News on Exclusive Diffractive Higgs studies

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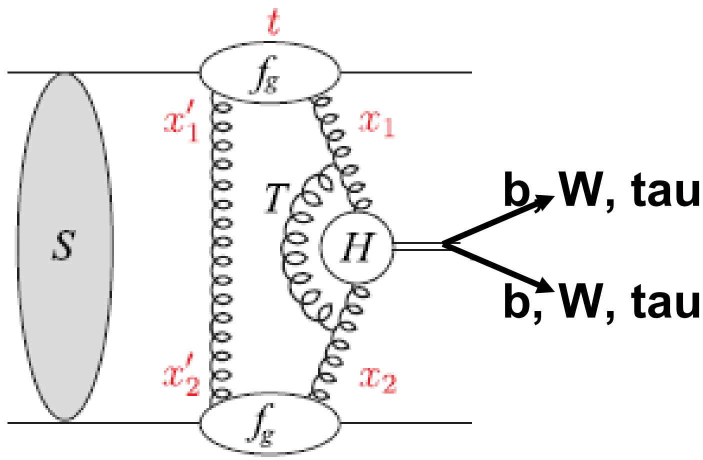
Low-x workshop, Kavala, Greece - 25/06 2010

CED Higgs in SM and MSSM

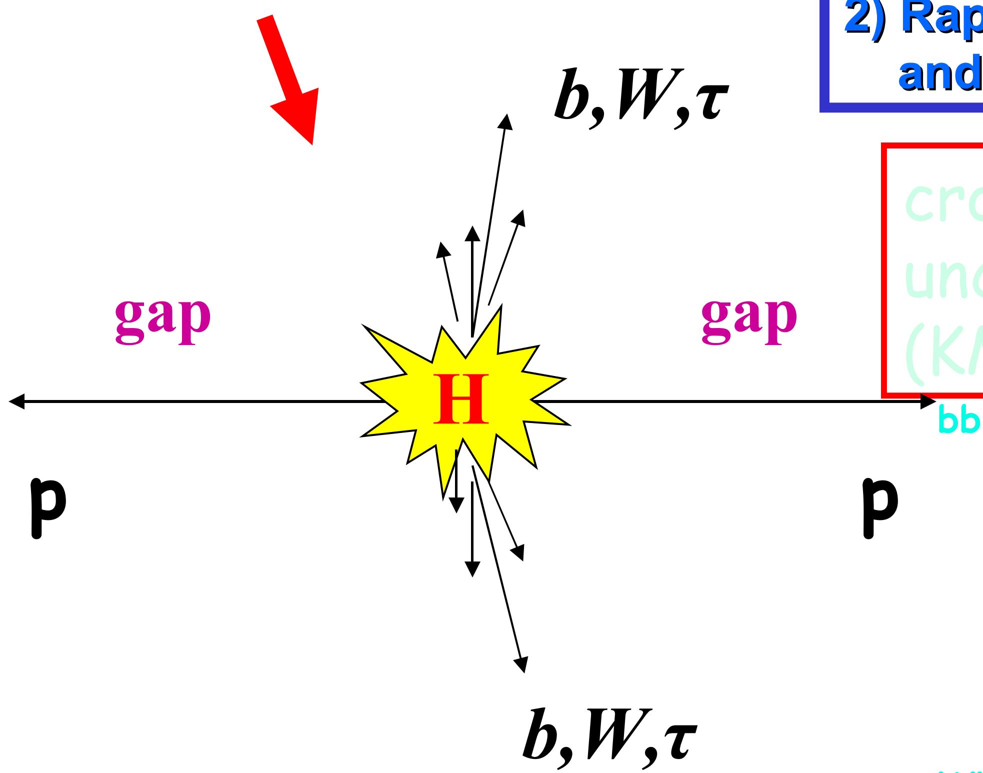
Updates to EPJC 53 (2008) 231

Central Exclusive Diffraction: Higgs production



This process is the core of the physics case of Forward detector upgrades (AFP in ATLAS, HPS in CMS)

1) **Protons remain undestroyed and can be detected in forward detectors**
2) **Rapidity gaps between leading protons and Higgs decay products**



cross-sections predicted with uncertainty of 3 !! (or more?) (KMR group, CHIDe model)

bb

: at 120 GeV needs a special diffractive trigger

WW

Central Exclusive Diffraction: Higgs production

Advantages:

I) Forward detectors give much better mass resolution than the central detector

II) J_Z = 0, CP-even selection rule:

- strong suppression of CED gg→bb background (by (m_b/M_H))
- produced central system is 0 → **just a few events are enough to determine Higgs quantum numbers. Standard searches need high stat. (φ-angle correlation of jets in VBF of Higgs) and coupling to Vector bosons.**

III) Access to main Higgs decay modes in one (CED) process: bb, WW, tautau

↓

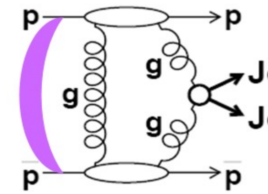
information about Yukawa coupling
(Hbb difficult in standard searches due to huge bg.)

IV) In MSSM, CED Higgs process give very important information on the Higgs sector, and in addition, for sufficiently high tanβ values, it allows direct measurement of the Higgs width.

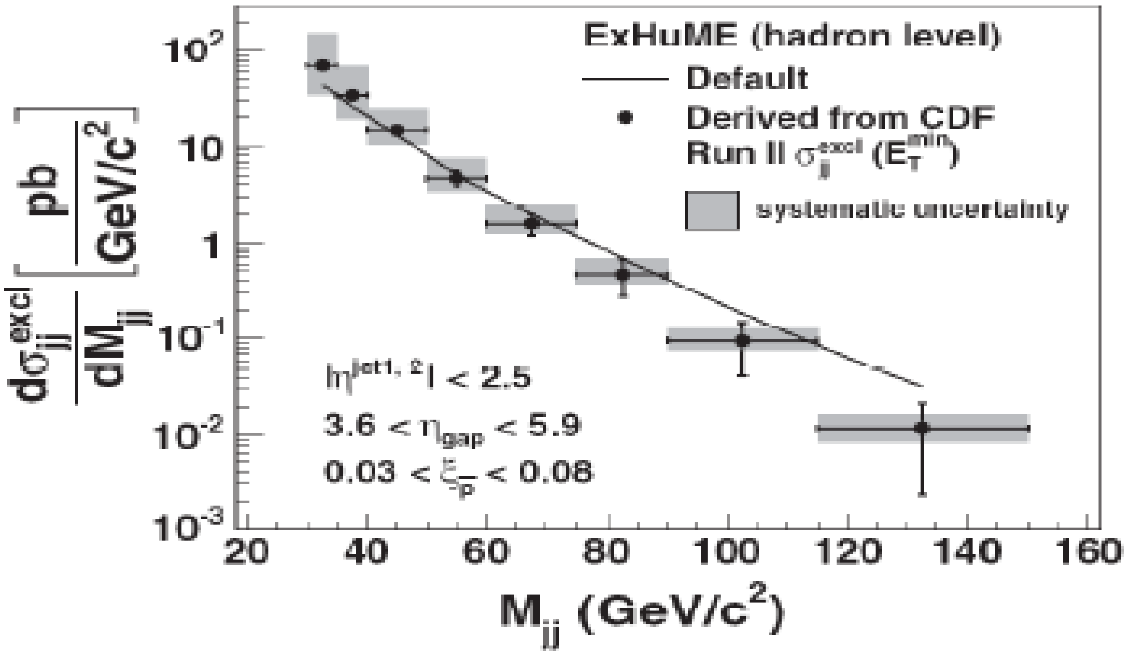
Disadvantages:

- Low signal x-section
- Large Pile-up

Exclusive dijet x-section vs. M_{jj}



arXiv:0712.0604 , PRD-2008



curve: ExHuME hadron-level exclusive dijet cross sections vs. dijet mass

points: derived from CDF excl. dijet x-sections using ExHuME

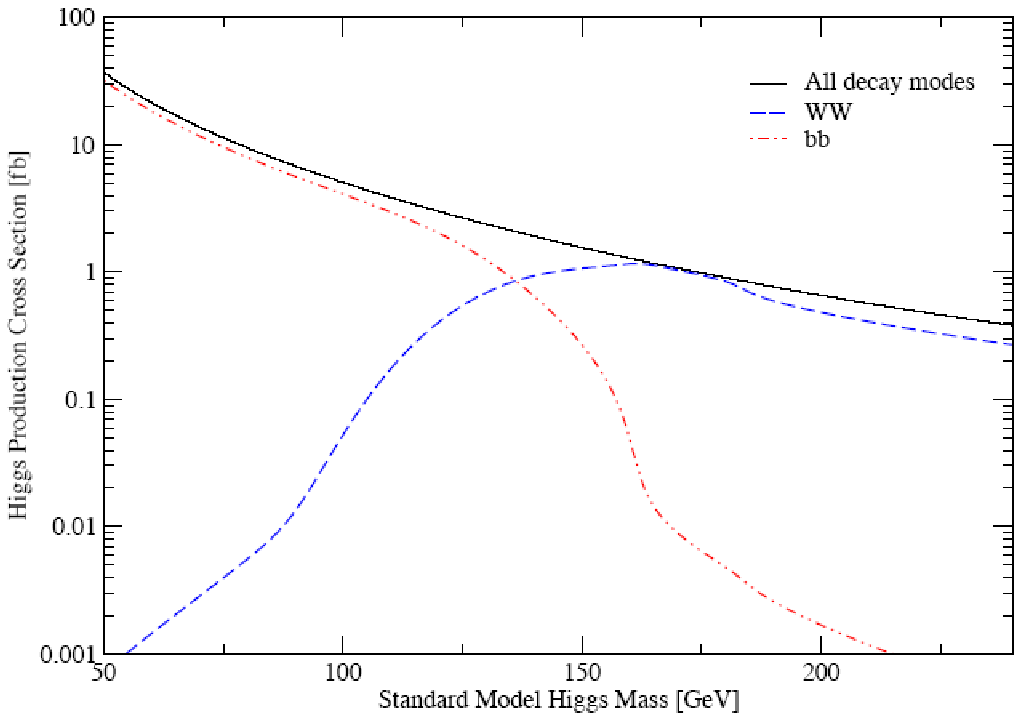
Stat. and syst. errors are propagated from measured cross section uncertainties using M_{jj} distribution shapes of ExHuME generated data.

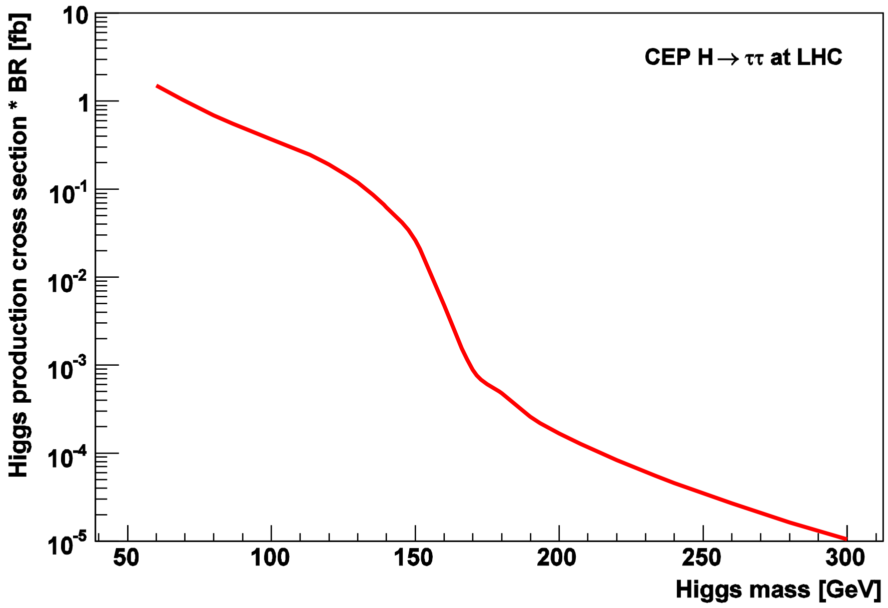
Use ExHuMe as the standard event generator

Cross sections (KMR) and FD Acceptances

M_H [GeV]	σ (bb) [fb]	σ (WW^*) [fb]	Acc (420+420)	Acc(420+220)
120	1.9	0.37	0.20	0.17
130		0.70	0.15	0.24
140	0.6	0.87	0.11	0.31
160	0.045	1.10	0.04	0.43
180	0.0042	0.76	0.01	0.53

Acceptances for AFP detectors at (220,420) m and 2.5mm,4mm from the beam (1mm dead space)





Analyses on CED Higgs production

CMS:

H→bb: fast simulation, $100 < M_H < 300$ GeV, d_{220}~1.5mm, d_{420}~4.5mm, Acc=Acc(ξ,t,φ)

- track variables (N_C, $N_C^{\perp}$) not used →PU bg overestimated
- L1 trigger: single-sided FD220 .AND. Etjet1>40.AND. Etjet2>40. No efficiencies applied
- published in CMS-Totem document CERN/LHCC 2006-039/G-124
- signal selection efficiencies used in MSSM study (EPJC 53 (2008) 231)

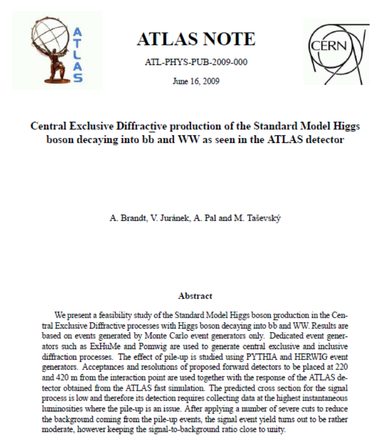
ATLAS:

H→bb: 1) gen.level + smearing of basic quantities, M_H = 120 GeV

- L1 trigger: fixed rates of dijet triggers with prescales
- one MSSM point (tanβ = 40): JHEP 0710 (2007)090

2) fast simulation, M_H = 120 GeV

- L1 trigger: a dedicated H→bb trigger (ATLAS-COM-DAQ-2009-062).
  Efficiencies and prescales easily applicable offline
- common ATLAS note just released


ATLAS NOTE

ATL-PHYS-PUB-2009-000

June 16, 2009

Central Exclusive Diffractive production of the Standard Model Higgs boson decaying into bb and WW as seen in the ATLAS detector

A. Brandt, V. Juránek, A. Pal and M. Taševský

Abstract

We present a feasibility study of the Standard Model Higgs boson production in the Central Exclusive Diffractive processes with Higgs boson decaying into bb and WW. Results are based on events generated by Monte Carlo event generators only. Dedicated event generators such as ExHuMe and Pomwig are used to generate central exclusive and inclusive diffraction processes. The effect of pile-up is studied using PYTHIA and HERWIG event generators. Acceptances and resolutions of proposed forward detectors to be placed at 220 and 420 m from the interaction point are used together with the response of the ATLAS detector obtained from the ATLAS fast simulation. The predicted cross section for the signal process is low and therefore its detection requires collecting data at the highest instantaneous luminosities where the pile-up is an issue. After applying a number of severe cuts to reduce the background coming from the pile-up events, the signal event yield turns out to be rather moderate, however keeping the signal-to-background ratio close to unity.

H→WW: fast + full simulation, M_H = 160 GeV

- common ATLAS note just released

H→tautau: full simulation, $100 < M_H < 300$ GeV (designed for a MSSM study)

All ATLAS analyses use d ~2-3mm, d ~4-5mm, Acc=Acc(ξ,t)

Analysis strategy for H→bb

1) Proton detection: in Forward proton taggers at 220m and 420m

2) jets: two b-tagged jets: ET1 > 45 GeV, ET2 > 30 GeV, |η1,2| < 2.5, 3.0 < |φ1 – φ2| < 3.3

3) Kinematics constraints – matching criteria: 0.75 < Rj < 1.2, |Δy| < 0.1

4) L1 triggers:
- **420+220:** J20J40 + FD220 + ¯η <0.5 + |Δη|<2 + fT>0.45 → special diffractive trigger
- **420+420:** J20J40 + ¯η <0.5 + |Δη|<2 + fT>0.45 → FD420 cannot be included in L1

5) Mass windows: 117.6 < M420 < 122.4,
114.2 < M420+220 < 125.8 (3σ – window

6) PU bg suppressors: Few tracks outside the dijet
reduction factor ~20 from fast timing detector

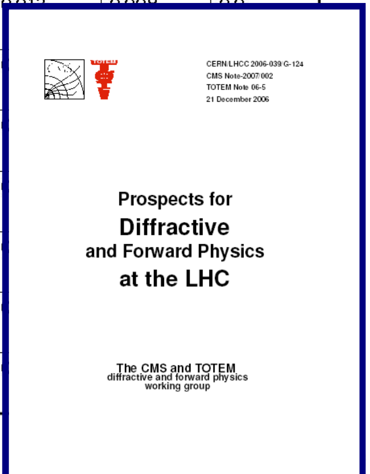
Take the experimental efficiencies **ε** and calculate

7) Cross sections: σ**SM** x **ε** x Γ(gg→H)**NP** / Γ(gg→H)**S**

8) Decays: BR(H→bb)**NP** from FeynHiggs
(MSSM: incl. Δ**b** dep.)

Efficiencies for SM H→bb (CMS+Totem)

Mh [GeV]	Acc_{420}	Acc_{comb}	Acc_{220}	ε_{420}	ε_{comb}	ε_{220}
100	0.37	0.13	0.0	[illegible]	[illegible]	[illegible]
120	0.31	0.25	0.0	[illegible]	[illegible]	[illegible]
140	0.25	0.37	0.0	[illegible]	[illegible]	[illegible]
160	0.19	0.49	0.0	[illegible]	[illegible]	[illegible]
180	0.14	0.60	0.0	[illegible]	[illegible]	[illegible]
200	0.09	0.69	0.0	[illegible]	[illegible]	[illegible]
300	0.0	0.76	0.13	[illegible]	[illegible]	[illegible]

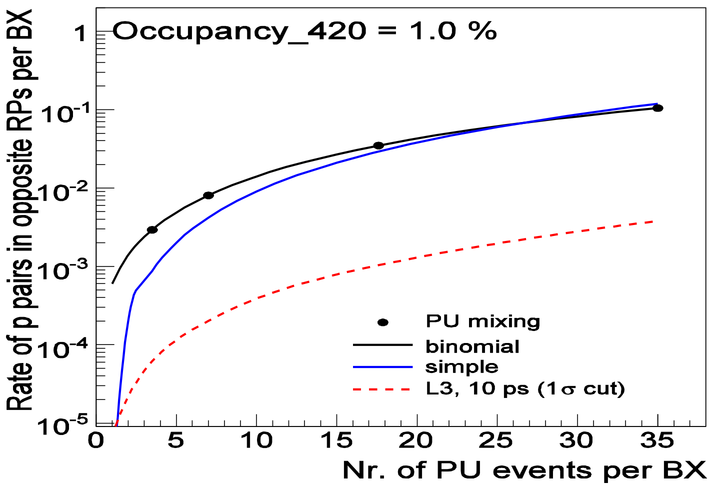

CERN/LHCC 2006-039/G-124
CMS Note-2007/002
TOTEM Note 06-5
21 December 2006

Prospects for
Diffractive
and Forward Physics
at the LHC

The CMS and TOTEM
diffractive and forward physics
working group

CED experimental challenges: Pile-up

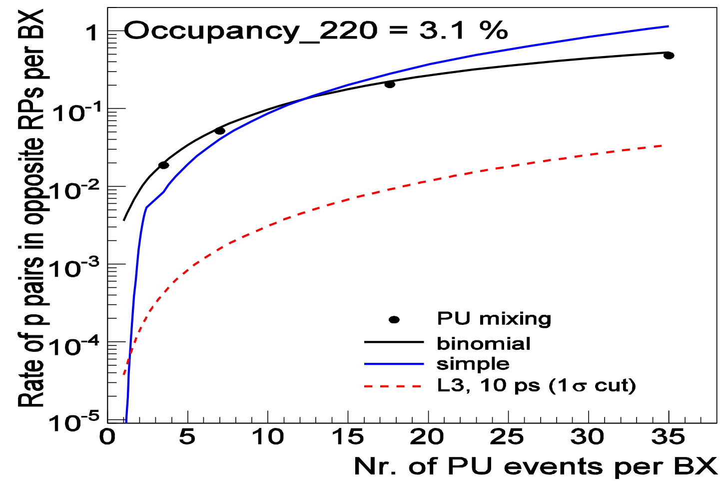
Huge Pile-up bg for diffractive processes: overlap of three events (2* SD + non-diffr. Dijets). Can be reduced by Fast Timing detectors: t-resol. required: few ps for high lumi!



Huge rates

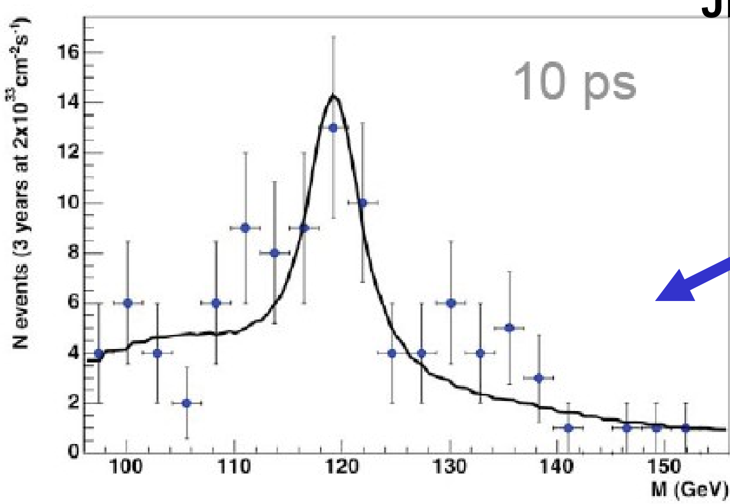
Reduced by

Fast timing Detectors (factor ~20)



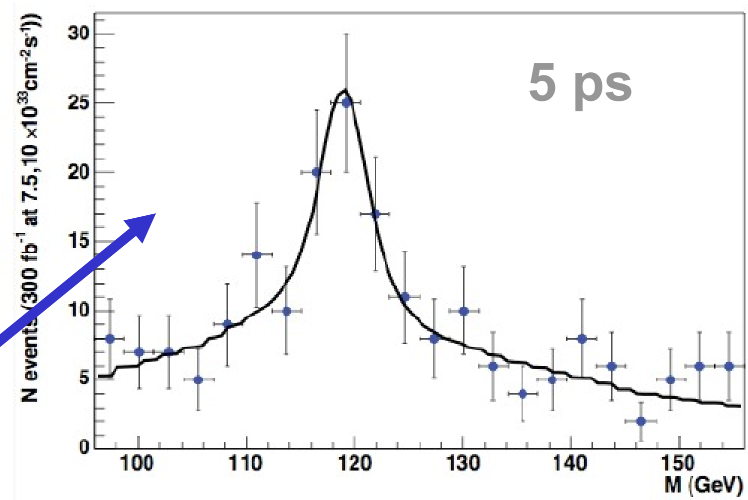
h→bb, mhmax scenario, standard ATLAS L1 triggers, 420m only, 5 mm from beam

JHEP 0710:090,2007



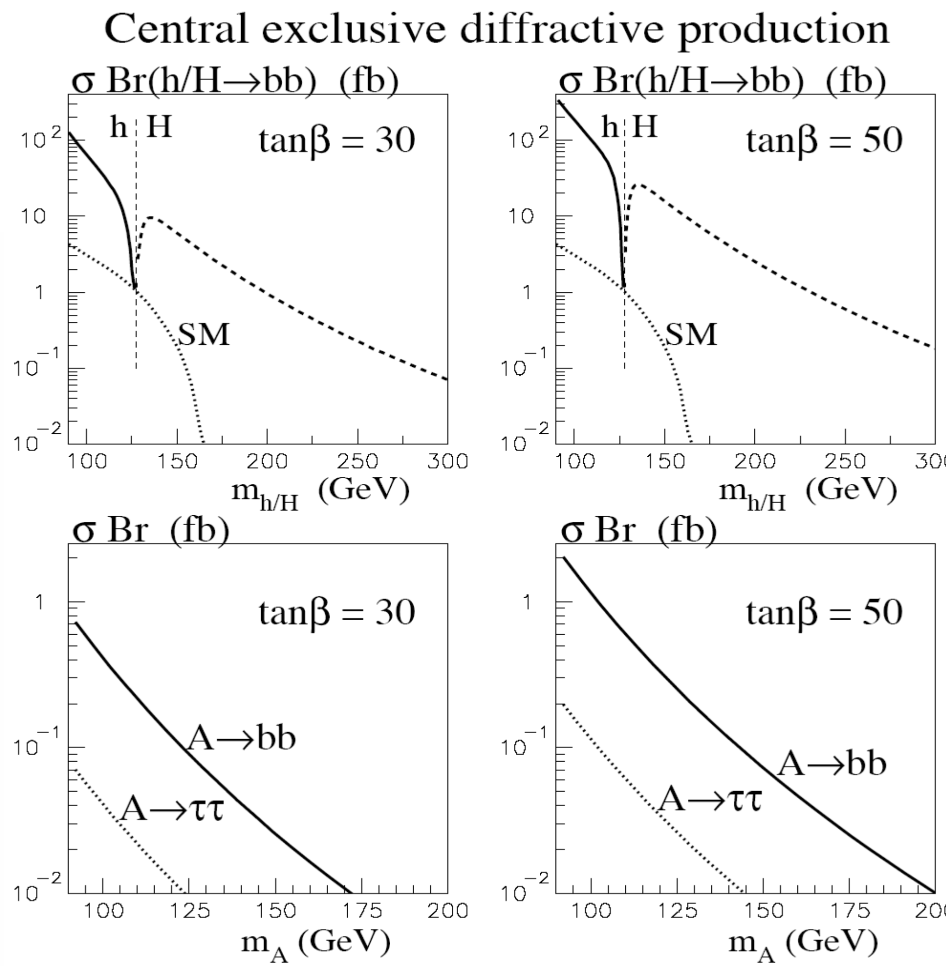
60 fb collected at 2x10 cm s

150 fb at 7.5x10 cm s plus 150 fb at 10 cm s



MSSM and CED go quite well together

The intense coupling regime is where the masses of the 3 neutral Higgs bosons are close to each other and tan β is large



Extended Higgs sectors: "typical" features

Search for heavy MSSM Higgs bosons ($M_A, M_H \gg M_Z$):

Decouple from gauge bosons

⇒ no HVV coupling

⇒ no Higgs production in weak boson fusion

⇒ no decay $H \to ZZ \to 4\mu$

Large enhancement of coupling to $b\bar{b}$, $\tau^+\tau^-$ for high $\tan\beta$

⇒ Decays into $b\bar{b}$ and $\tau^+\tau^-$ play a crucial role

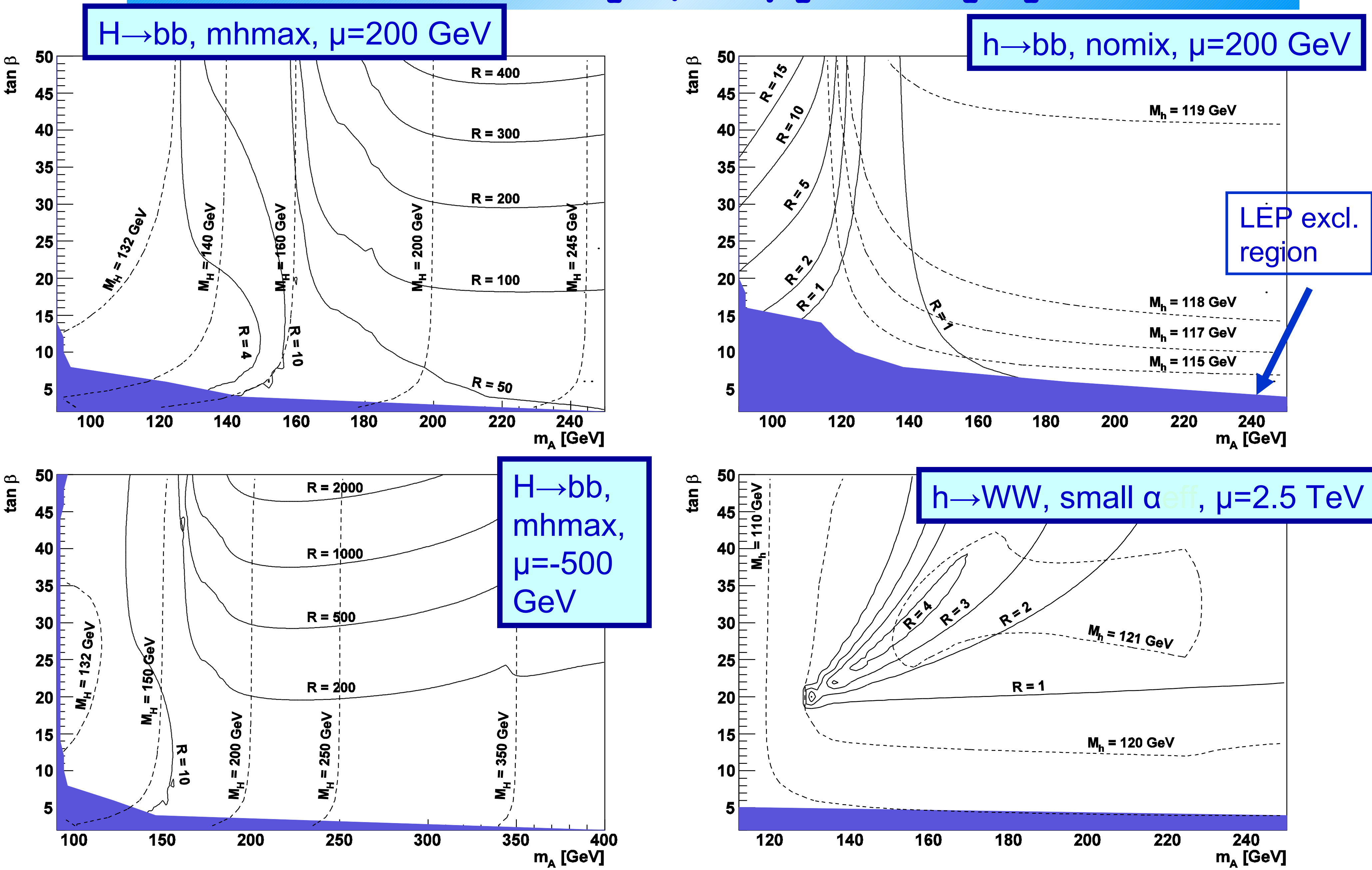
"Typical" features of models with an extended Higgs sector:

- A light Higgs with SM-like properties, couples with about SM-strength to gauge bosons
- Heavy Higgs states that decouple from the gauge bosons

Studying the MSSM Higgs Sector by Forward Proton Tagging at the LHC, Georg Weiglein, EPS07, Manchester, 07/2007 – p.3

Well known difficult region for conventional channels, tagged proton channel may well be the discovery channel and is certainly a powerful spin/parity filter

R=MSSM[M,tanβ] / SM[M]



Update of EPJC 53 (2008) 231

(HKRSTW = Heinemeyer, Khoze, Ryskin, Stirling, Tasevsky, Weiglein)

1) FeynHiggs 2.3.0 → most recent FeynHiggs 2.6.2

2) NLO formula for CED gg→bb background

3) Tevatron exclusion areas added

4) A few Cold Dark Matter scenarios tried

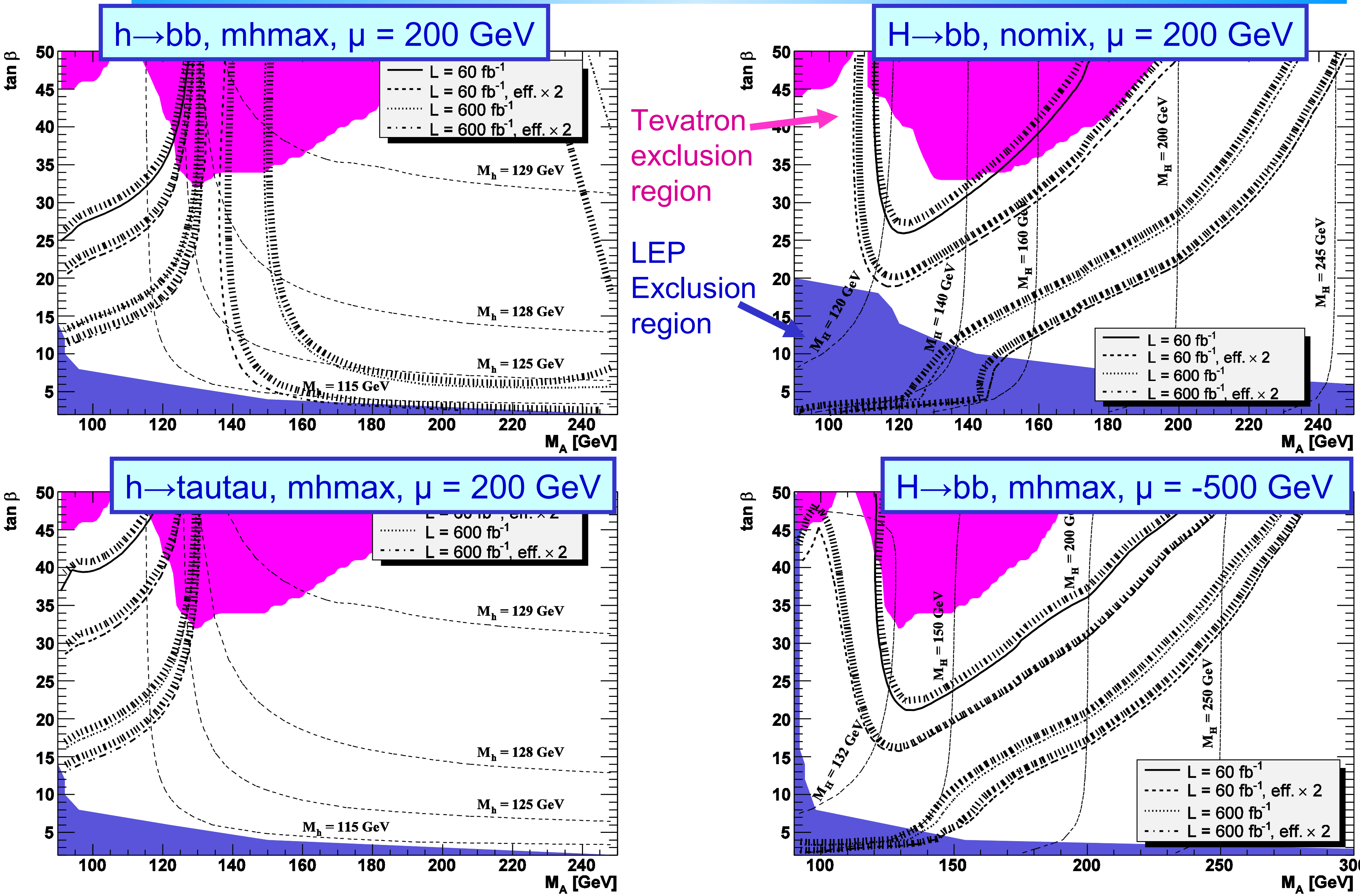
5) 4 generation

A new paper is close to publication

Four luminosity scenarios (ATLAS+CMS):

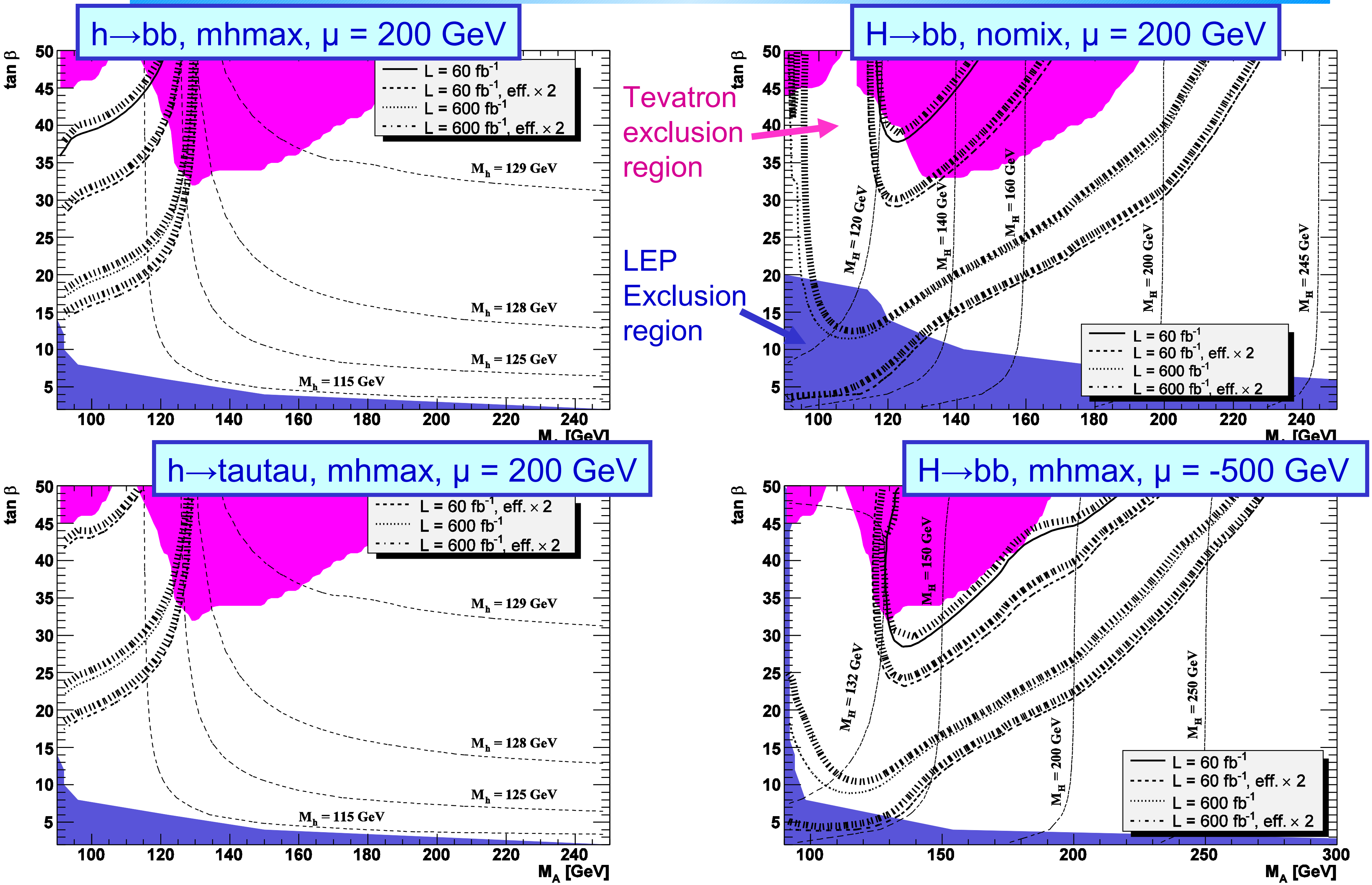
1) 60 fb-1 – low lumi (no pile-up)
2) 60 fb-1 x 2 – low lumi (no pile-up) but improved signal efficiency
3) 600 fb-1 - high lumi (pile-up suppressed)
4) 600 fb-1 x2 – high lumi (pile-up suppressed) but improved signal efficiency

3σ-contours



h→bb, mhmax, μ = 200 GeV
H→bb, nomix, μ = 200 GeV
h→tautau, mhmax, μ = 200 GeV
H→bb, mhmax, μ = -500 GeV
Tevatron exclusion region
LEP Exclusion region
tan β
M_A [GeV]
L = 60 fb^-1
L = 60 fb^-1, eff. × 2
L = 600 fb^-1
L = 600 fb^-1, eff. × 2
M_h = 129 GeV
M_h = 128 GeV
M_h = 125 GeV
M_h = 115 GeV
M_H = 120 GeV
M_H = 140 GeV
M_H = 160 GeV
M_H = 200 GeV
M_H = 245 GeV
M_H = 132 GeV
M_H = 150 GeV
M_H = 250 GeV

5σ-contours



h→bb, mhmax, μ = 200 GeV
H→bb, nomix, μ = 200 GeV
h→tautau, mhmax, μ = 200 GeV
H→bb, mhmax, μ = -500 GeV
Tevatron exclusion region
LEP Exclusion region
tan β
M_A [GeV]
L = 60 fb^-1
L = 60 fb^-1, eff. × 2
L = 600 fb^-1
L = 600 fb^-1, eff. × 2
M_h = 129 GeV
M_h = 128 GeV
M_h = 125 GeV
M_h = 115 GeV
M_H = 120 GeV
M_H = 140 GeV
M_H = 160 GeV
M_H = 200 GeV
M_H = 245 GeV
M_H = 132 GeV
M_H = 150 GeV
M_H = 250 GeV

Cold Dark Matter scenarios

- Follow the ideas of arXiv: 0709.0098v2 (J.Ellis, T.Hahn, S.Heinemeyer, K.Olive and G.Weiglein):

- **Explore new benchmark surfaces for MSSM Higgs phenomenology so that the supersymmetric relic density is compatible with the cosmological density of cold dark matter inferred from WMAP and other observations.**

  The allowed range of cold dark matter density: $0.0882 < \Omega_{CDM}h^2 < 0.1204$

- The benchmark surfaces may be presented as (M_A, tanβ) planes with fixed or systematically varying values of NUHM parameters, such as scalar mass m_0, gaugino mass $m_{1/2}$, trilinear parameter A_0 and the Higgs mixing parameter μ.

Plane P1: m_0=800 GeV, μ=1000 GeV, A_0=0, varying $9/8M_A-12.5\text{ GeV}<m_{1/2}<9/8M_A+37.5\text{ GeV}$

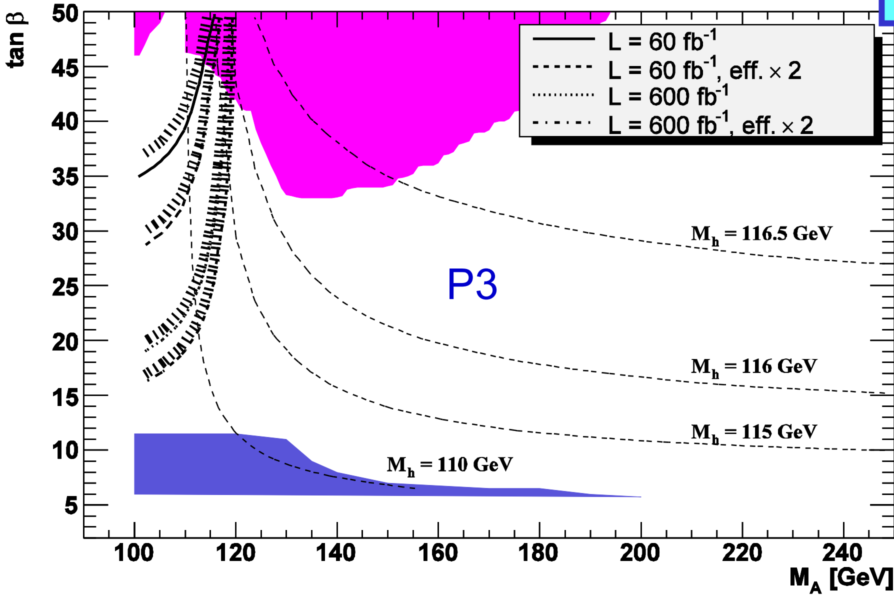
Plane P2: m_0=300 GeV, μ=800 GeV, A_0=0, varying $1.2M_A - 40\text{ GeV} < m_{1/2} < 1.2M_A + 40\text{ GeV}$

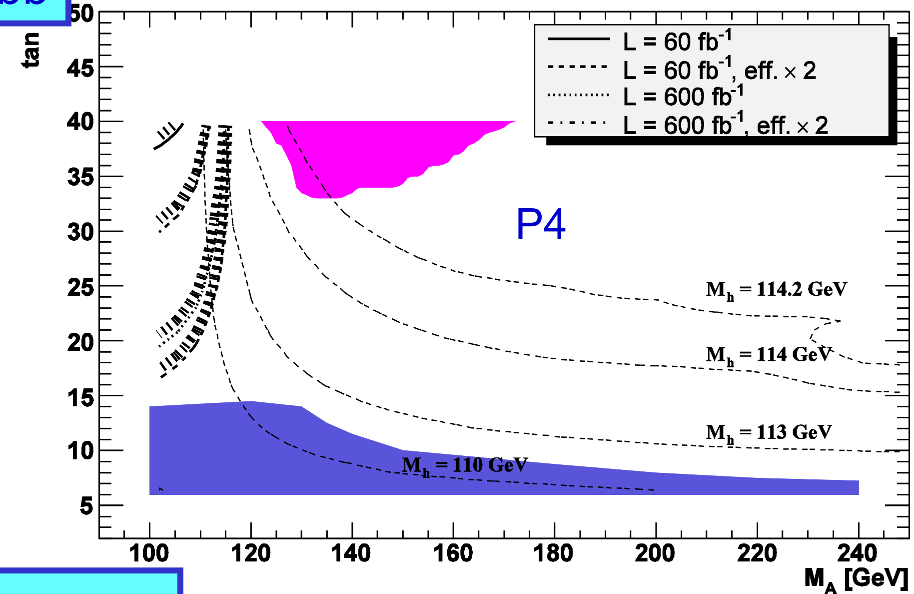
Plane P3: $m_{1/2}$=500 GeV, m_0=1000 GeV, A_0=0, $200 < \mu < 400$ GeV

Plane P4: $m_{1/2}$=300 GeV, m_0= 300 GeV, A_0=0, $200 < \mu < 350$ GeV

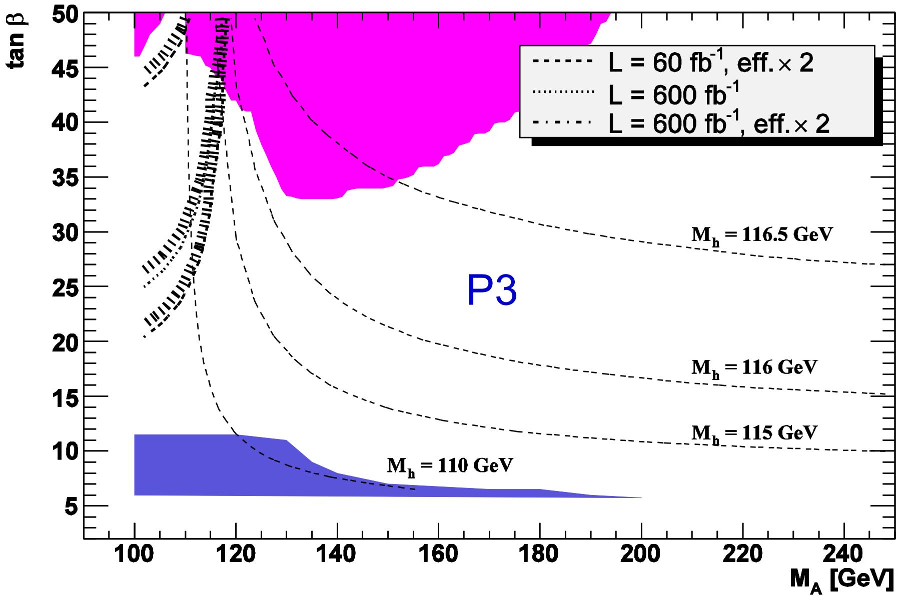
Cold Dark Matter: h→bb,tautau, 5σ-contours

h → bb



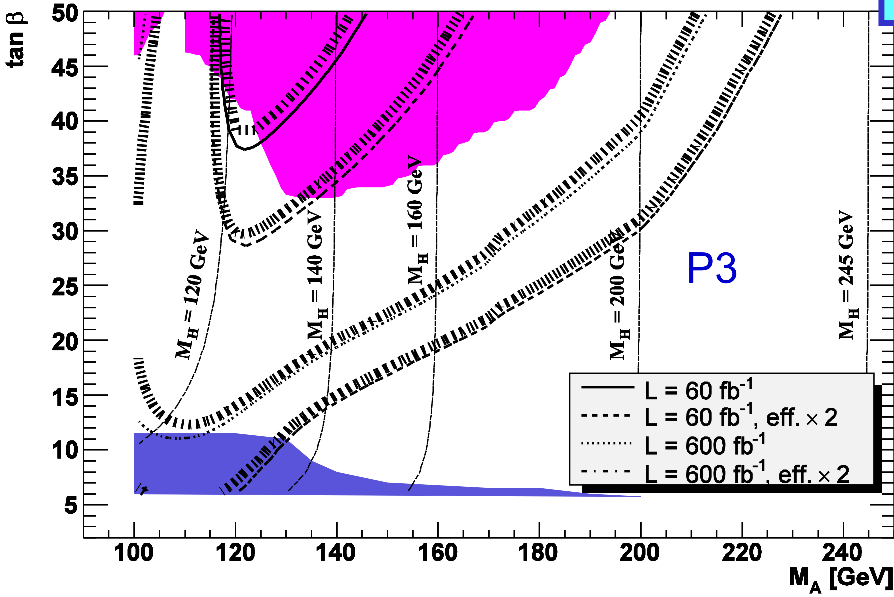


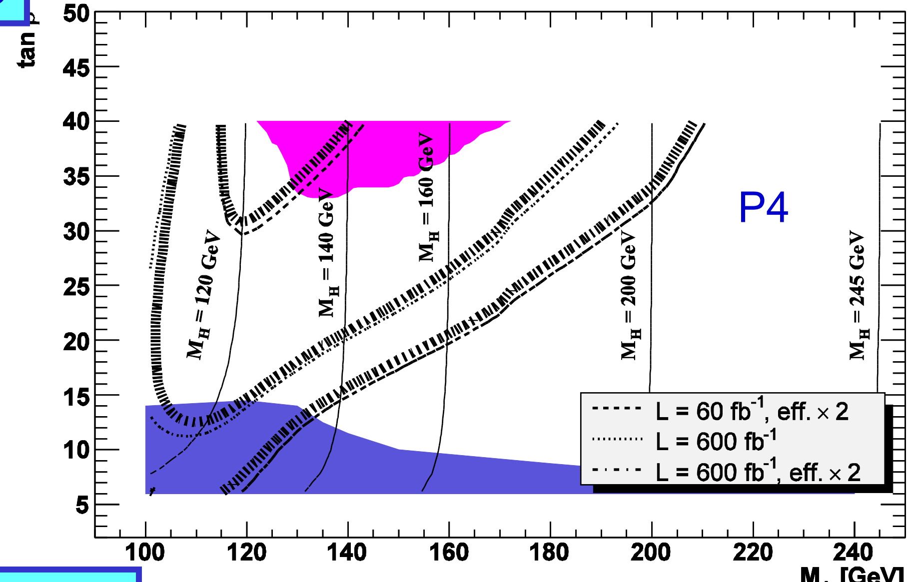
h → tautau



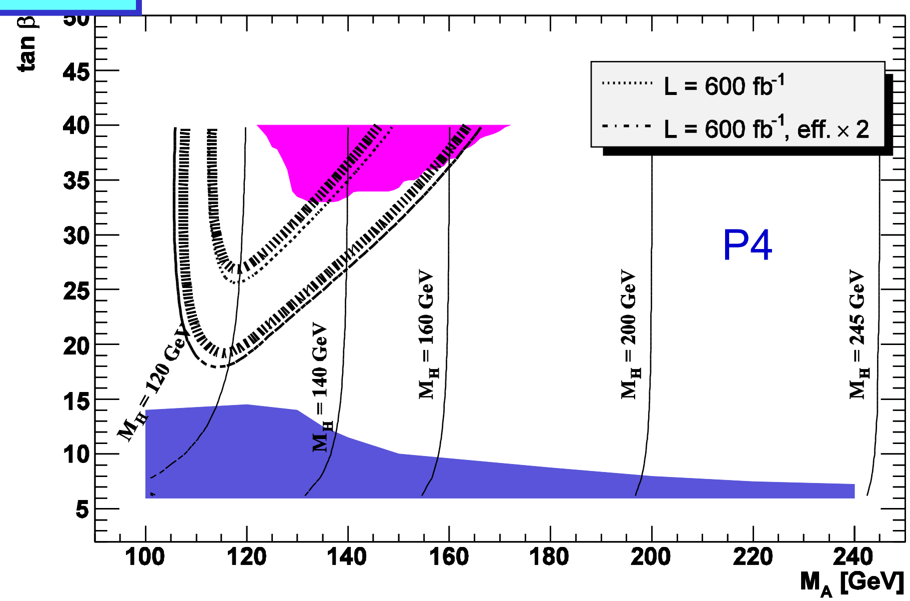
Cold Dark Matter: H→bb, tautau, 5σ-contours

H → bb





H → tautau



Determination of Higgs CP properties

Existing SM analyses for LHC:

- rely largely on the coupling of Higgs boson to heavy gauge bosons:

WBF $H \to W\,W \to ll\nu\nu$

WBF $H \to \tau\,\tau$

WBF $H \to ZZ \to 4l$

Backgrounds: $gg \to H$, WWjj(EW), WWjj(QCD)
tt, tW, Zjj(EW), Zjj(QCD)

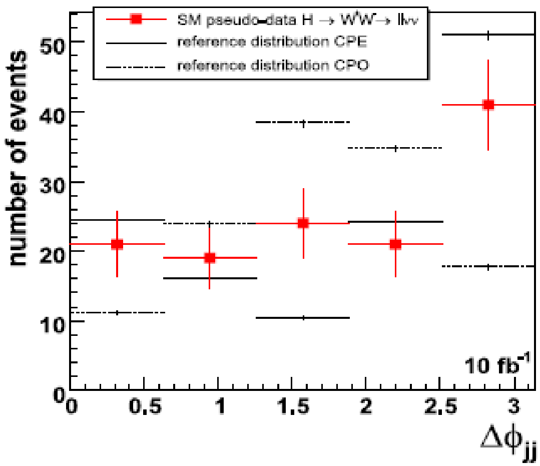
Prerequisites for these SM(-like) analyses: Higgs with

- sufficiently large HVV coupling
- sufficiently large BR($H \to VV$) – M_H >140 GeV to suppress $H \to bb$;
- possibly large BR($H \to \tau\tau$)

SM analyses of the structure of the HVV coupling: *CP-even vs. CP-odd*

[T. Plehn et al., 2001] (theory)
[V. Hankele et al., 2006] (theory)
[C. Ruwiedel et al., 2007] (experiment)

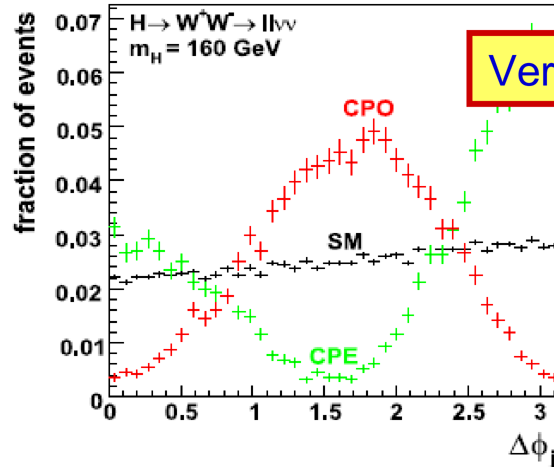
Higgs coupling structure: HWW, HVV



10 fb-1

W → llνν, M_H = 1

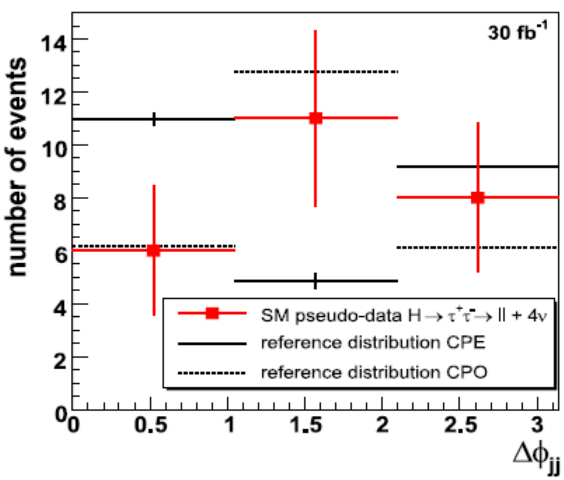
Δφjj =
Difference in azimuthal angle of two tagging jets



Very large statistics

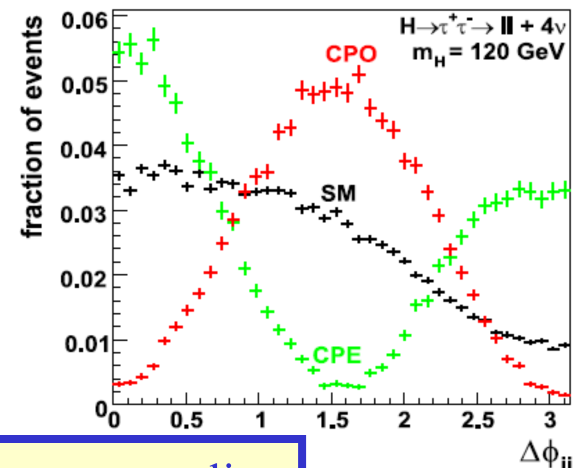
5σ - discrimination of anomalous couplings already with 10 fb-1

SM = signal with SM couplings + backgrounds, **CPE** = signal with CP-even couplings + backgrounds
CPO = signal with CP-odd couplings + backgrounds



30 fb-1

H → τ+τ- →ll+4ν, M_H = 120 GeV



3σ - discrimination of anomalous CP-even coupling

Situation in MSSM

Light Higgs: M_h < 135 GeV: too small BR($h \to VV^{(*)}$)

Heavy Higgses:

$$g_{hVV} = g_{HVV}^{\text{SM}} \times \sin(\beta - \alpha)$$
$$g_{HVV} = g_{HVV}^{\text{SM}} \times \cos(\beta - \alpha)$$
$$g_{AVV} = 0 \qquad \text{at tree-level}$$

H A

M ≈ M > 150 GeV:

β-α → π/2 => h has substantial VV coupling, but not sufficient BR(h→ττ)

H and A have negligible VV coupling

H A

M ≈ M < 130 GeV => |sin(β-α)| << 1 possible:

H has substantial VV coupling, but not sufficient BR(H→ττ)

Heavy Higgses: method relyin

Central Exclusive Diffraction!

Lig

Z

J = 0, C-even, P-even selection rule leads to a clear determination of quantum numbers of the centrally produced resonance. A few events are enough.

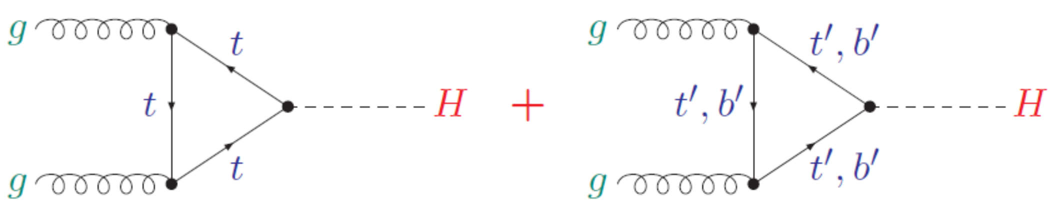
4^{th} Generation Model

LEP and Tevatron limits

Assume the SM with a 4th generation of heavy fermions

Relevant changes:

1. additional contribution to $gg \to H$:



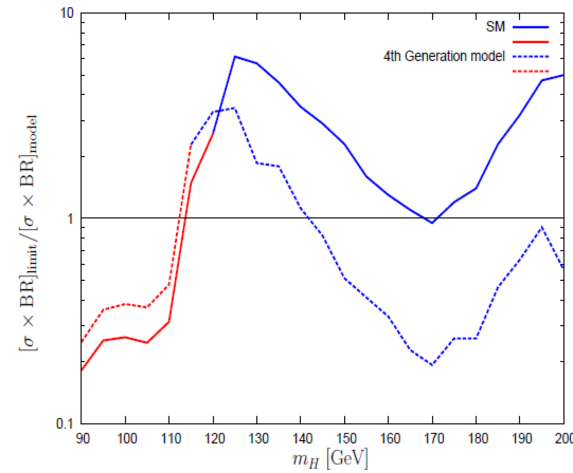
   $\Rightarrow$ factor of ~ 9 in Higgs production cross section

2. $\Rightarrow$ factor of ~ 9 in $\Gamma(H \to gg)$

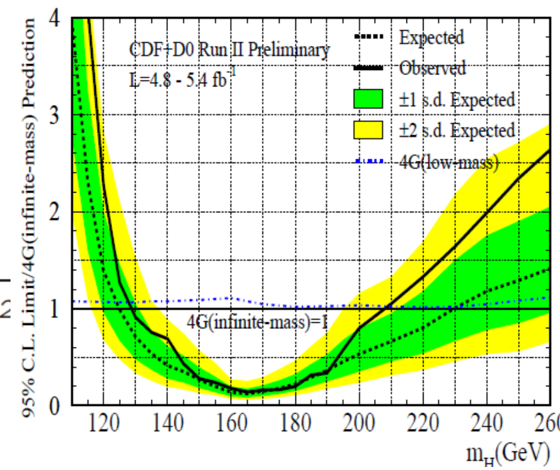
   $\Rightarrow$ reduced $\mathrm{BR}(H \to b\bar{b})$, $\mathrm{BR}(H \to \tau^+\tau^-)$

Evaluation of SM quantities with FeynHiggs
subsequent application of reduction and enhancement factors

[P. Bechtle et al., 2008]

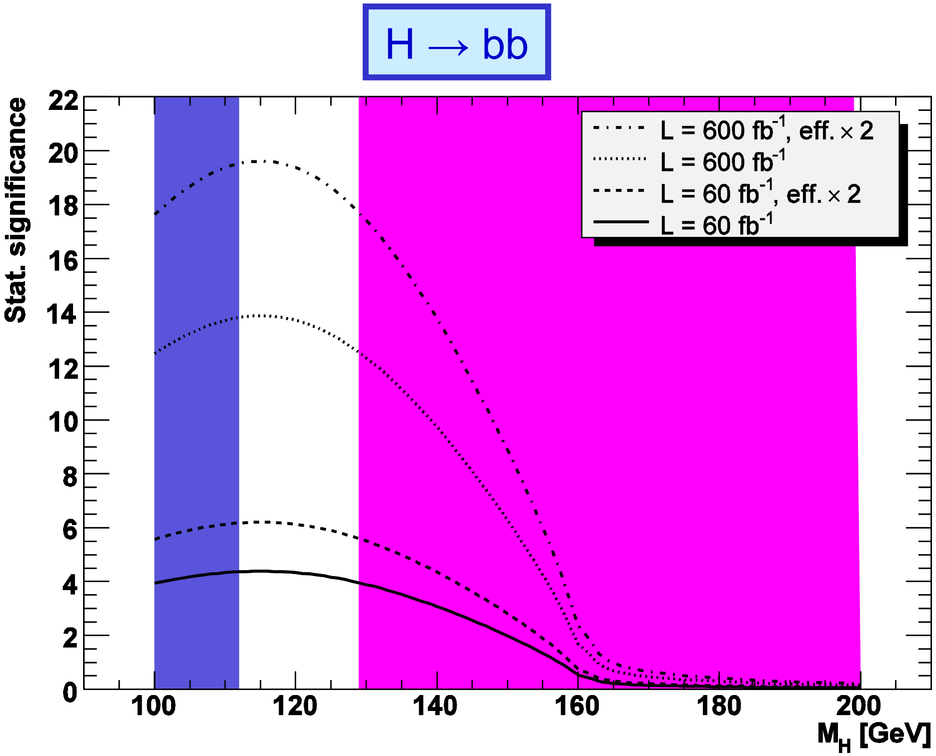


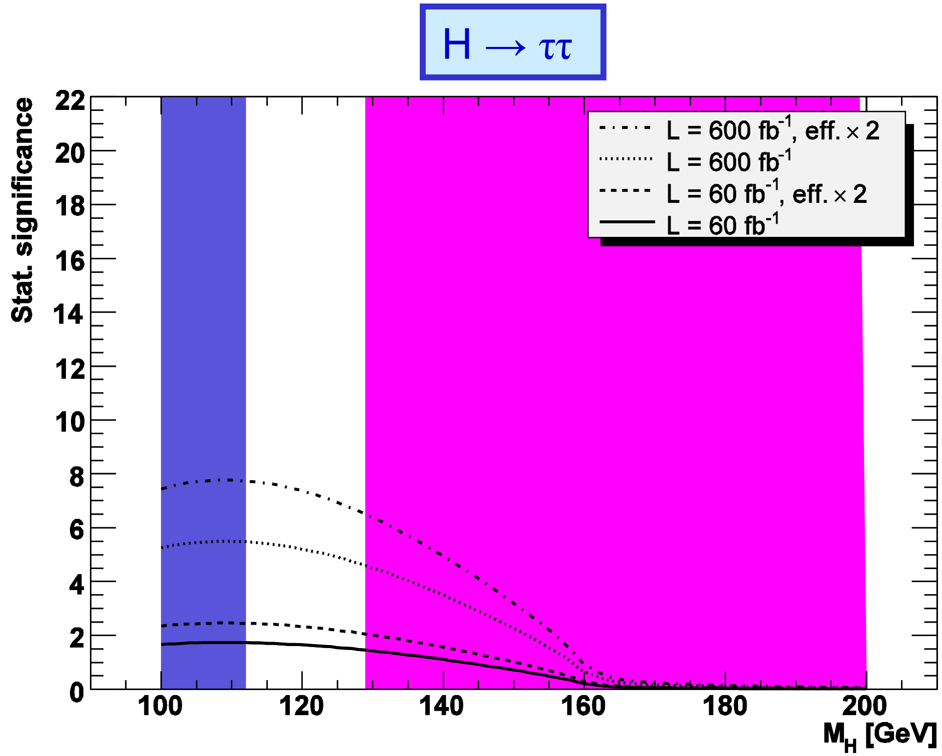
[CDF, D0, 2010]



only 112 GeV $\lesssim M_H \lesssim$ 130 GeV, $M_H \gtrsim$ 210 GeV still allowed

CED in 4th Generation Model





Good prospects for H→bb at low luminosities and for H→ττ at high luminosities.

For MH > 200 GeV: BR(H→bb, H→ττ) too small.

Summary

1) CED Higgs production in SM

- provides a moderate signal yields but it is attractive because

a few events are enough to establish the quantum numbers of a Higgs candidate. No need of coupling to vector bosons

- gives information about Hbb Yukawa coupling – which is difficult in standard searches

2) CED Higgs production in MSSM

- in MSSM the signal yields are greatly enhanced
- in MSSM it gives information about Higgs sector
- in MSSM the Higgs width may be directly measured (for large tanβ)

Update of the 2007 analysis:

- background NLO CED $gg \to bb$
- LEP/Tevatron exclusion regions (HiggsBounds)
- improved theory calculations (FeynHiggs)
- new CDM benchmark planes (similar results as for mhmax benchmark)

3) CED Higgs production in 4   Generation Model

- LEP/Tevatron searches: 112 < MH < 130 GeV allowed
- good prospects for $H \to bb$ at low lumi, for $H \to \tau\tau$ at high lumi

BACKUP SLIDES

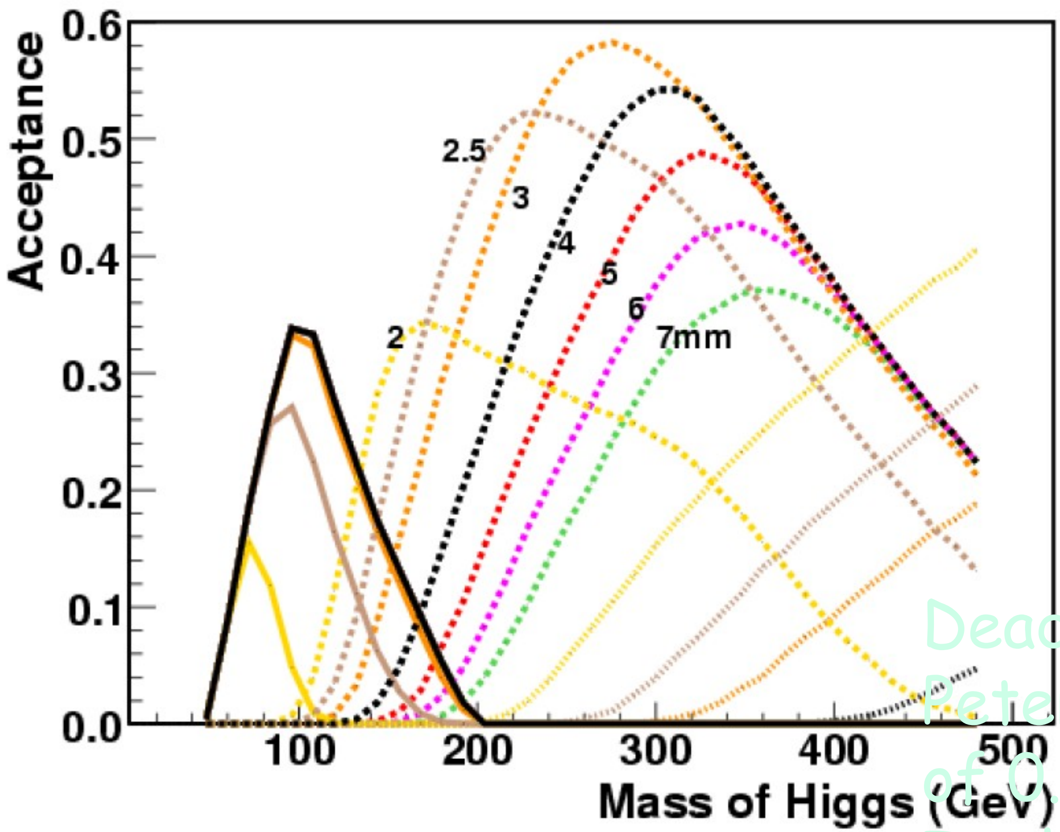
Acceptances

Acceptances depend heavily on the distance from the beam and dead space!

(if protons hit the dead space in 220 station, they are lost for 420 measurement)

Acceptance for 420+420, 420+220 and 220+220. Numbers mean total distances.

420 at 6 mm everywhere, 220 varying from 2mm to 7mm



Peter

Dead space = 1.1mm

220 at 2mm obstructs the tracking at 420 !

Dead space of 1.1 mm is too cautious.
Peter will make this plot for dead sp
of 0.5mm.
In the following analyses, dead space

15 σ**beam** ~ 1.5 mm

(thin window (400μm) + safety offset (300μm) + edge (5μm) + alignment) ~ 0.7 mm

Basics of MSSM

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)

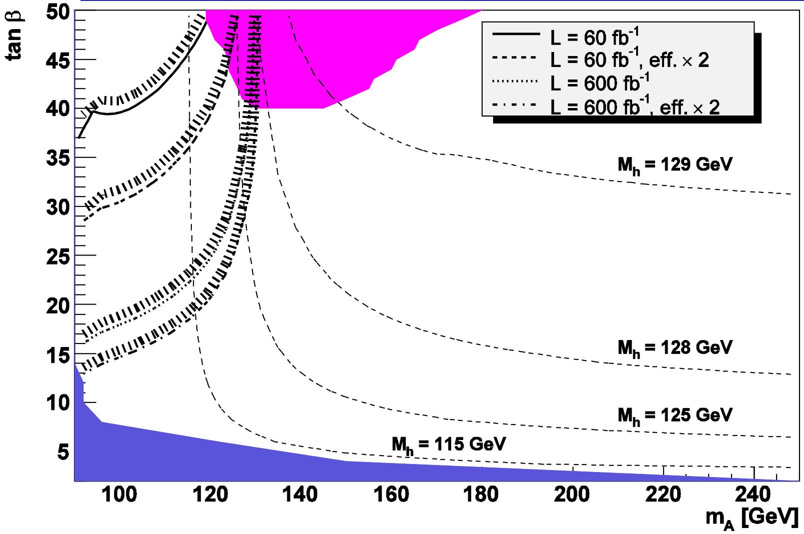
$$\tan\beta = \frac{v_2}{v_1}, \qquad M_A^2 = -m_{12}^2(\tan\beta + \cot\beta)$$

H → tau tau in MSSM

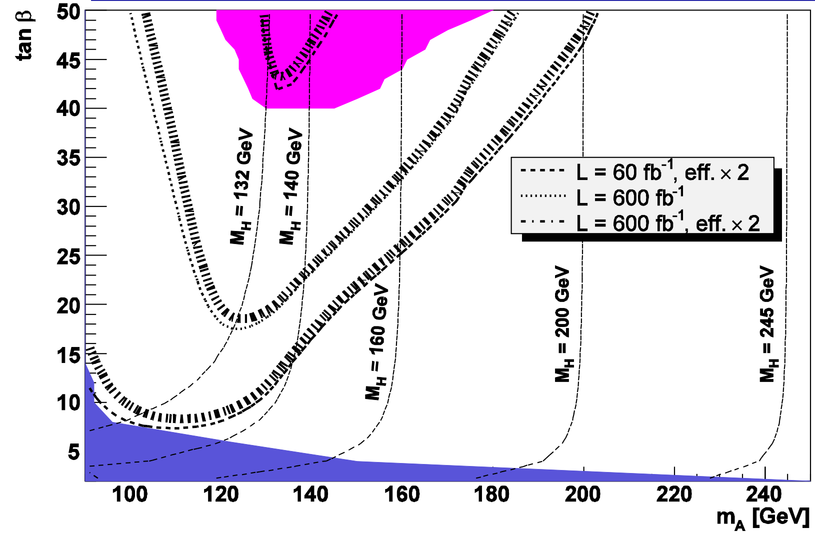
- In MSSM, BR(h,H→ττ) ~ 10%, if decays to SUSY particles not allowed
- Studied in EPJC 53 (2008) 231: the same efficiencies assumed as in the bb case
- Background: QED γγ→ll (suppressed by p_T^{prot} > 0.2 GeV)

  CEP gg→gg (suppressed by $|\eta_{j1} - \eta_{j2}|$ < 1.1 and P(g/τ)~1/500)

3σ: h→tautau, mhmax, μ=200 GeV



3σ: H→tautau, mhmax, μ=200 GeV



- In ATLAS the proper efficiencies now being estimated with full sim.
- All tau-decays studied.
- Backgrounds expected to be very low:

 - fully leptonic have high-pt leptons

 - fully hadronic have two tau-jets: very-few-particle jets going sharply back-to-back in φ

No problems expected with triggering