Studying the MSSM Higgs Sector by Forward Proton Tagging at the LHC

Georg Weiglein

IPPP Durham

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Based on collaboration with *S. Heinemeyer, V.A. Khoze, M.G. Ryskin, W.J. Stirling, M. Tasevsky*

- Introduction
- Prospects for $h, H \to b\bar{b}, \tau^+\tau^-$ channels in CED production
- Pseudoscalar Higgs production in diffractive processes
- Conclusions

Introduction

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

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Precise information on the couplings, spin, $\mathcal{CP}$ properties, etc. of a Higgs candidate will be crucial for

– determining the nature of the detected particle

– experimentally verifying the Higgs mechanism

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

$\Rightarrow$ no HVV coupling

$\Rightarrow$ no Higgs production in weak boson fusion

$\Rightarrow$ no decay $H \to ZZ \to 4\mu$

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

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

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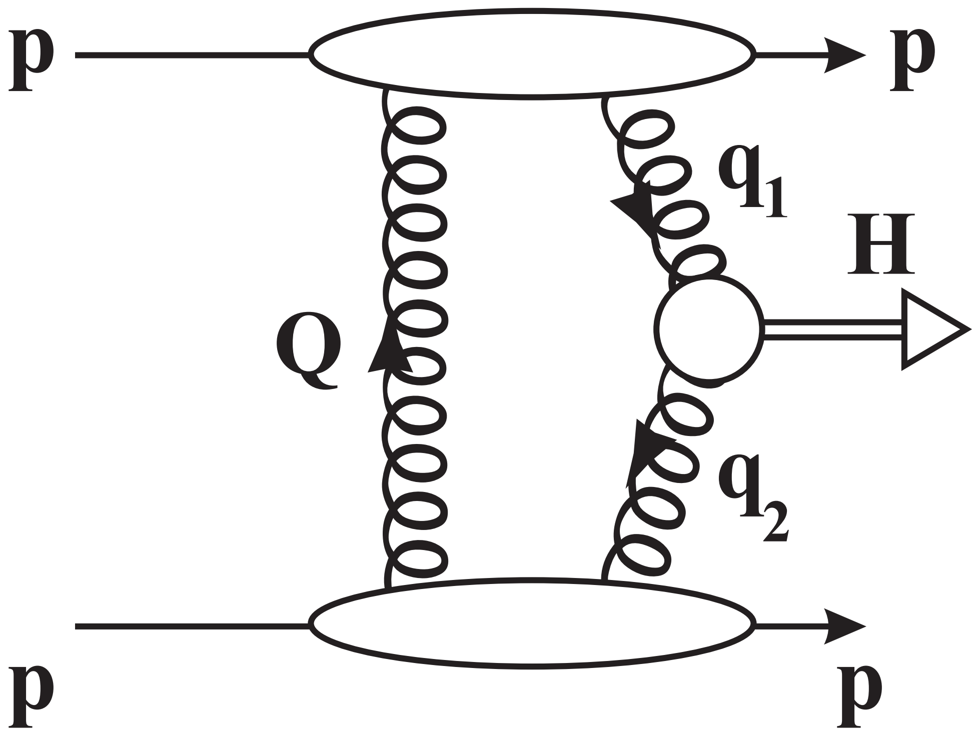
"Typical" features of models with an extended Higgs sector:

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

Central exclusive diffractive (CED) Higgs production at the LHC, $pp \to p \oplus H \oplus p$



Protons remain undestroyed, forward proton tagging in "roman pot" (RP) detectors

$\Rightarrow$ determination of final state kinematics

Exchange of colour-singlet

$\Rightarrow$ no hadronic activity between outgoing protons and Higgs decay products

CED Higgs production at the LHC

$J_Z = 0$, $\mathcal{CP}$-even selection rule

$\Rightarrow$ Strong suppression of QCD background

Information about quantum numbers of produced state

Reconstruct mass of produced state from proton momenta

$\Rightarrow$ Excellent mass resolution possible, independently of decay mode of produced state

Access to main Higgs decay modes: $H \to b\bar{b}, WW, \tau^+\tau^-$

$\Rightarrow$ Information about bottom Yukawa coupling

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$\Rightarrow$ CED Higgs production could provide crucial information on SM-like Higgs and heavy states of extended Higgs sector

MSSM: possibility to measure total Higgs width (high $\tan\beta$) and to distinguish between nearly degenerate Higgs states

[*J. Ellis, J.-S. Lee, A. Pilaftsis '05*]

Prospects for $h, H \to b\bar{b}, \tau^+\tau^-$ channels in CED production

Experimental analyis:

FP 420 project: proton taggers at ± 420 m around ATLAS, CMS

Combination with foreseen proton detectors at ± 220 m

$\Rightarrow$ Coverage of fractional momentum loss of the proton in the range 0.002–0.2

Collect information from all possible configurations:
$420 + 420$, $420 + 220$ or $220 + 420$, $220 + 220$

Selection criteria for $h, H \to b\bar{b}$ channel:

require either two b-tagged jets or two jets with at least one b-hadron decaying into a muon

Assume (conservatively) the same selection efficiencies for $h, H \to \tau^+\tau^-$ channel

Level 1 trigger conditions

- Single-sided 220 m RP and at least two jets, each with $E_{\mathrm{T}} > 40\ \mathrm{GeV}$, measured in the central detector
- A jet with $E_{\mathrm{T}} > 40\ \mathrm{GeV}$ and at least one muon with $E_{\mathrm{T}} > 3\ \mathrm{GeV}$, both measured in the central detector
- At least two jets each with $E_{\mathrm{T}} > 90\ \mathrm{GeV}$ measured in the central detector
- leptonic triggers, requiring electrons or muons in the central detector

Background from pile-up events

Main experimental challenge at high instantaneous luminosity ($10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$): pile-up events that contain protons within the acceptances of the RPs

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Detailed studies are ongoing in ATLAS and CMS, further work needed

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Possible handles against pile-up background:

fast timing detectors, precise vertex detectors, different track multiplicity properties of signal and pile-up events, kinematic reconstruction using whole information from proton 4-momenta

Signal cross sections and considered luminosity scenarios

Predictions for cross section of SM Higgs production

[*V.A. Khoze, A.D. Martin, M. Ryskin ’00, ’01, ’02*]

[*A. Bialas, P.V. Landshoff ’90*]

[*J. Forshaw ’05*]

rescaled with $\Gamma(h/H \to gg)$ and decay branching ratios in the MSSM obtained with *FeynHiggs*

[*S. Heinemeyer, W. Hollik, G. W. ’99, ’00*]

[*G. Degrassi, S. Heinemeyer, W. Hollik, P. Slavich, G. W. ’03*]

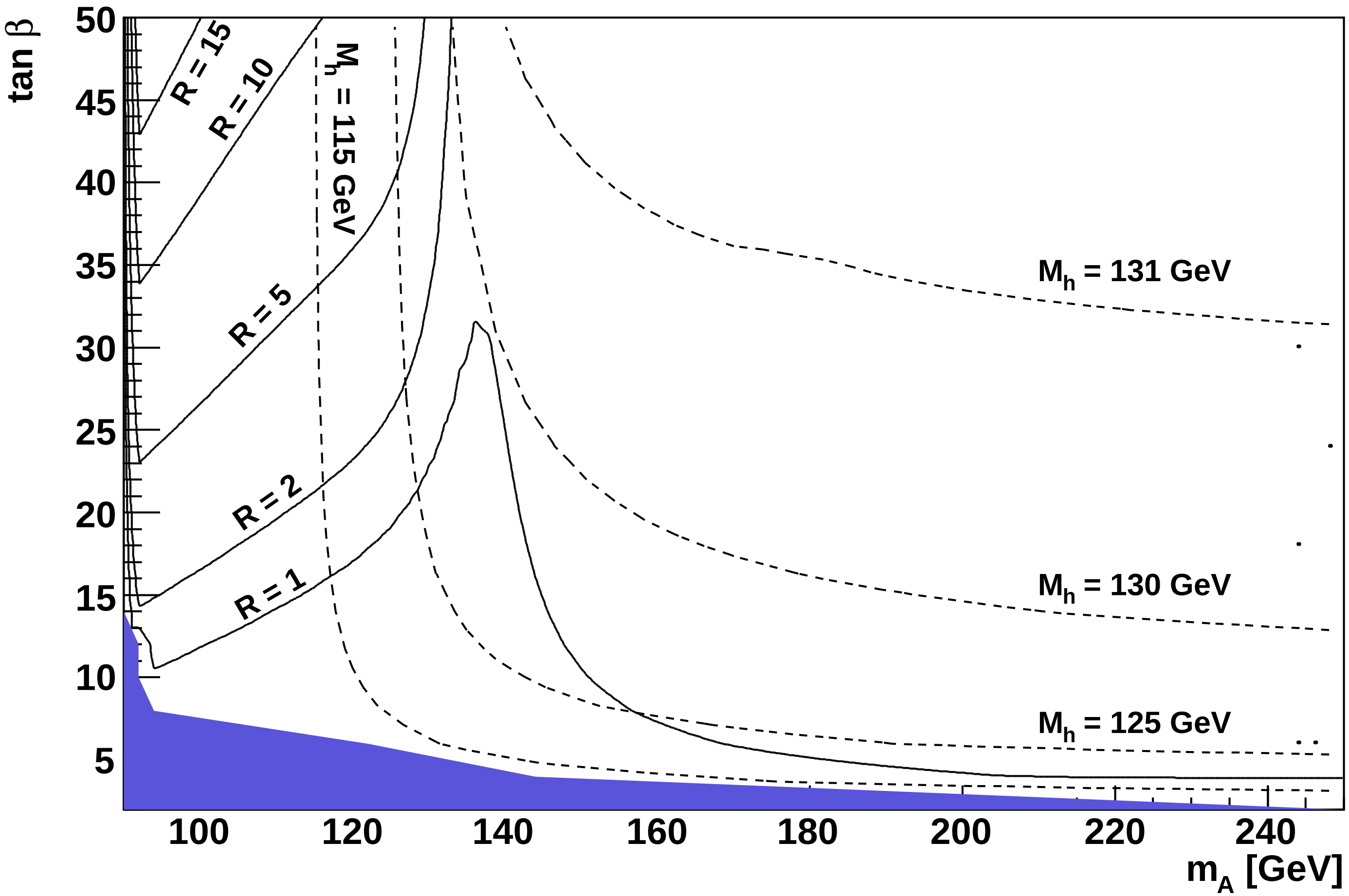
[*M. Frank, T. Hahn, S. Heinemeyer, W. Hollik, H. Rzehak, G. W. ’07*]

Analyses done for four luminosity scenarios:

$60~\text{fb}^{-1}$, $60~\text{fb}^{-1} \times 2$, $600~\text{fb}^{-1}$, $600~\text{fb}^{-1} \times 2$

Ratio of signal rate for the light MSSM Higgs boson over the SM rate in the $h \to b\bar{b}$ channel

m_h^{max} benchmark scenario:



⇒ Large enhancement possible for relatively small M_A and large $\tan\beta$

5σ discovery contours for CED production of the light MSSM Higgs boson in the $h \to b\bar{b}$ channel

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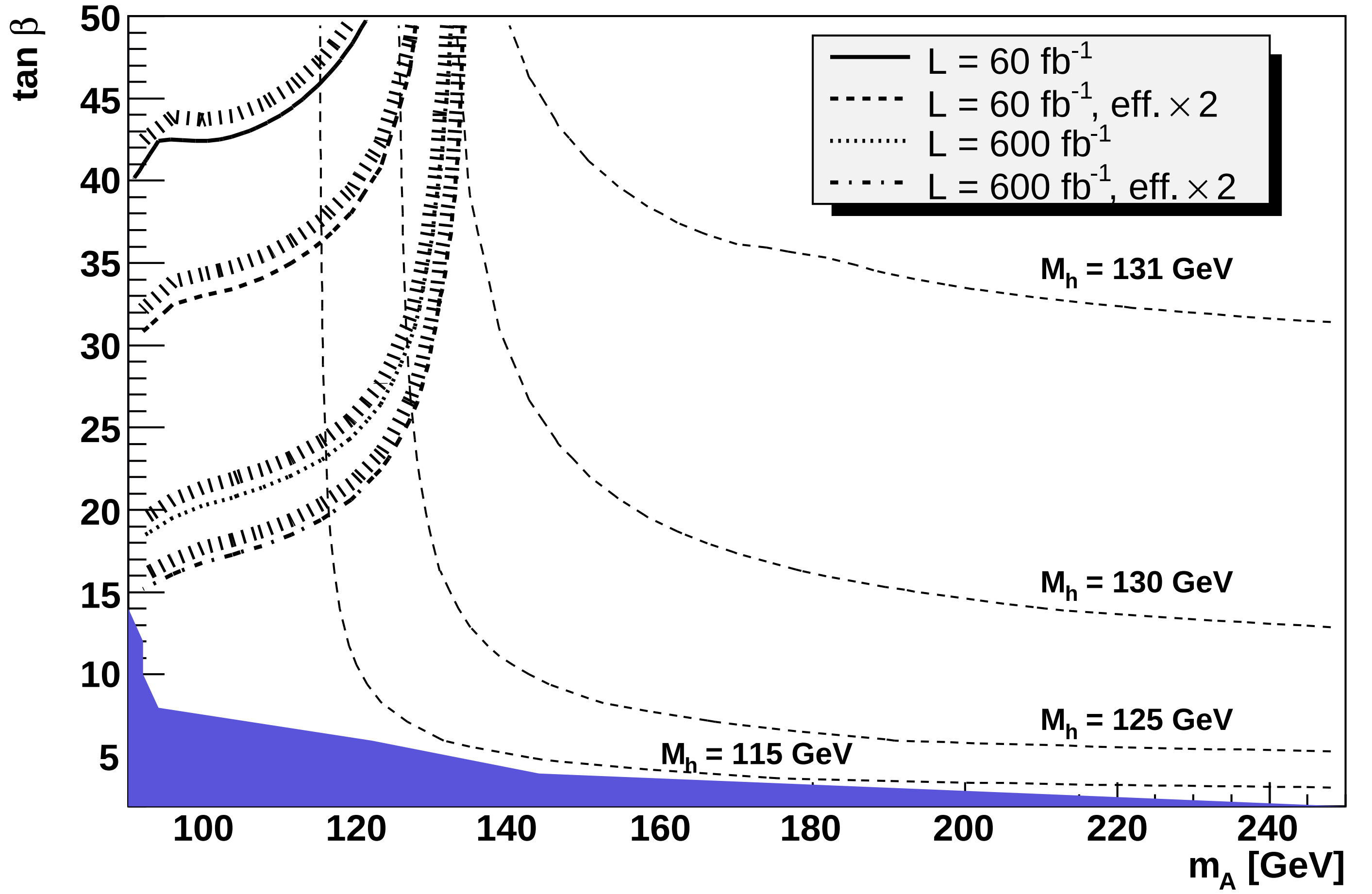
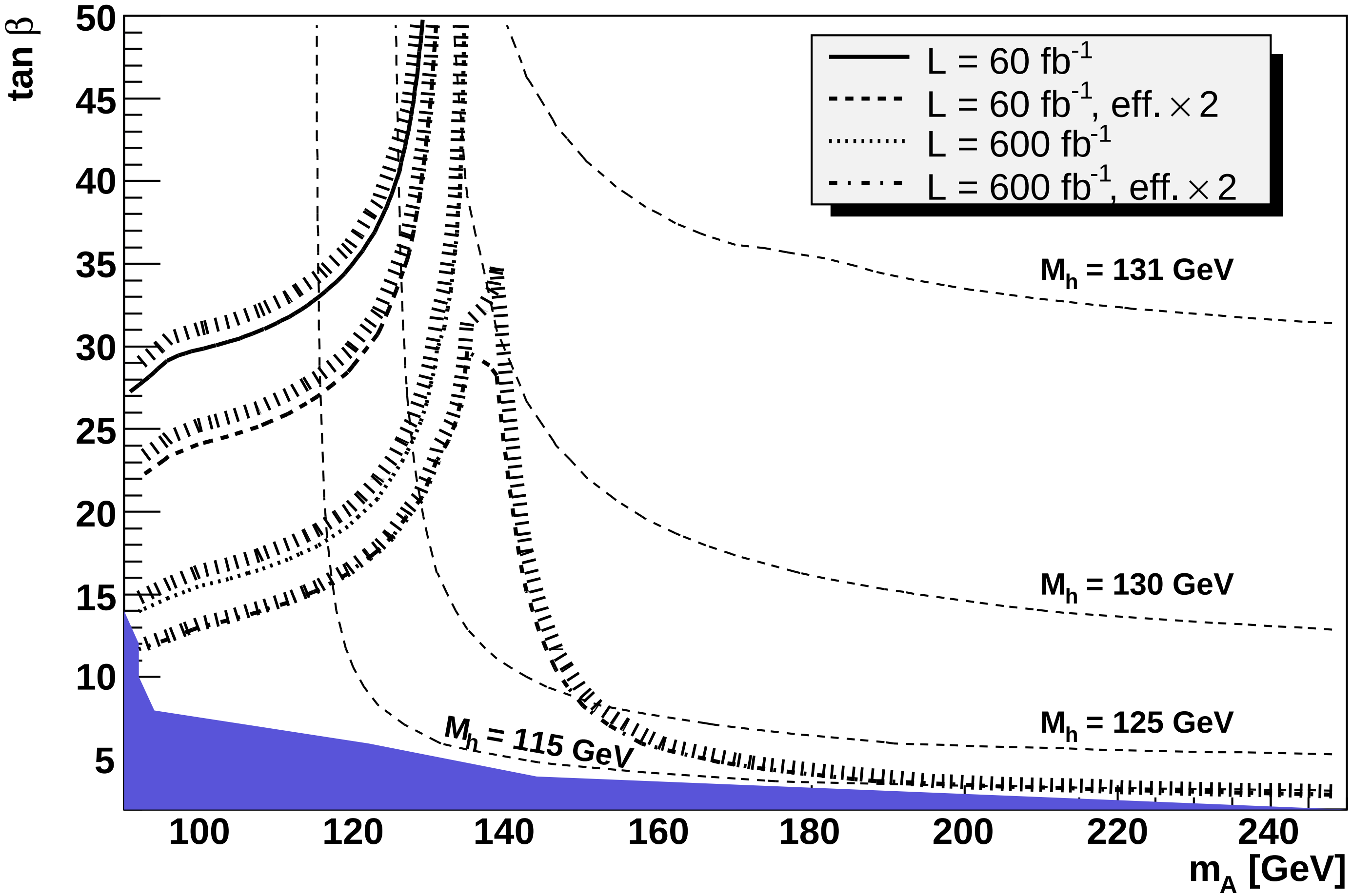


$\Rightarrow$ Discovery possible in region of rel. small M_A and large $\tan\beta$

3σ *contours for CED production of the light MSSM Higgs boson in the* $h \to b\bar{b}$ *channel*

$m_{\rm h}^{\rm max}$ benchmark scenario:



⇒ Almost complete coverage with $600\ \mathrm{fb}^{-1} \times 2$

⇒ CED channel may yield crucial information on $hb\bar{b}$ coupling

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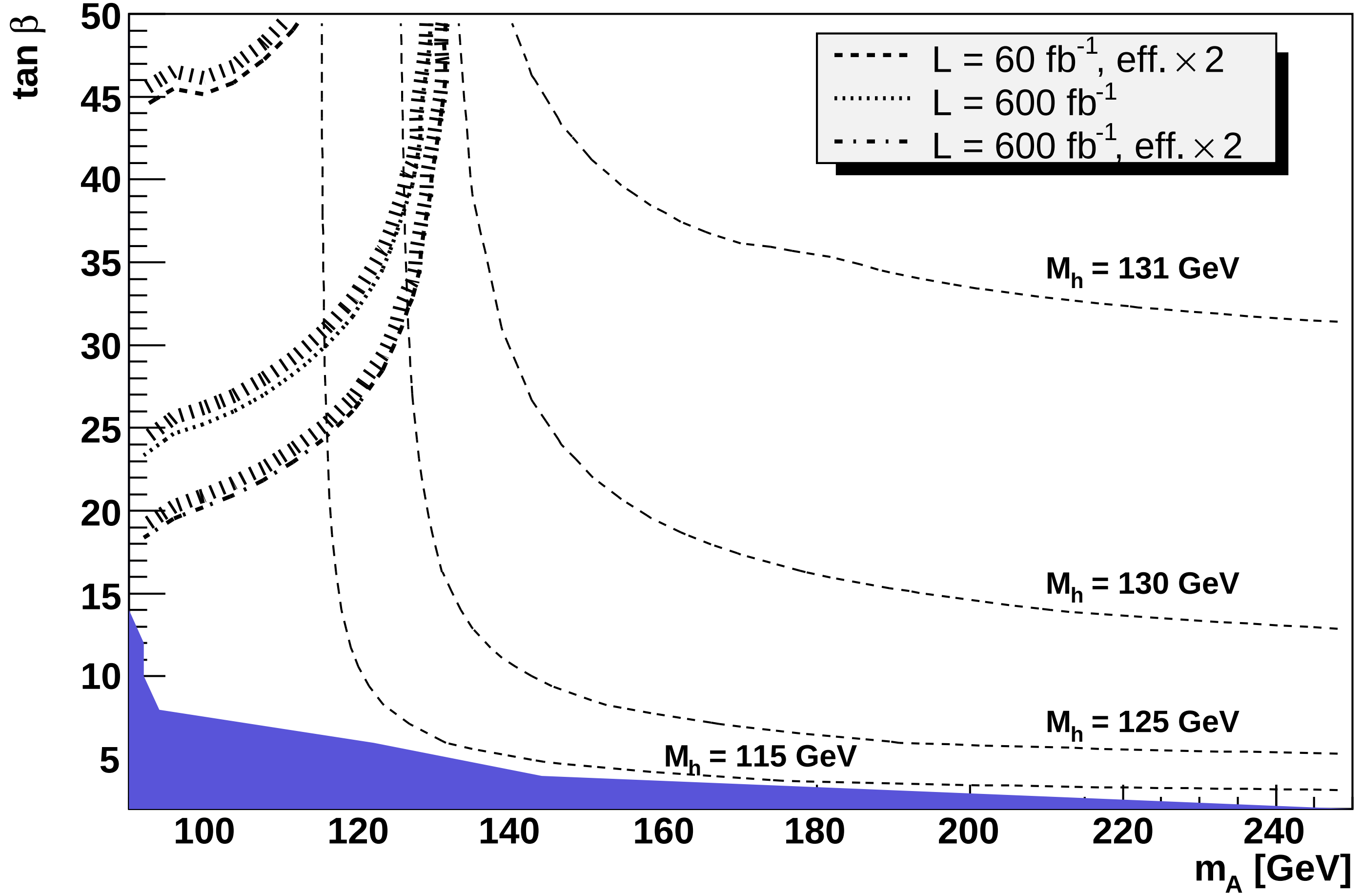
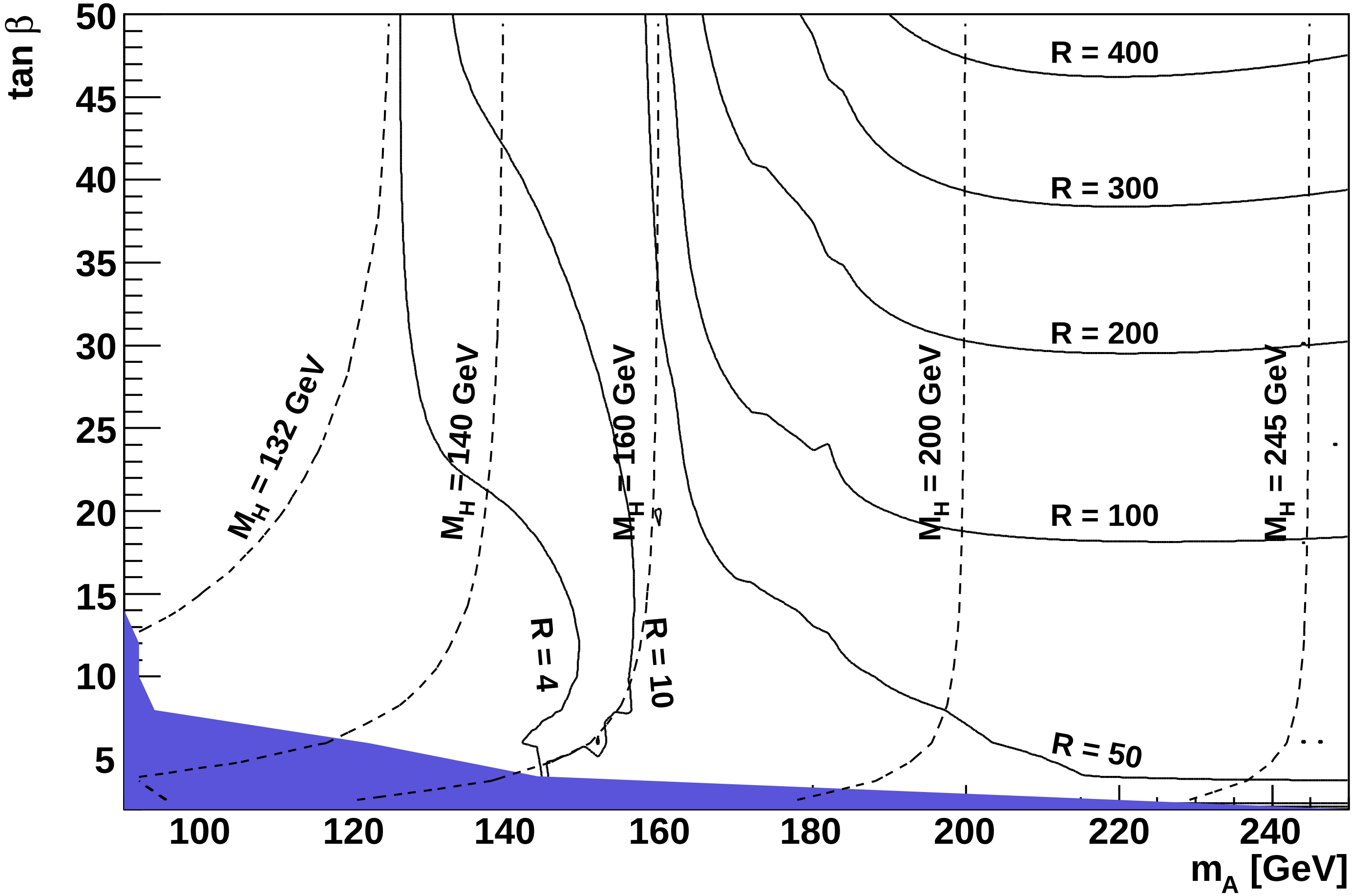


⇒ Slightly worse coverage than $h \to b\bar{b}$ channel
could improve with more efficient selection procedure

Ratio of signal rate for the heavy $\mathcal{CP}$-even MSSM Higgs boson over the SM rate, $H \to b\bar{b}$ channel

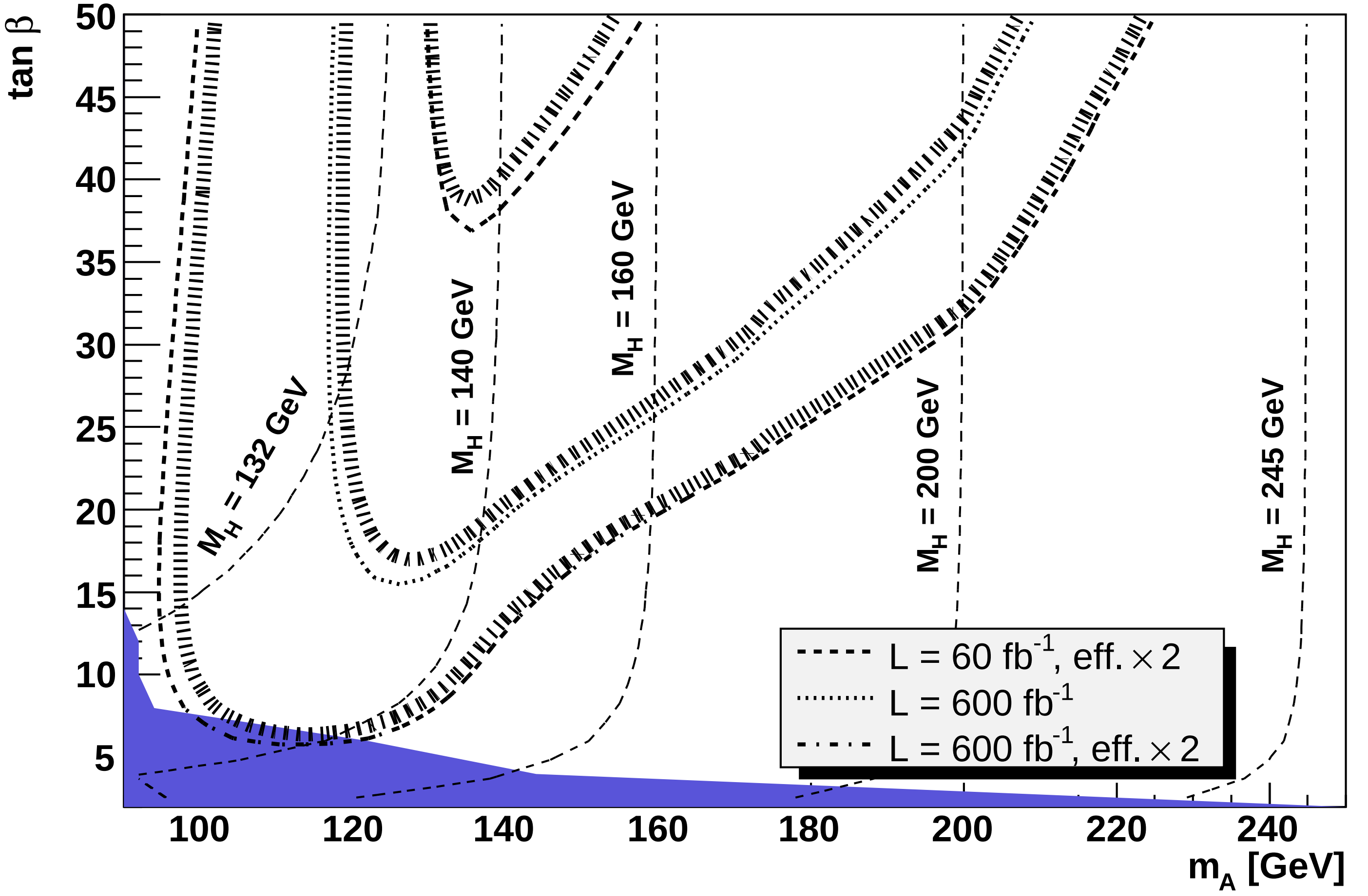
$m_h^{\max}$ benchmark scenario:



$\Rightarrow$ Huge enhancement compared to SM case, up to factor 400

5σ *discovery contours for CED production of the heavy $\mathcal{CP}$-even MSSM Higgs, $H \to b\bar{b}$ channel*

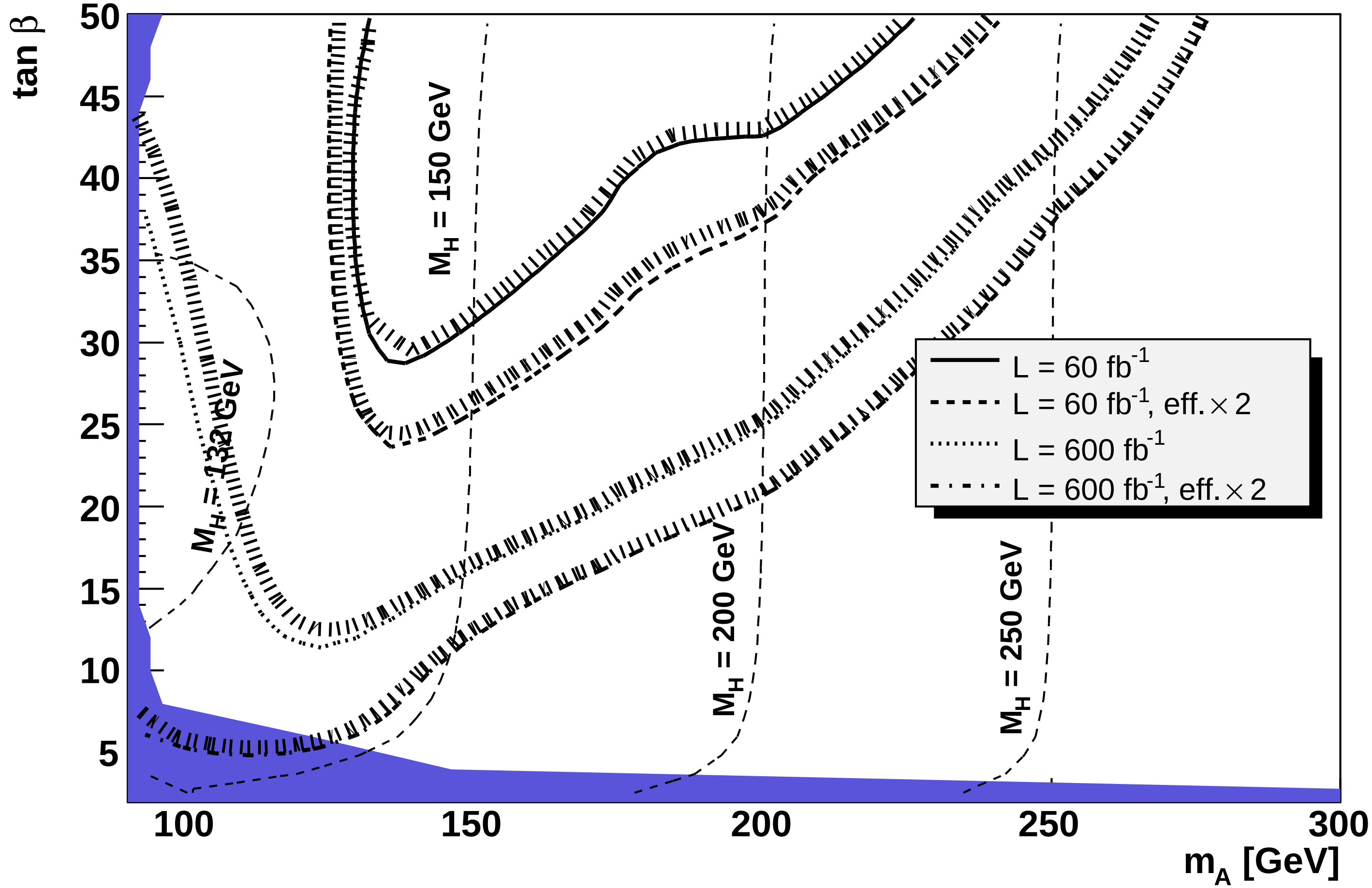
$m_h^{\max}$ benchmark scenario:



⇒ Significant discovery reach, discovery of a 140 GeV Higgs for all values of $\tan\beta$ with $600\ \text{fb}^{-1} \times 2$

5σ *discovery contours for CED production of heavy* $\mathcal{CP}$*-even Higgs,* $H \to b\bar{b}$*,* $\mu = -500$ GeV

m_h^{max} benchmark scenario, $\mu = -500$ GeV:



⇒ Large $\tan\beta$, $600\ \mathrm{fb}^{-1} \times 2$: 5σ reach beyond $M_H \approx 250$ GeV

⇒ Access to $Hb\bar{b}$ coupling even for rel. heavy Higgs

Pseudoscalar Higgs production in diffractive processes

CED production of pseudoscalar A is strongly suppressed by $\mathcal{P}$-even selection rule

$\Rightarrow$ Consider 'semi-exclusive' reaction $pp \rightarrow X + A, H + Y$

A, H separated by large rapidity gaps from proton remnants

Larger cross section, but severe QCD background

$\Rightarrow$ Experimentally very challenging

detailed experimental studies would be desirable

Conclusions

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$\Rightarrow$ Interesting physics potential for probing MSSM Higgs sector; further experimental + theoretical efforts desirable