

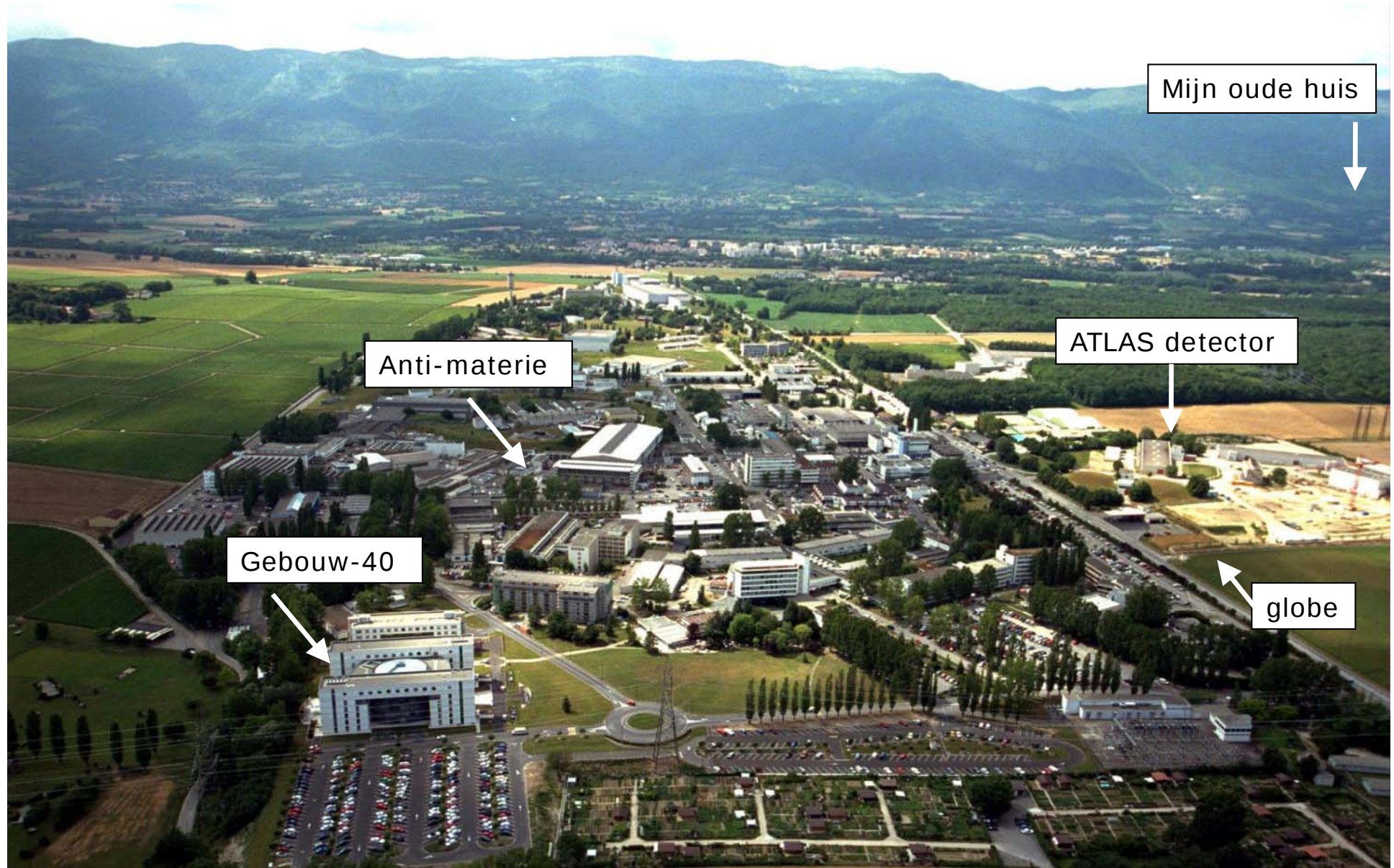
Zoektocht naar de elementaire bouwstenen van de natuur

Het atoom:
hoe beter men keek
hoe kleiner het leek

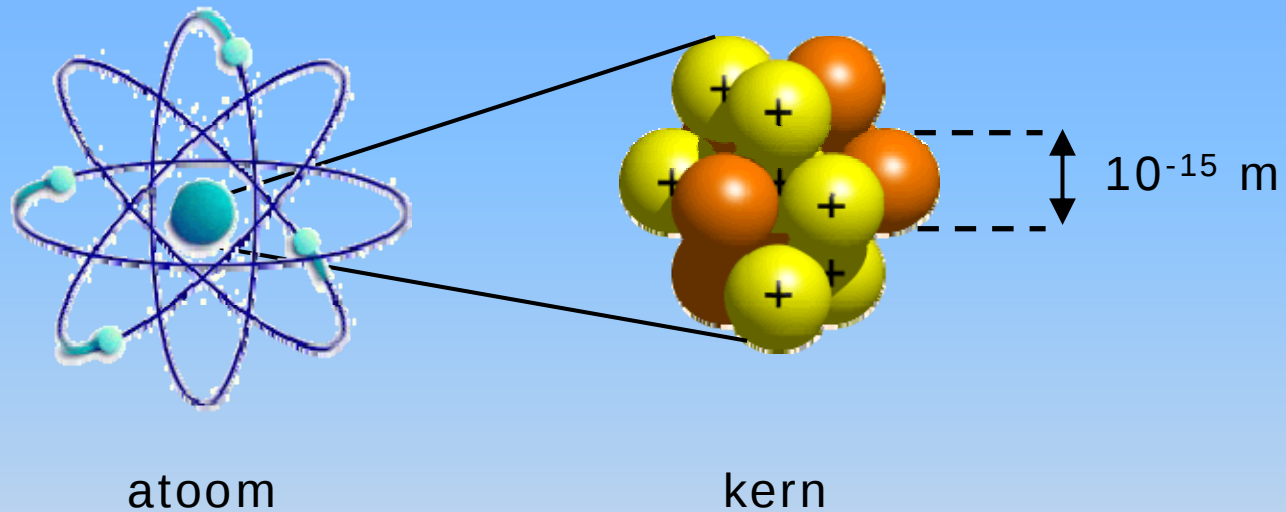


Ivo van Vulpen

CERN



Deeltjesfysica



Wat zijn de bouwstenen van de dingen om ons heen ?



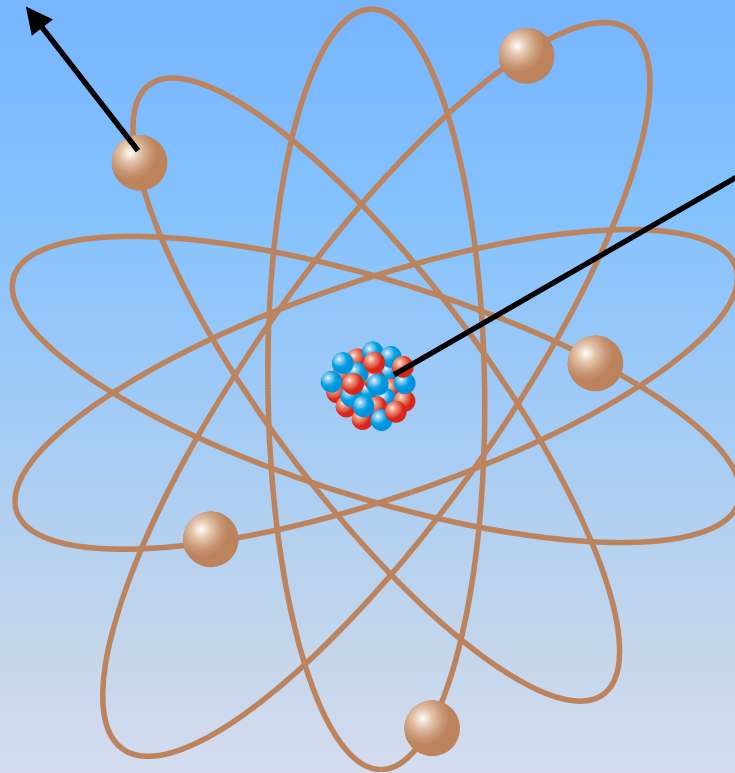


[1] Wow, mooi ! ... fascinerende complexe patronen !

[2] Gewoon 4 gekleurde draadjes en simpel symmetrisch patroon

Wat waren de problemen 100 jaar geleden ?

elektron:lading -1



proton:lading +1

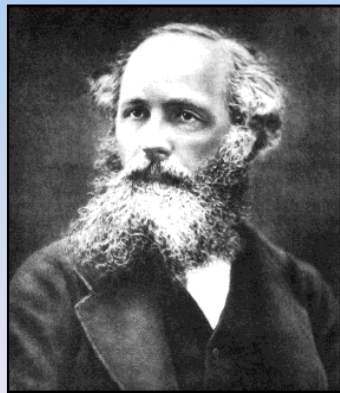
Waarom valt het elektron niet op de kern ?

Zwaartekracht en Electromagnetisme

“zelfde krachten ... nieuwe modellen”



Newton



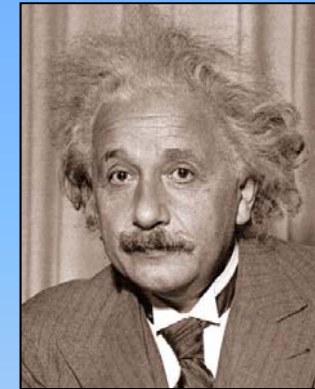
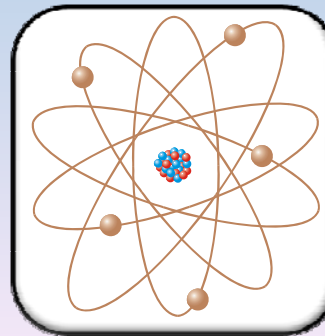
Maxwell



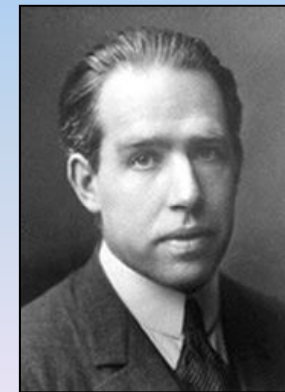
Relativiteitstheorie



Quantummechanica



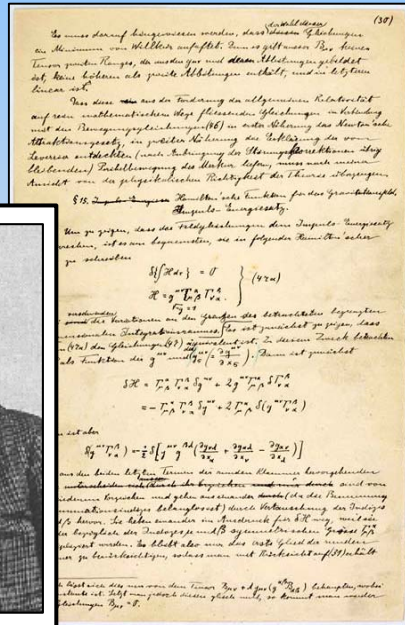
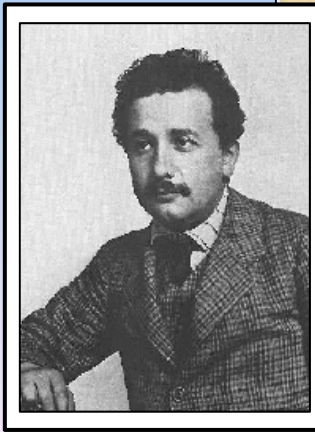
Einstein



Bohr

Relativiteitstheorie ... nuttig ?

Relativiteitstheorie ?



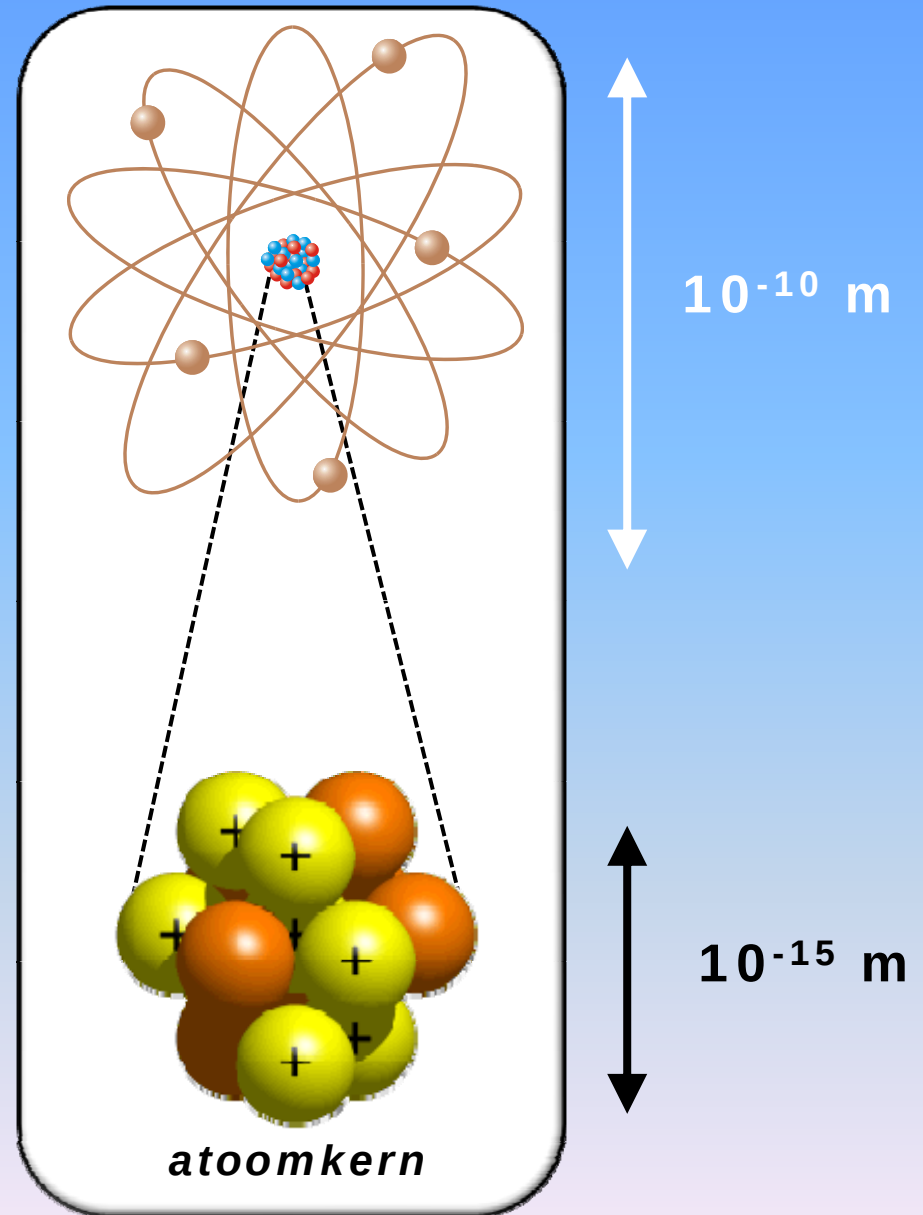
"Zonder relativiteitstheorie zit de GPS er 10 km per dag naast!"

De kernkrachten

- 1] Positieve deeltjes stoten elkaar toch af ?
- 2] Wat houdt de neutrale deeltjes bij elkaar ?

2 nieuwe natuurkrachten:

- zwakke kernkracht
- sterke kernkracht



De stand van zaken in september 2010



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

De elementaire deeltjes



up

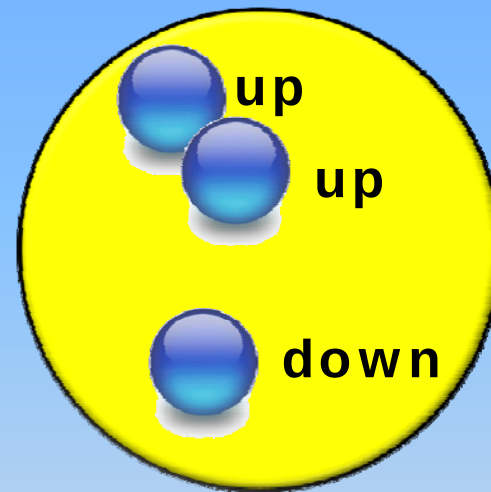


down

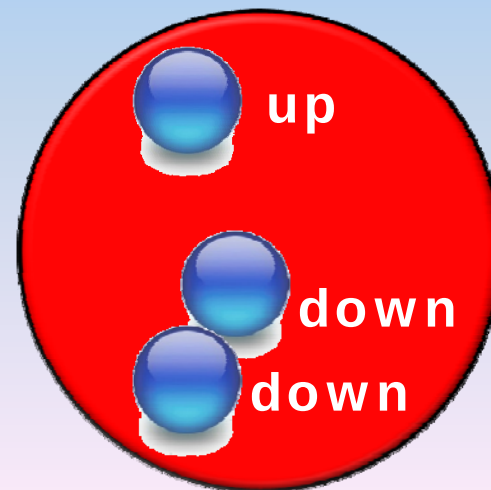


elektron

+ 4 natuurkrachten



Proton

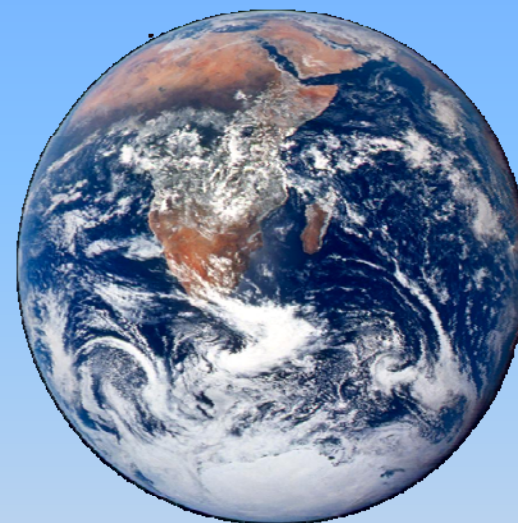


Neutron

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!



Wetenschapper



Dichter

Wat snappen we nog niet:





Paar 'kleine' dingetjes:

1

96% van de materie in het heelal is onbekend
→ donkere materie

2

Waar is alle anti-materie gebleven ?

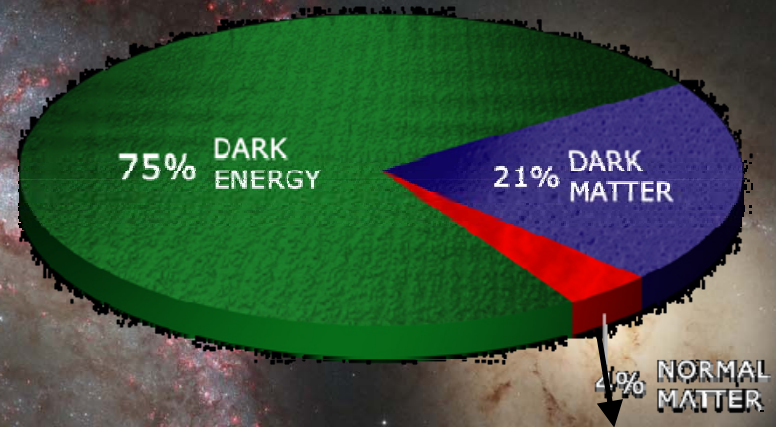
3

Higgs boson

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

1

Donkere-materie



Normale materie
(4 %)

Revolutie in kosmologie laatste paar jaar
Structuur van het heelal:
we hebben al die tijd maar 4% van het
heelal bestudeerd

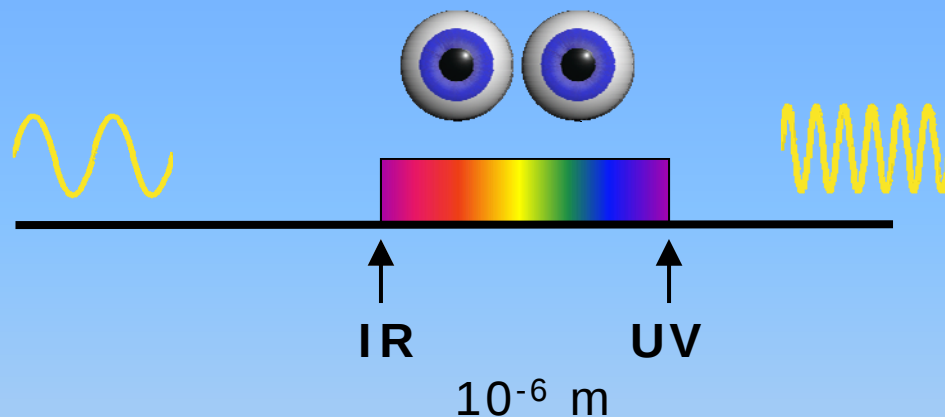
We gaan proberen de donkere materie
deeltjes in het laboratorium maken

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

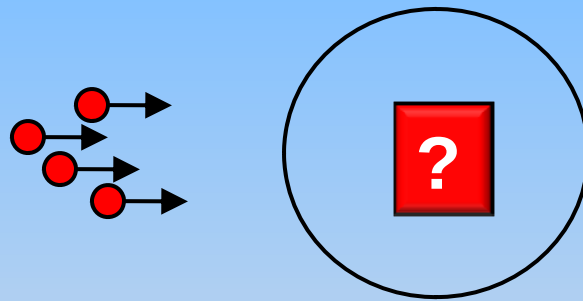
2] Kijken met deeltjes

Idee: laat kleine deeltjes afketsen van het object

- deeltjes-microscoop:
- klein: elektronen microscoop
 - kleinst: protonen microscoop (LHC)

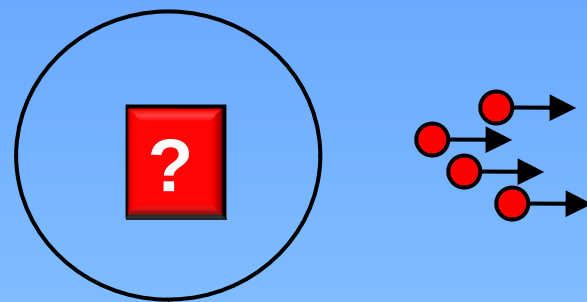
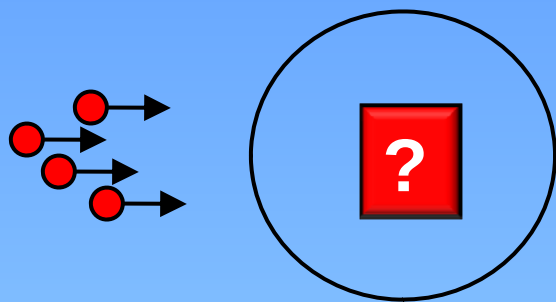
onbekend voorwerp achter een gordijn
... en 100 kogeltjes

bovenaanzicht

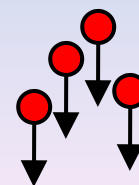
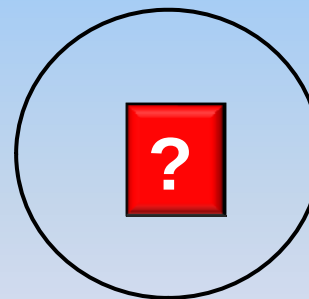
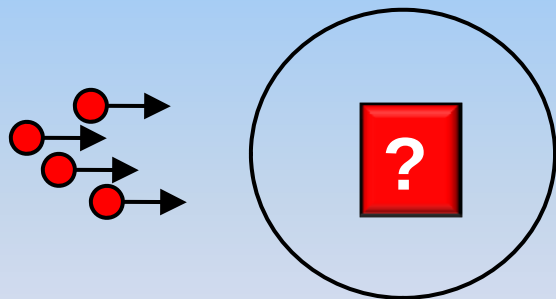


Hoe ketsen de kogels af ?

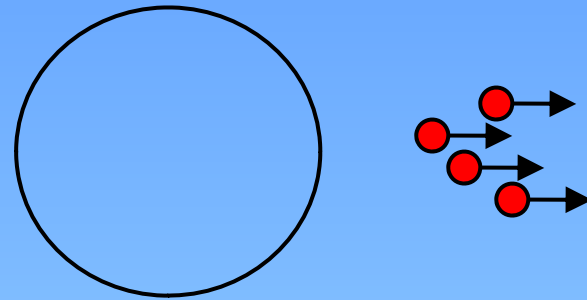
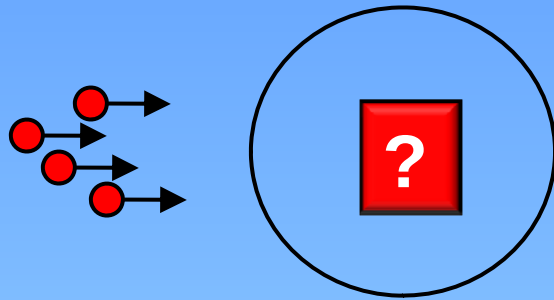
Experiment 1



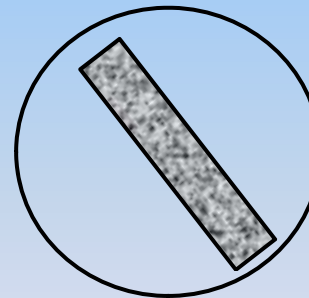
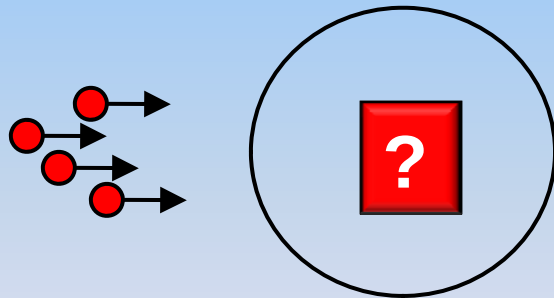
Experiment 2



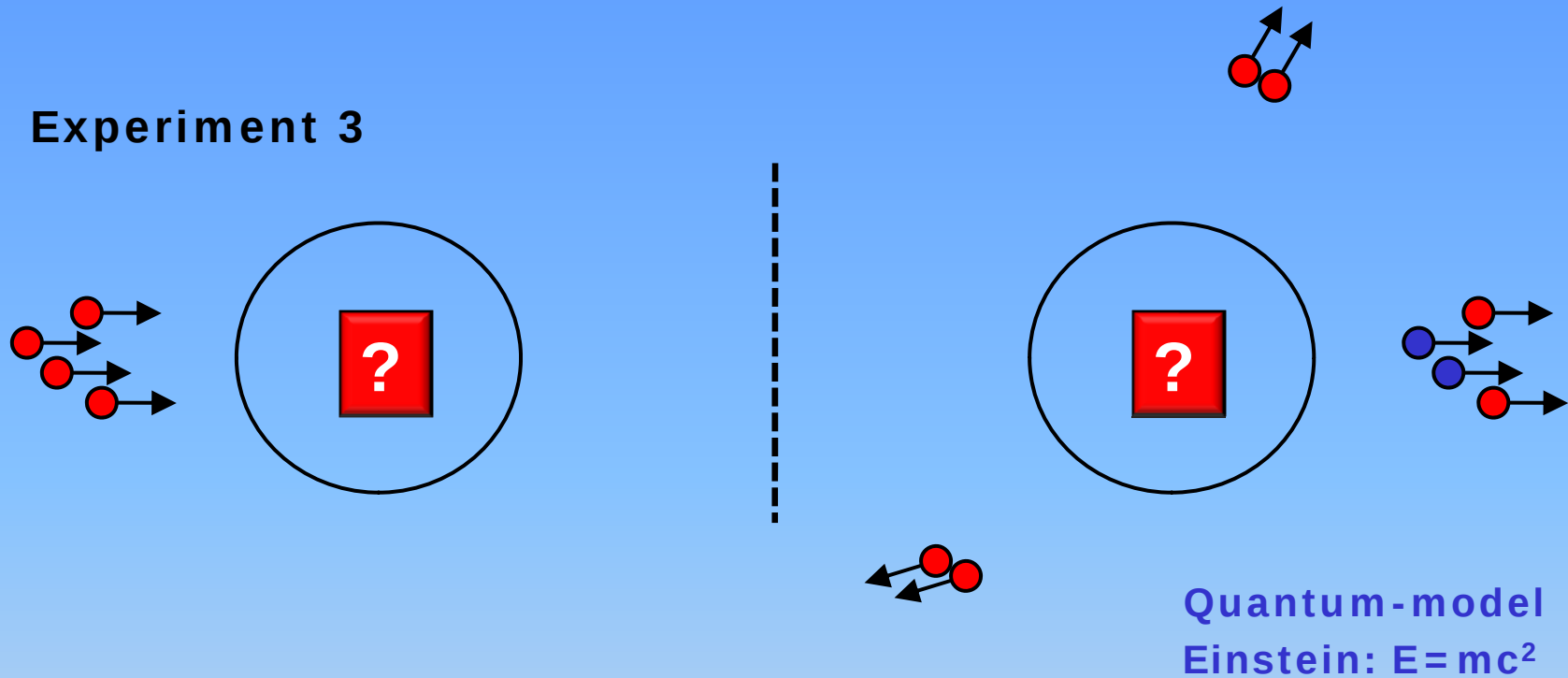
Experiment 1



Experiment 2



Experiment 3



‘Kijken’ naar sub-atomaire structuren:

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

Deeltjesversneller
Theorie
Detector

An aerial photograph of the CERN facility near Geneva, Switzerland. A large red oval is drawn over the landscape, representing the path of the Large Hadron Collider (LHC) tunnel. The landscape is a patchwork of green fields and some buildings. In the background, there are blue mountains and a range of snow-capped peaks under a clear blue sky.

De grootste microscoop op aarde
de Large Hadron Collider (LHC)
op CERN bij Genève

The LHC machine

Versnellen is een eitje



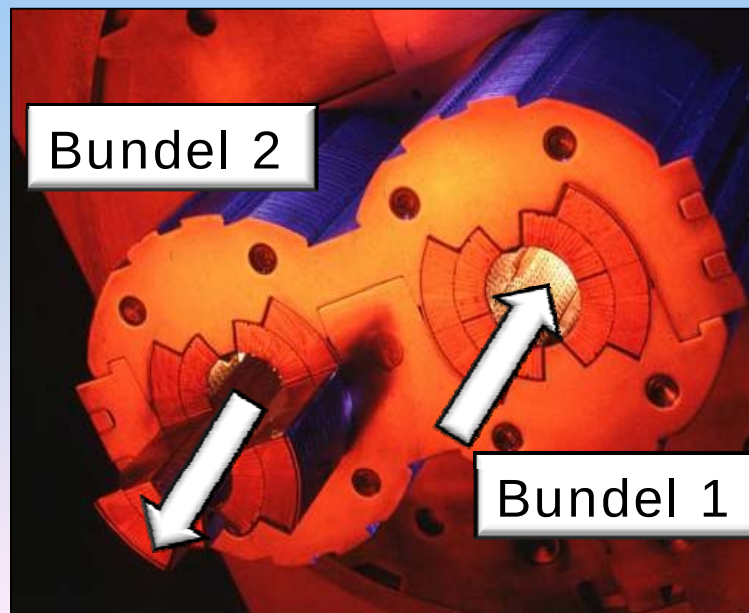
Energie is gelimiteerd door de kracht van 1232 dipool magneten: $B = 8.4 \text{ T}$

• <http://public.web.cern.ch/public/en/LHC/Facts-en.html>

Energie van 1 proton
in de LHC

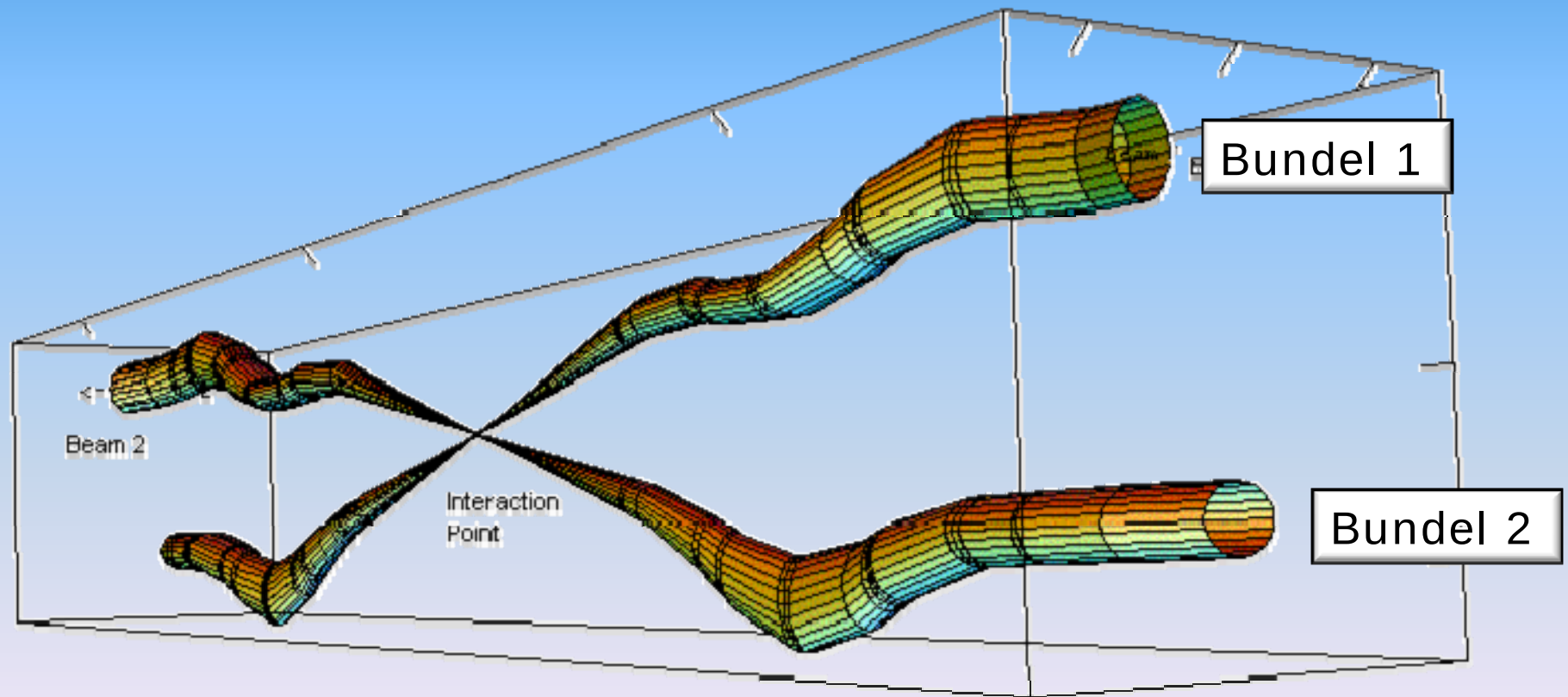


Energie LHC bundel
 $3000 \times 100.000.000.000$ protonen



*Doorsnede LHC
bundelpijp*

40 miljoen botsingen per seconde





Klassiek botsen

Quantummechanisch botsen



Wat verwacht je ?

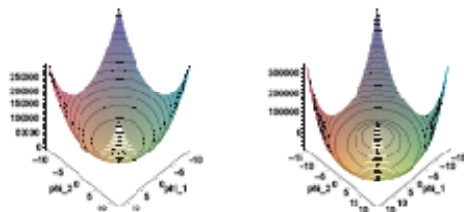


FIG. 1: The potential $V(\phi)$ ($\phi = \phi_1 + i\phi_2$) plotted for an arbitrary positive value of λ and for an arbitrary positive (right) or negative (left) value of μ^2 .

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:

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

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:

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

the λ 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 *unitary 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.

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

$$\Gamma = \frac{G_F \alpha^2 M_H^3}{128\sqrt{2}\pi^1} \left| \sum_f N_f^2 Q_f^2 A_f^H(\tau_f) + A_W^H(\tau_W) \right|^2 , \quad (102)$$

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

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

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

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

$$\Gamma = \frac{G_F \alpha^2 M_H^3}{\pi^4} \left(1 - \frac{M_Z^2}{M_H^2} \right)^2 \left| \sum_f A_f^H(\tau_f, \lambda_f) + A_W^H(\tau_W, \lambda_W) \right|^2 , \quad (105)$$

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

$$2N_f^2 \frac{Q_f(I_{1f} - 2Q_f \sin^2 \theta_W)}{\cos \theta_W} [I_1(\tau, \lambda) - I_2(\tau, \lambda)] , \quad (106)$$

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

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

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

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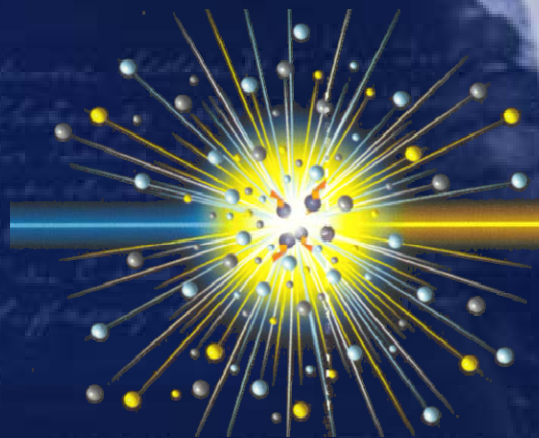
$$\frac{\tau^2 \lambda^2}{\lambda} + \frac{\tau^2 \lambda^2}{2(\tau - \lambda)^2} [f(\tau) - f(\lambda)] + \frac{\tau^2 \lambda}{(\tau - \lambda)^2} [g(\tau) - g(\lambda)] ,$$

Klopt het ?

Inderdaad nieuwe fenomenen ?

Albert Einstein

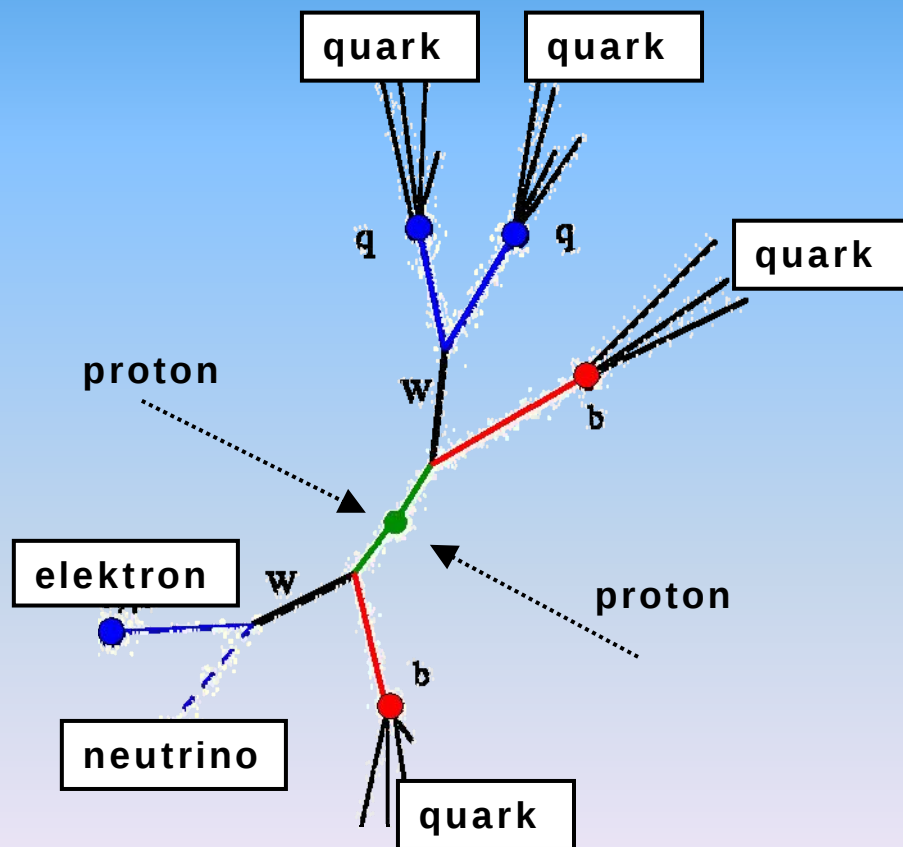
$$E = mc^2$$



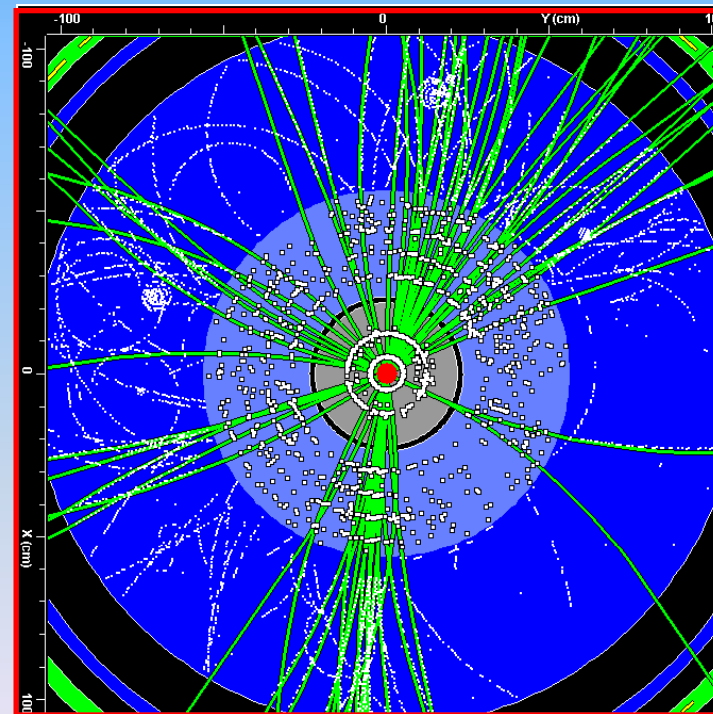
Energie en massa zijn equivalent

→ je kan *nieuwe* deeltjes maken

Hoe zien die botsingen er nou uit ?



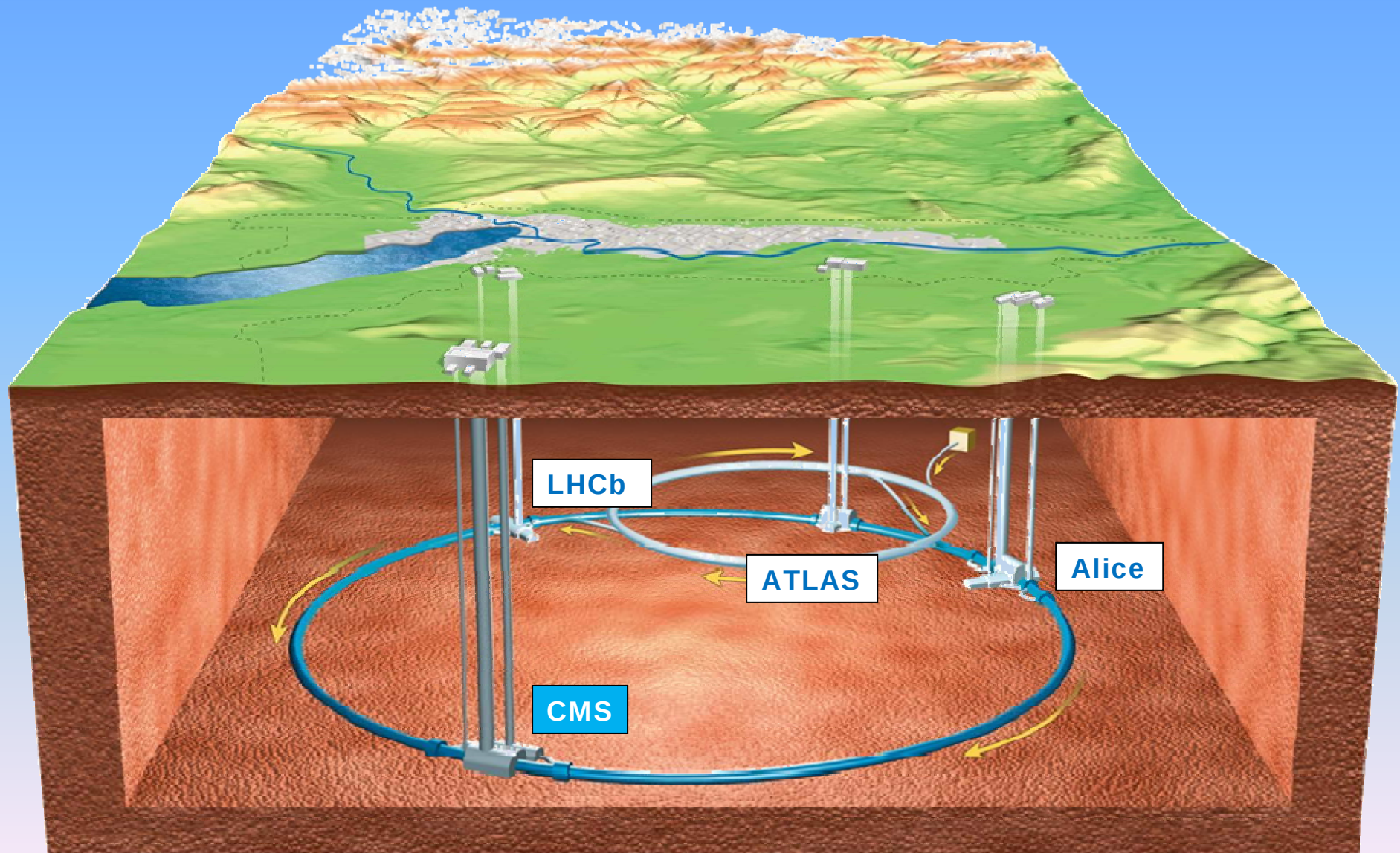
Simulatie top quark productie



Onze 'fototoestellen'

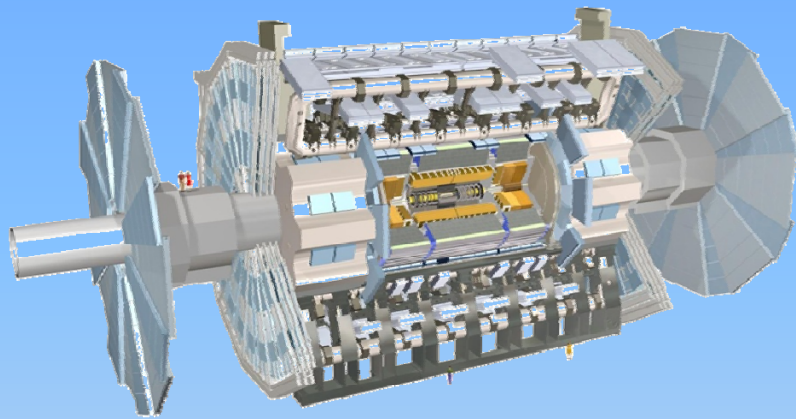


De vier experimenten

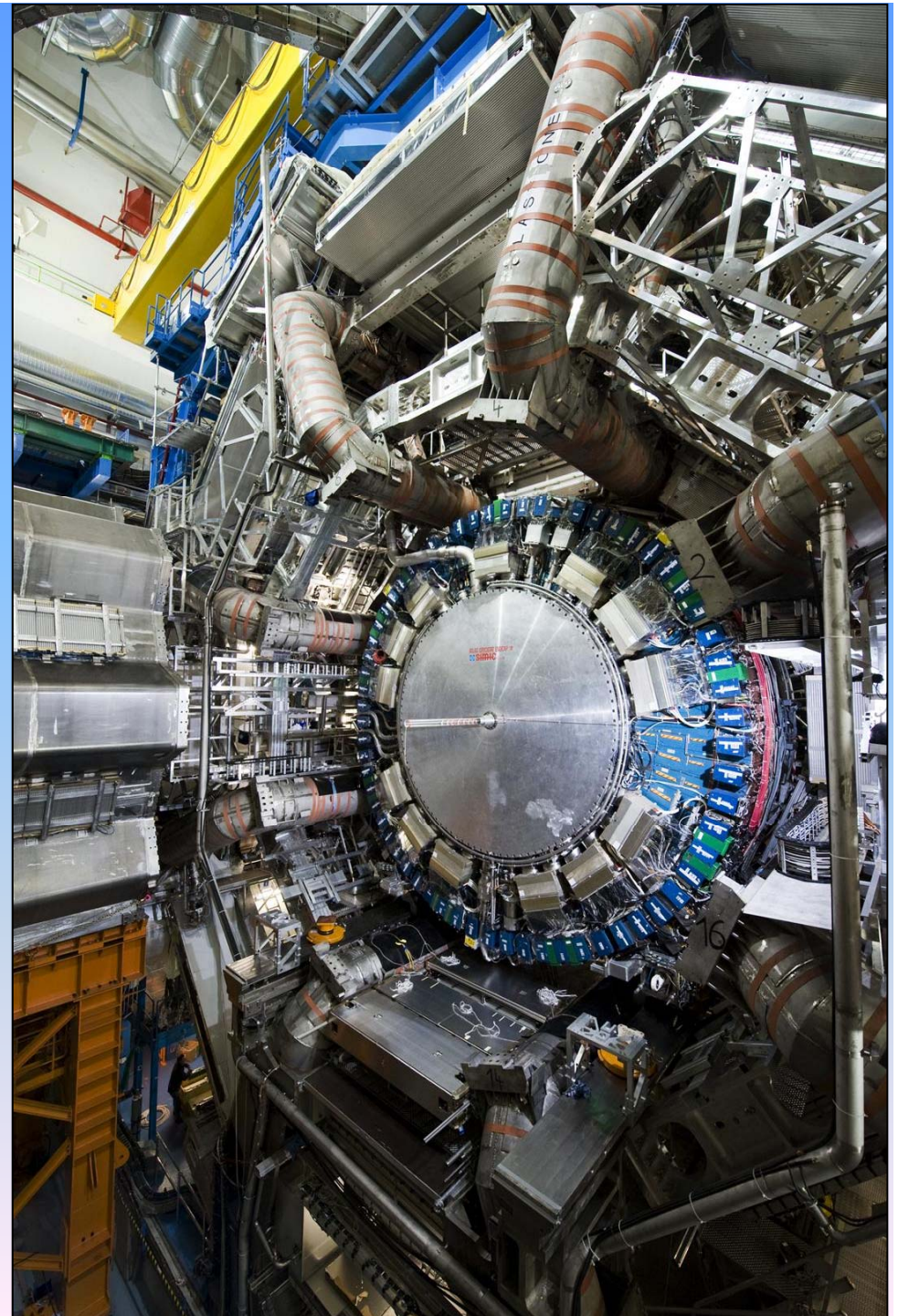




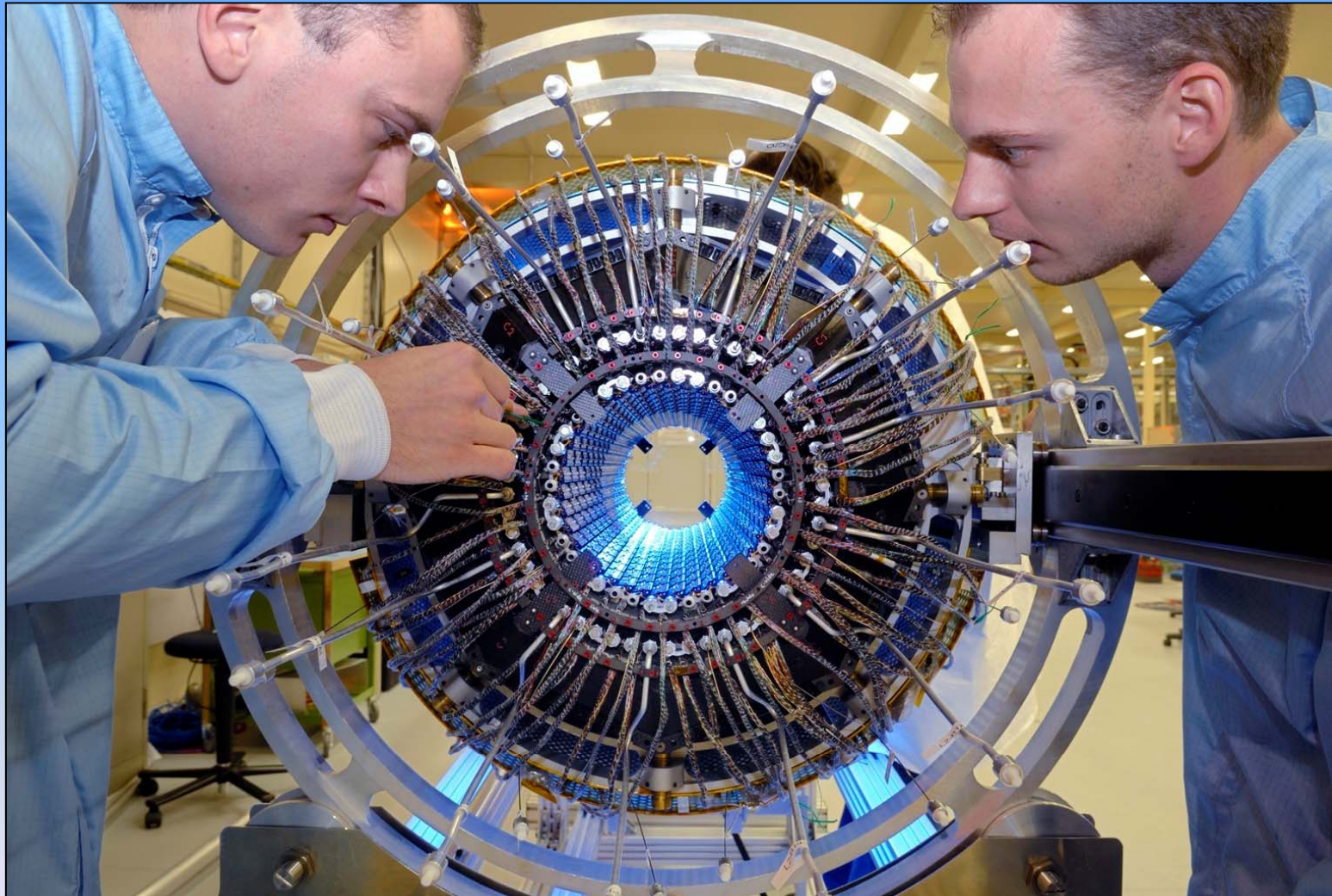
ATLAS detector



45 m lang, 25 m hoog, 7000 ton



De Atlas pixel detector



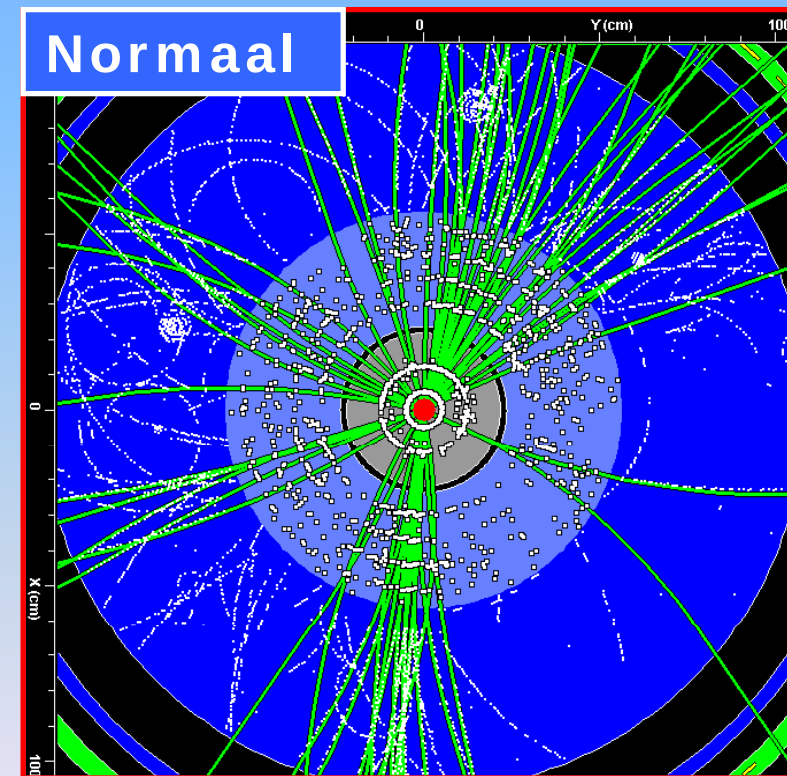
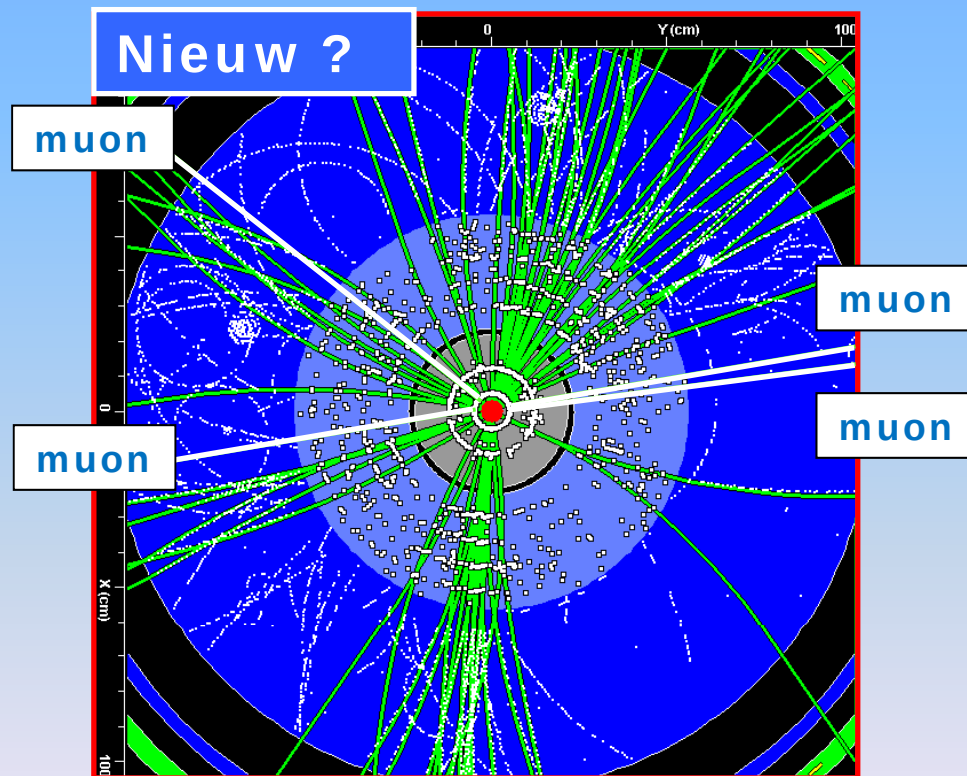
80 MegaPixel camera 40.000.000 foto's per seconde

... hoe ontdek je nou nieuwe dingen ?



Hoe ontdek je nou nieuwe dingen

Nieuwe afstandschaal EN nieuwe detector



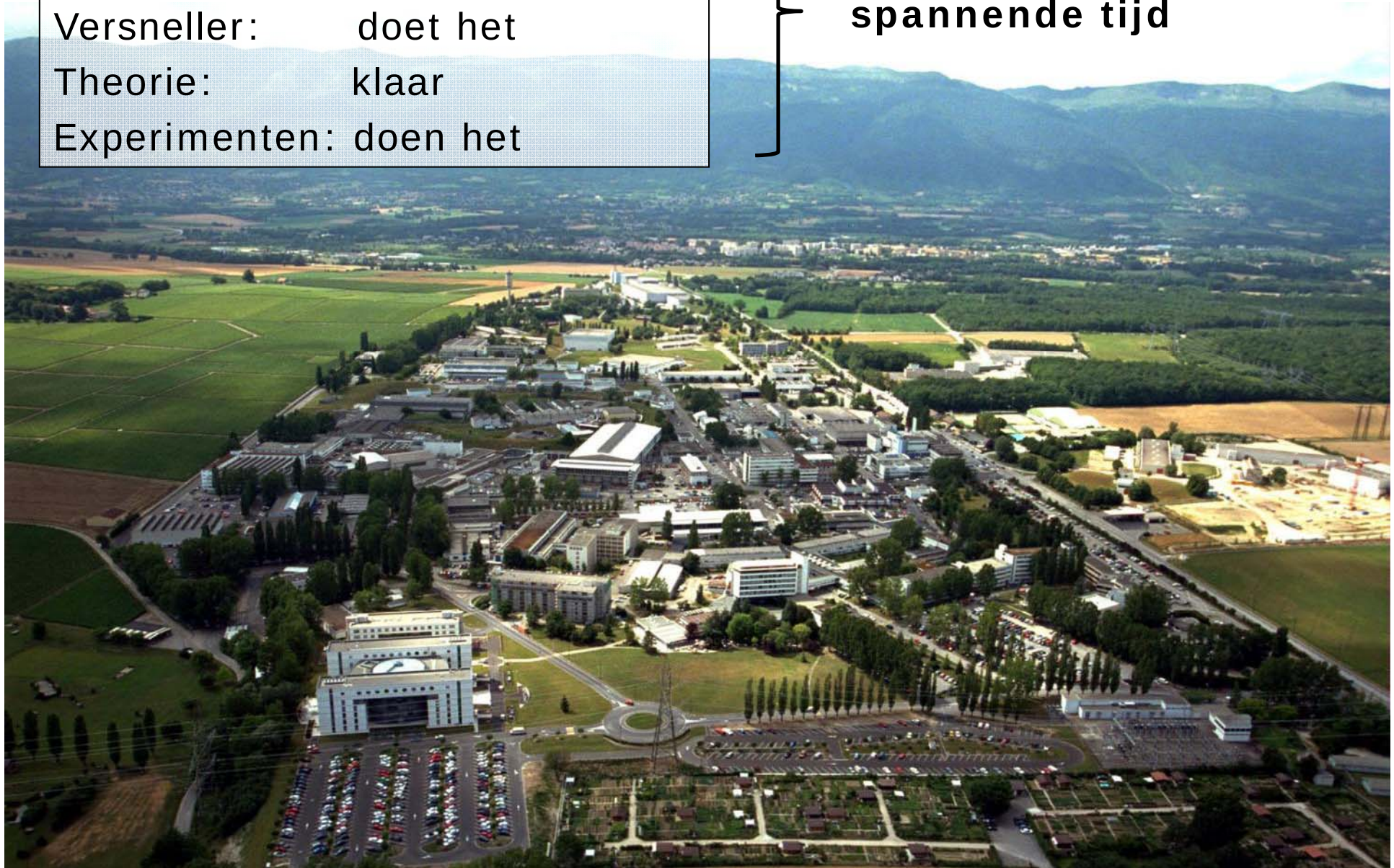
Ja ... Higgs schijnt het wel

Heel veel vragen
Heel veel mogelijke oplossingen

Versneller: doet het
Theorie: klaar
Experimenten: doen het

CERN

spannende tijd



**Bedankt voor de aandacht,
... mooie avond verder !**

Ivo.van.Vulpen@nikhef.nl