H^+H^- at a $\gamma\gamma$ Collider

Victoria Martin & Michael Schmitt
Northwestern University

27 - August - 2002

Motivations – Scope – Cross Sections & Branching Ratios – Analysis – Results – Comments – Future Directions

Motivations

The GOAL will be to explore and check the Higgs sector.

assuming it is not trivial...

- Are there FIVE Higgs bosons?
- Do the MSSM constraints apply?
- Are couplings Yukawa-like?
- Is there CP Violation?

$\Longrightarrow$ $H^\pm$ is "immune" to CPV

SM: one Higgs, h

2HDM: five Higgses,
h, H, A, H^+ & H^-

⋆ How could a $\gamma\gamma$ collider augment what comes from e^+e^-?

SCENARIO: 500 GeV e^+e^- LC ... PLUS concurrent $\gamma\gamma$ collider

Scope

Previous study by Bowser-Chao, Cheung, Thomas (1993) looked at three final states

$$\gamma\gamma \to H^+H^- \to \quad \tau^+\nu_\tau\,\tau^-\bar{\nu}_\tau, \quad \tau^+\nu_\tau\,\bar{c}s + \text{c.c}, \quad c\bar{s}\,\bar{c}s$$

In this study, we begin with $\boxed{\gamma\gamma \to H^+H^- \to \tau^+\nu_\tau\,\tau^-\bar{\nu}_\tau}$

since this has the largest rate in the MSSM.

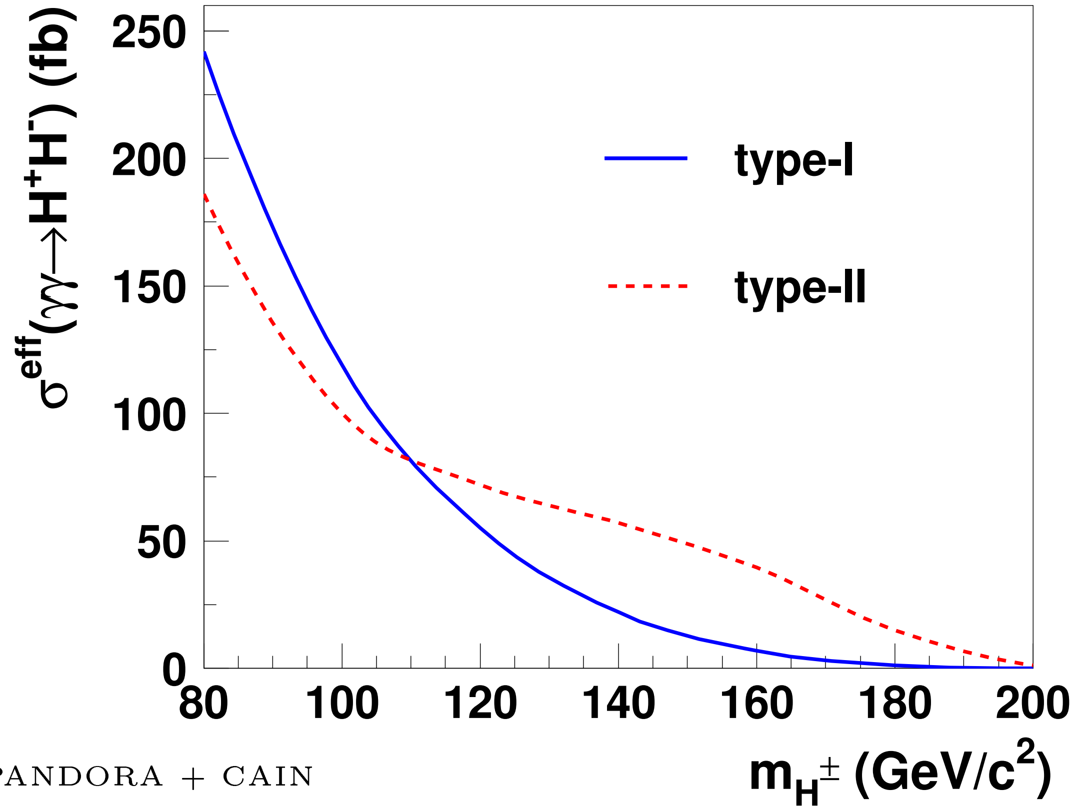
- Take $E_{e^-} = 250$ GeV, $\mathcal{P}_e = 0.8$, $\mathcal{P}_{\text{laser}} = -1$
- Use CAIN simulation of the beam $\longrightarrow$
  much more realistic than a simple analytical beam treatment
- Use FASTMC detector simulation (a LC standard)
  group tracks & showers into τ-jets

Cross Sections

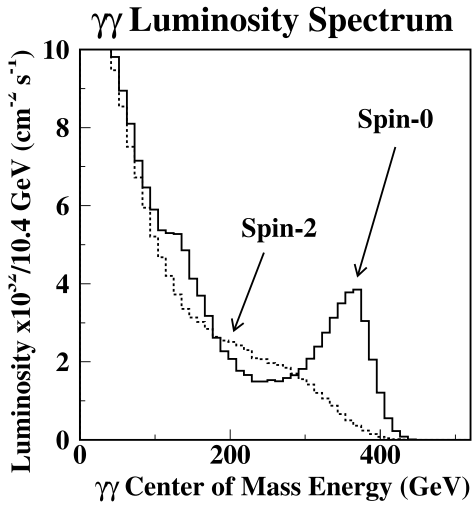
Since the photons couple to the charged Higgs according to charge only, there is no model dependence to this cross section.

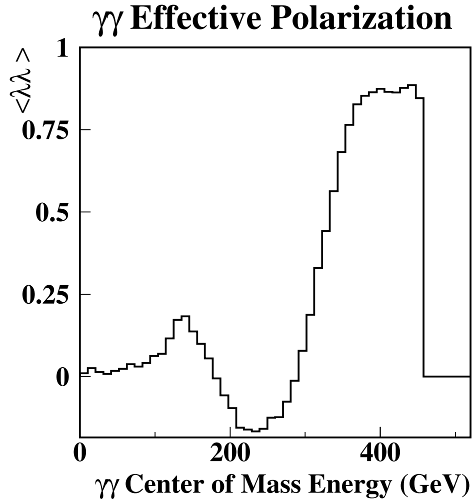
The cross section is generally large.

After convoluting with the CAIN spectra,



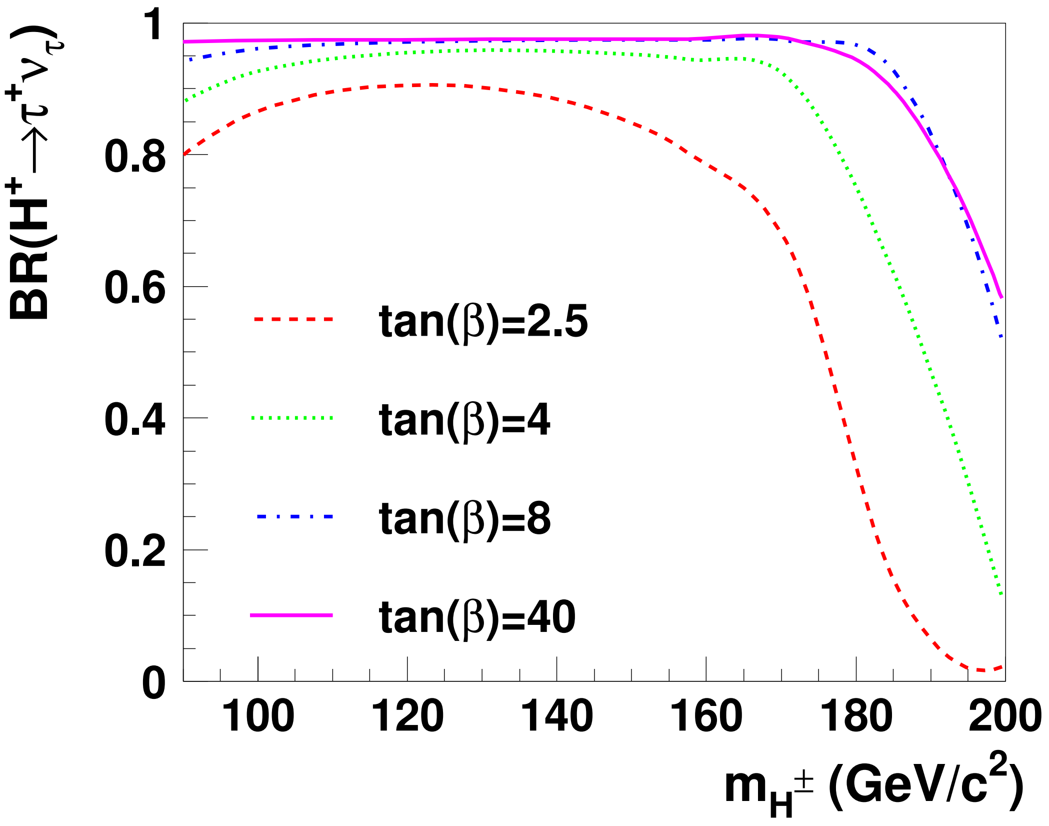
PANDORA + CAIN





Branching Ratios

$H^+ \to \tau^+\nu_\tau$ dominates for $H^\pm$ above LEP bounds & below $t\bar{b}$ threshold,



main BR's (%): ($\tan\beta = 10$)

$H^+ \to$	140 GeV	190 GeV
$\tau^+\nu_\tau$	97.5	70.8
$t\bar{b}$	-	27.5
$\bar{b}c$	1.4	0.9
$c\bar{s}$	0.6	0.4

$\Longrightarrow$ Concentrate on extracting a signal for di-τ events.

Analysis

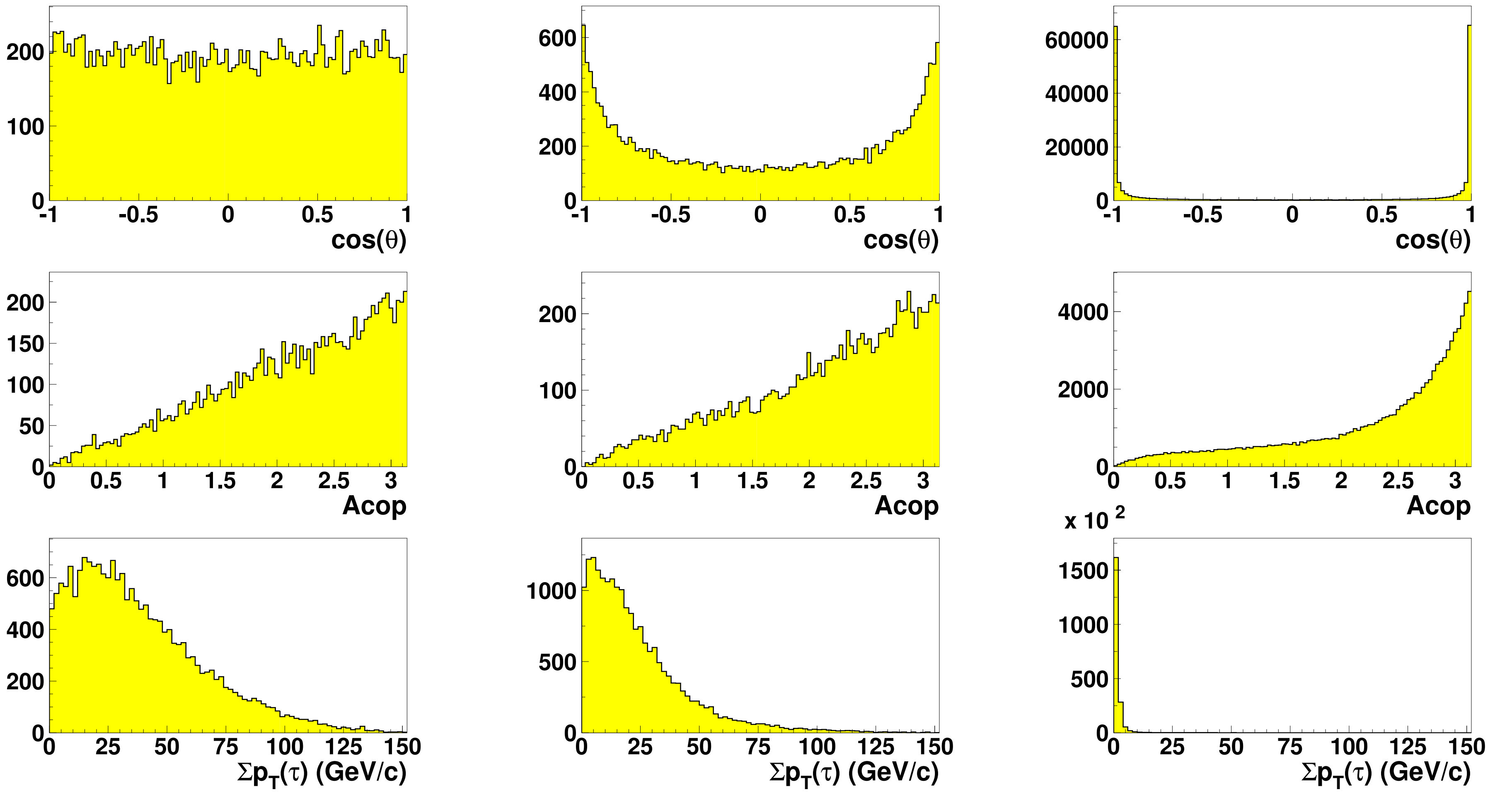
main backgrounds:

- $\gamma\gamma \to W^+W^- \to \tau^+\nu_\tau\,\tau^-\bar{\nu}_\tau$ (4× bigger than H^+H^-)
- $\gamma\gamma \to \tau^+\nu_\tau\,\tau^-\bar{\nu}_\tau$ (5000× bigger)

handles:

- direction of τ wrt beam
- angle between the τ jets
- energy of the τ jets

H^+H^- W^+W^- $\tau^+\tau^-$



cuts:

1) $|\cos\theta_\tau| < 0.8$ 2) $\Delta\phi < 3$ rad. 3) $\sum p_T > 35 + 25 \cdot (\Delta\phi - \frac{\pi}{2})^2$ GeV

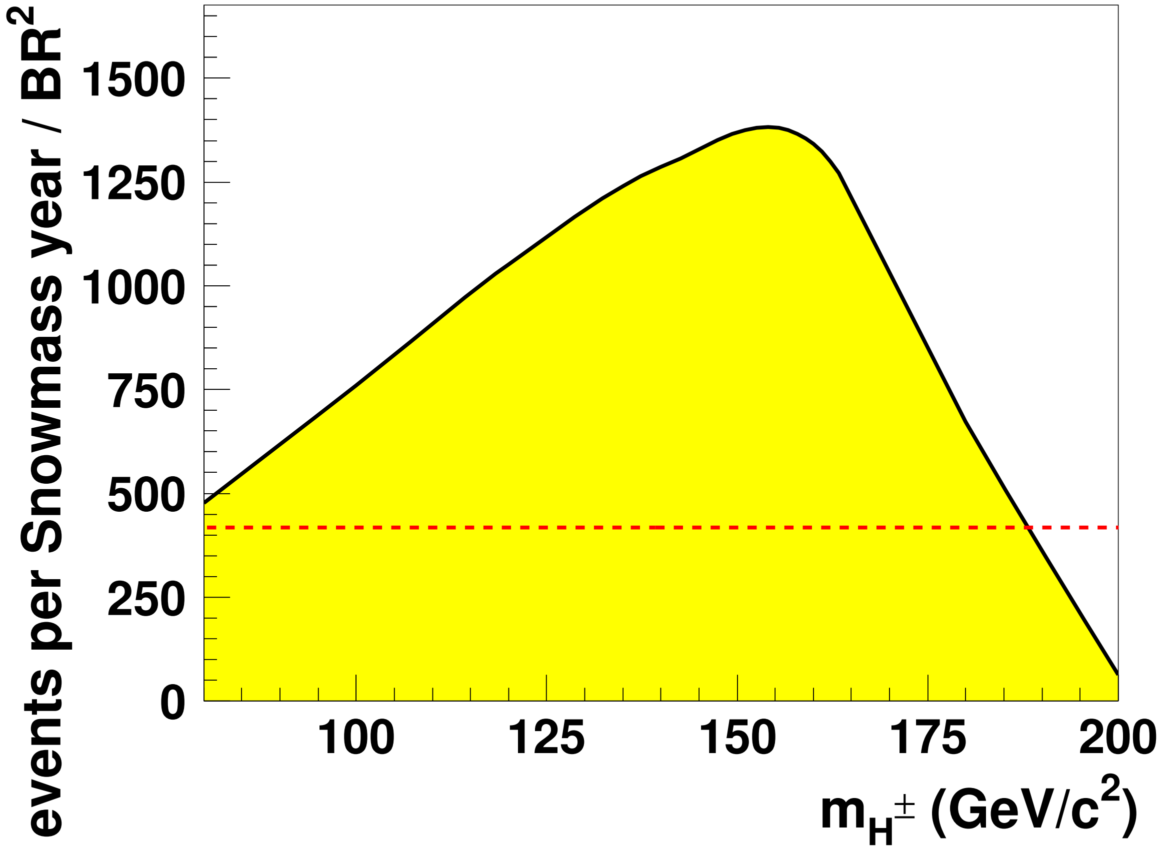
Results:

$m_{H^\pm}$ (GeV)	$\sigma(H^+H^-)$ (fb)	a (%)	$a\cdot\sigma$ (fb)	$\mathcal{S}/100\ \mathrm{fb}^{-1}$	$\mathcal{S}/\mathcal{B}$
80	492	1.4	6.74	674	2.2
100	262	2.9	7.60	760	2.4
120	180	4.7	8.41	841	2.7
140	157	6.9	10.90	1090	3.5
160	136	8.6	11.63	1163	3.7
180	86	11.4	9.77	977	3.1
190	44	13.0	5.72	572	1.8
200	4	13.4	1.20	120	0.4
$\gamma\gamma\to W^+W^-$	644	0.47	3.12	312	

($\tau^+\tau^-$ is negligible. Will investigate $\tau^+\tau^-Z$.)

Event yield as a function of mass:

recall: $\sqrt{s_{ee}} = 500$ GeV, NLC parameters; 1 Snowmass year $= 10^7$ s



red dashed line: W^+W^-

(could be calibrated from di-μ)

Obtain a clean, large signal up to $M_{H^\pm} \sim 195$ GeV

~ 200 H^+H^- vs. ~ 410 W^+W^-

corresponds to 3–5% on $\sigma \times BR^2$

for 5% uncertainty on W^+W^- background

Unfortunately, mass reconstruction impossible in $\tau^+\nu_\tau\,\tau^-\bar{\nu}_\tau$ mode.

Comment on Mass Reconstruction

Mass reconstruction may be possible in the 'mixed mode' $H^+H^- \to \tau\nu\, q\,\bar{q}'$.

According to Bowser-Chou *et al.*, this mode can be separated easily from W^+W^- background. (Reconstruct $M_{q\bar{q}'}$ which should be much higher than M_W.)

Assume

1. $BR(\tau\nu) = 0.95$ and $BR(q\bar{q}') = 0.05$
2. acceptance is the same as for $\tau^+\nu_\tau\,\tau^-\bar{\nu}_\tau$ mode
3. background is relatively low under mass peak

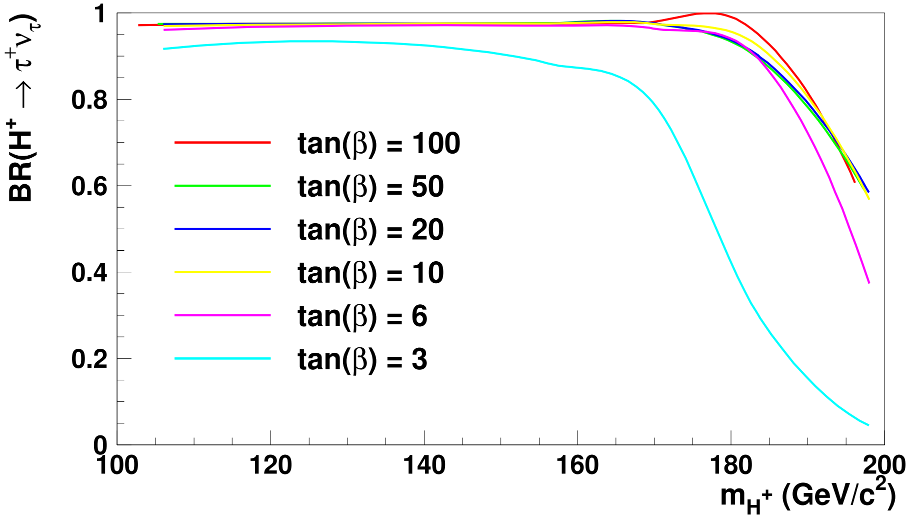
$\Longrightarrow$ 50–100 events per year.

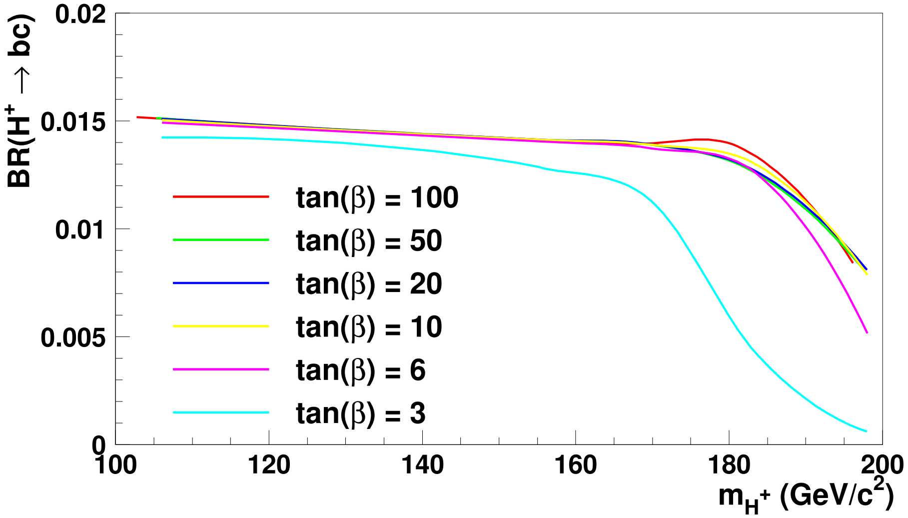
For jet energy resolution $\sigma_E/E = 0.6$ and $m_{H^\pm} \sim 180$ GeV,
mass resolution will be about 10%

$\Longrightarrow$ mass measurement could be as good as 1–2%.

This needs a real study, of course!

Comment on Ratio of Branching Ratios

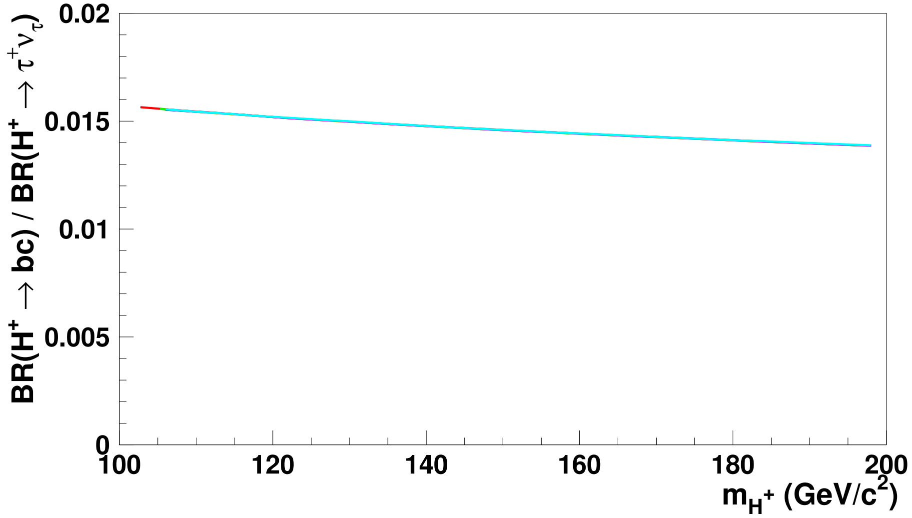




In the MSSM, $q\bar{q}'/\tau\nu$ is nearly fixed, independent of $\tan\beta$; $M_{H^\pm}$ almost.

$\Longrightarrow$ **robust test of MSSM!**

rough estimate says this ratio could be measured to about 20%, maybe better.



from HDECAY

Are the Branching Ratios Interesting?

- The running of m_c (up to $M_{H^\pm}$) is responsible for the ‘suppression’ of $BR(c\bar{s})$ relative to $BR(\tau^+\nu)$.
  $\Longrightarrow$ test our understanding of this running;

  perhaps get a clean measure of m_c, finally.

- The charged Higgs Yukawa-couplings to fermions are chirality-dependent, and this is model-dependent.
  $\Longrightarrow$ good test of the model using beam polarization.

  (He, Kanemura, Yuan, hep-ph/0203090)

- Perhaps the branching ratios provide a good test of the 2HDM...
  $\Longrightarrow$ is it Type-II or Type-I?

Further Speculations on the Usefulness of $\gamma\gamma \to H^+H^-$...

- $\sigma(\gamma\gamma \to H^+H^-)$ depends only on electric charge;
  $\sigma(e^+e^- \to H^+H^-)$ also depends on the weak isospin of the $H^\pm$.
  $\Longrightarrow$ comparison tests weak isospin assignment

  Perhaps the 4-point vertex is also of interest?

- $t\bar{b}$ Yukawa corrections are large (20-30%)! (Wen-Gan, Li, Liang 1996)
  $\Longrightarrow$ test these corrections

- $\sigma(\gamma\gamma \to H^+H^-)$ is much larger than $\sigma(e^+e^- \to H^+H^-)$,
  in addition is suppressed only by one factor of β.
  $\Longrightarrow$ surprisingly good kinematic reach
  Furthermore, $H^+\,b\bar{c}$ may be viable past the threshold for H^+H^-.

- Switching beam polarizations should allow a test of the '$H^\pm$' spin.
  Nontrivial: beam contains both $J = 0$ and $J = 2$ which vary with $\sqrt{s_{\gamma\gamma}}$.

Summary and Future Directions

Interesting signals for $\gamma\gamma \to H^+H^-$ can be obtained easily.

$\Longrightarrow$ explore the 'other' part of the Higgs sector...

(comparison with $e^+e^- \to H^+H^-$ might be suprising)

To Do:

1. study 'mixed' topology $\longrightarrow$ mass measurement
2. study channels with $H^+ \to t\bar{b}$
3. check signal dependence on '$H^\pm$' spin