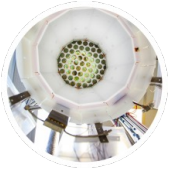
Bem vindos (remotamente ...) ao LIP !

Experimental particle and **astroparticle physics**



Development of **new instruments** and **methods**

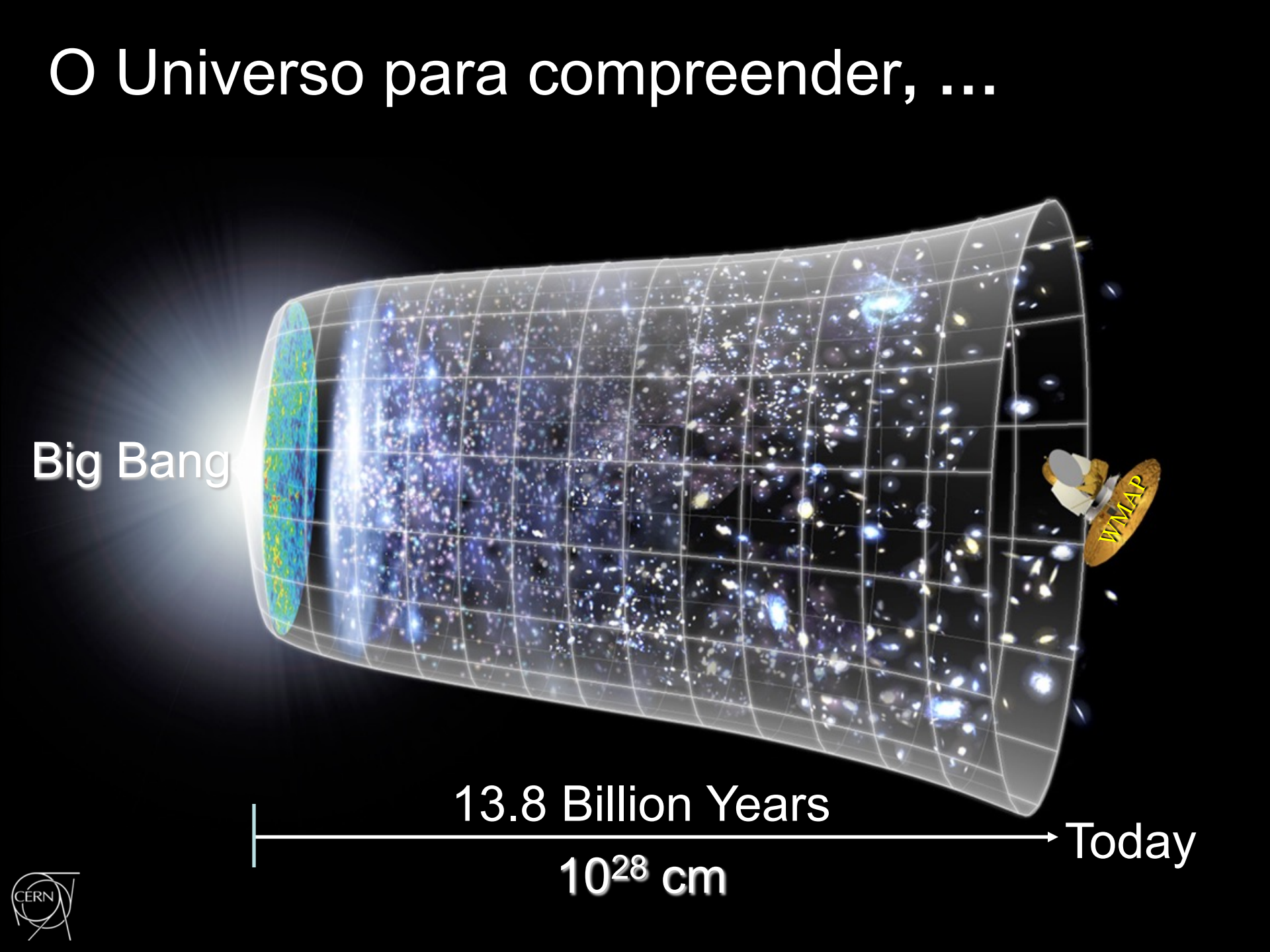
Scientific computing

Knowledge transfer, education and **outreach**

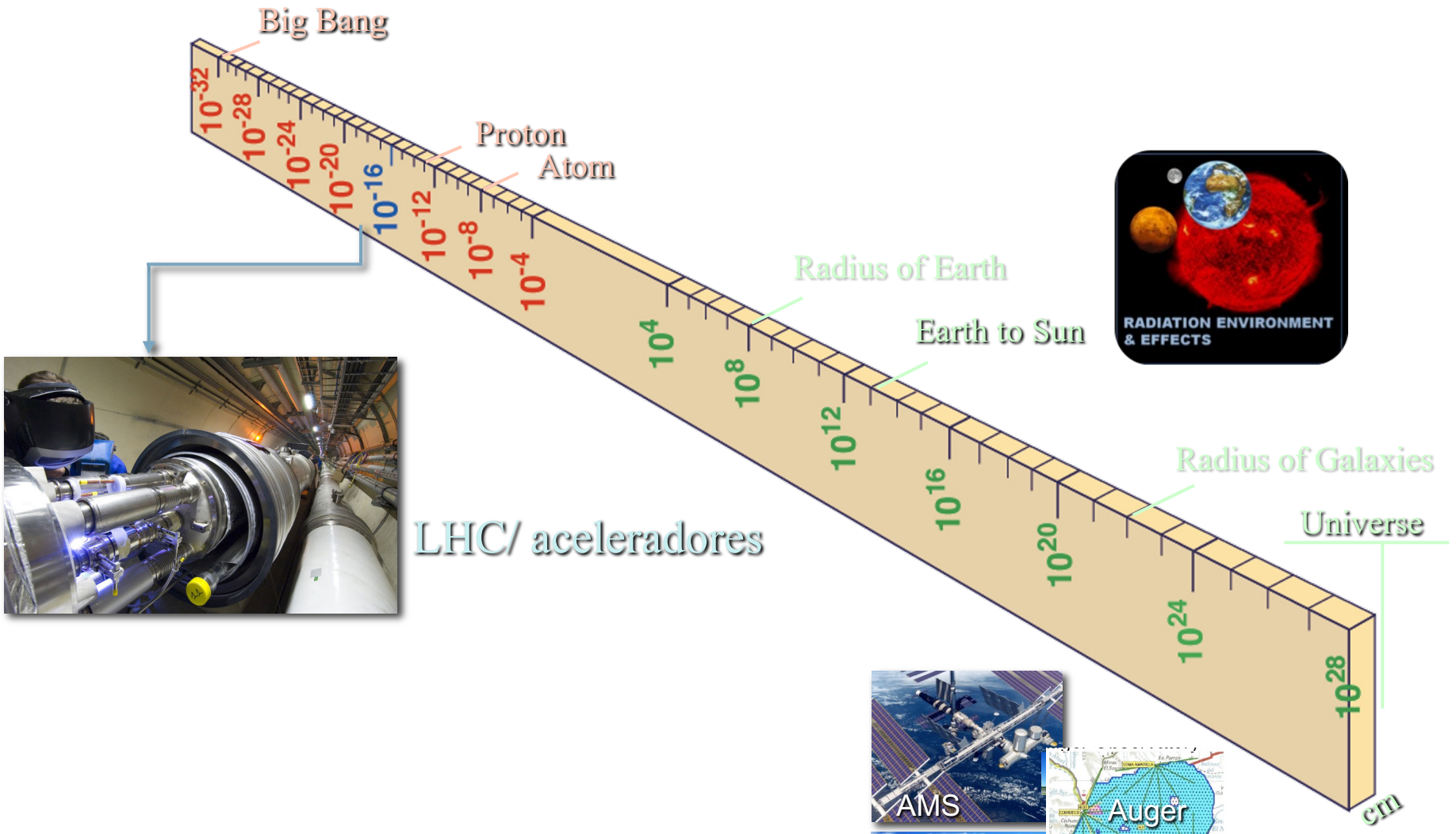
A aventura da Física de Partículas e Astropartículas

Mário Pimenta
Lisboa, Julho 2023

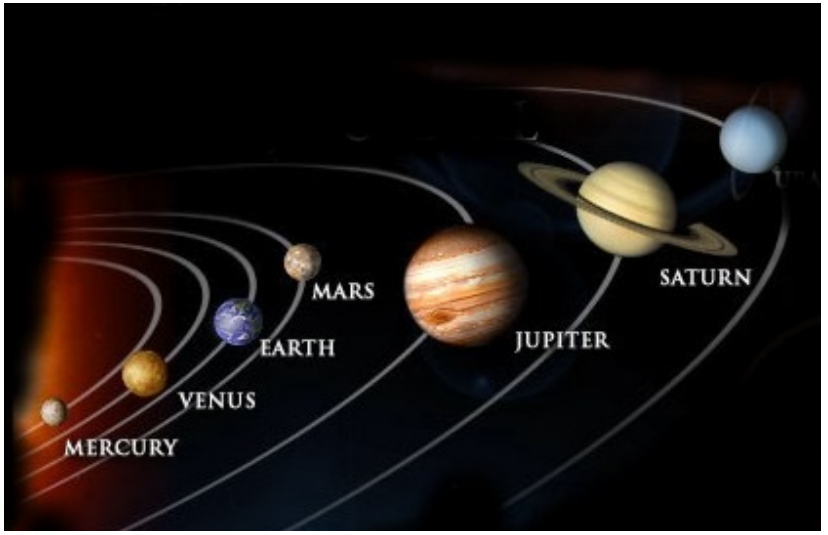
O Universo para compreender, ...



Escalas, ...


Big Bang
Proton
Atom
Radius of Earth
Earth to Sun
Radius of Galaxies
Universe
10^{-32}
10^{-28}
10^{-24}
10^{-20}
10^{-16}
10^{-12}
10^{-8}
10^{-4}
10^{4}
10^{8}
10^{12}
10^{16}
10^{20}
10^{24}
10^{28}
cm
RADIATION ENVIRONMENT & EFFECTS
LHC/ aceleradores
AMS
Auger
SWGO
Malargüe
m

Da maçã ao Universo



I. Newton

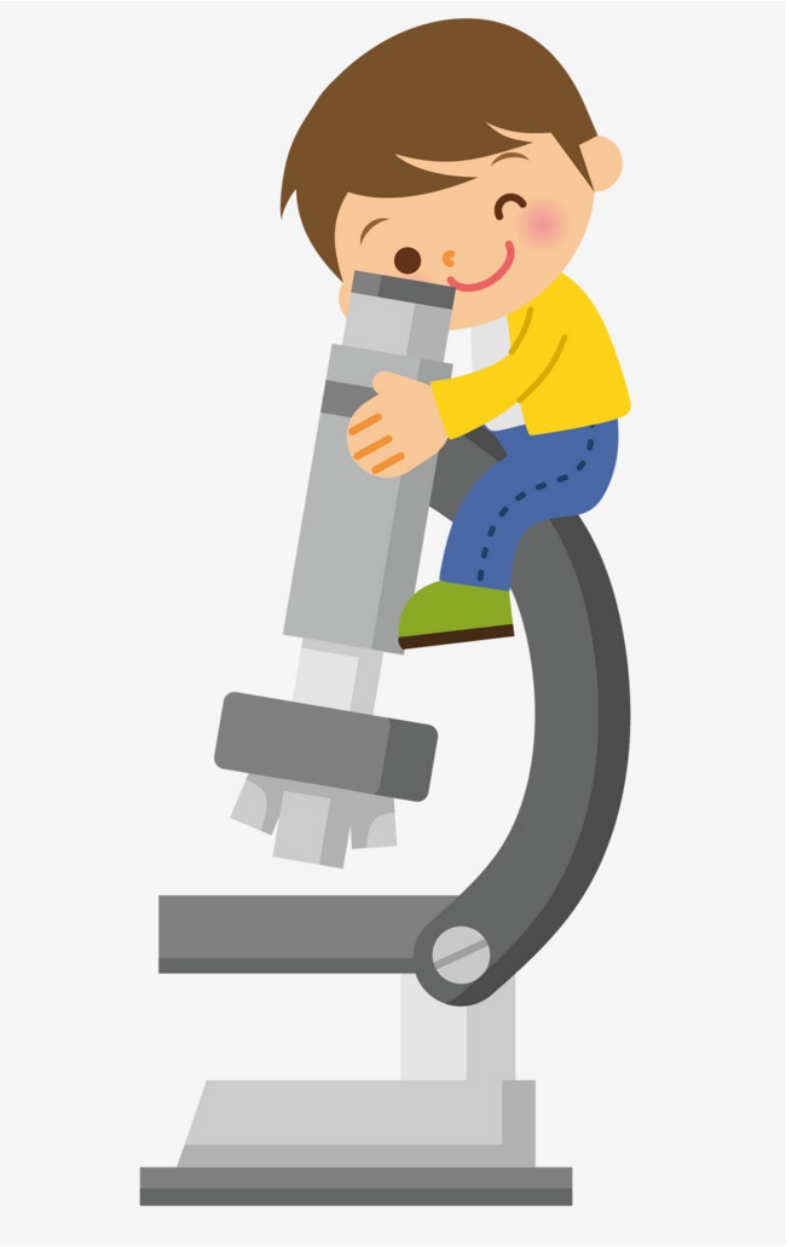
Lei da atracção Universal:

$$F = G \frac{m_{1g}\, m_{2g}}{r_{12}^{\,2}}$$

A gravidade !

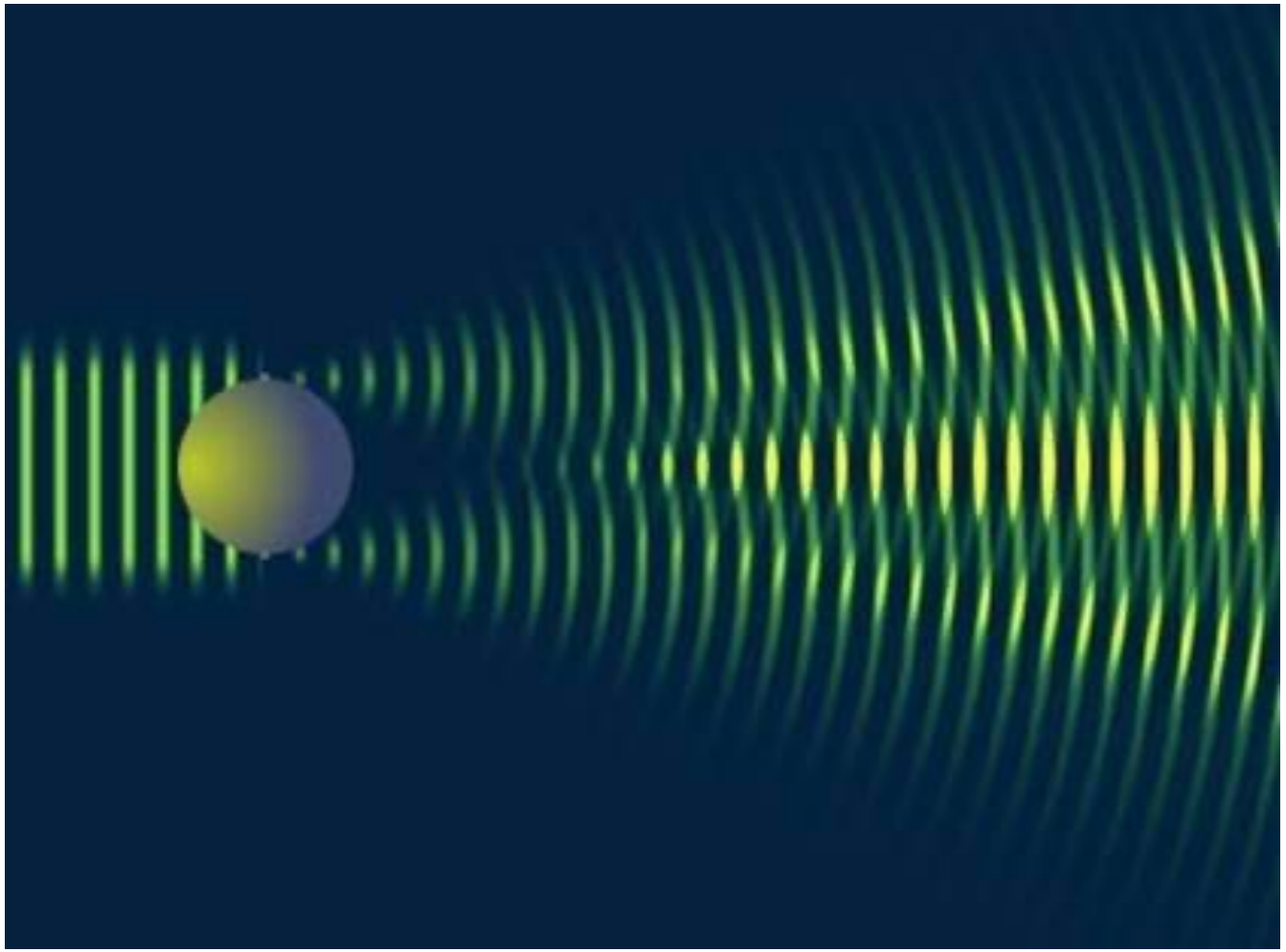
Será que a maçã é elementar?

Ver o interior da maçã ???



As ondas difractam-se ...

Se λ for da ordem do tamanho do objecto



Só se podem ver objectos com uma dimensão maior que λ !

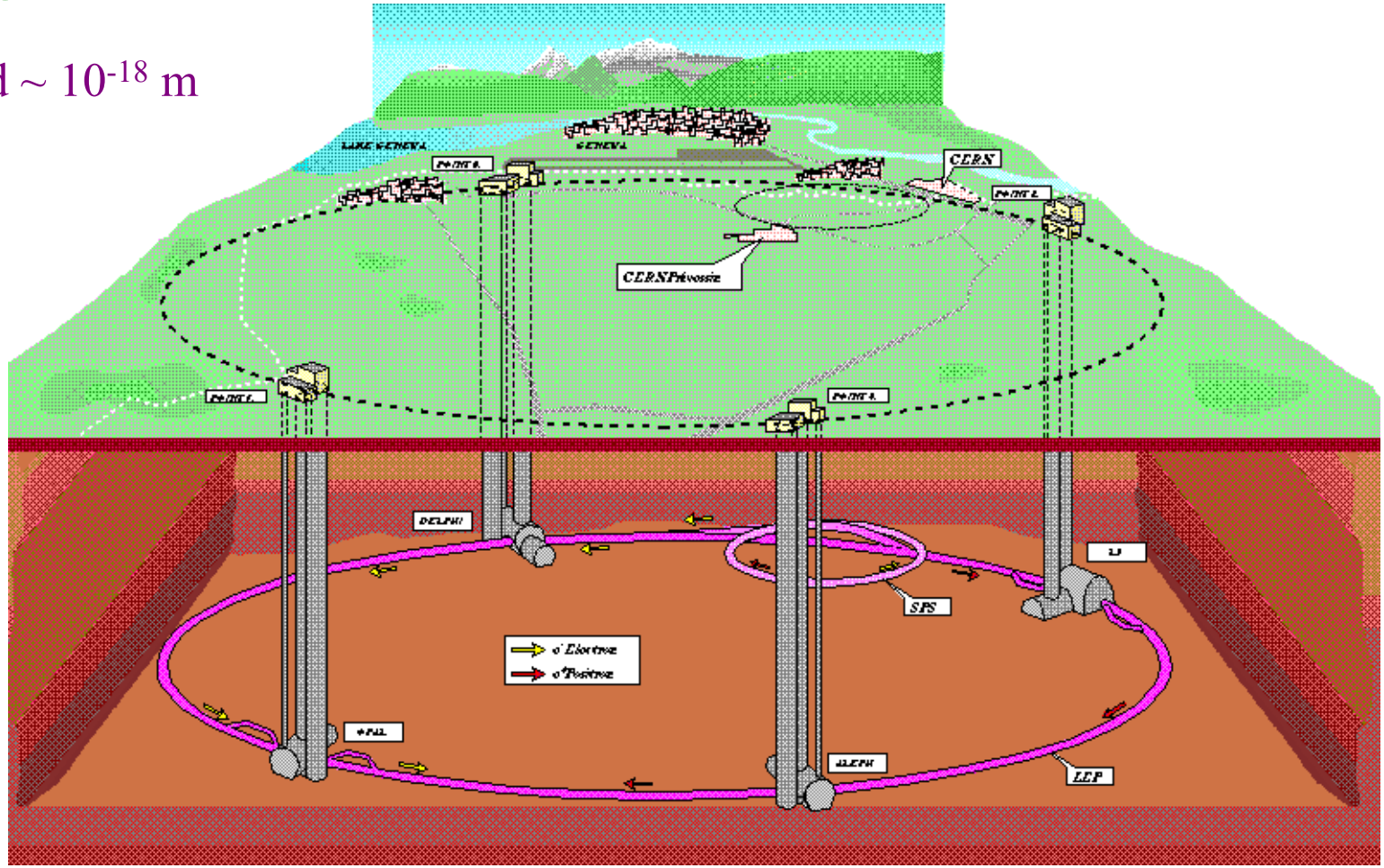
Ver com partículas

Louis de Broglie

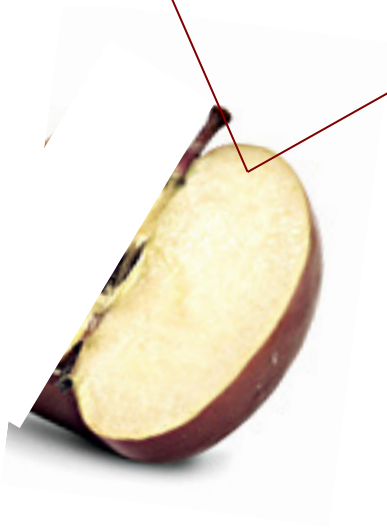
$$\lambda = \frac{h}{p}$$

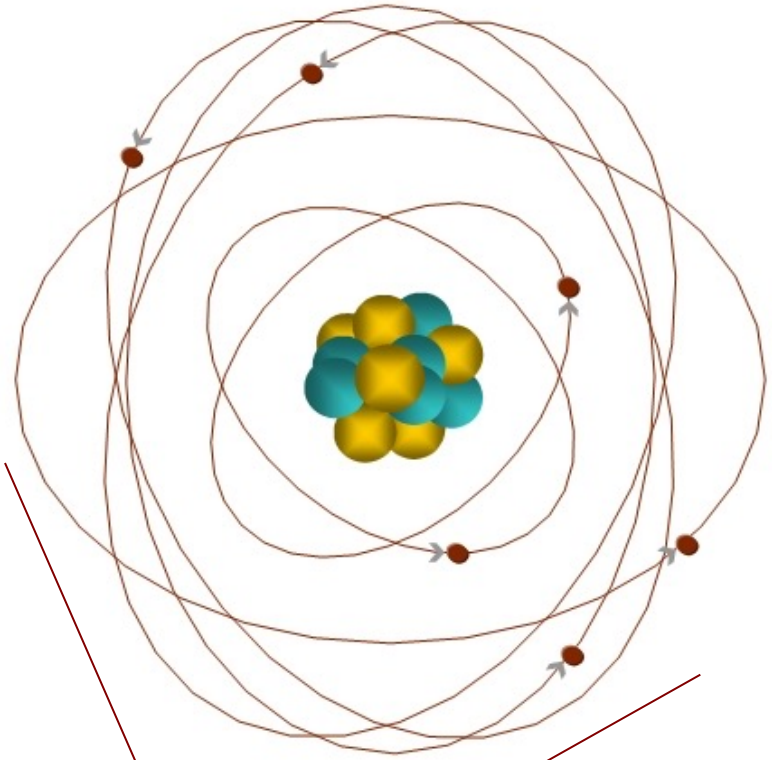
CERN

d ~ 10^{-18} m



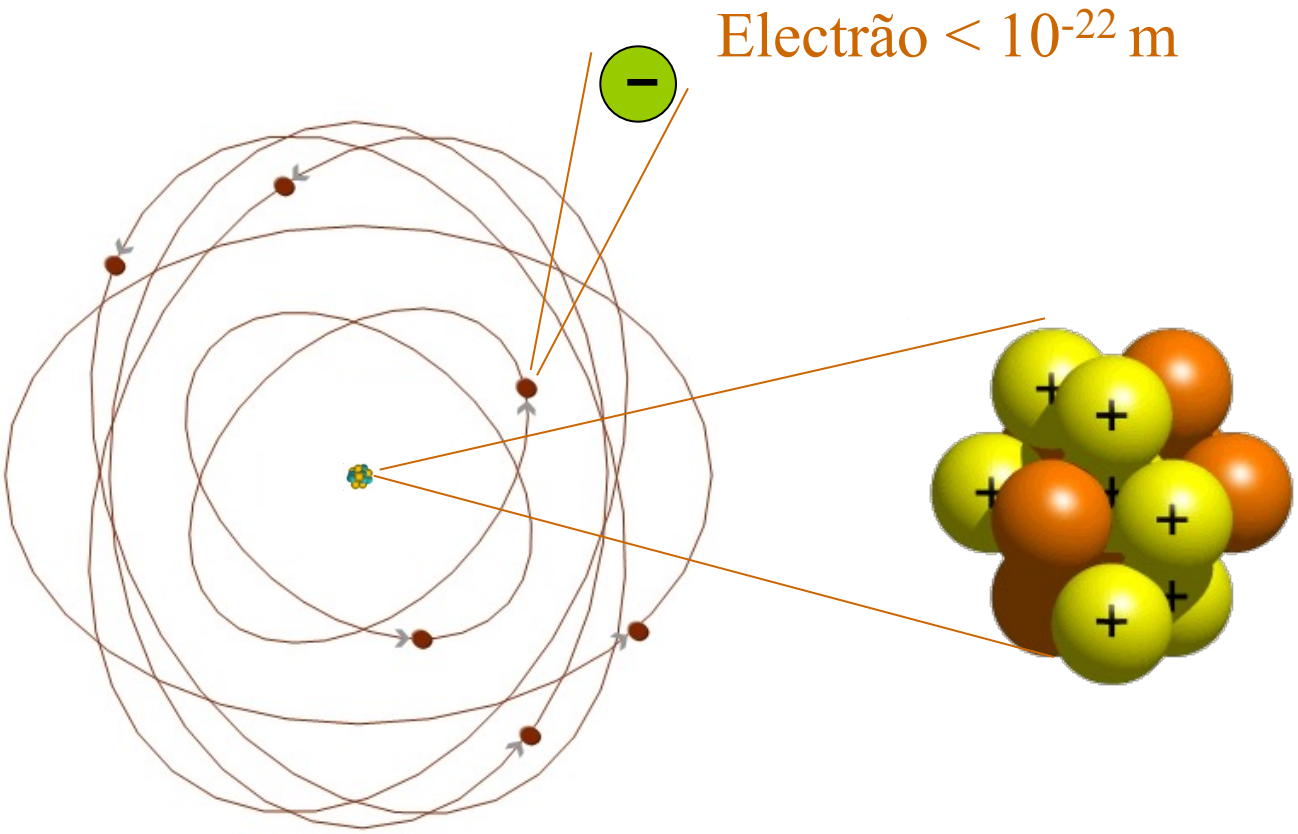
Será que a maçã é elementar?



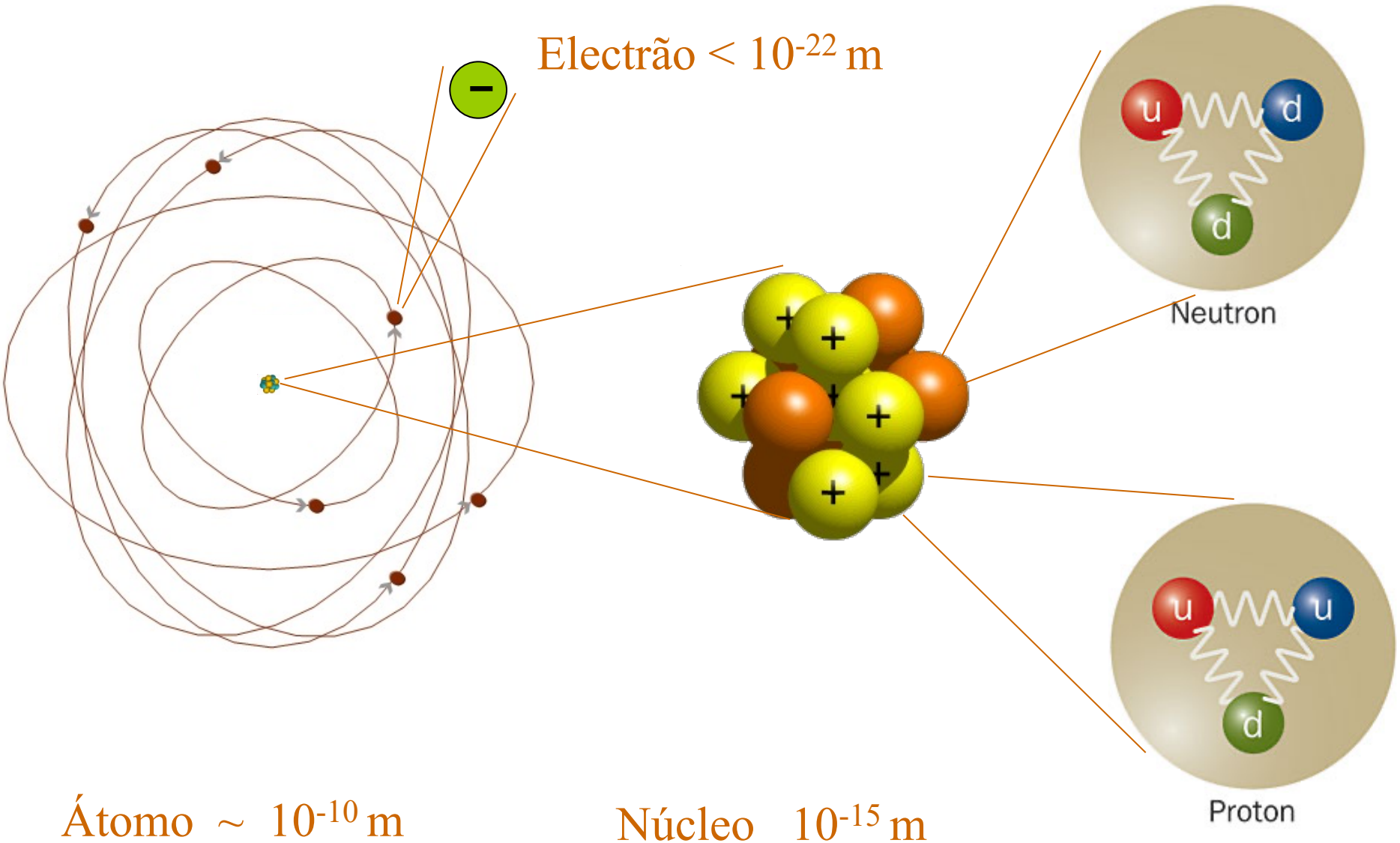


Átomo ~ 10^{-10} m

No interior dos átomos



No interior dos átomos



Vários quarks, muitas partículas !!!

Quarks:

$$\begin{pmatrix} u \\ d \end{pmatrix}$$

$Q = +\ 2/3$

$Q = -\ 1/3$

Vários quarks, muitas partículas !!!

Quarks:

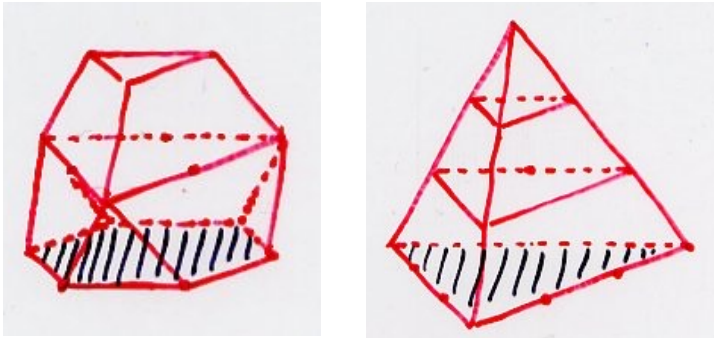
$$\begin{pmatrix} u \\ d \end{pmatrix} \quad \begin{pmatrix} c \\ s \end{pmatrix} \quad \begin{pmatrix} t \\ b \end{pmatrix} \quad \begin{pmatrix} ? \\ ? \end{pmatrix}$$

Q = + 2/3

Q = - 1/3

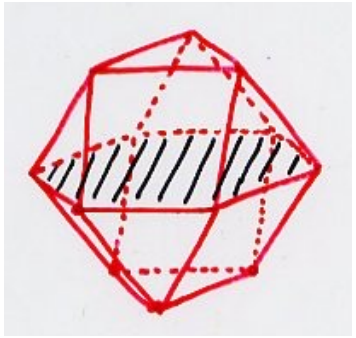
Combinar

$q_i q_j q_k$



$p\ ,n\ ,\Sigma\ ,\lambda\ ,\Xi\ ,\Delta\ ,\ldots$

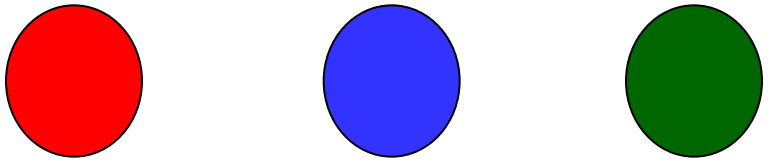
$q_i \bar{q}_i$



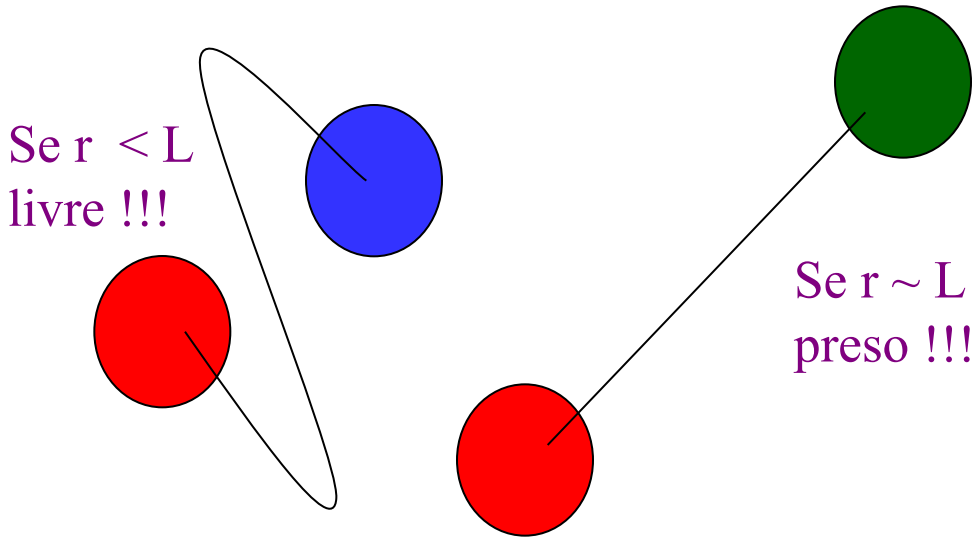
$\pi\ ,k\ ,\eta\ ,\rho\ ,\psi,\ldots$

A força forte

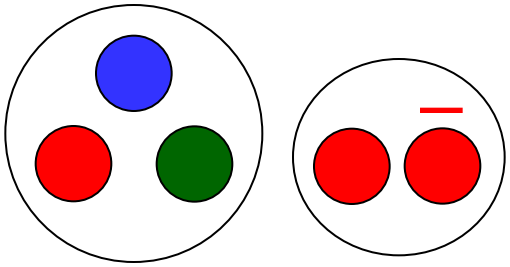
Quarks de três cores:



Ligados por “cordas”

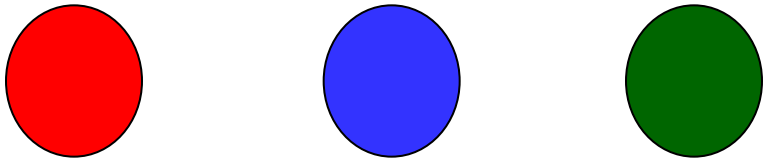


Partículas “sem cor”

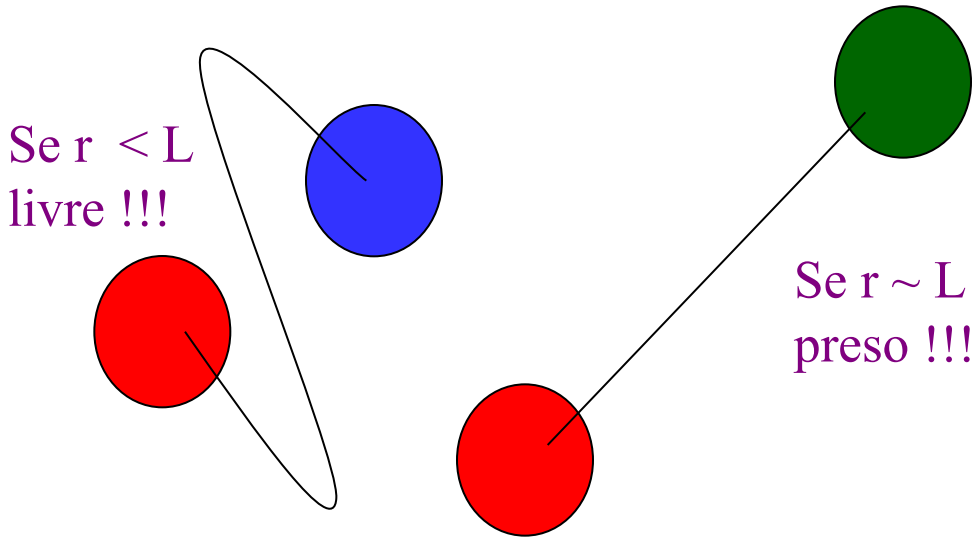


A força forte

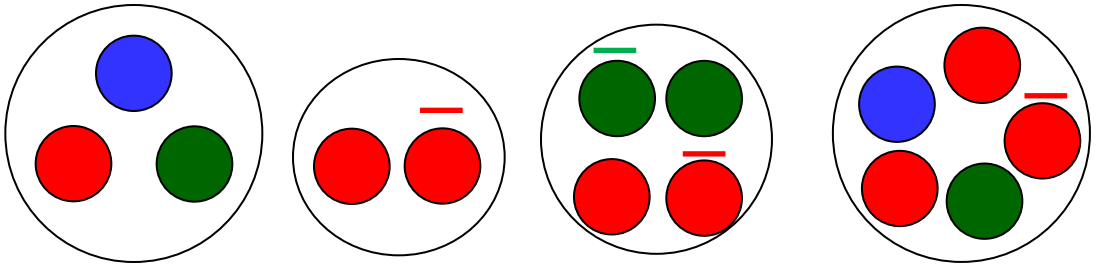
Quarks de três cores:



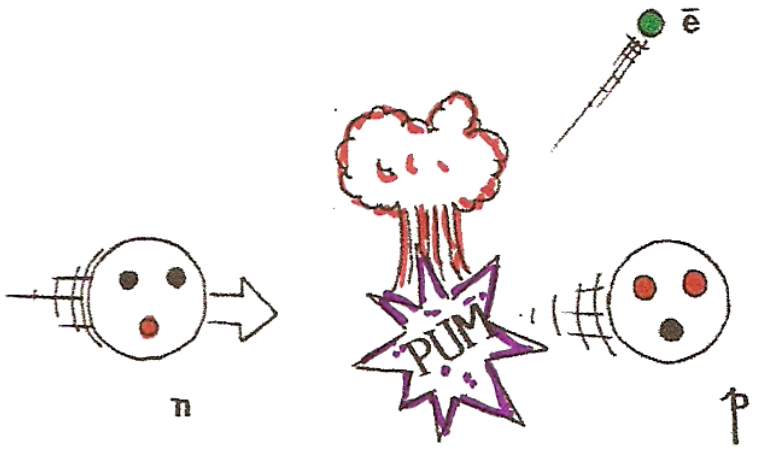
Ligados por “cordas”



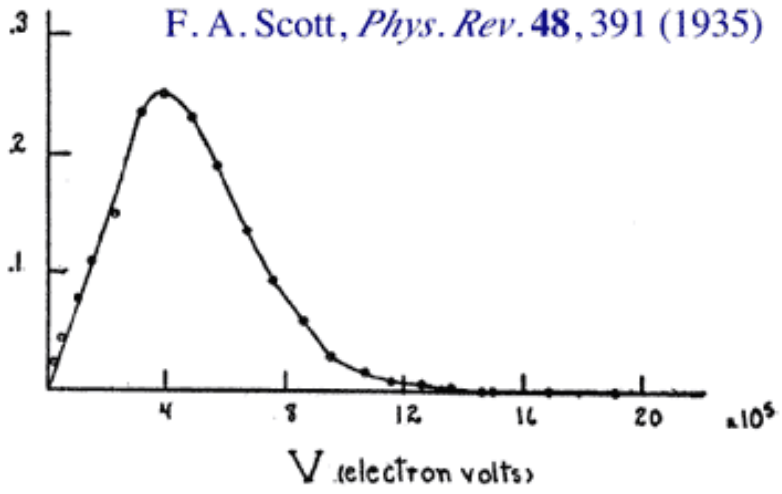
Partículas “sem cor”



O neutrão decai…



conservação E e $\vec{P}$???



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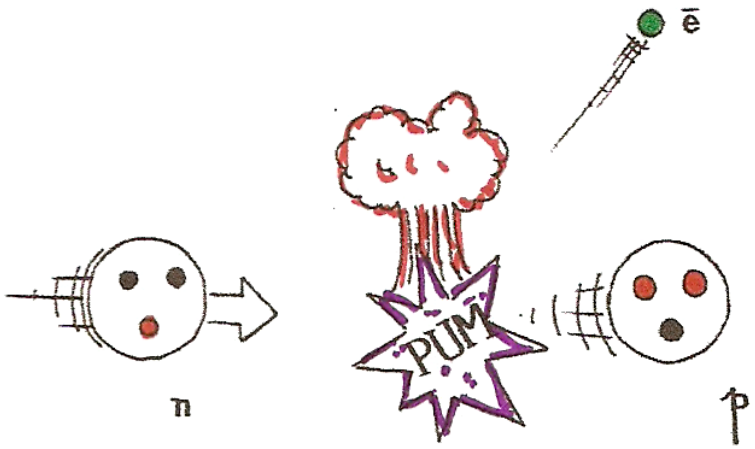
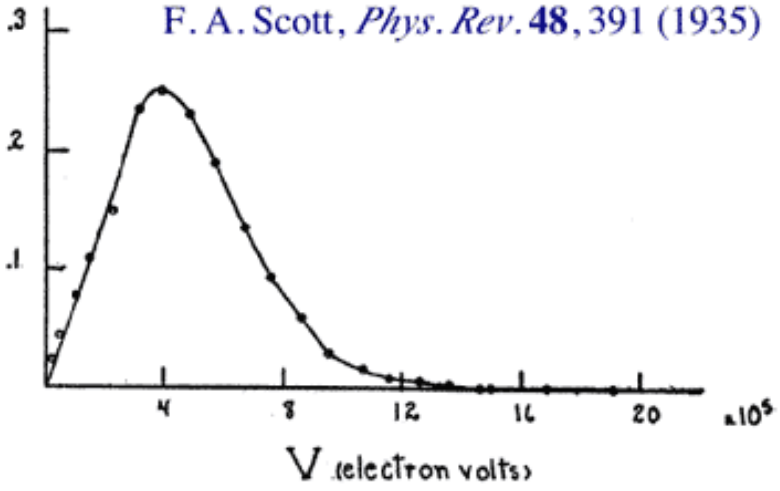


Pauli (1930)

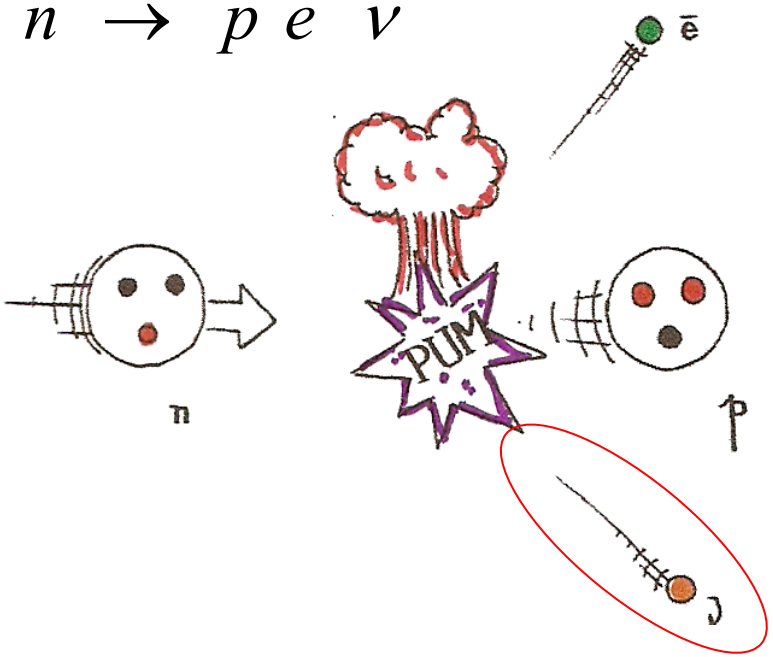
conservação E e $\vec{P}$???

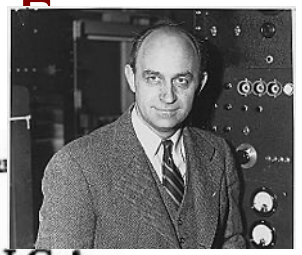


O neutrino !!!

A força fraca

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





ANNO IV - VOL. II - N. 12 QUINDICINALE 31 DICEMBRE

LA RICERCA SCIENTIFICA

ED IL PROGRESSO TECNICO NELL'ECONOMIA NAZIONALE

Letter Submitted to Nature (1933) REJECTED

Tentativo di una teoria dell'emissione dei raggi "beta"

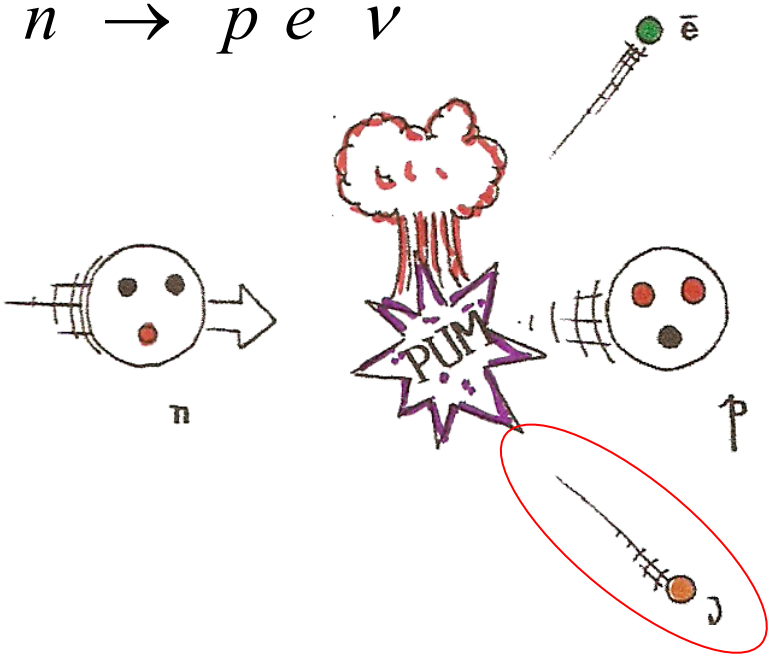
Nota del prof. ENRICO FERMI

Riassunto: Teoria della emissione dei raggi β delle sostanze radioattive, fondata sull'ipotesi che gli elettroni emessi dai nuclei non esistano prima della disintegrazione ma vengano formati, insieme ad un neutrino, in modo analogo alla formazione di un quanto di luce che accompagna un salto quantico di un atomo. Confronto della teoria con l'esperienza.

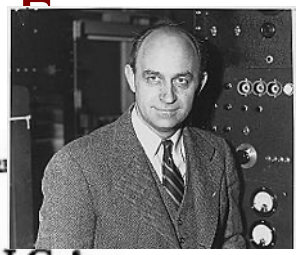
Nuovo Cimento and Zeitschrift fur Physik

A força fraca

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



E



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Letter Submitted to Nature (1933)
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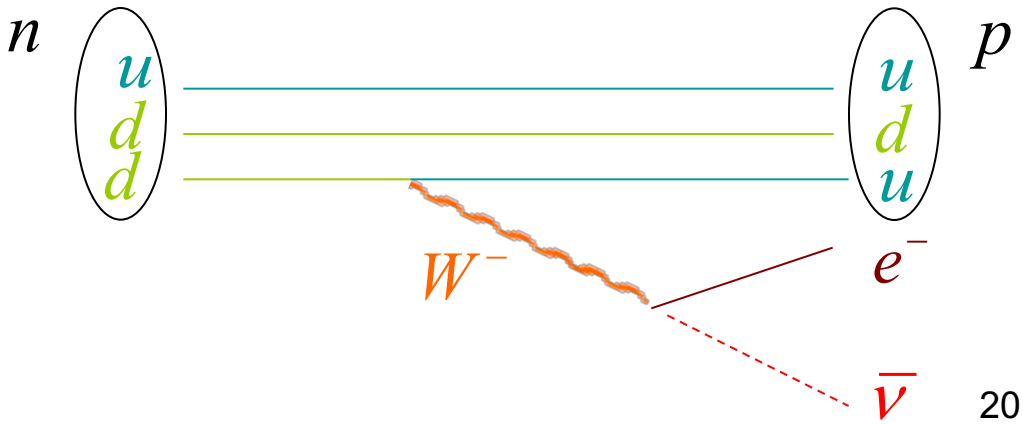
Nuovo Cimento and Zeitschrift fur Physik

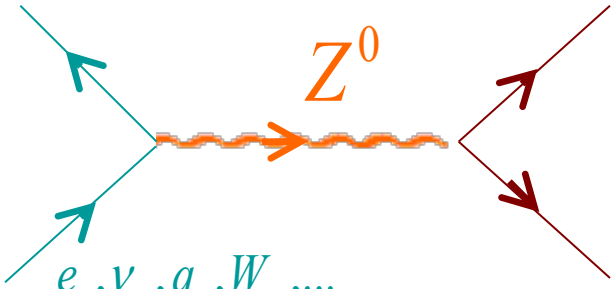
A visão moderna !

Um quark d transforma-se num quark u emitindo um bosão W que "decai" num par electrão, anti-neutrino

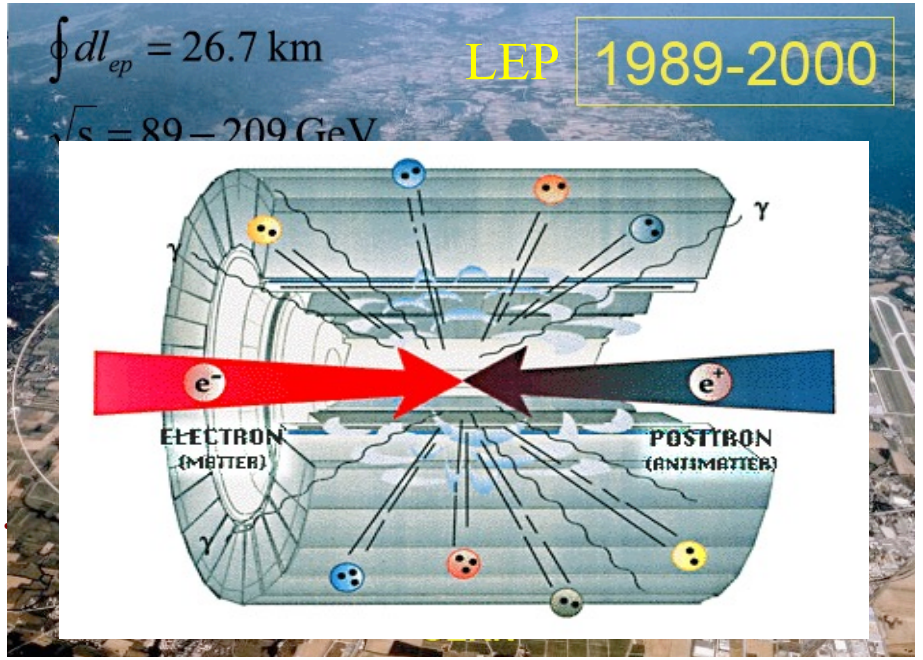


O Z^0

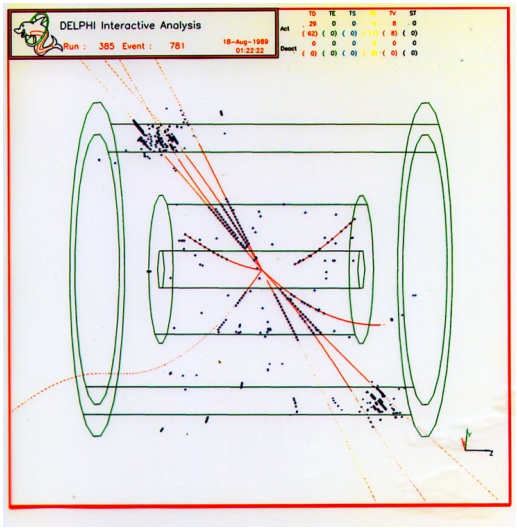
Parceiro neutro dos W´s

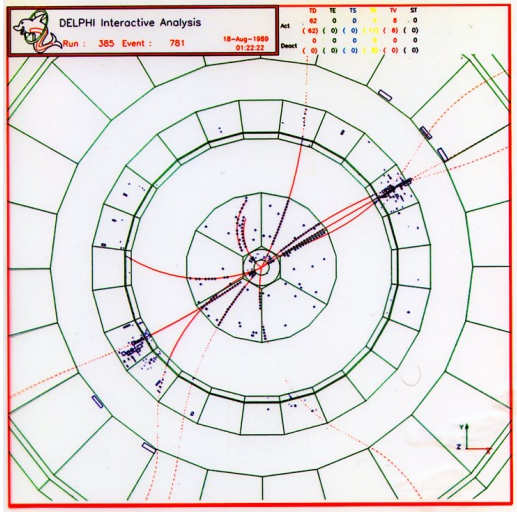


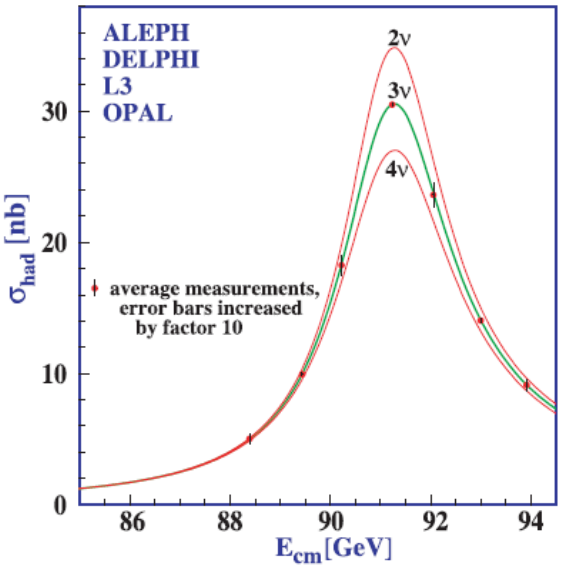
$e, \nu, q, W, \ldots$



$e^+e^- \rightarrow q\bar{q}$



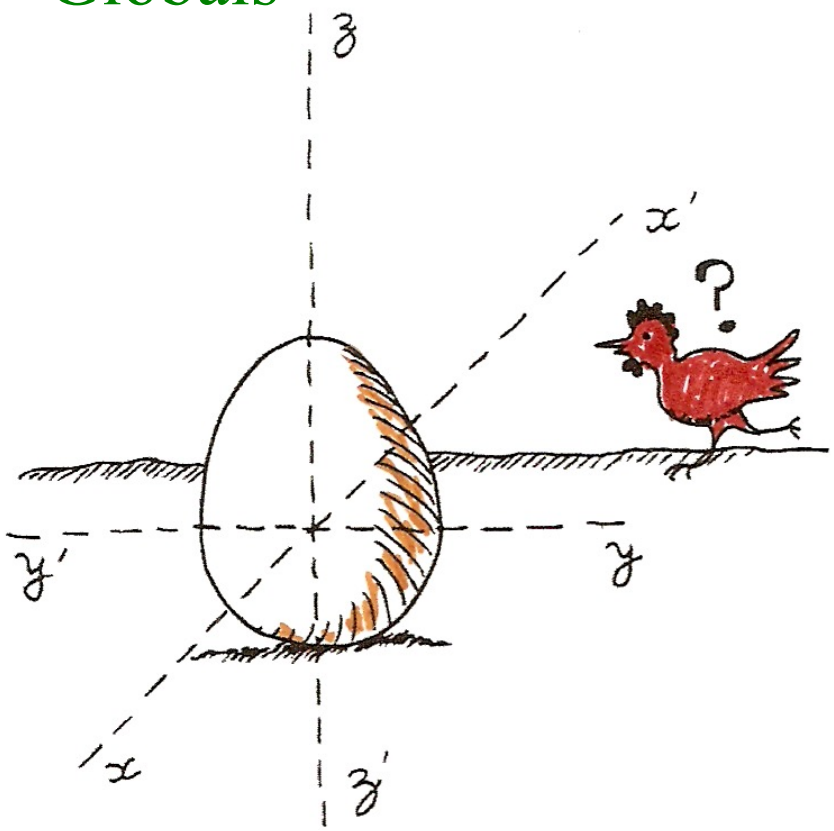




$M_z = 91.1875 \pm 0.0021$ GeV/c

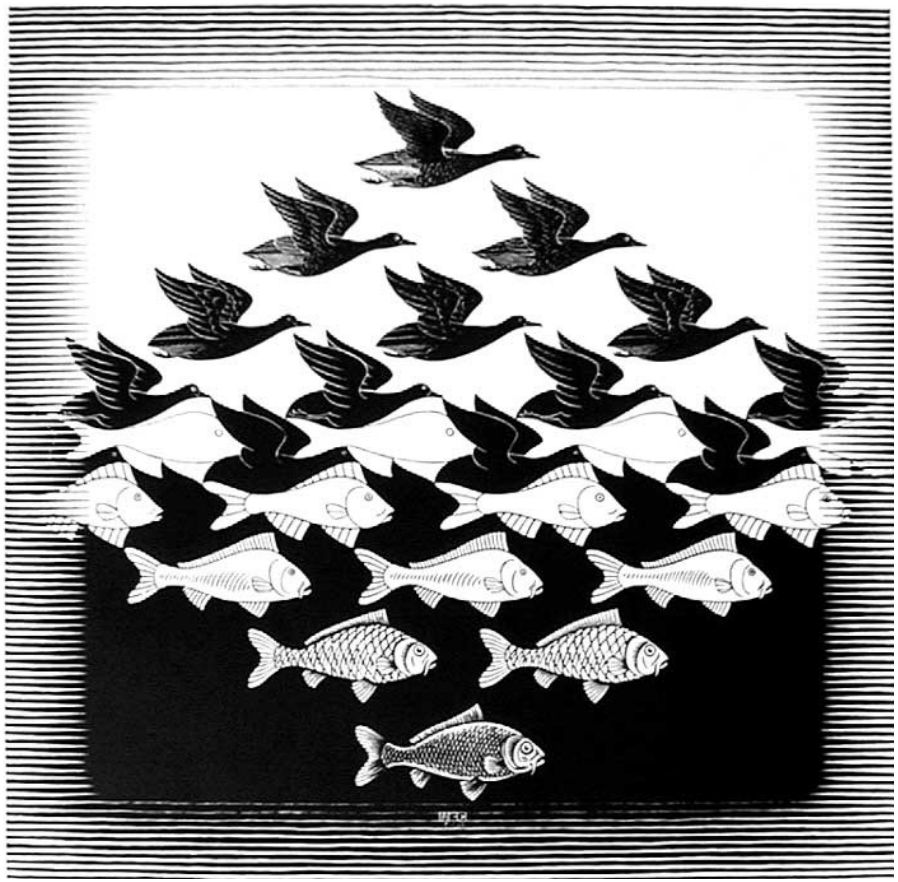
Simetrias !!!

Globais



Locais

M.C.Escher



Leis de conservação:
Energia, Momento linear,
Momento Angular

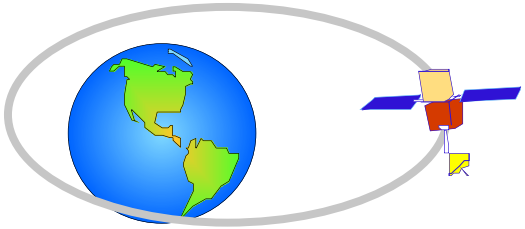
Campos de interacção:
Electromagnético,fraco,forte,
gravítico???,

As interações

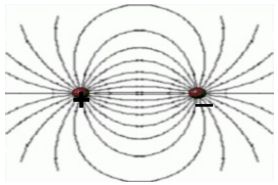
Unificação e Simetrias (locais)

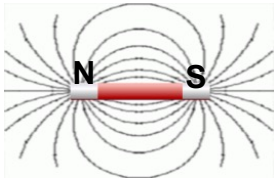
?

gravíticas

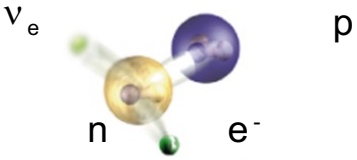


electromagneticas

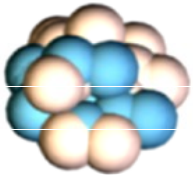




fracas

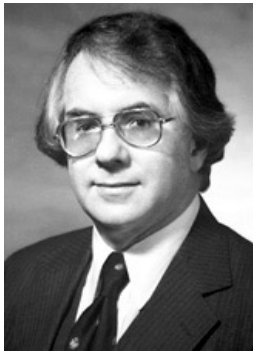


fortes



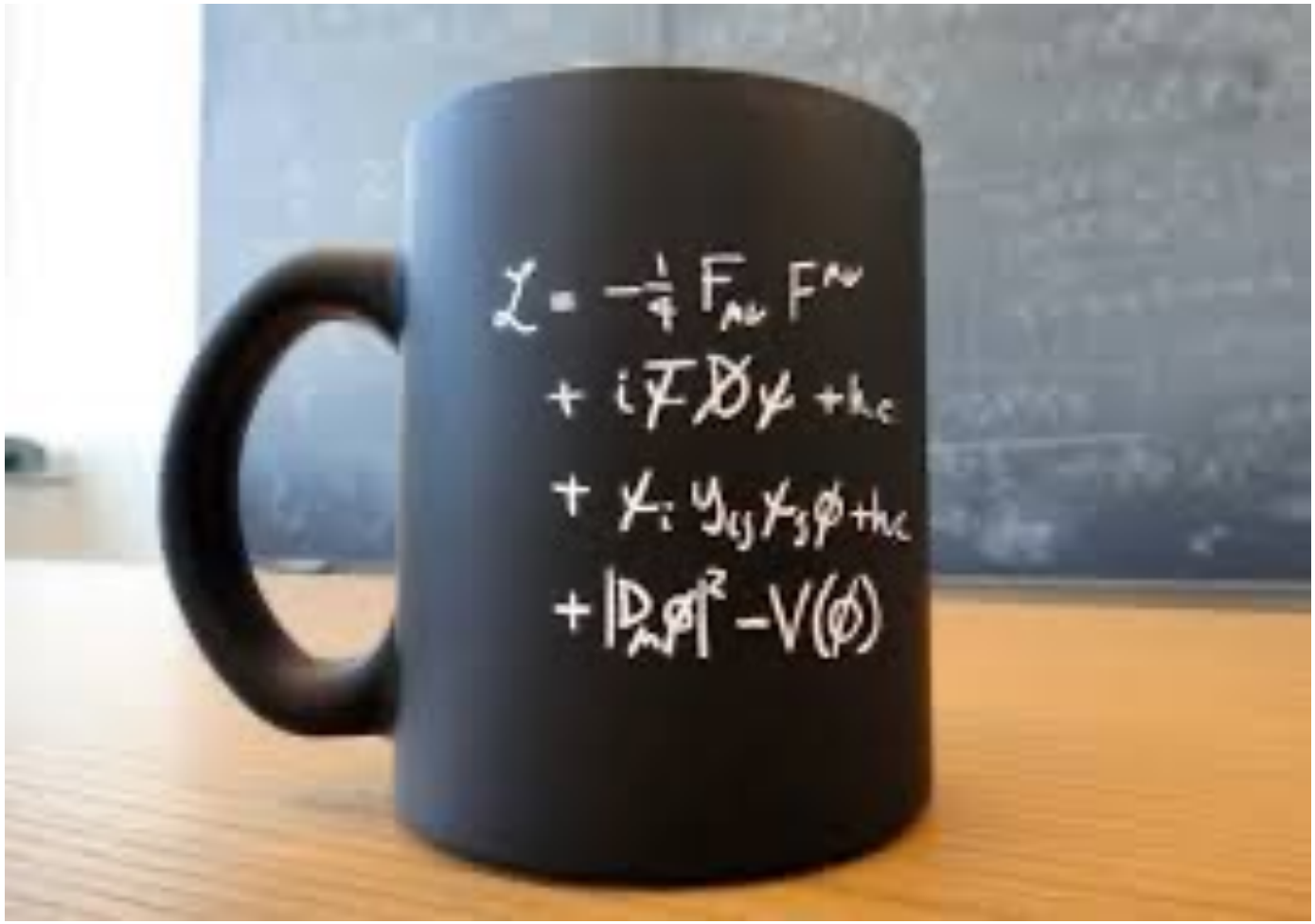
O Modelo Padrão: $SU(2)_L \otimes U_1$

Glashow



Salam

Weinberg



Mas as Partículas têm massa

em eV/c^2

$m_\nu \sim 10^{-1}$

$m_e \sim 500\ 10^{3}$

$m_u \sim 5\ 10^{6}$

$m_t \sim 174\ 10^{9}$

…

$m_\gamma = 0$

$m_W \sim 80\ 10^{9}$

$m_Z \sim 91\ 10^{9}$

$m_H \sim 125\ 10^{9}$

Como é que as massas são geradas ???

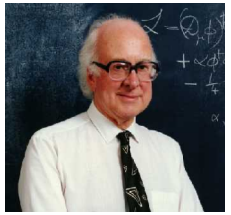
Por é que são tão diferentes ???

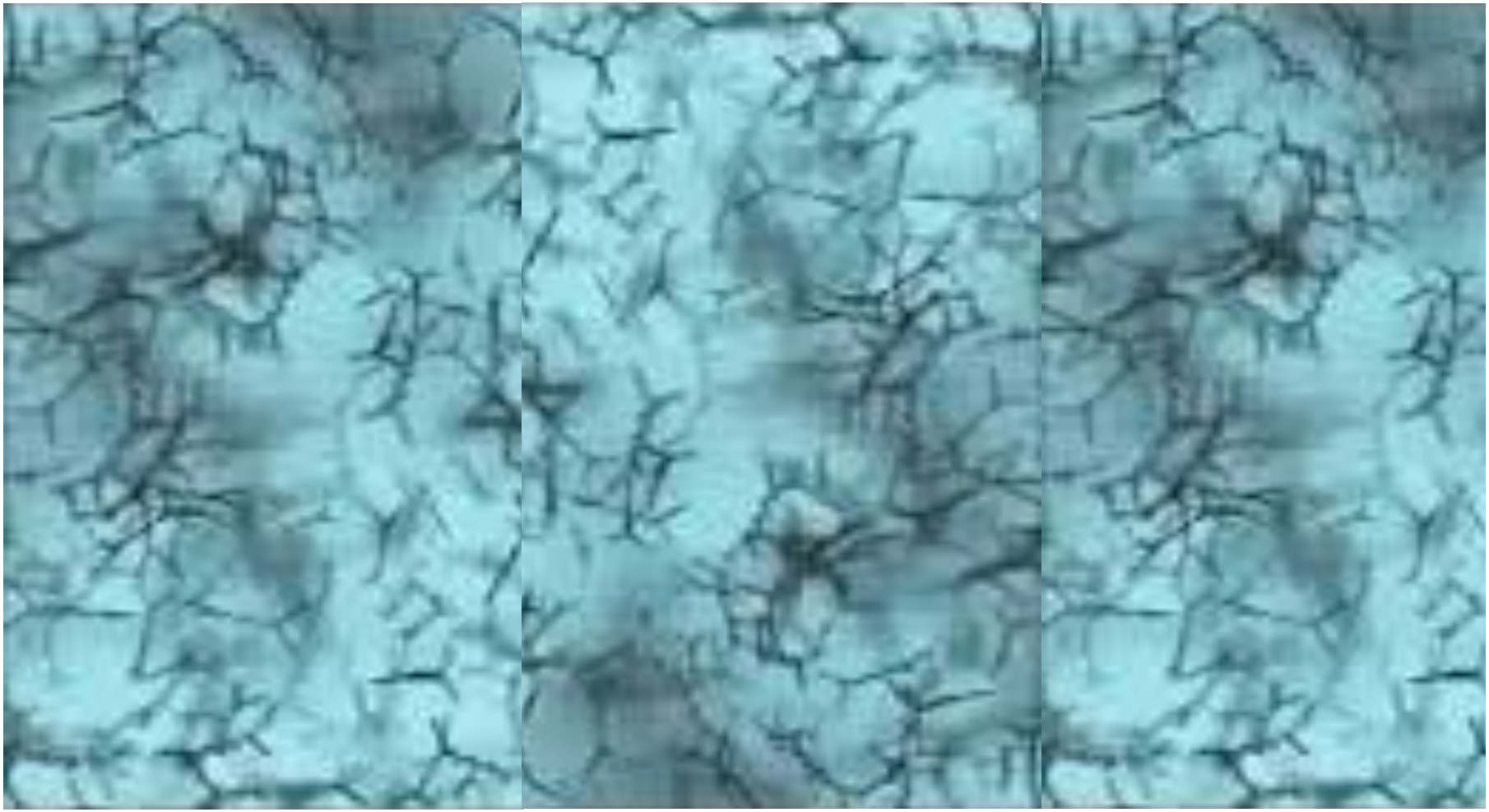
$1\ eV \sim 1.8\ 10^{-36} Kg$

O campo de Higgs

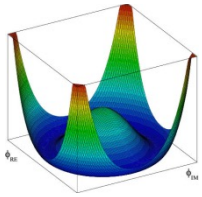
Higgs, Englert, Brout - 1964

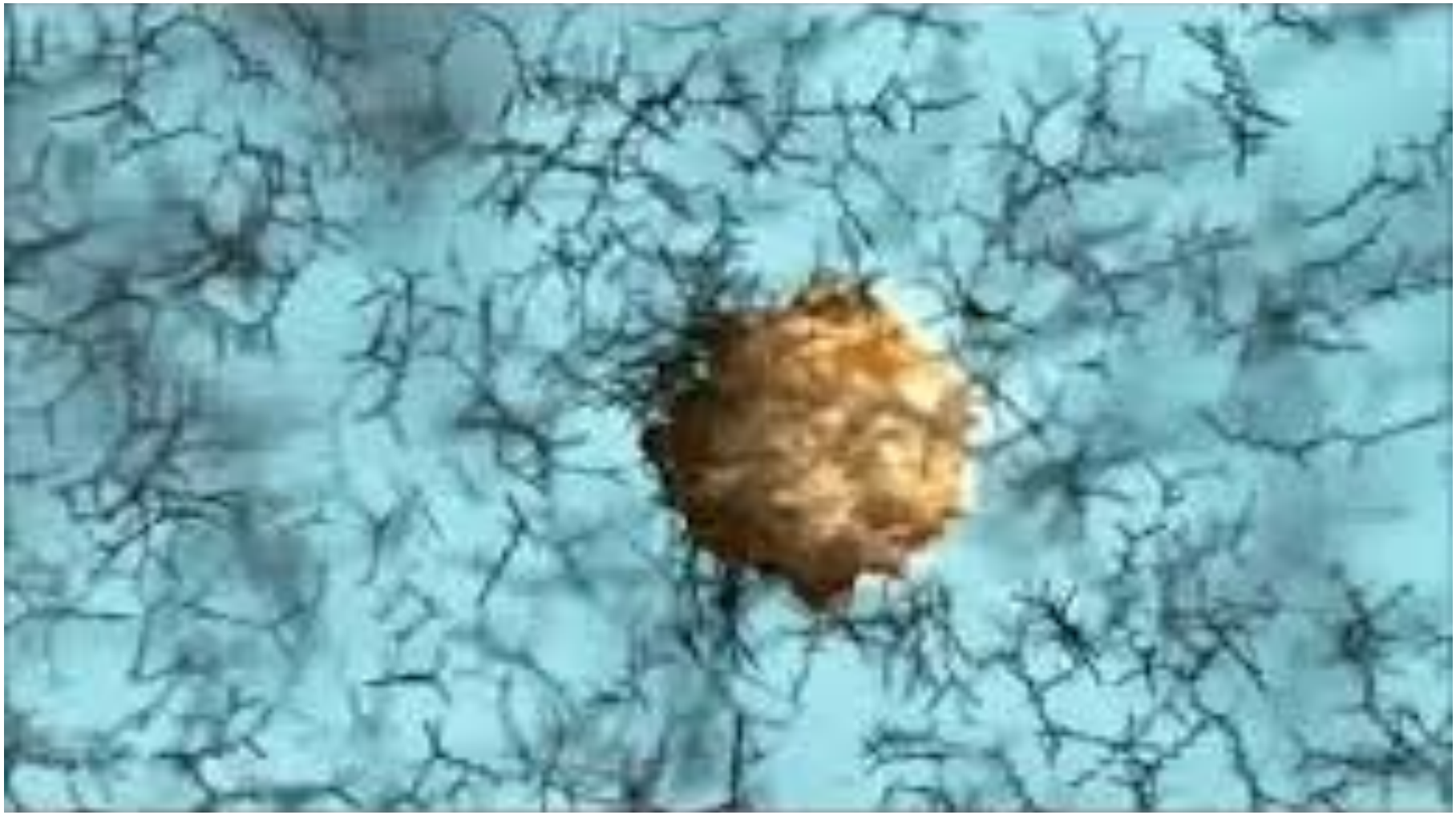
Peter Higgs





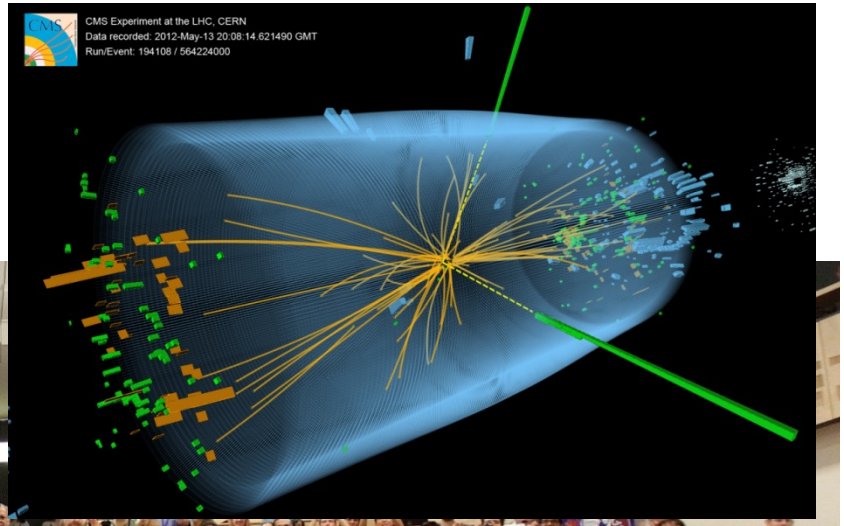
O mecanismo de Higgs





A massa é gerada na interacção com o campo

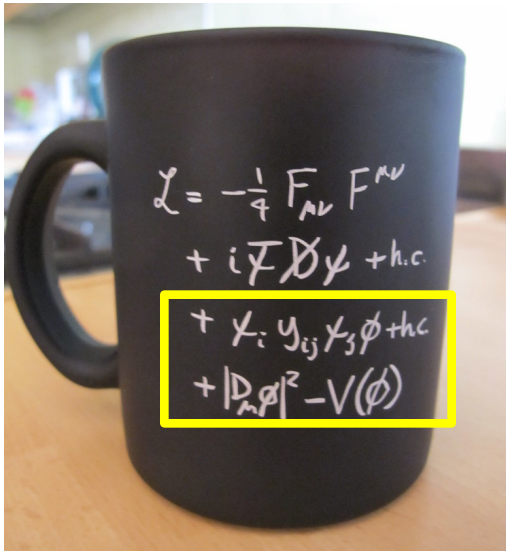
O bosão de Higgs



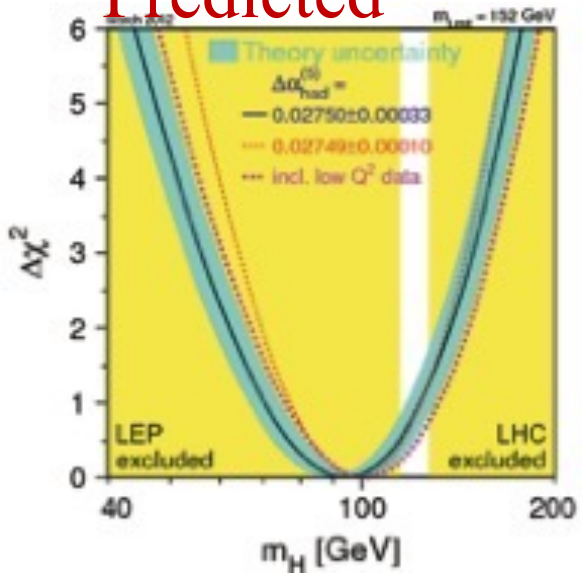
4 Julho 2012: CERN

Higgs Field in the SM

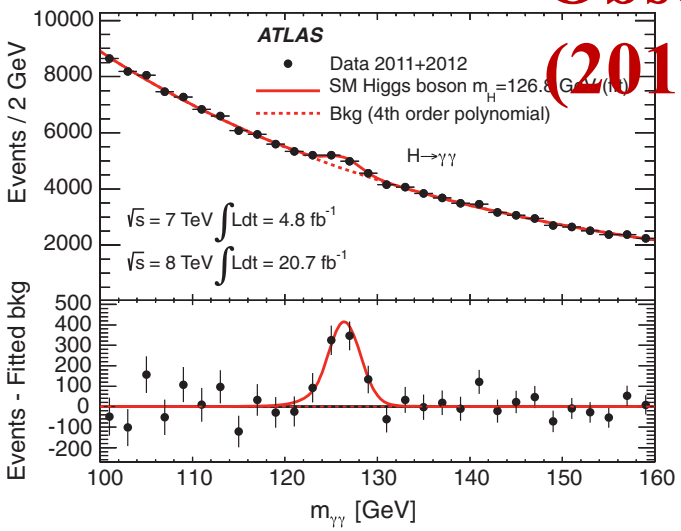
- A scalar Higgs field that permeates all the Space is introduced **(a new "ether")**
- The W^+,W^-, Z^0 masses are generated trough the Spontaneous Symmetry Breaking of this new Higgs field but **an extra massive Higgs Boson** appears!
- The fermion masses are generated by their coupling to the Higgs field
- The Higgs boson couples at tree level with all massive particles and at a loop level with all particles …

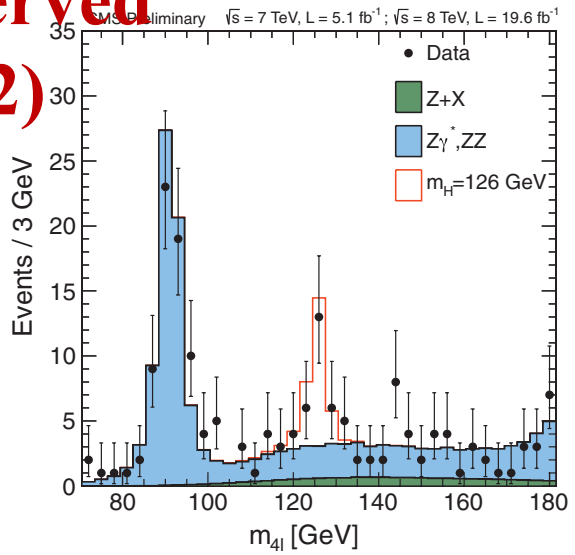


Predicted

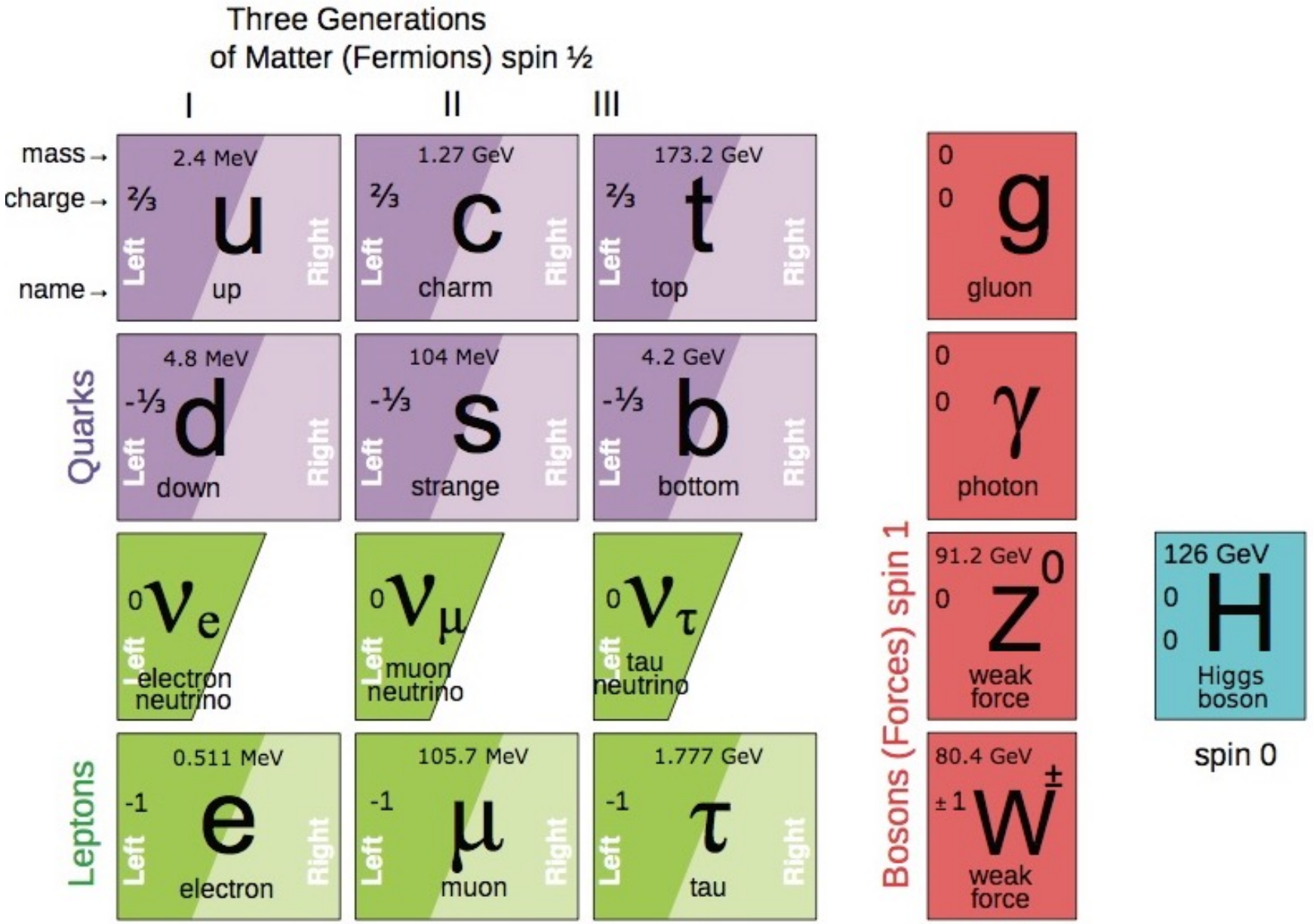


Observed (2012)

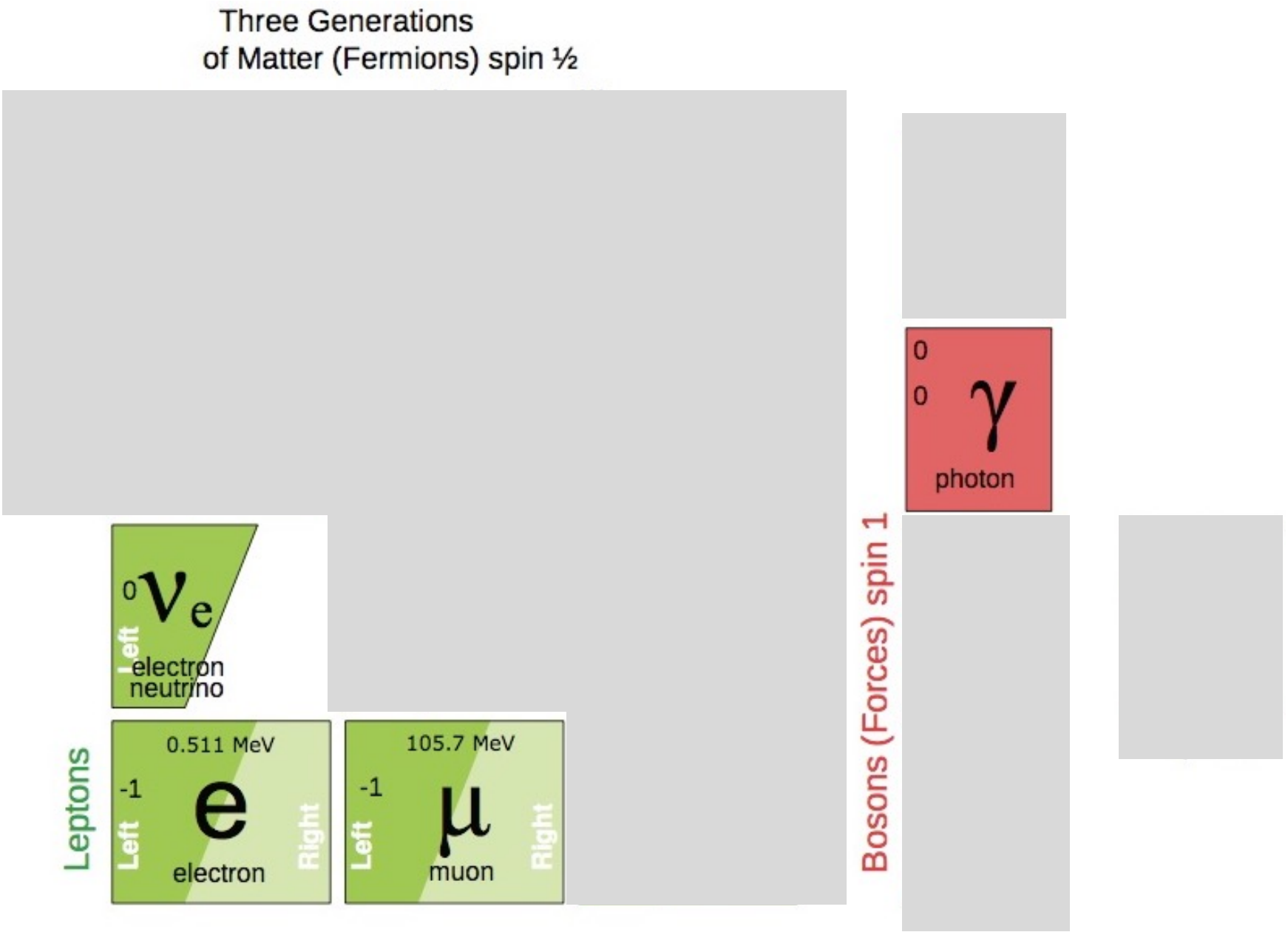




As partículas elementares hoje!



As partículas elementares em 1957



Neutrino sector

The Nobel Prize in Physics 2002: Raymond Davis Jr,

The detection of cosmic neutrinos

The Nobel Prize in Physics 2015: Takaaki Kajita, Arth

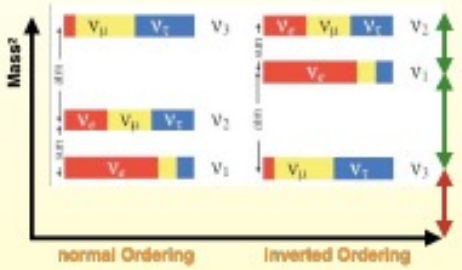
The discovery of neutrino oscillations

Present status: Dirac vs Majorana? Mixing?

ν physics: PMNS; 3x3 or 4x4? nature (Majorana or Dirac); mass ordering

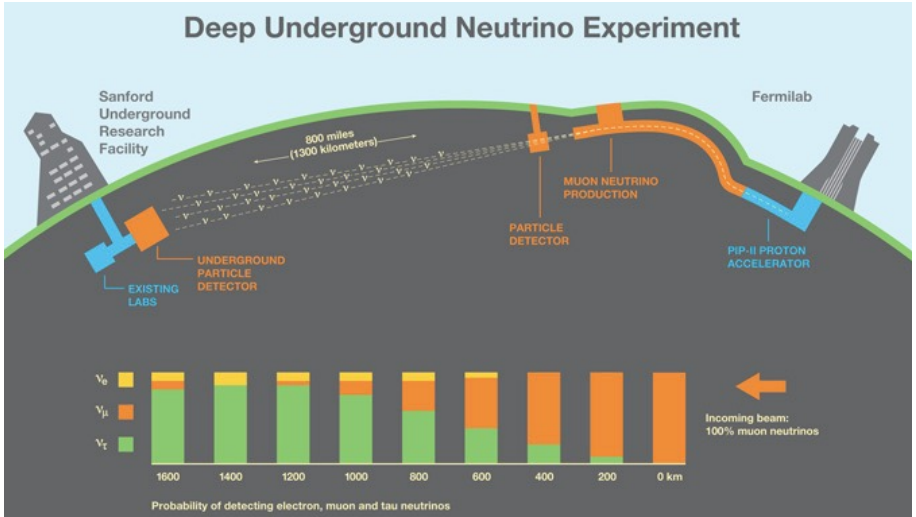
$$U_{3\times3} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix} \begin{pmatrix} \cos\theta_{13} & 0 & \sin\theta_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -\sin\theta_{13}e^{i\delta} & 0 & \cos\theta_{13} \end{pmatrix} \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \times (U_{Maj})$$

atmospheric + accelerator disapp | SBL reactor + accelerator app | solar + KamLAND



A rich experimental program in the next 10/20 years:

- Accelerator-based long-baseline;



"Extended" SM parameters

26 "magic numbers" (if Majorana neutrinos + 2)

Gauge sector

Three gauge constants: g, g', g_s

Higgs sector

Two Higgs potential Parameters: μ, λ

Fermionic sector

Twelve fermion masses (or Yukawa couplings): $m_{\nu 1}$, $m_{\nu 2}$, $m_{\nu 3}$, m_e, m_μ, m_τ, m_u, m_d, m_c, m_s, m_t, m_b

CKM quark matrix

Four mixing parameters: λ, A, ρ, η

PMNS neutrino matrix

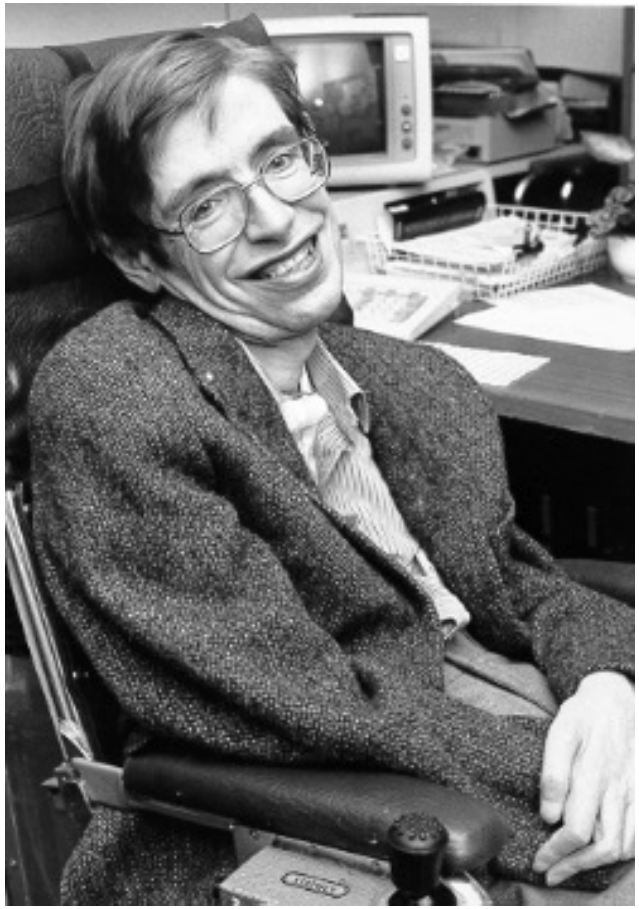
Four mixing parameters: θ_{12} , θ_{13} , θ_{23} , δ

Strong CP sector

CP "violating phase": θ_{CP}

Numerical values differs by more than 10 orders of

The End of Physics?



1980 – "The goal of theoretical physics might be achieved in the not too distant future … we might have a complete, consistent and unified theory of the physical interactions which would describe all possible observations".

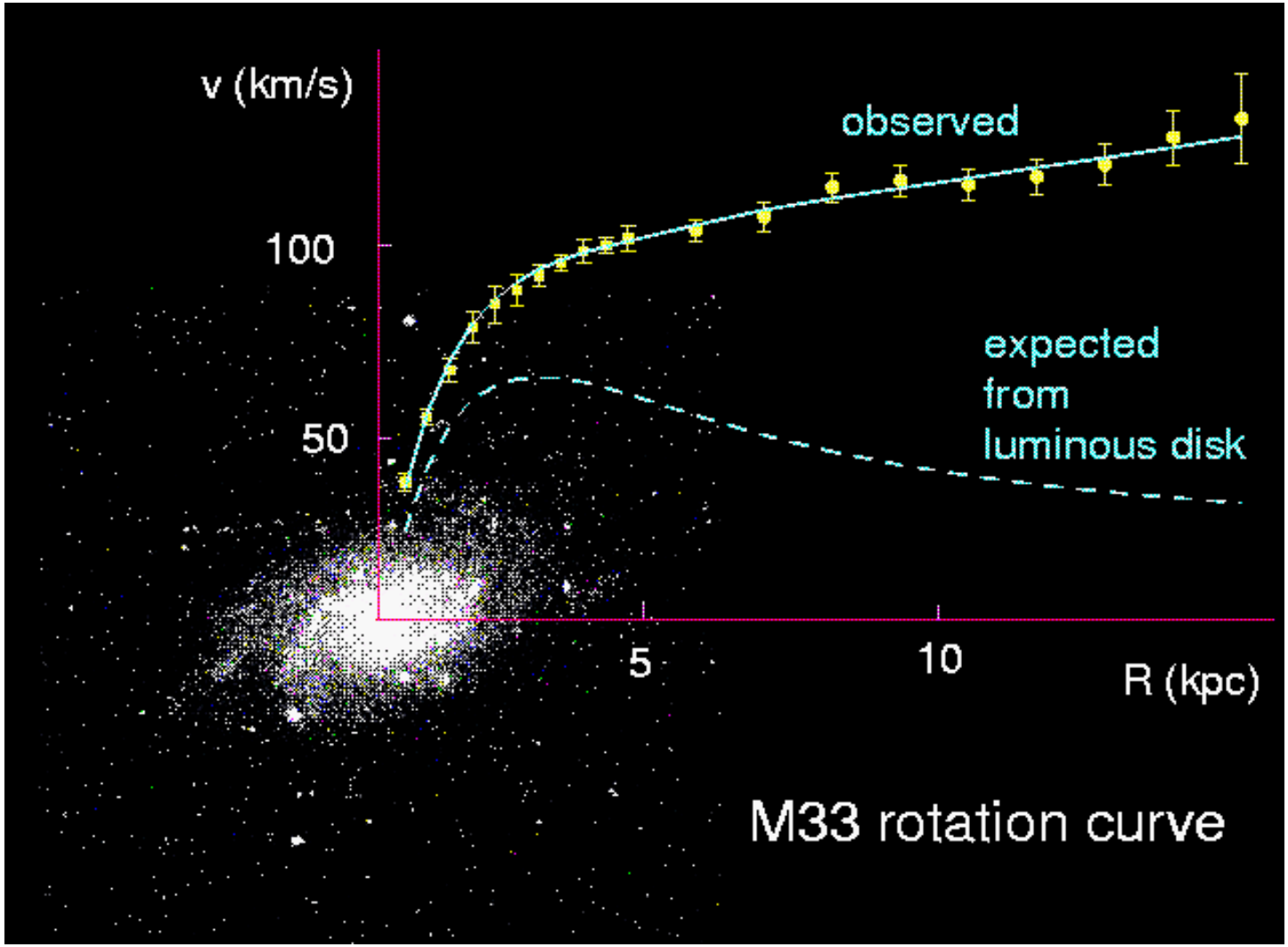
2002 – "I have changed my mind. I'm now glad that our search for understanding will never come to an end, and that we will always have the challenge of new discovery without it, we would stagnate"

Stephen Hawking

A matéria luminosa

A velocidade de rotação das estrelas periféricas

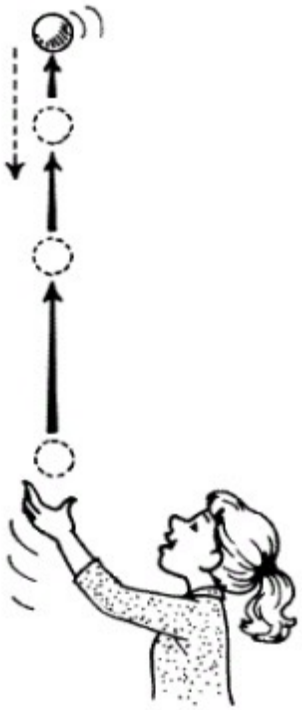
Rodar em torno do centro da galáxia



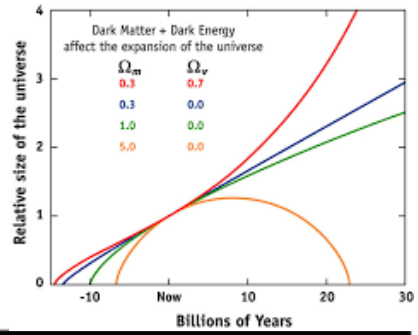
Um halo de matéria escura!

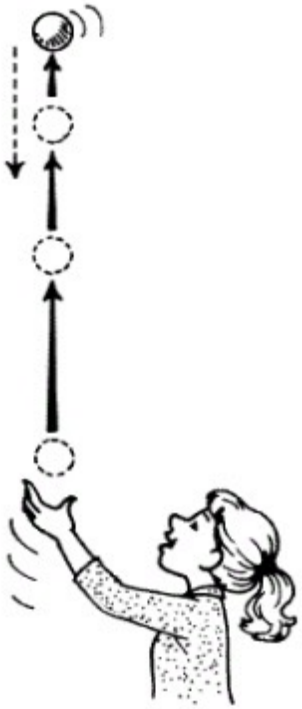
A matéria escura

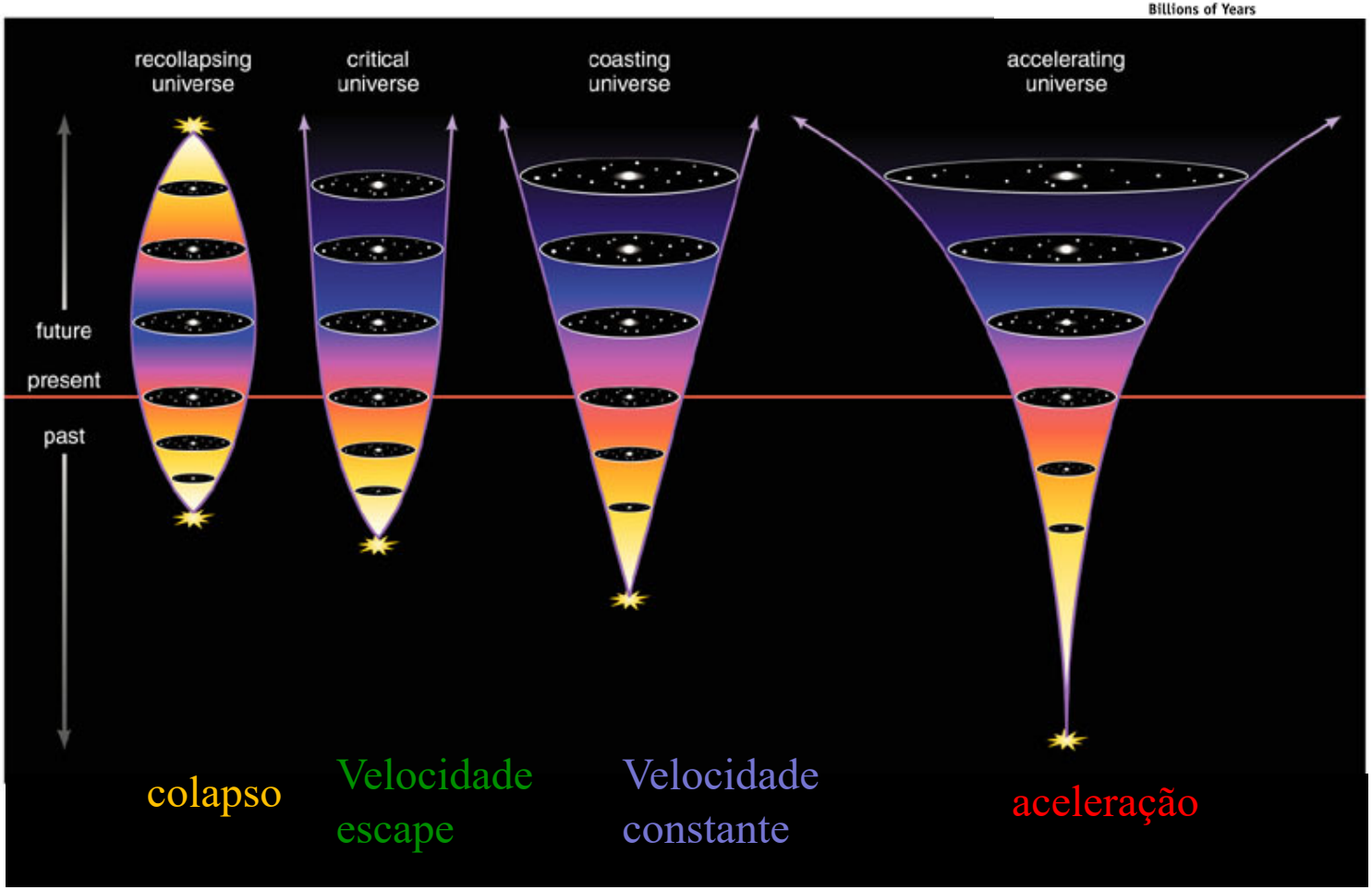
A expansão do Unverso



A expansão do Unverso

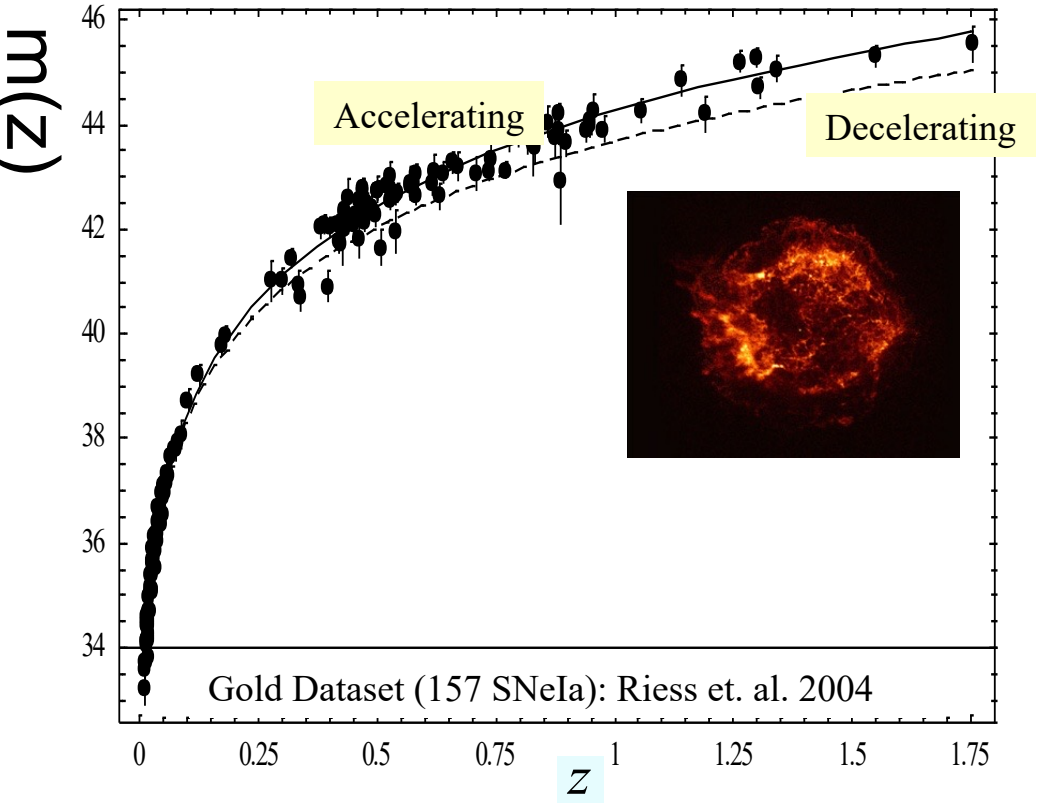


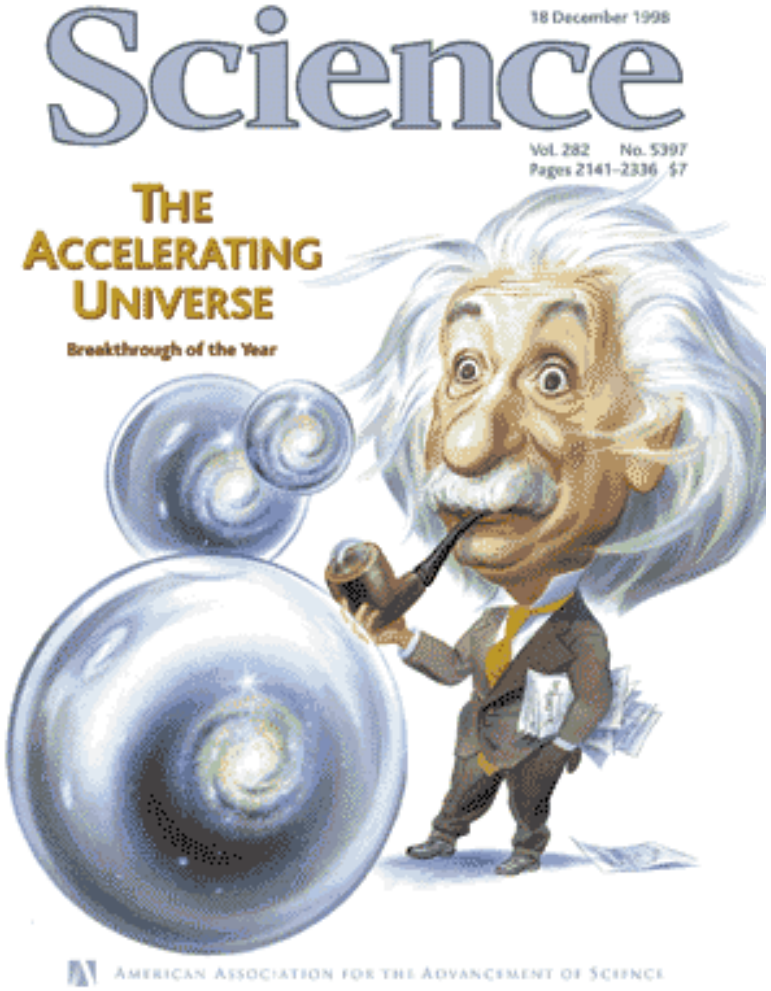




A energia escura !

Diagrama de Huble

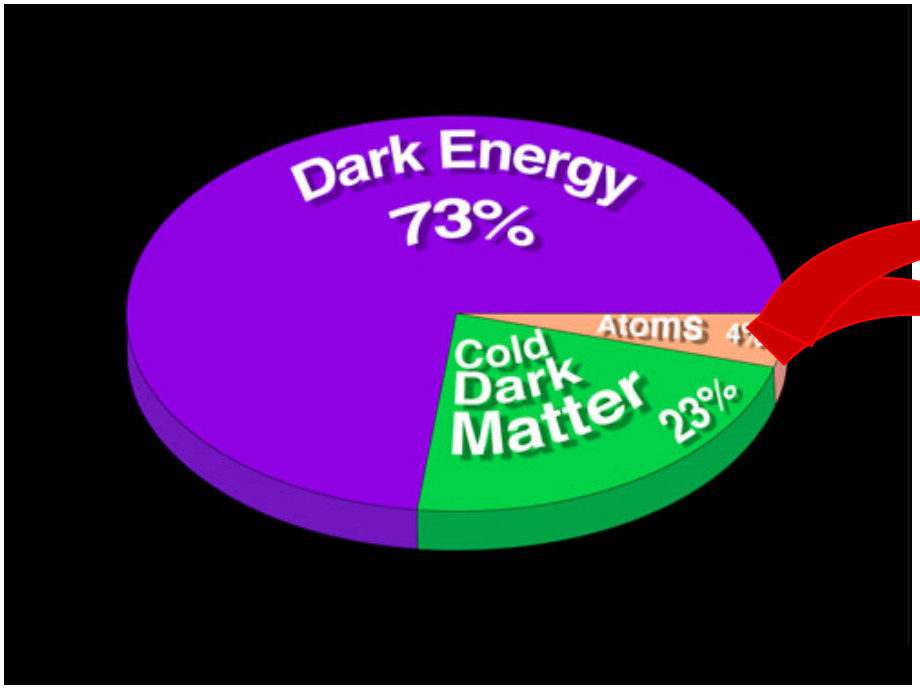




O Universo encontra-se numa expansão acelerada !!!

Energia escura – anti-gravítica

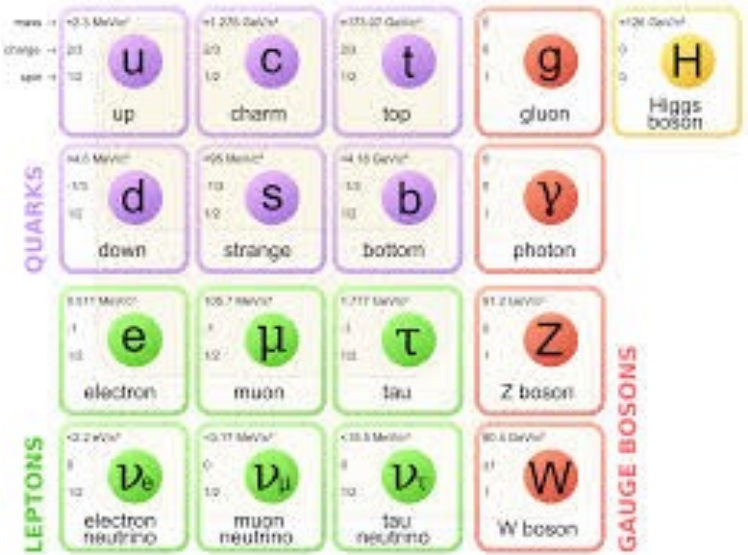
Fronteiras do nosso (des)conhecimento

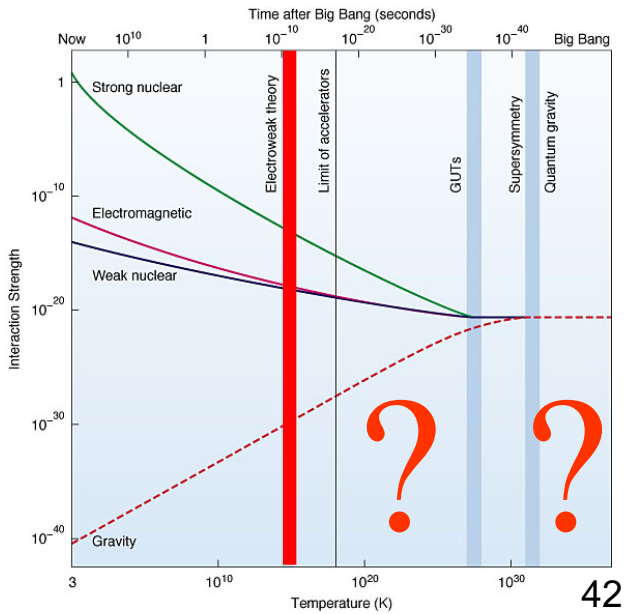


O modelo padrão

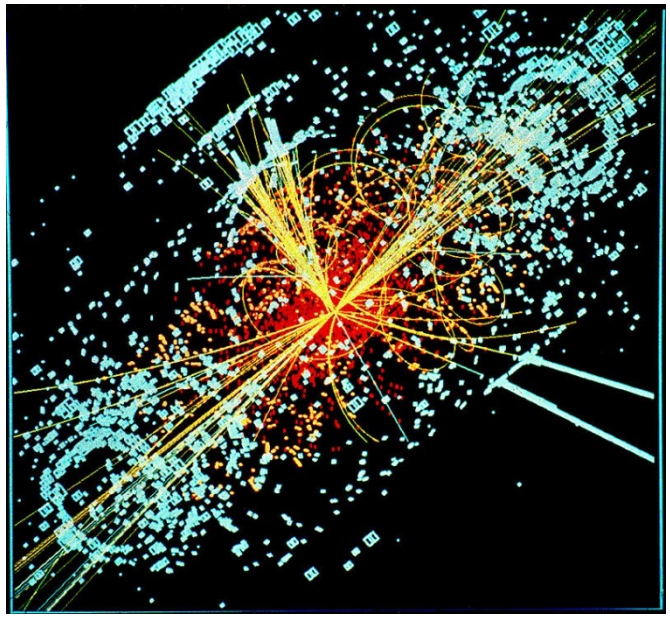
E_{CM} ~ 1 TeV

R ~ 10^{-18} m



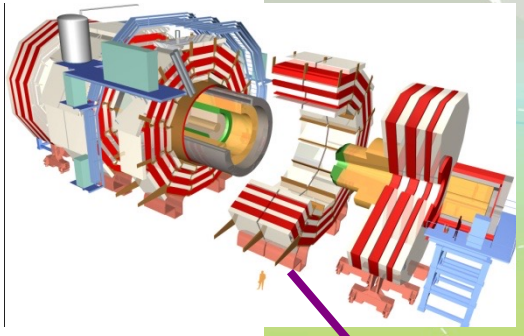


Olhar o Universo no sec. XXI

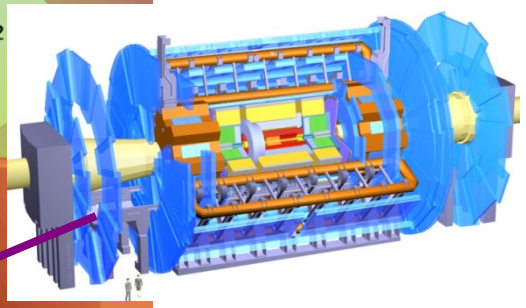


O LHC no CERN

CMS

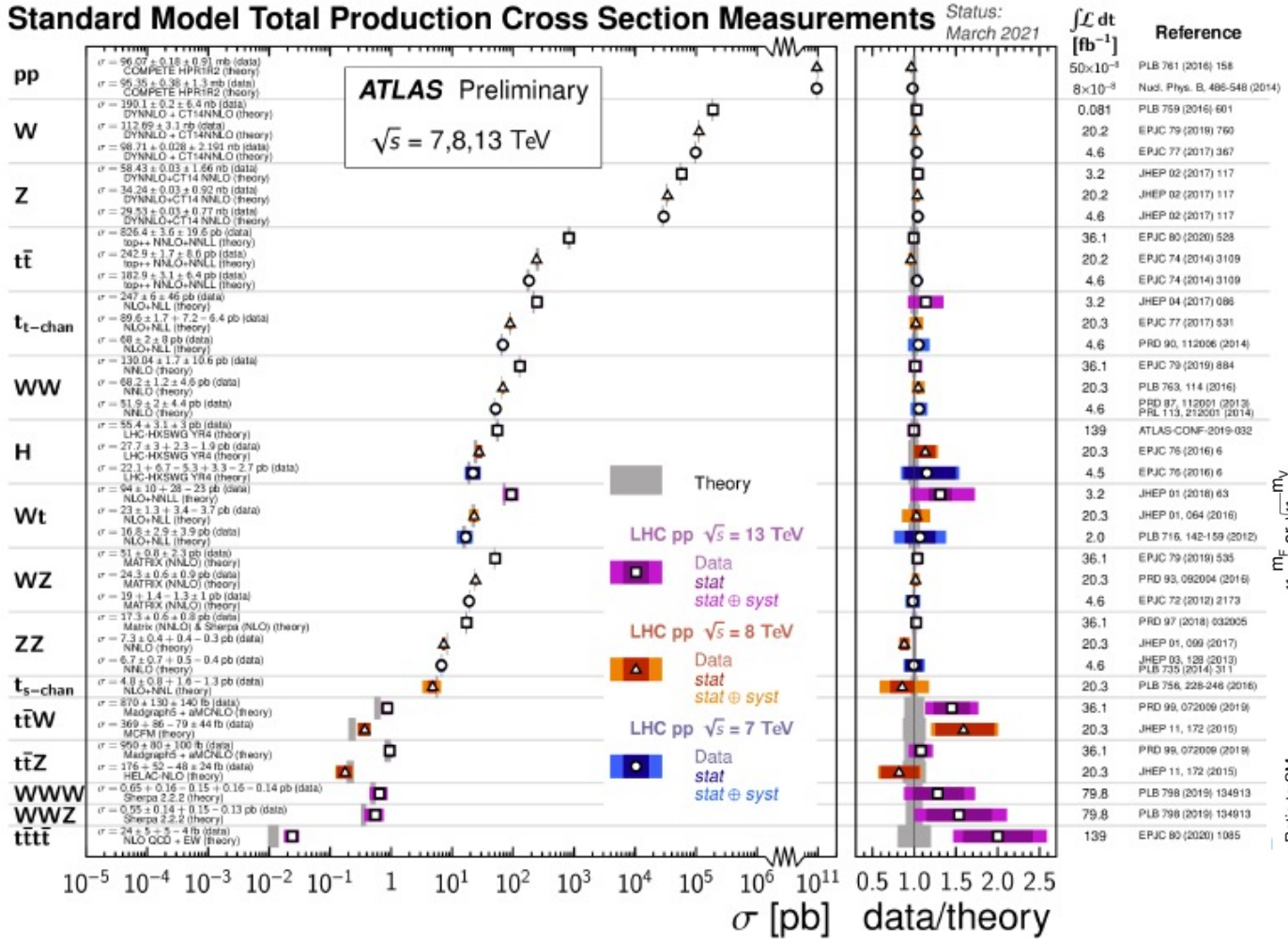


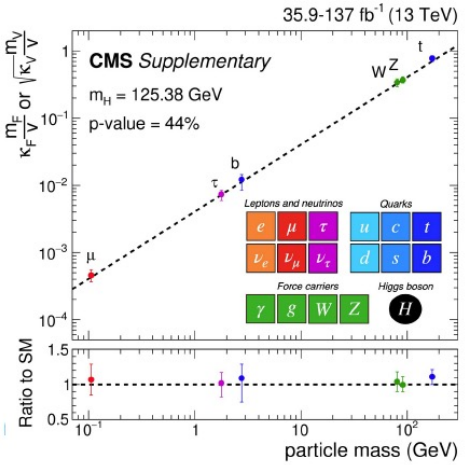
ATLAS



SM (Particle Physics) extensively tested

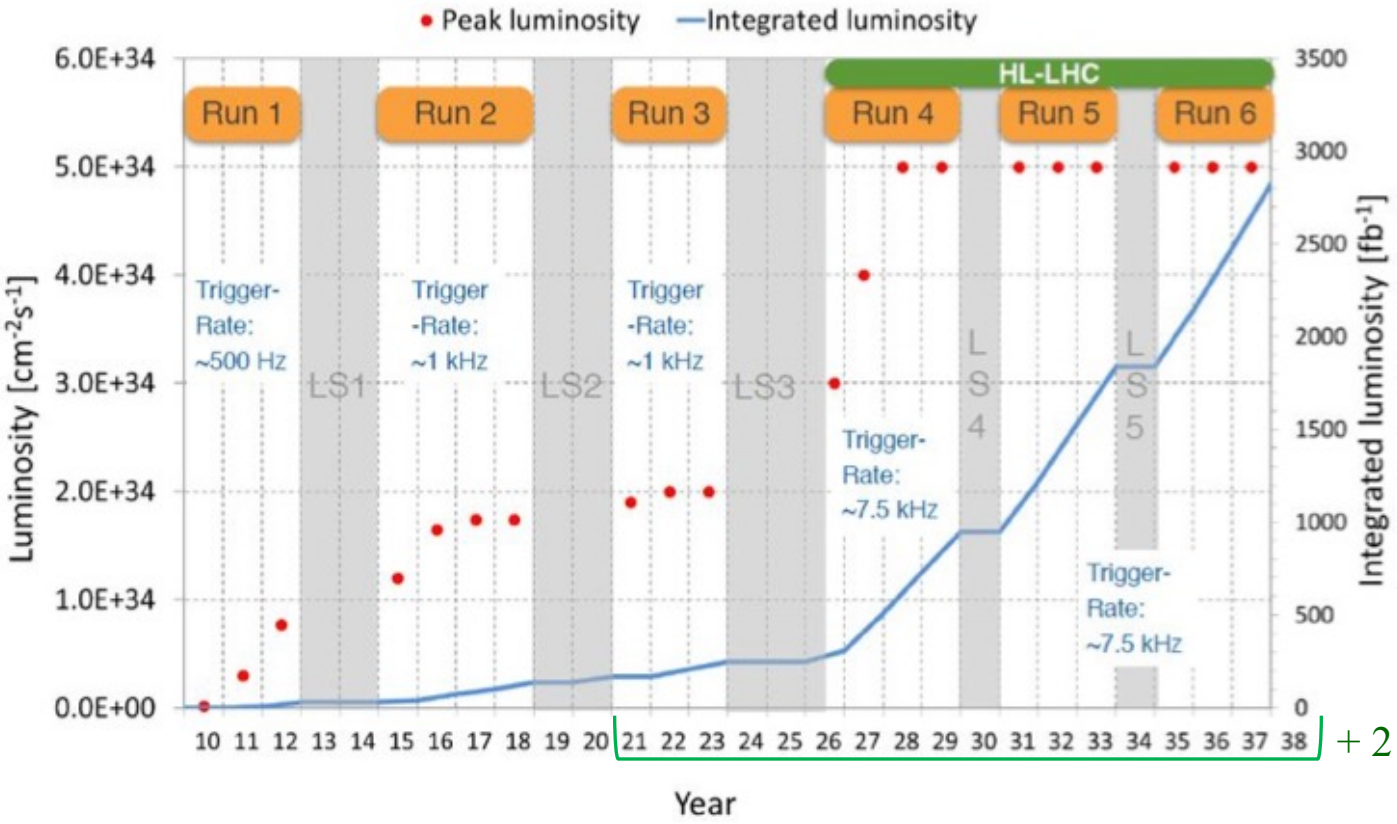
10 years of LHC

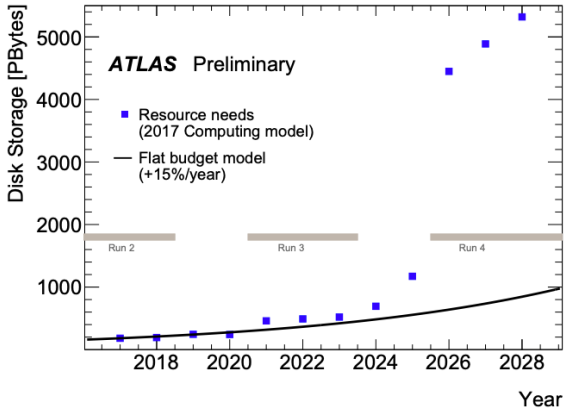


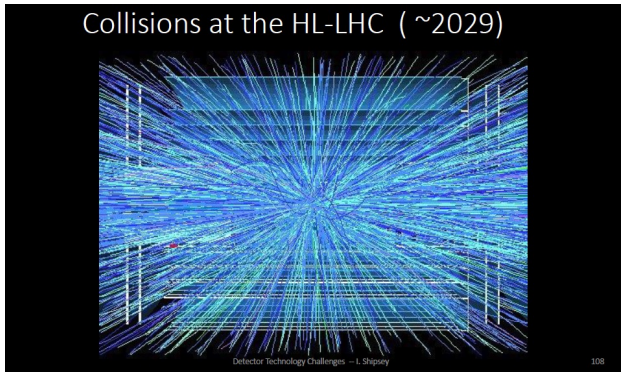


45

O LHC/ HL-LHC


Peak luminosity
Integrated luminosity
HL-LHC
Run 1
Run 2
Run 3
Run 4
Run 5
Run 6
LS1
LS2
LS3
LS4
LS5
Trigger-Rate: ~500 Hz
Trigger-Rate: ~1 kHz
Trigger-Rate: ~1 kHz
Trigger-Rate: ~7.5 kHz
Trigger-Rate: ~7.5 kHz
Luminosity [cm-2s-1]
Integrated luminosity [fb-1]
6.0E+34
5.0E+34
4.0E+34
3.0E+34
2.0E+34
1.0E+34
0.0E+00
3500
3000
2500
2000
1500
1000
500
0
10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38
+ 2
Year


ATLAS Preliminary
Resource needs (2017 Computing model)
Flat budget model (+15%/year)
Run 2
Run 3
Run 4
Disk Storage [PBytes]
5000
4000
3000
2000
1000
2018
2020
2022
2024
2026
2028
Year

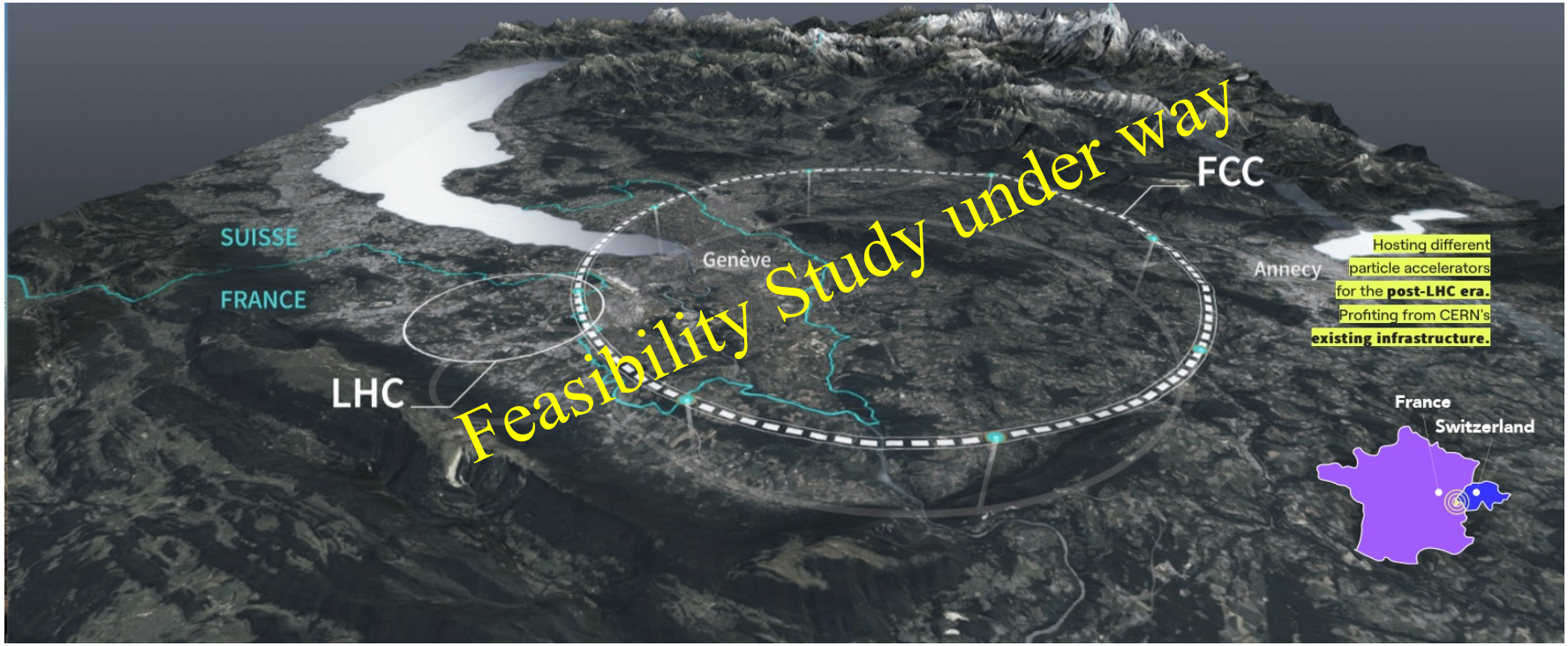

Collisions at the HL-LHC (~2029)

The long-term …

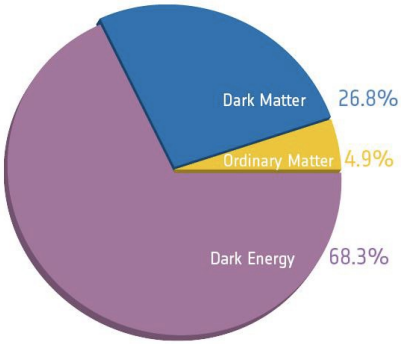
FCC (Future CERN Collider)

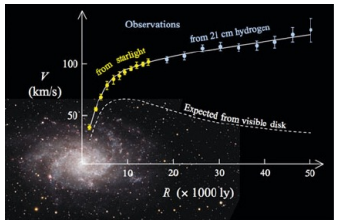
The precision frontier: FCC – ee (Higgs Factory) $\lesssim$ 2040

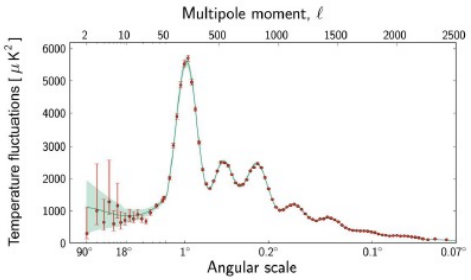
The energy frontier: FCC – pp (100 TeV) $\lesssim$ 2055

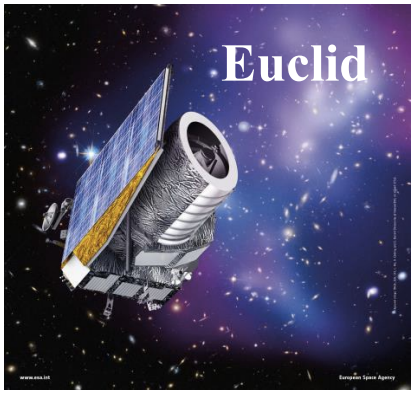


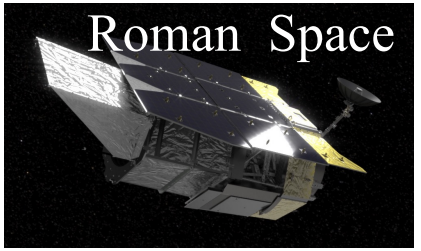
Dark Matter/Dark Energy

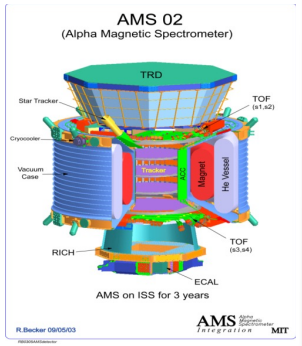


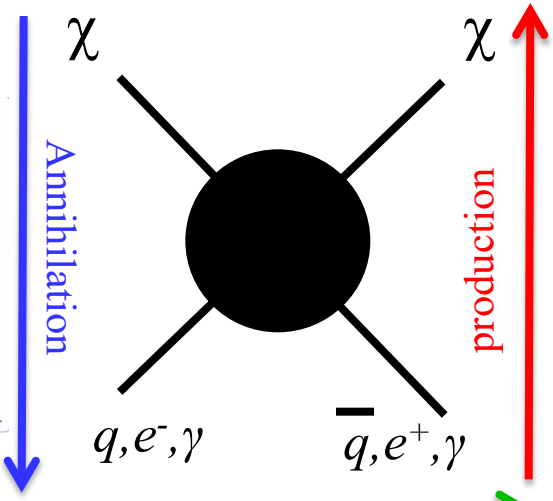




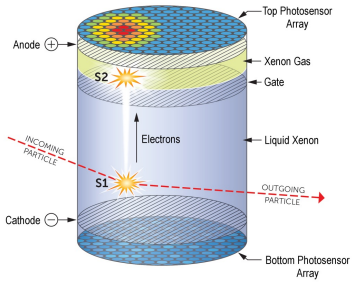




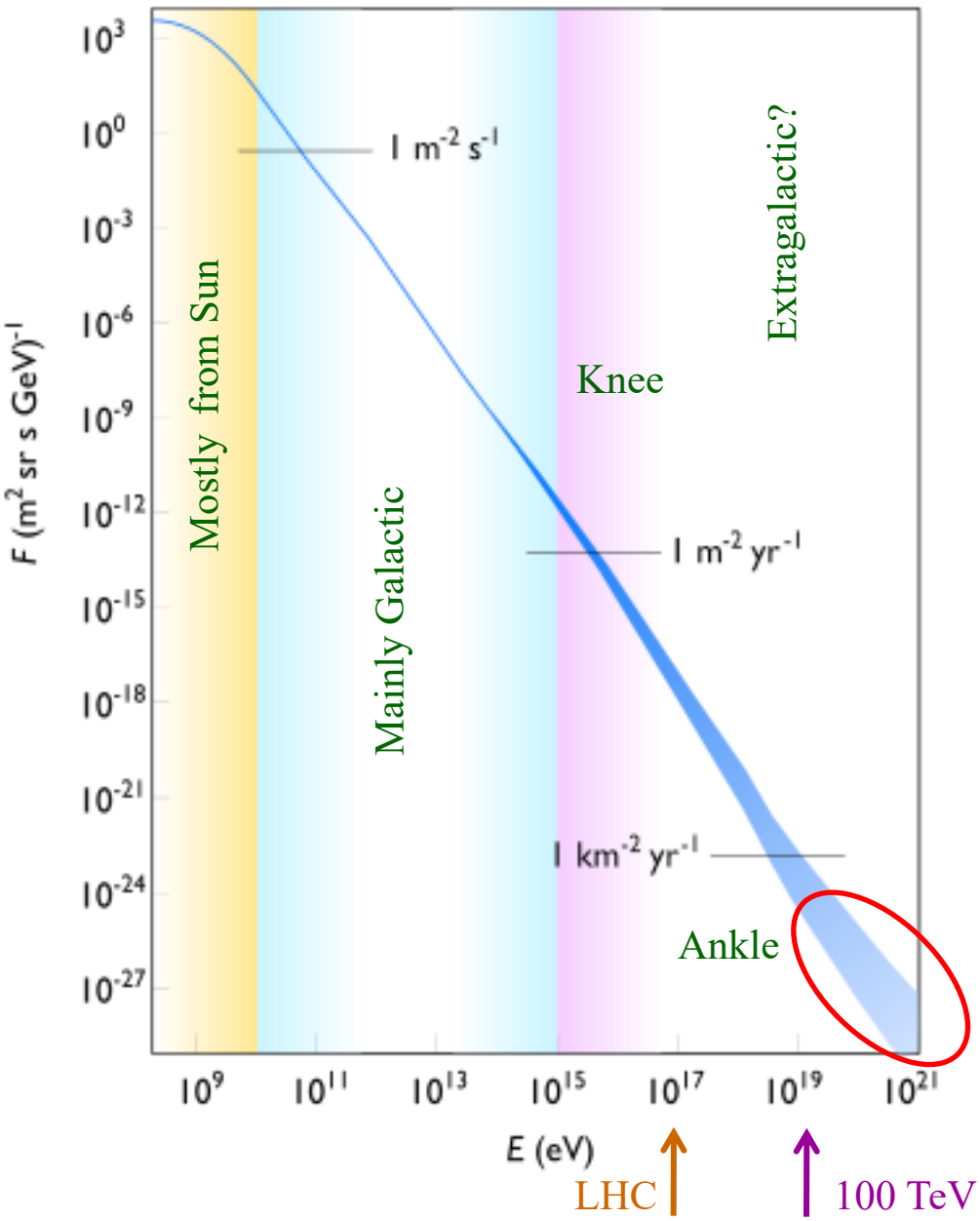




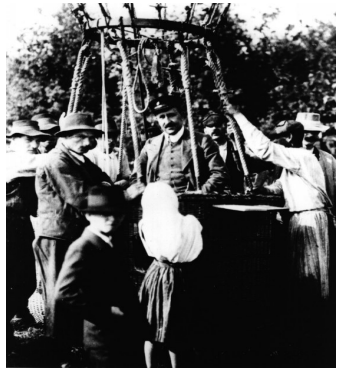
XLZD.
Next DM
experiment

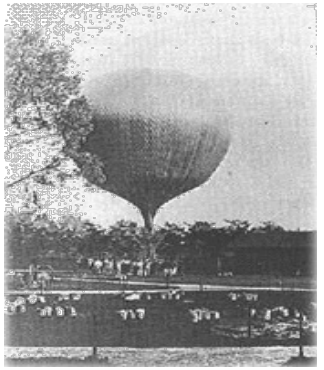


Raios cósmicos carregados



Viktor Hess, 1912



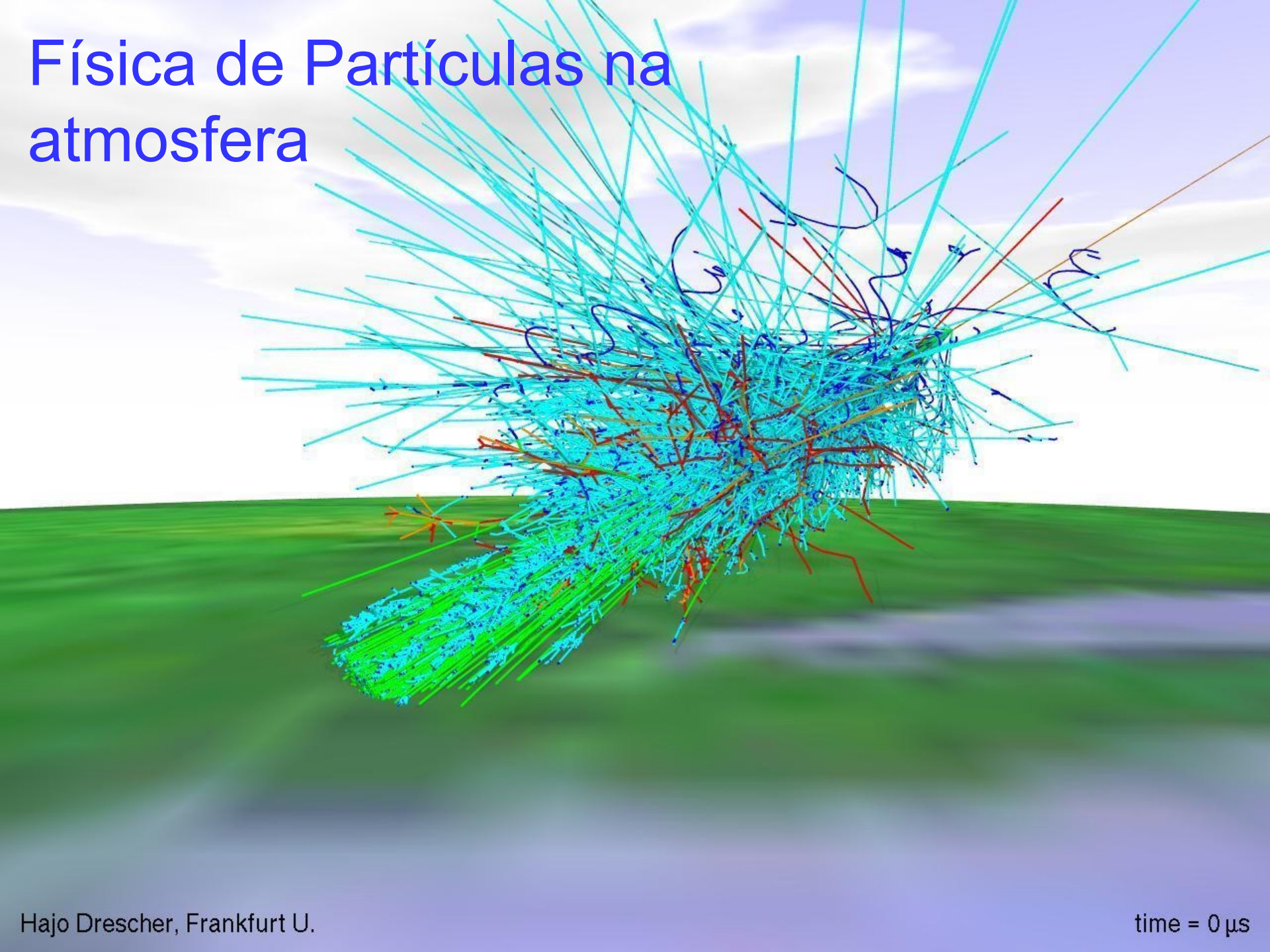


$$\frac{dN}{dE} \propto E^{-\alpha}$$

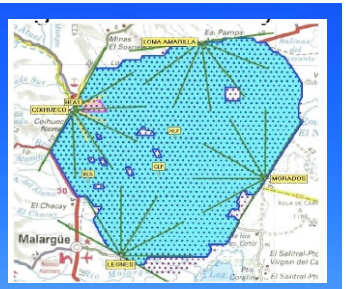
$$\alpha = \begin{cases} 2.7 & E < 10^{16} \\ 3.0 & 10^{16} < E < 10^{18} \\ 2.7? & E > 10^{18} \end{cases}$$

Um LHC do tamanho da órbita de Mercúrio !!!

Física de Partículas na atmosfera



Na pampa argentina

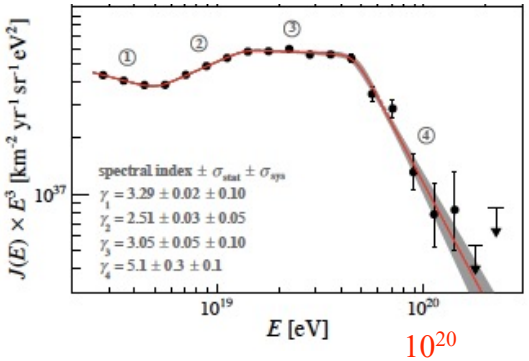


Ultra High Energy Cosmic Rays (UHECR)

Present

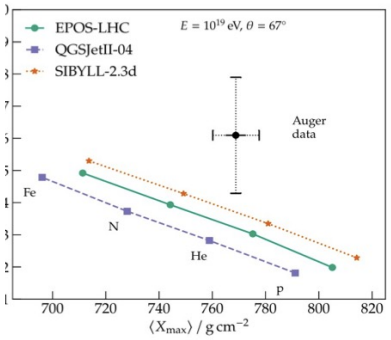
Pierre Auger Observatory

Energy spectrum



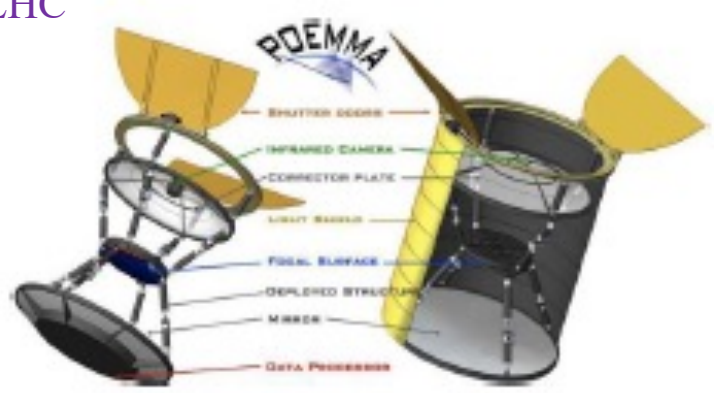
10^{20}

Muons …



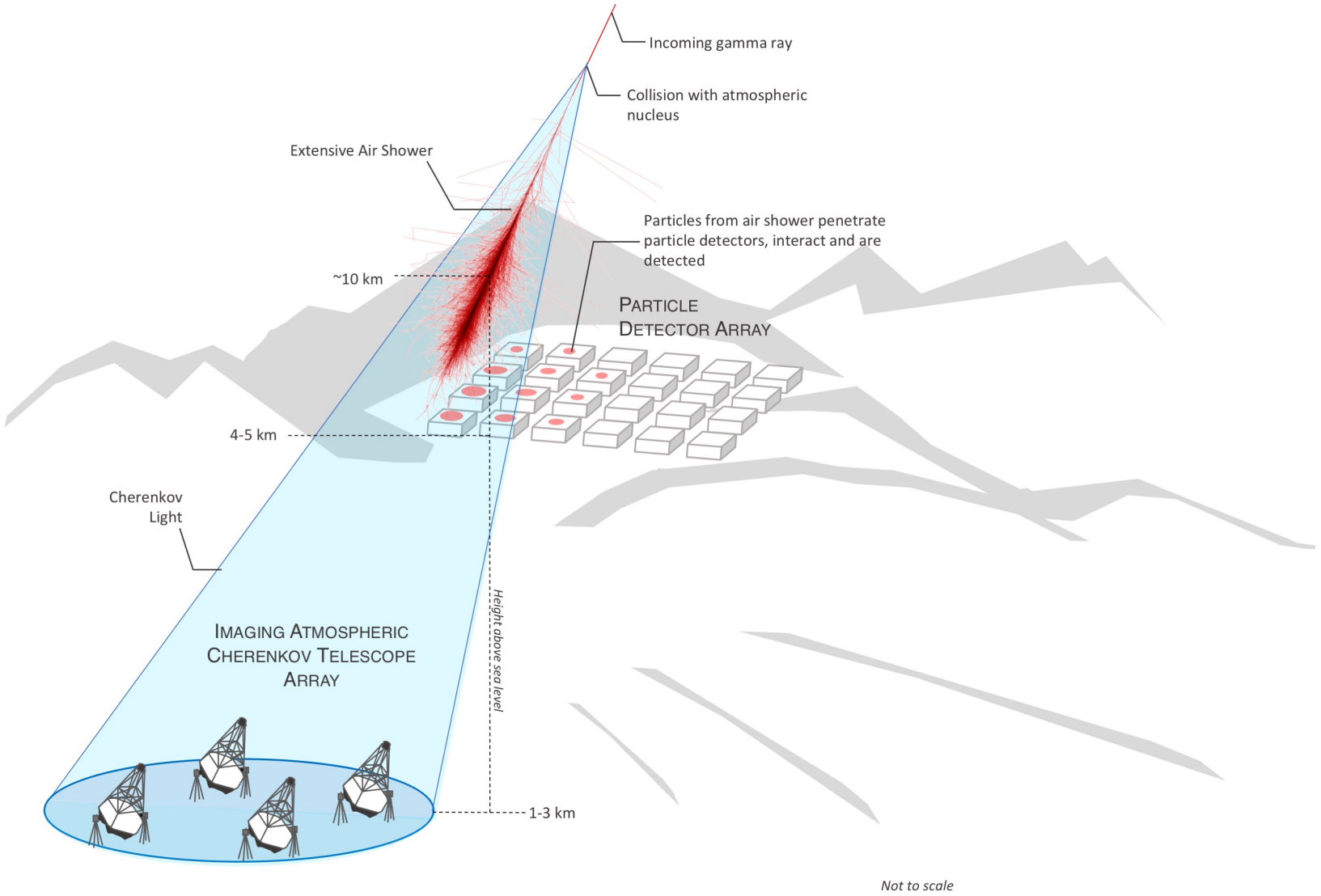
Future

HL-LHC



GRAND

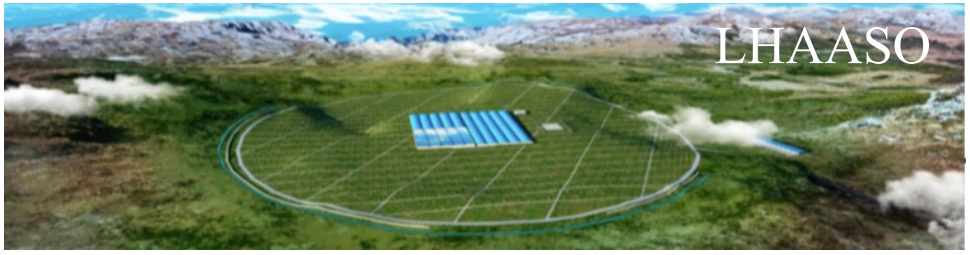
Detectar fotões no alto das montanhas ..

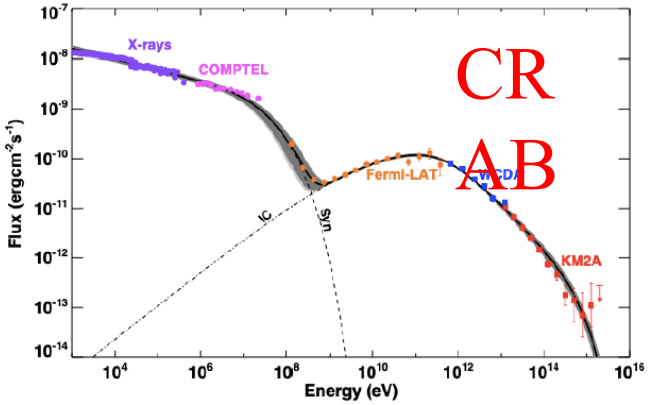


High Energy Gamma Rays

Just a few examples

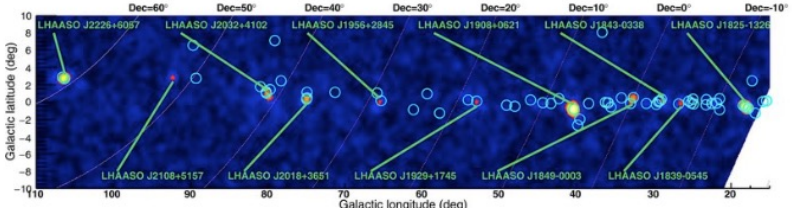
Present



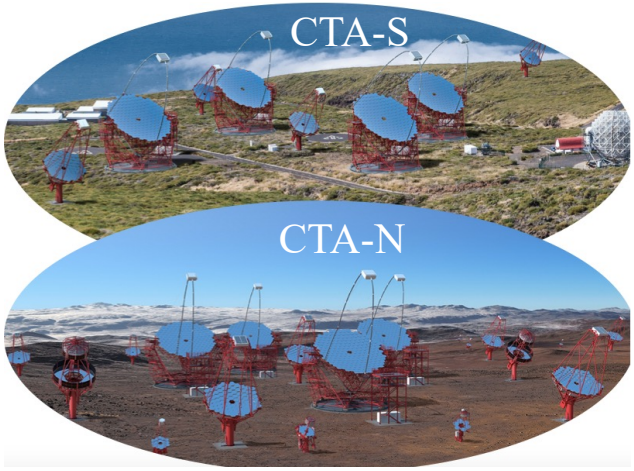


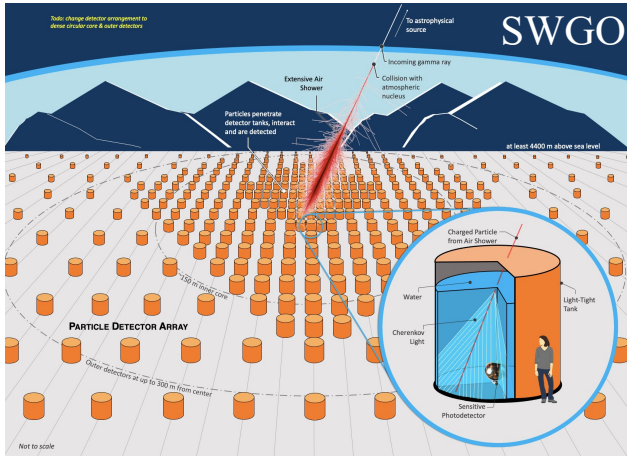
10^{15} eV

12 Pevatron sources

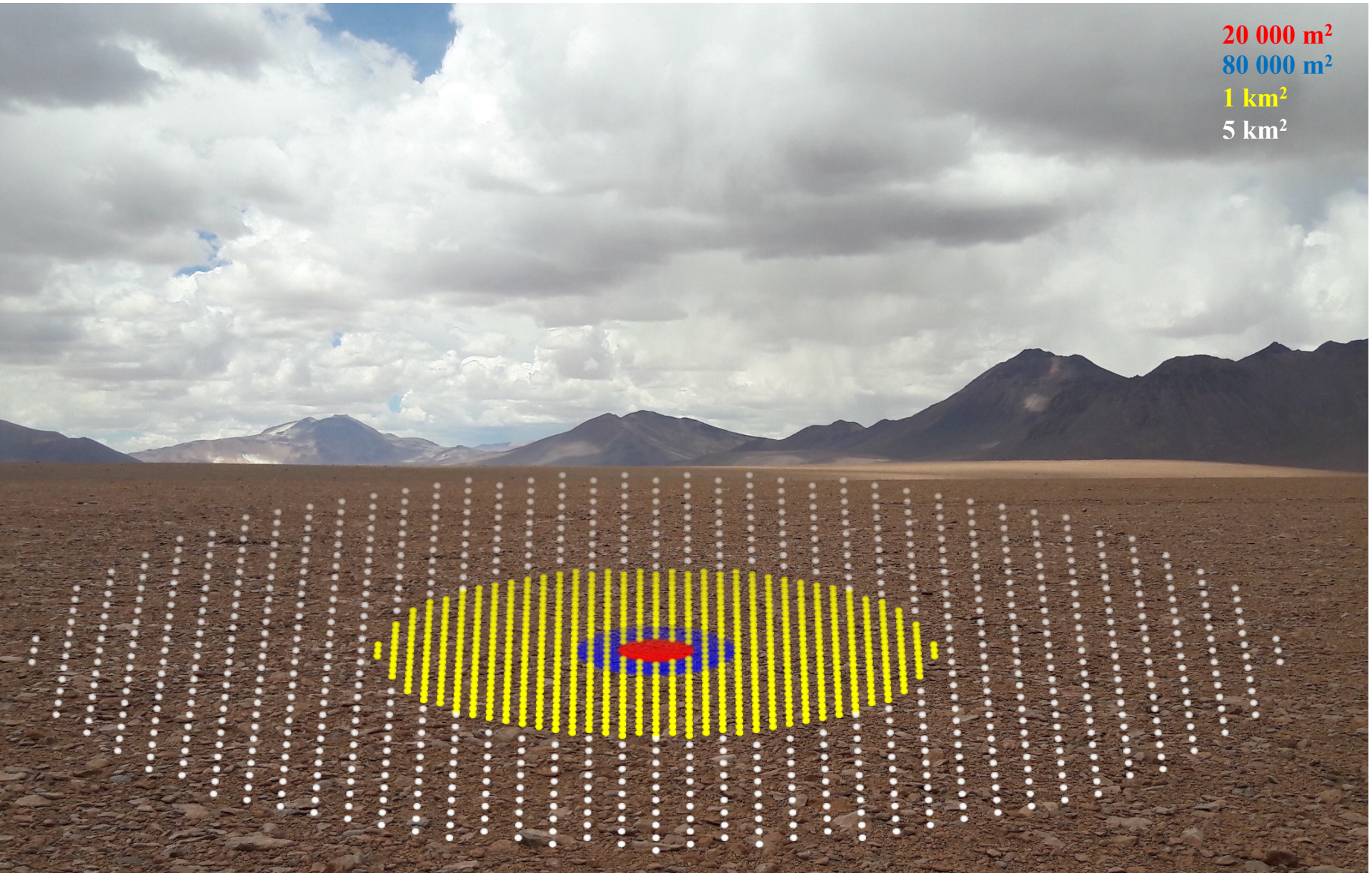


Future





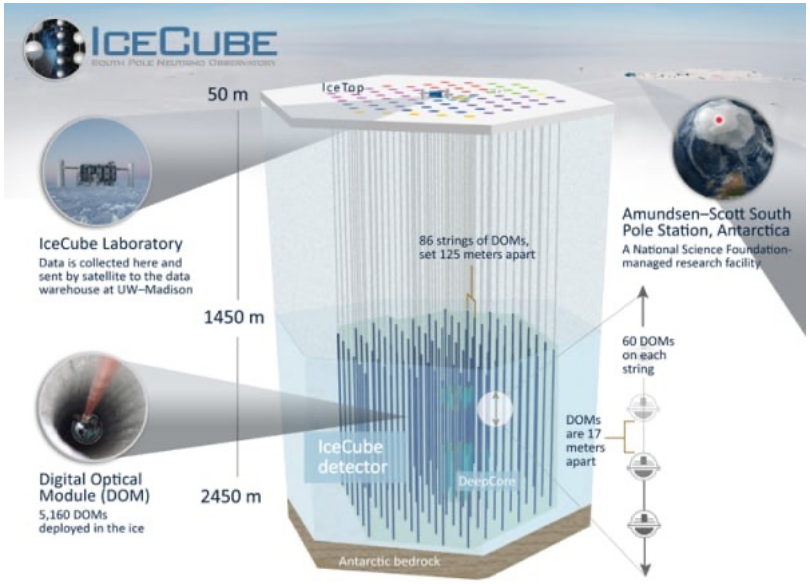
Olhar para o centro da galáxia e para o Universo a 4500-5000 m de altitude na América do Sul com um detector de fotões energéticos



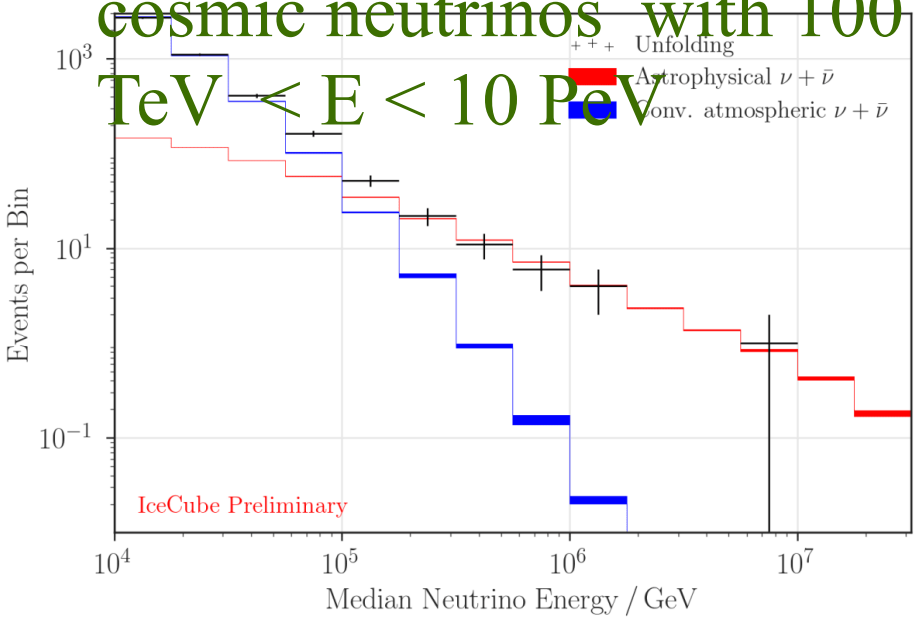
Astrophysical neutrinos

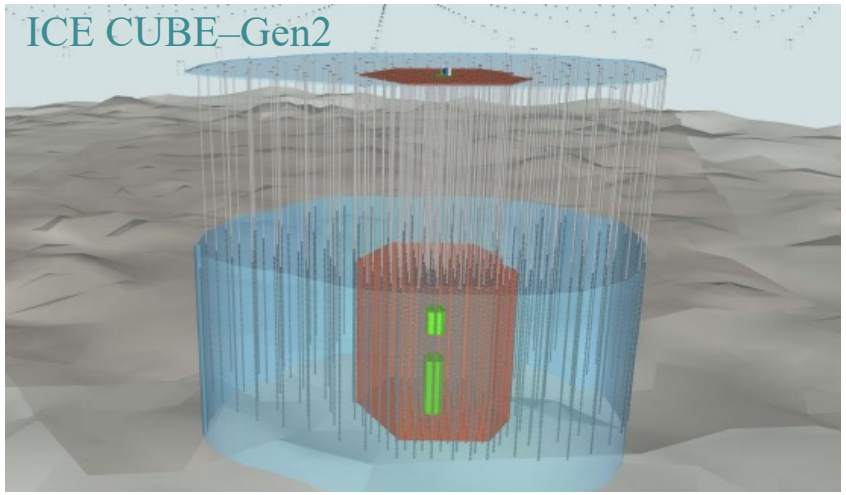
7/10/2023: Francis Halzen@IST

ICE CUBE

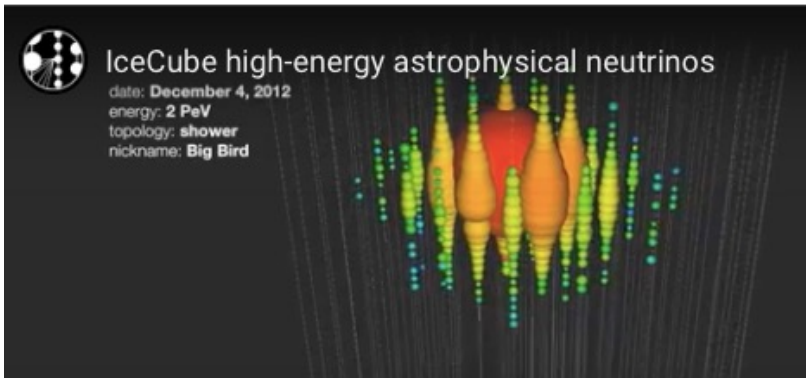


More than 100 high-energy cosmic neutrinos with 100 TeV < E < 10 PeV

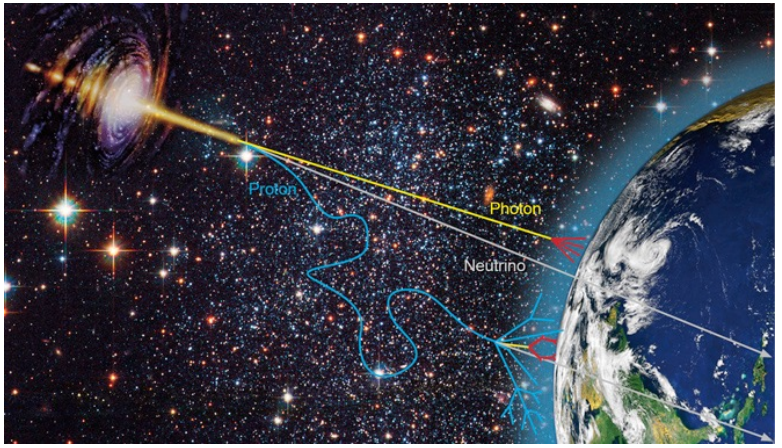




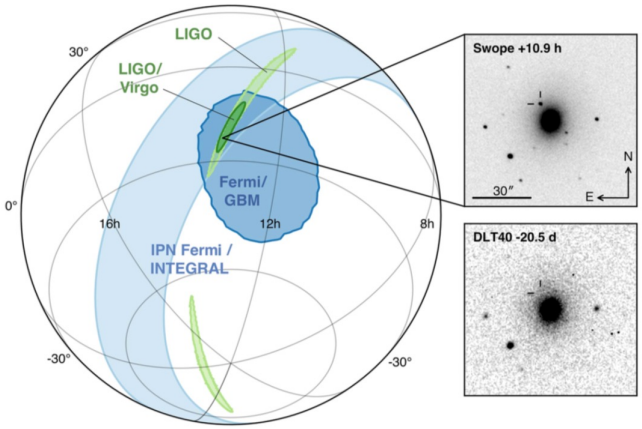
2 PeV



The Multi-messenger Era



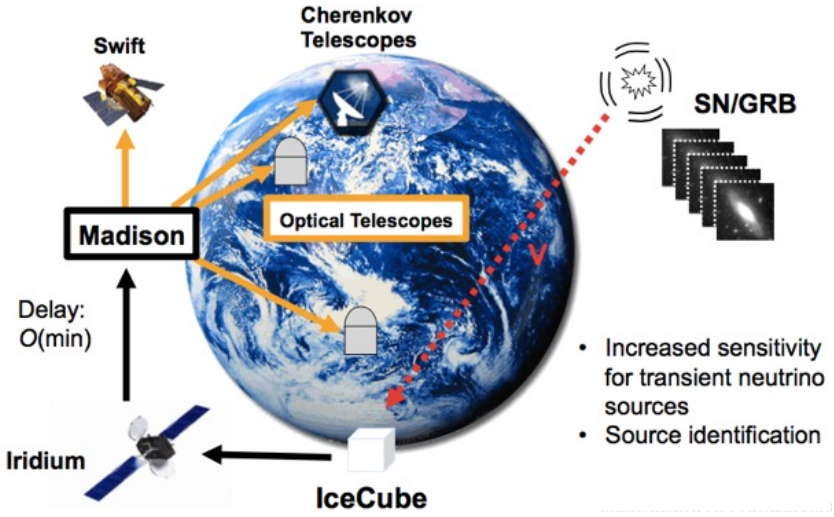
GW170817



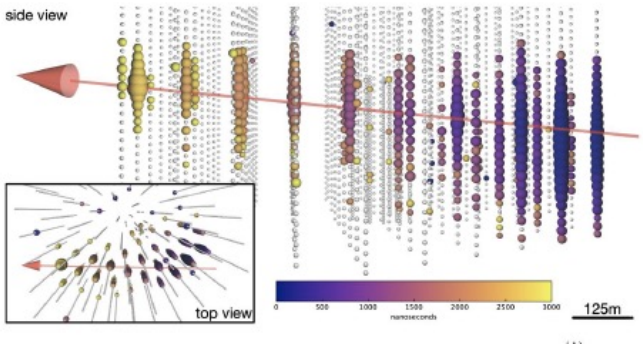
physicsworld
BREAKTHROUGH OF THE YEAR
2017

First multi-messenger discovery of a binary neutron star merger

γ-ray blazar TXS 0506+056

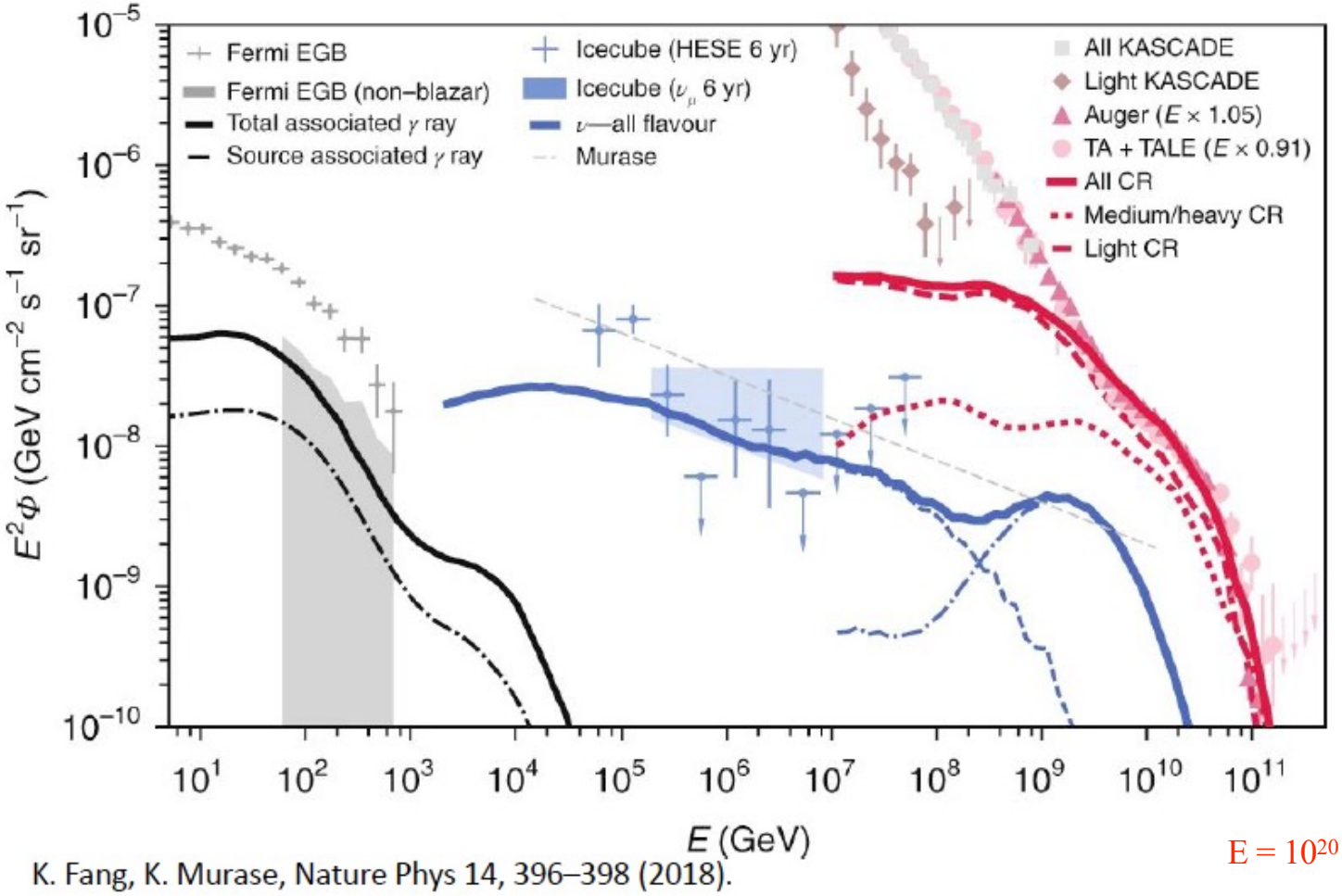


First simultaneous observation of very high energy neutrino and of electromagnetic waves



ICE Cube muon

The Universe at the highest energies



K. Fang, K. Murase, Nature Phys 14, 396–398 (2018).

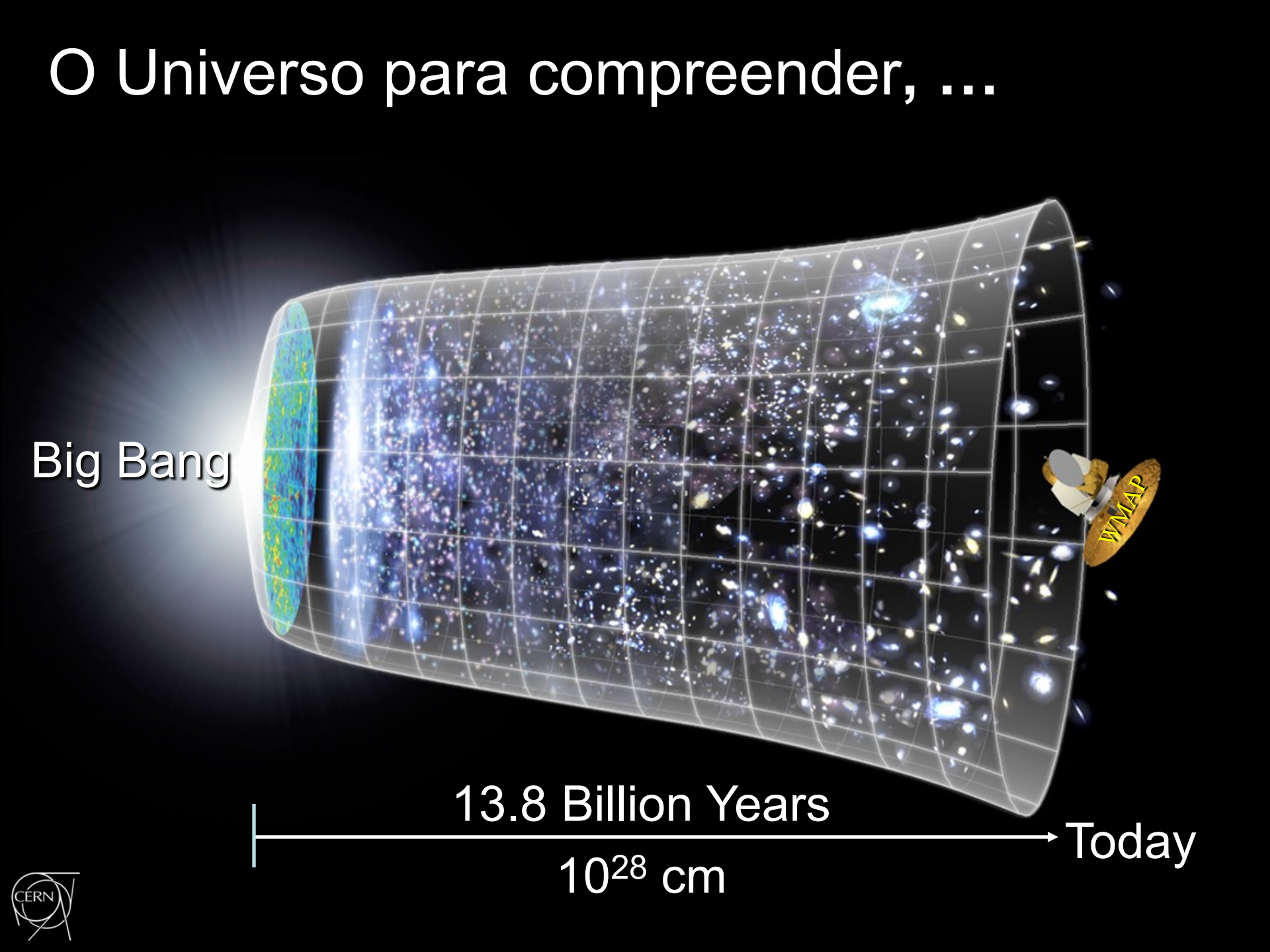
$E = 10^{20}$ eV

The energy density per decade is similar in all the three messenger particles

$$E^2 \frac{dN}{dE} = E \frac{dN}{d\ln E}$$

$$\rho_{\text{decade}} = \int_{\text{decade}} E \frac{dN}{d\ln E} \, d\ln E$$

O Universo para compreender, ...

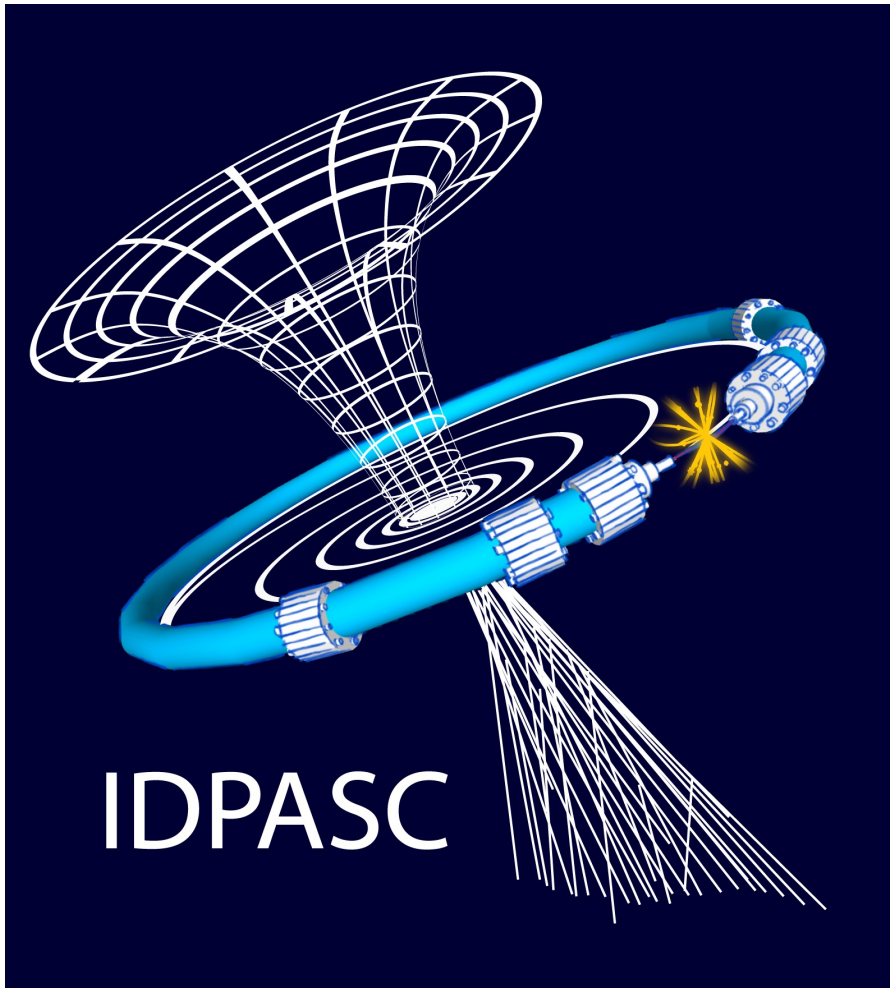


Many open questions

- What is the origin of the masses and mixing parameters?
- How quarks and gluons interact to form nuclei?
- Why matter dominates (locally…) over anti-matter?
- What is dark matter made of?
- What is the nature of Dark Energy?
- What is the complexity of the Higgs Field sector?
- How inflation started and stopped?
- How to couple GR and QM?
- What is the origin of the highest energy cosmic rays?
- ….
- ….
- ….

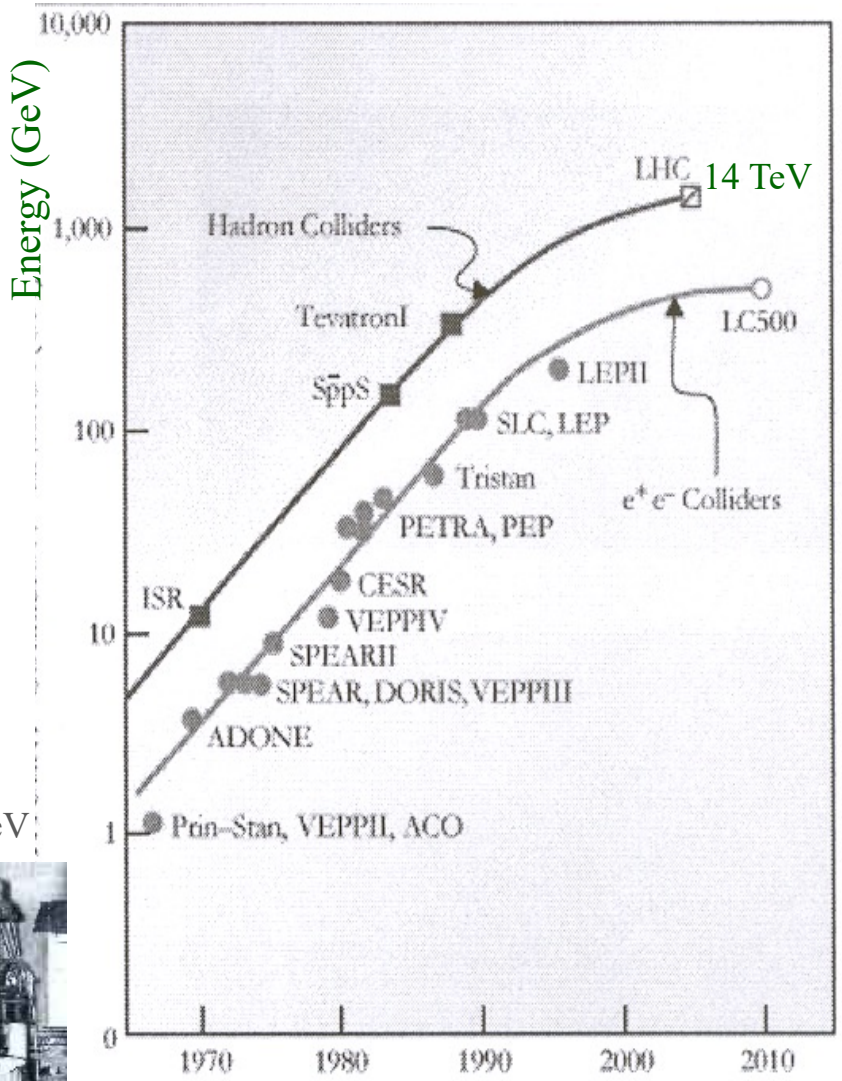
Frontiers of Energy

Frontiers of Precision



International Doctorate Network in Particle Physics, Astrophysics and Cosmology

Accelerators

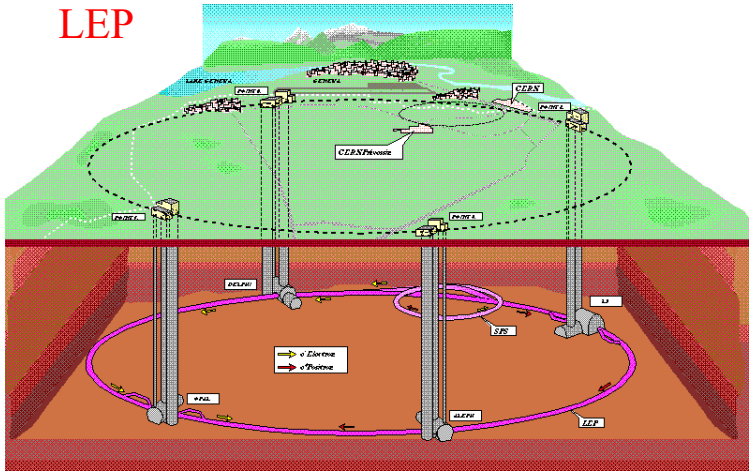


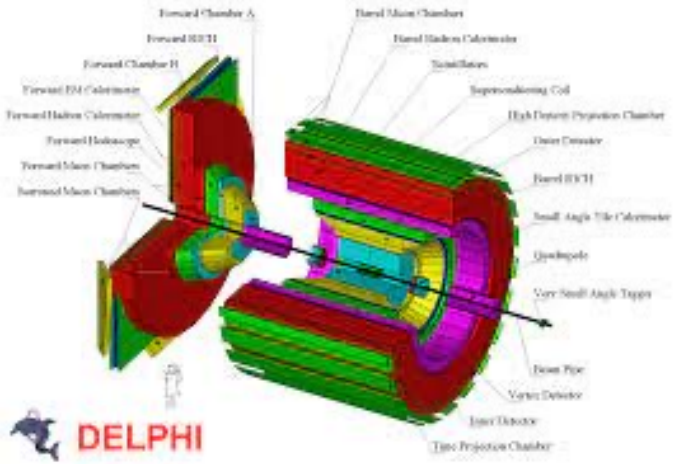
Year of completion

~ 10 MeV

~1930

LEP

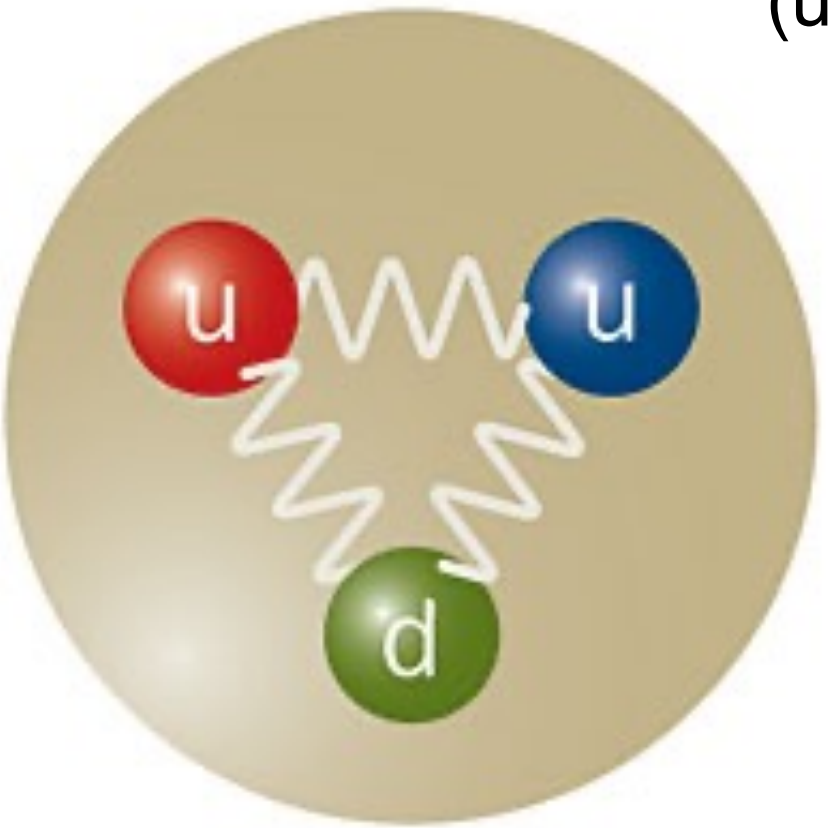




high Luminosity, sophisticated detectors

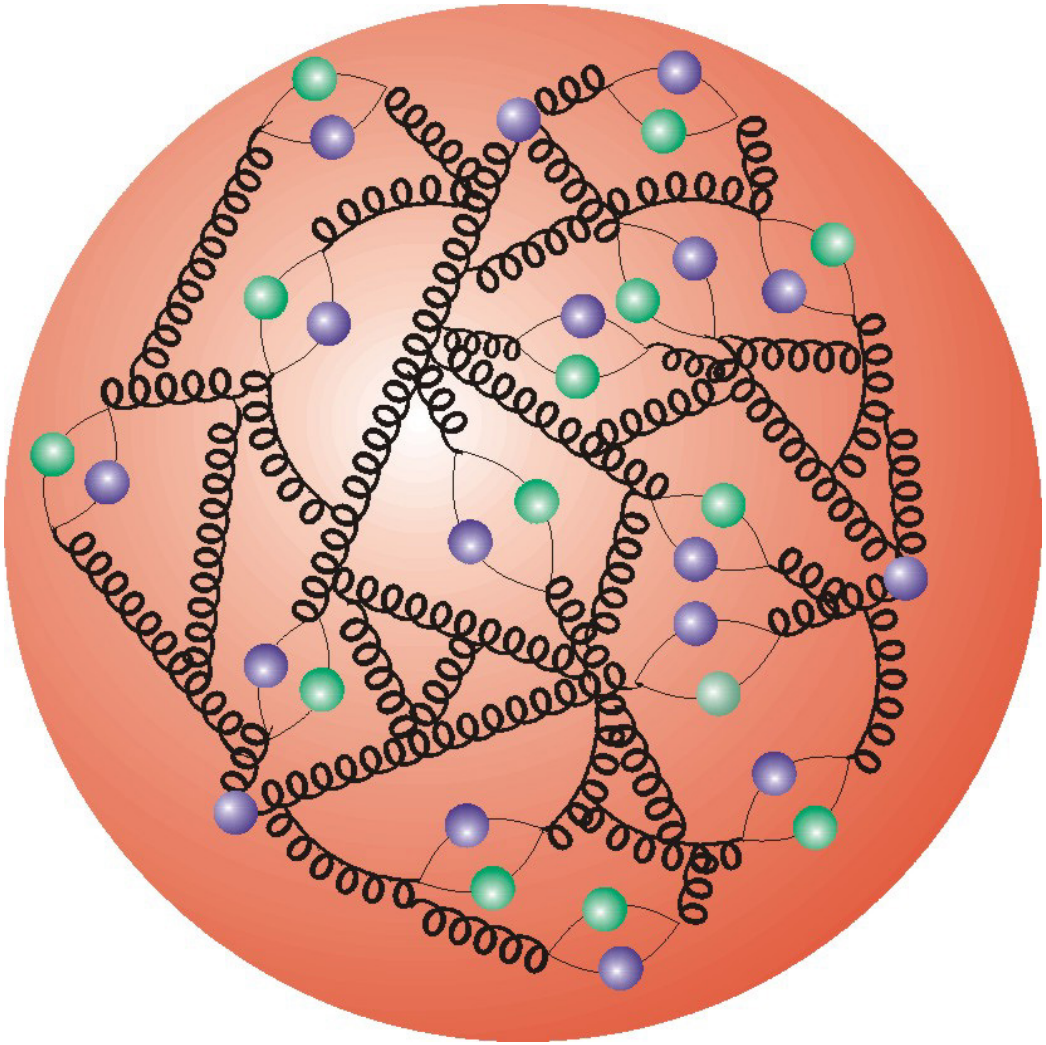
O Protão

(uud)



10^{-14} m

O Protão



A massa do Protão

$$M = \sum m_{quarks} + E_{campo}/c^2$$

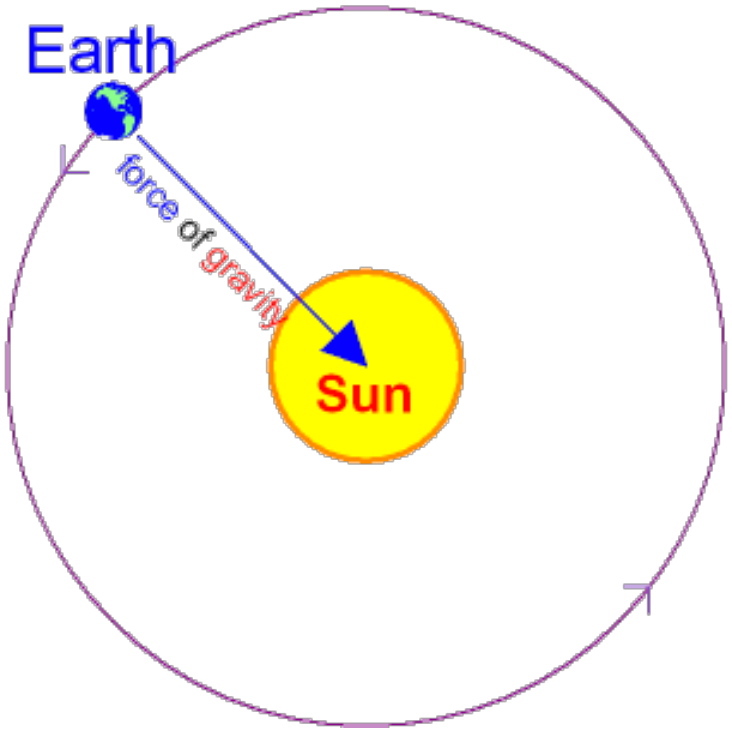
A massa do Protão

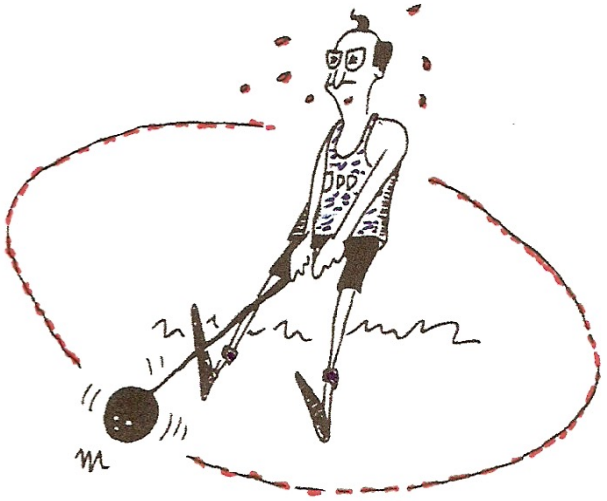
$$M = \sum m_{quarks} + E_{campo}/c^2$$

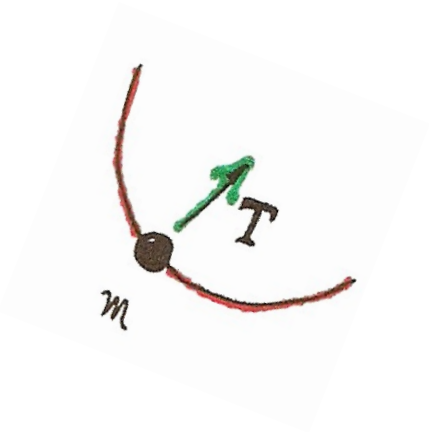
$$938 \sim (\quad 15 \quad + \quad 925)\ MeV/c^2$$

$$1\ MeV/c^2 \sim 1.8\ 10^{-30} Kg$$

A massa do Sol





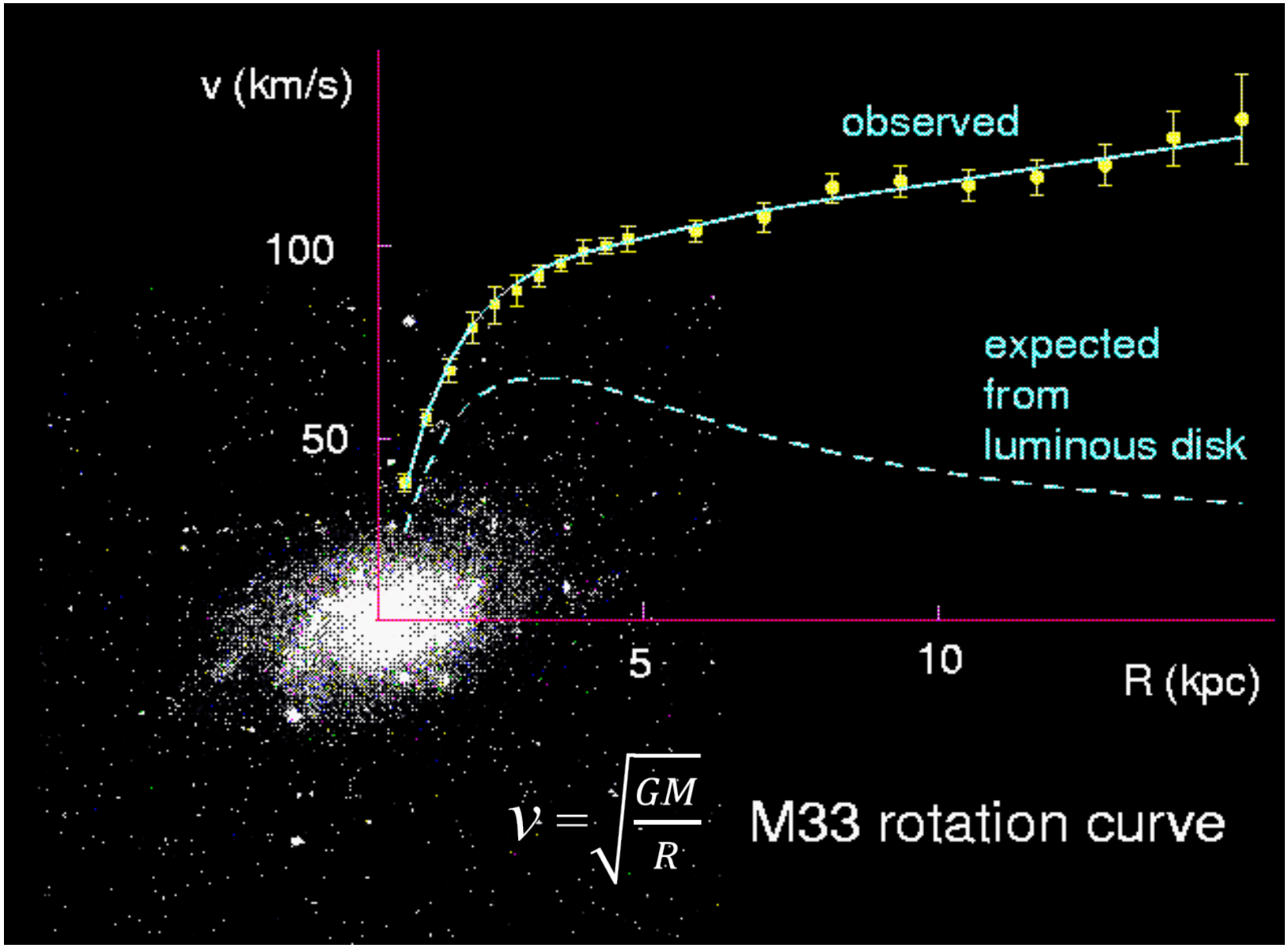


$$F_c = \frac{m\ v^2}{r}$$

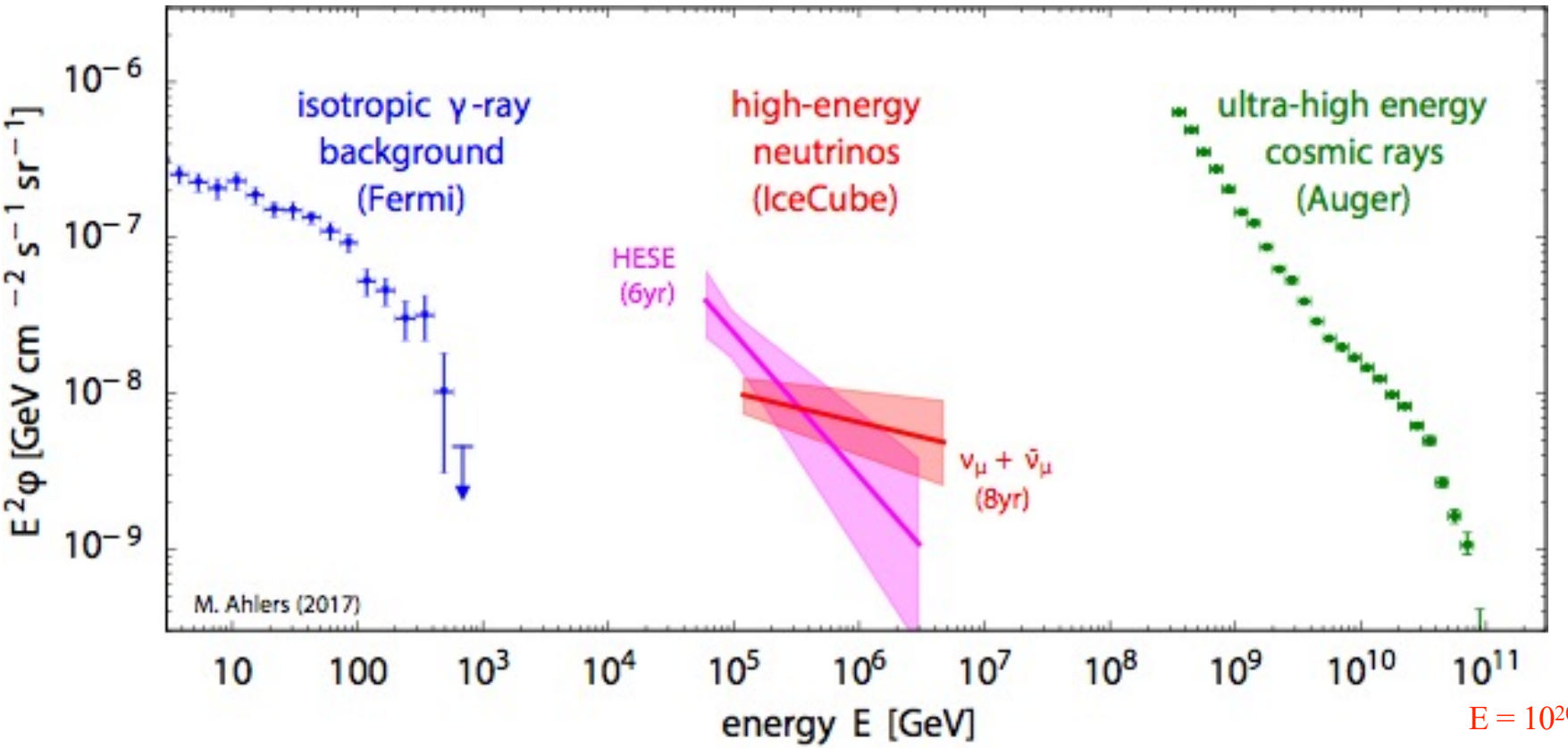
$$\frac{m_T\ v^2}{R} \approx G\ \frac{m_T\ M_S}{R^2}$$

$$M_S \sim 1.98\ 10^{30}\ kg$$

A velocidade de rotação das estrelas periféricas

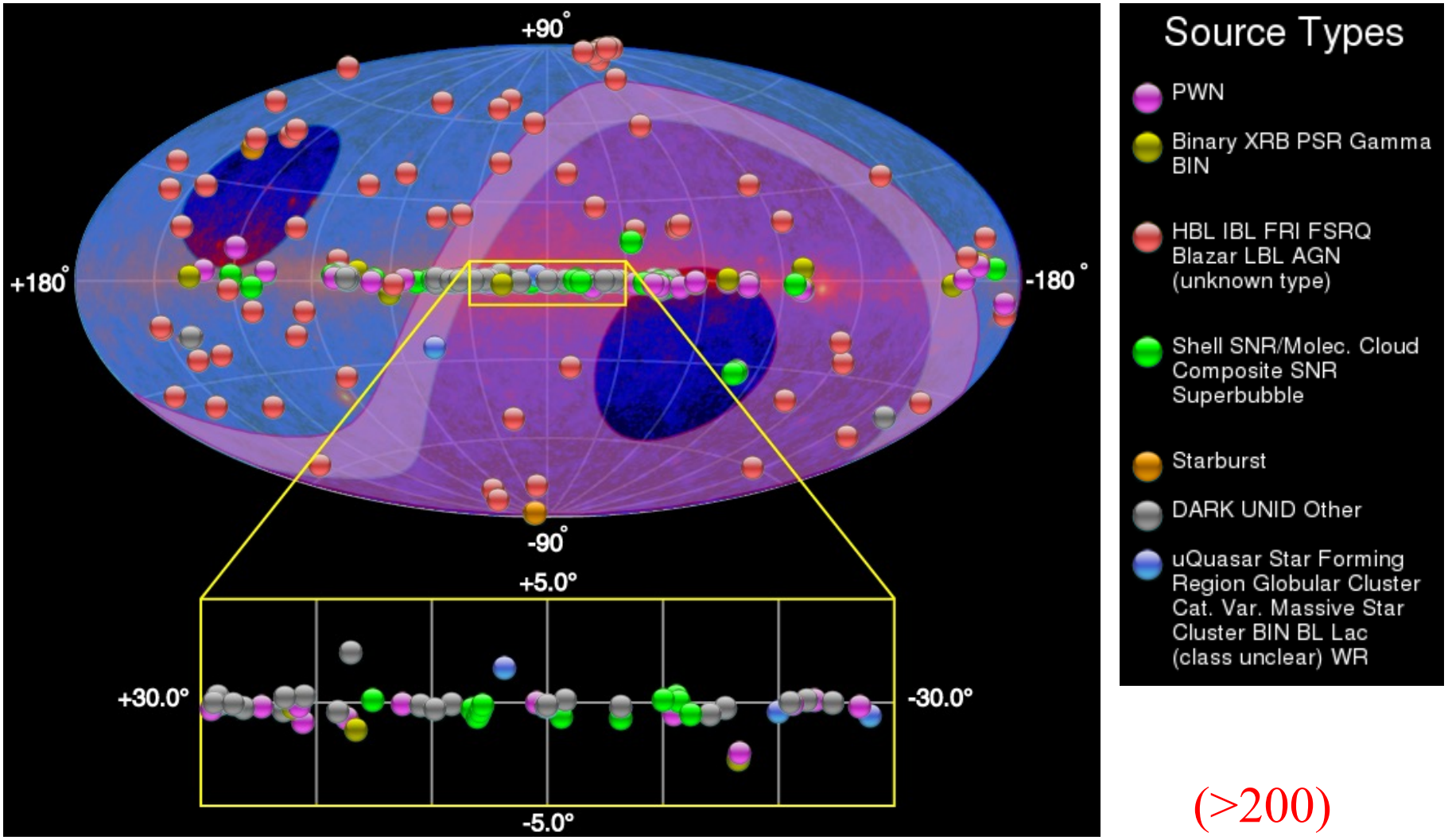


The Universe at the highest energies !



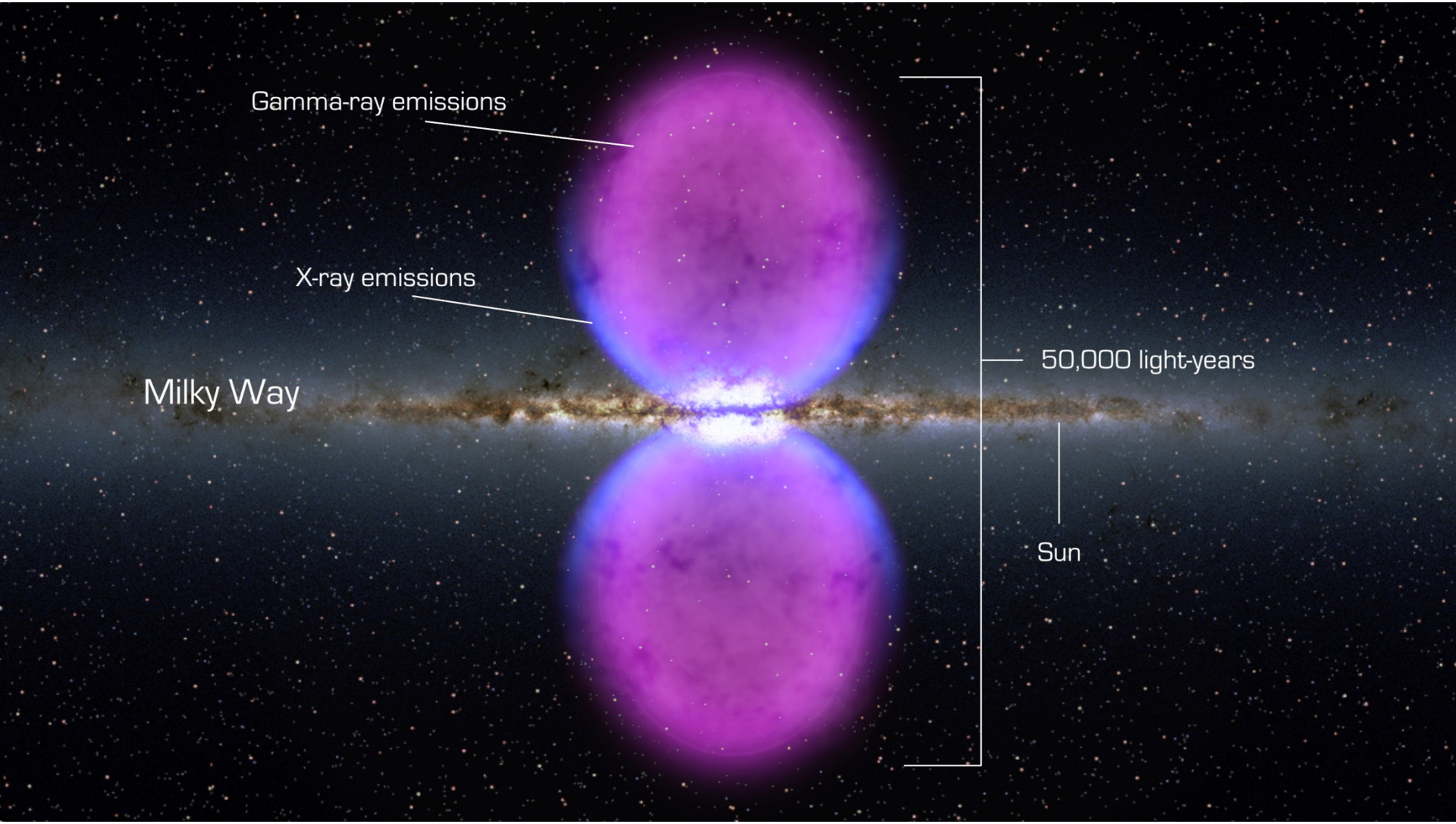
Energy density per decade similar in all three messenger particles

Fontes raios gamma de alta energia (TeV)



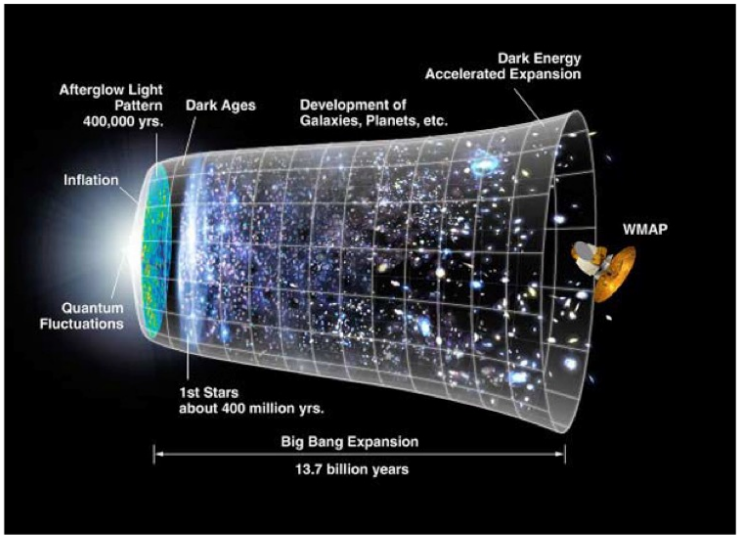
(>200)

As bolhas de Fermi



The Big Bang

Expansion and cooling



Big Bang Expansion Source - WMAP