

10 april 2018, Beurts van Berlage (FCC)



De magische wereld van het allerkleinste

Ivo van Vulpen (UvA/Nikhef)



$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

ALBERT EINSTEIN (1879-1955) 

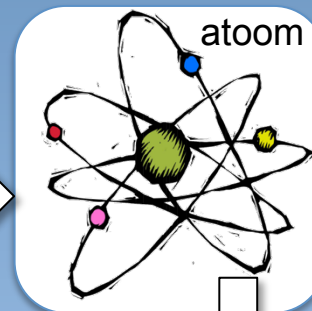
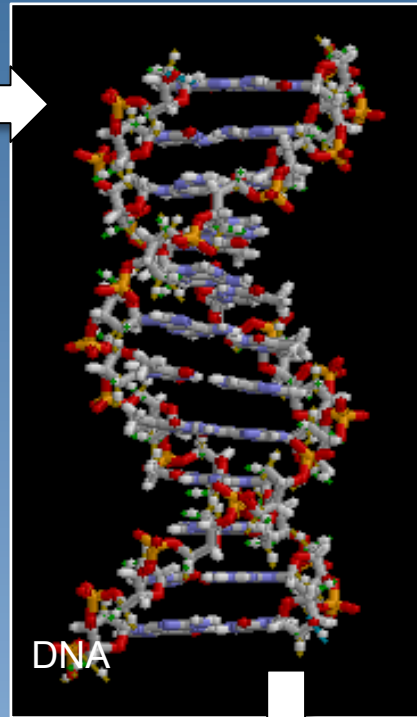
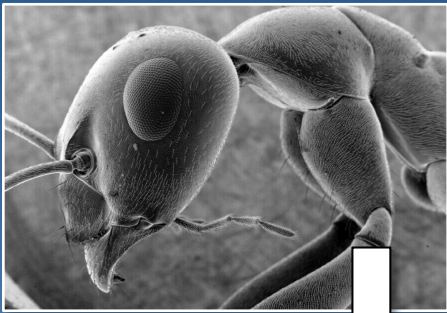
toneel

acteurs

CERN in Genève, Zwitterland



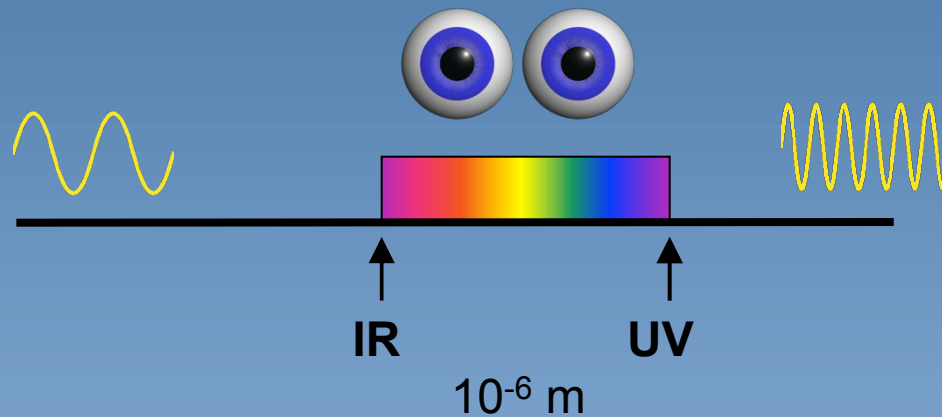
Zoektocht naar de elementaire bouwstenen van de natuur



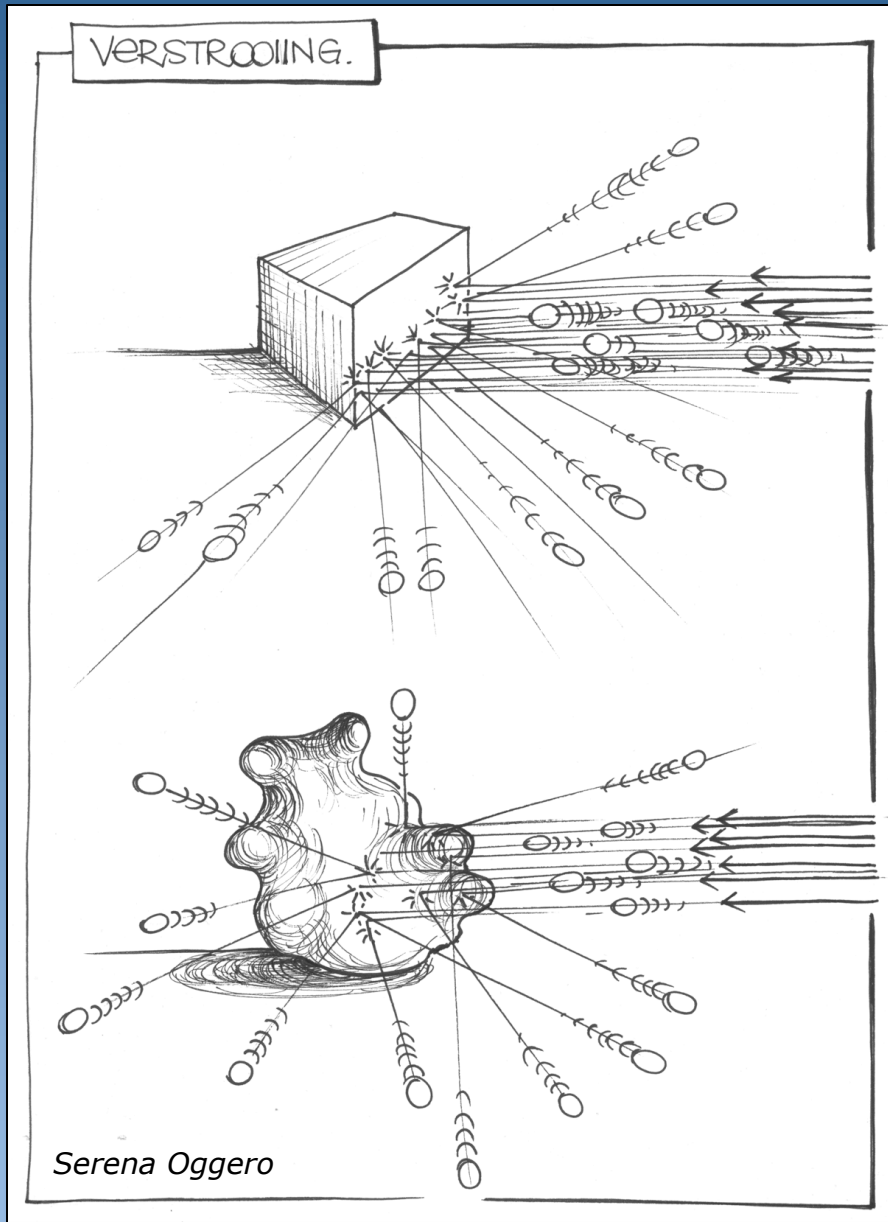
atoomkern

Hoe onderzoek je de wereld
van het allerkleinste ?

Kijken naar de wereld om ons heen



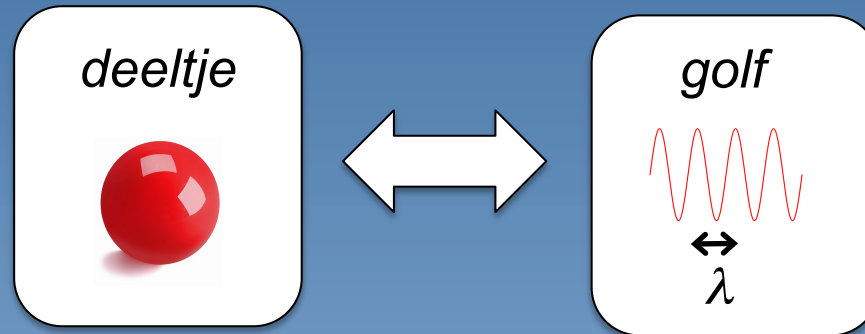
Licht ketst alleen af van objecten die groter zijn dan zijn golflengte



Kijken zonder je ogen
te gebruiken

kleine projectielen afketsen

De wereld van de quantummechanica

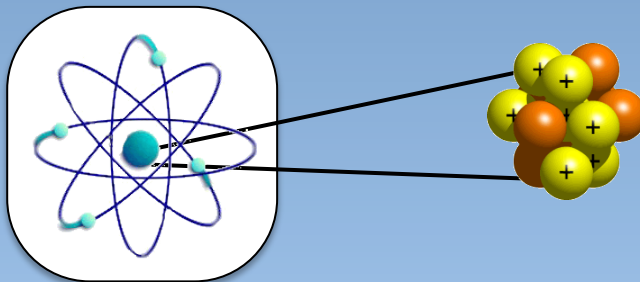
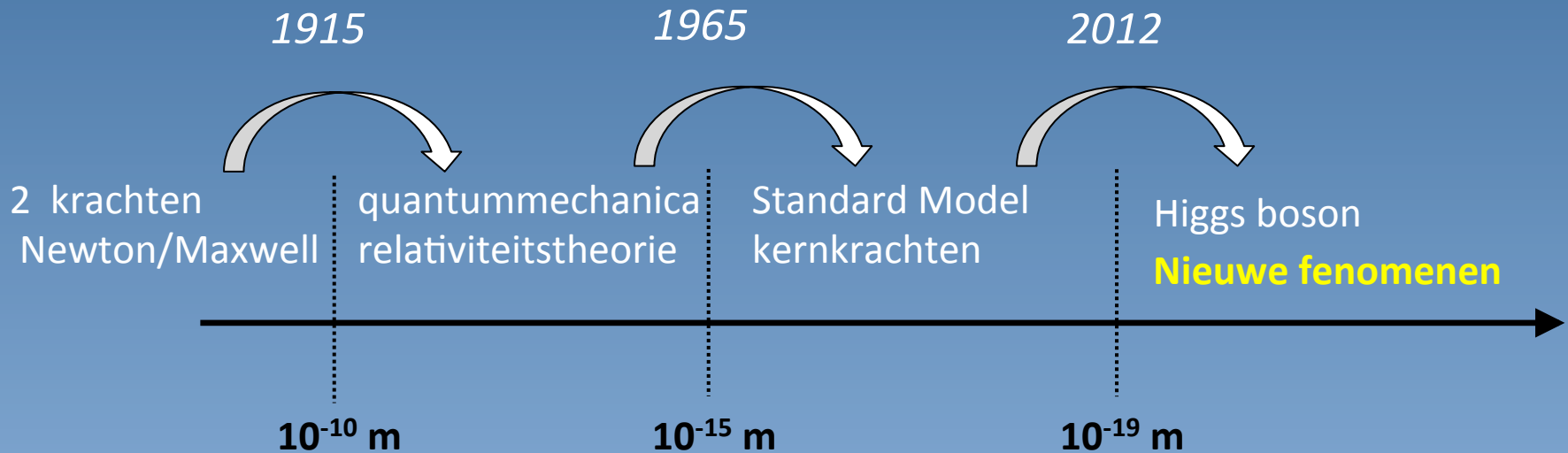


“Hoe hoger de energie, hoe kleiner het deeltje/golfje”

zichtbaar licht: 10^{-7} [m]

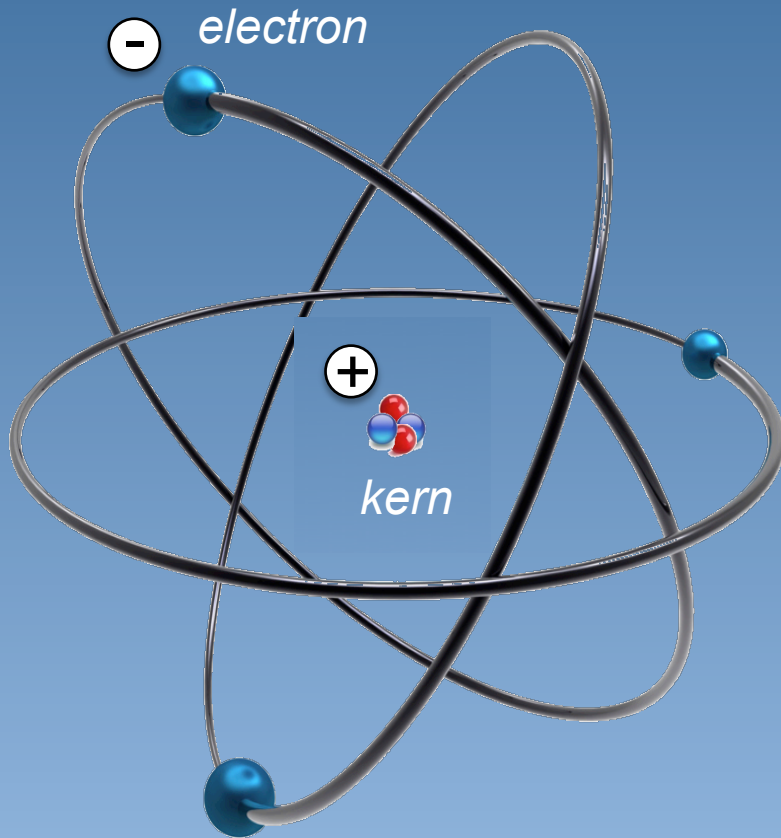
wereldrecord: 10^{-20} [m]

Honderd jaar fundamentele natuurkunde



De wereld van het atoom

Schatgraven in de atoomwereld



1) *elektron vallen niet op de kern!*
→ **wet: quantummechanica**

2) *kerndeeltjes kleven aan elkaar!*
→ **kracht: kernkrachten**

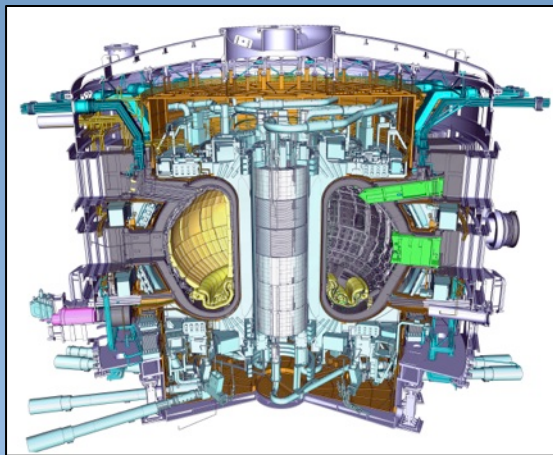
3) *maar 2 elektronen in 1^e baan!*
→ **eigenschap: spin**

$$\Psi_{nlm}(r, \theta, \varphi) = R_{nl}(r) Y_l^m(\theta, \varphi) \chi_{s, s_z}$$



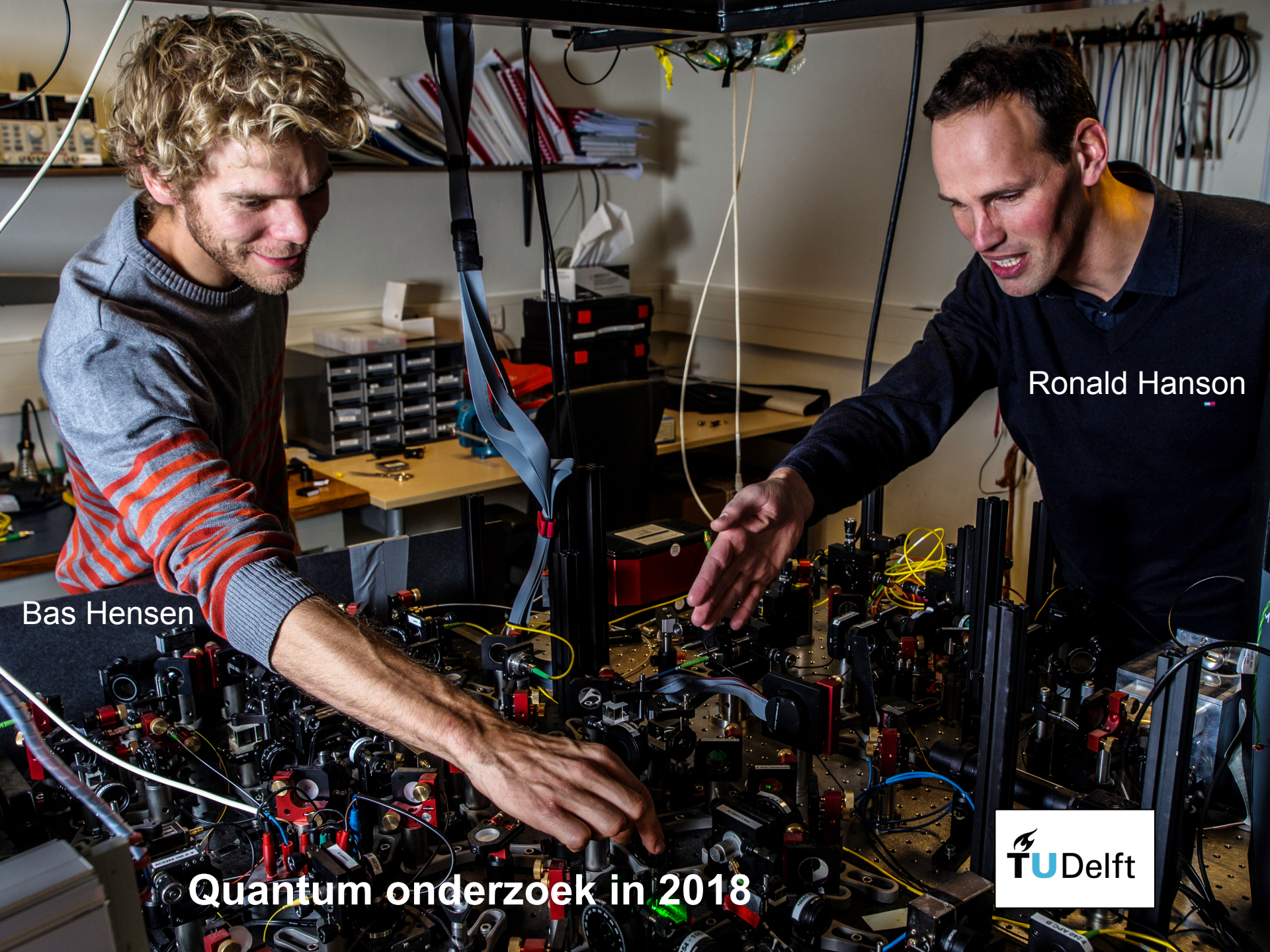
Hoe brandt de zon?

kernkrachten



ITER (fusieractor)





Bas Hensen

Ronald Hanson

Quantum onderzoek in 2018



Het Standaard Model

Drie families van deeltjes en drie quantum krachten

De (drie) elementaire deeltjes



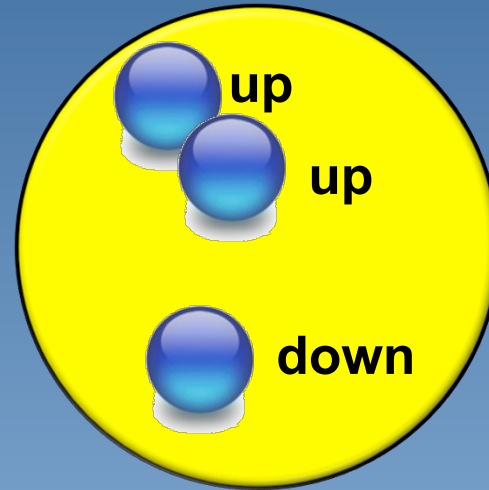
up



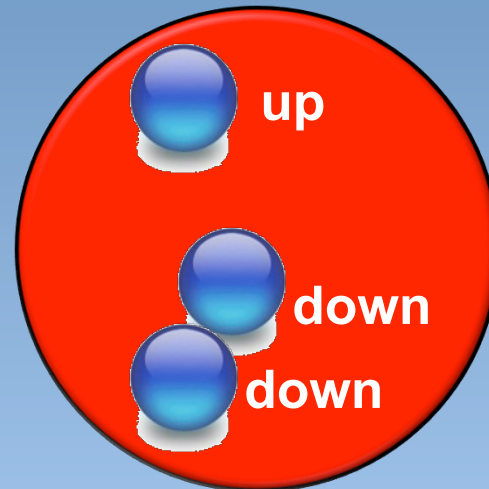
down



elektron















Proton



Neutron

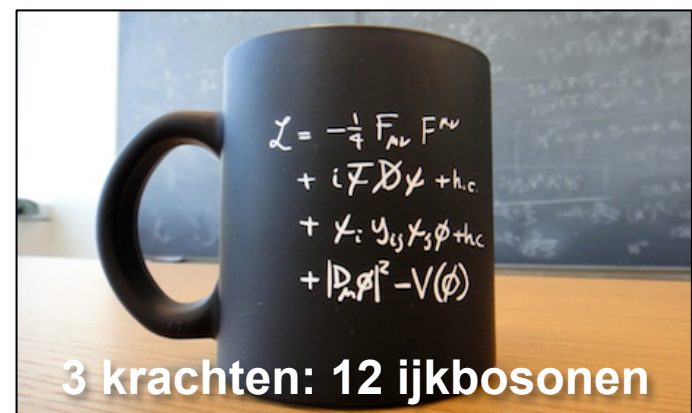
Het Standaard Model

Elementaire deeltjes

up-quark			
down-quark			
elektron			
neutrino			

muon

Interacties



Er is meer tussen hemel en aarde

antenne

“Er zweven electromagnetische golven in deze zaal die stemmen en beelden bevatten”

radio



Er is meer tussen hemel en aarde

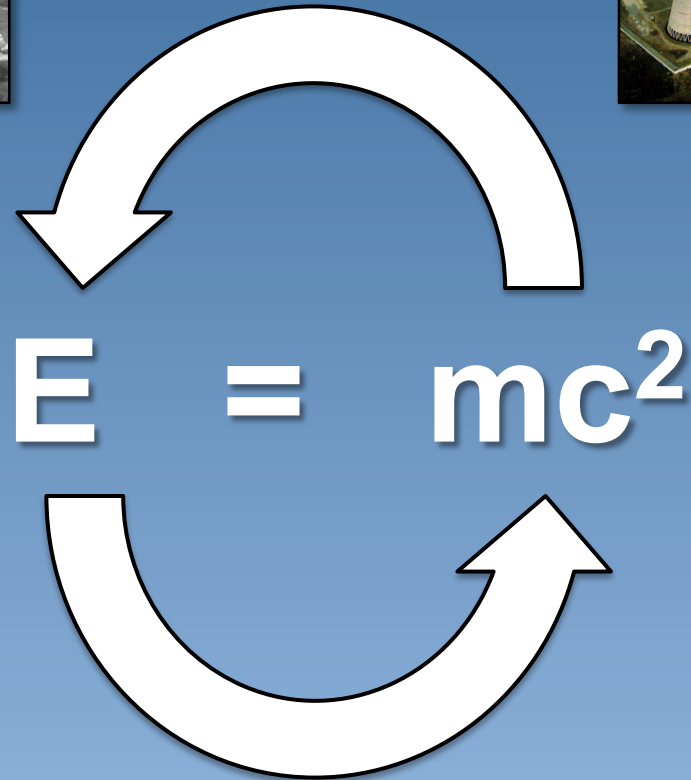


“Er schieten exotische deeltjes door de Beurs van Berlage die 0.000002 seconde leven”

“Ze worden gemaakt als kosmische stralen op luchtmoleculen botsen in de atmosfeer”

Deeltjesversnellers

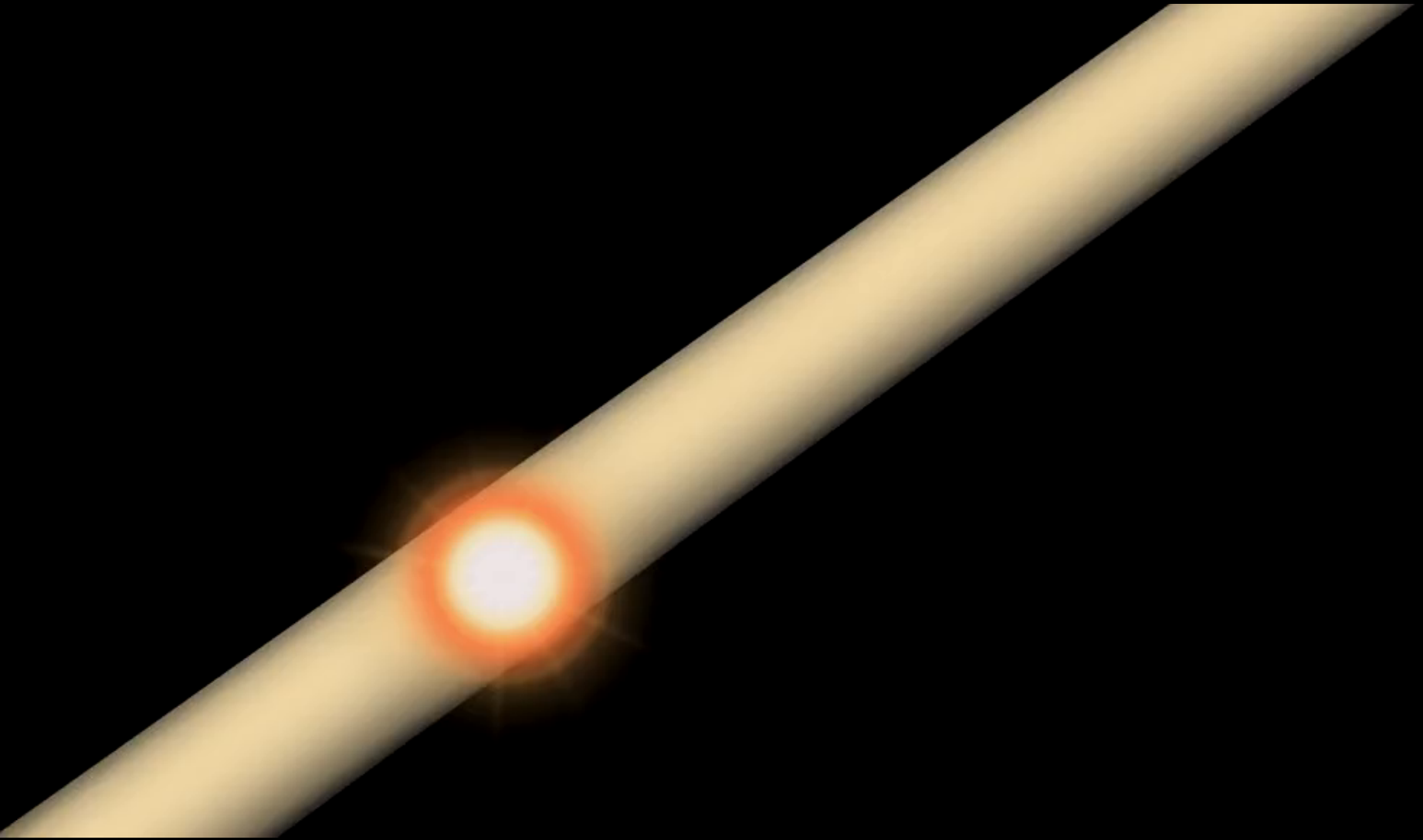
zelf deeltjes maken

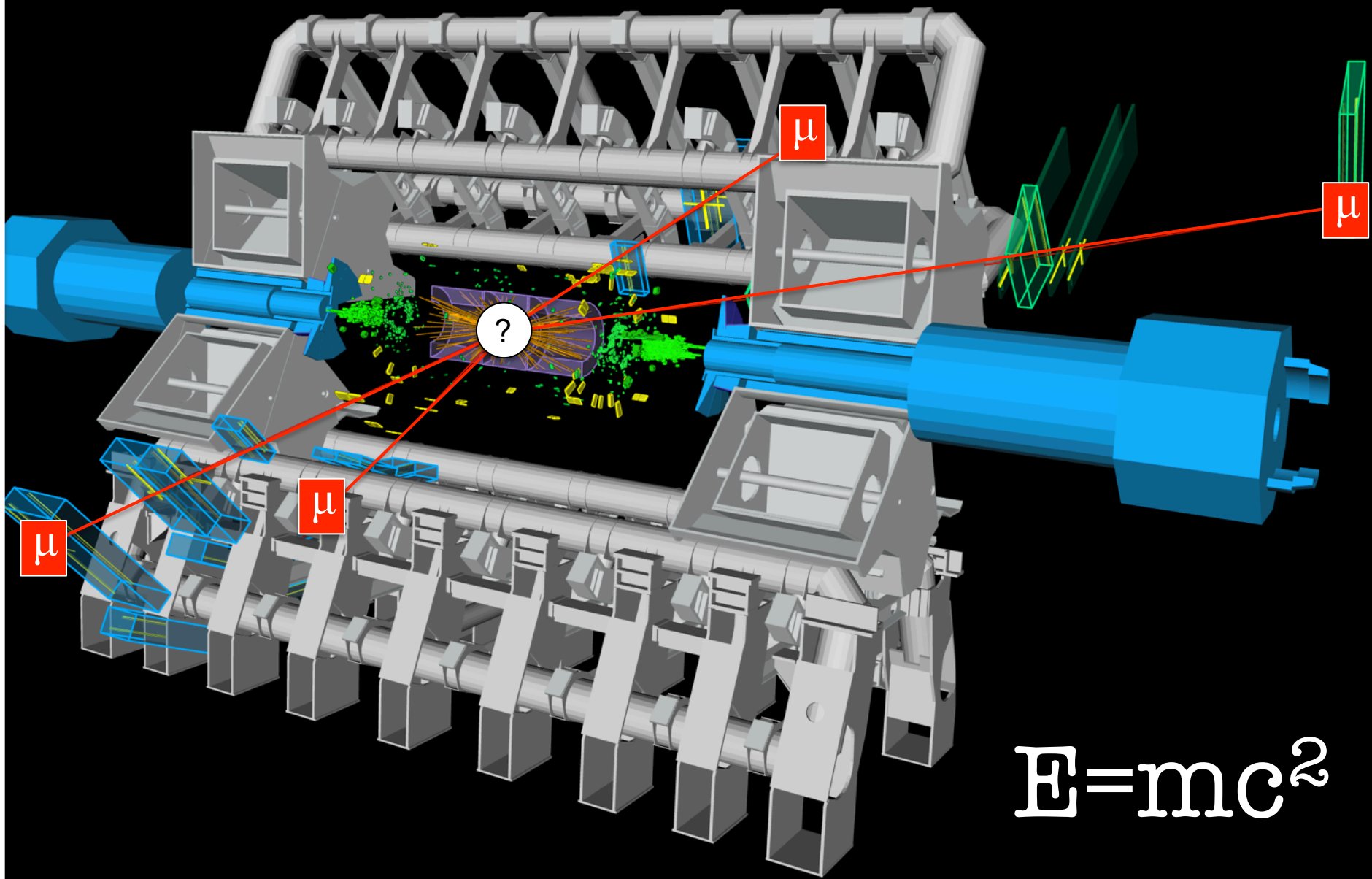


An aerial photograph of the Geneva region in Switzerland. In the background, there are snow-capped mountains and a large lake. The foreground shows a patchwork of green fields and some buildings. A red oval is drawn around a central area of the landscape, indicating the location of the Large Hadron Collider (LHC) tunnel. The text 'Nieuwe deeltjes maken' is overlaid in white on this oval.

Nieuwe deeltjes maken

De Large Hadron Collider (LHC)
op CERN bij Genève



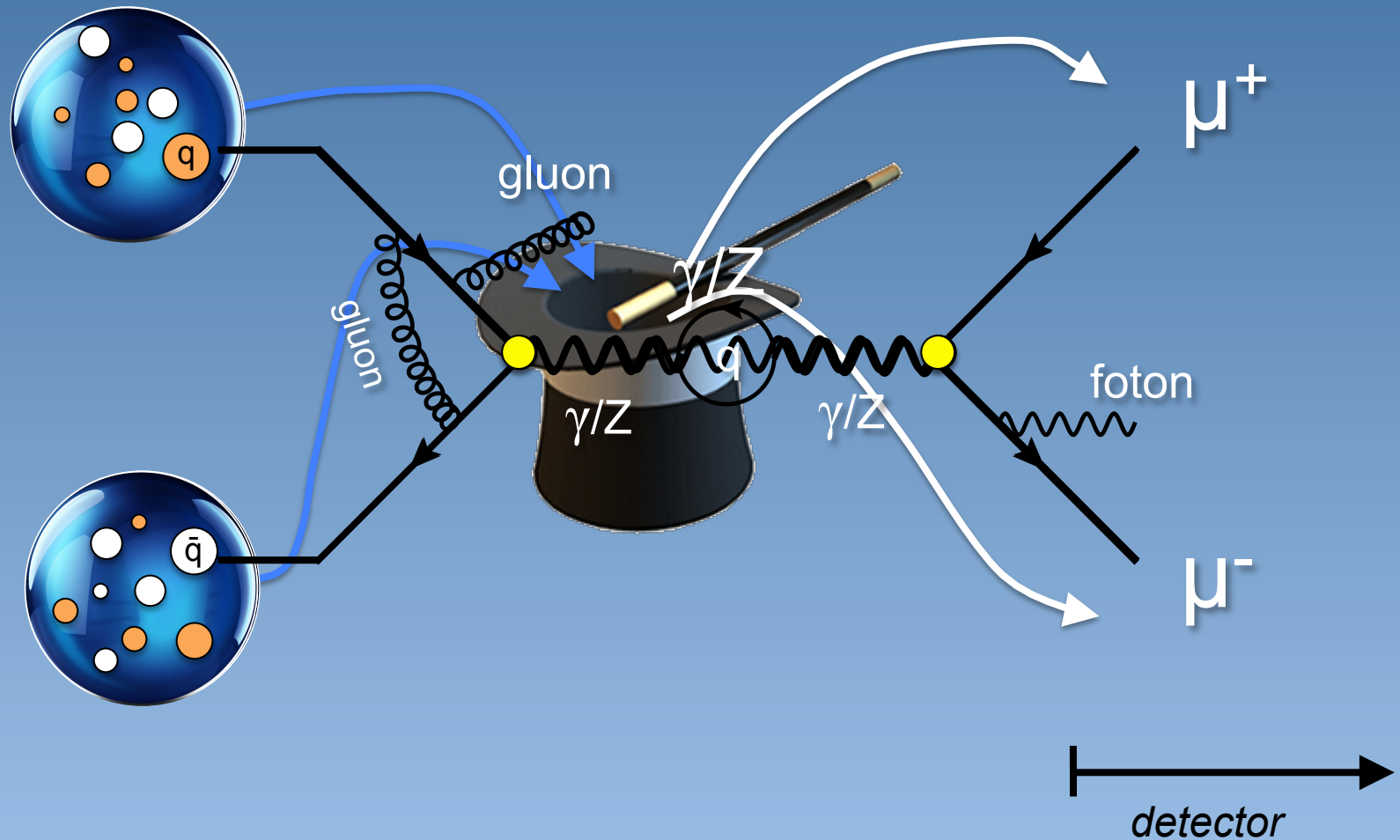


$$E=mc^2$$

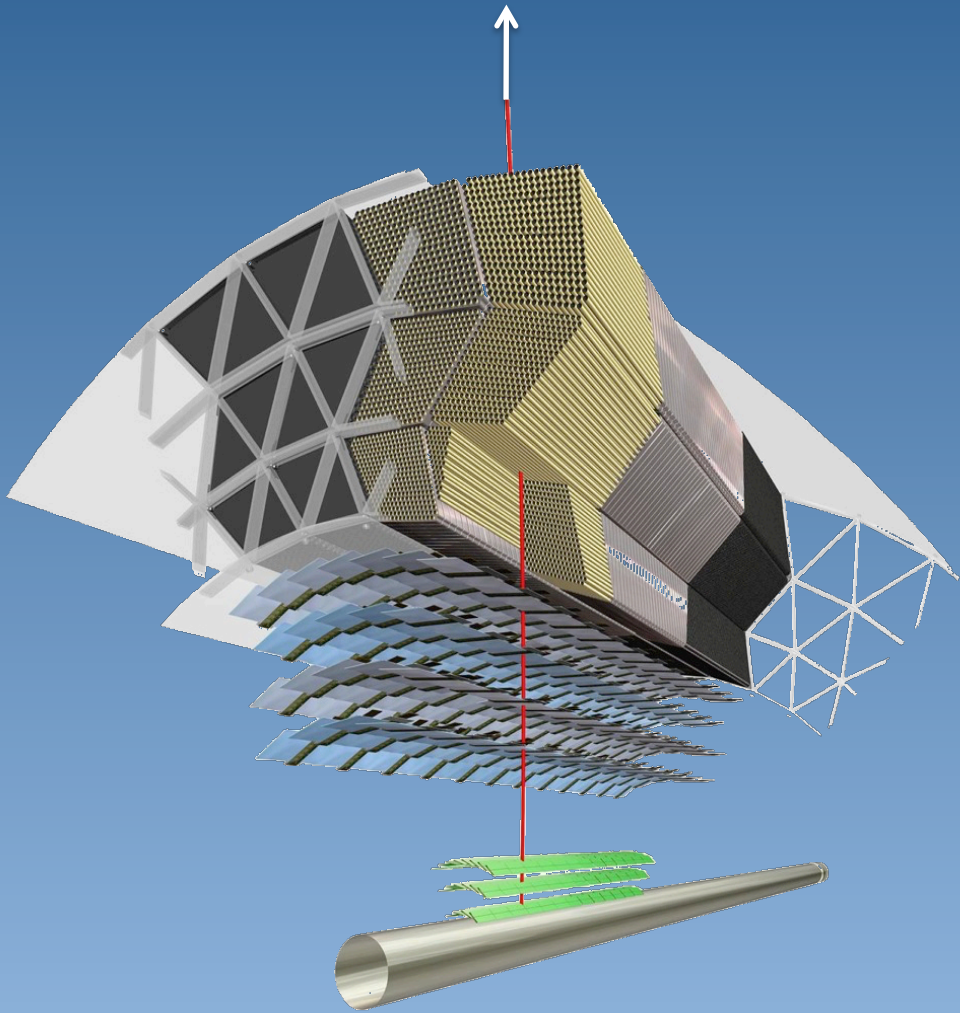
Iets reconstrueren uit overblijfselen



Overgangen in het Standaard Model



muon of electron ?

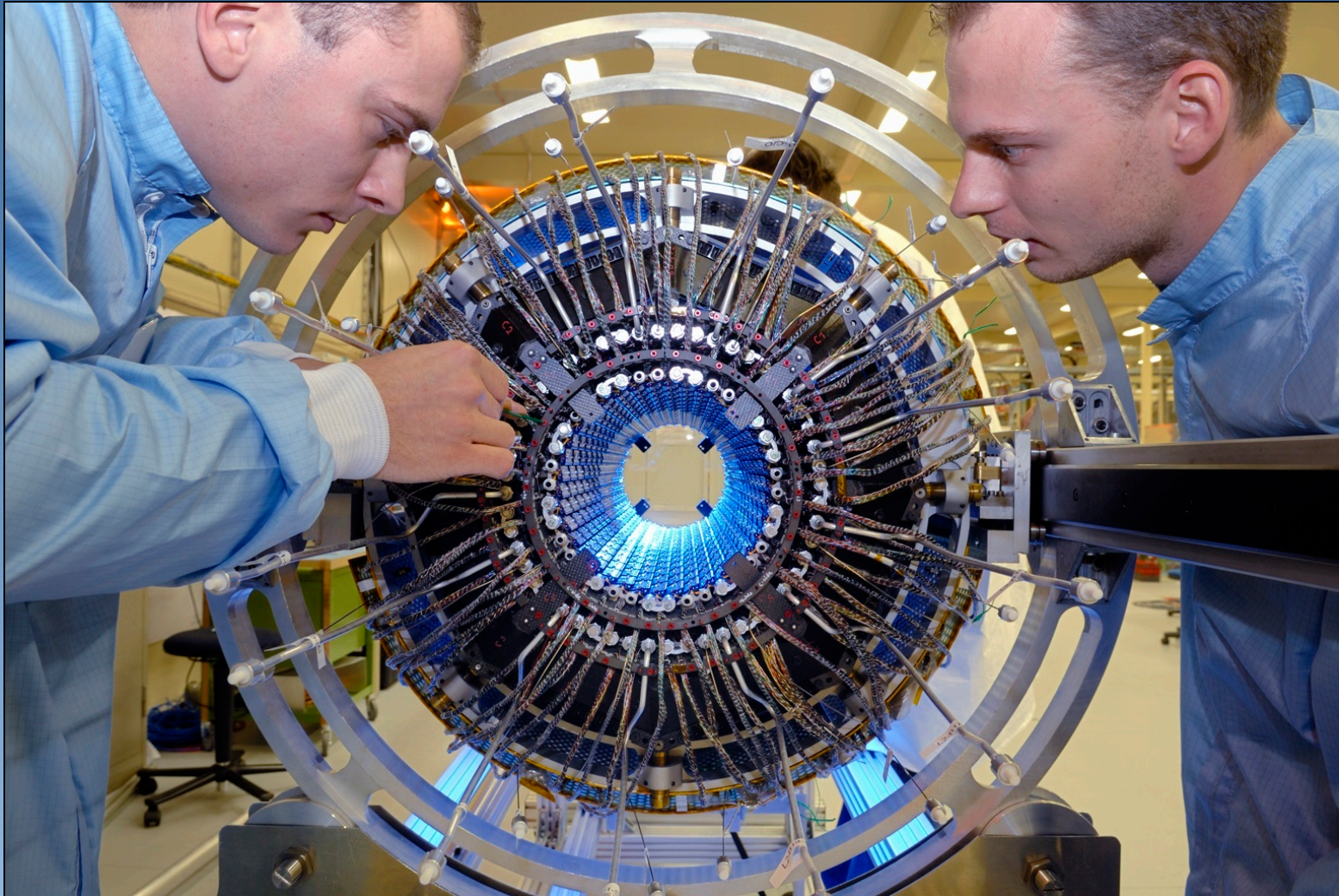


Identificatie

konijn of mens ?



The Atlas pixel detector



80 MegaPixel camera

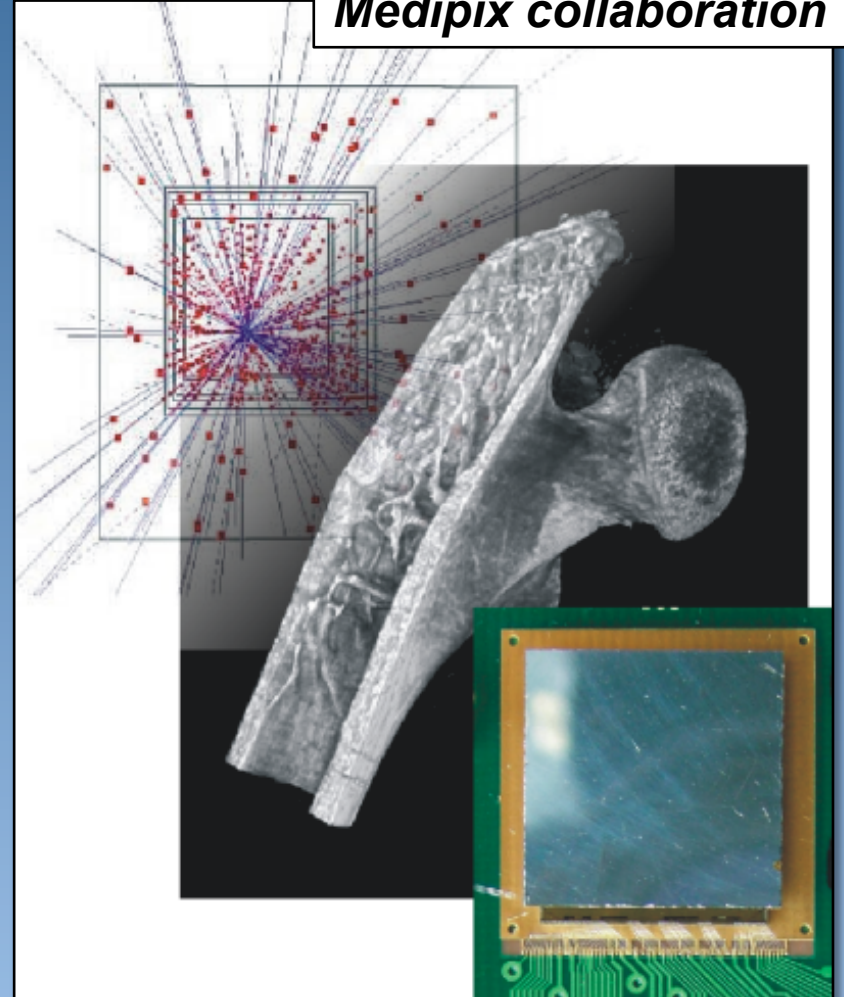
1.000.000.000 pictures per second

Deeltjes(versnellers) in het ziekenhuis

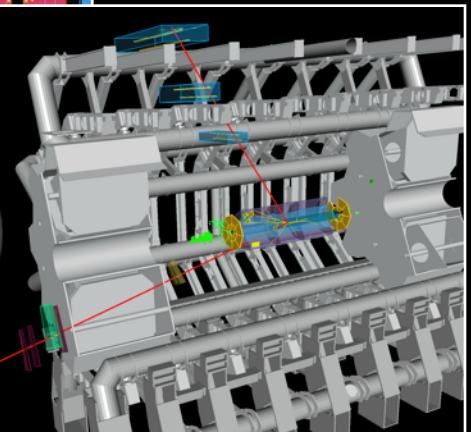
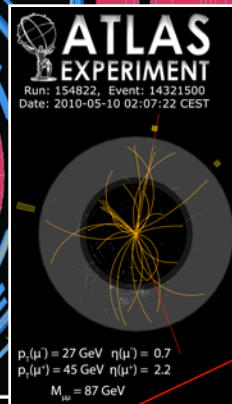
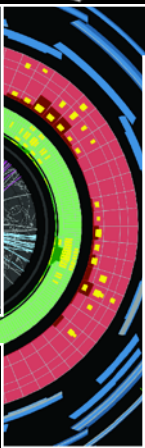
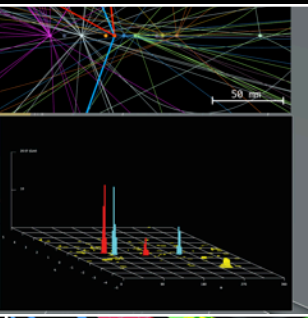
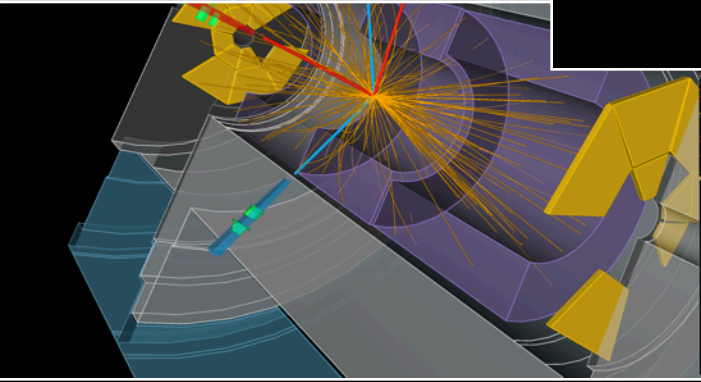
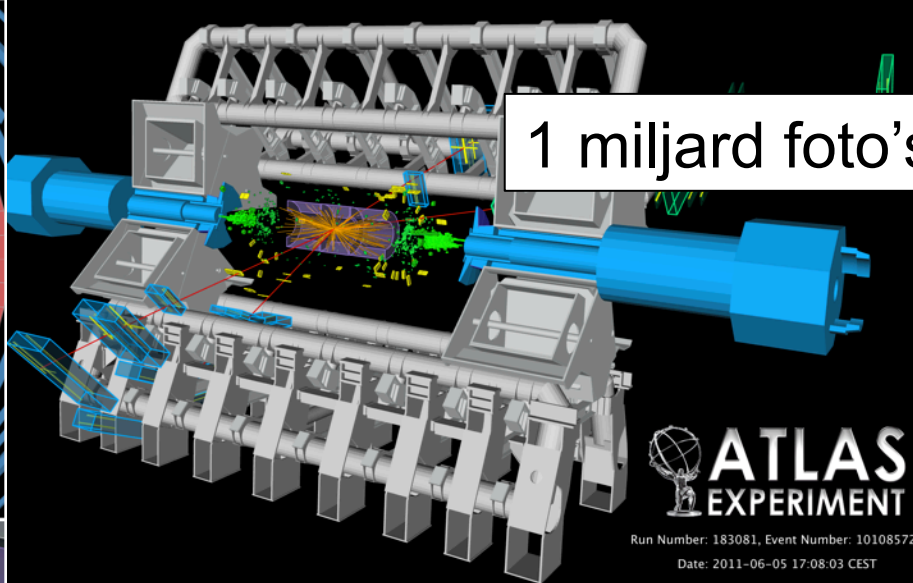
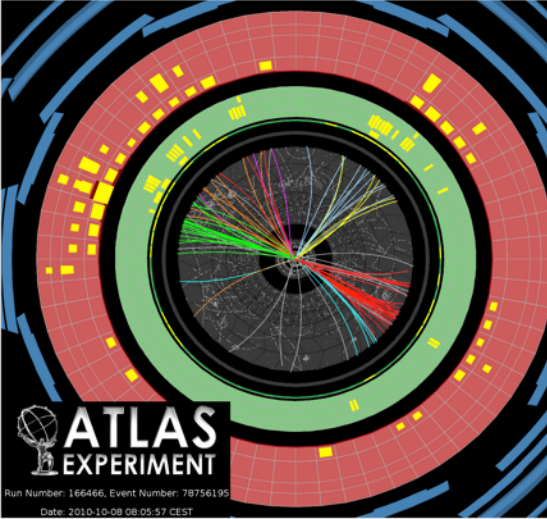
Röntgen



Medipix collaboration

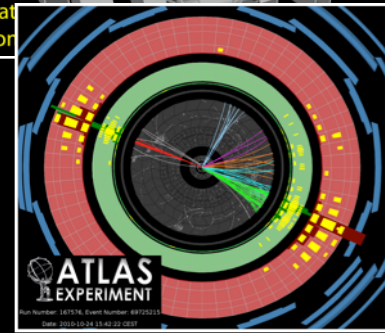
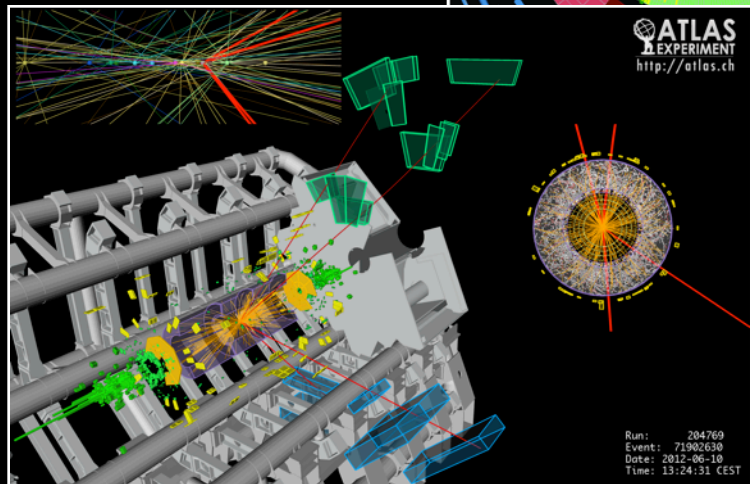


1 miljard foto's per seconde



$p_{T}(\mu^+) = 27 \text{ GeV}$ $\eta(\mu^+) = 0.7$
 $p_{T}(\mu^-) = 45 \text{ GeV}$ $\eta(\mu^-) = 2.2$
 $M_{\mu\mu} = 87 \text{ GeV}$

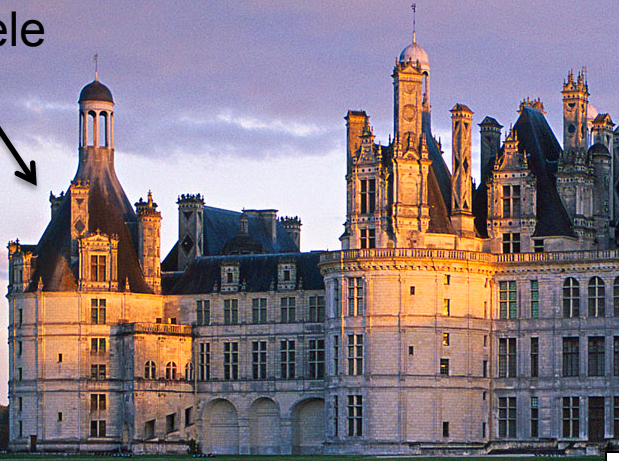
Z → μμ candidate
 in 7 TeV collision



Higgs boson

deeltjes

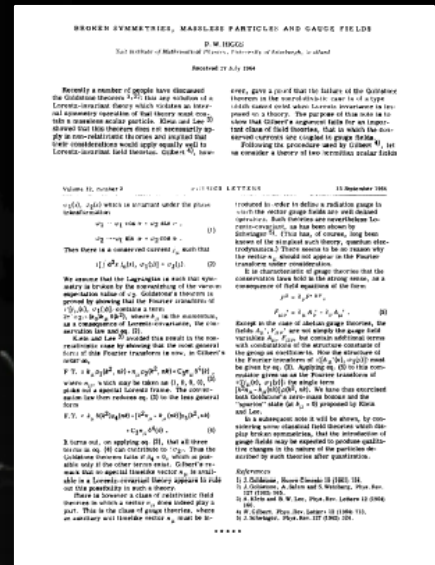
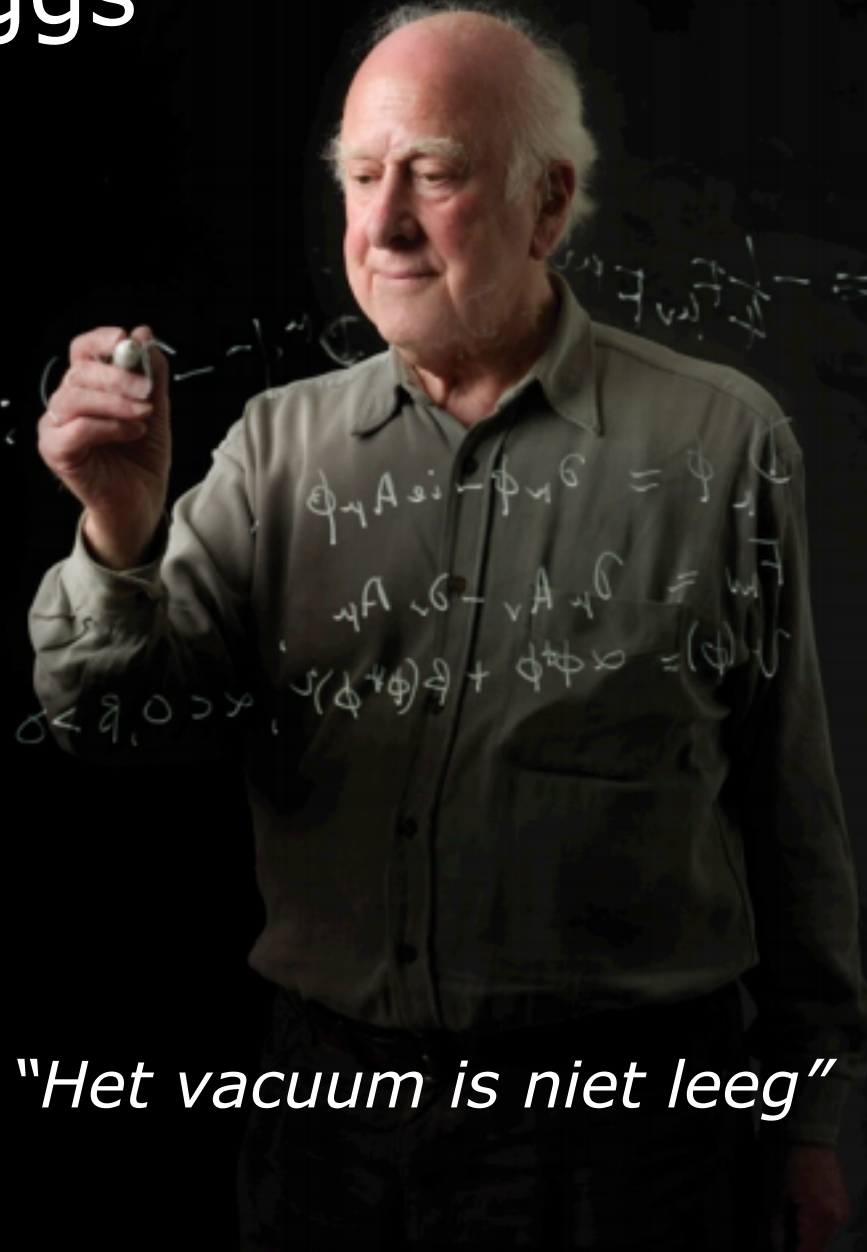
de stabiele
wereld



Het Standaard Moed



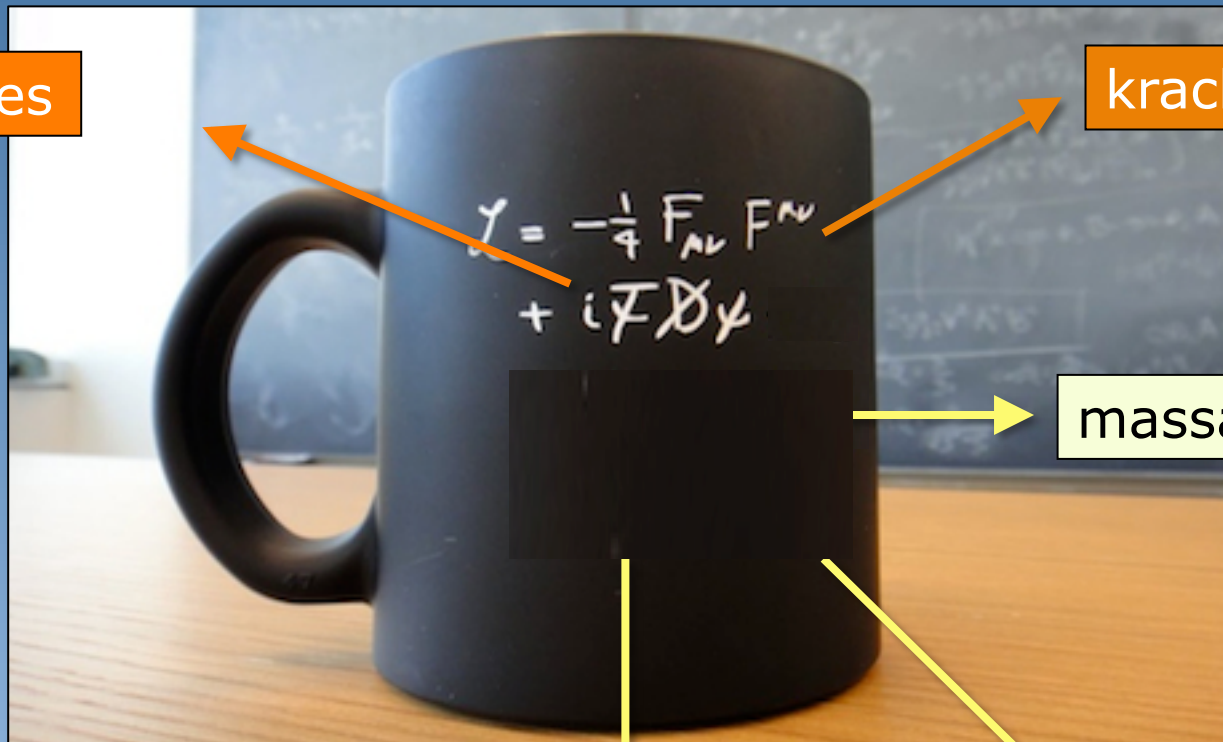
Peter Higgs



1964, 1 pagina

"Het vacuum is niet leeg"

Structuur Standaard Model



interacties

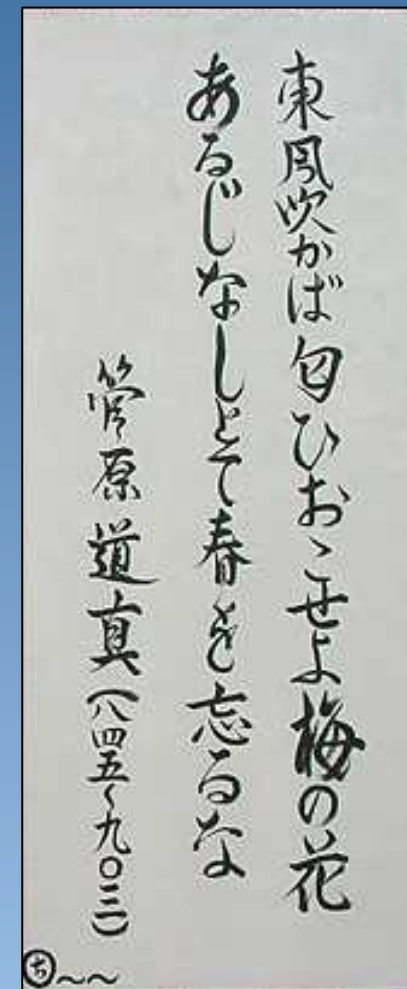
krachtdeeltjes

massa fermionen

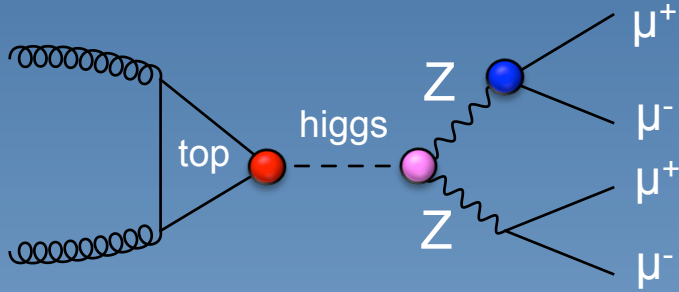
massa krachtdeeltjes

Higgs boson

Nieuwe taal ... nieuwe inzichten ?



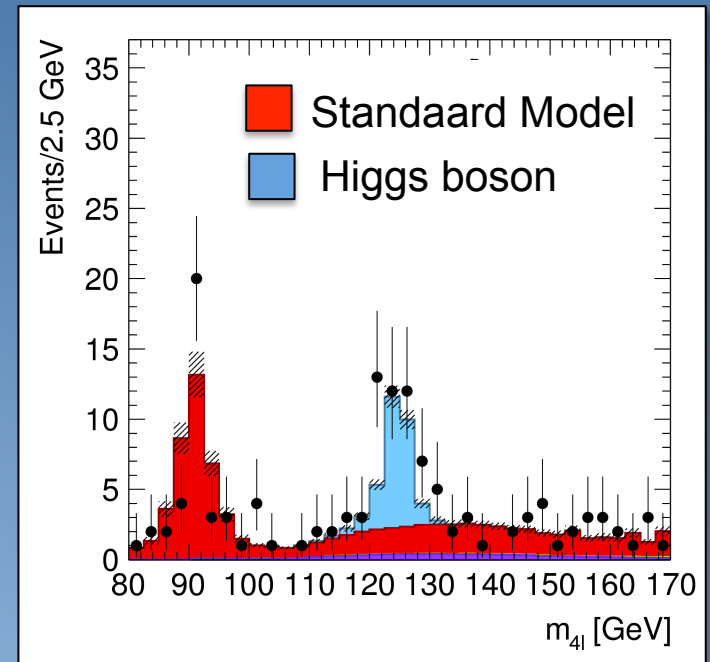
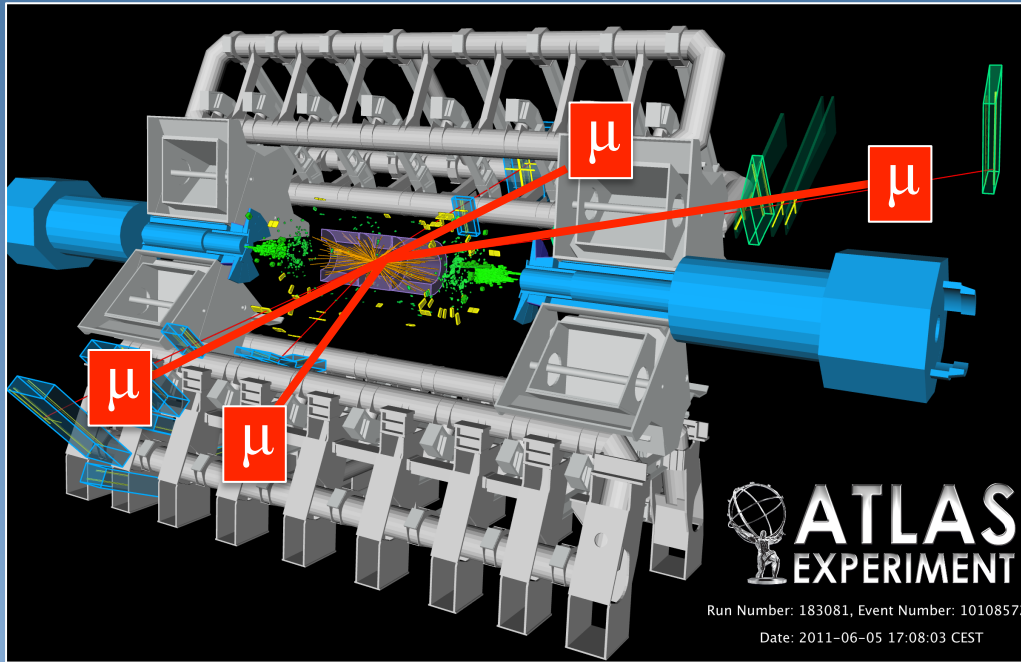
Higgs boson



Standard Model Lagrangiaan

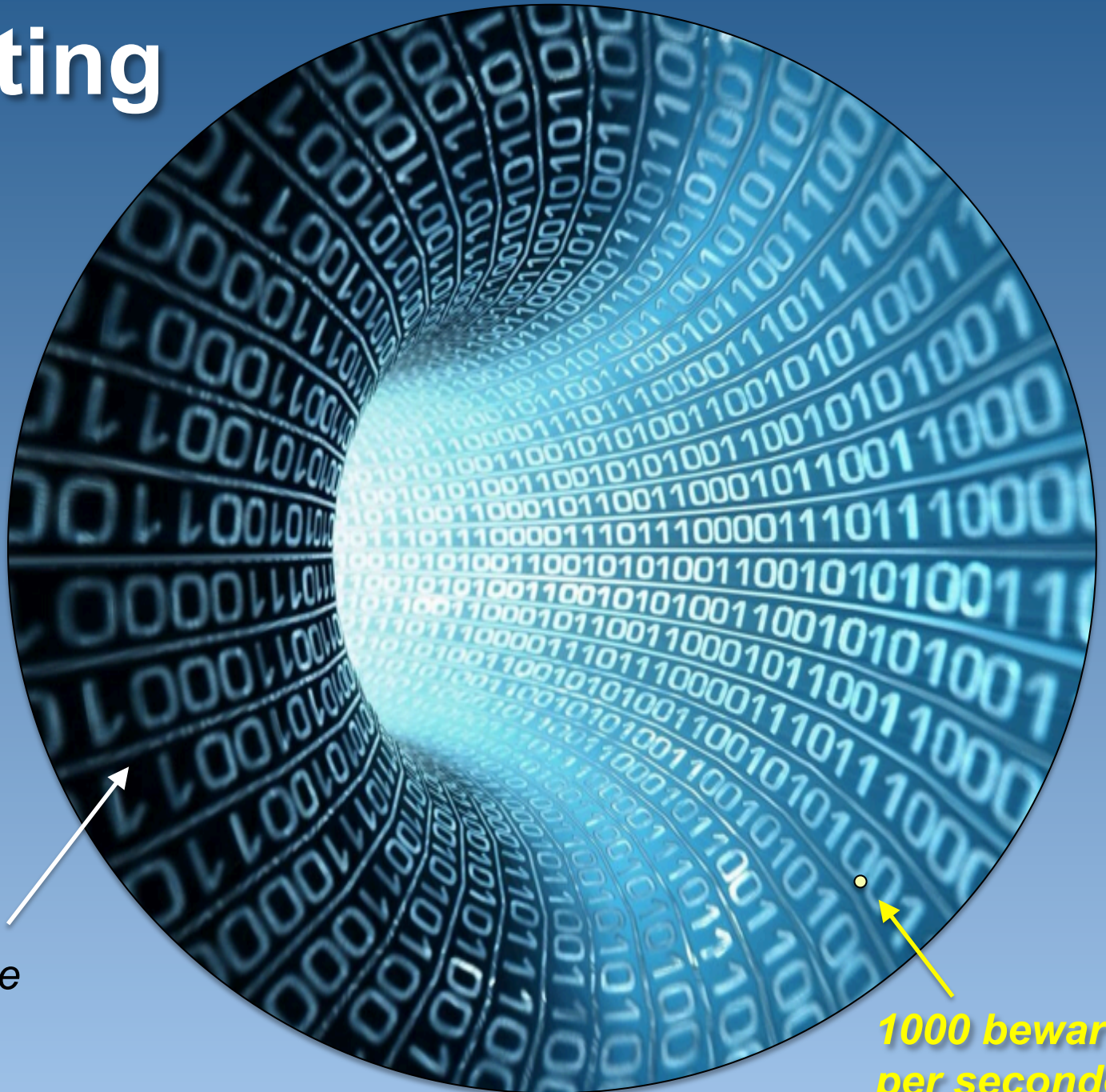
$$\begin{aligned}
 \mathcal{L}_{\text{SM}} = & -\frac{1}{2}(\partial_\mu W_\nu^+ - \partial_\nu W_\mu^+)(\partial^\mu W^{-\nu} - \partial^\nu W^{\mu-}) - \frac{1}{4}(\partial_\mu Z_\nu - \partial_\nu Z_\mu)^2 - \frac{1}{4}(\partial_\mu A_\nu - \partial_\nu A_\mu)^2 \\
 & - \frac{1}{4}(\partial_\mu G_\nu^a - \partial_\nu G_\mu^a)^2 + i\frac{g^2}{\sqrt{g^2 + g'^2}}(g^{\alpha\gamma}g^{\beta\delta} - g^{\alpha\delta}g^{\beta\gamma})(W_\gamma^- Z_\delta \partial_\alpha W_\beta^+ + Z_\gamma W_\delta^+ \partial_\alpha W_\beta^- \\
 & + W_\gamma^+ W_\delta^- \partial_\alpha Z_\beta) + i\frac{gg'}{\sqrt{g^2 + g'^2}}(g^{\alpha\gamma}g^{\beta\delta} - g^{\alpha\delta}g^{\beta\gamma})(W_\gamma^- A_\delta \partial_\alpha W_\beta^+ + A_\gamma W_\delta^+ \partial_\alpha W_\beta^- \\
 & + W_\gamma^+ W_\delta^- \partial_\alpha A_\beta) - g_s f^{abc} G_\mu^a G_\nu^b \partial^\mu G^{c\nu} + \frac{g^2 g'^2}{g^2 + g'^2}(g^{\alpha\gamma}g^{\beta\delta} - g^{\alpha\beta}g^{\gamma\delta})W_\alpha^+ W_\beta^- A_\gamma A_\delta \\
 & + \frac{g^4}{g^2 + g'^2}(g^{\alpha\gamma}g^{\beta\delta} - g^{\alpha\beta}g^{\gamma\delta})W_\alpha^+ W_\beta^- Z_\gamma Z_\delta + g^2(g^{\alpha\beta}g^{\gamma\delta} - g^{\alpha\gamma}g^{\beta\delta})W_\alpha^+ W_\beta^+ W_\gamma^- W_\delta^- \\
 & + \frac{g^3 g'}{g^2 + g'^2}(g^{\alpha\delta}g^{\beta\gamma} + g^{\alpha\gamma}g^{\beta\delta} - 2g^{\alpha\beta}g^{\gamma\delta})W_\alpha^+ W_\beta^- A_\gamma Z_\delta - \frac{1}{4}g_s^2 f^{rab} f^{rcd} G_\mu^a G_\nu^b G^{c\mu} G^{d\nu} \\
 & + i\bar{\psi}_e \gamma_\mu \partial^\mu \psi_e + i\bar{\psi}_{\nu_L} \gamma_\mu \partial^\mu \psi_{\nu_L} + i\sum_n \bar{\psi}_{q_n} \gamma_\mu \partial^\mu \psi_{q_n} - \frac{gg'}{\sqrt{g^2 + g'^2}}\bar{\psi}_e \gamma_\mu A^\mu \psi_e \\
 & + \frac{g}{\sqrt{2}}(\bar{\psi}_{\nu_L} \gamma_\mu W^{+\mu} \psi_{e_L} + \bar{\psi}_{e_L} \gamma_\mu W^{-\mu} \psi_{\nu_L}) + \frac{1}{2}\sqrt{g^2 + g'^2}\bar{\psi}_{\nu_L} \gamma_\mu Z^\mu \psi_{\nu_L} \\
 & + \frac{1}{2}\sqrt{g^2 + g'^2}\left(\bar{\psi}_e \gamma_\mu Z^\mu \left[\frac{2g'^2}{g^2 + g'^2} - \frac{1}{2}(1 - \gamma_5)\right] \psi_e\right) + g_s \sum_n \bar{\psi}_{q_n} G_\mu^a \gamma^\mu t^a \psi_{q_n} \\
 & + g \sum_{I,i} (\bar{\psi}_{q_i} \gamma_\mu W^{+\mu} \psi_{q_{iL}} V_{Ii}^+ + \bar{\psi}_{q_i} \gamma_\mu W^{-\mu} \psi_{q_{iL}} V_{iI}) + \frac{gg'}{\sqrt{g^2 + g'^2}} \sum_n Q_n \bar{\psi}_{q_n} \gamma_\mu A^\mu \psi_{q_n} \\
 & + \frac{1}{2}\sqrt{g^2 + g'^2} \sum_I \left(\bar{\psi}_{q_i} \gamma_\mu Z^\mu \left[\frac{1}{2}(1 - \gamma_5) - \frac{2Q_I g'^2}{g^2 + g'^2}\right] \psi_{q_i}\right) \\
 & + \frac{1}{2}\sqrt{g^2 + g'^2} \sum_i \left(\bar{\psi}_{q_i} \gamma_\mu Z^\mu \left[-\frac{1}{2}(1 - \gamma_5) - \frac{2Q_i g'^2}{g^2 + g'^2}\right] \psi_{q_i}\right) \\
 & + \frac{1}{2}(\partial_\mu \phi)^2 - \frac{1}{2}m_h^2 \phi^2 + \frac{1}{4}v^2 g^2 W_\mu^+ W^{-\mu} + \frac{1}{8}v^2 (g^2 + g'^2) Z_\mu^2 + \frac{1}{2}v g^2 \phi W_\mu^+ W^{-\mu} \\
 & - \frac{1}{4}v(g^2 + g'^2)\phi Z_\mu^2 + \frac{1}{4}g^2 \phi^2 (W_\mu^+ W^{-\mu} + 2Z_\mu^2) - \frac{m_h^2}{2v}\phi^3 - \frac{m_h^2}{8v^2}\phi^4 \\
 & - m_e \bar{\psi}_e \psi_e - \sum_n m_n \bar{\psi}_{q_n} \psi_{q_n} - \frac{m_e}{v}\phi \bar{\psi}_e \psi_e - \frac{1}{v} \sum_n m_n \phi \bar{\psi}_{q_n} \psi_{q_n}
 \end{aligned}$$

Higgs boson verval: 4 muonen



Yes, ... gevonden!

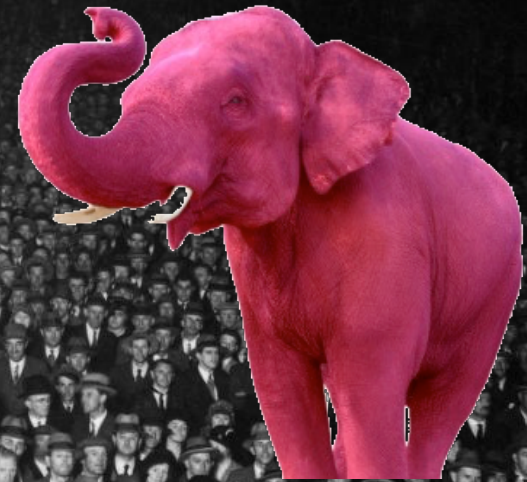
computing



1.000.000.000
foto's per seconde

1000 bewaren
per seconde

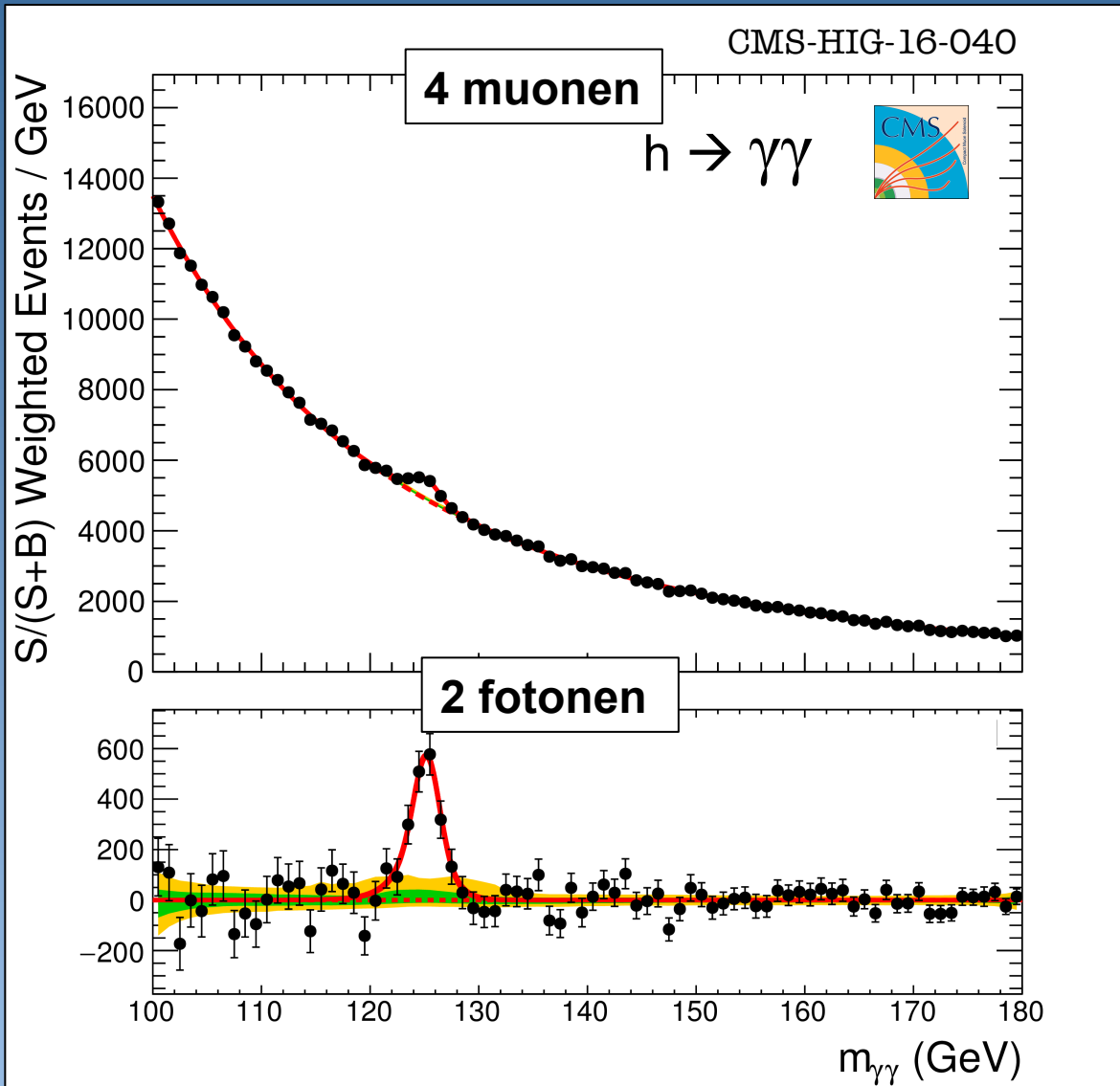
4 muonen



Liu Bolin

Of is het verstopt in de achtergrond ?

CMS resultaat: even genieten



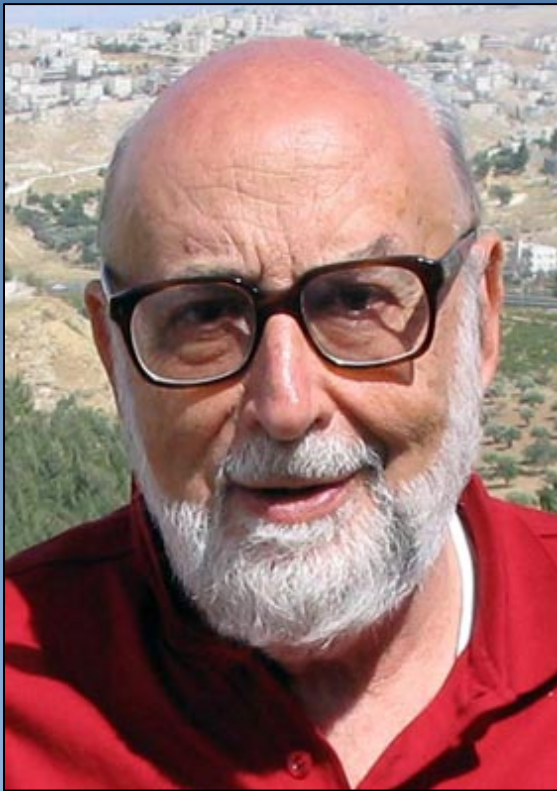
@freyablekman

An underwater photograph looking up towards the surface of the ocean. Sunlight filters through the water, creating a shimmering, dappled pattern of light and dark blue. The water's surface is visible at the top, with ripples and bright reflections of the sun. The overall color palette is various shades of blue, from deep navy to bright cyan.

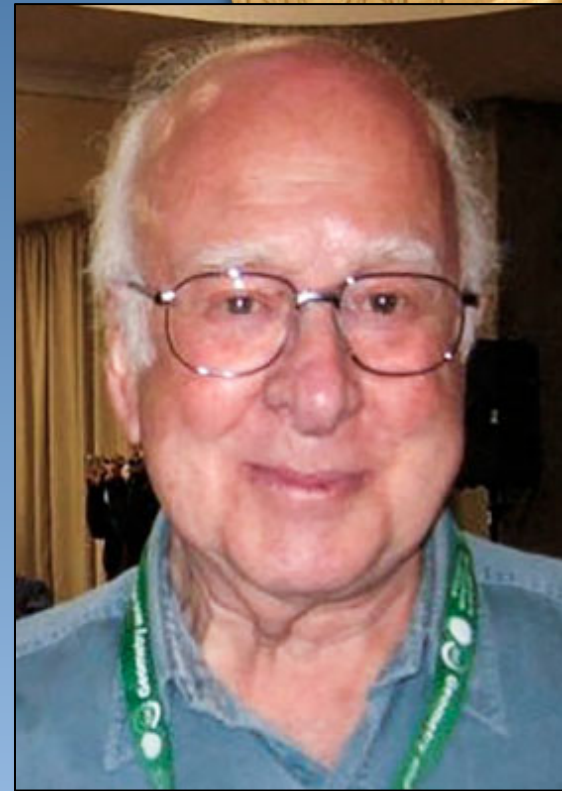
Elke m^3 ruimte zit vol met Higgs veld

Nobelprijs natuurkunde 2013

“Er is een Higgs-veld in het vacuüm”



François Englert















Peter Higgs

de problemen

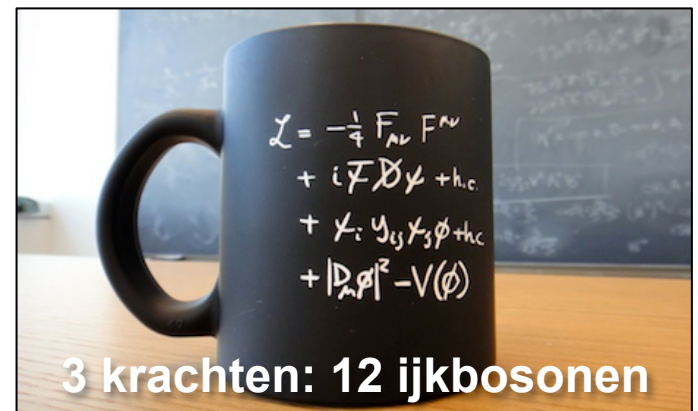


Het Standaard Model

Elementaire deeltjes

up-quark			
down-quark			
elektron			
neutrino			

Interacties





Paar 'kleine' dingetjes:

1

80% van alle massa in het heelal is onbekend

2

Waar is alle anti-materie gebleven?

3

Problemen met het Higgs boson

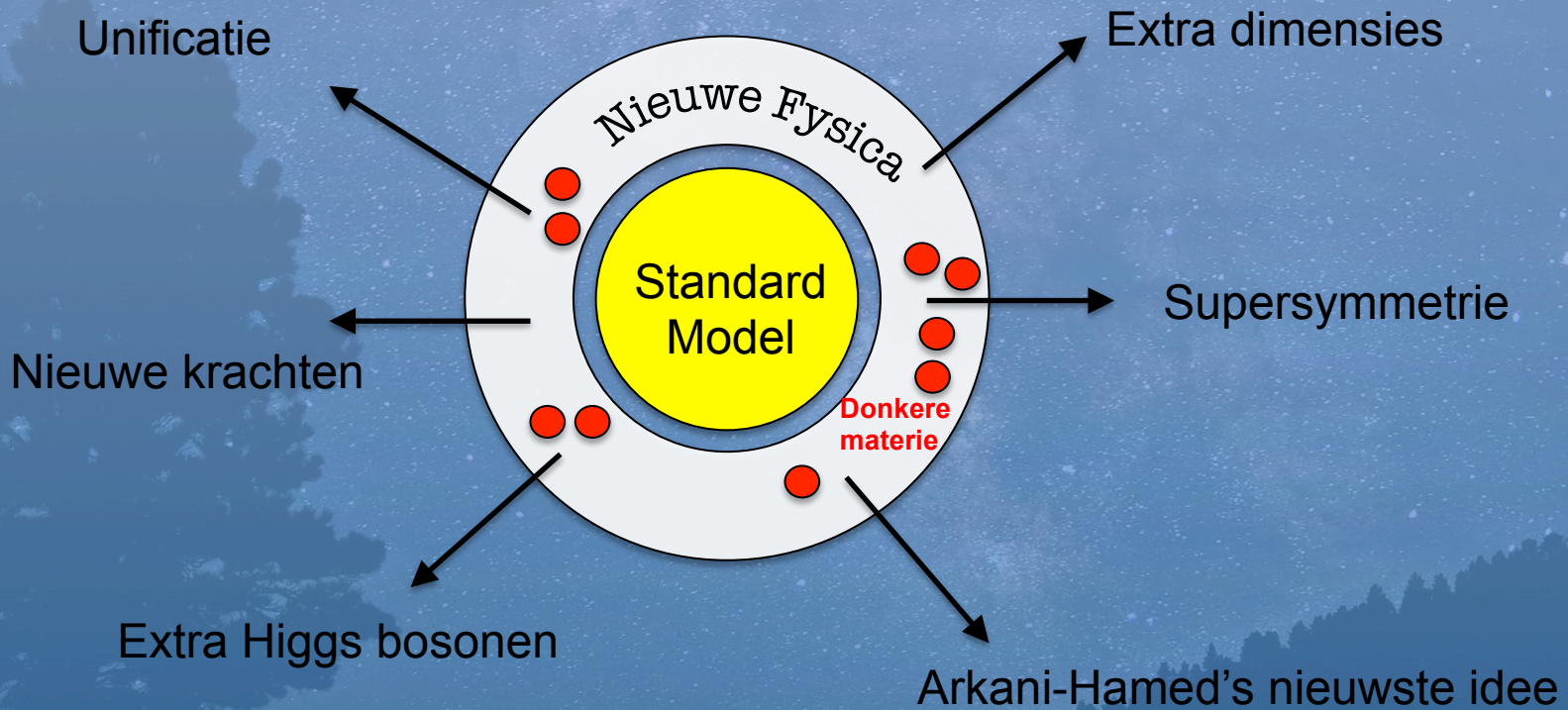
4

Waarom is de zwaartekracht zo zwak?

5

drie families, kracht-unificatie, patronen, ...

Standaard Model is niet de ultieme theorie



Nieuwe deeltjes, nieuwe krachten, nieuwe fenomenen

avontuur



de avonturiers



Sascha Caron

Supersymmetrie



Freya Blekman

top quarks



Tristan du Pree

Higgs-boson

3

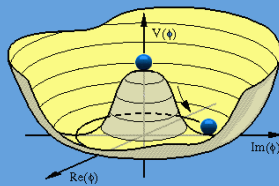
Het massa-mysterie: Higgs boson



“Het Higgs veld is overal in de lege ruimte”

Uitbreiding Higgs sector

Standaard Model



SM-doublet &
 $V(\phi) = \mu^2\phi^2 + \lambda\phi^4$

Standaard Model:
 1 doublet, CP-even neutral scalar

(1) compositeness



(2) extra EW singlet



(3) Two Higgs doublet models



h A H H^+ H^-

(4) Dark Matter portal

Invisible Higgs decays

Coupling scale factor	Type I	Type II	Type III	Type IV
κ_V	$\sin(\beta - \alpha)$	$\sin(\beta - \alpha)$	$\sin(\beta - \alpha)$	$\sin(\beta - \alpha)$
κ_u	$\cos(\alpha) / \sin(\beta)$	$\cos(\alpha) / \sin(\beta)$	$\cos(\alpha) / \sin(\beta)$	$\cos(\alpha) / \sin(\beta)$
κ_d	$\cos(\alpha) / \sin(\beta)$	$-\sin(\alpha) / \cos(\beta)$	$\cos(\alpha) / \sin(\beta)$	$-\sin(\alpha) / \cos(\beta)$
κ_l	$\cos(\alpha) / \sin(\beta)$	$-\sin(\alpha) / \cos(\beta)$	$-\sin(\alpha) / \cos(\beta)$	$\cos(\alpha) / \sin(\beta)$

specific couplings to fermions/bosons

Wereldkampioenen rekenen



Jos Vermaseren

$$\gamma_{L,1}^{(3)}(N) = 16 \left(-353/48 + 11917/864 D_1^2 + 15689/324 D_1^3 + 433/72 D_1^4 + 19/3 D_1^5 + 5/3 D_1^6 \right. \\ - 112979/2592 \eta + 13405/648 \eta^2 - 8045/1296 \eta^3 - 61/18 \eta^4 - 1/2 \eta^5 - 5/6 \eta^6 - 5 \zeta_5 \\ - 15 \zeta_5 \eta + 10 \zeta_5 \eta^2 - 33/8 \zeta_4 - 11/4 \zeta_4 \eta + 235/16 \zeta_3 + 8/3 \zeta_3 D_1^2 + 2 \zeta_3 D_1^3 + 83/8 \zeta_3 \eta \\ + 3/2 \zeta_3 \eta^2 + 2/3 \zeta_3 \eta^3 - 39883/1296 S_1 + 19009/324 S_1 D_1^2 + 77/9 S_1 D_1^3 + 79/6 S_1 D_1^4 \\ + 20/3 S_1 D_1^5 - 19927/324 S_1 \eta + 1453/81 S_1 \eta^2 - 7/24 S_1 \eta^3 + 38/9 S_1 \eta^4 + 3 S_1 \eta^5 \\ + 10 S_1 \zeta_5 + 11/2 S_1 \zeta_4 - 317/12 S_1 \zeta_3 + 4 S_1 \zeta_3 D_1^2 + 8/3 S_1 \zeta_3 \eta - 8/3 S_1 \zeta_3 \eta^2 - 4 S_1 \zeta_3 \eta^3 \\ + 85175/2592 S_2 - 1873/54 S_2 D_1^2 - 20/3 S_2 D_1^3 - 4 S_2 D_1^4 + 4943/648 S_2 \eta + 95/216 S_2 \eta^2 \\ + 229/36 S_2 \eta^3 + 25/6 S_2 \eta^4 + 2/3 S_2 \zeta_3 + 2 S_2 \zeta_3 \eta - 4 S_2 \zeta_3 \eta^2 - 22247/648 S_3 + 241/18 S_3 D_1^2 \\ + 2/3 S_3 D_1^3 - 113/54 S_3 \eta + 37/18 S_3 \eta^2 + 19/6 S_3 \eta^3 - 8/3 S_3 \zeta_3 + 725/24 S_4 - 16/3 S_4 D_1^2 \\ - 73/36 S_4 \eta + 5/3 S_4 \eta^2 - 46/3 S_4 + 8/3 S_4 \eta + 20/3 S_6 + 8/3 S_{1,1} D_1^2 + 8/3 S_{1,1} D_1^3 + 8 S_{1,1} D_1^4 \\ + 4/3 S_{1,1} \eta + 9/4 S_{1,1} \eta^2 - 12 S_{1,1} \eta^3 - 14/3 S_{1,1} \eta^4 - 8 S_{1,1} \zeta_3 \eta + 8 S_{1,1} \zeta_3 \eta^2 + 6673/324 S_{1,2} \\ - 28/3 S_{1,2} D_1^2 + 28/3 S_{1,2} \eta - 8/3 S_{1,2} \eta^2 - 8/3 S_{1,2} \eta^3 + 4 S_{1,2} \zeta_3 - 605/54 S_{1,3} + 4/3 S_{1,3} D_1^2 \\ - 14/3 S_{1,3} \eta - 1/3 S_{1,3} \eta^2 + 2 S_{1,3} \eta^3 + 181/18 S_{1,4} + 10/3 S_{1,4} \eta - 16/3 S_{1,5} + 6673/324 S_{2,1} \\ - 28/3 S_{2,1} D_1^2 + 28/3 S_{2,1} \eta - 8/3 S_{2,1} \eta^2 - 8/3 S_{2,1} \eta^3 + 4 S_{2,1} \zeta_3 - 1021/54 S_{2,2} + 4 S_{2,2} D_1^2 \\ + 2/3 S_{2,2} \eta - 2 S_{2,2} \eta^2 + 181/18 S_{2,3} - 8/3 S_{2,3} \eta + 2 S_{2,3} \eta^2 - 2 S_{2,4} - 479/18 S_{3,1} \\ + 16/3 S_{3,1} D_1^2 + 59/9 S_{3,1} \eta - 2 S_{3,1} \eta^2 - 2 S_{3,1} \eta^3 + 275/18 S_{3,2} - 10/3 S_{3,2} \eta - 22/3 S_{3,3} \\ + 343/18 S_{4,1} - 4/3 S_{4,1} \eta - 2 S_{4,1} \eta^2 - 12 S_{4,2} - 12 S_{5,1} + 4 S_{1,1,3} \eta - 4 S_{1,1,3} \eta^2 - 20/3 S_{1,1,4} \\ - 20/3 S_{1,2,2} + 4/3 S_{1,2,3} - 94/9 S_{1,3,1} - 20/3 S_{1,3,1} \eta + 4 S_{1,3,1} \eta^2 + 20/3 S_{1,3,2} + 20/3 S_{1,4,1} \\ - 20/3 S_{2,1,2} + 4/3 S_{2,1,3} - 20/3 S_{2,2,1} + 4 S_{2,2,2} + 8/3 S_{2,3,1} - 20/3 S_{3,1,1} + 4/3 S_{3,1,1} \eta \\ + 16/3 S_{3,1,2} + 16/3 S_{3,2,1} + 28/3 S_{4,1,1} + 16/3 S_{1,1,3,1} - 8/3 S_{1,3,1,1} \Big) . \quad (3.7)$$

$$\begin{aligned} & \left[10317600287587322672417525639 \zeta_5 - 22176170947759 \zeta_6 \right] \\ & + C_1^2 C_2^2 \left[-44014119696332728422480000 \zeta_5 - 33508344870 \zeta_6 \right] \\ & + C_1^2 C_2^2 \left[-13762838063490015696346356725691463249848729 \zeta_5 \right. \\ & \quad \left. - 6830915722139930955406722725291852240000000 \zeta_6 \right] \\ & + 15923437134502520764317446141 \zeta_5 - 59290512768143 \zeta_6 + 40278295293893 \zeta_7 \\ & + 234741971713774551586560000 \zeta_5 - 284313229200 \zeta_6 + 42646984380 \zeta_7 \\ & + C_1^2 C_2^2 \left[258914251298466366542816679113637834371 \zeta_5 \right. \\ & \quad \left. - 92035679216332067581789246208000000 \zeta_6 \right] \\ & + 22014640304042236864687668923 \zeta_5 - 59290512768143 \zeta_6 - 1804393628665651 \zeta_7 \\ & + 16767283693841039399040000 \zeta_5 - 189542152800 \zeta_6 - 625489104240 \zeta_7 \\ & + C_1^2 C_2^2 \left[14183627547279601657840082208324742517 \zeta_5 \right. \\ & \quad \left. - 1284300051716686447602065376000000 \zeta_6 \right] \\ & + 2649527312649305104376683 \zeta_5 - 59290512768143 \zeta_6 - 101176031536771 \zeta_7 \\ & + 3862475881756882790400 \zeta_5 - 56826458400 \zeta_6 + 6370476570 \zeta_7 \\ & + n_1 C_1^2 C_2^2 \left[94403012063925170595517180859037562017787057 \zeta_5 \right. \\ & \quad \left. - 31714965852792536579259784081711104000000 \zeta_6 \right] \\ & + 25725252164686212840197 \zeta_5 - 59290512768143 \zeta_6 - 128839202 \zeta_7 \\ & + 86215979503501848000 \zeta_5 - 1563722760600 \zeta_6 - 153153 \zeta_7 \\ & + n_1 n_2 C_1^2 C_2^2 \left[2893023190248781306760837247560962327027 \zeta_5 \right. \\ & \quad \left. - 724780973828615032206903013888000000 \zeta_6 \right] \\ & + 63010566480259446207079 \zeta_5 - 54163986863623 \zeta_6 - 64419601 \zeta_7 \\ & + 5747731969001232000 \zeta_5 - 104281840400 \zeta_6 - 459459 \zeta_7 \\ & + n_1 C_1^2 C_2^2 C_3^2 \left[6747367121955880468279822790325451 \zeta_5 \right. \\ & \quad \left. - 993803611447435941596860416000000 \zeta_6 - 766564262253497600 \zeta_7 \right] \\ & + 1506311935054583 \zeta_5 - 4569891743 \zeta_6 \\ & + 3124445521200 \zeta_5 + 7209972 \zeta_6 \\ & + n_1^2 C_1^2 C_2^2 \left[1499767303942721479649857809345185131 \zeta_5 \right. \\ & \quad \left. - 28885034779593394007378225049600000 \zeta_6 - 14073504845400 \zeta_7 \right] \\ & + 64419601 \zeta_5 \\ & + 765765 \zeta_6 \\ & + n_1^2 C_1 C_2 C_3^2 \left[9521719981900843482793882523227 \zeta_5 \right. \\ & \quad \left. - 3549298612312271219988787200000 \zeta_6 - 14073504845400 \zeta_7 - 64419601 \zeta_8 \right] \\ & + n_1^2 C_2^2 C_3^2 \left[54369636195548207942967542719 \zeta_5 \right. \\ & \quad \left. - 3802819941763147735702720000 \zeta_6 - 20675655 \zeta_7 \right] \\ & + \frac{d^{3\text{loop}} d^{1\text{loop}}}{N_R} \left[1354462049501491403276515417 \zeta_5 \right. \\ & \quad \left. - 5744913623184647 \zeta_6 \right. \\ & \quad \left. - 469116828180 \zeta_7 \right] \\ & + n_1^2 \frac{d^{3\text{loop}} d^{3\text{loop}}}{N_R} \left[63048309341247319711503473 \zeta_5 \right. \\ & \quad \left. + 1361755723179569 \zeta_6 \right. \\ & \quad \left. + 108438494006543500800000 \zeta_7 + 2020810952160 \zeta_8 \right] \end{aligned}$$

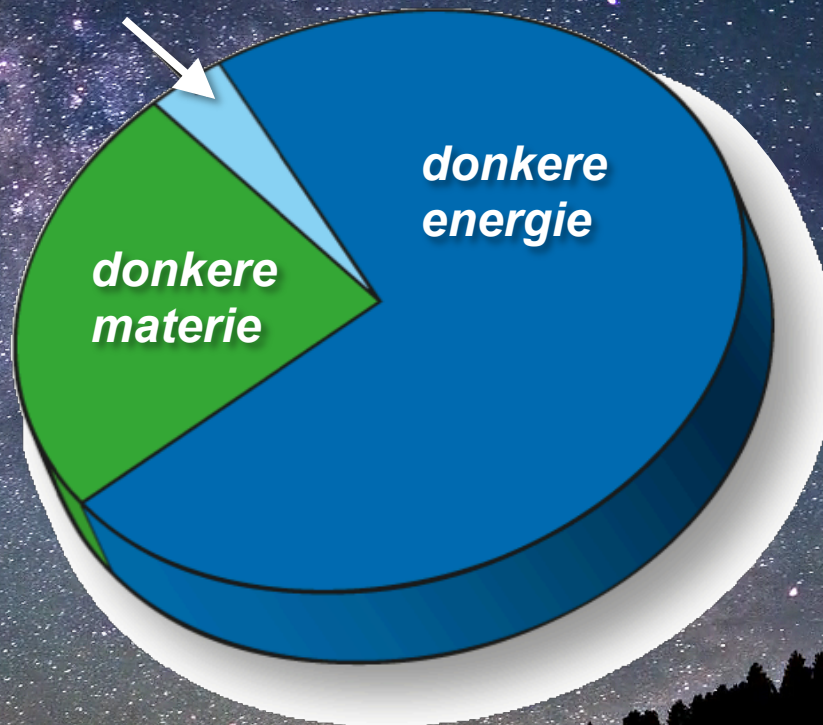
1707.08315

2 maanden rekenen op 25000 computers tegelijk
 En dat is alleen om de formule te krijgen
 (samen met Franz Herzog en anderen)

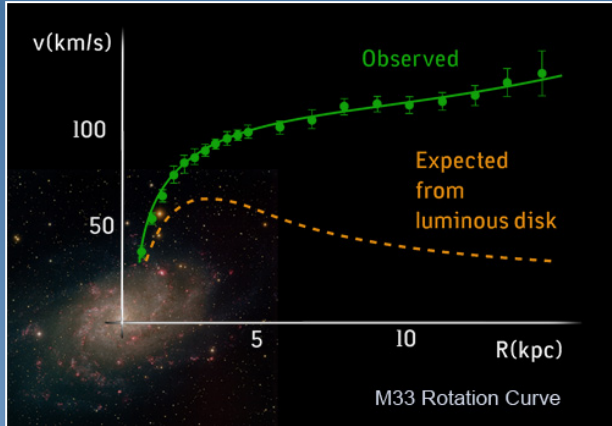


Donkere materie

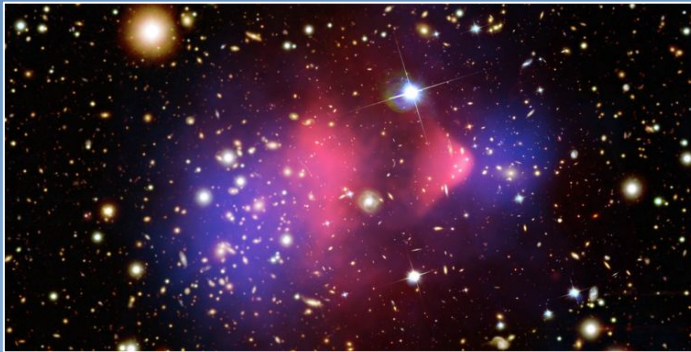
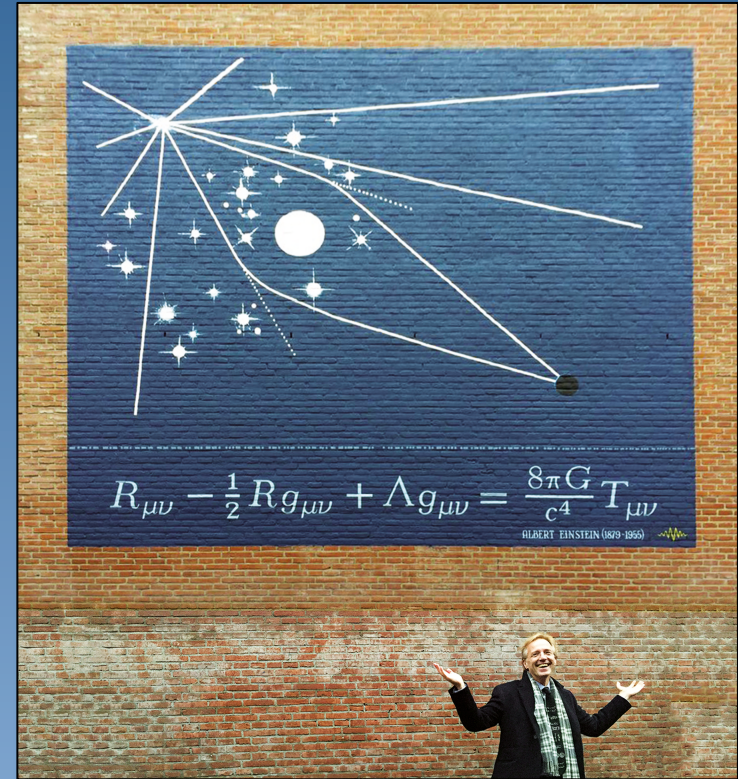
sterren, planeten, gas, pulsars, ...



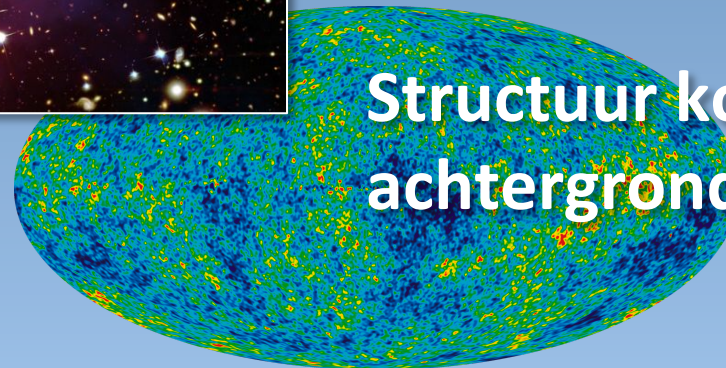
rotatiesnelheden in sterrenstelsels



Gravitationele lensing



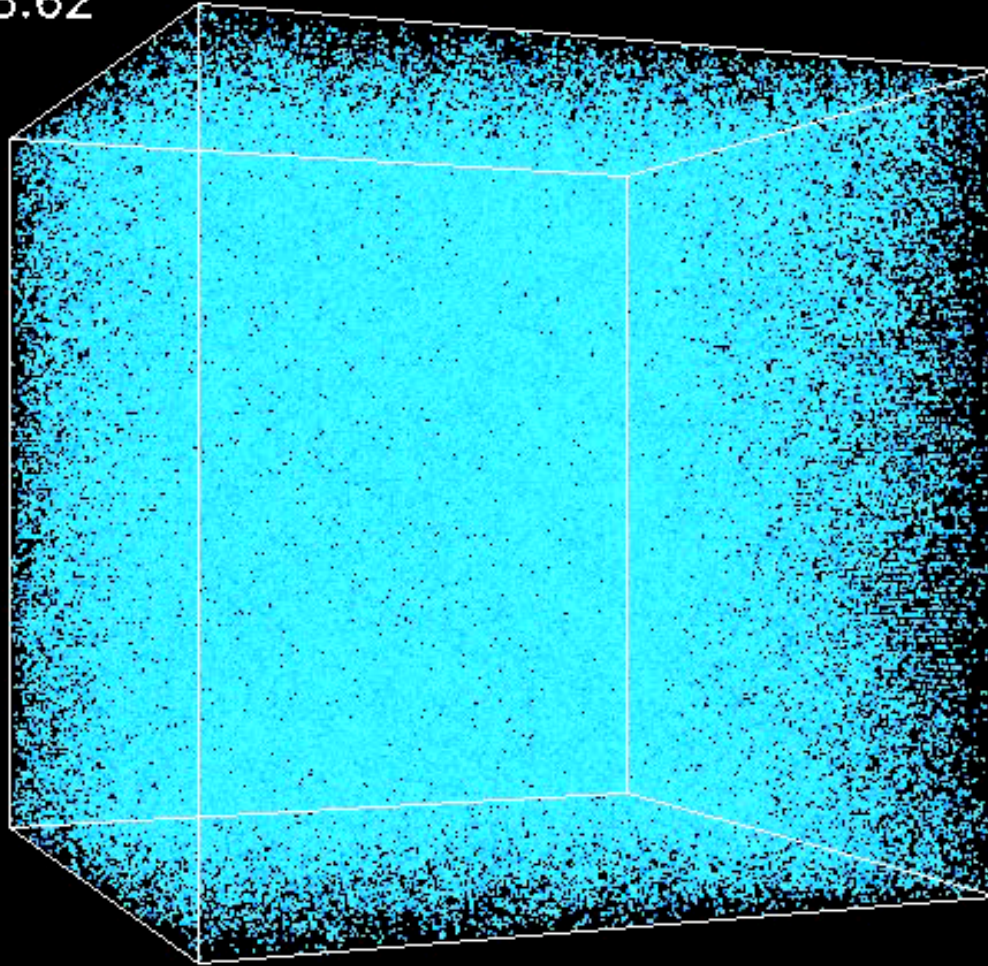
Botsende stelsels



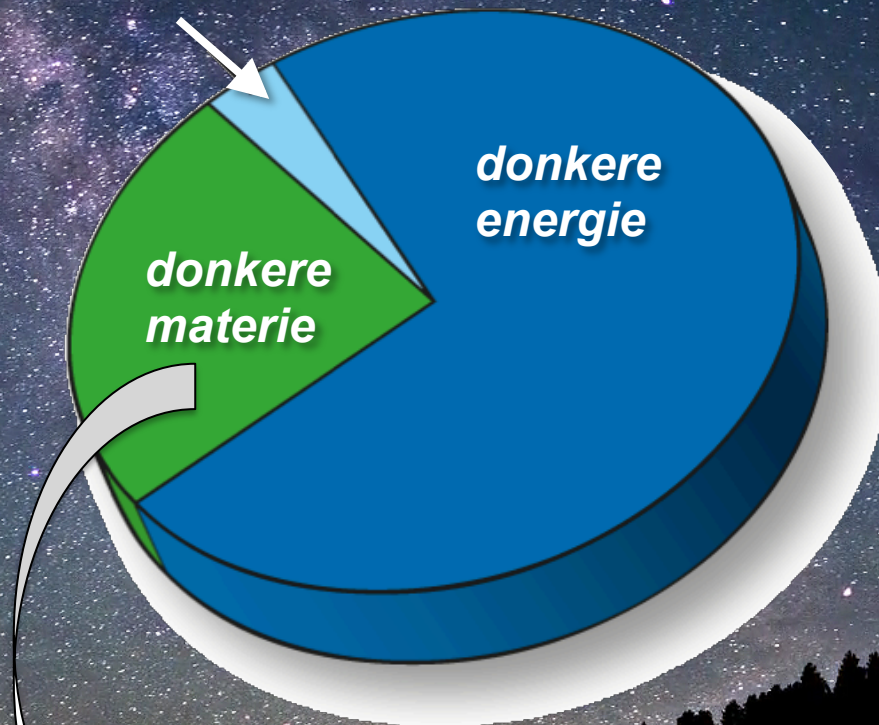
Structuur kosmische achtergrondstraling

Large scale structure formation = (klonteren)

Z=28.62



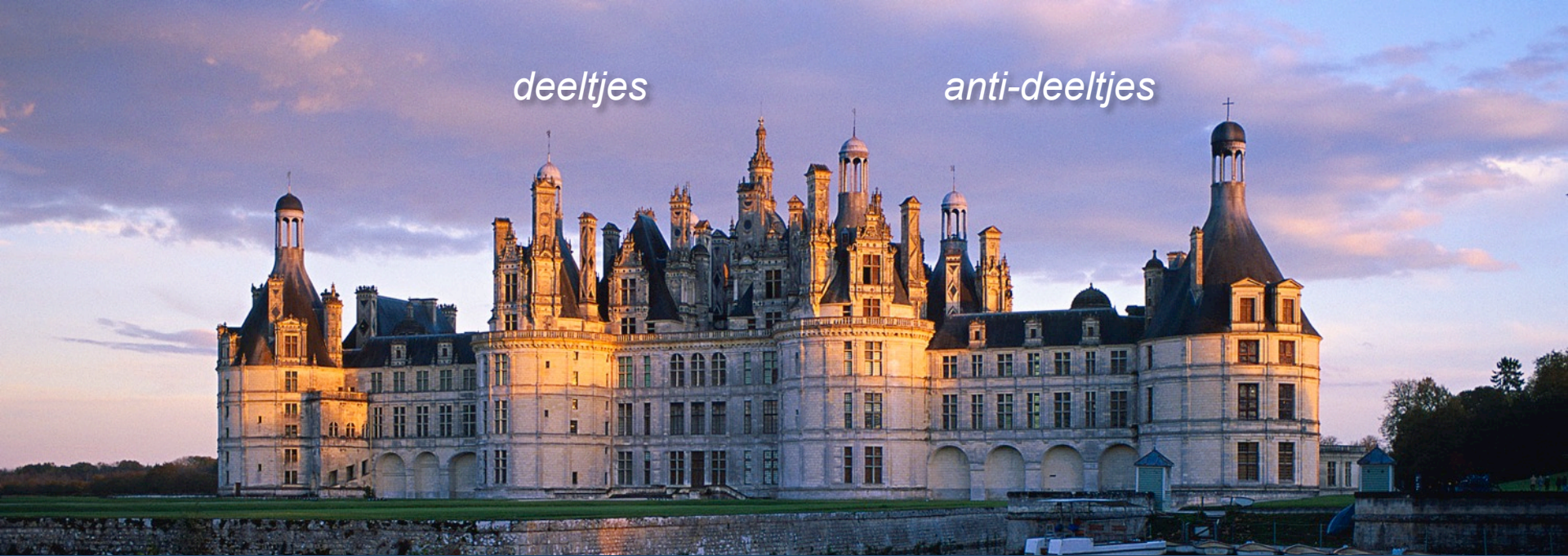
sterren, planeten, gas, pulsars, ...



deeltje uit een spiegelwereld ?

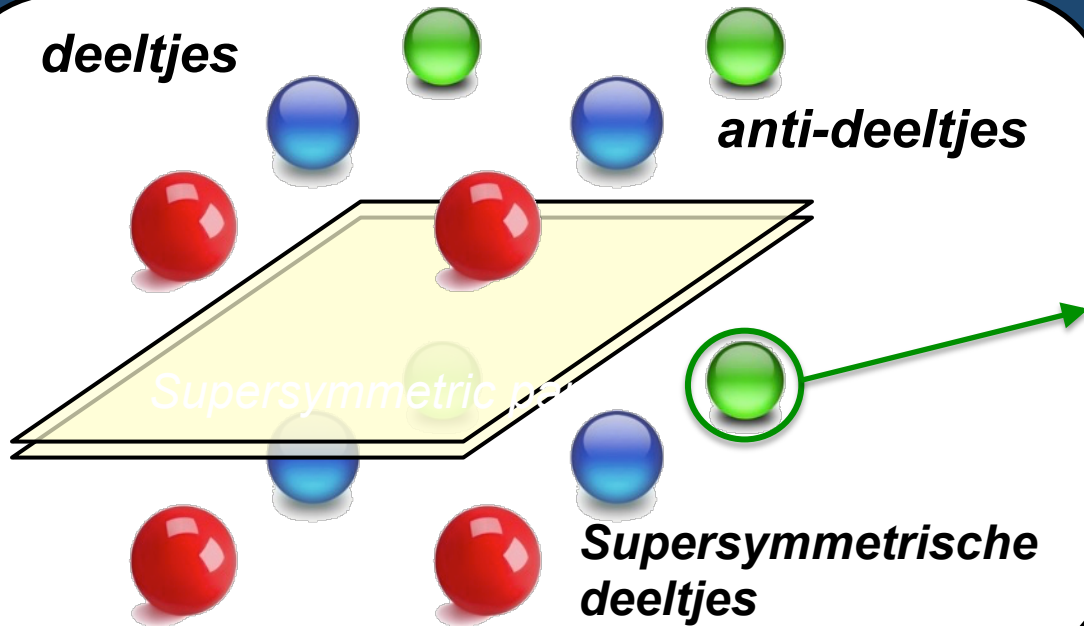
deeltjes

anti-deeltjes



deeltjes

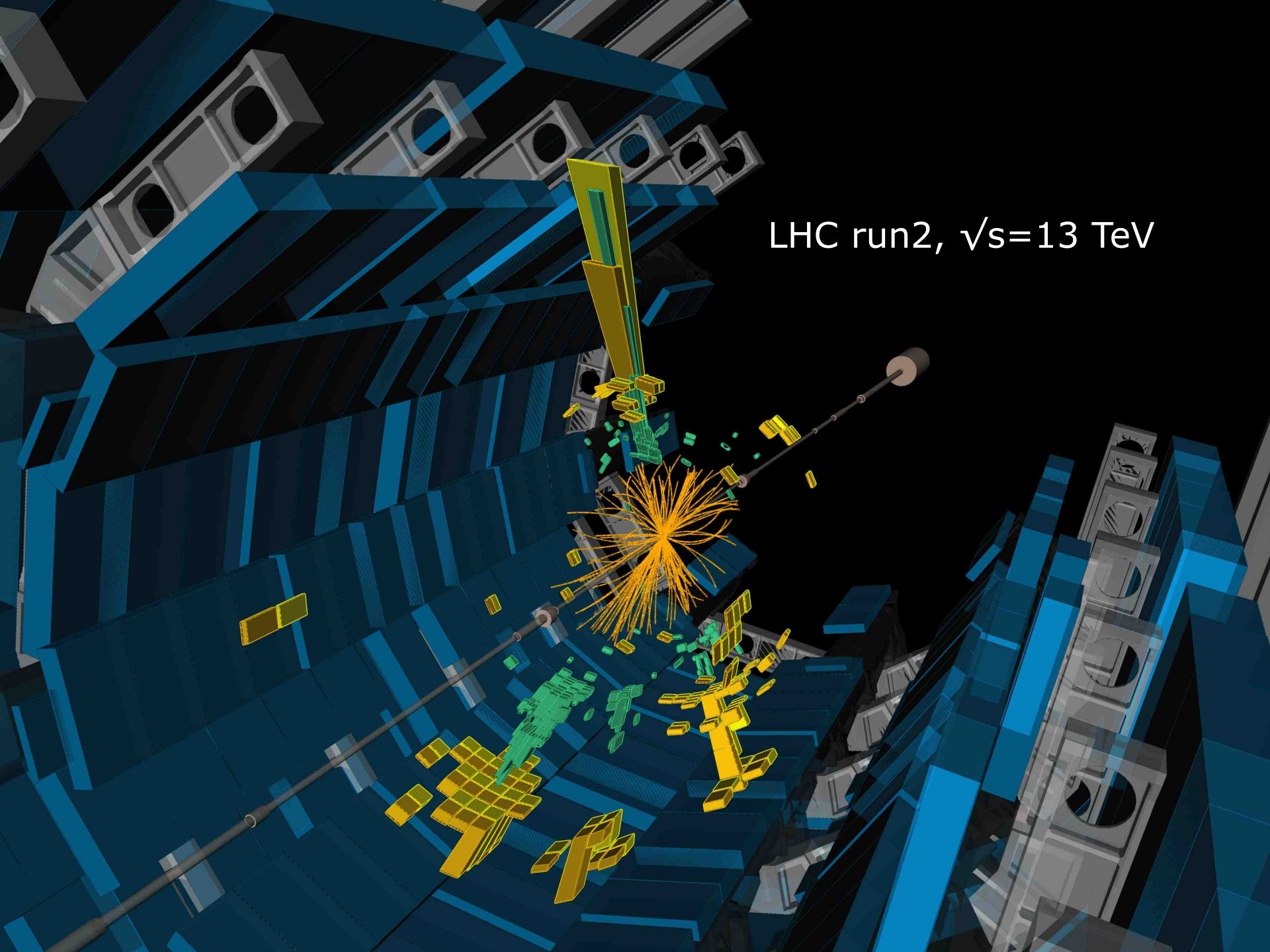
anti-deeltjes



lichtste deeltje is stabiel

→ donkere materie?

LHC run2, $\sqrt{s}=13$ TeV





1 miljard foto's per seconde
storage rate = 750 Hz

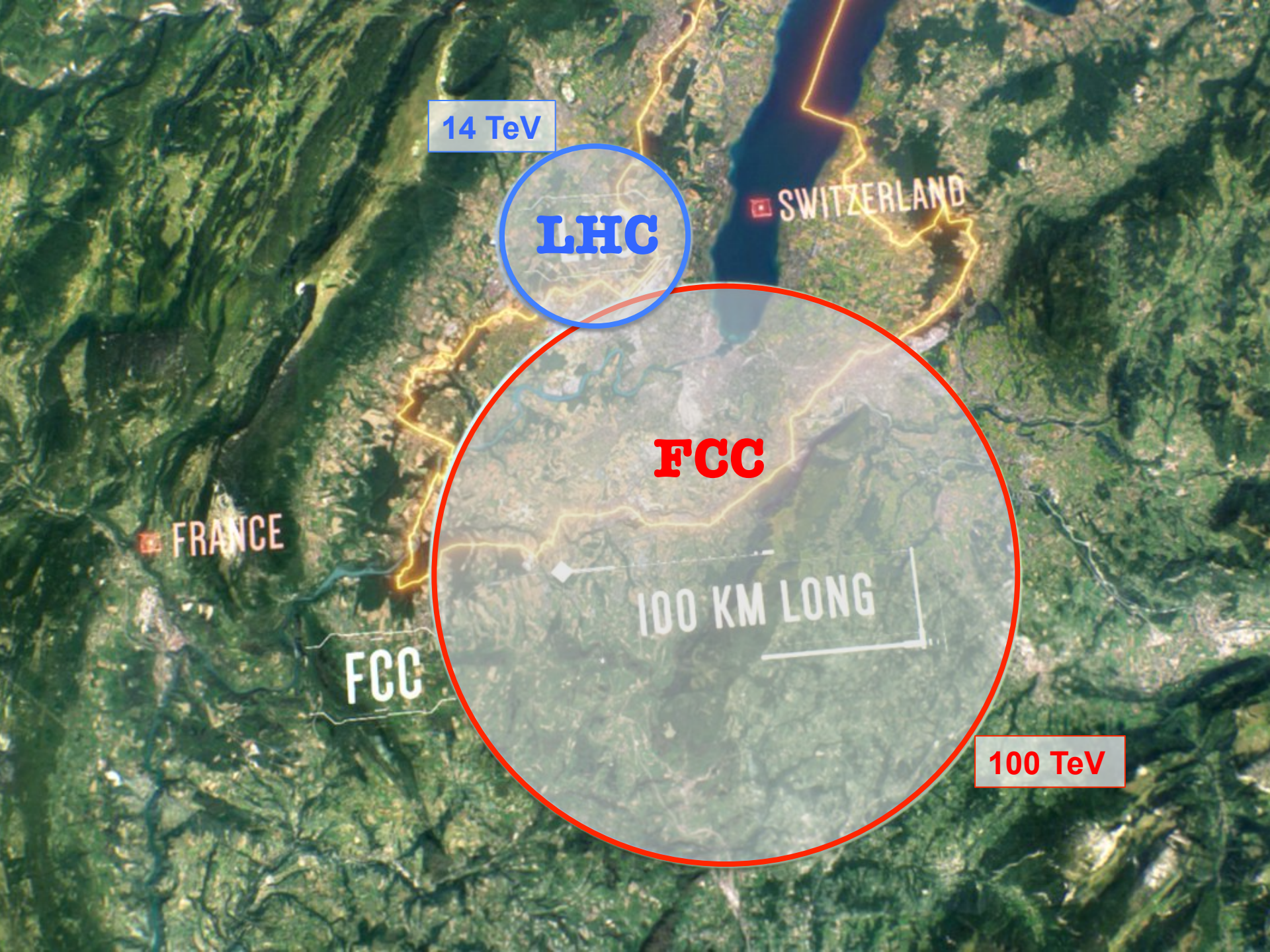
ATLAS experiment



We hebben nog maar een paar % van de data verzameld

Nieuwe versnellers

FCC week in Amsterdam deze week



14 TeV

LHC

SWITZERLAND

FRANCE

FCC

100 KM LONG

FCC

100 TeV

*"Ivo, waarom doen jullie
het niet gewoon zo?"*

Jan Vink per E-mail

*"Hendrik Antoon Lorentz zit
in de weg Jan"*

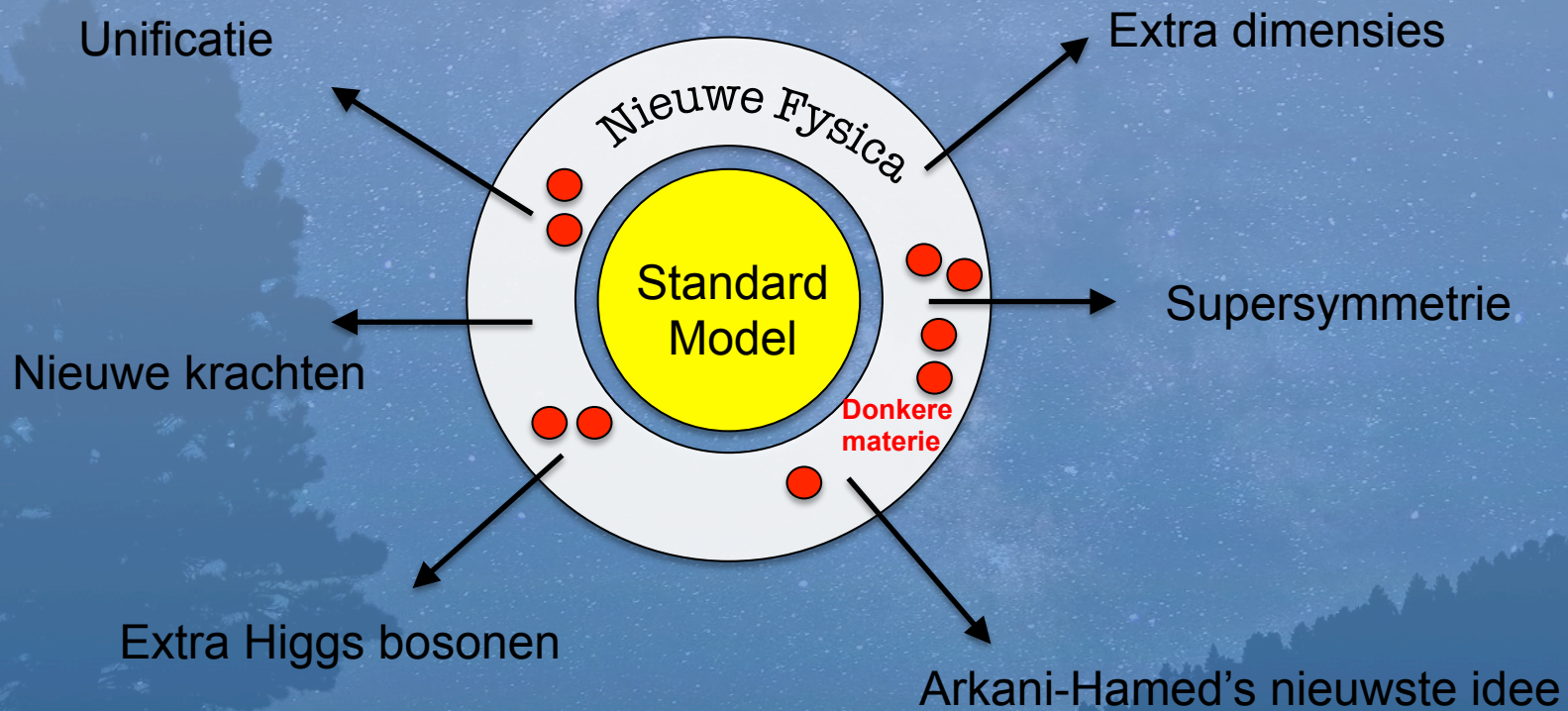


26,9 kilometer
afbuigen

100 meter
versnellen

$$mv = qBr$$

Standaard Model is niet de ultieme theorie



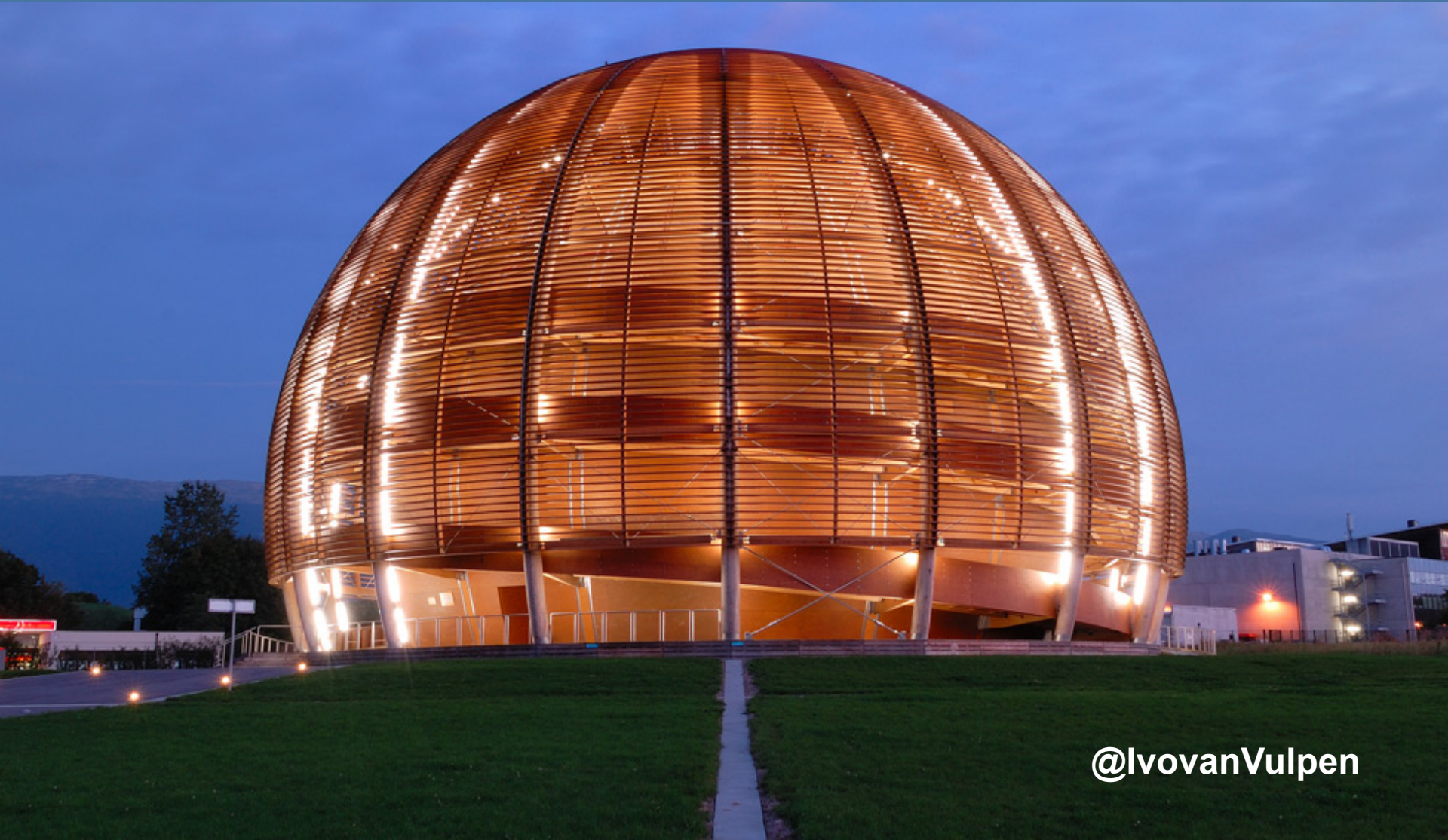
De wereld van elementaire deeltjes

Standaard Model werkt prima

Higgs boson is ontdekt

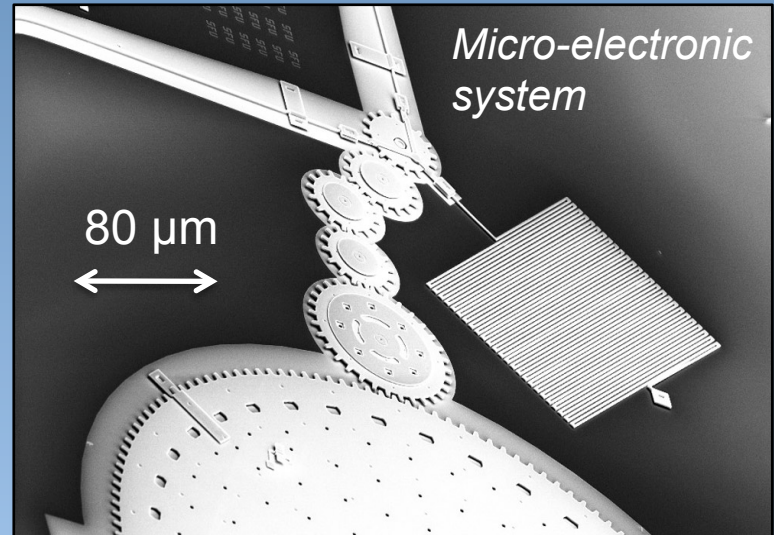
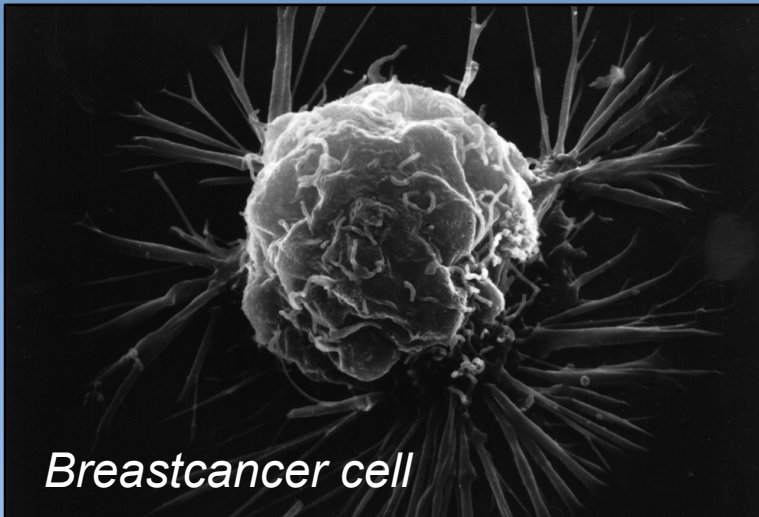
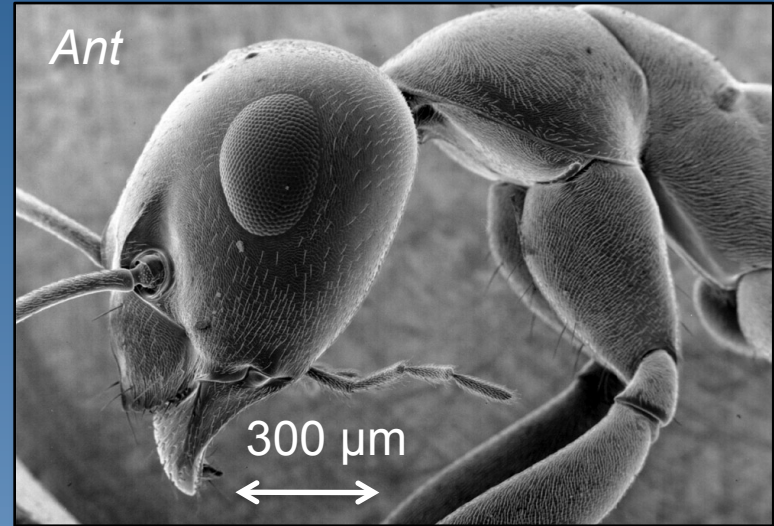
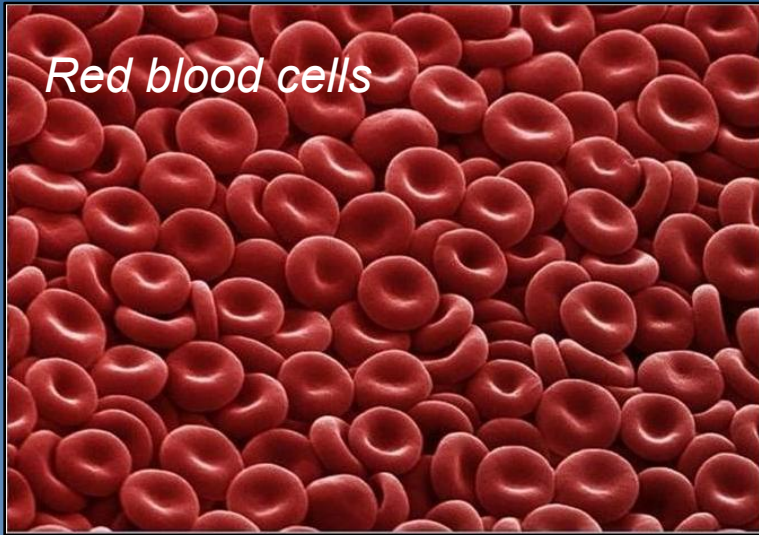
- *Quarks vs leptonen*
- *neutrino massa's*
- *donkere materie*
- *(anti-)materie mysterie*
- *supersymmetrie*
- *extra dimensies*
- *unificatie krachten*
- *quantum-zwaartekracht*
- *extra ruimte-dimensies*
- *oorsprong 3 families, ...*

Schitterend avontuur de komende jaren!



@lvovanVulpen

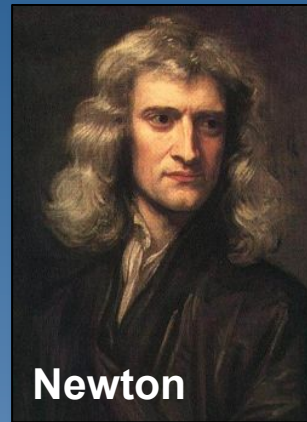
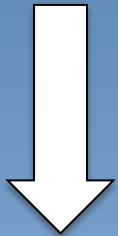
BACKUP



Een microscoop is niet altijd het beste gereedschap

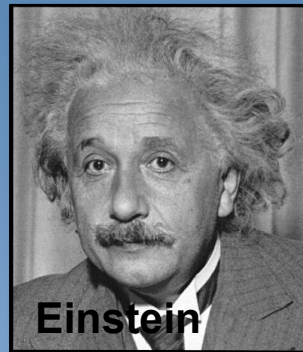


Waarom valt een
appel naar beneden ?



massa's trekken elkaar aan

$$F = G_N \frac{m_1 m_2}{r^2}$$



ruimte-tijd is gekromd

$$G_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G_N}{c^4} T_{\mu\nu}$$



Entropie (informatie) ?



Dromen van de deeltjesfysica

supersymmetrie

extra Higgs bosonen



extra krachtdeeltjes

extra dimensies