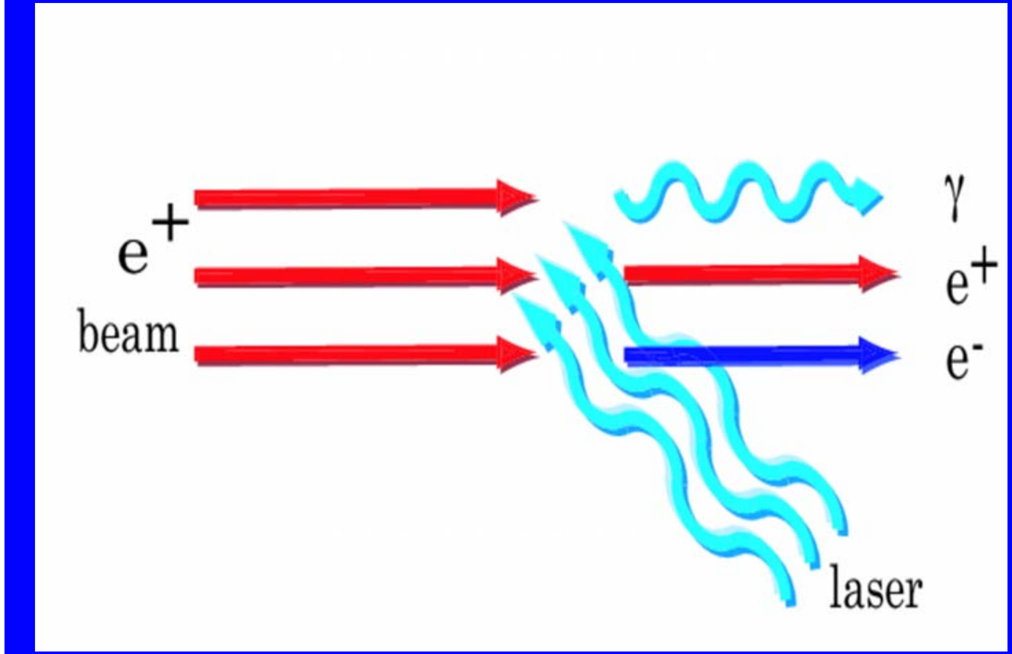
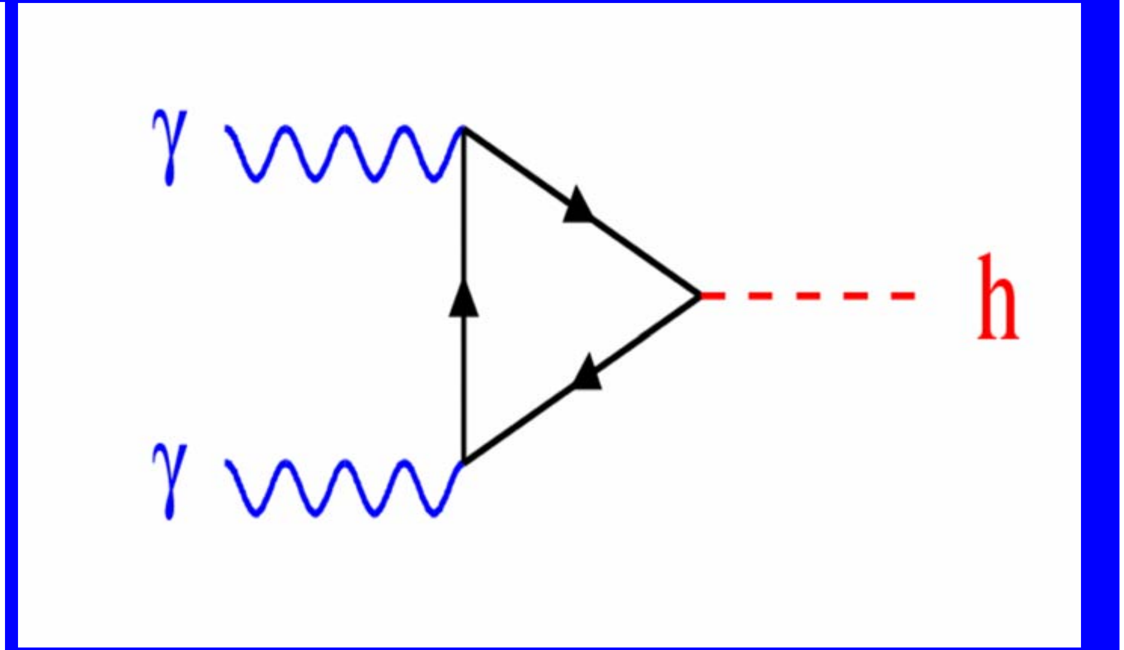
CP Violations studies at Gamma Gamma Colliders





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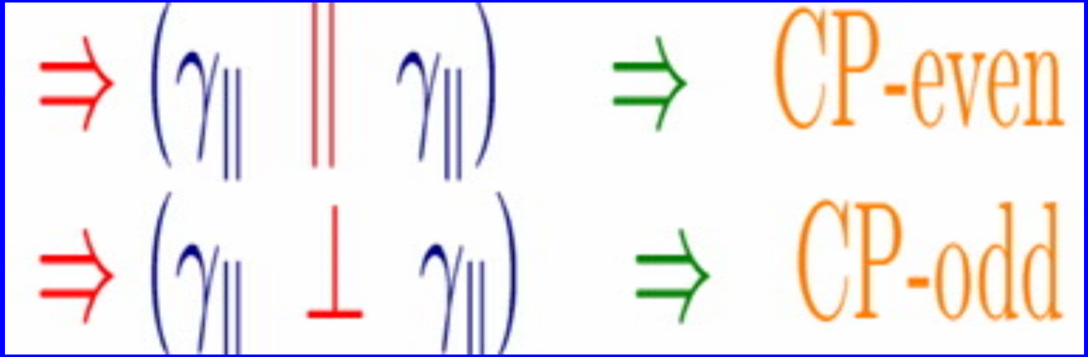
Northwestern Univ.

Dec. 2, 2004

CPNSH - 2004 CERN

Why gC are important in CP violations?

- **Well known:**
  - **Ability to manipulate the beam polarization provides an unique opportunities:** ***i.e.*** **Measurements of CP admixture (from polarization asymmetries)**



$$\Rightarrow (\gamma_{\parallel} \parallel \gamma_{\parallel}) \Rightarrow \text{CP-even}$$

$$\Rightarrow (\gamma_{\parallel} \perp \gamma_{\parallel}) \Rightarrow \text{CP-odd}$$

-- Complemented in important ways the LC & the LHC program: ***i.e.*** **attractive production mechanism**

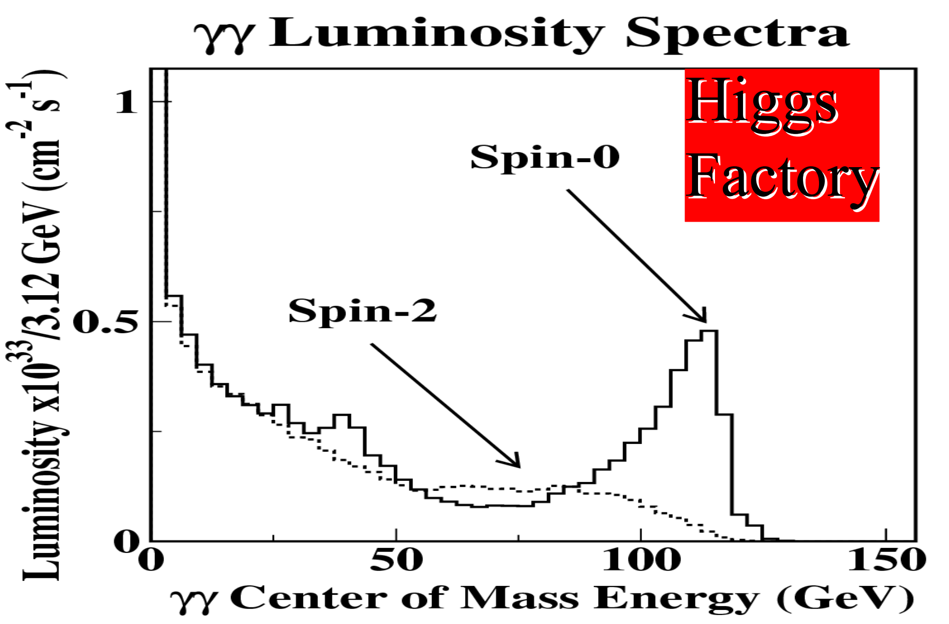
$\Gamma_{\gamma\gamma}$ **asymmetries from the decay products**

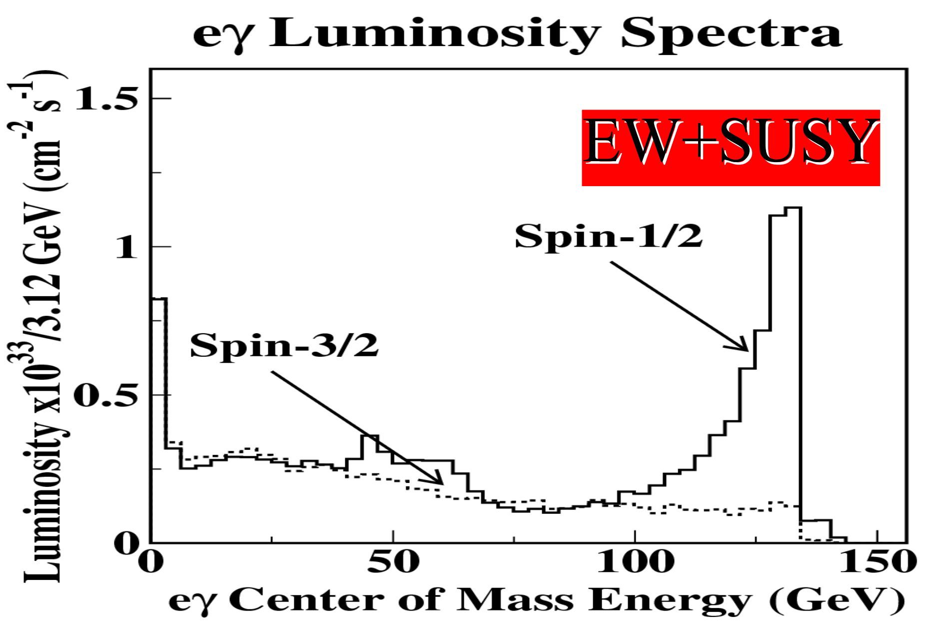
Continue...Why gC are important in CP violations?

- **Well known:**
  - **Interference Effects:** ***i.e. t t-bar & WW.***
  - **More recently:**
    - **Interference Effects:** ***i.e.*** τ***- leptons.***
    - **Clean experimental environment for more exotic channels:** ***i.e.***
      - $\gamma\gamma \rightarrow h_2 \rightarrow h_1 h_1$ vs $\gamma\gamma \rightarrow 2X\,2Y$
      - $\gamma\gamma \rightarrow \tau\tau h_i$ vs $\gamma\gamma \rightarrow 2\tau\,2X$

High event rate expected at a low energy gC: Light SM Higgs

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


γγ Luminosity Spectra

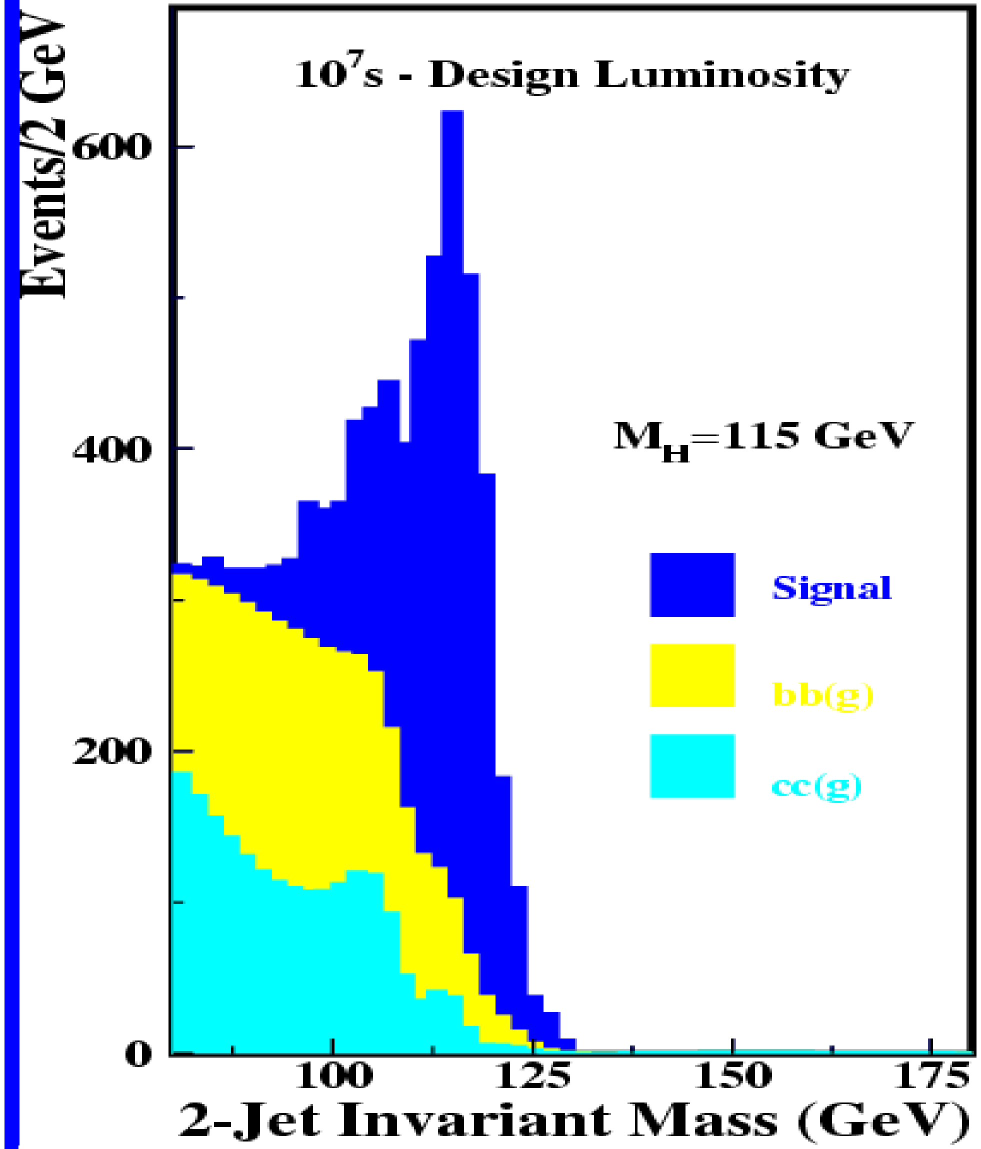

eγ Luminosity Spectra

* Is a 10% CLIC TEST MACHINE # DESIGNS @ SNOWMASS

Example: gC for 115-120 GeV SM Higgs

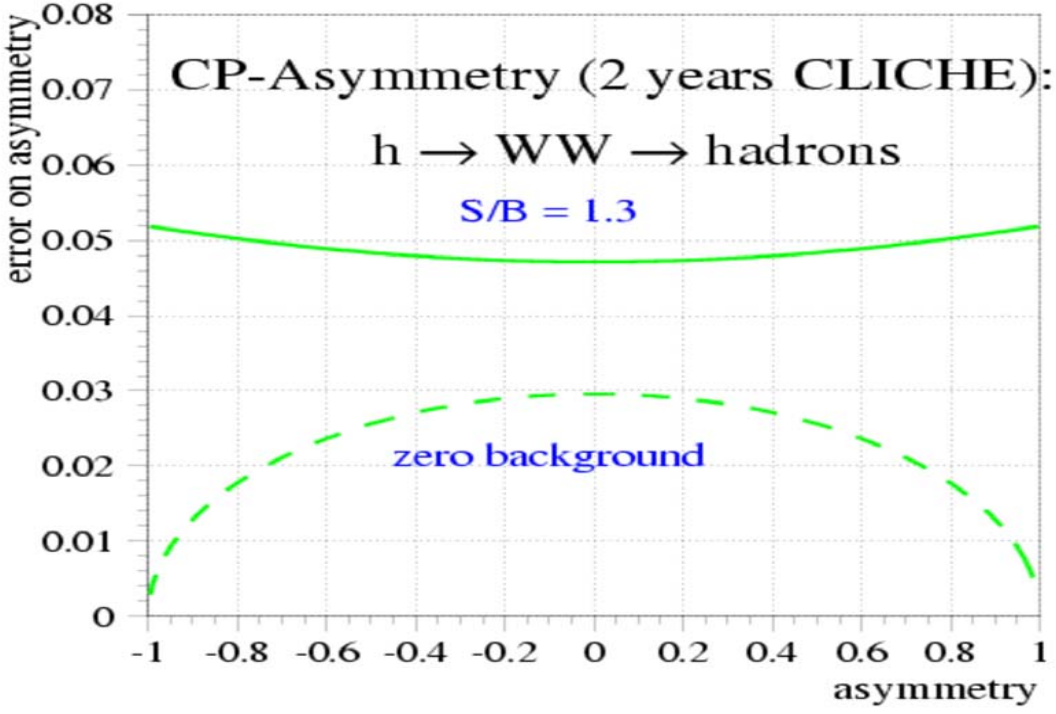
@ gC in one year

Asner, Schmitt,Velasco



Measurement	Precision
$\Gamma_{\gamma\gamma} \times Br(h \to bb)$	2%
$\Gamma_{\gamma\gamma} \times Br(h \to WW)$	5%*
$\Gamma_{\gamma\gamma} \times Br(h \to \gamma\gamma)$	22%

* Only hep-ex/0110056 available



- bb study in great detail

-----> ASIA, EUROPE & USA

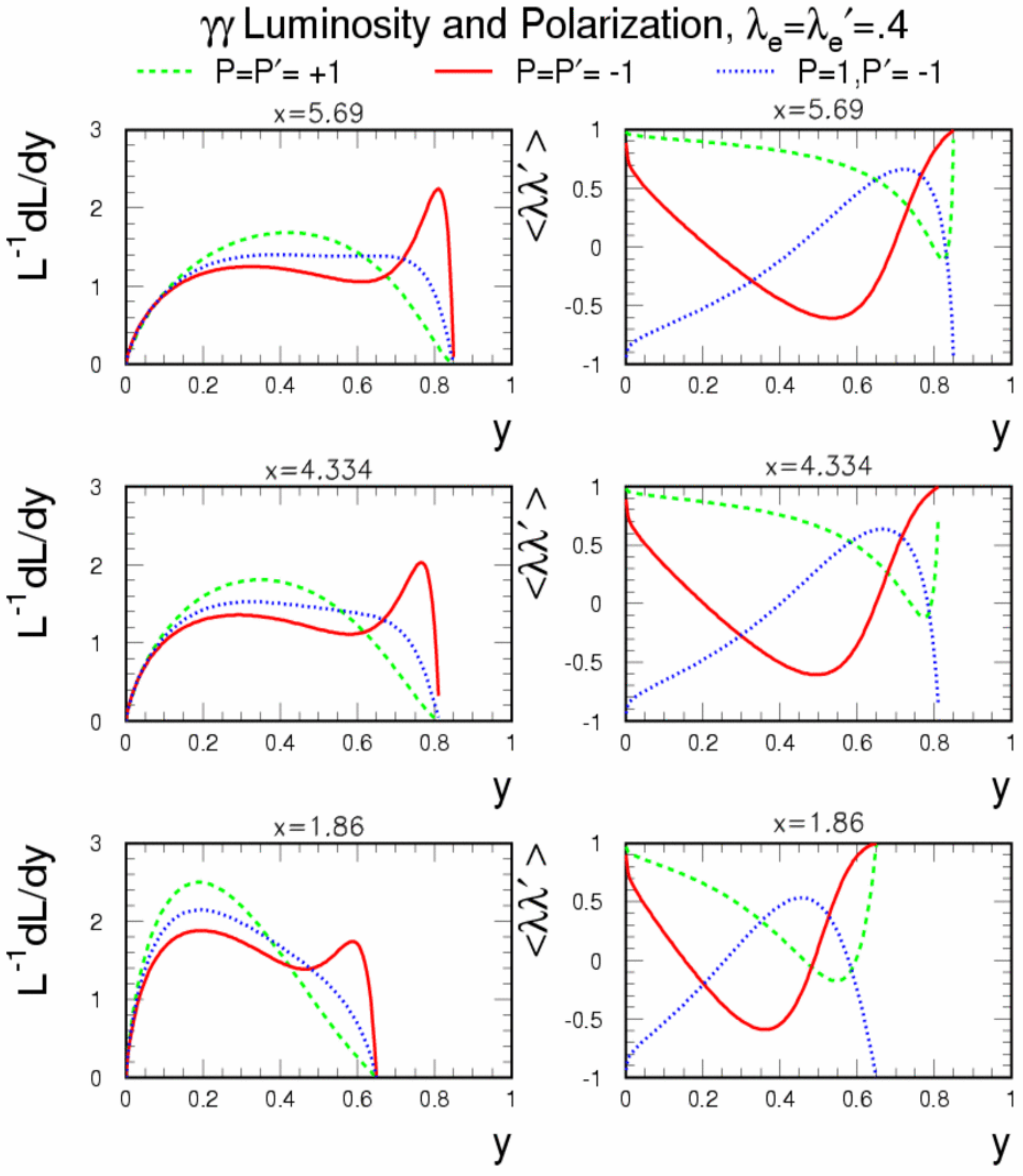
CP violation... Special role for polarization in gC… warning:

- Competitive asymmetry measurements from linearly polarized beams requires different beam and laser parameters, than those discussed so far… That is:
  - <u>10 μm laser</u> instead of 1 or 0.3 μm
  - increasing beam energy by a factor of a least two

➔The reason is to get higher degree of linear polarization (higher luminosity for “free”).

➔Let me explain…

Compton Laser Backscattering Facts



$$E_e + w_o \rightarrow E_{e'} + E_\gamma$$

$$x_{max} = \frac{4E_e w_o}{m_e^2}$$

$$E_\gamma = \frac{x}{x+1} E_e$$

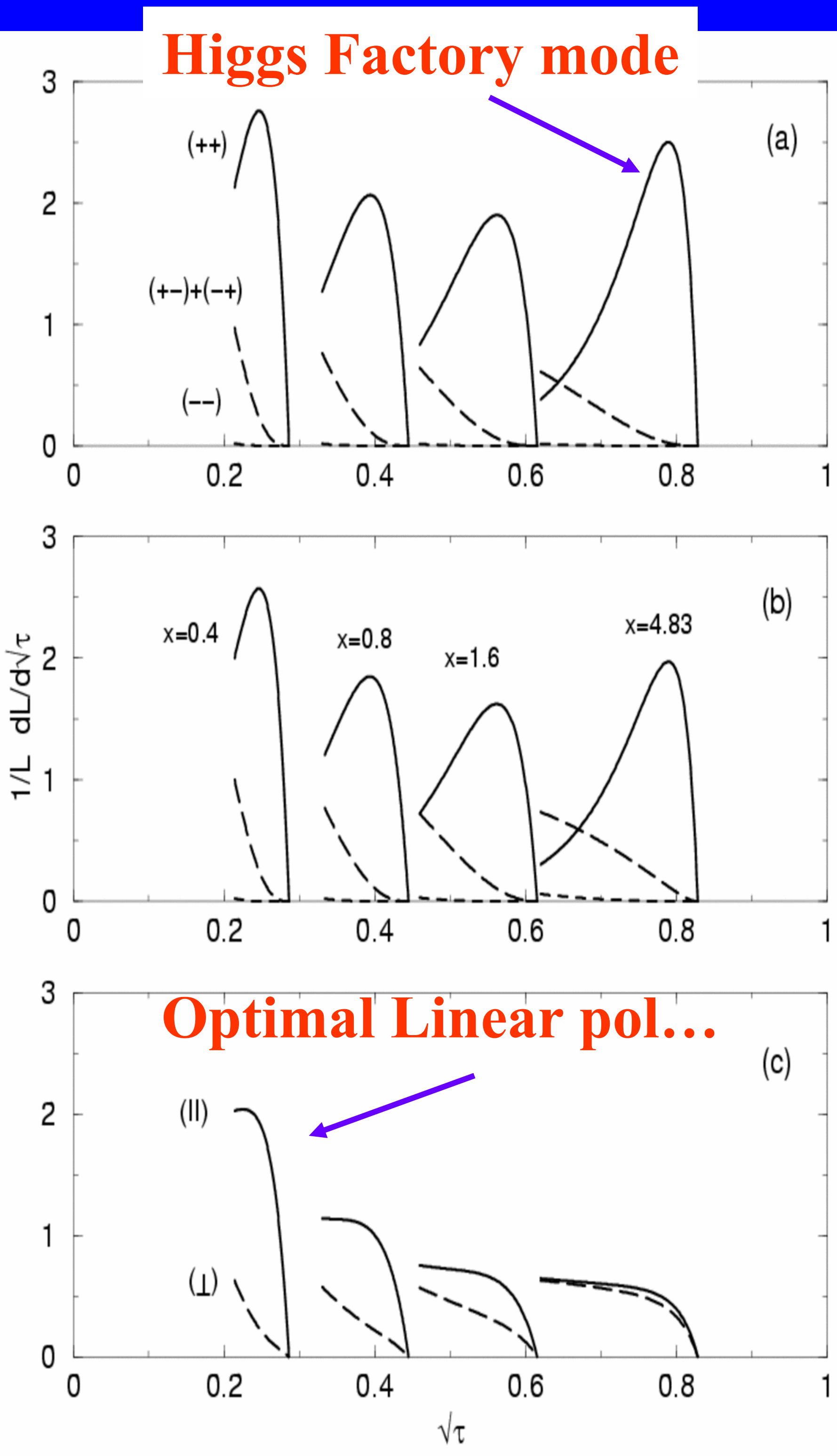
$$y_{max} = \frac{E_\gamma}{E_e}$$

Available:

$$w_o = 1.17(3.53)\ eV$$
$$= 1.0(0.351) \mu m\ laser$$

Circular polarization…

Polarization and Luminosity issues in gC using linear polarization … requires low x



Higgs Factory mode

Optimal Linear pol…

- $\sqrt{\tau} = E_{\gamma\gamma}/E_{e^+e^-}$, L=luminosity
- (a) assumes 100% polarization of e^-, $\pm$ stands for helicity of photons
- (b) assumes 80% polarization of e^-
- (c) assumes 0% polarization of e^-; need small x to have one of the polarization orientations dominating

For heavier Higgs (>300 GeV), might be best to focus on asymmetries that do not require linear polarization

- **Linear polarization** $\alpha\ \zeta_1, \zeta_3$
- **Circular polarization** $\alpha\ \zeta_2$

$A_3 > (<)\ 0$ for CP EVEN(ODD)

$$dN = dL_{\gamma\gamma}\, d\Gamma\, \tfrac{1}{4}\left(|M_{++}|^2 + |M_{--}|^2\right)\Big\{\left(1 + \langle \zeta_2 \tilde{\zeta}_2 \rangle\right) + \left(\langle \zeta_2 \rangle + \langle \tilde{\zeta}_2 \rangle\right)\mathcal{A}_1 + \left(\langle \zeta_3 \tilde{\zeta}_1 \rangle + \langle \zeta_1 \tilde{\zeta}_3 \rangle\right)\mathcal{A}_2 + \left(\langle \zeta_3 \tilde{\zeta}_3 \rangle - \langle \zeta_1 \tilde{\zeta}_1 \rangle\right)\mathcal{A}_3\Big\},$$

Grzadkowski & Gunion (1992)

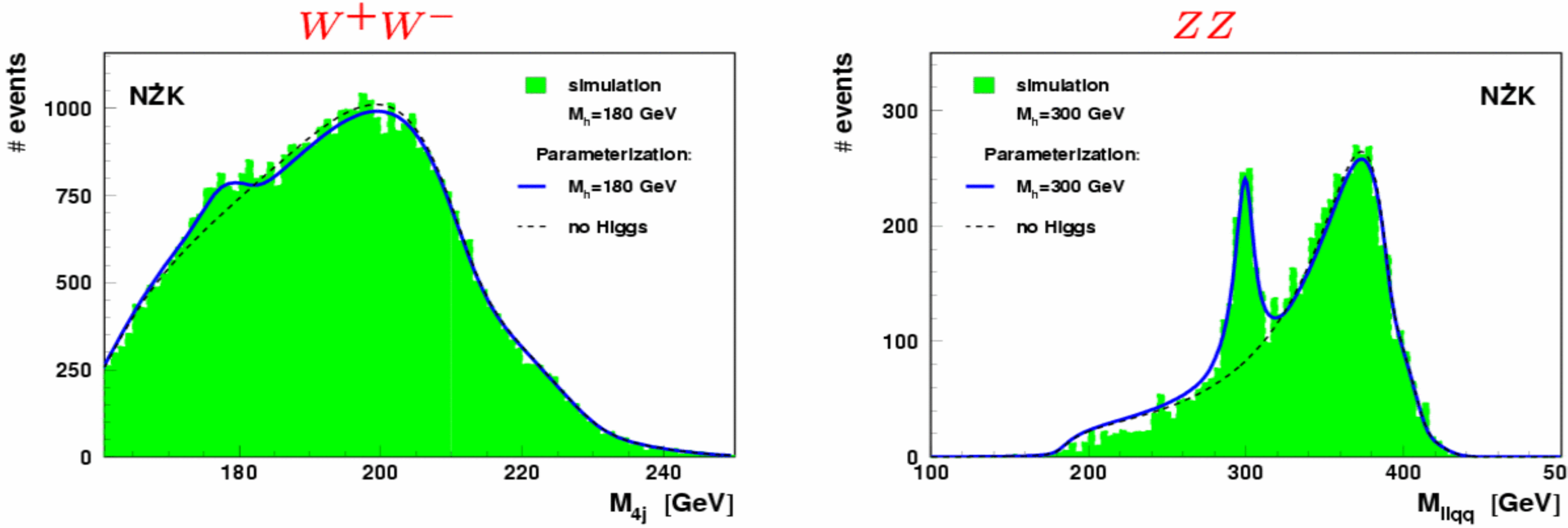
$A_1 = A_2 = 0$ if there is no CP admixture

SM heavy Higgs (200-350 GeV) @ gC can measure $\Gamma_{\gamma\gamma}$ & $\varphi_{\gamma\gamma}$

$$\boxed{\gamma\gamma \to \mathcal{H} \to WW,\ ZZ}$$

Niezurawski
Zarnecki
Krawczyk

From the simultaneous fit to the observed W^+W^- and ZZ mass spectra both the two-photon width $\Gamma_{\gamma\gamma}$ and phase $\phi_{\gamma\gamma}$ can be determined.

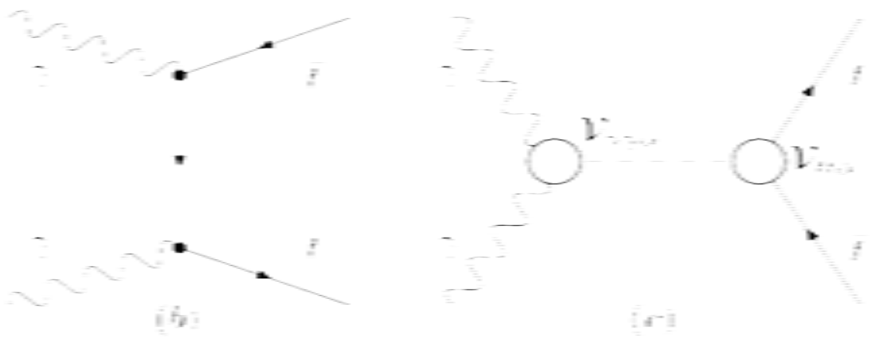


For SM: $\Gamma_{\gamma\gamma}$ with precision $\sim 4-9\%$, $\phi_{\gamma\gamma}$ with precision $40-120$ mrad

JHEP 0211 (2002) 034 [hep-ph/0207294]

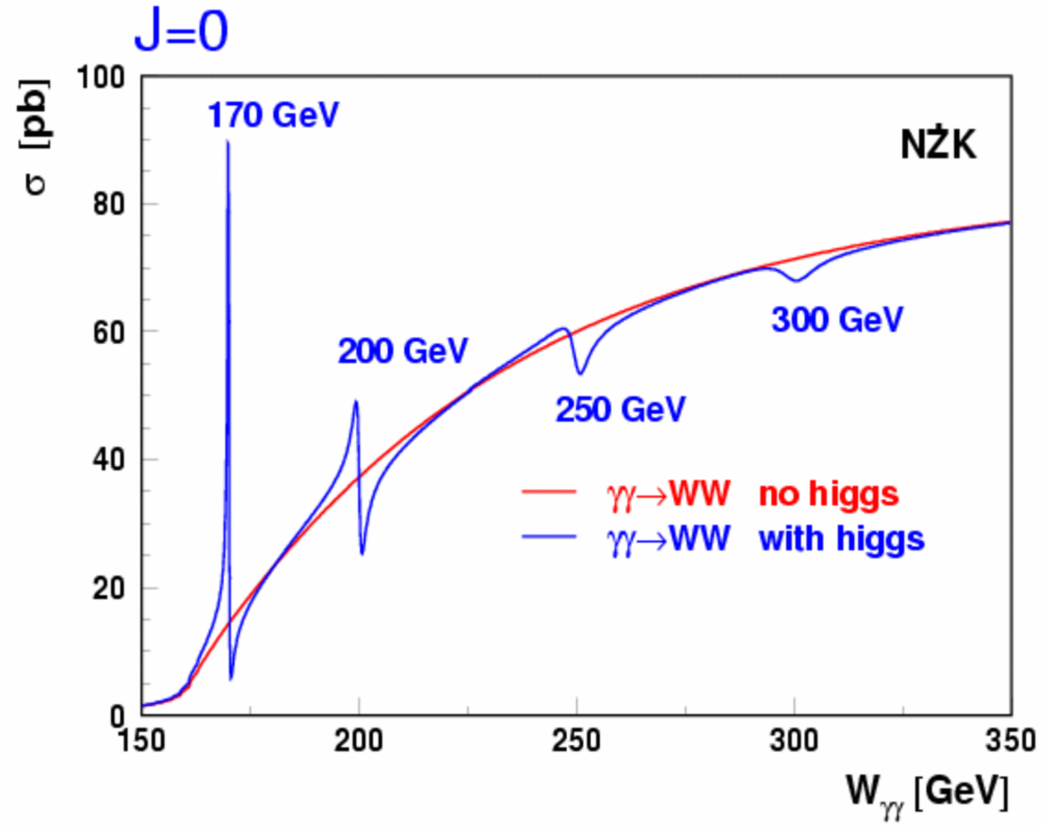
A.F.Żarnecki, ECFA/DESY workshop, November 2002, Praha (including systematic uncertainties)

Only in gC can we exploit interference effects to extract phases needed to study CP violations in an effective way



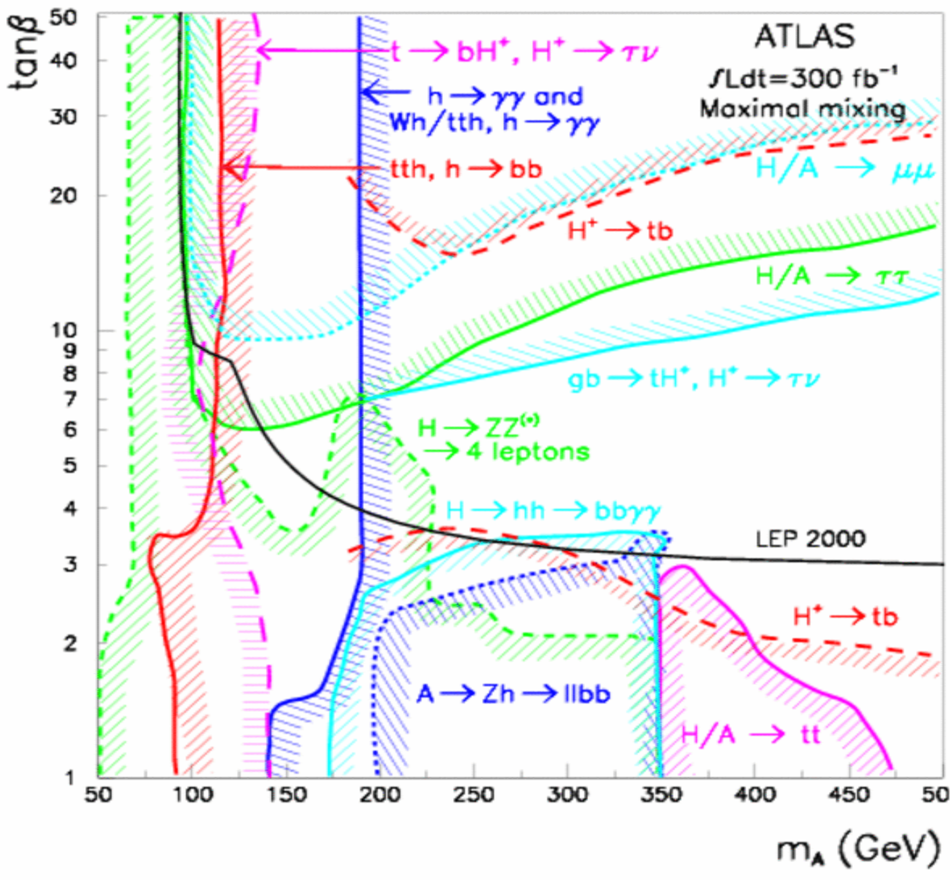
- **Exploit interference:**
  - **W$^+$W-, Warsaw & Krawczyk**
  - **Top pairs, Asakawa et al, Godbole *et al*, Lee *et al***

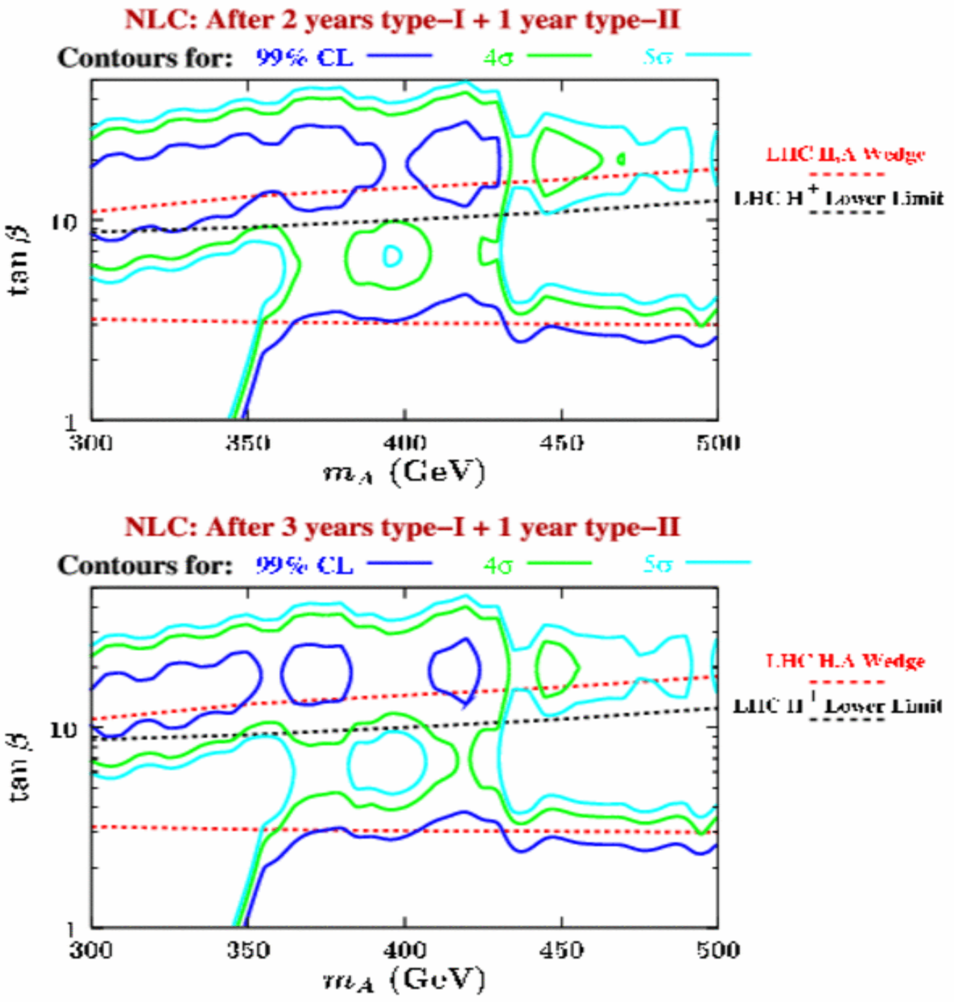
Large interference effects are expected in the considered mass range



MSSM Heavy Higgs in gC fills LHC wedge! I s this an interesting CP regions. If so, should repeat with latest machine designs

Asner, Gromberg, Gunion





Comments on Complex MSSM: we have MASS and CP Eigenstates

- **CP Eigenstates**
  - ✔ **h, H (CP-EVEN)** $VV\phi:\ c_V \frac{g m_V^2}{m_W} g_{\mu\nu}$
  - ✔ **A (CP-ODD)** $= 0$
- **Mass Eigenstates** $M_{h_1} < M_{h_2} < M_{h_3}$

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

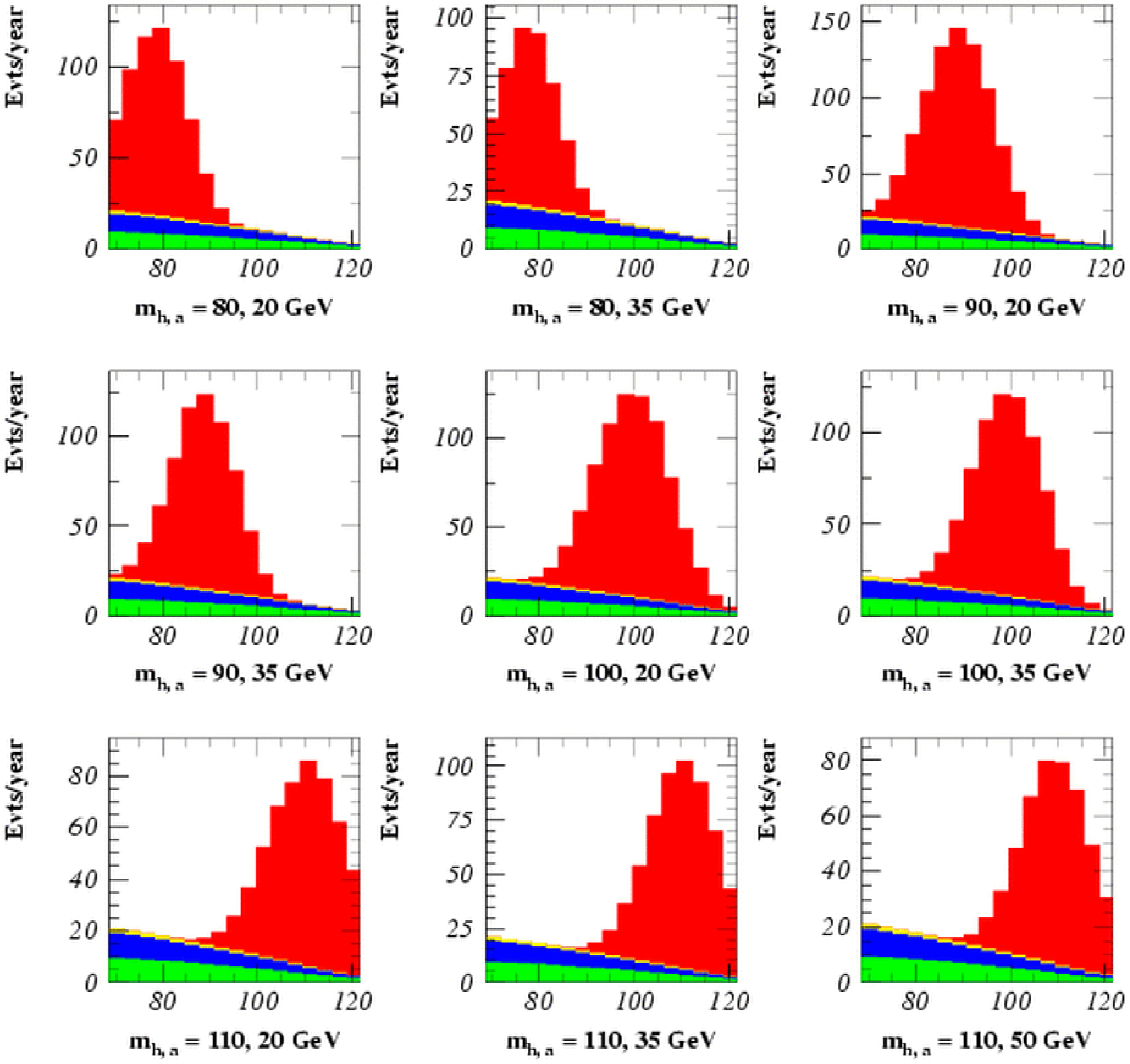
$h_2 \rightarrow h_1 h_1'$ gC will do the job...

Gunion, Szleper

In some parameter space for the Complex MSSM this topology can occur.

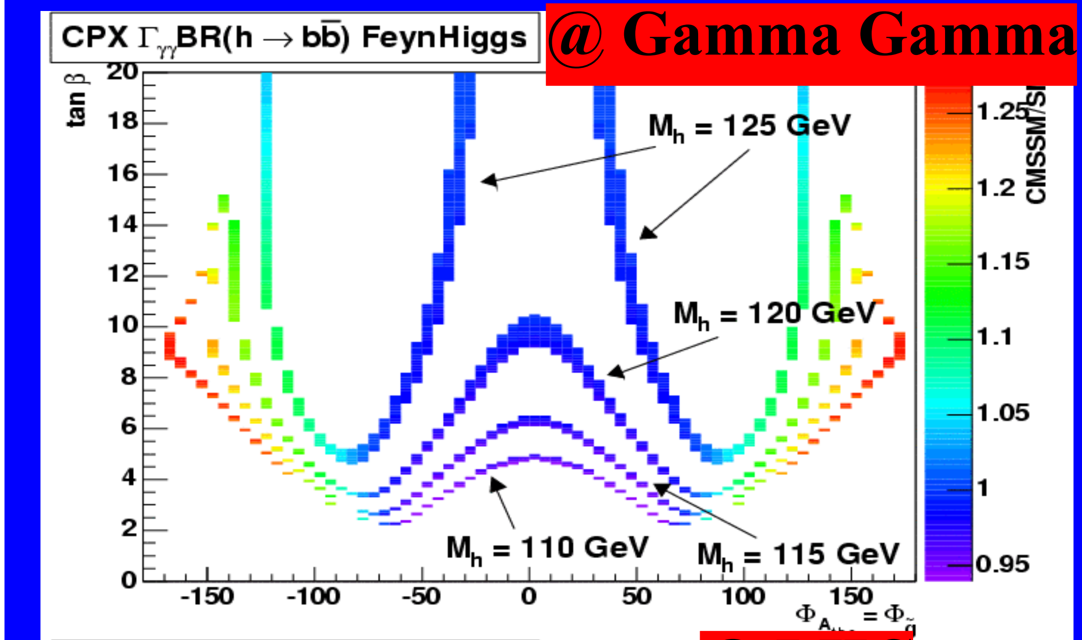
==> WORRIES FOR WHEN COUPLING TO THE Z GETS LOST BY h & H & h1,h2,h3 CLOSE IN MASS (Small M_{H+}).

==> bbbb,ττbb,ττττ all available... clear signal

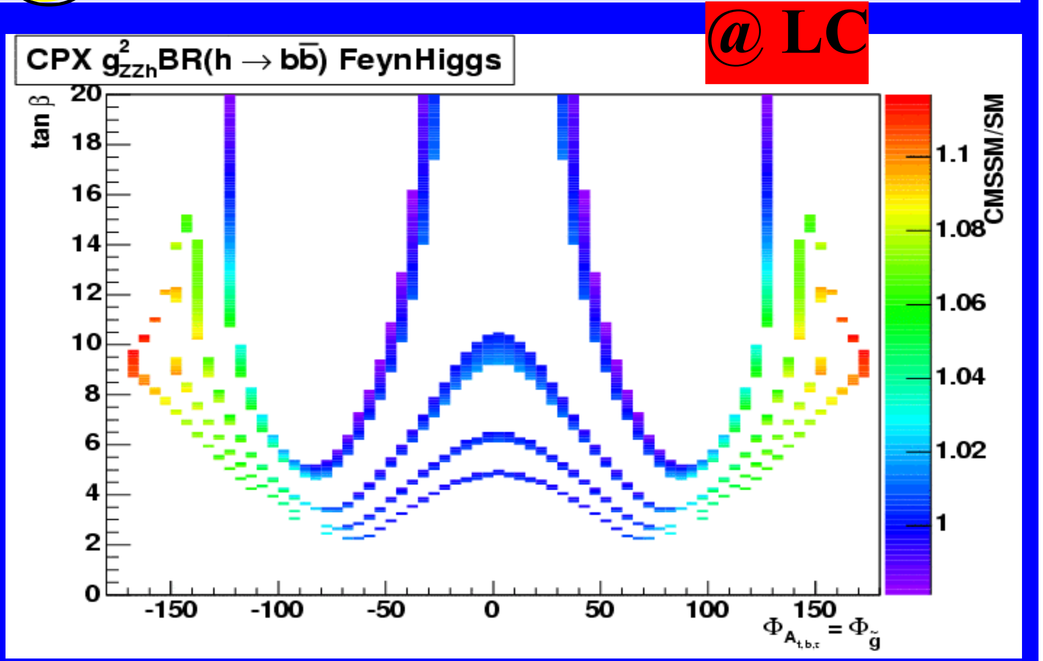


Now available

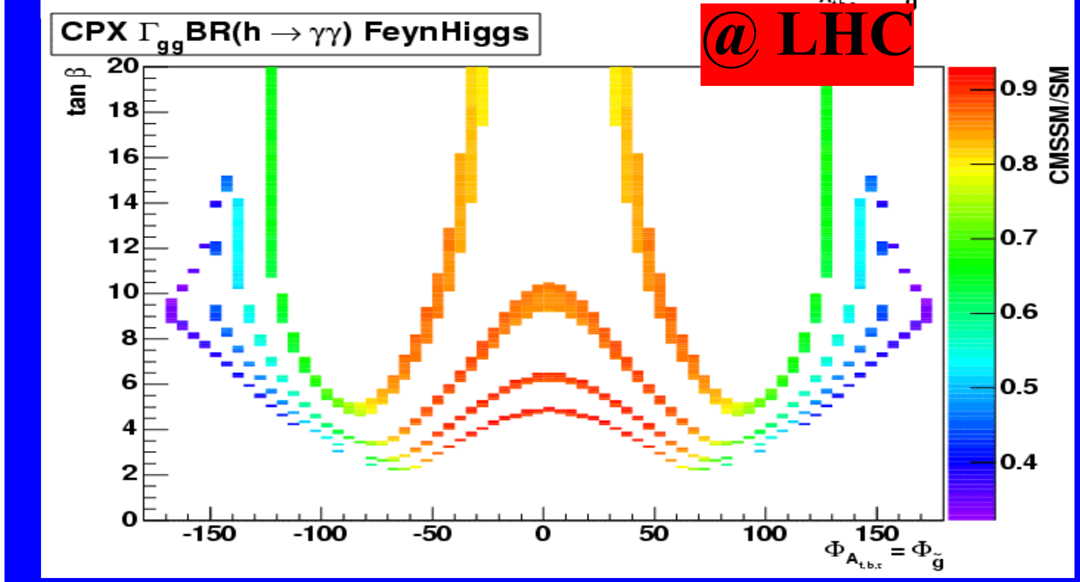
Example: CP violation bigger @ gC than @ LC in bb decay & filling regions difficult @ LHC



@ Gamma Gamma



@ LC



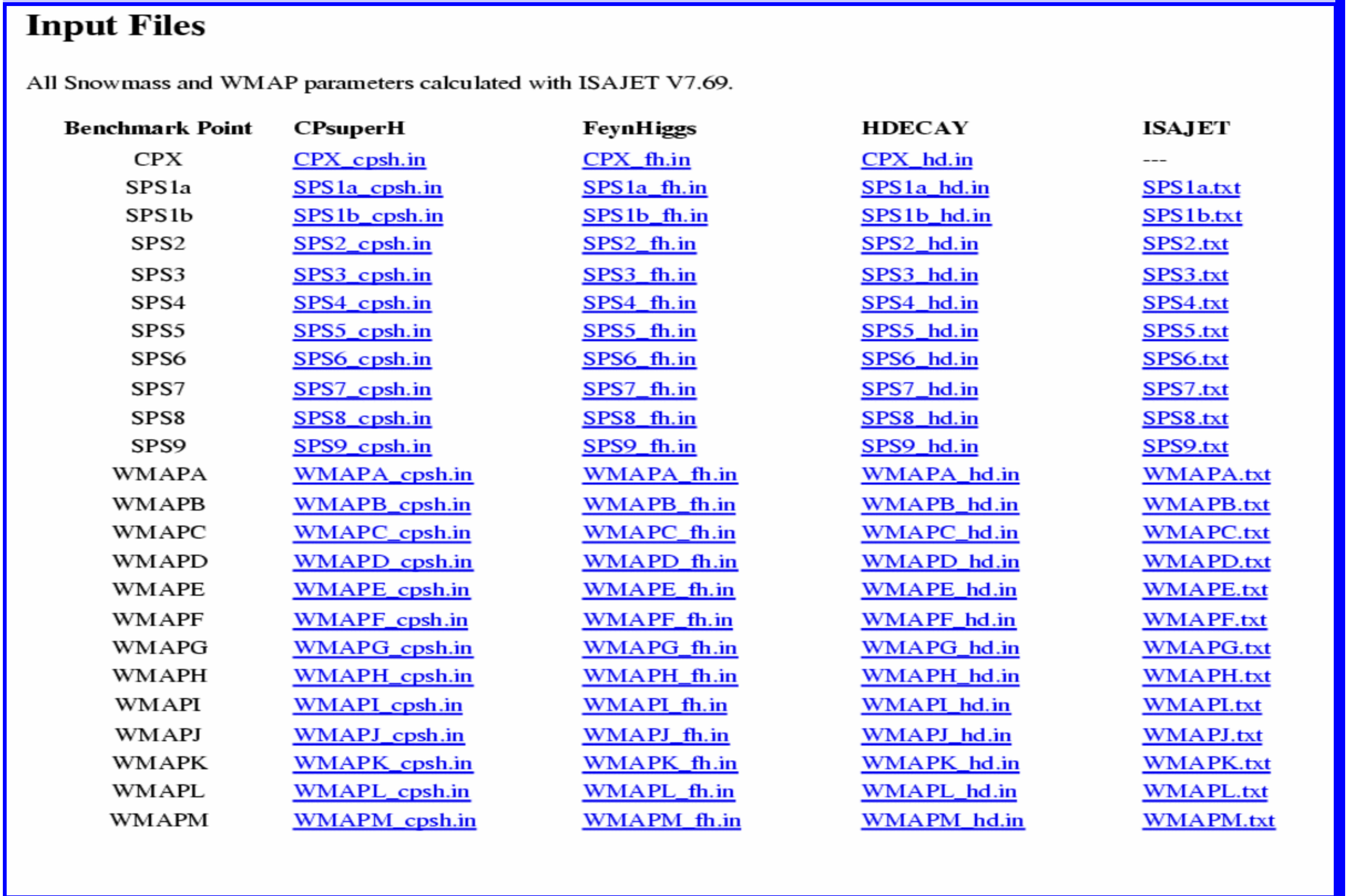
@ LHC

MSSM

- LHC Suppresion ↓
- LC Small Effect ↔
- gC Enhacement ↑

Heinemeyer Velasco Wood

We are ready to run whatever...



Input Files

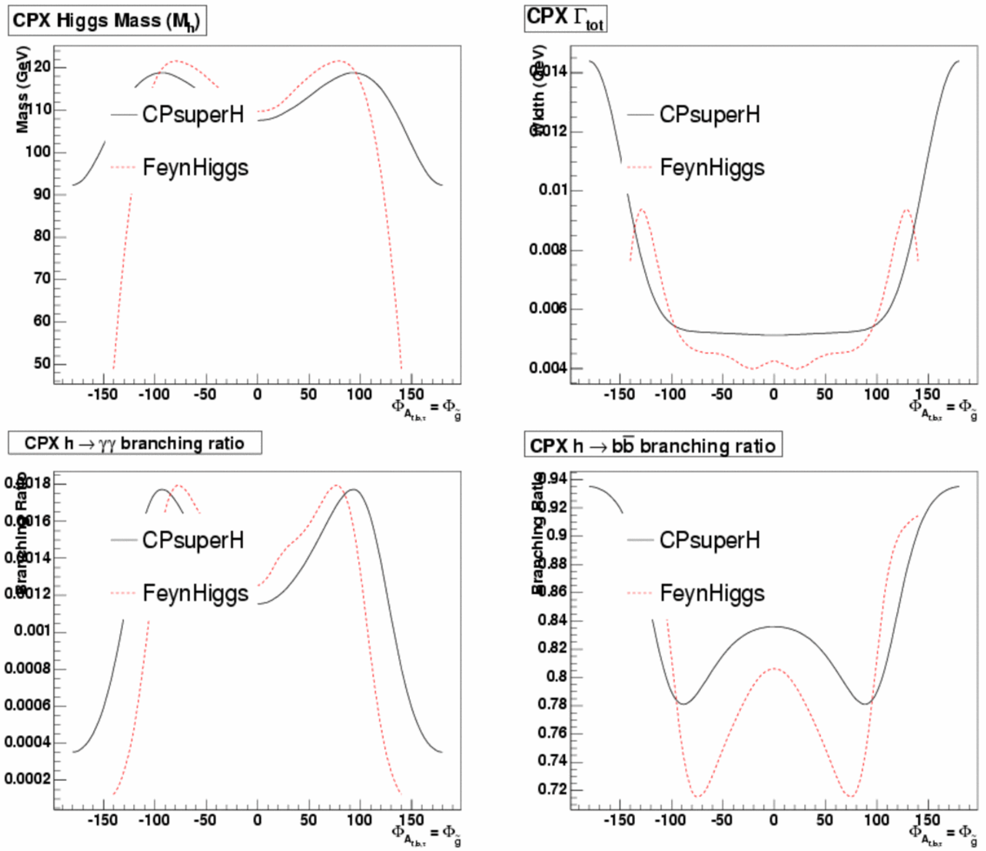
All Snowmass and WMAP parameters calculated with ISAJET V7.69.

Benchmark Point	CPsuperH	FeynHiggs	HDECAY	ISAJET
CPX	CPX_cpsh.in	CPX_fh.in	CPX_hd.in	---
SPS1a	SPS1a_cpsh.in	SPS1a_fh.in	SPS1a_hd.in	SPS1a.txt
SPS1b	SPS1b_cpsh.in	SPS1b_fh.in	SPS1b_hd.in	SPS1b.txt
SPS2	SPS2_cpsh.in	SPS2_fh.in	SPS2_hd.in	SPS2.txt
SPS3	SPS3_cpsh.in	SPS3_fh.in	SPS3_hd.in	SPS3.txt
SPS4	SPS4_cpsh.in	SPS4_fh.in	SPS4_hd.in	SPS4.txt
SPS5	SPS5_cpsh.in	SPS5_fh.in	SPS5_hd.in	SPS5.txt
SPS6	SPS6_cpsh.in	SPS6_fh.in	SPS6_hd.in	SPS6.txt
SPS7	SPS7_cpsh.in	SPS7_fh.in	SPS7_hd.in	SPS7.txt
SPS8	SPS8_cpsh.in	SPS8_fh.in	SPS8_hd.in	SPS8.txt
SPS9	SPS9_cpsh.in	SPS9_fh.in	SPS9_hd.in	SPS9.txt
WMAPA	WMAPA_cpsh.in	WMAPA_fh.in	WMAPA_hd.in	WMAPA.txt
WMAPB	WMAPB_cpsh.in	WMAPB_fh.in	WMAPB_hd.in	WMAPB.txt
WMAPC	WMAPC_cpsh.in	WMAPC_fh.in	WMAPC_hd.in	WMAPC.txt
WMAPD	WMAPD_cpsh.in	WMAPD_fh.in	WMAPD_hd.in	WMAPD.txt
WMAPE	WMAPE_cpsh.in	WMAPE_fh.in	WMAPE_hd.in	WMAPE.txt
WMAPF	WMAPF_cpsh.in	WMAPF_fh.in	WMAPF_hd.in	WMAPF.txt
WMAPG	WMAPG_cpsh.in	WMAPG_fh.in	WMAPG_hd.in	WMAPG.txt
WMAPH	WMAPH_cpsh.in	WMAPH_fh.in	WMAPH_hd.in	WMAPH.txt
WMAPI	WMAPI_cpsh.in	WMAPI_fh.in	WMAPI_hd.in	WMAPI.txt
WMAPJ	WMAPJ_cpsh.in	WMAPJ_fh.in	WMAPJ_hd.in	WMAPJ.txt
WMAPK	WMAPK_cpsh.in	WMAPK_fh.in	WMAPK_hd.in	WMAPK.txt
WMAPL	WMAPL_cpsh.in	WMAPL_fh.in	WMAPL_hd.in	WMAPL.txt
WMAPM	WMAPM_cpsh.in	WMAPM_fh.in	WMAPM_hd.in	WMAPM.txt

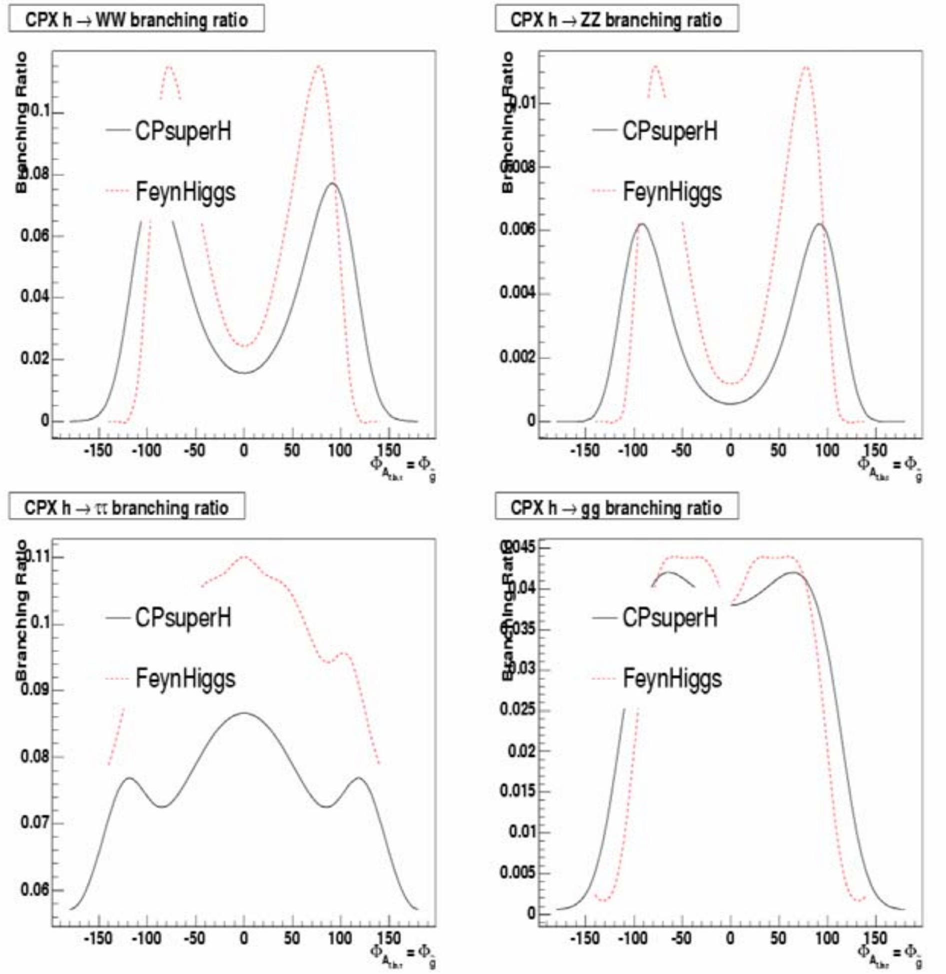
However... what are we going to do with the current difference between CPSuperH and FeynHiggs?

Table 1: CPX Low Energy Parameters

$\tan\beta$		$\lvert\mu\rvert$		$M_{H^\pm}^{\rm pole}$		$M_t^{\rm pole}$	
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



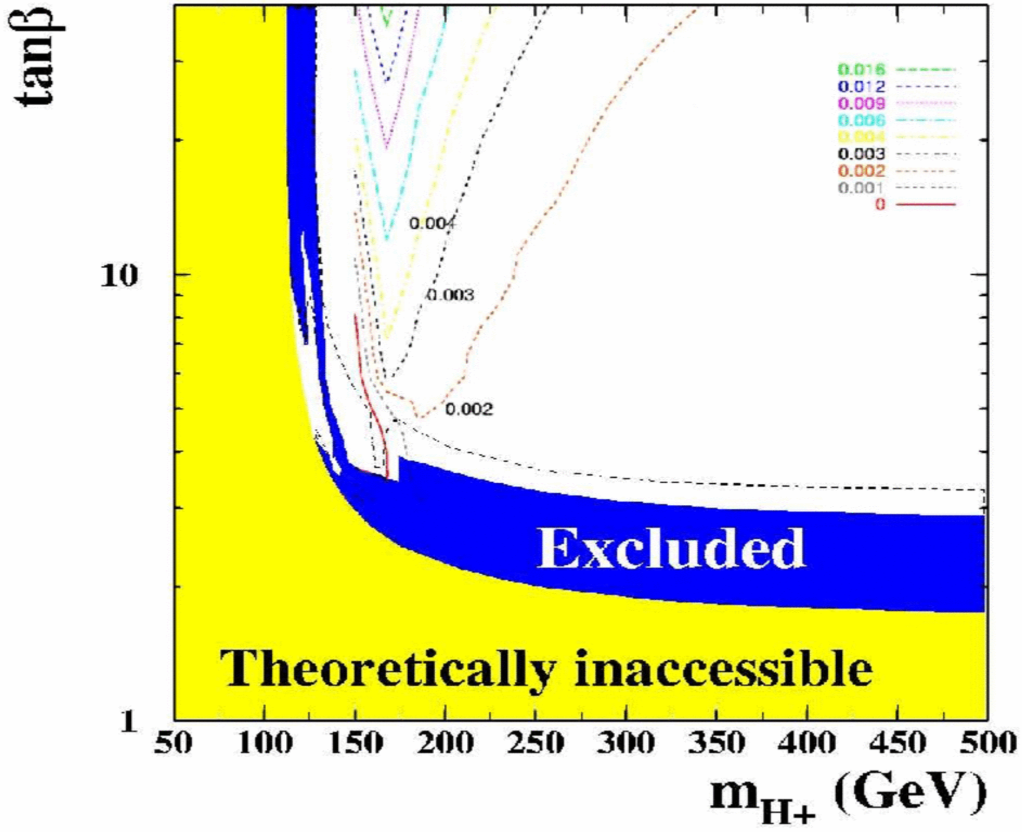
Add systematic error due to predictions is the minimum …



What is next?

τ, τ, τ and more τ

CP violation for <u>Light Higgs</u> in the MSSM using interference & tau polarization (no need for mass peak)



Scan over MSSM parameters

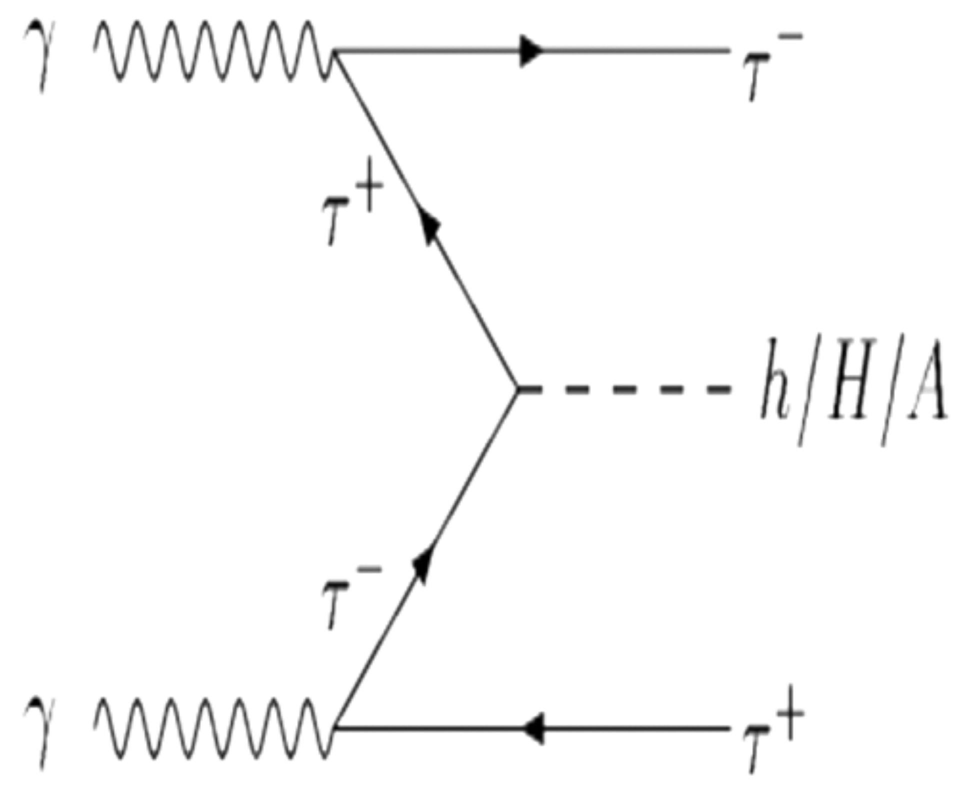
Predicted change in the tau polarization measureable in regions of parameter space not excluded by LEP

Godbole & Krans

To Do... A proper study with beam distributions and detector simulation!!!

Tau polarization in the initial and final state...Should we check what CP info we get ?

Choi, Kalinowski, Lee, Muhlleitner, Spira, Zerwas



- Error on Δ(*tan* β) ~ 1 for *tan* β > 10
- All tools available to make the experimental study ($h_2 \rightarrow h_1 h_1$)

Conclusion → To do List

- **Once Benchmarks are selected, we are ready to check how sensitive we are to CP effects from precision measurements of the Higgs Branching ratios and partial widths.**
- **More important… need to understand how to fully use CP asymmetries, that is not only linear polarization, but also circular polarization… and what this imply on the analysis and experimental conditions.**
- **τ's are a powerful tool so far ignored in experimental studies at γC because a clear mass peak is not possible:**
  - **Time to change that!**
  - **Exceptions: $H^{\pm}$ & $h_2 \rightarrow h_1 h_1$**