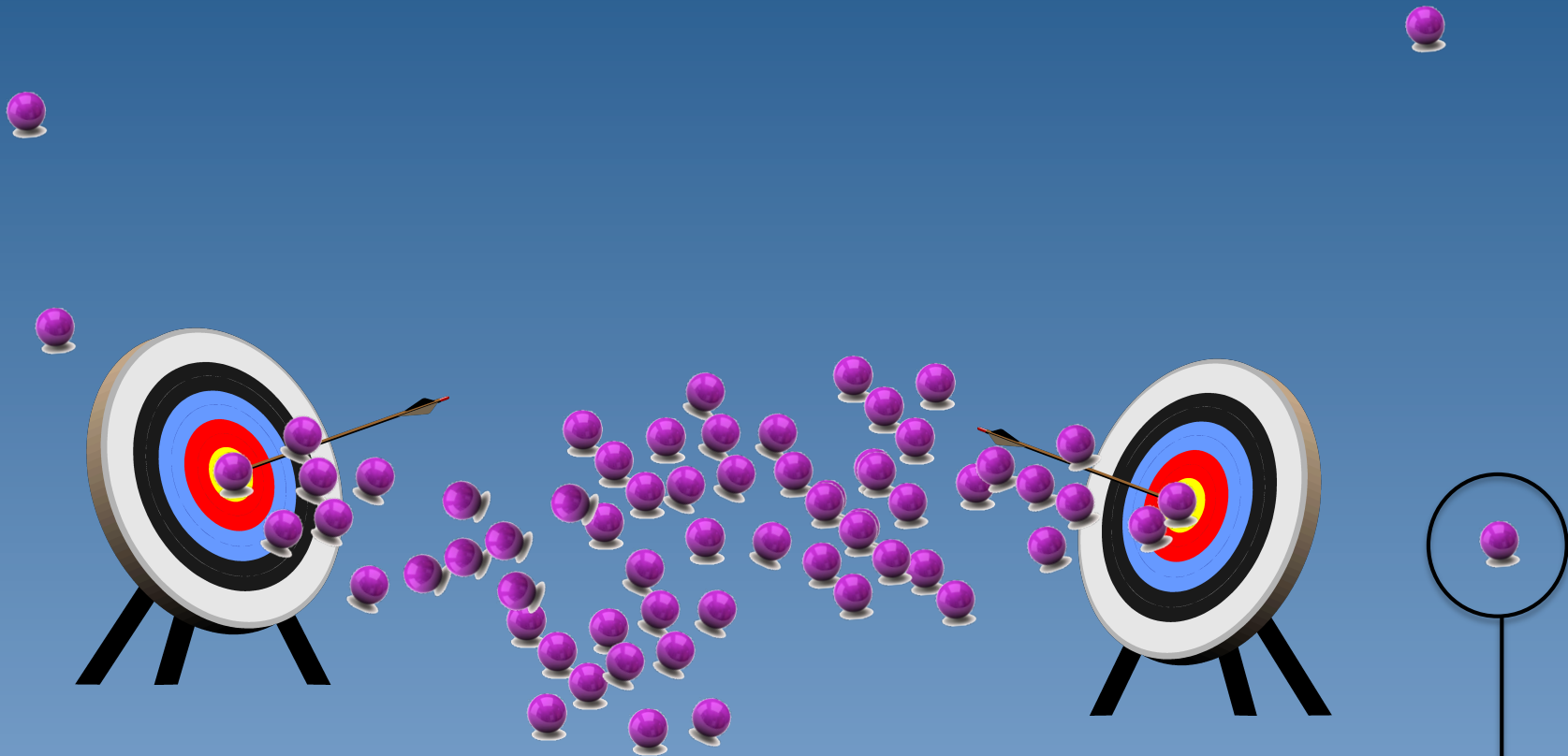




DE ONTDEKKING VAN HET HIGGS BOSON

Ivo van Vulpen

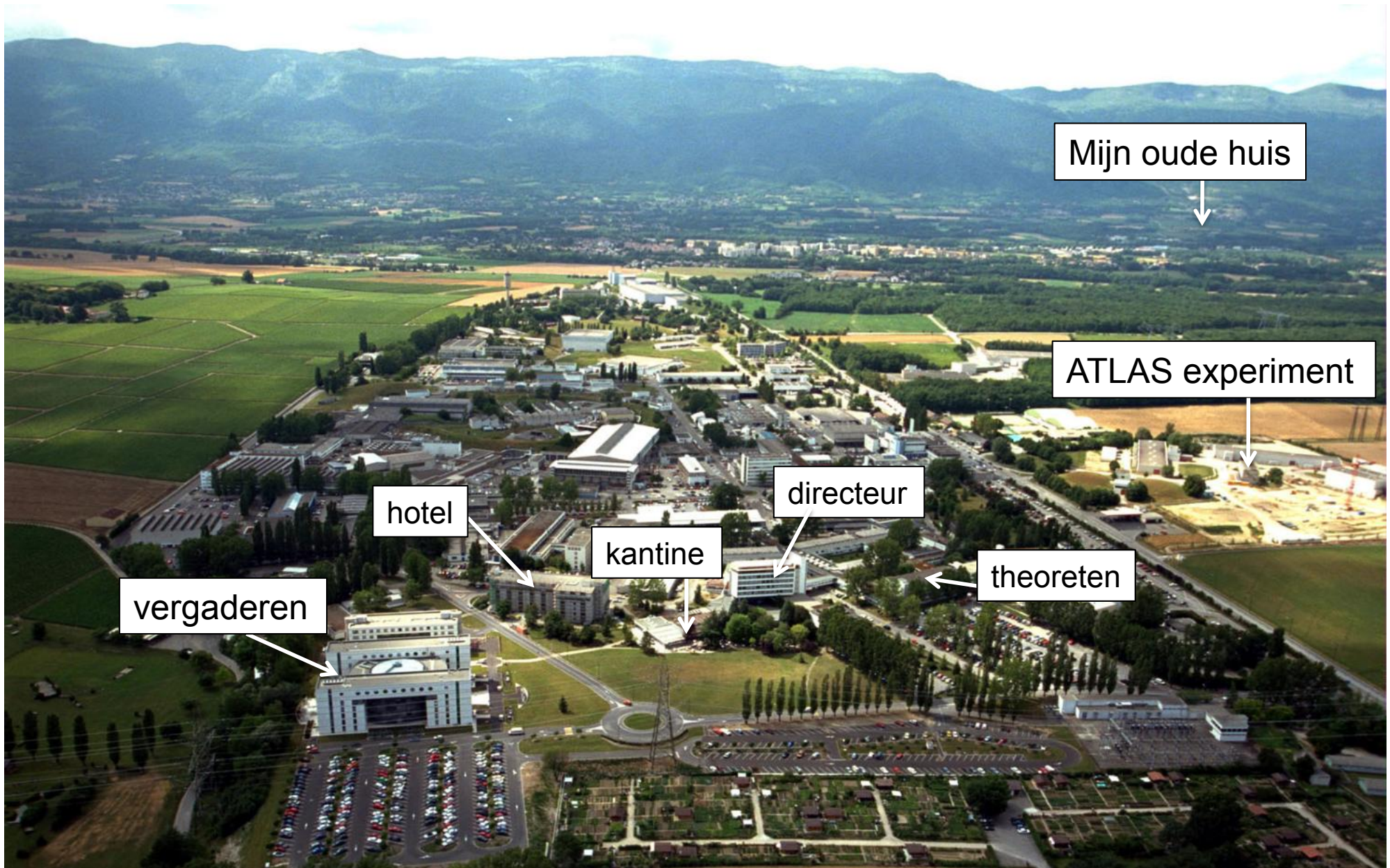


sportvrienden

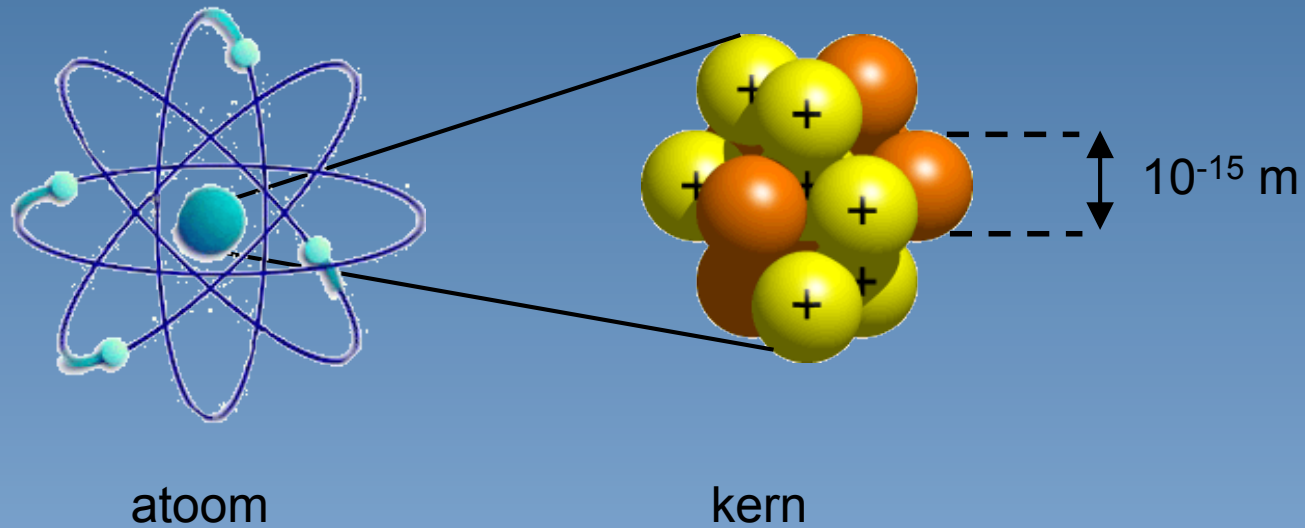
UvA collega's

Ultieme buzzword (slide 13):
“Lokale ijkvariantie”

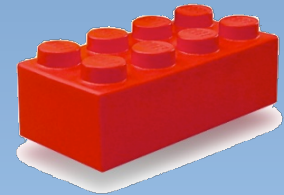
CERN in Genève, Zwitserland



Deeltjesfysica



Wat zijn de fundamentele bouwstenen en interacties ?



Klassieke mechanica

Algemeen:

Lagrangiaan

$$L = T - V$$

Euler-Lagrange

$$\frac{d}{dt} \frac{\partial L}{\partial \dot{q}_i} - \frac{\partial L}{\partial q_i} = 0$$

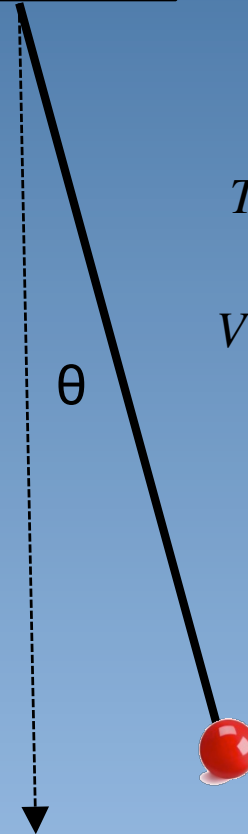


Bewegingsvergelijking

$$\ddot{\theta} - \frac{g}{l} \sin(\theta) = 0$$

De slinger:

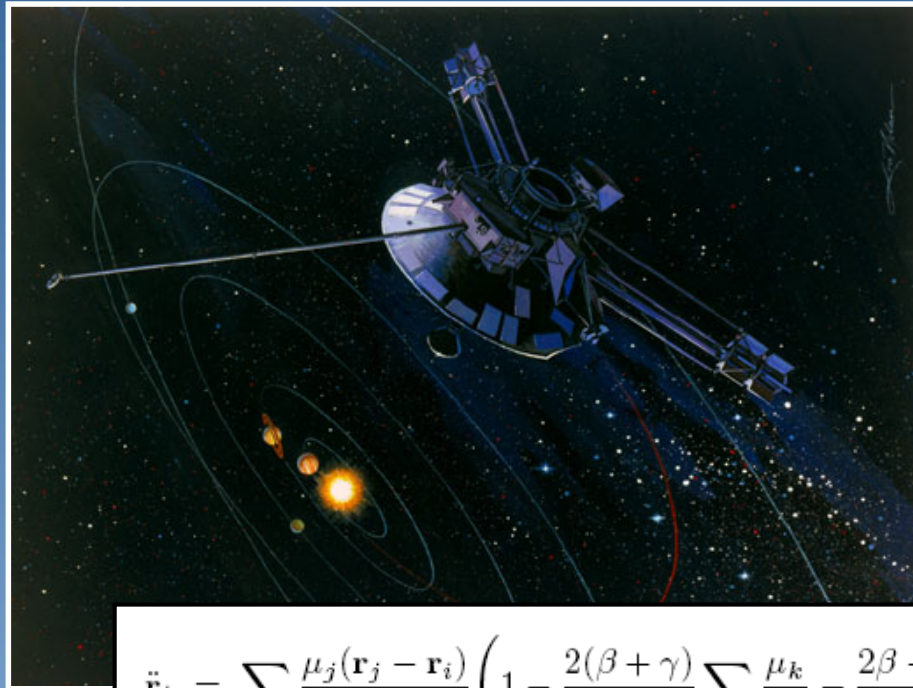
Hoe beweegt een slinger ?



$$T = \frac{1}{2} m (l \dot{\theta})^2$$

$$V = -mgl \cos(\theta)$$

Klassieke mechanica



Pioneer ruimtevaartuig

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

*Lastige wiskunde en veel rekenen niet belangrijk**inzicht** in de natuurwetten, daar gaat het om!*

De atoomwereld

1) De electronen vallen niet op de kern

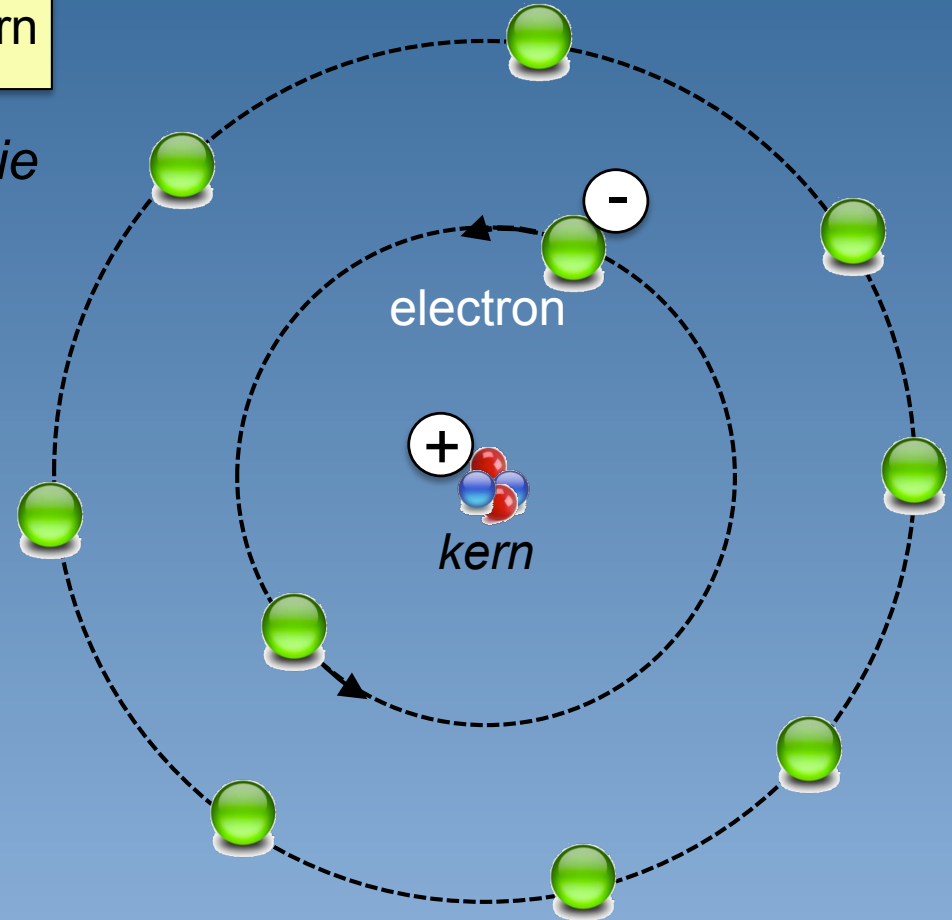
WETMATIGHEID: *quantisatie*

2) De kerndeeltjes kleven aan elkaar

KRACHT: *zwakke & sterke*

3) Patroon aantal electronen per baan

EIGENSCHAP: *spin*



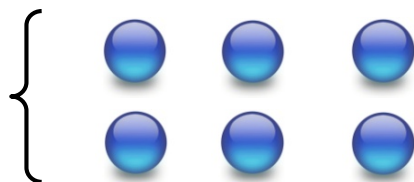
De stand van zaken op 1 februari 2013



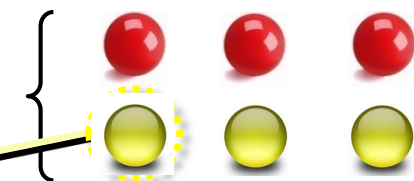
[http:// pdg.lbl.gov](http://pdg.lbl.gov)

Deeltjes

Quarks



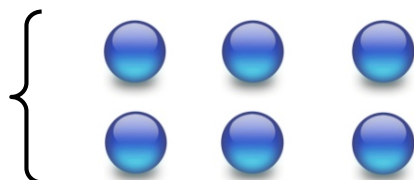
Leptonen



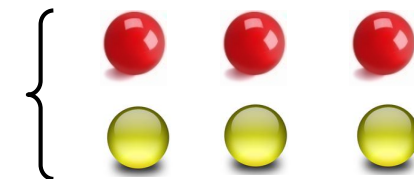
neutrino

Anti-deeltjes

Anti-
Quarks



Anti-
Leptonen



Krachten

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

Modelleren van interactie

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}ig_s^2 (\bar{q}_i^c \gamma^\mu q_j^c) 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 \left[\frac{2M^2}{g^2} + \frac{2M}{g} H + \frac{1}{2}(H^2 + \phi^0 \phi^0 + 2\phi^+ \phi^-) \right] + \frac{2M^4}{g^2} \alpha_h - ig_{cw} [\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^+) - ig_{sw} [\partial_\nu (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_\mu^- W_\nu^+ + g^2 c_w^2 (Z_\mu^0 W_\nu^+ Z_\mu^0 W_\nu^- - Z_\mu^0 W_\nu^+ Z_\mu^0 W_\nu^-) + g^2 s_w^2 (A_\mu W_\nu^+ A_\mu W_\nu^- - \\ & A_\mu A_\nu W_\nu^+ W_\nu^-) + g^2 s_w c_w [A_\mu Z_\mu^0 (W_\nu^+ W_\nu^- - W_\nu^- W_\nu^+) - 2A_\mu Z_\mu^0 W_\nu^+ W_\nu^-] - g\alpha [H^3 + \\ & H \phi^0 \phi^0 + 2H \phi^+ \phi^-] - \frac{1}{8}g^2 \alpha_h [H^4 + (\phi^0)^4 + 4(\phi^+ \phi^-)^2 + 4(\phi^0)^2 \phi^+ \phi^- + 4H^2 \phi^+ \phi^- + \\ & 2(\phi^0)^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}ig [W_\mu^+ (\phi^0 \partial_\mu \phi^- - \phi^- \partial_\mu \phi^0) - W_\mu^- (\phi^0 \partial_\mu \phi^+ - \\ & \phi^+ \partial_\mu \phi^0)] + \frac{1}{2}g [W_\mu^+ (H \partial_\mu \phi^- - \phi^- \partial_\mu H) - W_\mu^- (H \partial_\mu \phi^+ - \phi^+ \partial_\mu H)] + \frac{1}{2}g \frac{1}{c_w} (Z_\mu^0 (H \partial_\mu \phi^0 - \\ & \phi^0 \partial_\mu H) - ig \frac{s_w}{c_w} M Z_\mu^0 (W_\mu^+ \phi^- - W_\mu^- \phi^+) + ig_{sw} M A_\mu (W_\mu^+ \phi^- - W_\mu^- \phi^+) - ig \frac{1-2c_w^2}{2c_w} Z_\mu^0 (\phi^+ \partial_\mu \phi^- - \\ & \phi^- \partial_\mu \phi^+) + ig_{sw} 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}ig^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}ig^2 s_w A_\mu H (W_\mu^+ \phi^- - \\ & W_\mu^- \phi^+) - g^2 \frac{s_w}{c_w} (2c_w^2 - 1) Z_\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 + ig_{sw} 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{ig}{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{ig}{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{ig}{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{ig}{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{ig}{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{ig}{2M\sqrt{2}} \phi^- [m_\lambda^2 (\bar{d}_j^\lambda C_{\lambda\kappa}^\dagger (1 + \gamma^5) u_j^\lambda) - m_\lambda^2 (\bar{d}_j^\lambda C_{\lambda\kappa}^\dagger (1 - \\ & \gamma^5) u_j^\lambda) - \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{ig}{2} \frac{m_\lambda^2}{M} \phi^0 (\bar{u}_j^\lambda \gamma^5 u_j^\lambda) - \frac{ig}{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 + ig_{cw} W_\mu^+ (\partial_\mu \bar{X}^0 X^- - \\ & \partial_\mu \bar{X}^+ X^0) + ig_{sw} W_\mu^+ (\partial_\mu \bar{Y} X^- - \partial_\mu \bar{X}^+ Y) + ig_{cw} W_\mu^- (\partial_\mu \bar{X}^- X^0 - \partial_\mu \bar{X}^0 X^+) + \\ & ig_{sw} W_\mu^- (\partial_\mu \bar{X}^- Y - \partial_\mu \bar{Y} X^+) + ig_{cw} Z_\mu^0 (\partial_\mu \bar{X}^+ X^- - \partial_\mu \bar{X}^- X^+) + ig_{sw} 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} ig M [\bar{X}^+ X^0 \phi^- + \\ & \bar{X}^- X^0 \phi^+] + \frac{1}{2c_w} ig M [\bar{X}^0 X^- \phi^+ - \bar{X}^0 X^+ \phi^-] + ig M s_w [\bar{X}^0 X^- \phi^+ - \bar{X}^0 X^+ \phi^-] + \\ & \frac{1}{2}ig M [\bar{X}^+ X^+ \phi^0 - \bar{X}^- X^- \phi^0] \end{aligned}$$

Bladmuziek (J.S. Bach)

bladmuziek



De stand van zaken op 1 februari 2013



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

Krachten en symmetrieën: niet-zo-klassieke mechanica

$$L = i\bar{\psi}\gamma_{\mu}\partial^{\mu}\psi - m\bar{\psi}\psi$$

Ψ =electron

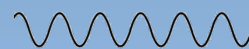
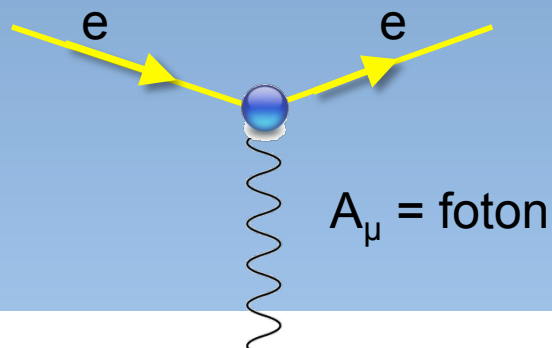


eis: lokale ijkvariantie

$$\psi(x) \rightarrow e^{iq\alpha(x)}\psi(x)$$

$$L = i\bar{\psi}\gamma_{\mu}D^{\mu}\psi - m\bar{\psi}\psi$$

$$D_{\mu} \equiv \partial_{\mu} - iqA_{\mu}$$



A_{μ} = spin-1 deeltje
= foton



electron

In het Standard Model

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

Electrozwak:
 W^+, W^-, Z, γ

QCD:
8 gluons

1 foton en 8 gluonen ($m=0$)

W^+, W^-, Z ($m=80/90$ GeV) $\rightarrow$ eindige dracht (10^{-15} m)

deeltjes



Het Standaard Mod



Theorie

Het Standaard Model

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

Beschrijft alle fenomenen in de natuur

Massieve (kracht-)deeltjes

Realiteit

$\neq$



Massieve (kracht-)deeltjes

(In)famous Higgs boson



Het Higgs boson



Paris Hilton

Beroemd zijn is niet hetzelfde als belangrijk

Theorie

Realiteit

Het Standaard Model

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

=



Massieve (kracht-)deeltjes



Het Higgs mechanisme

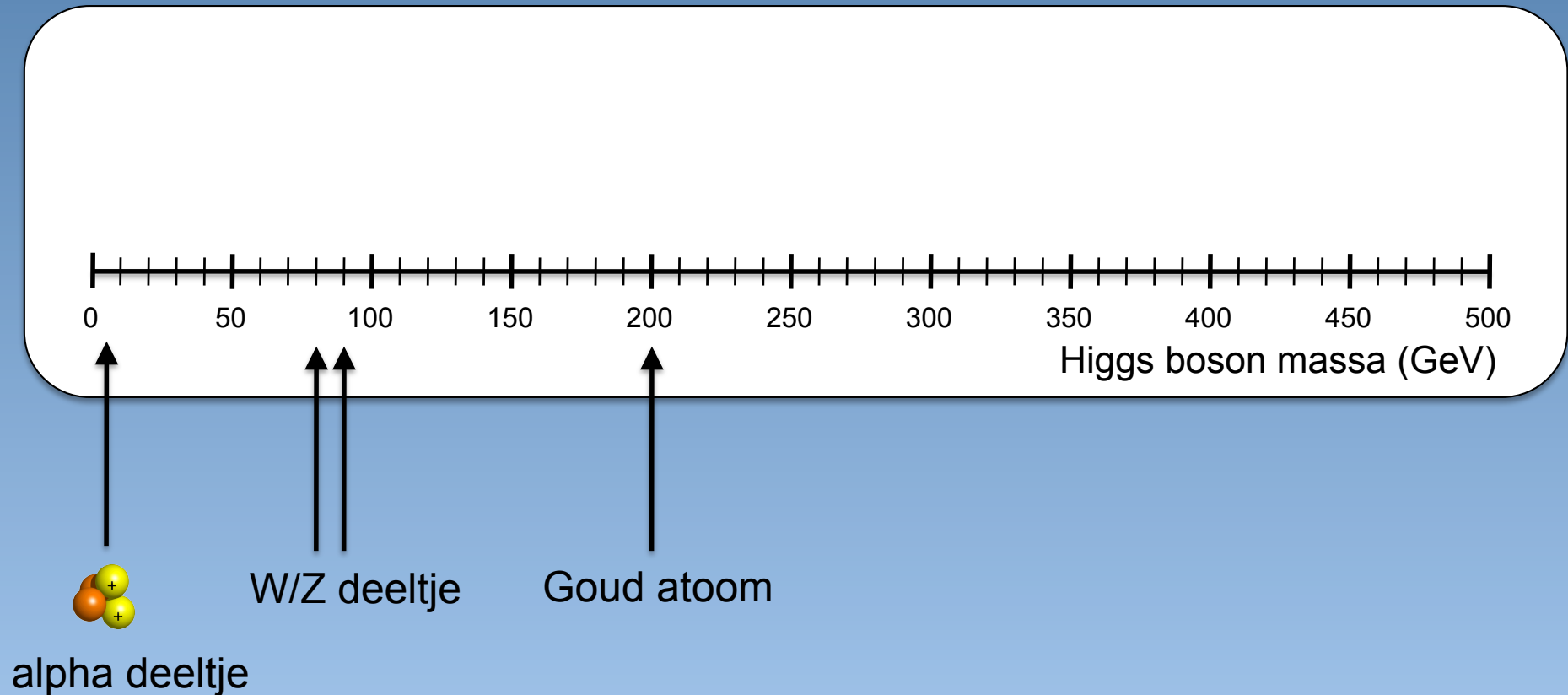
Higgs veld in het vacuum

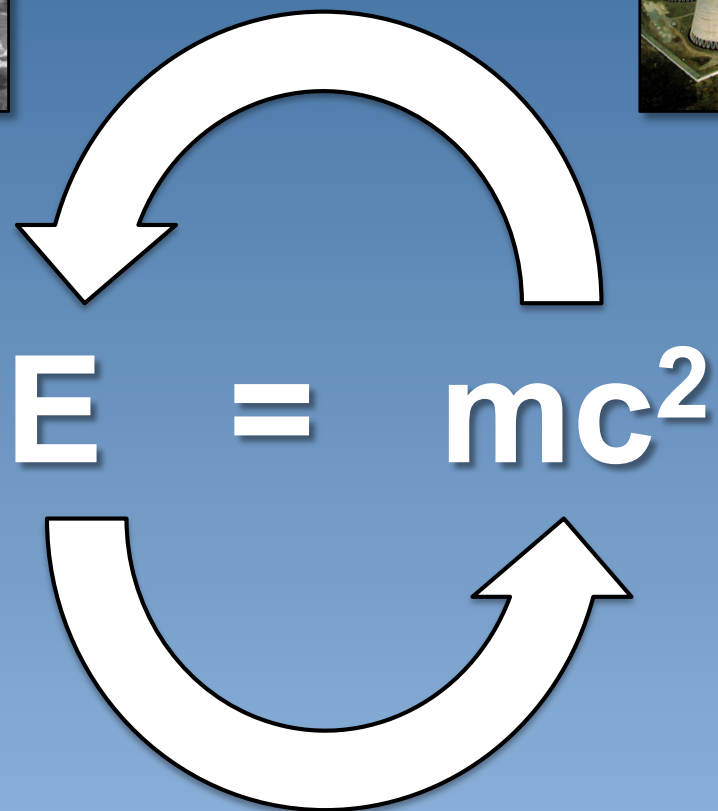
“Als ik gelijk heb moet er ook een nieuw deeltje bestaan: het Higgs boson”

- September 1964 -

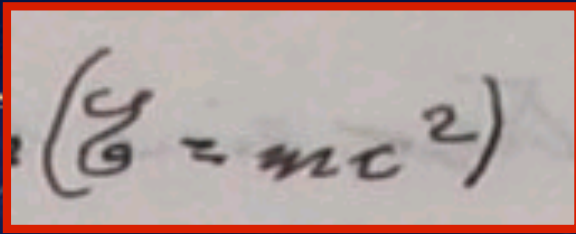
De massa van het Higgs boson

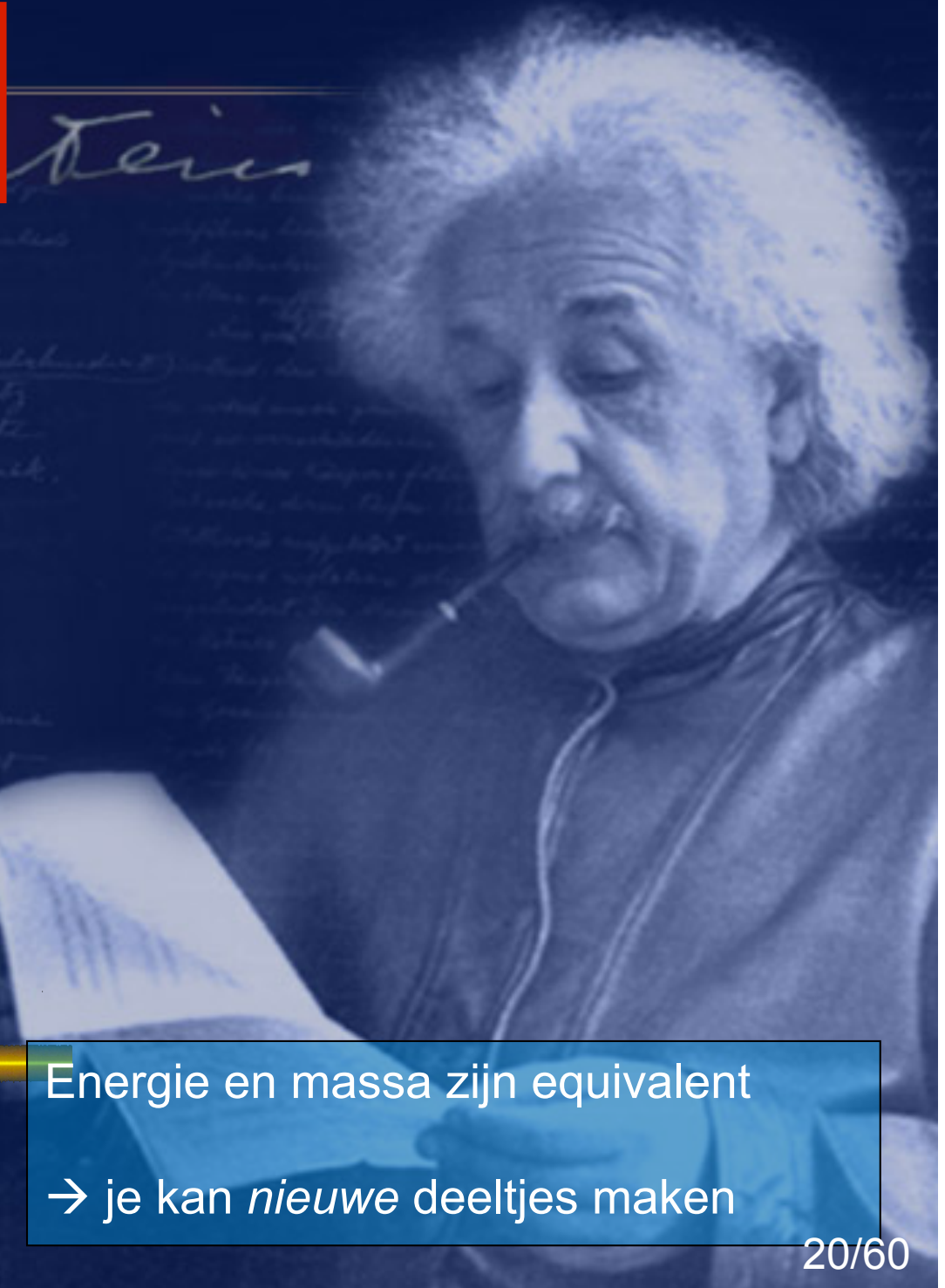
1 GeV $\rightarrow$ massa proton = massa Waterstof atoom





Albert Einstein


$$E = mc^2$$

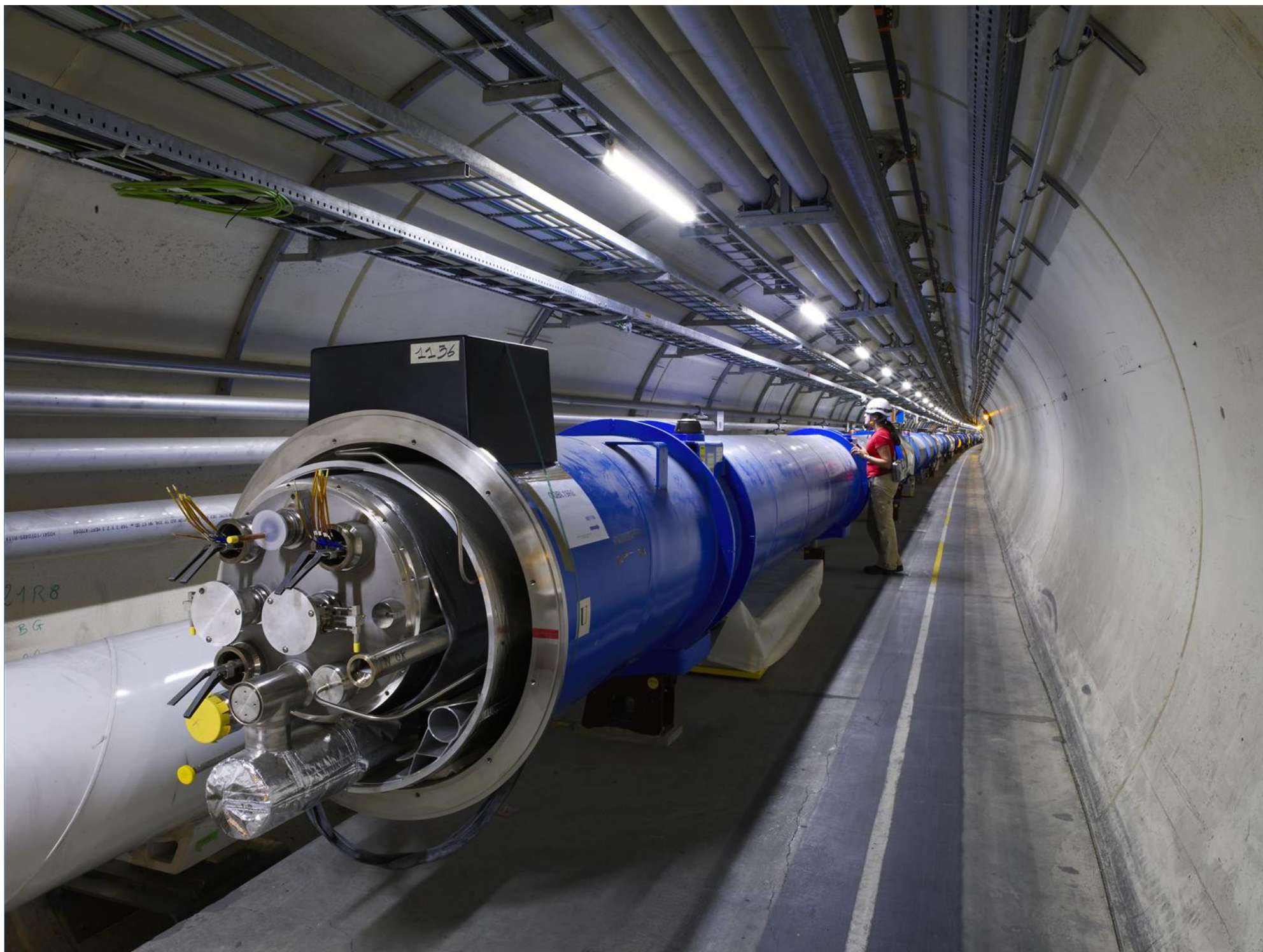


Energie en massa zijn equivalent

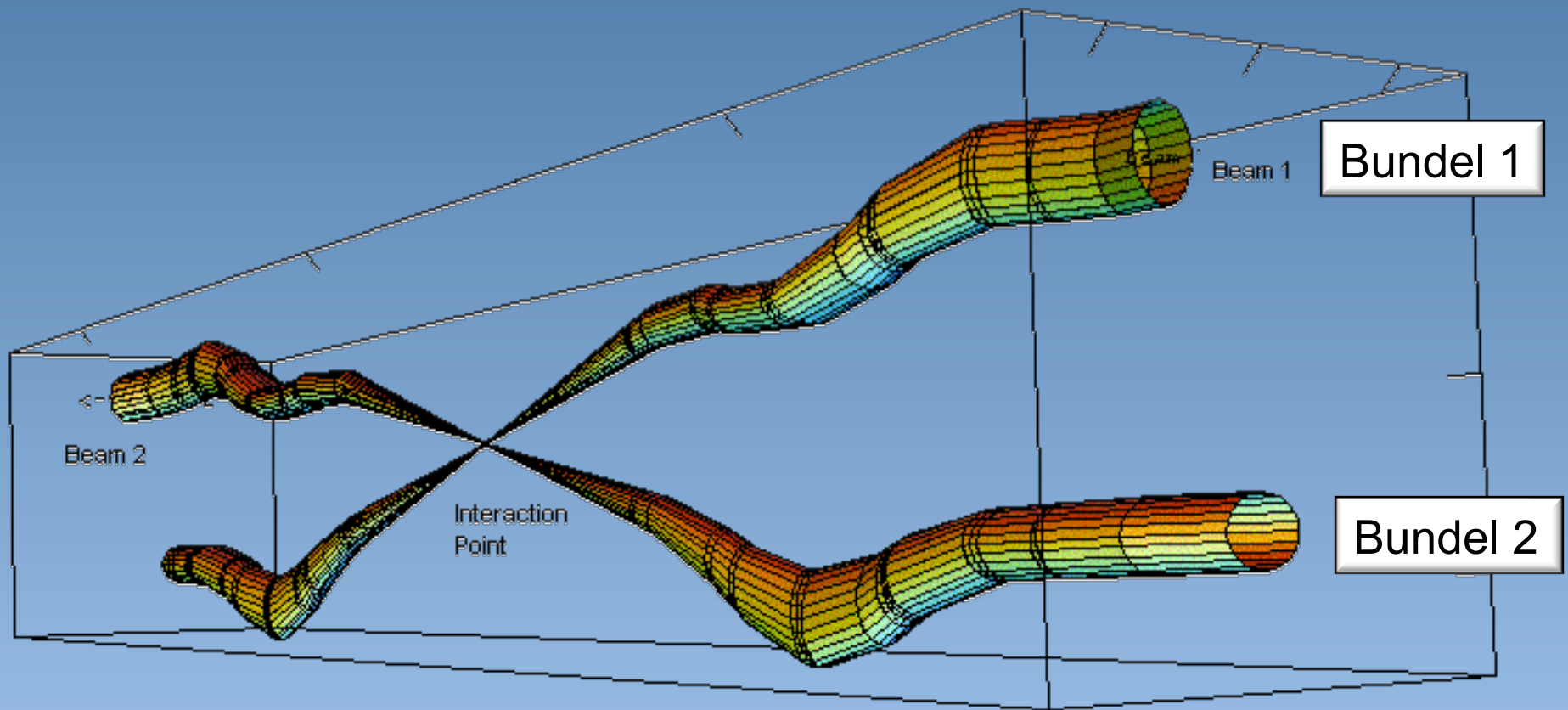
→ je kan *nieuwe* deeltjes maken

An aerial photograph of the CERN facility near Geneva, Switzerland. A large red oval is superimposed on the image, representing the path of the Large Hadron Collider (LHC) tunnel. The oval passes over the city of Geneva, the Lake of Geneva, and extends into the surrounding landscape. In the background, the snow-capped Alps are visible under a clear blue sky. A blue rectangular box with a white border is centered over the oval, containing text in Dutch and English.

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



40 miljoen botsingen per seconde

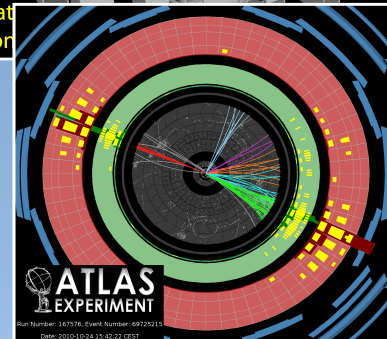
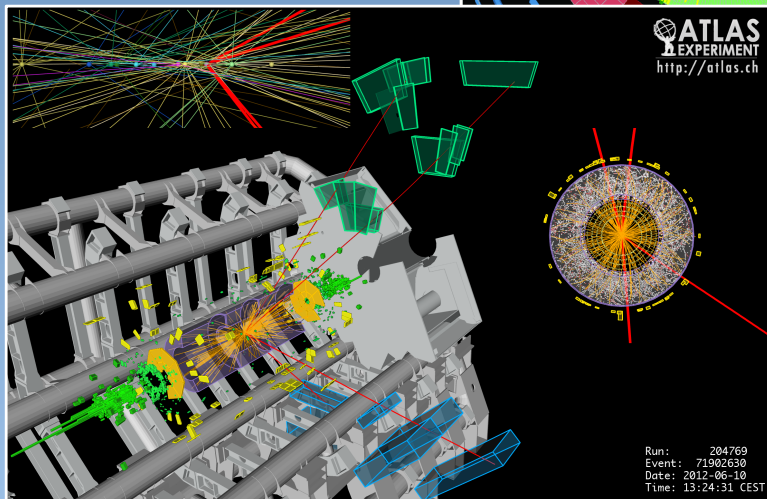
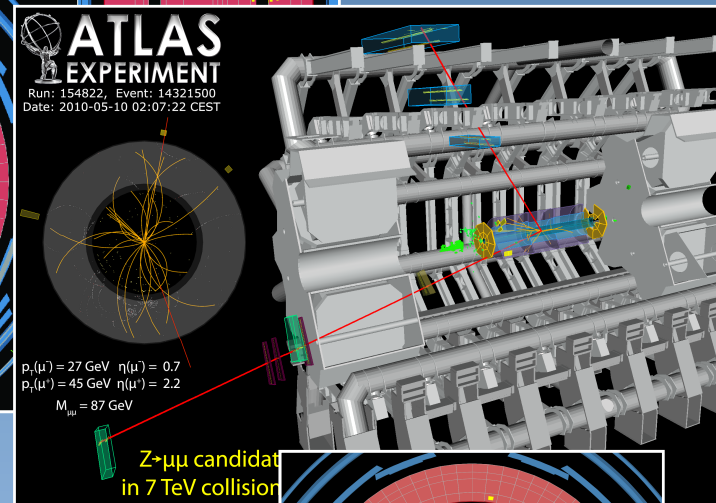
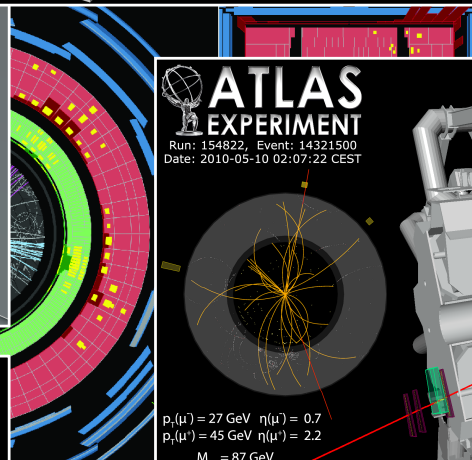
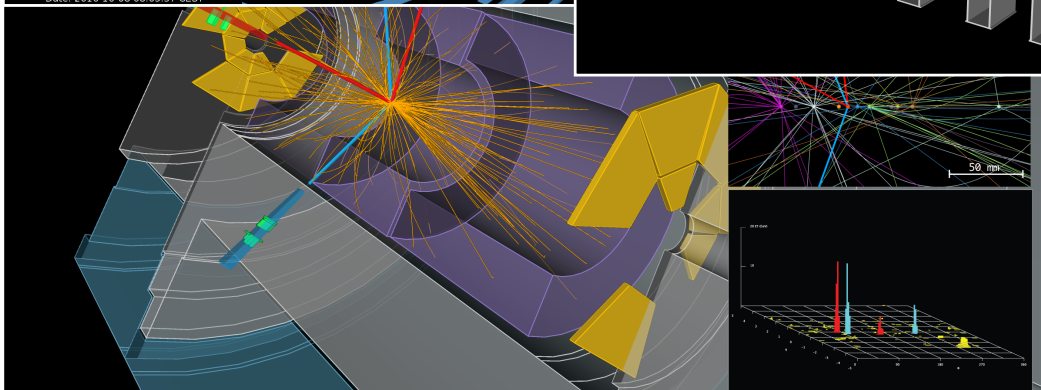
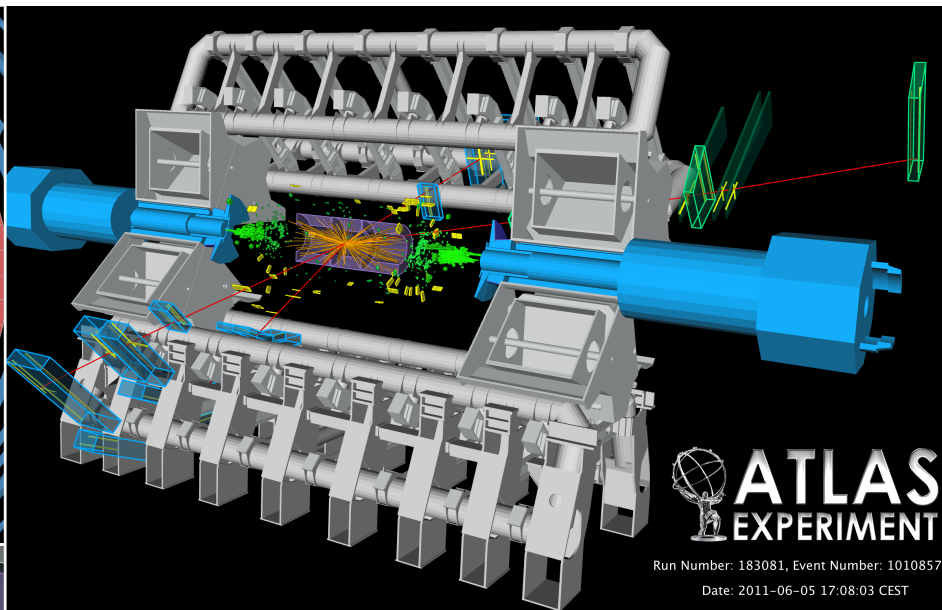
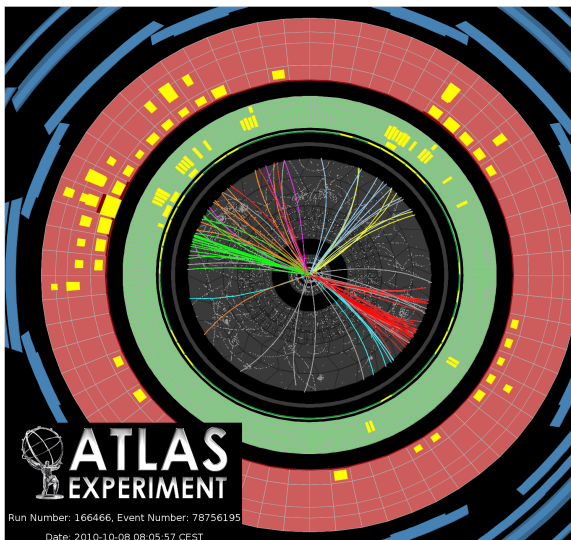




Klassiek botsen

Quantummechanisch botsen

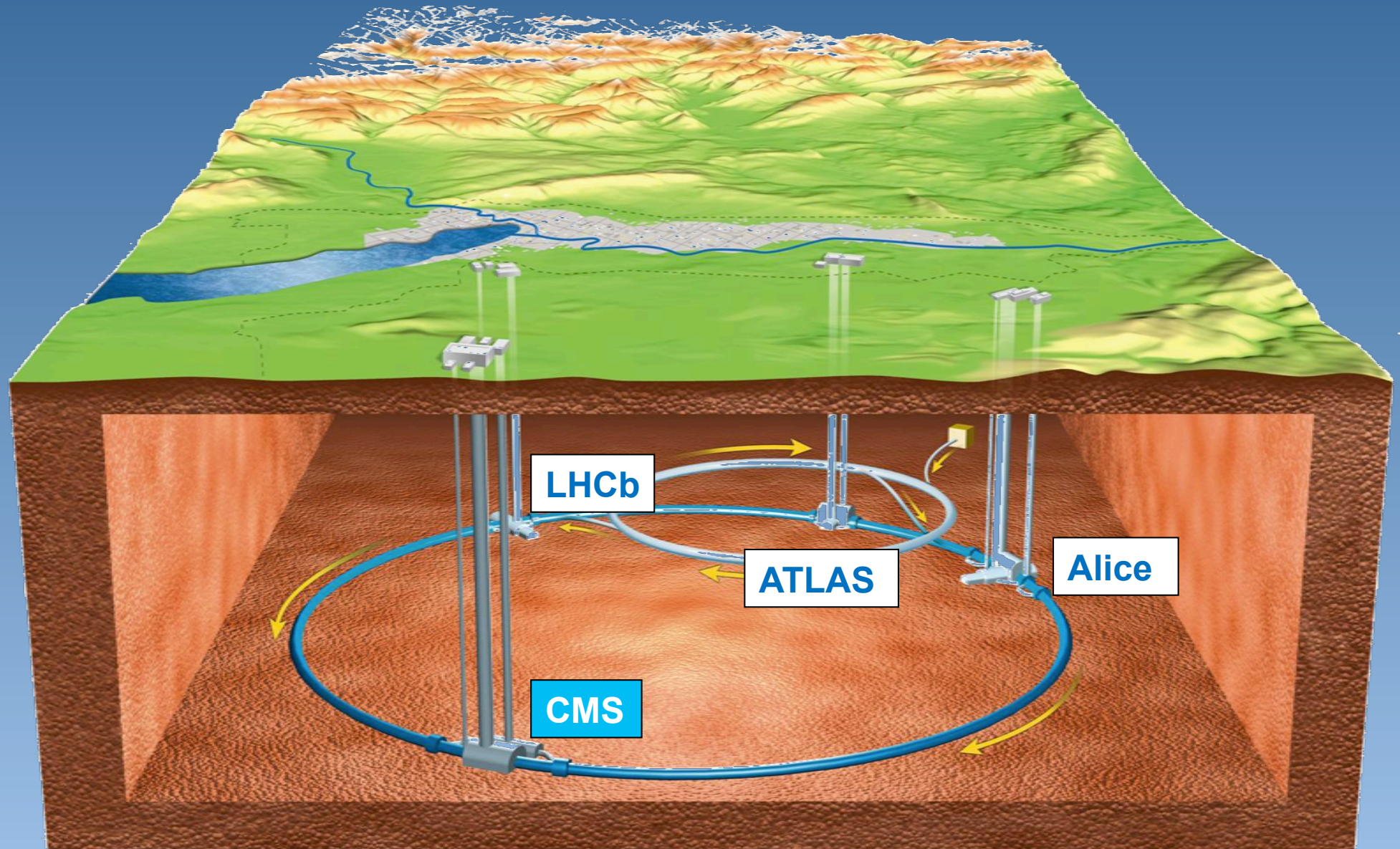


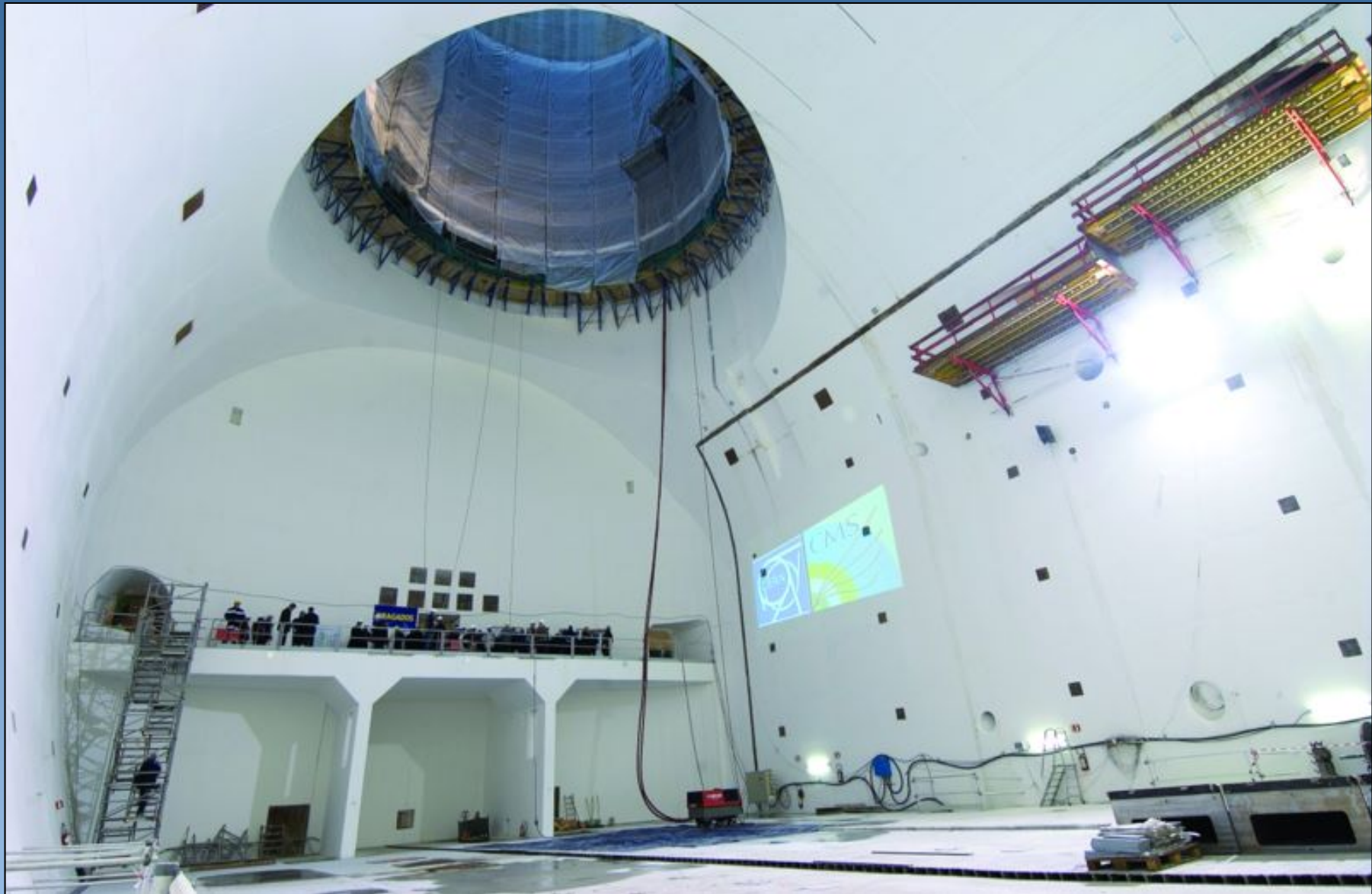


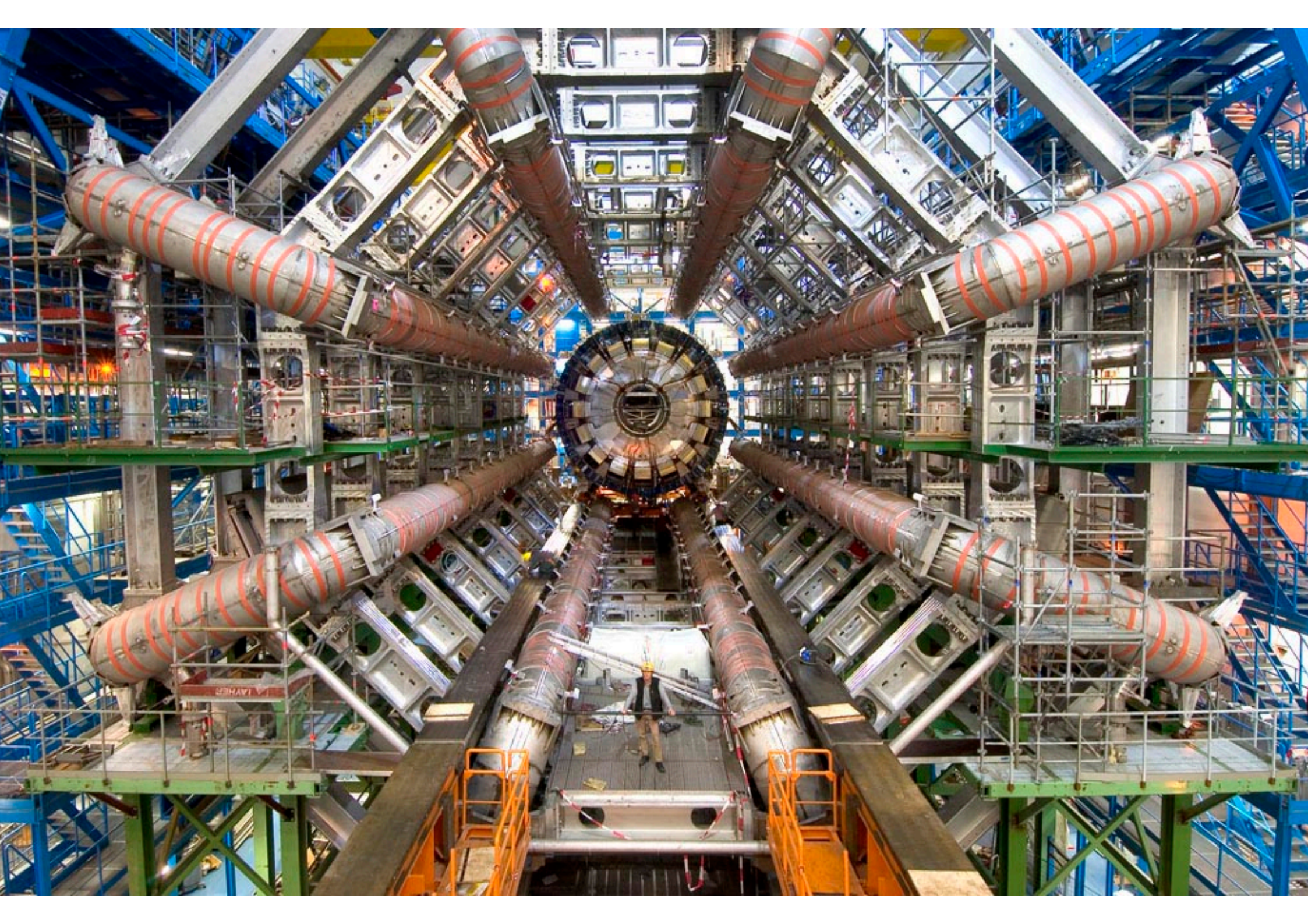
Onze 'fototoestellen'



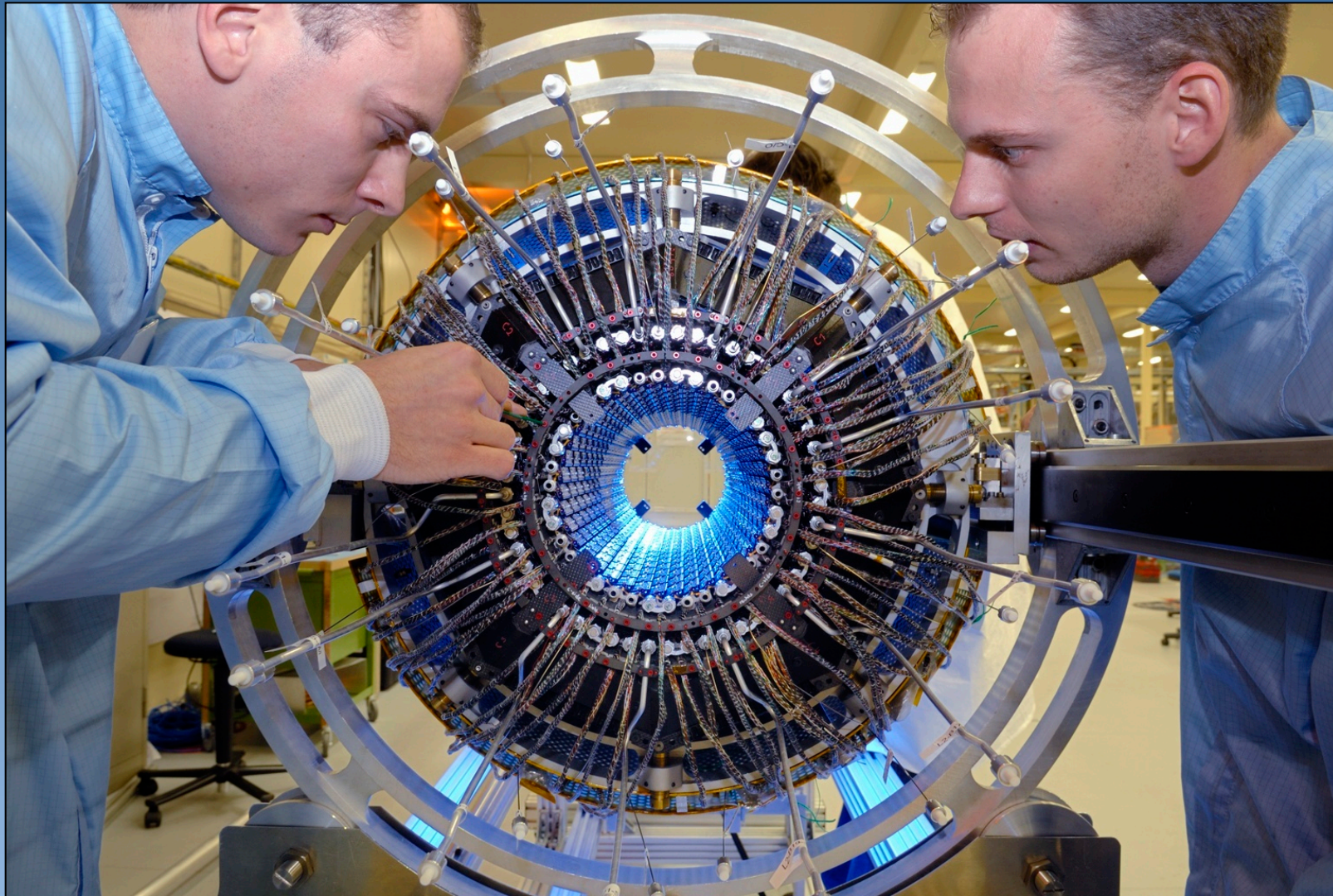
De vier experimenten





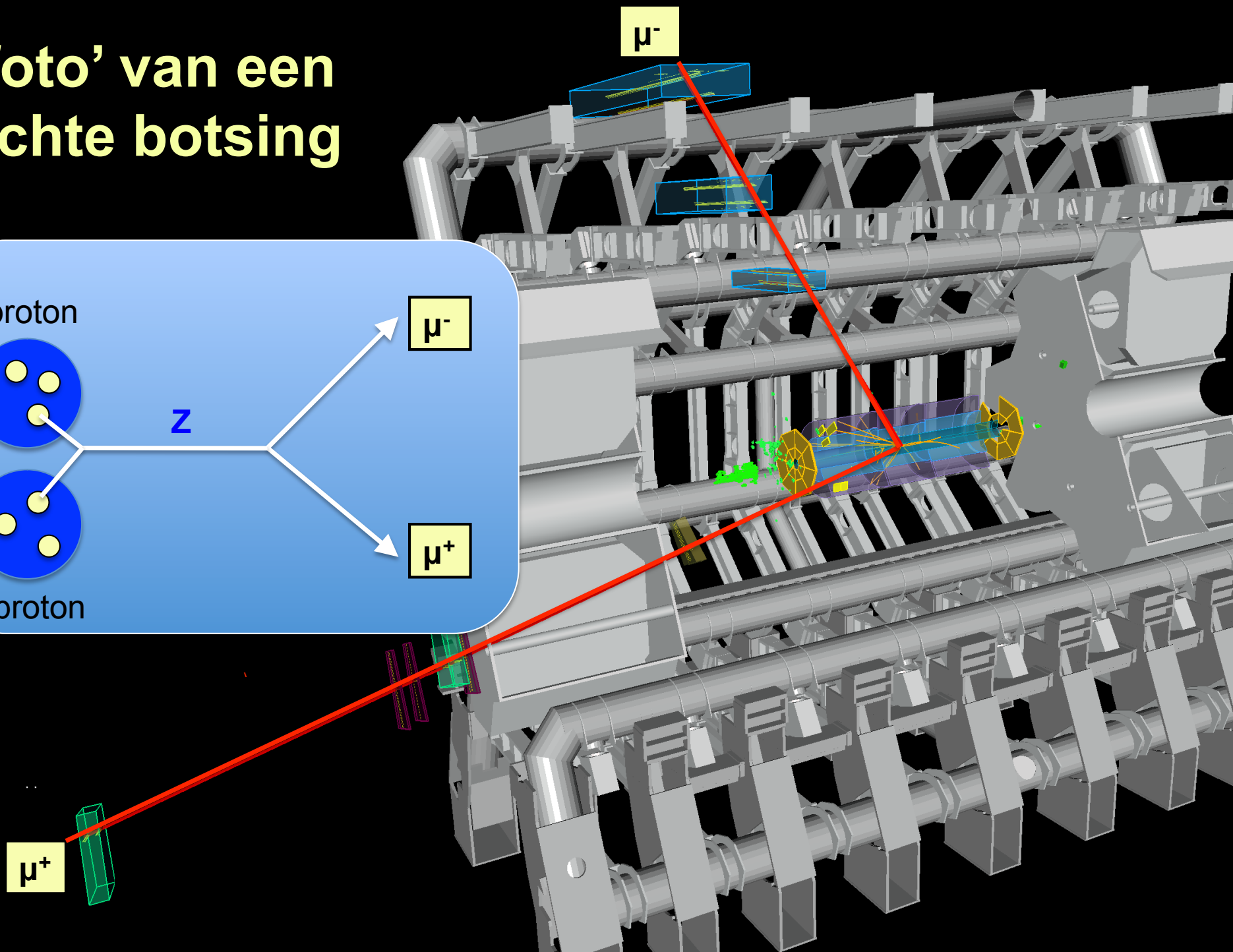
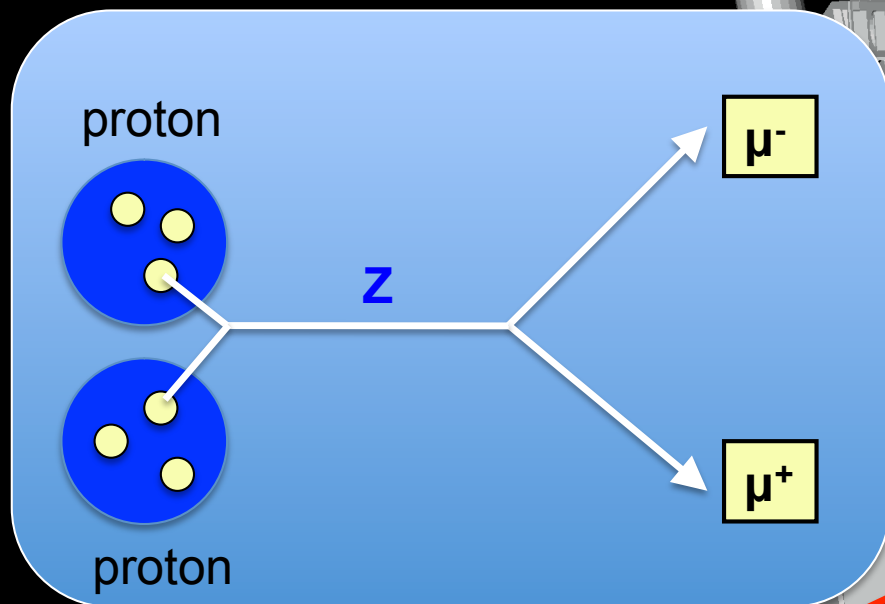


De Atlas pixel detector



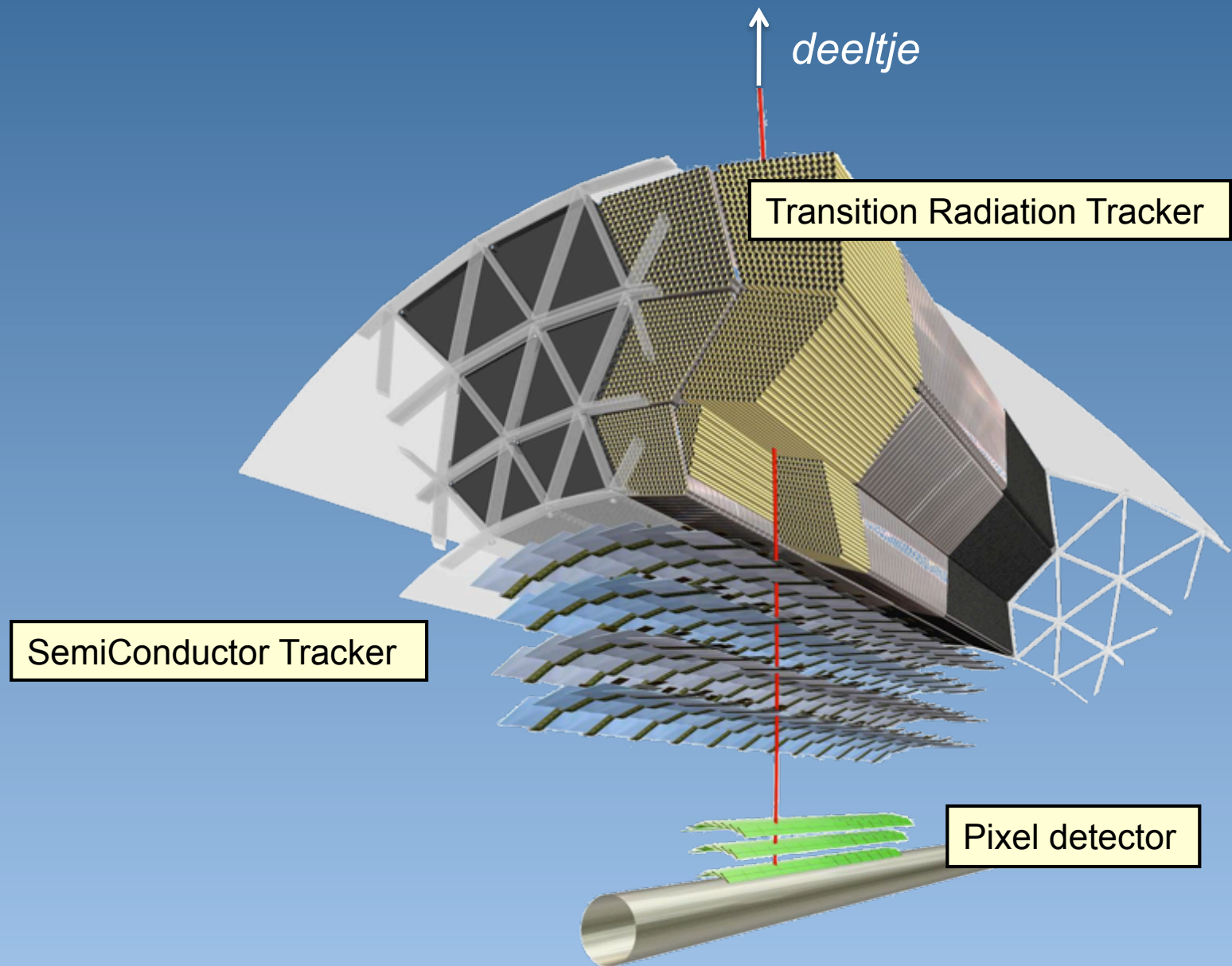
80 MegaPixel camera 40.000.000 foto's per seconde

‘foto’ van een echte botsing

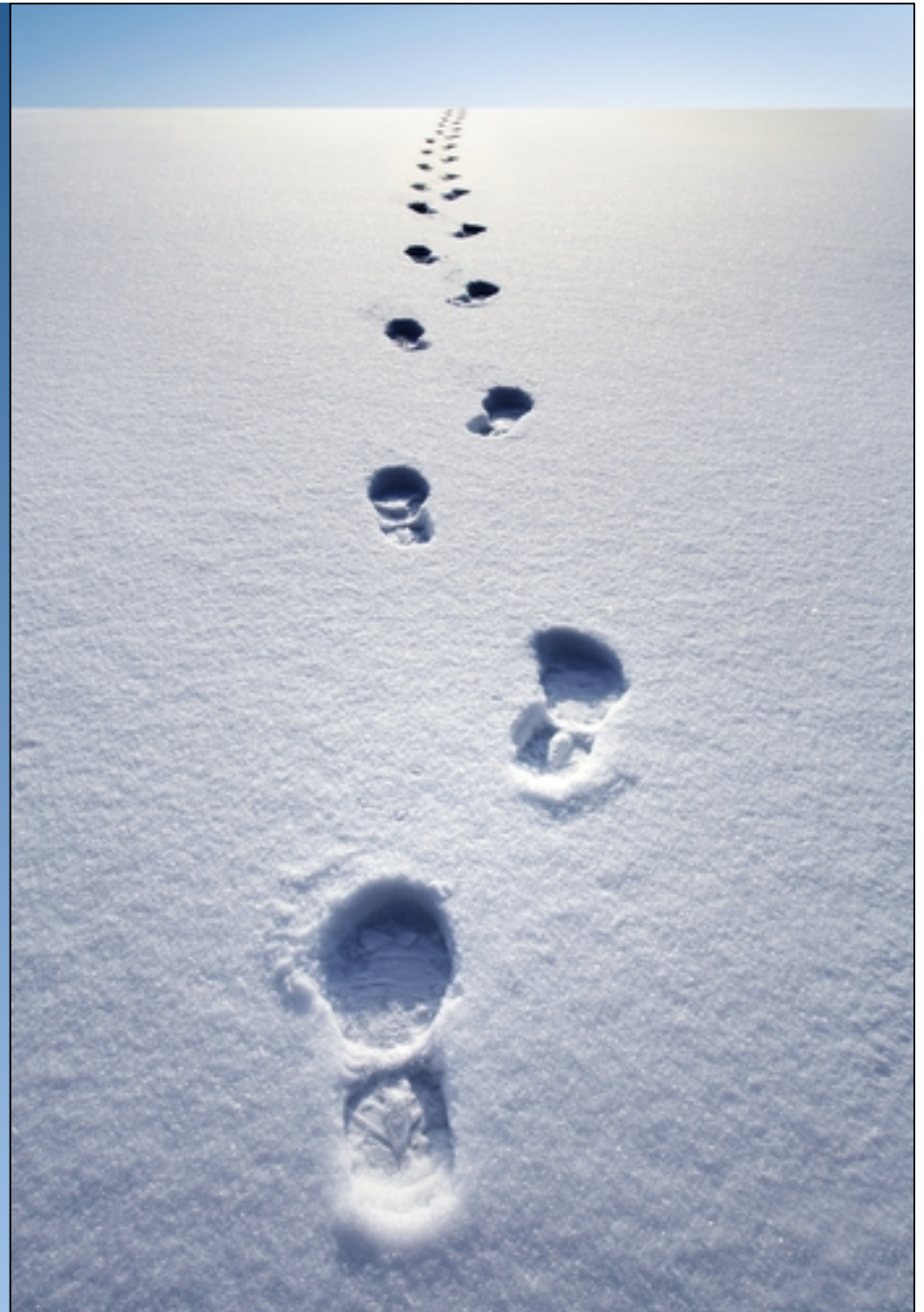


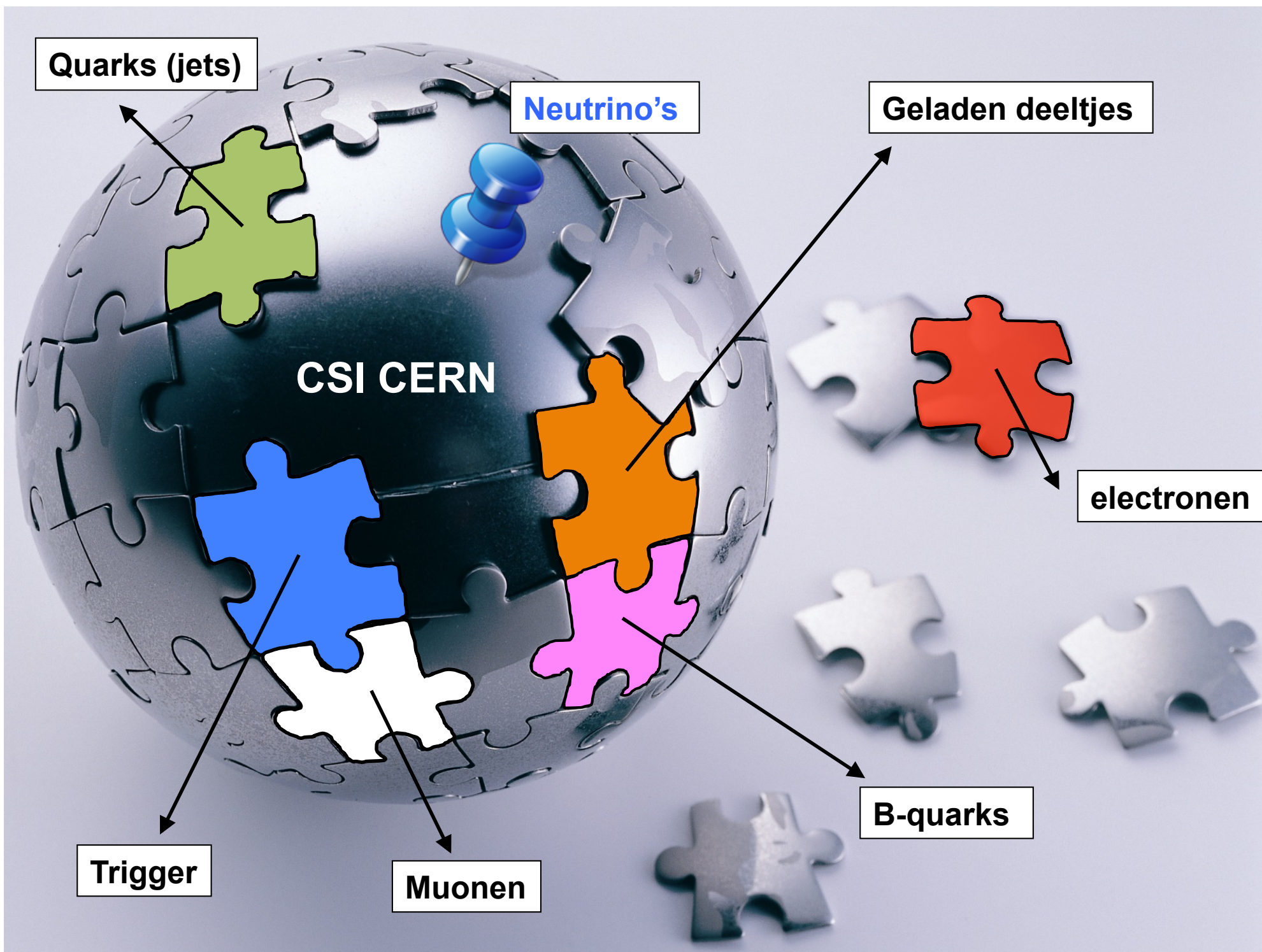
Waarom is die ATLAS detector nou zo complex ?

Het ene deeltje is het andere niet



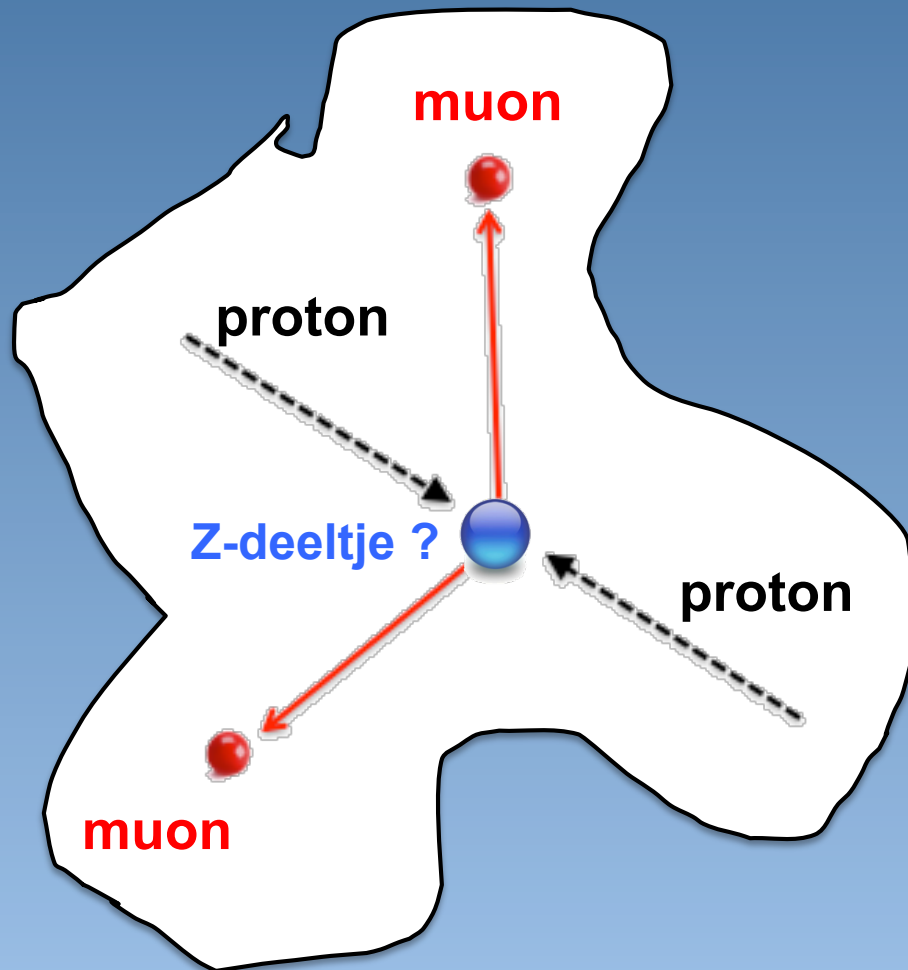
Konijn, auto of mens ?



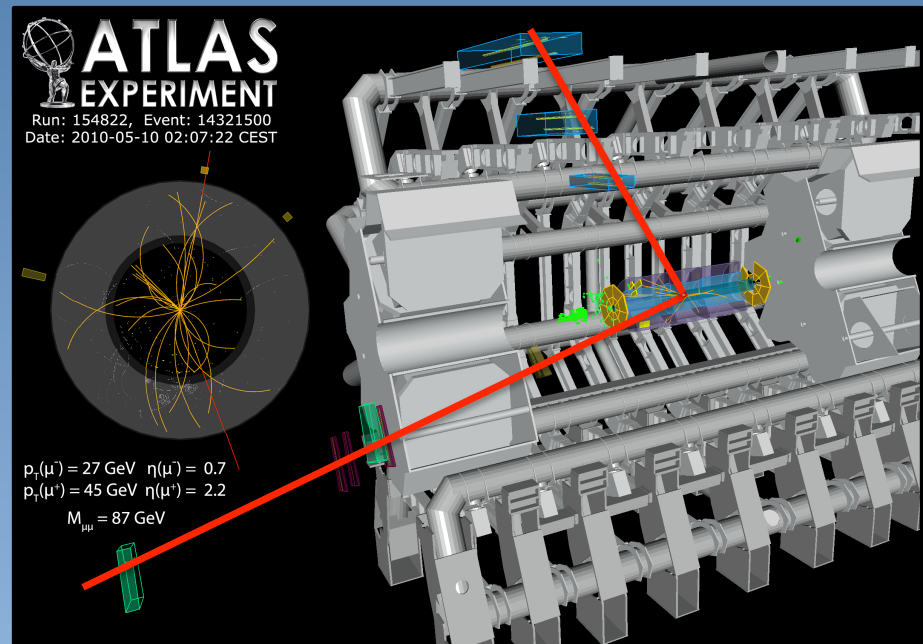


Hoe bewijs je dat er een Z-deeltje bestaat ?

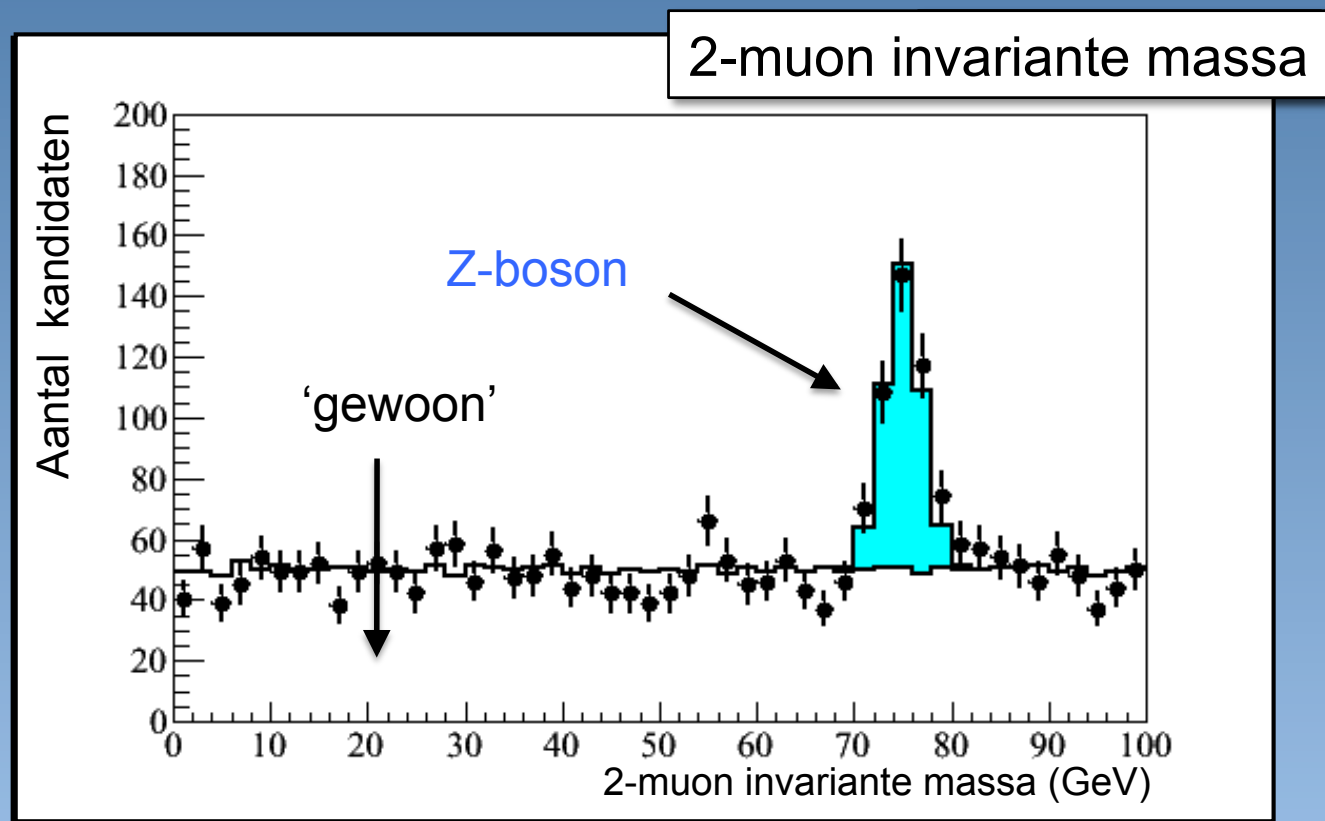
Afwijking van de voorspelling in een model zonder Z-boson



2-muonen gezien in de ATLAS detector

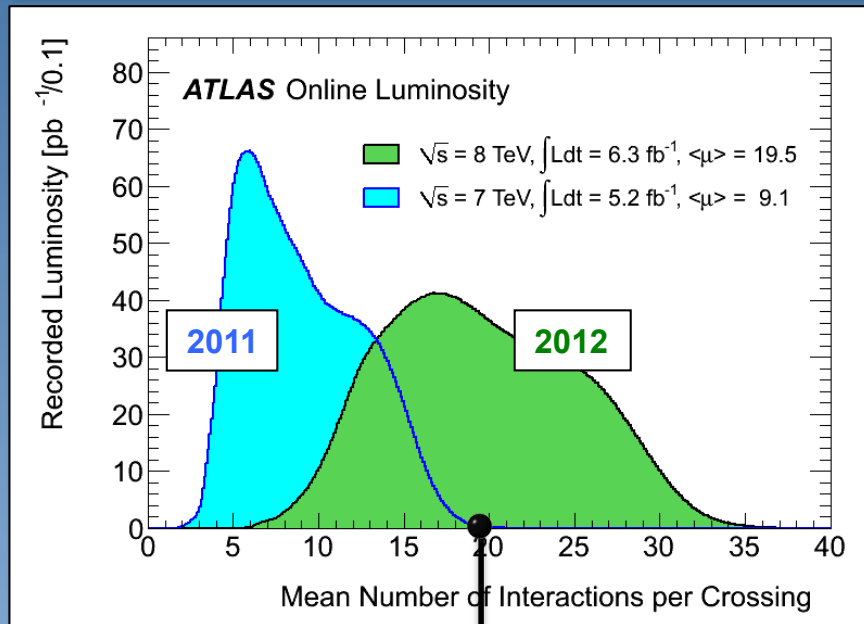


De ATLAS data

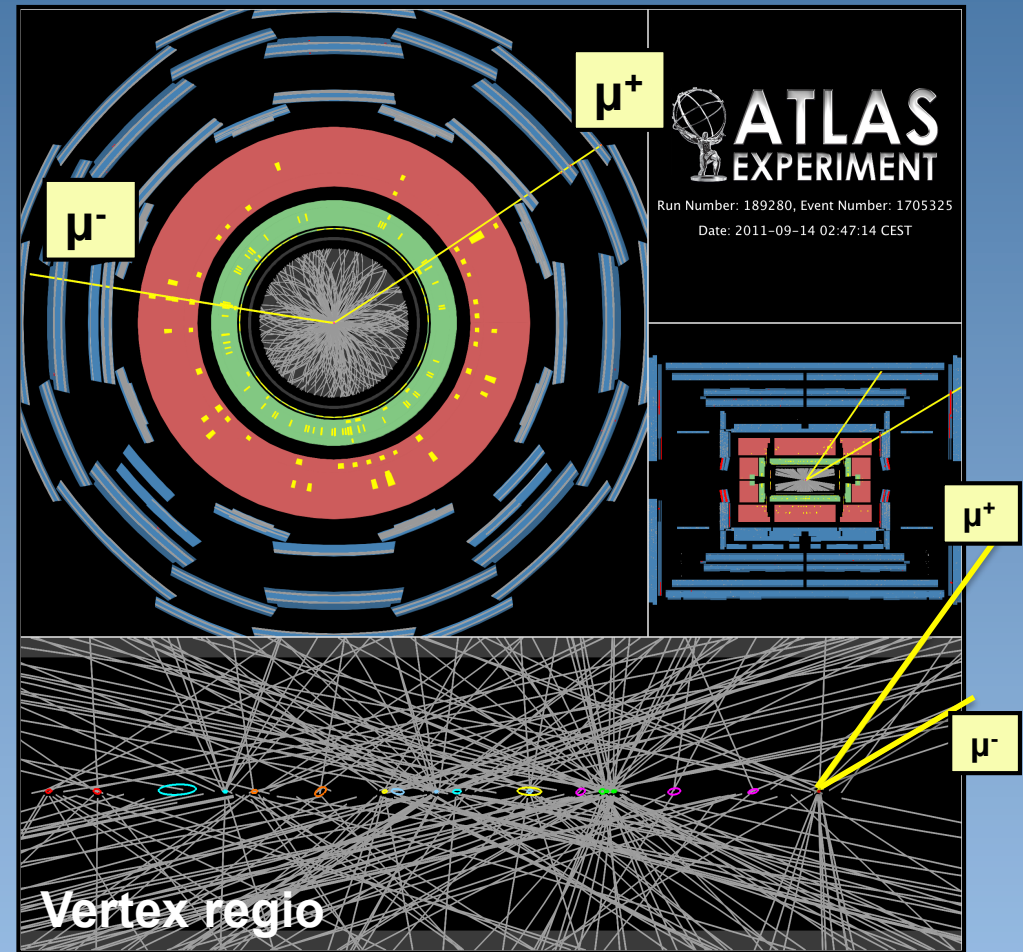


Uitdagingen: LHC is geen rustige omgeving

Aantal interacties per bundelkruising



$Z \rightarrow \mu^+ \mu^-$ botsing met 20 vertices



Als het Higgs boson bestaat:

1) Dan vervalt hij in 2 fotonen

- zie je meer 2-foton botsingen dan je verwacht ?
- zie je een piekje ?

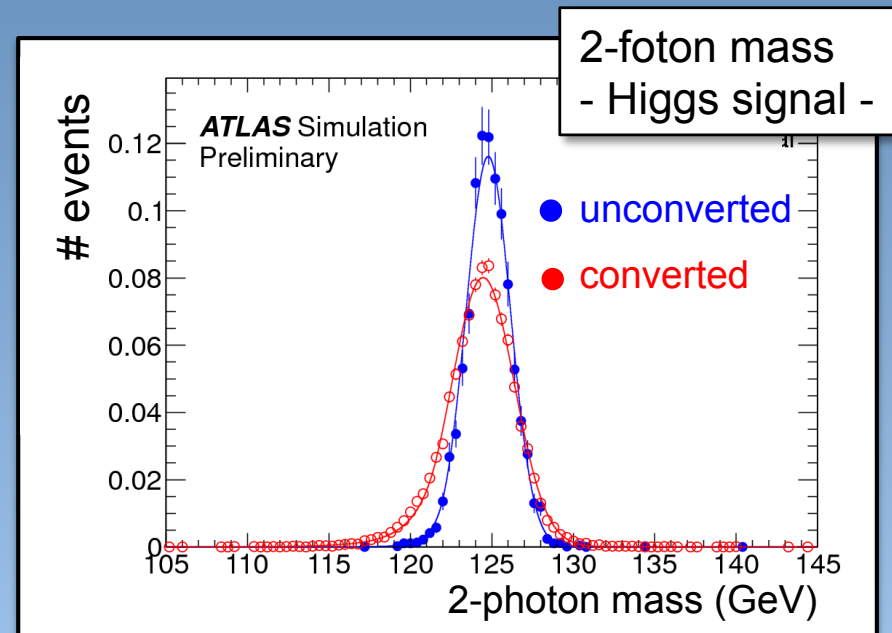
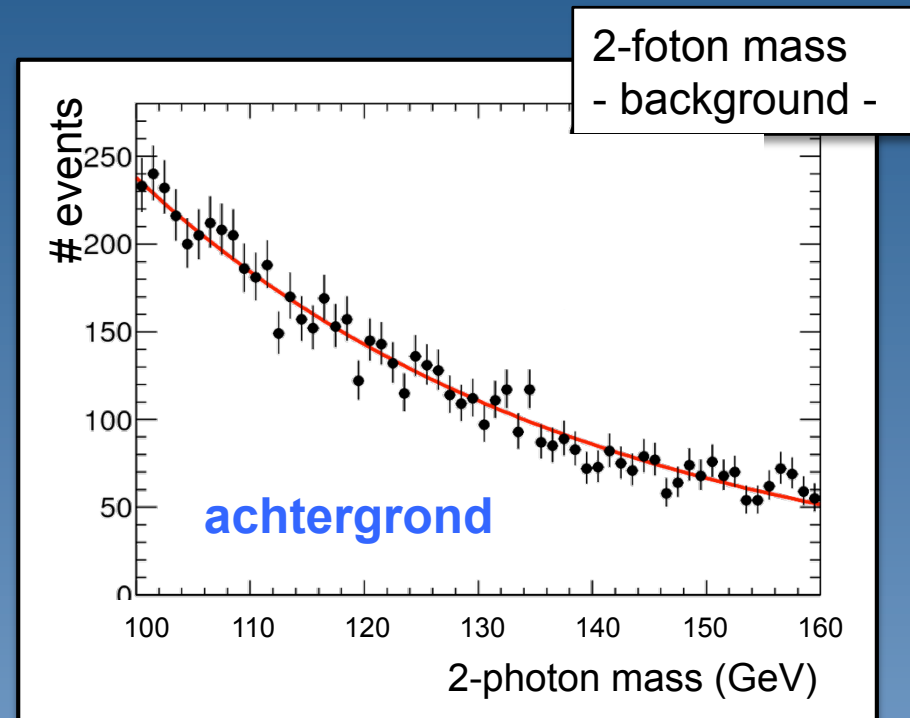
2-foton massa's

Higgs boson bestaat niet

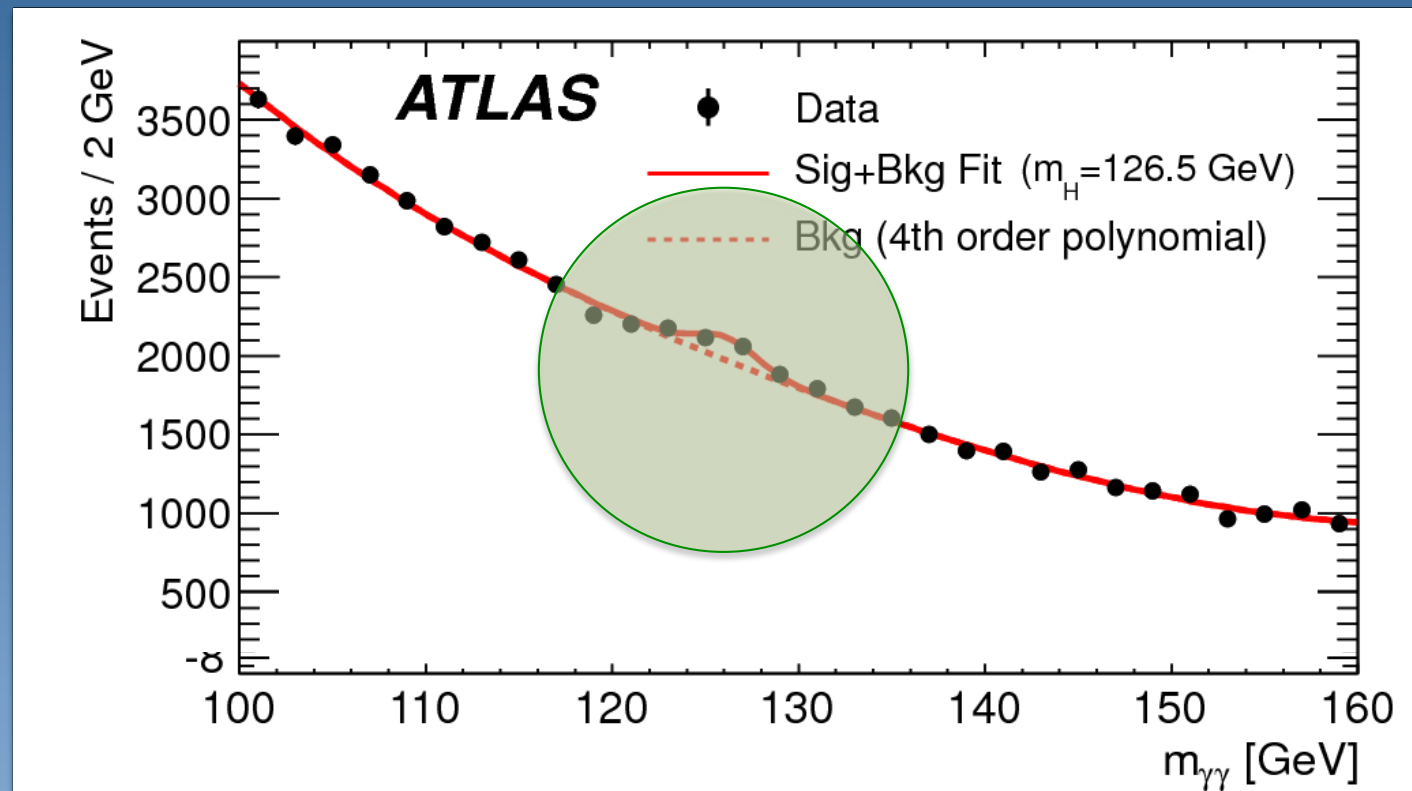
~ 60,000 events

Extra: Higgs boson ?

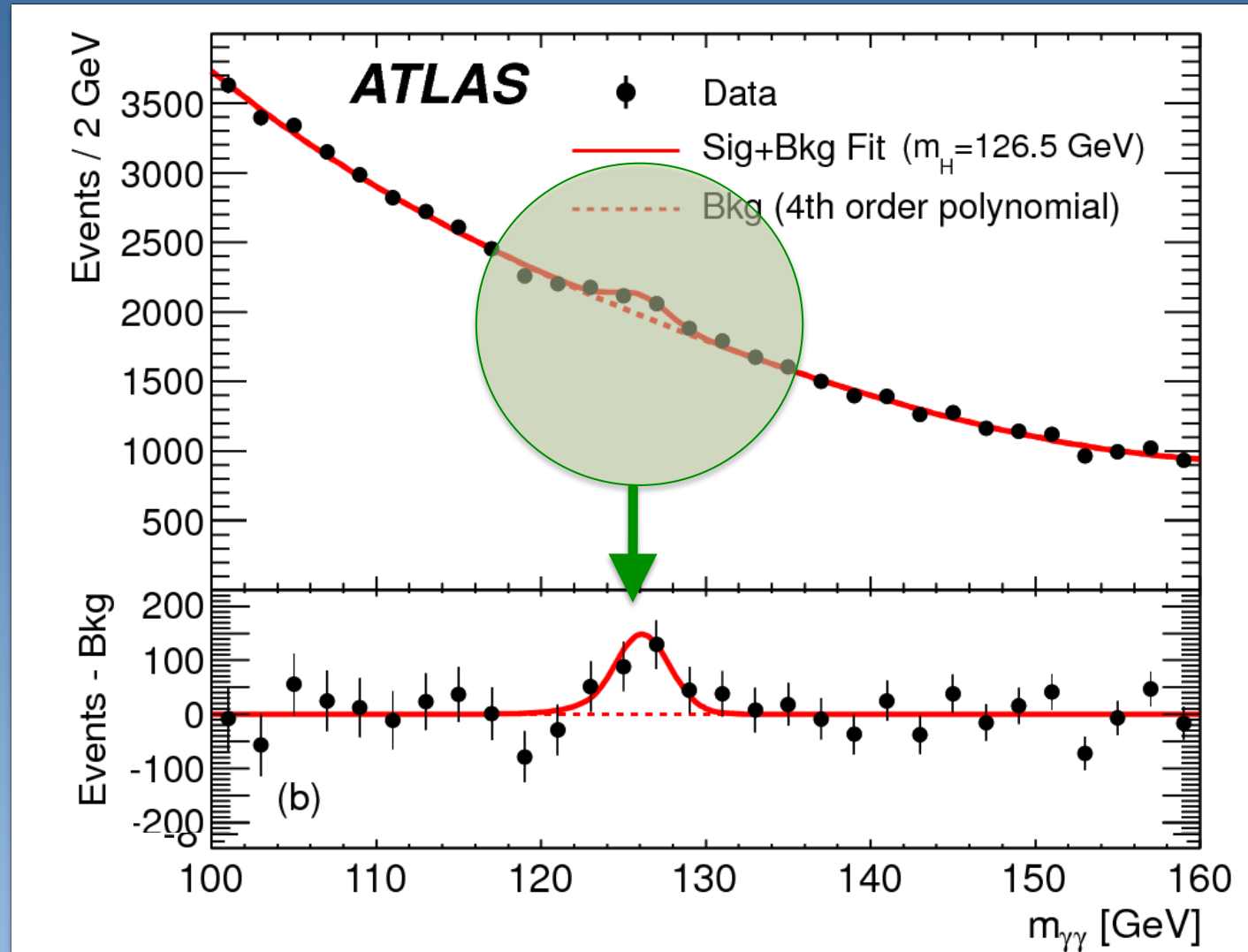
~ 200 events



De ATLAS data



De ATLAS data



Is dit toeval ? Quantificeer het overschot

Zoek naar meer bewijs



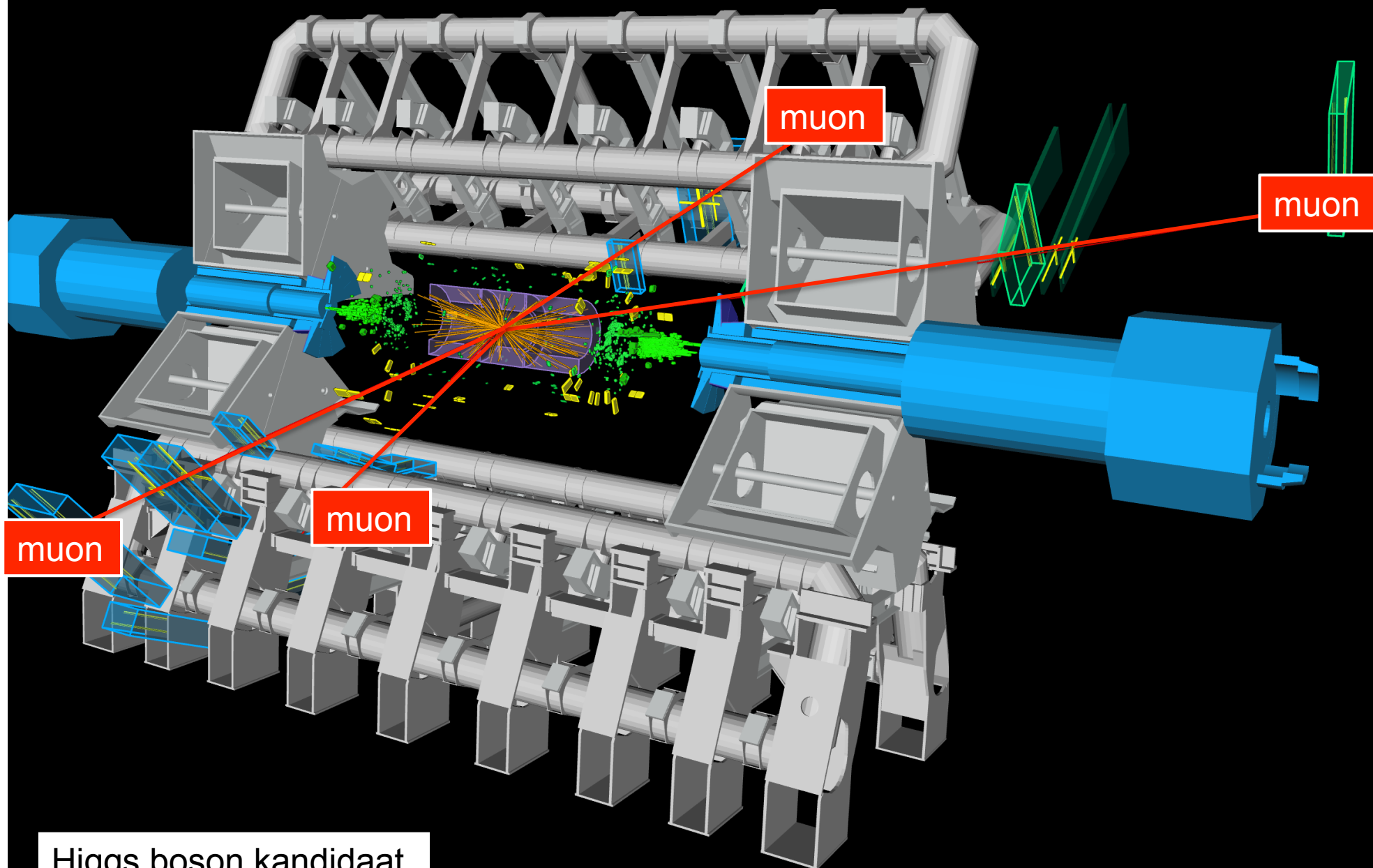
Als het Higgs boson bestaat:

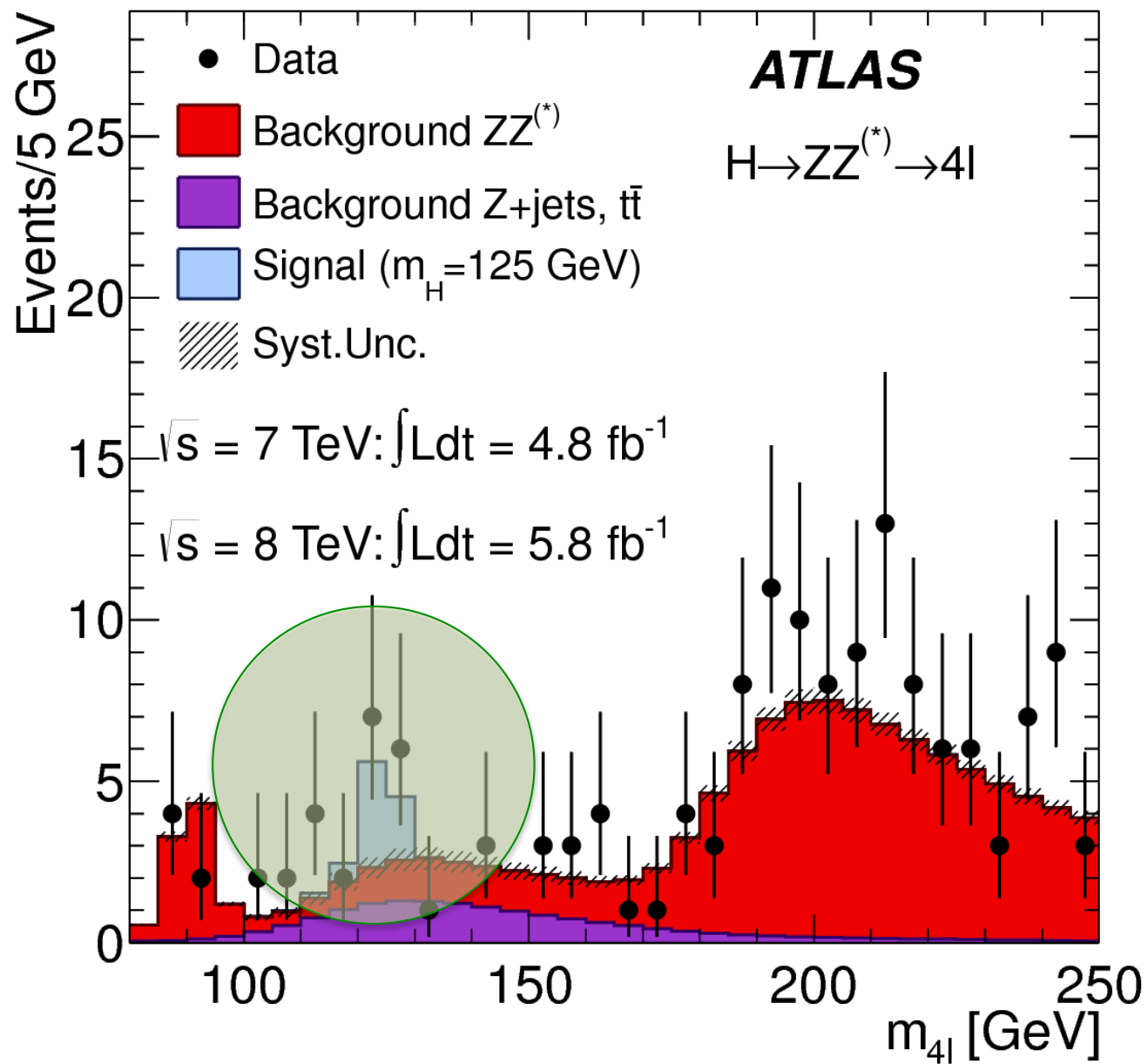
1) Dan vervalst hij in 2 fotonen

- zie je meer 2-foton botsingen dan je verwacht ?
- zie je een piekje ?

2) Dan vervalst hij ook in 4 muonen

- zie je meer 4-muon botsingen dan je verwacht ?
- zie je een piekje ?





Interpretatie overschot in ATLAS



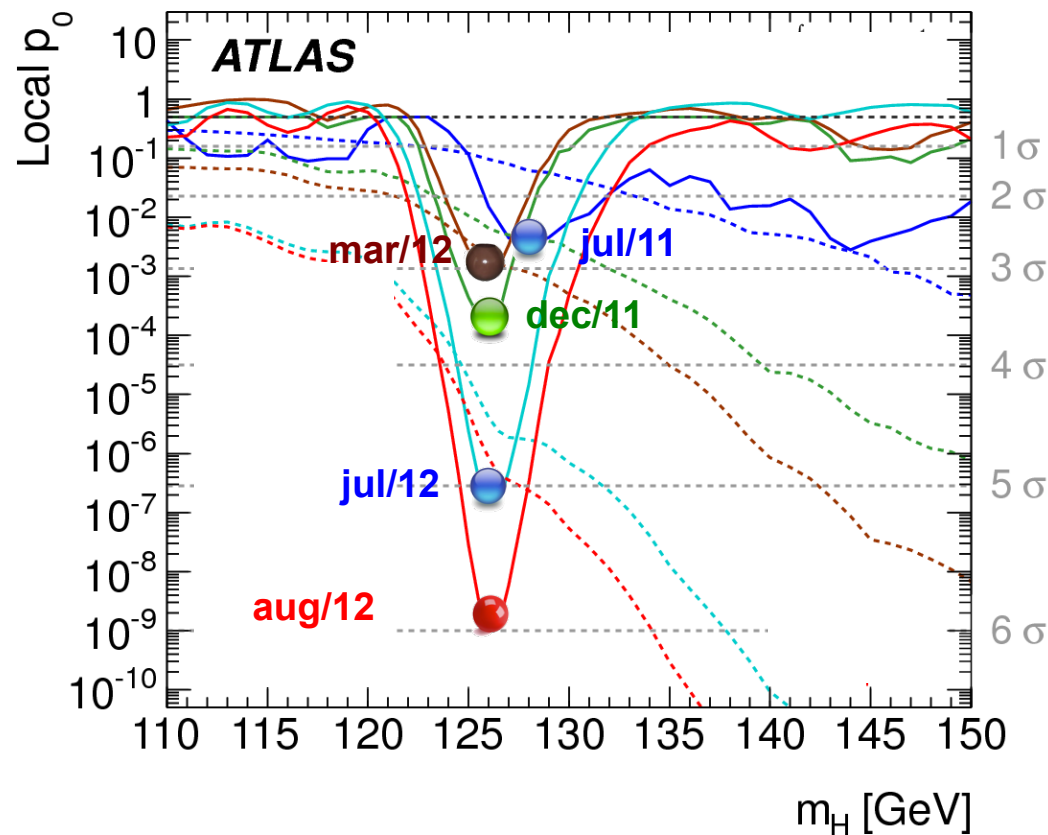
Claim pas ontdekking als:

Kans op toevallige fluctuatie zoals geobserveerd kleiner dan 1 op 1 miljoen

8 keer 6 gooien achter elkaar

Een ontdekking in slow-motion

Time-line higgs ontdekking



EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)



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

The ATLAS Collaboration

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

Abstract

A search for the Standard Model Higgs boson in proton-proton collisions with the ATLAS detector at the LHC is presented. The datasets used correspond to integrated luminosities of approximately 4.8 fb^{-1} collected at $\sqrt{s} = 7 \text{ TeV}$ in 2011 and 5.8 fb^{-1} at $\sqrt{s} = 8 \text{ TeV}$ in 2012. Individual searches in the channels $H \rightarrow ZZ^{(0)} \rightarrow 4\ell$, $H \rightarrow \gamma\gamma$ and $H \rightarrow WW^{(0)} \rightarrow \ell\nu\ell\nu$ in the 8 TeV data are combined with previously published results of searches for $H \rightarrow ZZ^{(0)} \rightarrow 4\ell$, $WW^{(0)} \rightarrow \ell\nu\ell\nu$, $b\bar{b}$ and $\tau^+\tau^-$ in the 7 TeV data and results from improved analyses of the $H \rightarrow ZZ^{(0)} \rightarrow 4\ell$ and $H \rightarrow \gamma\gamma$ channels in the 7 TeV data. Clear evidence for the production of a neutral boson with a measured mass of $126.0 \pm 0.4 (\text{stat}) \pm 0.4 (\text{syst}) \text{ GeV}$ is presented. This observation, which has a significance of 5.9 standard deviations, corresponding to a background fluctuation probability of 1.7×10^{-9} , is compatible with the production and decay of the Standard Model Higgs boson.

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L. Tolosomymya⁹⁸, A. Torit⁹⁹, R. Yoshida¹⁰⁰, C. Young¹⁰¹, S.P. Yousef¹⁰², D. Yu¹⁰³, J. Yu¹⁰⁴, L. Yuan^{105,106}, A. Yurkiewicz¹⁴⁸, V.G. Zales¹²⁸, R. Zaidan⁶³, A.M. Zaitsev¹²⁷, Z. Zajacova²⁰, Yo.K. Zalite¹²¹, L. Zanelli^{138,132b}, P. Zarzhitsky³⁰, A. Zaytsev¹⁰⁷, M. Zdranić¹⁴, C. Zeintnis¹⁷⁴, M. Zeller¹⁷⁵, P.F. Zemp²⁰, A. Zemla³⁸, C. Zendler³⁰, A.V. Zenin¹²⁸, O. Zenin¹²⁸, T. Ženis^{144a}, Z. Zenonos^{122a,122b}, S. Zeng¹⁴, D. Zerwas¹¹⁸, G. Zevi della Porta³⁷, Z. Zhang¹³⁴, H. Zhang³⁸, J. Zhang⁶, X. Zhang¹²⁴, Z. Zhang¹¹⁵, L. Zhao¹⁶², T. Zhao¹³⁸, Z. Zhao^{27b}, A. Zherchugov⁶⁵, S. Zheng³², J. Zhong^{151,a,b}, B. Zhou⁸⁷, N. Zhou⁶¹, Y. Zhou¹⁵¹, C.G. Zhu^{32d}, H. Zhu¹⁵¹, Y. Zhu^{12c}, X. Zhu³², F. Zhu³², J. Zuo⁶², Z. Zuo¹⁵¹, Z. Zuo¹⁵¹

H. Zhu¹, Y. Zhu², A. Zhuang³, V. Zhuraviov⁴, D. Zieminska⁵, B. Zuka^{6,7}, R. Zimmermann⁸,
S. Zimmermann²⁰, S. Zimmermann⁴⁸, M. Ziolkowski¹⁴¹, R. Zitoun⁴, I. Zivkovic²³⁴, V.V. Zmouchouk^{128,*},
G. Zobernig¹⁷², A. Zoccolì^{10a,10b}, Y. Zolnierowski⁴, A. Zsenni²⁹, M. zur Nedden¹⁵, V. Zutshi¹⁰⁶, I. Zwalinski²⁹.

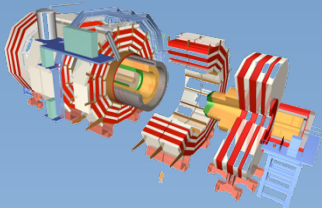
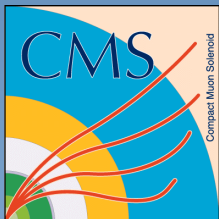
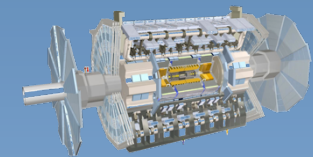
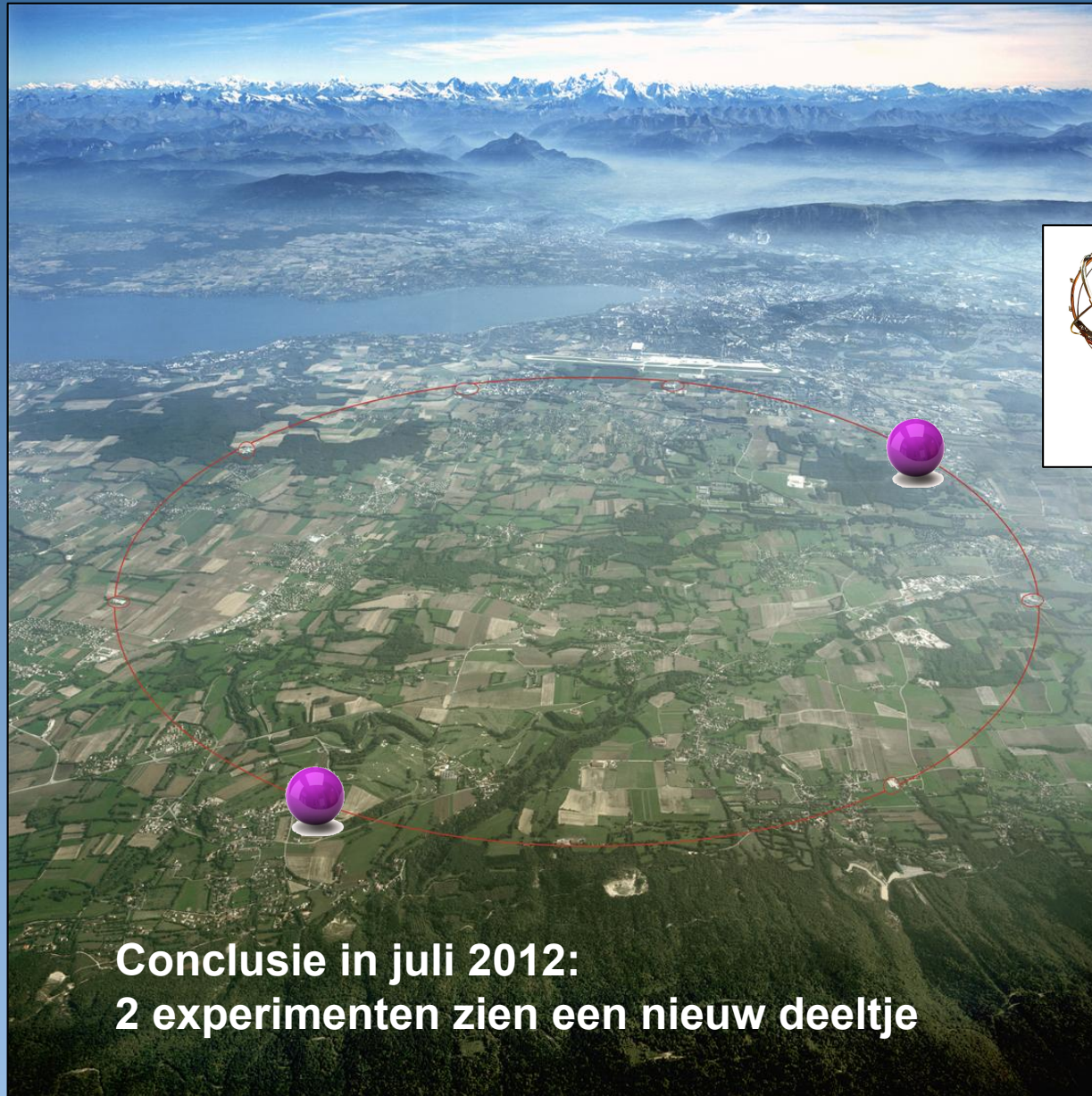
'Are you sure Ivo ?'

'Yes Diederik, we're pretty sure'

'Independent cross-check ?' 'Yep!'



We hebben 2 experimenten op CERN: ATLAS en CMS

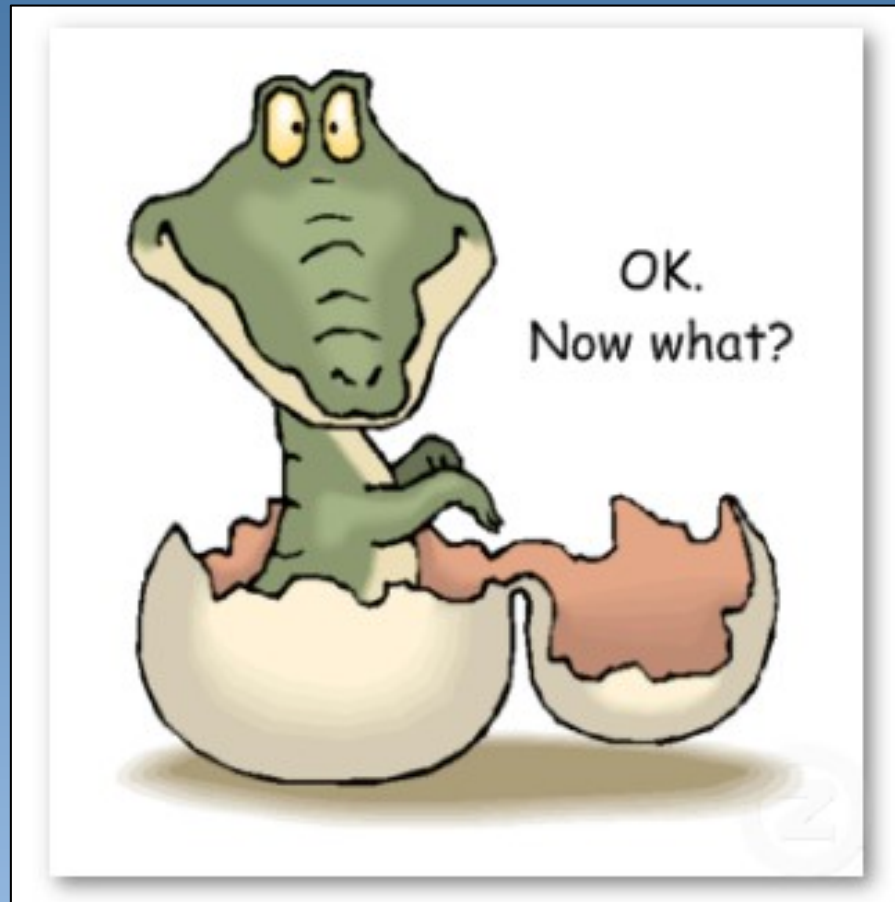


**Conclusie in juli 2012:
2 experimenten zien een nieuw deeltje**

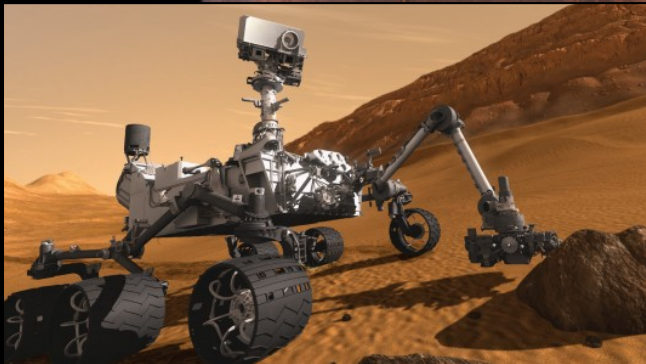
4 juli 2012: feest !!



5 juli 2012: wat nu ?



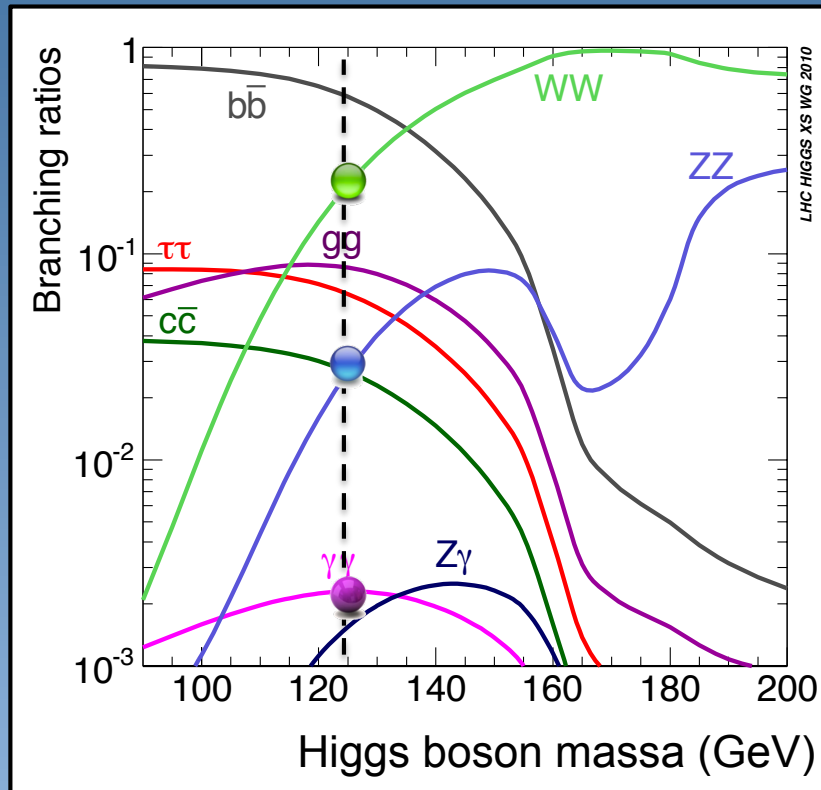
Als de marslander
leven vindt ...



... heb je 1000
nieuwe vragen

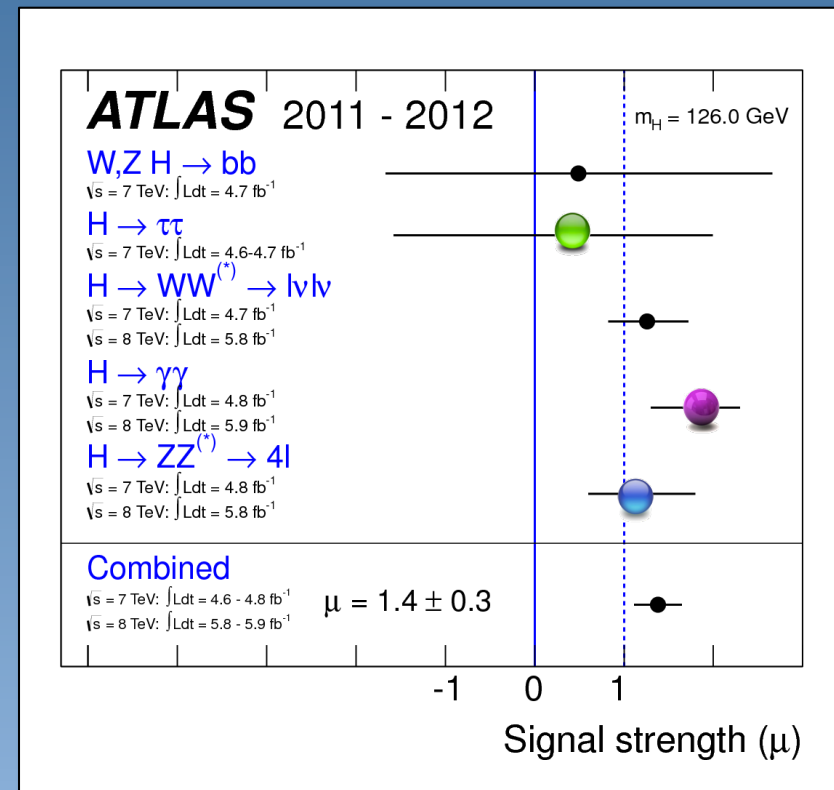
Kloppen Higgs' eigenschappen ?

$m_h = 125 \text{ GeV}$



voorspelling

Standaard Model



meting

Wat snappen we nog niet:



Paar 'kleine' dingetjes:

1

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

2

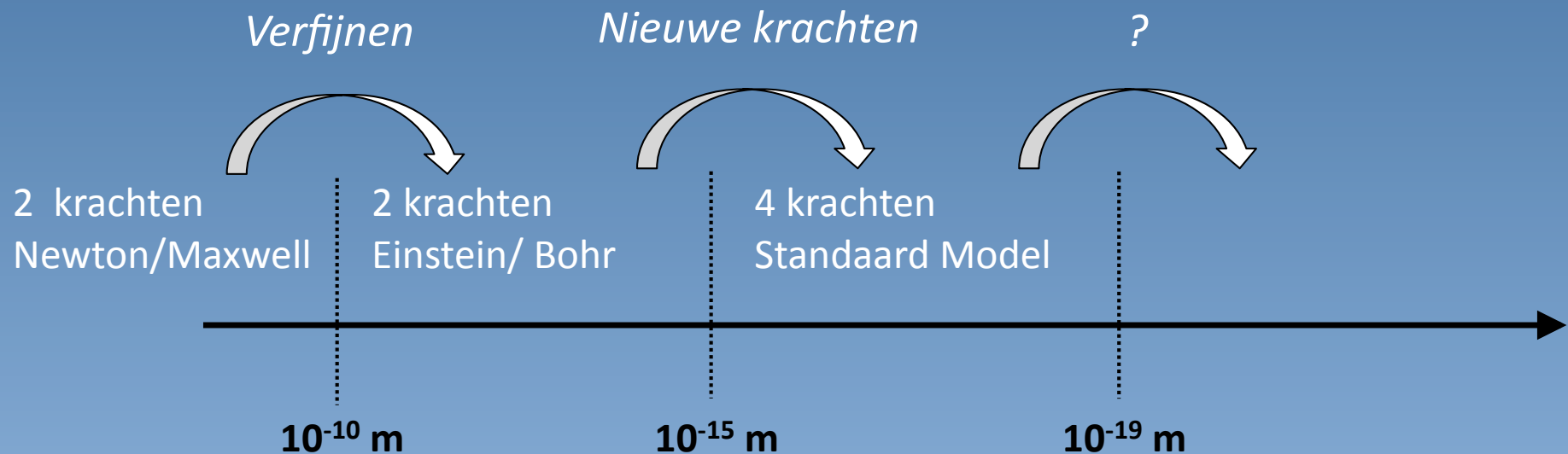
Waar is alle anti-materie gebleven ?

3

Higgs boson (hoe krijgen deeltjes massa) ?

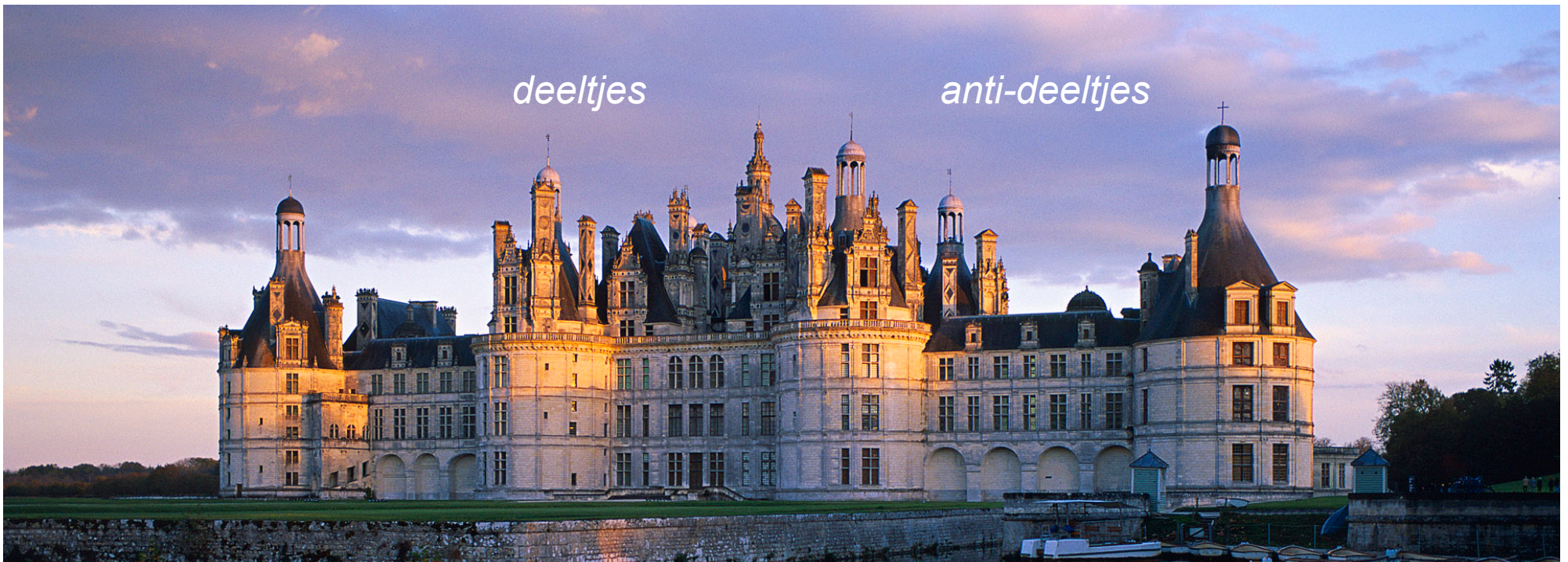
- waarom past gravitatie niet in SM, extra dimensies, waarom 3 families, fermionen fundamentele deeltjes, supersymmetrie, protonen stabiel, quantisatie elektrische lading, exploderende quantumcorrecties, kleine neutrino massa's, string theorie, ...

Nieuwe fenomenen, nieuwe krachten ??



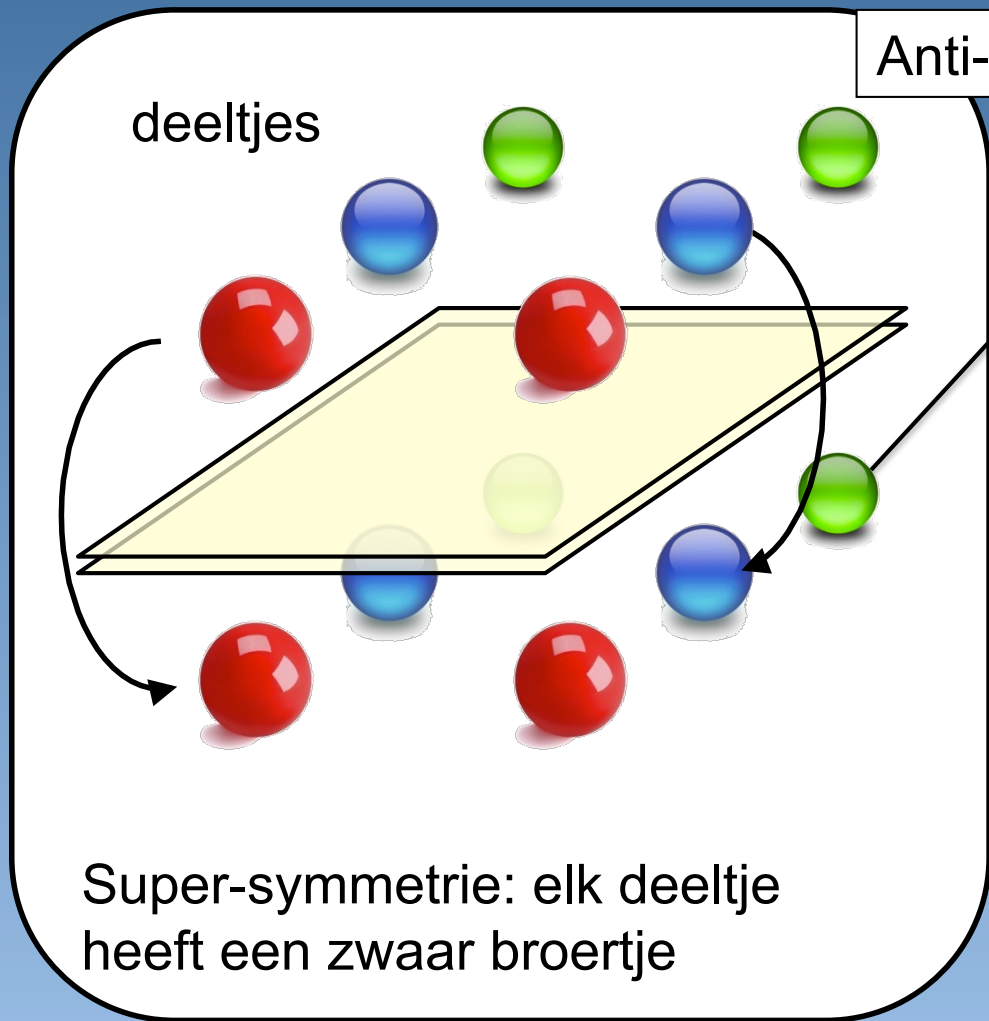
deeltjes

anti-deeltjes



Donkere Materie

Theoretisch idee: Supersymmetrie:

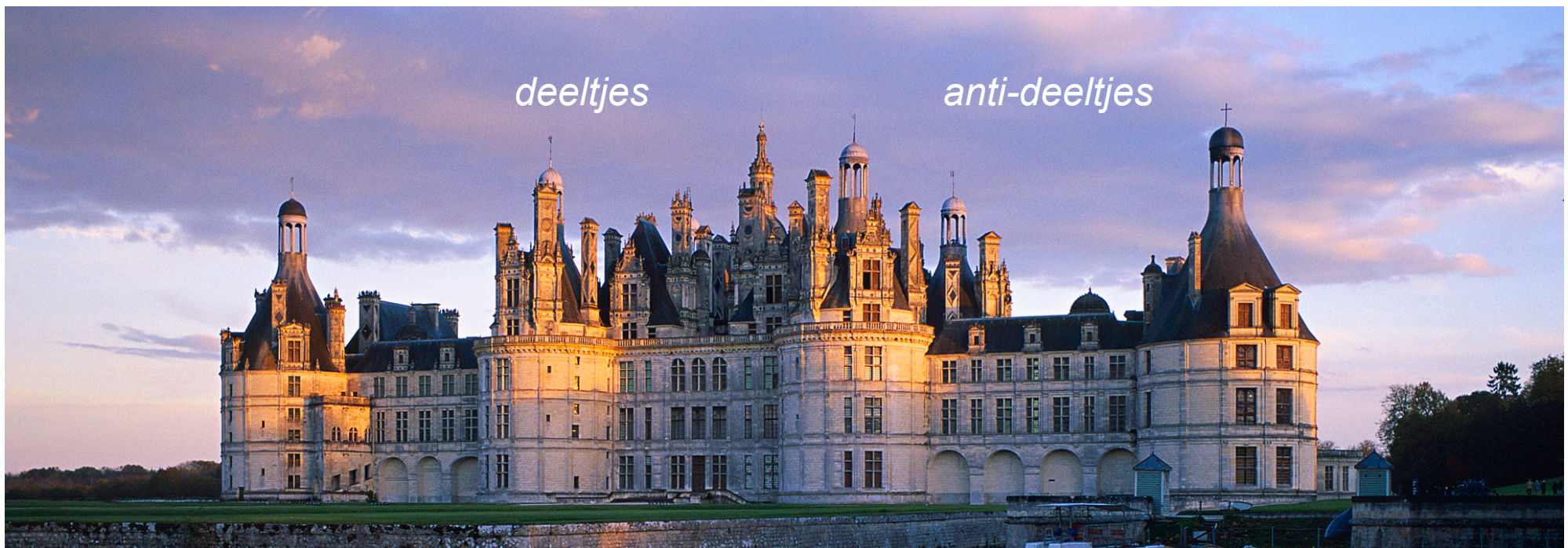


Lichtste = donkere materie ?

- Dit deeltje zelf produceren (**LHC**)
- Zoeken naar botsingen van deze deeltjes in de aarde (**Xenon**) ?
- Teken in heelal (**Fermi**)



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deeltjes

anti-deeltjes

Wat weten we *wel*:

De natuur zit vol vreemde spelregels

De LHC werkt!

Het Standaard Model werkt prima!

Hoe krijgen (kracht-) deeltjes massa

Wat weten we nog *niet*:

Waarom de spreiding in massa's ?

Waar is donkere materie van gemaakt ?

Waarom is gravitatie zo anders ?

Waar is alle anti-materie gebleven ?

Schitterend avontuur de komende jaren!