Studying the MSSM Higgs sector by forward proton tagging at LHC

Marek Taševský (Institute of Physics Prague)

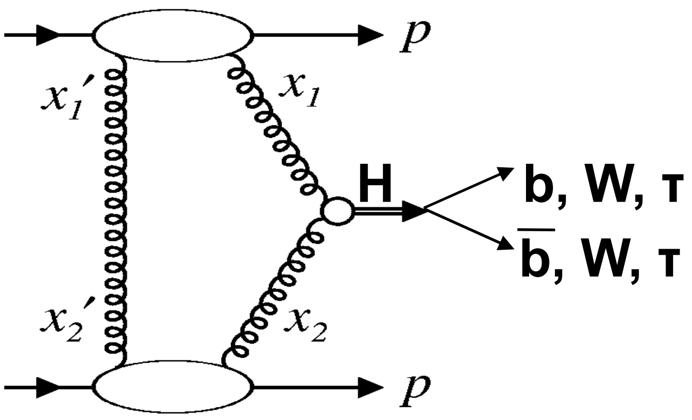
DIS 2008 conference - London 08/04 2008

Collaboration of S.Heinemeyer, V.Khoze, M.Ryskin, J.Stirling, M.T. and G.Weiglein

MSSM scan for CED H→bb/WW/tautau

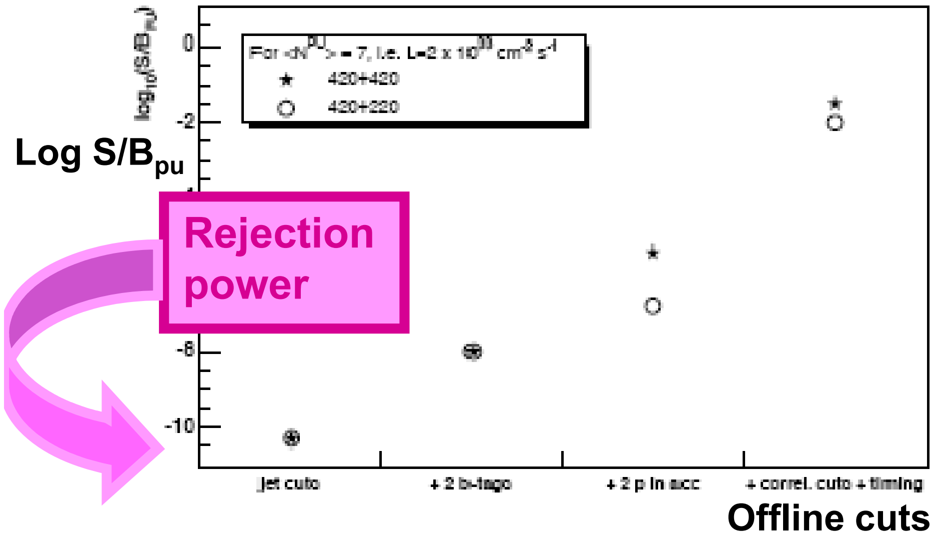
EPJC 53 (2008) 231

Central Exclusive Diffraction: Higgs production



Pile-up is issue for Diffraction at LHC!

[CMS-Totem : Prospects for Diffractive and Fwd physics at LHC]



But can be kept under control !

1) Protons remain undestroyed and can be detected in forward detectors

2) Rapidity gaps between leading protons and Higgs decay products

Advantages:

I) Roman Pots give much better mass resolution than central detector

II) $J_Z = 0$, CP-even selection rule:
  - strong suppression of QCD bg
  - produced central system is 0^{++}

III) Access to main Higgs decay modes: bb, WW, tautau → information about Yukawa coupling

CED Higgs production could provide info about SM-like Higgs and heavy states of extended Higgs sector

Disadvantages: Large Pile-up + Irreducible BG, Low signal x-section

SM Higgs discovery challenging: low signal yield ⟶ try MSSM

Introduction to MSSM

Higgs sector of the MSSM: physical states $h, H, A, H^{\pm}$

Described by two parameters at lowest order: M_{A}, $\tan\beta \equiv \frac{v_2}{v_1}$

Dominant decay mode of a light SM-like Higgs: $h \to b\bar{b}$

However: $h \to b\bar{b}$ is difficult to access in Higgs searches at the LHC ($t\bar{t}h$, $h \to b\bar{b}$, $\ldots$)

Knowledge of $hb\bar{b}$ coupling is important for determining any Higgs-boson coupling at the LHC

[*M. Dührssen, S. Heinemeyer, H. Logan, D. Rainwater, G. W., D. Zeppenfeld '04*]

Extended Higgs sectors: "typical" features

Search for heavy MSSM Higgs bosons ($M_{\mathrm{A}}, M_{\mathrm{H}} \gg M_{\mathrm{Z}}$):

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 bb and $\tau^+\tau^-$ play a crucial role

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

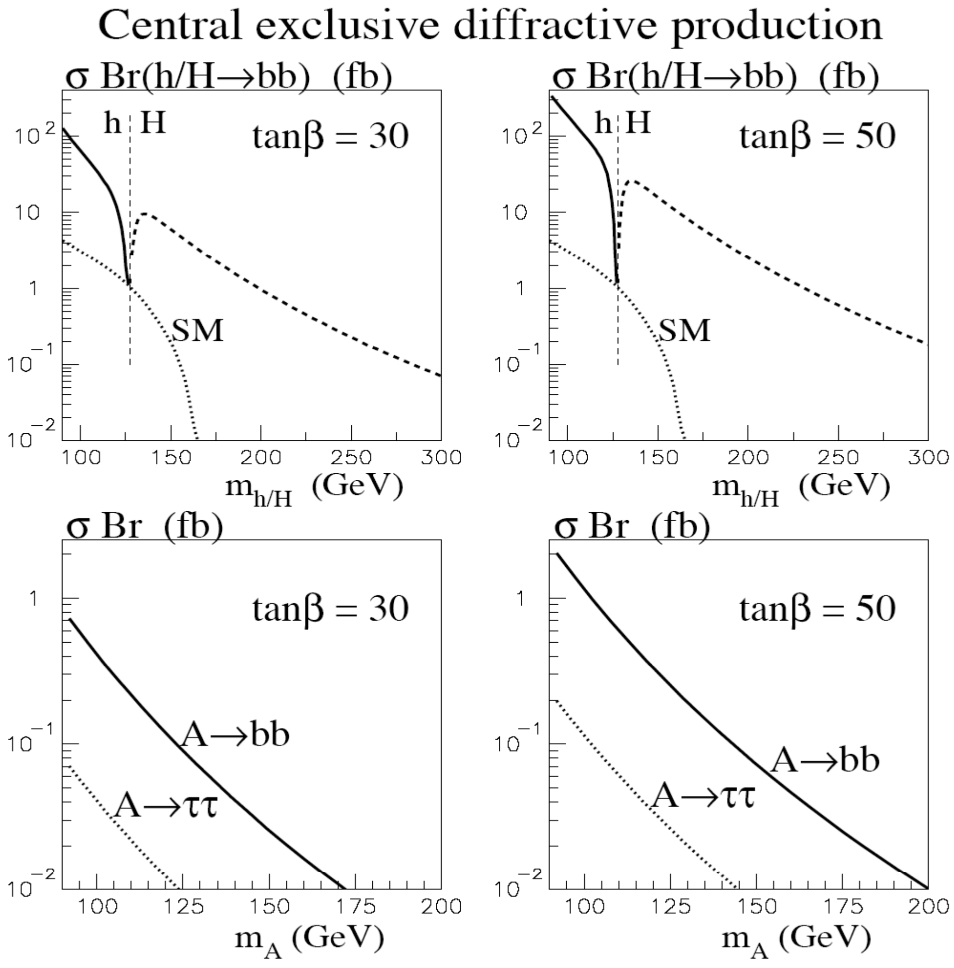
- A light Higgs with SM-like properties, couples with about SM-strength to gauge bosons
- Heavy Higgs states that decouple from the gauge bosons

MSSM and CED go quite well together

SM: Higgs discovery challenging

MSSM:
1) higher x-sections than in SM in certain scenarios and certain phase-space regions
2) the same BG as in SM

MSSM: Possibility to measure total Higgs width (high tanβ) and to distinguish between nearly degenerate Higgs states
[J. Ellis, J-S. Lee, A. Pilaftsis, ’05]



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

Enhancement in MSSM for CED

The enhancement is evaluated by comparing the CED in SM and MSSM

Ratio = $[\Gamma(H\rightarrow gg)[M,\tan\beta]*BR(H\rightarrow pp)[M,\tan\beta]]^{MSSM}$ / $\Gamma(H\rightarrow gg)[M]*$ $BR(H\rightarrow pp)[M]]^{SM}$

H = h, H, A;   p = W, b, tau; M = M_A, M_H, M_h

The cross section is calculated as $\sigma^{MSSM} = \sigma^{SM}$ *** Ratio**

σ^{SM} = KMR formula for CED production of Higgs

[Khoze, Martin, Ryskin ’00, ’01, ’02], [Bialas, Landshoff ’90], [Forshaw ’05]

All MSSM quantities obtained using FeynHiggs code (www.feynhiggs.de)
[Heinemeyer, Hollik, Weiglein ’99, ’00], [Degrassi, Heinemeyer, Hollik, Slavich, Weiglein ’03], [Frank, Hahn, Heinemeyer, Hollik, Rzehak, Weiglein ’07]

Benchmark scenarios

MSSM has very large number of parameters => introduce benchmarks in which all SUSY parameters are fixed and only M_A and tanβ are varied.
(Higgs sector of MSSM at tree level governed by M_A and tanβ [sauf M_Z and SM gauge couplings])

M_h^{max} scenario:

- Parameters chosen such that max.possible M_h as a function of tanβ is obtained (for fixed $M_{SUSY} = M_A = 1\text{TeV}$)

No-mixing scenario:

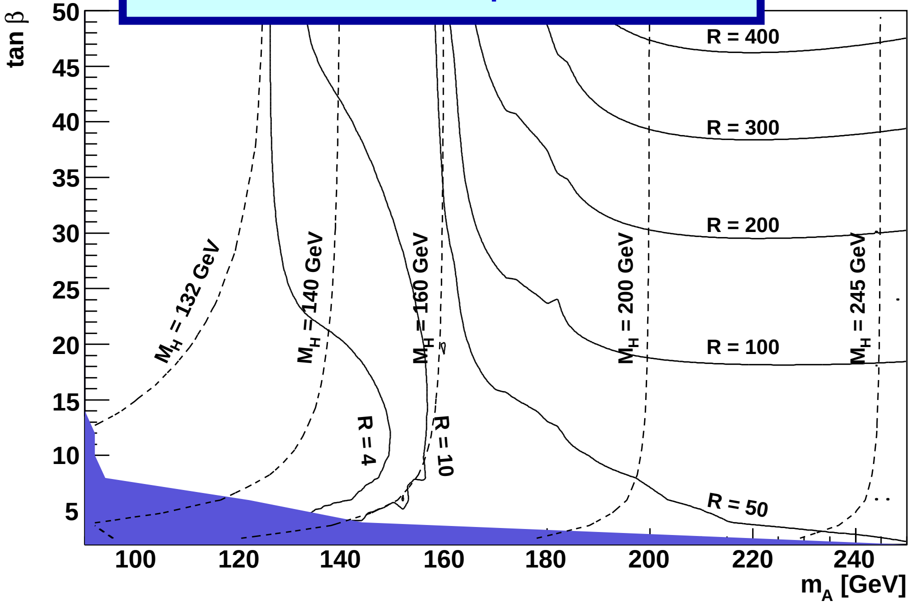
- The same as M_h^{max} but with vanishing mixing in $\tilde{t}$ sector and with higher M_{SUSY} to avoid LEP Higgs bounds

Small α_{eff} scenario:

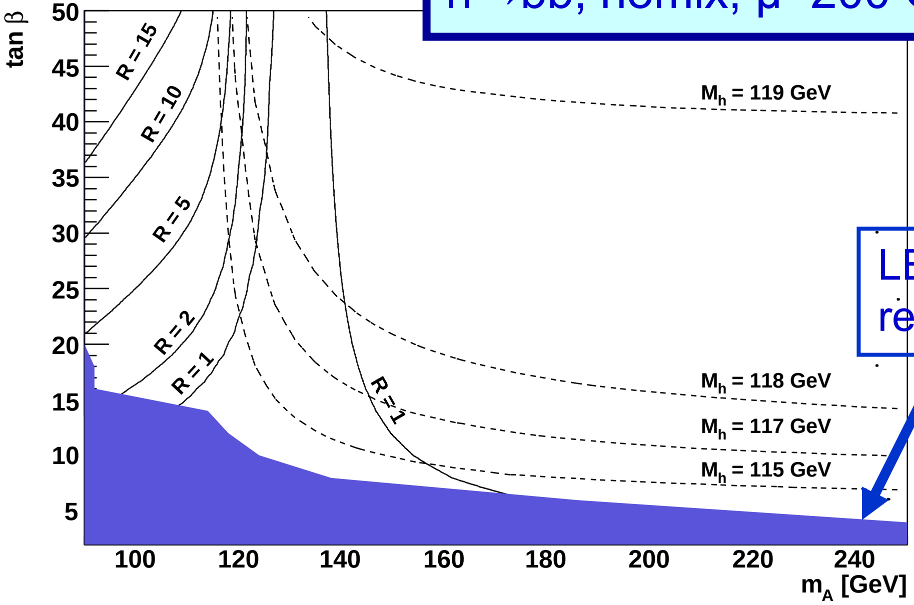
- For small α_{eff}, h→bb and h→ττ strongly suppressed (at large tanβ and not too large M_A)
- Suitable for h→WW

R=MSSM[M,tanβ] / SM[M]

H→bb, mhmax, μ=200 GeV

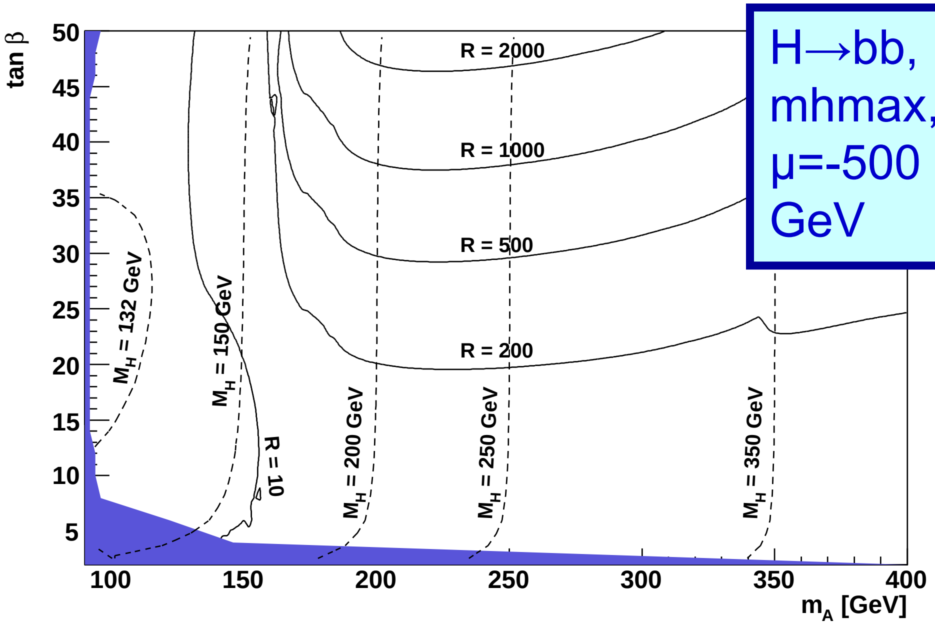


h→bb, nomix, μ=200 GeV

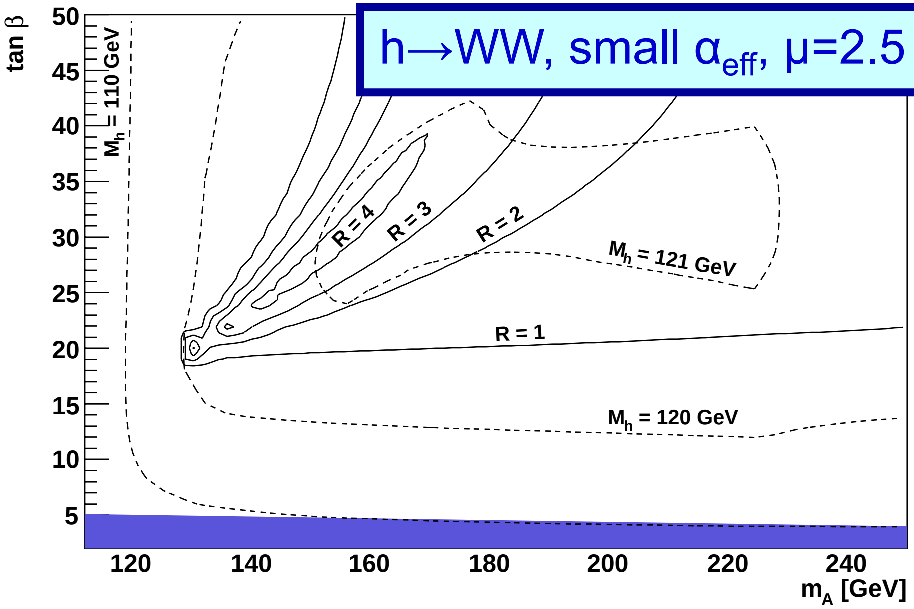


LEP exc
region

H→bb, mhmax, μ=-500 GeV



h→WW, small α_{eff}, μ=2.5 TeV



Summary on MSSM enhancement

X-sections for bb and tautau enhanced most in nomix scenario.
X-sections for WW enhanced most in small α_{eff} scenario.

Enhancement increasing with tanβ.

H→bb: up to 500 for M_H~180—300 GeV and tanβ ~ 50 (2000 for μ=-500 GeV)
h→bb (tautau): up to 15 for M_h~ 115 GeV and tanβ ≈ 50
h→WW: max. 4 for M_h~120—123 GeV and tanβ ~ 30

Signal (statistical) significance

Signal significance S_{cP} found by solving equations (using program scpf by S.Bityukov)

$\beta = 1/\sqrt{2\pi}\int^{\infty}_{S_{cP}} e^{x*x/2}dx$, $\beta = \Sigma^{\infty}_{S+B}$ Pois(i|B) (Type II error)

CED Signal and CED Bg calculated using KMR formulas and FeynHiggs code:

$S = Lumi*\sigma^{MSSM}*[\varepsilon_{420} *I(\Delta M_{420}) + \varepsilon_{comb} *I(\Delta M_{comb})]$, I = reduction due to mass window

$B = Lumi*[\varepsilon_{420}* \int\sigma^{BG}\Delta M_{420} + \varepsilon_{comb}* \int\sigma^{BG}\Delta M_{comb}]$

S and B taken without syst.errors

σ^{BG} : Only exclusive processes considered because:

1) Contribution of inclusive processes considered to be negligible after including new HERA Pomeron pdfs – see Valery's talk at HERA-LHC 2007
2) Contribution of PU bg assumed to be negligible anticipating a big progress in developing cuts suppressing PU bg, such as track mult. and vtx rejection. Note also that if SM Higgs exists, it will be first measured by standard techniques and the knowledge of its mass will be greatly exploited in diffractive searches.

ε_{420}, ε_{comb} **: selection efficiencies of 420+420 and 420+220 RP config. taken from CMS/Totem Note CERN-LHC 2006-039/G-124 [***Prospects for diffractive and forward physics at the LHC*****]**

Experimental analysis: Selection cuts for H→bb

Experimental analysis using RPs at 220m (from Totem) and foreseen FP420 devices at CMS side (see CMS-Totem document for full detail)

1) RP acceptances: (420.and.420).or.(420.and.220).or.(220.and.420).or.(220.and.220)

Acc(ξ,t,φ): $0.002 < \xi < 0.2$, $0.001 < t < 10$ GeV^2, $0 < \varphi < 2\pi$

2) jets: either two b-tagged jets or two jets with at least one b-hadron decaying into μ

$E_{T1} > 45$ GeV, $E_{T2} > 30$ GeV, $|\eta_{1,2}| < 2.5$, $|\eta_1 - \eta_2| < 1.1$, $2.85 < |\varphi_1 - \varphi_2| < 3.43$

3) Kinematics constraints – matching criteria: $0.8 < M_{2j}/M_{RP} < 1.2$, $|\xi_{2j} - \xi_{RP}| < 0.3$

4) L1 triggers: OR between: a) 220-single side .and. 2jets ($E_T > 40$ GeV)

b) 1 jet ($E_T > 40$ GeV) + muon, c) 2jet $E_T > 90$ GeV, d) leptonic triggers

5) Additional PU bg suppressors: fast timing detector, track multiplicity

Conservatively assuming the same selection efficiencies for H→tautau

Four integrated luminosity scenarios

1. **L = 60fb^{-1}:** 30 (ATLAS) + 30 (CMS): 3 yrs with L=10^{33}cm^{-2}s^{-1}

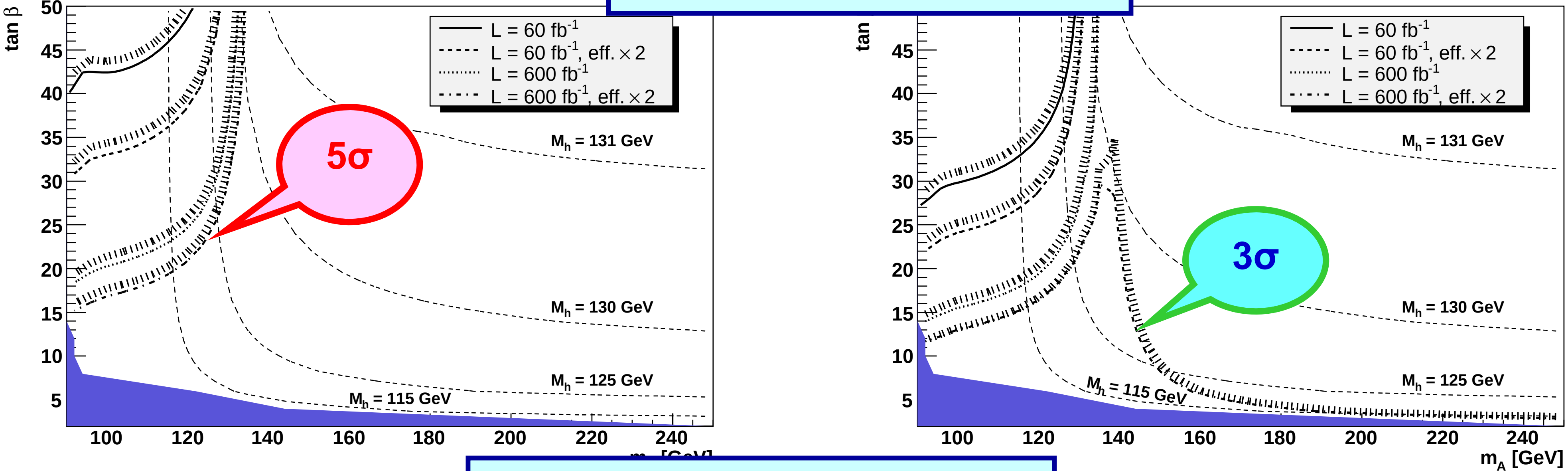
2. **L = 60fb^{-1}, effx2:** like 1. but asssuming doubled exper. eff.

3. **L = 600fb^{-1}:** 300 (ATLAS) + 300 (CMS) : 3 yrs with L=10^{34}cm^{-2}s^{-1}

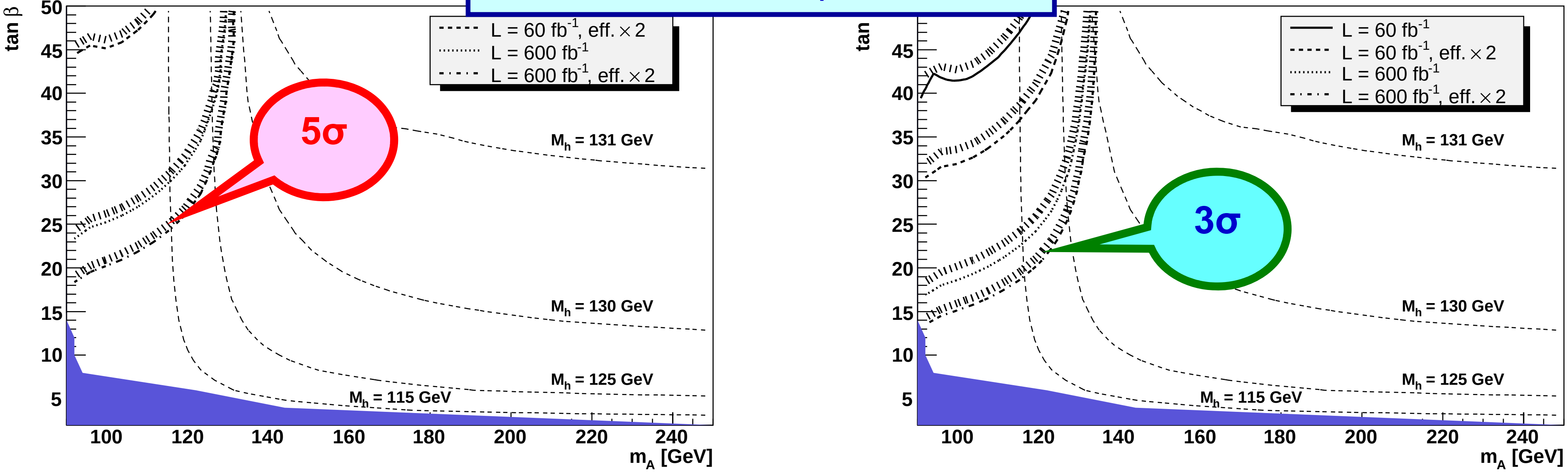
4. **L = 600fb^{-1},effx2:** like 3. but assuming doubled exper. eff.

Stat.significance for h→bb (tautau): from 5 to 3

h→bb, mhmax, μ = 200 GeV



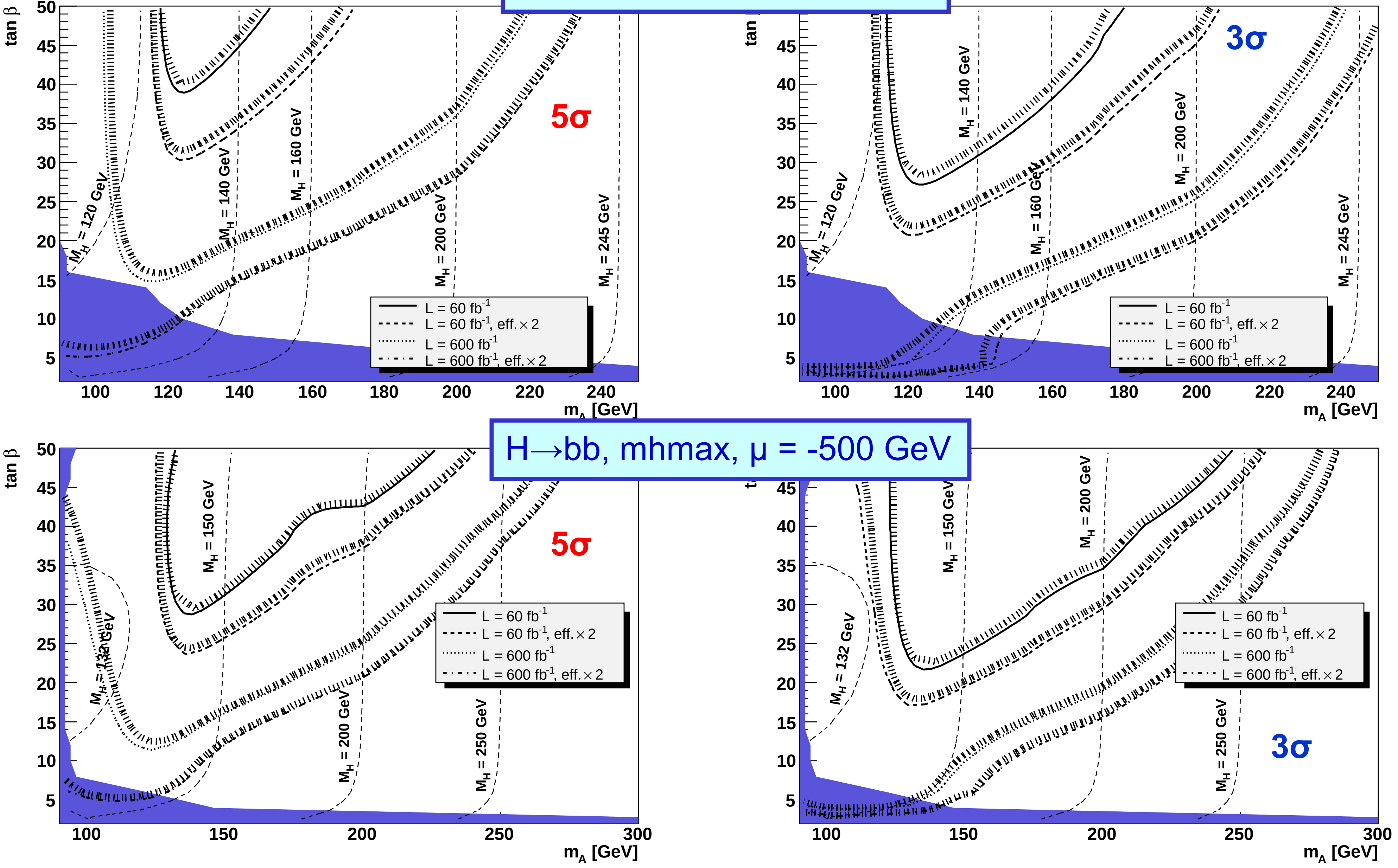
h→tautau, mhmax, μ = 200 GeV



Stat. significance for H→bb: from 5 to 3

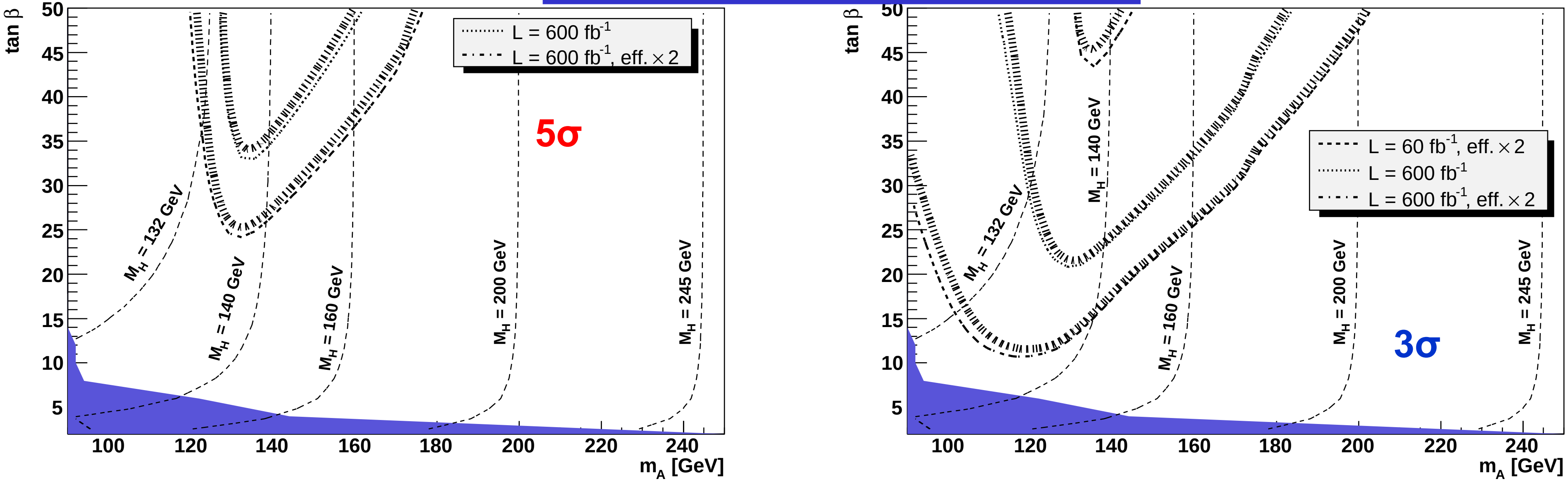
H→bb, nomix, μ = 200 GeV

H→bb, mhmax, μ = -500 GeV



Stat.significance for H→tautau: from 5 to 3

H→tautau, mhmax, μ = 200 GeV



Discovery numbers ($\sigma>5.0$) for L = 60 fb^{-1}

- **h→bb: mhmax, μ=200 GeV:**

M_h~90 GeV, tanβ=40: S=29, B=24, S=46

M_h~90 GeV, tanβ=50: S=42, B=30, S=67

M_h~110 GeV, tanβ=44: S=32, B=32, S=51

M_h~120 GeV, tanβ=50: S=32, B=28, S=48

- **H→bb: mhmax, μ=200 GeV:**

null

- **H→bb: mhmax, μ=-500 GeV:**

M_H~138 GeV, tanβ=30: S=25, B=14, S=38

M_H~138 GeV, tanβ=50: S=124, B=65, S=175

h→bb: nomix, μ=200 GeV:

M_h~90 GeV, tanβ=36: S=30, B=24, S=46

M_h~90 GeV, tanβ=50: S=57, B=36, S=90

M_h~108 GeV, tanβ=40: S=57, B=33, S=52

M_h~113 GeV, tanβ=50: S=41, B=35, S=61

H→bb: nomix, μ=200 GeV:

M_H~125 GeV, tanβ=40: S=28, B=21, S=43

M_H~125 GeV, tanβ=50: S=43, B=26, S=64

H→bb: nomix, μ=-500 GeV:

M_H~125 GeV, tanβ=34: S=28, B=21, S=42

M_H~125 GeV, tanβ=50: S=67, B=35, S=99

In optimum mass windows

Total signal

The numbers S and B for L=120, 600, 1200 obtained by scaling the above by 2,10,20.

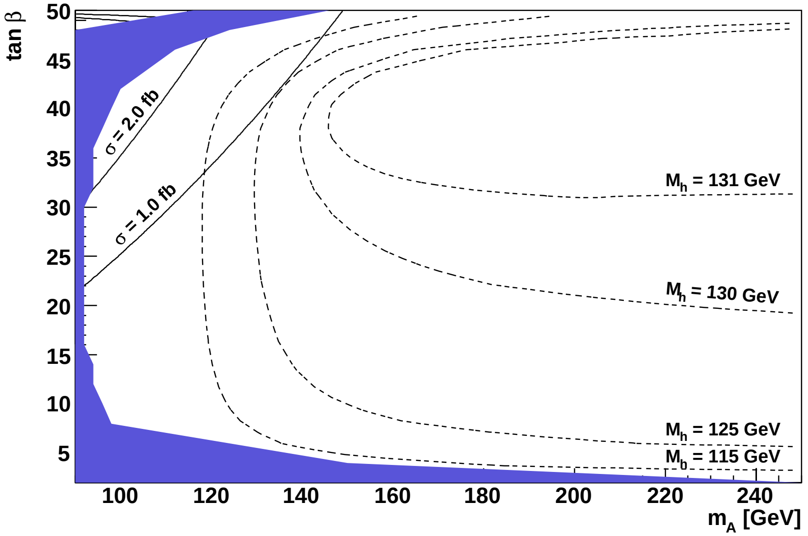
Semi-exclusive CP-odd A production

CED production of pseudoscalar A is strongly suppressed by P-even selection rule.

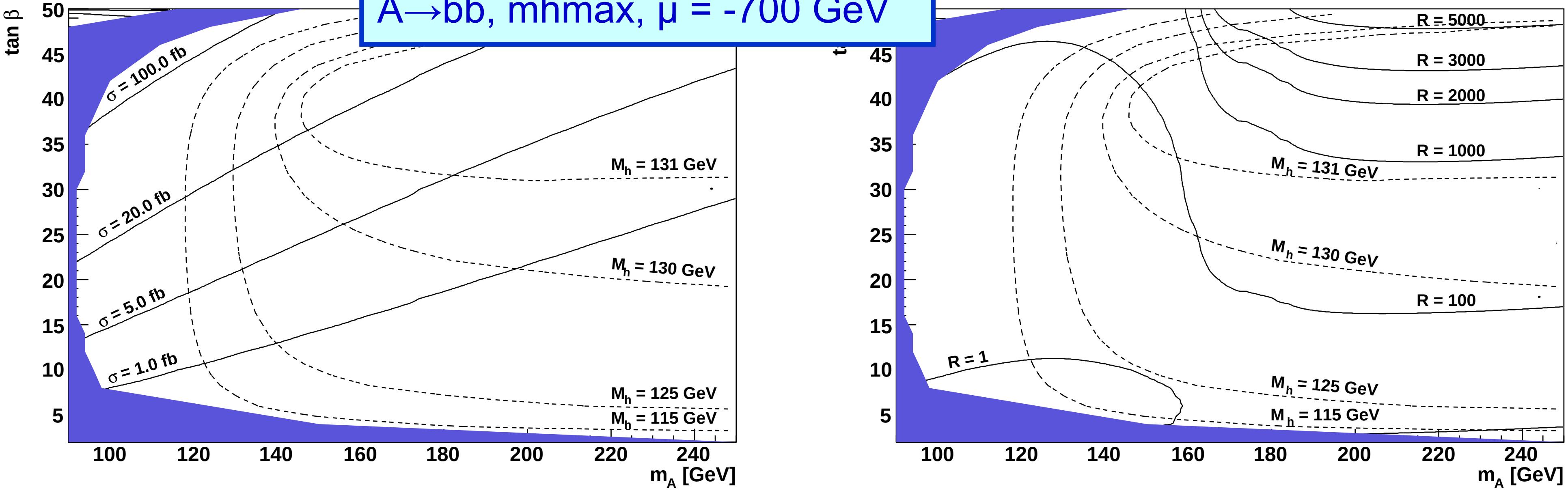
Consider 'semi-exclusive' A production:
$pp \to X + H,A + Y$ **where H,A separated by large rap.gaps from proton remnants X and Y.**

Large x-section than CED but also larger QCD bg.

A→tautau, mhmax, μ = -700 GeV



A→bb, mhmax, μ = -700 GeV



Conclusions

- Detailed analysis of prospects for CED production of CP-even Higgs bosons, pp→p + H,h + p.

- **h→bb**: almost complete coverage of M_A-tanβ plane at 3σ level at $L=600fb^{-1}$, effx2
  CED channel may yield crucial information on bottom Yukawa coupling and CP properties
- **H→bb:** discovery of a 140 GeV Higgs boson for all values of tanβ with $L=600fb^{-1}$, effx2

 - In high tanβ region: discovery reach beyond M_H~200 GeV also for lower lumi

- Semi-exclusive production of A looks challenging

If standard techniques to search for SM Higgs fail, then the diffractive MSSM search may become the Higgs discovery project.

At high enough tanβ, the MSSM Higgs may be distinguished from the SM Higgs by a broader mass spectrum.

BACKUP SLIDES

Selection cuts for H->bb at mh=120 GeV

cut 1 $= \mathrm{N_{jet}} > 1$

cut 2 $= \mathrm{E_{T,jet1} * JES} > 45\ \mathrm{GeV} \quad \wedge \quad \mathrm{E_{T,jet2} * JES} > 30\ \mathrm{GeV}$

cut 3 $= |\eta_{\mathrm{jet1}}| < 2.5 \quad \wedge \quad |\eta_{\mathrm{jet2}}| < 2.5$

cut 4 = $|\eta_{jet1} - \eta_{jet2}| < 1.1$ – equiv. to $60° < \eta_{jet1,2} < 120°$ in Higgs cms (used in KMR formulas)

cut 5 $= 2.85 < |\phi_{\mathrm{jet1}} - \phi_{\mathrm{jet2}}| < 3.43$

cut 7 $= 0.85 < \mathrm{M_{dijet}/M_{420}} < 1.15,\ 0.8 < \mathrm{M_{dijet}/M_{comb}} < 1.2$

cut 9 $= 118 < \mathrm{M_{420}} < 122, \quad 115 < \mathrm{M_{comb}} < 125$

cut 10 = both jets b-tagged (Discr > 1.0)

cut 11 $= |\xi^{\mathrm{L}}_{\mathrm{jet}} - \xi^{\mathrm{R}}_{420}|/\xi^{\mathrm{R}}_{420} < 0.3 \quad \wedge \quad |\xi^{\mathrm{R}}_{\mathrm{jet}} - \xi^{\mathrm{L}}_{420}|/\xi^{\mathrm{L}}_{420} < 0.3,$

$|\xi^{\mathrm{L}}_{\mathrm{jet}} - \xi^{\mathrm{R}}_{\mathrm{comb}}|/\xi^{\mathrm{R}}_{\mathrm{comb}} < 0.3 \quad \wedge \quad |\xi^{\mathrm{R}}_{\mathrm{jet}} - \xi^{\mathrm{L}}_{\mathrm{comb}}|/\xi^{\mathrm{L}}_{\mathrm{comb}} < 0.3,$

$0.002 < \xi_{420} < 0.04 \quad \wedge \quad 0.002 < \xi_{\mathrm{comb}} < 0.04$

cut L1 $= (\mathrm{Acc}^{\mathrm{L}}_{220} > 0 \vee \mathrm{Acc}^{\mathrm{R}}_{220} > 0) \quad \wedge \quad (\mathrm{E_{T,jet1,2}} > 40\ \mathrm{GeV})$

Efficiencies for SM Γ(H→gg)~MeV

Mh [GeV]	Acc_{420}	Acc_{comb}	Acc_{220}	ε_{420}	ε_{comb}	ε_{220}
100	0.37	0.13	0.0	0.012	0.008	0.0
120	0.31	0.25	0.0	0.017	0.025	0.0
140	0.25	0.37	0.0	0.016	0.051	0.0
160	0.19	0.49	0.0	0.015	0.076	0.0
180	0.14	0.60	0.0	0.012	0.096	0.0
200	0.09	0.69	0.0	0.004	0.11	0.0
300	0.0	0.76	0.13	0.0	0.125	0.02

Optimum mass windows

To get high stat.significance but also reasonable signal statistics, we need to choose an optimum mass window.

S ~ $\Gamma(H \to gg)$ - increases with increasing tanβ:

Mass spectrum at large tanβ is then a convolution of Breit-Wigner function with Gaussian function given by RP resolution => optimum mass window thus depends on $\Gamma(H \to gg)$ and mass (or tanβ and mass).

B: depends linearly on the mass window

A natural choice: ΔM_{420} = 2*sqrt(($\sigma^M{}_{420})^2 + \Gamma^2$), ΔM_{comb} = 2*sqrt(($\sigma^M{}_{comb})^2 + \Gamma^2$),
Syst.cross-check:
ΔM_{420} = sqrt((2.7$\sigma^M{}_{420})^2$ + (1.5$\Gamma)^2$), ΔM_{comb} = sqrt((2.7$\sigma^M{}_{comb})^2$ + (1.5$\Gamma)^2$),

Both options give very similar results, the former gives reduction $I_{420}=I_{comb}\sim0.67$.

Mass spectra for different Γ(H→gg): ExHuMe