LHCb

Wat doen wij?

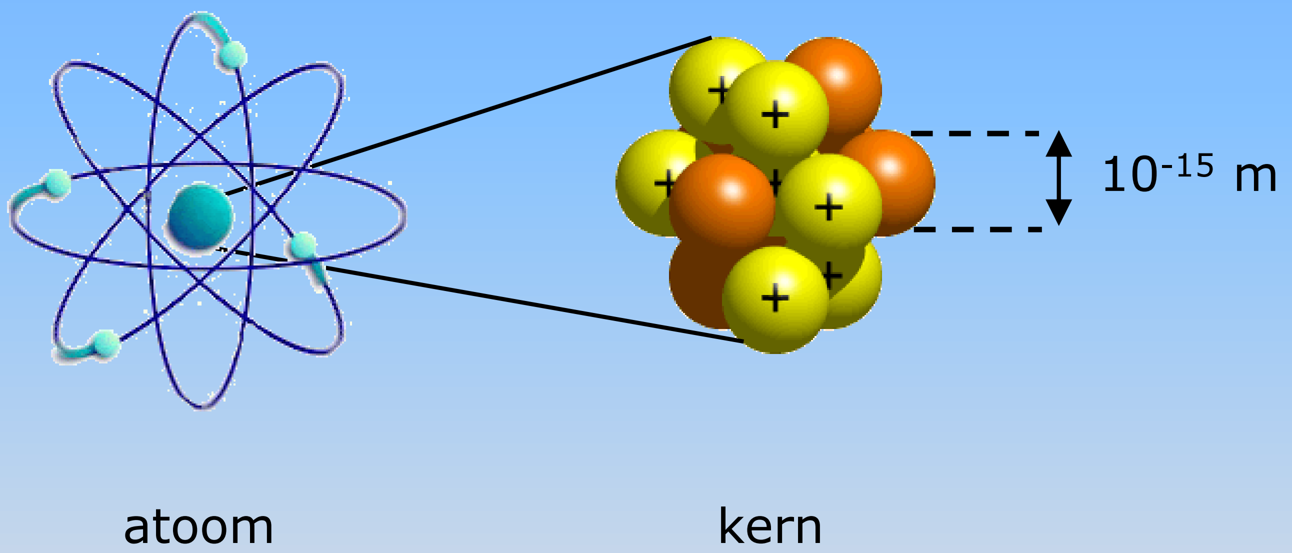
Niels Tuning – 9 okt 2024

LHCb

- Waarom deeltjesfysica?
- Waarom LHCb?
- Resultaten
- Higgs en LHCb

Deeltjesfysica

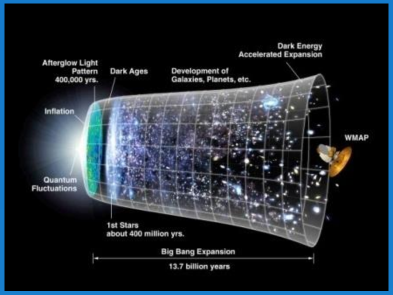
Bestudeert de natuur op afstanden < 10^{-15} m



Quantum theorie beschrijft alle metingen tot 10^{-18} m

(Ter vergelijk: 10^{+18} m = 100 lichtjaar)

Machten van tien …



Heelal

10^{26} m

Spin

10^{-2} m

Melkweg

10^{21} m

Atoom

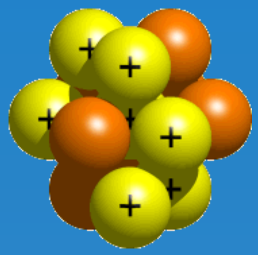
10^{-10} m

Zonnestelsel

10^{13} m

Kern

10^{-15} m

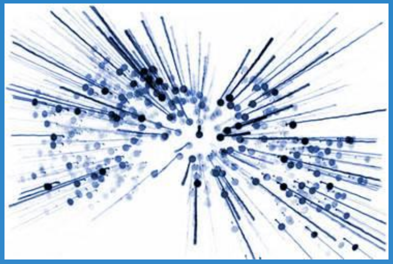


Aarde

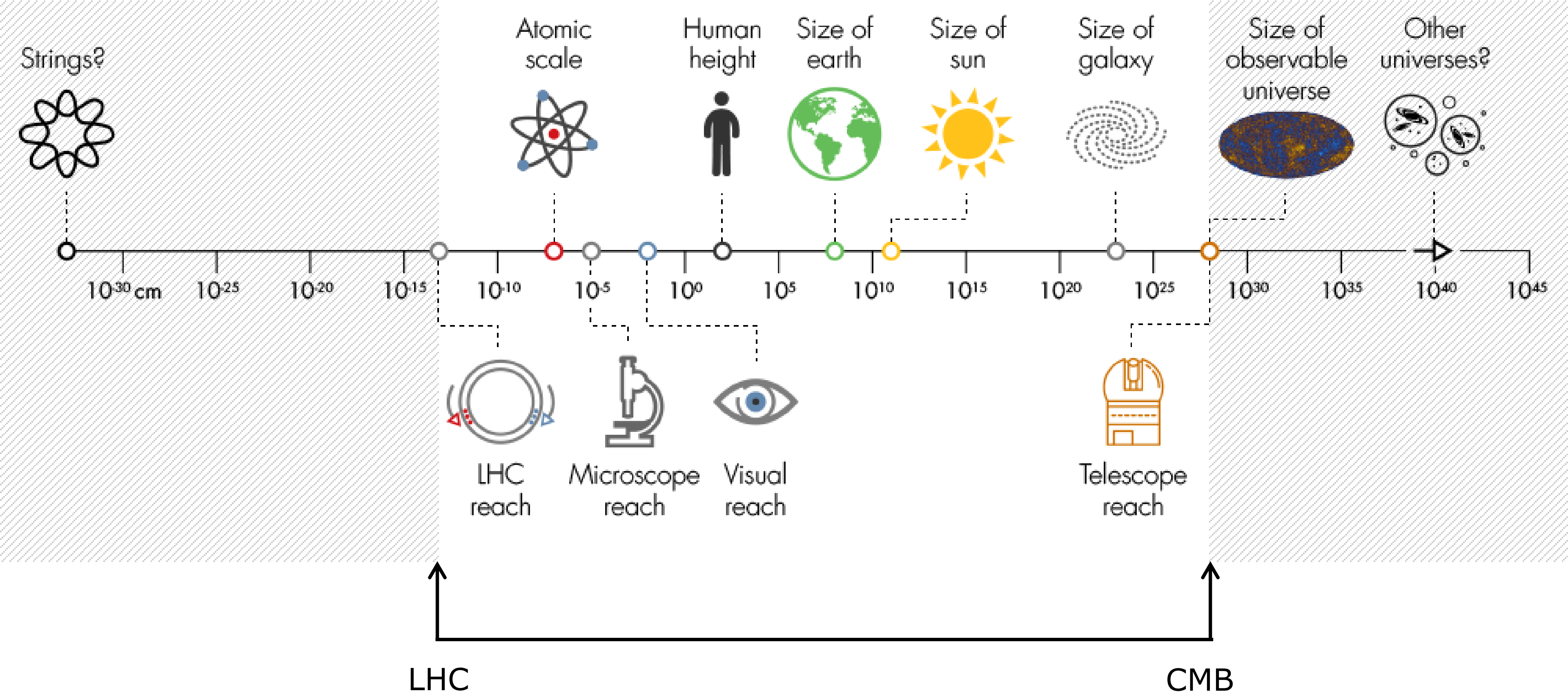
10^{7} m

Botsingen

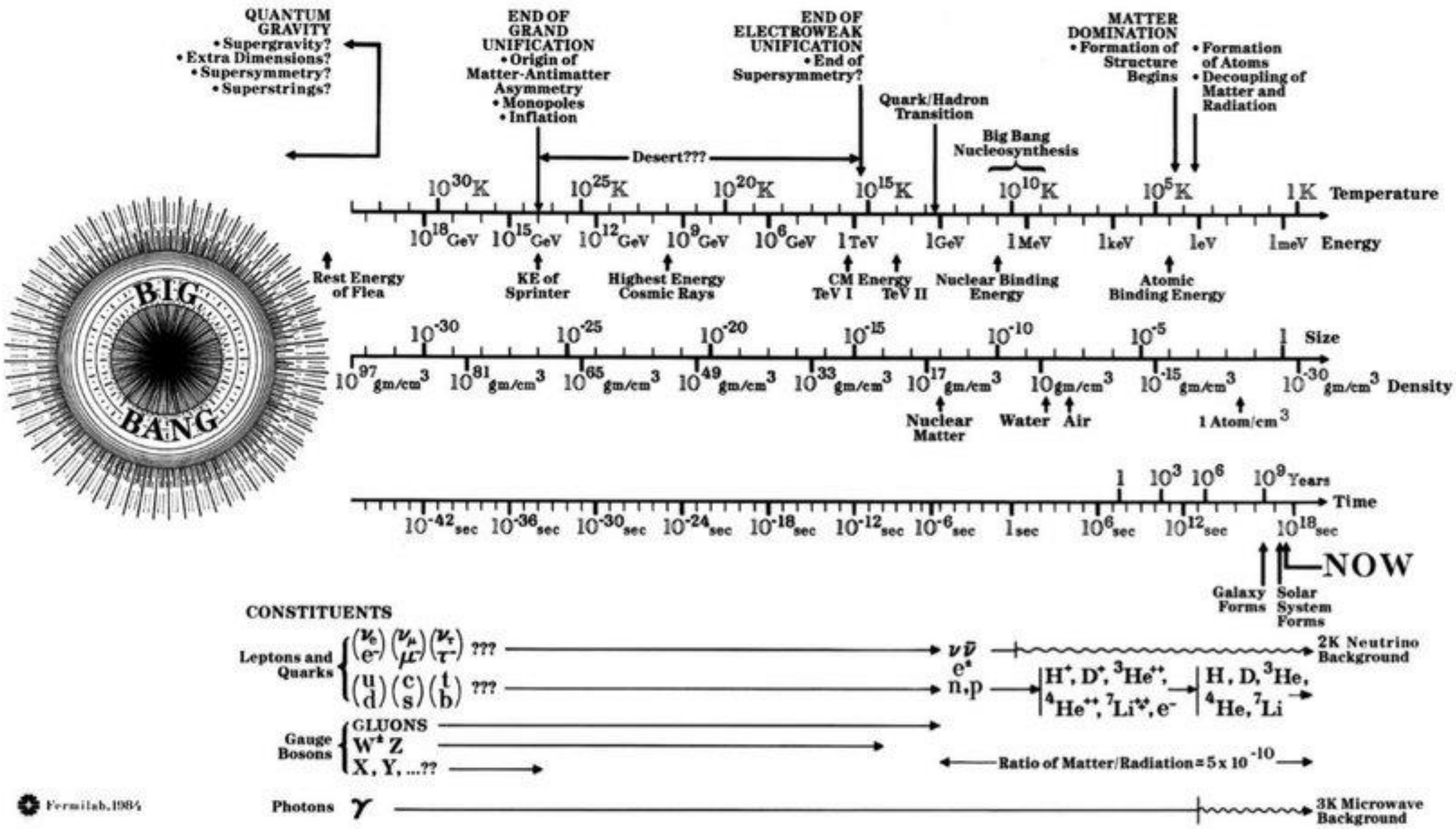
10^{-18} m



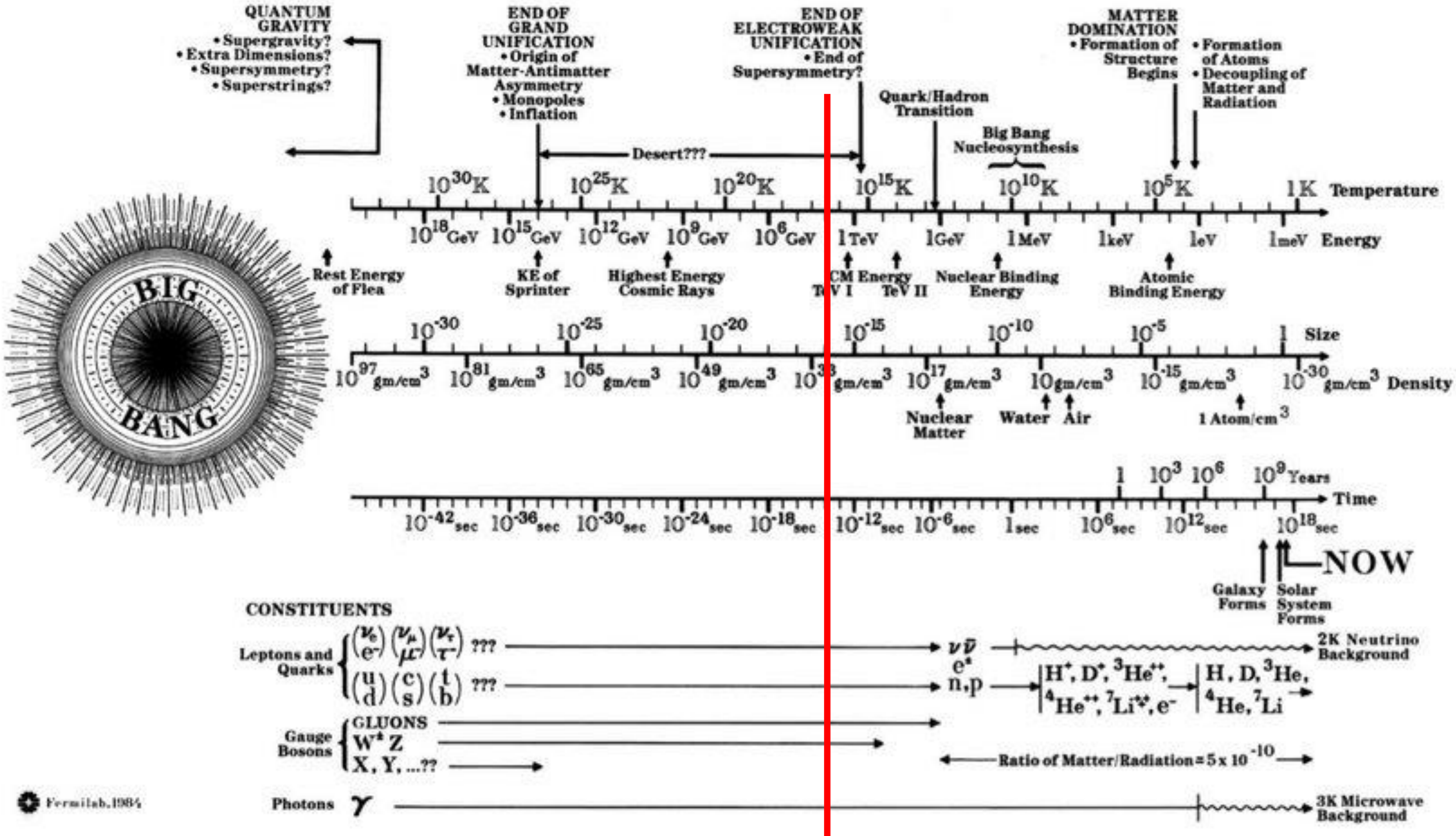
Schaal


Strings?
Atomic scale
Human height
Size of earth
Size of sun
Size of galaxy
Size of observable universe
Other universes?
10^{-30} cm
10^{-25}
10^{-20}
10^{-15}
10^{-10}
10^{-5}
10^{0}
10^{5}
10^{10}
10^{15}
10^{20}
10^{25}
10^{30}
10^{35}
10^{40}
10^{45}
LHC reach
Microscope reach
Visual reach
Telescope reach
LHC
CMB

Complete History of the Universe



Complete History of the Universe



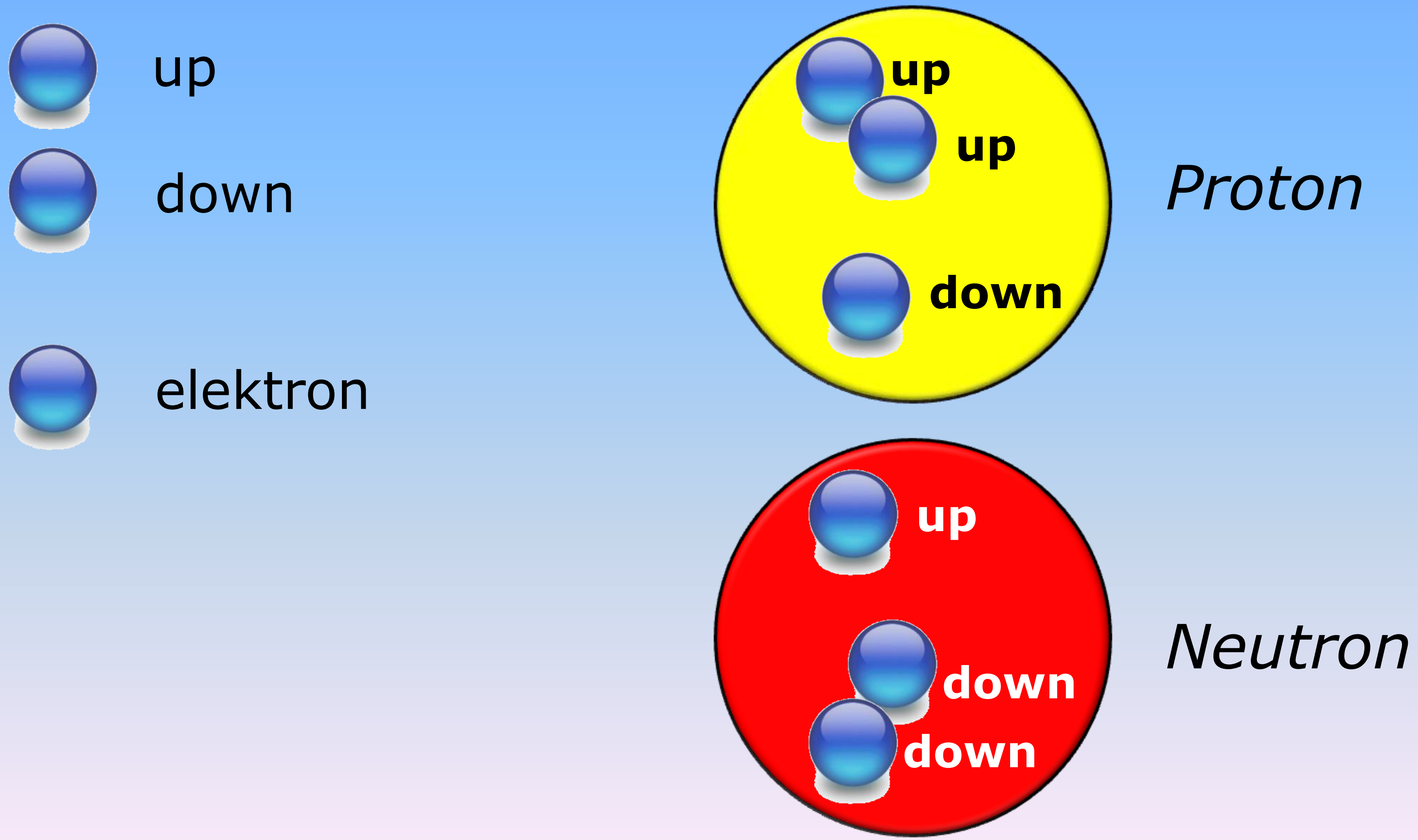
U bent hier: ◆ 10^{-16} m, 10^{-14} s, 10^{16} K

https://www.researchgate.net/publication/357823952/figure/fig1/AS:1111988524589069@1642130132503/Complete-history-of-the-Universe-a-collaboration-of-Angela-Gonzalez-of-Fermilab-and-the.jpg

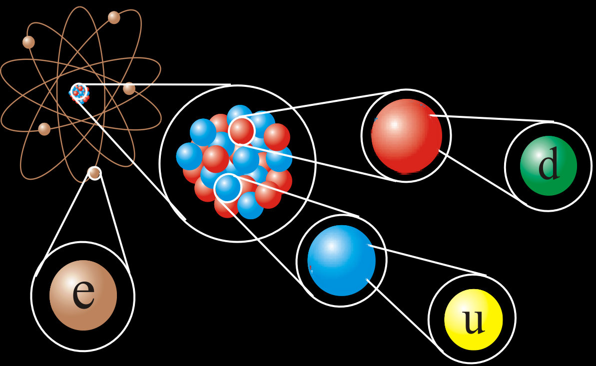
De stand van zaken in 2022

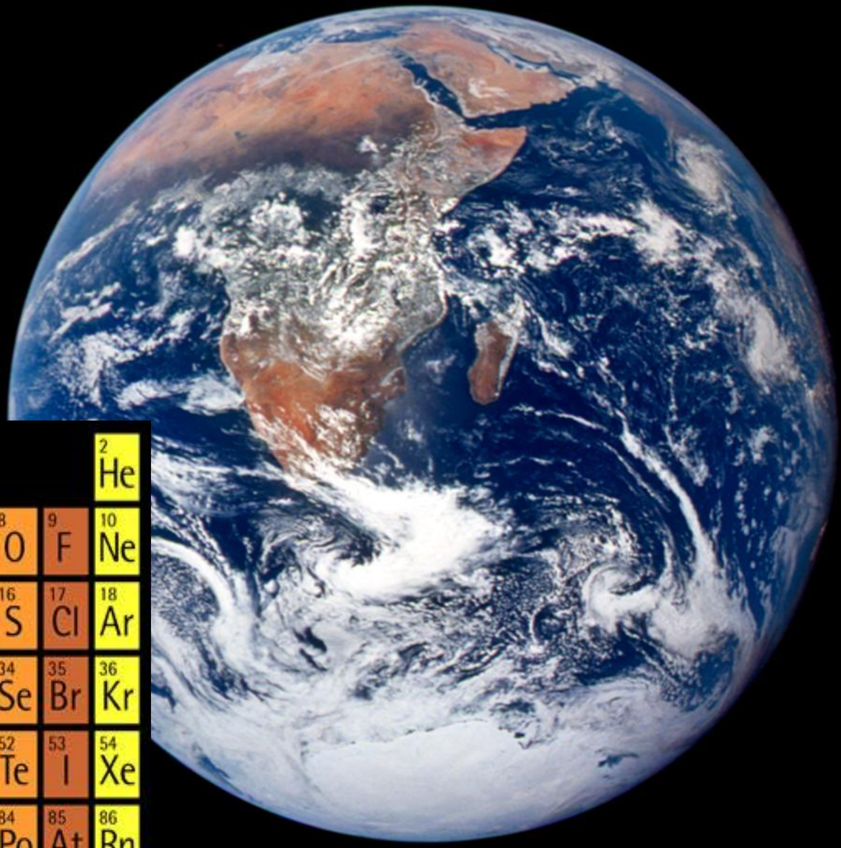
http:// pdg.lbl.gov

De elementaire deeltjes

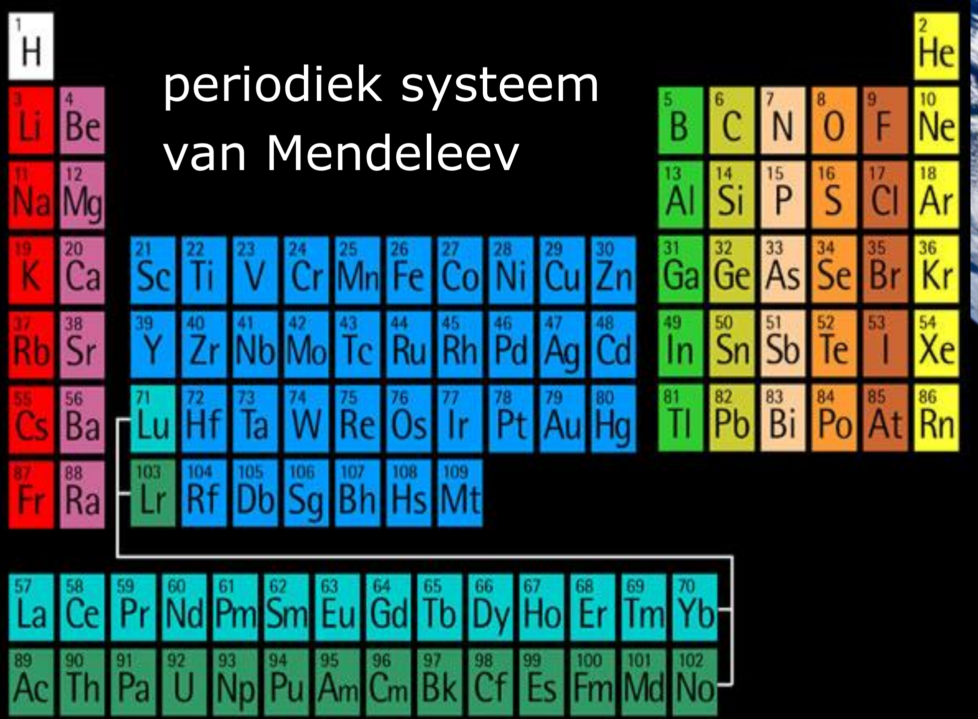


Wat kan je maken van deze 3 bouwstenen?





periodiek systeem van Mendeleev

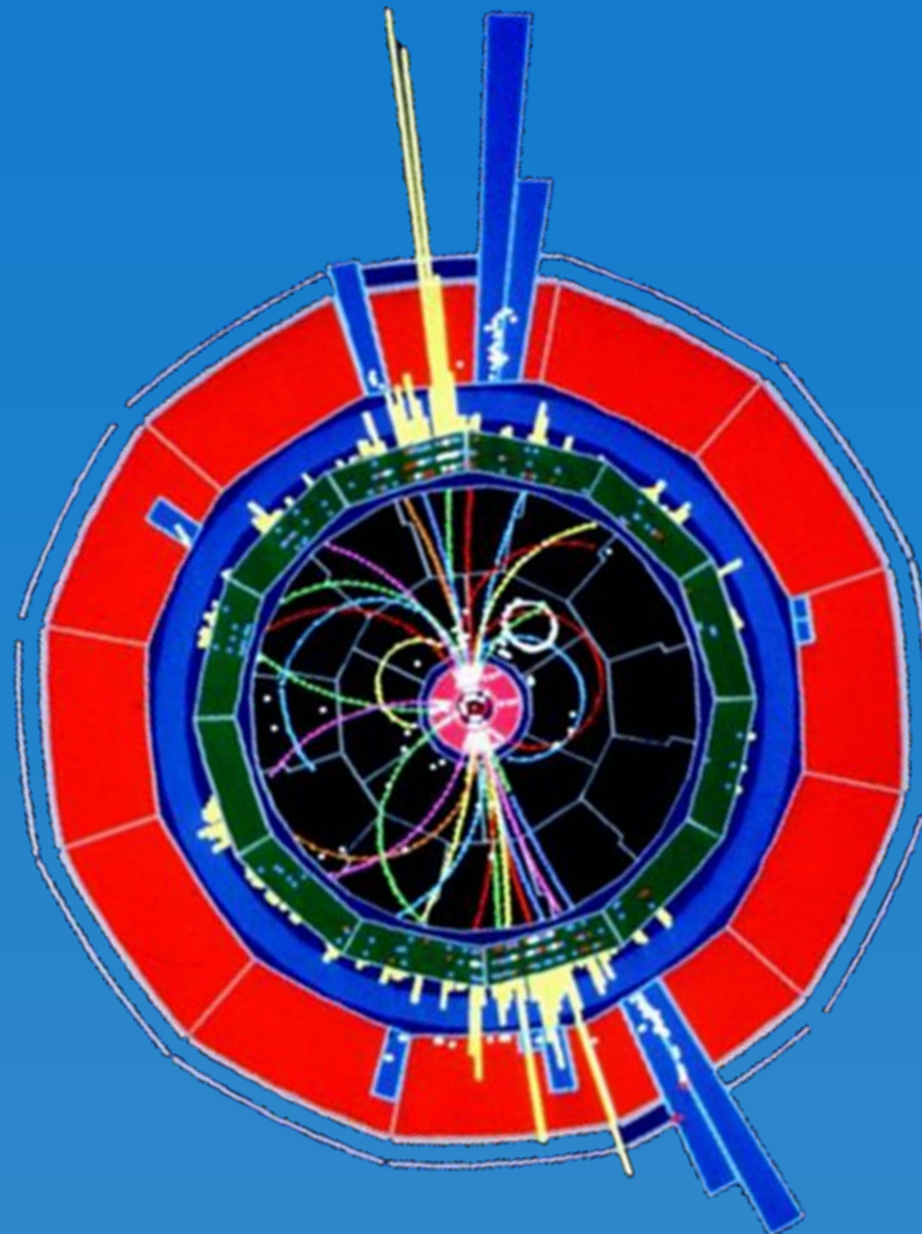


Alles!

De elementaire deeltjes

Niet één serie, maar drie!

	I	II	III
quarks	u	c (1976)	t (1995)
	d	s (1947)	b (1978)
leptons	e (1895)	μ (1936)	τ (1973)
	ν_e (1956)	ν_μ (1963)	ν_τ (2000)

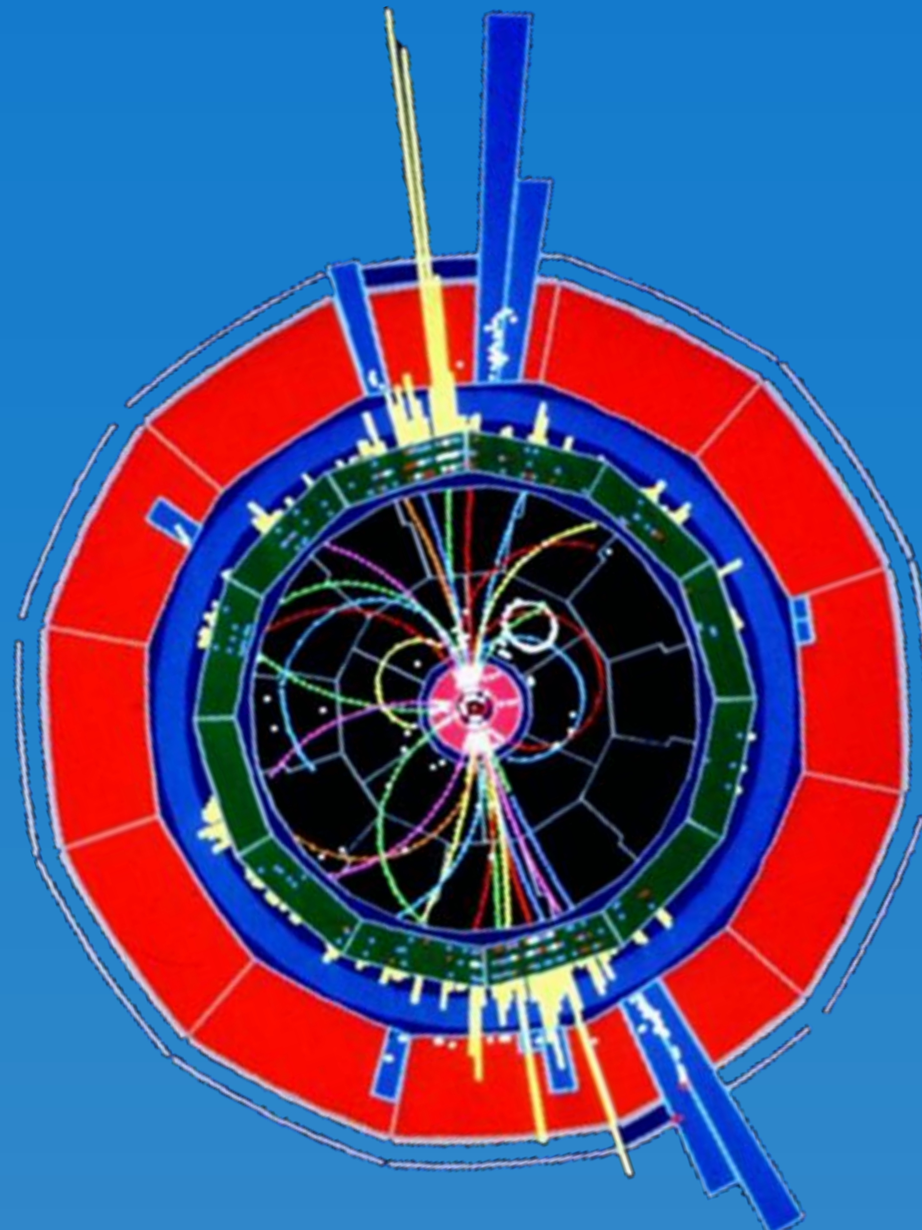


De elementaire deeltjes

Generatie:

	I	II	III	Lading
quarks	u	c (1976)	t (1995)	+2/3 e
	d	s (1947)	b (1978)	-1/3 e
leptons	e (1895)	μ (1936)	τ (1973)	-1 e
	ν_e (1956)	ν_μ (1963)	ν_τ (2000)	0 e

Materie



Is dit alles?

Generatie:

	I	II	III	Lading
quarks	u	c *(1976)*	t *(1995)*	+2/3 e
	d	s *(1947)*	b *(1978)*	-1/3 e
leptons	e *(1895)*	μ *(1936)*	τ *(1973)*	-1 e
	ν_e *(1956)*	ν_μ *(1963)*	ν_τ *(2000)*	0 e

Materie

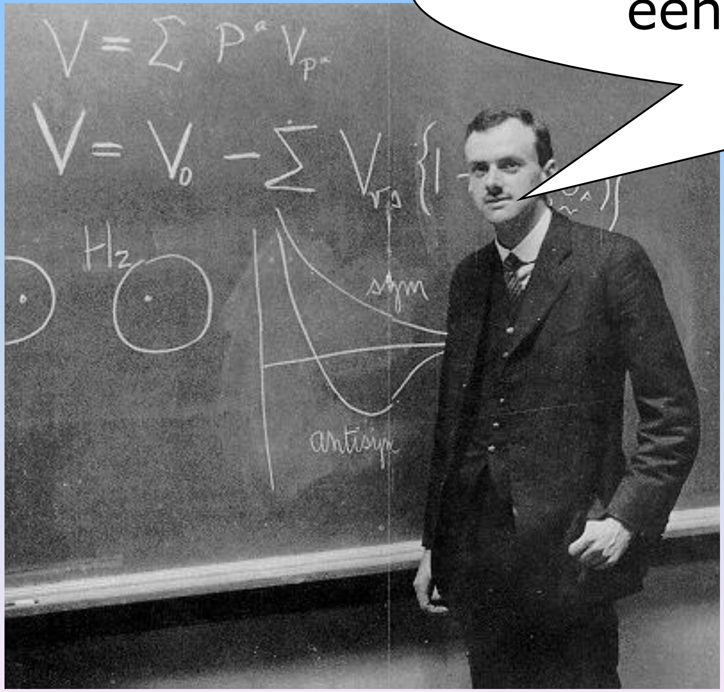
Anti-materie

Revoluties begin vorige eeuw:

- Relativiteitstheorie
- Quantum Mechanica

Paul Dirac (1928): relativistische quantum theorie!

Voor elk materiedeeltje bestaat een anti-materiedeeltje!



Anti-materie deeltje:

- Zelfde massa
- Tegenovergestelde lading

De elementaire deeltjes

	I	II	III	Lading
quarks	**u**	**c** (1976)	**t** (1995)	+2/3 e
	d	**s** (1947)	**b** (1978)	-1/3 e
leptons	**e** (1895)	**μ** (1936)	**τ** (1973)	-1 e
	ν_e (1956)	**ν_μ** (1963)	**ν_τ** (2000)	0 e

Materie

De elementaire deeltjes

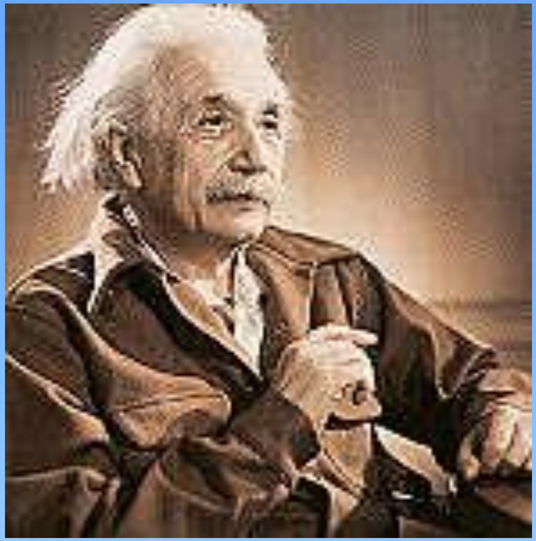
Materie

	I	II	III	Lading
quarks	u	c *(1976)*	t *(1995)*	+2/3 e
	d	s *(1947)*	b *(1978)*	-1/3 e
leptons	e *(1895)*	μ *(1936)*	τ *(1973)*	-1 e
	ν_e *(1956)*	ν_μ *(1963)*	ν_τ *(2000)*	0 e

Anti-materie

Lading	I	II	III
-2/3 e	$\bar{u}$	$\bar{c}$	$\bar{t}$
+1/3 e	$\bar{d}$	$\bar{s}$	$\bar{b}$
+1 e	$\bar{e}$	$\bar{\mu}$	$\bar{\tau}$
0 e	$\bar{\nu}_e$	$\bar{\nu}_\mu$	$\bar{\nu}_\tau$

Hoe maak je anti-materie??

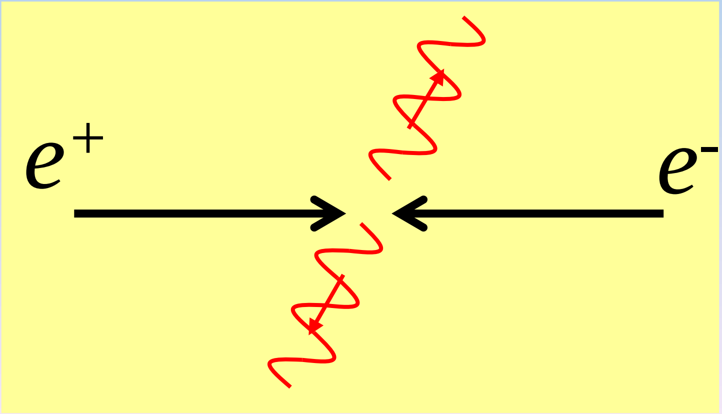


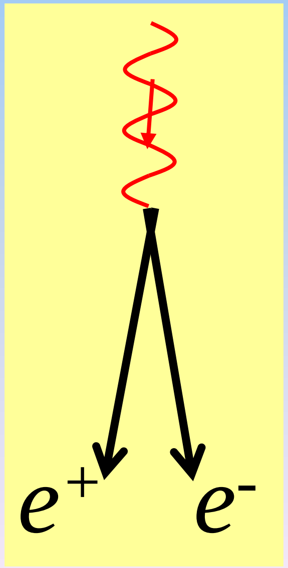
Albert Einstein:

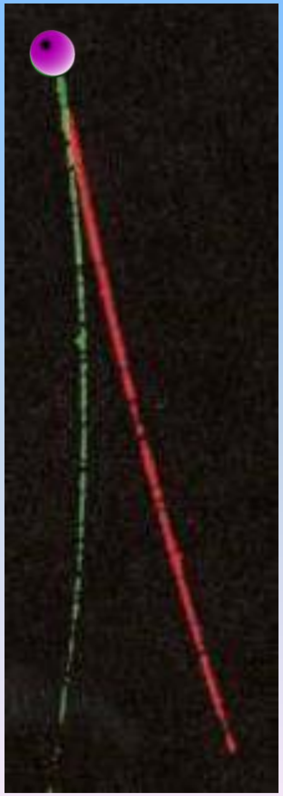
$E=mc^2$

materie + antimaterie = licht !

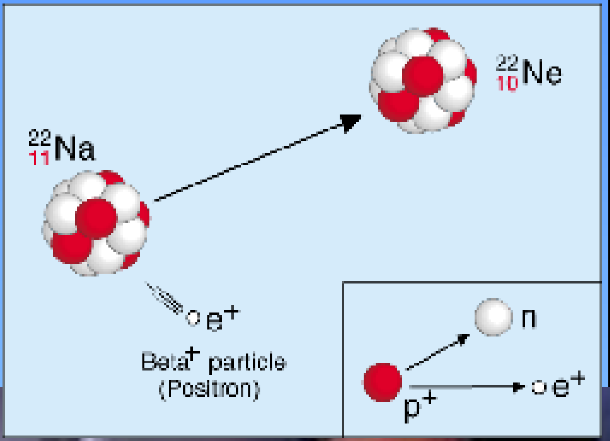
(en vice versa)

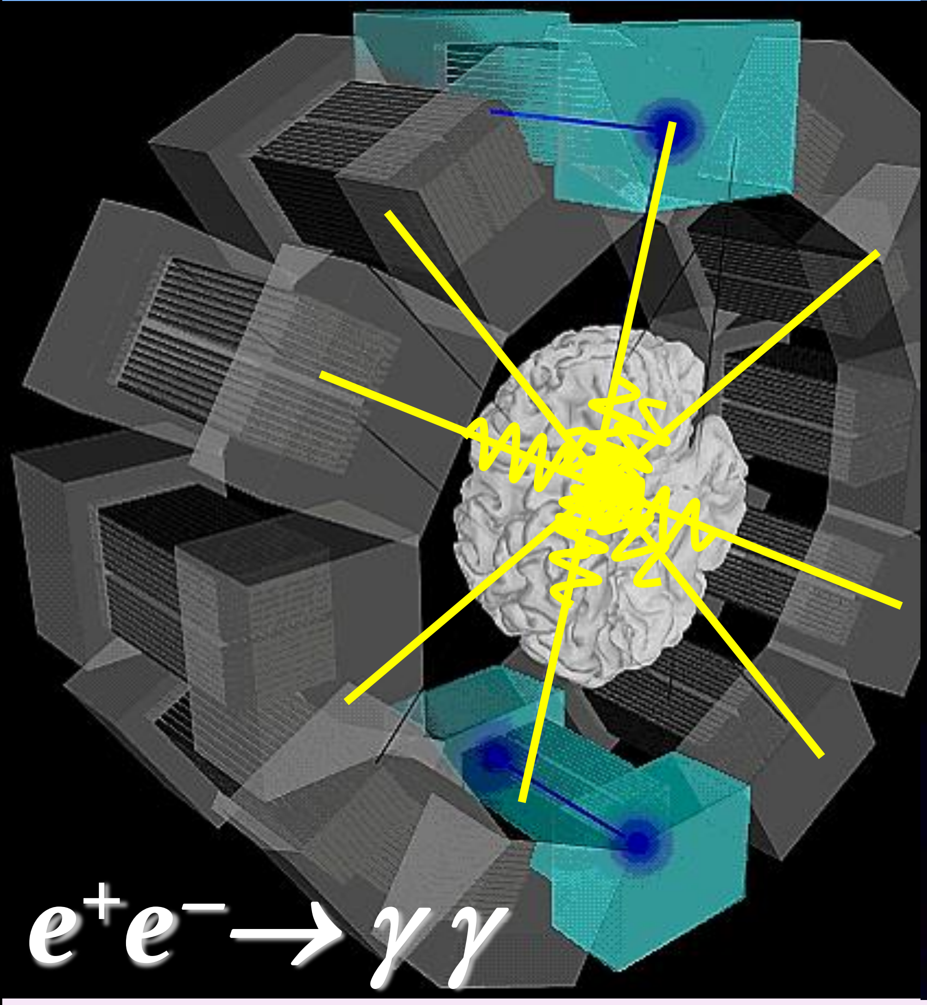






Anti-materie in ziekenhuizen: de PET-scan



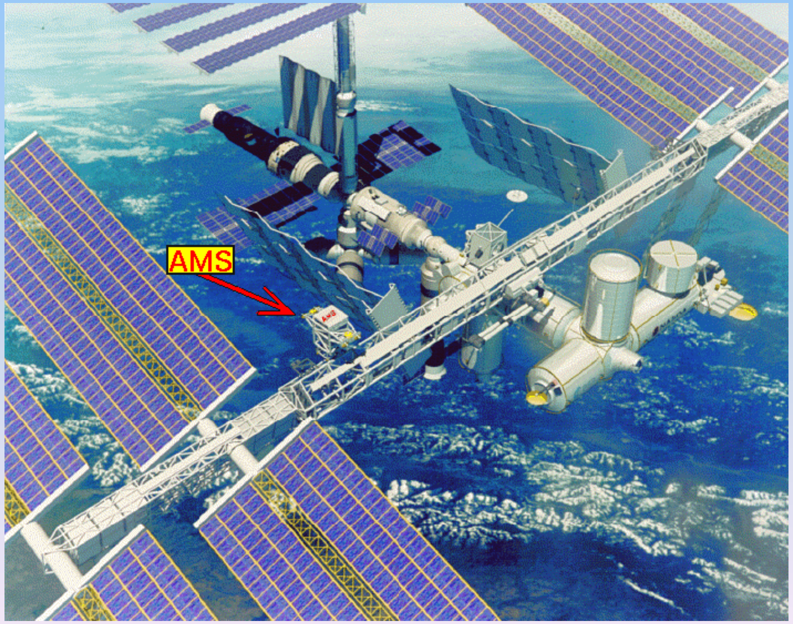


Wat snappen we nog niet:

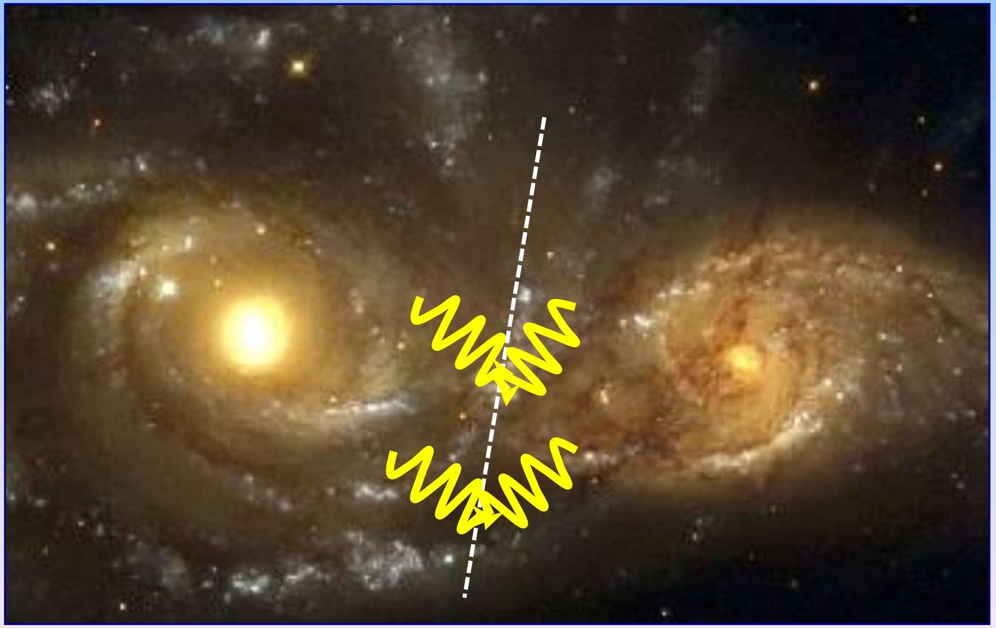
I. Wat snappen we nog niet? "*Anti-materie*"

Waar is de anti-materie gebleven?

Geen anti-materie met satellieten



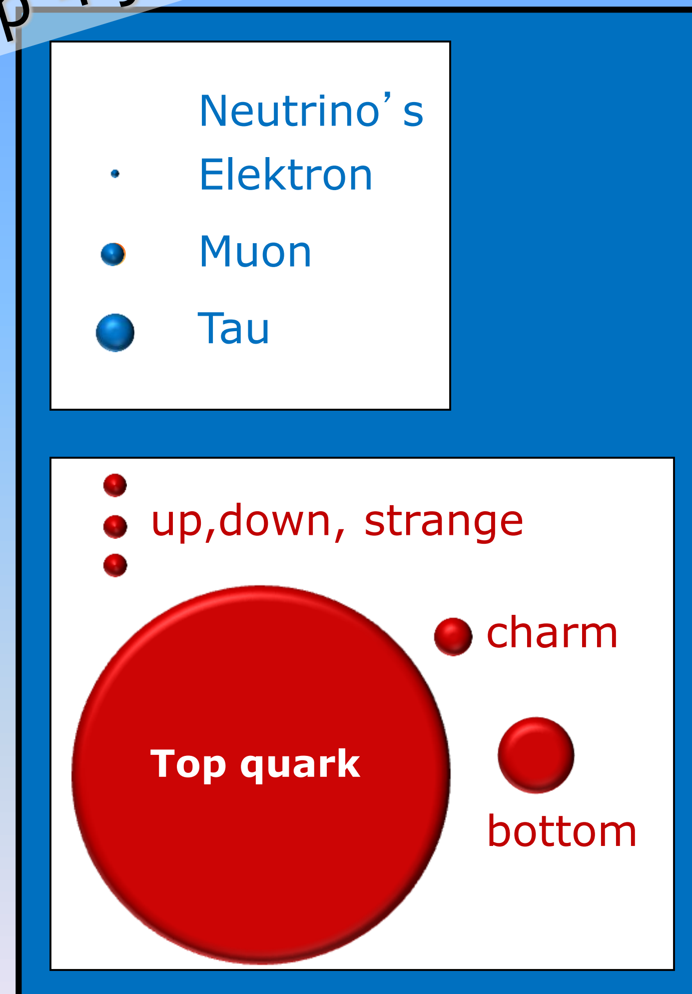
Geen anti-materie sterrenstelsels



II. Wat snappen we nog niet? “*Higgs*”

(Gedeeltelijk beantwoord op 4 juli 2012 !)

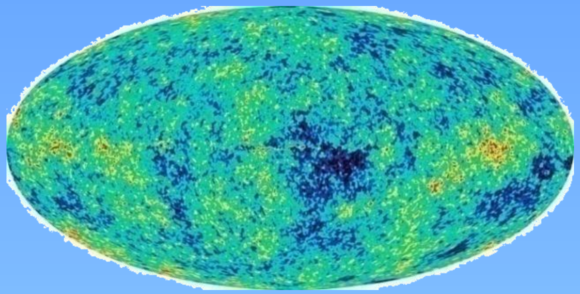
Massa van deeltjes



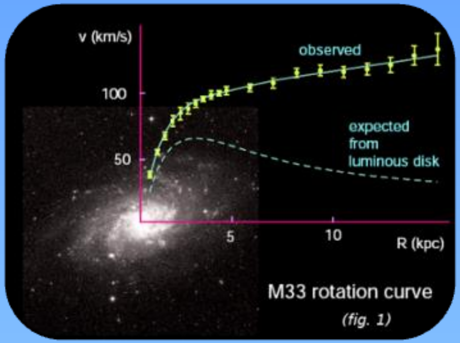
Bijzondere voorspelling:

Het Higgs boson:
zorgt ervoor dat deeltjes massa kunnen hebben in de theorie

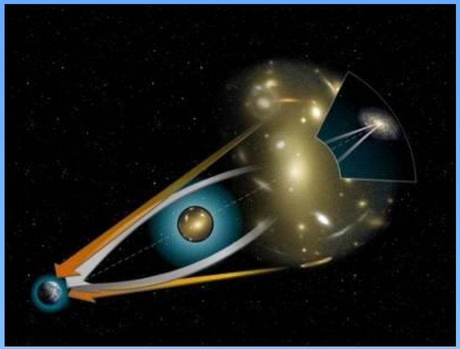
III. Wat snappen we nog niet? "*Donkere materie*"



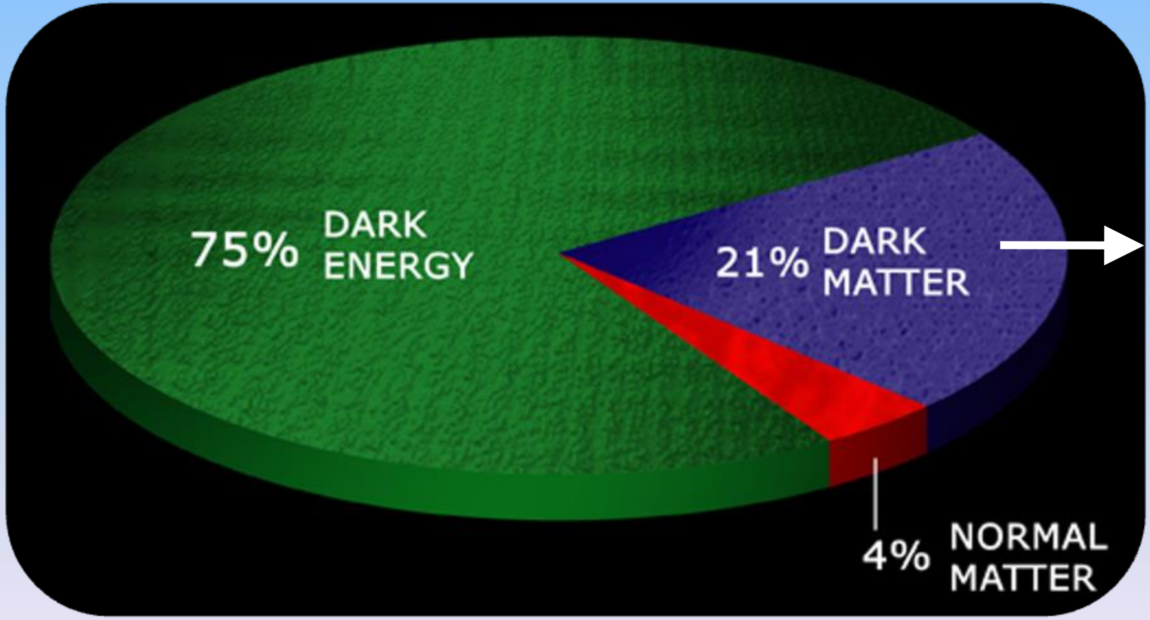
Temperatuurfluctuaties structuur van het heelal



Rotatie-curves



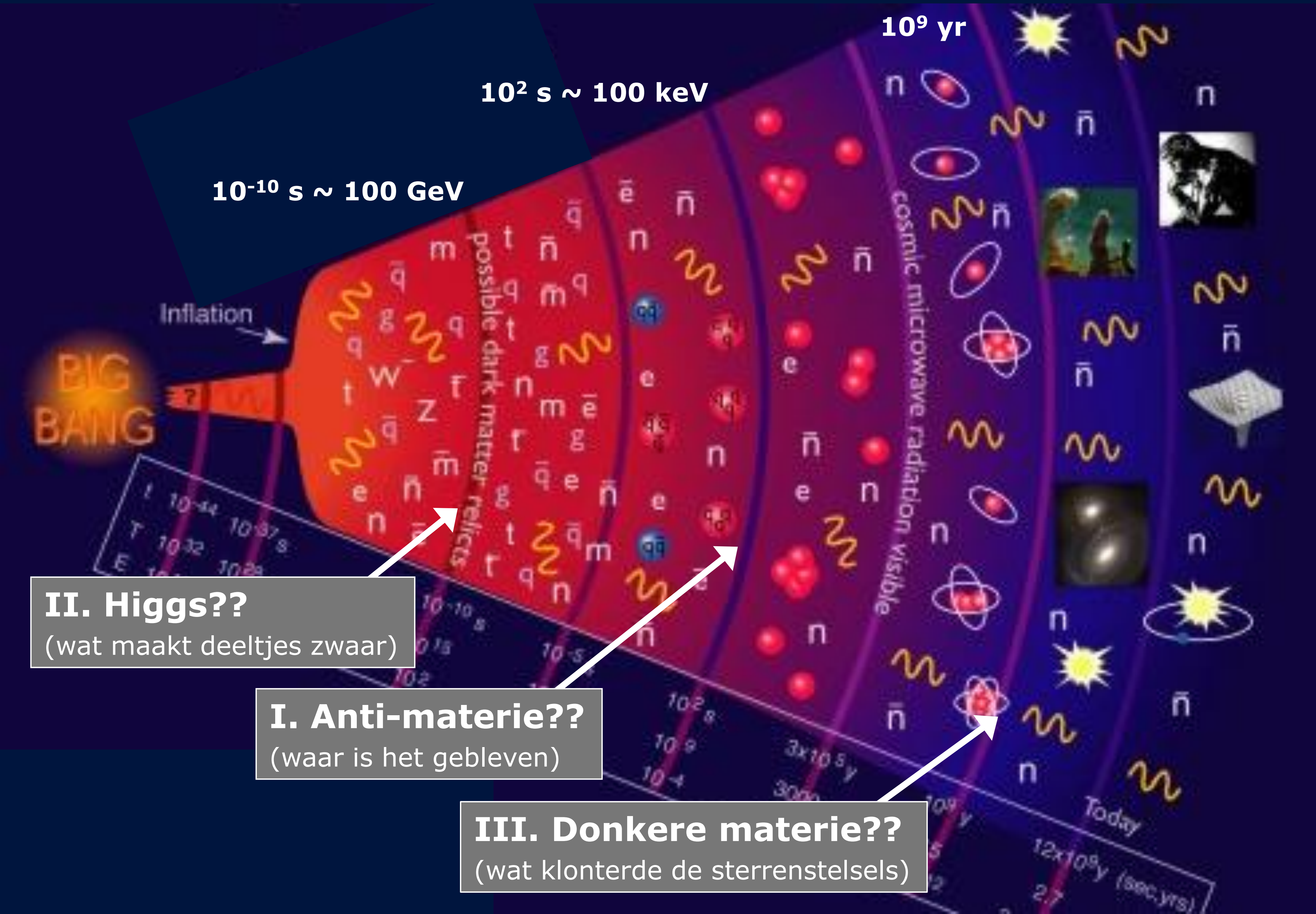
Gravitationele lens



Wat is de donkere materie ?

We hebben al die tijd maar 4% van het heelal bestudeerd!

Wat snappen we niet? Drie Grote Vragen




Astronomie
Deeltjes
fysica
Fundamenteel
(nieuwsgierigheid gedreven)
onderzoek

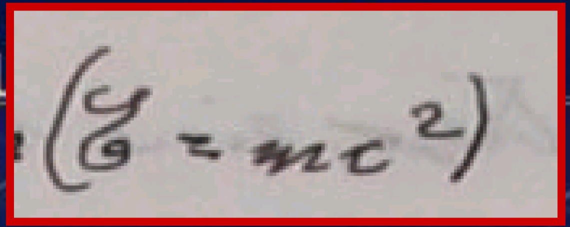
Klassiek botsen

Quantummechanisch botsen

Wat verwacht je ?

$$-\frac{1}{2}\partial_\nu g^a_\mu \partial_\nu g^a_\mu - g_s f^{abc}\partial_\mu g^a_\nu g^b_\mu g^c_\nu - \frac{1}{4}g_s^2 f^{abc} f^{ade} g^b_\mu g^c_\nu g^d_\mu g^e_\nu +$$
$$\frac{1}{2}ig_s^2(\bar{q}^\sigma_i \gamma^\mu q^\sigma_j)g^a_\mu + \bar{G}^a\partial^2 G^a + g_s f^{abc}\partial_\mu \bar{G}^a G^b g^c_\mu - \partial_\nu W^+_\mu \partial_\nu W^-_\mu -$$
$$M^2 W^+_\mu W^-_\mu - \frac{1}{2}\partial_\nu Z^0_\mu \partial_\nu Z^0_\mu - \frac{1}{2c_w^2}M^2 Z^0_\mu Z^0_\mu - \frac{1}{2}\partial_\mu A_\nu \partial_\mu A_\nu - \frac{1}{2}\partial_\mu H \partial_\mu H -$$
$$\frac{1}{2}m_h^2 H^2 - \partial_\mu \phi^+ \partial_\mu \phi^- - M^2 \phi^+ \phi^- - \frac{1}{2}\partial_\mu \phi^0 \partial_\mu \phi^0 - \frac{1}{2c_w^2}M\phi^0\phi^0 - \beta_h[\frac{2M^2}{g^2} +$$
$$\frac{2M}{g}H + \frac{1}{2}(H^2 + \phi^0\phi^0 + 2\phi^+\phi^-)] + \frac{2M^4}{g^2}\alpha_h - igc_w[\partial_\nu Z^0_\mu(W^+_\mu W^-_\nu -$$
$$W^+_\nu W^-_\mu) - Z^0_\nu(W^+_\mu \partial_\nu W^-_\mu - W^-_\mu \partial_\nu W^+_\mu) + Z^0_\mu(W^+_\nu \partial_\nu W^-_\mu -$$
$$W^-_\nu \partial_\nu W^+_\mu)] - igs_w[\partial_\nu A_\mu(W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - A_\nu(W^+_\mu \partial_\nu W^-_\mu -$$
$$W^-_\mu \partial_\nu W^+_\mu) + A_\mu(W^+_\nu \partial_\nu W^-_\mu - W^-_\nu \partial_\nu W^+_\mu)] - \frac{1}{2}g^2 W^+_\mu W^-_\mu W^+_\nu W^-_\nu +$$
$$\frac{1}{2}g^2 W^+_\mu W^-_\nu W^+_\mu W^-_\nu + g^2 c_w^2(Z^0_\mu W^+_\mu Z^0_\nu W^-_\nu - Z^0_\mu Z^0_\mu W^+_\nu W^-_\nu) +$$
$$g^2 s_w^2(A_\mu W^+_\mu A_\nu W^-_\nu - A_\mu A_\mu W^+_\nu W^-_\nu) + g^2 s_w c_w[A_\mu Z^0_\nu(W^+_\mu W^-_\nu -$$
$$W^+_\nu W^-_\mu) - 2A_\mu Z^0_\mu W^+_\nu W^-_\nu] - g\alpha[H^3 + H\phi^0\phi^0 + 2H\phi^+\phi^-] -$$
$$\frac{1}{8}g^2\alpha_h[H^4 + (\phi^0)^4 + 4(\phi^+\phi^-)^2 + 4(\phi^0)^2\phi^+\phi^- + 4H^2\phi^+\phi^- + 2(\phi^0)^2H^2] -$$
$$gMW^+_\mu W^-_\mu H - \frac{1}{2}g\frac{M}{c_w^2}Z^0_\mu Z^0_\mu H - \frac{1}{2}ig[W^+_\mu(\phi^0\partial_\mu\phi^- - \phi^-\partial_\mu\phi^0) -$$
$$W^-_\mu(\phi^0\partial_\mu\phi^+ - \phi^+\partial_\mu\phi^0)] + \frac{1}{2}g[W^+_\mu(H\partial_\mu\phi^- - \phi^-\partial_\mu H) - W^-_\mu(H\partial_\mu\phi^+ -$$
$$\phi^+\partial_\mu H)] + \frac{1}{2}g\frac{1}{c_w}(Z^0_\mu(H\partial_\mu\phi^0 - \phi^0\partial_\mu H) - ig\frac{s_w^2}{c_w}MZ^0_\mu(W^+_\mu\phi^- - W^-_\mu\phi^+) +$$
$$igs_w MA_\mu(W^+_\mu\phi^- - W^-_\mu\phi^+) - ig\frac{1-2c_w^2}{2c_w}Z^0_\mu(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) +$$
$$igs_w A_\mu(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) - \frac{1}{4}g^2 W^+_\mu W^-_\mu[H^2 + (\phi^0)^2 + 2\phi^+\phi^-] -$$
$$\frac{1}{4}g^2\frac{1}{c_w^2}Z^0_\mu Z^0_\mu[H^2 + (\phi^0)^2 + 2(2s_w^2 - 1)^2\phi^+\phi^-] - \frac{1}{2}g^2\frac{s_w^2}{c_w}Z^0_\mu\phi^0(W^+_\mu\phi^- +$$
$$W^-_\mu\phi^+) - \frac{1}{2}ig^2\frac{s_w^2}{c_w}Z^0_\mu H(W^+_\mu\phi^- - W^-_\mu\phi^+) + \frac{1}{2}g^2 s_w A_\mu\phi^0(W^+_\mu\phi^- +$$
$$W^-_\mu\phi^+) + \frac{1}{2}ig^2 s_w A_\mu H(W^+_\mu\phi^- - W^-_\mu\phi^+) - g^2\frac{s_w}{c_w}(2c_w^2 - 1)Z^0_\mu A_\mu\phi^+\phi^- -$$
$$g^1 s_w^2 A_\mu A_\mu\phi^+\phi^- - \bar{e}^\lambda(\gamma\partial + m_e^\lambda)e^\lambda - \bar{\nu}^\lambda\gamma\partial\nu^\lambda - \bar{u}^\lambda_j(\gamma\partial + m_u^\lambda)u^\lambda_j -$$
$$\bar{d}^\lambda_j(\gamma\partial + m_d^\lambda)d^\lambda_j + igs_w A_\mu[-(\bar{e}^\lambda\gamma^\mu e^\lambda) + \frac{2}{3}(\bar{u}^\lambda_j\gamma^\mu u^\lambda_j) - \frac{1}{3}(\bar{d}^\lambda_j\gamma^\mu d^\lambda_j)] +$$
$$\frac{ig}{4c_w}Z^0_\mu[(\bar{\nu}^\lambda\gamma^\mu(1+\gamma^5)\nu^\lambda) + (\bar{e}^\lambda\gamma^\mu(4s_w^2 - 1 - \gamma^5)e^\lambda) + (\bar{u}^\lambda_j\gamma^\mu(\frac{4}{3}s_w^2 -$$
$$1 - \gamma^5)u^\lambda_j) + (\bar{d}^\lambda_j\gamma^\mu(1 - \frac{8}{3}s_w^2 - \gamma^5)d^\lambda_j)] + \frac{ig}{2\sqrt{2}}W^+_\mu[(\bar{\nu}^\lambda\gamma^\mu(1+\gamma^5)e^\lambda) +$$
$$(\bar{u}^\lambda_j\gamma^\mu(1+\gamma^5)C_{\lambda\kappa}d^\kappa_j)] + \frac{ig}{2\sqrt{2}}W^-_\mu[(\bar{e}^\lambda\gamma^\mu(1+\gamma^5)\nu^\lambda) + (\bar{d}^\kappa_j C^\dagger_{\lambda\kappa}\gamma^\mu(1 +$$
$$\gamma^5)u^\lambda_j)] + \frac{ig}{2\sqrt{2}}\frac{m_e^\lambda}{M}[-\phi^+(\bar{\nu}^\lambda(1-\gamma^5)e^\lambda) + \phi^-(\bar{e}^\lambda(1+\gamma^5)\nu^\lambda)] -$$
$$\frac{g}{2}\frac{m_e^\lambda}{M}[H(\bar{e}^\lambda e^\lambda) + i\phi^0(\bar{e}^\lambda\gamma^5 e^\lambda)] + \frac{ig}{2M\sqrt{2}}\phi^+[-m_d^\kappa(\bar{u}^\lambda_j C_{\lambda\kappa}(1-\gamma^5)d^\kappa_j) +$$
$$m_u^\lambda(\bar{u}^\lambda_j C_{\lambda\kappa}(1+\gamma^5)d^\kappa_j] + \frac{ig}{2M\sqrt{2}}\phi^-[m_d^\lambda(\bar{d}^\lambda_j C^\dagger_{\lambda\kappa}(1+\gamma^5)u^\kappa_j) - m_u^\kappa(\bar{d}^\lambda_j C^\dagger_{\lambda\kappa}(1 -$$
$$\gamma^5)u^\kappa_j] - \frac{g}{2}\frac{m_u^\lambda}{M}H(\bar{u}^\lambda_j u^\lambda_j) - \frac{g}{2}\frac{m_d^\lambda}{M}H(\bar{d}^\lambda_j d^\lambda_j) + \frac{ig}{2}\frac{m_u^\lambda}{M}\phi^0(\bar{u}^\lambda_j\gamma^5 u^\lambda_j) -$$
$$\frac{ig}{2}\frac{m_d^\lambda}{M}\phi^0(\bar{d}^\lambda_j\gamma^5 d^\lambda_j) + \bar{X}^+(\partial^2 - M^2)X^+ + \bar{X}^-(\partial^2 - M^2)X^- + \bar{X}^0(\partial^2 -$$
$$\frac{M^2}{c_w^2})X^0 + \bar{Y}\partial^2 Y + igc_w W^+_\mu(\partial_\mu\bar{X}^0 X^- - \partial_\mu\bar{X}^+ X^0) + igs_w W^+_\mu(\partial_\mu\bar{Y}X^- -$$
$$\partial_\mu\bar{X}^+ Y) + igc_w W^-_\mu(\partial_\mu\bar{X}^- X^0 - \partial_\mu\bar{X}^0 X^+) + igs_w W^-_\mu(\partial_\mu\bar{X}^- Y -$$
$$\partial_\mu\bar{Y}X^+) + igc_w Z^0_\mu(\partial_\mu\bar{X}^+ X^+ - \partial_\mu\bar{X}^- X^-) + igs_w A_\mu(\partial_\mu\bar{X}^+ X^+ -$$
$$\partial_\mu\bar{X}^- X^-) - \frac{1}{2}gM[\bar{X}^+ X^+ H + \bar{X}^- X^- H + \frac{1}{c_w^2}\bar{X}^0 X^0 H] +$$
$$\frac{1-2c_w^2}{2c_w}igM[\bar{X}^+ X^0\phi^+ - \bar{X}^- X^0\phi^-] + \frac{1}{2c_w}igM[\bar{X}^0 X^-\phi^+ - \bar{X}^0 X^+\phi^-] +$$
$$igMs_w[\bar{X}^0 X^-\phi^+ - \bar{X}^0 X^+\phi^-] + \frac{1}{2}igM[\bar{X}^+ X^+\phi^0 - \bar{X}^- X^-\phi^0]$$

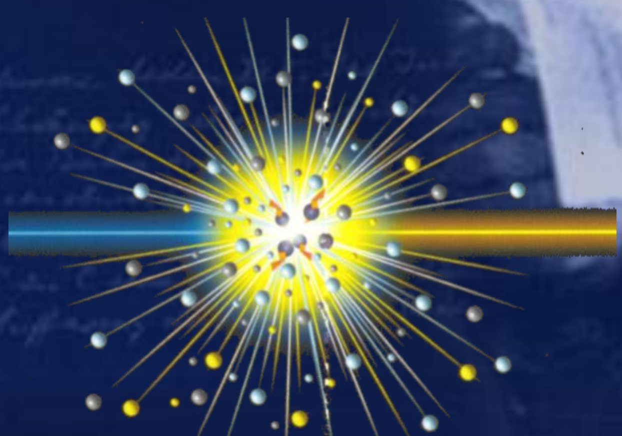
Al 40 jaar bestaan er precieze wiskundige voorspellingen!

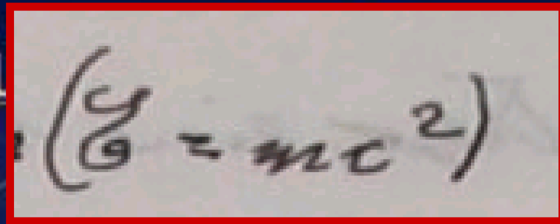


Hoe ontdekken we nieuwe deeltjes?

Bij de LHC op Cern:

1) Verander energie in materie!





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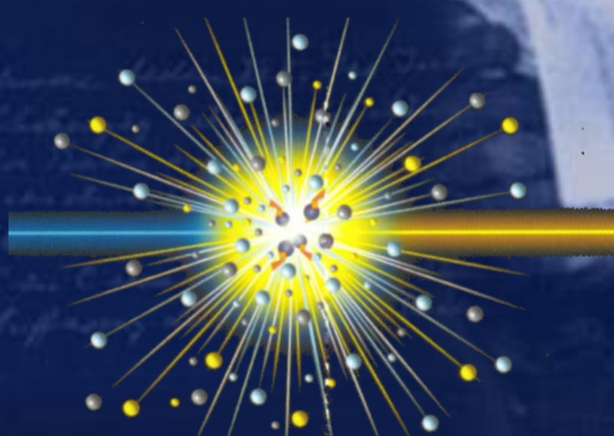
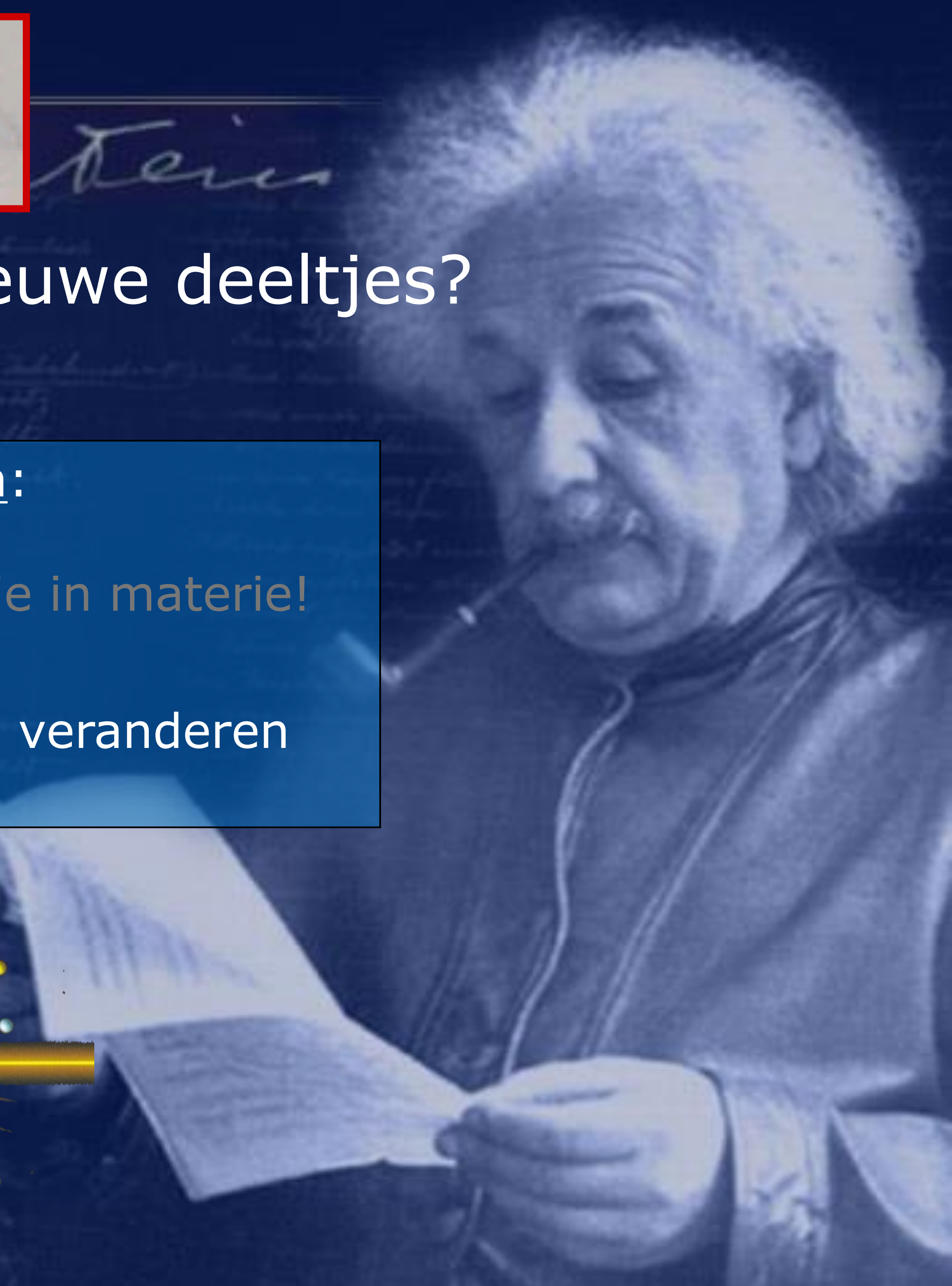
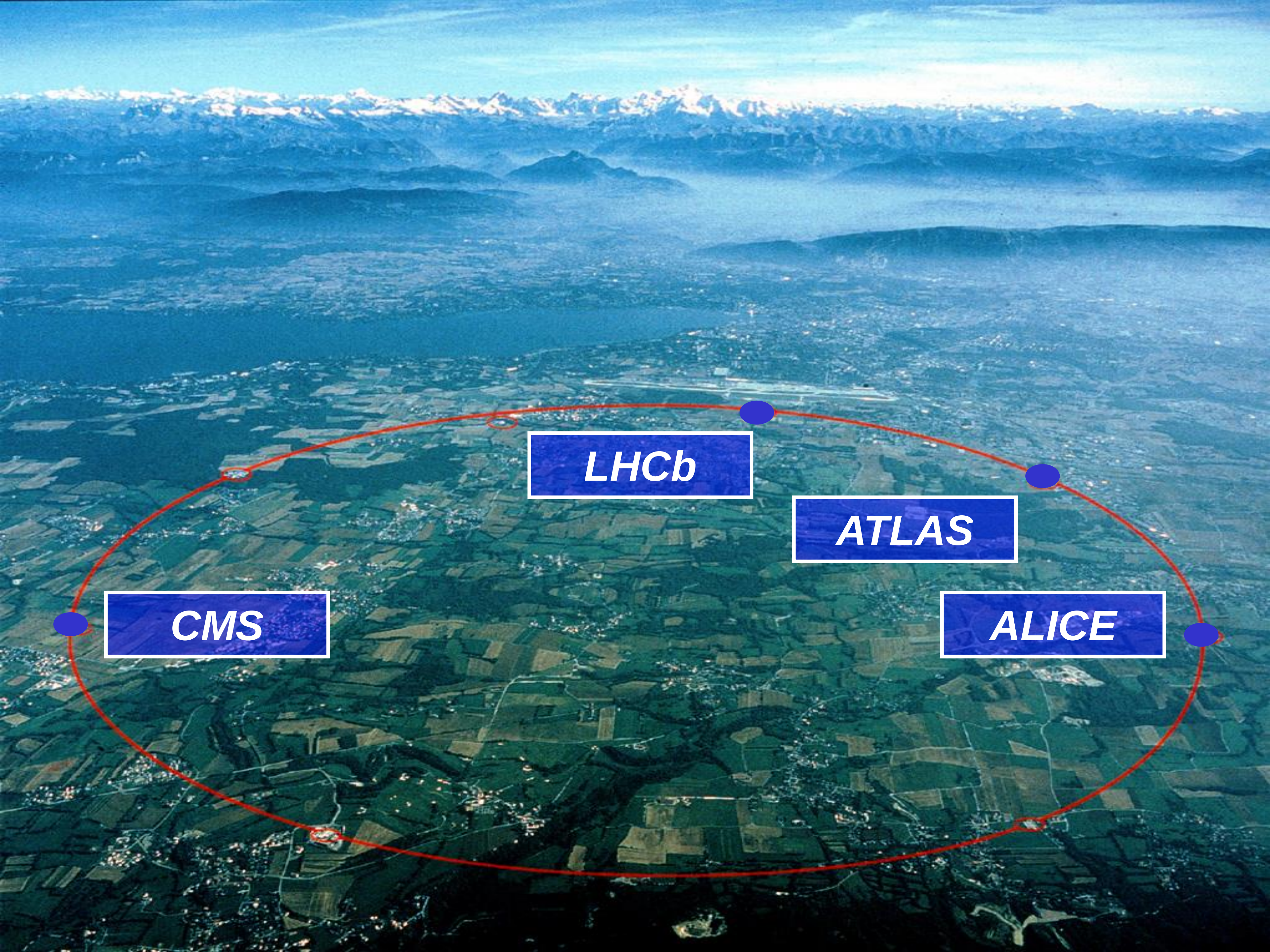
Bij de LHC op Cern:

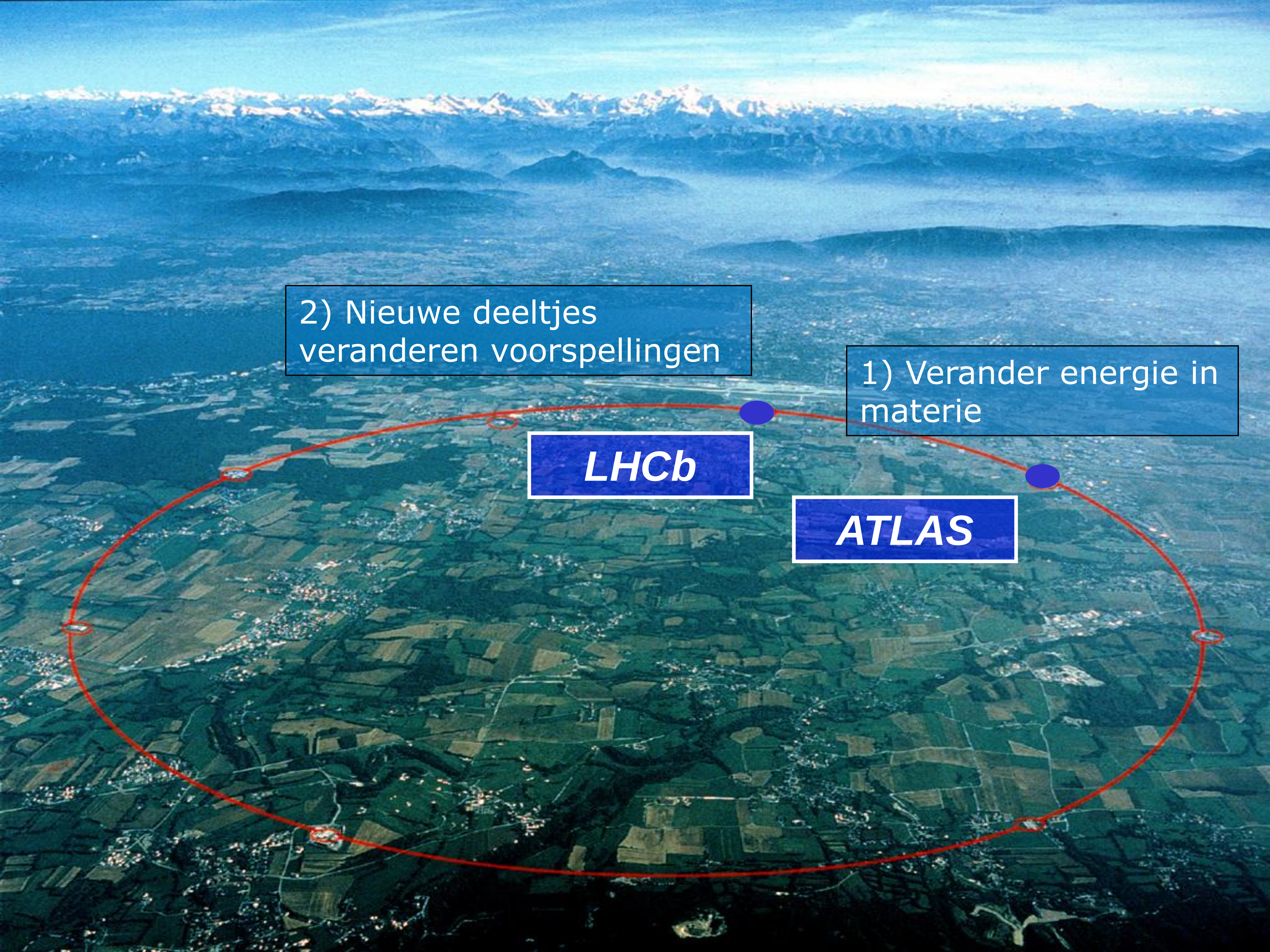
1) Verander energie in materie!

2) Nieuwe deeltjes veranderen voorspellingen

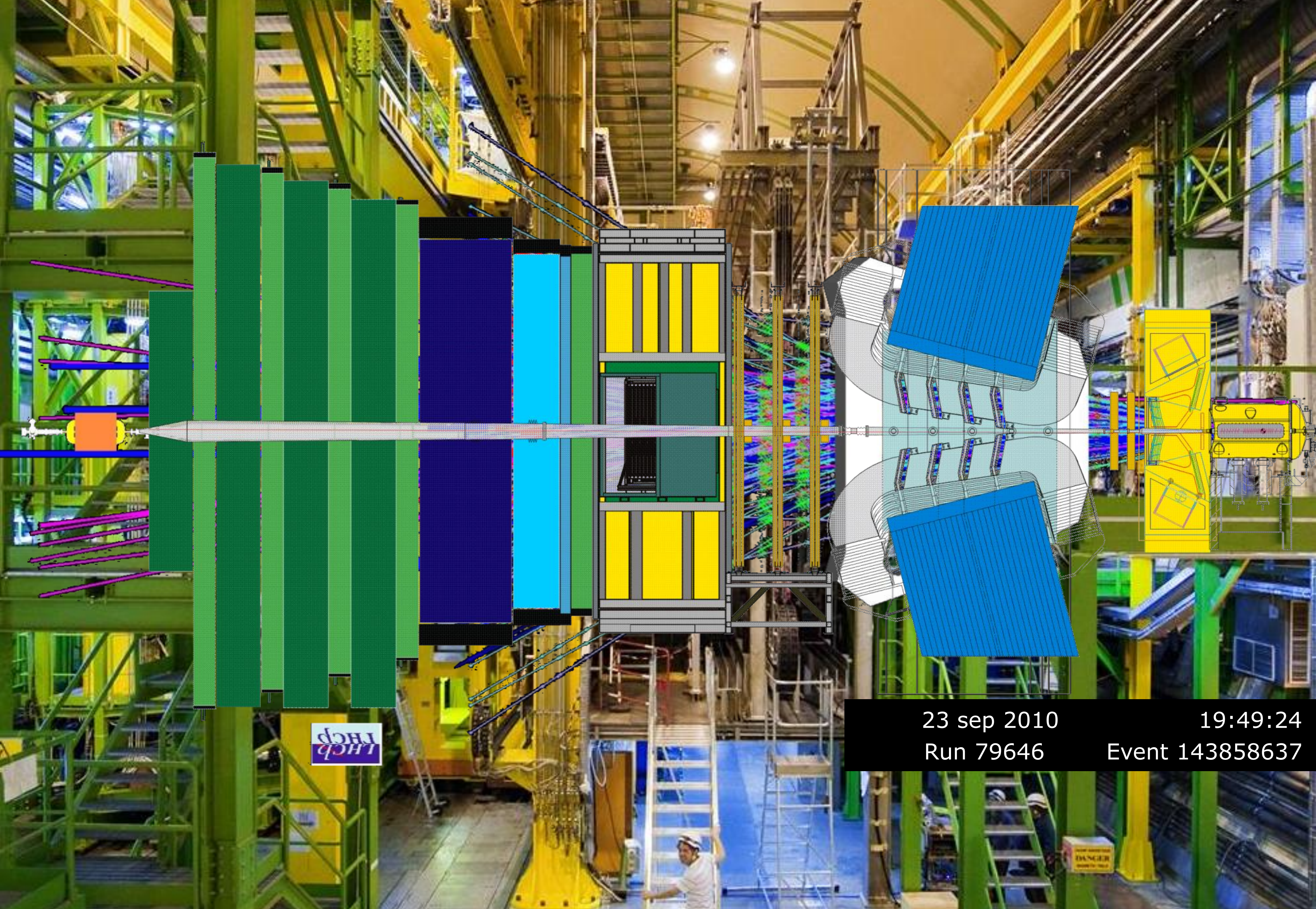





LHCb
ATLAS
CMS
ALICE


2) Nieuwe deeltjes veranderen voorspellingen
1) Verander energie in materie
LHCb
ATLAS

The LHCb Detector



$$-\tfrac{1}{2}\partial_\nu g^a_\mu \partial_\nu g^a_\mu - g_s f^{abc}\partial_\mu g^a_\nu g^b_\mu g^c_\nu - \tfrac{1}{4}g_s^2 f^{abc} f^{ade} g^b_\mu g^c_\nu g^d_\mu g^e_\nu +$$
$$\tfrac{1}{2}ig_s^2(\bar{q}^\sigma_i \gamma^\mu q^\sigma_j)g^a_\mu + \bar{G}^a\partial^2 G^a + g_s f^{abc}\partial_\mu \bar{G}^a G^b g^c_\mu - \partial_\nu W^+_\mu \partial_\nu W^-_\mu -$$
$$M^2 W^+_\mu W^-_\mu - \tfrac{1}{2}\partial_\nu Z^0_\mu \partial_\nu Z^0_\mu - \tfrac{1}{2c_w^2}M^2 Z^0_\mu Z^0_\mu - \tfrac{1}{2}\partial_\mu A_\nu \partial_\mu A_\nu - \tfrac{1}{2}\partial_\mu H \partial_\mu H -$$
$$\tfrac{1}{2}m_h^2 H^2 - \partial_\mu \phi^+ \partial_\mu \phi^- - M^2\phi^+\phi^- - \tfrac{1}{2}\partial_\mu \phi^0 \partial_\mu \phi^0 - \tfrac{1}{2c_w^2}M\phi^0\phi^0 - \beta_h[\tfrac{2M^2}{g^2} +$$
$$\tfrac{2M}{g}H + \tfrac{1}{2}(H^2 + \phi^0\phi^0 + 2\phi^+\phi^-)] + \tfrac{2M^4}{g^2}\alpha_h - igc_w[\partial_\nu Z^0_\mu(W^+_\mu W^-_\nu -$$
$$W^+_\nu W^-_\mu) - Z^0_\nu(W^+_\mu \partial_\nu W^-_\mu - W^-_\mu \partial_\nu W^+_\mu) + Z^0_\mu(W^+_\nu \partial_\nu W^-_\mu -$$
$$W^-_\nu \partial_\nu W^+_\mu)] - igs_w[\partial_\nu A_\mu(W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - A_\nu(W^+_\mu \partial_\nu W^-_\mu -$$
$$W^-_\mu \partial_\nu W^+_\mu) + A_\mu(W^+_\nu \partial_\nu W^-_\mu - W^-_\nu \partial_\nu W^+_\mu)] - \tfrac{1}{2}g^2 W^+_\mu W^-_\mu W^+_\nu W^-_\nu +$$
$$\tfrac{1}{2}g^2 W^+_\mu W^-_\nu W^+_\mu W^-_\nu + g^2 c_w^2(Z^0_\mu W^+_\mu Z^0_\nu W^-_\nu - Z^0_\mu Z^0_\mu W^+_\nu W^-_\nu) +$$
$$g^2 s_w^2(A_\mu W^+_\mu A_\nu W^-_\nu - A_\mu A_\mu W^+_\nu W^-_\nu) + g^2 s_w c_w[A_\mu Z^0_\nu(W^+_\mu W^-_\nu -$$
$$W^+_\nu W^-_\mu) - 2A_\mu Z^0_\mu W^+_\nu W^-_\nu] - g\alpha[H^3 + H\phi^0\phi^0 + 2H\phi^+\phi^-] -$$
$$\tfrac{1}{8}g^2\alpha_h[H^4 + (\phi^0)^4 + 4(\phi^+\phi^-)^2 + 4(\phi^0)^2\phi^+\phi^- + 4H^2\phi^+\phi^- + 2(\phi^0)^2H^2] -$$
$$gMW^+_\mu W^-_\mu H - \tfrac{1}{2}g\tfrac{M}{c_w^2}Z^0_\mu Z^0_\mu H - \tfrac{1}{2}ig[W^+_\mu(\phi^0\partial_\mu\phi^- - \phi^-\partial_\mu\phi^0) -$$
$$W^-_\mu(\phi^0\partial_\mu\phi^+ - \phi^+\partial_\mu\phi^0)] + \tfrac{1}{2}g[W^+_\mu(H\partial_\mu\phi^- - \phi^-\partial_\mu H) - W^-_\mu(H\partial_\mu\phi^+ -$$
$$\phi^+\partial_\mu H)] + \tfrac{1}{2}g\tfrac{1}{c_w}(Z^0_\mu(H\partial_\mu\phi^0 - \phi^0\partial_\mu H) - ig\tfrac{s_w^2}{c_w}MZ^0_\mu(W^+_\mu\phi^- - W^-_\mu\phi^+) +$$
$$igs_w MA_\mu(W^+_\mu\phi^- - W^-_\mu\phi^+) - ig\tfrac{1-2c_w^2}{2c_w}Z^0_\mu(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) +$$
$$igs_w A_\mu(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) - \tfrac{1}{4}g^2 W^+_\mu W^-_\mu[H^2 + (\phi^0)^2 + 2\phi^+\phi^-] -$$
$$\tfrac{1}{4}g^2\tfrac{1}{c_w^2}Z^0_\mu Z^0_\mu[H^2 + (\phi^0)^2 + 2(2s_w^2 - 1)^2\phi^+\phi^-] - \tfrac{1}{2}g^2\tfrac{s_w^2}{c_w}Z^0_\mu\phi^0(W^+_\mu\phi^- +$$
$$W^-_\mu\phi^+) - \tfrac{1}{2}ig^2\tfrac{s_w^2}{c_w}Z^0_\mu H(W^+_\mu\phi^- - W^-_\mu\phi^+) + \tfrac{1}{2}g^2 s_w A_\mu\phi^0(W^+_\mu\phi^- +$$
$$W^-_\mu\phi^+) + \tfrac{1}{2}ig^2 s_w A_\mu H(W^+_\mu\phi^- - W^-_\mu\phi^+) - g^2\tfrac{s_w}{c_w}(2c_w^2 - 1)Z^0_\mu A_\mu\phi^+\phi^- -$$
$$g^1 s_w^2 A_\mu A_\mu\phi^+\phi^- - \bar{e}^\lambda(\gamma\partial + m_e^\lambda)e^\lambda - \bar{\nu}^\lambda\gamma\partial\nu^\lambda - \bar{u}^\lambda_j(\gamma\partial + m_u^\lambda)u^\lambda_j -$$
$$\bar{d}^\lambda_j(\gamma\partial + m_d^\lambda)d^\lambda_j + igs_w A_\mu[-(\bar{e}^\lambda\gamma^\mu e^\lambda) + \tfrac{2}{3}(\bar{u}^\lambda_j\gamma^\mu u^\lambda_j) - \tfrac{1}{3}(\bar{d}^\lambda_j\gamma^\mu d^\lambda_j)] +$$
$$\tfrac{ig}{4c_w}Z^0_\mu[(\bar{\nu}^\lambda\gamma^\mu(1 + \gamma^5)\nu^\lambda) + (\bar{e}^\lambda\gamma^\mu(4s_w^2 - 1 - \gamma^5)e^\lambda) + (\bar{u}^\lambda_j\gamma^\mu(\tfrac{4}{3}s_w^2 -$$
$$1 - \gamma^5)u^\lambda_j) + (\bar{d}^\lambda_j\gamma^\mu(1 - \tfrac{8}{3}s_w^2 - \gamma^5)d^\lambda_j)] + \tfrac{ig}{2\sqrt{2}}W^+_\mu[(\bar{\nu}^\lambda\gamma^\mu(1 + \gamma^5)e^\lambda) +$$
$$(\bar{u}^\lambda_j\gamma^\mu(1 + \gamma^5)C_{\lambda\kappa}d^\kappa_j)] + \tfrac{ig}{2\sqrt{2}}W^-_\mu[(\bar{e}^\lambda\gamma^\mu(1 + \gamma^5)\nu^\lambda) + (\bar{d}^\kappa_j C^\dagger_{\lambda\kappa}\gamma^\mu(1 +$$
$$\gamma^5)u^\lambda_j)] + \tfrac{ig}{2\sqrt{2}}\tfrac{m_e^\lambda}{M}[-\phi^+(\bar{\nu}^\lambda(1 - \gamma^5)e^\lambda) + \phi^-(\bar{e}^\lambda(1 + \gamma^5)\nu^\lambda)] -$$
$$\tfrac{g}{2}\tfrac{m_e^\lambda}{M}[H(\bar{e}^\lambda e^\lambda) + i\phi^0(\bar{e}^\lambda\gamma^5 e^\lambda)] + \tfrac{ig}{2M\sqrt{2}}\phi^+[-m_d^\kappa(\bar{u}^\lambda_j C_{\lambda\kappa}(1 - \gamma^5)d^\kappa_j) +$$
$$m_u^\lambda(\bar{u}^\lambda_j C_{\lambda\kappa}(1 + \gamma^5)d^\kappa_j] + \tfrac{ig}{2M\sqrt{2}}\phi^-[m_d^\lambda(\bar{d}^\lambda_j C^\dagger_{\lambda\kappa}(1 + \gamma^5)u^\kappa_j) - m_u^\kappa(\bar{d}^\lambda_j C^\dagger_{\lambda\kappa}(1 -$$
$$\gamma^5)u^\kappa_j] - \tfrac{g}{2}\tfrac{m_u^\lambda}{M}H(\bar{u}^\lambda_j u^\lambda_j) - \tfrac{g}{2}\tfrac{m_d^\lambda}{M}H(\bar{d}^\lambda_j d^\lambda_j) + \tfrac{ig}{2}\tfrac{m_u^\lambda}{M}\phi^0(\bar{u}^\lambda_j\gamma^5 u^\lambda_j) -$$
$$\tfrac{ig}{2}\tfrac{m_d^\lambda}{M}\phi^0(\bar{d}^\lambda_j\gamma^5 d^\lambda_j) + \bar{X}^+(\partial^2 - M^2)X^+ + \bar{X}^-(\partial^2 - M^2)X^- + \bar{X}^0(\partial^2 -$$
$$\tfrac{M^2}{c_w^2})X^0 + \bar{Y}\partial^2 Y + igc_w W^+_\mu(\partial_\mu\bar{X}^0 X^- - \partial_\mu\bar{X}^+ X^0) + igs_w W^+_\mu(\partial_\mu\bar{Y}X^- -$$
$$\partial_\mu\bar{X}^+ Y) + igc_w W^-_\mu(\partial_\mu\bar{X}^- X^0 - \partial_\mu\bar{X}^0 X^+) + igs_w W^-_\mu(\partial_\mu\bar{X}^- Y -$$
$$\partial_\mu\bar{Y}X^+) + igc_w Z^0_\mu(\partial_\mu\bar{X}^+ X^+ - \partial_\mu\bar{X}^- X^-) + igs_w A_\mu(\partial_\mu\bar{X}^+ X^+ -$$
$$\partial_\mu\bar{X}^- X^-) - \tfrac{1}{2}gM[\bar{X}^+ X^+ H + \bar{X}^- X^- H + \tfrac{1}{c_w^2}\bar{X}^0 X^0 H] +$$
$$\tfrac{1-2c_w^2}{2c_w}igM[\bar{X}^+ X^0\phi^+ - \bar{X}^- X^0\phi^-] + \tfrac{1}{2c_w}igM[\bar{X}^0 X^-\phi^+ - \bar{X}^0 X^+\phi^-] +$$
$$igMs_w[\bar{X}^0 X^-\phi^+ - \bar{X}^0 X^+\phi^-] + \tfrac{1}{2}igM[\bar{X}^+ X^+\phi^0 - \bar{X}^- X^-\phi^0]$$

Quantummechanisch botsen

LHCb in getallen

120,000 B events per sec

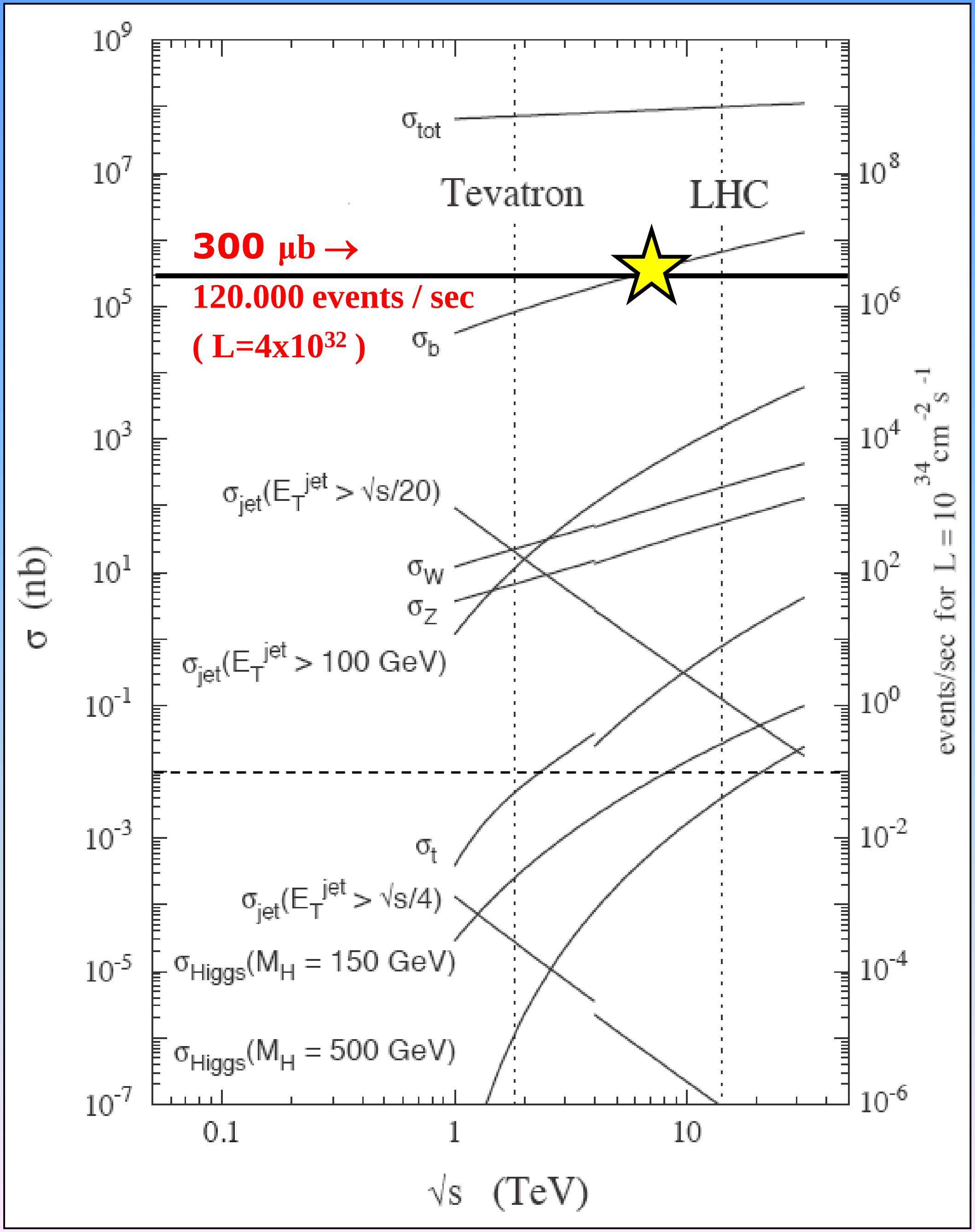
(ter vergelijk: in ATLAS : 1 Higgs in 100 sec)

10^{12} B events in 2022

(ter vergelijk: Babar heeft in totaal 10^9 B events)

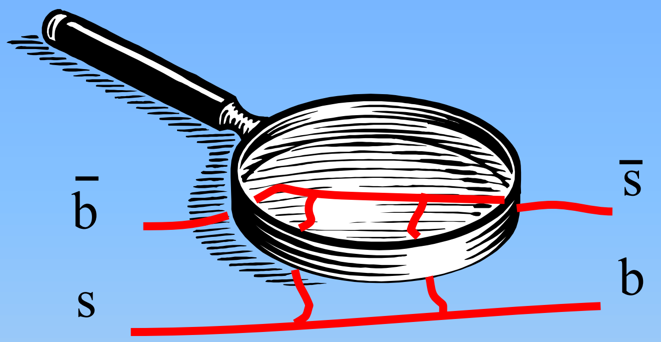
5 kHz naar tape

(ter vergelijk: ATLAS schrijft 200 Hz weg)

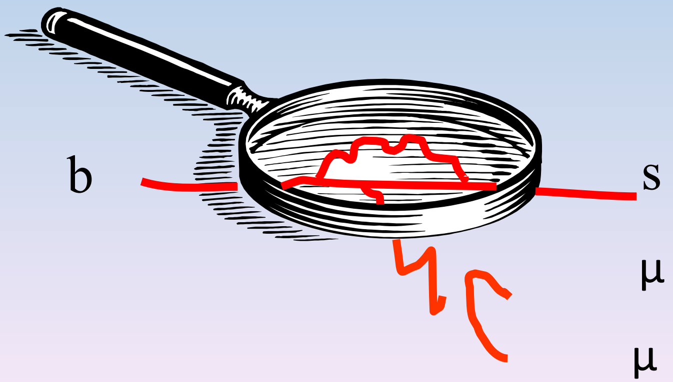


LHCb: bestuderen van *B* deeltje

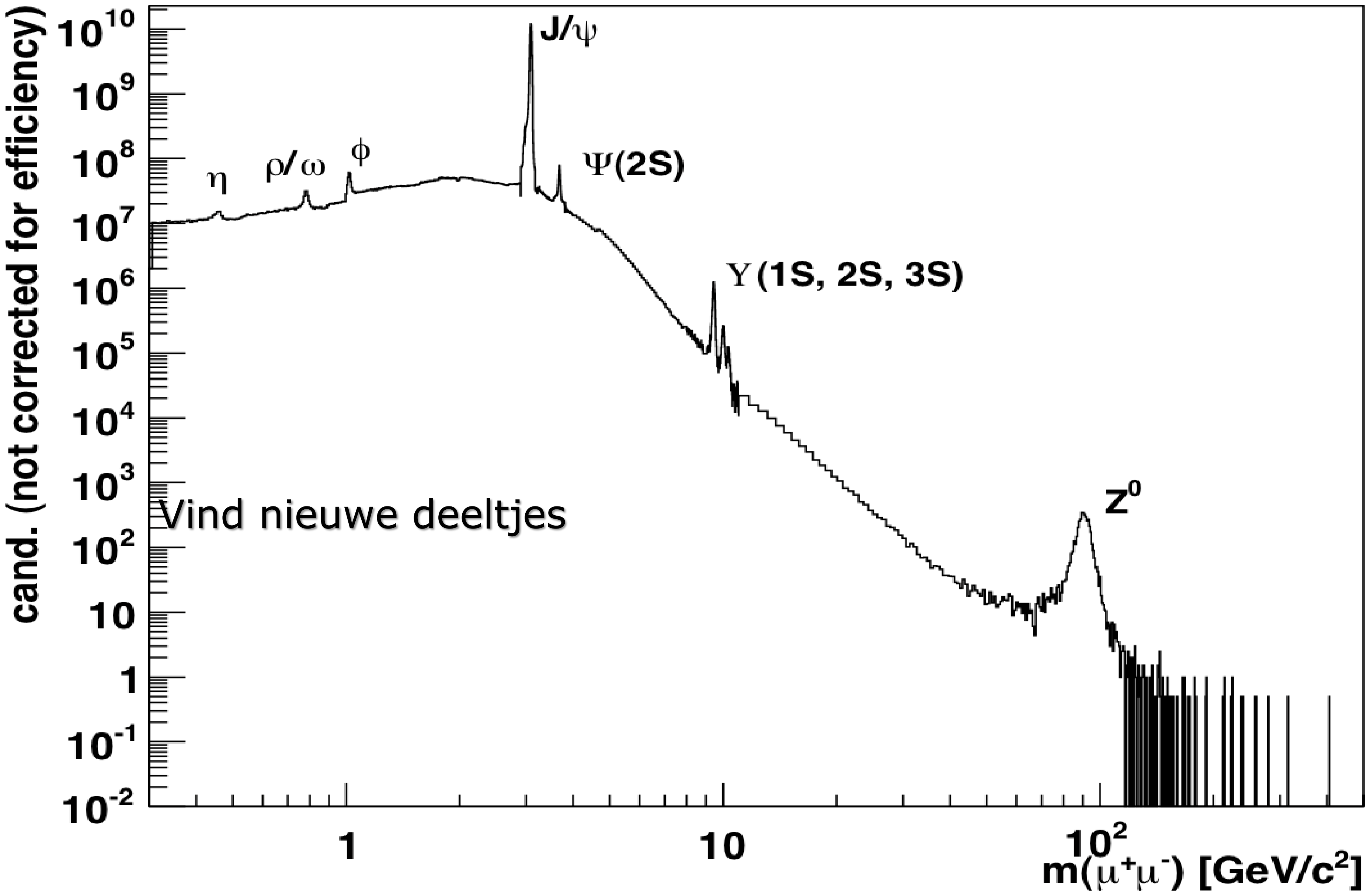
1) Vind verschillen tussen materie en anti-materie



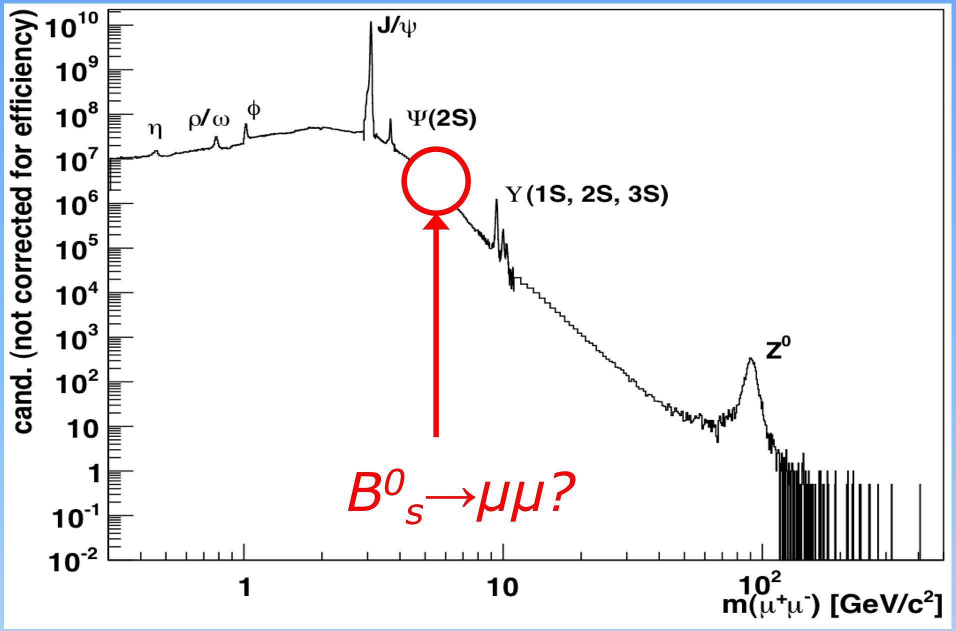
2) Vind nieuwe deeltjes



LHCb: bestuderen van *B* deeltje

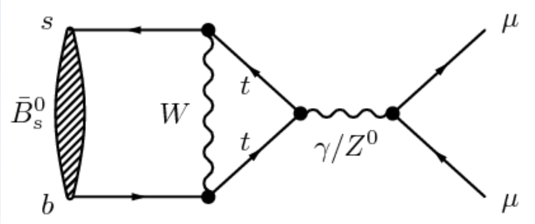


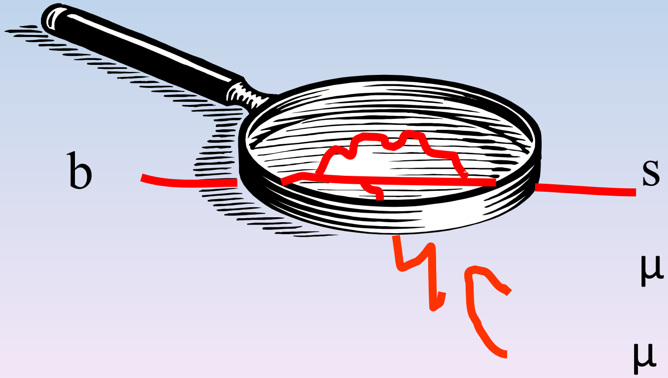
LHCb: bestuderen van *B* deeltje



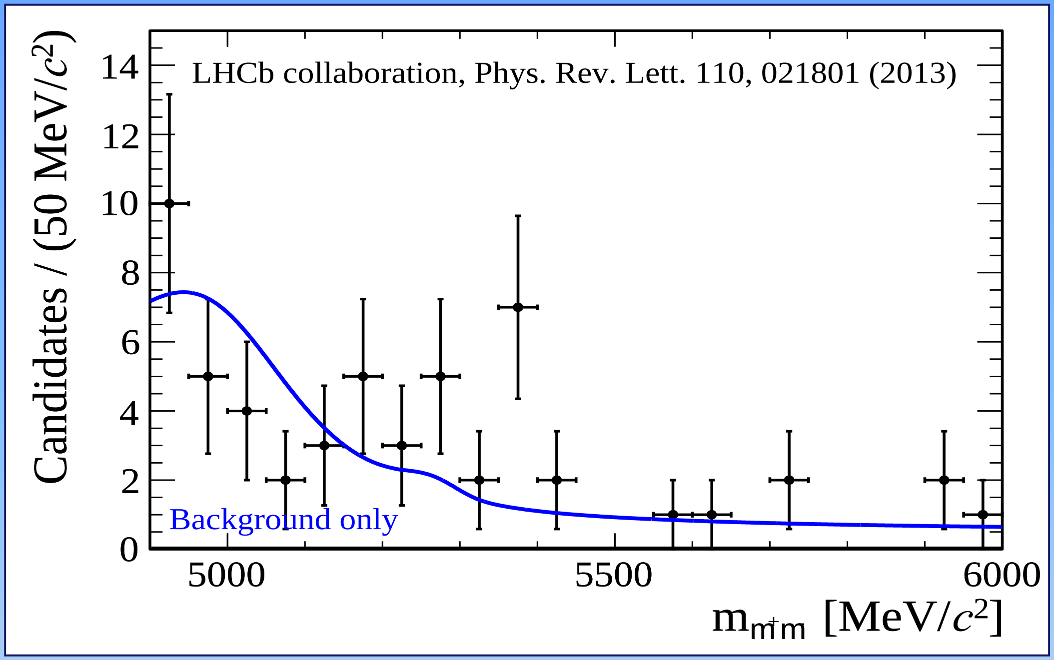
2) Vind nieuwe deeltjes

$B^0_s \rightarrow \mu\mu$



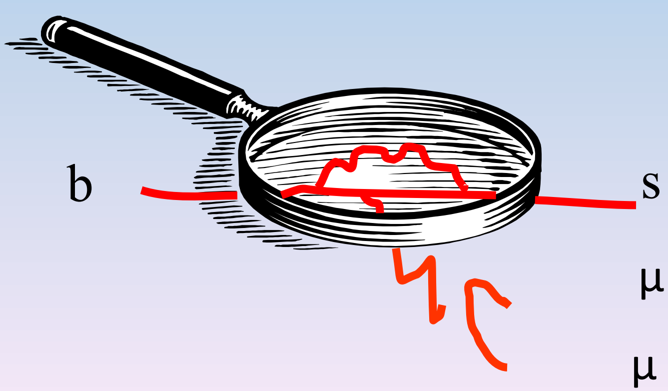


LHCb: bestuderen van *B* deeltje

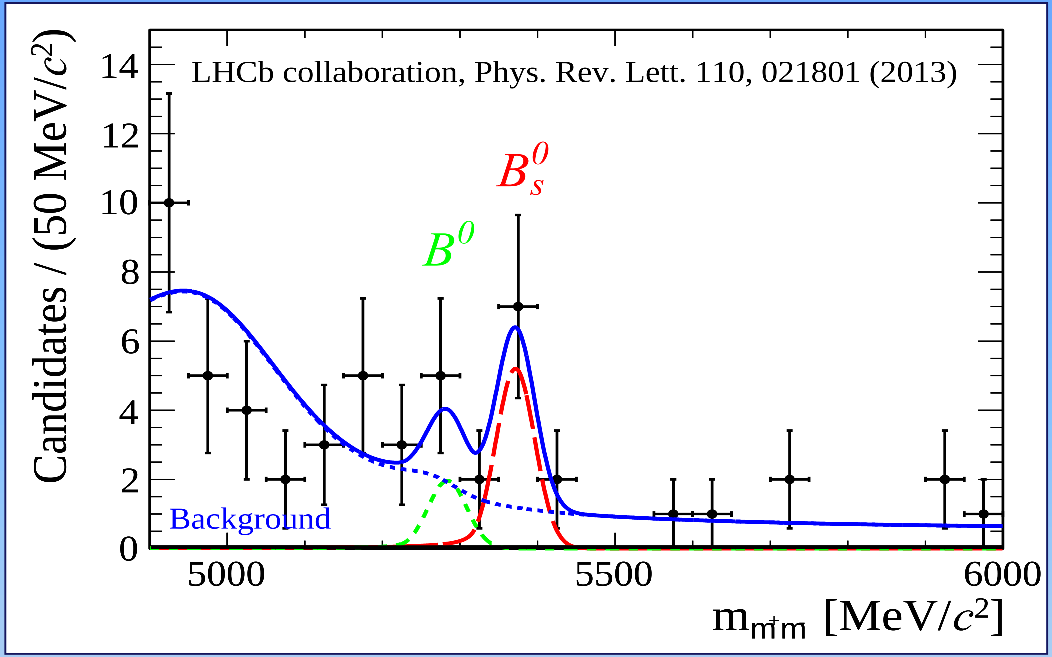


Slechts 3 op de miljard *B* deeltjes vervalt naar 2 muonen

Bestaan er nieuwe deeltjes?

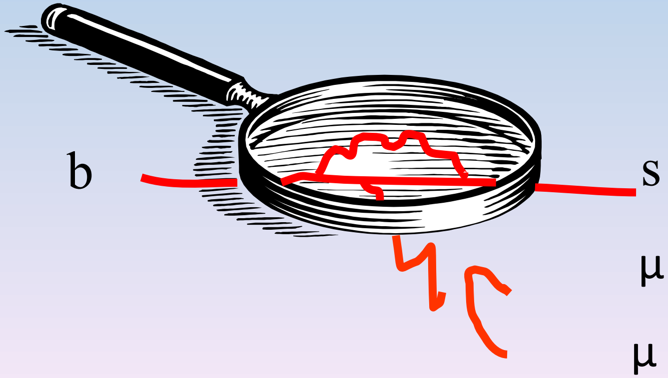


LHCb: bestuderen van *B* deeltje

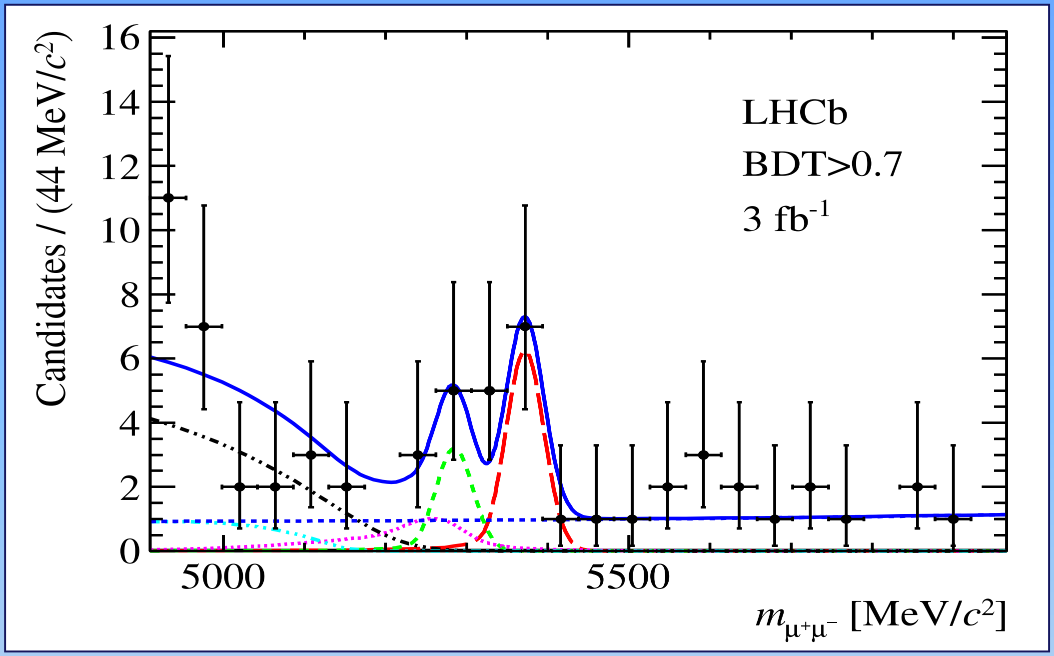


Slechts 3 op de miljard *B* deeltjes vervalt naar 2 muonen

Bestaan er nieuwe deeltjes?

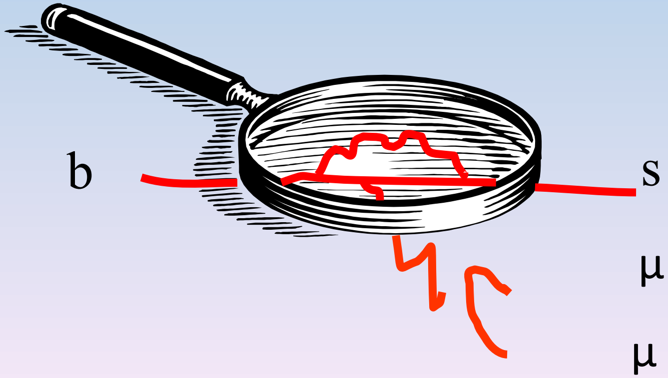


LHCb: bestuderen van *B* deeltje

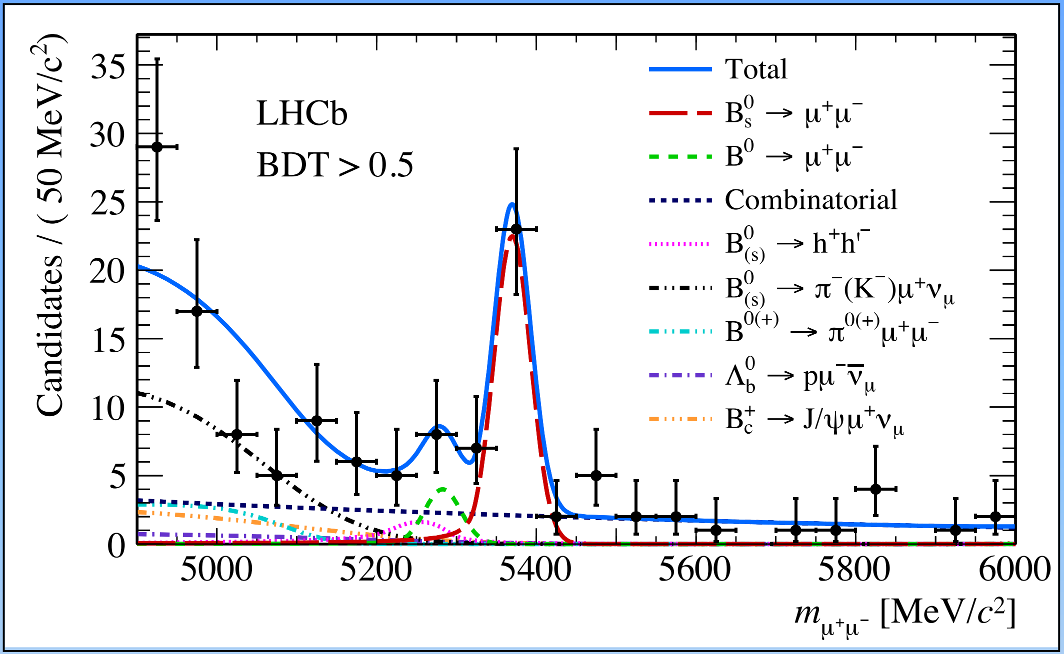


Slechts 3 op de miljard *B* deeltjes vervalt naar 2 muonen

Bestaan er nieuwe deeltjes?

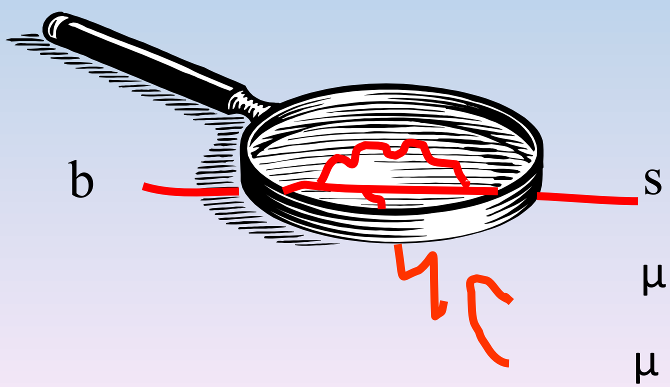


LHCb: bestuderen van *B* deeltje

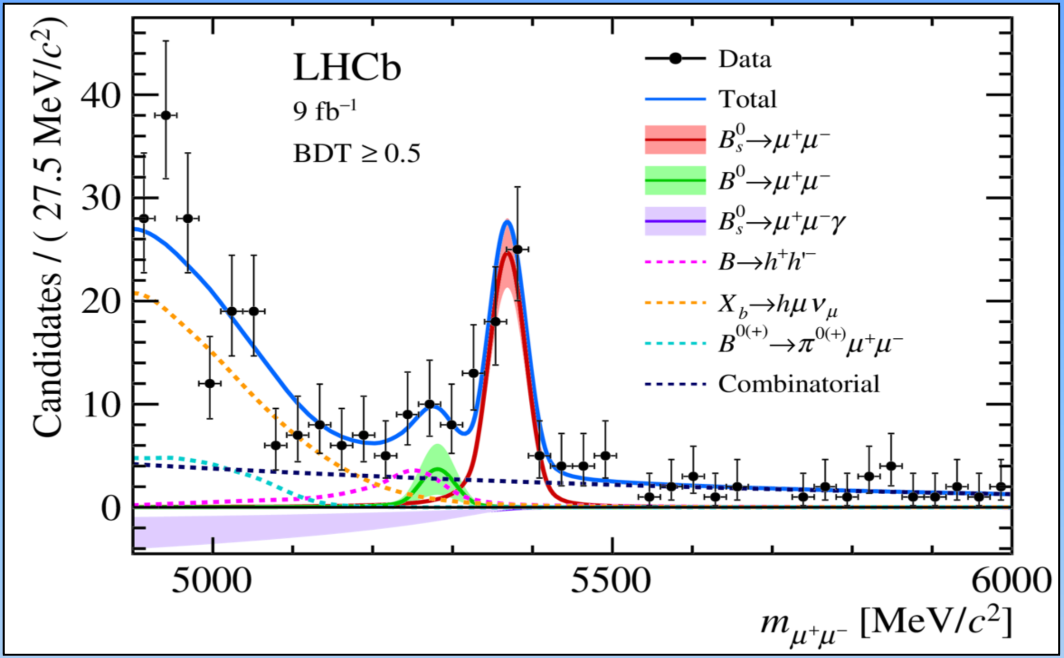


Slechts 3 op de miljard *B* deeltjes vervalt naar 2 muonen

Bestaan er nieuwe deeltjes?



LHCb: bestuderen van *B* deeltje



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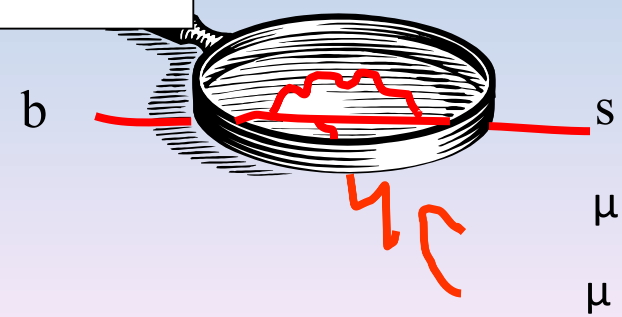
$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = \left(3.09\,^{+0.46}_{-0.43}\,^{+0.15}_{-0.11}\right) \times 10^{-9}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) = \left(1.2\,^{+0.8}_{-0.7} \pm 0.1\right) \times 10^{-10}$$

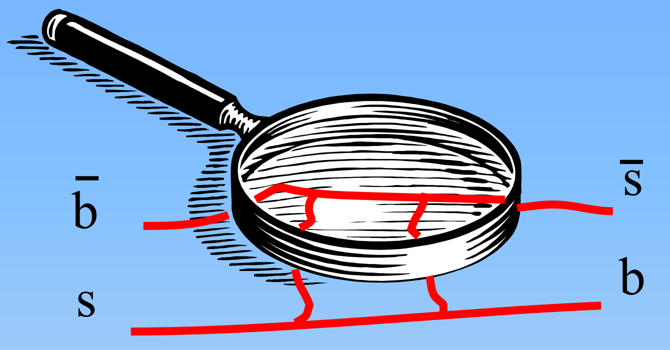
Theory:

$$B(B_s^0 \to \mu^+\mu^-) = (3.65 \pm 0.23) \times 10^{-9}$$
$$B(B^0 \to \mu^+\mu^-) = (1.06 \pm 0.09) \times 10^{-10}$$

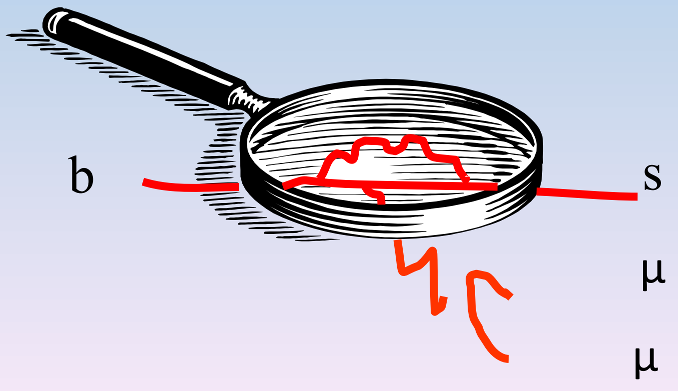


LHCb: bestuderen van *B* deeltje

1) Vind verschillen tussen materie en anti-materie



2) Vind nieuwe deeltjes



LHCb: highlights

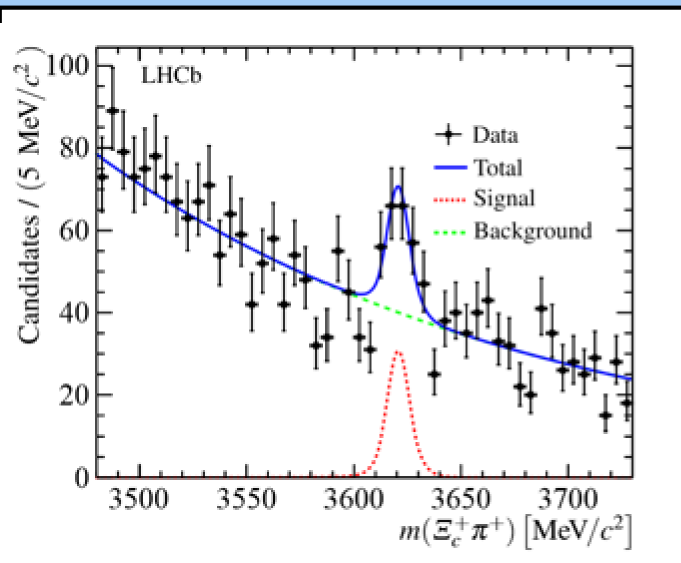
1) Nieuwe ‘gewone’ hadronen
2) Nieuwe ‘exotische’ hadronen: Tetraquark en pentaquark
3) Ontdekking ‘CP schending’ B_s
4) Ontdekking ‘CP schending’ charm

Hot topic:

5) Verschil electron, muon, tau??

LHCb: nieuwe 'gewone' hadronen

(ccu): Ξ_{cc}^{++}



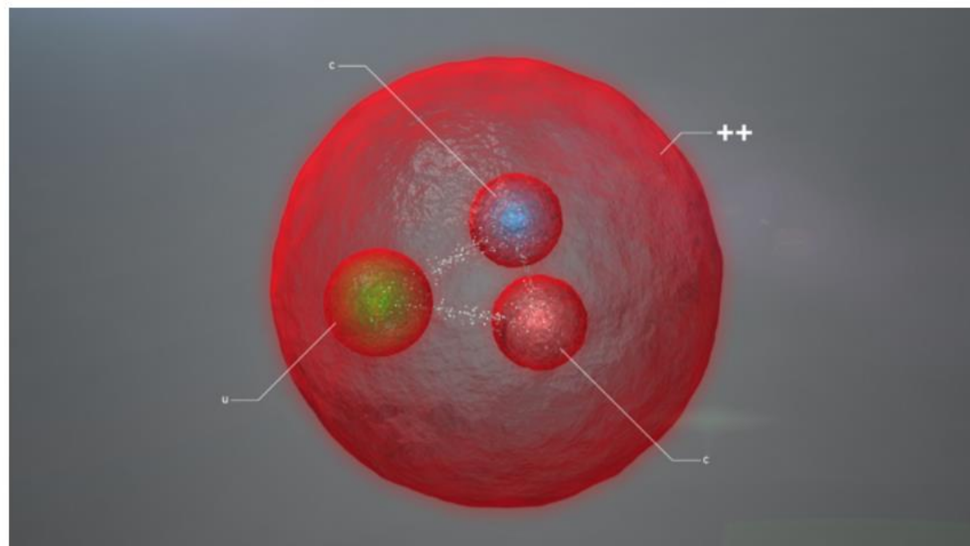
NewScientist

IDEEËN DIE DE WERELD VERANDEREN

Nieuw zwaar deeltje legt sterke kernkracht op de pijnbank

12 juli 2017

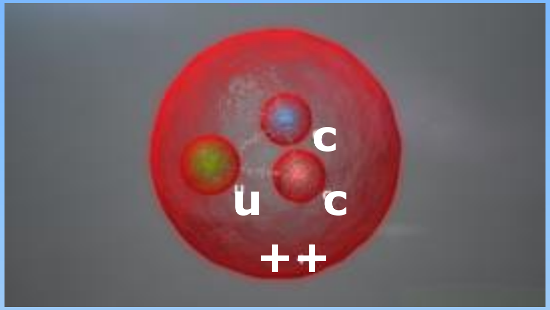
Jacob Aron en Leah Crane

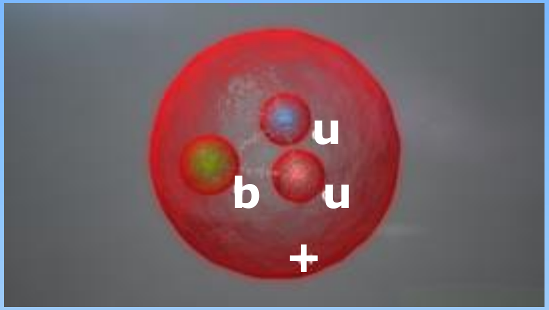


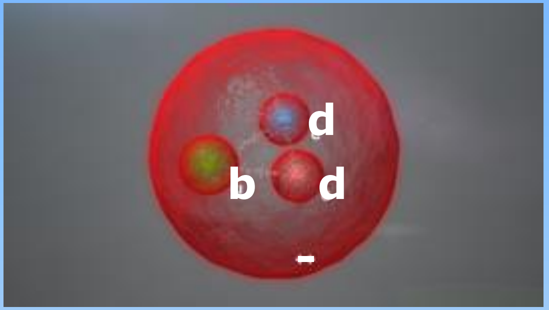
Het nieuwe deeltje bevat twee charm-quarks in het midden en een up-quark daaromheen. Beeld: Daniel Dominguez/CERN.

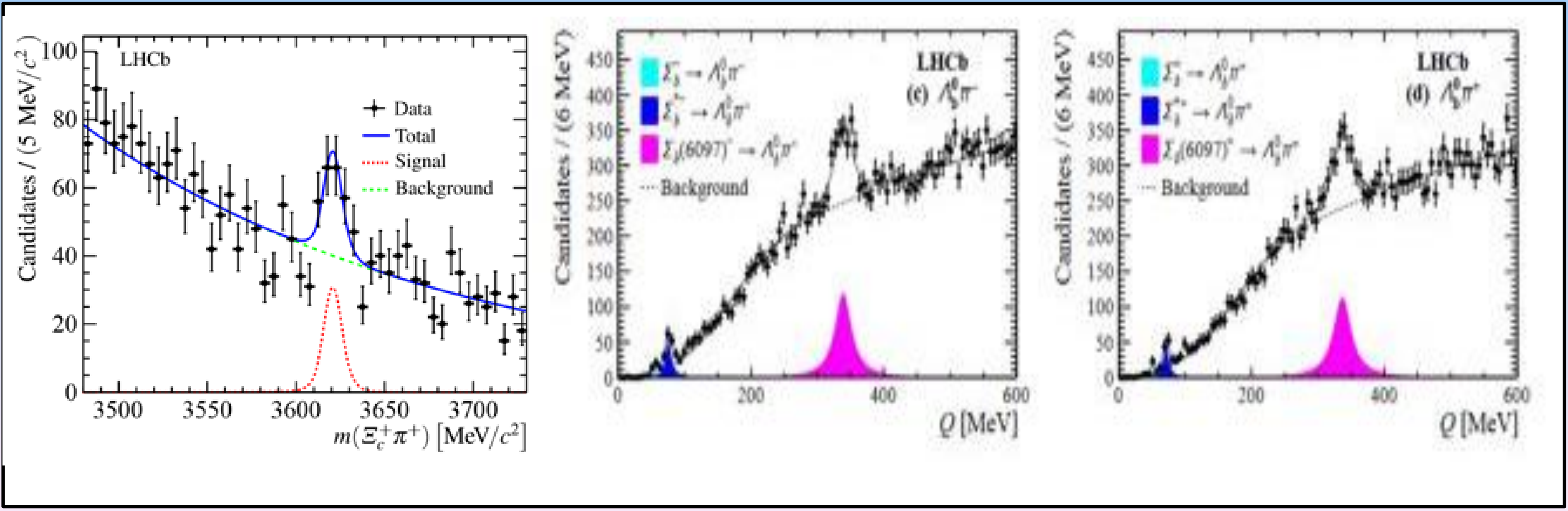
LHCb: nieuwe ‘gewone’ hadronen

(ccu): $\mathbf{\Xi_{cc}^{++}}$ (buu): $\mathbf{\Sigma_b(6097)^{+}}$ (bdd): $\mathbf{\Sigma_b(6097)^{-}}$





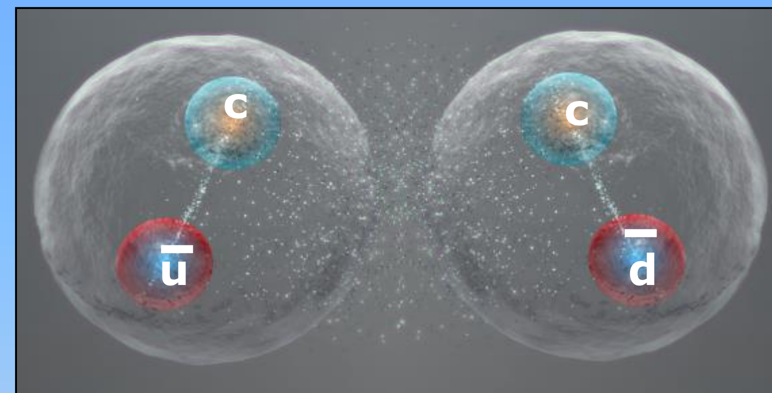


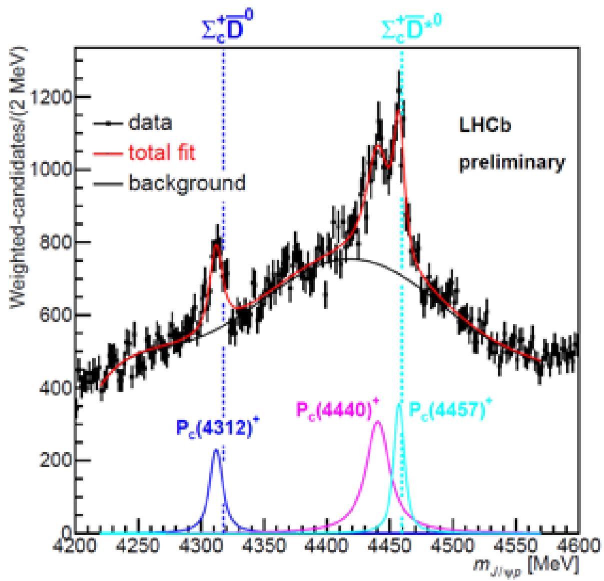


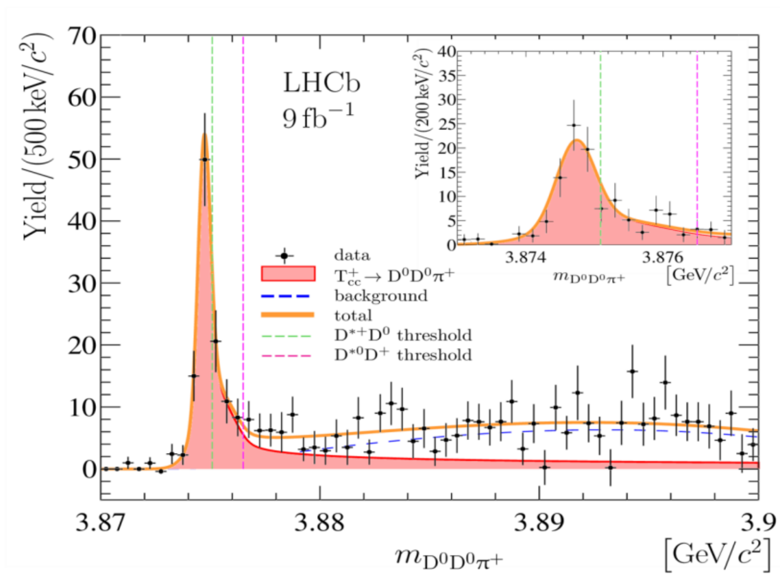
LHCb: nieuwe 'exotische' hadronen

$(c\bar{c}duu)$: $\mathbf{P_c(4312)^+}$

$(c\bar{u}\ c\bar{d})$: $\mathbf{T_{cc}^+(3875)}$



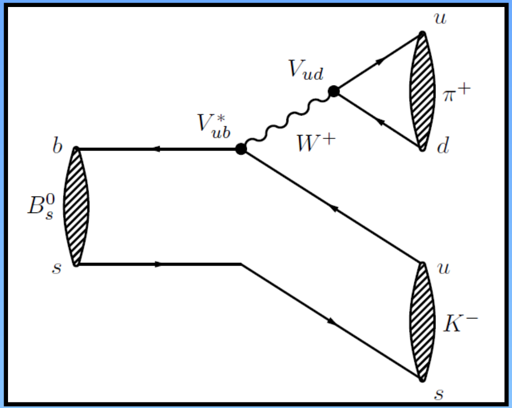


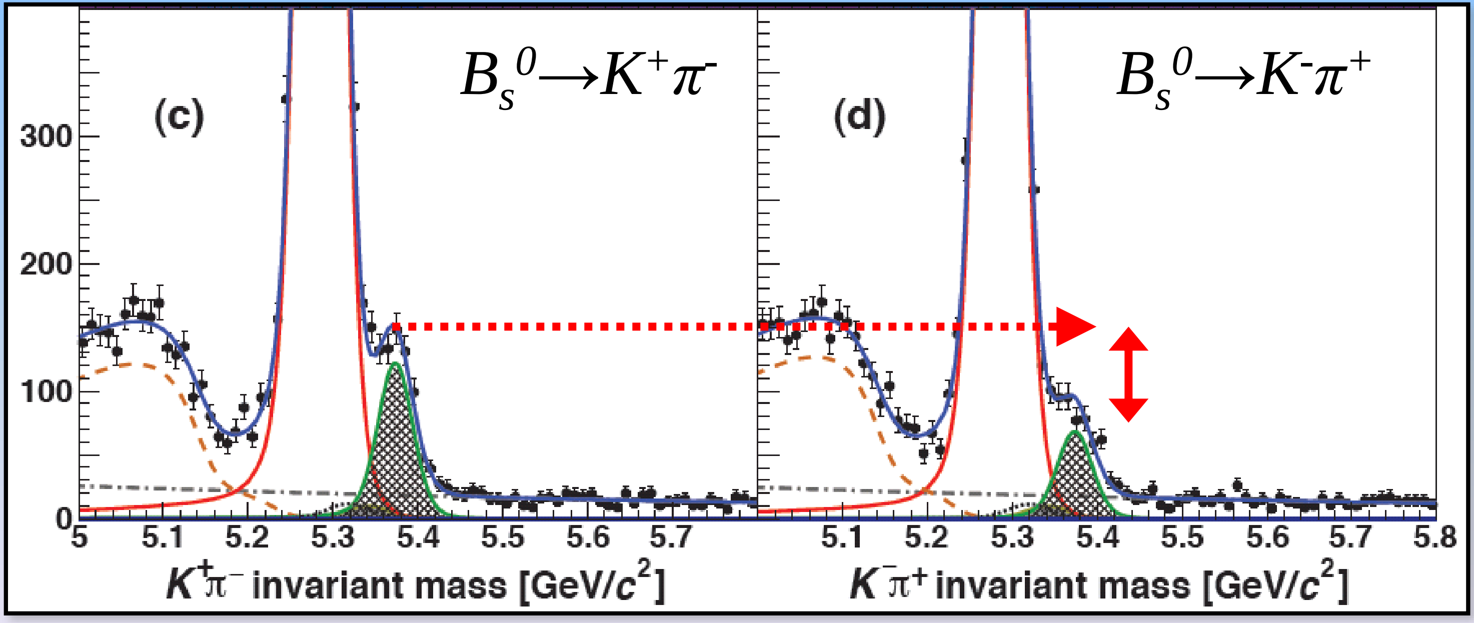


Nature Commun. 13 (2022) 1, 3351

LHCb: antimaterie verschil in B_s^0

CP schending in B_s^0





LHCb: antimaterie verschil in charm

"CP schending"

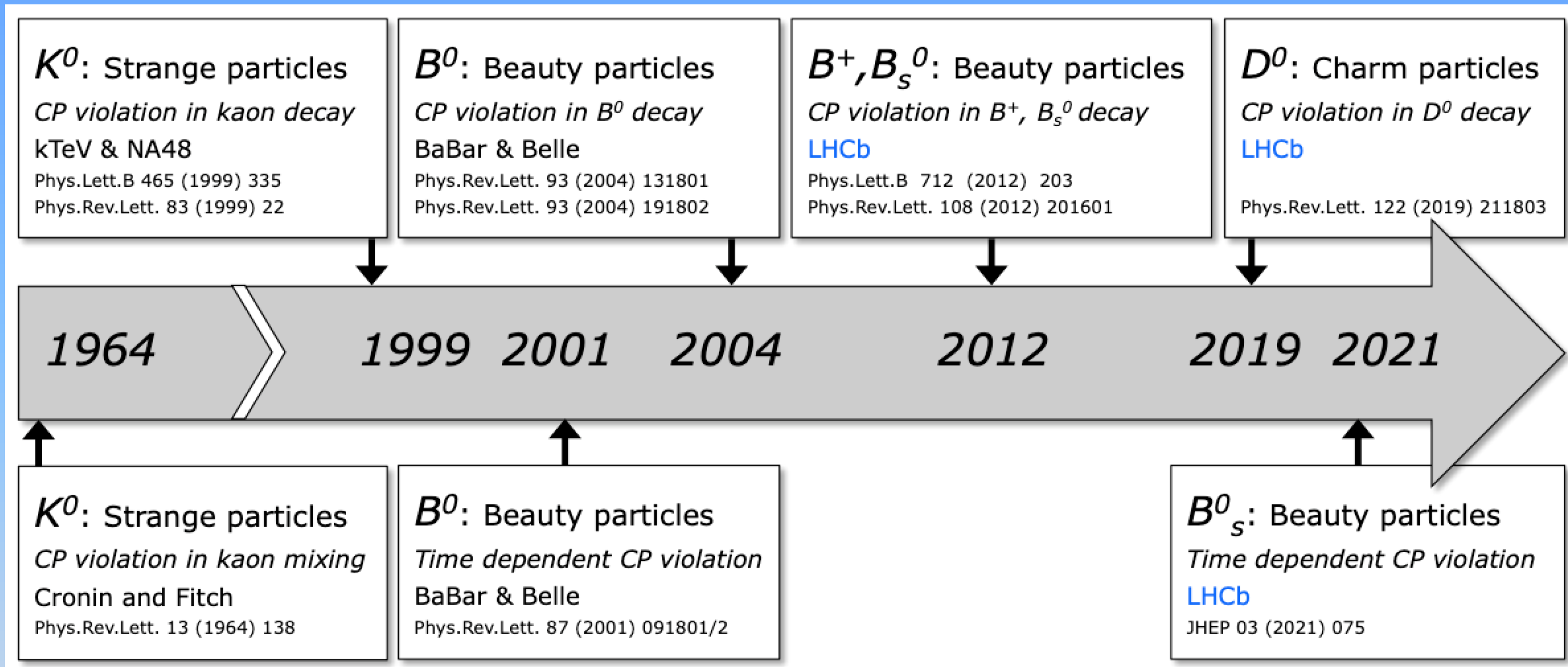
$D^0 \rightarrow K^+K^-$ same as

$\overline{D}^0 \rightarrow K^+K^-$??

at least it is different compared to $D^0 \rightarrow \pi^+\pi^-$...:

$$\Delta A_{CP} = (-15.4 \pm 2.9) \times 10^{-4}$$

LHCb: antimaterie verschillen



(ds)	**1964**: CP schending met K^0	(Nobelprijs 1980)
(bd)	**2000**: CP schending met B^0	(Nobelprijs 2008)
(bs)	**2012**: CP schending met B^0_s	(LHCb)
(cu)	**2019**: CP schending met D^0	(LHCb)

LHCb: highlights

1) Nieuwe ‘gewone’ hadronen
2) Nieuwe ‘exotische’ hadronen: Tetraquark en pentaquark
3) Ontdekking ‘CP schending’ B_s
4) Ontdekking ‘CP schending’ charm

Hot topic:

5) Verschil electron, muon, tau?

LHCb: hot topic

NewScientist
IDEEËN DIE DE WERELD VERANDEREN

Cern vindt nieuwe hint voor scheurtjes in standaardmodel

19 april 2017

George van Hal

mogelijke hint dat er meer is dan alleen het
rdmodel. Beeld: Cern.

deVolkskrant

CERN is 'voorzichtig opgewonden' over subtiele verschillen in deeltjeswereld

Een gevoel van 'voorzichtige opwinding' heeft zich meester gemaakt van deeltjesfysici van CERN in Genève. Dinsdag maakte de LHCb-detector daar bekend subtiele verschillen te zien tussen bepaalde deeltjes. De gangbare deeltjestheorie neemt aan dat deeltjes in essentie identiek zijn.

Martijn van Calmthout 19 april 2017, 21:29

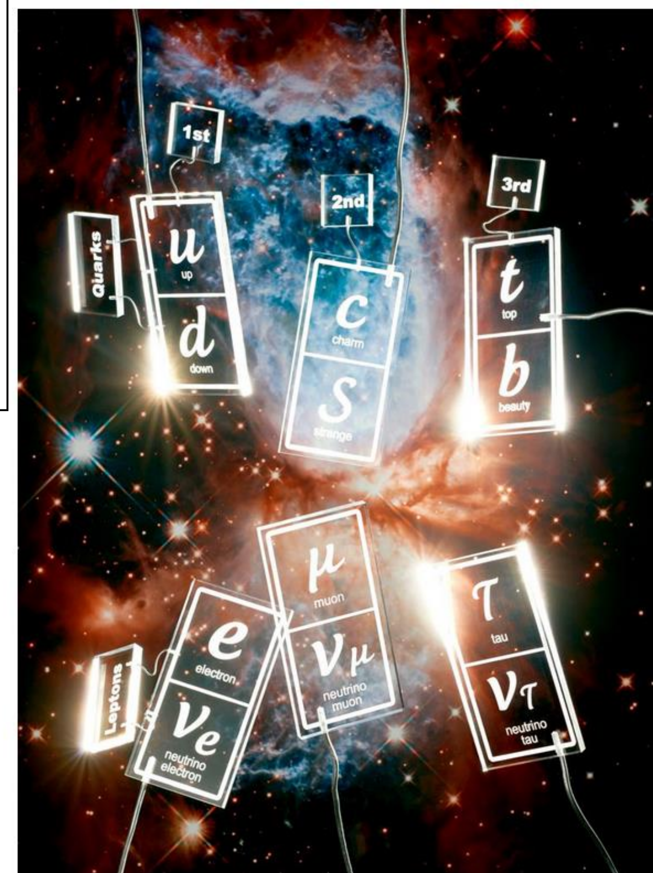
Wellicht is de deeltjeswereld niet zo democratisch als vooraf gedacht werd. Beeld epa

deVolkskrant

Moeder aller deeltjes: de zoektocht naar de leptoquark

Is het fundamenteelste deeltje in het universum altijd over het hoofd gezien? Komende week kan de wereld opgeschud worden, als natuurkundigen in Seoul hun resultaten bekendmaken. Leptoquark, onthoud dat woord.

Martijn van Calmthout 29 juni 2018, 11:25



Beeld Rein Janssen

LHCb: hot topic

deVolkskrant

Moeder aller deeltjes: de zoektocht naar de leptoquark

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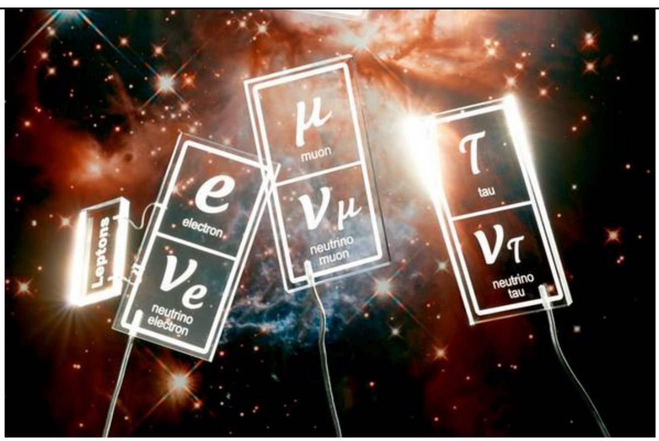
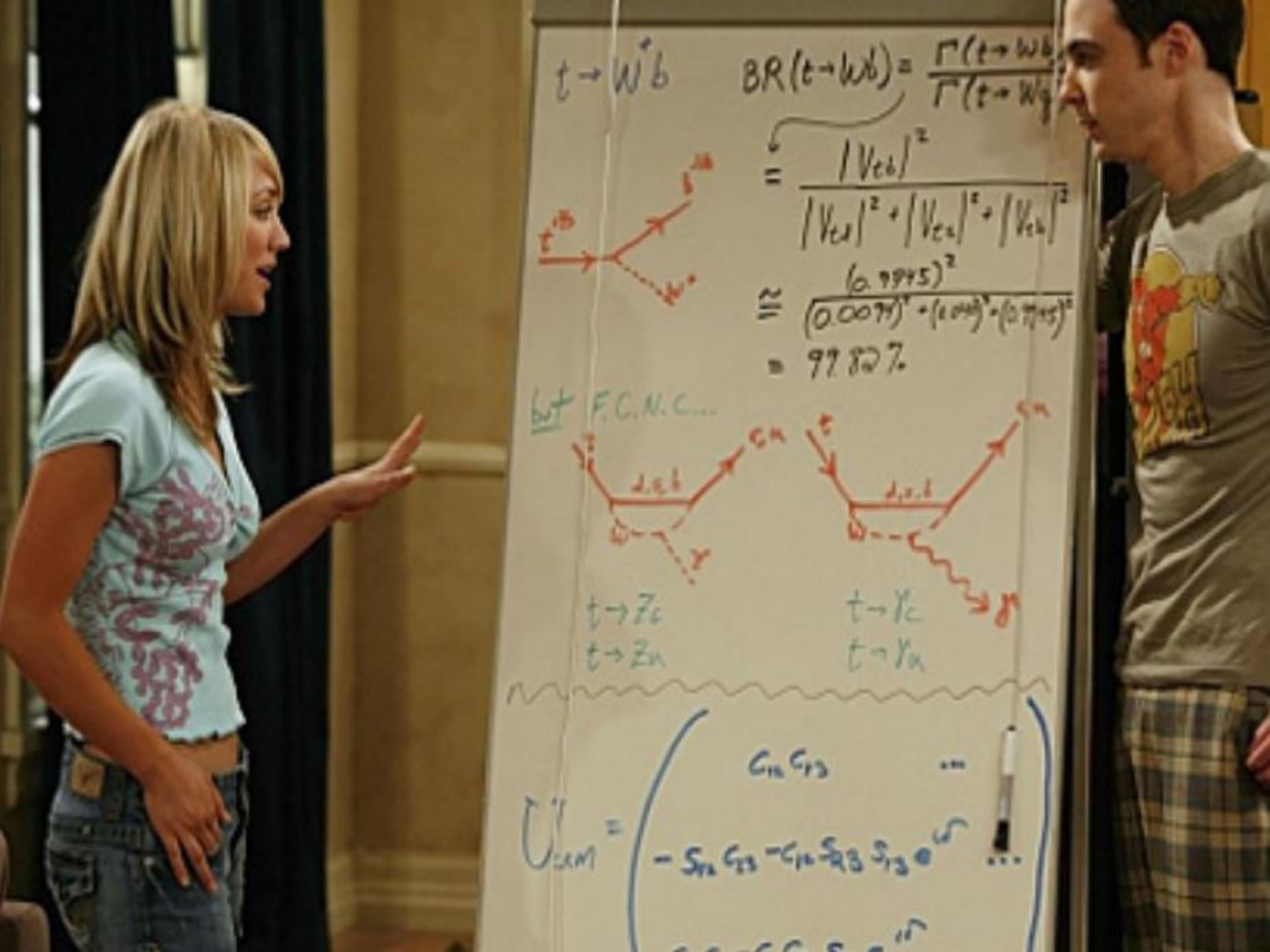
Martijn van Calmthout 29 juni 2018, 11:25

Maar de LHCb-metingen geven al jaren kleine hints dat er iets mis is met deze keurige lepton-universaliteit. En dat elektronen en muonen ergens diep van binnen toch net iets anders met quarks omgaan.

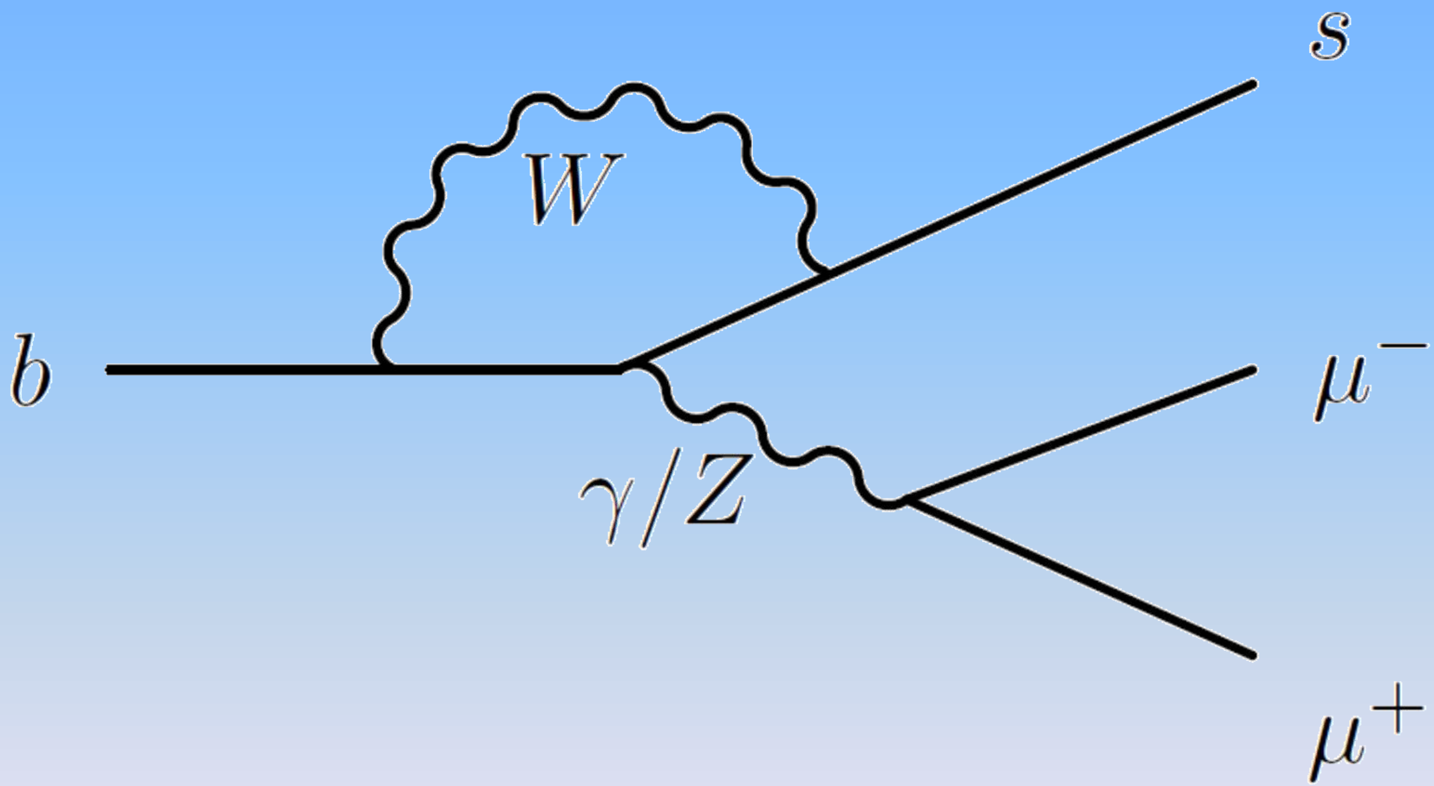


Beeld Rein Janssen

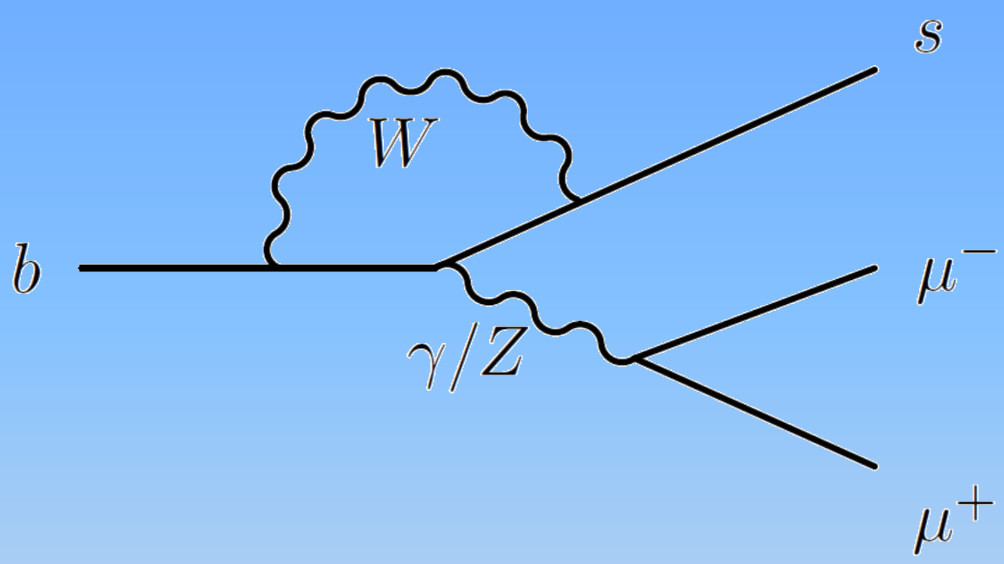

t → W⁺b
BR(t→Wb) =
= 99.82%
but F.C.N.C...
d,s,b
d,s,b
t→Zc
t→Zu
t→γc
t→γu


INTERNATIONAL JOURNAL OF HIGH-ENERGY PHYSICS
CERNCOURIER
VOLUME 55 NUMBER 9 NOVEMBER 2015
Tensions in the Standard Model

LHCb: hot topic



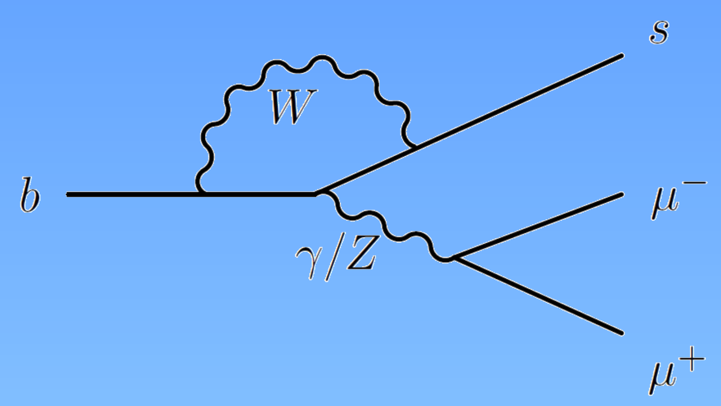
LHCb: hot topic



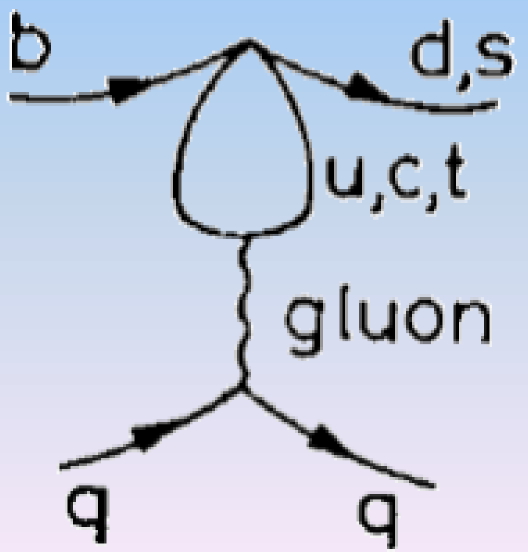
Flavour changing neutral current electroweak penguin

FCNC EWP

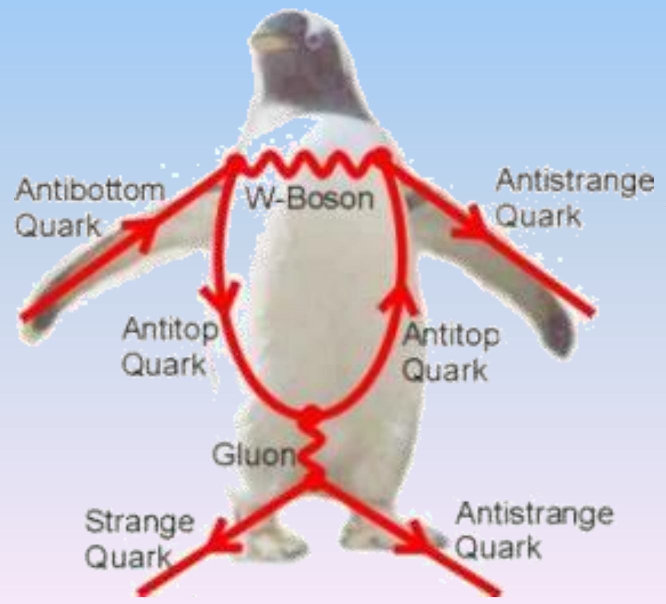
LHCb: hot topic



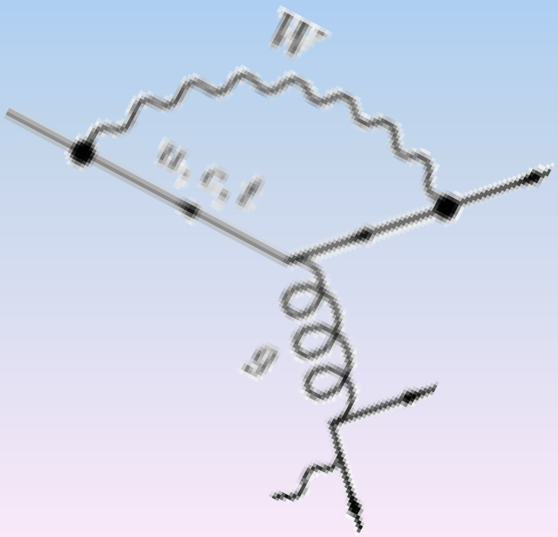
The original penguin:



A real penguin:

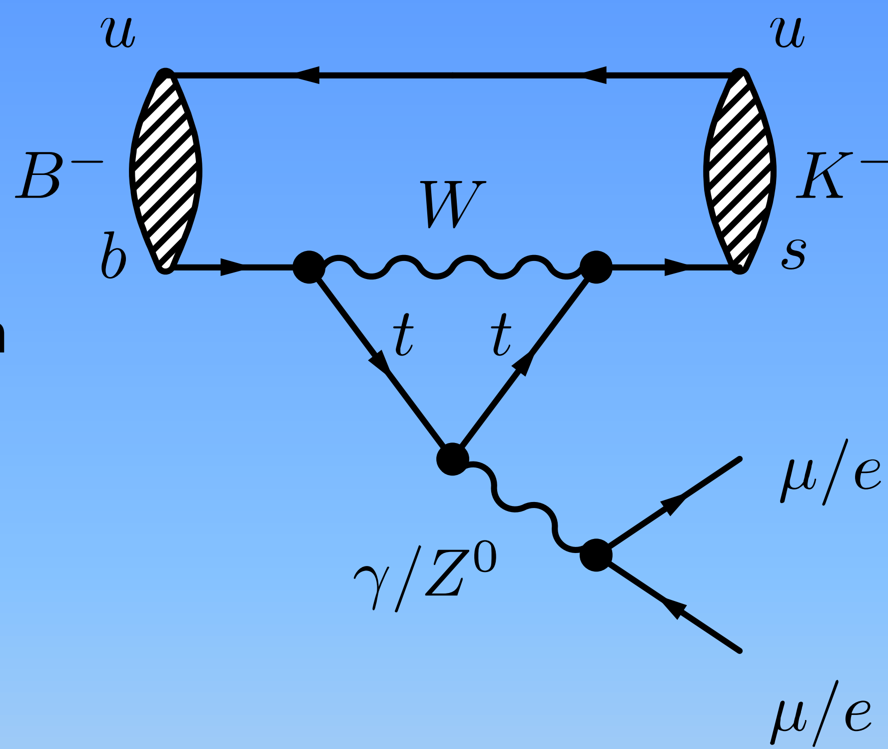


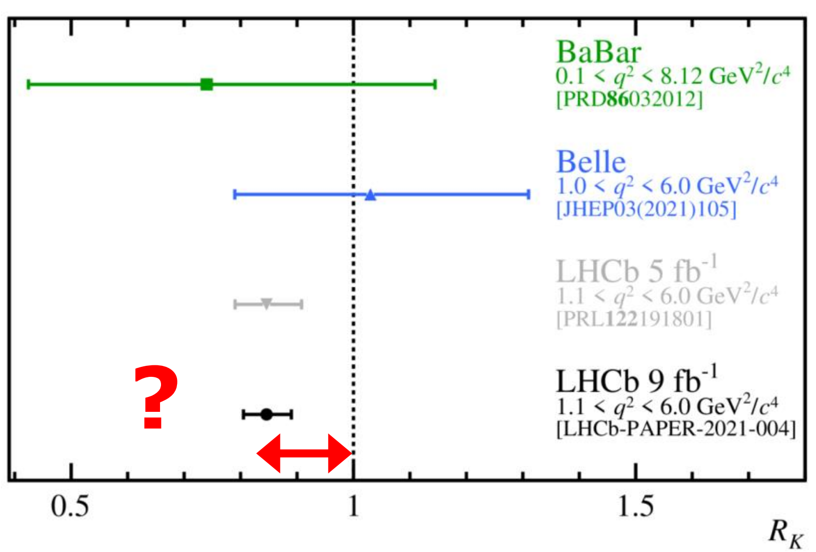
Our penguin:

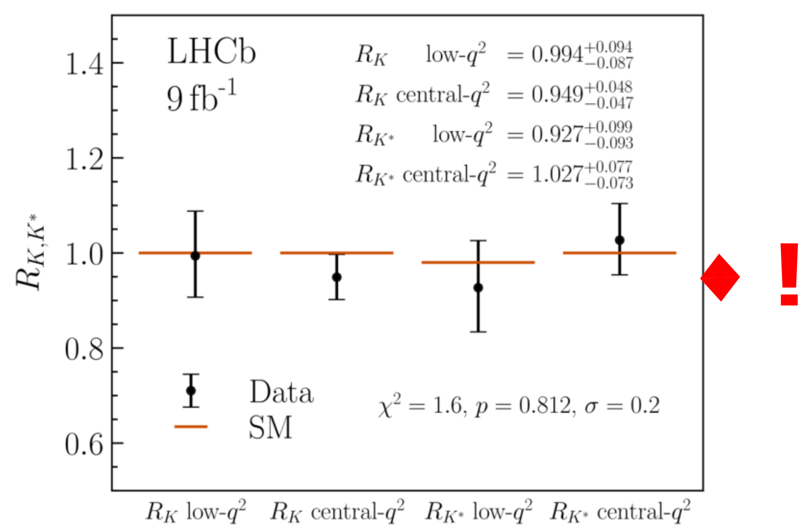


LHCb: hot topic

Electronen en muonen gedragen zich anders?

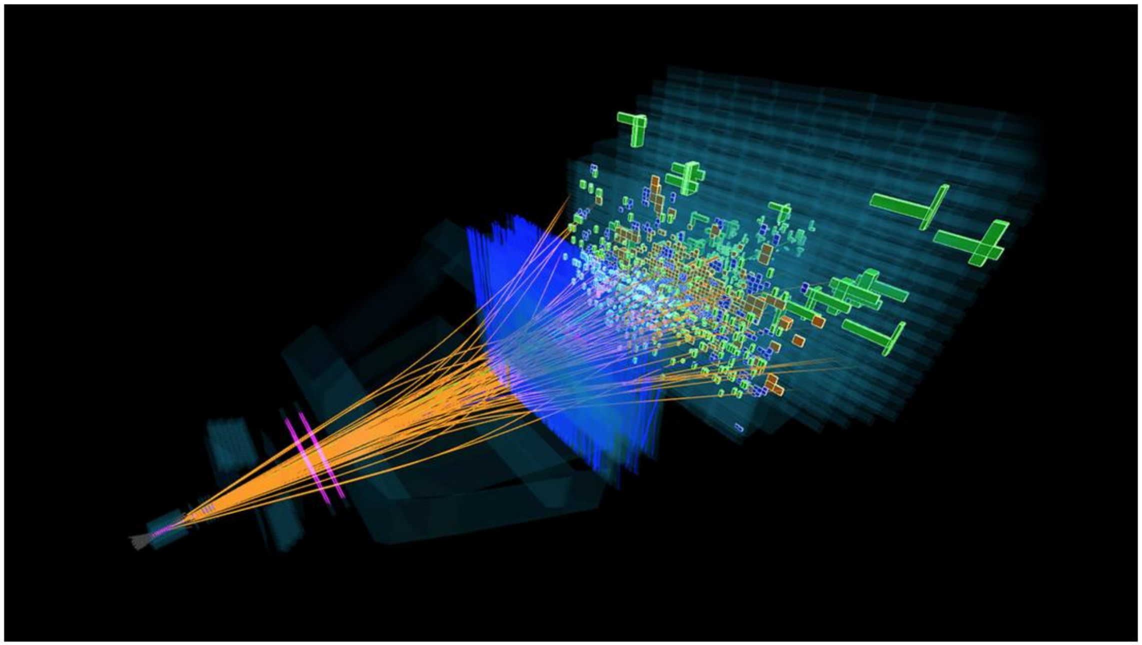






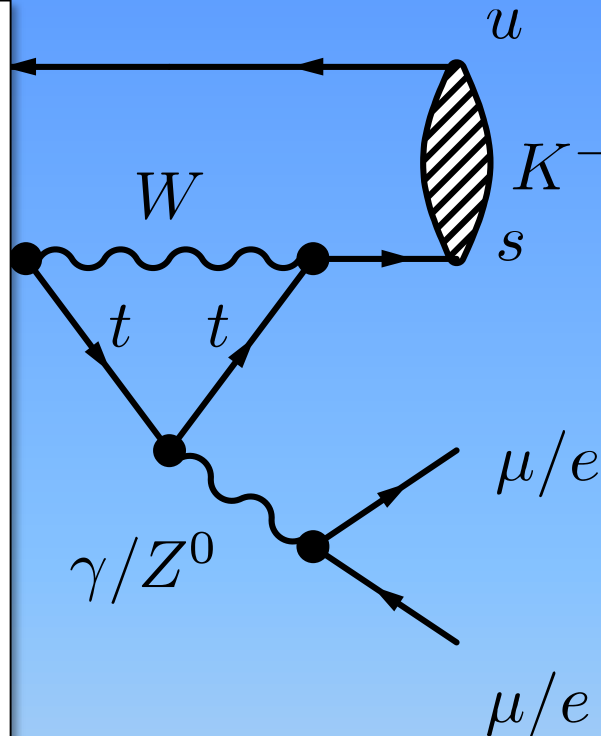
Muon gedraagt zich toch best normaal – of is er meer aan de hand?

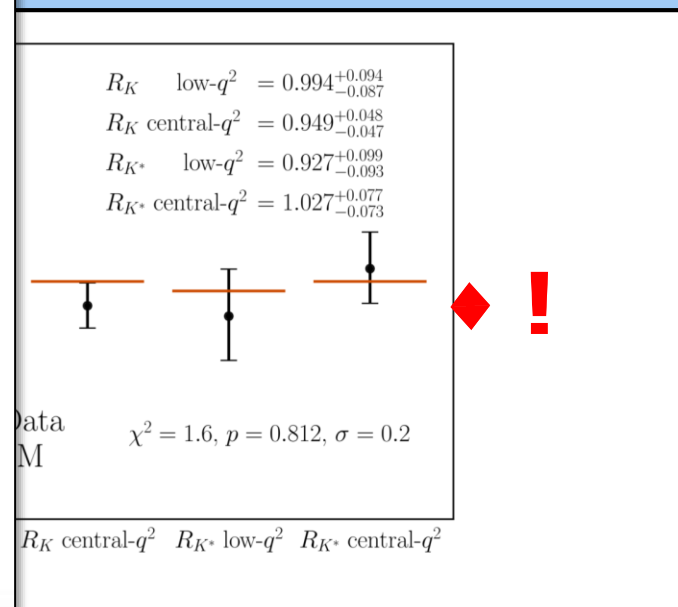
Nieuws Jean-Paul Keulen 29-12-2022 15:00:00 Deel dit artikel:


Vervallend B-deeltje in LHCb. Beeld: LHCb/CERN

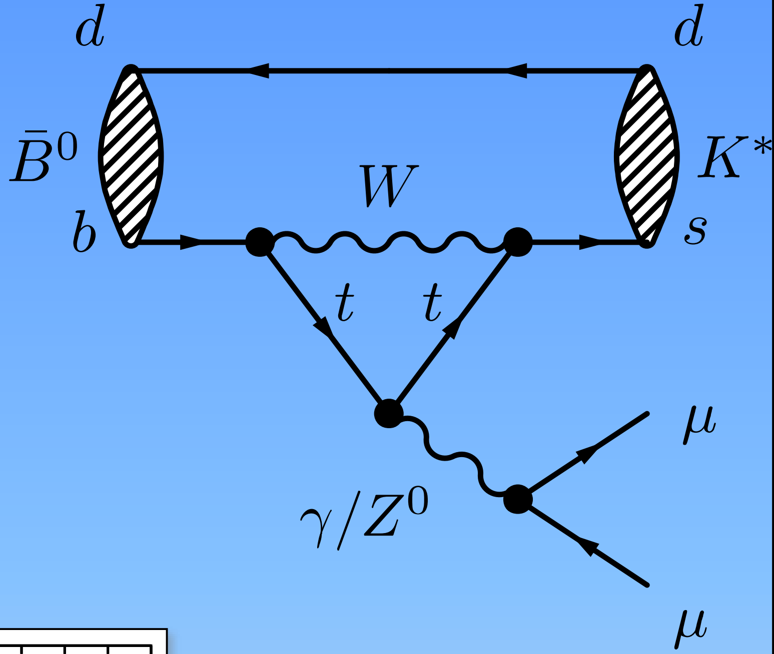
Een verrassend resultaat uit de deeltjesfysica lijkt te zijn afgeserveerd. Toch zijn er nog openstaande vragen.

Het gold als een van de interessantste resultaten binnen de deeltjesfysica sinds de ontdekking van het higgsdeeltje: het feit dat er bij het verval van bepaalde deeltjes **minder vaak muonen ontstaan dan je zou verwachten**. Zou die afwijking van onze huidige deeltjestheorie, blootgelegd met het deeltjesexperiment **LHCb**, wijzen op het bestaan van nieuwe deeltjes of nieuwe natuurkrachten?

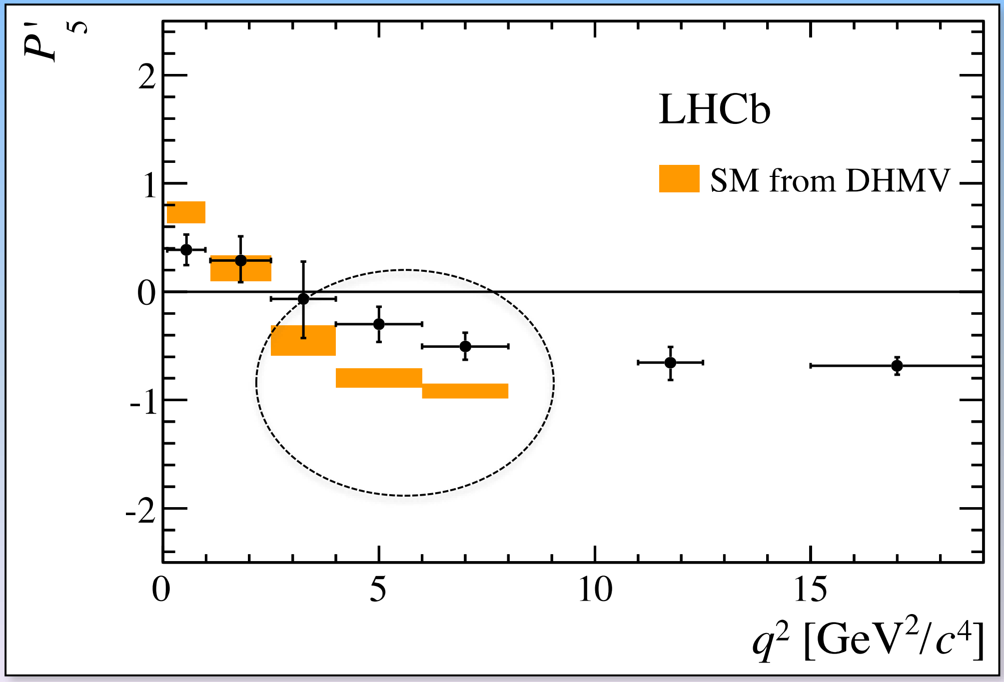




LHCb: hot topic

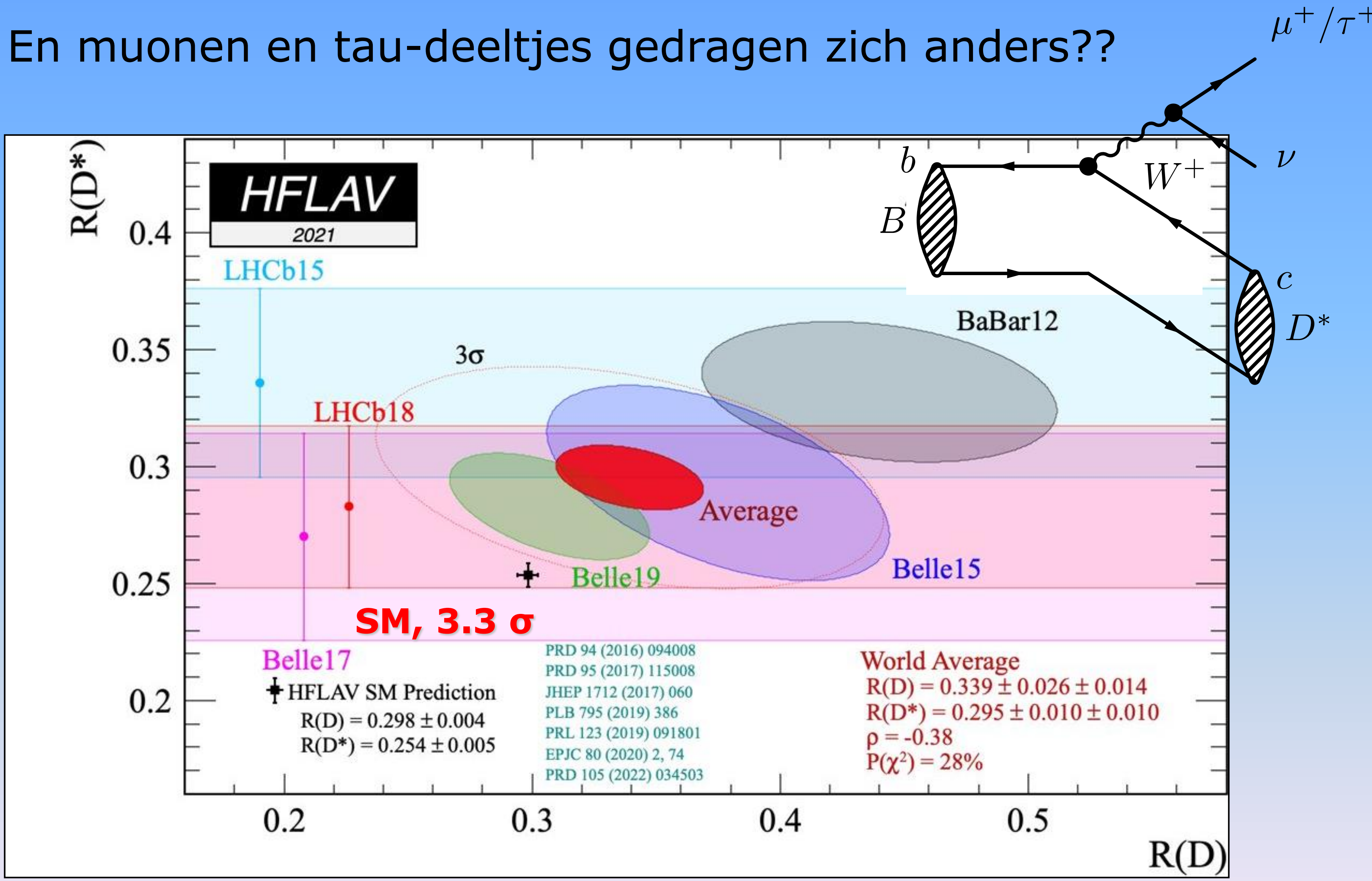


Ook hoekverdeling is anders…



LHCb: hot topic

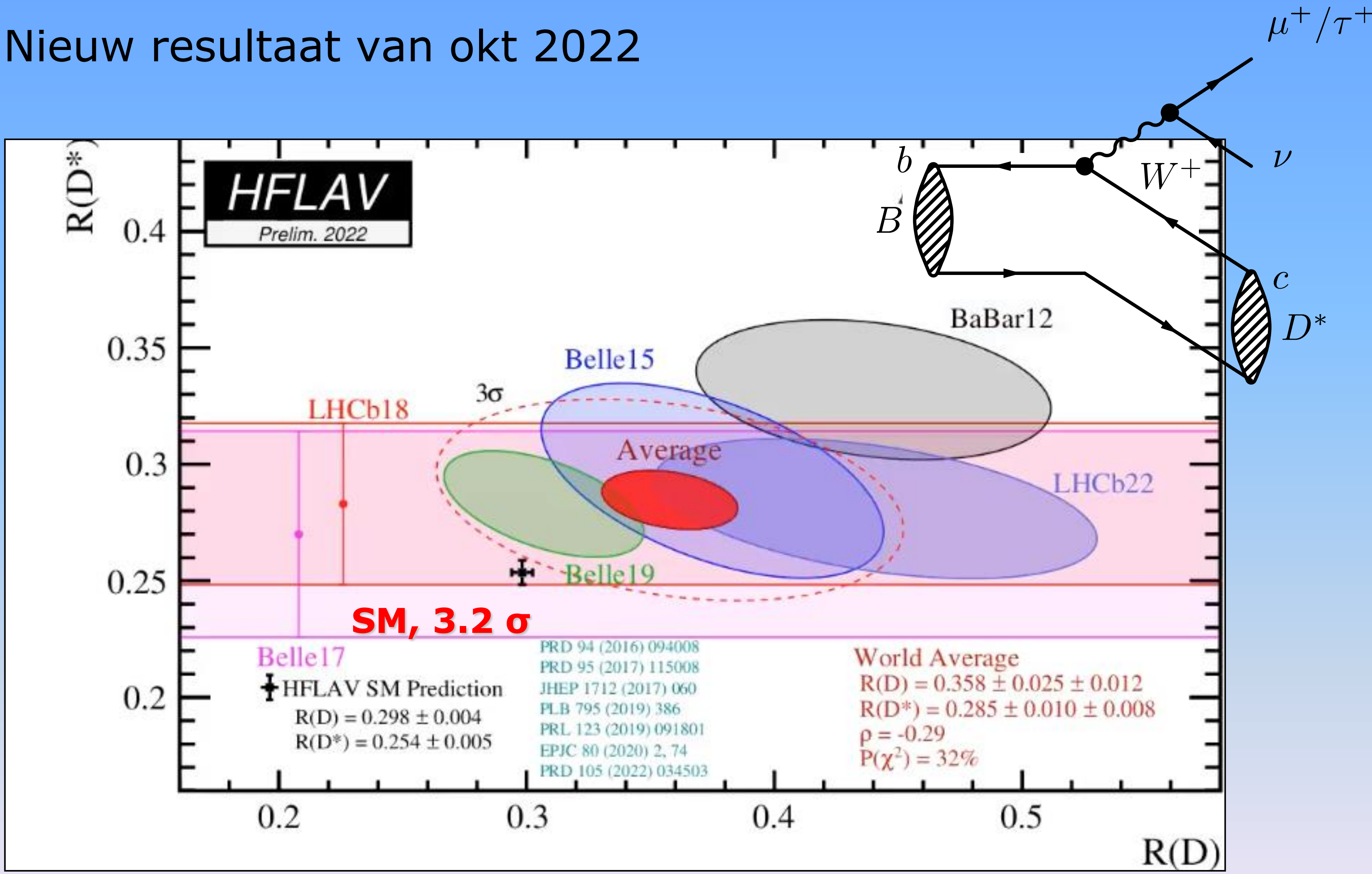
En muonen en tau-deeltjes gedragen zich anders??



NB: contours contain less than 68% CL…

LHCb: hot topic

Nieuw resultaat van okt 2022



LHCb: wat kan het zijn?

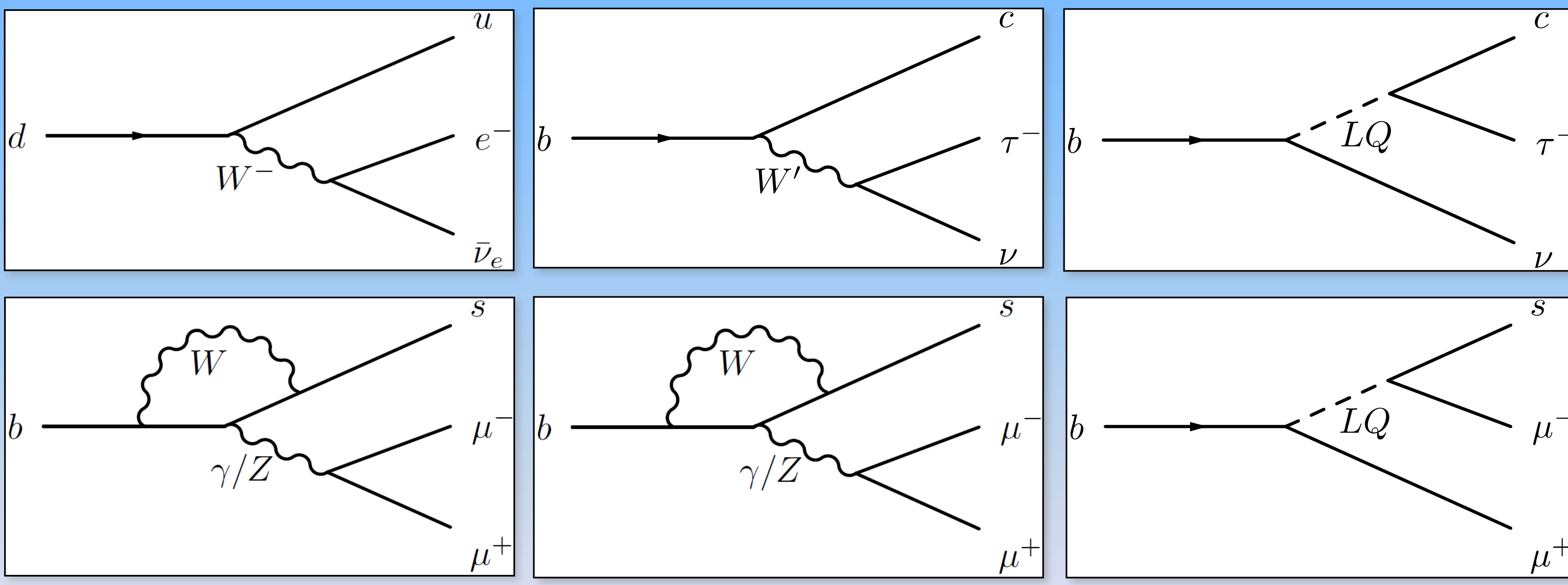
deVolkskrant

Moeder aller deeltjes: de zoektocht naar de leptoquark

Is het fundamenteelste deeltje in het universum altijd over het hoofd gezien? Komende week kan de wereld opgeschud worden, als natuurkundigen in Seoul hun resultaten bekendmaken. Leptoquark, onthoud dat woord.

Martijn van Calmthout 29 juni 2018, 11:25

SM | SU(2)′ | Leptoquark



Leptoquark, onthoud dat woord.

M. Van Calmthout

LHCb zoekt naar nieuwe deeltjes om antwoorden te zoeken op grote vragen

II. Higgs??
(wat maakt deeltjes zwaar)

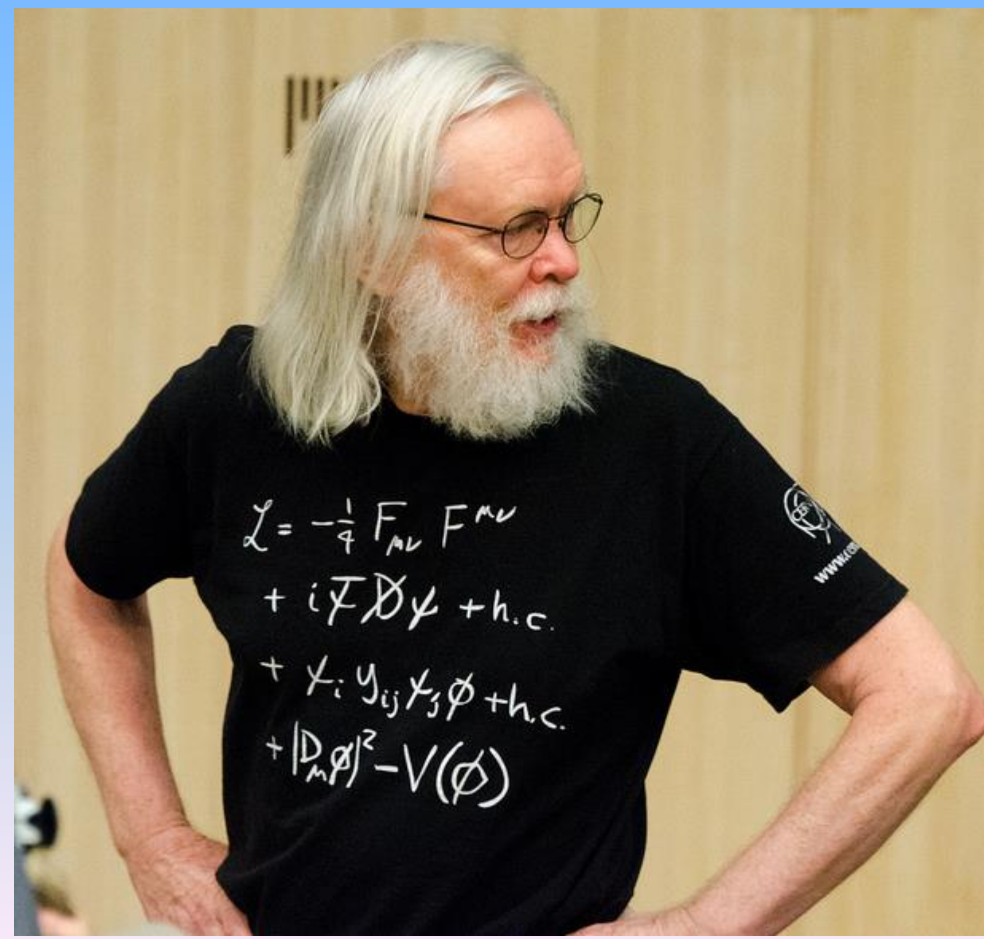
I. Anti-materie??
(waar is het gebleven)

III. Donkere materie??
(wat klonterde de sterrenstelsels)

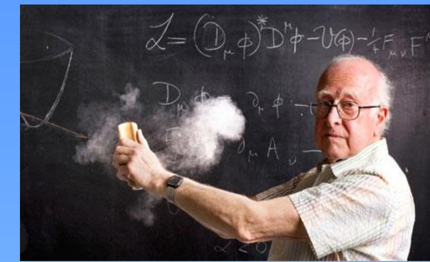
Dank!

Higgs en LHCb

Waarom is de Higgs zo bijzonder?



Waarom is de Higgs zo bijzonder?

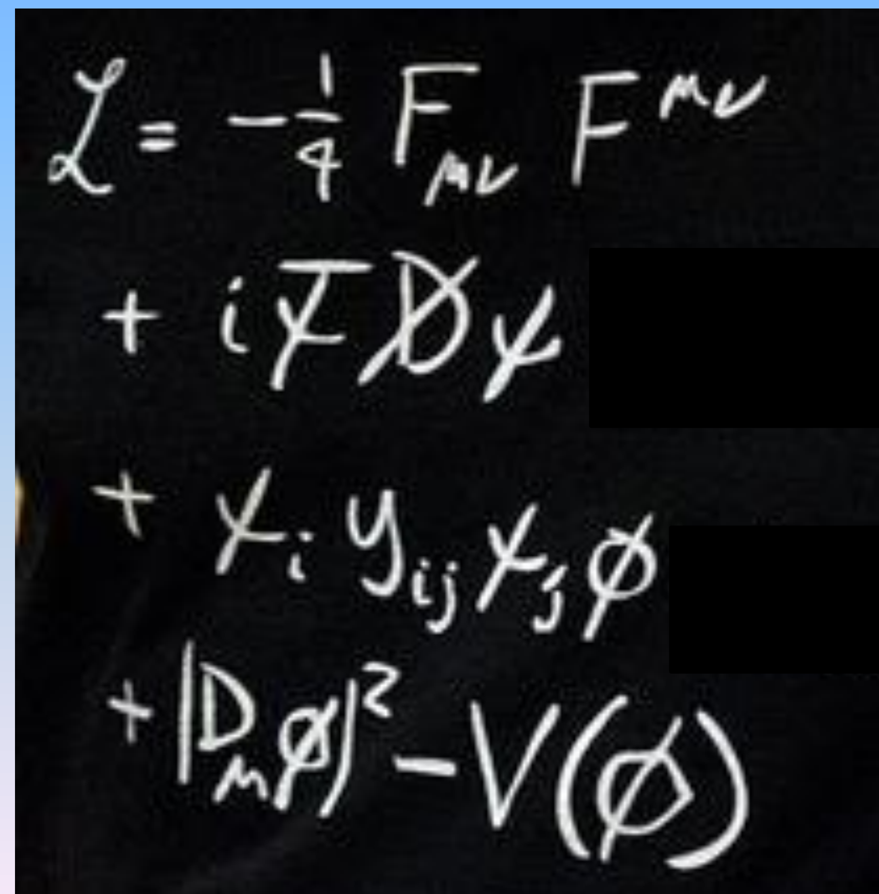


Higgs heeft unieke rol in de wereld van elementaire deeltjes

ψ: "normale" deeltjes

φ: Higgs

De helft van het T-shirt gaat over Higgs!

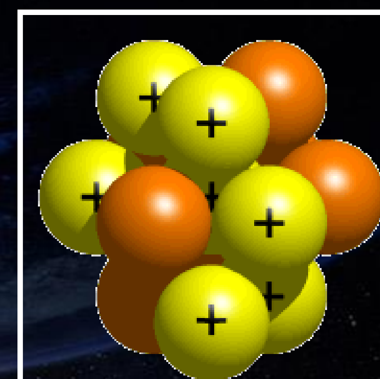


Quarks	u up	c charm	t top
	d down	s strange	b bottom
Leptons	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino
	e electron	μ muon	τ tau

12 deeltjes

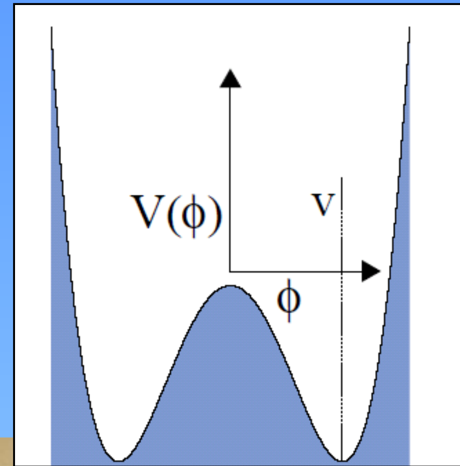
γ photon	Force carriers
Z Z boson	
W W boson	
g gluon	

4 krachten



+ Higgs

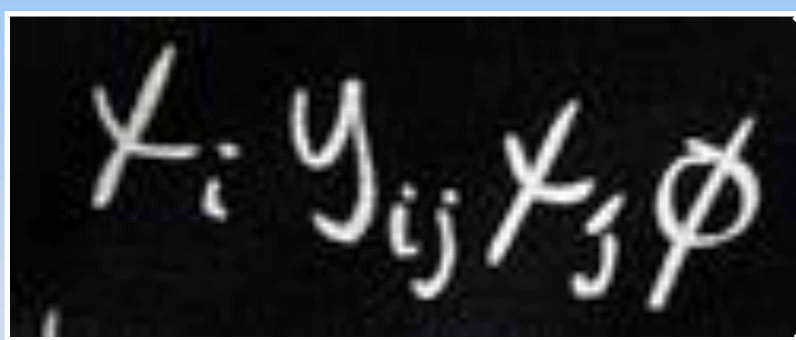
Higgs en LHCb?

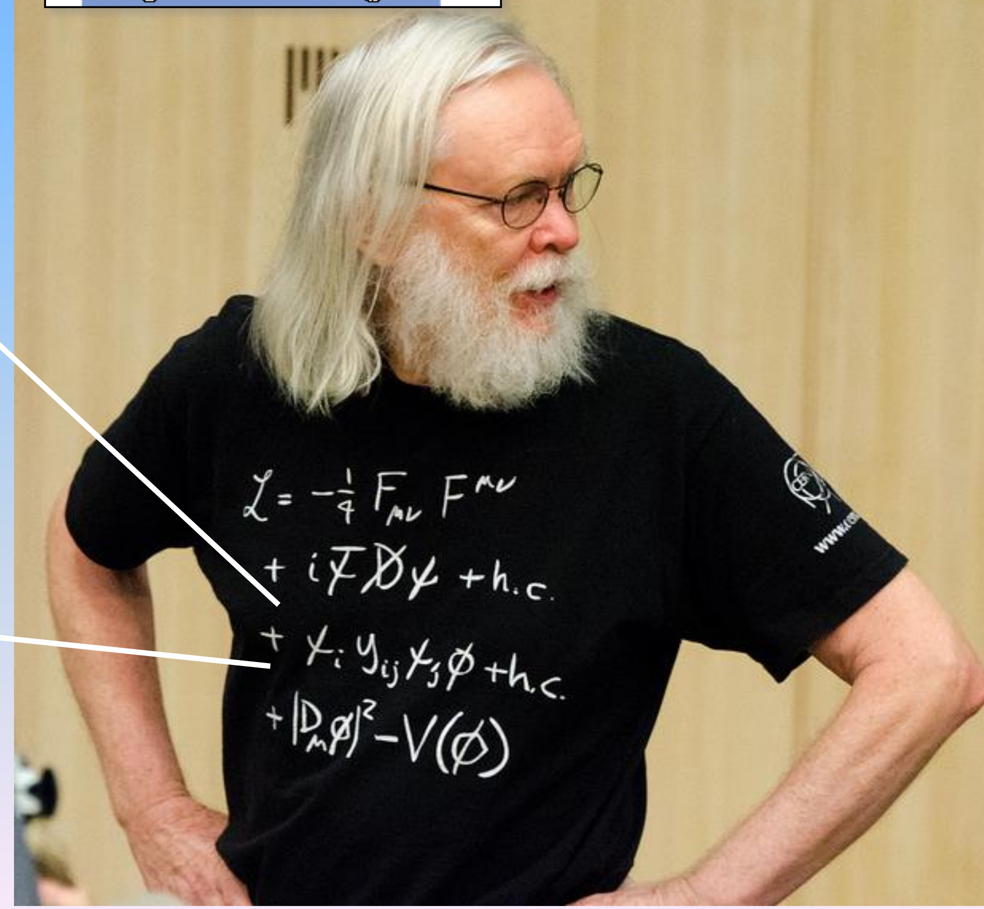


$$\phi = \frac{v+h}{\sqrt{2}} e^{i\chi/v}$$

$$Y_{ij}\psi_i\psi_j f \to \underbrace{Y_{ij}\psi_i\psi_j(v}+H)/\sqrt{2}$$

m: $Y_{ij}v$

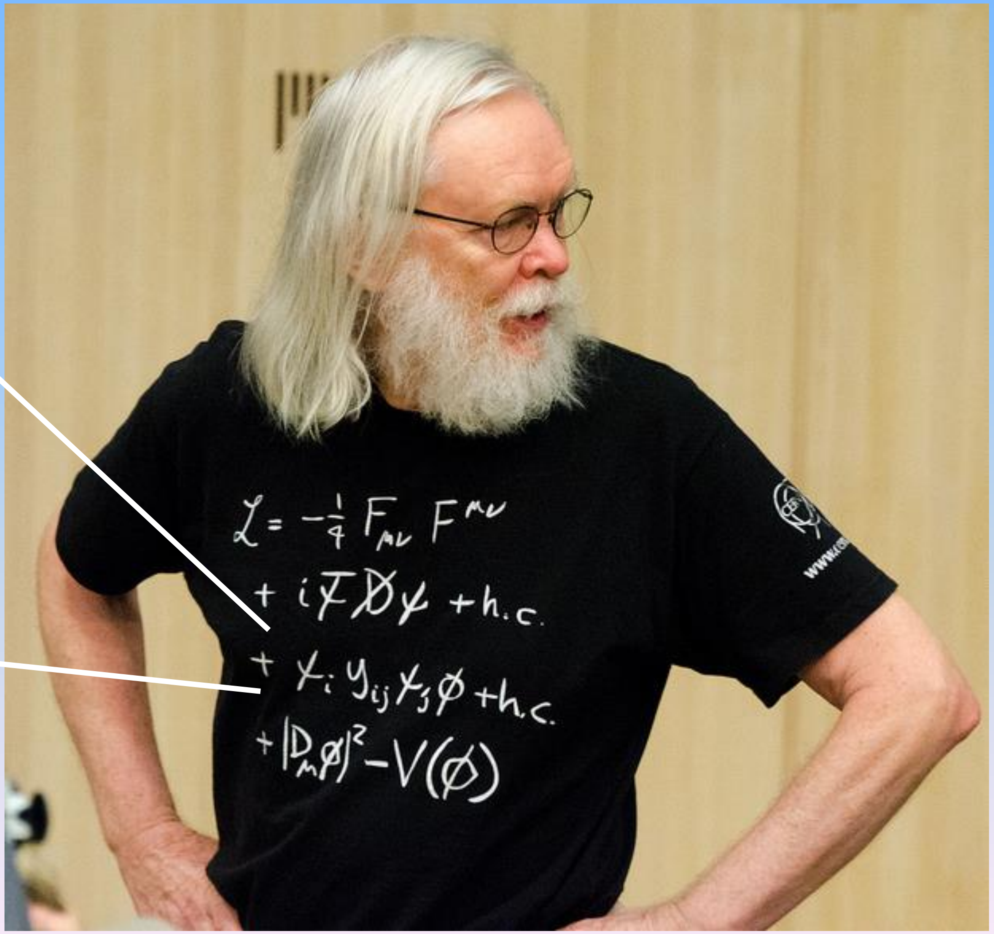




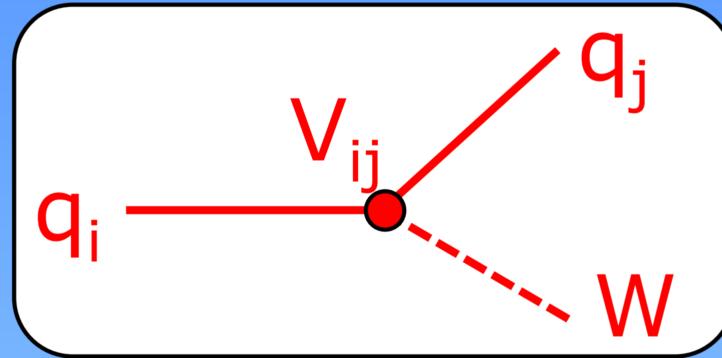
Higgs en LHCb?

ψ: quarks

Y_{ij}: koppeling tussen verschillende quarks i,j

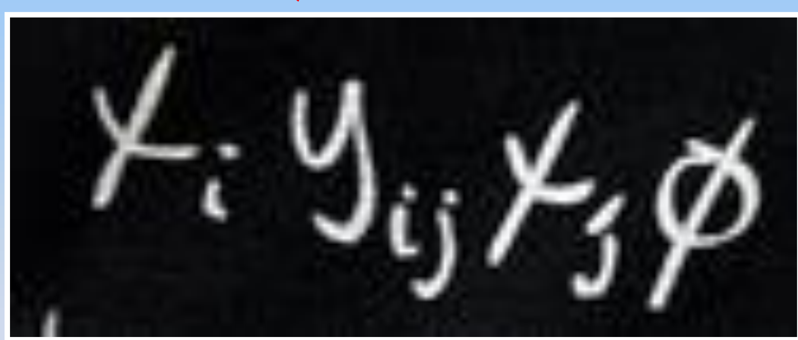


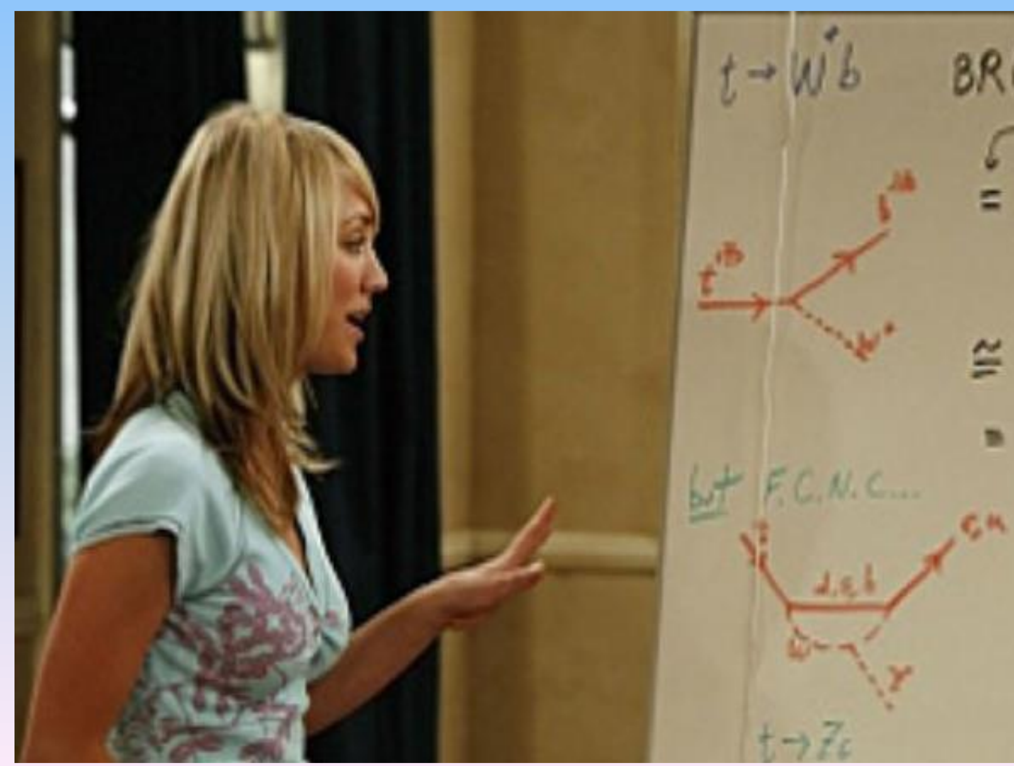
Higgs en LHCb?



ψ: quarks

Y_{ij}: koppeling tussen verschillende quarks i,j

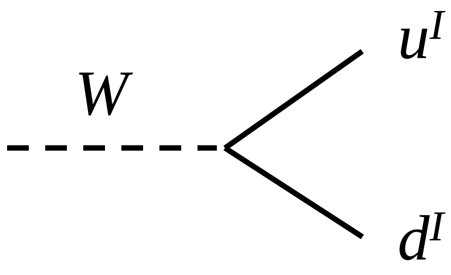




$$\mathcal{L}_{SM} = \mathcal{L}_{Kinetic} + \mathcal{L}_{Higgs} + \mathcal{L}_{Yukawa}$$

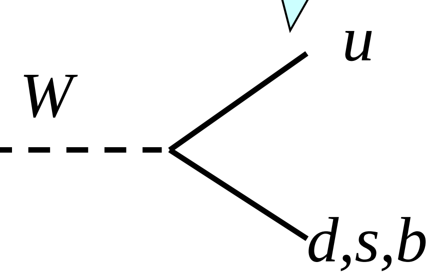
$$-\mathcal{L}_{Yuk} = Y_{ij}^{d} \, (\overline{u_L^I}, \overline{d_L^I})_i \begin{pmatrix} \varphi^+ \\ \varphi^0 \end{pmatrix} d_{Rj}^{I} + \ldots$$

$$\mathcal{L}_{Kinetic} = \frac{g}{\sqrt{2}} \overline{u_{Li}^I} \gamma^\mu W_\mu^- d_{Li}^I + \frac{g}{\sqrt{2}} \overline{d_{Li}^I} \gamma^\mu W_\mu^+ u_{Li}^I + \ldots$$



- Diagonalize Yukawa matrix Y_{ij}
  - Mass terms
  - Quarks rotate
  - Off diagonal terms in charged current couplings

$$\begin{pmatrix} d^I \\ s^I \\ b^I \end{pmatrix} \to V_{CKM} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$



$$-\mathcal{L}_{Mass} = (\overline{d}, \overline{s}, \overline{b})_L \begin{pmatrix} m_d & & \\ & m_s & \\ & & m_b \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}_R + (\overline{u}, \overline{c}, \overline{t})_L \begin{pmatrix} m_u & & \\ & m_c & \\ & & m_t \end{pmatrix} \begin{pmatrix} u \\ c \\ t \end{pmatrix}_R + \ldots$$

$$\mathcal{L}_{CKM} = \frac{g}{\sqrt{2}} \overline{u}_i \gamma^\mu W_\mu^- V_{ij} \left(1 - \gamma^5\right) d_j + \frac{g}{\sqrt{2}} \overline{d}_j \gamma^\mu W_\mu^+ V_{ij}^* \left(1 - \gamma^5\right) u_i + \ldots$$

$$\mathcal{L}_{SM} = \mathcal{L}_{CKM} + \mathcal{L}_{Higgs} + \mathcal{L}_{Mass}$$

What do we know about the CKM matrix?

Magnitudes of elements have been measured over time

– Result of a *large* number of measurements and calculations

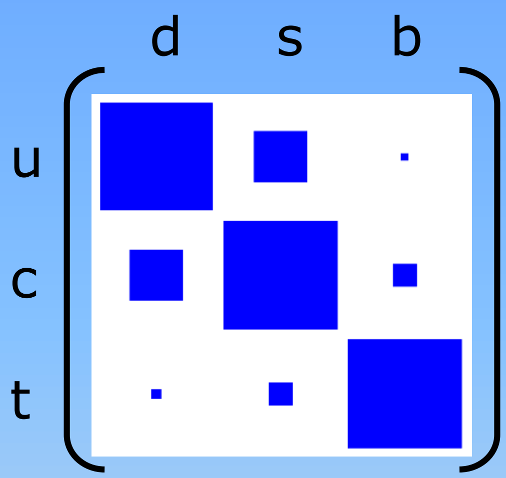
$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

$$\begin{pmatrix} |V_{ud}| & |V_{us}| & |V_{ub}| \\ |V_{cd}| & |V_{cs}| & |V_{cb}| \\ |V_{td}| & |V_{ts}| & |V_{tb}| \end{pmatrix} = \begin{pmatrix} 0.97419 & 0.2257 & 0.00359 \\ 0.2256 & 0.97334 & 0.0415 \\ 0.00874 & 0.0407 & 0.999133 \end{pmatrix} \pm \begin{pmatrix} 0.00022 & 0.0010 & 0.00016 \\ 0.0010 & 0.00023 & 0.0011 \\ 0.00037 & 0.0010 & 0.000044 \end{pmatrix}$$

•***Magnitude* of elements shown only, no information of phase**

Higgs en LHCb?

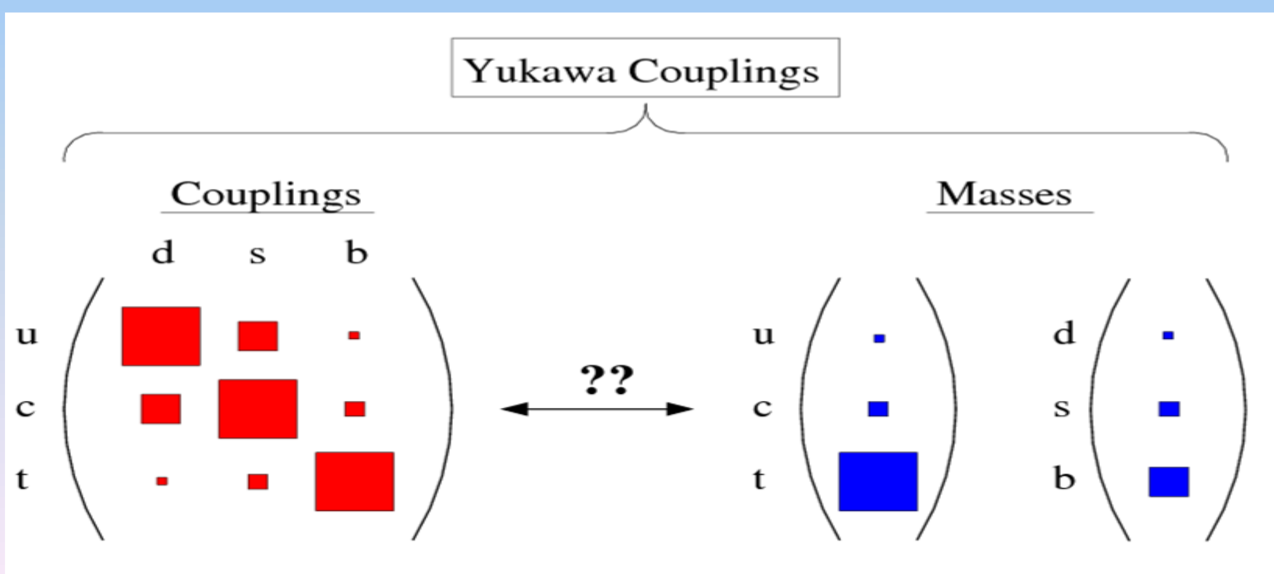
Quark koppelingen:



Waarom dit patroon in quark koppelingen?

Waarom dit patroon in quark massa's?

→ **Is er een verband?**



Intermezzo: How about the leptons?

the equivalent of the CKM matrix

- *Pontecorvo-Maki-Nakagawa-Sakata matrix*

$$\begin{bmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{bmatrix} = \begin{bmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{bmatrix} \begin{bmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{bmatrix}$$

• ***vs***

$$\begin{bmatrix} |d'\rangle \\ |s'\rangle \\ |b'\rangle \end{bmatrix} = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix} \begin{bmatrix} |d\rangle \\ |s\rangle \\ |b\rangle \end{bmatrix}.$$

a completely different hierarchy!

$$U_{MNSP} \approx \begin{pmatrix} 0.85 & 0.53 & 0 \\ -0.37 & 0.60 & 0.71 \\ -0.37 & 0.60 & -0.71 \end{pmatrix}$$

$$V_{CKM} = \begin{pmatrix} 0.97428 & 0.2253 & 0.00347 \\ 0.2252 & 0.97345 & 0.0410 \\ 0.00862 & 0.0403 & 0.999152 \end{pmatrix}$$

Intermezzo: How about the leptons?

- the equivalent of the CKM matrix
  - *Pontecorvo-Maki-Nakagawa-Sakata matrix*

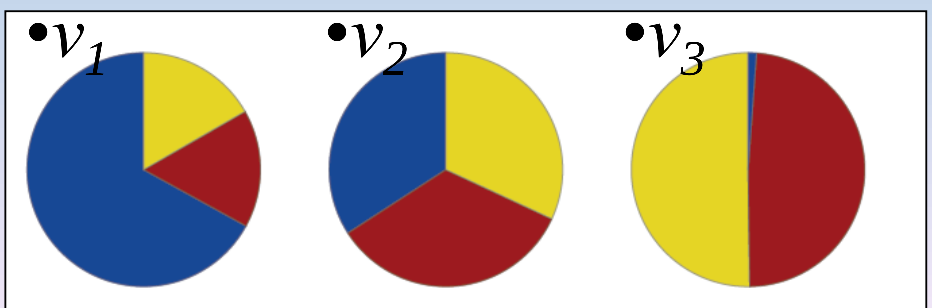
$$\begin{bmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{bmatrix} = \begin{bmatrix}U_{e1} & U_{e2} & U_{e3}\\ U_{\mu1} & U_{\mu2} & U_{\mu3}\\ U_{\tau1} & U_{\tau2} & U_{\tau3}\end{bmatrix}\begin{bmatrix}\nu_1\\ \nu_2\\ \nu_3\end{bmatrix}$$

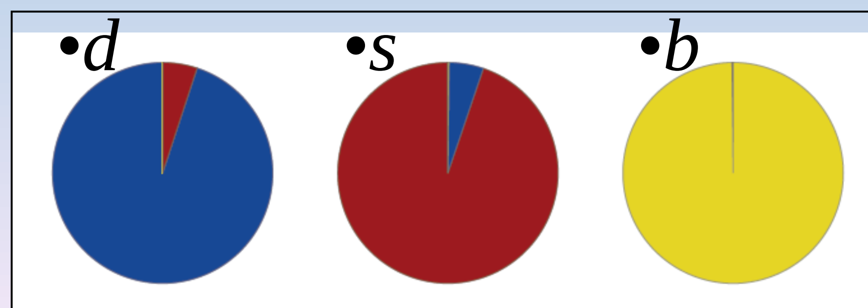
•vs

$$\begin{bmatrix}|d'\rangle\\ |s'\rangle\\ |b'\rangle\end{bmatrix} = \begin{bmatrix}V_{ud} & V_{us} & V_{ub}\\ V_{cd} & V_{cs} & V_{cb}\\ V_{td} & V_{ts} & V_{tb}\end{bmatrix}\begin{bmatrix}|d\rangle\\ |s\rangle\\ |b\rangle\end{bmatrix}.$$

- a completely different hi

$$\begin{pmatrix}|U_{e1}|^2 & |U_{e2}|^2 & |U_{e3}|^2\\ |U_{\mu1}|^2 & |U_{\mu2}|^2 & |U_{\mu3}|^2\\ |U_{\tau1}|^2 & |U_{\tau2}|^2 & |U_{\tau3}|^2\end{pmatrix} \approx \begin{pmatrix}\frac{2}{3} & \frac{1}{3} & 0\\ \frac{1}{6} & \frac{1}{3} & \frac{1}{2}\\ \frac{1}{6} & \frac{1}{3} & \frac{1}{2}\end{pmatrix}$$





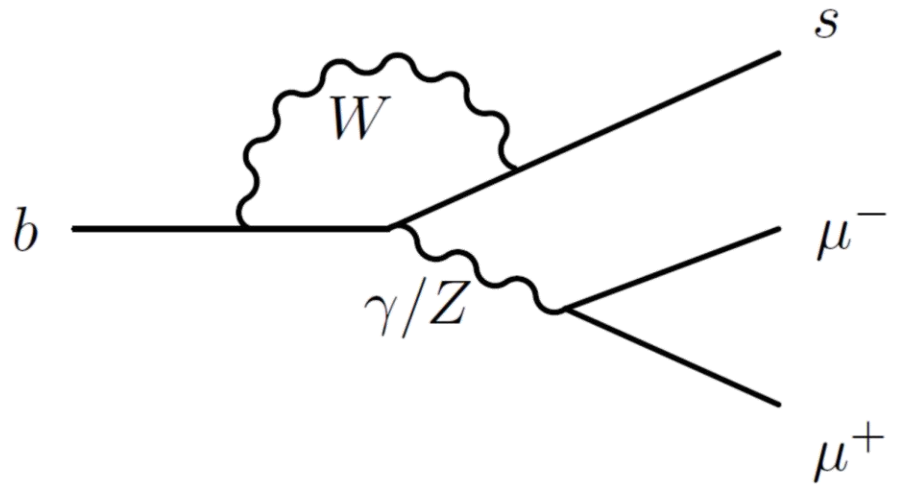
•See eg. PhD thesis R. de Adelhart Toorop

Take home message

1) LHCb zoekt verschillen tussen materie en antimaterie

2) LHCb kan zeer zware deeltjes vinden (maar alleen *virtueel*)

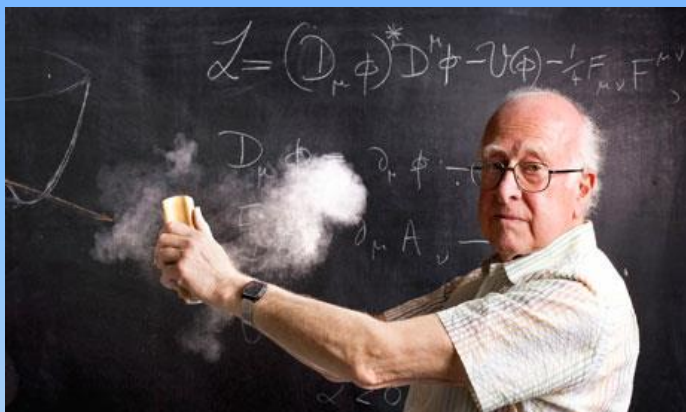
3) Nieuwe deeltjes helpen om grote vragen te beantwoorden

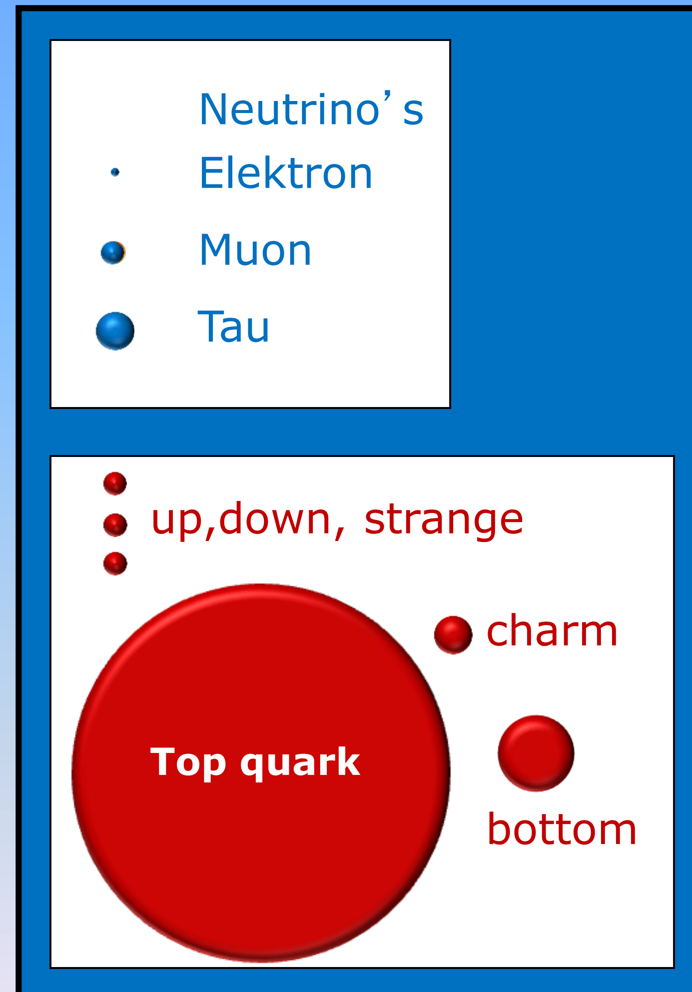


Einde

Wat snappen we nog niet?

Massa van deeltjes





Bijzondere voorspelling:

Het Higgs boson:
zorgt ervoor dat deeltjes massa kunnen hebben in de theorie

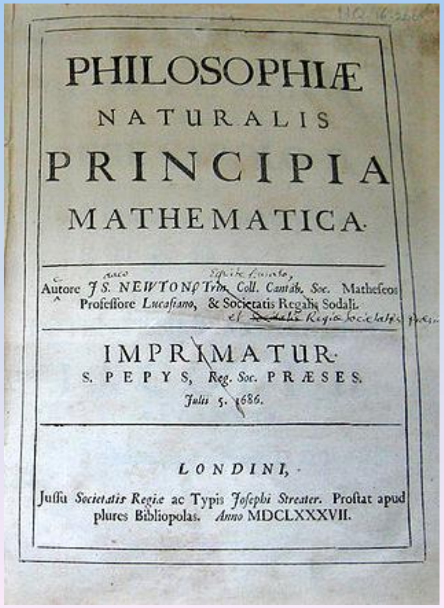
Wat is massa ?? Anno 1687

Massa is de ‘wisselkoers’ tussen kracht en versnelling:

Newton

$$\mathbf{F = m \times a}$$

Beschrijft niet wat massa **is** ...



PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

Autore J S. NEWTON, Trin. Coll. Cantab. Soc. Matheseos Professore Lucasiano, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, Reg. Soc. PRÆSES.
Julii 5. 1686.

LONDINI,
Jussu Societatis Regiæ ac Typis Josephi Streater. Prostat apud plures Bibliopolas. Anno MDCLXXXVII.

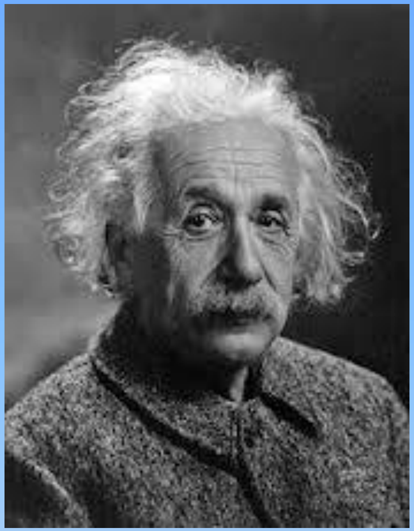
Wat is massa ?? Anno 1905

Massa is energie

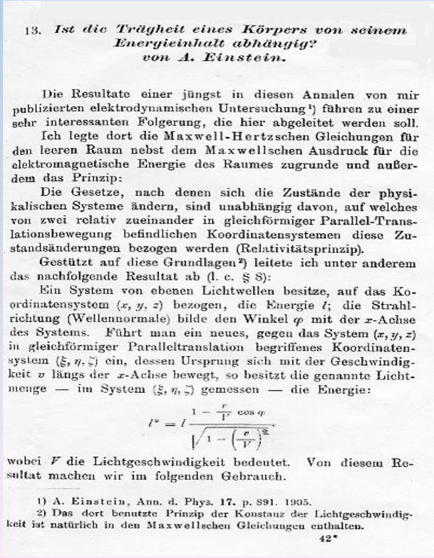
$$E = m \times c^2$$

Beschrijft wel wat massa ***is*** !

Maar niet waar het vandaan komt …



Einstein



13. ***Ist die Trägheit eines Körpers von seinem Energieinhalt abhängig?***
von A. Einstein.

Die Resultate einer jüngst in diesen Annalen von mir publizierten elektrodynamischen Untersuchung[1]) führen zu einer sehr interessanten Folgerung, die hier abgeleitet werden soll.

Ich legte dort die Maxwell-Hertzschen Gleichungen für den leeren Raum nebst dem Maxwellschen Ausdruck für die elektromagnetische Energie des Raumes zugrunde und außerdem das Prinzip:

Die Gesetze, nach denen sich die Zustände der physikalischen Systeme ändern, sind unabhängig davon, auf welches von zwei relativ zueinander in gleichförmiger Parallel-Translationsbewegung befindlichen Koordinatensystemen diese Zustandsänderungen bezogen werden (Relativitätsprinzip).

Gestützt auf diese Grundlagen[2]) leitete ich unter anderem das nachfolgende Resultat ab (l. c. § 8):

Ein System von ebenen Lichtwellen besitze, auf das Koordinatensystem (x, y, z) bezogen, die Energie l; die Strahlrichtung (Wellennormale) bilde den Winkel φ mit der x-Achse des Systems. Führt man ein neues, gegen das System (x, y, z) in gleichförmiger Paralleltranslation begriffenes Koordinatensystem (ξ, η, ζ) ein, dessen Ursprung sich mit der Geschwindigkeit v längs der x-Achse bewegt, so besitzt die genannte Lichtmenge — im System (ξ, η, ζ) gemessen — die Energie:

$$l^* = l \frac{1 - \frac{v}{V} \cos \varphi}{\sqrt{1 - \left(\frac{v}{V}\right)^2}},$$

wobei V die Lichtgeschwindigkeit bedeutet. Von diesem Resultat machen wir im folgenden Gebrauch.

1) A. Einstein, Ann. d. Phys. 17. p. 891. 1905.

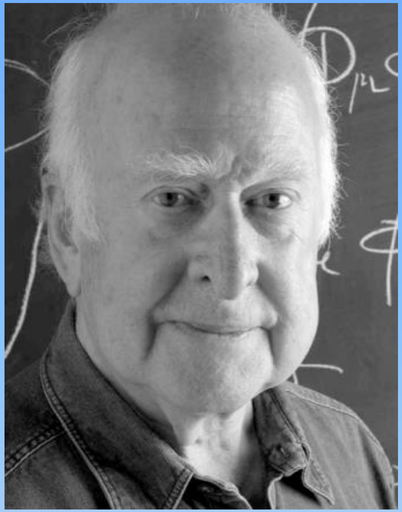
2) Das dort benutzte Prinzip der Konstanz der Lichtgeschwindigkeit ist natürlich in den Maxwellschen Gleichungen enthalten.

Wat is massa ?? Anno 1964

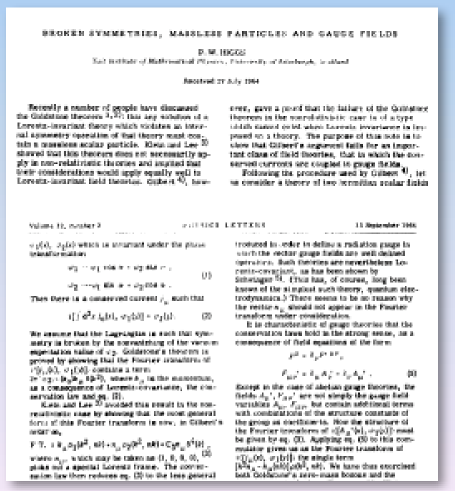
Massa van elementaire deeltjes komt door

"wrijving" met alomtegenwoordig 'Higgs veld'

m: ψψH



Higgs



BROKEN SYMMETRIES, MASSLESS PARTICLES AND GAUGE FIELDS

P. W. HIGGS

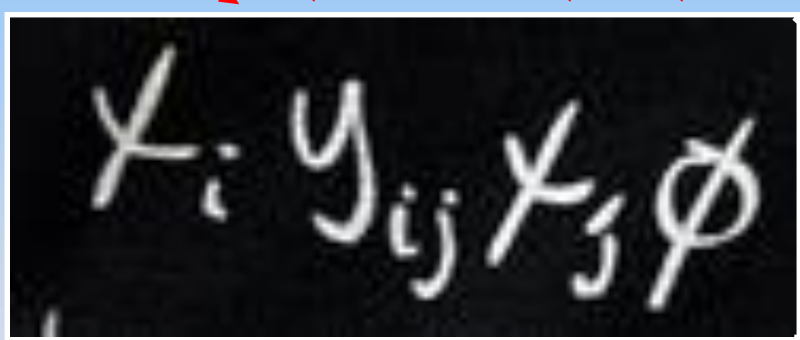
Huh?

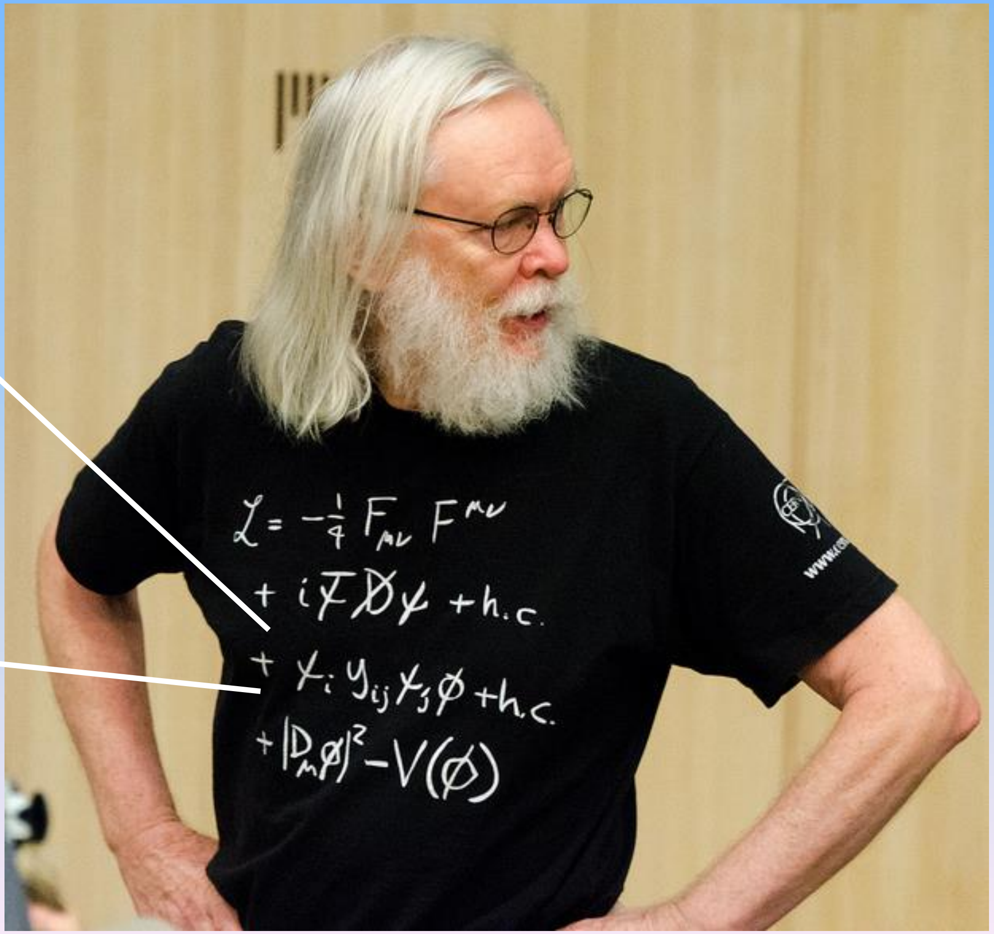
Wat is massa ?? Anno 1964

Massa van elementaire deeltjes komt door

“wrijving” met alomtegenwoordig ‘Higgs veld’

m: ψψH





Nee, dit is niet Pierre, dit is John Ellis

Modelleren van interactie

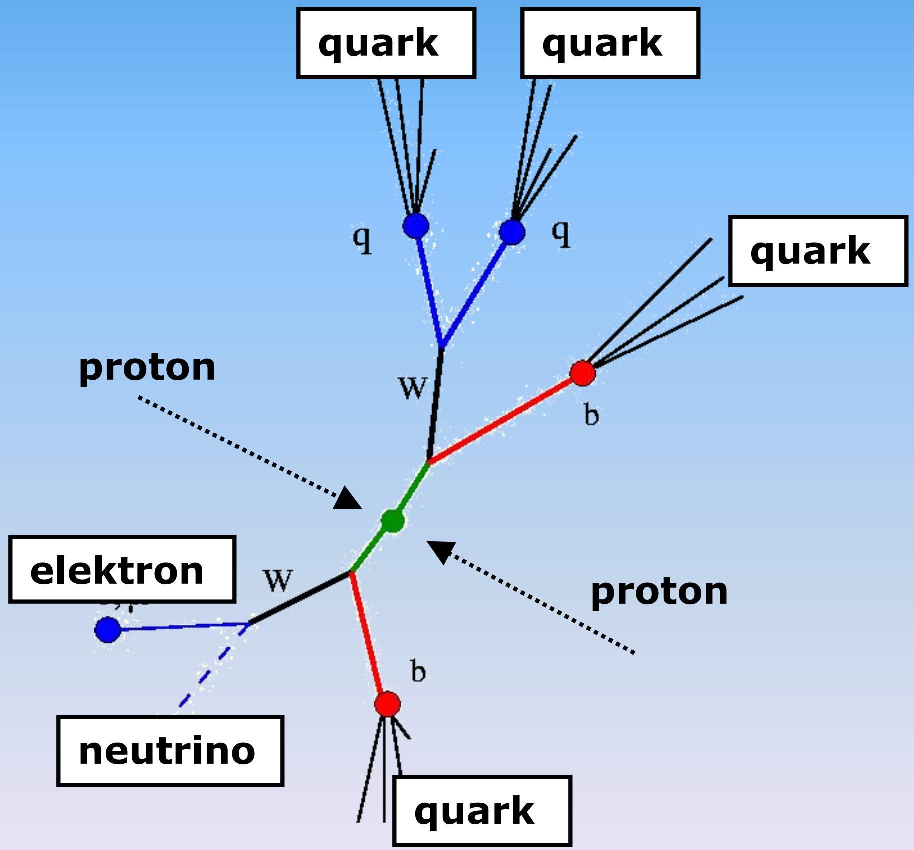
Standaard Model Lagrangiaan

$$
\begin{aligned}
&-\tfrac{1}{2}\partial_\nu g^a_\mu \partial_\nu g^a_\mu - g_s f^{abc}\partial_\mu g^a_\nu g^b_\mu g^c_\nu - \tfrac{1}{4}g_s^2 f^{abc}f^{ade}g^b_\mu g^c_\nu g^d_\mu g^e_\nu + \tfrac{1}{2}ig_s^2(\bar{q}^\sigma_i\gamma^\mu q^\sigma_j)g^a_\mu + \\
&\bar{G}^a\partial^2G^a + g_s f^{abc}\partial_\mu\bar{G}^aG^bg^c_\mu - \partial_\nu W^+_\mu\partial_\nu W^-_\mu - M^2W^+_\mu W^-_\mu - \tfrac{1}{2}\partial_\nu Z^0_\mu\partial_\nu Z^0_\mu - \tfrac{1}{2c_w^2}M^2Z^0_\mu Z^0_\mu - \\
&\tfrac{1}{2}\partial_\mu A_\nu\partial_\mu A_\nu - \tfrac{1}{2}\partial_\mu H\partial_\mu H - \tfrac{1}{2}m_h^2H^2 - \partial_\mu\phi^+\partial_\mu\phi^- - M^2\phi^+\phi^- - \tfrac{1}{2}\partial_\mu\phi^0\partial_\mu\phi^0 - \\
&\tfrac{1}{2c_w^2}M\phi^0\phi^0 - \beta_h[\tfrac{2M^2}{g^2} + \tfrac{2M}{g}H + \tfrac{1}{2}(H^2+\phi^0\phi^0+2\phi^+\phi^-)] + \tfrac{2M^4}{g^2}\alpha_h - igc_w[\partial_\nu Z^0_\mu(W^+_\mu W^-_\nu - \\
&W^+_\nu W^-_\mu) - Z^0_\nu(W^+_\mu\partial_\nu W^-_\mu - W^-_\mu\partial_\nu W^+_\mu) + Z^0_\mu(W^+_\nu\partial_\nu W^-_\mu - W^-_\nu\partial_\nu W^+_\mu)] - igs_w[\partial_\nu A_\mu(W^+_\mu W^-_\nu - \\
&W^+_\nu W^-_\mu) - A_\nu(W^+_\mu\partial_\nu W^-_\mu - W^-_\mu\partial_\nu W^+_\mu) + A_\mu(W^+_\nu\partial_\nu W^-_\mu - W^-_\nu\partial_\nu W^+_\mu)] - \tfrac{1}{2}g^2W^+_\mu W^-_\mu W^+_\nu W^-_\nu + \\
&\tfrac{1}{2}g^2W^+_\mu W^-_\nu W^+_\mu W^-_\nu + g^2c_w^2(Z^0_\mu W^+_\mu Z^0_\nu W^-_\nu - Z^0_\mu Z^0_\mu W^+_\nu W^-_\nu) + g^2s_w^2(A_\mu W^+_\mu A_\nu W^-_\nu - \\
&A_\mu A_\mu W^+_\nu W^-_\nu) + g^2s_wc_w[A_\mu Z^0_\nu(W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - 2A_\mu Z^0_\mu W^+_\nu W^-_\nu] - g\alpha[H^3 + \\
&H\phi^0\phi^0 + 2H\phi^+\phi^-] - \tfrac{1}{8}g^2\alpha_h[H^4 + (\phi^0)^4 + 4(\phi^+\phi^-)^2 + 4(\phi^0)^2\phi^+\phi^- + 4H^2\phi^+\phi^- + \\
&2(\phi^0)^2H^2] - gMW^+_\mu W^-_\mu H - \tfrac{1}{2}g\tfrac{M}{c_w^2}Z^0_\mu Z^0_\mu H - \tfrac{1}{2}ig[W^+_\mu(\phi^0\partial_\mu\phi^- - \phi^-\partial_\mu\phi^0) - W^-_\mu(\phi^0\partial_\mu\phi^+ - \\
&\phi^+\partial_\mu\phi^0)] + \tfrac{1}{2}g[W^+_\mu(H\partial_\mu\phi^- - \phi^-\partial_\mu H) - W^-_\mu(H\partial_\mu\phi^+ - \phi^+\partial_\mu H)] + \tfrac{1}{2}g\tfrac{1}{c_w}(Z^0_\mu(H\partial_\mu\phi^0 - \\
&\phi^0\partial_\mu H) - ig\tfrac{s_w^2}{c_w}MZ^0_\mu(W^+_\mu\phi^- - W^-_\mu\phi^+) + igs_wMA_\mu(W^+_\mu\phi^- - W^-_\mu\phi^+) - ig\tfrac{1-2c_w^2}{2c_w}Z^0_\mu(\phi^+\partial_\mu\phi^- - \\
&\phi^-\partial_\mu\phi^+) + igs_wA_\mu(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) - \tfrac{1}{4}g^2W^+_\mu W^-_\mu[H^2 + (\phi^0)^2 + 2\phi^+\phi^-] - \\
&\tfrac{1}{4}g^2\tfrac{1}{c_w^2}Z^0_\mu Z^0_\mu[H^2 + (\phi^0)^2 + 2(2s_w^2-1)^2\phi^+\phi^-] - \tfrac{1}{2}g^2\tfrac{s_w^2}{c_w}Z^0_\mu\phi^0(W^+_\mu\phi^- + W^-_\mu\phi^+) - \\
&\tfrac{1}{2}ig^2\tfrac{s_w^2}{c_w}Z^0_\mu H(W^+_\mu\phi^- - W^-_\mu\phi^+) + \tfrac{1}{2}g^2s_wA_\mu\phi^0(W^+_\mu\phi^- + W^-_\mu\phi^+) + \tfrac{1}{2}ig^2s_wA_\mu H(W^+_\mu\phi^- - \\
&W^-_\mu\phi^+) - g^2\tfrac{s_w}{c_w}(2c_w^2-1)Z^0_\mu A_\mu\phi^+\phi^- - g^1s_w^2A_\mu A_\mu\phi^+\phi^- - \bar{e}^\lambda(\gamma\partial + m_e^\lambda)e^\lambda - \\
&\bar{\nu}^\lambda\gamma\partial\nu^\lambda - \bar{u}^\lambda_j(\gamma\partial + m_u^\lambda)u^\lambda_j - \bar{d}^\lambda_j(\gamma\partial + m_d^\lambda)d^\lambda_j + igs_wA_\mu[-(\bar{e}^\lambda\gamma^\mu e^\lambda) + \tfrac{2}{3}(\bar{u}^\lambda_j\gamma^\mu u^\lambda_j) - \\
&\tfrac{1}{3}(\bar{d}^\lambda_j\gamma^\mu d^\lambda_j)] + \tfrac{ig}{4c_w}Z^0_\mu[(\bar{\nu}^\lambda\gamma^\mu(1+\gamma^5)\nu^\lambda) + (\bar{e}^\lambda\gamma^\mu(4s_w^2 - 1 - \gamma^5)e^\lambda) + (\bar{u}^\lambda_j\gamma^\mu(\tfrac{4}{3}s_w^2 - \\
&1 - \gamma^5)u^\lambda_j) + (\bar{d}^\lambda_j\gamma^\mu(1 - \tfrac{8}{3}s_w^2 - \gamma^5)d^\lambda_j)] + \tfrac{ig}{2\sqrt{2}}W^+_\mu[(\bar{\nu}^\lambda\gamma^\mu(1+\gamma^5)e^\lambda) + (\bar{u}^\lambda_j\gamma^\mu(1 + \\
&\gamma^5)C_{\lambda\kappa}d^\kappa_j)] + \tfrac{ig}{2\sqrt{2}}W^-_\mu[(\bar{e}^\lambda\gamma^\mu(1+\gamma^5)\nu^\lambda) + (\bar{d}^\kappa_jC^\dagger_{\lambda\kappa}\gamma^\mu(1+\gamma^5)u^\lambda_j)] + \tfrac{ig}{2\sqrt{2}}\tfrac{m_e^\lambda}{M}[-\phi^+(\bar{\nu}^\lambda(1 - \\
&\gamma^5)e^\lambda) + \phi^-(\bar{e}^\lambda(1+\gamma^5)\nu^\lambda)] - \tfrac{g}{2}\tfrac{m_e^\lambda}{M}[H(\bar{e}^\lambda e^\lambda) + i\phi^0(\bar{e}^\lambda\gamma^5e^\lambda)] + \tfrac{ig}{2M\sqrt{2}}\phi^+[-m_d^\kappa(\bar{u}^\lambda_jC_{\lambda\kappa}(1 - \\
&\gamma^5)d^\kappa_j) + m_u^\lambda(\bar{u}^\lambda_jC_{\lambda\kappa}(1+\gamma^5)d^\kappa_j] + \tfrac{ig}{2M\sqrt{2}}\phi^-[m_d^\lambda(\bar{d}^\lambda_jC^\dagger_{\lambda\kappa}(1+\gamma^5)u^\kappa_j) - m_u^\kappa(\bar{d}^\lambda_jC^\dagger_{\lambda\kappa}(1 - \\
&\gamma^5)u^\kappa_j] - \tfrac{g}{2}\tfrac{m_u^\lambda}{M}H(\bar{u}^\lambda_ju^\lambda_j) - \tfrac{g}{2}\tfrac{m_d^\lambda}{M}H(\bar{d}^\lambda_jd^\lambda_j) + \tfrac{ig}{2}\tfrac{m_u^\lambda}{M}\phi^0(\bar{u}^\lambda_j\gamma^5u^\lambda_j) - \tfrac{ig}{2}\tfrac{m_d^\lambda}{M}\phi^0(\bar{d}^\lambda_j\gamma^5d^\lambda_j) + \\
&\bar{X}^+(\partial^2 - M^2)X^+ + \bar{X}^-(\partial^2 - M^2)X^- + \bar{X}^0(\partial^2 - \tfrac{M^2}{c_w^2})X^0 + \bar{Y}\partial^2Y + igc_wW^+_\mu(\partial_\mu\bar{X}^0X^- - \\
&\partial_\mu\bar{X}^+X^0) + igs_wW^+_\mu(\partial_\mu\bar{Y}X^- - \partial_\mu\bar{X}^+Y) + igc_wW^-_\mu(\partial_\mu\bar{X}^-X^0 - \partial_\mu\bar{X}^0X^+) + \\
&igs_wW^-_\mu(\partial_\mu\bar{X}^-Y - \partial_\mu\bar{Y}X^+) + igc_wZ^0_\mu(\partial_\mu\bar{X}^+X^+ - \partial_\mu\bar{X}^-X^-) + igs_wA_\mu(\partial_\mu\bar{X}^+X^+ - \\
&\partial_\mu\bar{X}^-X^-) - \tfrac{1}{2}gM[\bar{X}^+X^+H + \bar{X}^-X^-H + \tfrac{1}{c_w^2}\bar{X}^0X^0H] + \tfrac{1-2c_w^2}{2c_w}igM[\bar{X}^+X^0\phi^+ - \\
&\bar{X}^-X^0\phi^-] + \tfrac{1}{2c_w}igM[\bar{X}^0X^-\phi^+ - \bar{X}^0X^+\phi^-] + igMs_w[\bar{X}^0X^-\phi^+ - \bar{X}^0X^+\phi^-] + \\
&\tfrac{1}{2}igM[\bar{X}^+X^+\phi^0 - \bar{X}^-X^-\phi^0]
\end{aligned}
$$

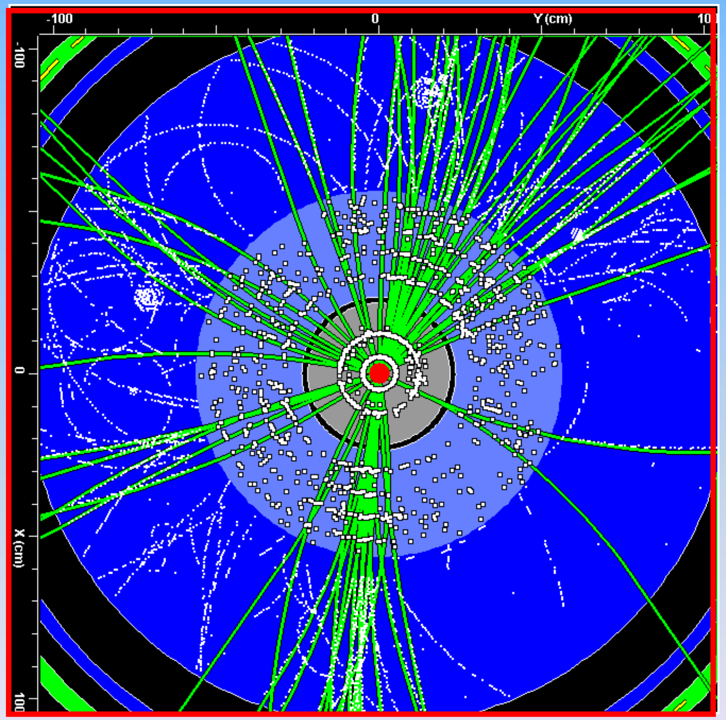
Bladmuziek (J.S. Bach)

bladmuziek

Hoe zien die botsingen er nou uit ?

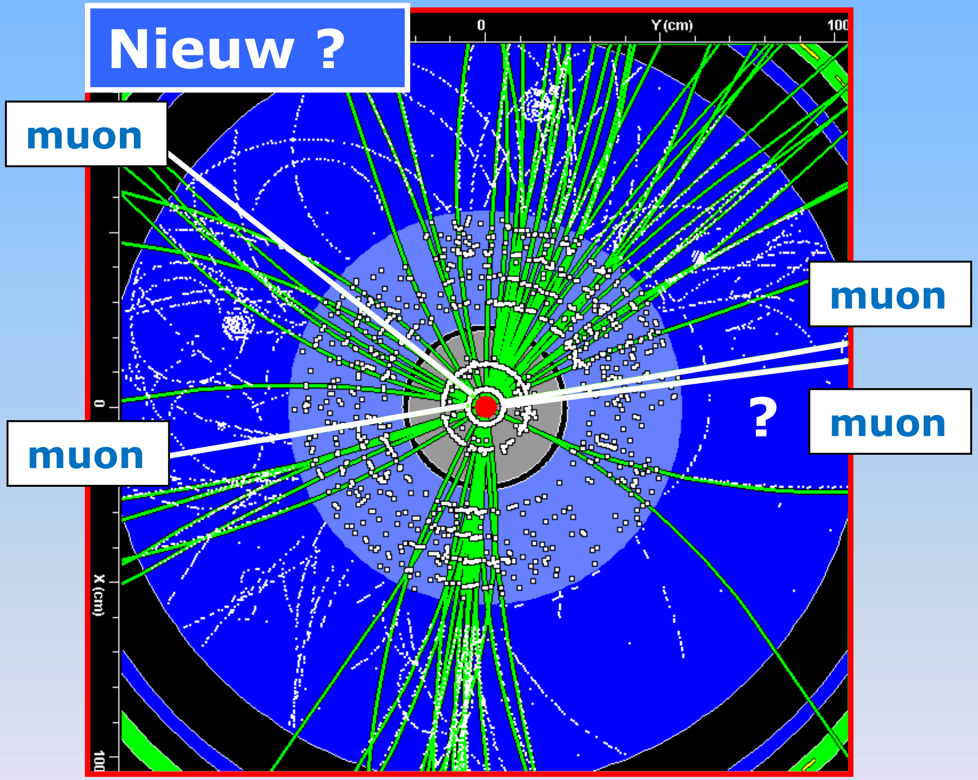


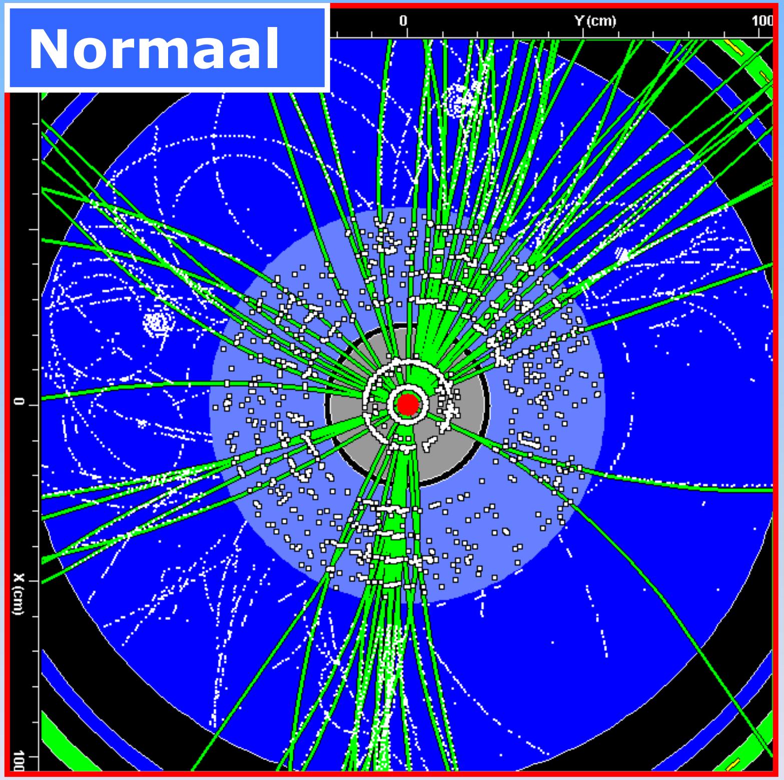
Simulatie top quark productie



Hoe ontdek je nou nieuwe dingen

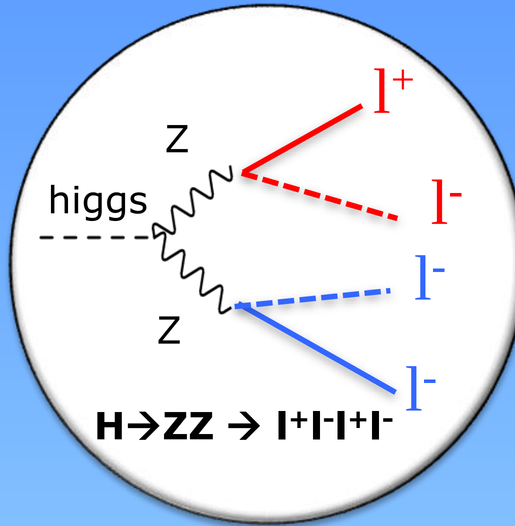
Nieuwe afstandschaal EN nieuwe detector





Higgs → ZZ → 4 leptonen

klein aantal schitterende botsingen



120.000 Higgs bosonen

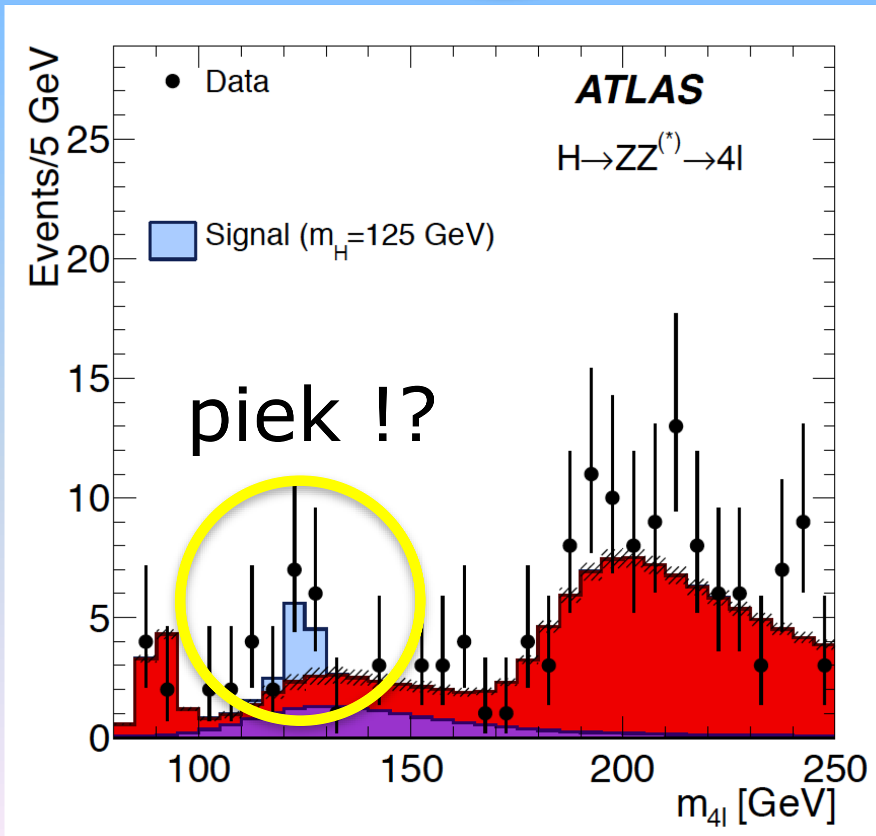
⇩

- Maar 1 op de 1000 Higgs bosonen vervalt naar 4 leptonen
- 50% kans dat ATLAS detector ze allemaal goed terugvindt

⇩

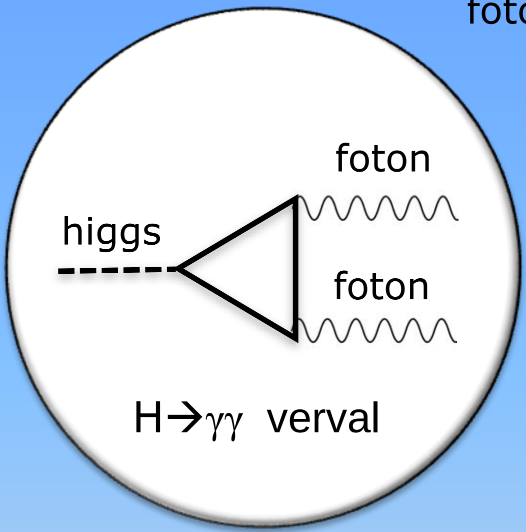
60 (Higgs → 4 lepton) events

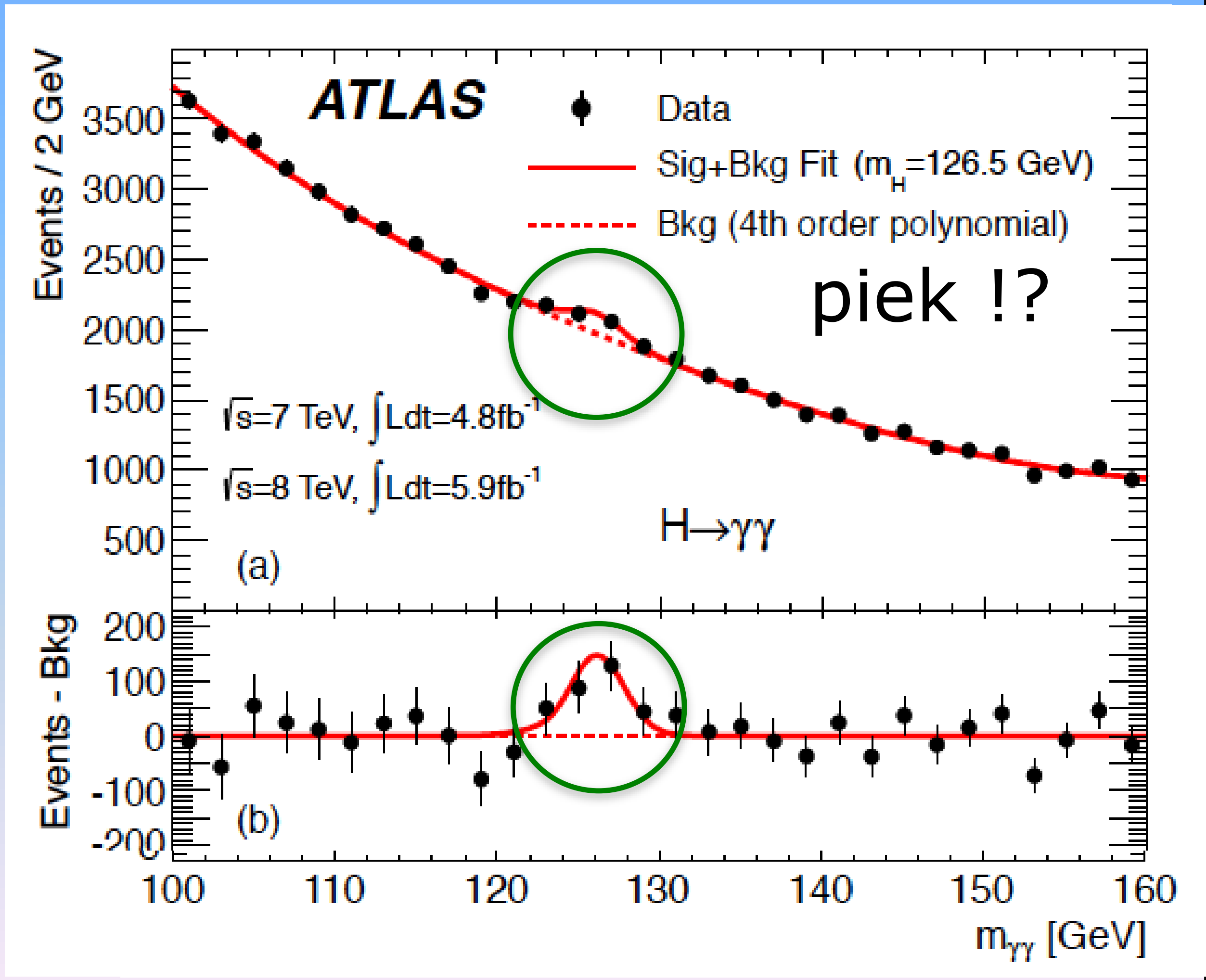
'overig'	52 events
Met Higgs	68 events



Higgs → 2 fotonen

foton





Interpretatie overschot in ATLAS

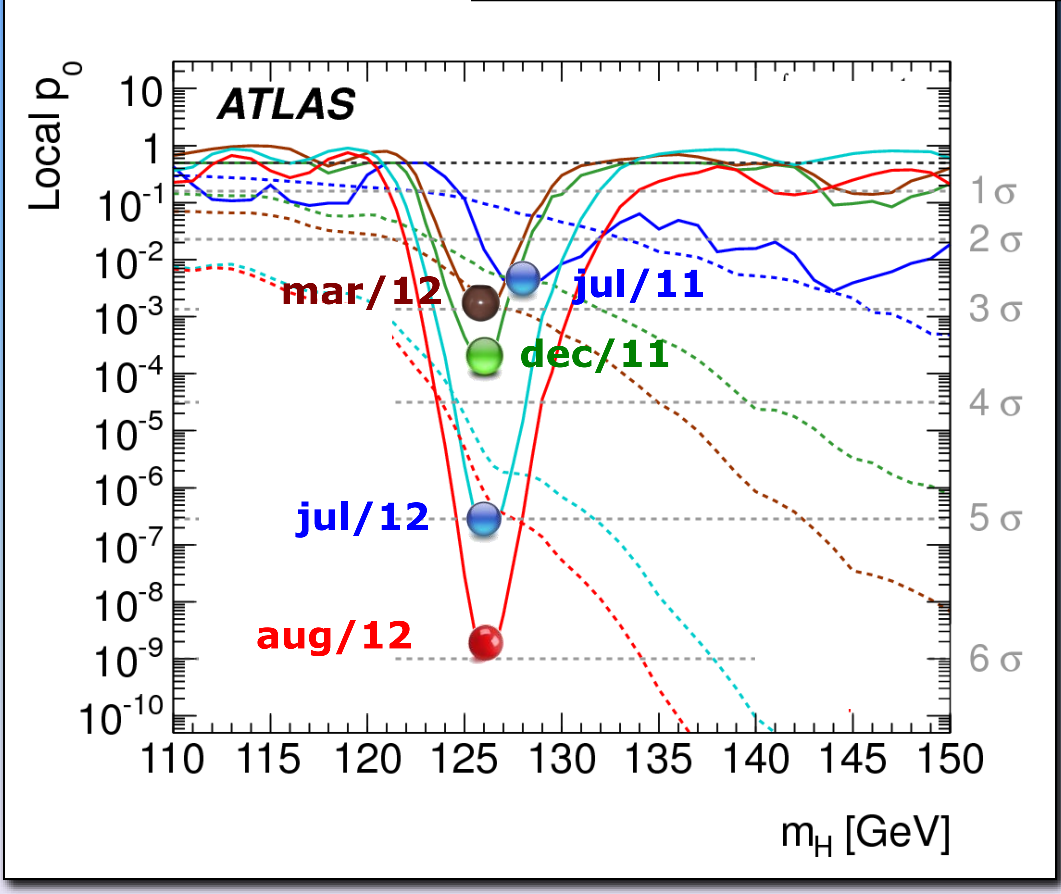
Claim pas ontdekking als:

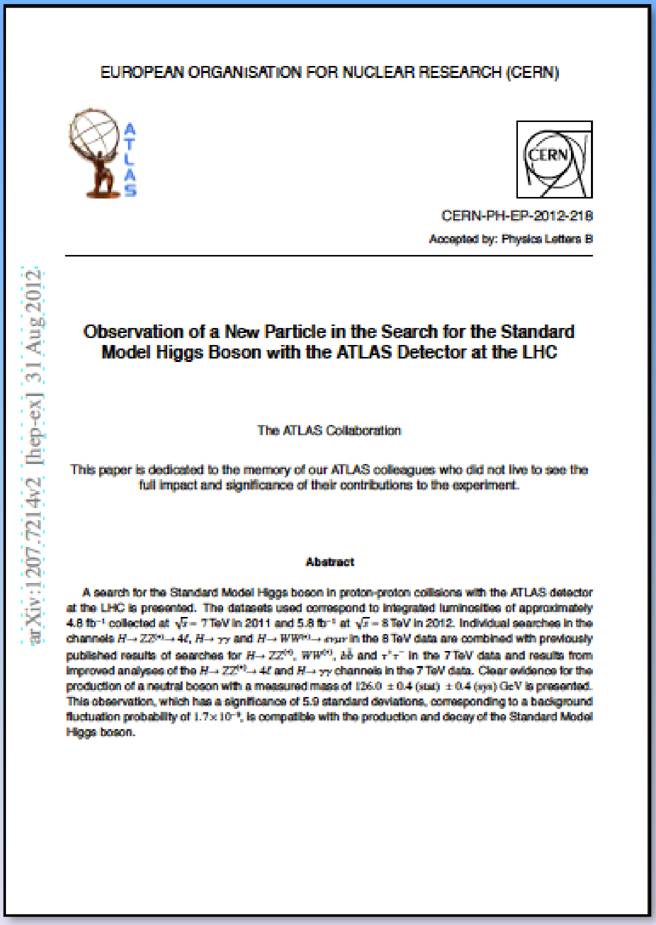
Kans op toevallige fluctuatie zoals ge-
observeerd kleiner dan 1 op 1 miljoen

8 keer 6 gooien achter elkaar

Een ontdekking in slow-motion

Time-line higgs ontdekking





EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

CERN-PH-EP-2012-218

Accepted by: Physics Letters B

arXiv:1207.7214v2 [hep-ex] 31 Aug 2012

Observation of a New Particle in the Search for the Standard Model Higgs Boson with the ATLAS Detector at the LHC

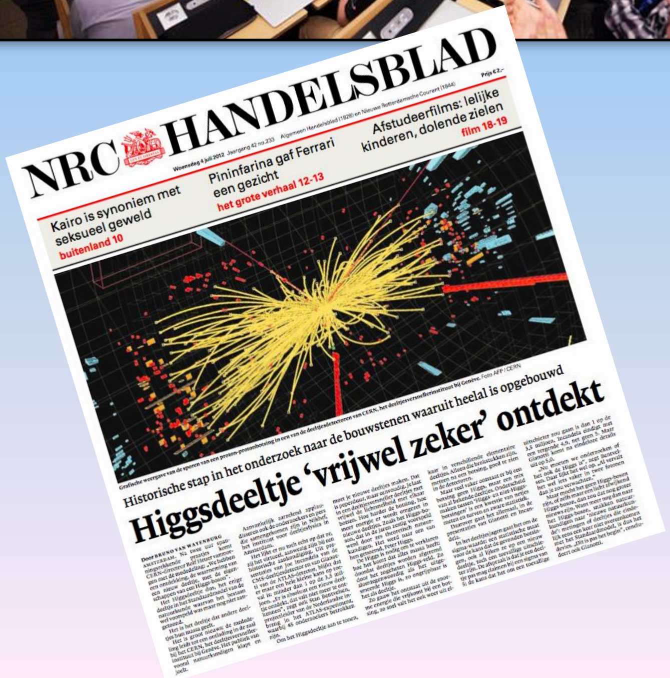
The ATLAS Collaboration

This paper is dedicated to the memory of our ATLAS colleagues who did not live to see the full impact and significance of their contributions to the experiment.

Abstract

A search for the Standard Model Higgs boson in proton-proton collisions with the ATLAS detector at the LHC is presented. The datasets used correspond to integrated luminosities of approximately 4.8 fb^{-1} collected at $\sqrt{s}$ = 7 TeV in 2011 and 5.8 fb^{-1} at $\sqrt{s}$ = 8 TeV in 2012. Individual searches in the channels $H \to ZZ^{(*)} \to 4\ell$, $H \to \gamma\gamma$ and $H \to WW^{(*)} \to e\nu\mu\nu$ in the 8 TeV data are combined with previously published results of searches for $H \to ZZ^{(*)}$, $WW^{(*)}$, $b\bar{b}$ and $\tau^+\tau^-$ in the 7 TeV data and results from improved analyses of the $H \to ZZ^{(*)} \to 4\ell$ and $H \to \gamma\gamma$ channels in the 7 TeV data. Clear evidence for the production of a neutral boson with a measured mass of 126.0 ± 0.4 (stat) ± 0.4 (sys) GeV is presented. This observation, which has a significance of 5.9 standard deviations, corresponding to a background fluctuation probability of 1.7×10^{-9}, is compatible with the production and decay of the Standard Model Higgs boson.

Ontdekking van het Higgs deeltje op 4 juli 2012



NRC HANDELSBLAD

Woensdag 4 juli 2012 Jaargang 42 no.233 Algemeen Handelsblad (1828) en Nieuwe Rotterdamsche Courant (1844) Prijs €2,-

Kairo is synoniem met seksueel geweld
buitenland 10

Pininfarina gaf Ferrari een gezicht
het grote verhaal 12-13

Afstudeerfilms: lelijke kinderen, dolende zielen
film 18-19

Grafische weergave van de sporen van een proton-protonbotsing in een van de deeltjesdetectoren van CERN, het deeltjesversnellerinstituut bij Genève. Foto AFP / CERN

Historische stap in het onderzoek naar de bouwstenen waaruit heelal is opgebouwd

Higgsdeeltje 'vrijwel zeker' ontdekt

Door BRUNO VAN WAYENBURG

Nog een paar ‘kleine’ dingetjes:

1. Waar is alle anti-materie gebleven ?

2. 80% van de materie in het heelal is onbekend
→ donkere materie

3. Higgs boson en quark koppelingen?
(wat is het verband) ?

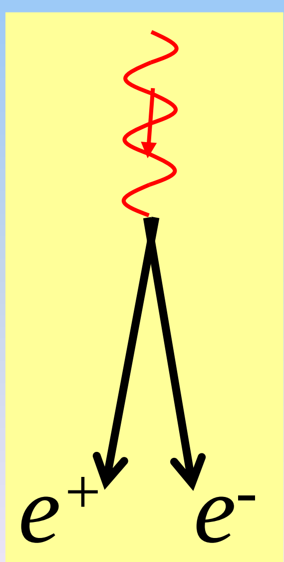
- waarom past gravitatie niet in SM, extra dimensies, waarom 3 families, fermionen fundamentele deeltjes, supersymmetrie, protonen stabiel, quantisatie electrische lading, exploderende quantumcorrecties, kleine neutrino massa’s, string theorie, …

Higgs en het Universum

Higgs: Deeltje? Veld?

<u>Deeltje</u>

Foton (lichtdeeltje)

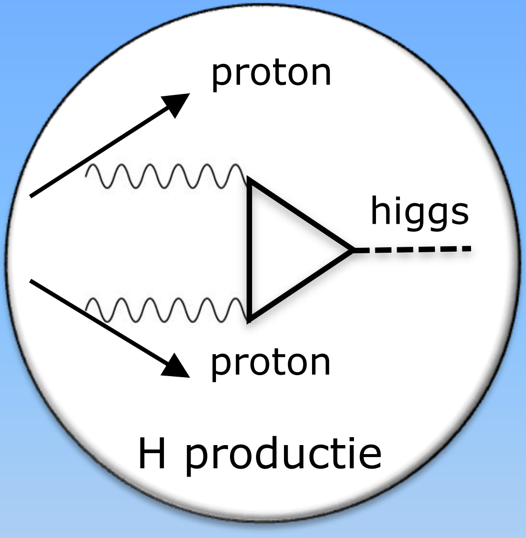


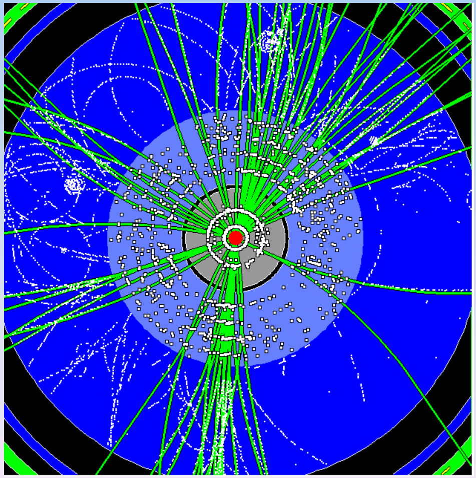
<u>Veld</u>

Elektrisch veld

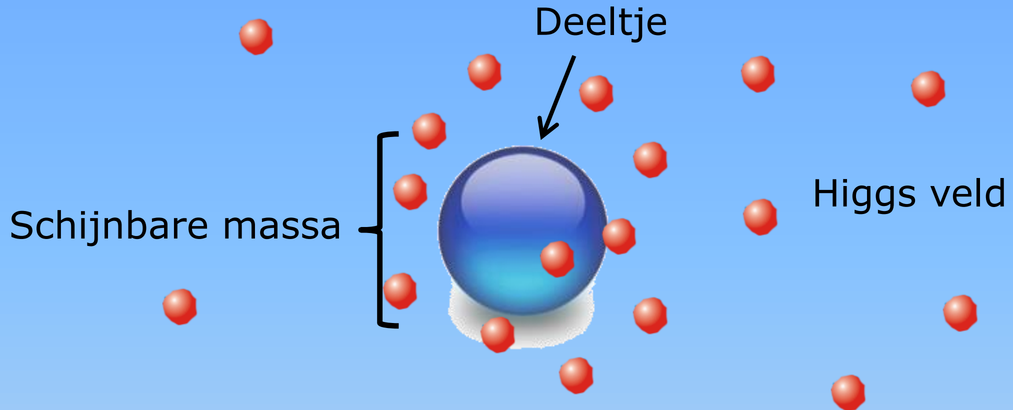
Waarom is de Higgs zo bijzonder?

Deeltje





Veld



Alsof de vis het water heeft ontdekt…

Het Higgs veld – kun je het zien?

Het Higgs veld is uniform – als het meer in deze foto

Het maken van een Higgs deeltje is als een rimpeling op het meer

De theorie van Higgs:

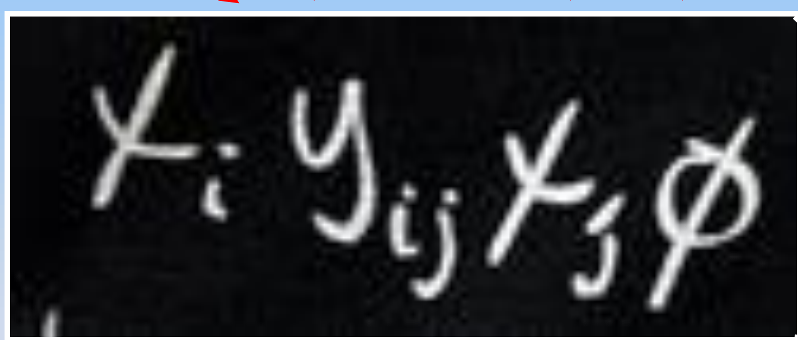
als het veld bestaat is er ook een bijbehorend deeltje

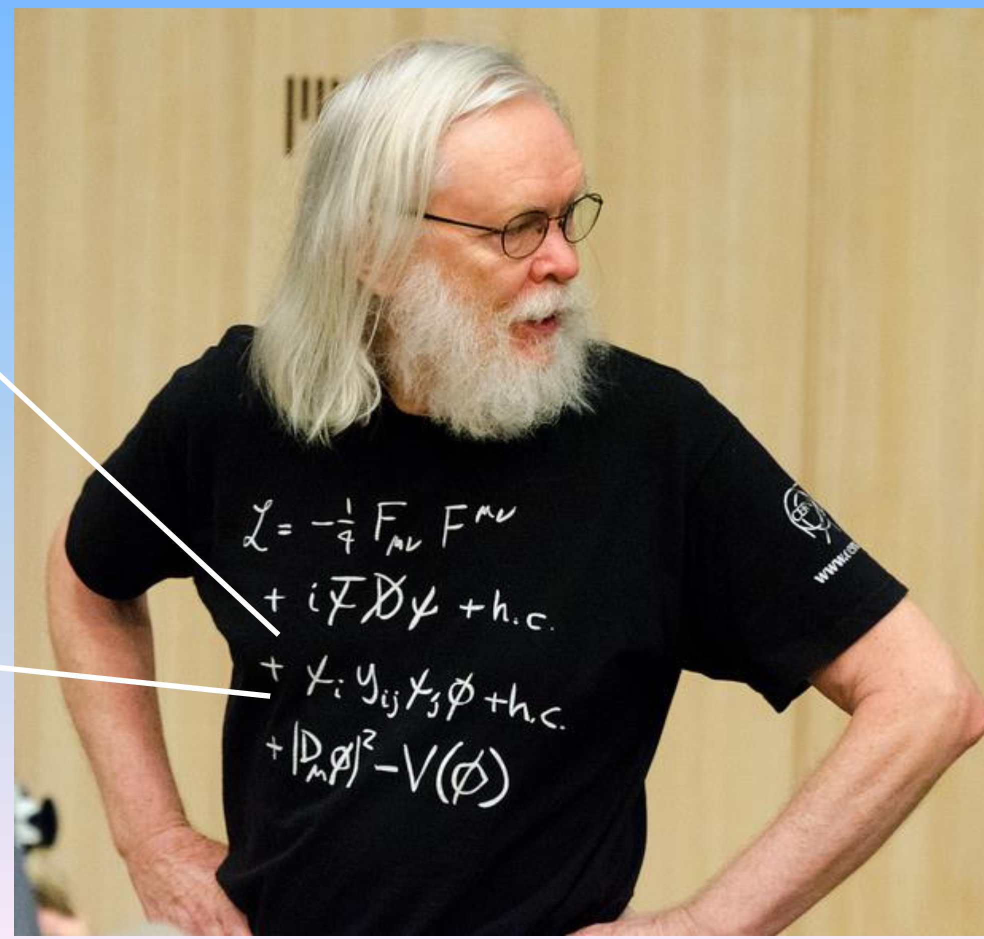
Wat is massa ?? Anno 1964

Massa van elementaire deeltjes komt door

"wrijving" met alomtegenwoordig 'Higgs veld'

m: ψψH





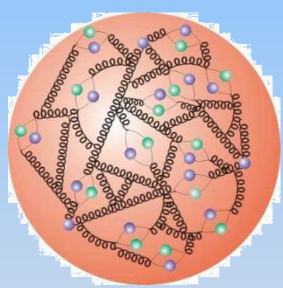
Nee, dit is niet Pierre, dit is John Ellis

Wat is massa ?

Massa van elementaire deeltjes komt door

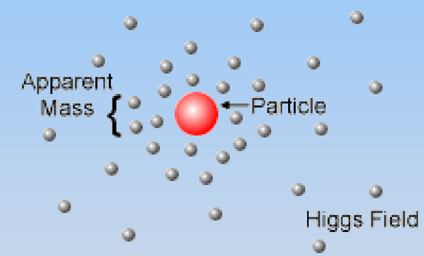
“wrijving” met alomtegenwoordig ‘Higgs veld’

Einstein:
proton massa =
bindings energie



Elementair deeltje
in lege ruimte:
geen rust-energie=
geen massa

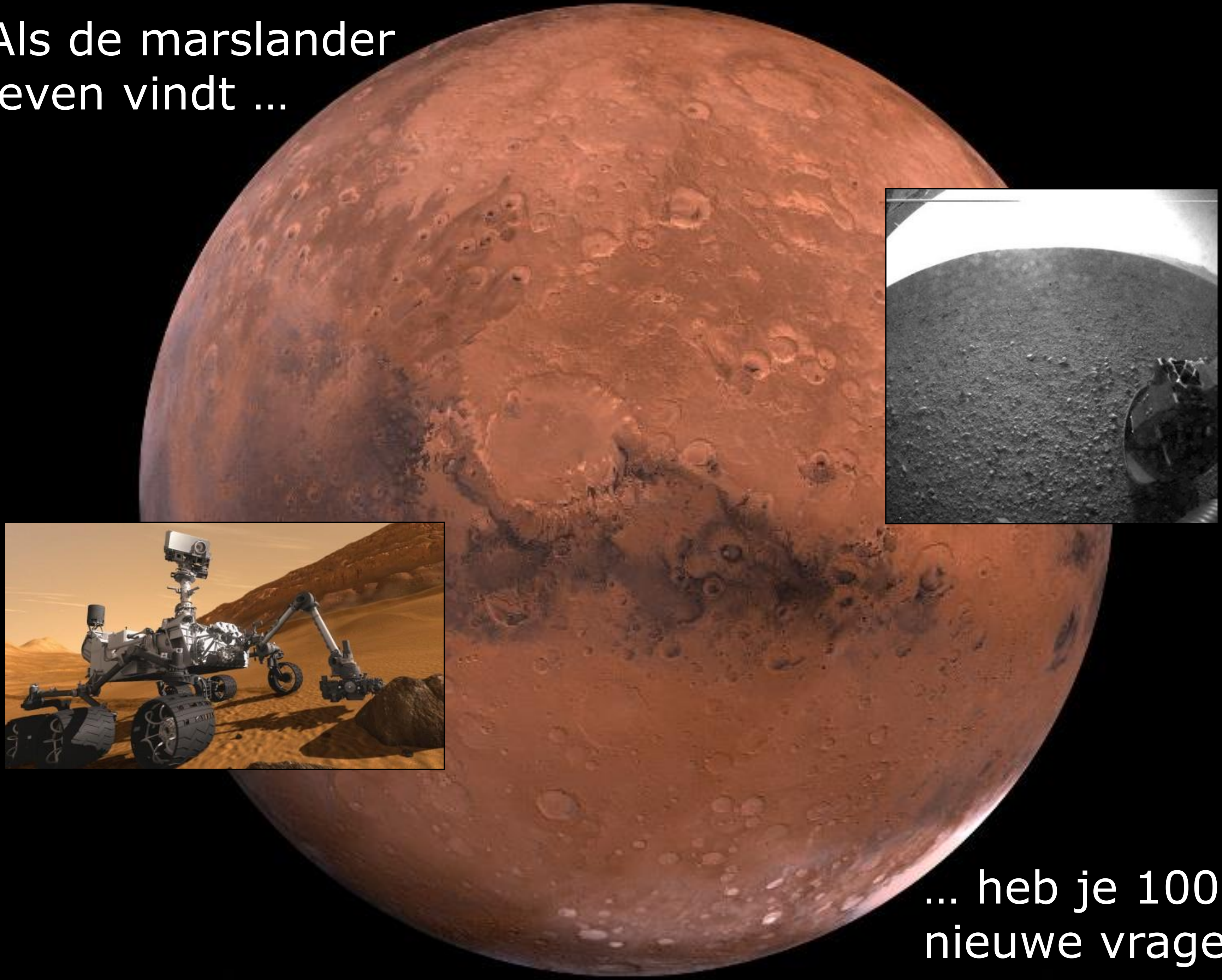
Elementair deeltje
in Higgs veld:
rust energie =
interactie met Higgs veld
= massa



Revolutionair – met spectaculaire consequenties :

de ruimte is *niet* leeg, maar gevuld met soort ‘ether’

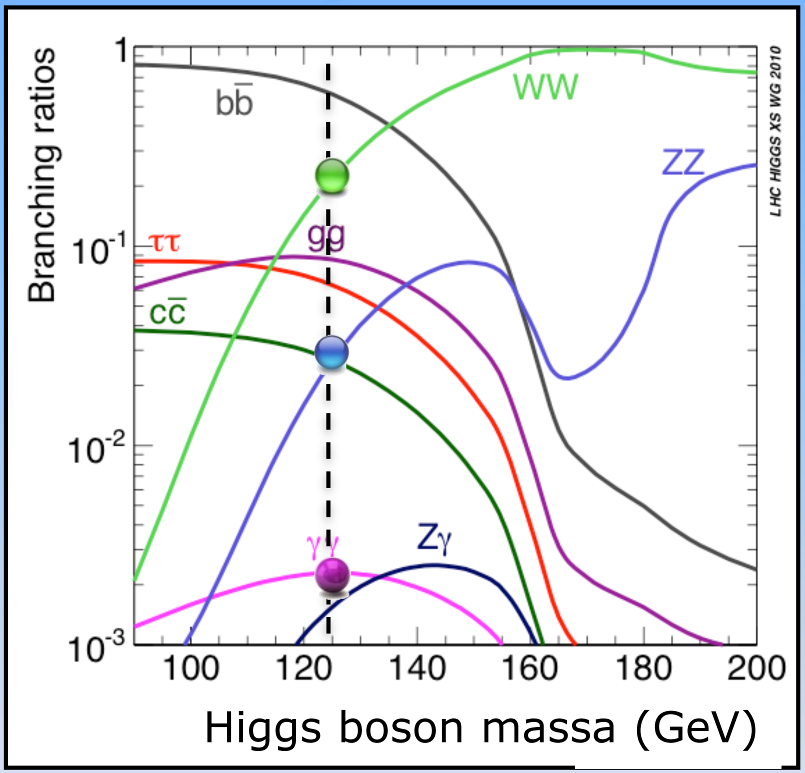
Als de marslander
leven vindt …



… heb je 1000
nieuwe vragen

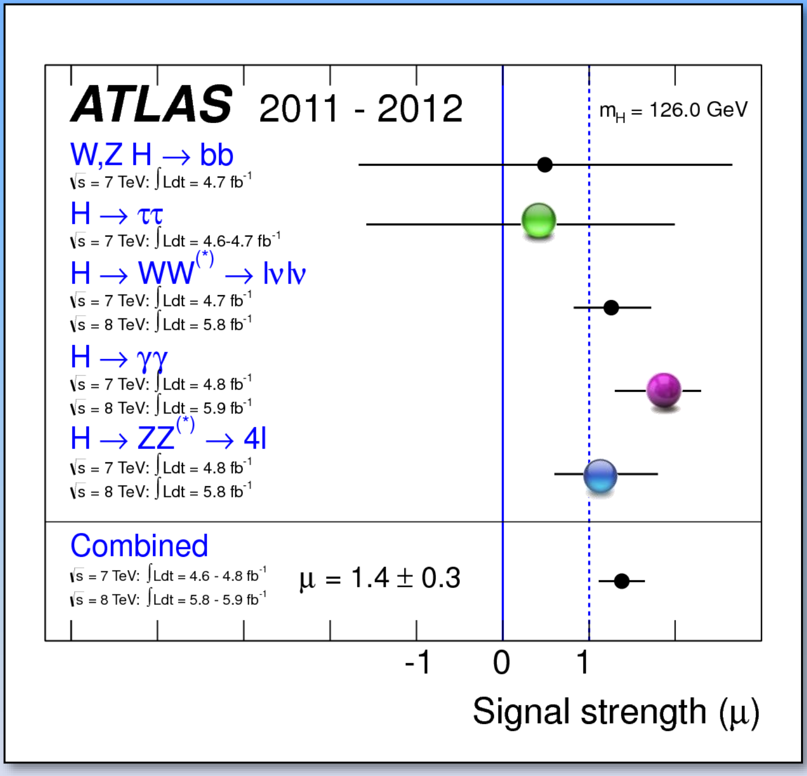
Kloppen Higgs' eigenschappen ?

m_h=125 GeV ↓



voorspelling

Standaard Model ↓



meting

Kloppen Higgs' eigenschappen ?

Zijn er nog meer soorten Higgs deeltjes ?

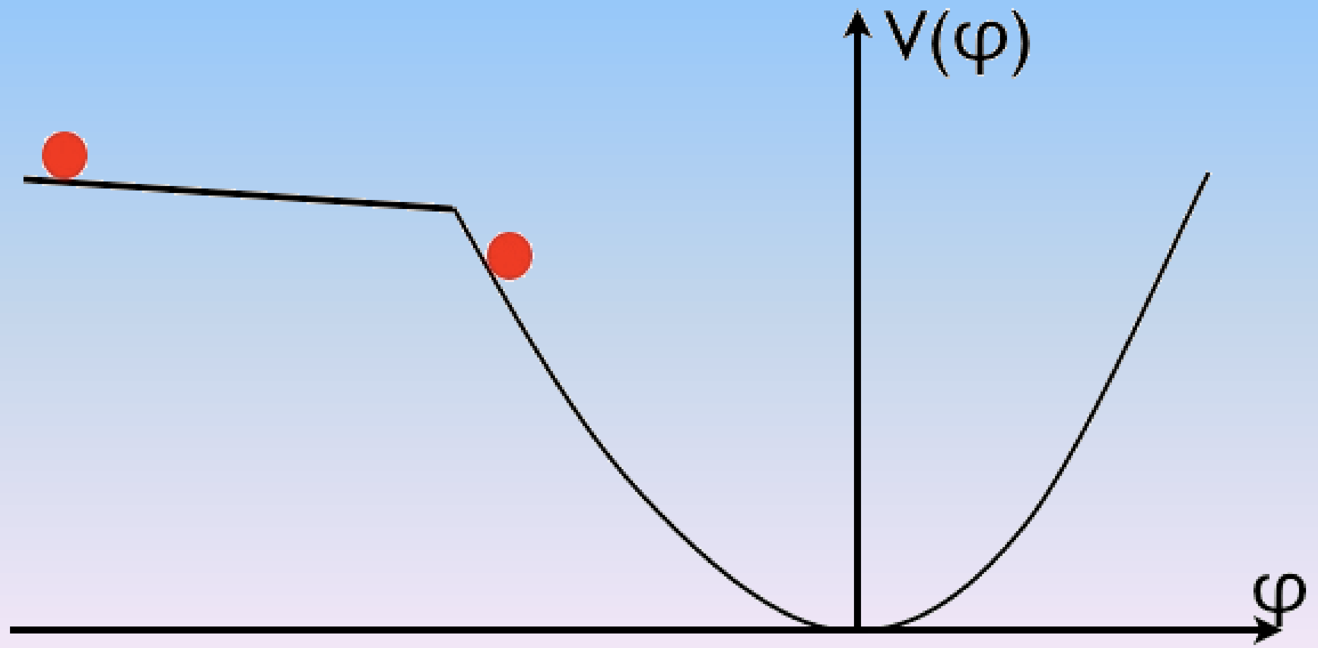
$$\mathcal{L}_{\rm susy} = -\frac{g^2}{8}\left(H_u^\dagger \sigma^a H_u + H_d^\dagger \sigma^a H_d\right)^2 - \frac{g'^2}{8}\left(H_u^\dagger H_u - H_d^\dagger H_d\right)^2$$
$$+ \lambda_{ij}^u H_u^T \epsilon \bar{u}_i q_j - \lambda_{ij}^d H_d^T \epsilon \bar{d}_i q_j - \lambda_{ij}^e H_e^T \epsilon \bar{e}_i \ell_j$$
$$- \frac{H_u^\dagger}{\sqrt{2}}\left(g\sigma^a \tilde{W}^a + g'\tilde{B}\right)\tilde{H}_u - \frac{H_d^\dagger}{\sqrt{2}}\left(g\sigma^a \tilde{W}^a - g'\tilde{B}\right)\tilde{H}_d + \text{h.c.}$$

Een stap verder...

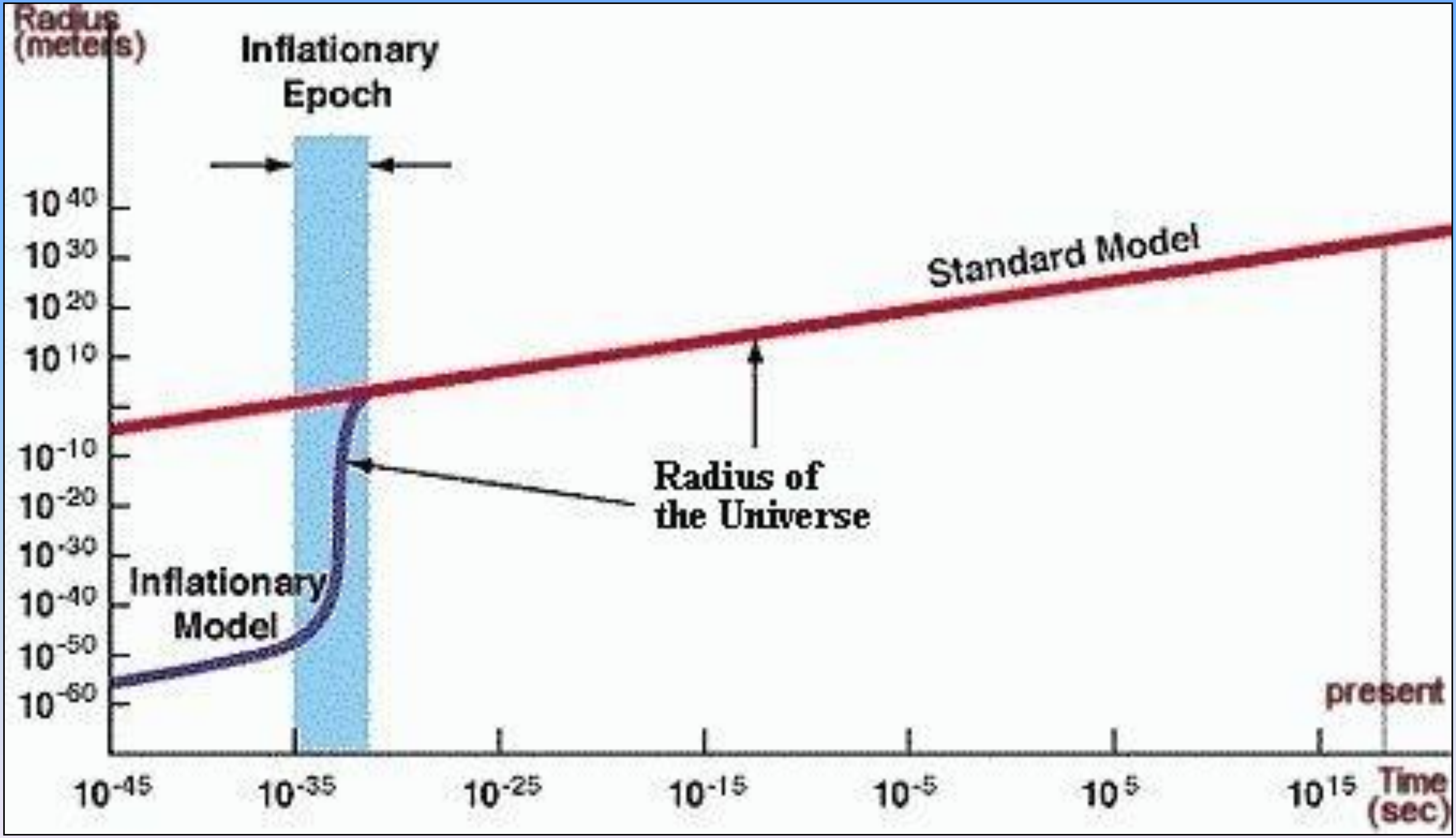
Een ander veld: de Big Bang

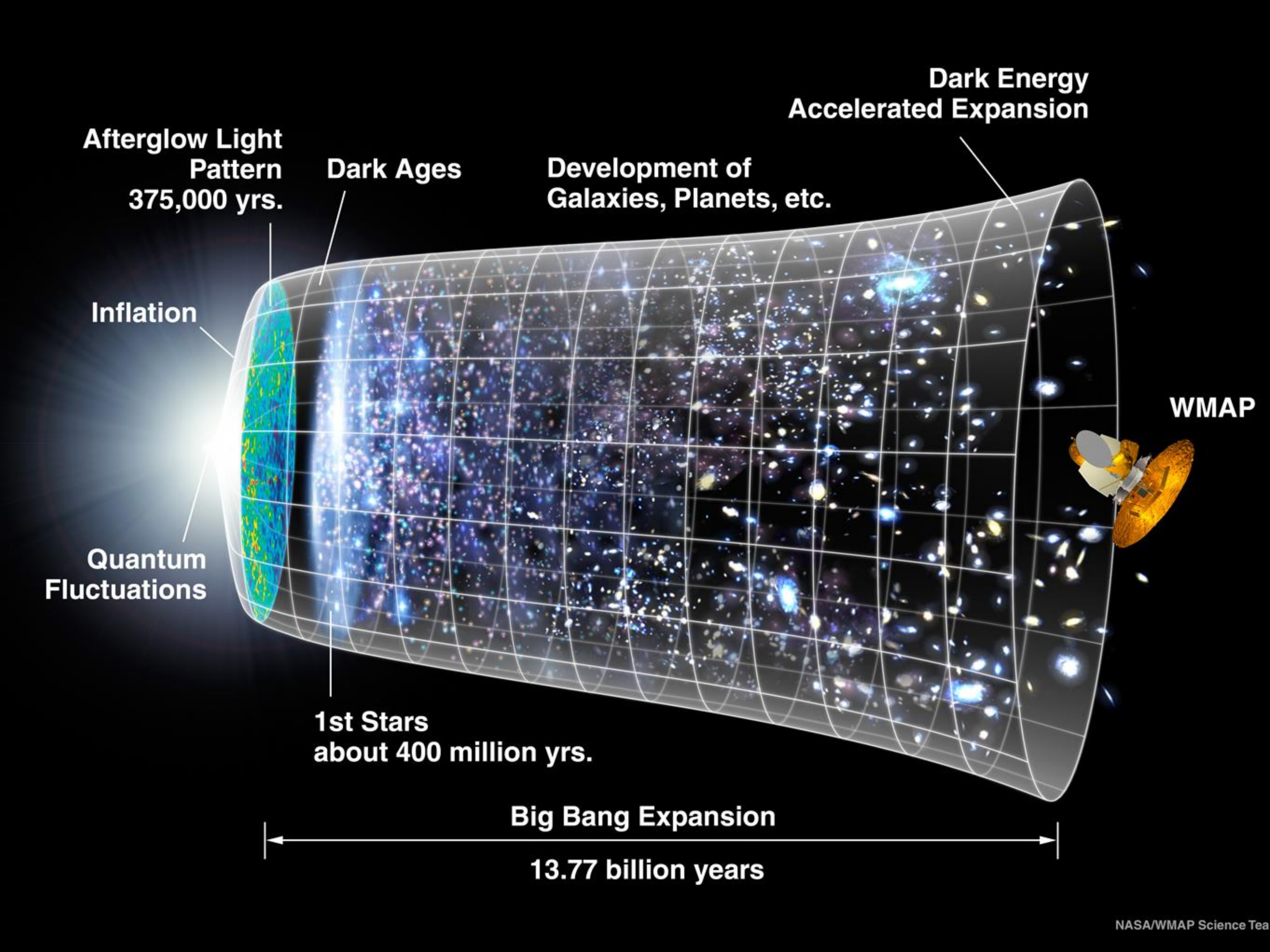
Een van Higgs' eigenschappen komt overeen met een ander veld…

Het *inflaton* dat de het heelal opblies tussen 10^{-33} en 10^{-32} seconde na de Big Bang



Een ander veld: de Big Bang




Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
375,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
WMAP
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.77 billion years
NASA/WMAP Science Tea

Higgs:

1. Een Higgs deeltje gevonden in Geneve
2. Heelal gevuld met Higgs veld
3. Kloppen zijn eigenschappen?

Nog een paar 'kleine' dingetjes:

4 80% van de materie in het heelal is onbekend
→ donkere materie

5 Waar is alle anti-materie gebleven ?

6 Higgs boson (hoe krijgen deeltjes massa) ?

- waarom past gravitatie niet in SM, extra dimensies, waarom 3 families, fermionen fundamentele deeltjes, supersymmetrie, protonen stabiel, quantisatie electrische lading, exploderende quantumcorrecties, kleine neutrino massa's, string theorie, …

EINDE

Wat is het nut van dit onderzoek?

Fundamenteel onderzoek

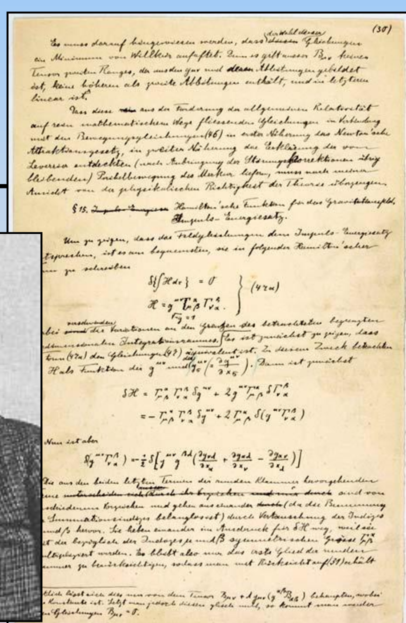
- Kan leiden tot verrassingen,
  - Soms zelfs nuttig…
  - Maar per definitie van te voren onbekend

"Oneindig veel toegepast onderzoek aan de kaars zou ons nooit het electrische licht hebben gebracht."

Wat is het nut van dit onderzoek?

Fundamenteel onderzoek

- Kan leiden tot verrassingen,
  - Soms zelfs nuttig…
  - Maar per definitie van te voren onbekend



"Zonder relativiteits-theorie zit de GPS er 10km/dag naast!"

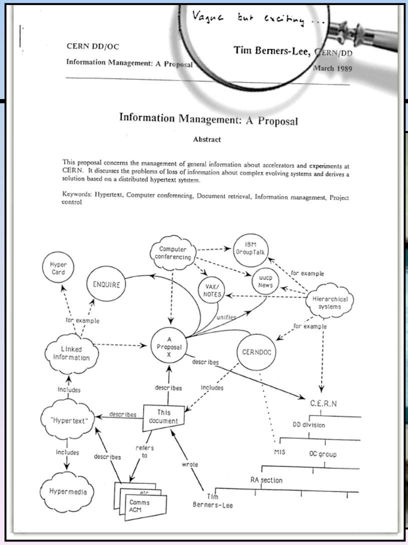
Wat is het nut van dit onderzoek?

Fundamenteel onderzoek

- Heeft nuttige bij-effecten
  - Medische toepassingen
  - Internet
  - Opleiden van onderzoekers voor de maatschappij (Philips, ASML, etc, etc)

PET scan

www



Vague but exciting ...

CERN DD/OC

Information Management: A Proposal

Tim Berners-Lee, CERN/DD

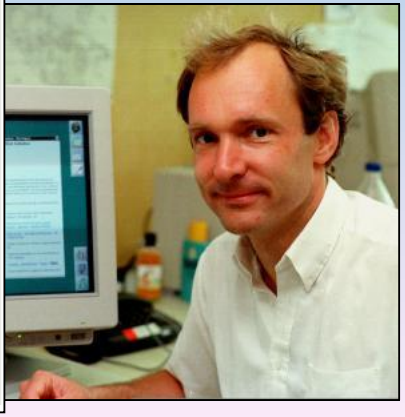
March 1989

Information Management: A Proposal

Abstract

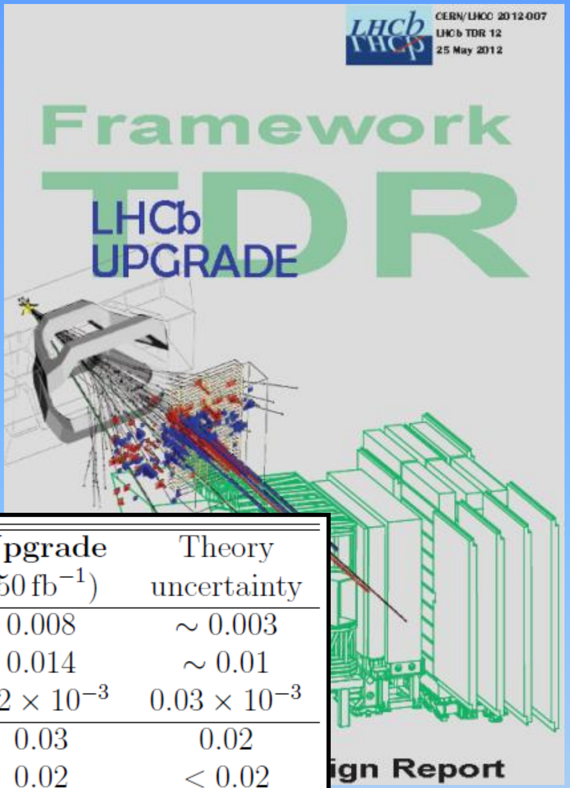
This proposal concerns the management of general information about accelerators and experiments at CERN. It discusses the problems of loss of information about complex evolving systems and derives a solution based on a distributed hypertext sytstem.

Keywords: Hypertext, Computer conferencing, Document retrieval, Information management, Project control



LHCb: Hoe verder?

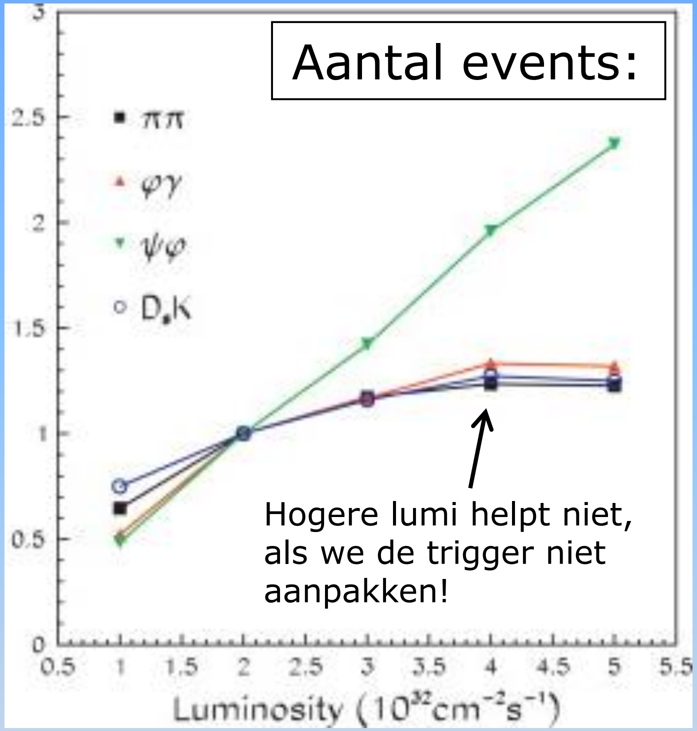
- Preciezer! → Upgrade (2018)



Type	Observable	Current precision	LHCb 2018	**Upgrade** ($50\,\text{fb}^{-1}$)	Theory uncertainty
B_s^0 mixing	$2\beta_s$ ($B_s^0 \to J/\psi\ \phi$)	0.10 [30]	0.025	0.008	~ 0.003
	$2\beta_s$ ($B_s^0 \to J/\psi\ f_0(980)$)	0.17 [32]	0.045	0.014	~ 0.01
	a_{sl}^s	6.4×10^{-3} [63]	0.6×10^{-3}	0.2×10^{-3}	0.03×10^{-3}
Gluonic penguins	$2\beta_s^{\text{eff}}(B_s^0 \to \phi\phi)$	–	0.17	0.03	0.02
	$2\beta_s^{\text{eff}}(B_s^0 \to K^{*0}\bar{K}^{*0})$	–	0.13	0.02	< 0.02
	$2\beta^{\text{eff}}(B^0 \to \phi K_S^0)$	0.17 [63]	0.30	0.05	0.02
Right-handed currents	$2\beta_s^{\text{eff}}(B_s^0 \to \phi\gamma)$	–	0.09	0.02	< 0.01
	$\tau^{\text{eff}}(B_s^0 \to \phi\gamma)/\tau_{B_s^0}$	–	5 %	1 %	0.2 %
Electroweak penguins	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\,\text{GeV}^2/c^4)$	0.08 [64]	0.025	0.008	0.02
	$s_0\ A_{\text{FB}}(B^0 \to K^{*0}\mu^+\mu^-)$	25 % [64]	6 %	2 %	7 %
	$A_{\text{I}}(K\mu^+\mu^-; 1 < q^2 < 6\,\text{GeV}^2/c^4)$	0.25 [9]	0.08	0.025	~ 0.02
	$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)/\mathcal{B}(B^+ \to K^+\mu^+\mu^-)$	25 % [29]	8 %	2.5 %	~ 10 %
Higgs penguins	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	1.5×10^{-9} [4]	0.5×10^{-9}	0.15×10^{-9}	0.3×10^{-9}
	$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	–	~ 100 %	~ 35 %	~ 5 %
Unitarity triangle angles	γ ($B \to D^{(*)}K^{(*)}$)	~ 10–$12°$ [40, 41]	4°	0.9°	negligible
	γ ($B_s^0 \to D_s K$)	–	11°	2.0°	negligible
	β ($B^0 \to J/\psi\ K_S^0$)	0.8° [63]	0.6°	0.2°	negligible
Charm CP violation	A_Γ	2.3×10^{-3} [63]	0.40×10^{-3}	0.07×10^{-3}	–
	ΔA_{CP}	2.1×10^{-3} [8]	0.65×10^{-3}	0.12×10^{-3}	–

LHCb: Upgrade - Trigger

- Precisie meting → Meer luminositeit
- Meer luminositeit → ~~Hogere trigger rate~~
- Meer luminositeit → Hogere threshold
- Hogere threshold → ~~Minder events …~~



<u>Oplossing:</u>

Slimmere trigger → *alle* events naar CPU farm:

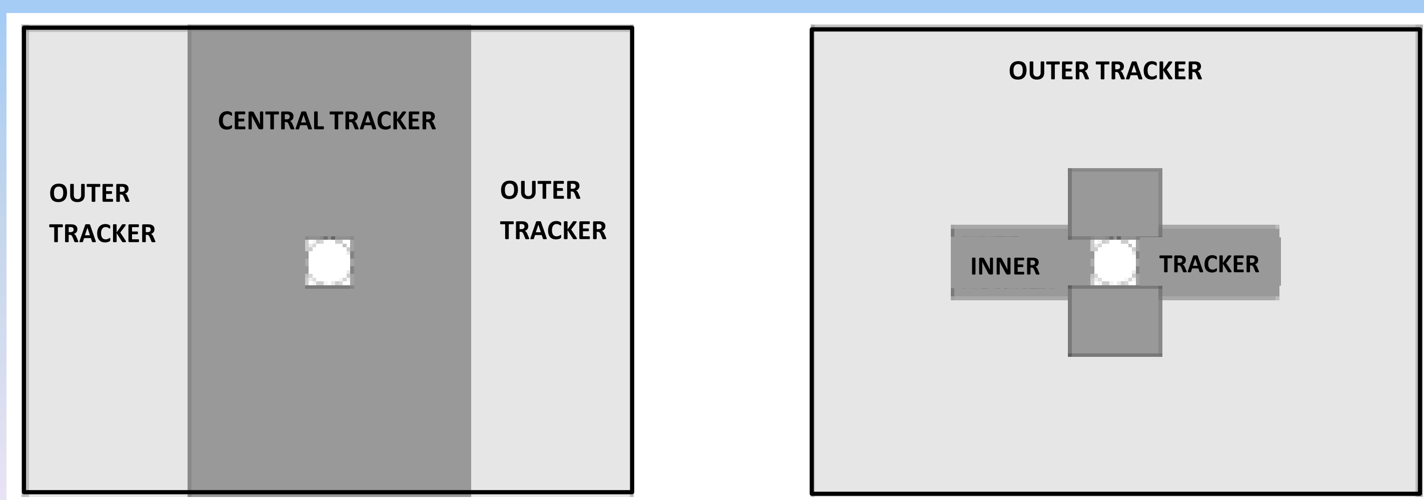
➢ Readout @40 MHz, niet 1 MHz …

LHCb: Upgrade - Detectors

- Precisie meting → Meer luminositeit
- Meer luminositeit → Hogere particle rate
- Hogere particle rate → Occupancy te hoog in de Outer Tracker

➢ <u>2 opties:</u>

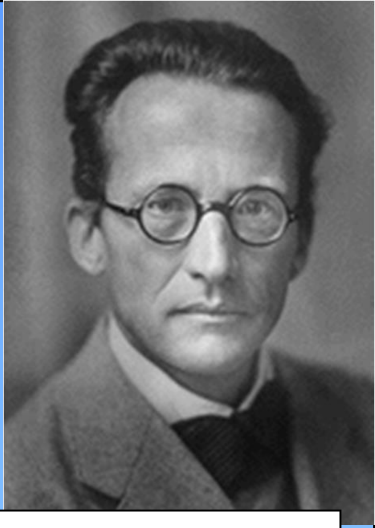
Beslissing in 2013



1) Inner Tracker wordt Scintil. Fiber, Outer Tracker wordt *minder*

2) Inner Tracker wordt groter, Outer Tracker wordt *kleiner*

Schrödinger



Klassiek verband tussen E and p:

$$E = \frac{\vec{p}^2}{2m}$$

Quantum mechanische substitutie:

(*operator acting on wave function* ψ)

$$E \rightarrow i\frac{\partial}{\partial t} \qquad \text{and} \qquad \vec{p} \rightarrow -i\vec{\nabla}$$

Schrodinger vergelijking:

$$i\frac{\partial}{\partial t}\psi = \frac{-1}{2m}\nabla^2\psi$$

Oplossing:

$$\psi = N\, e^{i(\vec{p}\vec{x} - Et)}$$

•(show it is a solution)

Klein-Gordon

Relativistisch verband tussen E and p: $E^2 = \vec{p}^2 + m^2$

Quantum mechanische substitutie: $E \rightarrow i\frac{\partial}{\partial t}$ and $\vec{p} \rightarrow -i\vec{\nabla}$

(*operator acting on wave function* ψ)

Klein Gordon vergelijking:

$$-\frac{\partial^2}{\partial t^2}\phi = -\nabla^2\phi + m^2\,\phi$$

or : $\left(\Box + m^2\right)\,\phi(x) = 0$

or : $\left(\partial_\mu \partial^\mu + m^2\right)\,\phi(x) = 0$

Oplossing: $\phi(x) = N\,e^{-ip_\mu x^\mu}$ $\quad E^2 = \vec{p}^2 + m^2$

Maar: negatieve energie oplossing?

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

Dirac

Paul Dirac zocht een vergelijking, die

- relativistisch correct is,
- Maar <u>*lineair*</u> in d/dt om negatieve energie te vermijden
- (en lineair in d/dx (or ∇) vanwege Lorentz covariantie)

Hij vond een vergelijking, die

- spin-1/2 deeltjes bleek te beschrijven en
- het bestaan van anti-deeltjes voorspelde

Dirac

- How to find that relativistic, linear equation ??

Write Hamiltonian in general form, $$H\psi = (\vec{\alpha}\cdot\vec{p} + \beta m)\ \psi$$

but when squared, it must satisfy: $$H^2\psi = \left(\vec{p}^2 + m^2\right)\ \psi$$

Let's find α_i and β !

$$\begin{aligned} H^2\psi &= (\alpha_i p_i + \beta m)^2\ \psi \qquad \text{with}:\ i = 1,2,3 \\ &= \left(\underbrace{\alpha_i^2}_{=1}\ p_i^2 + \underbrace{(\alpha_i\alpha_j + \alpha_j\alpha_i)}_{=0\quad i>j}\ p_i p_j + \underbrace{(\alpha_i\beta + \beta\alpha_i)}_{=0} p_i m + \underbrace{\beta^2}_{=1}\ m^2 \right)\ \psi \end{aligned}$$

So, α_i and β must satisfy:

- $\alpha_1^2 = \alpha_2^2 = \alpha_3^2 = \beta^2$
- $\alpha_1, \alpha_2, \alpha_3, \beta$ anti-commute with each other
- (not a unique choice!)

Dirac

$$H\psi = (\vec{\alpha}\cdot\vec{p} + \beta m)\ \psi$$

➢ What are **α** and **β** ??

- The lowest dimensional matrix that has the desired behaviour is 4x4 !?
- Often used
- Pauli-Dirac representation:

$$\vec{\alpha} = \begin{pmatrix} 0 & \vec{\sigma} \\ \vec{\sigma} & 0 \end{pmatrix} \quad ; \quad \beta = \begin{pmatrix} I & 0 \\ 0 & -I \end{pmatrix}$$

- with:

$$\sigma_1 = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \quad ; \quad \sigma_2 = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix} \quad ; \quad \sigma_3 = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

So, α_i and β must satisfy:

- $\alpha_1^2 = \alpha_2^2 = \alpha_3^2 = \beta^2$
- $\alpha_1, \alpha_2, \alpha_3, \beta$ anti-commute with each other
- (not a unique choice!)

Dirac

$$H\psi = \left(\vec{\alpha}\cdot\vec{p} + \beta m\right)\,\psi$$

Usual substitution: $H \rightarrow i\frac{\partial}{\partial t},\ \vec{p} \rightarrow -i\vec{\nabla}$

Leads to: $$i\frac{\partial}{\partial t}\psi = \left(-i\vec{\alpha}\cdot\vec{\nabla} + \beta m\right)\,\psi$$

Multiply by β: $$\left(i\beta\frac{\partial}{\partial t}\psi \quad + \quad i\beta\alpha_1\frac{\partial}{\partial x} + i\beta\alpha_2\frac{\partial}{\partial y} + i\beta\alpha_3\frac{\partial}{\partial z}\right)\,\psi - m\psi = 0$$

•(β^2=**1**)

Gives the famous Dirac equation:

$$\begin{aligned} \left(i\gamma^\mu\partial_\mu - m\right)\,\psi &= 0 \\ \text{with}:\ \gamma^\mu = \left(\beta, \beta\vec{\alpha}\right) &\equiv \text{Dirac } \gamma\text{–matrices} \end{aligned}$$

for each j=1,2,3,4 : $$\sum_{k=1}^{4}\left[\sum_{\mu=0}^{3} i\left(\gamma^\mu\right)_{jk}\,\partial_\mu - m\delta_{jk}\right]\left(\psi_k\right) = 0$$

$$H\psi = (\vec{\alpha}\cdot\vec{p} + \beta m)\ \psi$$

Dirac

The famous Dirac equation:

$$\begin{aligned}(i\gamma^\mu \partial_\mu - m)\ \psi &= 0 \\ \text{with}: \quad \gamma^\mu = (\beta, \beta\vec{\alpha}) &\equiv \text{Dirac } \gamma\text{−matrices}\end{aligned}$$

R.I.P. :

Dirac vergelijking

Schrödinger equation

- Time-dependence of wave function

$$E = \frac{\vec{p}^2}{2m}$$

$$i\frac{\partial}{\partial t}\psi = \frac{-1}{2m}\nabla^2\psi$$

Klein-Gordon equation

- Relativistic equation of motion of scalar particles

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

$$-\frac{\partial^2}{\partial t^2}\phi = -\nabla^2\phi + m^2\,\phi$$

Dirac equation

- Relativistically correct, and linear
- Equation of motion for spin-1/2 particles
- Prediction of anti-matter

$$(i\gamma^\mu\partial_\mu - m)\,\psi = 0$$

$$\psi = \begin{pmatrix}\psi_1\\ \psi_2\\ \psi_3\\ \psi_4\end{pmatrix}$$