Physics of top quarks and charged Higgs in CMS

S. Slabospitsky

IHEP, Protvino, RUSSIA
(for CMS Collaboration)

Outline

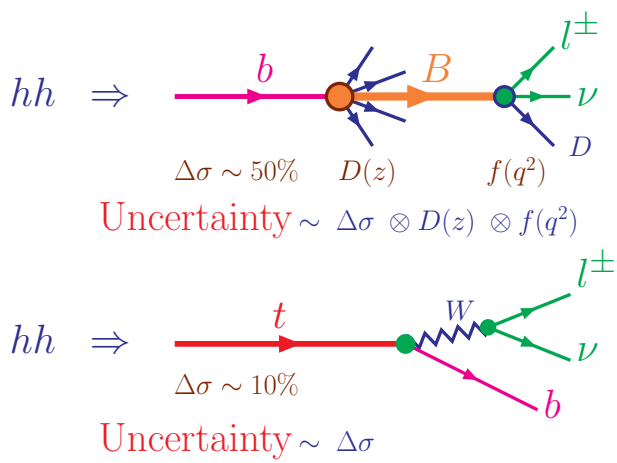
- why we like top quark
- current experimental status
- $t \to \bar{t}$ pair production
- top mass measurements
- single top production
- top quark decays
- top decays due to FCNC
- search for light charged Higgs
- search for heavy charged Higgs
- $q\bar{q}' \to H^{\pm}$
- conclusions

WHY WE LIKE TOP QUARK ?

almost all top quark decays and production rates can be evaluated by means of perturbation theory

- $m_t \approx 175$ GeV $\Longrightarrow$, t-quark properties are very unusual as compared to the light quarks (u, d, s, c, b)
- there are no top hadrons, $M(t\bar{q})$ $\Lambda(tqq)$, $T(t\bar{t})$

$$\tau_{life}(t) = \frac{1}{\Gamma_{tot}(\approx 1.5 \text{ GeV})} \ll \tau_h \sim \frac{1}{\Lambda_{QCD}(\approx 0.2 \text{ GeV})}$$



- **only one** observable decay channel, $t \to b\,W^+$, all other SM top decays have very small probabilities

top quark is unique and powerful 'instrument' for study of SM physics as well as for search for manifestation of New Physics beyond SM

CURRENT EXPERIMENTAL STATUS

- production cross section

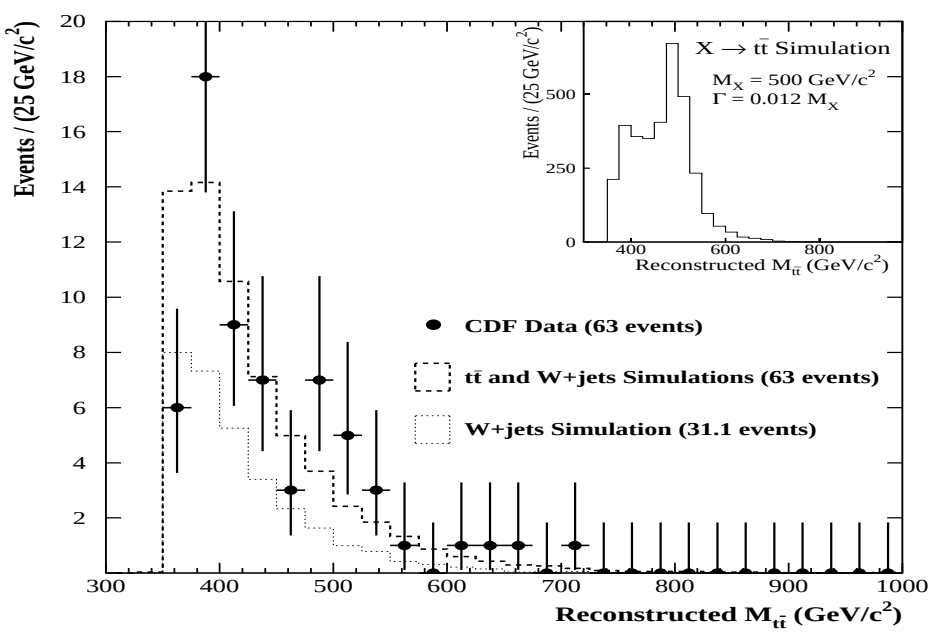
FNAL $\sqrt{s} = 1.8$ TeV

CDF	$\sigma_{t\bar{t}}$	$=$	$6.5^{+1.7}_{-1.4}$ pb
$D\emptyset$	$\sigma_{t\bar{t}}$	$=$	5.9 ± 1.7 pb
	$< \sigma_{t\bar{t}} >$	$=$	6.2 ± 1.7 pb
theory	$\sigma_{t\bar{t}}$	$=$	$4.8 \div 5.2$ pb

- t–quark mass

CDF	m_t	=	176.1 ± 6.6 GeV
$D\emptyset$	m_t	=	172.1 ± 7.1 GeV
RPP-2000	m_t	=	174.3 ± 5.1 GeV

- differential distributions



- electroweak (single) top production

	theory	CDF	$D\emptyset$
W^* $q\bar{q}' \to t\bar{b}$	$\sigma_{th} = 0.75 \pm 0.12$ pb	< 18 pb	< 17 pb
Wg $qg \to q't\bar{b}$	$\sigma_{th} = 1.47 \pm 0.22$ pb	< 13 pb	< 22 pb
Wt $gb \to tW$	$\sigma_{th} = 0.15 \pm 0.04$ pb		

- t–quark properties

$$R_b = \frac{\Gamma(t \to Wb)}{\Gamma(t \to Wq)} = 0.99 \pm 0.15$$
$$|V_{tb}| > 0.76 \text{ at } 95\% \text{ CL } (3 \text{ generations})$$
$$> 0.80 \text{ at } 90\% \text{ CL}$$
$$\Gamma_{W_{long}} = 55\,^{+48}_{-53}\,\% \ (70\% \text{ theory})$$

- FCNC decays: $t \to c\,Z$ and $t \to c\gamma$

CDF	$B(t \to \gamma\,(c+u))$	$<$	3.2 % (95% CL)
	$B(t \to Z\,(c+u))$	$<$	33 % (95% CL)
LEP-2	$B(t \to Z\,(c+u))$	$<$	7 % (95% CL)

top production mechanism and t–quark properties are in a well agreement with SM expectations

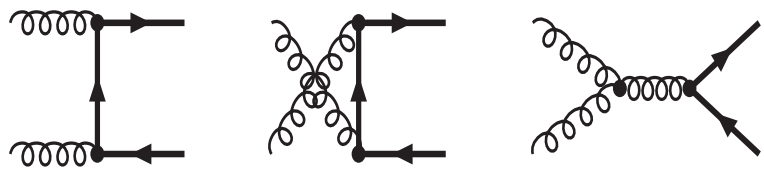
$$\sigma_{t\bar{t}}(1.8 \text{ GeV}) = 5.06 \text{ pb}, \quad \sigma_{t\bar{t}}(14 \text{ GeV}) = 830 \text{ pb}$$

$$\frac{\sigma_{LHC}}{\sigma_{FNAL}} \approx 160$$

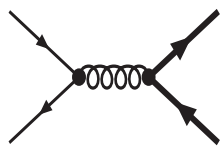
LHC will be a top–factory machine $N_{t\bar{t}}(100 \text{ fb}^{-1}) \sim 10^8$

$t\,\bar{t}$ pair production

$g\,g \to t\bar{t}$



$q\bar{q} \to t\bar{t}$



$t\bar{t}$ pair productions cross section and inclusive distributions are calculated at $\mathcal{O}(\alpha_s^3)$ and resummation of enhanced leading logarithms has been also performed
scale uncertainty ($\mu_R = m_t/2, ..., 2m_t$)
gives $\delta\sigma_{t\bar{t}}(\mu_R) \approx 6\%$
PDF dependence of $\sigma_{t\bar{t}}$ is also studied, $\Delta\sigma(PDF) \approx 10\%$

$$\frac{\Delta\sigma_{t\bar{t}}}{\sigma_{t\bar{t}}} = 12\%, \quad \Rightarrow \quad \sigma_{t\bar{t}}(\mathrm{LHC}) = 830 \pm 99 \ \ \mathrm{pb}$$

• an accurate determination of the top quark production cross section provides an independent indirect determination of m_t

$$\frac{\Delta\sigma}{\sigma} \sim 5\frac{\Delta m_t}{m_t} \quad \Rightarrow \quad \Delta\sigma \sim 5\%, \quad \rightarrow \quad \Delta m_t \sim 1\% \approx 2 \ \mathrm{GeV}$$

- p_T and $M_{t\bar{t}}$ distributions are under good control

$$\begin{array}{llll} \text{scale} & \text{variation} & \Rightarrow & 15\%, \\ \text{PDF} & \text{choice} & \Rightarrow & 10\% \end{array}$$

- non-QCD contributions, EW, SUSY EW, SUSY QCD, all these contributions can enhanced $\sigma_{t\bar{t}}$ by $\sim 10\%$ close to threshold $\sqrt{s} \geq 2m_t$, but after the convolution with PDF their contributions to total $t\bar{t}$ rate become much smaller for $|\sigma_{t\bar{t}}^{NLO} - \sigma_{t\bar{t}}^{LO}|/\sigma_{t\bar{t}}^{LO}$ one has

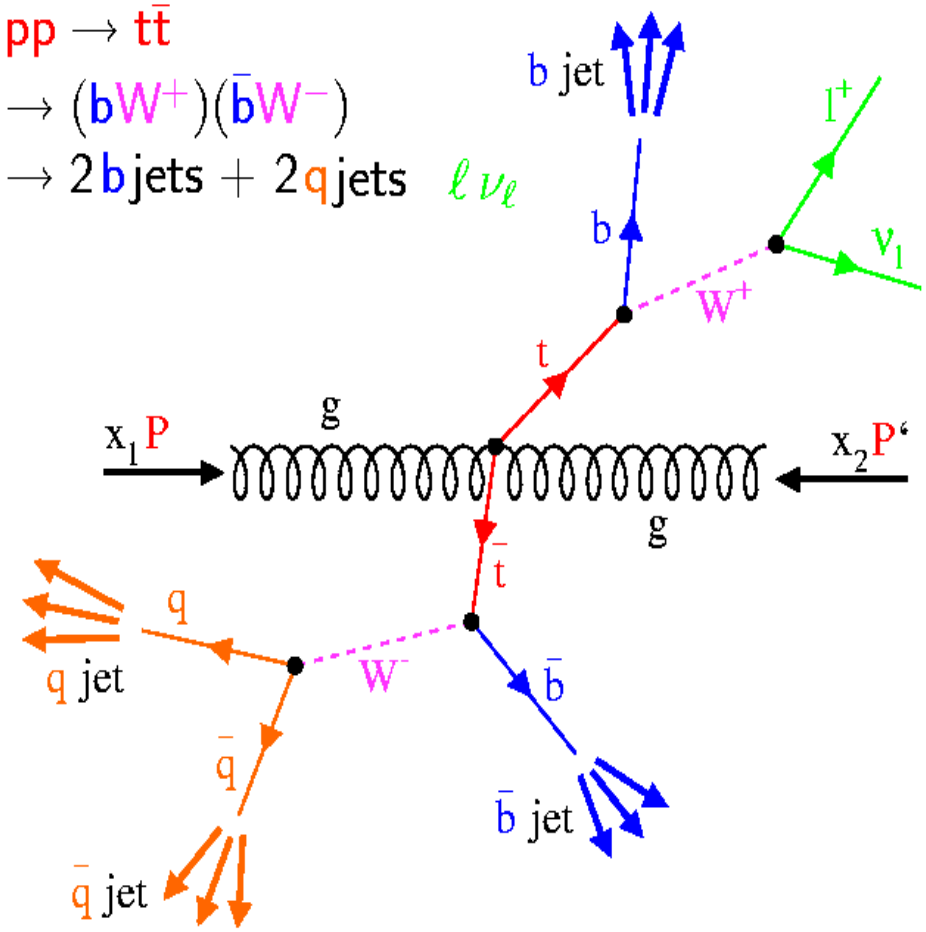
SM ($M_H = 100$ GeV)	G2HDM	SUSY EW	SUSY QCD
2.5%	$\leq 4\%$	$\leq 10\%$	$\leq 4\%$

- $d\sigma_{t\bar{t}}/dM_{t\bar{t}}$ is sensitive to new heavy objects (Higgs, η_T)

- the measurement of $\sigma_{t\bar{t}}$ at LHC will be limited by the uncertainty of the integrated luminosity, $\sim 5 \div 10\%$

top mass measurements

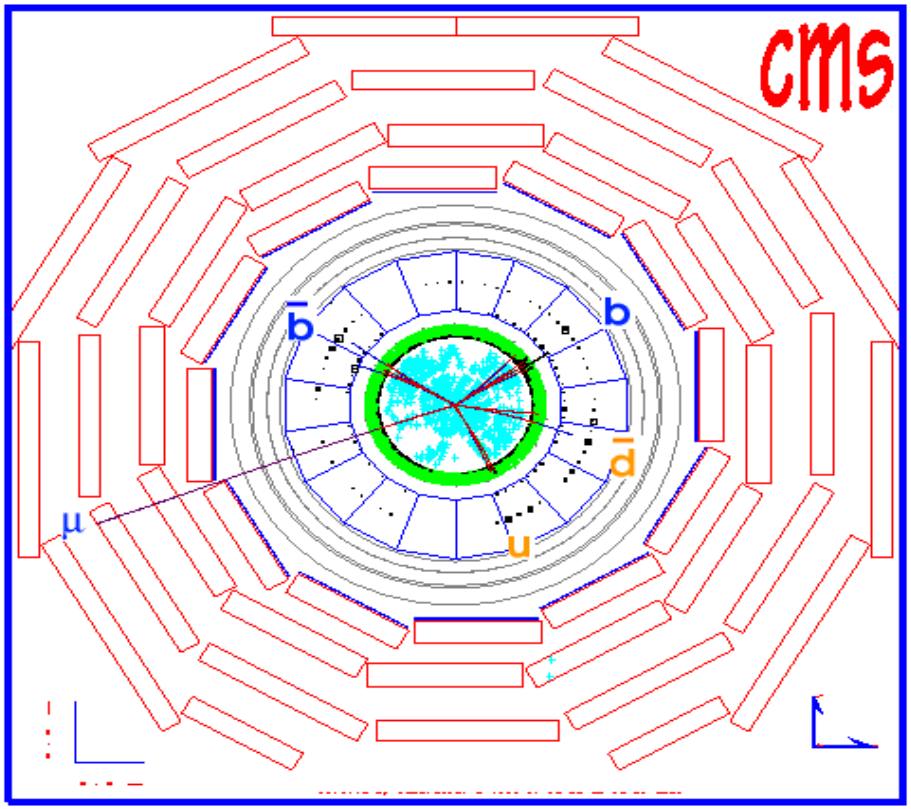
- semileptonic $t\bar{t}$ decays (Lars Sonnenschein)

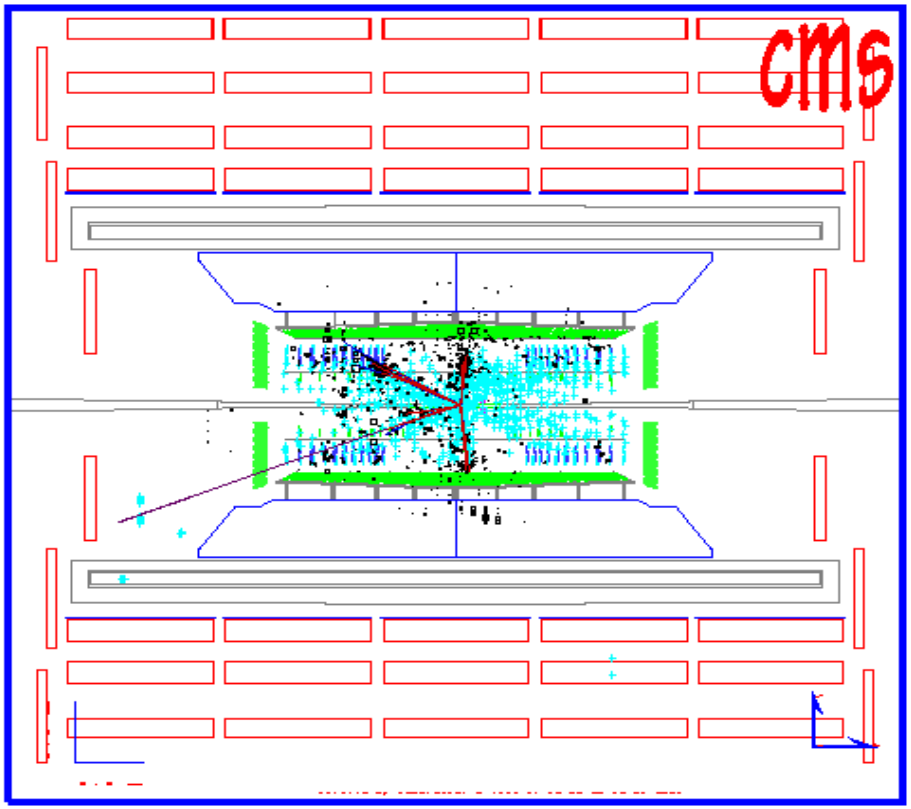


$\delta m_t = (0.9 \div 1.3)$ GeV, $\delta m_t \leq 0.7$ %

Semileptonic $t\bar{t}$ event in CMS

Lars Sonnenschein

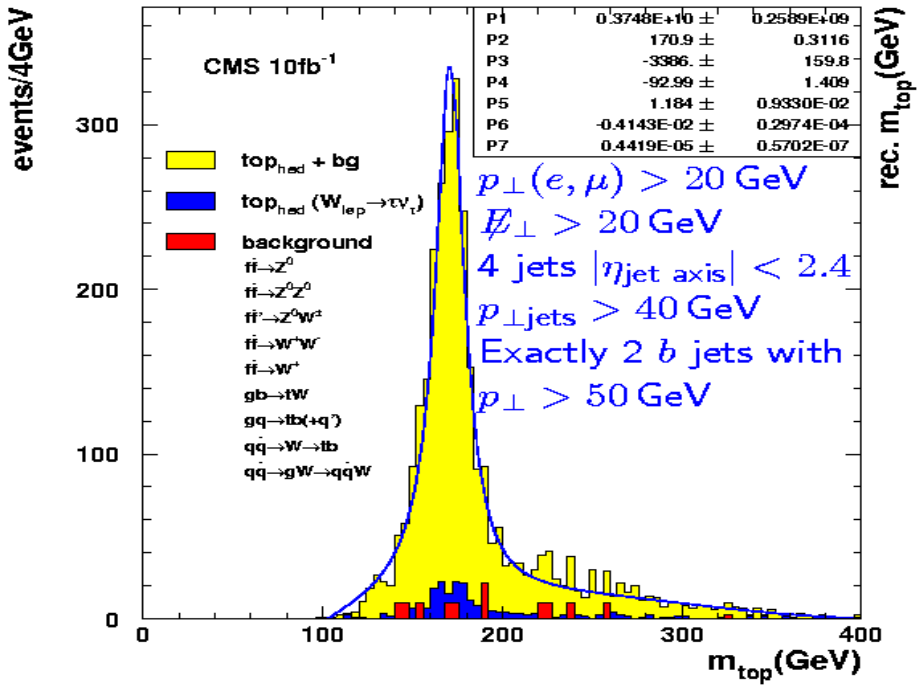




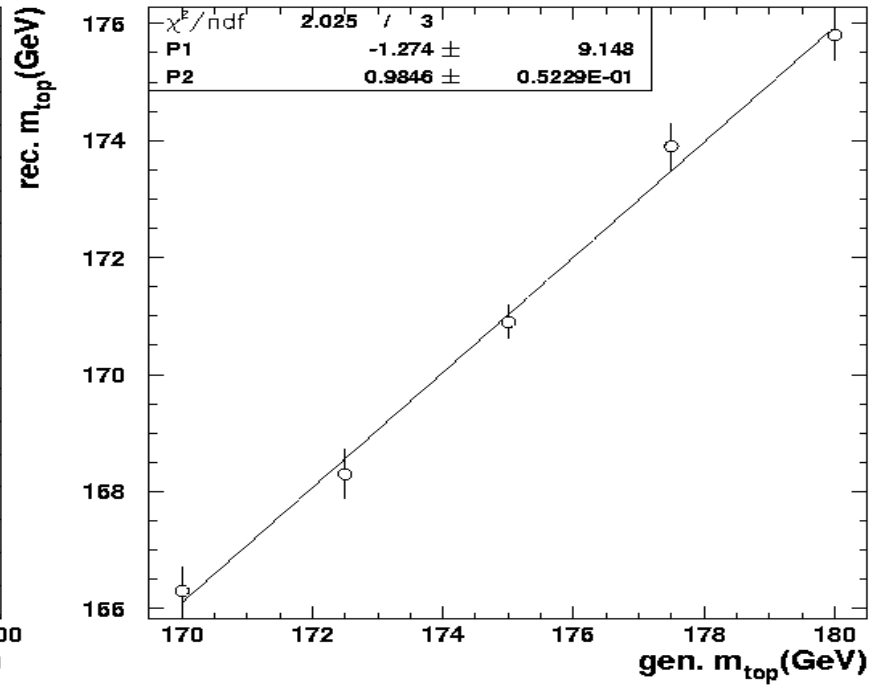
Semileptonic $t\bar{t}$ decay

Lars Sonnenschein

Three jet channel ($t \to bW \to bq\bar{q}$)



Reconstructed versus generated m_t



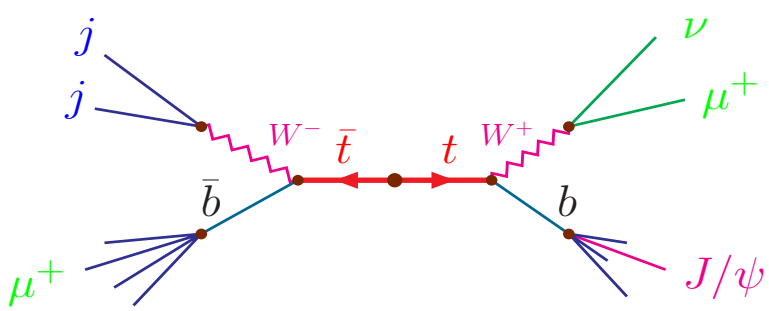
- dileptonic $t\bar{t}$ decays (R. Kaur, S.B. Beri, J.M. Kohli)

$$t\bar{t} \to bW^+\bar{b}W^- \to e^\pm\mu^\mp\nu\nu b\bar{b}$$

correlation between $M(e\,\mu)$ and $m_t \Longrightarrow \delta m_t \leq 2$ GeV

- m_t from $t \to \ell J/\psi\, X$ decays (A. Kharchilava)

$$t \to bW^+,\ W^+ \to \ell\nu,\ b \to J/\psi X, \Longrightarrow t \to \ell J/\psi$$



$M(\ell\, J/\psi)$ is correlated to m_t
◇ μ in jet, $p_\top(\mu) > 4$ GeV, $|\eta_\mu| < 2.4$
◇ isolated lepton, $p_\top(\ell) > 15$ GeV, $|\eta_\ell| < 2.4$
◇ μ from J/ψ, $p_\top(\mu) > 4$ GeV, $|\eta_\mu| < 2.4$
fitting maximum of the $M(\ell\, J/\psi)$ spectrum with a Gaussian
typical statistical error on $M(\ell\, J/\psi)$ is ≤ 0.5 GeV
$\Longrightarrow$ total error (stat.+syst.) is $\delta m_t \leq 1$ GeV

EW PRODUCTION OF TOP QUARK

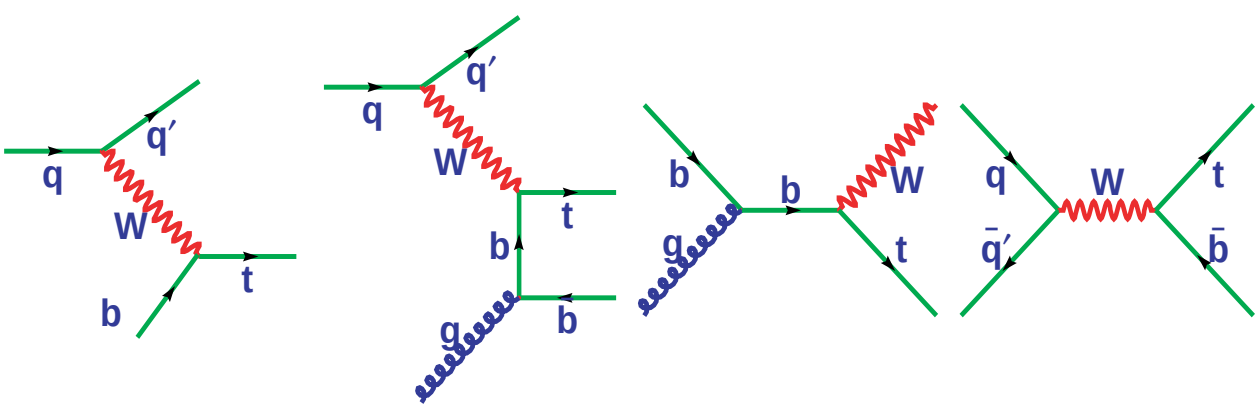
- electroweak top-quark quarks production provides to investigate
  - ◇ structure of $Wt\bar{b}$ vertex
  - ◇ value of CKM matrix element V_{tb}
  - ◇ search for New Physics
- $\Gamma_{tot} = 1.53$ GeV $\Rightarrow$ $\tau_0 = 4.3 \cdot 10^{-25}$ s

Γ_{tot} and V_{tb} could not measured directly top decays

$$\mathrm{B}(t \to bW) \Rightarrow \frac{|V_{tb}|^2}{|V_{td}|^2 + |V_{ts}|^2 + |V_{tb}|^2} \approx 1$$

on the other hand $\sigma_{EW}(top) \propto |V_{tb}|^2$

- single top at LHC can be produced via three subprocesses

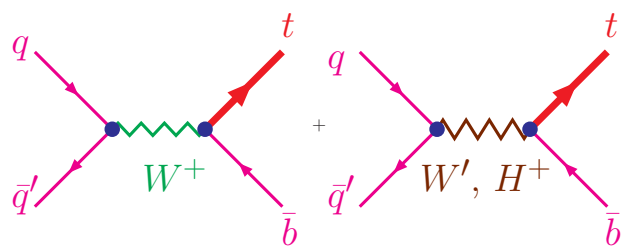


Wg fusion $\qquad$ Wt $\qquad$ W^*

$$\sigma(Wg) = 245 \pm 30 \text{ pb}$$
$$\sigma(tW) = 60 \pm 10 \text{ pb}$$
$$\sigma(W^*) = 10 \pm 1 \text{ pb}$$

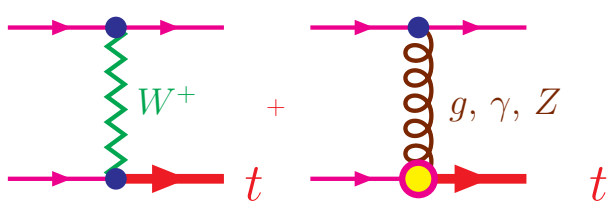
three channels of single top production have different sensitivities to New Physics

• new heavy charged bosons (W', H^+, ...) may increase $t\bar{b}$ (W^* channel) cross section



$$\frac{\sigma(W^*)_{New}}{\sigma(Wg)} > \frac{\sigma(W^*)_{SM}}{\sigma(Wg)}$$

• Wg channel sensitive to top couplings with other SM particles (FCNC, etc)



$$\frac{\sigma(W^*)}{\sigma(Wg)_{New}} < \frac{\sigma(W^*)}{\sigma(Wg)_{SM}}$$

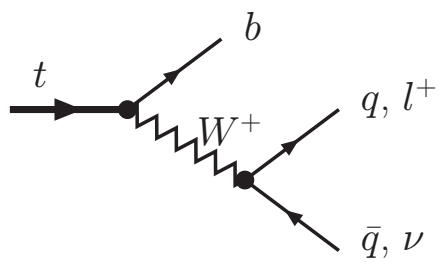
both CMS and ATLAS have investigated the possibility to investigate all three channels

- all three channels could be separated
- basic uncertainty comes from $\delta(\sigma(t)_{exp})$
- $\delta\,|V_{tb}| \leq 5\%$ could be achieved

	Tevatron		LHC
	RUN I	RUN II	
$\delta\sigma(t\bar{t})$	27%	9%	$(5 \div 10)\%$
δm_t	3%	1.5%	0.7%
δV_{tb}	–	13%	5%

TOP QUARK DECAYS

perturbation theory can be used for description of top decays (3 generations $\Rightarrow V_{tb} \approx 1$)



in the SM the decay $t \to bW$ is by far the dominant one

$$\Gamma_{tot} \simeq \Gamma(t \to bW) \simeq 0.17\,\mathrm{GeV}|V_{tb}|^2 \frac{m_t^3}{M_W^3} \simeq 1.55\,\mathrm{GeV}$$

other qW decay widths are very small ($\sim |V_{tq}|^2$)

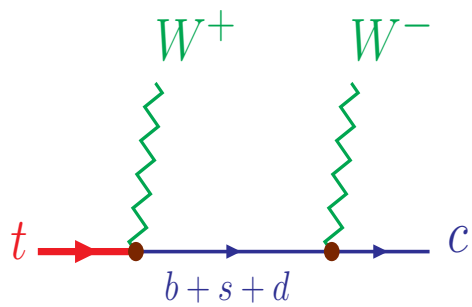
$$\begin{aligned} \mathrm{B}(t \to s\,W) &= (1.23 \div 1.76) \times 10^{-3} \\ \mathrm{B}(t \to d\,W) &= (0.16 \div 1.71) \times 10^{-4} \end{aligned}$$

any experimental evidence for rare top-quark process (production or decay) would be an indication of a New Physics beyond SM

• $t \to b\,W\,H$ almost closed within SM
• $t \to b\,W\,Z$ is very sensitive to the mass of top quark,
$m_t \approx m_b + m_W + m_Z$

$$\mathrm{B}(t \to bWZ) = \begin{pmatrix} 10. \\ 5.4 \\ 3.4 \end{pmatrix} \times 10^{-7} \quad \text{for} \quad m_t = \begin{cases} 179. \\ 173.8 \\ 168.6 \end{cases} \text{GeV}$$

• $t \to c\,W^+\,W^-$ is suppressed due to GIM mechanism,
for $m_j = 0 \Longrightarrow \sum_{j=d,s,b} V_{tj} V_{cj}^* = 0$



◇ new 4th generation may provide a significant contribution to W^+W^-q decay mode,
for new b'-quark with $m_{b'} = 100\ (300)$ GeV

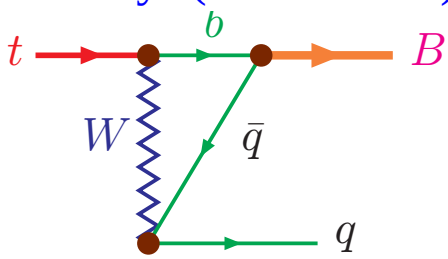
$$\mathrm{B}(t \to W^+ b'(\to W^- c)) \sim 10^{-3}(10^{-7})$$

• $t \to c\,Z\,Z$

$$\mathrm{B}(t \to cZZ)_{SM} \quad \approx \quad 10^{-13}$$

- $t \to jet +$ 'isolated' meson

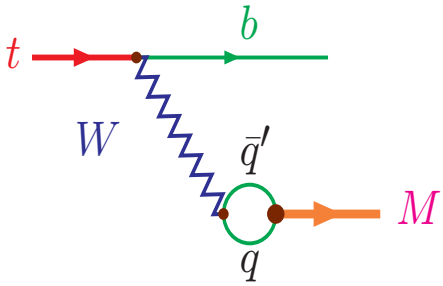
$t \to B\,q$ "exclusive" decays (on-shell W), $B = B_d, B_s, \Upsilon, \chi_b$



is very sensitive to $f_B (\sim \Psi(0))$ and to m_b/m_B ratio

$$\begin{array}{ll} \mathrm{B}(t \to \Upsilon q,\ \chi_b q) & \sim 10^{-9} \\ \mathrm{B}(t \to B^0(B_s)q) & \sim 10^{-6} \end{array}$$

- $t \to bM$ "exclusive" decays (off-shell W), $M = \pi^+, K^+, D^+, ...$



$$\begin{array}{ll} \mathrm{B}(t \to b\pi) & \sim 10^{-8} \\ \mathrm{B}(t \to bD_s) & \sim 10^{-7} \end{array}$$

TOP QUARK ANOMALOUS INTERACTIONS

◇ New Physics (beyond SM) can manifest itself by different ways

- anomalous $gt\bar{t}$ couplings
- anomalous $Wt\bar{b}$ couplings
- Flavour Changing Neutral Current (FCNC)
- new bosons ($H^{\pm}$, W', W_R, Z', η_T, ρ_T, ...)
- extra dimensions, ...

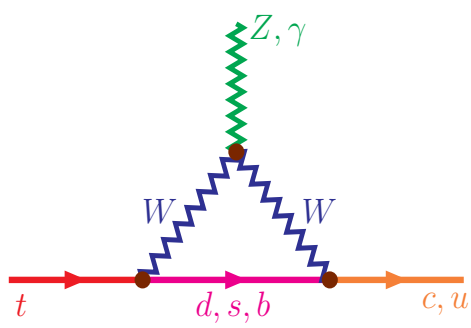
different interactions could affect on the same observable quantities

top decays due to FCNC

- Flavour Changing Neutral (FCN) interactions with a top-quark, $t \to qV$, $q = u$ or c, $V = g, \gamma, Z$

$$t \to qg$$
$$t \to q\gamma$$
$$t \to qZ$$

are highly suppressed within the SM



New Physics beyond the SM could increase the probability of these processes

	SM	two-Higgs	SUSY
$\mathrm{B}(t \to cg)$	$5 \cdot 10^{-11}$	10^{-6}	10^{-3}
$\mathrm{B}(t \to c\gamma)$	$5 \cdot 10^{-13}$	10^{-6}	10^{-5}
$\mathrm{B}(t \to cZ)$	$\sim 10^{-13}$	10^{-9}	10^{-4}

- Current constraints

$$\mathrm{CDF} : \mathrm{B}(t \to c\gamma + u\gamma) < 3.2\% \quad (95\% \text{ CL})$$
$$\mathrm{CDF} : \mathrm{B}(t \to cZ + uZ) < 33\% \quad (95\% \text{ CL})$$
$$\mathrm{LEP2} : \mathrm{B}(t \to cZ + uZ) < 7\% \quad (95\% \text{ CL})$$

two possibilities are considered for searches for FCNC

- ◇ top quarks production due to FCN interactions
  $gu \to t$, $gu \to tg$, $gu \to tZ$, $uu \to tt$, etc
- ◇ rare top decays
  $t \to qg, \quad t \to q\gamma, \quad t \to qZ$

• $t\bar{t}$ pair production

$$pp \to t\bar{t}X, \quad t \to qV, \; t \to bW(W \to e\nu, \mu\nu)$$

at $\sqrt{s} = 14$ TeV, $\int \mathcal{L}dt = 100$ fb^{-1} , PDF CTEQ5L

• number of signal events (S) are calculated with

$$\mathrm{B}_0(t \to uV + cV) = 1.0 \times 10^{-3}, \quad V = g, \gamma, Z$$

'reachable' branching ratio for $t \to qV$ decay is evaluated by using the criterion

$$\frac{S}{\sqrt{S+B} + \sqrt{B}} \geq \frac{3\sigma}{2}, \quad (\mathrm{CL} = 99\%)$$

- background process ($\sqrt{s} = 14$ TeV)
  - $t\bar{t}$ (600 pb)
  - single top (240 pb)
  - $W(\to e, \mu) + jets$ ($\sim$ 7500 pb for $\hat{k}_\top > 20$ GeV)
  - $WW + WZ + ZZ$ (110 pb)
  - $W\gamma$ (17.3 pb)

- B-tagging CMSJET:

efficiency(B-tag) $\approx$ 60%,
mistagging(C) $\approx$ 10%,
mistagging(q, g) $\approx (1 \div 2)$ %

$t \to q\gamma$ decay

$$t\bar{t} \;\to\; \gamma + l^{\pm} + \geq 2\text{jets}$$

minimal signature (PRECUT)

◇ one isolated photon with $E_{\top} \geq 75$ GeV, $|\eta_{\gamma}| \leq 2.5$

◇ one isolated lepton with $P_{\top} \geq 15$ GeV, $|\eta_{L}| \leq 2.5$

◇ two jets with $E_{\top} \geq 20$ GeV, $|\eta_{J}| \leq 4.5$

additional cuts

$|M(j\,\gamma) - m_t| \leq 15$ GeV, $|M(j\,W) - m_t| \leq 25$ GeV, jet veto: no additional jets with $E_{\top} \geq 30\ (50)$ GeV

not B-jet in $(j + \gamma)$ system and B-jet in $(j + W)$

number of events

	signal	bkg.
precut	6692	25252
all cuts	628	38

$$\mathrm{B}_{\mathrm{reachable}} = 2.5 \times 10^{-5}$$

$t \to qg$ decay

$$t\bar{t} \to \gamma + l^{\pm} + \geq 3\text{jets}$$

minimal signature (PRECUT)

- ◇ isolated lepton with $P_{\top} \geq 15$ GeV, $|\eta_L| \leq 2.5$
- ◇ three jets with $E_{\top} \geq 20$ GeV, $|\eta_J| \leq 4.5$
- ◇ one B-tagged jet

additional cuts

$|M(B\,W) - m_t|$ and $|M(j_1\,j_2) - m_t| \leq 25$ GeV
jet veto: no other jets with $E_{\top} \geq 20\,(50)$ GeV

$|M(B\,W) - M(j_1\,j_2)| < 20$ GeV

$|\vec{P}_{\top}(B\,W) + \vec{P}_{\top}(j_1\,j_2)| < 20$ GeV

$P_{\top}(B\,W) > 100$ GeV

number of events

	signal	bkg.
precut	3559	4.0×10^6
all cuts	233	14762

$$\mathrm{B}_{\mathrm{reachable}} = 1.6 \times 10^{-3}$$

$t \to qZ$ decay

$$t\bar{t} \;\to\; 3l^{\pm} + \geq 2\text{jets}$$

minimal signature (PRECUT)

◇ three isolated leptons with $P_{\top} \geq 15$ GeV, $|\eta_L| \leq 2.5$

◇ two jets with $E_{\top} \geq 20\ (50)$ GeV, $|\eta_J| \leq 4.5$

◇ one B-tagged jet

◇ Z-boson with $|M_{l^+l^-} - M_Z| \leq 15$ GeV

additional cuts

$|M(B\,W) - m_t|$ and $|M(Z\,j) - m_t| \leq 25$ GeV

jet veto: no other jets with $E_{\top} \geq 20\,(50)$ GeV

$P_{\top}(Z) \geq 75$ GeV

number of events

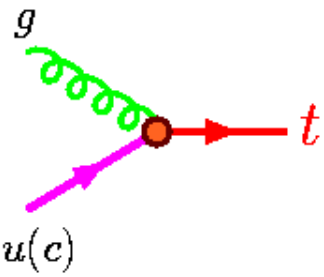
	signal	bkg.
precut	143	35.2
all cuts	31	3.9

$\mathrm{B}_{\mathrm{reachable}} = 1.63 \times 10^{-4}$

Decays versus Production

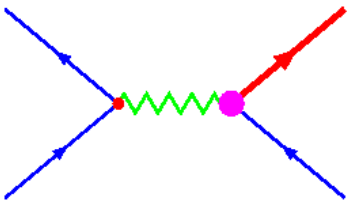
FCN interactions lead to several processes of t-quark production

g u -> t (2 -> 1)

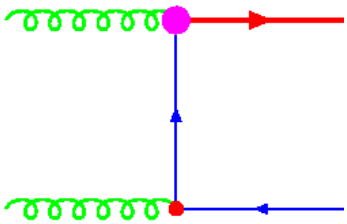


(2 -> 2)

q q -> t c
g g -> t c
g q -> t g

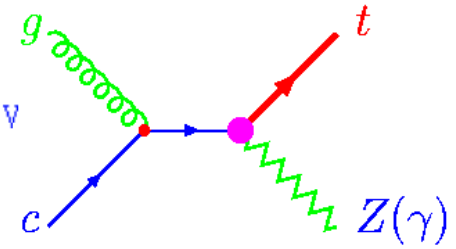


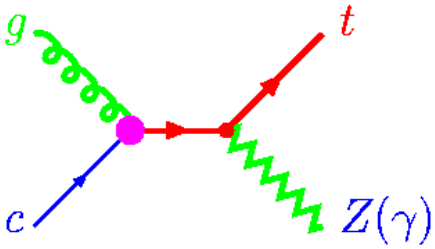
$q\bar{q} \to t\bar{c}$



$gg \to t\bar{c}$

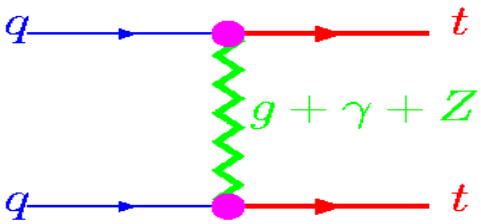
g q -> t V





'double' top

q q -> t t



• to compare with top quark production processes we assume that only one flavour ('up' or 'charm') contributes to FCN interaction

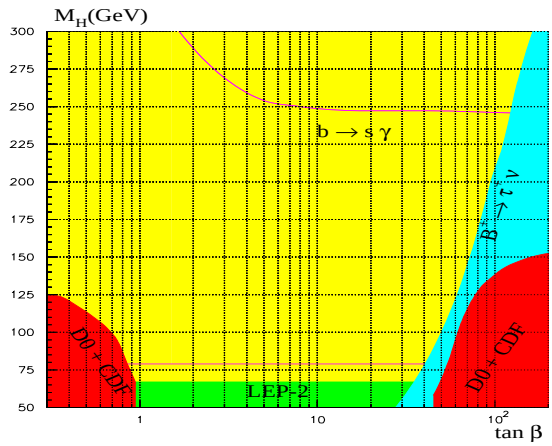
	decay	production
$t \to ug$	1.6×10^{-3}	$(0.3 \div 5.) \times 10^{-5}$
$t \to cg$	1.6×10^{-3}	$(2.1 \div 22.) \times 10^{-5}$
$t \to u\gamma$	2.5×10^{-5}	0.4×10^{-5}
$t \to c\gamma$	2.5×10^{-5}	3.5×10^{-5}
$t \to uZ$	1.6×10^{-4}	1.1×10^{-4}
$t \to cZ$	1.6×10^{-4}	4.8×10^{-4}

FCNC summary

	Run I	Run II	LHC
$t \to qg$	–	$6. \times 10^{-4}$	$1. \times 10^{-5}$
$t \to q\gamma$	0.032	2.8×10^{-3}	$2. \times 10^{-5}$
$t \to uZ$	0.33	1.3×10^{-2}	1.5×10^{-4}

Expectations for charged Higgs in CMS

CDF + DØ search for decay $t \to bH^+$, while at LEP-2 the direct production of H^+H^- is investigated



• light charged Higgs ($H^\pm$) with $M_H < m_t - m_b$ could be discovered in top quark decays

$$p\,p \to t\bar{t}X, \quad t(\bar{t}) \to H^\pm b, \; H^\pm \to \tau^\pm \nu$$

$t \to bW, W \to ell^\pm\nu$, $t \to bH^\pm, H^\pm \to \tau\nu$ (S. Banerjee, M. Maity)
two signatures: decreasing of $e^+\mu^-$ pairs yield and increasing $e(\mu)\tau$ pairs production
for $\mathcal{L} = 30$ fb^{-1} charged Higgs could be discovered for $2 < \tan\beta < 40$ and $M_{H^+} \leq 160$ GeV

for heavy charged Higgs, $M_H > m_t$ we can study direct production of $H^\pm$

$$g\,b \to tH^\pm,\ gg \to t\bar{b}H^\pm \text{ with } H^\pm \to \tau^\pm\nu,\ t\bar{b}$$
$$q\bar{q}' \to H^+ \to \tau\nu,\ t\bar{b}$$

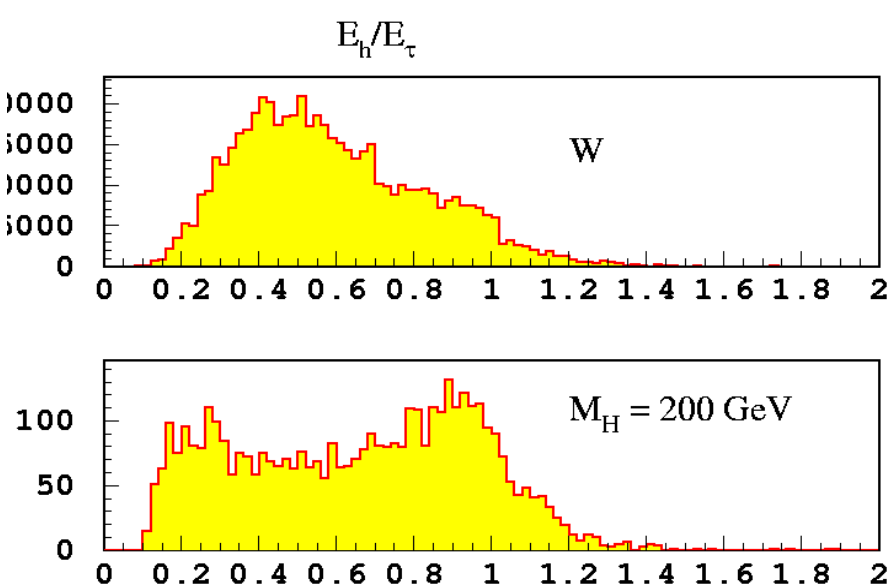
largest reach obtained in $H^+ \to \tau\nu, \tau \to$ hadronic jet thanks to the τ polarisation effects

- for any $\tan\beta$ τ-leptons from $H^\pm$ and $W^\pm$ decays have opposite polarisations

$$\mathcal{L}_W \propto \bar{\nu}\ \gamma^\alpha(1-\gamma^5)\tau \quad \mathcal{L}_H \propto \bar{\nu}\ (1+\gamma^5)\tau$$

W	$\tau_L(\leftarrow)$	$\Rightarrow$	$\nu_L(\leftarrow)\pi$	$\Rightarrow$	$p_\pi \ll p_\tau,\ p_\nu \sim p_\tau$
H	$\tau_R(\rightarrow)$	$\Rightarrow$	$\nu_L(\leftarrow)\pi$	$\Rightarrow$	$p_\pi \sim p_\tau,\ p_\nu \ll p_\tau$

W/H separation, $R_h = \frac{E_h}{E_{\tau jet}}$

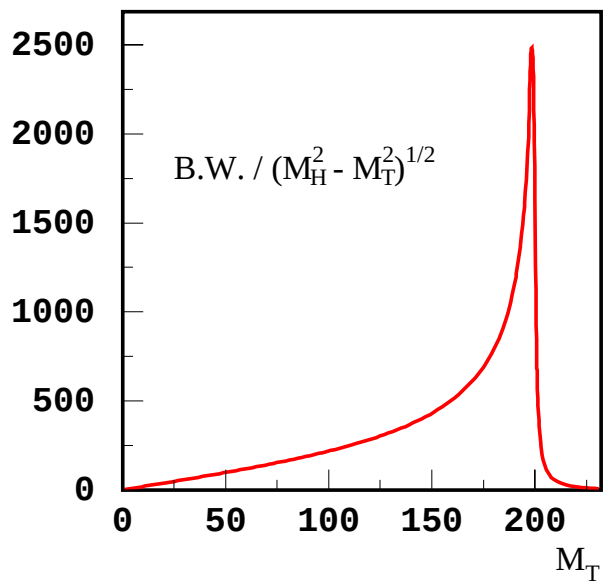


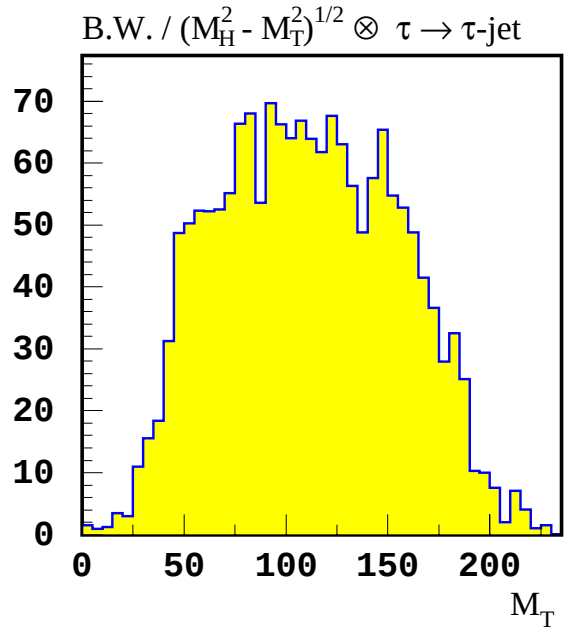
- $M(H^{\pm})$ could be determined from a fit to $M_{\top}$ distribution

$$M_{\top} = 2P_{\top\tau}E_{Tmis}(1 - \cos\phi_{\tau,E_{Tmis}})$$

however, $\vec{P}(J_{\tau}) \neq \vec{p}(\tau)$, $J_{\tau} \equiv \tau$-jet

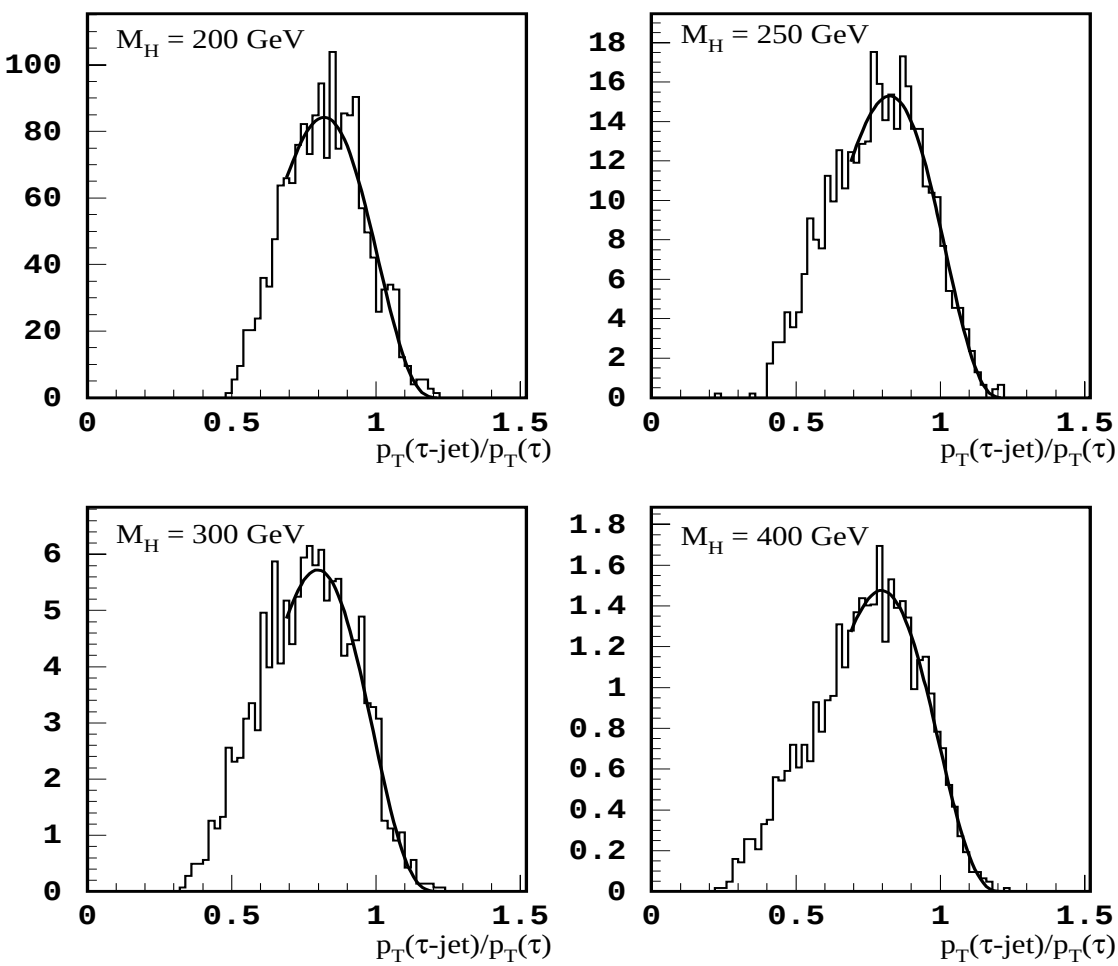
$$\frac{B.W.}{\sqrt{M_H^2 - M_{\top}^2}} \Rightarrow \frac{B.W.}{\sqrt{M_H^2 - M_{\top}^2}} \otimes (\tau \to J_{\tau})$$





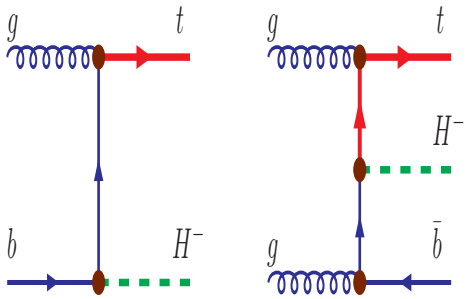
• $\tau \to jet$ can be described in terms of *fragmentation function* $D(z)$ with $z = p_\top(J_\tau)/p_\top(\tau)$

$$D(z) \propto z^{\alpha}(z_0 - z)^{\lambda} \approx z^{6.5}(1.22 - z)^{3.5}$$

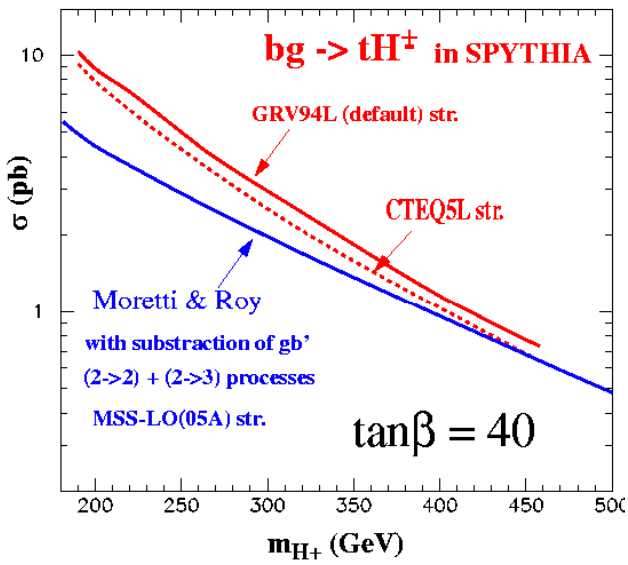


- $gb \to tH^{\pm}$ and $gg \to t\bar{b}H^{\pm}$

with $H^{\pm} \to \tau^{\pm}\nu,\ t\bar{b}$



Comparison of PYTHIA cross section with theory



event selection

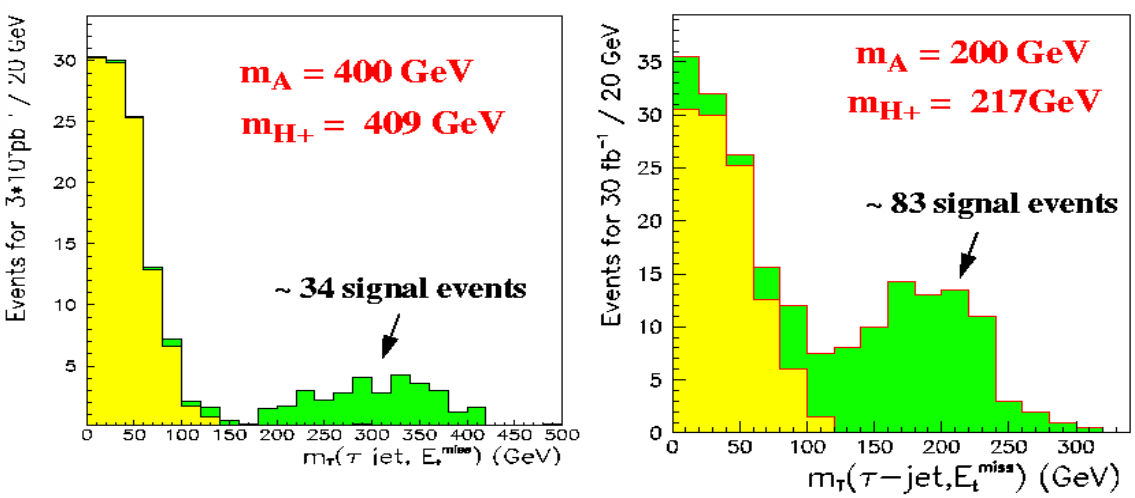
τ selection: jet, $E_\top > 100$ GeV, $|\eta| < 2.5$ containing one track with $R_h = p_h/E_j > 0.8$, ΔR(j, track) < 0.1

$E_\top^{\rm miss} > 100$ GeV

top quark $\rightarrow$ 3jets, second top veto

Signal superimposed on the total background, $3*10^4 pb^{-1}$

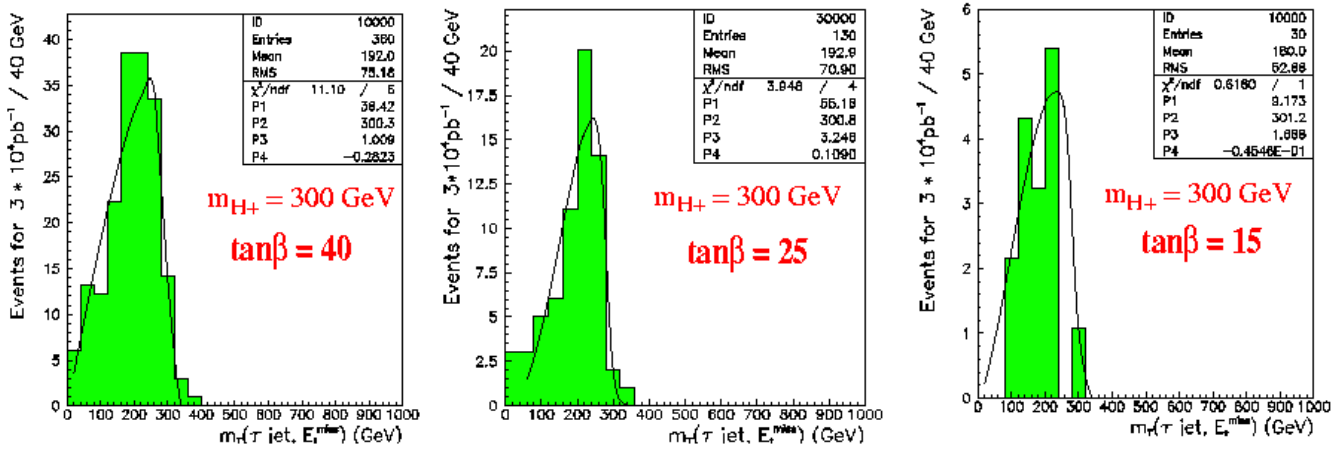
$\tan\beta = 40$



H^+ mass determination from $m_T(\tau\text{-jet}, E_t^{miss})$

A 4-parameter fit of the form: $dN / dm_T \sim \int D(z)\, dz / \sqrt{M_{fit}^2 - m_T^2}$

with $D(z) \sim z^{\alpha} (1 - z)^{\beta}$, $z = p_t^{\tau\text{-jet}} / p_t^{\tau}$

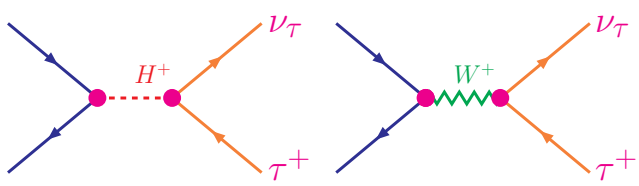


$M_{fit} = 300.3 + 0.4$ GeV $\quad M_{fit} = 300.8 + 1.2$ GeV $\quad M_{fit} = 301.2 + 4.0$ GeV

• charged Higgs can be produced in s-channel process due to annihilation of the light quarks

$$q\bar{q}' \to H^{\pm}, \quad q(q') = d, u, s, c, b$$

with $H^{\pm} \to \tau\nu_{\tau}$



• cross section production, $\sigma(q\bar{q}' \to H^{\pm})$, has strong dependence on the light quark masses

$$\sigma(\bar{q}' \to H^{\pm}) \propto (m_u^2 \cot^2\beta + m_d^2 \tan^2\beta)$$

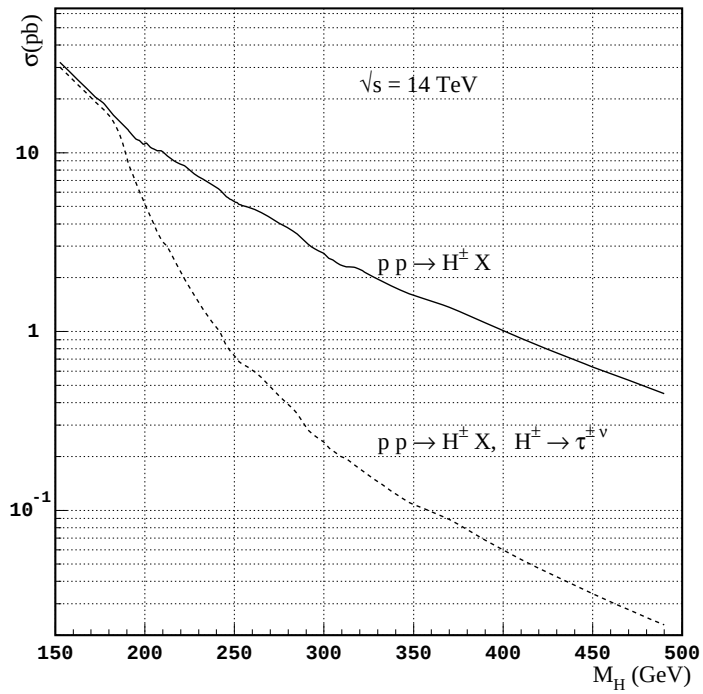
• RPP values for m_q are used

$$m_d = 9 \text{ MeV} \qquad m_s = 150 \text{ MeV} \qquad m_b = 4.8 \text{ GeV}$$
$$m_u = 5 \text{ MeV} \qquad m_c = 1.25 \text{ GeV}$$

• $M_H = 200 \div 400$ GeV and $\tan\beta = 50$

$$\sigma(pp \to H^{\pm} \to \tau\nu X) \approx 5 \text{ pb} \quad \text{at} \quad M_H = 200 \text{ GeV}$$

• cross section production (LO + NLO calculations)
for $\tan\beta = 50$



for $\tan\beta > 10$ and $M(H) > m_t$ one has
$\mathrm{B}(H^{\pm} \to \tau^{\pm}\nu) = const \Rightarrow \sigma(H^{\pm} \to \tau\nu) \propto \tan^2\beta$
for $\tan\beta > 10 \Rightarrow \tan\beta \propto \sqrt{N_S}$ for fixed $M(H)$

- most important background comes from

$$q\bar{q}' \to W^{\pm} \to \tau\nu, \quad \sigma(W) \approx 2.4 \times 10^4 \text{ pb}$$

- signal/background separation
  - ◇ explicitly one τ-jet, $E_{T\tau} > 50$ GeV $|\eta| < 2.0$ $R_{cone} = 0.4$, $r_E = 0.15$, only one charged prong with $E_{prong} > 10$ GeV, $(E+H)_{0.15}/(E+H)_{0.4} > 0.92$, $E_{0.15}/E_{0.4} > 0.92$, $H_{0.14}/E_{0.15} > 0.1$
  - ◇ $R_h = E_{prong}/E_\tau > 0.80$
  - ◇ no additional hadronic jets with $E_\top > 20$ GeV
  - ◇ $E_{Tmis} > 50$ GeV

$$M_\top = 2P_\top(J)E_{Tmis}(1 - \cos\phi_{\tau E_{Tmis}})$$

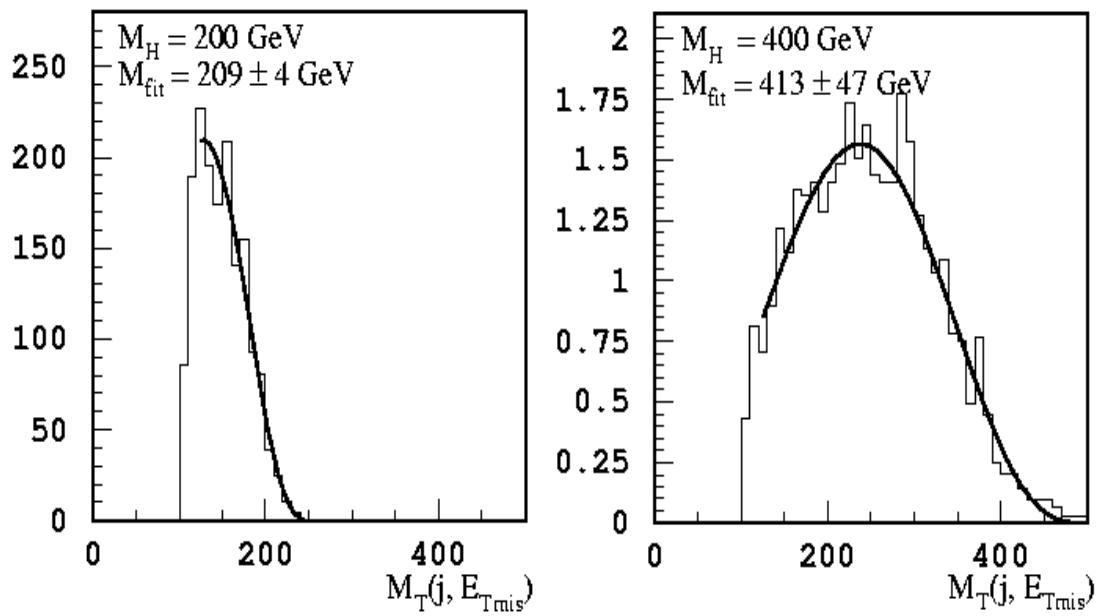
$M_\top \geq 100$ GeV, $\int \mathcal{L}dt = 30$ fb^{-1}

M_H, input	200	250	300	400	Bkg.
N_{ev}	1627	344	129	35	1756
$\frac{N_S}{\sqrt{N_S+N_B}}$	28	7.5	3.0	0.83	

large number of signal events ($\sim 10^2$) gives the possibility to determine M_H from a fit to $M_\top$-distribution with a function

$$F_0 \int D(z)dz\sqrt{M_{fit}^2 - M_\top^2}$$

where $D(Z)$ is the $\tau \rightarrow$ jet fragmentation function



and the background $M_\top$-distribution is parametrized by

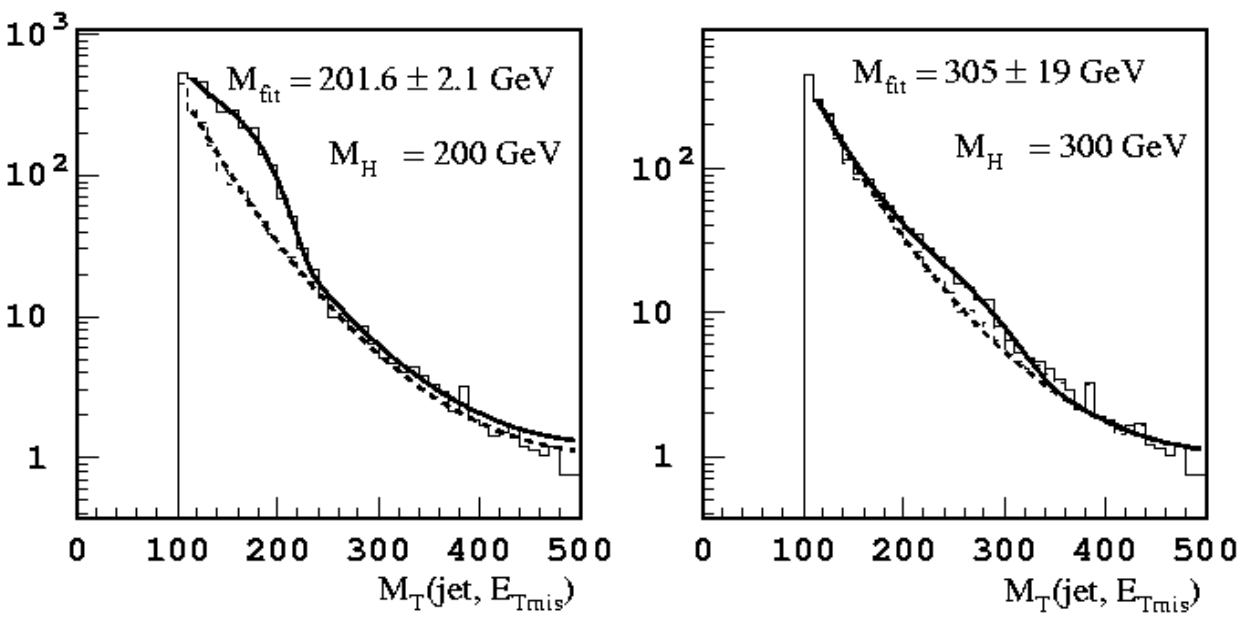
$$\exp(a_0 + a_1 M_\top + a_2 M_\top^\delta)$$

◇ $M(H)$ measurement

M_{fit} and the signal and background normalisations are considered as free parameters

fit results: $N_B(fit) = 1694$, while $N_B(gen) = 1756$

M_H	M_f	N_S^{gen}	N_S^{fit}	$\frac{N_S^{fit}}{\sqrt{N_B^{fit}+N_S^{fit}}}$
200	$202. \pm 2.1$	1627	1444	25.8
300	$305. \pm 20.$	128	115	2.7
400	$392. \pm 42.$	35	41	1.0
bkg.		1756	1694	



◇ $\tan\beta$ measurement

$\tan\beta$ can be obtained from the fit results, M^H_{fit} and N_S

$$\sigma(H^\pm) \propto \tan^2\beta \implies \tan\beta \propto \sqrt{N_S(fit)}$$

for $M(H) = 200$ GeV

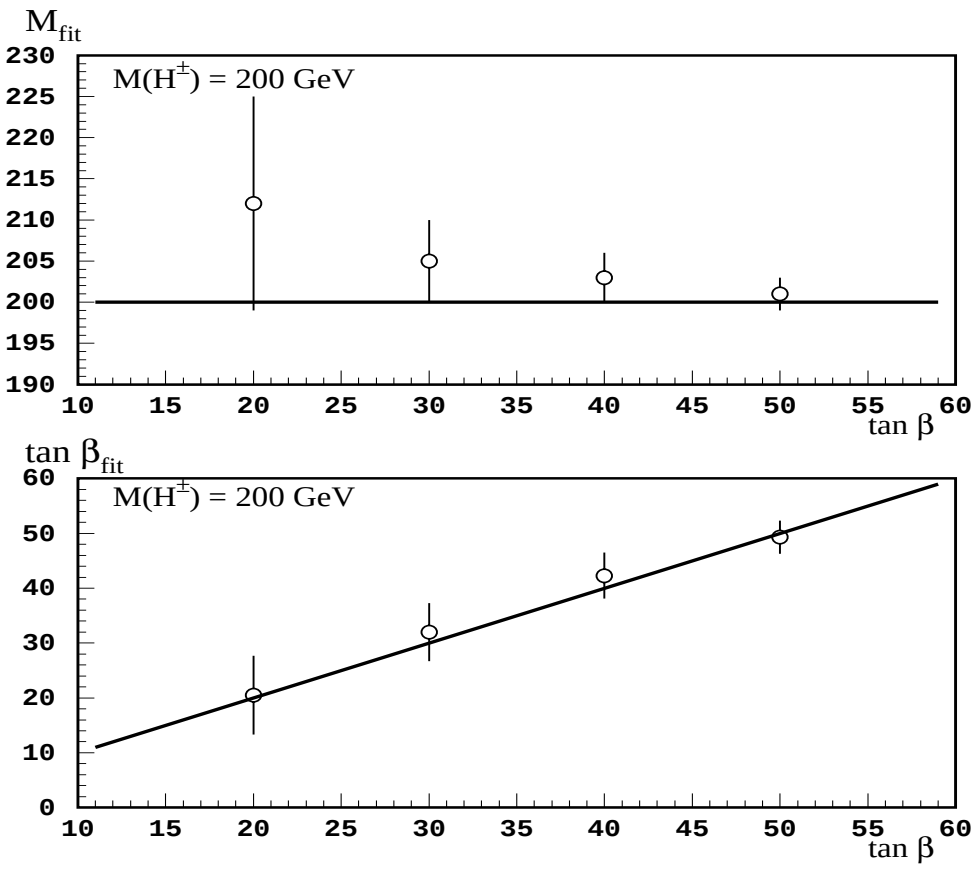
$\tan\beta$	50	40	30
M_{fit}	201 ± 2	203 ± 3	205 ± 5
$\tan\beta_{fit}$	48.3 ± 2.6	39.3 ± 4.1	31.3 ± 5.2

$\tan\beta$	20	15	
M_{fit}	212 ± 13	222 ± 28	
$\tan\beta_{fit}$	19.8 ± 7.6	16.2 ± 10.6	

expected measurement errors (statistical only)
for $M_H = 200$ GeV

$\delta M_H \leq 6\%$ for $\tan\beta > 15$

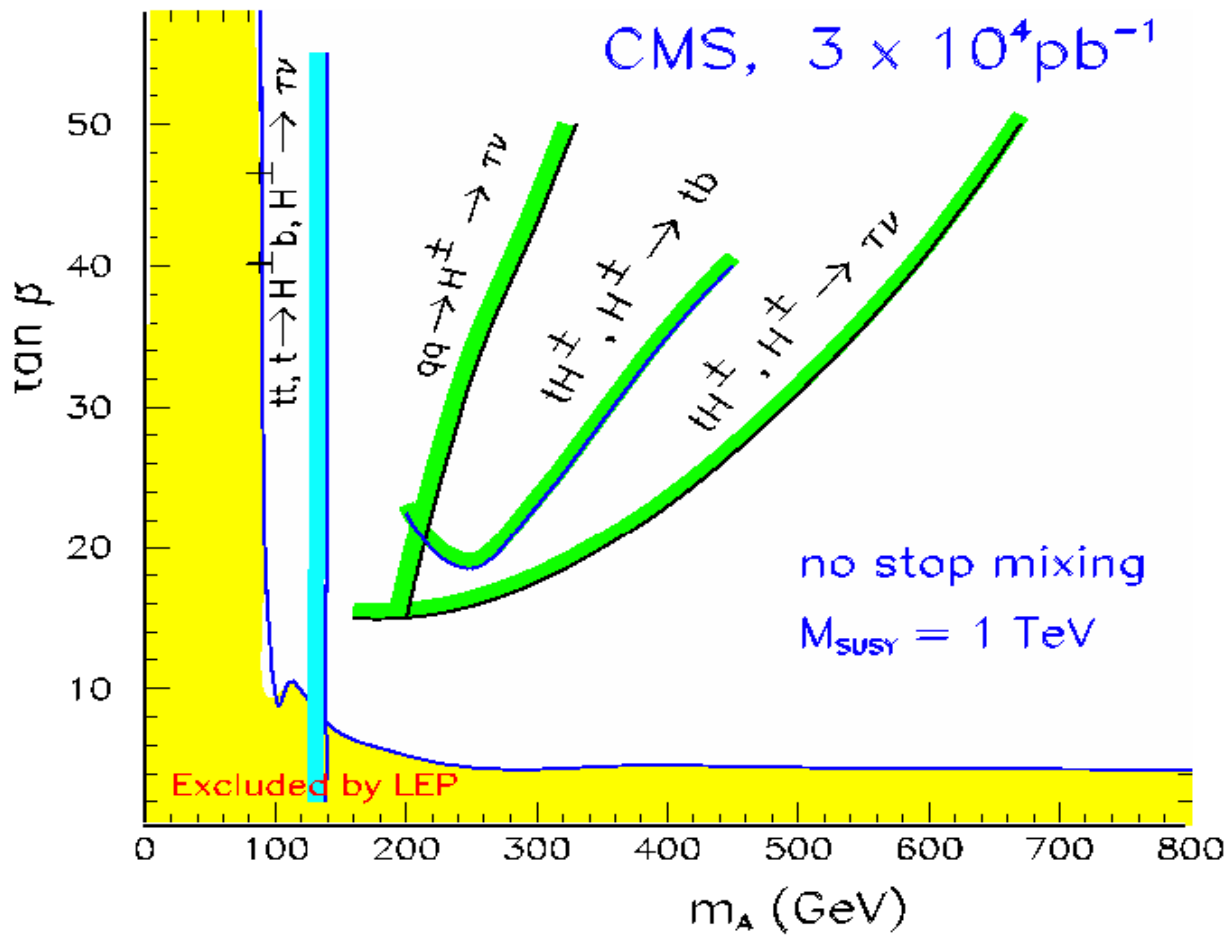
$\delta \tan\beta = (5 \div 65)\%$ for $\tan\beta 15\ div 50$



- expected discovery limit

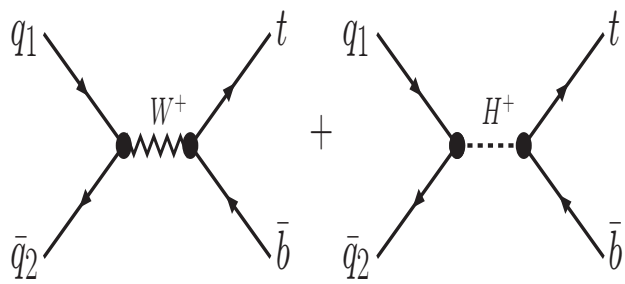
$$\frac{N_S}{\sqrt{N_S + N_B}} \geq 5$$

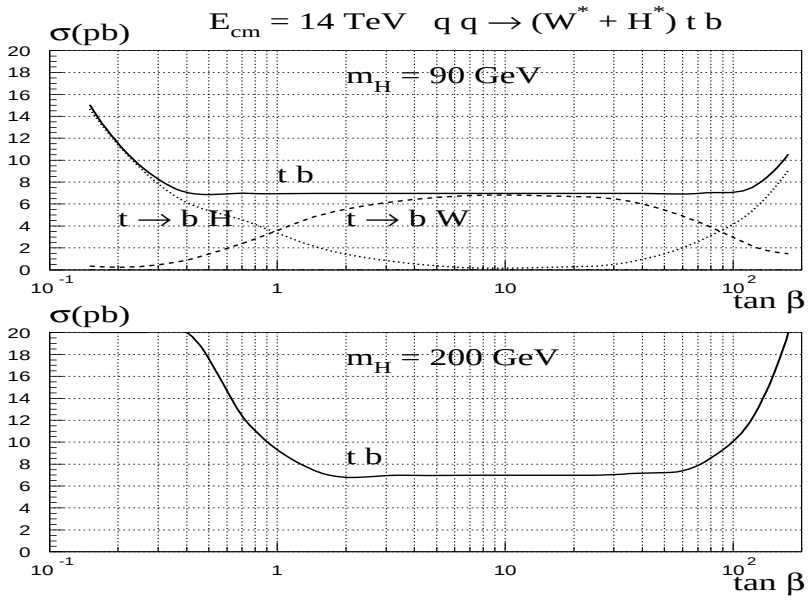
5σ–sigma discovery contours for charged Higgs in CMS



- charged Higgs contribution into $t\bar{b}$ production

$$q\bar{q}' \;\rightarrow\; H^*(W^*) \;\rightarrow\; t\bar{b}$$





$p_\top$ and η-distributions of top quark and its decay products resulted from W(SM) and $H^\pm$ exchange have similar shapes

Conclusions

- top quark production and decay processes could be investigated in CMS with high precision
- top mass could be measured with $\sim 0.7\%$ errors
- cross section for $t\bar{t}$ pair production could be measured with $\sim$ 10% accuracy
- CMS sensitivity for $|V_{tb}|$ is $\delta|V_{tb}| \sim (5-10)\%$
- top production would provide much better constraints on FCN top-gluon coupling, $\mathrm{B}(t \to qg) \sim 10^{-5}$
- searches for rare processes with top quark (decays $t \to q\gamma$, $t \to qZ$ and production) make possible to reach $\mathrm{B}(t \to q\gamma) \sim 2.5 \times 10^{-5}$ and $\mathrm{B}(t \to qZ) \sim 1.5 \times 10^{-4}$
- heavy charged Higgs could be discovered in CMS in a large part of the parameter space
  (for $\tan\beta \geq 10$ and up to $M_H^+ \sim 500$ GeV
- largest reach and an almost background-free signal could be obtained with tH^+ production, $H^+ \to \tau\nu$, $\tau \to$ hadrons, $t \to qq'b$
- mass determination in the expected discovery range possible with
  $\leq 2\%$ precision for $gb \to tH$, $H \to \tau\nu$
  $\leq 6\%$ precision for $q\bar{q}' \to H \to \tau\nu$