Belle 実験の目的・現状・将来

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2001 年 10 月 12 日

概要

Belle 実験の目的

2001 年夏までの最新結果

予定 —2002 年夏、およびその先へ

動機 —— 目的と手段と副産物

▷ CP 非保存の起源を探る

▷▷ 1964 年 K 崩壊で CP 非保存の発見

▷▷ 1973 年 小林・益川模型

▷▷ 1980 年 カーター・ビギ・三田、 B 崩壊での大きな CP 非保存を予言

標準模型
電弱相互作用・ヒッグス粒子
強い力の閉じ込め
3 世代のクォーク・レプトン
複素混合角 (小林益川模型)
ニュートリノ

B の寿命
B-$\bar{B}$ の混合
$B^0 \to J/\psi K^0$

⇒ これらの実験結果
⇒ CP 非保存 の検証は B ファクトリーが必要 / で可能

▷ B 崩壊 — 非常に多岐にわたる崩壊モード

▷▷ 標準模型を越える物理

▷▷ クォークのダイナミクス

▷▷ ハドロンの物理

クォークレベル
$b \to cq\bar{q}'$、 $b \to c\ell\bar{\nu}$
$b \to uq\bar{q}'$、 $b \to u\ell\bar{\nu}$
$b \to sq\bar{q}$、 $b \to s\gamma$、 $b \to s\ell^+\ell^-$
$b \to dq\bar{q}$、 $b \to s\gamma$、 $b \to s\ell^+\ell^-$
$b\bar{u} \to \ell\bar{\nu}(\gamma)$、 $b\bar{u} \to \tau\bar{\nu}(\gamma)$、 $b\bar{d} \to \ell^+\ell^-(\gamma)$

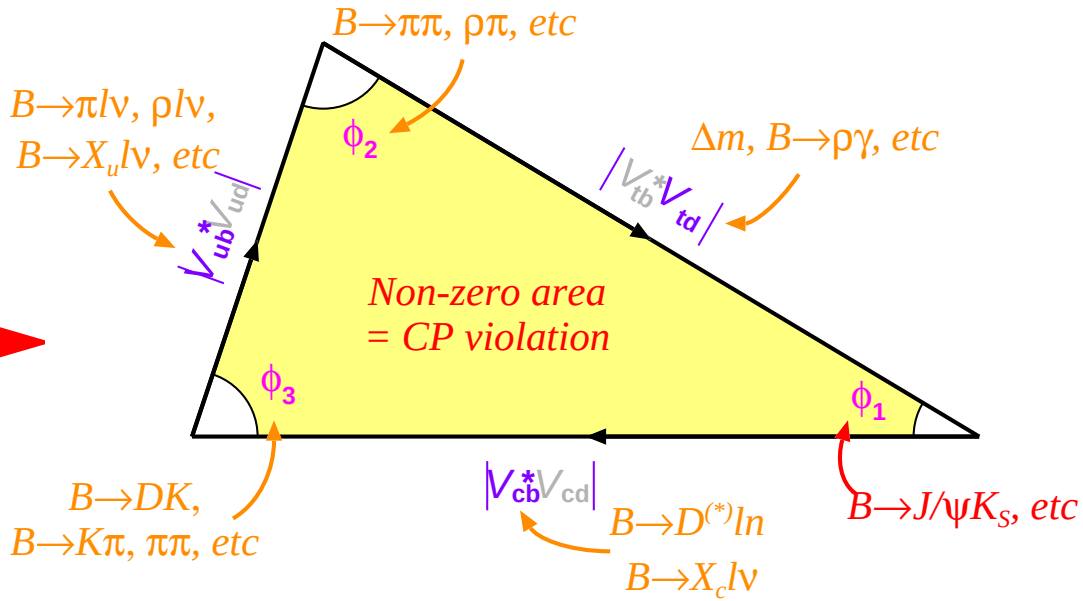
ユニタリ三角形

KM Matrix

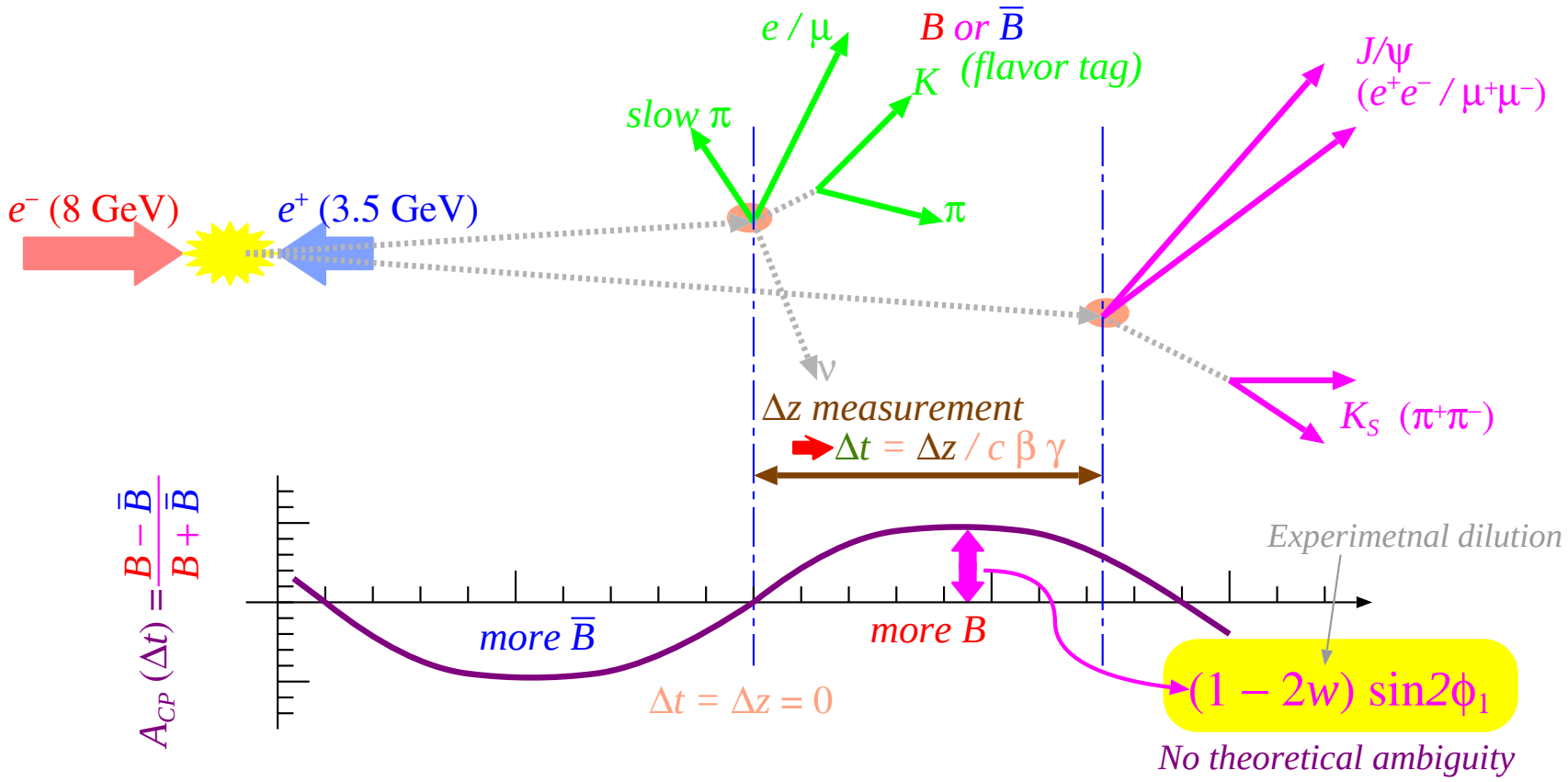
$$V_{KM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

Unitarity

$$(V_{ub}^{*}V_{ud} + V_{cb}^{*}V_{cd} + V_{tb}^{*}V_{td} = 0)$$



$\sin 2\phi_1$ の測定



▷ 非対称衝突 ($\beta\gamma = 0.425$)	▷ 崩壊点 ($\Delta z \sim 200\mu$m) ⇒ SVD	▷ 電子、 μ の同定 ⇒ CsI、 KLM
▷ 大量の B ($> 10^7$) ⇒ KEKB	▷ 運動量測定 ⇒ CDC	▷ K と π の識別 ⇒ ACC、 TOF、 dE/dx

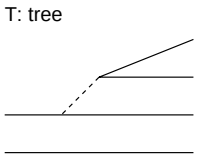
さまざまな B 崩壊

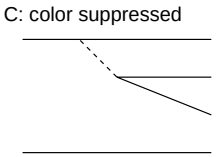
Semi-leptonic B decay
Radiative B decay ($b \to s\gamma, \ldots$)
Electroweak B decay ($b \to s\ell\ell, \ldots$)
Pure-leptonic B decay ($B \to \tau\nu, \ldots$)
Hadronic B^0 decay

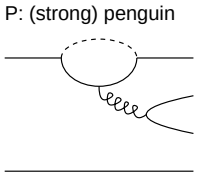
V_{cb}	$b \to c$ tree	$B^0 \to D^-\pi^+$,	D^-K^+,	D^-D^+,	$D^-D_s^+$		
	$b \to c$ color sup.	$B^0 \to J/\psi K^0$,	$J/\psi\pi^0$				
V_{ub}	$b \to u$ tree	$B^0 \to \pi^-\pi^+$,	π^-K^+,	π^-D^+,	$\pi^-D_s^+$		
	$b \to u$ color sup.	$B^0 \to \overline{D^0}K^0$,	$\overline{D^0}\pi^0$				
V_{ts}	$b \to s$ penguin	$B^0 \to \pi^0K^0$,	π^-K^+,	$K^0\phi$,	$D^-D_s^+$,	$J/\psi K^0$	
V_{td}	$b \to d$ penguin	$B^0 \to \pi^0\pi^0$,	$\pi^-\pi^+$,	$K^0\overline{K^0}$,	D^+D^-,	$J/\psi\pi^0$,	$\phi\pi^0$

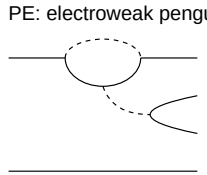
Hadronic B^- decay

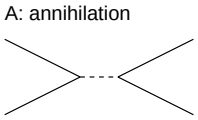
V_{cb}	$b \to c$ tree	$B^- \to D^0\pi^-$,	D^0K^-,	D^0D^-,	$D^0D_s^-$		
	$b \to c$ color sup.	$B^- \to J/\psi K^-$,	$J/\psi\pi^-$				
V_{ub}	$b \to u$ tree	$B^- \to \pi^0\pi^-$,	π^0K^-,	π^0D^-,	$\pi^0D_s^-$		
	$b \to u$ color sup.	$B^- \to \overline{D^0}K^-$,	$\overline{D^0}\pi^-$				
V_{ts}	$b \to s$ penguin	$B^- \to \pi^0K^-$,	$K^0\pi^-$,	ϕK^-,	$D^0D_s^-$,	$J/\psi K^-$	
V_{td}	$b \to d$ penguin	$B^- \to \pi^0\pi^-$,	K^0K^-,	D^0D^-,	$J/\psi\pi^-$		

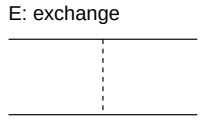


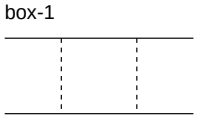


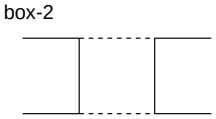




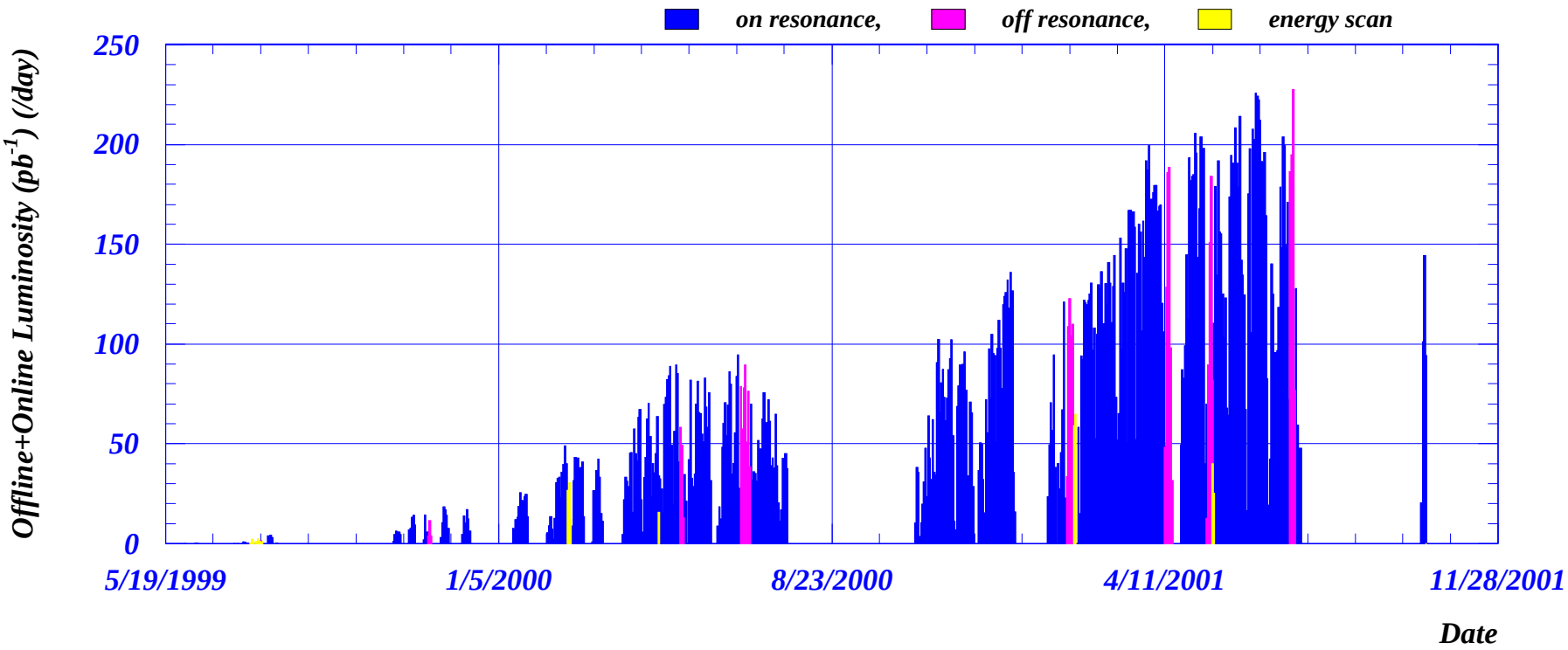








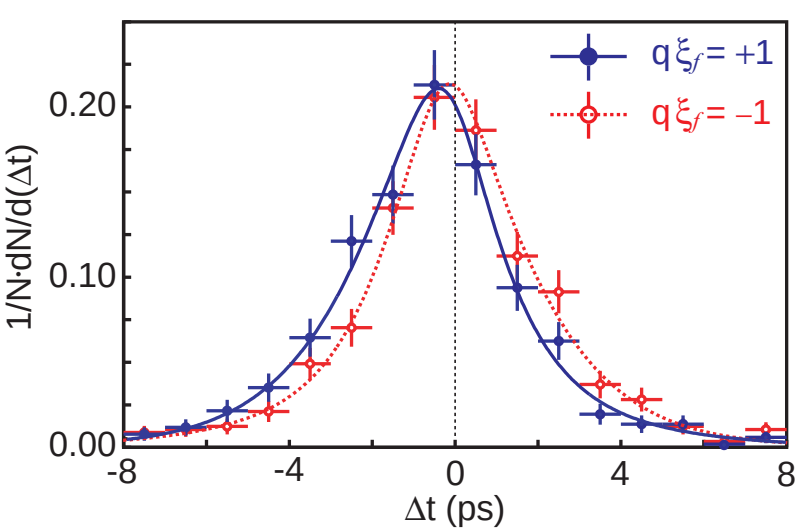
KEKB ルミノシティ

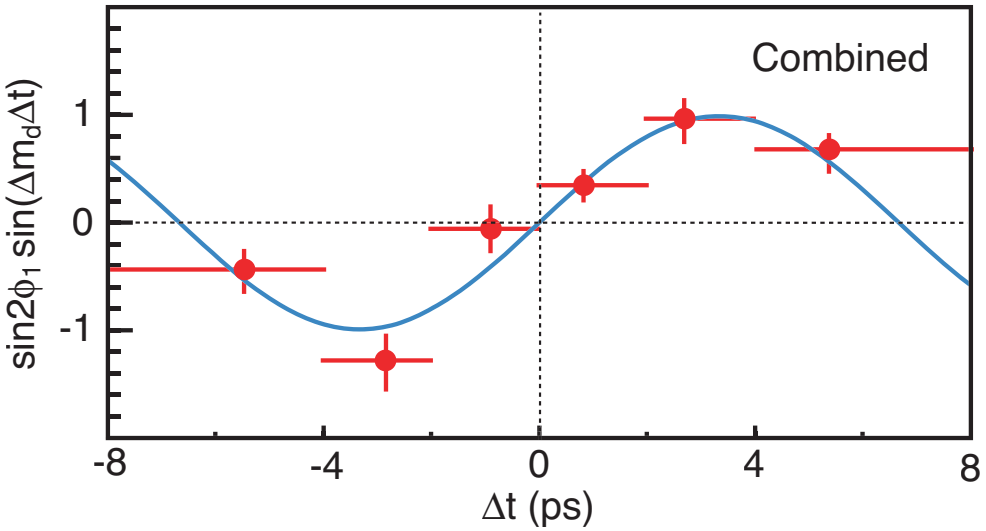


- ルミノシティー $4.49 \times 10^{33}\ \mathrm{cm^{-2}s^{-1}}$ (世界最高)
- 一日あたり 最大 $225\ \mathrm{pb^{-1}}$
- 積分ルミノシティー $32.8\ \mathrm{fb^{-1}}$ (夏まで) $+0.4\ \mathrm{fb^{-1}}$ (秋のラン、今日現在)

$\sin 2\phi_1$ の結果

- $B \to J/\psi K_S^0\ (CP = +1)$ の他に、 $\psi' K_S^0\ (+1)$, $J/\psi K_L^0\ (-1)$ などを使用。
- 1137 事象をフィットに使用。
- タギング効率は $27.0 \pm 1.2\%$。



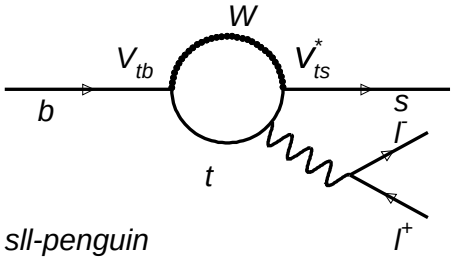


$$\sin 2\phi_1 = 0.99 \pm 0.14 \pm 0.06$$

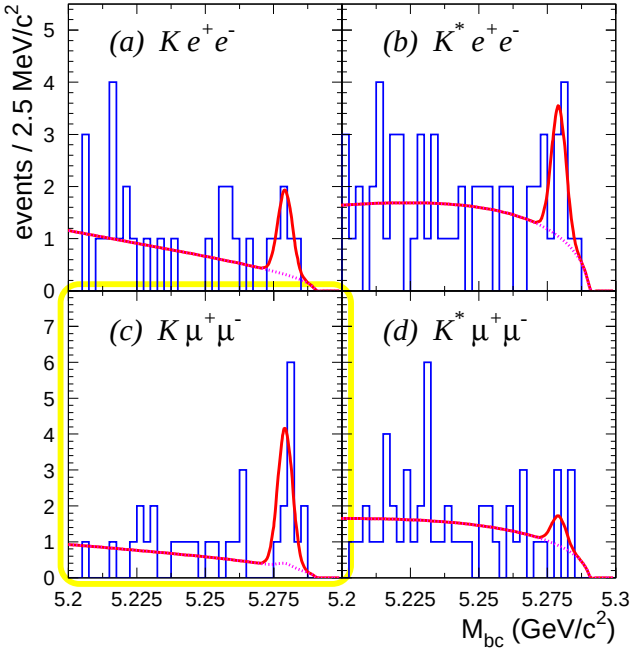
Large CP violation in B decay! ($> 6\sigma$)

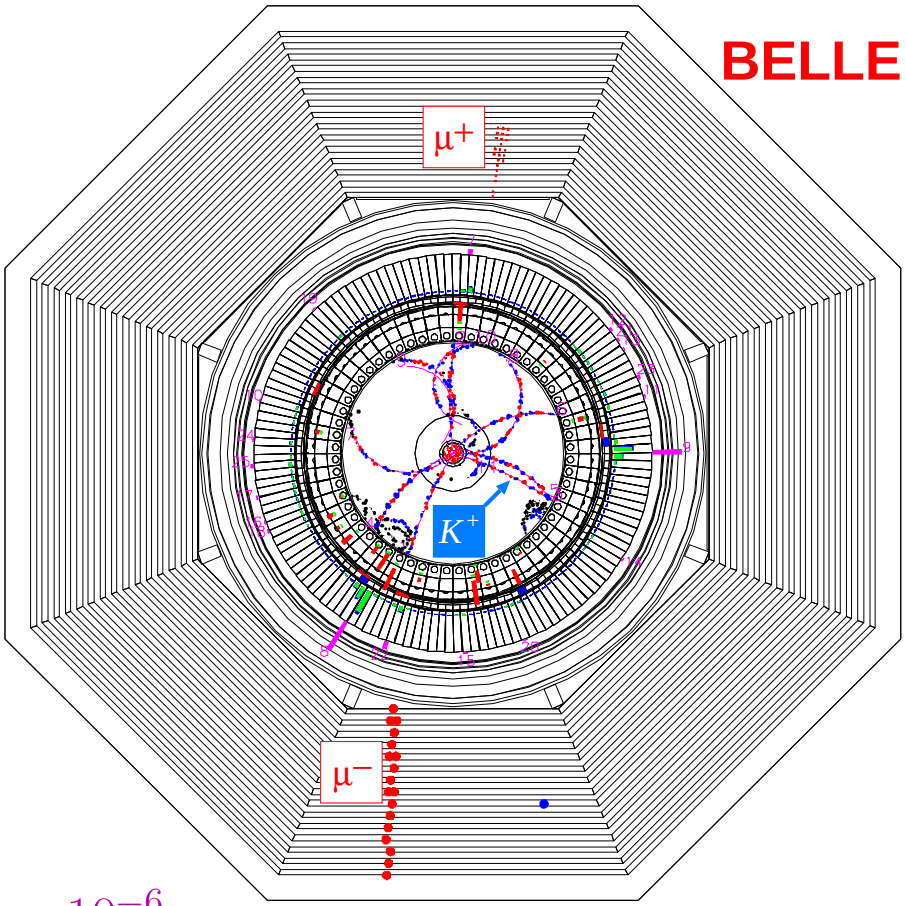
$B \to K\mu^+\mu^-$ の観測

標準模型での崩壊過程



sll-penguin





初観測

$Br = 0.99 \times 10^{-6}$

その他の成果

Belle Journal Publications

http://belle.kek.jp/bdocs/b_journal.html

1. Measurement of B^0_d-$\bar{B}^0_d$ mixing rate from the time evolution of dilepton events at $\Upsilon(4S)$ — PRL 86, 3228 (2001)
2. Measurement of the CP Violation Parameter $\sin 2\phi_1$ in B^0_d Meson Decays — PRL 86, 2509 (2001)
3. Measurement of Inclusive Production of Neutral Pions from $\Upsilon(4S)$ Decays — PRD 64, 072001 (2001)
4. A Measurement of the Branching Fraction for the Inclusive $B \to X_s\gamma$ Decays with Belle — PLB 511, 151 (2001)
5. Measurement of Branching Fractions for $B \to \pi\pi$, $K\pi$ and KK Decays — PRL 87, 101801 (2001)
6. Observation of Cabibbo suppressed $B \to D^{(*)}K^-$ decays at Belle — PRL 87, 111801 (2001)
7. Observation of $B \to J/\psi K_1(1270)$ — PRL 87, 161601 (2001)
8. Search for Direct CP Violation in $B \to K\pi$ Decays — PRD 64,071101 (2001)
9. Measurements of the Branching Fraction for $B \to \eta' K$ and Search for $B \to \eta'\pi^+$ — PLB 517, 309 (2001)
10. Observation of Large CP Violation in the Neutral B Meson System — PRL 87, 091802 (2001)
11. Observation of Color-suppressed $B^0 \to D^0\pi^0$, $D^{*0}\pi^0$, $D^0\eta$, and $D^0\omega$ — submitted to PRL
12. Observation of the Decay $B \to K\mu^+\mu^-$ — submitted to PRL
13. Production of Prompt Charmonia in e^+e^- Annihilation at $\sqrt{s} \approx 10.6$ GeV — submitted to PRL

0101 Measurement at Belle of Branching Fractions for Two-Body B Meson Decays with Charmonium
0103 Study of the decay $B^0 \to D^+ D^{*-}$ with D^{*-} partial reconstruction
0104 Measurements of the B meson decays $B \to D^{(*)} D^{(*)}$ and $B \to D^{(*)} D^{(*)} K$ at Belle
0105 Measurements of Polarization and CP Asymmetry in $B \to J/\psi + K^*$ decays
0107 Observation of Color-Suppressed $\bar{B} \to D^{(*)0} X^0$ Decays
0108 Search for Direct CP Violation in $B^- \to D_{cp} K^-$ decays at Belle
0109 Observation of Radiative B Meson Decays into Higher Kaonic Resonances
0110 Evidence for the Electroweak Penguin Decay $B \to X_s \ell^+ \ell^-$
0111 Measurement of the Branching Fraction for $B \to \eta' K$ and Search for $B \to \eta' \pi^+$
0112 Search for Direct CP Violation in $B \to K\pi$ Decays
0113 Observation of Charmless Decays $B \to \phi K$ and $B \to \phi K^*$ at Belle
0114 Study of three-body charmless B decays at Belle
0115 A Study of Charmless B Meson Decays to Pseudoscalar-Vector Final States at Belle
0116 Search for Exclusive Rare Baryonic Decays of B Mesons
0117 The $\pi\pi\pi^0$ final state in two-photon collisions at Belle
0118 Search for $\tau \to \mu\gamma$ decay at Belle
0119 A Search for the Electric Dipole Moment of the τ lepton
0120 Search for neutrinoless τ decays into $e/\mu K^0$
0121 Determination of $|V_{cb}|$ from the semileptonic decay $B \to D^{*+} \ell^- \nu$
0122 Measurement of $\mathcal{B}(\bar{B}^0 \to D^+ \ell^- \nu)$ and determination of $|V_{cb}|$
0123 Measurement of the inclusive semileptonic decay of B mesons with lepton tags
0124 Measurement of exclusive $B \to \pi \ell \nu$ decays at Belle
0125 Search for $B^0 \to D_s^+ \pi^-$ and $D_s^+ K^-$ decays at Belle
0126 Measurements of flavor-specific inclusive charged kaons from B decays
0127 Search for Leptonic Decays of B Mesons
0128 Prompt Charmonia Production in e^+e^- Annihilation at $\sqrt{s} \sim 10.6$ GeV
0129 Measurement of D^0 decays to $K_L \pi^0$ and $K_S \pi^0$ at Belle
0130 Observation of $\Lambda_c^+ \to \Lambda^0 K^+$, $\Lambda_c^+ \to \Sigma^0 K^+$ and $\Lambda_c^+ \to \Sigma^+ K^+ \pi^- decays$
0131 Precise Measurements of Charm Meson Lifetimes and Search for D^0-$\bar{D}^0$ Mixing at Belle
0133 Observation of $B \to J/\psi K_1(1270)$
0134 Measurement of Branching Fractions for $B \to \pi\pi$, $K\pi$ and KK Decays
0135 A Measurement of the Branching Fraction for the Inclusive $B \to X_s \gamma$ Decays with the Belle Detector
0136 Study of Ω_c^0 at Belle
0137 Two-Body Charmless B Decays to ηK^* and $\eta\rho$ at Belle
0138 Observation of $B \to \chi_{c0} K$ decay

The Belle Collaboration

Contributed papers

for 2001 Summer Conferences

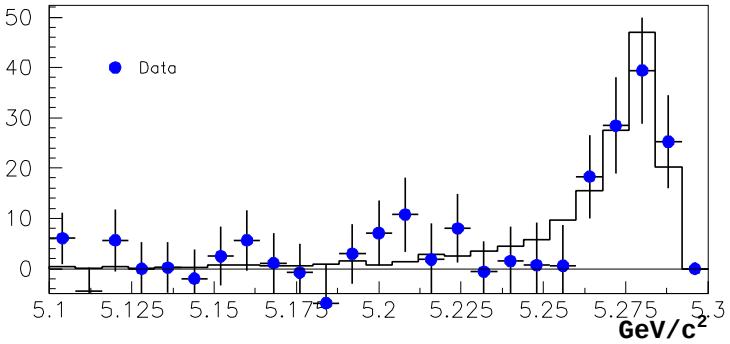
http://belle.kek.jp/conferences/LP01-EPS/

2002 年夏への目標

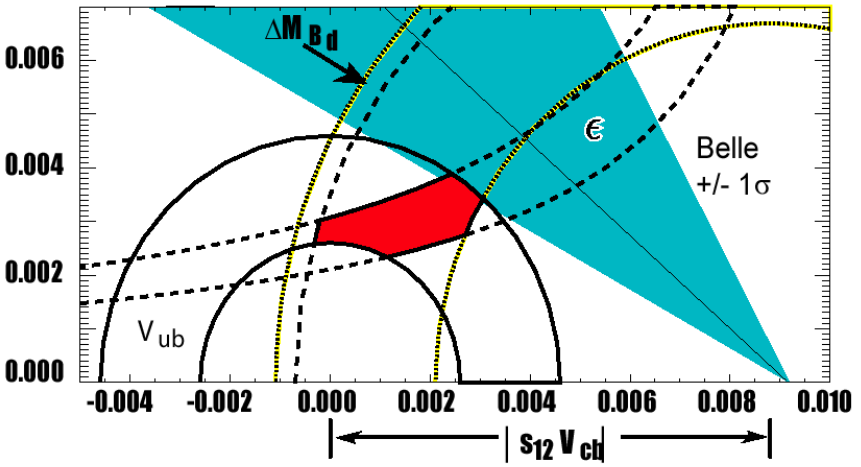
データセット — 30 fb^{-1} ⇒ 80 fb^{-1}

▷ $\sin 2\phi_1$ — CKM fit とのずれ?
— より精度よい測定
($\delta \sin 2\phi_1 \approx 0.08$)

▷ ユニタリティ三角形への制限
— $|V_{ub}|$ の測定



$Br(B^0 \to \pi^- \ell^+ \nu) = (1.28 \pm 0.20 \pm 0.26) \times 10^{-4}$
with 21 fb^{-1}



29.1 fb^{-1} での $\sin 2\phi_1$

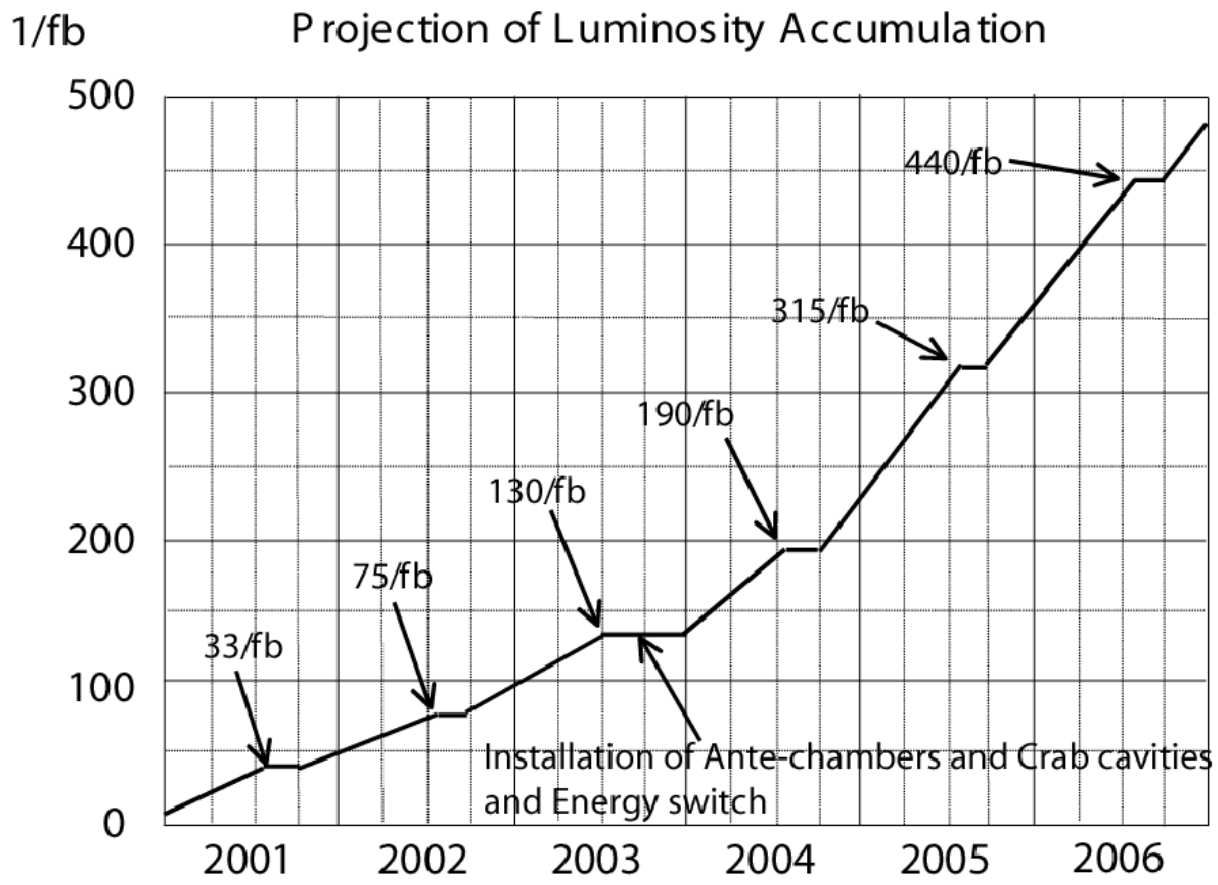
▷ より多くの B 崩壊の情報

▷▷ Charmless 崩壊 ⇒ ϕ_2, ϕ_3

▷▷ $B \to DK$ 崩壊 ⇒ ϕ_3

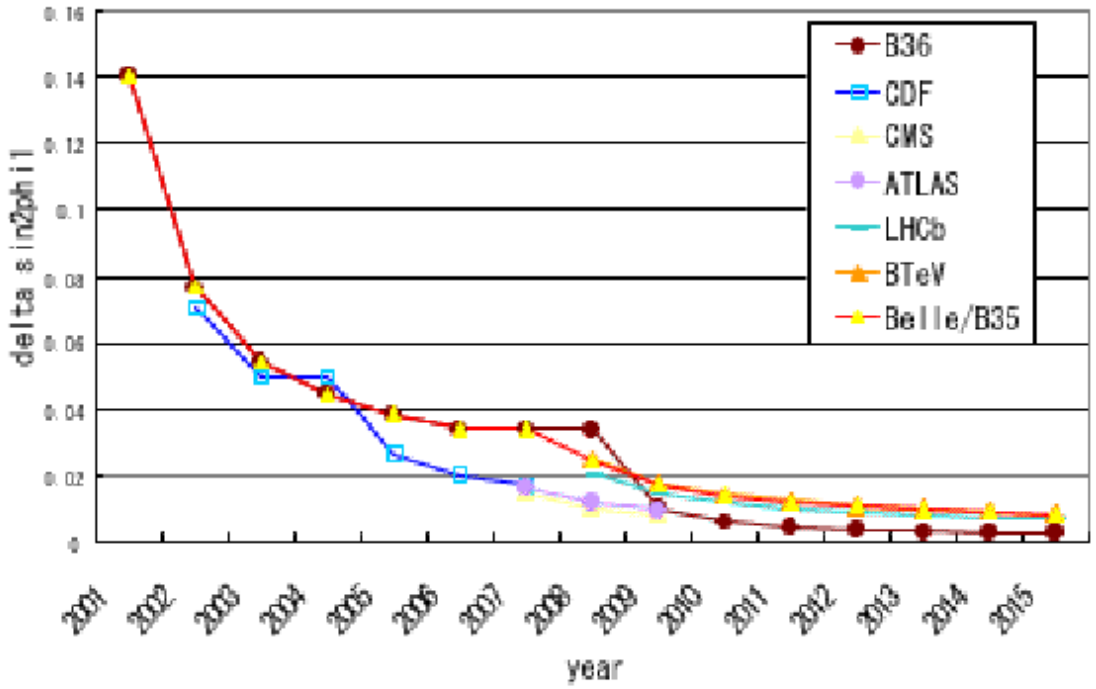
▷▷ 輻射崩壊 ⇒ non-SM probe, $|V_{ub}|$

KEKB ルミノシティの予測



$\sin 2\phi_1$ の行方

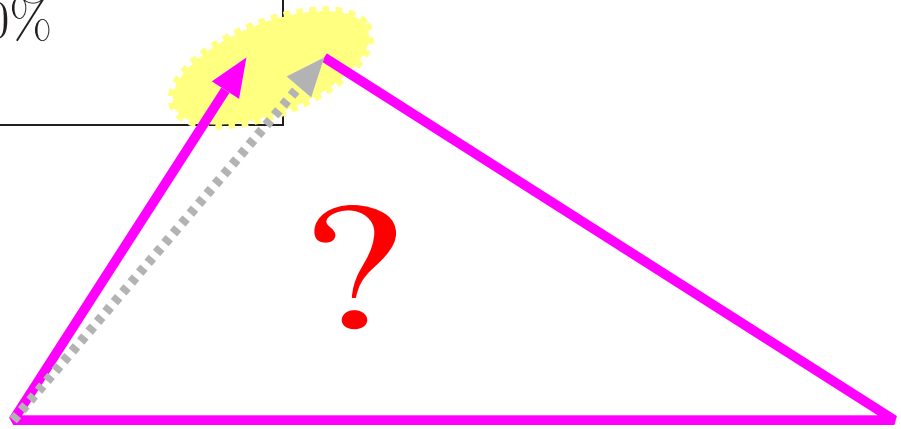
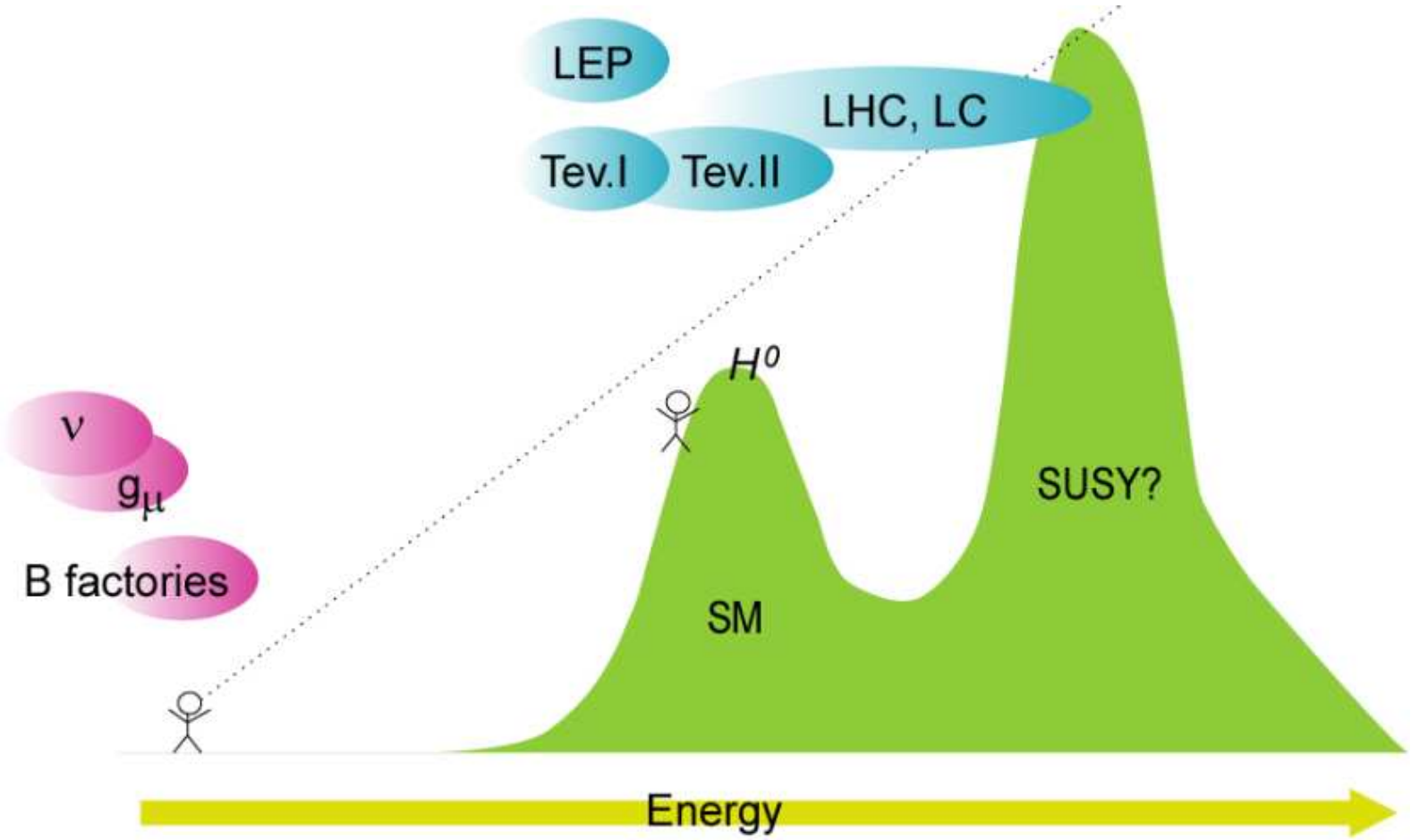
Example of the competition



August 24, 2001 Nobu Katayama 6

2006 年の三角形? 10 倍のデータ

Quantity	Method	Measurement error with 300 fb^{-1}
$\|V_{cb}\|$	$B \to D^{(*)}\ell\nu$	10%
$\|V_{ub}\|$	$B \to X_u\ell\nu$	15%
$\|V_{td}\|$	Δm	5% if f_B is determined
ϕ_1	$B \to K_S$	3.5°
ϕ_2	$B \to \pi\pi, \rho\pi$	$\delta A_{CP} = 20\%$
ϕ_3	$B \to K\pi, \pi\pi$	$\delta A_{CP} = 3\%$
	$B \to DK$	$\delta A_{CP} = 10\%$
$\phi_1 + \phi_2 + \phi_3$		13°



標準理論を越えて