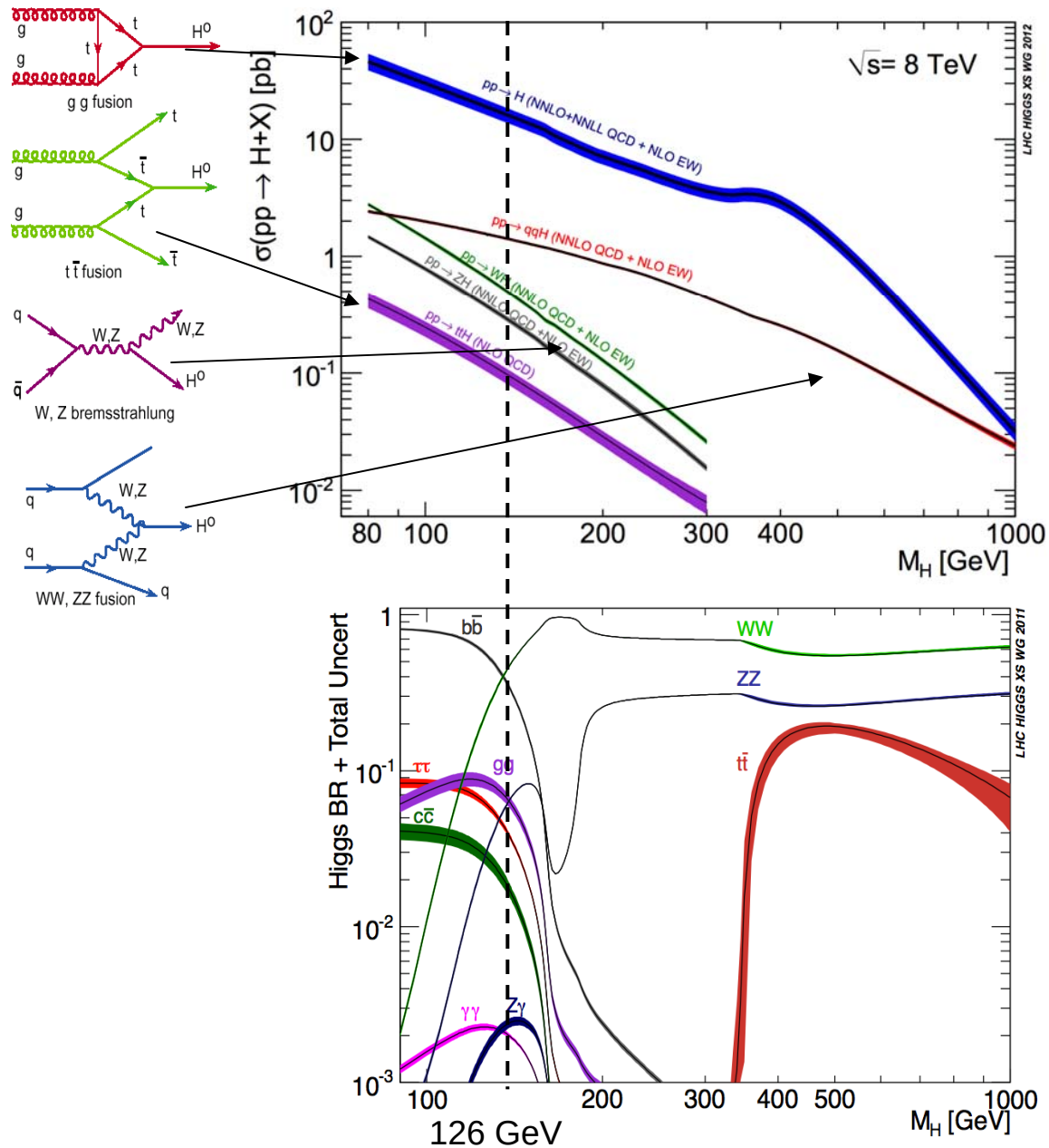


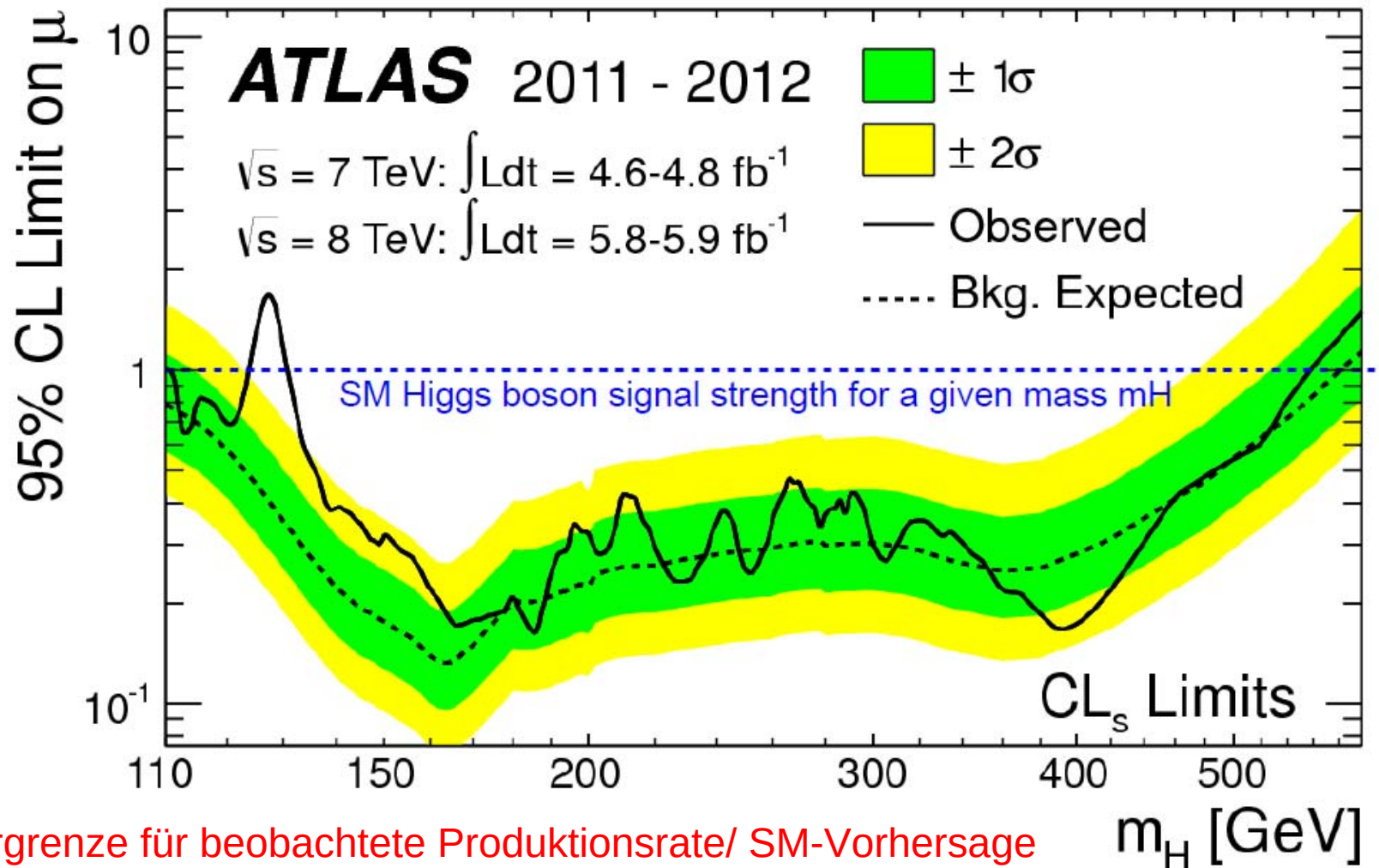
Physik am Large Hadron Collider



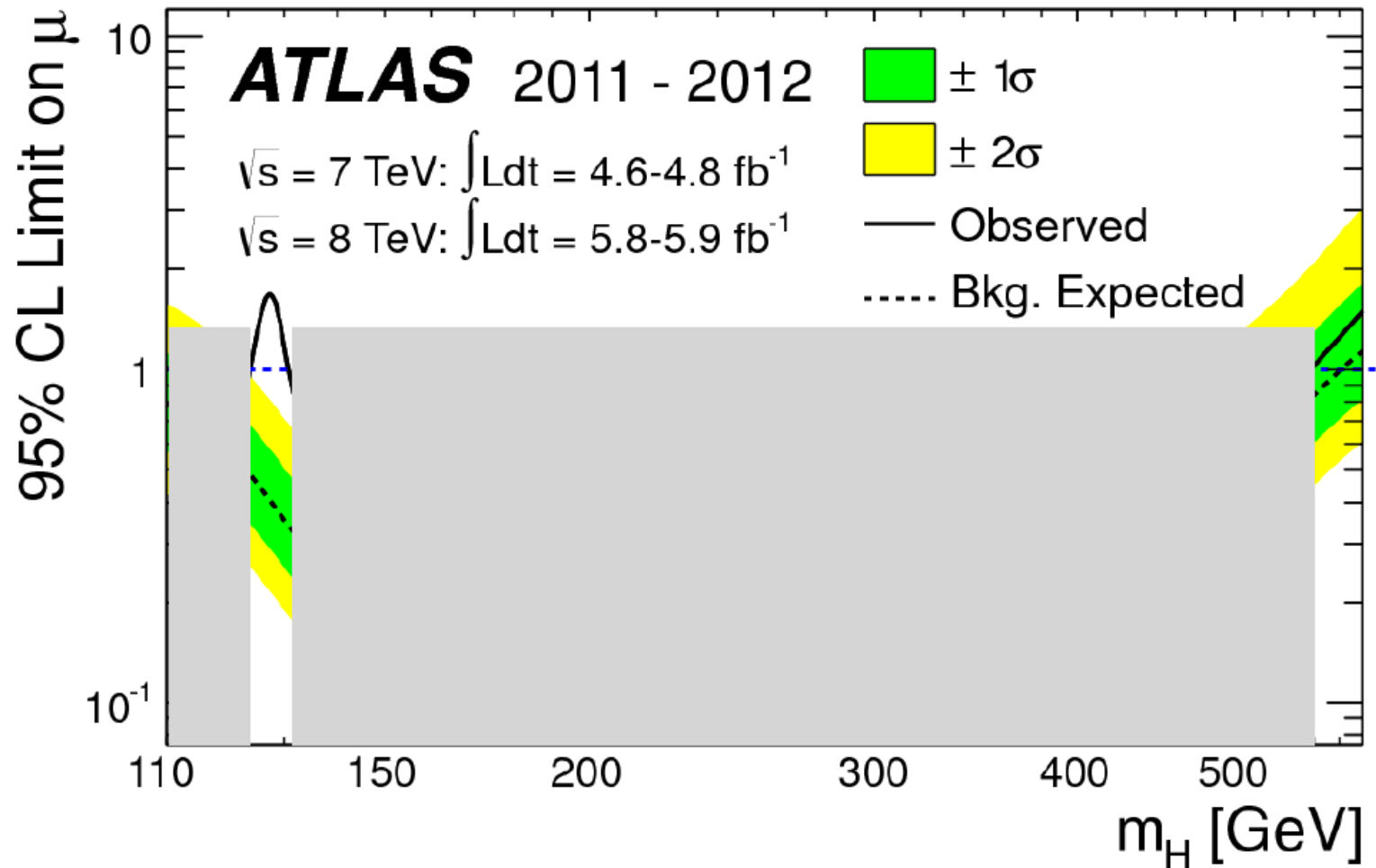
Higgs-Boson Produktion und Zerfall



Combined exclusion limits (July 2012)



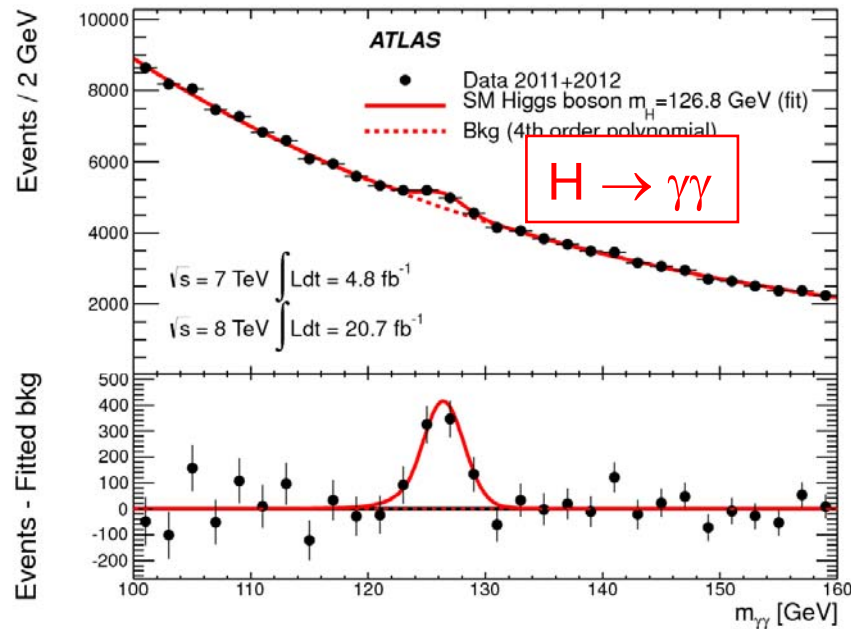
Combined exclusion limits (July 2012)



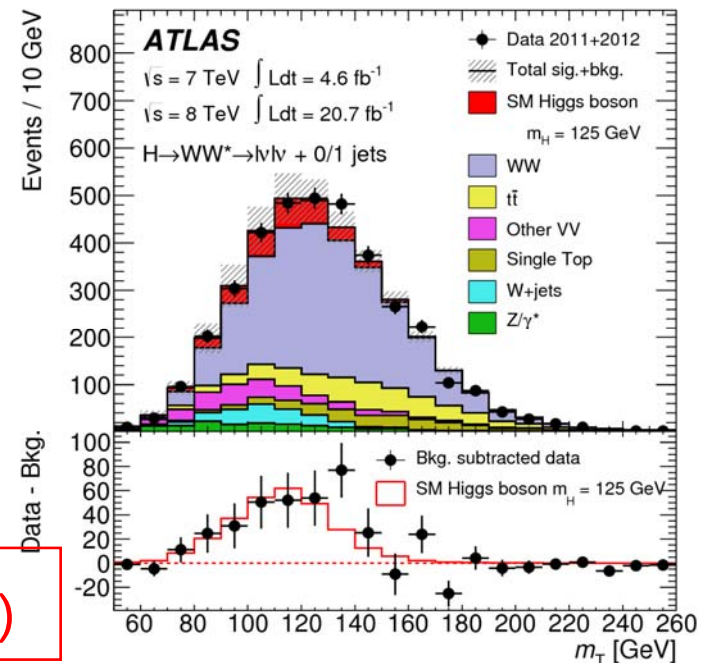
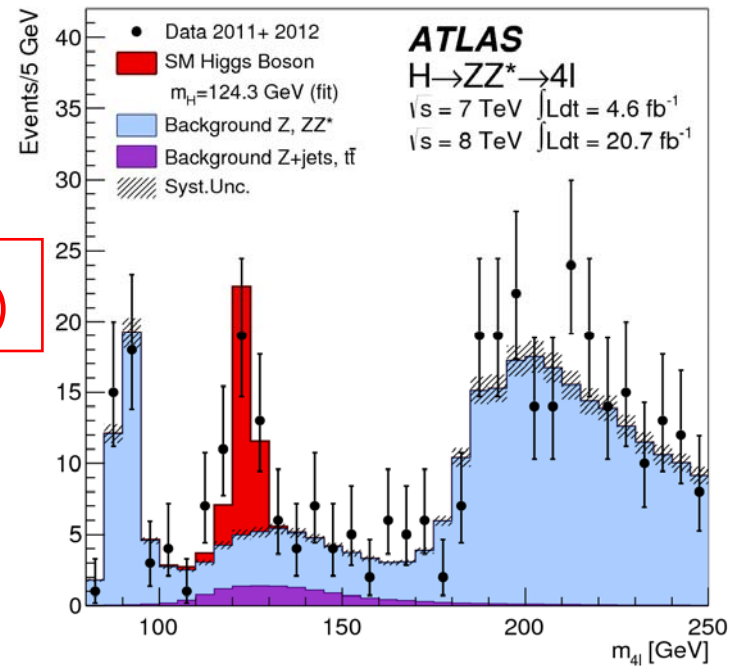
The existence of the Standard Model Higgs boson is **excluded with 95% confidence level** for almost all masses m_H from 110 GeV to 600 GeV, **except for $m_H \approx 120 - 130$ GeV where an excess of events is observed in few channels.**

Higgs-Boson-Signale - ATLAS

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

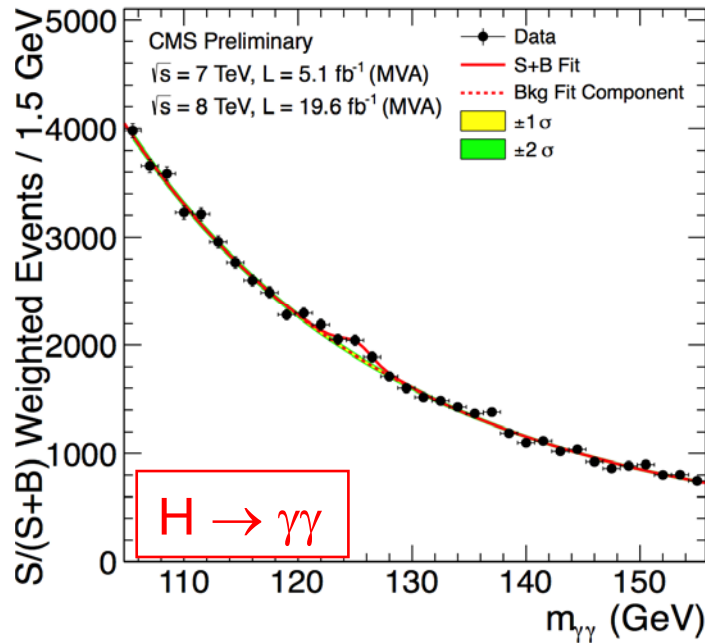


$$H \rightarrow WW^* \rightarrow (lv) (lv)$$

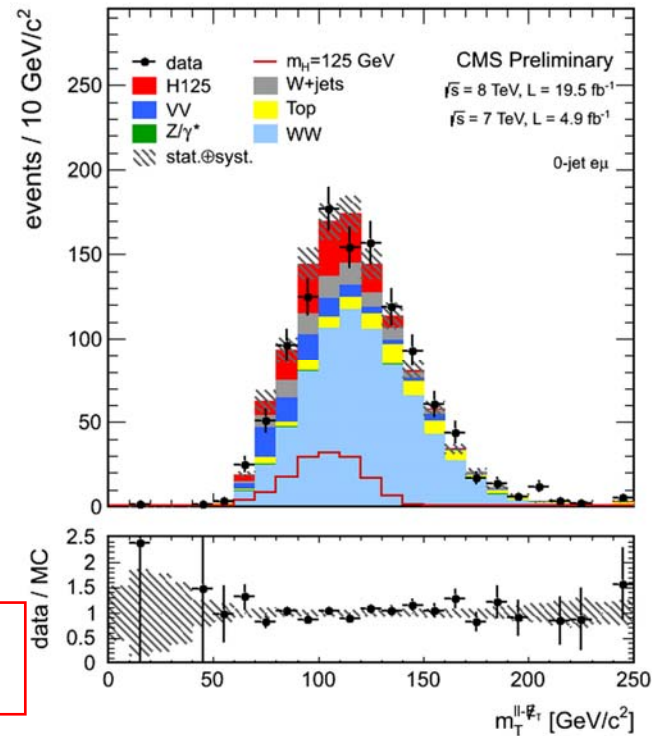
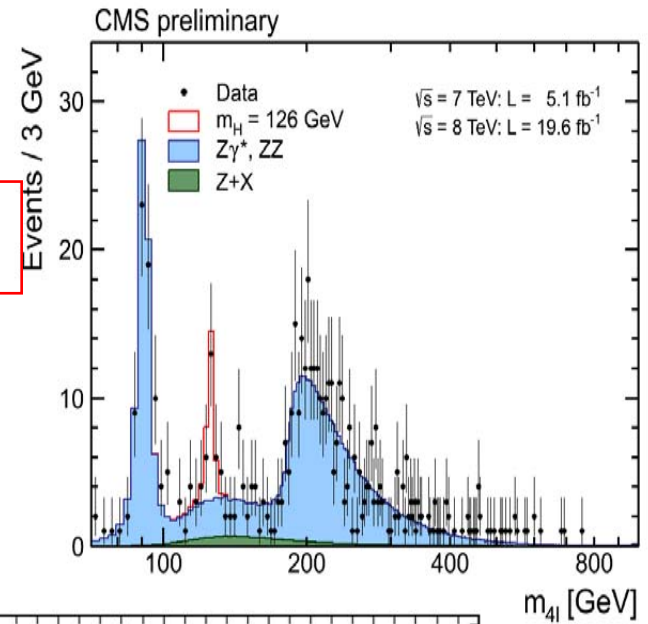


Higgs-Boson-Signale – CMS

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

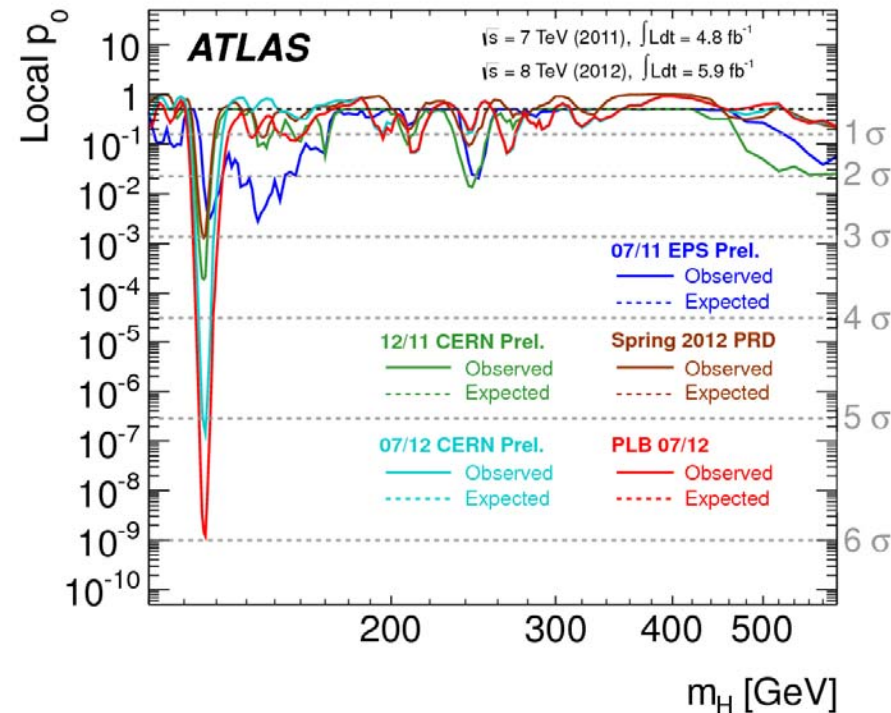


$$H \rightarrow WW^* \rightarrow (lv) (lv)$$

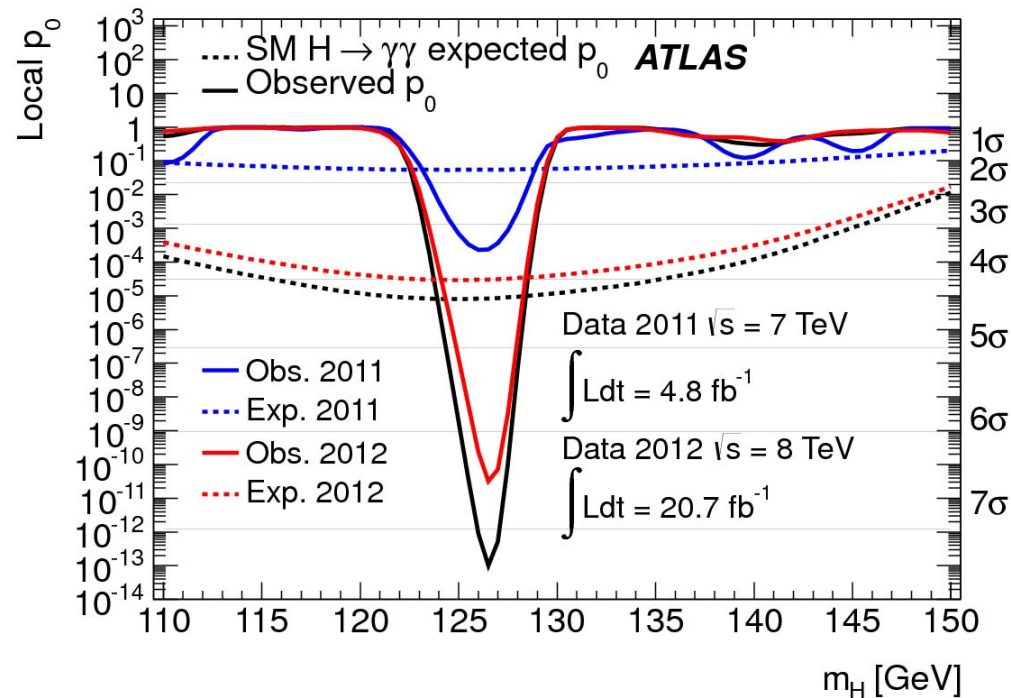


Higgs-Boson-Signal

Wahrscheinlichkeit einer Untergrundfluktuation

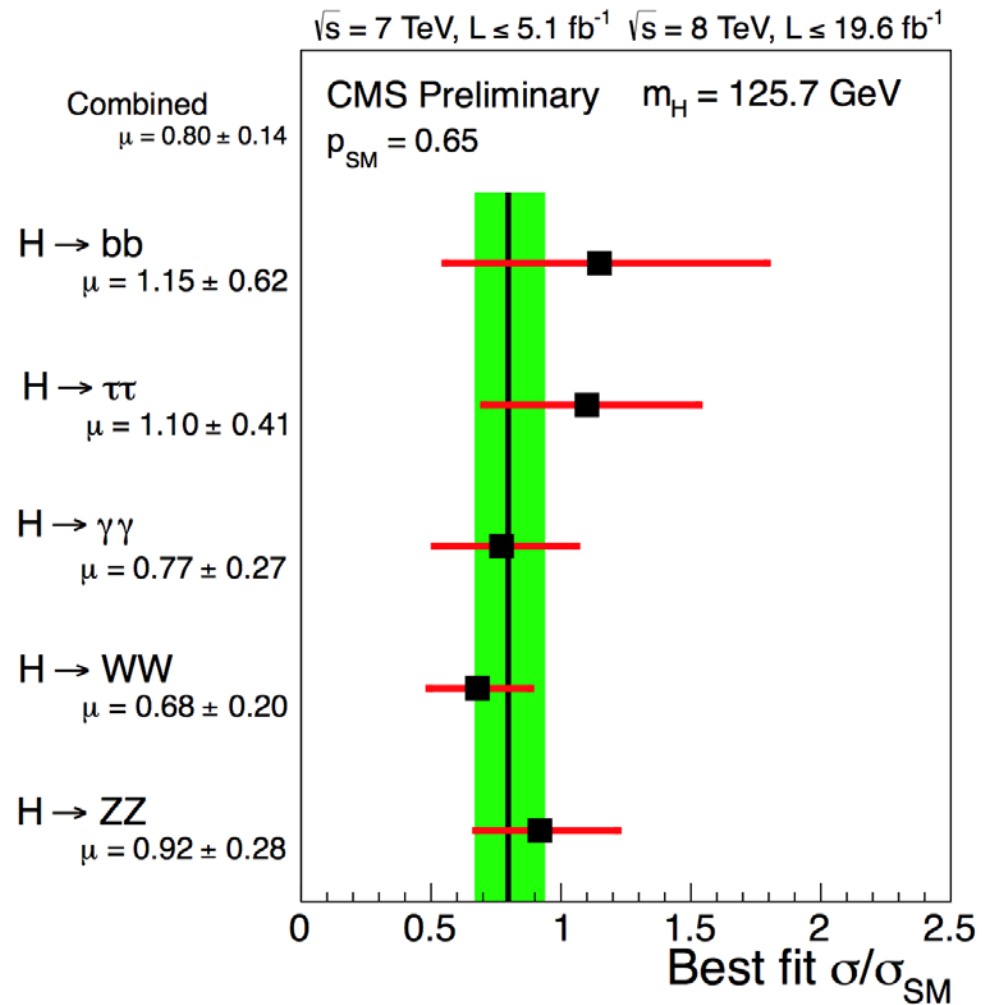
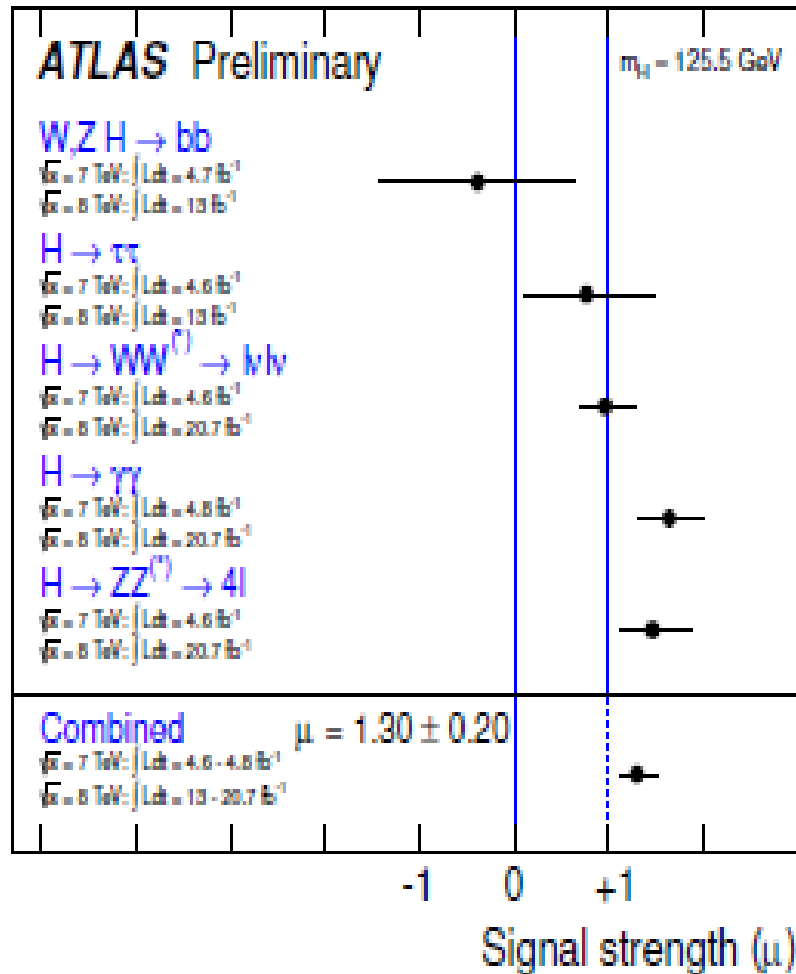


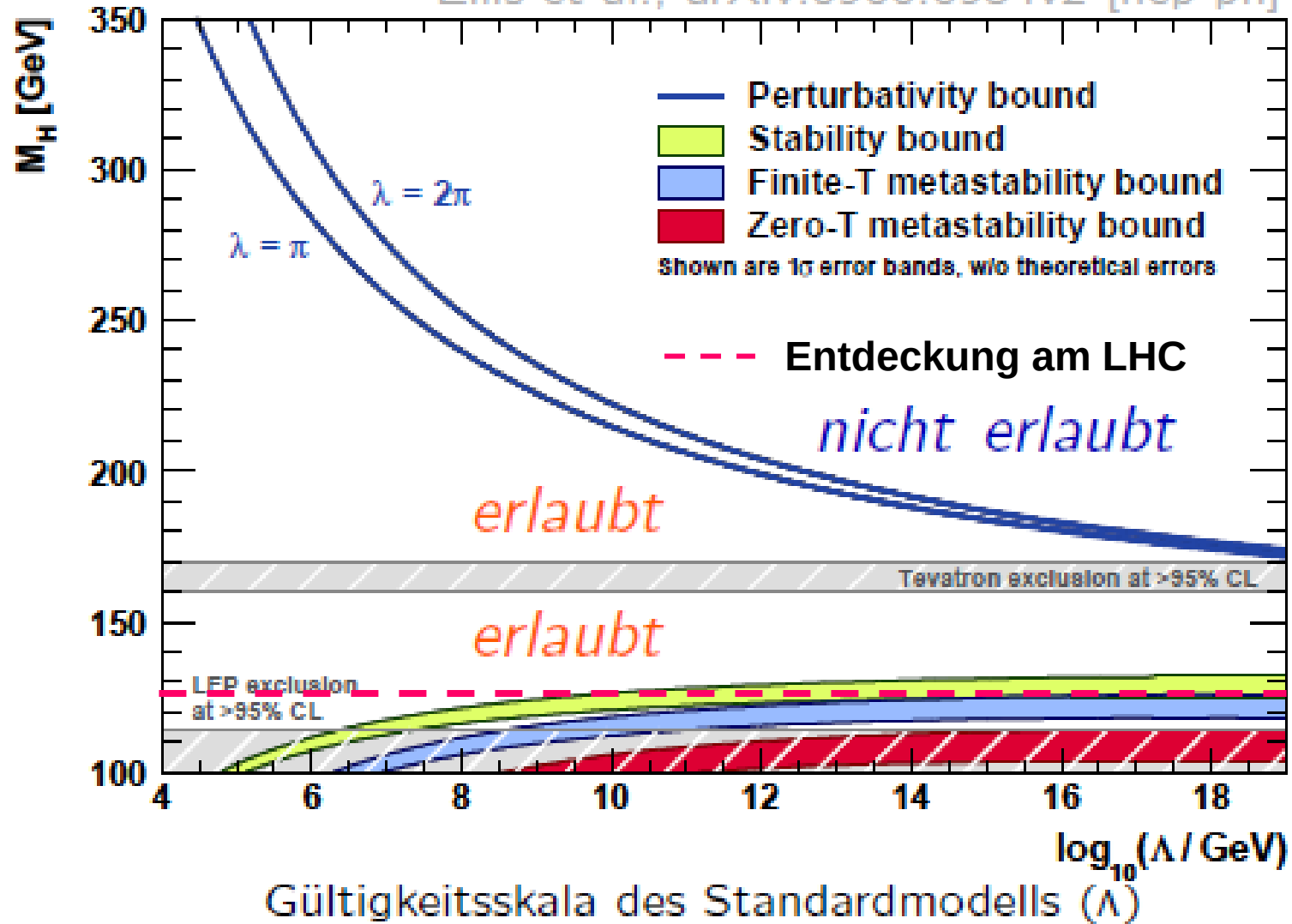
Entdeckung Juli 2012



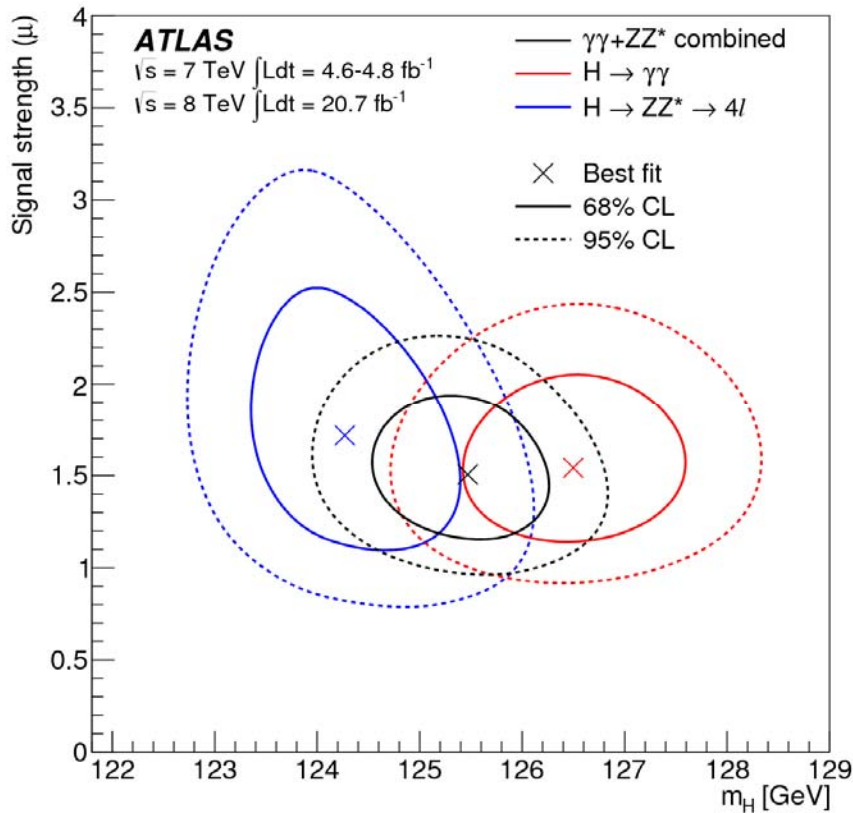
Endergebnis mit 7-8 TeV Daten April 2013

Higgs-Boson-Signalstärke



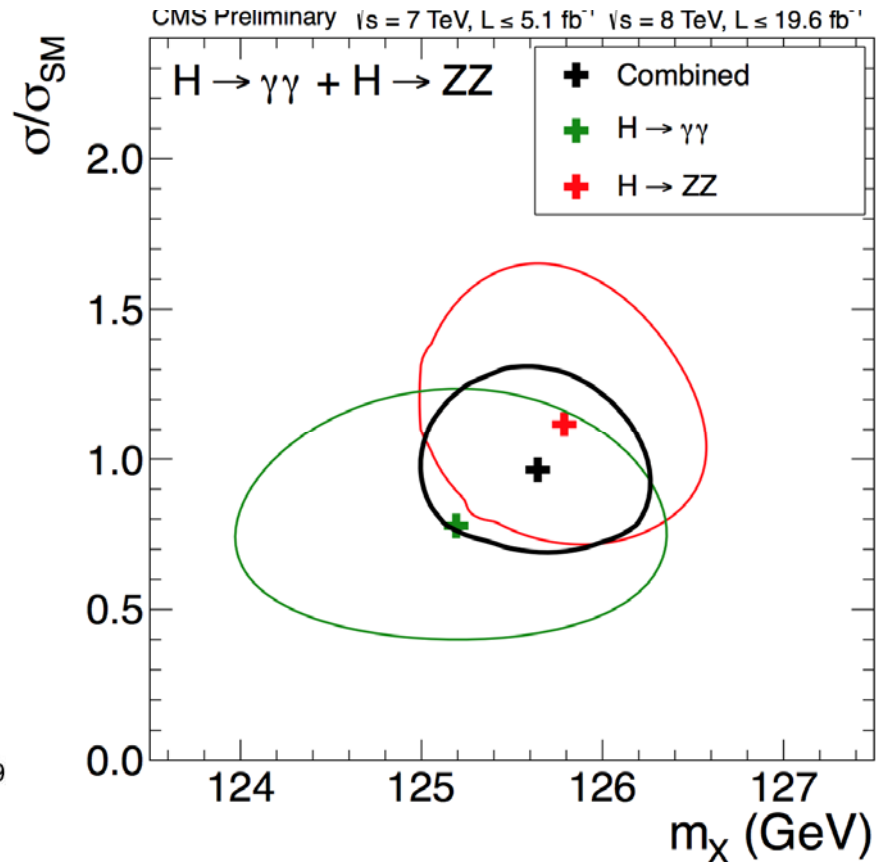


Higgs-Boson-Masse und Signalstärke



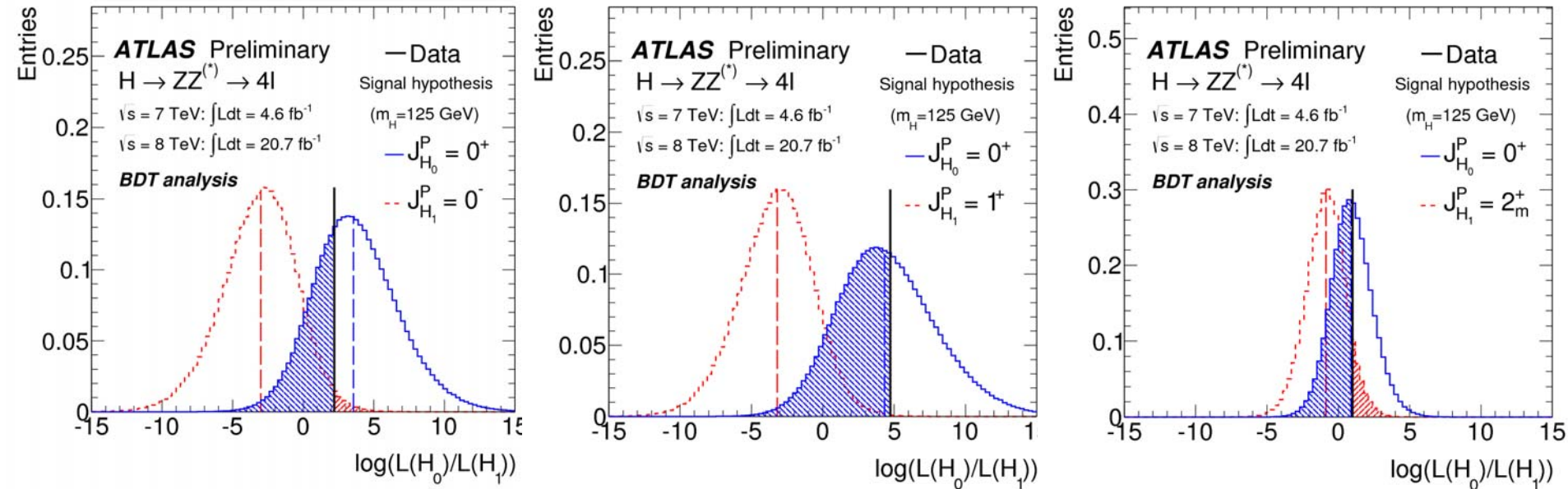
Präzisionsmessung:

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



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

Higgs-Boson-Spin und CP- Quantenzahl



Standardmodell: $\text{Spin}^{\text{CP}} = 0^+$.

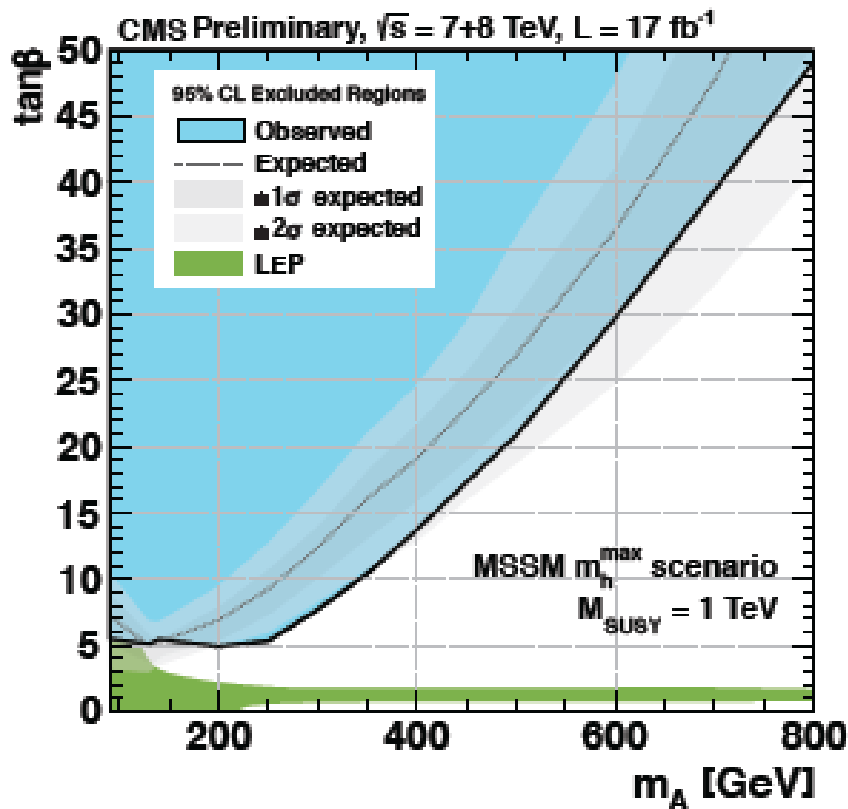
Isotrope Winkelverteilung von γ , W, Z im Higgs Ruhesystem für Spin 0.

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

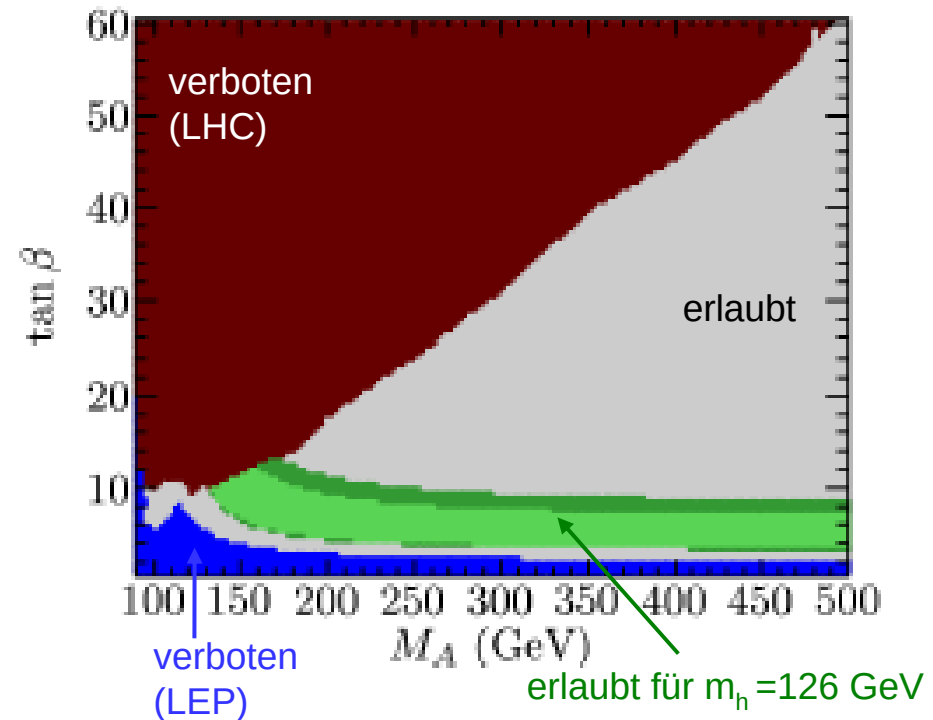
SUSY Higgs-Bosonen

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

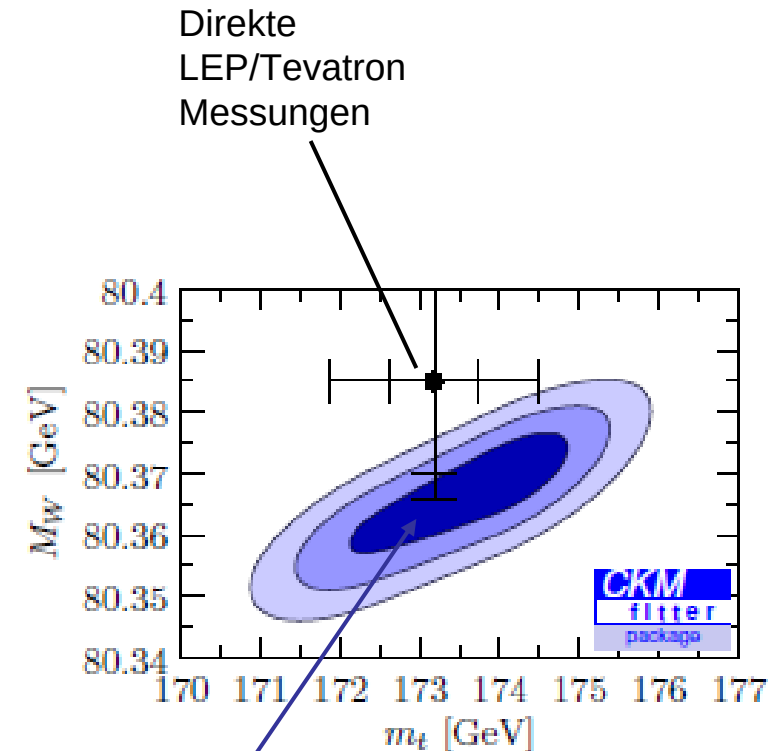
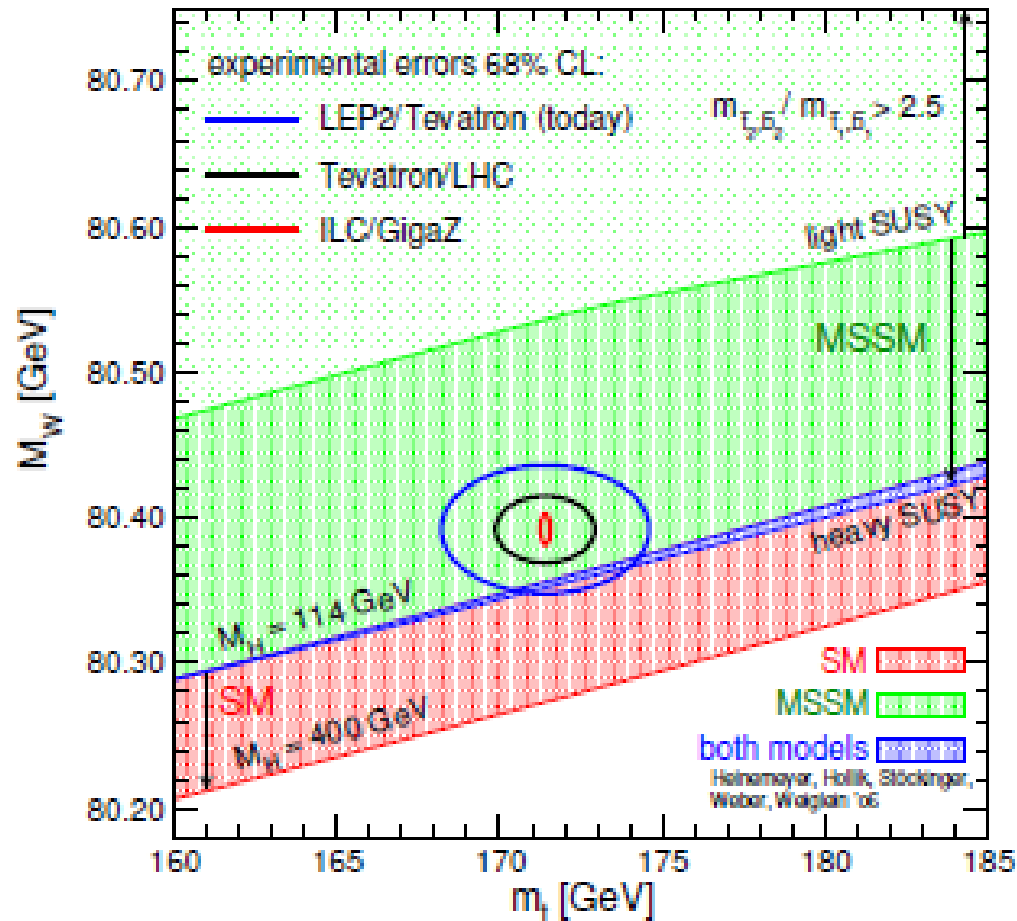
Zwei wesentliche Parameter in niedrigster Ordnung: M_A und $\tan \beta = v_{\text{up}} / v_{\text{down}}$.



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



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



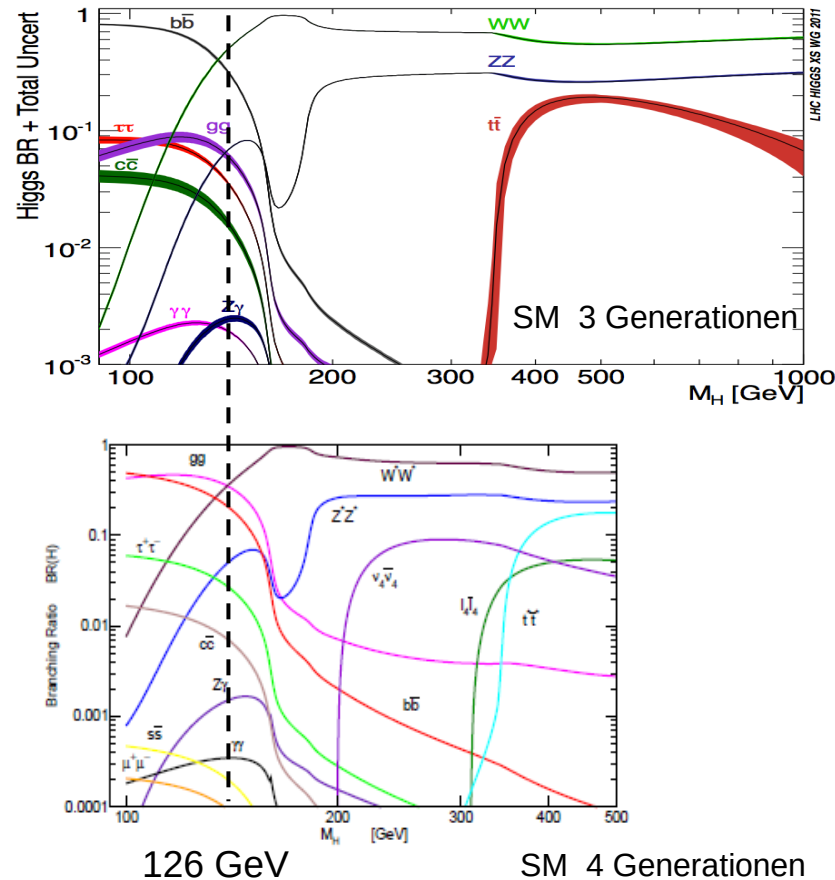
Standardmodell-Vorhersage von elektroschwachen Präzisionsmessungen und Messungen der Higgs-Produktions- und Zerfallsraten und der Higgs-Masse

Higgs und 4. Fermionengeneration (mit schweren Neutrinos)

LEP/Tevatron: $m(t') > 450 \text{ GeV}$, $m(b') > 361 \text{ GeV}$. $> 500 \text{ GeV}$ keine Störungstheorie mehr.

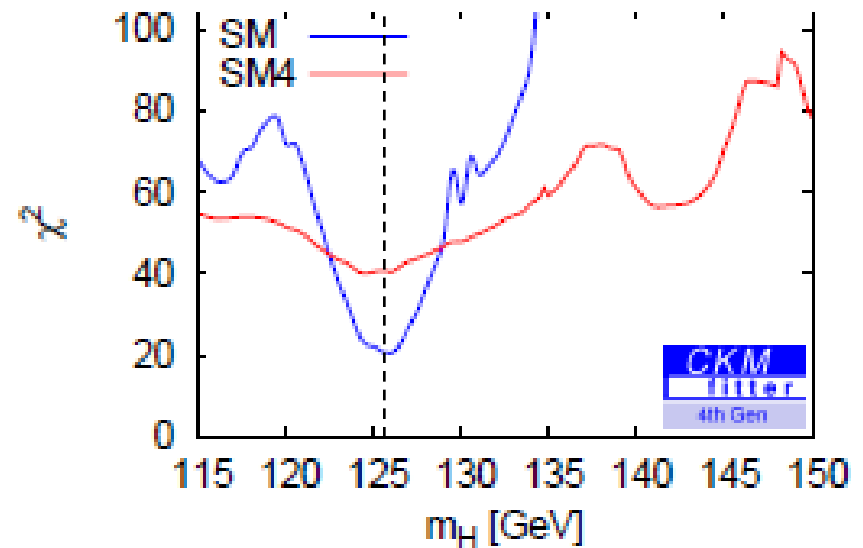
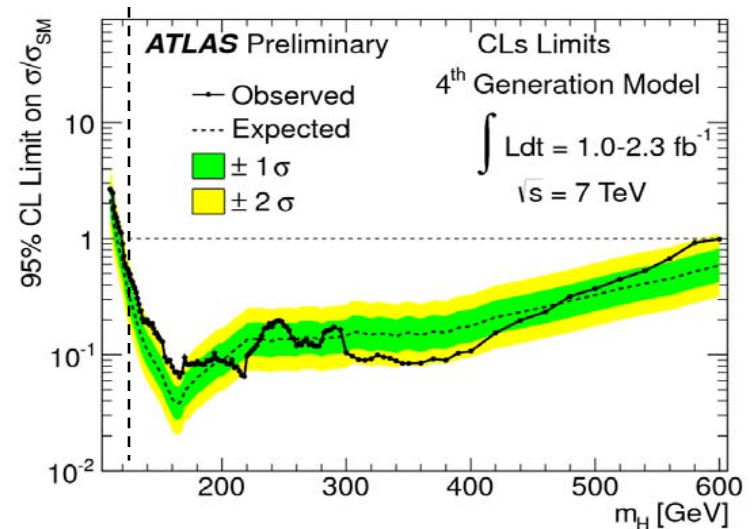
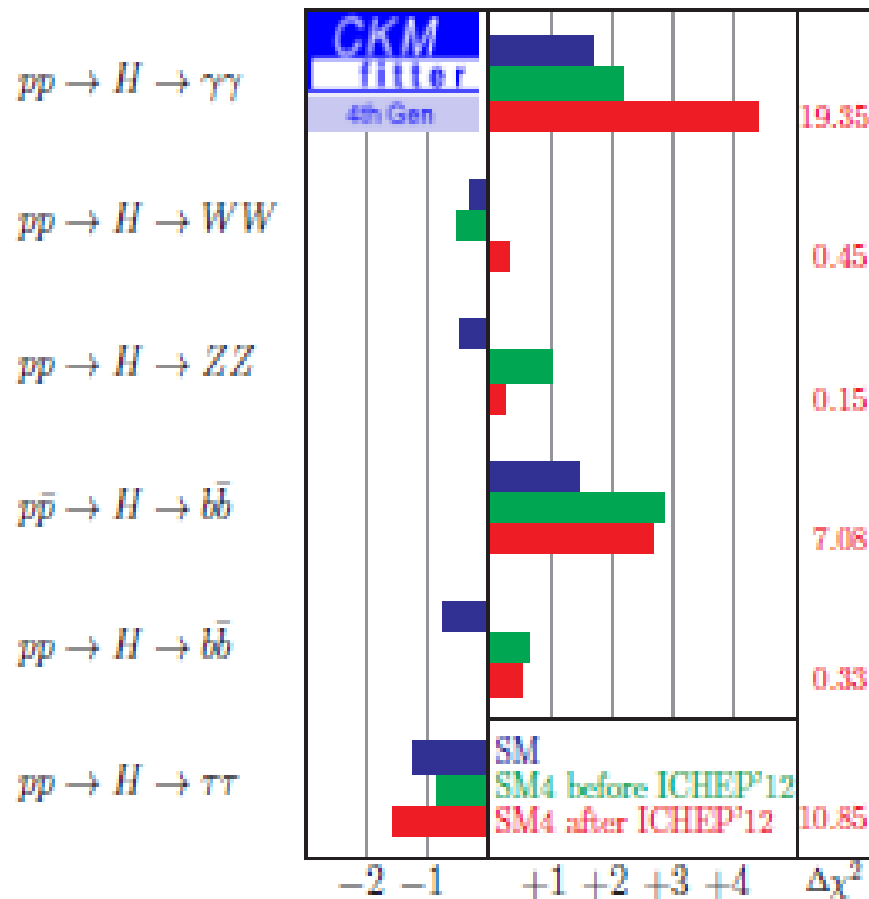
Starke Konsequenzen der zusätzlichen schweren Quarks (für Higgs-Produktions- und Zerfallsraten: Gluonfusionsproduktion **9 x verstärkt** durch 2 zusätzliche schwere Quark-loops, weitgehend unabhängig von der Masse.

Vergleich mit den Messungen:



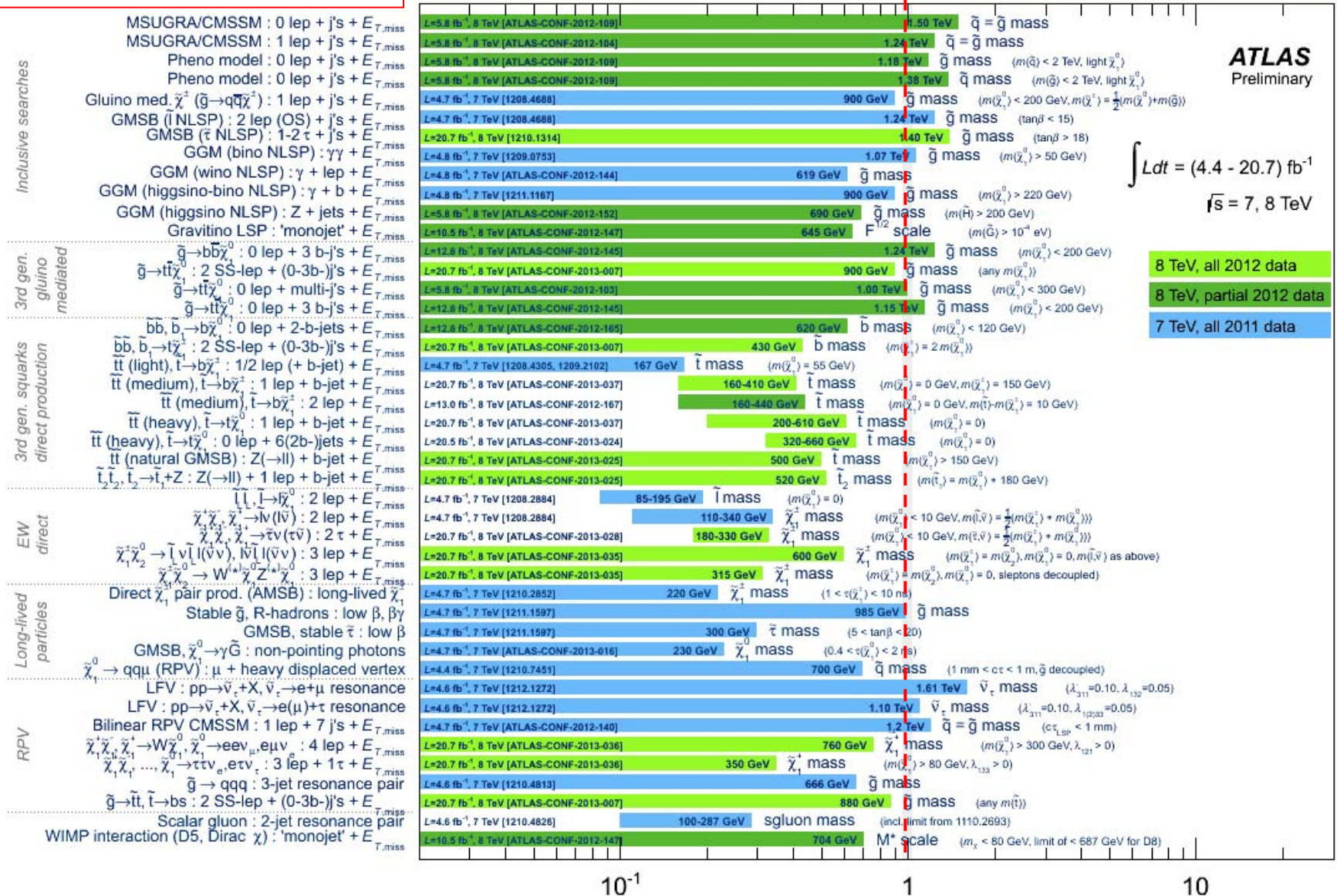
Higgs und 4. Fermionengeneration (mit schweren Neutrinos)

4. Generation ausgeschlossen:



Suche nach SUSY am LHC

ATLAS SUSY Searches* - 95% CL Lower Limits (Status: March 26, 2013)



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

⇒V]

Suche nach Erweiterungen des SM am LHC (ausser SUSY)

ATLAS Exotics Searches* - 95% CL Lower Limits (Status: HCP 2012)

Extra dimensions

Large ED (ADD) : monojet + $E_{T,miss}$
 Large ED (ADD) : monophoton + $E_{T,miss}$
 Large ED (ADD) : diphoton & dilepton, $m_{\gamma\gamma}/ll$
 UED : diphoton + $E_{T,miss}$
 S^1/Z_2 ED : dilepton, m_{ll}
 RS1 : diphoton & dilepton, $m_{\gamma\gamma}/ll$
 RS1 : ZZ resonance, m_{ll}/llj
 RS1 : WW resonance, $m_{T,l\nu/lj}$
 RS $g_{KK} \rightarrow tt$ (BR=0.925) : $tt \rightarrow l+jets$, $m_{t,boosted}$
 ADD BH ($M_{TH}/M_D=3$) : SS dimuon, $N_{ch,part.}$
 ADD BH ($M_{TH}/M_D=3$) : leptons + jets, Σp_T
 Quantum black hole : dijet, $F(m_{jj})$
 qqqq contact interaction : $\chi^2(m_{jj})$

CI

qqll CI : ee & $\mu\mu$, m_{ll}
 uutt CI : SS dilepton + jets + $E_{T,miss}$

V'

Z' (SSM) : $m_{ee/\mu\mu}$
 Z' (SSM) : $m_{\tau\tau}$
 W' (SSM) : $m_{T,e/\mu}$
 $W' (\rightarrow tq, g=1)$: m_{tq}
 $W'_R (\rightarrow tb, SSM)$: m_{tb}
 W^* : $m_{T,e/\mu}$

LQ

Scalar LQ pair ($\beta=1$) : kin. vars. in $eejj, evjj$
 Scalar LQ pair ($\beta=1$) : kin. vars. in $\mu\mu jj, \mu\nu jj$
 Scalar LQ pair ($\beta=1$) : kin. vars. in $\tau\tau jj, \tau\nu jj$

New quarks

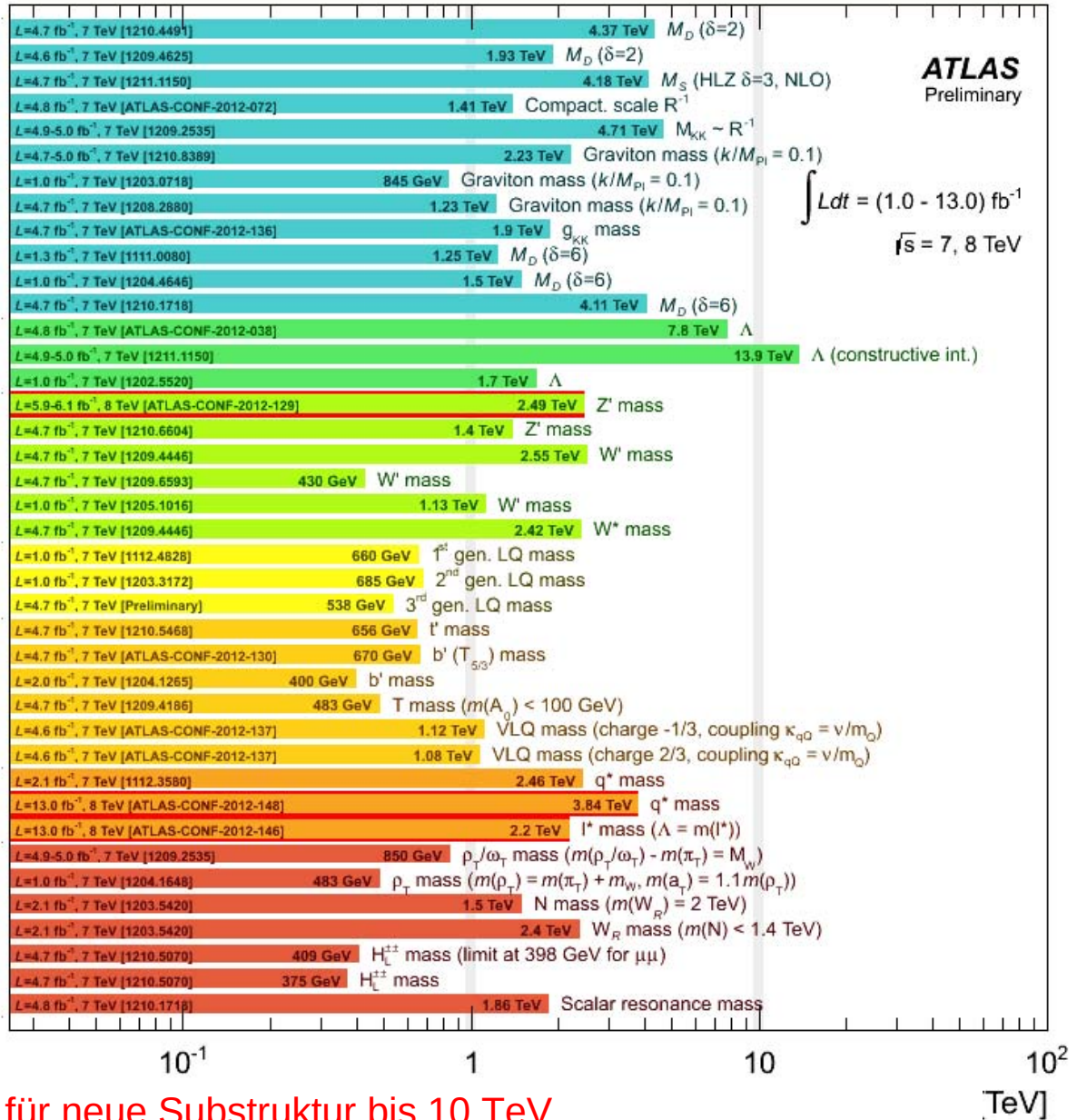
4th generation : $t't' \rightarrow WbWb$
 4th generation : $b'b' (T_{5/3}) \rightarrow WtWt$
 New quark b' : $b'b' \rightarrow Zb+X$, m_{Zb}
 Top partner : $TT \rightarrow tt + A_0 A_0$ (dilepton, M_{T2})
 Vector-like quark : CC, m_{lvq}
 Vector-like quark : NC, m_{llq}

Excit. ferm.

Excited quarks : γ -jet resonance, $m_{\gamma jet}$
 Excited quarks : dijet resonance, m_{jj}
 Excited lepton : l - γ resonance, $m_{l\gamma}$

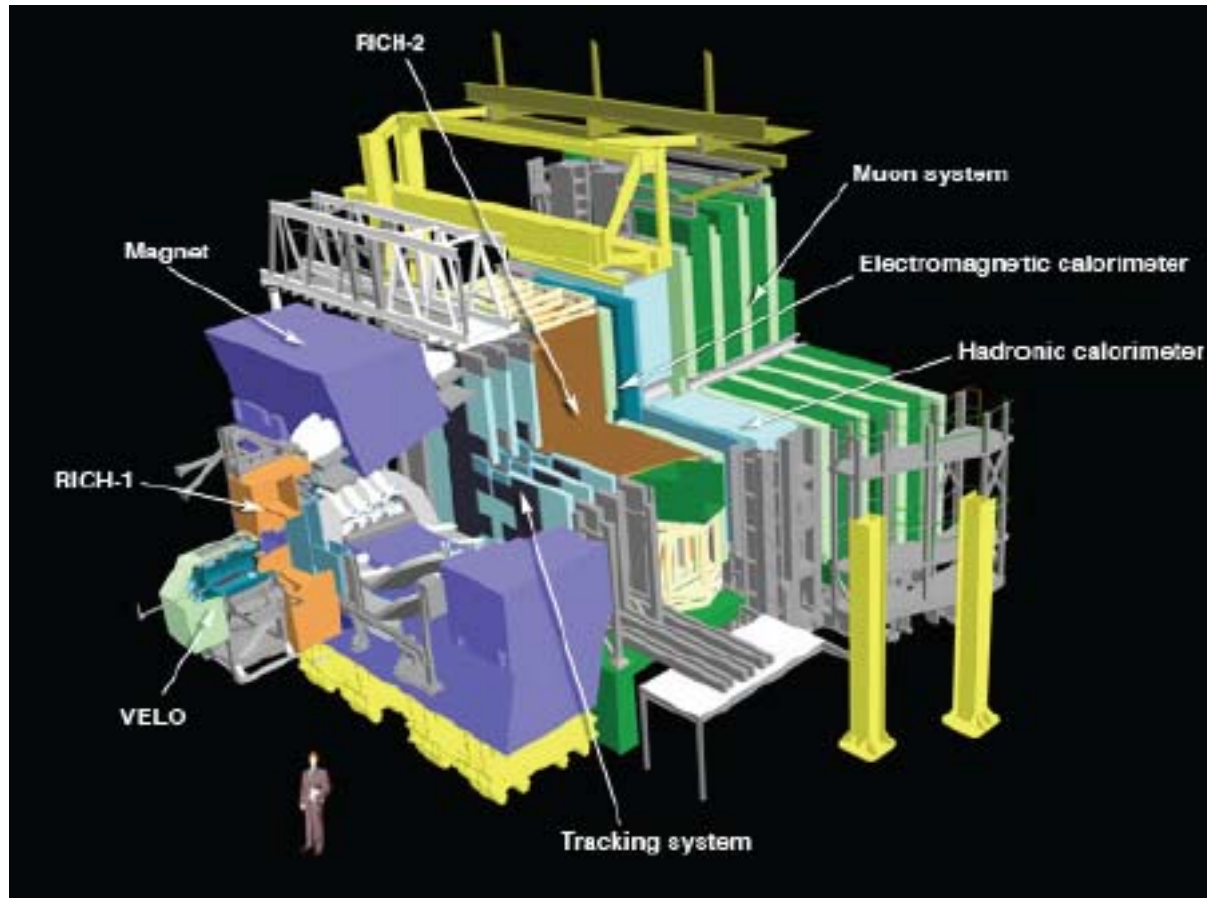
Other

Techni-hadrons (LSTC) : dilepton, $m_{ee/\mu\mu}$
 Techni-hadrons (LSTC) : WZ resonance ($vlll$), $m_{T,WZ}$
 Major. neutr. (LRSM, no mixing) : 2-lep + jets
 W_R (LRSM, no mixing) : 2-lep + jets
 $H_{\pm}^{\pm}$ (DY prod., BR($H_{\pm}^{\pm} \rightarrow ll$)=1) : SS ee ($\mu\mu$), m_{ll}
 $H_{\pm}^{\pm}$ (DY prod., BR($H_{\pm}^{\pm} \rightarrow e\mu$)=1) : SS $e\mu$, $m_{e\mu}$
 Color octet scalar : dijet resonance, m_{jj}



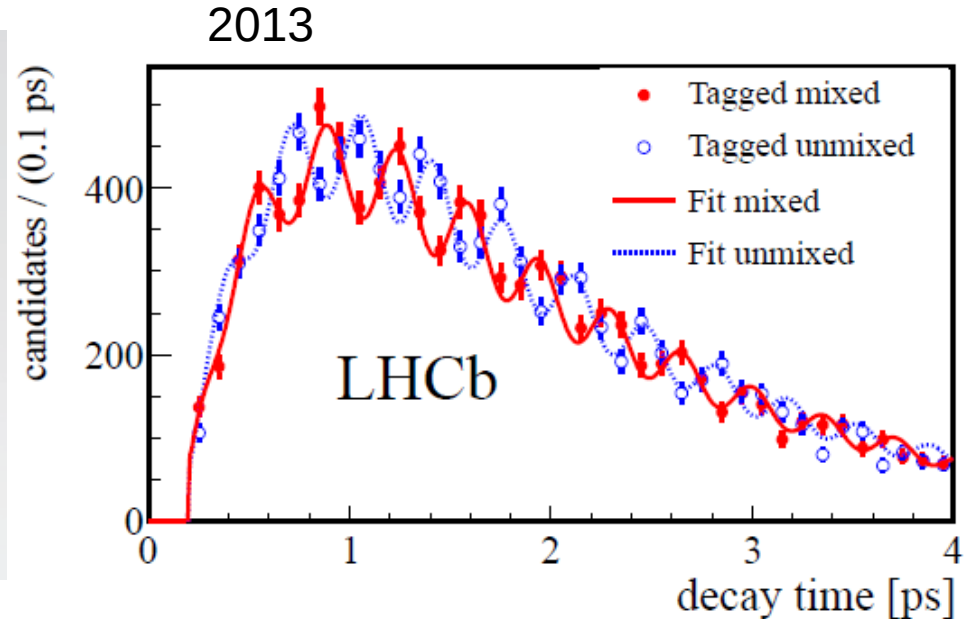
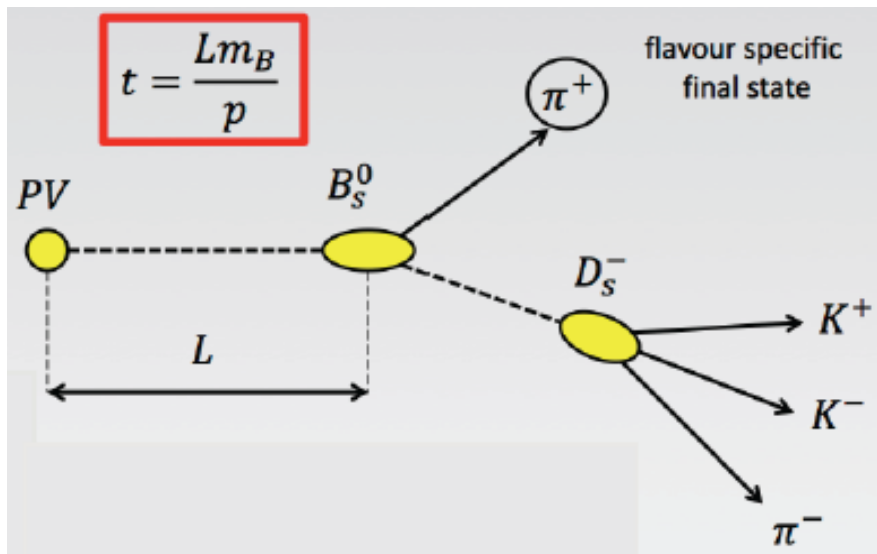
Indirekte Ausschlussgrenzen z.B. für neue Substruktur bis 10 TeV.

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

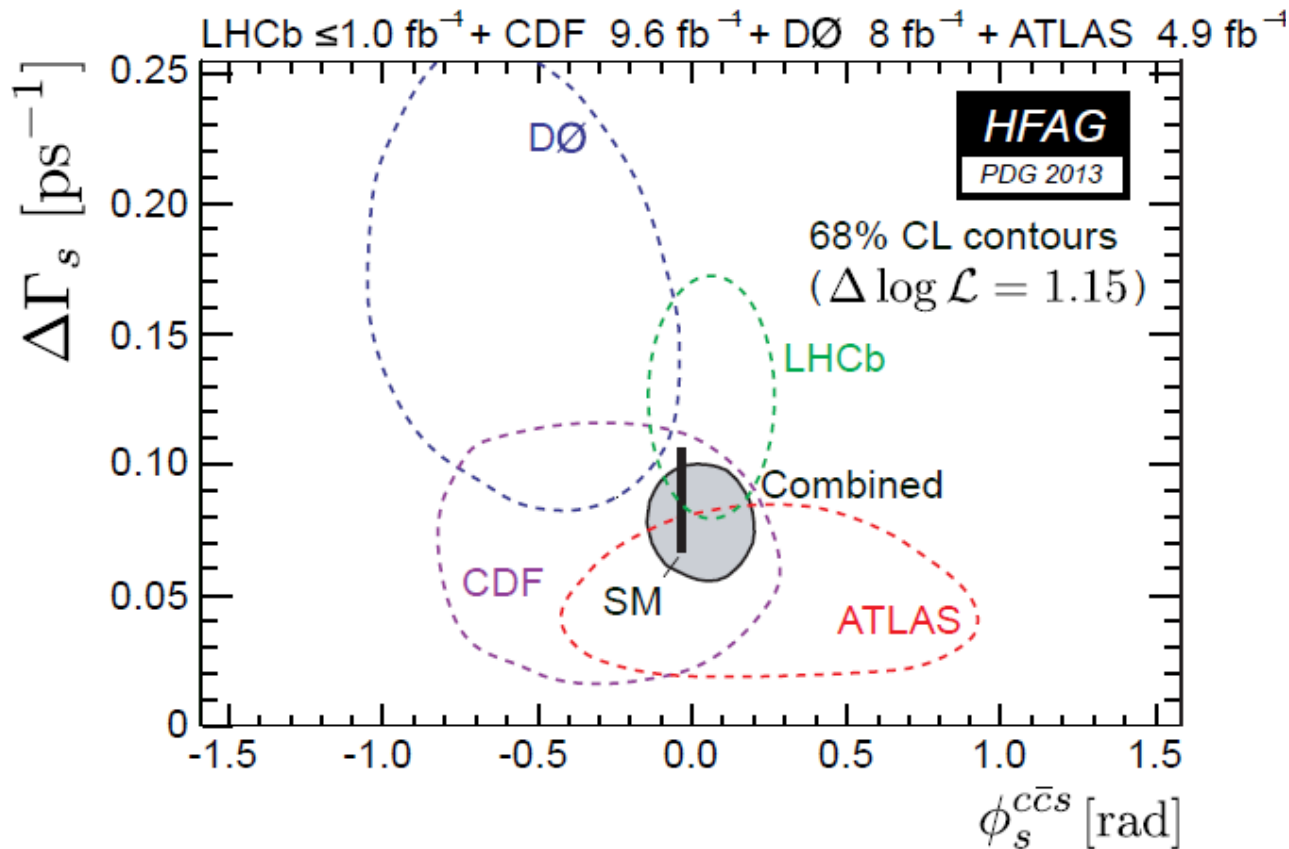


$$\Delta m_s = 17.768 \pm 0.023 \pm 0.006 \text{ ps}^{-1}$$

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

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

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



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:

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

2013:

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

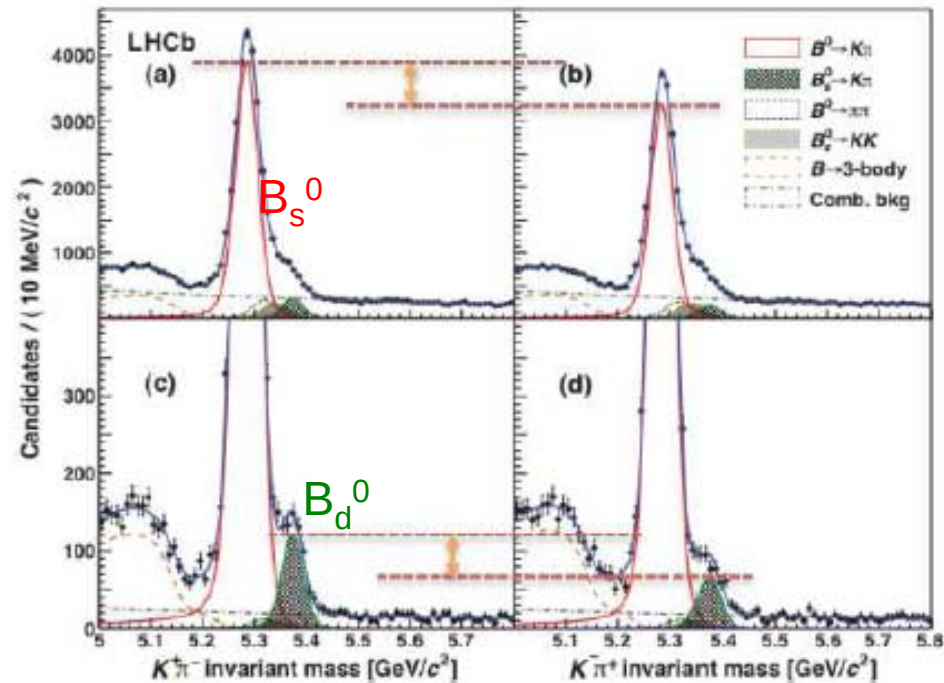
$$A_{CP}(B^0 \rightarrow K^+ \pi^-) = -0.083 \pm 0.013 \pm 0.003$$

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

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

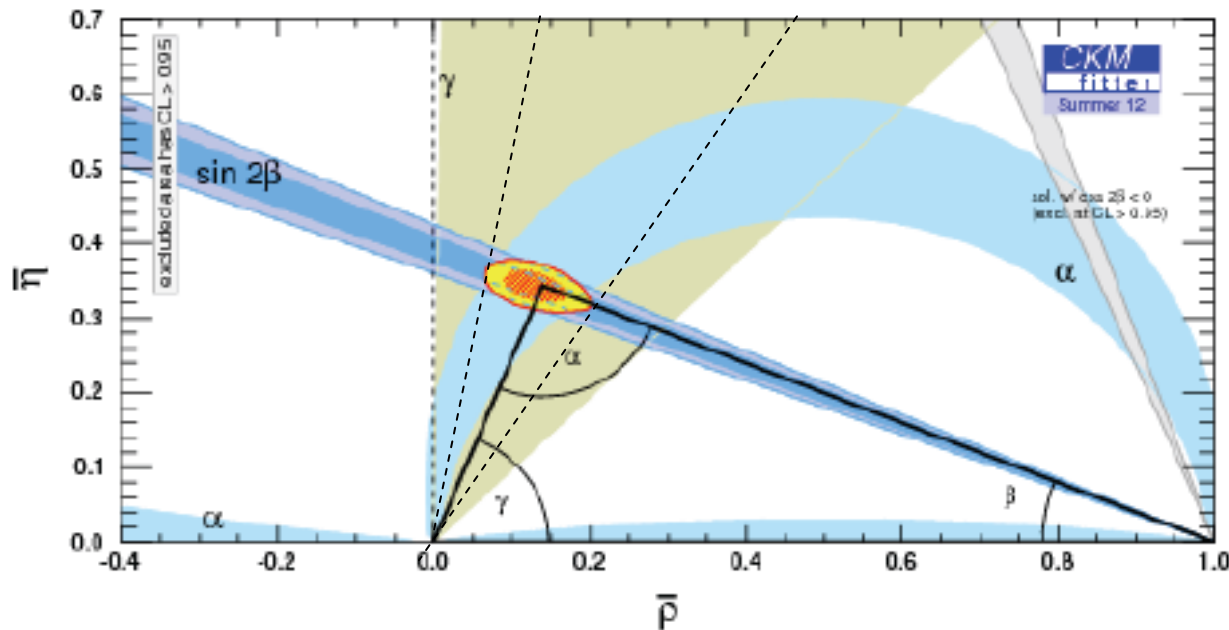
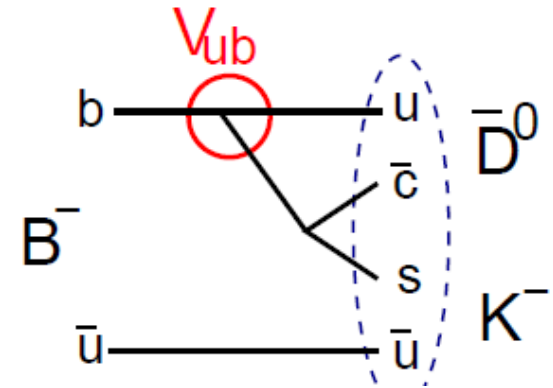
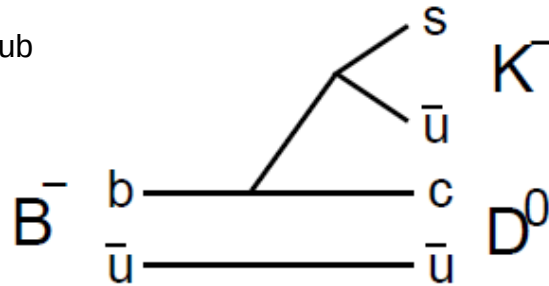
$$A_{CP}(B^0 \rightarrow K^+ \pi^-) = -0.080 \pm 0.007 \pm 0.003$$

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



Verbesserte Messungen des CKM Winkels γ

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



LHCb 2013:

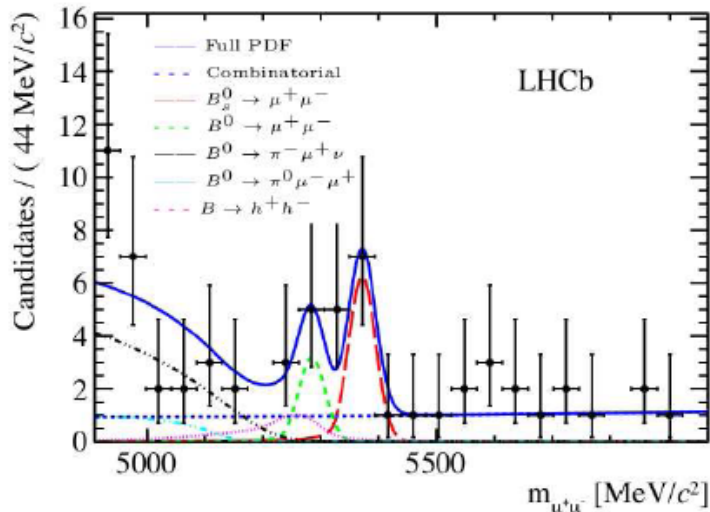
$$\gamma = (67 \pm 12)^\circ$$

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

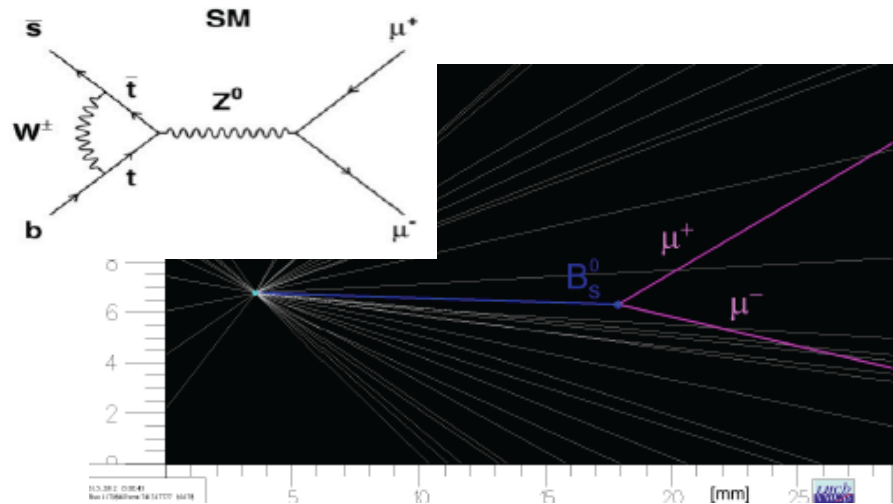
$$\text{BaBar: } \gamma = (69^{+17}_{-16})^\circ$$

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

Neu Juli 2013: LHCb und CMS



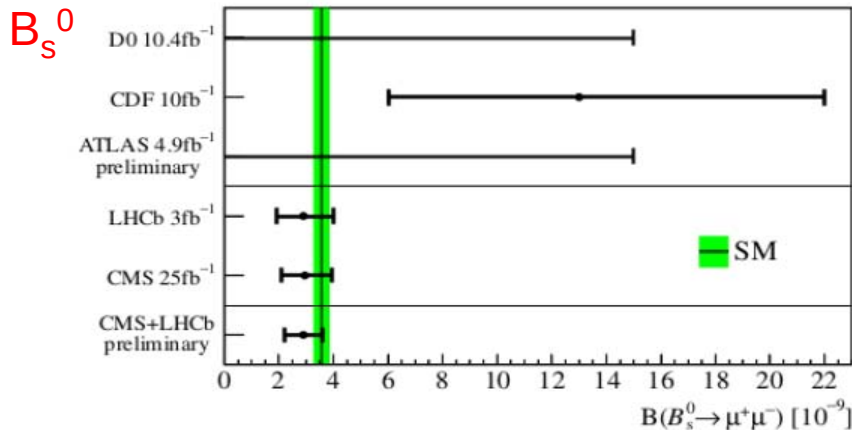
Gute Übereinstimmung mit der Messung, wenig Platz für neue (z.B. supersymmetrische) Teilchen in loops.



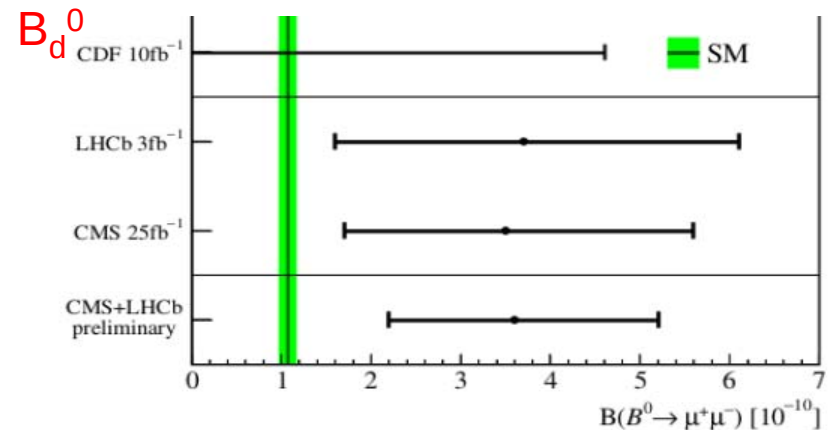
Standardmodell: 2. Ordnung loop-Prozesse, FCNC und Helizitätsunterdrückung:

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

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



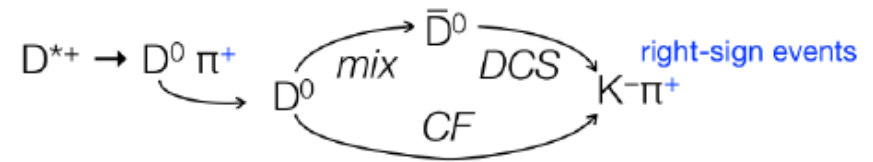
$$\text{BR}(B_s \rightarrow \mu^+\mu^-) = (2.9 \pm 0.7) \times 10^{-9}$$



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

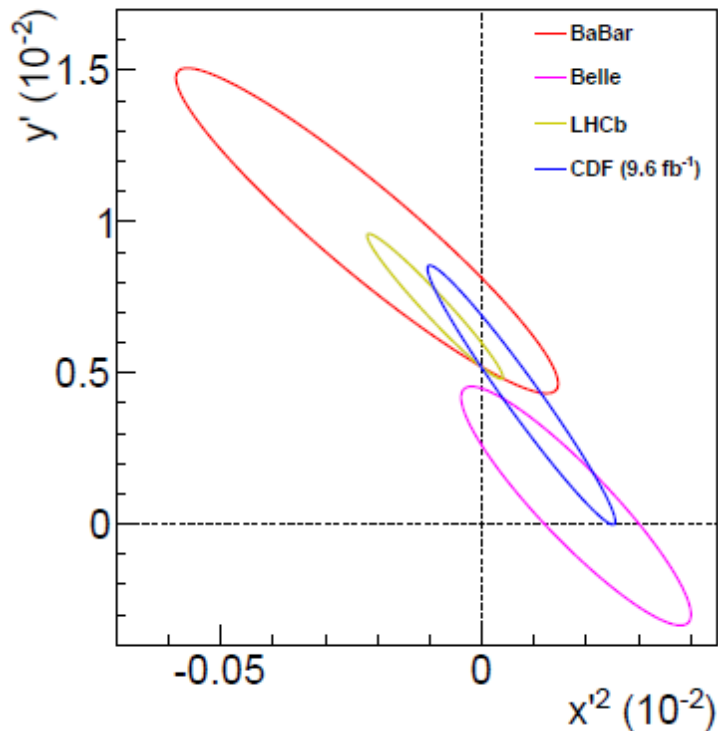
Nachweis der Oszillationen neutraler D-Mesonen

Parameter $x', y' \neq 0$, 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:

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

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

