CP-violation scenario: A light Higgs in SUSY cascades?

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Outline

MSSM Review

- Every SM particle gets supersymmetric partner:
- $\widetilde{f}$, $\widetilde{B}$, $\widetilde{W}^{\pm,3}$, $\widetilde{g}$, $\widetilde{h}_u^+$, $\widetilde{h}_d^-$, $\widetilde{h}_u^0$, $\widetilde{h}_d^0$
- 2 Higgs doublets $\Rightarrow$ 5 physical Higgs bosons
- Rich mixing structure:
  - $\widetilde{f}_{L,R}$ mix $\Rightarrow$ sfermions $\widetilde{f}_{1,2}$
  - $\widetilde{h}_{u,d}^{\pm}$,$\widetilde{W}^{\pm}$ mix $\Rightarrow$ charginos $\tilde{\chi}_{1,2}^{\pm}$
  - $\widetilde{h}_u^0$,$\widetilde{h}_d^0$,$\widetilde{B}$,$\widetilde{W}^3$ mix $\Rightarrow$ neutralinos $\tilde{\chi}_{1,2,3,4}^0$

New source of CP-violating complex phases: A_f, μ, $M_{1,2,3}$

May help explain matter-antimatter asymmetry of universe

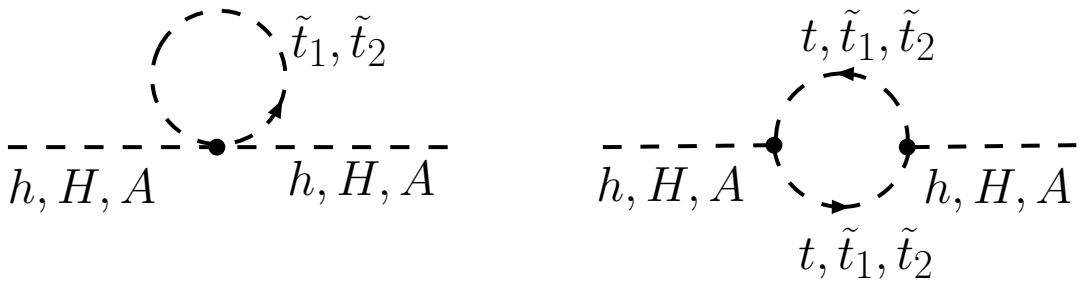
Higgs Sector

At tree-level:

- Higgs sector is CP-conserving:
  h^0,H^0 (CP-even), A^0 (CP-odd), H^+,H^-

Beyond tree-level:

- Loop corrections are large ($\mathcal{O} \sim 100\%$)
- Complex parameters $\phi_{A_{t,b,\tau}}$, ϕ_μ, $\phi_{M_{1,2,3}}$ enter via loops
- Mixing between h,H,A $\rightarrow$ h_1, h_2, h_3



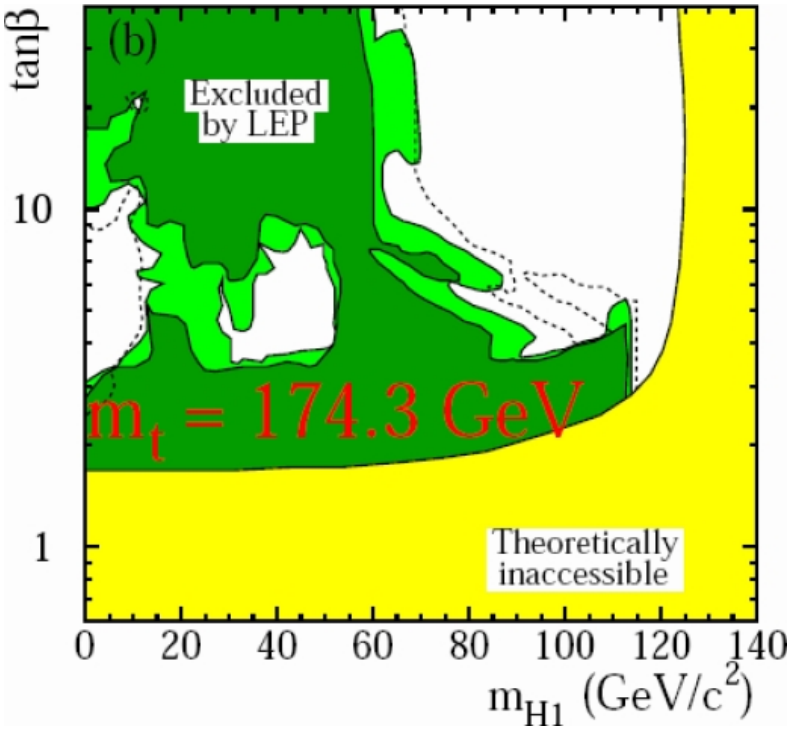
- Higgs sector is CP-violating at 1-loop level
- CP-violating mixing $\propto Im(A_t \mu)$

CPX Scenario at LEP

Extreme CP violating scenario with large h-H-A mixing.

μ	M_{SUSY}	$\lvert M_3 \rvert$	$\lvert A_{t,b,\tau} \rvert$	ϕ_{M_3}	$\phi_{At,b,\tau}$
2000	500	1000	900	$\pi/2$	$\pi/2$

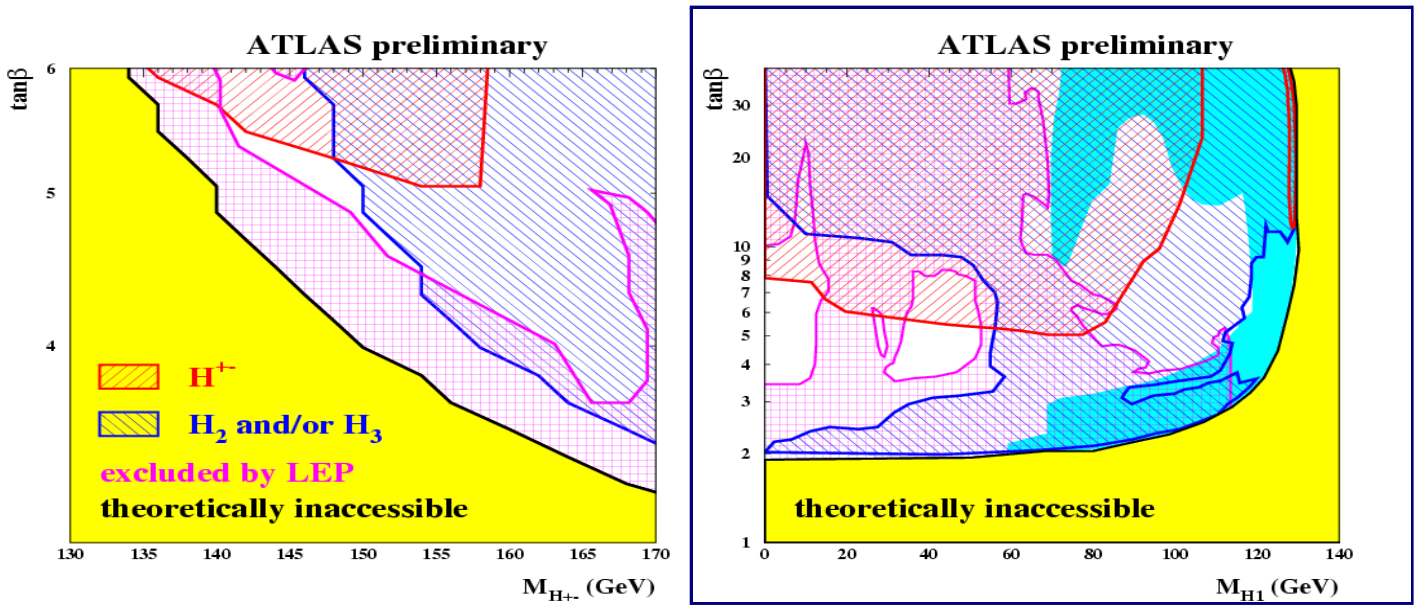
[M. Carena et al. '00]



- h_1 mostly CP-odd A^0
- Suppression of ZZh_1 coupling
- LEP: $e^+e^- \to Z^* \to Zh, hA$
- h_2 may be within LEP reach
- $h_2 \to h_1 h_1$: difficult final state
- $\therefore$ Light Higgs not excluded
- CPX hole at $t_\beta \approx 7$, $M_{h_1} \approx 40$GeV

[LEP Higgs Working Group 06]

CPX scenario at LHC



[M. Schumacher, ATLAS 07]

- CPX holes not covered by conventional channels at LHC (VVh_1, $t\bar{t}h_1$ suppressed)

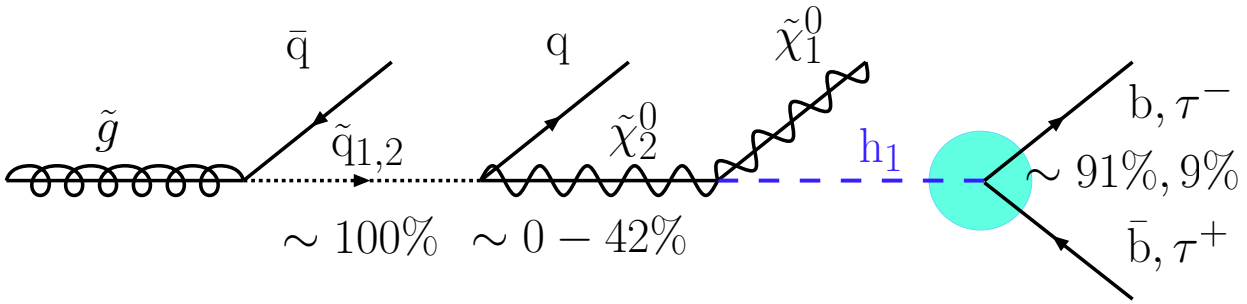
Higgs in SUSY cascade decays

- Direct Higgs production by SM-like processes well-known.
- Need to consider other production methods
  (eg. $\tilde{t}\tilde{t}h_1$ *[Datta et al. '07]* , H^+Wh_1 *[Godbole et al. '05]* , $\widetilde{\chi}_2^0\widetilde{\chi}_1^0 h_1$)
- SUSY cascade decays: another source of light Higgs.
  [Djouadi et al. '03]
  $$pp \rightarrow \widetilde{g}\widetilde{g}, \widetilde{q}\widetilde{q}, \widetilde{g}\widetilde{q} \rightarrow \widetilde{\chi}_i^0, \widetilde{\chi}_i^+ + X \rightarrow \widetilde{\chi}_j^0, \widetilde{\chi}_j^+ + X + h, H, A, H^{\pm}$$
- Higgs via cascade decays may complement SM-like searches.
- Also a probe to uncover parameters of EWSB.

CPX Cascades

CPX with $M_2 = 200$, $\tan\beta = 7$:

$M_{\tilde{\chi}^0_{3,4},\tilde{\chi}^+_2}$	$M_{\tilde{g}}$	$M_{\tilde{u},\tilde{d},\tilde{c},\tilde{s}}$	$M_{\tilde{t}_{1,2}}$	$M_{\tilde{b}_{1,2}}$	$M_{\tilde{\chi}^0_2,\tilde{\chi}^+_1}$	$M_{\tilde{\chi}^0_1}$
2000	1000	$\simeq$500	339,664	431,564	198.8	94.6



eg.

$\tilde{g} \xrightarrow{8.5\%} \tilde{u}_1 \xrightarrow{32.9\%} \tilde{\chi}^0_2$

$\tilde{g} \xrightarrow{8.5\%} \tilde{s}_1 \xrightarrow{25.8\%} \tilde{\chi}^0_2$

Total: 19% gluinos decay to $\tilde{\chi}^0_2$, which may decay to h_1.

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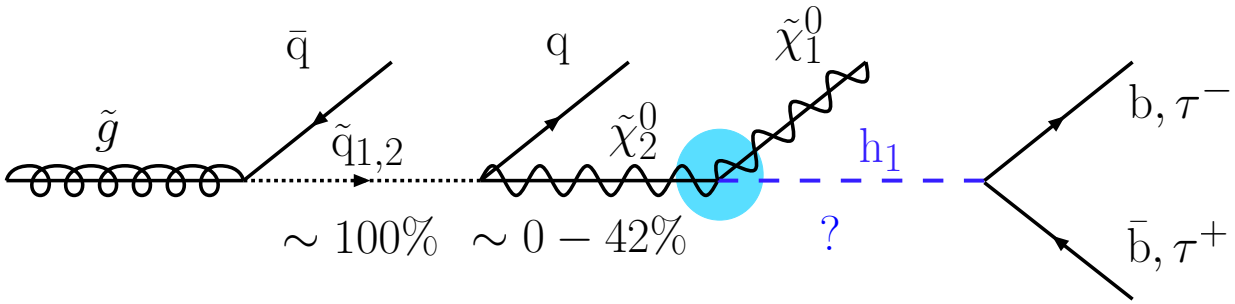

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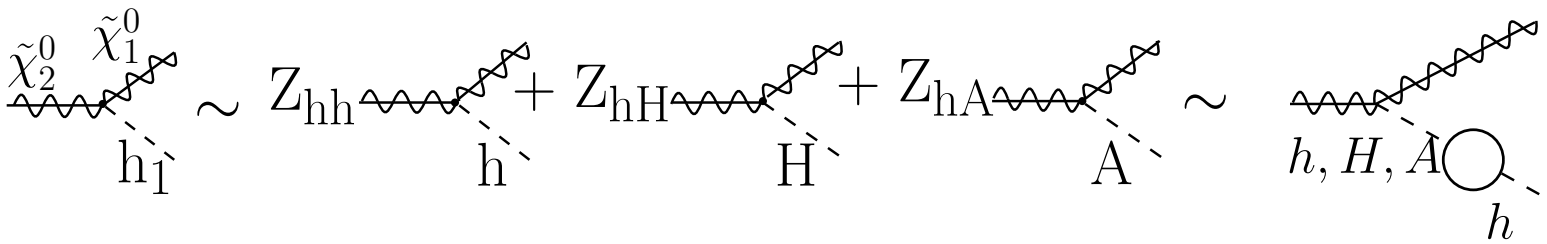
Loop Corrections in the Higgs Sector

How to describe neutral Higgs bosons?

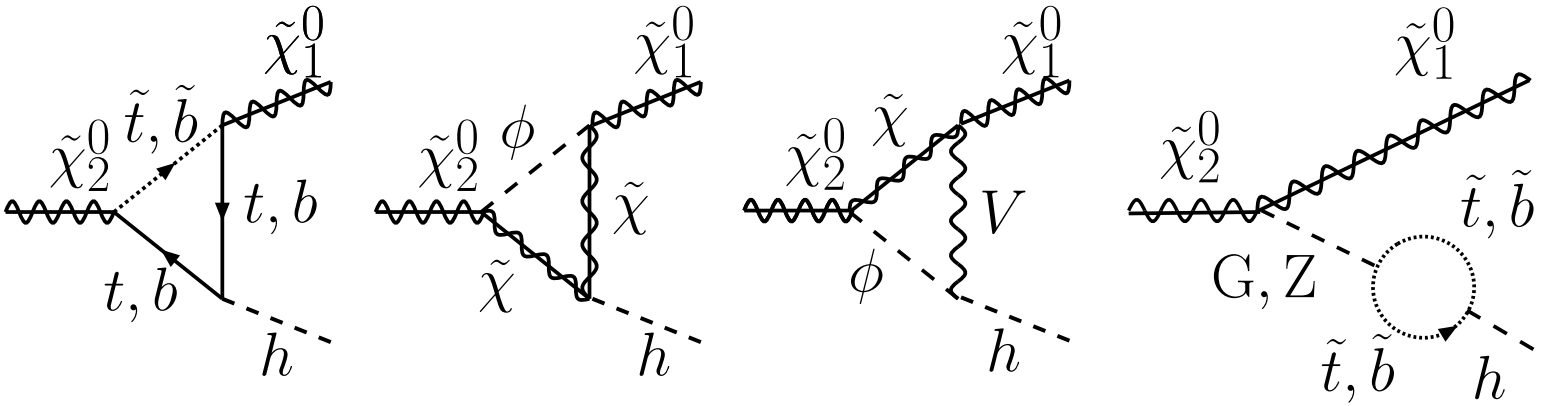
- 2 input parameters: $m_{H^\pm}$, $\tan\beta$
- m_h, m_H, m_A receive loop corrections.
- Factors Z_{ij} include mixing between h, H, A.

Improved born approximation



- Automatically includes h-H-A self-energy diagrams
- m_{h_i}, Z_{ij} are obtained from `FeynHiggs2.6.3`

For full vertex correction, also require triangle diagrams and additional self energy diagrams: eg.



Result based on complete 1-loop result supplemented with 2-loop propagator-type corrections:
i.e. 2-loop masses and 2-loop Z factors from `FeynHiggs`

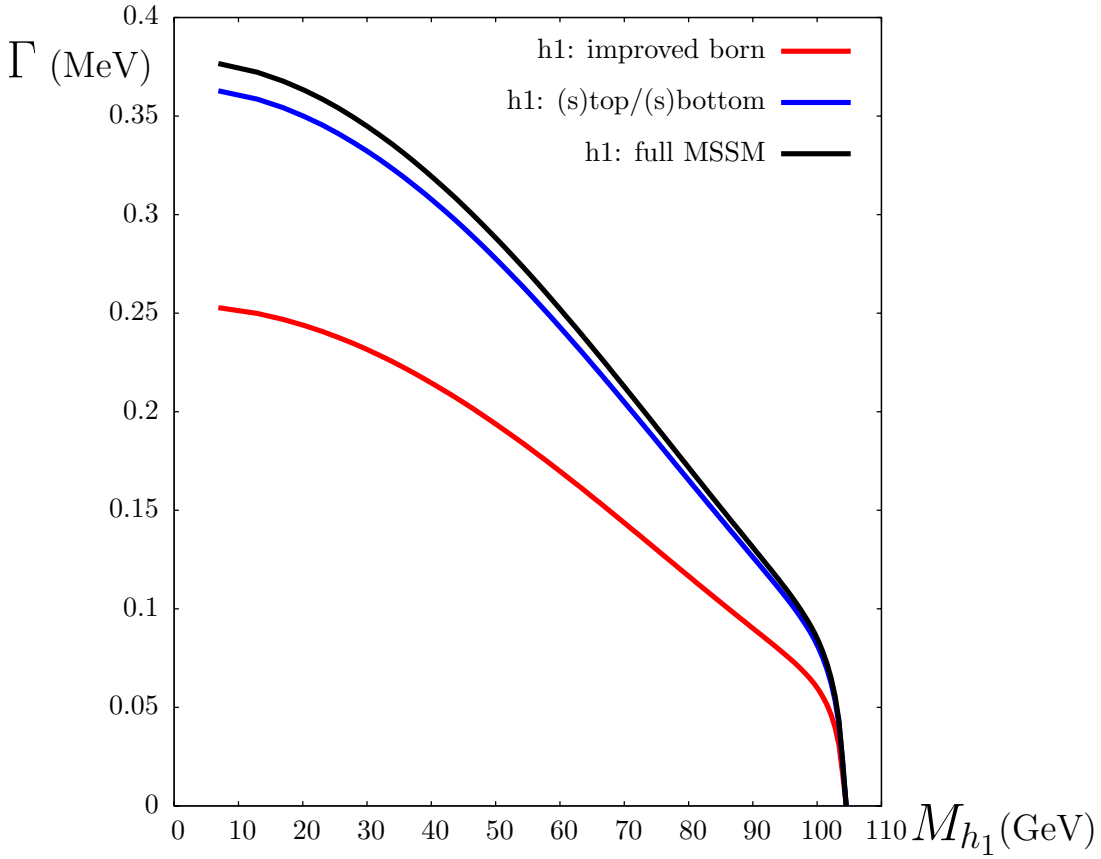
$\tilde{\chi}_2^0$ Decay Width

$\Gamma(\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 h_1)$

- Improved Born: $Z_{ij}^{(2)} \Gamma_j^{tree}$
- Full result: $Z_{ij}^{(2)} \Gamma_j^{(1)}$
- $t, \tilde{t}, b, \tilde{b}$ dominant.
- Genuine vertex corrections up to 50% in extreme CPX scenario.

[A.F, G.Weiglein, in preparation '08]

CPX: $\tan\beta = 7, M_2 = 200$



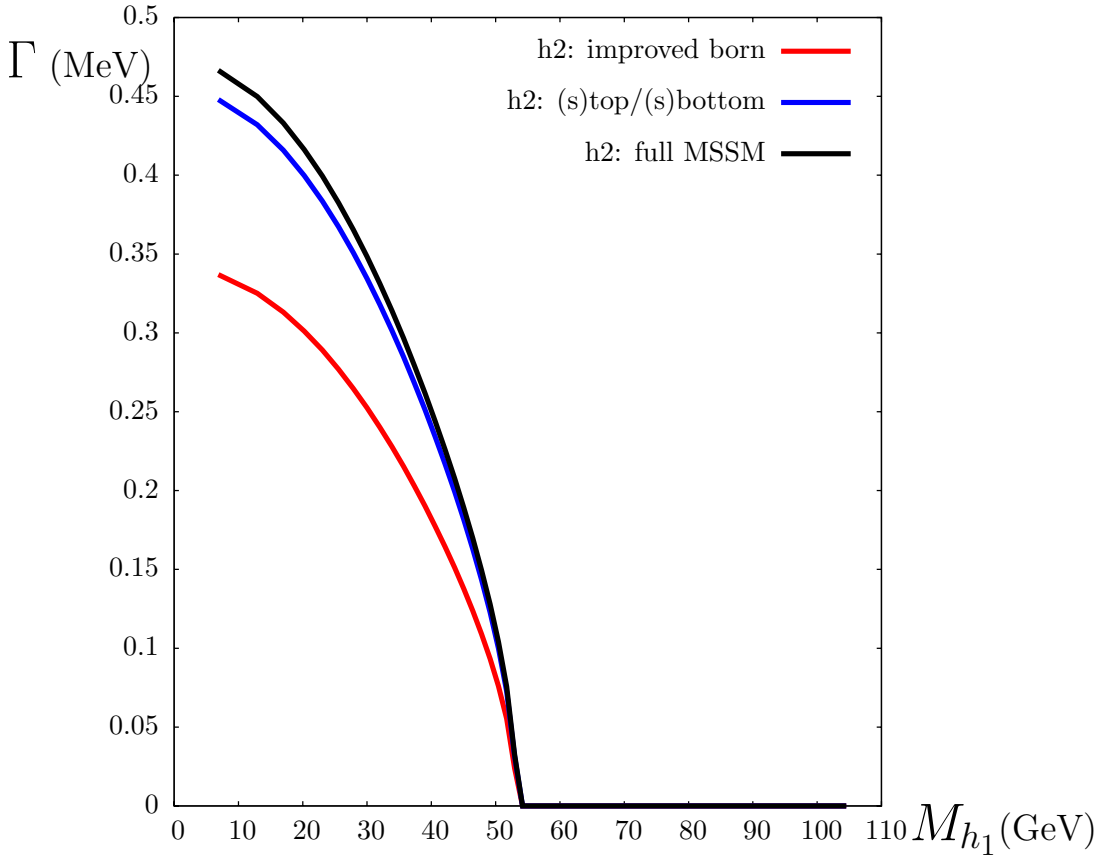
$\tilde{\chi}_2^0$ Decay Width

$\Gamma(\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 h_2)$

- Improved Born: $Z_{ij}^{(2)} \Gamma_j^{tree}$
- Full result: $Z_{ij}^{(2)} \Gamma_j^{(1)}$
- $t, \tilde{t}, b, \tilde{b}$ dominant.
- Genuine vertex corrections up to 40% in extreme CPX scenario.

[A.F, G.Weiglein, in preparation '08]

CPX: $\tan\beta = 7, M_2 = 200$

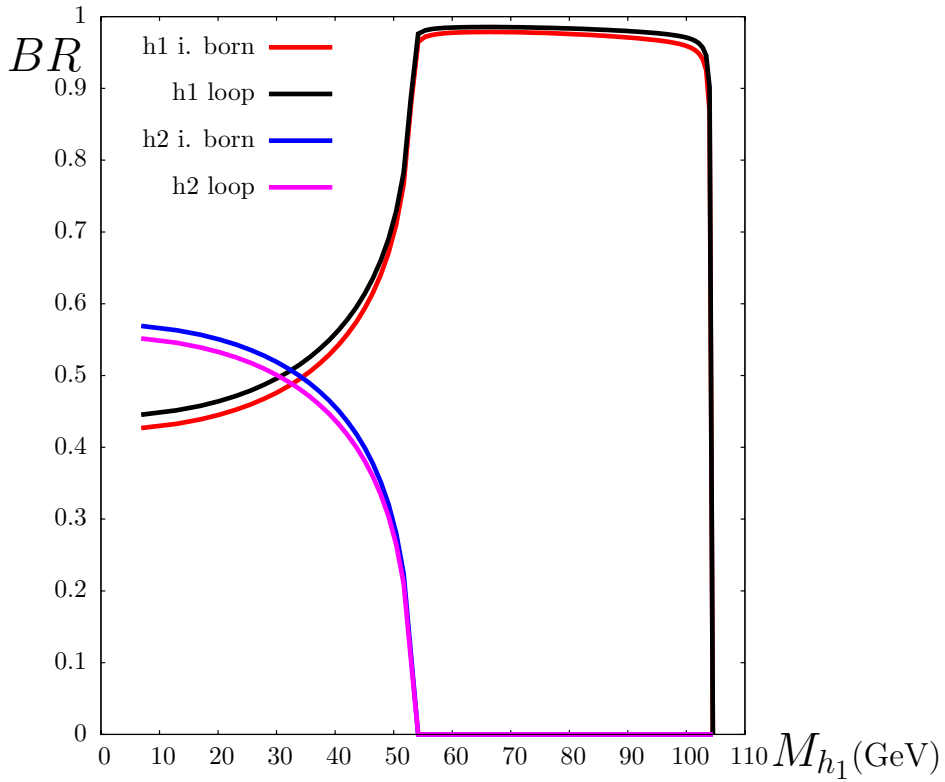


$\tilde{\chi}_2^0$ Branching Ratio

Decay modes:

$$\begin{aligned}\tilde{\chi}_2^0 &\to \tilde{\chi}_1^0 h_1 \ (44 - 98.5\%)\\ &\to \tilde{\chi}_1^0 h_2 \ (55 - 0\%)\\ &\to \tilde{\chi}_1^0 Z \ (\text{suppressed})\\ &\to \tilde{\chi}_1^0 f\bar{f} \ (\text{suppressed})\end{aligned}$$

Effect of loop corrections:
h_1, h_2 modes are each enhanced by $40, 50\%$
$\Rightarrow$ effect on BR is only 5%.



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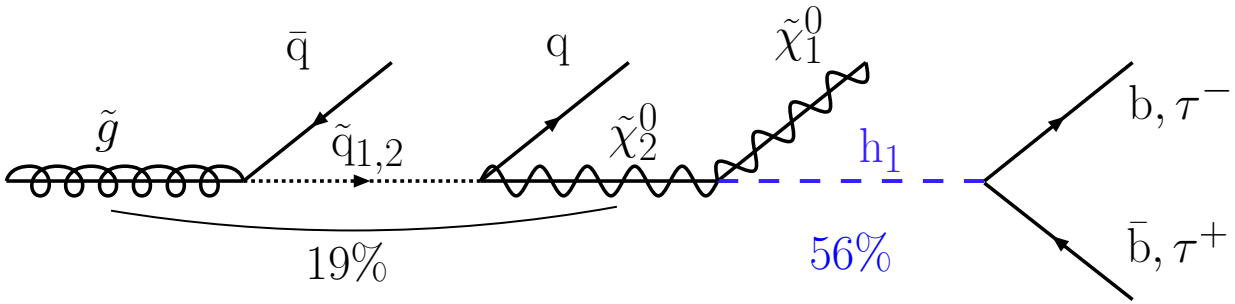
CPX Cascades

CPX hole with $\tan\beta = 7$, $M_{h_1} \sim 40 GeV$:



- Produce $\tilde{g}$ ($\sigma_{\tilde{g}\sim 1000} \sim 1pb$) $\rightarrow$ 11% cascade decay to h_1
- Or produce $\tilde{q}$ ($\sigma_{\tilde{q}\sim 500} \sim 50pb$) $\rightarrow$ up to 42% decay to h_1

Question: Is it possible to dig such a signal out of SM and SUSY backgrounds?

Summary

- In CP-violation scenarios, h_1 may be as light as 30-40GeV.
- Such a light h_1 may be significantly produced via $\tilde{\chi}_2^0$ decay.
- Genuine vertex corrections to $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \mathrm{h}_1$ are important.
- Results were presented for complete 1-loop result with 2-loop masses and Z factors: the most precise prediction for the process $\tilde{\chi}_i^0 \to \tilde{\chi}_j^0 h_k$
- Outlook:
  - Results will be provided as a public tool so that experimental studies can be carried out.