De zoektocht naar het Higgs boson

Ivo van Vulpen


Als de Higgs ontdekt wordt
gaat het de geschiedenisboeken in


Als de Higgs **niet** ontdekt wordt
gaat het **ook** de geschiedenisboeken in

Real Madrid - Barcelona

theguardian

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Sport › Football › La Liga

Real Madrid v Barcelona – as it happened

Real scored after only 21 seconds, but Barcelona came back at them to close the gap at the top

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Min-by-min | Observer report | Guardian report | Match facts | Ratings

A larger | smaller

La Liga

Real Madrid 1 — Benzema 1
Barcelona 3 — Sánchez 30, Xavi 53, Fábregas 66

Scott Murray
guardian.co.uk, Saturday 10 December 2011 22.54 GMT
Article history

Football
La Liga · Real Madrid · Barcelona

Sport

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More on this story

Illness rules out Fletcher indefinitely
Man Utd midfielder Darren Fletcher is not expected to play again this season

27 min: Two bookings in a minute. First Xabi Alonso for a needless rake across Messi's shins, then Alexis for a pointless hack on Di Maria. It's been played in a good spirit so far, but there we are with the first signs of it kicking off. Again, I suppose I'm duty bound to say we don't like to see this sort of thing, but we sort of do, don't we.

29 min: Dani Alves cries murder after Marcelo clatters into him. The referee sighs wearily. There's an edge now.

30 min: GOAL!!! Real Madrid 1-1 Barcelona. This was so simple, and so brilliant. Messi, from the centre circle, drives down the middle, drawing three white shirts. He eventually slides a pass down the inside-right channel to spring Alexis free. From the edge of the box, just to the right of goal, Alexis whips a low shot straight into the bottom-left corner. Casillas had no chance. That came from nothing. Barca, who have been poor so far, are right back in this! Ronaldo will rue that useless shot of a few mintues ago.

33 min: All of a sudden, Barcelona's pretty triangles are sticking to feet. Their confidence is back, after being knocked to buggery in the opening 21 seconds. "As a result of GB being cut off from all things eurozone by the mighty bluster of our PM, I fear this is the last el classico the Guardian will be allowed to cover. Soon a euro-sceptic curtain will descend behind which the UK and a trapped Tevez will sit in isolation." Ladies and gentlemen, that was the week that was, with Ian Copestake, the David Frost *de nos jours*.

35 min: Dani Alves leaves his foot in a 50-50 challenge with Xabi Alonso. He should be booked for his sauce, but isn't. Just for a

CERN Higgs seminar

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News › Science › Higgs boson

NOTES&THEORIES
DISPATCHES FROM THE SCIENCE DESK

Higgs boson seminar: have physicists found the 'God particle'? – live

Physicists announce the latest results from the proton-colliding experiments at the Large Hadron Collider (LHC) including tentative evidence for the existence of the Higgs boson

Tweet 230 | Recommend 1k | reddit this | Comments (281)

Alok Jha, science correspondent
guardian.co.uk, Tuesday 13 December 2011 17.24 GMT
Article history

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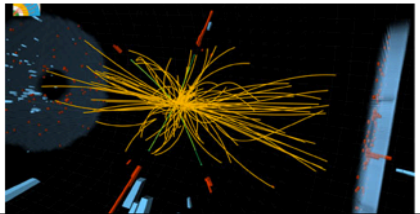
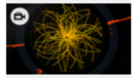
Science
Higgs boson · Cern · Particle physics · Physics

More minute by minutes

More on the Higgs





else that takes the role of the "standard" Higgs particle, perhaps a family of several Higgs particles or something even more exotic. The unexpected is always the most exciting.

1.33pm: Watching Fabiola's presentation, particle physicist @TaraShears has tweeted: "So this channel excludes 114-115, and 135-136 GeV. #higgsupdate"

It's worth following Tara (and our own @jonmbutterworth) if you want real-time updates on Twitter. Jon's latest: "126 GeV... (probably) #higgsupdate"

Also from Jon: "That 126 GeV was where the ATLAS excess Fabiola just showed is. Not conclusive, but suggestive. ZZ and CMS to come..."

1.43pm: From Cern: "#ATLAS sees a small excess at a Higgs mass of 126 GeV coming from 3 channels. Local significance: 3.6 sigma but only 2.4 sigma globally"

That's not enough for a "discovery" (which techically needs 5 sigma) but it is very interesting evidence for the Higgs.

Also: "#ATLAS excludes a #Higgs mass between 131 and 453 GeV at 95% confidence level at #CERN Higgs seminar"

1.49pm: Fabiola Gianotti has finished her presentation. So far, we know that Atlas seems to have found evidence for a bump around 126GeV for something that looks like the Higgs.

Live blog comments the Guardian

Het Higgs mechanisme

Massieve kracht(deeltjes) in een lokale ijkinvariante theorie

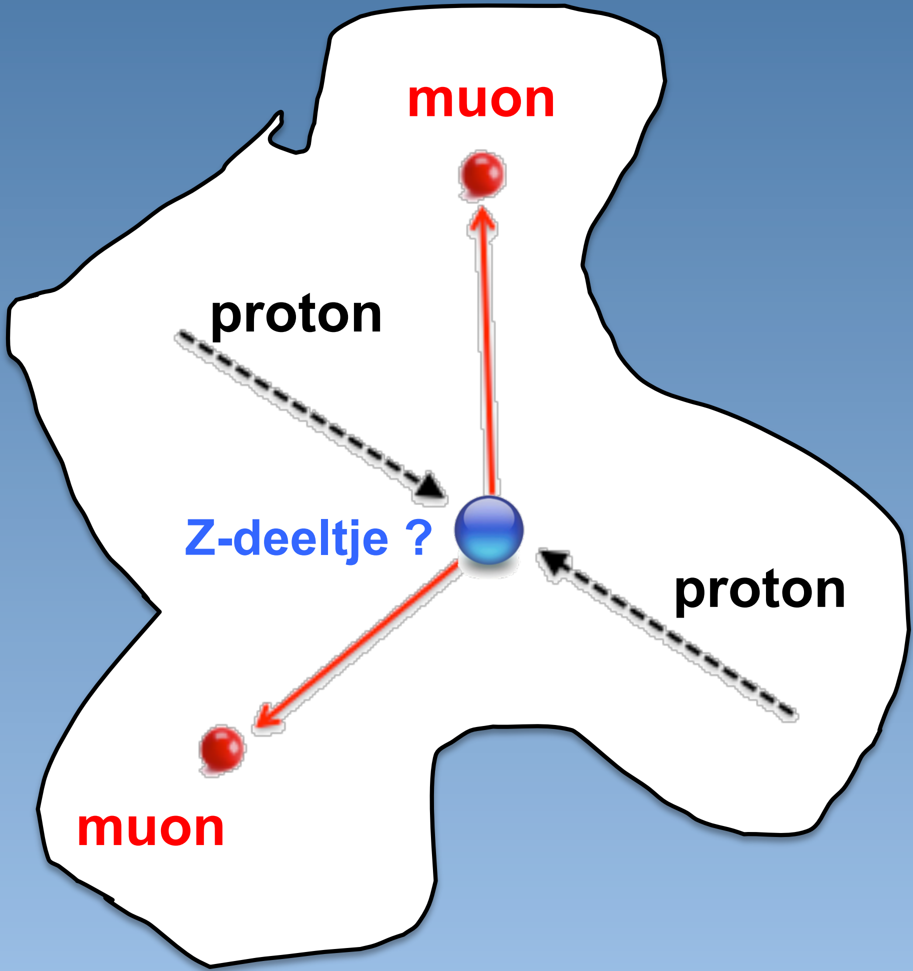
$$\boxed{SU(2)_L \otimes U(1)_Y \otimes SU(3)_C}$$

dan moet er een **Higgs boson** zijn

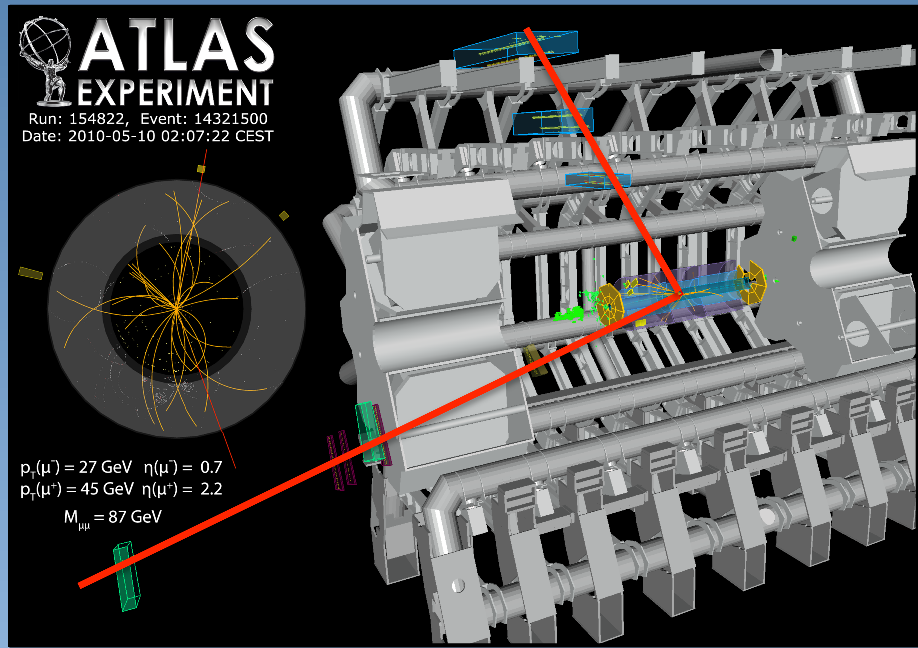
- September 1964 -

Hoe ontdek je het Z-deeltje ?

Afwijkingen van voorspelling zonder Z-boson



2-muonen gezien in ATLAS



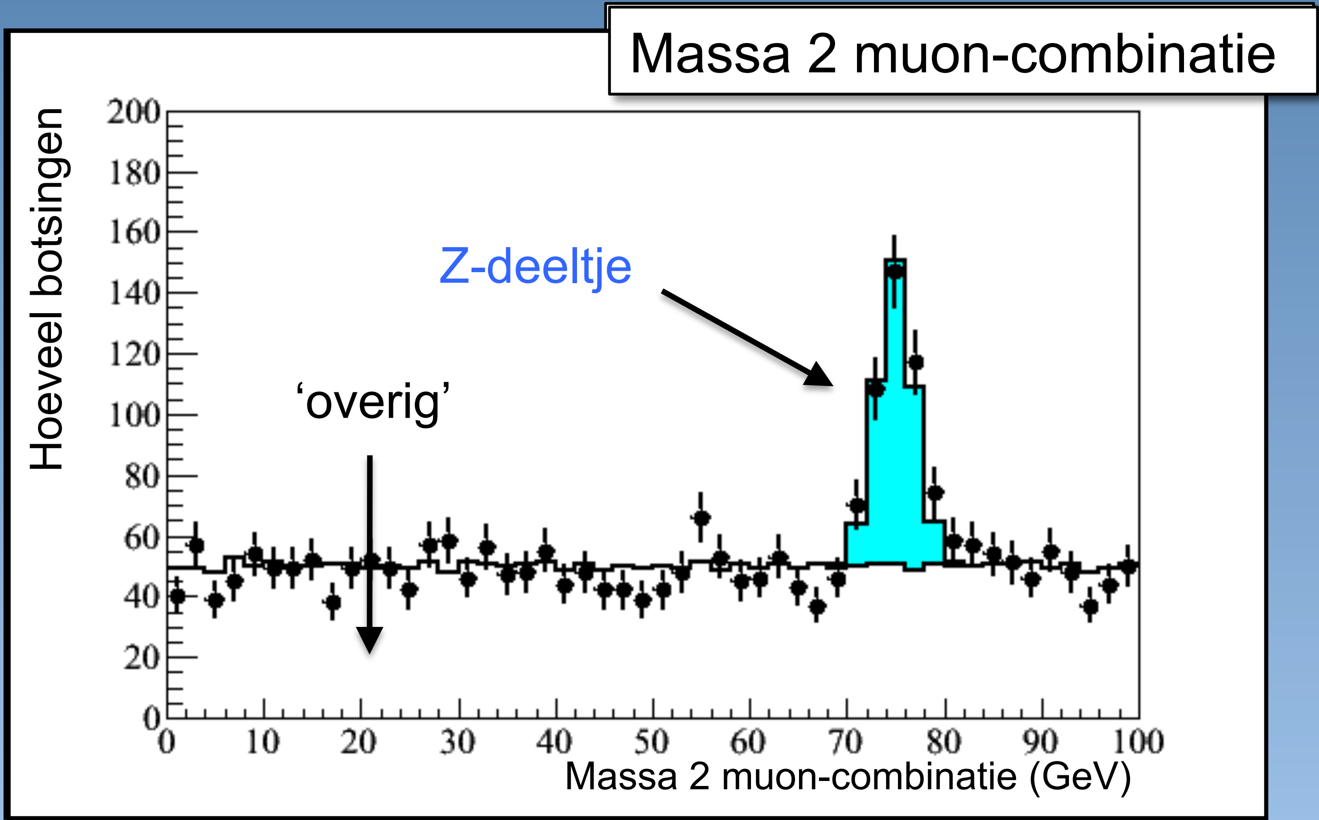
Wat is de ‘vingerafdruk’ van het Z-deeltje:
→ de massa van het 2-muon systeem

2-muon massa

‘overig’: geen voorkeur, vlak

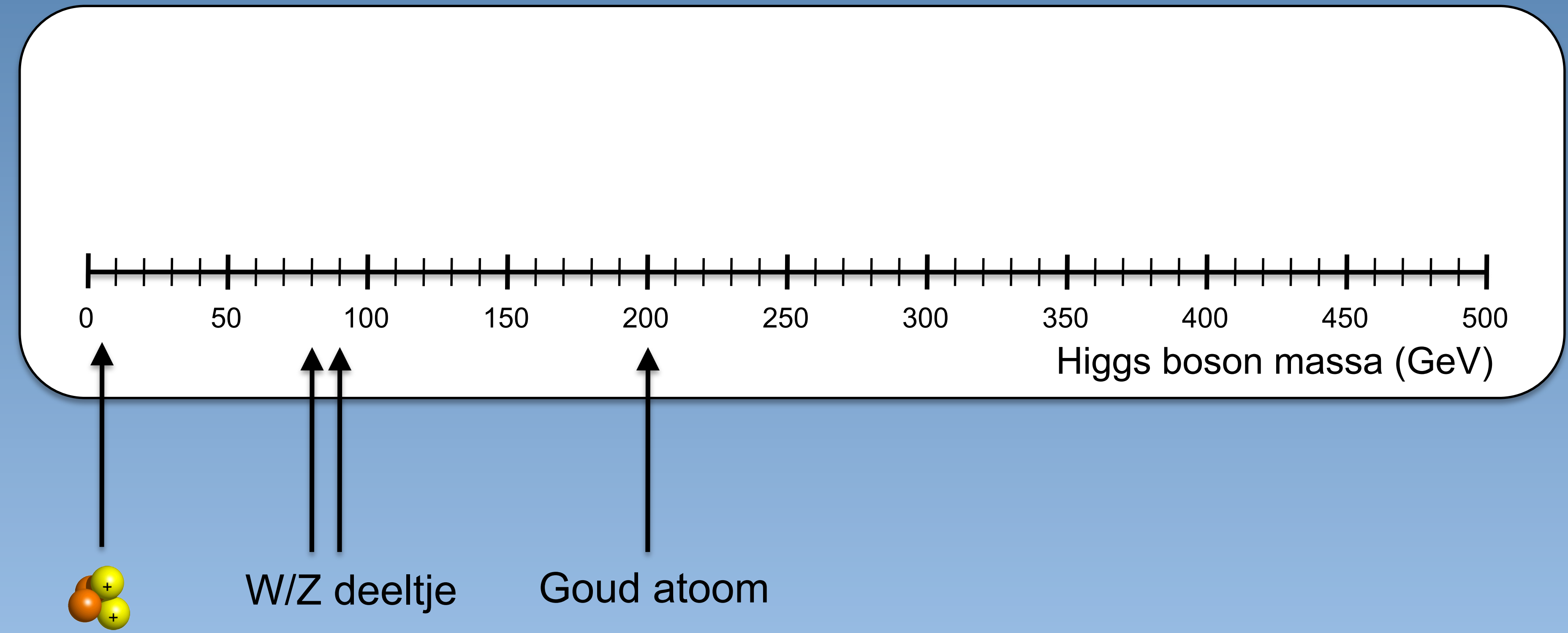
$E = mc^2$

Z-deeltje: bijna altijd dezelfde waarde (massa van het Z-deeltje)



De massa van het Higgs boson

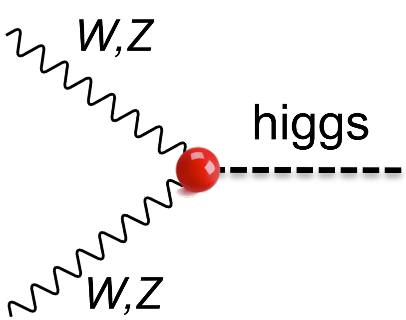
1 GeV → massa proton = massa Waterstof atoom



Hoe maak je een Higgs deeltje ?

Krachtdeeltjes

Massief krachtdeeltje ?
…dan koppelt het aan de Higgs!



Bouwstenen

Massief deeltje ?
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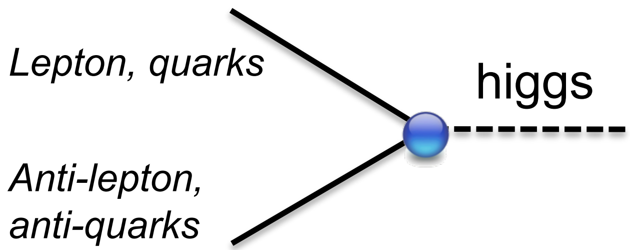

Higgs boson productie

Hoeveel Higgs bosons zijn
er geproduceerd in 2011 ?

Als hij niet bestaat:

0

‘gewoon’ even uitrekenen

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

he $H\gamma\gamma$ and $H\gamma Z$ couplings are induced at one loop via both a
At the lowest order the decay rate for $H \to \gamma\gamma$ can be written

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

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

$$\tau) = \begin{cases} \arcsin^2 \frac{1}{\sqrt{\tau}} & \tau \geq 1 \\ -\frac{1}{4}\left[\ln \frac{1+\sqrt{1-\tau}}{1-\sqrt{1-\tau}} - i\pi\right]^2 & \tau < 1 \end{cases} , \quad (103)$$

d A_W^H are given by:

$$A_f^H = 2\tau\left[1 + (1-\tau) f(\tau)\right] , \quad (104)$$
$$^H_W(\tau) = -\left[2 + 3\tau + 3\tau(2-\tau) f(\tau)\right] .$$

y rate for $H \to \gamma Z$ is given by:

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

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

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

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

ed after Eq. (102), and I_3^f is the weak isospin of the f fermion

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

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.

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decay rate for $H \to \gamma Z$ is given by:

$$\frac{M_W^2 \alpha M_H^3}{64\pi^4} \left(1 - \frac{M_Z^2}{M_H^2}\right)^3 \left| \sum_f A_f^H(\tau_f, \lambda_f) + A_W^H(\tau_W, \lambda_W) \right|^2 , \quad (105)$$

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

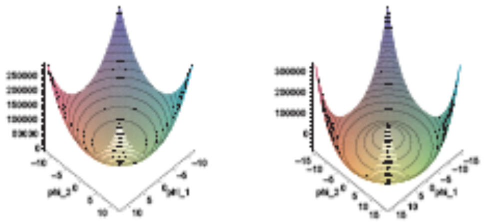


FIG. 1: The potential $V(\phi)$ $(\phi = \phi_1 + i\phi_2)$ plotted for an arbitrary positive value of λ and for an arbitrary positive (right) or negative (left) value of μ^2.

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:

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

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

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

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:

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

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:

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

Hoeveel Higgs bosons zijn
er geproduceerd in 2011 ?

Als hij wel bestaat:

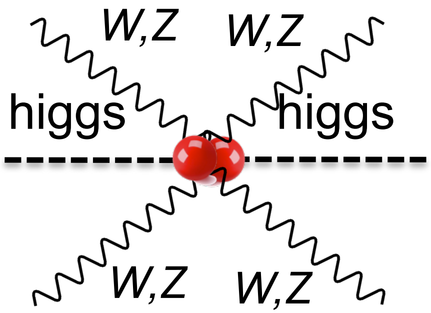
m_h = 120 GeV: 60.000

m_h = 200 GeV: 30.000

Hoe kom je weer van een Higgs boson af ?

Krachtdeeltjes

Massief krachtdeeltje ?
…dan koppelt het aan de Higgs!



Bouwstenen

Massief deeltje ?
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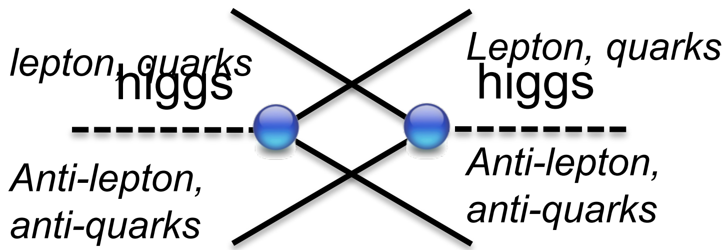


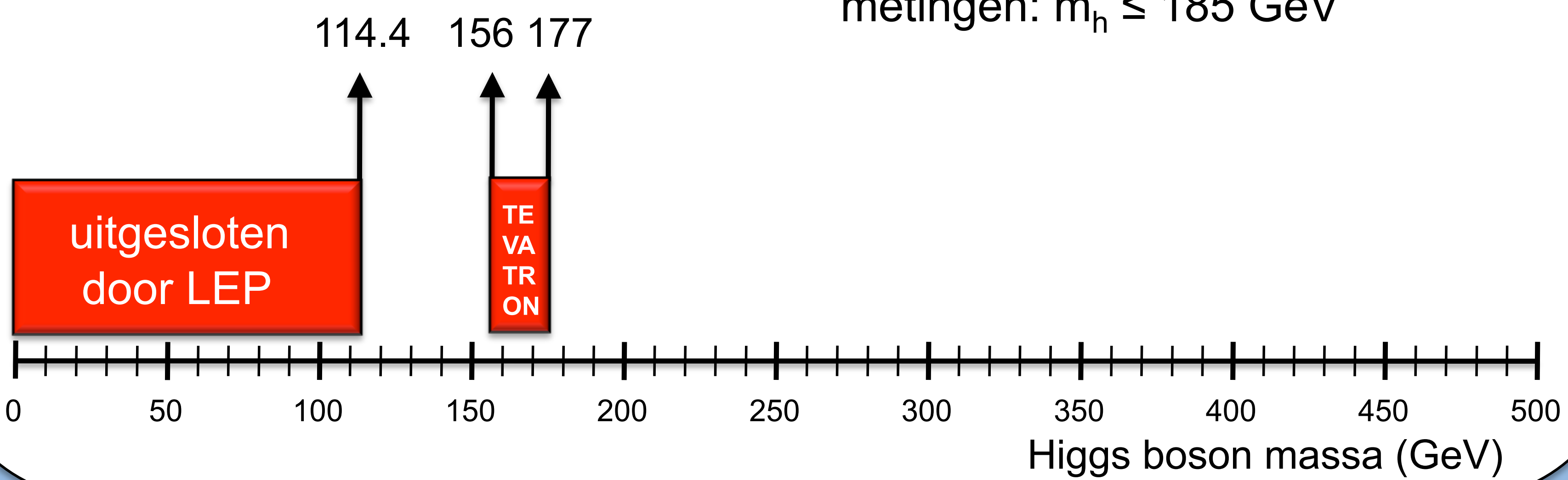
Higgs boson verval / productie

Stand van zaken voorjaar 2011

Indirect:

Theorie: $m_h \leq 600$ GeV

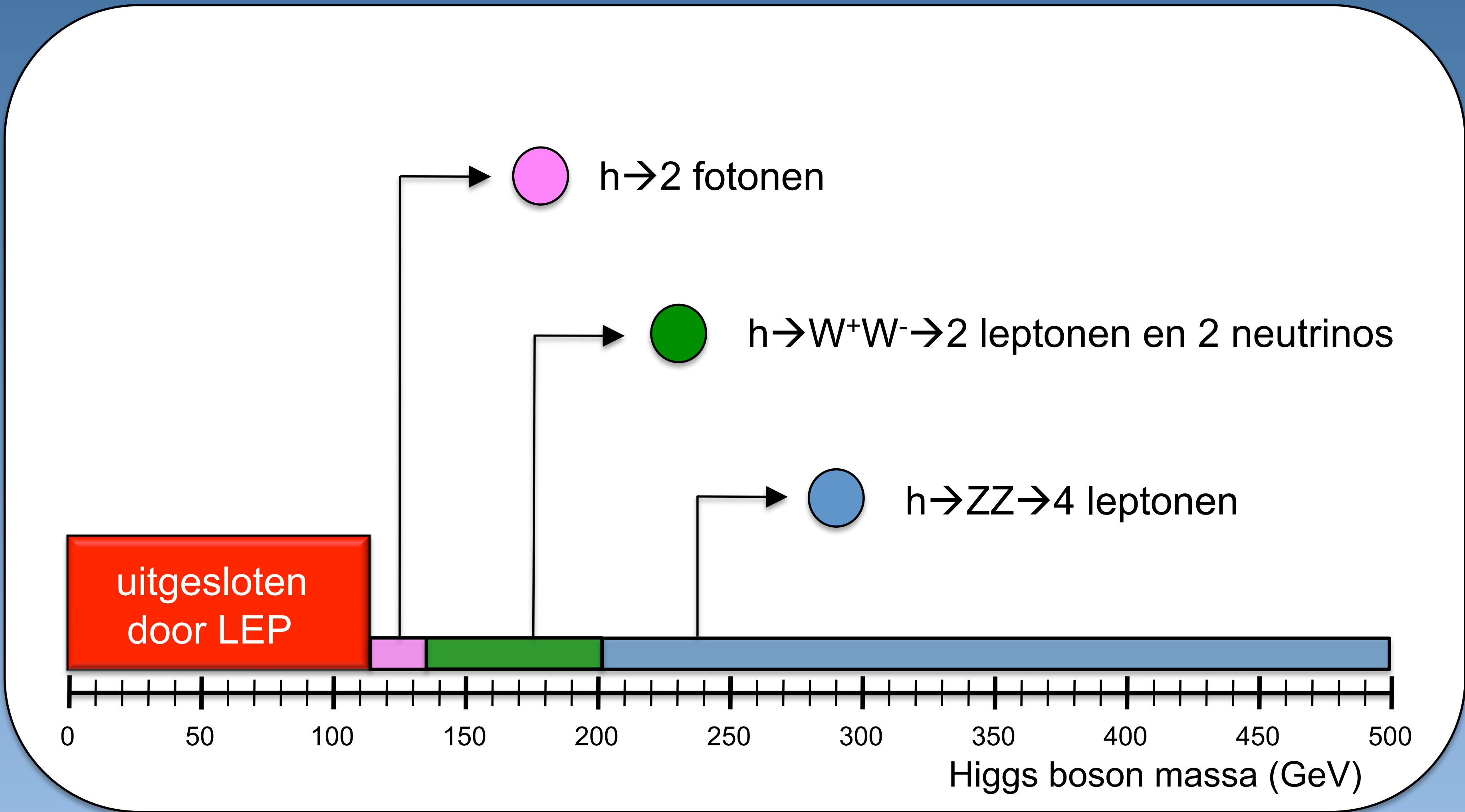
Electrozwakke precisie-metingen: $m_h \leq 185$ GeV



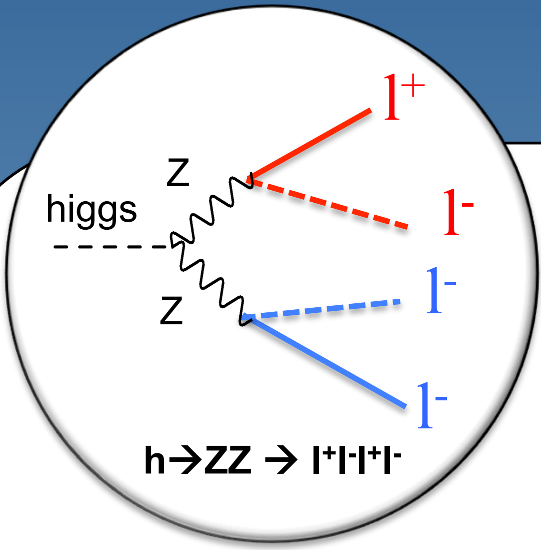
Experimenten bij de LHC gevoelig in het gebied 114-1000 GeV

De duidelijkste vingerafdruk van het Higgs boson

Voor elke massa zijn er meerdere kanalen: dit zijn de belangrijkste



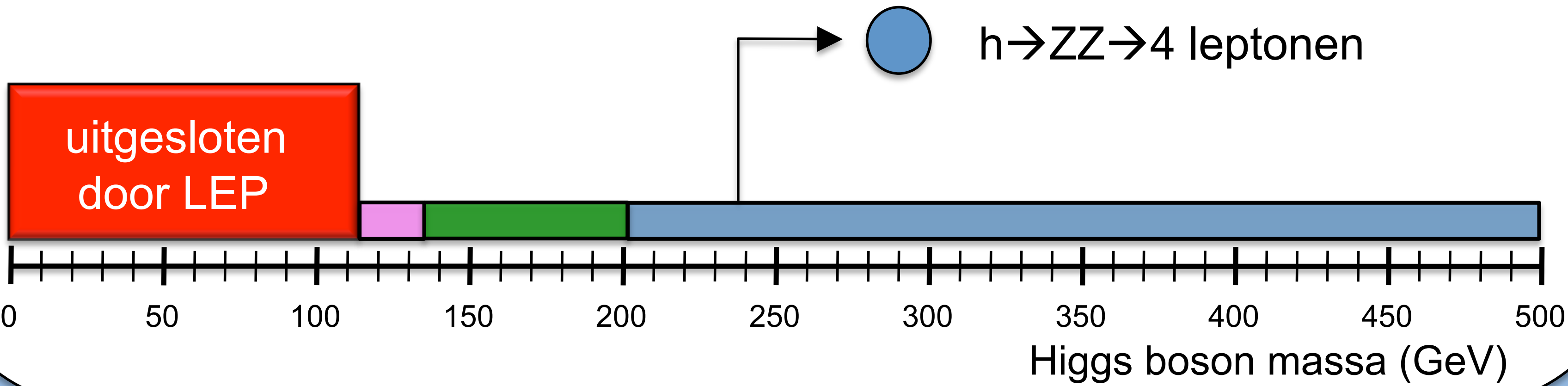
Hoge massa's: m_H > 200 GeV

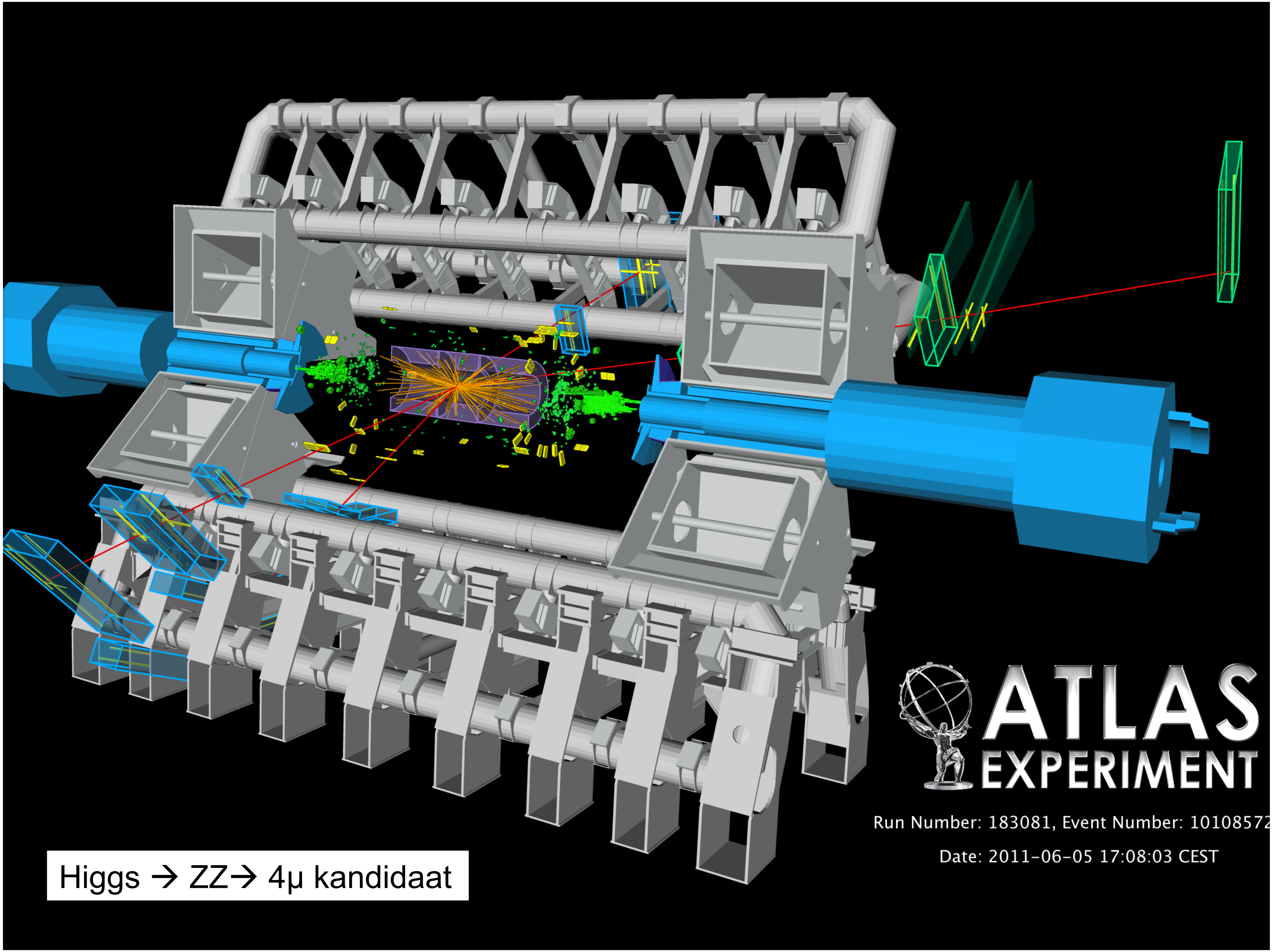


The golden channel

- 4 leptonen (e/μ)
- Erg zeldzaam: Higgs of ZZ

Vingerafdruk: 4-lepton massa





Higgs → ZZ→ 4μ kandidaat

Higgs → ZZ → 4 leptonen

klein aantal schitterende botsingen

30.000 Higgs bosonen

⇩

- Maar 1 op de 1000 Higgs bosonen vervalt naar 4 leptonen

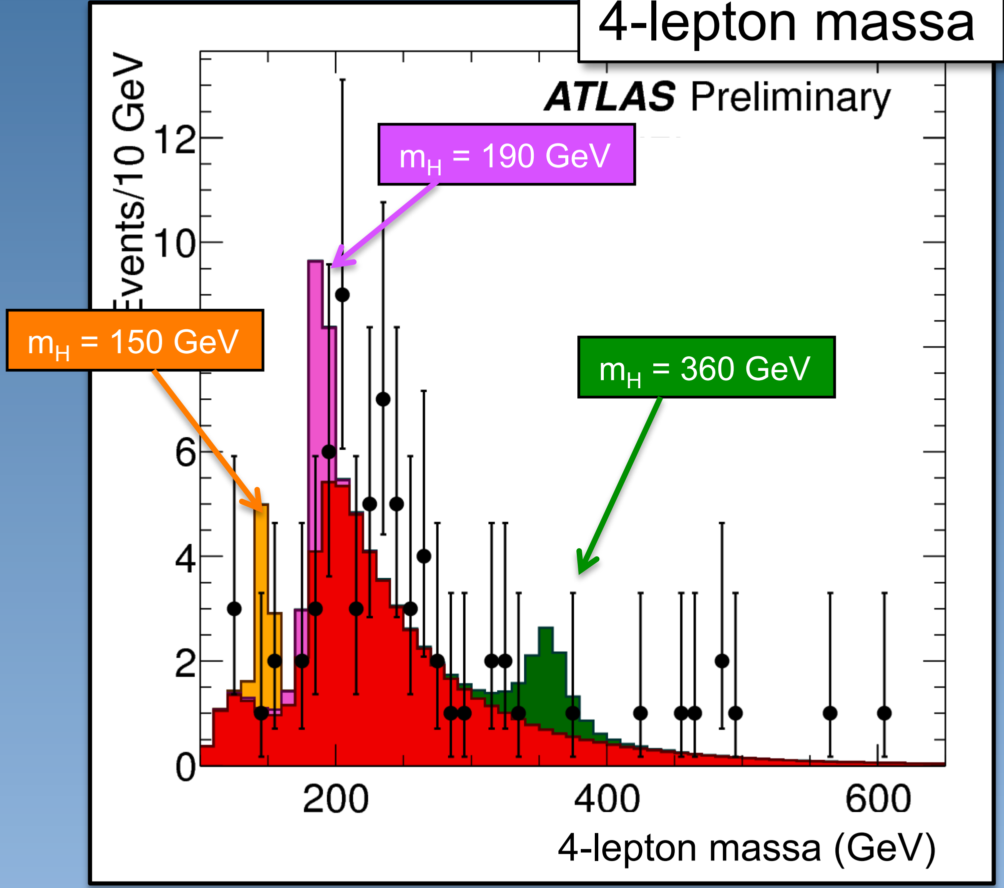
- 50% kans dat ATLAS detector ze allemaal goed terugvindt

⇩

16 Higgs → 4 lepton events

'overig'	52 events
Met Higgs	68 events

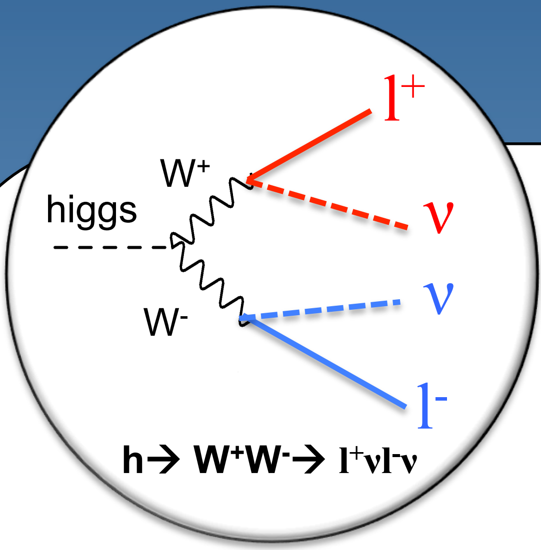
4-lepton massa



Geen duidelijk piekje helaas

→ m_h < 200 GeV

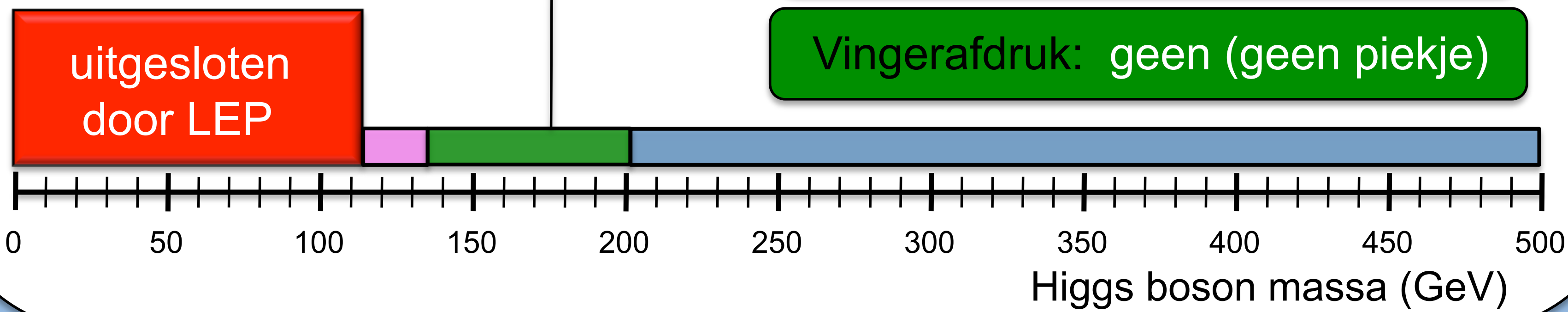
Midden-regio: 130 < m_H < 200 GeV

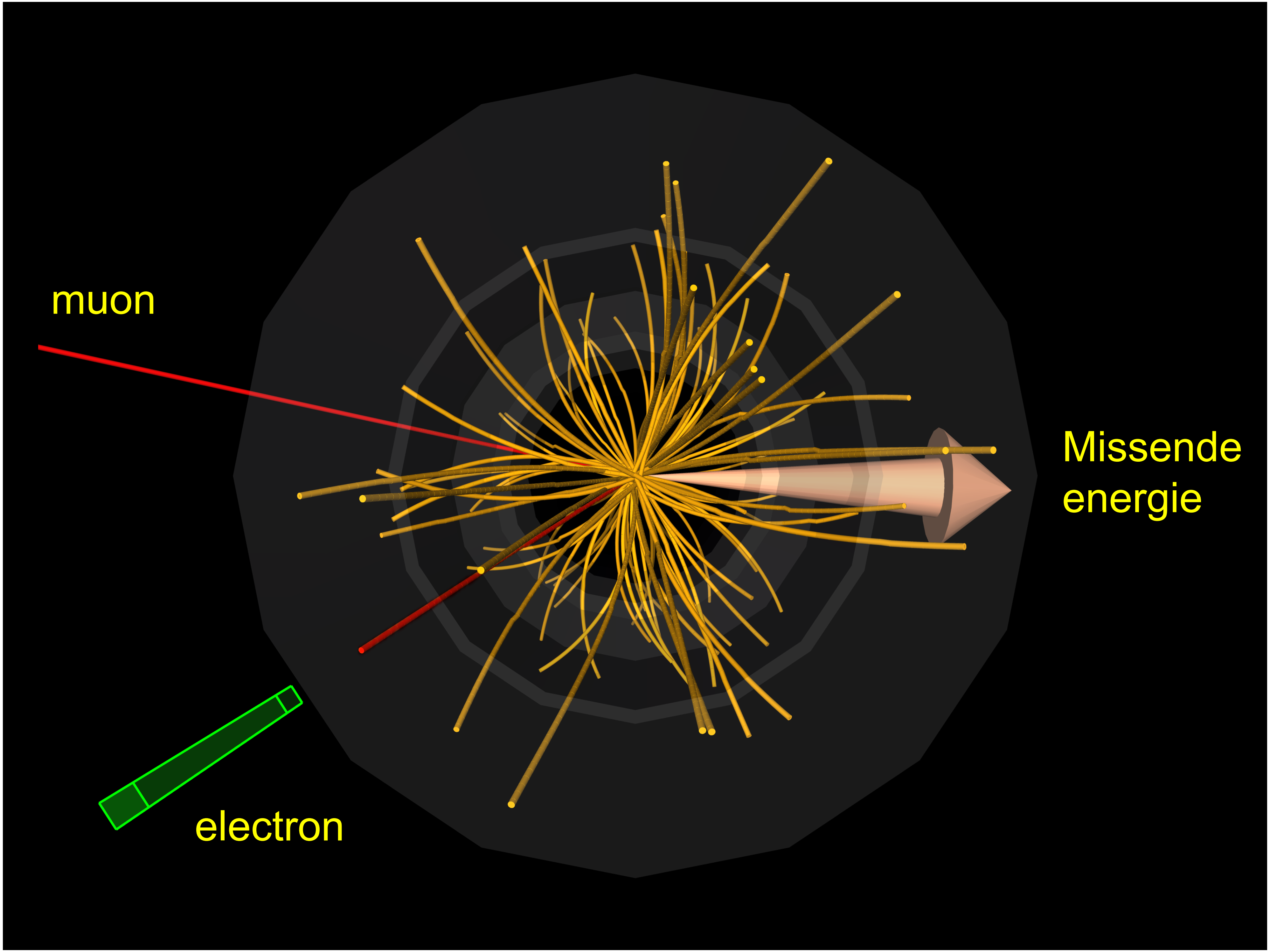


h→W+W-→2 leptonen en 2 neutrinos

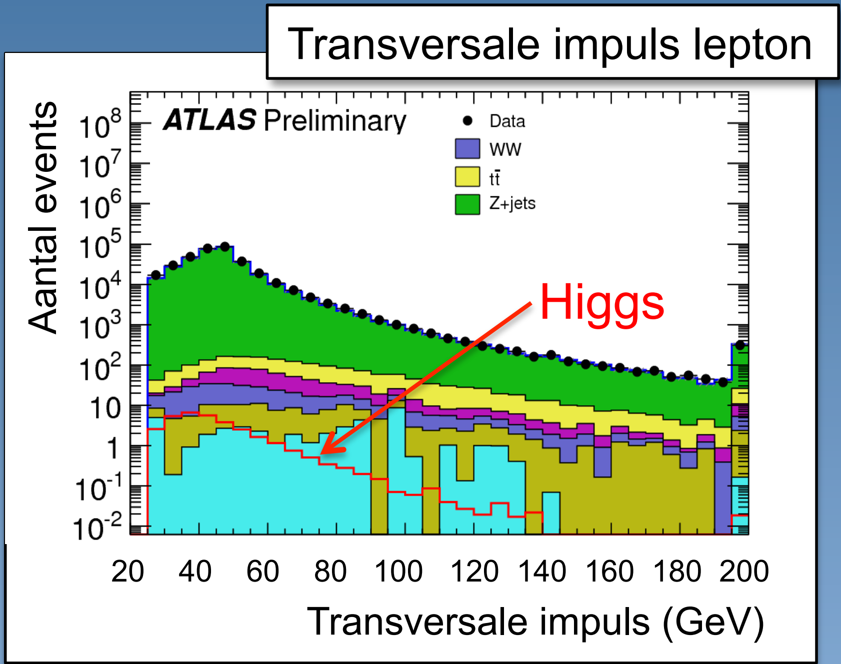
- veel voorkomend type botsing
- Lastig te isoleren

Vingerafdruk: geen (geen piekje)




muon
Missende
energie
electron

Het mogelijke Higgs signaal is goed verborgen



signaal < 1/10.000 van het totaal

Delicate multi-dimensionale selectie:

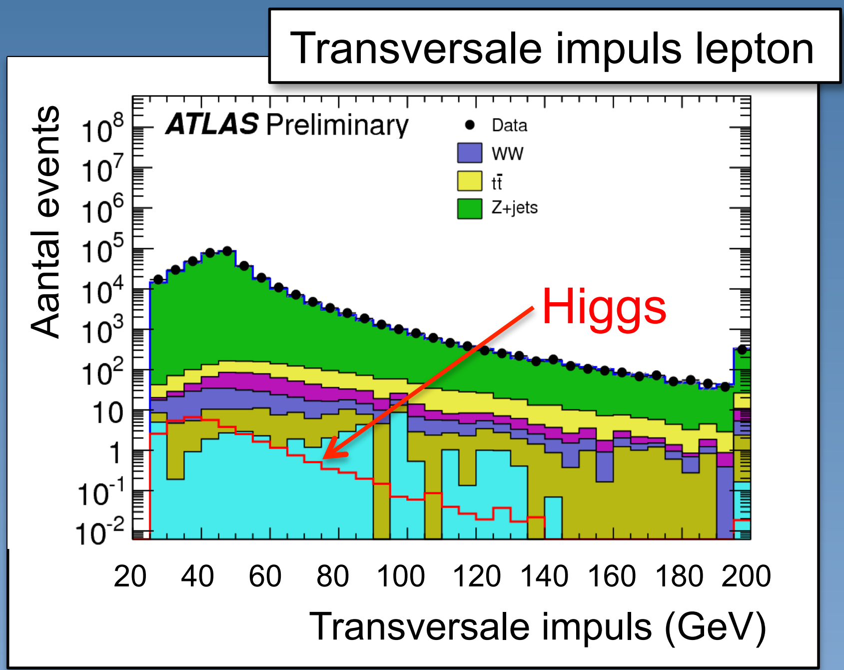
wegsnijden andere processen met behoud van (meeste) signaal

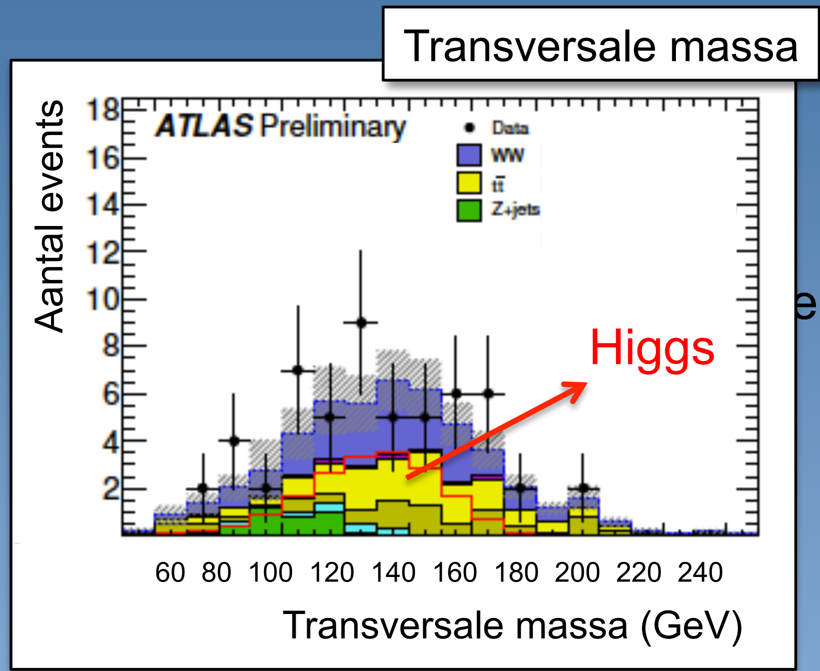
Diamanten zoeken

Hard werken … en slimme nieuwe ideeën zoeken

Veel slimme studenten nodig … hebben we gelukkig ook

Het mogelijke Higgs signaal is goed verborgen





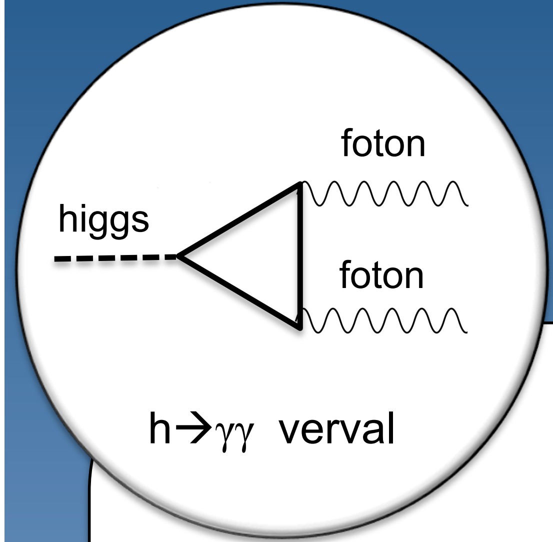
signaal = 1/10.000 van het totaal

signaal = 1/3 van het totaal

Overig	**23**
Met Higgs	35

LHC data: **23 (helaas)**

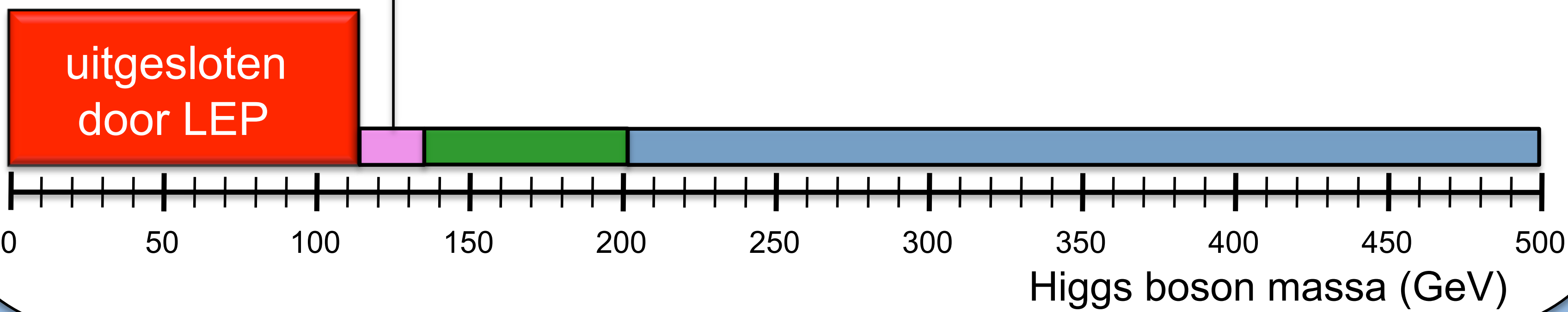
De laagste massa's



h→2 fotonen

- 2 energetische geïsoleerde fotonen
- detector gevoelig voor 'valse' signalen

Vingerafdruk: 2-foton massa



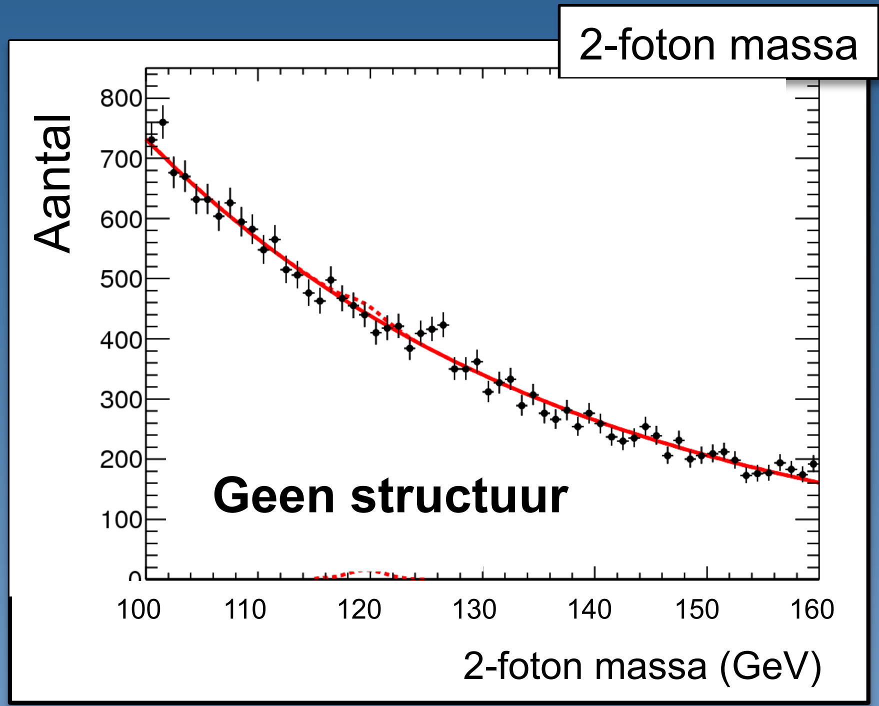
Event-type	Aantal events

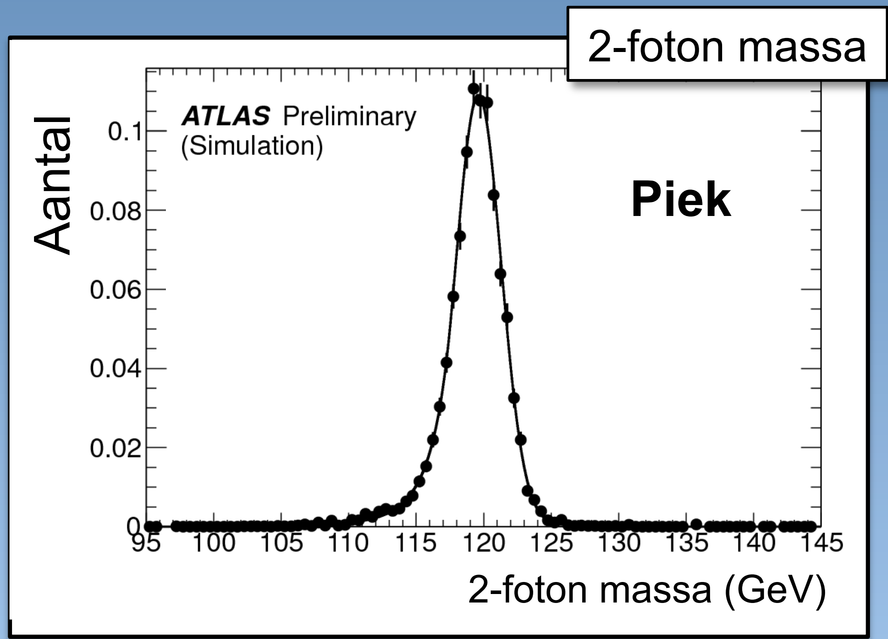
Overig

$\gamma\gamma$	3650 ±100 ±290
γ + jet	1110 ± 60 ±270
Di-jet	220 ± 20 ±130
Drell-Yan	86 ± 1 ± 14
‘normaal’	**5066**

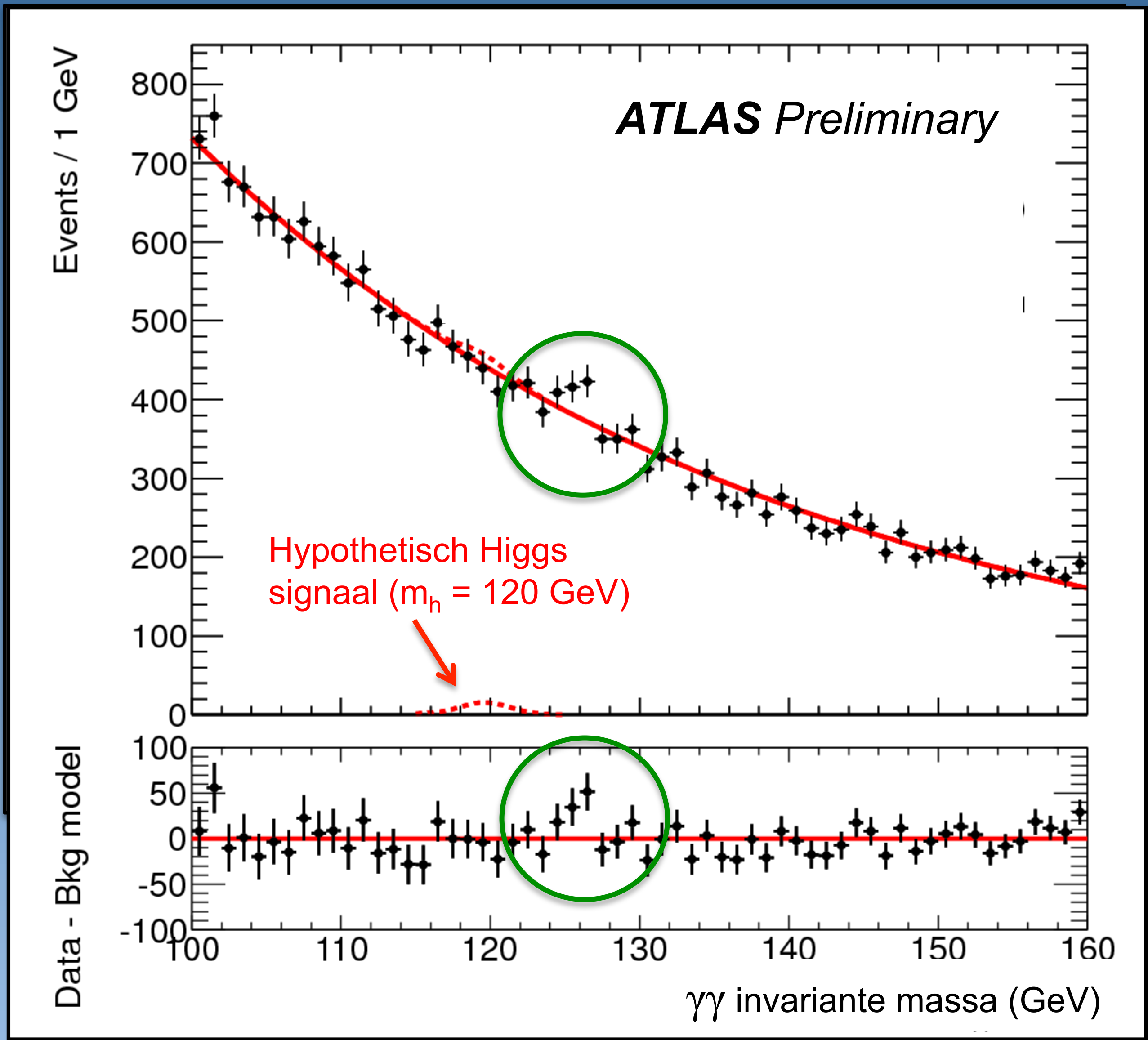
Higgs

Higgs signal	**17.6**



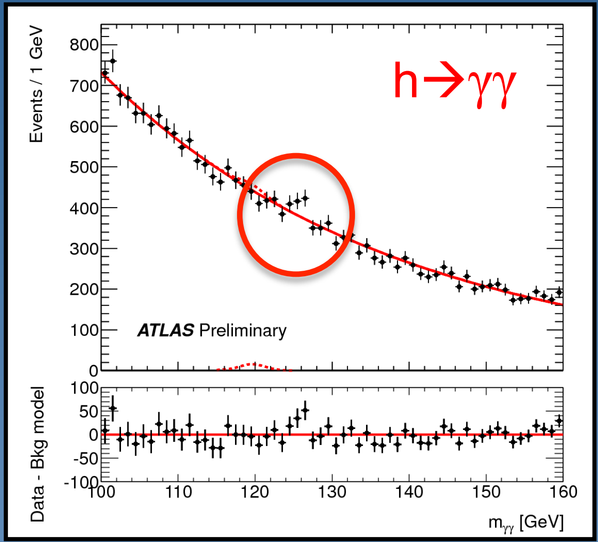


De ‘echte’ LHC data

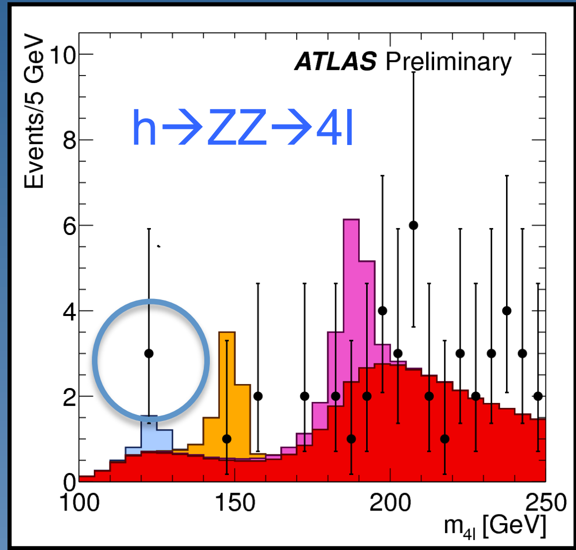


piekje ?

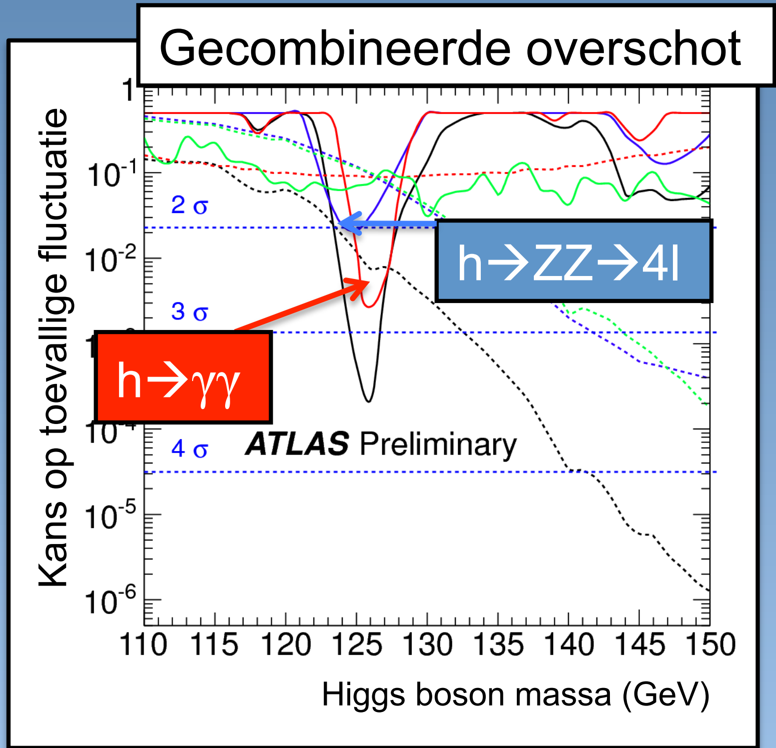
Higgs → 2 fotonen



Higgs → 4 leptonen



Overschot in twee kanalen zichtbaar



Kans ~ 1/100 (2.3 σ)

Interpretatie overschot in ATLAS

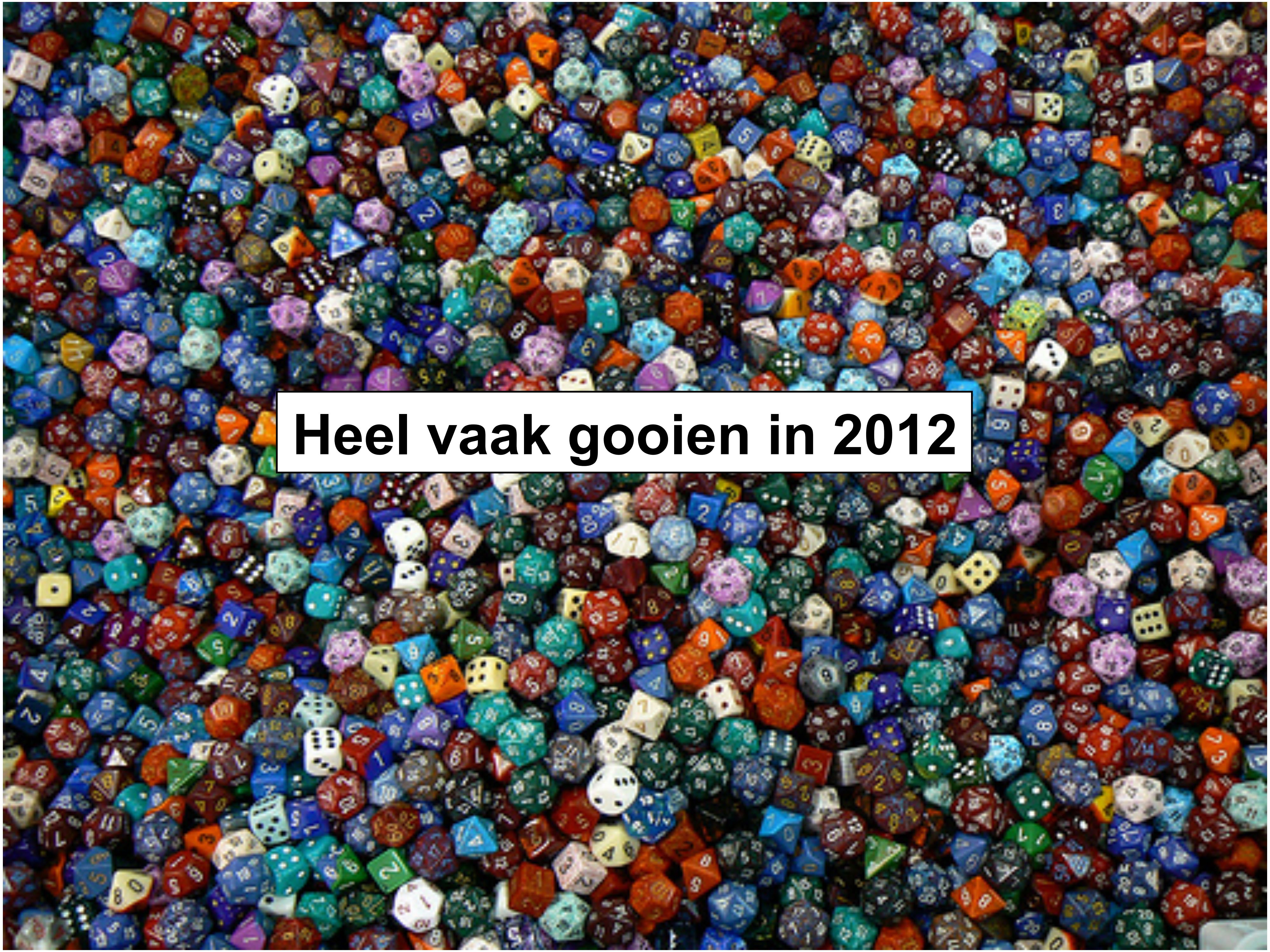
Kans op toevallige fluctuatie zoals geobserveerd of nog groter: ~ 1 op 100

Toeval of valse dobbelsteen ?

Claim pas ontdekking als:

Kans op toevallige fluctuatie zoals geobserveerd kleiner dan 1 op 1,000,000

8 keer 6 gooien achter elkaar


Heel vaak gooien in 2012

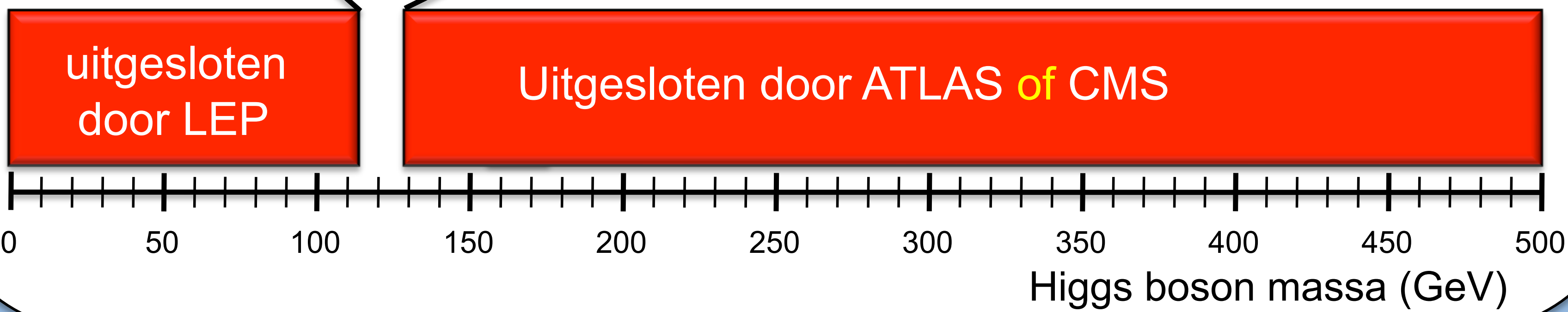
Stand van zaken 11 januari 2012

Indirect:

Theorie: $m_h \leq 600$ GeV

Electrozwakke precisie-metingen: $m_h \leq 185$ GeV

Toegestaan: 115.5 GeV< m_h < 127 GeV



… misschien hebben we hem al gezien

Samenvatting

0) Large Hadron Collider en experimenten
werken fan-tas-tisch!

1) Zoektocht de Higgs in 2011
Groot massa-gebied uitgesloten
Overschot bij lage massa (~ 125 GeV) → nog geen ontdekking

2) Zoektocht de Higgs in 2012
Als het Higgs boson bestaat zullen het CMS en ATLAS
experiment hem (samen) ontdekken

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backup

In het kader van openheid

ATLAS experiment

ATLAS Higgs resultaten:
http://www.atlas.ch/news/2011/status-report-dec-2011.html

Alle ATLAS resultaten: publicaties en plaatjes
https://twiki.cern.ch/twiki/bin/view/AtlasPublic

CMS experiment

Higgs resultaten:
http://cms.web.cern.ch/news/cms-search-standard-model-higgs-boson-lhc-data-2010-and-2011