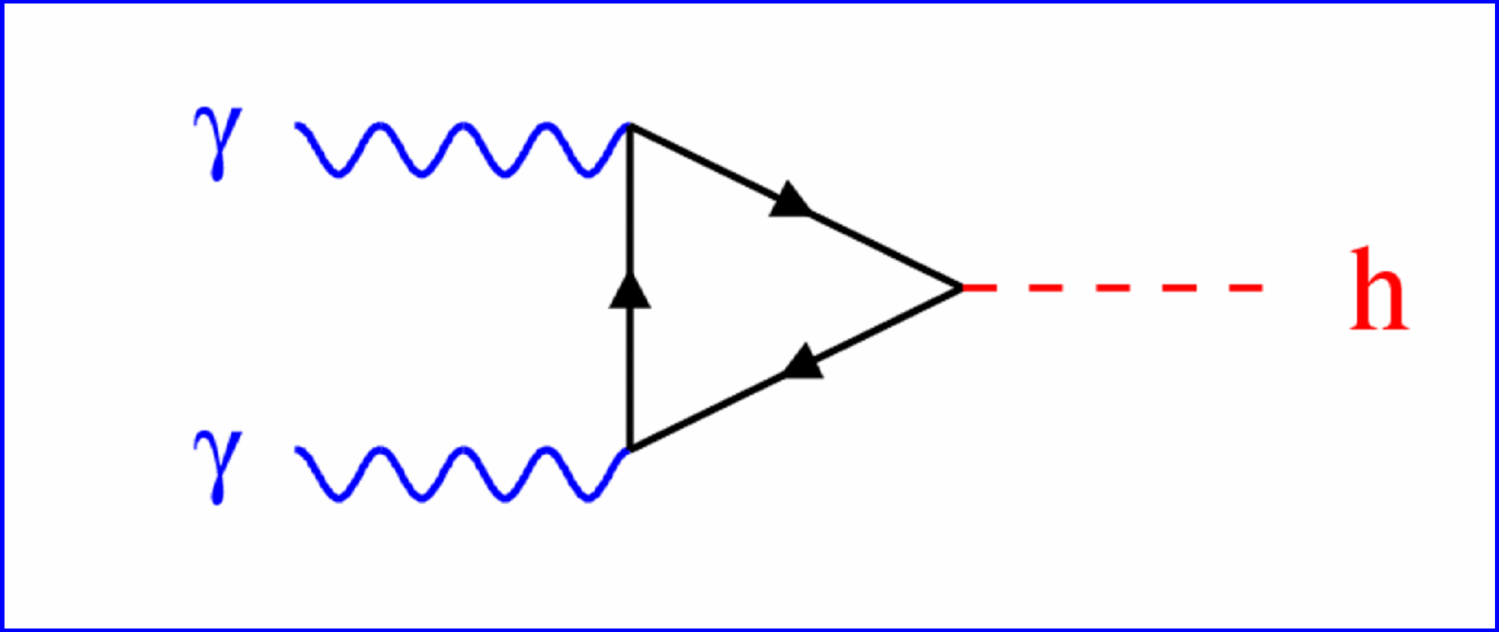
Explicit CP-violation in the Higgs Sector @ Gamma Gamma Colliders (gC) & Other Future Colliders



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In collaboration with Matthew D. Wood & Sven Heinemeyer

We should investigate the Complex MSSM… because:

- **Complex parameters are in principle allowed**
- **In combination with certain range of squark masses, CP violation in Higgs could give possible source of Cosmological Baryogenesis**

Done by adding 2 extra phases in the MSSM:

- ➔ **the gaugino mass and**
- ➔ **trilinear coupling**
  - ✓ **This is in addition to the already existing phase in the CKM matrix**

Complex MSSM: we have MASS and CP Eigenstates

“In zero momentum approximation”

- **CP Eigenstates**
  - ✓ **h, H** **CP-EVEN**
  - ✓ **A** **CP-ODD**
- **Mass Eigenstates** $M_{h_1} < M_{h_2} < M_{h_3}$

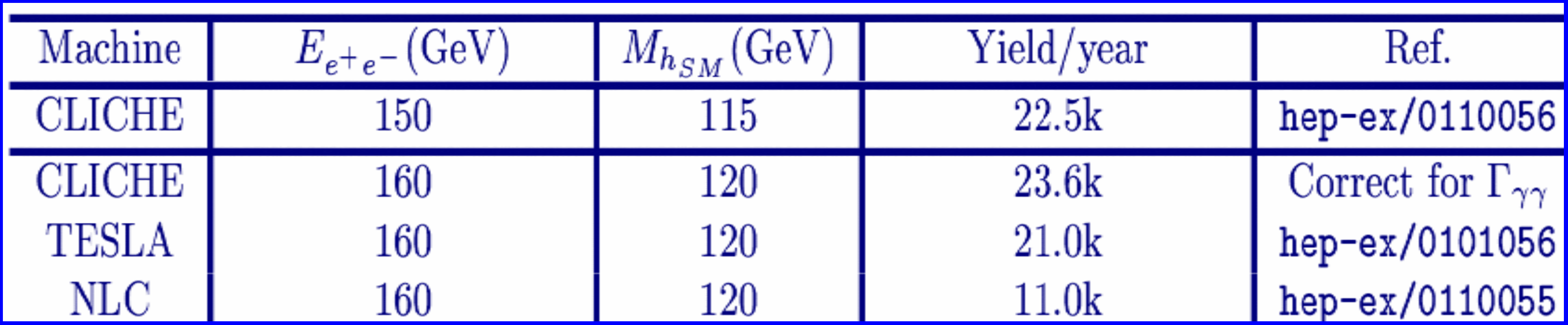
$$\begin{pmatrix} h_1 \\ h_2 \\ h_3 \end{pmatrix} = \boxed{\begin{pmatrix} u_{11} & u_{12} & u_{13} \\ u_{21} & u_{22} & u_{23} \\ u_{31} & u_{32} & u_{33} \end{pmatrix}} \begin{pmatrix} h \\ H \\ A \end{pmatrix} \equiv U \begin{pmatrix} h \\ H \\ A \end{pmatrix}$$

Today… Only focus on h_1 (mass < 135 GeV)

- Masses and decay width for h_1, h_2 & h_3 obtained from:
  - – **CPSuperH (CpsH)**
    - hep-ph/0307377
  - – **FeynHiggg**
    - hep-ph/0108059, hep-ph/0212037
- Note: For some parameters
  - – $h_{2,3}$ to h_1 h_1 and (M_{h_1} < 100 GeV) where h--> bb, ττ
    - This could be the dominant mode
    - Good discovery potential at γγ already discussed by Gunion's talk in the context of the NMSSM…

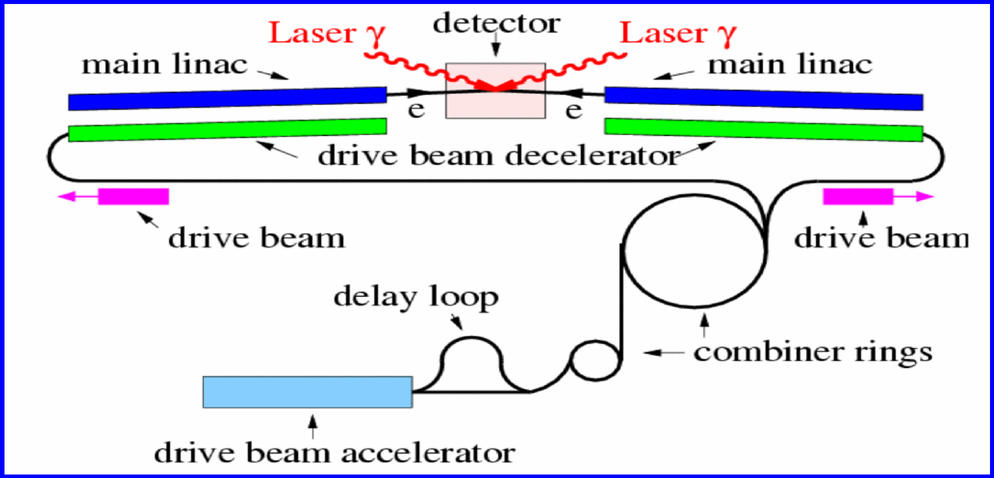
Focus on h_1 production & properties at gC

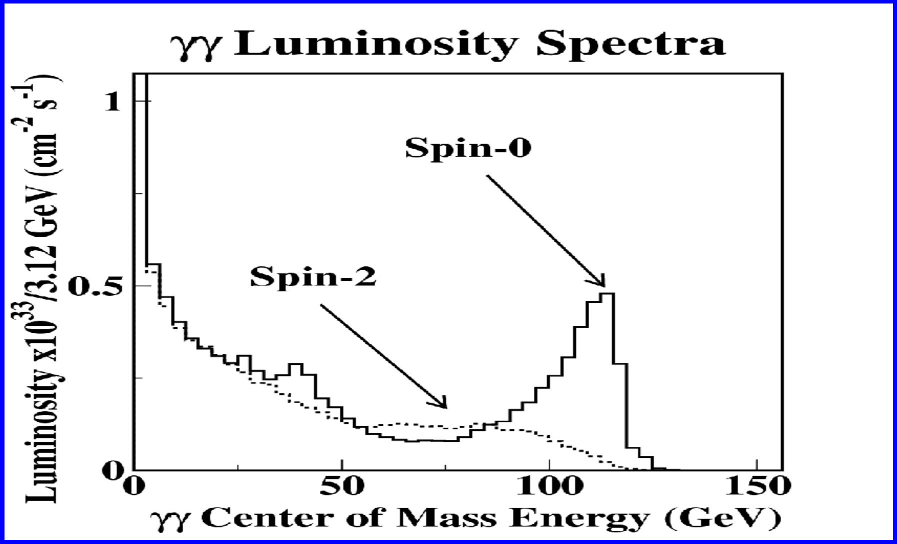
All comparisons made with respect to SM expectations



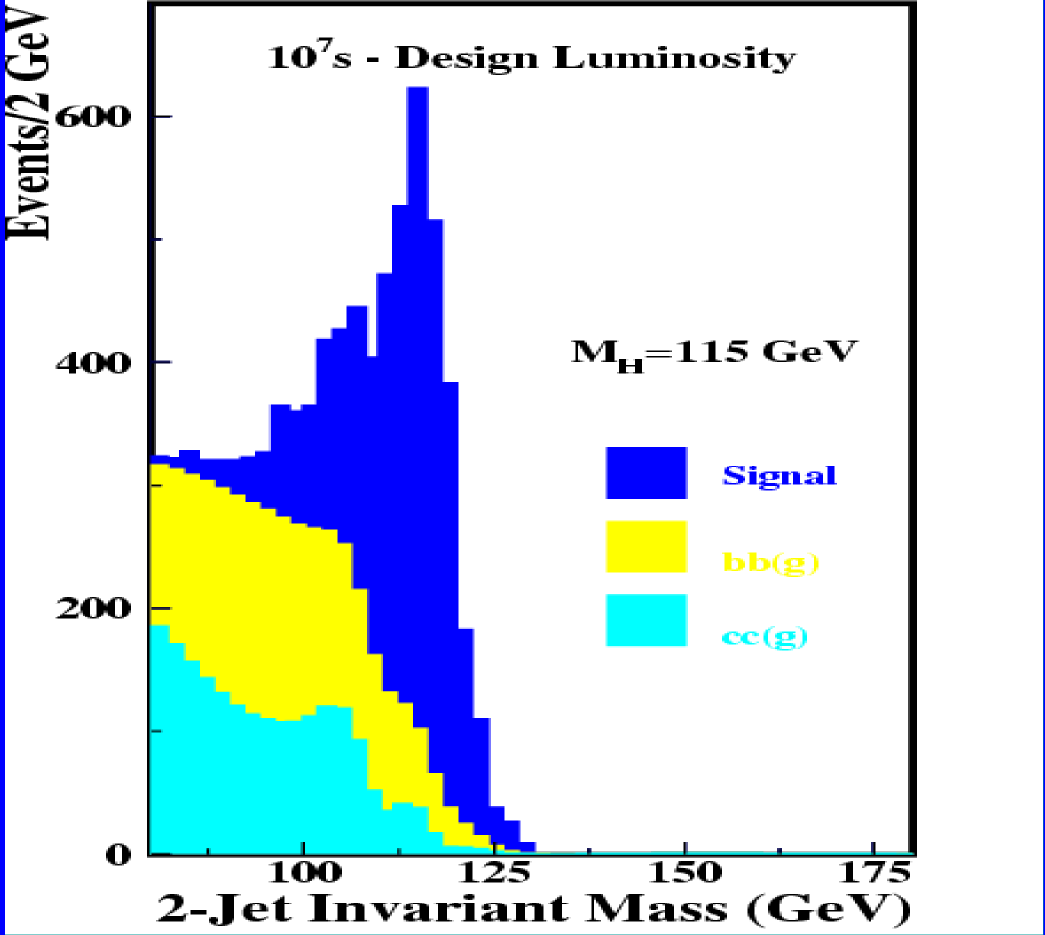
Machine	$E_{e^+e^-}$ (GeV)	$M_{h_{SM}}$ (GeV)	Yield/year	Ref.
CLICHE	150	115	22.5k	hep-ex/0110056
CLICHE	160	120	23.6k	Correct for $\Gamma_{\gamma\gamma}$
TESLA	160	120	21.0k	hep-ex/0101056
NLC	160	120	11.0k	hep-ex/0110055

CLICHé as an example





Consider gC based on CLICHé parameters for h_{SM} = 115 GeV



➔ **The h_{SM} to bb decay is the most important in this mass range**

Well defined $J = 0, 2$ final states,

when starting with *circularly* ($\lambda = \pm 1$) polarized γ's

⇒ important for controlling backgrounds,

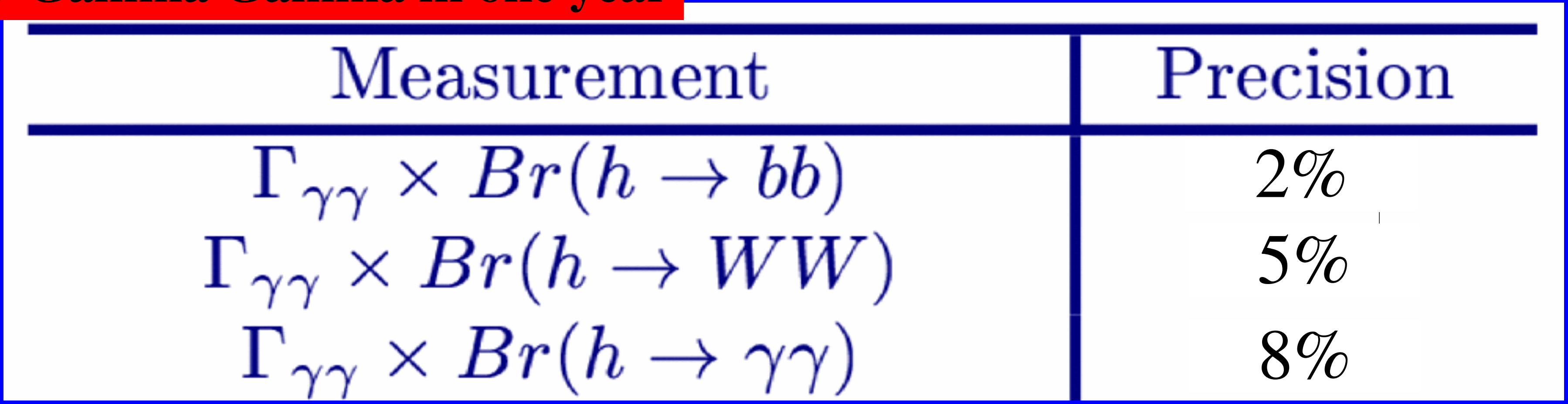
$\gamma\gamma \to f\bar{f}$ is a $J = 1$ state.

signal = two b-quark jets

background = continuum b & c production

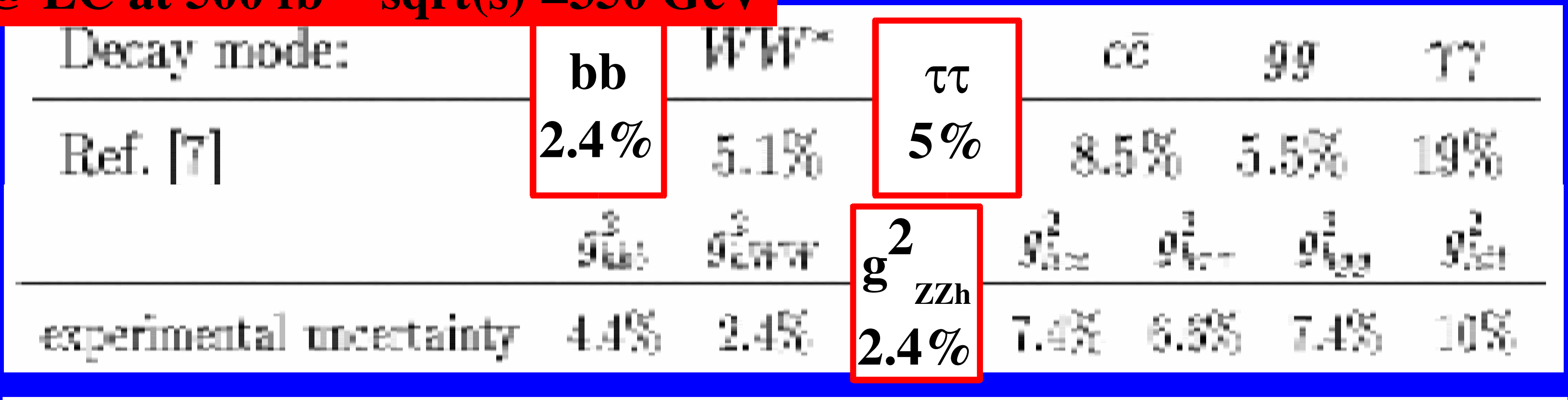
Expectation for SM h @ 120 GeV

@ Gamma Gamma in one year



Measurement	Precision
$\Gamma_{\gamma\gamma} \times Br(h \to bb)$	2%
$\Gamma_{\gamma\gamma} \times Br(h \to WW)$	5%
$\Gamma_{\gamma\gamma} \times Br(h \to \gamma\gamma)$	8%

@ LC at 500 fb^{-1} sqrt(s) =350 GeV



Decay mode:	**bb**	WW^*	**ττ**	$c\bar{c}$	gg	$\gamma\gamma$
Ref. [7]	**2.4%**	5.1%	**5%**	8.5%	5.5%	19%

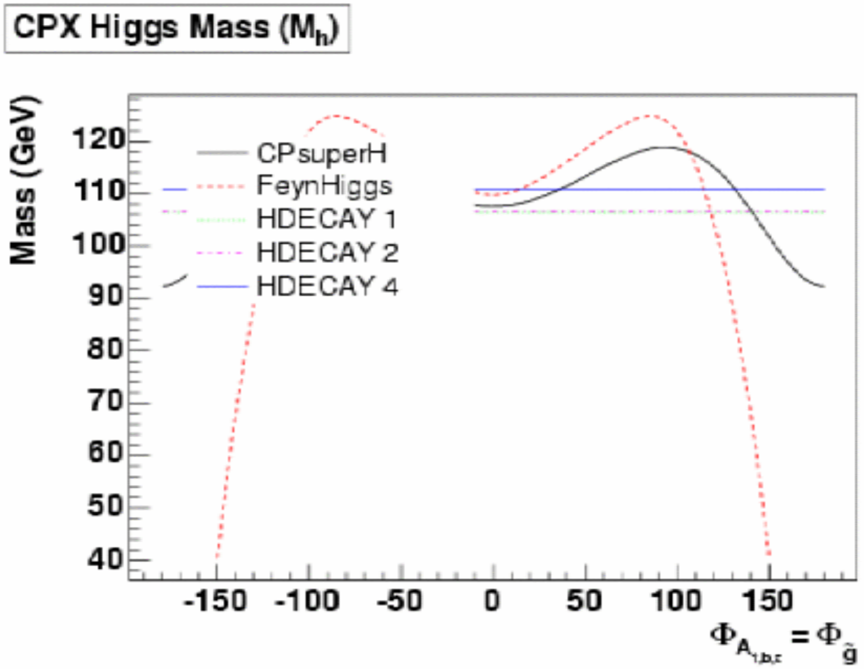
	g^2_{hbb}	g^2_{hWW}	g^2_{ZZh}	g^2_{hcc}	$g^2_{h\tau\tau}$	g^2_{hgg}	g^2_{htt}
experimental uncertainty	4.4%	2.4%	**2.4%**	7.4%	6.5%	7.4%	10%

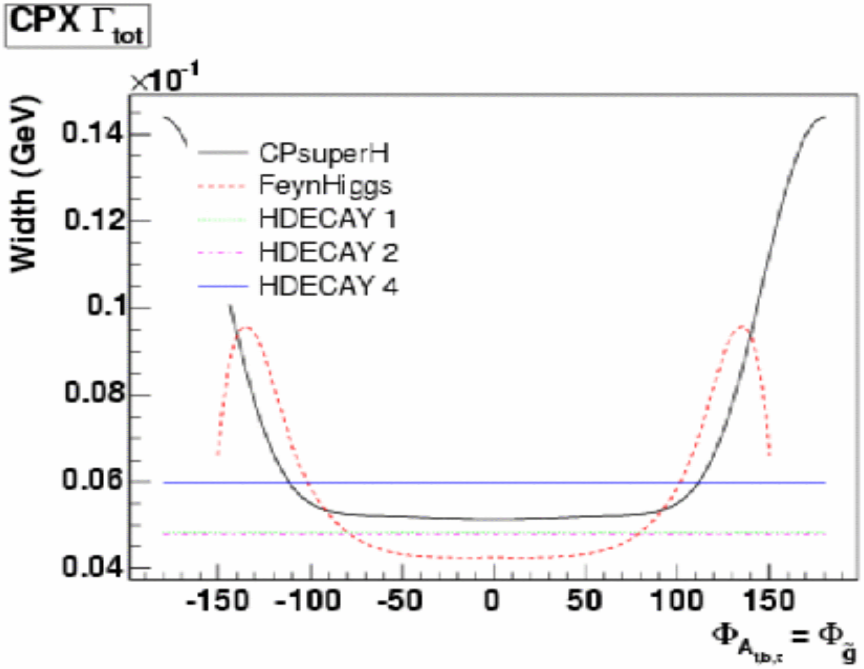
@ LHC 30 fb^{-1}

Γ(Z)/Γ(WW)	Γ(γ)/Γ(W)	Γ(τ)/Γ(W)	Γ(τ)/Γ(γ)	Γ(γ)/Γ(W)
29%	16%	15%	15%	15%

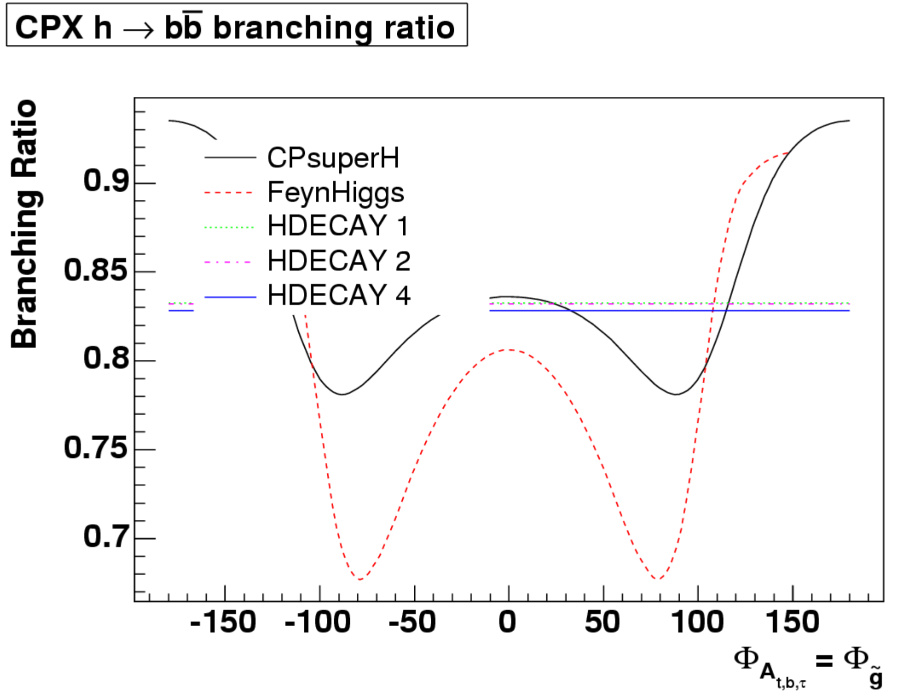
Comparison of CPX (maximizes the CP effects)

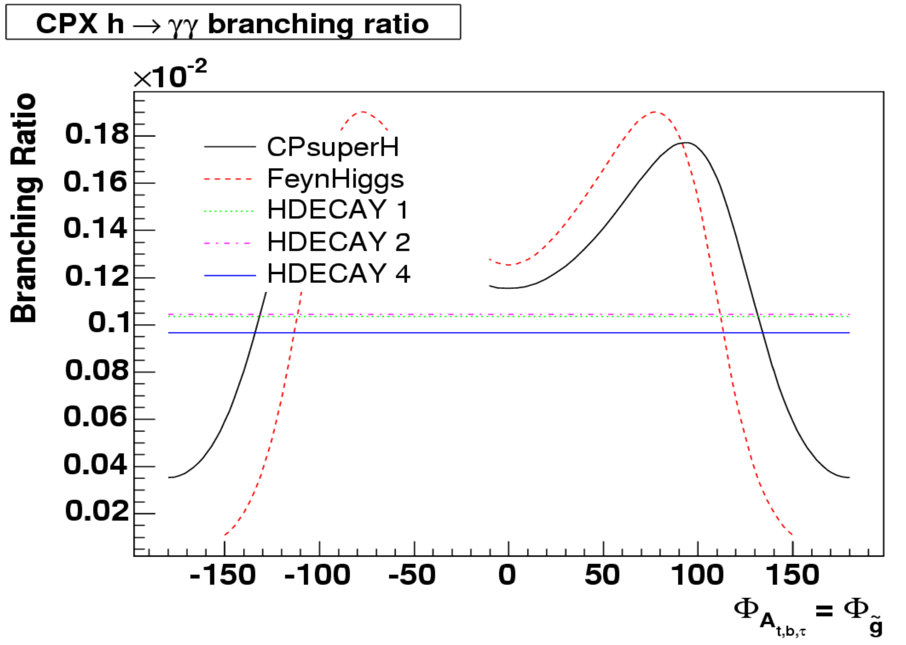
$\tan\beta$		$\lvert\mu\rvert$		$M_{H^\pm}^{\rm pole}$		$M_t^{\rm pole}$	
5		→ 2000.0		→ 300.0		175	
$m_{\tilde{Q}_3}$	$m_{\tilde{U}_3}$	$m_{\tilde{D}_3}$	$m_{\tilde{L}_3}$	$m_{\tilde{E}_3}$	$\lvert A_t\rvert$	$\lvert A_b\rvert$	$\lvert A_\tau\rvert$
500.0	500.0	500.0	500.0	500.0	1000.0	1000.0	1000.0
$m_{\tilde{Q}_2}$	$m_{\tilde{U}_2}$	$m_{\tilde{D}_2}$	$m_{\tilde{L}_2}$	$m_{\tilde{E}_2}$	$\lvert M_1\rvert$	$\lvert M_2\rvert$	$\lvert M_3\rvert$
500.0	500.0	500.0	500.0	500.0	50.0	100.0	1000.0





CPX: Some of the branching ratios to be used





- This is in part a reflection of the mass effects

- μ variation could be the cause of the quick drop at large phases

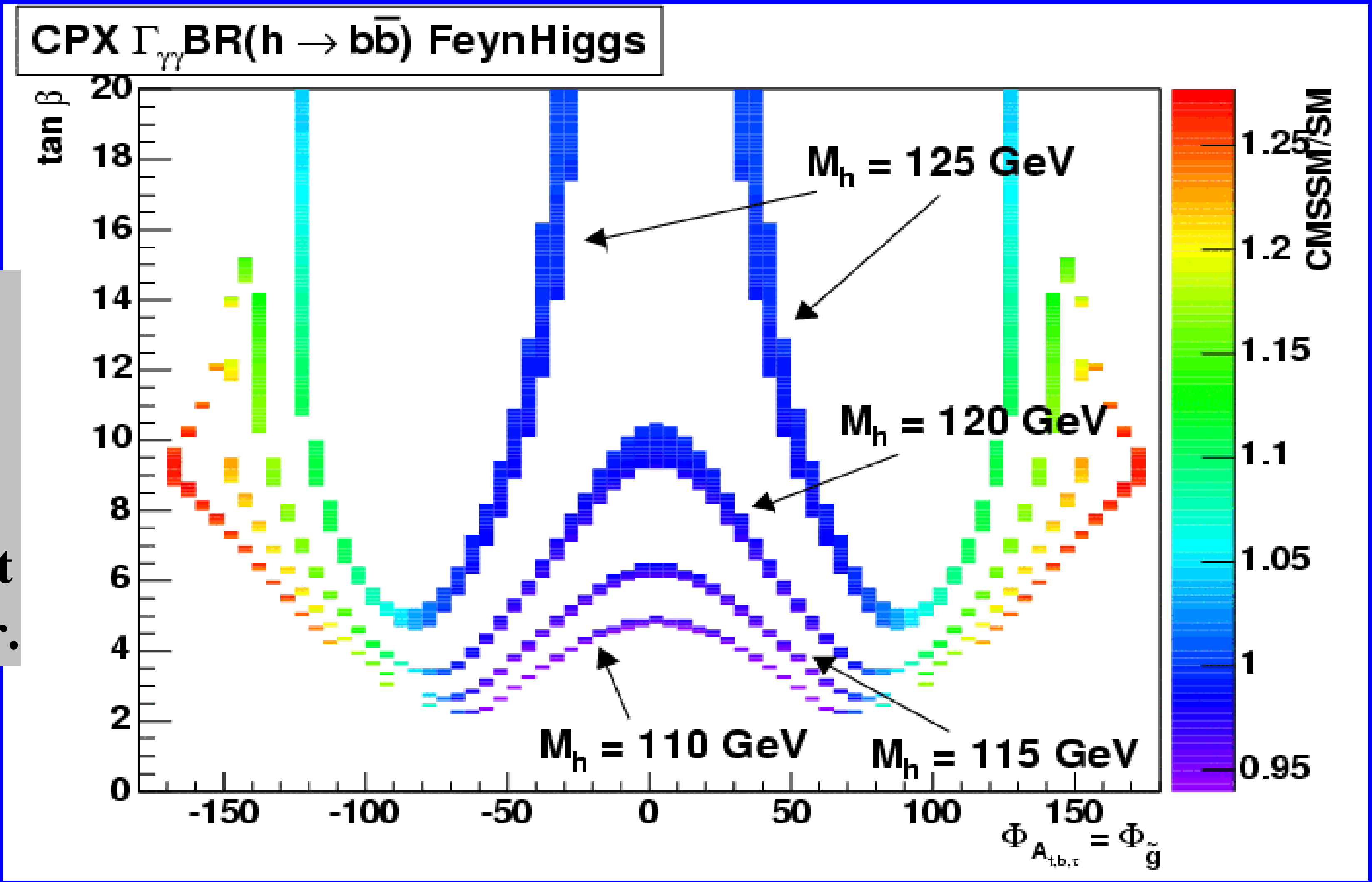
Comparison of CpsH & FeynHiggs
(M. Wood, S. Heinemeyer, M.Velasco)

- **CPSuperH:**
  - **Full complex phase dependence @** $O(\alpha_s , \alpha_t)$
  - **Approx for** $O(\alpha^2_t)$
  - **Approx @ 1Loop**
- **FeynHiggs:**
  - **Approx for phase dependence @** $O(\alpha_s , \alpha_t)$
  - **Full** $O(\alpha^2_t)$ **calculation**
  - **Full 1Loop calculation**

--->DIFFERENCES.... under investigation by the authors!

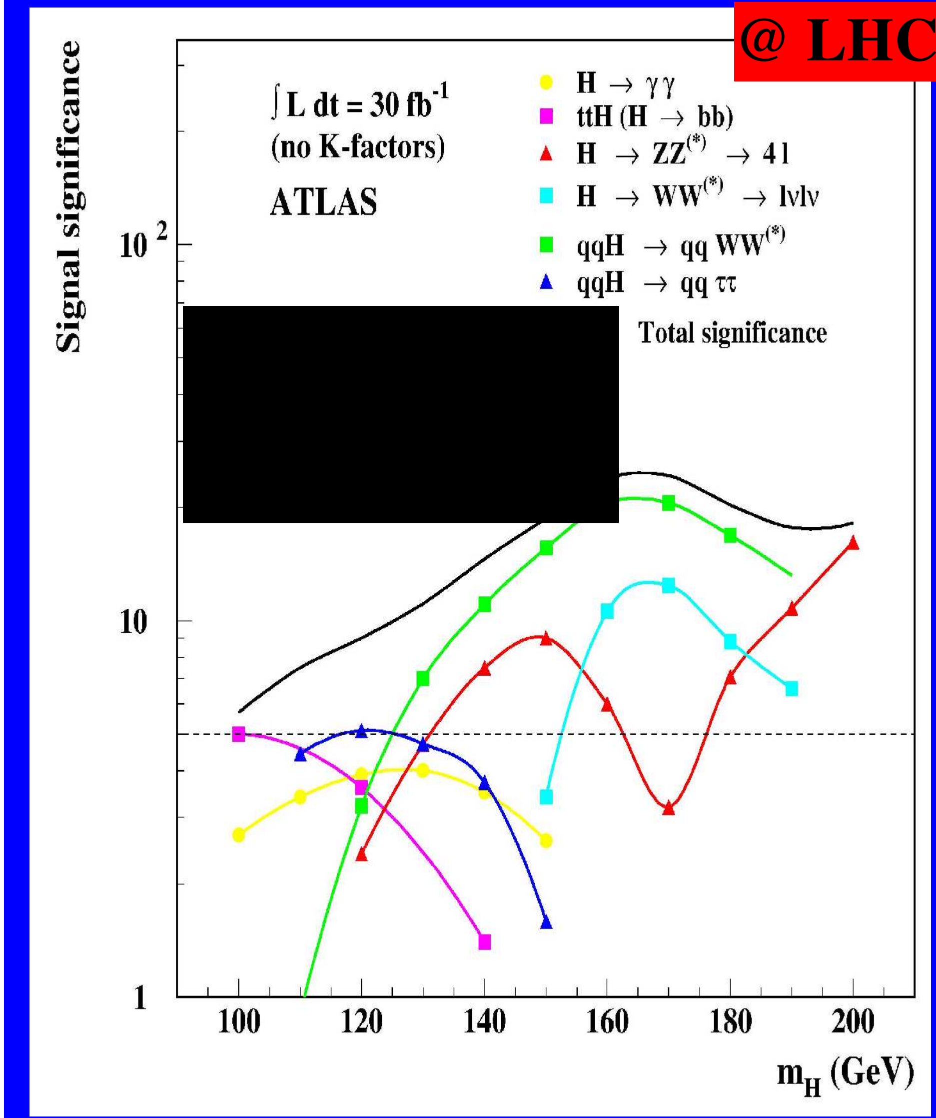
Changes in rate for CPX-Scenario @ fix m_h

Fix Masses: Overall enhacement in the full range of phases & tan β



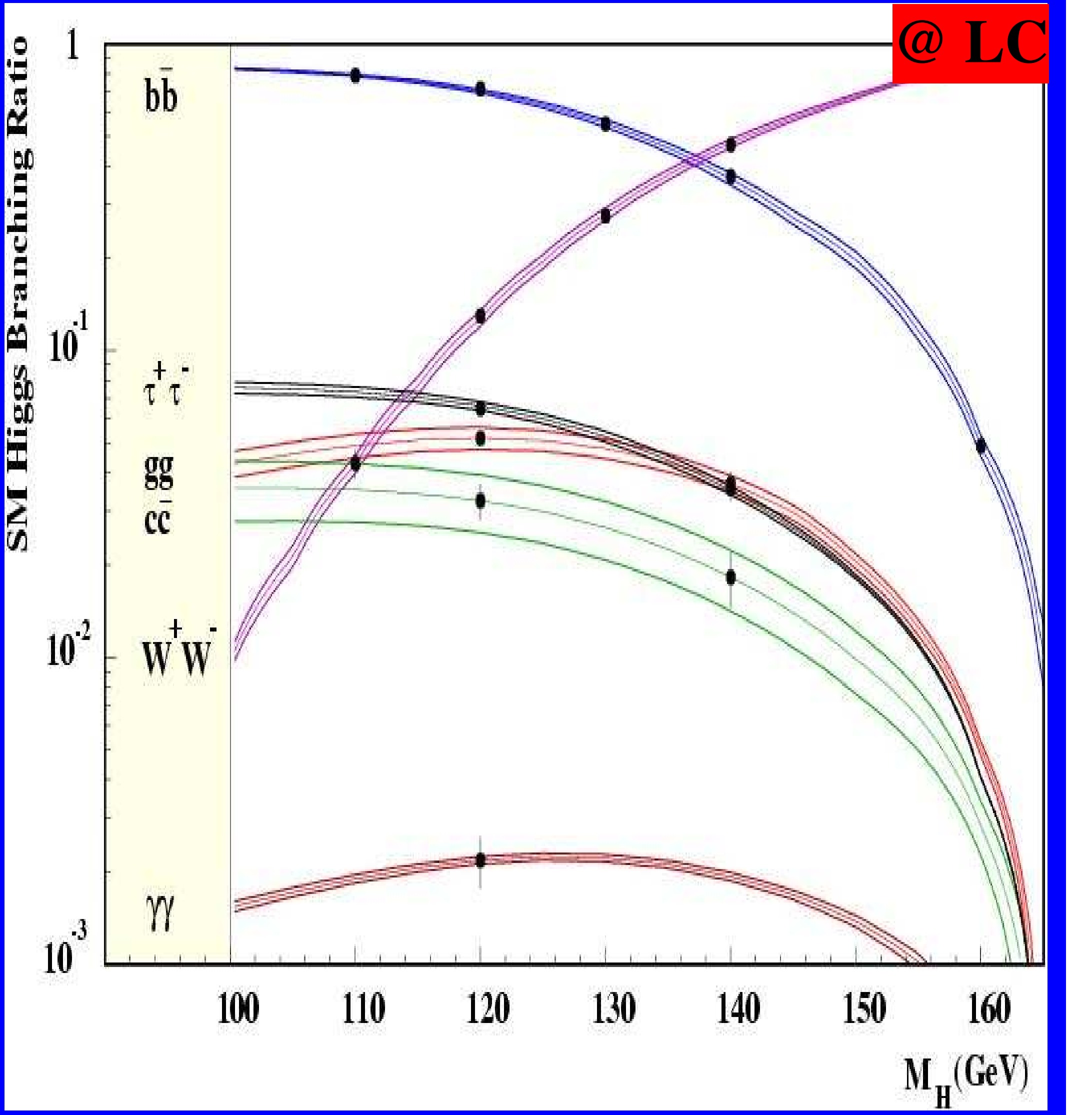
Recall:
In the SM
we expect
a 2%
measument
with a year.

Recall LHC and LC capabilities for h_{SM}



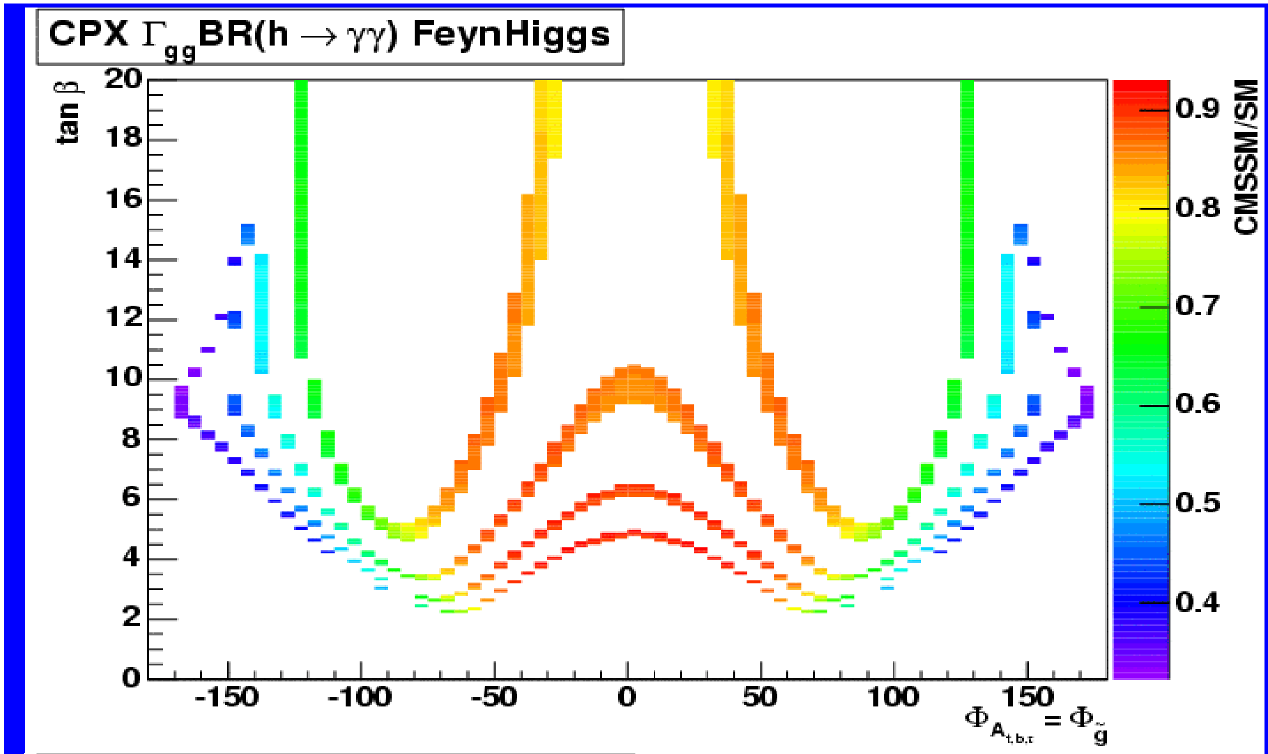
@ LHC

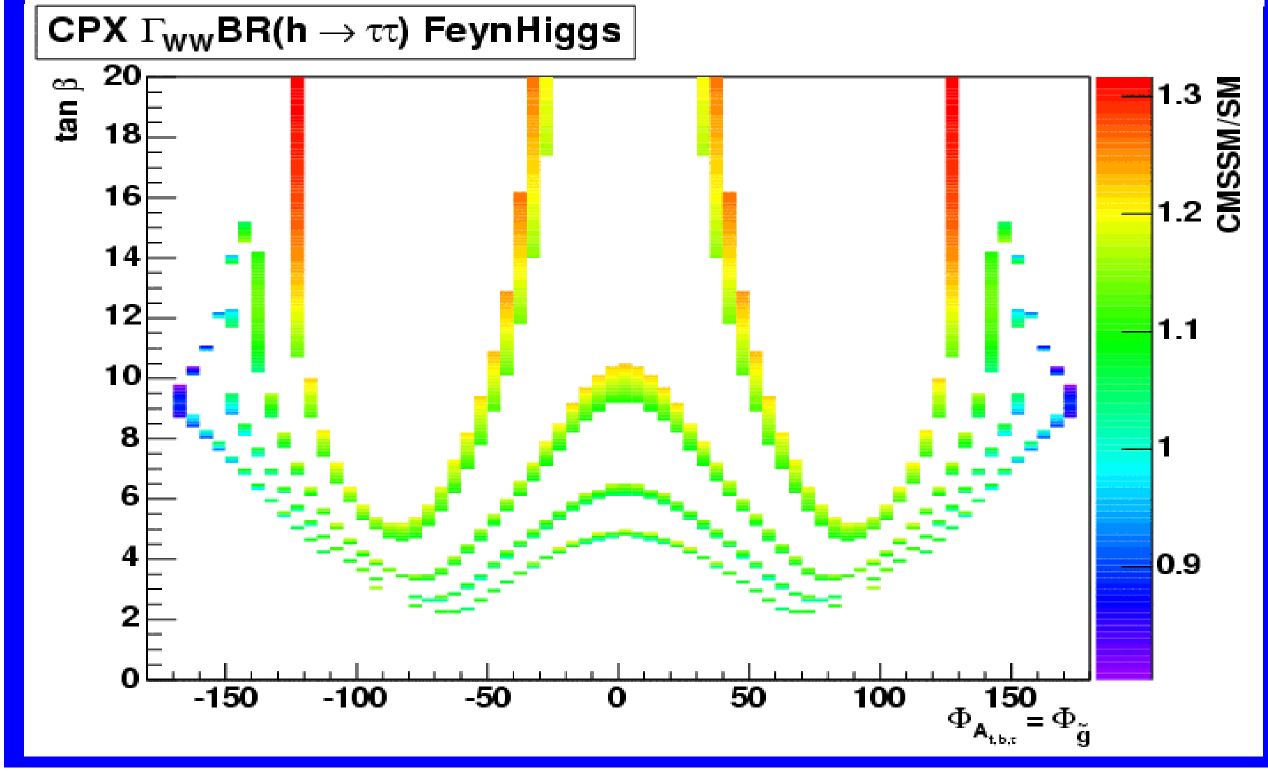
[redacted]



@ LC

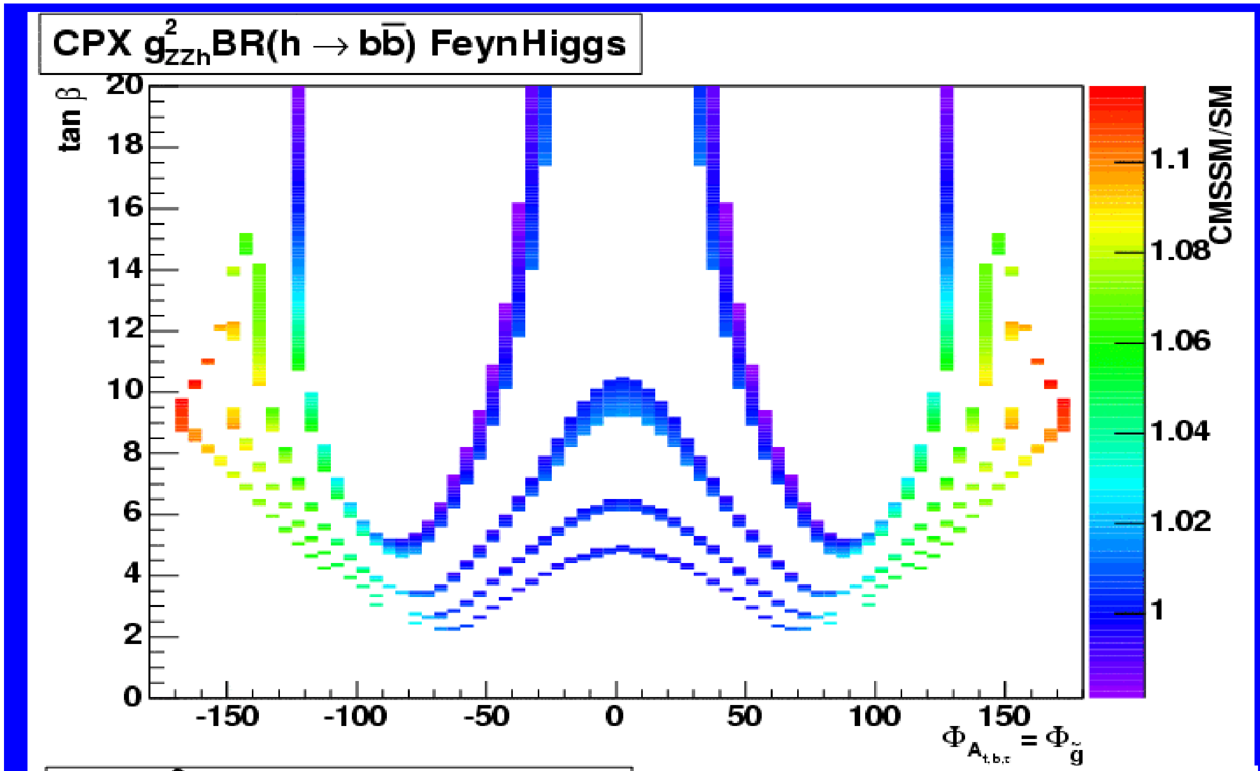
LHC signals

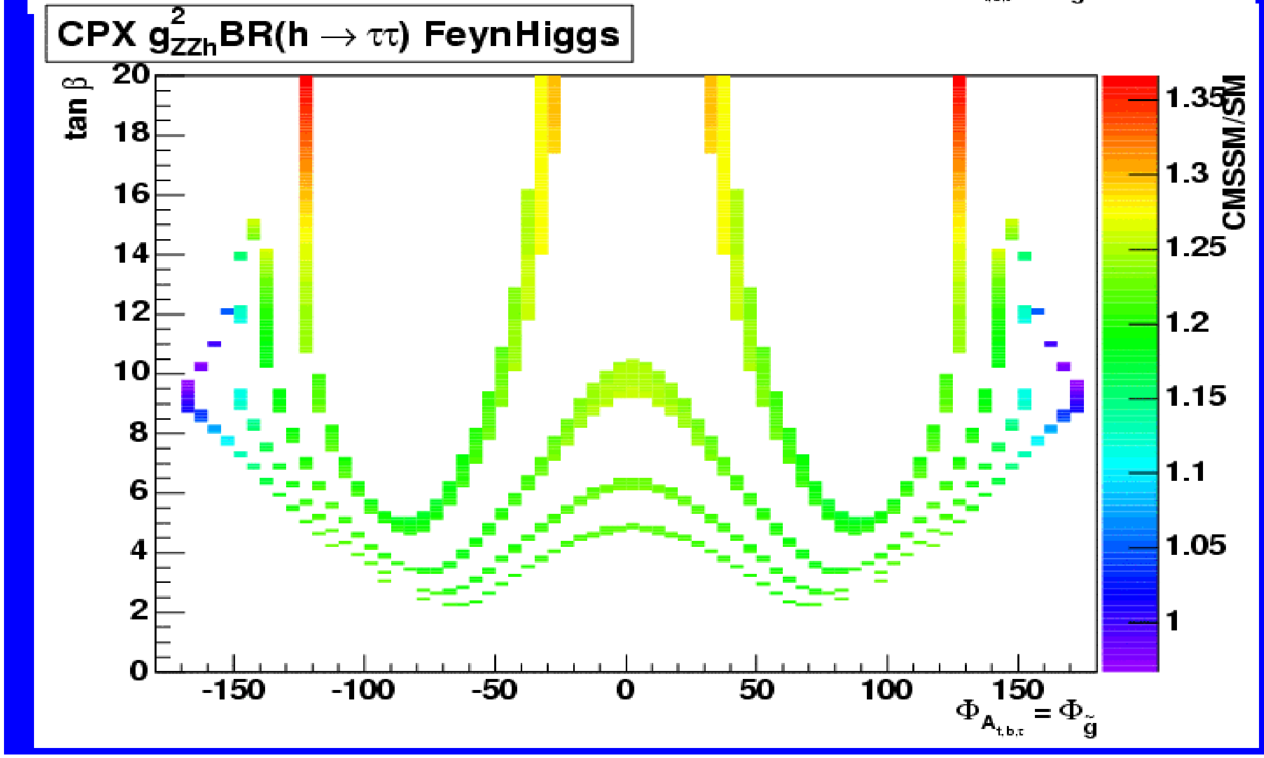

CPX Γ_{gg}BR($h \to \gamma\gamma$) FeynHiggs


CPX Γ_{WW}BR($h \to \tau\tau$) FeynHiggs

- Suppresion in LHC anti-correlated with enhacement observed in $\gamma\gamma$

- The $\tau\tau$ channel guarantees observation of this Higgs



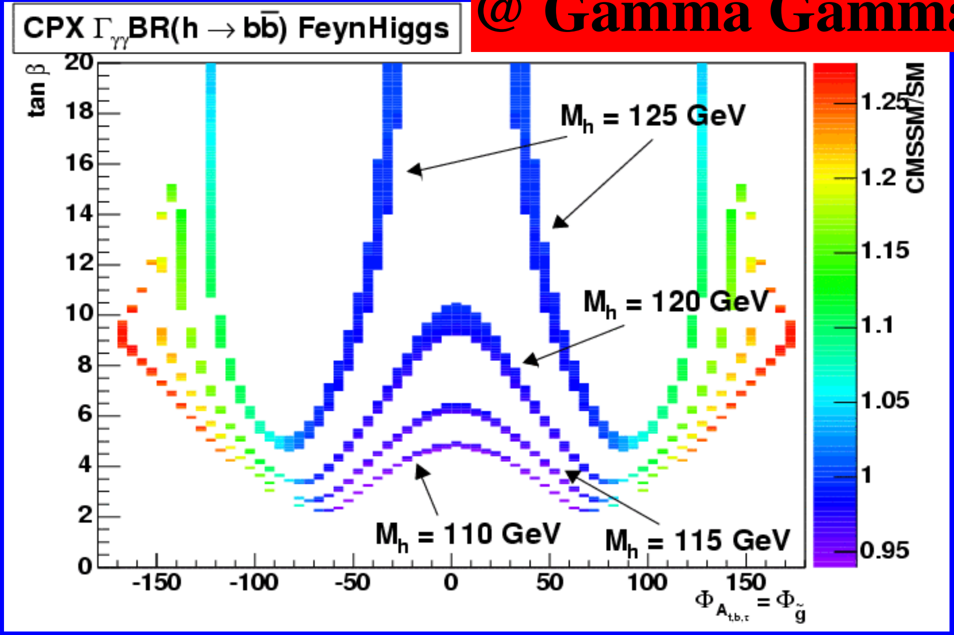


LC signals

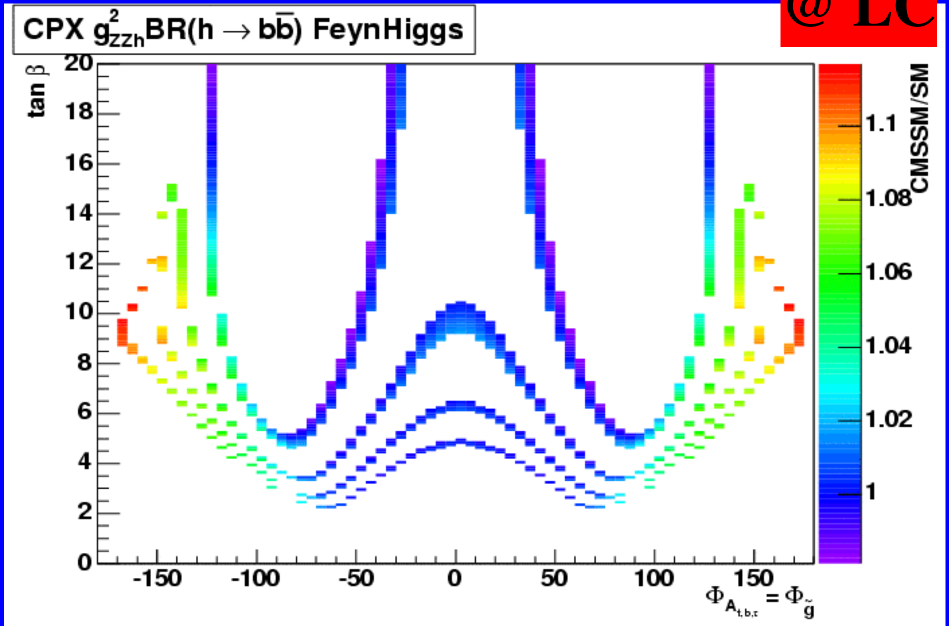
- M_{H+} = 300 GeV, therefore g_{ZZh} not affected much as for lower values M_{H+}

Comparing all machines

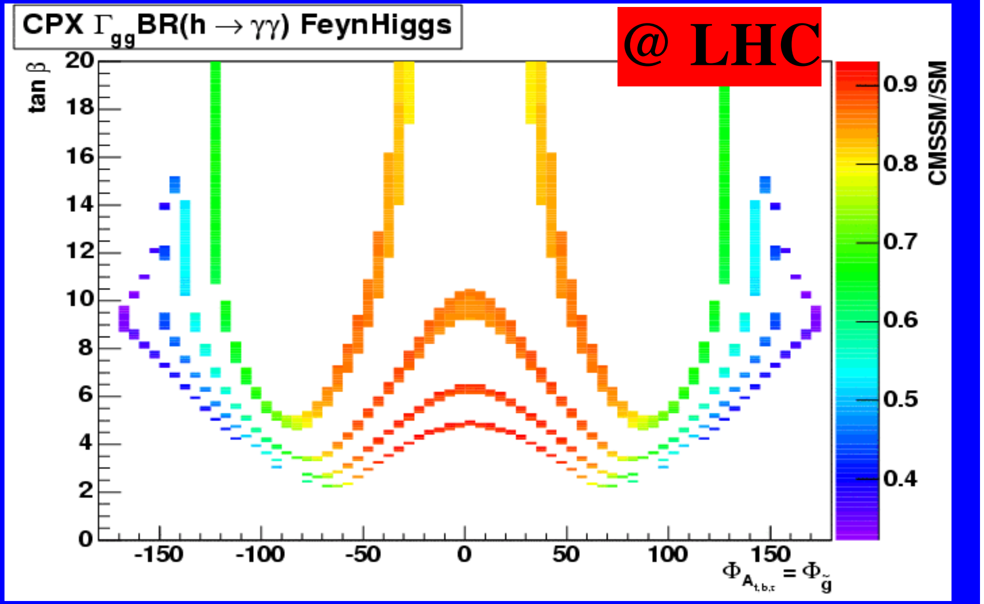
@ Gamma Gamma



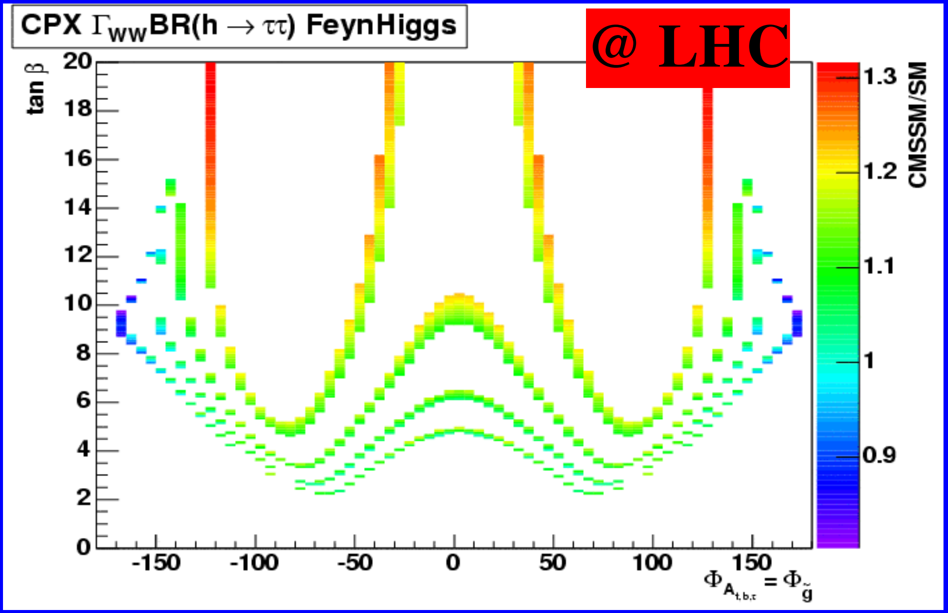
@ LC



@ LHC



@ LHC



Conclusions...

gC, e+e- and LHC colliders are all complementary & highly desirable in the presence of Complex phases in the MSSM:

- **These phases causes explicit CP violation in the Higgs sector that could explain baryogenesis**
- **gC and e+e- coll. both will see an enhancement in the scenarios study so far, the difference being that gC has more sensitivity due to the "Loop" nature of the production mechanism**
- **gC and LHC both see a bigger effect as the absolute value of the phases increases... but the have opposite behaviour (enhancement @ gC, suppression at LHC)**