

Zoektocht naar de elementaire bouwstenen van de natuur



Ivo van Vulpen

CERN



- Waarom deeltjesfysica en grote versnellers
 - Wat weten we al
 - Wat willen we nog meer weten
- CERN & de LHC
 - Wat komt er bij kijken
 - Wat hopen we te vinden

Het grootste en het kleinste

... volgens mijn dochter van 3

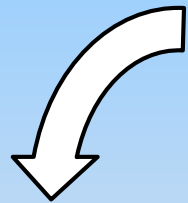
... volgens haar vader



Olifant



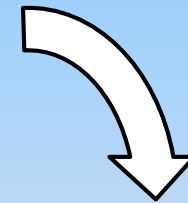
Klein muisje



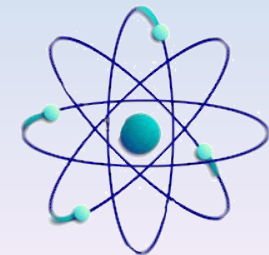
Grootst



10^{+22} m



Kleinst

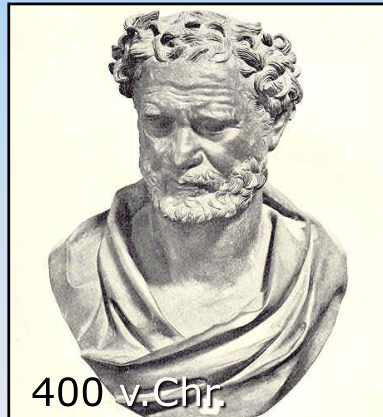


10^{-9} m

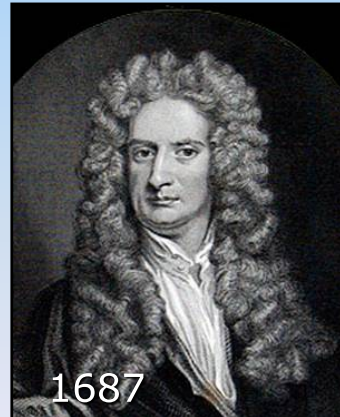
Elementaire deeltjes fysica

Vragen die de mensheid al 2000 jaar bezighouden:

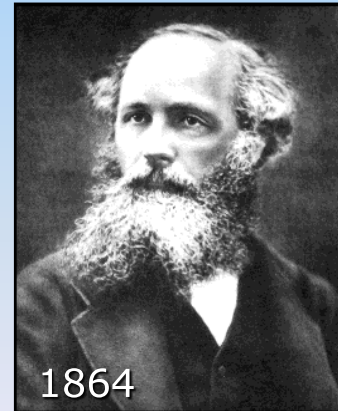
- Wat zijn de bouwstenen van de materie ?
- Welke krachten werken op deze bouwstenen ?



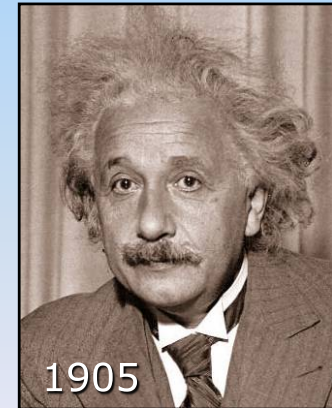
Demokritos
atoom



Newton
krachten



Maxwell
electromagnetisme



Einstein
van alles...

Klassieke mechanica ... hoe werkt de natuur

1) Lagrangiaan

$$L = T - V$$

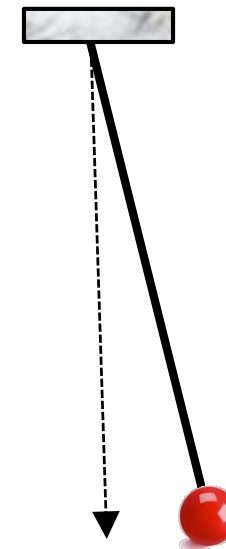
2) Euler-Lagrange vergelijking

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

→ bewegingsvergelijking

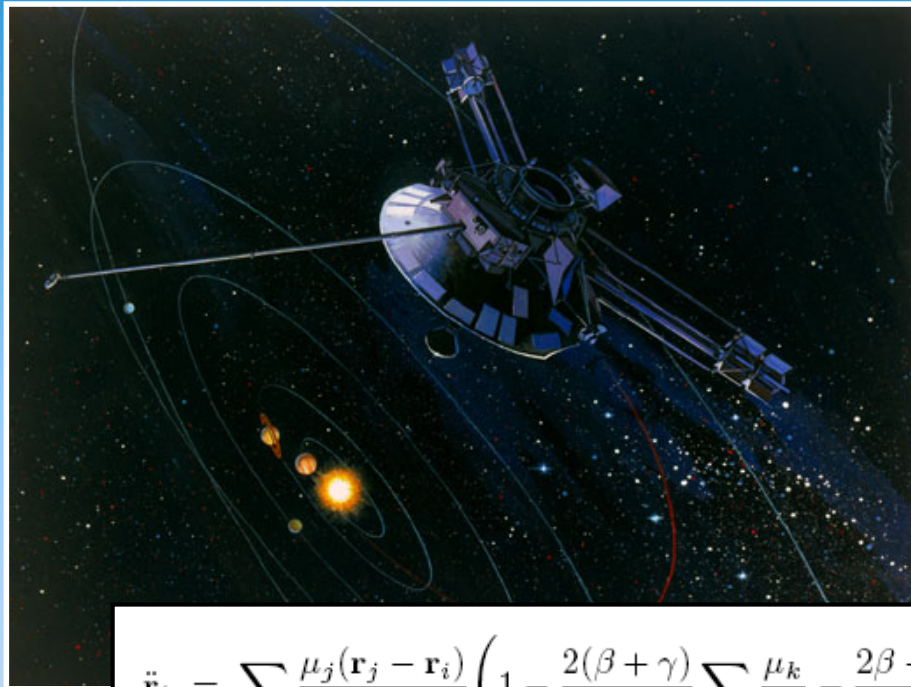
$$T = \frac{1}{2} m (l \dot{\theta})^2$$
$$V = -mgl \cos(\theta)$$

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



de slinger

Klassieke mechanica ... moeilijk zat !



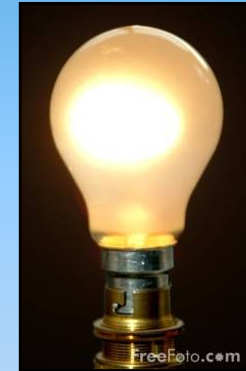
Pioneer ruimtevaartuig

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

Het nut van fundamenteel onderzoek?



"Oneindig veel toegepast onderzoek aan de kaars zou ons nooit het elektrische licht hebben gebracht."



Heeeeeeeel snelle stoomtrein



Bugatti Veyron

Spin-off fundamenteel onderzoek ?

Nuttige bij-effecten:

- Medische toepassingen
- Computing ontwikkelingen (Internet, Grid)
- Opleiden van onderzoekers voor de maatschappij (Philips, ASML, etc ...)
- ...

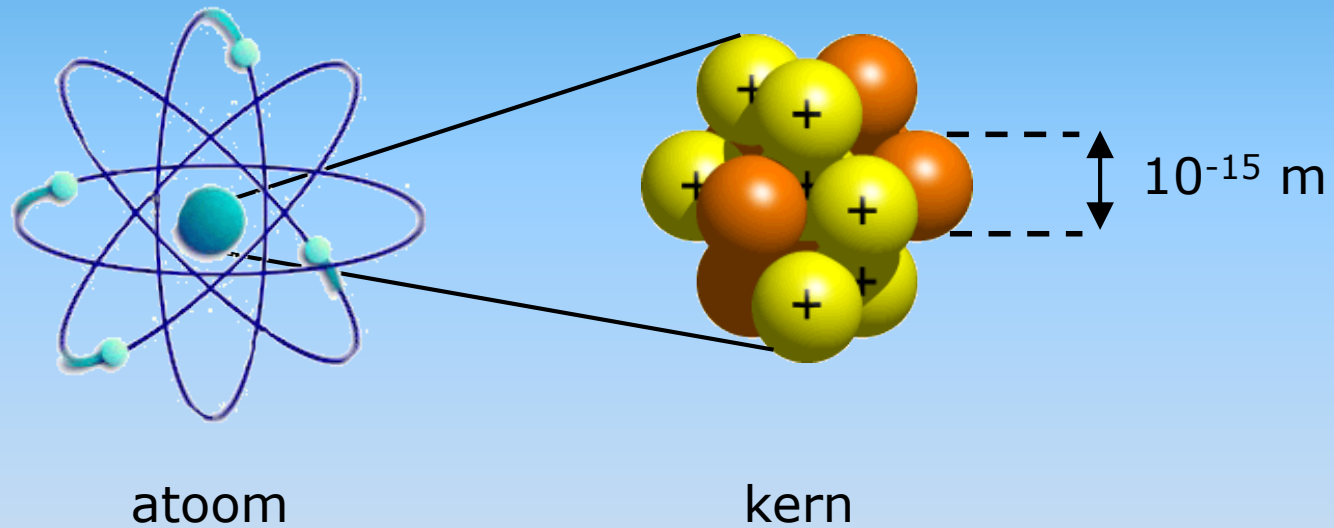


Mensen vooral erg nieuwsgierig!! Hoe? Wat? Waar? ... **Waarom?**

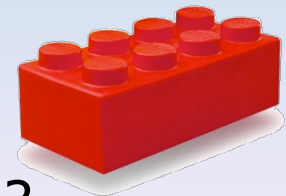
A photograph of a bright blue sky with several fluffy white clouds. The clouds are scattered across the frame, with a larger one in the center-left and another in the lower-right. The sky is a deep, uniform blue.

Waarom is de lucht blauw ?

Deeltjesfysica



Wat zijn de bouwstenen van de dingen om ons heen ?

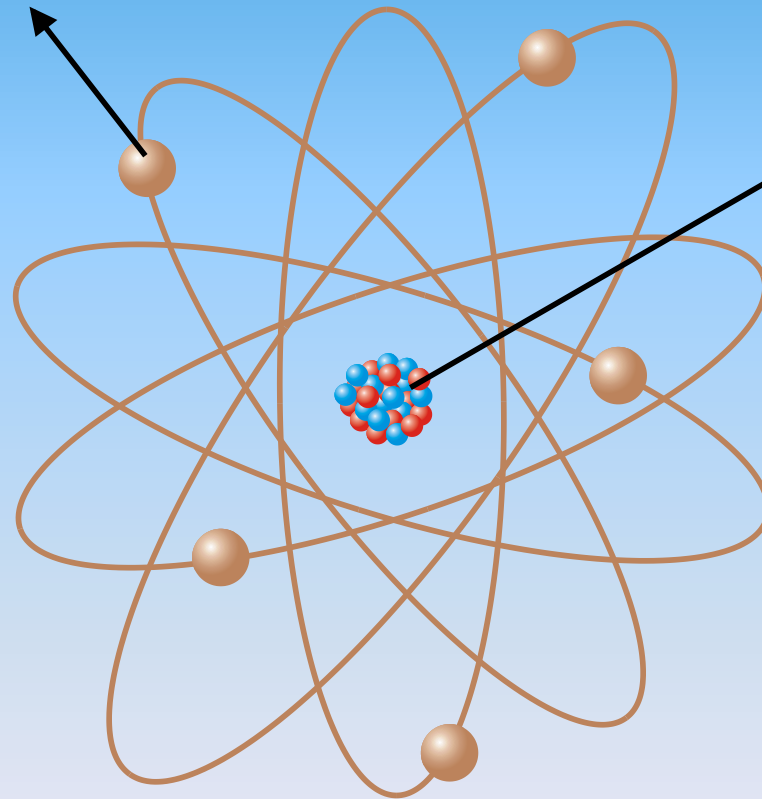




**Atoomkern in een atoom is als
een een vlieg in een kathedraal**

Wat waren de problemen 100 jaar geleden ?

elektron:lading -1



proton:lading +1

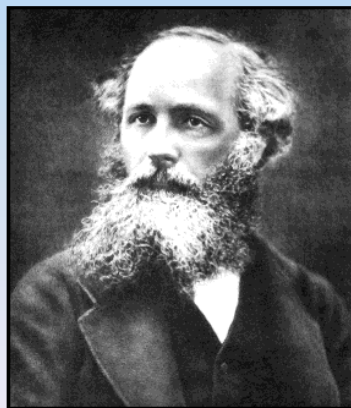
Waarom valt het elektron niet op de kern ?

Zwaartekracht en Electromagnetisme

“zelfde krachten ... nieuwe modellen”



Newton



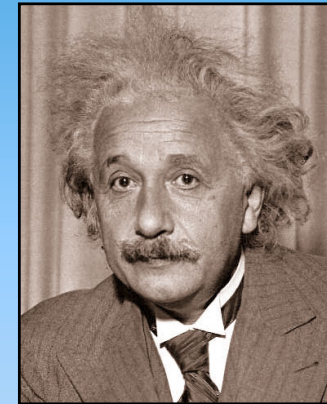
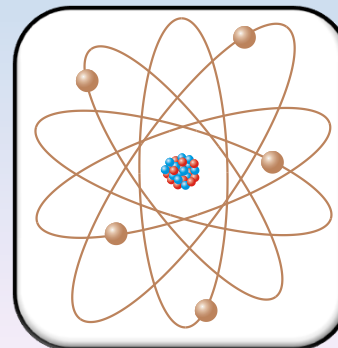
Maxwell



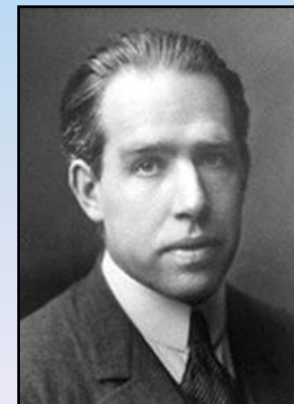
Relativiteitstheorie



Quantummechanica



Einstein



Bohr

Quantummechanica ... nuttig ?

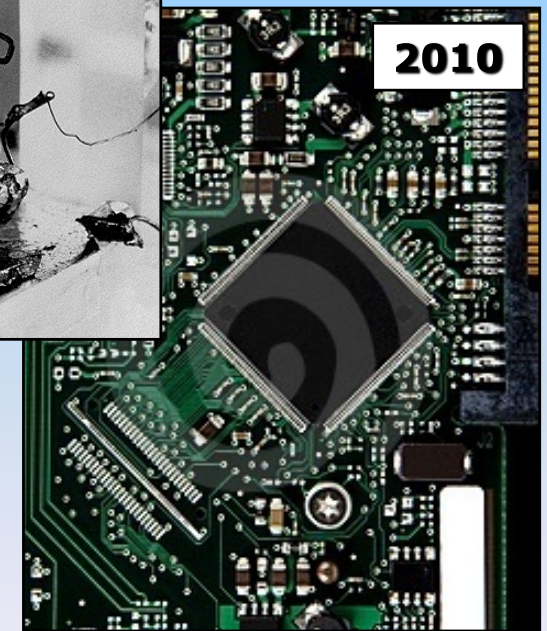
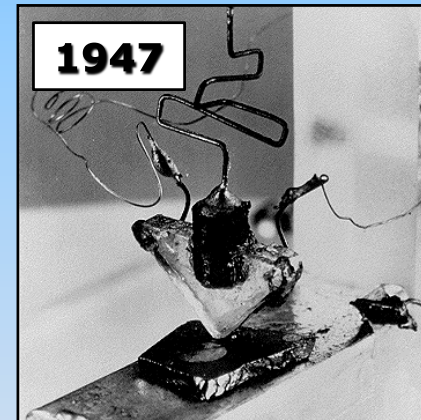
Quantum mechanica ?



Niels Bohr

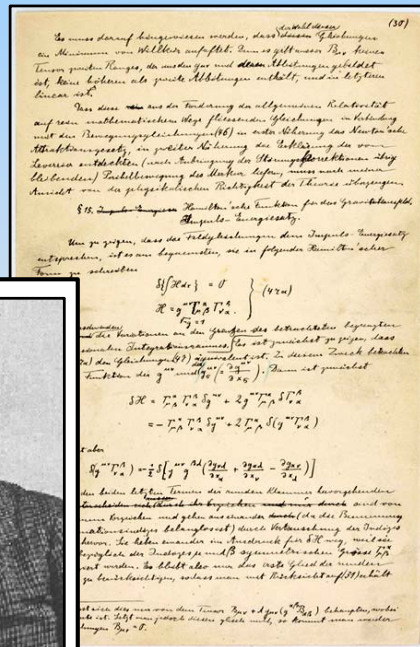
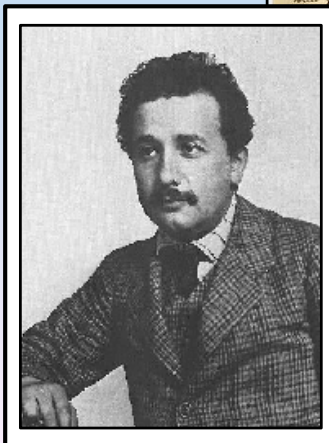


"Quantum mechanica en begrip van atomen cruciaal voor transitors."



Relativiteitstheorie ... nuttig ?

Relativiteitstheorie ?



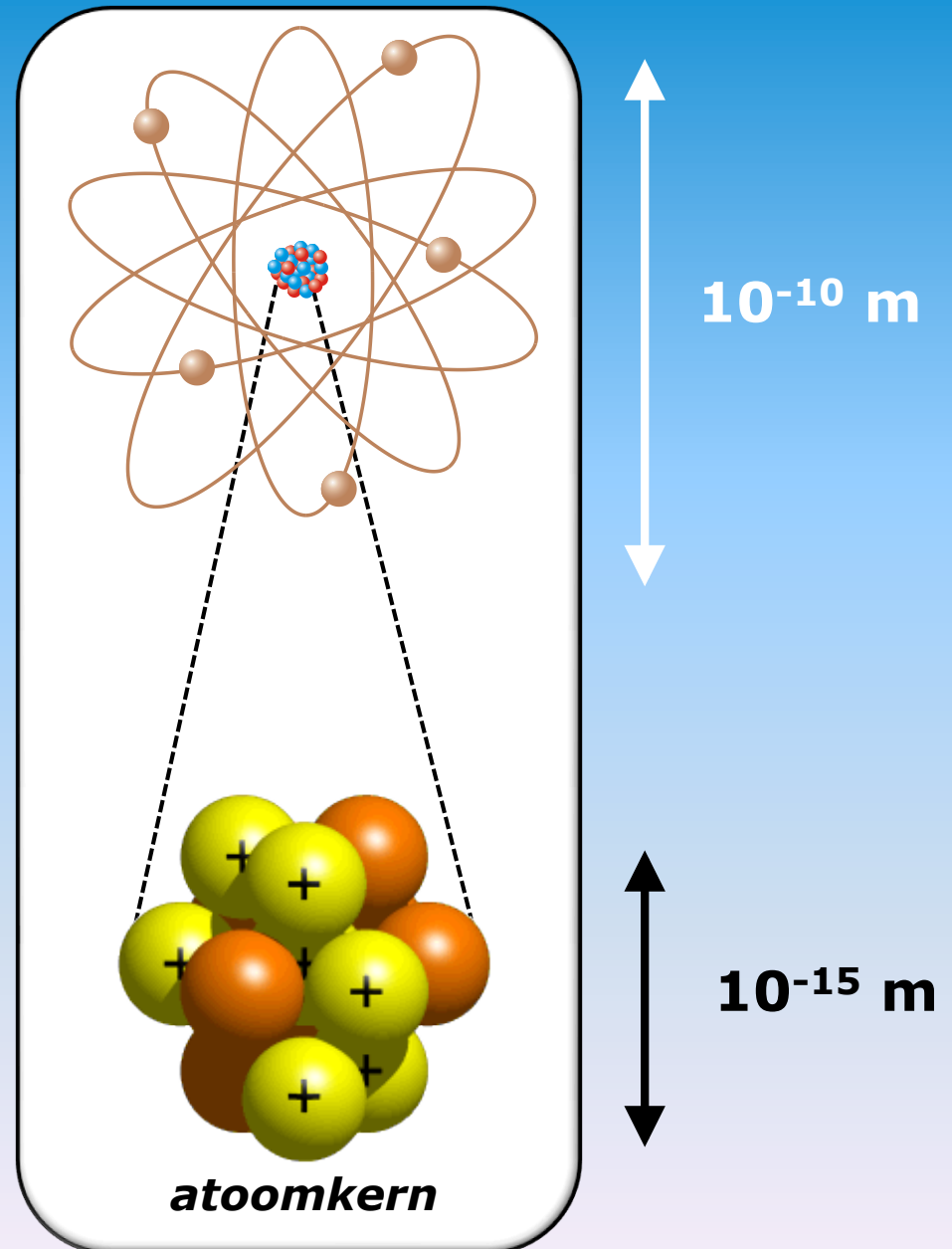
"Zonder relativiteitstheorie zit de GPS er 10 km per dag naast!"

De kernkrachten

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

2 nieuwe natuurkrachten:

- zwakke kernkracht
- sterke kernkracht





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

[2] Gewoon 4 gekleurde draadjes en simpel symmetrisch patroon

De stand van zaken in april 2010



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

De elementaire deeltjes



up

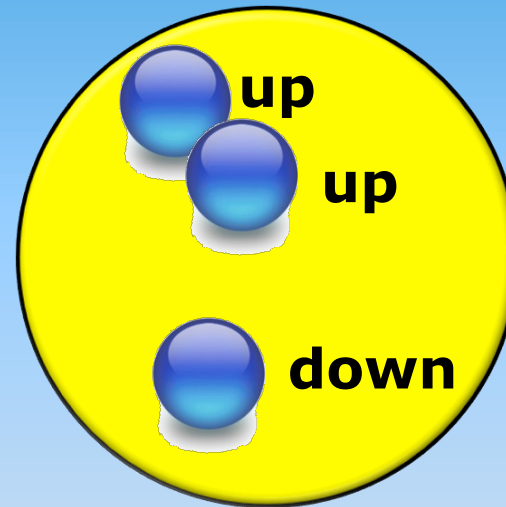


down

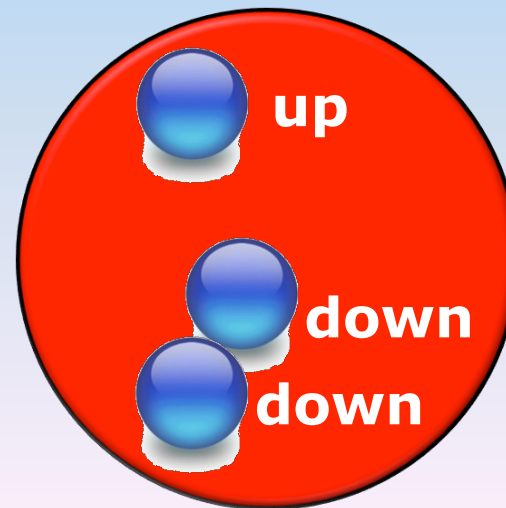


elektron

+ 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!



Alles wat we nodig hebben !



Voorzitter NWO 20/100

Deeltjes

Krachten

bouwstenen van
proton/neutron

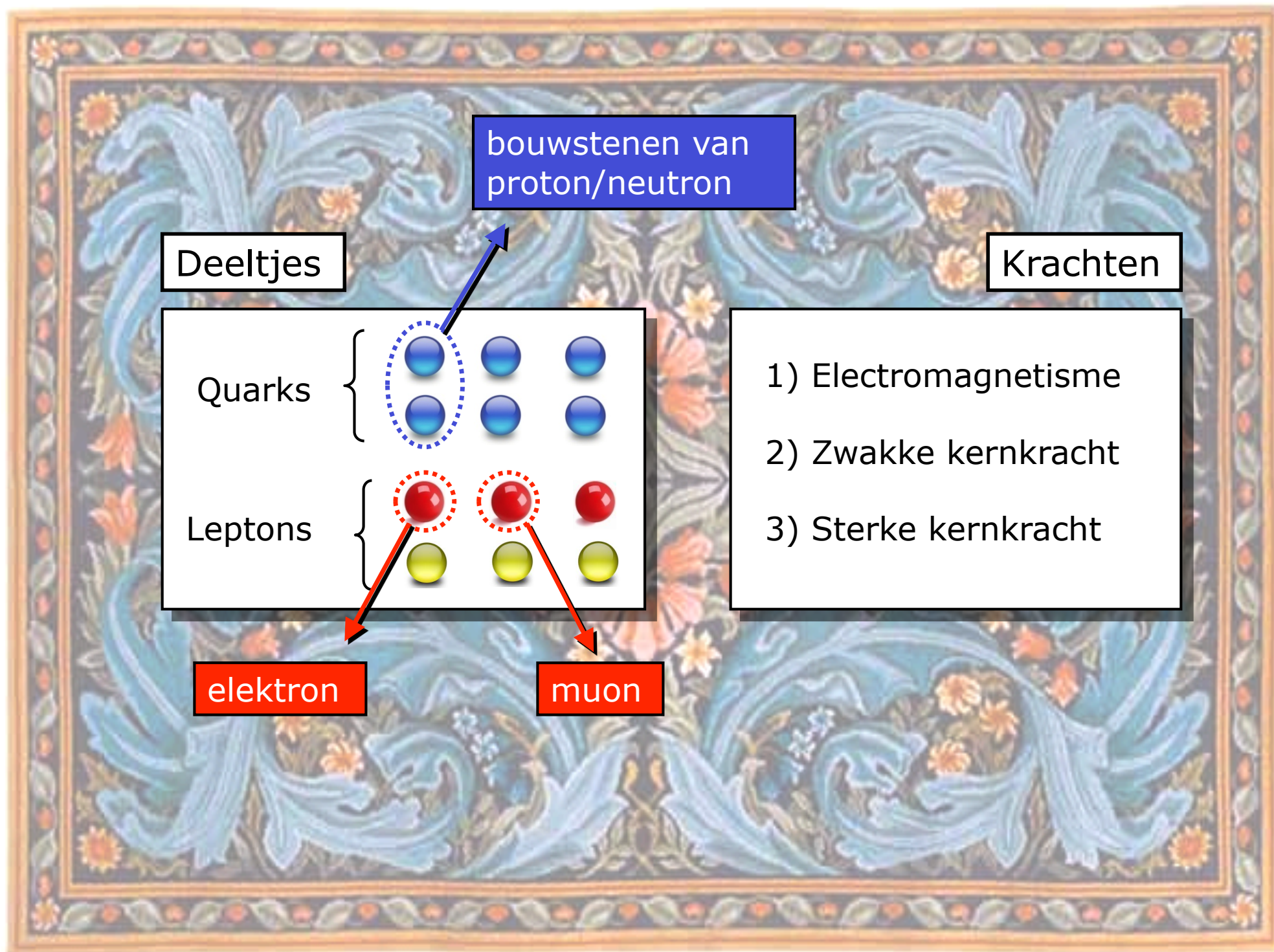
Quarks

Leptons

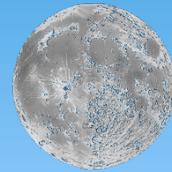
- 1) Electromagnetisme
- 2) Zwakke kernkracht
- 3) Sterke kernkracht

elektron

muon



Begrijpen we ook het 'iets verderop' ?



Maan



Aarde



Mars



Is dit nu alle materie die er is ?

Waar bestaat het heelal uit?



Wat snappen we nog niet:





Paar 'kleine' dingetjes:

1

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

2

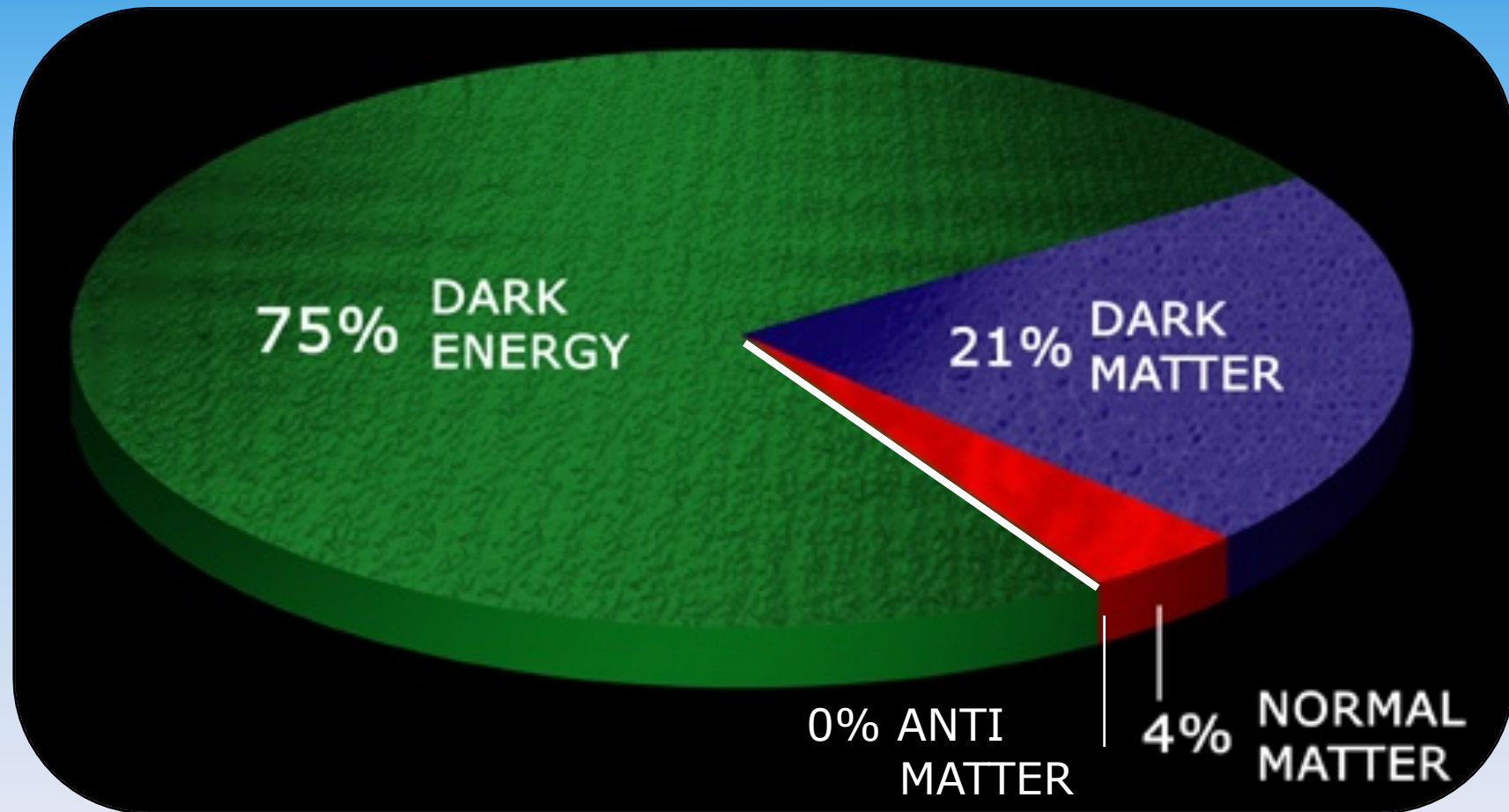
Waar is alle anti-materie gebleven ?

3

Higgs boson

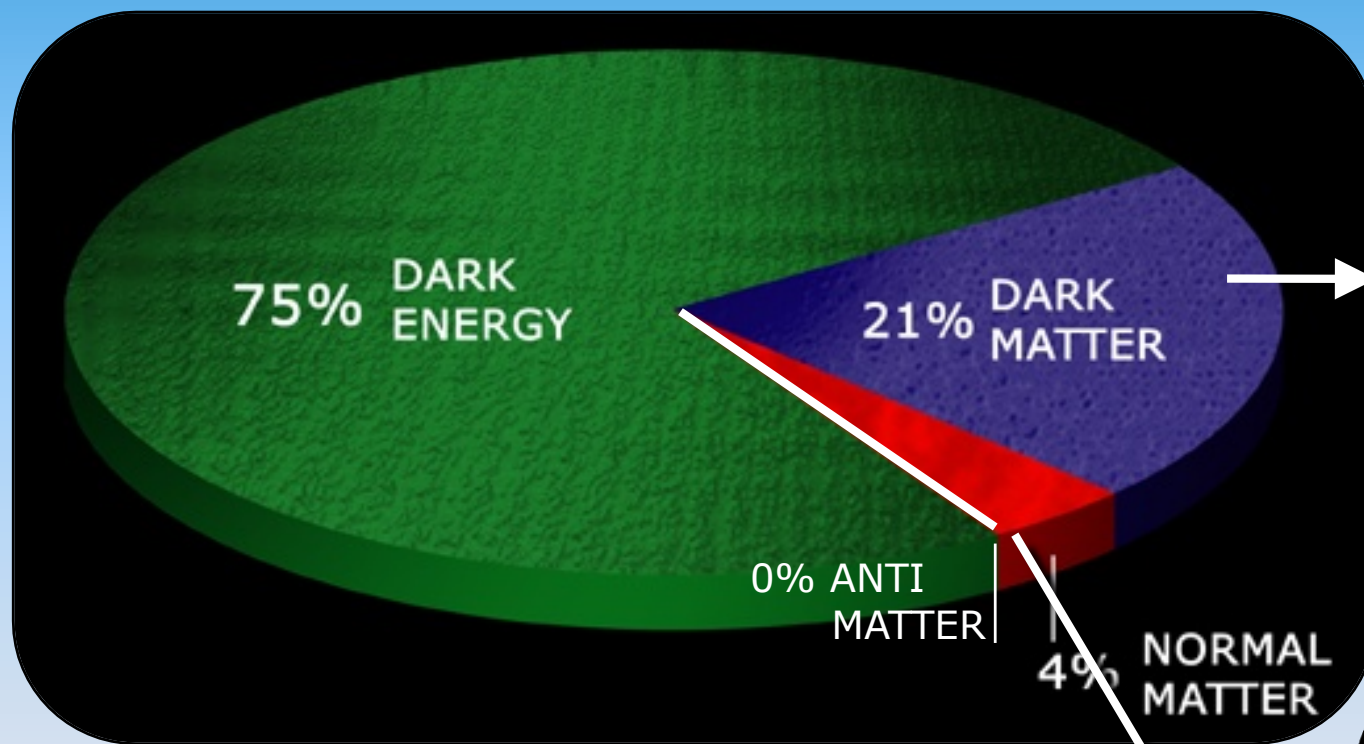
- waarom past gravitatie niet in SM, extra dimensies, waarom 3 families, fermionen fundamentele deeltjes, supersymmetrie, protonen stabiel, quantisatie elektrische lading, exploderende quantumcorrecties, kleine neutrino massa's, string theorie, ...

Waar bestaat het heelal uit?



Slechts 4% is normale materie...

Wat snappen we niet?



1

Wat is donkere materie ?

2

Waar is de anti-materie gebleven ?

Nieuwe fenomenen: anti-materie



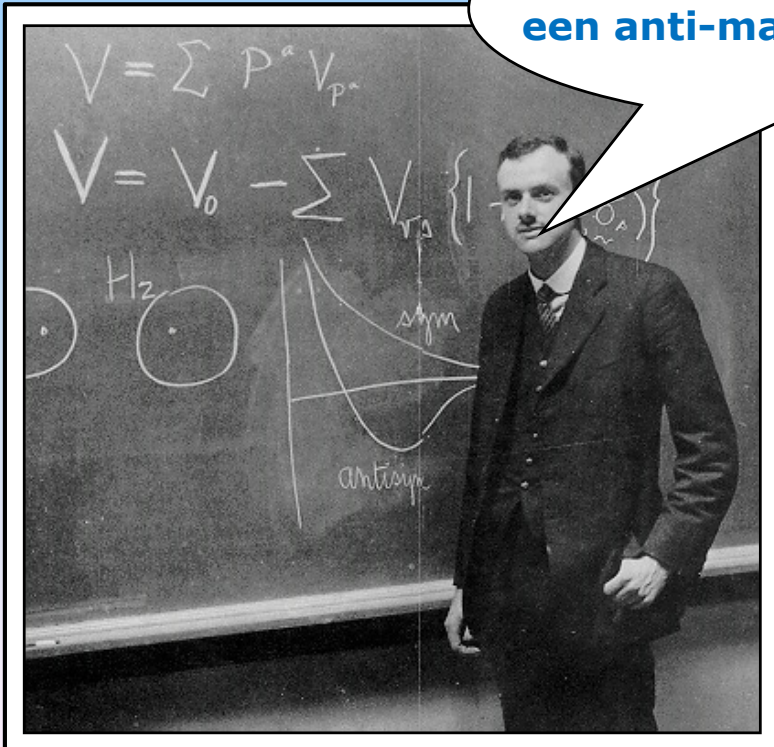
Mooie een-twee'tje theorie-experiment

- Revoluties begin vorige eeuw:
Relativiteitstheorie & Quantummechanica
- Paul Dirac (1928):
Relativistische quantum theorie!

Dirac vergelijking

$$(i\gamma_{\mu}\partial^{\mu} - m)\psi = 0$$

**Voor elk materiedeeltje bestaat
een anti-materiedeeltje!**



↓
Anti-materie deeltje:

- Zelfde massa
- Tegenovergestelde lading

Materie



up



down



elektron



Anti-materie



anti-up

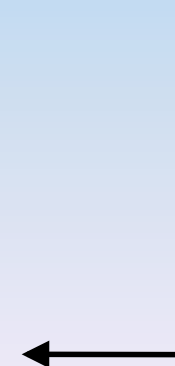


anti-down

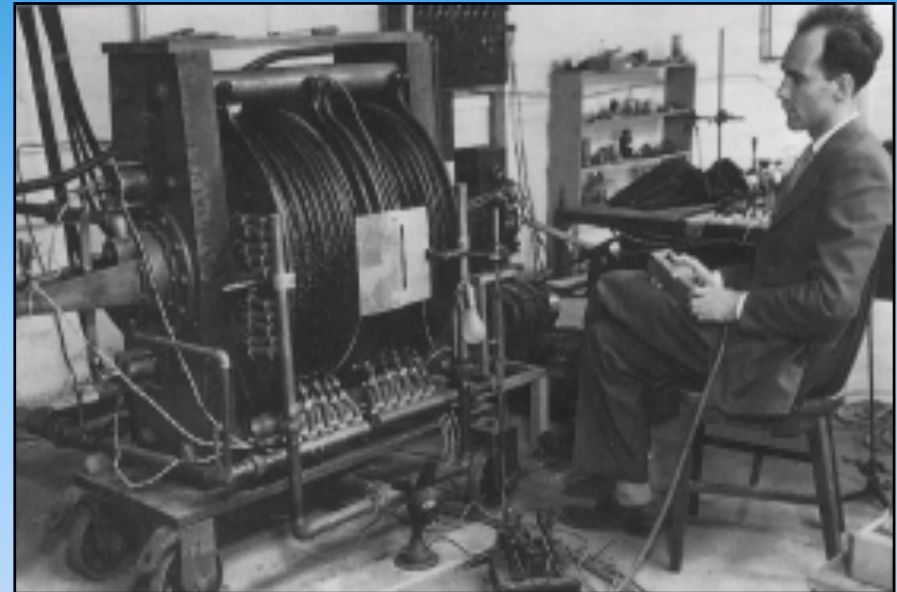
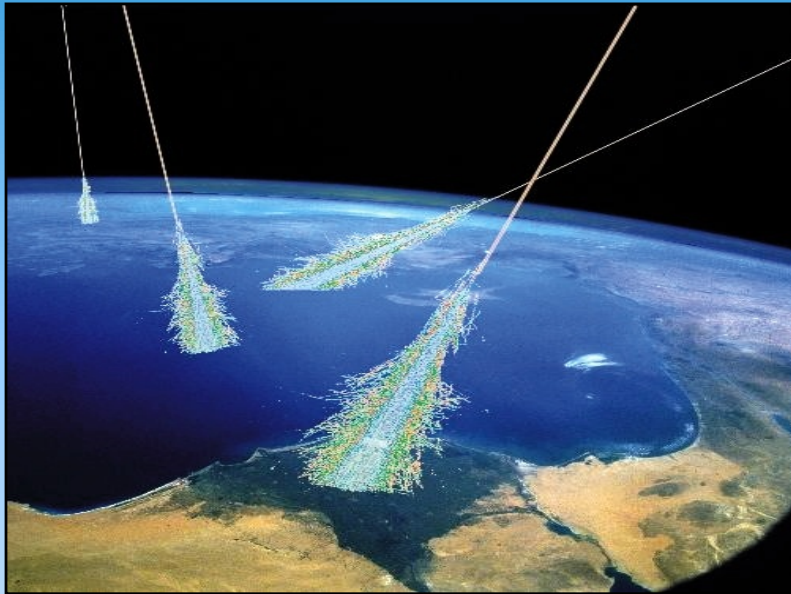


positron

Voorspelling: anti-elektron



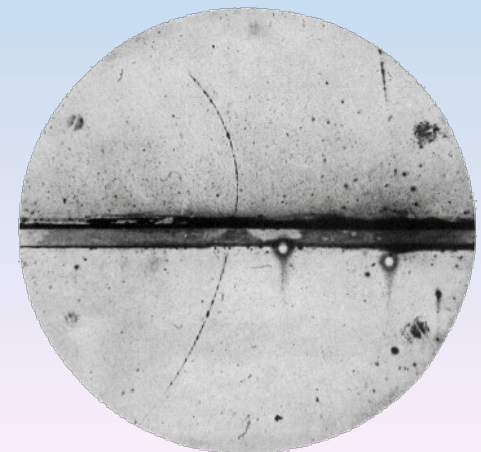
1932: Anderson ontdekt het anti-elektron (Caltech)



Hij observeerde in kosmische straling een elektron met een 'verkeerde' lading: het positron (e^+)

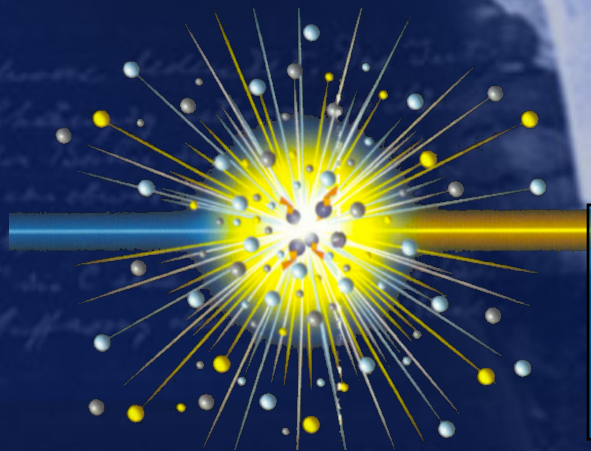
1955: ontdekking anti-proton (Berkeley)

1956: ontdekking anti-neutron (Berkeley)



Albert Einstein

$$E = mc^2$$



Energie en massa zijn equivalent

→ je kan *nieuwe* deeltjes maken

Anti-materie: $\gamma \rightarrow e^+e^-$



γ maakt via $E=mc^2$ een deeltje-antideeltje paar



Anti-materie: $\gamma \rightarrow e^+e^-$

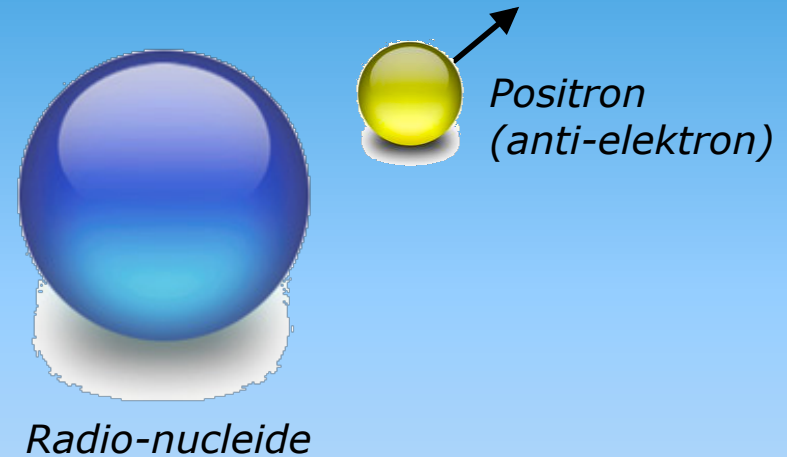


Deeltje-antideeltje paar maakt via $E=mc^2$ een γ

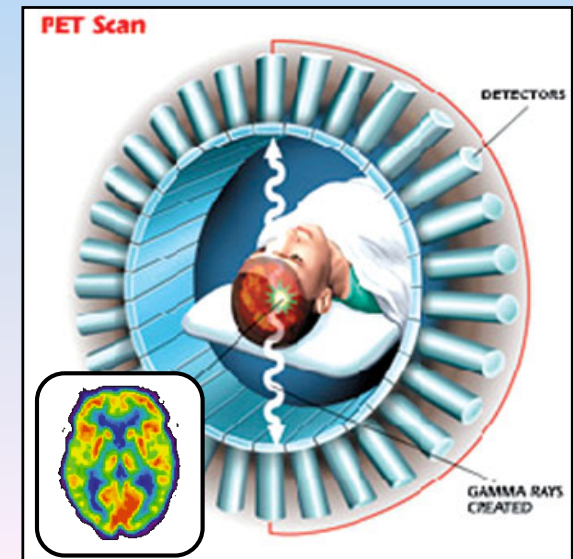
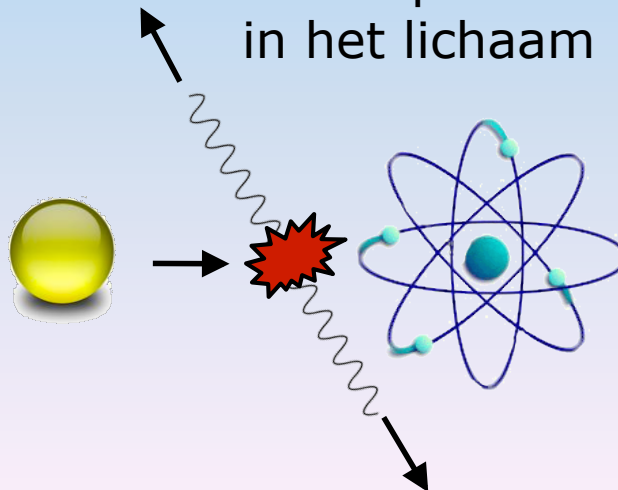


Anti-materie in het ziekenhuis: de PET scan

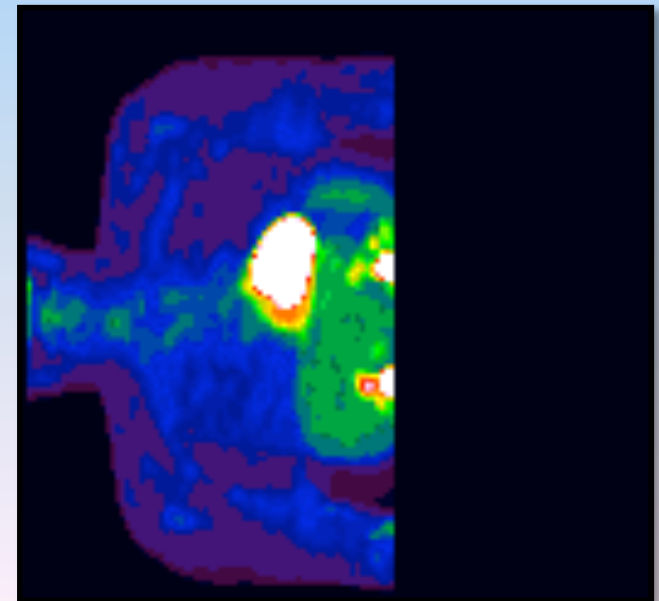
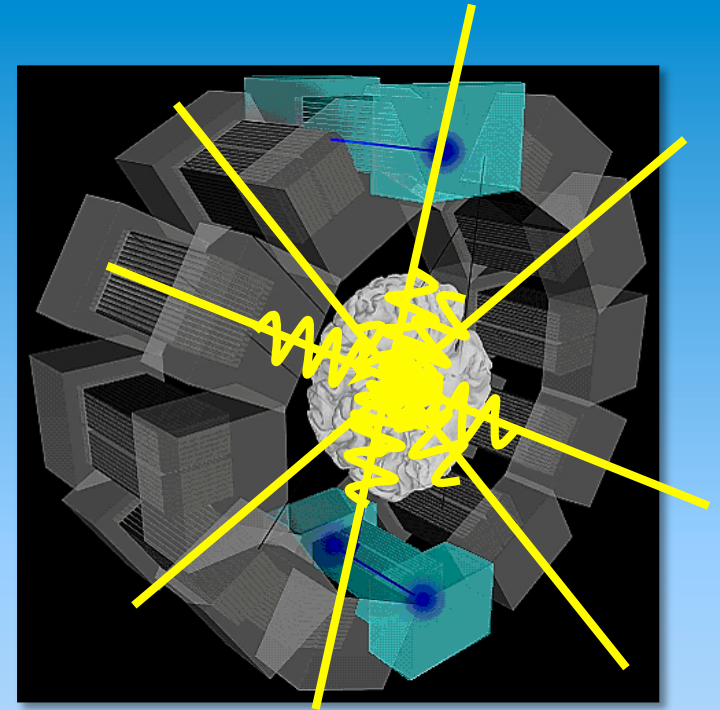
- 1) Injectie met radio-nuclide stof
→ zendt positronen uit



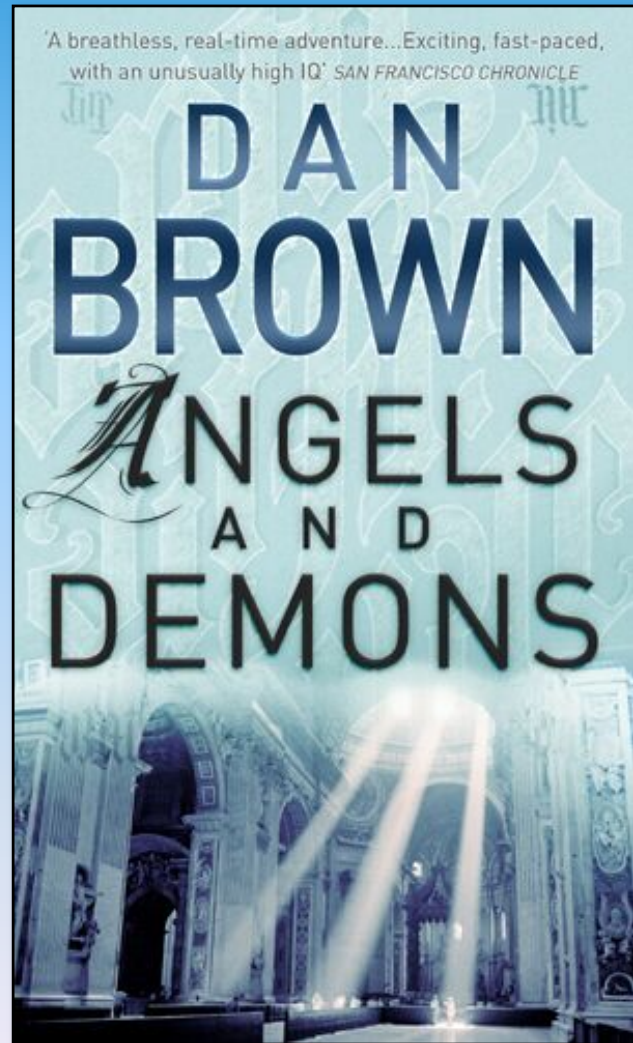
- 2) positron
botst op elektron van atoom
in het lichaam → 2 fotonen



Positron Emissie Tomografie



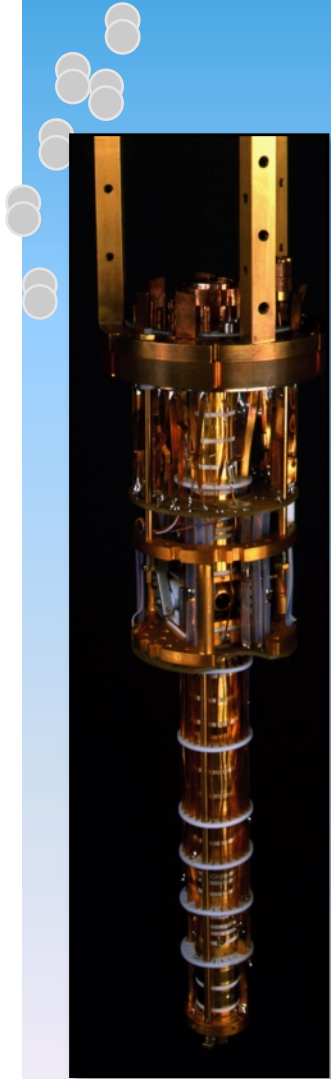
Dan Brown



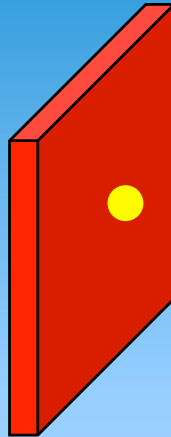
1/4 gram anti-protonen van CERN gestolen

Gebruik om het Vaticaan op te blazen

Productie van anti-waterstof: CERN vs Angels&Demons



CERN

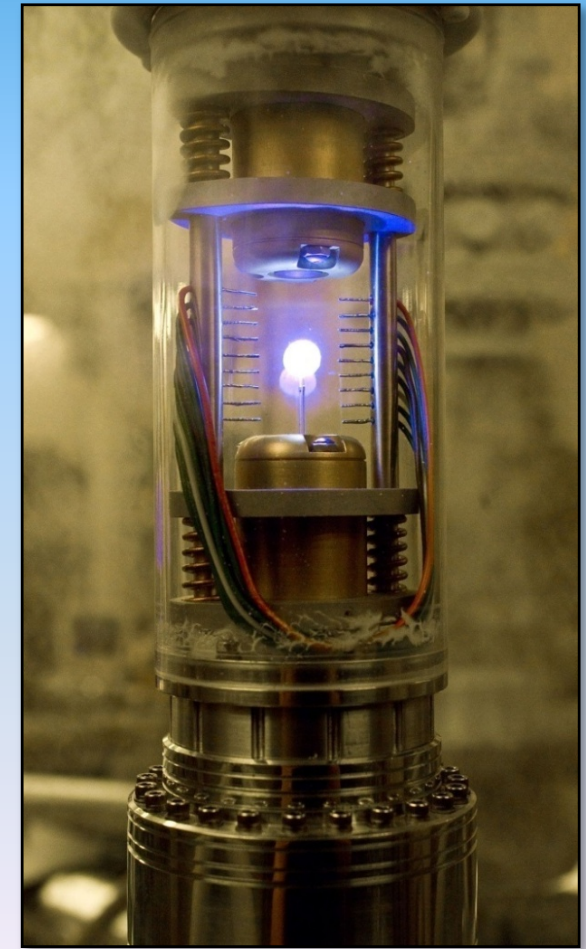


CERN kan 10 miljoen anti-protonen per seconde maken!

1 gram protonen ~
602,214,150,000,000,000,000,000

Hoe lang duurt het om $\frac{1}{4}$ gram anti-protonen te maken ?

~ $\frac{1}{2}$ miljard jaar !



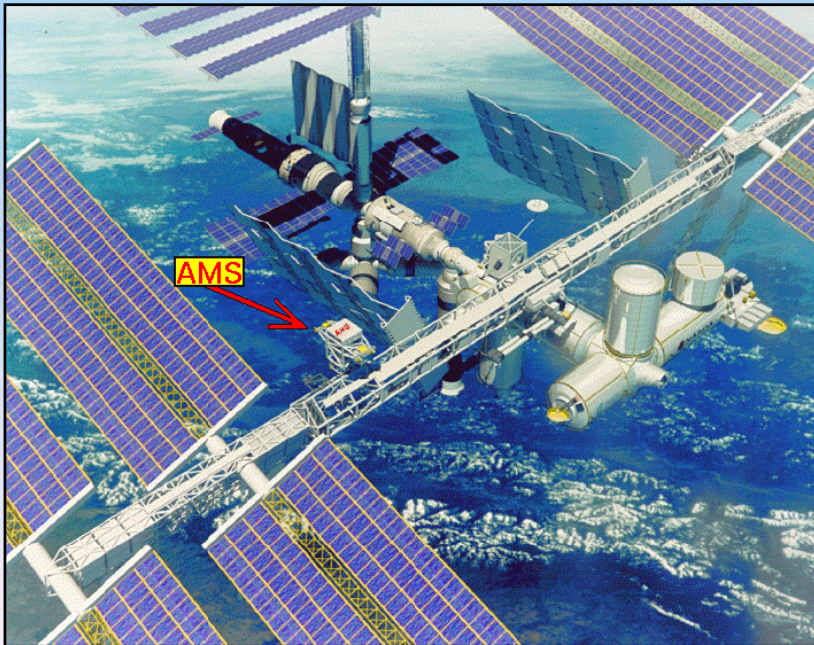
Dan Brown

2

Anti-materie: waar is het gebleven ?

Theorie: materie en anti-materie zijn 'gelijk'

Geen anti-materie in satellieten



Geen anti-materie sterrenstelsels

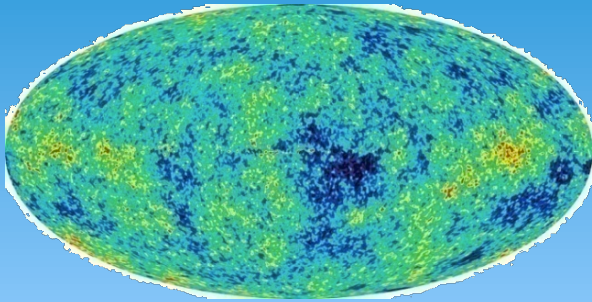




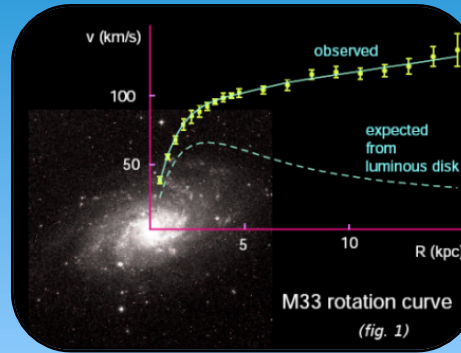
Revolutie in kosmologie laatste paar jaar
Structuur van het heelal

1

Donkere-materie



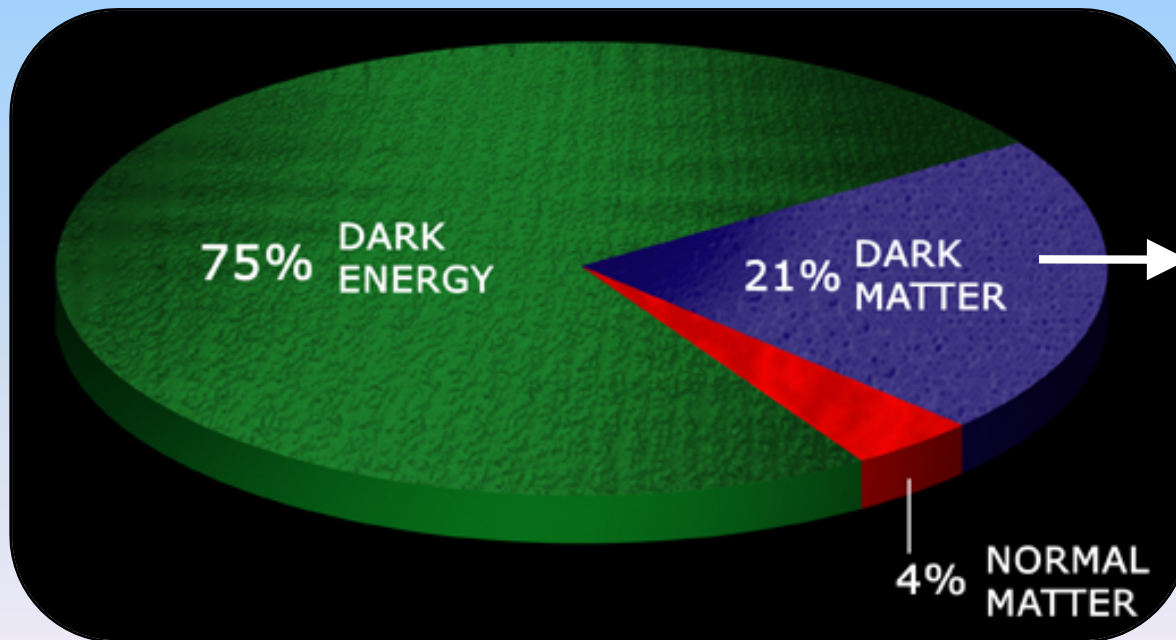
Temperatuurfluctuaties
structuur van het heelal



Rotatie-curves

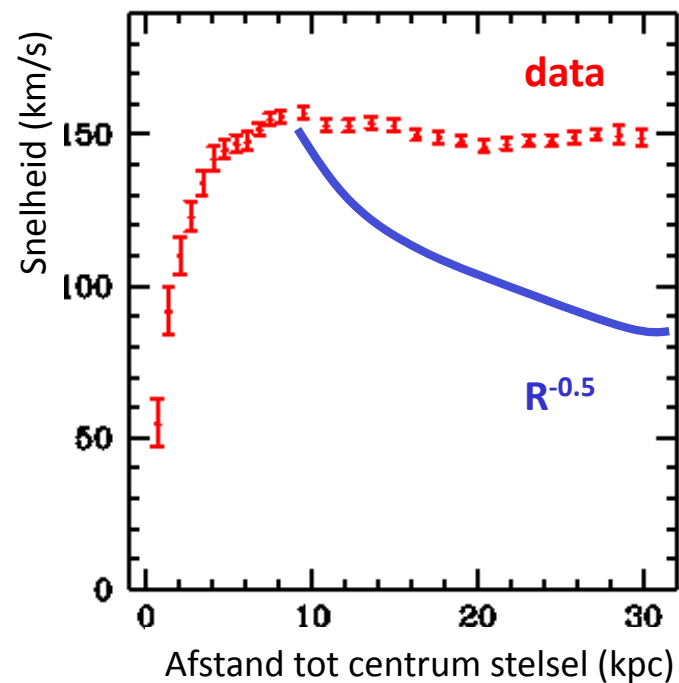
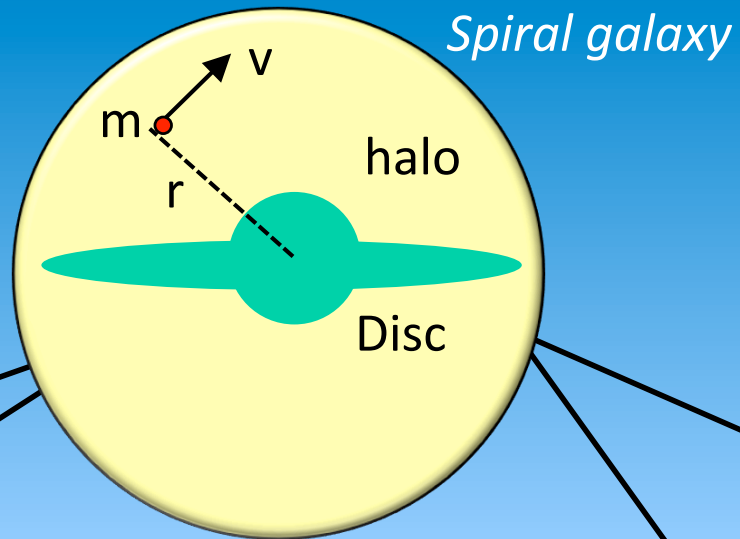


Cluster formaties &
gravitationele lens



Wat is de
donkere materie ?

We hebben al die tijd maar 4% van het heelal bestudeerd!



Rotatie

Gravitatie vs centrifugale kracht:

$$\frac{mv^2}{R} = G \frac{mM(R)}{R^2}$$

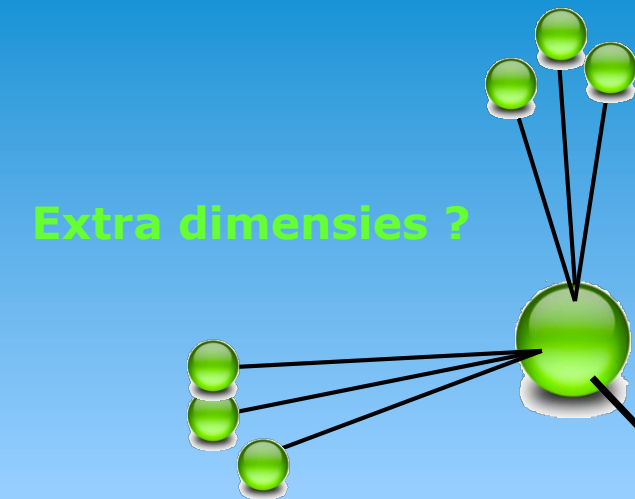
$$v = \sqrt{\frac{GM(R)}{R}}$$

Er is dus meer massa dan we kunnen zien ... donkere materie deeltjes ?



Revolutie in kosmologie laatste paar jaar
Structuur van het heelal

We proberen de donkere materie deeltjes
in het laboratorium maken



- Het Standard Model is 'effectief' deel van een meer fundamentele theorie
- Model verliest voorspellende waarde rond 1-10 TeV

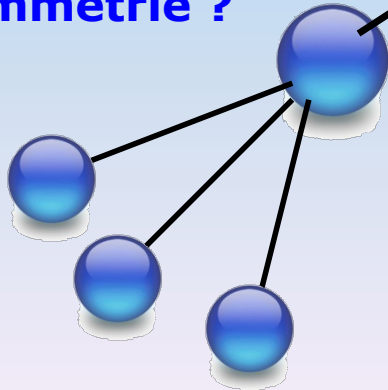


Nieuwe fenomenen bij $\sim 10^{-19}$ m

2010

String theorie ?

Supersymmetrie ?



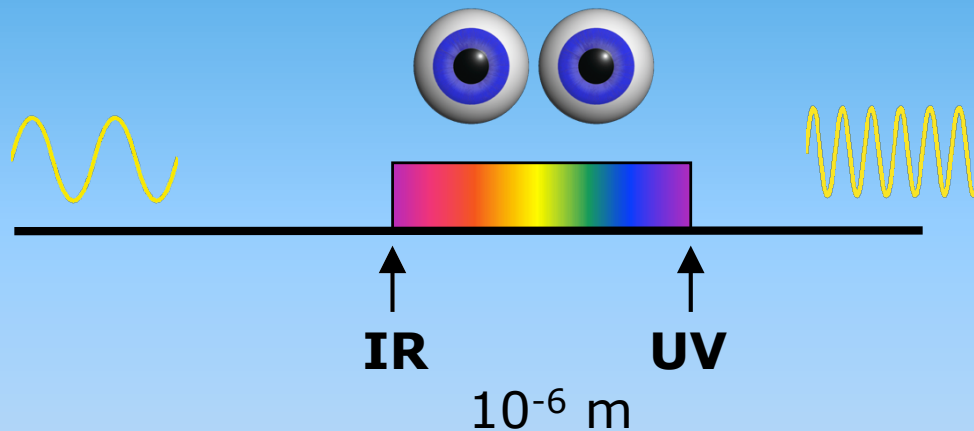
Edward Witten's
laatste inzicht.

kijken zonder je ogen te gebruiken



1] Kijken met licht

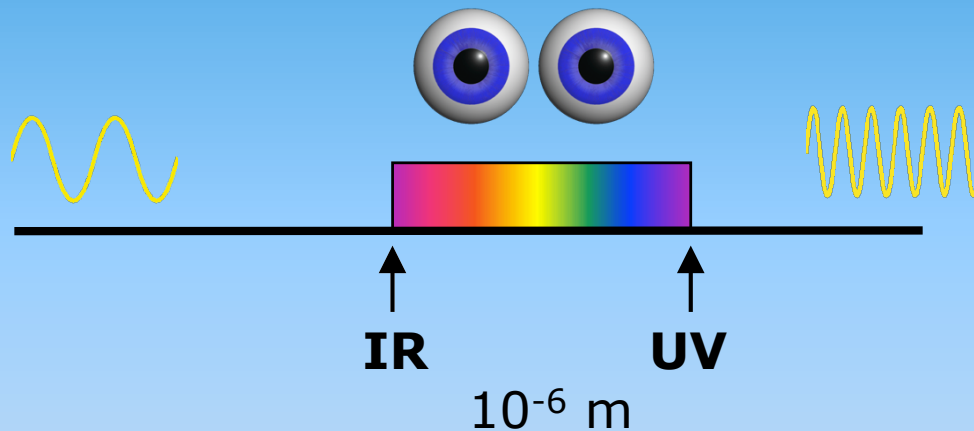
Licht verstrooit aan objecten die groter zijn dan zijn golflengte



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



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

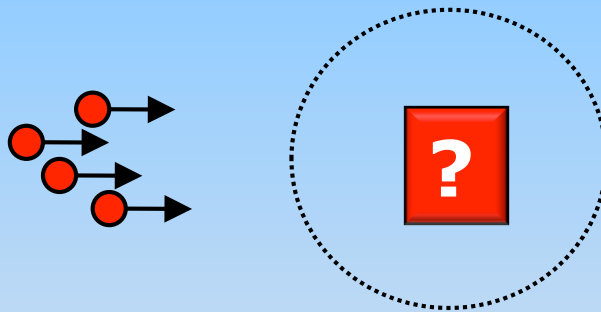
2] Kijken met deeltjes

Idee: laat kleine deeltjes afketsen van het object

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

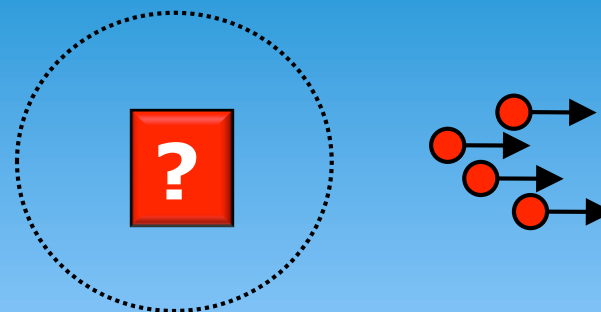
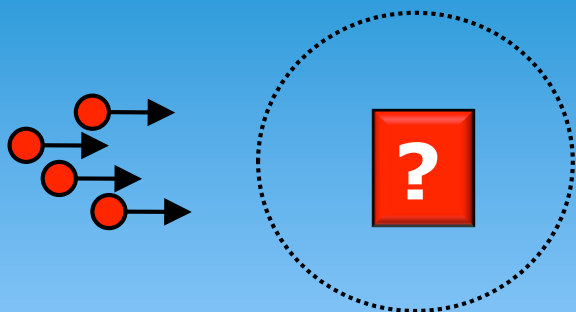
onbekend voorwerp achter een gordijn ... en 100 kogeltjes

bovenaanzicht

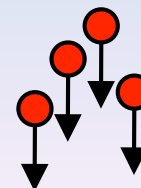
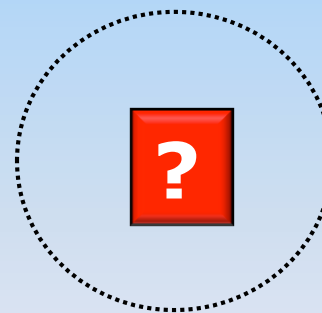
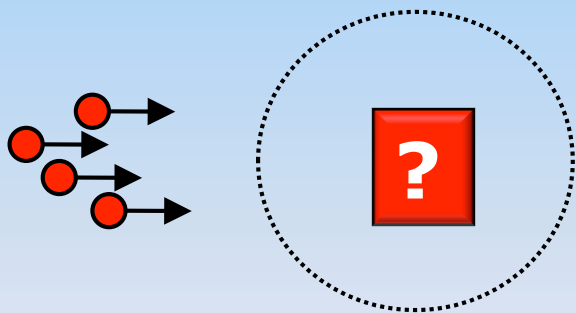


Hoe ketsen de kogels af ?

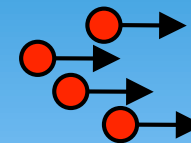
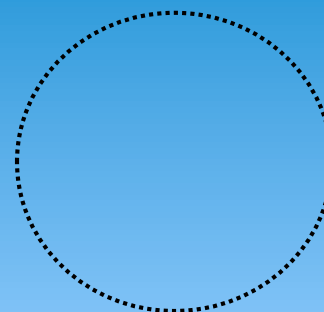
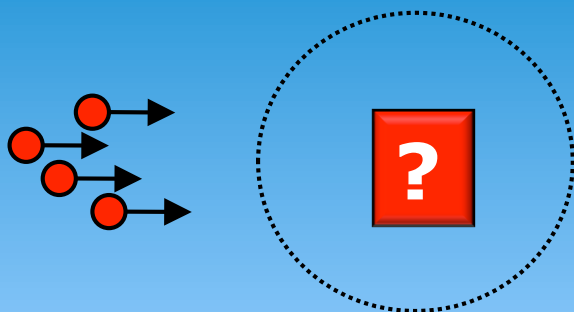
Experiment 1



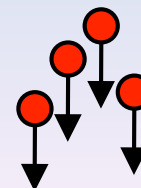
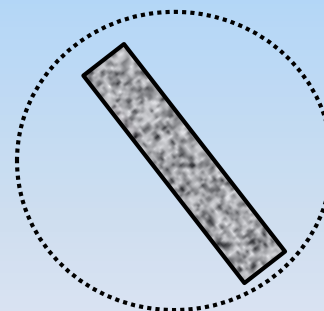
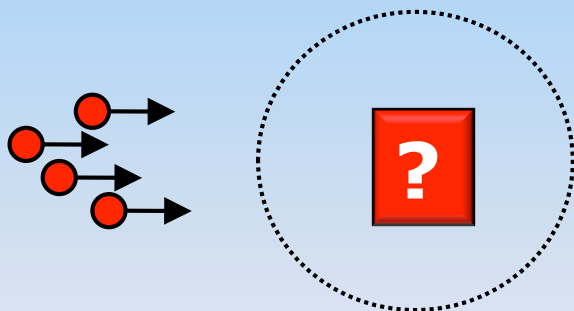
Experiment 2



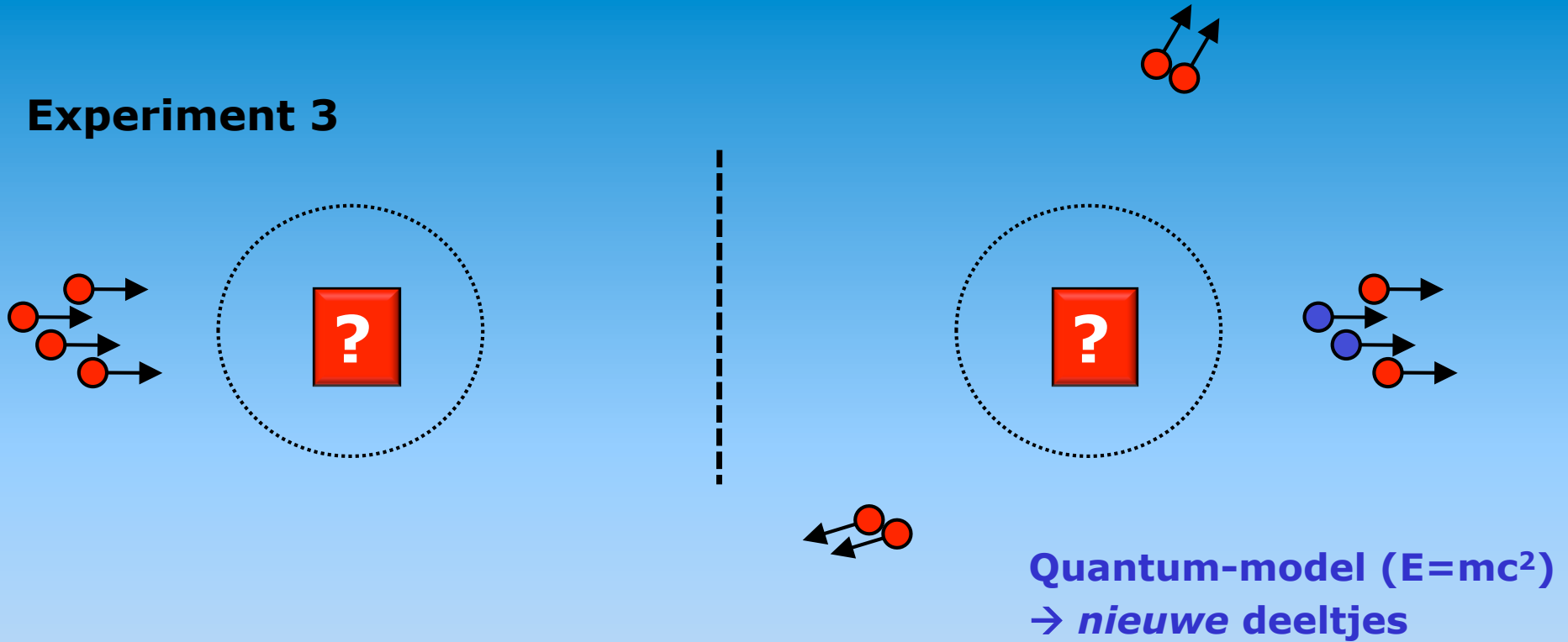
Experiment 1



Experiment 2



Experiment 3

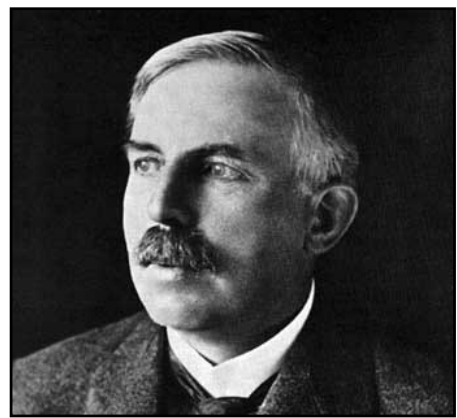


'Kijken' naar sub-atomaire structuren:

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

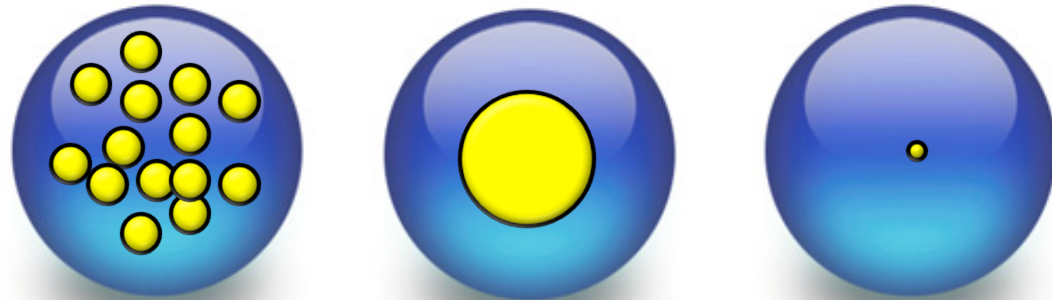
Deeltjesversneller
Theorie
Detector

Het atoom

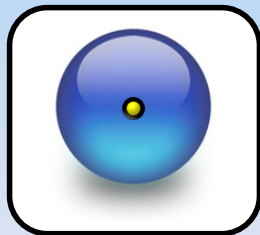


Rutherford

Thomson



Hypothese:



en

$$F \propto \frac{1}{r^2}$$

$$\frac{d\sigma}{d\Omega}(\theta) = \left(\frac{ZZ'}{4E} \right)^2 \frac{1}{\sin^4\left(\frac{\theta}{2}\right)}$$

Meting:

Scattering of α and β Particles by Matter.

681

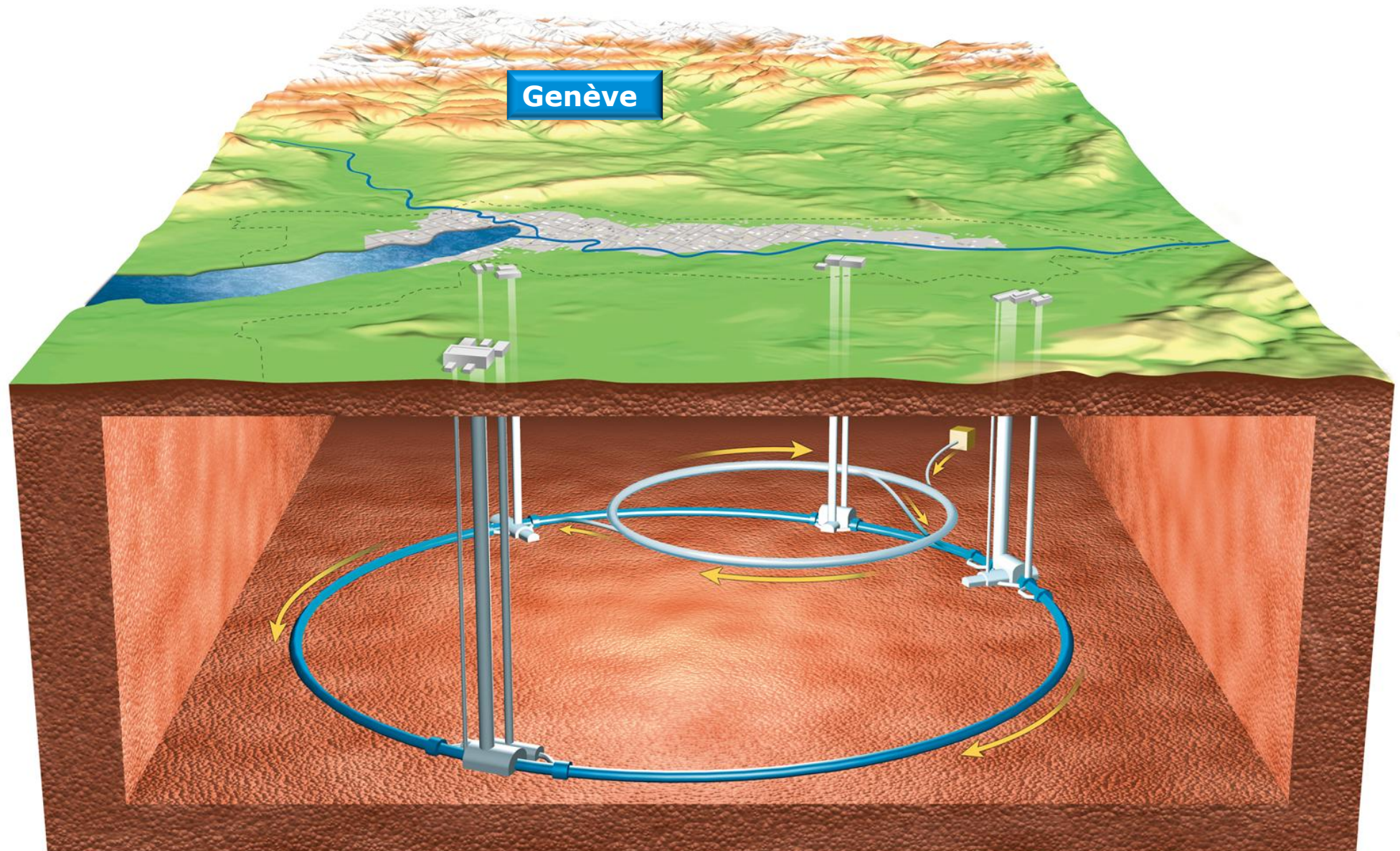
Metal.	Atomic weight.	z .	$z/A^{3/2}$.
Lead	207	62	208
Gold	197	67	242
Platinum	195	63	232
Tin	119	34	226
Silver	108	27	241
Copper	64	14.5	225
Iron	56	10.2	250
Aluminium ...	27	3.4	243
Average			233

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.

Pauze

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

De LHC deeltjesversneller



De Large Hadron Collider

LHC: 27 km



A10: 32 km



De LHC machine

Versnellen is een eitje



Hoge energie: 14 TeV

Energie begrensd door sterkte van de 1232
dipool magneten, met $B = 8.4 \text{ T}$ bij 1.9 K

→ *Mogelijke productie zware deeltjes (tot 4 TeV)*

→ 7 x Tevatron

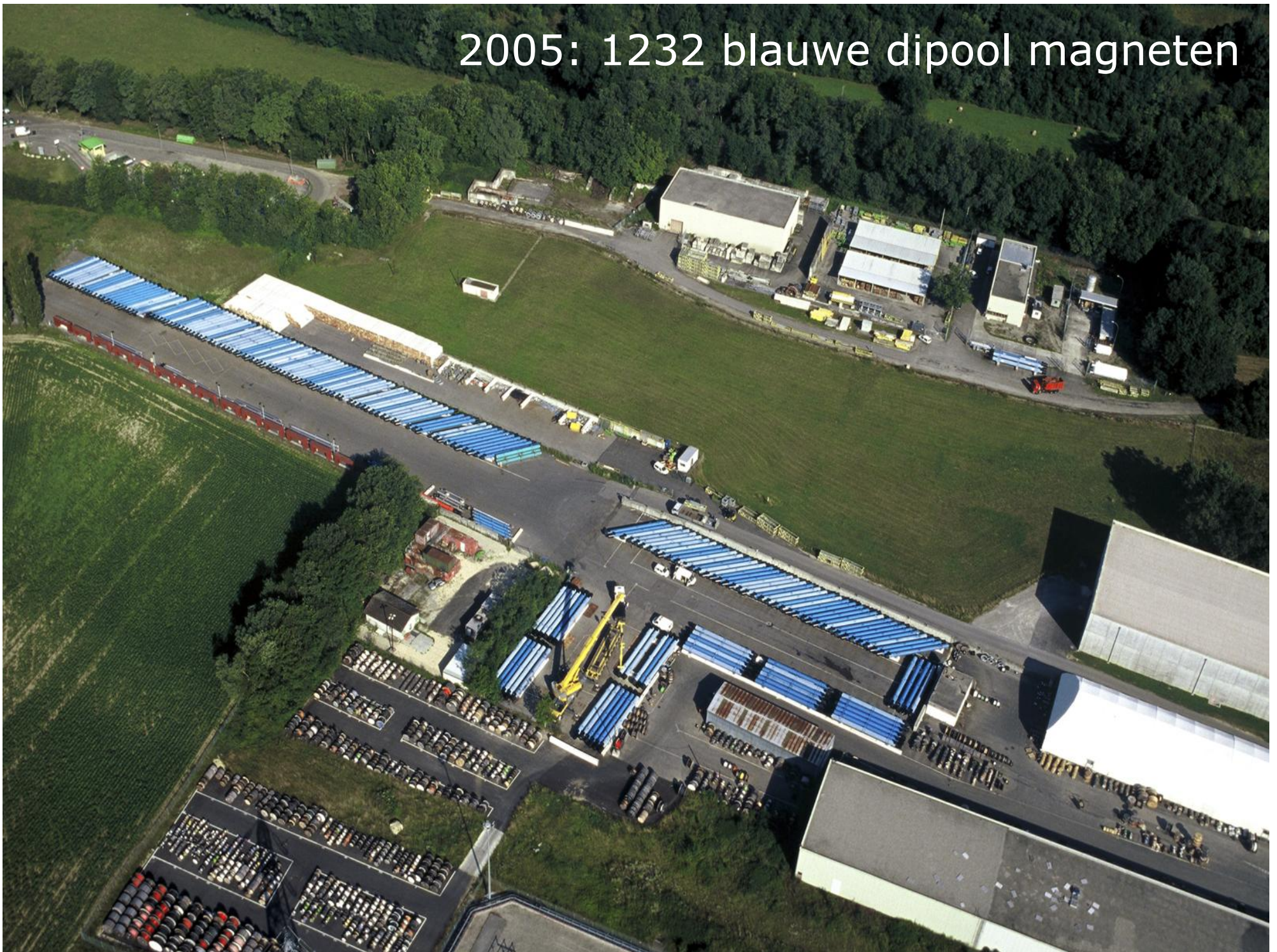
20 goud atomen

Hoge intensiteit: $10^{33/34} \text{ cm}^{-2}\text{s}^{-1}$ (40 M bots/sec)

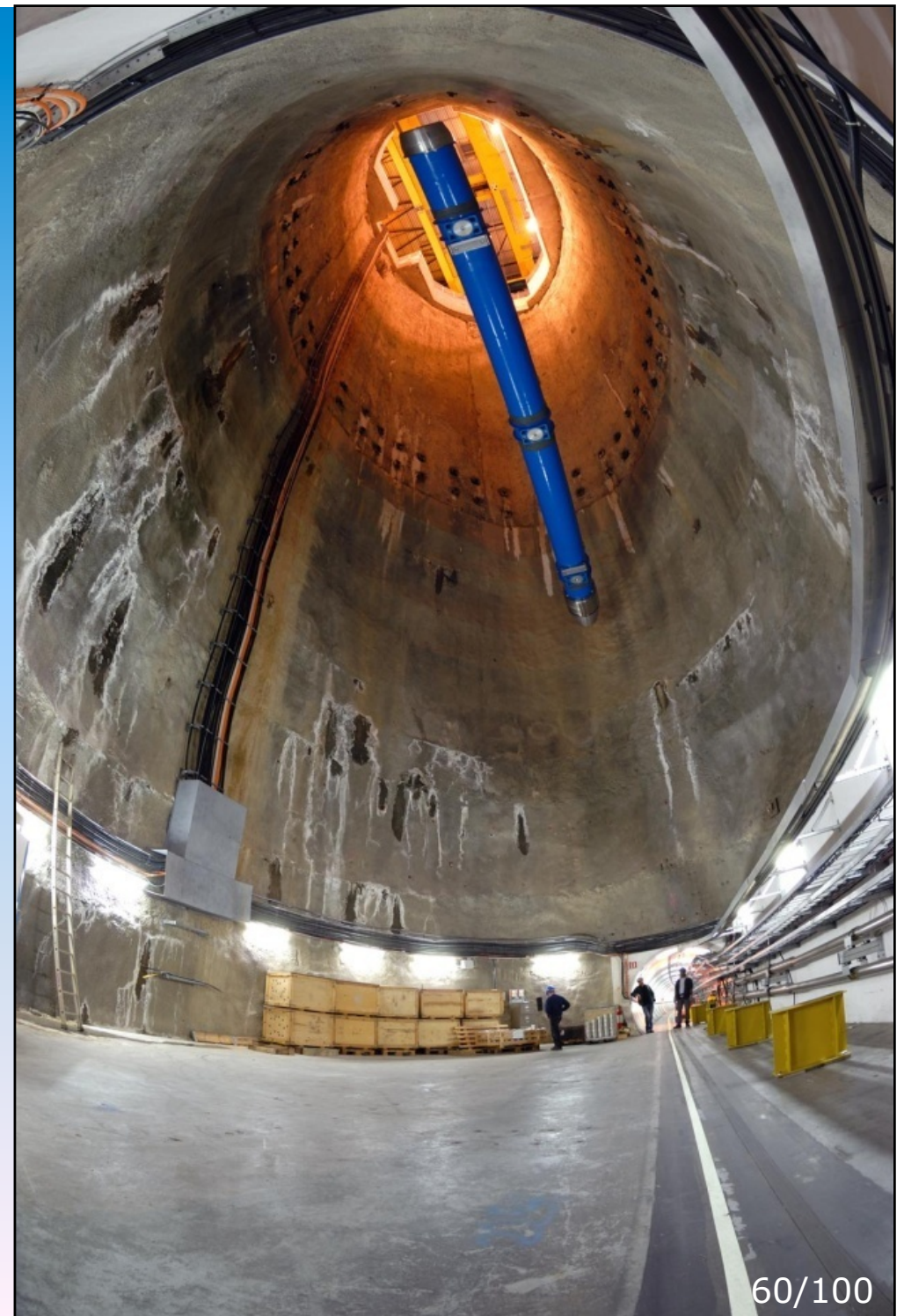
→ *Zoeken naar zeldzame gebeurtenissen*

→ 100 x LEP &
Tevatron

2005: 1232 blauwe dipool magneten

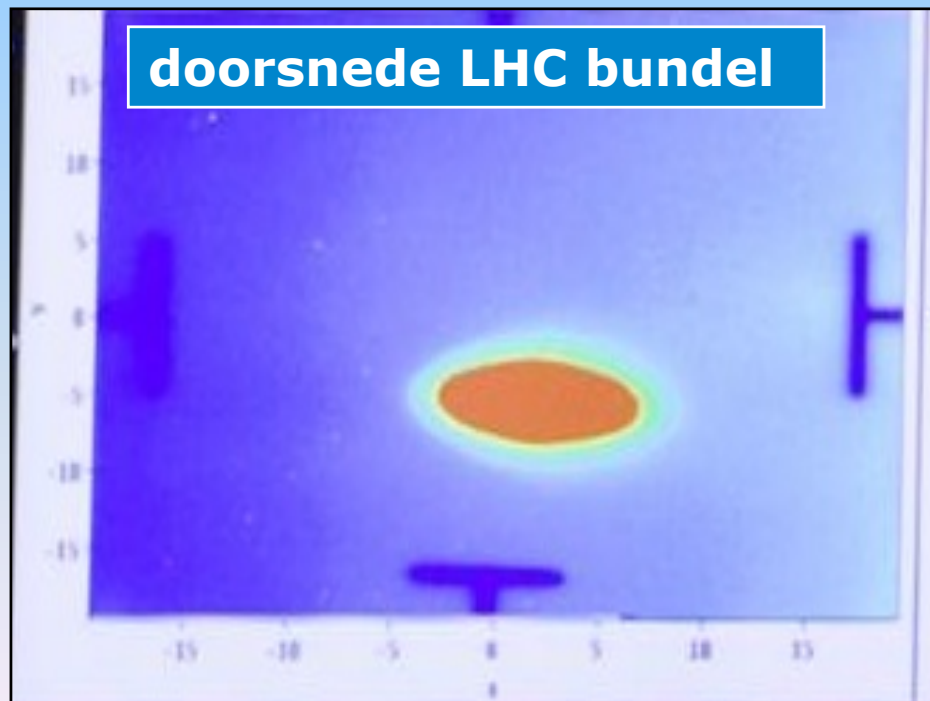


Logistieke nachtmerrie
maar gelukt



De LHC is rond !

“Op 10 september 2008 hebben bundels protonen een rondje in LHC gemaakt”

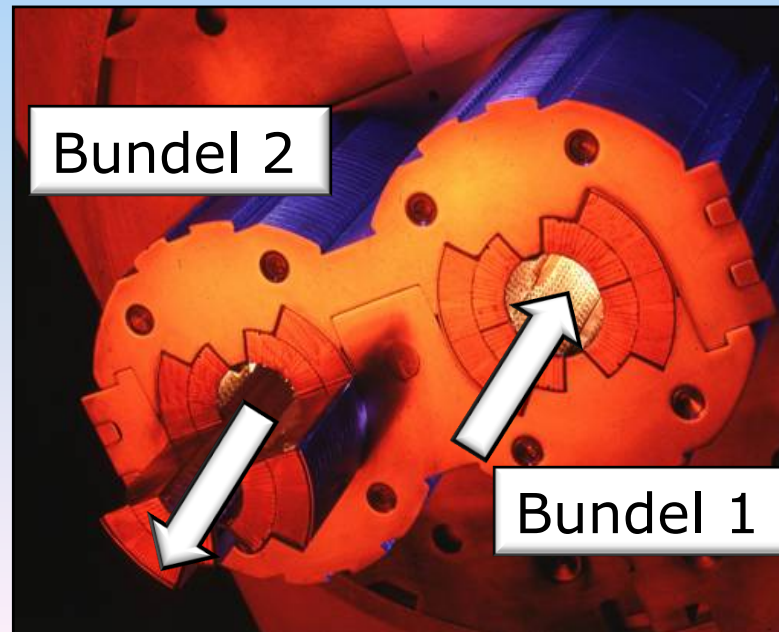


Energie 1 proton (LHC)



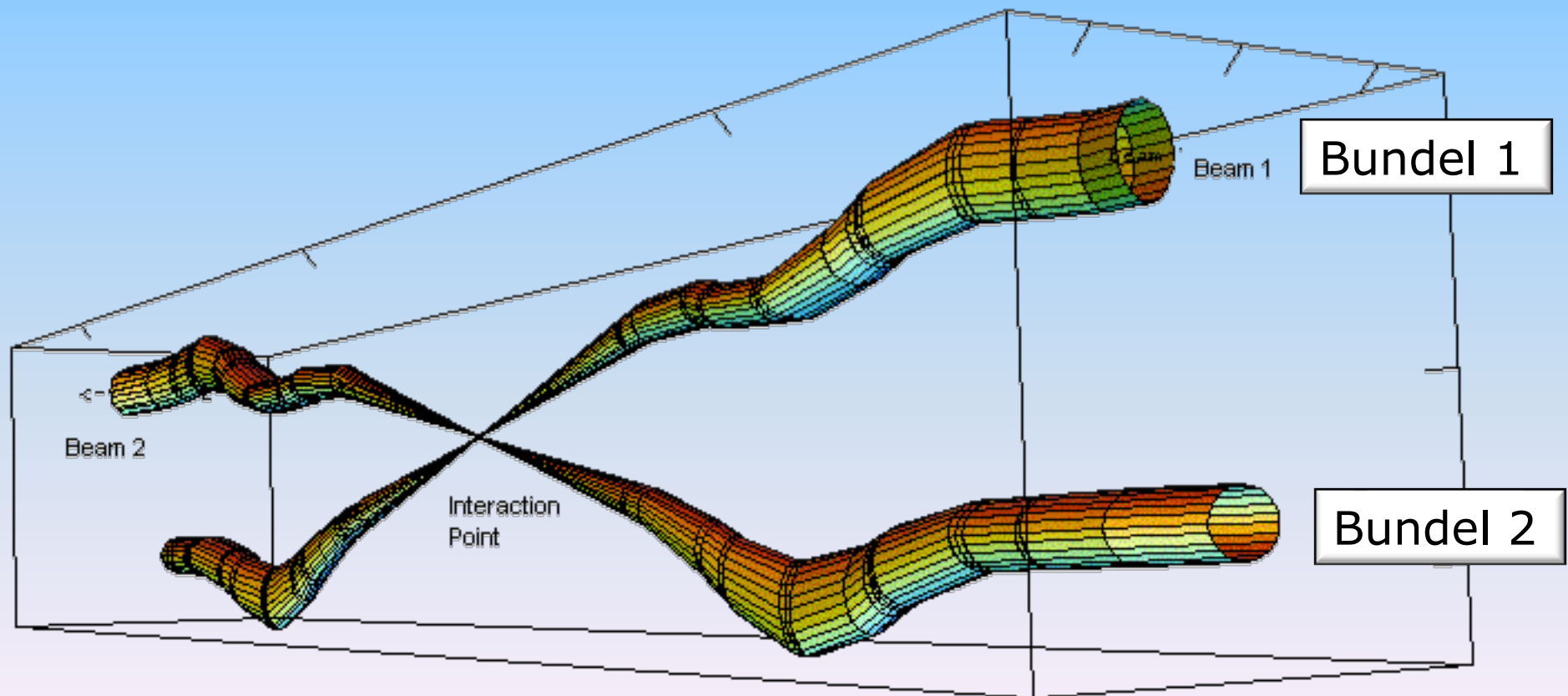
Energie LHC bundel

$3000 \times 100.000.000.000$ protonen



*Doorsnede LHC
bundelpijp*

40 miljoen botsingen per seconde





Klassiek botsen

Quantummechanisch botsen



Wat verwacht je ?

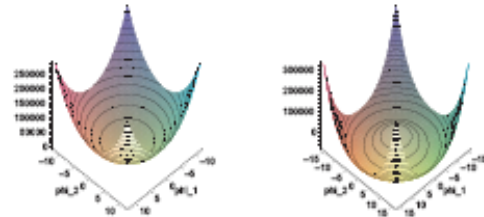


FIG. 1: The potential $V(\phi)$ ($\phi = \phi_1 + i\phi_2$) plotted for an arbitrary positive value of λ and for an arbitrary positive (right) or negative (left) value of μ^2 .

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:

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

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 *unitary gauge* or *unitarity gauge*, the Lagrangian becomes:

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

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: $H \rightarrow \gamma\gamma, \gamma Z, gg$

At the lowest order the decay rate for $H \rightarrow \gamma\gamma$ can be written

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

where 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:

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

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

At the lowest order the decay rate for $H \rightarrow \gamma Z$ is given by:

$$\Gamma(H \rightarrow \gamma Z) = \frac{M_W^2 \alpha M_H^2}{64\pi^4} \left(1 - \frac{M_Z^2}{M_H^2}\right)^2 \left| \sum_f A_f^H(\tau_f, \lambda_f) + A_W^H(\tau_W, \lambda_W) \right|^2 , \quad (105)$$

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

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

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

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

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

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

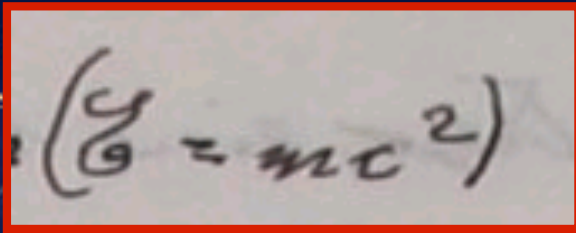
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$$\frac{\tau\lambda}{(\tau-\lambda)} + \frac{\tau^2\lambda^2}{2(\tau-\lambda)^2}[f(\tau) - f(\lambda)] + \frac{\tau^2\lambda}{(\tau-\lambda)^2}[g(\tau) - g(\lambda)] ,$$

Klopt het ?

Inderdaad nieuwe deeltjes ?

Albert Einstein


$$E = mc^2$$



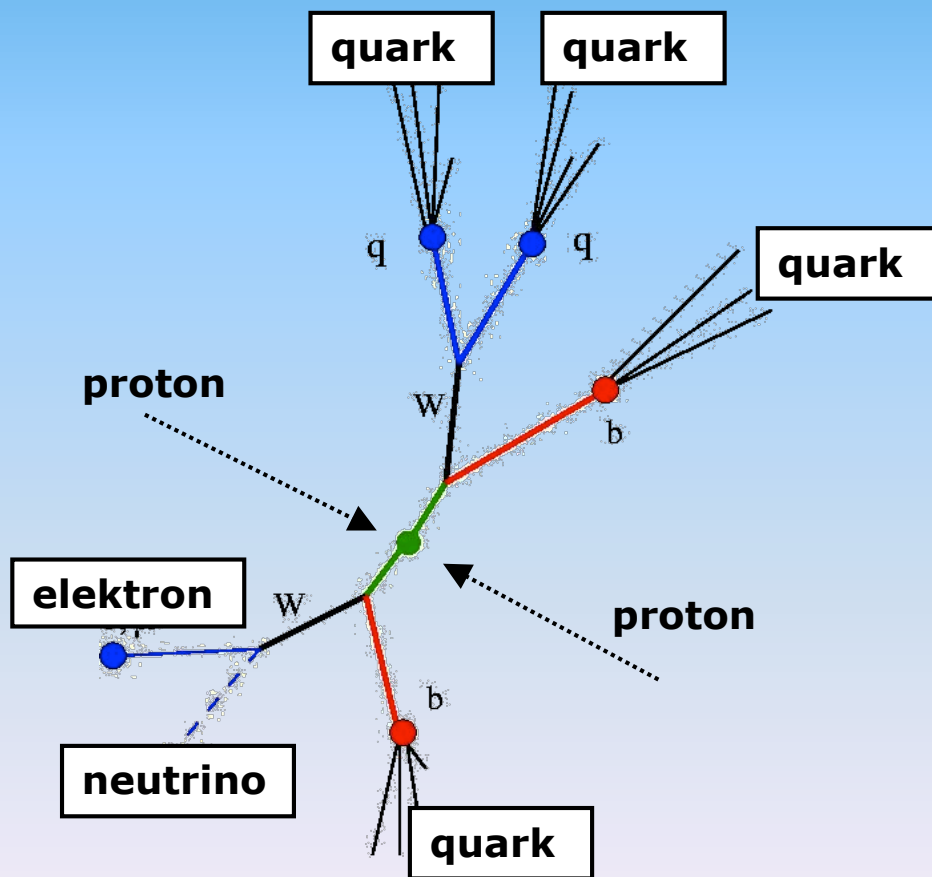
Bij de LHC op CERN:

Energie omzetten in massa (deeltjes)
→ je kan *nieuwe* deeltjes maken

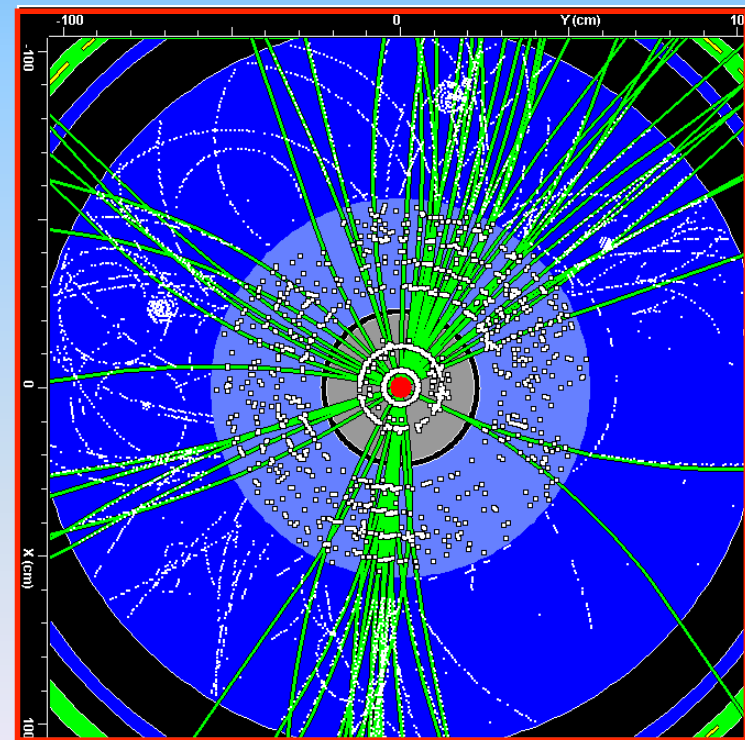


Heel vaak botsen

Hoe zien die botsingen er nou uit ?



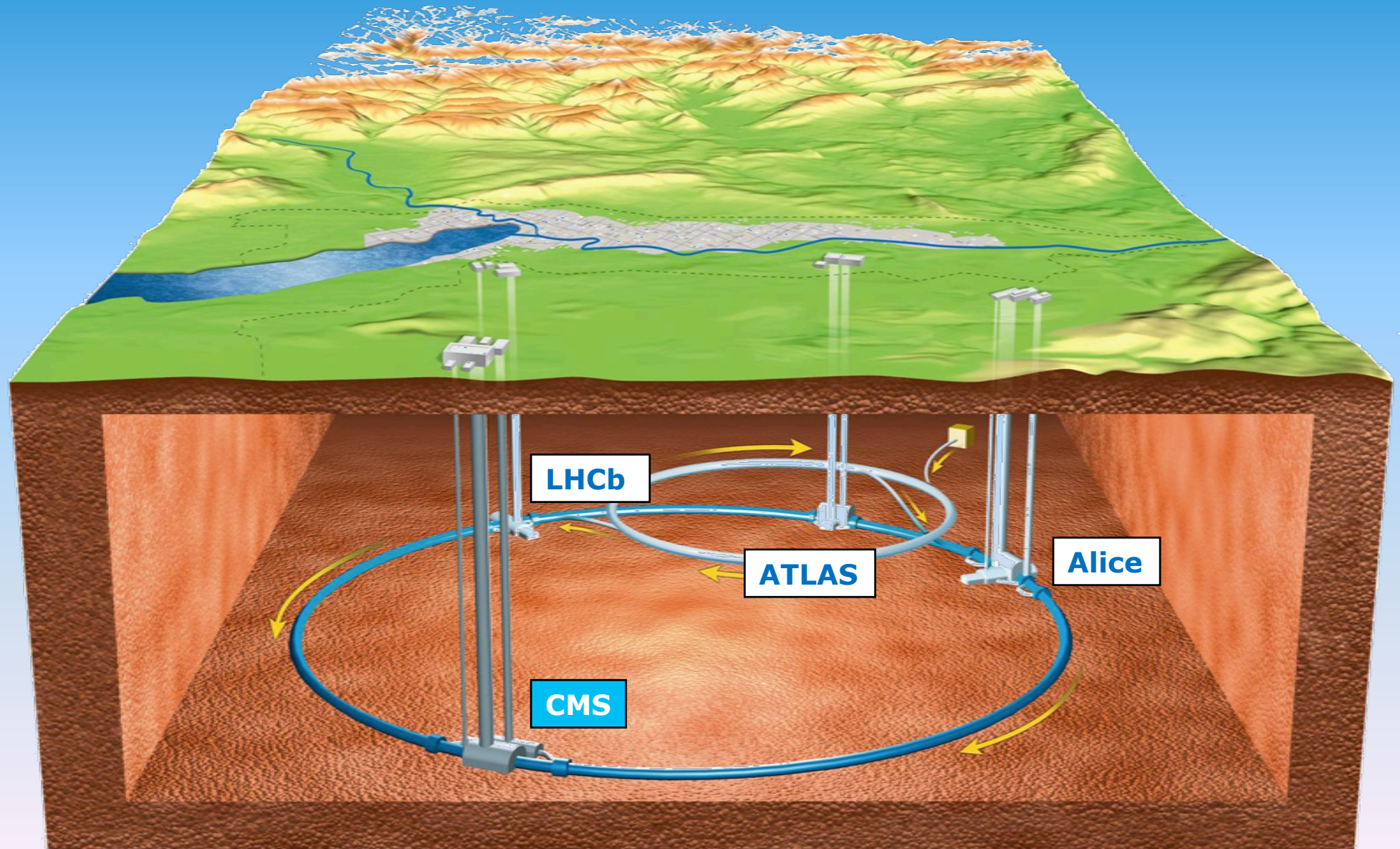
Simulatie top quark productie



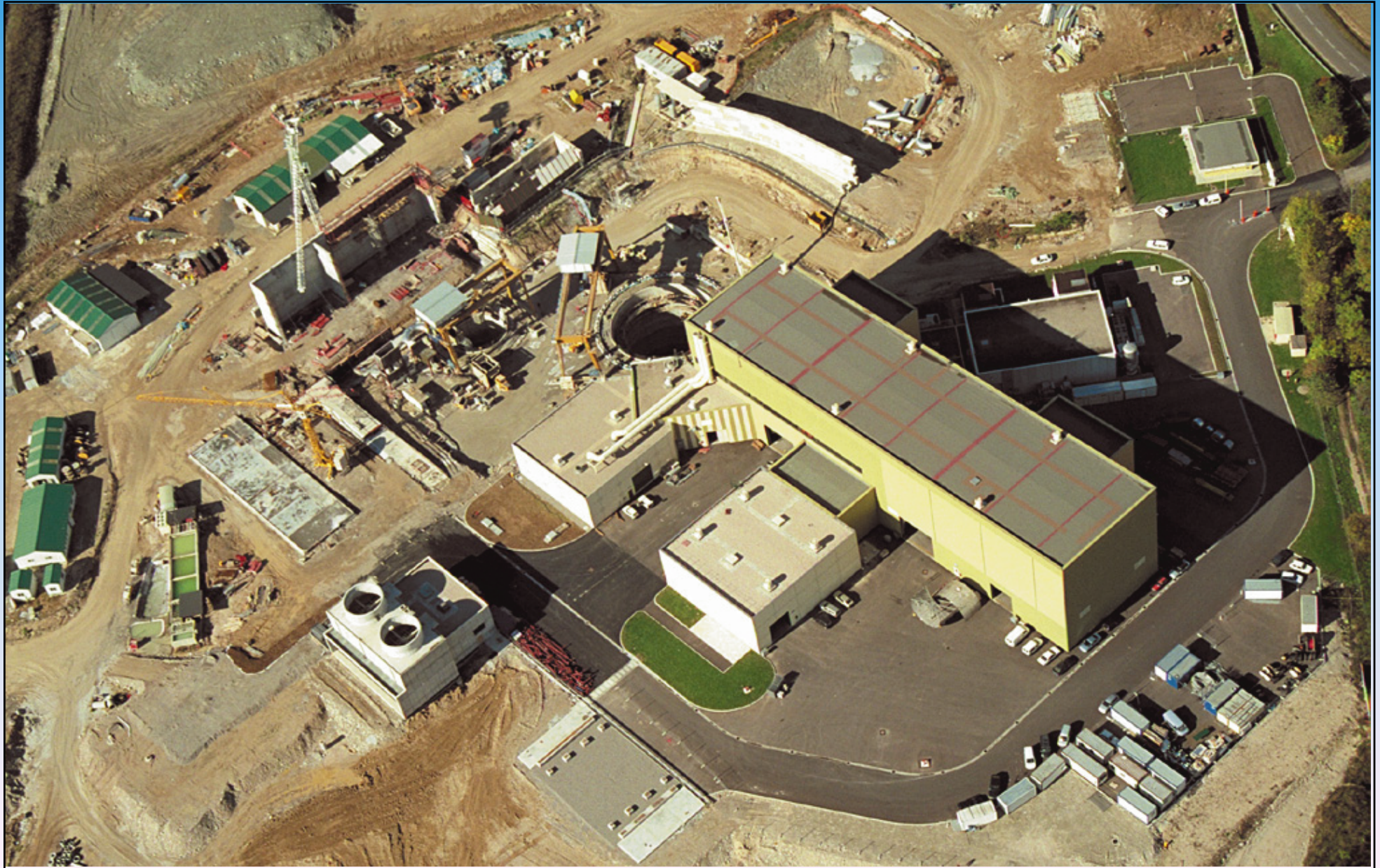
Onze 'fototoestellen'



De vier experimenten



Een gat in de grond ... ongeveer 100 meter diep



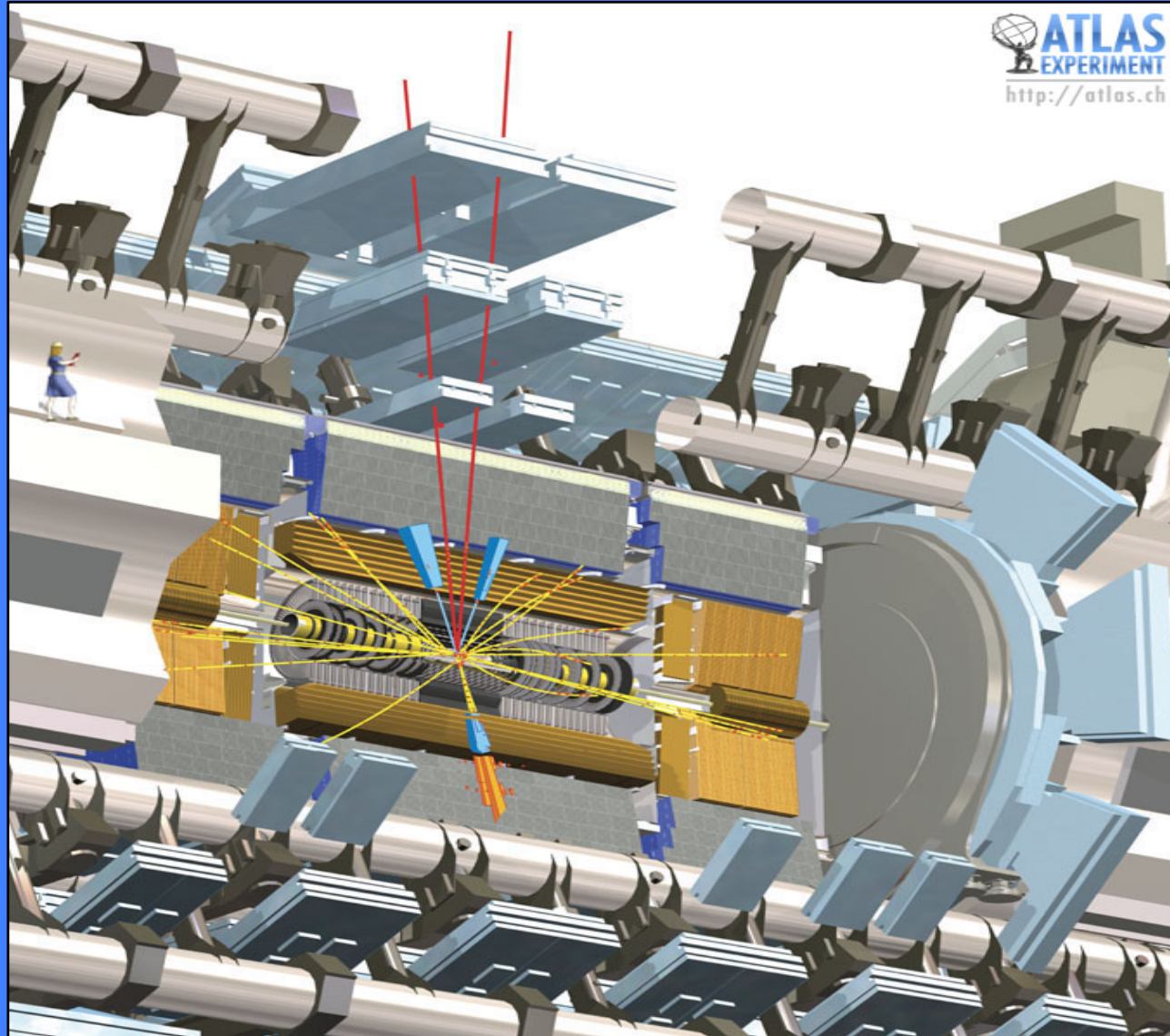
Op 100 meter diep een grote grot maken



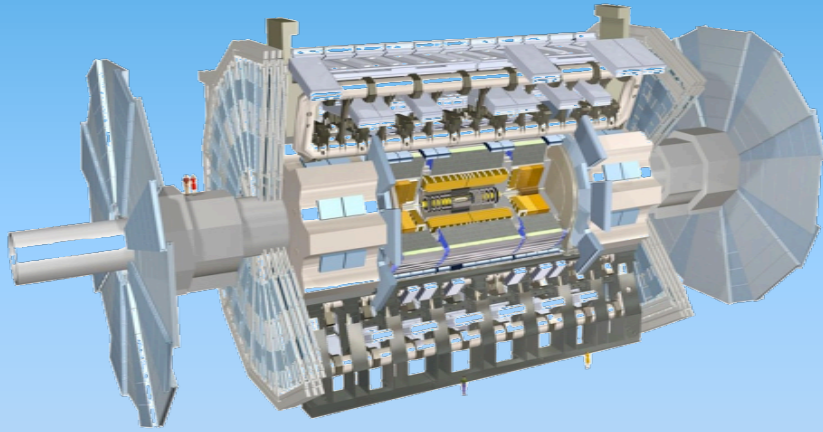


De Atlas detector

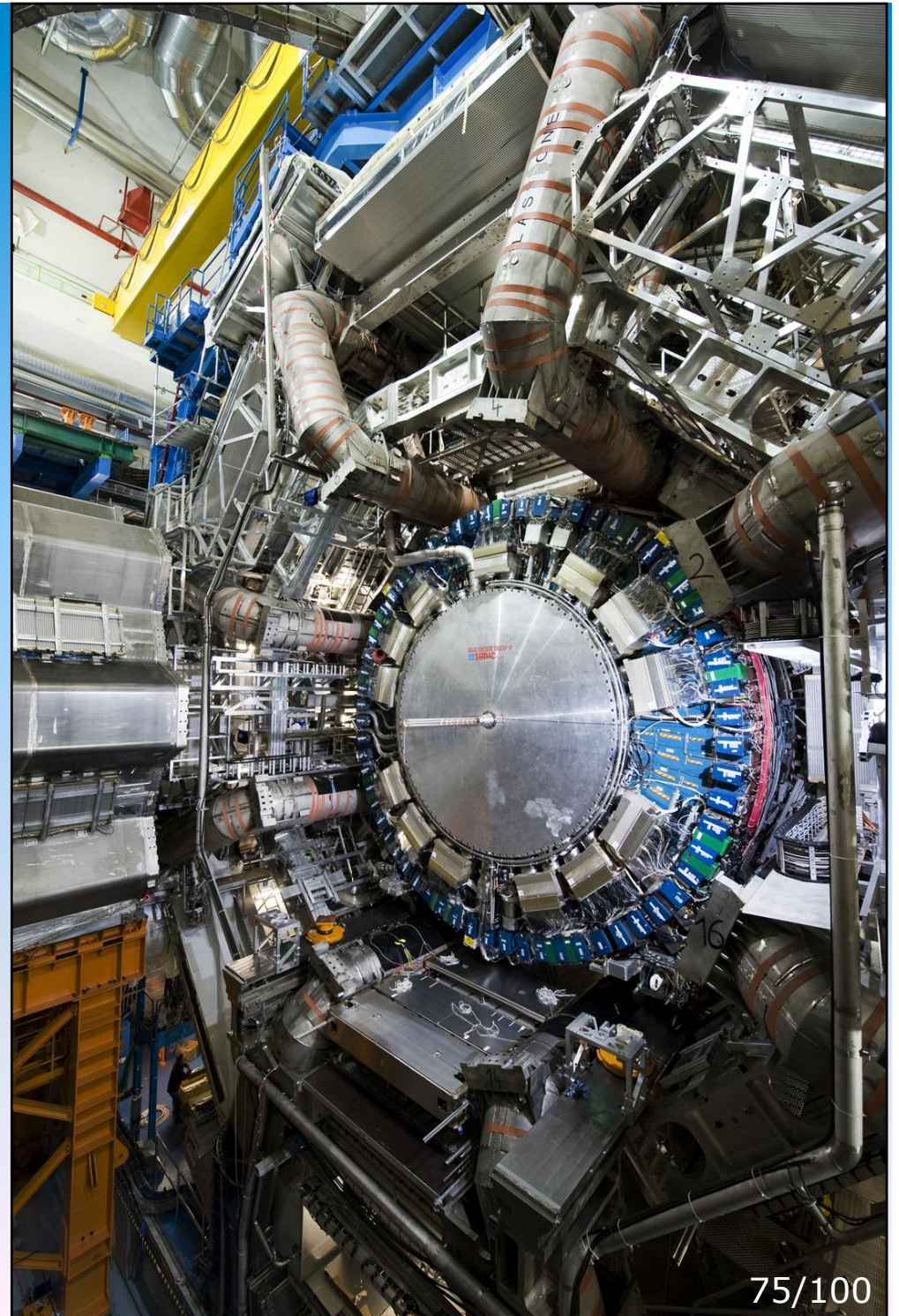
het grootste fototoestel op aarde



De ATLAS detector



45 m lang, 25 m hoog, 7000 ton





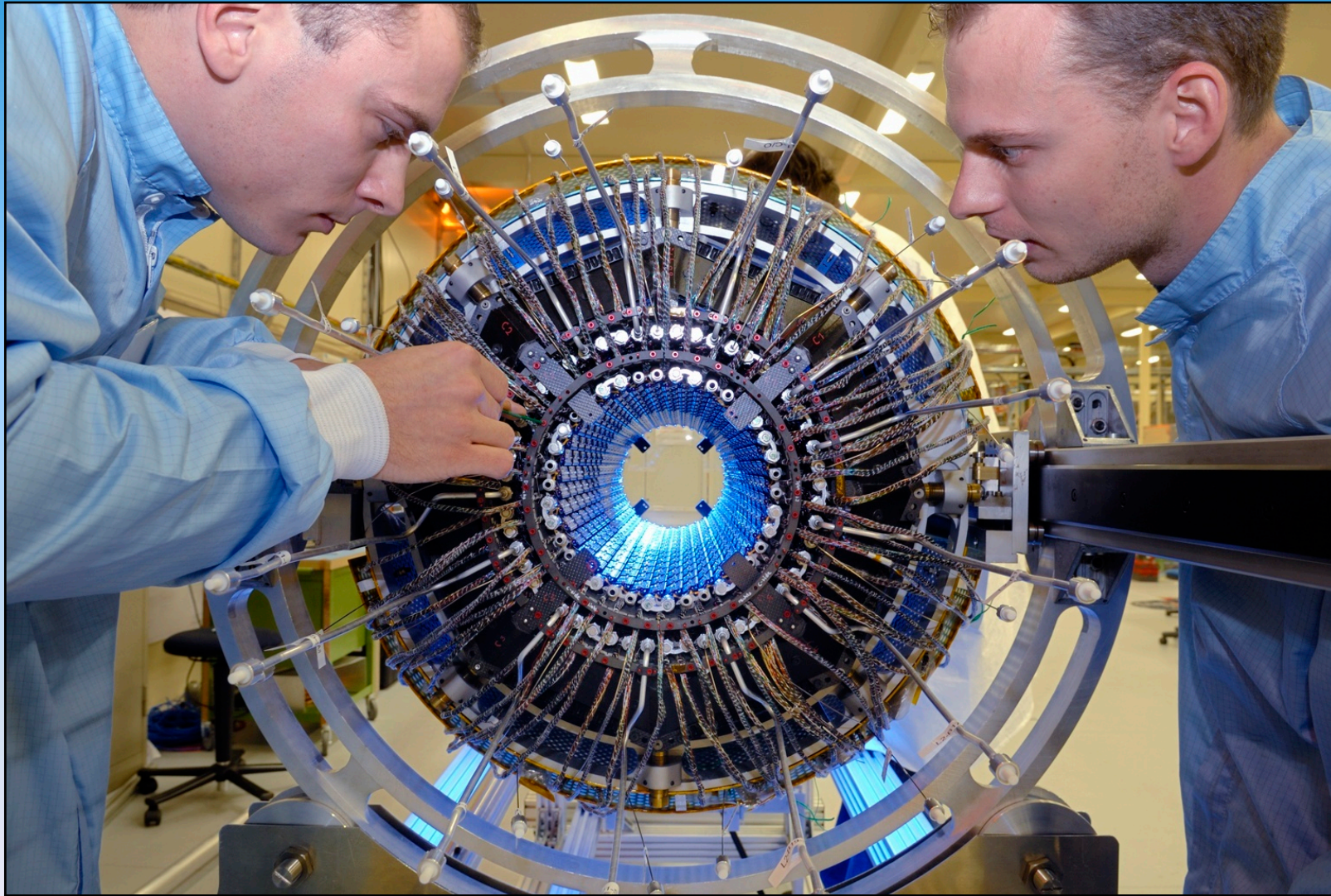
De Atlas detector bestaat echt



nieuwe baas

oude baas

De Atlas pixel detector



80 MegaPixel camera 40.000.000 foto's per seconde

De Atlas SCT detector

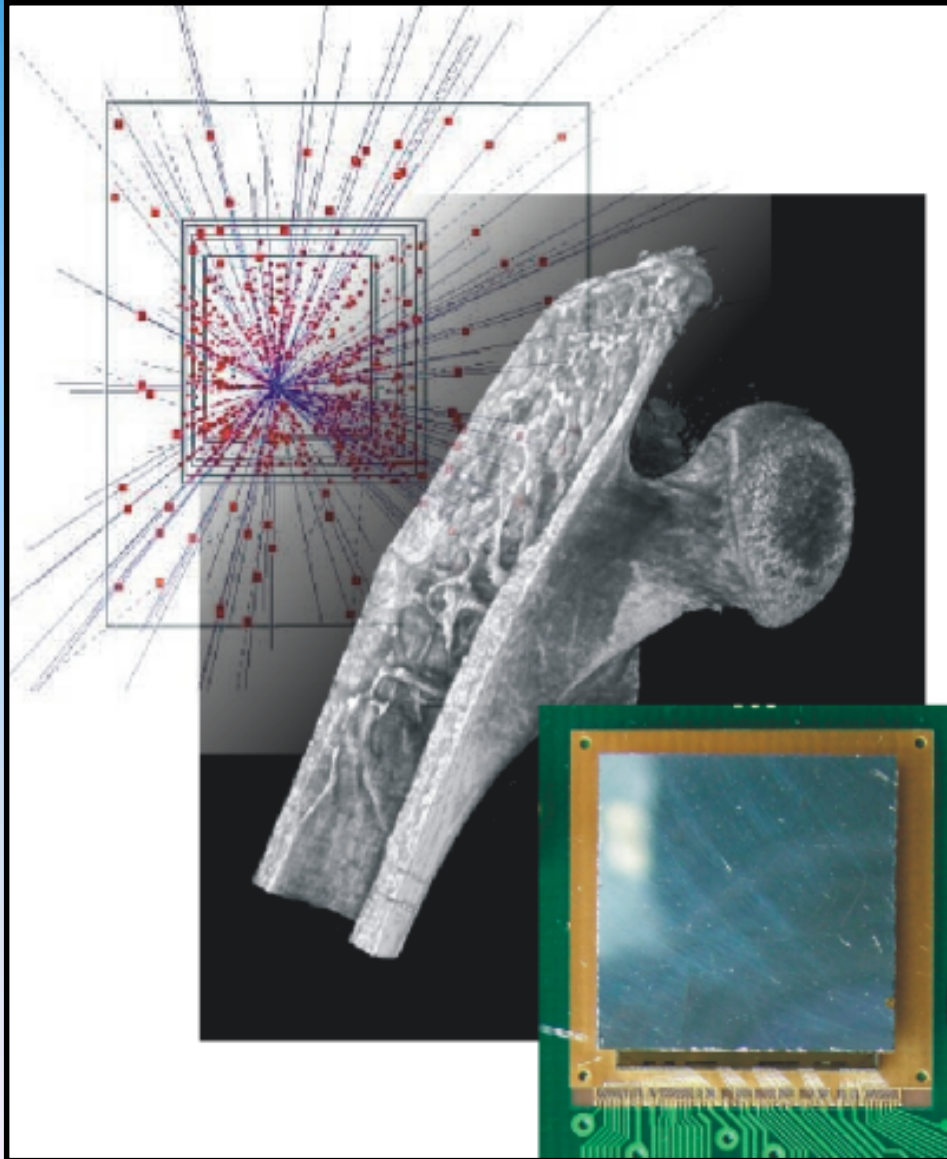


Foto in de cleanroom op het Nikhef (Amsterdam)

Puzzelen voor gevorderden



Detectietechnieken: Medipix

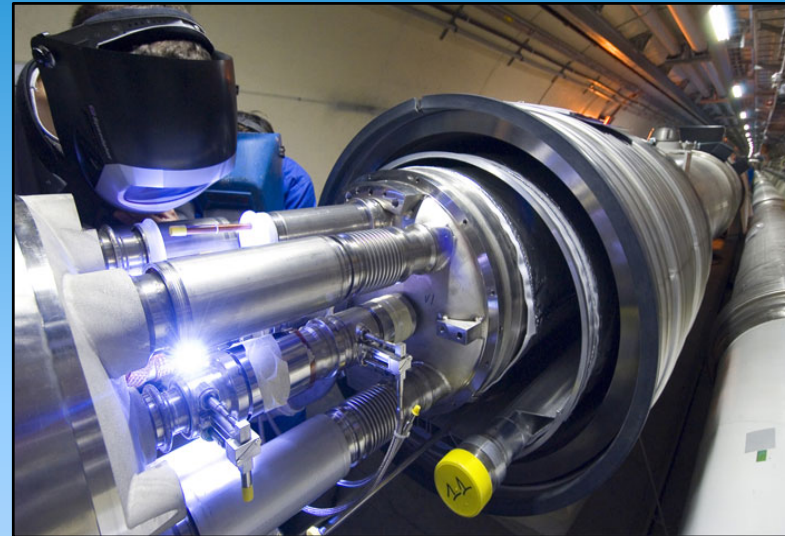


Minder dosis
Hogere resolutie

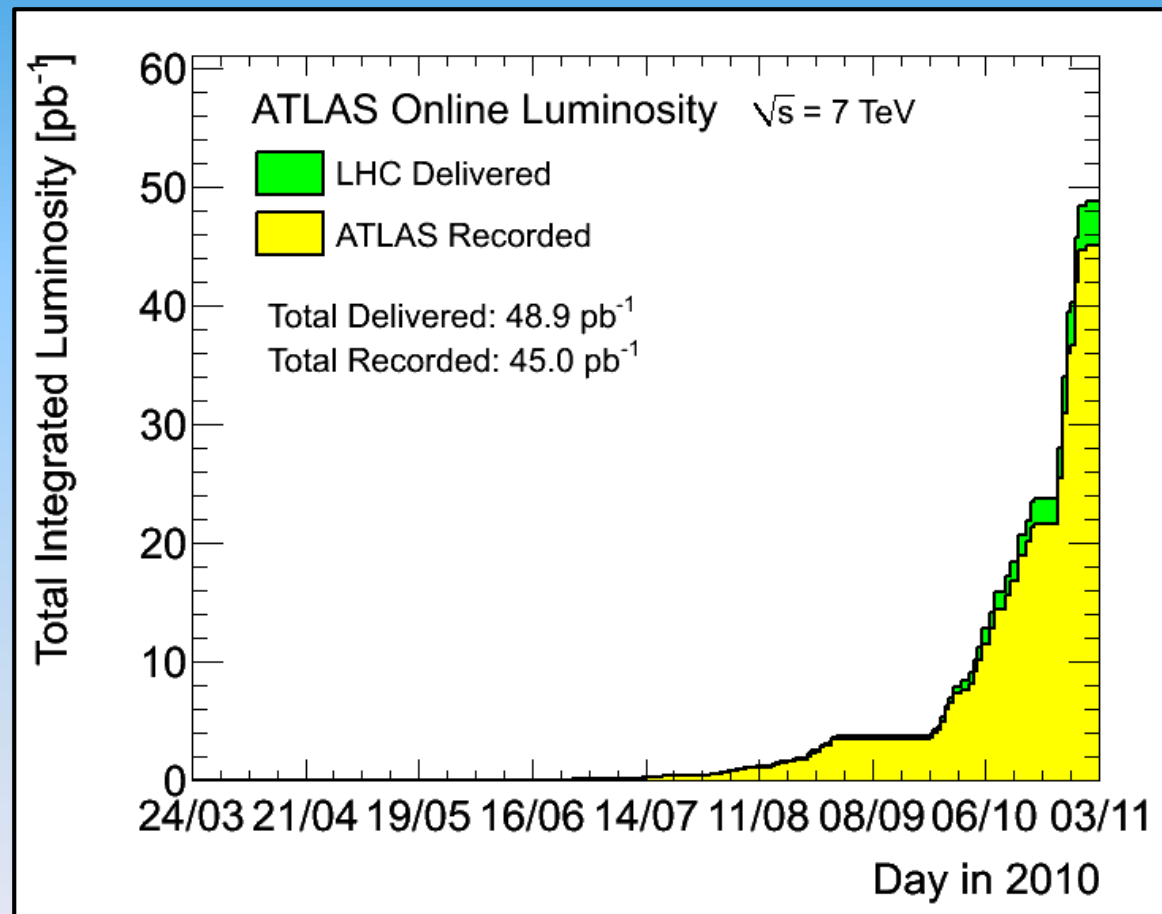
TUSSENDOORTJE

Grote inbreng Nederland (Nikhef)

Omgaan met teleurstellingen (2009 'uit')



2010: de LHC doet het



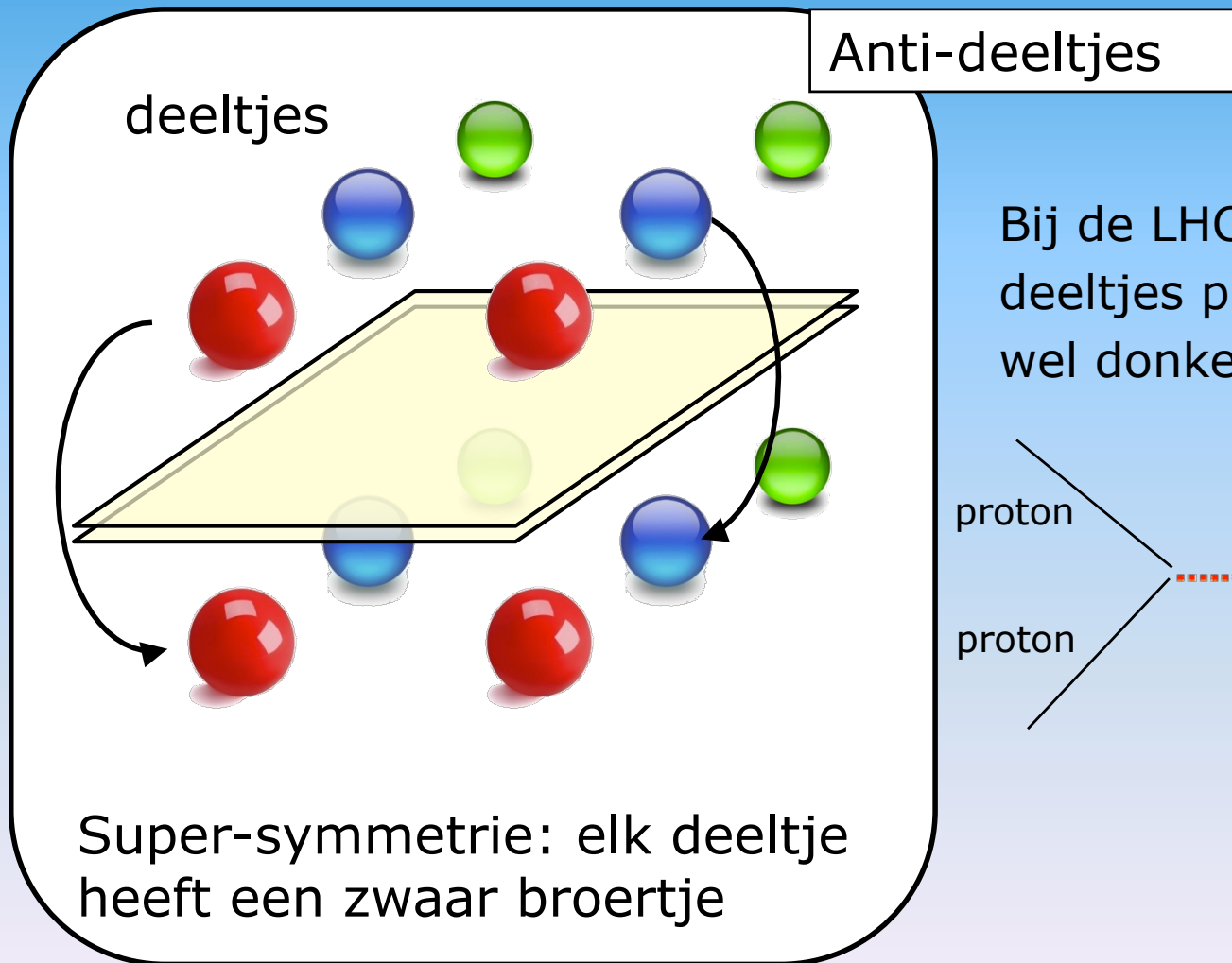
... het echte werk!



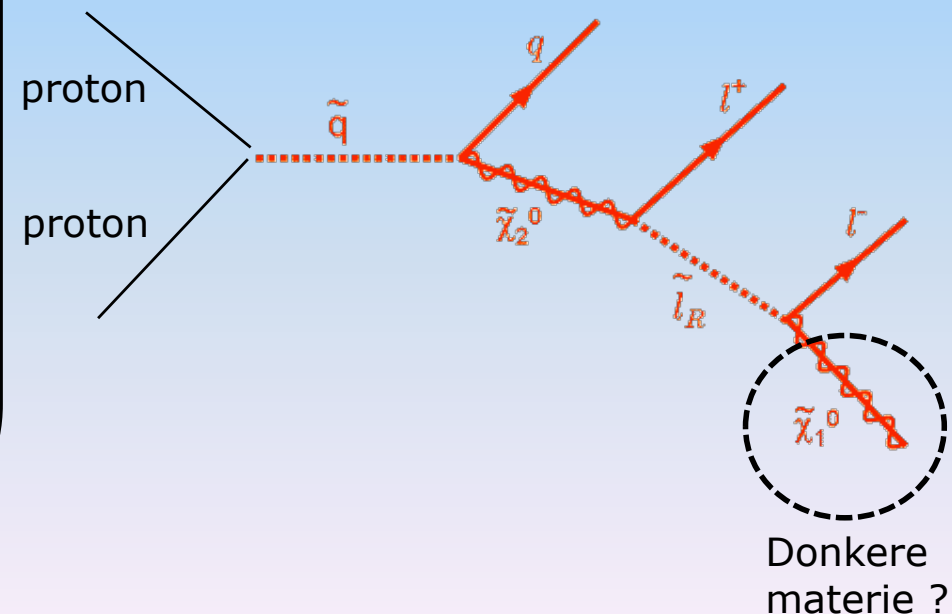
Donkere Materie



Theoretisch idee: Supersymmetrie:

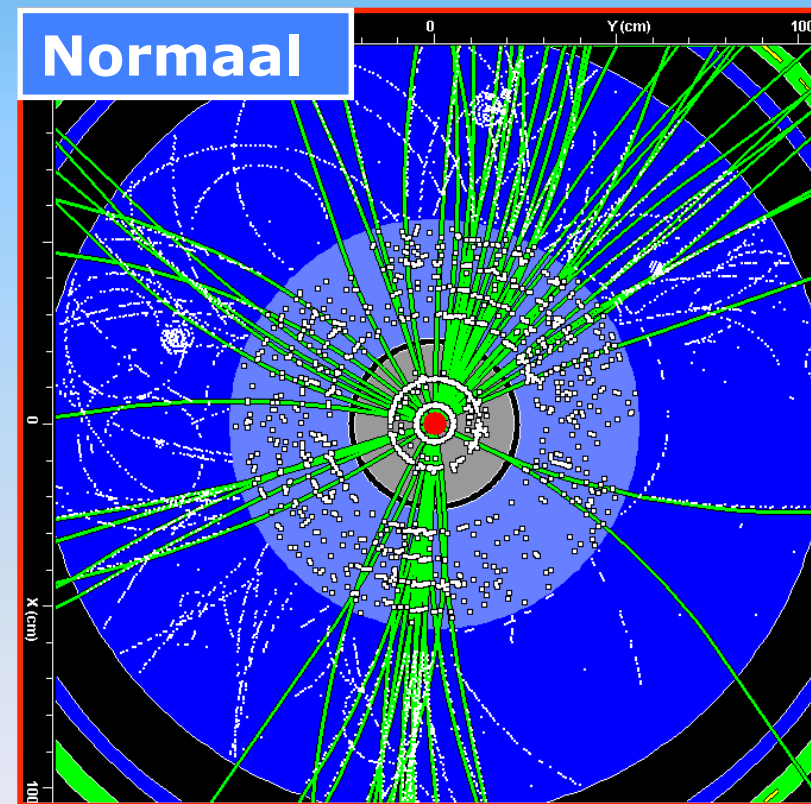
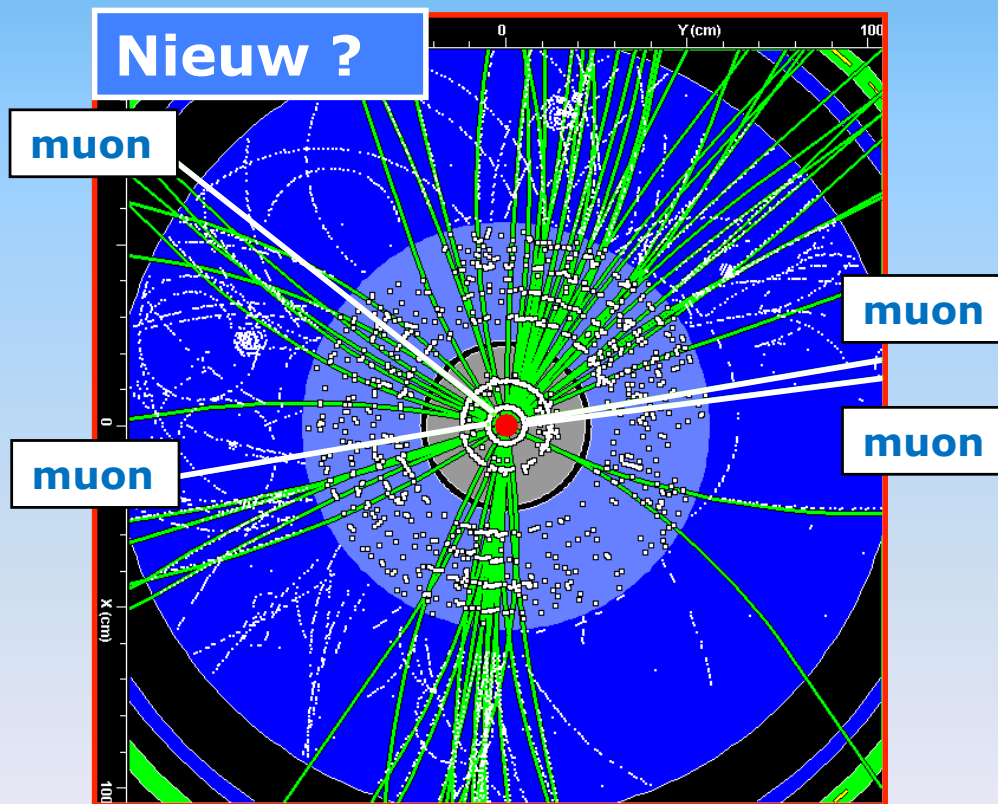


Bij de LHC kunnen we deze superdeeltjes produceren. En misschien wel donkere materie maken.



Hoe ontdek je nou nieuwe dingen: Higgs boson

Nieuwe afstandschaal EN nieuwe detector

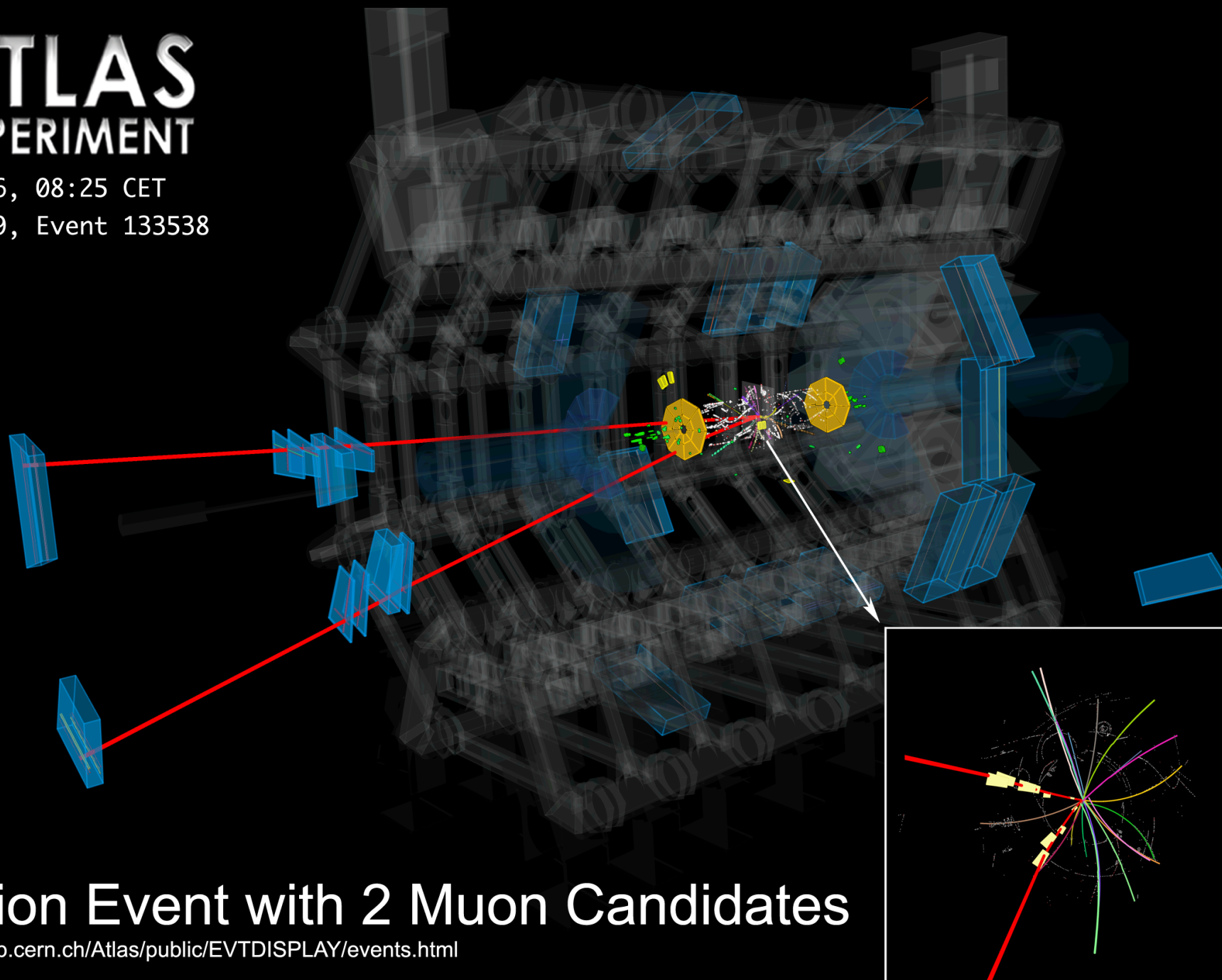


Ja ... Higgs is heel klein wel



2009-12-06, 08:25 CET

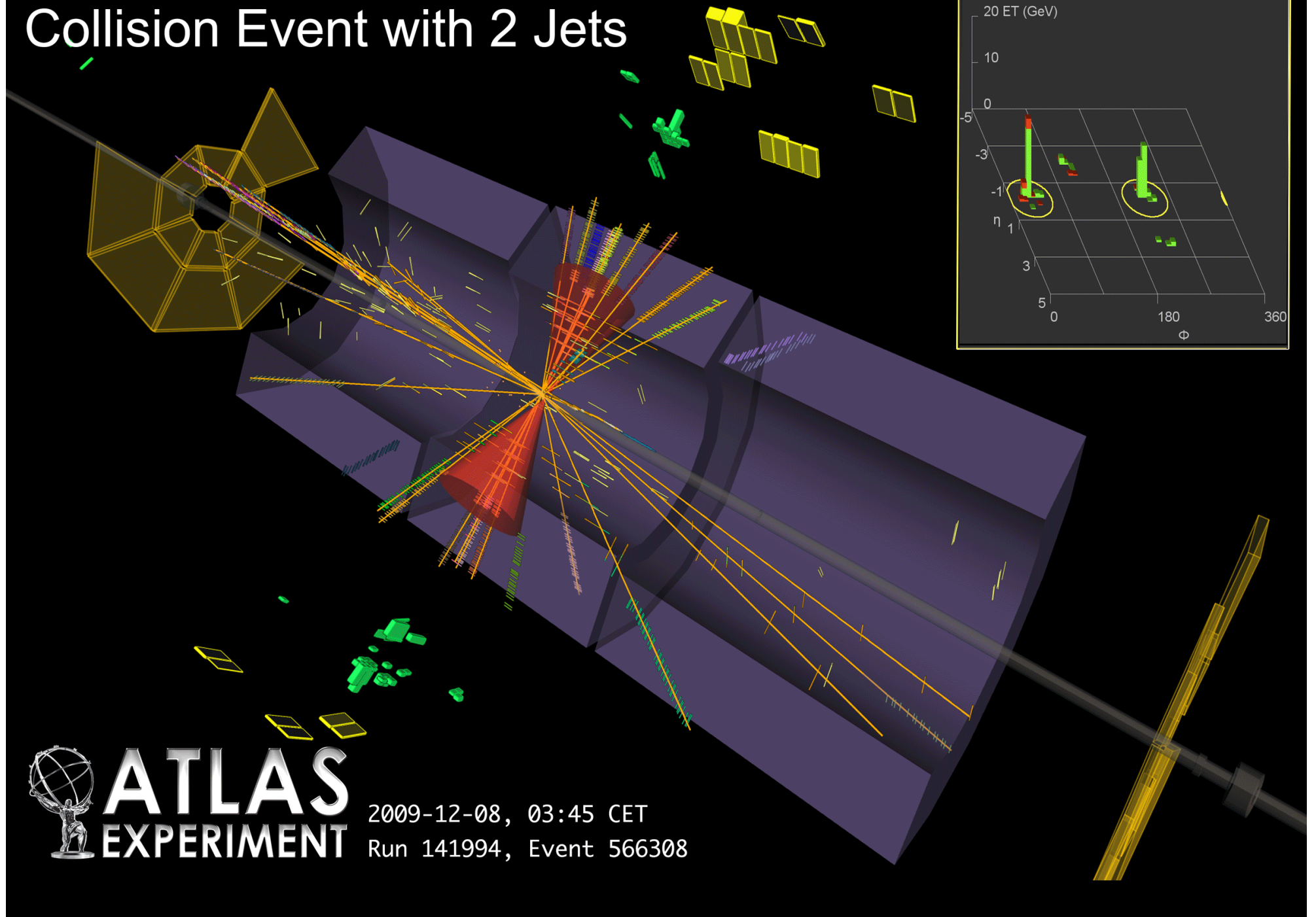
Run 141749, Event 133538



Collision Event with 2 Muon Candidates

<http://atlas.web.cern.ch/Atlas/public/EVTDISPLAY/events.html>

Collision Event with 2 Jets



ATLAS
EXPERIMENT

2009-12-08, 03:45 CET
Run 141994, Event 566308

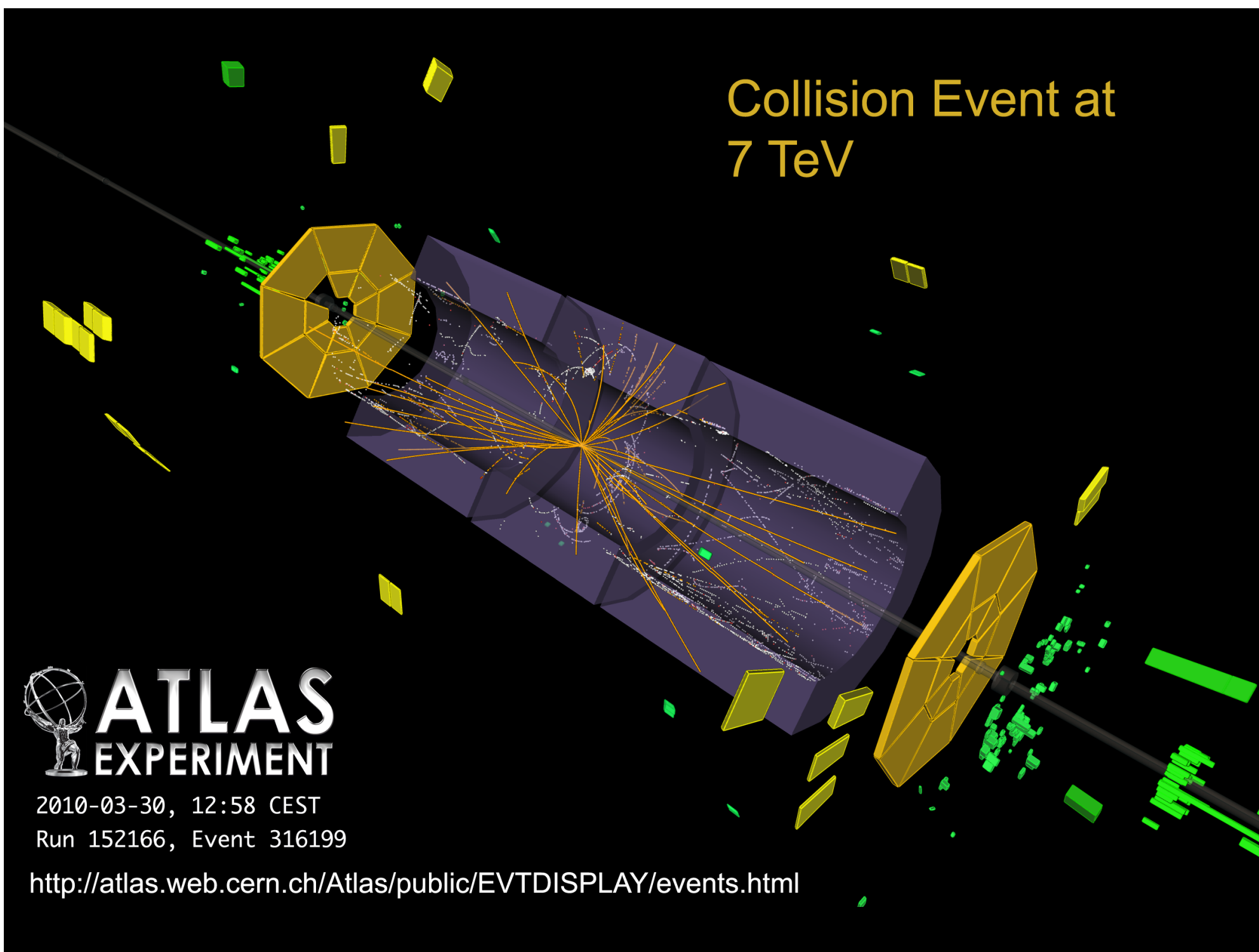
Collision Event at 7 TeV



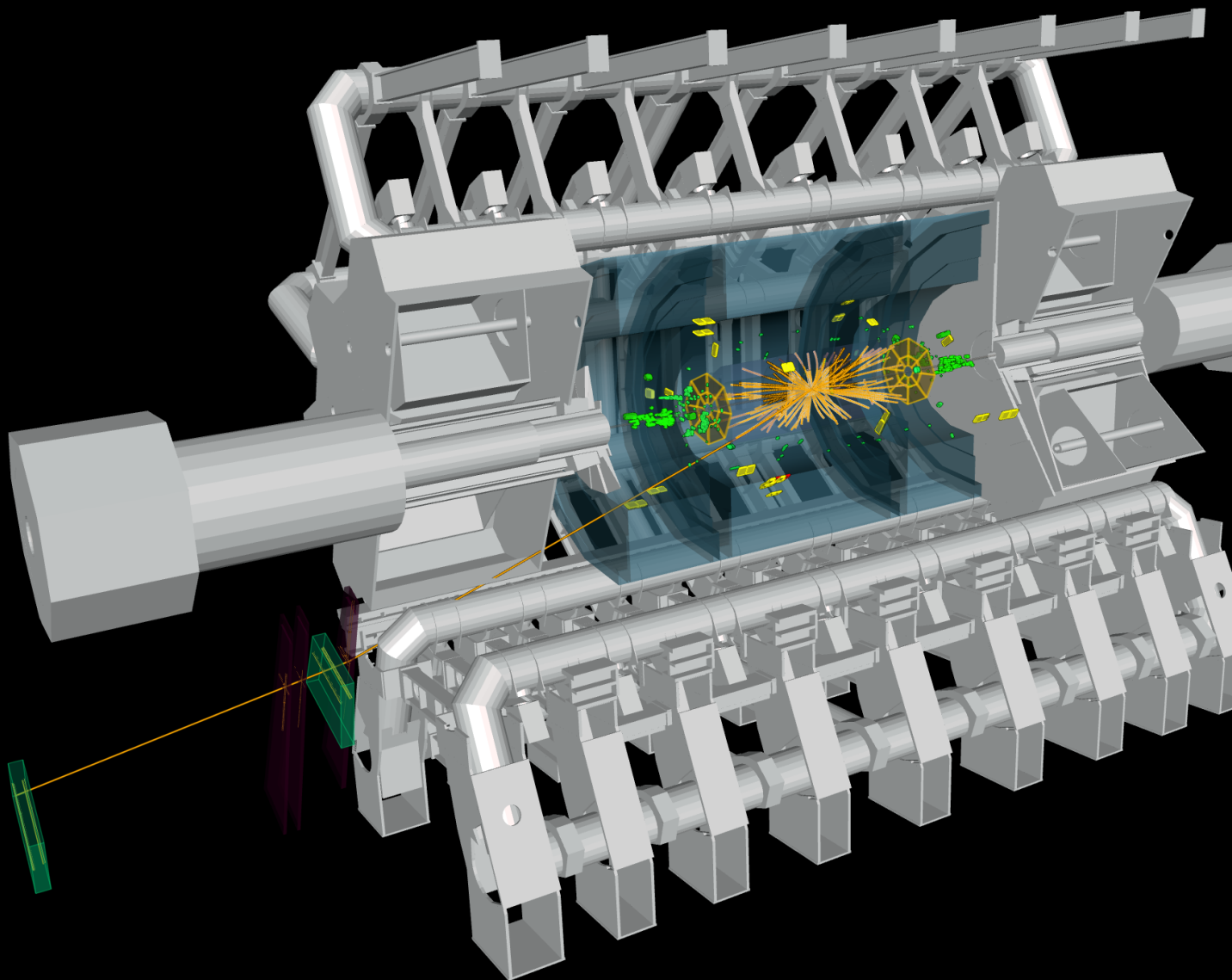
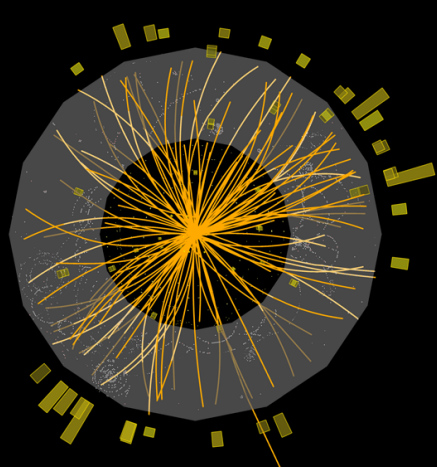
2010-03-30, 12:58 CEST

Run 152166, Event 316199

<http://atlas.web.cern.ch/Atlas/public/EVTDISPLAY/events.html>



Collision Event at 7 TeV with Muon Candidate



2010-03-30, 12:59 CEST
Run 152166, Event 322215

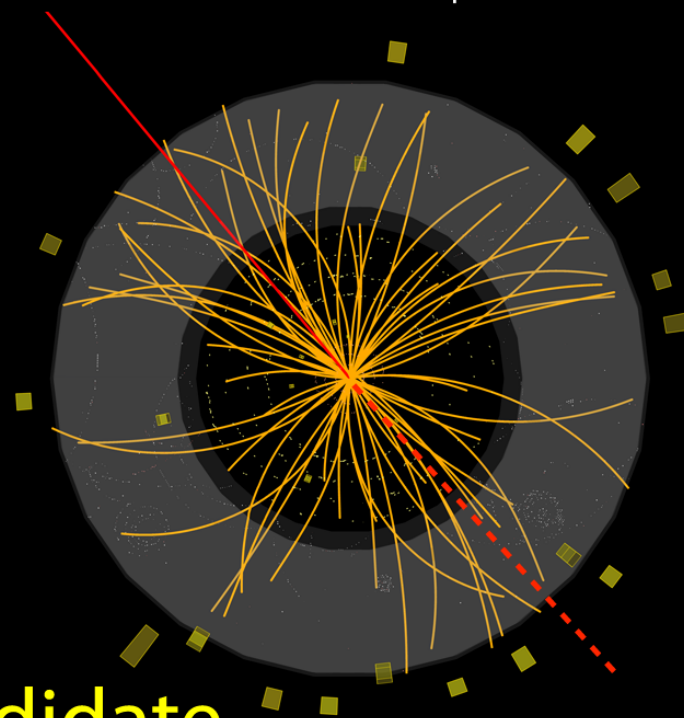
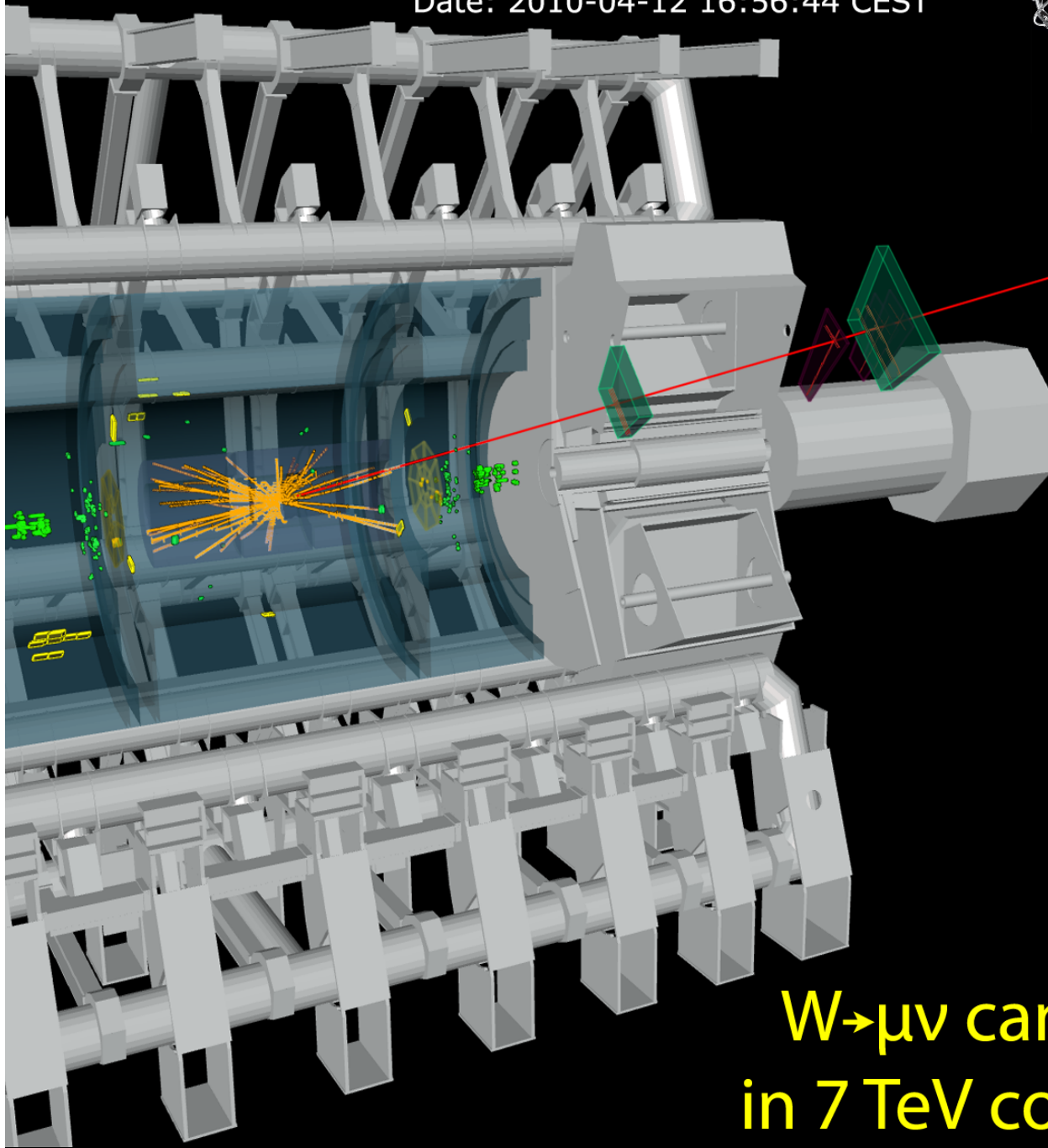
<http://atlas.web.cern.ch/Atlas/public/EVTDISPLAY/events.html>

Run: 152845, Event: 3338173
Date: 2010-04-12 16:56:44 CEST



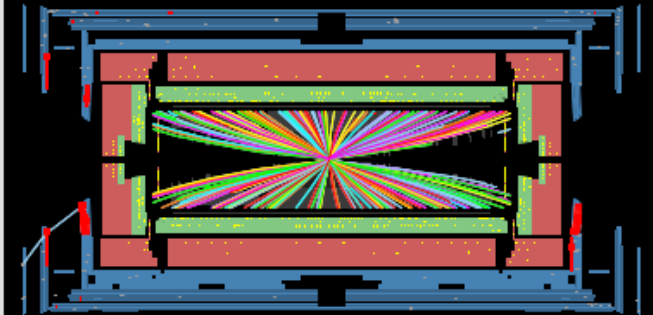
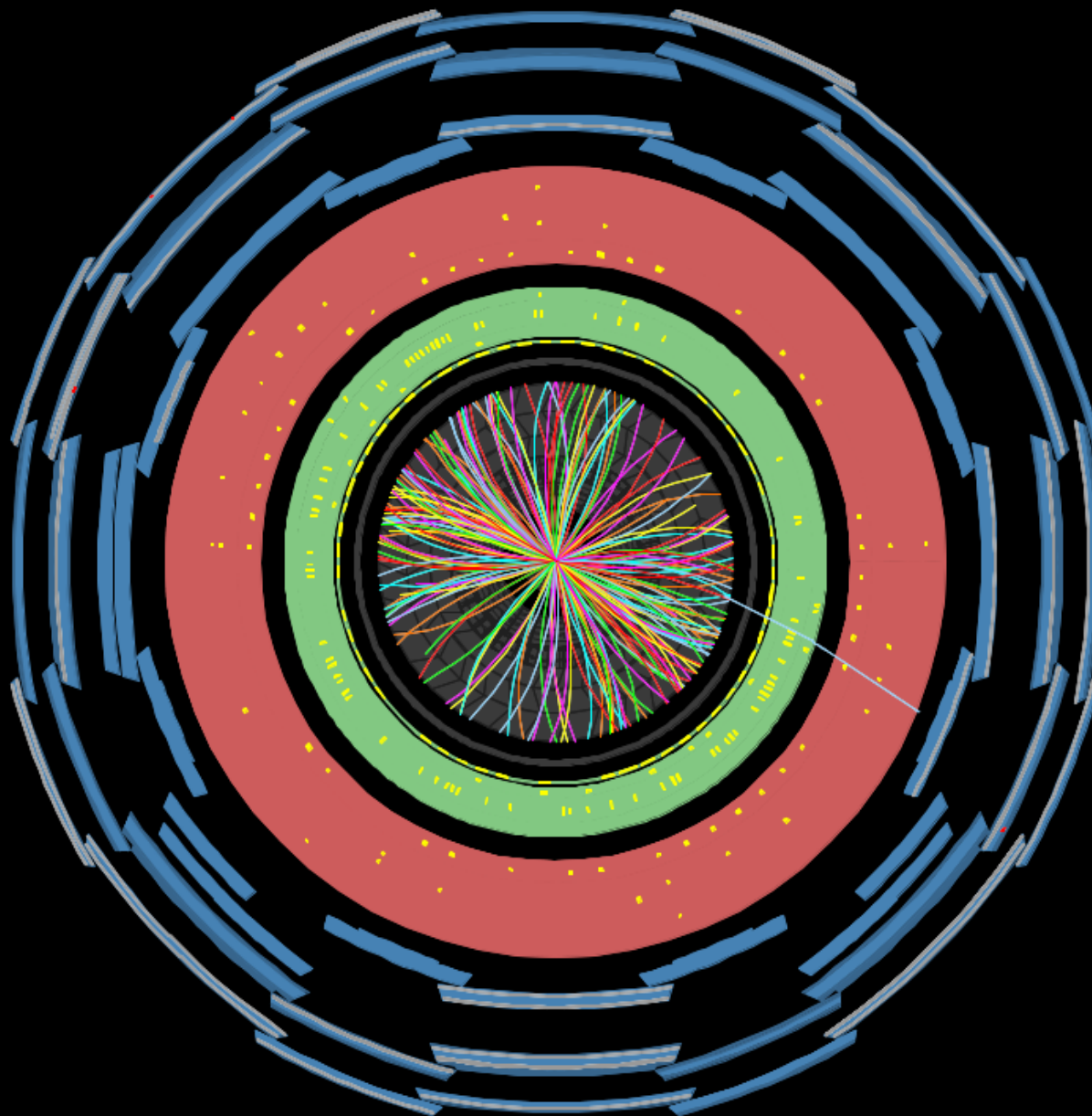
ATLAS EXPERIMENT

$p_T(\mu^-) = 40 \text{ GeV}$
 $\eta(\mu^-) = 2.0$
 $E_T^{\text{miss}} = 41 \text{ GeV}$
 $M_T = 83 \text{ GeV}$



**$W \rightarrow \mu \nu$ candidate
in 7 TeV collisions**

GISTEREN



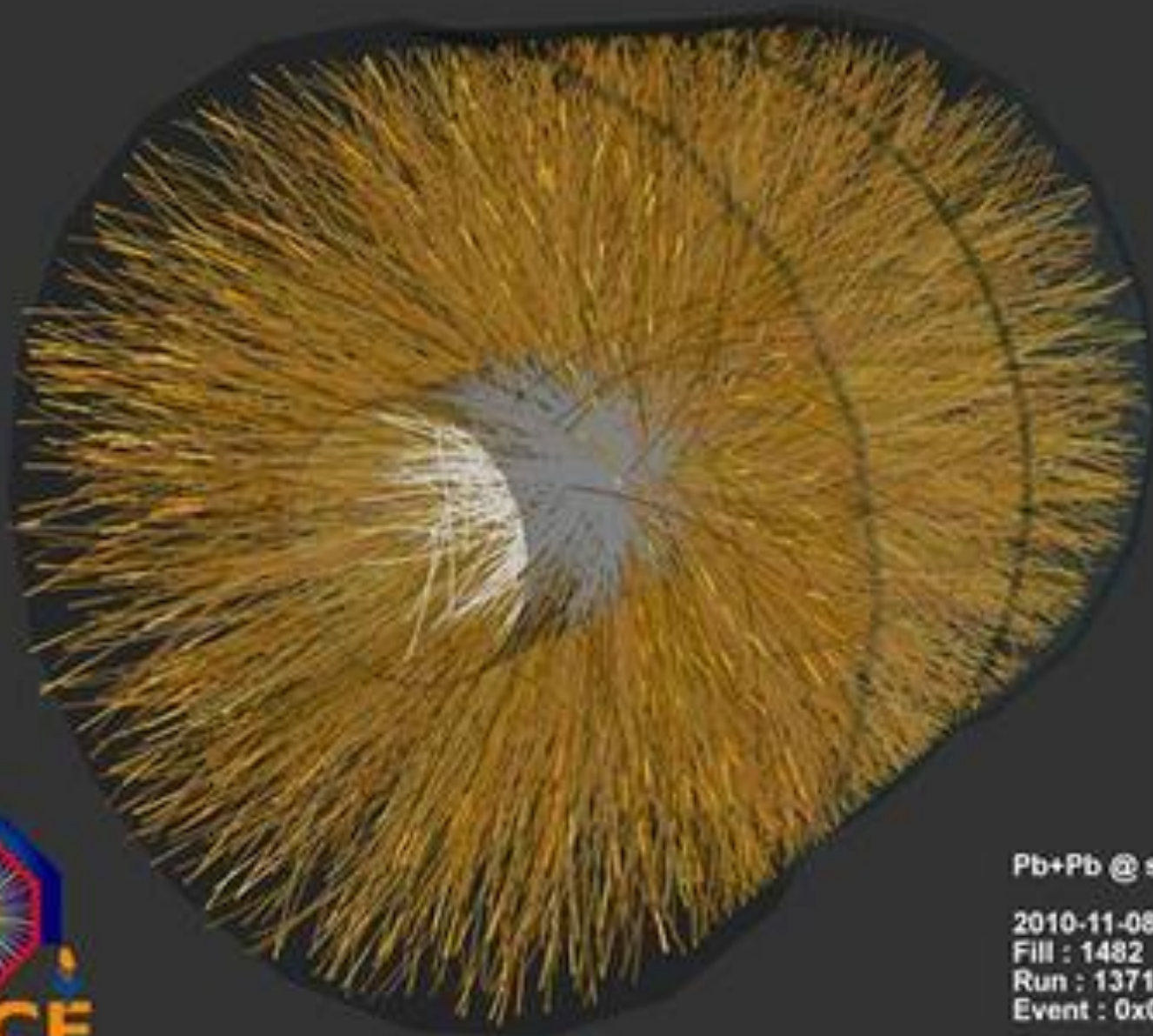
Run Number: 168726, Event Number: 52141

Date: 2010-11-08 19:25:03 CET

Snapshot of a heavy ion collision
directly from the ATLAS experiment

ALICE experiment

GISTEREN



Pb+Pb @ $\sqrt{s} = 2.76$ ATeV

2010-11-08 11:30:46

Fill : 1482

Run : 137124

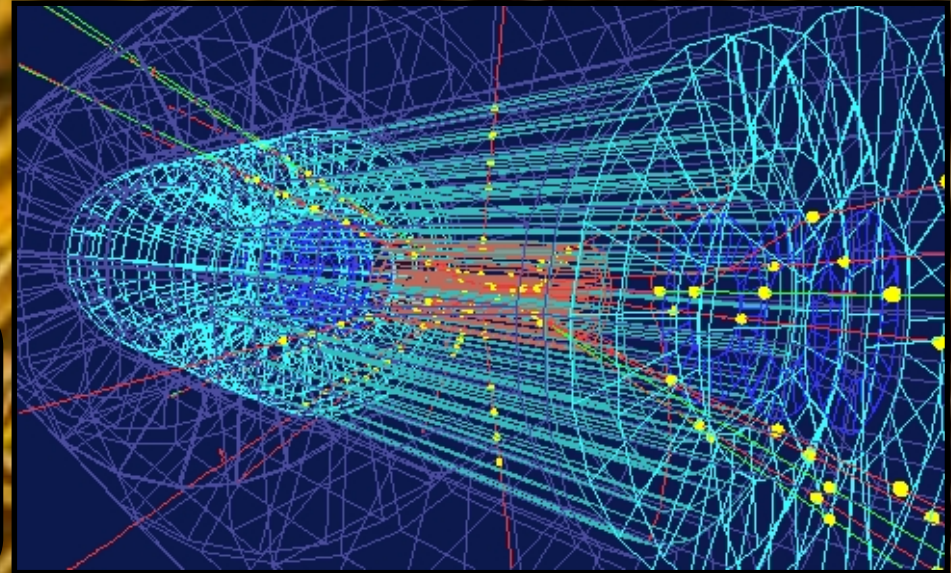
Event : 0x00000000D3BBE693

... computing ... ook geen eitje



Fotootjes kijken

40 miljoen botsingen per seconde
mag maar 200 per seconde opslaan

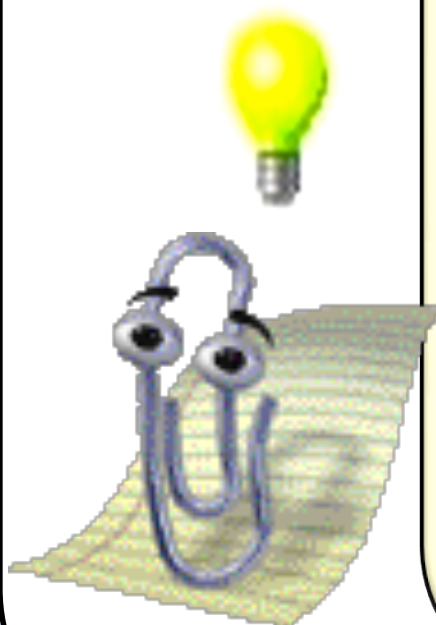


1 naald in 40 miljoen hooibergen
..... per seconde !



ongeveer 1 Higgs boson per dag

Wist je dat je maar 200 botsingen per seconde op kan slaan ?



... dat is nl. al 6 PetaByte per jaar
(6000 Tb = 100.000 DVD's)

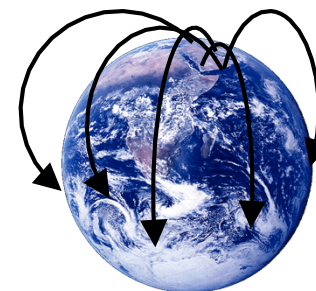
... je moet dus 99.9995 % van de foto's
weggooien ... elke seconde weer

YES

NO

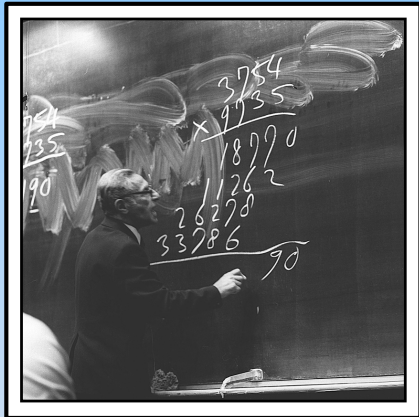
Cancel

De data wordt verspreid over de hele wereld
Ook naar SARA/Nikhef (Amsterdam)



(Grid-) computing

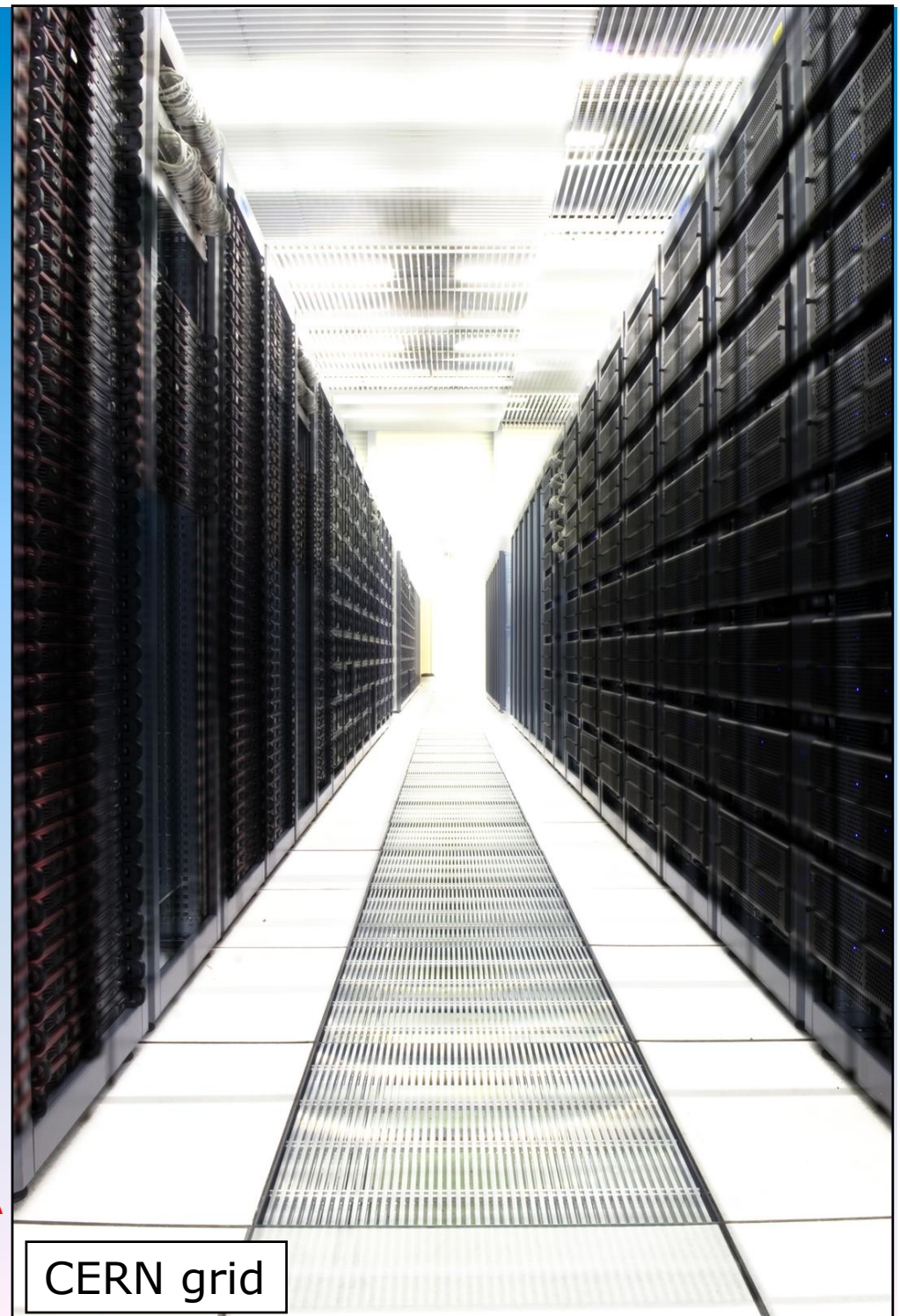
ATLAS: 40 miljoen botsingen/sec
→ 200 Hz op tape
'gewoon' 3000 PC's



CERN's eerste computer
Wim Klein

Data-storage:

- ATLAS produceert 50 Pb per jaar
- 10 Tier-1 sites, met **Nikhef/SARA**

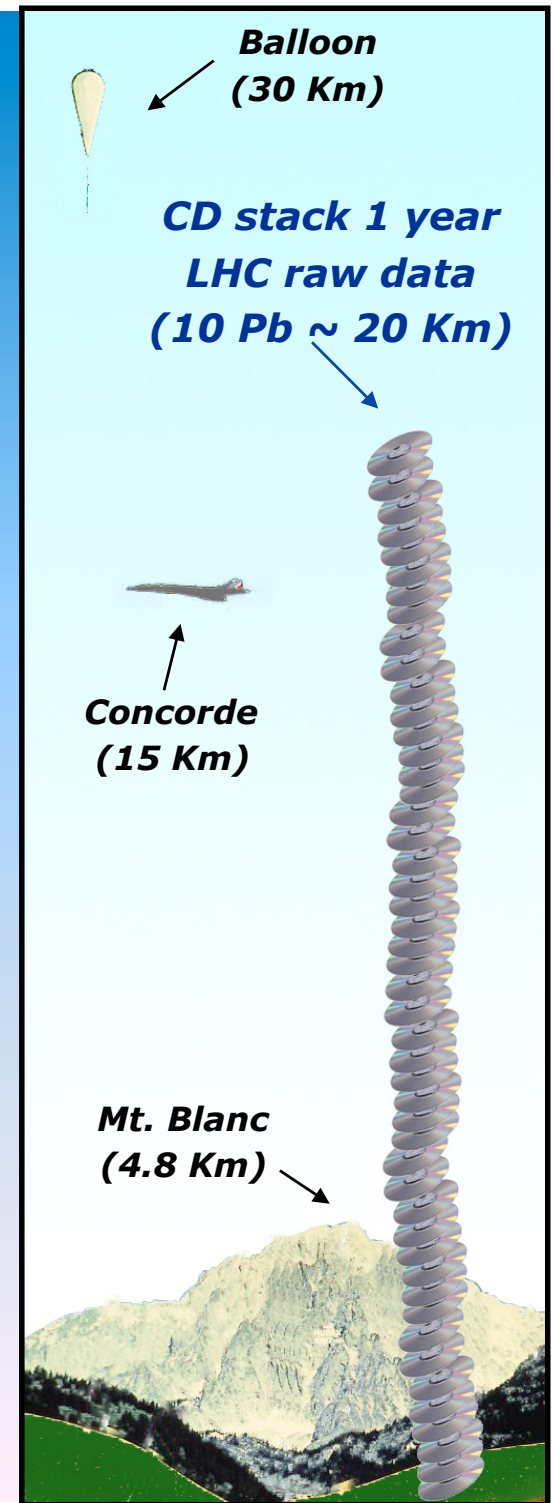


CERN grid

LHC data

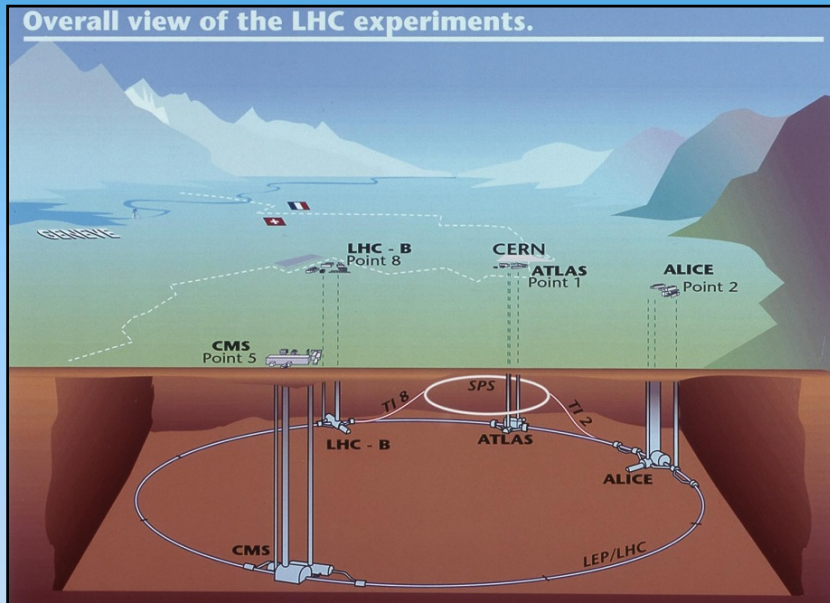
... is het nou echt zoveel ?

... ja !



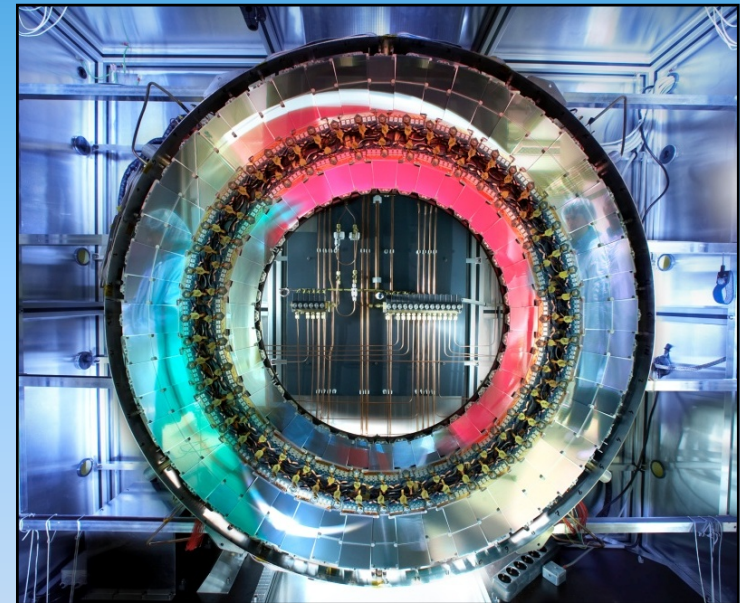
We zijn er klaar voor

LHC versneller

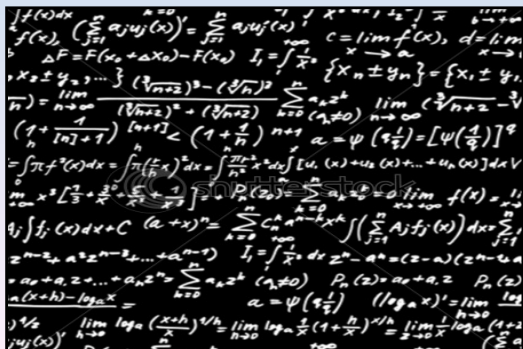


Herstart september 2009

Detectoren



Vier detector zijn klaar



Theorie

Meer dan genoeg vragen
... meer dan genoeg ideeën/oplossingen

Einde

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