Karlsruher Institut für Technologie

Searches for Higgs Bosons in Supersymmetric Models

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Course "Higgs Physics"

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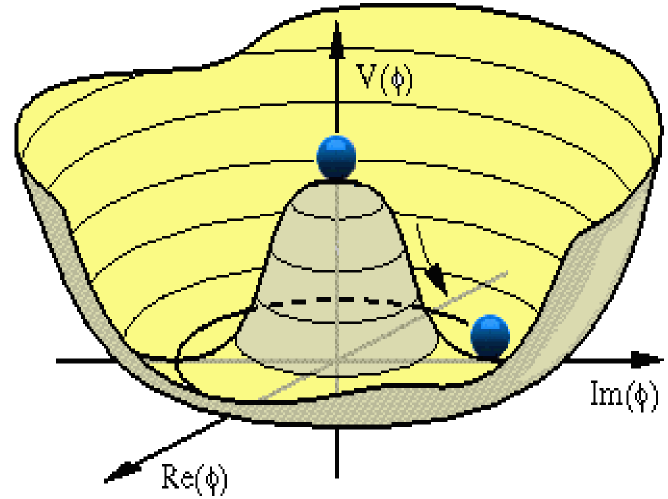
Deficiencies of Standard Model

- One Higgs doublet is miminum, which required to generate particle masses

$$\Phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} \qquad V(\Phi^\dagger\Phi) = \lambda\left(\Phi^\dagger\Phi - \frac{v^2}{2}\right)^2$$



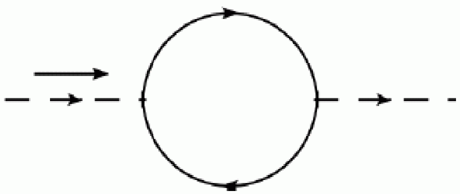
- No strong theoretical arguments favoring this minimal choice

Flaws of Standard Model

- Higgs mechanism ad hoc
- more than 20 unexplained model parameters
- does not include gravity in a consistent way as a quantum field theory
- does not explain the source of CP-violation
- Does not give explanation of Cold Dark Matter in Universe
- Hierarchy (fune-tuning) problem
- …

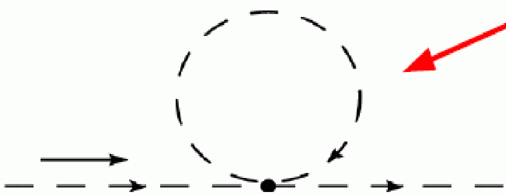
Supersymmetry

- **fermions ↔ bosons**
  - **stabilizes radiative corrections to Higgs self-energy**



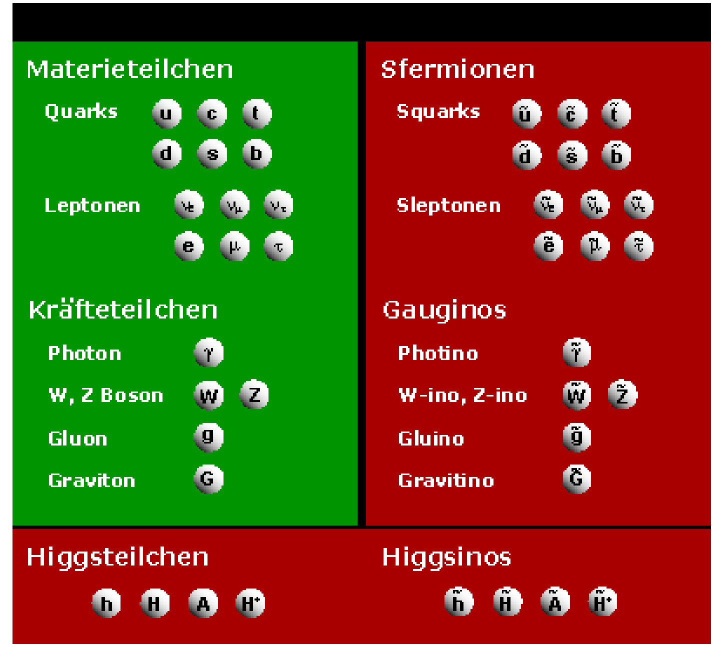
$$\Delta_{M_H^2} = -\frac{\lambda_f^2}{8\pi^2}\Lambda^2$$

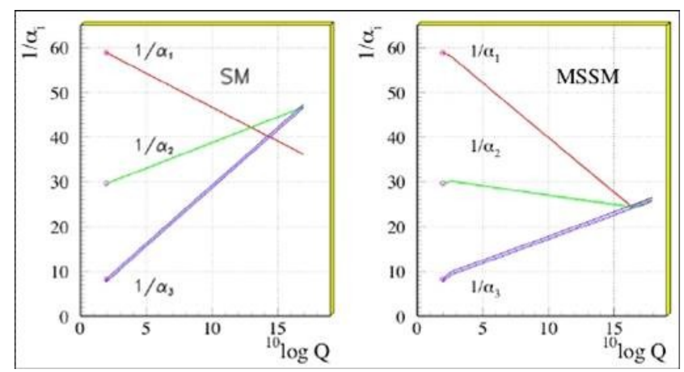
superpartner scalar



$$\Delta_{M_H^2} = \frac{\lambda_s}{16\pi^2}\Lambda^2$$

- Both contribution chancel if $\lambda_s = 2\lambda_f^2$





  - **Points towards unification of gauge constants**
  - **Provides a candidate for dark matter**
    - **Lightest supersymmetric particle, e.g. in R-parity conserving SUSY models** $\tilde{\chi}_1^0$

Higgs Sector in MSSM

Higgs Sector in MSSM → Two Higgs Doublet Model

$$\Phi_1 = \begin{pmatrix} \Phi_1^+ \\ \Phi_1^0 \end{pmatrix} \qquad \Phi_2 = \begin{pmatrix} \Phi_2^+ \\ \Phi_2^0 \end{pmatrix}$$

$$\langle \Phi_1 \rangle = \begin{pmatrix} 0 \\ \nu_1 \end{pmatrix} \qquad \langle \Phi_2 \rangle = \begin{pmatrix} 0 \\ \nu_2 \end{pmatrix}$$

- 2HDM in MSSM
  - Φ_1 couples to down-type quarks and charged leptons
  - Φ_2 couples to up-type quarks
- **Modified couplings to gauge and fermion fields**

$$\text{5 physical states: h, H, A, H}^{\pm}$$

$$\tan\beta = \nu_1/\nu_2$$

$$\begin{pmatrix} h \\ H \end{pmatrix} = \begin{pmatrix} \cos\alpha & \sin\alpha \\ -\sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} \phi_1^0 \\ \phi_2^0 \end{pmatrix}$$

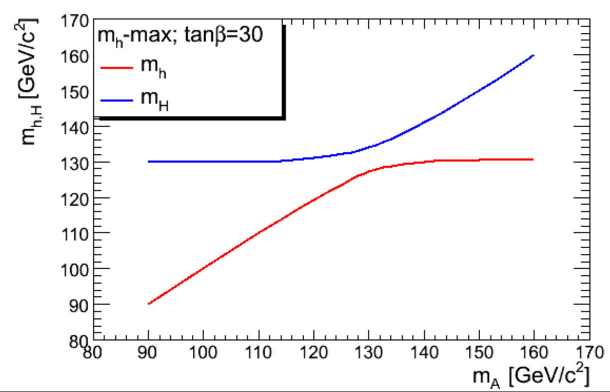
	h	H	A
W^+W^-	$\sin(\beta-\alpha)$	$\cos(\beta-\alpha)$	0
ZZ	$\sin(\beta-\alpha)$	$\cos(\beta-\alpha)$	0
$u\bar{u}$ (up-type quarks)	$\cos\alpha/\sin\beta$	$\sin\alpha/\sin\beta$	$\cot\beta$
$d\bar{d}$ (down-type quarks)	$\sin\alpha/\cos\beta$	$\cos\alpha/\cos\beta$	$\tan\beta$
$\ell\bar{\ell}$ (charged leptons)	$\sin\alpha/\cos\beta$	$\cos\alpha/\cos\beta$	$\tan\beta$

Decoupling limit : large m_A

$m_A \approx m_H \approx m_{H+}$

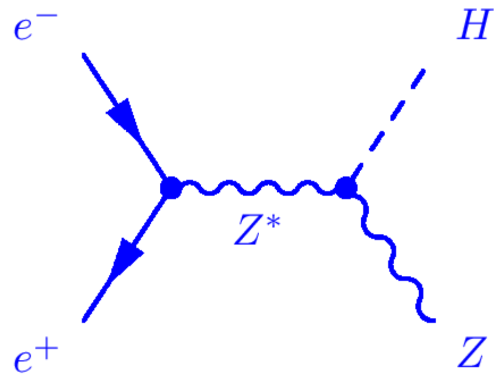
$\cos(\beta-\alpha) \to 0$: H decouples from W, Z

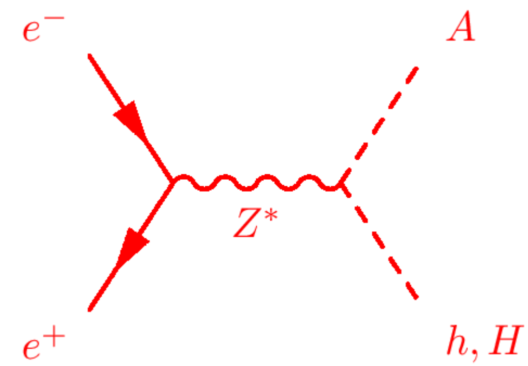
$\sin(\beta-\alpha) \to 1$: h has properties of the SM Higgs



MSSM Higgs Searches at LEP

Higgs-strahlung… **is complemented by Higgs-pair production**





dominates at low *tanβ*

dominates at high *tanβ*

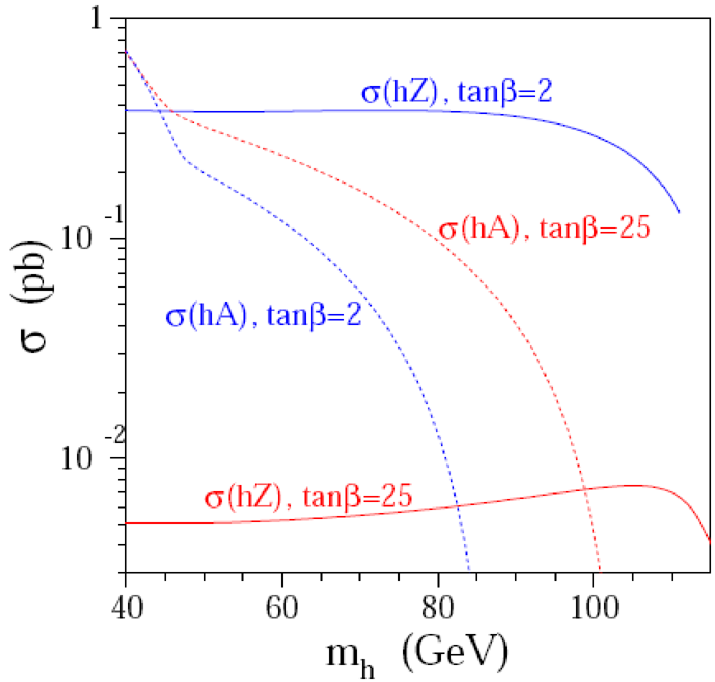
- **Low *tanβ* : SM-like properties of *h*, $e^+e^- \to hZ$ dominates**

→ reuse SM Higgs analyses

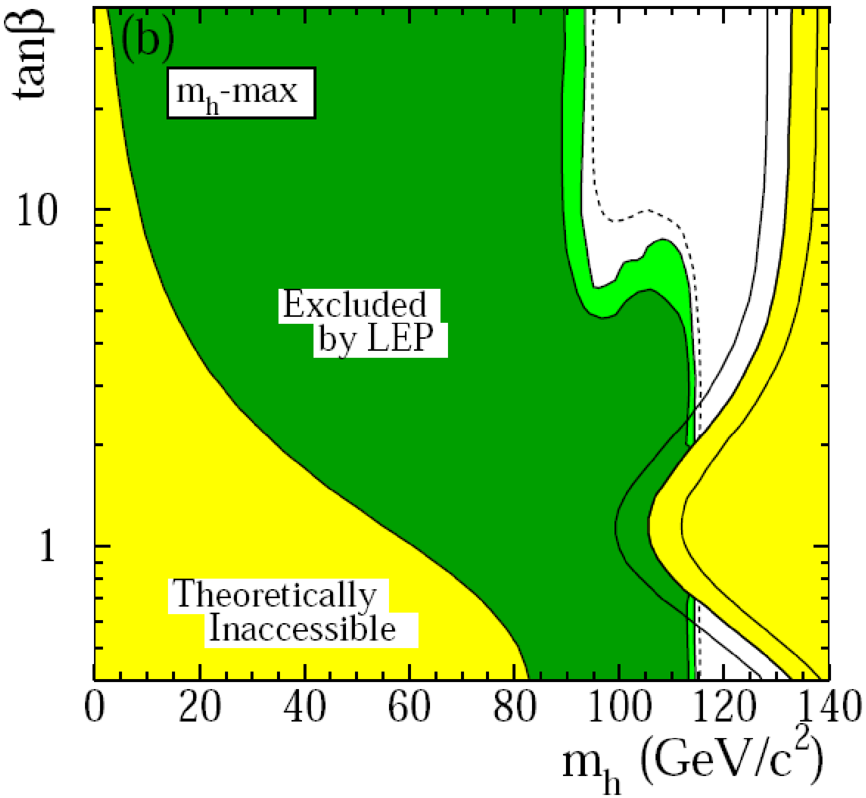
- **High *tanβ* : $e^+e^- \to hA$ dominates**

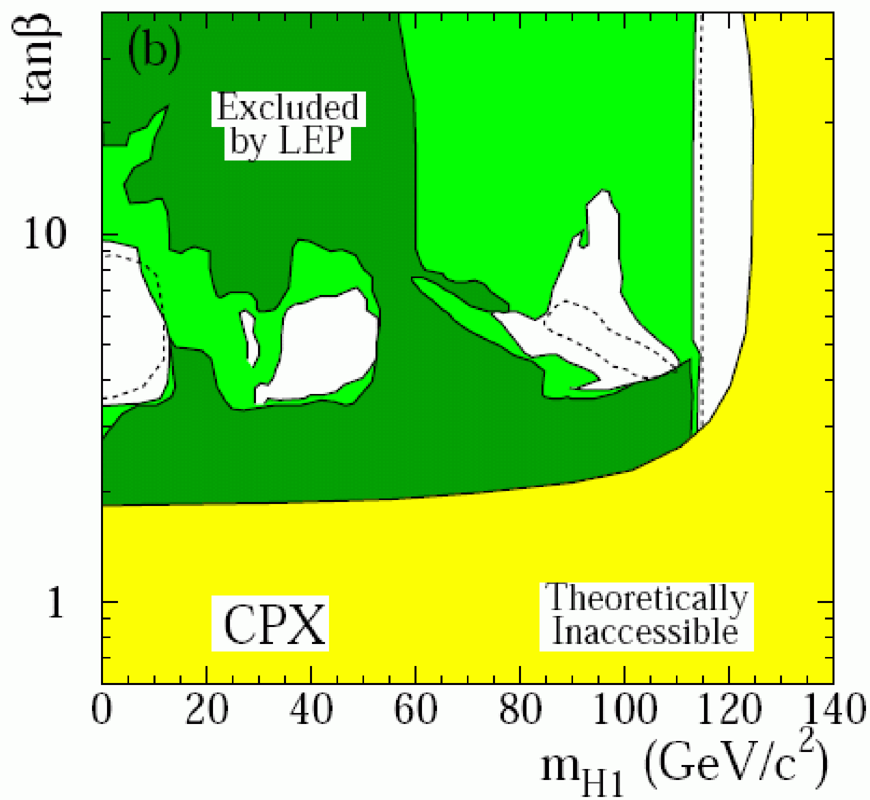
– ***Br(h,A→bb)≈90%, Br(h,A→ττ)≈10%***

→ *dedicated analyses of 4b and bbττ final states*



LEP Limits on MSSM Higgs Bosons





"m_h-max" scenario:

- ***m_A , m_h > 93 GeV @ 95% C.L.***
- ***0.7<tanβ<2.1 excluded @ 95C.L. for m_{top} = 174.3 GeV***

CPX scenarios:

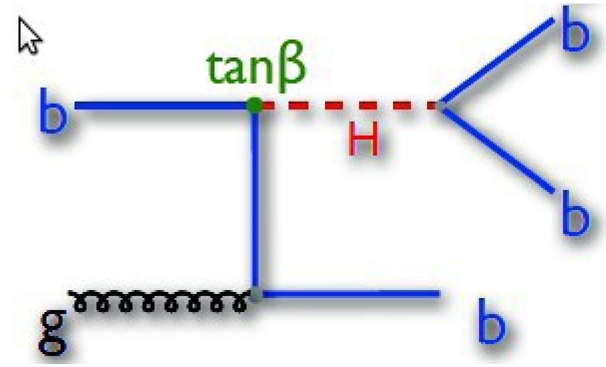
reduced couplings to Z boson
→ reduced production rates
not all complicated final states covered ($H_2H_1 \rightarrow H_1H_1H_1 \rightarrow 6f$)
→ Exclusions are weaker

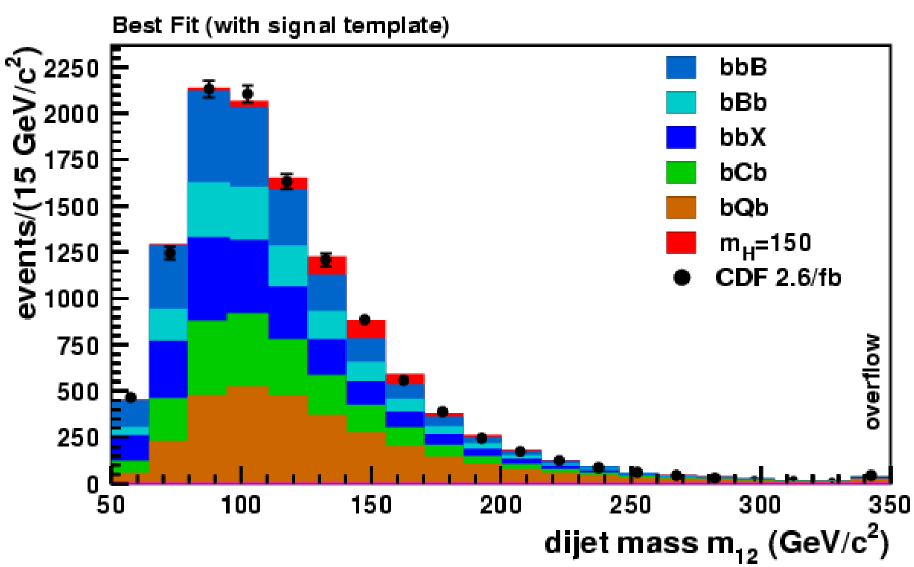
SUSY Higgs at TEVATRON : bΦ→3b Search

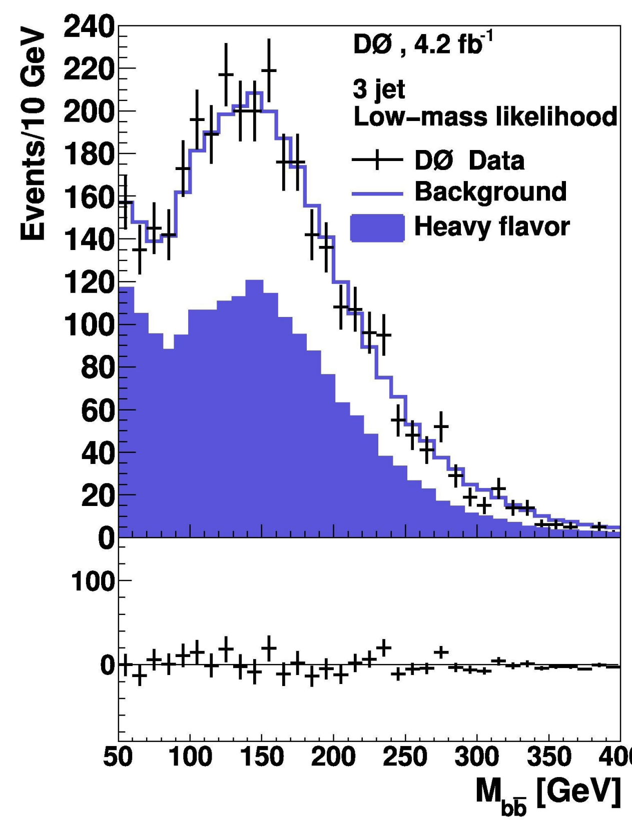
- Challenging final state
- B-tagging essential
- Cannot rely on simulation of multi-jet QCD background

→ Data-driven determination of multi-jet template shapes with different flavor composition

- Fit templates to data → normalizations for different multi-jet backgrounds

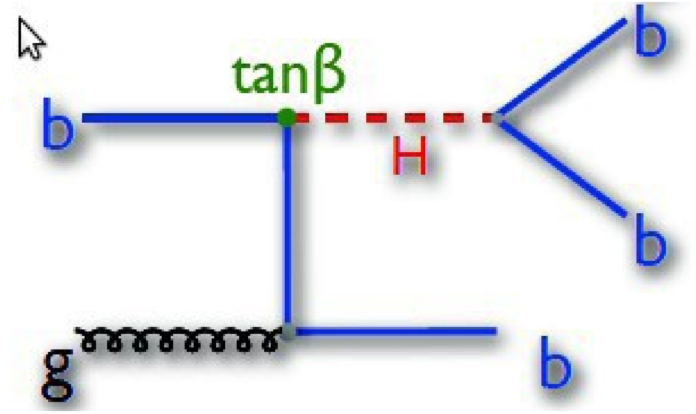


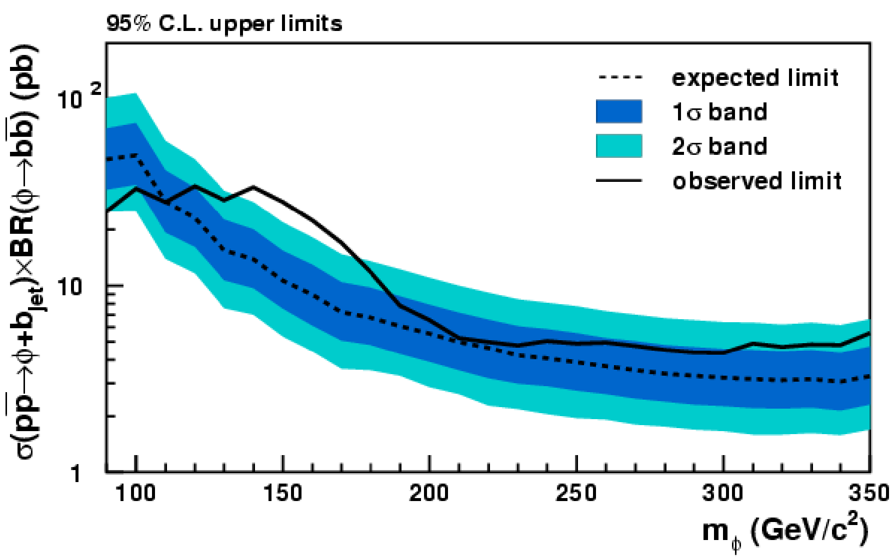


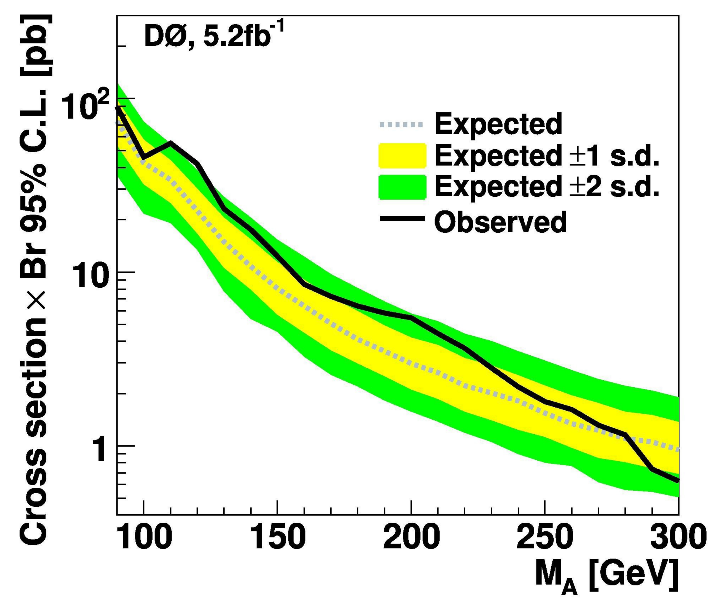


SUSY Higgs at Tevatron : bΦ→3b Search

- **No evidence for signal…**
- **but both experiments see ≈2σ excess over background expectation in the mass range 120 GeV < m_A < 160 GeV**
- **Analyses of larger datasets and combination in progress**
- **motivated LHC experiments to pursue similar searches**







Search for MSSM Higgs bosons at CMS

channels used so far in CMS : $H \to \tau\tau \to e+\mu$, $\mu+\tau_{had}$, $e+\tau_{had}$

$\tau\tau \to \mu\mu$ ($\tau_{had}\tau_{had}$) $H \to \mu\mu$ channels are being analyzed

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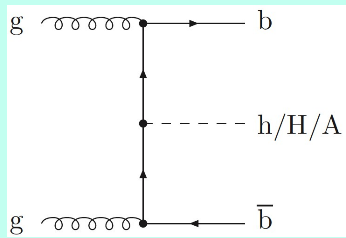
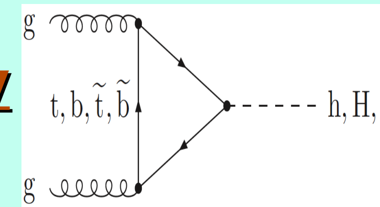
B - category



$\geq$ 1 b-jets with p_T > 20 GeV/c

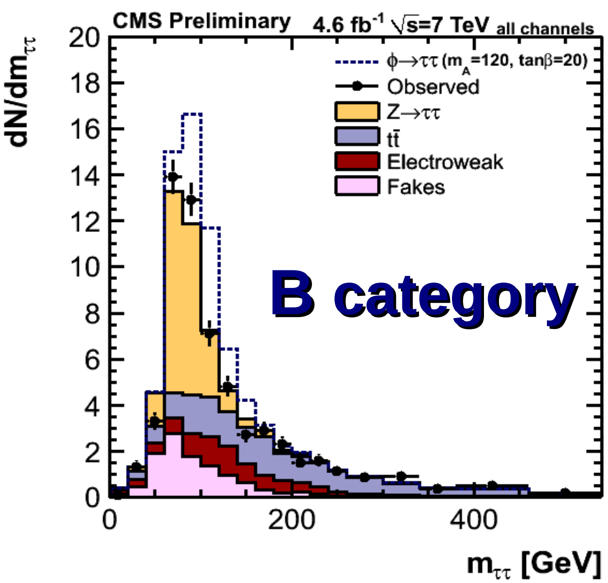
< 2 jets with p_T >30 GeV/c

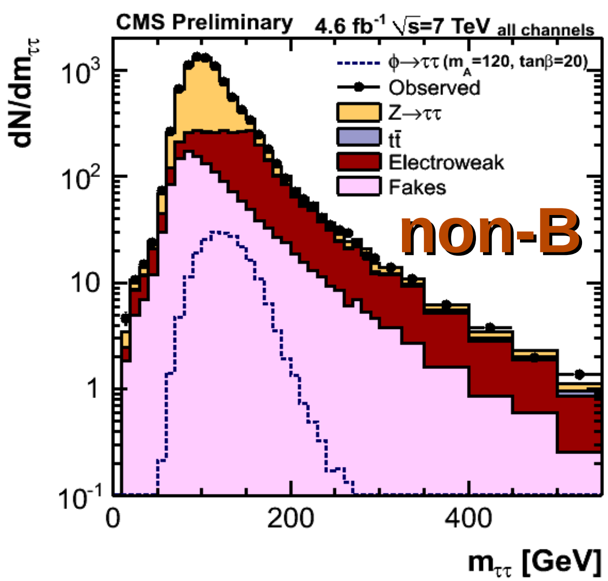
non-B category

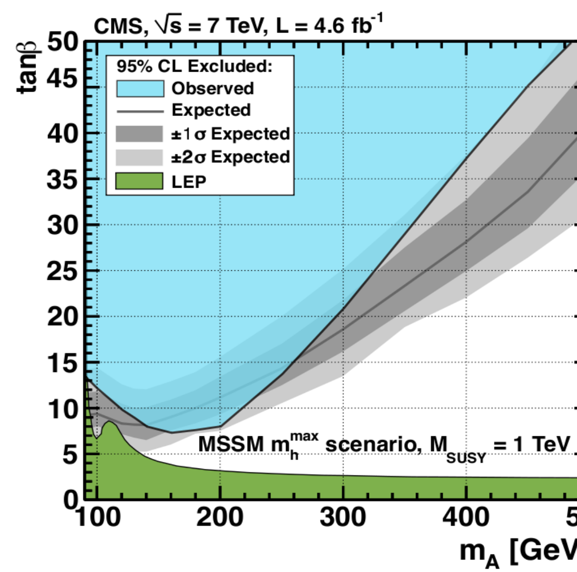


no b-jets with p_T > 20 GeV/c

< 2 jets with p_T > 30 GeV/c



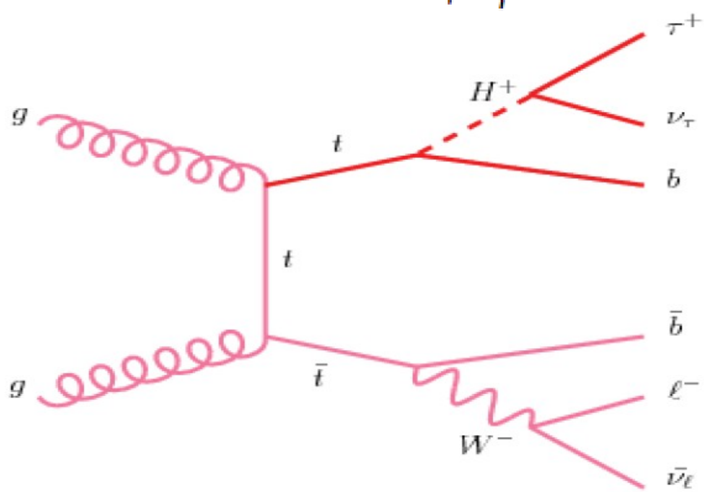


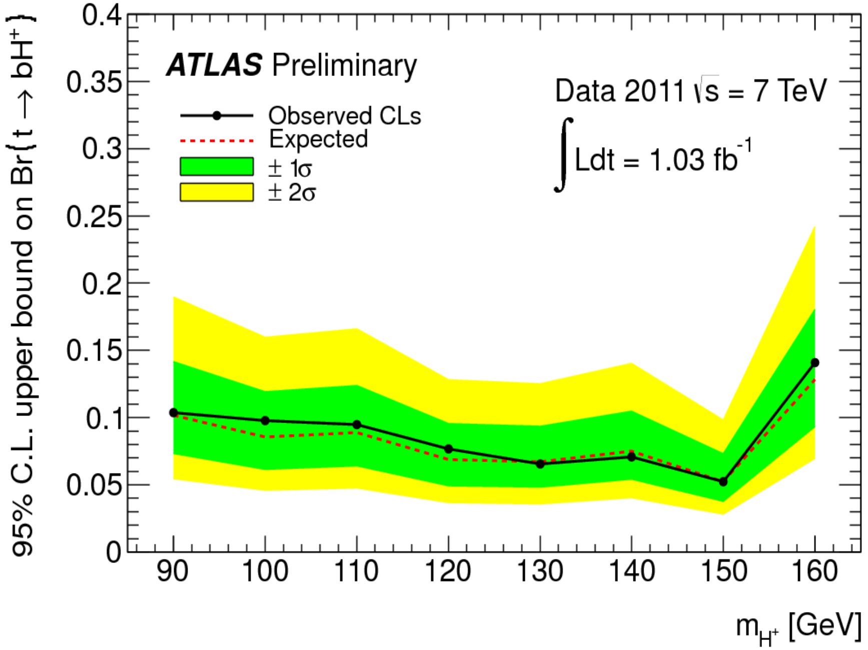


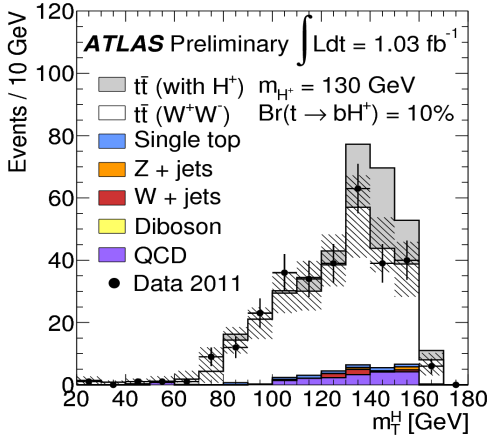
Search for Charged Higgs Bosons at ATLAS

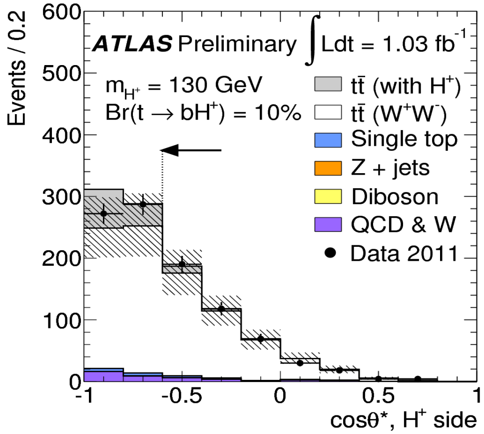
Search for H^+ is pursued in $t\bar{t}$ decays

$t\bar{t} \to H^+ W^- b\bar{b} \to \tau\nu_\tau l\nu_l b\bar{b}$









current Tevatron limit : 0.15 – 0.2