Outline

- Charged Higgs in B decays;
- Experimental challenges;
- Results
  - leptonic decays - $B \rightarrow \tau \nu_{\tau}$;
  - semileptonic B - decays $B \rightarrow D^{(*)} \tau \nu_{\tau}$;
  - radiative $B \rightarrow X_s \gamma$ decays;
- Prospects;
- Summary.

**Charged Higgs 2010**
Uppsala, September 27-30

Maria Różańska, INP PAS, Poland
Charged Higgs occurs in well motivated extensions of the standard model.

Anticipating (or lacking) direct observation of $H^\pm$, we have to study its impact on flavour physics.

Beauty sector is an appropriate place for indirect searches of charged Higgs.

Large mass of $b$ quark

$\Rightarrow$ enhanced couplings to $H^\pm$

$\Rightarrow$ reliable theoretical predictions
Data samples

Luminosity at B factories

(fb⁻¹)

> 1 ab⁻¹
On resonance:
Y(5S): 121 fb⁻¹
Y(4S): 711 fb⁻¹
Y(3S): 3 fb⁻¹
Y(2S): 24 fb⁻¹
Y(1S): 6 fb⁻¹
Off reson./scan:
~ 100 fb⁻¹

~ 550 fb⁻¹
On resonance:
Y(4S): 433 fb⁻¹
Y(3S): 30 fb⁻¹
Y(2S): 14 fb⁻¹
Off resonance:
~ 54 fb⁻¹

⇒ 14 M Bₛ
⇒ 770 M BB
⇒ 470 M BB
Charged Higgs in B decays

- Look for sensitive and theoretically clean modes

### Leptonic

- \( B \rightarrow \tau \nu_\tau \)

### Semileptonic

- \( B \rightarrow D^{(*)} \tau \nu_\tau \)

### Inclusive Radiative

- \( B \rightarrow X_s \gamma \)

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- Inclusive final states, or multiple neutrinos - lack of kinematic constraints which can be used for signal identification and background suppression

⇒ Need clean experimental environment of B-factories
**Experimental techniques**

B→τν → lνν, πν...

B→Dτν → lνν, πν...

the only detectable daughters of signal decay

At B-factories: e^+e^-→γ(4S)→ BB

**signature:** e + nothing

B\textsubscript{tag} reconstruction ⇒

- BB event
- rest of the event comes from B\textsubscript{sig}
- kinematical constraints on B\textsubscript{sig}

**效率 < 1%** ⇒ need compromise between efficiency and purity

details depend on analysis channel
From inclusive semileptonic $B$ decays
HFAG ICHEP08

$|V_{ub}| = (4.32 \pm 0.16 \pm 0.29) \times 10^{-3}$

$f_B = 190 \pm 13$ MeV,

$BF(B \rightarrow l\nu)_{SM} = \frac{G_F^2 m_B}{8\pi} \left( 1 - \frac{m_l^2}{m_B^2} \right)^2 f_B^2 |V_{ub}|^2 \tau_B$

the most accessible leptonic $B$ decay

$BF(B \rightarrow \tau\nu)_{SM} = [1.20 \pm 0.25] \times 10^{-4}$

W. S. Hou, PR D 48, 2342 (1993)

$BF(B^+ \rightarrow l^+\nu_l) = BF(B^+ \rightarrow l^+\nu_l)_{SM} \times r_H$

TYPE II 2HDM

$r_H = \left( 1 - \frac{m_B^2 \tan^2 \beta}{m_{H^\pm}^2} \right)^2$

MSSM

$r_H = \left( 1 - \frac{m_B^2 \tan^2 \beta}{m_{H^\pm}^2} \frac{1}{1 + \varepsilon_0 \tan \beta} \right)^2$

e.g. G. Isidori, arXiv:07010.5377

SUSY loop corr.

possible large $BF$ effects

$\varepsilon_0 \frac{m_{H^\pm}^2}{100 \text{GeV}}$

$0.01$

$0.0$

$+0.01$
**B → τντ - analysis strategy**

**statistically independent samples**

**Hadronic tags:** \( B_{\text{tag}} \rightarrow D(\ast)X \) (\( X = \pi/\rho/D_s \) etc...)

- **Efficiency:** 0.16%
- **Purity:** ~27%

**Semileptonic tags:** \( B_{\text{tag}} \rightarrow D(\ast)\nu \) etc.

\[
M_{bc} = \sqrt{E_{\text{beam}}^2 - (\sum \vec{p}_i)^2}
\]

- **B**\(_{\text{sig}}\) – select \( \tau \) daughter candidates
  - require no other tracks/clusters remain in the event;
  - \( E_{\text{ECL}}(E_{\text{extra}}) \) - residual energy in the calorimeter

\[
\cos \theta_{BD(\ast)\nu} = \frac{2E_{\text{beam}}E_{D(\ast)\nu} - m_B^2 - M_{D(\ast)\nu}^2}{2p_B p_{D(\ast)\nu}}
\]
**B → τντ - results**

**hadronic tags**

**449M B̅B**

\[
BF(B \to τν) = [1.79^{+0.56}_{-0.49}(stat) +0.46(syst)] \times 10^{-4}
\]

**first evidence** 3.5\(σ\)


**significance**

**semileptonic tags**

**NEW 657M B̅B**

\[N_{sig} = 143^{+36}_{-35}\]

3.6\(σ\)

Belle Collab., arXiv: 1006.4201 submitted to PRD-RC

**hadronic tags**

**NEW, preliminary**

**468 M B̅B**

\[
BF(B \to τν) = [1.80^{+0.57}_{-0.54}(stat) \pm 0.26] \times 10^{-4}
\]

3.3\(σ\)

BaBar Collab., arXiv: 1008.0104

**semileptonic tags**

**NEW, preliminary**

\[
BF(B \to τν) = [1.54^{+0.38}_{-0.37}(stat) +0.29(syst)] \times 10^{-4}
\]

3.6\(σ\)

Belle Collab., arXiv: 1006.4201 submitted to PRD-RC

**semileptonic tags**

\[
BF(B \to τν) = [1.7 \pm 0.8(stat) \pm 0.2] \times 10^{-4}
\]

2.3\(σ\)

BaBar Collab., PRD 81, 051101 (2010)
Results consistent within uncertainties, but all above the SM prediction

$r_H = 1.37\pm0.39$

$\bf{1} \quad$ HFAG, [1]

$\bf{2} \quad$ $|V_{ub}| = (4.32\pm0.16\pm0.29)\times10^{-3}$

$|f_B| = 190\pm13\text{MeV}$

HFAG ICHEP08

HPQCD arXiv:0902.1815
Alternative approach (within SM): extract $BF(B \rightarrow \tau \nu_\tau)$ from CKM fit using other flavour observables

$BF(B^+ \rightarrow \tau^+ \nu_\tau)$

$BF(B \rightarrow \tau \nu)$ (within SM) = [0.763$^{+0.114}_{-0.061}$] $\times 10^{-4}$

CKM fitter, S. T'Jampens @ ICHEP2010

$BF(B \rightarrow \tau \nu)$ (within UT) = [0.805$^{+0.071}$] $\times 10^{-4}$

UTfit, C. Tarantino @ ICHEP2010

>2.5$\sigma$ difference
Example of constraints within TYPE II 2HDM

\[ r_H = 1.37 \pm 0.39 \text{ (LQCD)} \]

\[ r_H = 2.14^{+0.55}_{-0.48} \text{ (CKMfitter)} \]

\[ r_H = 2.04 \pm 0.46 \text{ (UTfit)} \]

Exclude different \( \tan \beta / m_{H^\pm} \) regions

Higgs contribution = double SM contribution
different theory uncertainties:

- free from $f_B$, depends on the $B \to D^{(*)}\tau\nu_\tau$ formfactors;
- $|V_{cb}|$ better known than $|V_{ub}|$,
- $|V_{cb}|$ and large part of theoretical and experimental uncertainties cancel in the ratio

\[ R = \frac{BF(B \to D\tau\nu)}{BF(B \to D\bar{\nu})} \quad R_{SM} = 0.302 \pm 0.015 \]

- 3-body decay $\Rightarrow$ more observables,
  e.g. $q^2$-distribution, $\tau$ polarization, $D^*$ polarization,…

- universality between:  
  H-b-t (direct production at LHC),
  H-b-u ($B \to \tau\nu_\tau$)
  H-b-c ($B \to D\tau\nu_\tau$)  

\( B \to D^{(*)}\tau\nu_\tau \) - sensitivity to \( H^\pm \)

\[
\begin{align*}
B^+ & \to \tau^+\nu_\tau \\
B & \to \bar{D}\tau^+\nu_\tau
\end{align*}
\]

\[
\frac{r_H}{R_{SM}} = 1 + 1.5 \text{Re}(C_{NP}^\tau) + 1.1 |C_{NP}^\tau|^2 \\
C_{NP}^\tau = -\frac{m_b m_\tau}{m_{H^\pm}^2} \frac{\tan^2 \beta}{1 + \varepsilon_0 \tan \beta}
\]

\[
R = \frac{BF(B \to D\tau\nu)}{BF(B \to D\nu\tau)}
\]

B → Dτ⁺ντ more sensitive in the "B → τ⁺ντ pathological" region.

Examples of other observables:

**longitudinal \( \tau \) polarization in \( B \rightarrow \bar{D} \tau^+\nu_\tau \)**

\[ \tan \beta = 50 \]
\[ \tan \beta = 20 \]
\[ \tan \beta = 10 \]

\[ M_H \text{ (GeV)} \]


**longitudinal \( \tau \) polarization in \( B \rightarrow \bar{D}^* \tau^+\nu_\tau \)**

\[ \tan \beta = 50 \]
\[ \tan \beta = 20 \]
\[ \tan \beta = 10 \]

\[ M_H \text{ (GeV)} \]

**\( \theta = \text{angle between } \pi \text{ (from } \tau \rightarrow \pi \nu) \text{ and } D \) in \( B \) rest frame**

\[ E_D = 2 \text{ GeV}, \quad E_\pi = 1 \text{ GeV} \]


**transverse \( \tau \) polarization**

\[ p_\perp^\tau \sim \vec{S}_\tau \cdot \vec{p}_\tau \times \vec{p}_D \]

CP-odd variable, vanishes in the SM

e.g. R. Garisto, PRD.\textbf{51},1107(1995)
hadronic tags; use leptonic $\tau$ decays: $\tau \rightarrow l\nu$, $l=e,\mu$

extract signal

- simultaneous fit $\text{BaBar}:(M_{\text{miss}}^2, \rho^*)$, $\text{Belle}:(M_{\text{mis}}^2, E_{\text{ECL}})$ to 4 signal and light lepton modes
- normalization to $D l \nu$ and $D^* l \nu$ with the same tag

$B \rightarrow D^{(*)}\tau\nu_\tau$ - results

232 M $\bar{B}B$

657M $\bar{B}B$ preliminary

$B^+ \rightarrow D^0\tau^+\nu_\tau$

$B^0 \rightarrow D^-\tau^+\nu_\tau$

$BF(\%)$  $R$  $\sigma$

$B^+ \rightarrow D^0\tau^+\nu_\tau$  2.25 ± 0.48 ± 0.22 ± 0.17  0.35 ± 0.07 ± 0.03  5.3$

$B^0 \rightarrow D^-\tau^+\nu_\tau$  1.11 ± 0.51 ± 0.04 ± 0.04  0.21 ± 0.09 ± 0.01  2.7$

$B^+ \rightarrow D^{0}\tau^+\nu_\tau$  0.67 ± 0.37 ± 0.11 ± 0.07  0.31 ± 0.17 ± 0.05  1.8$

$B^0 \rightarrow D^{-}\tau^+\nu_\tau$  1.04 ± 0.35 ± 0.15 ± 0.10  0.49 ± 0.16 ± 0.07  3.3$

projections at $M_{\text{miss}}^2 > 1 \text{GeV}^2$
"inclusive" tags – take the advantage of clean signature from $D^{(*)}$ in $B_{\text{sig}}$

- select signal candidate
  - use decay chains that combine high reconstruction efficiency with a low background level

- reconstruct $B_{\text{tag}}$ "inclusively" from remaining particles at large $M_{\text{mis}}$ flat $M_{\text{tag}}$ distribution for most background components

- extract signal yield from $M_{\text{tag}}$

**$B \rightarrow D^{(*)}\tau\nu\tau$ - results**

$\tau$ decay modes

\[ \tau^+ \rightarrow e^+\nu\nu, \mu^+\nu\nu, \pi^+\nu \]

$D^{(*)}$ decay modes

\[
\begin{align*}
D^0 & \rightarrow K^+\pi, \ K^+\pi\pi^0 \\
\bar{D}^* & \rightarrow \bar{D}^0\pi \\
D_0 & \rightarrow K^+\pi, \ K^+\pi\pi^0 \\
\bar{D}^* & \rightarrow \bar{D}^0\pi \\
D_* & \rightarrow D_0\pi, \ D_0\pi\pi^0 \\
\bar{D}^{*0} & \rightarrow \bar{D}^0\pi, \ \bar{D}^0\pi\pi^0 \\
\bar{D}^{*+} & \rightarrow \bar{D}^0\pi, \ \bar{D}^0\pi\pi^0 \\
\bar{D}^{*-} & \rightarrow \bar{D}^0\pi, \ \bar{D}^0\pi\pi^0 \\
\end{align*}
\]

$M_{\text{tag}} = \sqrt{E_{\text{beam}}^2 - \left(\sum_{i=\text{sig}} p_i\right)^2}$

$BF (B^0 \rightarrow D^*_\tau^+\nu\tau) = (2.02^{+0.40}_{-0.37} \pm 0.37) \times 10^{-2}$


first observation of exclusive B decay with $b \rightarrow c\tau\nu\tau$ transition
NEW 657 M \( \bar{B}B \) \( B^+ \to D^{(*)+}\nu_\tau \) - results

**"inclusive" tags:**

- simultaneous extraction of signals in \( B^+ \to \bar{D}^{*0+}\nu_\tau \) and \( B^+ \to \bar{D}^0+\nu_\tau \) modes;
- signal extraction from fit to 2-dim distributions in \( M_{\text{tag}} \) and \( P_{D0} \)
  
  \( (P_{D0} = \text{momentum of } \bar{D}^0 \text{ in } \gamma(4S) \text{ rest frame}) \)

**Results**

\[ BF(B^+ \to \bar{D}^{*0+}\nu_\tau) = (2.12^{+0.28}_{-0.27} \pm 0.29) \times 10^{-2} \quad 8.1\sigma \]

\[ BF(B^+ \to \bar{D}^0+\nu_\tau) = (0.77^{+0.22}_{-0.22} \pm 0.12) \times 10^{-2} \quad 3.5\sigma \]

Belle Collab., arXiv:1005.2302[hep-ex],
to be published in PRD
B → D^{(*)}\tau\nu_\tau - results

\[ BF(B \rightarrow \bar{D}^{(*)}\tau^+\nu_\tau) \]

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Example of H^± constraints


\[ R = 0.40 \pm 0.08 \]

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Results consistent within uncertainties, but most of them above the SM predictions
Inclusive B→X_{sγ}

FCNC process in SM occurs via loop diagram

new physics can enter with size comparable to SM contributions

 BF-enhancement due to the amplitudes with H^{±} depends on m_{H^{±}} but is almost independent of tanβ
more NP processes complicate the interpretation...

inclusive processes: more reliable theoretical calculations

NNLO SM: $BF_{SM} = (3.15 ± 0.24) \times 10^{-4}$ (for $E_γ > 1.6 \text{ GeV}$)

M. Misiak et al., PRL 98,022002(2007)
more difficult experimentally

The lower $E_γ$ threshold the smaller theory uncertainties but the larger background in measurement.
Several experimental approaches:

- untagged – only a high energy photon measured
- lepton tag – require high energy lepton $1.26 \text{ GeV} < E_l < 2.20 \text{ GeV}$
- reconstruct $B_{\text{tag}}$
- sum of exclusive final states of signal modes ($B \rightarrow K \gamma$, $B \rightarrow K^* \gamma$...)

657 $\bar{M} \bar{B}$ untagged + lepton tag

Bkg. subtracted $\gamma$ spectrum for combined samples

$BF = (3.45 \pm 0.15 \pm 0.40) \times 10^{-4}$ for $E_\gamma > 1.7 \text{ GeV}$

Most precise $BF(B \rightarrow X_s \gamma)$ measurement; lowest $E_\gamma$ threshold

Belle Collab., PRL 103, 241801 (2009)
Inclusive $B \to X_s \gamma$

HFAG $E_\gamma > 1.6$ GeV

Constraints on type-II 2HDM

HFAG 2010 $(3.55 \pm 0.24 \pm 0.09) \times 10^{-4}$

SM $(3.15 \pm 0.23) \times 10^{-4}$

$M_{H^+} > 295$ GeV/c$^2$ @ 95% C.L. for all $\tan \beta$
Prospects

• Finalizing results with full data samples (most of the results shown today do not use full data sets)
  • Belle – data reprocessed with improved tracking efficiency;
    – improved hadronic tag efficiency \Rightarrow \text{gain factor 2 in effective luminosity}

• Super B factories: SuperB (in Italy) and SuperKEKB/BelleII in (KEK – Japan)
  • KEKB upgrade has been approved, construction started;
    – 50 ab\(^{-1}\) by 2020-2021
Prospects

• explore polarization observables in $B\to D\tau\nu$
  
  - limited information on $\tau$ kinematics, however several variables sensitive to $\tau$ polarization are accessible, especially for semileptonic $\tau\to h\nu_\tau$ decays;
  
  - the most sensitive channel is $B\to D\tau\nu$, $\tau\to\pi\nu$;
  
  - the main issue is background, mainly from $B\to D^*\tau\nu$ and $\tau\to\rho\nu$;

• $B\to l\nu$
  
  - In TYPE II 2HDM or MSSM $H^\pm$ has the same effect in all leptonic modes:
    \[ BF(B^+\to l^+\nu_l)_{2HDM} = BF(B^+\to l^+\nu_l)_{SM} \times r_H \]
  
  - at one loop level, lepton flavour violation effects (LFV) ($B\to l\nu_l$, $l\neq l'$)
    
    can affect the ratio: $R_B^{l/\tau} = BF(B^+\to l^+\nu_l)/BF(B^+\to \tau^+\nu_\tau)$
    e.g. G. Isidori and P. Paradisi, hep-ph/0605012
  
  - uncertainties from $f_B$ and $|V_{ub}|$ cancel in the ratio:
  
  - current experimental limits on $B\to \mu\nu_\mu$ are a factor 2–3 above SM.
- constraints on the charged Higgs are currently dominated by indirect measurements;

- studying charged Higgs effects in flavour physics will remain important also after direct discovery of $H^\pm$;

- optimal observables have to compromise between theory and experiment uncertainties;

- new results with full data samples collected at B-factories coming soon;

- looking forward to super B factories…. 
backups
Inclusive $B \rightarrow X_s \gamma$

Belle, PRL 103, 241801 (2009)

untagged

lepton tag

Efficiency corrected and averaged
Unblinded spectrum after bg. subtraction

- Continuum Control Region:
  OnPeak  On – Off Data:
  1825  => -100 ± 138 events

- B̅B̅ Control Region:
  OnPeak  On – Off Data – BB MC
  3.6×10^4  => 1252 ± 272 ± 841
  (1.4σ IF no signal)
  a tail of signal ~100-400 (models)
  => 0.9-1.3σ

- Control region checks show good understanding of backgrounds.
- \( A_{CP} \) is insensitive to photon energy cut, statistical optimization
  => (2.1-2.8) GeV for the \( A_{CP} \).