An Excursion into the Attouniverse and Beyond

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Vienna, 19.10.2010

Overture

1676

A very important year for the humanity !

1676 : The Discovery of the Microuniverse (Animalcula) (The Empire of Bacteria)

10^{-6}m

Antoni van Leeuwenhoek
***24.10.1632 ✝27.08.1723**

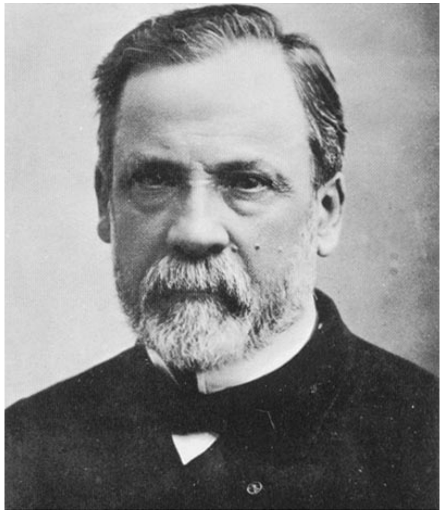
~500 Microscopes

(Magnification by ~300)

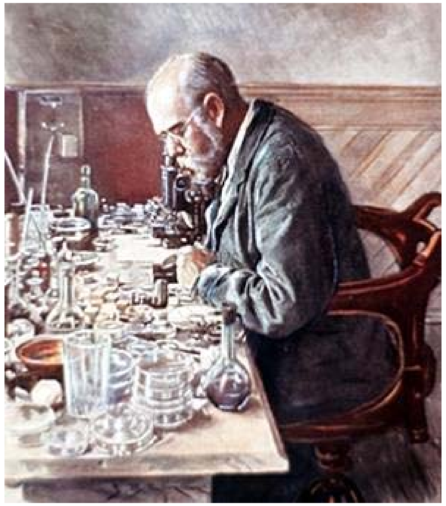
Microbe Hunters

Antoni van Leeuwenhoek
*24.10.1632 ✝27.08.1723

Lazzaro Spallanzani
*12.01.1729 ✝12.02.1799



L. Pasteur
*27.12.1822 ✝28.09.1895



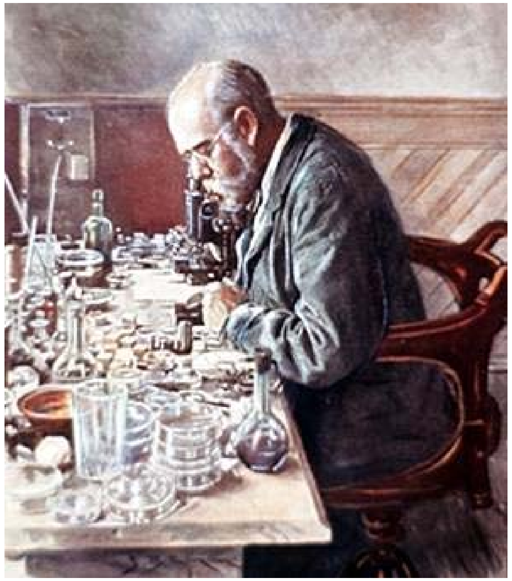
Robert Koch
*11.12.1843 ✝27.05.1910

An Excursion towards the Very Short Distance Scales:

1676 - 2020

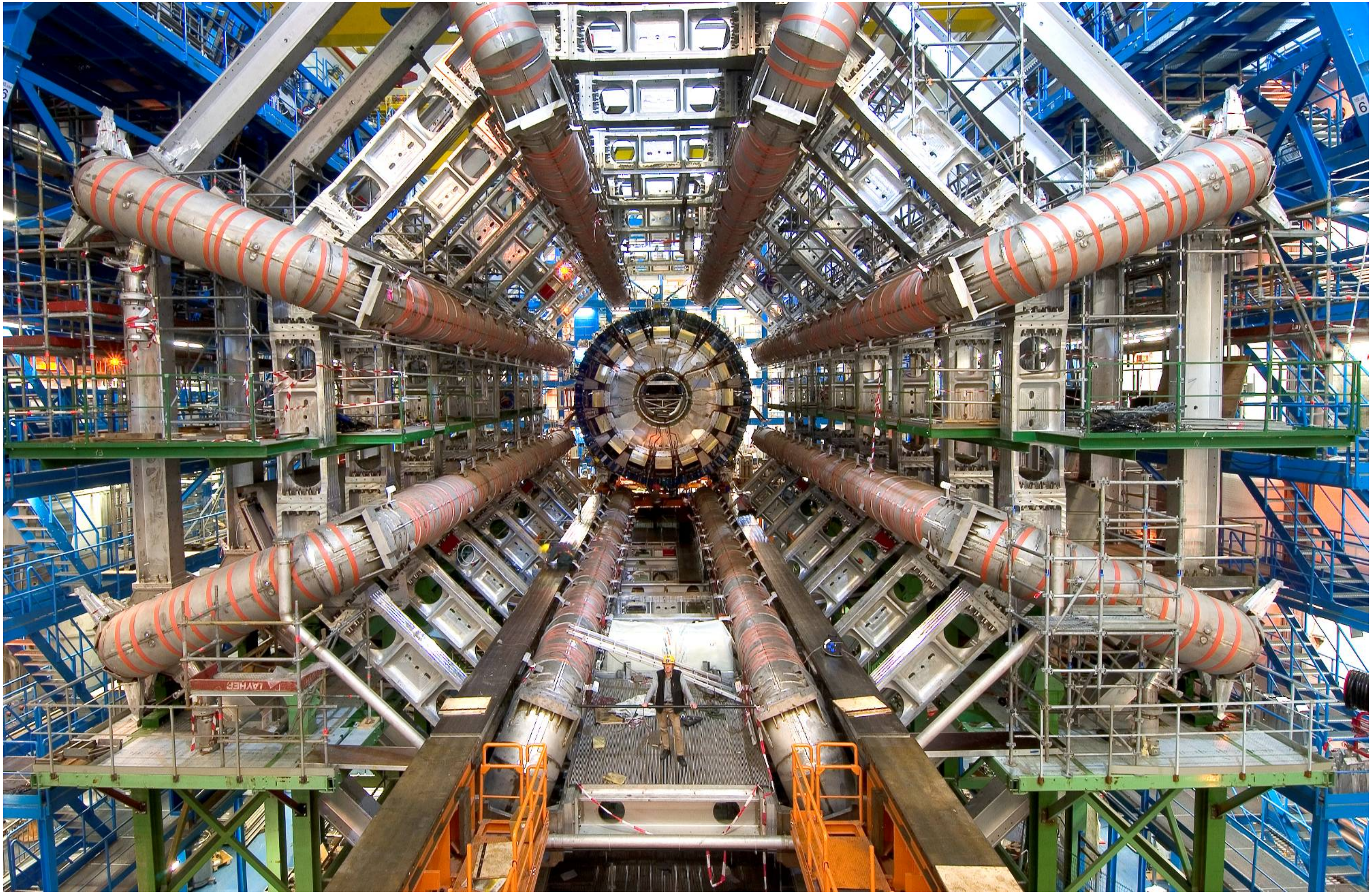
Microuniverse	10^{-6}m	Bacteriology Microbiology
Nanouniverse	10^{-9}m	Nanoscience
Femtouniverse	10^{-15}m	Nuclear Physics Low Energy Elementary Particle Physics
Attouniverse	10^{-18}m	High Energy Particle Physics (present)
High Energy Proton-Proton Collisions at the LHC	$5 \cdot 10^{-20}$m	Frontiers of Elementary Particle Physics in 2010´s
High Precision Measurements of Rare Processes (Europe, Japan, USA)	10^{-22}m	

The Technology for the Microuniverse



Robert Koch
***11.12.1843 ✝27.05.1910**

Technology to go beyond the Attouniverse



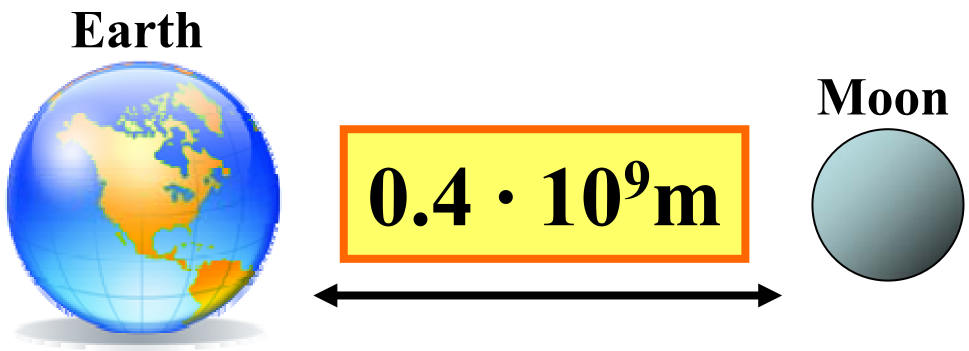
Large Hadron Collider at CERN

How small is really 10^{-18}m ?

How small is really 10^{-18}m ?

10^{9}m

3 light seconds



How small is really 10^{-18}m ?

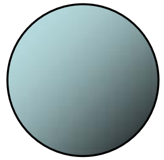
10^{9}m

3 light seconds

Earth

$0.4 \cdot 10^{9}$m

Moon



10^{18}m

105 light years

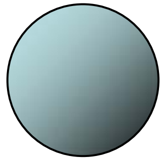
How small is really 10^{-18}m ?

10^{9}m

3 light seconds

Earth

Moon



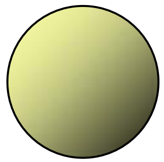
$0.4 \cdot 10^{9}$m

10^{18}m

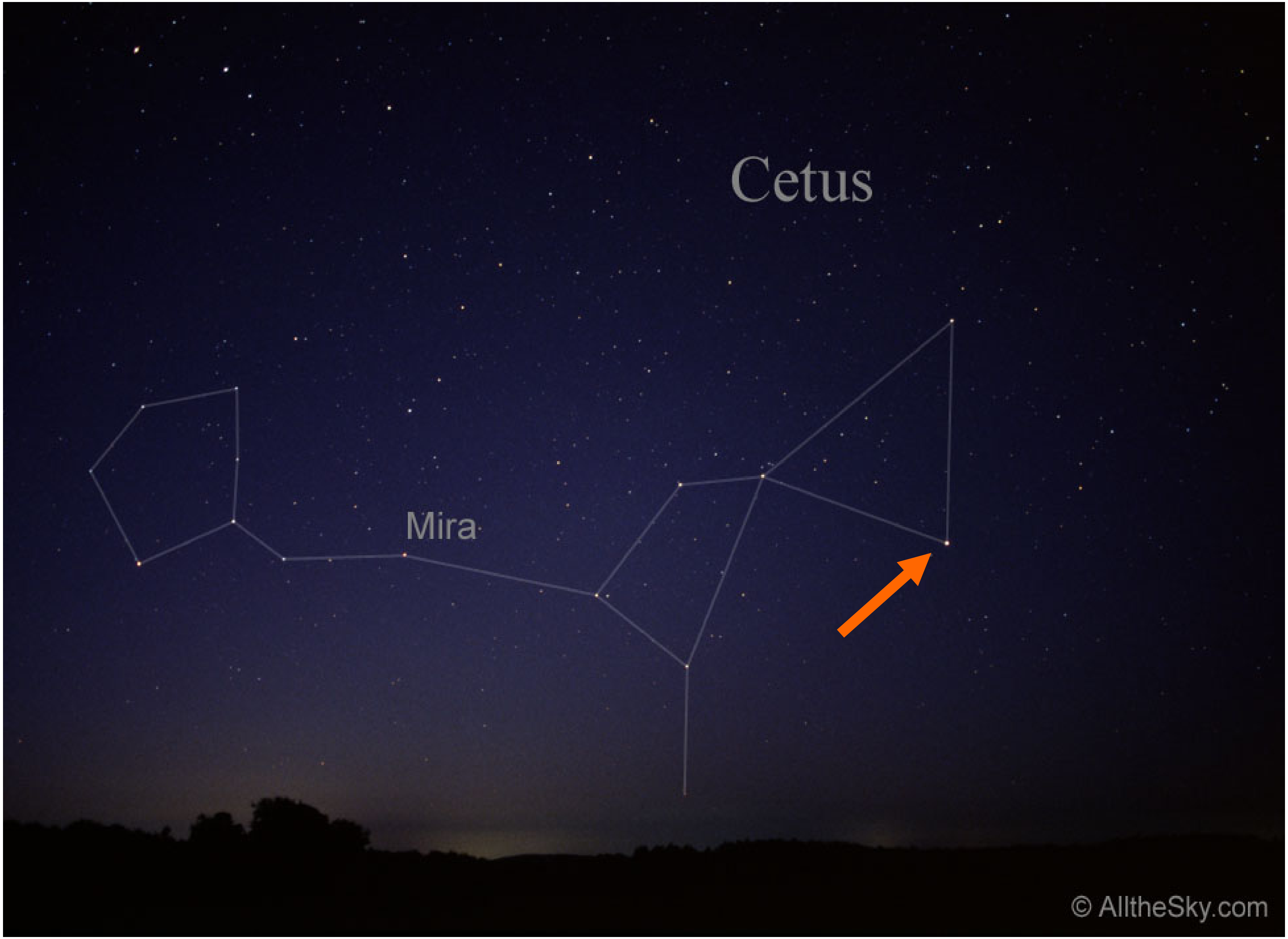
105 light years

Earth

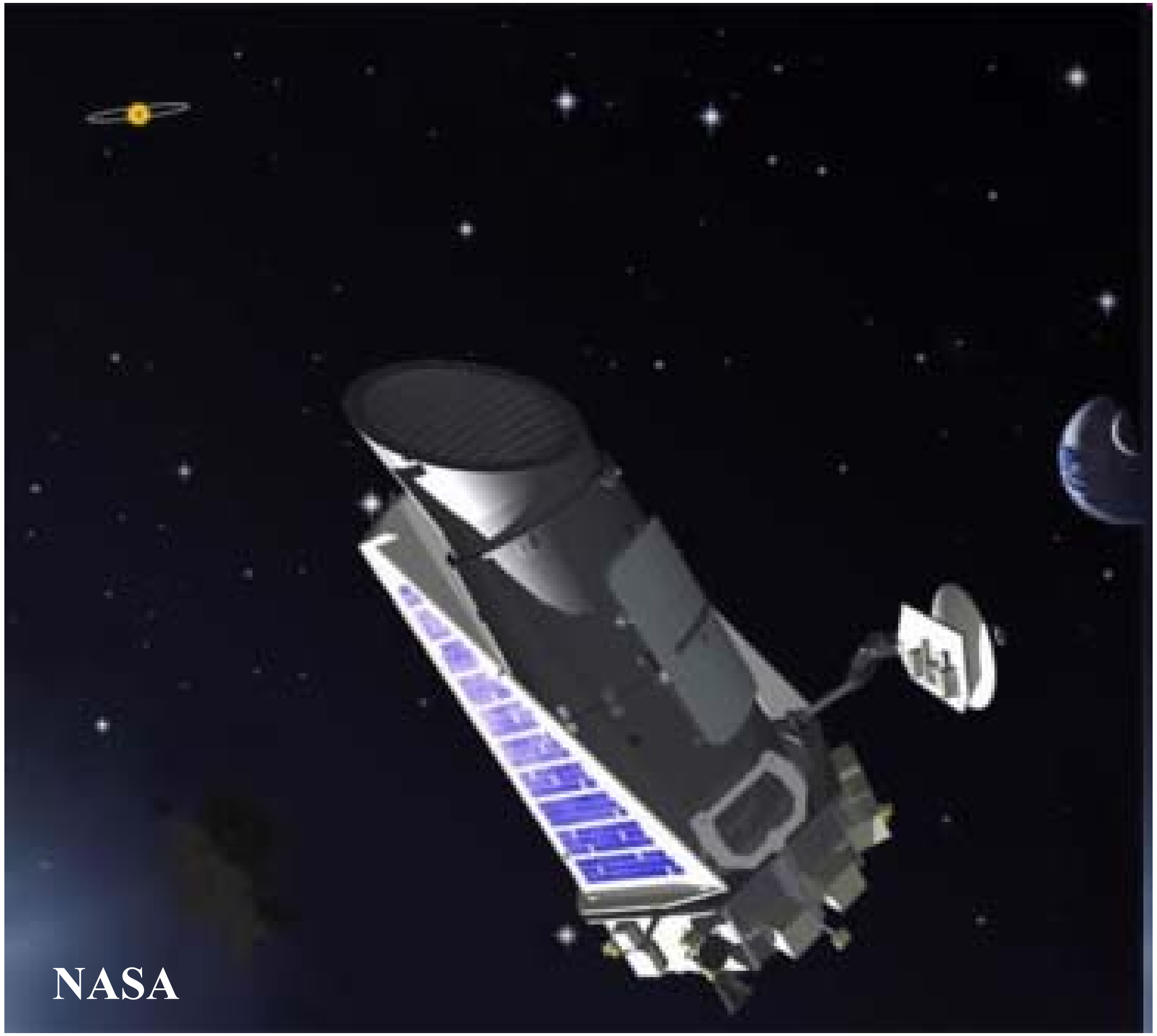
92 light years



Beta Ceti
(Deneb Kaitos
in the constellation
Cetus)


Cetus
Mira
© AlltheSky.com

Kepler Searching for new Planetary Systems and New Lifes



March 2009

Most important Message from this Talk

Antoni van Leeuwenhook discovered in 1676

Das Reich des mikroskopisch Kleinen (Animalcula)

Elementary Particle Physicists expect to discover

New Animalcula in the coming years with the help

of LHC and High Precision Experiments

Next 57 min

1st Movement	:	Introducing the Attouniverse (33 min)
2nd Movement	:	Expectations for New Animalcula (10 min)
3rd Movement	:	First Messages from New Animalcula (7 min)
4th Movement	:	Final Messages (TUM, IAS, EC) (7 min)

1st Movement

Introducing the Attouniverse

How to explore the Attouniverse ?

Heisenberg's Uncertainty Principle :

$$\underbrace{\Delta x}_{\text{Distance Interval}} \cdot \underbrace{\Delta p}_{\text{Momentum Interval}} \geq \frac{\hbar}{2}$$

$$\hbar = \frac{h}{2\pi}$$

h=Planck's constant

Use $\hbar = c = 1$:

Speed of light

$$E = mc^2$$

⬇

$$E = m$$

$(p = 0)$

$$E = \sqrt{p^2c^2 + m^2c^4}$$

⬇

$$E = \sqrt{p^2 + m^2}$$

$$\approx \sqrt{p^2} \text{ for } p^2 >> m^2$$

In order to explore:

Femtouniverse : $E \approx 200$ MeV $\approx m_\pi$

Attouniverse : $E \approx 200$ GeV $\approx m_{top}$
10^{-19}m $E \approx 2000$ GeV = 2 TeV

MeV = 10^6eV

GeV = 10^9eV (proton mass)

What do we know about the Attouniverse ?

Periodic Table of Elementary Particles

(Fermions : Spin ½)

Families ↓

Families	Generation 1	Generation 2	Generation 3	Charge	
1	ν_e	ν_μ	ν_τ	0	Neutrinos
2	e^-	μ^-	τ^-	-1	Charged Leptons
3	u u u	c c c	t t t	2/3	Quarks
4	d d d	s s s	b b b	-1/3	Quarks

Generations: 1, 2, 3

6 Flavours

u = up
d = down
c = charm
s = strange
t = top
b = bottom

Masses of Elementary Particles

in units of GeV = 10^9eV

$$\begin{pmatrix} m_\nu, \\ m_u, \\ \vdots \end{pmatrix}$$

Families ↓

Families				
1	ν_e (≈0)	ν_μ (≈0)	ν_τ (≈0)	$< 10^{-9}$
2	e^- ($5\cdot10^{-4}$)	μ^- (0.105)	τ^- (1.78)	
3	u ($3\cdot10^{-3}$)	c (1.3)	t (170)	
4	d ($6\cdot10^{-3}$)	s (0.110)	b (4.5)	

Very hierarchical structure

Particles in a given family distinguished only by the mass!

Interactions between Elementary Particles

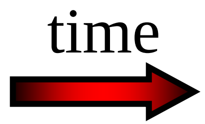
Mediated by Gauge Bosons (Spin 1)

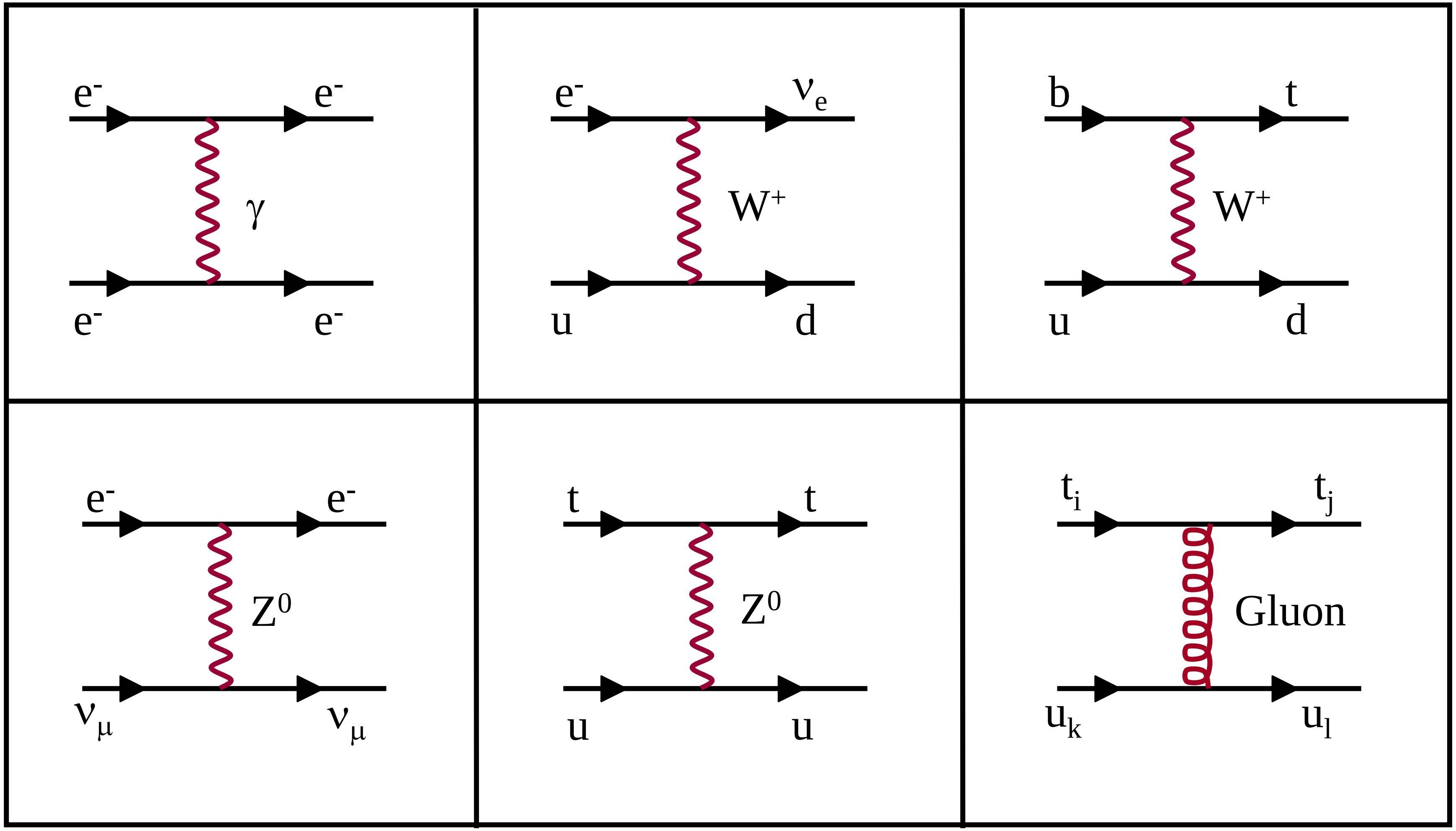
	Photon	Charge = 0	(QED)	(massless)
$W^{\pm}$	W-Boson	Charge = ±1	Weak Interactions	**Electroweak Interactions** (massive) 80 GeV
Z^0	Z-Boson	Charge = 0		91 GeV
8G	G_a-Gluons (a = 1,...8)	Charge = 0 (massless)	(QCD)	**Strong Interactions**

Confinement of Quarks at "Large" (10^{-15}m) scales

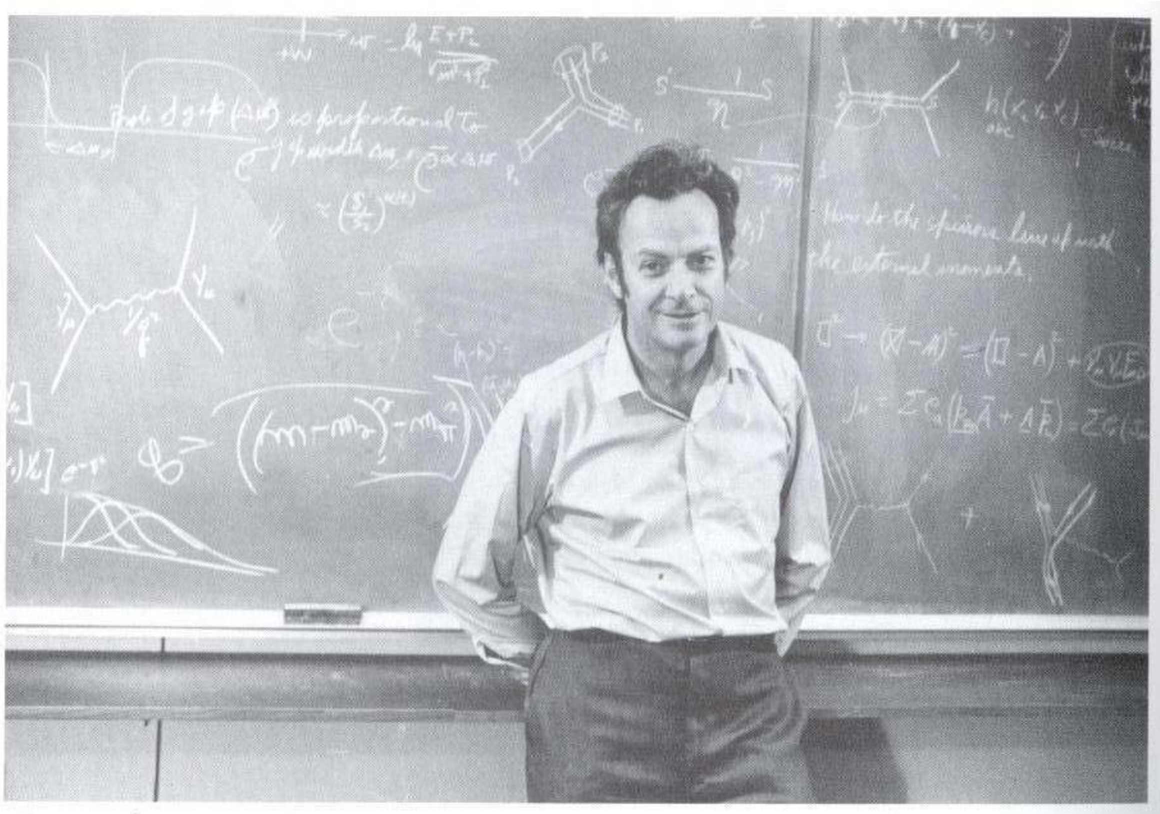
But carry new "Charge" - Colour

Feynman Diagrams at Work





The Great Master at Work

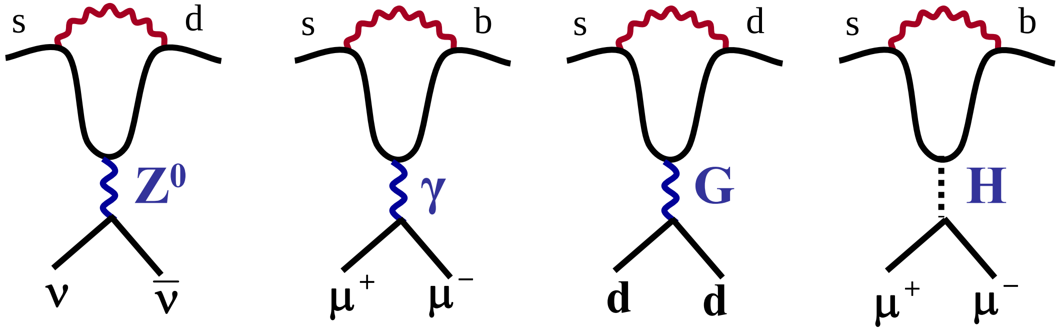


Richard Feynman

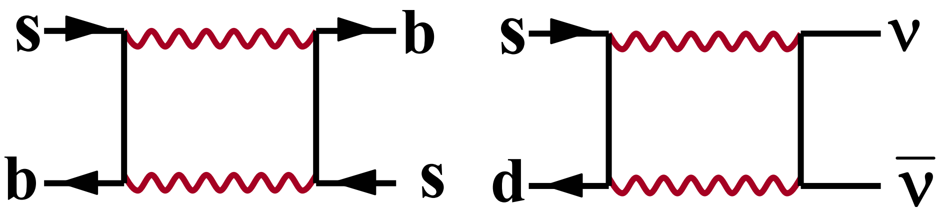
Phys. Rev. Bd 76 (1949) 769

More Complicated Feynman Diagrams

Penguin Family :

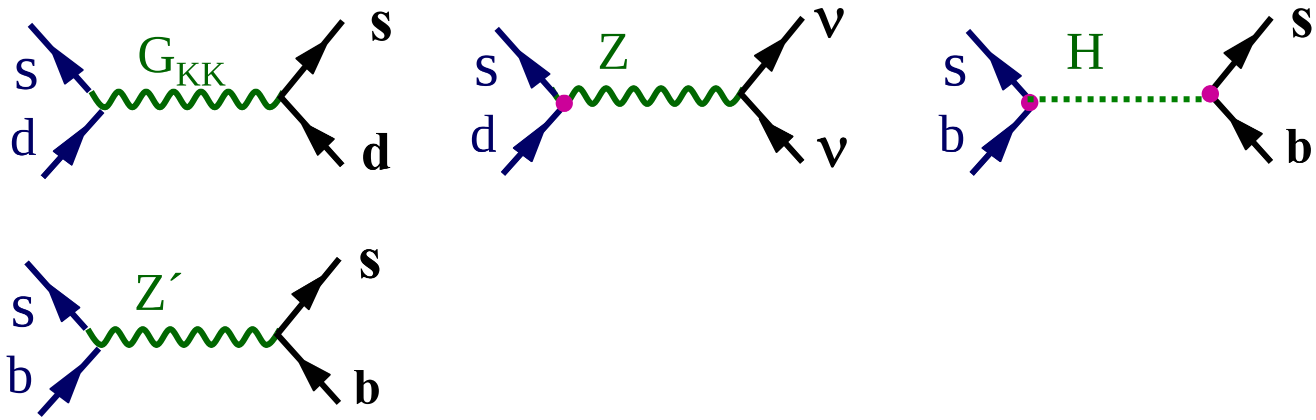


Box Diagrams



+ **other box diagrams**

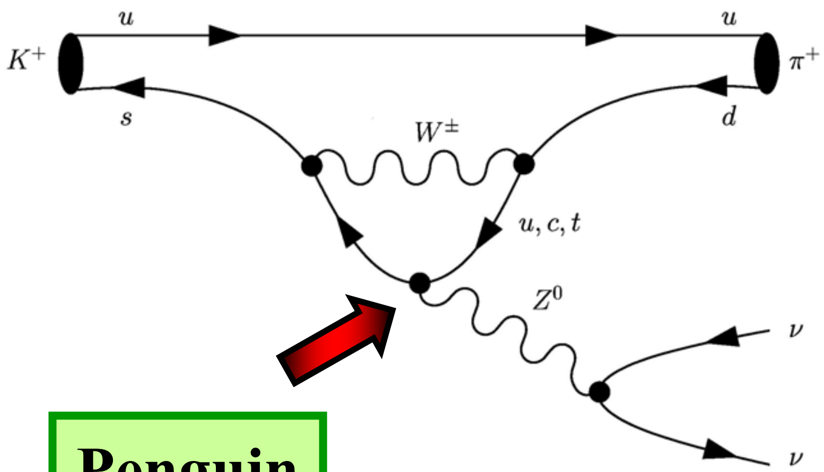
Tree Diagrams



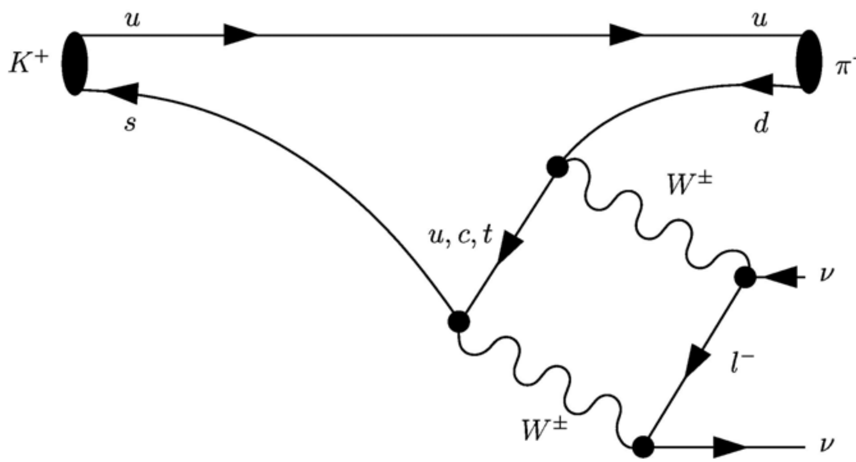
$K^+ \to \pi^+ \nu\bar{\nu}$

$K^+ = (u\bar{s})$

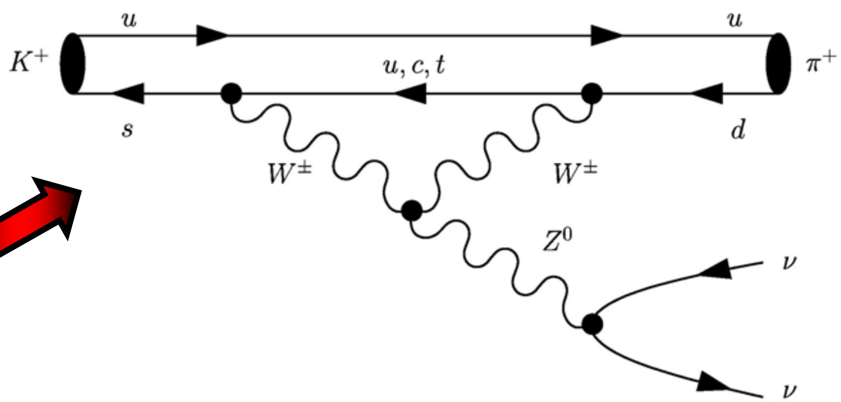
$\pi^+ = (u\bar{d})$



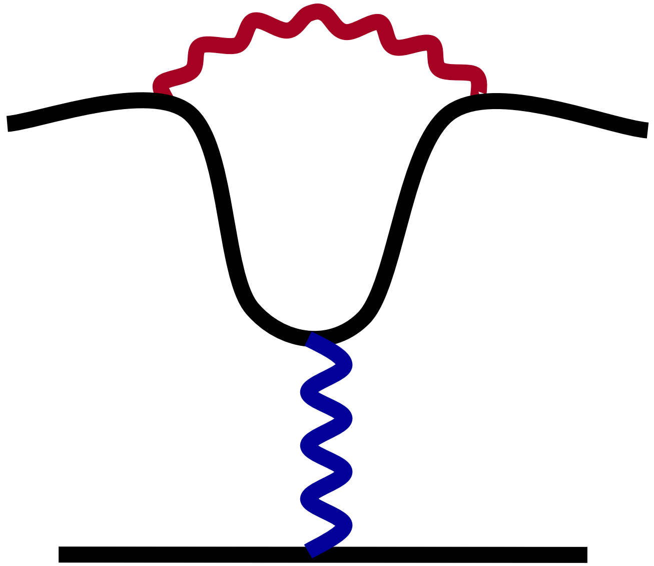
Penguin



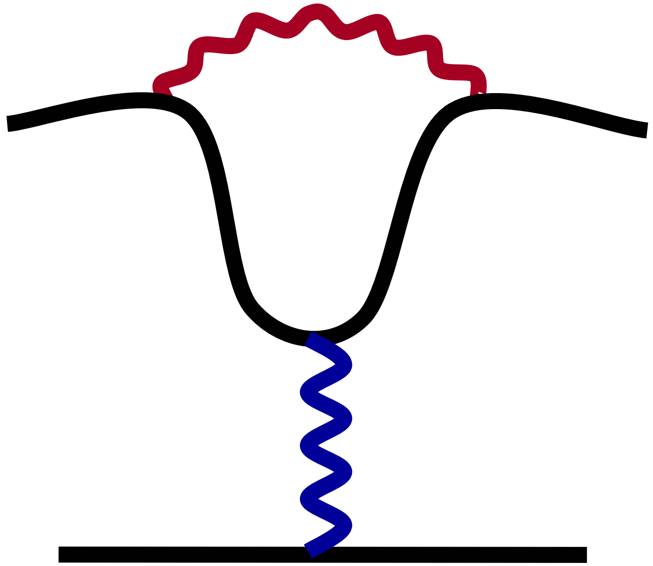
Box

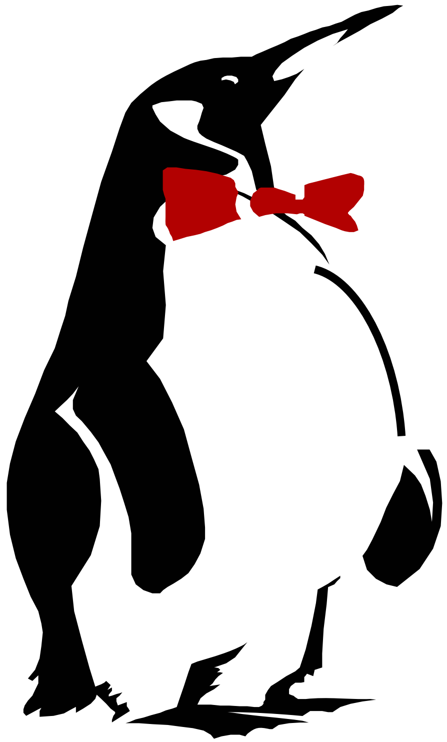


Still another Penguin



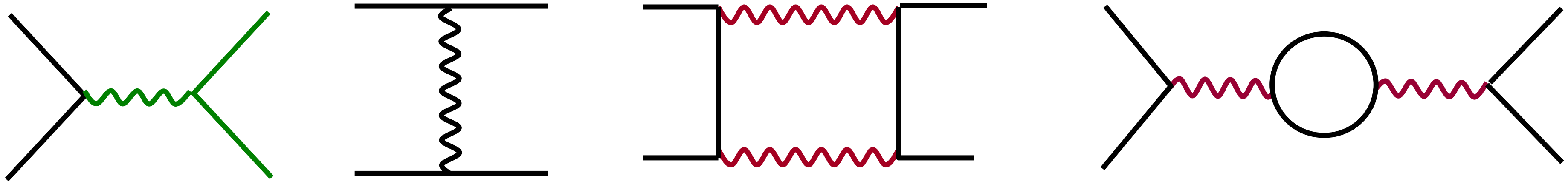
Penguin Diagram



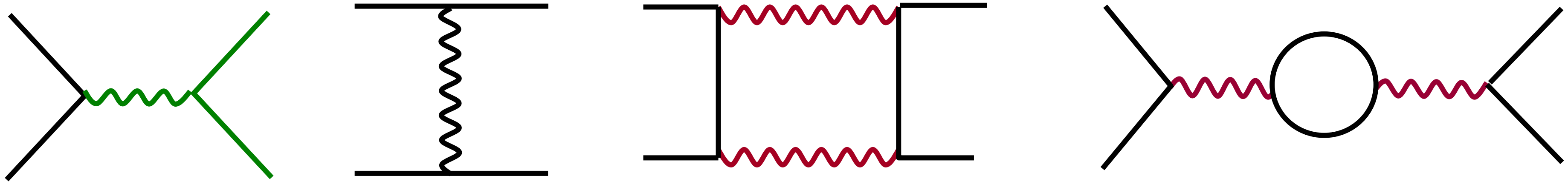


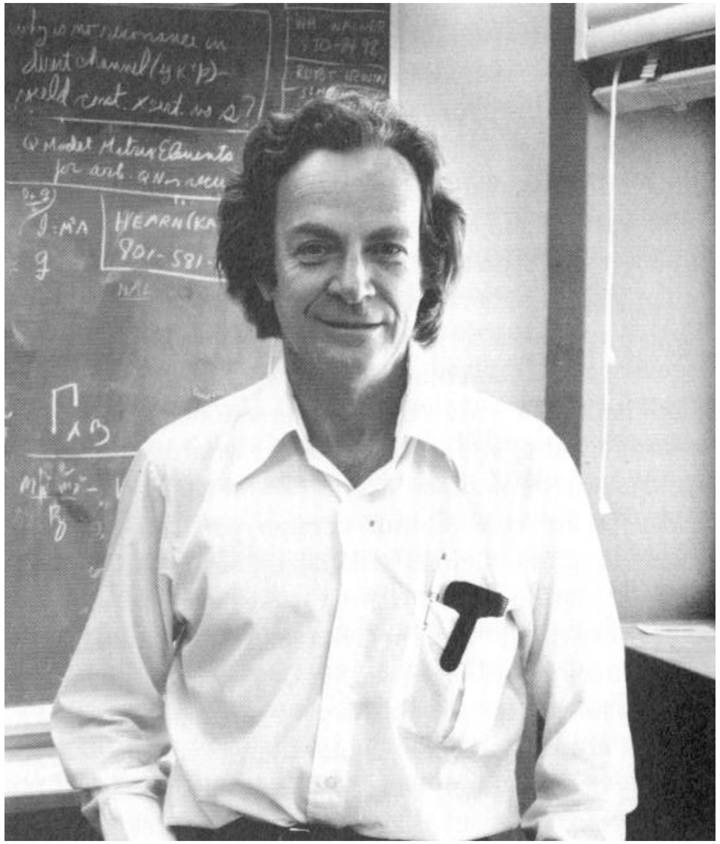
Penguin Diagram

Feynman Diagrams

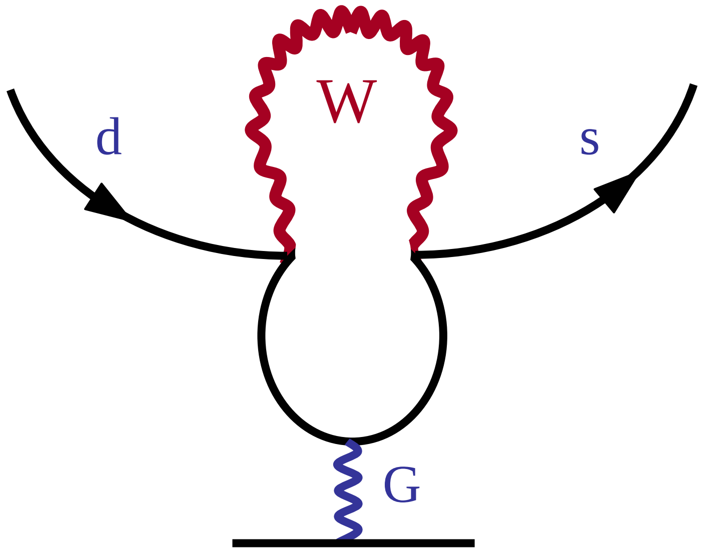


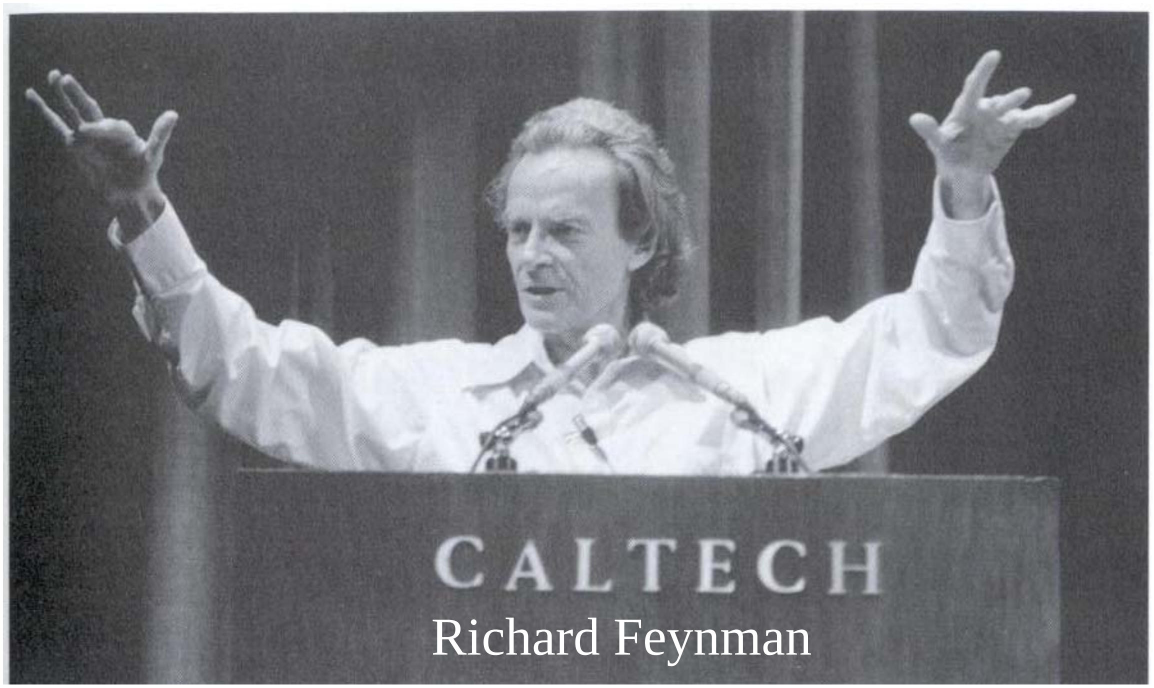
Feynman Diagrams



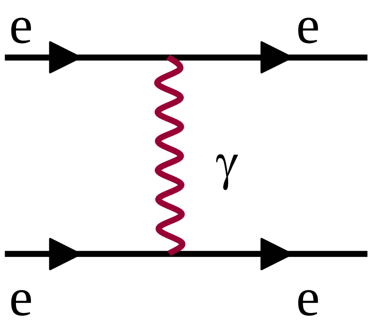


Richard Feynman


W
d
s
G

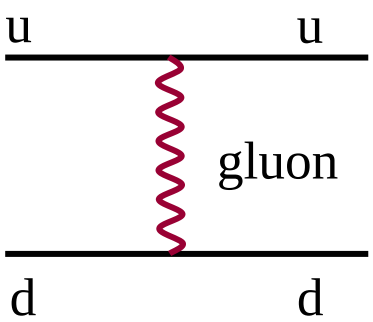

CALTECH
Richard Feynman

Strength of Interactions



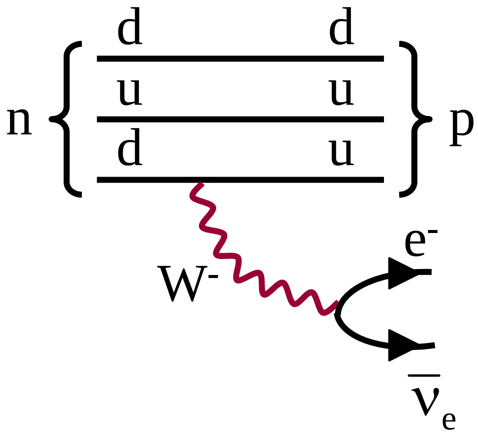
$$\alpha_{QED} \approx \frac{1}{137}$$

Sommerfeld's Structure Constant

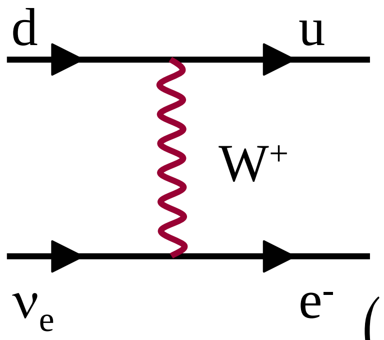


$$\alpha_{QCD} \approx 0(1)$$

Strong Interactions Structure Constant



$$n \to p e^- \bar{\nu}_e$$



$$\underset{\text{at low Energies}}{\sim} \frac{\alpha_{weak}}{M_W^2} \sim \underbrace{G_F}_{\text{Fermi Constant}} \cong 1 \cdot 10^{-5} \frac{1}{\text{GeV}^2}$$

$$(E \leq 1\text{GeV})$$

Fermi Constant

$$\alpha_{weak} \approx 4\alpha_{QED}$$

Weak Structure Constant

At low energies Weak Interactions are weak because of the large mass of $W^{\pm}$ (similarly for Z^0)

Basic Framework

Gauge Theories:
Relativistic Quantum Field Theories with elementary Forces following from Gauge Symmetries

Quantum Electrodynamics (QED)	Quantum Flavourdynamics (QFD)	Quantum Chromodynamics (QCD)
Symmetry: $U(1)_Q$	Symmetry: $SU(2)_L \otimes U(1)_Y$	Symmetry: $SU(3)_C$
Theory of electromagnetic interactions	Unified theory of weak and electromagnetic interactions	Theory of strong interactions (also basic for Nuclear Physics)
Mediated by Photon (γ) ($m_\gamma = 0$)	Mediated by weak gauge bosons Photon (γ), $W^\pm$ Z^0 ($m_\gamma = 0$) (80 GeV) (91 GeV)	Mediated by 8 Gluons ($m_G = 0$)

More Messages from the Attouniverse

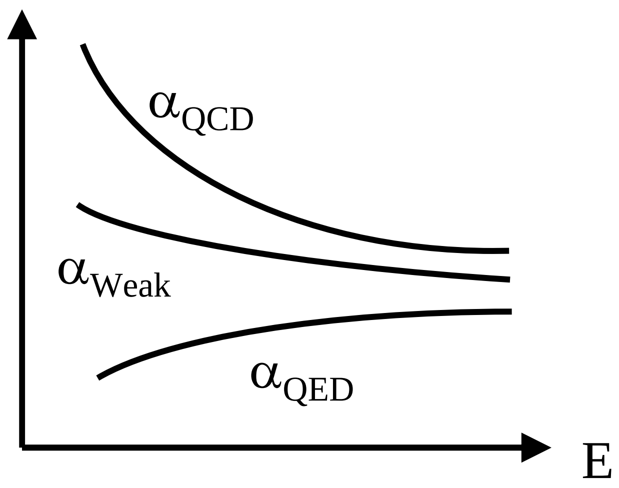
1.

At <u>very high energies</u> ($E \approx M_W, M_Z, m_t$)
supressions $1/M_W^2$, $1/M_Z^2$ not important

Weak Interactions as strong as electromagnetic ones.

2.

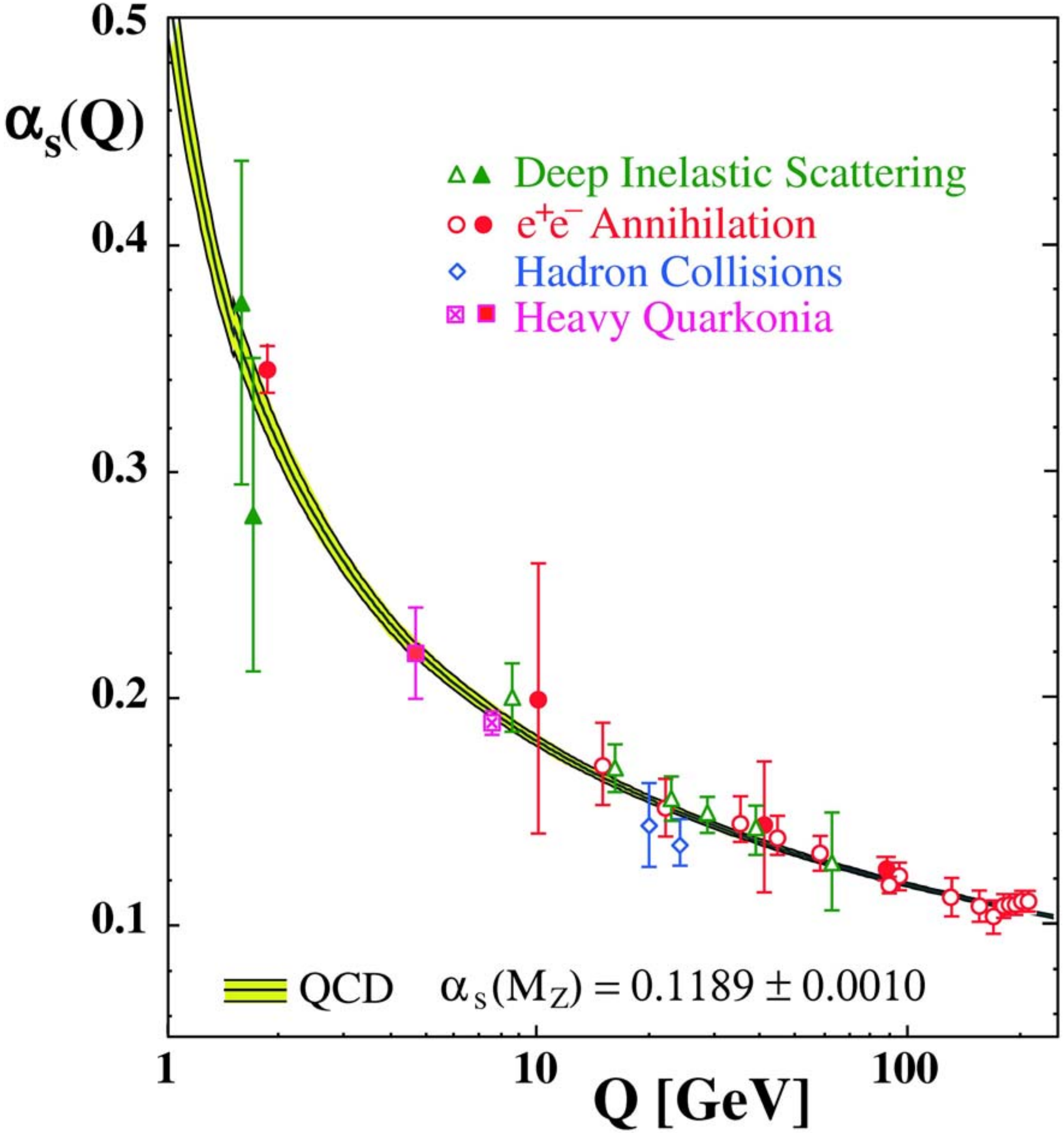
At <u>super high energies</u> ($E \approx 10^{16}$ GeV)



All interactions could have the same strength (Grand Unification of Forces)

In a Quantum Field Theory structure constants are energy dependent

Asymptotic Freedom in QCD



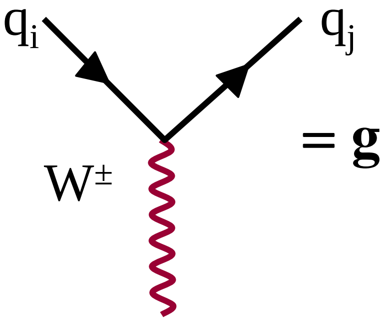
Bethke
hep-ex/0606035

Gross
Politzer
Wilczek

(1973)

Nobel Prize 2004

Hierarchical Structure of Quark Flavour-Changing Interactions



$= g_{Weak} V_{ij}$

$$\alpha_{Weak} = \frac{g_{Weak}^2}{4\pi}$$

Cabibbo-Kobayashi-Maskawa matrix

V_{ud}	V_{us}	V_{ub}
V_{cd}	V_{cs}	V_{cb}
V_{td}	V_{ts}	V_{tb}

Nobel Prize 2008

(would be a unit matrix for m_i=0)

u	c	t
d	s	b
①	②	③

≈ 1	≈ 0.2	$0.004e^{-i\gamma}$
≈ -0.2	≈ 1	0.04
$0.008e^{-i\beta}$	-0.04	≈ 1

Complex Phases (β,γ) responsible for violation of CP Symmetry

Matter – Antimatter Symmetry

$\beta \approx 23^{o}$

$\gamma \approx 70^{o}$

CKM (Nobel Prize 2008)

Dirac Medal (2010)

N. Cabibbo (1935-2010)

M. Kobayashi

T. Maskawa

Crucial Question

What is the Origin of Particle Masses and the Reason for their Hierarchy and Hierarchy of their Flavour-Changing Interactions ?

Explored in the Research Area C of our Universe Cluster

But the $SU(2)_L \otimes U(1)_Y$ Symmetry of the Standard Model

implies that

$W^\pm$, Z^0, quarks and leptons all should have masses 0 !

Total disaster !

Higgs Mechanism

Early 1960´ → Now

1. Add a system of scalar particles H that causes spontaneous breakdown

$SU(2)_L \otimes U(1)_Y \rightarrow U(1)_{QED}$

Breakdown only in vacuum! Not in $\mathcal{L}_{SM}$

Many properties of TH remain

2. Interactions of H with $W^\pm$, Z^0 give $M_{Z^0} \neq 0$, $M_{W^\pm} \neq 0$ while $m_\gamma = 0$

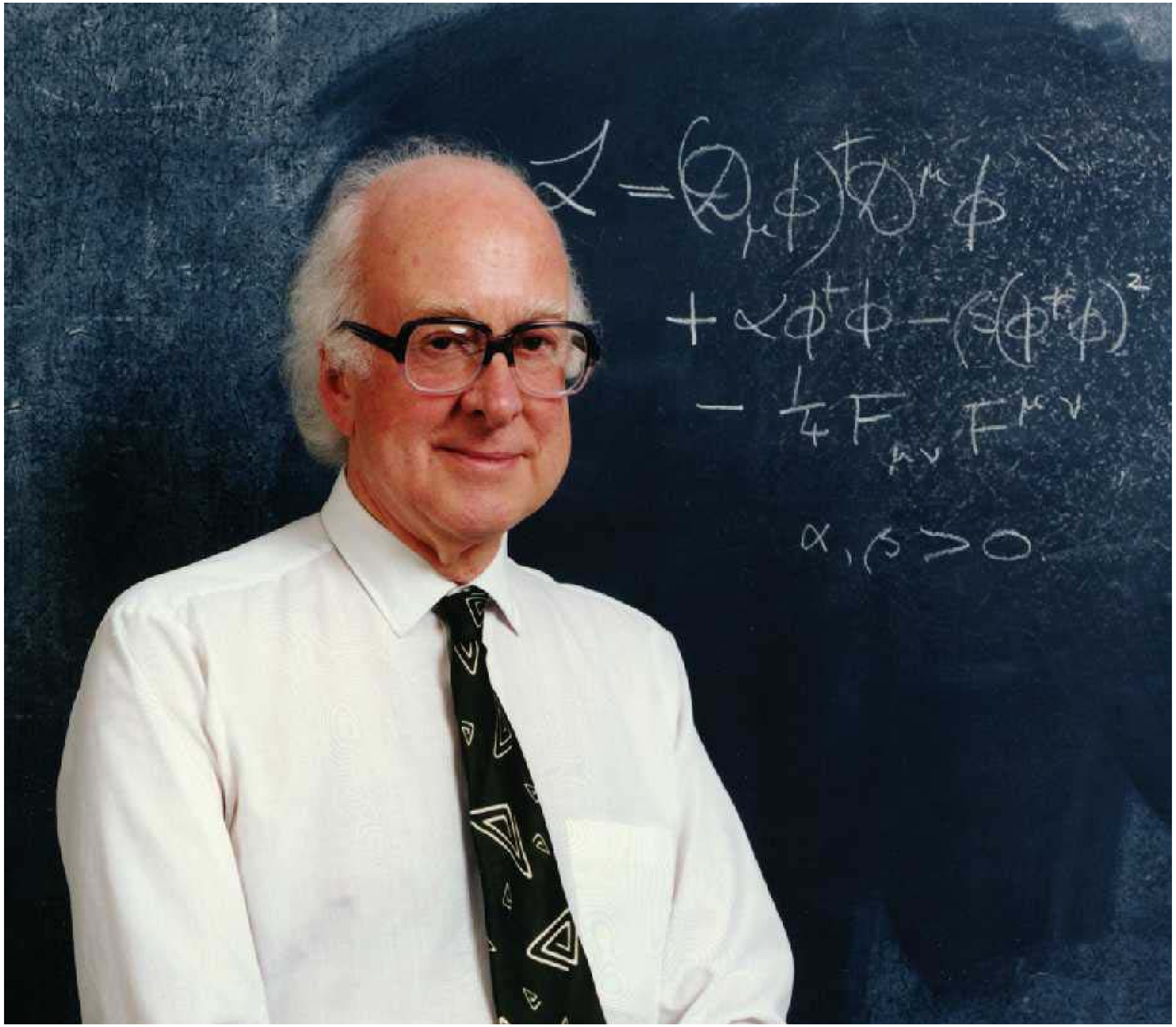
3. Interactions of H with quarks and leptons

→

$m_q \neq 0$	$V_{CKM} \neq 1$
$m_l \neq 0$	$V_{PMNS} \neq 1$

Parametrization of quark and lepton mass and of flavour-changing interactions possible

The only Higgs found : Peter Higgs



his mass (LEP)

$m_H > 114$ GeV

but in SM at most

190 GeV

Standard Model of Strong and Electroweak Interactions

Low Energy Effective Quantum Field Theory based on (< 200 GeV)

$$SU(3)_C \otimes SU(2)_L \otimes U(1)_Y \xrightarrow[\text{broken}]{\text{spontaneously}} SU(3)_C \otimes U(1)_{QED}$$

which describes low energy phenomena in terms of 28 Parameters that have to be determined from experiment.

The agreement of the Standard Model with the existing experimental data is very impressive

But there are Questions !

Where is the Higgs ?

How could we reduce the number of free parameters ?

What is the origin of different generations ? (Why only 3 ?)

Are there only 3 + 1 Dimensions ?

Matter-Antimatter Asymmetry ?

How can Higgs mass be protected from becoming $M_{Planck} \approx 10^{19}$ GeV ?

What is the origin of mass spectrum of Quarks and Leptons ?

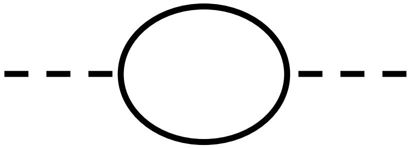
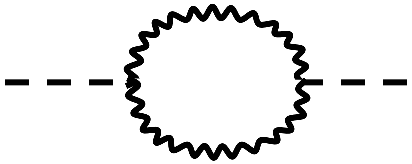
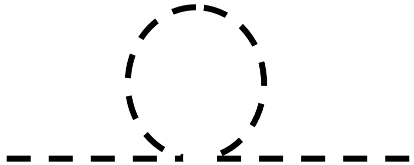
How could one unify all forces including Gravity ?

Dark Matter ?

Hierarchy (Naturalness) Problem

(Quadratic divergences in Higgs mass)

$m_H^2 \sim \Lambda^2_{cut\text{-}off}$ **through radiative effects**

Disaster for $\Lambda_{cut\text{-}off} >> 1$ **TeV**

$\Lambda_{cut\text{-}off} \approx \Lambda_{Planck}$

Must fine tune parameters to 34 decimal places to keep $m_H \sim$ few 100´s GeV

or postulate New Physics at scales 0 (1 TeV) = 10^3GeV which would remove these divergences

$\sim 10^{-19}$m

We need

New Physics

(new particles and forces)

in order to answer
all these questions and
solve all existing problems !

New Animalcula

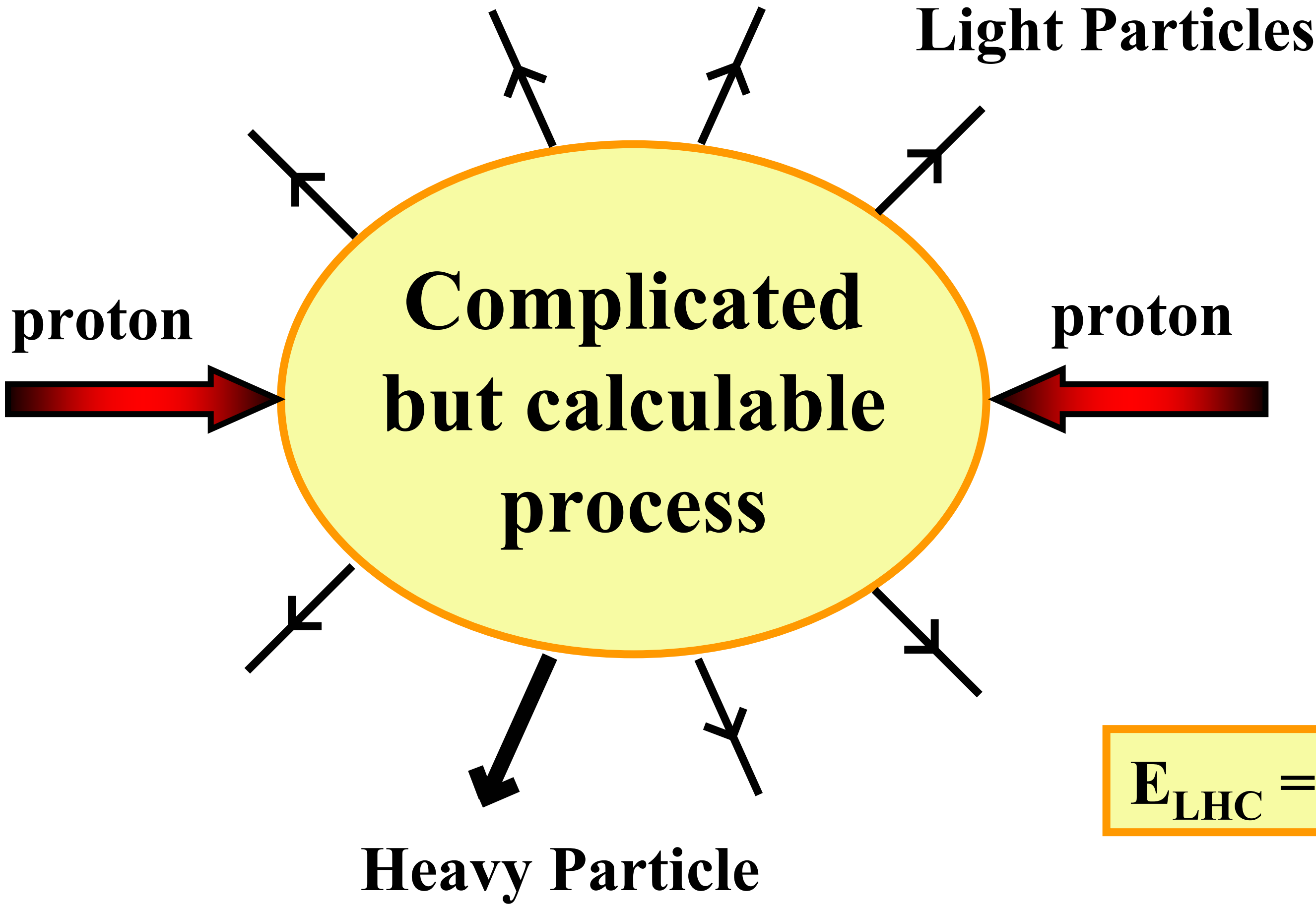
Complementary Methods to Search for New Physics

Direct Searches : **Limited by the available Energy**

Indirect Searches : **Quantum Fluctuations**

(Limited by precision)

Direct Search: Production of New Heavy Particles



$E_{LHC} = 14$ TeV

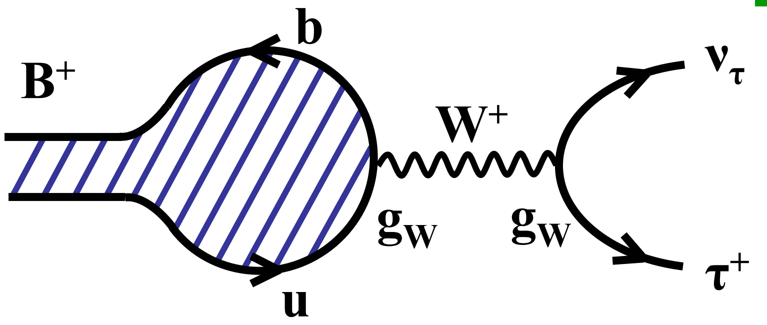
$c = 1$

For a Heavy Particle with mass M we need at least

at least	$E_{pp} = M$	if single produced	(t)
	$E_{pp} = 2M$	if pair produced	($t\bar{t}$)

Indirect Search: Precision Measurement of Decays of Mesons and Leptons

$B^+ \to \tau^+ \nu_\tau$

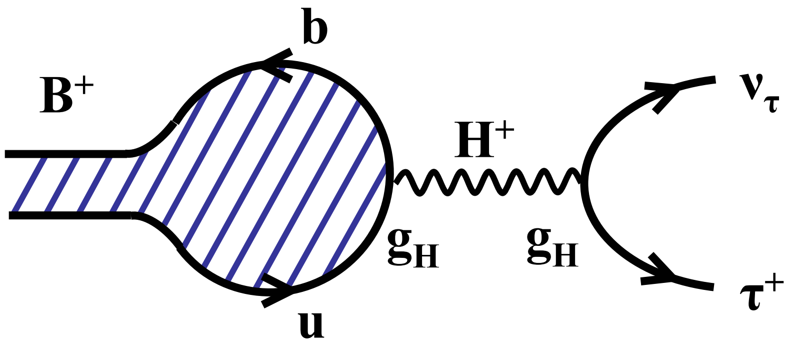


Standard Model

$$Br\left(B^+ \to \tau^+ \nu_\tau\right)_{SM} = \left| A \frac{g_W^2}{M_W^2} \right|^2$$

$m_B \approx 5$ GeV

A, B – parameters of a given theory



Contribution of a new charged Heavy Particle

$$Br\left(B^+ \to \tau^+ \nu_\tau\right) = \left| A \frac{g_W^2}{M_W^2} + B \frac{g_H^2}{M_H^2} \right|^2$$

$$\Delta = Br\left(B^+ \to \tau^+ \nu_\tau\right) - Br\left(B^+ \to \tau^+ \nu_\tau\right)_{SM} \neq 0$$

Signal of a new particle

Still Large Room for New Physics

Standard Model	Exp Upper Bound
$A_{CP}(B_s) \approx 0.04$	< 1.0
$Br(B_s \to \mu^+\mu^-) \cong 3 \cdot 10^{-9}$	$\sim 6 \cdot 10^{-8}$
$Br(K_L \to \pi^0 \nu\bar{\nu}) \cong 3 \cdot 10^{-11}$	$\sim 6 \cdot 10^{-8}$
$Br(K_L \to \mu e) \cong 10^{-40}$	$\sim 10^{-12}$
$Br(\mu \to e\gamma) \approx 10^{-54}$	$\sim 10^{-11}$
d_n electric dipole moment of the neutron $\approx 10^{-32}$ ecm	$\sim 10^{-26}$ ecm

2nd Movement

Expectations for New Animalcula

Elementary Scalar Particles (Spin = 0)

(Perturbative Framework for Electroweak Symmetry Breaking)

1. h^0 = Higgs of the Standard Model (Charge = 0)

2. But many models predict more Higgs particles (Neutral) h^0, H^0, A^0 and $H^{\pm}$ (charged)

3. Super-Partners of Quarks and Leptons in Supersymmetry (+2/3, -1/3, -1)

But

Higgs could be a bound state of new very heavy fermions: $H = (\bar{F}F)$ bound by a New strong force: (Technicolour)

Dynamical Breakdown of Electroweak Symmetry $SU(2)_L \otimes U(1)_Y \rightarrow U(1)_{QED}$

Similar to the BCS Theory of Superconductivity

4^{th} Generation of Quarks and Leptons

Heavy Quarks : $\begin{pmatrix} t' \\ b' \end{pmatrix}$ Charge $\begin{matrix} +2/3 \\ -1/3 \end{matrix}$

Heavy Leptons : $\begin{pmatrix} N \\ E \end{pmatrix}$ Charge $\begin{matrix} 0 \\ -1 \end{matrix}$

$$300 \text{ GeV} \leq m_t,\ m_b, \leq 600 \text{ GeV}$$

$$100 \text{ GeV} \leq m_N,\ m_E, \leq 600 \text{ GeV}$$

If they exist, LHC will find them !

Most important implication

New source of CP violation in 4 x 4 CKM-like Matrix required for matter-antimatter asymmetry observed in the universe

Standard Model cannot explain this asymmetry!

Two Pecularities of Weak Interactions within the Standard Model

1.

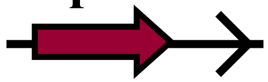
Breakdown of Parity Symmetry (conserved in QED and QCD)

Quark or Lepton

Spin

momentum

(left-handed)

Spin

momentum

(right-handed)

$W^{\pm}$ interact only with left-handed quarks and leptons

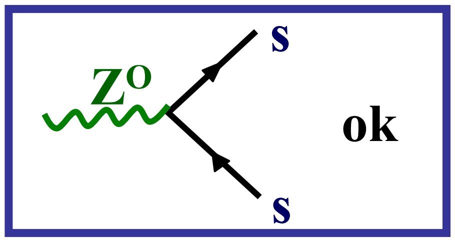
2.

No elementary Flavour-violating Couplings of Neutral Gauge Bosons

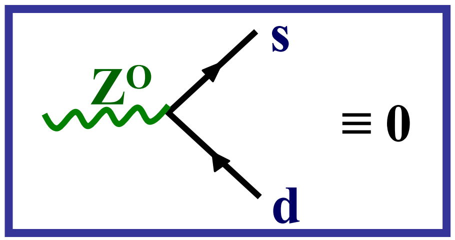
(Z^0, Photon, Gluons)

Glashow-Maiani-Iliopoulos Mechanism

<u>Example</u>



but



New Electroweak Forces

Most interesting : **Left-right symmetric models**
$SU(2)_L \otimes SU(2)_R \otimes U(1)$

New Heavy Gauge Bosons $W_R^{\pm}$, Z' masses ~ **1 TeV** **Order of magnitude heavier than** $W^{\pm}$ Z

Interacting with right-handed fermions

Implication : **Parity Conservation at Ultra short distances ~10^{-20}m!**

Spontaneous Breakdown of Parity :

$SU(2)_L \otimes SU(2)_R \otimes U(1) \rightarrow SU(2)_L \otimes U(1) \rightarrow U(1)$

Parity Violation in weak interactions at distances > 10^{-19}m

3rd Movement

First Messages from New Animalcula

Departures from Standard Model Expectations

(Most spectacular)

1. ν´s have masses! $(m_\nu)_{SM} = 0$

2. Anomalous Magnetic Moment of the muon $\left((g\text{-}2)_\mu\right)$

   disagrees by 3σ with the SM

3. CP violation in $B_s \equiv (\bar{b}s)$ decays much larger than predicted (3σ)

   hopes for the matter-antimatter asymmetry

DNA Tests of Flavour Models

O_i : Observables ***M_i : Models beyond SM***

	M_1	M_2	M_3	M_4	M_5
O_1	★★★	★	★	★	★★
O_2	★	★★	★★★	★★	★
O_3	★★	★★★	★★	★	★
O_4	★★★	★★	★	★★★	★★
O_5	★	★★★	★	★★	★★★

★★★ **Very large New Physics effect**

★★ **Moderate New Physics effect**

★ **Very small New Physics effect**

Models investigated by T31-Teams

(Last decade)

SM	MFV	MSSM+MFV	Z´-Models
General MSSM	Universal Extra Dimensions	RS with custodial protection	Right-Handed Currents
Littlest Higgs	Littlest Higgs with T-Parity	SUSY+Flavour Abelian Symmetry (Agashe+Carone)	2 Higgs Doublet Models
SUSY with SU(3) Flavour (Ross et al) (RVV2)	SUSY with SU(2) Flavour (LH-currents)	Flavour Blind MSSM	4G

"DNA" Patterns of New Physics Models

	AC	RVV2	AKM	δLL	FBMSSM	LHT	RS	4G
$D^0 - \bar{D}^0$	★★★	★	★	★	★	★★★	?	★★
ϵ_K	★	★★★	★★★	★	★	★★	★★★	★★
$S_{\psi\phi}$	★★★	★★★	★★★	★	★	★★★	★★★	★★★
$S_{\phi K_S}$	★★★	★★	★	★★★	★★★	★	?	★★
$A_{\rm CP}\,(B \to X_s\gamma)$	★	★	★	★★★	★★★	★	?	★
$A_{7,8}(B \to K^*\mu^+\mu^-)$	★	★	★	★★★	★★★	★★	?	★★
$A_9(B \to K^*\mu^+\mu^-)$	★	★	★	★	★	★	?	★★
$B \to K^{(*)}\nu\bar{\nu}$	★	★	★	★	★	★	★	★
$B_s \to \mu^+\mu^-$	★★★	★★★	★★★	★★★	★★★	★	★	★★★
$K^+ \to \pi^+\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★	★★★
$K_L \to \pi^0\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★	★★★
$\mu \to e\gamma$	★★★	★★★	★★★	★★★	★★★	★★★	★★★	★★★
$\tau \to \mu\gamma$	★★★	★★★	★	★★★	★★★	★★★	★★★	★★★
$\mu + N \to e + N$	★★★	★★★	★★★	★★★	★★★	★★★	★★★	★★★
d_n	★★★	★★★	★★★	★★	★★★	★	★★★	★
d_e	★★★	★★★	★★	★	★★★	★	★★★	★
$(g-2)_\mu$	★★★	★★★	★★	★★★	★★★	★	?	★

2020 Vision

	NEW SM
$D^0 - \bar{D}^0$	★★
ϵ_K	★★
$S_{\psi\phi}$	★★★
$S_{\phi K_S}$	★★
$A_{\rm CP}\,(B \to X_s\gamma)$	★
$A_{7,8}(B \to K^*\mu^+\mu^-)$	★★
$A_9(B \to K^*\mu^+\mu^-)$	★
$B \to K^{(*)}\nu\bar{\nu}$	★★★
$B_s \to \mu^+\mu^-$	★★★
$K^+ \to \pi^+\nu\bar{\nu}$	★★
$K_L \to \pi^0\nu\bar{\nu}$	★★★
$\mu \to e\gamma$	★★★
$\tau \to \mu\gamma$	★★★
$\mu + N \to e + N$	★★★
d_n	★★★
d_e	★★★
$(g-2)_\mu$	★★

4^{th} Movement

Final Messages (TUM, IAS, EC)

Many Thanks to my Collaborators

SUSY


W. Altmannshofer


S. Gori


P. Paradisi


D. Straub

LHT


M. Blanke


B. Duling


S. Recksiegel


C. Tarantino

RS


M. Albrecht


M. Blanke


B. Duling


K. Gemmler


S. Gori


A. Weiler

4 G

B. Duling

T. Heidsieck

C. Promberger

T. Feldmann

S. Recksiegel

2 HDM

M.V.Carlucci

S. Gori

G. Isidori

ε_K

D. Guadagnoli

RH Currents

K. Gemmler

G. Isidori

Focus Group : Fundamental Physics (TUM-IAS)

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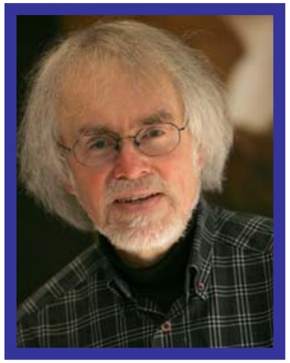
Carl von Linde
Fellow
(2008-2011)



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S. Pokorski

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(2009-2012)

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Contacts with other Groups at TUM

Low Energy QCD

Effective Theories

Lattice QCD


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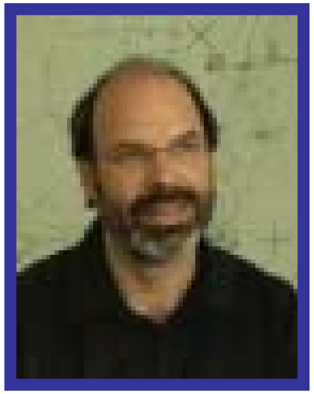
A. Vairo


N. Kaiser

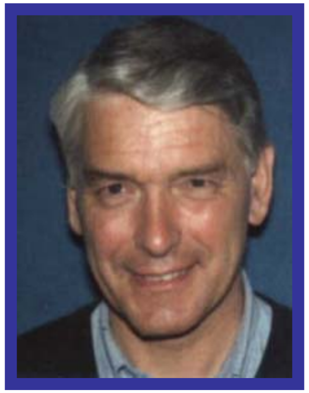

P. Hägler

Experimental Groups

Compass EDM's


S. Paul


T. Soldner


F. v. Feilitzsch


L. Oberauer

Neutrinos Dark Matter

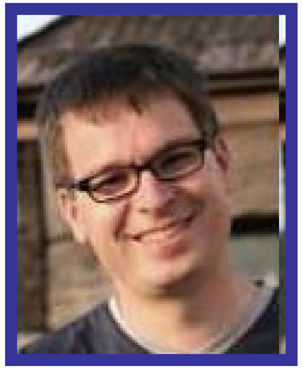
Excellence Cluster (Universe) MPI-Physics)

C. Kiesling

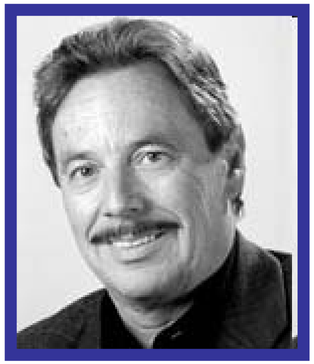
F. Simon

D. Schaile

O. Biebel



J. Schieck



W. Hollik

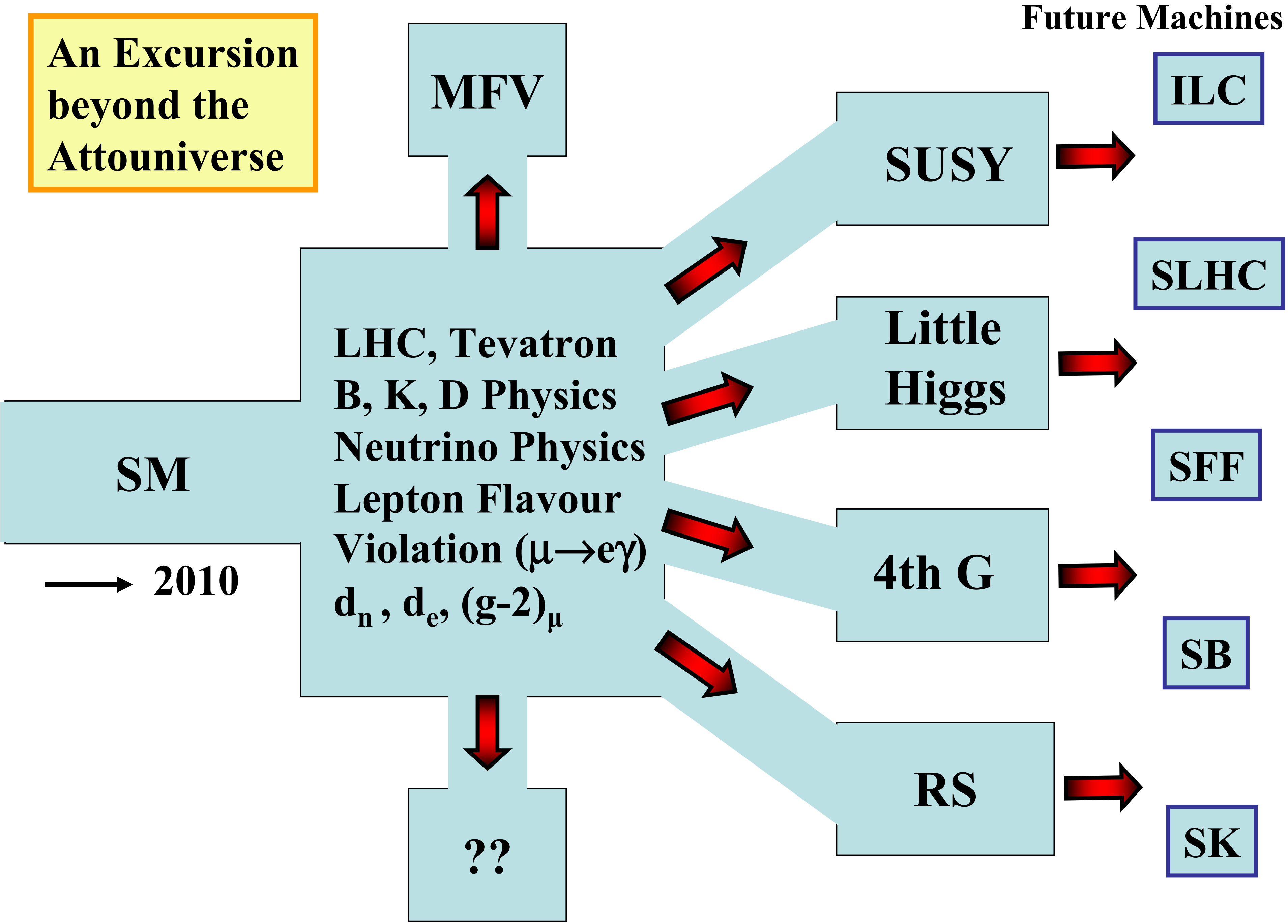
A. Hoang

S. Bethke

G. Raffelt

P. Fierlinger

Rondo Vivace !


An Excursion beyond the Attouniverse
Future Machines
MFV
SM
2010
LHC, Tevatron
B, K, D Physics
Neutrino Physics
Lepton Flavour
Violation (μ→eγ)
d_n , d_e, $(g-2)_\mu$
SUSY
Little Higgs
4th G
RS
??
ILC
SLHC
SFF
SB
SK

Bombastic Expectations of Particle Physicists for this Decade

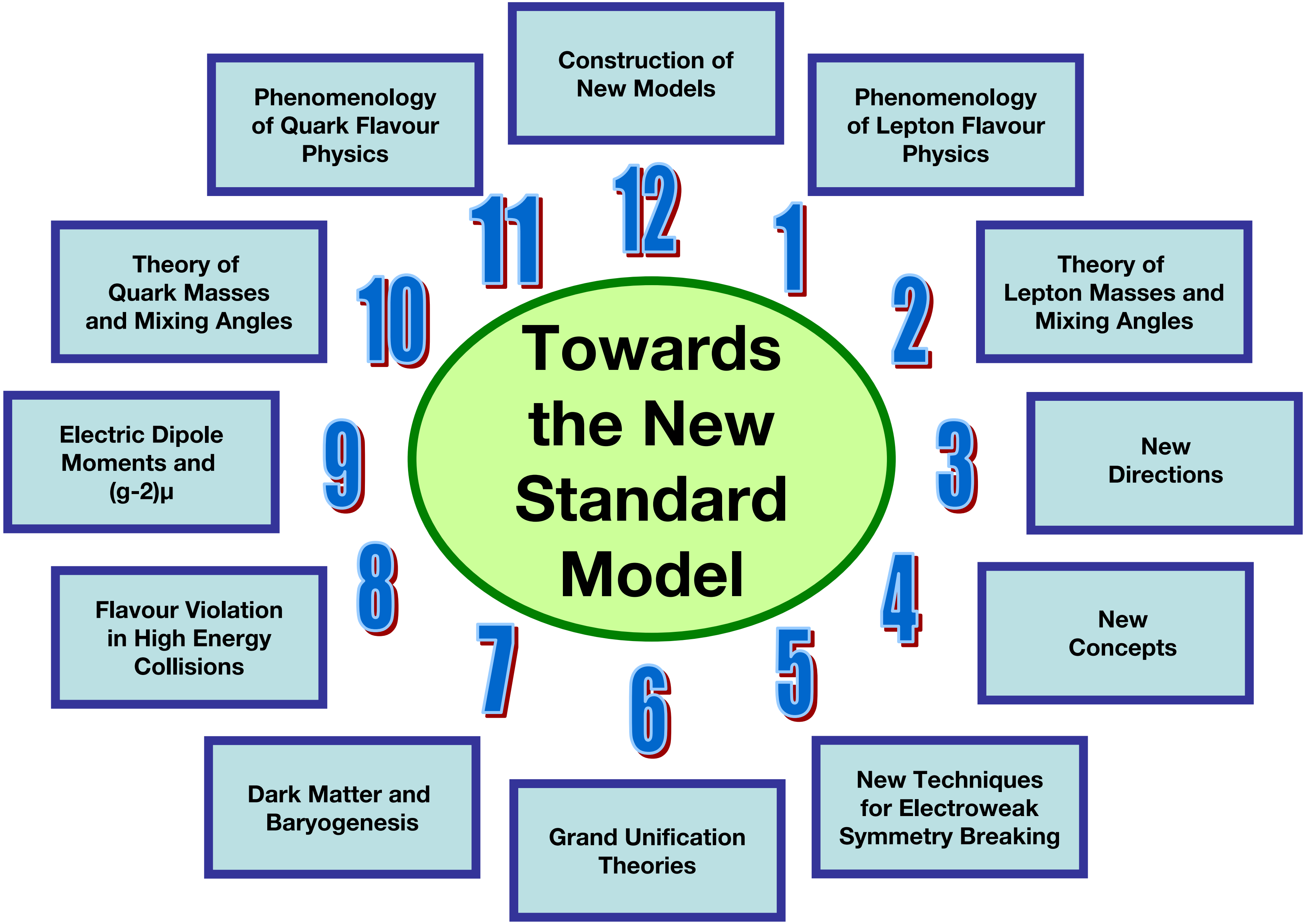
Threshold of a new and exciting era of discovery

Unprecented accuracy

Long-standing puzzles such as the origin of mass, the matter-antimatter asymmetry of the universe and dark matter will be resolved

These results will have a profound impact on the way we see our universe

Vie


Towards the New Standard Model
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Construction of New Models
1
Phenomenology of Lepton Flavour Physics
2
Theory of Lepton Masses and Mixing Angles
3
New Directions
4
New Concepts
5
New Techniques for Electroweak Symmetry Breaking
6
Grand Unification Theories
7
Dark Matter and Baryogenesis
8
Flavour Violation in High Energy Collisions
9
Electric Dipole Moments and (g-2)μ
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Theory of Quark Masses and Mixing Angles
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Thank You!

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