# *CPV and Charged Higgs at SuperKEKB*

**References**

- **"SuperKEKB Letter of Intent (LoI)", KEK Report 2004-4.**
- **"Physics at Super B Factory", A. G. Akeroyd et al., hep-ex/0406071.**
- **6th Workshop at Higher Luminosity B Factories, Nov. 16-18, 2004 at KEK ( http://belle.kek.jp/superb/workshop/2004/HL6/ ).**

**M. Hazumi (KEK)**

**CPNSH2, Dec. 2-3, 2004**

# Introduction

Abstract

SuperKEKB is a proposed major upgrade of the KEK B factory to achieve an unprecedented luminosity of $5\times10^{35}$ cm$^{-2}$s$^{-1}$, about 40 times larger than the present world record achieved by the KEKB collider. It is an ideal machine to elucidate the **new physics flavor problem in the LHC era**. In this talk we explain **clean new physics signals in *CP* violation in B decays**, which can be studied at SuperKEKB but can not at LHC. We also briefly mention charged Higgs studies in B decays, which are also unique at SuperKEKB.

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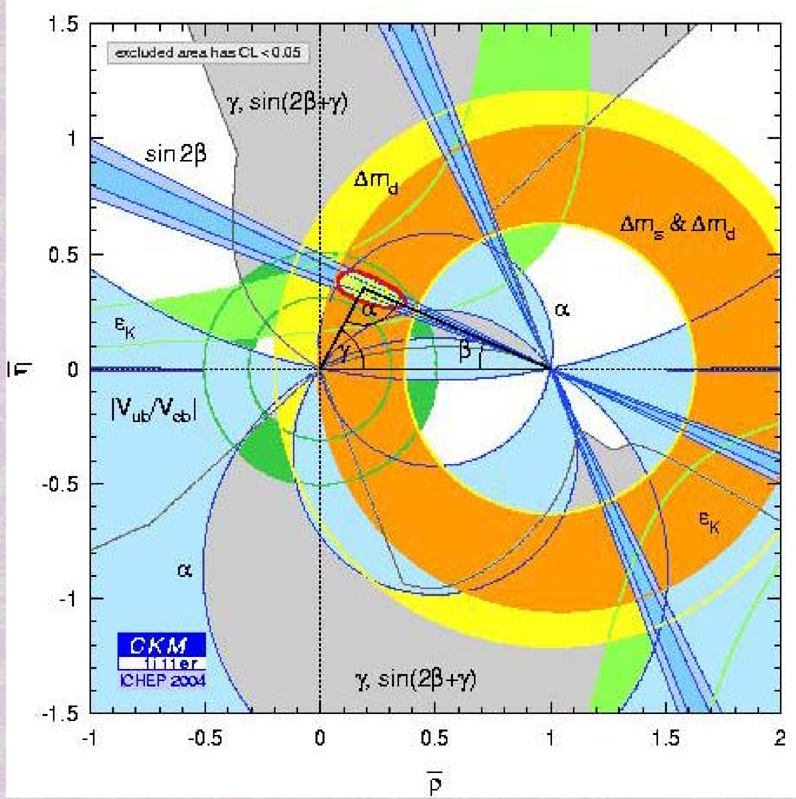
We also show that different SUSY breaking scenarios can be discriminated by using these measurements.

# Kobayashi-Maskawa (KM) model of *CP* violation

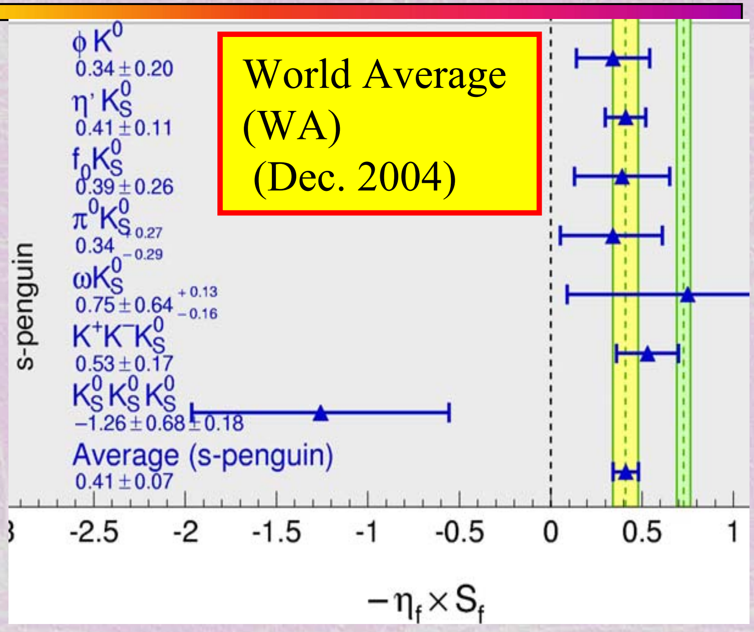
- Beautiful agreements so far!
  - KM is fairly well tested !
  - Unlikely to see a large deviation from KM
- New paradigm: search for corrections to KM from BSM
  - Difficulty in Baryogenesis
  - Many *CP*-violating phases in BSM
- Present constraints mainly with transitions between
  - $3^{rd} \leftrightarrow 1^{st}$ generations
  - $2^{nd} \leftrightarrow 1^{st}$ generations




**$b \leftrightarrow s$ ($3^{rd} \leftrightarrow 2^{nd}$ ) should be explored !**

# Possible discovery before LHC

$$\sin 2\phi_1(b \to s\bar{q}q) = \begin{cases} 0.39 \pm 0.11 & \text{(Belle)} \\ 0.42 \pm 0.10 & (BABAR) \end{cases}$$




**WA**

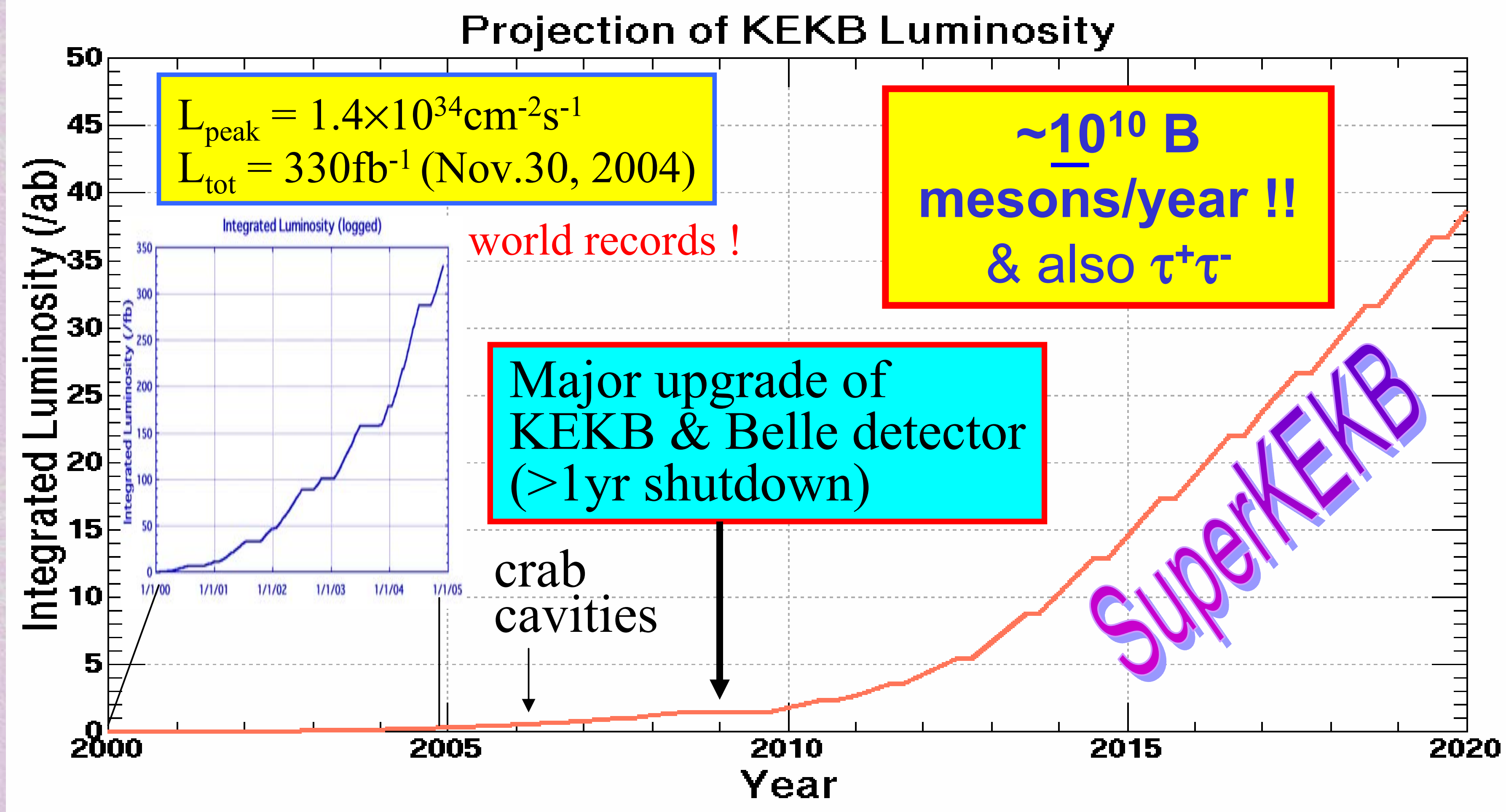
$$\sin 2\phi_1(b \to s\bar{q}q) = 0.41 \pm 0.07$$
$$\sin 2\phi_1(b \to c\bar{c}s) = 0.726 \pm 0.037$$

**$CL = 1.2 \times 10^{-4}\ (3.8\sigma)$**

~1ab$^{-1}$ (by 2008) from each → >7σ observation if the central value unchanged.
Large impact on LHC physics and cosmology if new CPV in b → s:
e.g. ~~MFV (mSUGRA etc.)~~ ? ~~Gauge-mediated SUSY breaking~~ ?

To know what the new physics really is, however,
we need much higher luminosity and "synergy" with LHC.

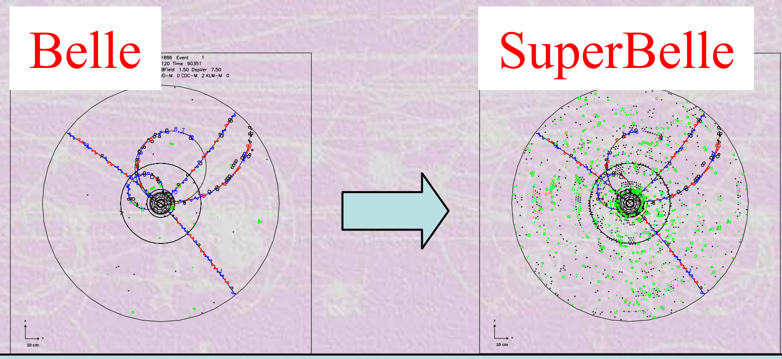
# KEKB Collider Upgrade Scenario




| | | | |
|---|---|---|---|
| $L_{peak}$ ($cm^{-2}s^{-1}$) | $1.4x10^{34}$ | $5x10^{34}$ | $5x10^{35}$ |
| $L_{int}$ | 330 $fb^{-1}$ | ~1 $ab^{-1}$ | ~10 $ab^{-1}$ |

# Measurements in Clean Environment

- Cleaner than hadron machines even after the upgrade
  - Many off-timing hits, but typical track eff. 91% → 89%

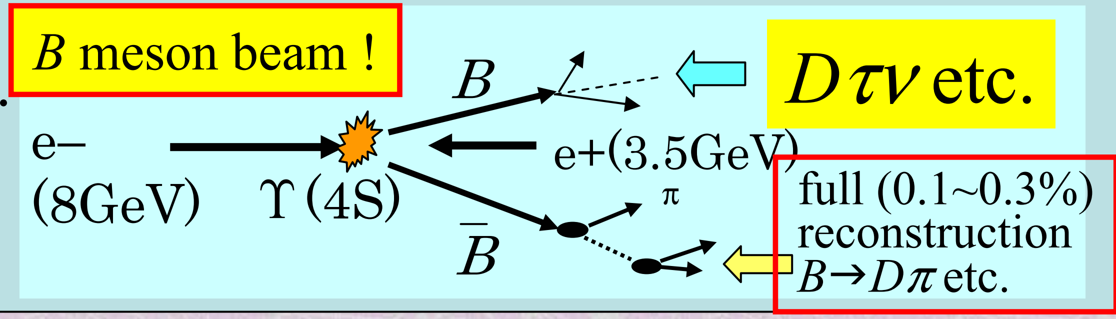



- *B* decays with neutrinos

  $B \to \underline{D\tau\nu, \tau\nu}, \underline{ul\nu}$ etc.

  Charged Higgs

  Vub




- *B* decays with γ, $\pi^0$

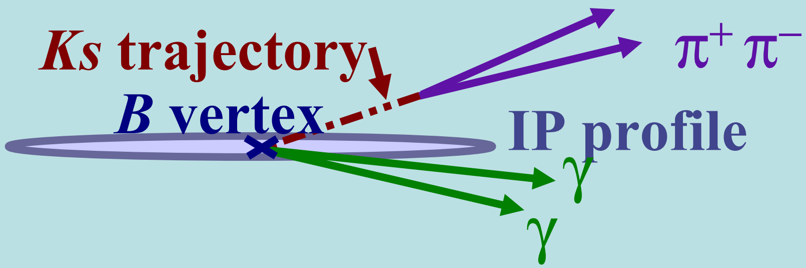
  direct *CPV*

  $\phi_2(\alpha)$ isospin analysis

  $B \to X_s\gamma, \pi^0\pi^0$ etc.

- *B* vertex reconstruction with *Ks* only !

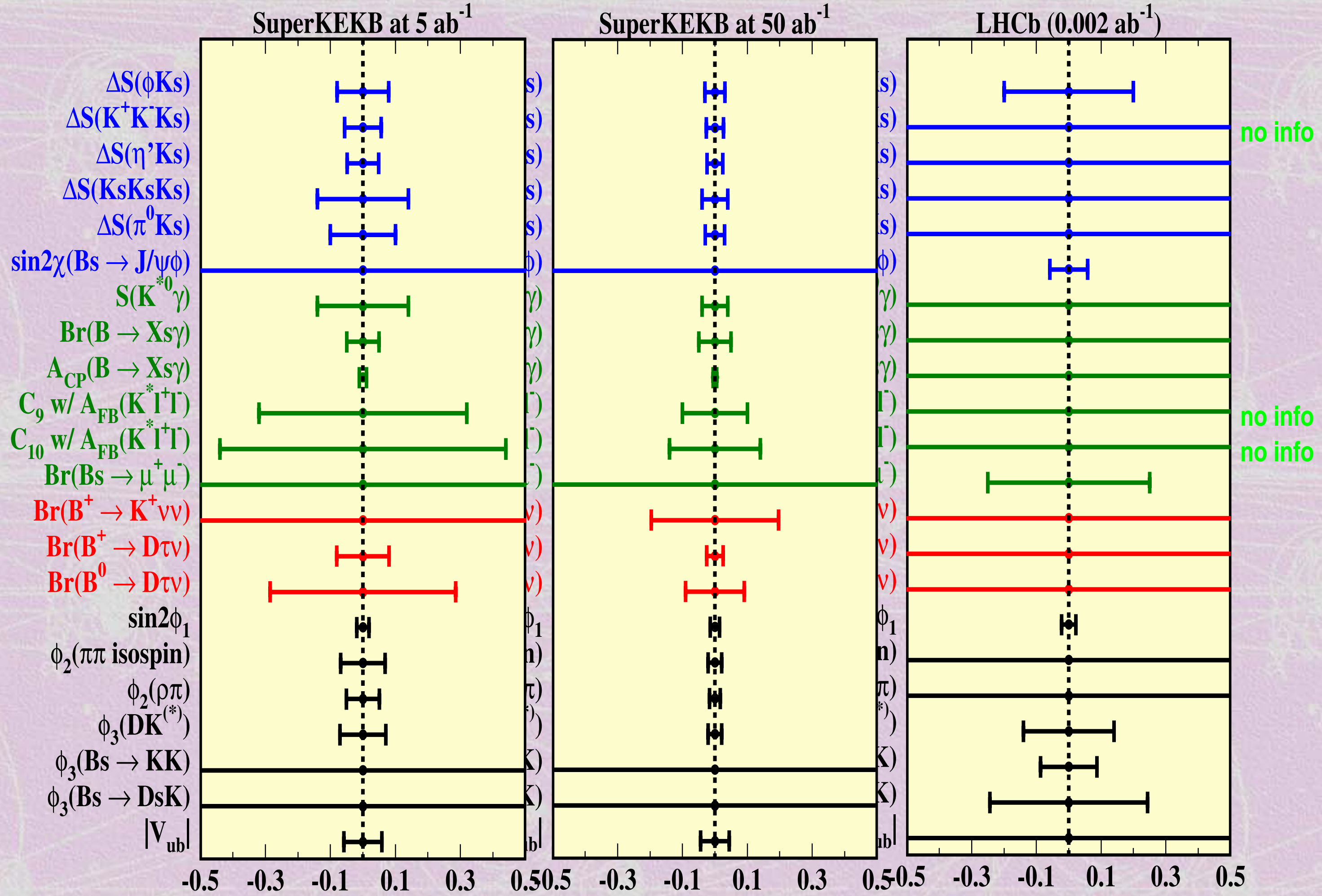
  $B \to K_s\pi^0, K_s\pi^0\gamma$ etc.



# Expected Sensitivities at SuperKEKB

SuperKEKB 5ab$^{-1}$ 50ab$^{-1}$ LHCb 2fb$^{-1}$

| | SuperKEKB (5 ab$^{-1}$) | (50 ab$^{-1}$) |
|---|---|---|
| CPV ($b \to s$) | 0.079 | 0.031 |
| | 0.056 | 0.026 |
| | 0.049 | 0.024 |
| | 0.14 | 0.04 |
| | 0.10 | 0.03 |
| | × | × |
| FCNC | 0.14 | 0.04 |
| | 5% | 5% |
| | 0.011 | $5\times10^{-3}$ |
| | 32% | 10% |
| | 44% | 14% |
| | × | × |
| w/ ν | | $5.1\sigma$ |
| | 8% | 2.5% |
| | $3.5\sigma$ | 9% |
| CKM | 0.019 | 0.014 |
| | 3.9° | 1.2° |
| | 2.9° | 0.9° |
| | 4° | 1.2° |
| | × | × |
| | × | × |
| | 5.8% | 4.4% |




and rich τ physics


# Rare B decay Reach
# super B fac. & hadron facilities

All numbers are per year except current B factories (cumulative Through 2005)

Best measurement ●

**Greater reach?**
Hadronic: $B \to \mu\mu$
e+e-: $s\nu\nu$, $\tau\upsilon$, $\gamma\gamma$, $K^*\gamma$

Including additional rare $\Lambda b$ and Bs modes not in Table
$10^{35}$ reach < BTeV/LHCb
$10^{36}$ reach ~ BTeV/LHCb

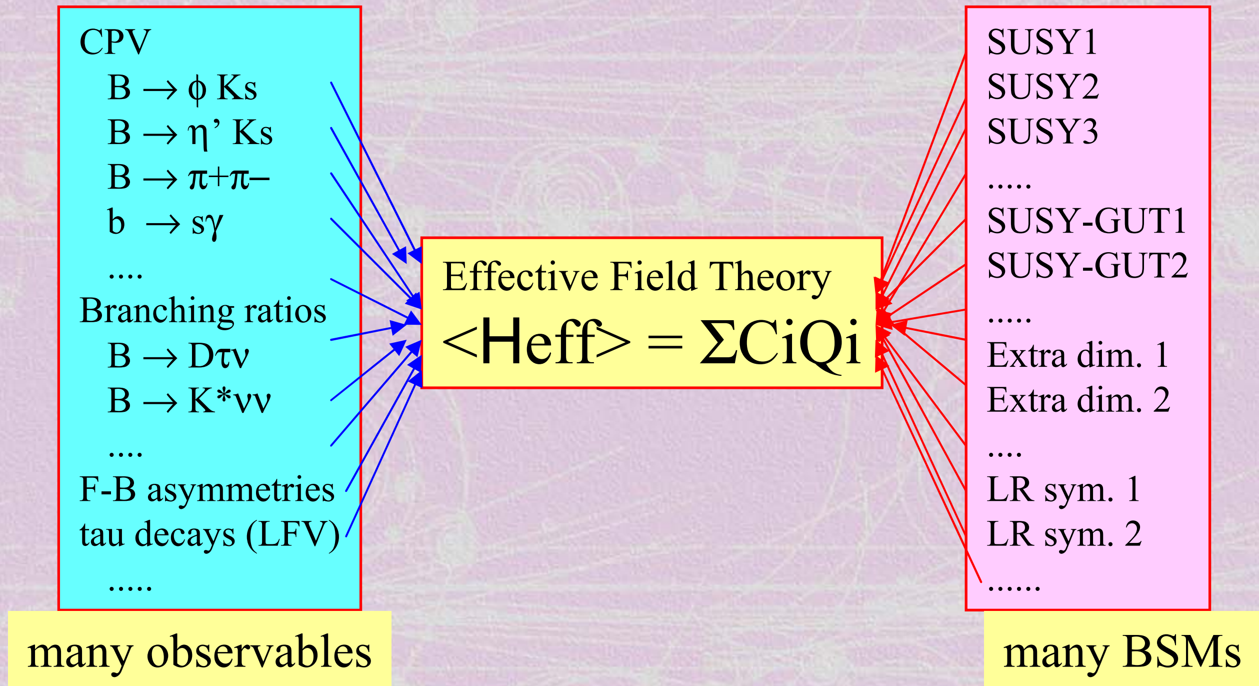
(Table compiled by SBF E2 subgroup & E2 convenors)

Burdman/Butler/Shipsey/Yamamoto

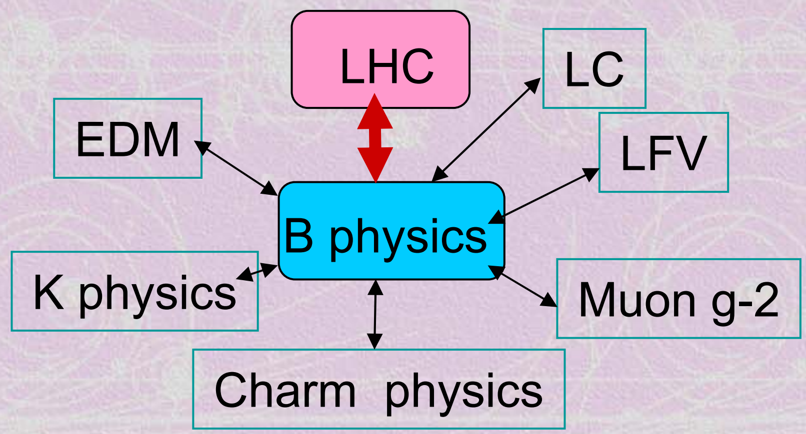
| | HADRONIC EXP. | | | B-FACTORY | | |
|---|---|---|---|---|---|---|
| Decay Mode (Br. Ratio) | CDF /D0 ($2\ fb^{-1}$) | BTeV /LHC-b ($10^7$ s) | ATLAS /CMS (1 Year) | BABAR /BELLE ($0.5\ ab^{-1}$) | $10^{35}$ ($1\ ab^{-1}$) | $10^{36}$ ($10\ ab^{-1}$) |
| $B \to X_s\gamma$ | | | | | ● | ● |
| $(3.29 \pm .21 \pm .21) \times 10^{-4}$ | | | | 11K | 22K | 220K |
| With B Tags | | | | 1.7K | 3.4K | 34K |
| $B \to K^*\gamma$ | | | | | | ● |
| $(3-8) \times 10^{-5}$ | 170/– | 27K/24K | | 6K | 12K | 120K |
| $\delta(A_{CP})$ | | 0.01 | | 0.02 | 0.01 | $< 0.01$ |
| $B \to X_s\nu\overline{\nu}$ | | | | | | ● |
| $(4.1 \pm 0.9) \times 10^{-5}$ | | | | 8 | 16 | 160 |
| $B \to K^*\nu\overline{\nu}$ | | | | | | |
| $(5 \times 10^{-6})$ | | | | 1.5 | 3 | 30 |
| $B \to X_s\mu^+\mu^-$ | | ● | | | | ● |
| $(6.0 \pm 1.5) \times 10^{-6}$ | | 7.2K/- | | 300 | 600 | 6K |
| $B \to X_s e^+e^-$ | | | | 350 | 700 | 7K |
| $B \to K^*\mu^+\mu^-$ | | ● | ● | | | ● |
| $(2 \pm 1) \times 10^{-6}$ | 61/60-150 | 4.4 k /4.5k | 665/4.2K | 120 | 240 | 2.4K |
| $B \to K^*e^+e^-$ | | | | 150 | 300 | 3K |
| $B_d^0 \to \tau^+\tau^-$ | | | | | ● | ● |
| $(10^{-7})$ | | | | $< 10^{-5}$ | $< 5 \times 10^{-6}$ | $< 10^{-6}$ |
| $B^0 \to \mu^+\mu^-$ | | ● | ● | | | |
| $B_s(10^{-9})$ | 5/1.5-6 | 10/11 | 9/7 | | | |
| $B_d(8 \times 10^{-11})$ | 0/0 | 2/2 | 0.7/20 | $< 10^{-8}$ | $< 5 \times 10^{-9}$ | $< 10^{-9}$ |
| $B_d^0 \to e^+e^-$ | | | | | ● | ● |
| $(10^{-14})$ | | | | $< 10^{-8}$ | $< 5 \times 10^{-9}$ | $< 10^{-9}$ |
| $B \to \tau\nu$ | | | | | | ● |
| $(5 \times 10^{-5})$ | | | | 17 | 34 | 350 |
| $B \to \mu\nu$ | | | | | | ● |
| $(1.6 \times 10^{-7})$ | | | | 8 | 16 | 150 |
| $B^0 \to \gamma\gamma$ | | | | | | ● |
| $(10^{-8})$ | | | | 0.4 | 0.8 | 8 |

# Two Key Questions

- How can we synthesize these measurements to identify flavor structure and differentiate new physics models ?

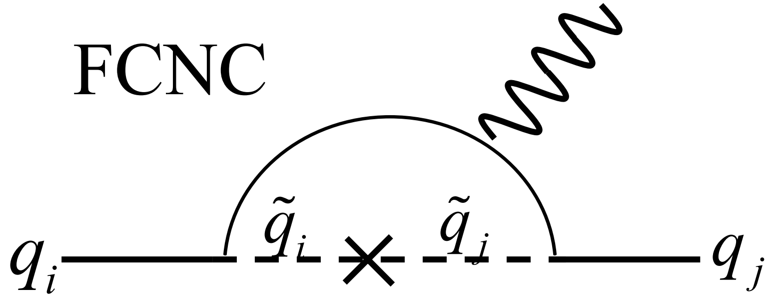



- What is a possible “synergy” with LHC (and others) ?



# If LHC discovers SUSY, then …

FCNC




$(m^2_{\tilde{q}})_{23(13)}$

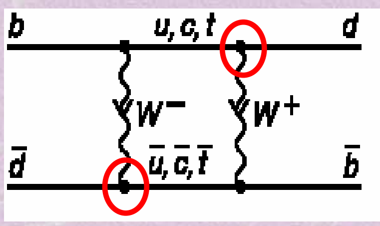
squark/slepton mass matrix

$$\left(m^2_{\tilde{q}}\right)_{ij} = \begin{pmatrix} m^2_{11} & m^2_{12} & m^2_{13} \\ m^2_{21} & m^2_{22} & m^2_{23} \\ m^2_{31} & m^2_{32} & m^2_{33} \end{pmatrix}$$

**Off-diagonal terms**
Flavor Structure
Luminosity frontier

**Diagonal terms**
Mass Spectrum
Energy frontier
(LHC, LC)

Cf. Physics of top quark
(the heaviest elementary particle today)
Direct production, Mass, width etc. → CDF/D0
Off-diagonal couplings, phase → BaBar/Belle




$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

# SUSY breaking at SuperKEKB

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

**Representative SUSY scenarios a la SUGRA**

## SUSY Models

squark $(m^2_{\tilde{d}_R})_{23}$ ⟺ slepton $(m^2_{\tilde{l}_L})_{23}$

1
- **mSUGRA**
  - $\mathfrak{L}$soft is flavor blind
  - KM mixings → mixing in $\tilde{q}_L$

2, 3
- **SUSY SU(5) w/ $\nu_R$**
  - Large mixing in $\nu$ → mixing in $\tilde{d}_R, \tilde{l}_L$
  - KM mixings → mixing in $\tilde{q}_L$

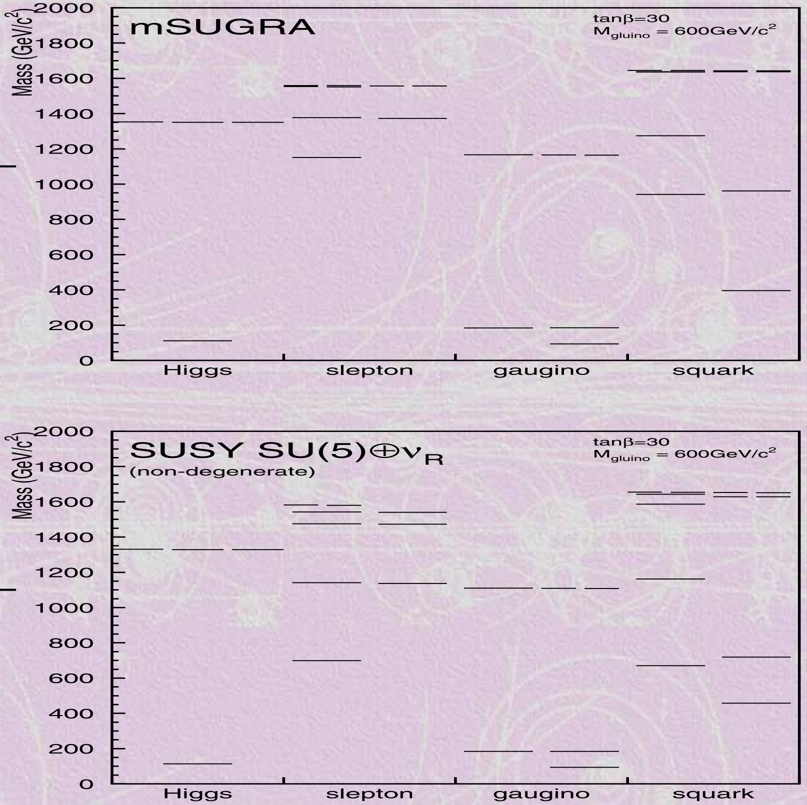
  New CP phase

  Mass of $\nu_R$
  - Degenerate: small 2-3 mixing in $\tilde{d}_R$
  - Non-degenerate: large 2-3 mixing in $\tilde{d}_R$

4
- **U(2) flavor symmetry**
  - 1,2 gen. (u,d,c,s,e,μ): U(2) doublet
  - 3rd gen. (t,b,τ): U(2) singlet

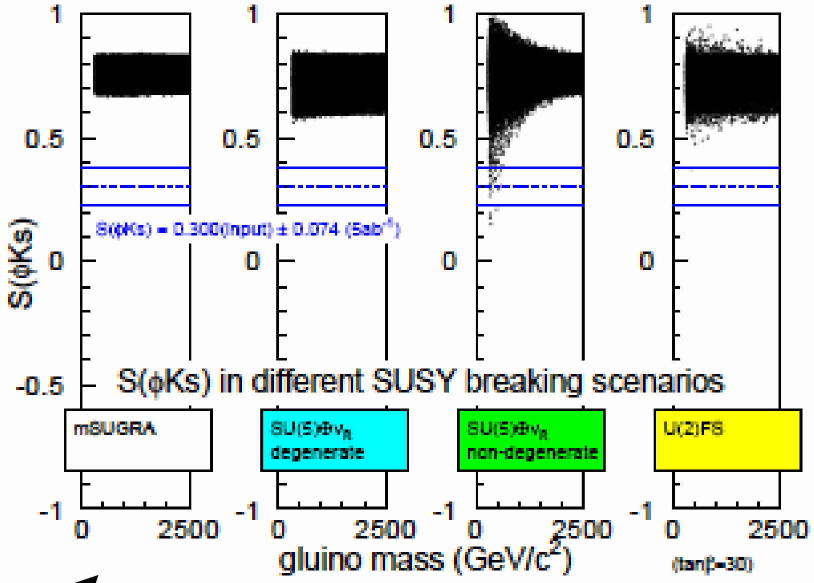
  → O($\lambda^2$) 2-3 mixing in $\tilde{q}_L$

Similar SUSY mass spectra (hard to distinguish)

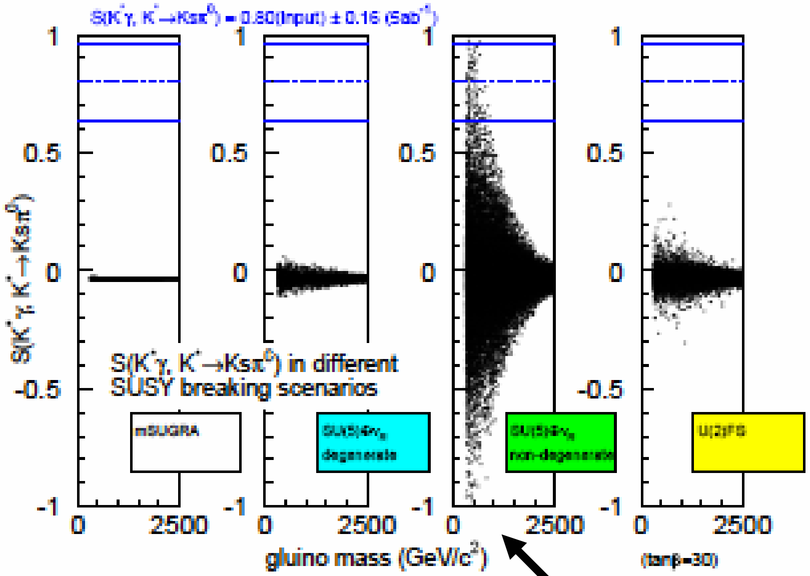



Can we differentiate these 4 scenarios at SuperKEKB ?

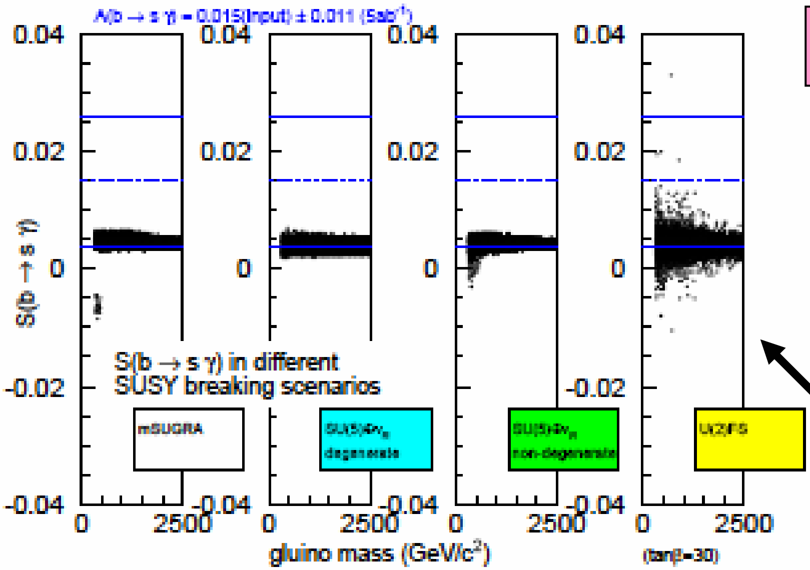
# SUSY breaking at SuperKEKB

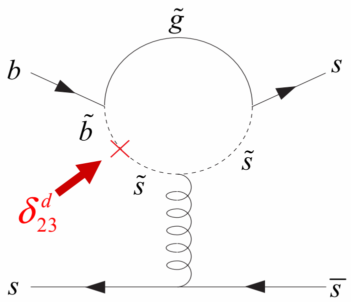



TCPV in B –>φ Ks



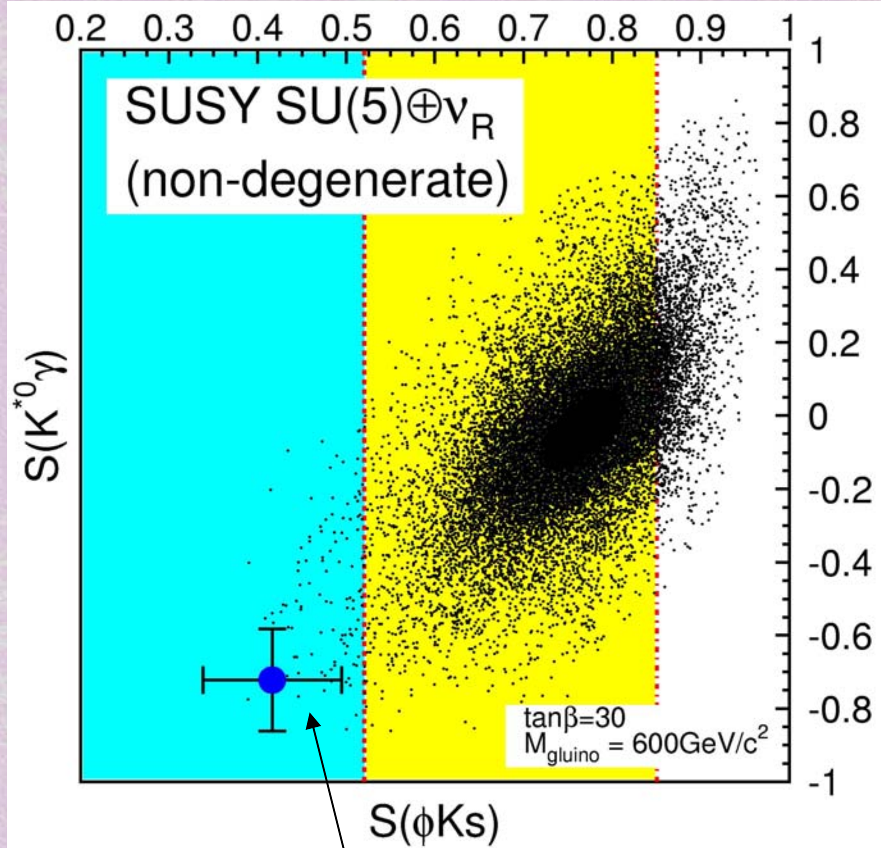

TCPV in B –> K*γ

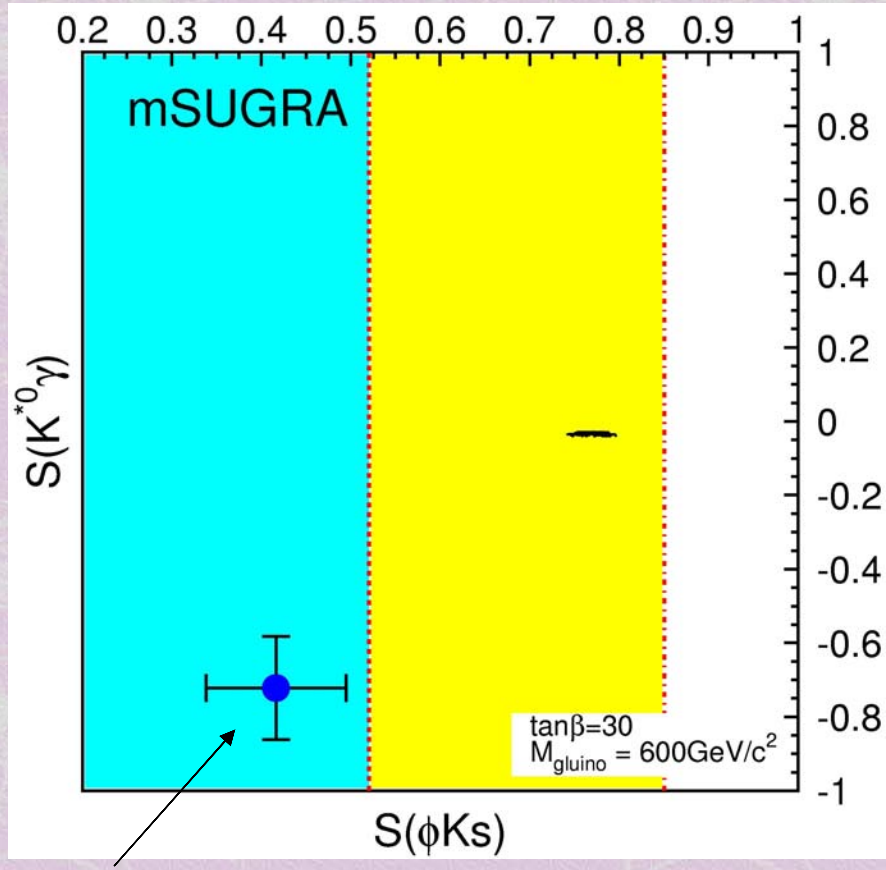



Direct asymmetry in b –> s γ

# CPV in b → s and SUSY breaking




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

- Correlations are useful to differentiate new physics models

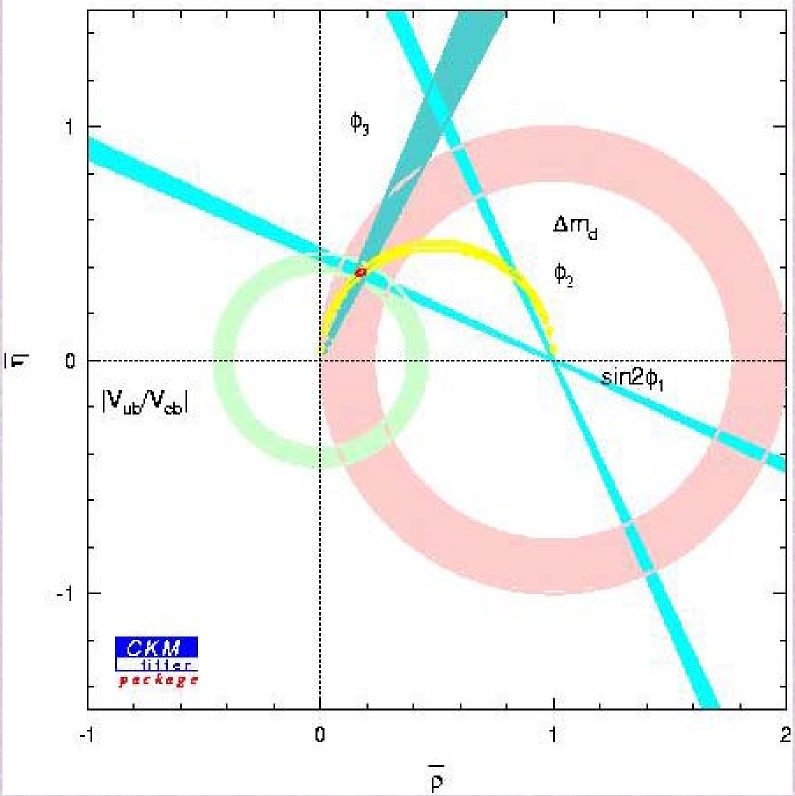
# Pattern of the deviation from the SM

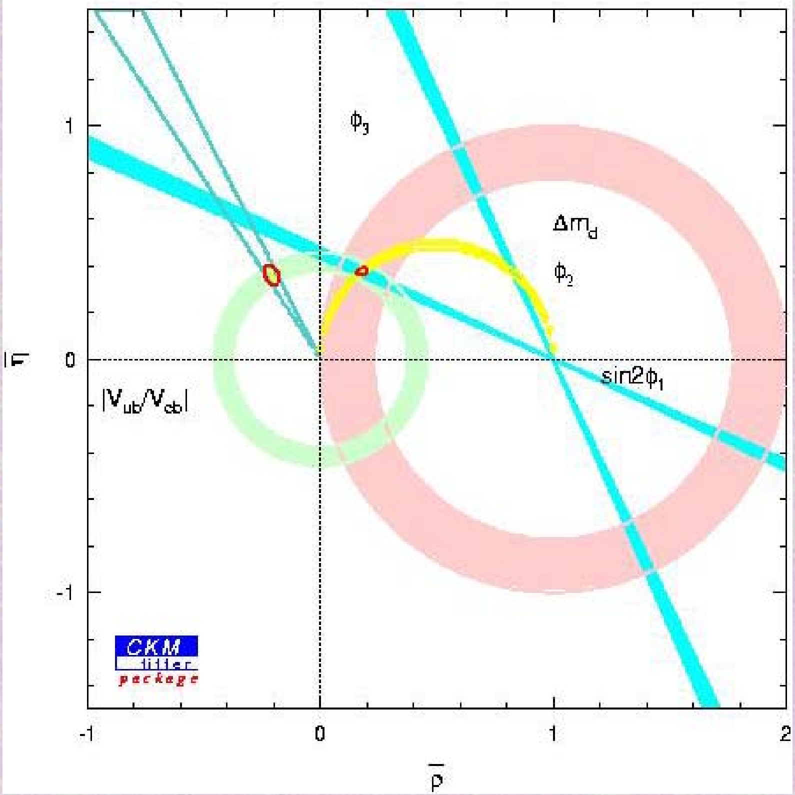
| | Unitarity triangle | | | Rare decays | | |
|---|---|---|---|---|---|---|
| | Bd-unitarity | ε | Δ m(Bs) | B->φKs | B->Msγ indirect CP | b->sγ direct CP |
| **mSUGRA** | - | - | - | - | - | + |
| **SU(5)SUSY GUT + νR** (degenerate) | - | + | + | - | + | - |
| **SU(5)SUSY GUT + νR** (non-degenerate) | - | - | + | ++ | ++ | + |
| **U(2) Flavor symmetry** | + | + | + | ++ | ++ | ++ |

++: Large, +: sizable, -: small

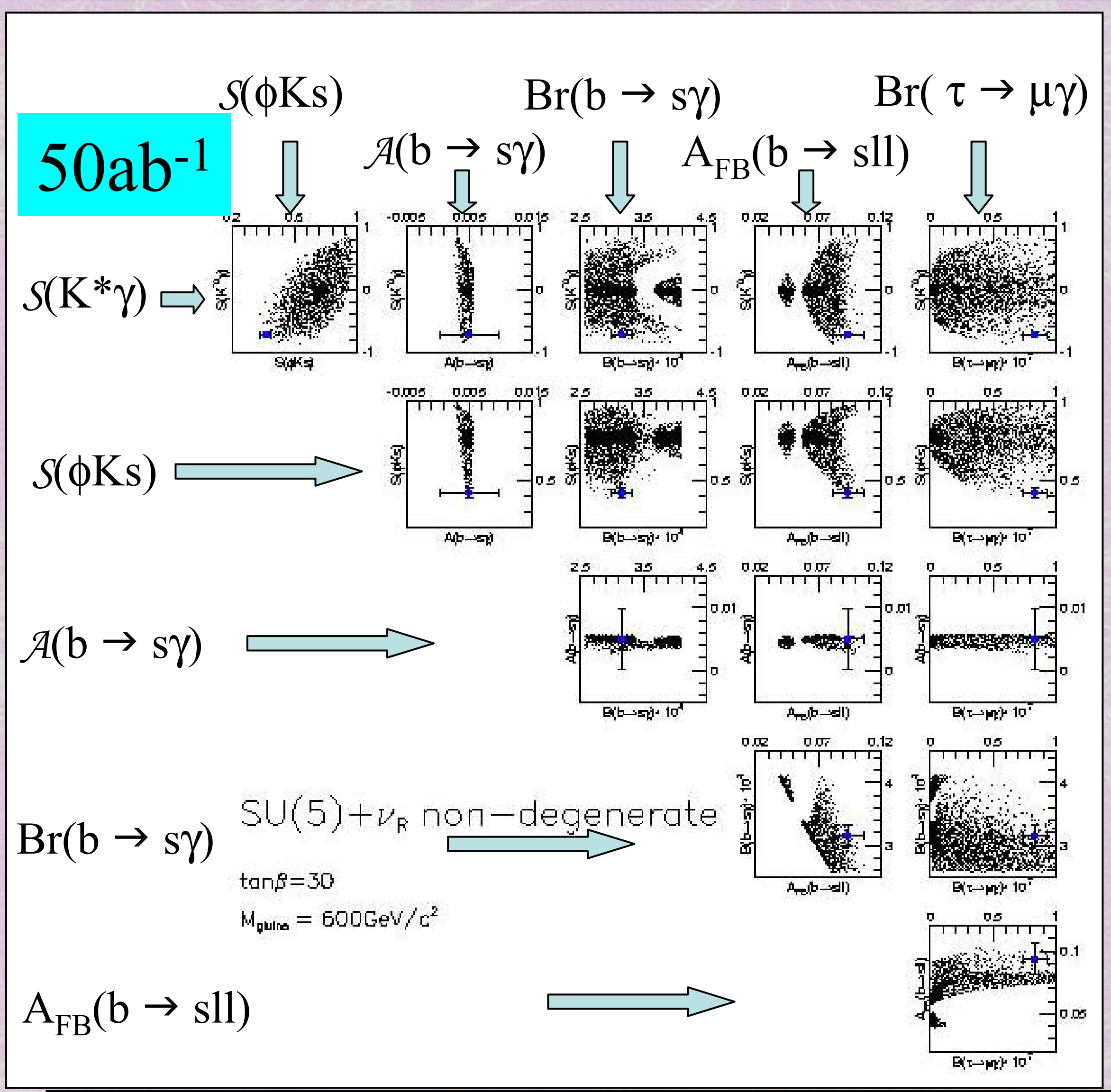
# CKM Unitarity Triangle (in)consistency

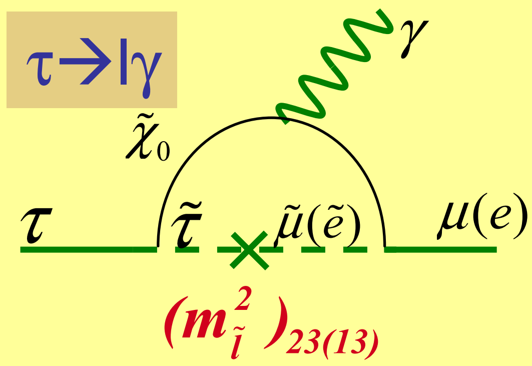
Two cases at $50\ ab^{-1}$



# More tests of SUSY breaking scenarios



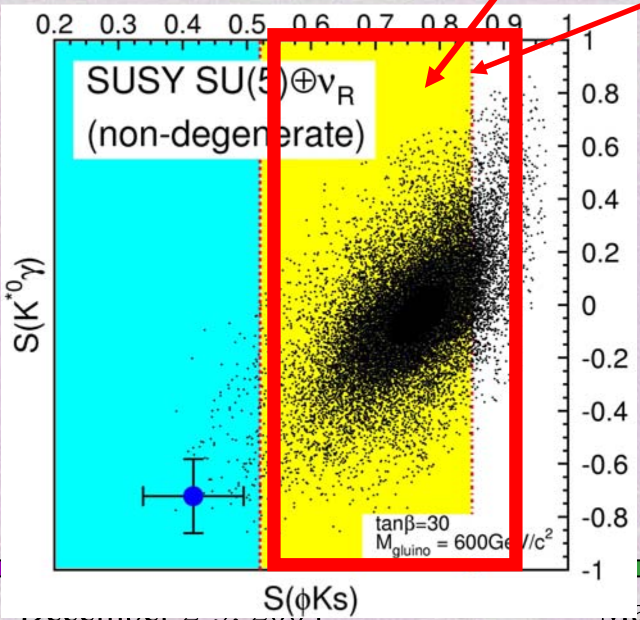

correlation to b → s under GUT

# SUSY vs. Warped Extra Dimensions

Agashe, Perez, Soni, hep-ph/0406101(PRL); hep-ph/0408134

at LHCb | SuperKEKB

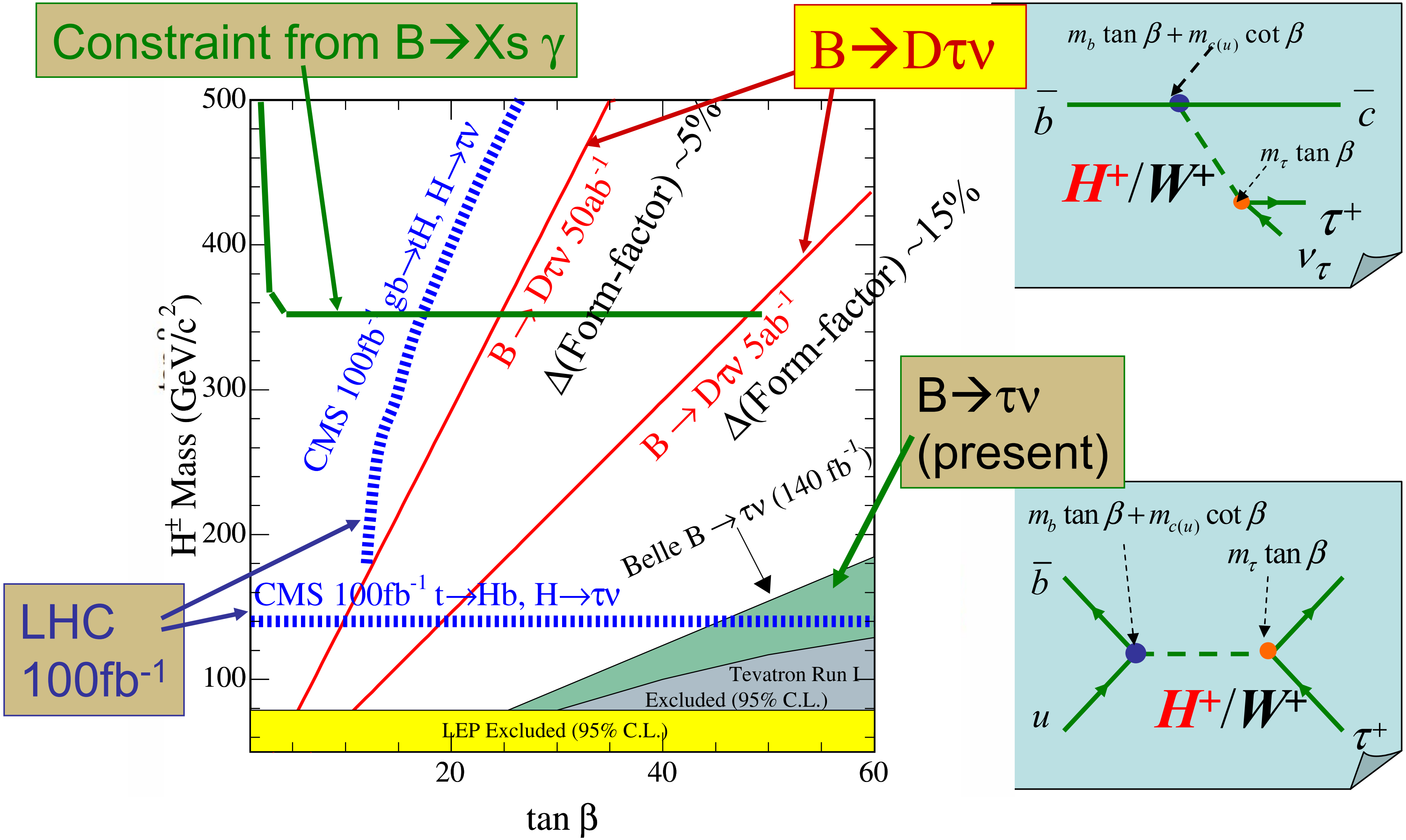
| | $\Delta m_{B_s}$ | $S_{B_s\to\psi\phi}$ | $S_{B_d\to\phi K_s}$ | $Br[b\to sl^+l^-]$ | $S_{B_{d,s}\to K^*,\phi\gamma}$ | $S_{B_{d,s}\to\rho,K^*\gamma}$ |
|---|---|---|---|---|---|---|
| RS1 | $\Delta m_{B_s}^{SM}[1+O(1)]$ | $O(1)$ | $\sin 2\beta \pm O(.2)$ | $Br^{SM}[1+O(1)]$ | $O(1)$ | $O(1)$ |
| SM | $\Delta m_{B_s}^{SM}$ | $\lambda_c^2$ | $\sin 2\beta$ | $Br^{SM}$ | $\frac{m_s}{m_b}\left(\sin 2\beta, \lambda_c^2\right)$ | $\frac{m_d}{m_b}\left(\lambda_c^2, \sin 2\beta\right)$ |




B(B → Xsl+l-) = (4.5±1.0) x $10^{-6}$ (present WA) also constrains RR and LL mass insertions: i.e. related to $\mathcal{S}$(φKs)

**"DNA Identification" of New Physics from Flavor Structure**

# Sensitivity for Charged Higgs (no CPV study yet)



# Summary

- **SuperKEKB will provide O($10^{10}$) *B* mesons in a very clean environment, allowing us to reconstruct rare *B* decays to final states with neutrals ($\nu$, $\gamma$, $\pi^0$, $K_L$ etc.), and to reconstruct *B*-decay vertices with *Ks*.**

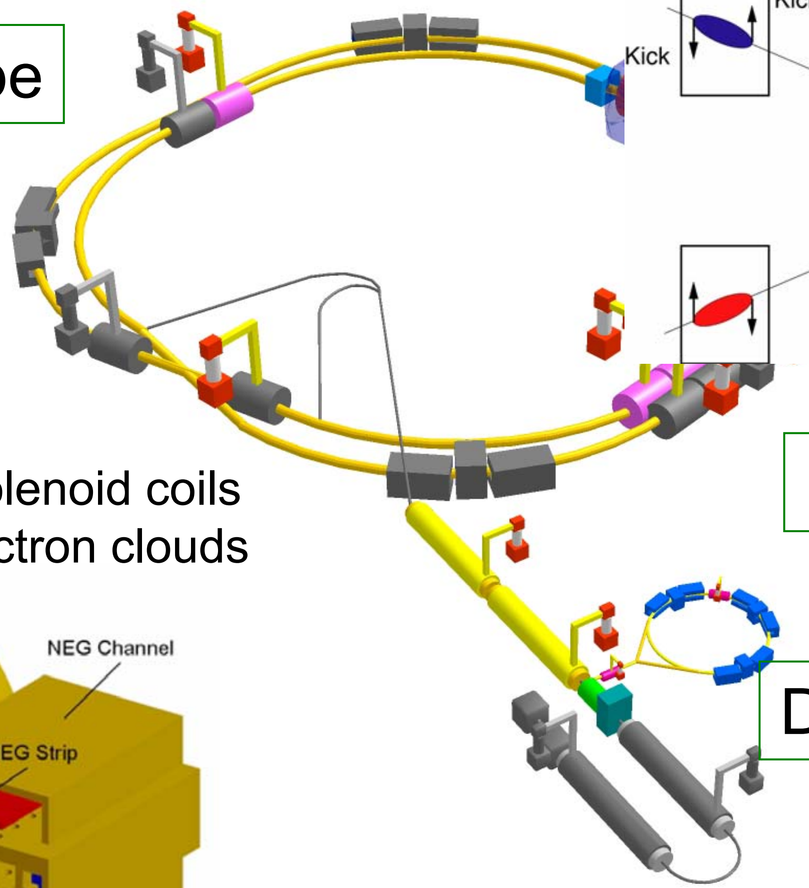
- **SuperKEKB will offer a unique possibility to differentiate new physics models, which can not be performed at LHC.**

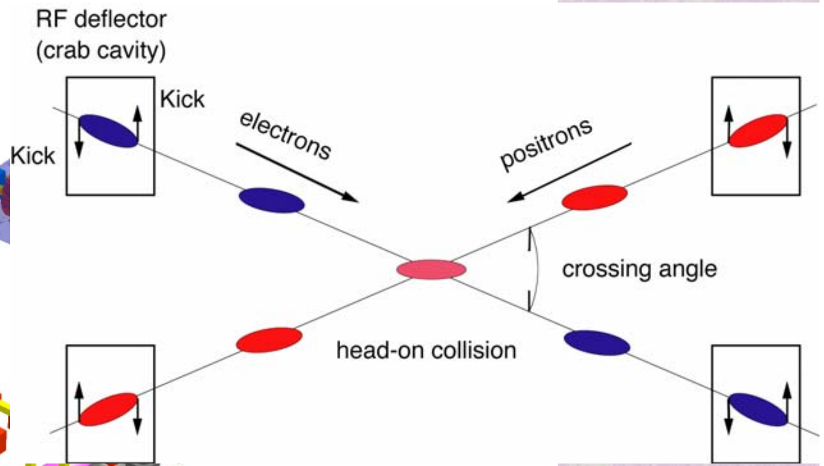
- **Synergy with LHC and flavor experiments is essential. Common Benchmark Models (CBMs) will be very useful to demonstrate "synergy" effect and make a world-wide consensus.**

# Backup slides

# SuperKEKB

New Beam pipe

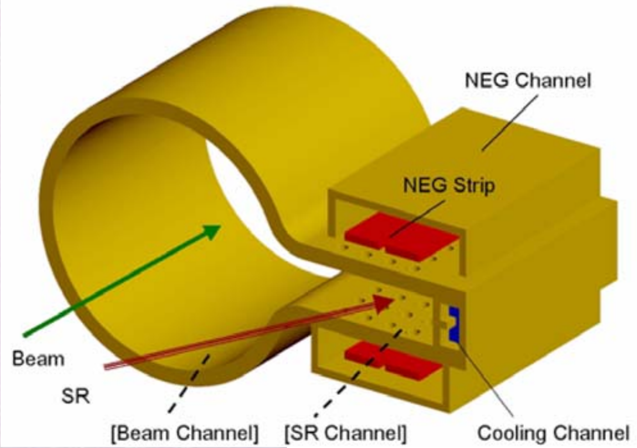





More RF power

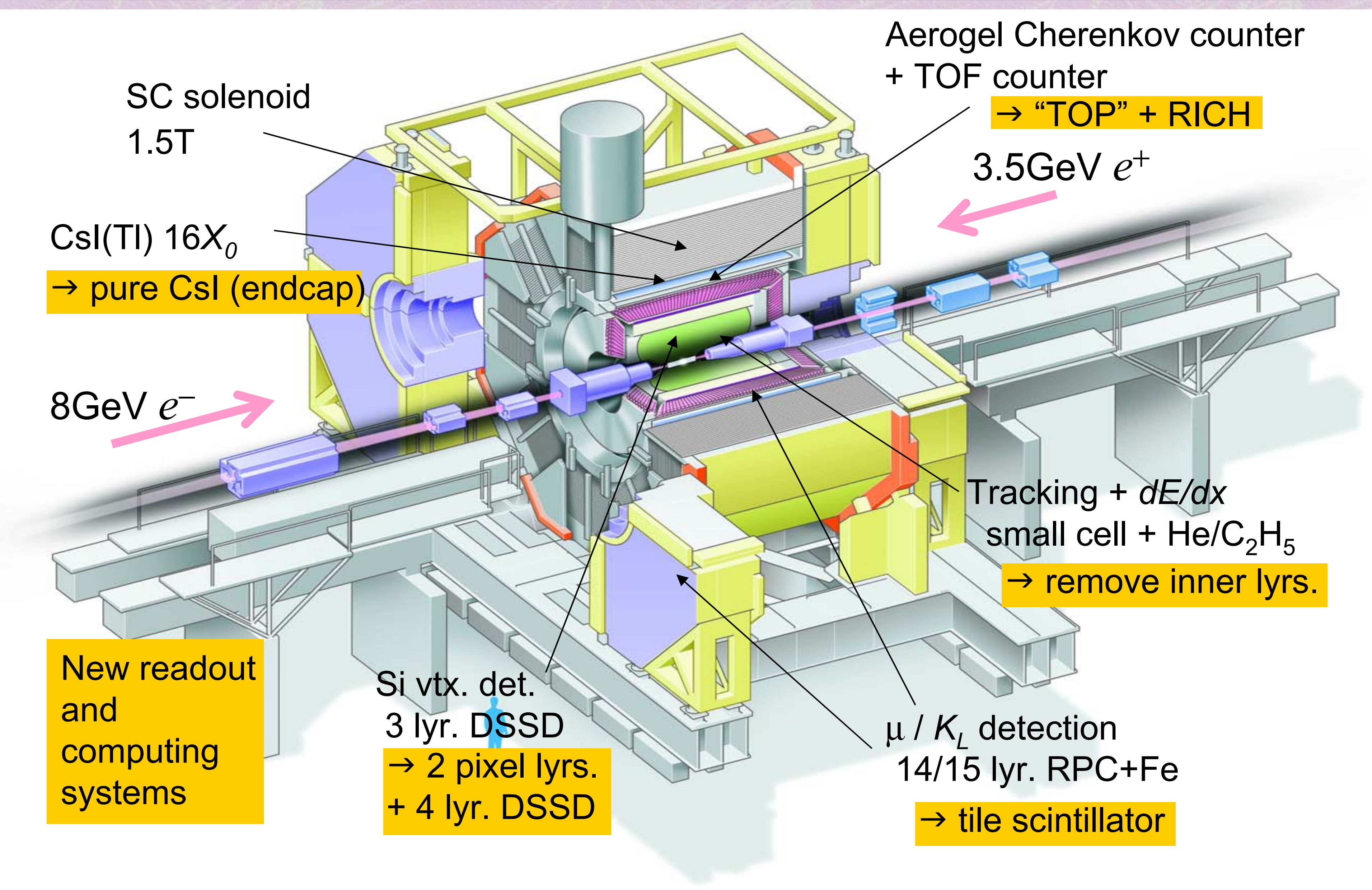
Damping ring

Ante-chmaber & solenoid coils
for reduction of electron clouds




Linac upgrade

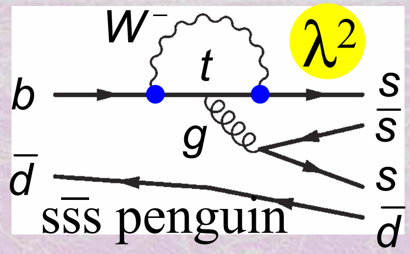
# Belle Upgrade

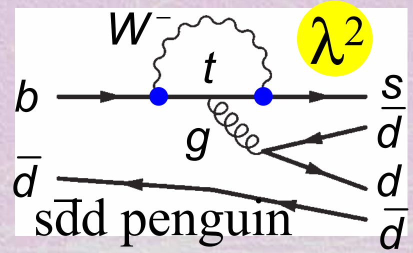


# Other decay modes: $B^0 \rightarrow X^0 K_S$

| $X^0$ | $\xi_{CP}$ | $X^0$ decay | P | P' | T | T' |
|---|---|---|---|---|---|---|
| $K^+K^-$ | ~+1 | | O | O | O | O |
| $\eta'$ | –1 | $\eta' \rightarrow \rho\gamma$, $\eta\pi^+\pi^-$<br>$\rho \rightarrow \pi^+\pi^-$<br>$\eta \rightarrow \gamma\gamma$, $\pi^+\pi^-\pi^0$ | O | O | O | × |
| $f_0(980)$ | +1 | $f_0(980) \rightarrow \pi^+\pi^-$ | O | O | O | × |
| $\omega$ | –1 | $\omega \rightarrow \pi^+\pi^-\pi^0$ | × | O | O | × |
| $\pi^0$ | –1 | $\pi^0 \rightarrow \gamma\gamma$ | × | O | O | × |

- $K_S \rightarrow \pi^+\pi^-$ for all modes
- $K_S \rightarrow \pi^0\pi^0$ only by *BABAR* for $\eta' K_S$
  - not used for $\eta \rightarrow \pi^+\pi^-\pi^0$
- $\omega K_S$ only by Belle

P



P'
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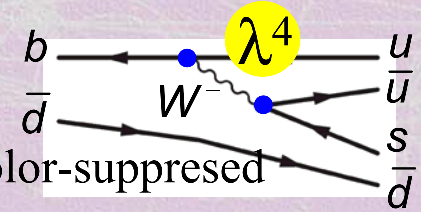


T'
color-allowed