Indirect charged Higgs searches at B factories

Outline

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

Charged Higgs 2010
Uppsala, September 27-30

Maria Różańska, INP PAS, Poland

Charged Higgs in B decays

- 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.

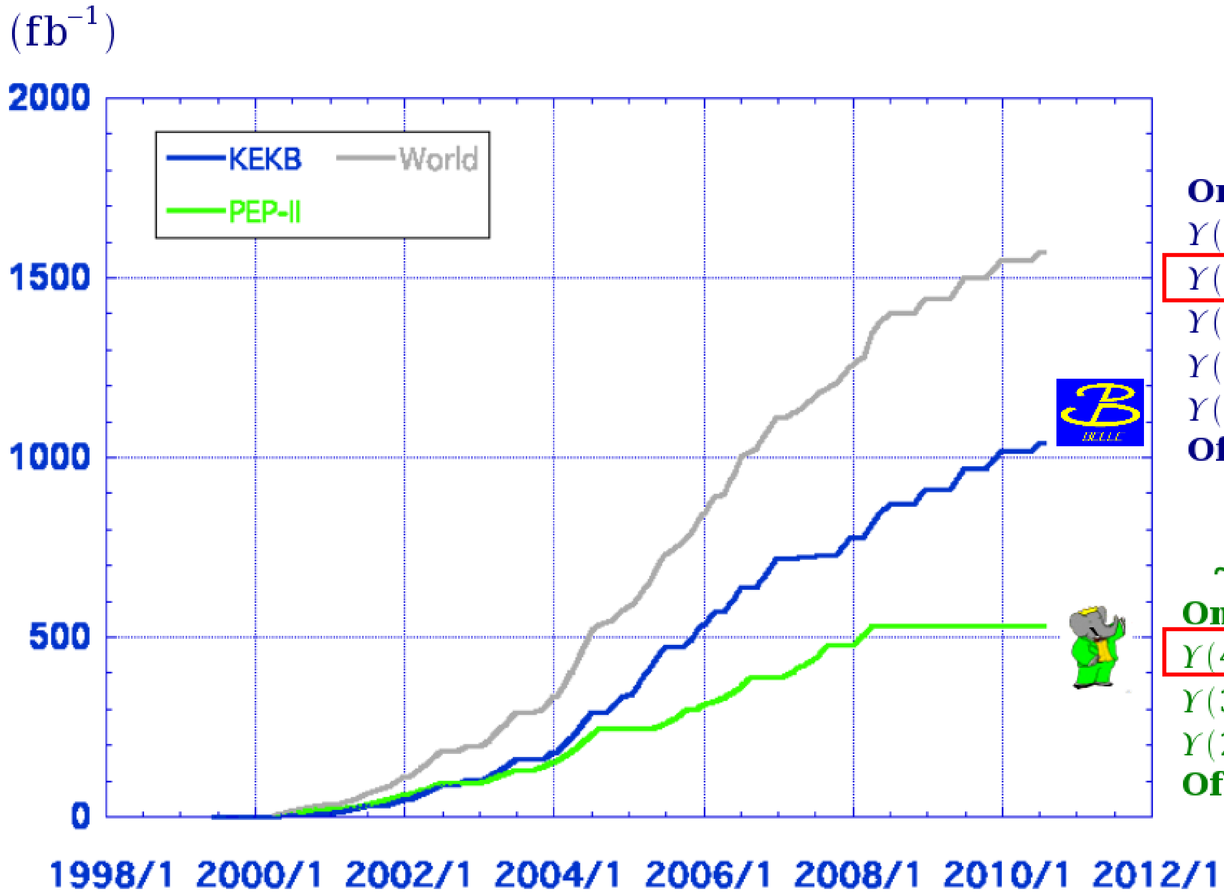
large mass of b quark

$\Rightarrow$ enchanced couplings to $H^{\pm}$

$\Rightarrow$ realible theoretical predictions

Data samples

Luminosity at B factories



$> 1\ ab^{-1}$

On resonance:

$\Upsilon(5S)$: 121 fb^{-1} $\Rightarrow$ 14 M B_s

$\Upsilon(4S)$: 711 fb^{-1} $\Rightarrow$ **770 M $B\bar{B}$**

$\Upsilon(3S)$: 3 fb^{-1}

$\Upsilon(2S)$: 24 fb^{-1}

$\Upsilon(1S)$: 6 fb^{-1}

Off reson./scan:

$\sim$ 100 fb^{-1}

$\sim$ 550 fb^{-1}

On resonance:

$\Upsilon(4S)$: 433 fb^{-1} $\Rightarrow$ **470 M $B\bar{B}$**

$\Upsilon(3S)$: 30 fb^{-1}

$\Upsilon(2S)$: 14 fb^{-1}

Off resonance:

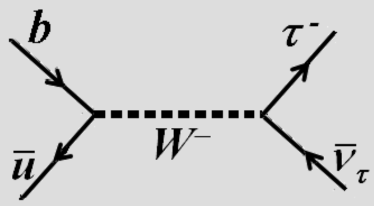
$\sim$ 54 fb^{-1}

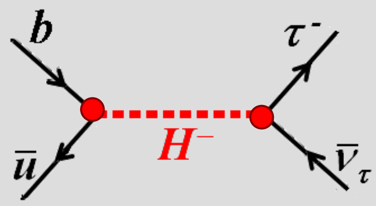
Charged Higgs in B decays

❖ look for sensitive and theoretically clean modes

leptonic

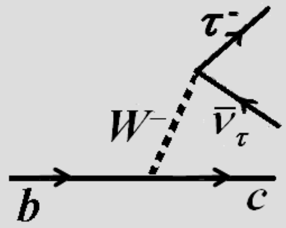
- $B \to \tau \nu_\tau$

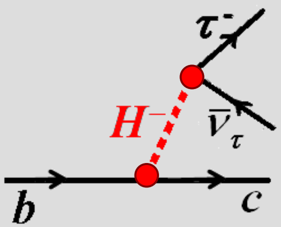




semileptonic

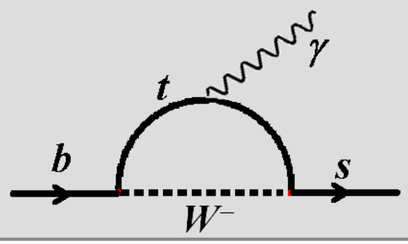
- $B \to D^{(*)} \tau \nu_\tau$

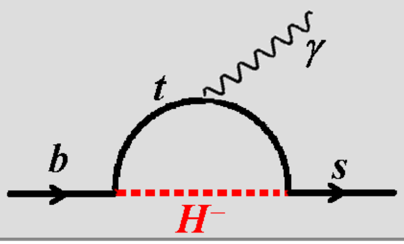




inclusive radiative

- $B \to X_s \gamma$





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

⇒ need clean experimental enviornment of B-factories

Experimental techniques

$B \to \tau\nu$
$\quad \hookrightarrow l\nu\nu,\ \pi\nu \ldots$

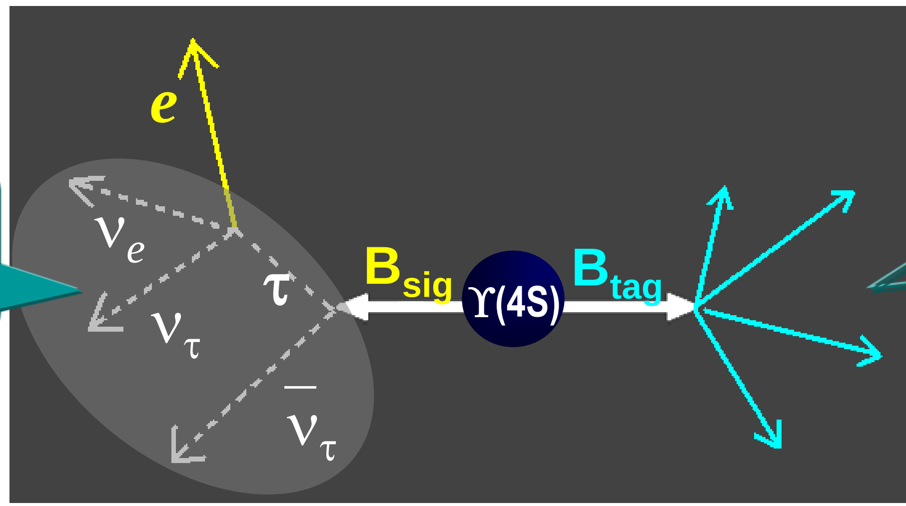
$B \to D\tau\nu$
$\quad \hookrightarrow l\nu\nu,\ \pi\nu \ldots$
$\quad \hookrightarrow K\pi,\ K\pi\pi \ldots$

the only detectable daughters of signal decay

at B-factories:
$e^+e^- \to \Upsilon(4S) \to \bar{B}B$

e.g. $B \to \tau\nu_\tau$
$\tau \to e\nu_e\nu_\tau$

signature:
e* + *nothing



reconstruct decay of non-signal B (B_{tag})

B_{tag} reconstruction ⇒

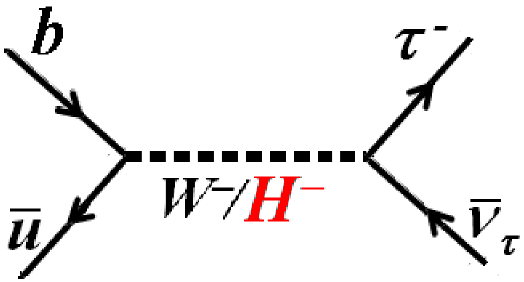
- ☺ $\bar{B}B$ event
- ☺ rest of the event comes from B_{sig}
- ☺ kinematical constraints on B_{sig}

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

details depend on analysis channel

$B \to \tau\nu_\tau$

SM: W-mediated annihilation



$$BF(B \to l\nu)_{SM} = \frac{G_F^2 m_B}{8\pi} m_l^2 (1 - \frac{m_l^2}{m_B^2})^2 f_B^2 |V_{ub}|^2 \tau_B$$ *the most accessible leptonic B decay*

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

$|V_{ub}| = (4.32 \pm 0.16 \pm 0.29) \times 10^{-3}$ From inclusive semileptonic B decays HFAG ICHEP08

$f_B = 190 \pm 13$MeV, From LQCD HPQCD arXiv:0902.1815

Sensitive to charged Higgs:

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

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

TYPE II 2HDM

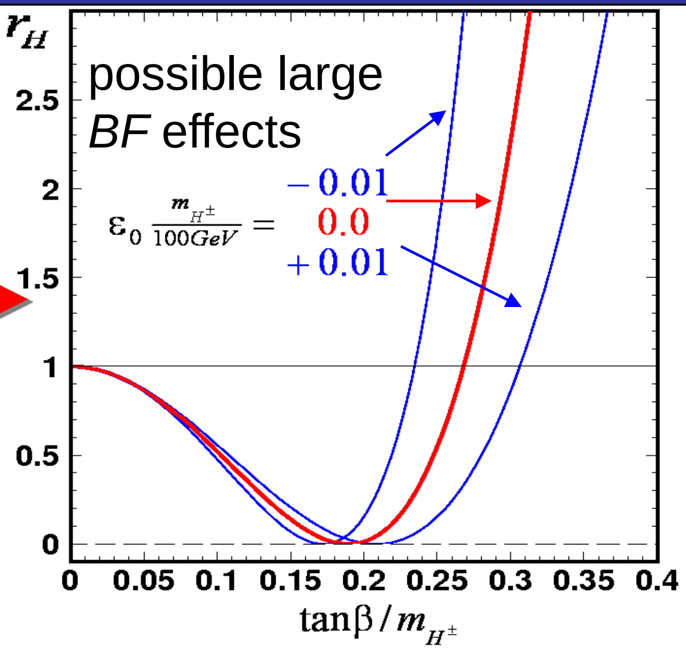
$$r_H = (1 - \frac{m_B^2 \tan^2\beta}{m_{H^\pm}^2})^2$$

MSSM

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

e.g. G. Isidori, arXiv:07010.5377

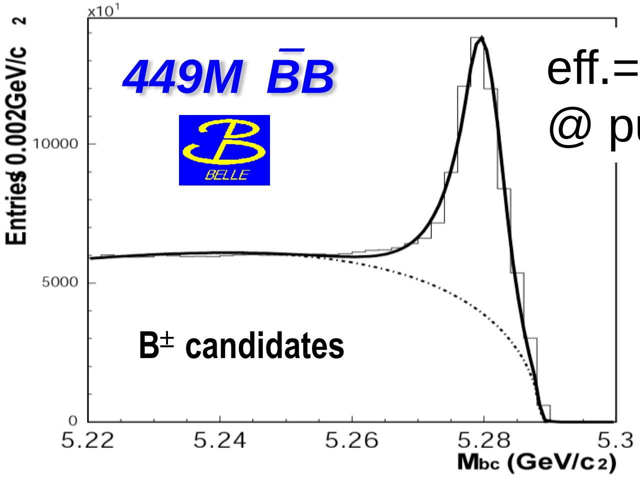
SUSY loop corr.



$B\to\tau\nu_\tau$ - analysis strategy

statistically independent samples

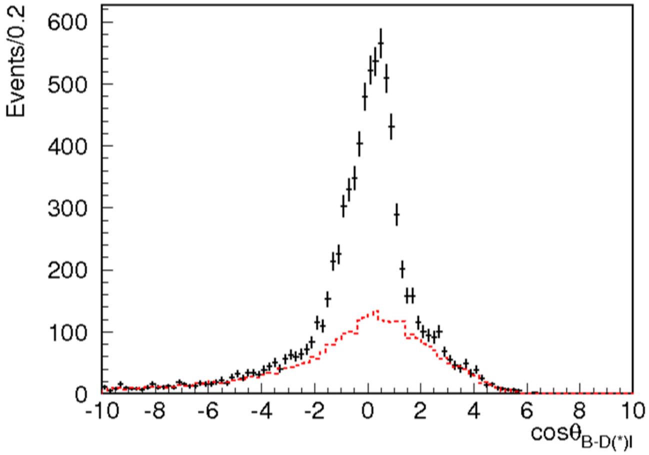
hadronic tags: $B_{tag}\to D^{(*)}X$ ($X=\pi/\rho/D_s$ etc…)



eff.= 0.16%
@ purity ~27%

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

semileptonic tags: $B_{tag}\to D^{(*)}l\nu_l$ etc

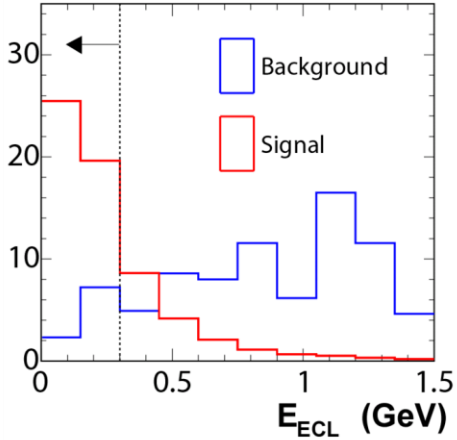


$$\cos\theta_{BD^{(*)}l}=\frac{2E_{beam}E_{D^{(*)}l}-m_B^2-M_{D^{(*)}l}^2}{2p_Bp_{D^{(*)}l}}$$

B_{sig} – select τ daughter candidates

– require no other tracks/clusters remain in the event;

$\Rightarrow E_{ECL}(E_{extra})$ - residual energy in the calorimeter



$B \to \tau\nu_\tau$ - results

hadronic tags

449M $B\bar{B}$

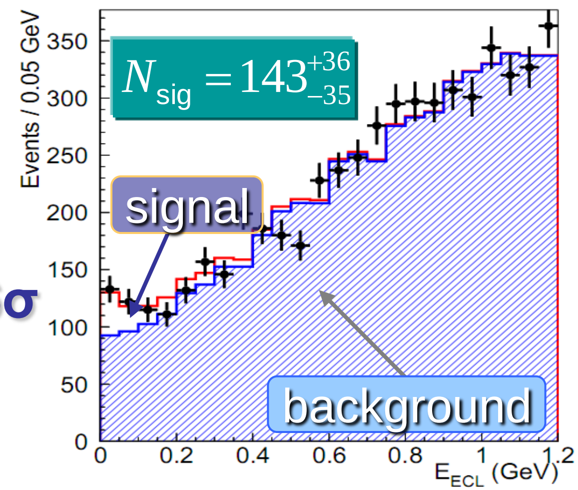
$$BF(B \to \tau\nu) = [\mathbf{1.79}^{+0.56}_{-0.49}(stat)^{+0.46}_{-0.51}(syst)] \times 10^{-4}$$

first evidence **3.5σ** ← significance

Belle Collab., PRL **97**, 251802 (2006)

semileptonic tags

NEW 657M $B\bar{B}$



3.6σ

$$BF(B \to \tau\nu) = [\mathbf{1.54}^{+0.38}_{-0.37}(stat)^{+0.29}_{-0.31}(syst)] \times 10^{-4}$$

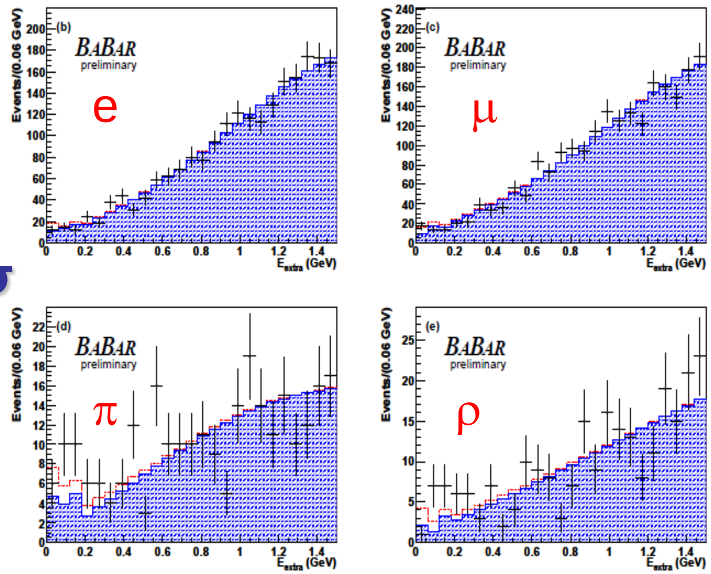
Belle Collab., arXiv: 1006.4201 submitted to PRD-RC

hadronic tags

NEW, *preliminary*

468 M $B\bar{B}$

3.3σ



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

BaBar Collab., arXiv: 1008.0104

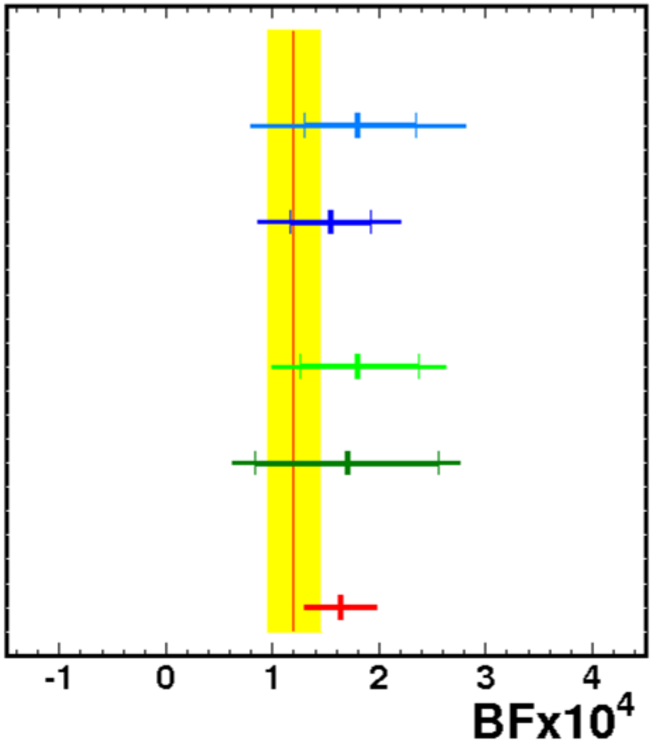
semileptonic tags

$$BF(B \to \tau\nu) = [\mathbf{1.7} \pm \mathbf{0.8}(stat) \pm 0.2] \times 10^{-4}$$ **2.3σ**

BaBar Collab., PRD **81**, 051101 (2010)

$B \to \tau\nu_\tau$ - summary of BF's

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



stat. syst.

$[\mathbf{1.79}^{+0.56}_{-0.49}(stat)^{+0.46}_{-0.51}(syst)]\times10^{-4}$ — hadronic tags

$[\mathbf{1.54}^{+0.38}_{-0.37}(stat)^{+0.35}_{-0.37}(syst)]\times10^{-4}$ — semileptonic tags

BELLE

$[\mathbf{1.80}^{+0.57}_{-0.54}(stat)\pm0.26(syst)]\times10^{-4}$ — hadronic tags

$[\mathbf{1.7}\pm\mathbf{0.8}(stat)\pm0.2(syst)]\times10^{-4}$ — semileptonic tags

$[\mathbf{1.64}\pm\mathbf{0}.34]\times10^{-4}$

HFAG
Aug. 2010

average[1]

Standard Model[2]

Results consistent within uncertainties, but all above the SM prediction

r_H = 1.37±0.39

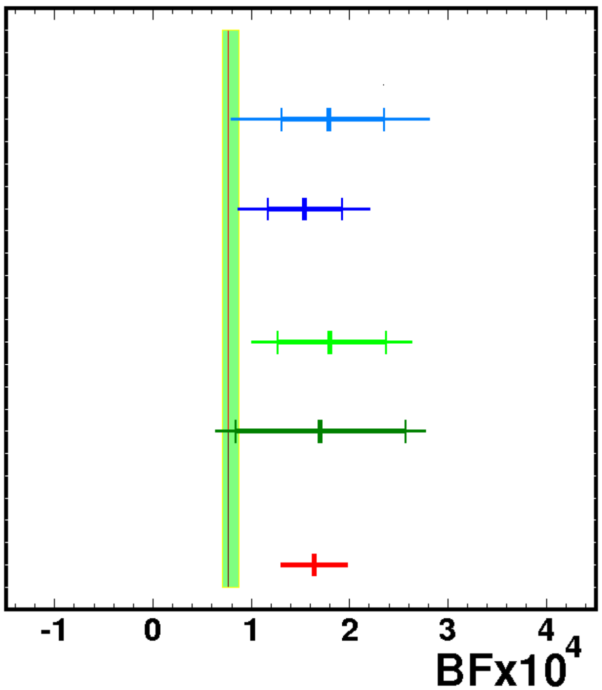
[1] HFAG, http://www.slac.stanford.edu/xorg/hfag

[2] $|V_{ub}|$=(4.32±0.16±0.29)×10^{-3} HFAG ICHEP08

f_B=190±13MeV HPQCD arXiv:0902.1815

$B\to\tau\nu_\tau$ vs CKM

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



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

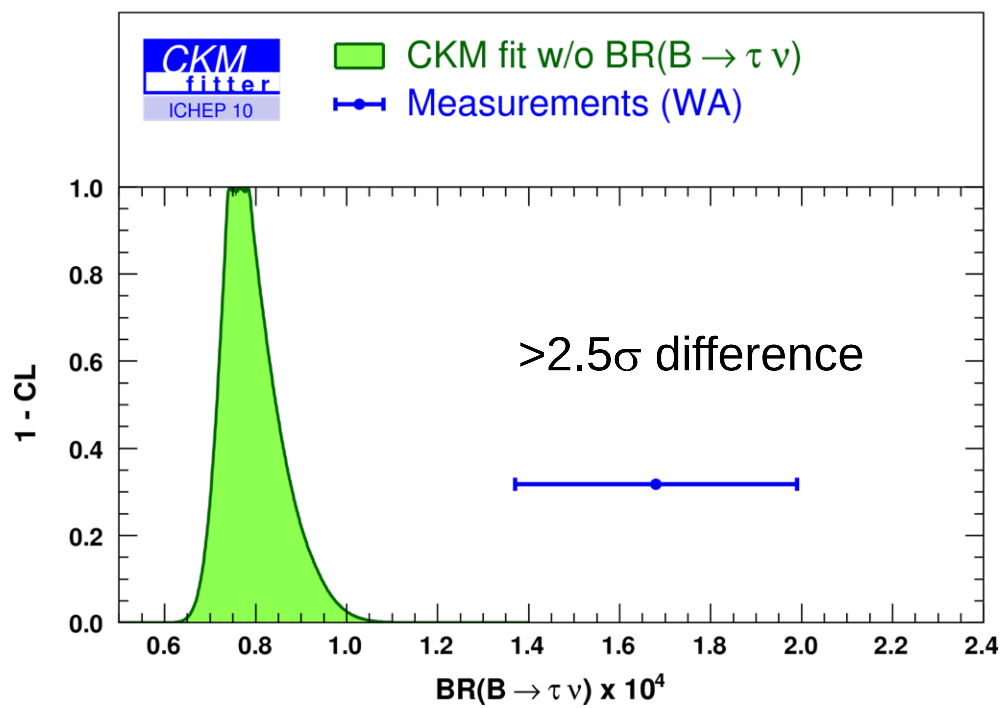
output of the CKM fit w/o BF(B→τν) in the input

$BF(B\to\tau\nu)_{SM(CKM)} = [\mathbf{0.763}^{+0.114}_{-0.061}]\times10^{-4}$

CKM fitter, S. T'Jampens @ ICHEP2010

$BF(B\to\tau\nu)_{SM(UT)} = [\mathbf{0.805}\pm0.071]\times10^{-4}$

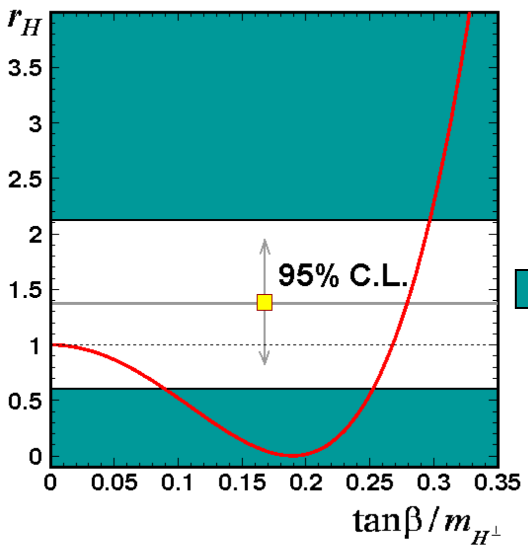
UTfit, C. Tarantino @ ICHEP2010

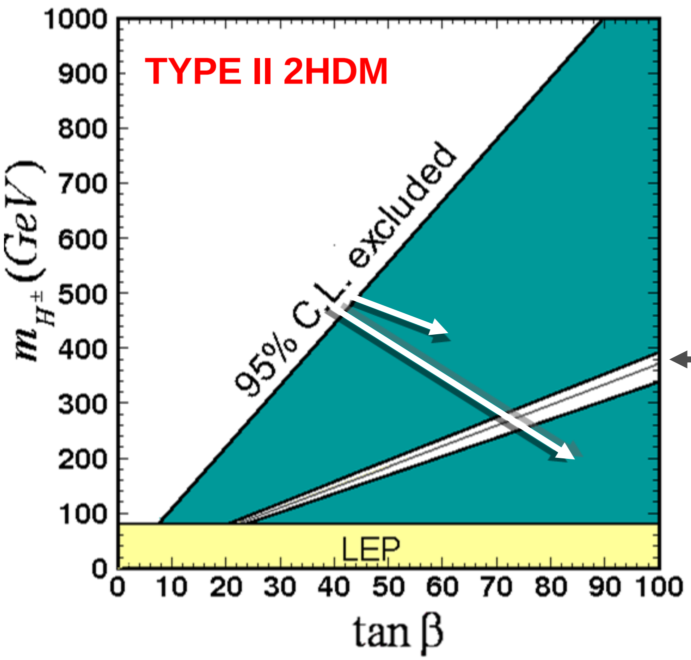


$B \to \tau\nu_\tau$ - interpretation $\Rightarrow$ talk by T. Hurth

Example of constraints whitin TYPE II 2HDM

$r_H = 1.37 \pm 0.39$ (LQCD)





Higgs contribution = double SM contribution

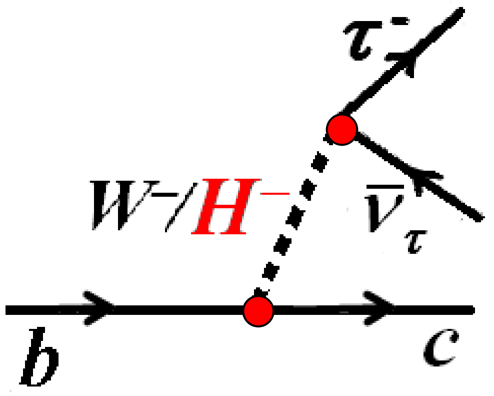
$r_H = 2.14^{+0.55}_{-0.48}$ (CKMfitter)

$r_H = 2.04 \pm 0.46$ (UTfit)

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

$B \to D^{(*)}\tau\nu_\tau$

complementary to and competitive with $B^+ \to \tau^+\nu$



- 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

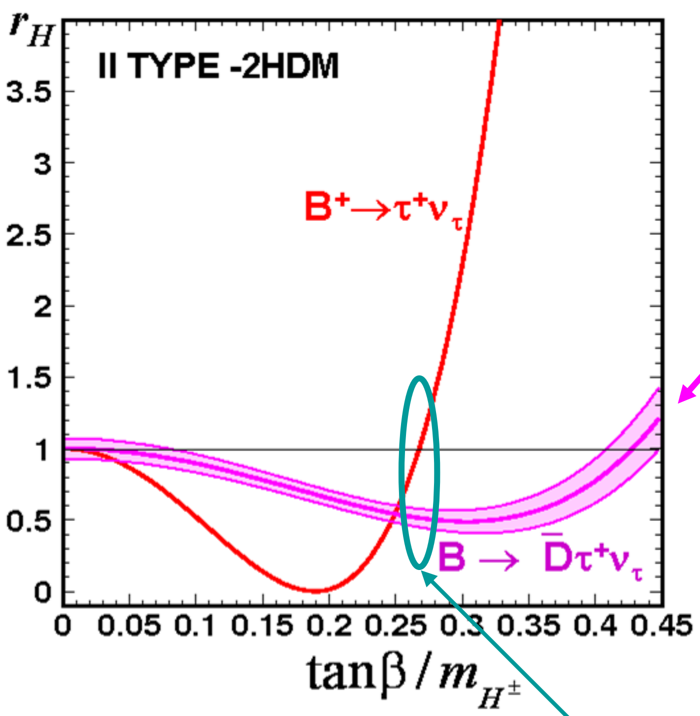
$$R = \frac{BF(B \to D\tau\nu)}{BF(B \to Dl\nu)} \qquad R_{SM} = 0.302 \pm 0.015$$

M. Tanaka, R. Watanabe, arXiv:1005.4306[hep-ph]

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

- universality between: H-b-t (direct production at LHC),
  H-b-u ($B \to \tau\nu_\tau$)
  H-b-c ($B \to D\tau\nu_\tau$) A. Cornell *et al*., arXiv:0906.1652 [hep-ph]

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



J.F. Kamenik @ CKM2010
and J. F.Kamenik, F. Mescia, arXiv:0802.3790 [hep-ph]

$$r_H = R / R_{SM} = 1 + 1.5\,\mathrm{Re}(C^\tau_{NP}) + 1.1\,|C^\tau_{NP}|^2$$

$$C^\tau_{NP} = -\frac{m_b m_\tau}{m^2_{H^\pm}} \frac{\tan^2\beta}{1+\varepsilon_0 \tan\beta}$$

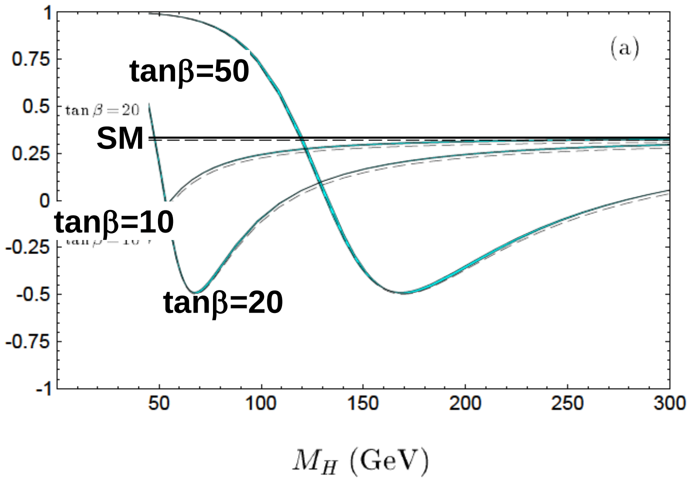
$$R = \frac{BF(B \to D\tau\nu)}{BF(B \to De\nu)}$$

$B \to \bar{D}\tau^+\nu_\tau$ more sensitive in the „$B \to \tau^+\nu_\tau$ pathological" region

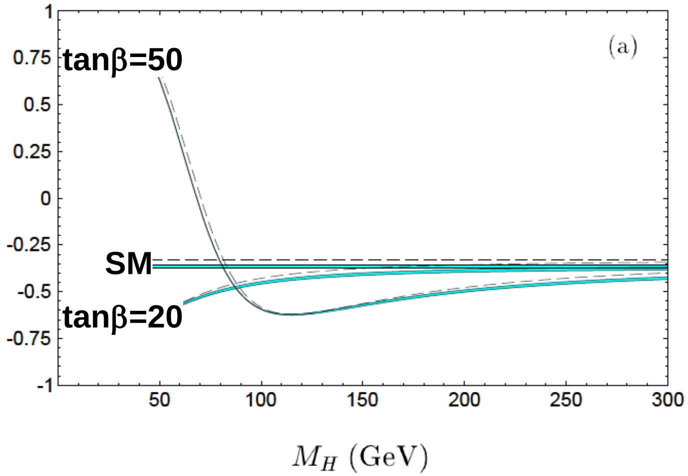
$B \to D^{(*)}\tau\nu_\tau$ - sensitivity to $H^\pm$

Examples of other observables:

longitudinal τ polarization in $B \to \bar{D}\tau^+\nu_\tau$ in virtual W* rest frame

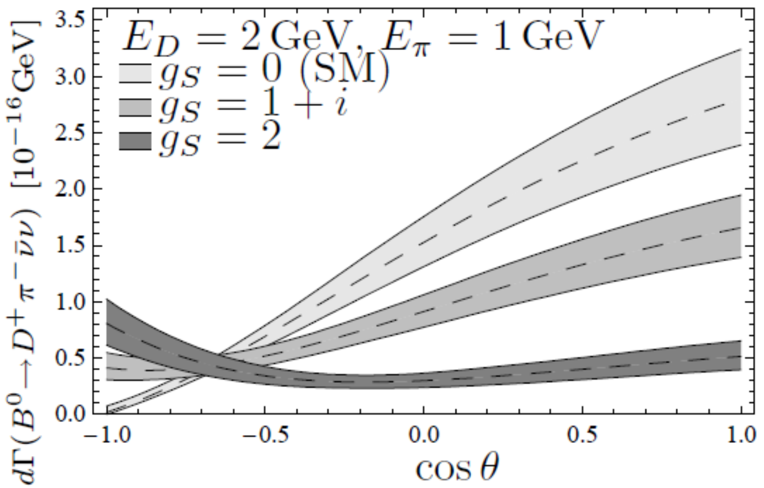


longitudinal τ polarization in $B \to \bar{D}^*_L\tau^+\nu_\tau$



M. Tanaka, Z.Phys.**C67**,321(1995)

θ = angle between π (from $\tau \to \pi\nu$) and D in B rest frame



U. Nierste, S. Trine, S. Westhoff, PRD.**78**:015006(2008)

transverse τ polarization

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

CP-odd variable, vanishes in the SM

e.g. R. Garisto, PRD.**51**,1107(1995)

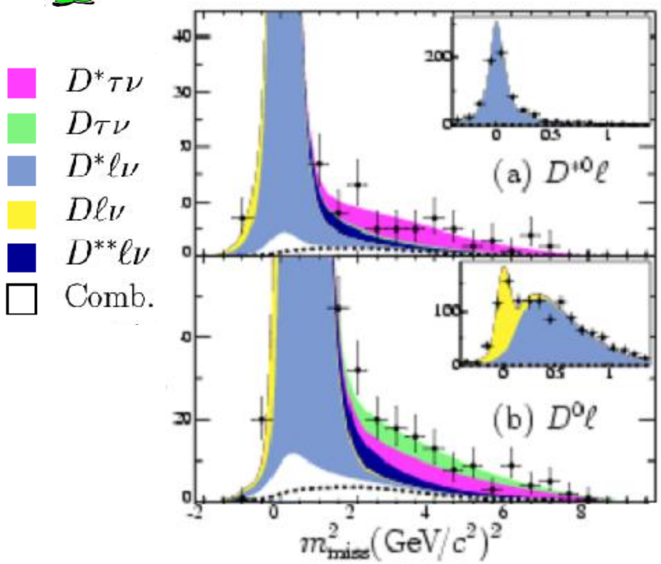
$B \to D^{(*)}\tau\nu_\tau$ - results

hadronic tags; **use leptonic τ decays: $\tau \to l\nu\nu$, $l=e,\mu$**

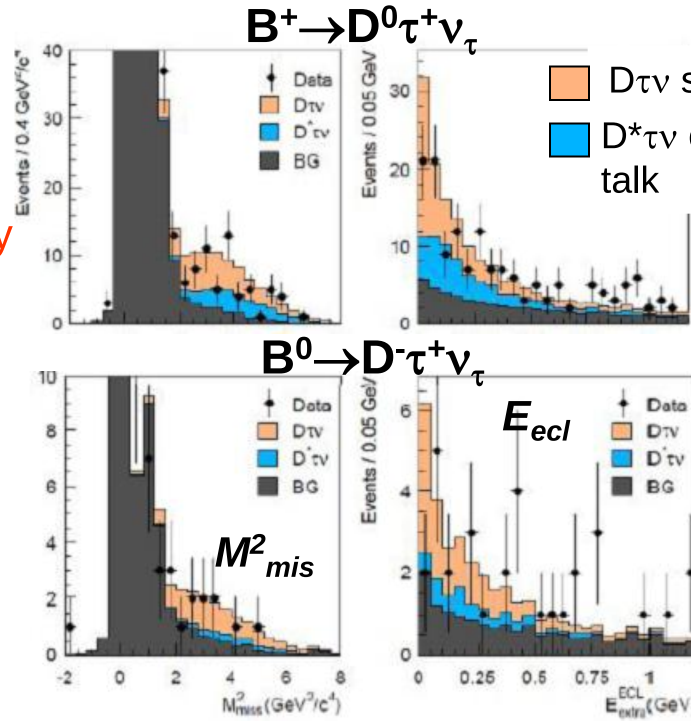
extract signal

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

232 M $B\bar{B}$



657M $B\bar{B}$
preliminary



Dτν signal

D*τν cross-talk

	BF(%)	R	σ
$B^+ \to \bar{D}^{*0}\tau^+\nu_\tau$	**2.25** $\pm 0.48 \pm 0.22 \pm 0.17$	$0.35 \pm 0.07 \pm 0.03$	5.3
$B^0 \to D^{*-}\tau^+\nu_\tau$	**1.11** $\pm 0.51 \pm 0.04 \pm 0.04$	$0.21 \pm 0.09 \pm 0.01$	2.7
$B^+ \to \bar{D}^{0}\tau^+\nu_\tau$	**0.67** $\pm 0.37 \pm 0.11 \pm 0.07$	$0.31 \pm 0.17 \pm 0.05$	1.8
$B^0 \to D^{-}\tau^+\nu_\tau$	**1.04** $\pm 0.35 \pm 0.15 \pm 0.10$	$0.49 \pm 0.16 \pm 0.07$	3.3

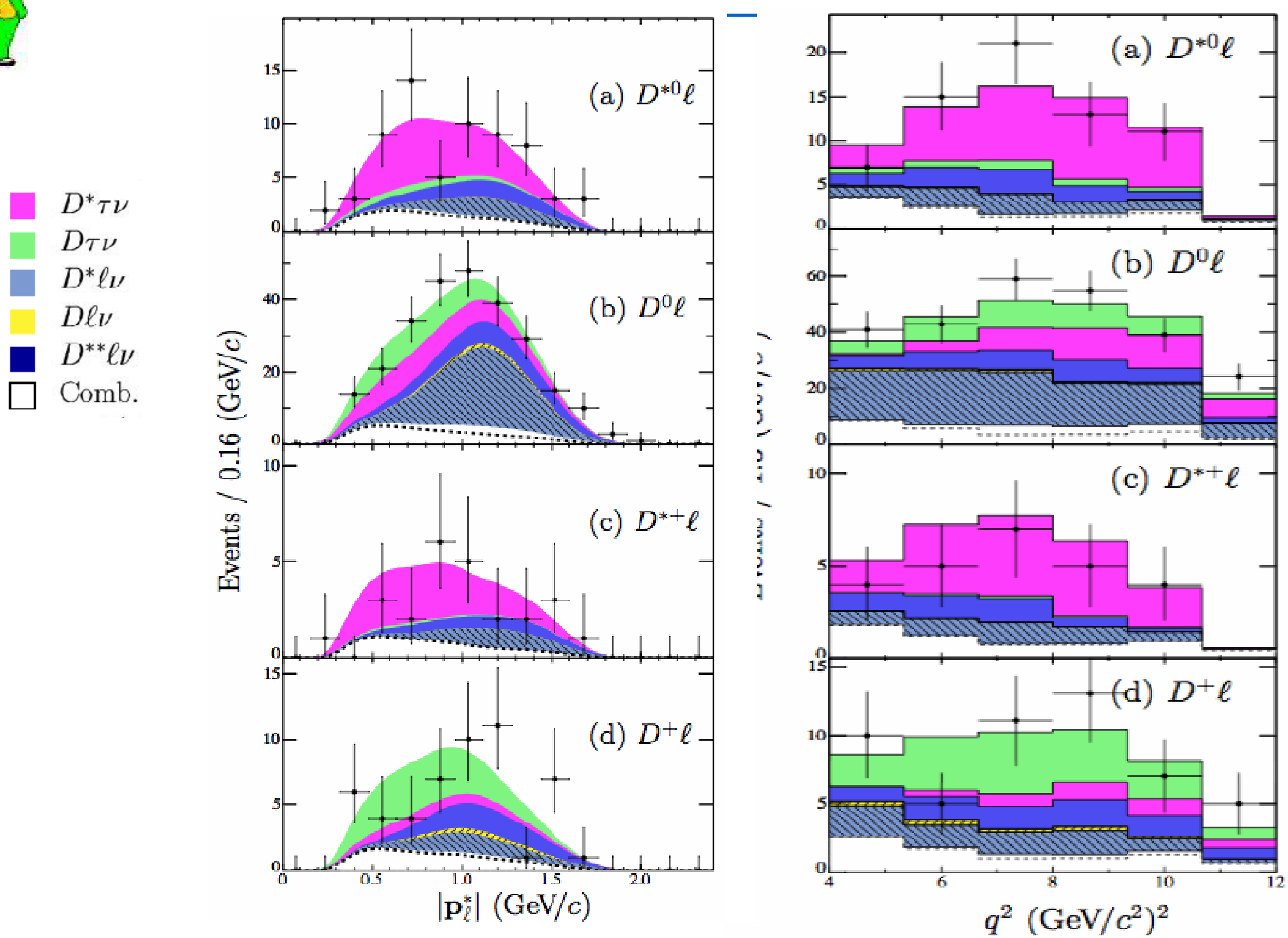
BaBar Collab., PRL **100**, 021801 (2008) and PRD **79**, 092002 (2009)

BF(%)	R	σ
3.04 $^{+0.69+0.40}_{-0.66-0.47} \pm 0.22$	$0.47^{+0.11+0.06}_{-0.10-0.07}$	3.9
2.56 $^{+0.75+0.31}_{-0.66-0.22} \pm 0.10$	$0.48^{+0.14+0.06}_{-0.12-0.04}$	4.7
1.51 $^{+0.41+0.24}_{-0.39-0.19} \pm 0.15$	$0.70^{+0.19+0.11}_{-0.18-0.09}$	3.8
1.01 $^{+0.46+0.18}_{-0.41-0.11} \pm 0.10$	$0.48^{+0.22+0.06}_{-0.19-0.05}$	2.6

Belle Collab., arXiv:0910.4301[hep-ex]

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

projections at $M^2_{miss} > 1 GeV^2$



BaBar Collab., PRD **79**, 092002 (2009)

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

"inclusive" tags – take the advantage of clean signature from $D^{(*)}$ in B_{sig}

- **select signal candidate**

  use decay chains that combine high reconstruction efficiency with a low background level

$\bar{D}^{(*)}$ decay modes

$\bar{D}^0 \to K^+\pi,\ K^+\pi\pi^0$

$\bar{D}^* \to \bar{D}^0\pi$

τ decay modes

$\tau^+ \to e^+\nu\nu,\ \mu^+\nu\nu,\ \pi^+\nu$

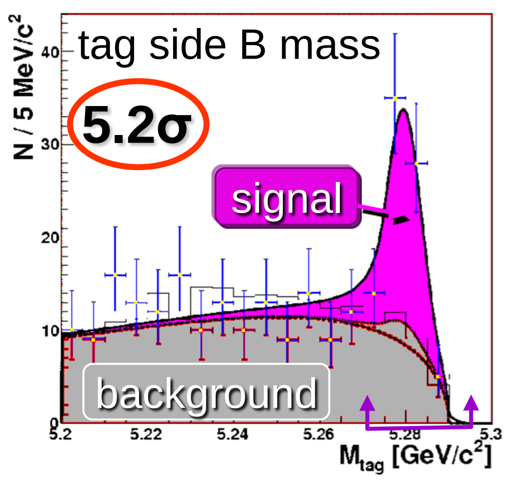
- **reconstruct B_{tag} "inclusively" from remaining particles**

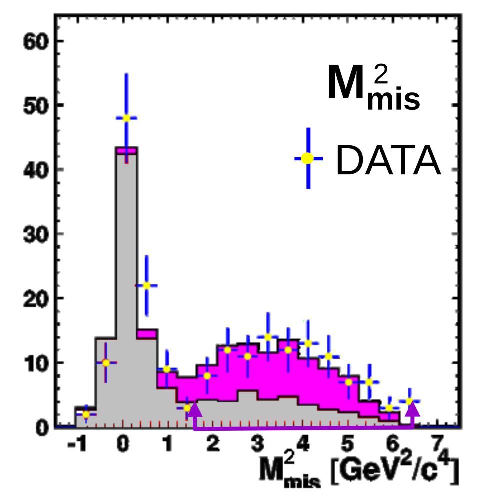
  at large M_{mis} flat M_{tag} distribution for most background components

$$M_{tag} = \sqrt{E_{beam}^2 - (\sum_{i \notin sig} \vec{p}_i)^2}$$

- **exctract signal yield from M_{tag}**

535 M $B\bar{B}$ $B^0 \to D^{*-}\tau^+\nu_\tau$





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

Belle Collab., PRL **99**, 191807 (2007)

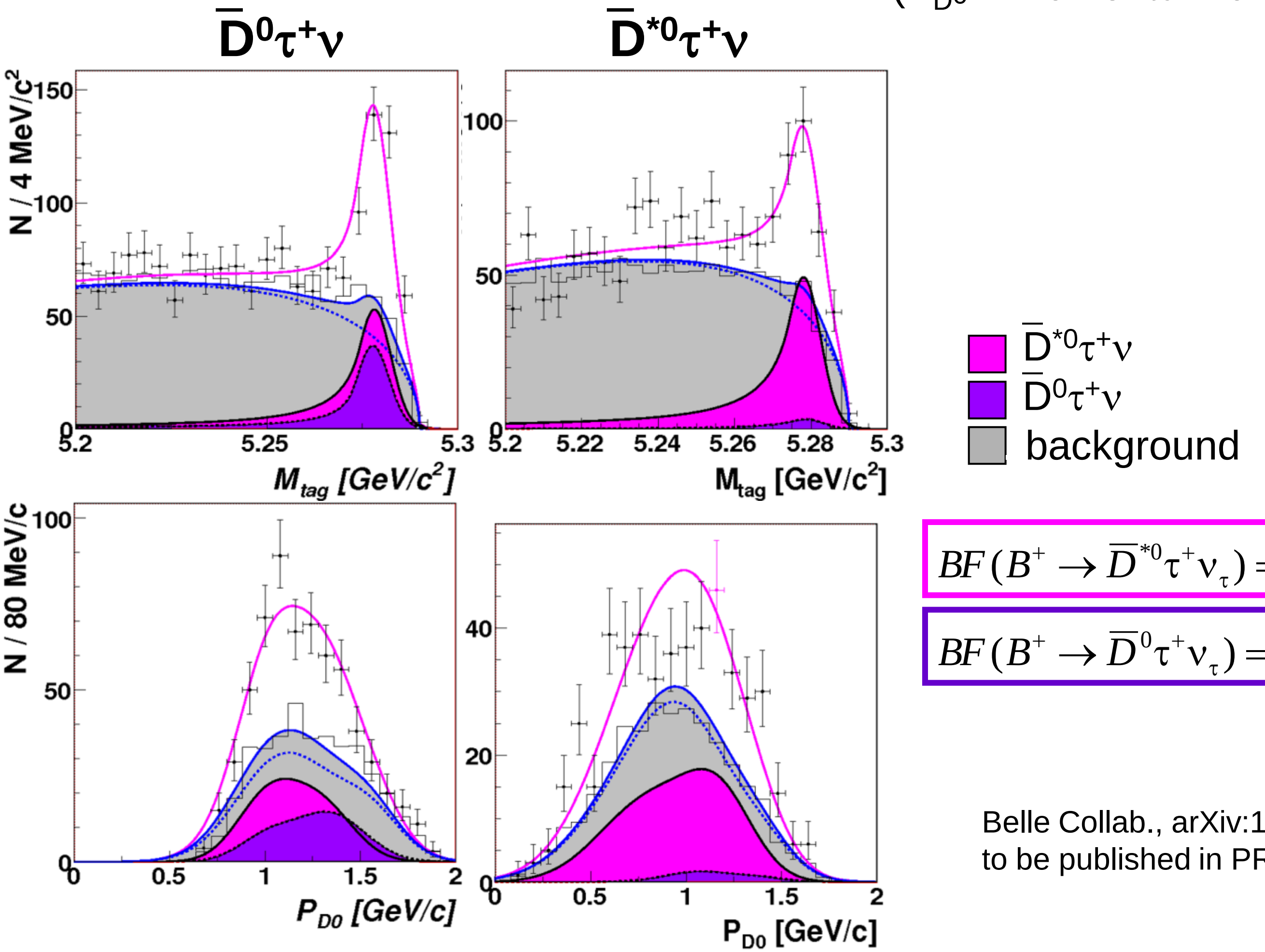
first observation of exclusive B decay with $b \to c\tau\nu_\tau$ trsnsition

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

NEW 657 M $\bar{B}B$ $B^+\to D^{*-}\tau^+\nu_\tau$ "inclusive" tags;

- simultaneous extraction of signals in $B^+\to \bar{D}^{*0}\tau^+\nu_\tau$ and $B^+\to \bar{D}^0\tau^+\nu_\tau$ modes;
- signal extraction from fit to 2-dim distributions in M_{tag} and P_{D0}

(P_{D0} = *momentum of $\bar{D}^0$ in $\Upsilon(4S)$ rest frame*)



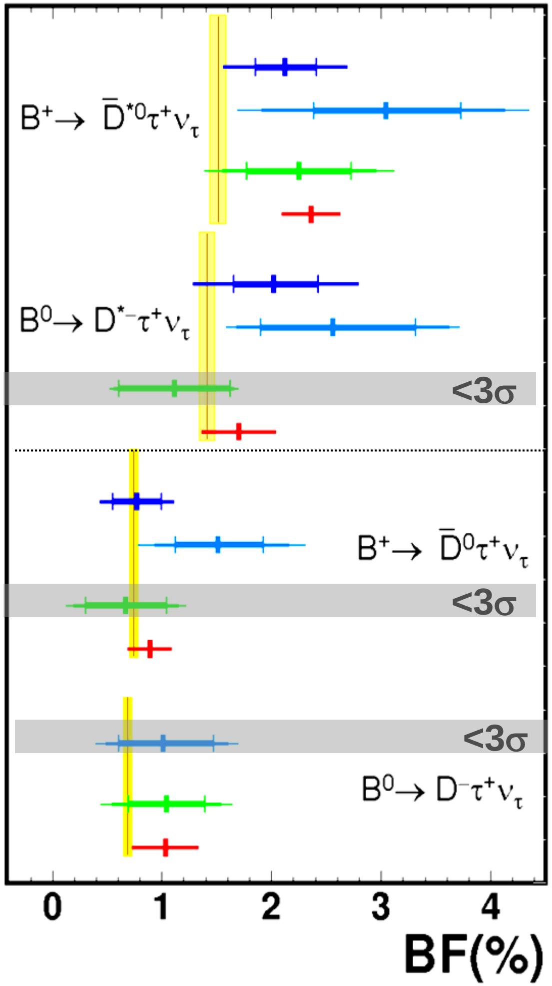
$$BF(B^+\to\bar{D}^{*0}\tau^+\nu_\tau) = (\mathbf{2.12}^{+0.28}_{-0.27}\pm 0.29)\times 10^{-2} \quad \mathbf{8.1\sigma}$$

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

Belle Collab., arXiv:1005.2302[hep-ex], to be published in PRD

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

$BF(B \to \overline{D}^{(*)}\tau^+\nu_\tau)$



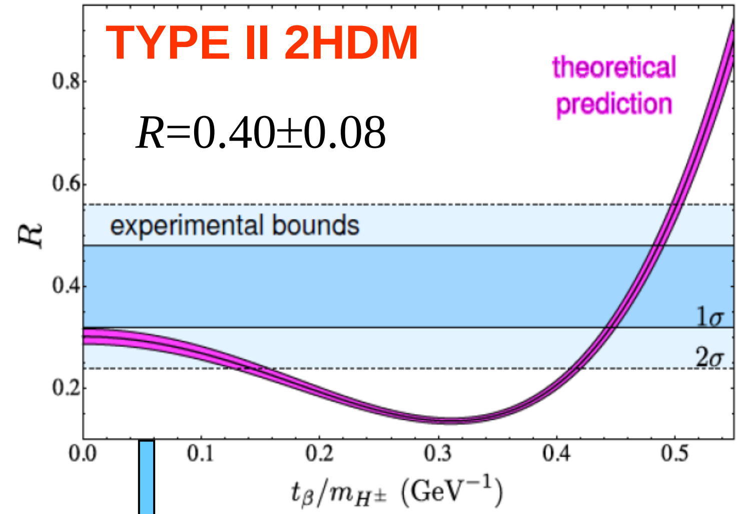
inclusive tags
hadron tags
hadron tags
"naïve" average[1]
SM [2]

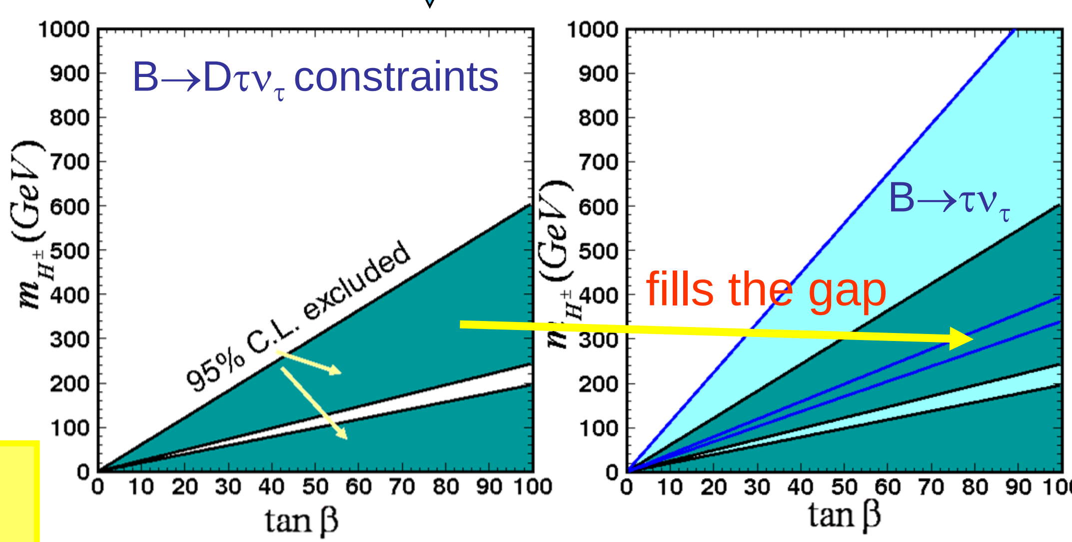
[1] A. Bozek, talk at CKM2010

[2] C.-H. Chen and C.-Q. Geng, JHEP **0610**, 053 (2006

Example of $H^\pm$ constraints

M. Tanaka, R. Watanabe, arXiv:1005.4306[hep-ph]

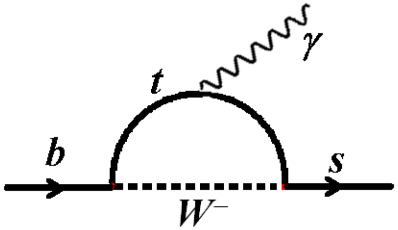




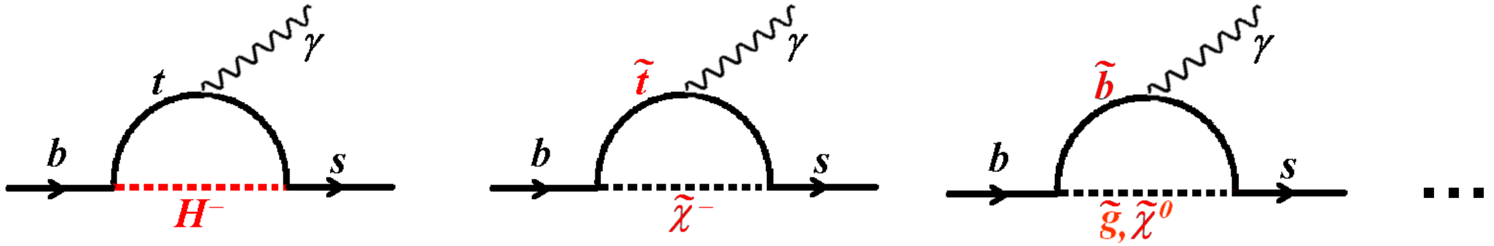
Results consistent within uncertainties, but most of them above the SM predictions

Inclusive $B \to X_s \gamma$

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 $H^{\pm}$ depends on $m_{H^{\pm}}$
but is almost independent of tanβ
☹ more NP processes complicate the interpretation…

inclusive processes: more realible theoretical calculations

NNLO SM: $BF_{SM} = (3.15 \pm 0.24) \times 10^{-4}$ (for $E_{\gamma} > 1.6\, GeV$)

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.

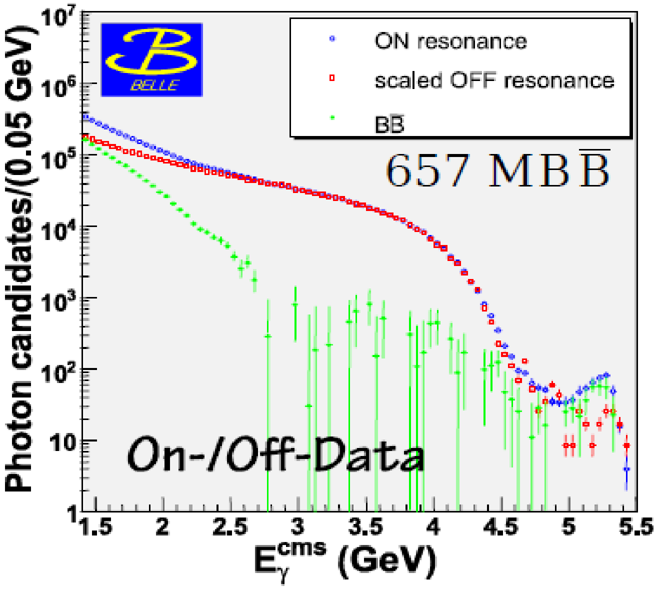
Inclusive $B \to X_s \gamma$

Several experimental approaches:

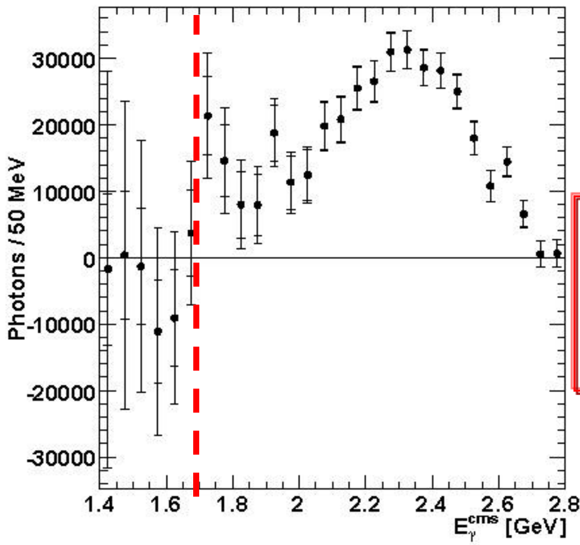
- untagged – only a high energy photon measured
- lepton tag – require high energy lepton 1.26 GeV<E_l<2.20 GeV
- reconstruct B_{tag}
- sum of exclusive final states of signal modes($B \to K\gamma$, $B \to K^*\gamma$…)

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

continuum bkg. evaluation



bkg. subtracted γ spectrum for combined samples



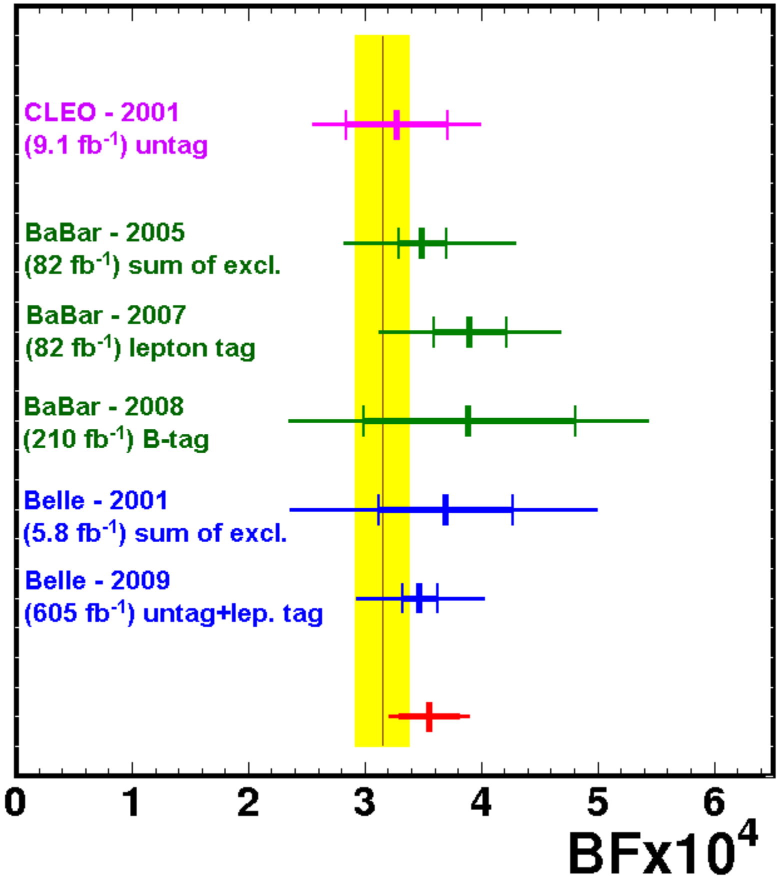
$$BF = (3.45 \pm 0.15 \pm 0.40) \times 10^{-4}$$
for $E_\gamma > 1.7\,GeV$

Most precise $BF(B \to X_s\gamma)$ measurement; lowest E_γ threshold

Belle Collab., PRL **103**, 241801 (2009)

Inclusive $B \to X_s \gamma$

HFAG $E_\gamma > 1.6$ GeV

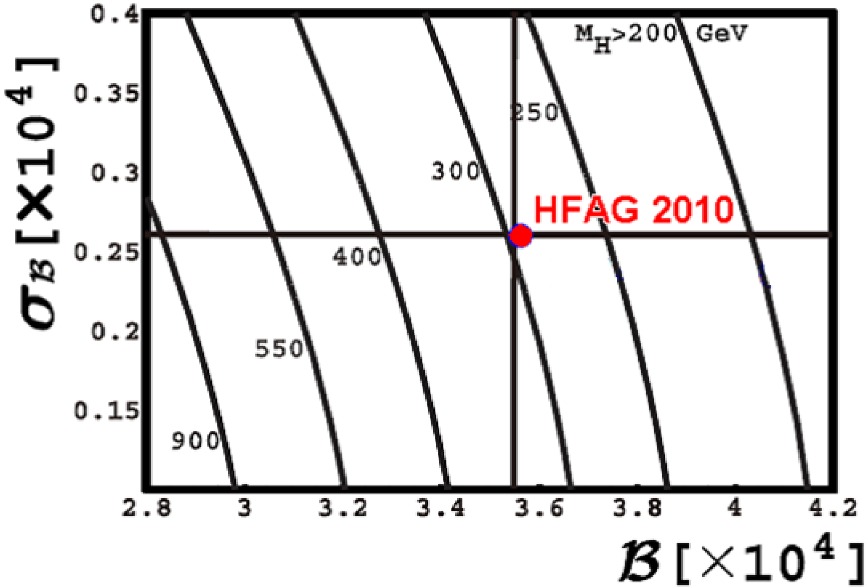


SM M. Misiak *et al*.., PRL **98**,022002(2007)

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

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

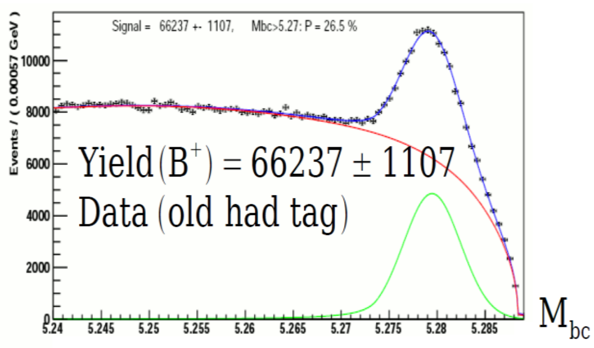
Constraints on type-II 2HDM

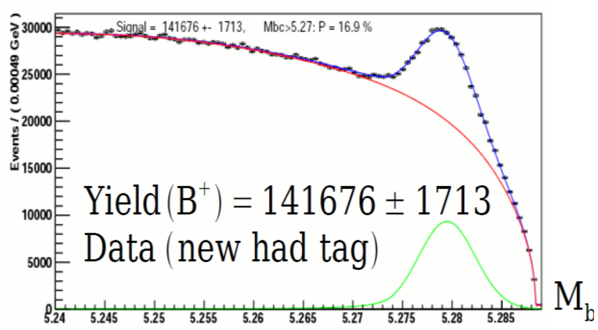


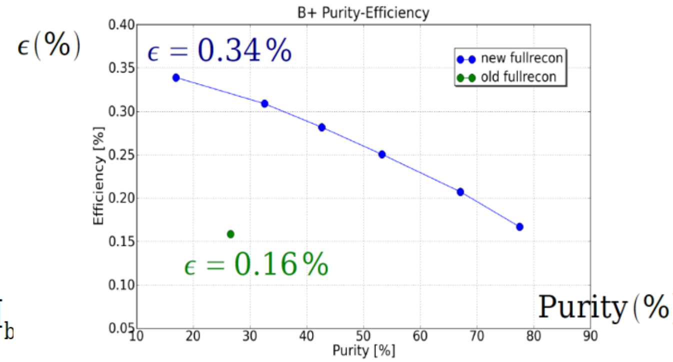
$M_{H^+} > 295$ GeV/c^2 @ 95% C.L. for all $\tan\beta$

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 ⇒ gain factor 2 in effective luminosity







new results coming soon

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

Prospects

- **explore polarization observables in B→Dτν**
  - limited information on τ kinematics, however several variables sensistive to τ polarization are accessible, especially for semileptonic $\tau \to h\nu_\tau$ decays;
  - the most sensitive channel is B→D τν, τ→πν;
  - the main issue is background, mainly from B→D*τν and **τ→ρν**;

- ***B→l ν***
  - In TYPE II 2HDM or MSSM ***H±*** has the same effect in all leptonic modes:

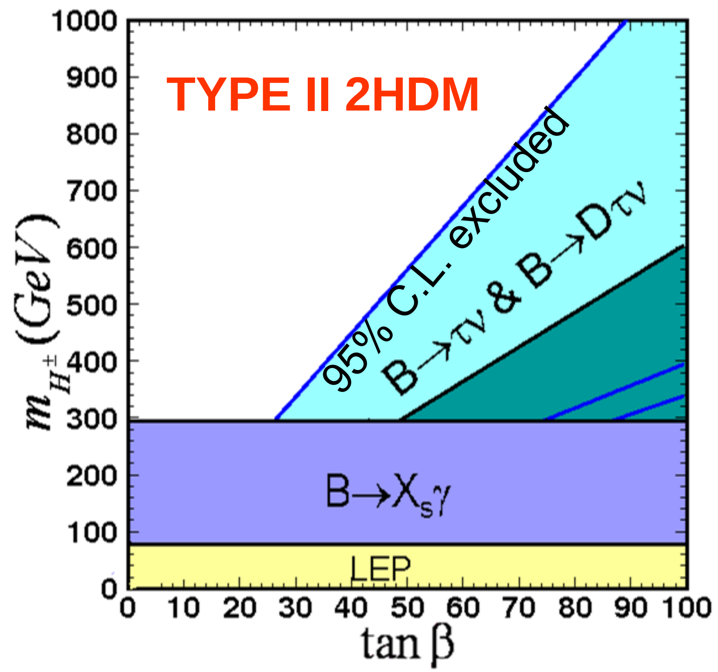
$$BF(B^+ \to l^+\nu_l)_{2HDM} = BF(B^+ \to l^+\nu_l)_{SM} \times r_H$$

  - 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.

Summary

- ❑ constraints on the charged Higgs are currently dominated by indirect mesurements;



- ❑ 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;

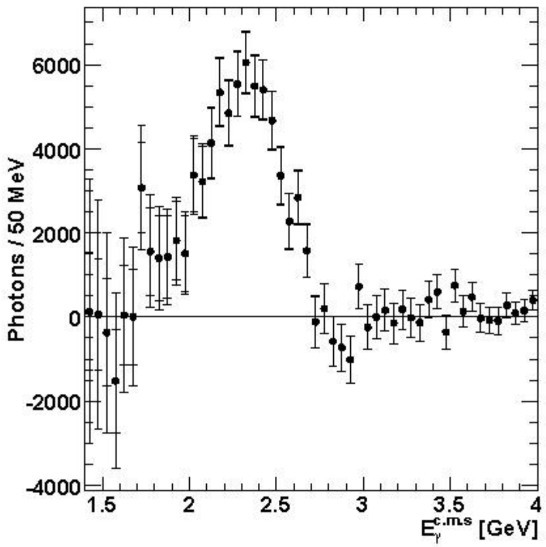
- ❑ looking forward to super B factories….

backups

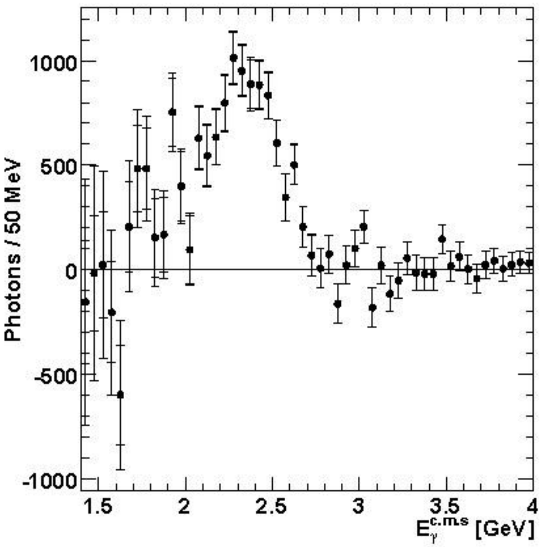
Inclusive $B \to X_s \gamma$

Belle, PRL **103**,241801(2009)

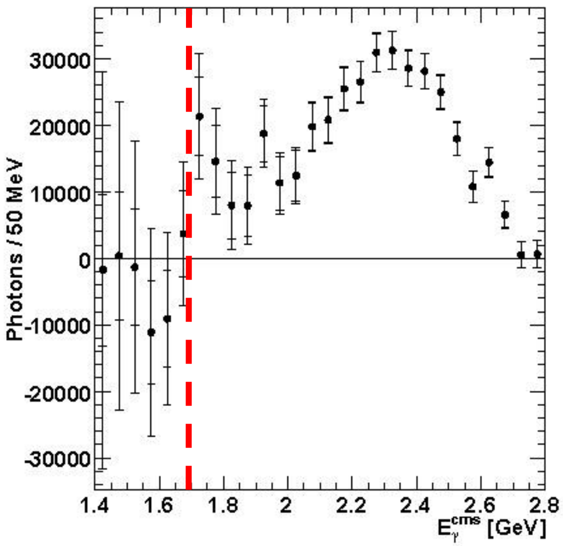
untagged



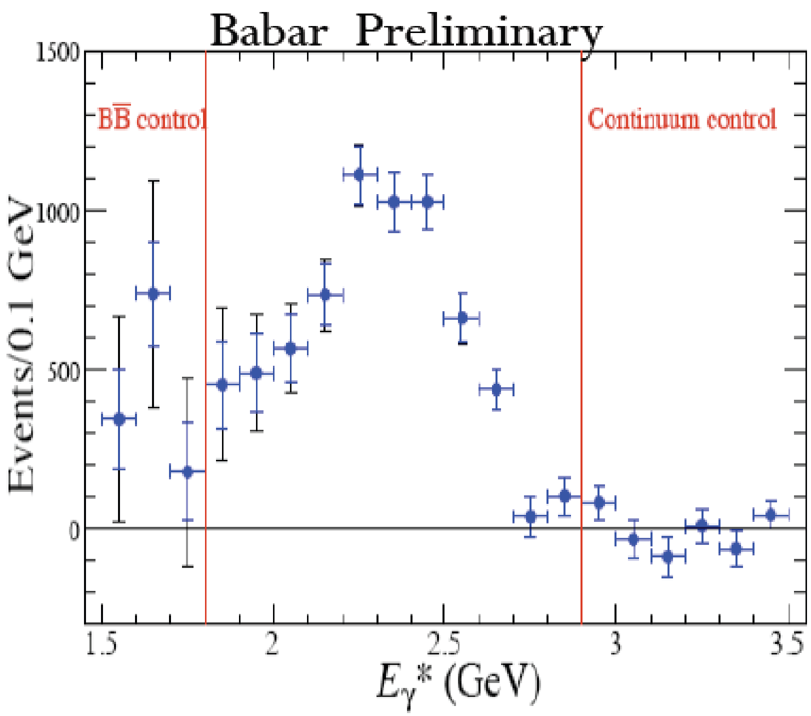
lepton tag



Efficiency corrected and averaged



Unblinded spectrum after bg. subtraction



- Continuum Control Region:
  - OnPeak On – Off Data:
  - 1825 => -100 ± 138 events
- $B\bar{B}$ 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} .