Visita ai Laboratori dell'INFN
11-12 Gennaio 2019
Laboratori Nazionali del Gran Sasso

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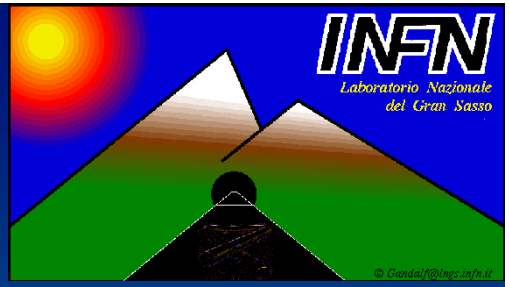
Istituto Nazionale di Fisica Nucleare

L’Istituto Nazionale di Fisica Nucleare

Laboratori Nazionali
del Gran Sasso (LNGS)

Laboratori Nazionali del Gran Sasso



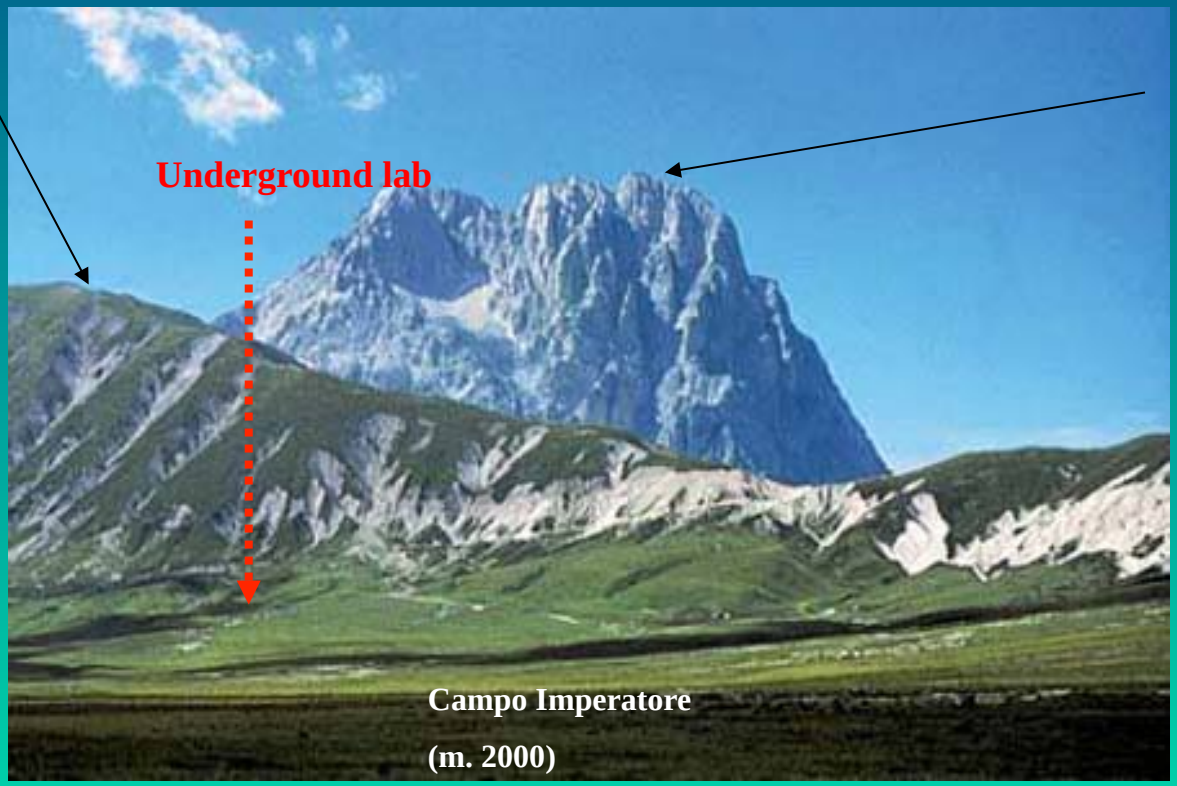
Location: Gran Sasso Tunnel (Abruzzi, Italy)

Depth: 1400 m (3800 mwe)

Operating Institution: Istituto Nazionale di Fisica Nucleare (INFN)

LNGS permanent staff: ~100 (physicists, technicians, administration)

Scientists involved in LNGS experiments: 1100 from 29 countries



The area of Campo Imperatore above LNGS

Nel **1979**, durante la costruzione della autostrada A24 fra Roma e L'Aquila, A. Zichichi ha proposto l'idea di costruire un **laboratorio sotterraneo** sotto il **Gran Sasso**

- **1982:** il Parlamento approva la costruzione
- **1984:** nuovi finanziamenti
- **1989:** il primo esperimento, MACRO, inizia a prendere dati

- Fra i primi progetti ci sono:
  - MACRO: Ricerca di monopoli magnetici
  - LVD: rivelazione di supernovae e fisica dei neutrini
  - Gallex: rivelazione di neutrini solari

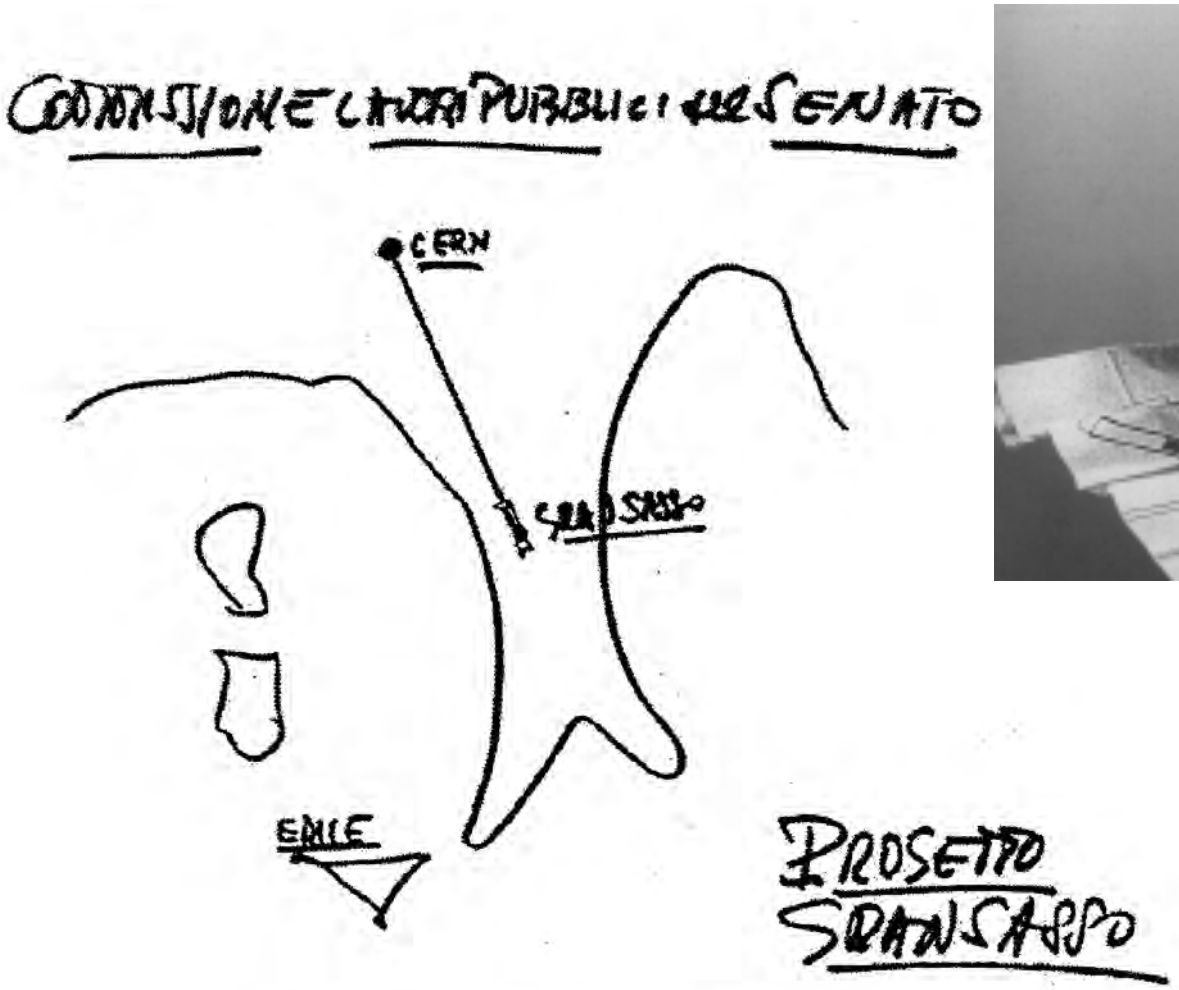
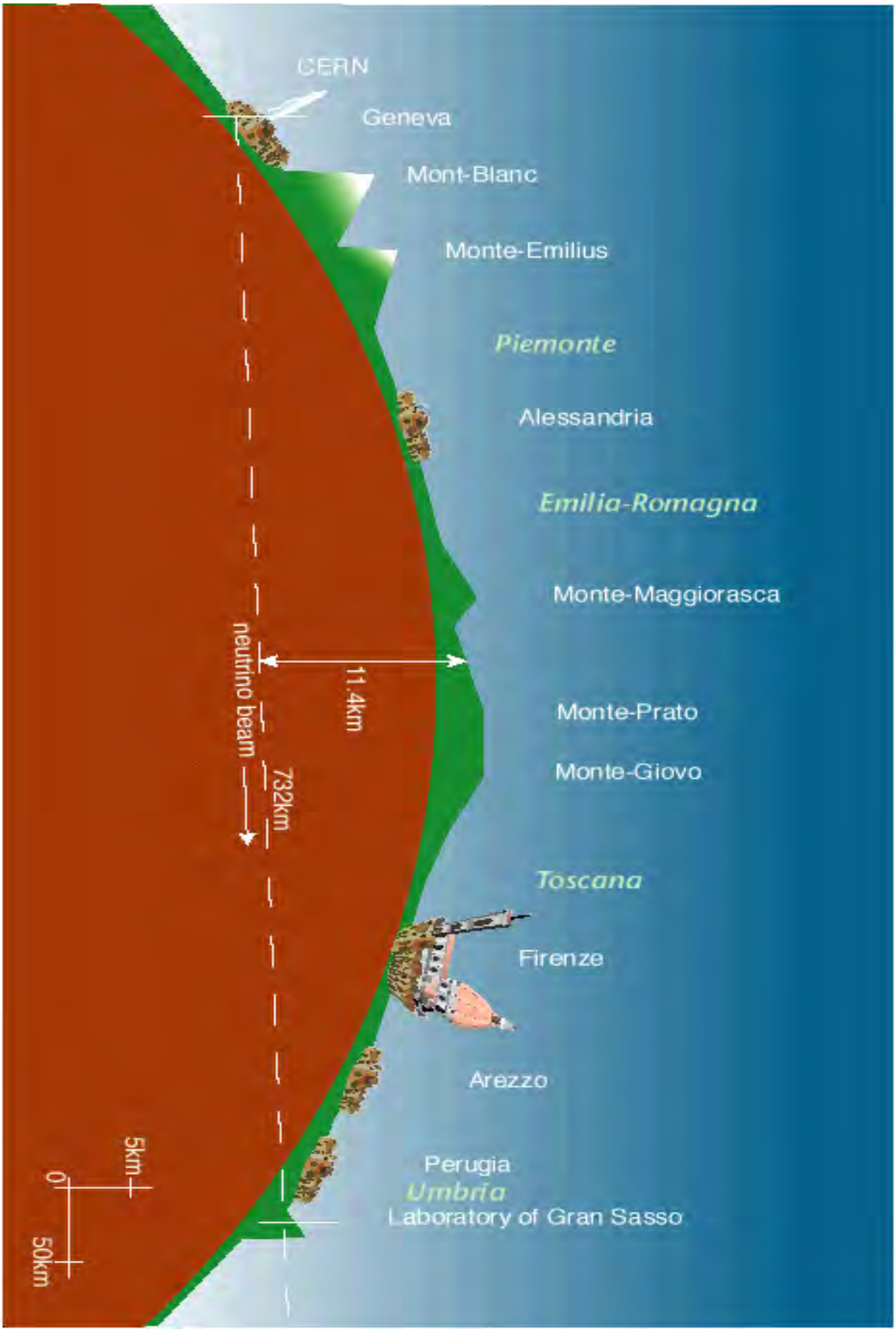
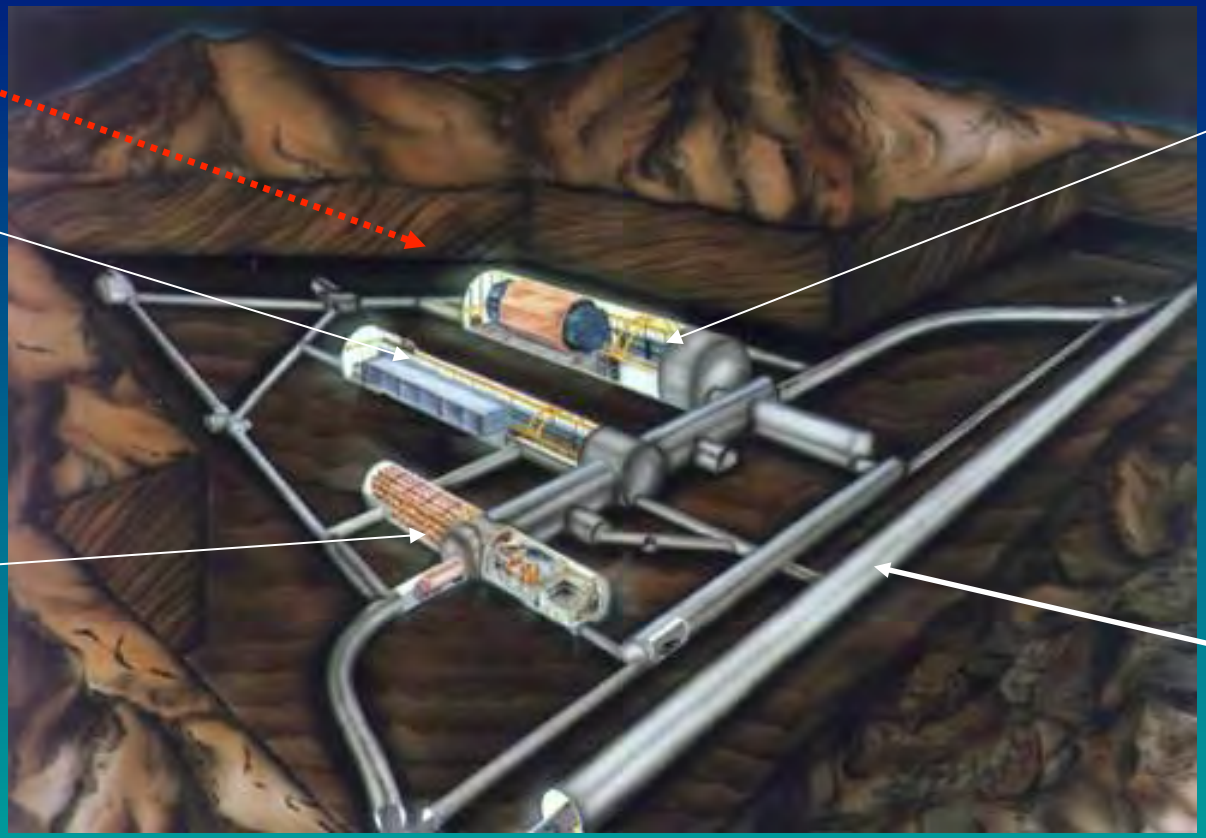


Figure 1.1.1: Sketch by A. Zichichi, 1979


CERN
Geneva
Mont-Blanc
Monte-Emilius
Piemonte
Alessandria
Emilia-Romagna
Monte-Maggiorasca
neutrino beam
11.4km
Monte-Prato
Monte-Giovo
732km
Toscana
Firenze
Arezzo
5km
0
Perugia
Umbria
Laboratory of Gran Sasso
50km

The LNGS Underground area

CERN ν beam



Underground area : 3 halls (100m x 20m x 15m) + service tunnels
Total volume : 180000 m^3

Surface: > 6000 m^2

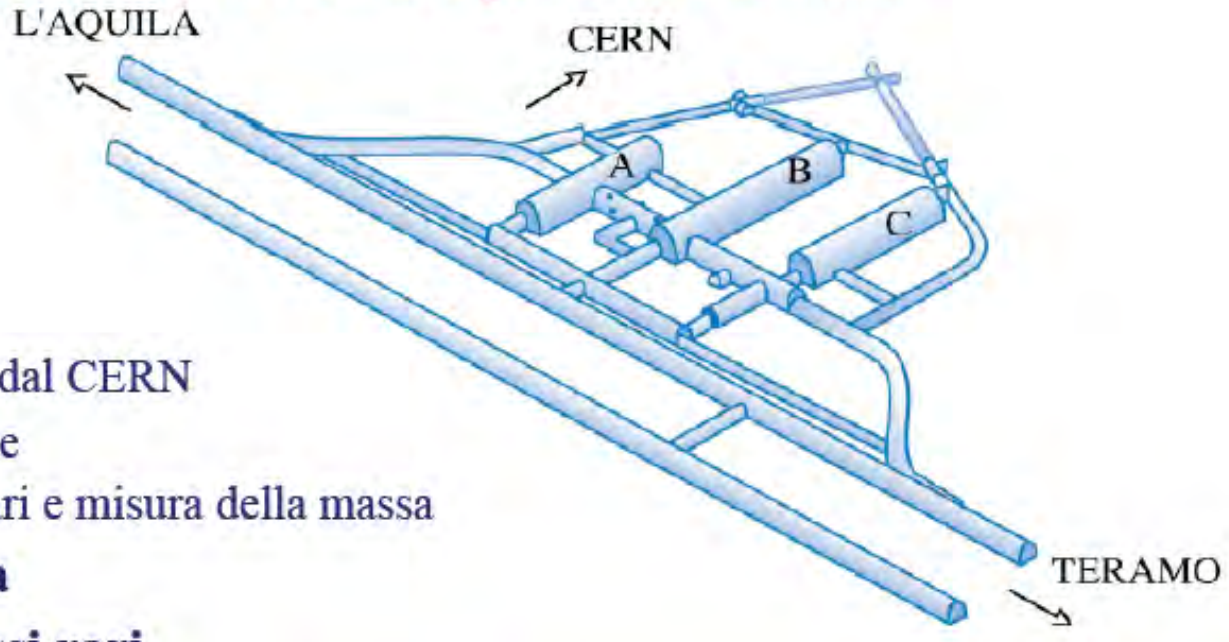
La sala B durante gli scavi e appena completata

E' il principale Laboratorio di Fisica delle Astroparticelle del mondo

~130 Km da Roma, 1 ½ dall'aeroporto di Fiumicino

Scienza @ LNGS

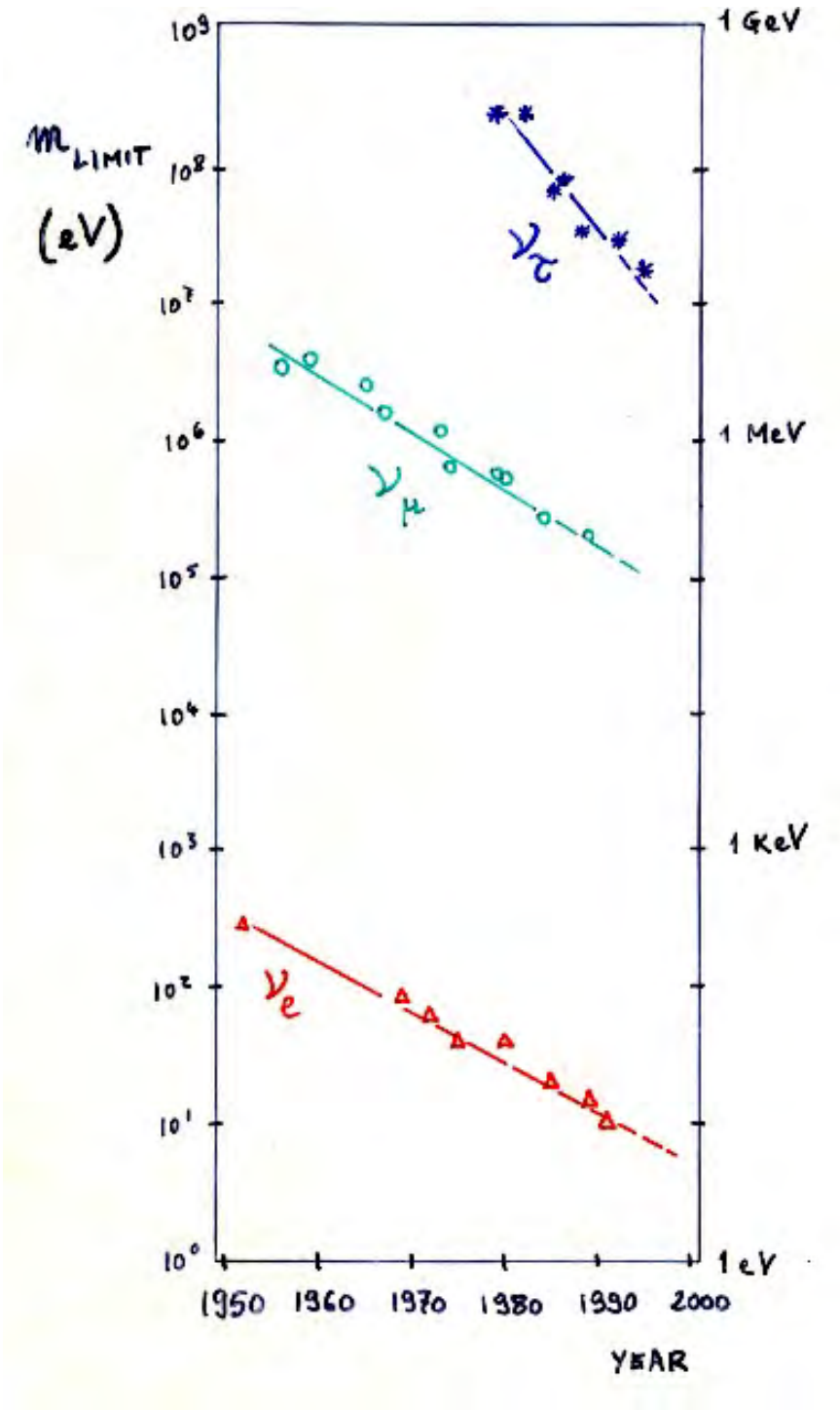
- **Fisica dei neutrini**
  - Neutrini solari
  - Esperimenti con neutrini dal CERN
  - Rivelazione di supernovae
  - Ricerca di decadimenti rari e misura della massa
- **Ricerca di materia oscura**
- **Fisica nucleare dei processi rari**
- **Geofisica**
- **Biologia**



Tunnel:	**10.4 Km**
Copertura:	**~ 3200 m.w.e.**
Riduzione flusso muoni:	**~ 10^6**

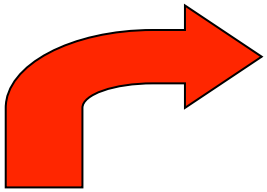
Limiti Sperimentali per la Massa dei Neutrini

(50 anni di misure)



Oscillazioni dei Neutrini

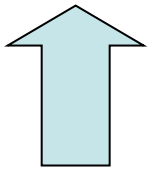
- Idea della massa dei neutrini suggerita per la prima volta da Bruno Pontecorvo



I Neutrini Interagiscono (Produzione o Rivelazione) come Autostati dell'Interazione Debole

$|\nu_e\rangle$, $|\nu_\mu\rangle$, $|\nu_\tau\rangle$ =Autostati dell'Interazione Debole

$|\nu_1\rangle$, $|\nu_2\rangle$, $|\nu_3\rangle$ =Autostati di Massa (H → Evoluzione t)

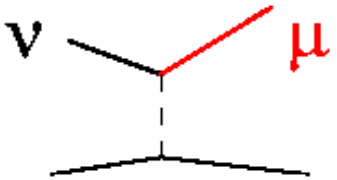


- I Neutrini si propagano (evolvono) come sovrapposizione di autostati di **massa: MESCOLAMENTO**

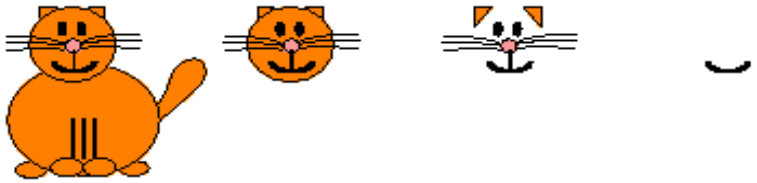
Comparsa/Appearance

"Appearance Experiments"
see the new neutrino type
in the detector

A *"Disappearance Experiment"* observes
fewer



than expected



Scomparsa/Desappearance

Esperimenti con Neutrini :

1) Sorgenti (Molto) Potenti

2)Apparati (Molto) Sensibili e (Molto) Massivi

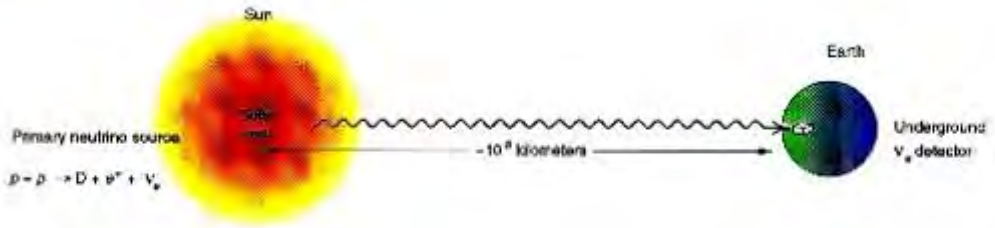
Sorgenti naturali:

Sole, Supernovae, Raggi cosmici

Sorgenti Artificiali:

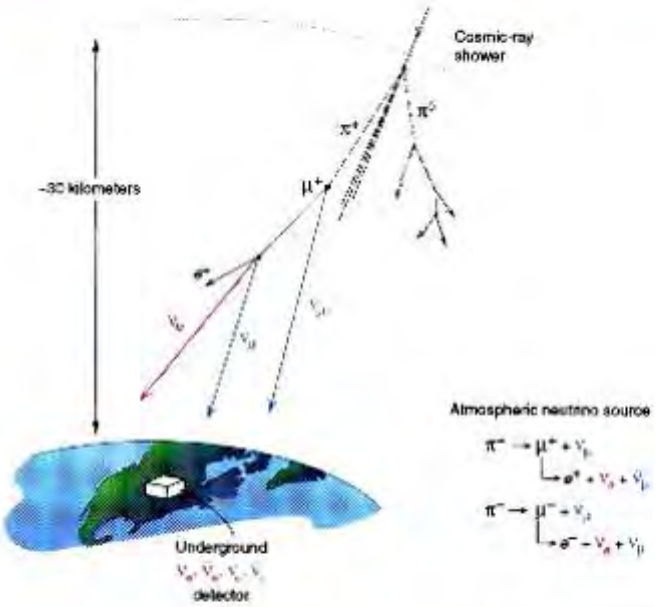
Acceleratori, Reattori Nucleari

SOLAR ν : (ν_e)



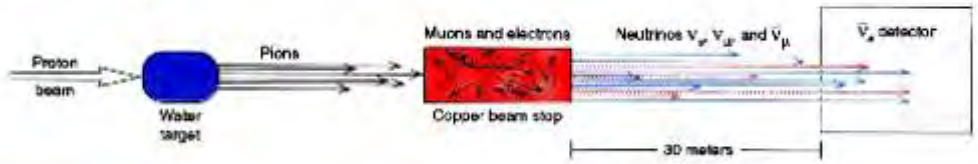
ATMOSPHERIC ν:

(ν_μ $\bar{\nu}_\mu$ ν_e $\bar{\nu}_e$)



ACCELERATOR ν :

(ν_μ $\bar{\nu}_\mu$ ν_e)

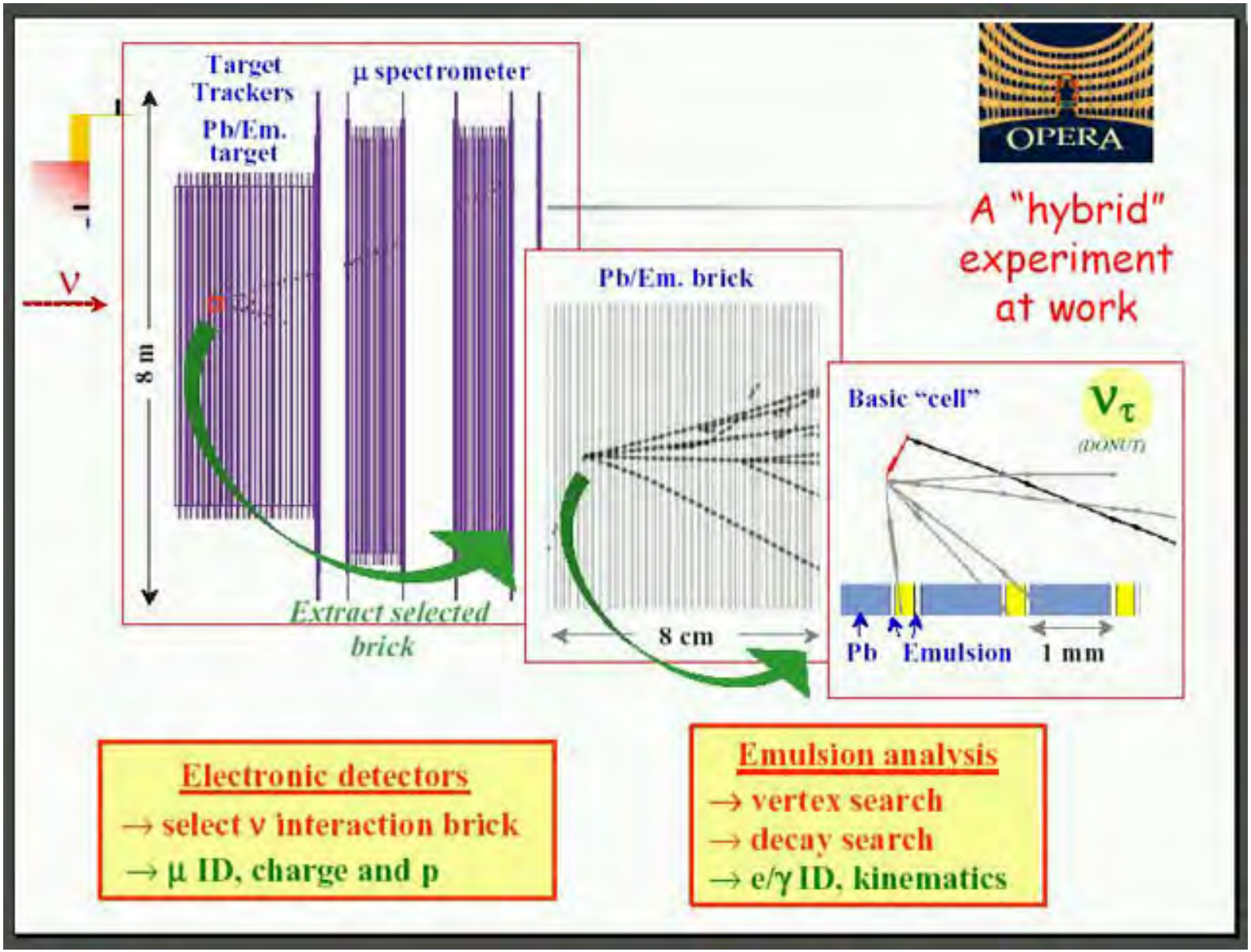


REACTOR ν :

($\bar{\nu}_e$)

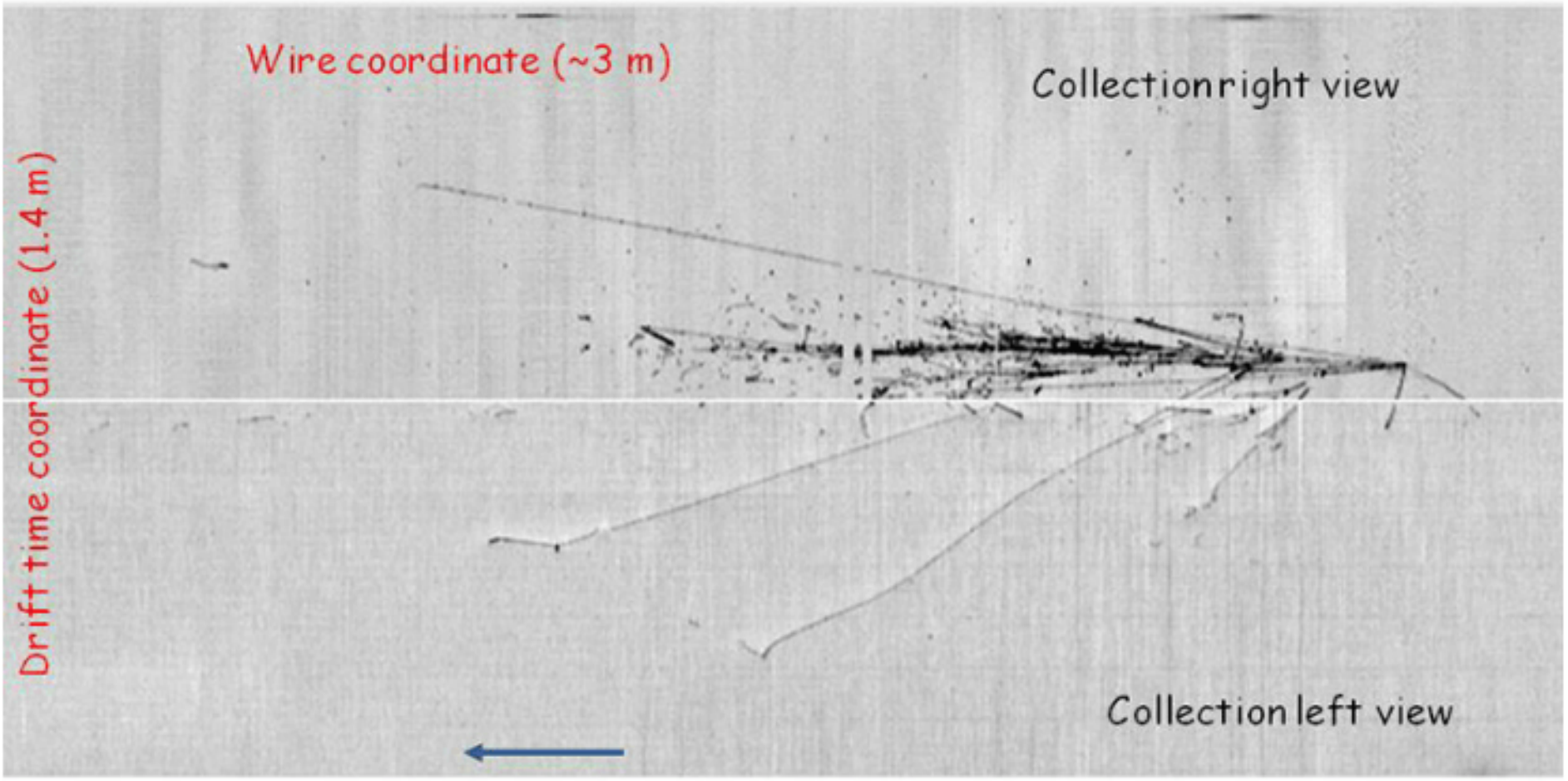
Opera

Opera


Target Trackers
μ spectrometer
Pb/Em. target
8 m
ν
Extract selected brick
Pb/Em. brick
8 cm
Basic "cell"
ν_τ
(DONUT)
Pb
Emulsion
1 mm
OPERA
A "hybrid" experiment at work
Electronic detectors
→ select ν interaction brick
→ μ ID, charge and p
Emulsion analysis
→ vertex search
→ decay search
→ e/γ ID, kinematics

Icarus

Icarus


Wire coordinate (~3 m)
Collection right view
Drift time coordinate (1.4 m)
Collection left view
CNGS ν beam direction

Astrofisica Nucleare e Subnucleare

(Fisica Astroparticellare/Astrofisica Particellare)

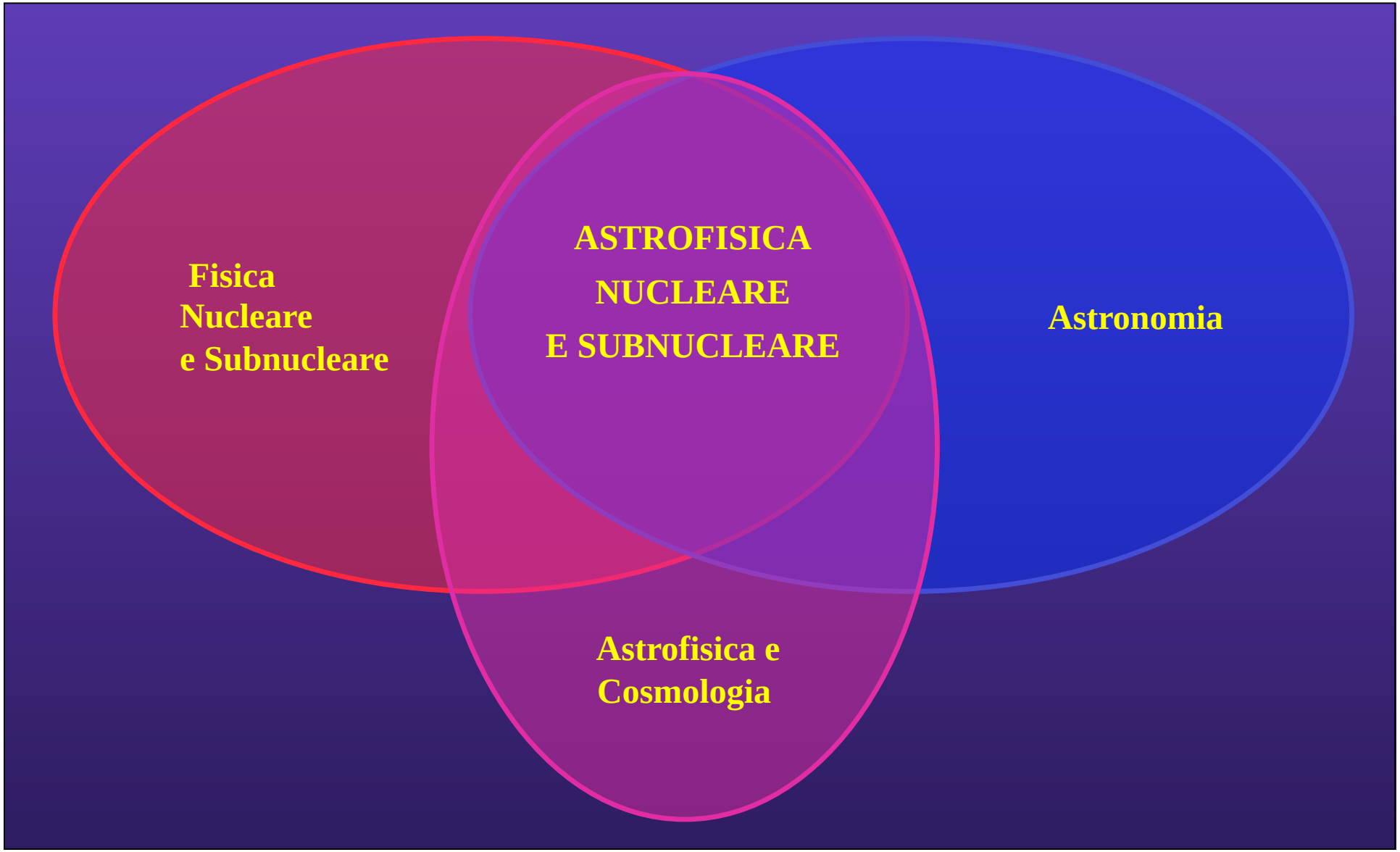
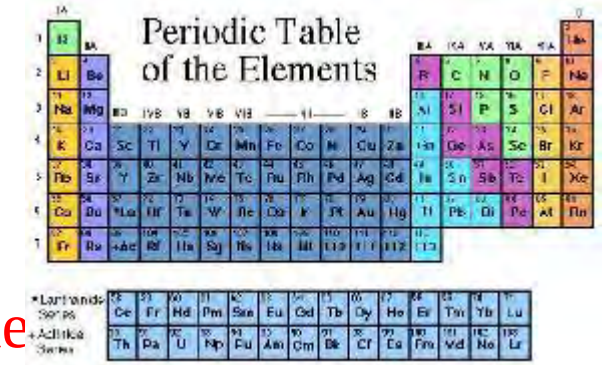
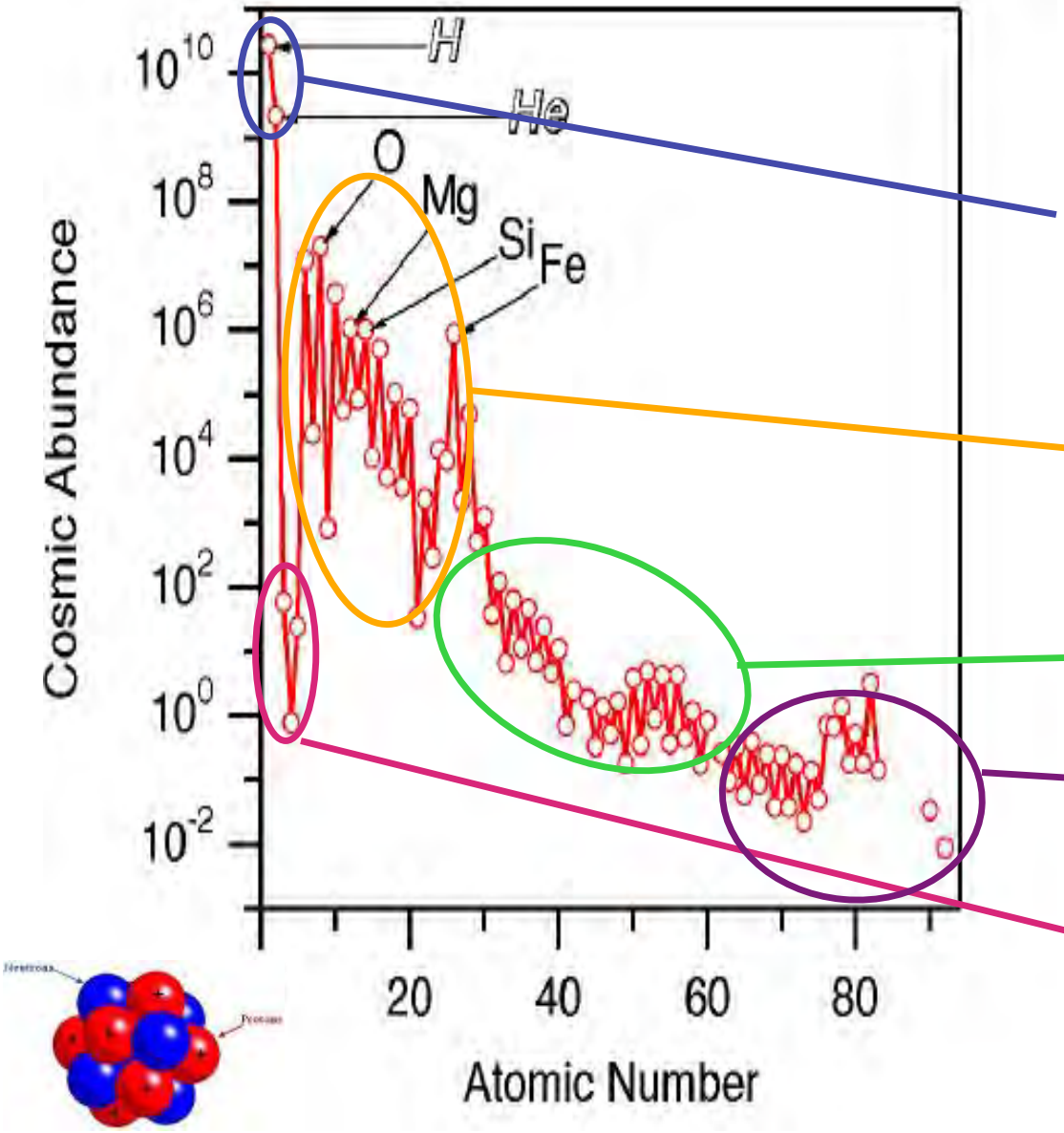


Tavola periodica degli elementi ========== >



Origine



Big Bang Nucleosintesi

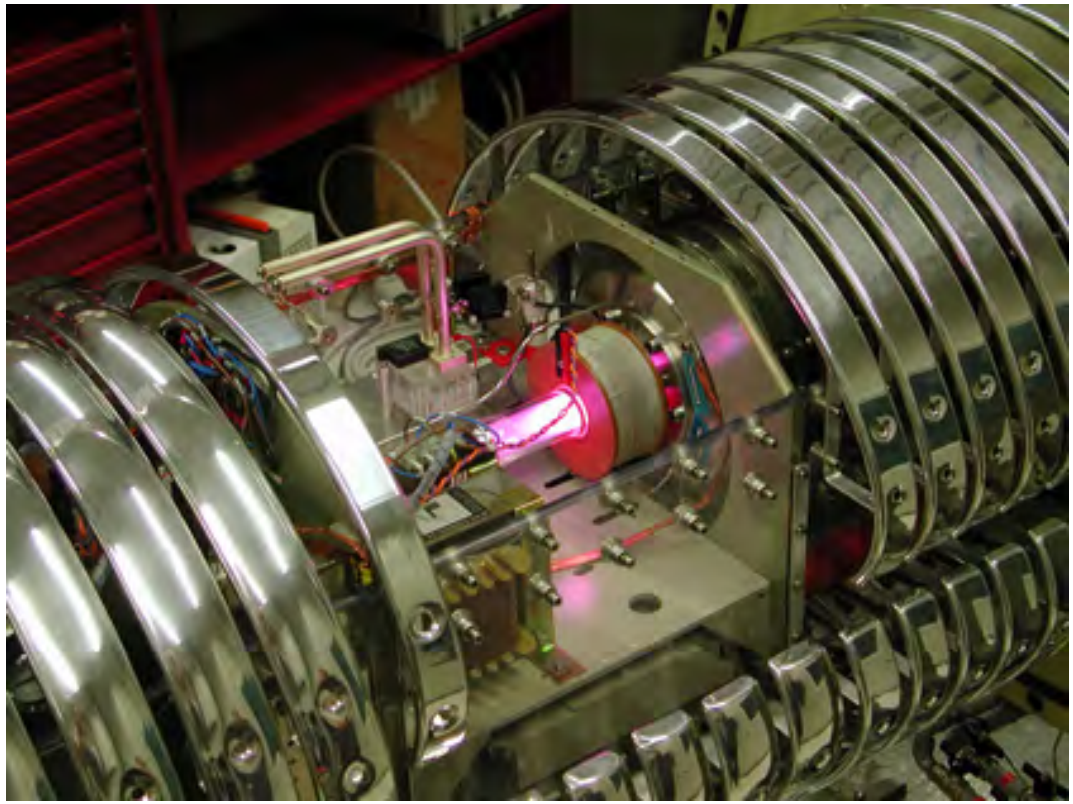
Stelle calde

Esplosioni di Supernova

Merging di Stelle di Neutroni

Interazioni con raggi cosmici

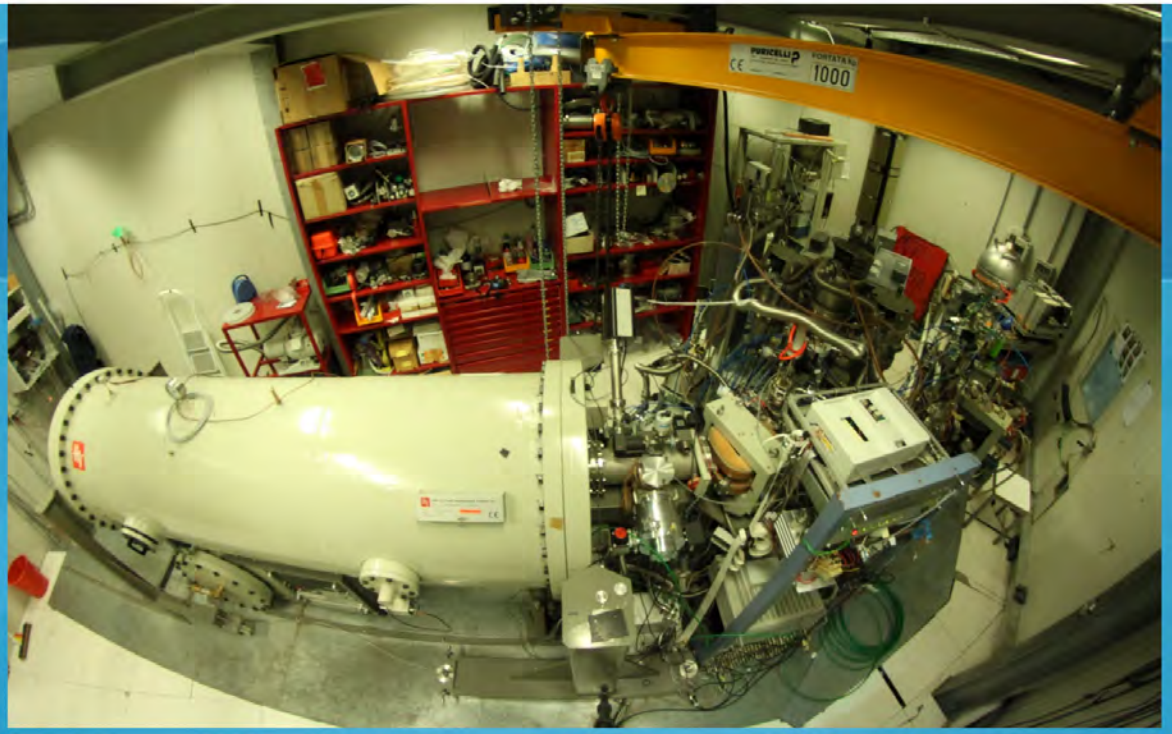
Astrofisica Nucleare - LUNA



The LUNA (Laboratory for Underground Nuclear Astrophysics) main aim is to investigate nuclear fusion reactions that generate most of the stellar energy and allowed the synthesis of the elements in stars and in the primordial Universe. Such reactions have a very low probability (cross section) at energies of astrophysical interest and are thus very difficult to be measured in a laboratory at the Earth's surface, where the cosmic background would mask the feeble signal. During the last 25 years, LUNA installed two accelerators in the underground laboratories of LNGS and measured a few key reactions of the Hydrogen burning and of primordial nucleosynthesis.

Astrofisica Nucleare - LUNA

LUNA 400 kV accelerator



$E_{beam} \approx 50 - 400$ keV

$I_{max} \approx 500\ \mu A$ protons

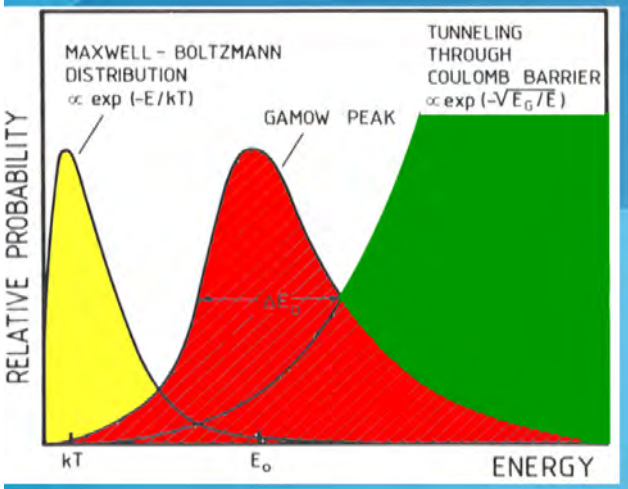
$I_{max} \approx 250\ \mu A$ alphas

Energy spread ≈ 70 eV

Long term stability ≈ 5eV/h

Astrofisica Nucleare - LUNA

Underground nuclear astrophysics: Why?



Sun:
kT = 1 keV
$E_C \approx$ 0.5-2 MeV
$E_0 \approx$ 5-30 keV
for reactions of H burning

kT but also $E_0 \ll E_C$!!

$$\sigma(E) = \frac{1}{E} \exp(-31.29 Z_1 Z_2 \sqrt{\mu/E}) S(E)$$

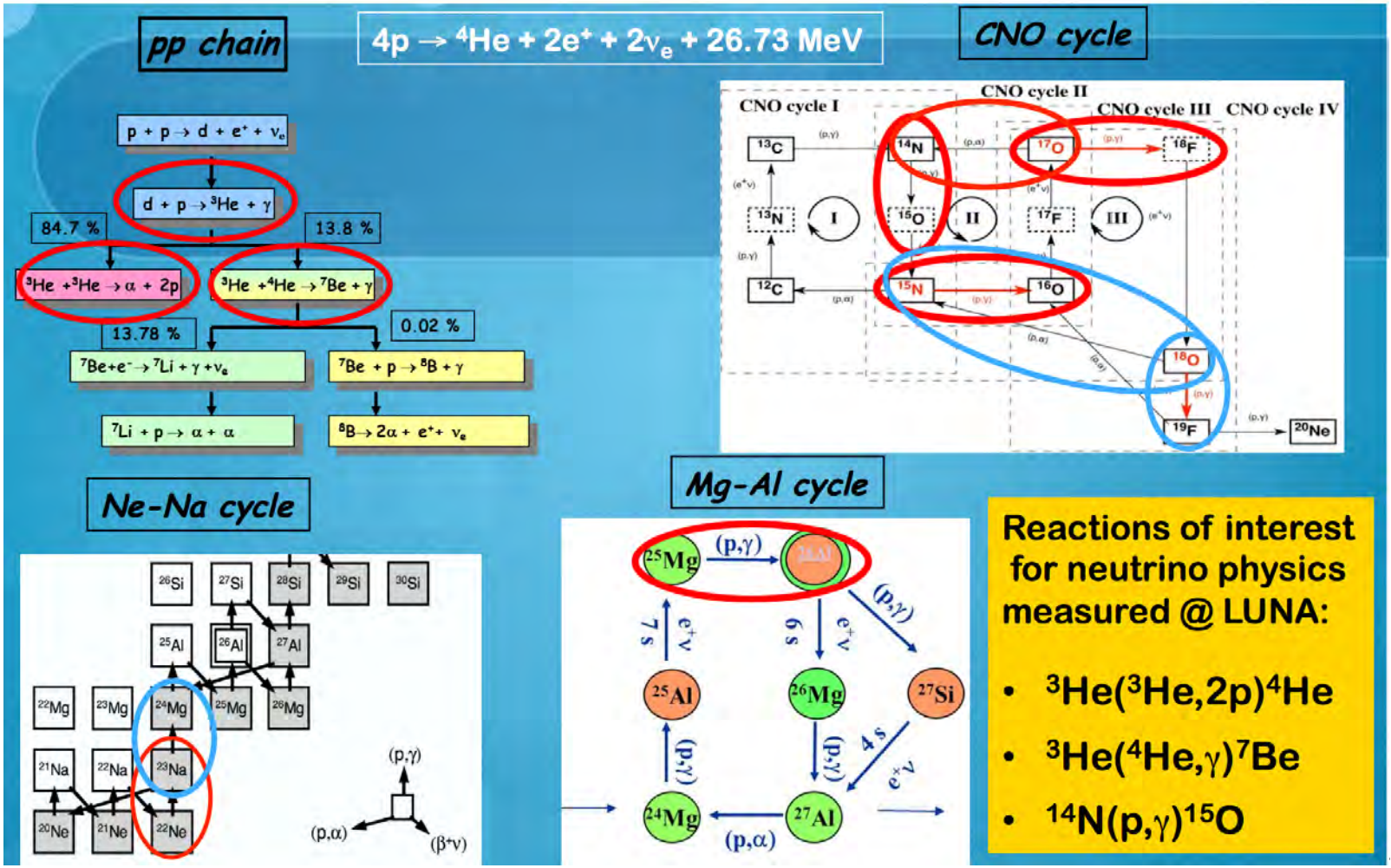
Astrophysical factor

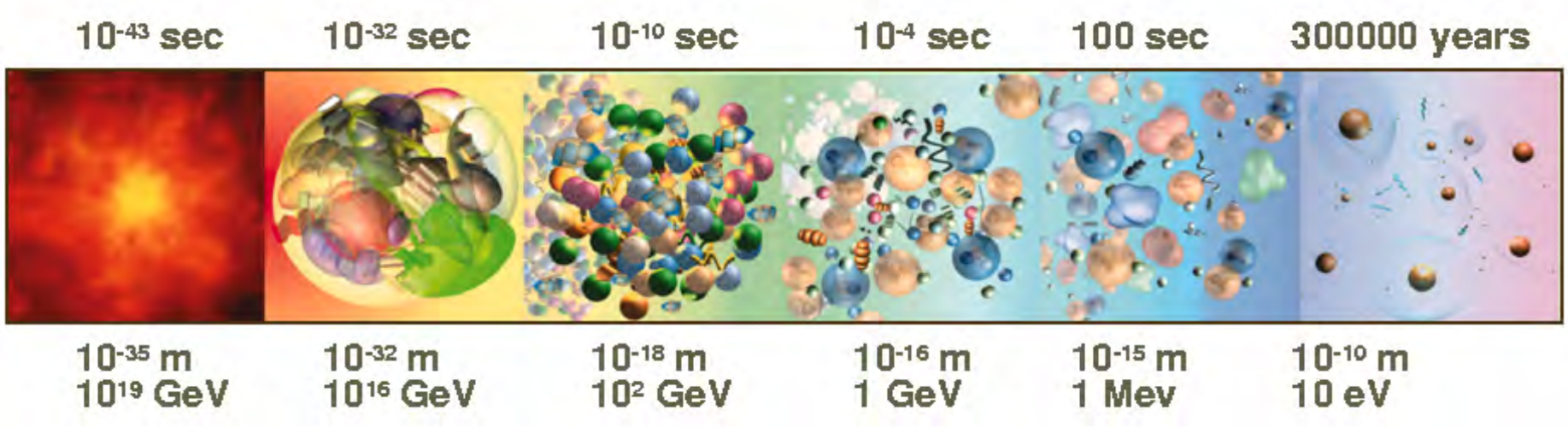
Cross sections in the range of pb-fb at stellar energies

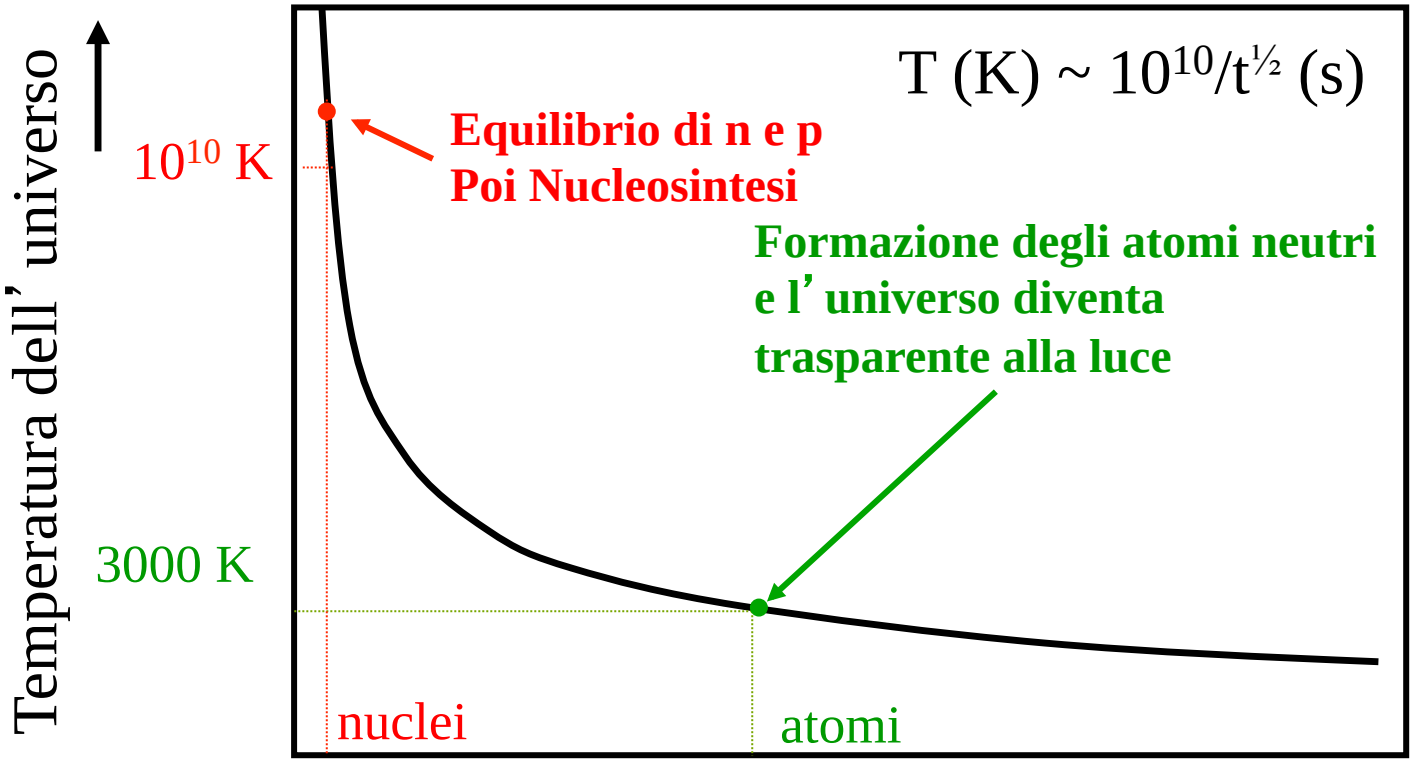
with typical laboratory conditions reaction rate R can be as low as few events per month

Astrofisica Nucleare - LUNA

25 years @ LUNA : H burning

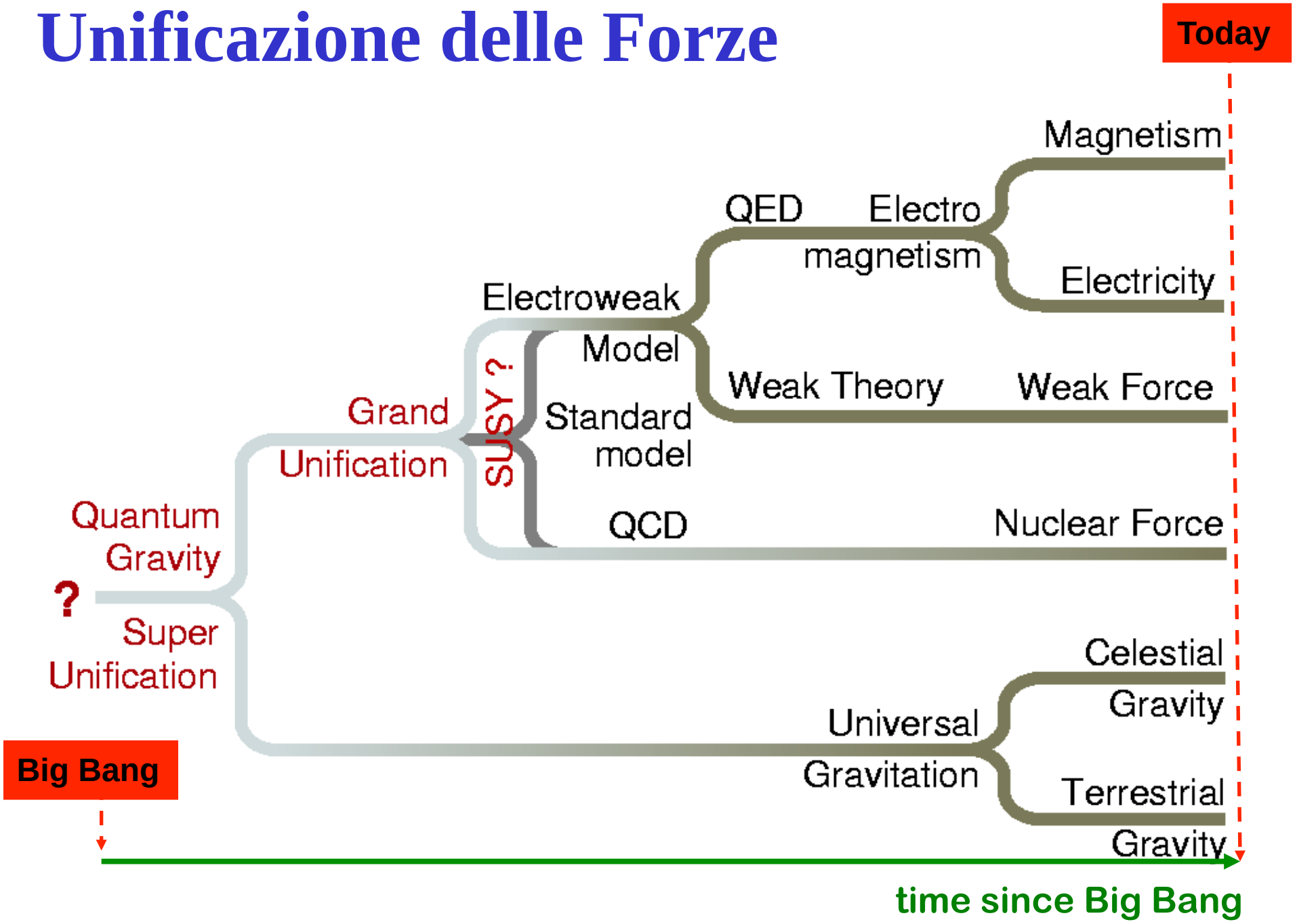



10-43 sec
10-32 sec
10-10 sec
10-4 sec
100 sec
300000 years
10-35 m
1019 GeV
10-32 m
1016 GeV
10-18 m
102 GeV
10-16 m
1 GeV
10-15 m
1 Mev
10-10 m
10 eV

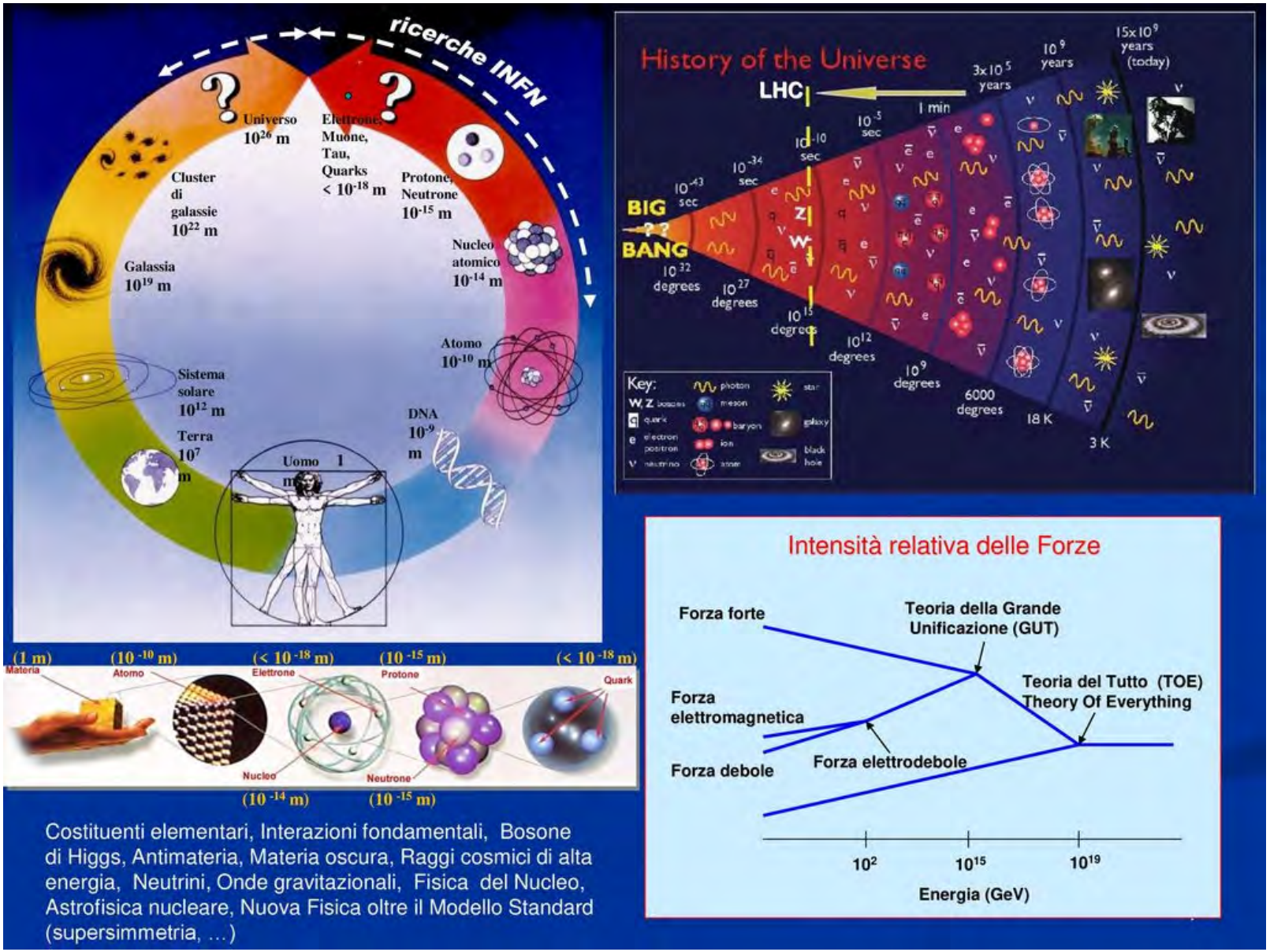

Temperatura dell'universo
T (K) ~ 10^10/t^½ (s)
10^10 K
Equilibrio di n e p
Poi Nucleosintesi
Formazione degli atomi neutri
e l'universo diventa
trasparente alla luce
3000 K
nuclei
atomi
100 s
300000 anni
tempo dopo il big bang

Big Bang

Unificazione delle Forze

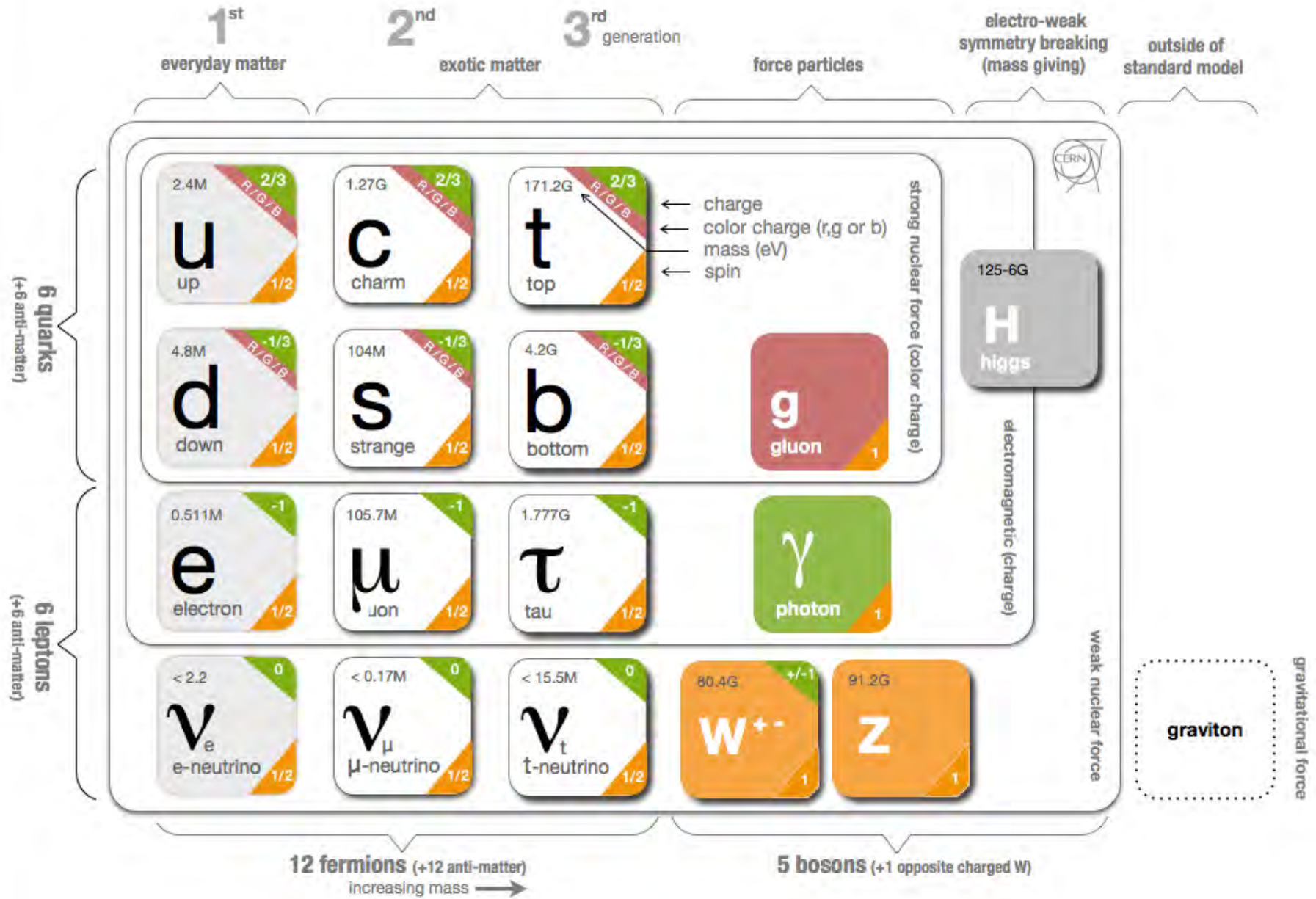


Universe and Particles



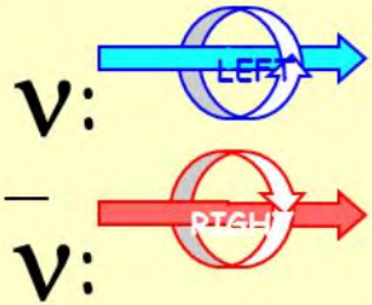
Costituenti elementari, Interazioni fondamentali, Bosone di Higgs, Antimateria, Materia oscura, Raggi cosmici di alta energia, Neutrini, Onde gravitazionali, Fisica del Nucleo, Astrofisica nucleare, Nuova Fisica oltre il Modello Standard (supersimmetria, …)

MODELLO STANDARD : Fermioni (Costituenti) e Bosoni (Mediatori)



La fisica del neutrino

Dirac or Majorana neutrino?



$\nu \neq \overline{\nu}$ $\qquad$ $\nu = \overline{\nu}$

→ → $\qquad$ Majorana

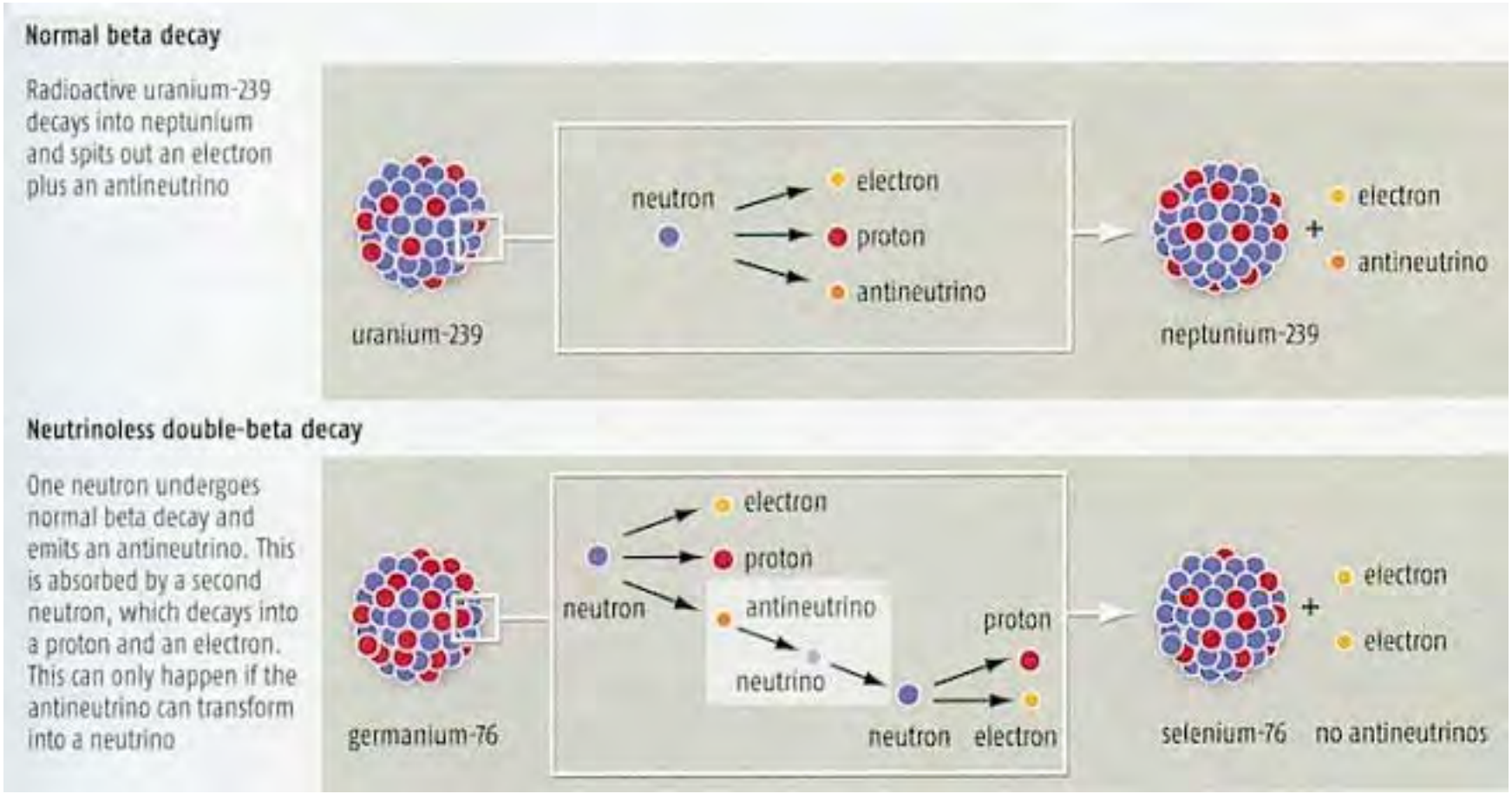
<= => $\qquad$ =>1937

Dirac particle

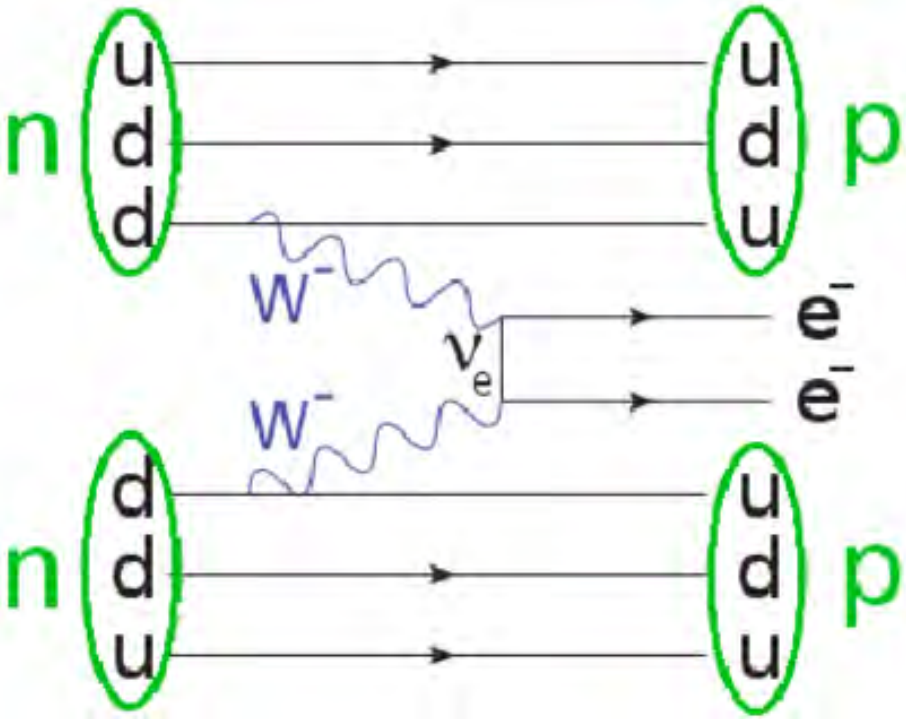
ν

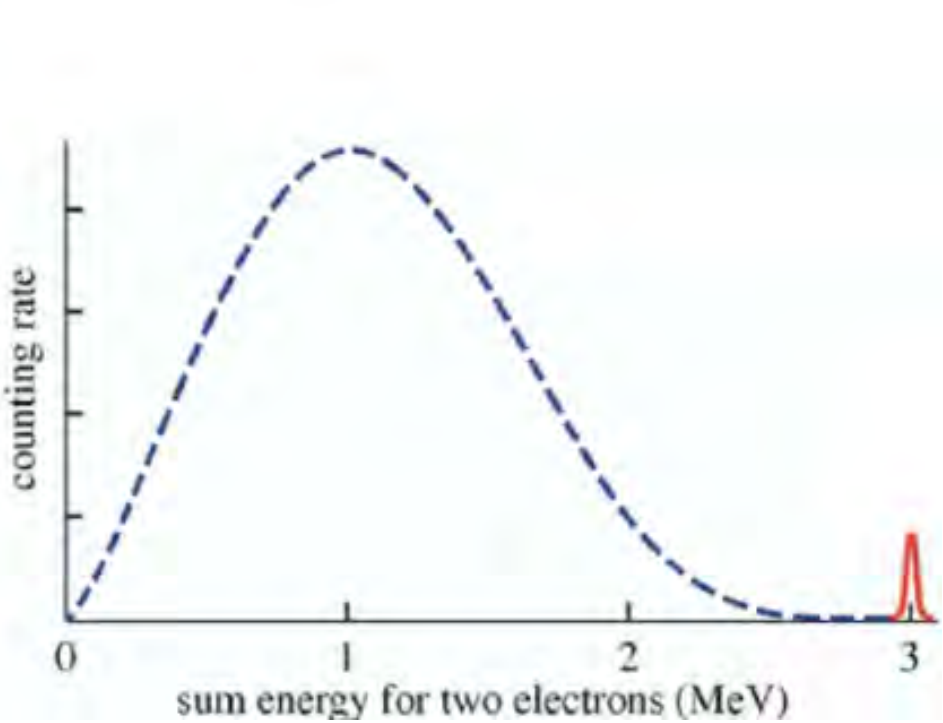
Majorana particle

Neutrino-less double beta decay



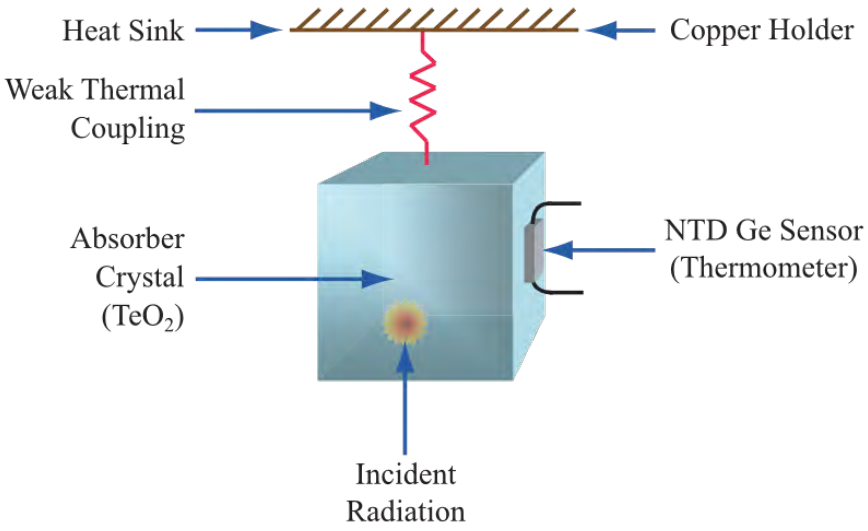
Neutrino-less double beta decay

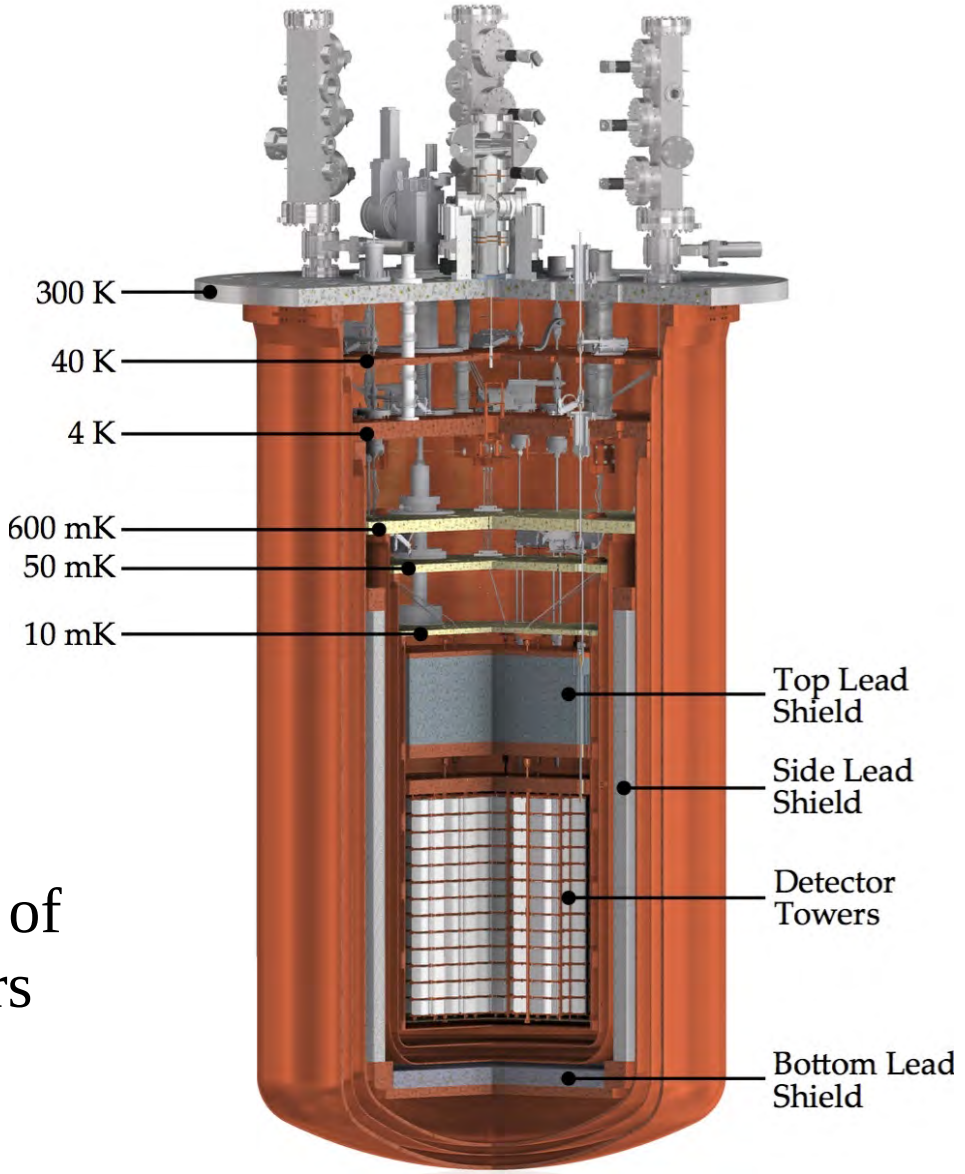




Cuore

Cuore



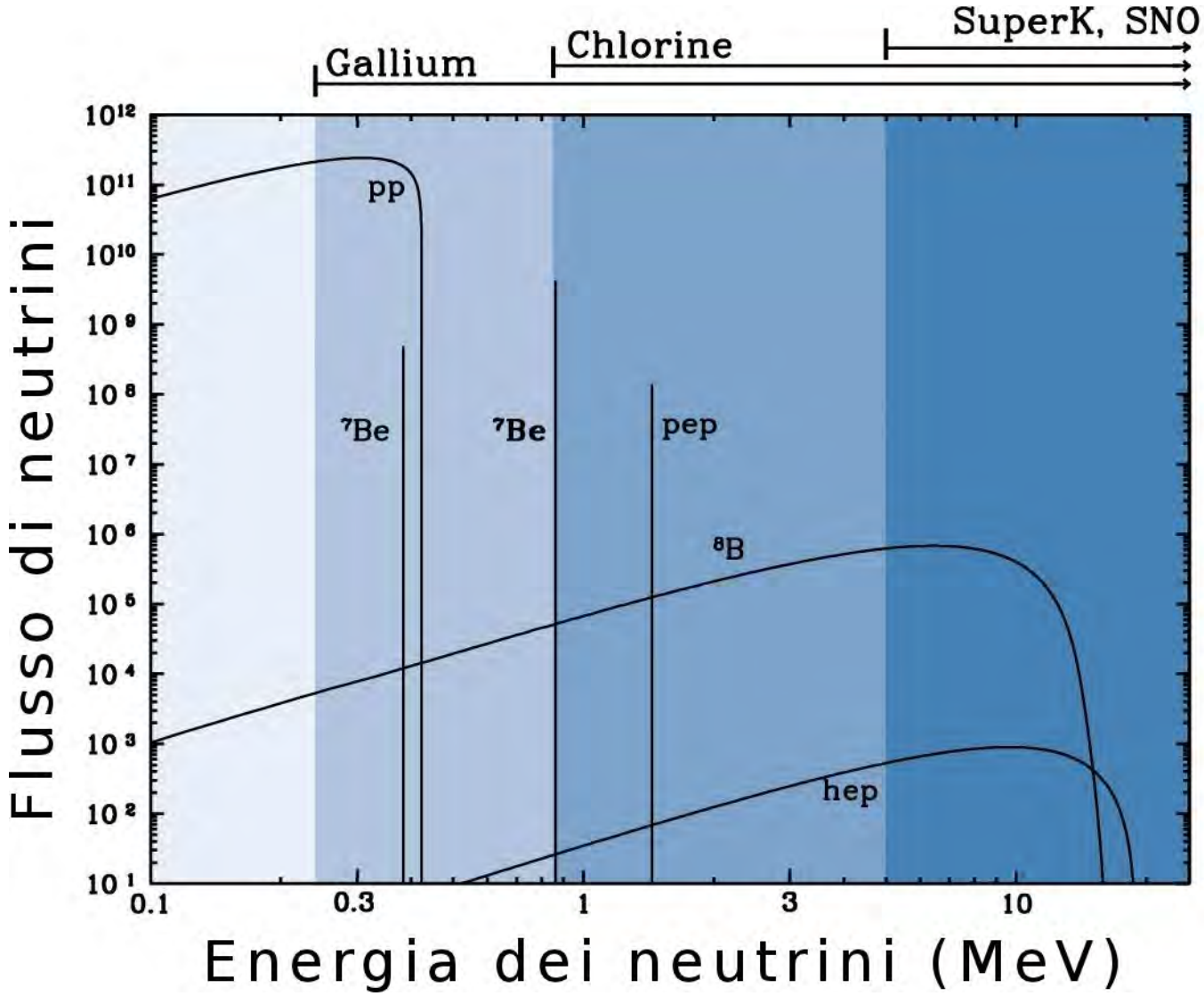


CUORE is the largest volume of cryogenic tellurium bolometers ever built

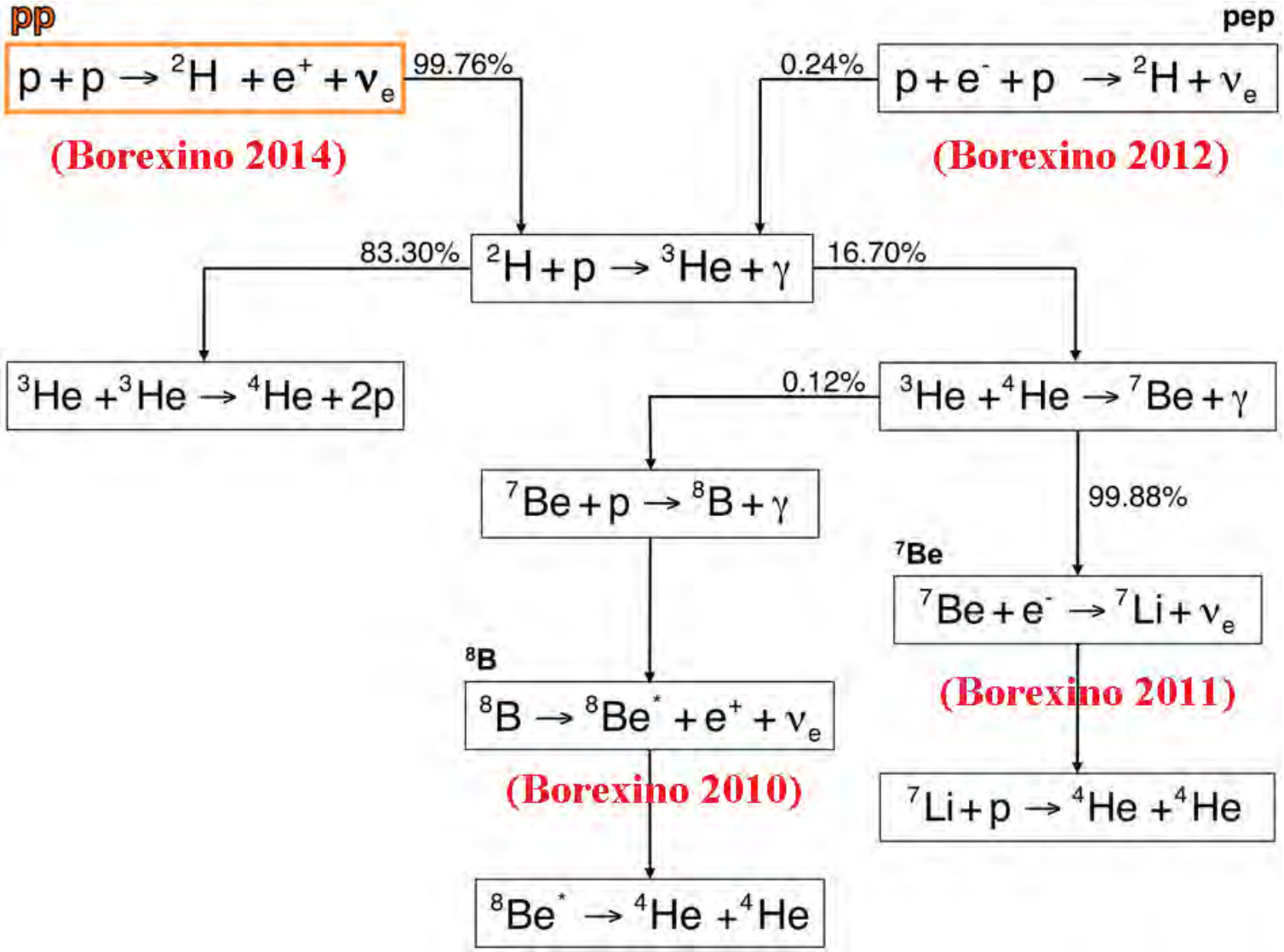
Gerda

The GERDA experiment has been proposed in 2004 as a new ^{76}Ge double-beta decay experiment at LNGS. The GERDA installation is a facility with germanium detectors made out of isotopically enriched material.

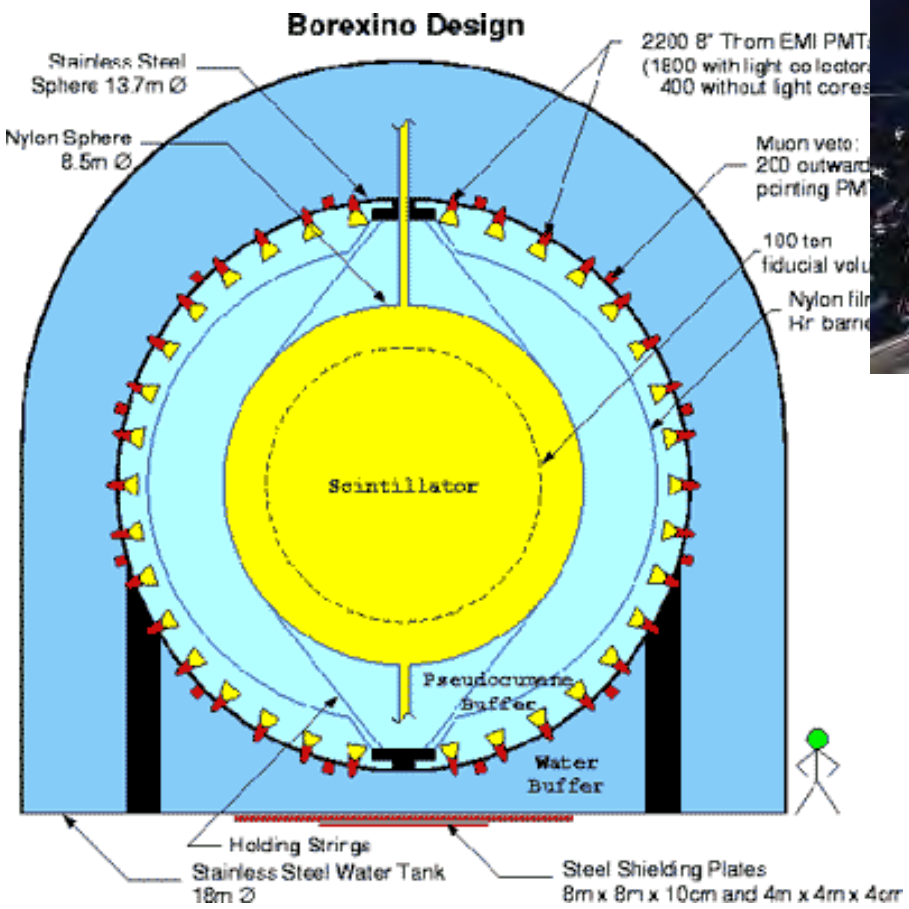
Neutrini Solari



Neutrini Solari

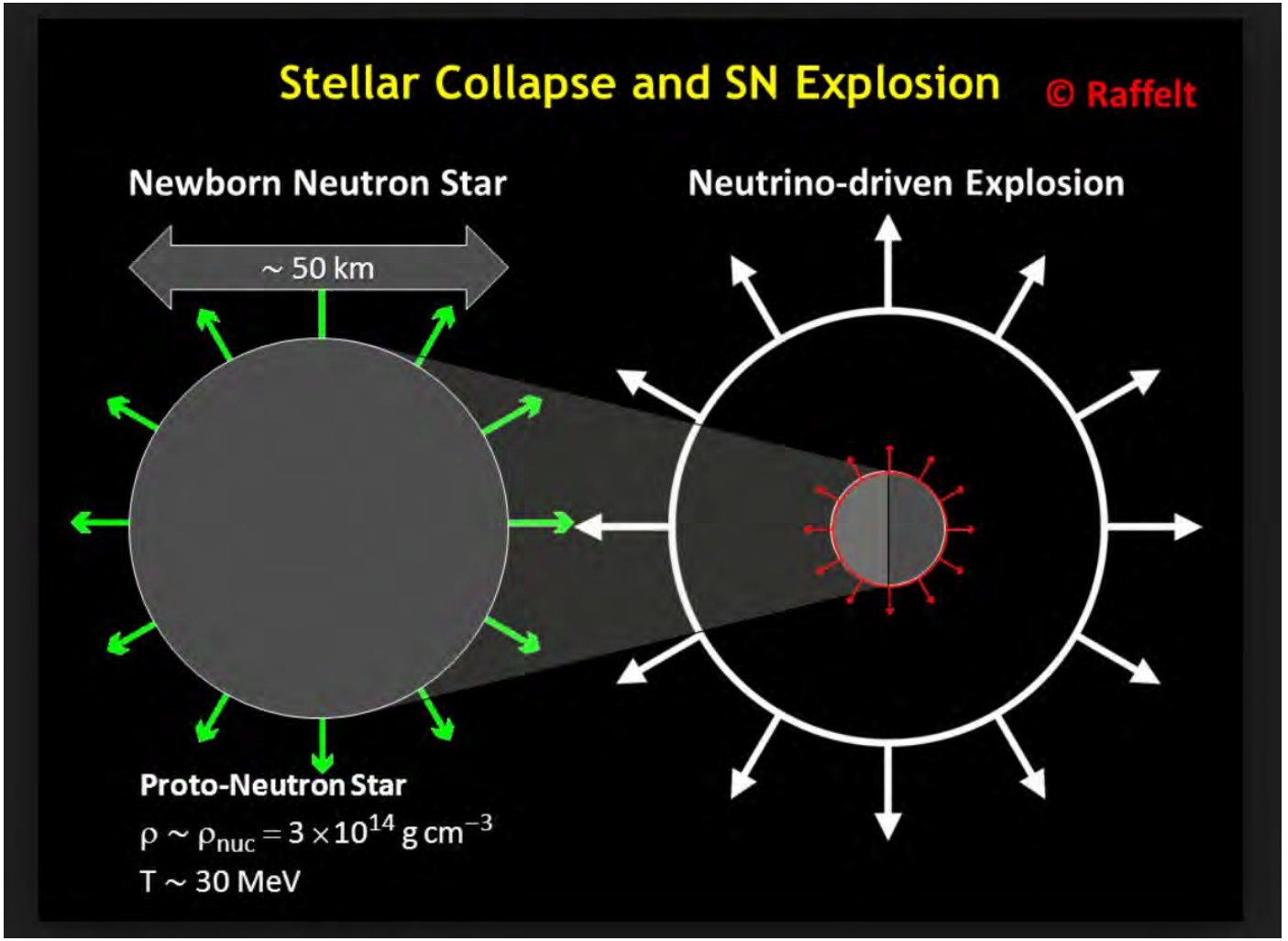


Borexino

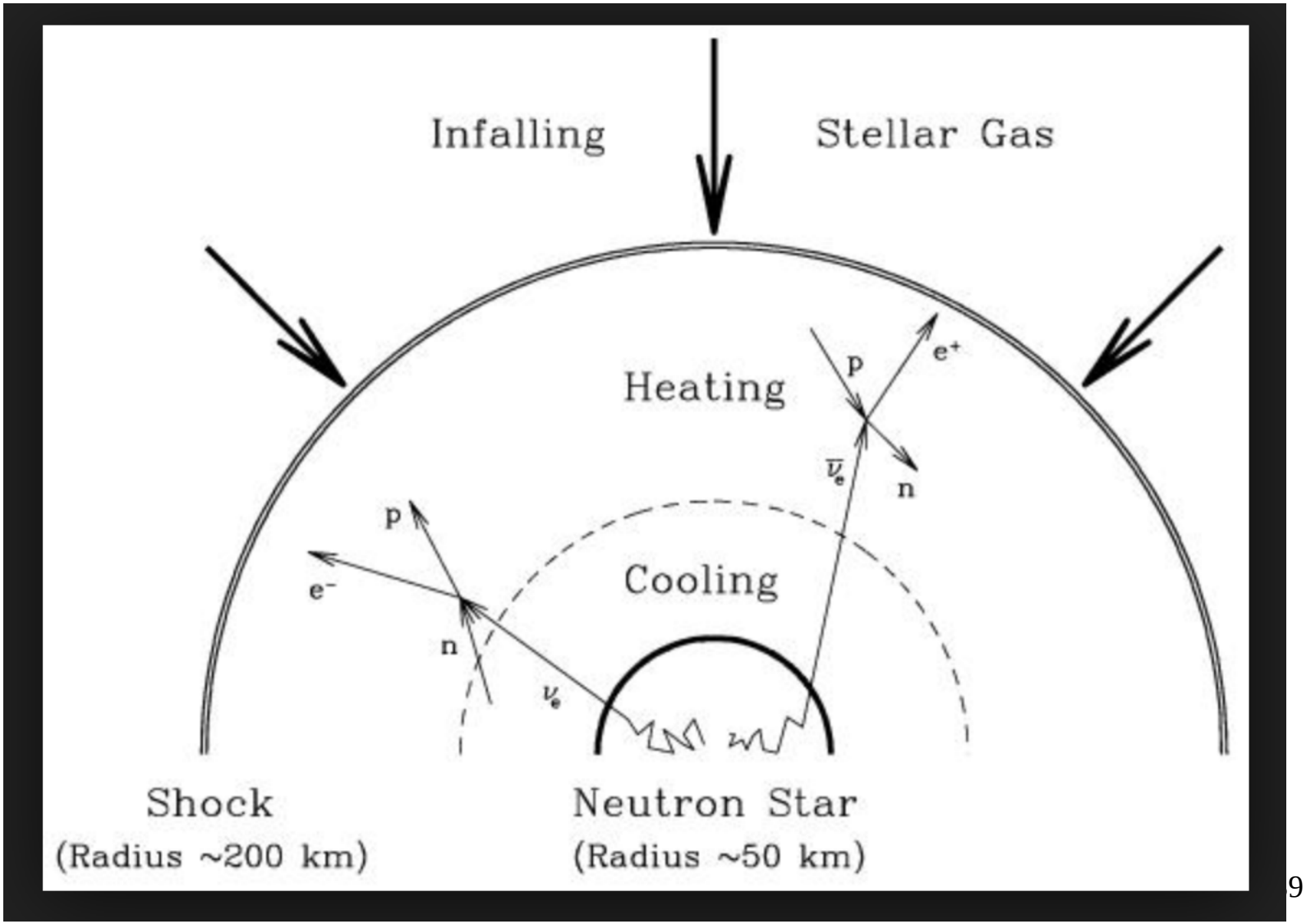


It is a large liquid scintillator detector whose main goal is the study of the properties of low energy solar neutrinos. It has achieved exceptional levels of radiopurity.

Neutrini da Supernova



Neutrini da Supernova

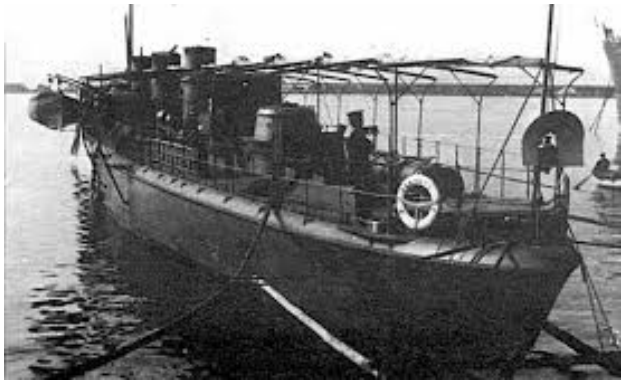


LVD

The detector consists of a three-dimensional array of 840 scintillator counters, 1.5 m^3 each, arranged in a modular geometry

Raggi Cosmici

Nel fondo di laghi e del mare:
Pacini 1911!

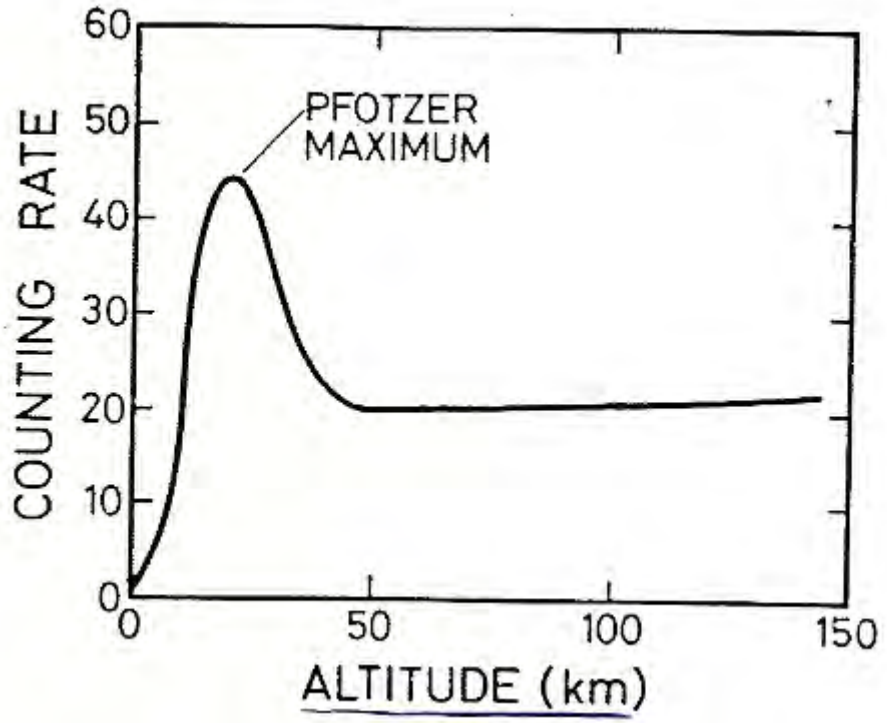


Ascese su Pallone:
Hess 1912 @ 5km

Altitude (km)	Difference between observed ionisation and that at sea-level (ions cm^{-3}) s^{-1}
1	−1.5
2	+1.2
3	+4.2
4	+8.8
5	+16.9
6	+28.7
7	+44.2
8	+61.3
9	+80.4

Colhoster 1914 @ 9km

Millikan scettico sui "…Raggi … Cosmici"



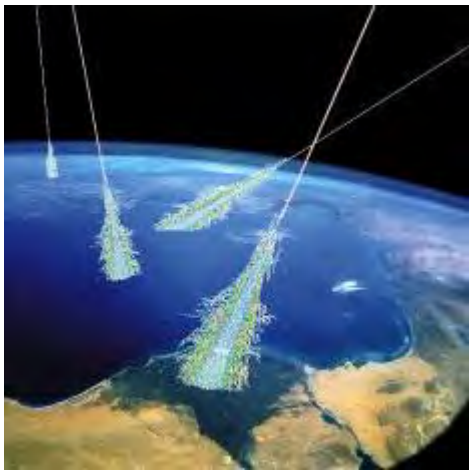
Composizione dei Raggi Cosmici

PRIMARI:

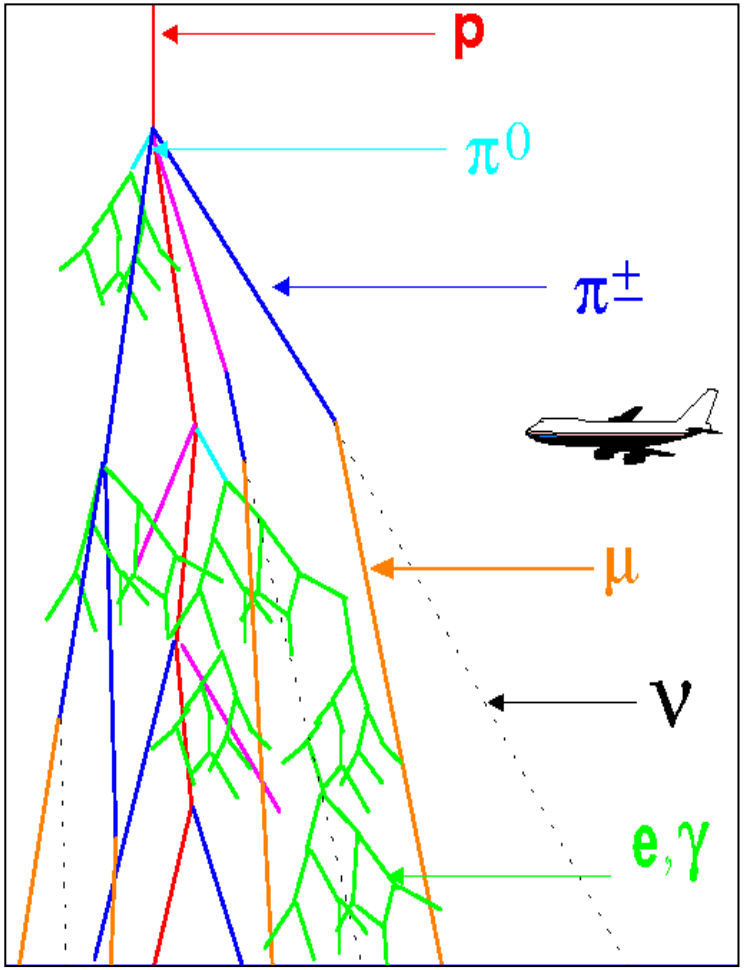
p ~ 87 %, α~10 %, N~1 %

e ~2 %

γ ~0.1 %, ν~0.1 % ?



Alta atmosfera :~ 1000/m²/s



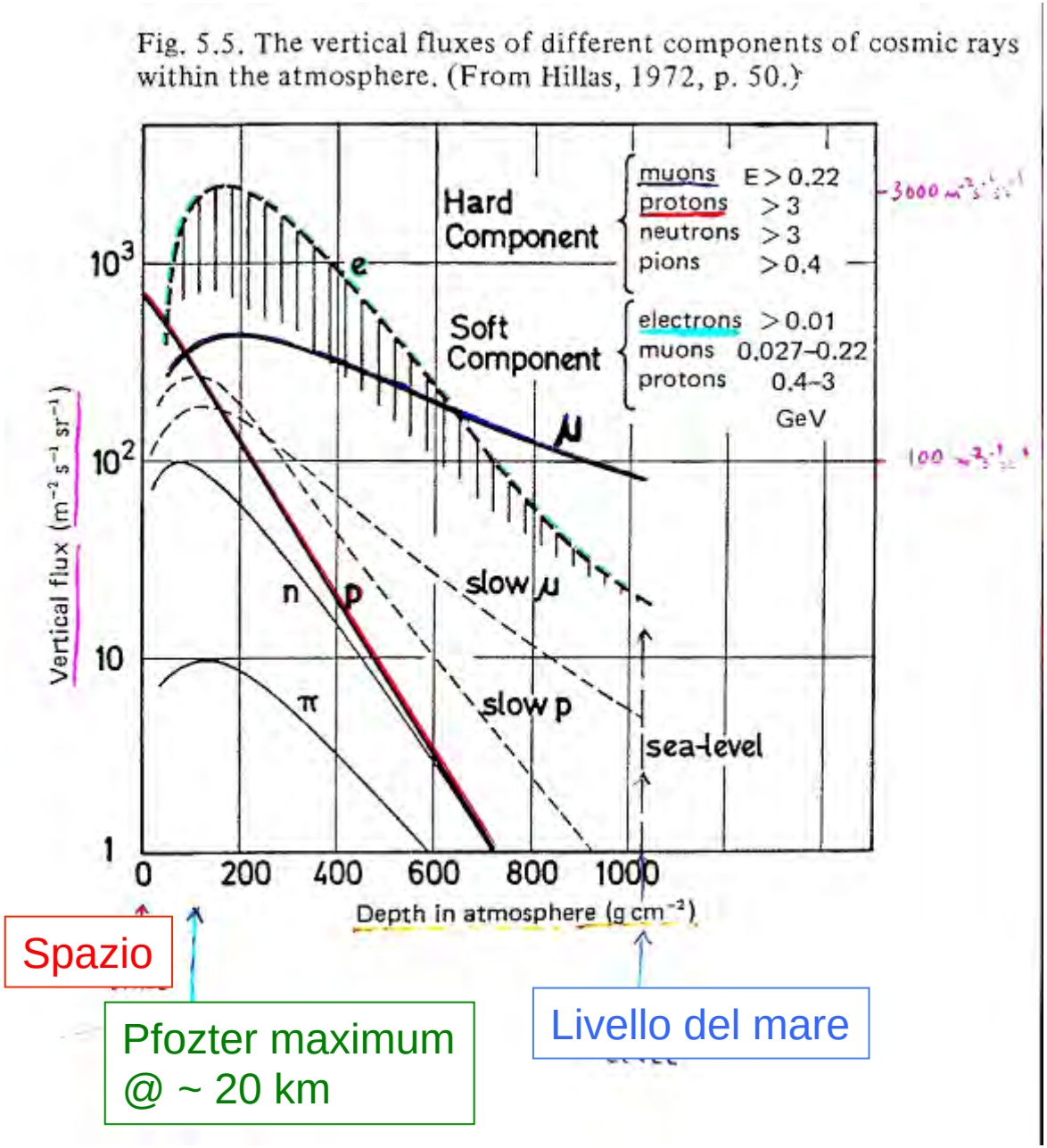
SECONDARI al livello del mare

μ ~ 30 %

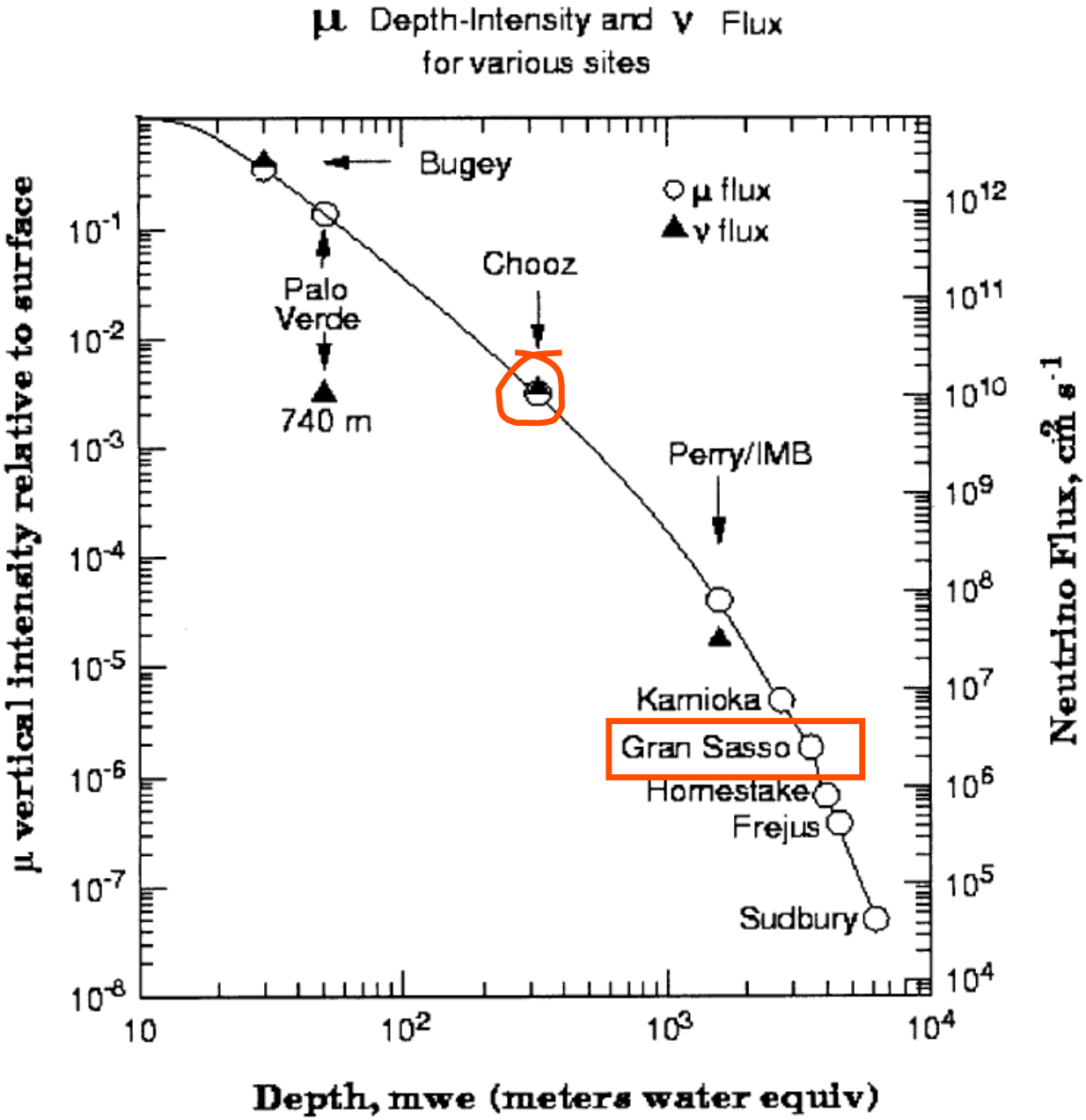
p, n, ... ~ 2 %

ν ~ 68 %

Flusso verticale di Raggi Cosmici vs. profondita' nell'atmosfera



Flusso di μ


μ Depth-Intensity and ν Flux
for various sites
μ vertical intensity relative to surface
Neutrino Flux, cm^{-2} s^{-1}
Depth, mwe (meters water equiv)
Bugey
Palo Verde
740 m
Chooz
Perry/IMB
Kamioka
Gran Sasso
Homestake
Frejus
Sudbury
μ flux
ν flux
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{12}
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
10^{4}
10
10^{2}
10^{3}
10^{4}

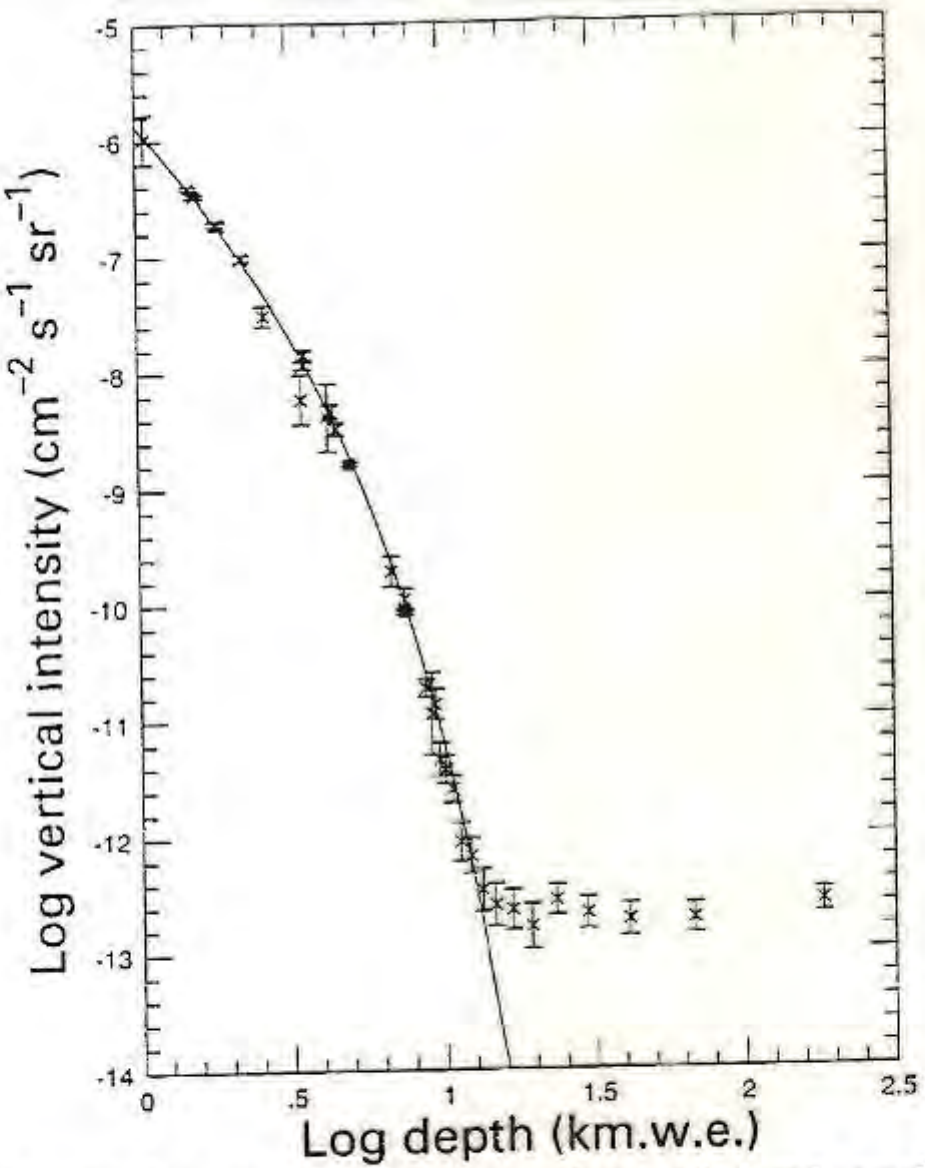
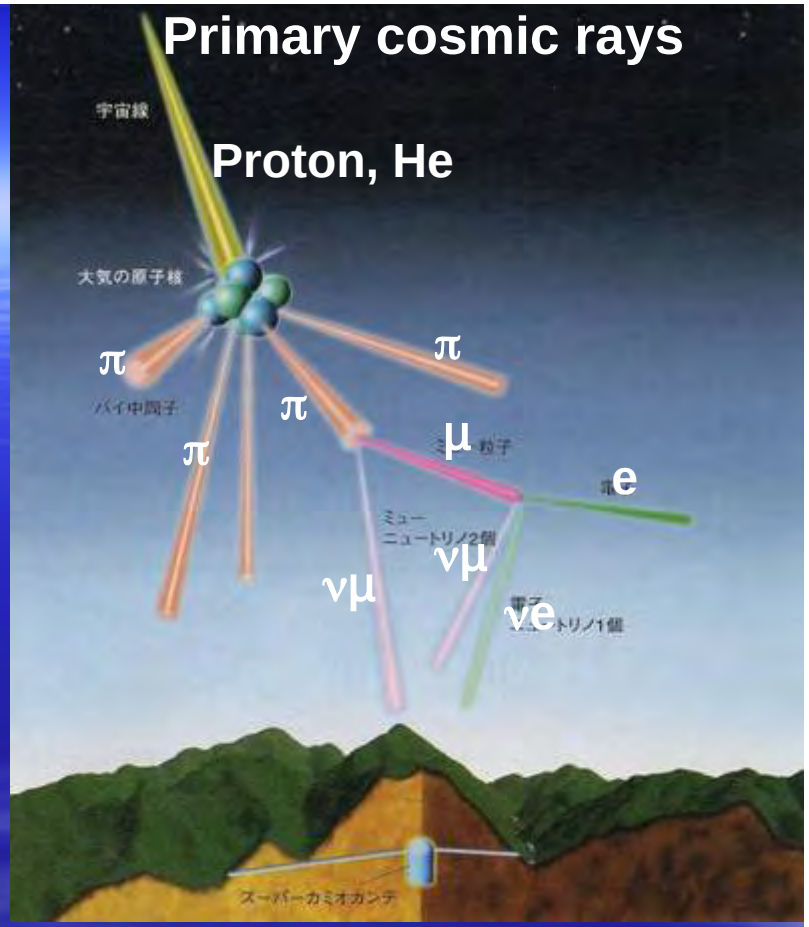
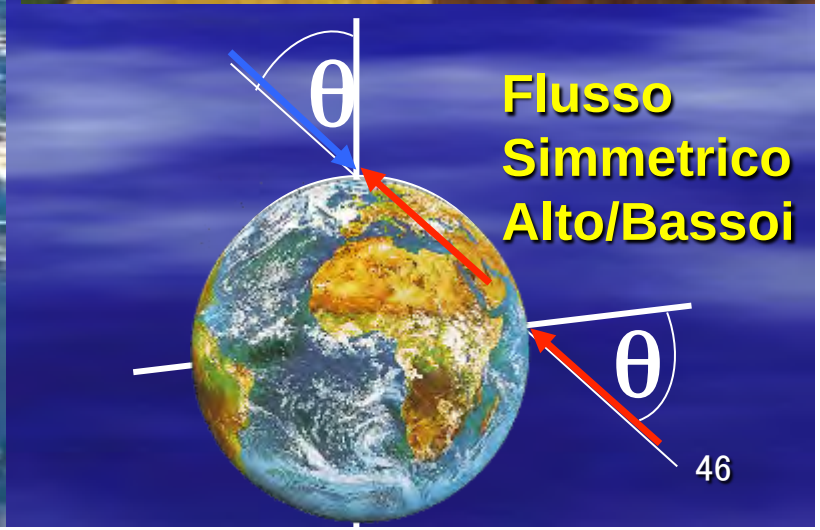


Figure 6.3: Relation between muon intensity and depth underground. The data are taken from a summary by Crouch (1987) with the addition of recent data from the Frejus experiment (Berger et al., 1989 – filled squares).

Sorgente Raggi Cosmici: ν Atmosferici

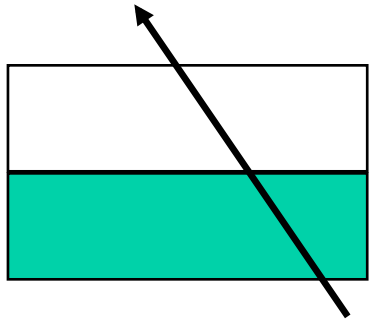




Gli esperimenti “storici”

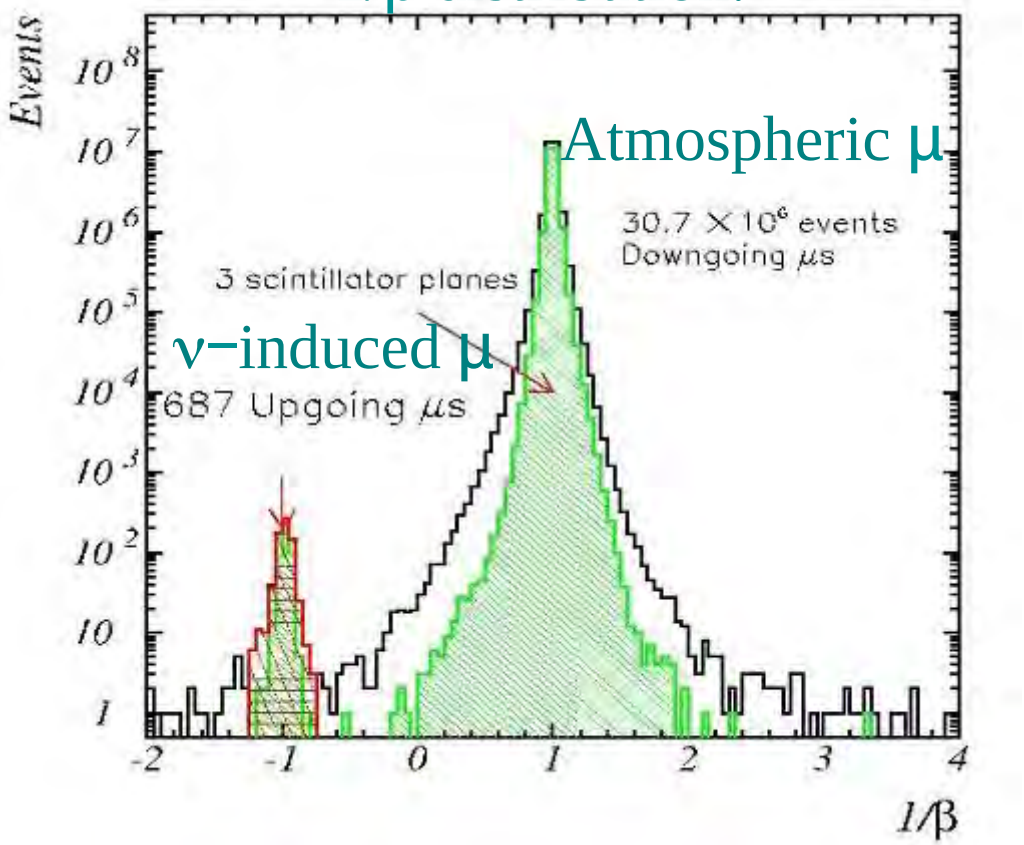
- Macro
  - Ricerca dei monopoli magnetici

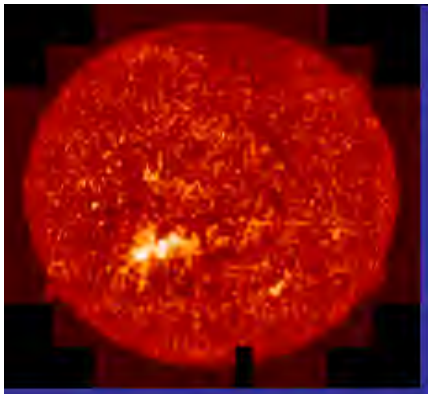
- LVD
  - Ricerca di supernovae
- Gallex
  - Studio di neutrini solari



MACRO Upward throughgoing muons

1/β distribution:

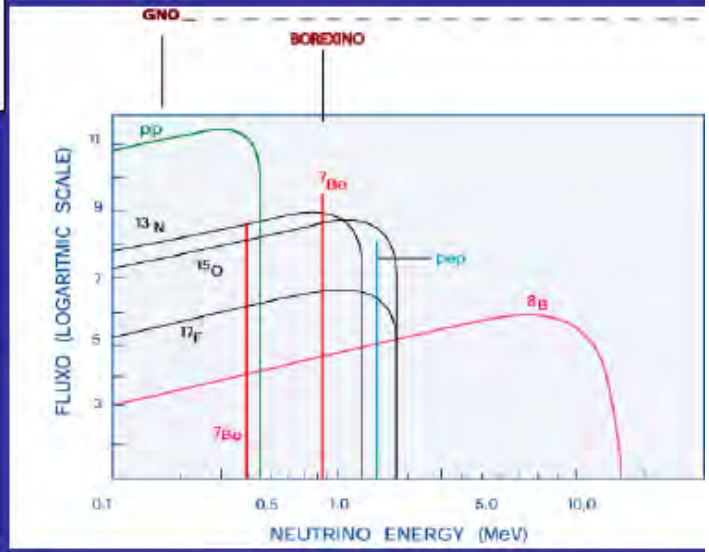




GNO

Collab.:
Italy, France, Germany

Goals: measurement of the interaction rate with an accuracy of 4-5% and monitoring the neutrino flux over a complete solar cycle.



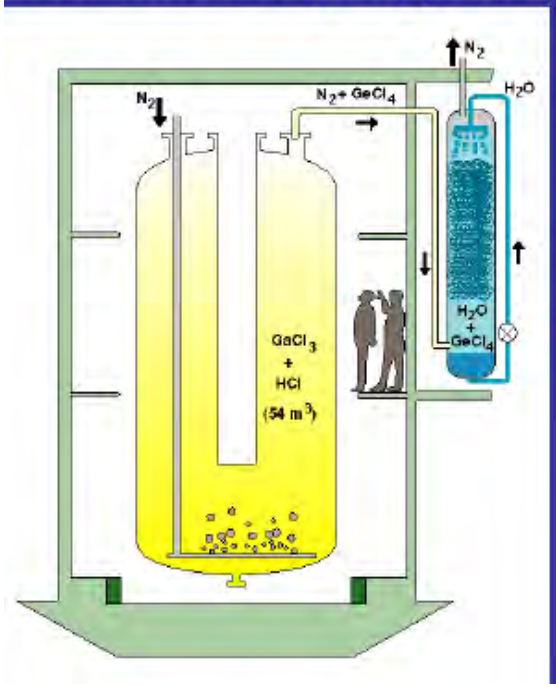
101 tons Gallium Cloride solution

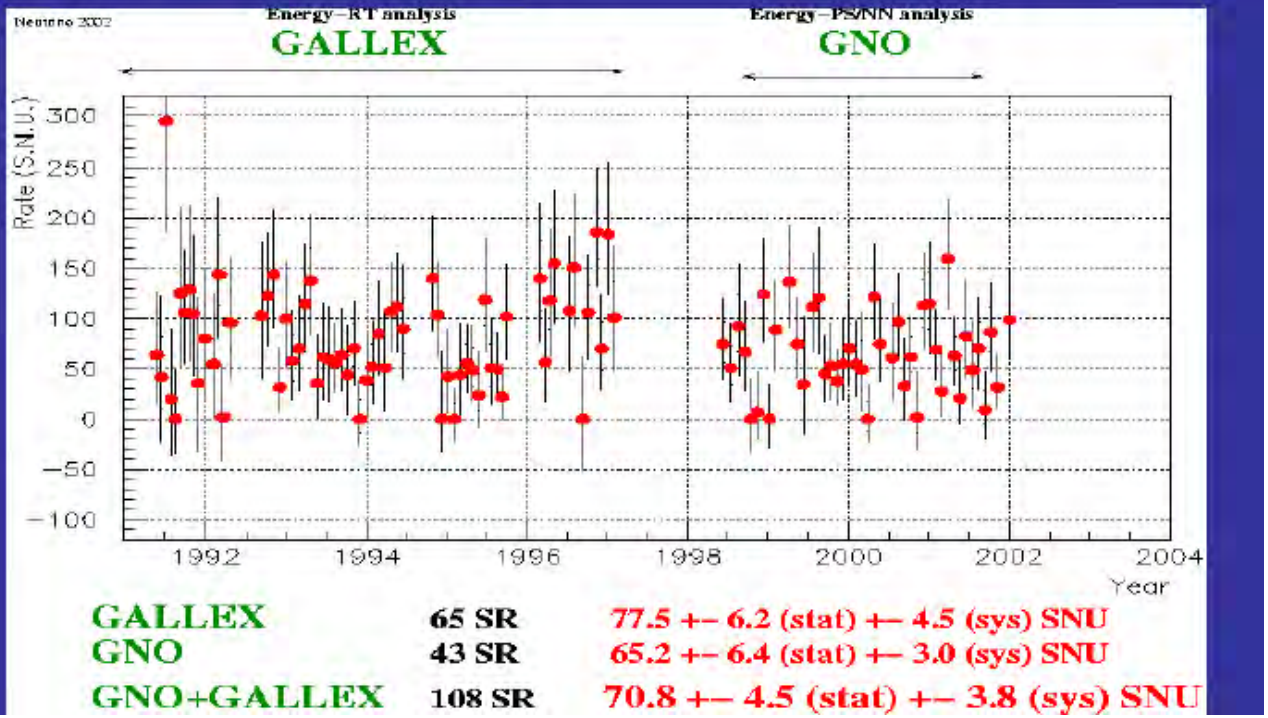
^{71}Ge(ν_e,e)^{71}Ge

Energy threshold > 233 keV

Sensitive mainly to pp -neutrinos

SSM ⟹ 115 -135 SNU

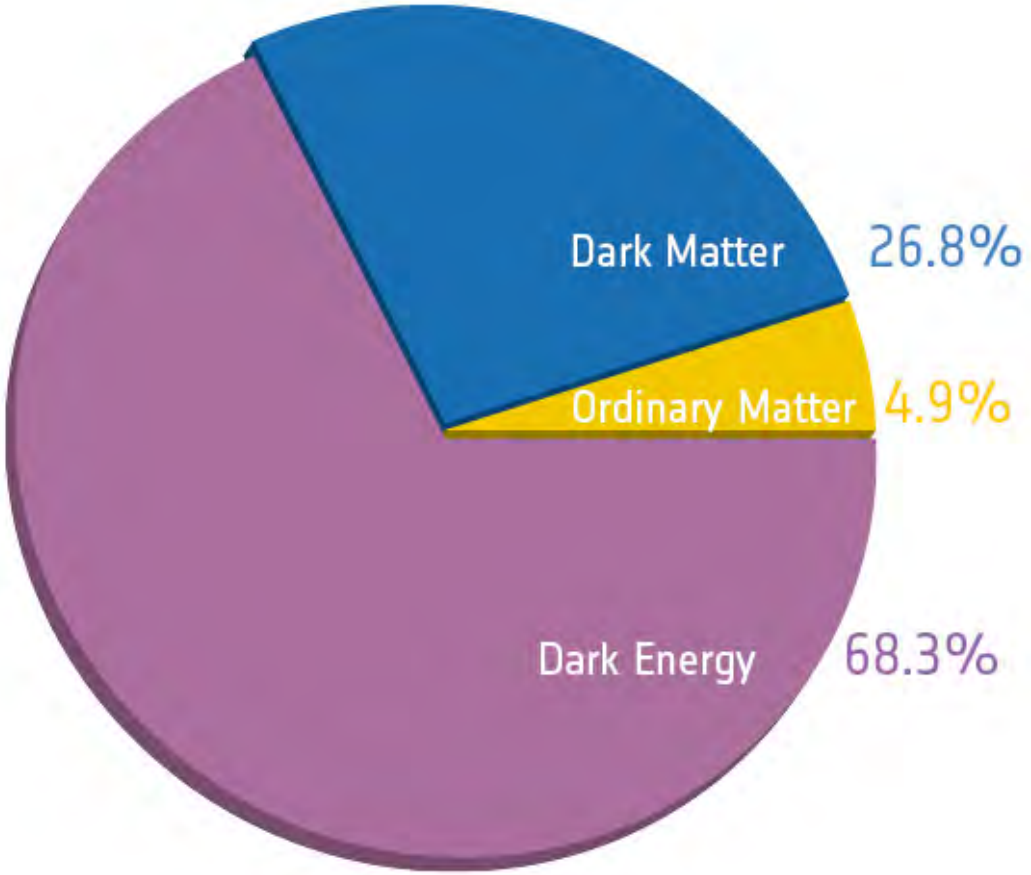




GALLEX	65 SR	77.5 +– 6.2 (stat) +– 4.5 (sys) SNU
GNO	43 SR	65.2 +– 6.4 (stat) +– 3.0 (sys) SNU
GNO+GALLEX	108 SR	70.8 +– 4.5 (stat) +– 3.8 (sys) SNU

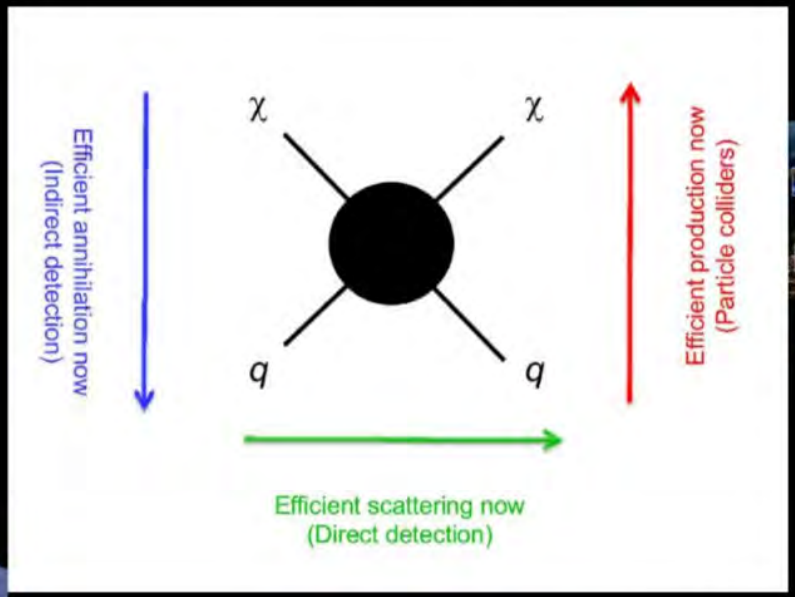
Materia Oscura

Materia Oscura

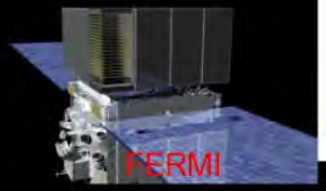


Materia Oscura

Come cercare la materia oscura



Con acceleratori
di particelle

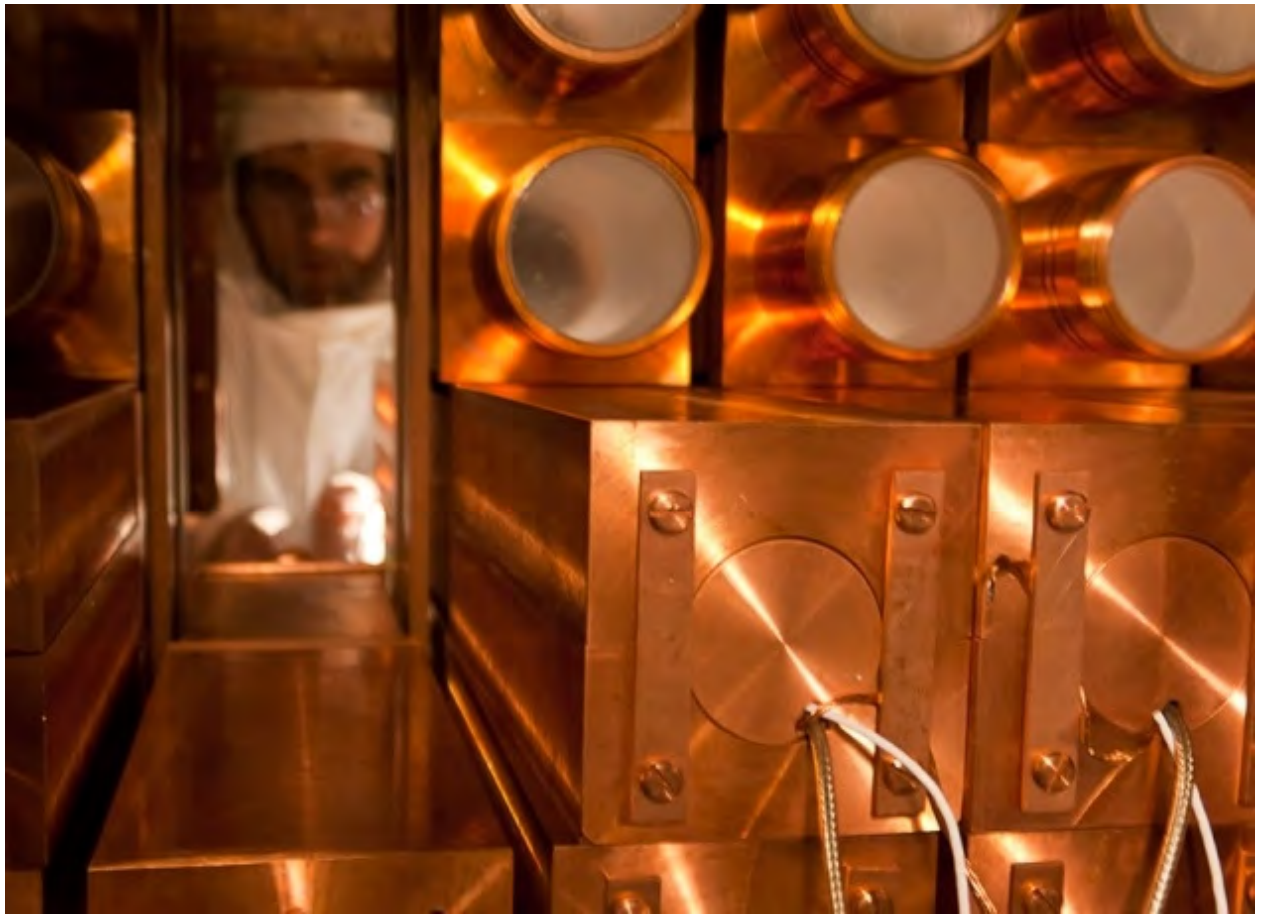


Nello spazio

Adapted from P. Lipari

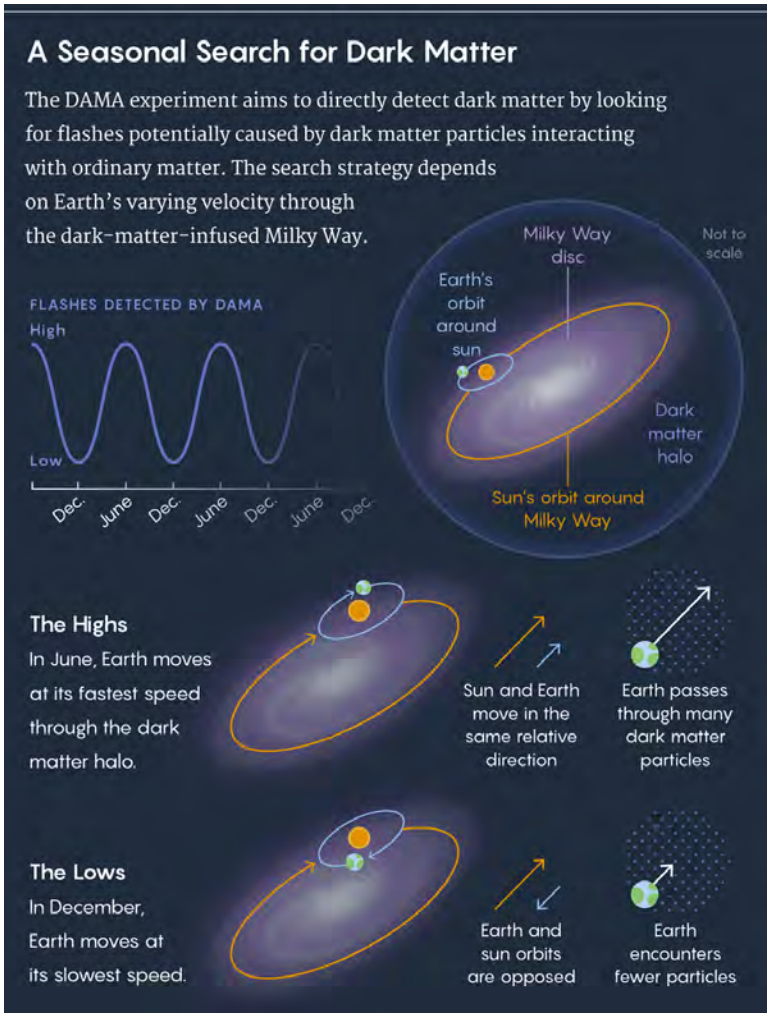
Sottoterra

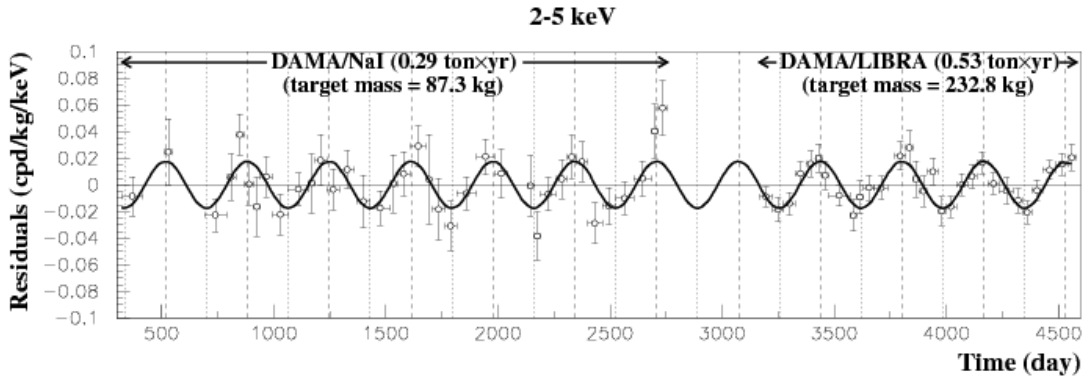
Dama

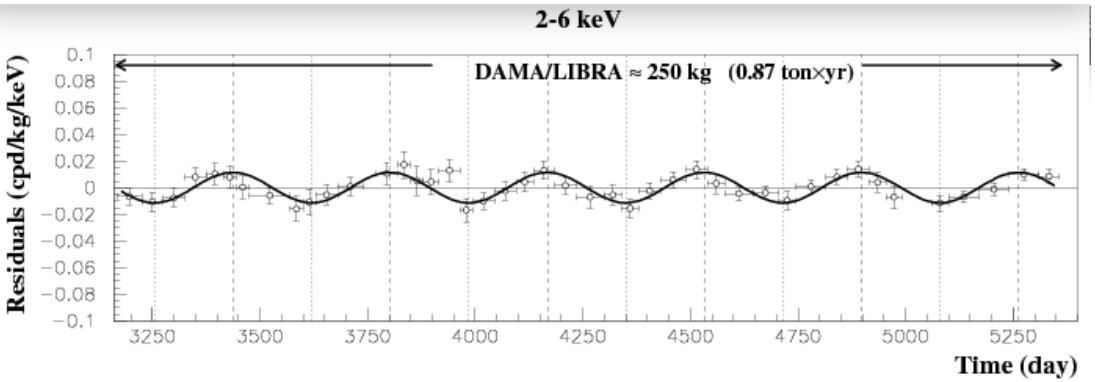


The DAMA project at the Gran Sasso National Laboratories of the I.N.F.N. is an observatory for rare processes thanks to the development and use of large mass highly radiopure scintillator set-ups.

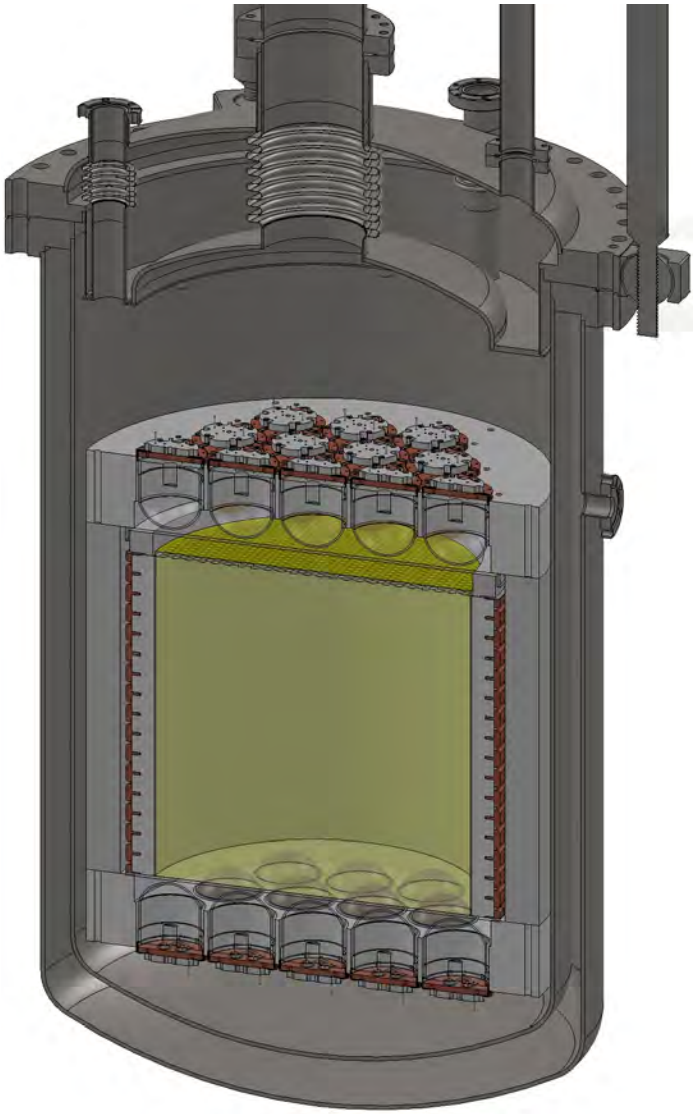
Dama


A Seasonal Search for Dark Matter
The DAMA experiment aims to directly detect dark matter by looking for flashes potentially caused by dark matter particles interacting with ordinary matter. The search strategy depends on Earth's varying velocity through the dark-matter-infused Milky Way.
FLASHES DETECTED BY DAMA
High
Low
Dec.
June
Dec.
June
Dec.
June
Dec.
Milky Way disc
Not to scale
Earth's orbit around sun
Dark matter halo
Sun's orbit around Milky Way
The Highs
In June, Earth moves at its fastest speed through the dark matter halo.
Sun and Earth move in the same relative direction
Earth passes through many dark matter particles
The Lows
In December, Earth moves at its slowest speed.
Earth and sun orbits are opposed
Earth encounters fewer particles


2-5 keV
DAMA/NaI (0.29 ton×yr)
(target mass = 87.3 kg)
DAMA/LIBRA (0.53 ton×yr)
(target mass = 232.8 kg)
Residuals (cpd/kg/keV)
Time (day)


2-6 keV
DAMA/LIBRA ≈ 250 kg (0.87 ton×yr)
Residuals (cpd/kg/keV)
Time (day)

DarkSide



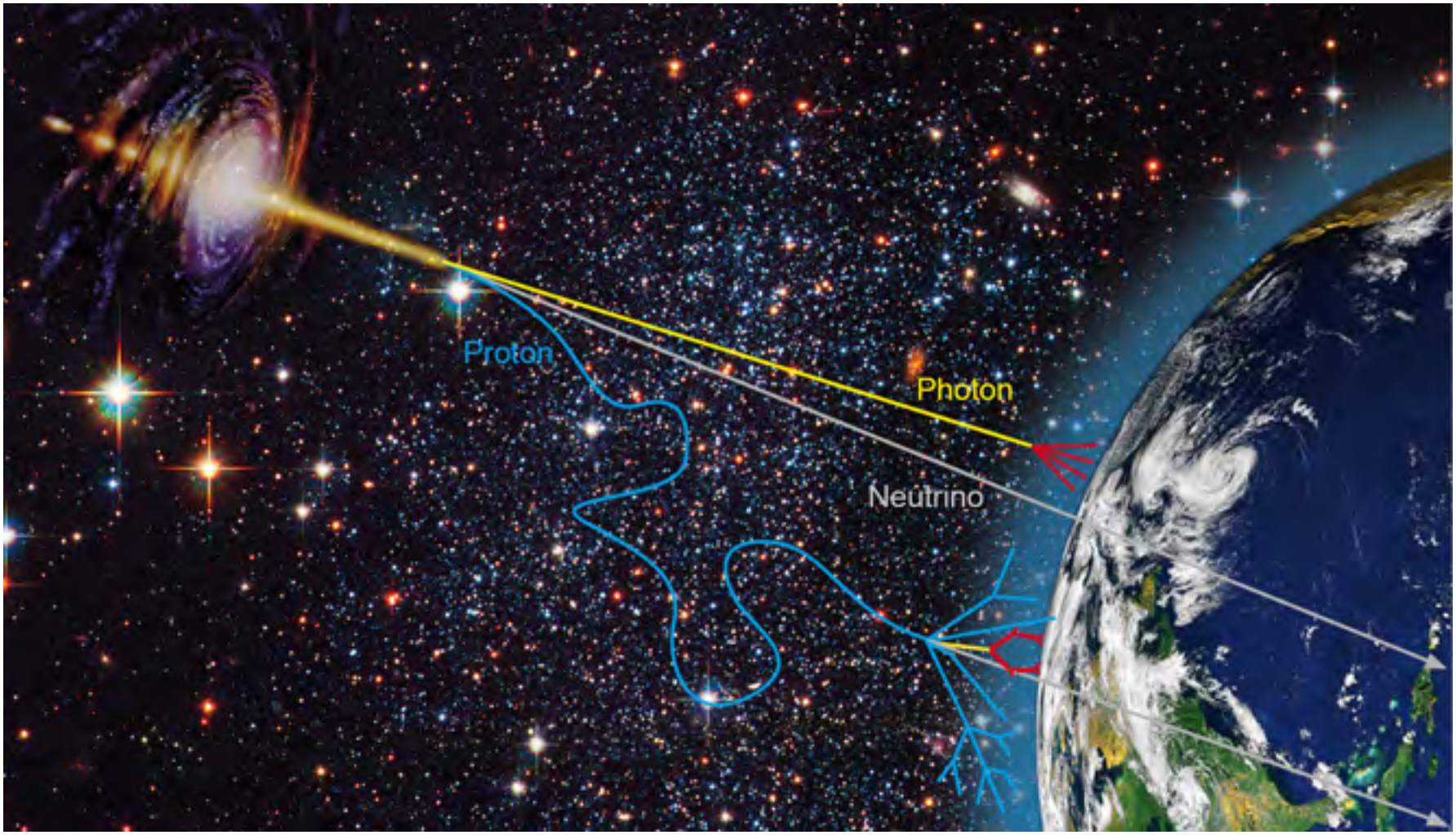
DarkSide-50 is a dual-phase argon Time Projection Chamber (TPC)

Il Gruppo II dell'INFN

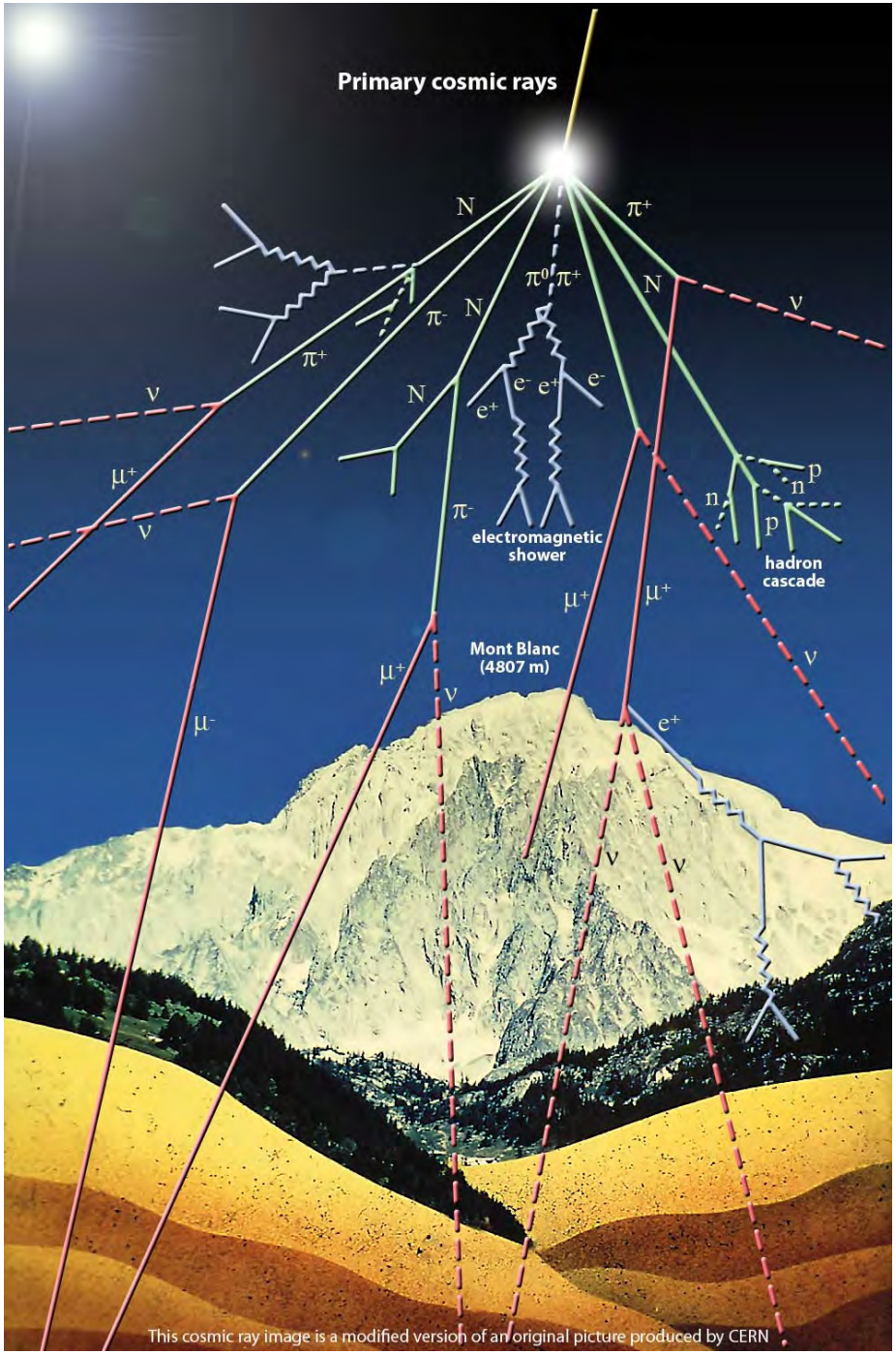
Neutrino Physics					
BOREXINO	CUORE	CUPID	ENUBET_2	GERDA	ICARUS
JUNO	NU_AT_FNAL	T2K			
Radiation from the Universe					
AMS2	AUGER	CTA	DAMPE	FERMI	GAMMAMEV*
GAPS	IXPE_INFN*	KM3	LSPE	QUBIC	
The Dark Universe					
CRESST	DAMA	DARKSIDE	EUCLID	NEWS	QUAX
SABRE	XENON				
Gravitational Waves, General and Quantum Physics					
ARCHIMEDES_2*	FISH	G-GRANSASSO-RD	HUMOR	LARASE	LIMADOU_CSN2
LISA*	MAGIA_ADV	MOONLIGHT2	SUPREMO	VIRGO	

http://www.infn.it/csn2/

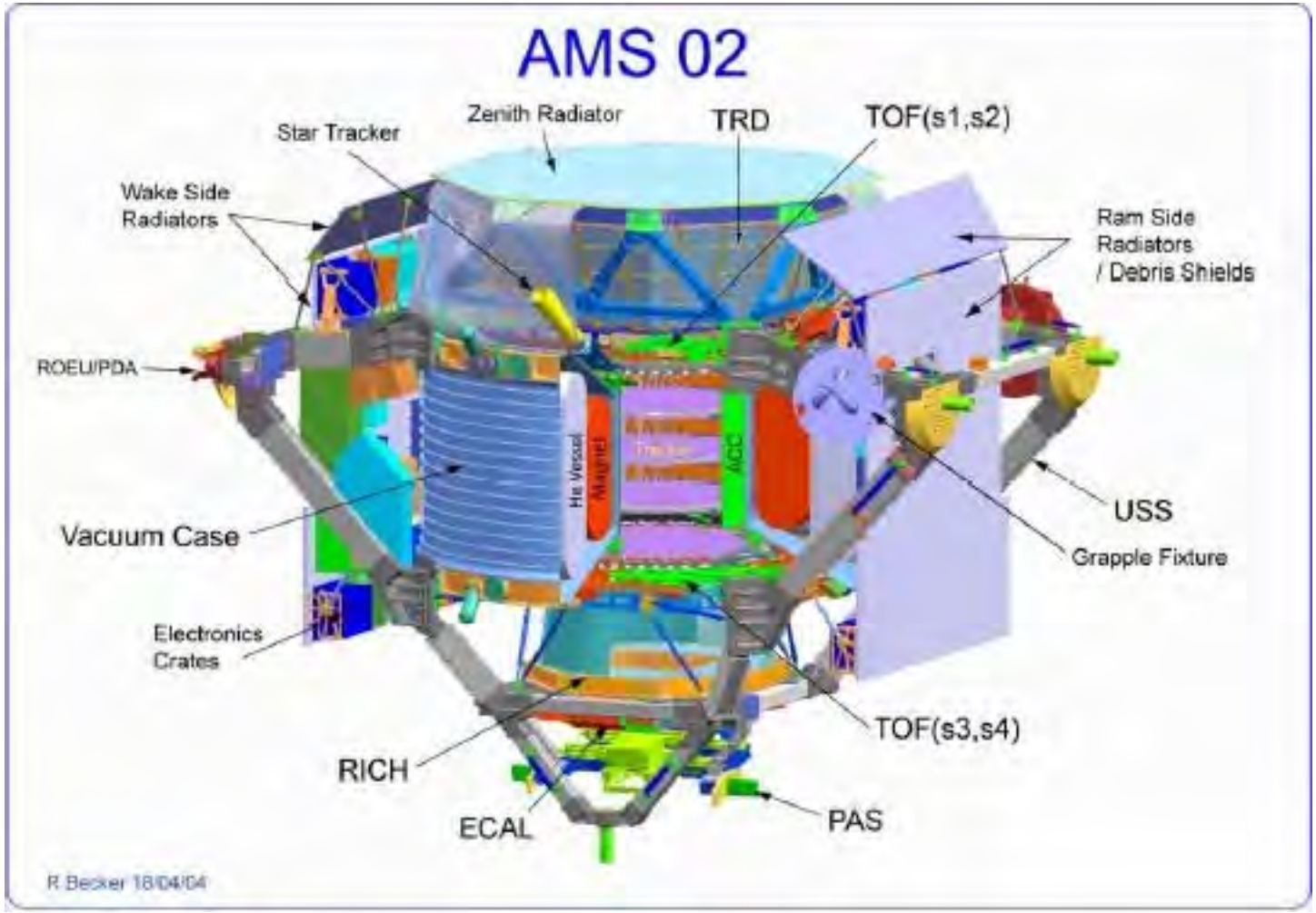
Fisica della Radiazione Cosmica



I raggi cosmici

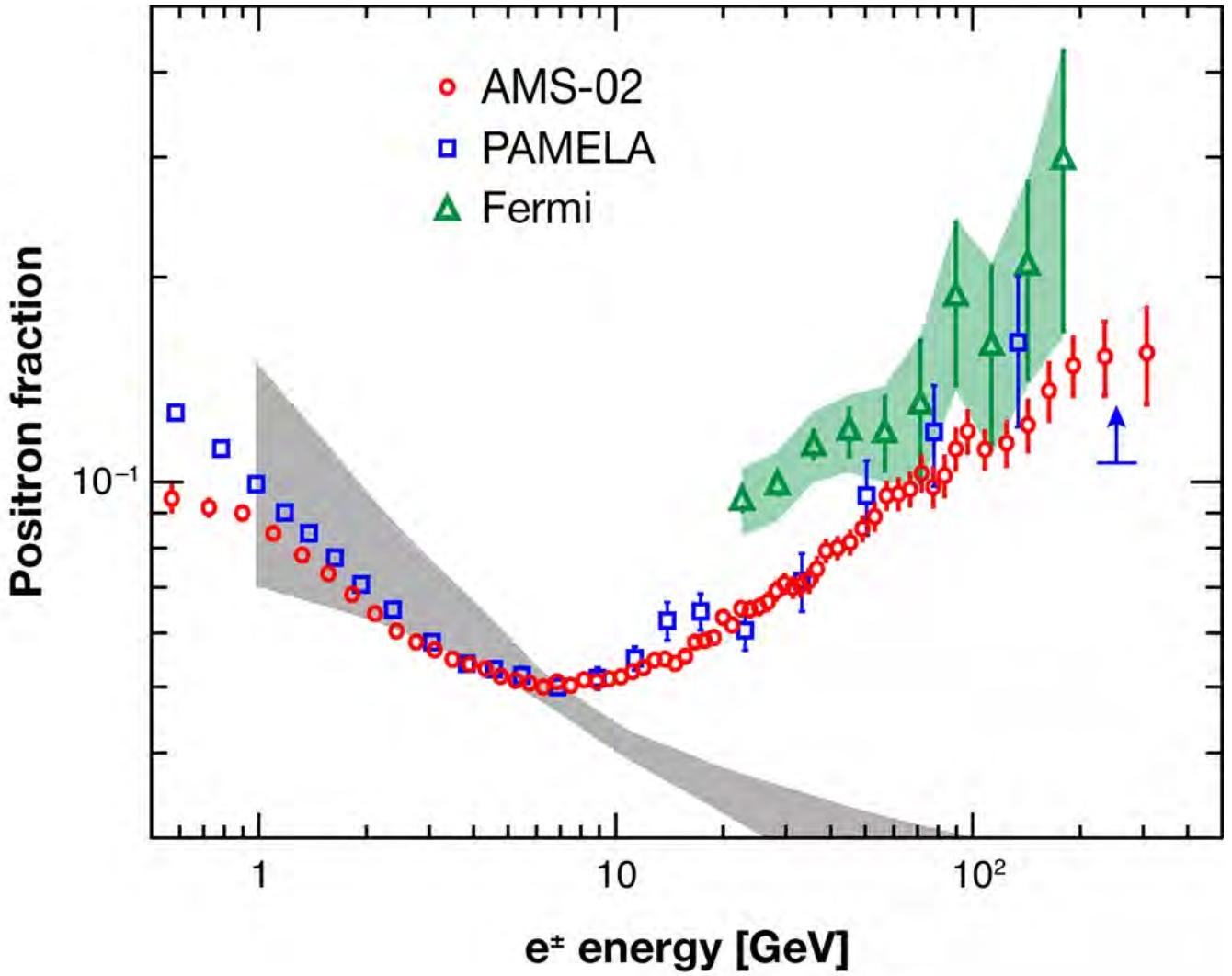


Fisica della Radiazione Cosmica

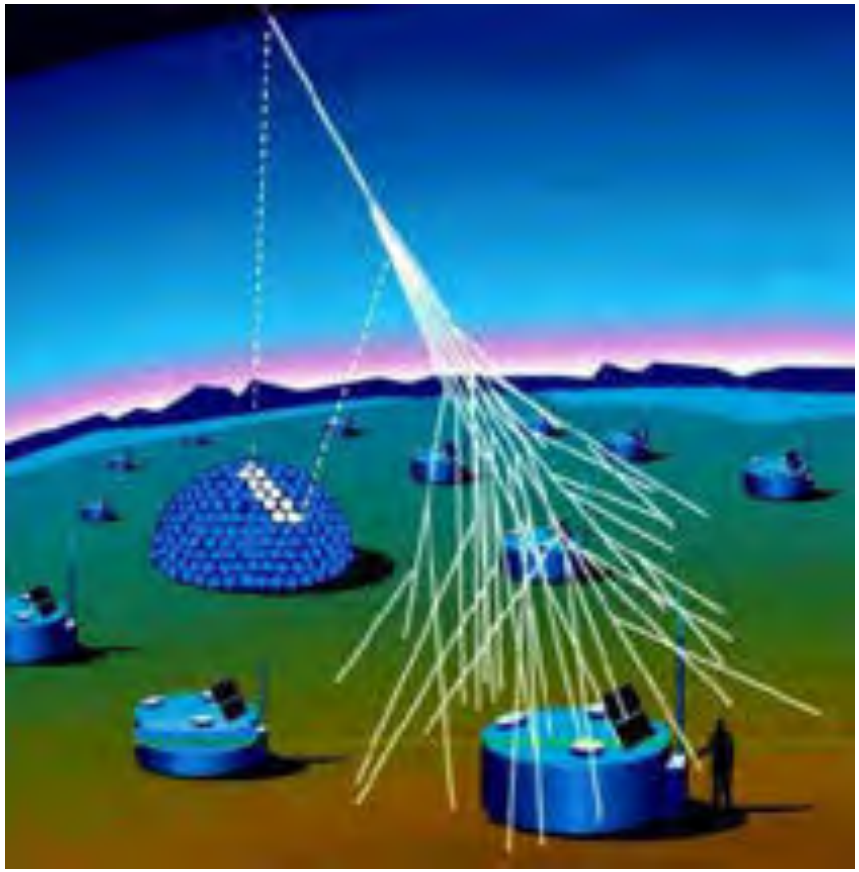


Studio dei raggi cosmici da satellite

Fisica della Radiazione Cosmica

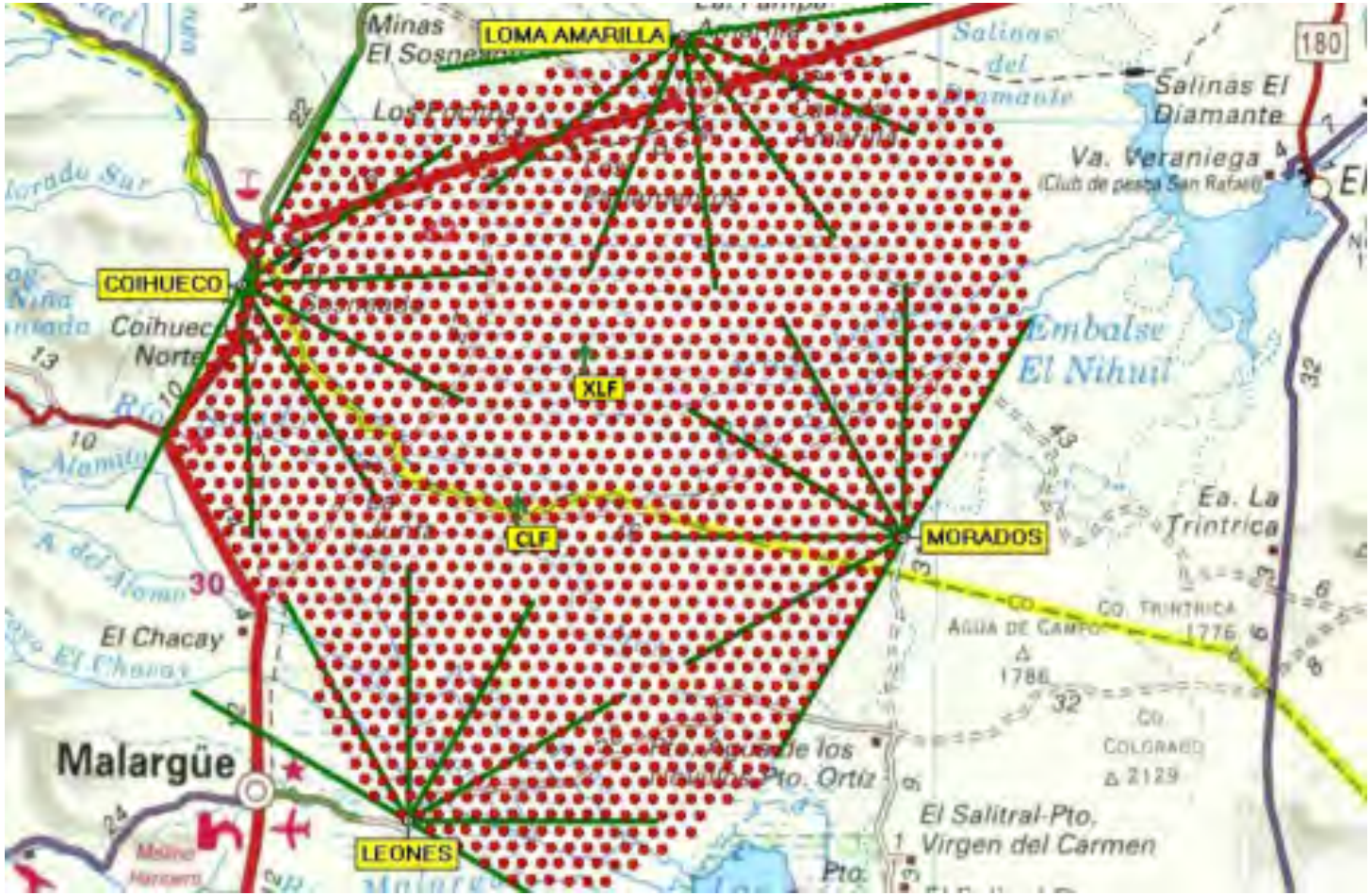


Fisica della Radiazione Cosmica



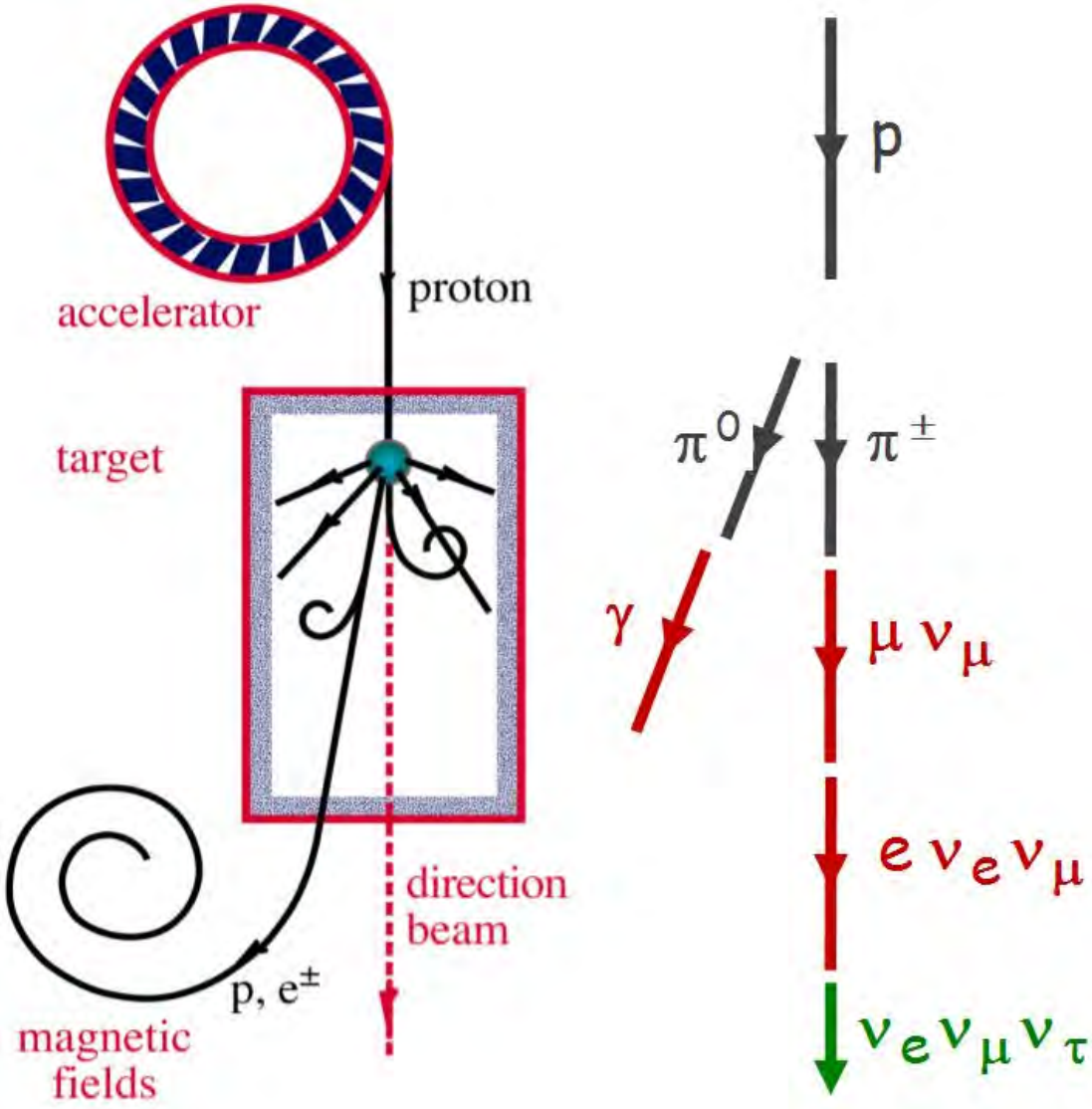
Studio dei raggi cosmici da terra

Fisica della Radiazione Cosmica

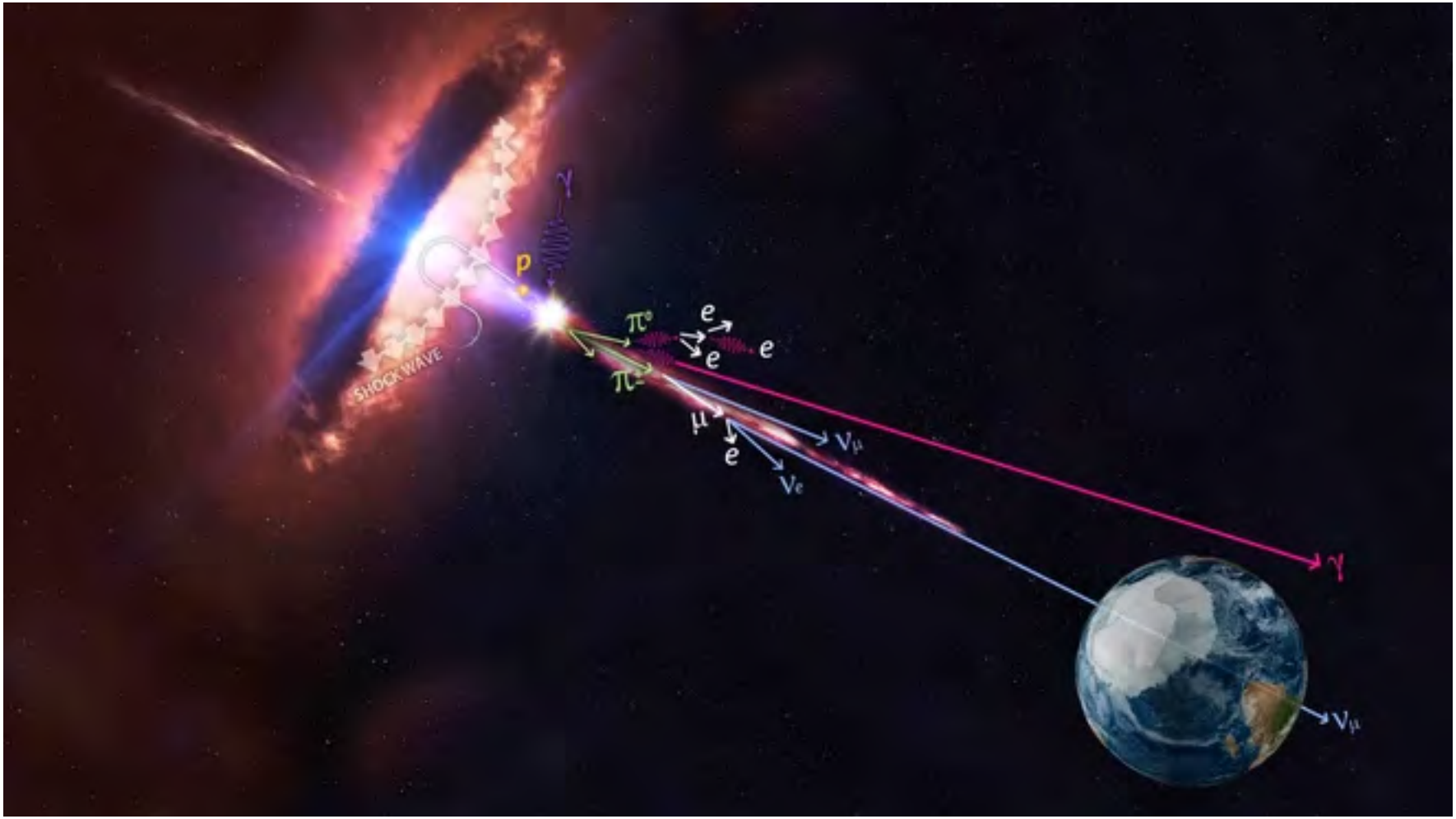


Esperimento AUGER

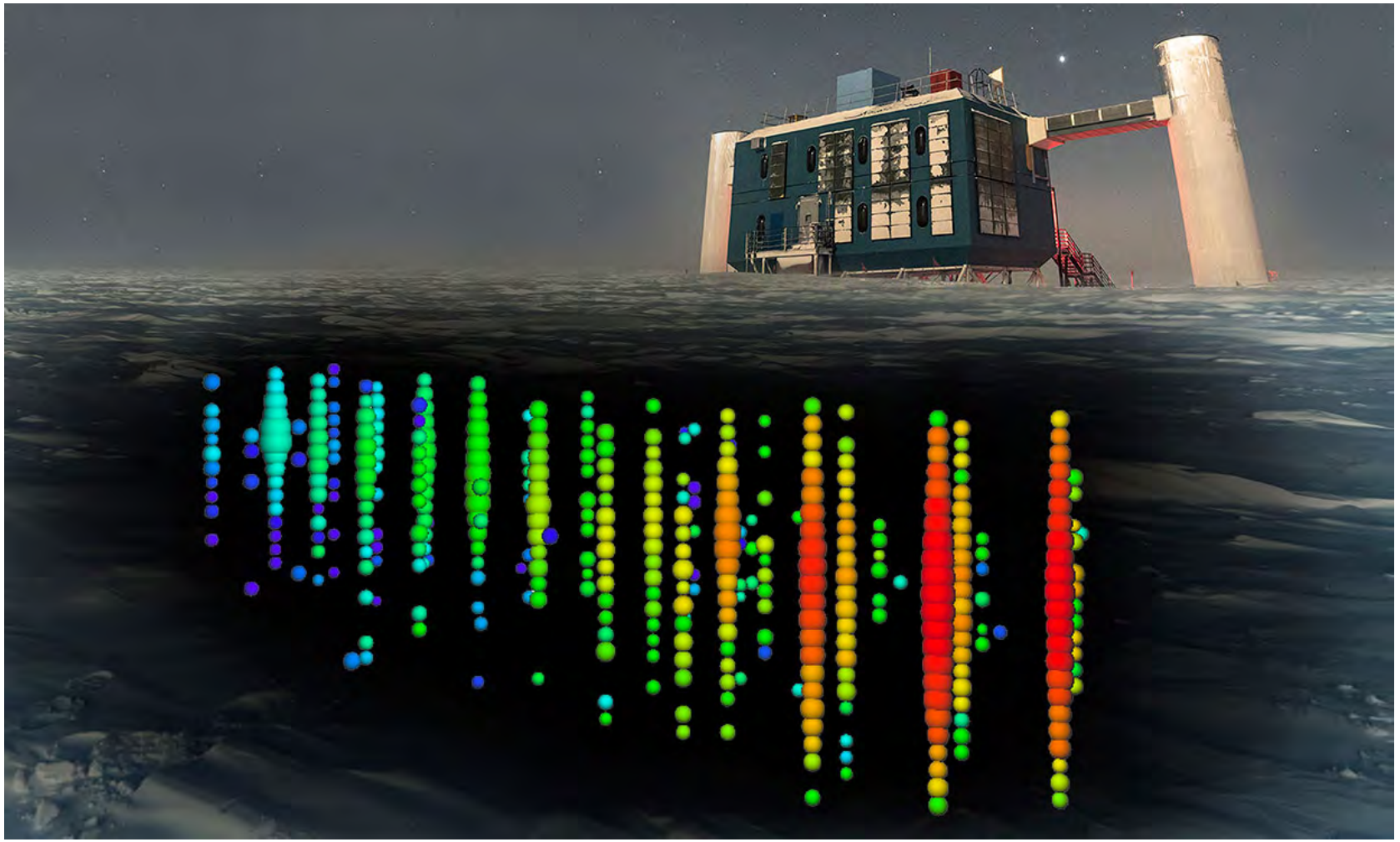
Fisica del Neutrino



Neutrini Astrofisici

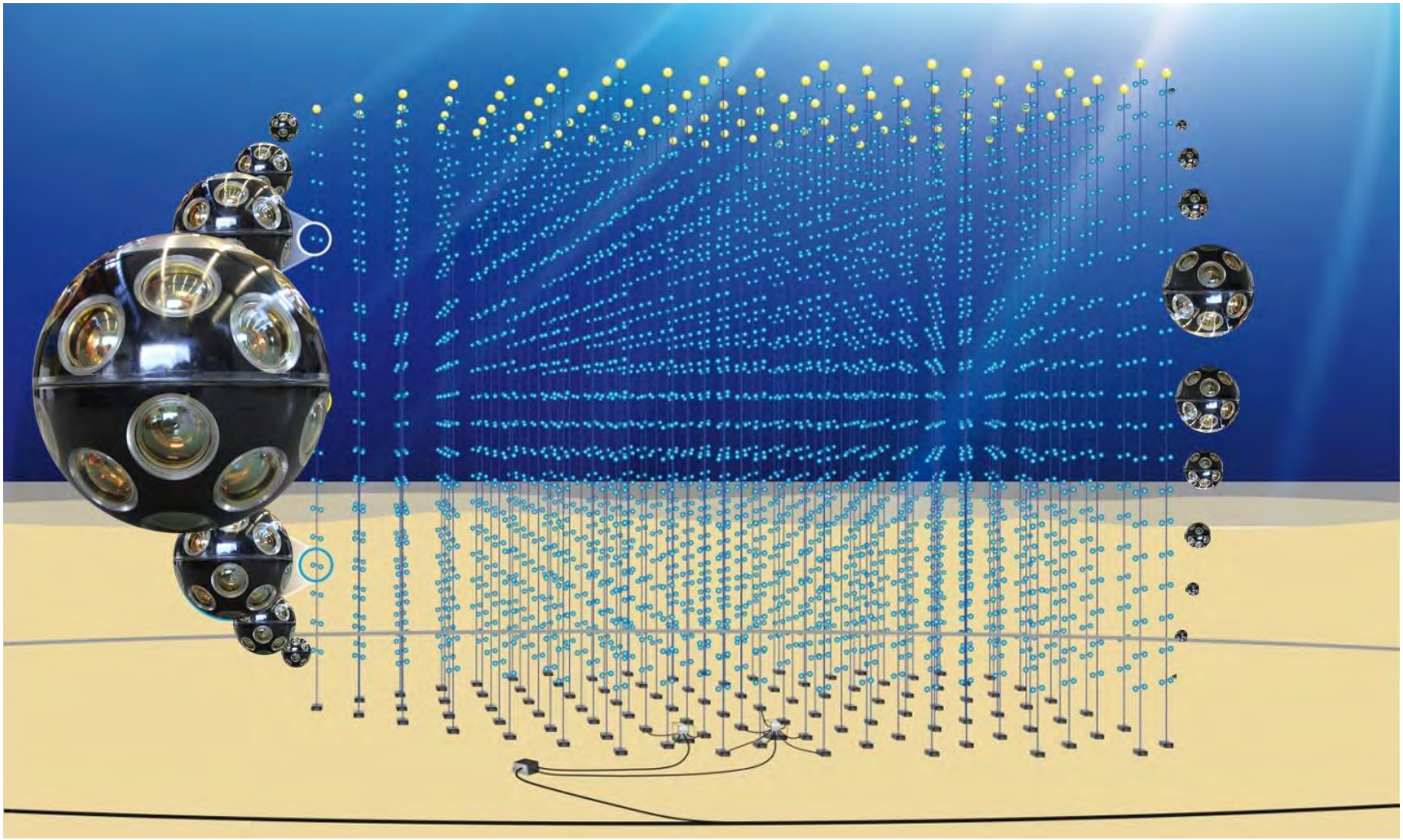


Fisica del Neutrino



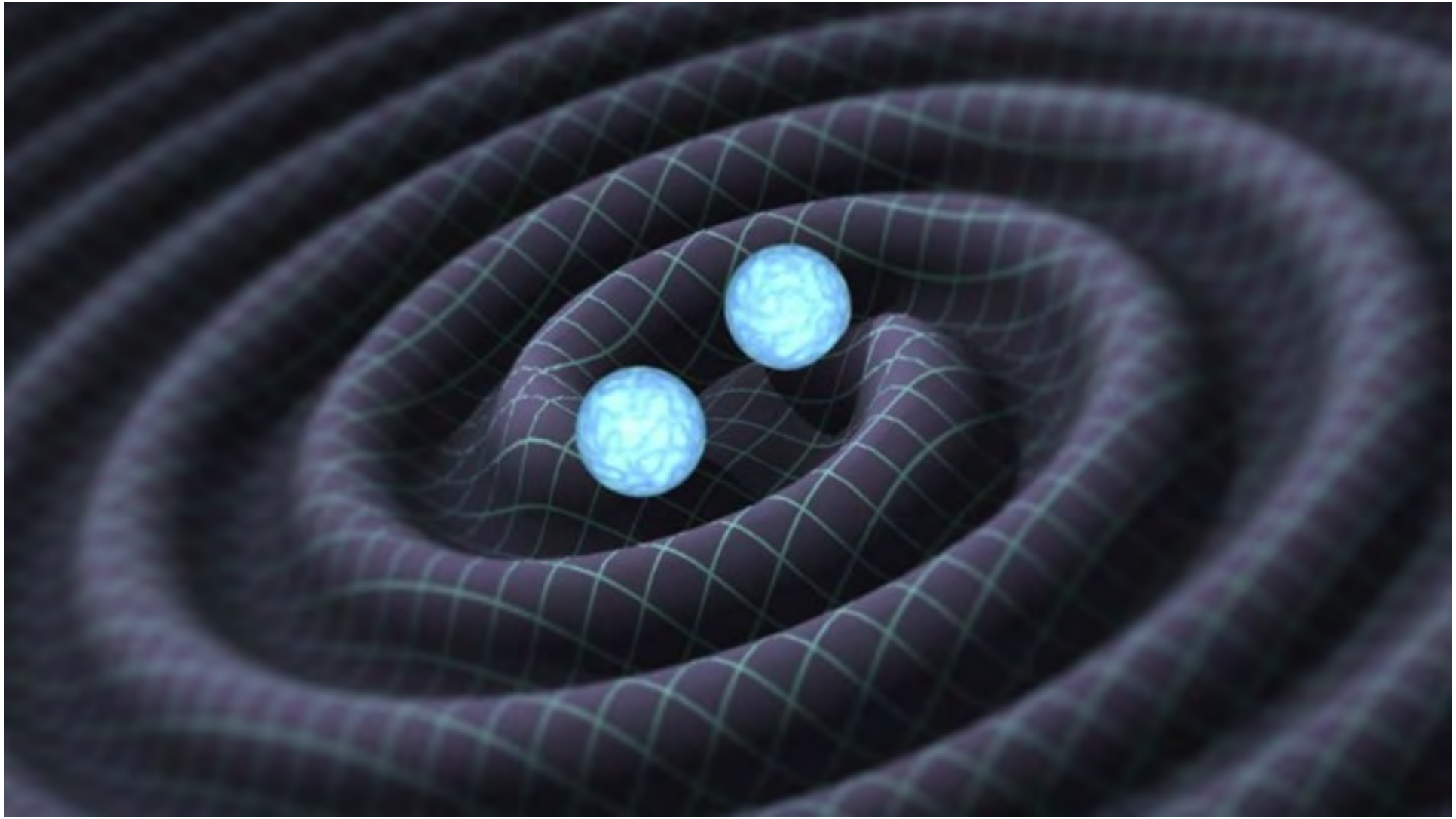
Esperimento Icecube

Fisica del Neutrino



Esperimento Km3NET

Fisica delle Onde Gravitazionali



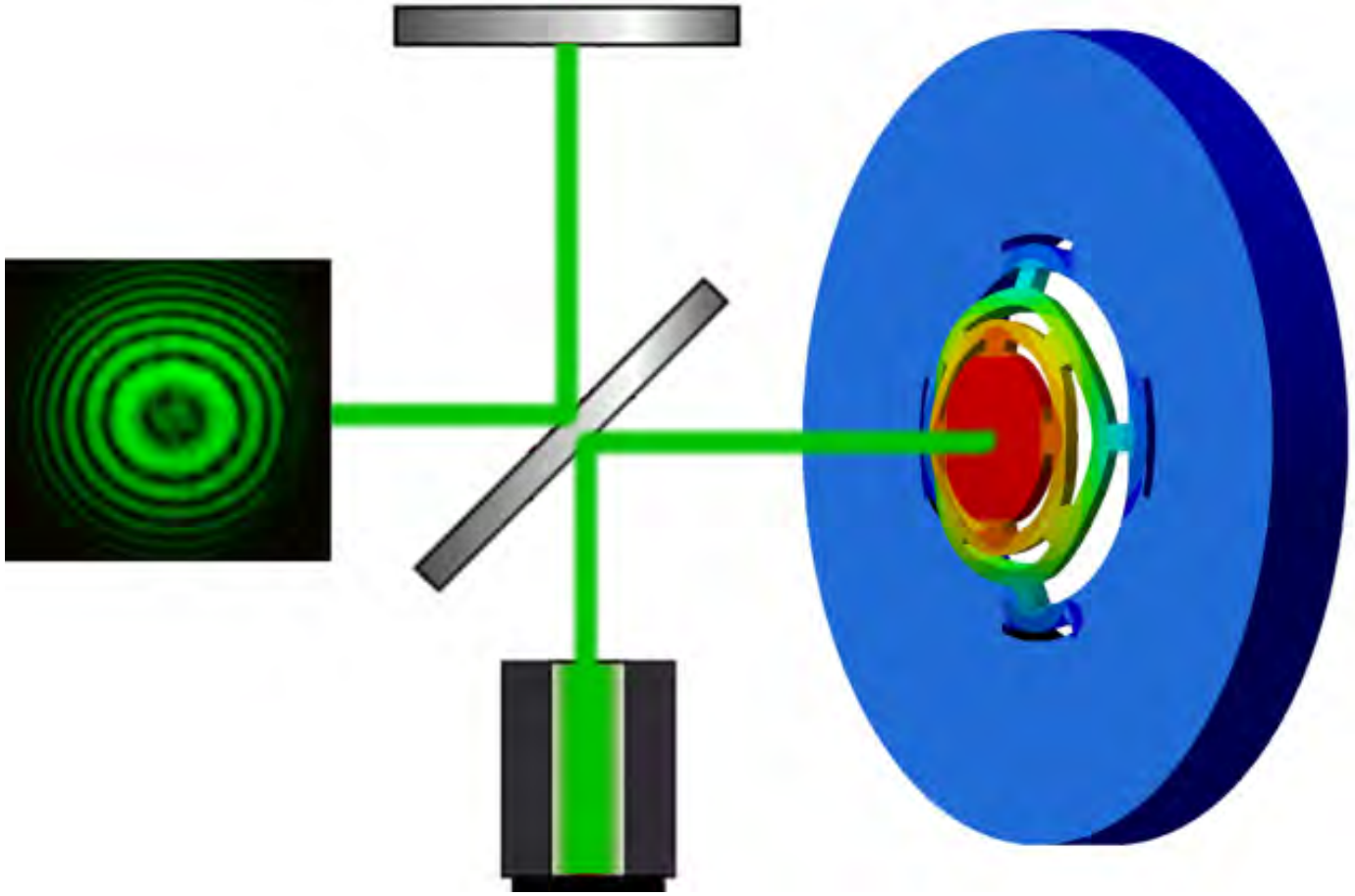
Fisica delle Onde Gravitazionali

Esperimento Virgo

Fisica Fondamentale

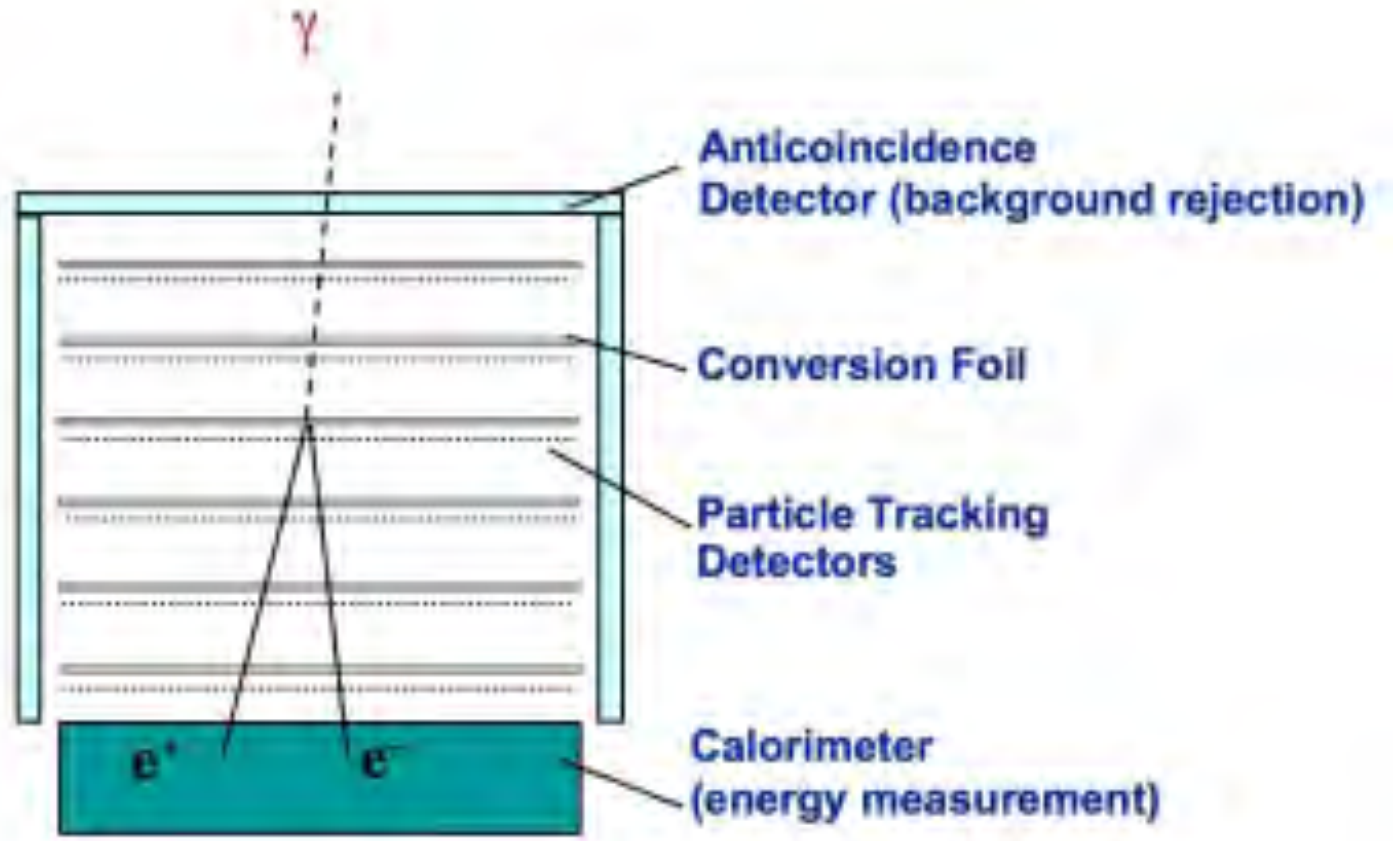
Fundamental Interactions Simulations with quantum gases

Fisica Fondamentale

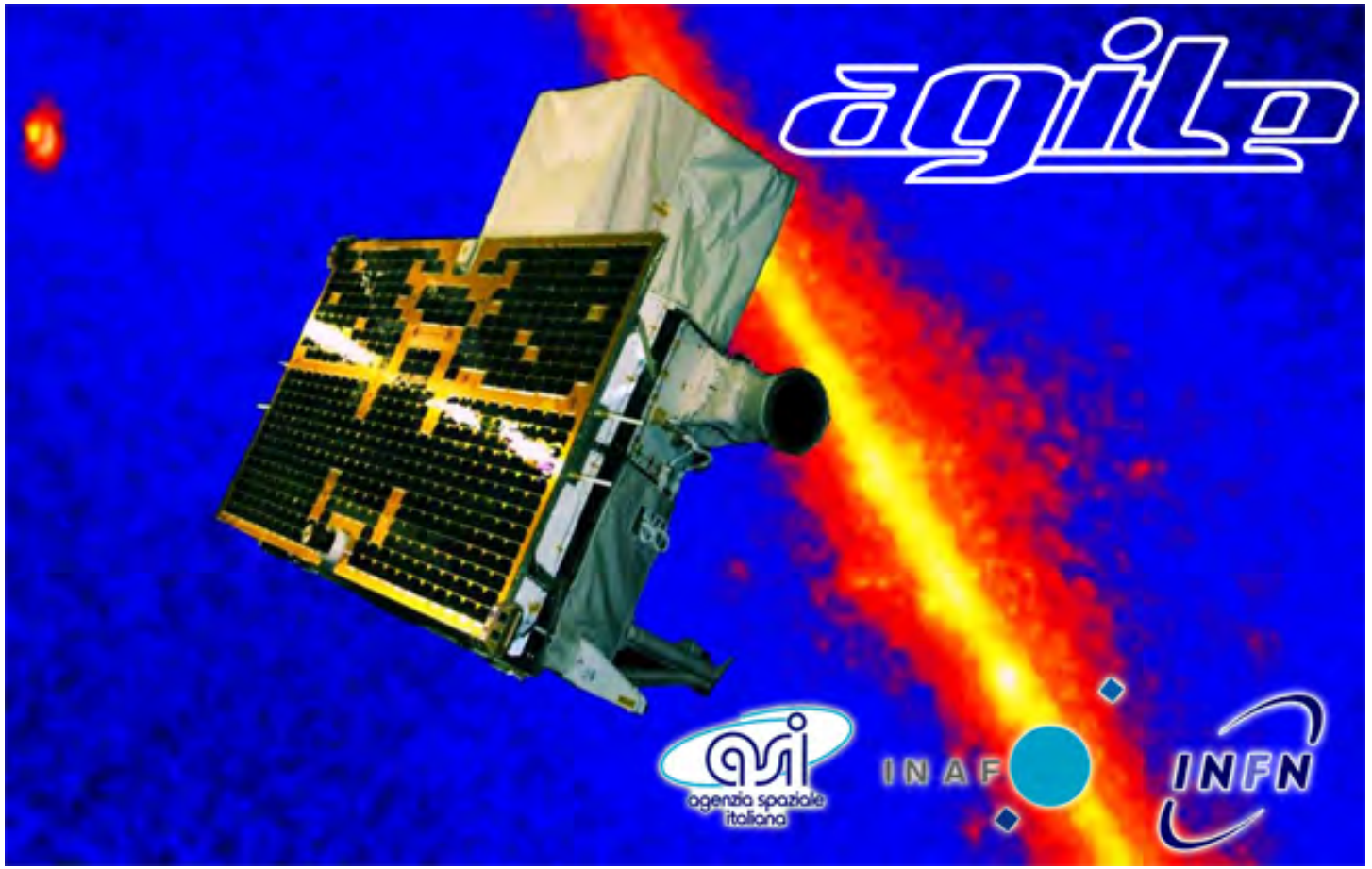


Oscillatori micro-meccanici

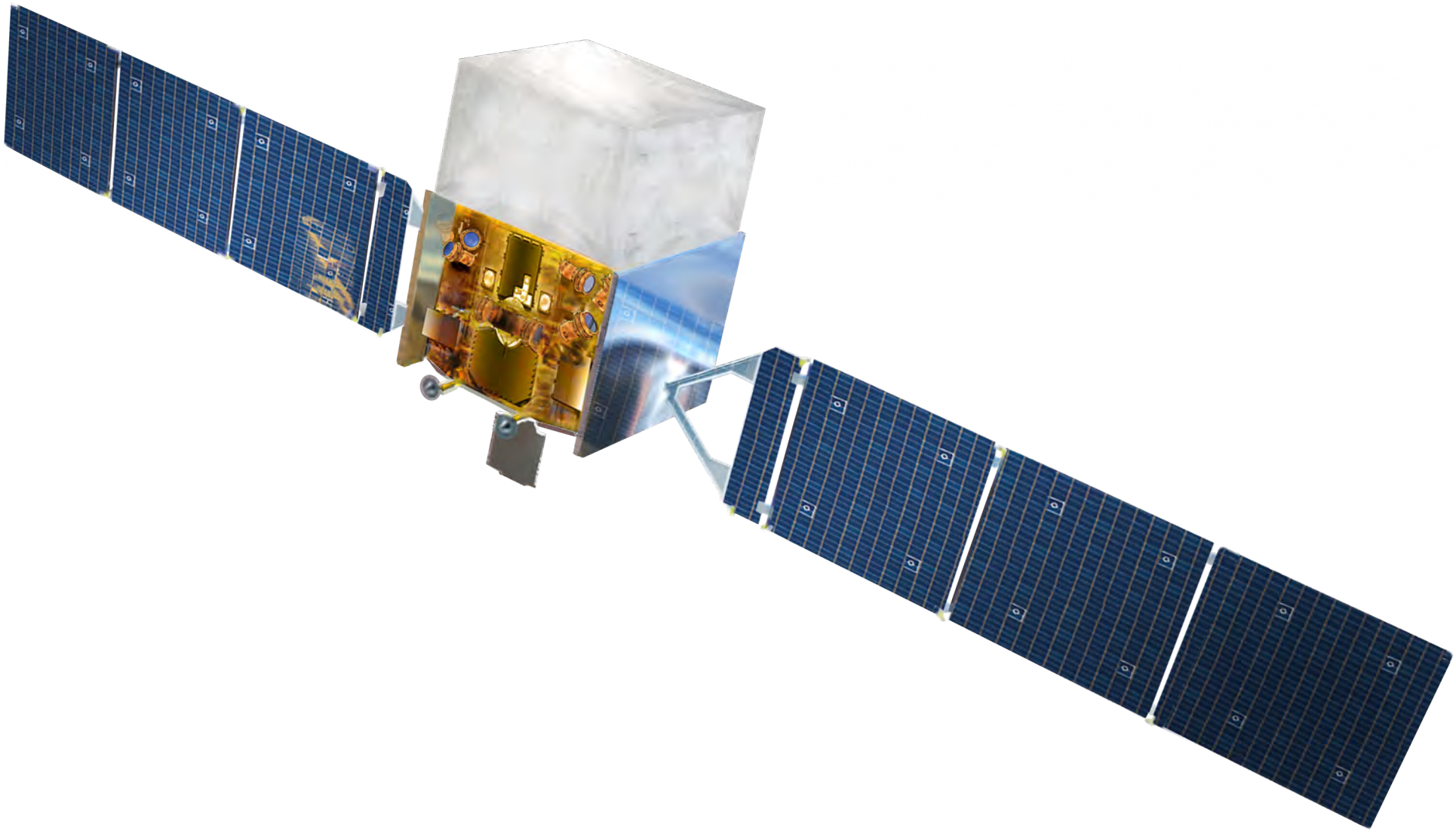
L'Astrofisica Gamma



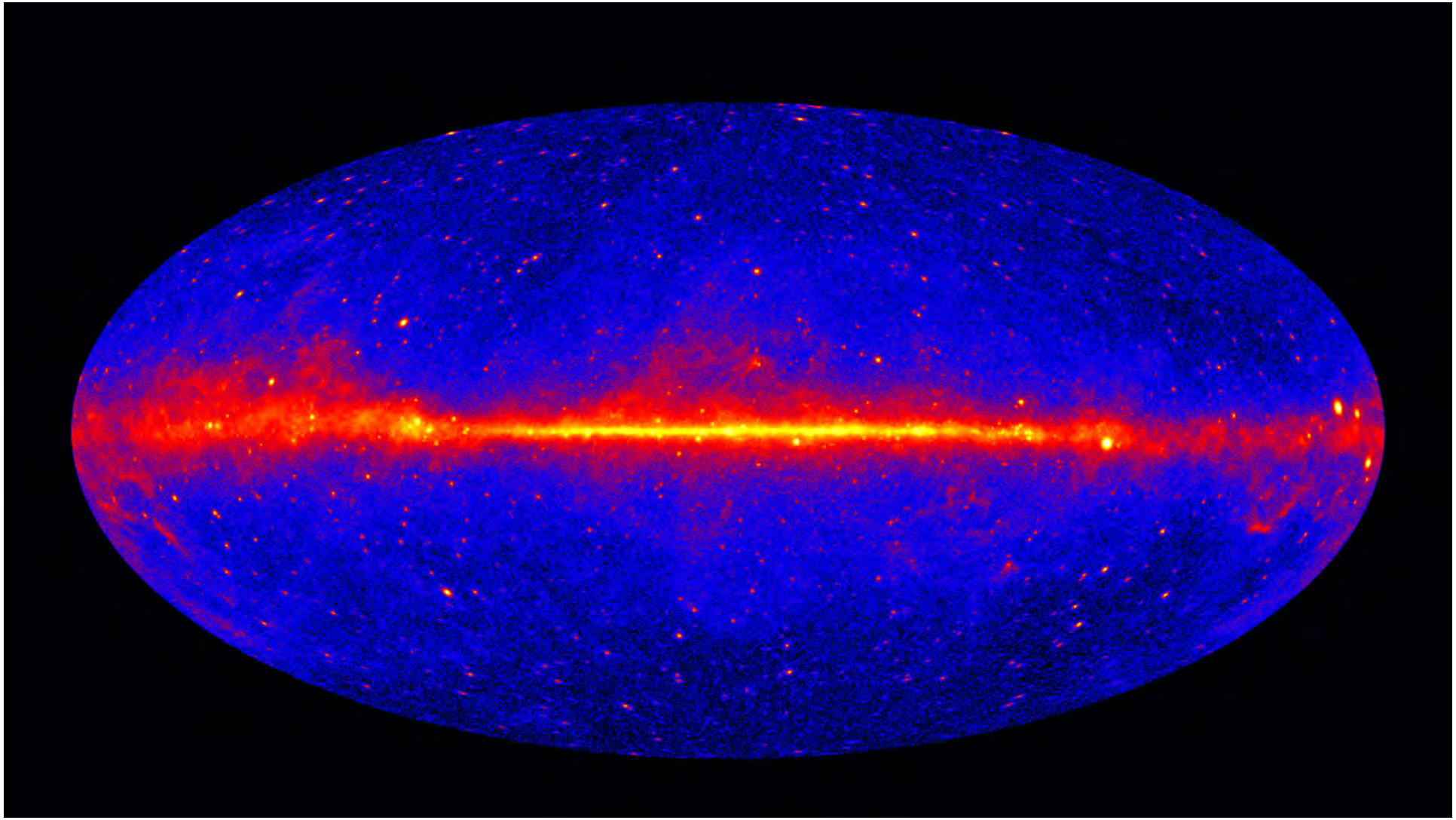
A Trieste … esperimento AGILE



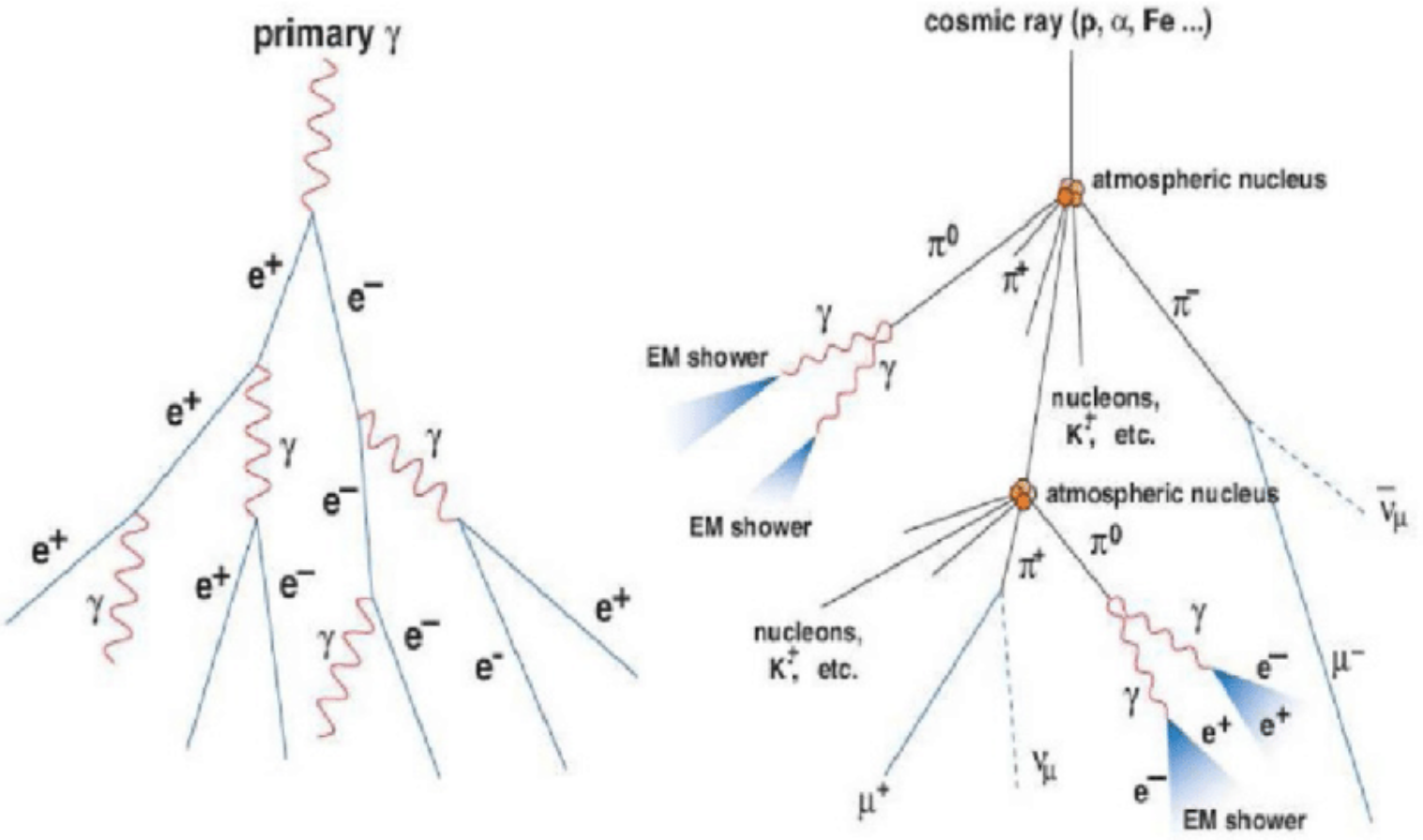
A Trieste … esperimento Fermi



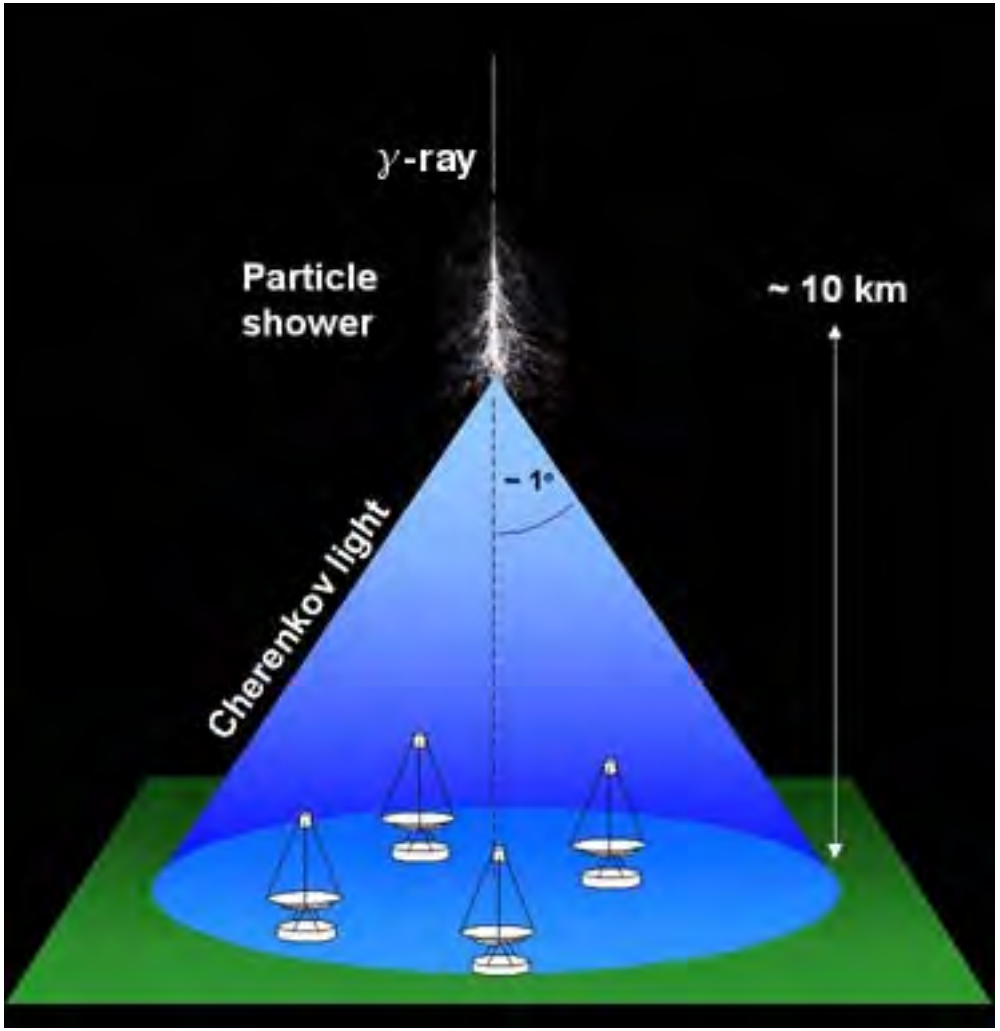
A Trieste … esperimento Fermi



L’astrofisica gamma da Terra



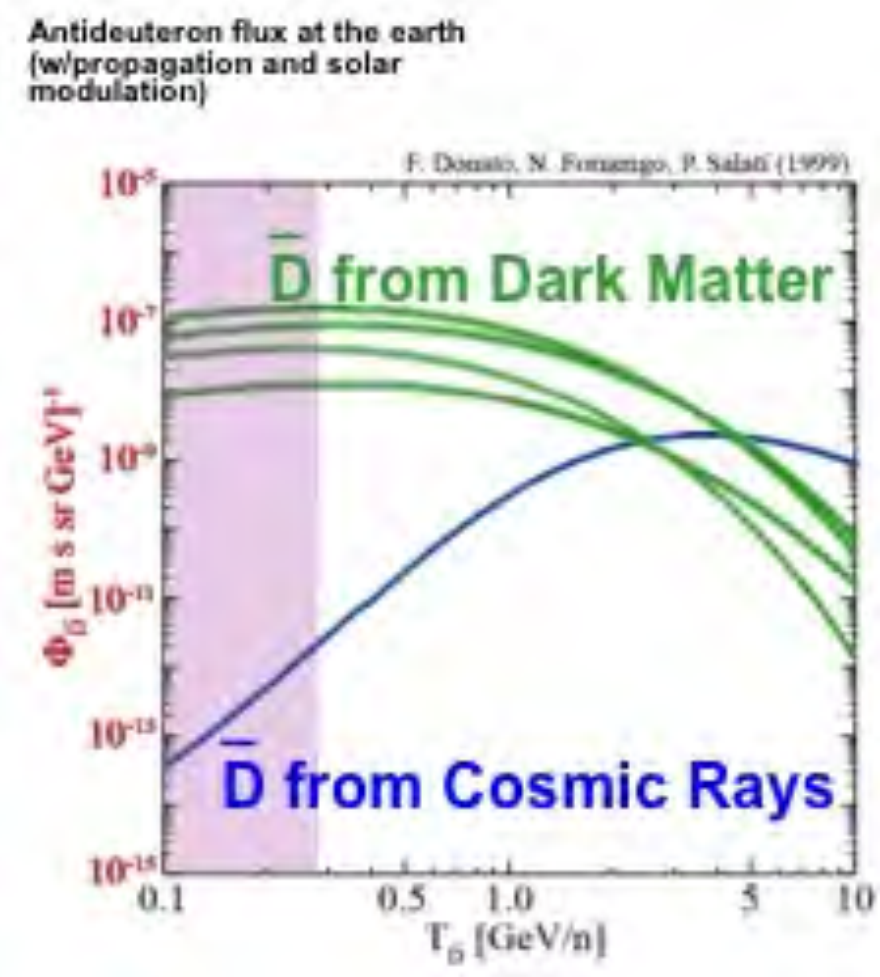
L’astrofisica gamma da Terra



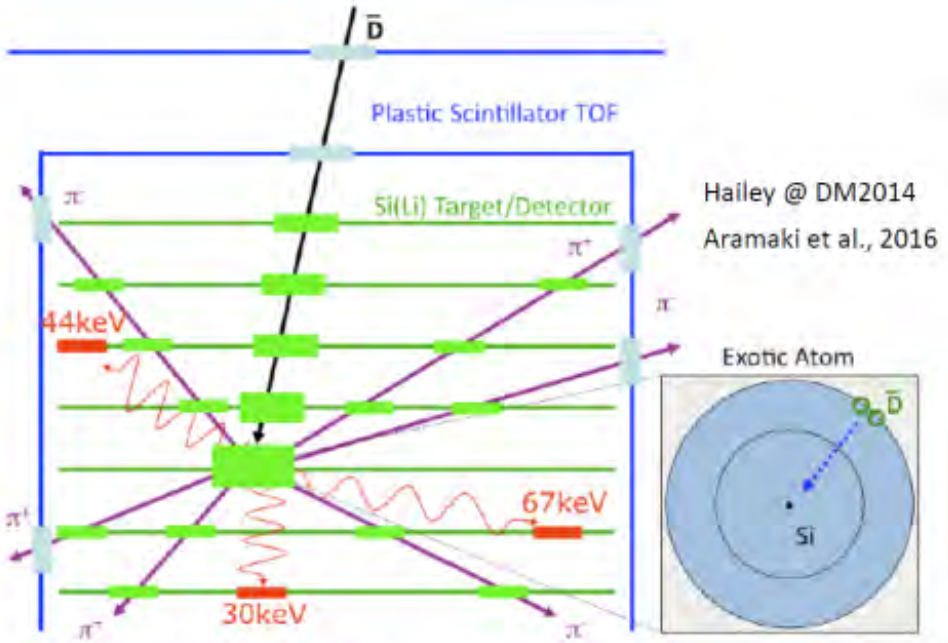
A Trieste … esperimento MAGIC

A Trieste … esperimento CTA

A Trieste … esperimento GAPS



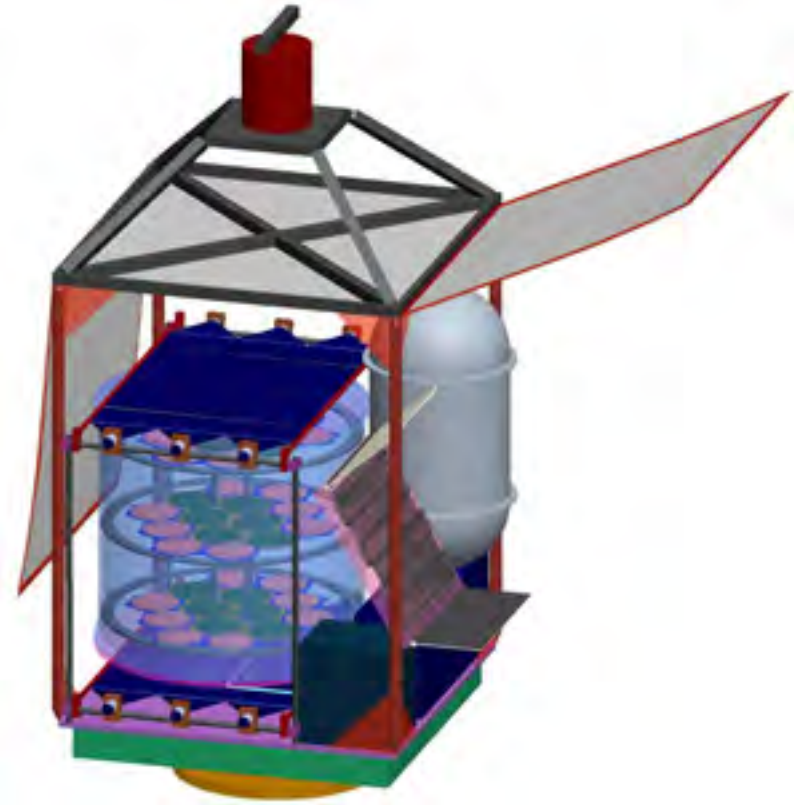
A Trieste … esperimento GAPS



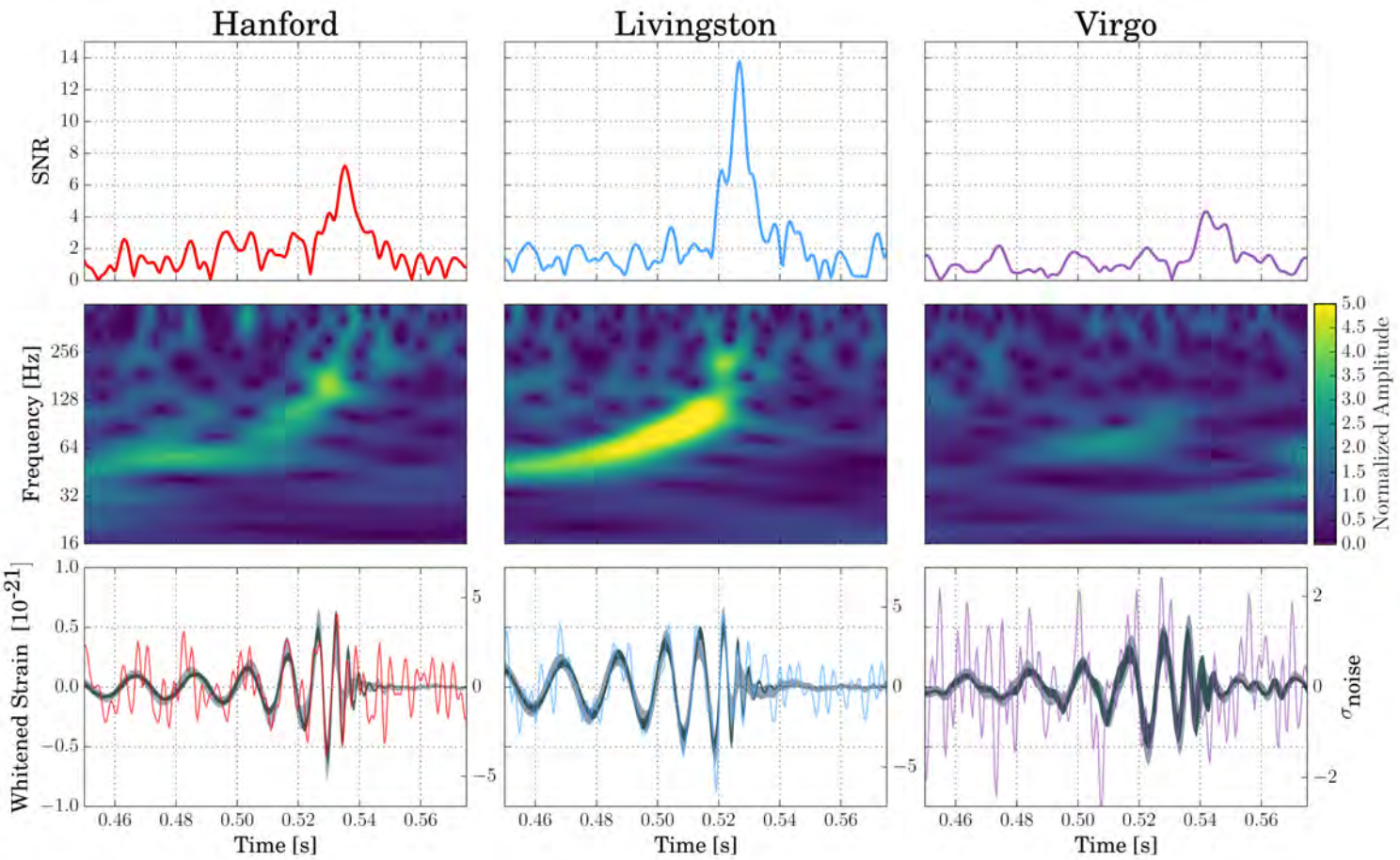
$\bar{p}$ / $\bar{D}$ separation based on:

- Time-of-light measurement along antiparticle trajectory
- Multiple dE/dx measurements
- X-ray energies
- Pion/proton multiplicity

~novel ntimatter detection technique



A Trieste … esperimento Virgo



La fisica delle Astroparticelle