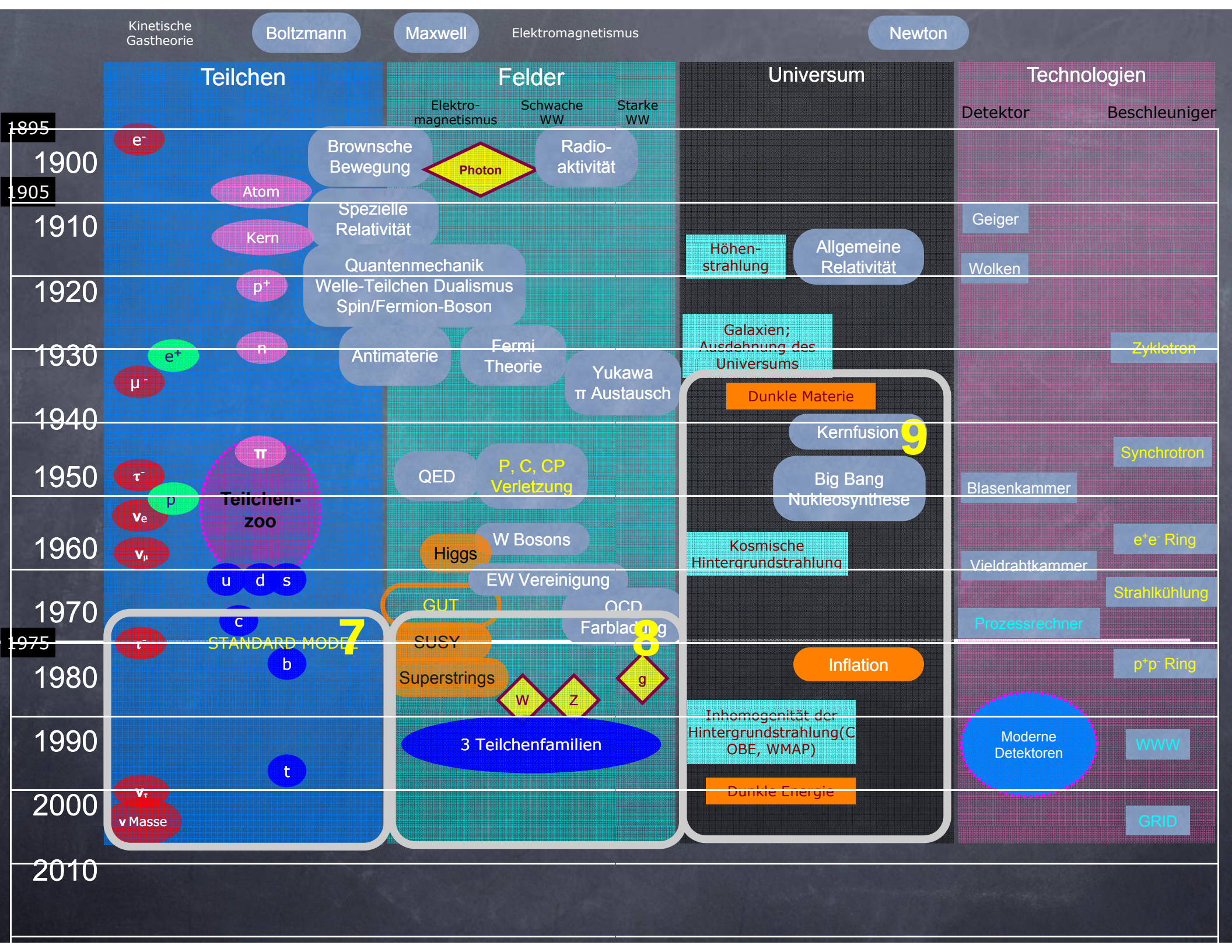
Kinetische Gastheorie
Boltzmann
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Elektromagnetismus
Newton
Teilchen
Felder
Elektro-magnetismus
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Fermi Theorie
Yukawa π Austausch
Höhen-strahlung
Allgemeine Relativität
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Galaxien; Ausdehnung des Universums
Zyklotron
Dunkle Materie
Kernfusion
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QED
P, C, CP Verletzung
Big Bang Nukleosynthese
Synchrotron
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W Bosons
Higgs
Kosmische Hintergrundstrahlung
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Inflation
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Z
Inhomogenität der Hintergrundstrahlung(COBE, WMAP)
Moderne Detektoren
WWW
3 Teilchenfamilien
t
Dunkle Energie
νT
ν Masse
GRID

TEILCHENSPEKTRUM

Gerade war das Standard-Modell mit zwei Familien von Leptonen und Quarks etabliert ...

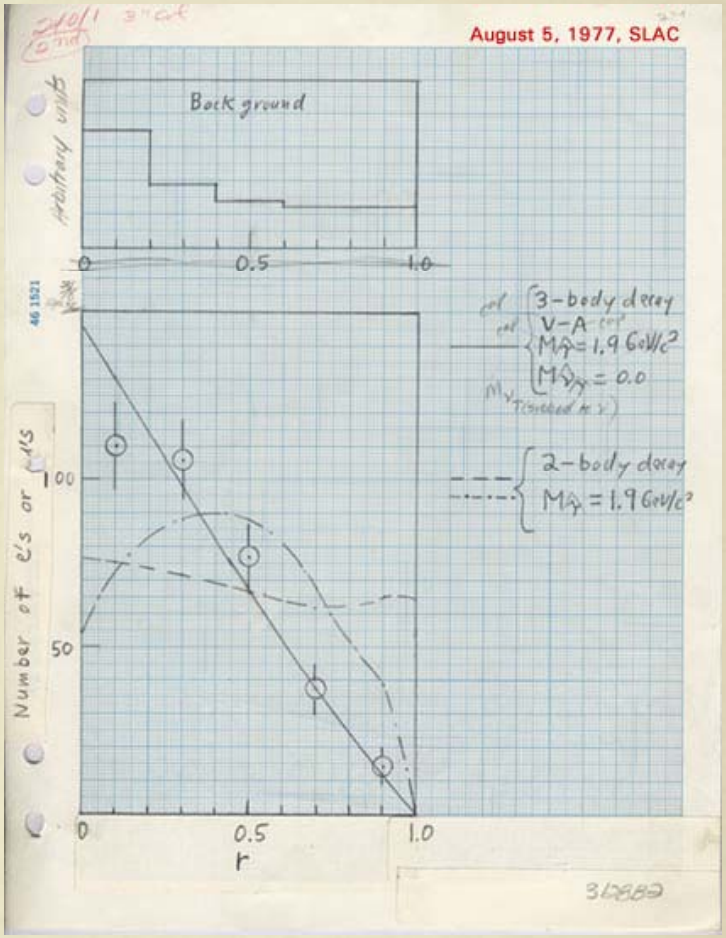
...da fand man am SLAC ein drittes Lepton!

Ein neues 'schweres Elektron' mit M= 3500 m_e

... und wer hatte das bestellt?

MIT DER NEUEN LOGIK DER LEPTON-QUARK SYMMETRIE

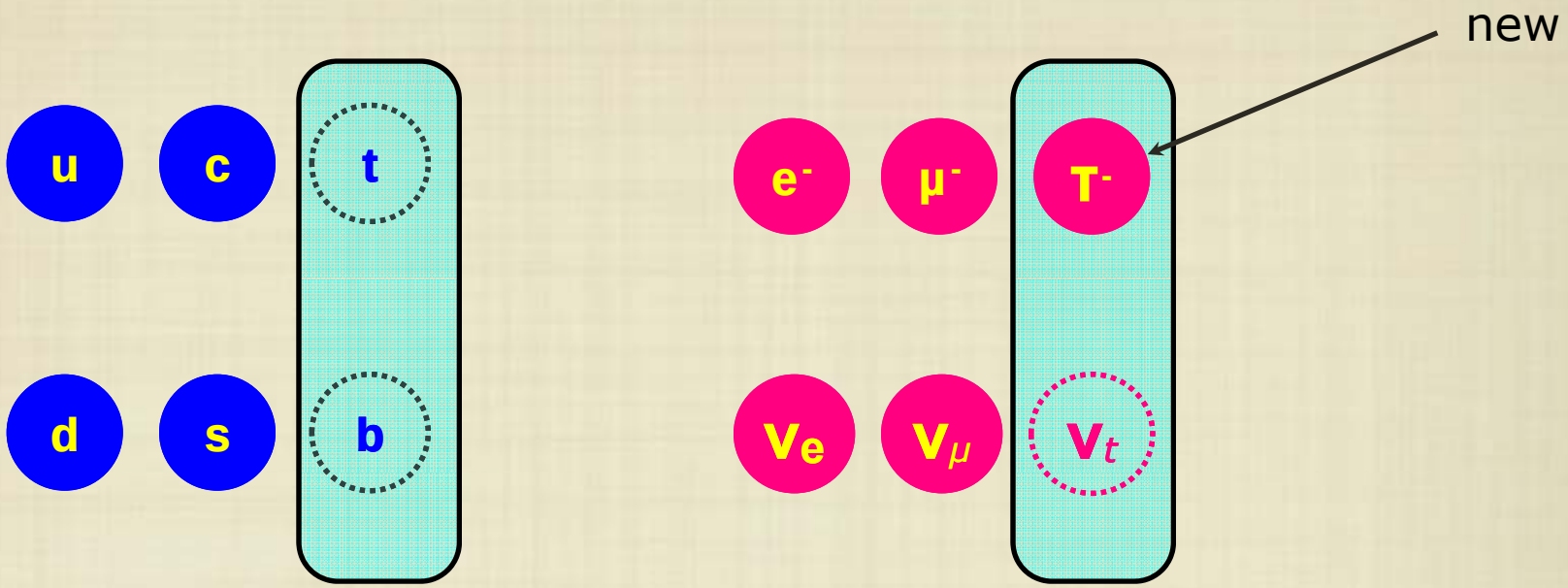
ein weiteres Neutrino (the 'tau neutrino'),
und zwei weitere Quarks ('top' and 'bottom').



Marty Perl's Logbook

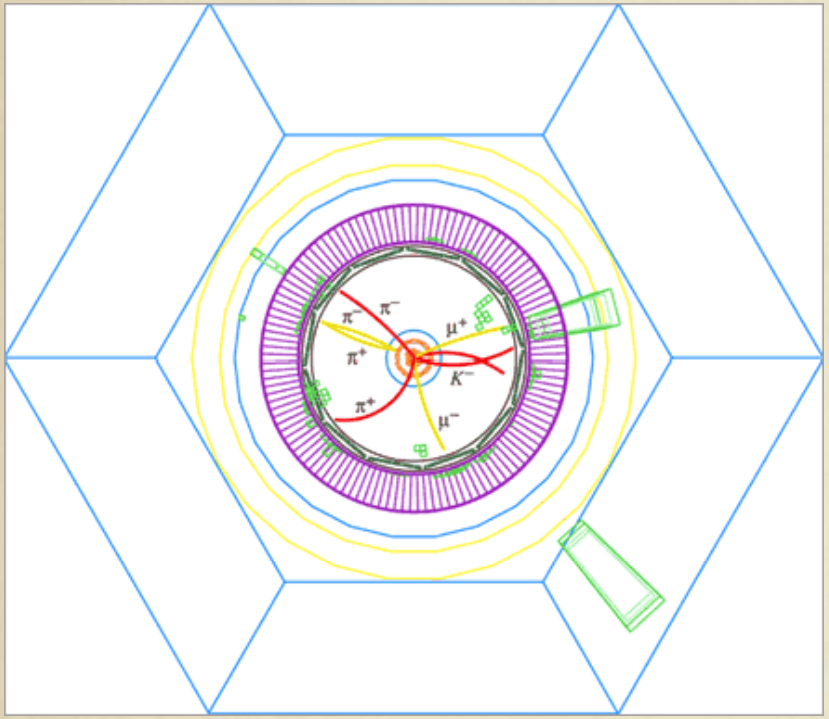
TEILCHENSPEKTRUM

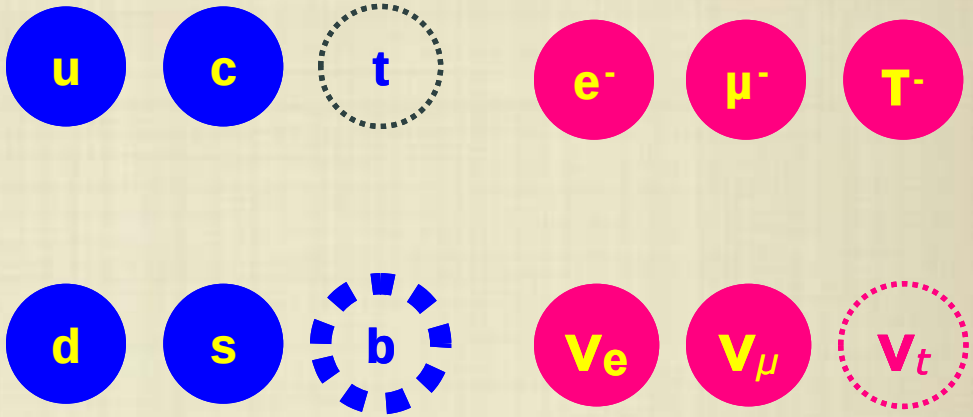
Die Suche nach den fehlenden Familienmitgliedern begann ...



TEILCHENSPEKTRUM

Entdeckung des **'Bottom' Quark (Fermilab)**





Quarks Leptons

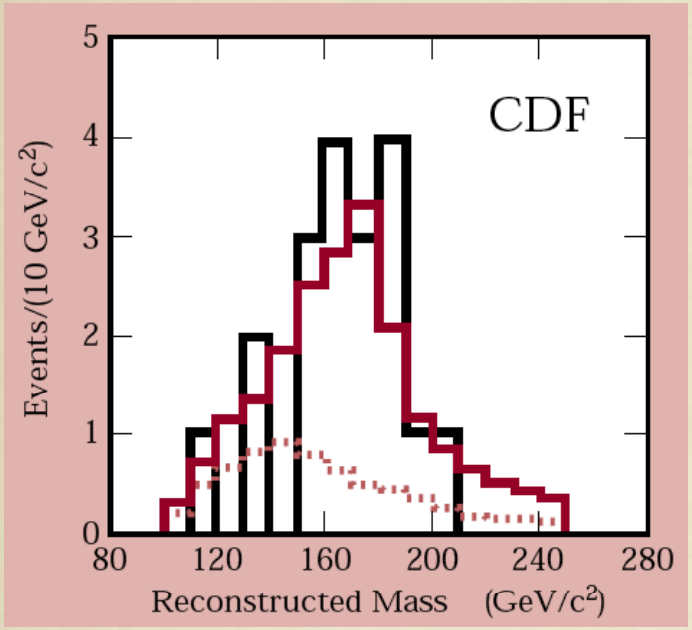
1977 entdeckten Physiker am Fermilab (nahe Chicago) ein neues Meson (genannt 'Upsilon')

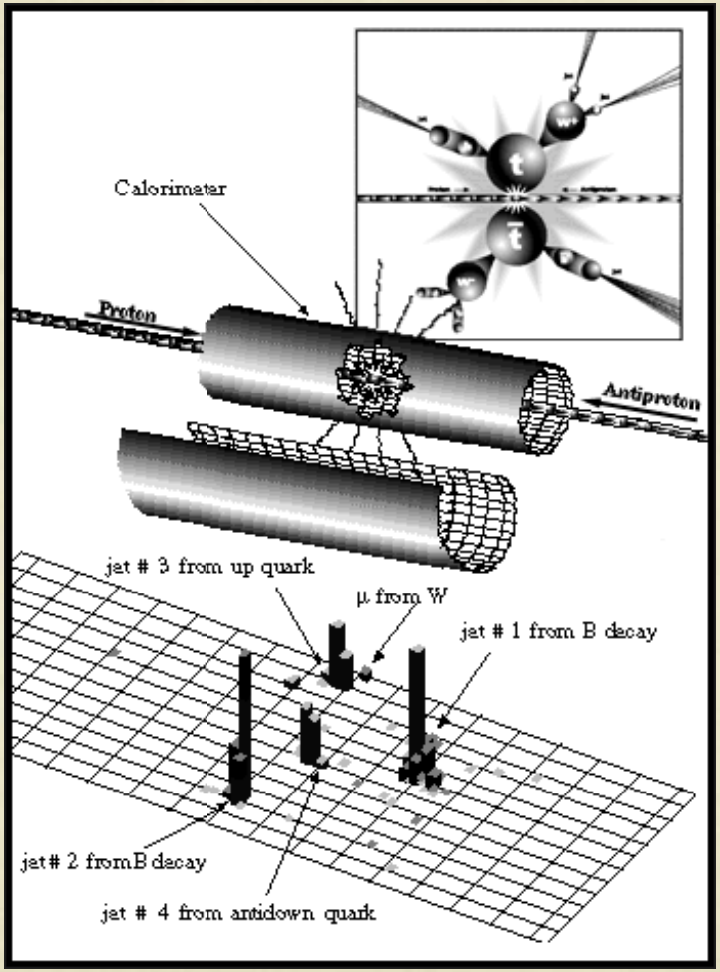
Seine Eigenschaften passten auf den 'Steckbrief' eines Mesons, das aus einem bottom/anti-bottom Quark Paar bestand.

Daraus folgte dass das Bottom quark die elektrische Ladung -1/3 und eine Masse von ca. 5 GeV hatte.

TEILCHENSPEKTRUM

Entdeckung des **'Top' Quark (Fermilab)**

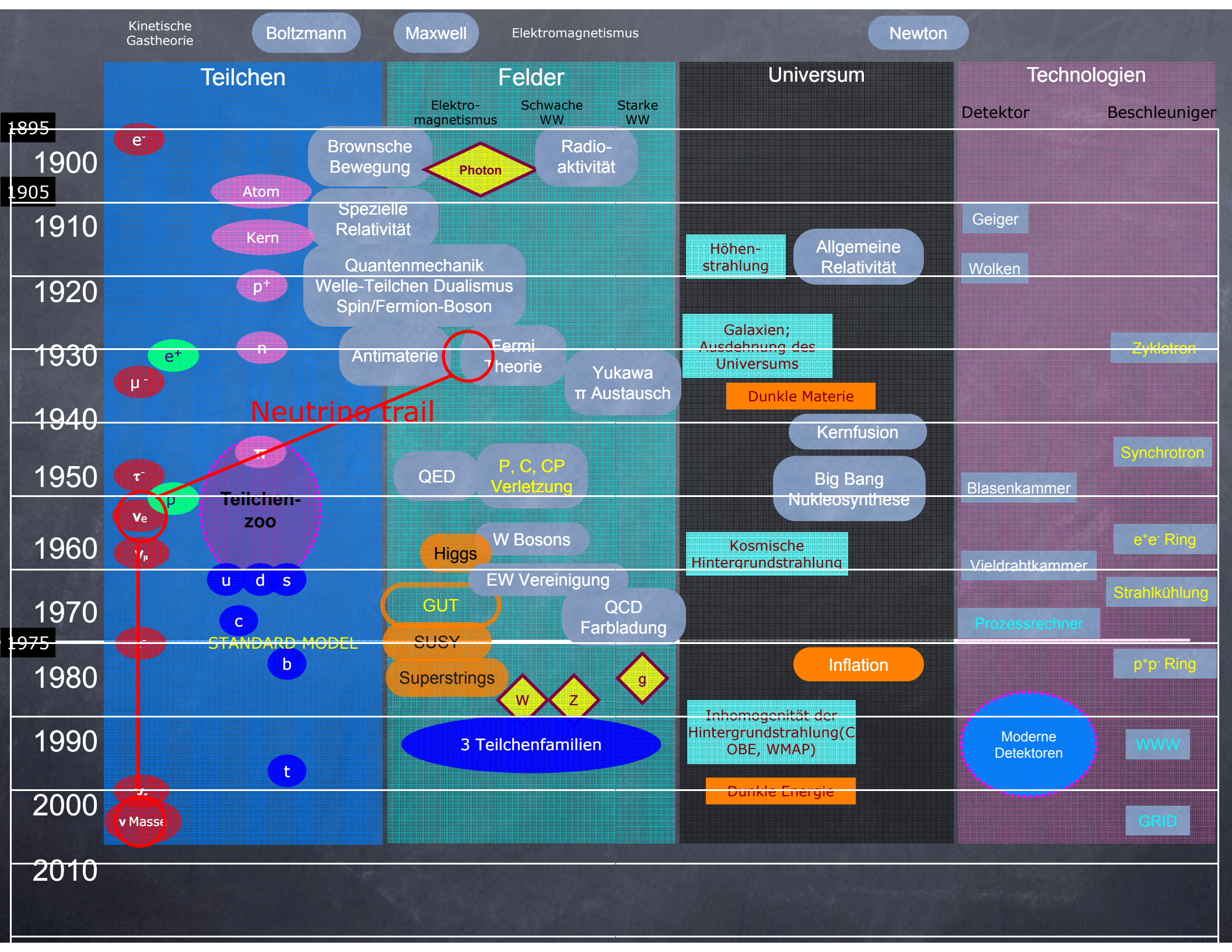




u c t

d s b

Quarks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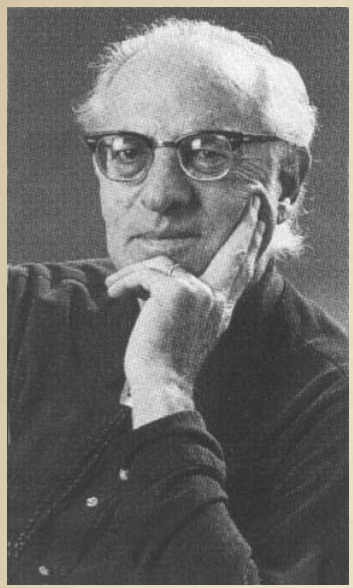


Fred Reines

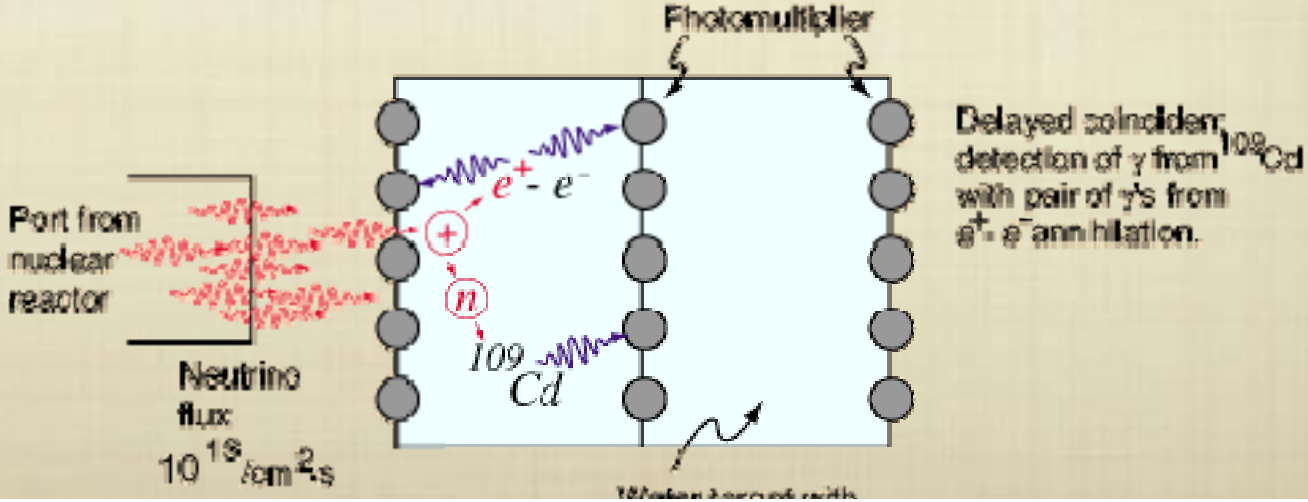
Die Geschichte der Neutrinos

Entdeckung des (Elektron) Neutrinos

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

Kernreaktoren (n-Zerfall) sind eine starke Anti-Neutrino-Quelle

Koinzidenz-Signal von Positron-Annihilation und Neutroneneinfang



TEILCHENSPEKTRUM

Jack Steinberger, 1962

"Muon" Neutrino

Leptonenerhaltungssatz: es muss auch ein 'Muon'-Neutrino geben

OBSERVATION OF HIGH-ENERGY NEUTRINO REACTIONS AND THE EXISTENCE OF TWO KINDS OF NEUTRINOS*

G. Danby, J-M. Gaillard, K. Goulianos, L. M. Lederman, N. Mistry, M. Schwartz,† and J. Steinberger†

Columbia University, New York, New York and Brookhaven National Laboratory, Upton, New York

(Received June 15, 1962)

In the course of an experiment at the Brookhaven AGS, we have observed the interaction of high-energy neutrinos with matter. These neutrinos were produced primarily as the result of the decay of the pion:

$$\pi^{\pm} \rightarrow \mu^{\pm} + (\nu/\bar{\nu}). \qquad (1)$$

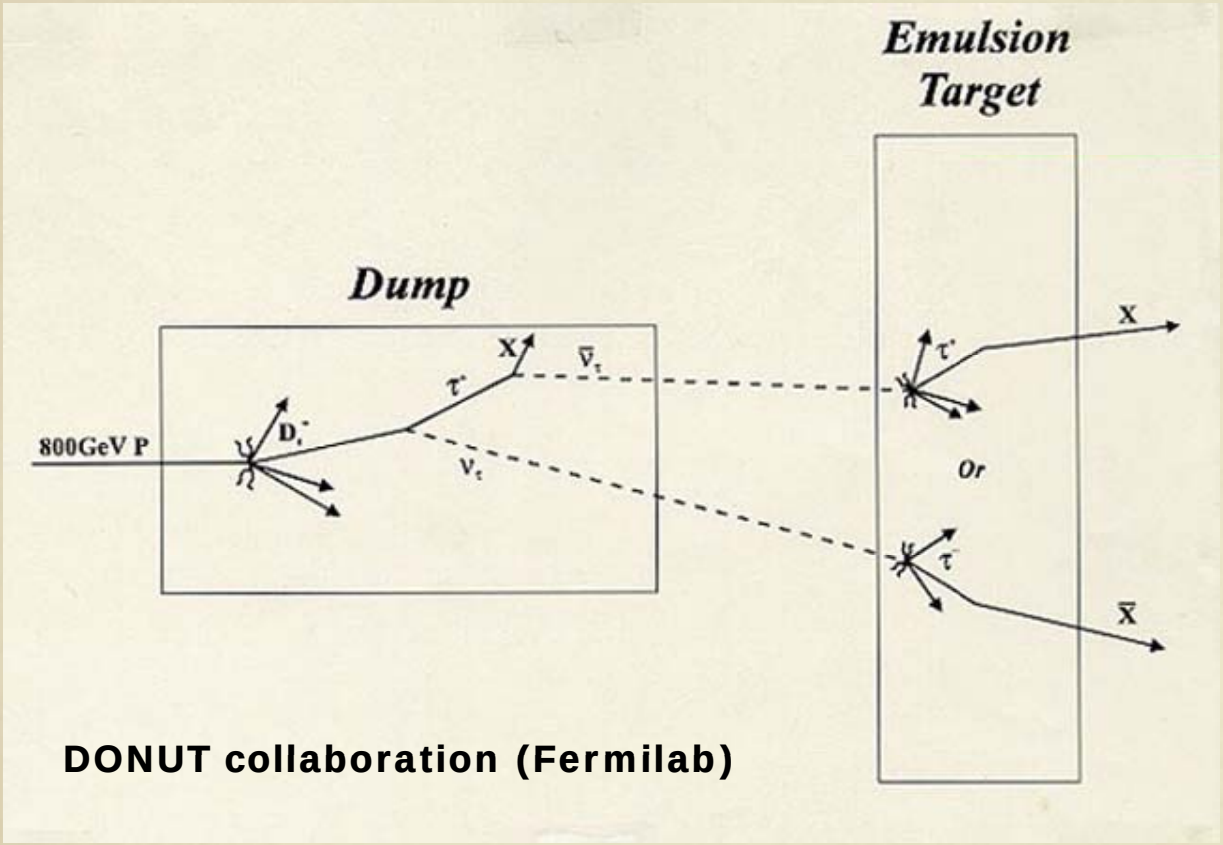
It is the purpose of this Letter to report some of the results of this experiment including (1) demonstration that the neutrinos we have used produce μ mesons but do not produce electrons, and hence are very likely different from the neutrinos involved in β decay and (2) approximate cross sections.

Behavior of cross section as a function of energy. The Fermi theory of weak interactions which works well at low energies implies a cross section for weak interactions which increases as phase space. Calculation indicates that weak interacting cross sections should be in the neigh-

Jack Steinberger, HST 2002

Haben Neutrinos eine Masse? Können sie ihre 'Flavour' wechseln ('Oszillationen') ?

Entdeckung des Tau-Neutrinos (2000)

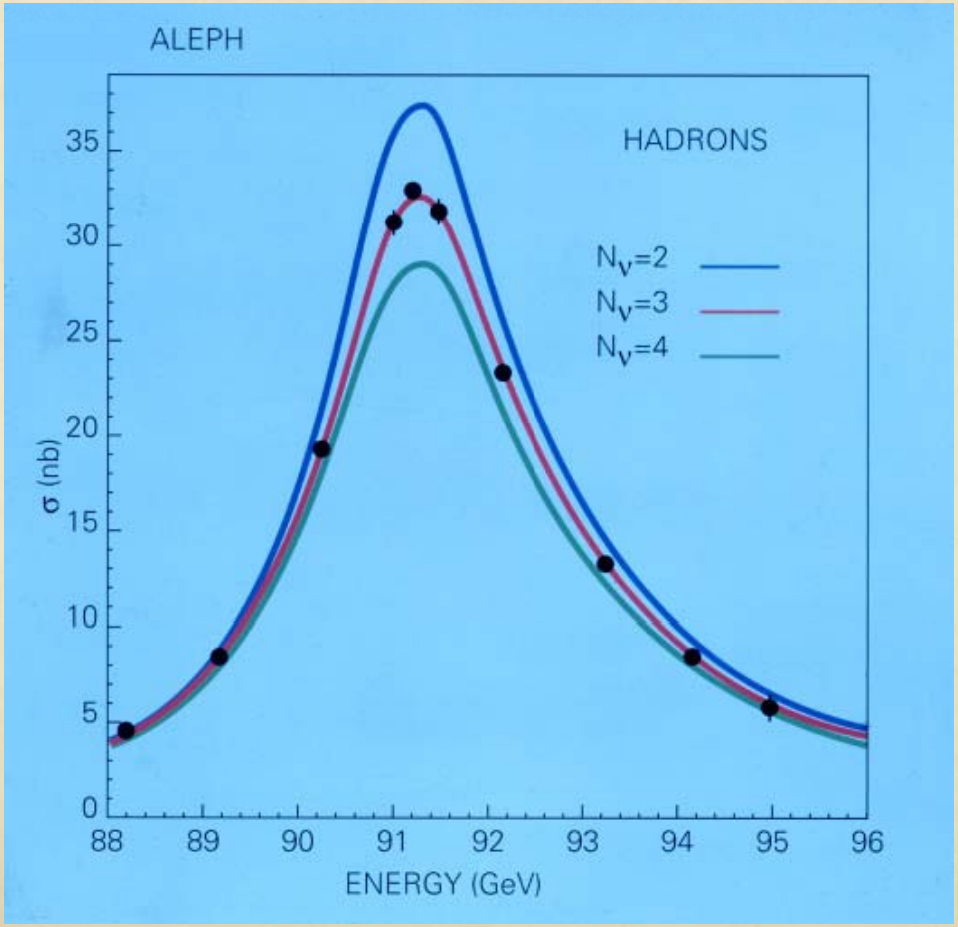


DONUT collaboration (Fermilab)

TEILCHENSPEKTRUM

Es gibt genau 3 Familien von Neutrinos (mit M < 45 GeV)

Am LEP wurde die Zerfallsbreite des Z^o gemessen

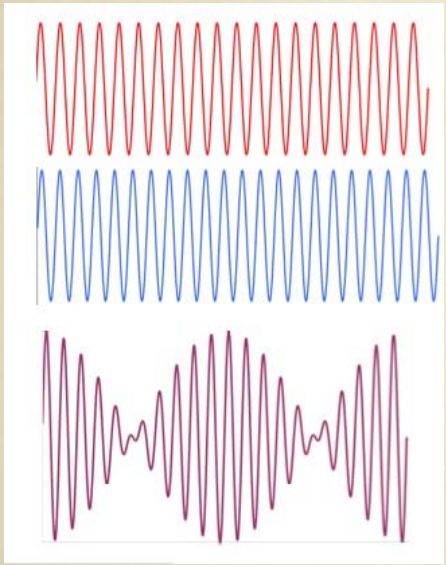


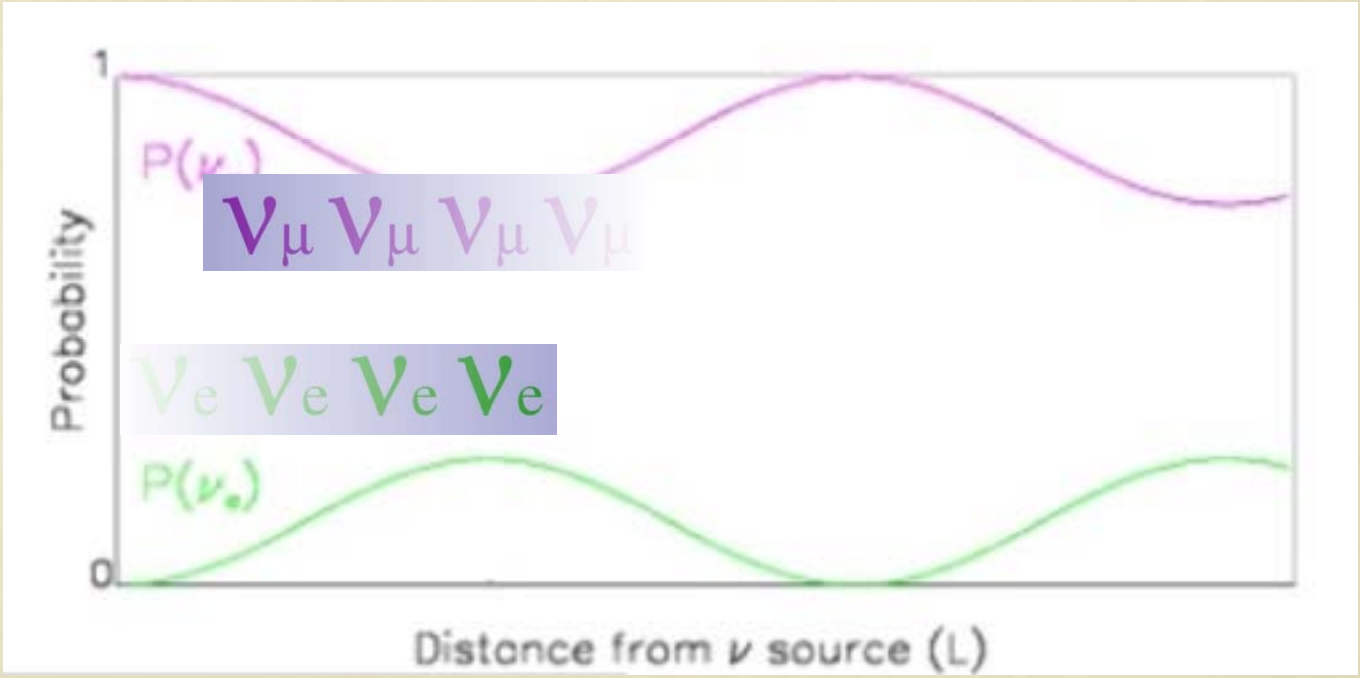
TEILCHENSPEKTRUM

Haben Neutrinos eine Ruhemasse ?

$\nu_e \longleftrightarrow \nu_\mu \longleftrightarrow \nu_t$

Neutrino-Oszillationen





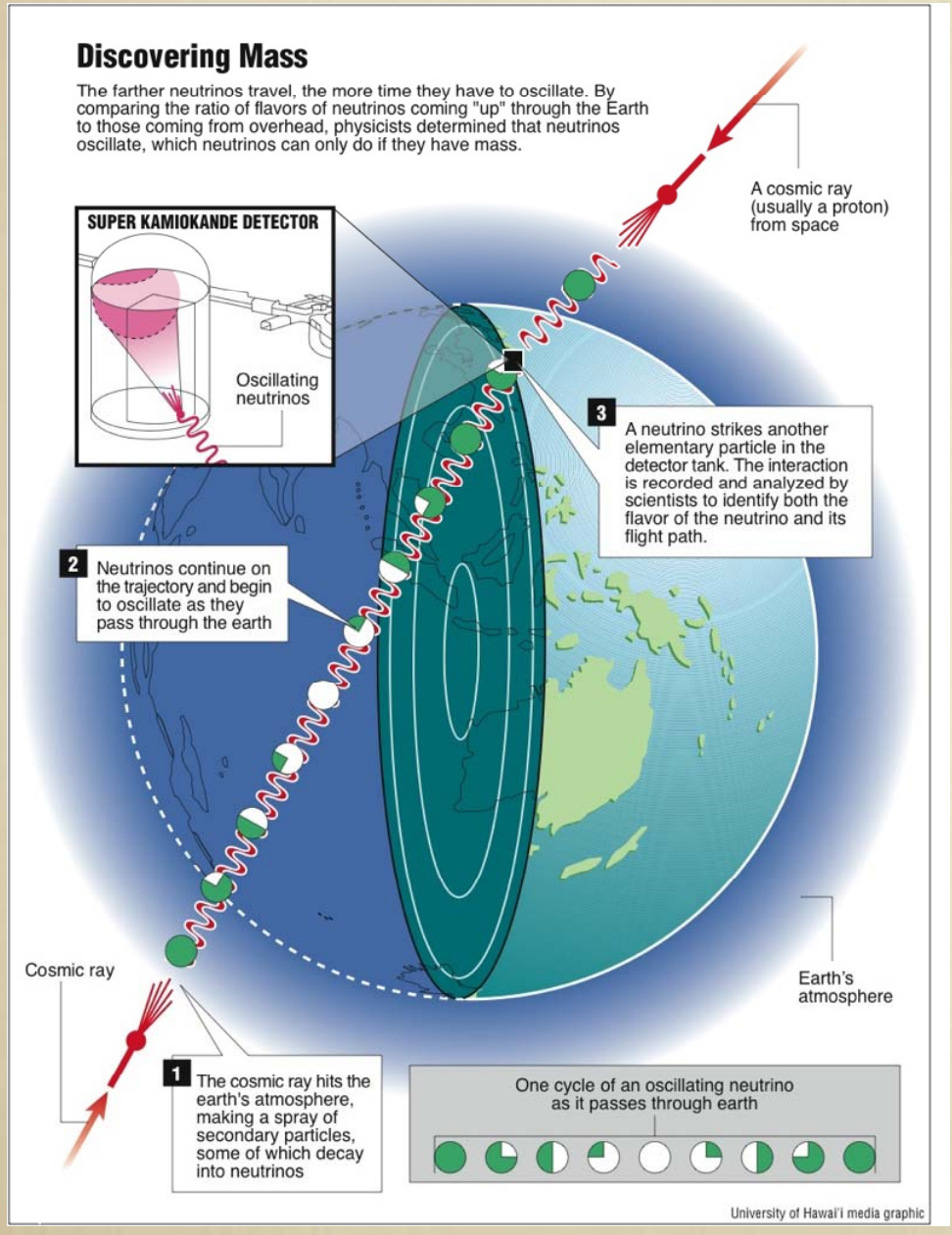
Teilchen werden durch Wellen (mit definierter Frequenz) beschrieben

Wenn die Frequenz ähnlich ist, dann können zwei Teilchenwellen 'Schwebungen' erzeugen ---> Neutrino-Oszillationen

TEILCHENSPEKTRUM

1998

Entdeckung von Neutrino-Oszillationen



Muon-Neutrinos werden von kosmischen Strahlen in der oberen Atmosphäre und nachfolgendem Pion- und Muon-Zerfall erzeugt.

Beobachtung:

ein Defizit von etwa 50% dieser Muon-Neutrinos, die von "unten" kommen sollten (Erddurchquerer)

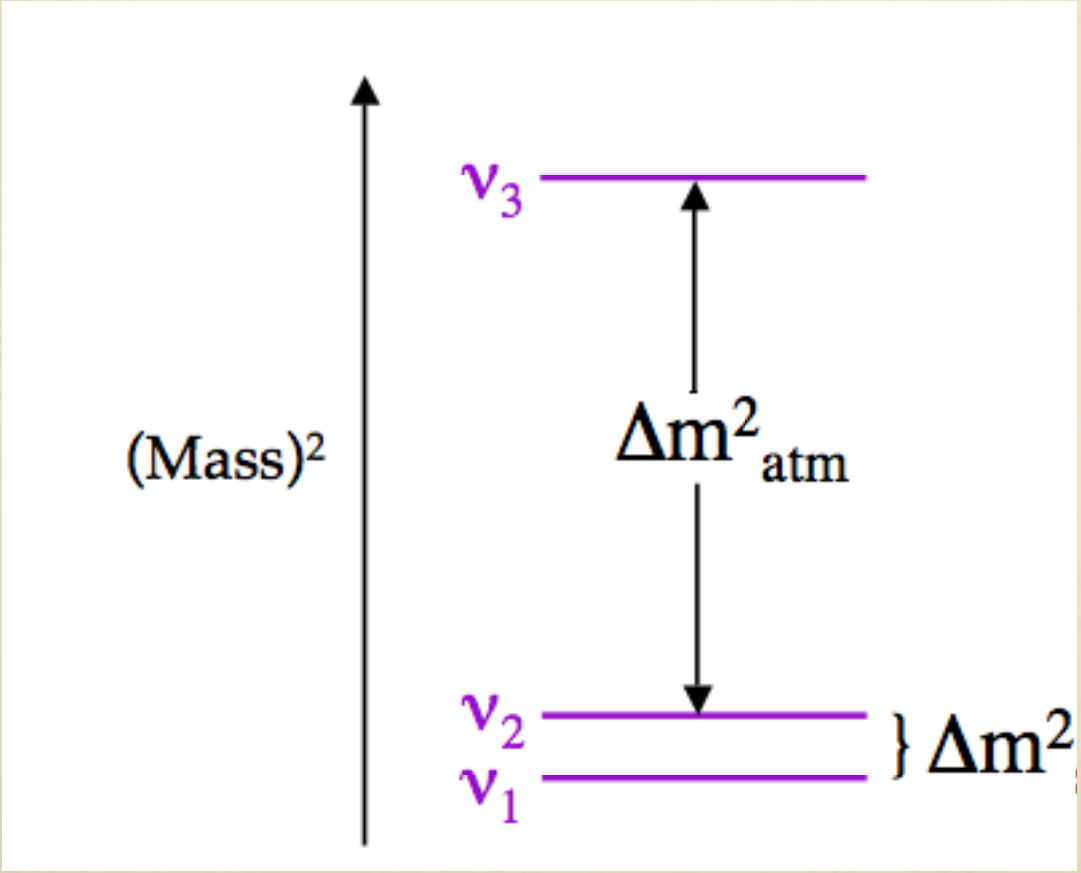
Erklärung:

diese Muon-Neutrinos oszillieren in einen anderen Neutrino-Typ (z.B. Tau-Neutrinos)

TEILCHENSPEKTRUM

Neutrinos besitzen eine Masse

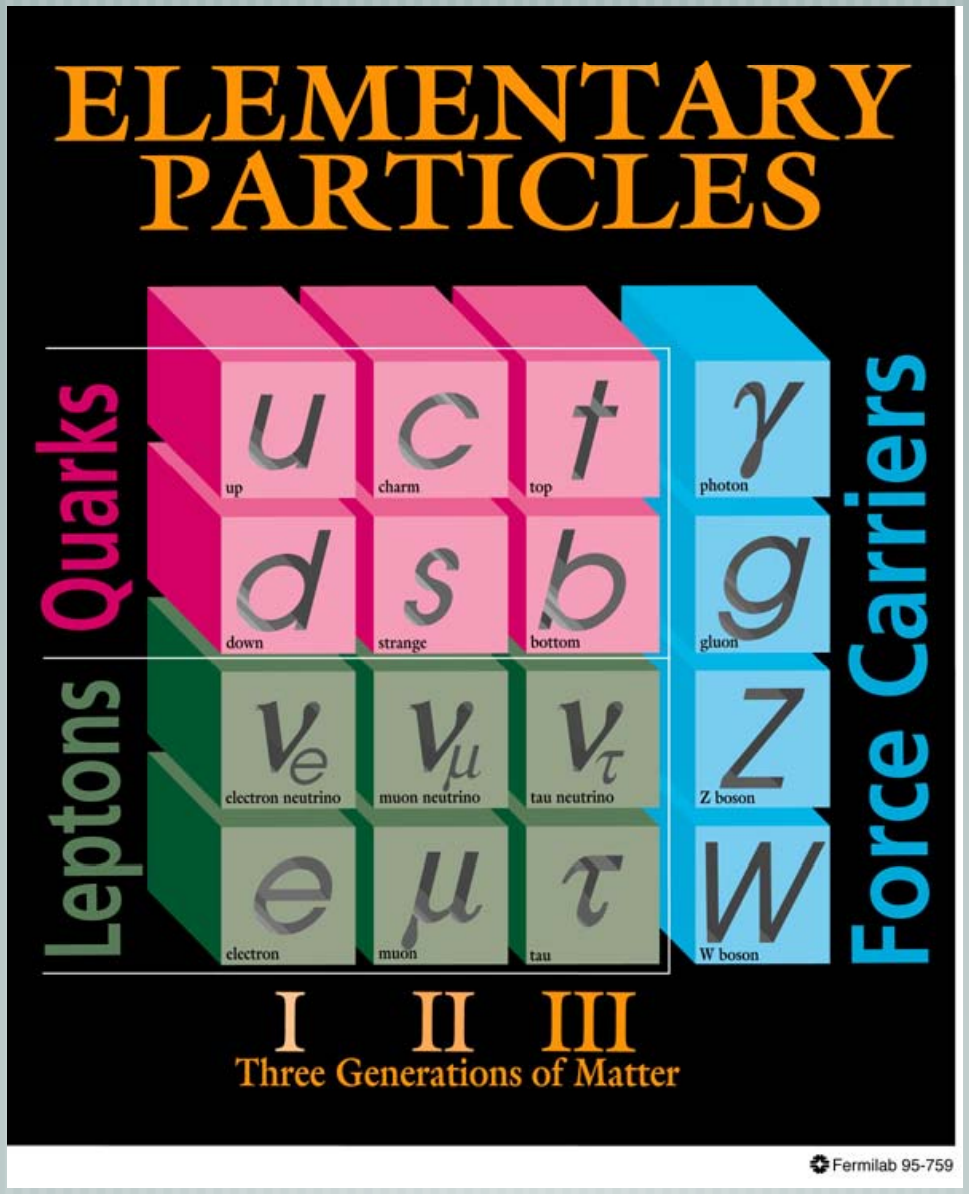
Man kennt zwar ihre absolute Masse nicht (der Limit für das Elektron-Neutrino ist ca. 3 eV), aber man kennt die Massendifferenzen.

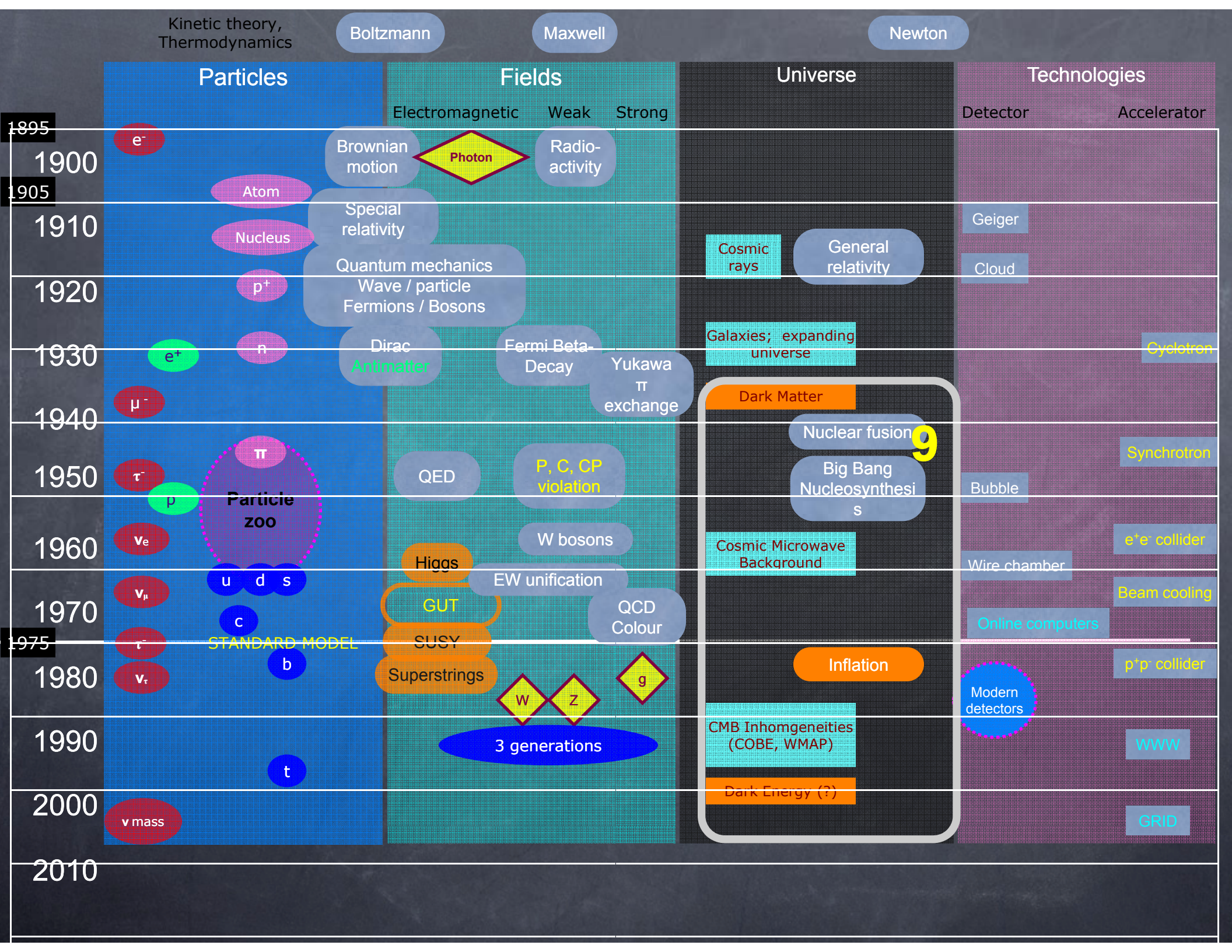


~ $2.5 \cdot 10^{-3}$ eV²

~$8 \cdot 10^{-5}$ eV²

DAS STANDARD MODEL (2006)




Kinetic theory, Thermodynamics
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Maxwell
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Particles
Fields
Universe
Technologies
Electromagnetic
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Strong
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Accelerator
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Brownian motion
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Atom
Special relativity
Nucleus
Quantum mechanics
Wave / particle
Fermions / Bosons
p+
Geiger
Cosmic rays
General relativity
Cloud
n
e+
Dirac
Antimatter
Fermi Beta-Decay
Yukawa
π
exchange
Galaxies; expanding universe
Cyclotron
μ-
Dark Matter
Nuclear fusion
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Particle zoo
QED
P, C, CP violation
Big Bang Nucleosynthesis
Synchrotron
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W bosons
Cosmic Microwave Background
e+e- collider
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Wire chamber
Beam cooling
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GUT
QCD
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Modern detectors
3 generations
CMB Inhomgeneities (COBE, WMAP)
WWW
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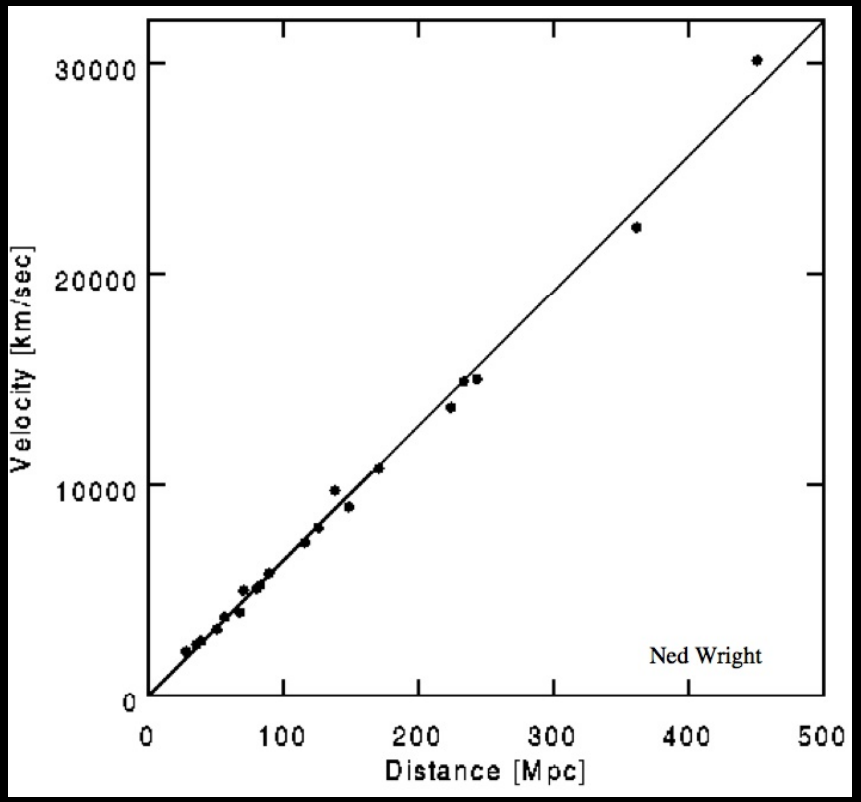
Dark Energy (?)
ν mass
GRID

Universe (1960)

Age of cosmic objects
less than ~ 12-13 billion yr
Sun ~ 4.7 billion yr

Universal Ratio H:He ~ 3:1
Snapshot at t ~ 3 min

Cosmic Microwave Background ?
Predicted (Gamov), ~ 5 K

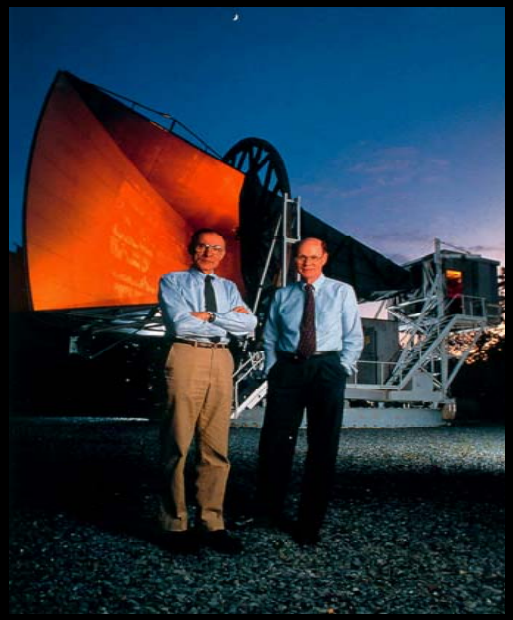


Today: H = 70±3 km s^{-1} Mpc^{-1}

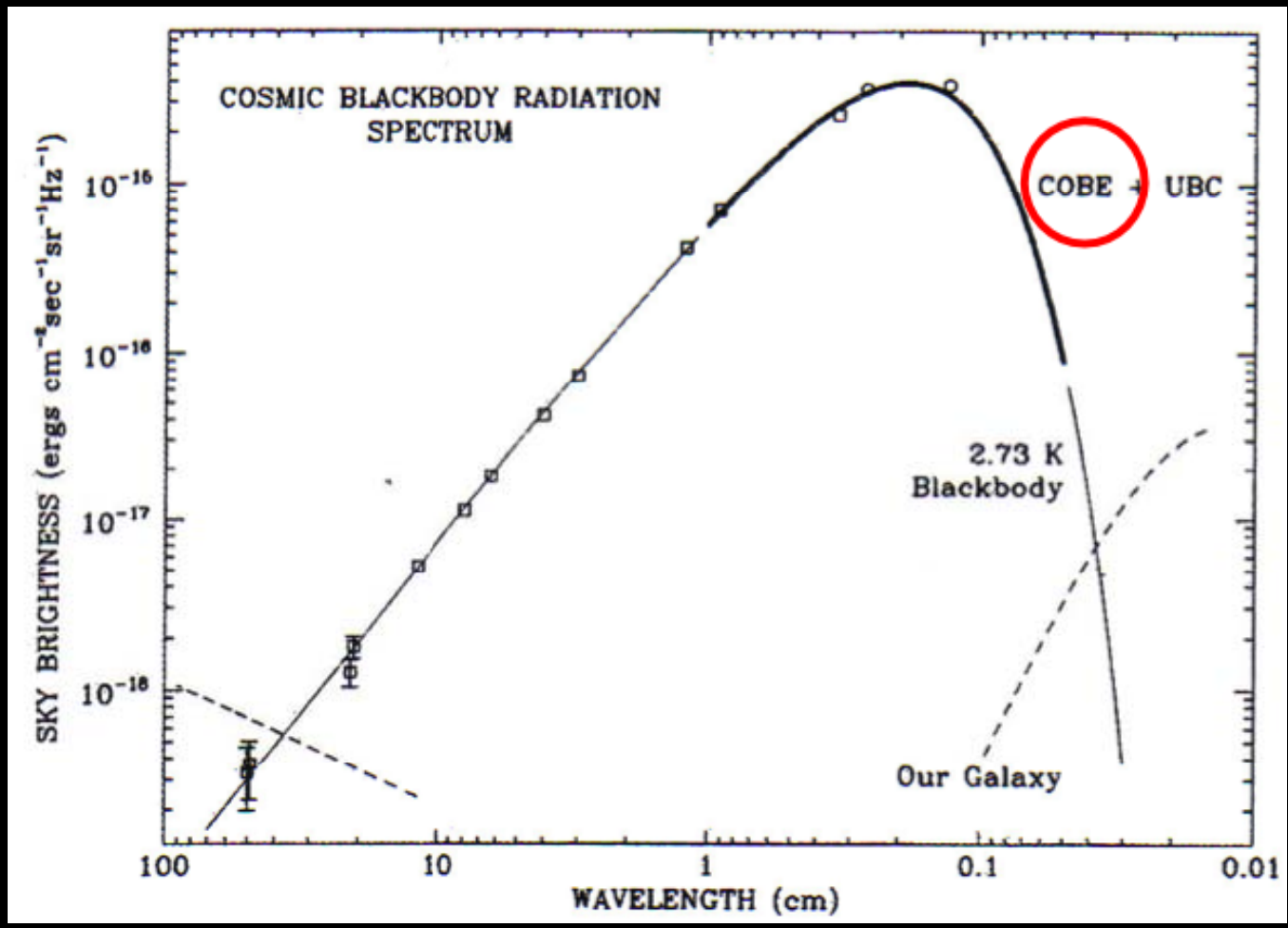
Hubble age (H^{-1}) ~ 13.4 billion years

Universe

The discovery of the 'Cosmic Microwave Background' (1963)



Penzias and Wilson



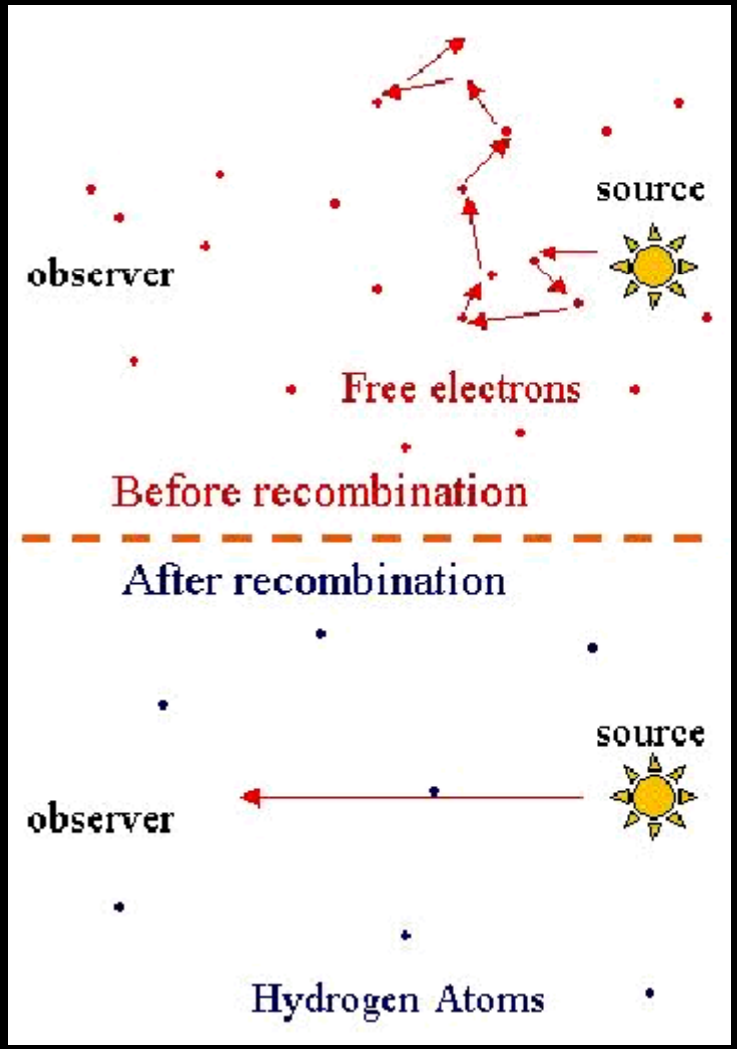
The Universe is a perfect ‘black body’ with T = 2.73 K

Universe

How was the cosmic background radiation produced?

By the recombination of free electrons and nuclei

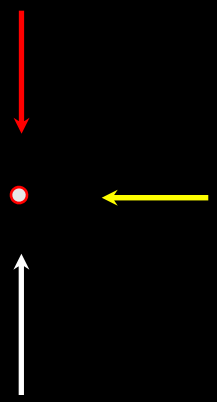
(this was possible when the average energy per photon was smaller than the binding energy)



Universe

The beginning

Energy ~ 10^{72} J



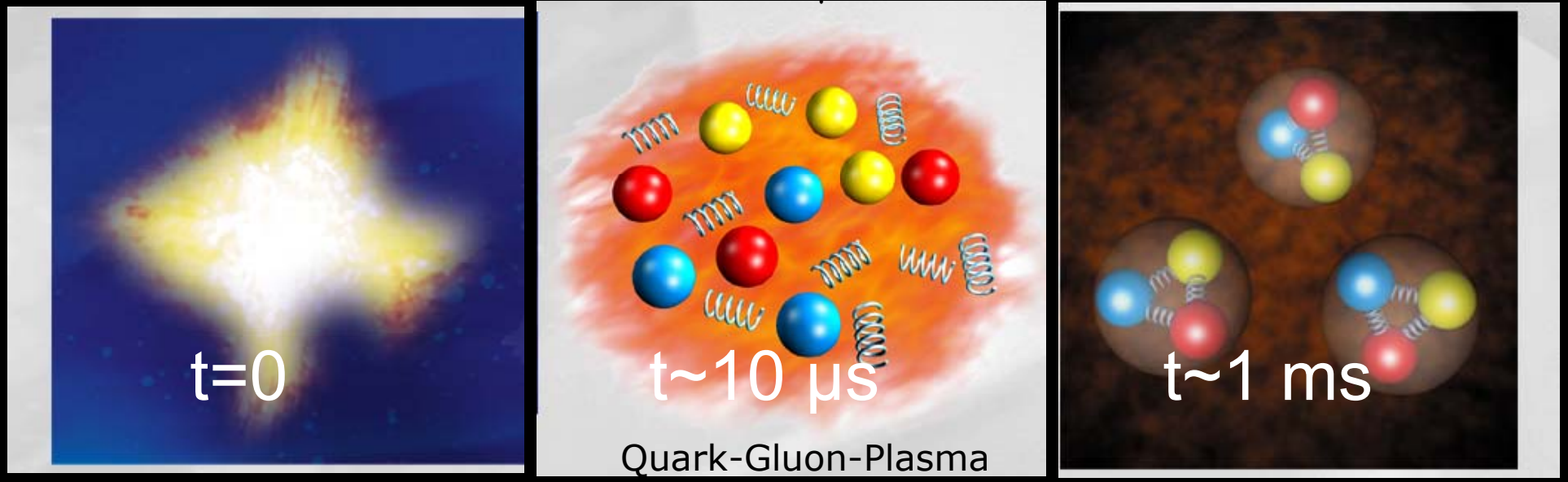
What are the Laws of Nature here?

Size of the visible Universe x 100

At t = 1/1,000 000 000 000 000 000 000 000 000 000 000 000 s

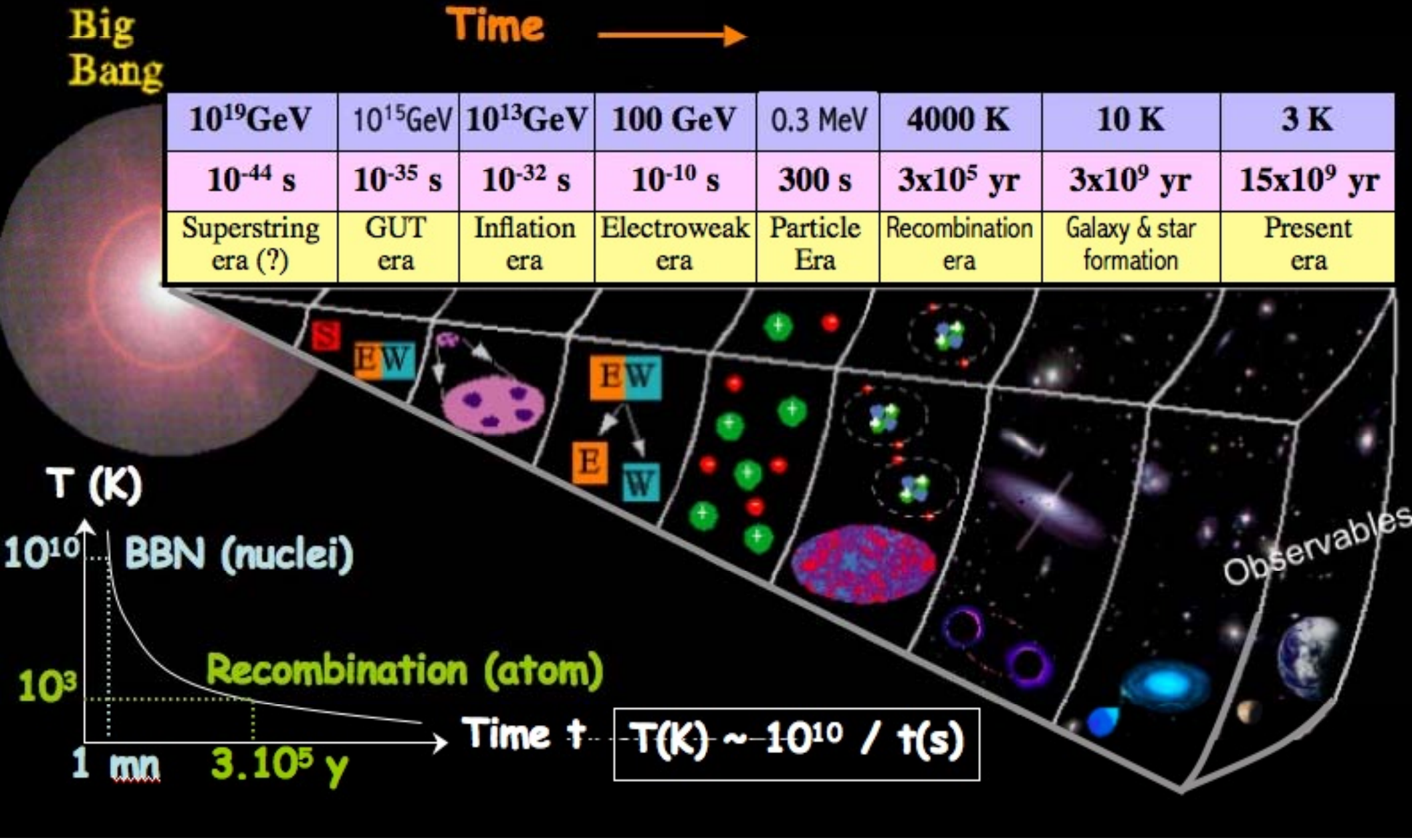
Universe

Particle Physics pushes the limit of knowledge towards shorter times



Universe

The reconstruction of the History of the Universe



Universe

Big Bang evolution

Time (sec)	Temperature (eV/K)	Phase
10^{-43} s	10^{19} GeV	Grand Unified Theory ?
10^{-35} s	10^{15} GeV	Inflation (GUT breaking) ?
10^{-10} s	10^{2} GeV	Electroweak symmetry breaking (W/Z mass)
10^{-5} s	300 MeV	Quarks form hadrons (neutrons, protons, etc)
1-3 min	0.3 MeV	Nucleosynthesis (H, He, Li)
10^{5} yrs	0.4 eV = 4000 K	Recombination of nuclei and electrons (transparent!)
10^{9} yrs	10 K	Stars, Galaxies; Supernovae produce heavy elements
10^{10} yrs	3 K	Today

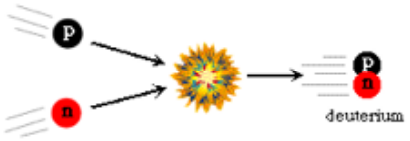
Universe

Big Bang Nucleosynthesis

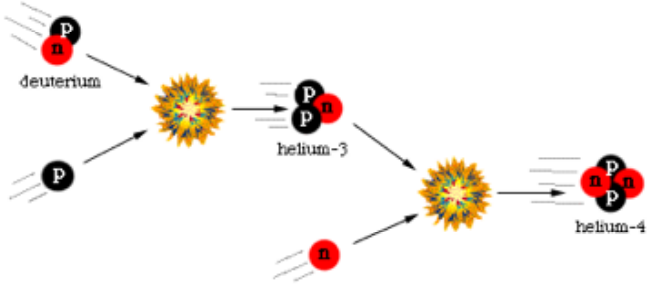
t=1-3 mn, T=0.3-0.1 MeV

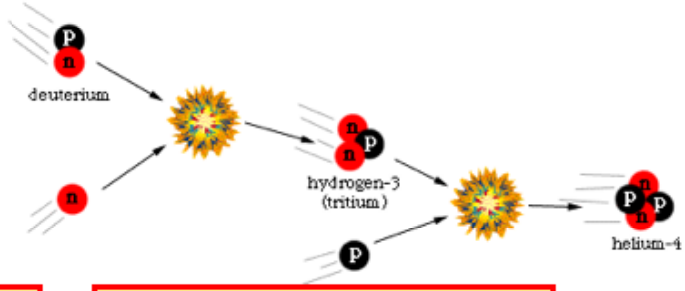
- neutron decay: $n \longrightarrow p + e^- + \bar{\nu} \Rightarrow n/p \sim 1/7$

- Deuterium (all n):



- Helium (all D ie all n + equal number of p):



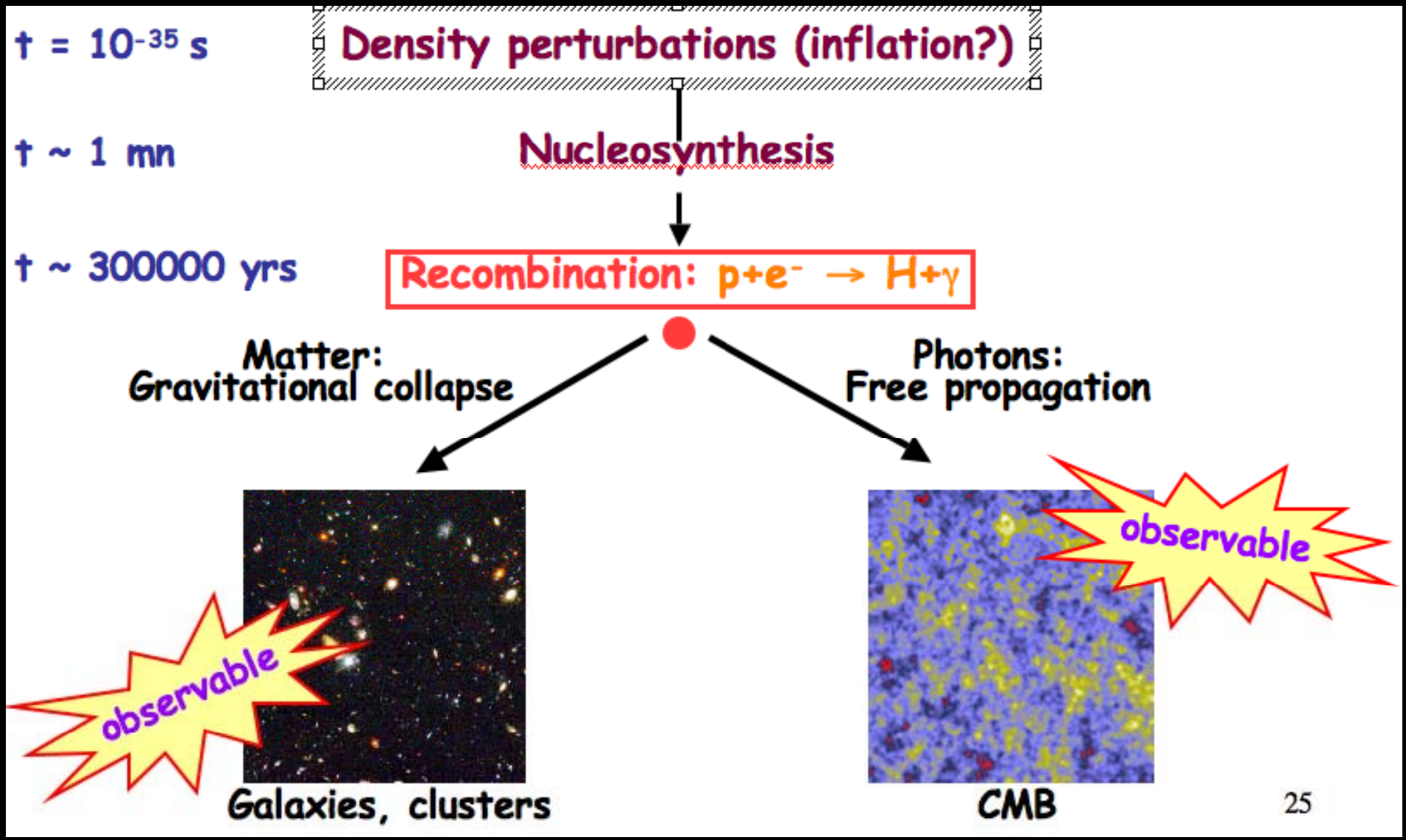


Helium abundance ~ $\frac{2n}{n+p}$ ~ 0.25

H abundance ~ 0.75

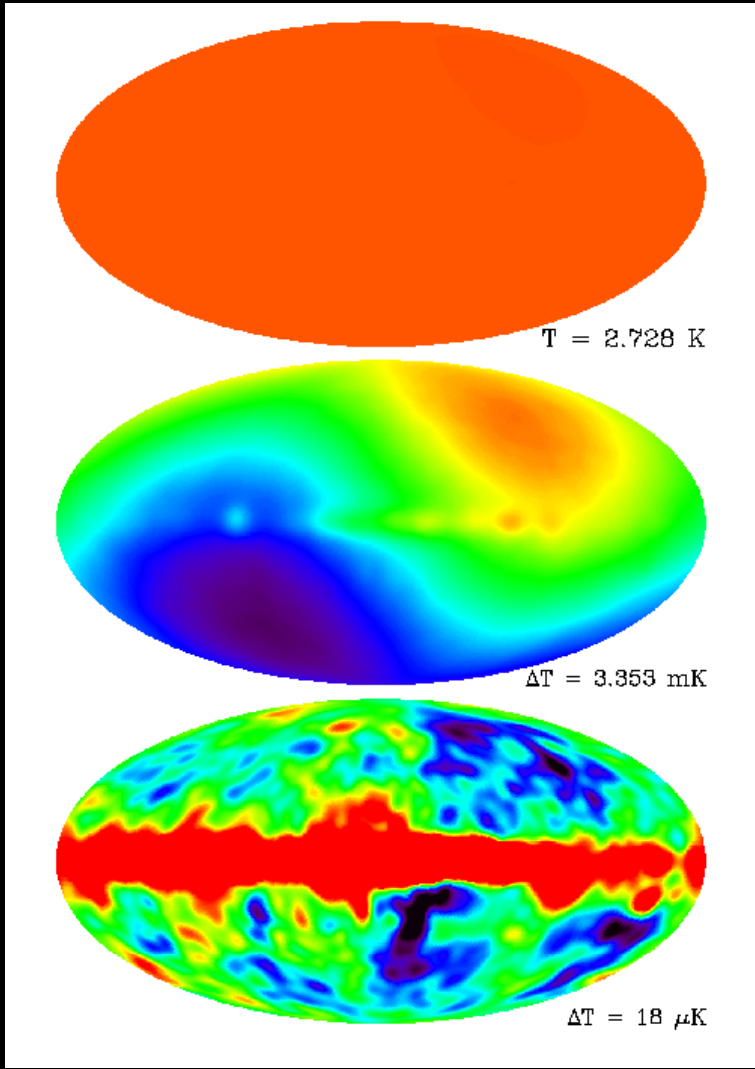
$\eta = n_b/n_\gamma$ | $\Rightarrow$ D bottleneck lasts less $\Rightarrow$ n/p | $\Rightarrow$ He^4|

Back to the Beginning



Universe

Study of the Cosmic Microwave Background (COBE)
(Nobel prize 2006)



T= 2.7 K

Δελτα–T= 3.3 mK

(after subtraction of constant emission)

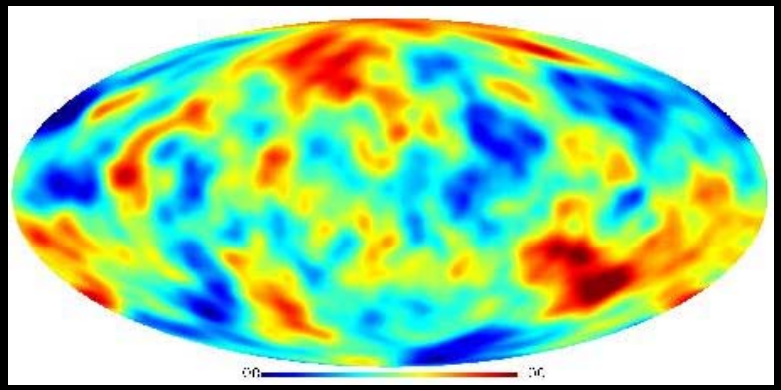
Δελτα–T= 18 μK

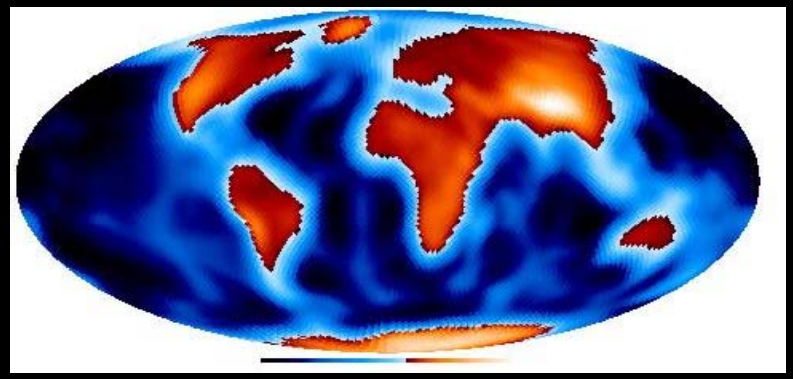
(after correcting for motion of Earth)

Universe

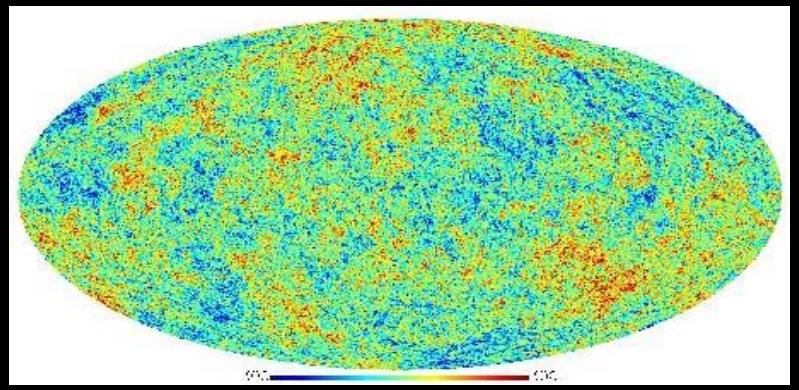
The most precise observation today (WMAP)

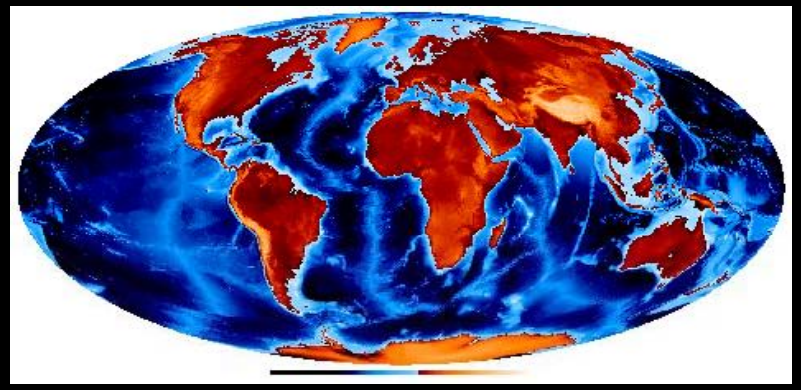
COBE
(7 degree resolution)



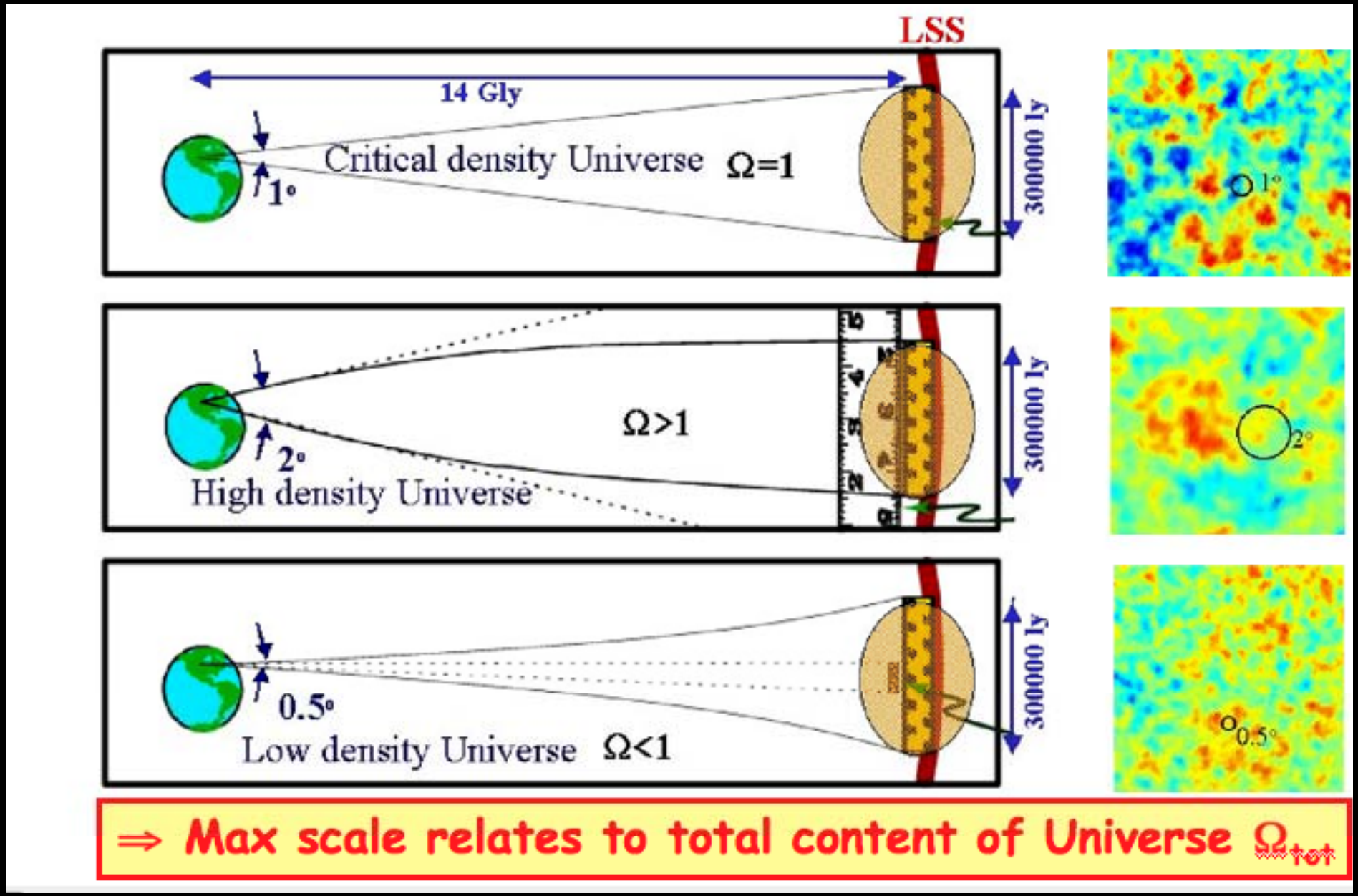


WMAP
(0.25 degree resolution)



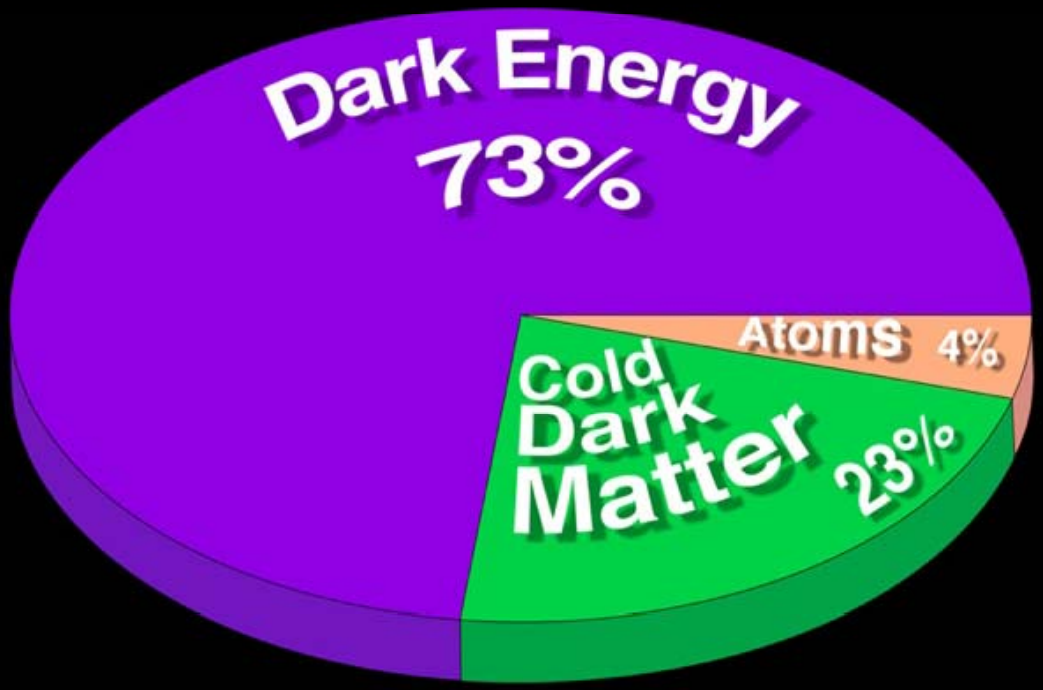


Analysis of inhomogeneities reveals the composition of the Universe



Universe

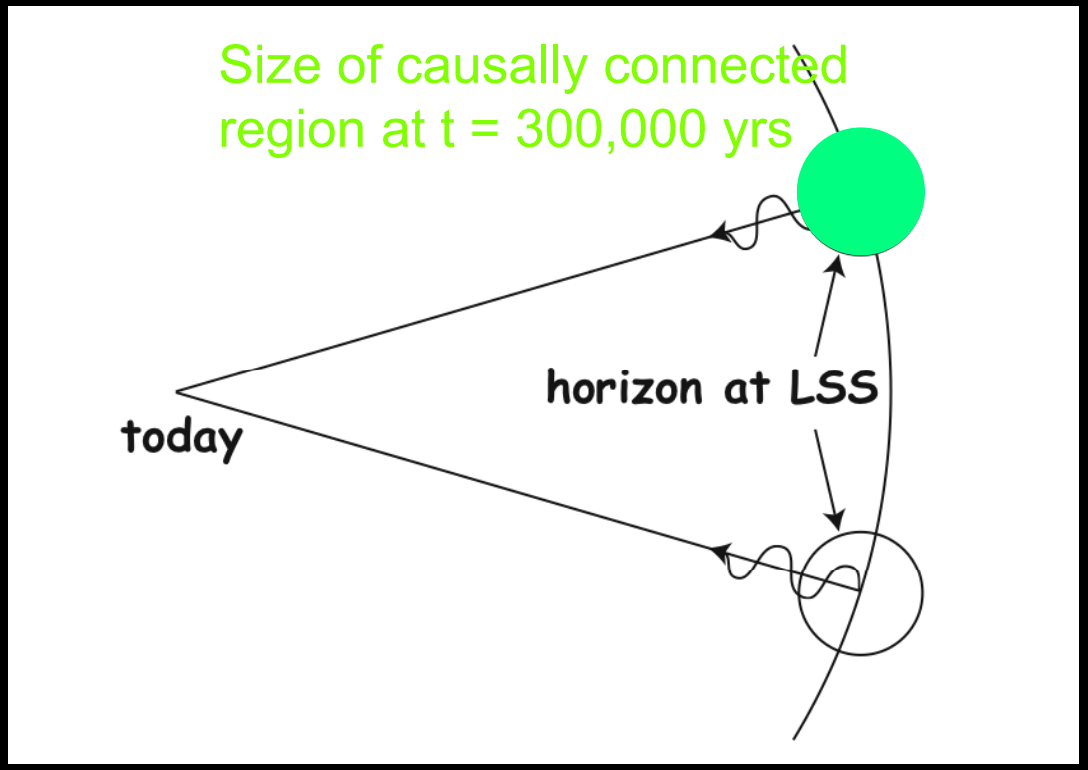
The strange composition of the Universe



Universe

The horizon problem :

How can the CMB radiation be so homogeneous when there are 10^{88} regions which have never been causally connected ?

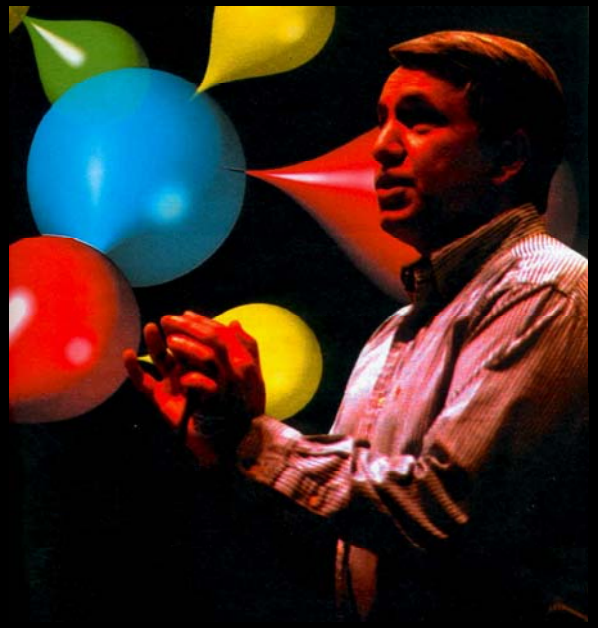


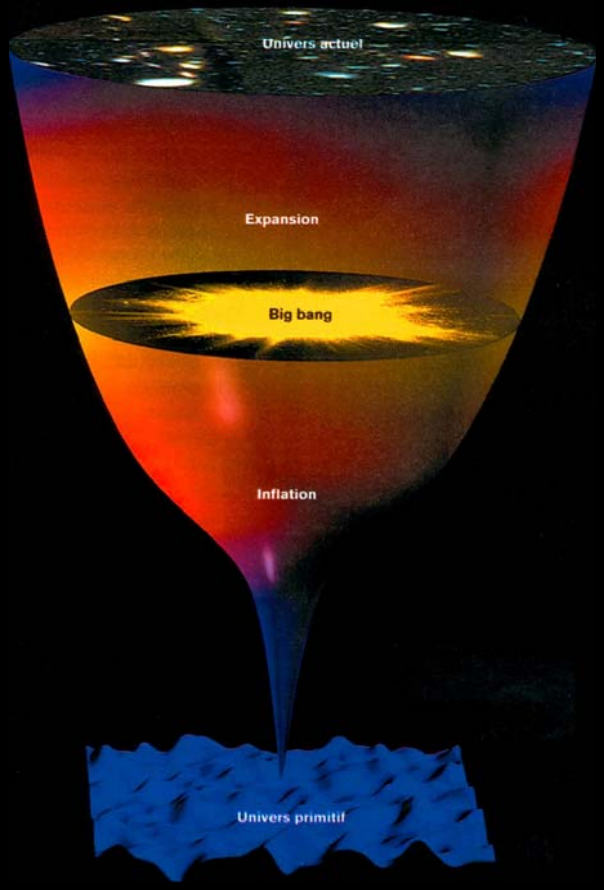
$$\text{Angle} \sim \frac{10^3 \times 3.10^5}{14.10^9} \text{ rad} \sim 1°$$

Universe

Guth/Linde (1980)

The Universe went through a phase of superluminal expansion, driven by an 'inflaton' field

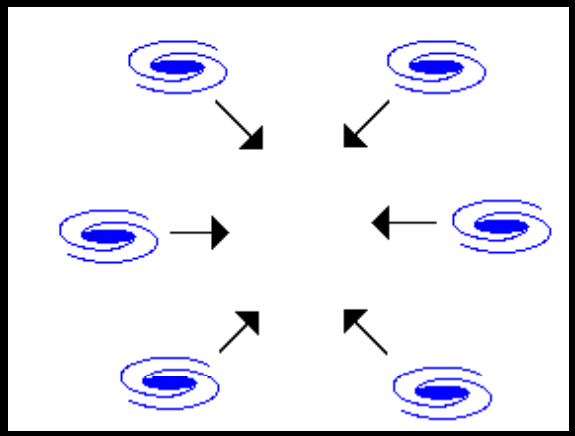


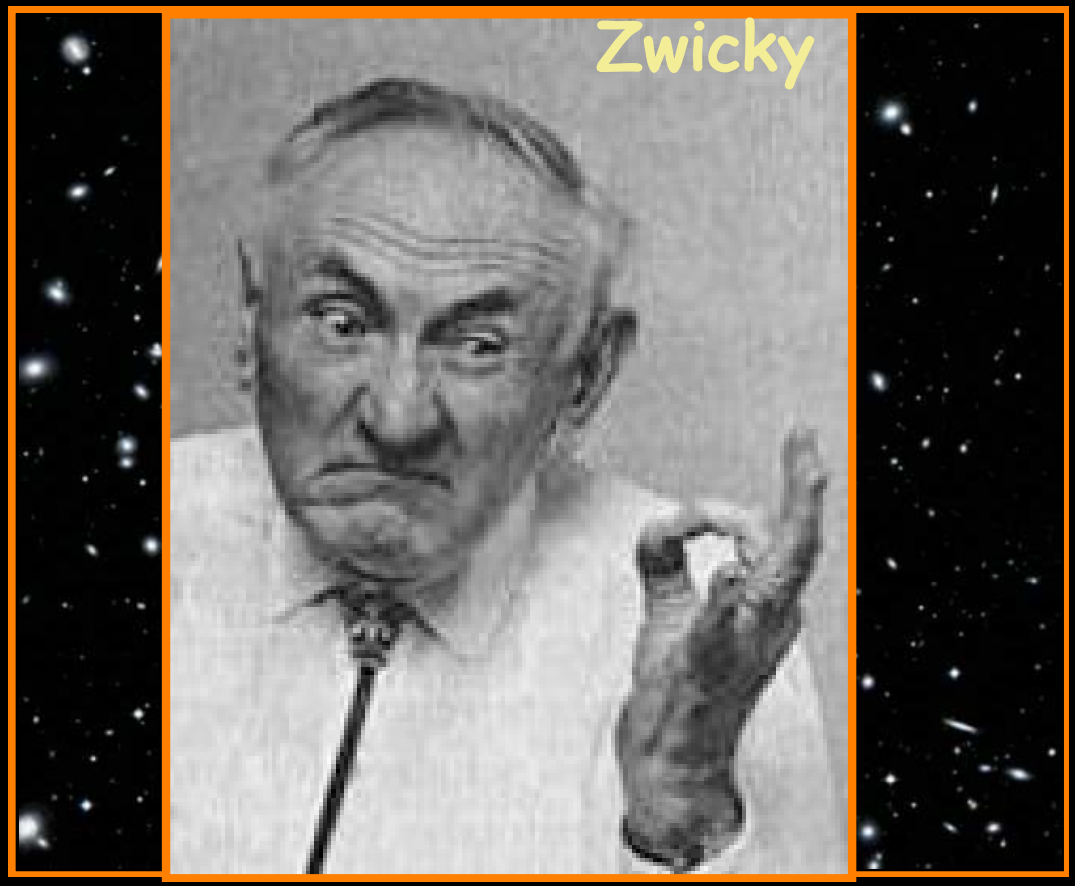


solves two big problems:
1) the flatness of the Universe
2) the horizon problem

Universe

Evidence for Dark Matter (1933)



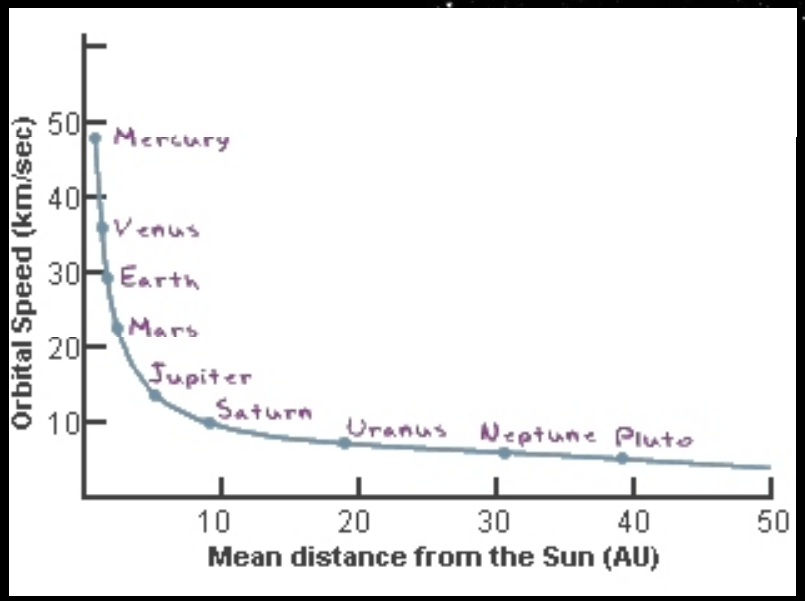


Mass of luminous matter
=
10%
Gravitational mass

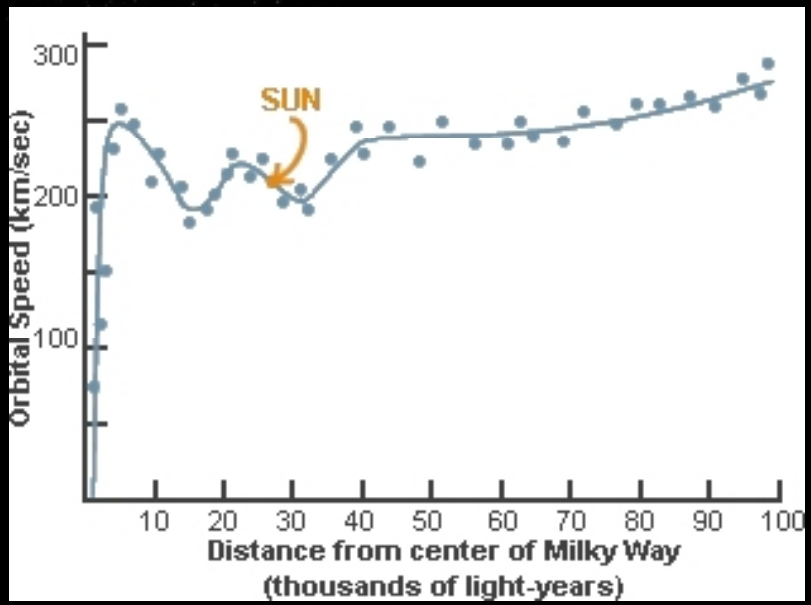
Universe

MORE EVIDENCE FOR “DARK MATTER”

Orbital speed vs Distance from center
(Kepler - expect $r^{-1/2}$ dependence)



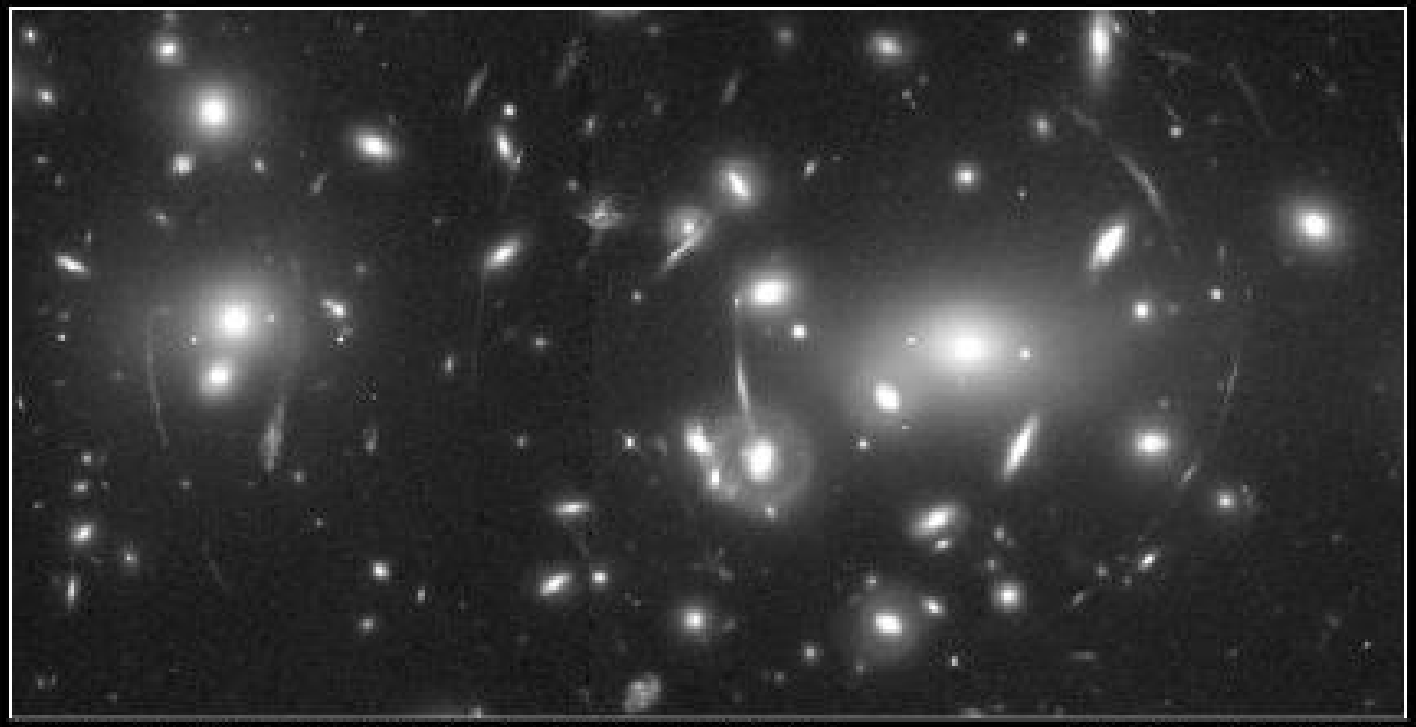
One central mass (Sun)



Milky Way

Universe

AND EVEN MORE EVIDENCE FOR “DARK MATTER”



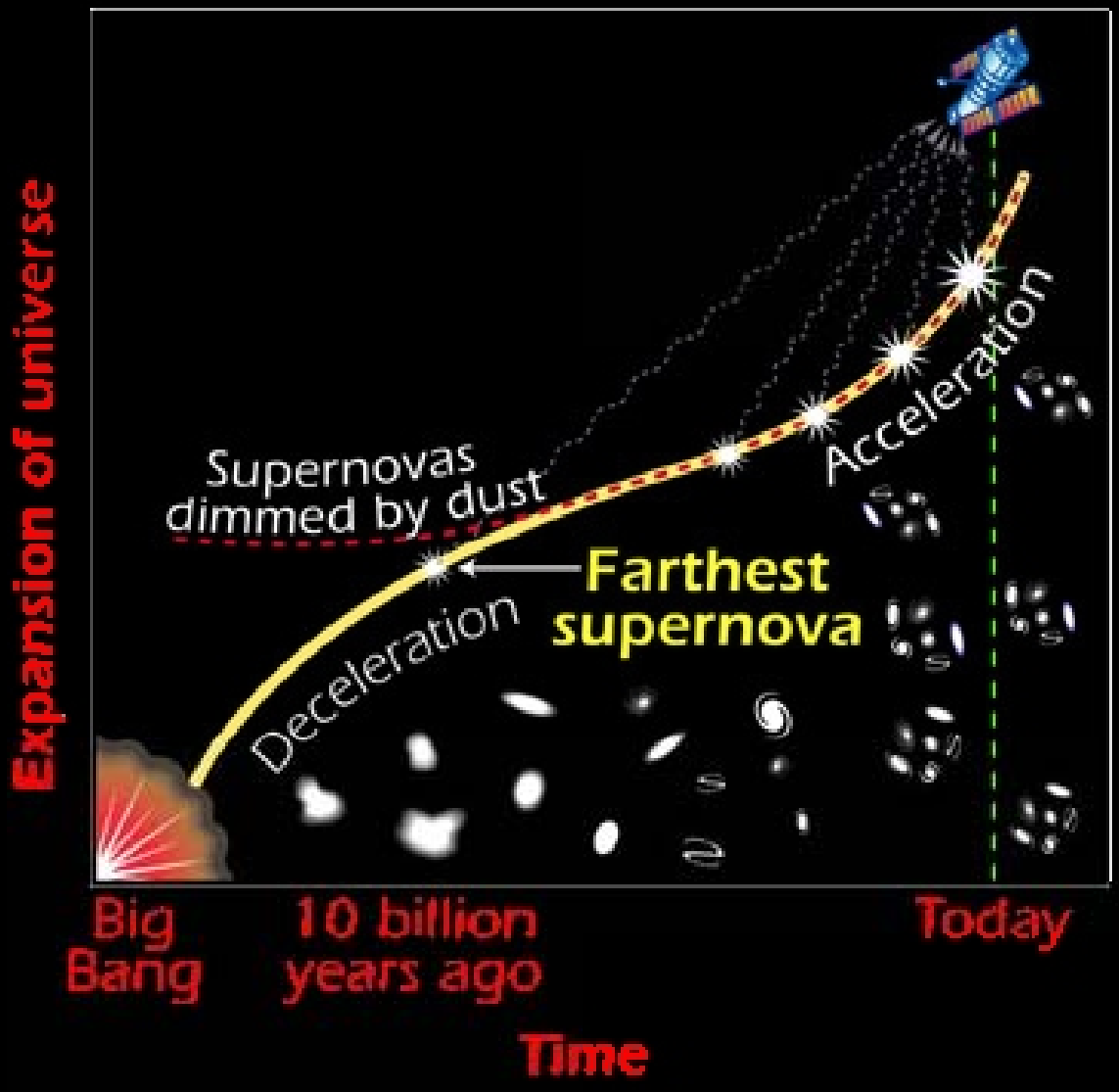
Gravitational Lens in Abell 2218 HST • WFPC2

PF95-14 · ST ScI OPO · April 5, 1995 · W. Couch (UNSW), NASA

GRAVITATIONAL LENSING

Universe

Evidence for Dark Energy



DIE RÄTSEL DES 21. JAHRHUNDERTS

1) Wie kommen Teilchen zu ihrer Masse - durch das “Higgs” Feld ?

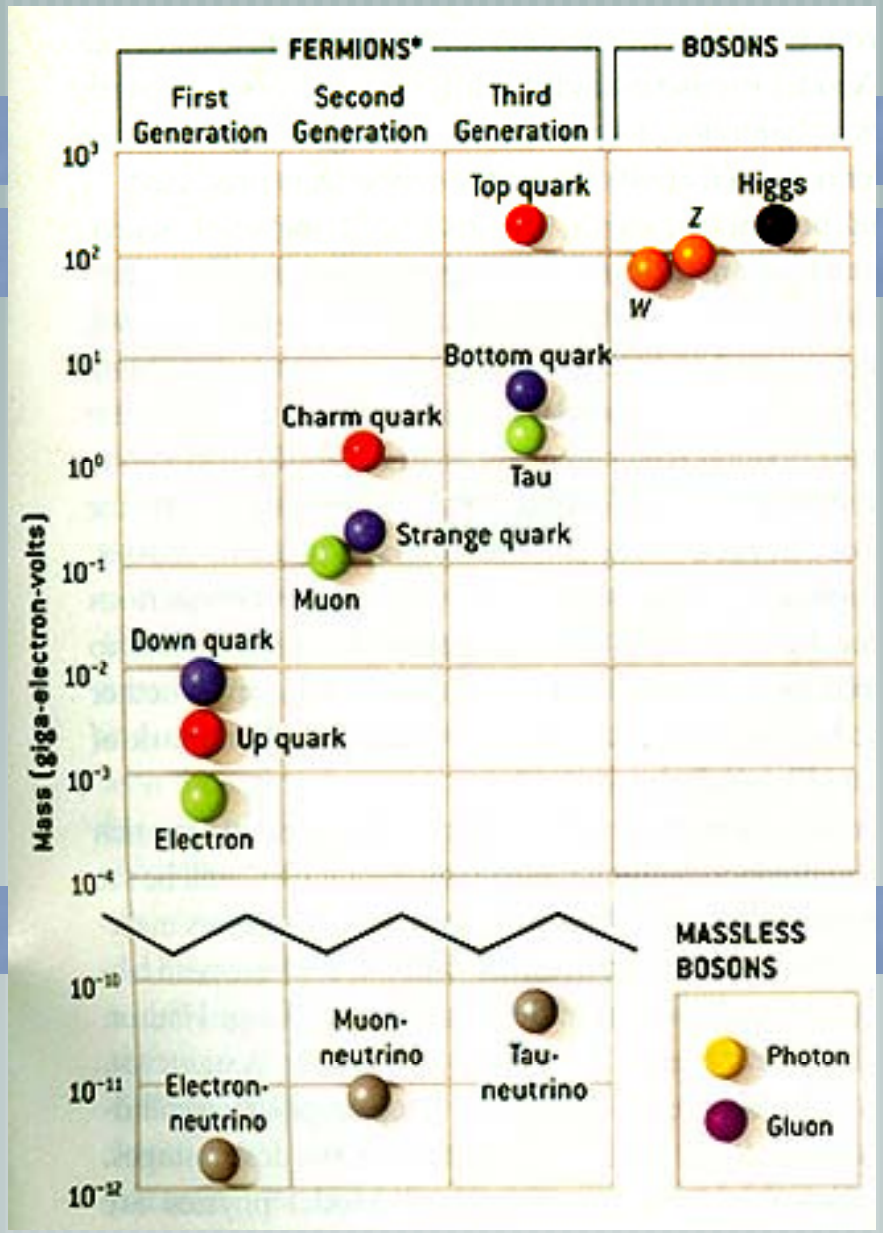
1 TeV →

100 GeV →

1 GeV →

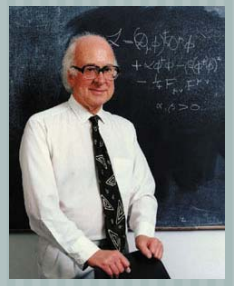
1 MeV →

0.01 eV →



DIE RÄTSEL DES 21. JAHRHUNDERTS

Was ist so besonders am Higgs-Feld?



Sir Peter Higgs

Es füllt das gesamte Universum gleichmässig (seit dem Big Bang)

Es gibt jedem Teilchen (auch den neu entstehenden) seine exakte Masse

Es ist wie eine ‘kosmische DNS’ (die ‘Erbinformation’ des Universums)

QuickTime™ and a
GIF decompressor
are needed to see this picture.

QuickTime™ and a
GIF decompressor
are needed to see this picture.

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GIF decompressor
are needed to see this picture.

Eine Party-Gesellschaft ...

Das Higgs-Feld ...

.. ein berühmter Gast will den Raum durchqueren...

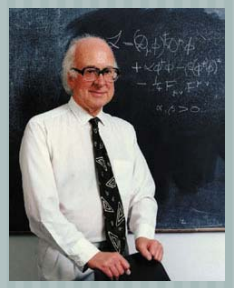
... ein neues Teilchen wird erzeugt ...

.. wird aber von den Gästen umringt und kommt nur schwer voran...

... das Higgs-Feld macht das Teilchen ‘schwer’ ...

DIE RÄTSEL DES 21. JAHRHUNDERTS

Das Higgs-Teilchen



Sir Peter Higgs

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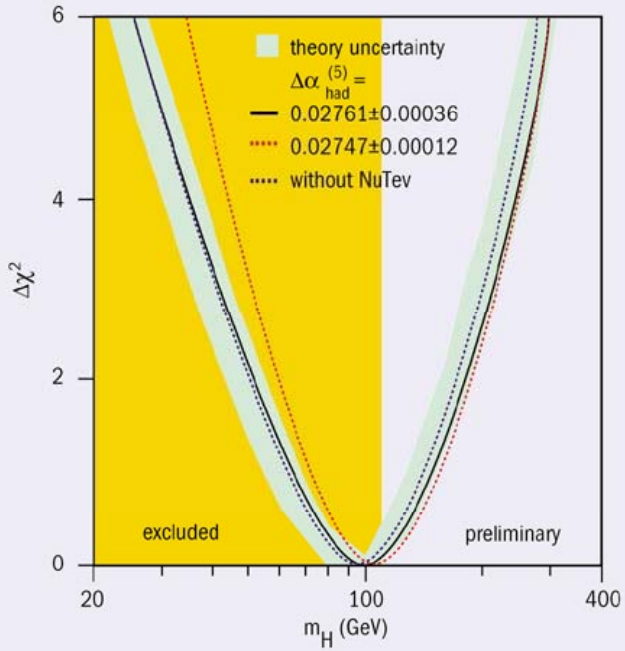


Ein Gerücht wird in die Party-Gesellschaft gerufen ...

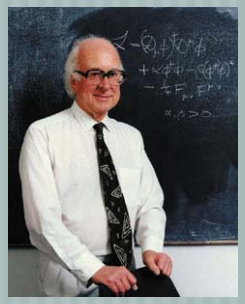
Das Higgs-Feld ...

.. alle kommen zusammen und tuscheln über die Nachricht...

... erzeugt seine erste Anregung, das Higgs-Teilchen ...

Aus früheren Messungen wird vorhergesagt,
dass die Masse des Higgs-Teilchens zwischen 120-200 GeV liegen sollte.

QUESTIONS FOR THE 21st CENTURY



The ‘Higgs’ field gives mass (inertia) to particles
“friction with the vacuum “

QuickTime™ and a
Microsoft Video 1 decompressor
are needed to see this picture.

Important note:

There could also be other (new) fields or particles that have the same effect as the Higgs field

How electrons and quarks acquire a mass

QUESTIONS FOR THE 21st CENTURY

2) Are particles and fields connected - Supersymmetry ?

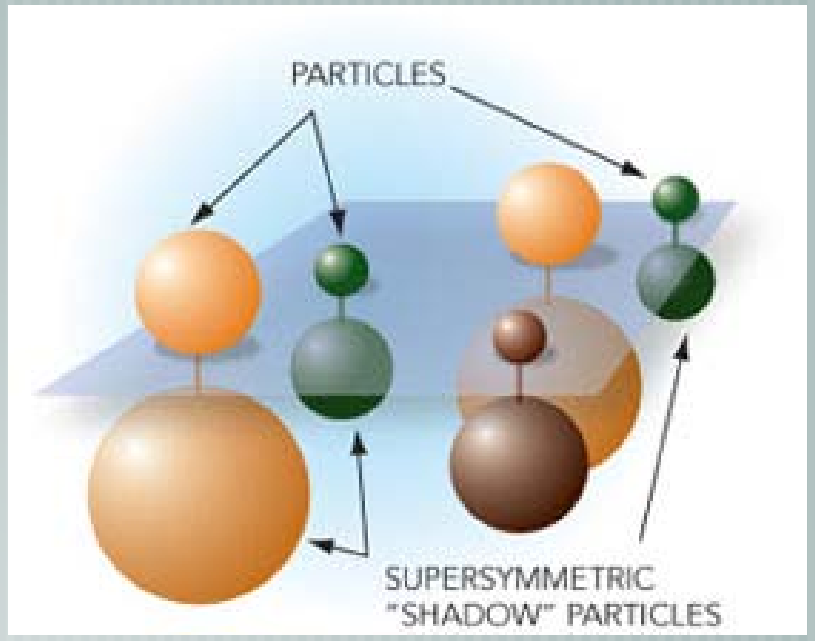
'Matter' particles (Spin 1/2=fermion)) interact by exchanging 'field' (Spin 1=boson) particles:

all particles (electrons, neutrinos, quarks) interact through 'gravitons' and W/Z fields
particles with electric charge (e.g. electrons, quarks) emit photons
particles with colour charge (quarks) emit gluons

Is there a deeper SUPERSYMMETRY between matter and fields? If yes:

all matter particles have a field partner
all field particles have a matter partner

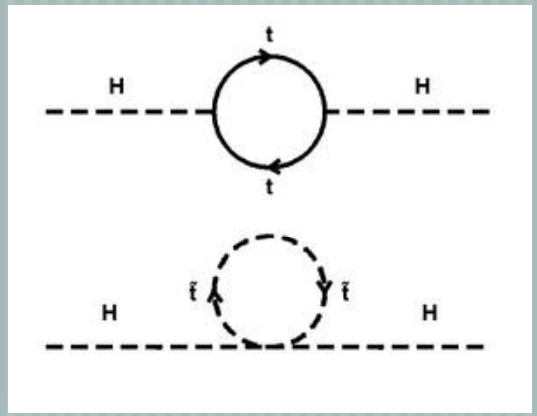
Spin 1/2	Integer spin
electron	selectron (S=0)
quark	squark (S=0)
photino	photon (S=1)
gluino	gluon (S=1)



If they exist - they must be VERY MASSIVE (> 200 GeV)

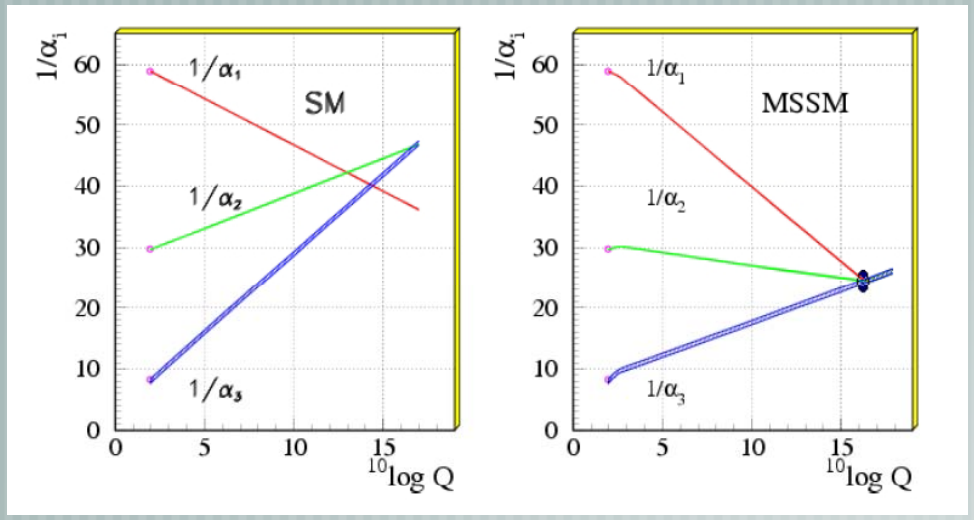
Reasons for Supersymmetry

1) A fundamental symmetry of space and time



2) "Protection" of SM particle masses (< 10^3 GeV)
from vacuum fluctuations up to Planck Scale (10^{19} GeV)

3) Suggests unification of three forces at a single unification point (~10^{17} GeV)

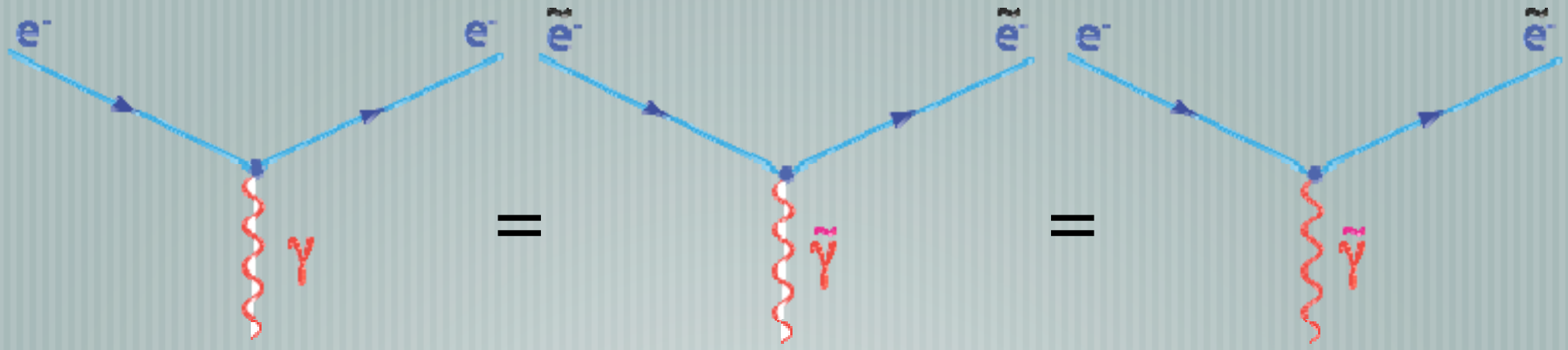


4) Possible explanation of cosmological matter-antimatter asymmetry

5) **Dark matter** ?

If Nature was supersymmetric, then:

Particles and their Super-Partners can be interchanged



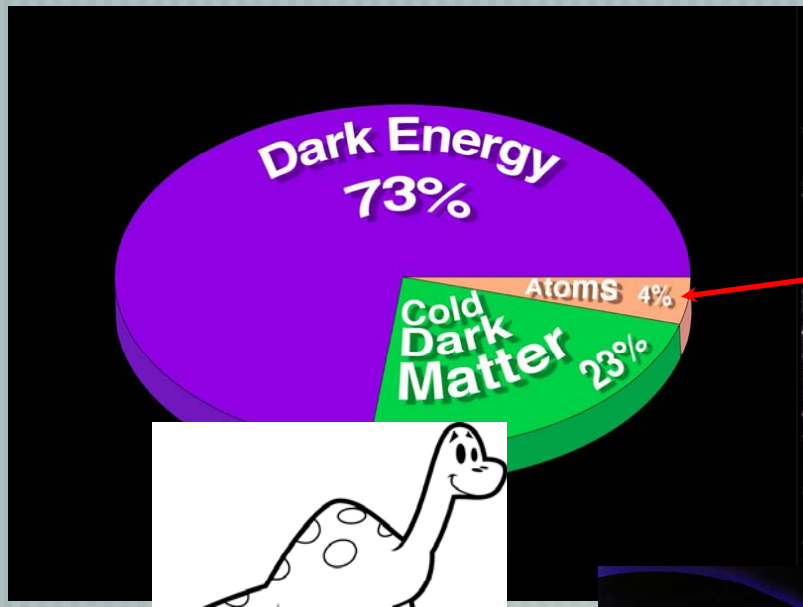
e = electron

$\tilde{e}$ = selectron

© = photon

$\tilde{©}$ = photino

DIE RÄTSEL DES 21. JAHRHUNDERTS

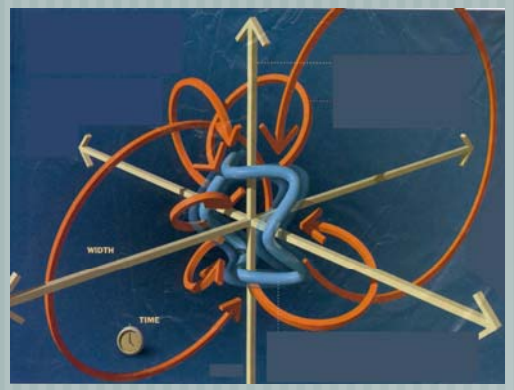


Wir+Planeten+Sterne

SUSY = Dunkle Materie-Teilchen?
Überbleibsel vom Big Bang?

DIE RÄTSEL DES 21. JAHRHUNDERTS

Was sind Teilchen?

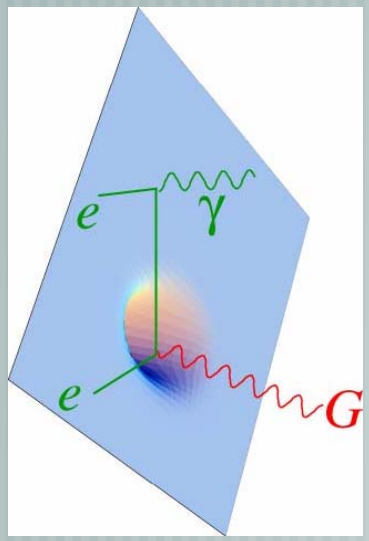


Superstrings in 10 Dimensionen?

Sind Teilchen kleine 'Strings' die im 10-dimensionalen Raum vibrieren?
Länge $\sim 10^{-35}$ m (Planck Länge)
Verschiedene Schwingungsmoden entsprechen verschiedenen Teilchen
Graviton ist im Spektrum enthalten!

Schwierigkeiten:
Es gibt keine Voraussage, warum und wie die zusätzlichen Dimensionen verschwunden sind.
Es gibt keine Möglichkeit, die Eigenschaften der Teilchen vorherzusagen.

Quanten-Gravitation ?



'Sieht' ein Graviton **mehr als 3 Raumdimensionen?**

Die Gravitation könnte deshalb so schwach sein weil sich die Gravitation in 4 oder mehr Raum-Dimensionen ausbreitet und damit aus unserem 3-dimensionalen Universum entkommt.

Kollisionen im LHC könnten dann mikroskopische schwarze Löcher erzeugen.

Ein Blick in die Zukunft

1900 - 2000: Phantastischer Fortschritt im Verständnis von Materie und Universum

Wir wissen heute woraus die Materie besteht.
Wir kennen auch die wichtigsten Etappen in der Entstehung des Universums

Heute stellen sich neue, tiefere Fragen:

Was sind Teilchen? Sind Quarks und Leptonen wirklich elementar?
Wo liegt die Verbindung zwischen Quarks und Leptonen (identische Ladung!!)
Was ist die dunkle Materie?
Gibt es neue Kräfte in der Natur?
Was macht die 'Teilchenfamilien' aus? Warum gibt es genau drei?
Was ist der Ursprung der Naturkonstanten? Was bestimmt ihre relative Grösse?
Ist das Leben im Universum ein Zufall?
Wie ist die Antimaterie verschwunden?
Was hat die kosmische Inflation ausgelöst?
Kann die Natur durch ein einziges Gesetz beschrieben werden?
Warum hat das Vakuum eine so geringe Energie?

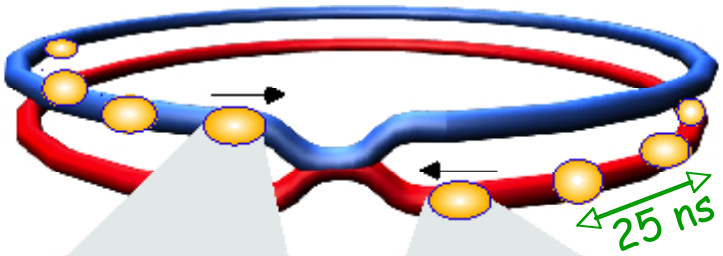
Die Physik des 21. Jahrhunderts ...

DIE RÄTSEL DES 21. JAHRHUNDERTS

LHC START IM JAHR 2008

Neue Entdeckungen !

Collisions at LHC



Proton-Proton

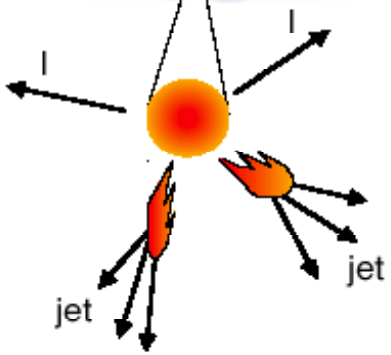
Protons/bunch	10^{11}
Beam energy	7 TeV (7×10^{12} eV)
Luminosity	10^{34} cm^{-2} s^{-1}

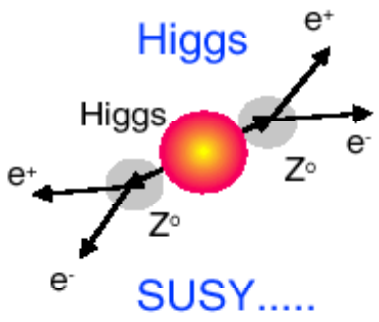
Bunch

Proton

Parton
(quark, gluon)

Particle





SUSY.....

Event rate in ATLAS :

N = L x σ (pp) ≈ 10^9 interactions/s

Mostly soft (low p_T) events

Interesting hard (high- p_T) events are rare

Selection of 1 in
10,000,000,000,000