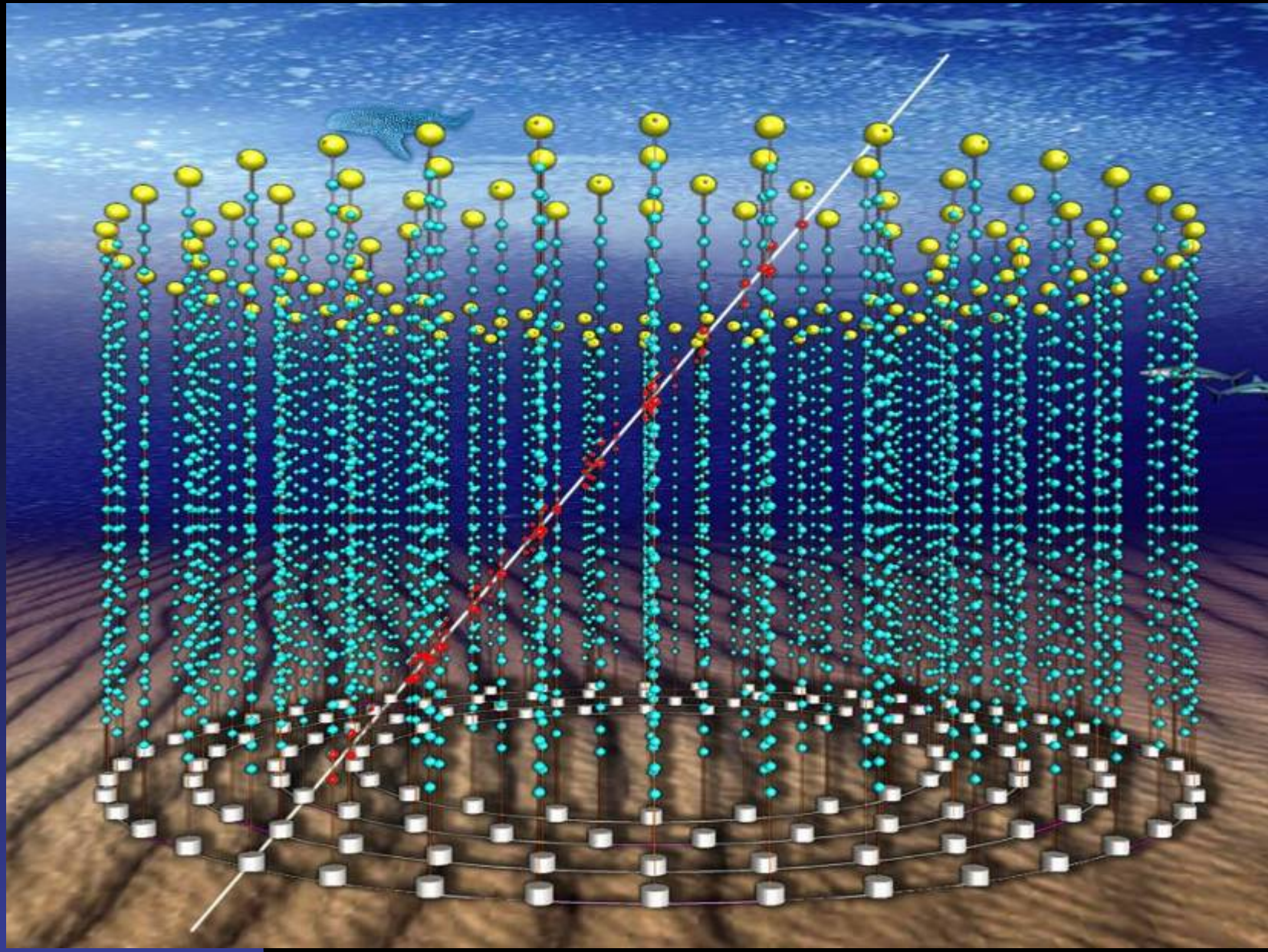
# Neutrino's high energy



# Neutrino's high energy



# Neutrino's high energy



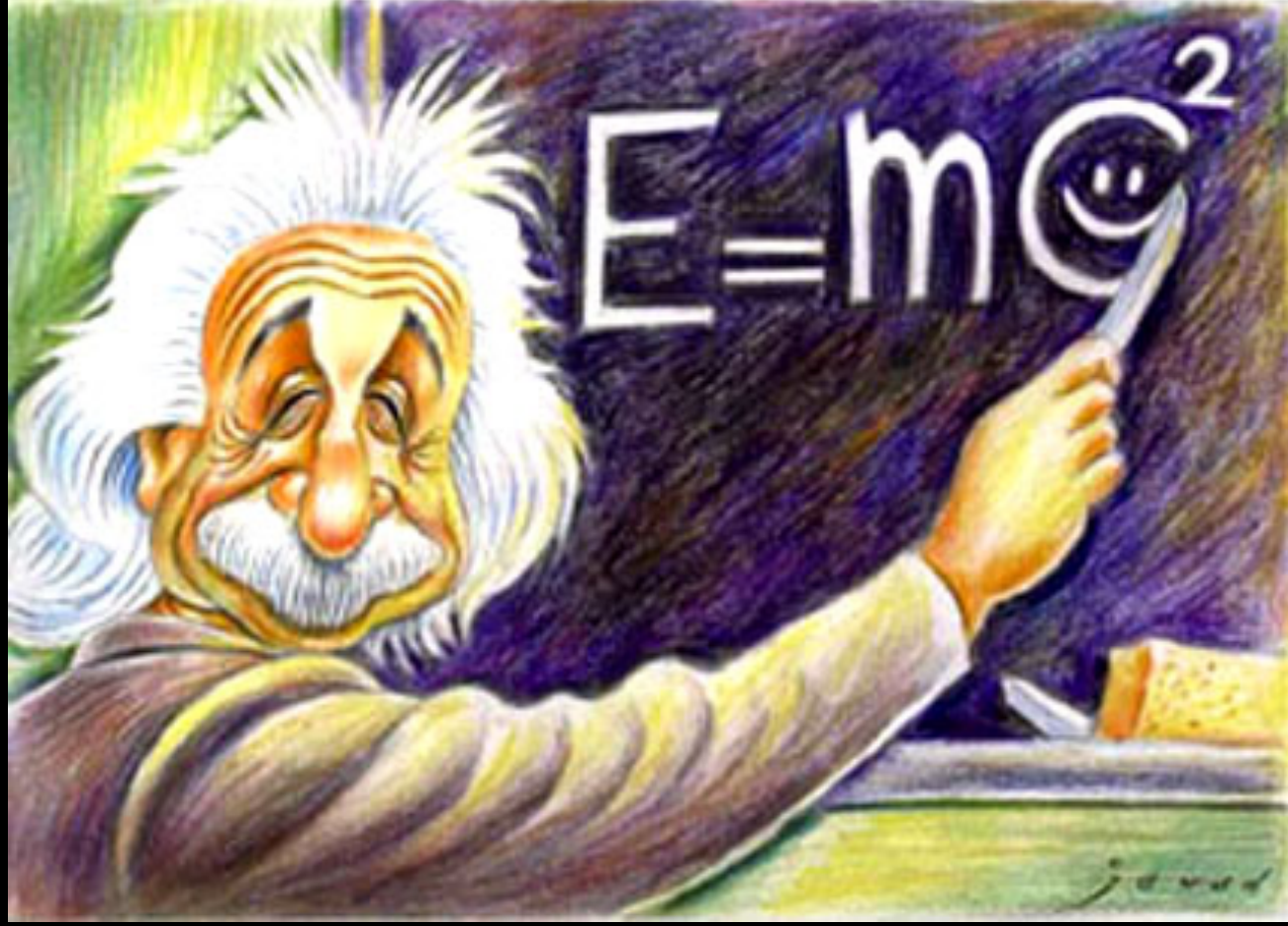


# Neutrino's high energy



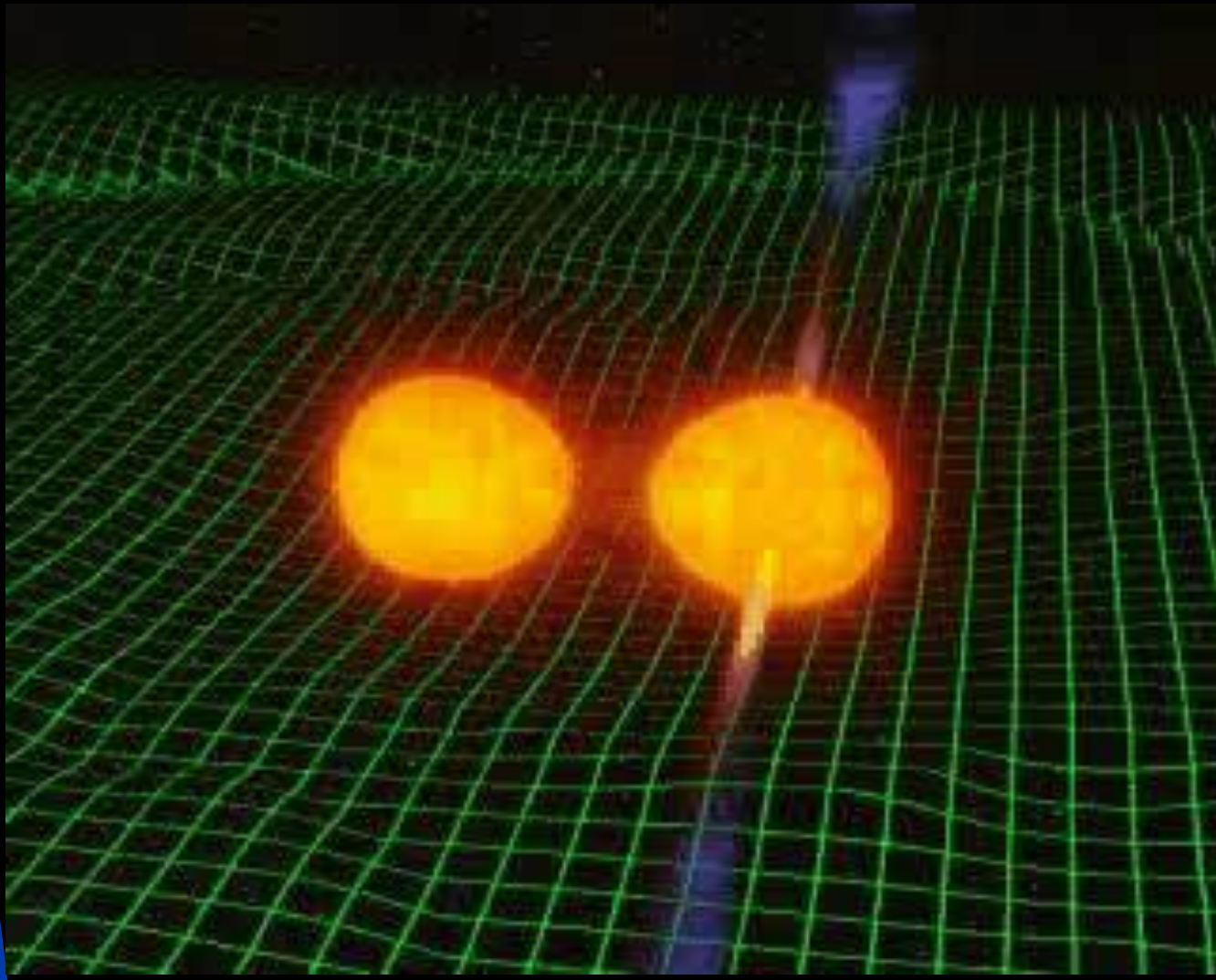
(general) relativity

Gravitational waves



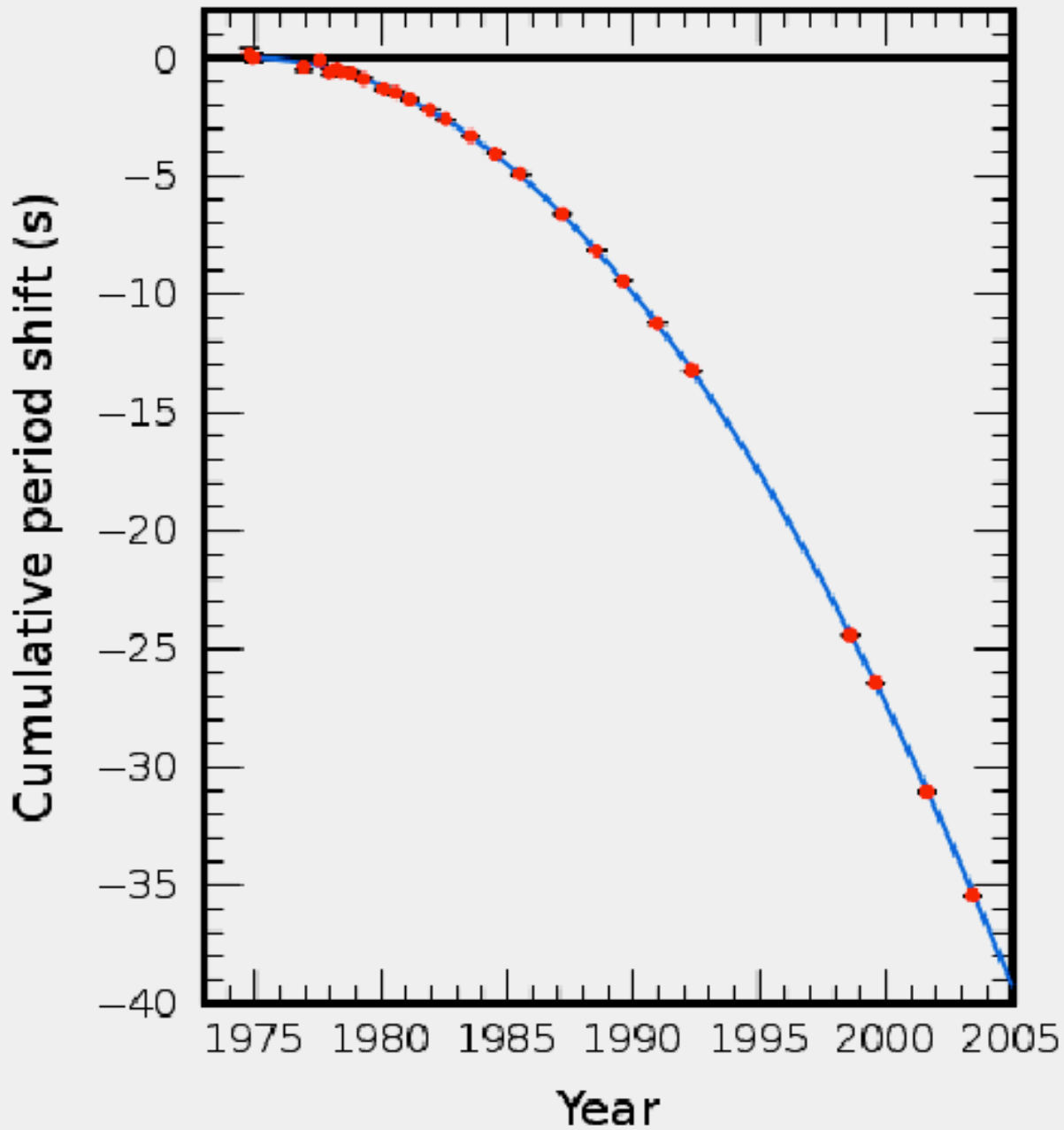
# (general) relativity

## *Gravitational waves*



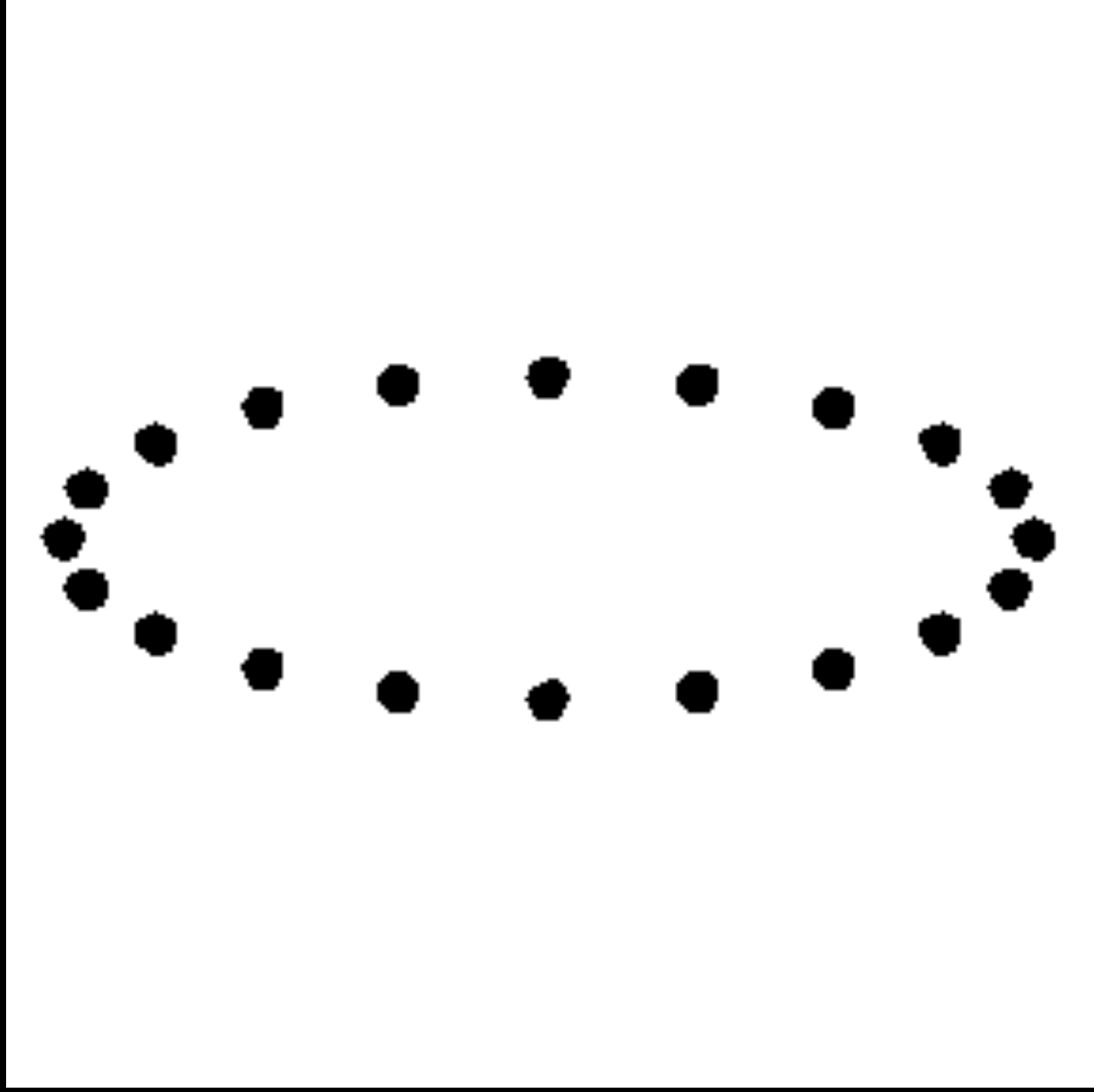
# (general) relativity

## *Gravitational waves*



# (general) relativity

## *Gravitational waves*



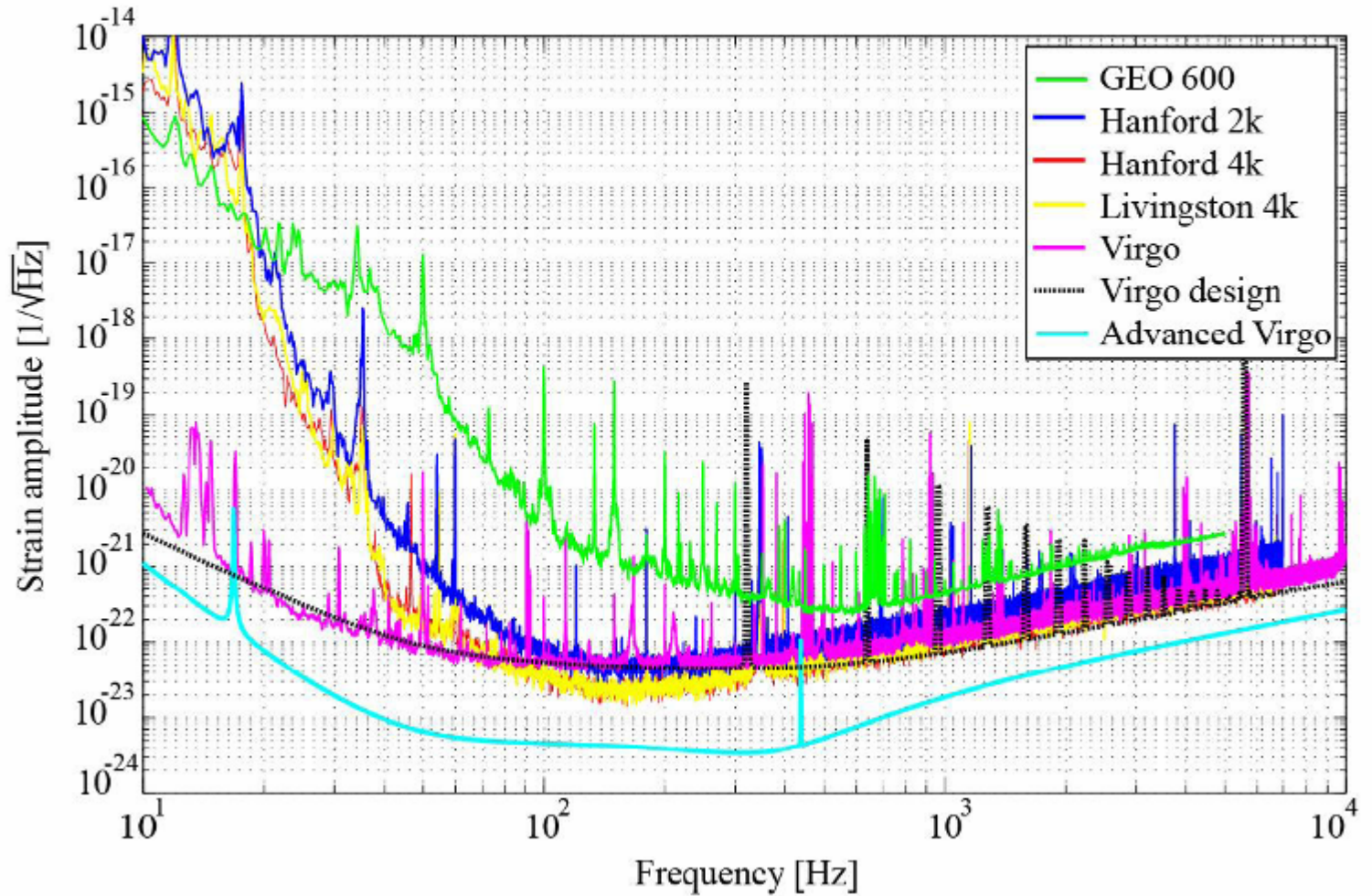
# (general) relativity

## *Gravitational waves*



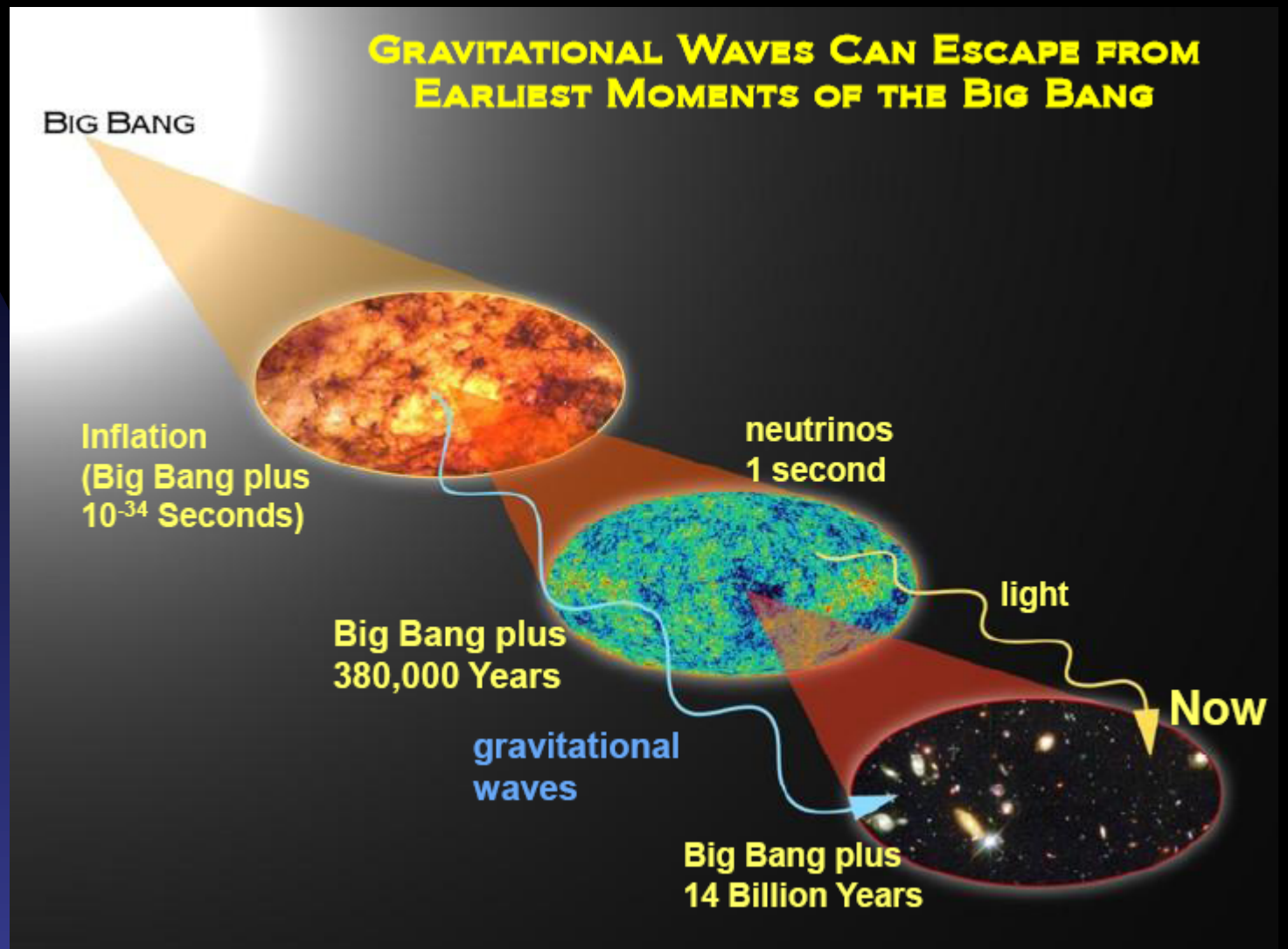
# (general) relativity Gravitational waves

## INTERFEROMETERS – SENSITIVITY



# (general) relativity

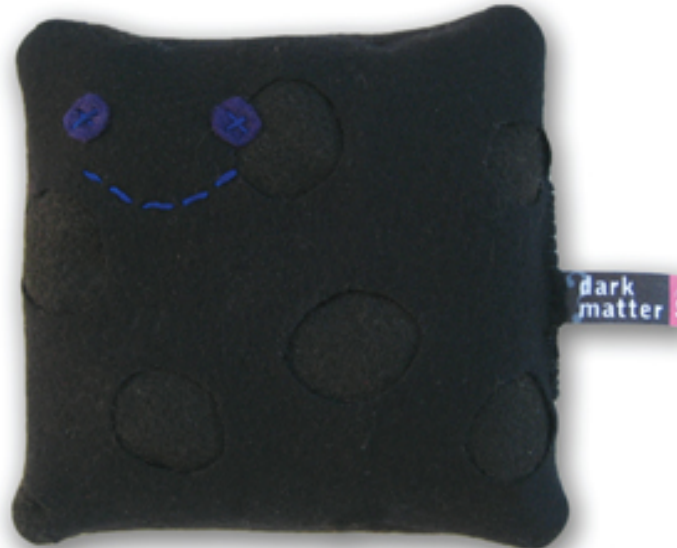
## Gravitational waves





# Dark matter

## DARK MATTER



**DARK MATTER** is the name given to material in the Universe that does not emit or reflect light but is necessary to explain observed gravitational effects in galaxies and stars. Dark matter, along with dark energy, totals 96% of the Universe, yet it remains a mystery as to what exactly it *is*.

*Acrylic felt, wool felt, and fleece with gravel fill for maximum mass.*

*Packaged in a black opaque bag designed for concealing contents.*

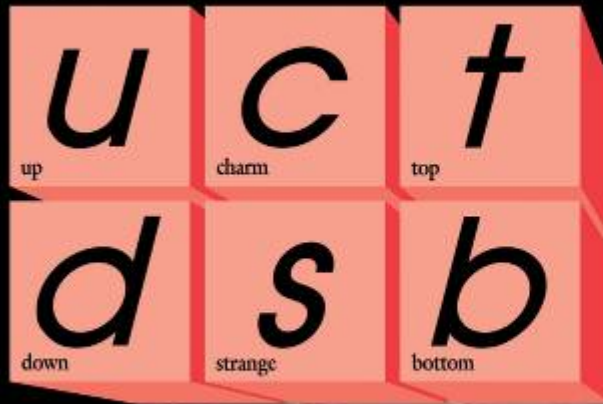


**\$10.49** PLUS SHIPPING

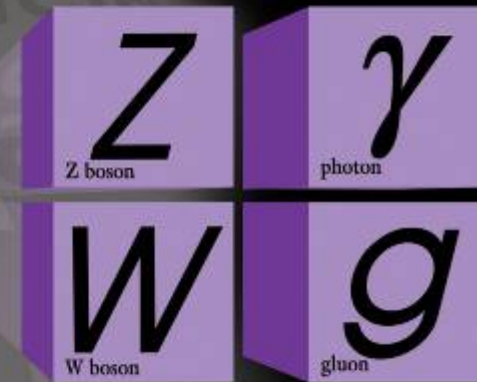
The **PARTICLE ZOO**

# Building blocks of the Universe

## Quarks

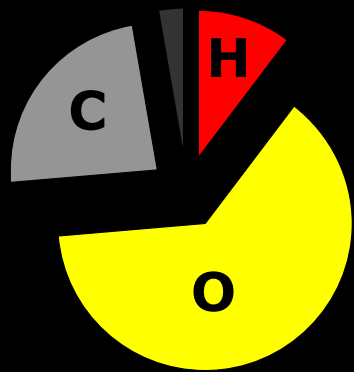
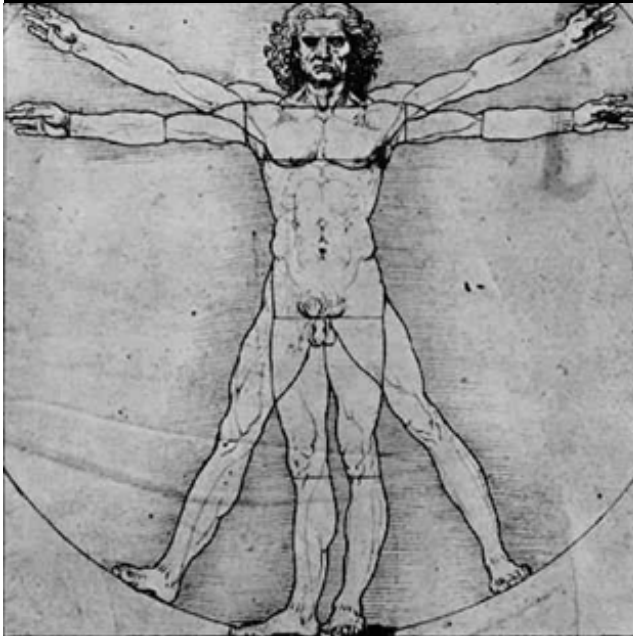


## Forces

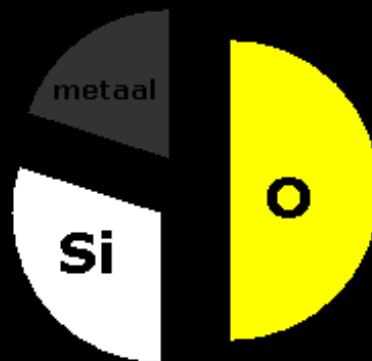


## Leptons

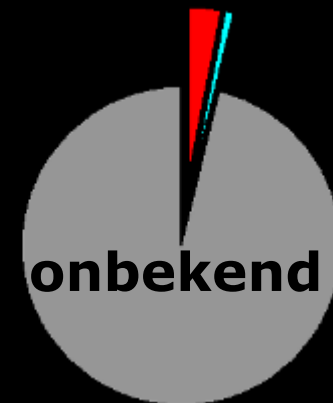
# Building blocks of .....



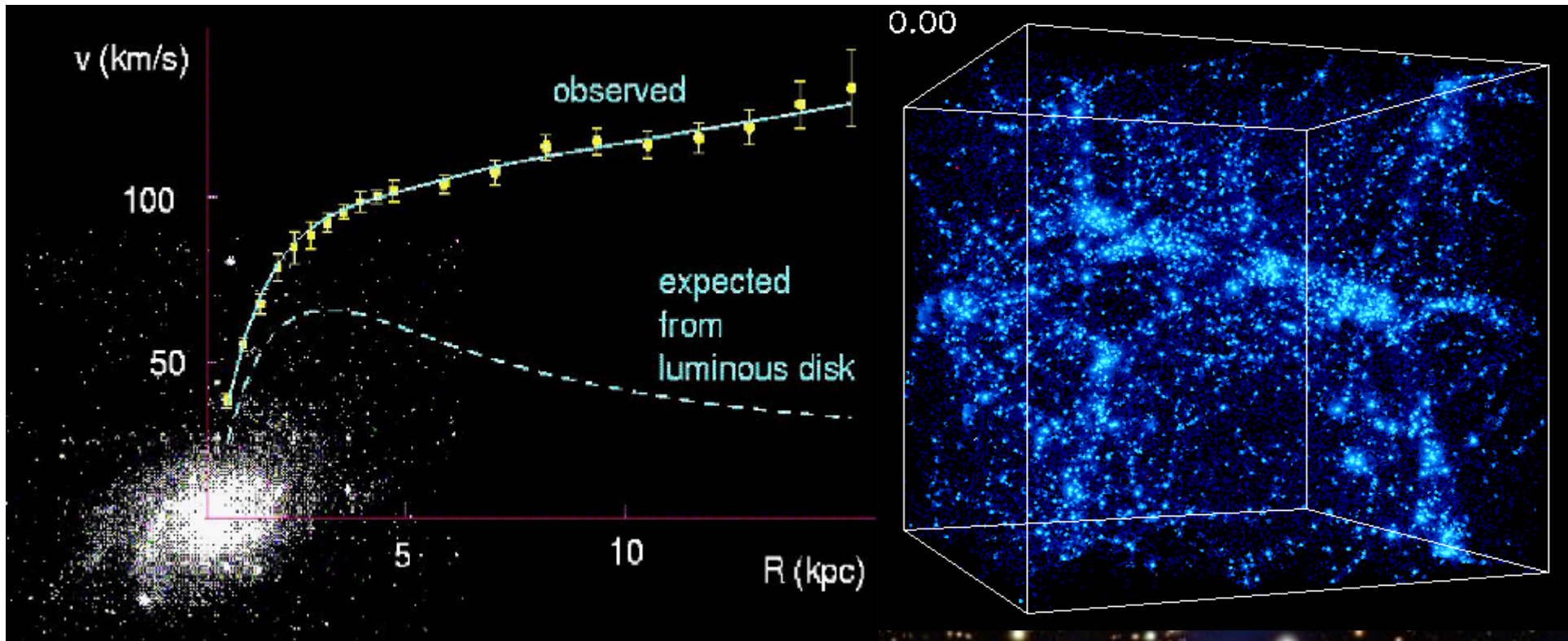
lots of water (H<sub>2</sub>O)



Lots of oxides



96% out there unknown!



# Building blocks of the Universe



# Building blocks of the Universe



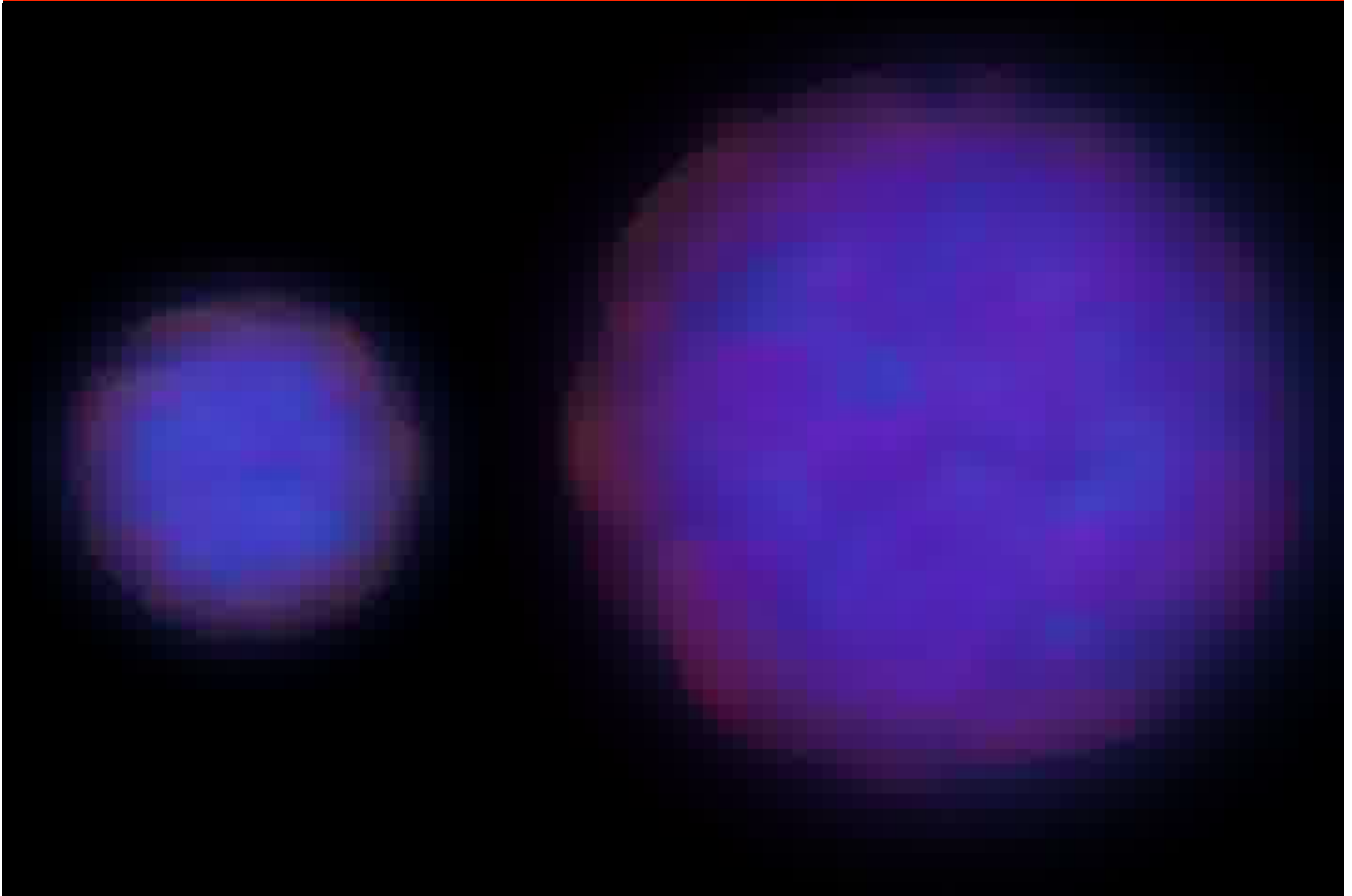
# Building blocks of the Universe



waterstof (H)

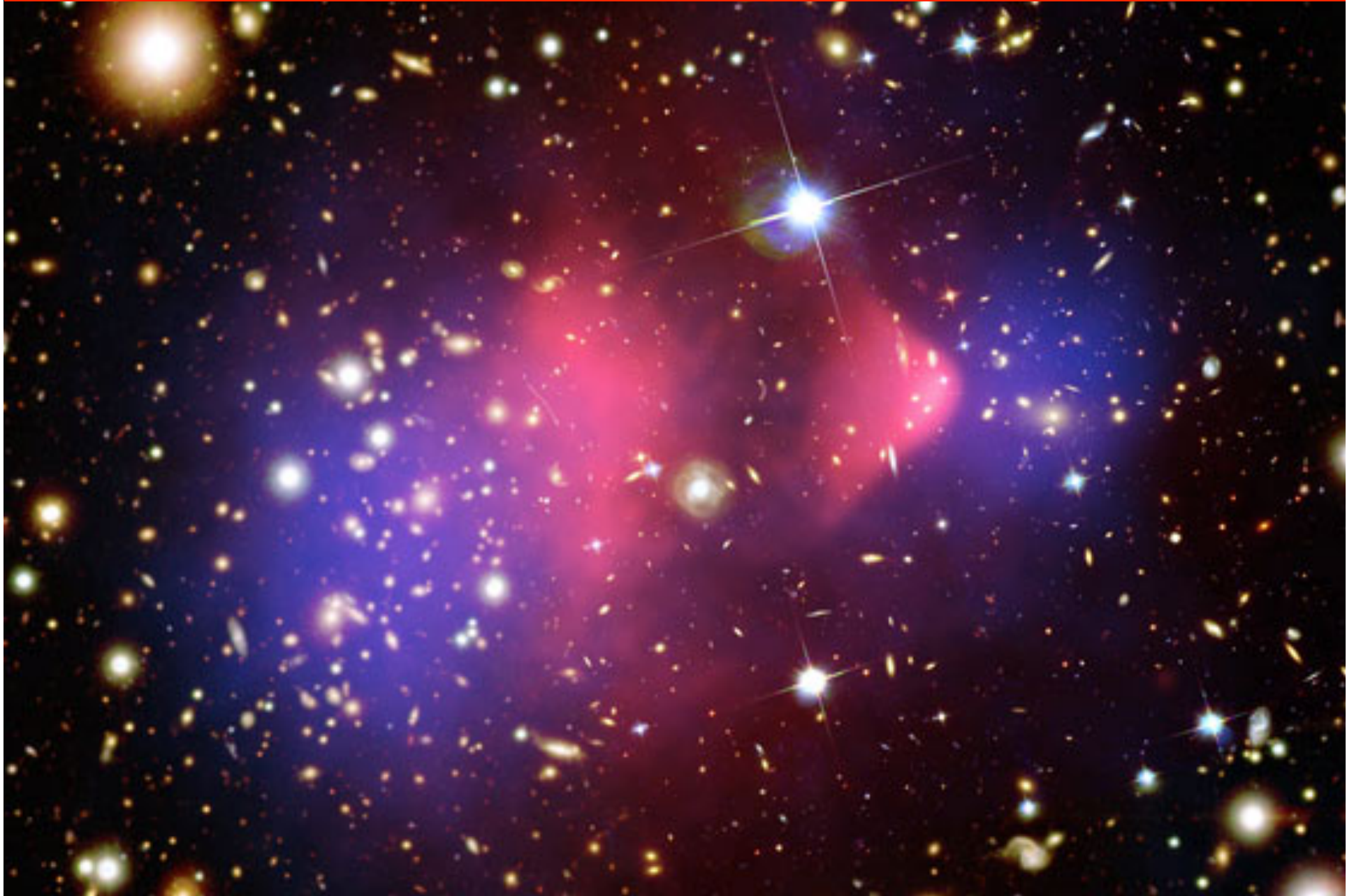
helium (He)

# Building blocks of the Universe





# Building blocks of the Universe



# Building blocks of the Universe



He H

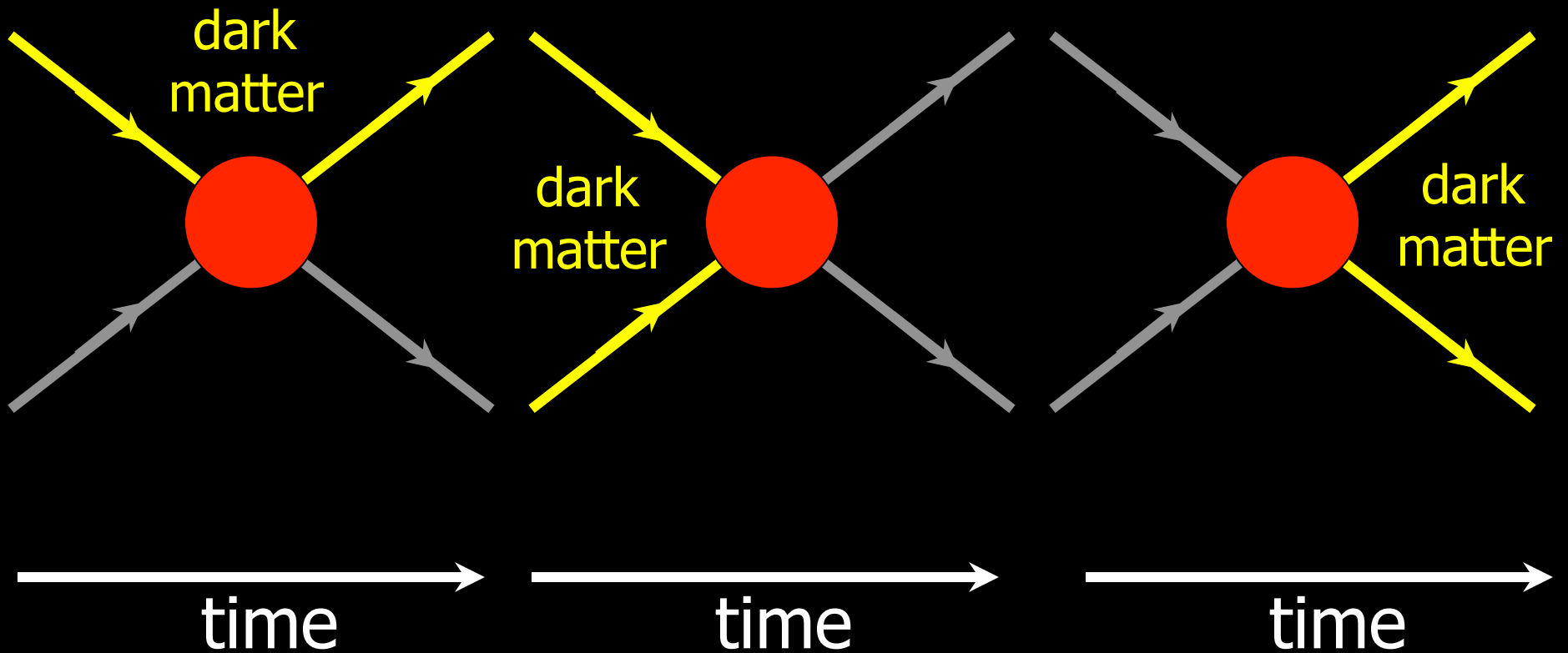
dark energy & dark matter

# How to discover *dark matter*

scattering

annihilation

creation



# Laboratori Nazionali del Gran Sasso, Italy

LNGS 1400 m Rock (3100 w.m.e)

**XENON10 / XENON100**

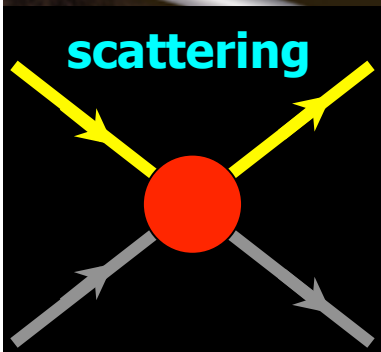
LVD

ICARUS

WARP

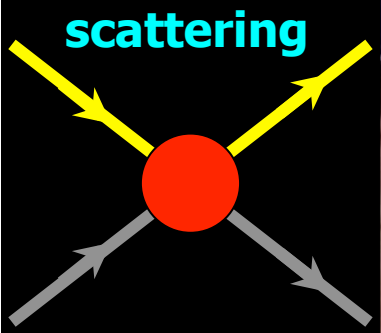
OPERA

**XENON IT**



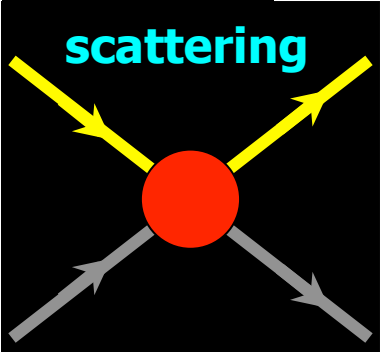
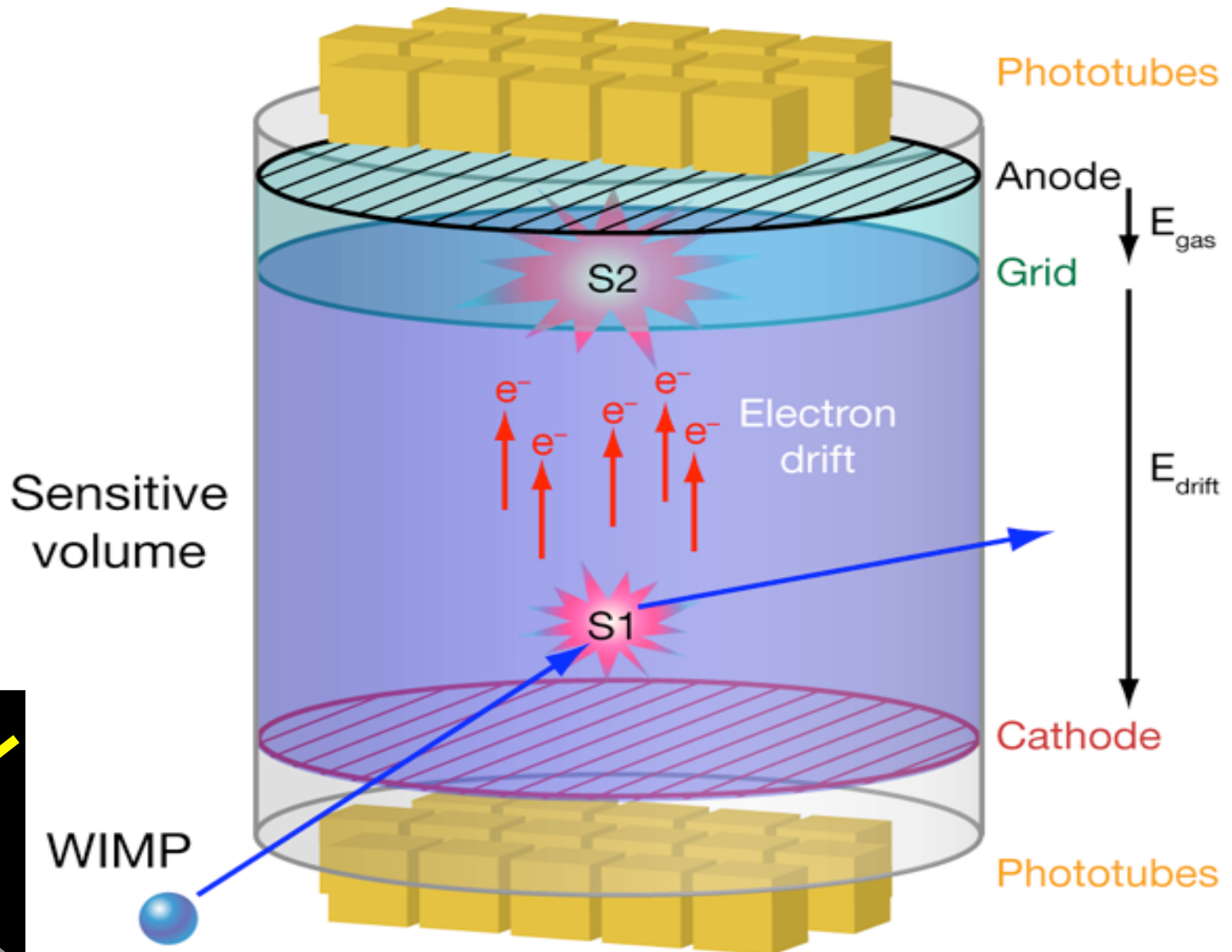
# *XENON-1t* dark matter detector

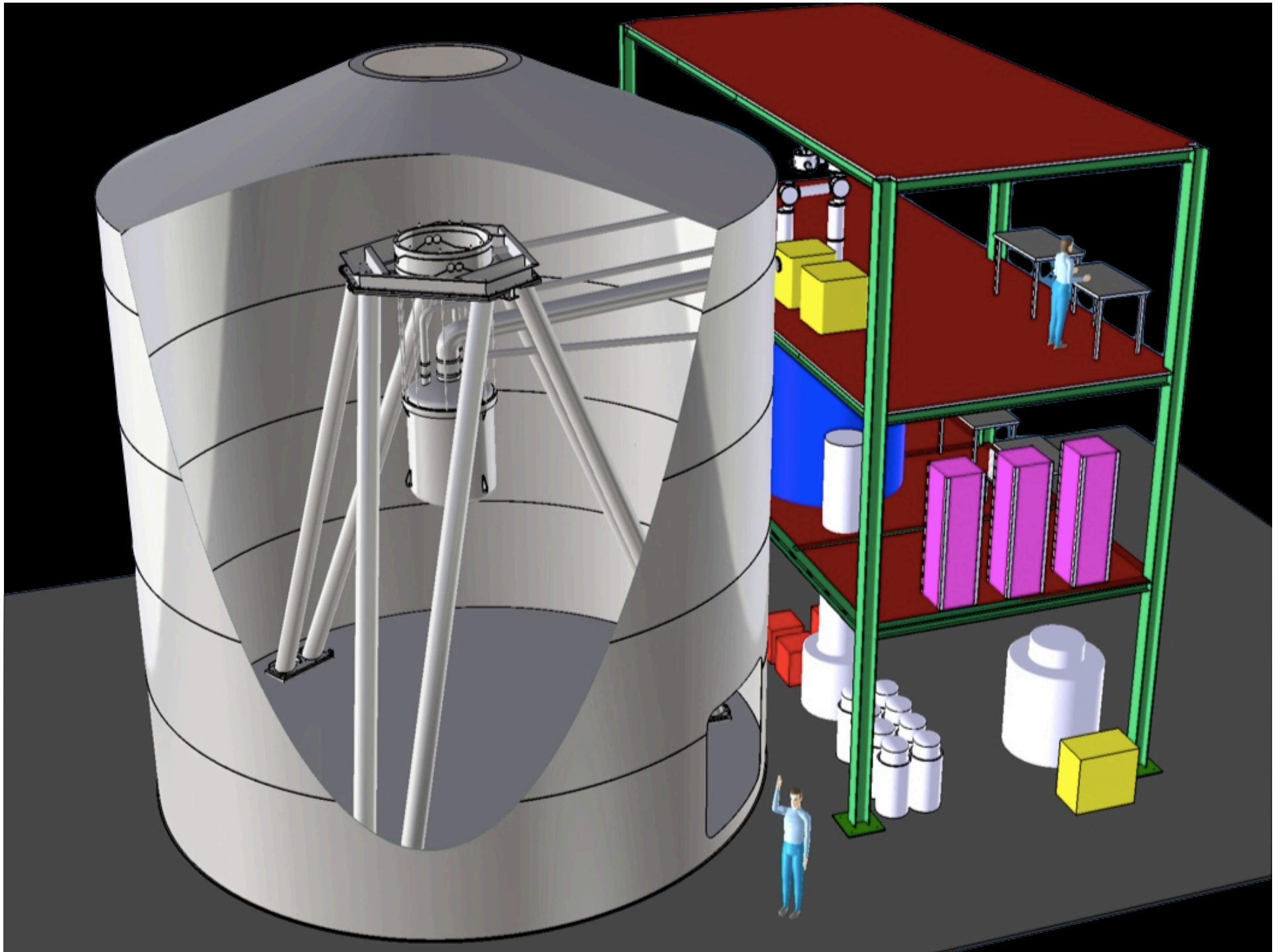
Italy (Gran Sasso, Aquila)

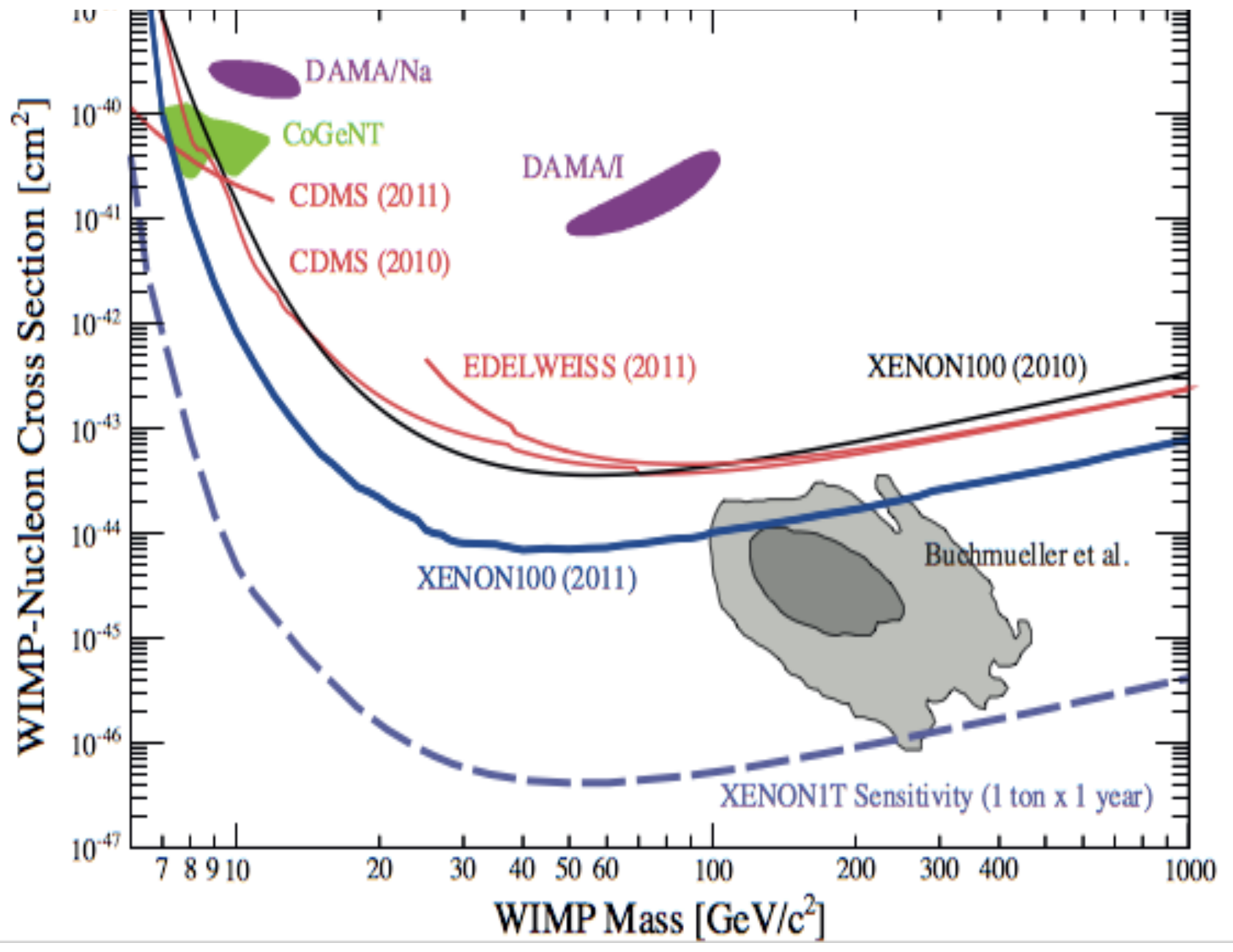


# XENON-1t dark matter detector

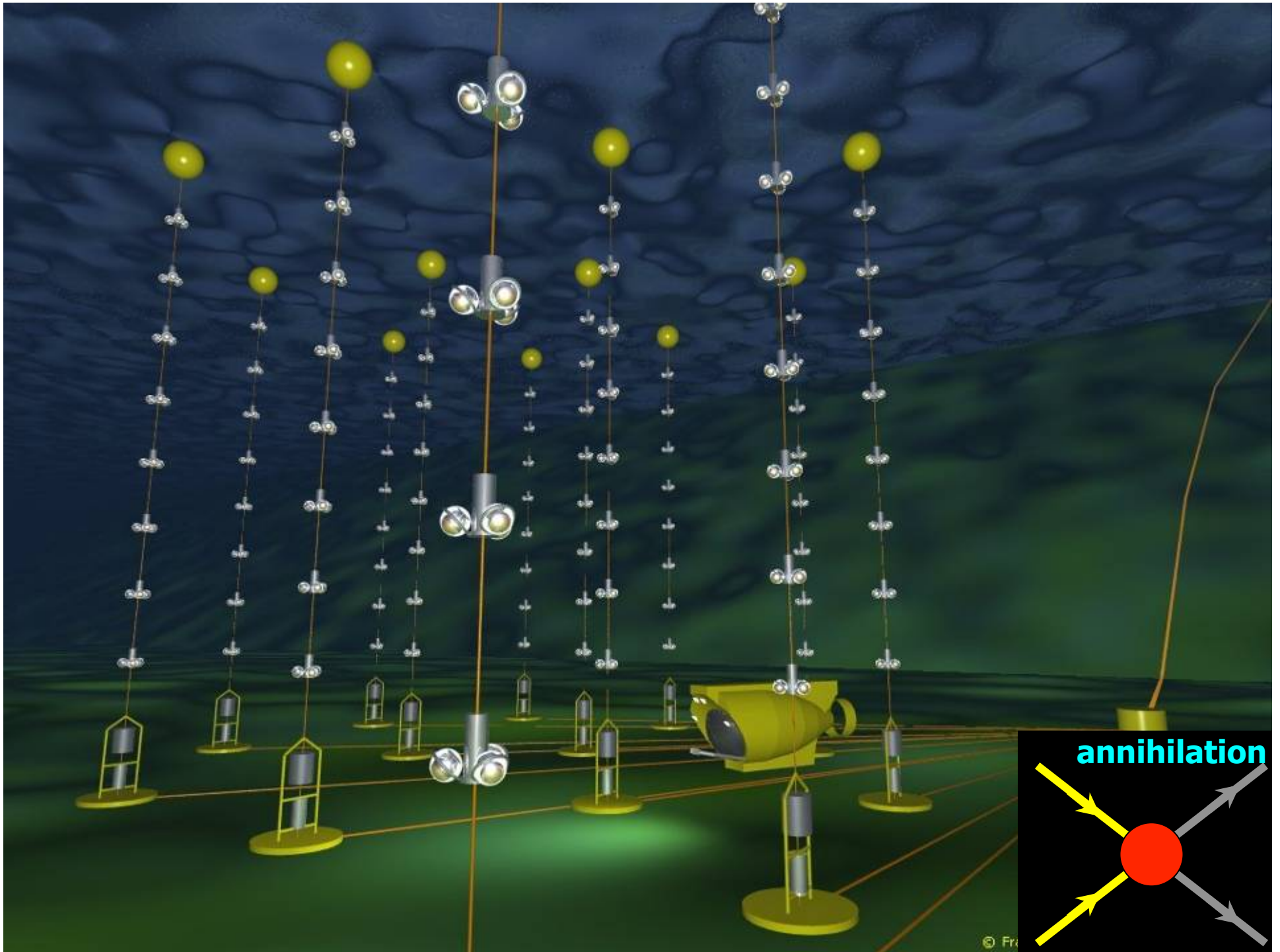
Italy (Gran Sasso, Aquila)





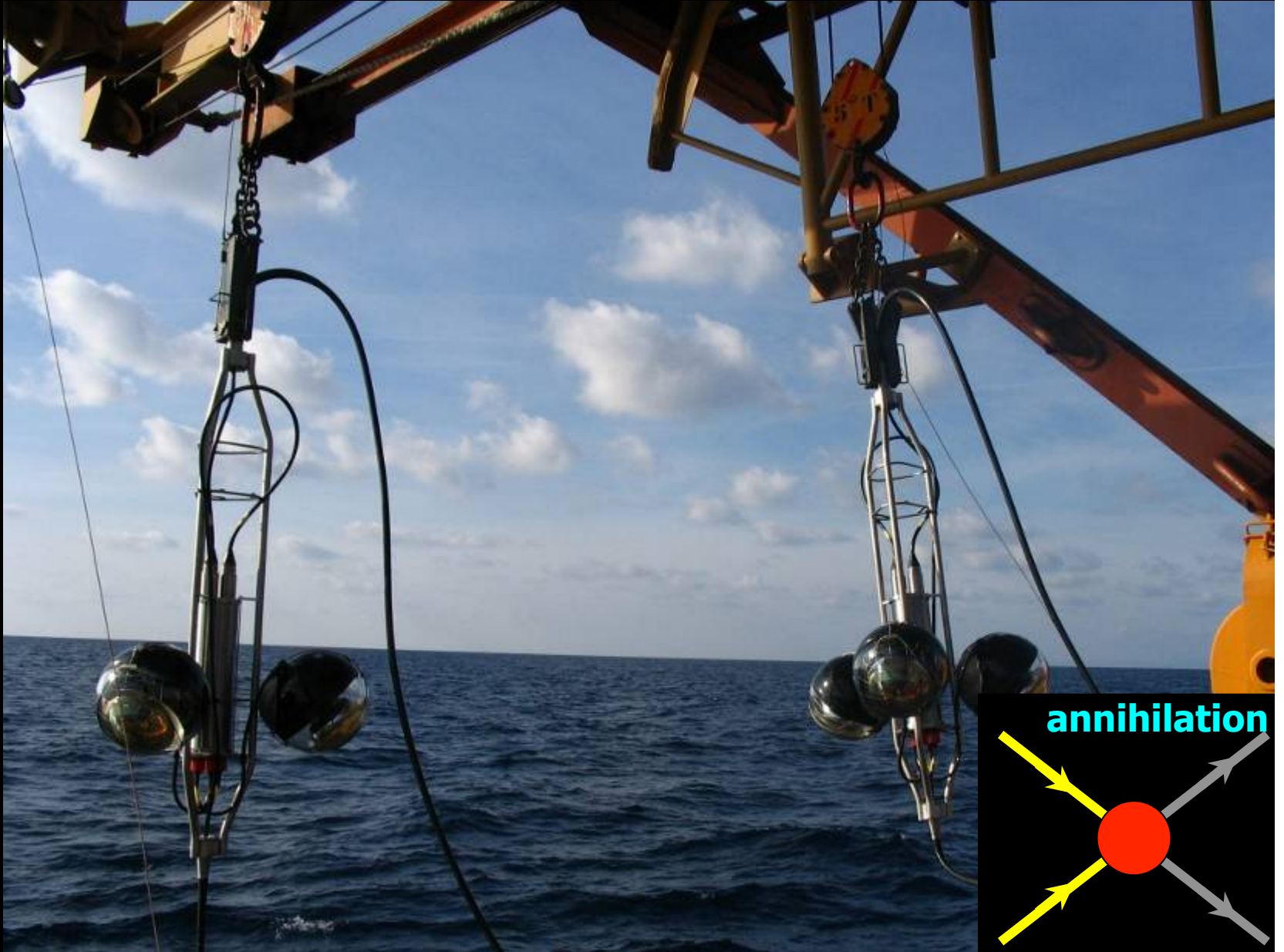






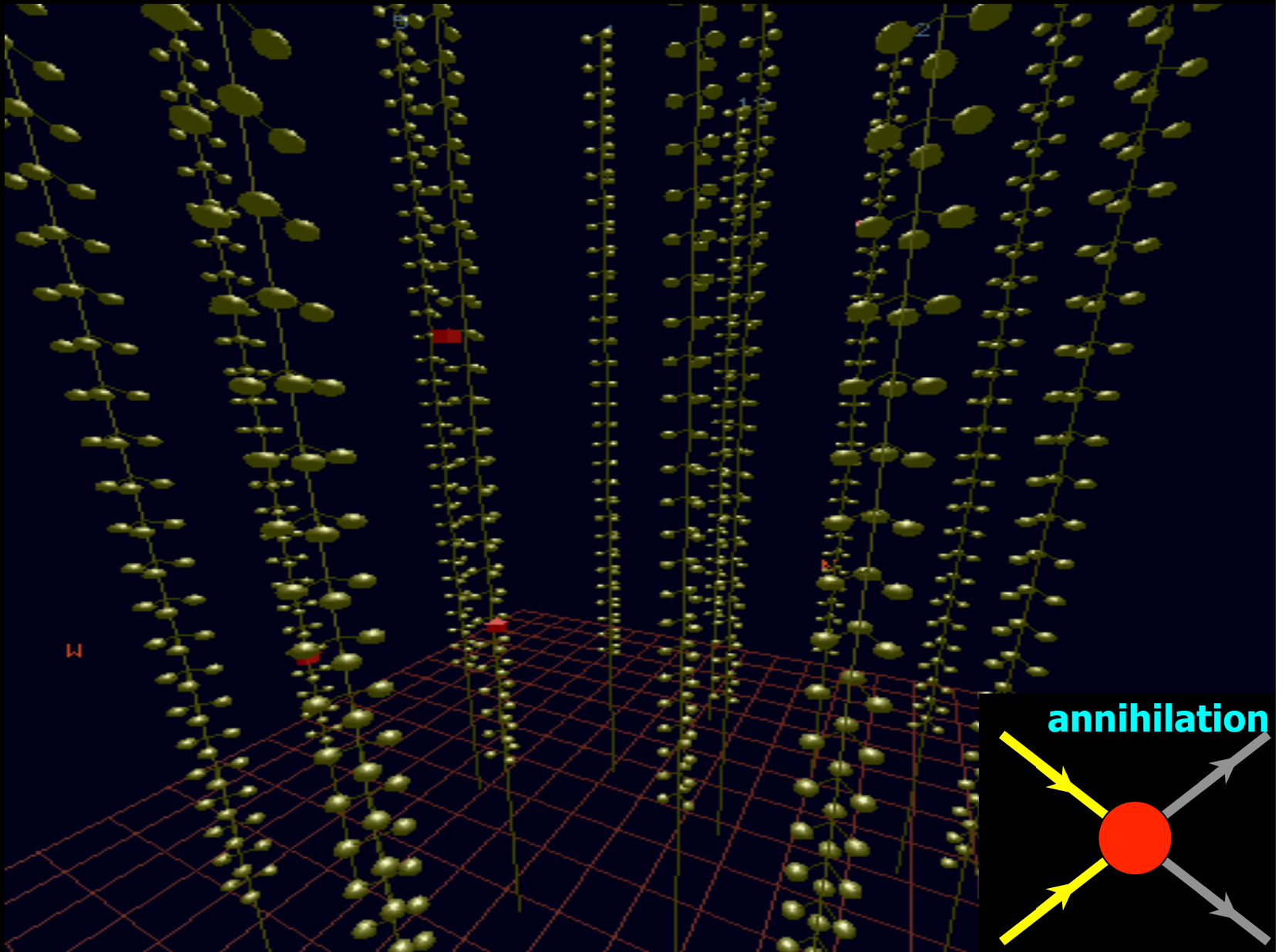
# *ANTARES* neutrino telescope

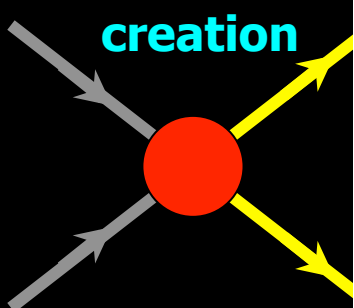
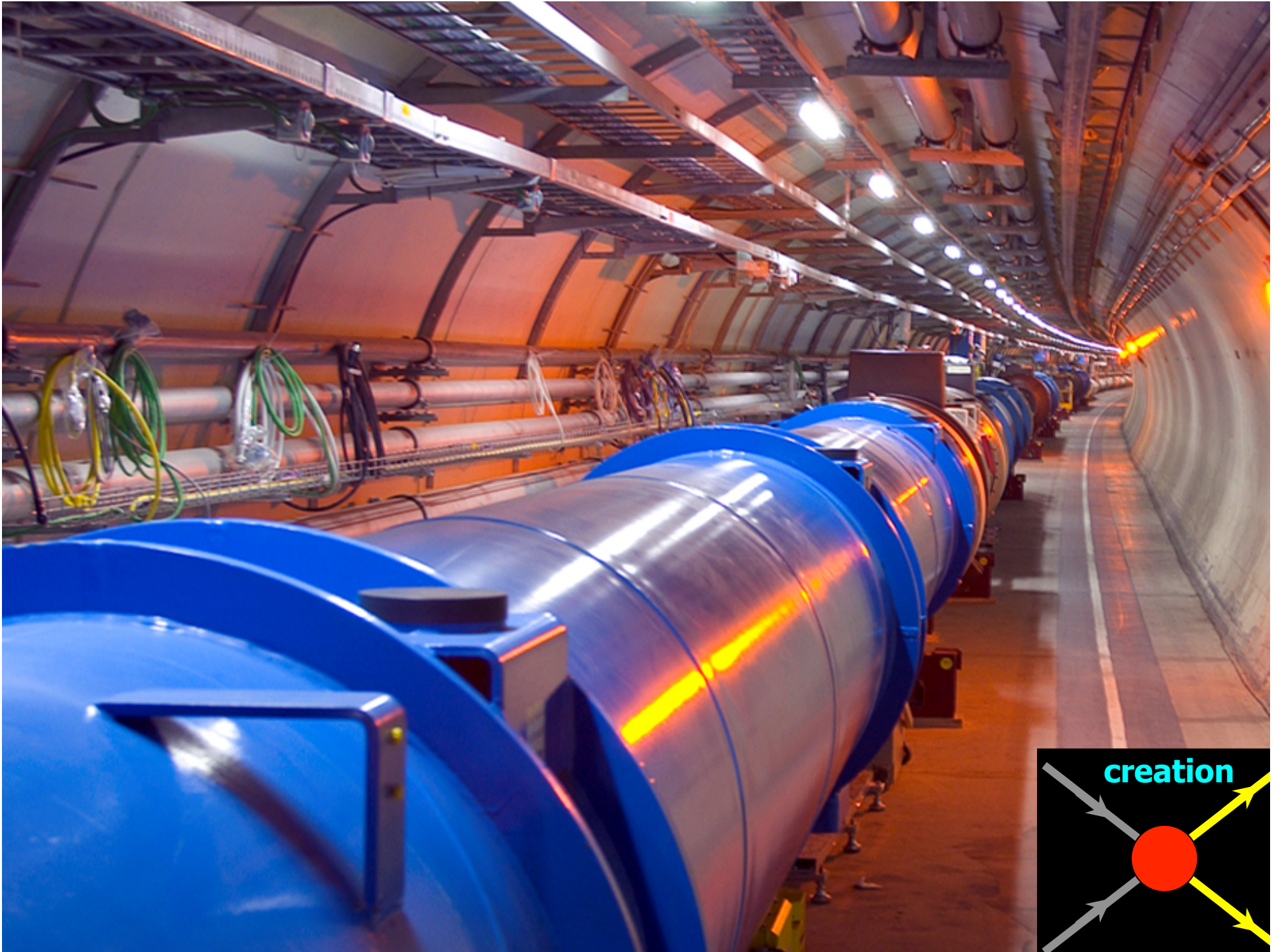
Mediterranean Sea (2.5 km deep)



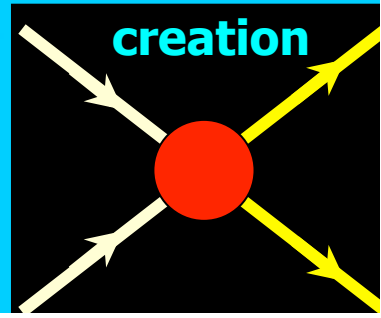
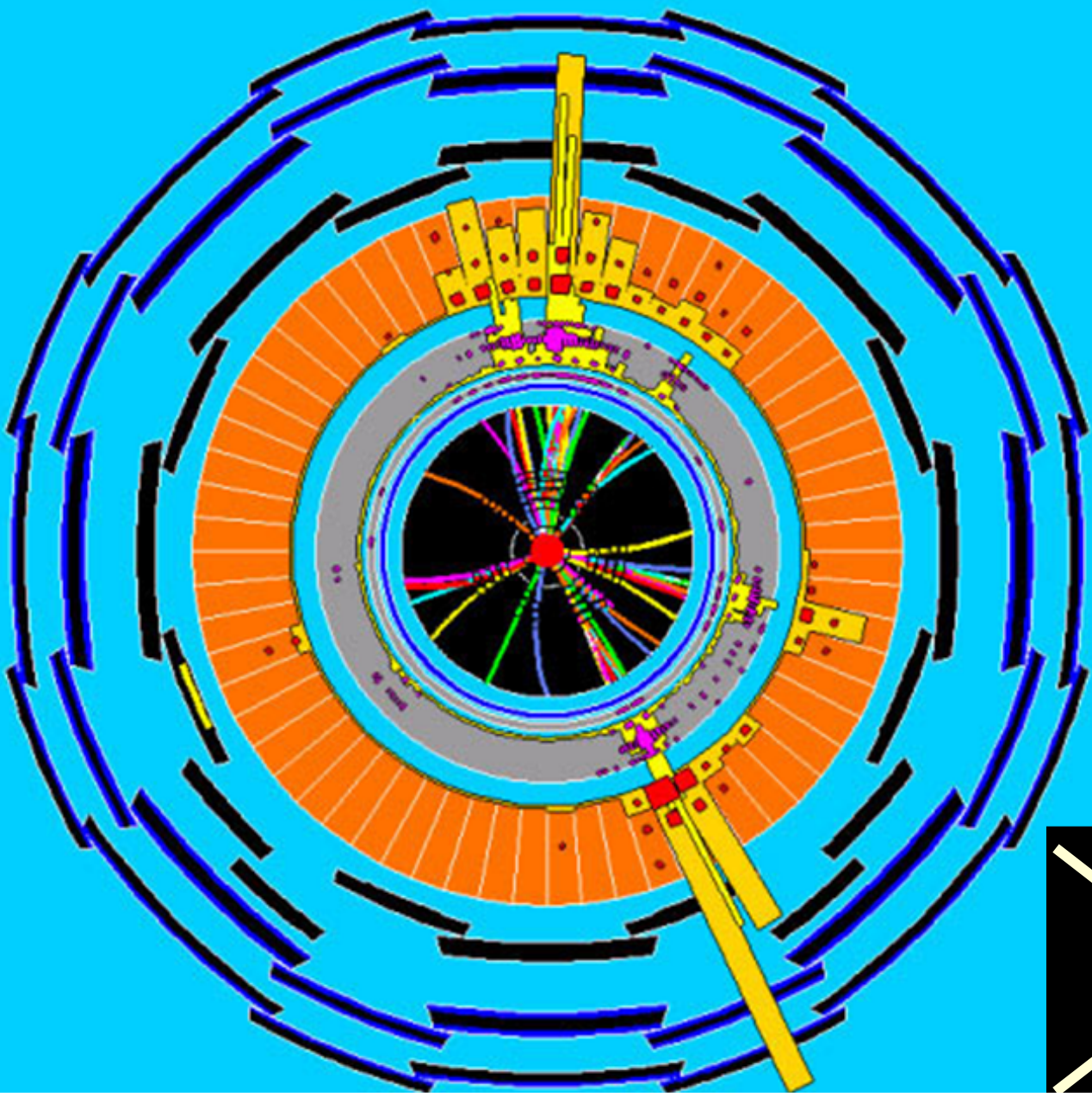
# *ANTARES* neutrino telescope

Mediterranean Sea (2.5 km deep)





LHC: supersymmetrische deeltjes



# *Elementary Particle Physics*

## Microcosmos

*Thank you for your attention  
& enjoy the tours at CERN!*

Frank Linde  
Nikhef & UvA  
+31-205925001  
f.linde@nikhef.nl

# Interesting books

- Bais, Sander *The Equations: Icons of Knowledge*
- Bais, Sander *Very Special Relativity: An Illustrated Guide*
- Bodanis, David *Electric universe* (well-written history of the electron)
- Brown, Dan *Angels and Demons*
- Feynman, Richard *QED*
- Feynman, Richard *Surely you're joking Mr. Feynman*
- Gell-Mann, Murray *The quark and the Jaguar. Adventures in the Simple and the Complex* (A true classic in physics by the Nobel laureate)
- Green, Brian *The fabric of the cosmos*
- Hawking, Lucy & Stephen *George's Secret Key to the Universe* (children's book by the great Stephen Hawking and his daughter)
- *Infinitely CERN, memories from fifty years of research (1954-2004)* (zie illustratie)
- Kaku, M. *Hyperspace* (Een vlot boek about modern physics)
- Krauss, L.M. *Atom : an odyssey from the Big Bang to life on earth ... and beyond*
- Lederman, Leon *The God Particle* (Must read!)
- Lindley, David *Boltzmann's atom* (gives great insight into a physician's life at the end of the 19th century)
- McEvoy, J.P. & Oscar Zarate *Stephen Hawking for beginners* (with loads of illustrations)
- Ne'eman, Yuval & Yoram Kirsh *The particle hunters* (Modern physics for VWO 6)
- Pais, Abraham *Inward bound: Of matter and forces in the physical world*
- Pais, Abraham *Subtle is the Lord: The science and the life of Albert Einstein*
- Pais, Abraham *Niels Bohr's Times: In physics, philosophy, and polity*
- Penrose, Roger *The Road to Reality*
- Riordan, Michael *The hunting of the quark*
- Smolin, Lee *The trouble with physics*
- Veltman, Martinus *Facts and mysteries in elementary particle physics*
- Weinberg, Steven *The first three minutes: A Modern View Of The Origin Of The Universe* (a fascinating account of atoms and everything surrounding them)

# For high-school: HiSPARC project



HiSPARC

About HiSPARC

Teacher & Student

HiSPARC Data

News

Software

NL | EN

## Welcome at HiSPARC

HiSPARC is a project in which secondary schools and academic institutions join forces and form a network to measure cosmic rays with extremely high energy.

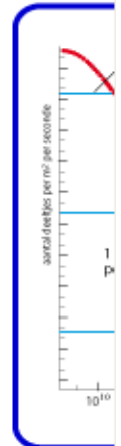
HiSPARC offers students the opportunity to participate in real research, with the purpose of finding out more about these mysterious and rare cosmic particles. In addition, students participating in the experiment can use this for their profile paper for the final exam.

On the roofs of the participating schools you can find the HiSPARC detectors which were built by the students themselves. These setups are connected to a central computer at the scientific institute **Nikhef** through the internet, forming a large network. In Nijmegen data has been collected since 2002 and in Amsterdam since 2004. There are HiSPARC detectors in the regions Eindhoven, Enschede, Leiden, Utrecht and Groningen as well. Currently the project is being expanded to other countries like Denmark and England. The project is coordinated from Nikhef in Amsterdam.

Find a list of the HiSPARC [sponsors](#) here.



## network status



## Nieuwtjes

### 24-04-2012: Nagios notification reactivated

Our station-monitoring-system Nagios has been with keeping a good connection with all stations: reports of problems even though everything is fine. Because... [more](#) »

### 23-04-2012: Presentaties en foto's van het HiSPARC Leiden symposium

De presentaties en foto's van het HiSPARC Leiden staan nu op de pagina van het Symposium verslag volgt later. [more](#) »

22-03-2012: HiSPARC in CERN



# Nikhef website



Nationaal instituut voor subatomaire fysica



» [Nikhef Gebruikers](#)

 Zoek

[Over Nikhef](#)



[Wetenschap & Techniek](#)



[Onderwijs](#)



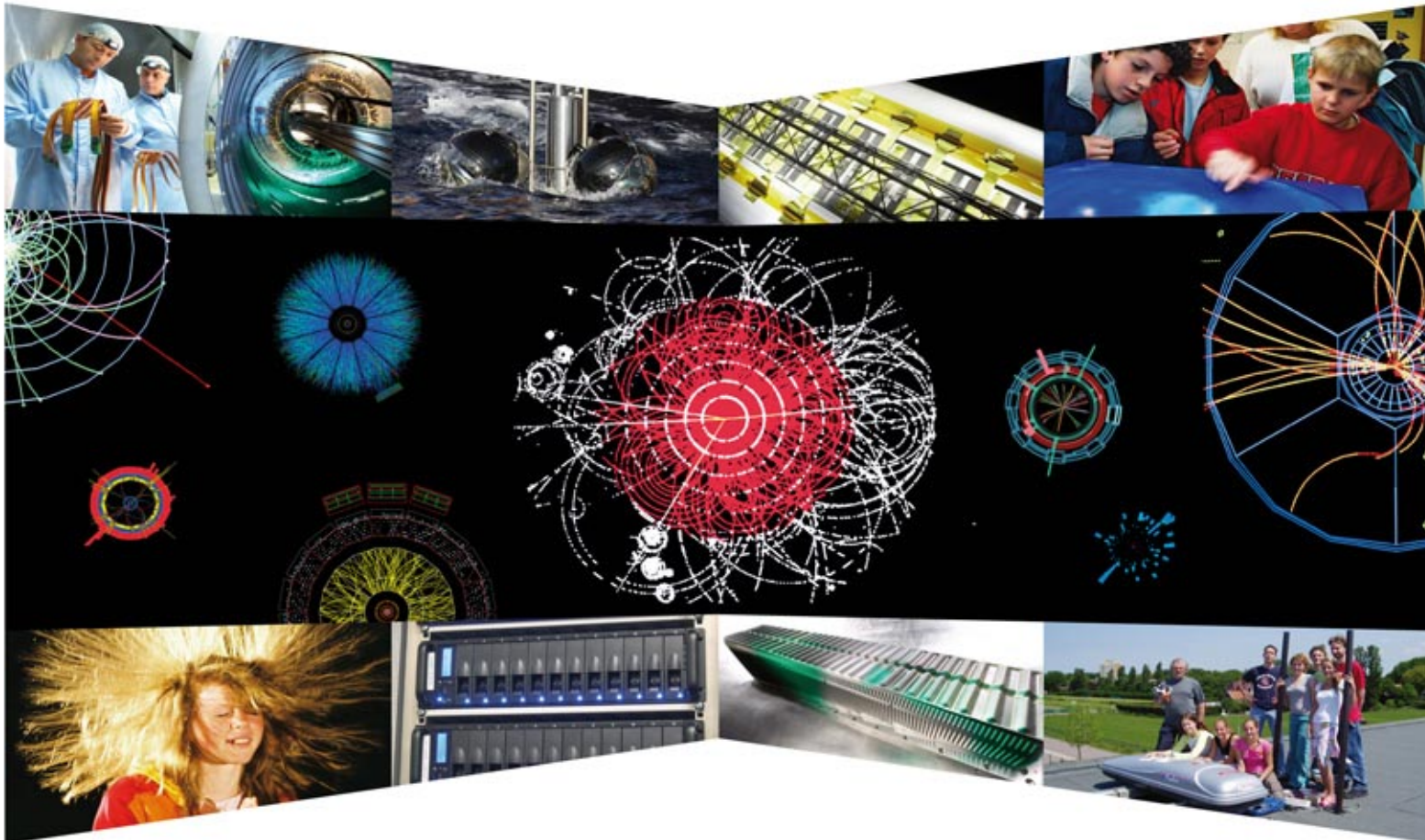
[Bedrijfsamenwerking](#)



[Media](#)



[Actueel](#)



## Nieuws

20-04-2012: LHC reaches record collision rate at 4TeV per beam

16-04-2012: Documentaire over Higgs-zoektocht ontvangt filmprijs

05-04-2012: Nikhef welcomes Prof. dr. Bernard de Wit and his group

05-04-2012: LHC physics data taking gets underway at new record collision energy of 8TeV

29-03-2012: Nikhef Annual Report 2011 now available

## Evenementen

03-05-2012: PhD defense Marek Chojnaki @ UU

08-05-2012: Special colloquium Walter Lewin

10-05-2012: 16th