Improvements of charged Higgs Signal at LHC including 3-prong decay of τ

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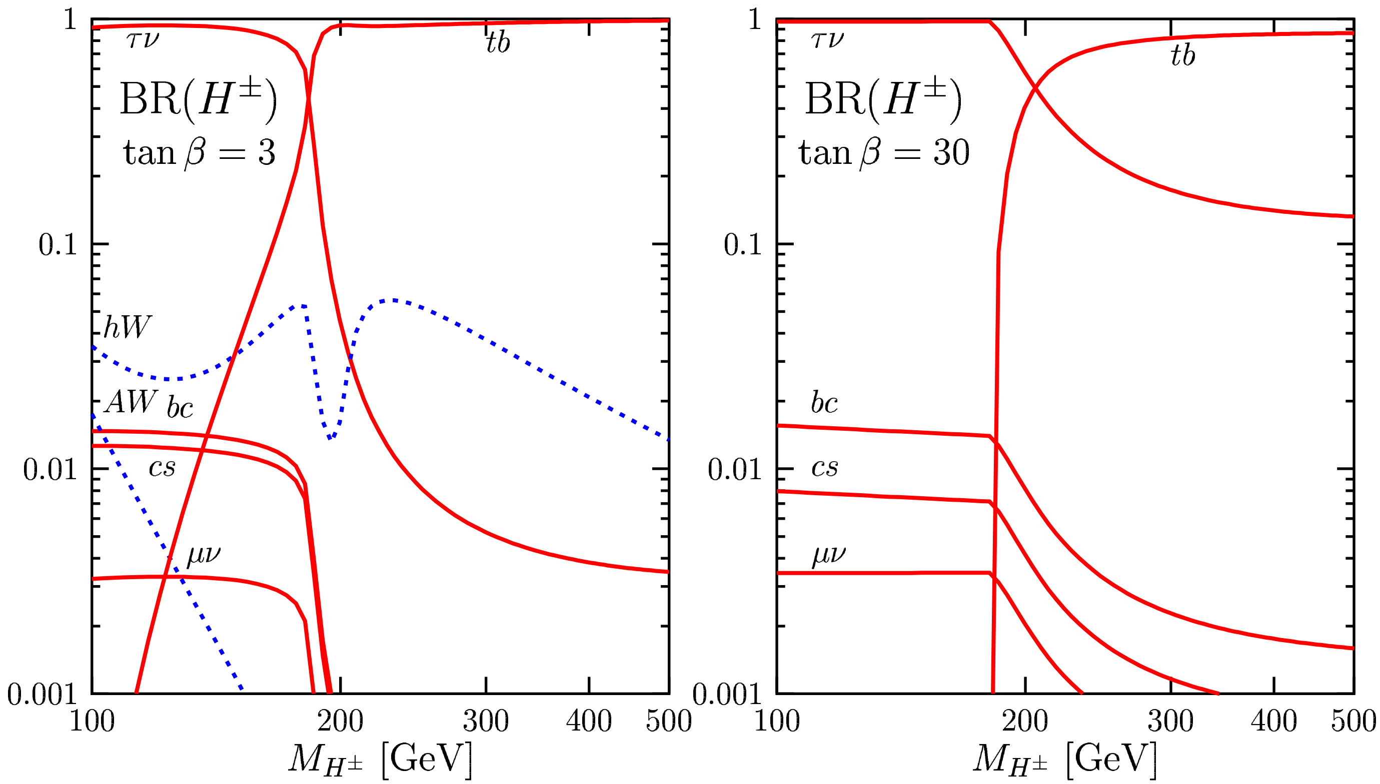
Outline

- Charged Higgs
- Charged Higgs decay
- Charged Higgs production in colliders
- Charged Higgs signal: $H^{\pm} \to \tau^{\pm}\nu_{\tau}$
- τ decay and polarization
- Analysis: Results

Charged Higgs

- Supersymmetric extension of Standard Model : SM + $S\tilde{M}$+2 HD
- Extended Higgs sector : Needs two oppositely Hyper charged($+1$ and -1) Higgs doublet to cancel Chiral anomaly.(Minimal model)
- This two oppositely hyper charged Higgs doublets give masses also to up-type and down type quarks.
- Two Higgs doublet $\Rightarrow$ 8 d.o.f present. After EWSB three are eaten by $W^{\pm}$,Z and 5 Higgs scalars: h, H, A and $H^{\pm}$
- SUSY extension of the SM predict a physial $H^{\pm}$.
  Tree level: $m_{H^{\pm}}^2 = m_W^2 + M_A^2$; Radiatitve corrections: Large for $\tan\beta <$1, less for $\tan\beta >$1, $\delta m_{H^{\pm}} \sim$ few GeV. Tree level gives good description. CPV SUSY can give large corrections.
- The $H^{\pm}$ carries the unambigous hallmark of the MSSM Higgs sector $\Rightarrow$ New Physics



BR($H^{\pm}$)
$\tan\beta = 3$
$\tau\nu$
tb
hW
AW
bc
cs
$\mu\nu$
1
0.1
0.01
0.001
100
200
300
400
500
$M_{H^{\pm}}$ [GeV]
BR($H^{\pm}$)
$\tan\beta = 30$
$\tau\nu$
tb
bc
cs
$\mu\nu$
1
0.1
0.01
0.001
100
200
300
400
500
$M_{H^{\pm}}$ [GeV]

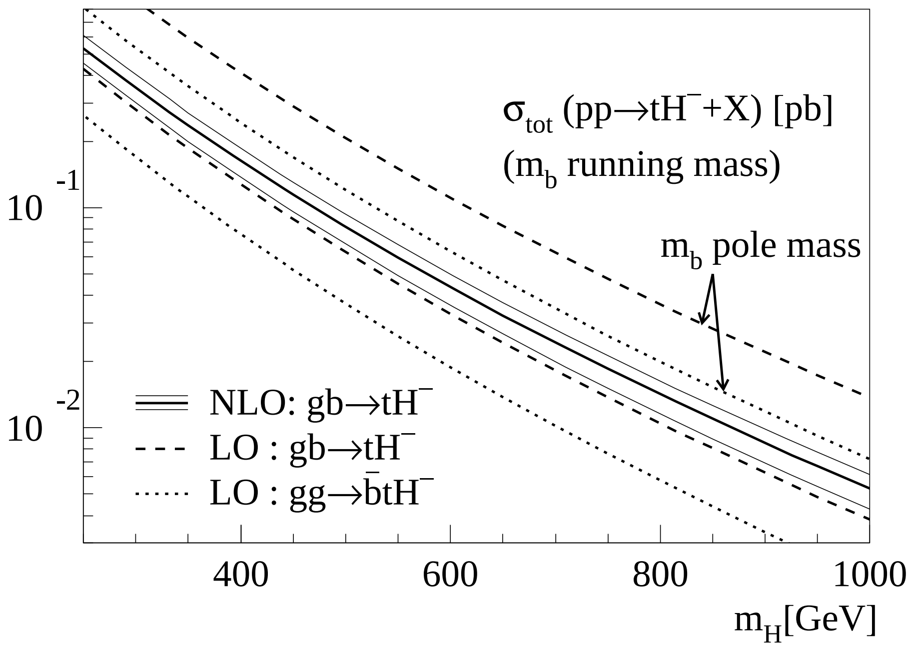
Charged Higgs Production at LHC

The LO process:

(a) $m_t > m_H$: $\sigma_{t\bar{t}} \times Br(t \to bH^{\pm})$.

(b)$m_t < m_H$: through bottom splitting $bg \to tH^{\pm}$+h.c

Strong $\tan\beta$ dependence, $t-b-H$ coupling $\sim m_t \cot\beta + m_b \tan\beta$



$\sigma \sim$ 0.5 - 005 pb

K-factor +30 to +40 %

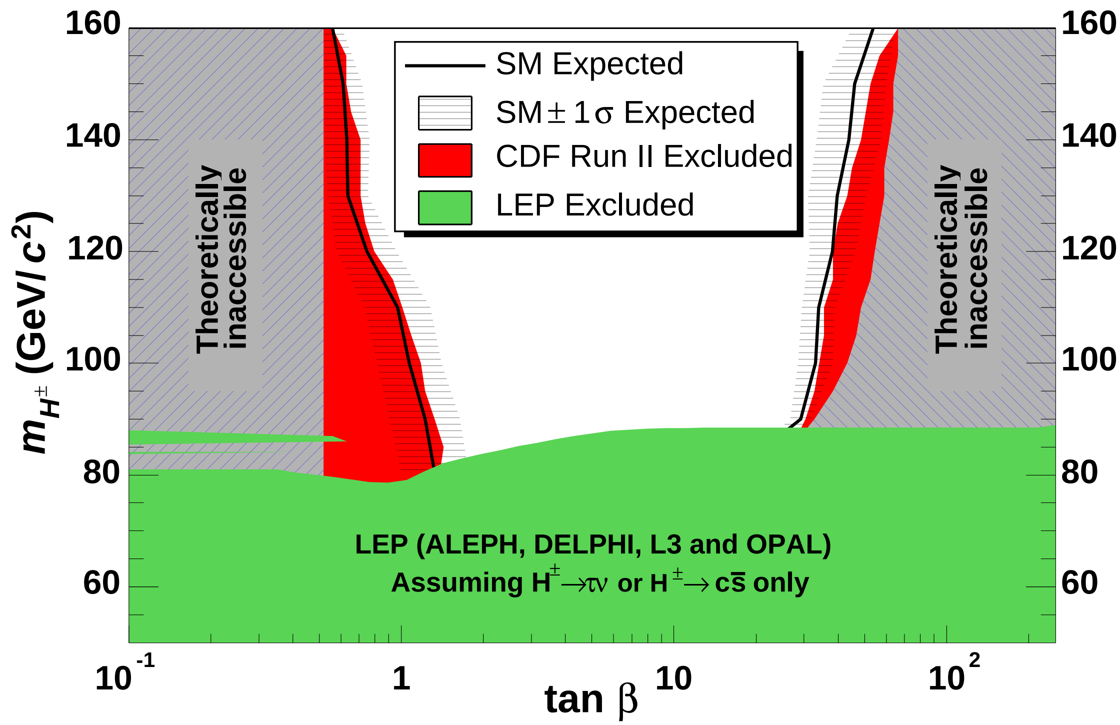
for $\tan\beta$=30

M_H=250 - 1000 GeV

T.Plehn,'02

Charged Higgs Signature

- $PP \to tH^{\pm}; t \to Wqq', H \to \tau\nu, tb, Wh$
- Low $m_{H^{\pm}}$, dominant decay mode: $H \to \tau\nu$
- 1-prong decay mode of τ promising channel, τ polarization plays a crucial role CMS Note 2006/100
- High $m_{H^{\pm}}$, dominant decay mode: $H \to tb$, Signal suffers by large QCD. CMS Note 2006/109



Tevatron search:
$H \to \tau\nu$

τ decay and Polarization

- Signal: $H^- \to \tau_R^- \nu; \Rightarrow P_\tau = +1$
- Bg: $W^- \to \tau_L^- \nu; \Rightarrow P_\tau = -1$

$$\begin{aligned} \tau^- &\to \pi^- \nu_\tau (12.5\%) \\ &\to \rho^- \nu_\tau \to \pi^- \pi^0 (24\%) \\ &\to a_1^- \nu_\tau \to \pi^- \pi^0 \pi^0 \nu_\tau (15\%) \end{aligned}$$

"1-prong" channel, 90% of hadronic τ decay($\sim$50%)

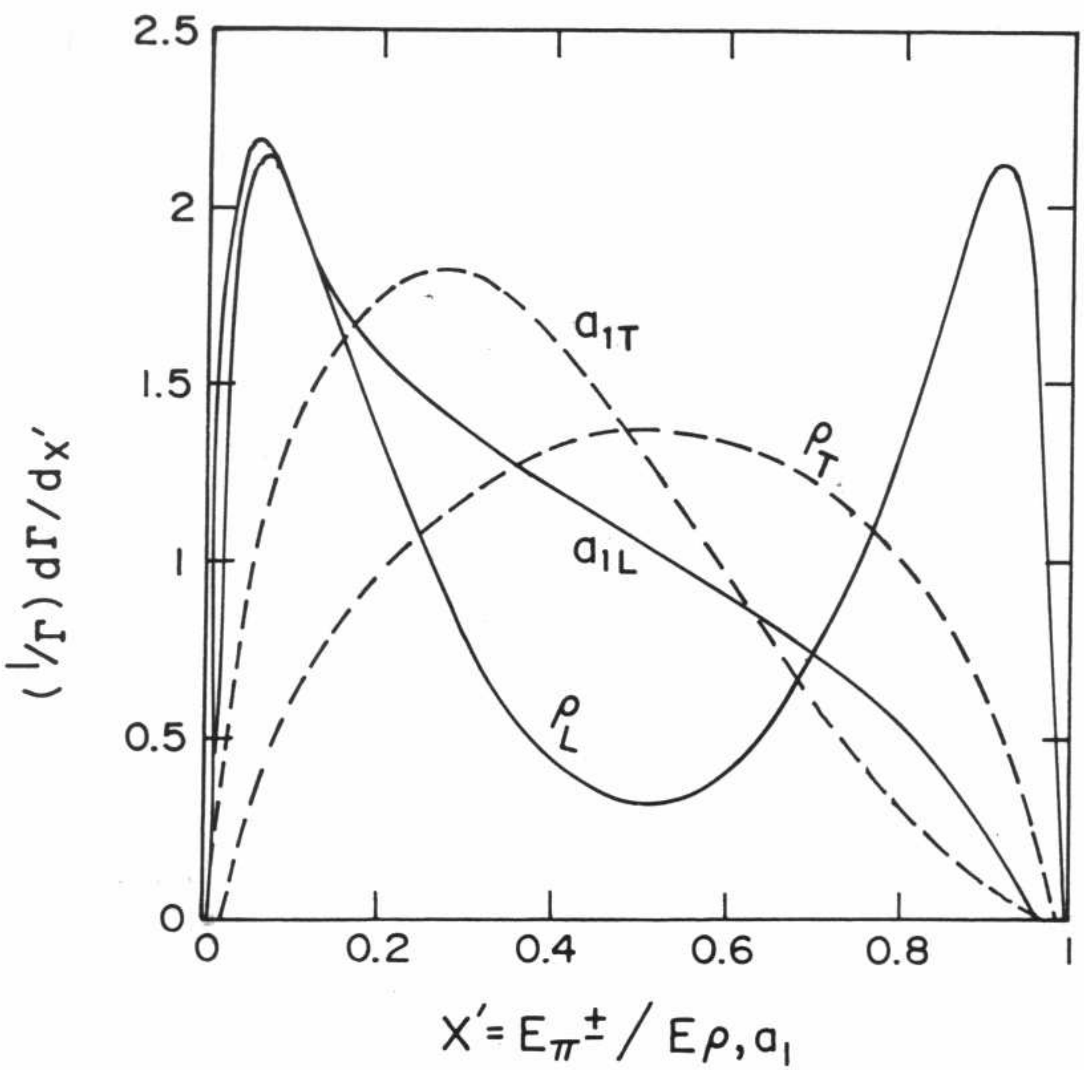
$a_1 \to \pi^\pm \pi^\pm \pi^\mp$ "3- prong" channel

$$\begin{aligned} \frac{1}{\Gamma_\pi} \frac{d\Gamma_\pi}{d(\cos\theta)} &= \frac{1}{2}(1 + P_\tau \cos\theta) \\ \frac{1}{\Gamma_\pi} \frac{d\Gamma_{v,L}}{d(\cos\theta)} &= \frac{m_\tau^2/2}{m_\tau^2 + 2m_v^2}(1 + P_\tau \cos\theta) \\ \frac{1}{\Gamma_\pi} \frac{d\Gamma_{v,T}}{d(\cos\theta)} &= \frac{m_v^2}{m_\tau^2 + 2m_v^2}(1 - P_\tau \cos\theta) \end{aligned}$$

For $E \gg m_\tau$,

$$\cos\theta = \frac{2x - 1 - m_{\pi,v}^2/m_\tau^2}{1 - m_{\pi,v}^2}$$

$$P_\tau = +1; \Rightarrow \tau_{jet} \sim \pi, \rho_L, a_{1L}$$
$$P_\tau = -1; \Rightarrow \tau_{jet} \sim \rho_T, a_{1T}$$



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Energy sharing among decay products, π^+ and π^0:

$$\rho^- \to \pi^-\pi^0$$

$$\frac{1}{\Gamma_{\pi\pi}}\frac{d\Gamma(\rho_L \to \pi^+\pi^0)}{d(\cos\theta')} \simeq \frac{3}{2}(2x'-1)^2$$

$$\frac{1}{\Gamma_{\pi}}\frac{d\Gamma(\rho_T \to \pi^+\pi^0)}{d(\cos\theta')} \simeq 3x'(1-x')^2$$

$$x' = \frac{1+\sqrt{1-4m_\pi^2/m_\rho^2}\cos\theta'}{2} = \frac{p_\pi}{p_\rho}$$

$\rho_L \to \pi^+\pi^0$; asymmetric sharing; x' $\to 0/1$

$\rho_T \to \pi^+\pi^0$; equal sharing; x' $\to 0.5$

Similar features also hold for $a_1^- \to \pi^-\pi^0\pi^0$

Application: Measure energy of charged track and τ jet energy

1-prong case: $R_1 = \frac{E_\pi}{E_{\tau-jet}}$

- Also manage to suppress the fake τ bg from QCD effectively.

" 3-prong channel", 15% from τ decay, 2/3rd comes from

$$\tau \to a_1 \nu \to \pi^\pm \pi^\pm \pi^\mp \nu_\tau$$

$$R_3 = \frac{E_{\pi^\pm \pi^\pm}}{E_{\tau-jet}} \neq 0.2 - 0.8$$

- Like sign pair of pion in the 3-prong decay of a_1 is analogus to the neutral pion pair in its 1-prong decay.i.e. $R_3 = 1 - R_1$
- Enhance the contribution to a_{1L}

Analysis

- Signal: $pp \to tH^- \to (bqq)(\tau\nu)$;
- Background $pp \to t\bar{t} \to (bqq)(b\tau\nu)$; W+multijet..

$\tau \to \pi^\pm\pi^0, \pi^\pm\pi^\pm\pi^\mp$

- Final state: one reconstructed top quark, at least 3 jets, missing energy and τ-jet

Tools: `PYTHIA + TAUOLA`, `CMSJET` is used only for jet and missing energy reconstruction.

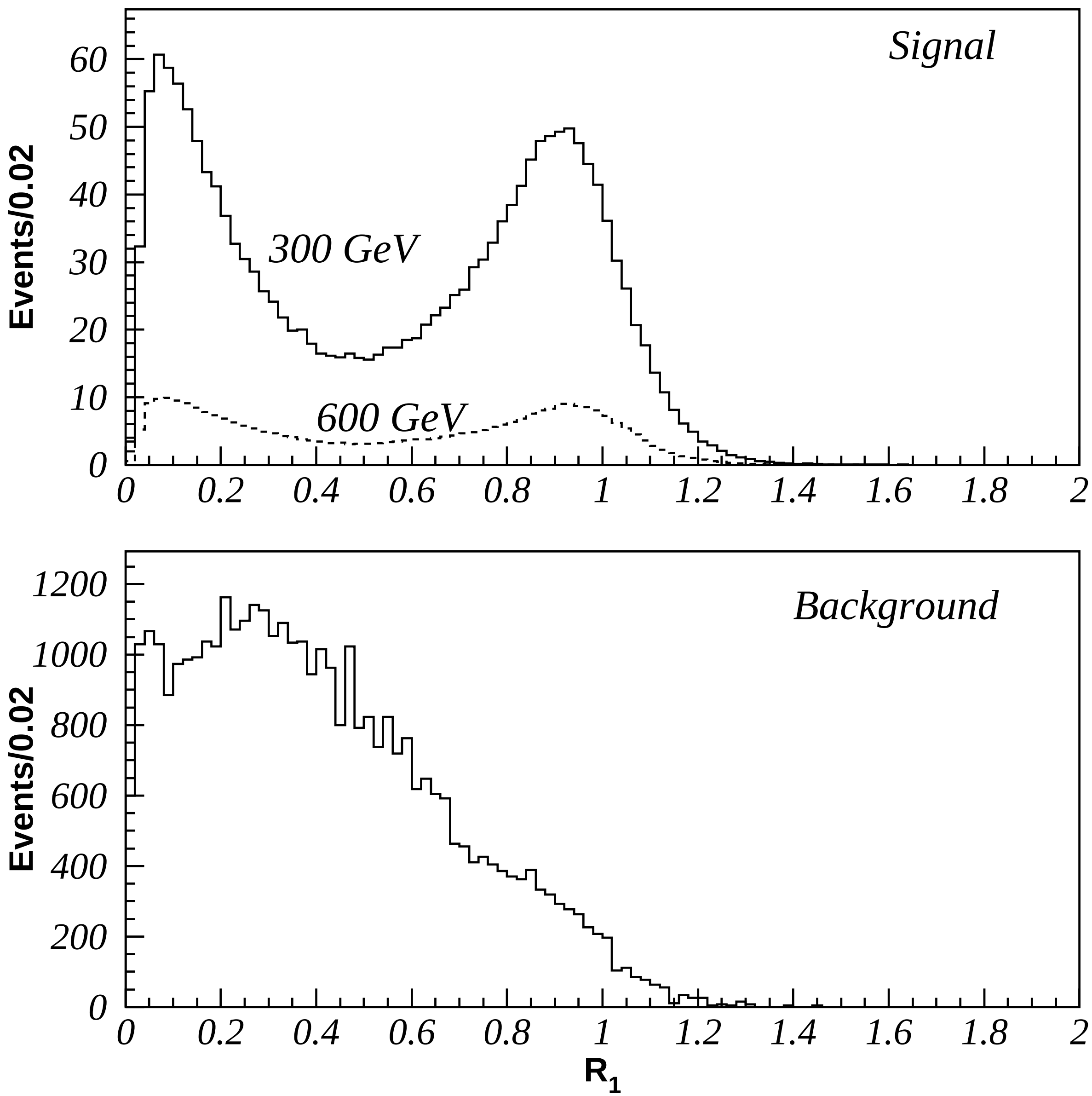
τ-jet identification:

- From the narrowness of the τ-jet, Define a signal cone=$\Delta R_s = 0.1$ and isolation cone $\Delta R_I = 0.4$
- 1 or 3 charged track with $\eta < 2.5$ and p_T >3 GeV
- No other charged tracks with $p_T > 1$GeV inside the isolation cone.
- To ensure that no π^0 by requiring

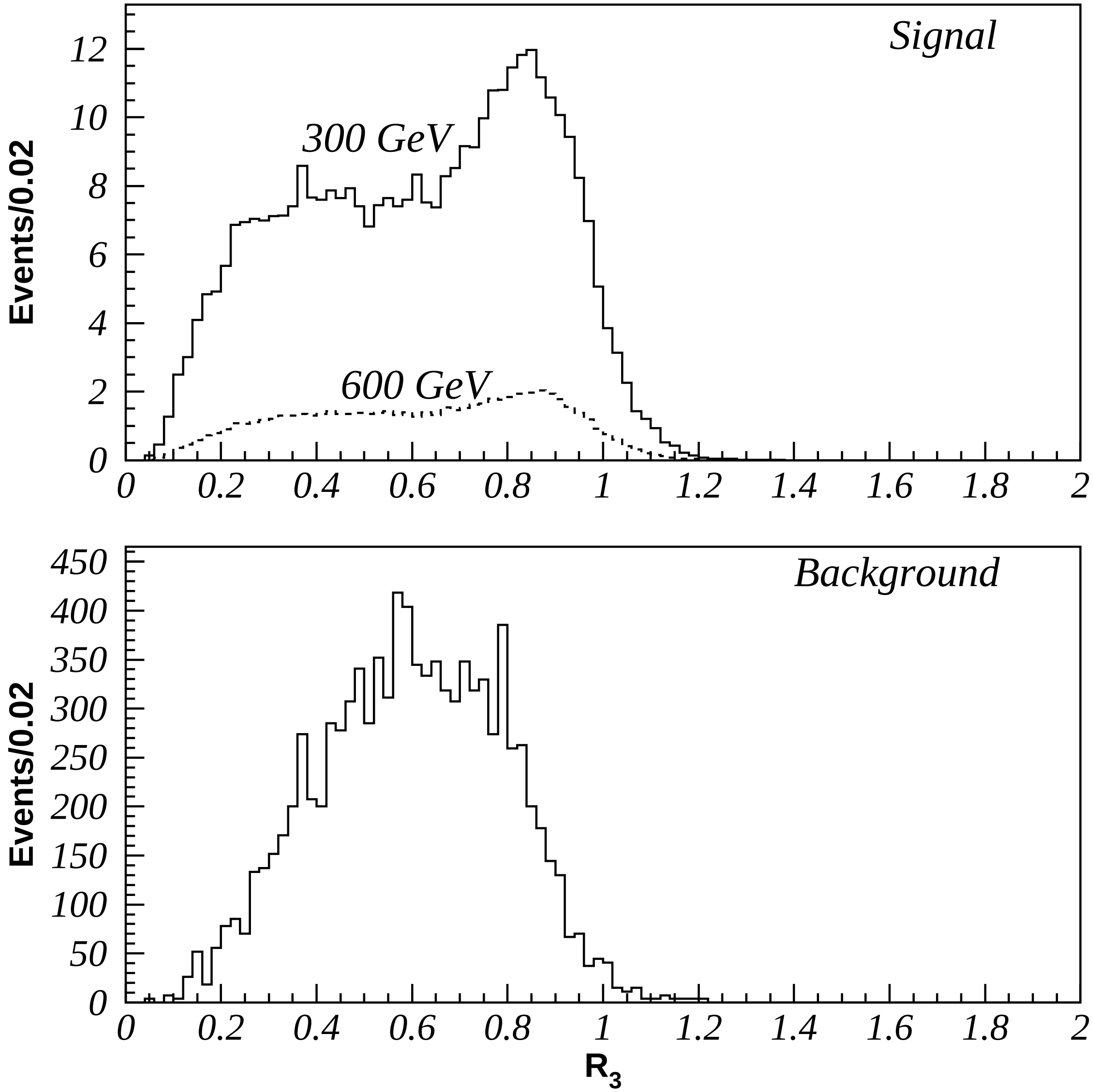
$$\Delta E = |E_{trk}^{tot} - E_{cal}^{tot}| < 10\ GeV.$$

Selection cuts:
$p_T^j >$ 20 GeV,$|\eta^j|$ <4.5; $\Delta R >$ 0.5
$\not{E}_T >$ 30 GeV

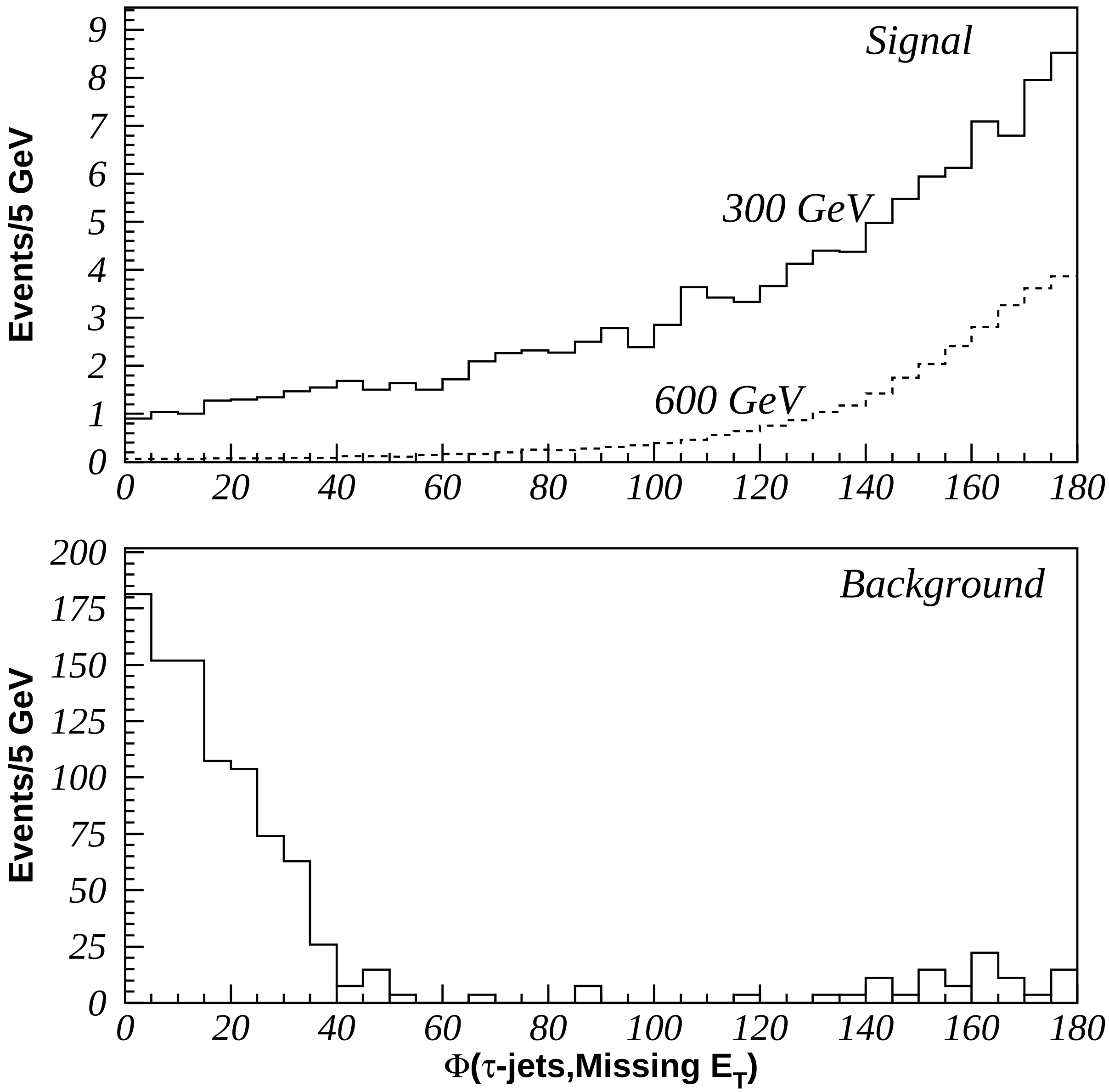
1-prong case: Distribution of $R_1 = \frac{E_\pi}{E_{\tau-jet}}$;$E_{\tau-jet}$ >100 GeV



3-prong case: Distribution of $R_3 = \frac{E^{\pm}_{\pi}\pi^{\pm}}{E_{\tau-jet}}$;$E_{\tau-jet}$ >100 GeV



3-prong case: Distribution of $\Delta\phi(\tau - jet, \not{E}_T)$



$E_{\tau-jet}$ >100 GeV

$\not{E}_T > 100$ GeV

$R_3 < 0.2$ or > 0.8

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1-prong case: 10^6 events generated

Cuts	$m_H, \tan\beta$ (300,40)	$m_H, \tan\beta$ (600,40)	Bg $t\bar{t}$
No. of had.τ decay event	640531	641346	641009
Identified tau jets	448288	465556	229622
$E_T^{\tau-jet}$ >100 GeV	212491	370562	17875
1 prong decay	158865	281428	10182
$R_{1\pi}$ >0.8	57240	103470	1046
$\not{E}_T > 100$ GeV	32441	89587	410
Number of jets $\geq$3	15083	41783	308
W mass rec, $m_{jj} = m_W \pm 15\mathrm{GeV}$	9861	27091	147
Top mass rec,$m_{jW} = m_t \pm 30\mathrm{GeV}$	6376	17339	87
$\Delta\phi(\tau - jets, \not{E}_T) > 60^0$	5154	16394	2
$\sigma\times$BR (pb)	0.431	0.045	73
Cross section $\times$ efficiency$\times\epsilon_b$(fb)	1.1	0.37	.15

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3-prong case: 10^6 events generated

Cuts	$m_H, \tan\beta$ (300,40)	$m_H, \tan\beta$ (600,40)	Bg $t\bar{t}$
No. of had.τ decay event	640531	641346	641009
Identified tau jets	448288	465556	229622
$E_T^{\tau-jet}$ >100 GeV	212491	370562	17875
3 prong decay	53626	89134	7683
$\Delta E < 10$ GeV	32886	54901	2610
$R_{3\pi}$ <0.4 or > 0.8	18159	29714	858
$\not{E}_T > 100$ GeV	10456	26173	269
Number of jets $\geq$3	4854	12161	206
W mass rec, $m_{jj} = m_W \pm 15$GeV	3138	7886	110
Top mass rec, $m_{jW} = m_t \pm 30$GeV	2010	5073	60
$\Delta\phi(\tau - jets, \not{E}_T) > 60^0$	1676	4881	1
$\sigma\times$Br(pb)	.431	0.045	73
Cross section $\times$ efficiency$\times\epsilon_b$ (fb)	0.36	0.11	0.07

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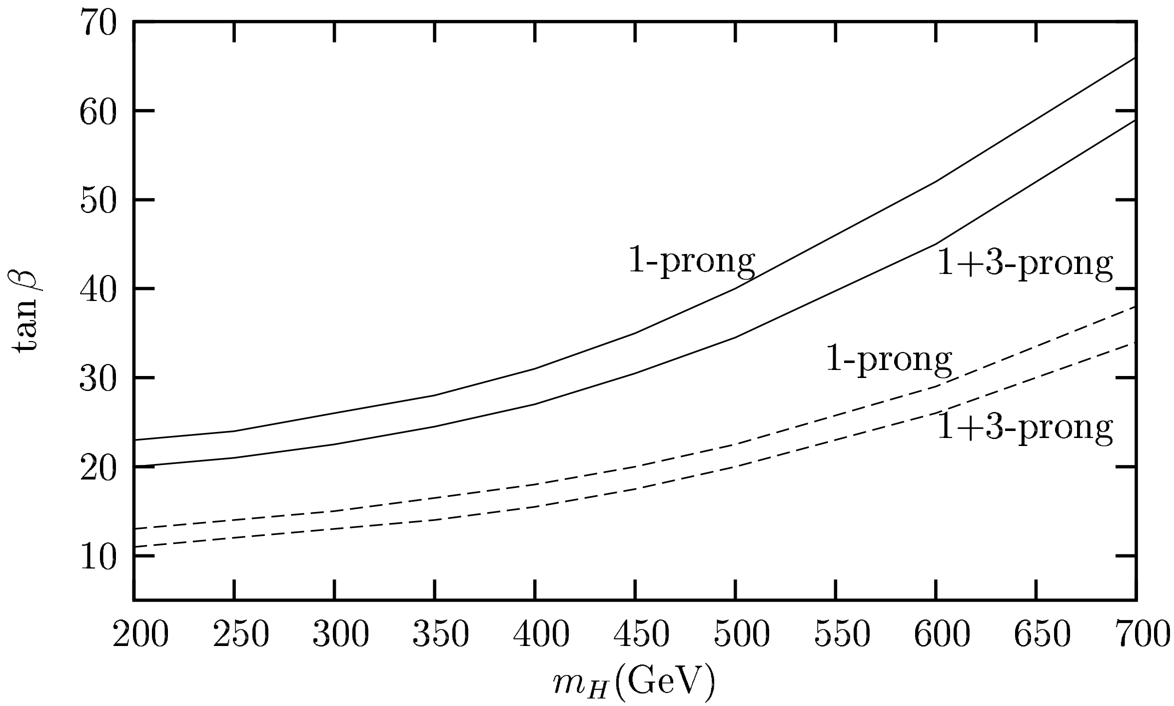
1+3-prong case: Discovery limits at 5σ for $\mathcal{L}$=30/fb and 100/fb


70
60
50
40
30
20
10
tan β
200
250
300
350
400
450
500
550
600
650
700
m_H(GeV)
1-prong
1+3-prong
1-prong
1+3-prong

D.P.Roy, Ritva Kinnunen, MG hep-ph/0608324

Outlook

- Charged Higgs signal in $H \to \tau\nu$ channel is very promising.

- The polarization of τ can be exploited in both 1-prong and as well as 3-prong channel. Also useful to kill QCD backgrounds

- Adding 3-prong contribution increases the discovery limit, e.g for m_H =400 GeV, for 1-prong case $\tan\beta > 30$, with 1+3-prong, $\tan\beta > 24$ can be probed. (D.P.Roy, Ritva Kinnunen, MG hep-ph/0608324)

- Planned for full Simulation with Sami Lehti and R.Kinnunen