

# *Waarom bestaat er iets in plaats van niets?*

*Nikhef TechnoBorrel, 1-5-2023*

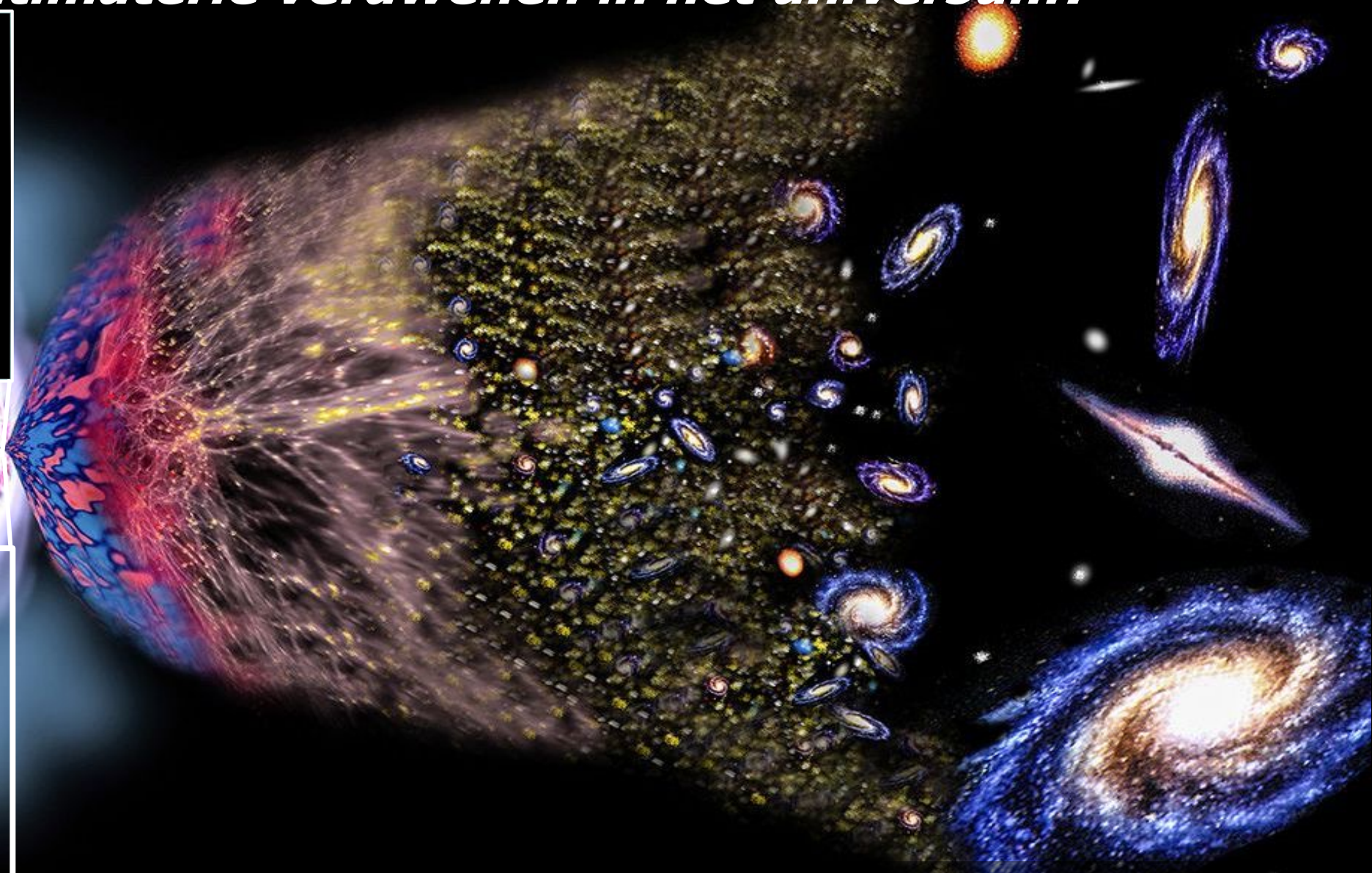
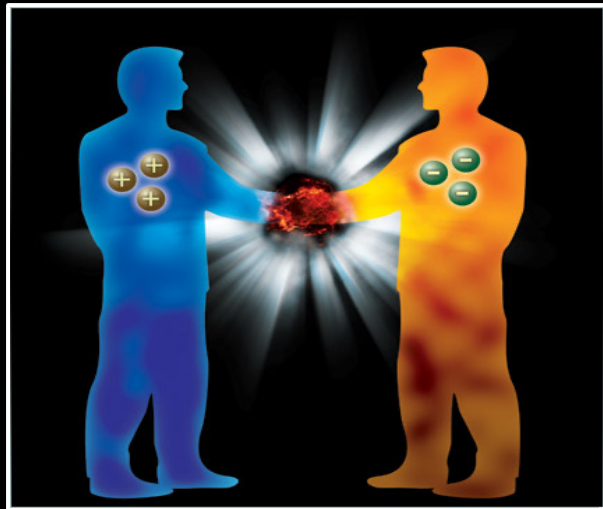
Nikhef



*"Over Beauty-deeltjes, antimaterie  
en een nieuwe natuurkracht"*



# Hoe is de antimaterie verdwenen in het universum?



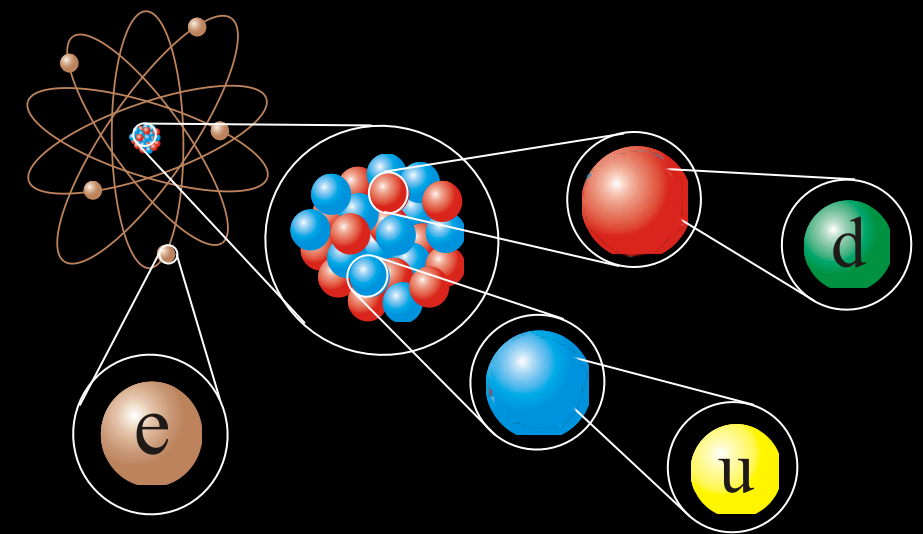
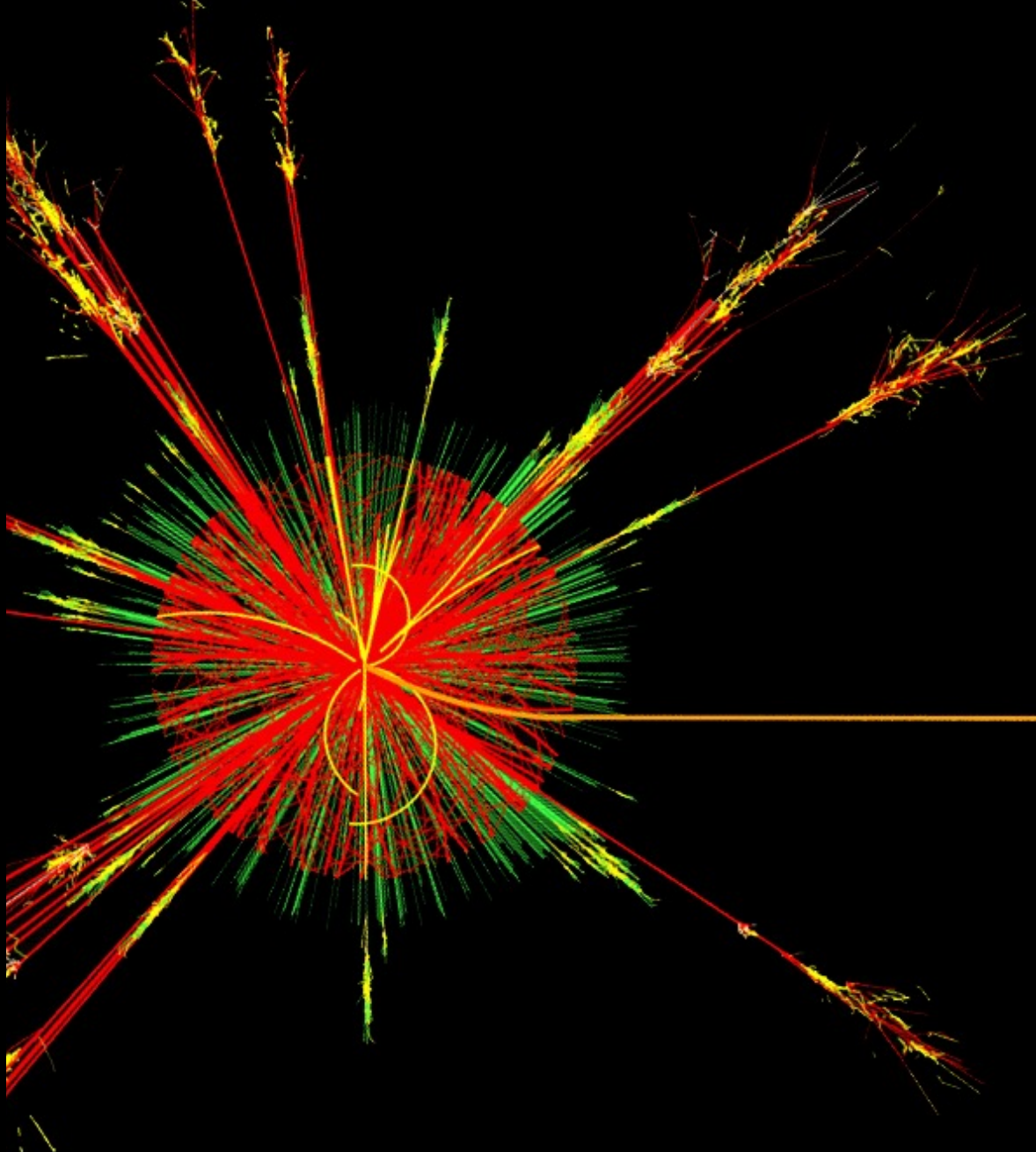
Fermionen: spin=1/2 deeltjes

Quarks			H	Krachten	
1	2	3		Z	$\gamma$
u	c	t	W	g	
d	s	b			
$\nu_e$	$\nu_\mu$	$\nu_\tau$			
e	$\mu$	$\tau$			

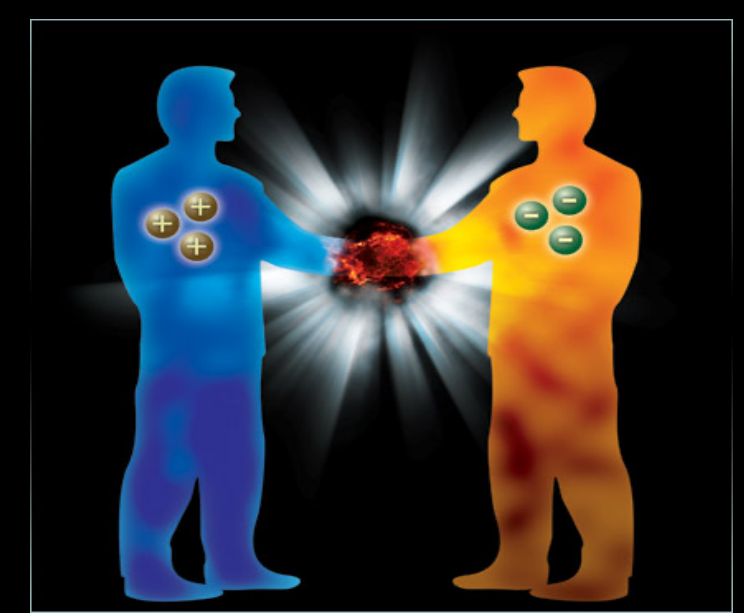
Leptonen

**Flavor puzzle: waarom bestaan er drie generaties identieke deeltjes?**

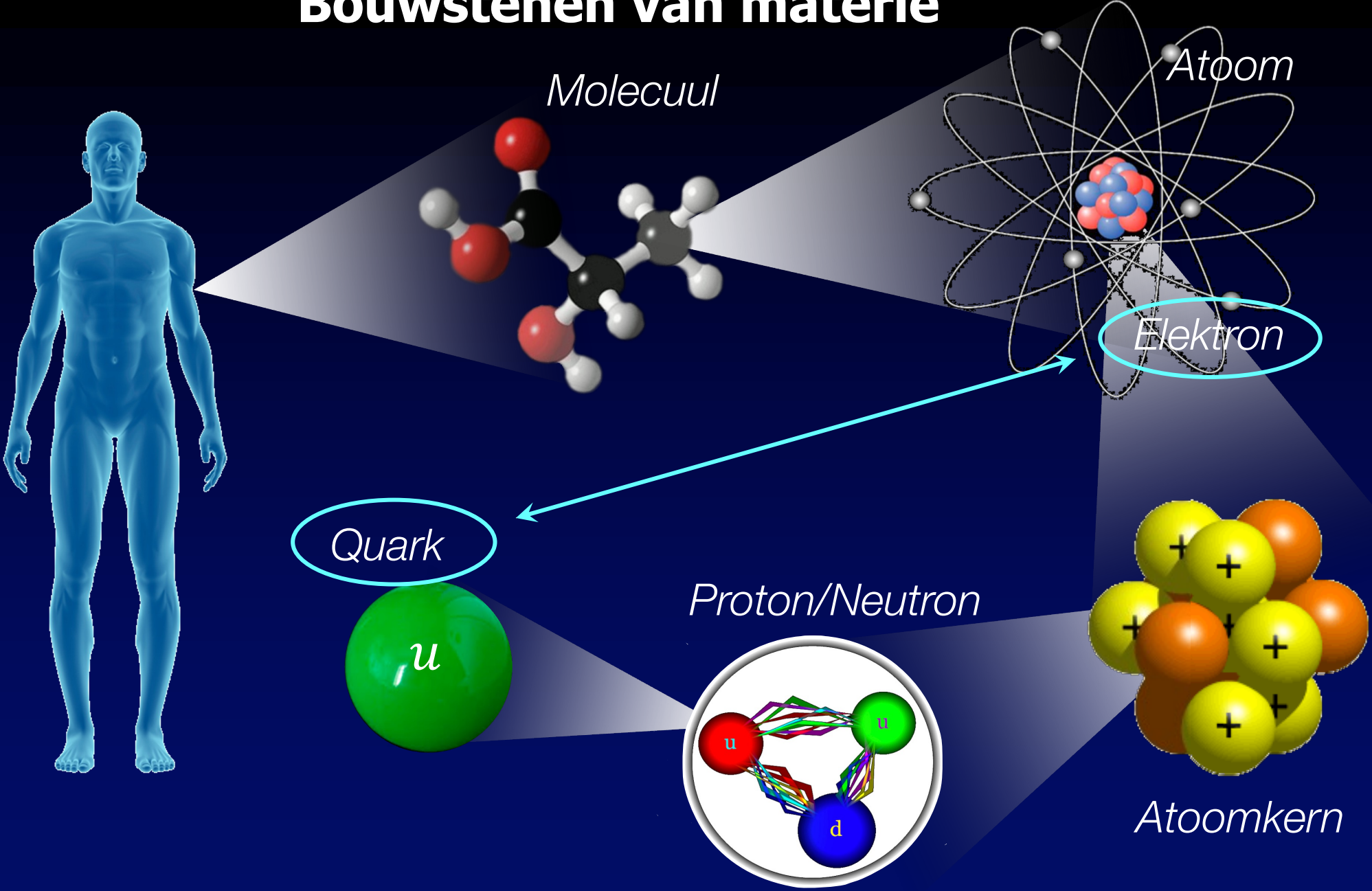




# Materie en Antimaterie

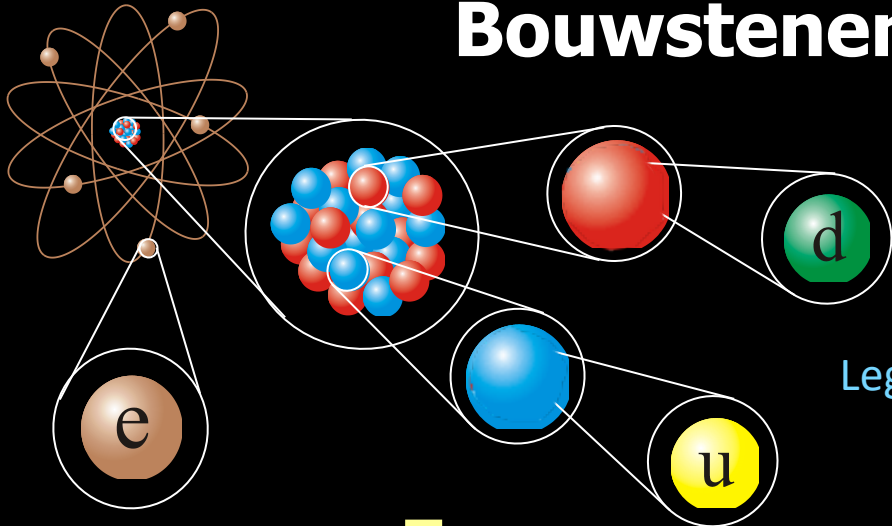


# Bouwstenen van materie





# Bouwstenen van materie

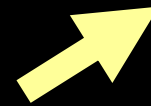


Lego blokken van de natuur



periodiek systeem

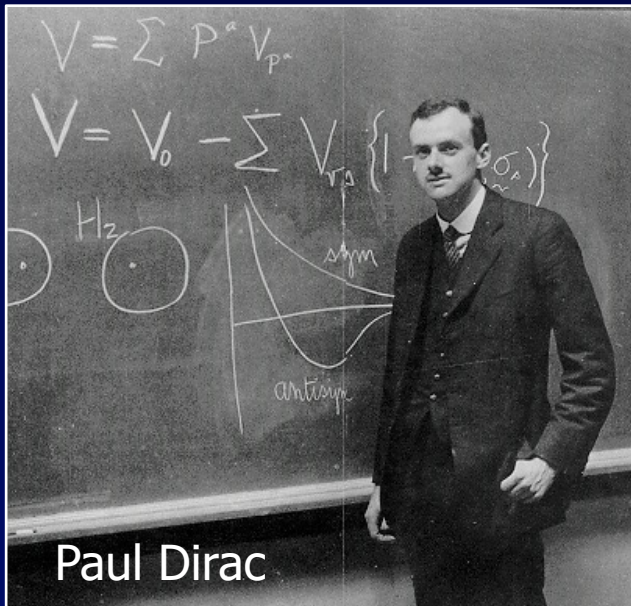
1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt									



58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

# Paul Dirac en antimaterie

- 1928:
  - Dirac's relativistische quantum theorie
  - Voorspelling: *voor elk type deeltje bestaat er een identiek anti-deeltje!*
- 1932:
  - Anderson ontdekt het anti-elektron



Paul Dirac



Carl Anderson

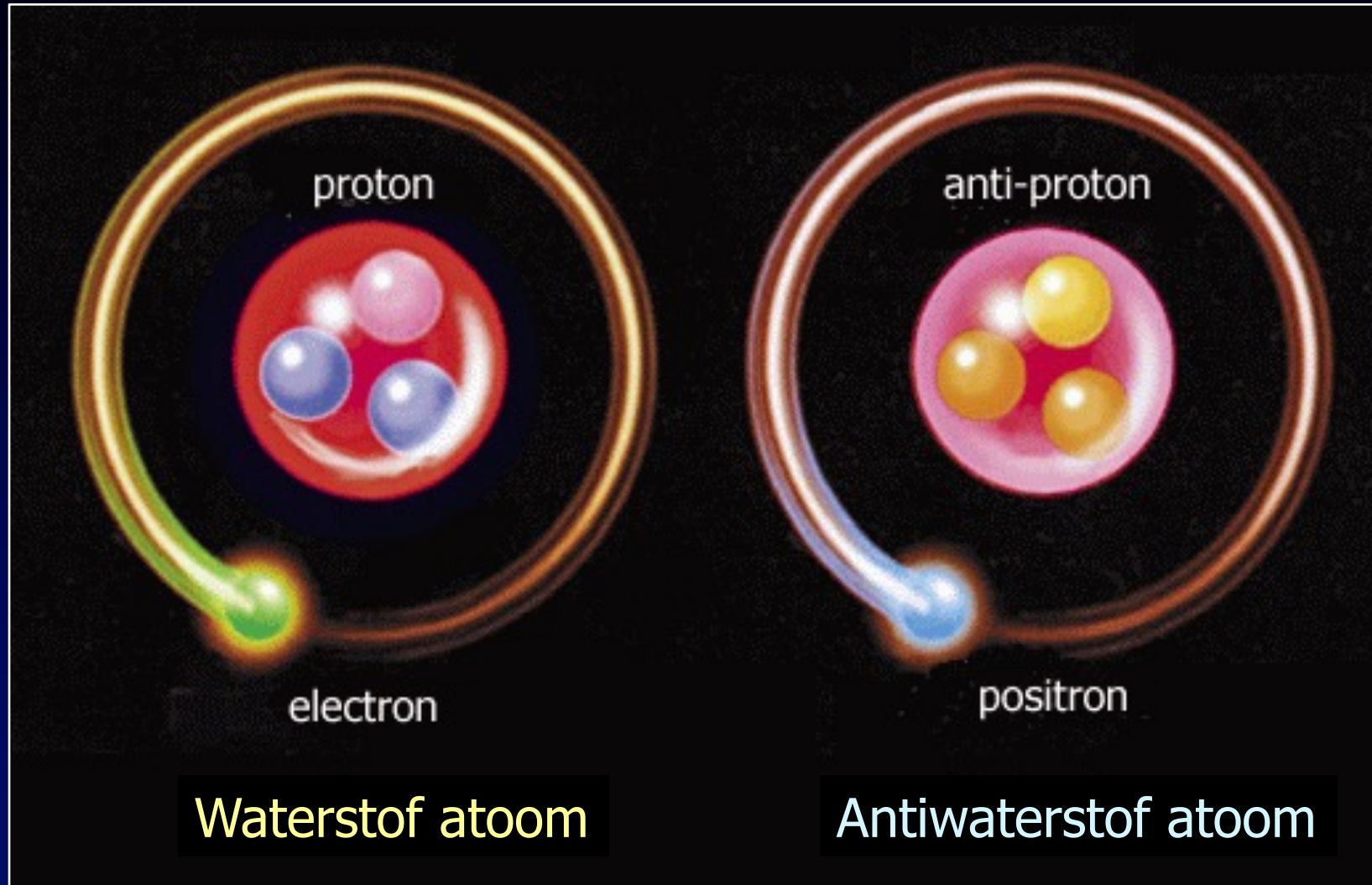


Dirac

AntiDirac

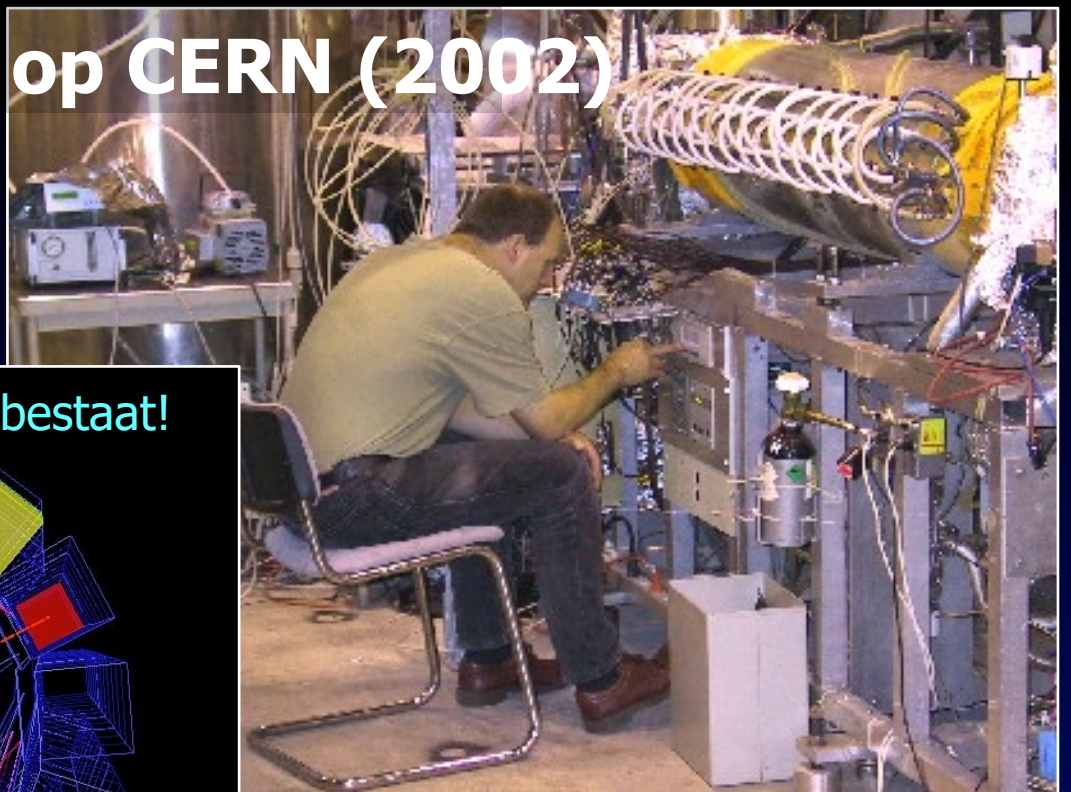
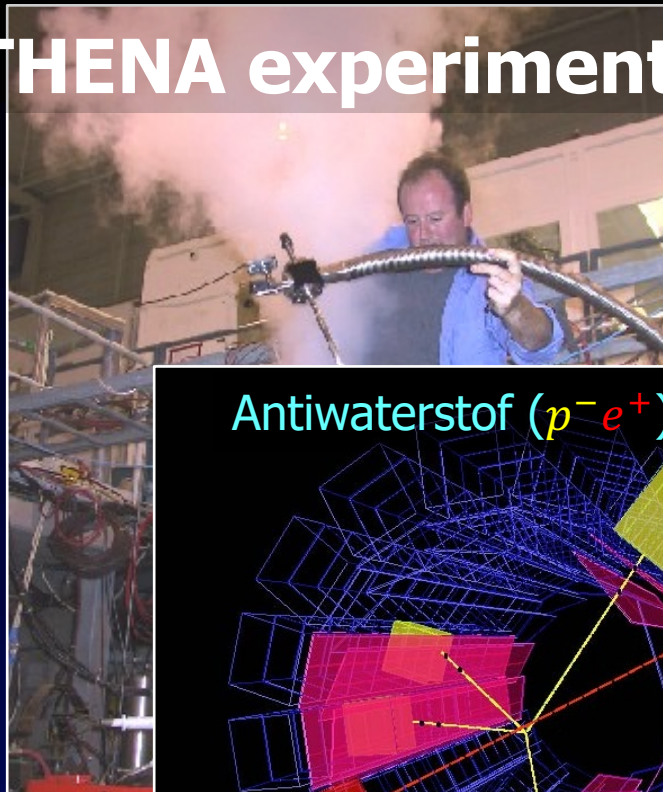


# Antimaterie

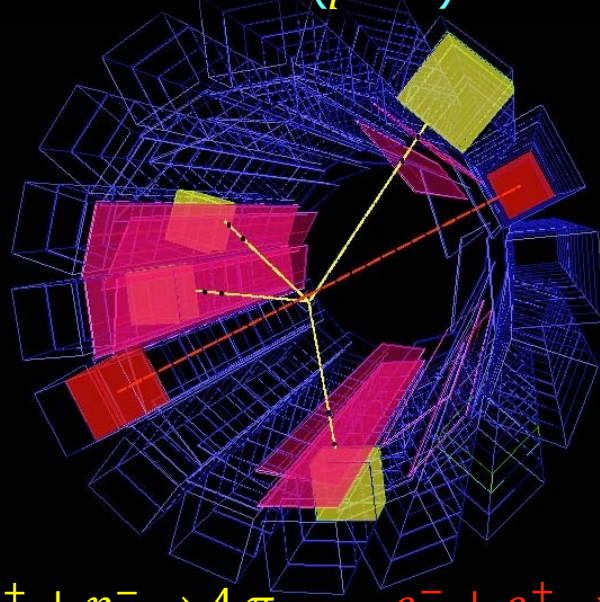




# Het ATHENA experiment op CERN (2002)



Antiwaterstof ( $p^- e^+$ ) bestaat!



$$p^+ + p^- \rightarrow 4\pi$$

$$e^- + e^+ \rightarrow \gamma\gamma$$





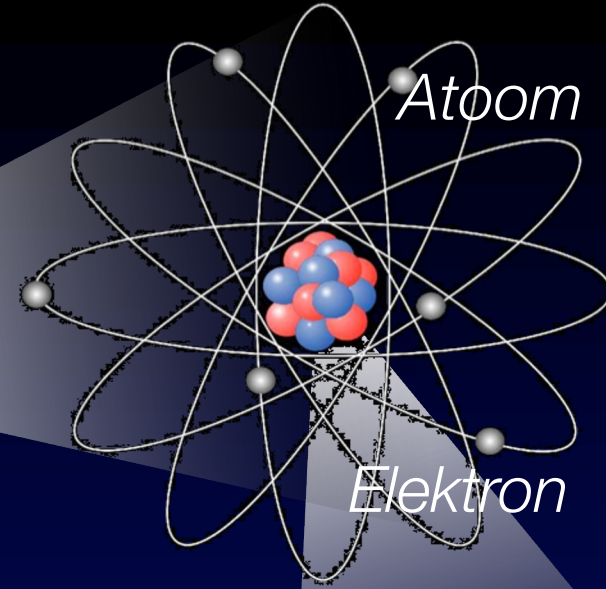
# Een wereld van materie en ...



*Molecuul*

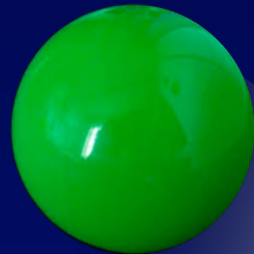


*Atoom*

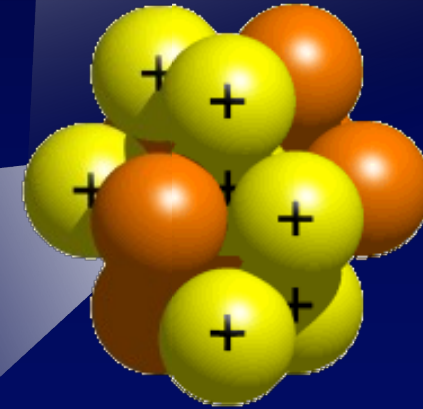
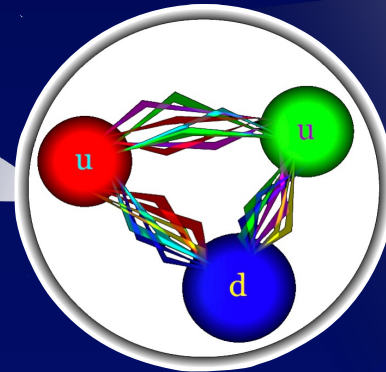


*Elektron*

*Quark*



*Proton/Neutron*



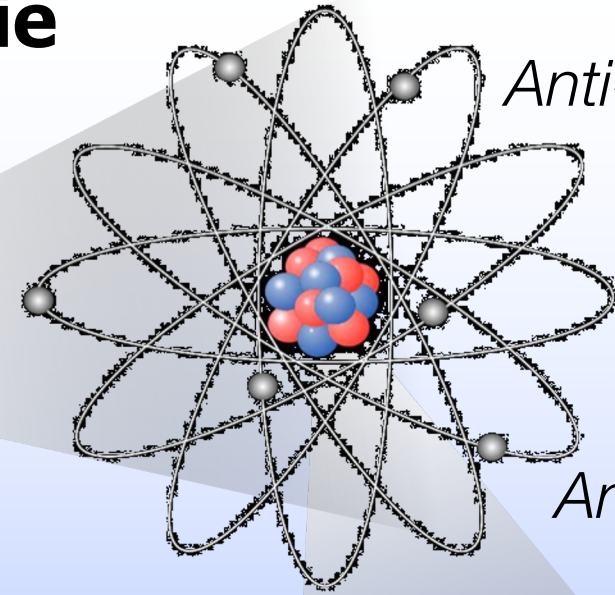
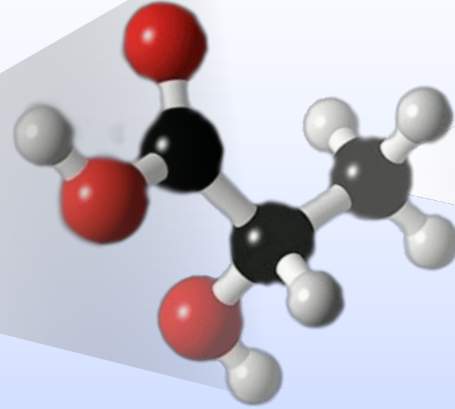
*Atoom kern*

# ... een wereld van antimaterie



**Identieke  
anti-wereld**

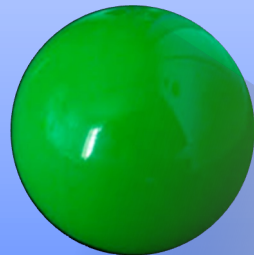
*Anti-Molecuul*



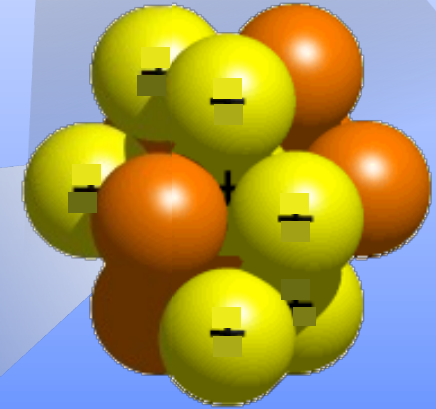
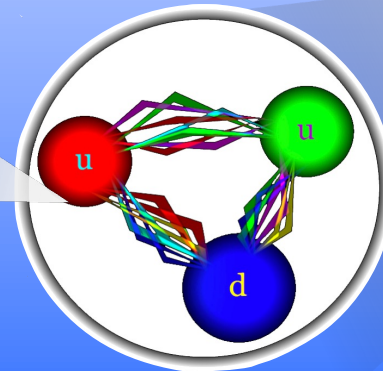
*Anti-Atoom*

*Anti-elektron*

*Anti-Quark*



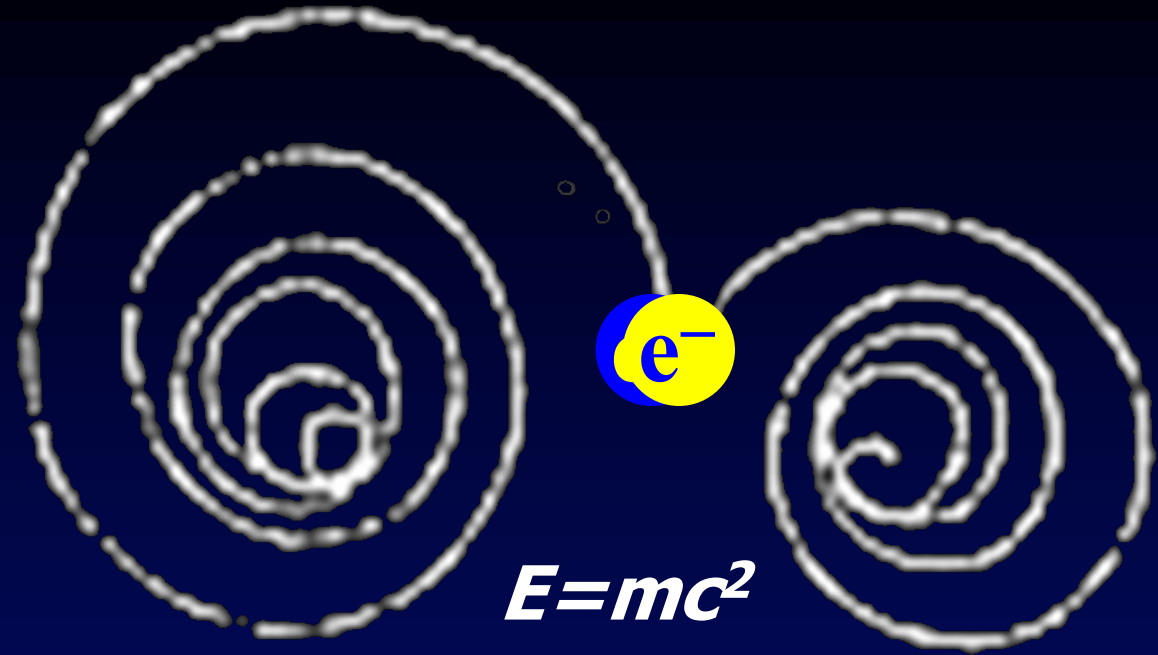
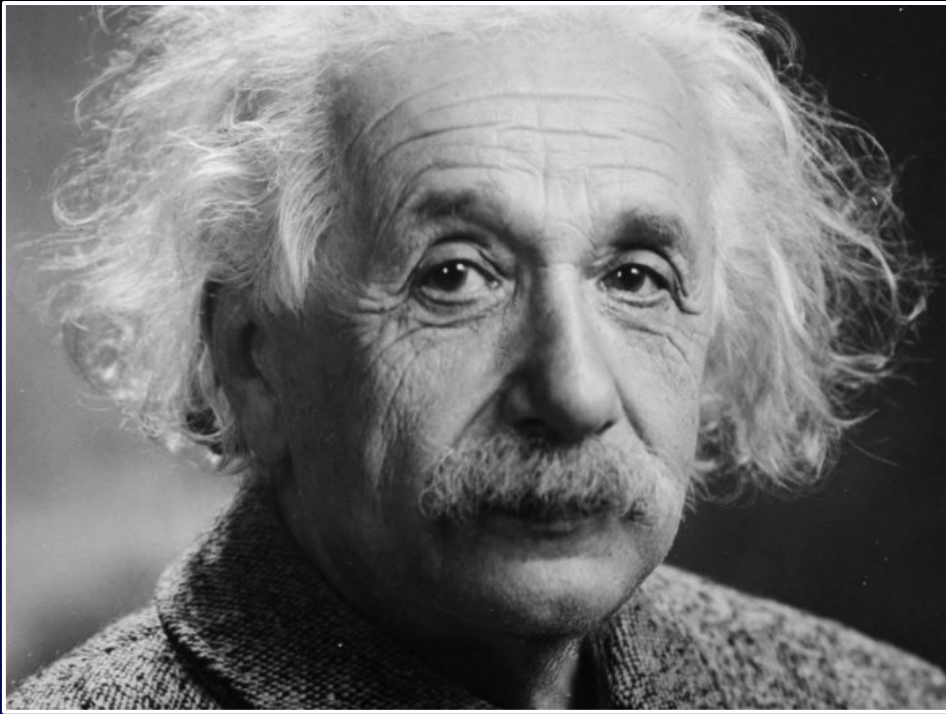
*Anti-Proton /  
anti-Neutron*



*Anti-atoomkern*



# Albert Einstein: Energie = materie + antimaterie



## Creatie:

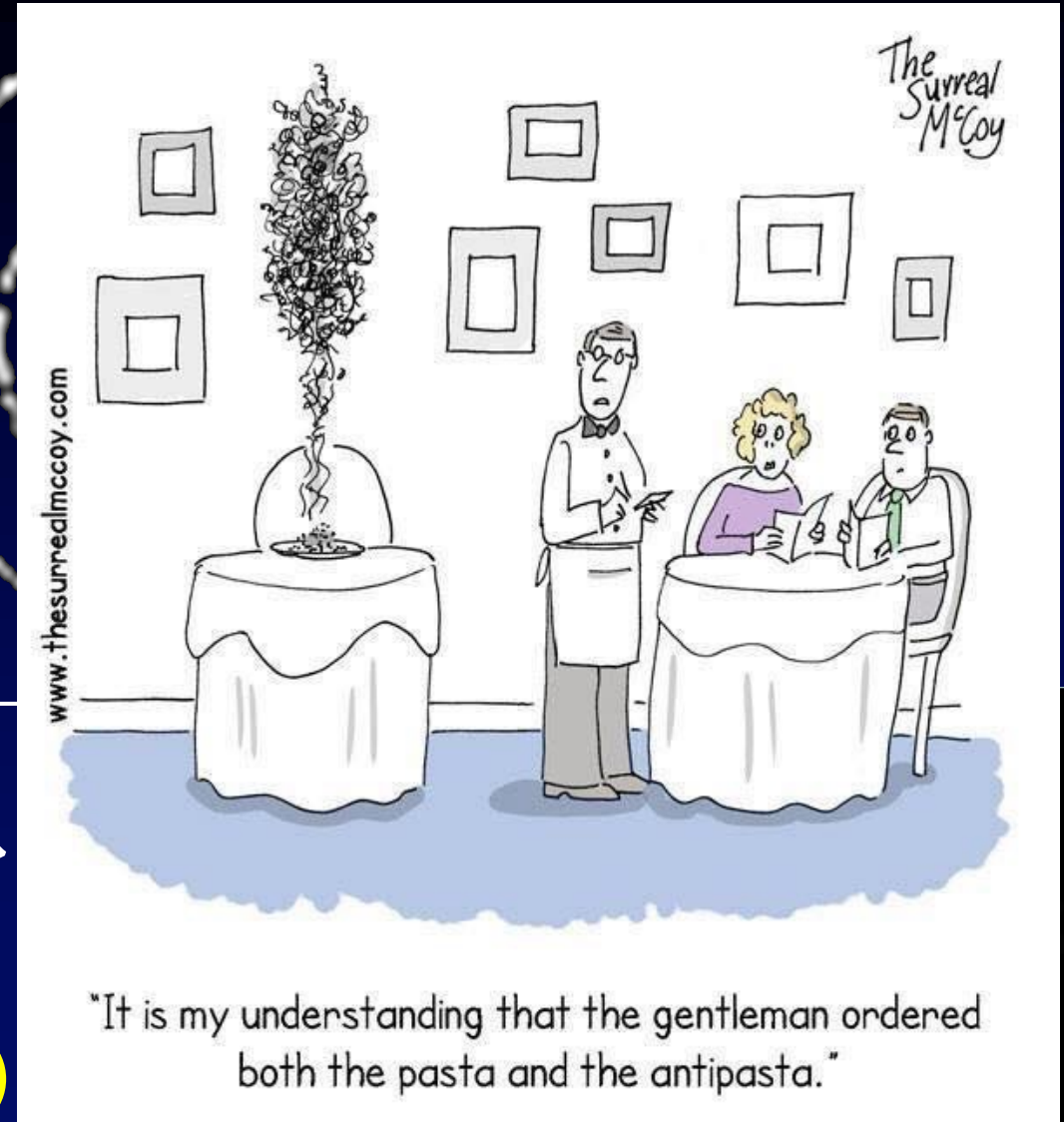
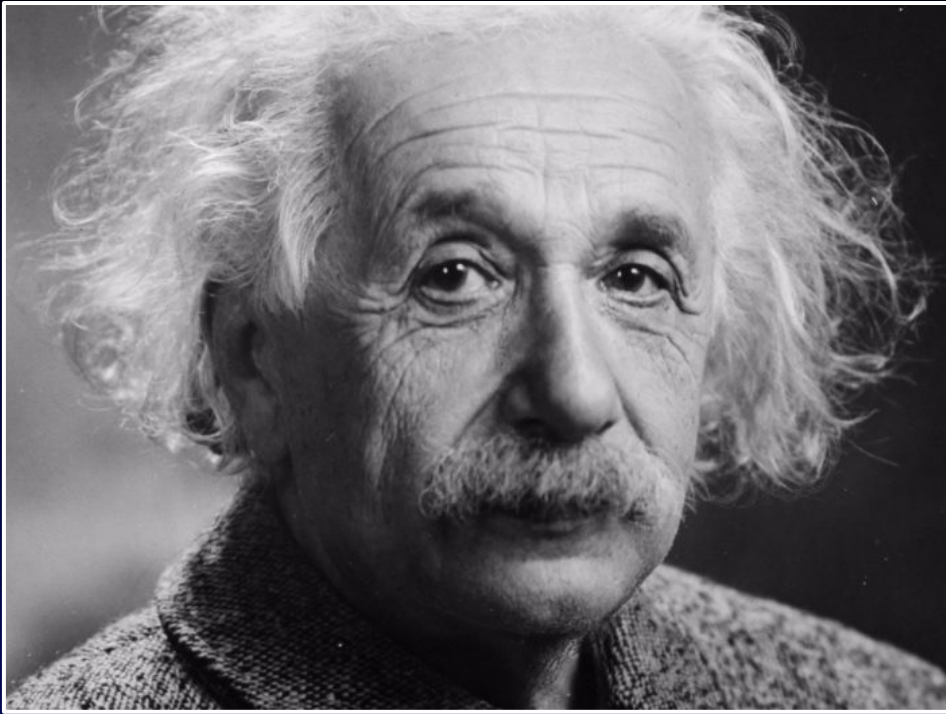
Energie → materie + antimaterie :  →  

## Annihilatie:


materie + antimaterie → energie :   →  



# Albert Einstein: Energie = materie + antimaterie



Creatie:

Energie  $\rightarrow$  materie + antimaterie :   $\rightarrow$

Anihilatie:

materie + antimaterie  $\rightarrow$  energie :  

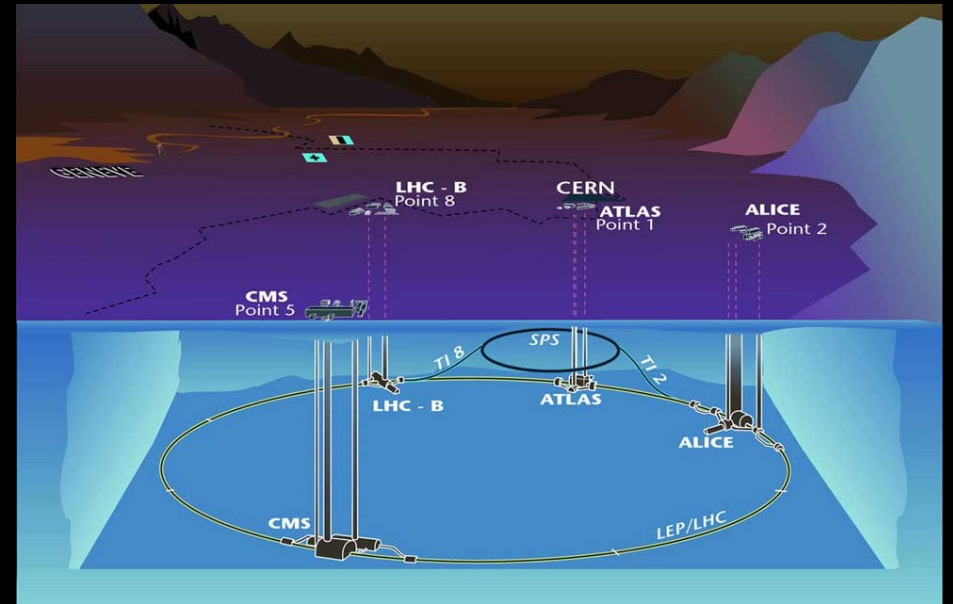
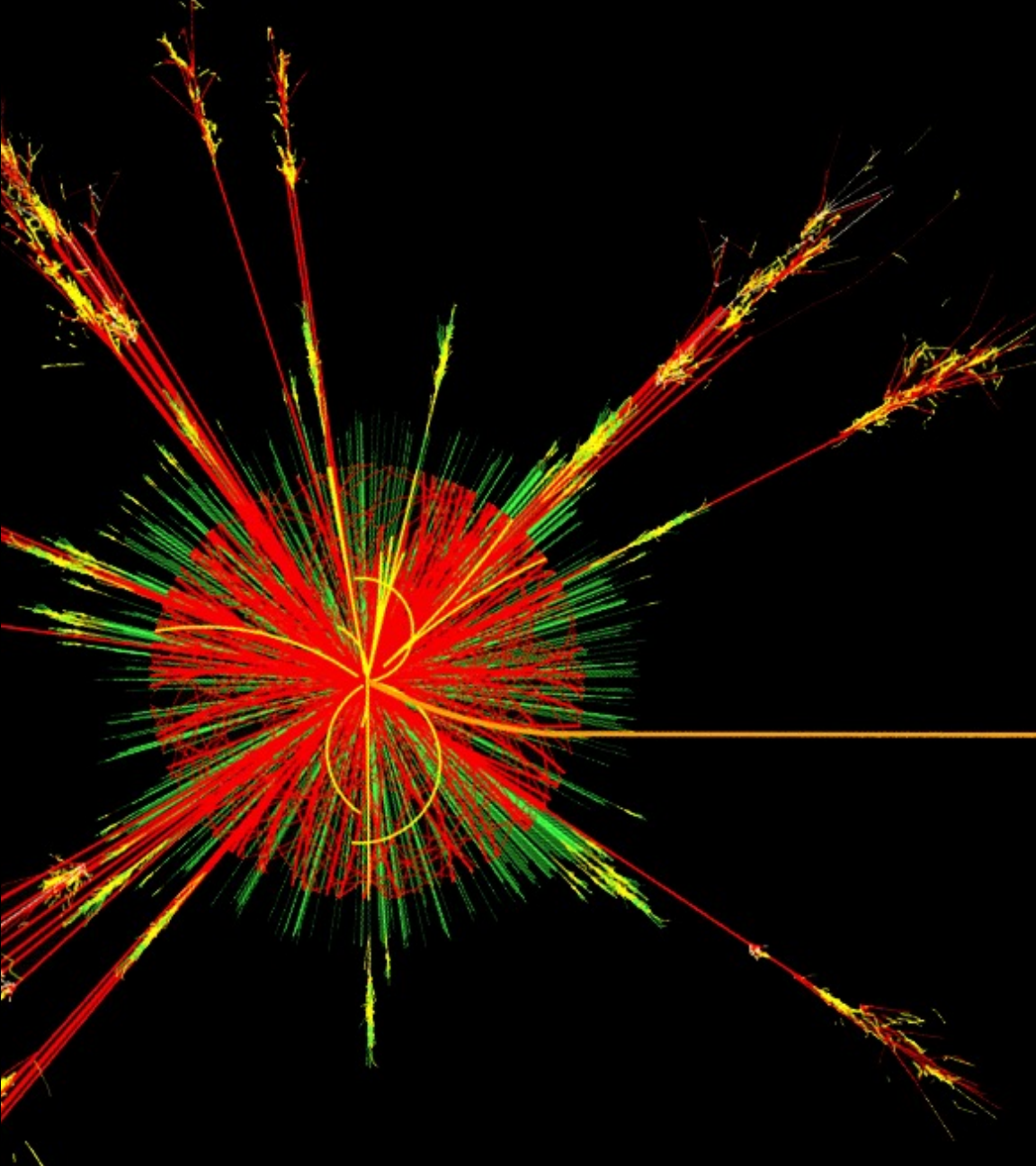
"It is my understanding that the gentleman ordered both the pasta and the antipasta."



# *Vroege Universum: waar is de antimaterie heen?*



*Inderdaad: Waarom is er eigenlijk iets in plaats van niets?!*



# CERN

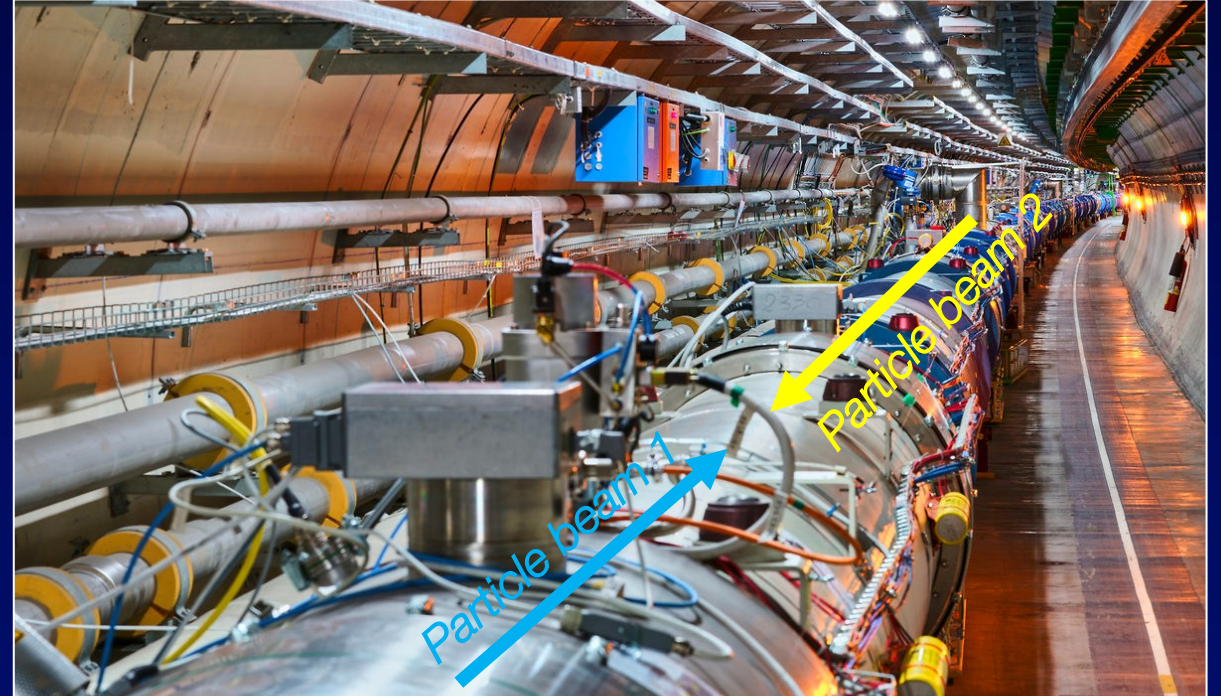
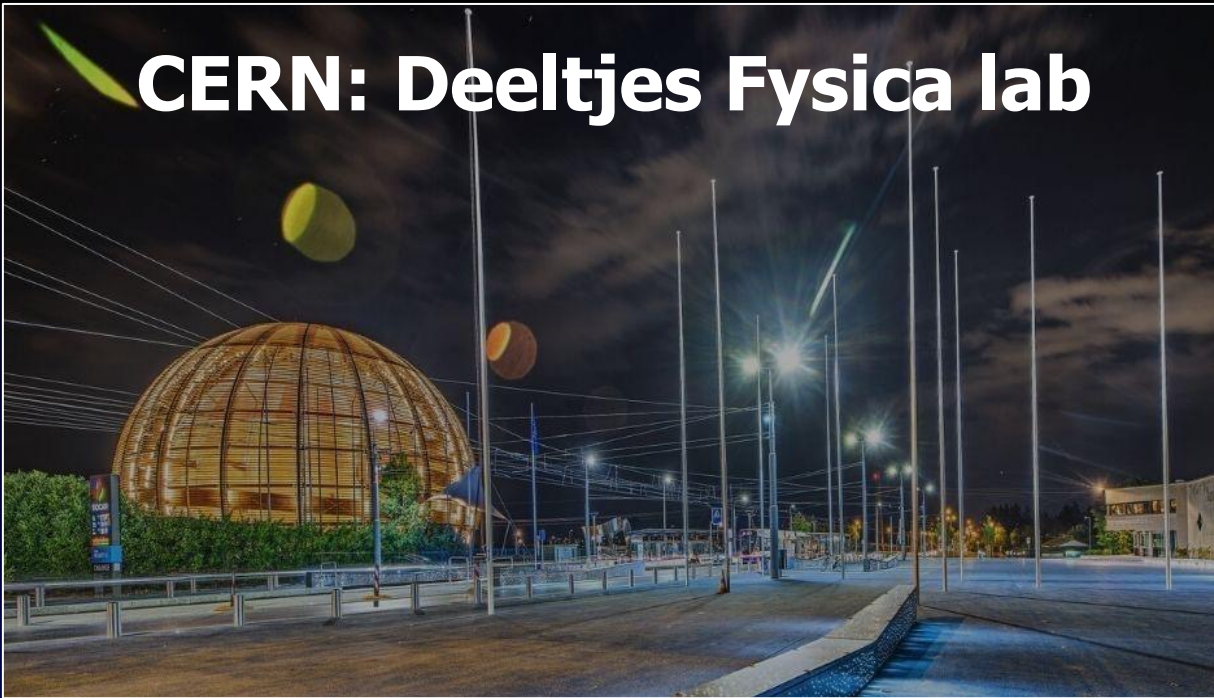


Member States (Dates of Accession)

AUSTRIA (1959)	DENMARK (1953)	GREECE (1953)	NORWAY (1953)	SPAIN (1/1961-12/1968-1/1983)
BELGIUM (1953)	FINLAND (1991)	HUNGARY (1992)	POLAND (1991)	SWEDEN (1953)
BULGARIA (1999)	FRANCE (1953)	ITALY (1953)	PORTUGAL (1986)	SWITZERLAND (1953)
CZECH FR (1993)	GERMANY (1953)	NETHERLANDS (1953)	SLOVAK FR (1993)	UNITED KINGDOM (1953)

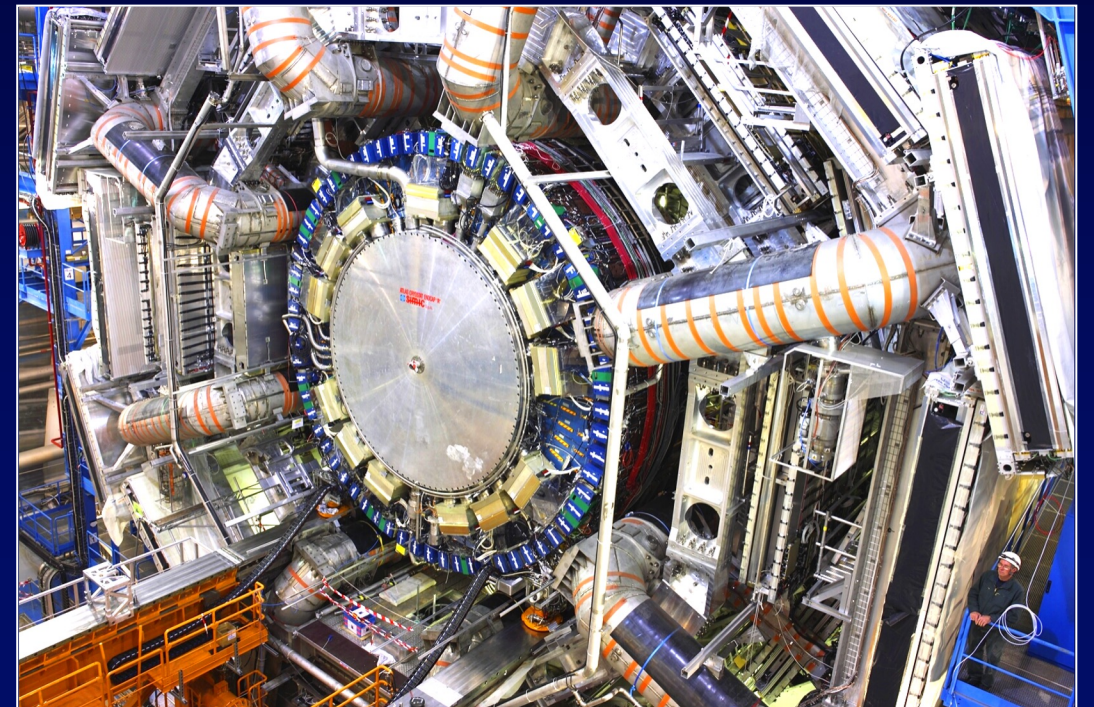
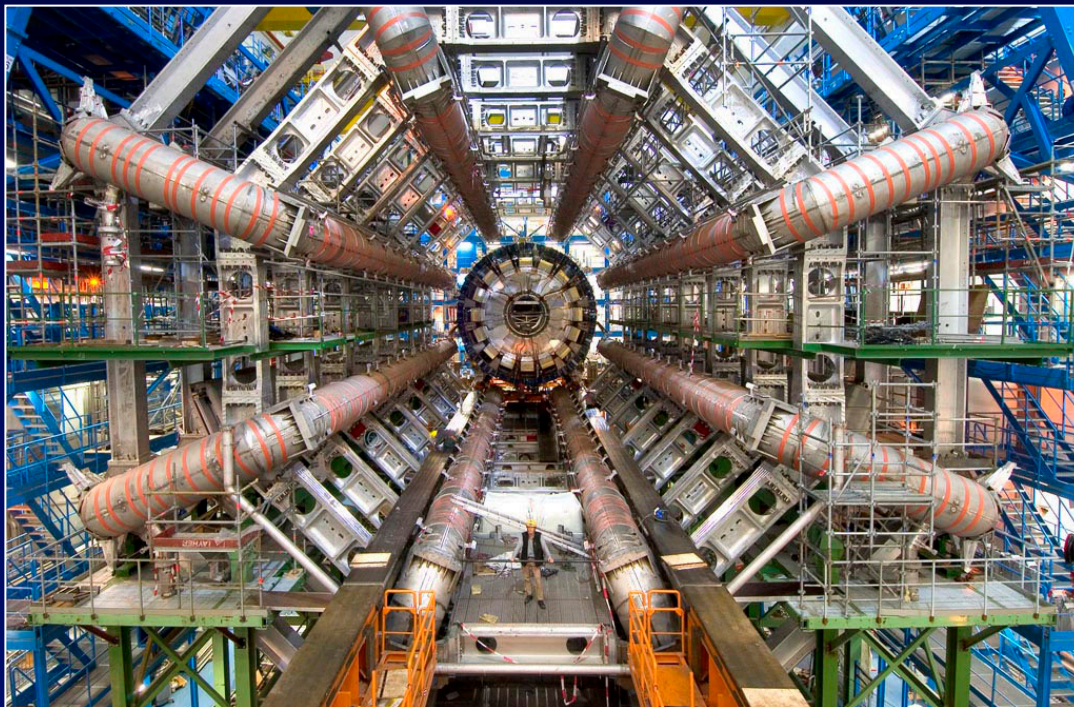
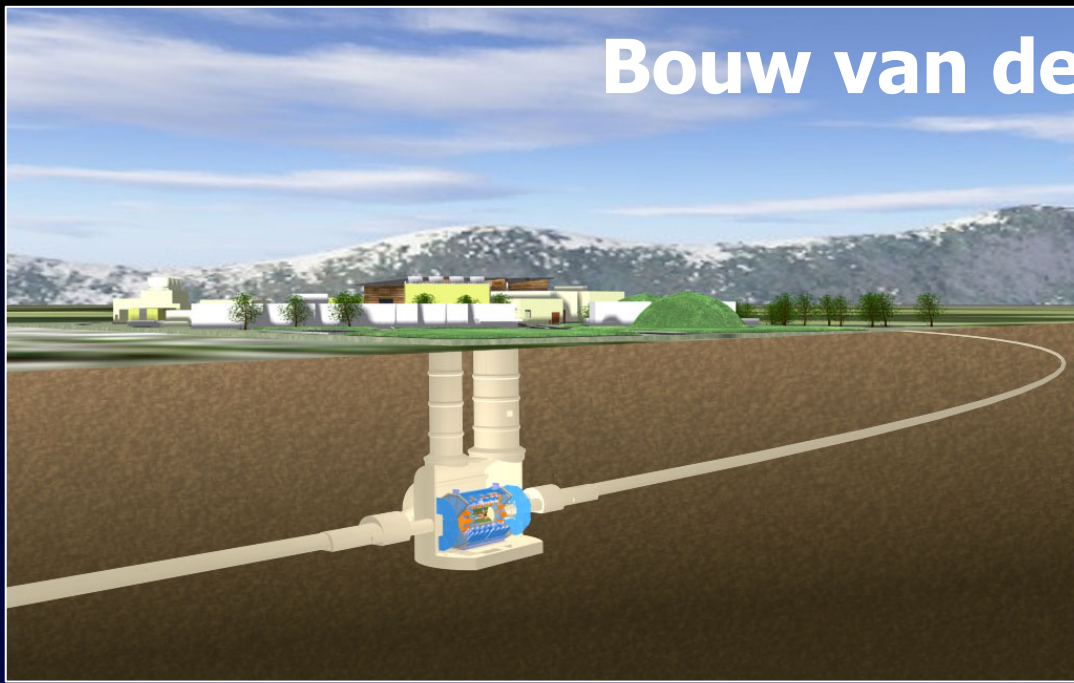


# CERN: Deeltjes Fysica lab





# Bouw van de Atlas detector

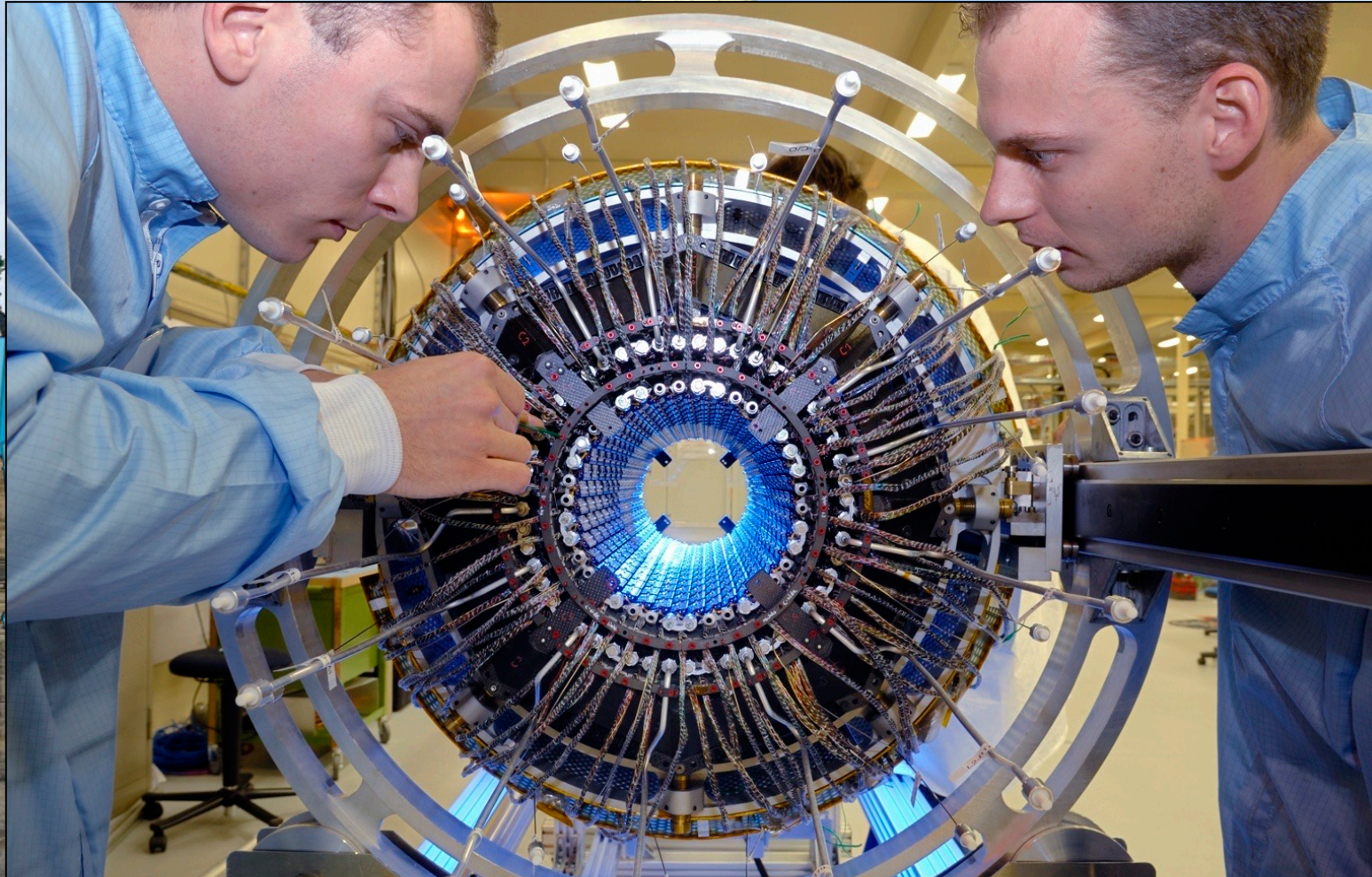




# Het Atlas Experiment

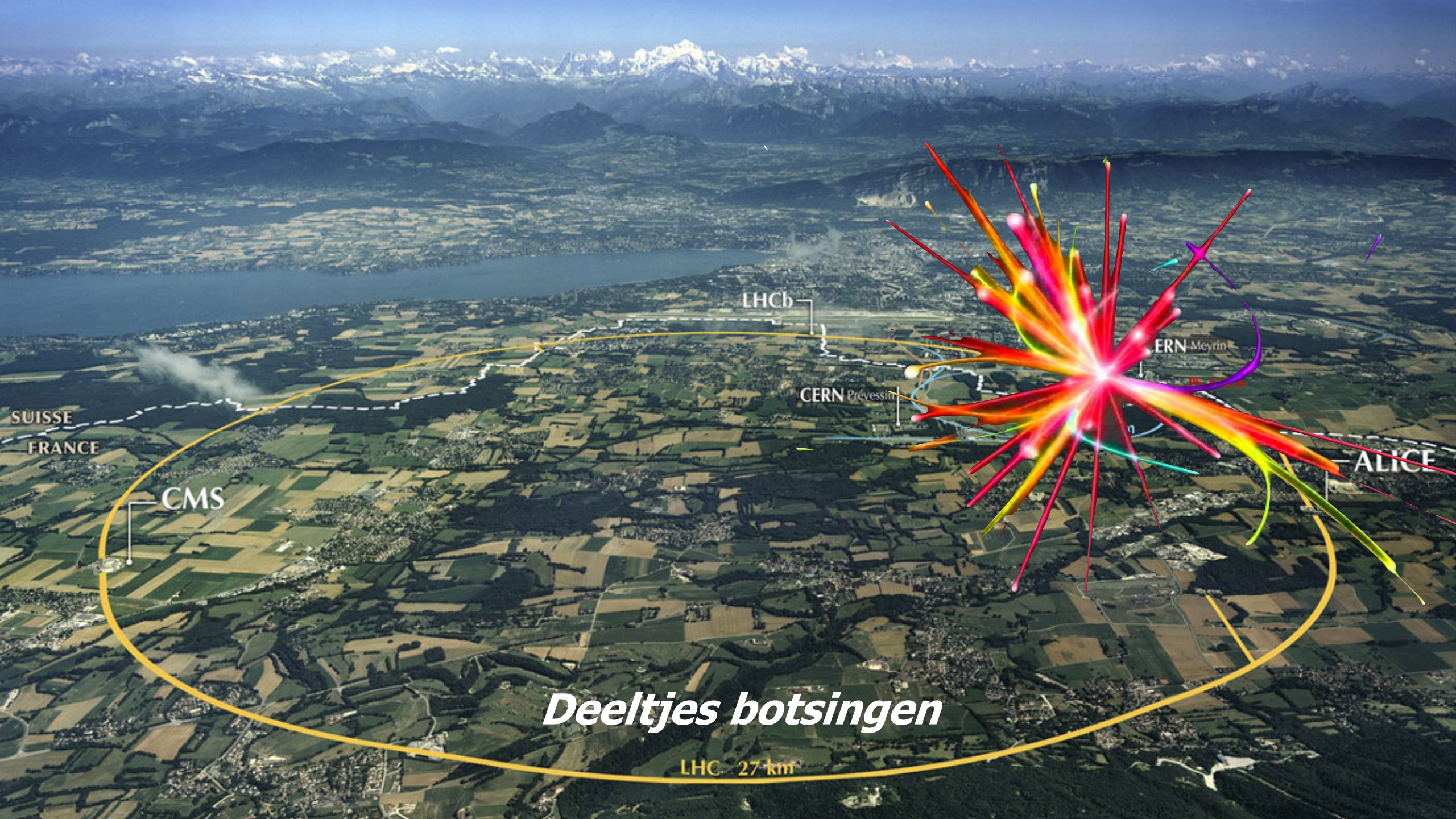
*Het grootste fototoestel op aarde*

- 45 m x 25 m
- 3000 fysici



80 MegaPixel "camera": 40.000.000 foto's per seconde





LHCb

CERN Meyrin

CERN Prévessin

SUISSE  
FRANCE

CMS

ALICE

# Deeltjes botsingen

LHC 27 km



QM: "Alles dat **kan** gebeuren **zal** gebeuren"



SUISSE  
FRANCE

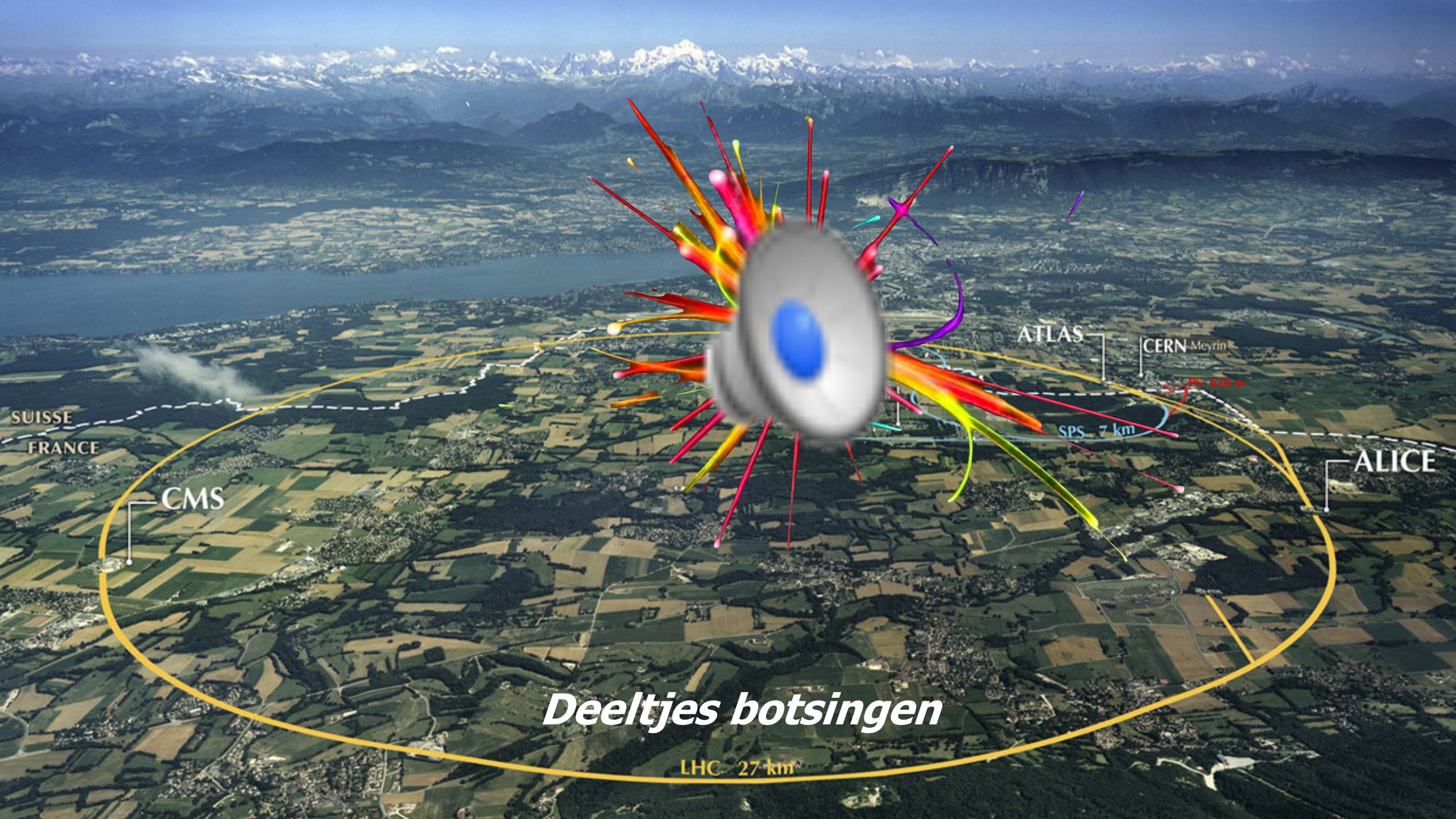
CMS

ALICE

*Deeltjes botsingen*

LHC 27 km





SUISSE  
FRANCE

CMS

ATLAS

CERN Meyrin

PS 6.28 km

SPS 7 km

ALICE

# Deeltjes botsingen

LHC 27 km



# De Elementaire Deeltjes

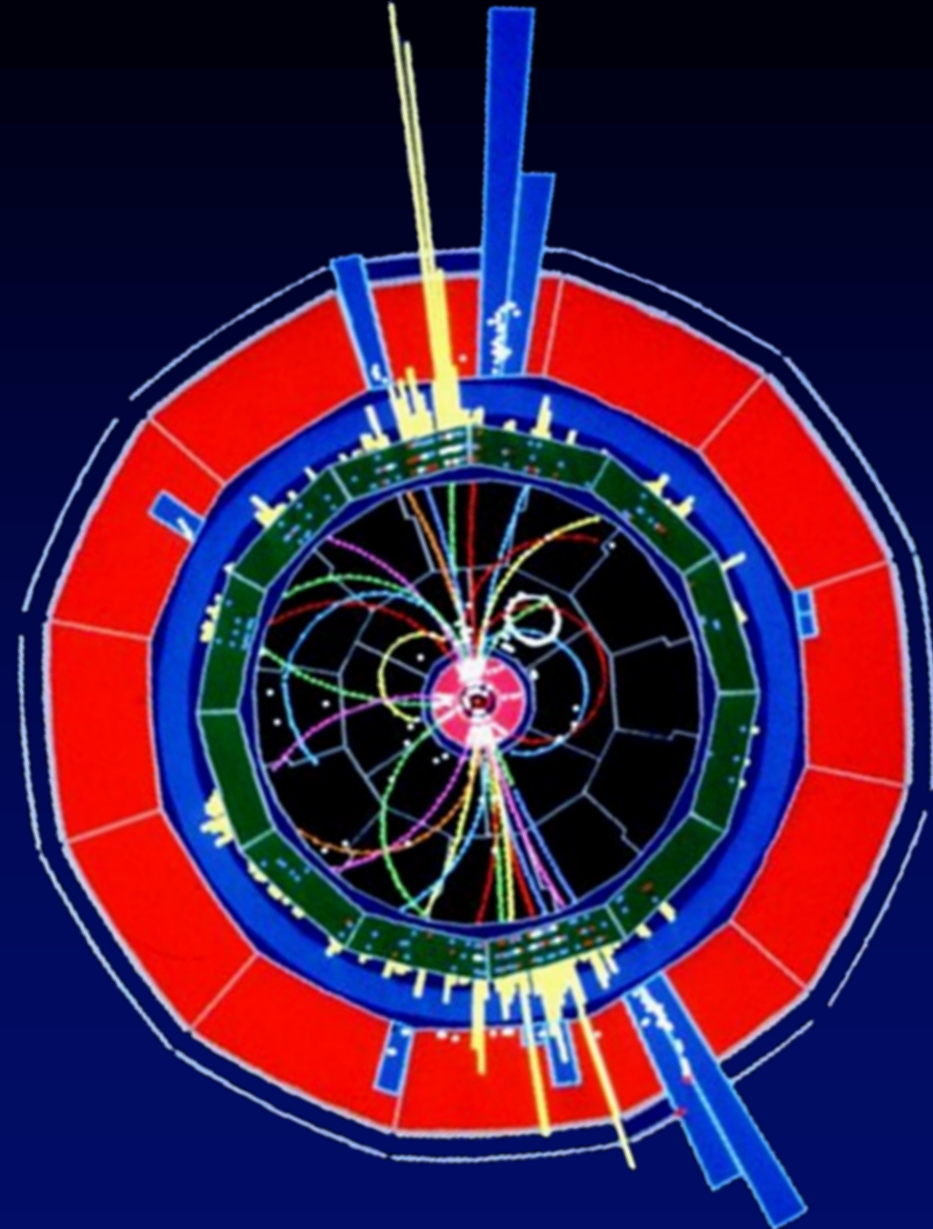
Generatie:

	I	II	III	<u>Lading</u>
quarks	<b>u</b> (1976)	<b>c</b> (1976)	<b>t</b> (1995)	+2/3 e
	<b>d</b> (1947)	<b>s</b> (1947)	<b>b</b> (1978)	-1/3 e

3 "generaties" van deeltjes!

leptons	<b>e</b> (1895)	<b><math>\mu</math></b> (1936)	<b><math>\tau</math></b> (1973)	-1 e
	<b><math>\nu_e</math></b> (1956)	<b><math>\nu_\mu</math></b> (1963)	<b><math>\nu_\tau</math></b> (2000)	0 e

Materie



# De Elementaire Deeltjes

Generatie:

	I	II	III	<u>Lading</u>
quarks	<b>u</b>	<b>c</b>	<b>t</b>	+2/3 e
	<b>d</b>	<b>s</b>	<b>b</b>	-1/3 e

3 "generaties" van deeltjes!

leptons	<b>e</b>	<b><math>\mu</math></b>	<b><math>\tau</math></b>	-1 e
	<b><math>\nu_e</math></b>	<b><math>\nu_\mu</math></b>	<b><math>\nu_\tau</math></b>	0 e

Materie

	<u>Lading</u>	I	II	III
-2/3 e	<b><math>\bar{u}</math></b>	<b><math>\bar{c}</math></b>	<b><math>\bar{t}</math></b>	
+1/3 e	<b><math>\bar{d}</math></b>	<b><math>\bar{s}</math></b>	<b><math>\bar{b}</math></b>	

3 "generaties" van anti-deeltjes!

+1 e	<b><math>\bar{e}</math></b>	<b><math>\bar{\mu}</math></b>	<b><math>\bar{\tau}</math></b>
0 e	<b><math>\bar{\nu}_e</math></b>	<b><math>\bar{\nu}_\mu</math></b>	<b><math>\bar{\nu}_\tau</math></b>

Anti-materie



# De Elementaire Deeltjes

Generatie:

	I	II	III	<u>Lading</u>
quarks	<b>u</b>	<b>c</b>	<b>t</b>	+2/3 e
	<b>d</b>	<b>s</b>	<b>b</b>	-1/3 e

<u>Lading</u>	I	II	III
-2/3 e	<b><math>\bar{u}</math></b>	<b><math>\bar{c}</math></b>	<b><math>\bar{t}</math></b>
+1/3 e	<b><math>\bar{d}</math></b>	<b><math>\bar{s}</math></b>	<b><math>\bar{b}</math></b>

Waarom 3 "generaties" van deeltjes?

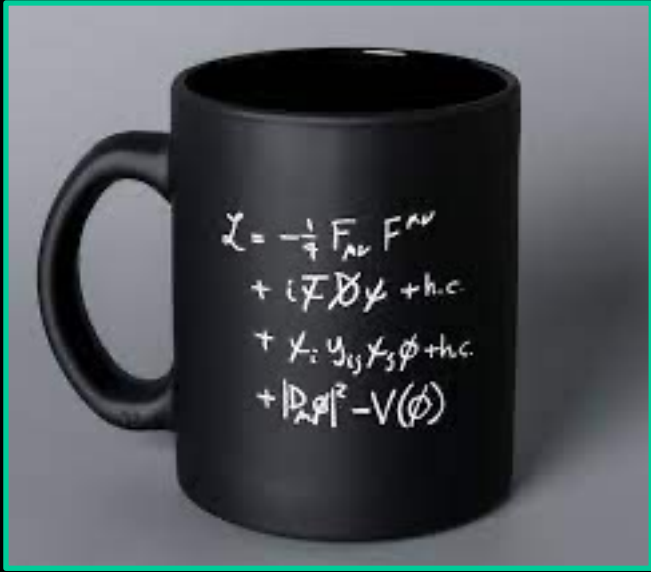
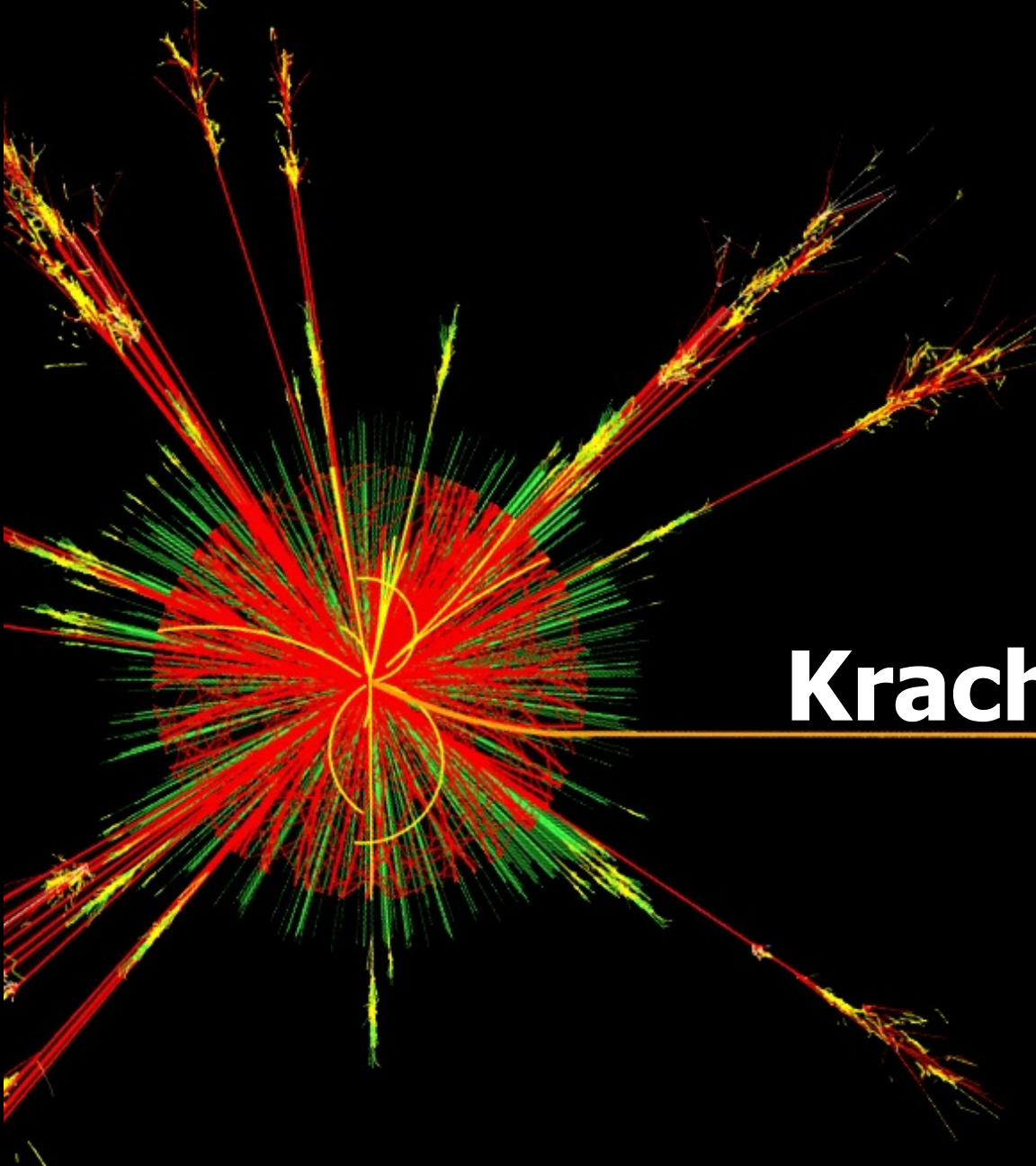
leptons	<b>e</b>	<b><math>\mu</math></b>	<b><math>\tau</math></b>	-1 e
	<b><math>\nu_e</math></b>	<b><math>\nu_\mu</math></b>	<b><math>\nu_\tau</math></b>	0 e

+1 e	<b><math>\bar{e}</math></b>	<b><math>\bar{\mu}</math></b>	<b><math>\bar{\tau}</math></b>
0 e	<b><math>\bar{\nu}_e</math></b>	<b><math>\bar{\nu}_\mu</math></b>	<b><math>\bar{\nu}_\tau</math></b>

Materie

Anti-materie





# Krachten: "Standaard Model"

Fermionen: spin=1/2 deeltjes

Quarks		
u	c	t
d	s	b

Higgs field

bosonen spin=1 deeltjes

Krachten	
Z	$\gamma$
W	g

H

Leptonen		
$\nu_e$	$\nu_\mu$	$\nu_\tau$
e	$\mu$	$\tau$

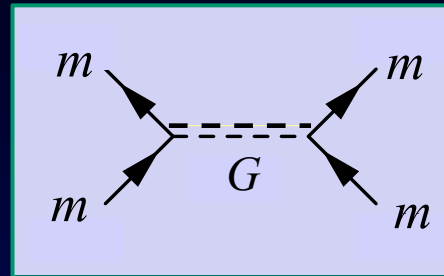


# Vier fundamentele natuurkrachten

## Zwaartekracht:

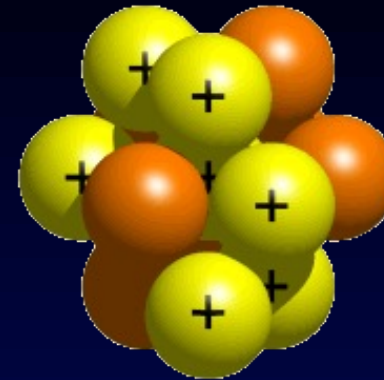


Quantum  
Graviton exchange?



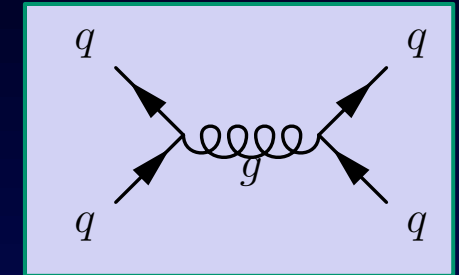
Werkt op alle deeltjes met massa

## Sterke kernkracht:



Werkt op alle quarks

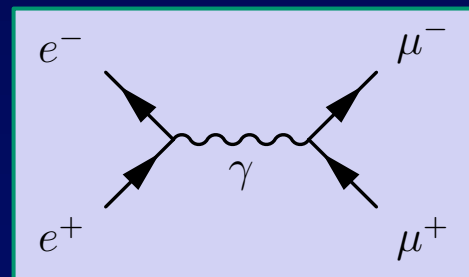
Quantum  
gluon exchange:



## Elektromagnetisme:



Quantum  
photon exchange:



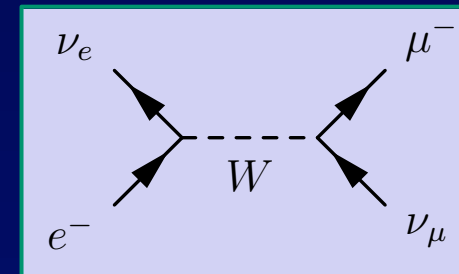
Werkt op alle elektrisch geladen deeltjes

## Zwakke kernkracht:



Werkt op alle deeltjes

Quantum  
W, Z exchange:





# Vier fundamentele natuurkrachten

## Zwaartekracht:

Quantum

Fermionen: spin=1/2 deeltjes

**Quarks**

u	c	t
d	s	b

**Krachten**

Z	$\gamma$
W	g

**H**

bosonen: spin=1 deeltjes

**Leptonen**

$\nu_e$	$\nu_\mu$	$\nu_\tau$
e	$\mu$	$\tau$

Werkt op alle elektrisch geladen deeltjes

## Sterke kernkracht:

Quantum  
gluon exchange:

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu}$$

$$+ i\bar{\psi} \not{D} \psi + \text{h.c.}$$

$$+ \chi_i y_{ij} \chi_j \phi + \text{h.c.}$$

$$+ |D_\mu \phi|^2 - V(\phi)$$

Werkt op alle deeltjes



# Vier fundamentele natuurkrachten

## Zwaartekracht:

Quantum

Fermionen: spin=1/2 deeltjes

**Quarks**

u	c	t
d	s	b

bosonen: spin=1 deeltjes

**Krachten**

Z	$\gamma$
W	g

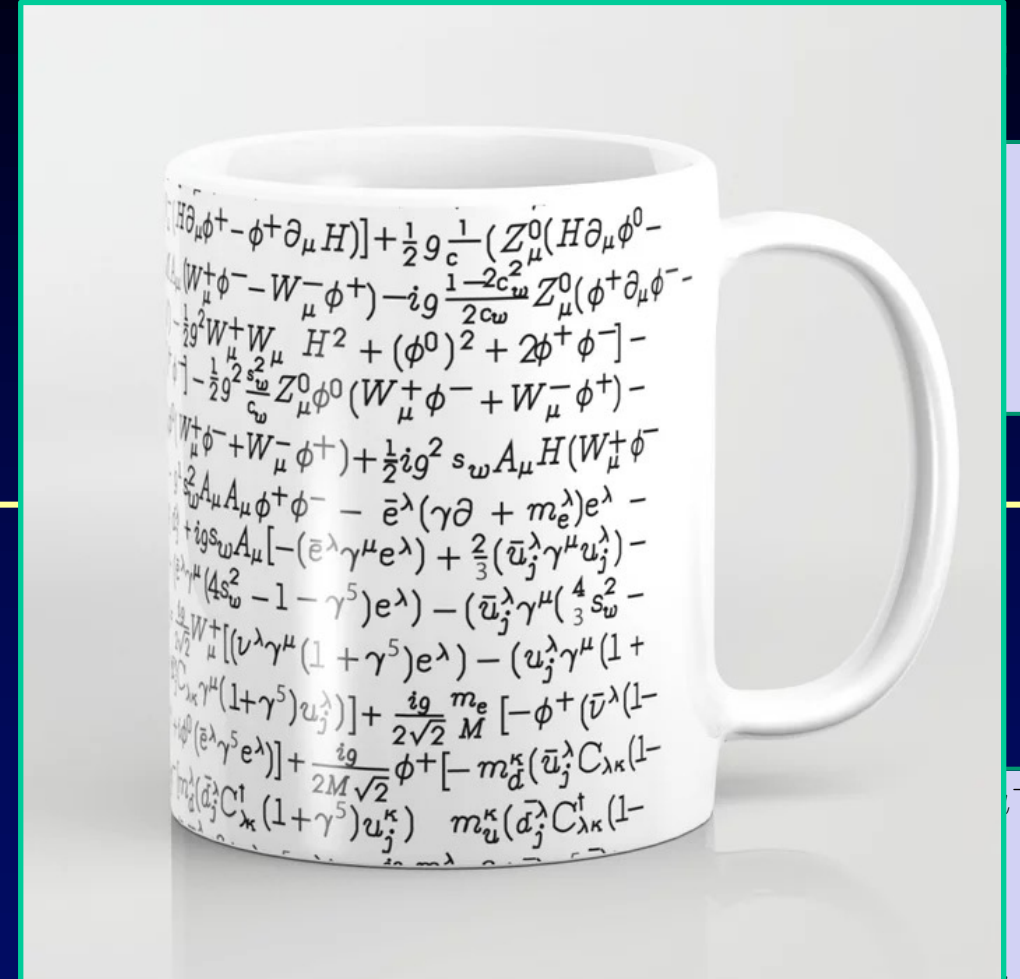
**H**

**Leptonen**

$\nu_e$	$\nu_\mu$	$\nu_\tau$
e	$\mu$	$\tau$

## Sterke kernkracht:

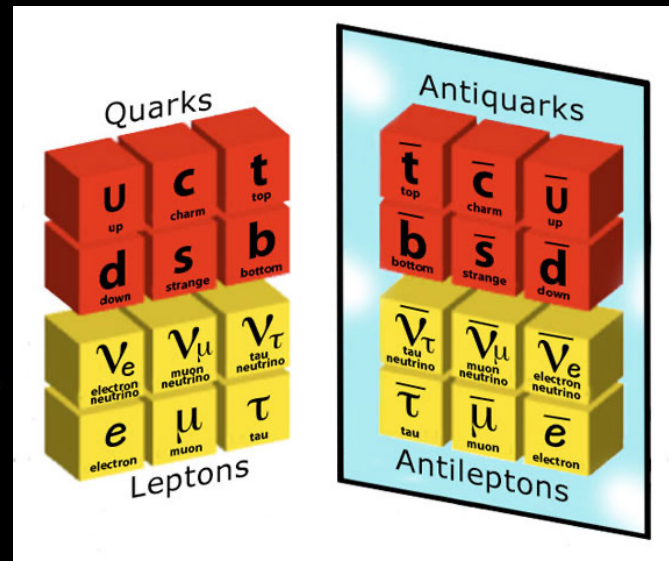
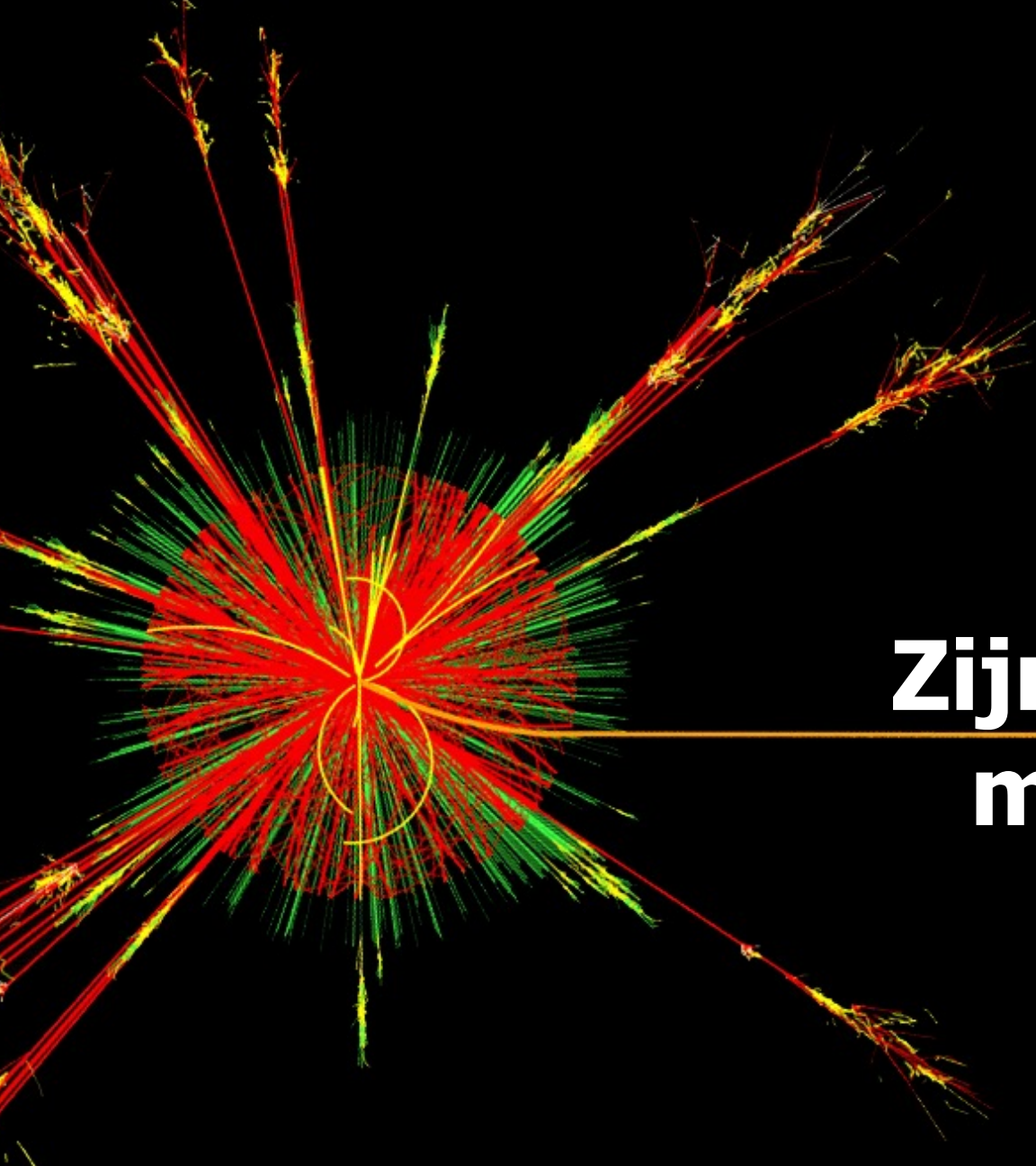
Quantum



Werkt op alle elektrisch geladen deeltjes

Werkt op alle deeltjes

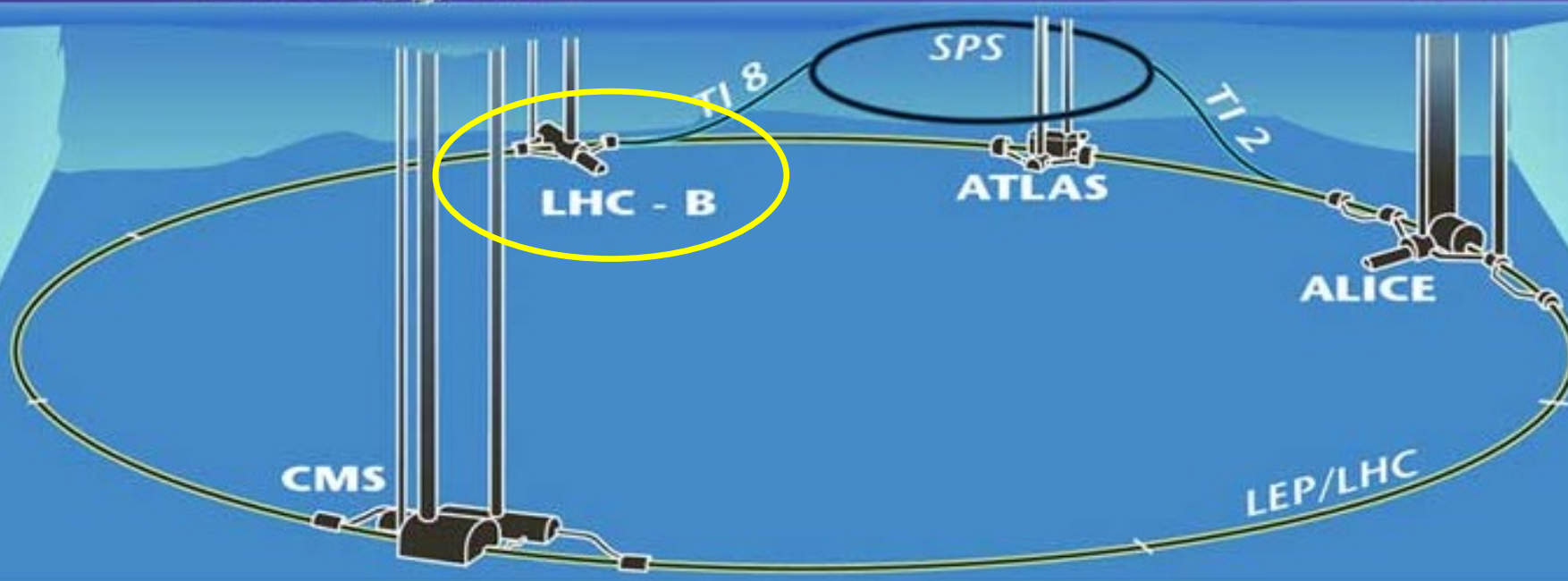
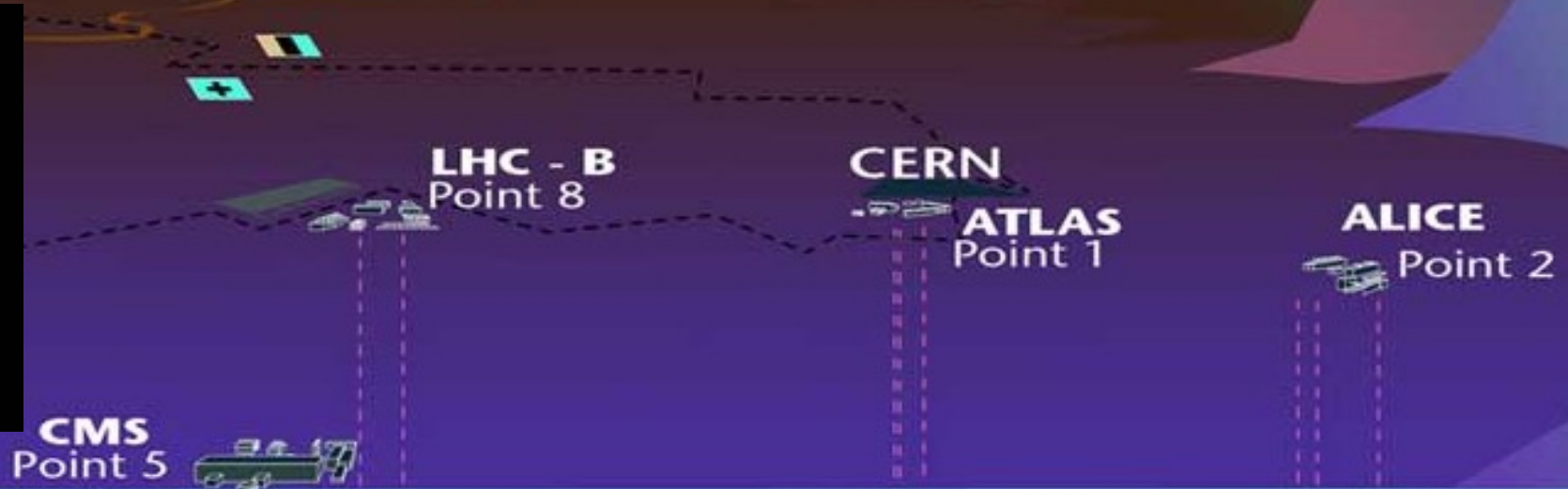
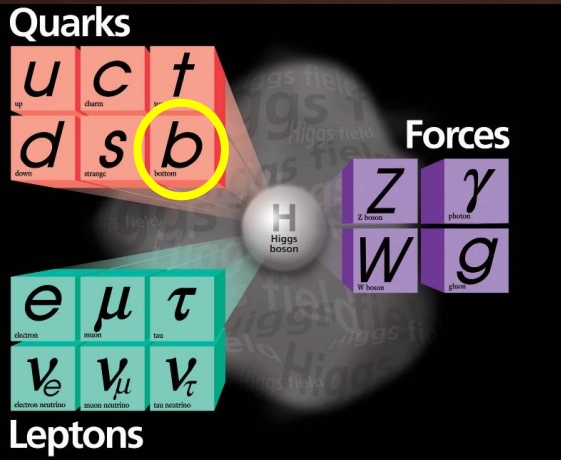




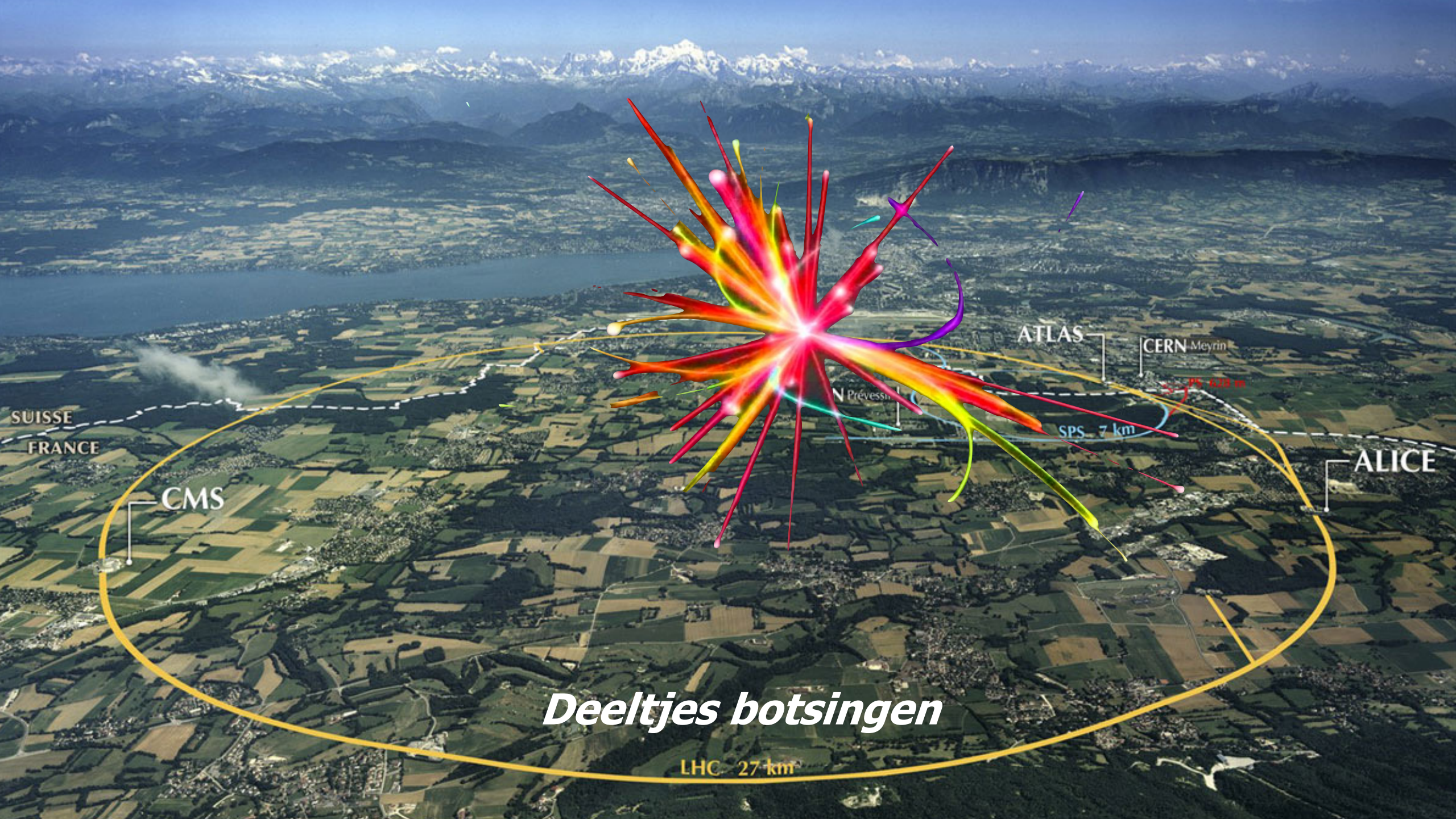
**Zijn krachten identiek voor materie and antimaterie?**



# LHCb experiment: vervallen van **B** deeltjes







SUISSE  
FRANCE

CMS

ATLAS

CERN Meyrin

Prévessin

SPS 7 km

PS 628 m

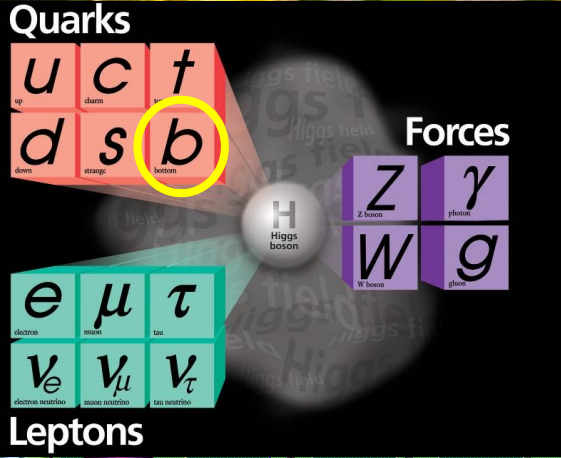
ALICE

# Deeltjes botsingen

LHC 27 km



# LHCb Detector: B-particles



Zoom in op  
botsingspunt

Reconstrueer miljoenen  $B$ -deeltjes vervallen  
en selecteer interessante gevallen.  
Is materie anders dan antimaterie?



23 sep 2010  
Run 79646

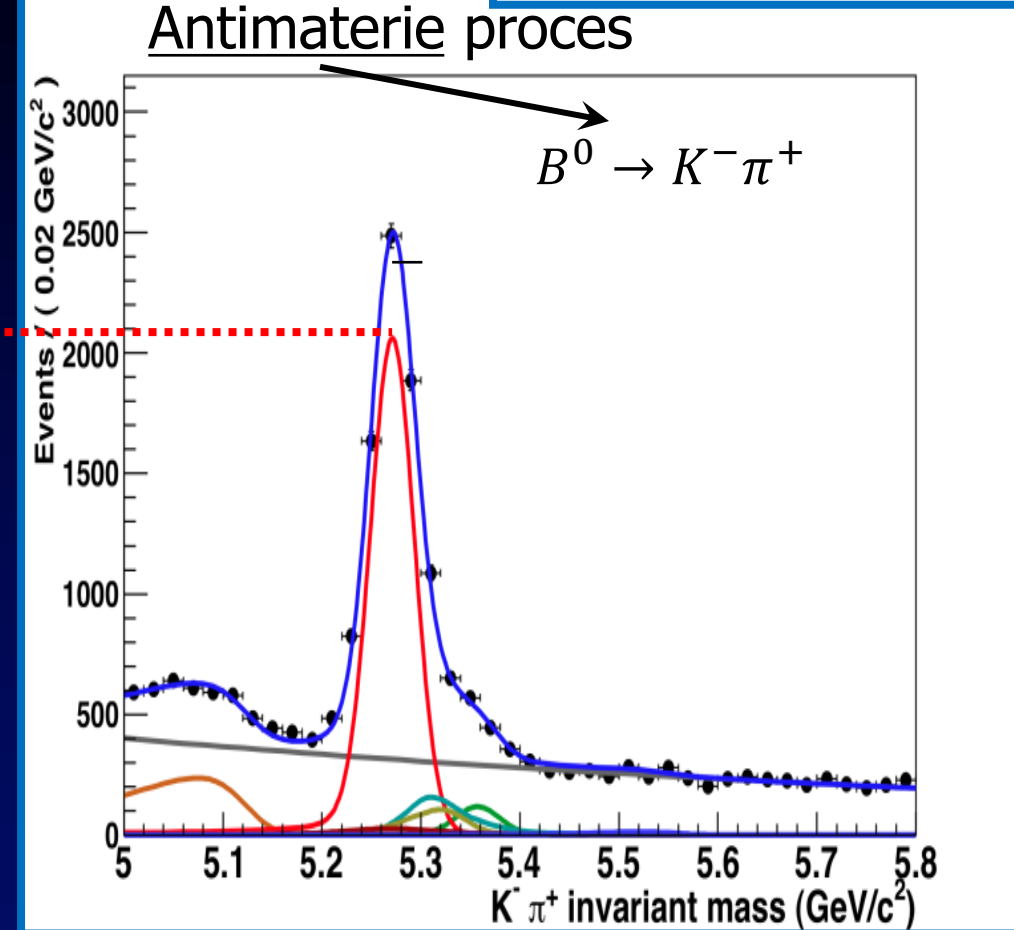
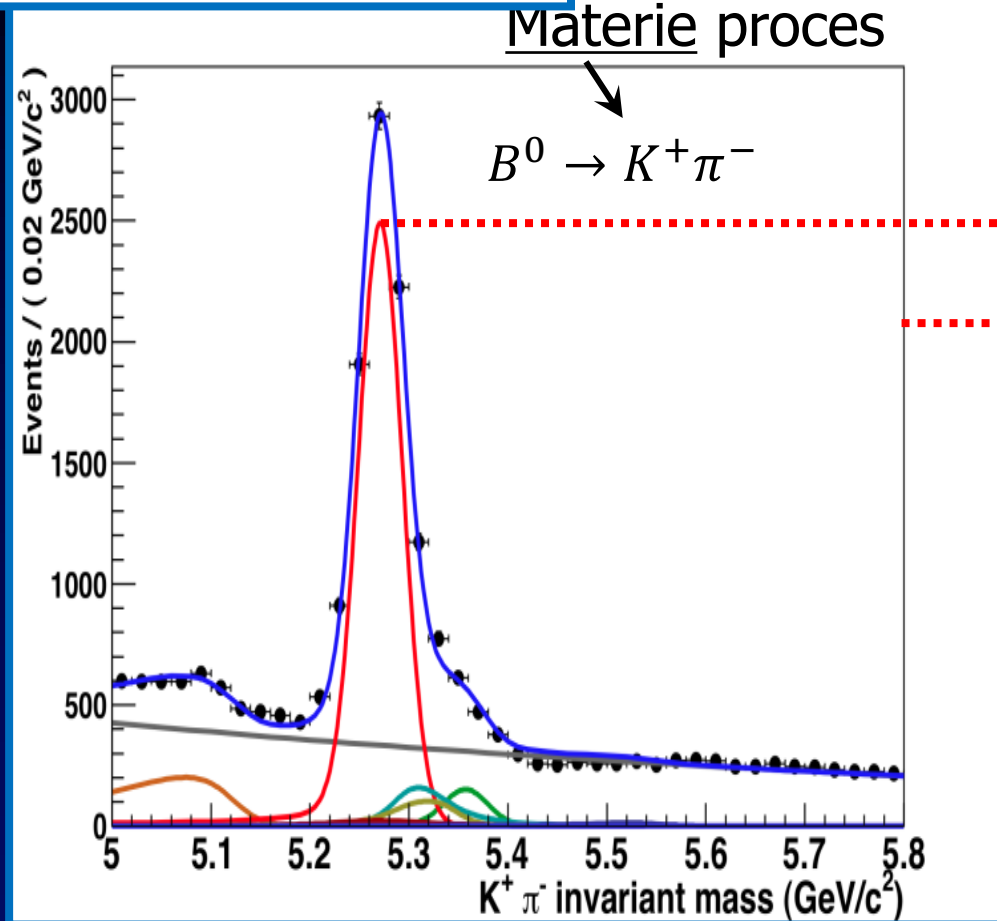
19:49:24  
Event 143858637



# B-vervalsproces: materie vs antimaterie

*B deeltje* verval naar  
een  $K^+$  en een  $\pi^-$  particle

*anti-B deeltje* verval naar  
een  $K^-$  en een  $\pi^+$  deeltje



Materie vervalproces anders dan antimaterie versie!

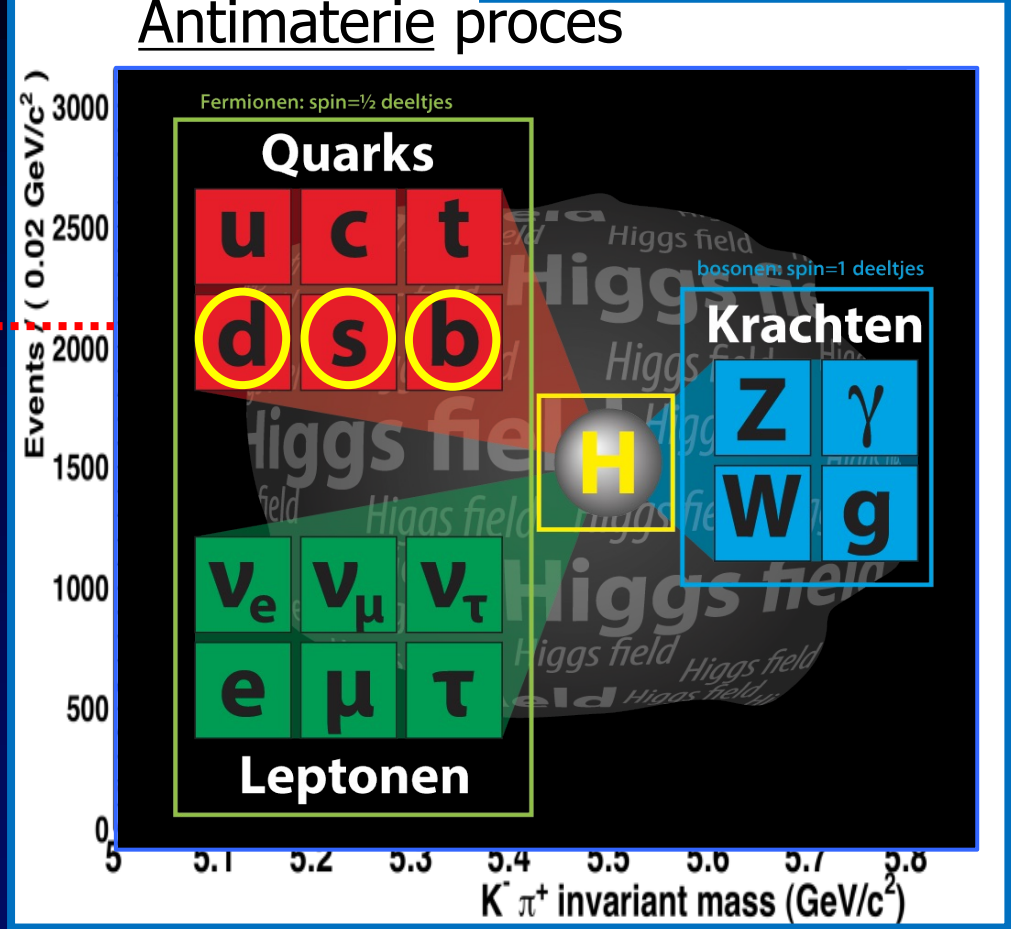
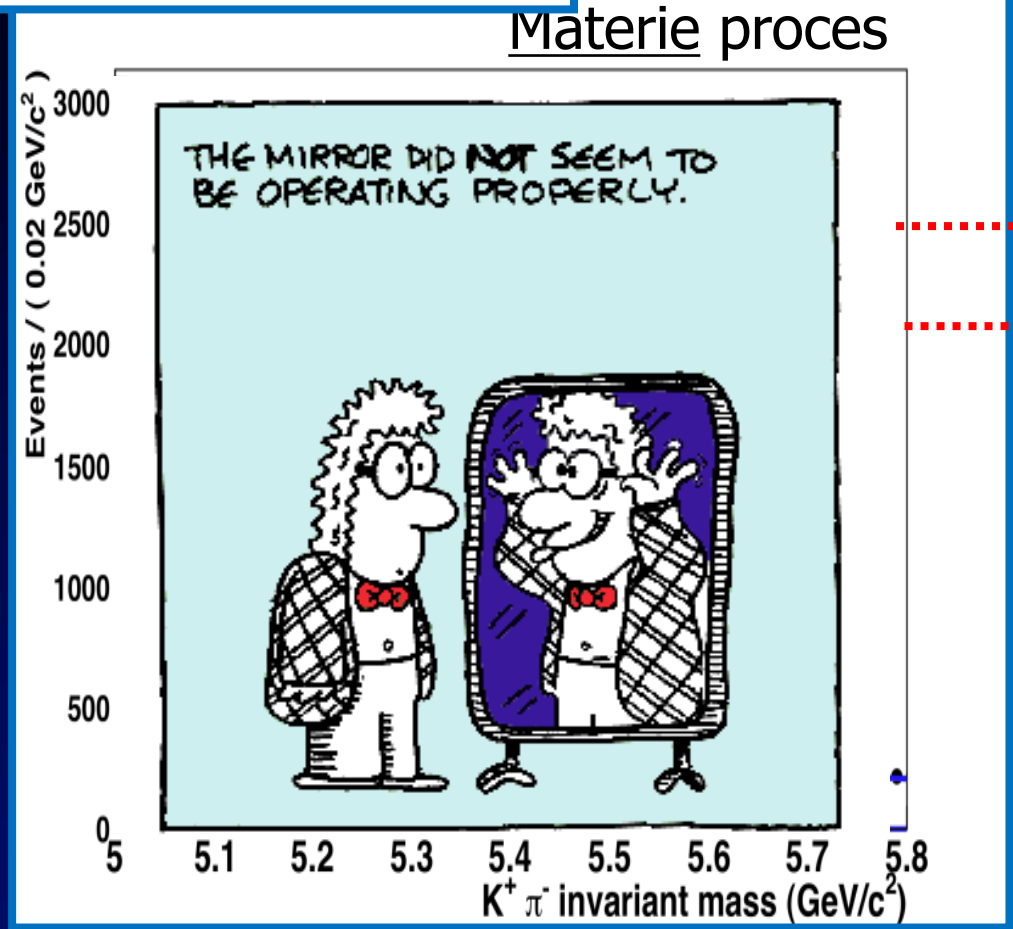
Quantum krachten tussen deeltjes en anti-deeltjes niet geheel identiek!



# B-vervalsproces: materie vs antimaterie

**B deeltje** verval naar een  $K^+$  en een  $\pi^-$  particle

**anti-B deeltje** verval naar een  $K^-$  en een  $\pi^+$  deeltje

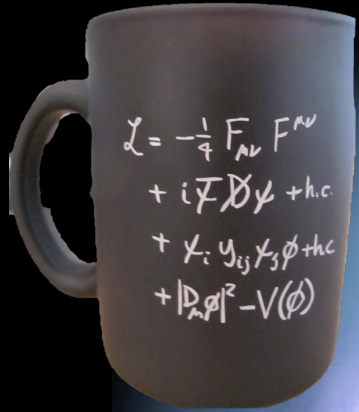


The materie – antimaterie symmetrie is verbroken

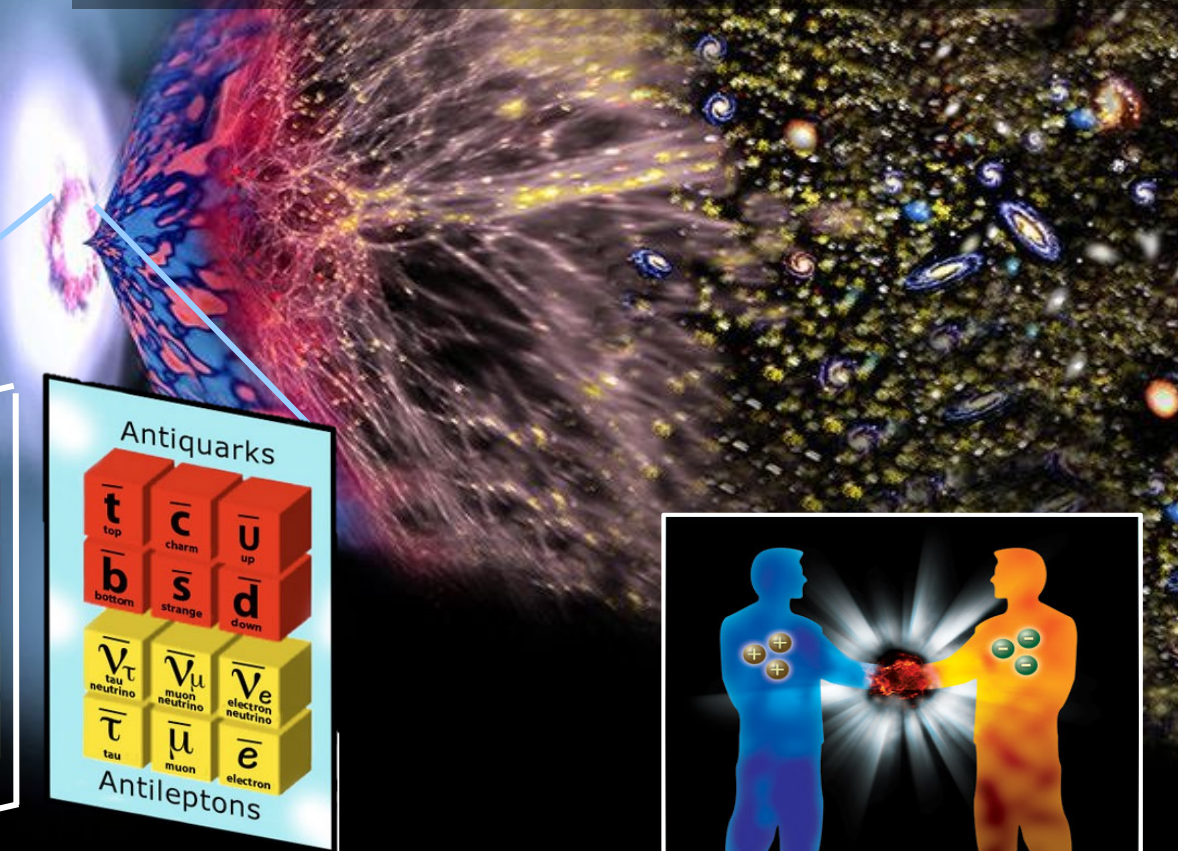
Dit gebeurt **alleen** als er tenminste **drie generaties** deeltjes bestaan!!!



# Vroege Universum: waar is de antimaterie heen?



- Asymmetrie in kracht
- Beetje meer materie dan antimaterie
- Rest annihileert
- Materie universum blijft over



**Quarks**

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

**Leptons**

$\nu_e$ electron neutrino	$\nu_\mu$ muon neutrino	$\nu_\tau$ tau neutrino
e electron	$\mu$ muon	$\tau$ tau

50.000001%

**Antiquarks**

$\bar{t}$ top	$\bar{c}$ charm	$\bar{u}$ up
$\bar{b}$ bottom	$\bar{s}$ strange	$\bar{d}$ down

**Antileptons**

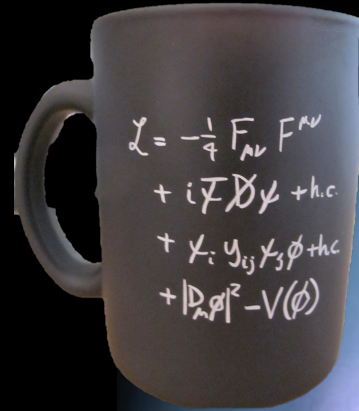
$\bar{\nu}_\tau$ tau neutrino	$\bar{\nu}_\mu$ muon neutrino	$\bar{\nu}_e$ electron neutrino
$\bar{\tau}$ tau	$\bar{\mu}$ muon	$\bar{e}$ electron

49.999999%



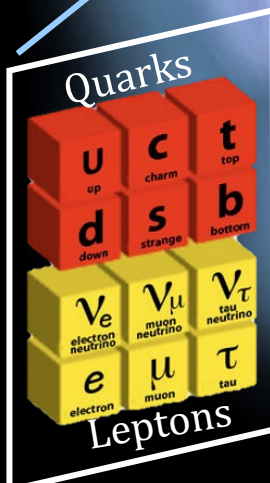


# Vroege Universum: waar is de antimaterie heen?

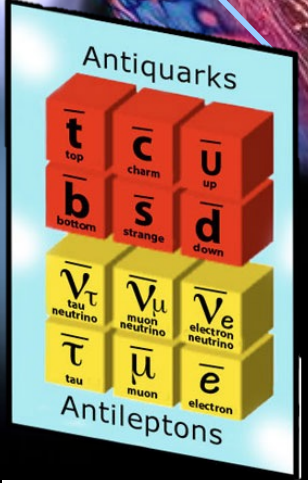


- Asymmetrie in kracht
- Beetje meer materie dan antimaterie
- Rest annihileert
- Materie universum blijft over

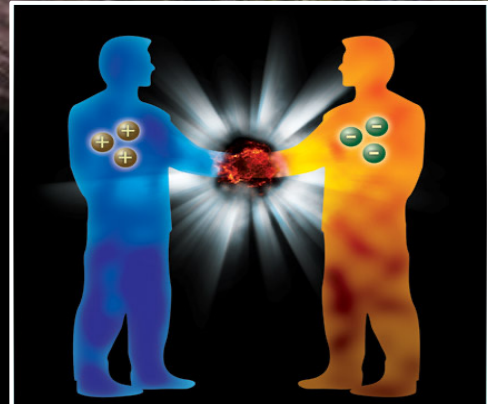
Helaas: het werkt niet!  
 Asymmetrie is *niet groot genoeg*.  
**Verklaring vereist nieuwe kracht!**



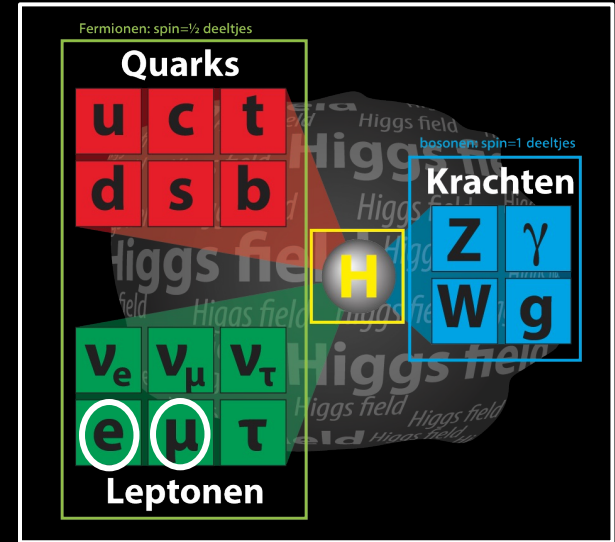
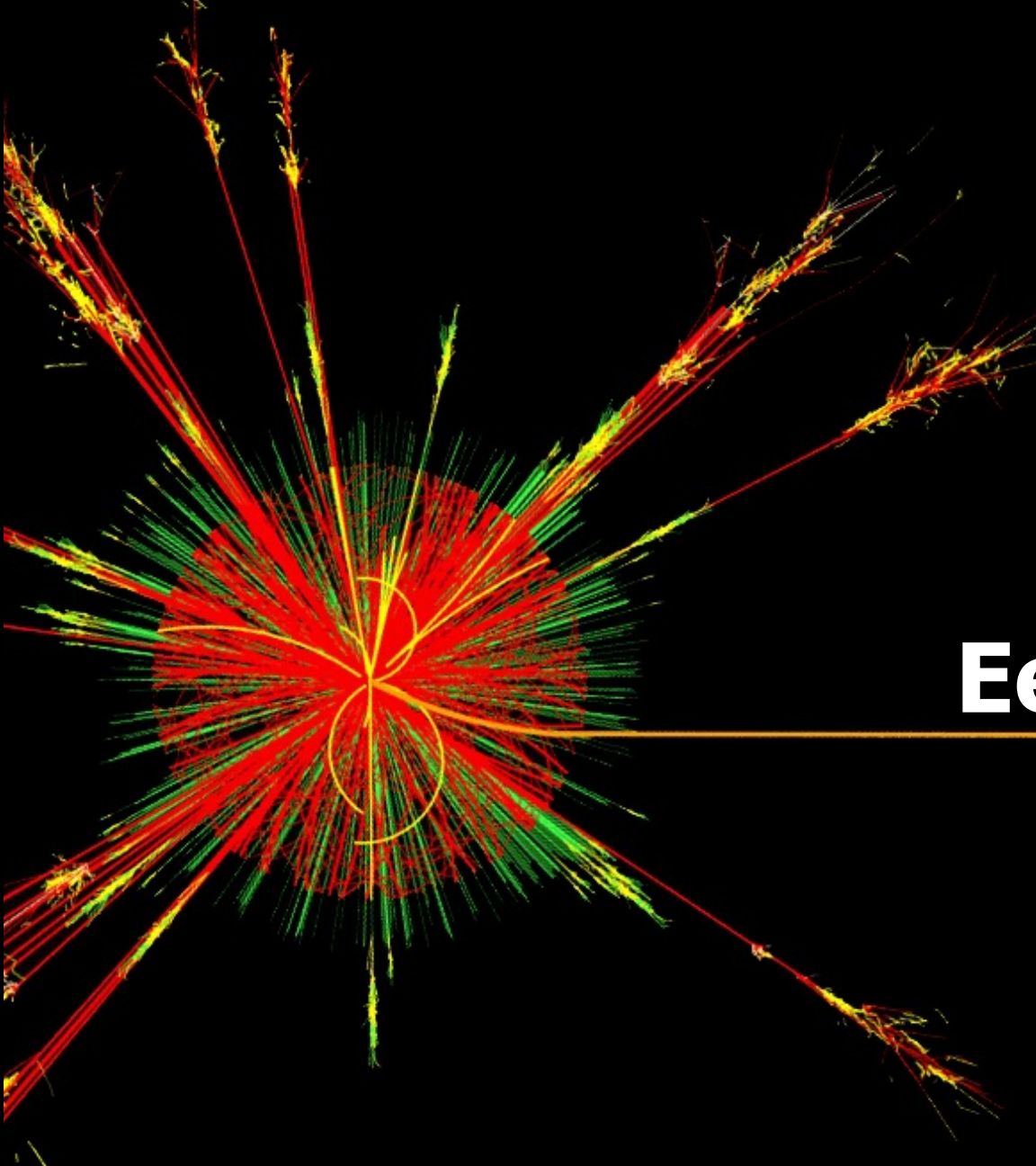
50.000001%



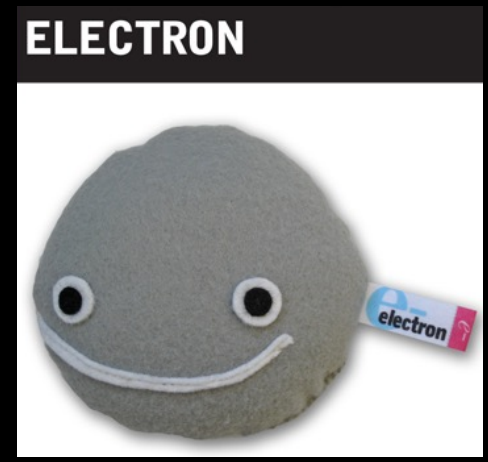
49.999999%





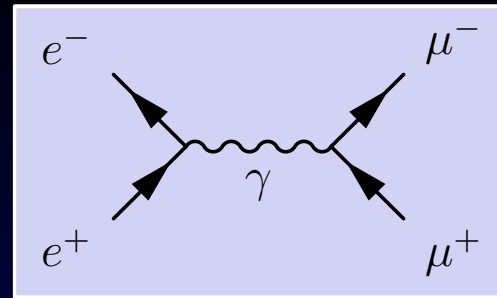
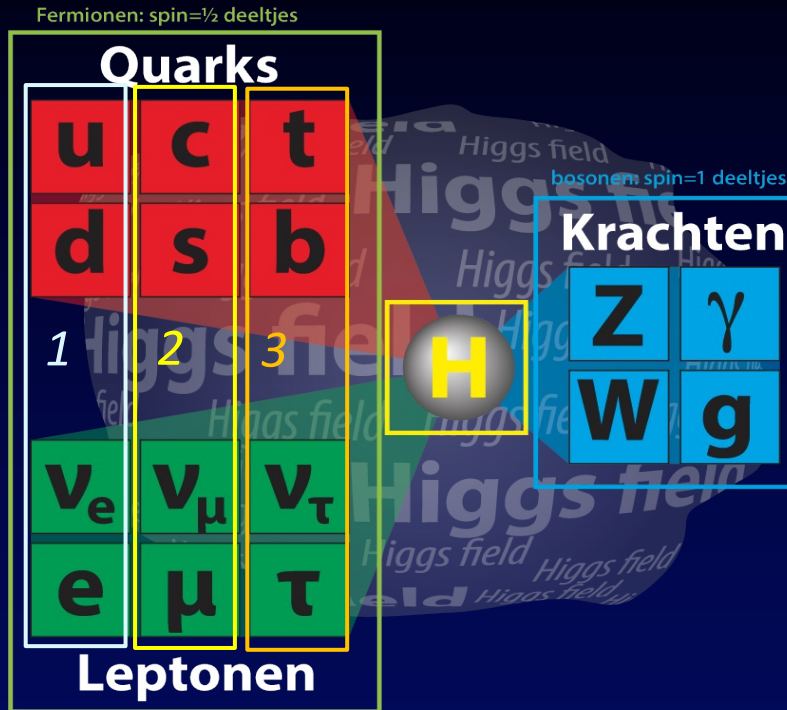


# Een nieuwe natuurkracht?

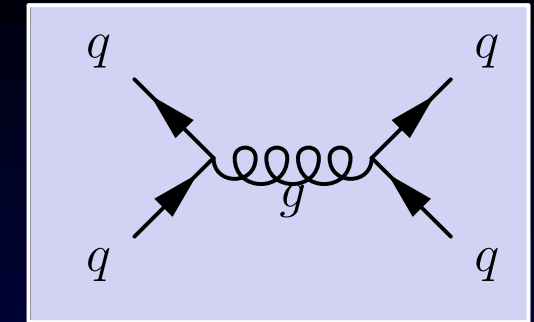




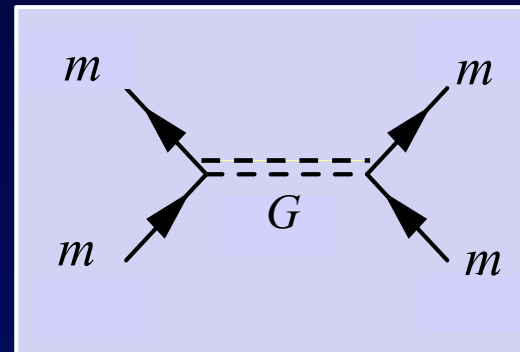
# Standaardmodel: Universaliteit van de Krachten



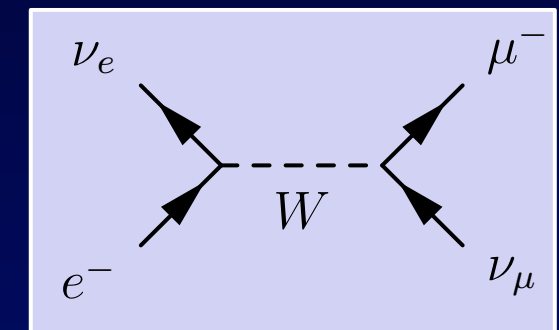
**Elektromagnetisme**



**Sterke kernkracht**



**Zwaartekracht**



**Zwakke kernkracht**

Krachten zijn identiek voor deeltjes van 1<sup>e</sup>, 2<sup>e</sup> en 3<sup>e</sup> generatie.

→ "Universaliteit"



Fermionen: spin=1/2 deeltjes

**Quarks**

u	c	t
d	s	b

Higgs field

**Krachten**

Z	$\gamma$
W	g

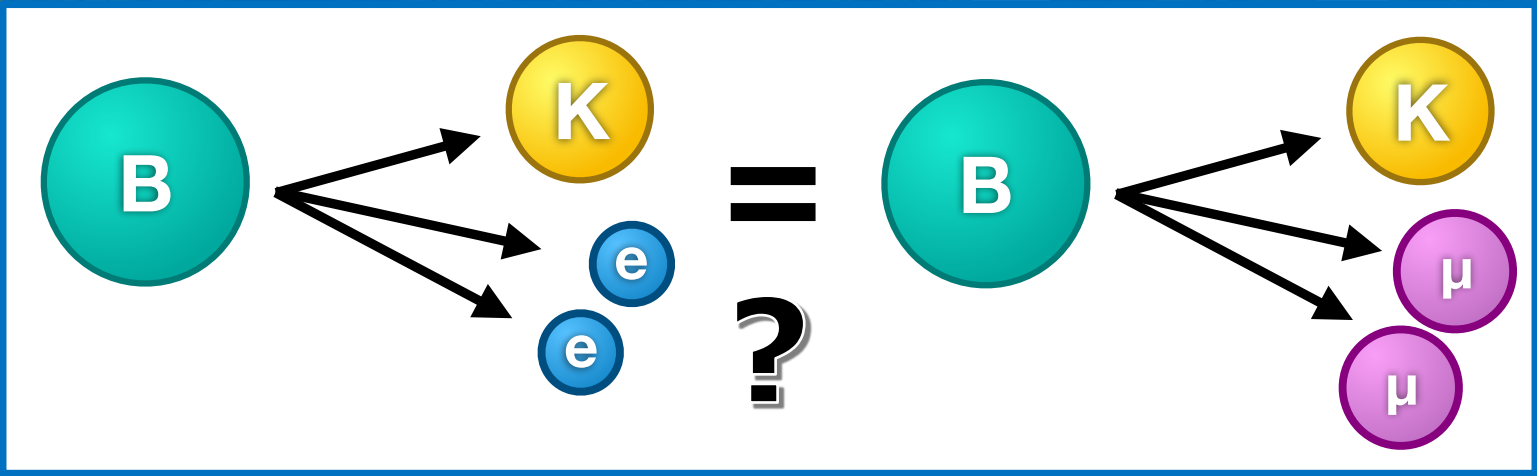
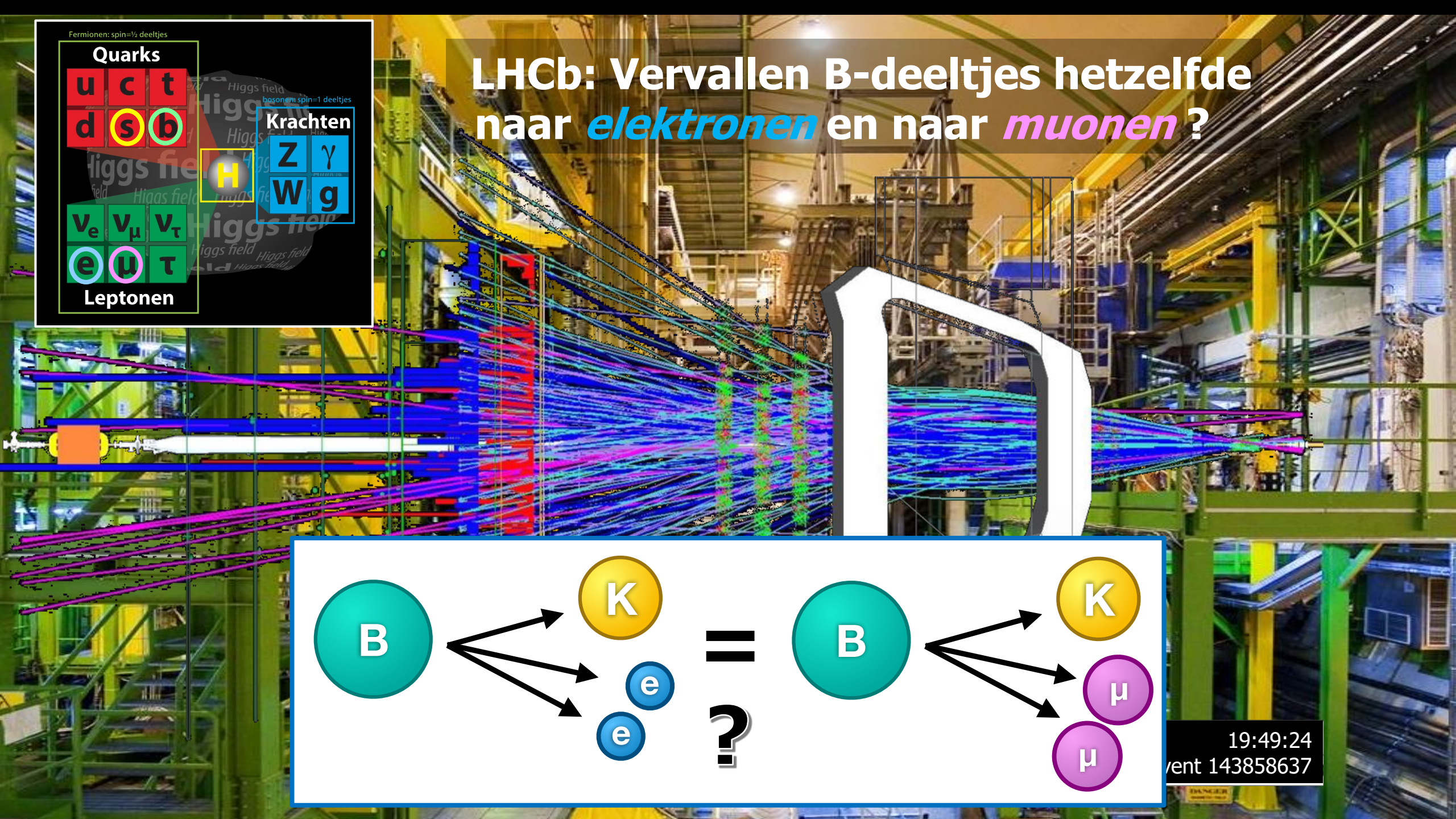
Higgs field

**Leptonen**

$\nu_e$	$\nu_\mu$	$\nu_\tau$
e	$\mu$	$\tau$

Higgs field

# LHCb: Vervallen B-deeltjes hetzelfde naar *elektronen* en naar *muonen*?





# LHCb: Vervallen B-deeltjes hetzelfde naar *elektronen* en naar *muonen*?

Fermionen: spin=1/2 deeltjes

**Quarks**

u	c	t
d	s	b

Higgs field  
bosonen spin=1 deeltjes

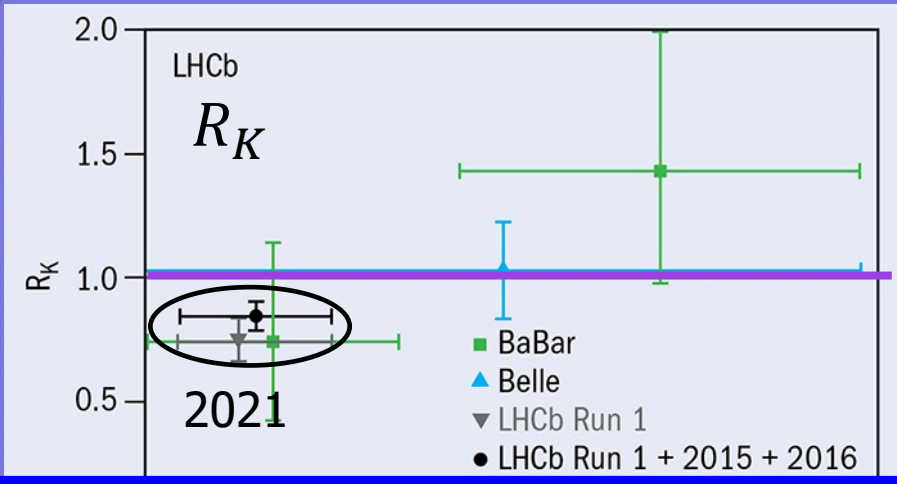
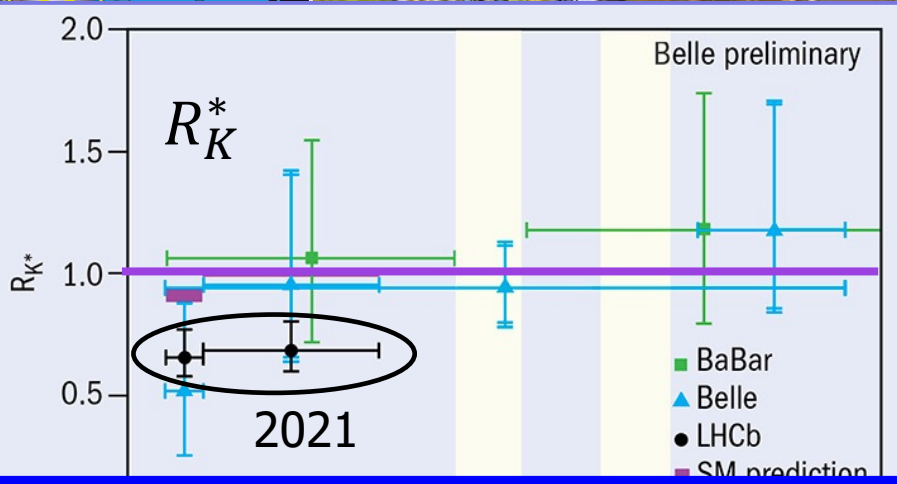
**Krachten**

Z	γ
---	---

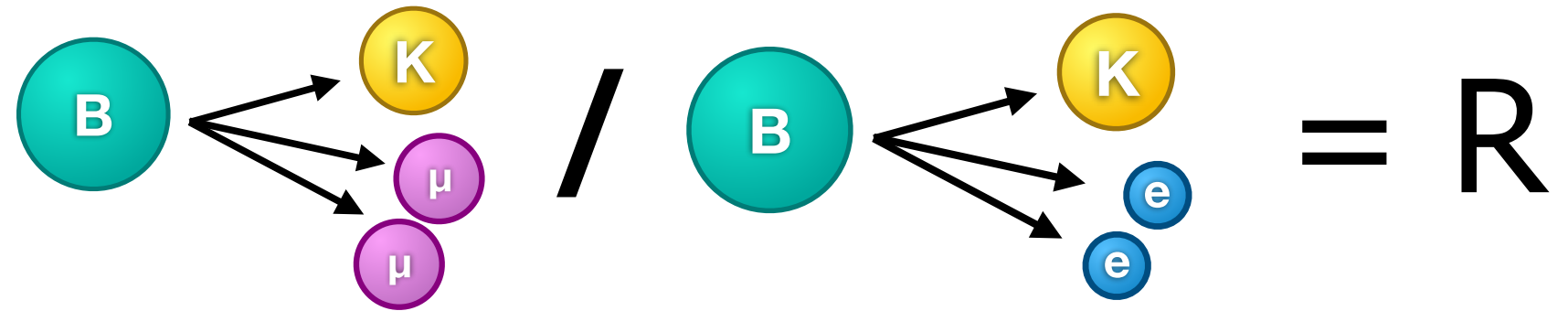
Higgs field

**Leptonen**

$\nu_e$	$\nu_\mu$	$\nu_\tau$
e	μ	τ



R niet precies gelijk aan 1??  
 → Verschillende kracht voor elektronen and muonen?!





# 23 Maart 2021: Krantenkoppen... "voorzichtige opwinding"

Menu **nrc**

## Voorzichtige opwinding onder fysici: deeltje gedraagt zich vreemd

**Deeltjesfysica** Het muon, het zware broertje van het elektron, gedraagt zich niet altijd als verwacht. Dat kan duiden op een barstje in het standaardmodel.

Margriet van der Heijden · 23 maart 2021 · Leestijd 3 minuten



## Cern experiment hints at new force of nature

- Guardian

### Experts reveal 'cautious excitement' over unstable particles that fail to decay as standard model suggests



de Volkskrant

NIEUWS

## Natuurkundigen van Cern vinden aanwijzing die ons begrip van de werkelijkheid op zijn kop kan zetten

Een gloednieuw deeltje, een nog onbekende natuurkracht... fysici bij onderzoeksinstituut Cern zien aanwijzing op zijn kop kan zetten. 'Dit is

George van Hal 23 maart 2021, 9:00

**Zijn we een nieuwe natuurkracht met muonen aan het ontdekken?!**



TELEGRAAF.NL

### Experts zijn nieuwe natuurkracht op het spoor: 'We trilden helemaal'

Na de vondst van het Higgs-deeltje, negen jaar geleden, klinken er nu opnieuw opgetogen ...

NEWS / LIFE

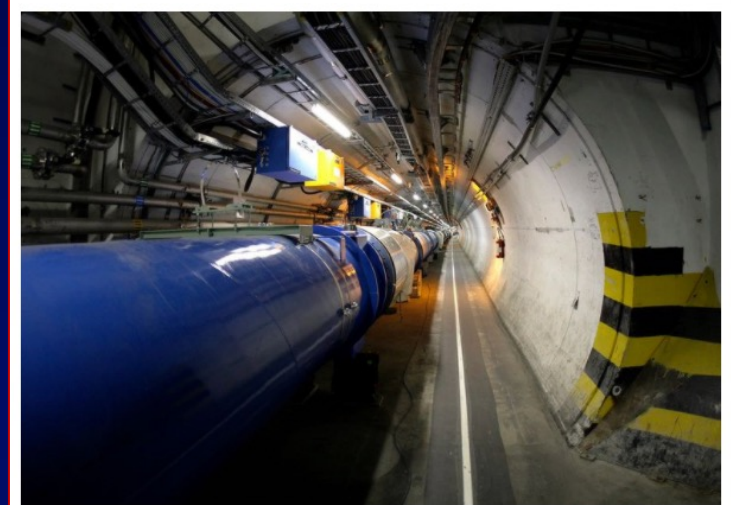
## CERN data on 'beauty quarks' behaviour may rewrite physics as we know it

24 MAR 2021

Beauty quarks or B mesons particles are not decaying as they should and while the findings may warrant "cautious excitement", more research needs to be done, scientists say.



FILE PHOTO: A view of the Large Hadron Collider at CERN, near Geneva, Switzerland. (CERN)



De tunnel van deeltjesversneller LHC bij Cern, Genève. In de blauwe buis zwiepen deeltjes met bijna de lichtsnelheid rond tot ze op elkaar knallen. Tussen de brokstukken van die botsing zoeken fysici naar aanwijzingen voor hoe de wereld op het kleinste niveau werkt. Beeld AP



# Twee weken later in Fermilab ... muon magnetisch moment?!

Menu **nrc**

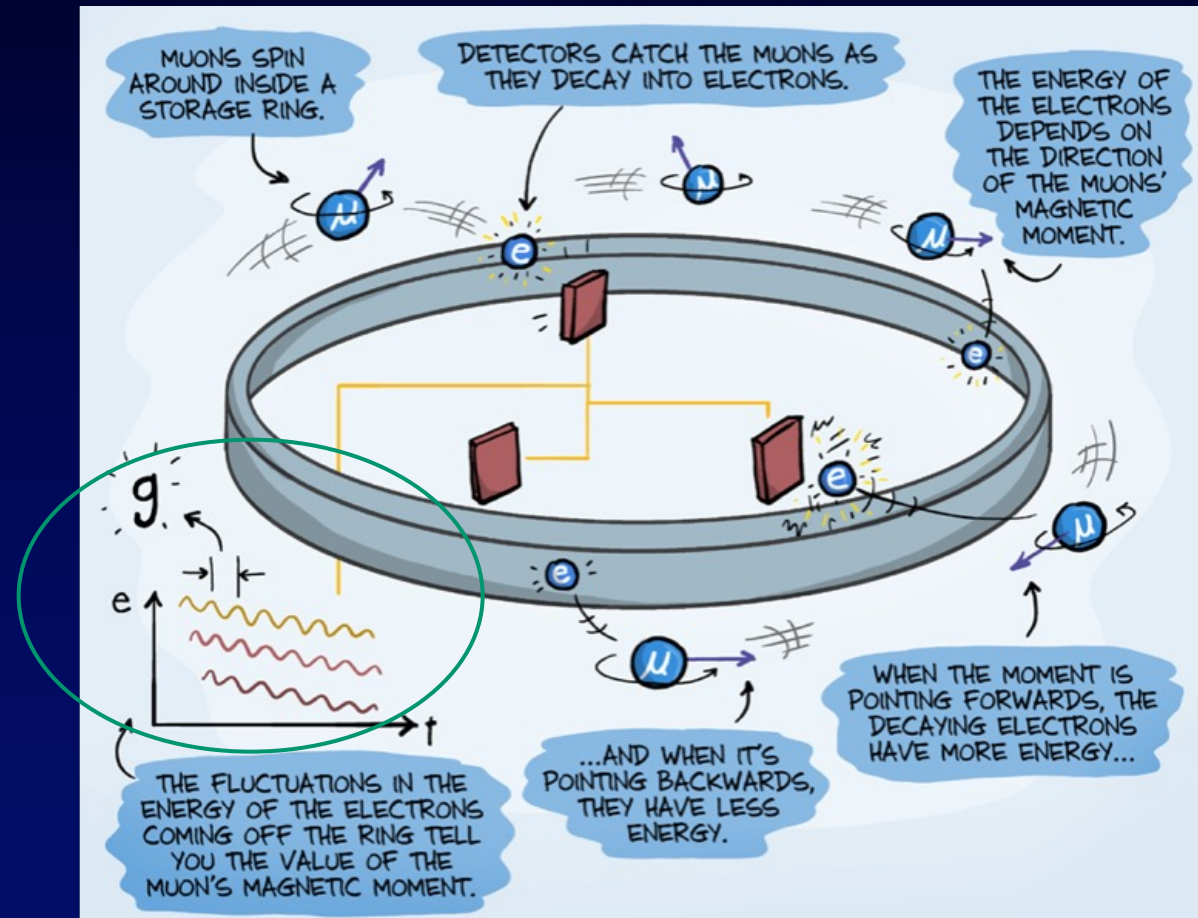
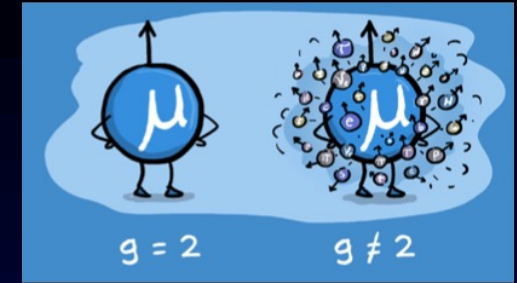
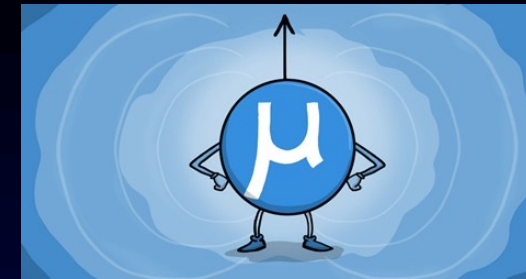
## Opnieuw barstje in standaardmodel van deeltjesfysica

**Natuurkunde** Gaat het standaardmodel van de deeltjesfysica breken? Resultaten uit een Amerikaans experiment leiden tot opwinding.

Dorine Schenk 7 april 2021 Leestijd 3 minuten



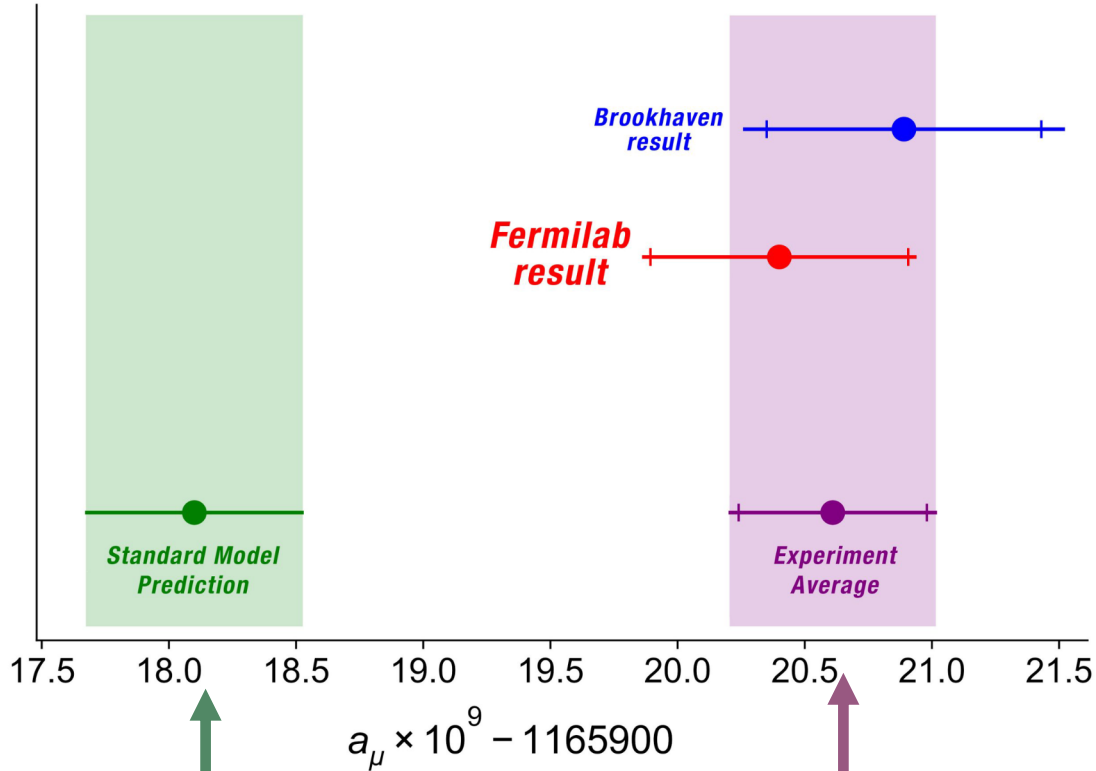
De Muon g-2-ring in het Fermilab in de buurt van Chicago. Het experiment wordt uitgevoerd bij een temperatuur van -268 graden Celsius. Foto Reidar Hahn/Fermilab





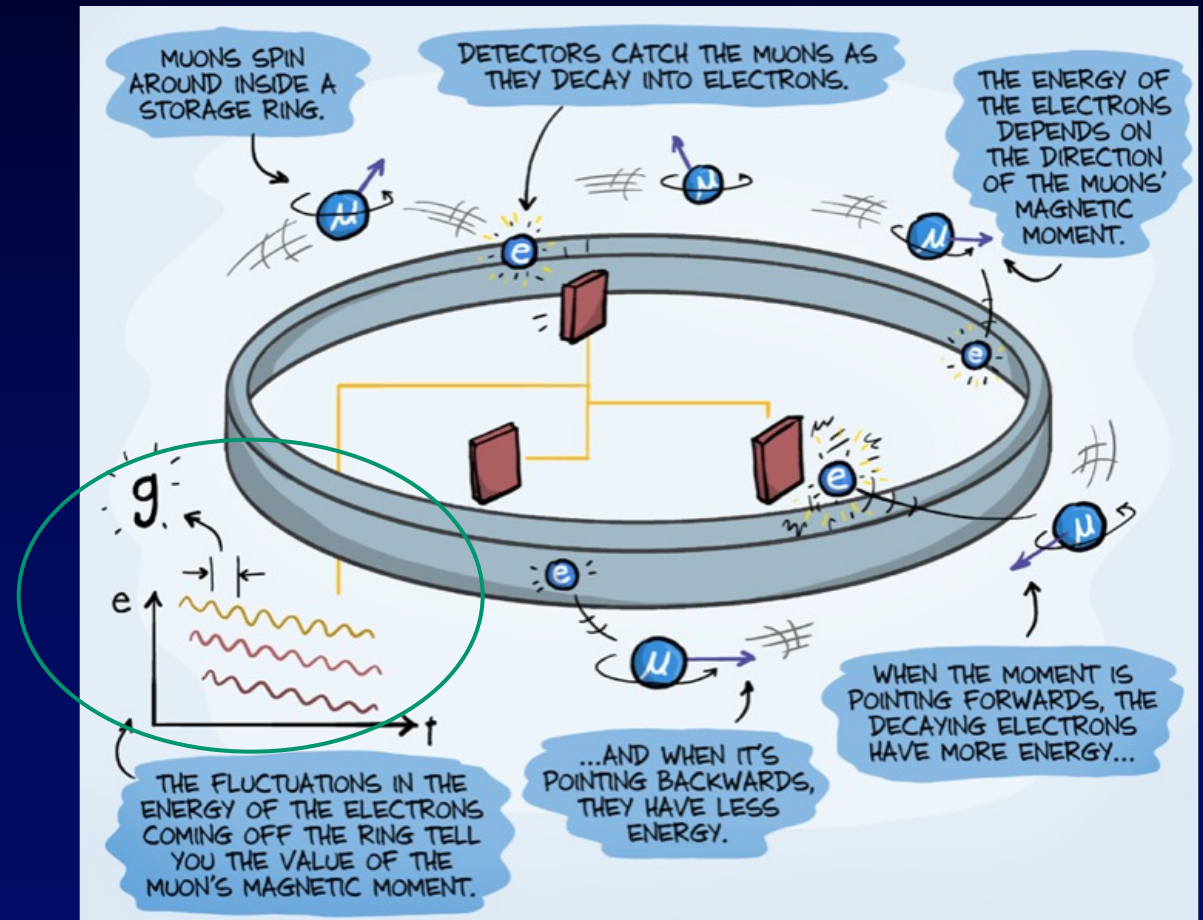
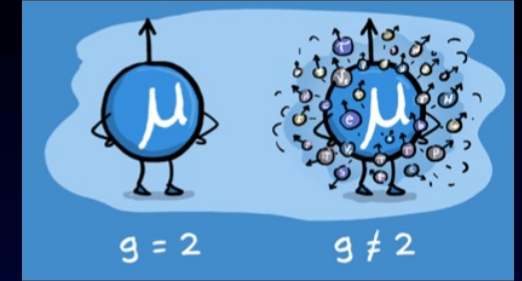
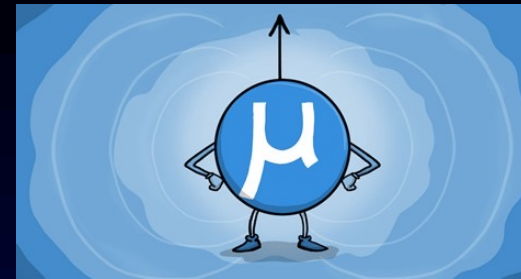
# Twee weken later in Fermilab ... muon magnetisch moment?!

Het Standaardmodel lijkt niet te voldoen  
 → Een nieuwe quantum kracht nodig?!



Standaard Model  
voorspelling

Experimentele  
meting





Fermionen: spin=1/2 deeltjes

**Quarks**

u	c	t
d	s	b

**Krachten**

Z	$\gamma$
W	g

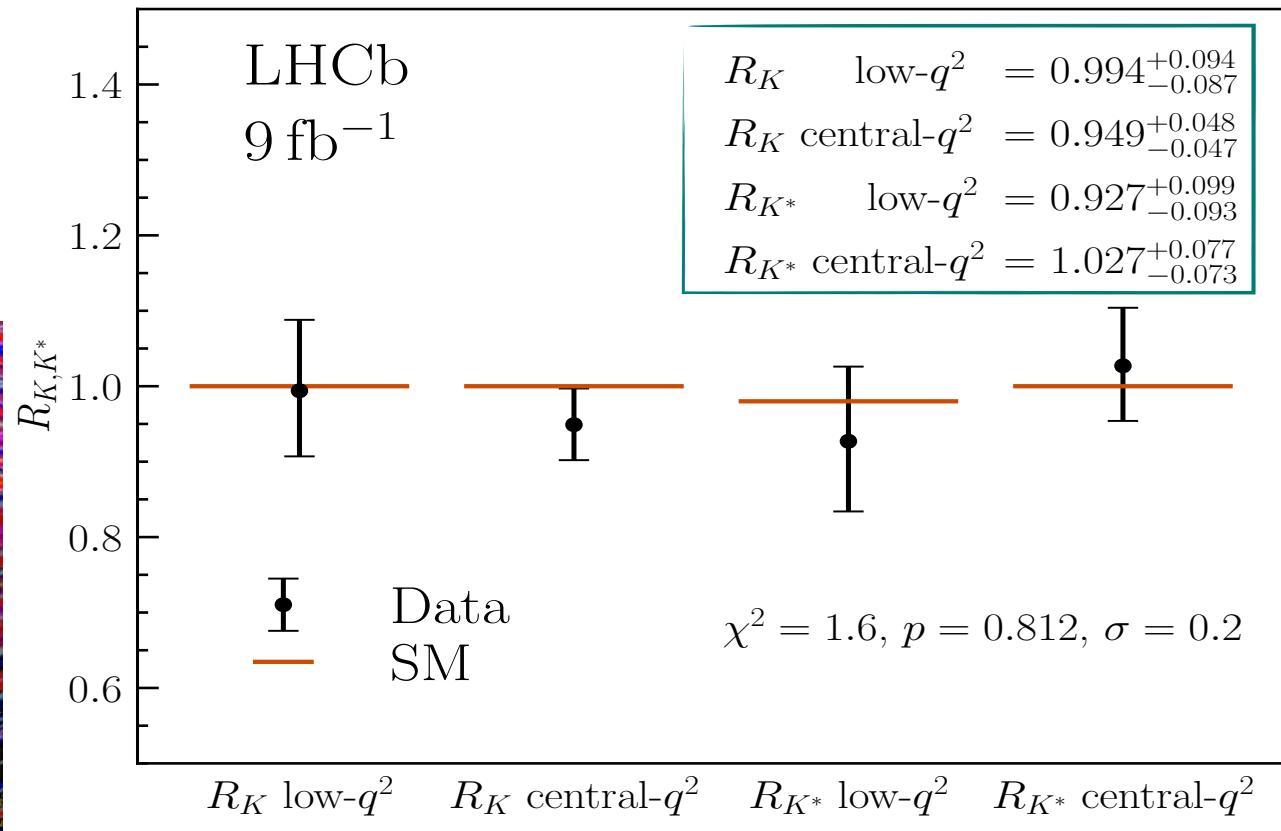
**Leptonen**

$\nu_e$	$\nu_\mu$	$\nu_\tau$
e	$\mu$	$\tau$

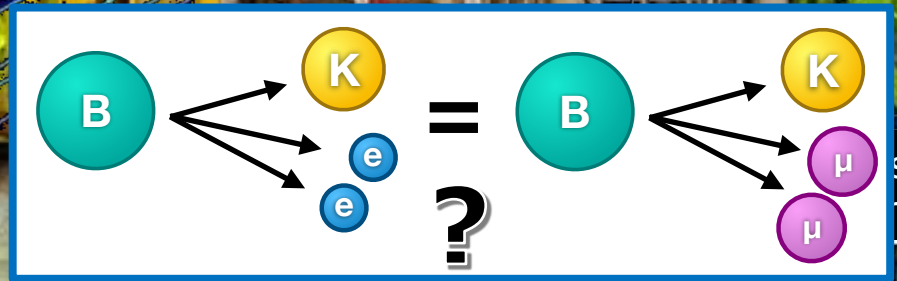
Higgs field

H

# LHCb: Vervallen B-deeltjes hetzelfde naar *elektronen* en naar *muonen*?



December 2022:  
verbeterde meting  
van de *elektronen*...





Fermionen: spin=1/2 deeltjes

**Quarks**

u	c	t
d	s	b

**Krachten**

Z	$\gamma$
W	g

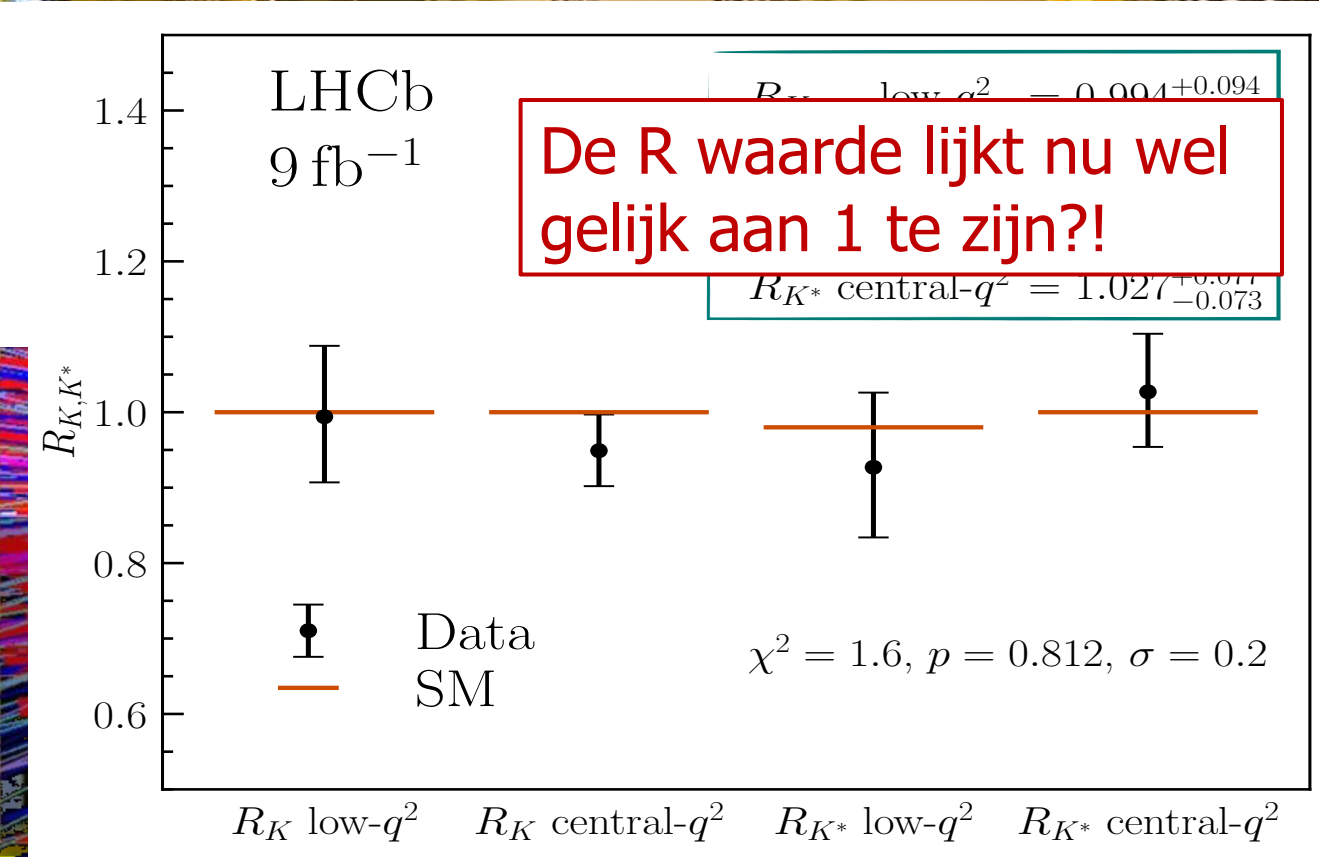
**Leptonen**

$\nu_e$	$\nu_\mu$	$\nu_\tau$
e	$\mu$	$\tau$

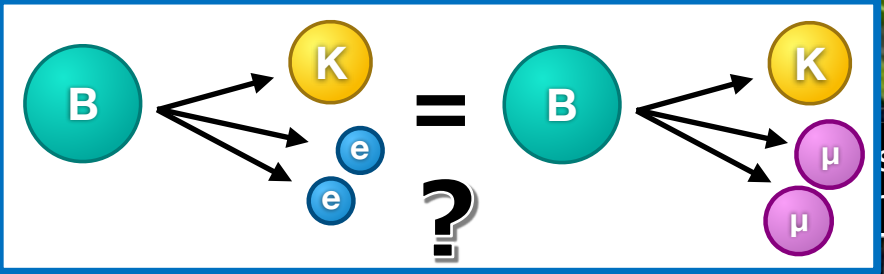
Higgs field

H

# LHCb: Vervallen B-deeltjes hetzelfde naar *elektronen* en naar *muonen*?

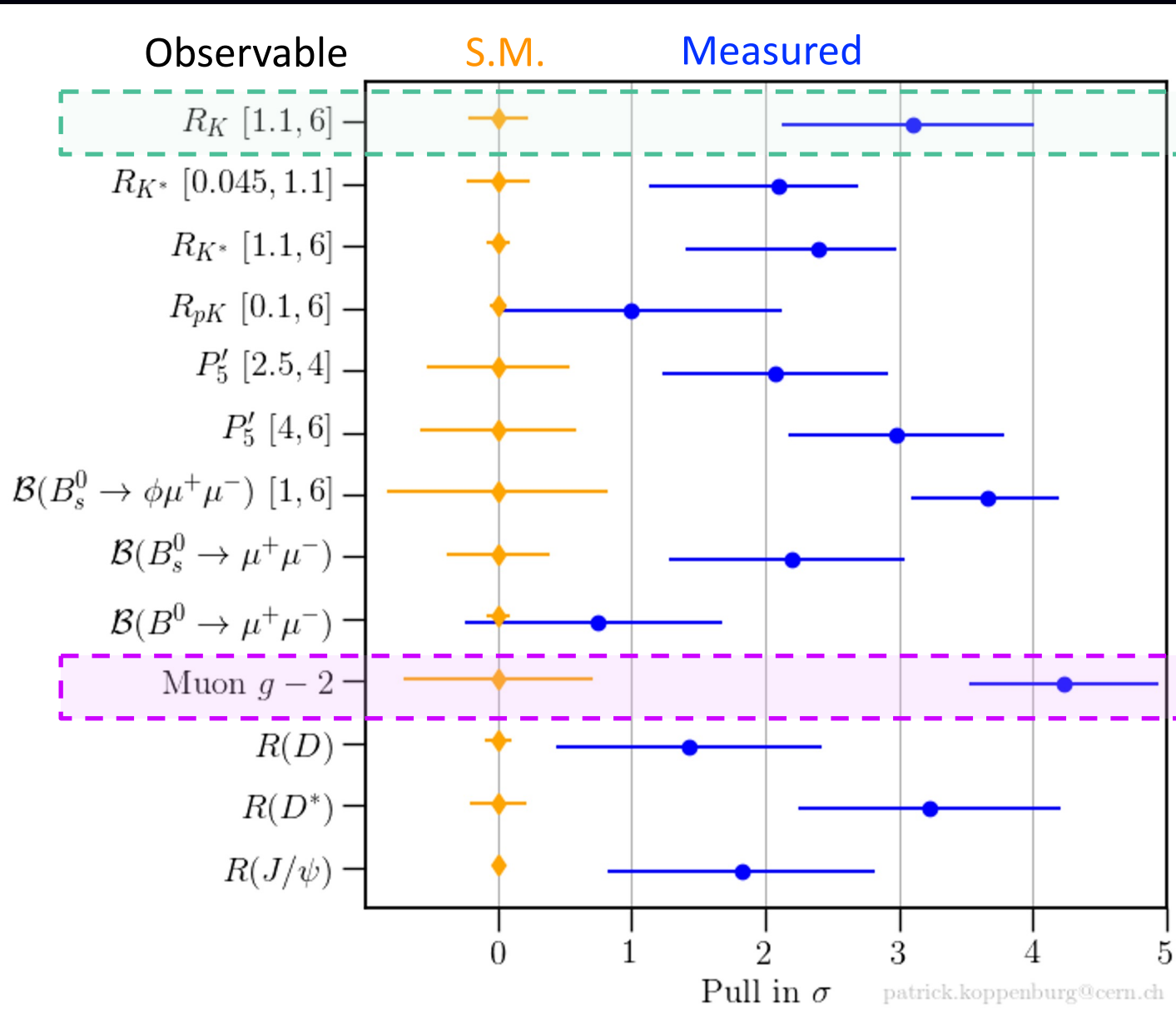


December 2022:  
verbeterde meting  
van de *elektronen*...





# Maar bij het muon kloppen steeds meer metingen niet!



LHCb resultaat

Fermilab g-2 resultaat

De puzzel wordt steeds dieper.

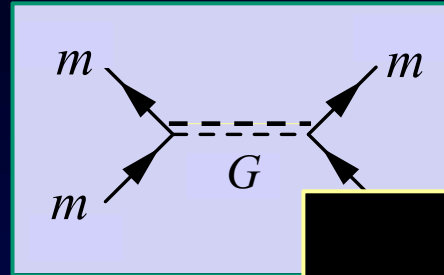


# Vier(?) fundamentele natuurkrachten

Zwaartekracht:

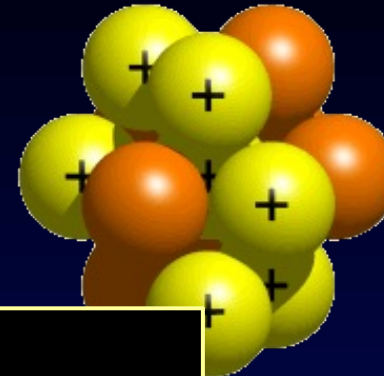


Quantum  
Graviton exchange?



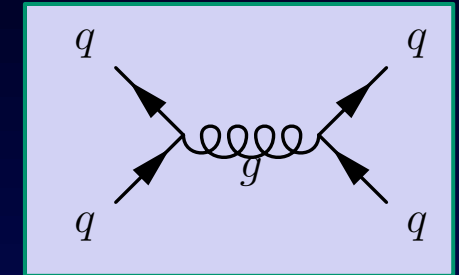
Werkt op alle deeltjes met massa

Sterke kernkracht:



alle quarks

Quantum  
gluon exchange:



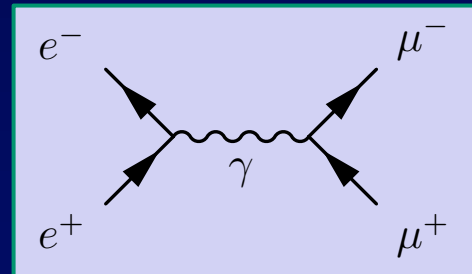
+ ????

Vijfde kracht?

Elektromagnetisme:

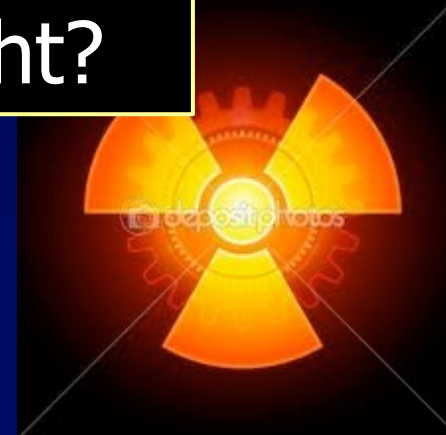


Quantum  
photon exchange



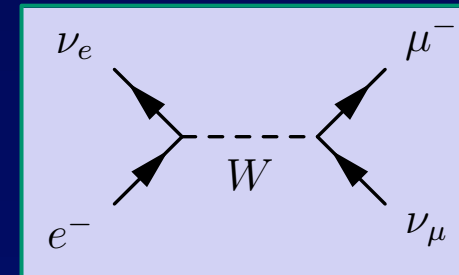
Werkt op alle elektrisch geladen deeltjes

Wakernkracht:



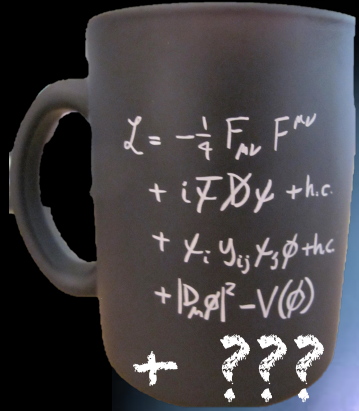
Werkt op alle deeltjes

Quantum  
W, Z exchange:

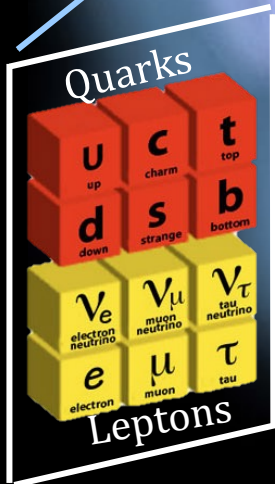




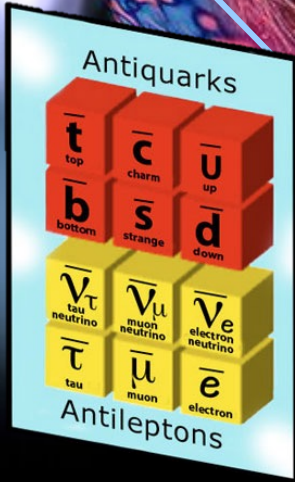
# Conclusie: Hoe is de antimaterie verdwenen in het universum?



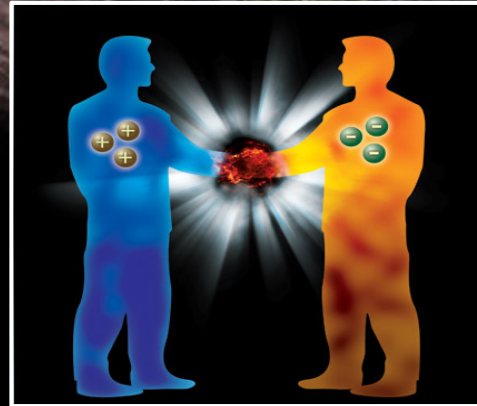
Door een vijfde kracht in de Big Bang?!



50.000001%



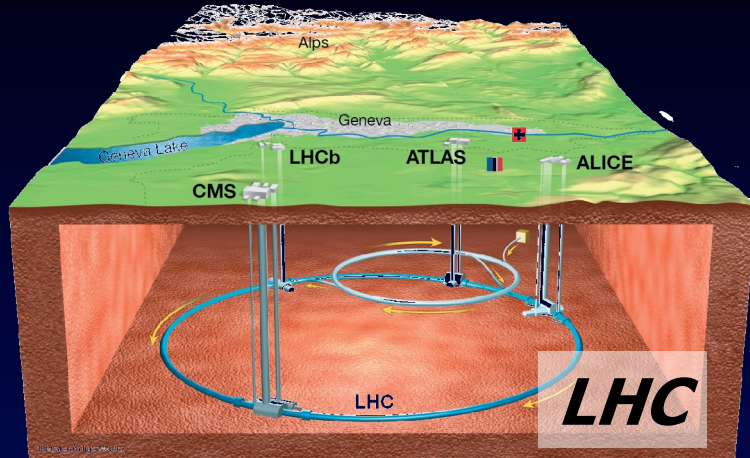
49.999999%



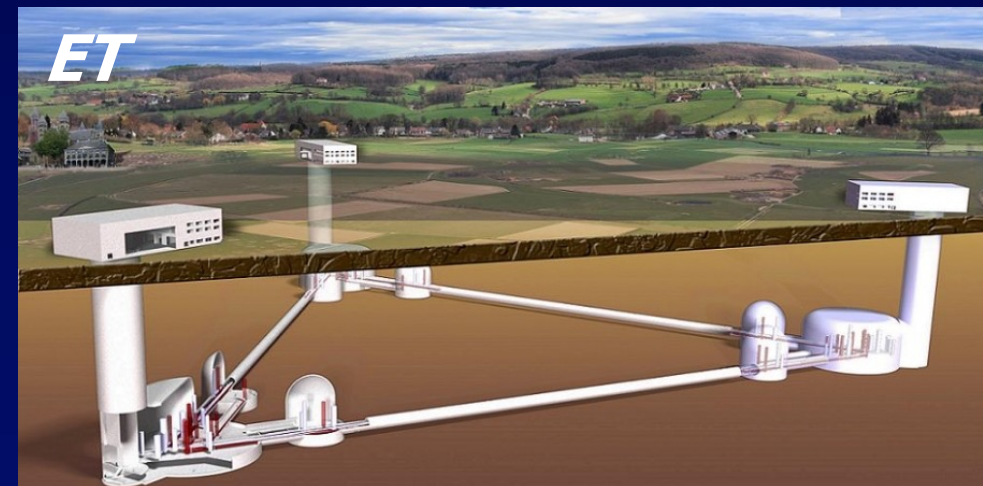
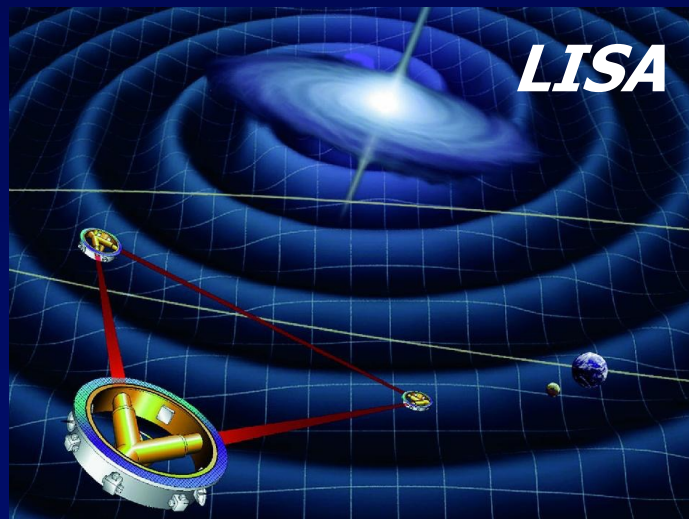


# Toekomst: "Cirkels en Driehoeken"

## Deeltjesversnellers: fysica van de Big Bang ...



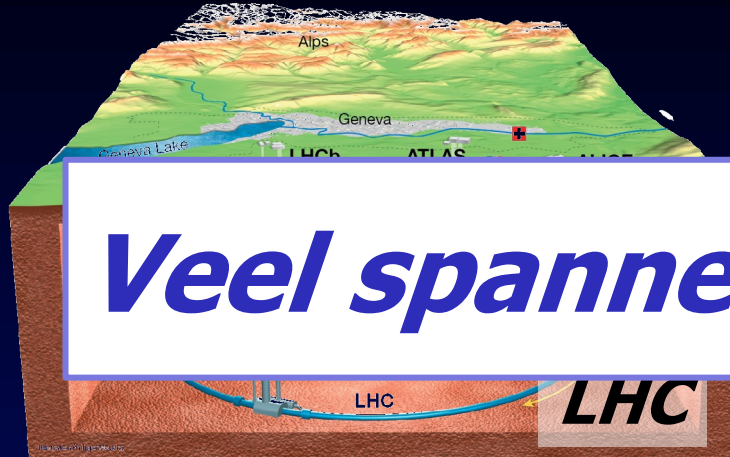
## Gravitatie-detectoren: luisteren naar de Big Bang...





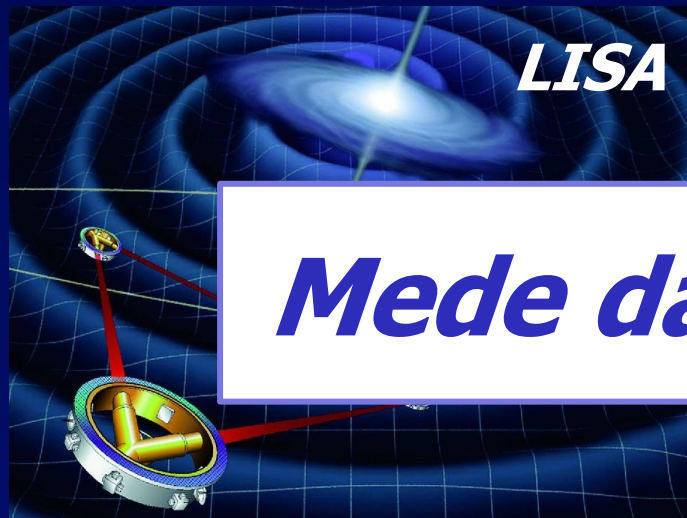
# Toekomst: "Cirkels en Driehoeken"

## Deeltjesversnellers: fysica van de Big Bang ...



***Veel spannend onderzoek onderweg***

## Gravitatie-detectoren: luisteren naar de Big Bang...



***Mede dankzij Nikhef Techno's!***

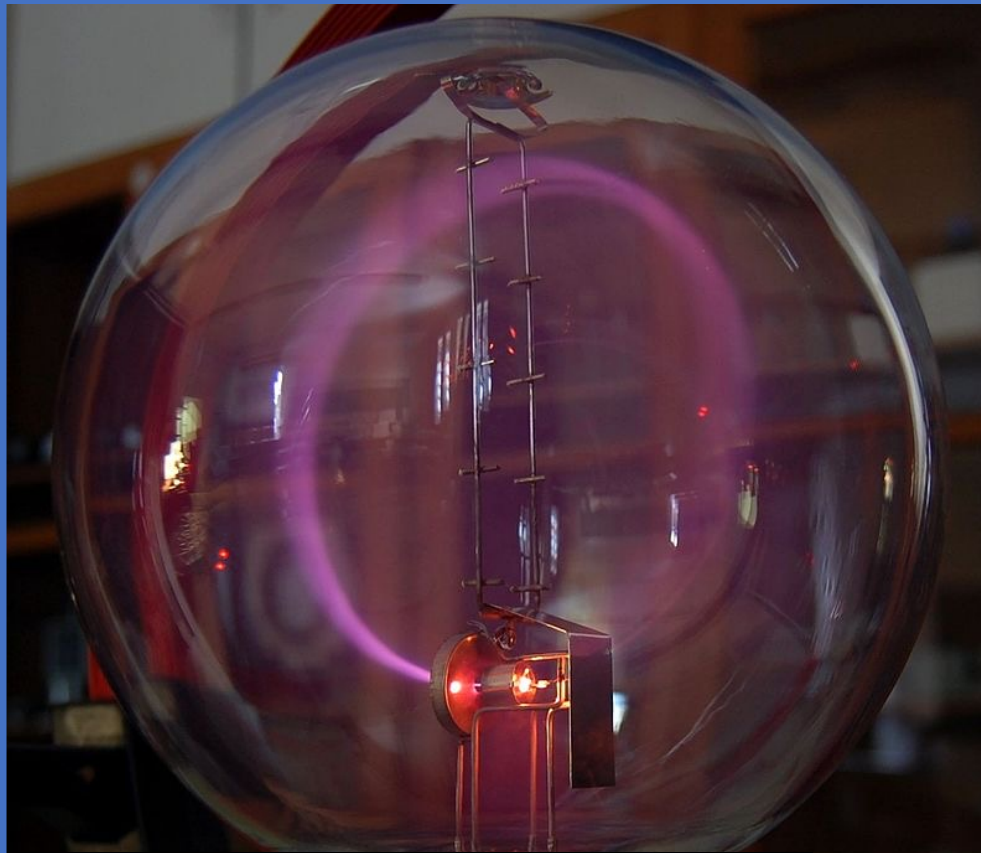


# 4 Forces of the Universe

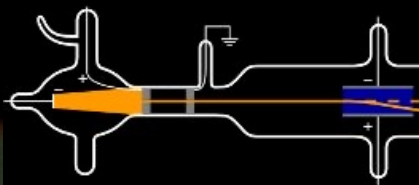
The image displays the path integral formulation of quantum field theory, where the wave function  $\Psi$  is expressed as an integral over all possible field configurations. The equation is: 
$$\Psi = \int e^{i/\hbar \int \left( \frac{R}{16\pi G} - \frac{1}{4}F^2 + \bar{\psi}_i \not{D} \psi - \lambda H \bar{\psi} \psi + |DH|^2 - V(H) \right)}$$
 The terms in the action are associated with various physicists and concepts:  $R$  is associated with Einstein and Newton;  $F^2$  is associated with Maxwell and Yang-Mills;  $\bar{\psi}_i \not{D} \psi$  is associated with Dirac;  $\lambda H \bar{\psi} \psi$  is associated with Yukawa;  $|DH|^2$  is associated with Kobayashi-Maskawa; and  $V(H)$  is associated with Higgs and Lagrange. The name Euler is associated with the exponential function  $e$ . The name Feynman is associated with the path integral symbol  $\int$ . The name Schrodinger is associated with the wave function  $\Psi$ . The name Planck is associated with  $\hbar$ . The text "ALL KNOWN PHYSICS" is written at the bottom.



# Elektron



Cathode rays



Thomson  
1879

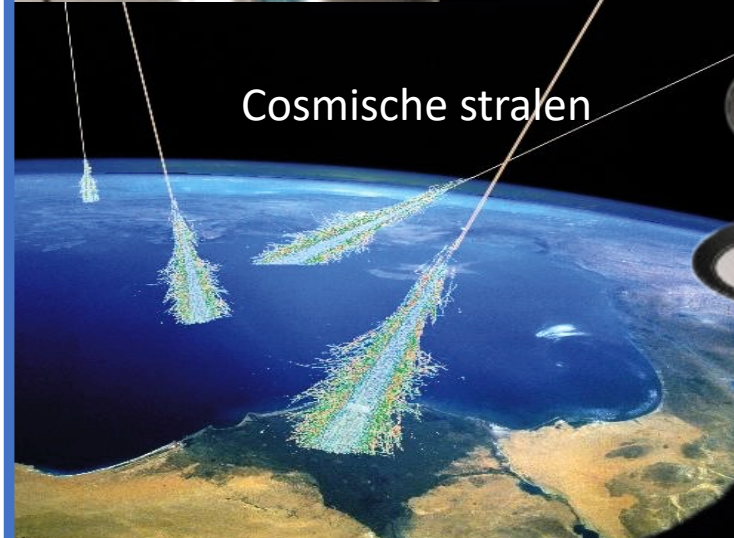
# Muon



Anderson  
1936



Isidor Rabi:  
"Who ordered that?"



Cosmische stralen





# 23 maart 2021: Nikhef en LHCb/CERN publieke website

<http://lhcb-public.web.cern.ch> :

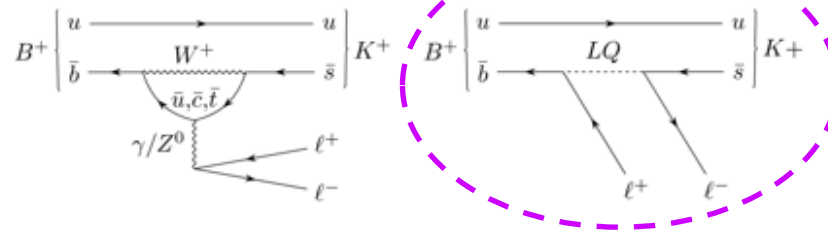
<https://www.nikhef.nl/news/> :

## 23 March 2021: Strengthened hints for a violation of lepton universality in B decays.

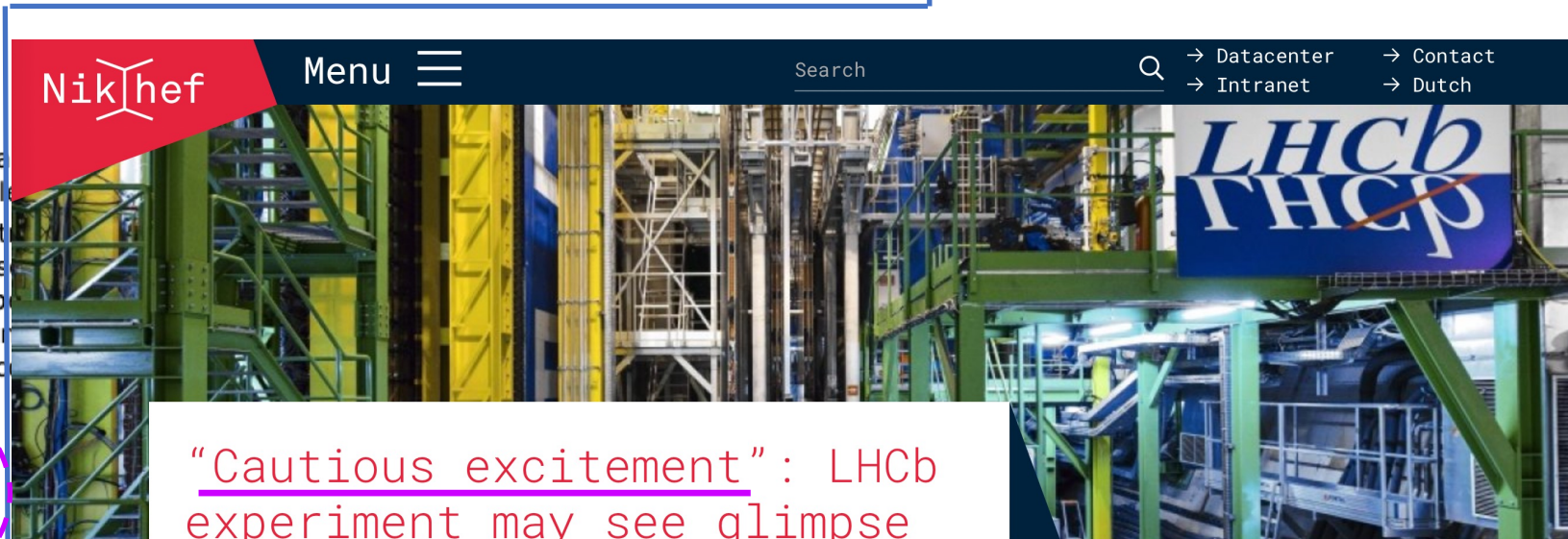
### Update of $R_K$ measurement

$$R_K = 0.846^{+0.044}_{-0.041}$$

Today at the Rencontres de [Moriond EW](#) conference and at a measurement of the ratio  $R_K$ , an important test of a principle "universality". This principle states that the Standard Model is identical, except for differences due to their different masses, for the interactions of leptons. Recent measurements indicate evidence for the breaking of lepton universality in B decays. "Evidence" is the term often used in the community to denote a deviation from the Standard Model at the 5 standard deviation level at which an "observation" is considered.



Standard Model and can be affected by the existence of new particles or fields at the Large Hadron Collider. The left graph shows Standard Model and the right graph shows a possible new physics contribution to the decay with new bosons, could have different interaction strengths with the quarks and leptons.



"Cautious excitement": LHCb experiment may see glimpse of new physics

23 March 2021

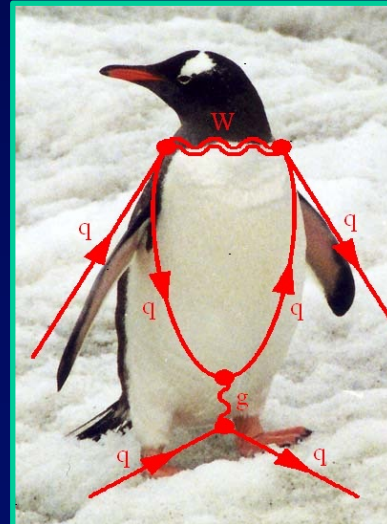
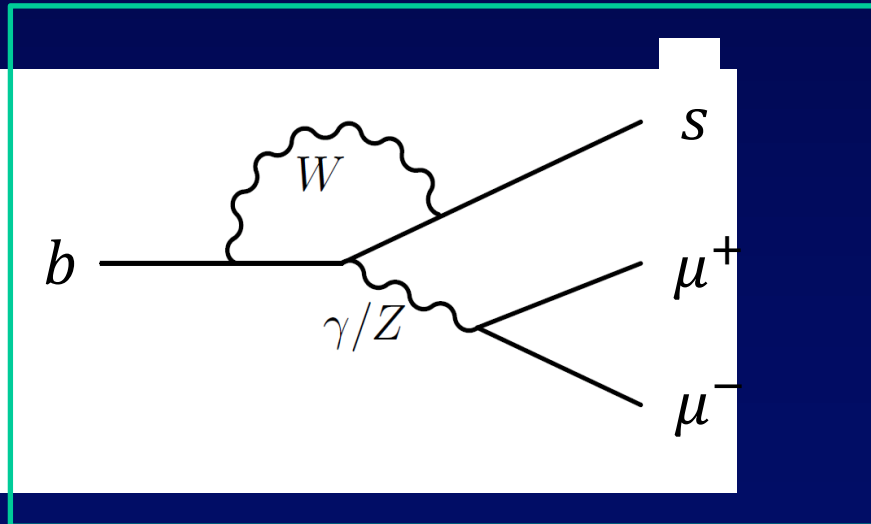
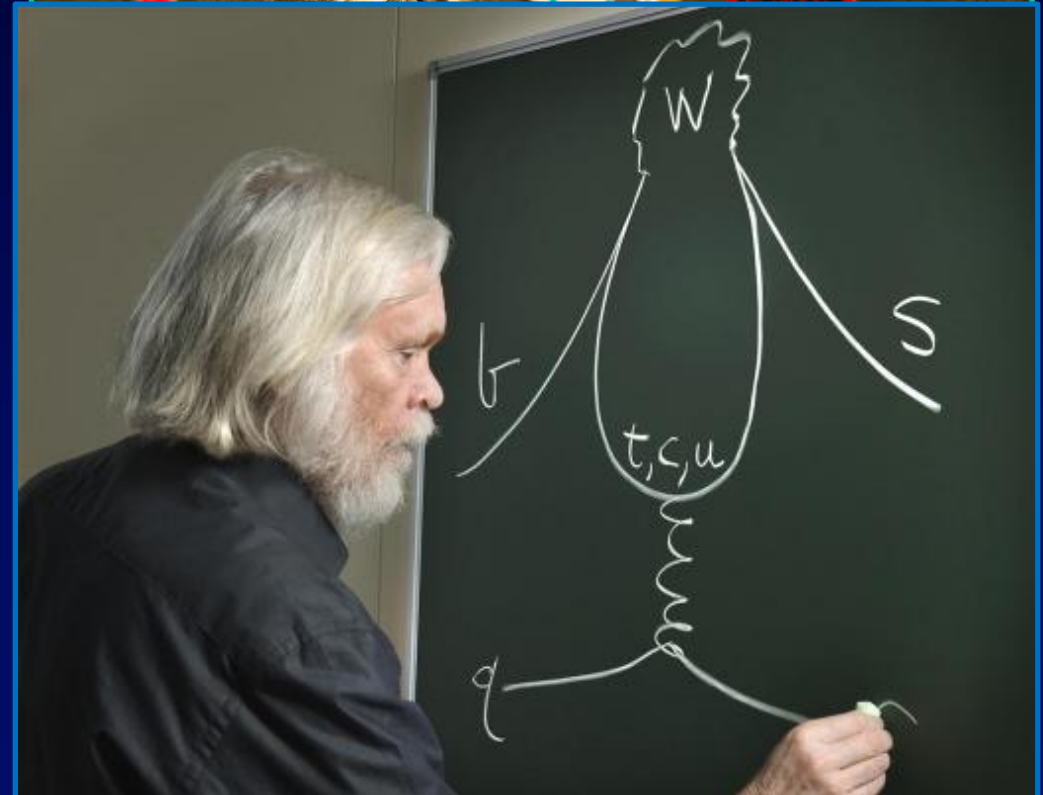
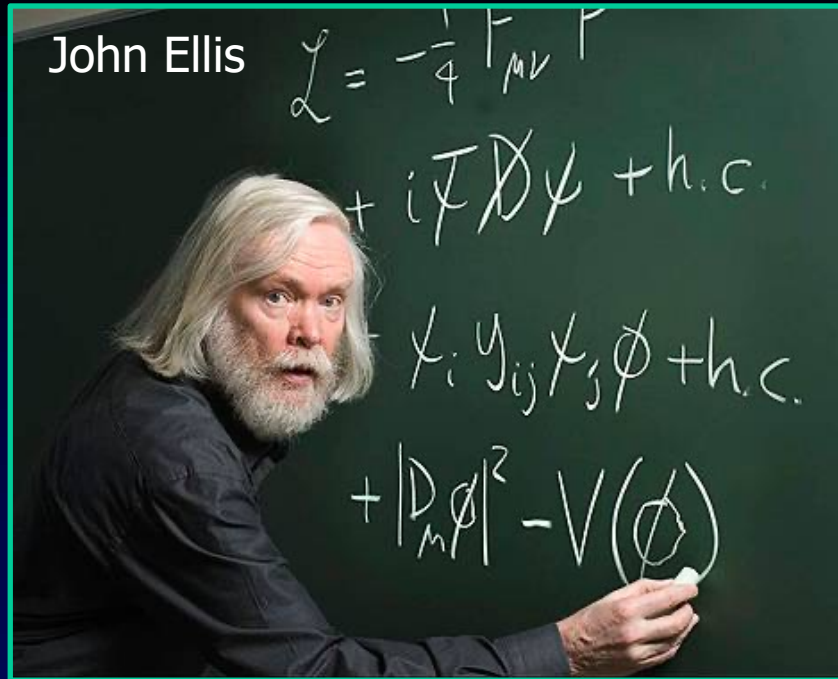
The LHCb experiment at CERN might be seeing a glimpse of new physics. The experiment has found a serious indication in its measurements that electrons and their heavier counterparts muons respond not exactly identically to forces.

HOME → NEWS → "CAUTIOUS EXCITEME..."

Particle Physics slang: "New Physics" = particles or fields beyond the Standard Model



# A story on darts and penguins





Penguins in de Big Bang theory...



$$t \rightarrow W^+ b \quad BR(t \rightarrow W^+ b) = \frac{\Gamma(t \rightarrow W^+ b)}{\Gamma(t \rightarrow W^+ b) + \Gamma(t \rightarrow W^+ c) + \Gamma(t \rightarrow W^+ s)}$$



$$= \frac{|V_{cb}|^2}{|V_{cb}|^2 + |V_{cb}|^2 + |V_{cb}|^2}$$

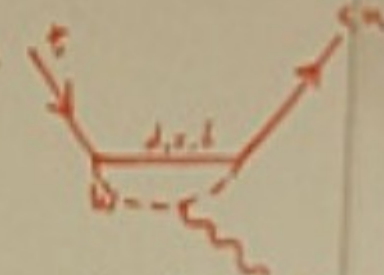
$$\approx \frac{(0.9945)^2}{(0.007)^2 + (0.04)^2 + (0.9945)^2}$$

$$= 99.82\%$$

but F.C.N.C...



$t \rightarrow Zc$   
 $t \rightarrow Zs$



$t \rightarrow Yc$   
 $t \rightarrow Ys$

$$U_{CKM} = \begin{pmatrix} c_{12}c_{13} & & \dots \\ -s_{12}c_{13} & -c_{12}s_{13}e^{i\phi} & \dots \\ \dots & \dots & \dots \end{pmatrix}$$









