Charged Higgs search with SuperB

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on behalf of Super*B*

The Super*B* project

- $\Upsilon(4S)$-peak asymmetric energy e^+e^- **Super Flavor Factory**
- flexible design will also allow **running at the charm threshold**
- **80% polarized electron beam** further defines the already clean initial e^+e^- state
- accelerator: **~100× *BABAR* & Belle luminosity** with same power with **nano-beams**
- detector: moderately improved *BABAR* detector (e.g. vertex detector closer to the beam)
- $\boldsymbol{L = 10^{36}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}}$ around the $\Upsilon(4S)$, 10 times less at the charm threshold
  - $\Upsilon(4S)$: **coherent *B* mesons** & time-dep. measurements, charm hadrons, **tau leptons**
  - charm threshold: **coherent *D* mesons** & time-dep. measurements, tau leptons
- Physics program
  - topics: bottom and charm physics, tau LFV, precision EW, light new physics
  - emphasis: new physics sensitivity **competitive** and **complementary** with LHC experiments
  - don't forget: e^+e^- clean data for precision measurements in almost every energy-accessible topic
- start data-taking in ~2018, collect $75\,\mathrm{ab}^{-1}$ around $\Upsilon(4S)$ in 5 years
  - also $0.5\,\mathrm{ab}^{-1}$ at charm threshold, $1\,\mathrm{ab}^{-1}$ at $\Upsilon(5S)$

The accelerator

- the most innovative element of Super*B* is the accelerator
- ~100× more luminosity using same power budget: **squeeze beams** or **larger currents & larger ring**
- **larger ring**: less synchroton radiation energy loss but **thicker beam because of less damping**

→ nano-beams (same strategy as ILC)

- ~25× thinner beam transverse section $\sigma_x \times \sigma_y$ in storage ring (low emittance)
- ~100× thinner $\sigma_x \times \sigma_y$ at collision (σ_y from ~3 μm to **20–40 nm**) (strong focusing)
- thinner beams → shorter lifetime by factor ~5, i.e. ~5 minutes (need continuous injection) however this does not mean significantly higher RF power:
  - to accelerate e^+/e^- one needs 4/7 GeV
  - every 1000 turns, synchroton radiation takes away ~17 GeV, providing beam damping
  - nano-beams have side benefit of moderate increase of background w.r.t. B-factories

Super*B* Detector

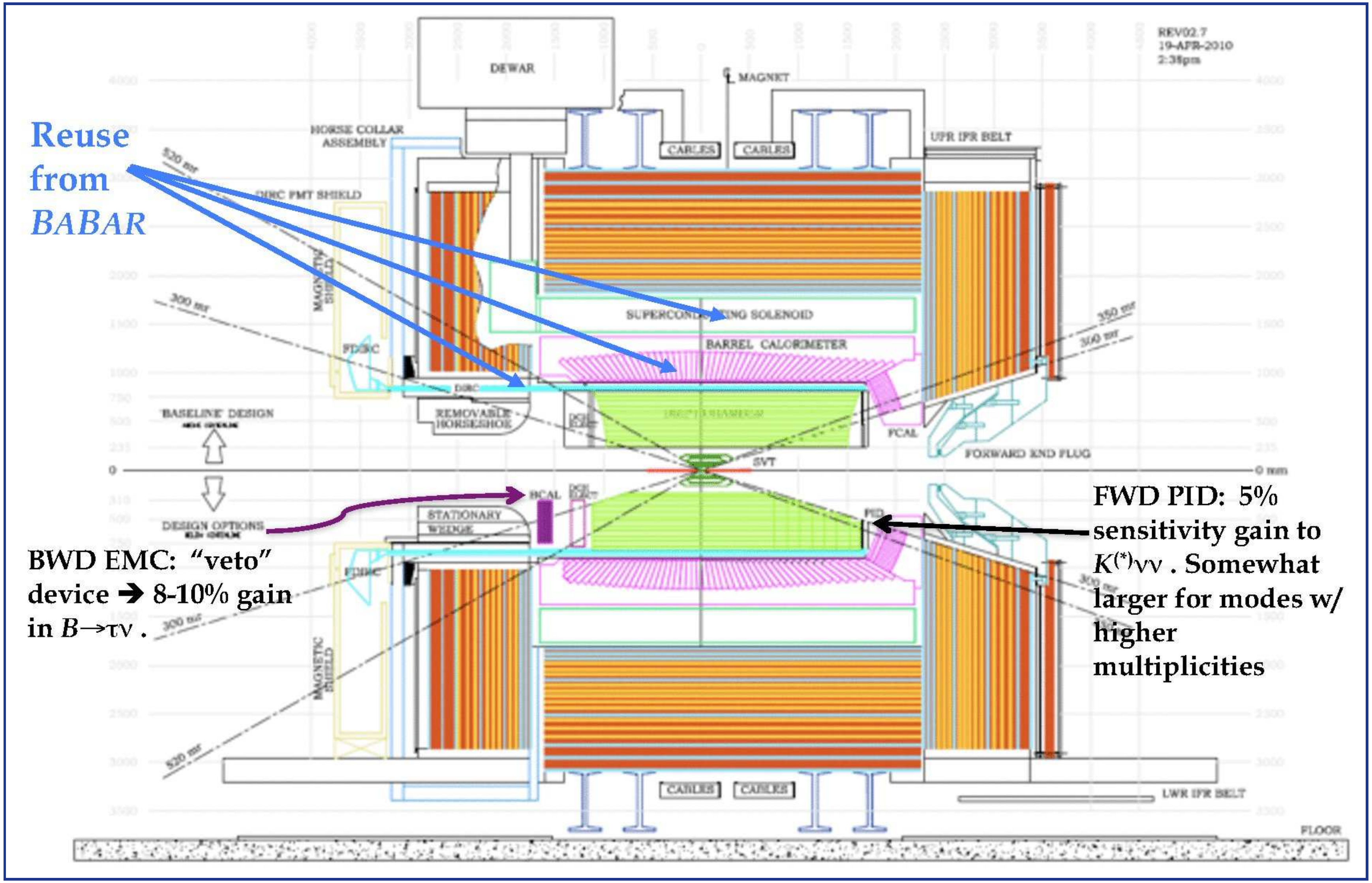
- similar requirement as B-factories
  - Large solid angle coverage, good lepton ID, $\pi - K$ PID up to 4 GeV
  - resolve B mesons decay time difference
  - good low momentum resolution, good low energy photon energy resolution
- main differences
  - lower machine boost ($\beta\gamma$ = 0.24 vs. $\beta\gamma$ = 0.56 in *BABAR*)

    ⟶ need to improve vertex detector resolution ⟶ SVT layer 0
  - much higher luminosity (and L-scaling background rates)

    ⟶ faster & more robust detectors

    ⟶ open, 100% efficient trigger
- thanks to low currents, can re-use parts of *BABAR* detector

Super*B* Detector



Super*B* physics reach documents

2005 Hewett et al., The Discovery Potential of a Super B factory, **hep-ph/0503261**

2007 Conceptual Design Report, **arXiv:0709.0451 [hep-ex]**

2008 Valencia retreat proceedings, **arXiv:0810.1312 [hep-ex]**

2010 SuperB white paper: Physics, **arXiv:1008.1541 [hep-ex]**

2011 The Discovery Potential of a Super B Factory, **arXiv:hep-ph/0503261**

2012 SuperB Physics Programme (submitted to ESG Cracow Sep 2012)

Super*B* golden modes

(indirect searches for NP need 1) good exp. precision & 2) good theory understanding)

$B_{u,d}$ Physics

- $B^+ \to \tau^+\nu$, $B^+ \to \mu^+\nu$, $B^+ \to K^{(*)+}\nu\bar{\nu}$, $b \to s\gamma$, $b \to s\ell\ell$
- precision $\sin 2\beta$ measurements, in particular $B \to \eta' K^0_S, \to K^0_S\pi^0\gamma$

τ Physics

- Lepton flavour violation in tau decays: especially $\tau \to \mu\gamma$ and $\tau \to 3\ell$

Charm Physics

- mixing parameters and *CP* violation.

B_s Physics

- Semi-leptonic *CP* asymmetry A^s_{SL}.
- $B_s \to \gamma\gamma$.

Other Physics

- Precision measurement of $\sin^2\theta_W$ at $\sqrt{s} = 10.58$ GeV/c^2.
- Direct searches for non-standard light Higgs bosons, Dark Matter and Dark Forces

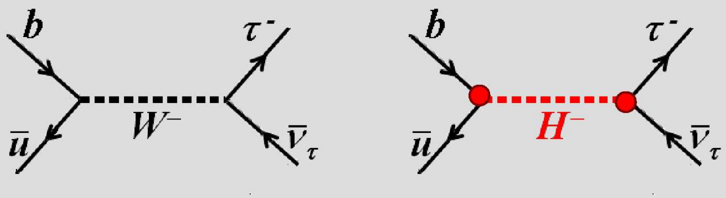
Super*B* strong-points

- fair share of measurements is **not systematically limited** $\longrightarrow$ $\boldsymbol{L = 1 \cdot 10^{36}}$ **worth doing**
- *B* physics measurements and searches with π^0, γ or many K^0's cannot be done at LHC
- most tau measurements and searches cannot be done at LHC
- **charm threshold production**: no competitor for measurements based on entanglement
- **beam polarization** allows
  - improved tau physics, with advantages over Belle2
  - even precision electro-weak physics (not presented here, see white paper)

Leptonic & radiative B decays sensitive to H^+

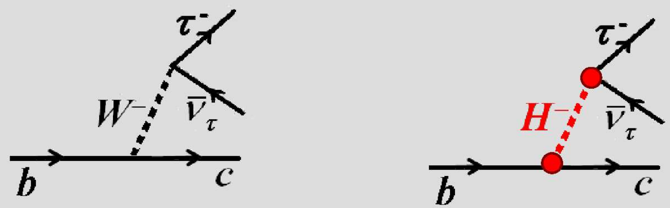
leptonic

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



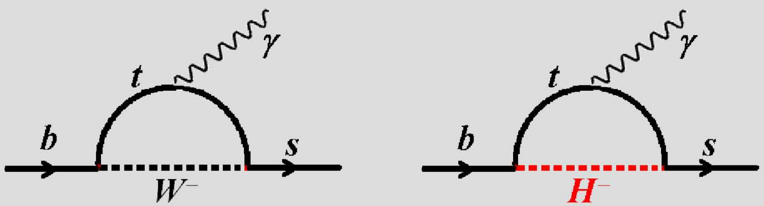
semileptonic

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



inclusive radiative

- $B \to X_s \gamma$



- ♦ suppressed in SM, reasonably clean SM predictions, potentially large effects from NP
- ♦ neutrinos, photons, inclusive final state require clean env. ➔ e^+e^- annihilations
- ♦ B-factories *BABAR* & Belle now, **Super*B*** and Belle2 in the future

$\mathcal{B}(B \to \tau\nu)$ theory predictions

Provides clean predictions of SM parameters without hadronic (QCD) final-state uncertainties

$$\mathcal{B}(B \to \ell\nu) = \frac{G_F^2 m_B}{8\pi} m_l^2 \left(1 - \frac{m_l^2}{m_b^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

Helicity suppression

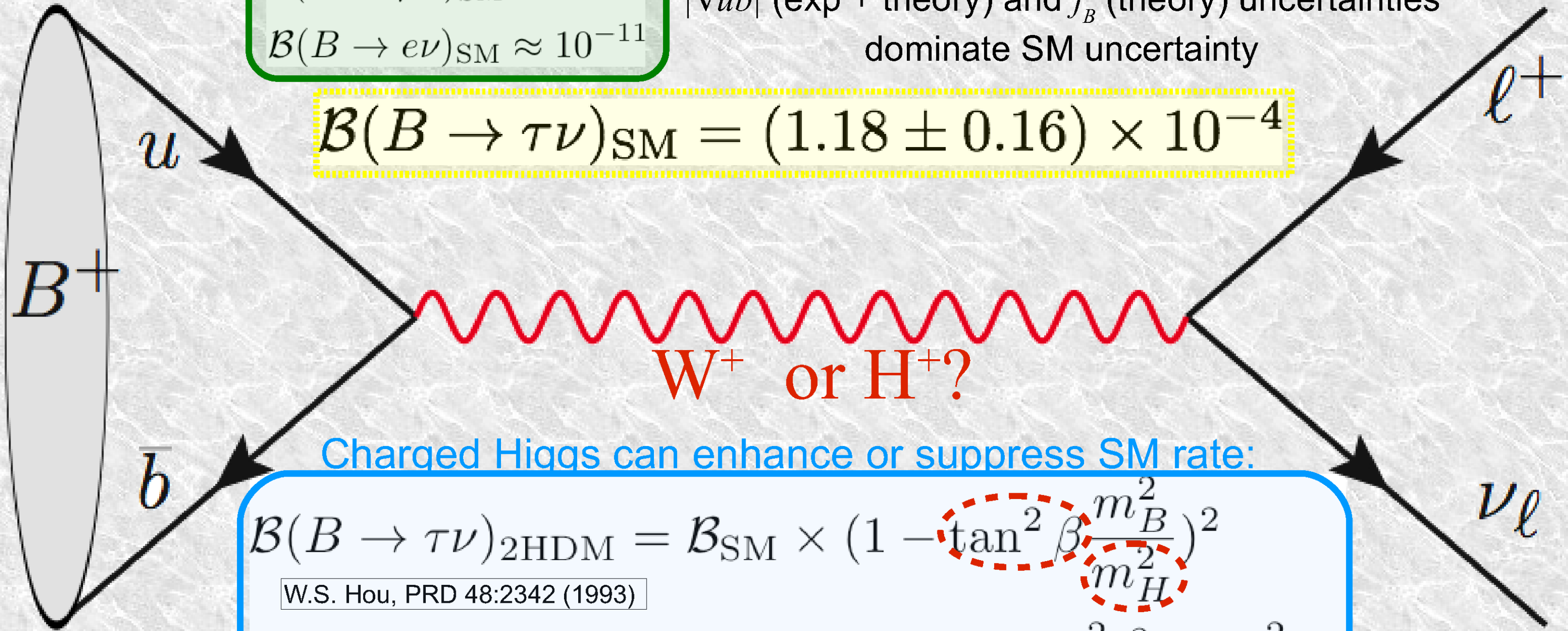
$\mathcal{B}(B \to \mu\nu)_{\rm SM} \approx 10^{-7}$

$\mathcal{B}(B \to e\nu)_{\rm SM} \approx 10^{-11}$

Experimental sensitivity to $f_B|Vub|$

$|Vub|$ (exp + theory) and f_B (theory) uncertainties dominate SM uncertainty

$$\mathcal{B}(B \to \tau\nu)_{\rm SM} = (1.18 \pm 0.16) \times 10^{-4}$$



Charged Higgs can enhance or suppress SM rate:

$$\mathcal{B}(B \to \tau\nu)_{\rm 2HDM} = \mathcal{B}_{\rm SM} \times \left(1 - \tan^2\beta \frac{m_B^2}{m_H^2}\right)^2$$

W.S. Hou, PRD 48:2342 (1993)

$$\mathcal{B}(B \to \tau\nu)_{\rm SUSY} = \mathcal{B}_{\rm SM} \times \left(1 - \frac{\tan^2\beta}{1 + \epsilon_0 \tan\beta} \frac{m_B^2}{m_H^2}\right)^2$$

Akeroyd and Recksiegel, J. Phys G29:2311 (2003)

$\mathcal{B}(B \to \tau\nu)$ experiment results (CKM 2012)

Previous Branching Fractions (x10^{-4})

BaBar Hadronic	(2008)	$1.8 \,^{+0.9}_{-0.8} \pm 0.4 \pm 0.2$	
BaBar SL	(2010)	$1.7 \pm 0.8 \pm 0.2$	
Belle Hadronic	(2006)	$1.79 \,^{+0.56}_{-0.49} \,^{+0.46}_{-0.51}$	
Belle SL	(2010)	$1.54 \,^{+0.38}_{-0.37} \,^{+0.29}_{-0.31}$	
Belle Hadronic	(2012)	$0.72 \,^{+0.27}_{-0.25} \pm 0.11$	
BaBar Hadronic	**(2012)**	$1.83^{+0.53}_{-0.49} \pm 0.24$	

BaBar combined $\mathcal{B}(B \to \tau\nu) = (1.79 \pm 0.48) \times 10^{-4}$

f_B = (189±4) MeV [(HPQCD) arXiv:1202.4914]

Inclusive BaBar |Vub| [arXiv:1112.0702]

$$\mathcal{B}_{\rm SM} = (1.18 \pm 0.16) \times 10^{-4}$$

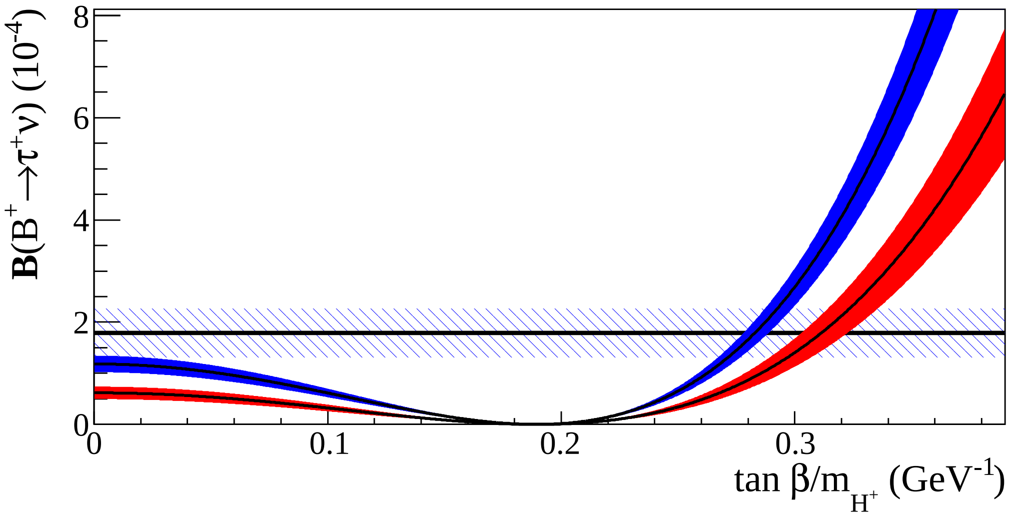
Exclusive BaBar |Vub| [PoS(EPS-HEP2011)155 (2011)]

$$\mathcal{B}_{\rm SM} = (0.62 \pm 0.12) \times 10^{-4}$$

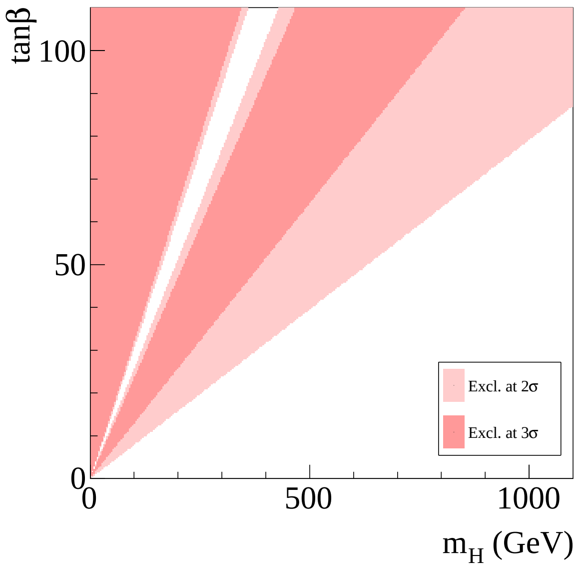
Measurement is 1.6σ larger than SM prediction

$\mathcal{B}(B \to \tau\nu)$: H^+ bounds (BABAR at CKM 2012)

SM prediction using $|V_{ub}|$ inclusive (red) and $|V_{ub}|$ exclusive (blue)



2HDM-II H^+ esclusion at 90% and 99% CL

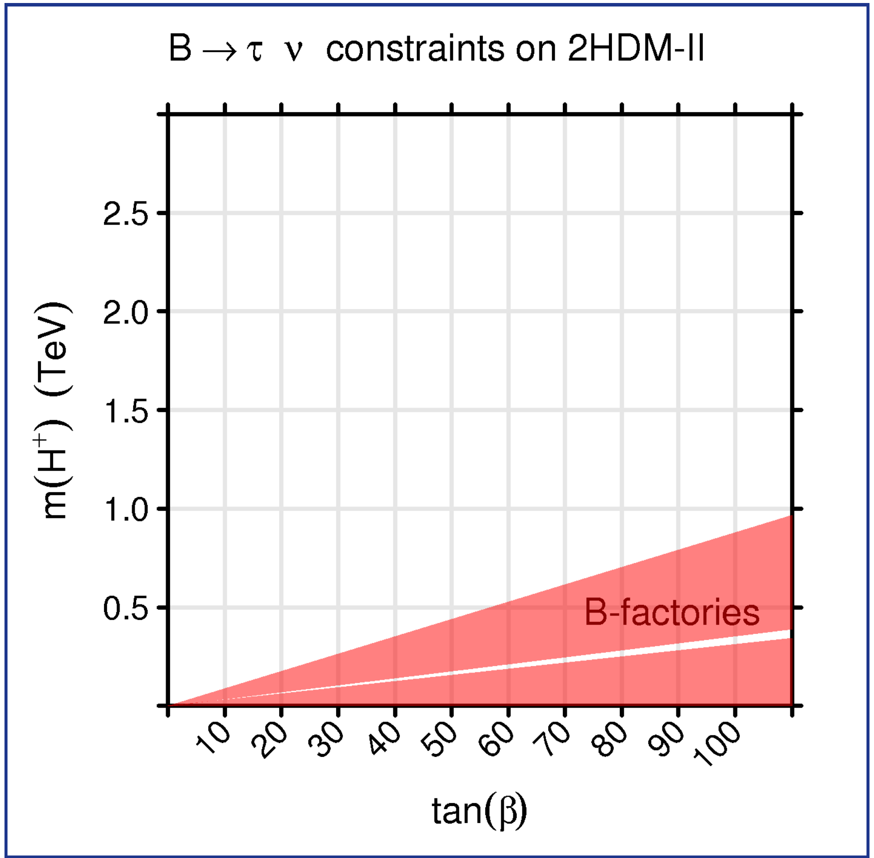


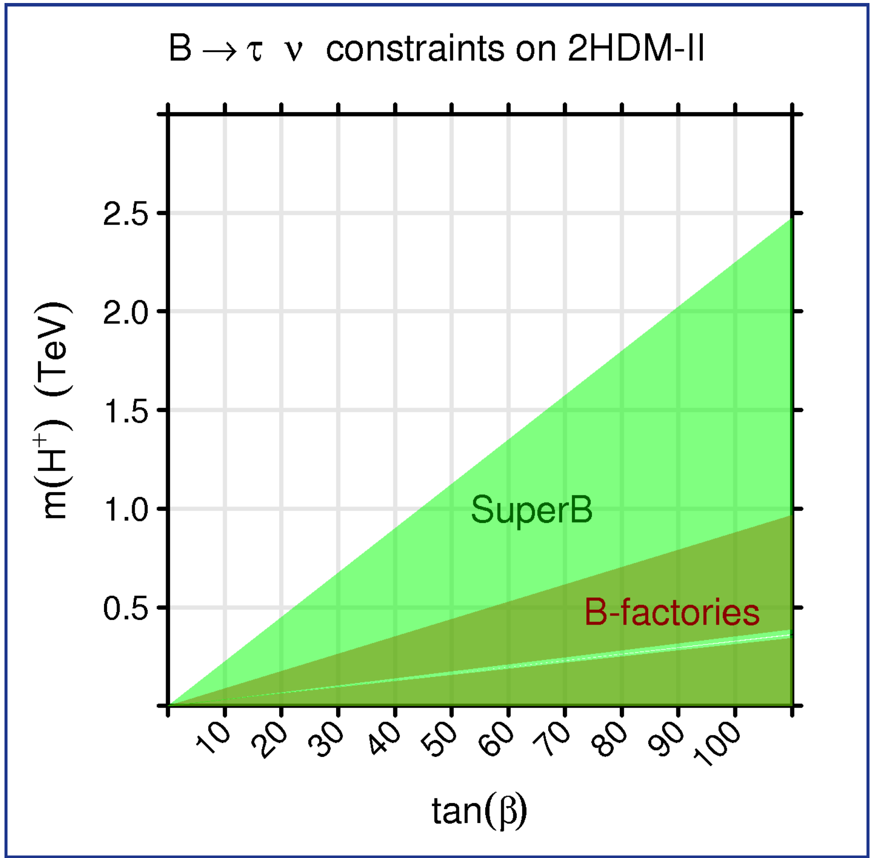
$\mathcal{B}(B \to \tau\nu)$: Super*B* sensitivity

- world average uncertainty $\sim$20% now
- use fully reconstructed hadronic tag (more clean, convenient with high statistics)
- tune MC prediction of “extra energy” distribution with data control samples
- scaling uncertainty of *BABAR* hadronic tag analysis (30%) from 468 fb^{-1} to 75 ab^{-1} yields **2.37%**
- Super*B* white paper estimate, including systematics: **3.5%**

$\mathcal{B}(B \to \tau\nu)$: 2HDM-II H^+ bounds from now to Super*B* (90% CL)

- assume to measure $\mathcal{B}(B \to \tau\nu)$ exactly at the SM prediction (no luck factor)
  - today with WA precistion
  - with Super*B* with 3.5% precision





$\mathcal{B}(B \to s\gamma)$: theory predictions

M.Misiak et al, Phys. Rev. Lett. 98, 022002 (2007)

- SM prediction: $\mathcal{B}(B \to s\gamma) = (315 \pm 23) \times 10^{-6}$
- bound on 2HDM-II H^+ (in 2007): $m(H^+) > 295$ **GeV 95% CL**
- paper includes information to compute H^+ bounds as function of BR value and uncertainty

$\mathcal{B}(B \to s\gamma)$: experiment results (HFAG 2012)

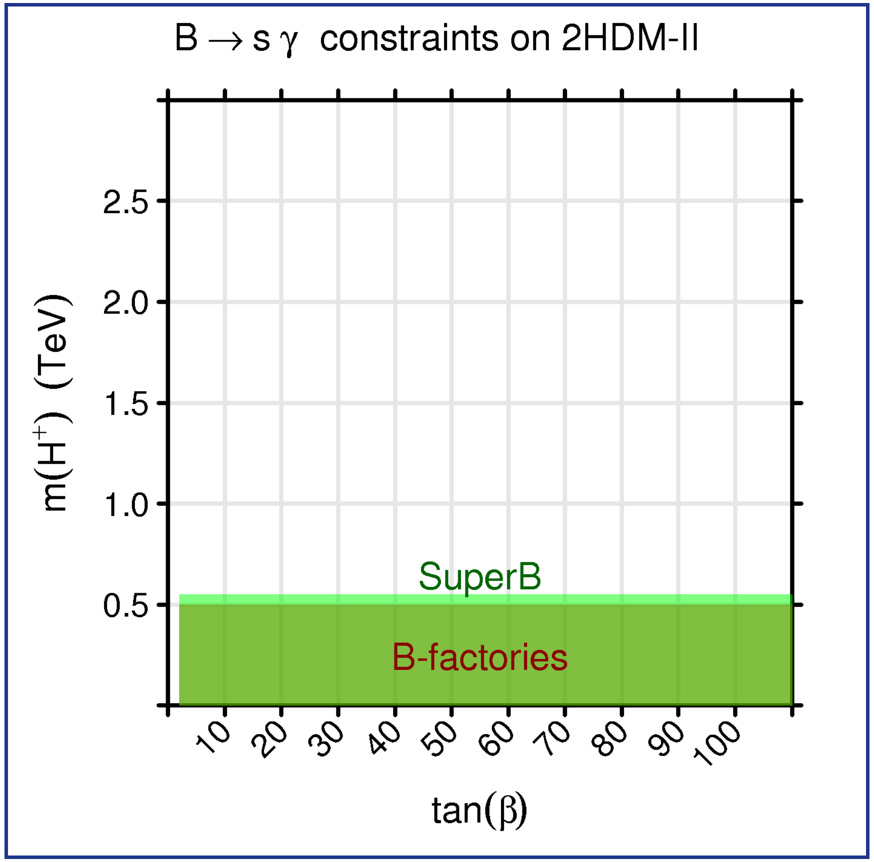
Mode	$\mathcal{B}$	$E_{\min}$	$\mathcal{B}(E_\gamma > E_{\min})$	$\mathcal{B}^{\text{cnv}}(E_\gamma > 1.6)$
CLEO Inc. [2]	$321 \pm 43 \pm 27^{+18}_{-10}$	2.0	$306 \pm 41 \pm 26$	$328 \pm 44 \pm 28 \pm 6$
Belle Semi.[3]	$336 \pm 53 \pm 42^{+50}_{-54}$	2.24	–	$369 \pm 58 \pm 46 \pm 60$
Belle Inc.[4]	–	1.7	$345 \pm 15 \pm 40$	$350 \pm 15 \pm 41 \pm 1$
BABAR Semi.[5]	–	1.9	$329 \pm 19 \pm 48$	$352 \pm 20 \pm 51 \pm 4$
BABAR Inc. [6]	–	1.8	$321 \pm 15 \pm 29 \pm 8$	$332 \pm 16 \pm 31 \pm 2$
BABAR Full [7]	$391 \pm 91 \pm 64$	1.9	$366 \pm 85 \pm 60$	$390 \pm 91 \pm 64 \pm 4$
Average				$343 \pm 21 \pm 7$

$\mathcal{B}(B \to s\gamma)$ prospects

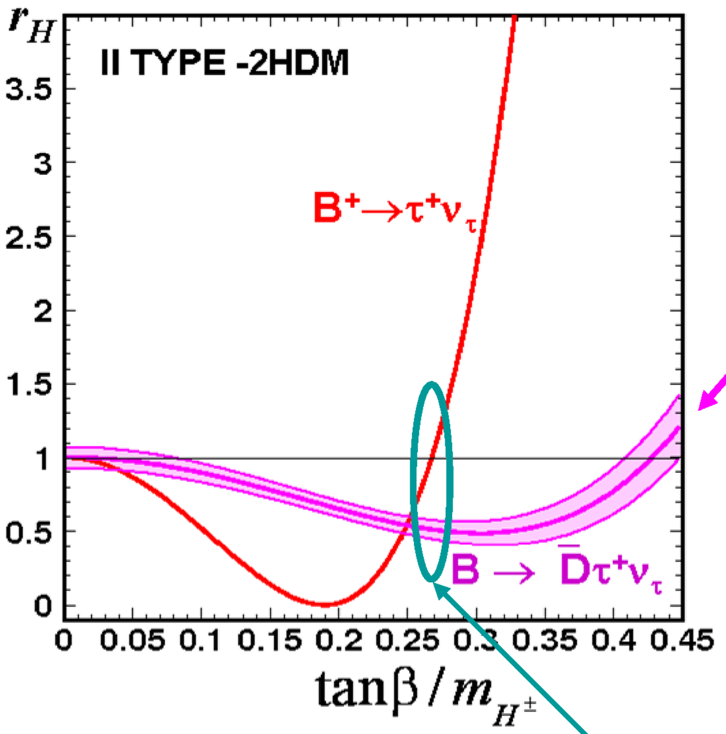
- both theory and experiment have ∼**7%** uncertainty
- plan to use fully inclusive anaysis with reconstracted hadronic recoil tag
  - more convenient than now with Super*B* statistics
- expect measurement systematically limited to **3%** uncertainty
- theory will soon improve to **5%** (A.Crivellin, private communication)
  - no consensus on feasibility & time-scale of further reduction theory error

$\mathcal{B}(B \to s\gamma)$: estimated Super*B* bounds on H^+

- assume to measure exactly the SM prediction
  - today: WA precision, with Super*B*: uncertainty = 3% (no improvement on theory error)



$\mathcal{B}(B \to D^{(*)}\tau\nu)$: theory predictions



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

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

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

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

- $\mathcal{B}(B \to D^*\tau\nu)$ less sensitive to NP contributions
- both channels less powerful than $\mathcal{B}(B \to \tau\nu)$

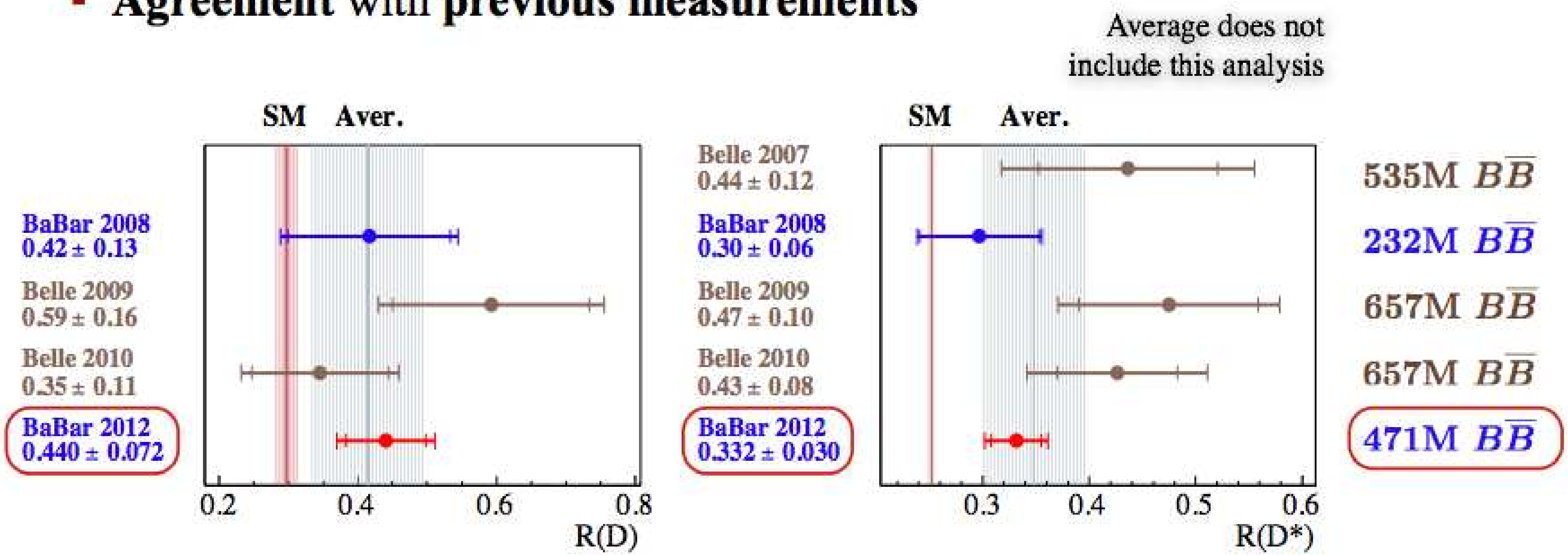
$B \to \bar{D}\tau^+\nu_\tau$ more sensitive in the „$B \to \tau^+\nu_\tau$ pathological”region

$\mathcal{B}(B \to D^{(*)}\tau\nu)$ experiment results (BABAR at CKM 2012)

Decay	N_{sig}	N_{norm}	$R(D^{(*)})$	$\mathcal{B}(B \to D^{(*)}\tau\nu)$ (%)	$\Sigma_{tot}(\sigma)$
$D\tau^-\overline{\nu}_\tau$	489 ± 63	2981 ± 65	$0.440 \pm 0.058 \pm 0.042$	$1.02 \pm 0.13 \pm 0.11$	6.8
$D^*\tau^-\overline{\nu}_\tau$	888 ± 63	11953 ± 122	$0.332 \pm 0.024 \pm 0.018$	$1.76 \pm 0.13 \pm 0.12$	13.2

- **First 5σ observation of B→Dτν**
- **Agreement** with **previous measurements**

SM prediction from
Phys. Rev. D 85, 094025 (2012

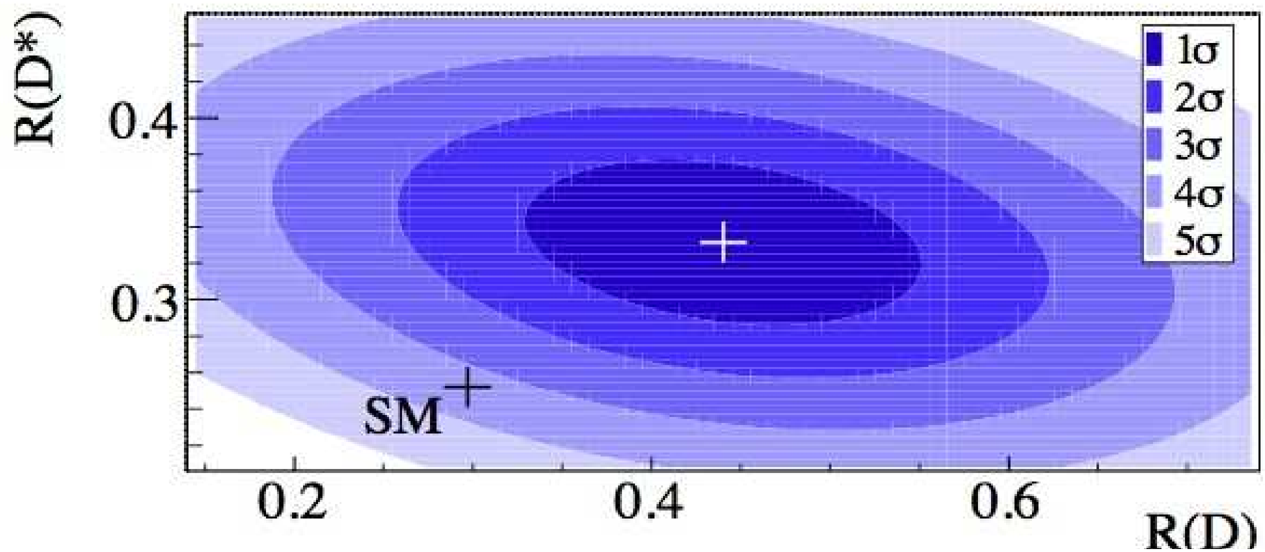


$\mathcal{B}(B \to D^{(*)}\tau\nu)$ experiment results (BABAR at CKM 2012)

$$R(D) = \begin{cases} 0.440 \pm 0.072 & \text{BABAR} \\ 0.297 \pm 0.017 & \text{SM} \end{cases} \quad 2.0\sigma$$

$$R(D^*) = \begin{cases} 0.332 \pm 0.030 & \text{BABAR} \\ 0.252 \pm 0.003 & \text{SM} \end{cases} \quad 2.7\sigma$$

Combined: 3.4σ

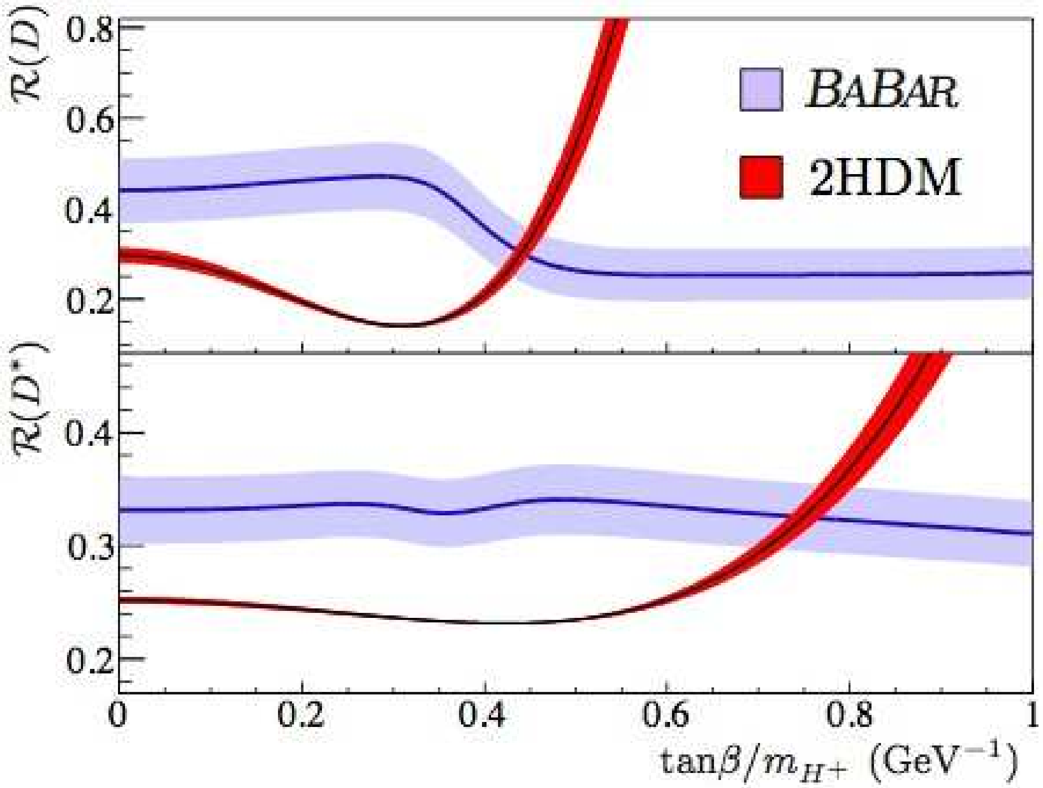


R(D) and R(D*) not independent

-27% correlation

$\mathcal{B}(B \to D^{(*)}\tau\nu)$: 2HDM-II H^+ bounds (BABAR at CKM 2012)

Measure R(D*) in full 2HDM parameter space

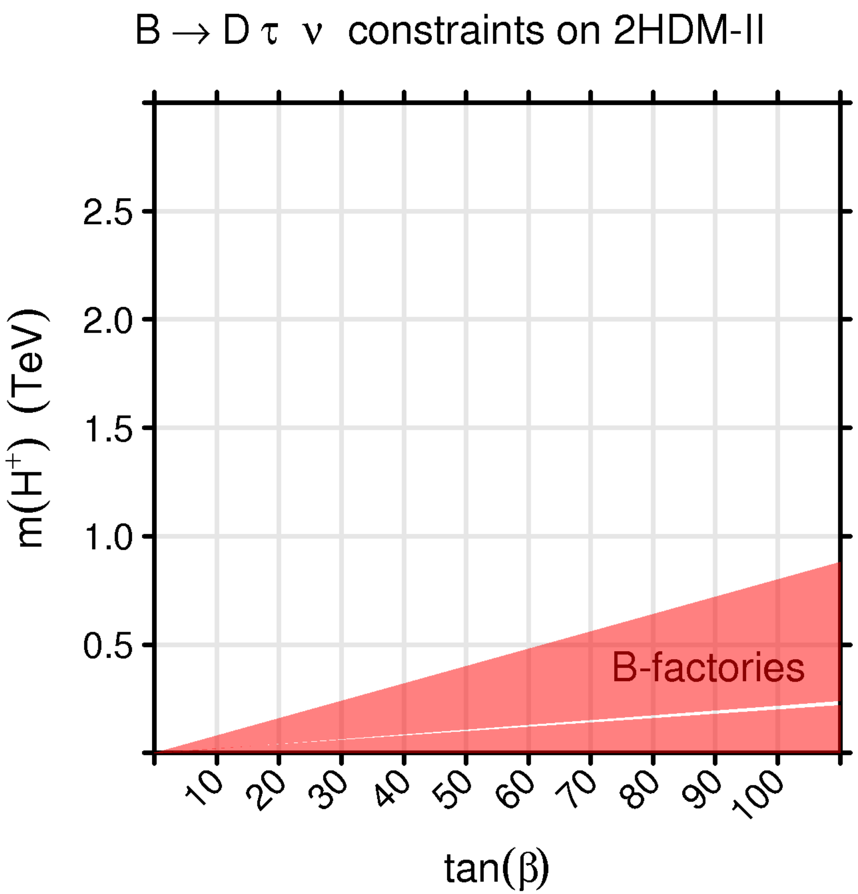


$\tan\beta/m_{H^+} =$
0.44 ± 0.02 GeV^{-1}

$\tan\beta/m_{H^+} =$
0.75 ± 0.04 GeV^{-1}

$\mathcal{B}(B \to D\tau\nu)$ 2HDM-II H^+ bounds

- assume to measure exactly the SM prediction with today's precision
- no estimate yet for $\mathcal{B}(B \to D^{(*)}\tau\nu)$ with Super*B*



Other decay modes sensitive to charged Higgs

- $B \to \mu\nu$ Super*B* will measure with about 6% precision
  - after 30 ab^{-1} this mode is more effective than $B \to \tau\nu$
- $b \to s l^+ l^-$
- CPV in tau decay ($H^+ - W$ interference, requires H^+ complex couplings)
  - CLEO 2002 paper, Phys.Rev.Lett.88:111803,2002, CPV in $\tau \to K\pi\nu$

Conclusions

- Super*B* will be able to set significant bounds on charged Higgs
- examined channels are not easily accessible in facilities other than e^+e^-