Tauonic, Radiative & Electroweak B Decays at Super-B

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November 9, 2005

"Flavour in the era of the LHC" workshop @ CERN

Based on results and studies by Belle

Letter of Intent for KEK Super B Factory (KEK Report 2004-4)
Physics at Super B Factory (hep-ex/0406071)

cf) SLAC-R-709, "The Discovery Potential of a Super B Factory"
Proceedings of the 2003 SLAC Workshops

Physics Targets at Super-B

Search for new origin of flavor mixing and CPV.

- CP violation

  $B \to \phi K^0, \eta' K^0, K^+ K^- K^0$
- Precise CKM

  $\phi_1, \phi_1, \phi_1, |V_{ub}|, |V_{td}|$
- Rare decays

  FCNC decays

  $b \to s\gamma, s\ell\ell, s\nu\bar{\nu}$ *etc.*

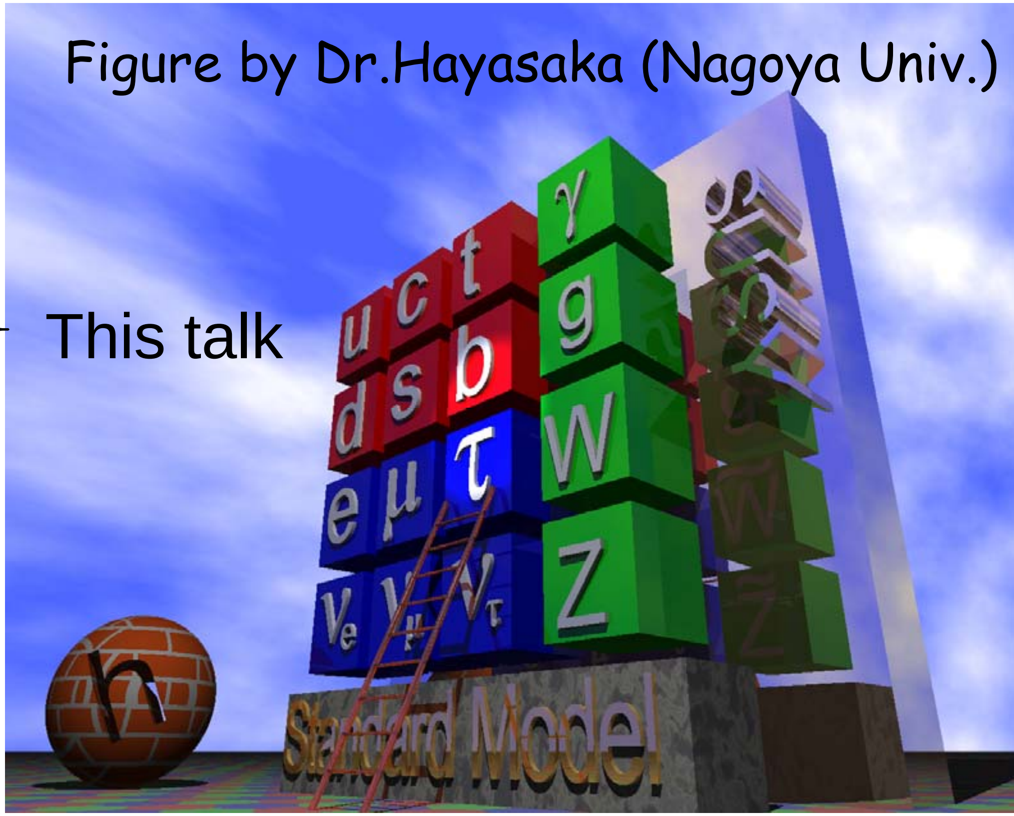
  Tauonic decays

  $b \to c\tau\nu, \tau\nu$ *etc.*

  This talk
- τ decays

  Lepton flavor violation

  $\tau \to \mu\gamma$ *etc.*

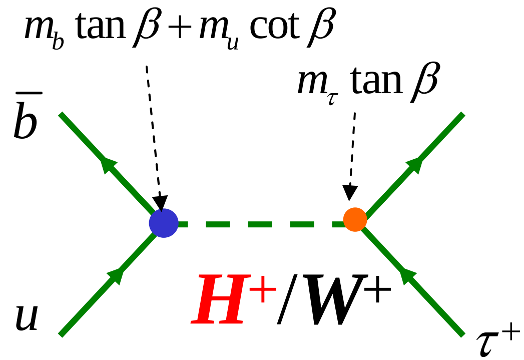


Using O(10^{10}) B and τ (~100 x now)

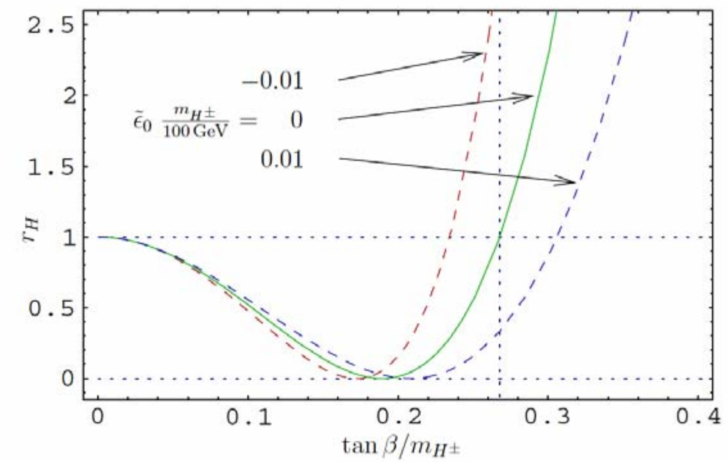
Tauonic B Decays

Charged Higgs contribution to B decays

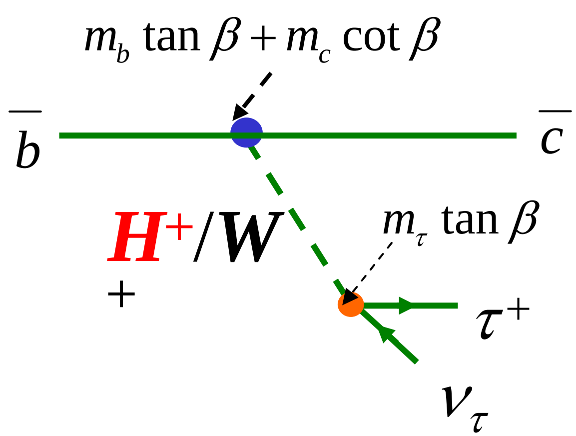
- Leptonic: B→τ ν



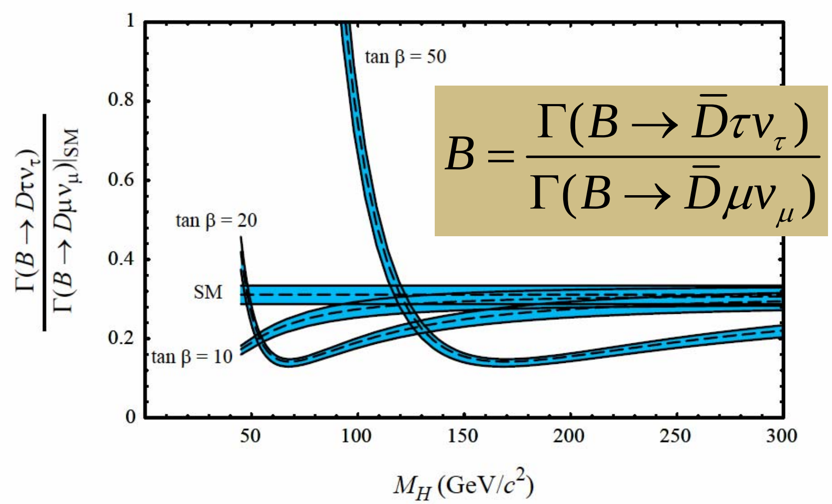
Br(SM)
~ 9 x 10^{-5}



- Semileptonic: B→D τ ν



Br(SM)
~ 8 x 10^{-3}

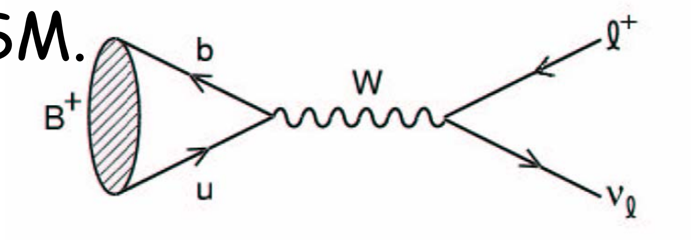


Decay amplitude $\propto m_b m_\tau \tan^2\beta$

Tauonic decay is the most sensitive !

$B \to \tau\,\nu$ (within the SM)

- Proceed via W annihilation in the SM.



- Branching fraction is given by

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

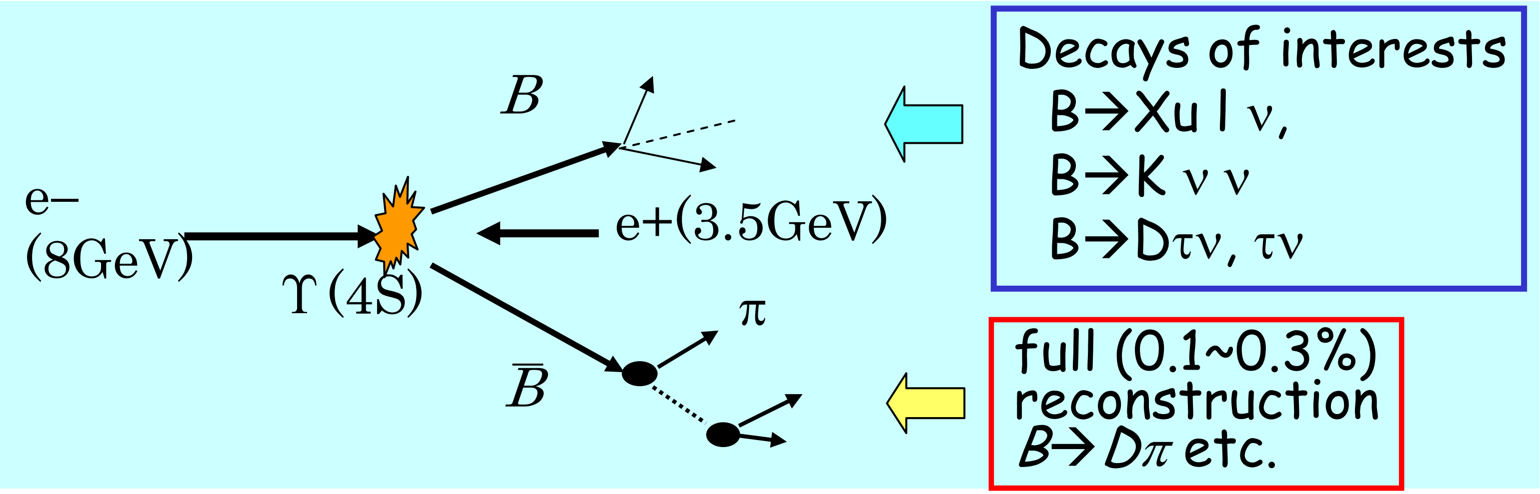
- Provide information of $f_B|V_{ub}|$
  - $|V_{ub}|$ from $B \to X_u\, l\, \nu$ ➡ f_B ⇔ cf) Lattice (δ~16%)
  - $Br(B \to \tau\nu)/\Delta m_d$ ➡ $|V_{ub}|$ / $|V_{td}|$

- Expected branching fraction

$$\left.\begin{aligned} |V_{ub}| &= (3.67 \pm 0.47) \times 10^{-3} \\ f_B &= (0.196 \pm 0.032)\ GeV \end{aligned}\right\} Br(B \to \tau\nu) = (9.3 \pm 3.9) \times 10^{-5}$$

Full Reconstruction Method

- Fully reconstruct one of the B's to tag
  - B production
  - B flavor/charge
  - B momentum



Single B meson beam in offline !

Powerful tools for B decays w/ neutrinos

Fully Reconstructed Sample

- Belle (253fb^{-1}): 275M $B\bar{B} \rightarrow 2.5\times10^5\ B^0\bar{B}^0 + 4.2\times10^5\ B^+B^-$

Fully reconstructed sample

Fit by Argus and Crystal Ball functions

Fully reconstructed sample

Clean environment but small sample: $\varepsilon_{reco} \approx 3\cdot10^{-3}$

Exclusive method: 180 decay channels

Reconstructed channels:

$B^0 \rightarrow D^{(*)-}\pi^+ / D^{(*)-}\rho^+ / D^{(*)-}a_1^+ / D^{(*)-} D_s^{(*)+}$

$B^+ \rightarrow D^{(*)0}\pi^+ / D^{(*)0}\rho^+ / D^{(*)0}a_1^+ / D^{(*)0} D_s^{(*)+}$

$D^{*0} \rightarrow D^0\pi^0$

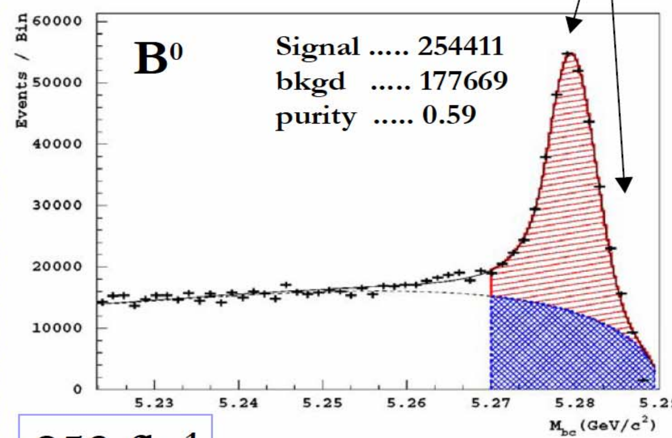
$D^* \rightarrow D^0\pi / D\pi^0$

$D_s^* \rightarrow D_s\gamma$

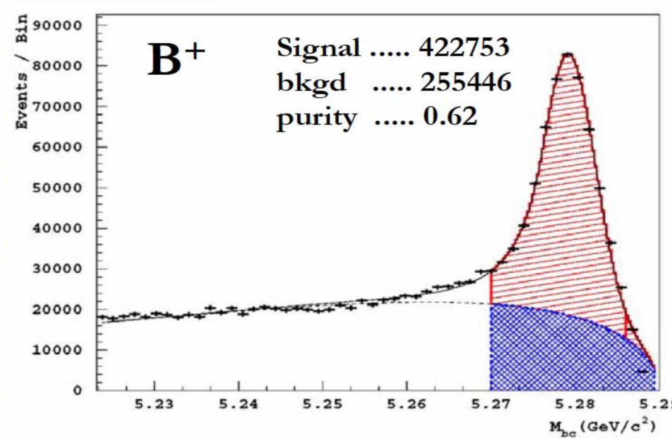
$D^0 \rightarrow K\pi / K\pi\pi^0 / K\pi\pi\pi / K_s\pi^0 / K_s\pi\pi / K_s\pi\pi\pi^0 / KK$

$D \rightarrow K\pi\pi / K\pi\pi\pi^0 / K_s\pi / K_s\pi\pi^0 / K_s\pi\pi\pi / KK\pi$

$D_s \rightarrow K_sK\pi / KK\pi$



253 fb^{-1}



Ilija Bizjak, Ljubljana @ CKM05, March 2005

$B \to \tau\nu$ Status (Belle LP05/EPS05)

- $N_{B\bar{B}}$ (produced) = 275M
- $N_{B^+B^-}$ (full recon.) = 4.0×10^5 (purity 0.55)
- Searched τ decay modes

  $$\tau^- \to \mu^-\nu\bar{\nu},\, e^-\nu\bar{\nu}$$

  $$\tau^- \to \pi^-\nu,\, \pi^-\pi^0\nu,\, \pi^-\pi^+\pi^-\nu$$

  - Cover 81% of the τ decay
- Event selection
  - Residual ECL energy

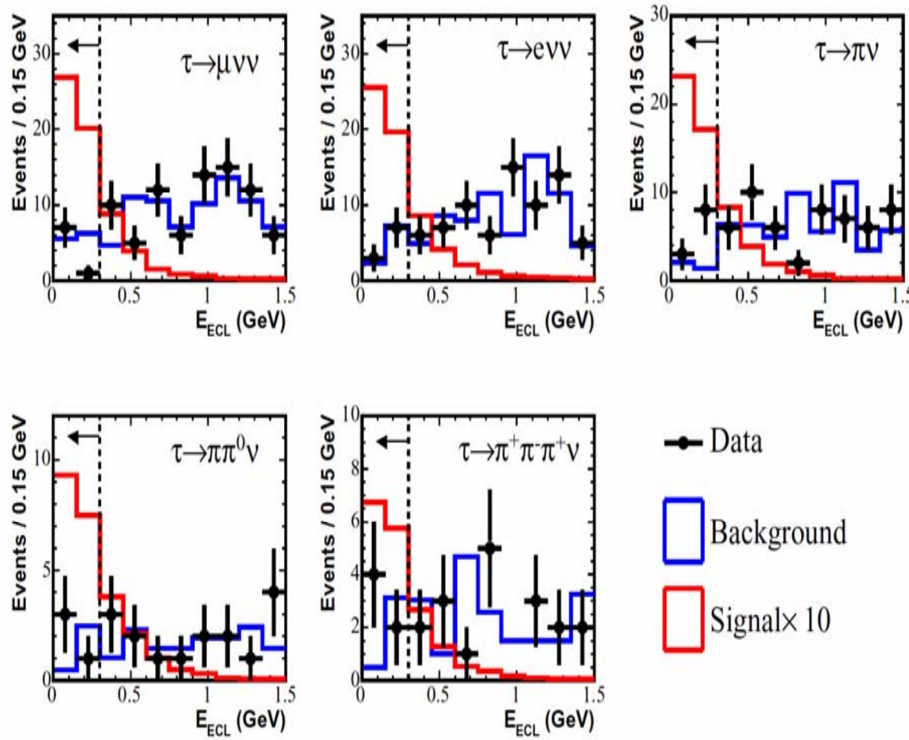
    $$E_{residual} < 0.3\,GeV$$

  - Total net charge

    $$\sum_i Q_i = 0$$

  etc.

Obtained Eresidual



- E_{ECL} shape in the sideband data is used to determine the background in the signal region

See K.Ikado's talk at EPS05 and hep-ex/0507034

Cont'd

- Overall
  - Signal efficiency = 33.7 %
  - Expected signal = 13.5 (SM)
  - Background est. = 31.4
  - N observed = 39

$$Br(B \to \tau\nu) < 1.8 \times 10^{-4} (90\% CL)$$

Upper limit calculated by M.L. fit.

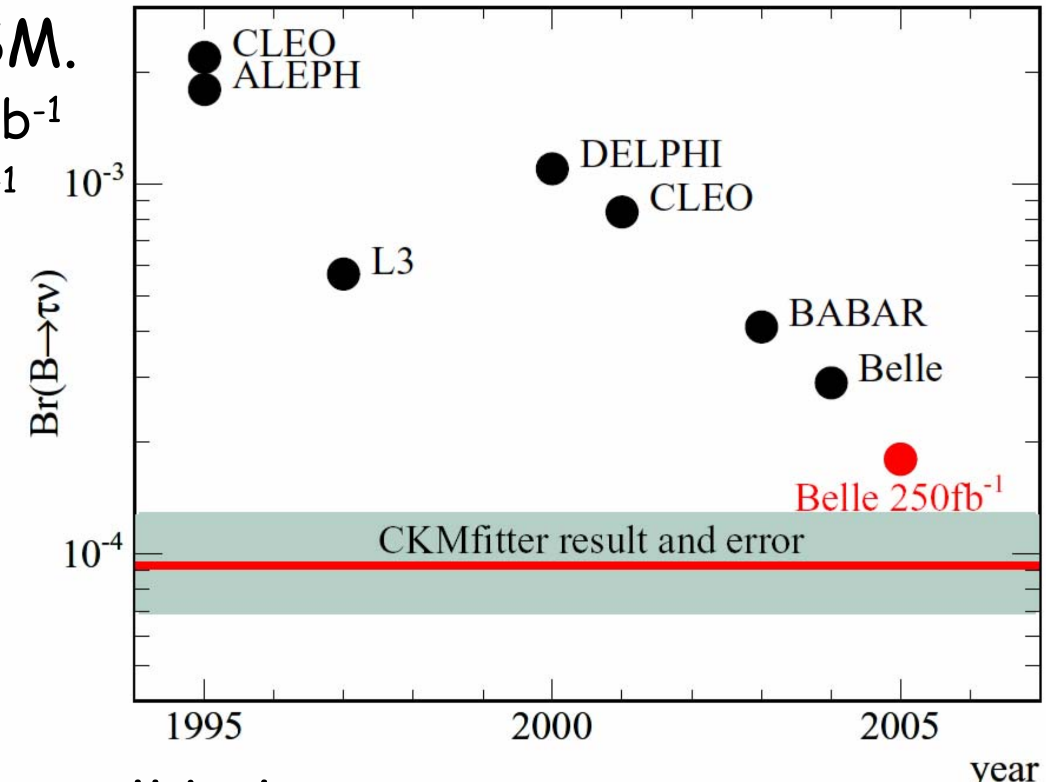
Decay Mode	Efficiency(%)	Signal expeced	Background expeced	Observe
$\tau^- \to \mu^- \nu\bar{\nu}$	9.8 ± 0.1	3.9 ± 0.1	11.8 ± 3.6	8
$\tau^- \to e^- \nu\bar{\nu}$	9.4 ± 0.1	3.8 ± 0.1	9.5 ± 3.2	10
$\tau^- \to \pi^- \nu$	8.4 ± 0.1	3.4 ± 0.1	3.5 ± 1.7	11
$\tau^- \to \pi^- \pi^0 \nu$	3.5 ± 0.1	1.4 ± 0.1	3.0 ± 1.8	4
$\tau^- \to \pi^- \pi^+ \pi^- \nu$	2.6 ± 0.1	1.0 ± 0.1	3.6 ± 2.2	6
Total	33.7 ± 1.4	13.5 ± 0.2	31.4 ± 5.9	39

No significant excess

$\tau \to \pi^- \nu$ mode has the best S/N ~1.

Prospect

- Will soon reach the SM.
  - 3σ evidence at ~700 fb^{-1}
  - 5σ discovery at ~2 ab^{-1}
- Expected precision at Super-B
  - 13% at 5 ab^{-1}
  - 7% at 50 ab^{-1}



- Search with $D^{(*)}\, l\, \nu$ tag will help.

  (BaBar 232M $B\bar{B}$, hep-ex/0507069)
  - Tag eff ~ 1.75 x 10-3
  - Signal selection eff. ~31%
  - Similar S/N to Belle

$$Br(B \to \tau\nu) < 2.8\times10^{-4}(90\%CL)$$

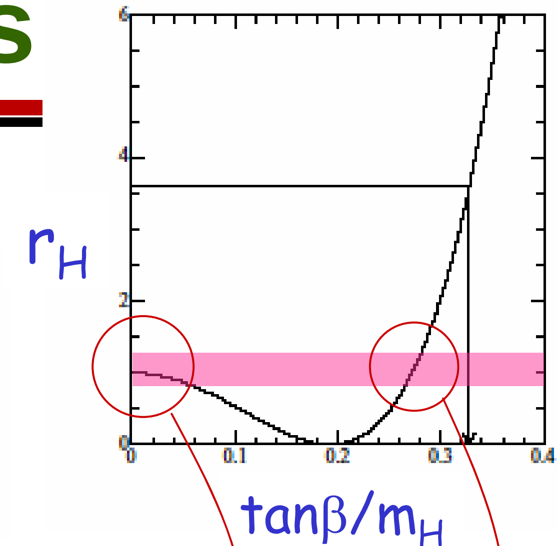
Impact to Charged Higgs

- $H^{\pm}$ effects to branching fraction

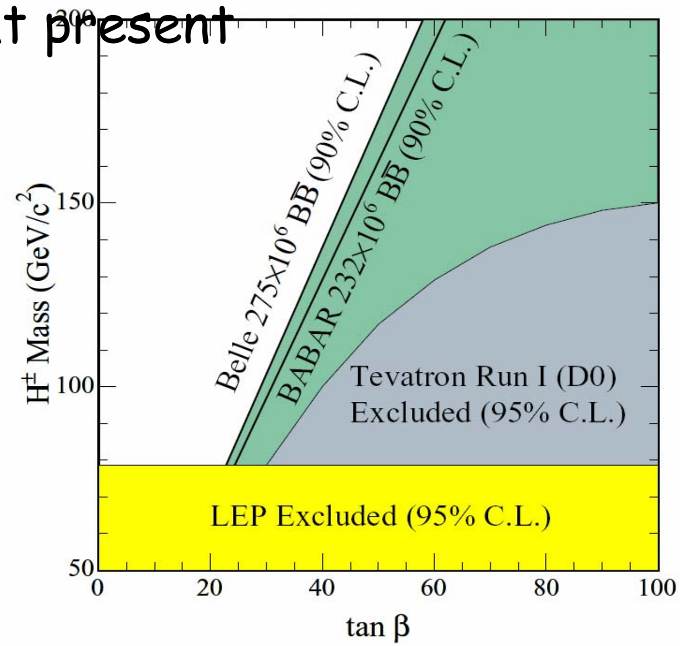
$$\mathcal{B}(B \to \tau\nu) = \mathcal{B}(B \to \tau\nu)_{\rm SM} \times r_H,$$

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

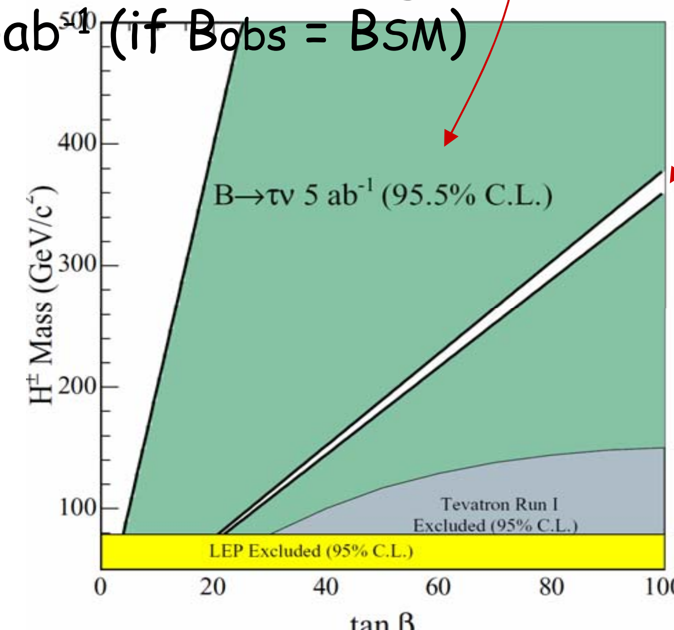
Phys. Rev. D **48**, 2342 (1993)



90%CL excluded region at present



95% CL excluded region at $5\,\mathrm{ab}^{-1}$ (if $B_{obs} = B_{SM}$)



B→D τ ν (MC studies)

- Use fully reconstructed samples.
- T decay modes

  $\tau^- \to \mu^- \nu\bar{\nu}, e^- \nu\bar{\nu}\ , \pi^- \nu, \rho^- \nu$

- Analysis cuts;
  - Reject events w/ *p, KL*
  - Reject *D*$^{(*)}$ $\tau\,\nu$ contamination

    $$\left|m_{D^{*0}} - m_{D^0} - 142\right| < 10\,\mathrm{MeV}/c^2$$

  - No remaining charged or π^0 tracks
  - ECL residual energy

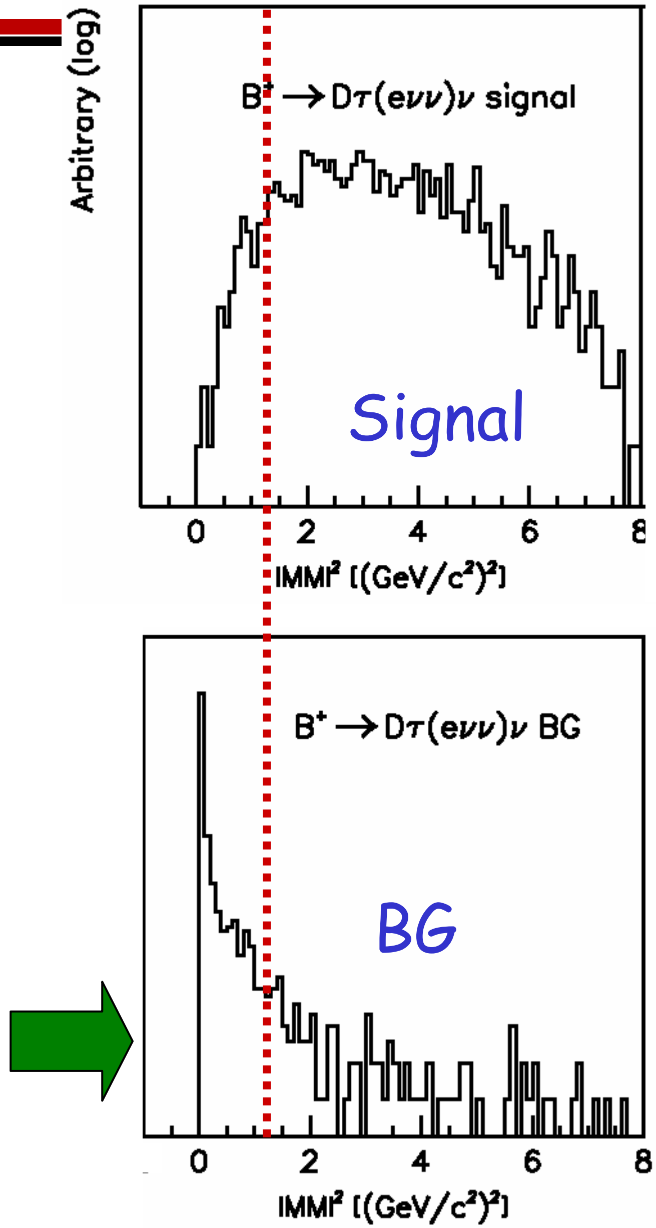
    $$E_{residual} < 100 MeV$$

  - Angle between two ν's

    $$-1.0 \le \cos\theta_{\nu\nu} \le 0.8$$

  - Missing mass

    $$\left|p_B - p_D - p_\ell\right|^2 > 1.2\,(GeV/c^2)^2$$



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- Signal selection efficiency

$\bar{D}^0\tau^+(e^+\bar{\nu}_\tau\nu_e)\nu_\tau$	10.2%	$\bar{D}^0\tau^+(\pi^+\bar{\nu}_\tau)\nu_\tau$	26.1%
$\bar{D}^0\tau^+(\mu^+\bar{\nu}_\tau\nu_e)\nu_\tau$	2.6%	$\bar{D}^0\tau^+(\rho^+\bar{\nu}_\tau)\nu_\tau$	13.3%

- Expectation at 5 / 50 ab^{-1} for B$^+$ decay

	5ab^{-1}				50ab^{-1}			
Mode	Nsig	Nbkg	Σ	dB/B	Nsig	Nbkg	Σ	dB/B
$\bar{D}^0\tau^+(\ell^+\bar{\nu}_\tau\nu_\ell)\nu_\tau$	280	550	12.7	7.9%	2800	5500	40.3	2.5%
$\bar{D}^0\tau^+(h^+\bar{\nu}_\tau)\nu_\tau$	620	3600			6200	36000		

5σ observation possible at 1ab^{-1}

- Major background source

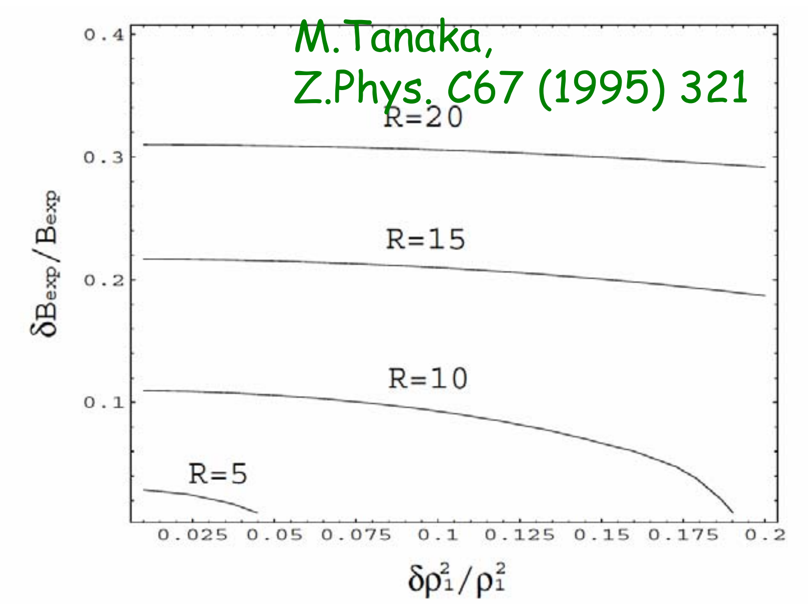
Missing charged and γ tracks from B→D$^{(*)}$ l ν X (incl. slow π)

Constraint to Charged Higgs

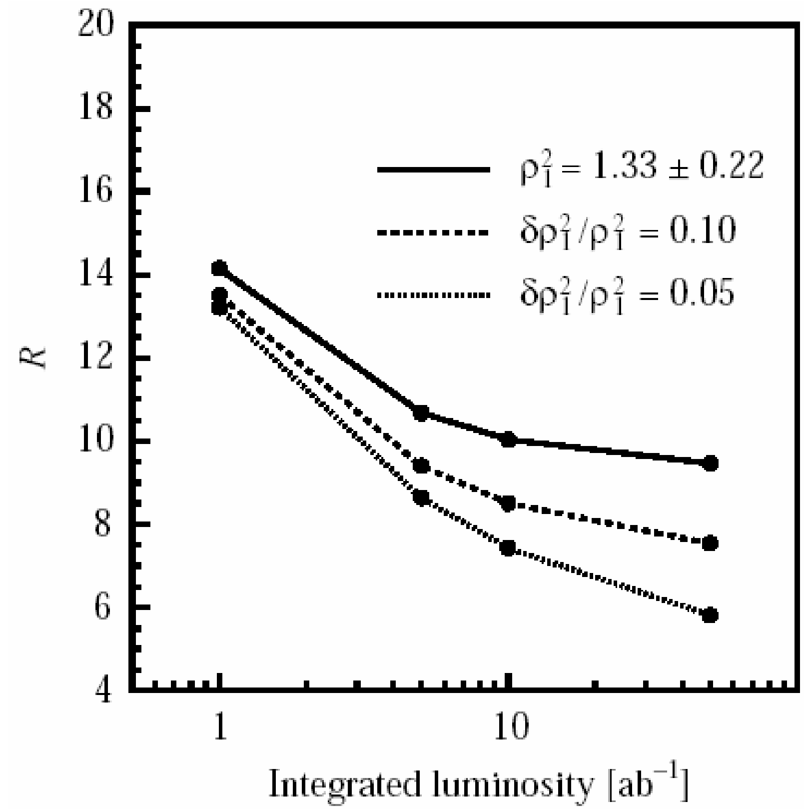
- Once branching fraction is measured, we can constrain R.

$$R \equiv \frac{M_W}{M_H} \tan \beta$$

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



Form factor error

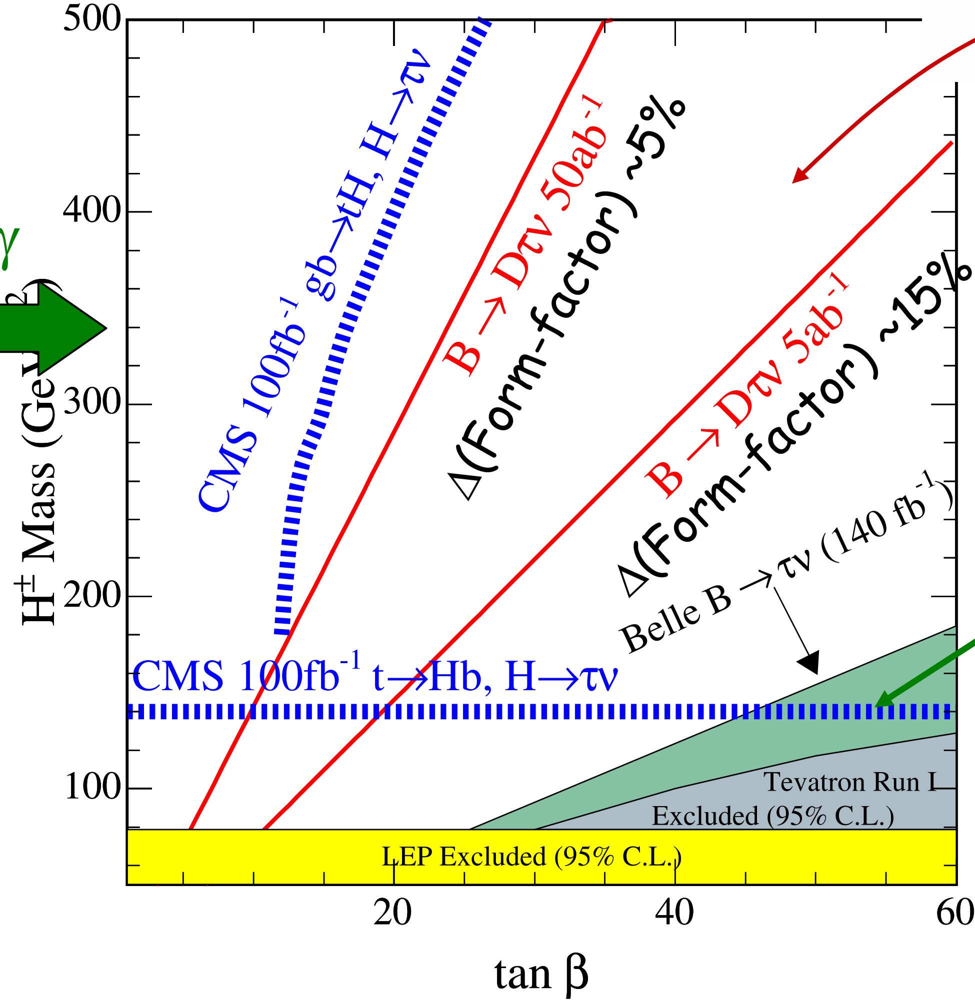


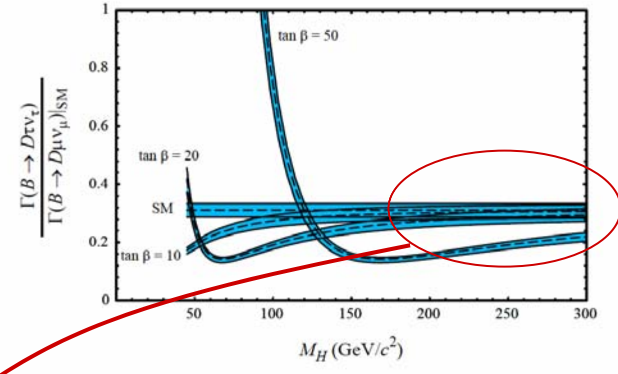
ρ can be determined experimentally by B semiletonic decays

$R < 11$ at 5ab^{-1}

Cont'd

Constraint
From b→sγ

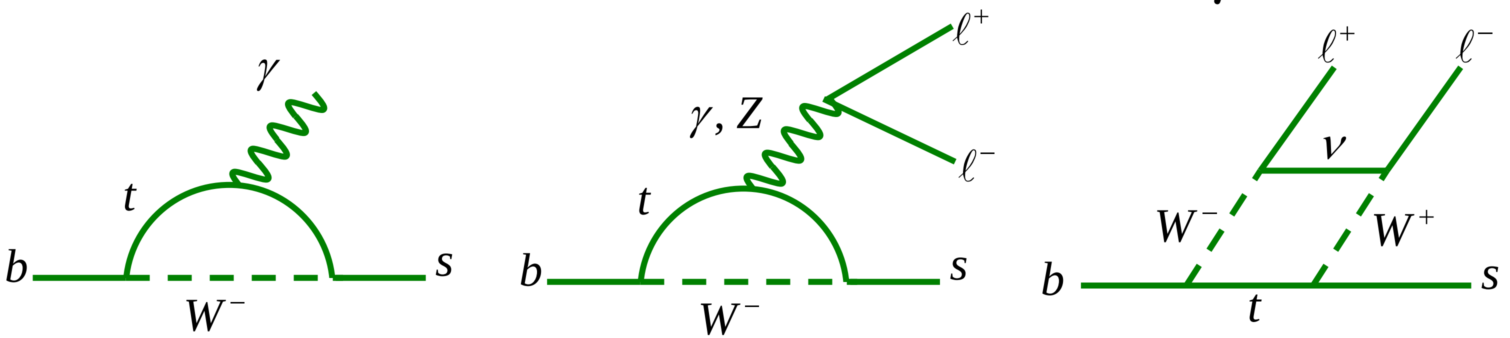




Present limit
From B→τ ν

b→sγ/sl$^+$l$^-$

- Possible to search for NP in theoretically clean way.



Effective Hamiltonian for b→s

$$H_{eff} = -\frac{4G_F}{\sqrt{2}} V_{ts}^* V_{tb} \sum_{i=1}^{10} C_i(\mu) O(\mu)$$

$|C_7|$ by B→Xsγ,
Sign of C_7, C_9, C_{10} by B→Xsll

- Many observables;
  - Branching fractions
  - Mixing indcued CPV
  - Direct CPV
  - Forward-backward asym.
  - Ratio of exclusive modes

M(H$^+$) > 350 GeV already in TYPE II 2HDM

Measurement of $B(B \to X_s l^+ l^-)$

- Semi-inclusive technique
  - X_s is reconstructed from K^+ or K_s + 0-4π (at most one π^0 is allowed)
  - $M_{Xs} < 2.0$ GeV
- Electron or muon pair
  - $M_{ll} > 0.2$GeV
  - Charmonium veto

$$\mathcal{B}(B \to X_s \ell^+ \ell^-) = (4.11 \pm 0.83\,^{+0.85}_{-0.81})10^{-6}$$

$$\mathcal{B}(B \to X_s e^+ e^-) = (4.04 \pm 1.30\,^{+0.87}_{-0.83})10^{-6},$$

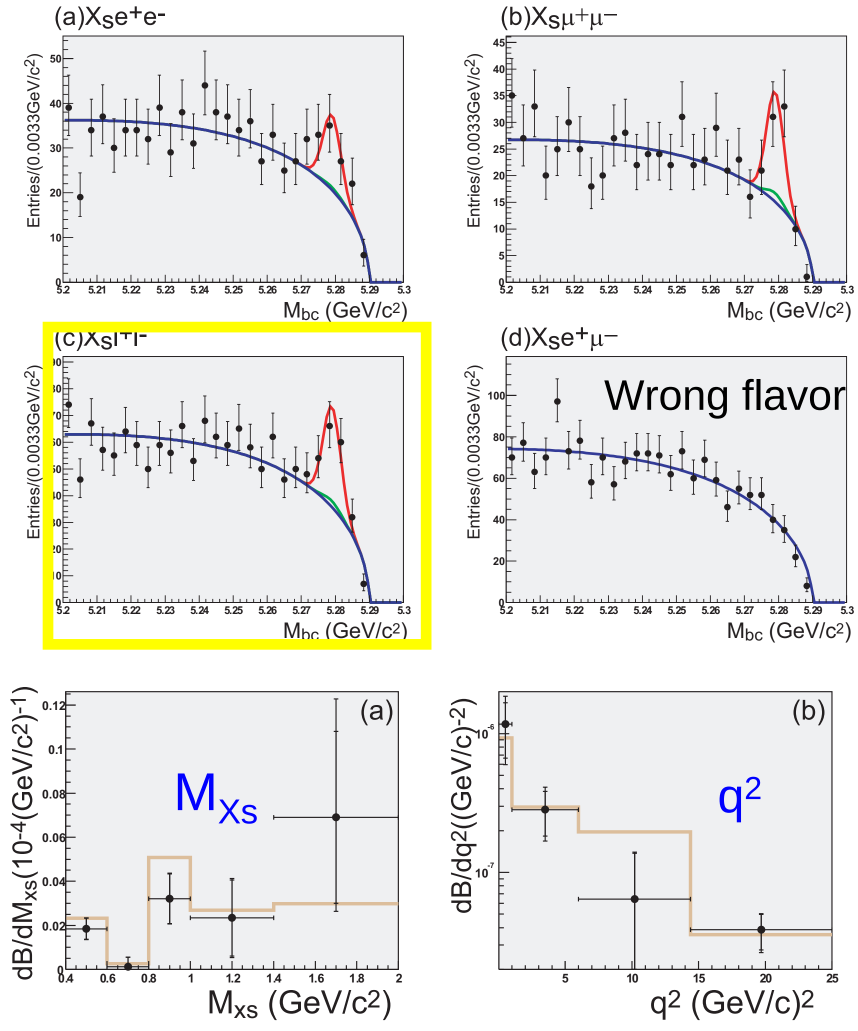
$$\mathcal{B}(B \to X_s \mu^+ \mu^-) = (4.13 \pm 1.05\,^{+0.85}_{-0.81})10^{-6}$$

Theoretical prediction by Ali et al.

$$\mathcal{B}(B \to X_s \ell^+ \ell^-) = (4.20 \pm 0.70)10^{-6}$$

M. Iwasaki et al. submitted to PRD, hep-ex/0503044

140/fb data

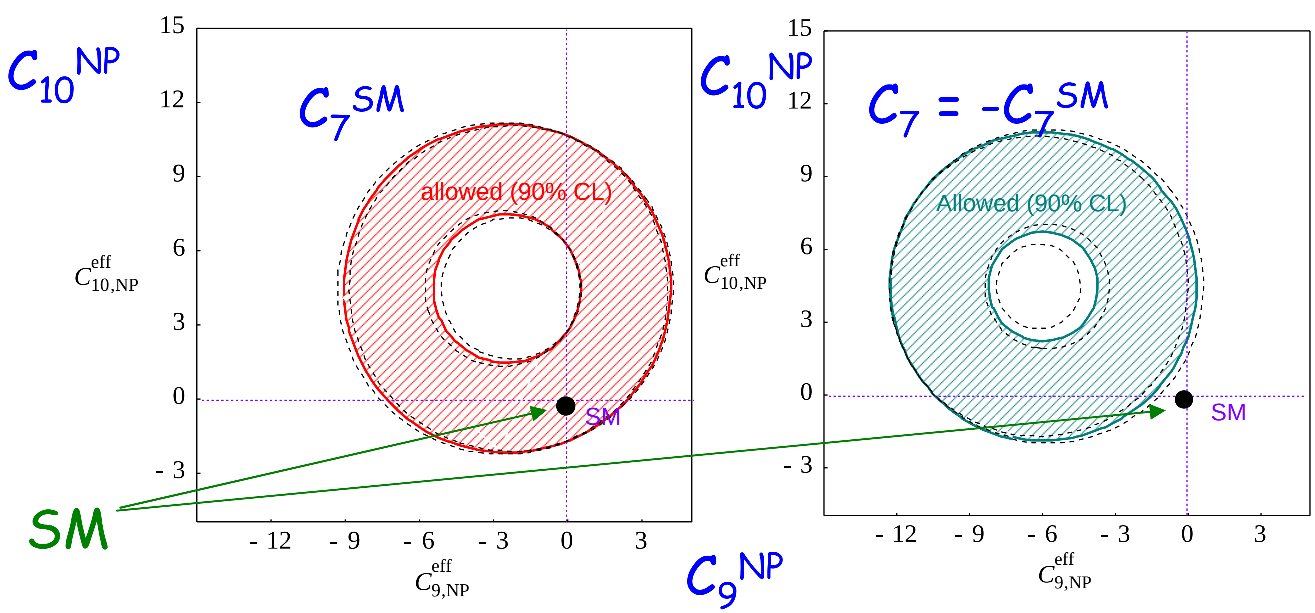


Constraints on C_i from $B(B \to X_s l^+ l^-)$

P.Gambino, U.Haisch and M.Misiak PRL 94 061803 (2005)

- Clean prediction for $B(B \to X_s ll)$ with $1<q^2<6GeV^2$ is available.
  - Combine Belle and Babar results
  - Sign of C_7 flipped case with SM C_9 and C_{10} value is unlikely.

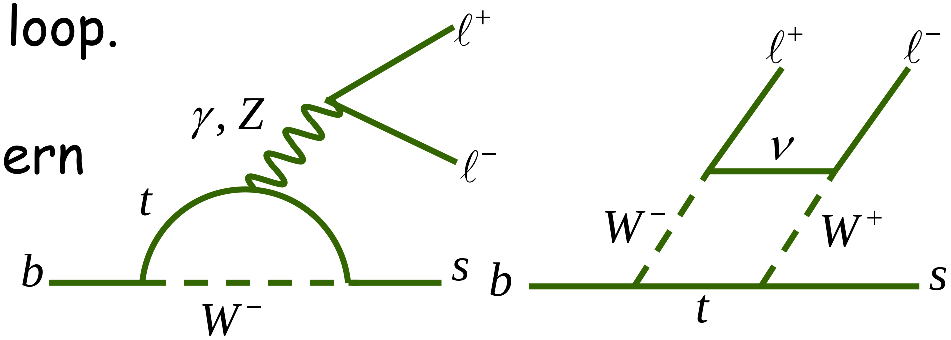
BF	Belle	Babar	WA	SM	$C_7 = -C_7^{SM}$
$q^2>(2m_\mu)^2$	4.11 ± 1.1	5.6 ± 2.0	4.5 ± 1.0	4.4 ± 0.7	8.8 ± 0.7
$1<q^2<6GeV^2$	1.5 ± 0.6	1.8 ± 0.9	1.60 ± 0.5	1.57 ± 0.16	3.30 ± 0.25



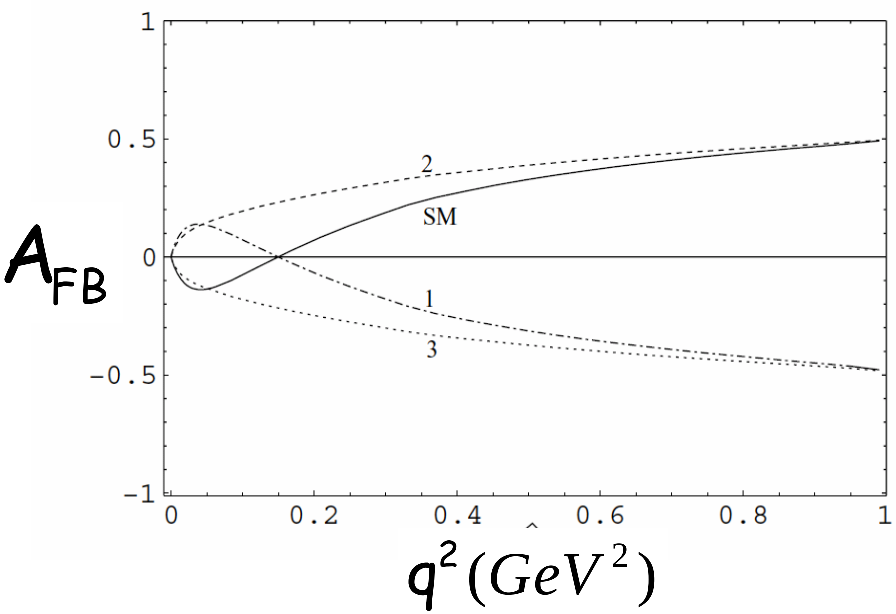
Donut : 90% CL allowed region

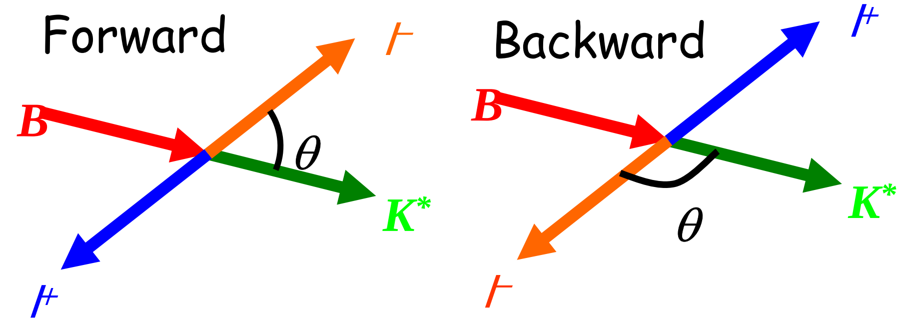
B→K*ll FB Asymmetry

- Good electroweak probe for b→s loop.
- q^2 distribution has different pattern depending on sign(C_7).



$$A_{FB} \propto \Re\left[C_{10}^{*}\left(sC_9^{eff}(s)+r(s)C_7\right)\right]$$





$$A_{\mathrm{FB}}(q^2) = \frac{\Gamma(q^2, \cos\theta_{B\ell^-} > 0) - \Gamma(q^2, \cos\theta_{B\ell^-} < 0)}{\Gamma(q^2, \cos\theta_{B\ell^-} > 0) + \Gamma(q^2, \cos\theta_{B\ell^-} < 0)}$$

q_0(the point w/ A_{FB}=0) is sensitive for New Physics

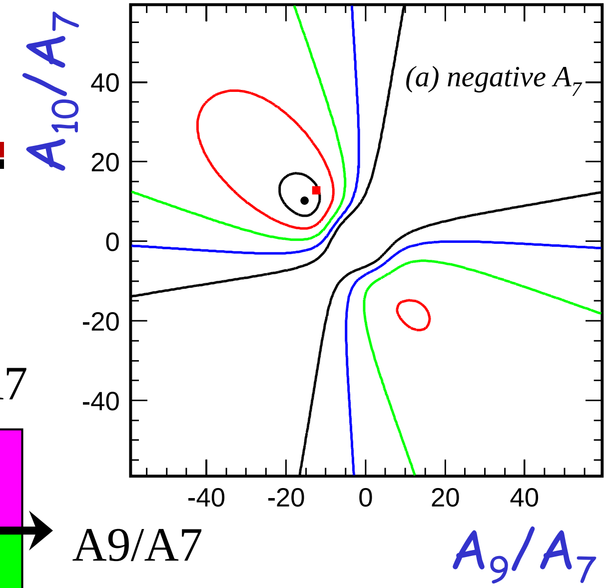
SM; $q_0^2=(4.2\pm0.6)GeV^2$

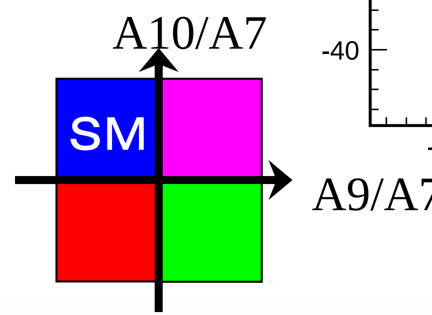
A_{FB}: Belle Summer '05

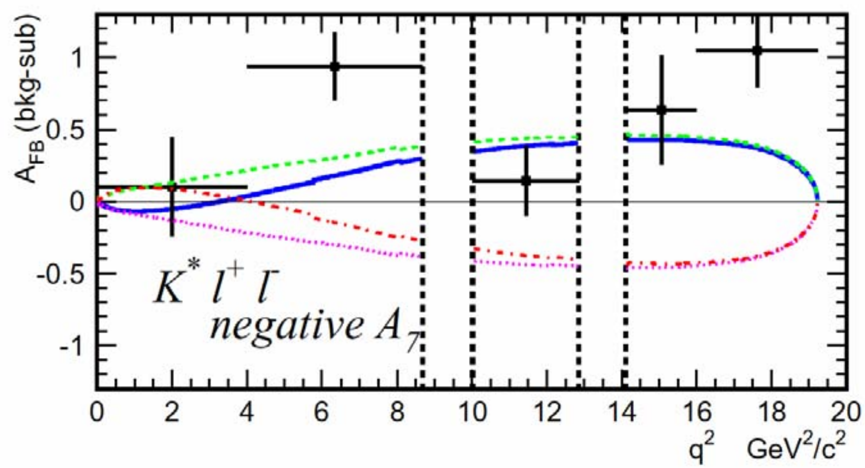
- $357 fb^{-1}$ (386M BB)
- N(K*ll)=114+-14 (purity 44%)
- Unbinned M.L. fit to $d\Gamma^2/dsd(\cos\theta)$
  - 8 event categories
    - Signal + 3 cross-feed + 4 bkg.
  - Ali et al's form factor
  - Fix $|A_7|$ to SM
  - Float A_9/A_7 and A_{10}/A_7
- $A_{FB}^{\text{bkg-sub}}(B \to K^*\ell\ell) = 0.56 \pm 0.13(\text{stat.})$

$$A_9/A_7 = -15.3^{+3.4}_{-4.8} \pm 1.1,$$
$$A_{10}/A_7 = 10.3^{+5.2}_{-3.5} \pm 1.8,$$

$$A_9/A_7 = -16.3^{+3.7}_{-5.7} \pm 1.4,$$
$$A_{10}/A_7 = 11.1^{+6.0}_{-3.9} \pm 2.4,$$





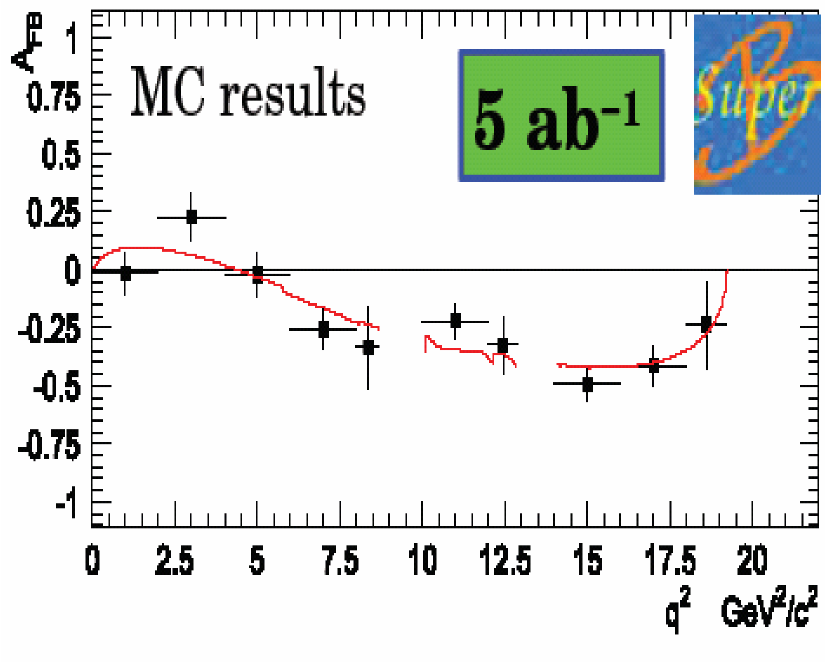


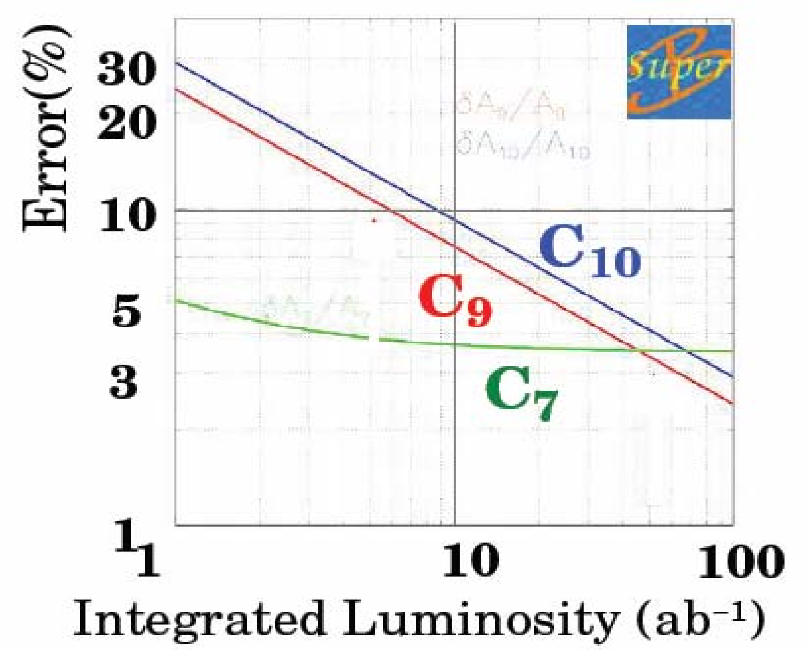
Sign of A_9A_{10} is negative !

See Hep-ex/0508009 &
A.Ishikawa's talk at EPS05

Prospect at Super-B

1000 pseudo experiments w/ SM input values





Expected precision @ 5ab^{-1}

δC_9 ~ 11%

δC_{10} ~14%

$\delta\, q_0^2/q_0^2$ ~11% → 5% at 50ab^{-1}

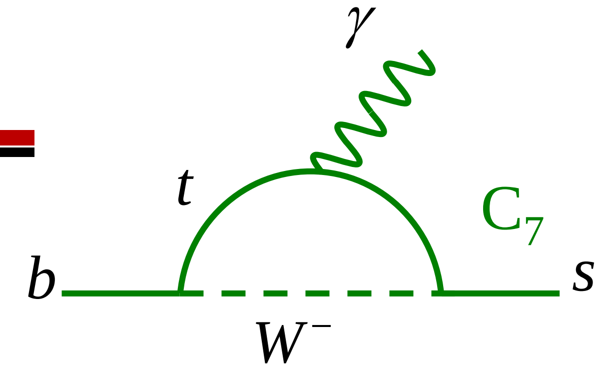
Radiative Decays

- Inclusive Br($b \to s\gamma$) — $|C_7|$, SF for $|V_{ub}|$
- $B \to K^*\gamma$ isospin asymmetry (Δ+-) — sign of C_7
- Mixing induced CPV
- Direct CPV in $B \to X_s\gamma$
- $B \to X_d\,\gamma$

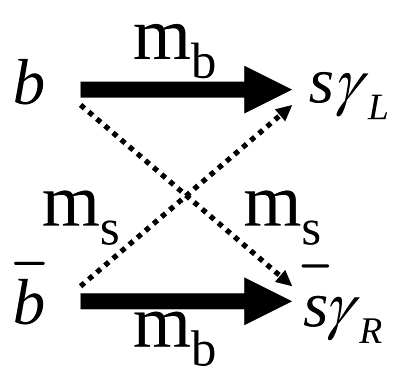
Summary by M.Nakao
1st Super-B workshop
at Hawaii

	$0.5\ \mathrm{ab}^{-1}$	$5\ \mathrm{ab}^{-1}$	$50\ \mathrm{ab}^{-1}$
Branching fraction			
$\mathcal{B}(B \to X_s\gamma)$	<10%	"5%"	still 5%
$\mathcal{B}(B \to X_d\gamma)$	—	—	possible?
Sign of C_7			
$\Delta_{0+}(B \to K^*\gamma)$	4%	2%	no better
$\Delta_{0+}(B \to \rho\gamma)$	possible?	reasonable	precise
Mixing CPV			
$S(K_S^0\pi^0\gamma)$	—	0.12	0.05
$S(K_S^0\phi\gamma)$	—	0.5	0.15
$S(K_1(1270)\gamma)$	—	difficult?	possible?
Direct CPV			
$A_{CP}(B \to X_s\gamma)$ inclusive	4.5%	1.4%	0.5%
$A_{CP}(B \to X_s\gamma)$ sum-of-excl.	3%	1%	0.5%
$A_{CP}(B \to K^*\gamma)$	1.8%	0.6%	0.2%

$B \to X_s\gamma$ CP Asymmetry

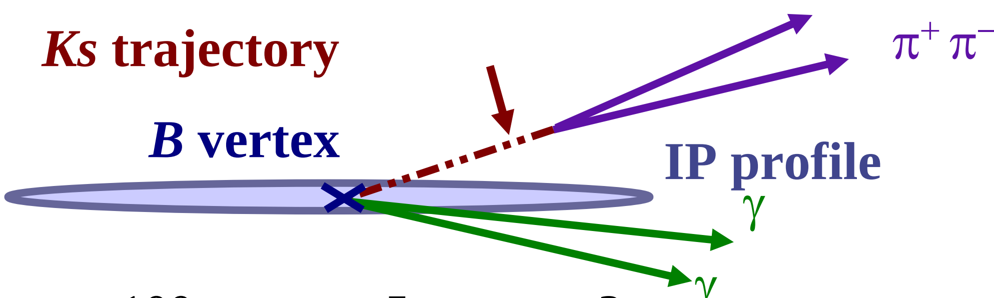


- Sensitive to NP.
- Theoretically clean.
- Standard Model "~Zero".
  - Gamma is polarized, and the final state is almost flavor specific.
  - Helicity flip of γ suppressed by $\sim m_s/m_b$



- Time dependent CPV requires vertex reconstruction with Ks $\to \pi+\pi-$

Vertex recon. Eff.
51% (SVD2)
40% (SVD1)



$\sigma_x = 100\mu m, \sigma_y = 5\mu m, \sigma_z = 3mm,$

Possible at e^+e^- B-factory

$B^0 \rightarrow K_S \pi^0 \gamma$ tCPV: Belle Summer '05

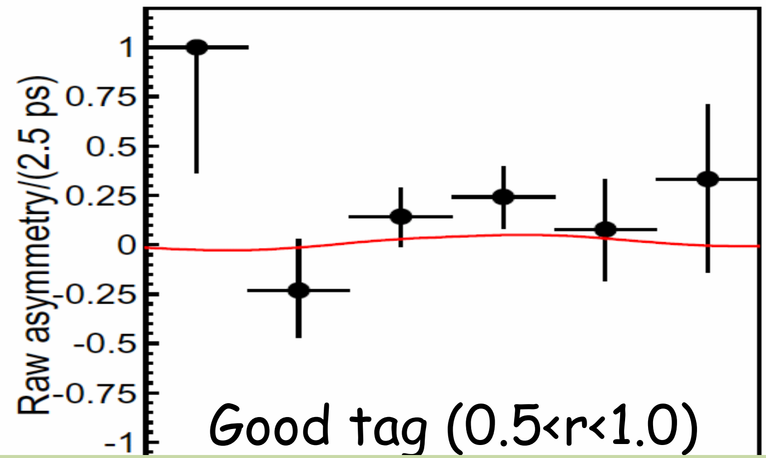
- 386MBB
- $M(Ks\pi^0) < 1.8GeV/c^2$
  - NP effect is independent of the resonance structure.
- Two $M(Ks\pi^0)$ regions(MR1:0.8-1.0GeV/c^2 / MR2: <1.8GeV/c^2)
- 70+-11 (45+-11) events in MR1(2).

Atwood, Gershon, Hazumi, Soni, PRD71, 076003 (2005)

Result

S= +0.08 ±0.41 ±0.10

A= +0.12±0.27±0.10

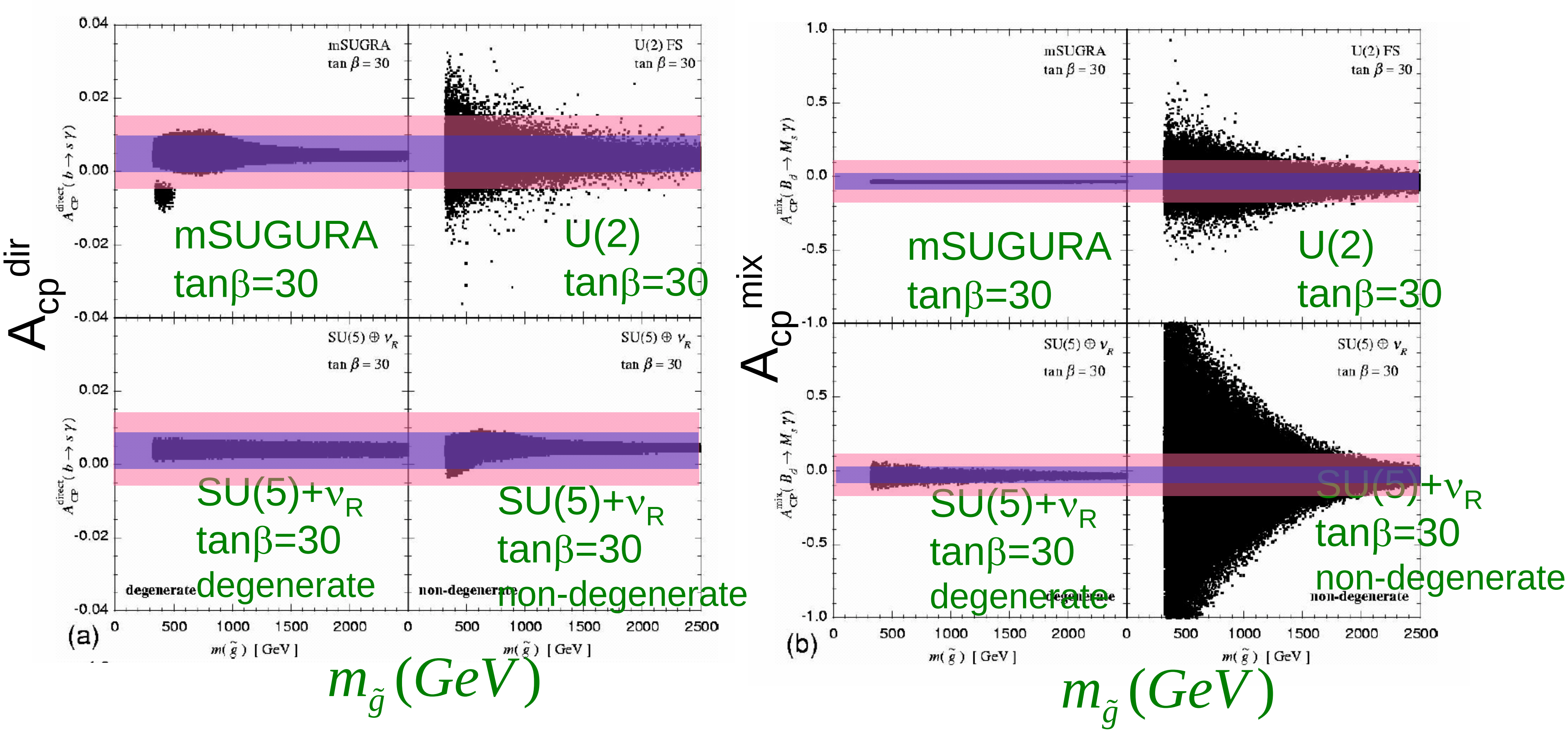


	Present Belle (stat./syst.)	$5ab^{-1}$	$50ab^{-1}$
$A_{cp}^{mix}(B \rightarrow K^*\gamma,\ K^* \rightarrow Ks\pi^0)$	0.41 / 0.10	0.14	0.04
$A_{cp}^{dir}(B \rightarrow Xs\gamma)$	0.051 / 0.038	0.011	0.005

$A_{cp}(B \rightarrow X_s\gamma)$ vs SUSY models

5ab^{-1} 50ab^{-1}

Direct CPV Mixing CPV



T. Goto, Y.Okada, Y.Shimizu,T.Shindou, M.Tanaka
hep-ph/0306093, also in SuperKEKB LoI

Summary

- Tauonic, Radiative and Electroweak B decays are of great importance to probe new physics.
- We are starting to measure $B \to \tau\nu$, $D\tau\nu$, $A_{FB}(K^*ll)$, $A_{CP}(K\pi^0\gamma)$ etc. at the current B factories.

  Hot topics in the coming years !
- For precise measurements, we need Super-B !

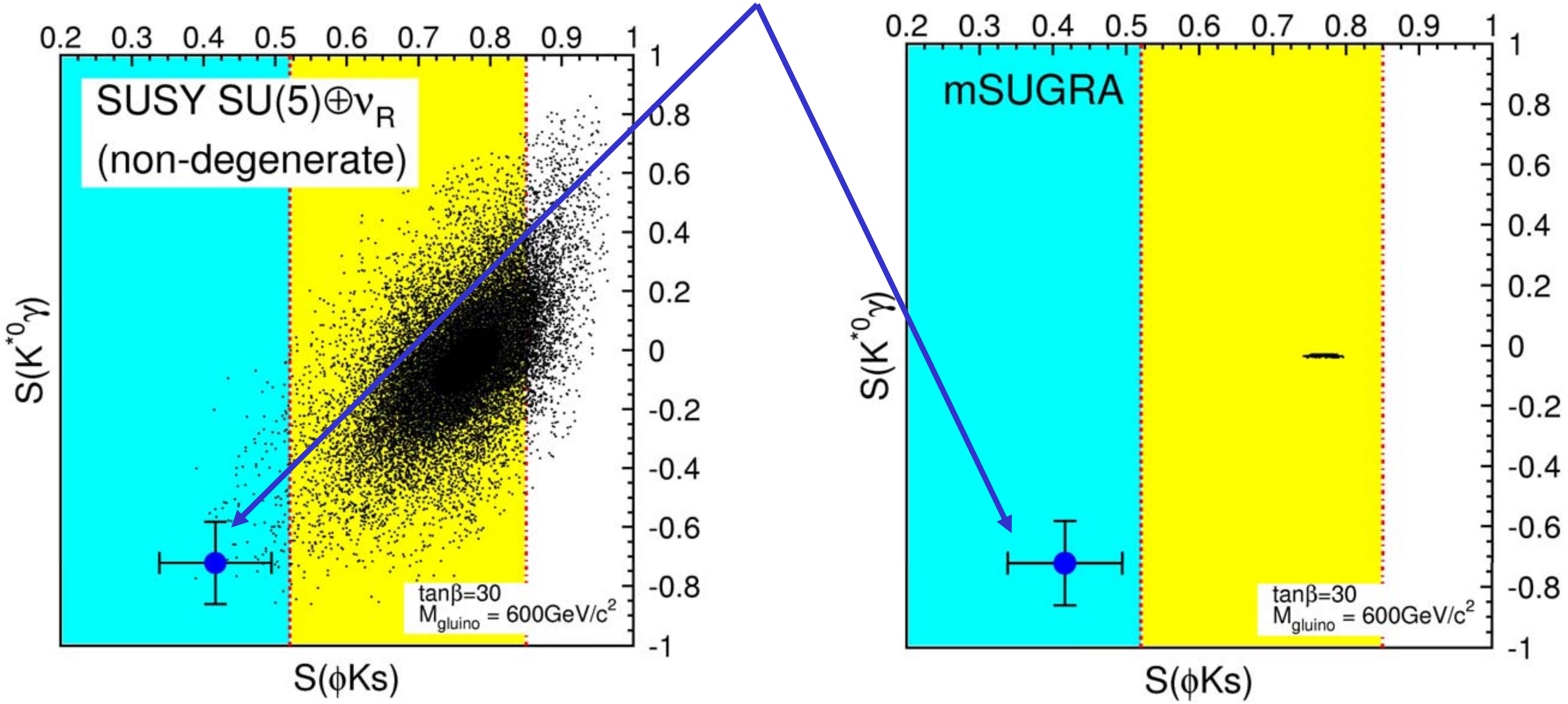
  Expected precision ($5ab^{-1} \to 50ab^{-1}$);
  - Br(tv): $13\% \to 7\%$
  - Br($D\tau\nu$): $7.9\% \to 2.5\%$
  - q_0^2 of $A_{FB}(K^*ll)$: $11\% \to 5\%$
  - $A_{CP}(K\pi^0\gamma)$ tCPV: $0.14 \to 0.04$

Backup Slides

CPV in b→s and SUSY Scenario

- Different SUSY breaking scenario can be distinguished in $A_{cp}^{mix}(\phi Ks)$ - $A_{cp}^{mix}(K^{*0}\gamma)$ correlation.

Expected precision at $5ab^{-1}$



Correlation of other ovservables are also useful.

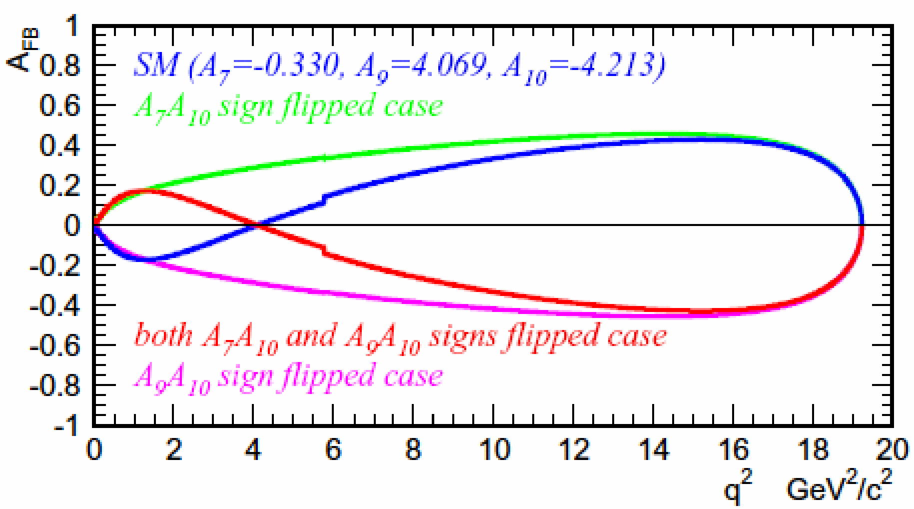
$A_{cp}^{dir}(X_s\gamma)$, $A_{FB}(X_s ll)$, $Br(\tau \rightarrow \mu\gamma)$, CKM

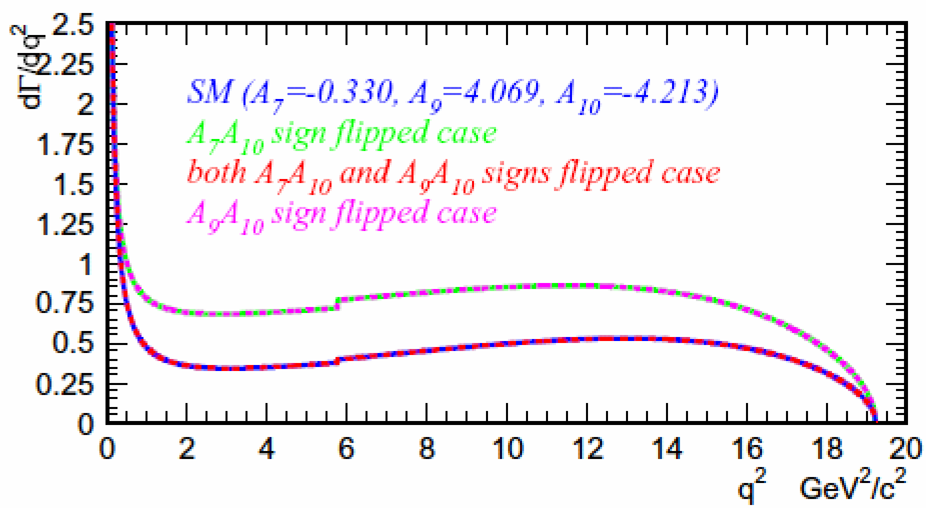
New Measurement of $A_{FB}(q^2)$ in K*ll

- Forward-backward asymmetry is induced by interference btw virtual photon and Z^0 contributions.
- Relative signs of C_7 to C_{10} and C_9 to C_{10} can be determined from $A_{FB}(B \rightarrow K^*ll)$!!

$$\frac{d}{d\hat{s}}(\Gamma_F^{K^*}-\Gamma_B^{K^*}) = -\frac{G_F^2\alpha^2 m_B^5}{2^8\pi^5}|V_{ts}^*V_{tb}|^2\,\hat{s}\hat{u}(\hat{s})^2$$
$$\times\left[\mathrm{Re}(C_9^{\mathrm{eff}})C_{10}VA_1+\frac{\hat{m}_b}{\hat{s}}C_7^{\mathrm{eff}}C_{10}(VT_2(1-\hat{m}_{K^*})+A_1T_1(1+\hat{m}_{K^*}))\right].$$

We do not use C_i but A_i which is leading coefficients.





Fit to q^2 and $\cos\theta$ for the di-lepton system

- Fit to normalized double differential decay width $(1/\Gamma)\, d^2\Gamma/dsd\cos\theta$
- 8 event categories
  - signal
  - 3 cross-feeds
    - Correctly flavor tagged K*ll
    - Incorrectly flavor tagged K*ll
    - $b \to sll$ process other than K*ll
  - 4 backgrounds (fraction)
    - di-lepton background (80%)
    - K*lh background (h=K, π) (17%)
    - K*hh background (1.7%)
    - ψ background (1.3%)
- Ali et al.'s form factor model is used.
- Event by event signal fraction is obtained from the M_{bc} fit.
- Fix A_7 to the SM value -0.330 or sign flipped value +0.330
- Float A_9/A_7 and A_{10}/A_7