

Zoektocht naar de elementaire bouwstenen van de natuur



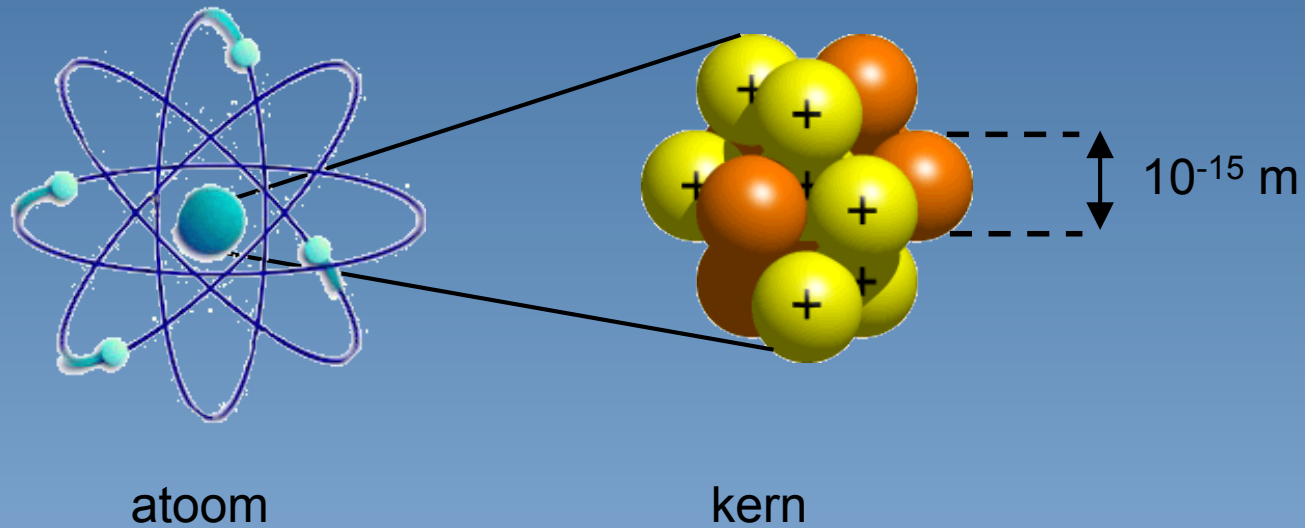
Week-end van de wetenschap, Groningen, 6 oktober 2013

Ivo van Vulpen

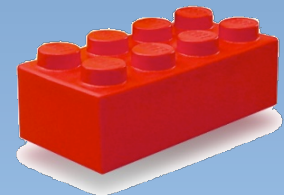
CERN in Genève, Zwitterland



Deeltjesfysica



Wat zijn de bouwstenen van de dingen om ons heen ?



Het grootste en het kleinste

... volgens mijn dochter van 3

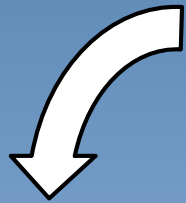
... volgens haar vader



Olifant



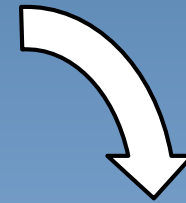
Klein muisje



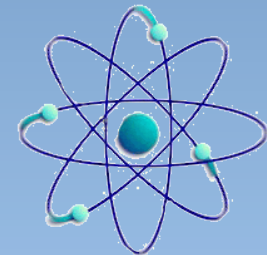
Grootst



10^{+22} m

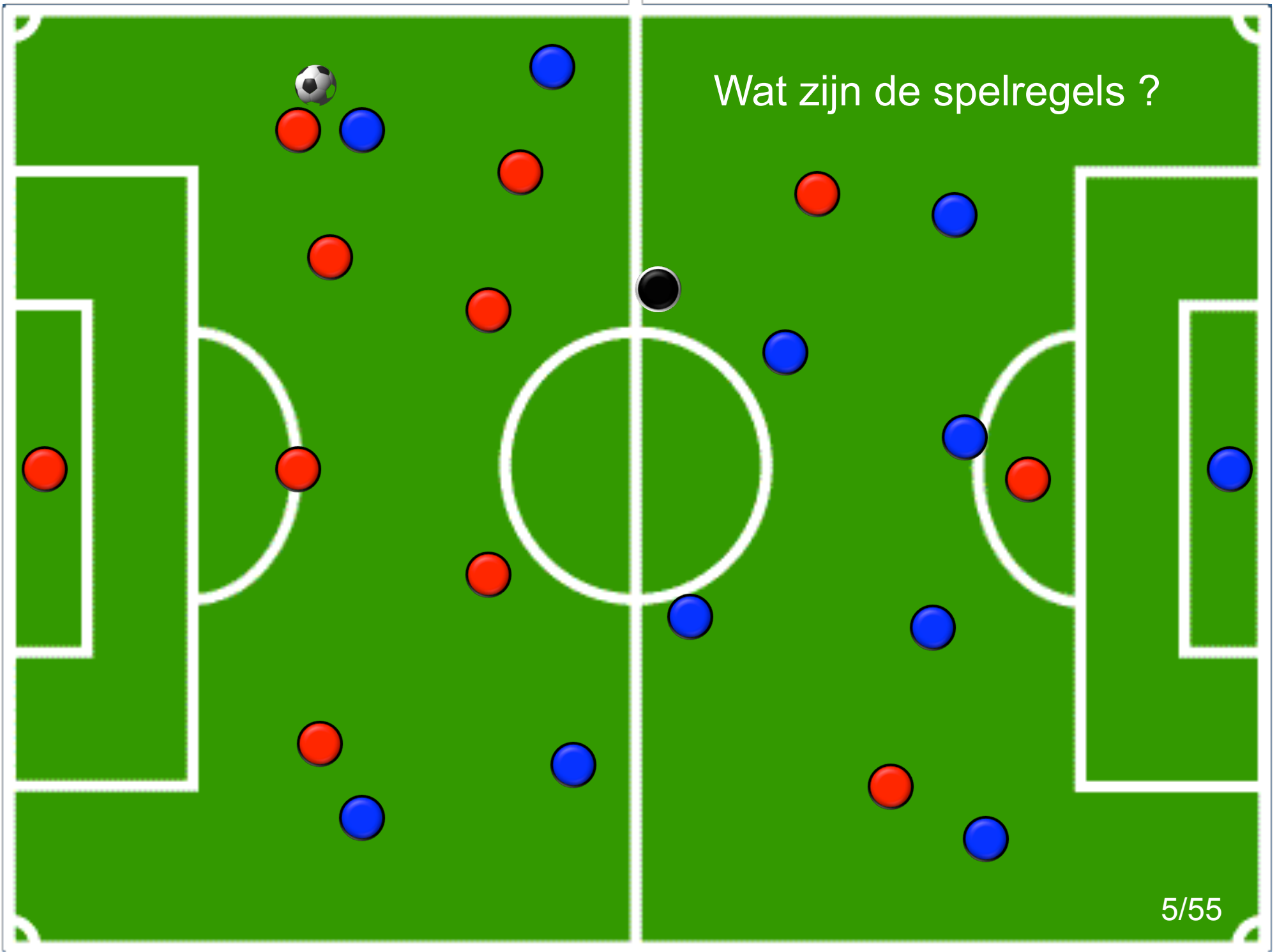


Kleinst



10^{-9} m

Wat zijn de spelregels ?

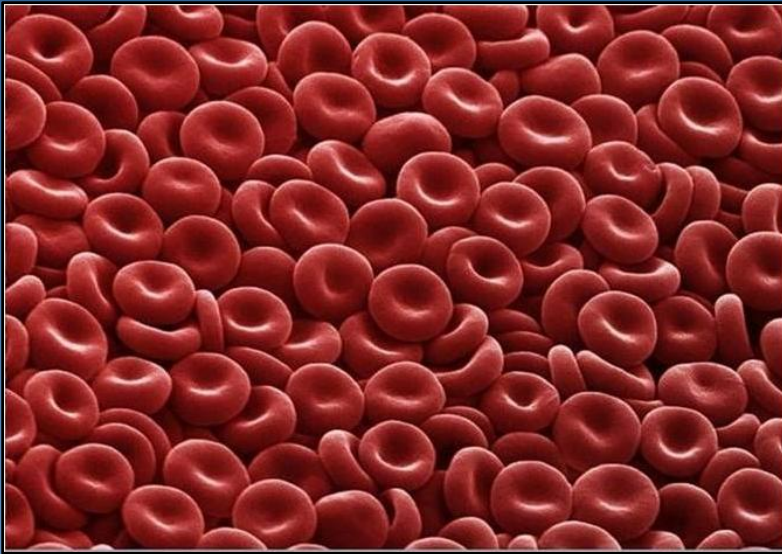


Röntgen foto

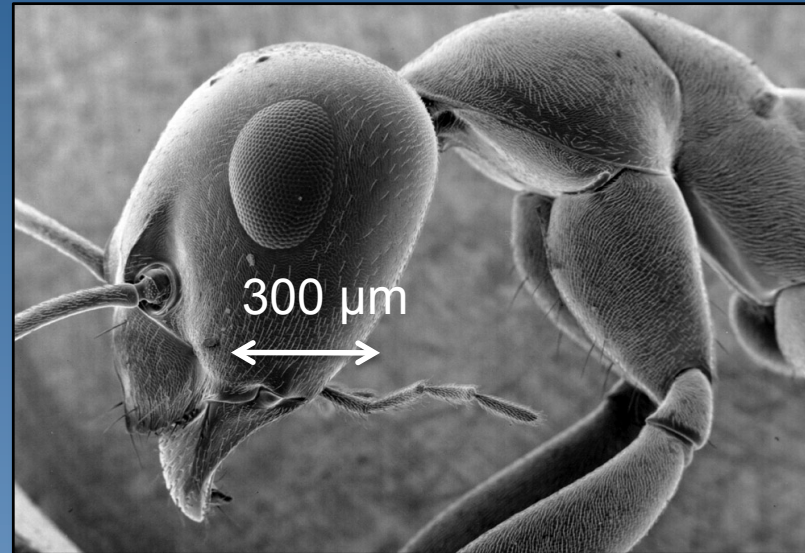


Het zichtbaar maken van
(niet-)afgeketste deeltjes

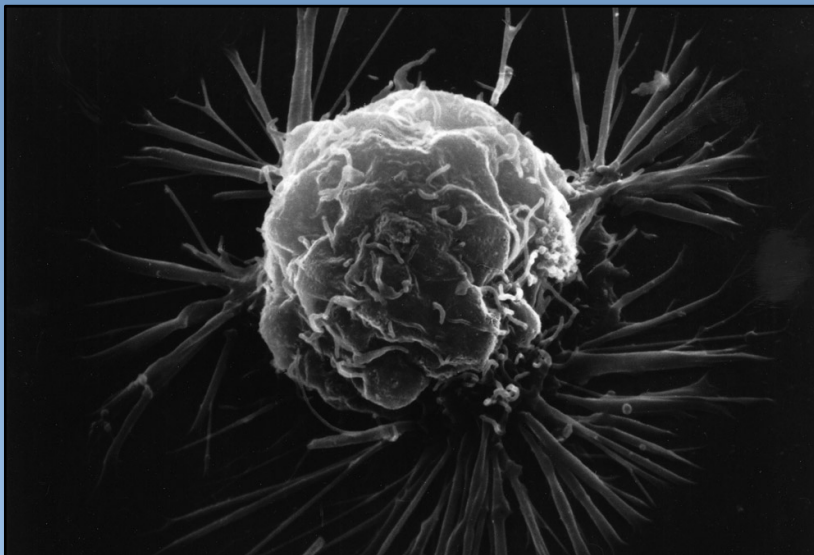
Rode bloedlichaampjes



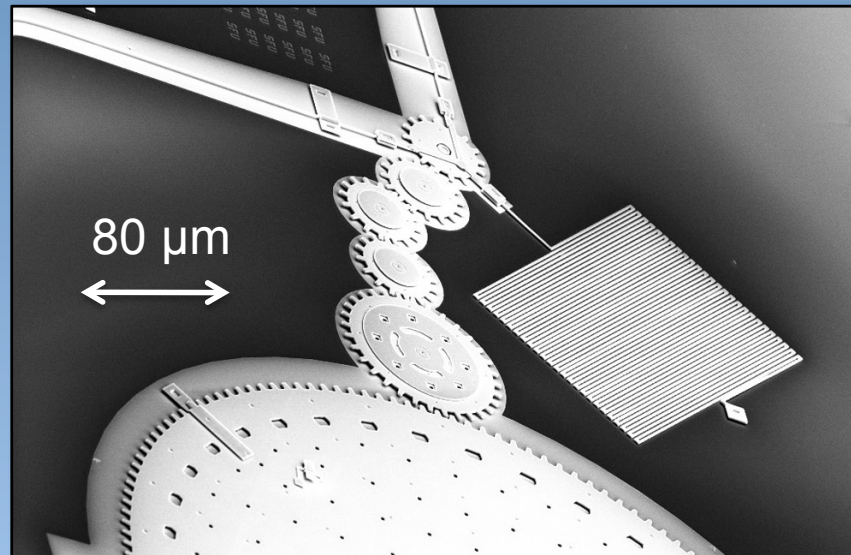
Mier



Borstkanker cel



Microelectronisch systeem



Van *wat* naar *hoe*

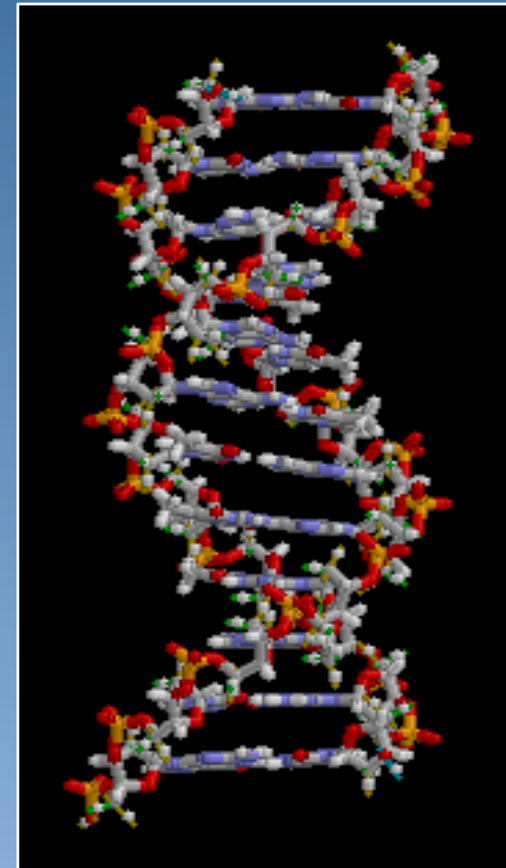
oogkleur ouders en kind

pa ma kans op oogkleur baby

	+		=	 75%	 18.75%	 6.25%
	+		=	 50%	 37.5%	 12.5%
	+		=	 50%	 0%	 50%
	+		=	 <1%	 75%	 25%
	+		=	 0%	 50%	 50%
	+		=	 0%	 1%	 99%



= ?

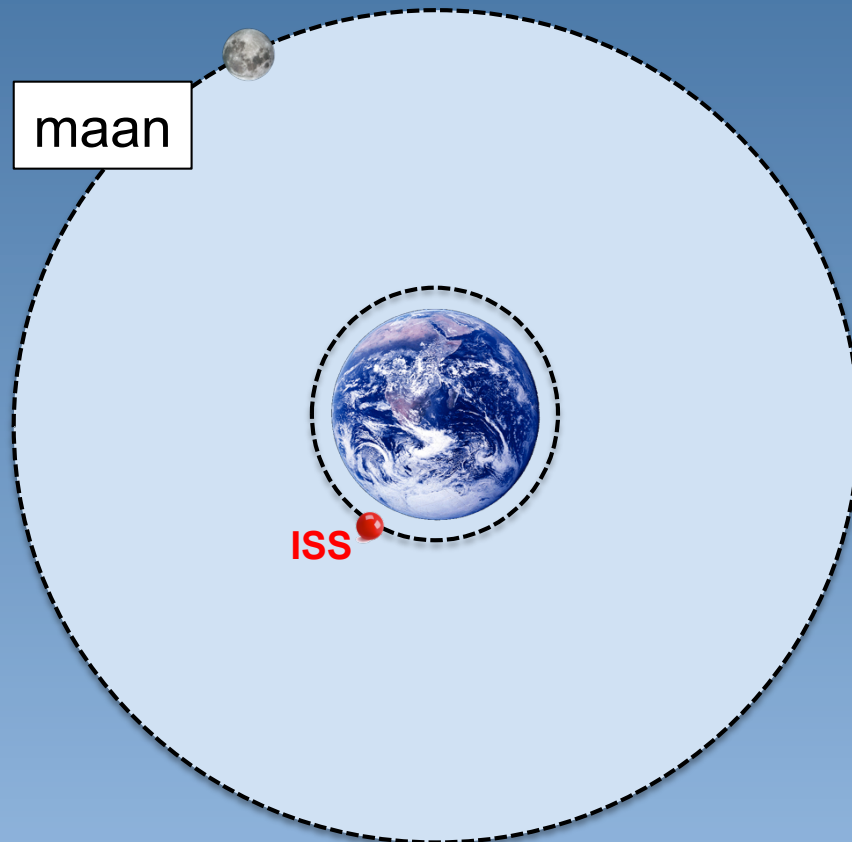


DNA: GTCA-nucleotiden

De atoomwereld: nieuwe fenomenen



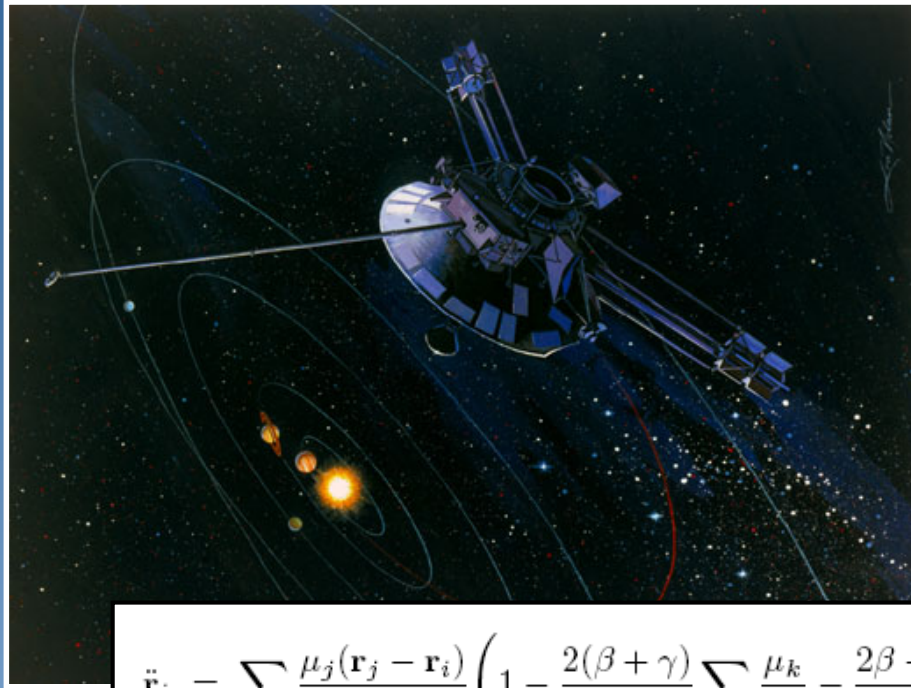
Klassieke mechanica



We begrijpen waarom de maan om de aarde draait

$$v \propto \frac{1}{\sqrt{r}}$$

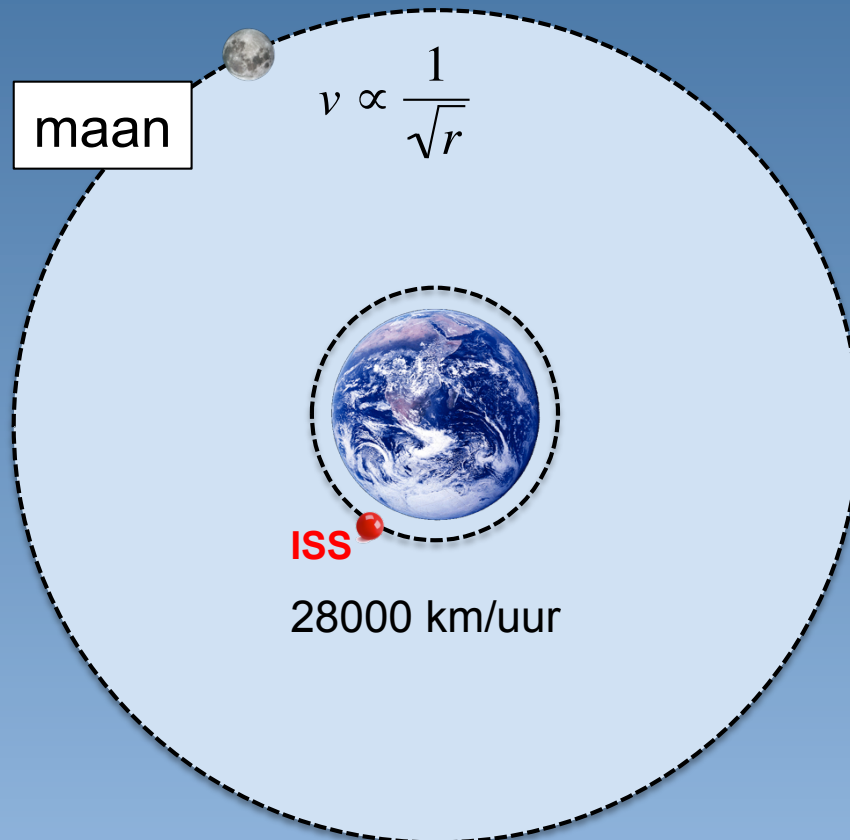
ISS: 400 km = 28.000 km/uur



satelliet (pioneer/ISS)

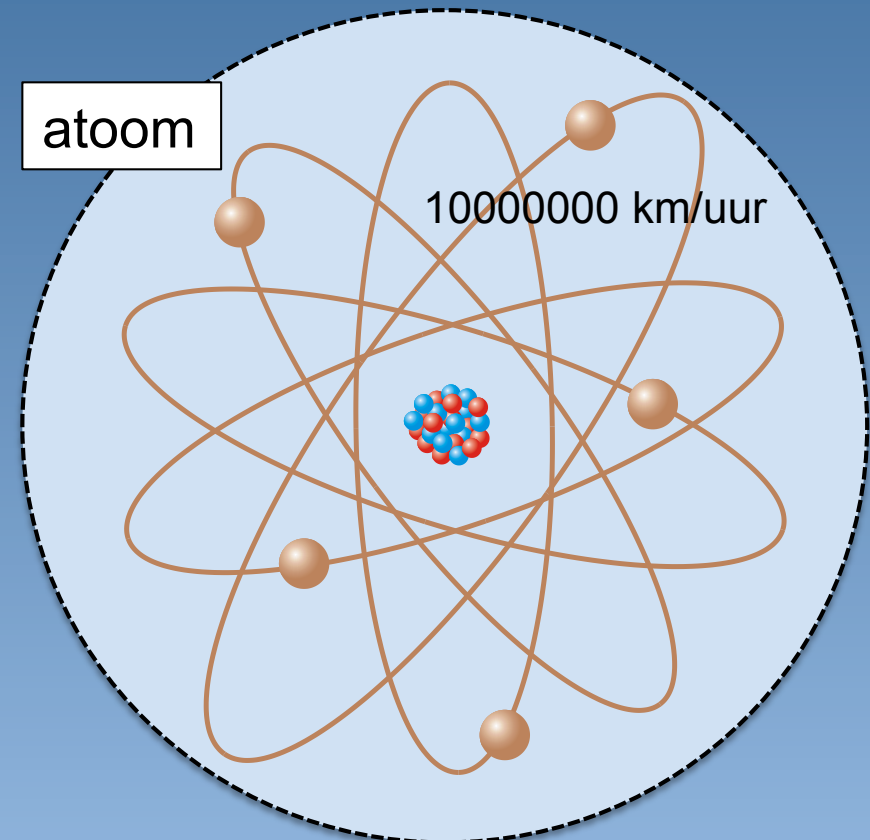
$$\ddot{\mathbf{r}}_i = \sum_{j \neq i} \frac{\mu_j (\mathbf{r}_j - \mathbf{r}_i)}{r_{ij}^3} \left(1 - \frac{2(\beta + \gamma)}{c^2} \sum_{k \neq i} \frac{\mu_k}{r_{ik}} - \frac{2\beta - 1}{c^2} \sum_{k \neq j} \frac{\mu_k}{r_{jk}} - \frac{3}{2c^2} \left[\frac{(\mathbf{r}_j - \mathbf{r}_i) \dot{\mathbf{r}}_j}{r_{ij}} \right]^2 + \frac{1}{2c^2} (\mathbf{r}_j - \mathbf{r}_i) \ddot{\mathbf{r}}_j - \frac{2(1 + \gamma)}{c^2} \dot{\mathbf{r}}_i \dot{\mathbf{r}}_j + \right. \\ \left. + \gamma \left(\frac{v_i}{c} \right)^2 + (1 + \gamma) \left(\frac{v_j}{c} \right)^2 \right) + \frac{1}{c^2} \sum_{j \neq i} \frac{\mu_j}{r_{ij}^3} \left([\mathbf{r}_i - \mathbf{r}_j] \cdot [(2 + 2\gamma) \dot{\mathbf{r}}_i - (1 + 2\gamma) \dot{\mathbf{r}}_j] \right) (\dot{\mathbf{r}}_i - \dot{\mathbf{r}}_j) + \frac{3 + 4\gamma}{2c^2} \sum_{j \neq i} \frac{\mu_j \ddot{\mathbf{r}}_j}{r_{ij}} \quad (3)$$

Klassieke mechanica



400.000.000 [m]

Quantummechanica



0.0000000001 [m]

De atoomwereld

1) De elektronen vallen niet op de kern

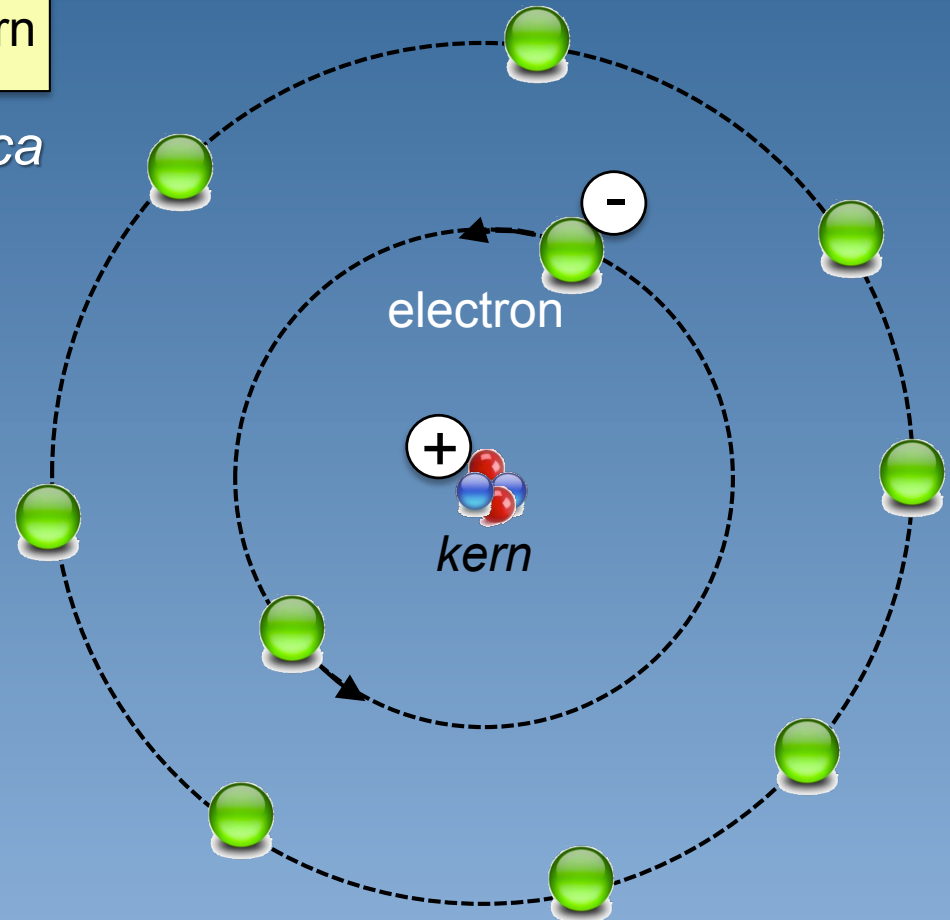
Natuurwet: *quantummechanica*

2) De kerndeeltjes kleven aan elkaar

Natuurkracht: *de kernkrachten*

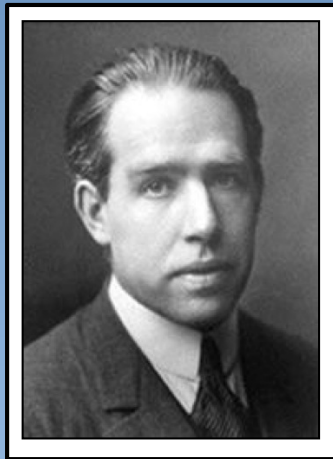
3) Maar 2 electronen in de 1^e baan

Fenomenen: *spin en Pauli's uitsluitingsprincipe*

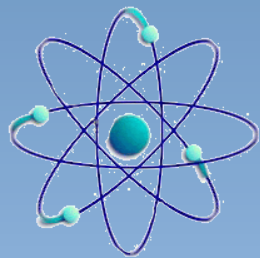


Quantummechanica ... nuttig ?

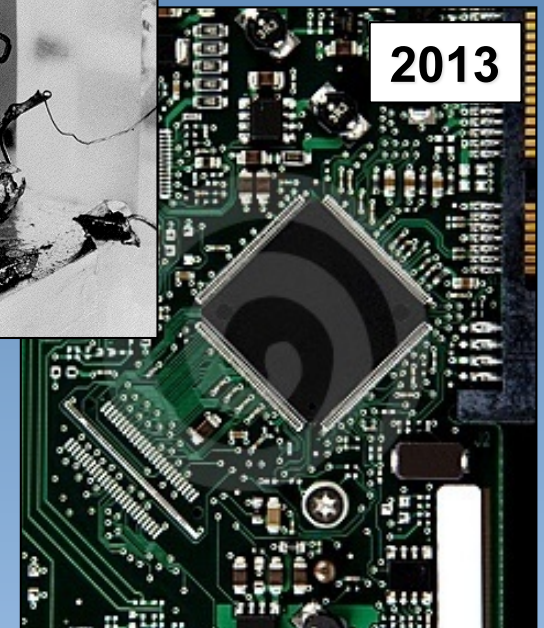
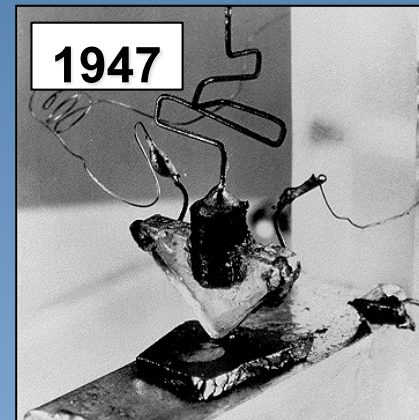
Quantummechanica



Niels Bohr



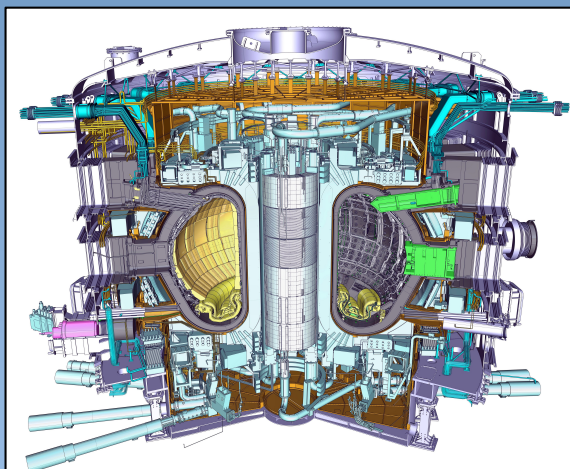
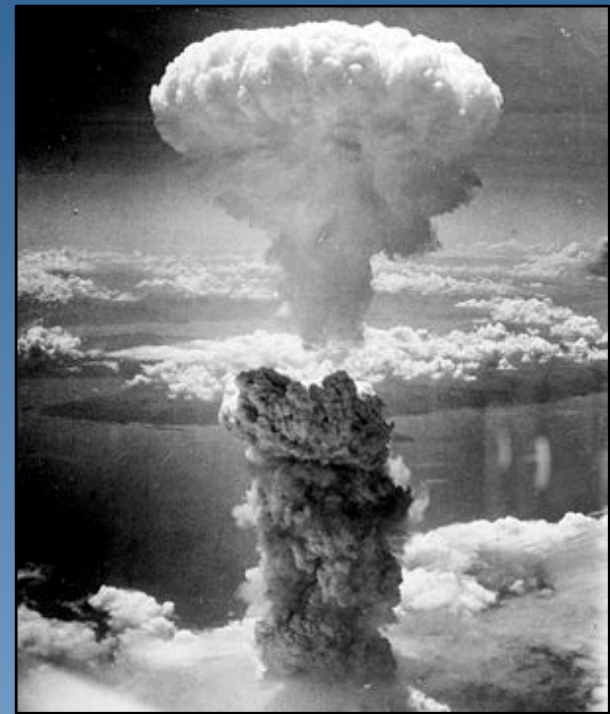
“Quantum mechanica en begrip van atomen cruciaal voor transitors.”





Hoe brandt de zon

Kernkrachten nuttig ?



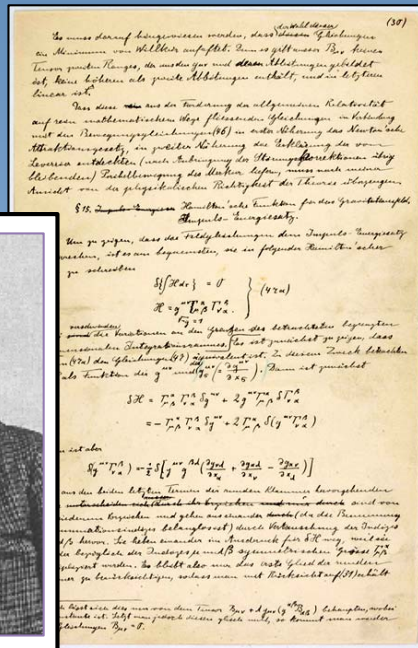
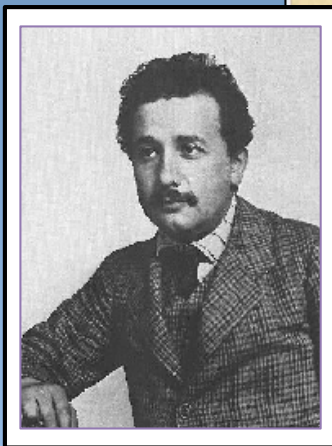
ITER (fusieractor)



Relativiteitstheorie ?

Net zo raar en onlogisch als de quantummechanica

- tijd gaat langzamer als je hard beweegt
- tijd gaat sneller als je verder weg bent van de aarde



“Zonder relativiteitstheorie zit de GPS er 10 km per dag naast!”

De stand van zaken op 6 oktober 2013



[http:// pdg.lbl.gov](http://pdg.lbl.gov)

De elementaire deeltjes



up

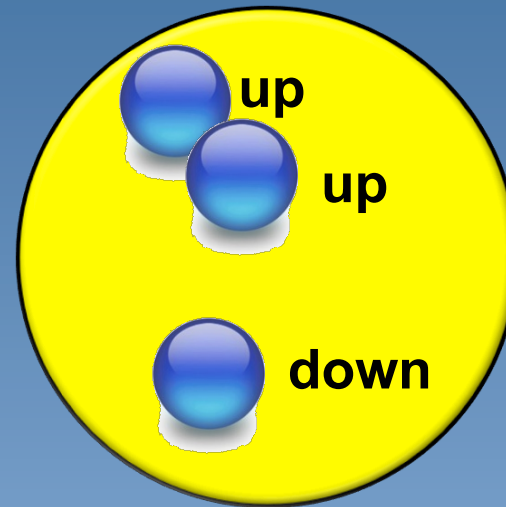


down

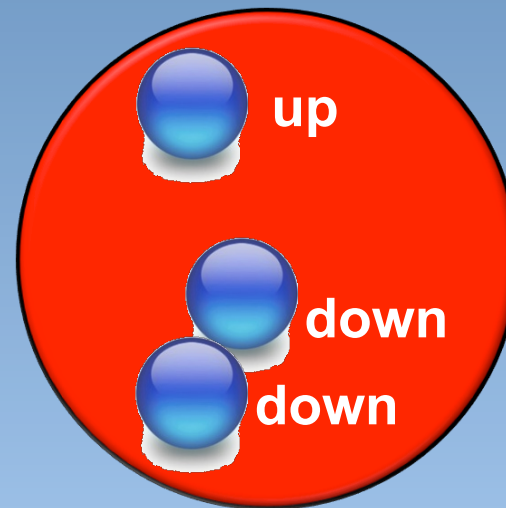


elektron

+ 4 natuurkrachten



Proton



Neutron

Wat kan je maken met deze 3 bouwstenen ?

*periodiek systeem
van Mendeleev*

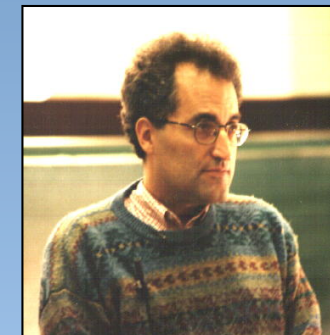
1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	103 Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt									
57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb				
89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No				



Alles!



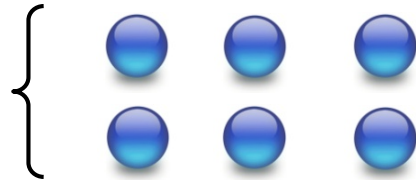
Alles wat we nodig hebben !



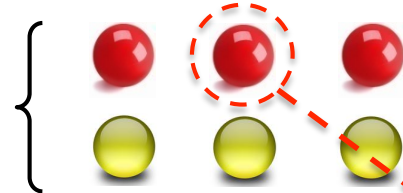
Edward Witten

Deeltjes

Quarks



Leptonen

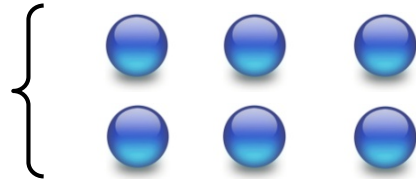


Krachten

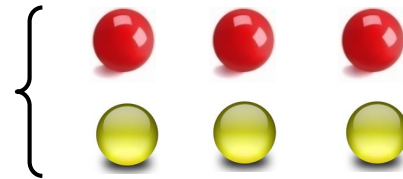
- 1) Electromagnetisme
- 2) Zwakke kernkracht
- 3) Sterke kernkracht
- 4) Zwaartekracht

Anti-deeltjes

Anti-
Quarks



Anti-
Leptonen



muon

Abstractie en patronen vinden

Standaard Model Lagrangiaan

$$SU(2)_L \otimes U(1)_Y \otimes SU(3)_C$$

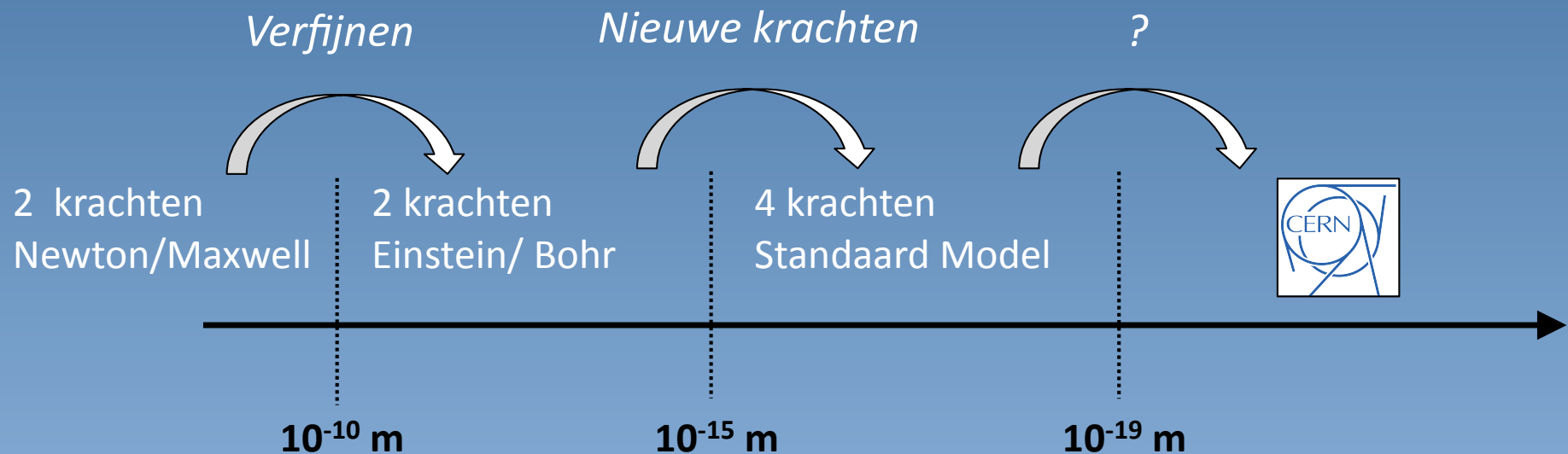
$$\begin{aligned} & -\frac{1}{2}\partial_\nu g_\mu^a \partial_\nu g_\mu^a - g_s f^{abc} \partial_\mu g_\nu^a g_\mu^b g_\nu^c - \frac{1}{4} g_s^2 f^{abc} f^{ade} g_\mu^a g_\nu^b g_\mu^c g_\nu^d + \frac{1}{2} i g_s^2 (\bar{q}_i^\alpha \gamma^\mu q_j^\alpha) g_\mu^a + \\ & G^a \partial^2 G^a + g_s f^{abc} \partial_\mu G^a G^b g_\mu^c - \partial_\mu W_\mu^+ \partial_\nu W_\mu^- - M^2 W_\mu^+ W_\mu^- - \frac{1}{2} \partial_\nu Z_\mu^0 \partial_\nu Z_\mu^0 - \frac{1}{2} M^2 Z_\mu^0 Z_\mu^0 - \\ & \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} 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 - i g c_w [\partial_\nu Z_\mu^0 (W_\mu^+ W_\nu^- - \\ & W_\mu^- W_\nu^+) - Z_\nu^0 (W_\mu^+ \partial_\nu W_\mu^- - W_\mu^- \partial_\nu W_\mu^+) + Z_\mu^0 (W_\nu^+ \partial_\nu W_\mu^- - W_\nu^- \partial_\nu W_\mu^+) - i g s_w [\partial_\nu A_\mu (W_\mu^+ W_\nu^- - \\ & W_\mu^- W_\nu^+) - 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_\nu^+ W_\mu^- + g^2 c_w^2 (Z_\mu^0 W_\nu^+ Z_\nu^0 W_\mu^- - Z_\nu^0 W_\mu^+ Z_\mu^0 W_\nu^-) + g^2 s_w^2 (A_\mu W_\nu^+ A_\nu W_\mu^- - \\ & A_\nu A_\mu W_\nu^+ W_\mu^-) + g^2 s_w c_w [A_\mu Z_\nu^0 (W_\mu^+ W_\nu^- - W_\nu^+ W_\mu^-) - 2 A_\mu Z_\mu^0 W_\nu^+ W_\nu^-] - g \alpha [H^3 + \\ & H \phi^0 \phi^0 + 2 H \phi^+ \phi^-] - \frac{1}{8} g^2 \alpha_h [H^4 + (\phi^0)^4 + 4(\phi^+ \phi^-)^2 + 4(\phi^0)^2 \phi^+ \phi^- + 4 H^2 \phi^+ \phi^- + \\ & 2(\phi^0)^2 H^2] - g M W_\mu^+ W_\mu^- H - \frac{1}{2} g \frac{M}{c_w} Z_\mu^0 Z_\mu^0 H - \frac{1}{2} i g [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_\mu^0 (H \partial_\mu \phi^0 - \\ & \phi^0 \partial_\mu H) - i g \frac{s_w}{c_w} M Z_\mu^0 (W_\mu^+ \phi^- - W_\mu^- \phi^+) + i g s_w M A_\mu (W_\mu^+ \phi^- - W_\mu^- \phi^+) - i g \frac{1-2c_w^2}{2c_w} Z_\mu^0 (\phi^+ \partial_\mu \phi^- - \\ & \phi^- \partial_\mu \phi^+) + i g s_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} Z_\mu^0 Z_\mu^0 [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_\mu^0 \phi^0 (W_\mu^+ \phi^- + W_\mu^- \phi^+) - \\ & \frac{1}{2} i g^2 \frac{s_w^2}{c_w} Z_\mu^0 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} i g^2 s_w A_\mu H (W_\mu^+ \phi^- - \\ & W_\mu^- \phi^+) - g^2 \frac{s_w}{c_w} (2c_w^2 - 1) Z_\mu^0 A_\mu \phi^+ \phi^- - g^1 s_w^2 A_\mu A_\mu \phi^+ \phi^- - e^\lambda (\gamma \partial + m_d^\lambda) e^\lambda - \\ & \bar{\nu}^\lambda \gamma \partial \nu^\lambda - \bar{u}_j^\lambda (\gamma \partial + m_u^\lambda) u_j^\lambda - \bar{d}_j^\lambda (\gamma \partial + m_d^\lambda) d_j^\lambda + i g s_w A_\mu [-(e^\lambda \gamma^\mu e^\lambda) + \frac{2}{3} (\bar{u}_j^\lambda \gamma^\mu u_j^\lambda) - \\ & \frac{1}{3} (\bar{d}_j^\lambda \gamma^\mu d_j^\lambda)] + \frac{i g}{4c_w} Z_\mu^0 [(\bar{\nu}^\lambda \gamma^\mu (1 + \gamma^5) \nu^\lambda) + (e^\lambda \gamma^\mu (4s_w^2 - 1 - \gamma^5) e^\lambda) + (\bar{u}_j^\lambda \gamma^\mu (\frac{4}{3}s_w^2 - \\ & 1 - \gamma^5) u_j^\lambda) + (\bar{d}_j^\lambda \gamma^\mu (1 - \frac{8}{3}s_w^2 - \gamma^5) d_j^\lambda)] + \frac{i g}{2\sqrt{2}} W_\mu^+ [(\bar{\nu}^\lambda \gamma^\mu (1 + \gamma^5) e^\lambda) + (\bar{u}_j^\lambda \gamma^\mu (1 + \\ & \gamma^5) C_{\lambda\kappa} d_j^\kappa)] + \frac{i g}{2\sqrt{2}} W_\mu^- [(\bar{e}^\lambda \gamma^\mu (1 + \gamma^5) \nu^\lambda) + (\bar{d}_j^\kappa C_{\lambda\kappa}^\dagger \gamma^\mu (1 + \gamma^5) u_j^\lambda)] + \frac{i g}{2\sqrt{2}} \frac{m_\lambda^2}{M} [-\phi^+ (\bar{\nu}^\lambda (1 - \\ & \gamma^5) e^\lambda) + \phi^- (\bar{e}^\lambda (1 + \gamma^5) \nu^\lambda)] - \frac{g}{2} \frac{m_\lambda^2}{M} [H (\bar{e}^\lambda e^\lambda) + i \phi^0 (\bar{e}^\lambda \gamma^5 e^\lambda)] + \frac{i g}{2M\sqrt{2}} \phi^+ [-m_\lambda^2 (\bar{u}_j^\lambda C_{\lambda\kappa} (1 - \\ & \gamma^5) d_j^\kappa) + m_\lambda^2 (\bar{u}_j^\lambda C_{\lambda\kappa} (1 + \gamma^5) d_j^\kappa)] + \frac{i g}{2M\sqrt{2}} \phi^- [m_\lambda^2 (\bar{d}_j^\kappa C_{\lambda\kappa}^\dagger (1 + \gamma^5) u_j^\kappa) - m_\lambda^2 (\bar{d}_j^\kappa C_{\lambda\kappa}^\dagger (1 - \\ & \gamma^5) u_j^\kappa)] - \frac{g}{2} \frac{m_\lambda^2}{M} H (\bar{u}_j^\lambda u_j^\lambda) - \frac{g}{2} \frac{m_\lambda^2}{M} H (\bar{d}_j^\lambda d_j^\lambda) + \frac{i g}{2} \frac{m_\lambda^2}{M} \phi^0 (\bar{u}_j^\lambda \gamma^5 u_j^\lambda) - \frac{i g}{2} \frac{m_\lambda^2}{M} \phi^0 (\bar{d}_j^\lambda \gamma^5 d_j^\lambda) + \\ & \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 + i g c_w W_\mu^+ (\partial_\mu \bar{X}^0 X^- - \partial_\mu \bar{X}^0 X^+) + \\ & i g s_w W_\mu^- (\partial_\mu \bar{X}^- Y - \partial_\mu \bar{Y} X^+) + i g c_w Z_\mu^0 (\partial_\mu \bar{X}^+ X^- - \partial_\mu \bar{X}^- X^+) + i g s_w A_\mu (\partial_\mu \bar{X}^+ X^- - \\ & \partial_\mu \bar{X}^- X^+) - \frac{1}{2} g M [\bar{X}^+ X^+ H + \bar{X}^- X^- H + \frac{1}{c_w} \bar{X}^0 X^0 H] + \frac{1-2c_w^2}{2c_w} i g M [\bar{X}^+ X^0 \phi^- + \\ & \bar{X}^- X^0 \phi^+] + \frac{1}{2c_w} i g M [\bar{X}^0 X^- \phi^+ - \bar{X}^0 X^+ \phi^-] + i g M s_w [\bar{X}^0 X^- \phi^+ - \bar{X}^0 X^+ \phi^-] + \\ & \frac{1}{2} i g M [\bar{X}^+ X^+ \phi^0 - \bar{X}^- X^- \phi^0] \end{aligned}$$

Bladmuziek (J.S. Bach)

bladmuziek



Nieuwe fenomenen, nieuwe krachten ??



deeltjes



Het Standaard Mod





Higgs
boson

Het laatste puzzelstukje

Theorie

Realiteit

Het Standaard Model

$$SU(2)_L \otimes U(1)_Y \otimes SU(3)_C$$

+ Higgs boson

≠



Deeltjes hebben *geen*

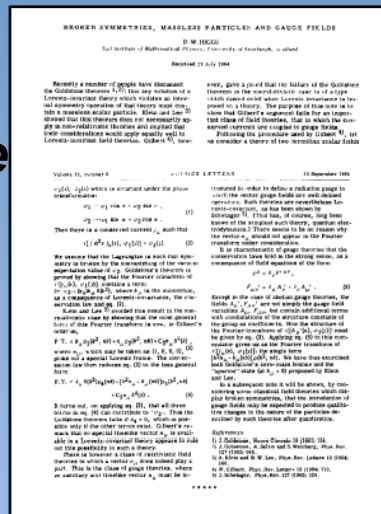


Het Higgs mechanisme

Deeltjes hebben *wel* massa

Higgs veld in het vacuum

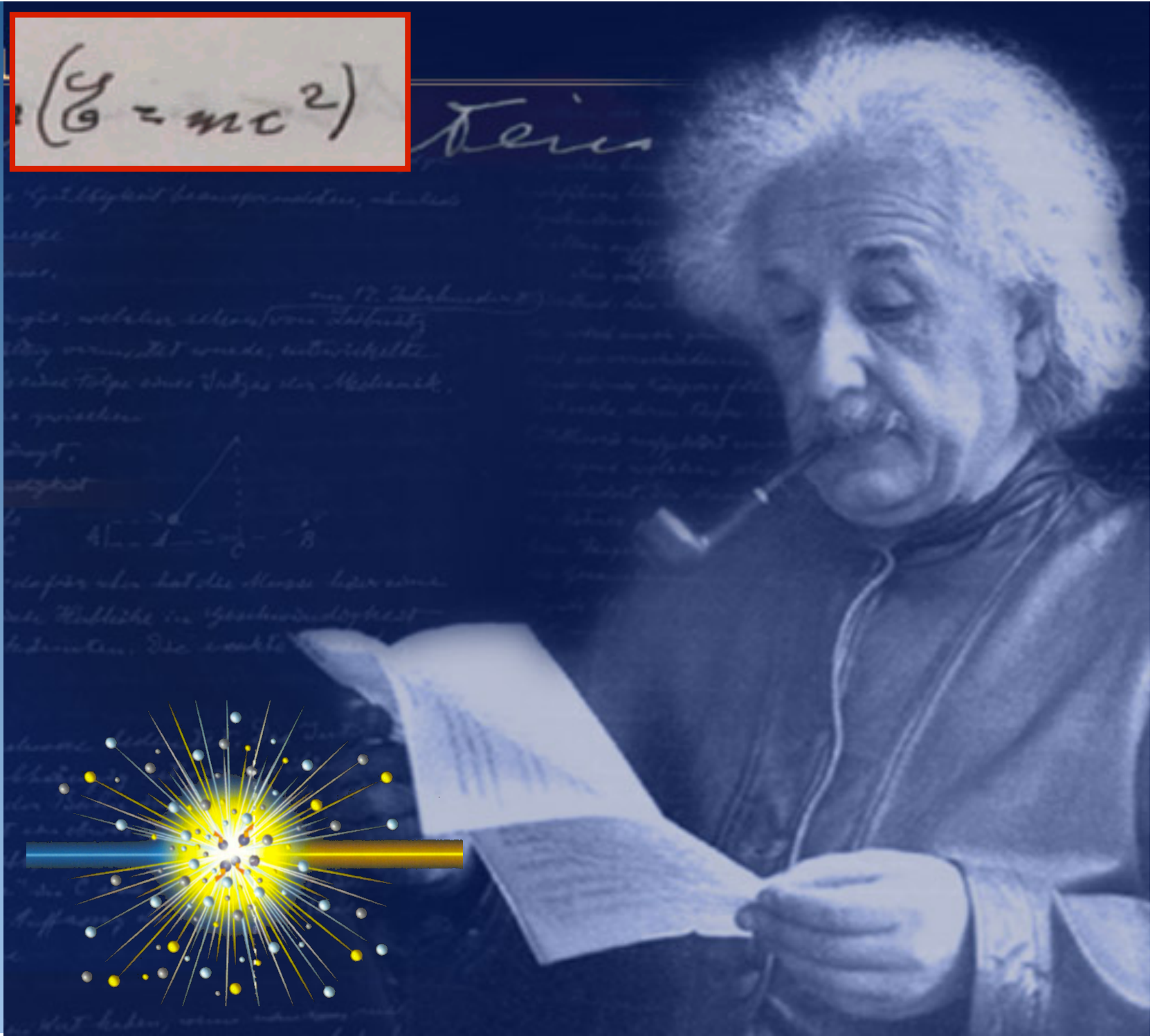
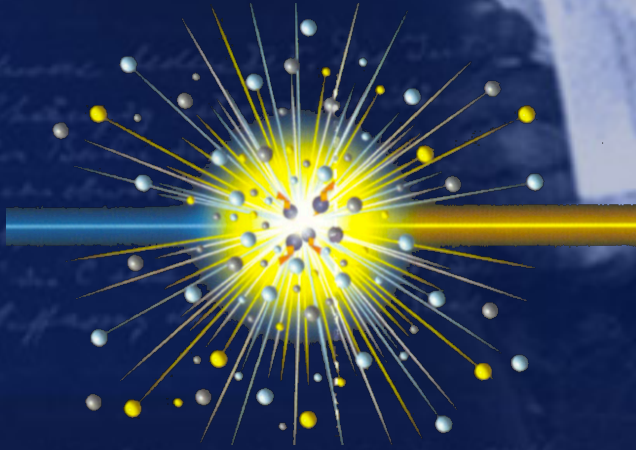
“Als ik gelijk heb moet er ook een nieuw deeltje bestaan: **het Higgs boson**”

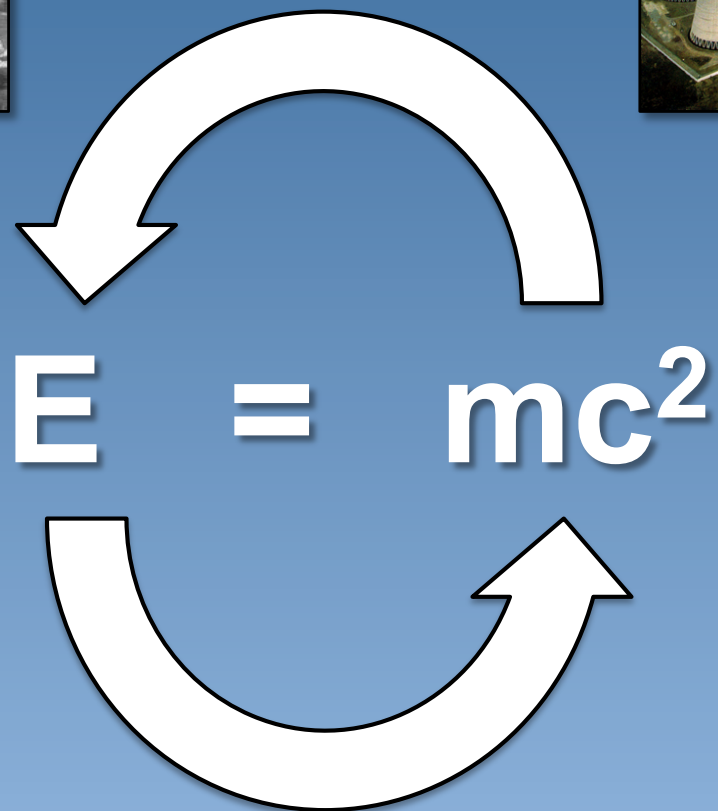


- September 1964 -

Albert Einstein

$$E = mc^2$$

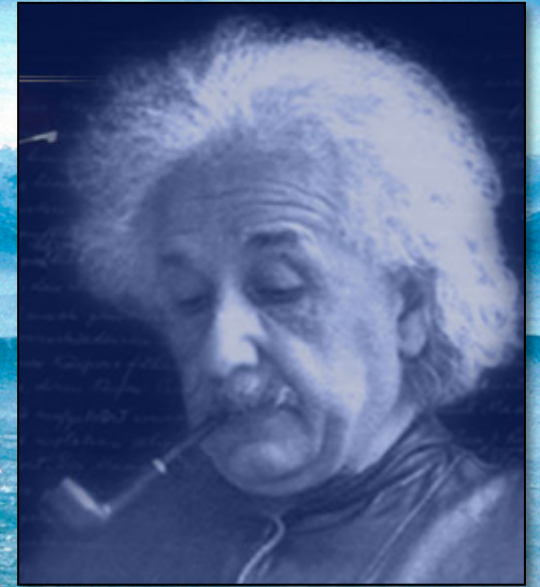


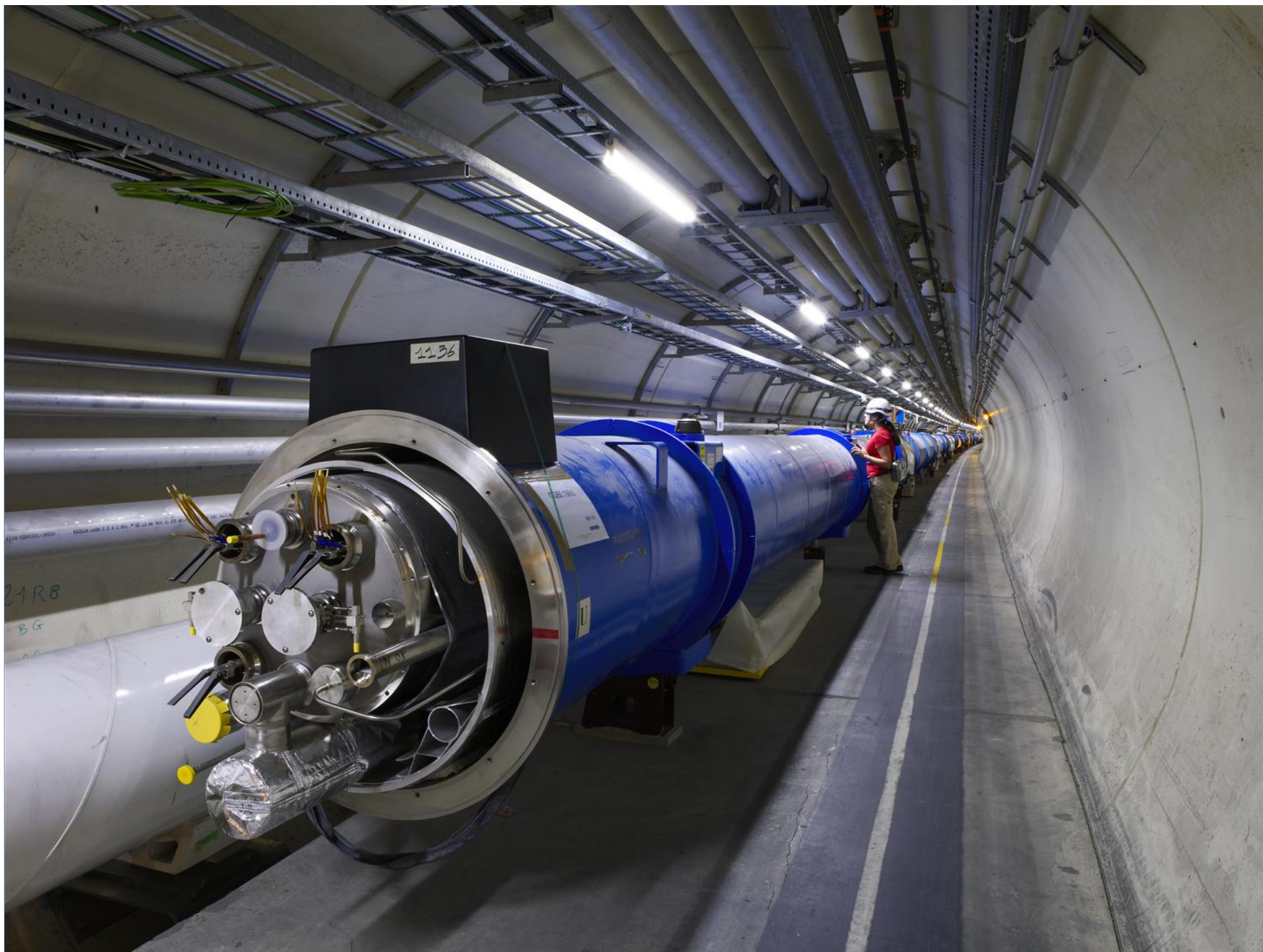


An aerial photograph of the Geneva region in Switzerland. The foreground shows a patchwork of green and brown agricultural fields. In the middle ground, the city of Geneva is visible, surrounded by a lake. In the background, there are rolling hills and a range of snow-capped mountains under a clear blue sky. A red oval is drawn over the landscape, representing the path of the Large Hadron Collider (LHC).

Nieuwe deeltjes maken

De Large Hadron Collider (LHC)
op CERN bij Genève



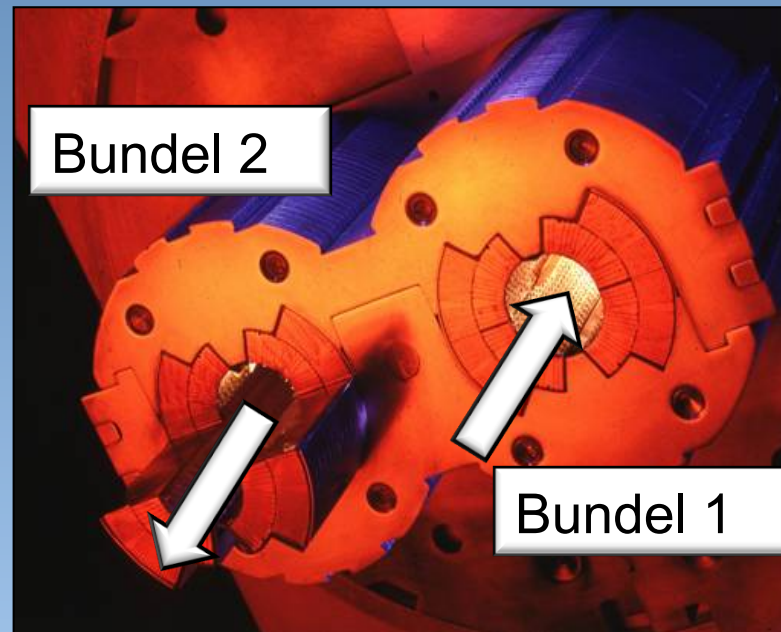


Energie 1 proton (LHC)



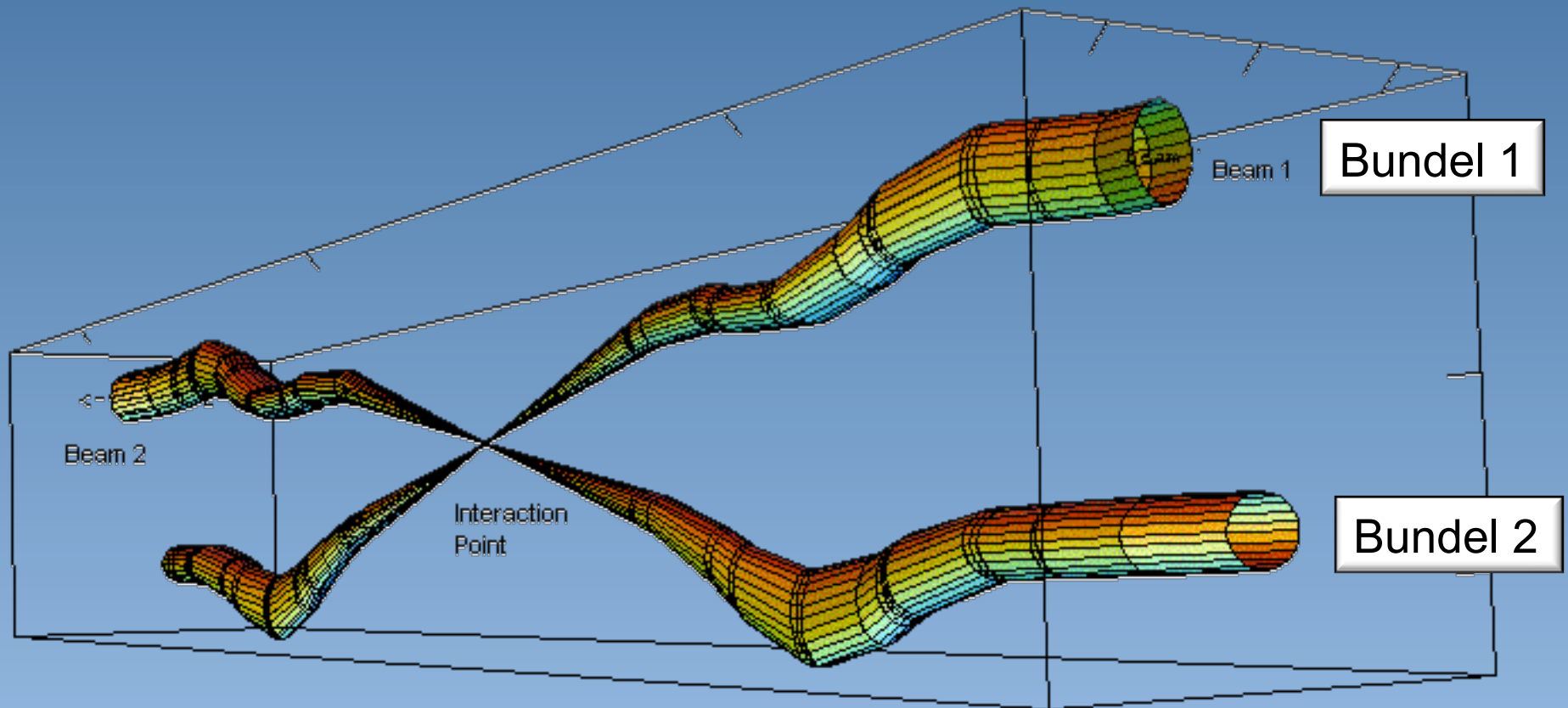
Energie LHC bundel

3000 x 100.000.000.000 protonen



*Doorsnede LHC
bundelpijp*

40 miljoen botsingen per seconde





Klassiek botsen

Quantummechanisch botsen



Wat verwacht je ?

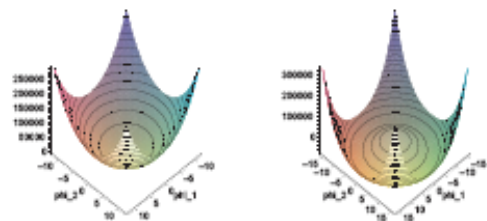


FIG. 1: The potential $V(\phi)$ ($\phi = \phi_1 + i\phi_2$) plotted for an arbitrary positive value of λ and for an arbitrary positive (right) or negative (left) value of μ^2 .

broken, and new interesting features emerge. To be more specific, let's pick the following ϕ_0 minimum (along the direction of the real part of ϕ , as traditional) and shift the ϕ field accordingly:

$$\phi_0 = \left(-\frac{\mu^2}{2\lambda} \right)^{1/2} = \frac{v}{\sqrt{2}} \rightarrow \phi(x) = \phi_0 + \frac{1}{\sqrt{2}} (\phi_1(x) + i\phi_2(x)) . \quad (5)$$

The Lagrangian in Eq. (3) can then be rearranged as follows:

$$\mathcal{L} = \underbrace{-\frac{1}{4}F^{\mu\nu}F_{\mu\nu}}_{\text{massive vector field}} + \underbrace{\frac{1}{2}g^2v^2A^\mu A_\mu + \frac{1}{2}(\partial^\mu\phi_1)^2 + \mu^2\phi_1^2}_{\text{massive scalar field}} + \underbrace{\frac{1}{2}(\partial^\mu\phi_2)^2}_{\text{Goldstone boson}} + gvA_\mu\partial^\mu\phi_2 + \dots \quad (6)$$

and now contains the correct terms to describe a massive vector field A^μ with mass $m_A^2 = g^2v^2$ (originating from the kinetic term of $\mathcal{L}_\phi$), a massive real scalar field ϕ_1 with mass $m_{\phi_1} = -2\mu^2$, that will become a *Higgs boson*, and a massless scalar field ϕ_2 , a so called *Goldstone boson* which couples to the gauge vector boson A^μ . The terms omitted contain couplings between the ϕ_1 and ϕ_2 fields irrelevant to this discussion. The gauge symmetry of the theory allows us to make the particle content more transparent. Indeed, if we parameterize the complex scalar field ϕ as:

$$\phi(x) = \frac{e^{i\chi(x)}}{\sqrt{2}}(v + H(x)) \xrightarrow{U(1)} \frac{1}{\sqrt{2}}(v + H(x)) , \quad (7)$$

the χ degree of freedom can be *rotated away*, as indicated in Eq. (7), by enforcing the $U(1)$ gauge invariance of the original Lagrangian. With this gauge choice, known as *unitarity gauge* or *unitarity gauge*, the Lagrangian becomes:

$$\mathcal{L} = \mathcal{L}_A + \frac{g^2v^2}{2}A^\mu A_\mu + \frac{1}{2}(\partial^\mu H\partial_\mu H + 2\mu^2 H^2) + \dots \quad (8)$$

a factor of two, making therefore almost a factor of four at the rate level. All other mass corrections, in the matrix element and phase space entering the calculation of the $H \rightarrow Q\bar{Q}$ decay rate, can in first approximation be safely neglected.

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4. Loop induced Higgs boson decays: $H \rightarrow \gamma\gamma, \gamma Z, gg$

Loop induced Higgs boson decays: $H \rightarrow \gamma\gamma, \gamma Z, gg$

the $H\gamma\gamma$ and $H\gamma Z$ couplings are induced at one loop via both a . At the lowest order the decay rate for $H \rightarrow \gamma\gamma$ can be written

$$\Gamma = \frac{G_F\alpha^2 M_H^2}{128\sqrt{2}\pi^3} \left| \sum_f N_f^2 Q_f^2 A_f^H(\tau_f) + A_W^H(\tau_W) \right|^2 , \quad (102)$$

l, q respectively), Q_f is the charge of the f fermion species, and $f(\tau)$ is defined as:

$$f(\tau) = \begin{cases} \arcsin^2 \frac{1}{\sqrt{\tau}} & \tau \geq 1 \\ -\frac{1}{4} \left[\ln \frac{1+\sqrt{1-\tau}}{1-\sqrt{1-\tau}} - i\pi \right]^2 & \tau < 1 , \end{cases} \quad (103)$$

and A_W^H are given by:

$$A_f^H = 2\tau [1 + (1-\tau)f(\tau)] , \quad (104)$$

$$A_W^H(\tau) = -[2 + 3\tau + 3\tau(2-\tau)f(\tau)] .$$

decay rate for $H \rightarrow \gamma Z$ is given by:

$$\Gamma = \frac{G_F\alpha^2 M_H^2}{\pi^4} \left(1 - \frac{M_Z^2}{M_H^2} \right)^2 \left| \sum_f A_f^H(\tau_f, \lambda_f) + A_W^H(\tau_W, \lambda_W) \right|^2 , \quad (105)$$

$\lambda_i = 4M_i^2/M_Z^2$ ($i = f, W$), and the form factors $A_f^H(\tau, \lambda)$ and

$$2N_f^2 \frac{Q_f(I_{3f} - 2Q_f \sin^2 \theta_W)}{\cos \theta_W} [I_1(\tau, \lambda) - I_2(\tau, \lambda)] , \quad (106)$$

$$\cos \theta_W \left\{ \left[\left(1 + \frac{2}{\tau} \right) \tan^2 \theta_W - \left(5 + \frac{2}{\tau} \right) \right] I_1(\tau, \lambda) + 4 \left(3 - \tan^2 \theta_W \right) I_2(\tau, \lambda) \right\} , \quad (107)$$

defined after Eq. (102), and I_2^f is the weak isospin of the f fermion

$$\frac{\tau^2 \lambda^2}{\lambda} + \frac{\tau^2 \lambda^2}{2(\tau - \lambda)^2} [f(\tau) - f(\lambda)] + \frac{\tau^2 \lambda}{(\tau - \lambda)^2} [g(\tau) - g(\lambda)] ,$$

the $H\gamma\gamma$ and $H\gamma Z$ couplings are induced at one loop via both a . At the lowest order the decay rate for $H \rightarrow \gamma\gamma$ can be written

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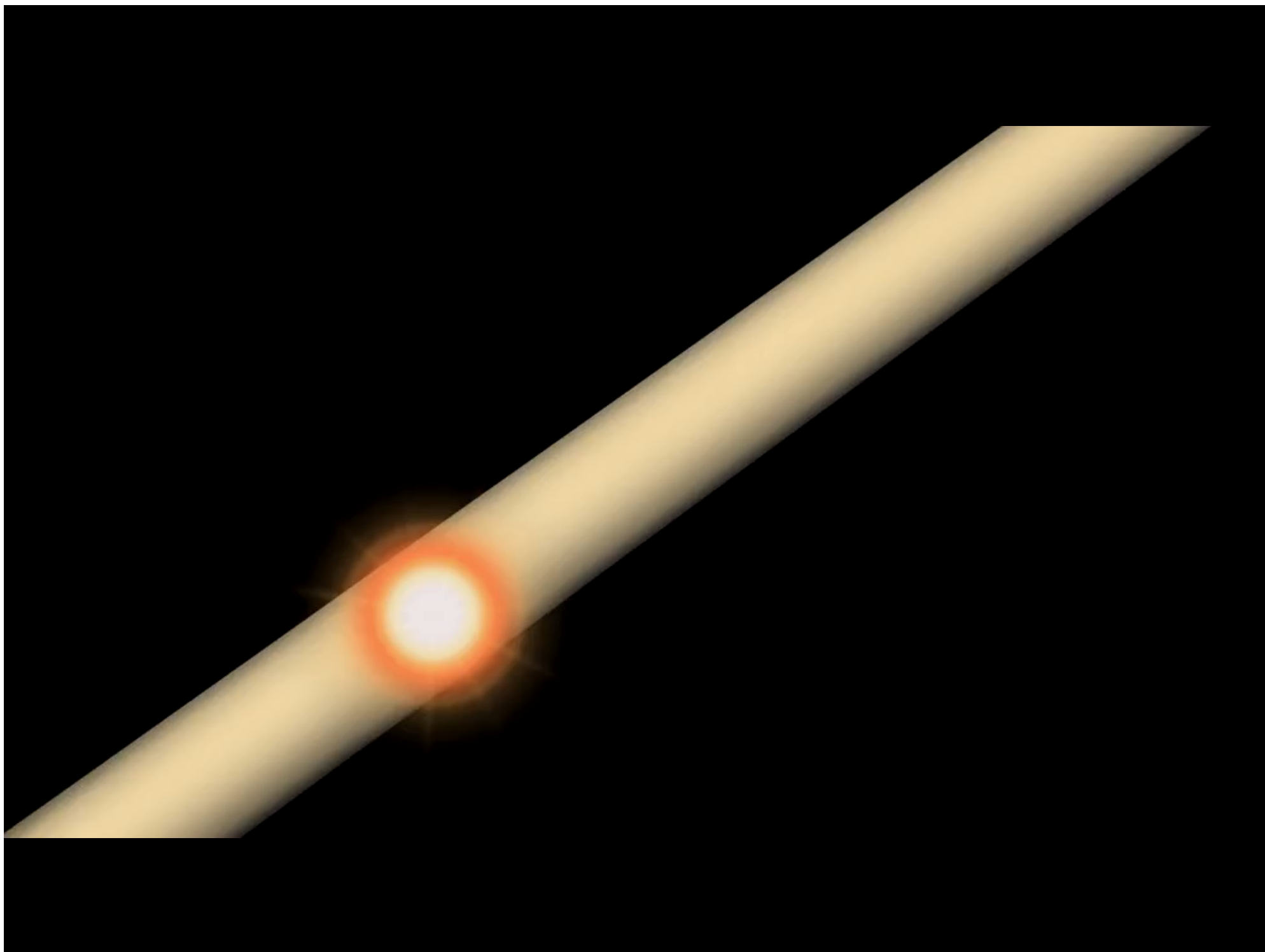
$$\cos \theta_W \left\{ \left[\left(1 + \frac{2}{\tau} \right) \tan^2 \theta_W - \left(5 + \frac{2}{\tau} \right) \right] I_1(\tau, \lambda) + 4 \left(3 - \tan^2 \theta_W \right) I_2(\tau, \lambda) \right\} , \quad (107)$$

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$$\frac{\tau^2 \lambda^2}{\lambda} + \frac{\tau^2 \lambda^2}{2(\tau - \lambda)^2} [f(\tau) - f(\lambda)] + \frac{\tau^2 \lambda}{(\tau - \lambda)^2} [g(\tau) - g(\lambda)] ,$$

Klopt het ?

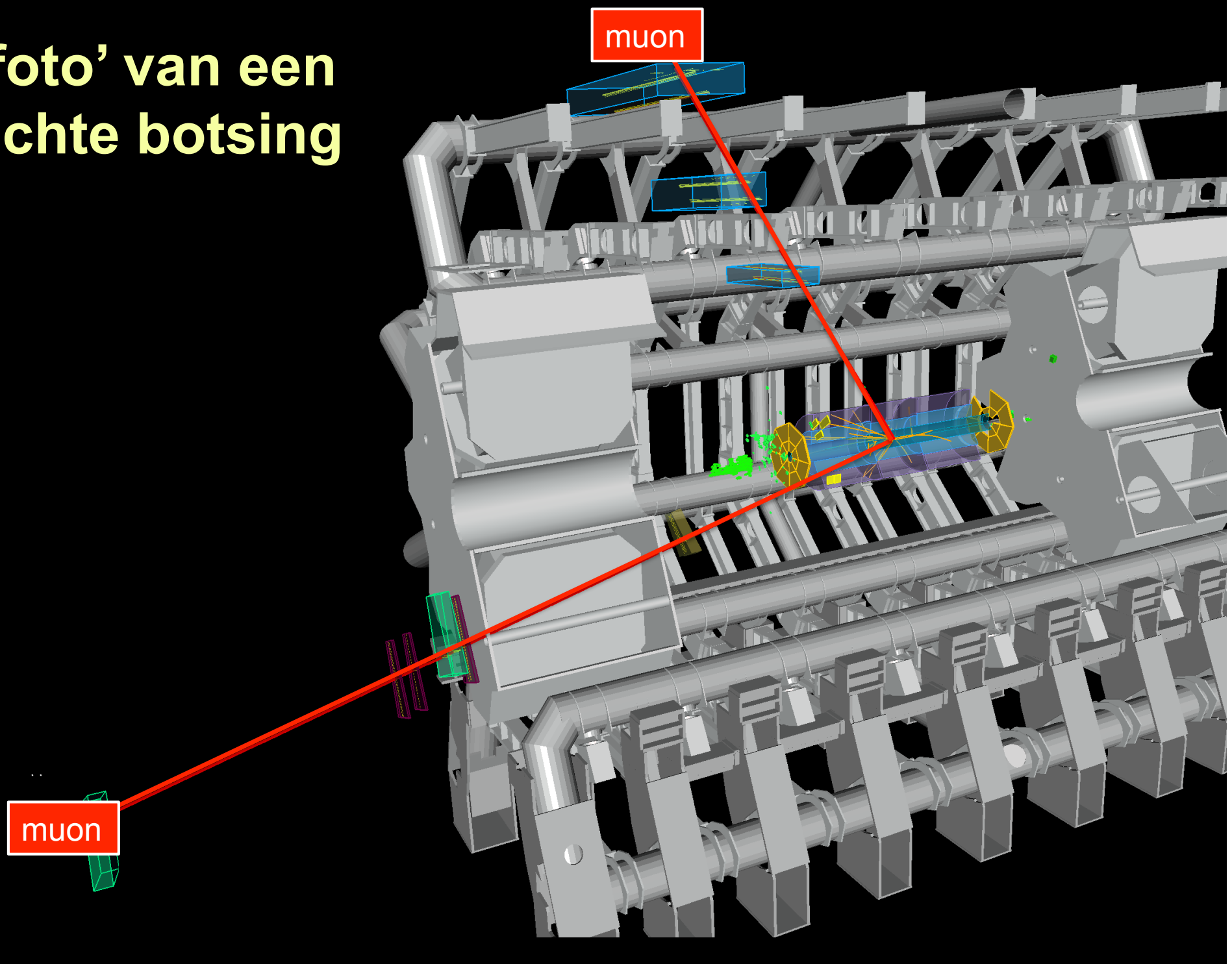
Inderdaad nieuwe deeltjes ?



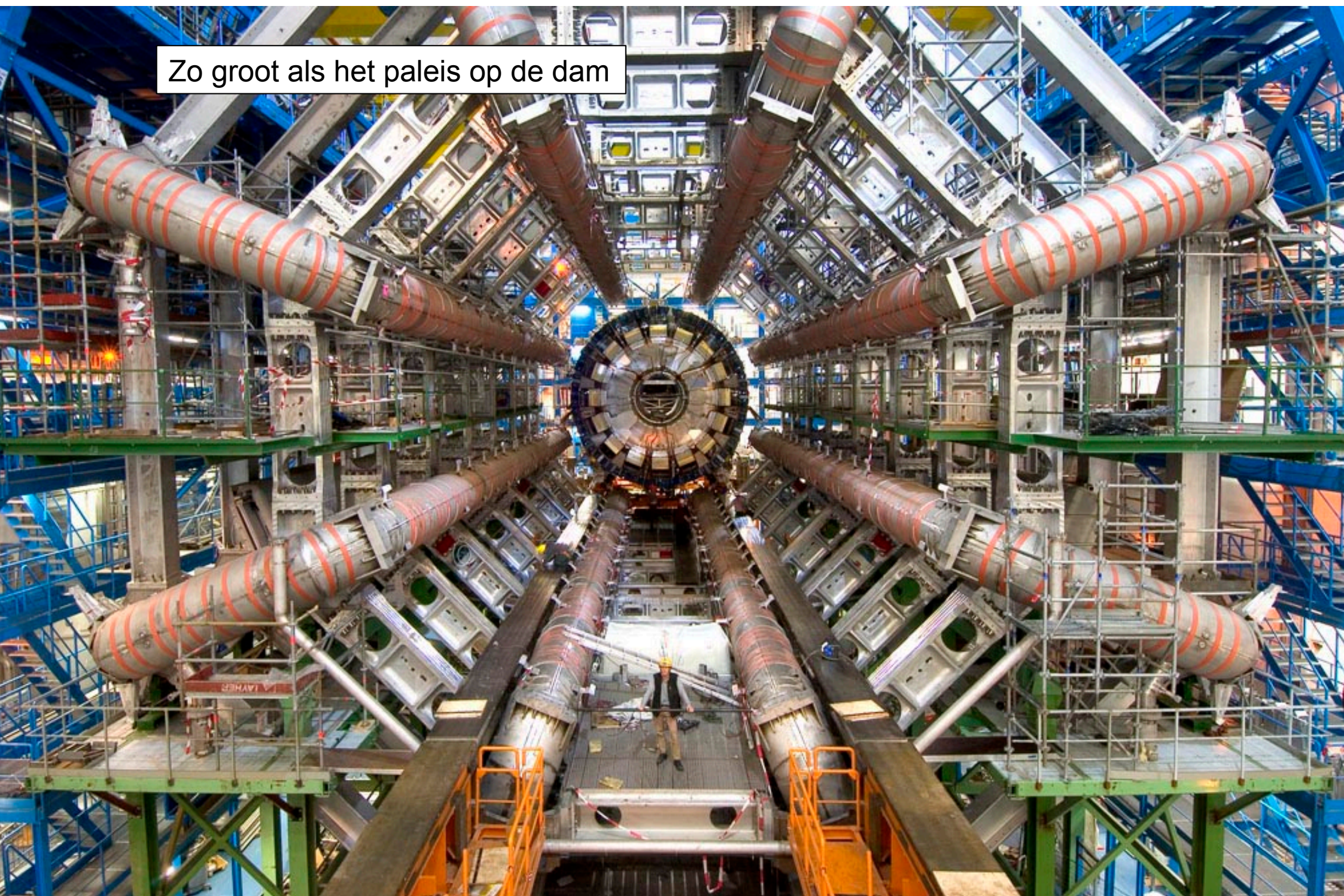
Onze 'fototoestellen'



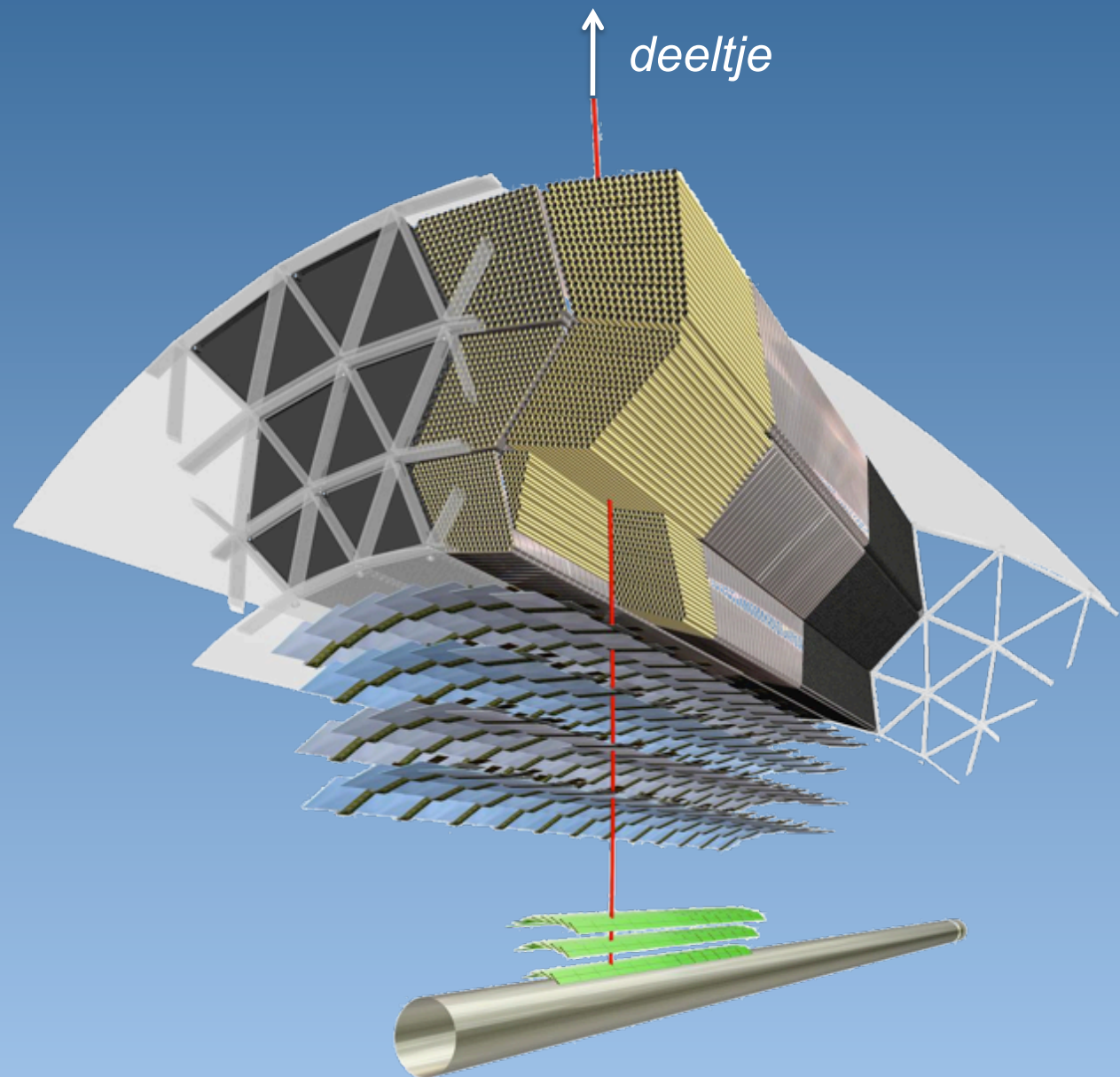
**‘foto’ van een
echte botsing**



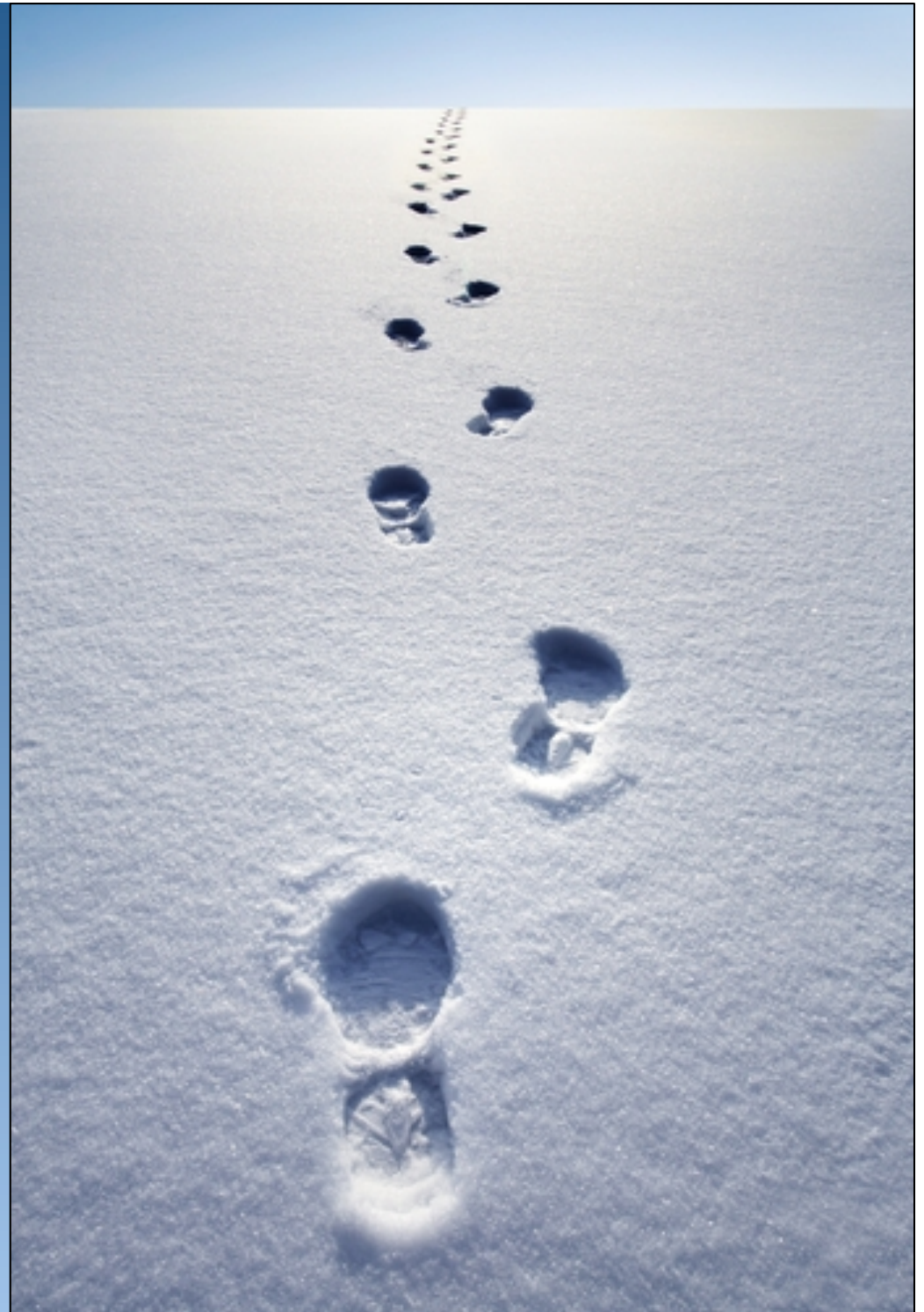
Zo groot als het paleis op de dam



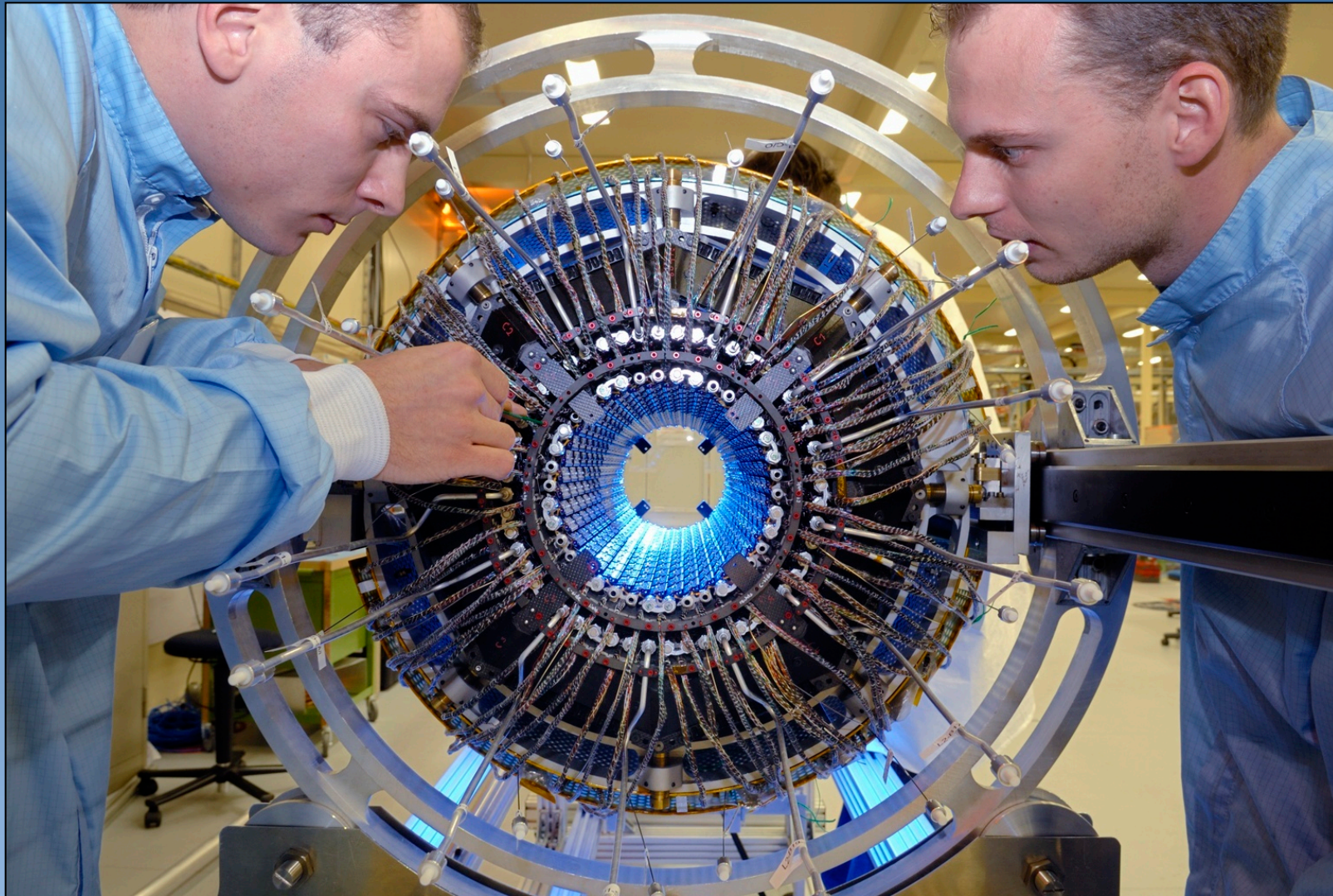
Waarom is die ATLAS detector nou zo complex ?



Konijn, auto of mens ?



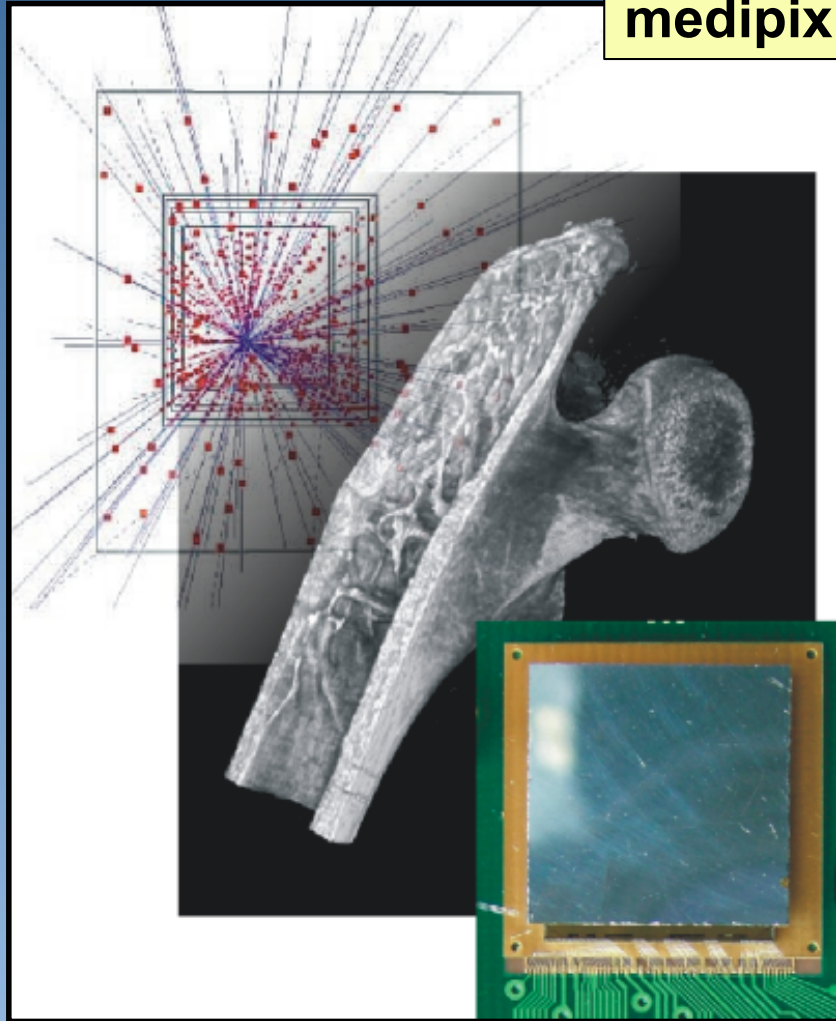
De Atlas pixel detector



80 MegaPixel camera 40.000.000 foto's per seconde

Medische toepassingen

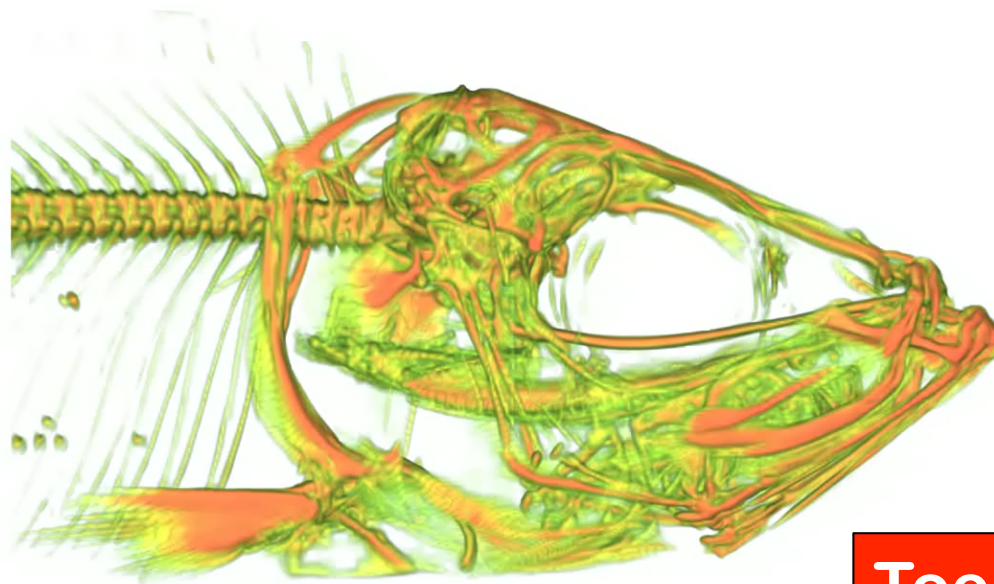
medipix



Normale CT scan ~ 200 Röntgen foto's

Kleinere pixel grootte: 1 mm $\rightarrow$ 50 μ m

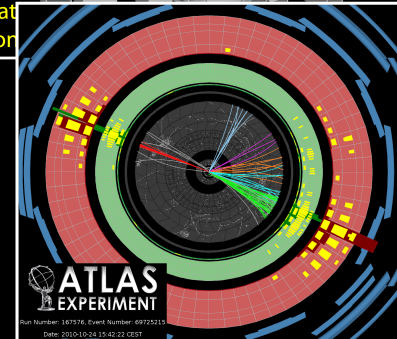
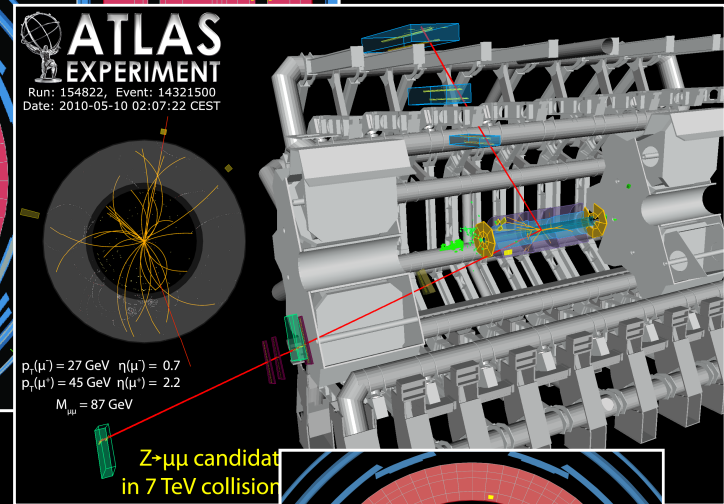
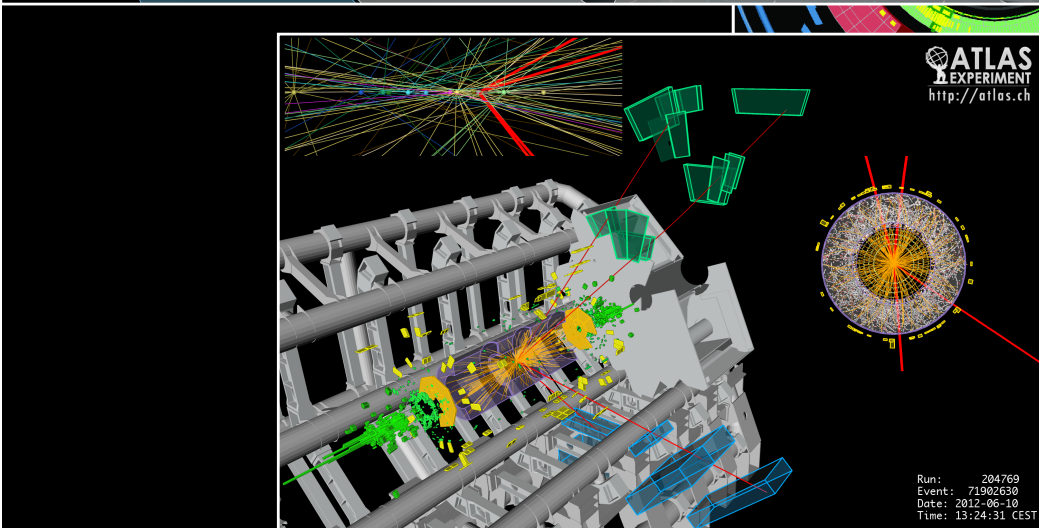
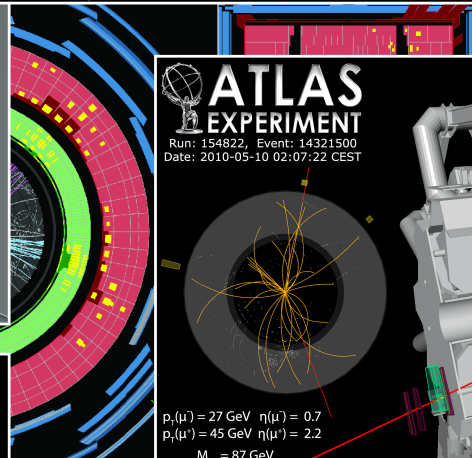
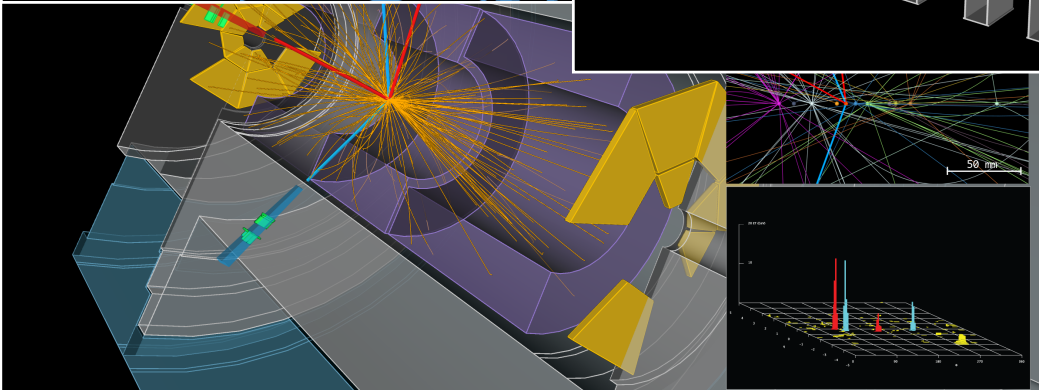
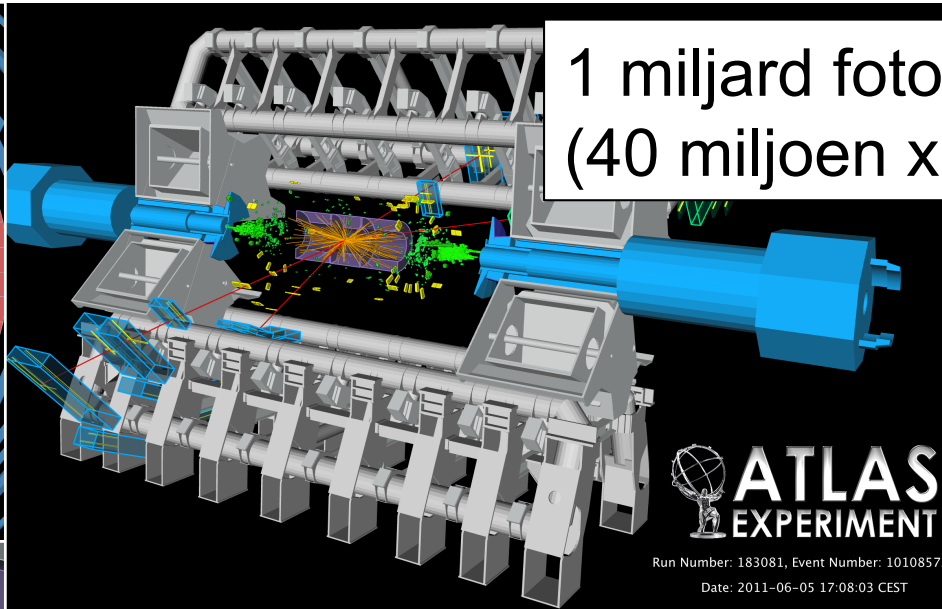
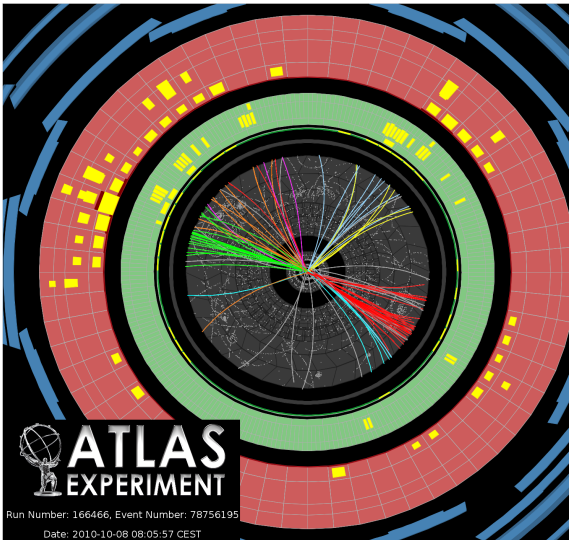
CT scan of a (spiering) of 2.4 cm length using MedPix



**Toekomst:
kleuren-Xrays**

Toepassing: minder X-rays voor zelfde resolutie

1 miljard foto's per seconde
(40 miljoen x 20 botsingen)



Computing

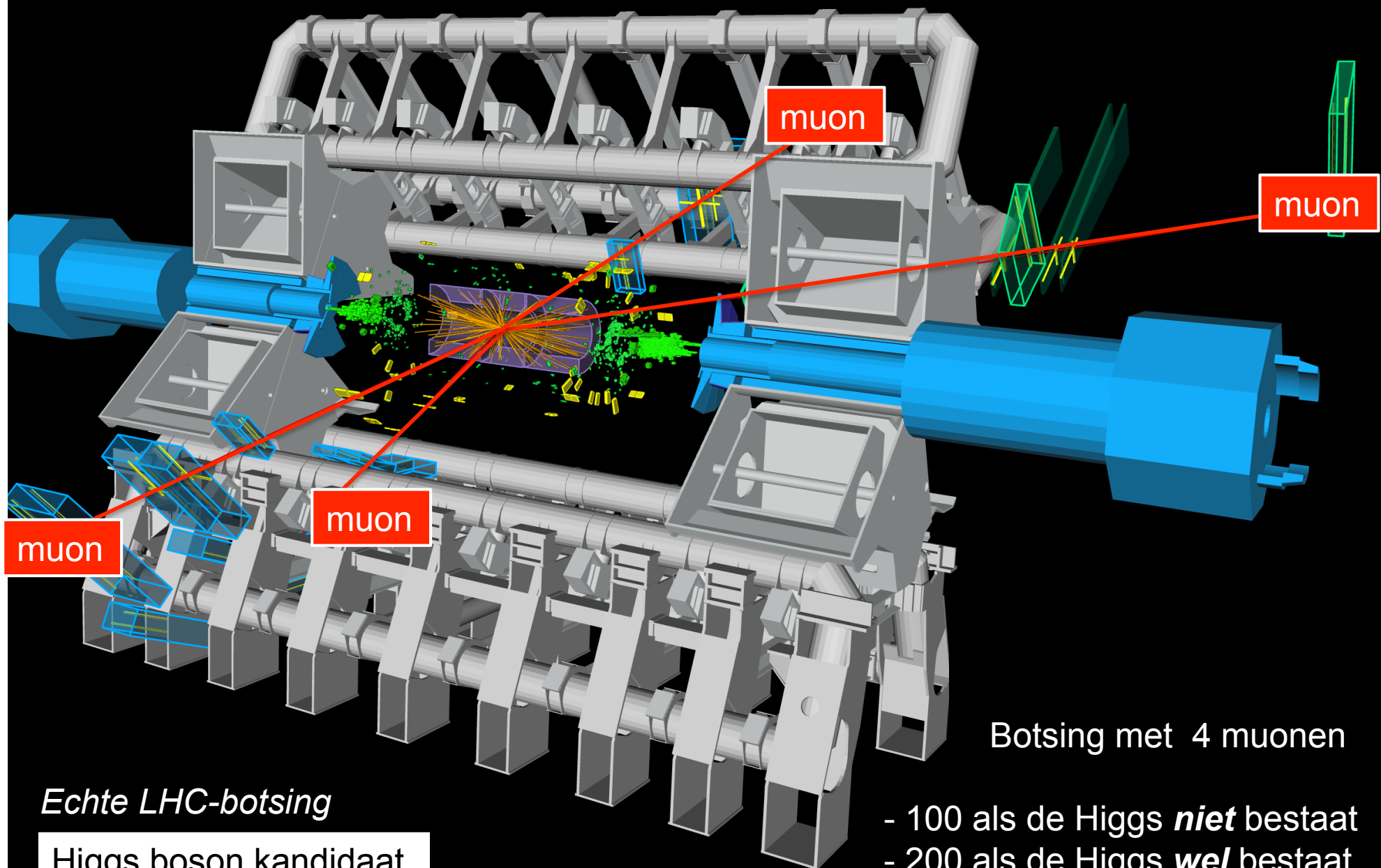
Lastig: Per seconde:

- 1 miljard botsingen (foto's)
- je mag er maar 200 bewaren (diskruimte)

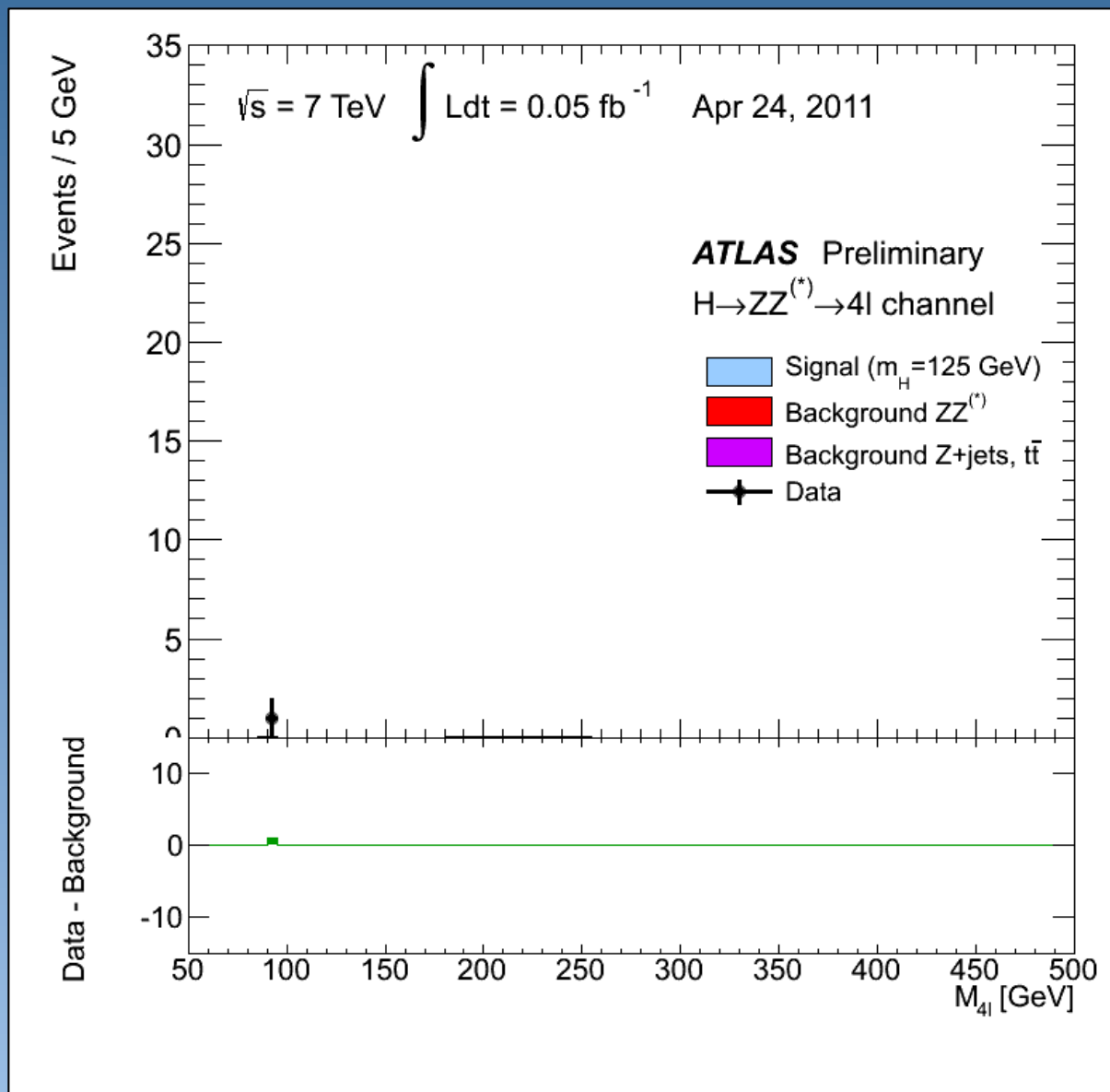
Big data: 15 Peta Bytes en 100,00 CPU's

... het echte werk!





Kijk hier ($m_h = 125$ GeV)



4 juli 2012: feest !!

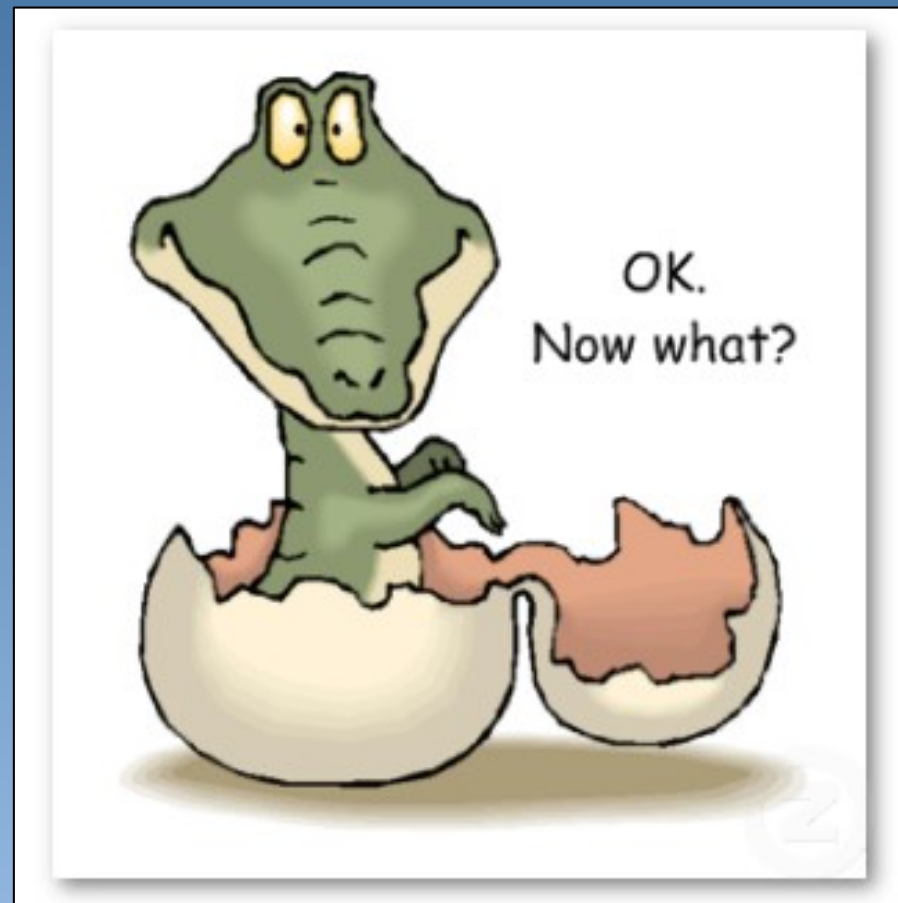


Dinsdag 8 oktober 11:45 uur

bekendmaking Nobelprijs natuurkunde



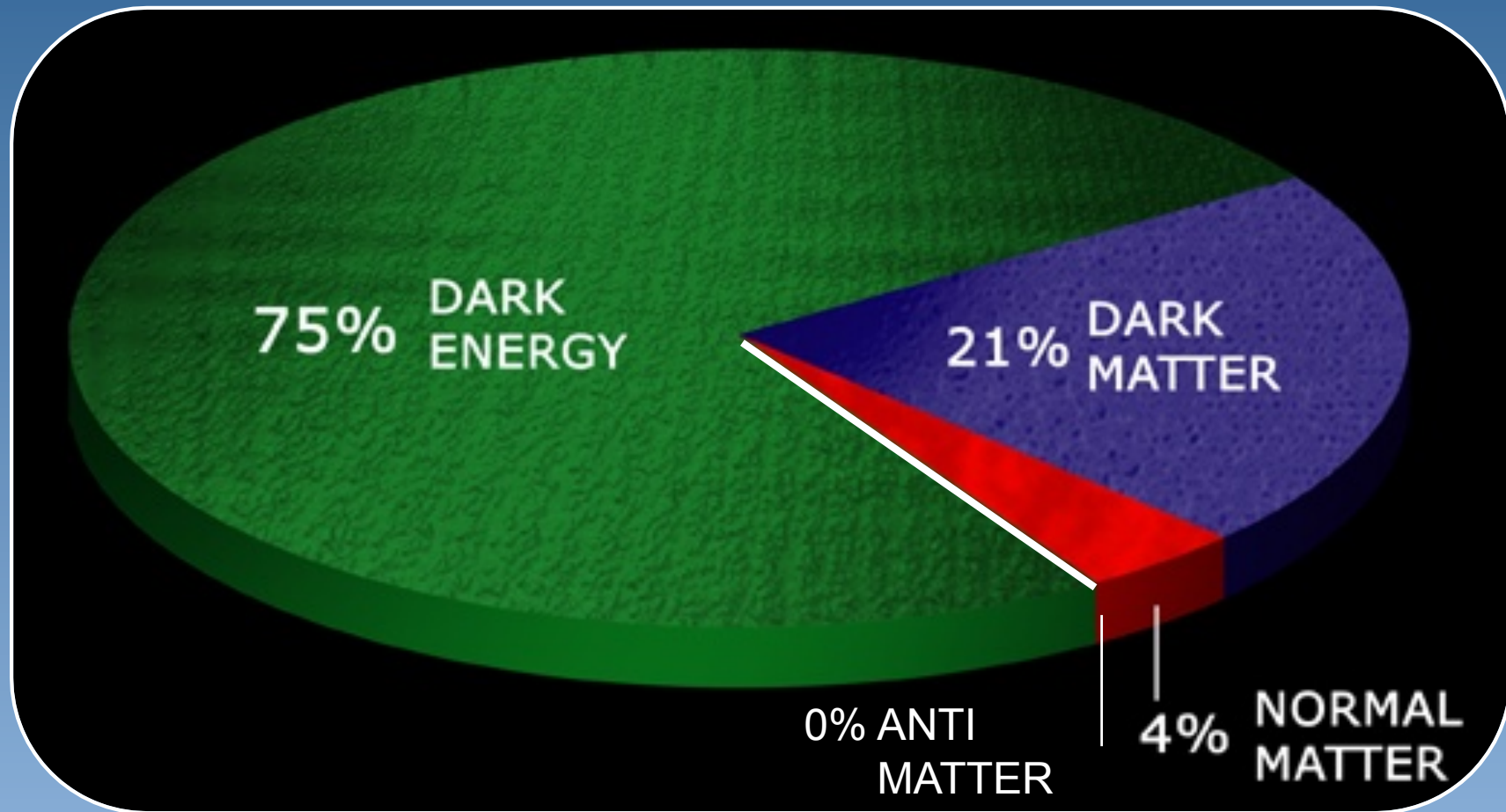
5 juli 2012: wat nu ?



Wat snappen we nog niet:



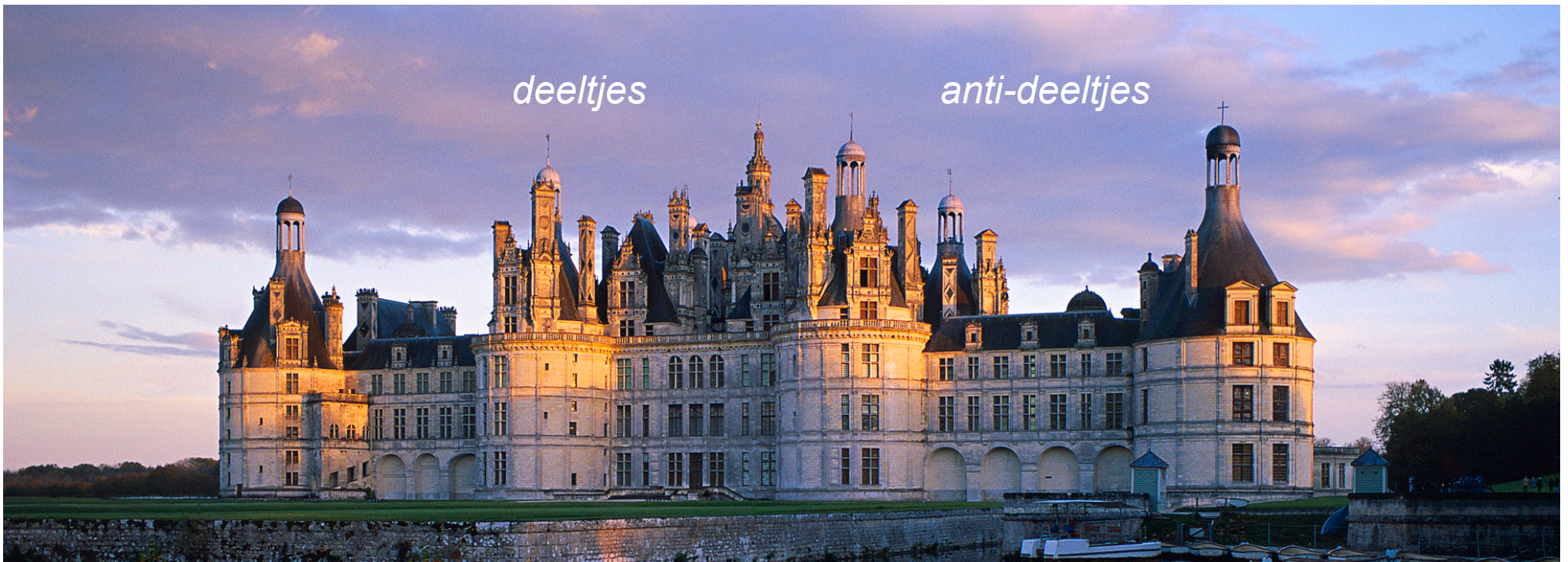




Wat is de donkere materie ?

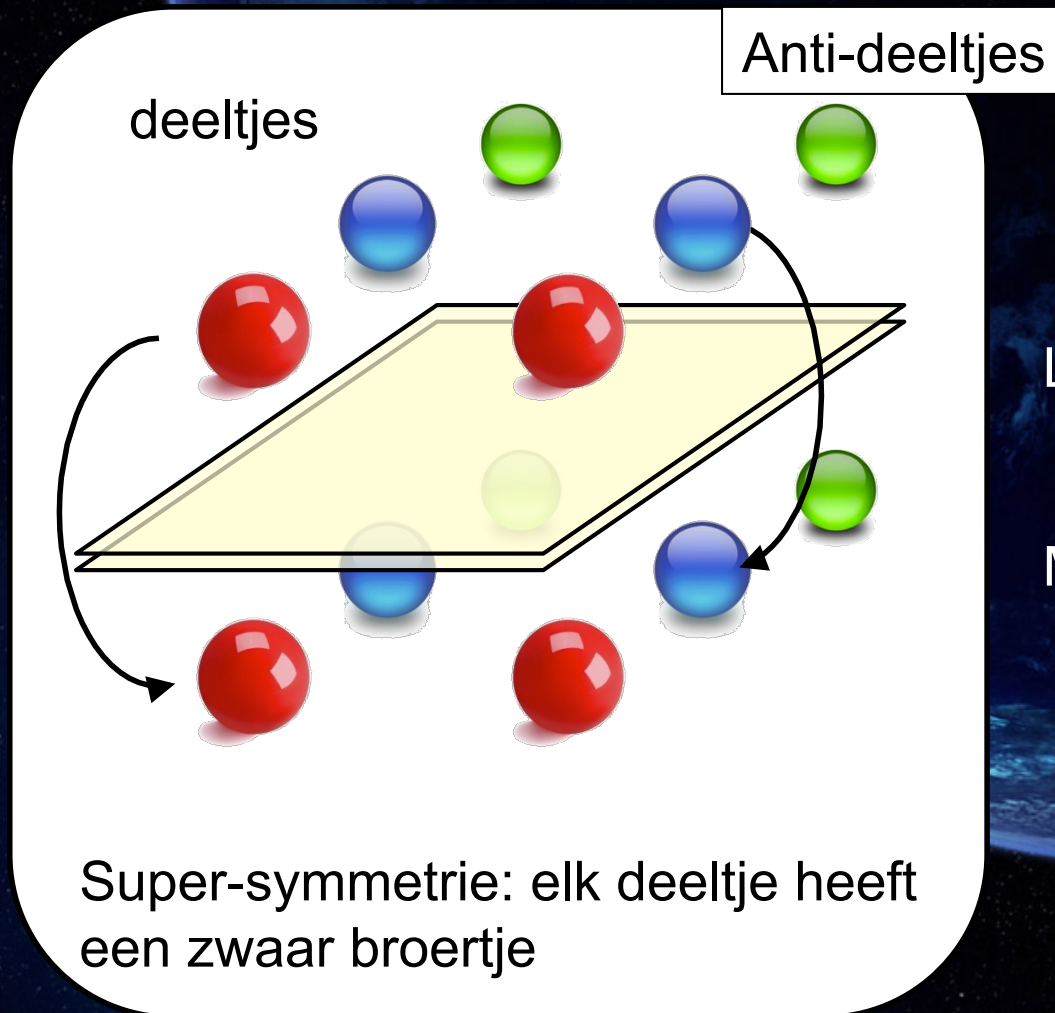
deeltjes

anti-deeltjes



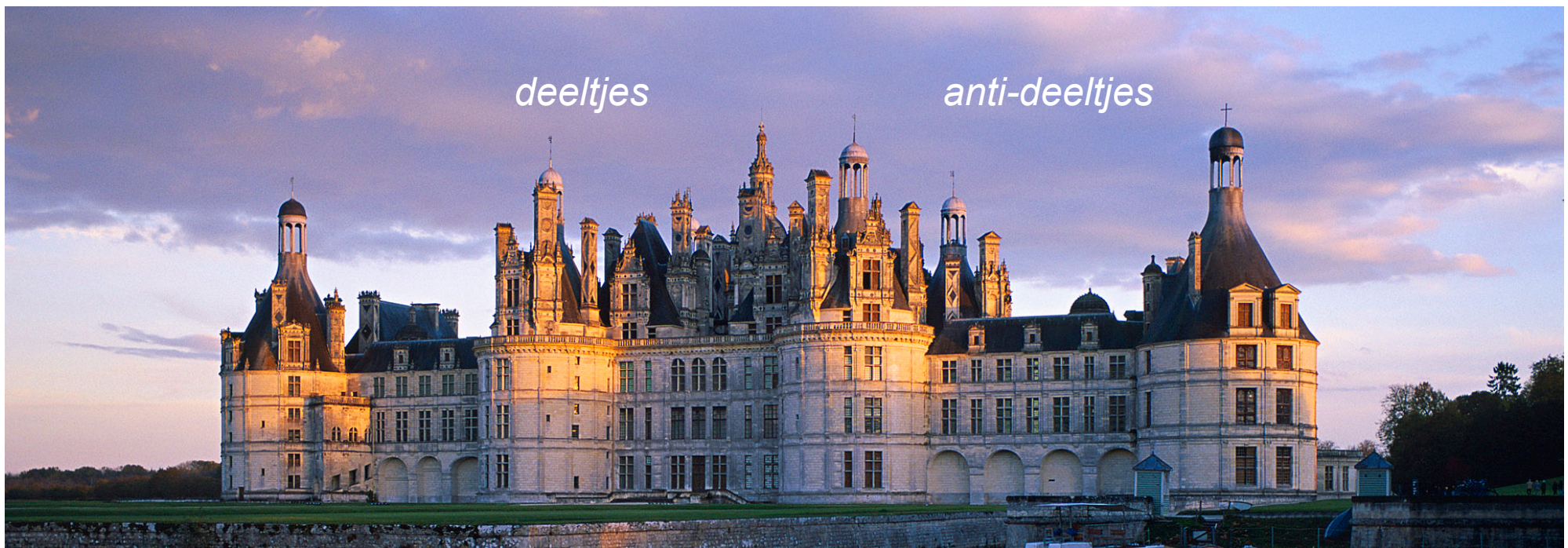
Donkere Materie zelf maken

Theoretisch idee: Supersymmetrie:



Lichtste is donkere materie deeltje ?

Maak ze bij de LHC !



deeltjes

anti-deeltjes

Natuurkunde

De natuur zit vol vreemde spelregels

Het Higgs boson bestaat

Wat is donkere materie / energie ?

Waarom is de zwaartekracht zo raar ?

Spin-off

Slimme jonge mensen voor de industrie

Computing, sensors, versnellers

Medische apparatuur

avontuur

BACKUP

Relativiteitstheorie



Relativiteitstheorie

“structuur van tijd en ruimte”

De snelheid van een tennisbal en een lichtstraal gezien vanuit de ogen van een bewegende waarnemer



$$v = 299.792.458 \text{ [m/s]}$$



$$v = 20 \text{ [m/s]}$$

Snelheid ?



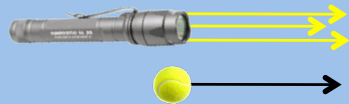
bal

lichtstraal

<i>bal</i>	<i>lichtstraal</i>
20	299.792.458

Hoe verandert dit als de waarnemer zelf beweegt ?

relatieve snelheid
bal lichtstraal



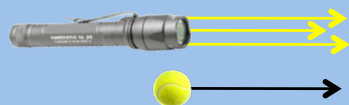
$$v = 299.792.458 \text{ [m/s]}$$

$$v = 20 \text{ [m/s]}$$



20

299.792.458



$$v = 299.792.458 \text{ [m/s]}$$

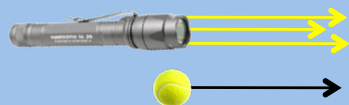
$$v = 20 \text{ [m/s]}$$



$$v = -10 \text{ [m/s]}$$

30

299.792.458



$$v = 299.792.458 \text{ [m/s]}$$

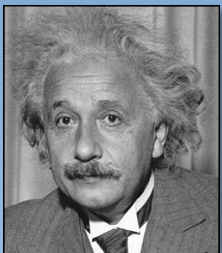
$$v = 20 \text{ [m/s]}$$



$$v = +10 \text{ [m/s]}$$

10

299.792.458



Idee (en observatie)

“de snelheid van het licht is constant voor elke waarnemer”

Albert Einstein Waarom: geen idee!

Consequenties:

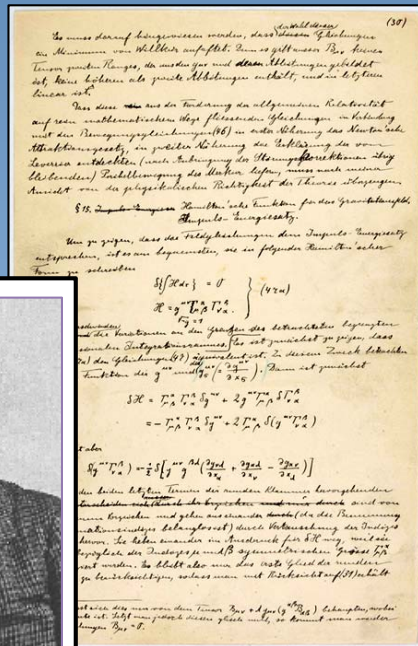
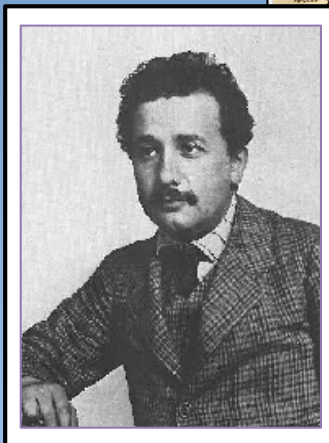
Ruimte en tijd verbonden, gelijktijdigheid niet uniek gedefiniëerd, ...

Speciale/algemene relativiteitstheorie:

tijd langzamer in een gravitatieveld

Relativiteitstheorie ... nuttig ?

Relativiteitstheorie ?



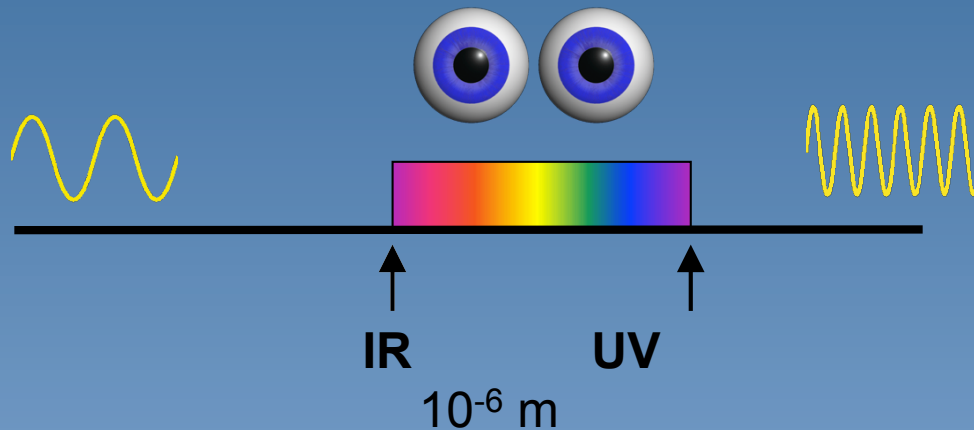
“Zonder relativiteitstheorie zit de GPS er 10 km per dag naast!”

Kijken zonder je ogen te gebruiken



1] Kijken met licht

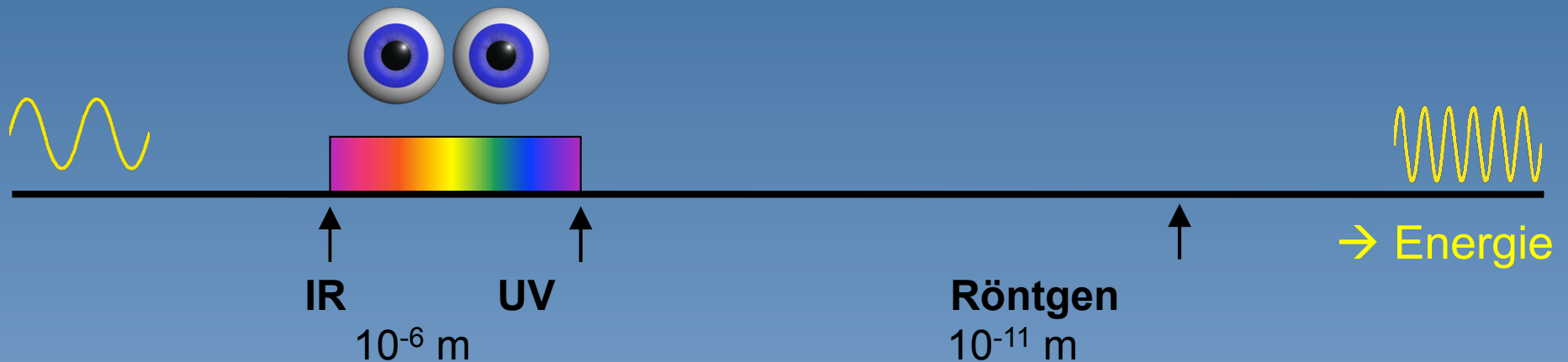
Licht verstrooit aan objecten die groter zijn dan zijn golflengte



Met je oog kan je niks zien
dat kleiner is dan 10^{-6} m

1] Kijken met licht

Licht verstrooit aan objecten die groter zijn dan zijn golflengte.



2] Kijken met deeltjes

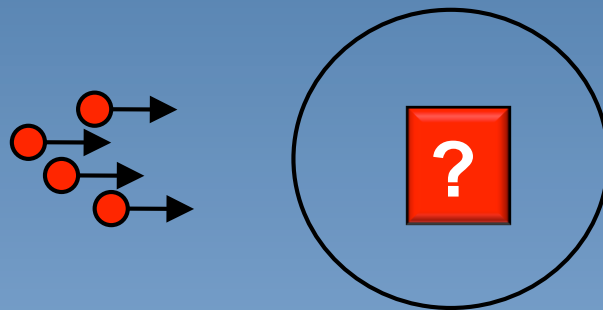
Quantummechanica: deeltjes zijn golven. Hoe meer energie hoe kleiner

→ microscoop voor zeer kleine afstanden:

- klein: elektronen microscoop
- kleinst: protonen micsoscoop

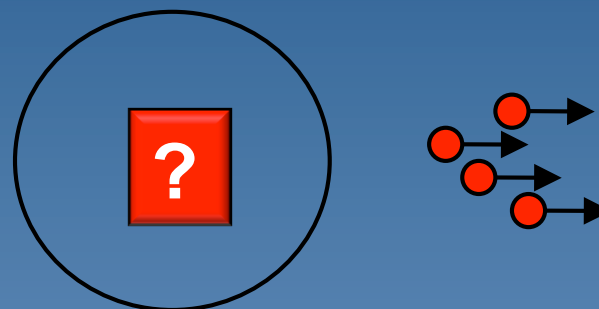
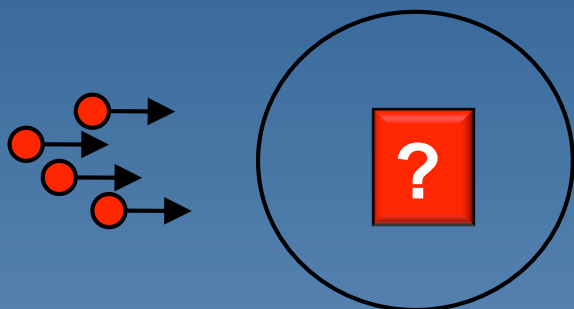
onbekend voorwerp achter een gordijn
... en 100 kogeltjes

bovenaanzicht

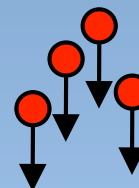
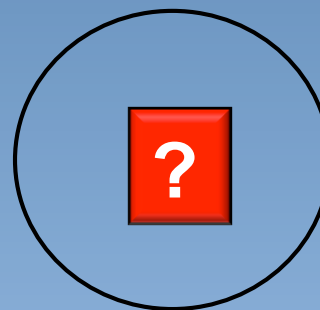
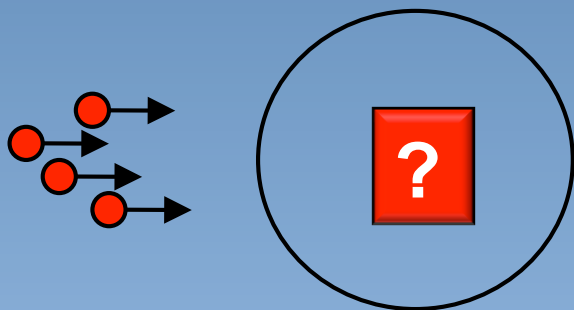


Hoe ketsen de kogels af ?

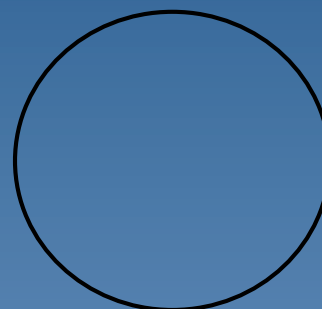
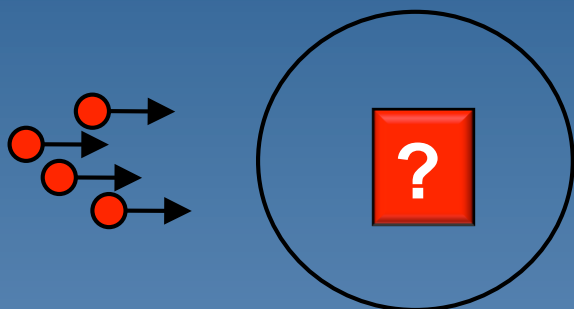
Situatie 1



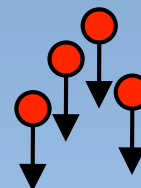
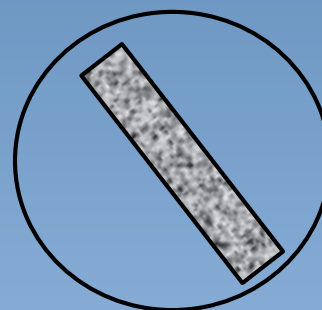
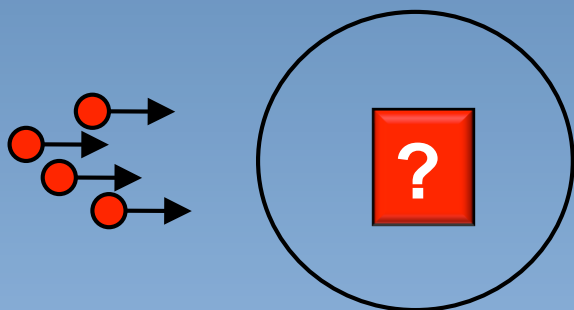
Situatie 2



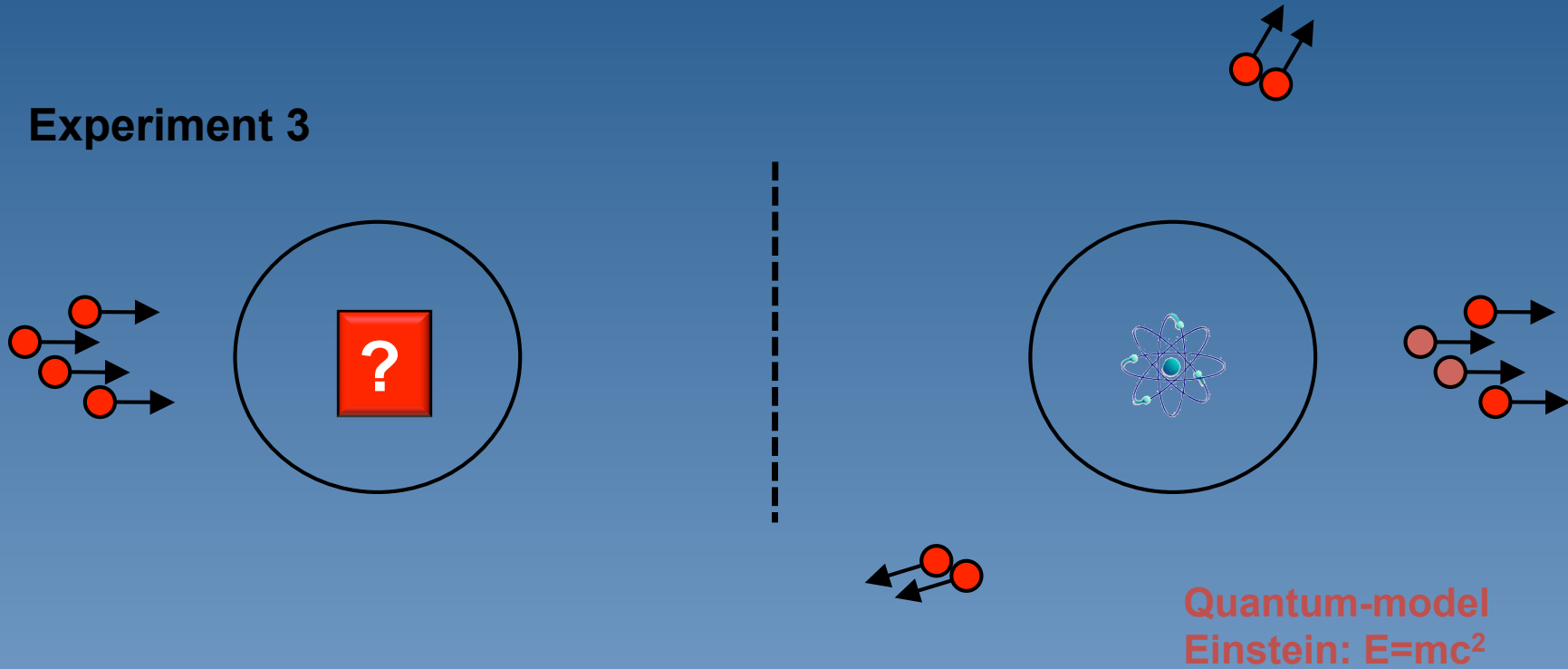
Situatie 1



Situatie 2



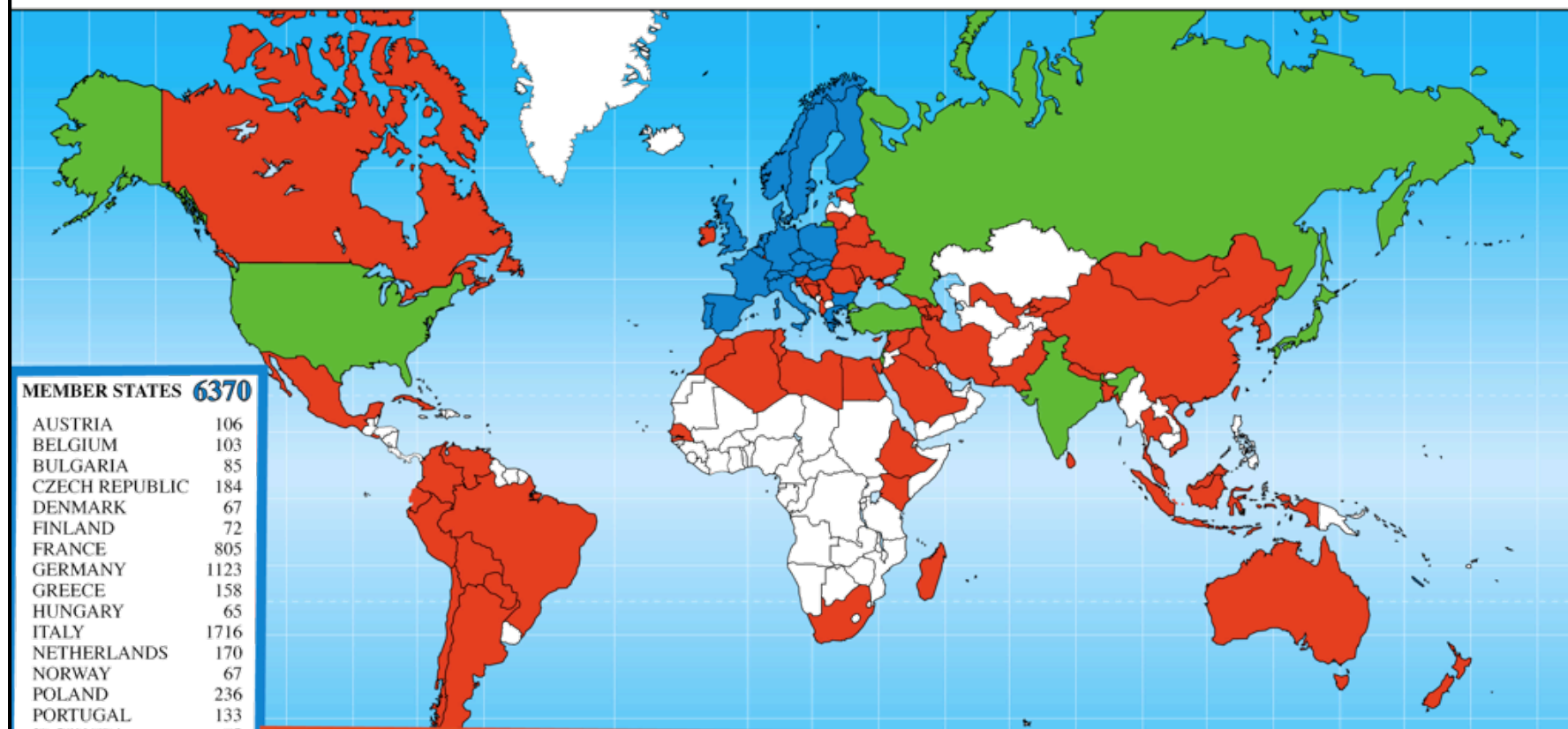
Experiment 3



‘Kijken’ naar sub-atomaire structuren:

- 1) Kleine kogels maken: Deeltjesversneller
- 2) Berekenen wat je verwacht voor een hypothese: Theorie
- 3) Afgeketste deeltjes kunnen bekijken: Detector

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SLOVAKIA	78
SPAIN	330
SWEDEN	67
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ALBANIA	2	BRAZIL	79	ESTONIA	9	KYRGYZSTAN	1	MOROCCO	16	SINGAPORE	1
ALGERIA	8	CANADA	136	ETHIOPIA	1	LEBANON	8	NEPAL	3	SLOVENIA	20
ARGENTINA	11	CHILE	3	GEORGIA	31	LITHUANIA	9	NEW ZEALAND	10	SOUTH AFRICA	9
ARMENIA	24	CHINA	202	GIBRALTAR	1	LUXEMBOURG	5	PAKISTAN	33	SRI LANKA	6
AUSTRALIA	20	CHINA (TAIPEI)	41	HONG KONG	2	LIBYA	1	PALESTINE (O.T.)	1	SYRIA	2
AZERBAIJAN	5	COLOMBIA	19	INDONESIA	1	MADAGASCAR	3	PARAGUAY	1	THAILAND	1
BANGLADESH	3	CROATIA	24	IRAN	20	MALAYSIA	7	PERU	2	TUNISIA	5
BELARUS	36	CUBA	4	IRAQ	1	MALTA	3	ROMANIA	101	UKRAINE	40
BOLIVIA	2	CYPRUS	12	IRELAND	20	MAURITIUS	1	SAN MARINO	1	UZBEKISTAN	2
BOSNIA AND HERZEGOVINA	1	ECUADOR	2	KENYA	2	MEXICO	46	SAUDI ARABIA	2	VENEZUELA	5
		EGYPT	6	KOREA, D.P.R.	3	MOLDOVA	1	SENEGAL	1	VIET NAM	6
		EL SALVADOR	1	KOREA REP.	85	MONGOLIA	1	SERBIA	34		