Physics Program

of the experiments at

Large Hadron Collider

Lecture 11

- **Higgs boson**
  - **Properties**
  - **MSSM sector**

    LEP, Tevatron, LHC

***parts based on slides from K. Jakobs, CERN, Academic Training, 2010**

Is it a Higgs Boson?

- can the LHC measure its parameters

- Mass
- Couplings to bosons and fermions
- Spin and CP
- Higgs self couplings

After the discovery of a "Higgs-like" resonance at the LHC one has to measure its parameters and consolidate the evidence for the Higgs boson.

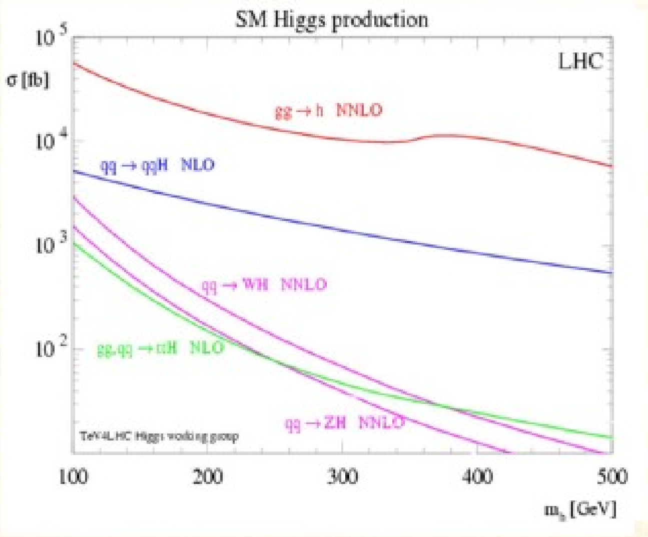
- As many parameters as possible
- Discriminate between: SM like Higgs , MSSM like Higgs composite Higgs,....

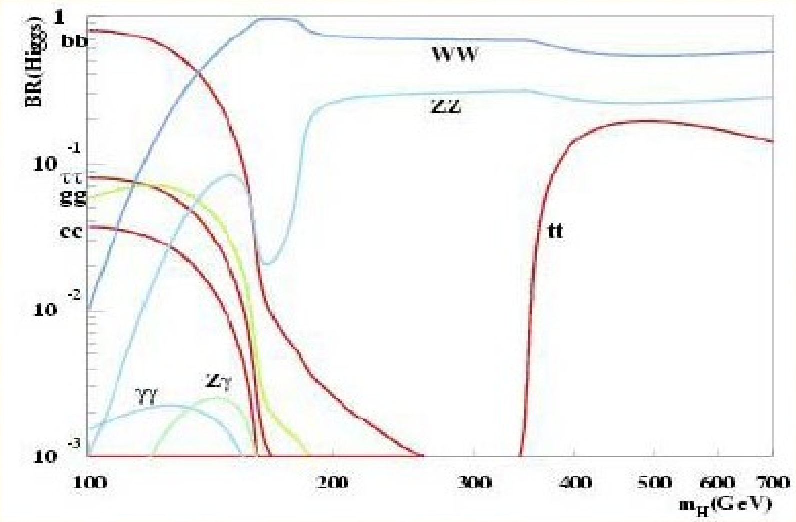
Measurement of the Higgs boson mass

- The mass value itself is important for precision tests of the Standard Model, but moderate precision seems to be adequate; (as compared to the anticipated m_t and m_W uncertainties)

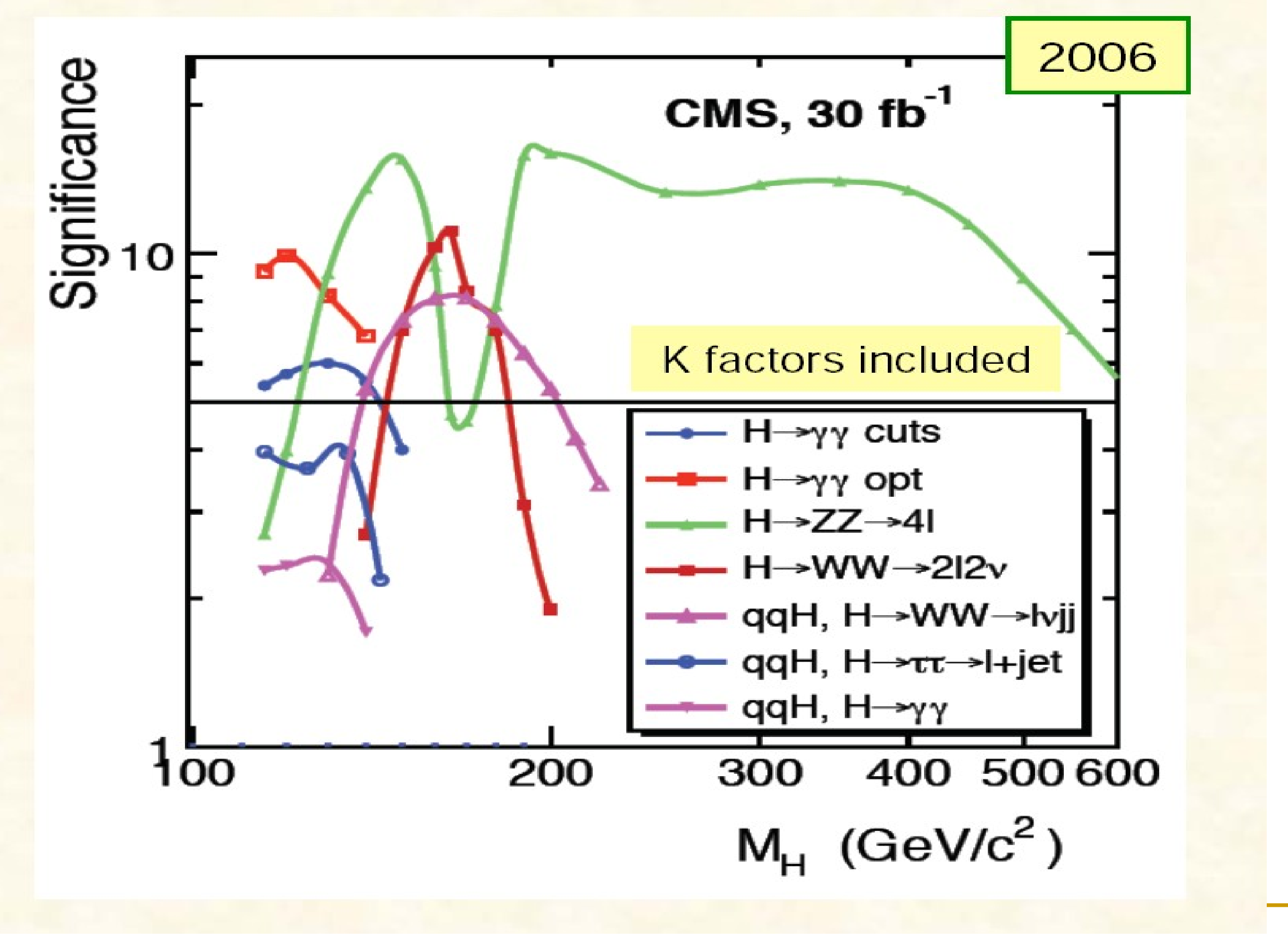
- In addition: the Higgs mass value is important for the parameter measurements (in particular for the extraction of ratios of couplings) …..

  … as many experimental observables / input values need to be compared to the theoretical predictions, which in turn depend -sometimes rather strongly- on m_H

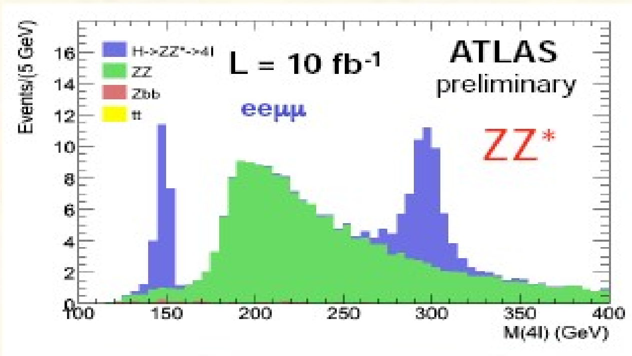


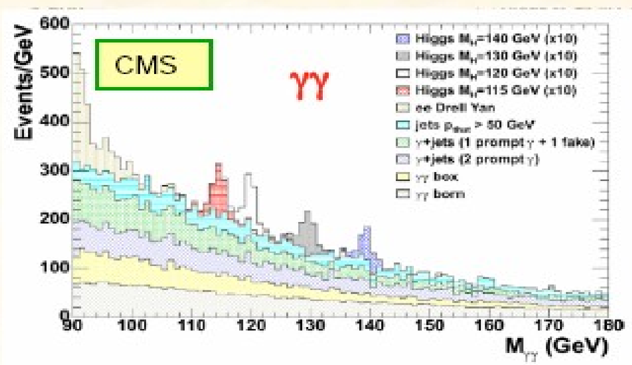


LHC Higgs boson discovery potential

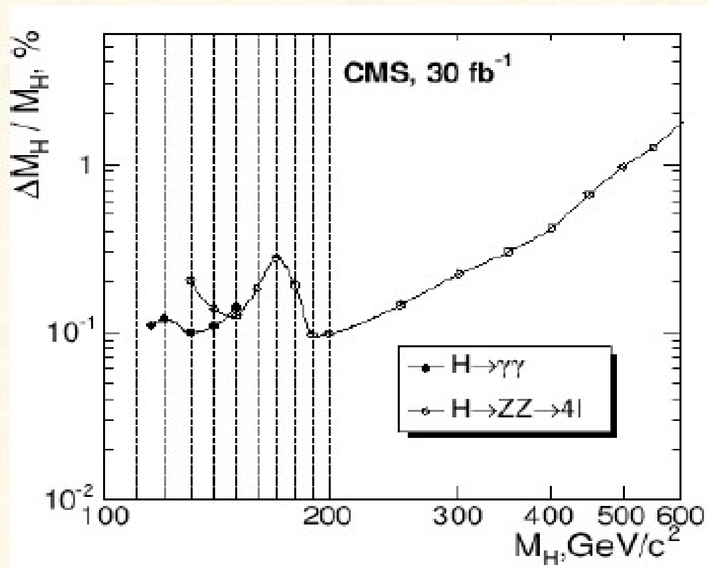


Measurement of the Higgs boson mass





Dominant systematic uncertainty:
γ / ℓ energy scale.
assumed: 1‰ (goal 0.2‰)
Scale from Z → ℓℓ (close to light Higgs)



Precision below 1% can be achieved over a large mass range for 30 fb^{-1};
syst. limit can be reached for higher integrated luminosities → 100 fb^{-1}

Note: no theoretical errors, e.g. mass shift for large Γ_H (interference resonant / non-resonant production) taken into account

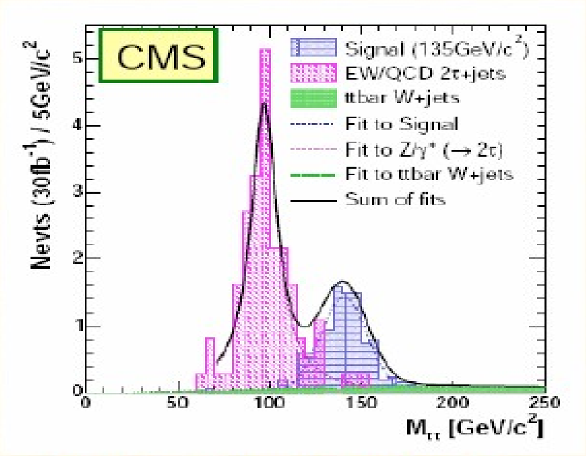
Measurement of the Higgs boson mass

In case of exotic Higgs boson couplings (e.g. suppressed $H \rightarrow WW / ZZ$ couplings) the situation is more difficult
(even the $\gamma\gamma$ decay mode would be affected, since the WW loop contribution is dominant)

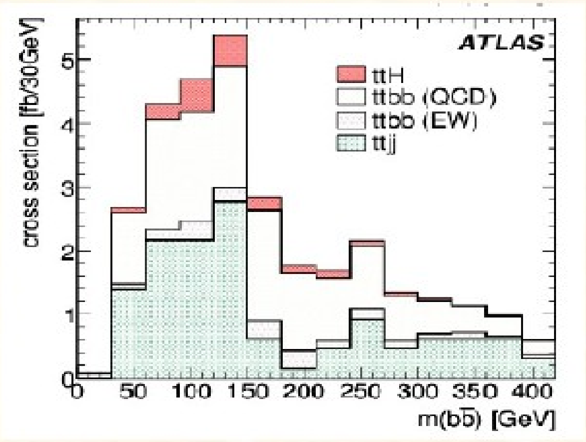
Remaining channels at low mass: $H \rightarrow \tau\tau$
$H \rightarrow bb$

(difficult S:B situation, difficult as a discovery channel; mass value is most likely needed to extract a signal, if background and mass known, it might be useful and add to coupling measurements)

$qq H \rightarrow qq \tau\tau \rightarrow qq \ \ell\nu\nu \ \text{had} \ \nu$



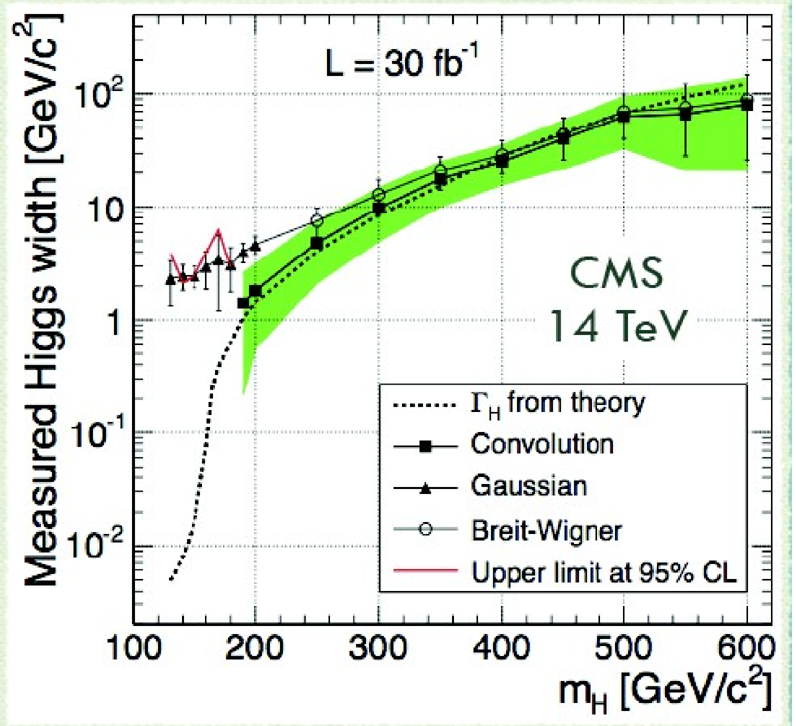
$tt H, \ H \rightarrow bb$



Requires good understanding of
the detector (τ, E_T^{miss}), resolution limited

Direct extraction of the Higgs boson width

- The decay width has strong dependence on the m_H
- For m_H< 200 GeV: no direct measurement
  - Indirect measurement: global maximum likelihood fit to determine the couplings parameters in mas range 110-190GeV (ATLAS studies)
- For m_H> 200 GeV: measured with 35% precision for 30fb-1 (one experiment)

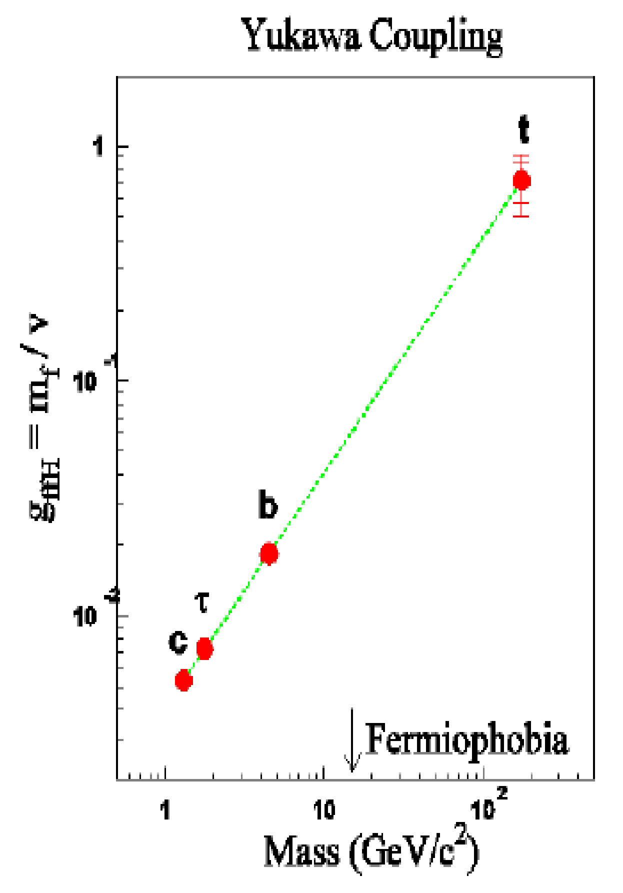


Expected performance in H→ZZ→4l
from: CMS Note 2006/107

Spin, CP , couplings

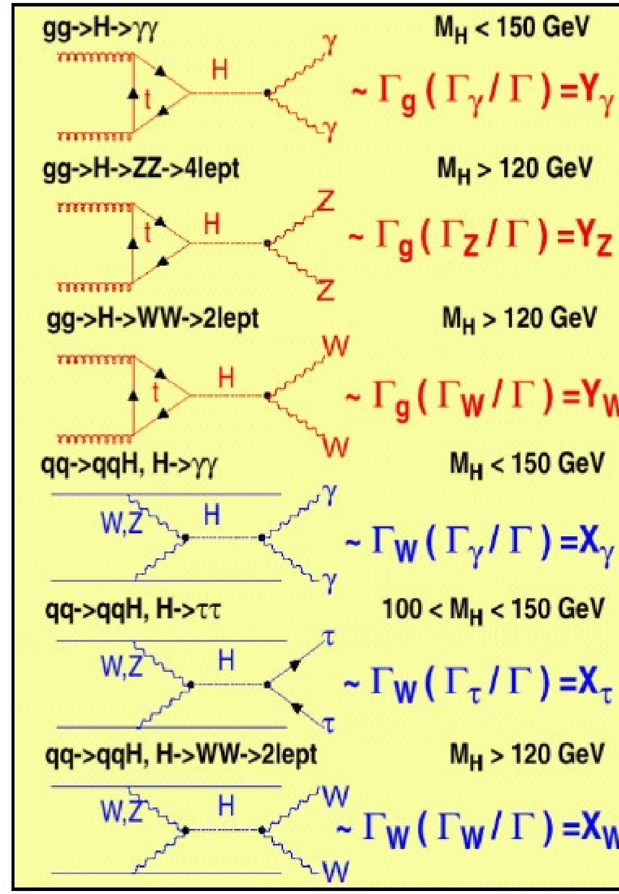
- Spin and CP (and anomalous coupling)
  - "H->γγ" -> spin = 0 or 2
  - H->WW $\Delta\phi_{ll}$ correlation -> spin = 0
  - H->ZZ->4l -> Spin and CP
  - Forward jets of VBF process
- Couplings
  - "Origin of mass" should be confirmed.
  - We expect that Yukawa coupling has a linearity with respect to the particle mass. That is the SM prediction.

  -> top, bottom and tau Yukawa coupling measurement can be done at the LHC.



Higgs boson couplings to fermions and bosons

Production		Decay	mass range
Gluon-Fusion	$(gg \to H)$	$H \to ZZ \to 4l$	110 GeV - 200 GeV
		$H \to WW \to l\nu l\nu$	110 GeV - 200 GeV
		$H \to \gamma\gamma$	110 GeV - 150 GeV
WBF	(qqH)	$H \to ZZ \to 4l$	110 GeV - 200 GeV
		$H \to WW \to l\nu l\nu$	110 GeV - 190 GeV
		$H \to \tau\tau \to l\nu\nu l\nu\nu$	110 GeV - 150 GeV
		$H \to \tau\tau \to l\nu\nu \, \mathrm{had}\nu$	110 GeV - 150 GeV
		$H \to \gamma\gamma$	110 GeV - 150 GeV
$t\bar{t}H$		$H \to WW \to l\nu l\nu (l\nu)$	120 GeV - 200 GeV
		$H \to b\bar{b}$	110 GeV - 140 GeV
		$H \to \gamma\gamma$	110 GeV - 120 GeV
WH		$H \to WW \to l\nu l\nu (l\nu)$	150 GeV - 190 GeV
		$H \to \gamma\gamma$	110 GeV - 120 GeV
ZH		$H \to \gamma\gamma$	110 GeV - 120 GeV



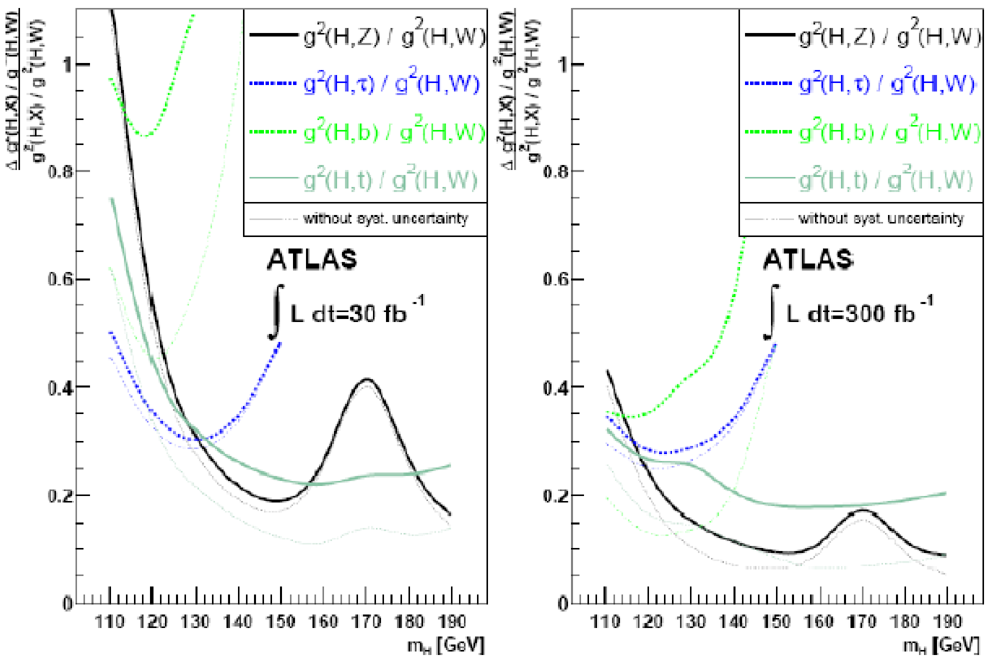
- Measure ratio of couplings
- With more theoretical assumptions measure also absolute values

Ratio of couplings

In the low mass region, we can measure event rates of Higgs with multi modes. So we can extract coupling information, particularly, determination of ratios is possible with a model-independent way.

ATLAS-PHYS-2003-030

Accuracy of measurement of "ratio of coupling constants" wrt $g^2(H,W)$



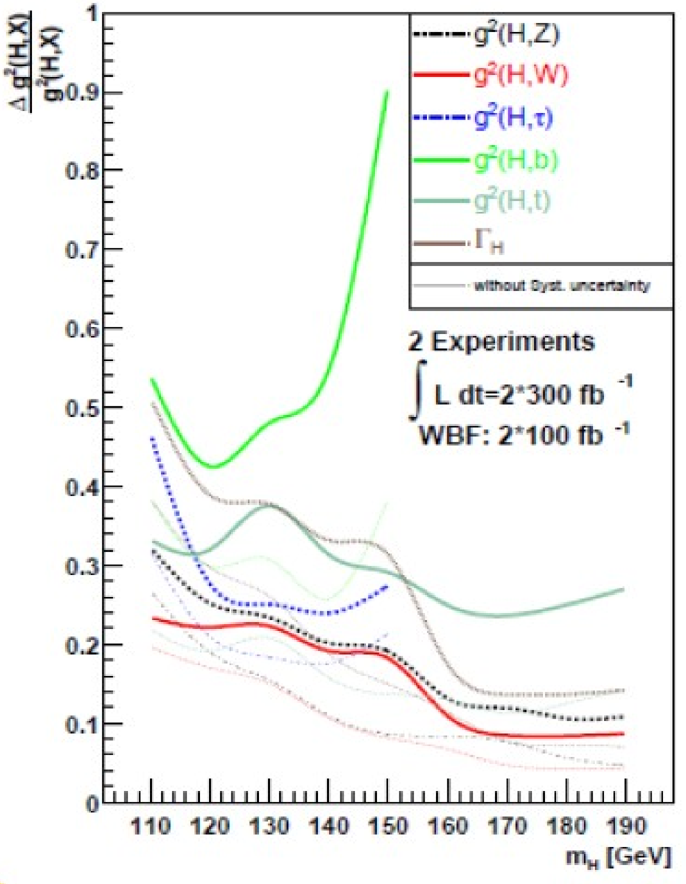
With $300 fb^{-1}$:

- Yukawa
  - g_t^2 : 15-30%
  - g_b^2 : 35-70%
  - g_τ^2 : 25-50%
- Gauge Boson
  - g_z^2 : 10-40%

This is slightly old result. (based on our old results)

Bottom Yukawa can be also measured by using WH/ZH, H->bb (high boosted Higgs). -> new technique, under investigation

Absolute coupling determination



- Need a help of theory to obtain the absolute values of couplings.

Assumption [hep-ph/0407190] :

- HVV (V=W,Z) couplings cannot be larger than the SM case, namely,
  - $g^2(H,W) < g^2_{SM}(H,W)$
  - $g^2(H,Z) < g^2_{SM}(H,Z)$

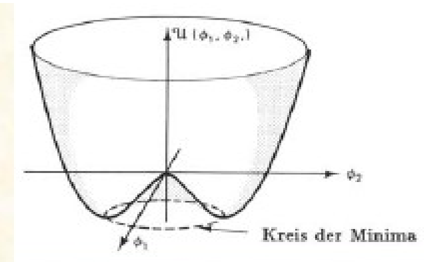
  This constraint is valid in generic multi-Higgs-doublet models. (eg. MSSM)

With $2\mathrm{x}300\mathrm{fb}^{-1}$:
- Yukawa
  - g_t^2 : 25-40%
  - g_b^2 : 45-90%
  - g_τ^2 : 25-50%
- Gauge Boson
  - g_Z^2 : 10-30%
  - g_W^2 : 10-25%
- Total Width : 15-50%

Summary of studies for SM

Production	Decay	Mass region and purpose	
Gluon Fusion	H -> $\gamma\gamma$	110-140GeV	**Discovery**, Mass
	H -> ZZ-> 4l	140-**800** GeV	**Discovery**, Mass, spin, coupling
	H -> WW	130-170 GeV	**Discovery**
Vector Boson Fusion	H -> $\tau\tau$	110-140GeV	**Discovery**, Mass, coupling
	H -> WW	130-200GeV	**Discovery**, W coupling
	H -> $\gamma\gamma$	110-140GeV	**Discovery**, Mass
	H -> bb	110-140GeV	Yb coupling (need study of trigger)
ttH	H -> bb	110-130GeV	Yt, Yb, Yτ, W coupling
	H -> $\tau\tau$	110-130GeV	
	H -> WW	130-180GeV	
WH/ZH	H -> WW	140-170GeV	W coupling
	H -> bb	110-130GeV	Yb coupling

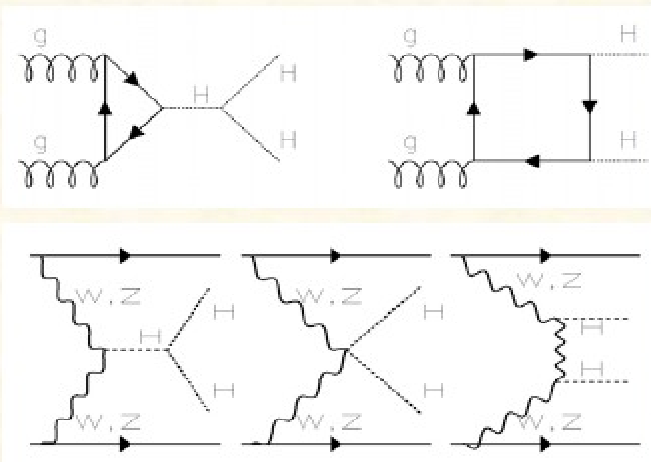
Higgs boson self-coupling

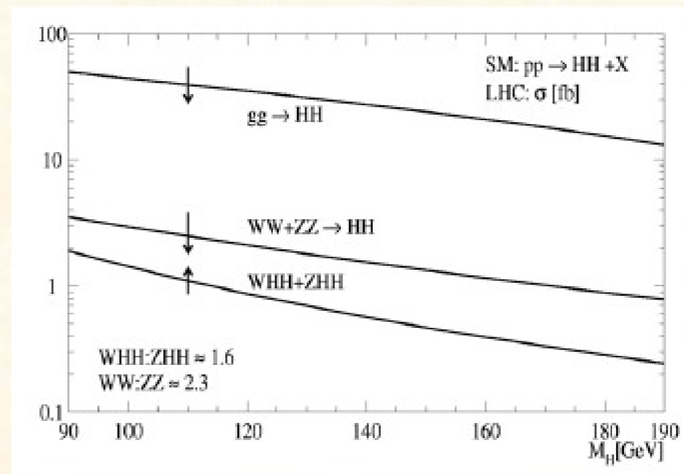


To finally establish the Higgs mechanism the Higgs boson self-coupling has to be measured:

$$\lambda_{HHH}^{SM} = 3\frac{m_H^2}{v}, \quad \lambda_{HHHH}^{SM} = 3\frac{m_H^2}{v^2}$$

Cross sections for HH production:





small signal cross-sections, large backgrounds from tt, WW, WZ, WWW, tttt, Wtt,...

⇒ no significant measurement possible at the LHC
need Super LHC L = 10^{35} cm^{-2} sec^{-1}, 6000 fb^{-1}
even there: a measurement is very difficult, needs more studies.

Summary: is it a Higgs boson?

1. **Mass**

   Higgs boson mass can be measured with high precision < 1% over a large mass range (130 - ~450 GeV) using $\gamma\gamma$ and $ZZ \to 4\ell$ resonances

2. **Couplings to bosons and fermions**

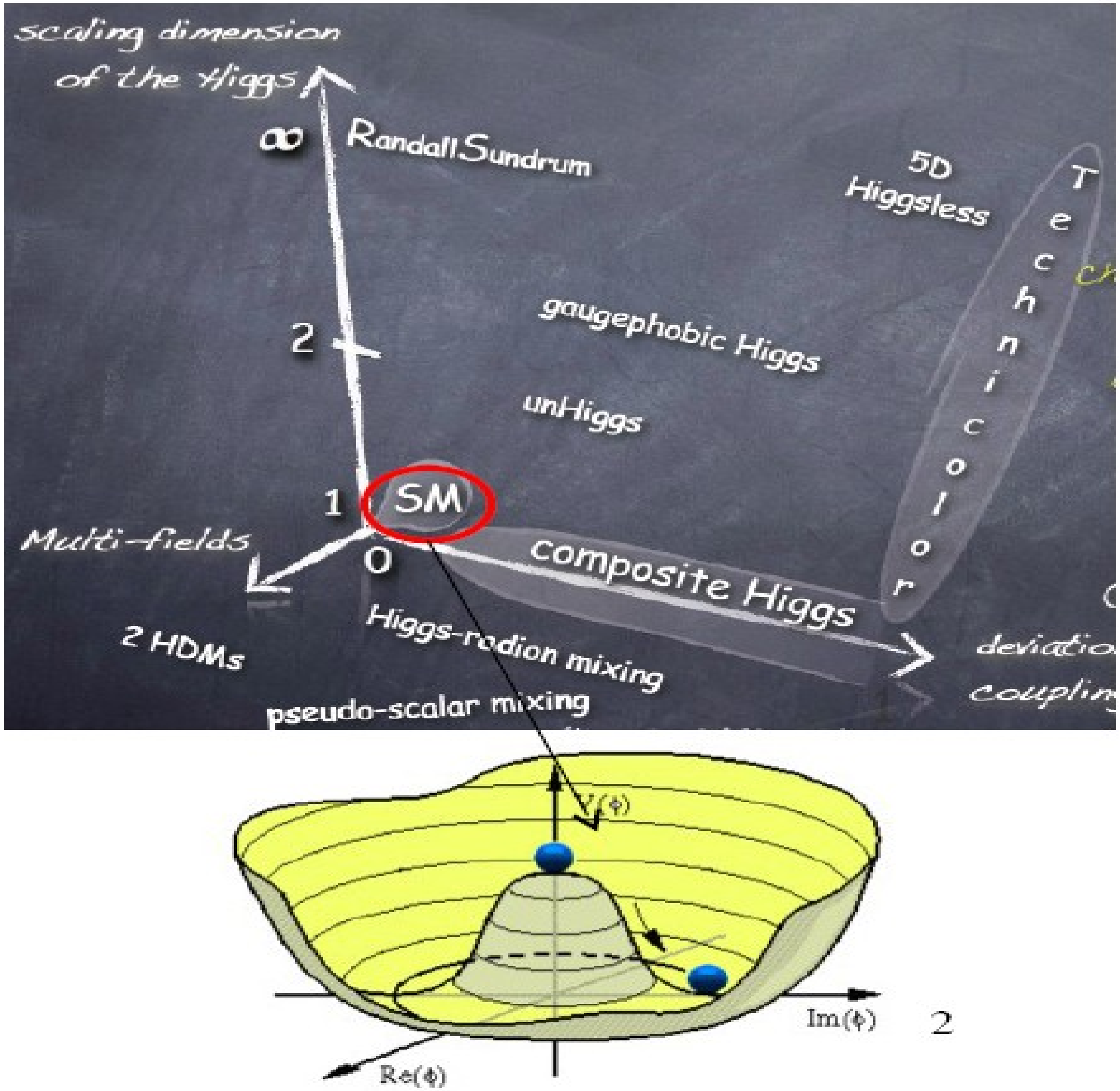
   - Ratios of major couplings can be measured with reasonable precision;
   - Absolute coupling measurements need further theory assumptions

3. **Spin and CP**

   Angular correlations in $H \to ZZ(^*) \to 4\ \ell$ and $\Delta\phi_{jj}$ in VBF events are sensitive to spin and CP (achievable precision is statistics limited, requires high luminosity)

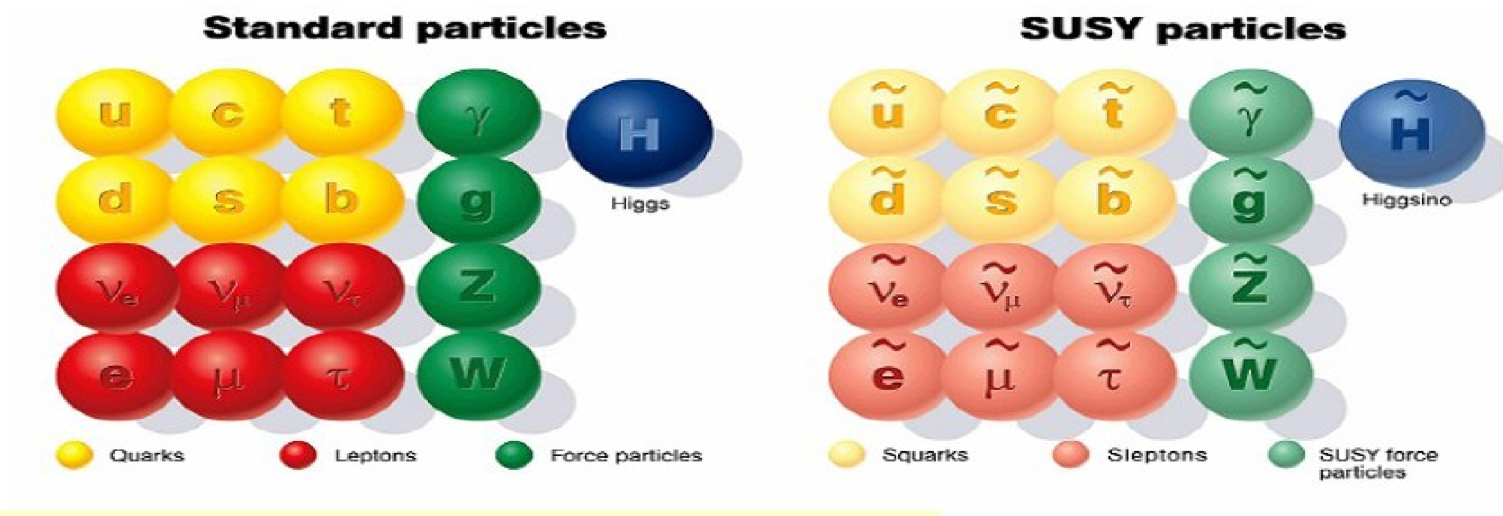
4. **Higgs self coupling**

   No measurement possible at the LHC;
   Very difficult at the sLHC, there might be sensitivity in $HH \to WW\ WW$ for $m_H \sim 160$ GeV

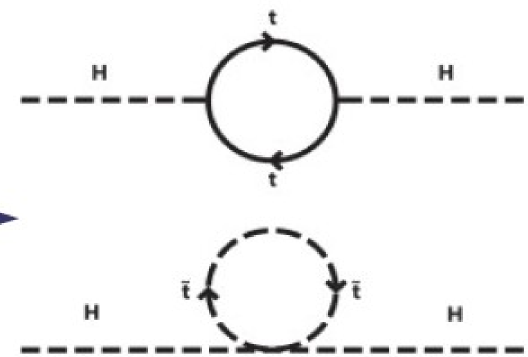


- Alternative models

Supersymmetry



- One of the most popular solutions for those open questions in the SM is the Supersymmetry (SUSY).
- In SUSY, every elementary particle has a super-partner differs by ½ spin.
- This provides a natural solution for the Hierarchy problem of the SM.
- The minimal extension of the SM is called Minimal Supersymmetric Standard Model (MSSM)



Minimal Supersymmetric Standard Model

Superpartners for Standard Model particles

$$\left[u, d, c, s, t, b\right]_{L,R} \quad \left[e, \mu, \tau\right]_{L,R} \quad \left[\nu_{e,\mu,\tau}\right]_L \qquad \text{Spin } \tfrac{1}{2}$$

$$\left[\tilde{u}, \tilde{d}, \tilde{c}, \tilde{s}, \tilde{t}, \tilde{b}\right]_{L,R} \quad \left[\tilde{e}, \tilde{\mu}, \tilde{\tau}\right]_{L,R} \quad \left[\tilde{\nu}_{e,\mu,\tau}\right]_L \qquad \text{Spin } 0$$

$$g \quad \underbrace{W^{\pm}, H^{\pm}} \quad \underbrace{\gamma, Z, H_1^0, H_2^0} \qquad \text{Spin 1 / Spin 0}$$

$$\tilde{g} \quad \tilde{\chi}^{\pm}_{1,2} \quad \tilde{\chi}^{0}_{1,2,3,4} \qquad \text{Spin } \frac{1}{2}$$

Enlarged Higgs sector: Two Higgs doublets

Problem in the MSSM: many scales

MSSM: Higgs sector

Enlarged Higgs sector: Two Higgs doublets

$$H_1 = \begin{pmatrix} H_1^1 \\ H_1^2 \end{pmatrix} = \begin{pmatrix} v_1 + (\phi_1 + i\chi_1)/\sqrt{2} \\ \phi_1^- \end{pmatrix}$$

$$H_2 = \begin{pmatrix} H_2^1 \\ H_2^2 \end{pmatrix} = \begin{pmatrix} \phi_2^+ \\ v_2 + (\phi_2 + i\chi_2)/\sqrt{2} \end{pmatrix}$$

$$V = m_1^2 H_1 \bar{H}_1 + m_2^2 H_2 \bar{H}_2 - m_{12}^2 (\epsilon_{ab} H_1^a H_2^b + \text{h.c.})$$

$$+ \underbrace{\frac{g'^2 + g^2}{8}} (H_1 \bar{H}_1 - H_2 \bar{H}_2)^2 + \underbrace{\frac{g^2}{2}} |H_1 \bar{H}_2|^2$$

gauge couplings, in contrast to SM

physical states: $h^0, H^0, A^0, H^\pm$

Goldstone bosons: $G^0, G^\pm$

Input parameters: (to be determined experimentally)

$$\tan\beta = \frac{v_2}{v_1}, \qquad M_A^2 = -m_{12}^2 (\tan\beta + \cot\beta)$$

Neutral Higgses within MSSM

- **At tree level, Higgs sector is described by tanβ and M_A.**
- **Higher order corrections introduce dependency on additional SUSY parameters.**

Five additional, relevant parameters:

M_{SUSY} Common Scalar mass
X_t Mixing Parameter
M_2 SU(2) gaugino mass term
μ Higgs mass parameter
m_g gluino mass

$$m^2_{H,h} = \frac{1}{2}\left(m_A^2 + m_Z^2 \pm \sqrt{(m_A^2+m_Z^2)^2 - 4m_Z^2 m_A^2 \cos^2 2\beta}\right)$$

$$m_h^2 \leq m_Z^2 \cos^2 2\beta \leq m_Z^2$$

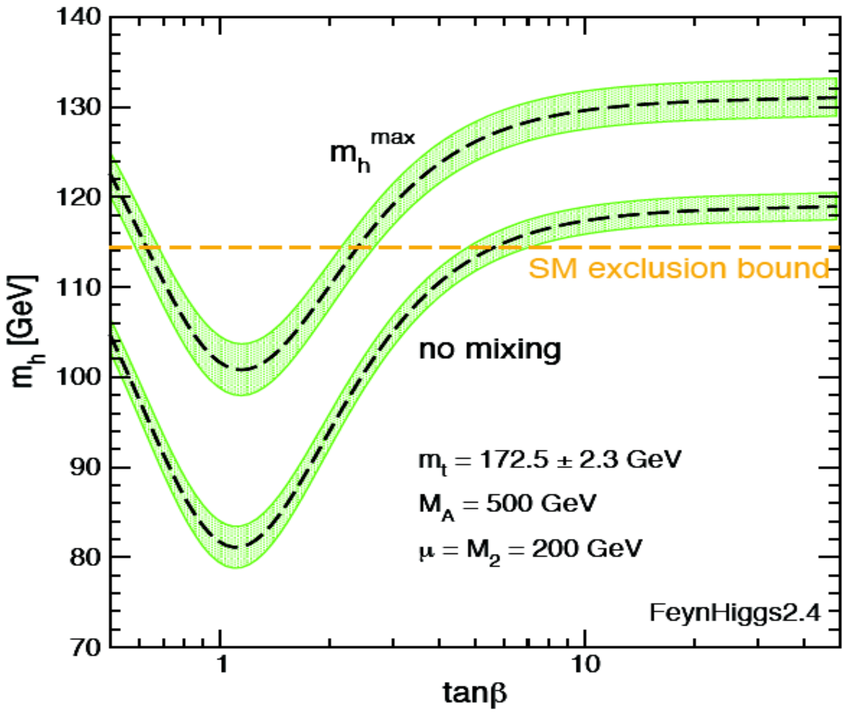
$$m_h^2 \leq m_Z^2 + \frac{3g^2 m_t^4}{8\pi^2 m_W^2}\left[\ln\left(\frac{M_S^2}{m_t^2}\right) + x_t^2\left(1 - \frac{x_t^2}{12}\right)\right]$$

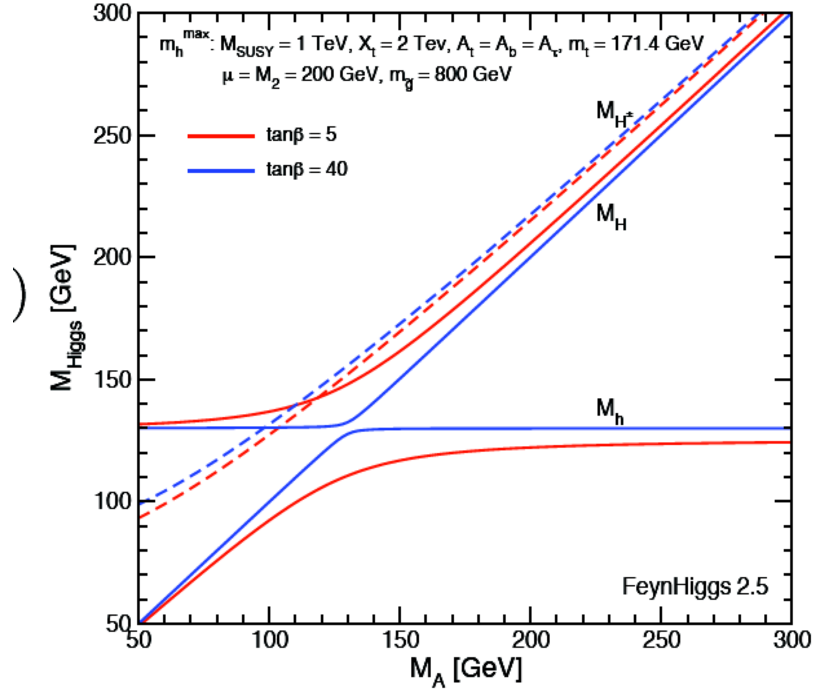
where: $M_S^2 = \frac{1}{2}\left(M_{\tilde{t}_1}^2 + M_{\tilde{t}_2}^2\right)$ and $x_t = (A_t - \mu \cot\beta) \,/\, M_S$

→ upper mass bound depends on top mass and mixing in the stop sector

MSSM Higgs mass

S. Heinemeyer, http://www.ifca.es/users/heinemey/uni/plots/





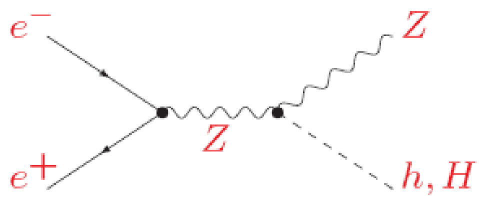
- Benchmark scenario (m_h^{max} scenario most popular)

Scenario	M_{SUSY} (GeV)	X_t^{OS} (GeV)	μ (GeV)	M_2 (GeV)	$M_{\tilde g}$ (GeV)	Upper bound on m_h (GeV)
m_h^{max}	1000	2000	200	200	800	133
no mixing	2000	0	200	200	800	116
gluophobic	350	-750	300	300	500	119
small •e•	800	-1100	2000	500	500	123

M. Carena et al., E.P.J. **C26** (2003) 601-607

Search for neutral MSSM Higgs boson at LEP

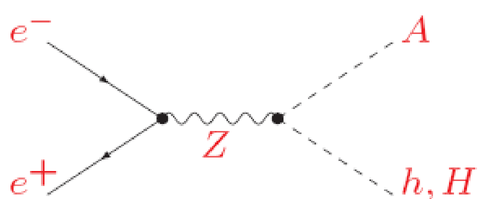
$e^+e^- \to Zh, ZH$



$$\sigma_{hZ} \approx \sin^2(\beta - \alpha_{\text{eff}})\sigma_{hZ}^{\text{SM}}$$

$$\sigma_{HZ} \approx \cos^2(\beta - \alpha_{\text{eff}})\sigma_{hZ}^{\text{SM}}$$

$e^+e^- \to Ah, AH$



$$\sigma_{hA} \propto \cos^2(\beta - \alpha_{\text{eff}})\sigma_{hZ}^{\text{SM}}$$

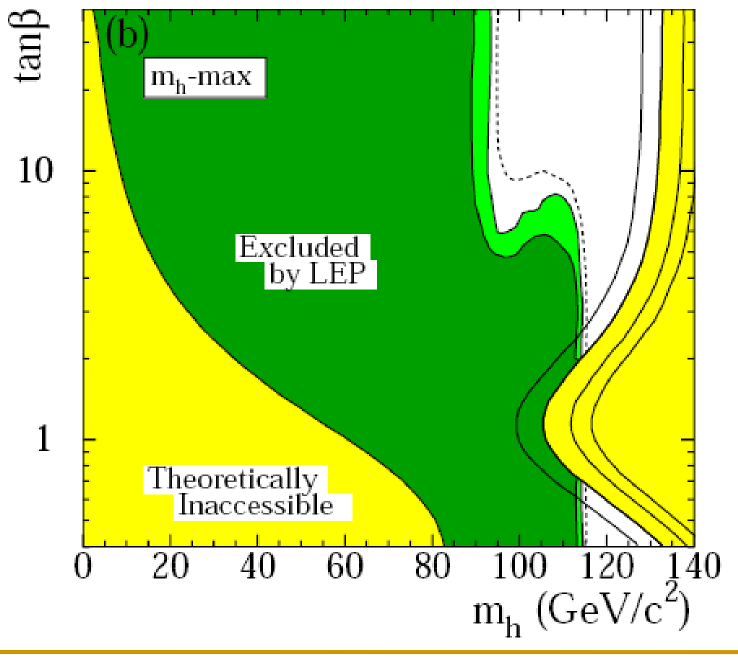
$$\sigma_{HA} \propto \sin^2(\beta - \alpha_{\text{eff}})\sigma_{hZ}^{\text{SM}}$$

Search for neutral MSSM Higgs boson at LEP

Constraints from the Higgs search at LEP [LEP Higgs Working Group '06]

Experimental search vs. upper M_h-bound (*FeynHiggs* 2.0)

$m_h^{\max}$-scenario ($m_t = 174.3$ GeV, $M_{\mathrm{SUSY}} = 1$ TeV):

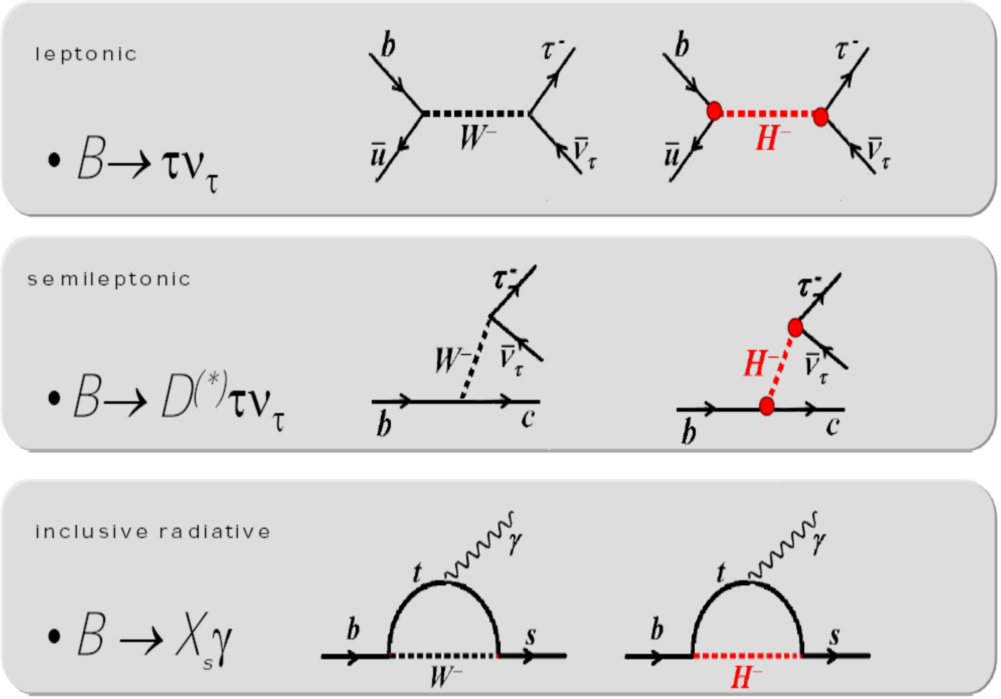


$m_h > 92.8$ GeV
(expected: 94.9 GeV), 95% C.L.

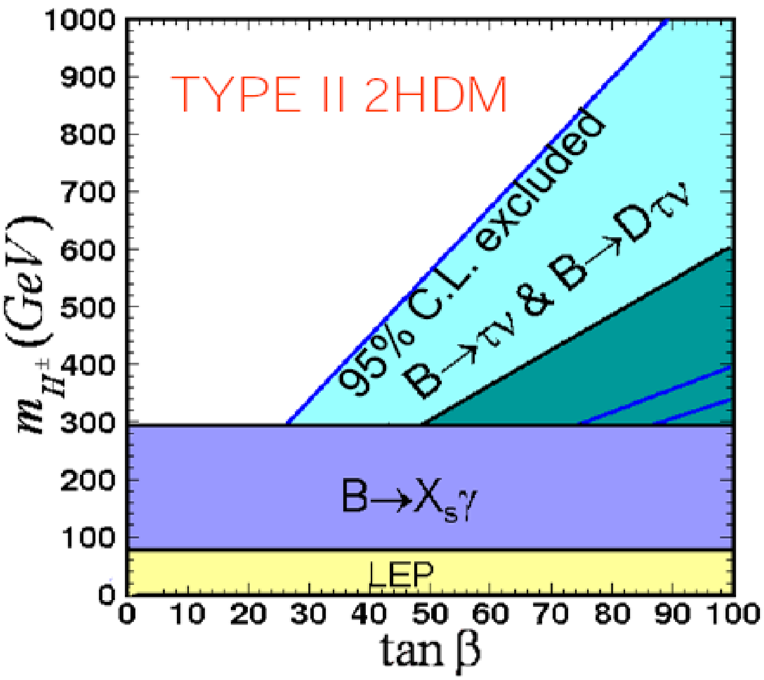
$M_A > 93.4$ GeV
(expected: 95.2 GeV)

Charged Higgs in B decays

- Look for sensitive and theoretically clean modes



- Results from B-factories: Babar, Belle



MSSM Higgs boson searches at Tevatron and LHC

Important channels in the MSSM Higgs boson search:

1. The Standard Model decay channels
   - $h \rightarrow \gamma\gamma$
   - $qq\,h,\ h \rightarrow \tau\tau$

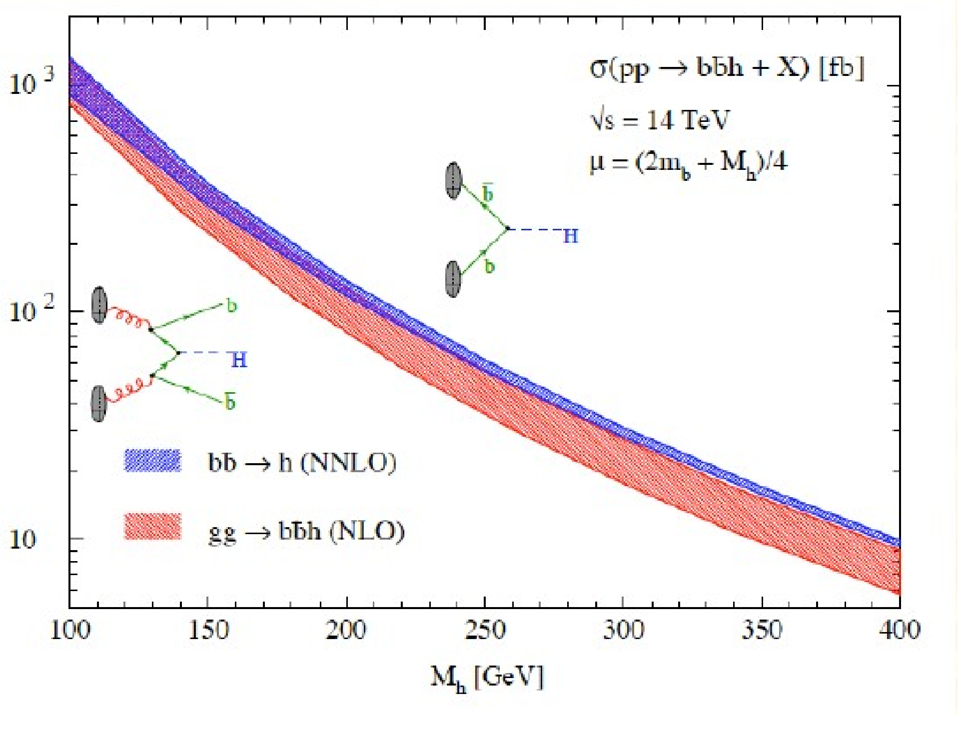
   evaluation of performance is based on SM results

2. Modes strongly enhanced at large tan β:
   - $H/A \rightarrow \tau^+\tau^-$ $\quad H^+ \rightarrow \tau\nu$
   - $H/A \rightarrow \mu^+\mu^-$

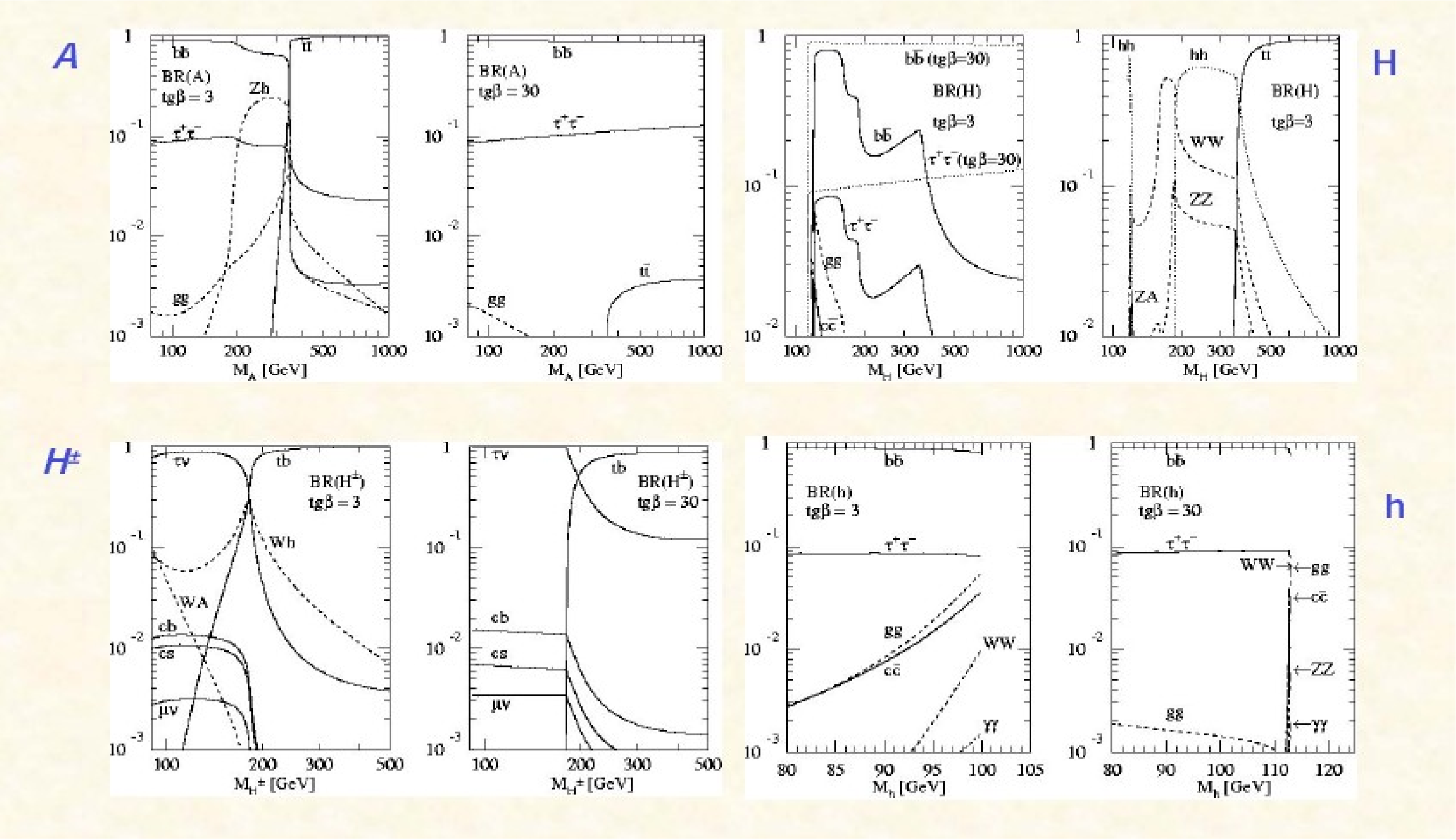
3. Other interesting channels:
   - $H/A \rightarrow Zh \rightarrow \ell\ell\,\gamma\gamma$
     $\rightarrow \ell\ell\,bb$
   - $H \rightarrow hh$

Production of MSSM Higgs bosons

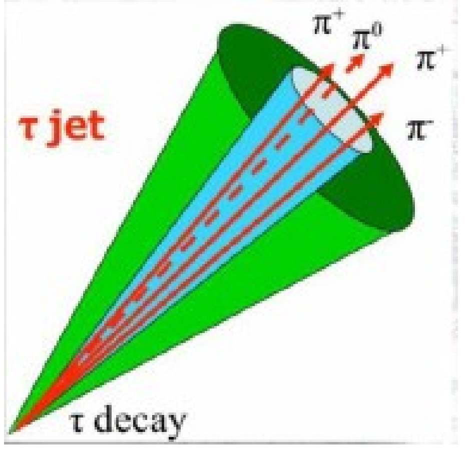
- Agreement between the four and five flavour scheme calculations



Branching ratios of MSSM Higgs bosons



Hadronic tau (τ_{had}) identification



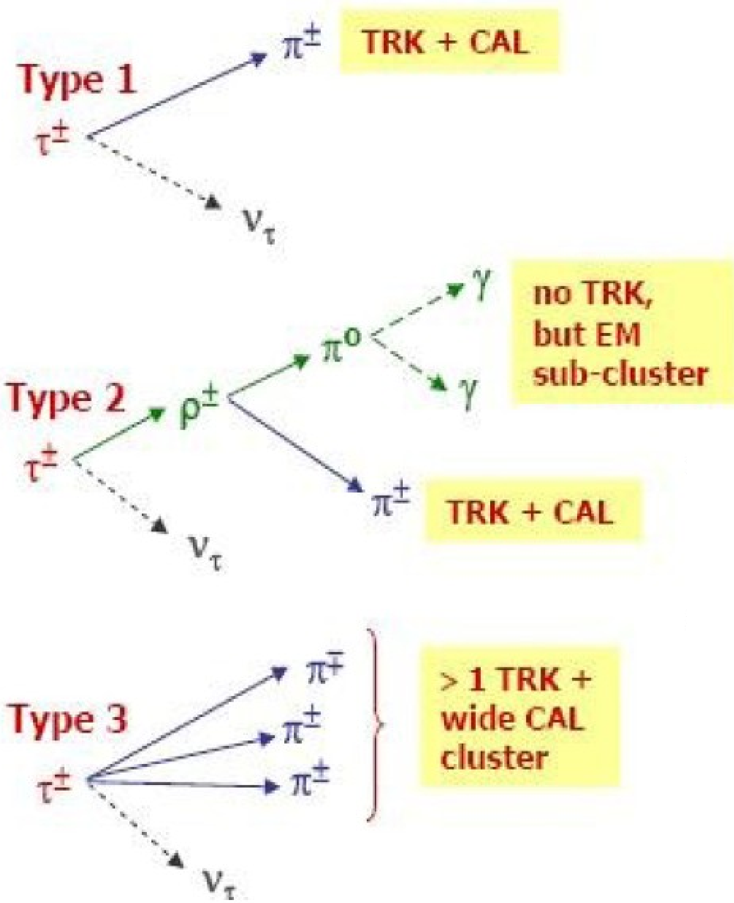
- τ lepton properties:
  - Mass: 1.78 GeV ; Short lifetime: $O(10^{-13}s)$
  - Decay prior to reaching any detector component.
- Main decay channels:

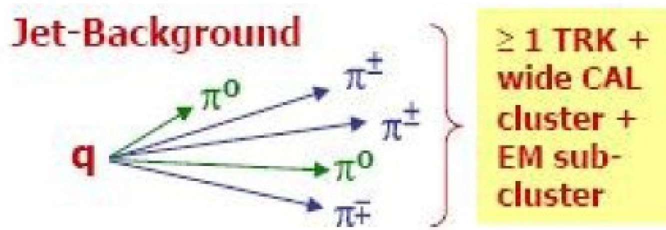
Decay products	BR (%)	Decay Type	
$e + \upsilon_e + \upsilon_\tau$	17.8	Leptonic (35.2%)	e
$\mu + \upsilon_\mu + \upsilon_\tau$	17.4		μ
$\pi^{\pm}(/K)+\upsilon_\tau$	11.8	1-prong (48.7%)	τ_h
$\pi^{\pm}(/K)+\geq 1\pi^0+\upsilon_\tau$	36.9		
$\pi^{\pm}\pi^{\pm}\pi^{\pm}+\geq 0\pi^0+\upsilon_\tau$	13.9	3-prong	

Detect using standard e/μ ID algorithms

Need dedicated tau ID to measure narrow , low multiplicity jet object

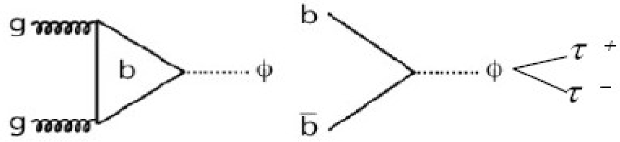
Hadronic tau identification

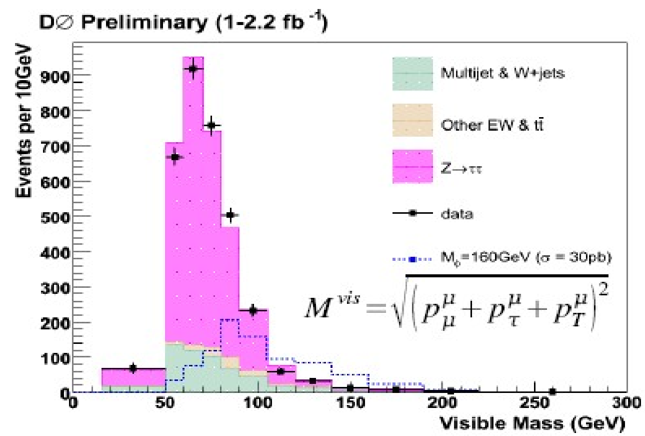




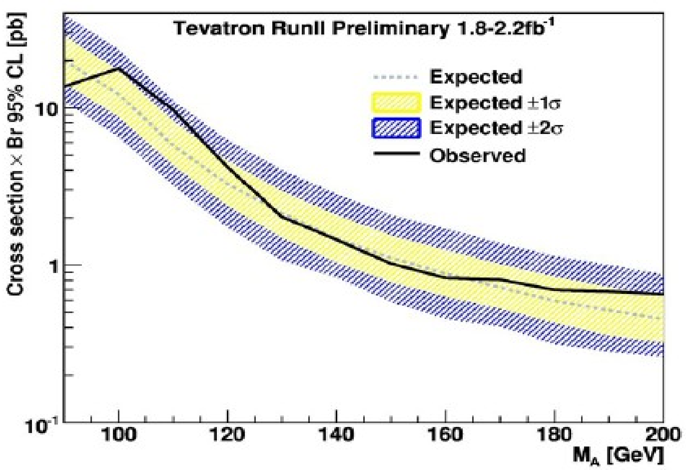
- Identification usually optimised for each type of tau's.
- Using multi-variate techniques (LL,NN,BDT) usually gives significant improvement

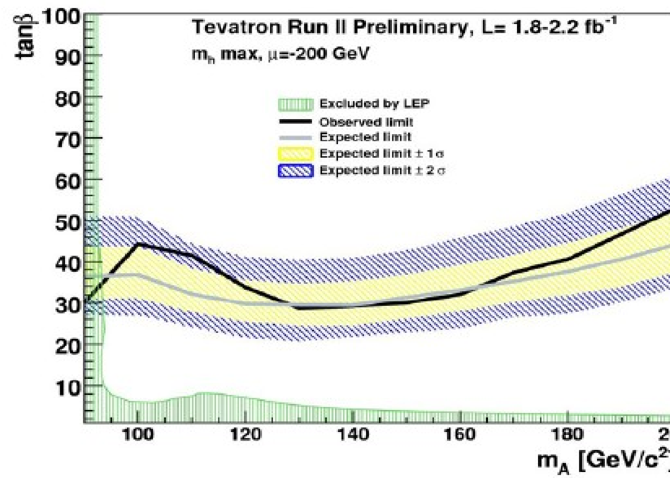
Inclusive Φ → ττ (Φ=h/H/A)



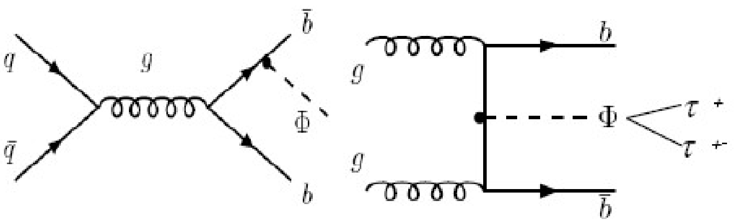


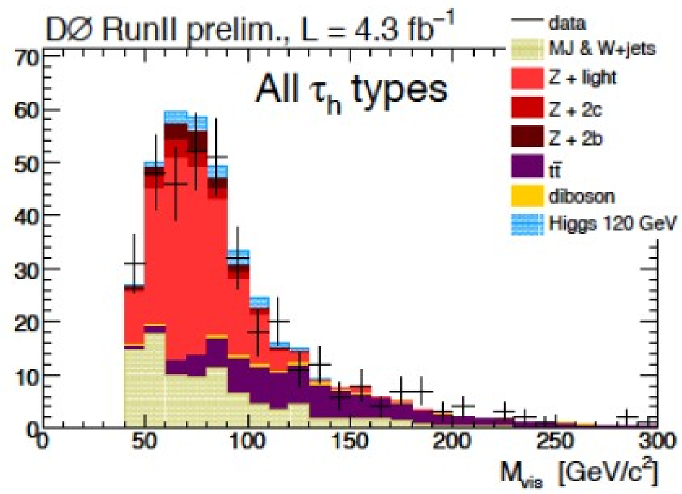
- Low BR ~10% but clean signature.
- Require ≥1 leptonic tau decays: $\tau_\mu \tau_{had}$, $\tau_e \tau_{had}$, $\tau_e \tau_\mu$ ..
- Main backgrounds: $Z \to \tau^+\tau^-$, W+jets, QCD multijets.



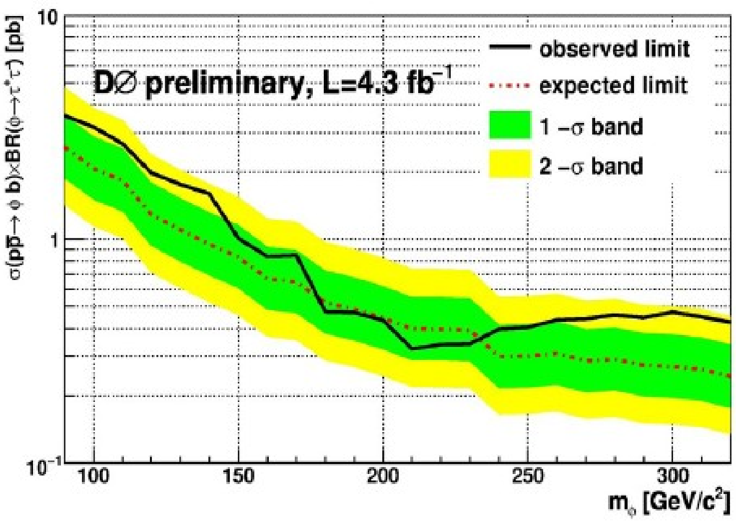


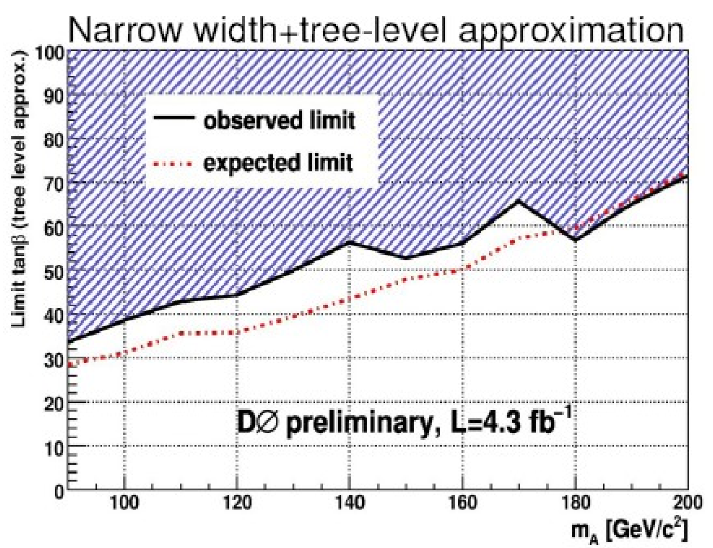
b(b) $\Phi \rightarrow$ b(b)$\tau\tau$



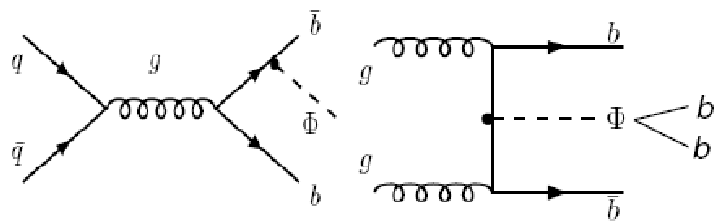


- Similar selection to inclusive $\Phi^0 \rightarrow \tau^+\tau^-$ search, requiring in addition ≥1 b-tagged jet.
  ➔ reduced impact of Z+jets background. Higher sensitivity down to lower mass.
  ➔ multivariate discriminant against ttbar, QCD multijets and Z+jets.



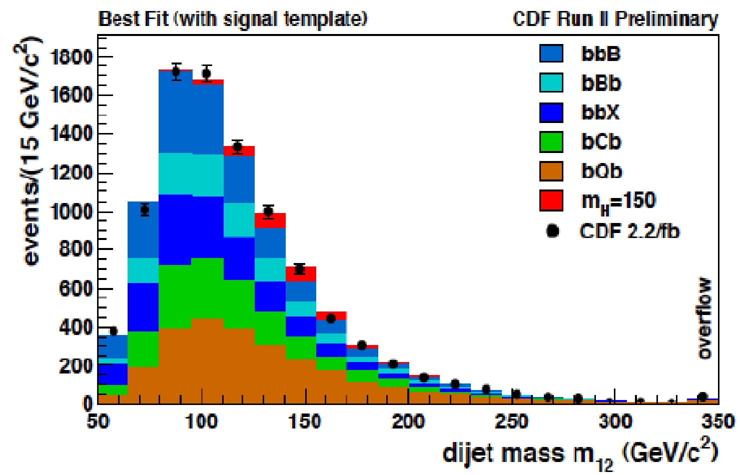


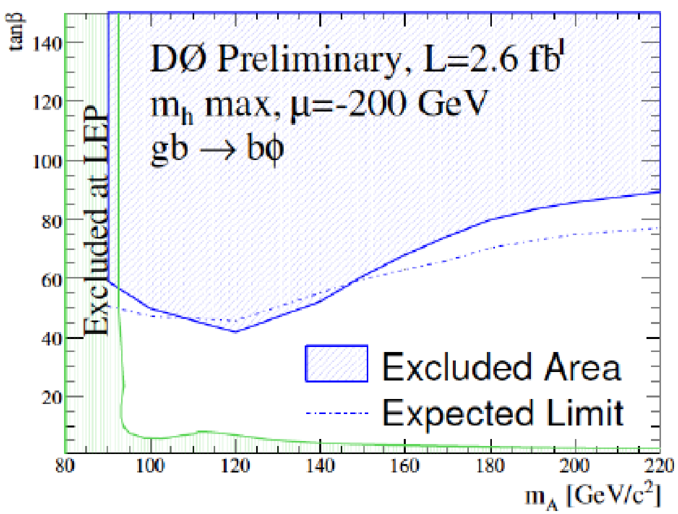
b(b) Φ → bbb(b)

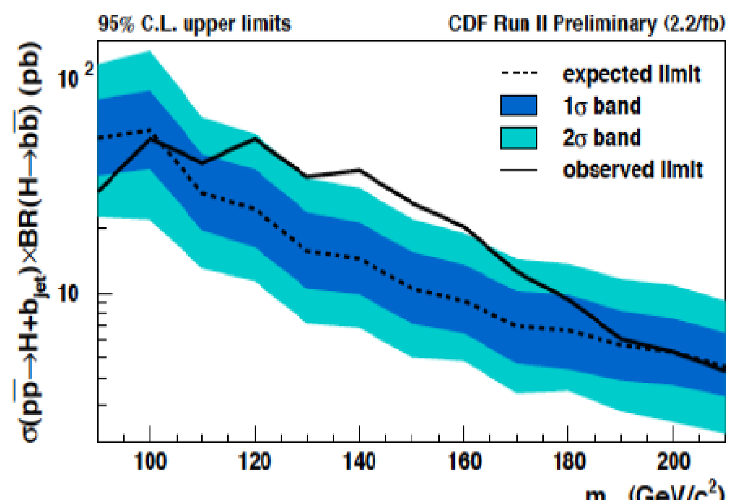


- Experimental signature:
  - 3, 4 or ≥ 5 jets; ≥ 3 b-tags
  - Look for resonance in dijet mass
- Backgrounds dominated by heavy flavor-enriched QCD multijets:

  ➔estimated from data.

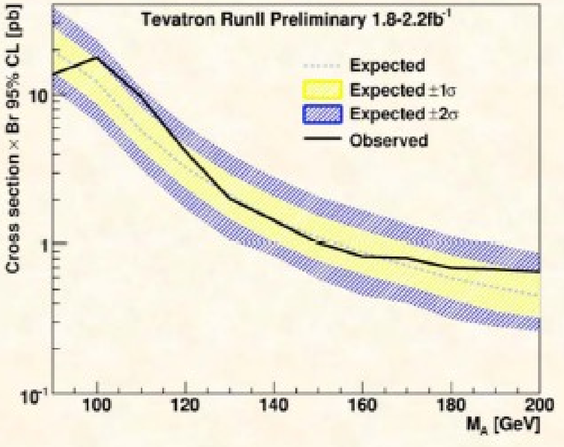






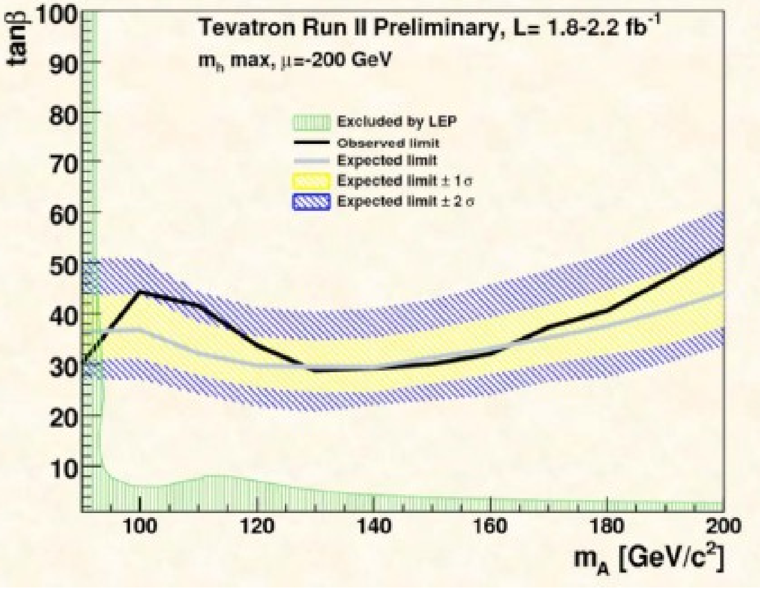
m_Φ=140 GeV; p-value: 0.9% (5.7% w/ trials factor)

Tevatron exclusions on MSSM Higgs bosons

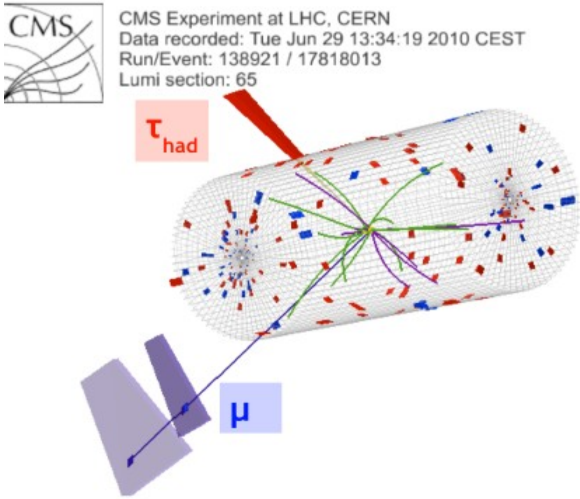


Excluded cross section (95% C.L. limits)

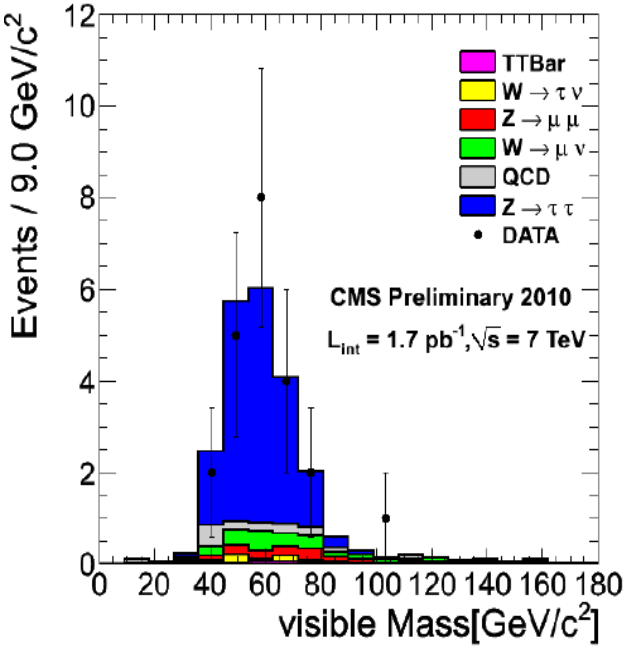
Combination of the CDF and D0 results on $bb\Phi$, $\Phi \rightarrow \tau\tau$



Z→ττ in CMS



- $\int L dt$ = 1.7 pb^{-1} analyzed



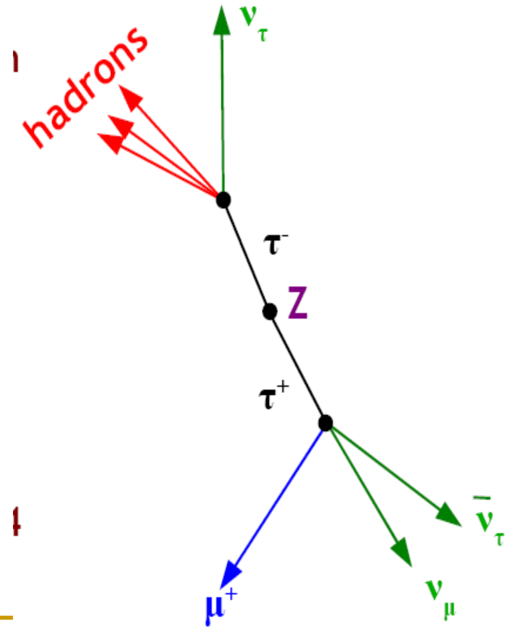
Clean Z → ττ signal observed

Final selection applied

- Muon P_T>15 GeV/c
- Tau P_T > 20 GeV/c
- Loose HPS Tau Isolation
- Muon relative PF combined Isolation
- MT(μ,MET)<40 GeV/c^2

22 events expected (signal + background)

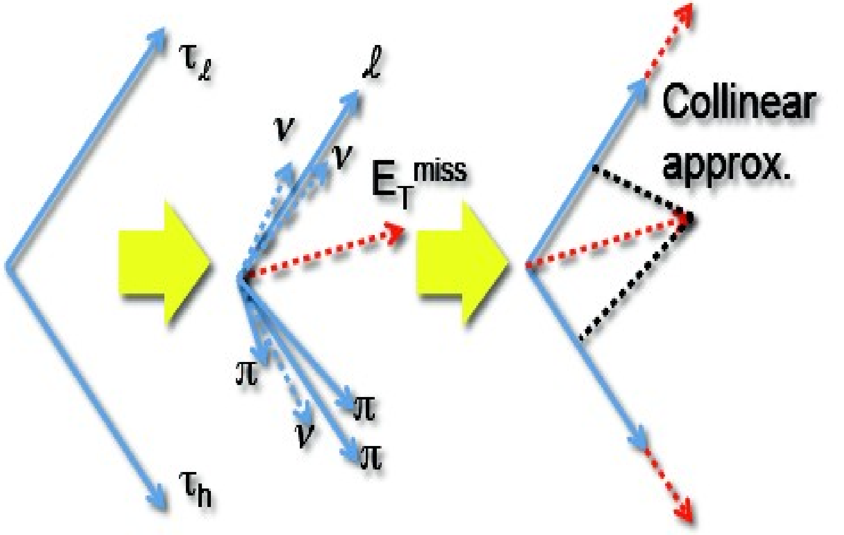
- 22 events observed
- Expected purity ~75%



ATLAS analysis: invariant mass with collinear approximation

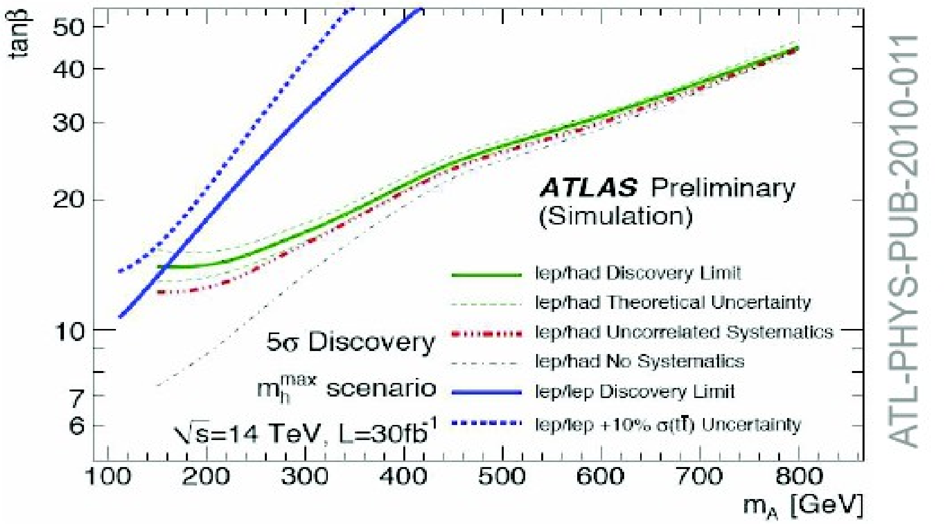
$$m_{\tau\tau} = \frac{m_{lh}}{\sqrt{x_l x_h}} \quad x_h = \frac{E_h}{E_h + E_{\nu h}} \quad x_l = \frac{E_l}{E_l + E_{\nu h}}$$

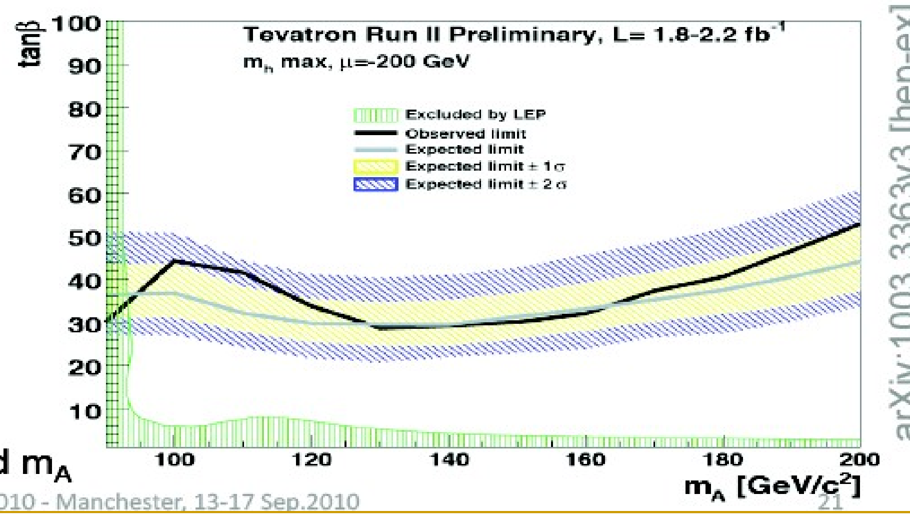
- $m_{\tau\tau}$ can be reconstructed in the collinear approximation with good resolution ($\delta m \approx 8 - 10$ GeV/c^2)
  - Assume τ decays to be only source of E_t^{miss}
  - Assume massles τ's
- Dominant background is $Z/\gamma^* \to \tau\tau$



Atlas analysis (simulation)

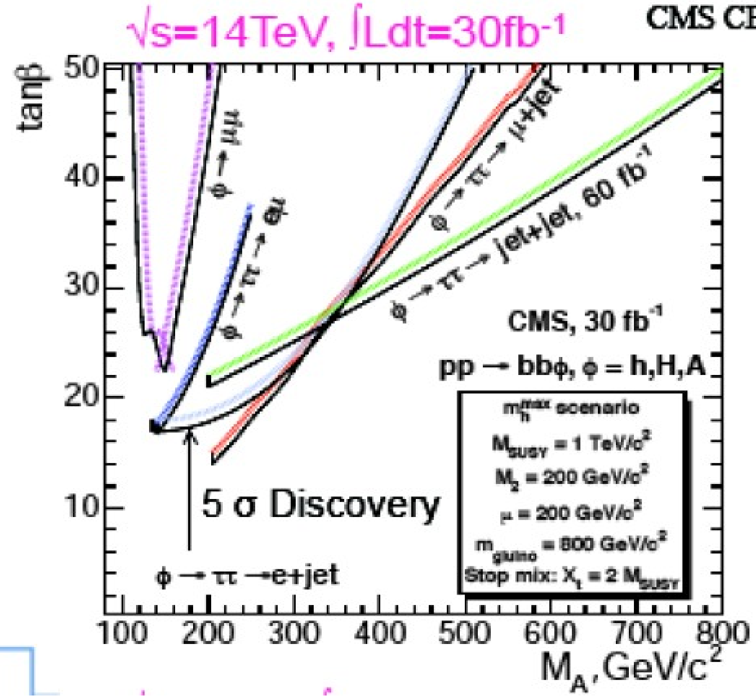
- Combined b-tagged and non b-tagged analyses
- Improvement for $M_A > 150$ GeV/c^2 over older ATLAS analysis of di-lepton final state $\tau_l\tau_l$ (CERN-OPEN-2008-020)
- Compares well with combined Tevatron results at 2.96 TeV obtained with 1.8 fb^{-1} (CDF) and 2.2 fb^{-1} (D0)

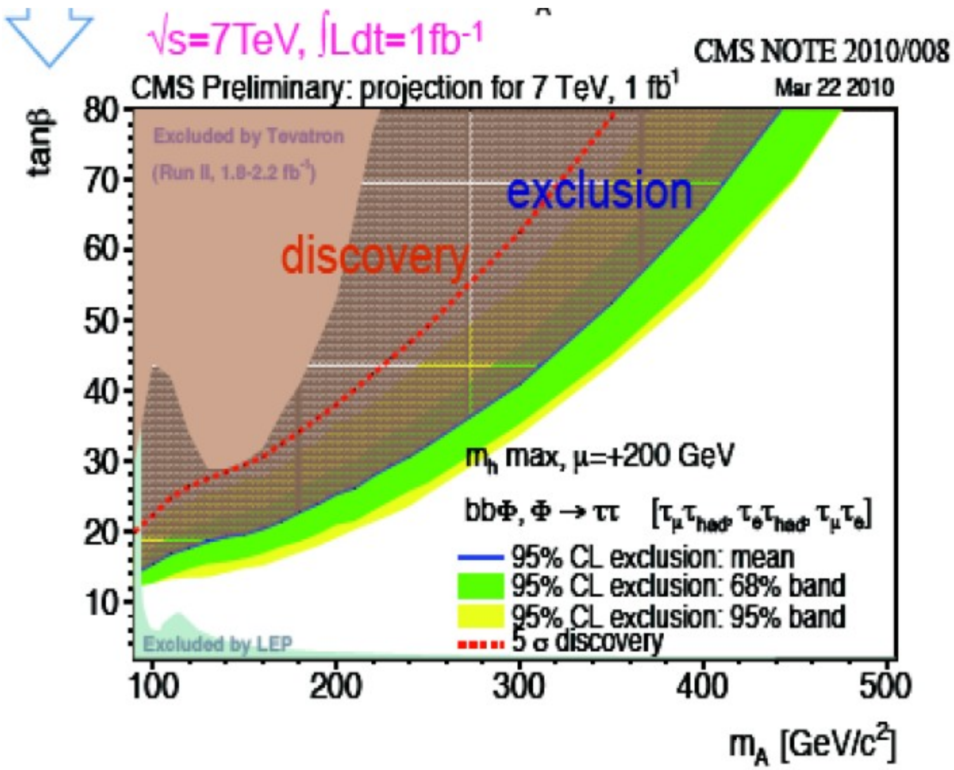




95% exclusion limit vs tanβ and m_A

Projection for discovery and exclusion potential with 7 TeV and L_{int}=1fb^{-1}

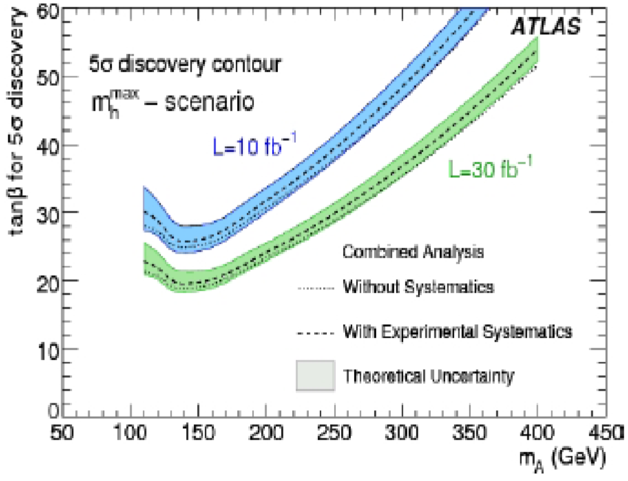


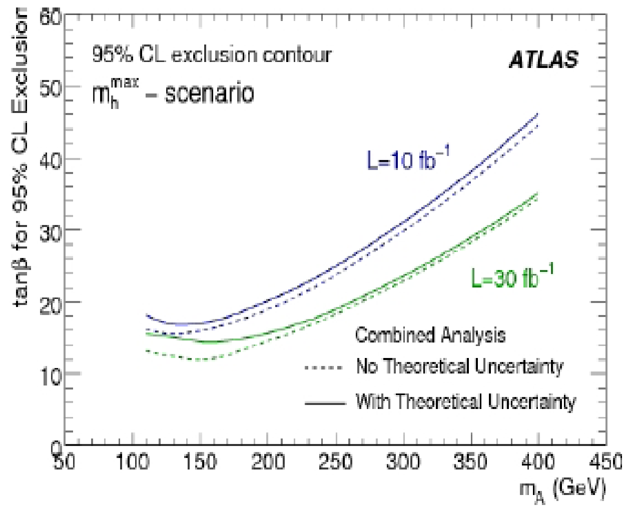


The MSSM neutral Higgses: di-muon channel

CERN-OPEN-2008-020

- **Not visible in SM , enhanced in MSSM**
- **Combine analyses**: 0-bjet and at least 1 b-jet
- Z+jets bgd dominates at low masses, tt becomes at important at higher.
- Average muon p_T resolution better than 3%, allows for **excellent di-muon mass resolution**.
- Theoretical uncertainty on the signal is up to 20% while the detector-related systematic uncertainties degradate signal significance by 5-10%.



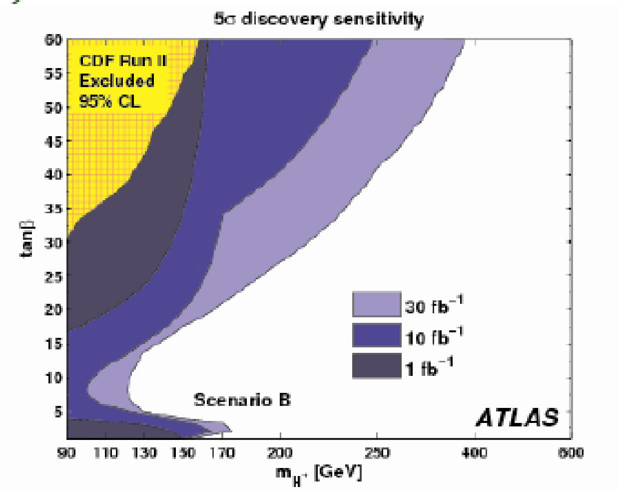


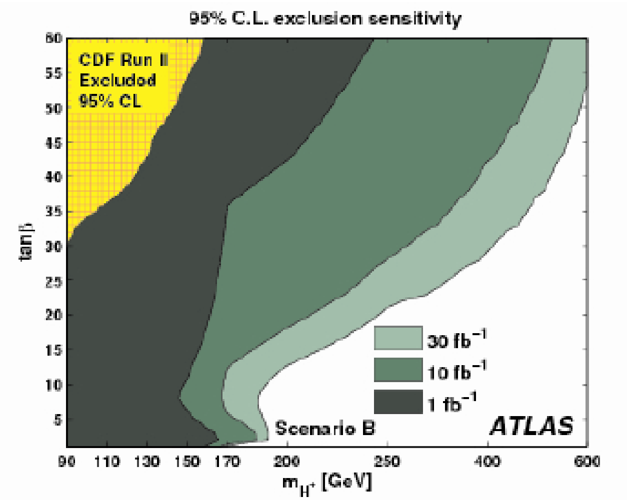
Sensitivity not as good as in ττ channel but may be easier at the beginning.

The MSSM charged Higgs

CERN-OPEN-2008-020

- Naturally **predicted in many non-minimal Higgs** scenarios, here presented typeII-2HDM, mh-max.
- **Light charged Higgs** (below top mass)
  - dominant production is tt, with $t \to H^{\pm}b$
  - dominant decay mode $H^{\pm} \to \tau\nu$
- **Heavy charged Higgs** (above top mass)
  - dominant production $gg/gb \to t(b)H^{\pm}$
  - dominant decay $H^{\pm} \to \tau\nu$ or $H^{\pm} \to tb$
- **Final states:** 2-4 b-jets, light jets from W decay, neutrinos, most channels with tau-lepton.
- **Several topologies** (i.e. five) studied.
- **Profile Likelihood** used for discovery or exclusion including 10% systematic uncertainties on bgd (data-driven control on tt background shape and normalisation).

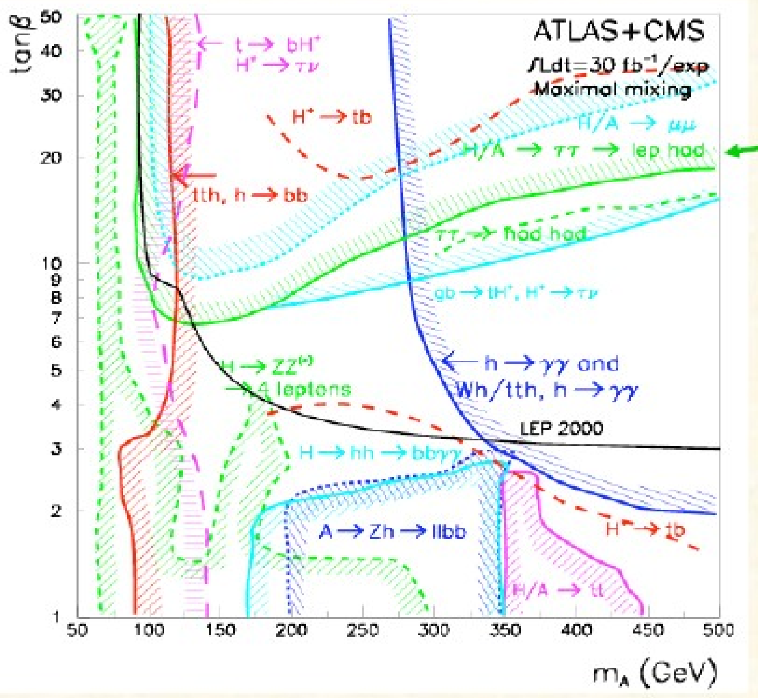




assuming infMC

Expect significant improvement of present day constraints already with $1fb^{-1}$.

MSSM Higgs boson searches at LHC



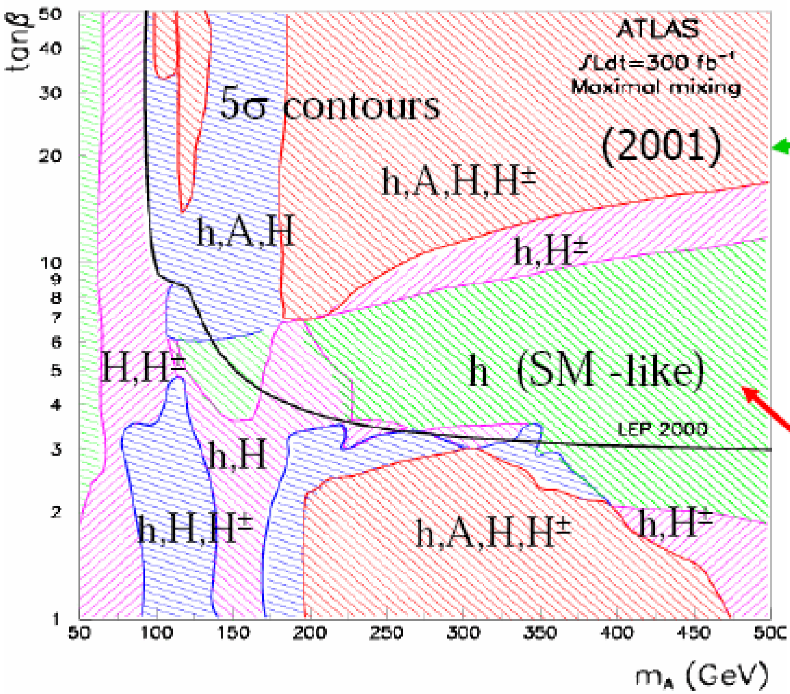
m_h < 135 GeV
$m_A \approx m_H \approx m_{H\pm}$ at large m_A

A, H cross-section ~ $\tan^2\beta$ (tree level)

- best sensitivity from A/H → $\tau\tau$, and H^+→ tb and $\tau\nu$

-A/H → $\mu\mu$ experimentally easier

LHC discovery potential for SUSY Higgs bosons



A, H, $H^\pm$ cross-sections ~ $\tan^2\beta$

-best sensitivity from

$A/H \to \tau\tau$, $H^\pm \to \tau\nu$

(not easy the first year ....)

- $A/H \to \mu\mu$ experimentally easier (esp. at the beginning)

Here only SM-like h observable if SUSY particles neglected.

- 4 Higgs observable
- 3 Higgs observable
- 2 Higgs observable
- 1 Higgs observable

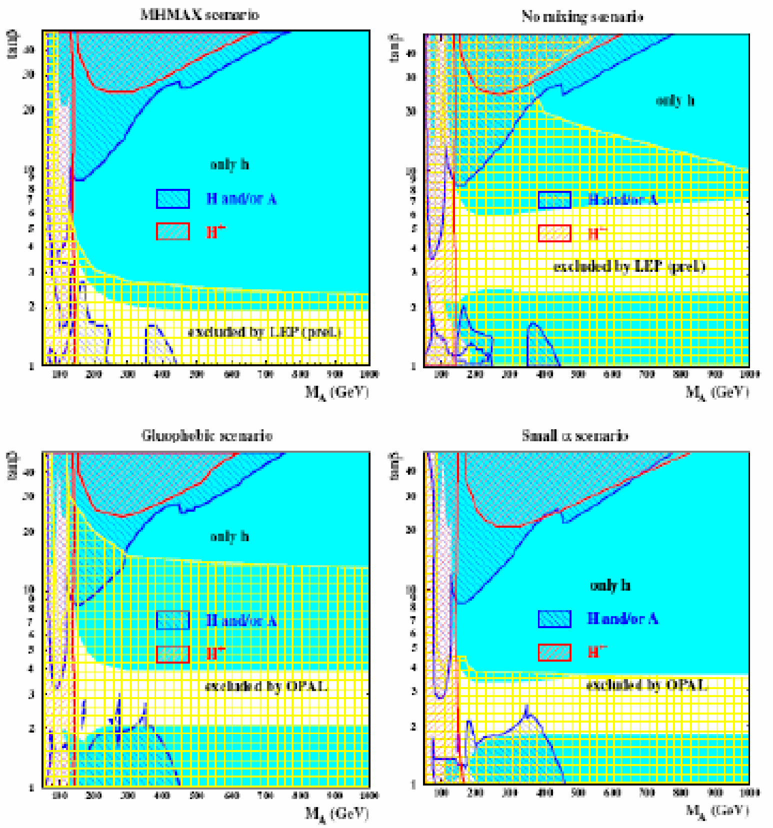
Coverage in the large m_A edge region can be improved (slightly) by:

- Higher luminosity: sLHC
- Additional SUSY decay modes (however, model dependent)

Different benchmark scenarios

Benchmark scenarios as defined by M.Carena et al. (h mainly affected)

ATLAS preliminary, 30 fb^{-1}, 5σ discovery (2004)



MHMAX scenario (M_{SUSY} = 1 TeV/c^2)

maximal theoretically allowed region for m_h

Nomixing scenario (M_{SUSY} = 2 TeV/c^2)

(1TeV almost excl. by LEP)

small m_h → difficult for LHC

Gluophobic scenario (M_{SUSY} = 350 GeV/c^2)

coupling to gluons suppressed

(cancellation of top + stop loops)

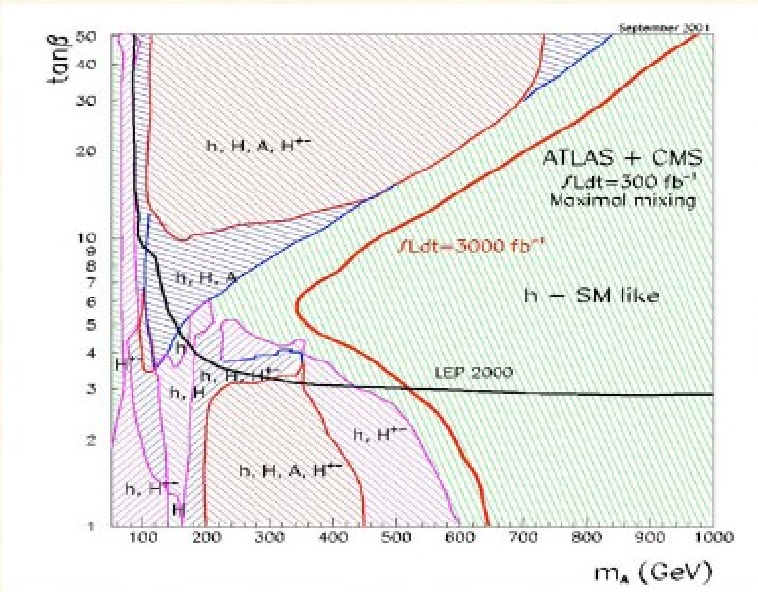
small rate for g g → H, H→ **gg** and Z→4 ℓ

Small a scenario (M_{SUSY} = 800 GeV/c^2)

coupling to b (and **t**) suppressed (cancellation of sbottom, gluino loops) for large tan b and M_A =100 to 500 GeV/c^2

MSSM Higgs sector in supe-LHC

ATLAS + CMS, 2 x 3000 fb^{-1}



- Situation can be improved, in particular for m_A < ~400 GeV
- But: (s)LHC can not promise a complete observation of the heavy part of the MSSM Higgs spectrum ....

.... although the observation of sparticles will clearly indicate that additional Higgs bosons should exist.

Next topics

- 5.01 - SUSY
- 12.01 - SUSY
- 19.01 - Wrapping up on data 2010:
  - SM physics: selected public results
  - Searches: new exclusion limits

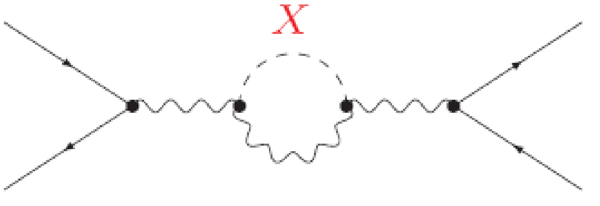
How to make predictions

Comparison of precision observables with theory:

Precision data:		Theory:
$M_W, \sin^2\theta_{\text{eff}}, a_\mu, \ldots$	$\leftrightarrow$	SM, MSSM , . . .

$\Downarrow$

Test of theory at quantum level: Sensitivity to loop corrections



$\Downarrow$

$\Rightarrow$ Information about unknown parameters

Very high accuracy of measurements and theoretical predictions needed

Predictions for M_W in SM and MSSM

Theoretical prediction for M_W in terms

of $M_Z, \alpha, G_\mu, \Delta r$:

$$M_W^2 \left(1 - \frac{M_W^2}{M_Z^2}\right) = \frac{\pi \alpha}{\sqrt{2}\, G_\mu} (1 + \Delta r)$$

$\Updownarrow$

loop corrections

$\rightarrow$ can be approximated with the ρ-**parameter:**

ρ measures the relative strength between neutral current interaction and charged current interaction

$$\rho = \frac{1}{1 - \Delta\rho}, \qquad \Delta\rho = \frac{\Sigma_Z(0)}{M_Z^2} - \frac{\Sigma_W(0)}{M_W^2}, \qquad \Delta M_W \approx \frac{M_W}{2} \frac{c_W^2}{c_W^2 - s_W^2} \Delta\rho$$

(leading, process independent terms)

Predictions for M_W in SM and MSSM

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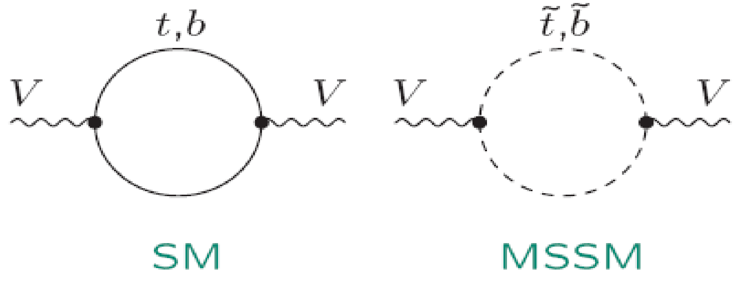

$\Delta\rho^{\text{SUSY}}$ from $\tilde{t}/\tilde{b}$ loops > 0 $\quad \Rightarrow M_W^{\text{SUSY}} \gtrsim M_W^{\text{SM}}$

Predictions for M_W in SM and MSSM

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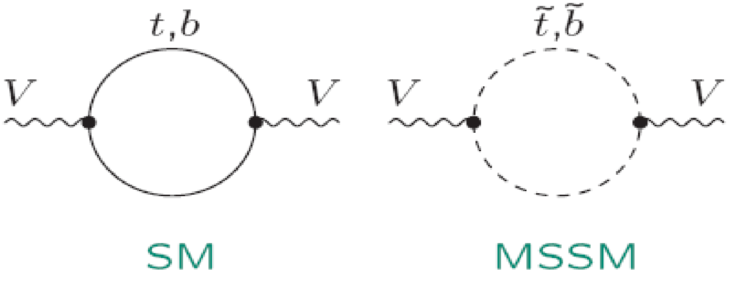
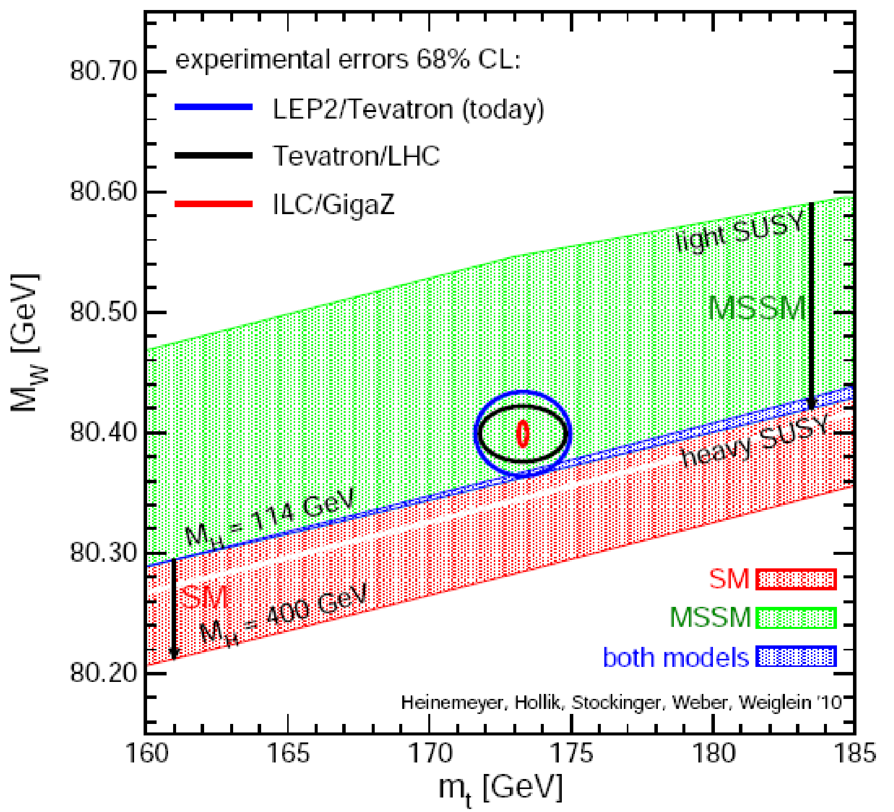


$\Delta\rho^{\text{SUSY}}$ from $\tilde{t}/\tilde{b}$ loops > 0 $\quad \Rightarrow M_W^{\text{SUSY}} \gtrsim M_W^{\text{SM}}$

Predictions for M_W in SM and MSSM

Example: Prediction for M_W in the SM and the MSSM :

[S.H., W. Hollik, D. Stockinger, A. Weber, G. Weiglein '07]



MSSM band:
scan over
SUSY masses

overlap:
SM is MSSM-like
MSSM is SM-like

SM band:
variation of M_H^{SM}