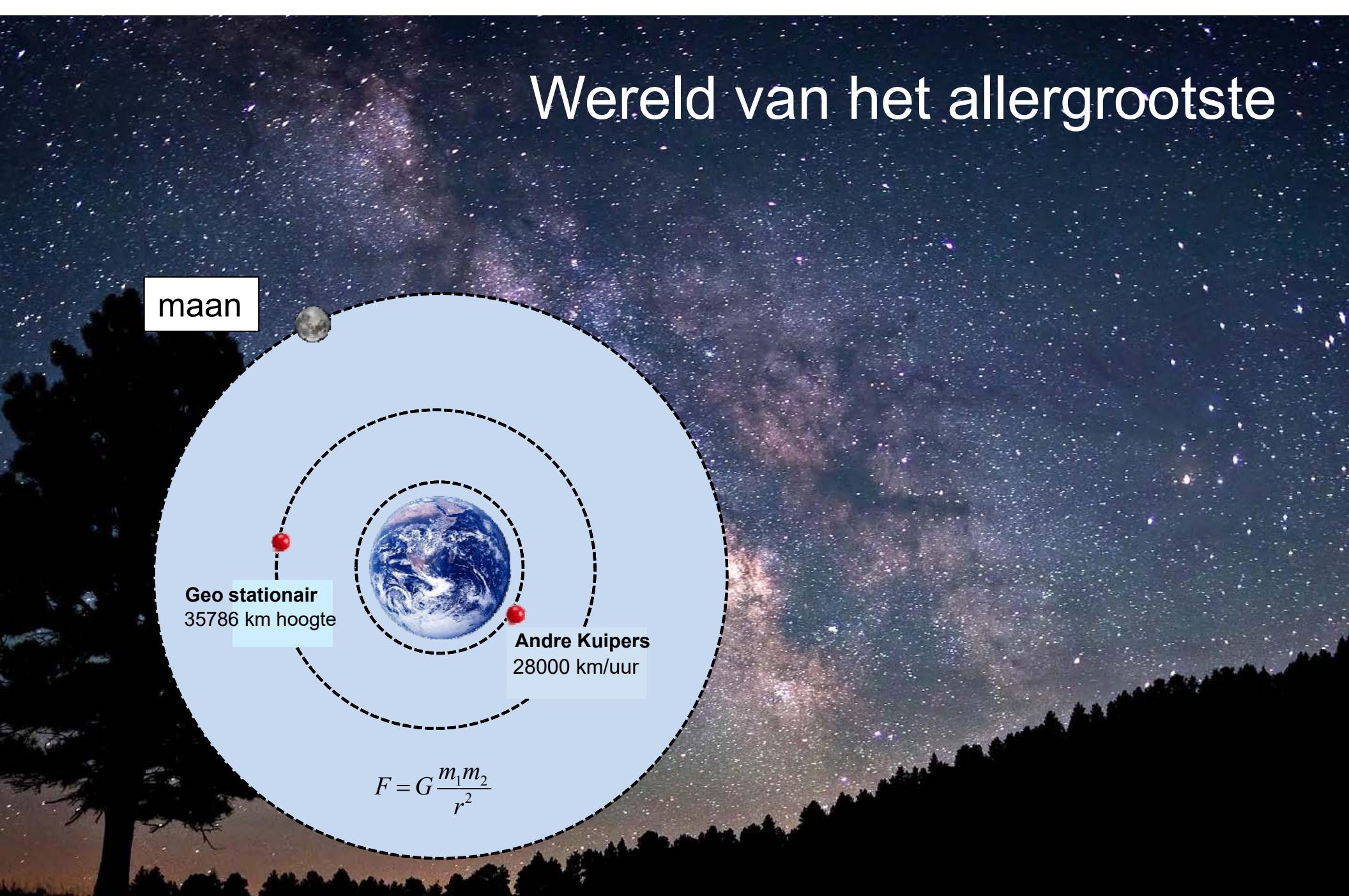


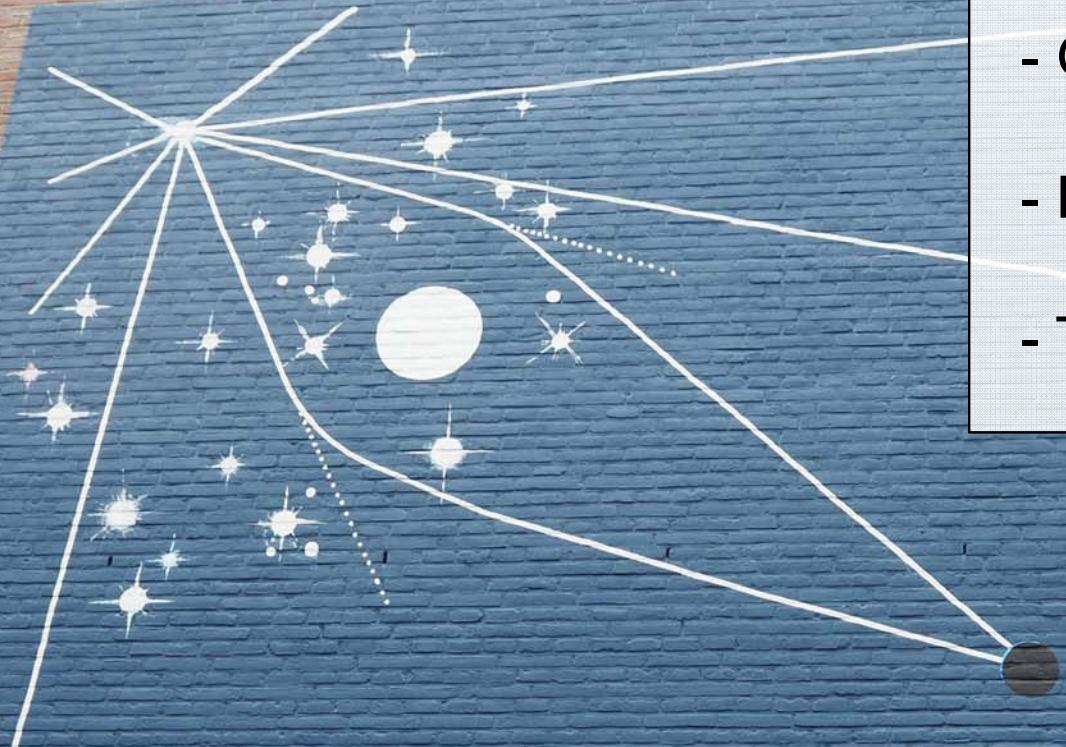
De magische wereld van het allerkleinste



Wereld van het allergrootste



- Gekromde ruimte-tijd
- $E=mc^2$, zwarte gaten, ...
- Tijd kan uitrekken (GPS)



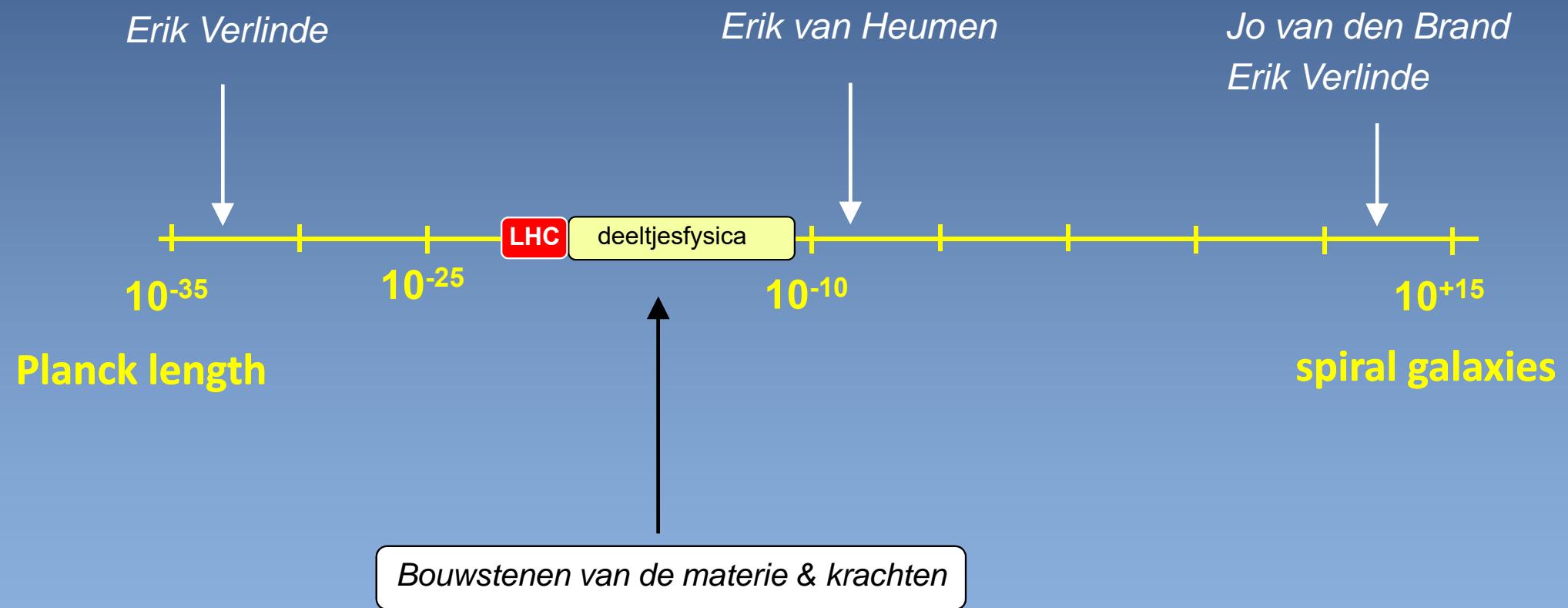
$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

ALBERT EINSTEIN (1879-1955) 

het toneel

de acteurs

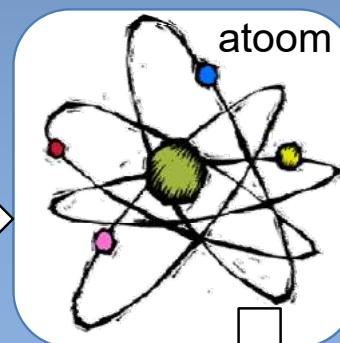
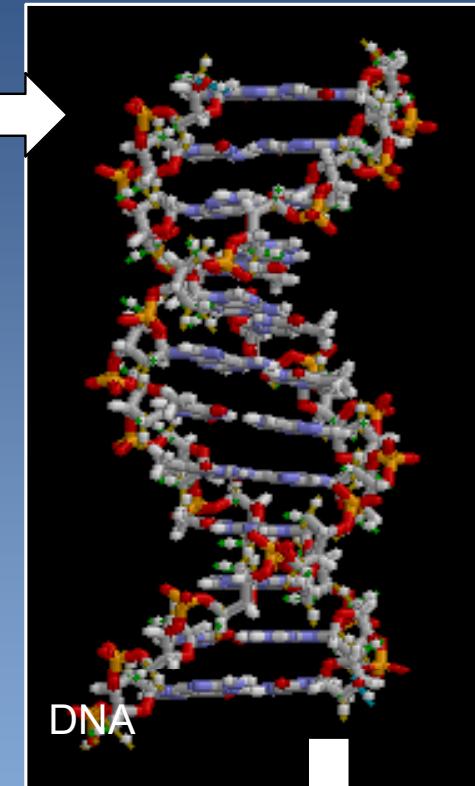
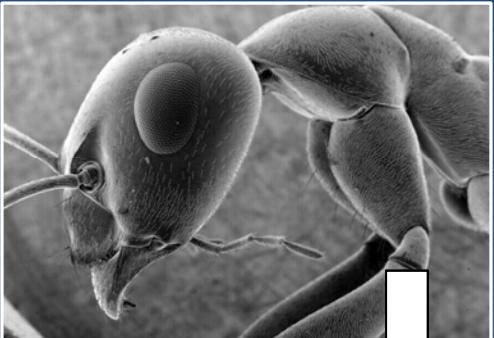
Afstandsschalen in de natuur



CERN in Genève, Zwitserland



Zoektocht naar de elementaire bouwstenen van de natuur



de wereld van de quantummechanica



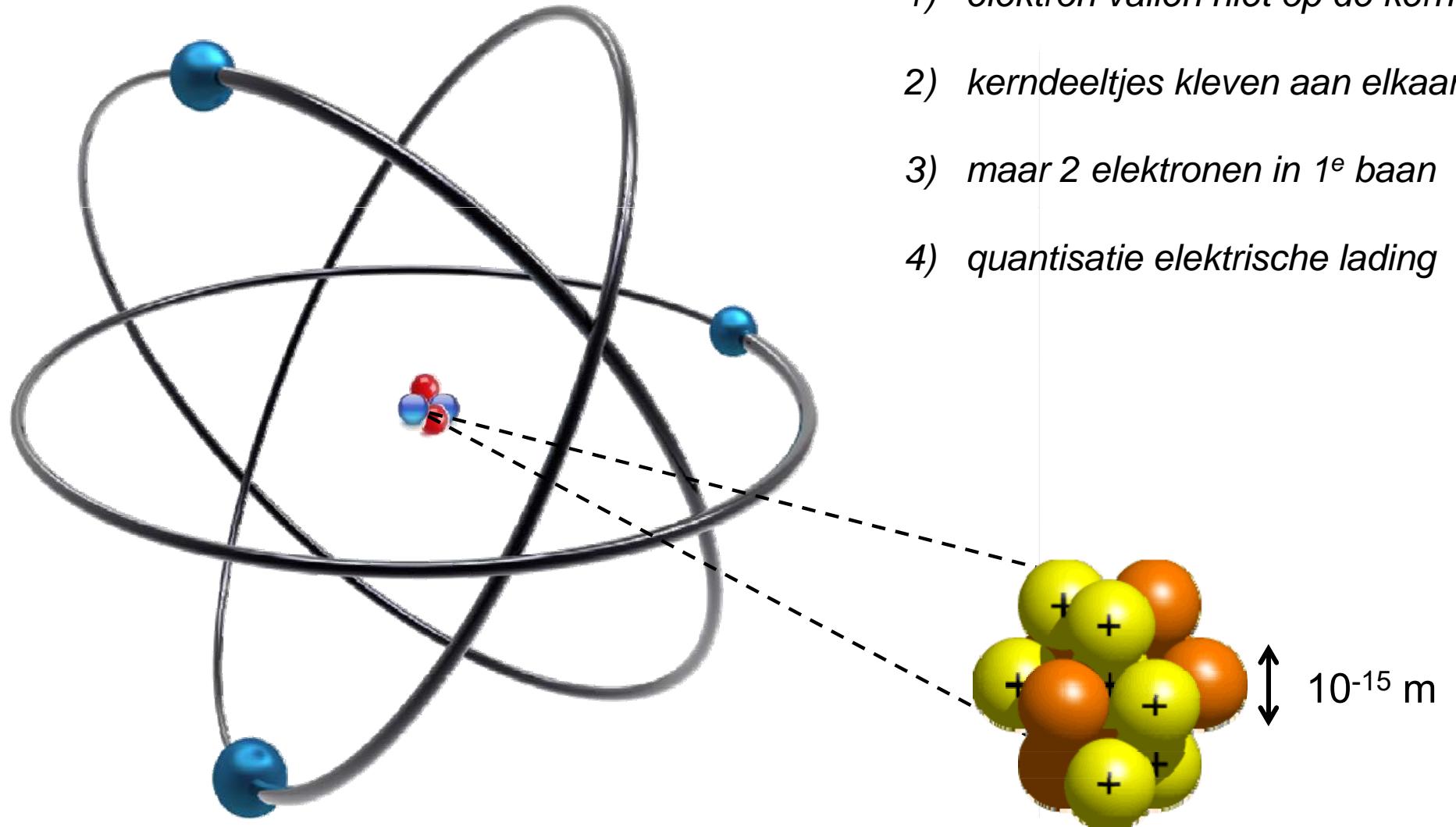
atoomkern

Wereldrecord: 10^{-20} [m]

kleiner en kleiner

Waarom, ... waarom, ... waarom ?

De wereld van het atoom



- 1) elektron vallen niet op de kern
- 2) kerndeeltjes kleven aan elkaar
- 3) maar 2 elektronen in 1^e baan
- 4) quantisatie elektrische lading

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



HALF JULI IS HET ZOVER. NA DRIE WEKEN METEN STAAT VAST DAT DE QUANTUMDEELTJES ELKAAR OP KILOMETERS AFSTAND VOelen, SNELLER DAN HET LICHT.

Standaard Model

The Standard Model

Elementary particles

up-quark



down-quark



elektron



neutrino



Interactions

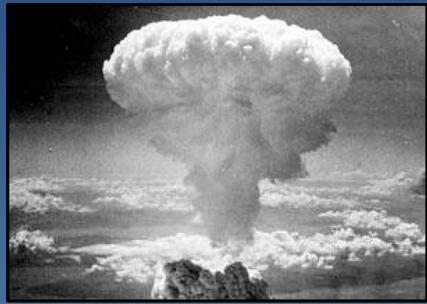
$$\begin{aligned} \mathcal{L} = & -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} \\ & + i \bar{\psi} \not{D} \psi + h.c. \\ & + Y_1 Y_2 Y_3 \phi + h.c \\ & + |\not{D}_\mu \phi|^2 - V(\phi) \end{aligned}$$

3 forces: 12 gauge bosons

muon

Standaard Model raar ? Gerri Eickhof, ... die is pas raar

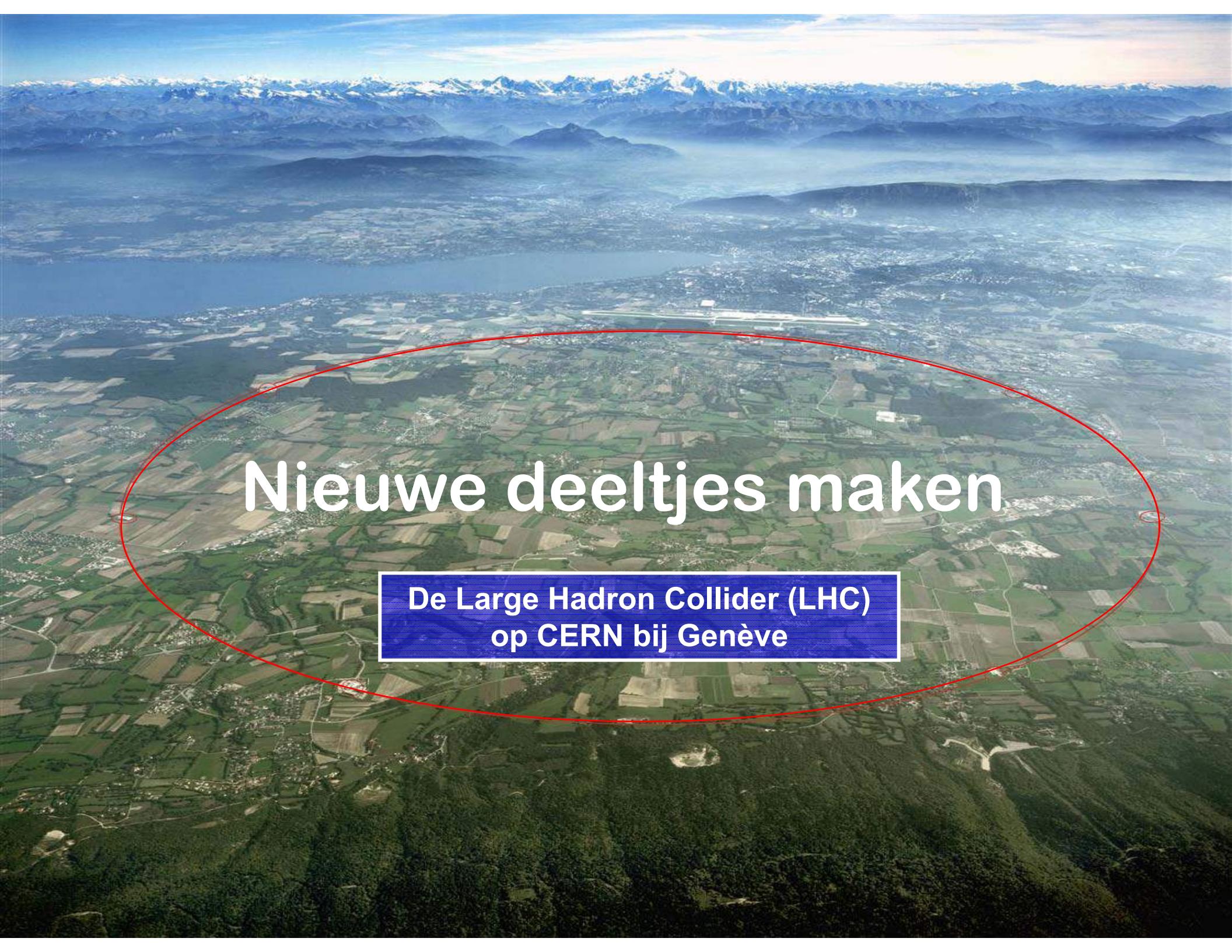




$$E = mc^2$$

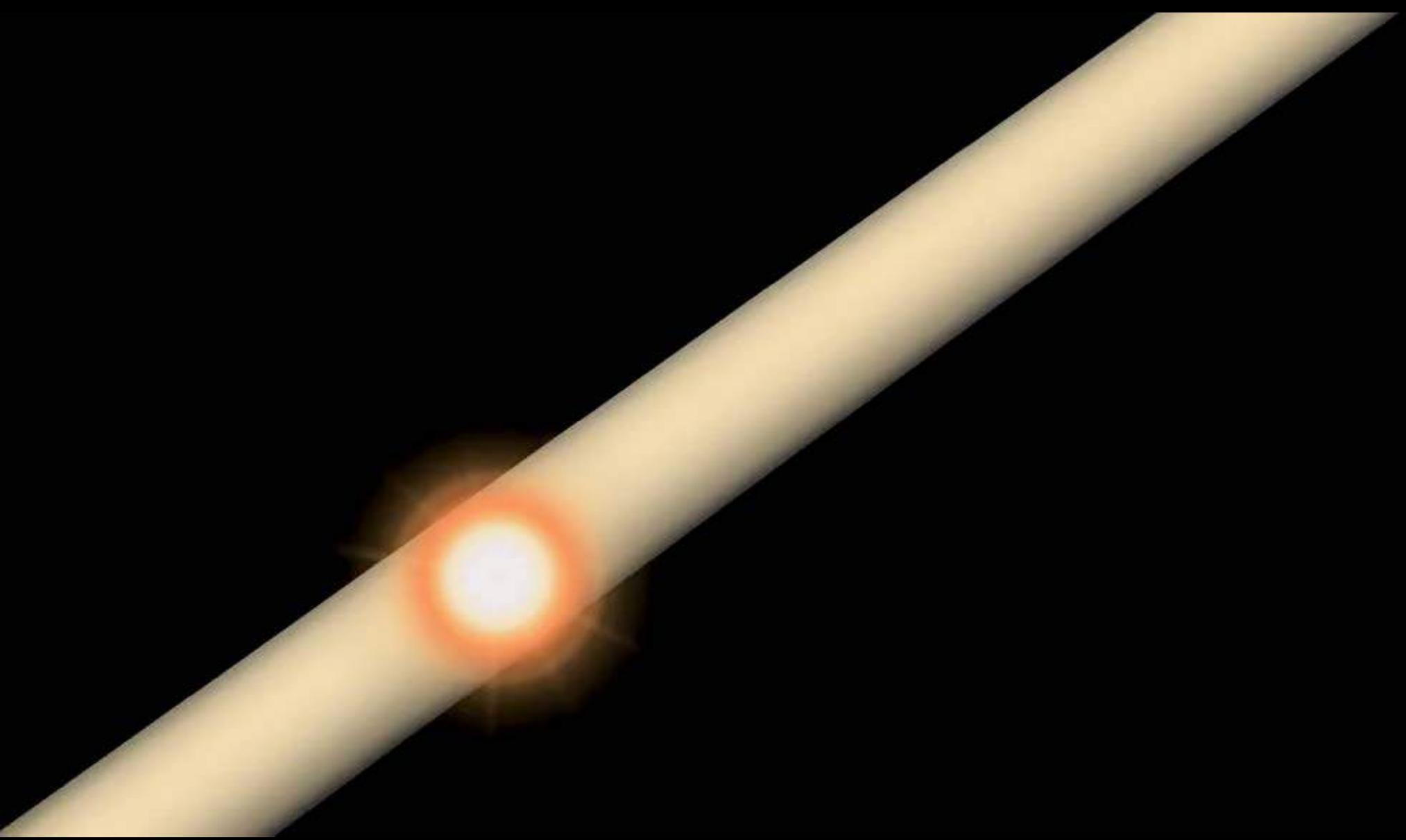
The equation $E = mc^2$ is centered within a large blue circle. A thick white curved arrow forms a loop around the circle, starting at the top left, going clockwise, and ending at the bottom right. The arrow is positioned such that it appears to be moving around the central equation.

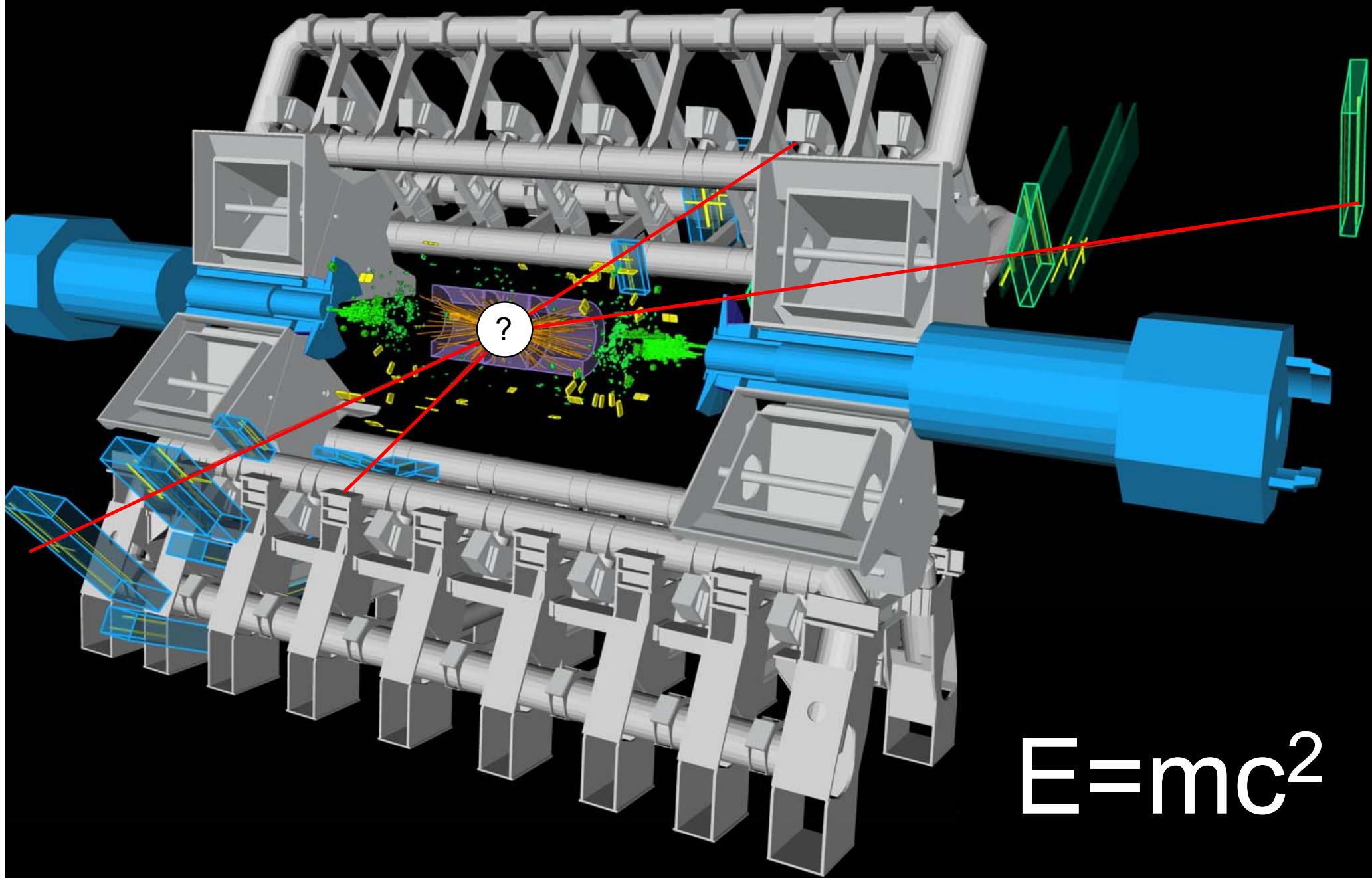




Nieuwe deeltjes maken

De Large Hadron Collider (LHC)
op CERN bij Genève



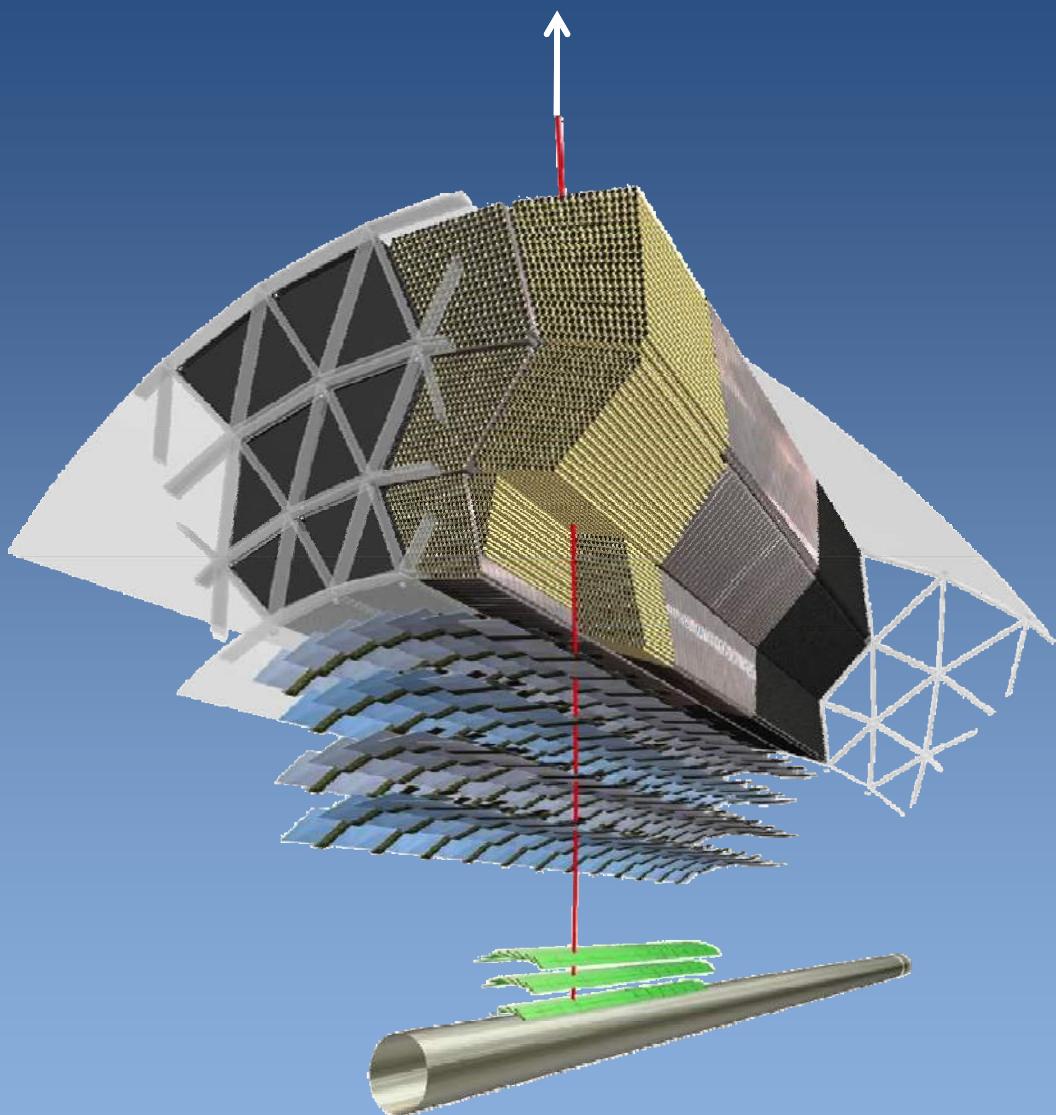


$$E=mc^2$$

lets reconstrueren uit overblijfselen



muon of electron ?

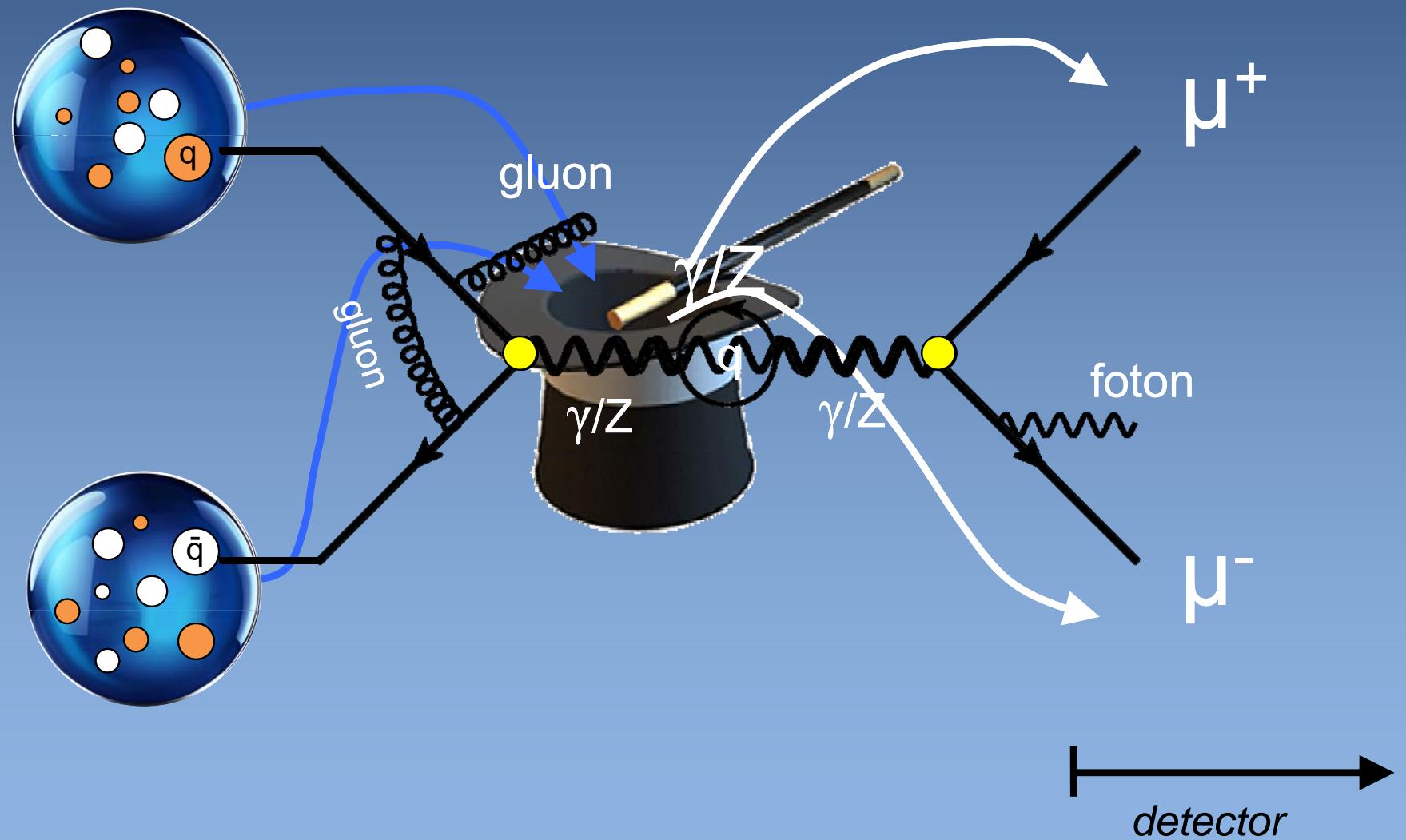


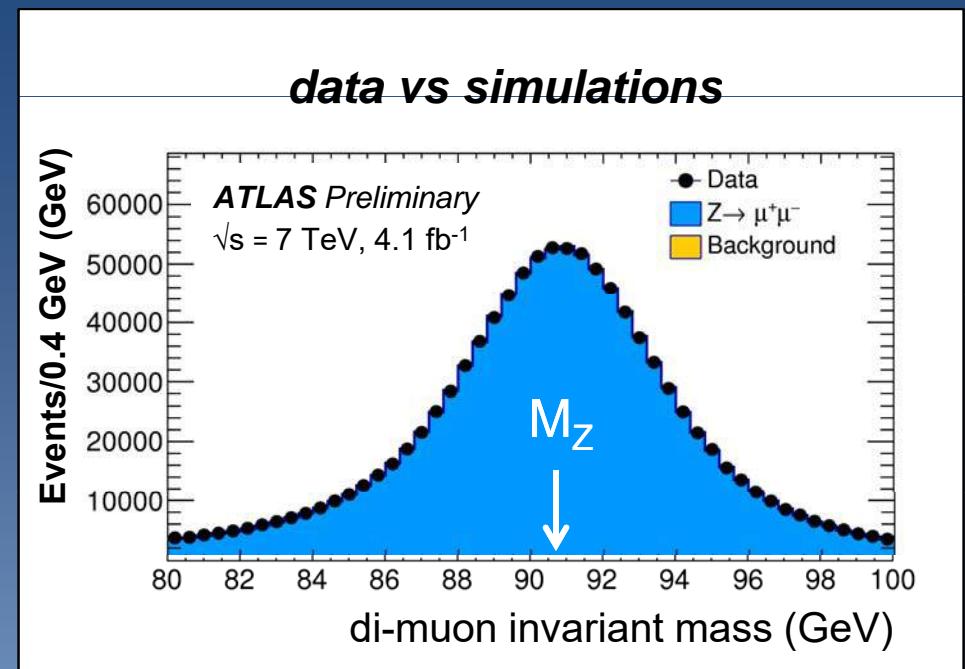
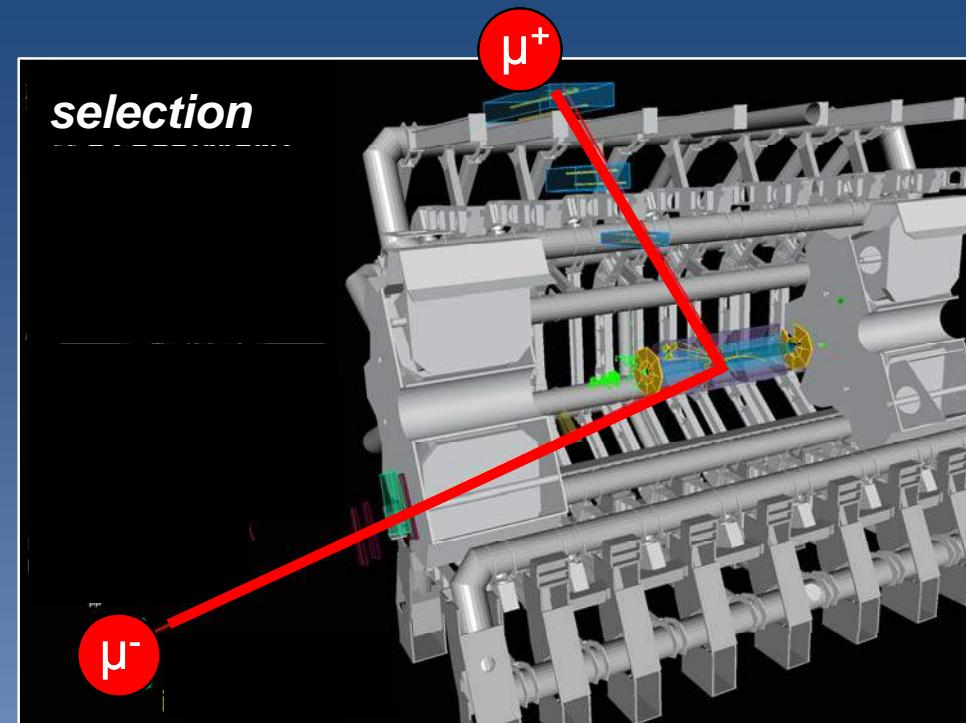
Identificatie

konijn of mens ?

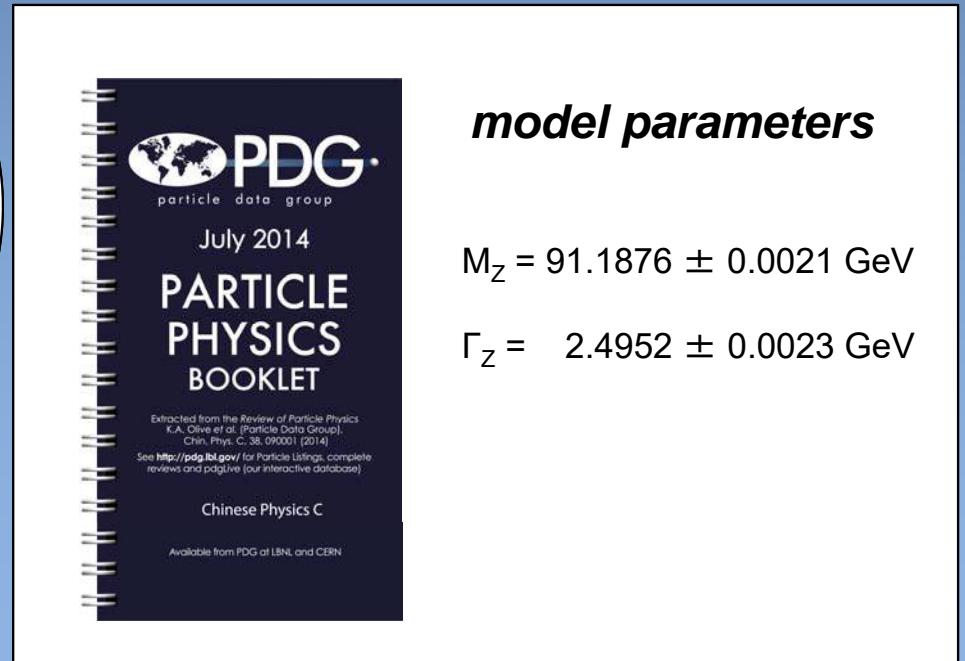


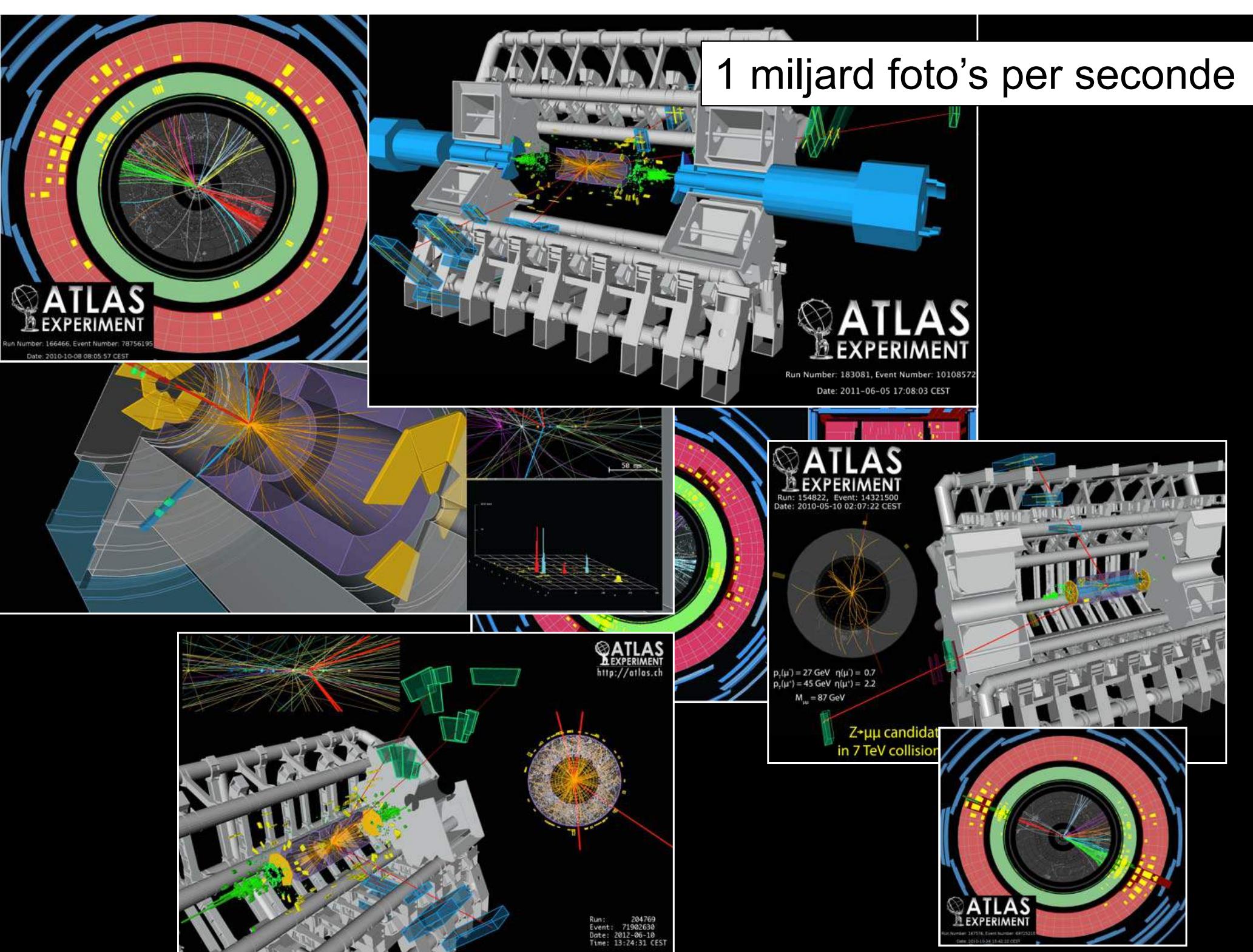
Transitions in the Standard Model





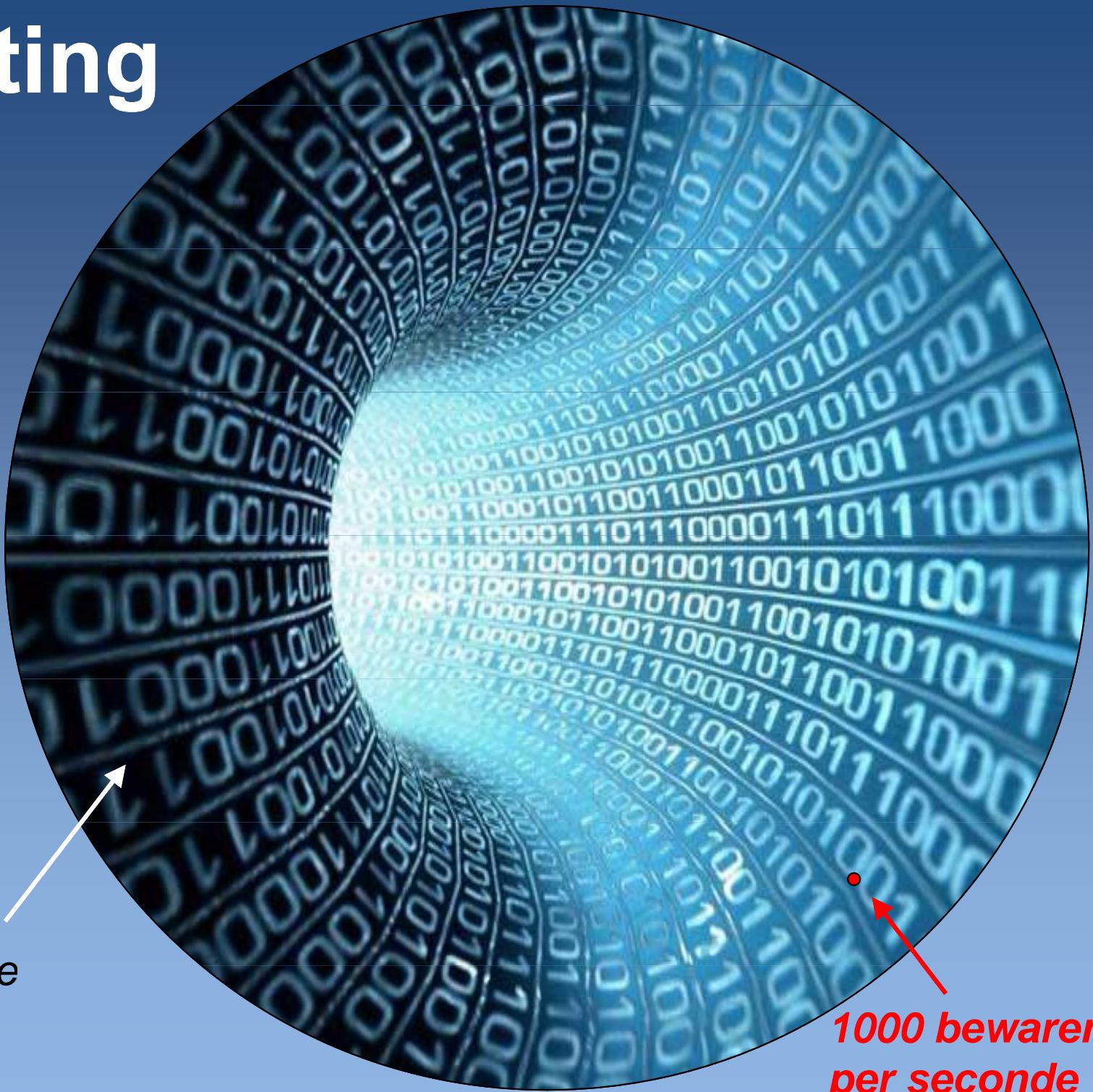
Heavy particle production:
the Z-boson





computing

1.000.000.000
foto's per seconde

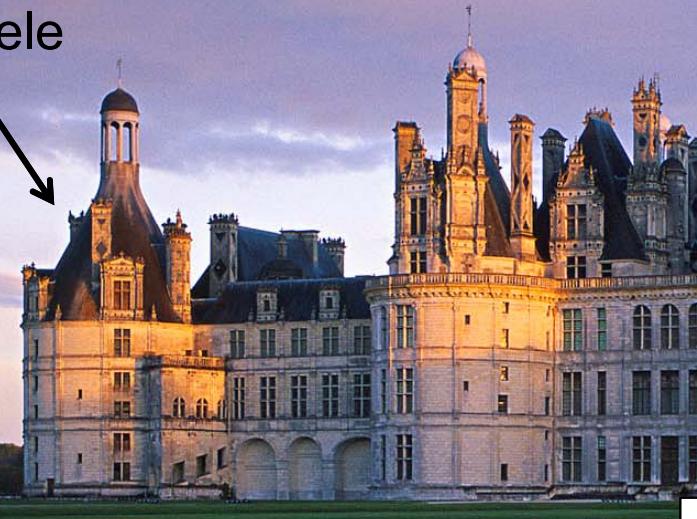


1000 bewaren
per seconde

Higgs boson

deeltjes

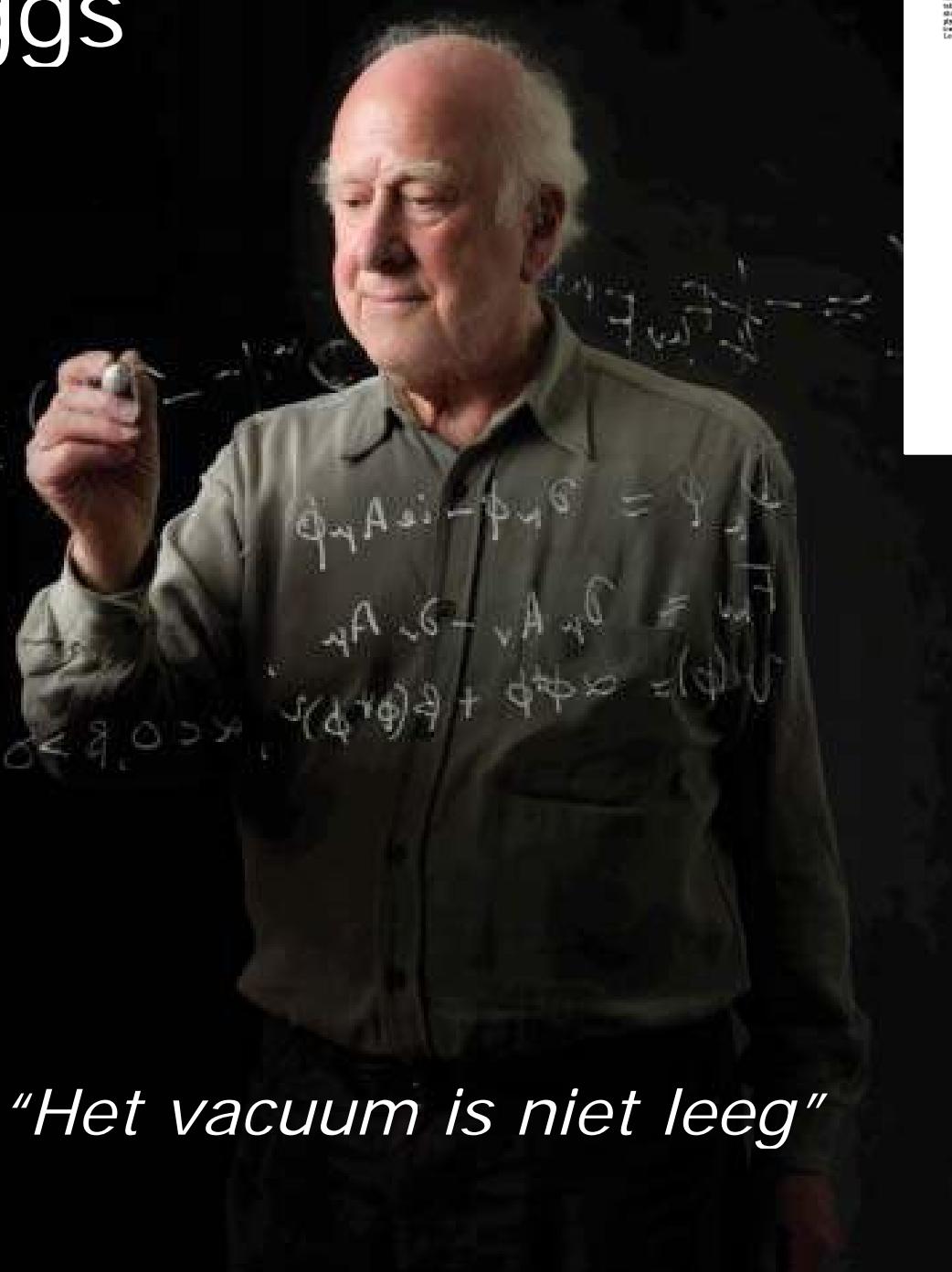
de stabiele
wereld



Het Standaard Model



Peter Higgs



"Het vacuum is niet leeg"

BRUNO SYMMETRIES, MASSLESS PARTICLES AND GAUGE FIELDS

P. M. HOGG

Institute of Mathematics and Physics, University of Edinburgh, Edinburgh, UK

Received 22 July 1984

Recently a number of people have discussed the Goldstone theorem^{2,3,4} that any solution of a classical field theory which is invariant under a global symmetry operation of that theory must admit a massless scalar particle. Klein and Lee⁵ showed that this theorem does not hold if the symmetry is not relativistic and ones might suggest that their considerations would apply equally well to Lorentz-invariant field theories. Gell-Mann⁶ has

given, a good case that the failure of the Goldstone theorem is the inevitable consequence of a type of gauge symmetry which cannot be imposed on a theory. The purpose of this note is to show that Gell-Mann's argument fails for an important class of theories, namely those in which the conserved currents are coupled to gauge fields.

Following the procedure used by Gell-Mann, we consider a theory of two fermions similar to his

VOLUME 12, NUMBER 2

NOTICE LETTERS

15 December 1984

$\psi_1(x) = \psi_1(x) + \epsilon \psi_2(x)$
 where $\psi_1(x)$ is unchanged under the gauge transformation

$$x^{\mu} \rightarrow x^{\mu} + \epsilon x^{\mu} \partial_{\nu} A^{\nu}, \quad (1)$$

$$\partial_{\mu} \psi_1(x) = \partial_{\mu} \psi_1(x) + \epsilon \partial_{\mu} \psi_2(x).$$

Then there is a conserved current j_{μ} such that

$$\{j_{\mu}^{\mu}(x), \psi_1(x)\} = \psi_1(x). \quad (2)$$

We assume that the Lagrangian is such that symmetries of the theory are not broken by the renormalization procedure so that e.g. Goldstone's theorem is guaranteed by showing that the Fourier components of $\langle j_{\mu}^{\mu}(x), \psi_1(x) \rangle$ are zero. Let $A_{\mu}(k)$ be the momentum, $a_{\mu}(k)$ the wavefunction and $\epsilon_{\mu}(k)$ the wavefunction of the gauge boson, the conservation law and eq. (2) give

$$\partial_{\mu} \epsilon_{\mu}(k) = \epsilon(k) \delta_{\mu\nu} \partial_{\nu} A_{\mu}(k), \quad (3)$$

whereas the equation of motion for the gauge bosons of this theory (obtained by varying the action) gives

$$F_{\mu\nu}(k) = \partial_{\mu} A_{\nu}(k) - \partial_{\nu} A_{\mu}(k) + \epsilon_{\mu\nu} C(k), \quad (4)$$

where $C(k)$ may be taken as 0, 1, 2, 3, ..., 50. This gives a set of coupled linear frame equations for the gauge fields and the renormalized theory is 1D in the limit of large k .

$$E(k) = \frac{1}{2} k^2 F_{\mu\nu}(k) + \epsilon(k) \partial_{\mu} A_{\mu}(k), \quad (5)$$

$$C(k) = \delta(k).$$

It turns out that $E(k) = 0$ for all values of $\epsilon(k)$ except $\epsilon(k) = \epsilon_0(k)$. Thus the Goldstone theorem fails if $\epsilon(k) = 0$, while in principle it holds if $\epsilon(k) \neq 0$. It is interesting to note that such a localised conserved vector j_{μ} appears to rule out the possibility of a massless scalar.

There is however a class of relativistic theories which do not have a conserved current part. This is the case of gauge theories where an auxiliary field (the vector ϵ_{μ}) must be intro-

duced in order to define a radiation gauge in which the gauge bosons have well defined masses. In this case the Goldstone theorem does not hold, as has been shown by Gell-Mann and Low⁷ and by others. We know of the simplest such theory, namely electrodynamics. There seems to be no reason why the same result should not hold for the more general transverse vector representations.

It is also interesting to observe that the conservation law holds at the strong sense, as a consequence of field equations of the form

$$j^{\mu} = \delta_{\mu} A_{\nu} - \delta_{\nu} A_{\mu}.$$

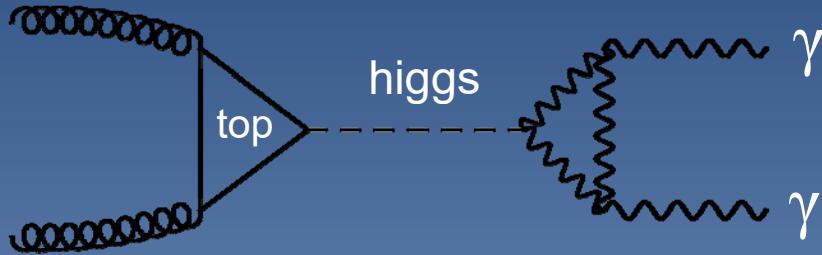
Except in the case of the transverse vectors, the fields $A_{\mu}(x)$, $\epsilon_{\mu}(x)$ are not simply the gauge field variables, but are the components of a more complex field containing all the structure constants of the group on each site. Now the structure of the theory is such that the equations of motion give us eq. (3). Applying eq. (5) to this configuration we find that the equations of motion reduce to $\{0,0\} = 0$, which is the same as $\{A_{\mu}, A_{\nu}\} = 0$ for the transverse vectors. We have therefore obtained Goldstone's theorem for the transverse vectors and the "spurious" state ($\delta_{\mu} A_{\nu}$) proposed by Klauber⁸ and by others.

It is unfortunate that it will be shown, by consideration of the theory in the momentum space basis, that the introduction of a gauge field may be required to provide qualitative differences between the theory described by such theory and other quantizations.

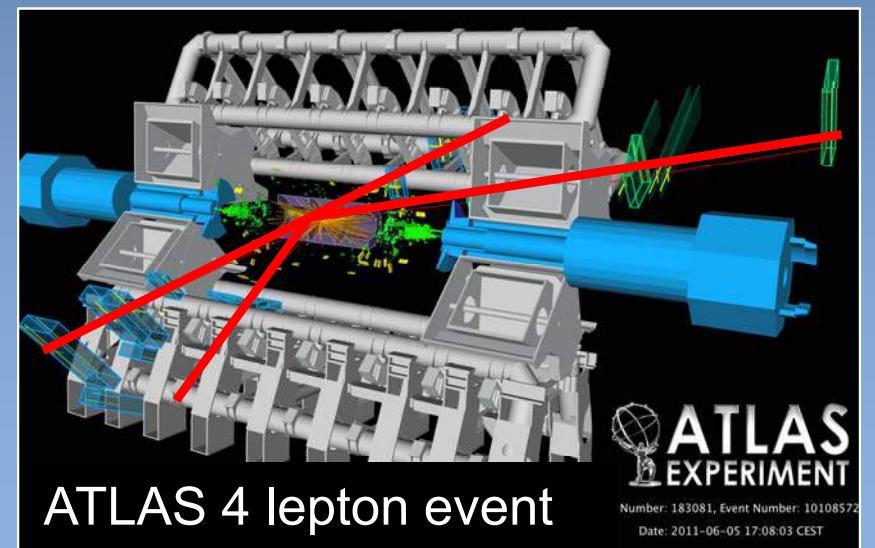
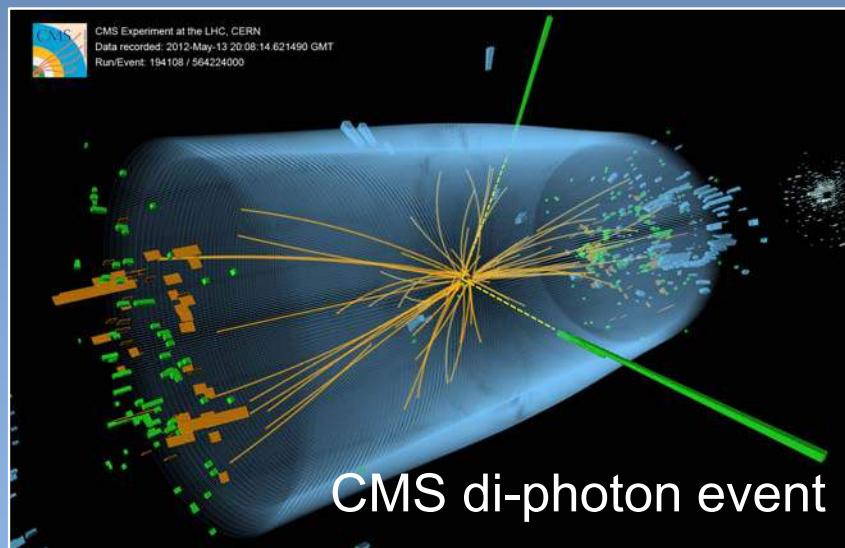
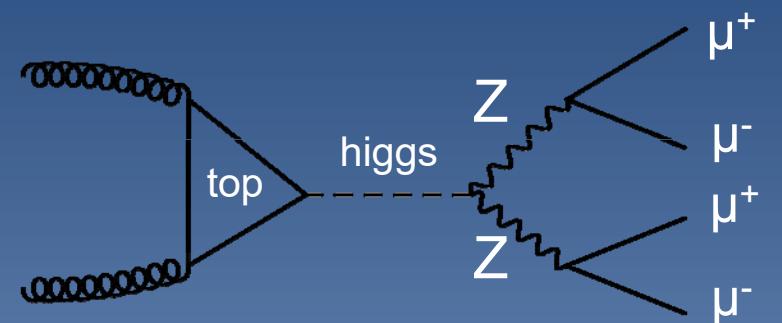
References

- J. J. Giambiagi, *Boson Currents* (J. IBM, 1971).
- R. P. Feynman and S. N. Wessley, *Phys. Rev.* **177**, 1575 (1969).
- J. S. Bell and R. W. Lee, *Phys. Rev. Letters* **12**, 3046 (1964).
- J. Gell-Mann, *Phys. Rev. Letters* **13**, 536 (1964).
- J. S. Schwinger, *Phys. Rev. Letters* **13**, 536 (1964).

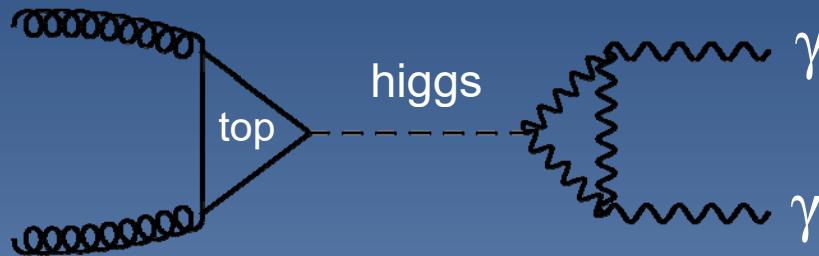
Higgs boson decay to 2 photons



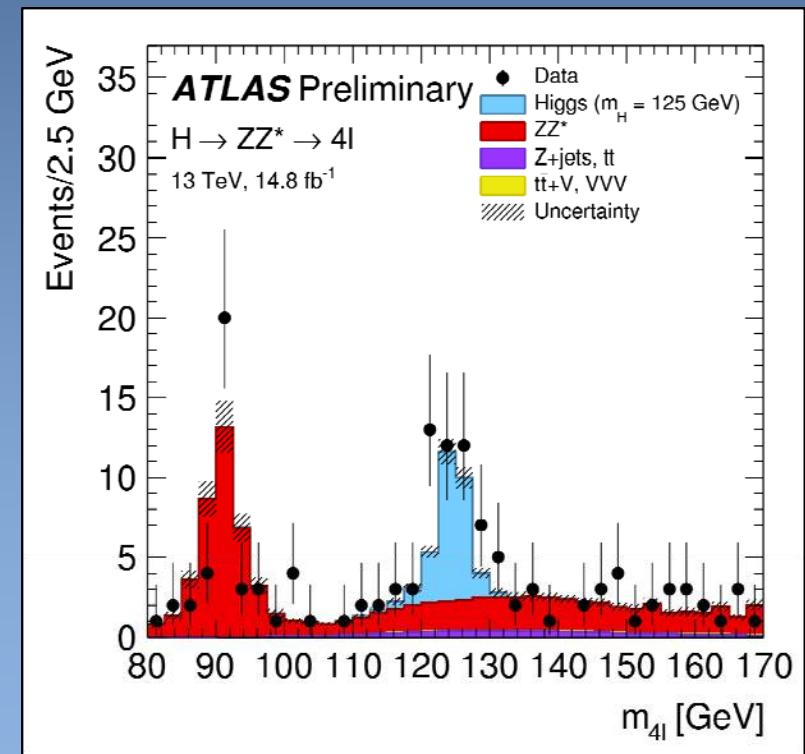
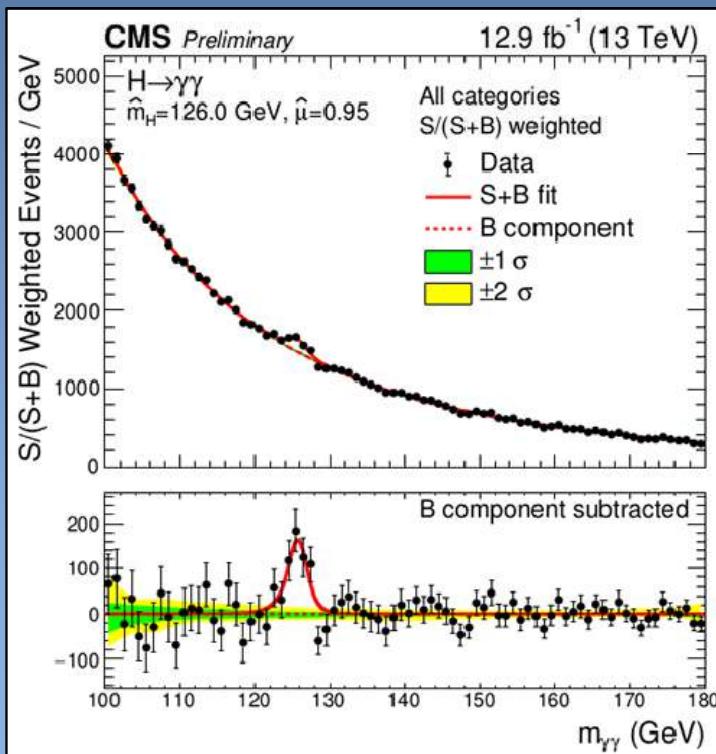
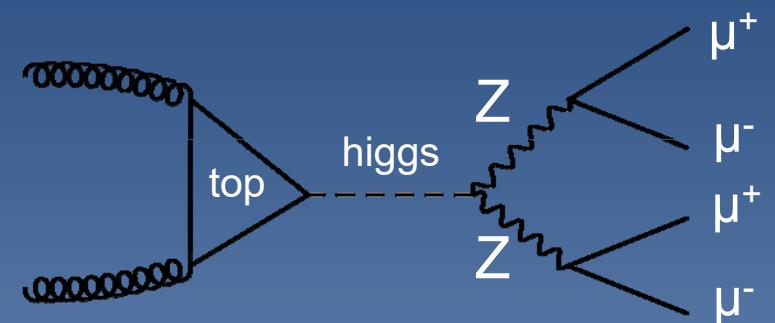
Higgs boson decay to 4 leptons



Higgs boson decay to 2 photons



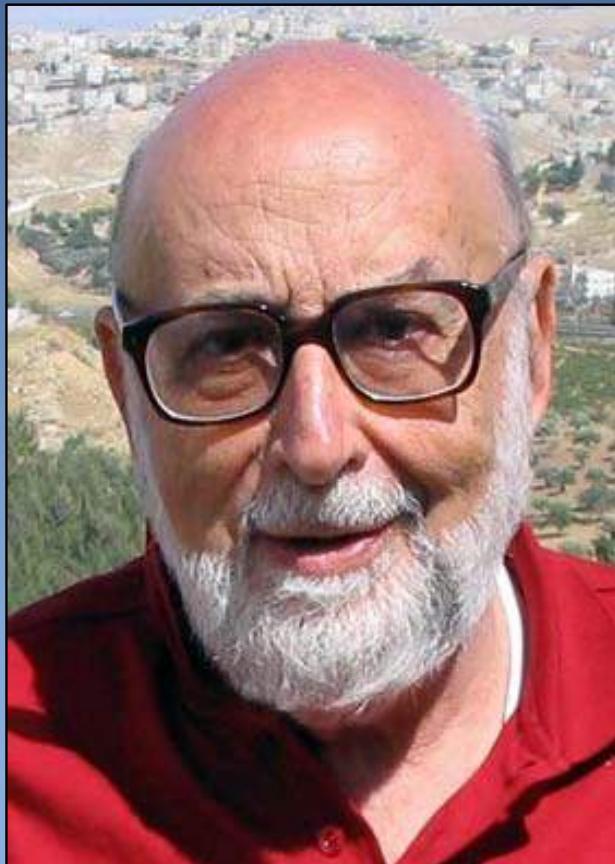
Higgs boson decay to 4 leptons



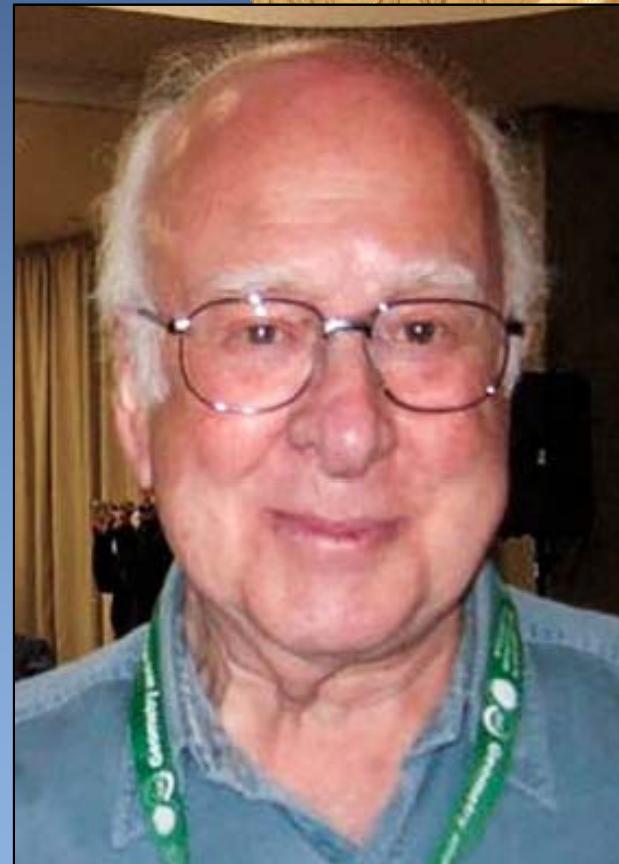
ATLAS+CMS: $m_h = 125.09 \pm 0.21(\text{stat}) \pm 0.11(\text{syst}) \text{ GeV}$

Nobelprijs natuurkunde 2013

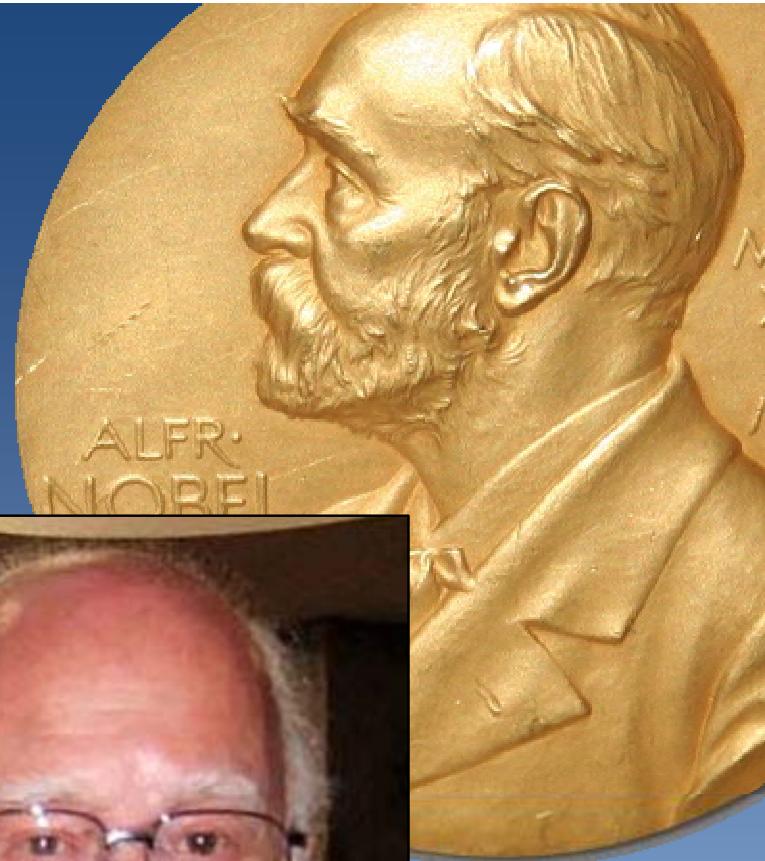
“Er is een Higgs-veld in het vacuüm”



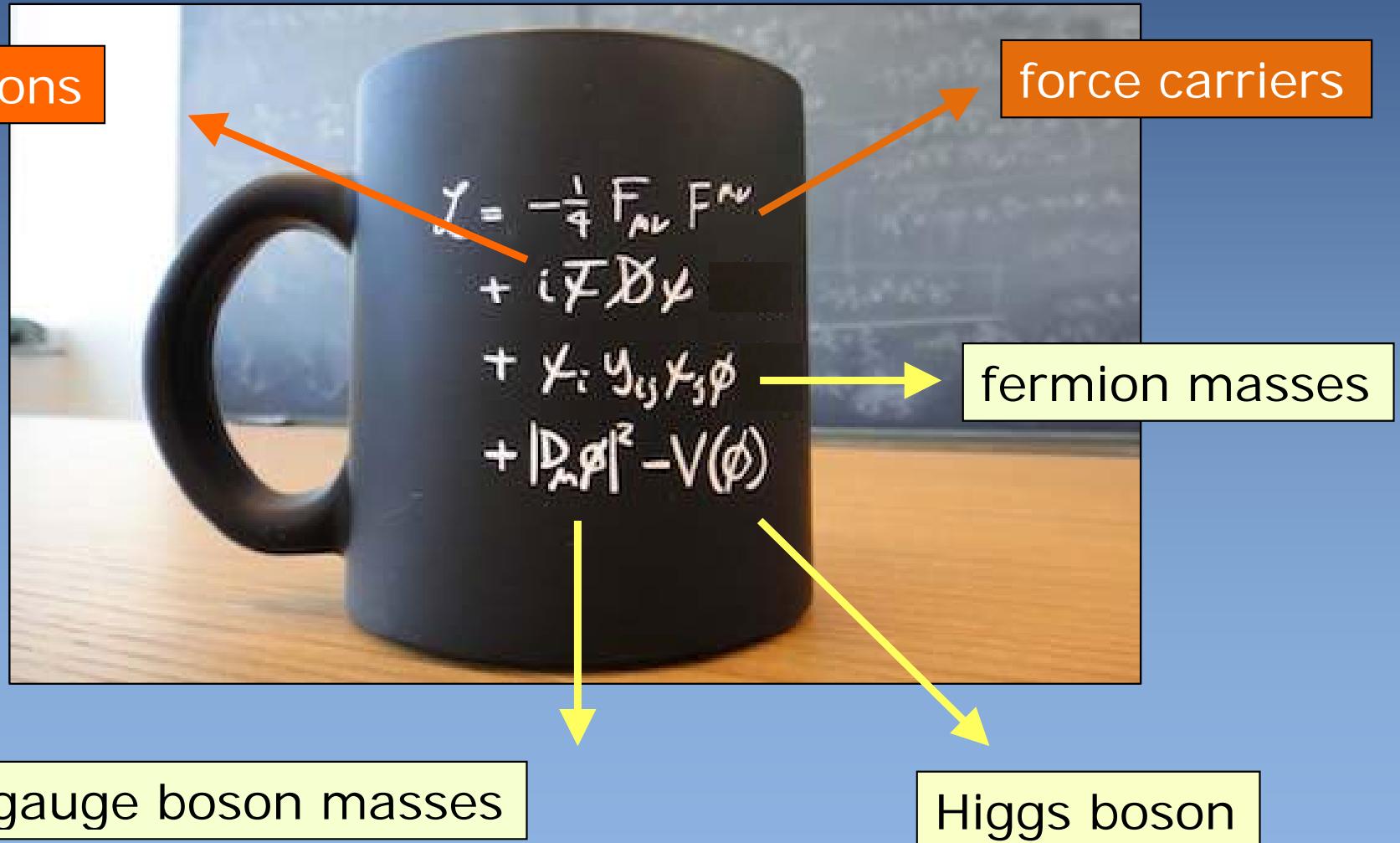
François Englert



Peter Higgs



Structure of the Standard Model



de problemen



Some more problems

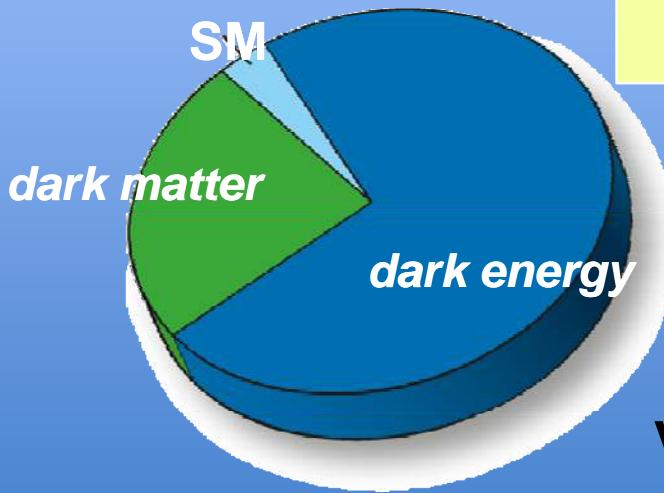
Elementary particles

up-quark			
down-quark			
elektron			
neutrino			

Standard Model problems

Baryogenesis:

Asymmetry between matter
and anti-matter



Dark Matter:

No DM candidate in
the Standard Model



Vacuum energy:

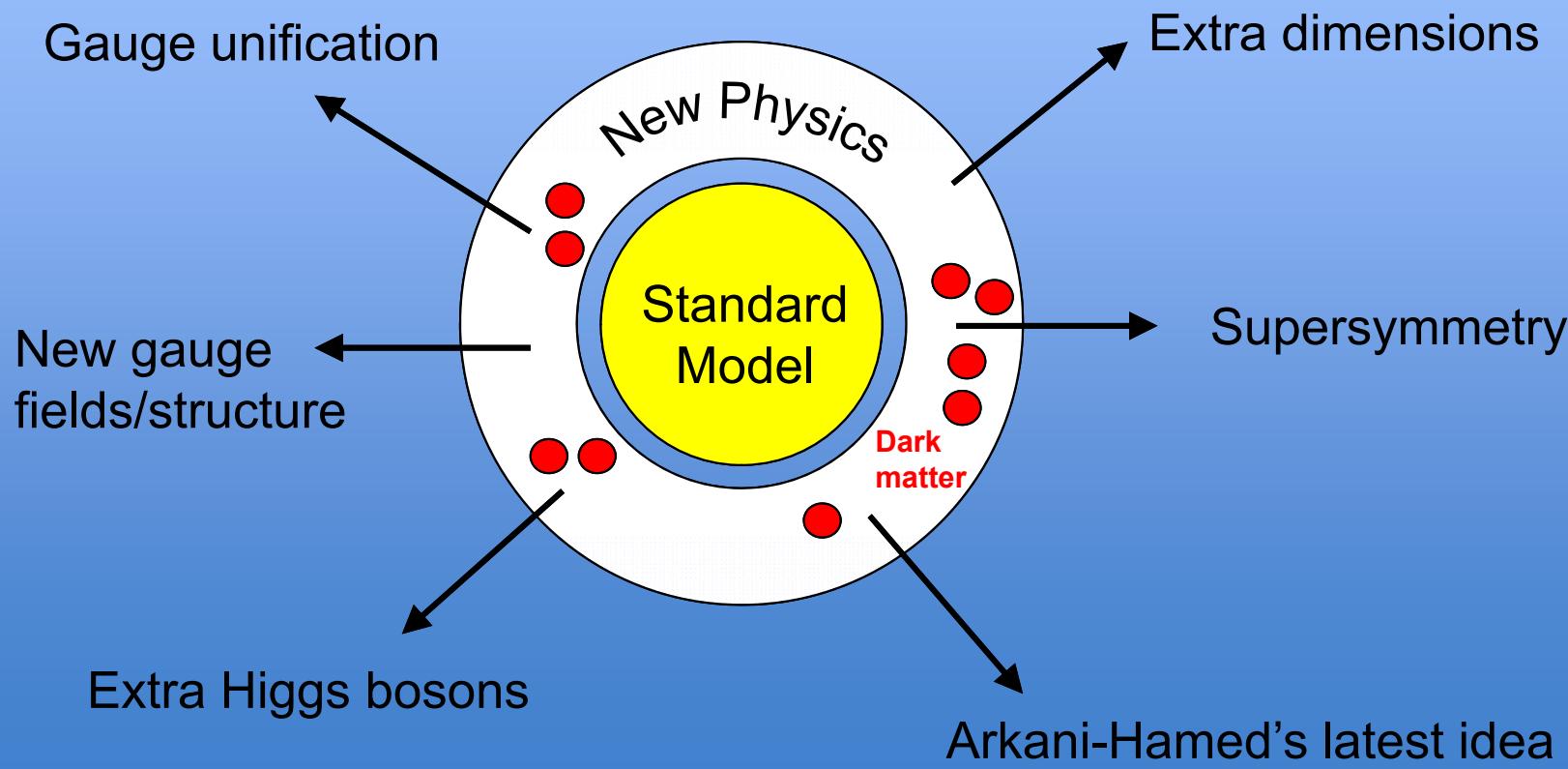
$\frac{\text{prediction (Higgs)}}{\text{observation}} > 10^{50}$

Heerlijk ... een probleem!

OH BOY OH BOY



Standard Model is not the final theory



Most models predict new phenomena/particles $\sim 1 \text{ TeV}$

De oplossing ?

bekende deeltjes

fantasie deeltjes



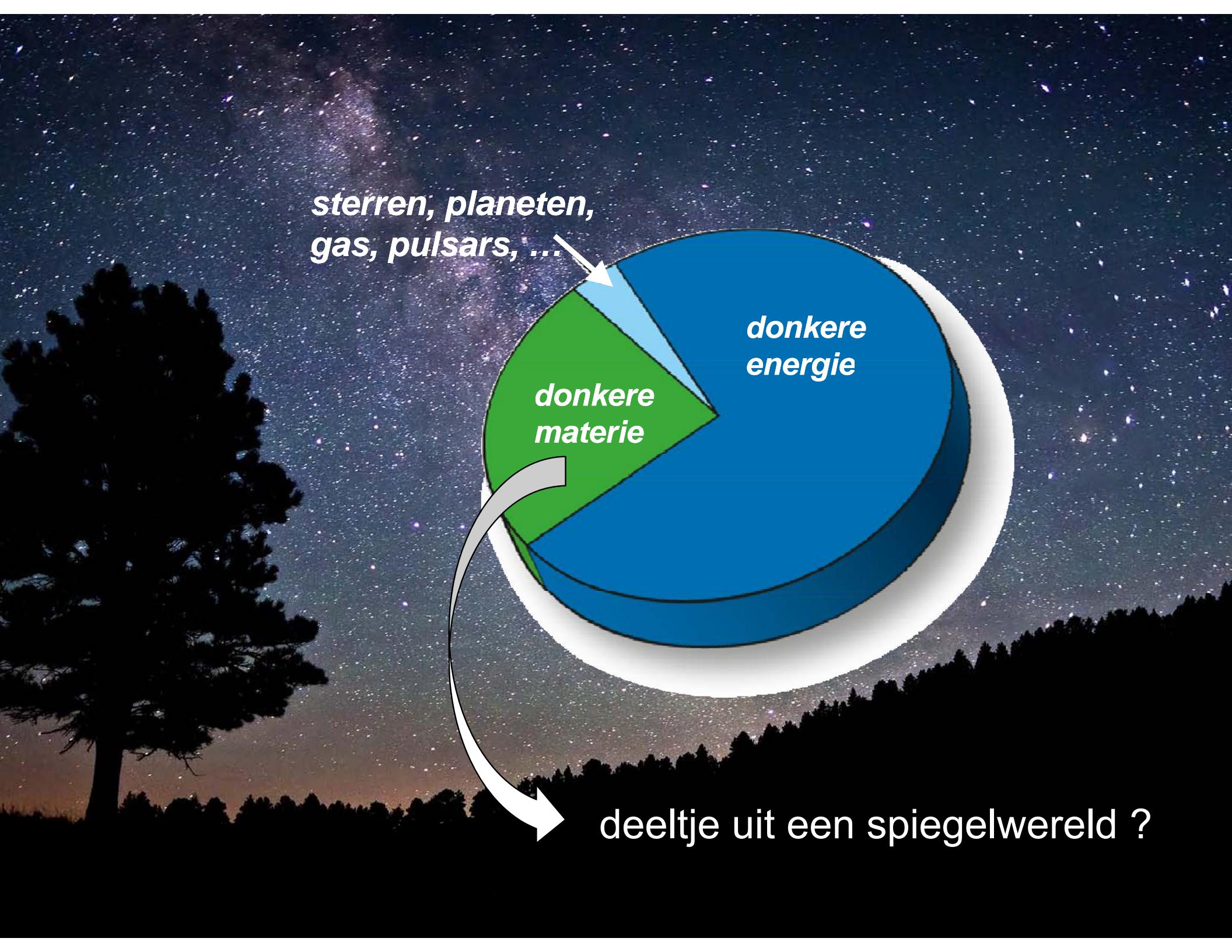
donkere materie deeltje ?



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

Donkere materie

Supersymmetrie – model met een natuurlijke plek voor donkere materie



*sterren, planeten,
gas, pulsars, ...*

*donkere
materie*

*donkere
energie*

deeltje uit een spiegelwereld ?



deeltjes

anti-deeltjes

de stabiele
wereld

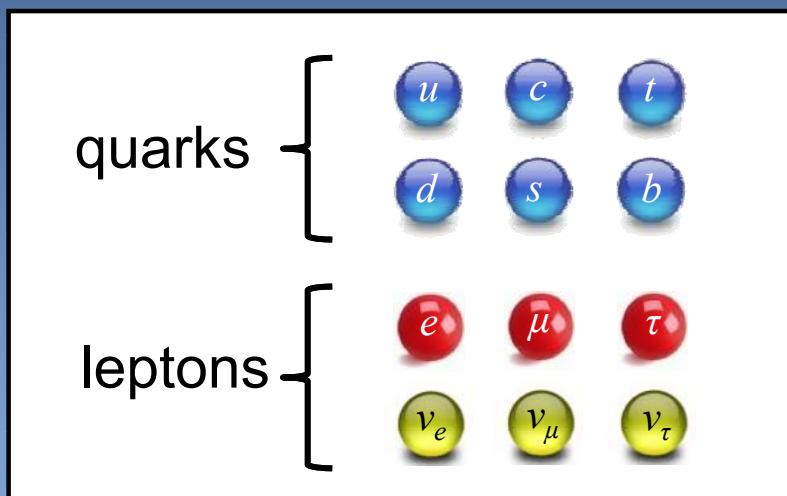
Bestaat er een verborgen spiegelwereld ?



Supersymmetry

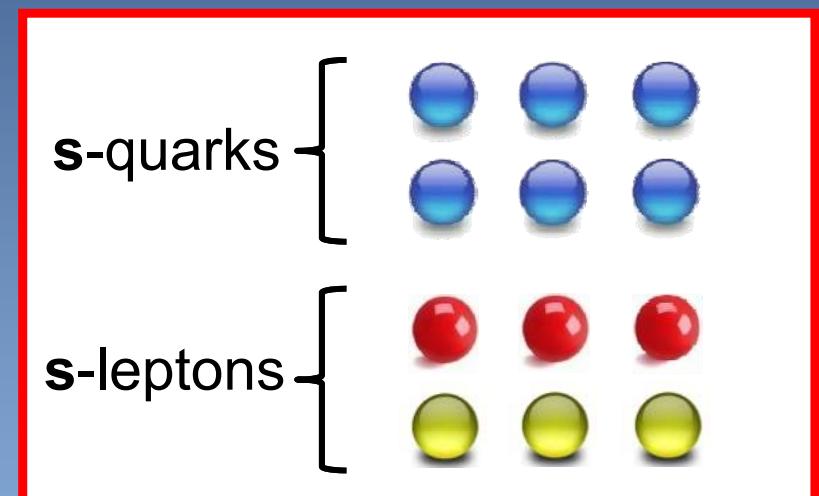


FERMIONS



quarks and leptons

BOSONS



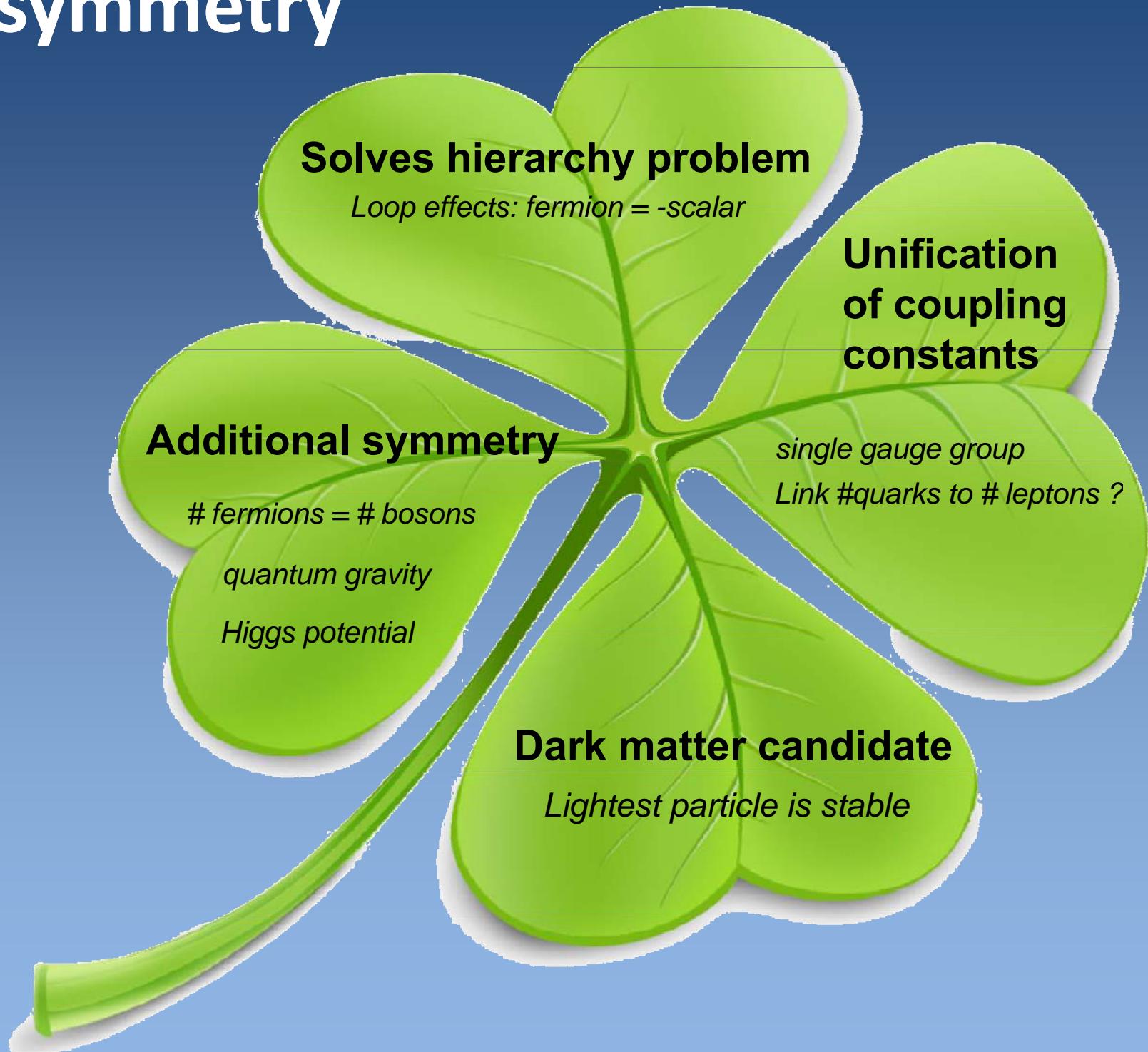
squarks and
sleptons



gaugino's

gauge bosons

Supersymmetry



Looking for new particles

Dark Matter



Can we produce it at the LHC ?

does it couple to SM particles

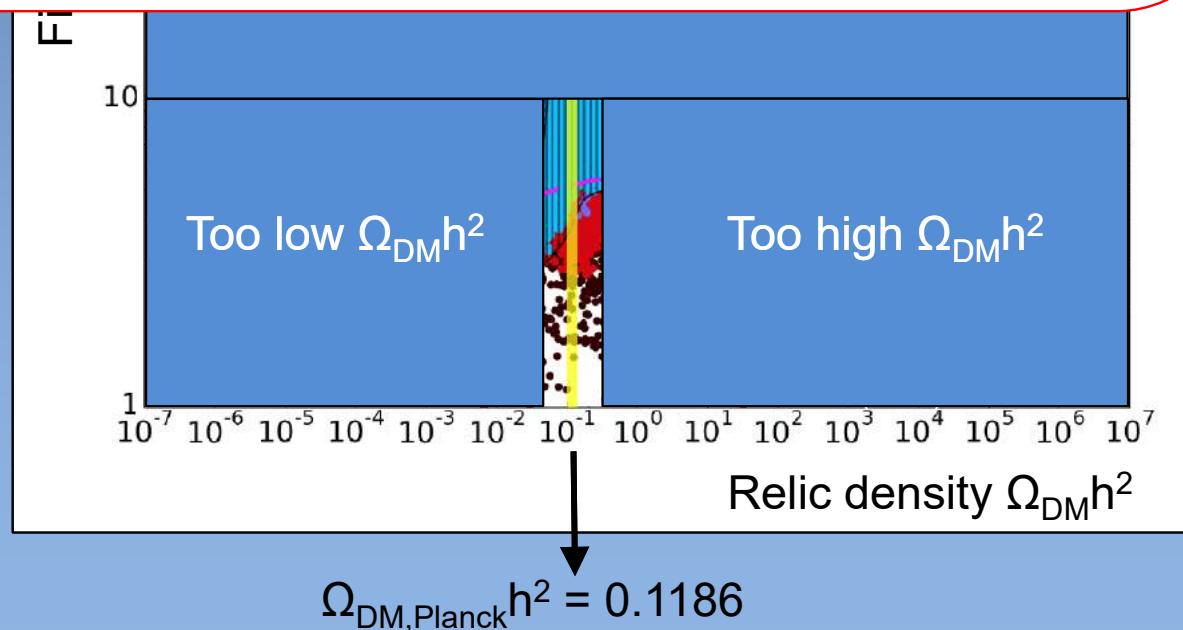
Can we see it at the LHC ?

not directly

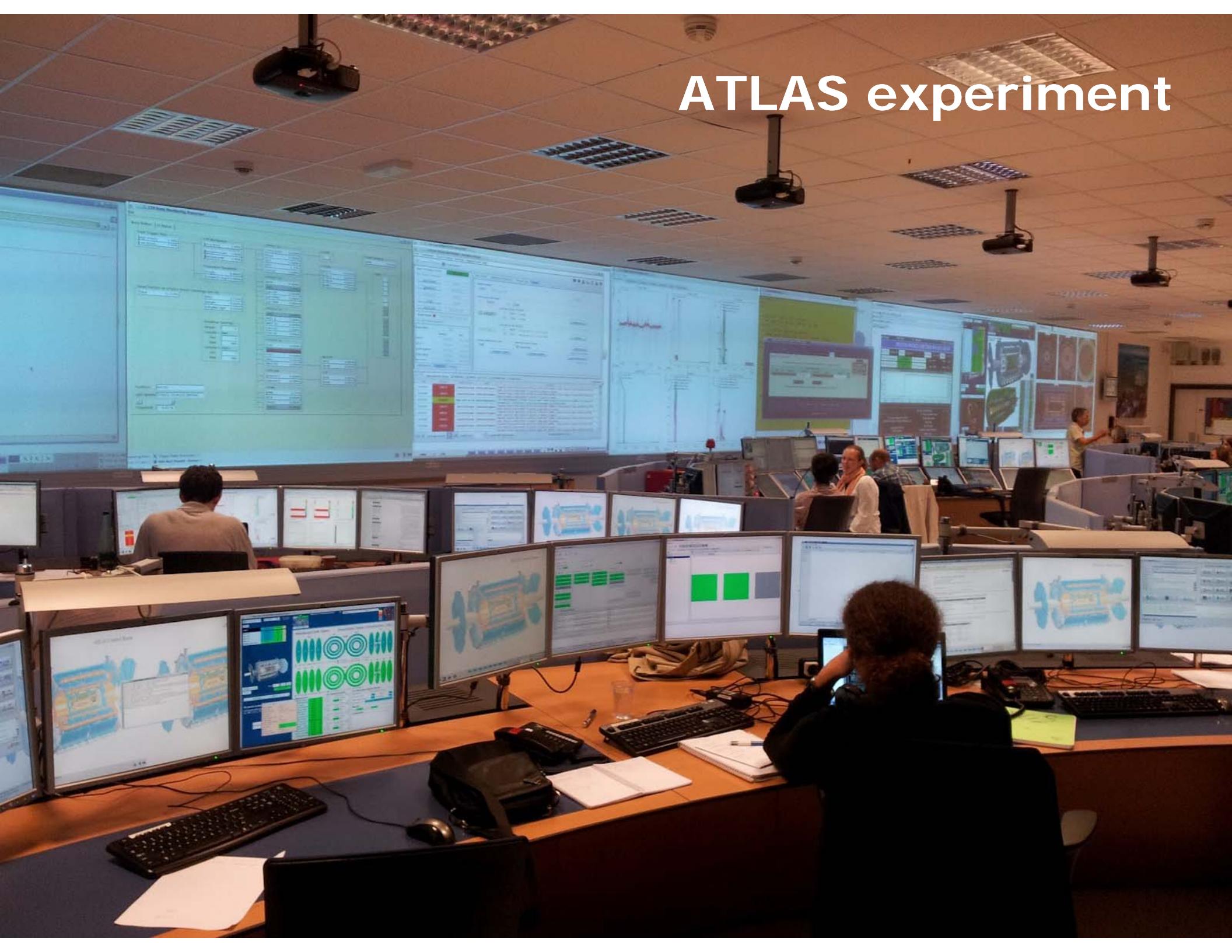
Open SUSY parameter space

Signalen die we tot nu toe nog niet hebben kunnen zien
... maar de komende 2 jaar (misschien) wel:

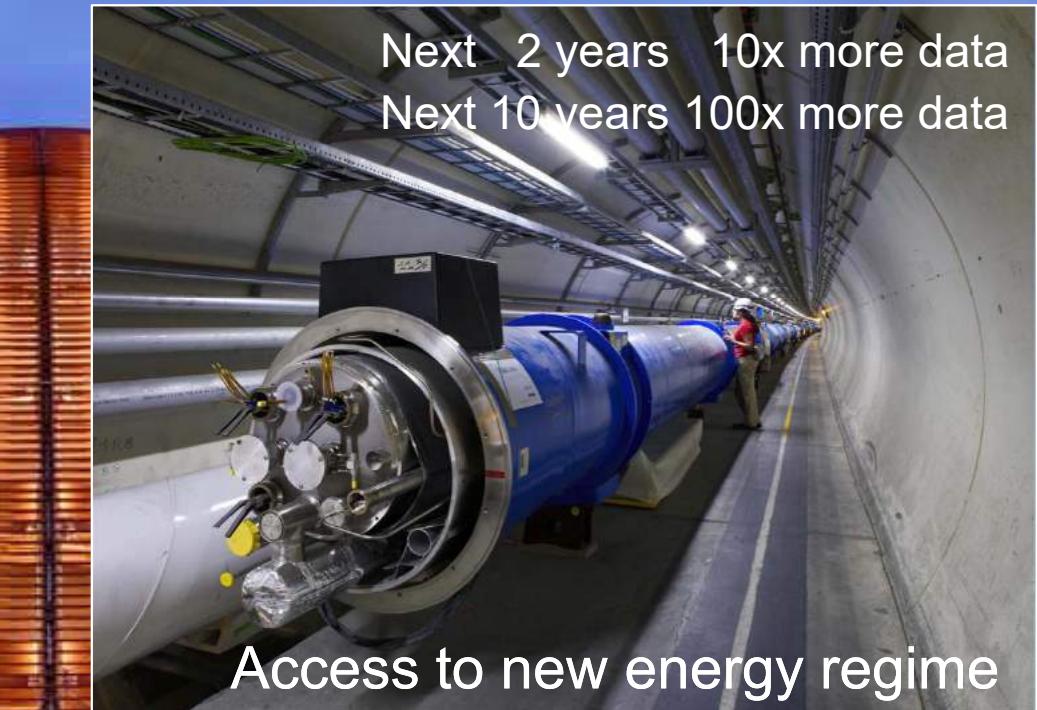
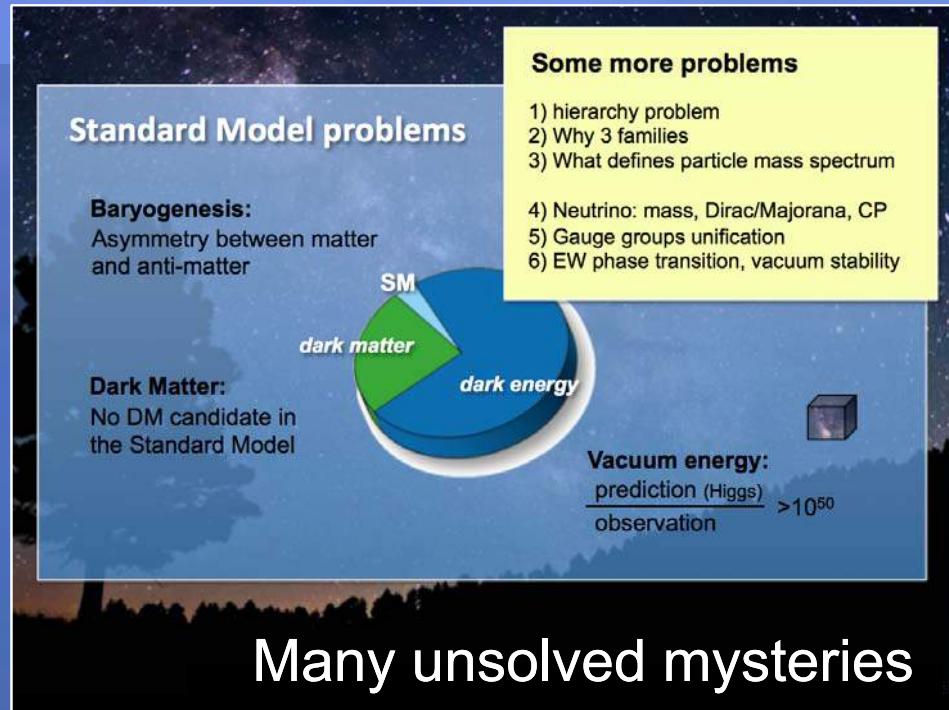
- we snappen de detector beter
- we weten nu precies waar we moeten zoeken
- we krijgen 10x(100x) meer data
- we hebben een lichting scholieren die allemaal natuurkunde gaan studeren om ons te helpen.



ATLAS experiment



Schatgraven bij de LHC. Nu!



Exciting times for (dark matter) searches at the LHC

!

@IvovanVulpen