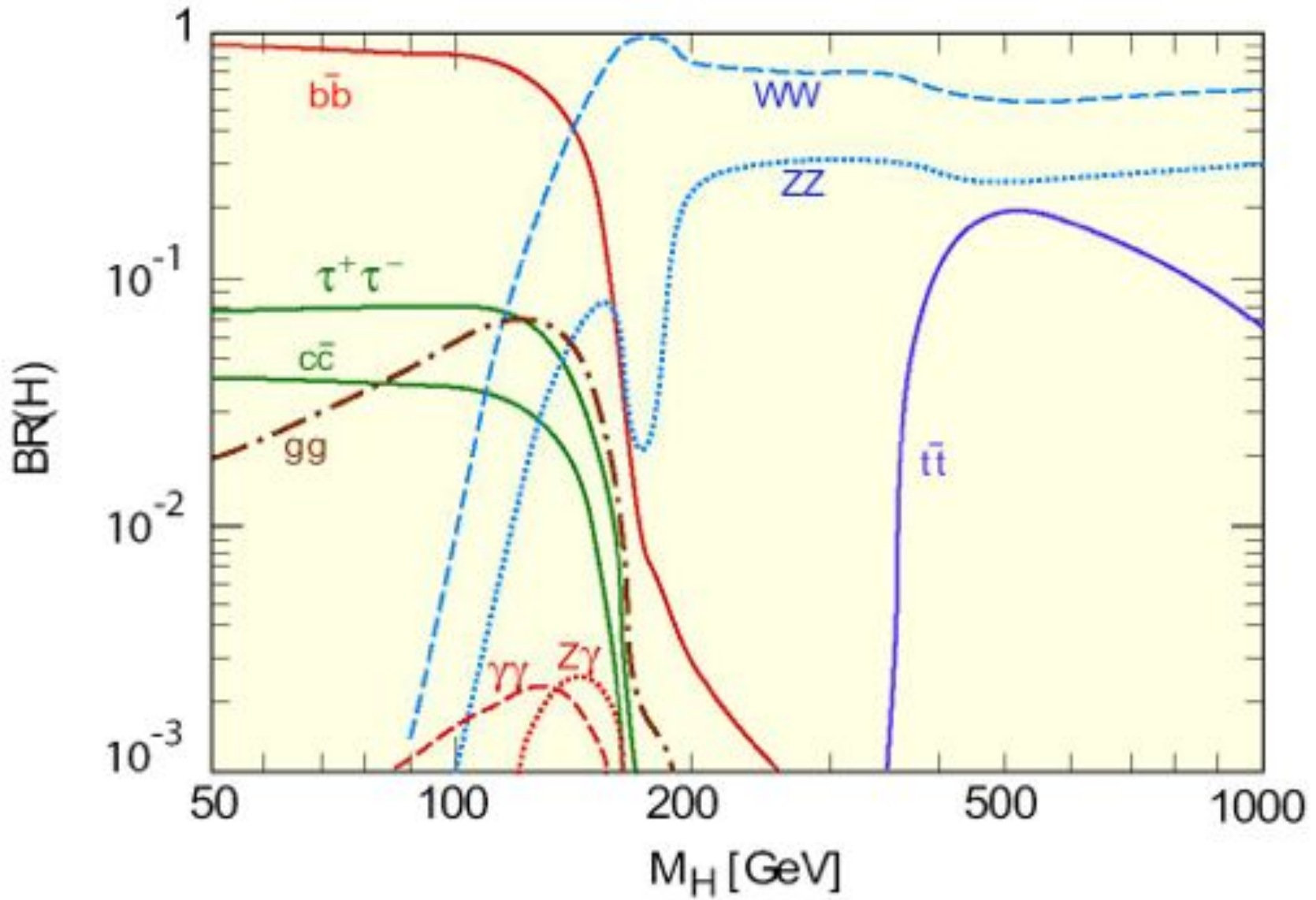


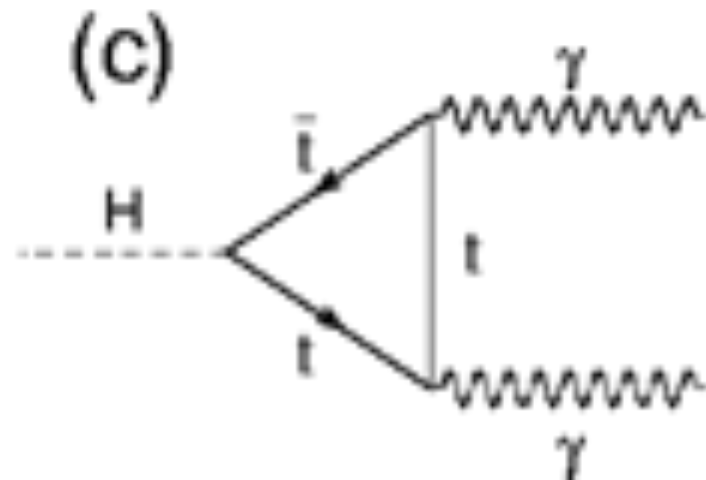
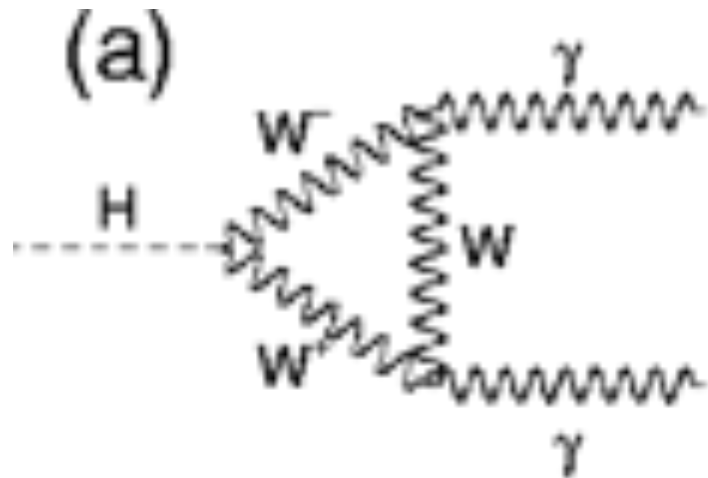
# Higgs eigenschappen

- Boson, spin 0
- Koppelingssterkte aan alle ander deeltjes bekend: proportioneel met de massa van het andere deeltje
- Zelfinteractie bekend
- Massa onbekend

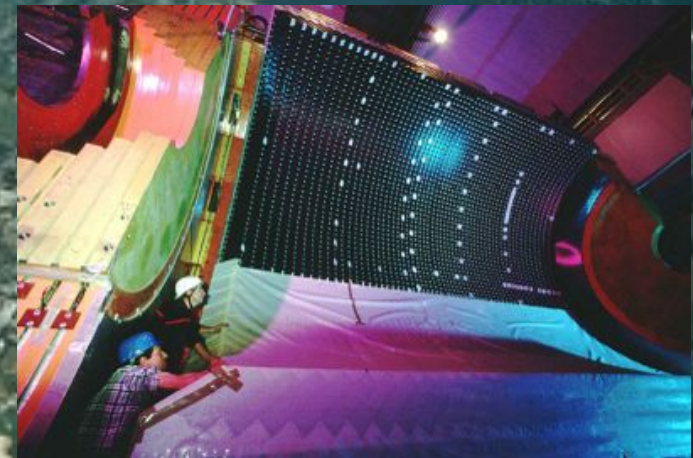
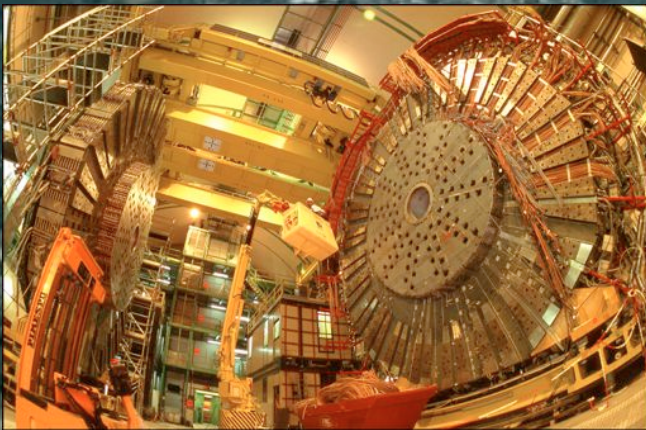
# Higgs verval: instantaan



# Higgs verval in fotonen ?!!!

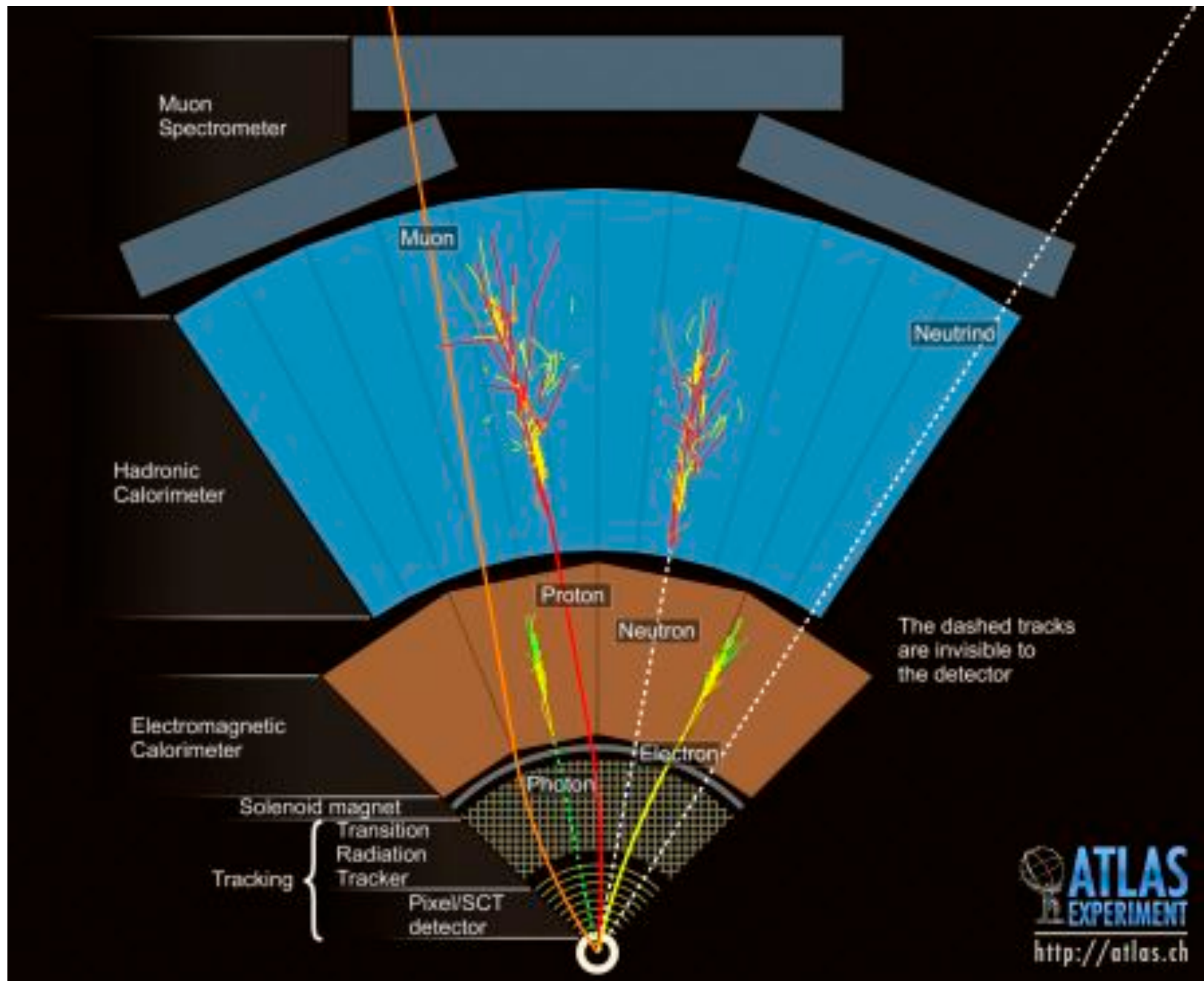


# LEP (1989-2000): ontworpen om H

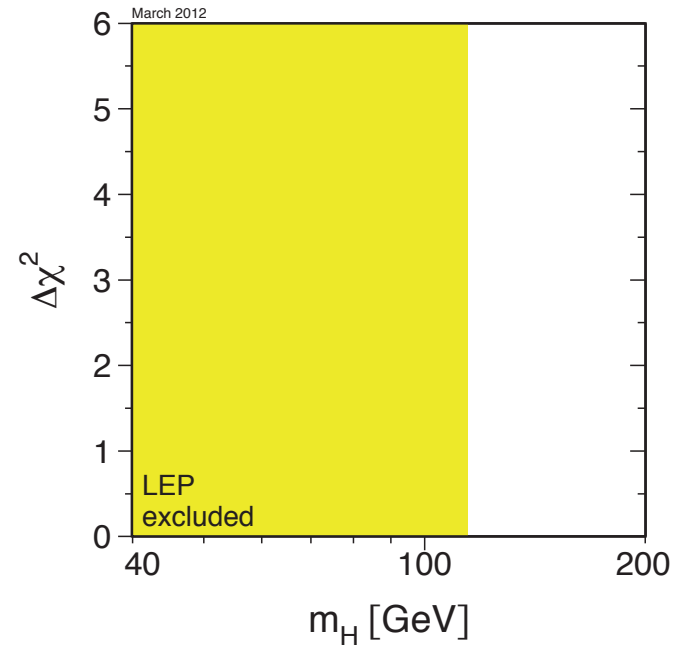
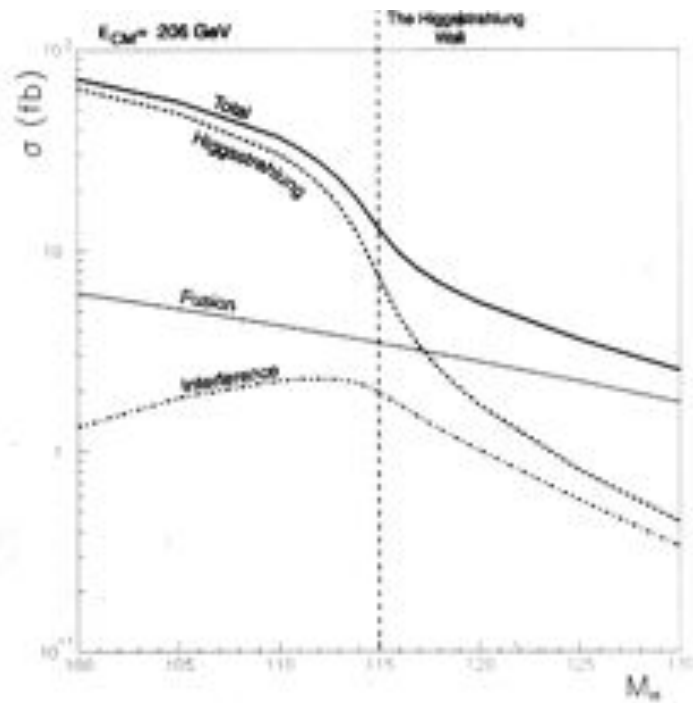
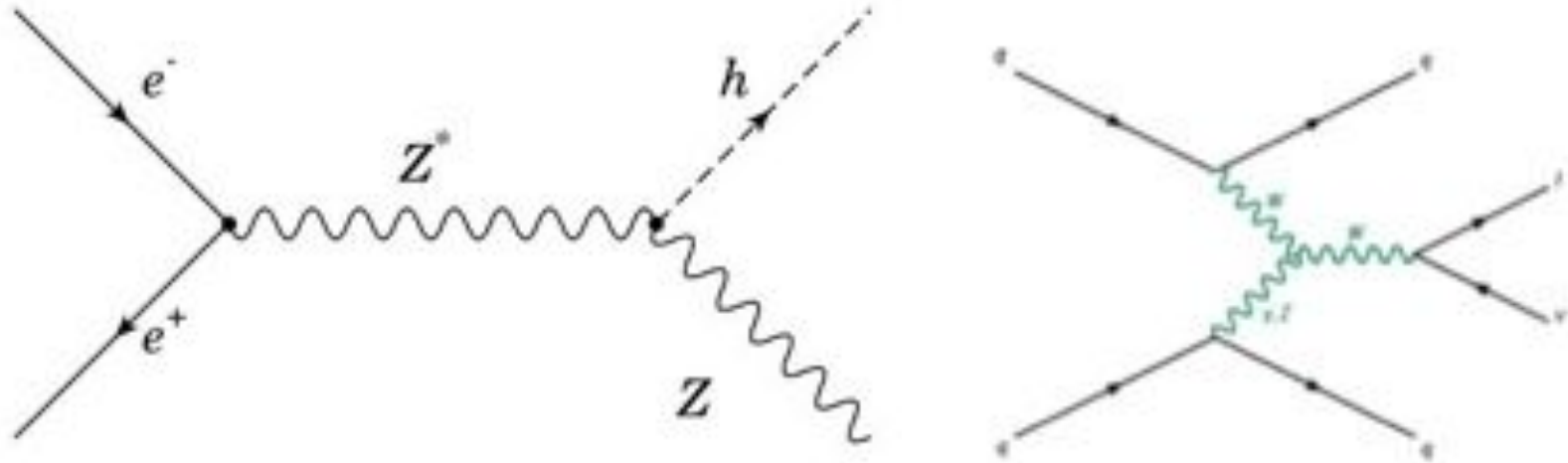




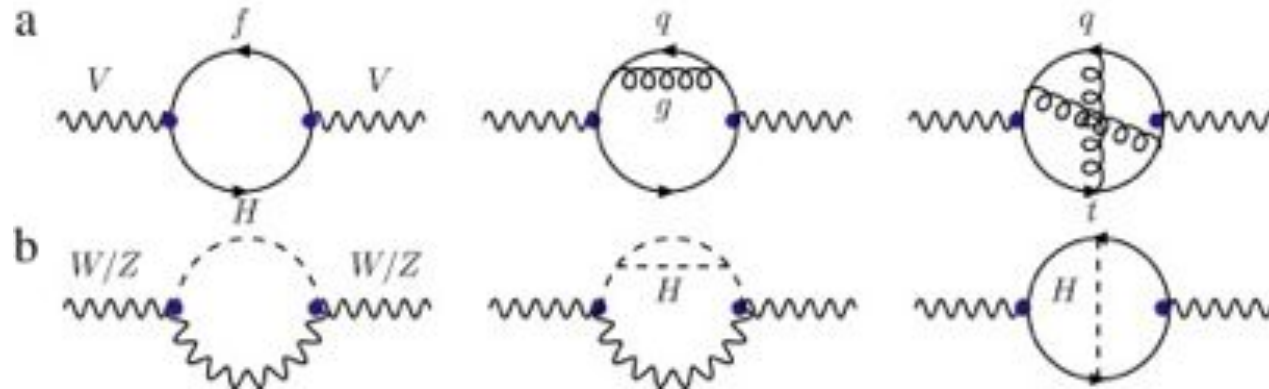
# deeltjes detectie en identificatie



# LEP (1989-2000): ontworpen om Higgs te maken

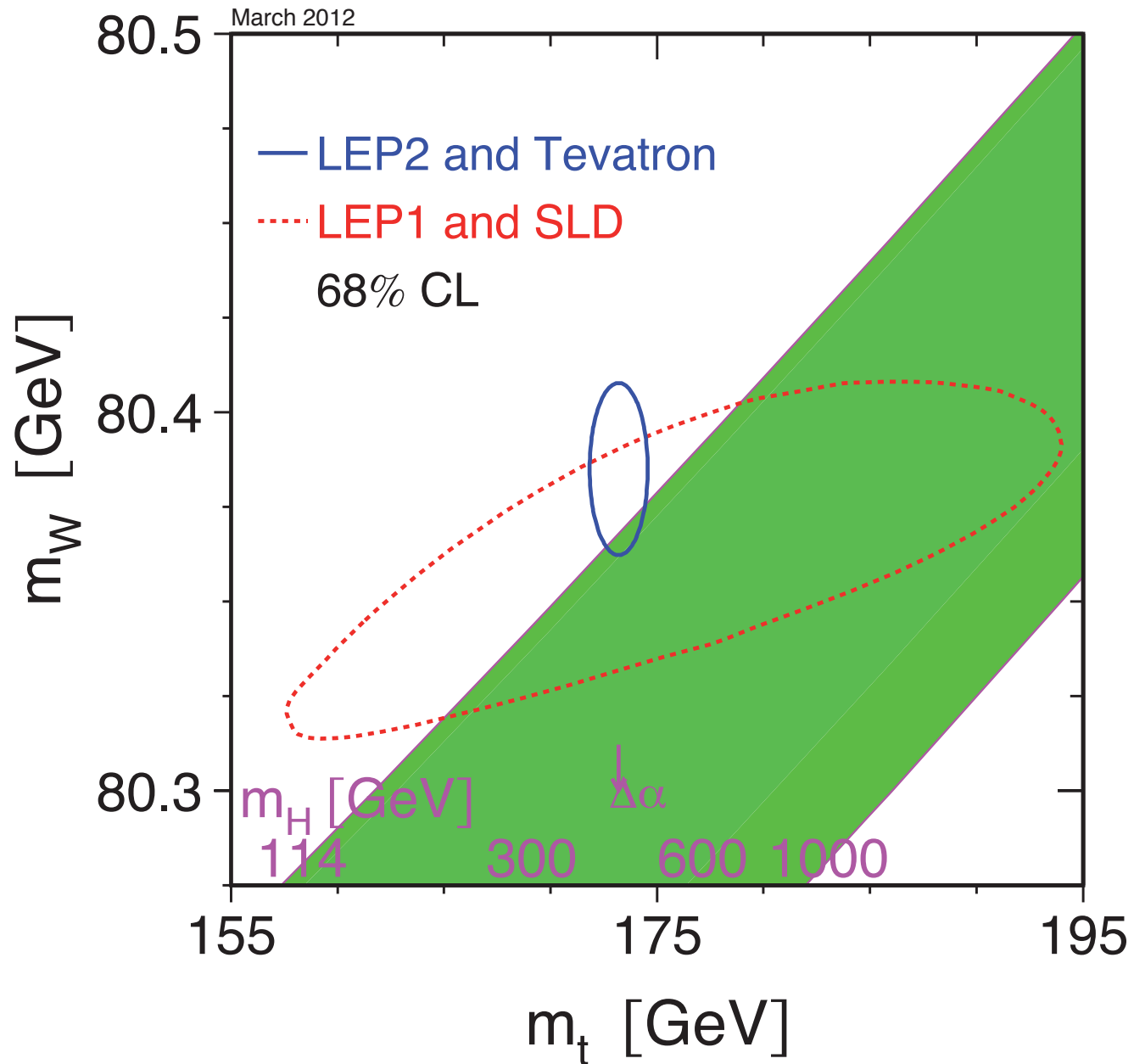


# Higgs virtuele productie



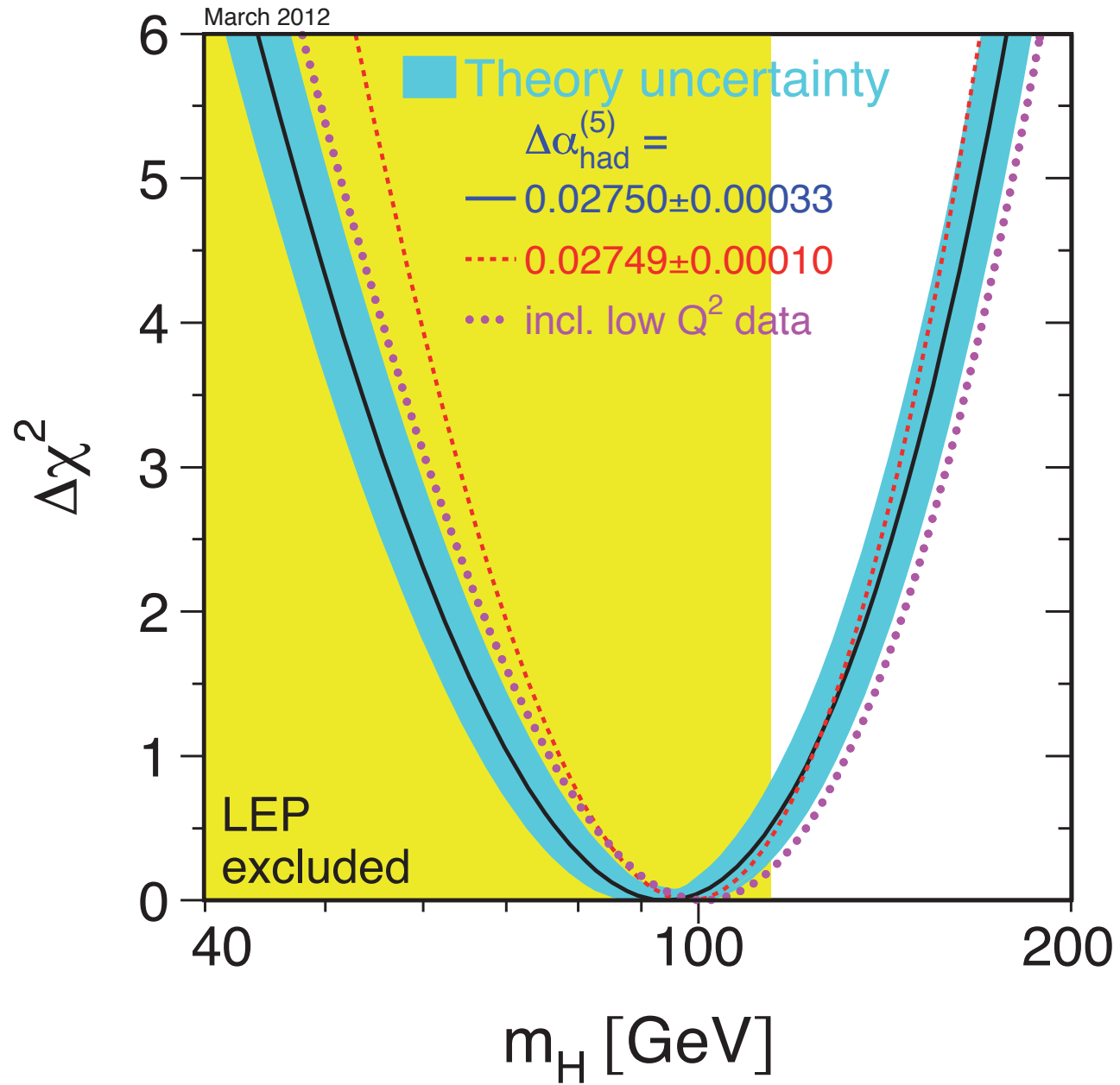
- Kan ook in processen die niet genoeg energie hebben om een echt Higgs deeltje te produceren
- Z (en W) parameters afhankelijk van  $\log(M_H)$

# Higgs virtuele productie

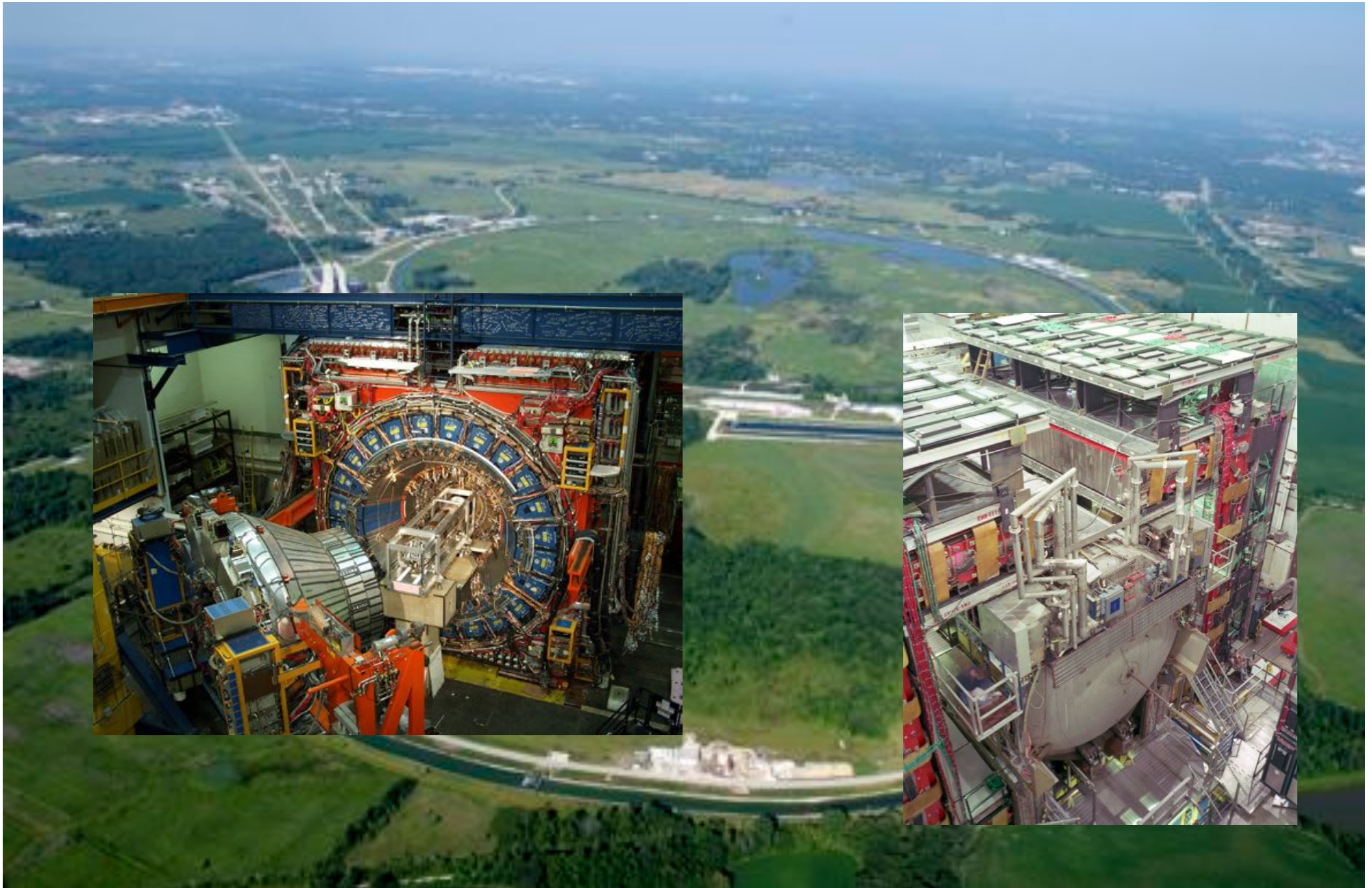




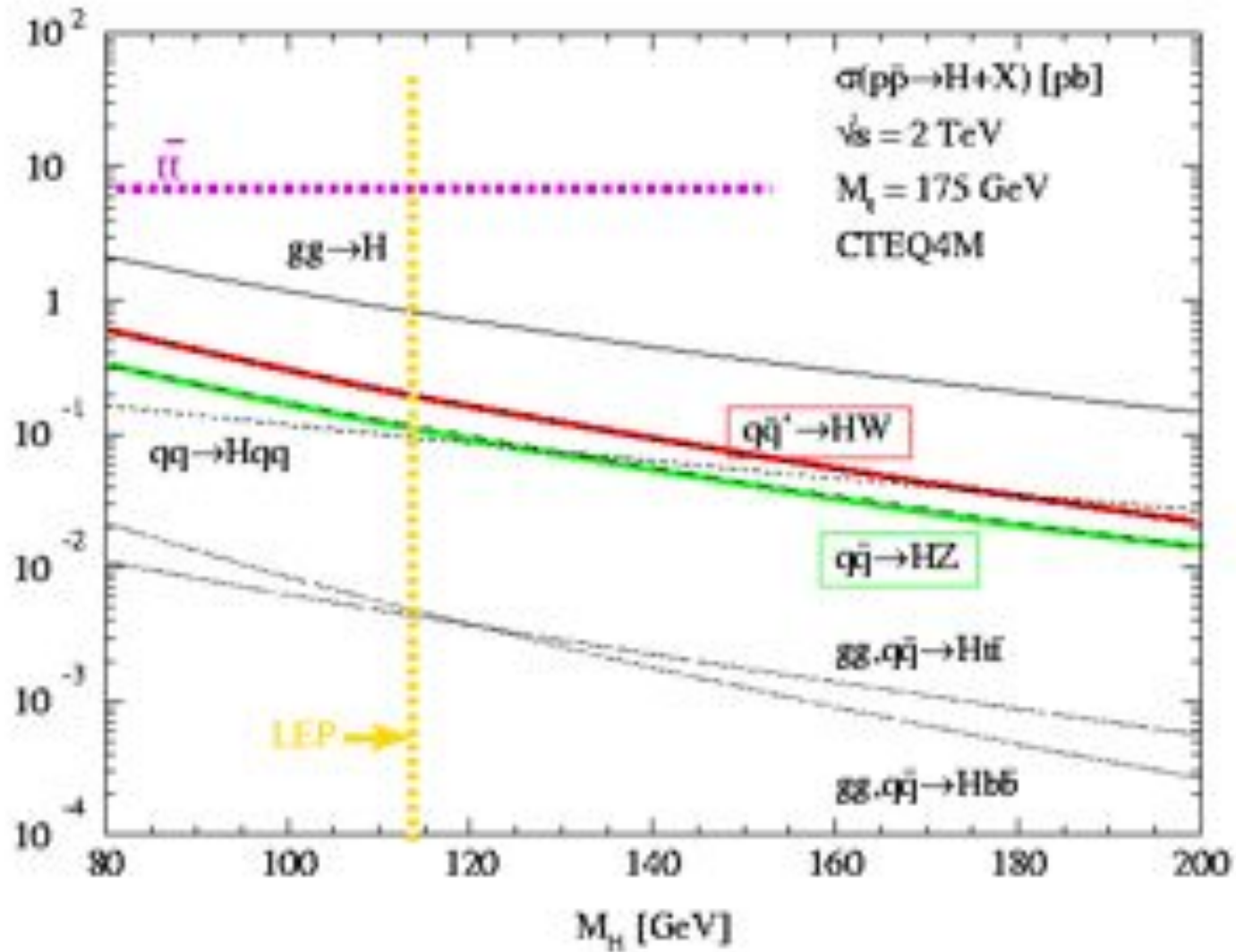
# Higgs virtuele productie



# Tevatron (1990-2011): ontworpen om top quarks te maken



# Higgs productie bij het Tevatron





| Channel   | Luminosity<br>( $\text{fb}^{-1}$ ) | $m_H$ range<br>( $\text{GeV}/c^2$ ) | Reference |
|---|------------------------------------|-------------------------------------|-----------|
| $WH \rightarrow \ell\nu b\bar{b}$ 2-jet channels $4 \times (\text{TT, TL, Tx, LL, Lx})$   | 9.45                               | 100-150                             | [17]      |
| $WH \rightarrow \ell\nu b\bar{b}$ 3-jet channels $3 \times (\text{TT, TL})$   | 9.45                               | 100-150                             | [17]      |
| $ZH \rightarrow \nu\bar{\nu} b\bar{b}$ (SS, SJ, 1S)   | 9.45                               | 100-150                             | [18]      |
| $ZH \rightarrow \ell^+ \ell^- b\bar{b}$ 2-jet channels $2 \times (\text{TT, TL, Tx, LL})$   | 9.45                               | 100-150                             | [19]      |
| $ZH \rightarrow \ell^+ \ell^- b\bar{b}$ 3-jet channels $2 \times (\text{TT, TL, Tx, LL})$   | 9.45                               | 100-150                             | [19]      |
| $H \rightarrow W^+ W^-$ $2 \times (0 \text{ jets, 1 jet}) + (2 \text{ or more jets}) + (\text{low-}m_{\ell\ell})$                             | 9.7                                | 110-200                             | [20]      |
| $H \rightarrow W^+ W^-$ $(e-\tau_{\text{had}}) + (\mu-\tau_{\text{had}})$   | 9.7                                | 130-200                             | [21]      |
| $WH \rightarrow WW^+ W^-$ (same-sign leptons) + (tri-leptons)   | 9.7                                | 110-200                             | [20]      |
| $WH \rightarrow WW^+ W^-$ tri-leptons with 1 $\tau_{\text{had}}$  | 9.7                                | 130-200                             | [21]      |
| $ZH \rightarrow ZW^+ W^-$ (tri-leptons with 1 jet) + (tri-leptons with 2 or more jets)  | 9.7                                | 110-200                             | [20]      |
| $H \rightarrow ZZ$ four leptons   | 9.7                                | 120-200                             | [22]      |
| $H + X \rightarrow \tau^+ \tau^-$ (1 jet) + (2 jets)  | 8.3                                | 100-150                             | [23]      |
| $WH \rightarrow \ell\nu\tau^+\tau^- / ZH \rightarrow \ell^+ \ell^- \tau^+ \tau^-$ $\ell-\tau_{\text{had}}-\tau_{\text{had}}$                  | 6.2                                | 100-150                             | [24]      |
| $WH \rightarrow \ell\nu\tau^+\tau^- / ZH \rightarrow \ell^+ \ell^- \tau^+ \tau^-$ $(\ell-\ell-\tau_{\text{had}}) + (e-\mu-\tau_{\text{had}})$ | 6.2                                | 100-125                             | [24]      |
| $WH \rightarrow \ell\nu\tau^+\tau^- / ZH \rightarrow \ell^+ \ell^- \tau^+ \tau^-$ $\ell-\ell-\ell$  | 6.2                                | 100-105                             | [24]      |
| $ZH \rightarrow \ell^+ \ell^- \tau^+ \tau^-$ four leptons including $\tau_{\text{had}}$ candidates  | 6.2                                | 100-115                             | [24]      |
| $WH + ZH \rightarrow jj b\bar{b}$ (SS, SJ)  | 9.45                               | 100-150                             | [25]      |
| $H \rightarrow \gamma\gamma$ (CC, CP, C'C, C'P)   | 10.0                               | 100-150                             | [26]      |
| $t\bar{t}H \rightarrow WW b\bar{b} b\bar{b}$ (lepton) (4jet, 5jet, $\geq 6$ jet) $\times$ (SSS, SSJ, SJJ, SS, SJ)                             | 9.45                               | 100-150                             | [27]      |
| $t\bar{t}H \rightarrow WW b\bar{b} b\bar{b}$ (no lepton) (low met, high met) $\times$ (2 tags, 3 or more tags)                                | 5.7                                | 100-150                             | [28]      |

| Channel   | Luminosity<br>( $\text{fb}^{-1}$ ) | $m_H$ range<br>( $\text{GeV}/c^2$ ) | Reference |
|---|------------------------------------|-------------------------------------|-----------|
| $H+(X) \rightarrow \ell\nu + \geq jj$ (0, 1, $\geq 2b$ tags) $\times$ (2, 3, 4+ jet)                  | 9.7                                | 100-200                             | [29]      |
| $ZH \rightarrow \nu\bar{\nu} b\bar{b}$ (MS, TS)   | 9.5                                | 100-150                             | [30]      |
| $ZH \rightarrow \ell^+ \ell^- b\bar{b}$ (TST, TLDT) $\times$ (ee, $\mu\mu$ , eeTCR, $\mu\mu\nu\tau$ ) | 9.7                                | 100-150                             | [31]      |
| $VH \rightarrow e^\pm \mu^\pm + X$  | 9.7                                | 115-200                             | [33]      |
| $H \rightarrow W^+ W^- \rightarrow \ell^\pm \nu \ell^\mp \nu$ (0, 1, 2+ jet)                          | 9.7                                | 115-200                             | [34]      |
| $H \rightarrow W^+ W^- \rightarrow \mu\nu\tau_{\text{had}}\nu$  | 7.3                                | 115-200                             | [32]      |
| $H \rightarrow W^+ W^- \rightarrow \ell\nu jj$  | 5.4                                | 130-200                             | [35]      |
| $VH \rightarrow \ell\ell + X$   | 9.7                                | 100-200                             | [36]      |
| $VH \rightarrow \tau\tau\mu + X$  | 7.0                                | 115-200                             | [37]      |
| $H \rightarrow \gamma\gamma$  | 9.7                                | 100-150                             | [38]      |

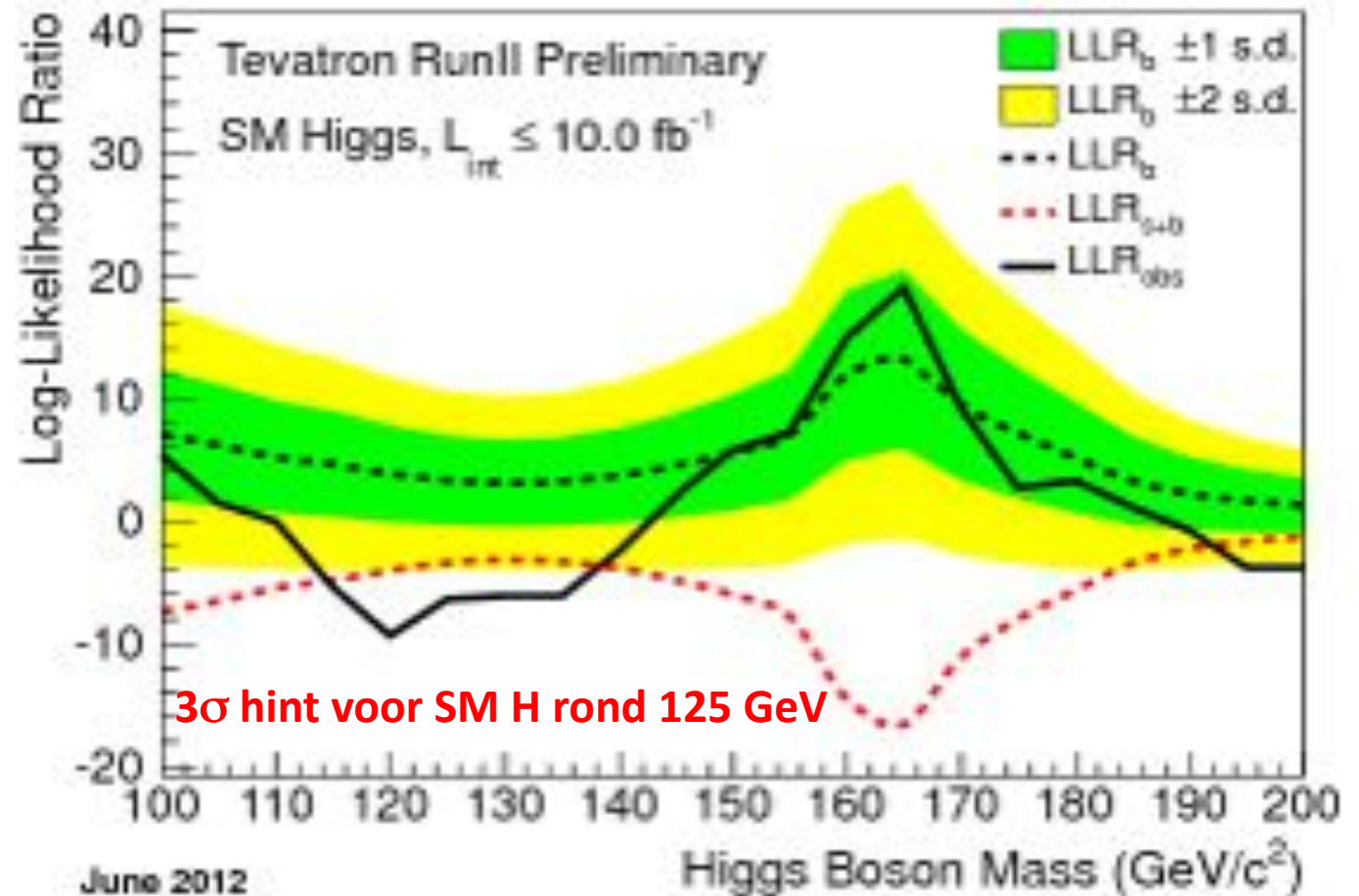
# Higgs productie bij hadron colliders: Tevatron

$$\mathcal{L}(R, \vec{s}, \vec{b} | \vec{n}, \vec{\theta}) \times \pi(\vec{\theta}) = \prod_{i=1}^{N_C} \prod_{j=1}^{N_b} \mu_{ij}^{n_{ij}} e^{-\mu_{ij}} / n_{ij}! \times \prod_{k=1}^{n_{np}} e^{-\theta_k^2/2}$$

achtergrond+SM Higgs

$$LLR = -2 \ln \frac{p(\text{data} | H_1)}{p(\text{data} | H_0)}$$

alleen achtergrond



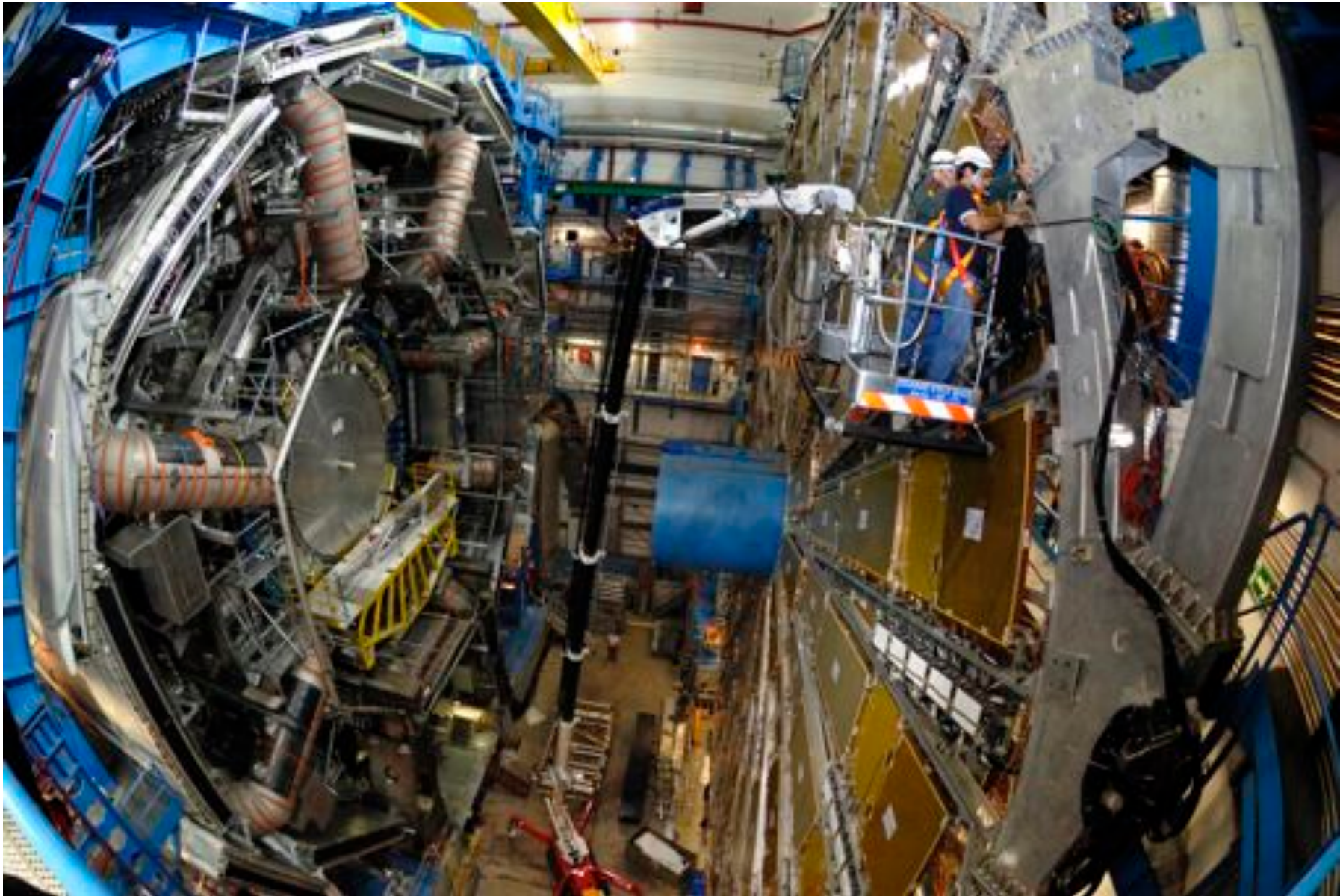


# LHC (2008-...): weer ontworpen om Higgs te maken



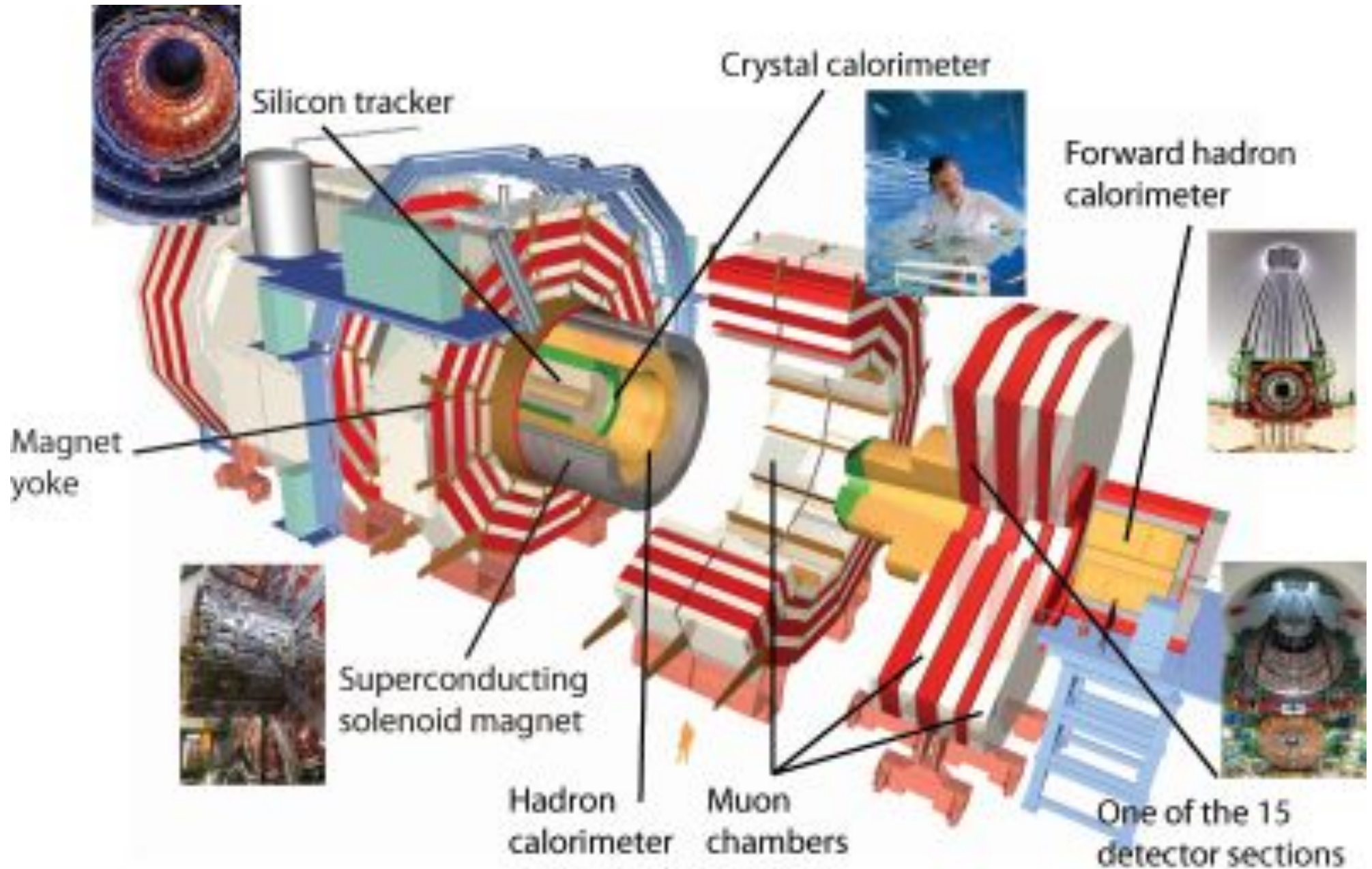


# De ATLAS detector

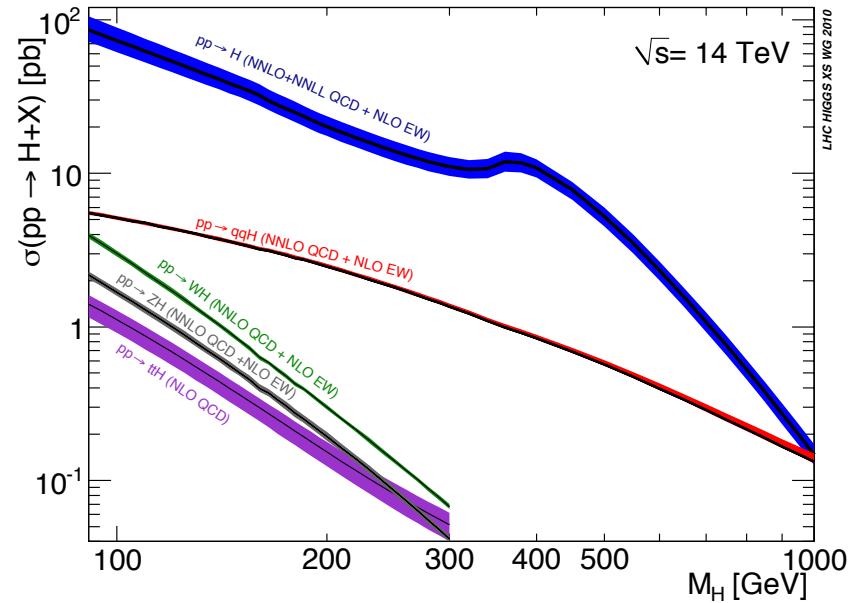
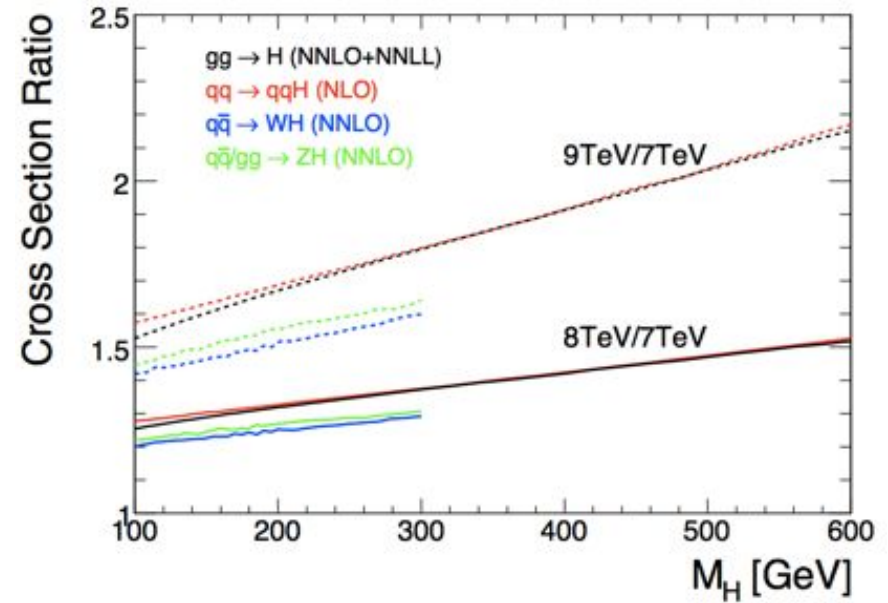
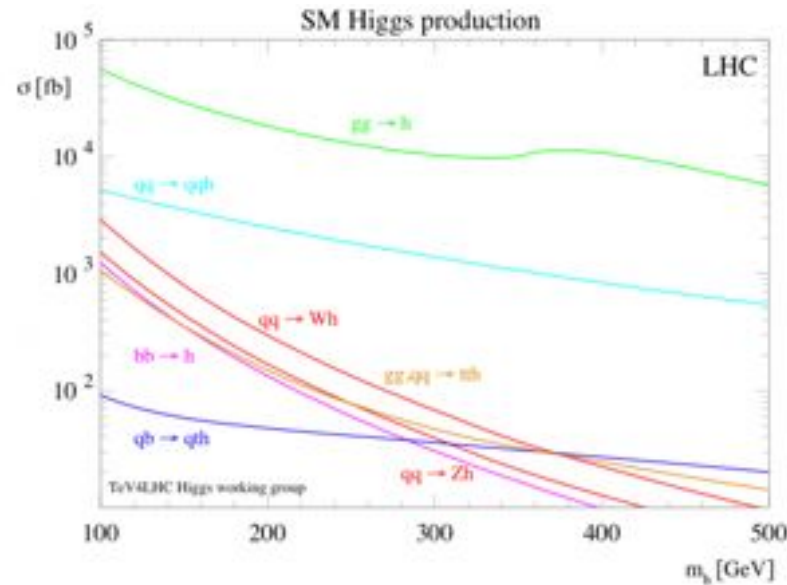




# De CMS detector

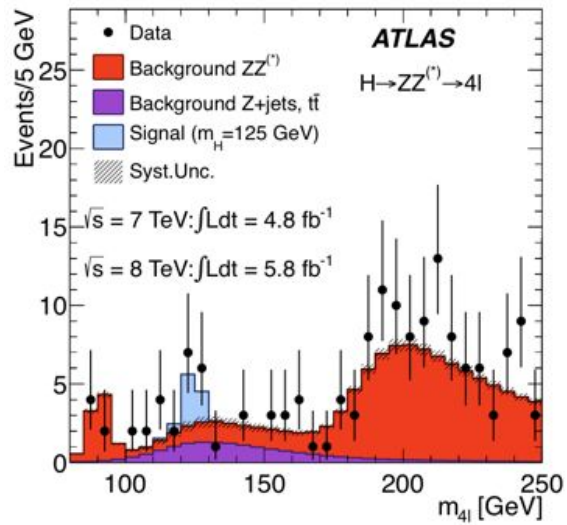


# LHC (2008-...): Higgs productie

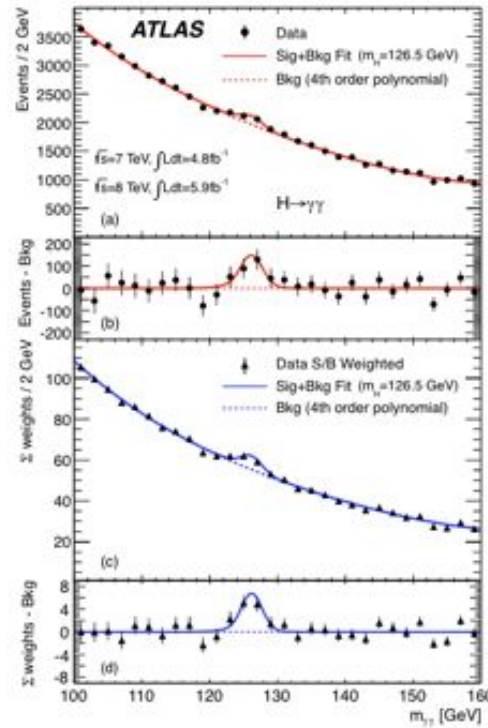


# Higgs zoek kanalen

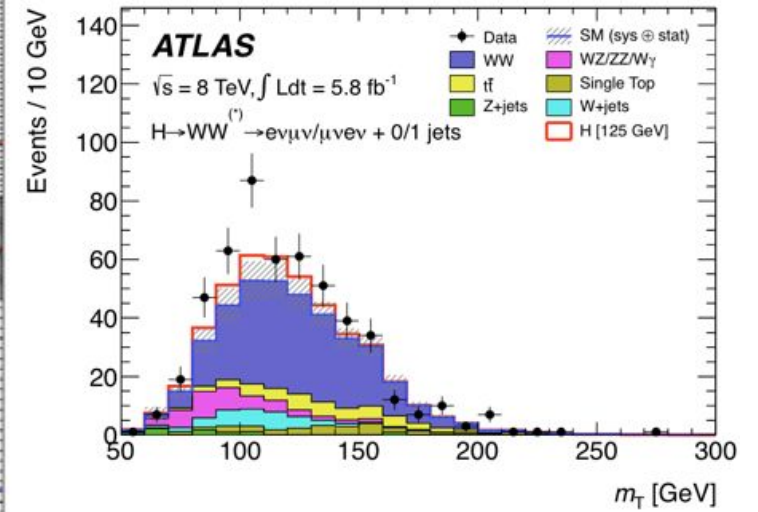
H → ZZ



H →  $\gamma\gamma$

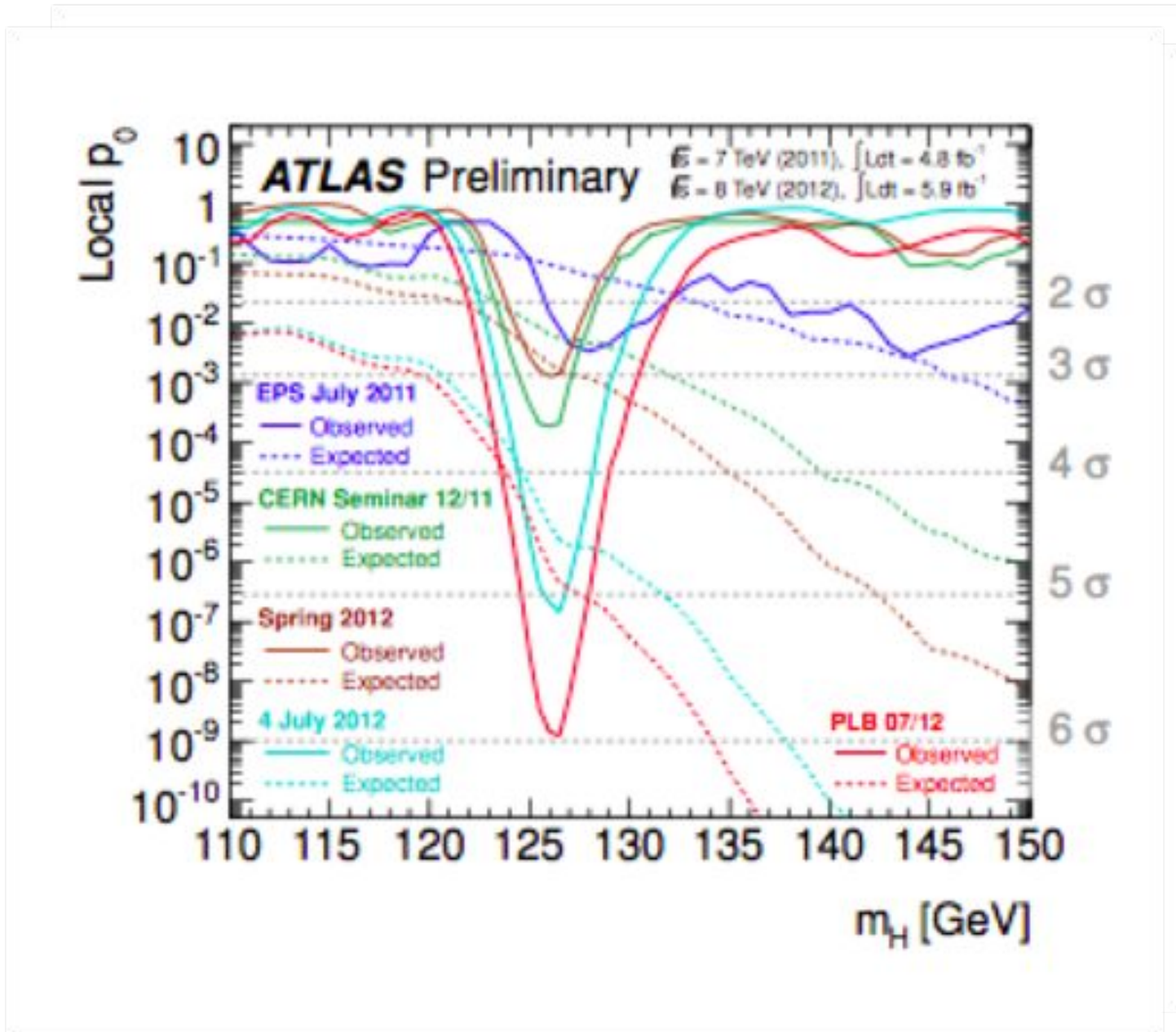


H → WW

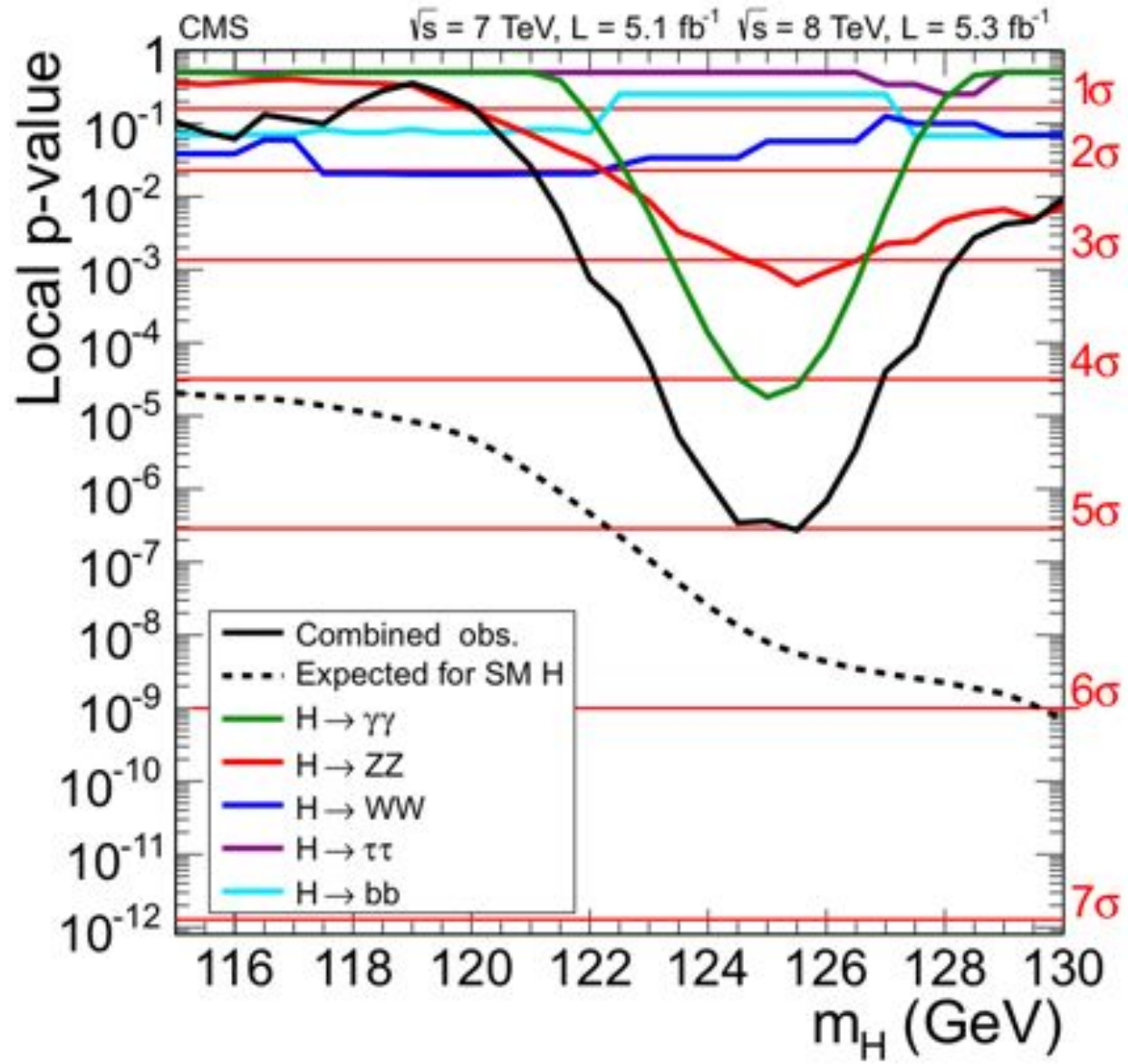




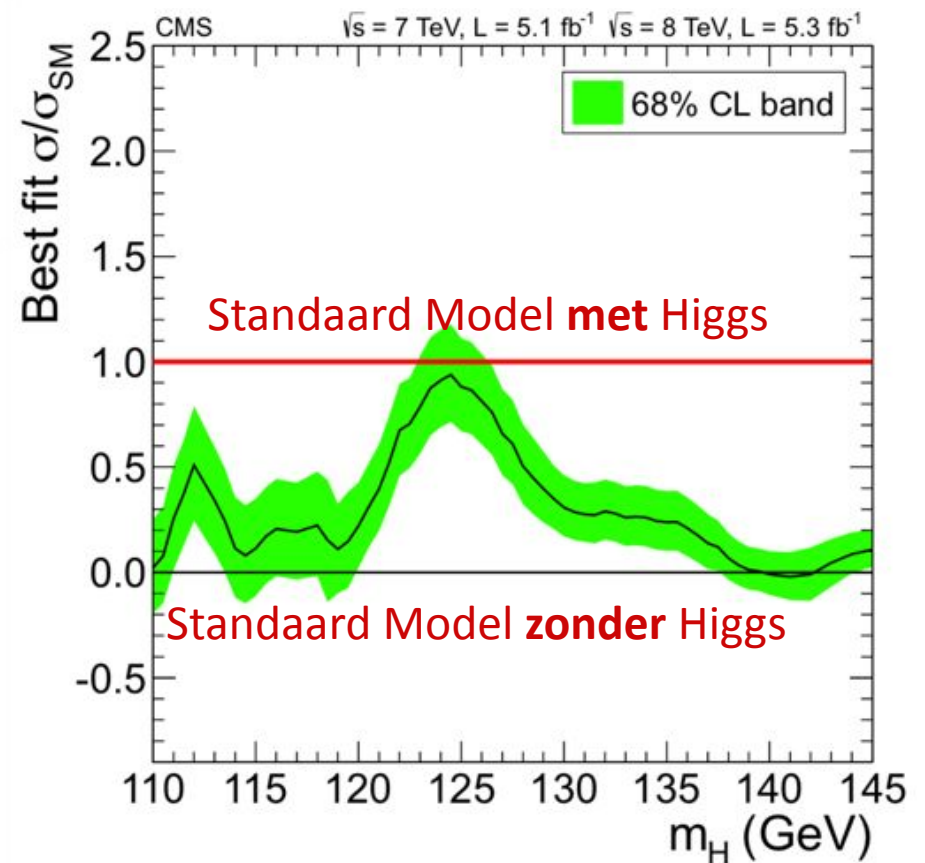
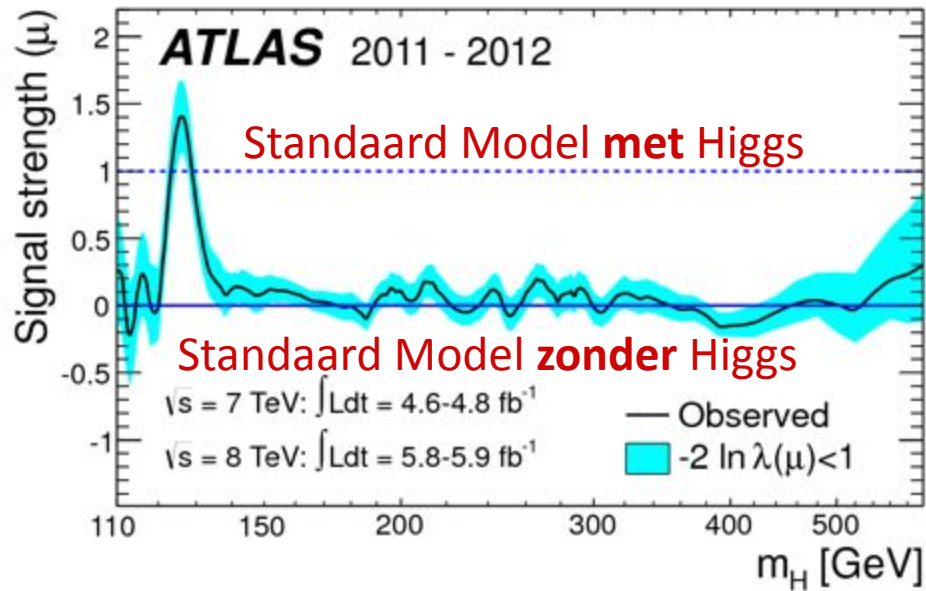
# ATLAS augustus 2012



# CMS



# Vergelijken met SM verwachting



Dus:

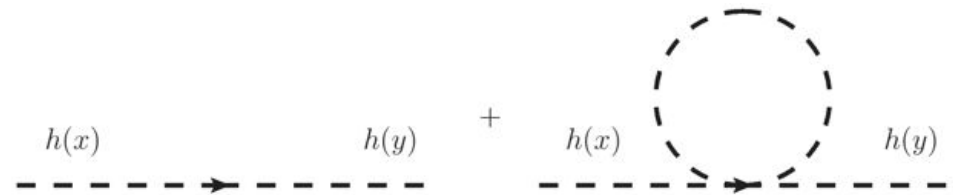
- Boson, spin 0: **nog niet gemeten**
- Koppelingssterkte aan alle ander deeltjes bekend:  
proportioneel met de massa van het andere deeltje:  
**zeer beperkt gemeten**
- Zelfinteractie bekend: **niet gemeten**
- Massa onbekend: **126 GeV**

Nog vele experimentele checks te doen !

# (Nieuwe) problemen

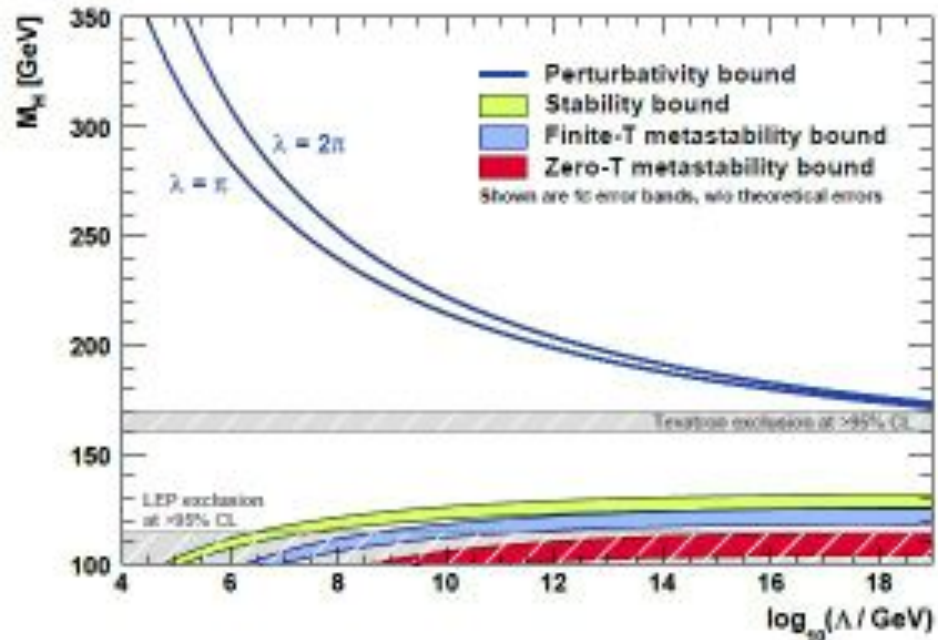
- Verschillende massa's nog niet verklaard
- Vacuumverwachtingswaarde van Higgs veld kromt ruimte extreem

- Hierarchieprobleem



- Vacuumstabiliteit

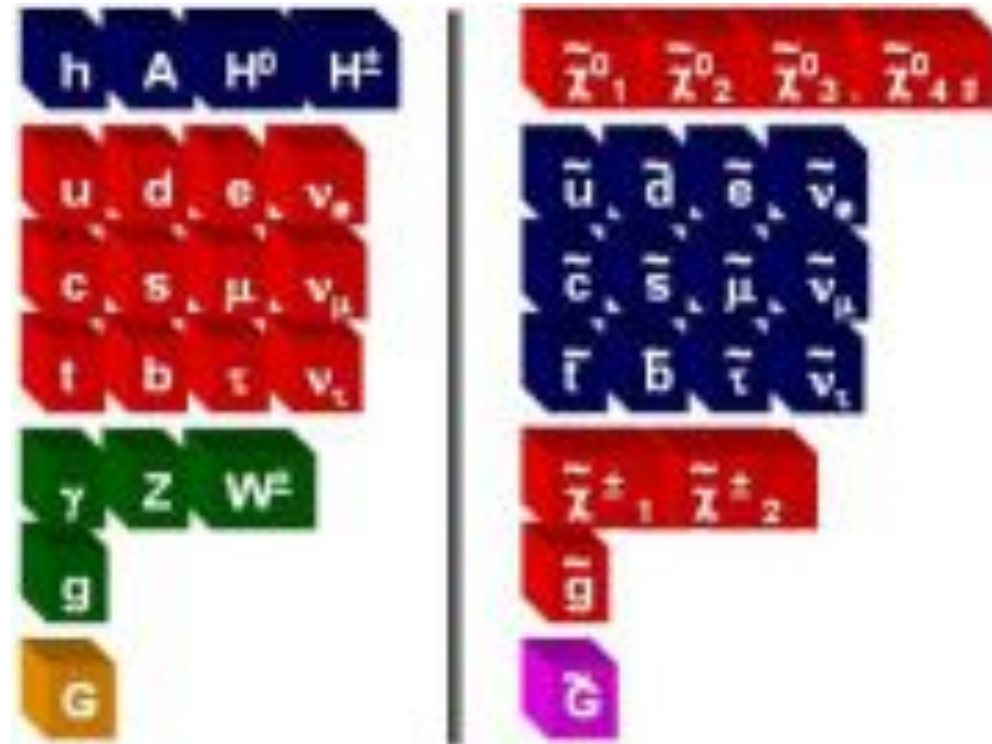
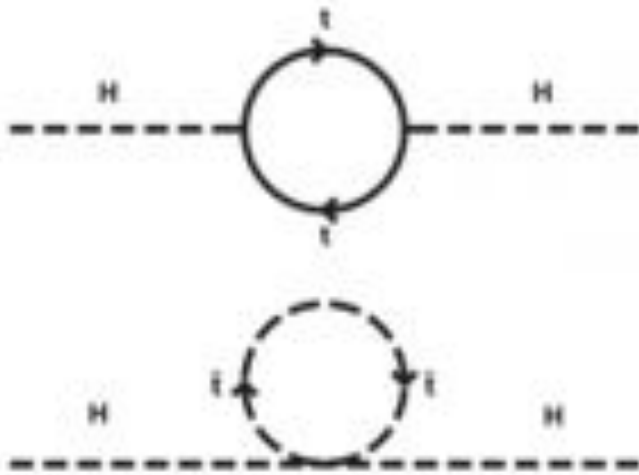
$$\underbrace{m_{\text{physical}}^2}_{\text{what we measure}} = \underbrace{m_h^2}_{\text{free parameter}} + \frac{3\lambda}{8\pi} \underbrace{\Lambda^2}_{\text{theory cutoff}} - \underbrace{\frac{3\lambda}{8\pi} m_h^2 \log\left(\frac{\Lambda^2 + m_h^2}{m_h^2}\right)}_{\text{much smaller than } \Lambda^2}$$



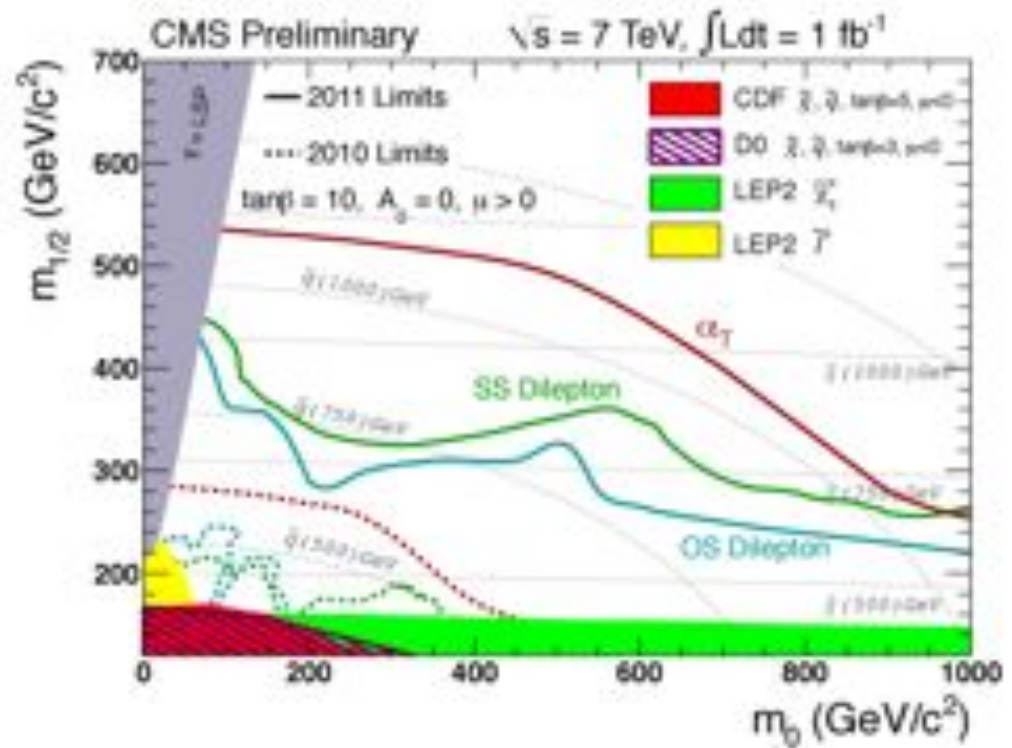
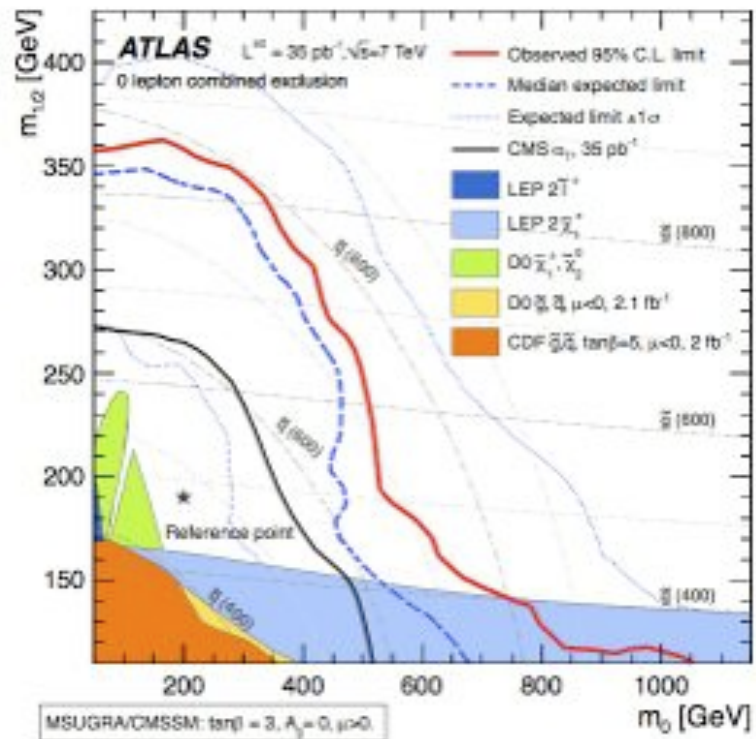


# Super symmetrie

- Verschillende massa's nog niet verklaard
- Vacuumverwachtingswaarde van Higgs veld kromt ruimte extreem
- Vacuumstabiliteit
- Hierarchieprobleem:



# Super symmetrie: nog nooit gezien



# Super symmetrie: nog nooit gezien

Predicted range for the Higgs mass

