Measuring the Higgs Yukawa Couplings at an NLC

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LCWS99, Barcelona

Associated Higgs production with heavy quark pairs:

$$e^+e^- \to t\bar{t}\phi \ , \ b\bar{b}\phi$$

in the SM and in the MSSM, including full QCD corrections.

with S. Dawson (BNL)

hep-ph/9812488 (to appear in PRD)

PRD 59 (1999) 054012

PRD 57 (1998) 5851

MOTIVATIONS

- Many indications of a light Higgs boson

SM
- Indirect limits $\longrightarrow M_h = 107^{+67}_{-45}$ GeV (Erler and Langacker)
- Scalar Potential $\longrightarrow 90 < M_h < 800$ GeV (scale of new physics)

SUSY $\longrightarrow$ $M_{h^0} < 130$ GeV

- Direct bounds from LEP2 :
  - $M_{h_{SM}} \geq 90 - 95$ GeV
  - $M_{h^0}, M_{A^0} \geq 78 - 84$ GeV $(\tan\beta > 2.1)$

- Discovery : LEP II, Tevatron RUN II, LHC

$90 < M_h < 140$ GeV : Problematic region

non leading production modes will also have to be used:

$p\bar{p} \to b\bar{b}\phi$ (RUN II) , $pp \to t\bar{t}\phi\,,\, b\bar{b}\phi$ (LHC)

MOTIVATIONS

Precision studies : HIGH ENERGY e^+e^- COLLIDERS ($\sqrt{s}$=500 GeV, 1 TeV)

- $e^+e^- \to t\bar{t}\phi$: top Yukawa coupling

  - direct measurement

    ($\phi \to gg$ or $gg \to \phi$: possible spurious contribution from heavy new particles)

  - high sensitivity to the $t\bar{t}\phi$ coupling, both in the SM and in the MSSM

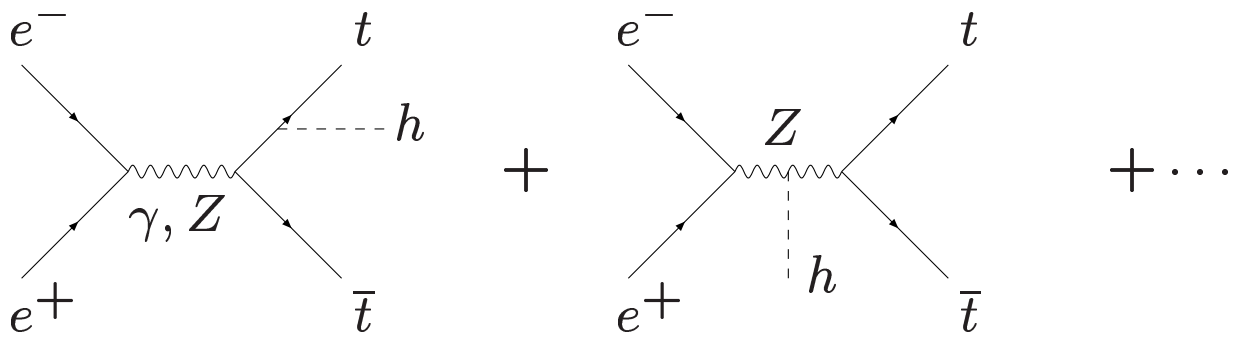
  – spectacular signature : $W^+W^-b\bar{b}b\bar{b}$

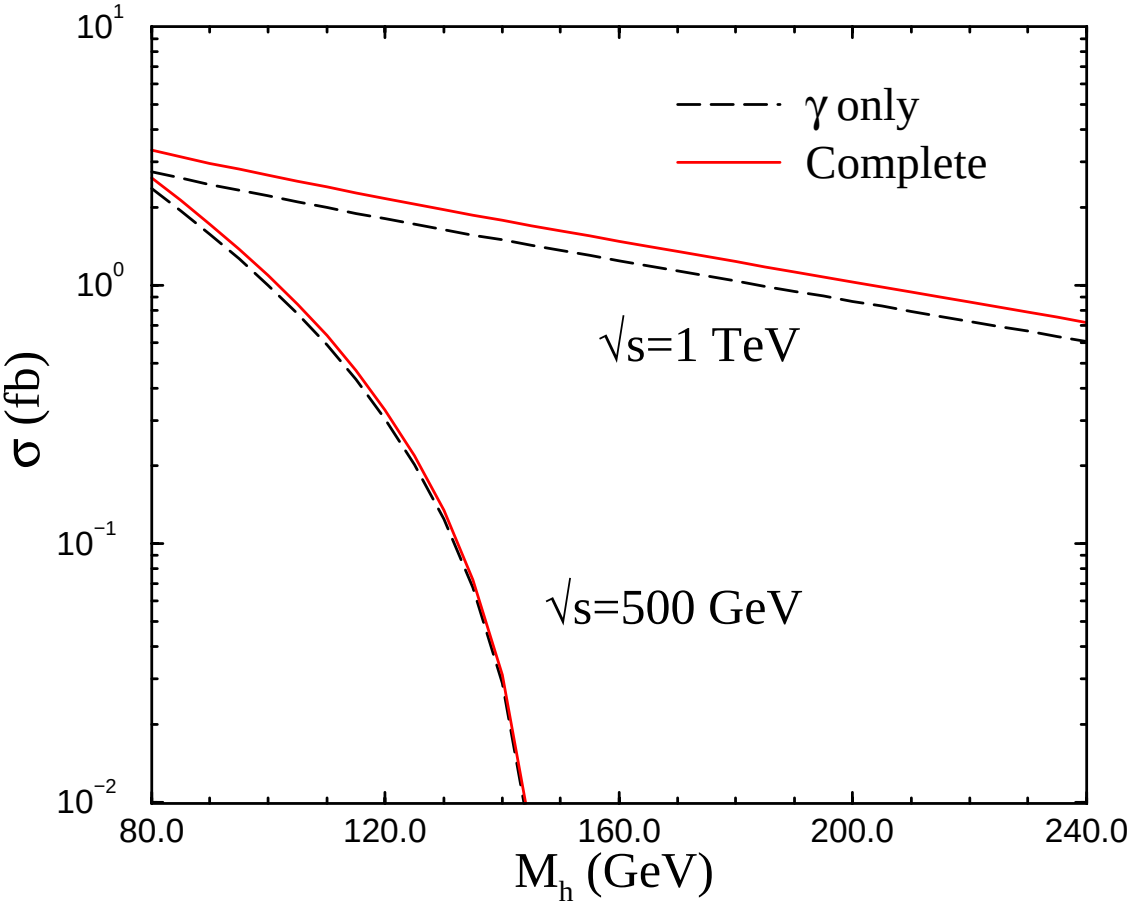
- $e^+e^- \to b\bar{b}\phi$: bottom Yukawa coupling

  - very distinctive in the MSSM

  - enhanced resonant production in the MSSM

$t\bar{t}\phi$: Standard Model

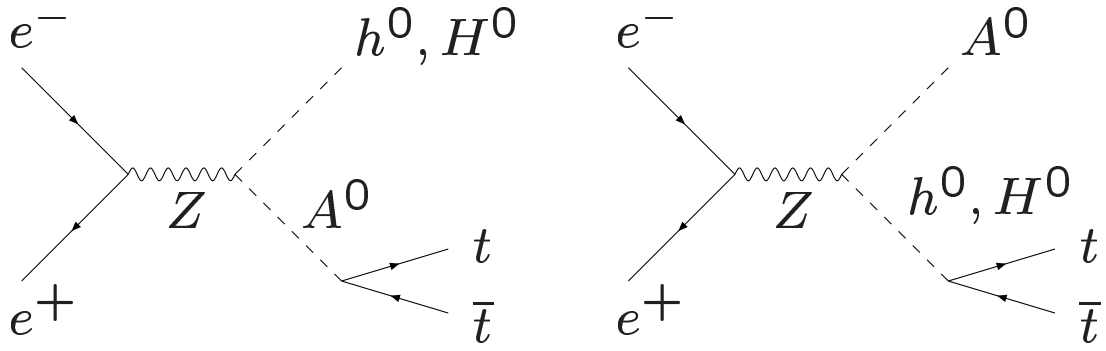




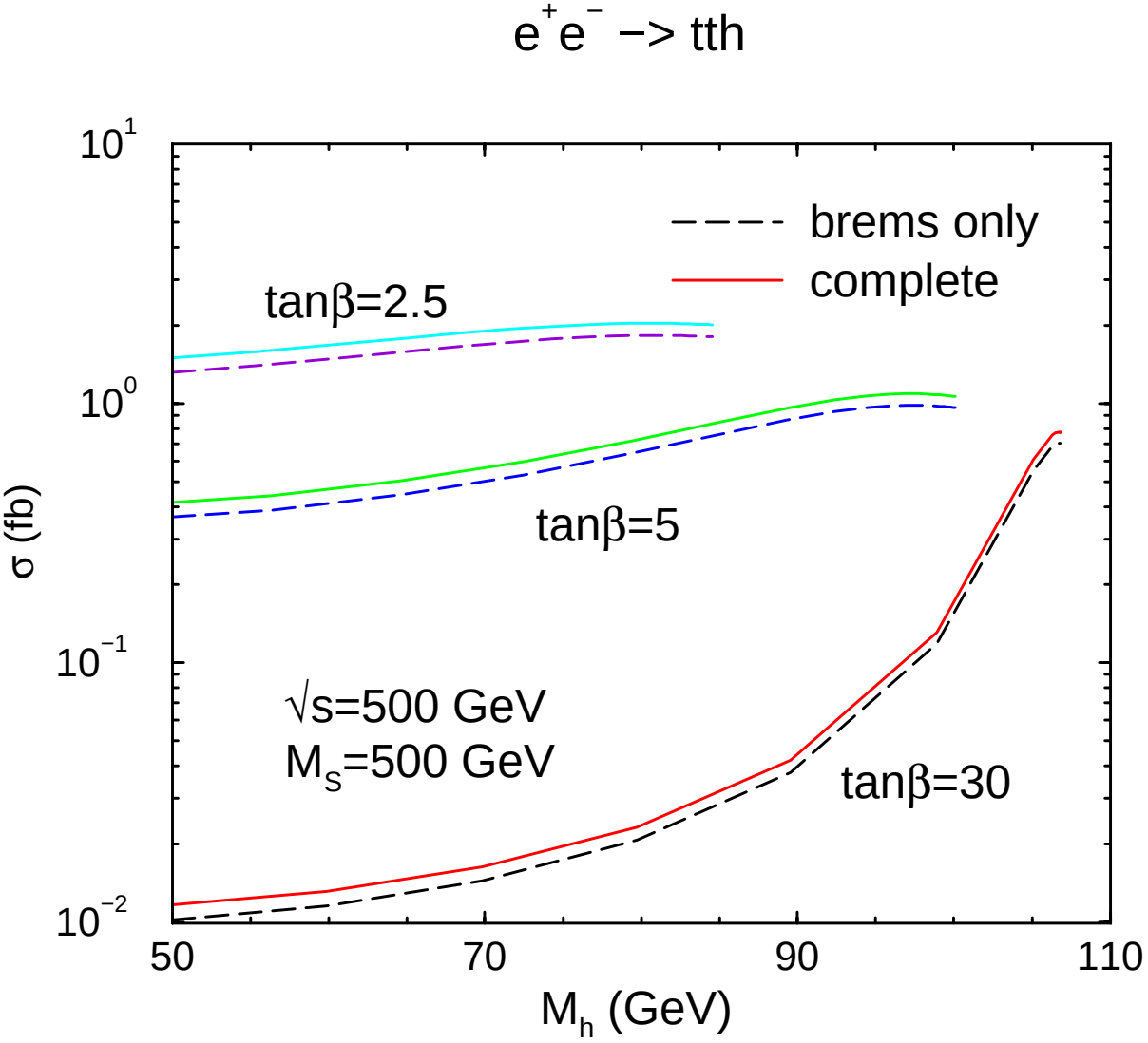
$\sqrt{s} = 500\,\text{GeV} \longrightarrow 98\%$

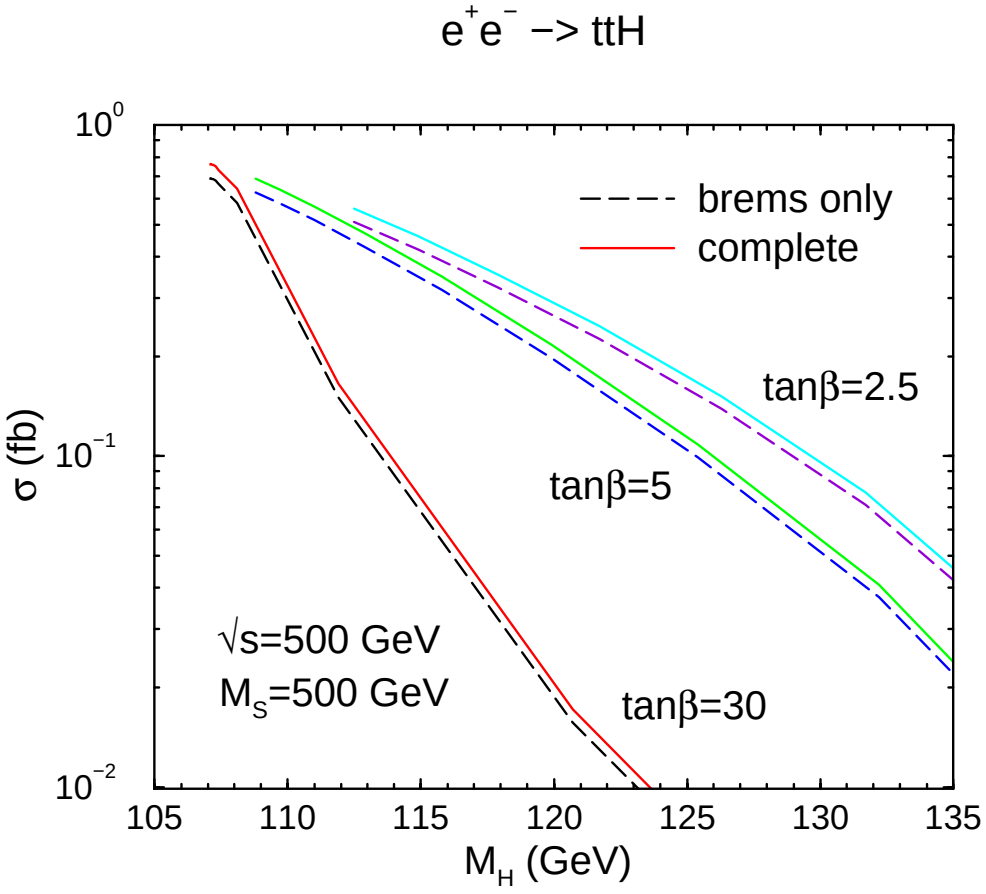
$\sqrt{s} = 1\,\text{TeV} \longrightarrow 90\%$

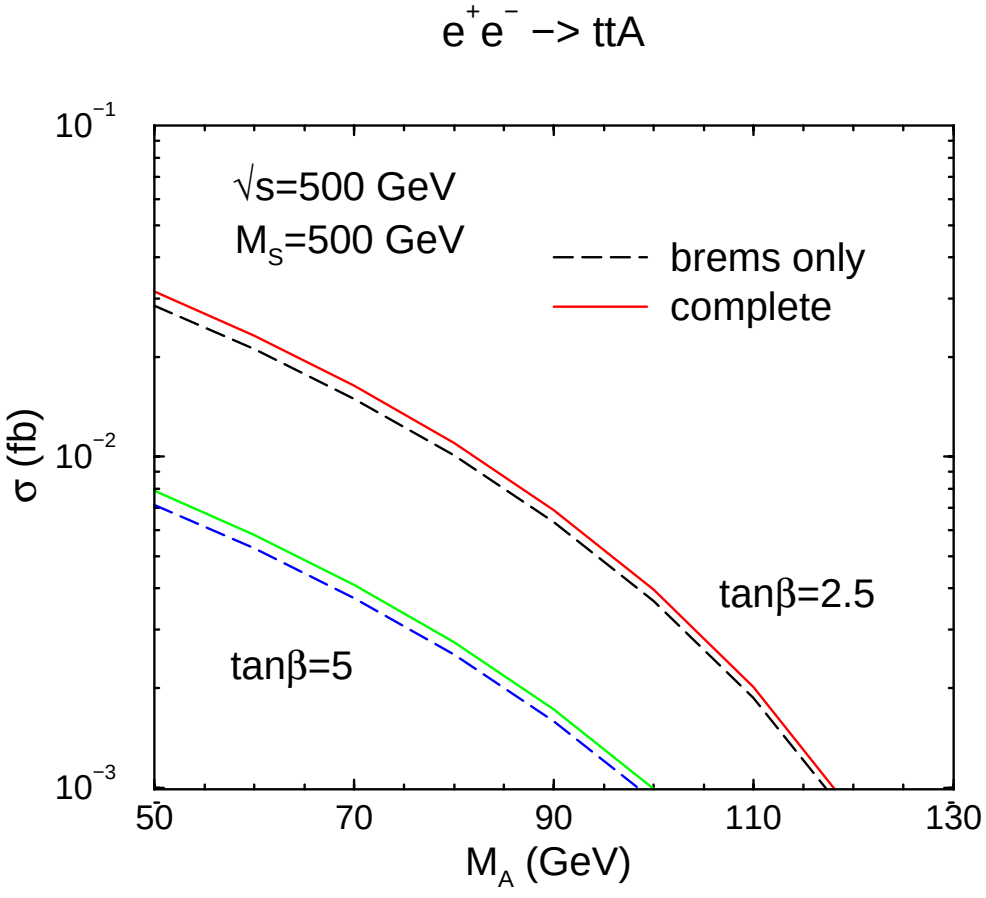
$t\bar{t}\phi$ MSSM : new contributions

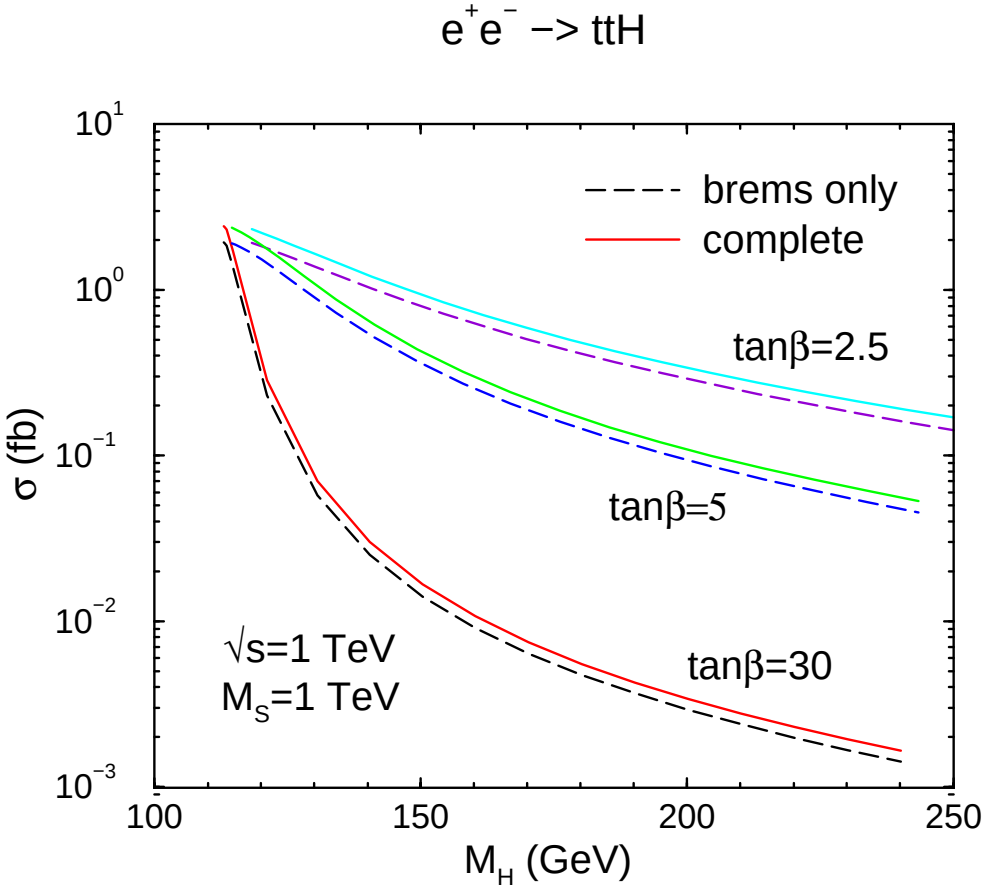


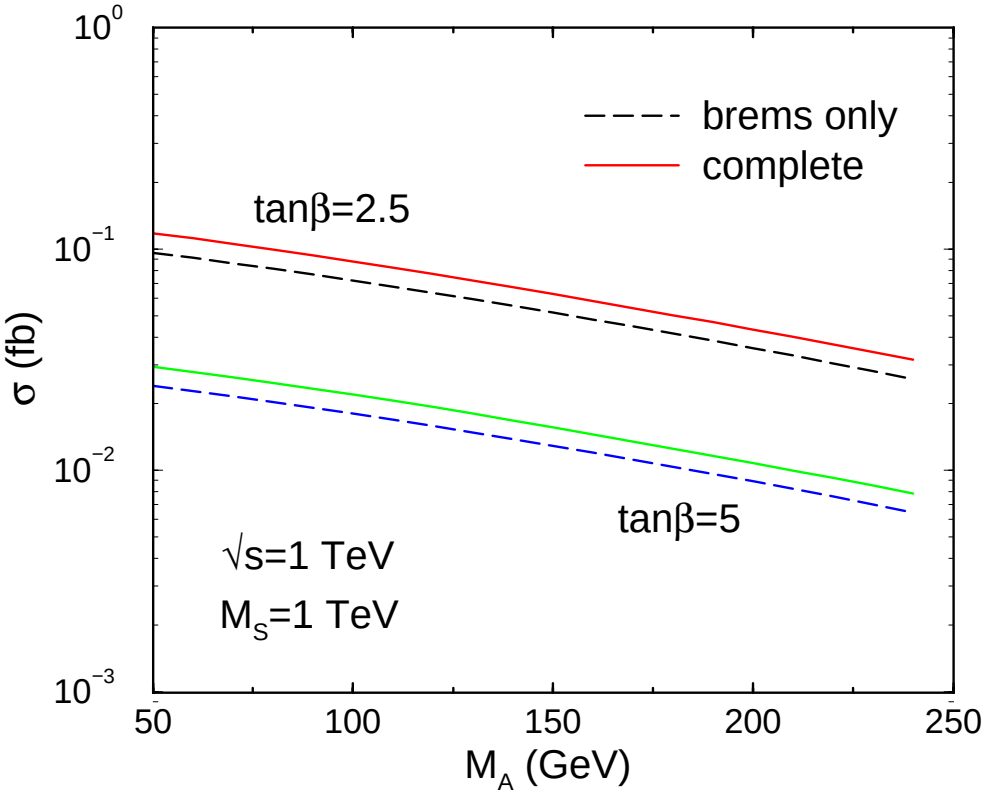
still




e+e− –> ttH
10^0
10^−1
10^−2
σ (fb)
brems only
complete
tanβ=2.5
tanβ=5
tanβ=30
√s=500 GeV
M_S=500 GeV
105
110
115
120
125
130
135
M_H (GeV)


e+e− –> ttA
10^−1
10^−2
10^−3
σ (fb)
√s=500 GeV
M_S=500 GeV
brems only
complete
tanβ=2.5
tanβ=5
50
70
90
110
130
M_A (GeV)


e+e− −> ttH
brems only
complete
tanβ=2.5
tanβ=5
tanβ=30
√s=1 TeV
MS=1 TeV
σ (fb)
MH (GeV)


e+e− −> ttA
brems only
complete
tanβ=2.5
tanβ=5
√s=1 TeV
MS=1 TeV
σ (fb)
MA (GeV)

$t\bar{t}\phi$: Towards a more precise prediction

- Snownass 96 : $t\bar{t}\phi$ only production mode for which QCD corrections are unknown

- First estimate of $t\bar{t}\phi$ at $O(\alpha_s)$ in the "Effective Higgs Approximation" (EHA)

  L.R., S.Dawson

- Exact $\sigma(e^+e^- \to t\bar{t}\phi)$ at $O(\alpha_s)$

  - negligible numerical errors
  - μ-dependence around 10%
  - $O(\alpha_s^2)$ corrections expected to be small
  - no error from PDF

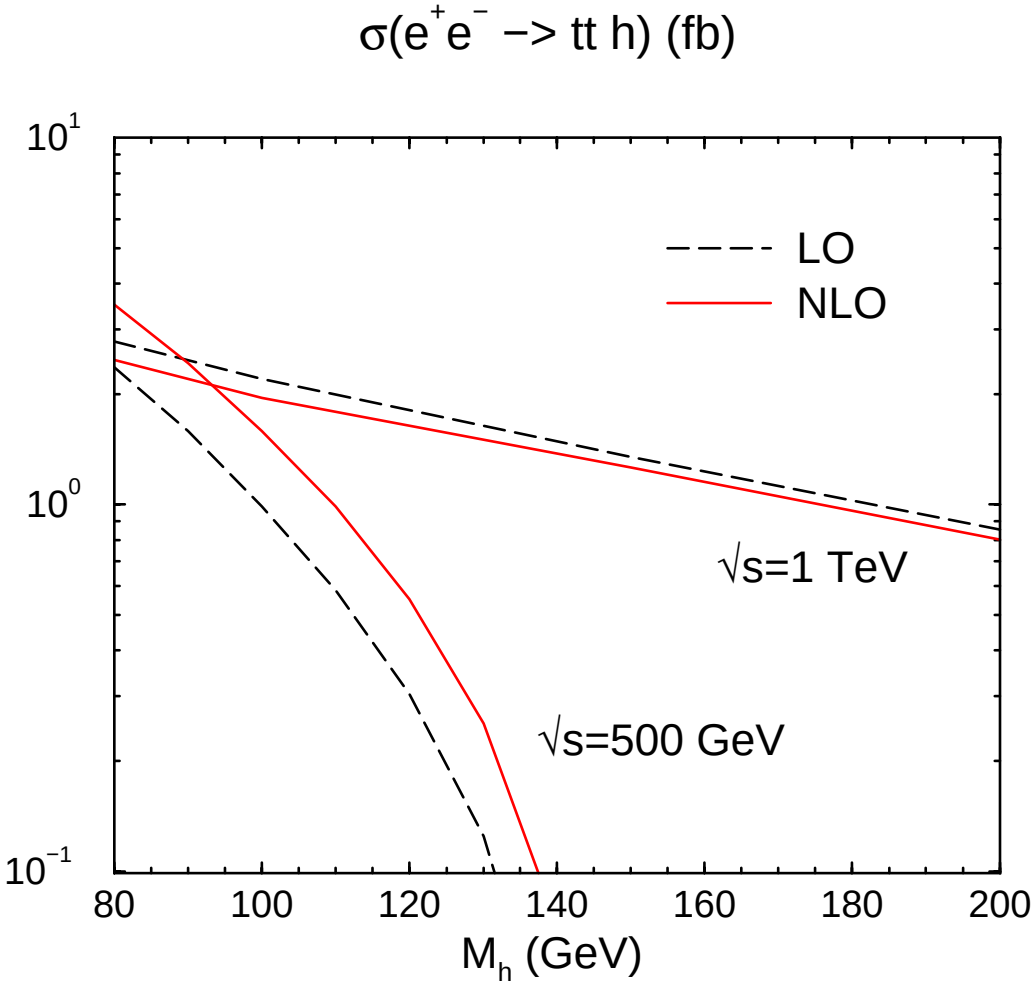
  L.R., S.Dawson

  Dittmaier, Krämer, Liao, Spira, Zerwas

$e^+e^- \to t\bar{t}h_{\rm SM}$: COMPLETE CALCULATION

$\sqrt{s}$=500 GeV $\to$ $K \simeq 1.4 - 2.4$

$\sqrt{s}$=1 TeV $\to$ $K \simeq 0.8 - 0.9$ ($\simeq$ EHA)



NLC Workshop (Oct 98) : benchmark process for b-tagging, interest in real simulations

$t\bar{t}h_{\rm SM}$: First estimate

$M_h < 110\,\text{GeV}$:

$$50\,\text{fb}^{-1} \longrightarrow \frac{\delta g_{tth}}{g_{tth}} < \pm 10\%$$

(Statistical error only)

for comparison : LHC ($pp \to t\bar{t}h$)

$M_h \sim 100\,\text{GeV}$ (Snowmass 96)

$$600\,\text{fb}^{-1} \longrightarrow \frac{g_{tth}}{g_{WWh}} \sim \pm 20\%$$

Interesting background study : S. Moretti hep-ph/9902214

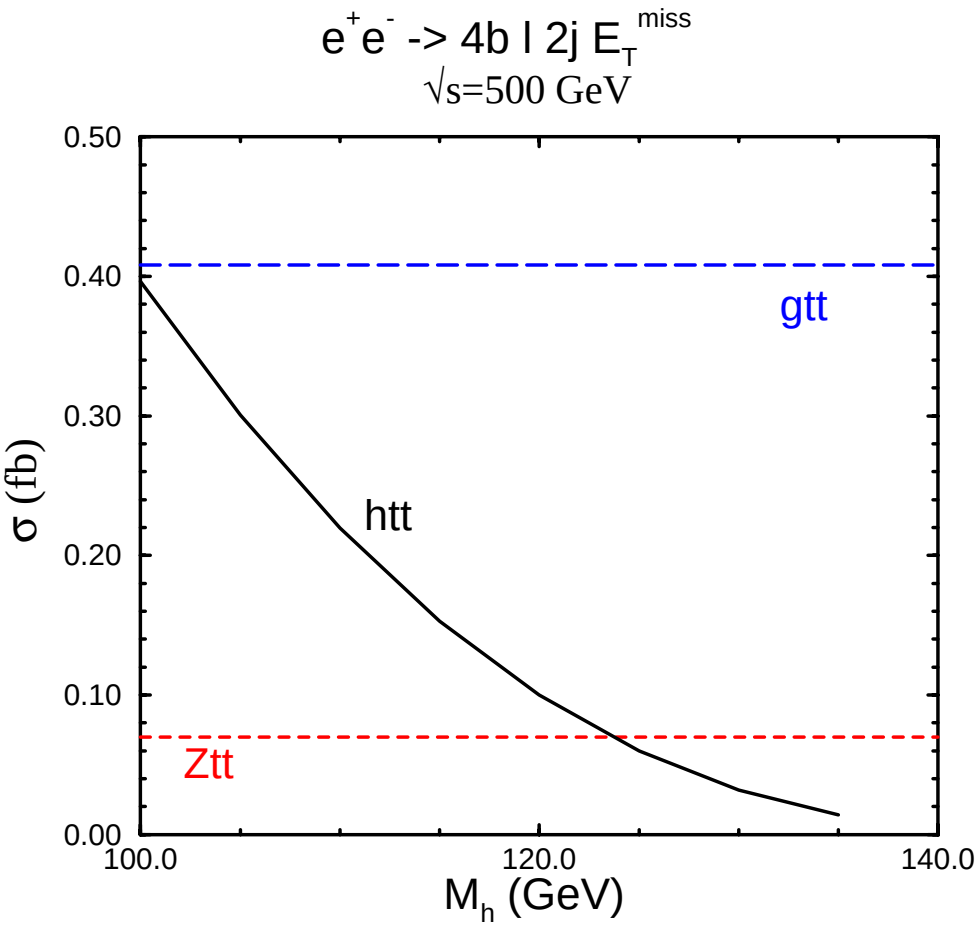
Ongoing study through real simulation:
H. Baer, S. Dawson, L.R. A. Juste, G. Merino

Background

$$e^+e^- \to t\bar{t}H \to Hb\bar{b}W^+W^- \to b\bar{b}b\bar{b}l^\pm\nu_l q\bar{q}'$$

$$e^+e^- \to t\bar{t}Z \to Zb\bar{b}W^+W^- \to b\bar{b}b\bar{b}l^\pm\nu_l q\bar{q}'$$

$$e^+e^- \to t\bar{t}g \to gb\bar{b}W^+W^- \to b\bar{b}b\bar{b}l^\pm\nu_l q\bar{q}'$$

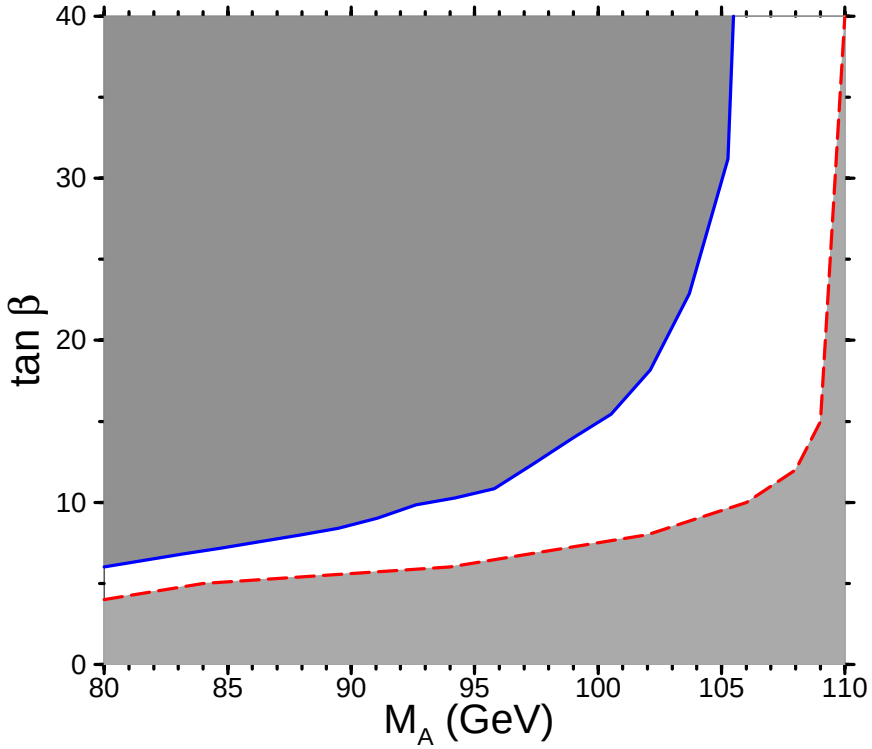


$e^+e^- \to t\bar{t}h_{\rm MSSM}$: COMPLETE CALCULATION

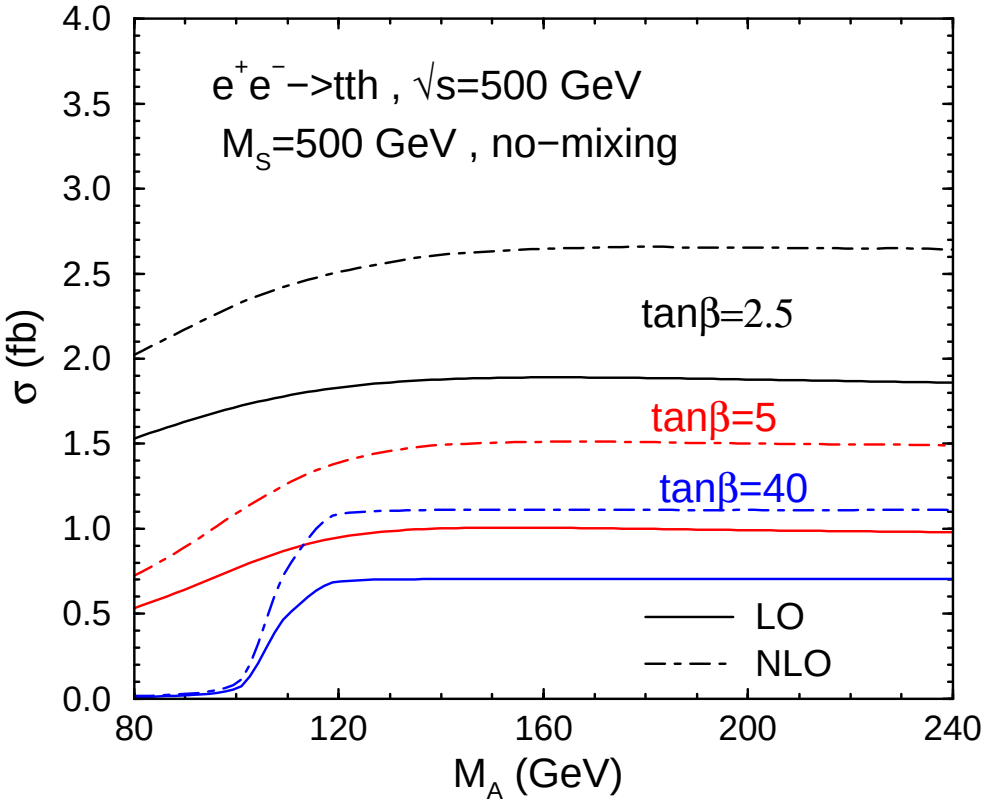
MSSM : Couplings different, new processes, still measures g_{tth_i} as in the SM

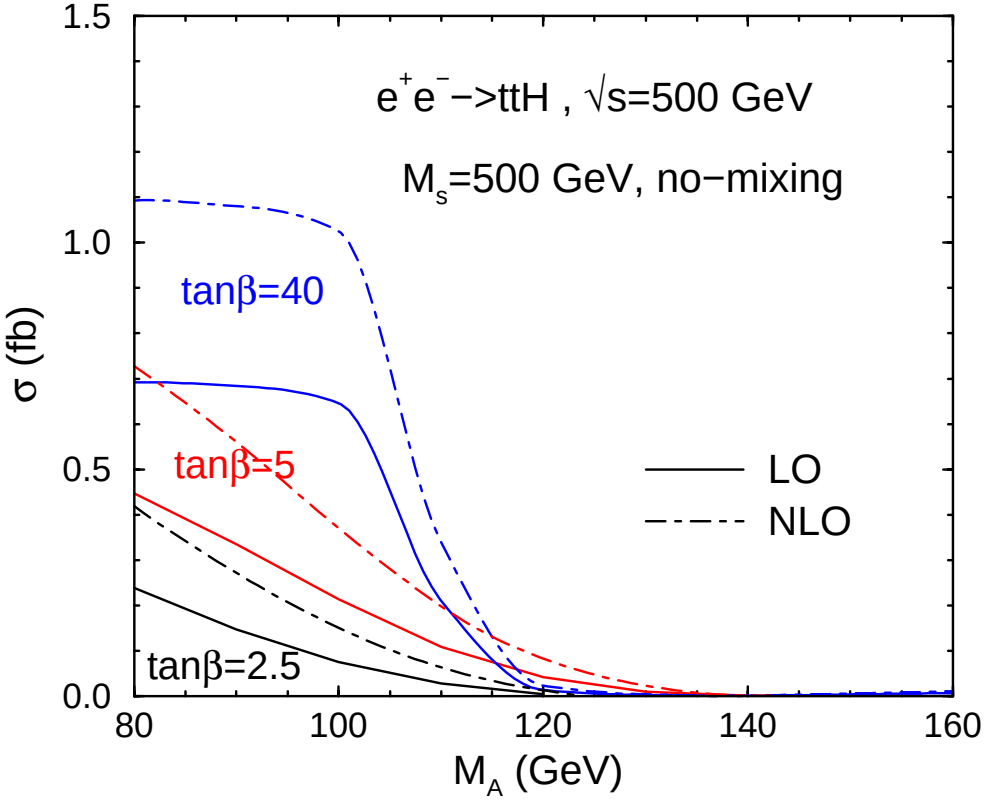
$$e^+e^- \to t\bar{t}h^0$$
$$e^+e^- \to t\bar{t}H^0$$

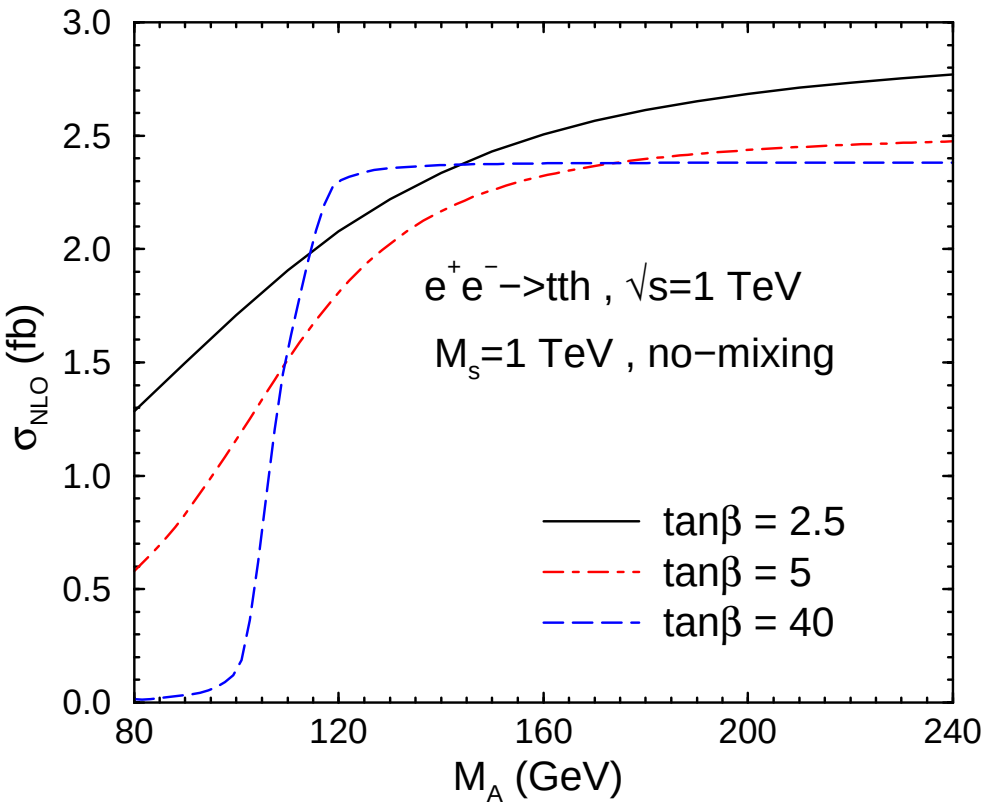
Regions with $\sigma > .75$ fb

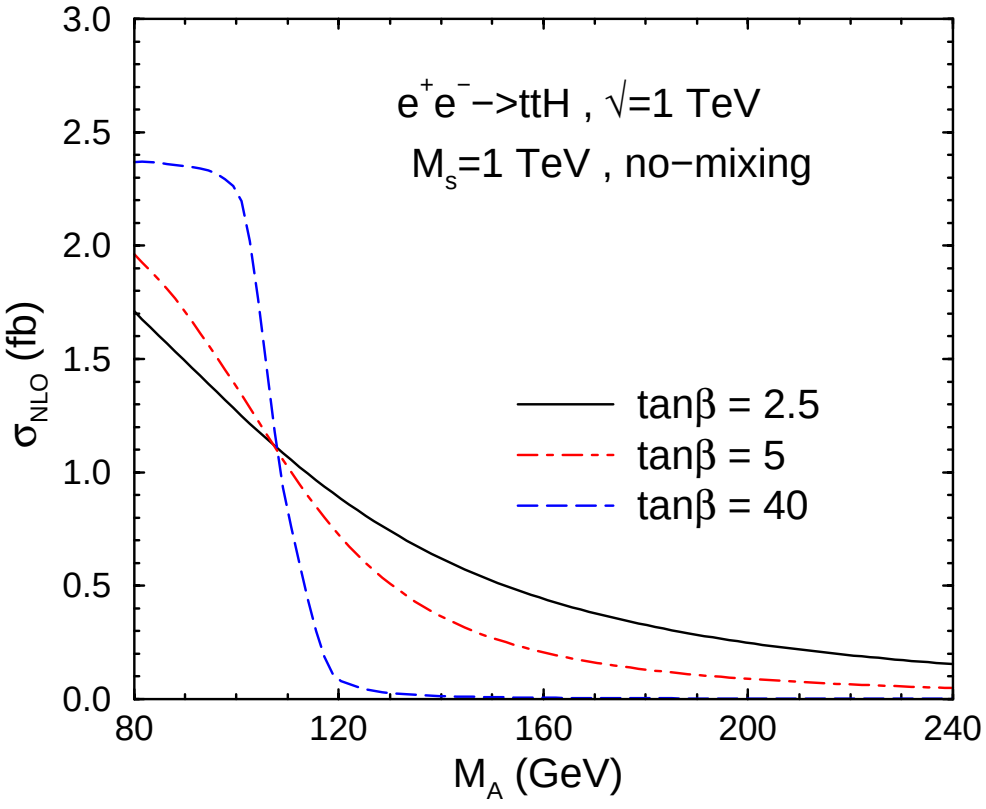


$e^+e^- \to t\bar{t}A^0$: highly suppressed

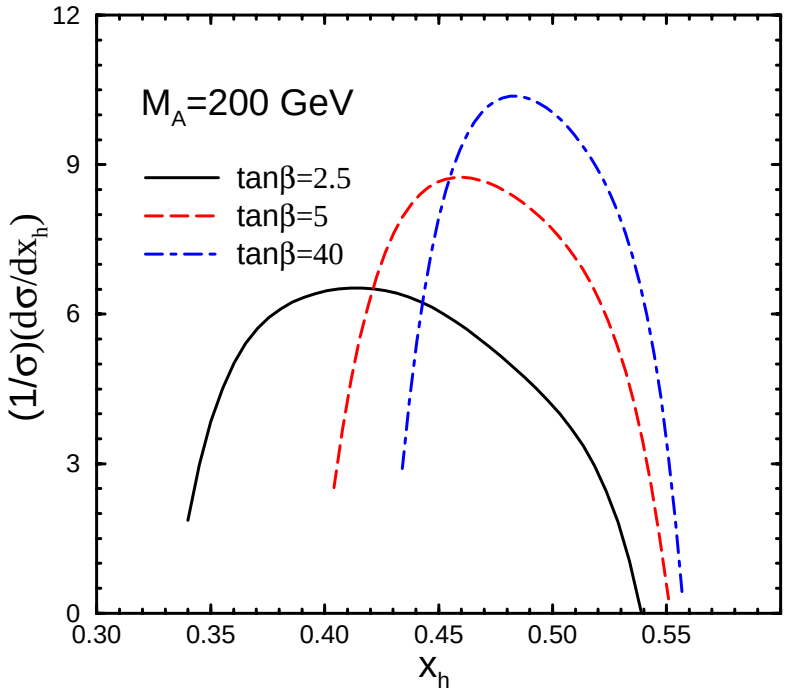

e+e−->tth , √s=500 GeV
MS=500 GeV , no−mixing
tanβ=2.5
tanβ=5
tanβ=40
LO
NLO
σ (fb)
MA (GeV)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
80
120
160
200
240

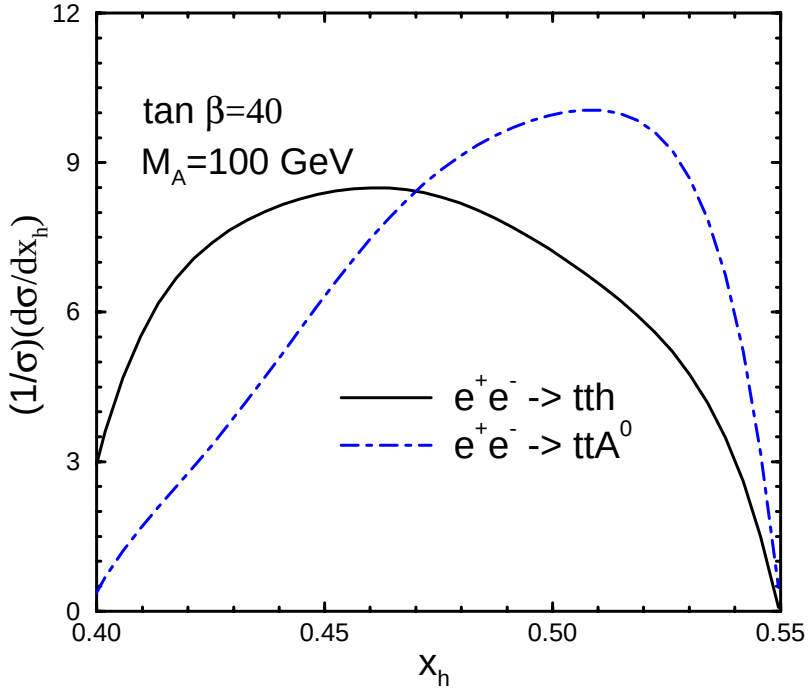

e+e−->ttH , √s=500 GeV
Ms=500 GeV, no−mixing
tanβ=40
tanβ=5
tanβ=2.5
LO
NLO
σ (fb)
MA (GeV)
0.0
0.5
1.0
1.5
80
100
120
140
160


3.0
2.5
2.0
1.5
1.0
0.5
0.0
80
120
160
200
240
σNLO (fb)
MA (GeV)
e+e−->tth , √s=1 TeV
Ms=1 TeV , no−mixing
tanβ = 2.5
tanβ = 5
tanβ = 40


3.0
2.5
2.0
1.5
1.0
0.5
0.0
80
120
160
200
240
σNLO (fb)
MA (GeV)
e+e−->ttH , √=1 TeV
Ms=1 TeV , no−mixing
tanβ = 2.5
tanβ = 5
tanβ = 40

Phase space distributions



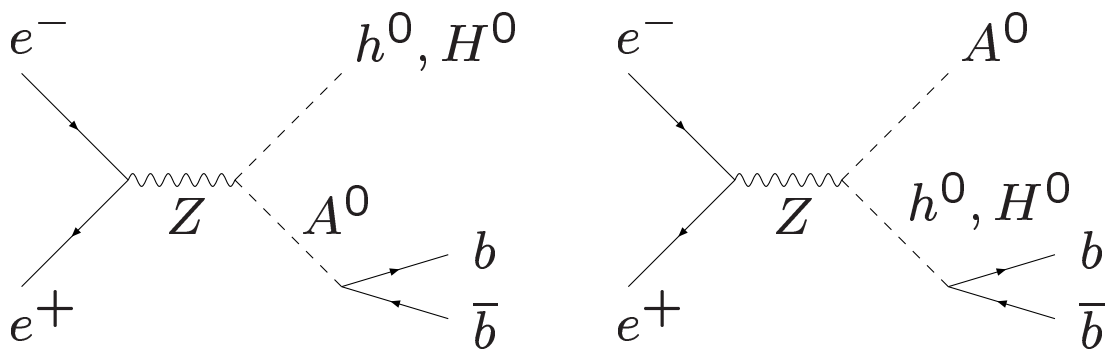


$e^+e^- \to b\bar{b}\phi$: MSSM versus SM

SM : small except near Z resonance,

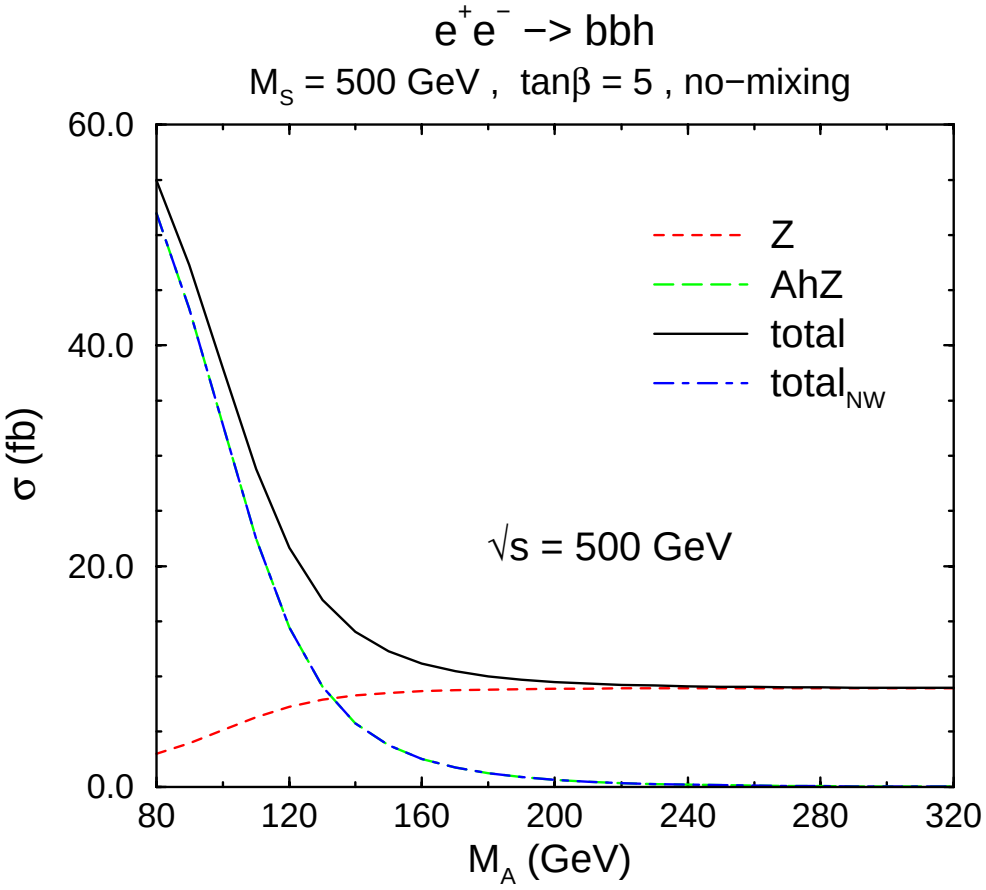
$$M_h \sim M_Z$$

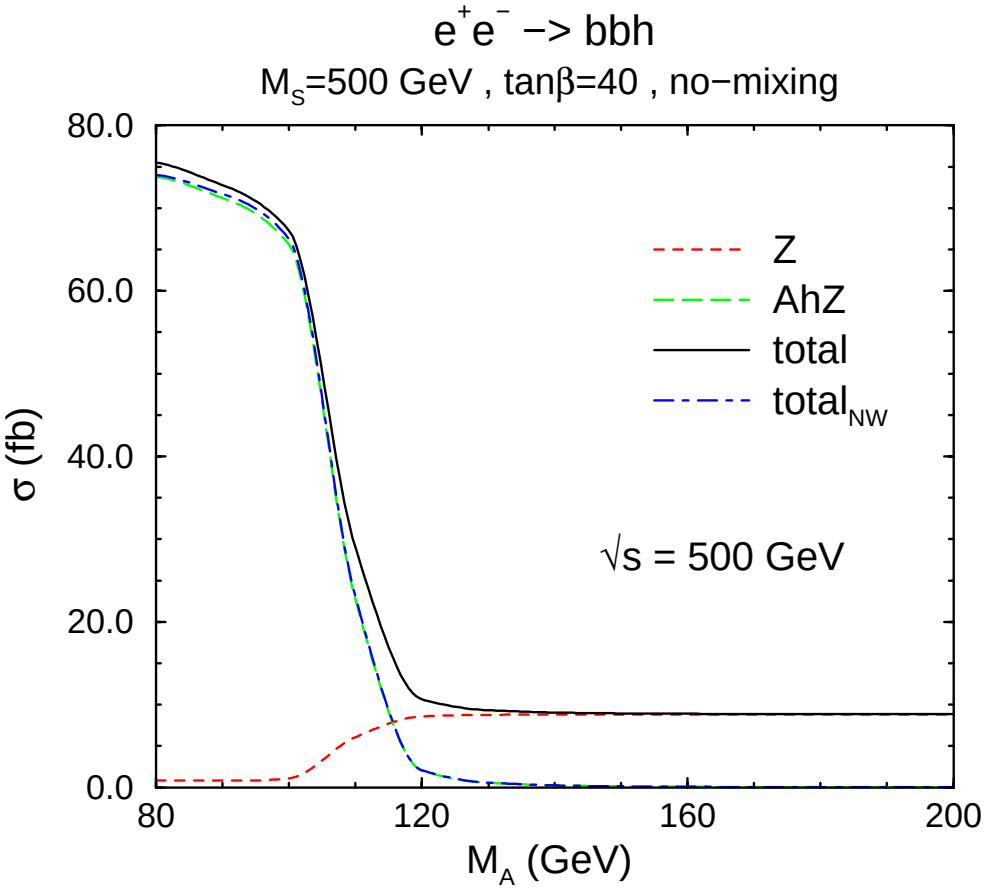
MSSM : new contributions

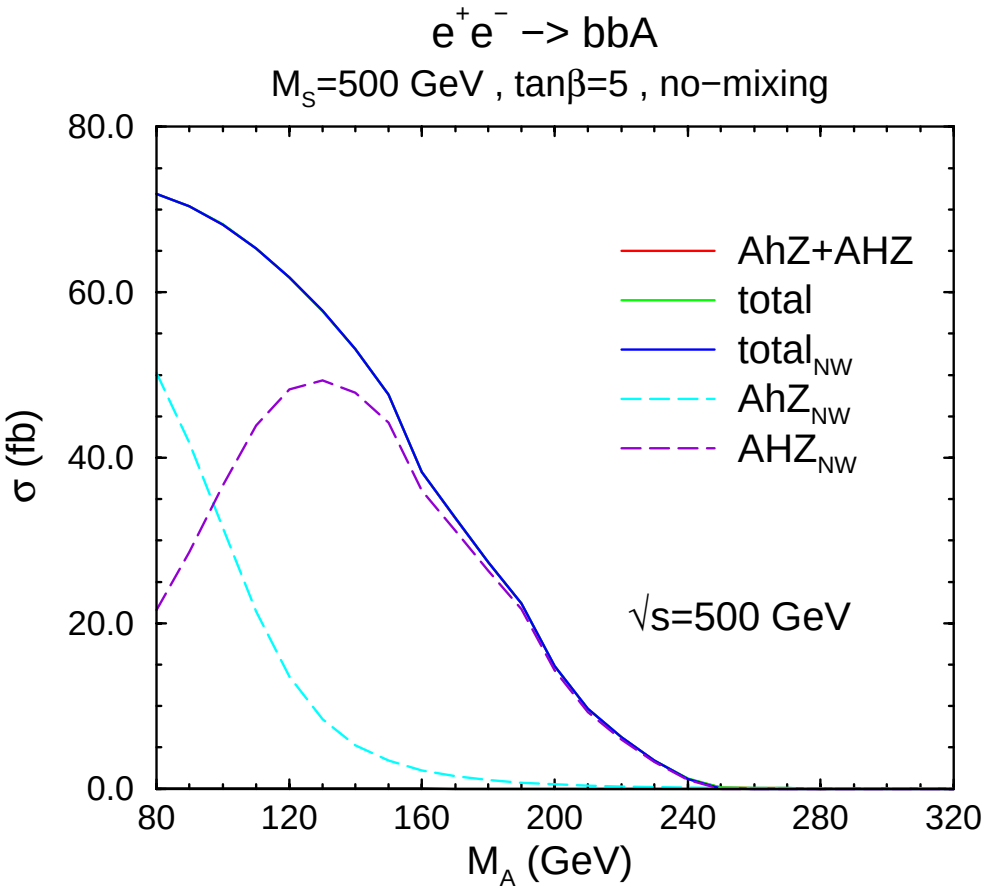


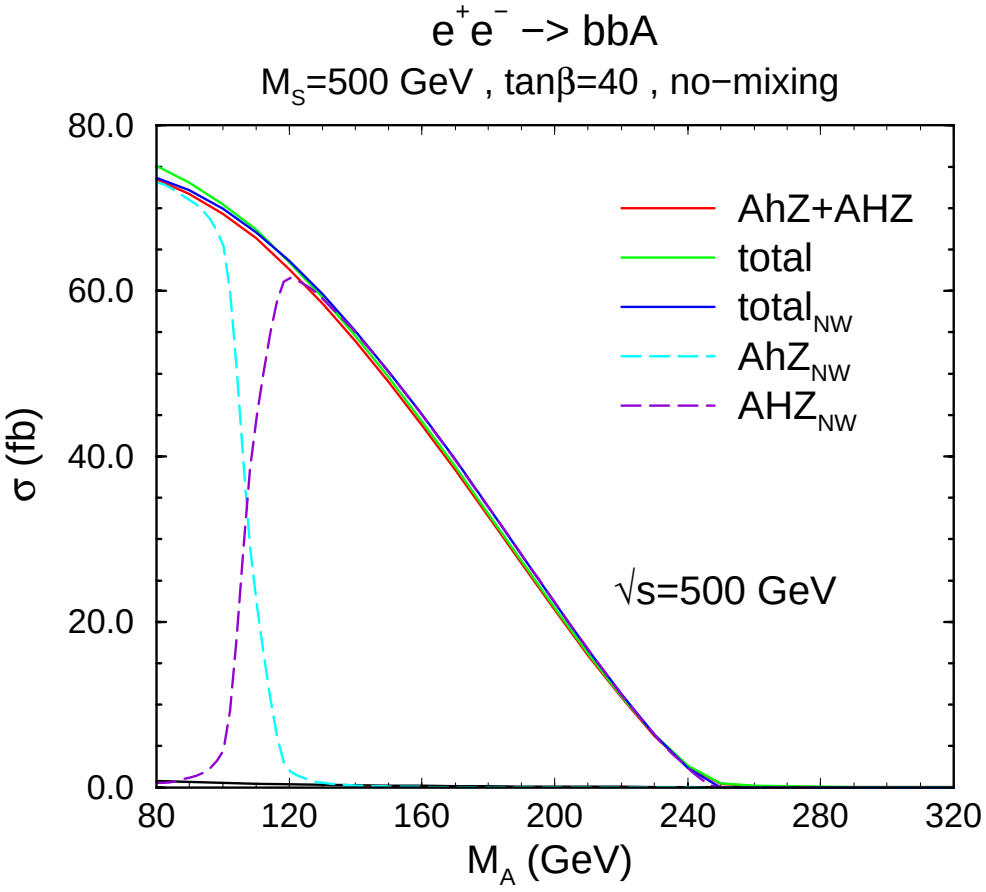
large resonance effects when $M_{h,H} \sim M_A$
(although not unique measurement of $g_{bb\phi}$)

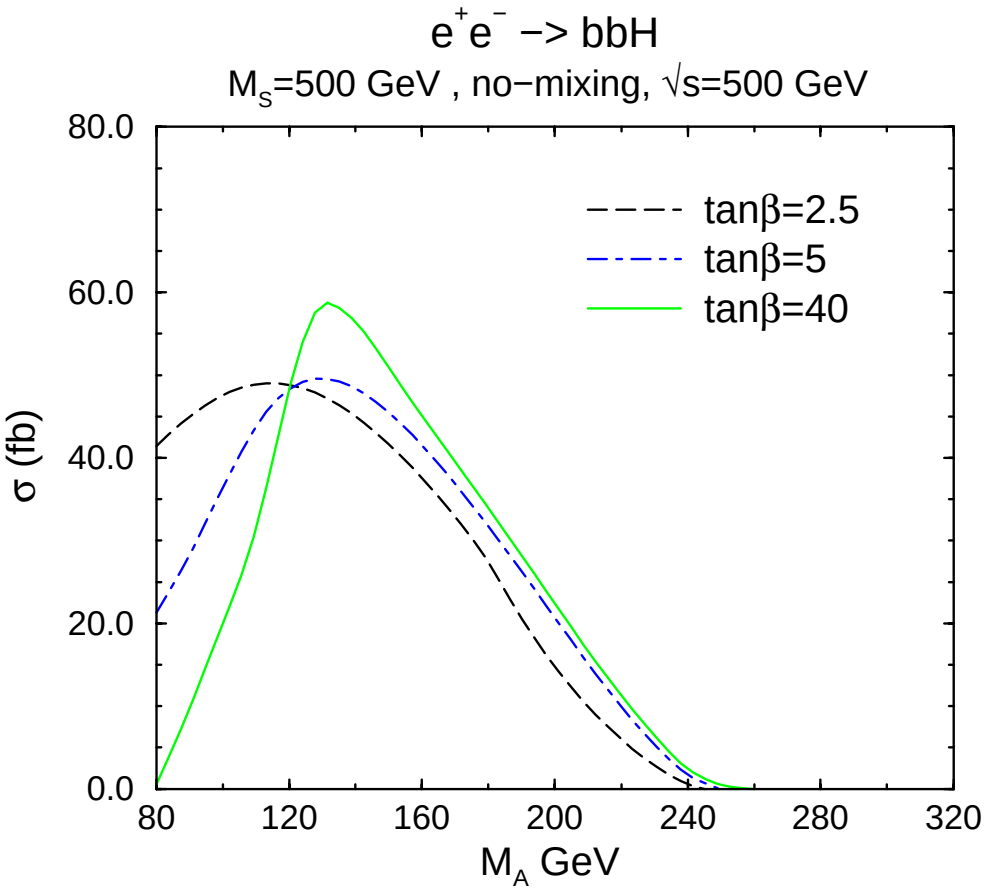
- A^0 production not suppressed anymore
- narrow width approximation
- QCD $\to$ width at $O(\alpha_s)$

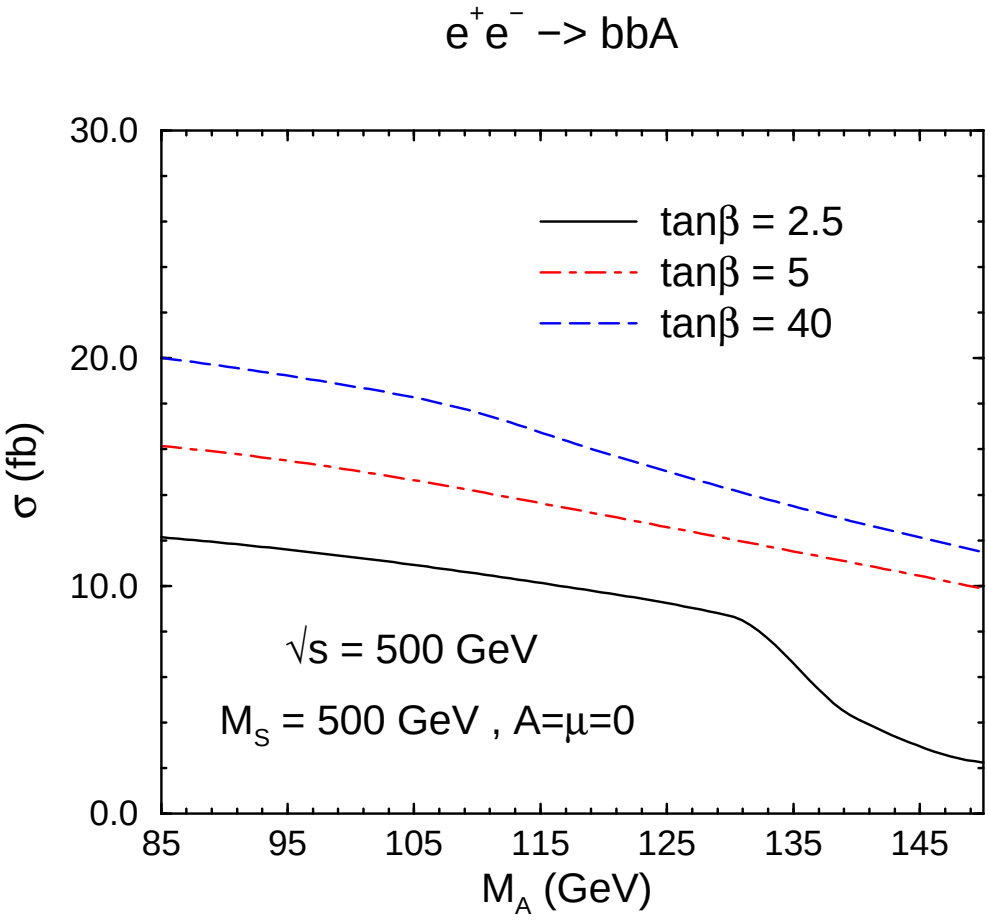

e+e− −> bbh
MS = 500 GeV , tanβ = 5 , no−mixing
60.0
40.0
20.0
0.0
σ (fb)
80
120
160
200
240
280
320
MA (GeV)
Z
AhZ
total
totalNW
√s = 500 GeV


e+e− −> bbh
MS=500 GeV , tanβ=40 , no−mixing
80.0
60.0
40.0
20.0
0.0
σ (fb)
80
120
160
200
MA (GeV)
Z
AhZ
total
totalNW
√s = 500 GeV


e+e− −> bbA
MS=500 GeV , tanβ=5 , no−mixing
σ (fb)
MA (GeV)
AhZ+AHZ
total
totalNW
AhZNW
AHZNW
√s=500 GeV
0.0
20.0
40.0
60.0
80.0
80
120
160
200
240
280
320


e+e− −> bbA
MS=500 GeV , tanβ=40 , no−mixing
σ (fb)
MA (GeV)
AhZ+AHZ
total
totalNW
AhZNW
AHZNW
√s=500 GeV
0.0
20.0
40.0
60.0
80.0
80
120
160
200
240
280
320


e+e− −> bbH
MS=500 GeV , no−mixing, √s=500 GeV
80.0
60.0
40.0
20.0
0.0
σ (fb)
tanβ=2.5
tanβ=5
tanβ=40
80
120
160
200
240
280
320
MA GeV


e+e− −> bbA
30.0
20.0
10.0
0.0
σ (fb)
tanβ = 2.5
tanβ = 5
tanβ = 40
√s = 500 GeV
MS = 500 GeV , A=μ=0
85
95
105
115
125
135
145
MA (GeV)

CONCLUSIONS

- $e^+e^- \to t\bar{t}\phi$ could provide a 10% determination of $g_{tt\phi}$

- $bb\phi$ can be large in the MSSM even away from resonance

- very distinctive signatures, need real simulations