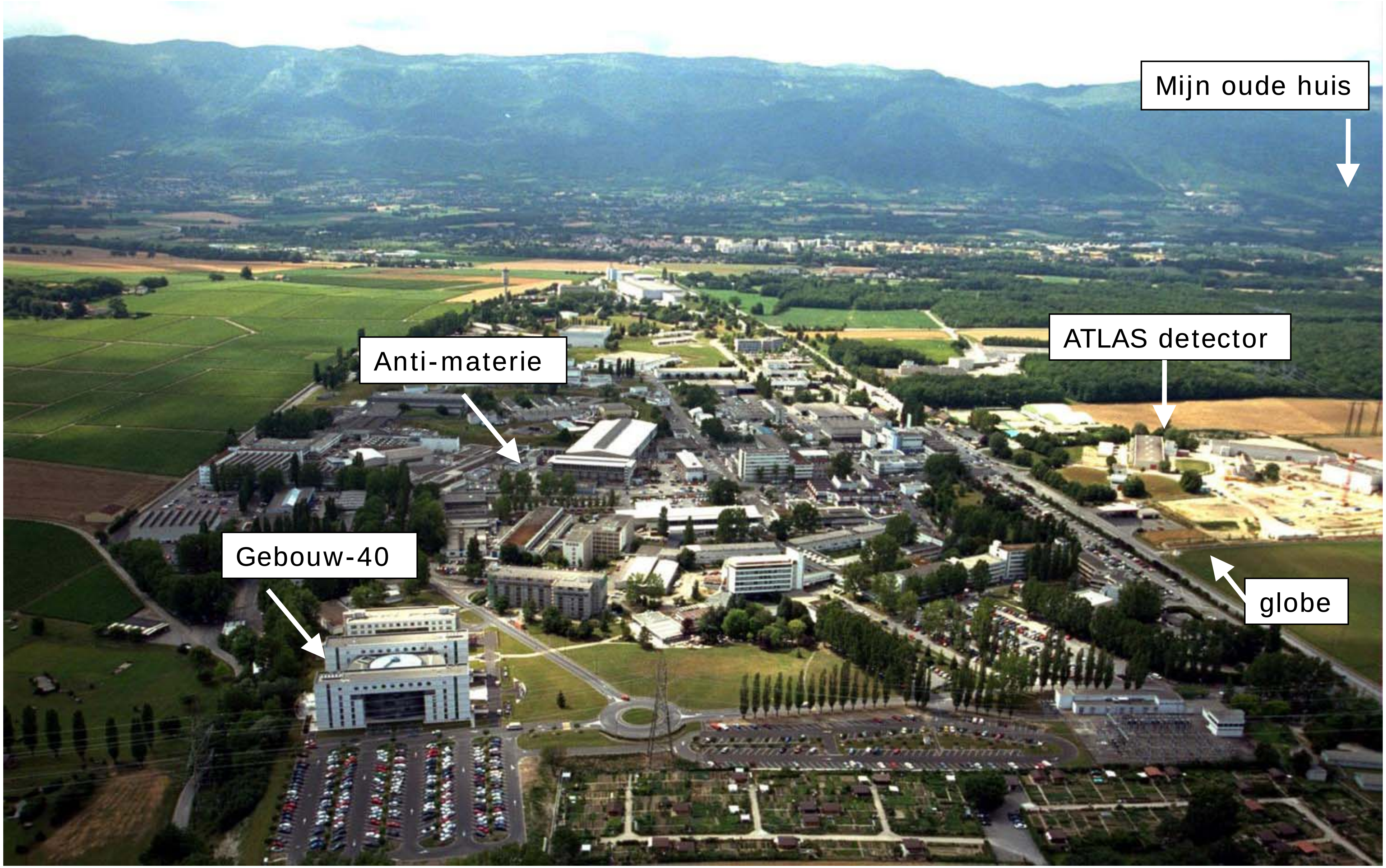
Zoektocht naar de elementaire bouwstenen van de natuur

Het atoom:

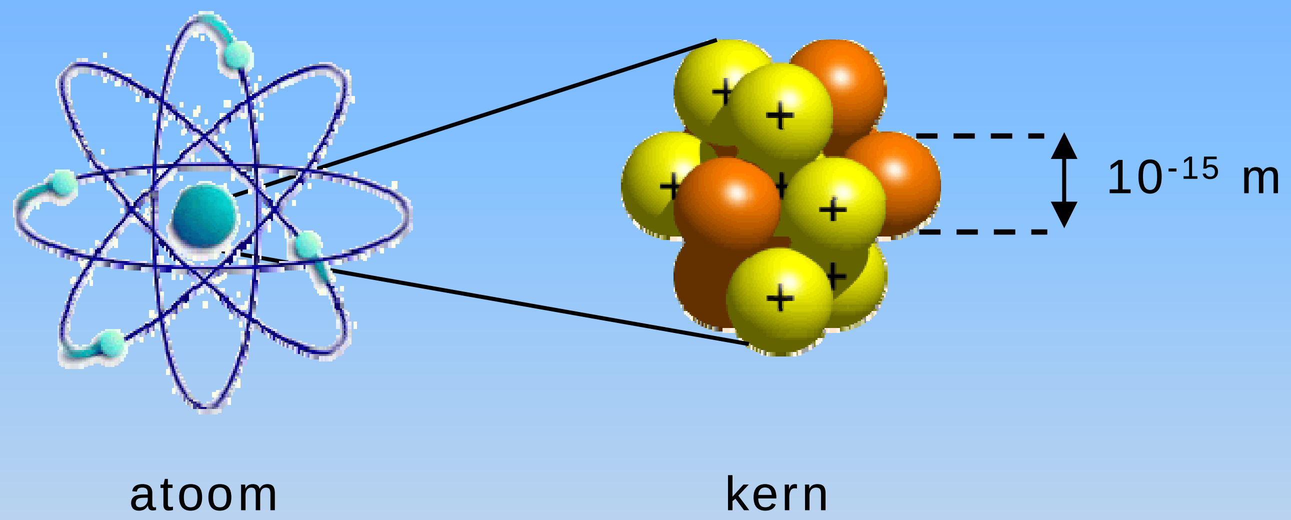
hoe beter men keek
hoe kleiner het leek

Ivo van Vulpen

CERN



Deeltjesfysica

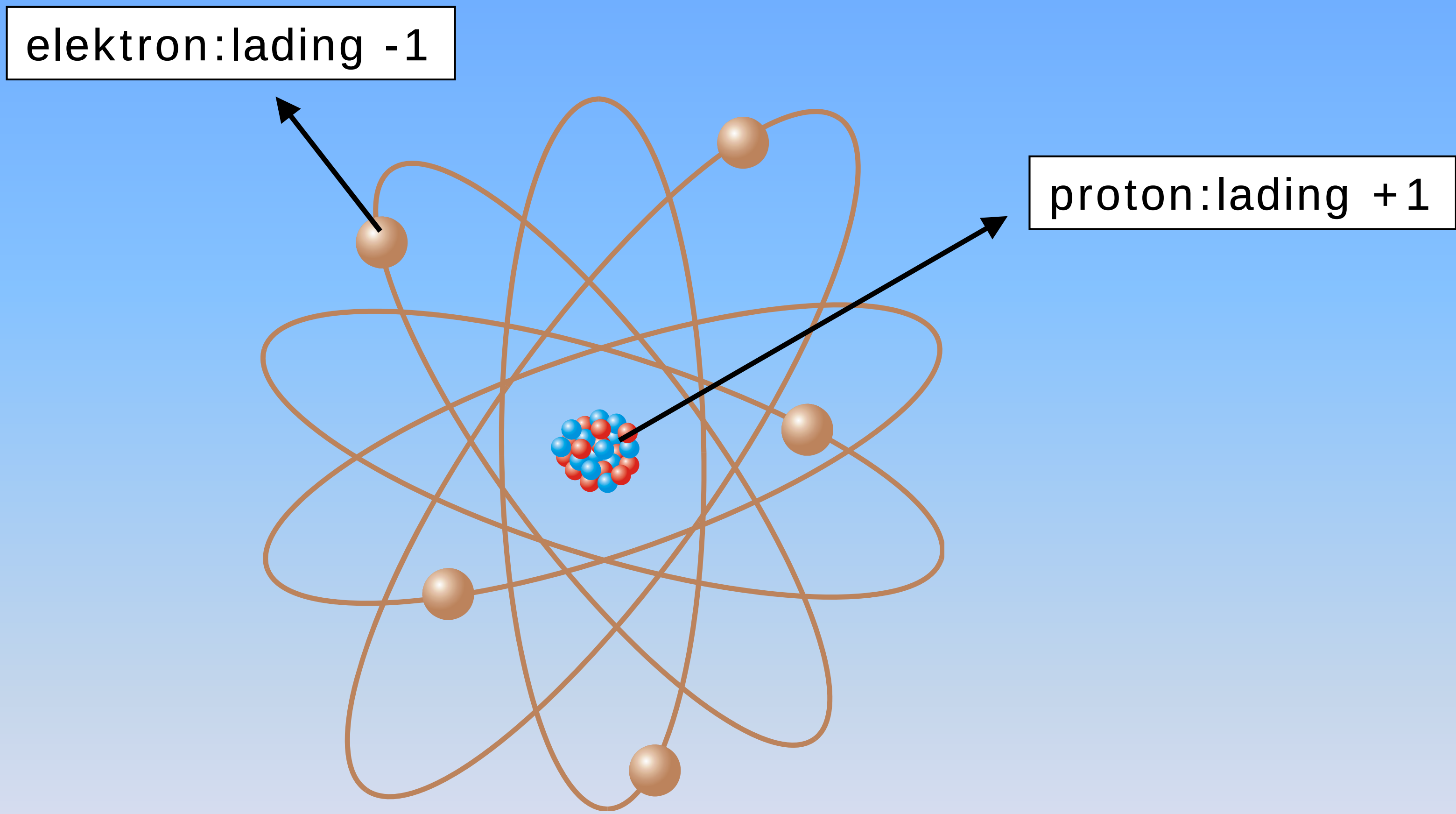


Wat zijn de bouwstenen van de dingen om ons heen ?

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

[2] Gewoon 4 gekleurde draadjes en simpel symmetrisch patroon

Wat waren de problemen 100 jaar geleden ?

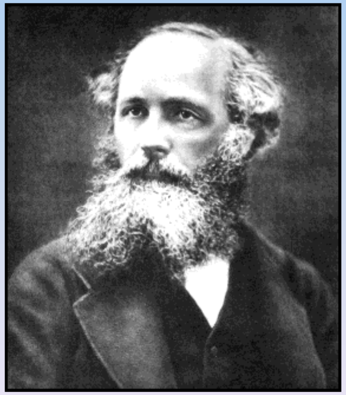


Waarom valt het elektron niet op de kern ?

Zwaartekracht en Electromagnetisme

“zelfde krachten … nieuwe modellen”

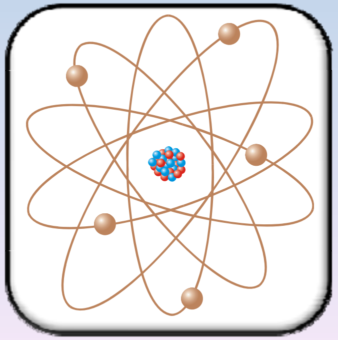
Newton

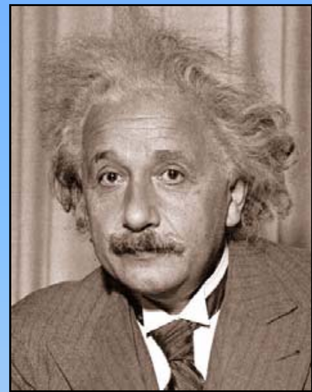


Maxwell

Relativiteitstheorie

Quantummechanica



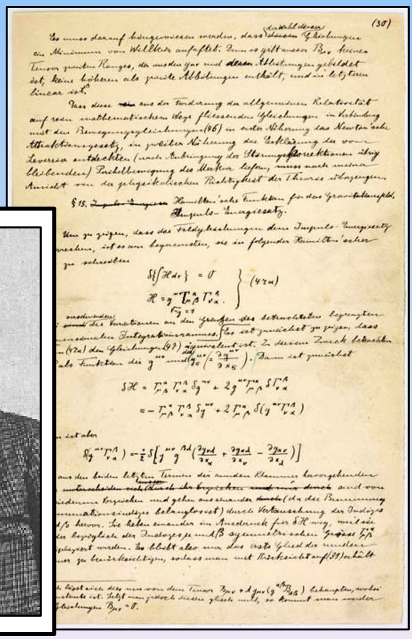


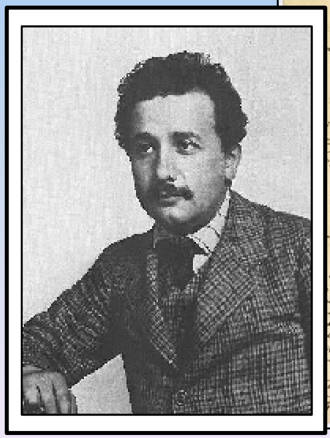
Einstein

Bohr

Relativiteitstheorie … nuttig ?

Relativiteitstheorie ?





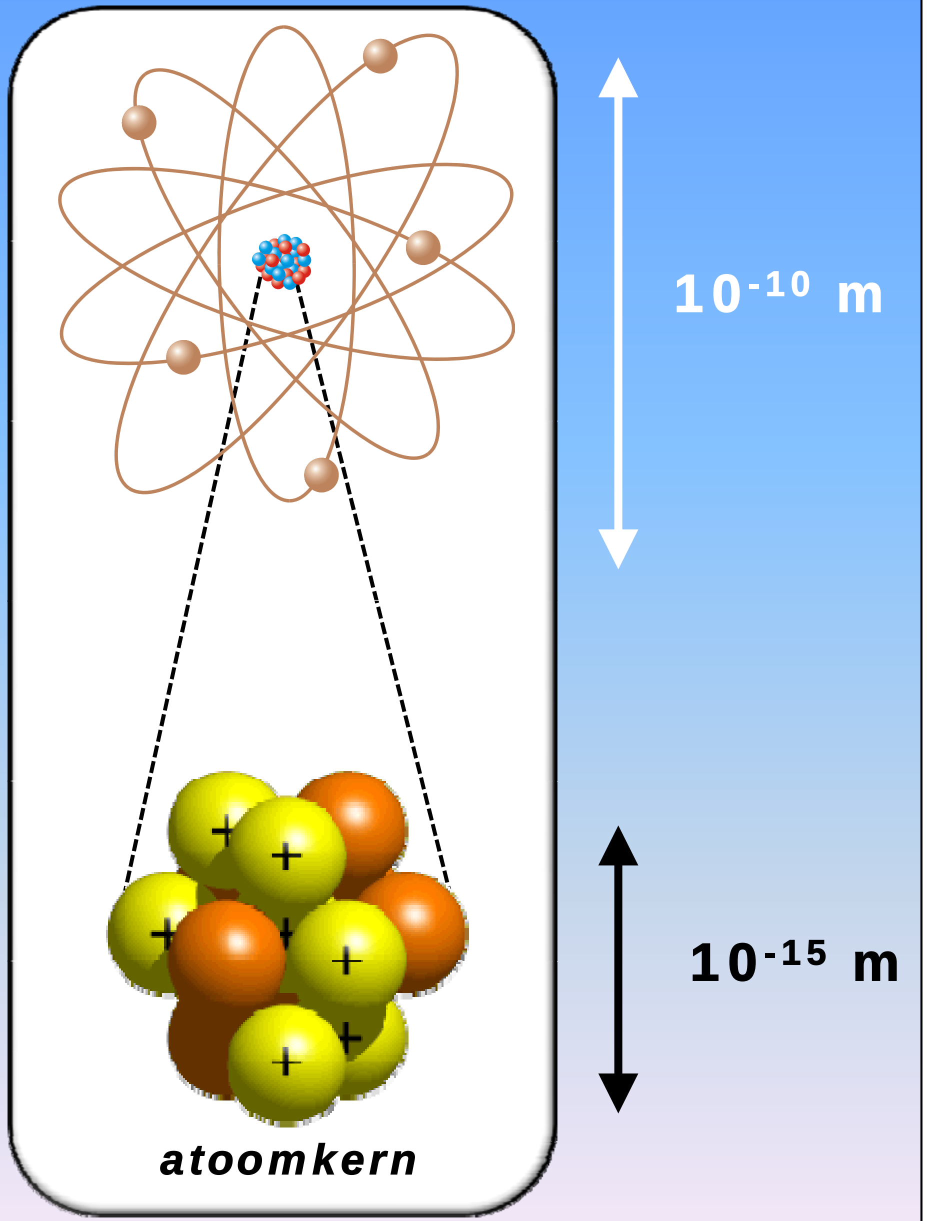
“Zonder relativiteitstheorie zit de GPS er 10 km per dag naast!”

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

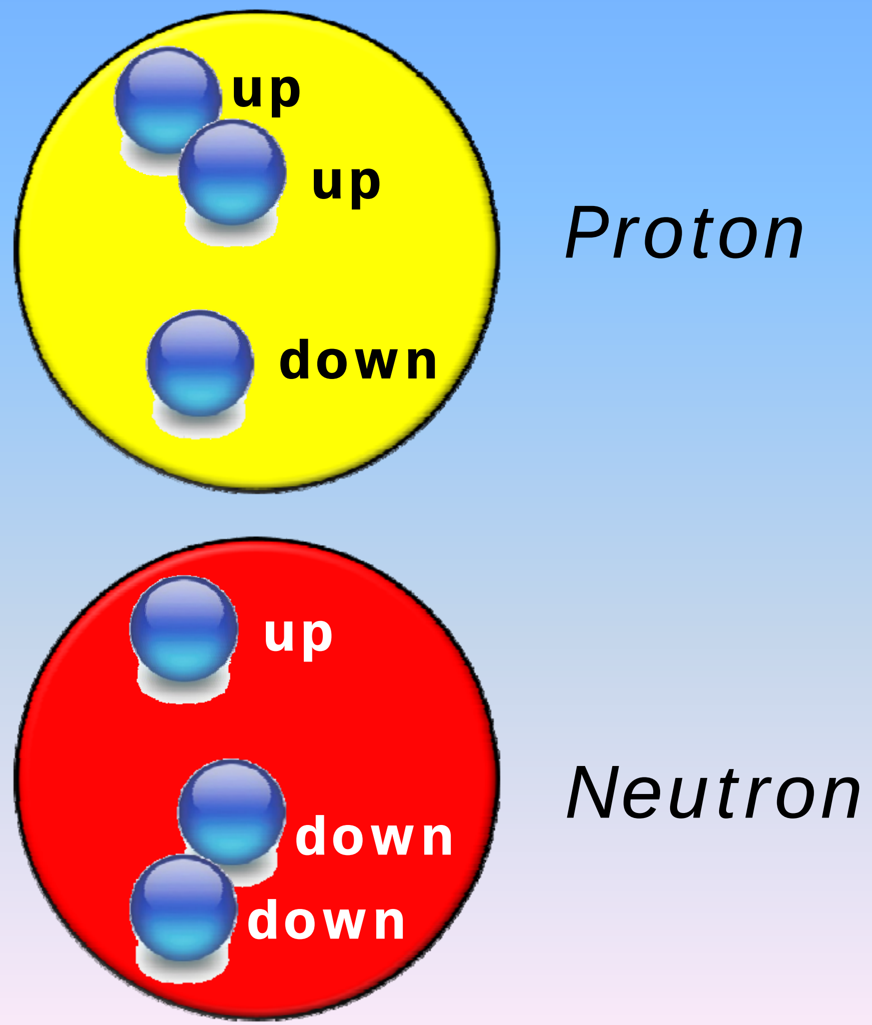
De elementaire deeltjes

up

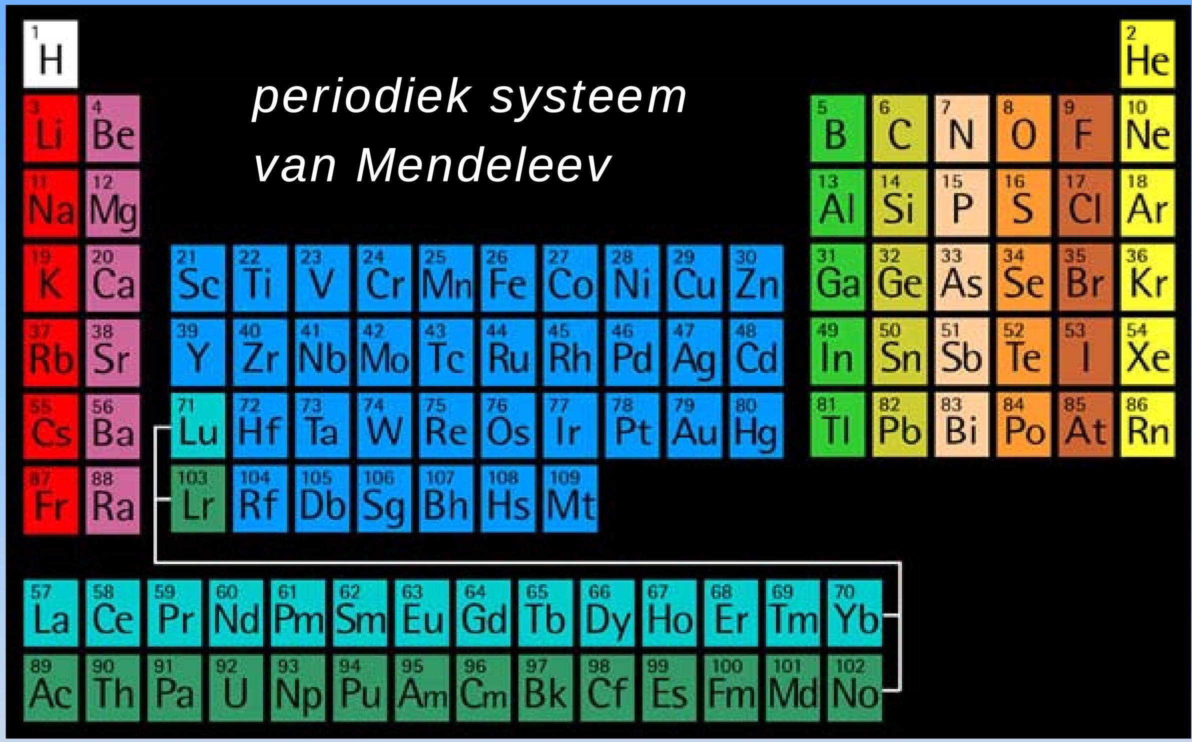
down

elektron

+ 4 natuurkrachten

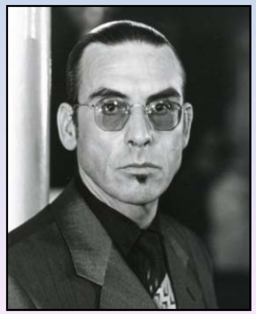


Wat kan je maken met deze 3 bouwstenen ?



Alles!

Wetenschapper



Dichter

Wat snappen we nog niet:

Paar ‘kleine’ dingetjes:

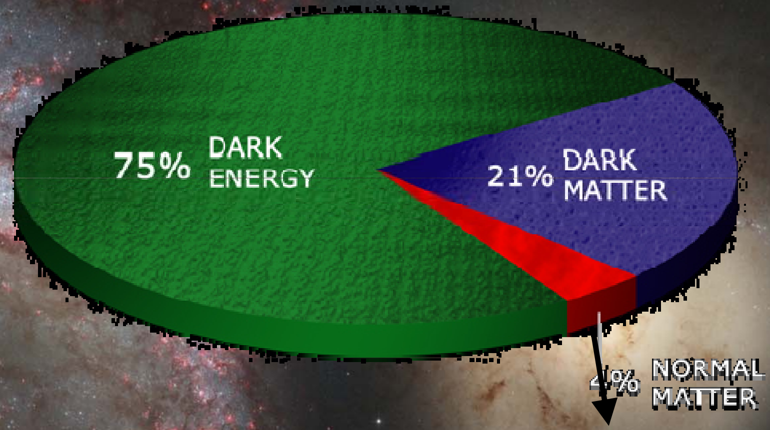
1. 96% van de materie in het heelal is onbekend
   → donkere materie

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 electrische lading, exploderende quantumcorrecties, kleine neutrino massa’s, string theorie, …

1 *Donkere-materie*



Normale materie (4%)

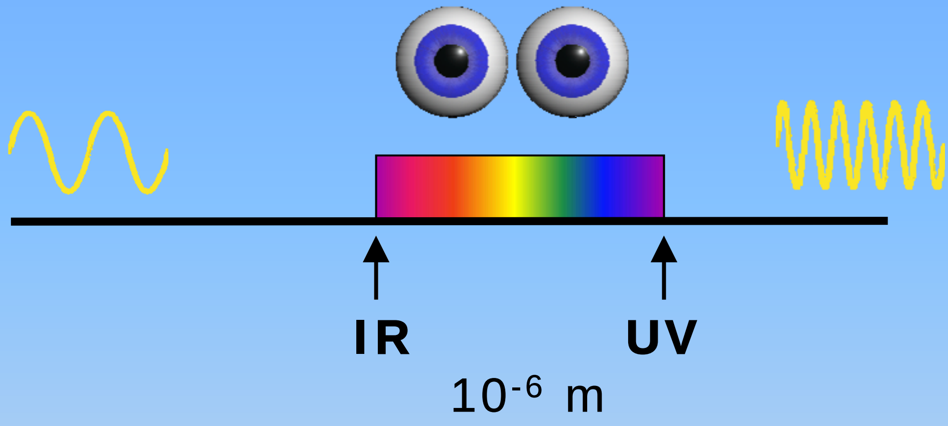
Revolutie in kosmologie laatste paar jaar
Structuur van het heelal:
we hebben al die tijd maar 4% van het heelal bestudeerd

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

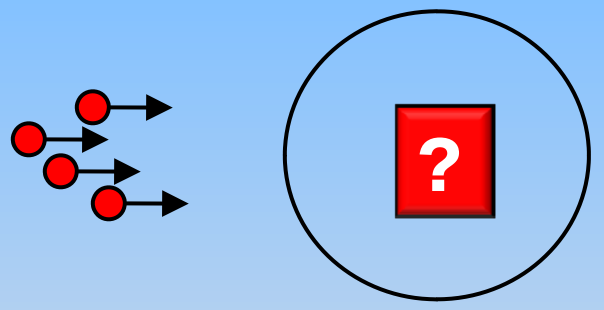
Idee: laat kleine deeltjes afketsen van het object

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

onbekend voorwerp achter een gordijn

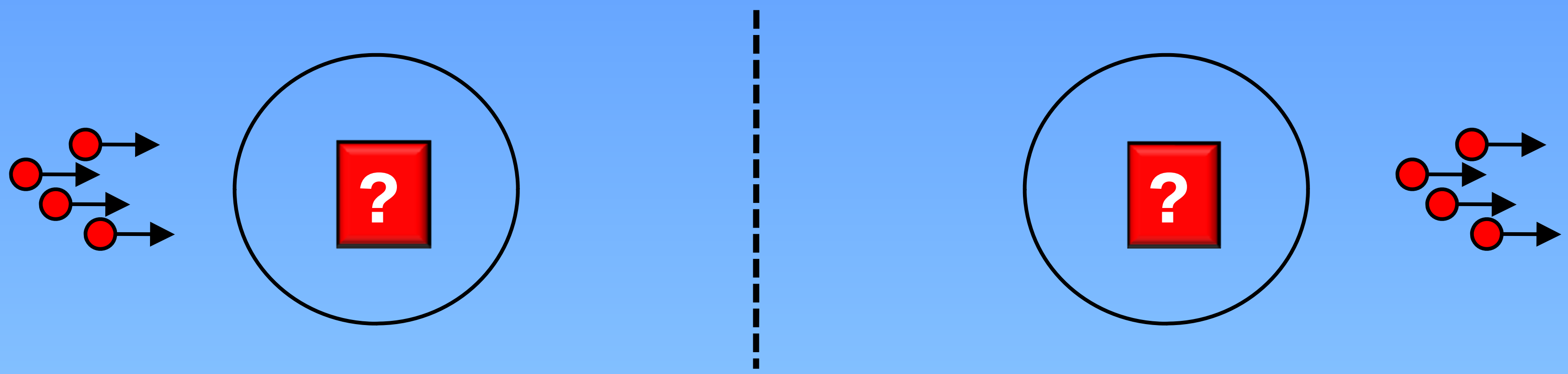
... en 100 kogeltjes

bovenaanzicht

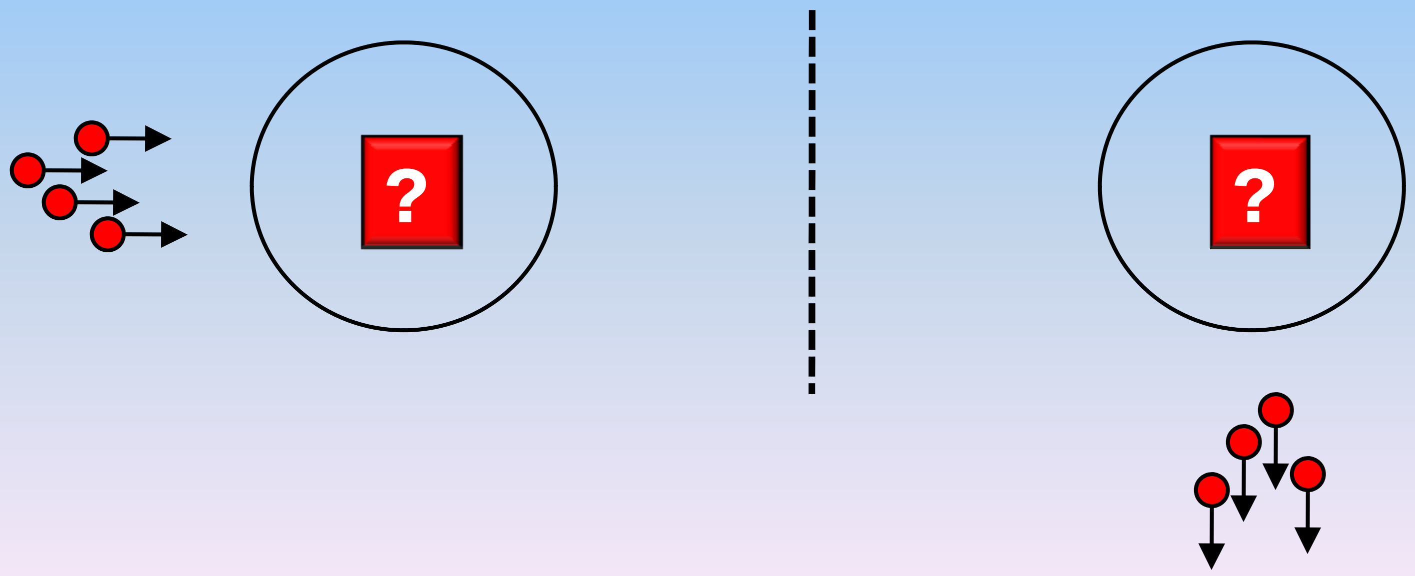


Hoe ketsen de kogels af ?

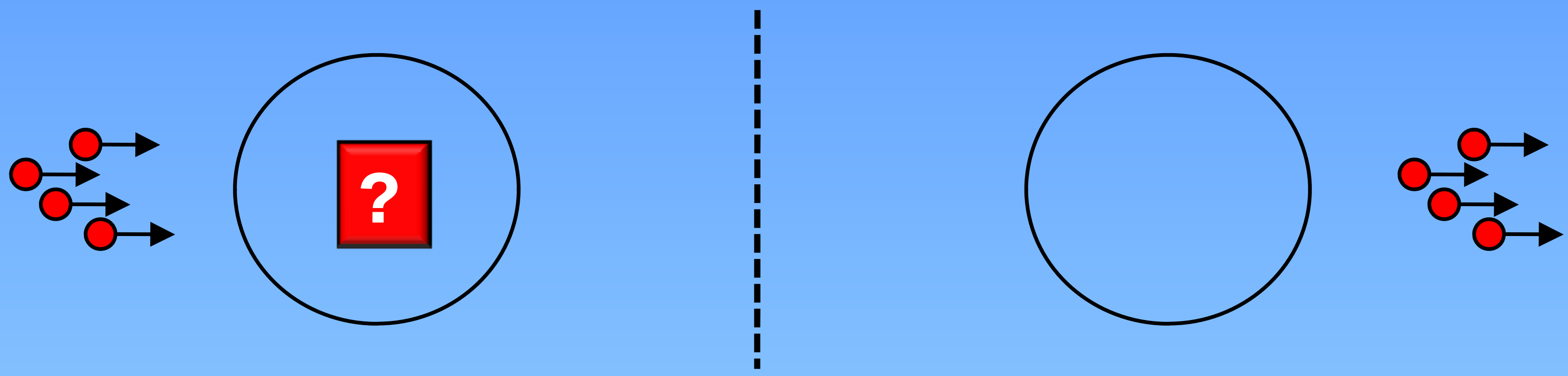
Experiment 1



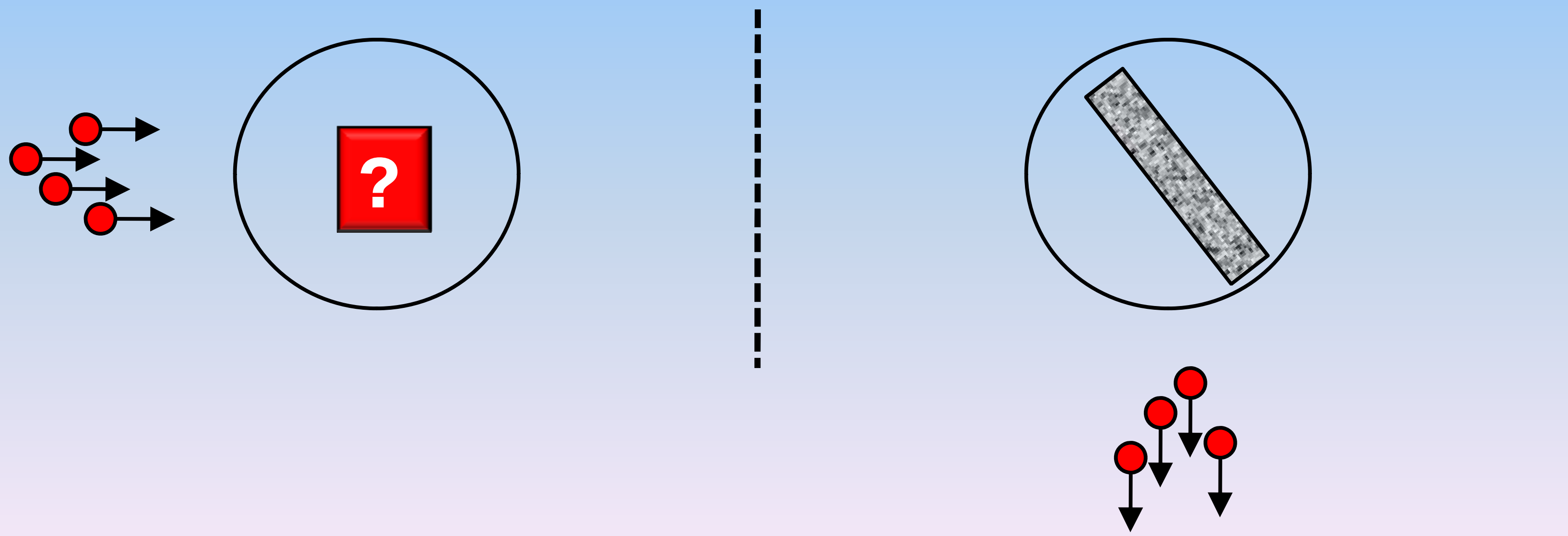
Experiment 2



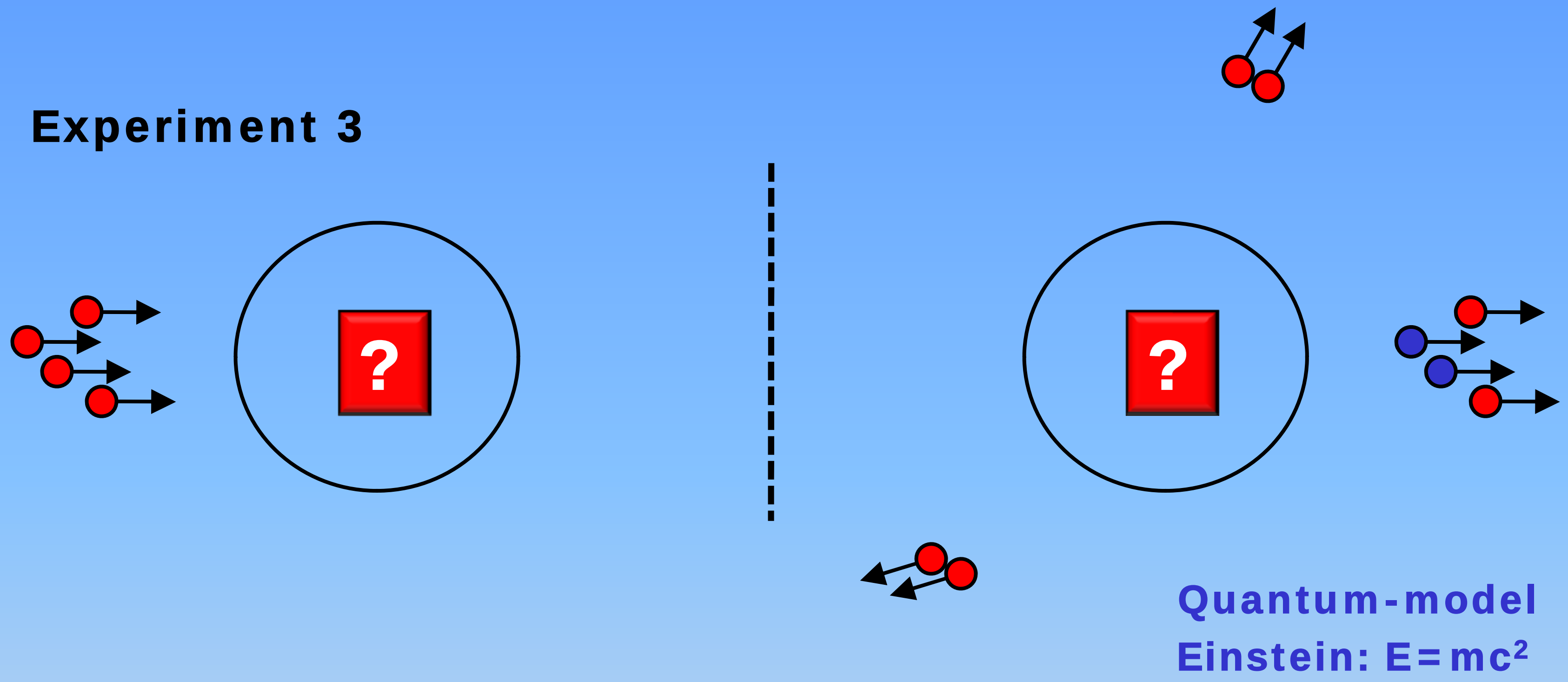
Experiment 1



Experiment 2

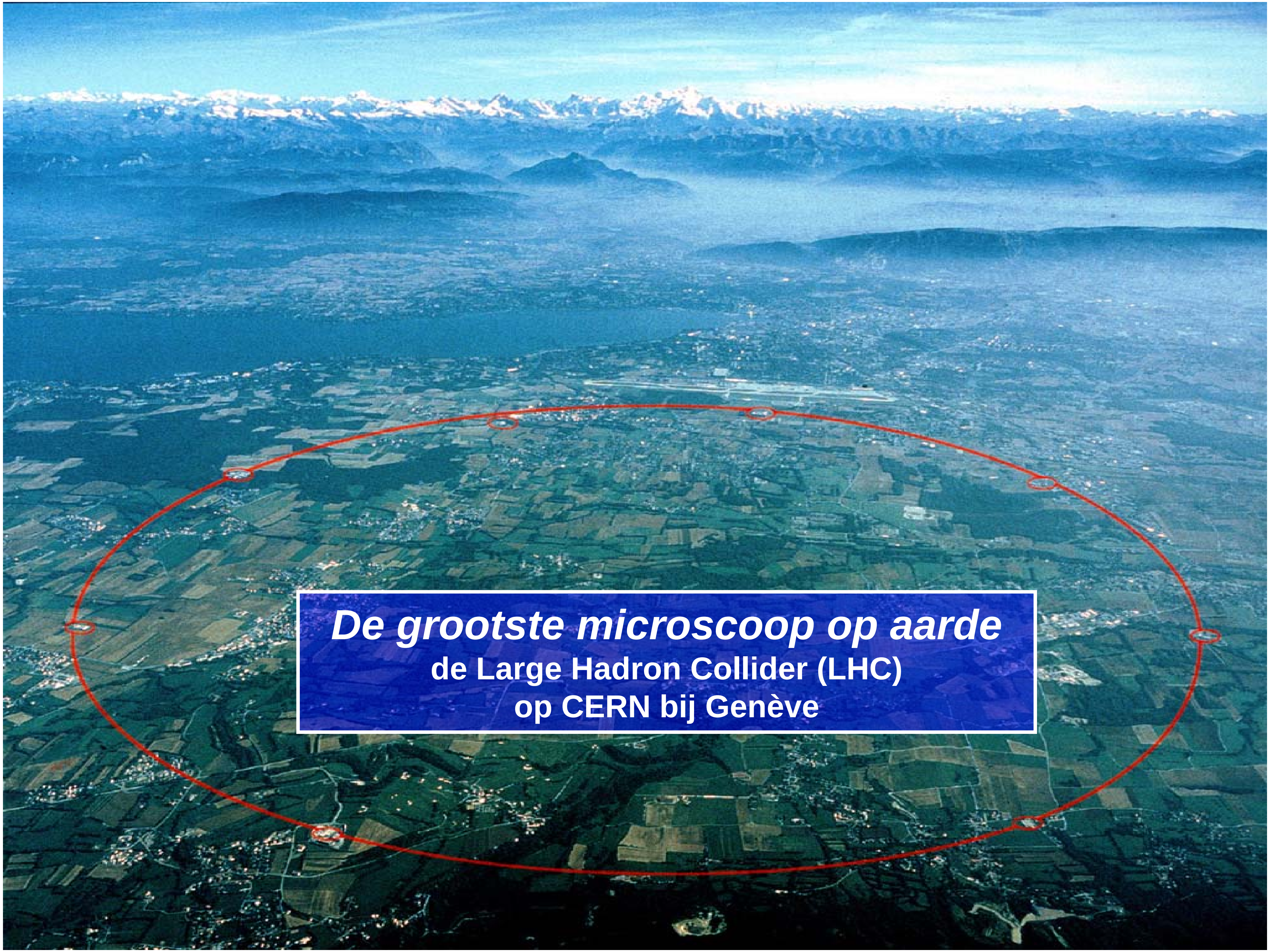


Experiment 3

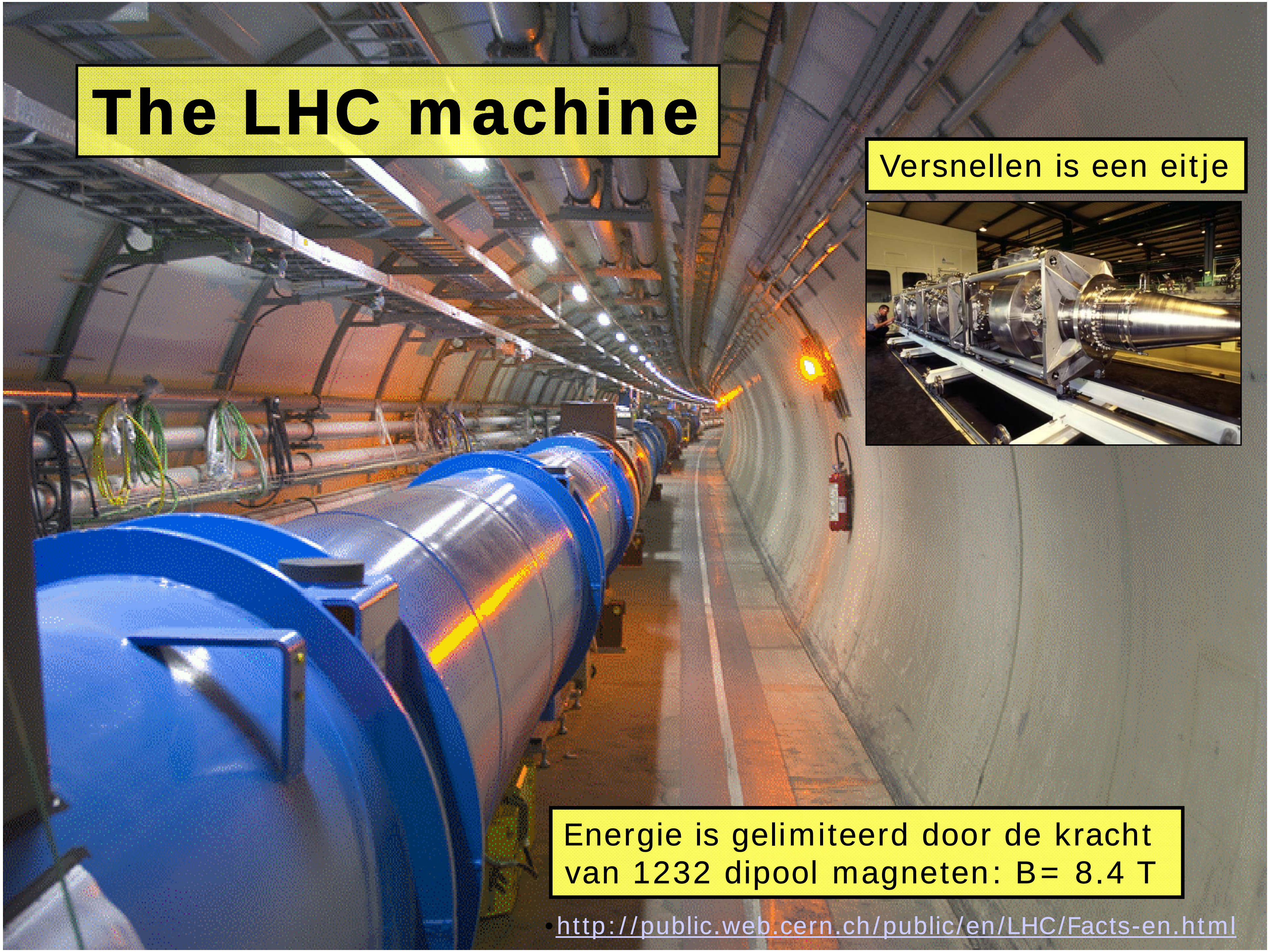


‘Kijken’ naar sub-atomaire structuren:

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


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

The LHC machine



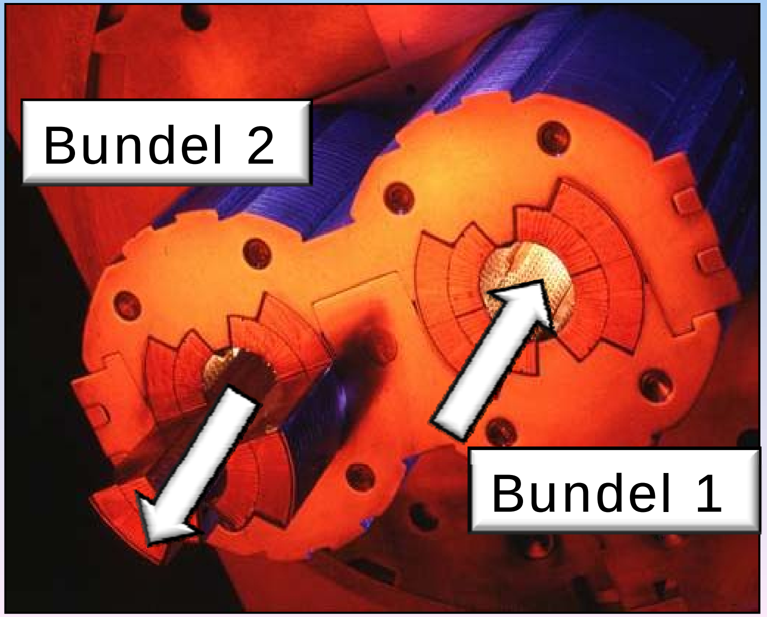
Versnellen is een eitje

Energie is gelimiteerd door de kracht van 1232 dipool magneten: B= 8.4 T

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

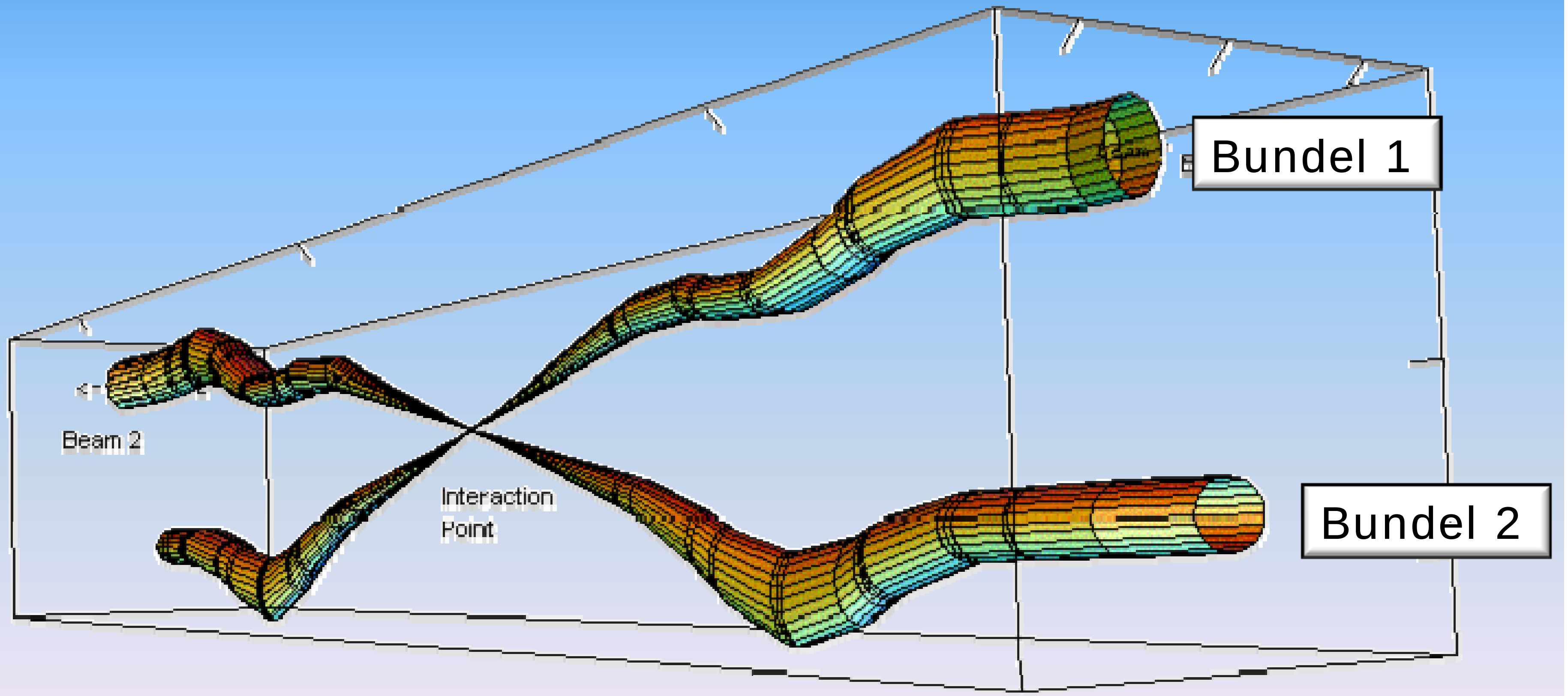
Energie van 1 proton
in de LHC

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 ?

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 $H \to Q\bar{Q}$ decay rate, can in first approximation be safely neglected.

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

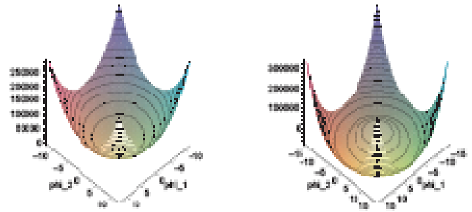


FIG. 1: The potential $V(\phi)$ ($\phi = \phi_1 + i\phi_2$) plotted for an arbitrary positive value of λ and for an arbitrary positive (right) or negative (left) value of μ^2.

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:

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

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

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

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:

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

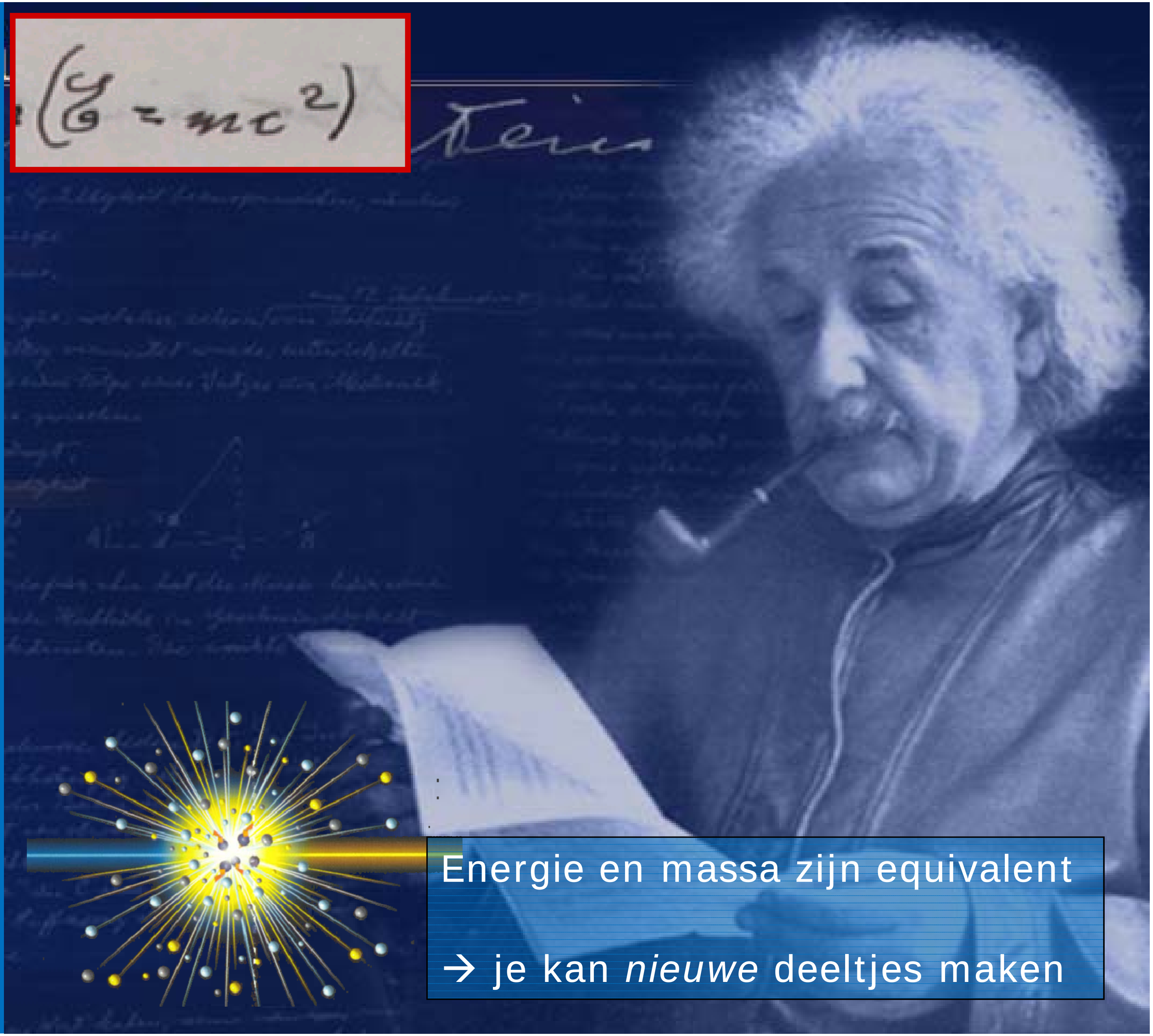
the χ degree of freedom can be *rotated away*, as indicated in Eq. (7), by enforcing the $U(1)$ gauge invariance of the original Lagrangian. With this gauge choice, known as *unitary gauge* or *unitarity gauge*, the Lagrangian becomes:

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

Klopt het ?

Inderdaad nieuwe fenomenen ?

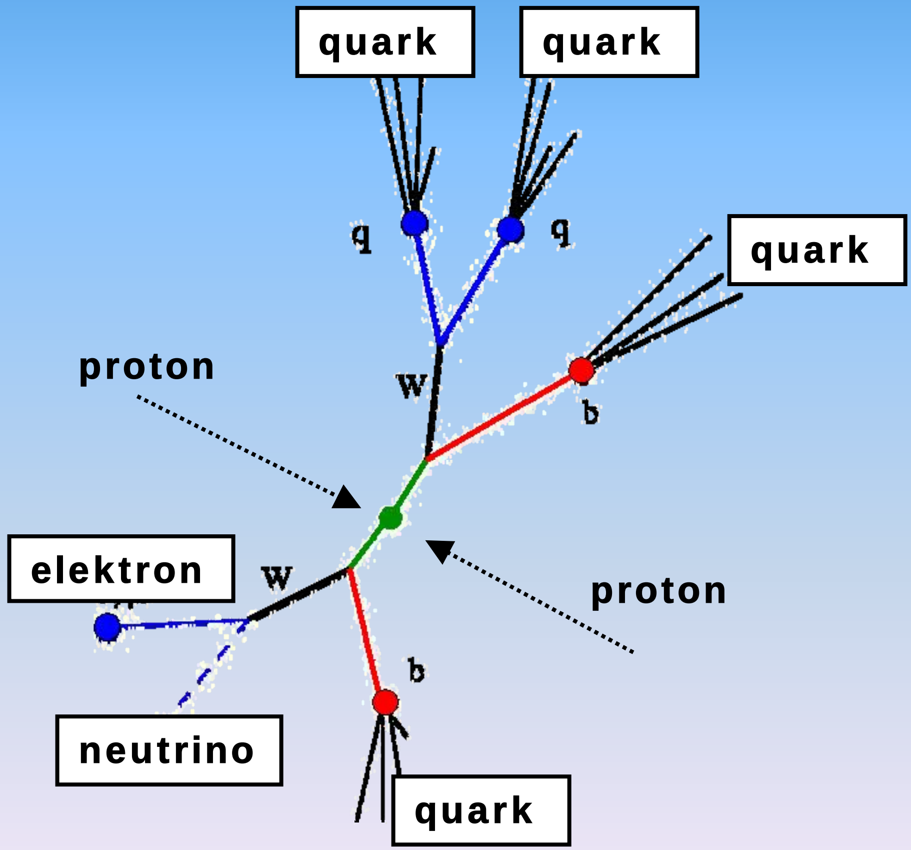
Albert Einstein



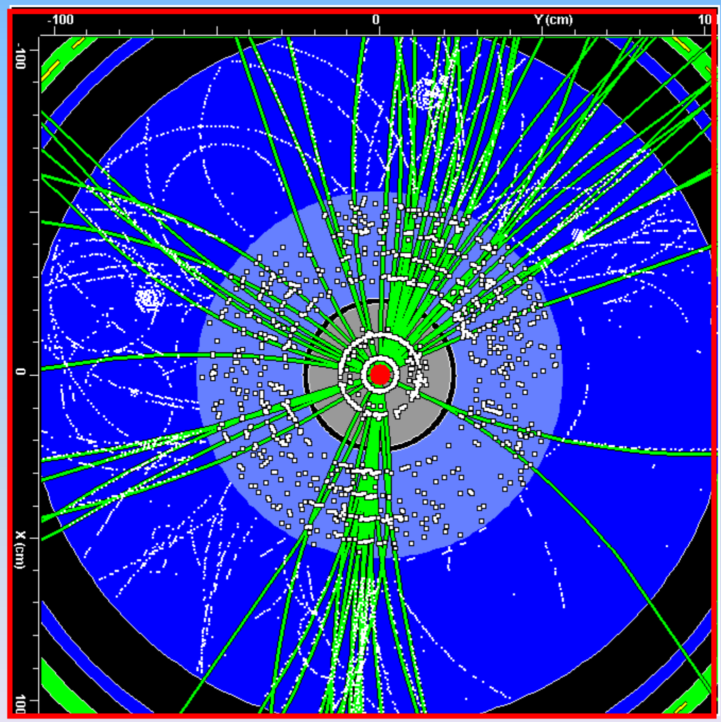
Energie en massa zijn equivalent

→ je kan *nieuwe* deeltjes maken

Hoe zien die botsingen er nou uit ?

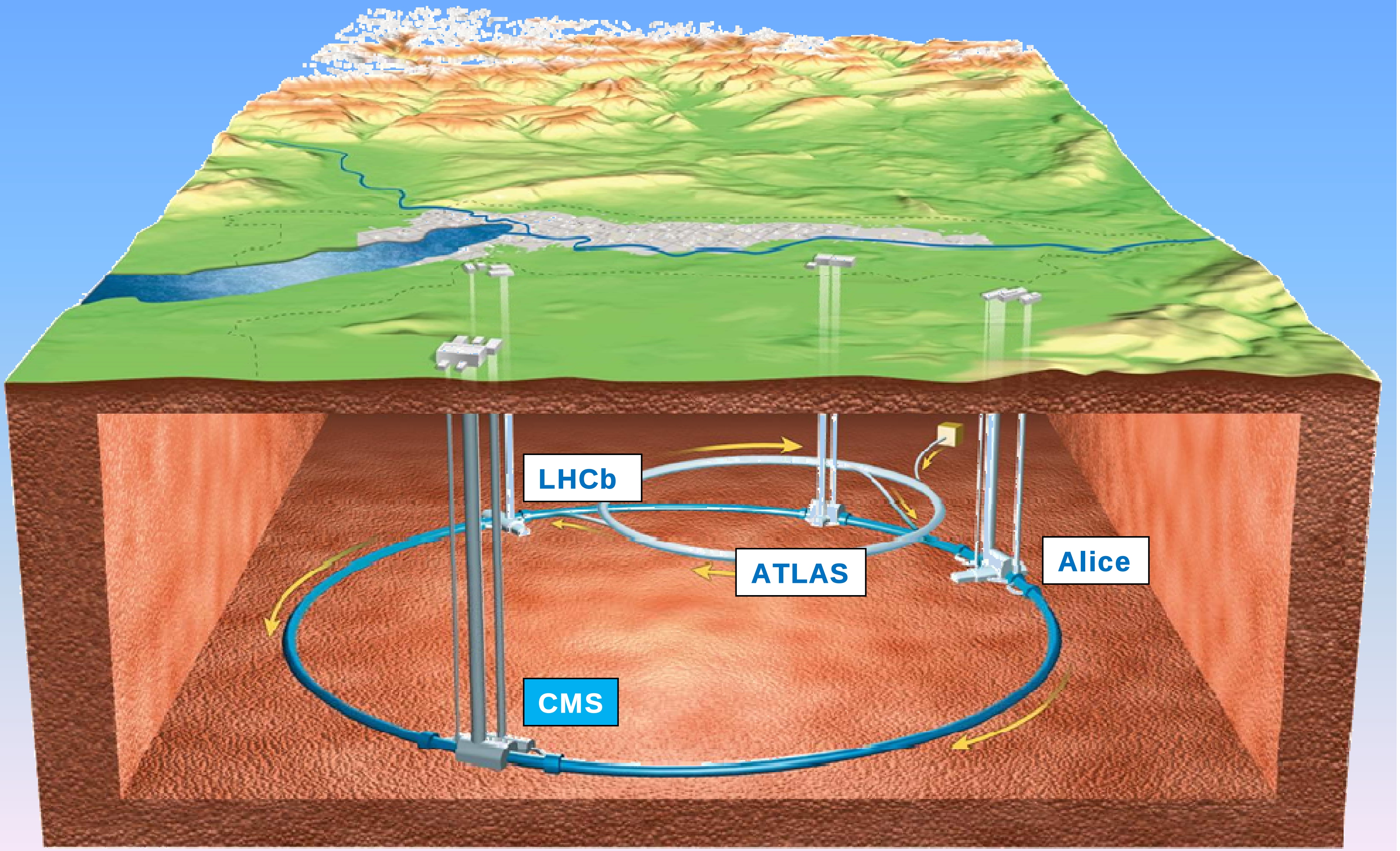


Simulatie top quark productie



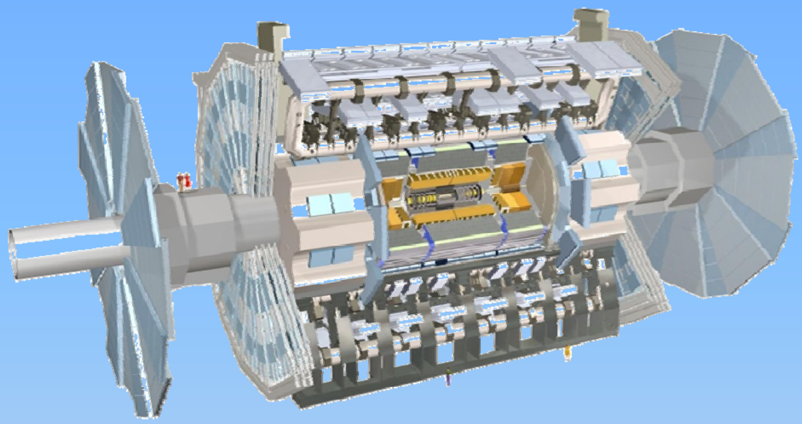
Onze ‘fototoestellen’

De vier experimenten

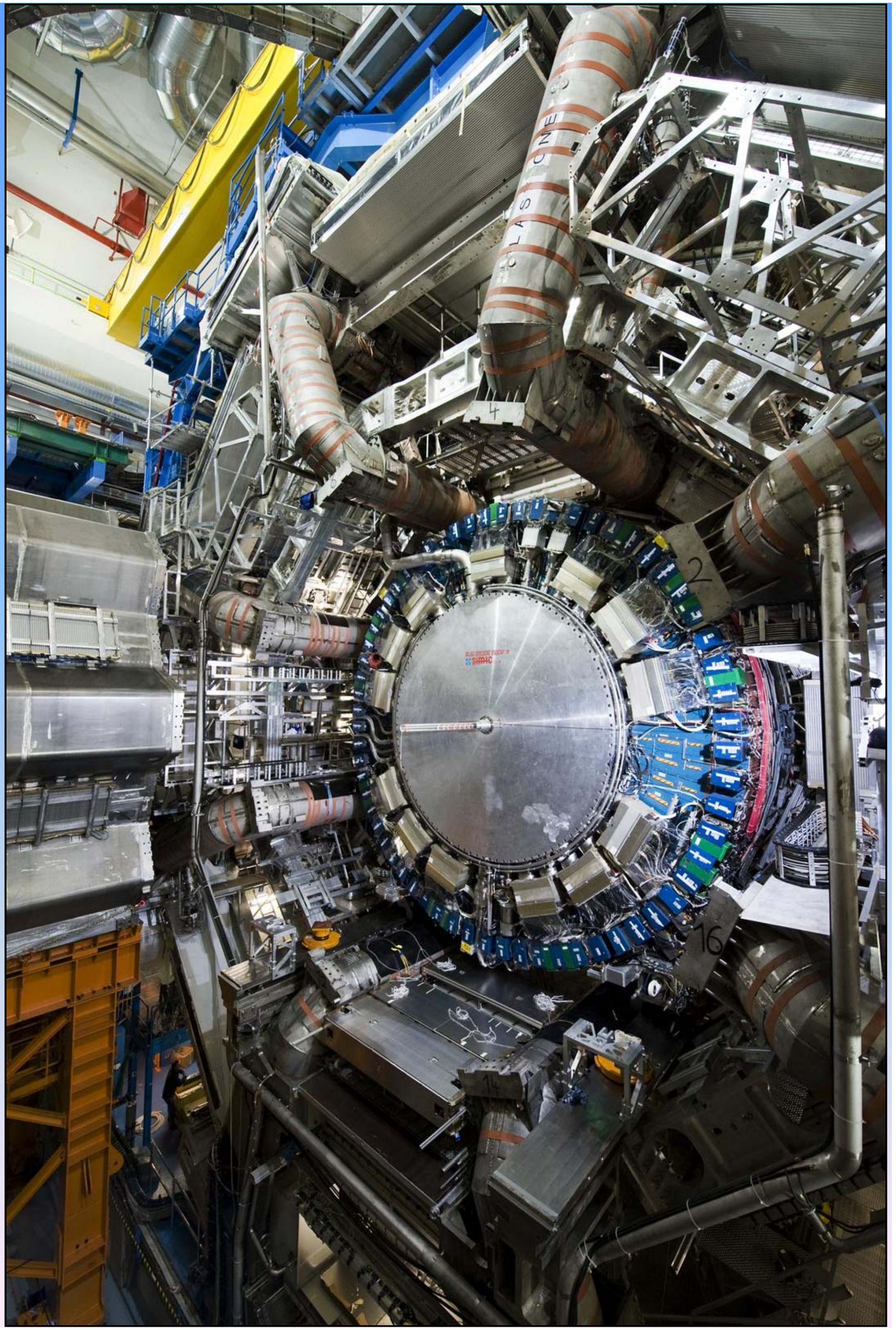



CMS

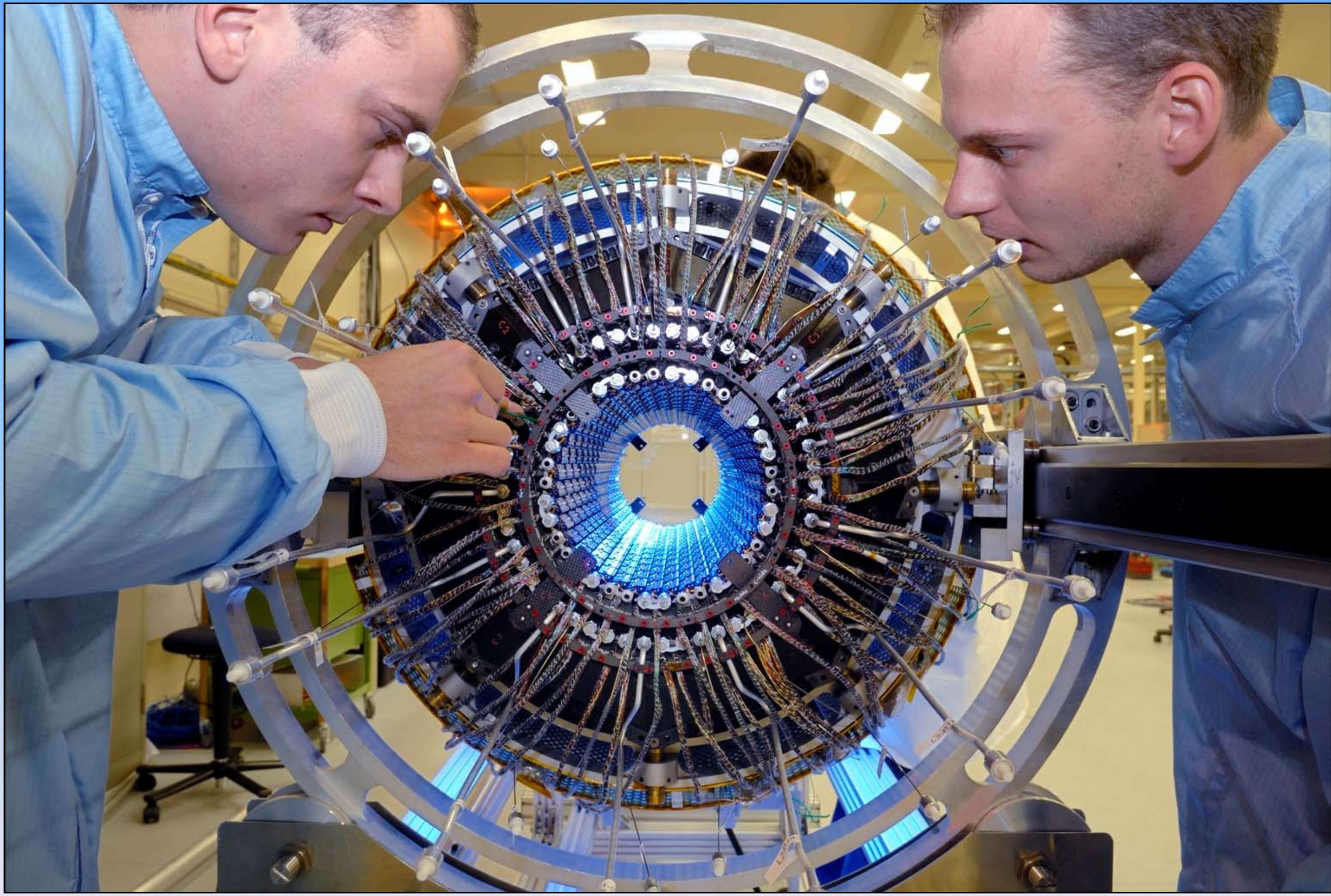
ATLAS detector



45 m lang, 25 m hoog, 7000 ton



De Atlas pixel detector

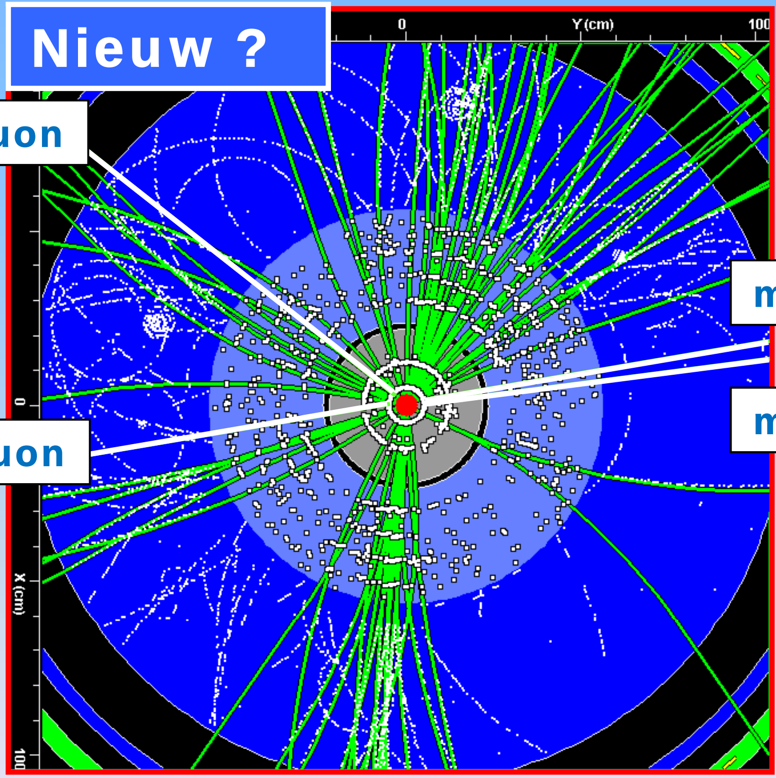


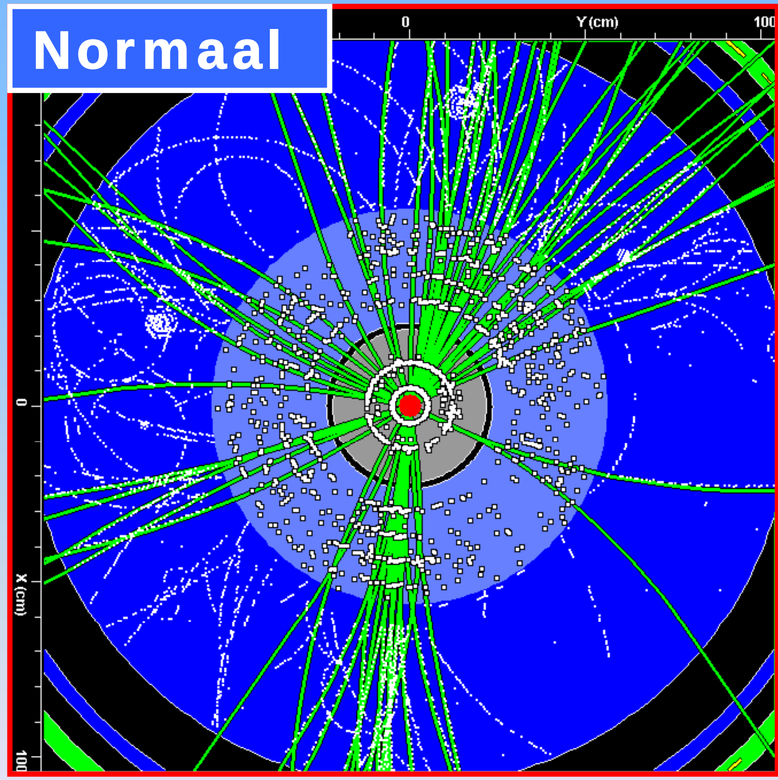
80 MegaPixel camera 40.000.000 foto’s per seconde

… hoe ontdek je nou nieuwe dingen ?

Hoe ontdek je nou nieuwe dingen

Nieuwe afstandschaal EN nieuwe detector





Higgs deeltje?

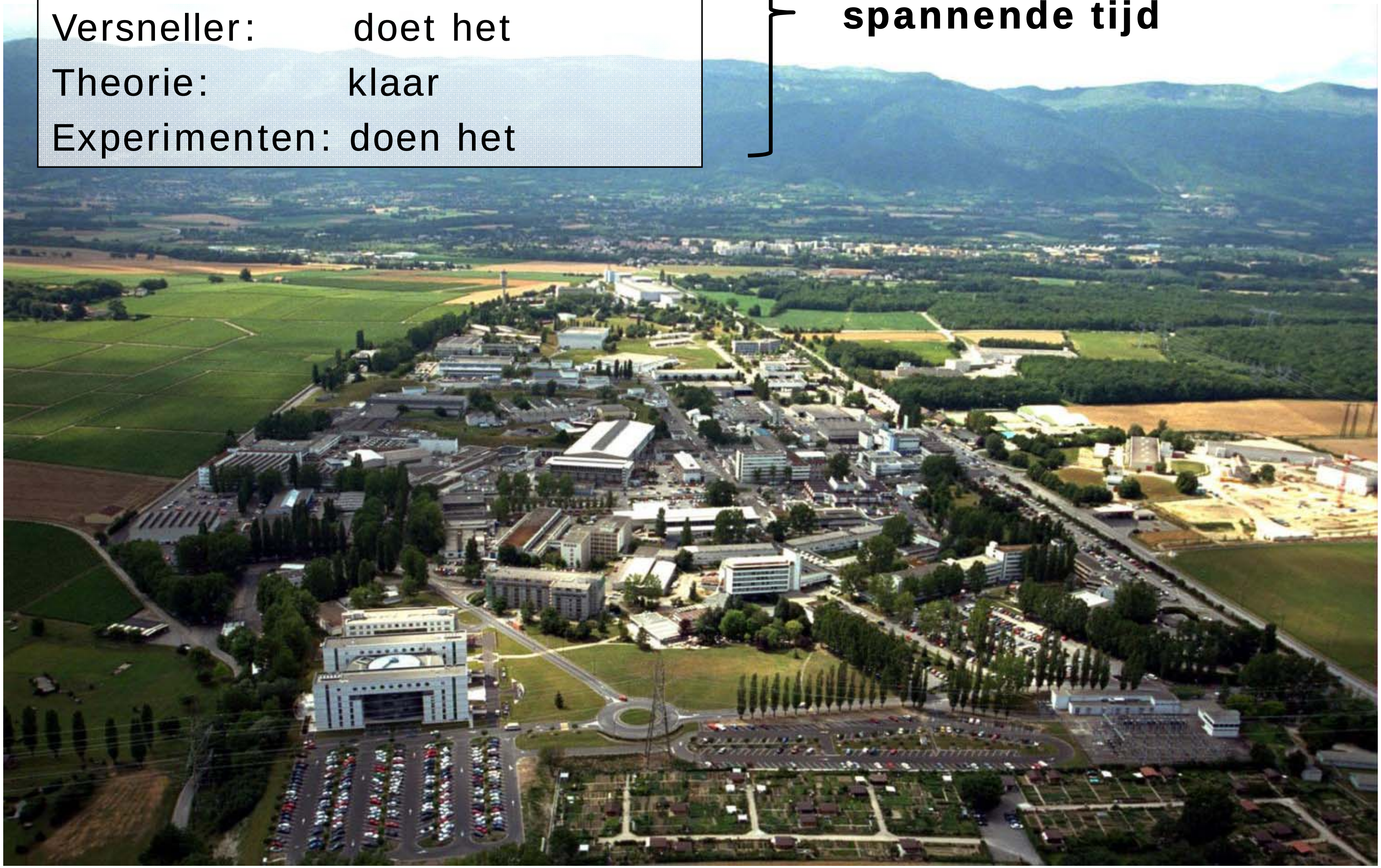
Ja ... waarschijnlijk wel

CERN

Heel veel vragen
Heel veel mogelijke oplossingen

Versneller: doet het
Theorie: klaar
Experimenten: doen het

spannende tijd



Bedankt voor de aandacht,

… mooie avond verder !

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