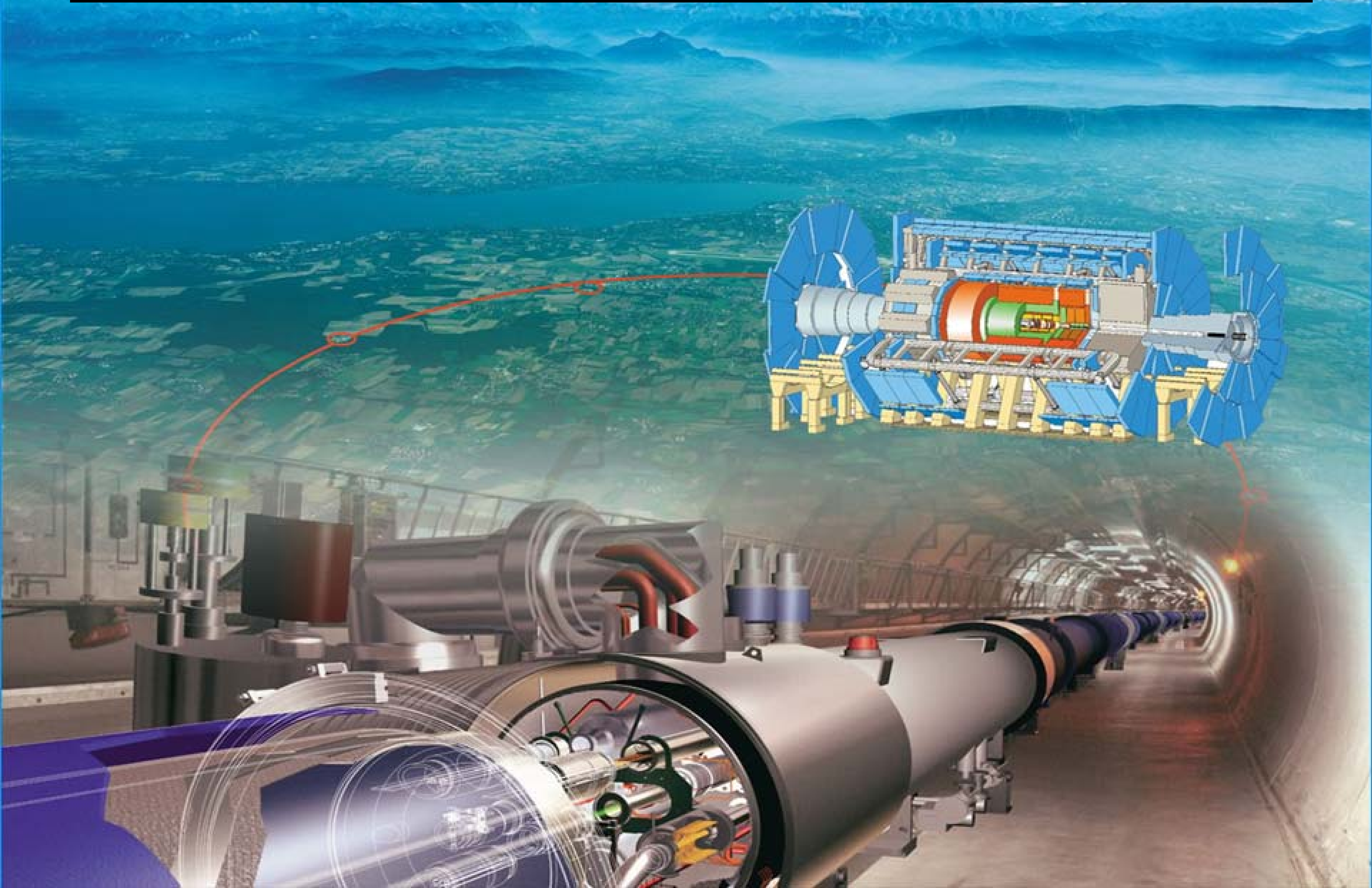
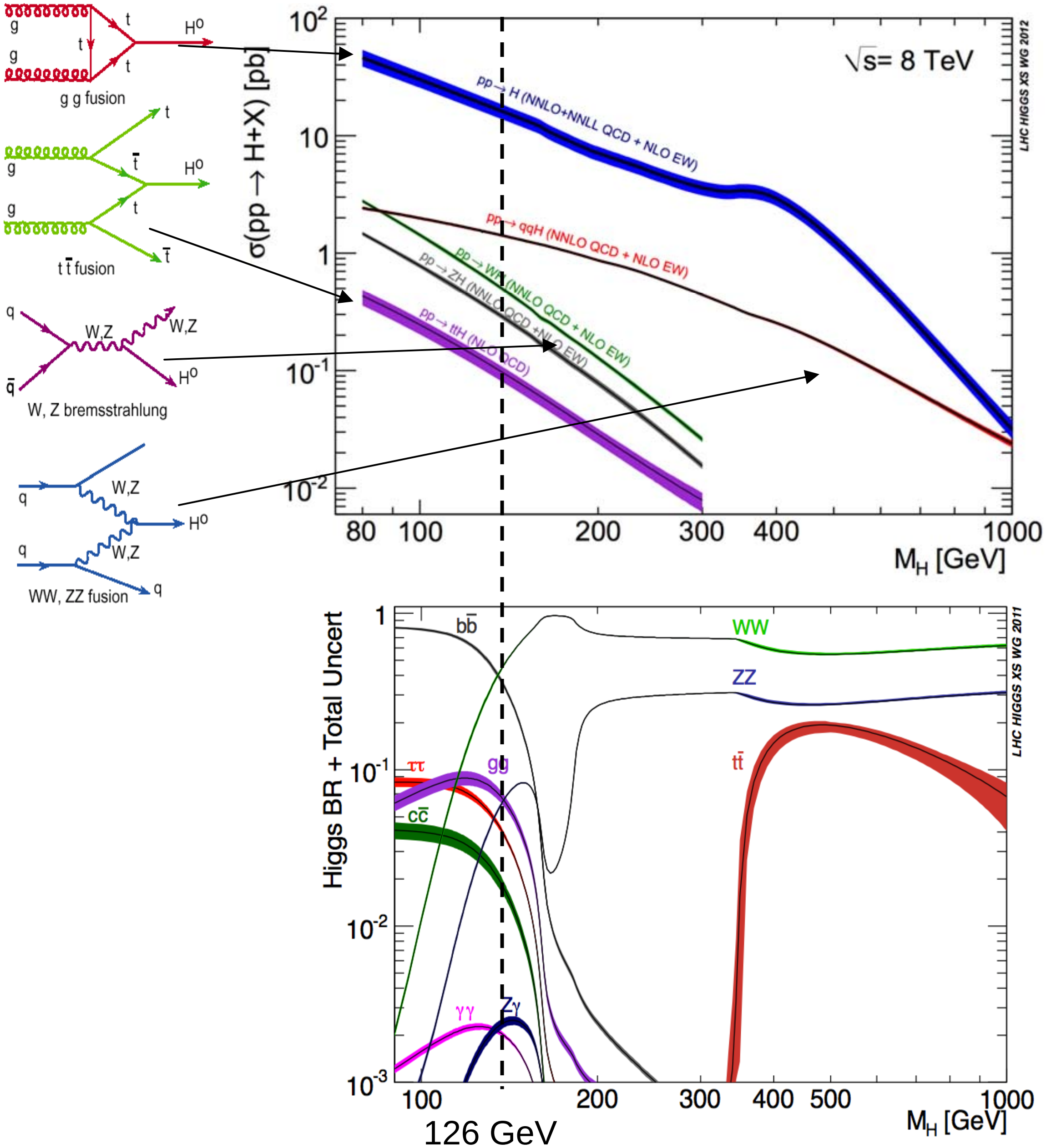
Physik am Large Hadron Collider

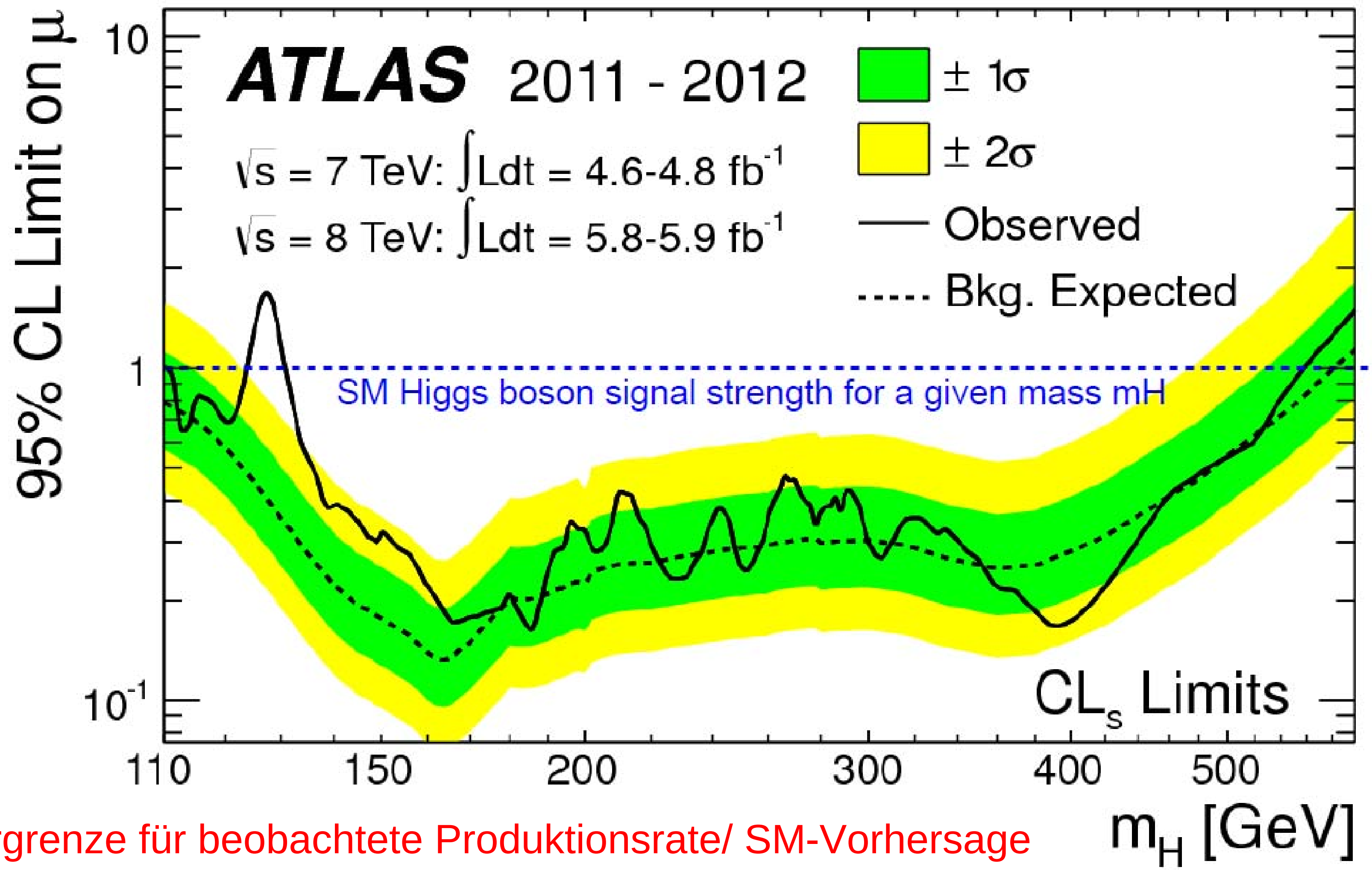


Higgs-Boson Produktion und Zerfall



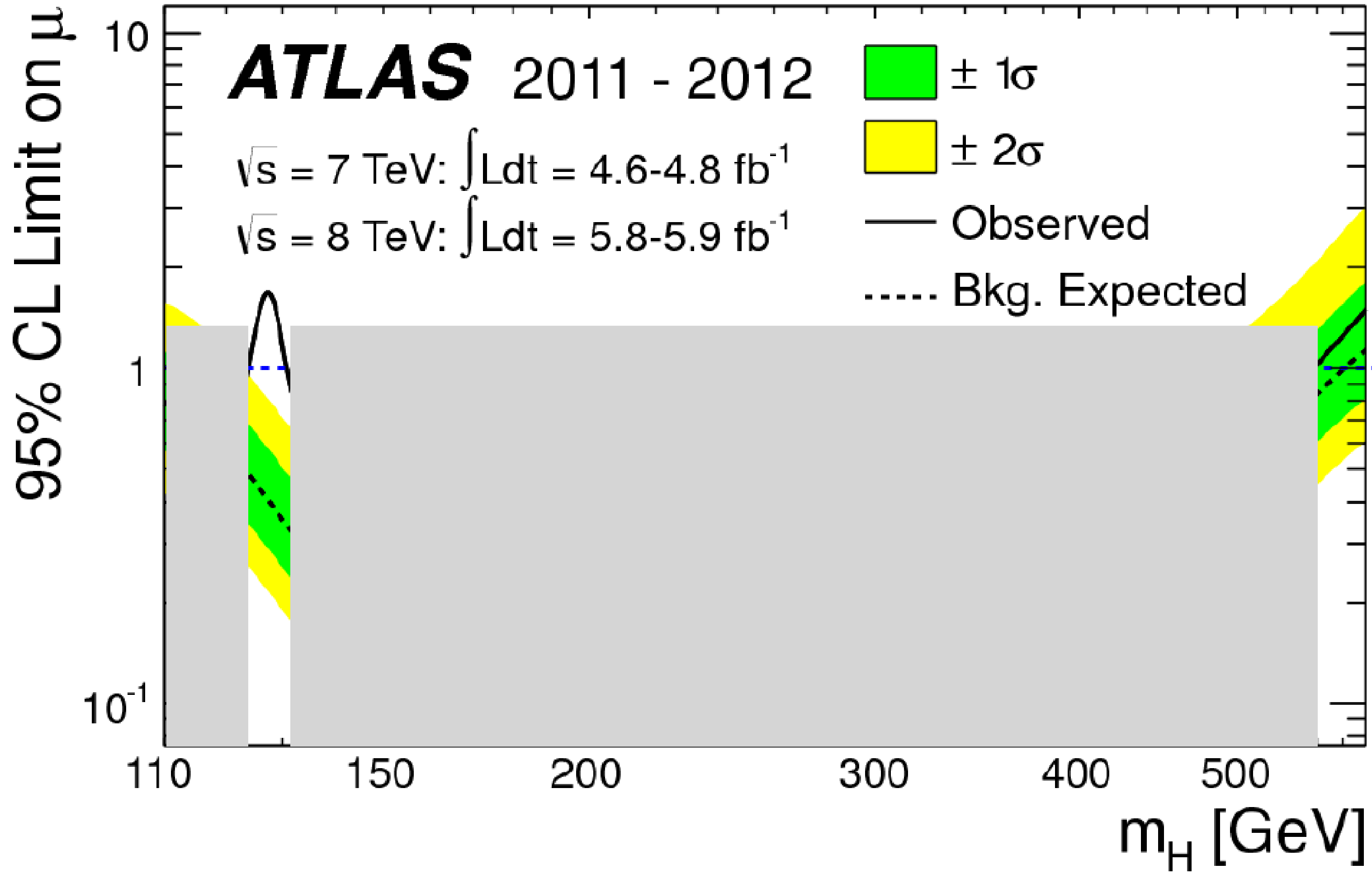
Suche nach dem Higgs-Boson

Combined exclusion limits (July 2012)



Obergrenze für beobachtete Produktionsrate/ SM-Vorhersage

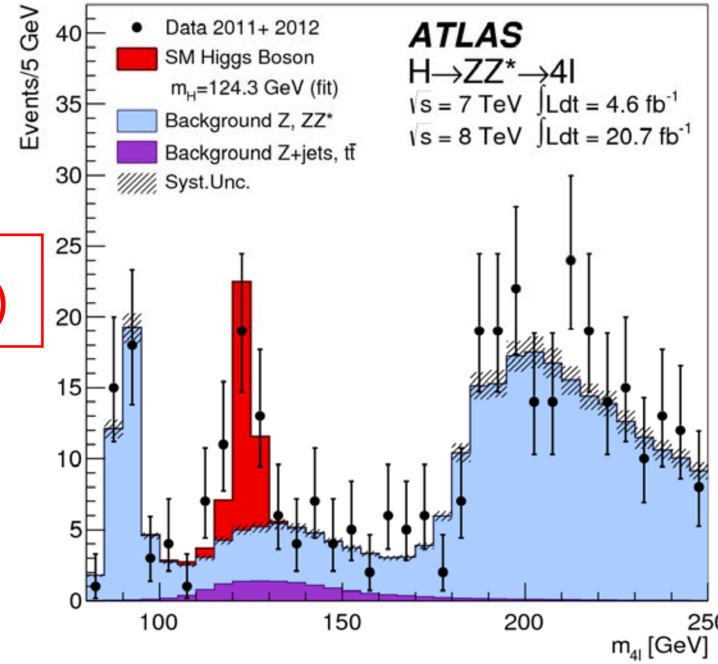
Combined exclusion limits (July 2012)

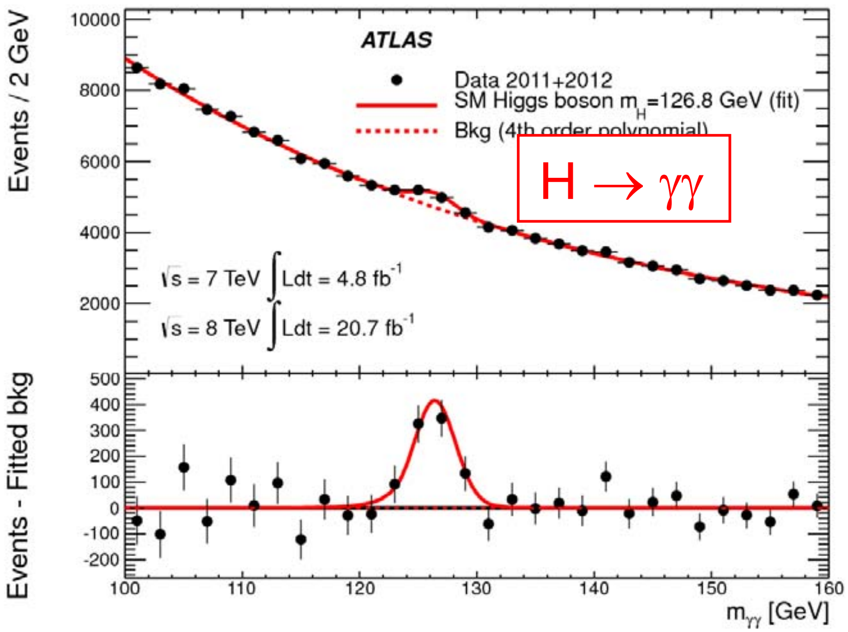


The existence of the Standard Model Higgs boson is excluded with 95% confidence level for almost all masses m_H from 110 GeV to 600 GeV,
except for $m_H \approx$ 120 - 130 GeV where an excess of events is observed in few channels.

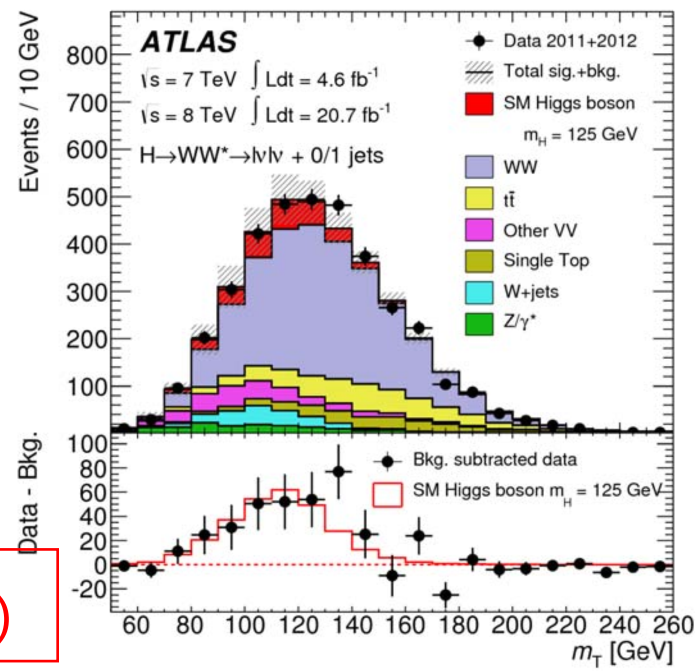
Higgs-Boson-Signale - ATLAS

$H \to ZZ^* \to (l^+ l^-)(l^+ l^-)$





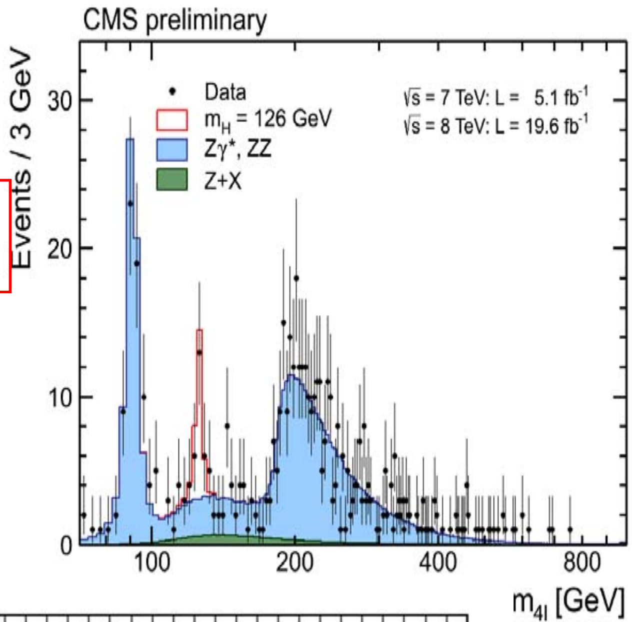
$H \to \gamma\gamma$

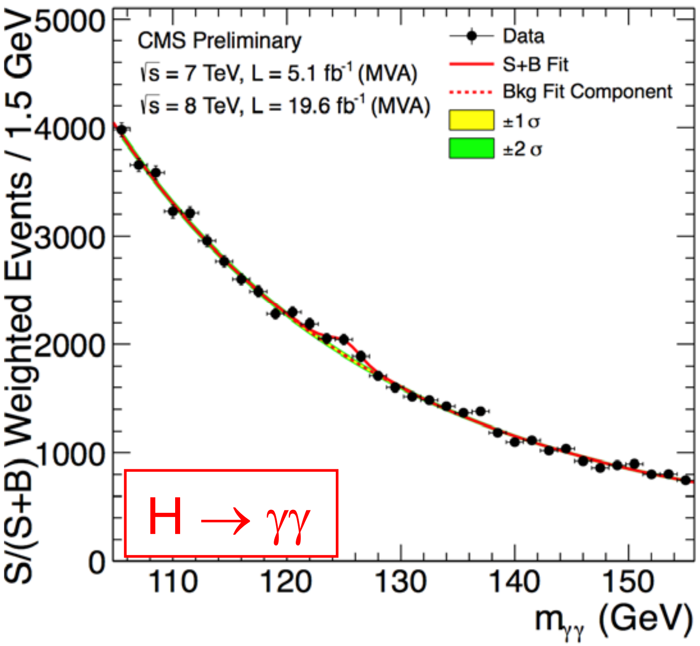


$H \to WW^* \to (l\nu)\ (l\nu)$

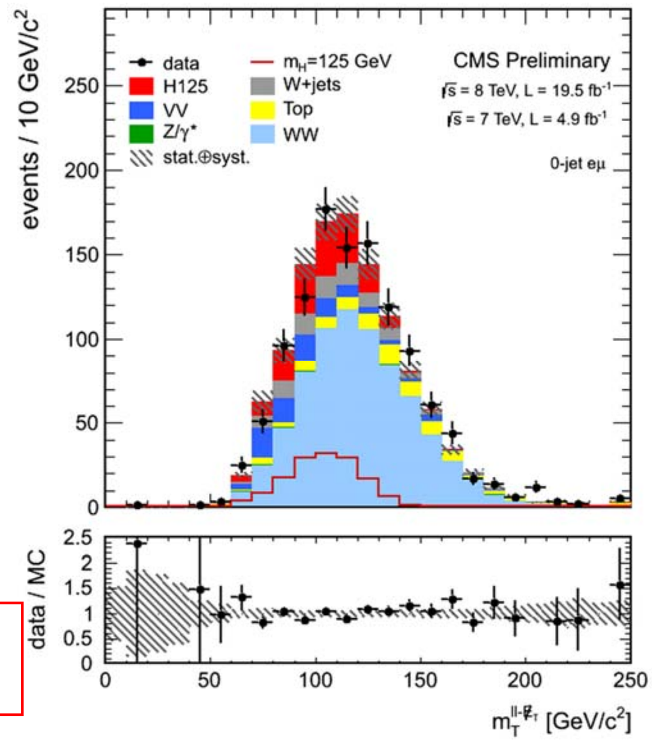
Higgs-Boson-Signale – CMS

$H \rightarrow ZZ^{*} \rightarrow (l^{+} l^{-})(l^{+} l^{-})$





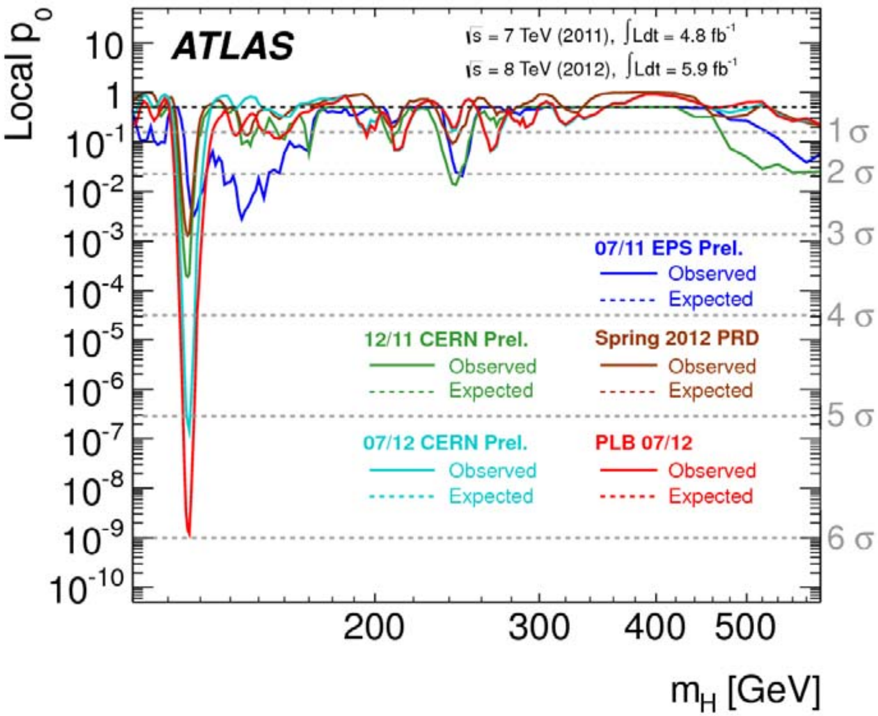
$H \rightarrow \gamma\gamma$



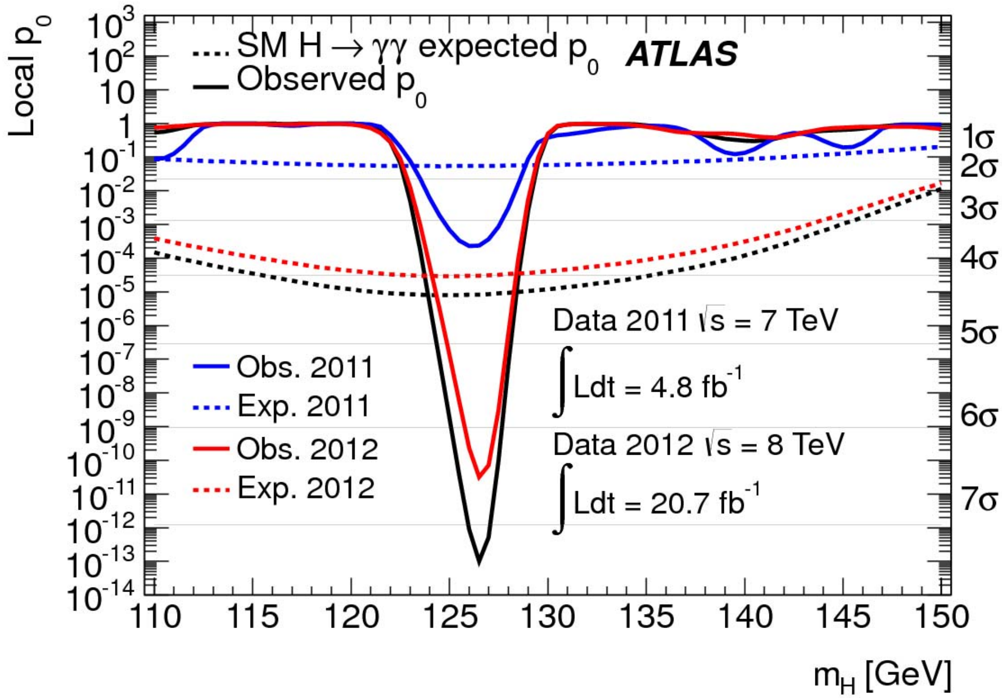
$H \rightarrow WW^{*} \rightarrow (l\nu)\ (l\nu)$

Higgs-Boson-Signal

Wahrscheinlichkeit einer Untergrundfluktuation

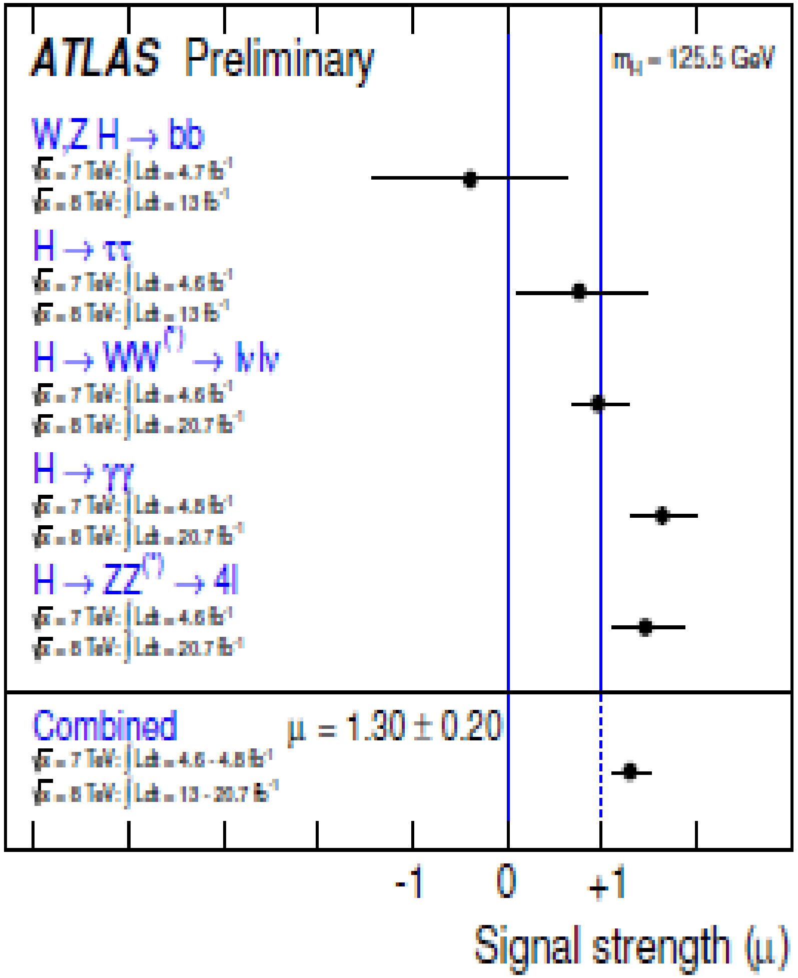


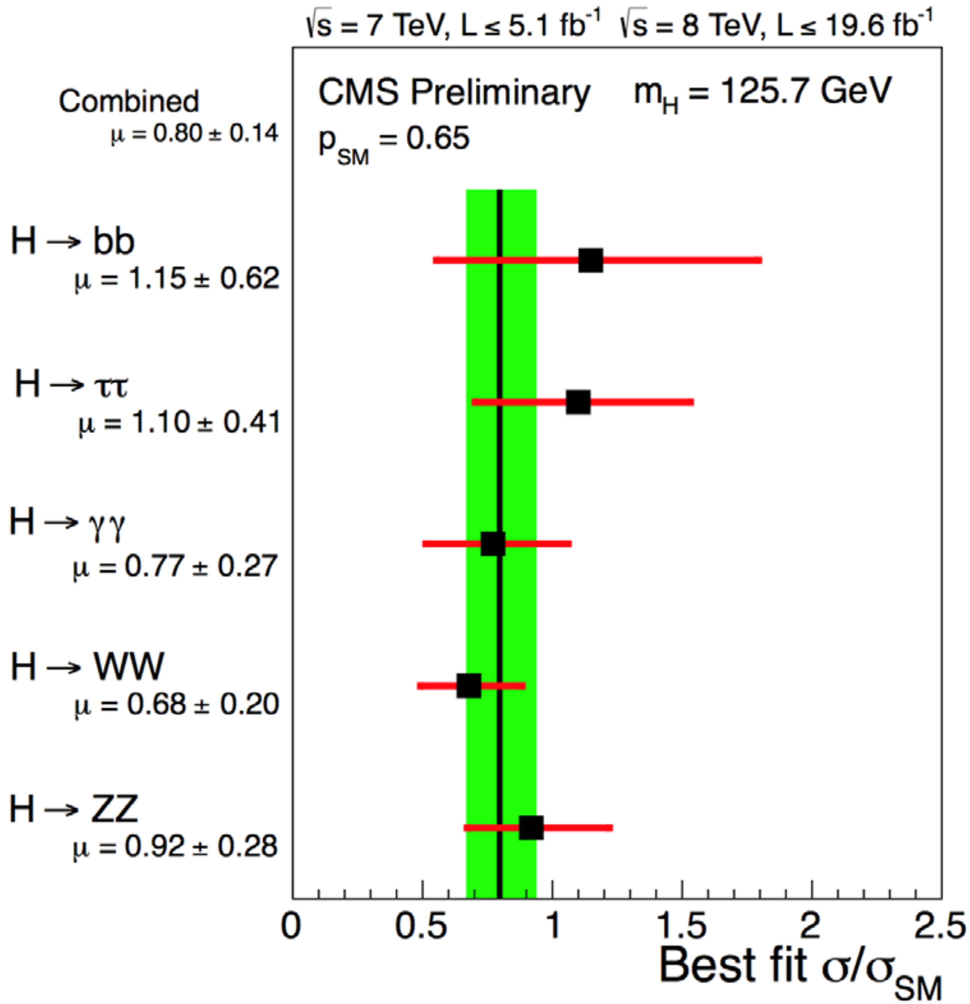
Entdeckung Juli 2012

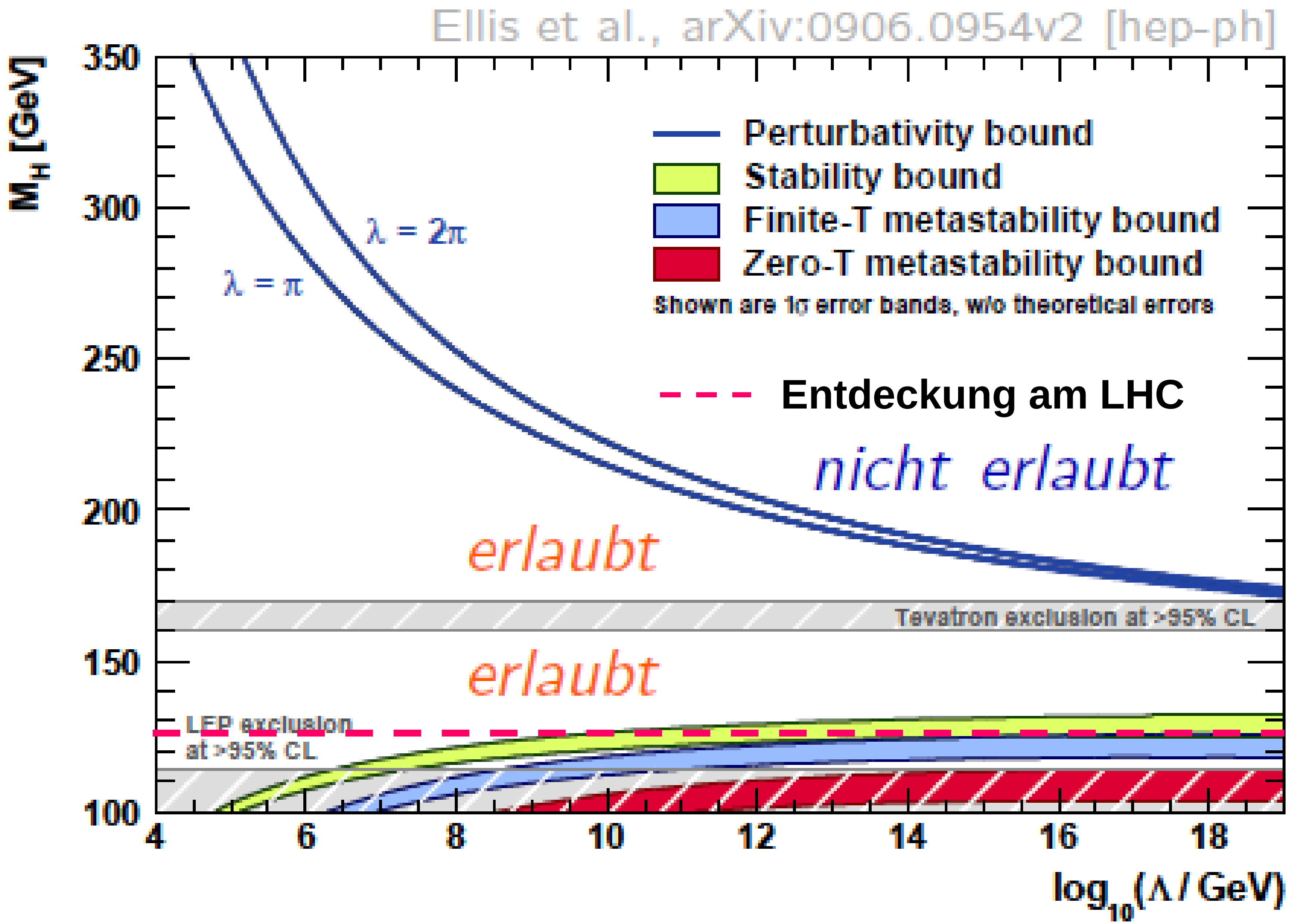


Endergebnis mit 7-8 TeV Daten April 2013

Higgs-Boson-Signalstärke

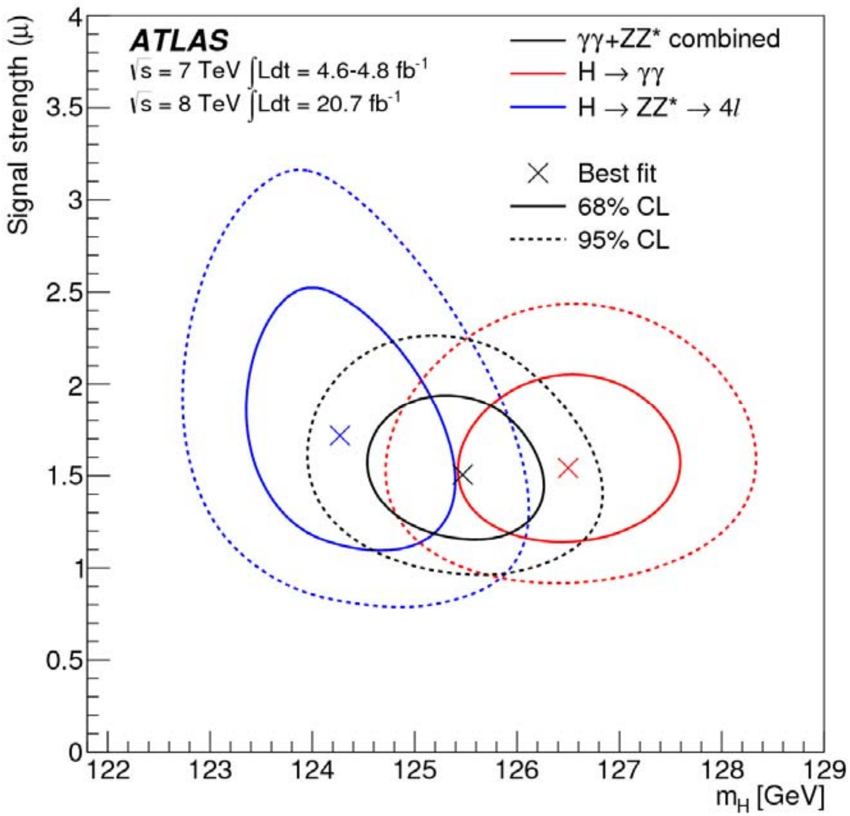


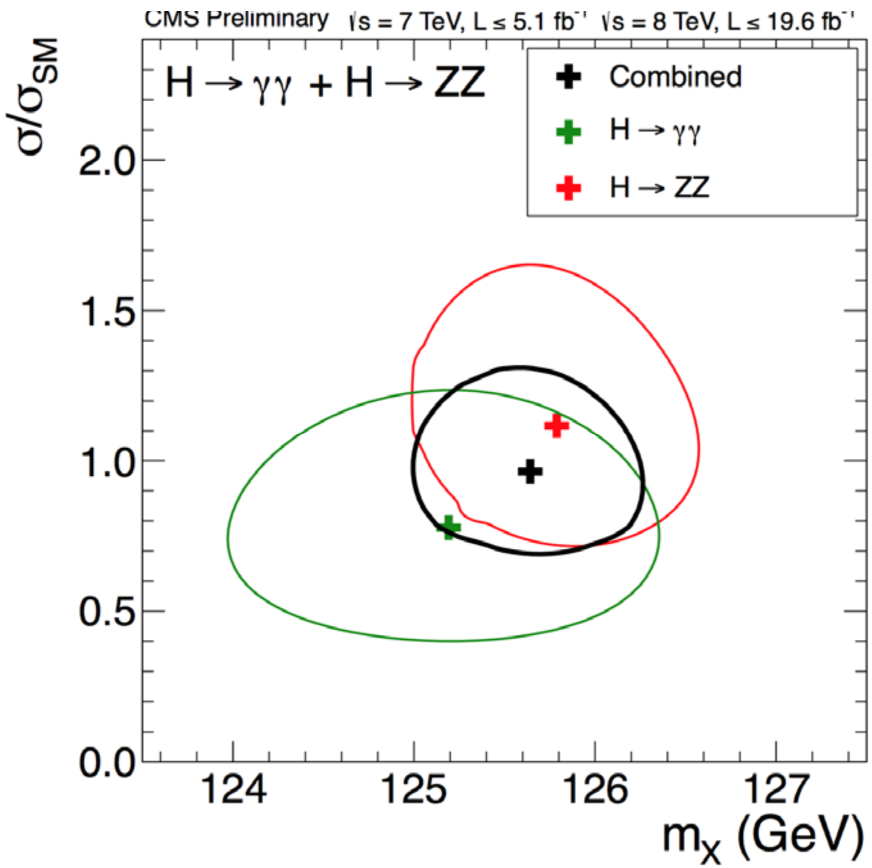




Gültigkeitsskala des Standardmodells (Λ)

Higgs-Boson-Masse und Signalstärke



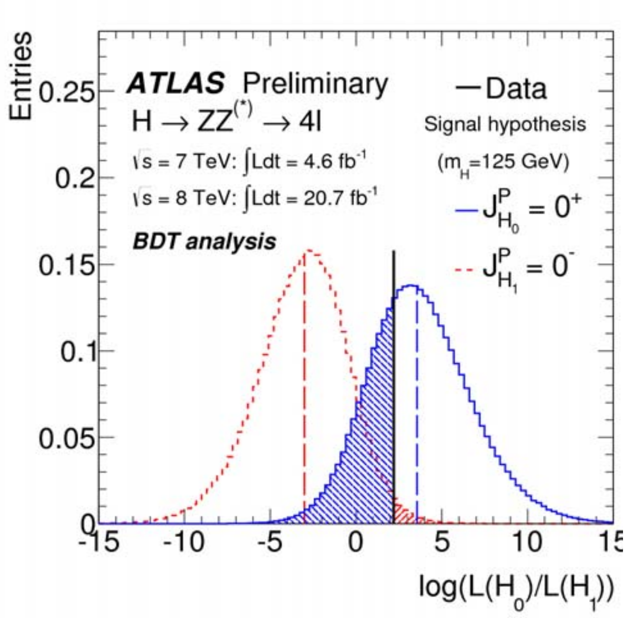


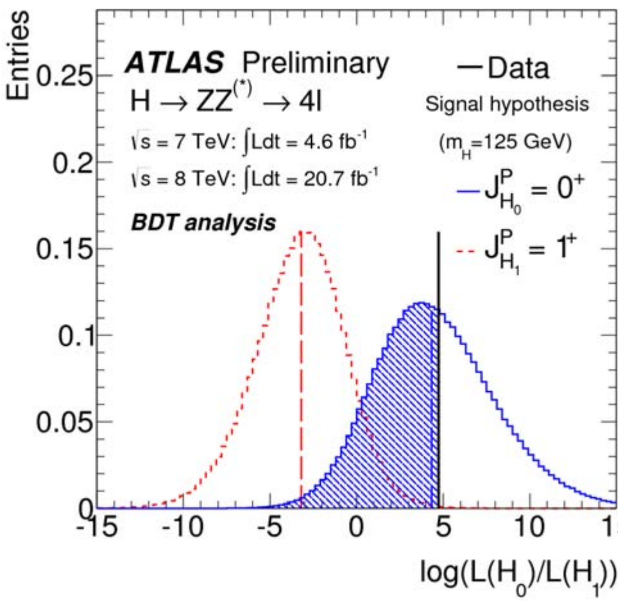
Präzisionsmessung:

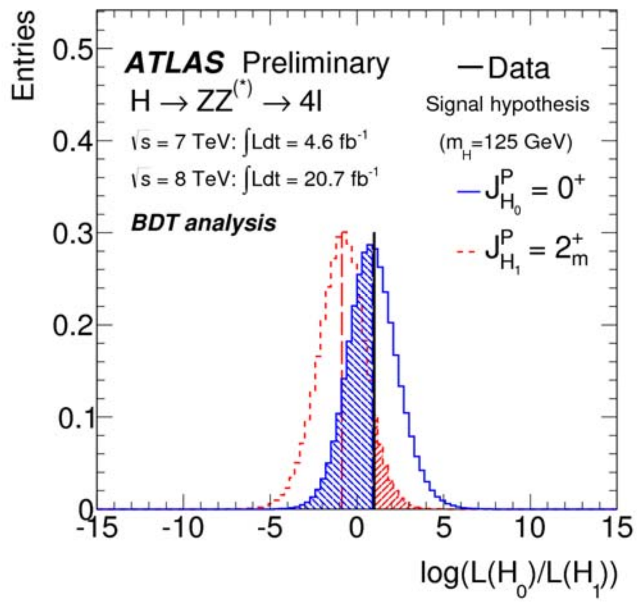
$m_H = 125.5 \pm 0.2^{(stat)} \pm 0.5^{(syst)}$ GeV

$m_H = 125.7 \pm 0.3^{(stat)} \pm 0.3^{(syst)}$ GeV

Higgs-Boson-Spin und CP- Quantenzahl







Standardmodell: Spin^{CP} = 0^+.

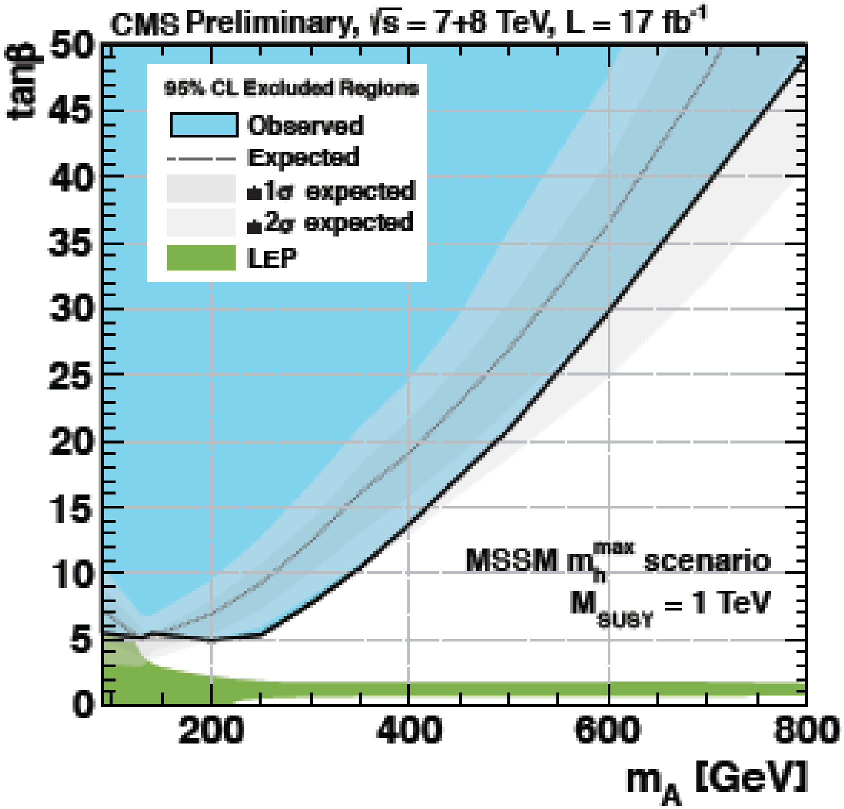
Isotrope Winkelverteilung von γ, W, Z im Higgs Ruhesystem für Spin 0.

Spin 1 verboten wegen $H \to \gamma\gamma$ Zerfall (Landau-Yang Theorem).

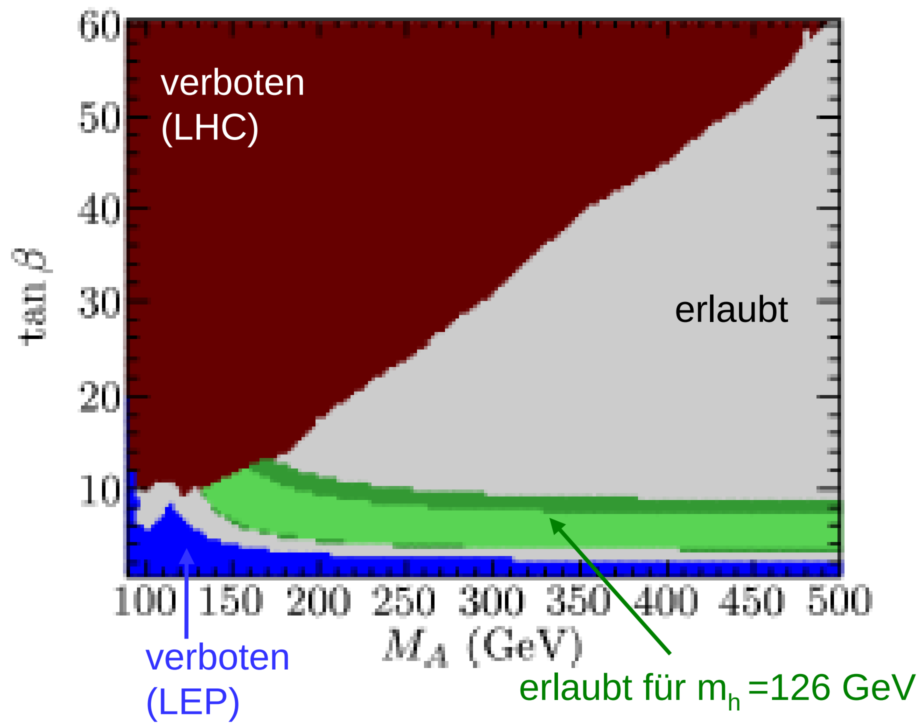
SUSY Higgs-Bosonen

Minimale supersymmetrische Erweiterung des Standardmodells (MSSM):
3 neutrale Higgs-Bosonen h, H (CP= +1), A (CP= –1) und zwei geladene $H^{\pm}$.

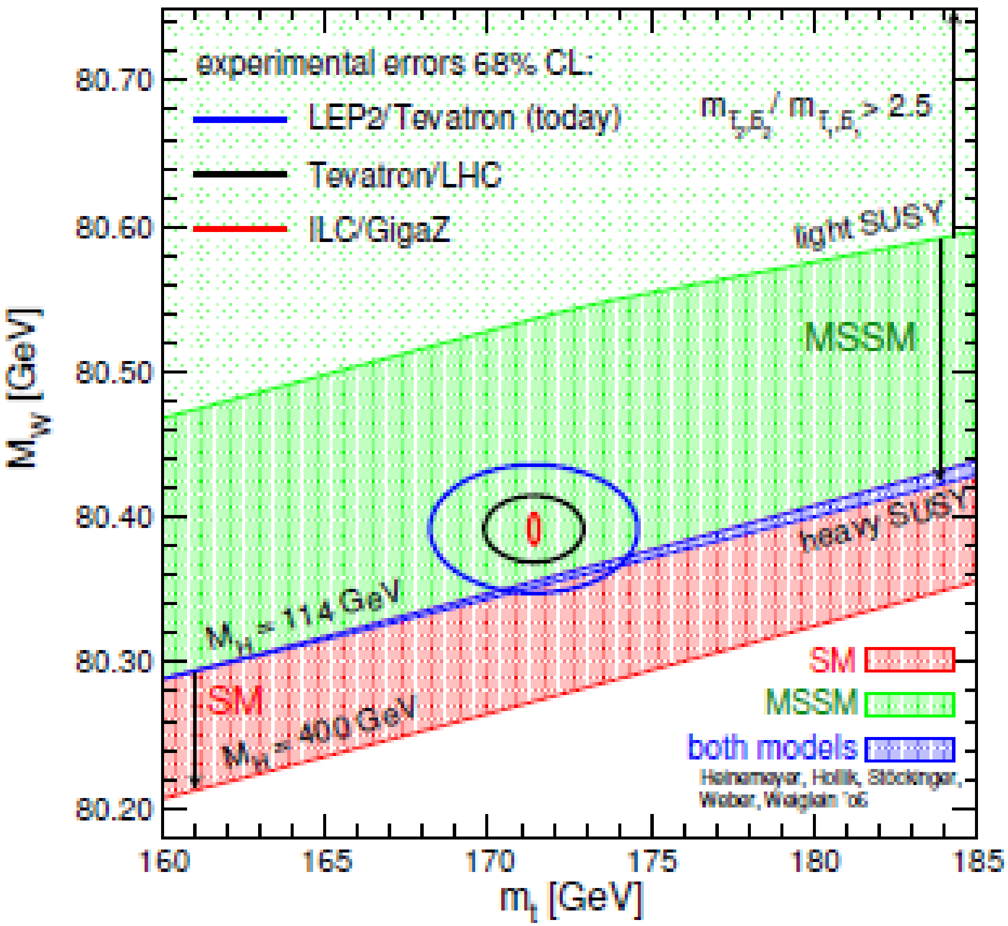
Zwei wesentliche Parameter in niedrigster Ordnung: M_A und $\tan\beta = v_{up} / v_{down}$.



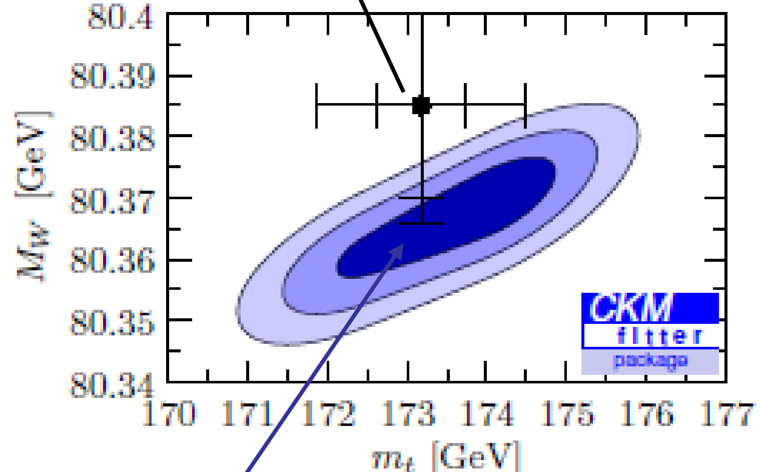
Entdecktes Higgs=Boson = $h \to \tau\tau$



Interpretation der elektroschwachen Präzisionsmessungen im Standardmodell und im MSSM (m_h < 130 GeV):



Direkte
LEP/Tevatron
Messungen



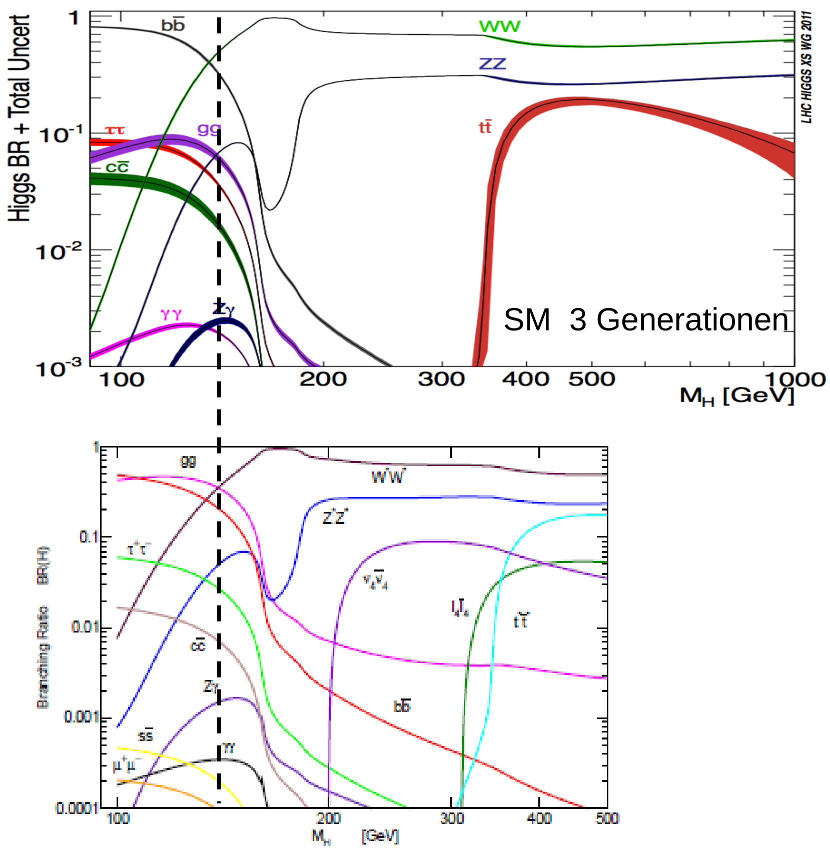
Standardmodell-Vorhersage von elektroschwachen Präzisionsmessungen und Messungen der Higgs-Produktions- und Zerfallsraten und der Higgs-Masse

Higgs und 4. Fermiongeneration (mit schweren Neutrinos)

LEP/Tevatron: m(t′) > 450 GeV, m(b′) > 361 GeV. > 500 GeV keine Störungstheorie mehr.

Starke Konsequenzen der zusätzlichen schweren Quarks (für Higgs-Produktions- und Zerfallsraten: Gluonfusionsproduktion 9 x verstärkt durch 2 zusätzliche schwere Quark-loops, weitgehend unabhängig von der Masse.

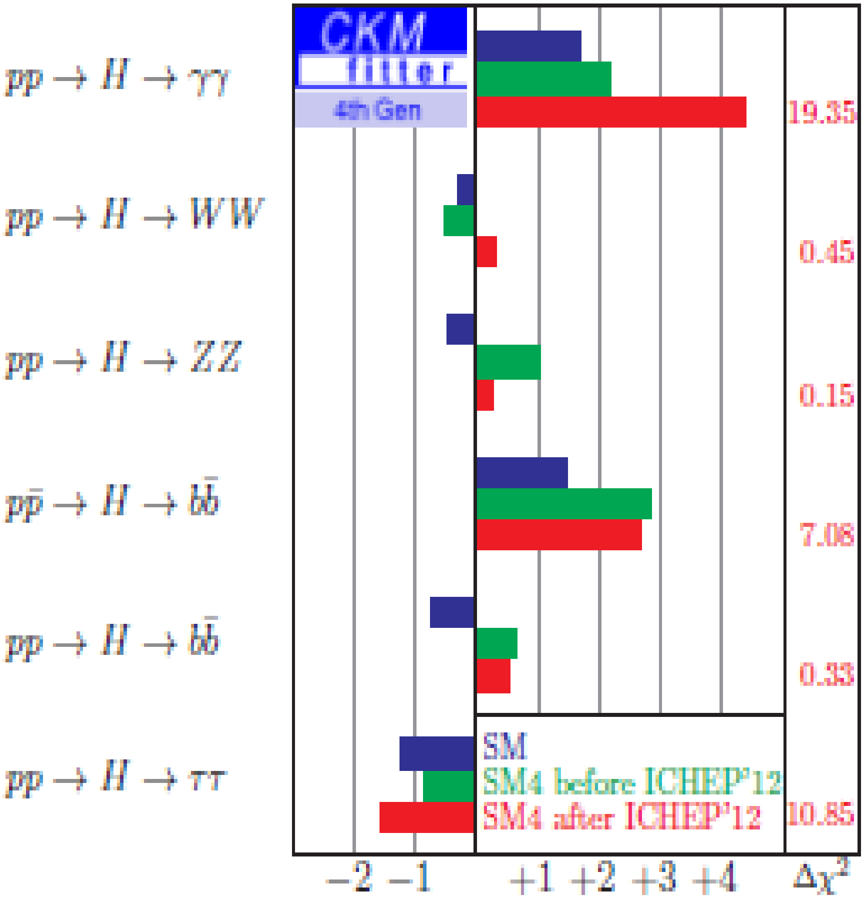
Vergleich mit den Messungen:

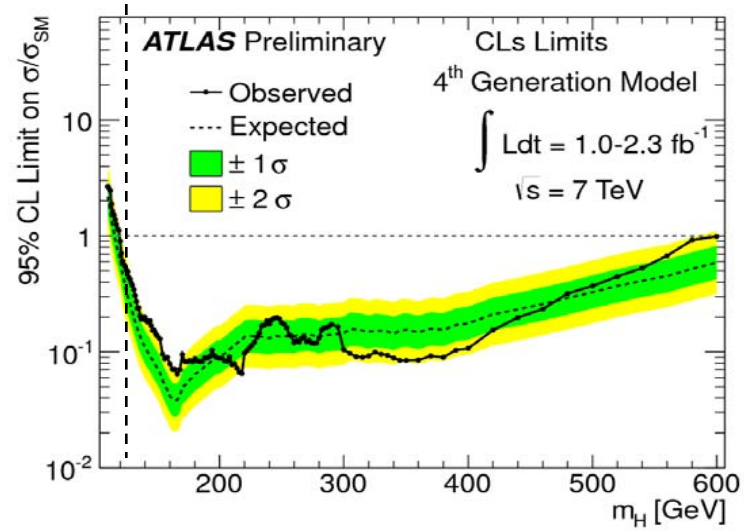


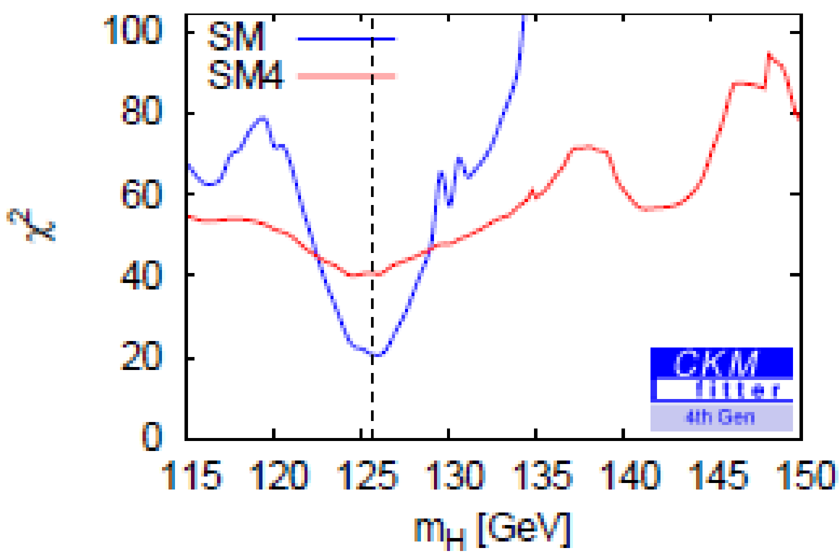
126 GeV SM 4 Generationen

Higgs und 4. Fermiongeneration (mit schweren Neutrinos)

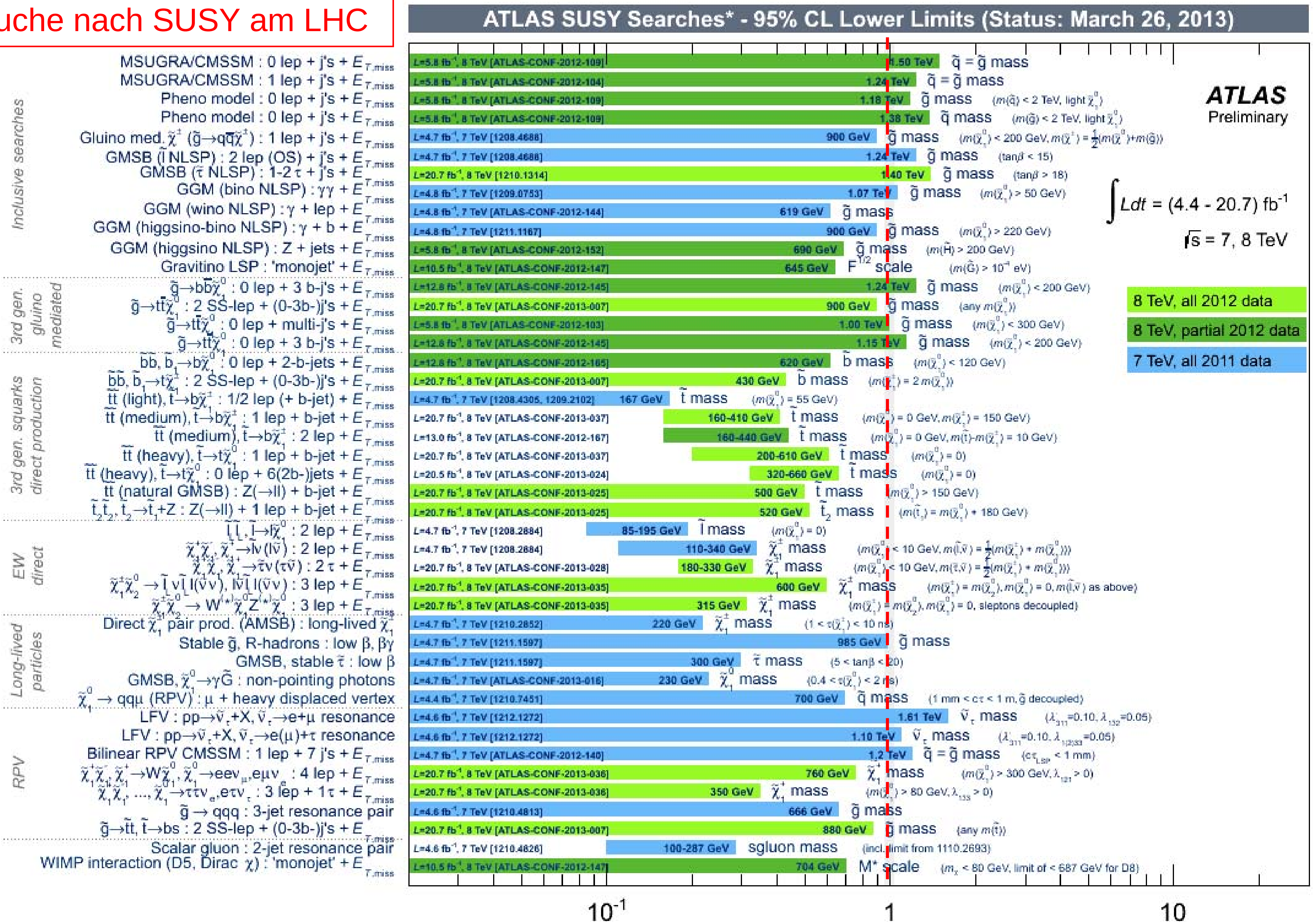
4. Generation ausgeschlossen:





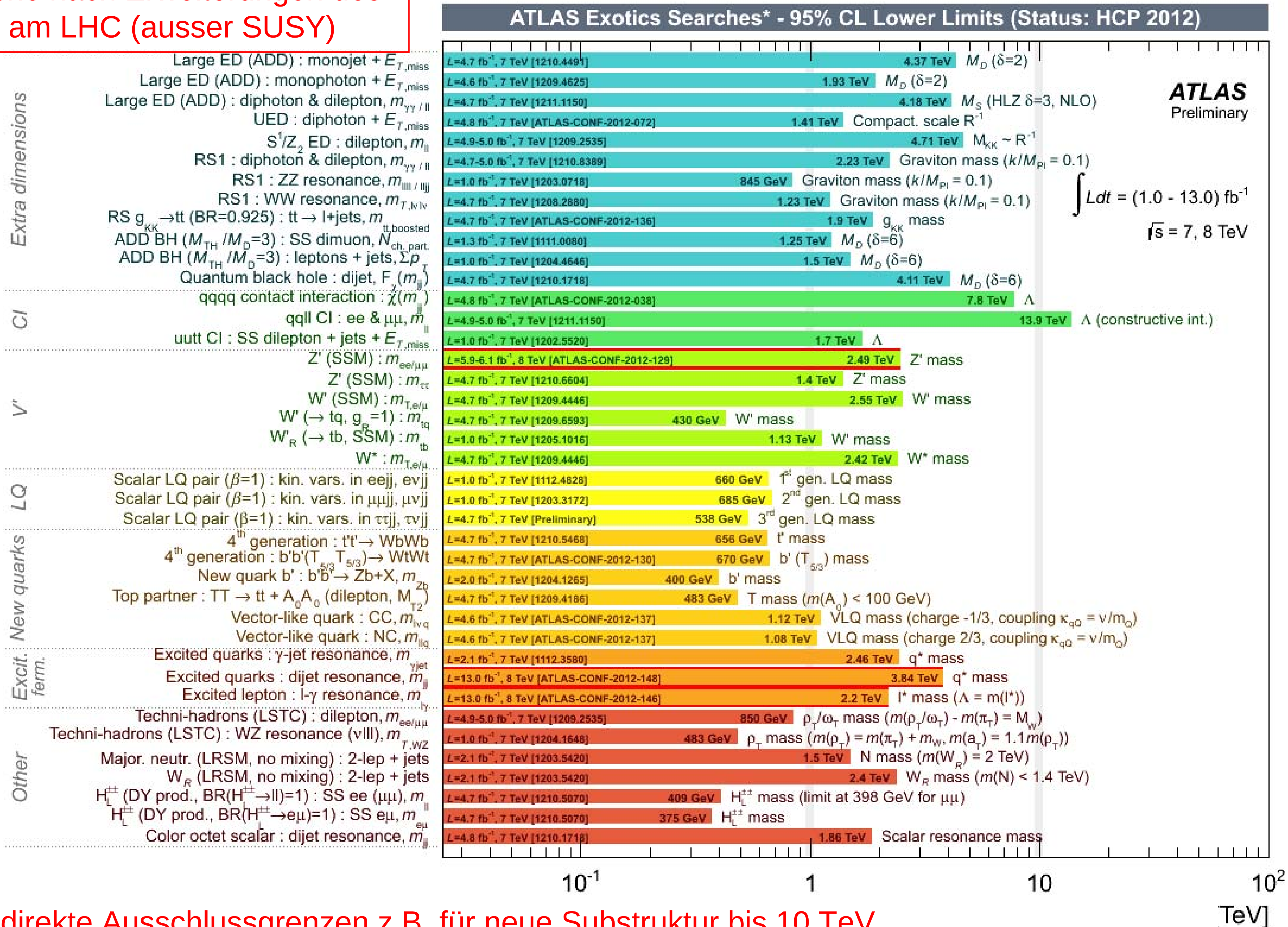


Suche nach SUSY am LHC



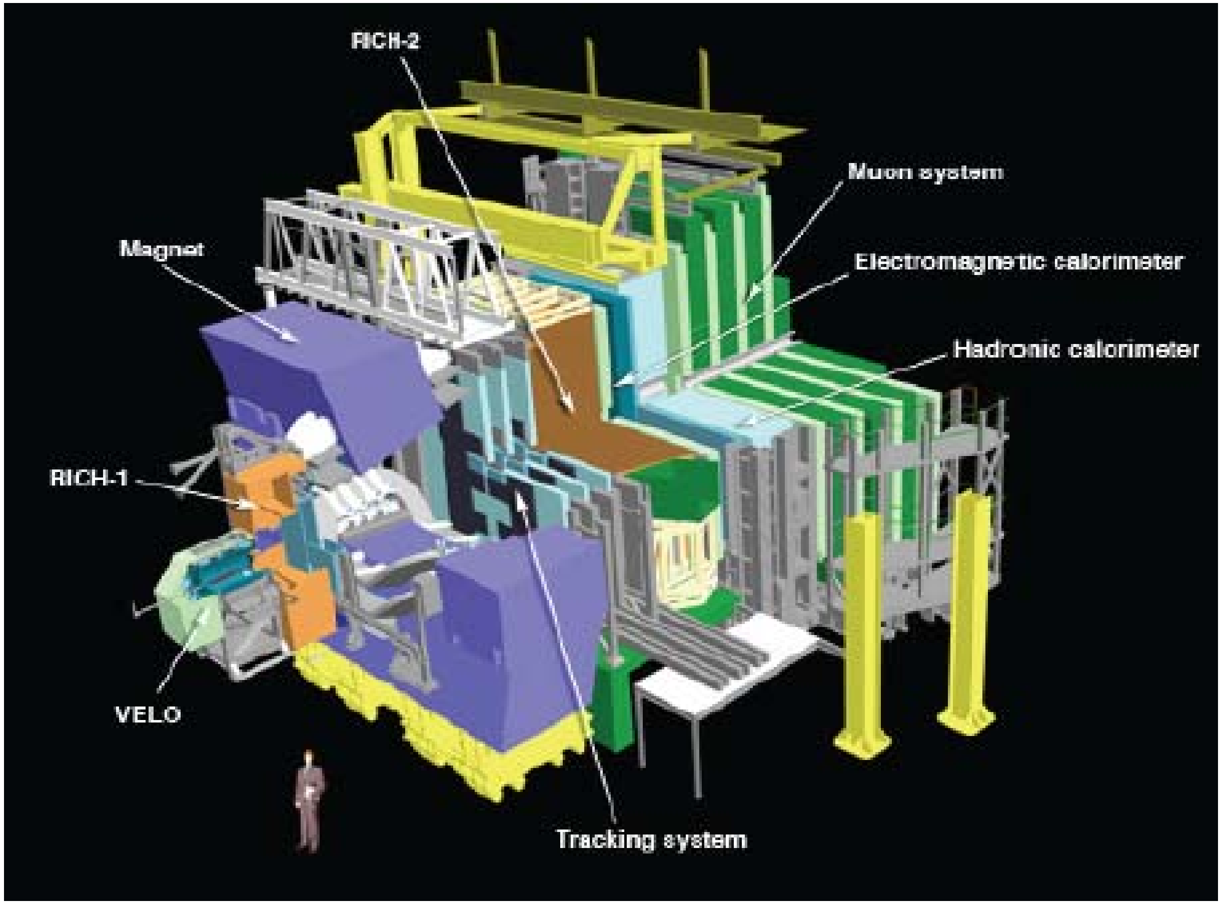
Erstmals direkte Erforschung der Energieskala um 1 TeV am LHC
(Skala der elektroschwachen Symmetriebrechung und möglicher neuer Teilchen).

Suche nach Erweiterungen des SM am LHC (ausser SUSY)



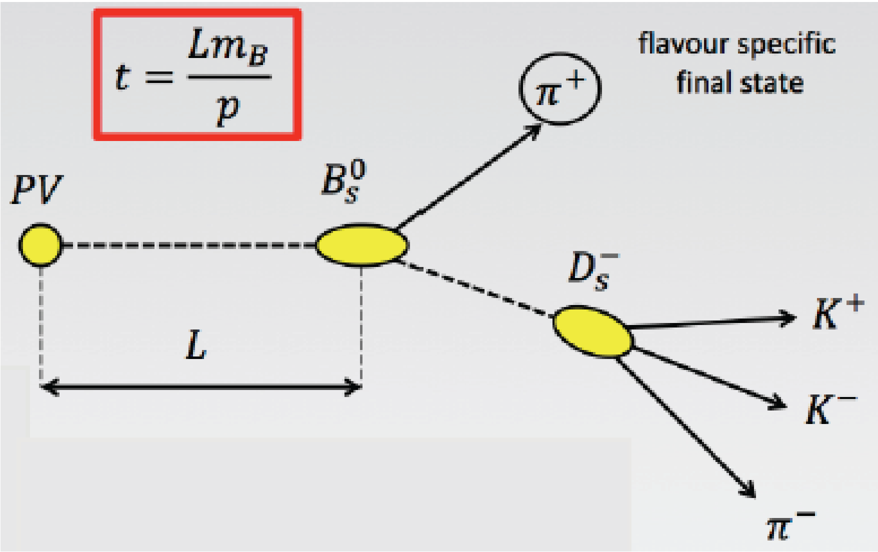
Indirekte Ausschlussgrenzen z.B. für neue Substruktur bis 10 TeV.

Messung der CP-Verletzung in B-Zerfällen und Suche nach Abweichungen vom Standardmodell bei LHCb

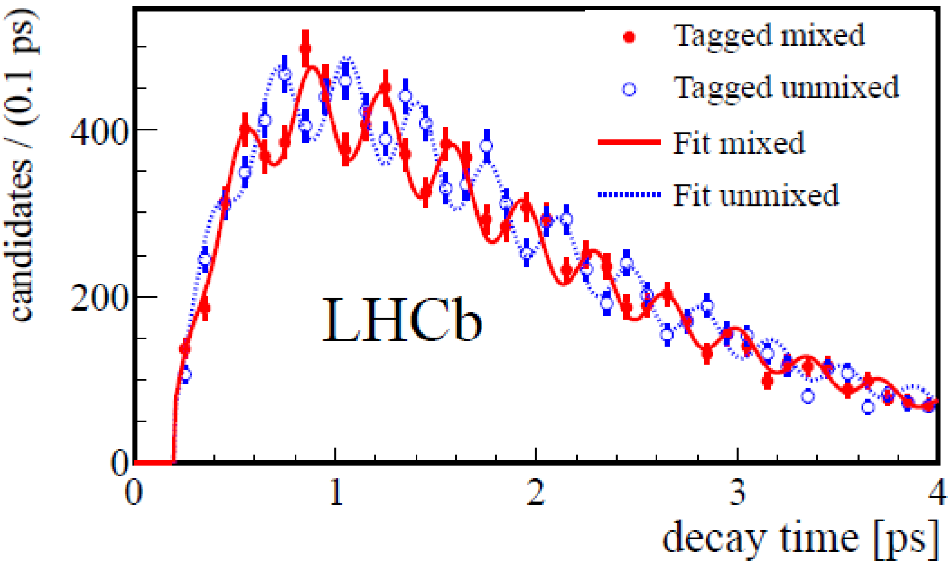


Pp-Kollisionen am LHC in einer (!) Vorwärtsrichtung gemessen.

Präzisionsmessung der B_s^0 –Oszillationen am LHC



2013

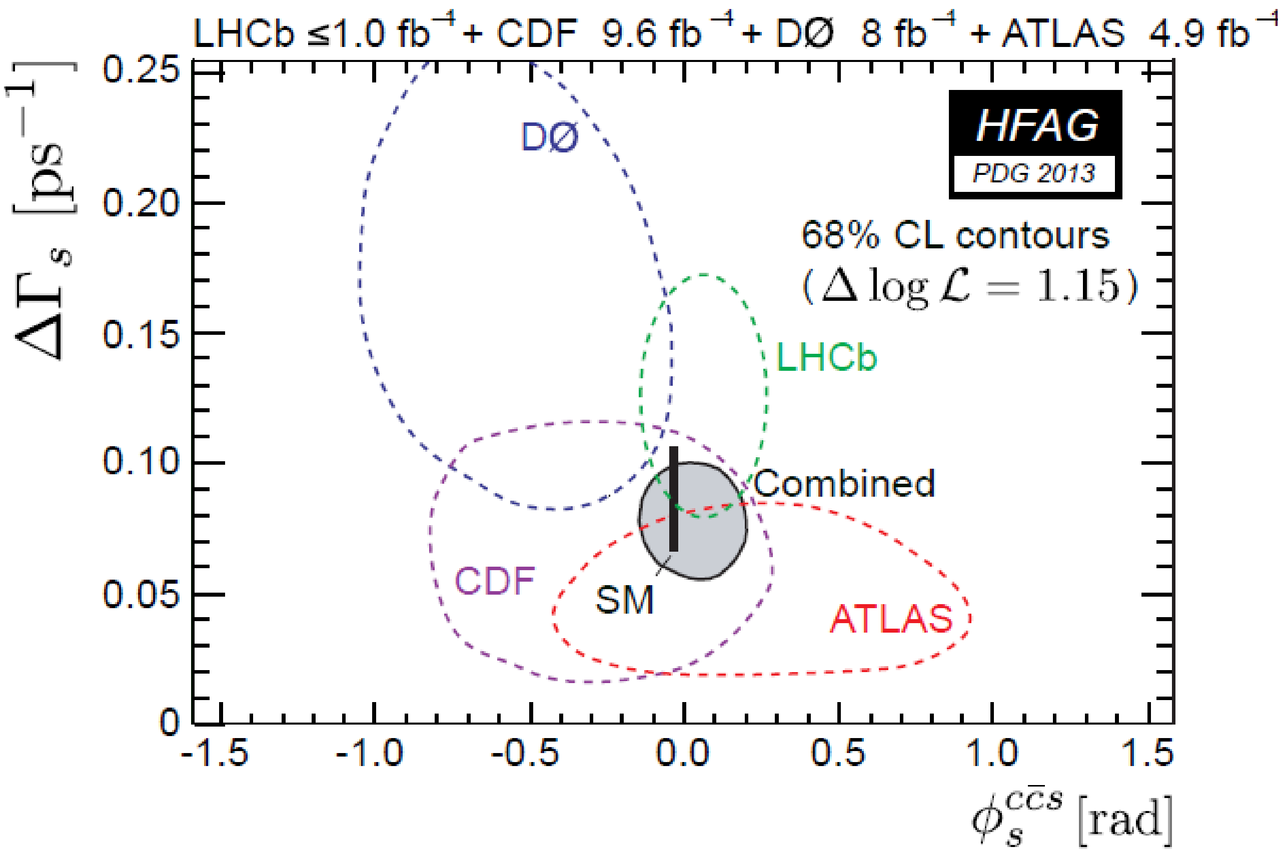


$$\Delta m_s = 17.768 \pm 0.023 \pm 0.006\ \mathrm{ps}^{-1}$$

CDF (D0) 2006: $\Delta m_s = 17.77 \pm 0.10(\mathrm{stat}) \pm 0.07(\mathrm{sys})$

Zeitabhängige CP-Asymmetrie in $B_s^0 \to J/\psi\ \phi$ Zerfällen

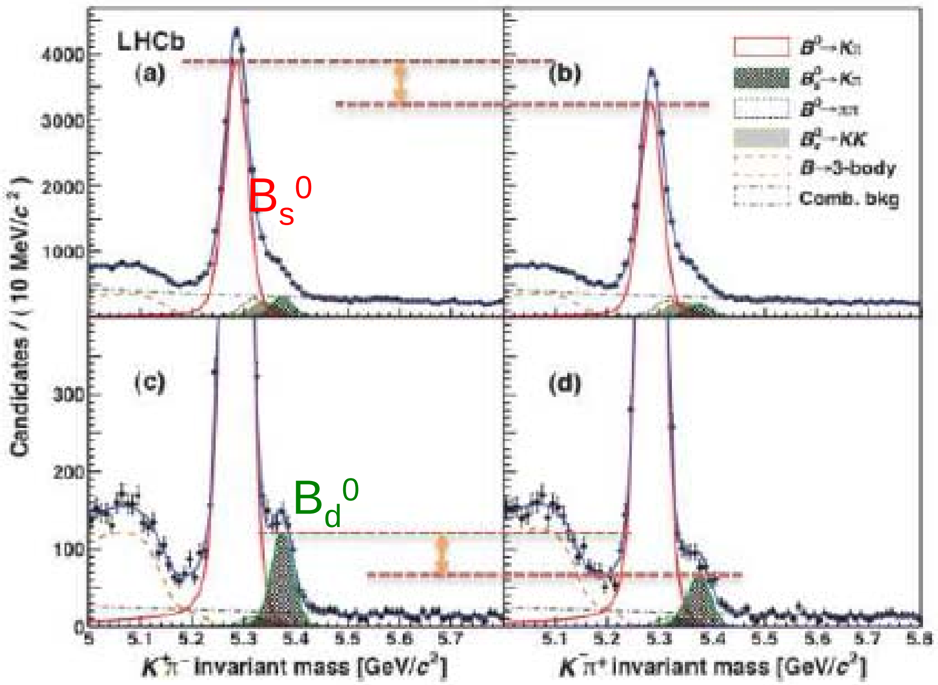
Messung der Mischungsphase ϕ_s und der Differenz der Zerfallsbreiten der Masseneiegnzustände durch Tevatron- und LHC-Experimente, vor allem LHCb, in guter Übereinstimmung mit dem Standardmodell ($\phi_s^{SM} \approx$ - 36 mrad):



Erster Nachweis der CP-Verletzung in B_s^0 –Zerfällen am LHC

Erster Nachweis direkter CP-Verletzung in B_d^0 – Zerfällen durch Babar, Belle und CDF, zeitintegrierte Zerfallsraten:

$$A_{K\pi} = \frac{\Gamma(\overline{B}^0 \to K^-\pi^+) - \Gamma(B^0 \to K^+\pi^-)}{\Gamma(\overline{B}^0 \to K^-\pi^+) + \Gamma(B^0 \to K^+\pi^-)}$$



2013:

CDF (CDF public note 10726: 9.3 fb^{-1})

$A_{CP}(B^0 \to K^+\pi^-)$ = -0.083 $\pm$ 0.013 $\pm$ 0.003

$A_{CP}(B_s \to K^-\pi^+)$ = +0.22 $\pm$ 0.07 $\pm$ 0.02

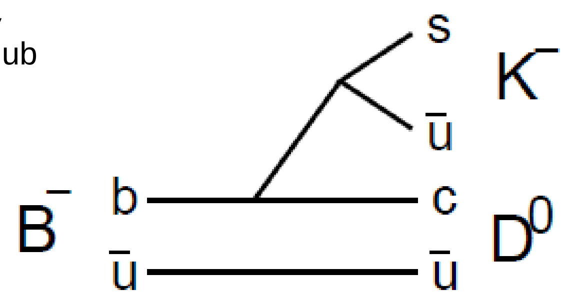
LHCb (PRL110(2013)221601: 1 fb^{-1})

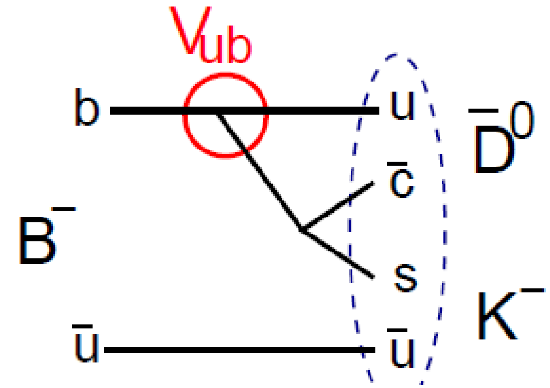
$A_{CP}(B^0 \to K^+\pi^-)$ = -0.080 $\pm$ 0.007 $\pm$ 0.003

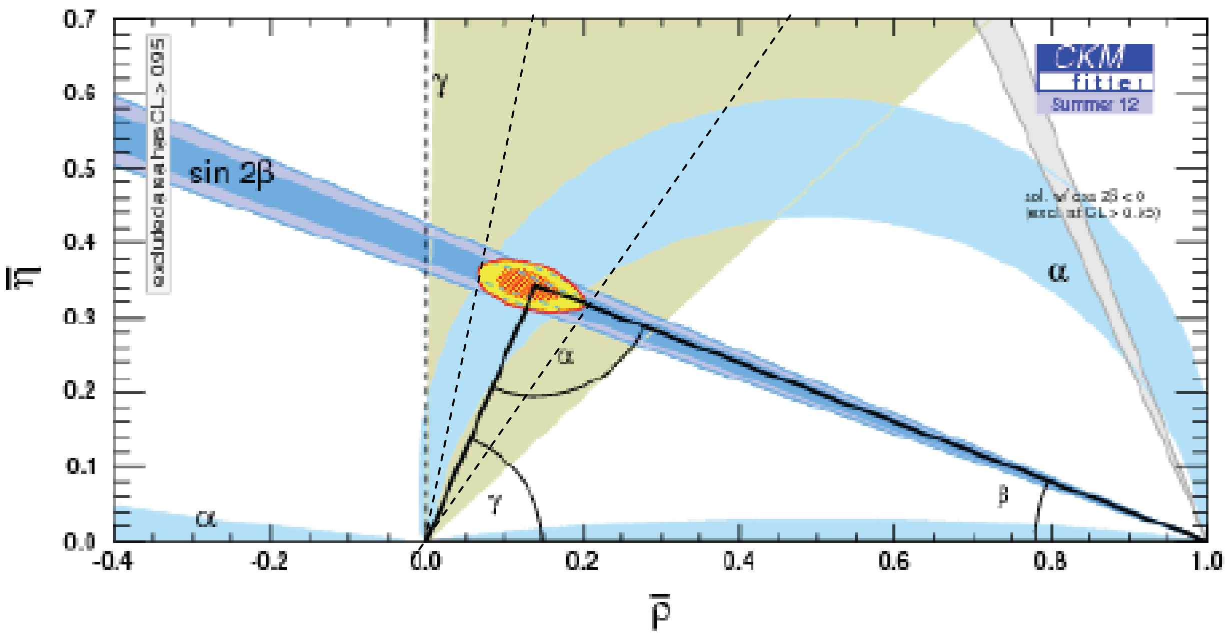
$A_{CP}(B_s \to K^-\pi^+)$ = +0.27 $\pm$ 0.04 $\pm$ 0.01

Verbesserte Messungen des CKM Winkels γ

Messung der Phase des CKM-Matrixelements V_{ub} in $B^- \to DK$ Zerfällen:







LHCb 2013:

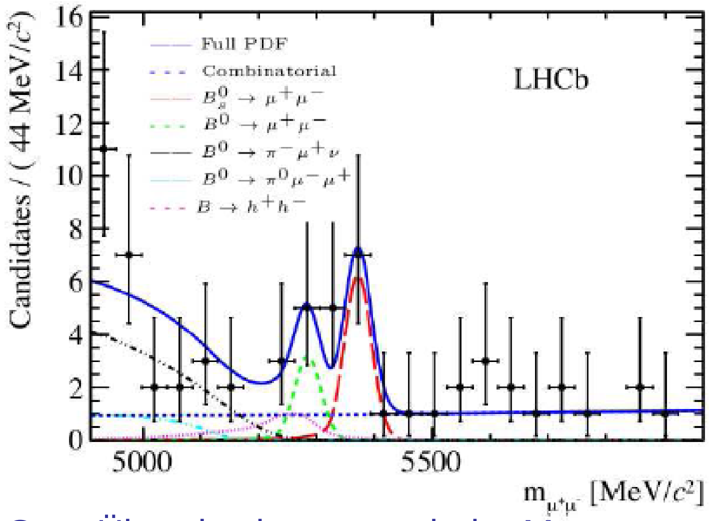
$\gamma = (67 \pm 12)^\circ$

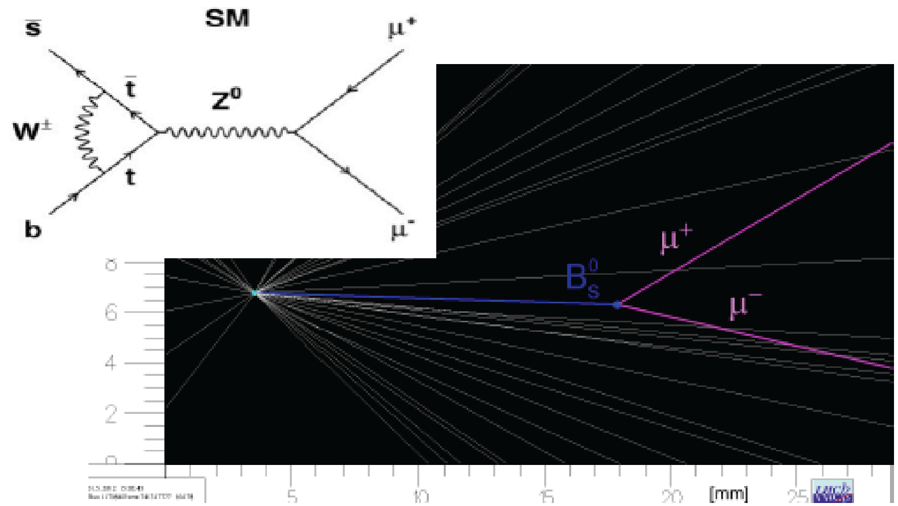
Belle: $\gamma = (68^{+15}_{-14})^\circ$

BaBar: $\gamma = (69^{+17}_{-16})^\circ$

Entdeckung der seltenen $B_s^0 \to \mu^+ \mu^-$ Zerfälle am LHC

Neu Juli 2013: LHCB und CMS





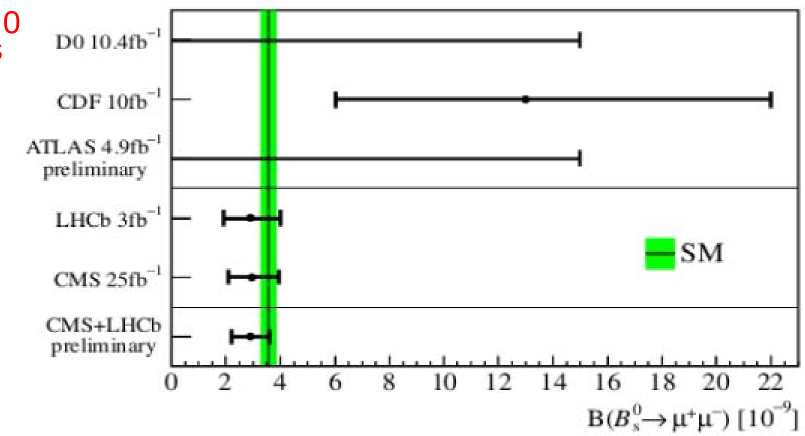
Gute Übereinstimmung mit der Messung, wenig Platz für neue (z.B. supersymmetrische) Teilchen in loops.

Standardmodell: 2. Ordnung loop-Prozesse, FCNC und Helizitätsunterdrückung:

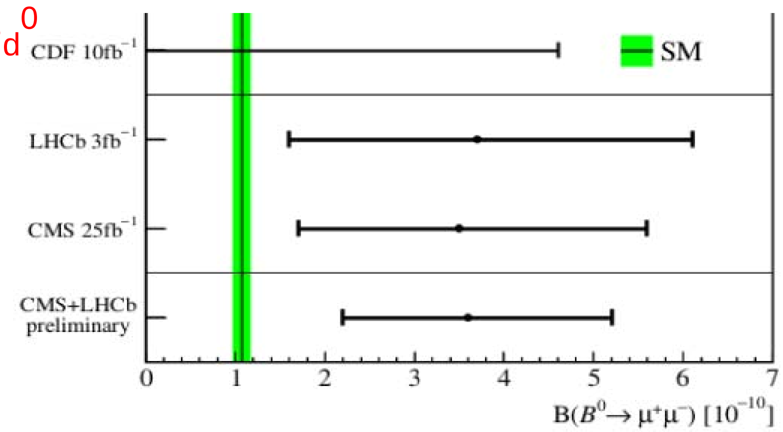
$\mathrm{BR}(B_s \to \mu^+\mu^-) = 3.34 \pm 0.27 \times 10^{-9}$

$\mathrm{BR}(B^0 \to \mu^+\mu^-) = 1.07 \pm 0.10 \times 10^{-10}$

B_s^0



B_d^0

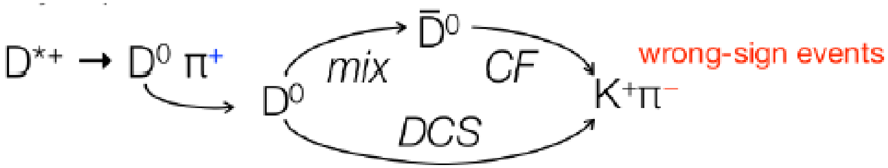


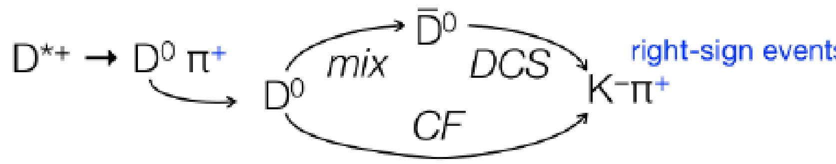
$\mathrm{BR}(B_s \to \mu^+\mu^-) = (2.9 \pm 0.7) \times 10^{-9}$

$\mathrm{BR}(B^0 \to \mu^+\mu^-) = 3.6^{+1.6}_{-1.4} \times 10^{-10}$

Nachweis der Oszillationen neutraler D-Mesonen

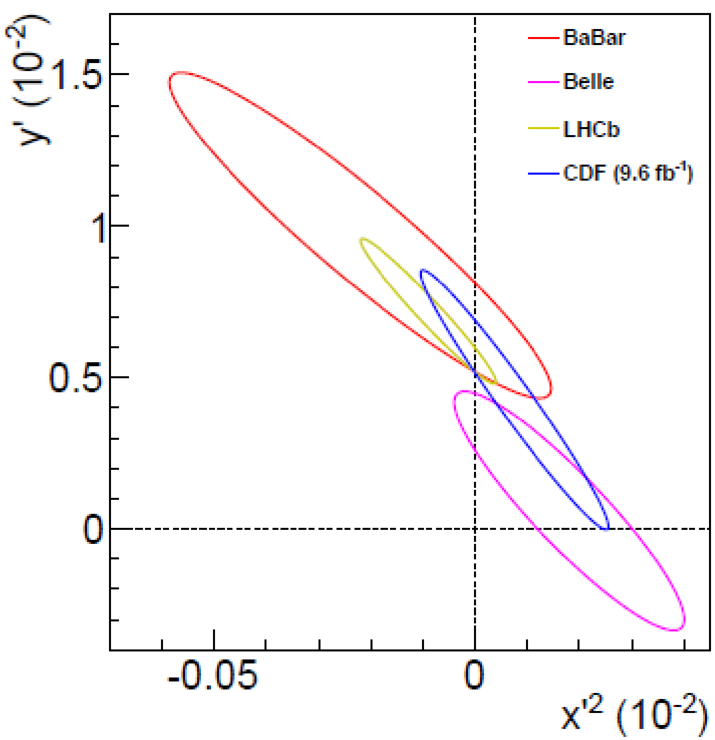
Parameter x′, y′ ≠ 0, sehr kleiner Effekt im Standardmodell, schwierige Vorhersage





DCS: doubly Cabibbo suppressed decay

CF: Cabibbo favoured decay



Noch kein Nachweis von CP-Verletzung in charm-Zerfällen:

$$A_{CP} = \frac{\Gamma(D^0 \to h^+h^-)}{\Gamma(\overline{D^0} \to h^+h^-)}$$

$$\Delta A_{CP} = A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-)$$