KEK Bファクトリーの物理

ー　現状と将来　ー

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@ICRR

Outline

- BのCPの破れ「虎の巻」
- 実験装置と基礎的な測定
- ユニタリティ三角形の角度
- b → s ペンギンと未知のCPの破れ
- Super *B* factory

BのCPの破れ「虎の巻」

CP非保存の研究の歴史

1960

1964 Discovery of CP violation in K meson decays (Fitch, Cronin et al.)
1967 Role of CP violation in the creation of the universe (Sakharov)

1970

1973 **Kobayashi-Maskawa's 6 quark model and CP violation**
1974 Discovery of charm quark（Ting, Richter et al.）
1979 Discovery of bottom quark (Lederman et al.）

1980

1981 Large CP violation in neutral B meson system（Bigi, Carter, Sanda）

1987 Discovery of large $B^0\overline{B}^0$ mixing (ARGUS)

1990

1995 Discovery of top quark (CDF, D0)

1999 Discovery of direct CP violation in K decays (KTeV, NA48)

2000

2001 Discovery of large CP violation in B decays（Belle, BaBar)

quark physics evolution just along the KM prediction !

CKM matrix and Unitarity Triangle (UT)

CKM quark mixing matrix

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

Wolfenstein parameterization based on very intriguing hierarchy

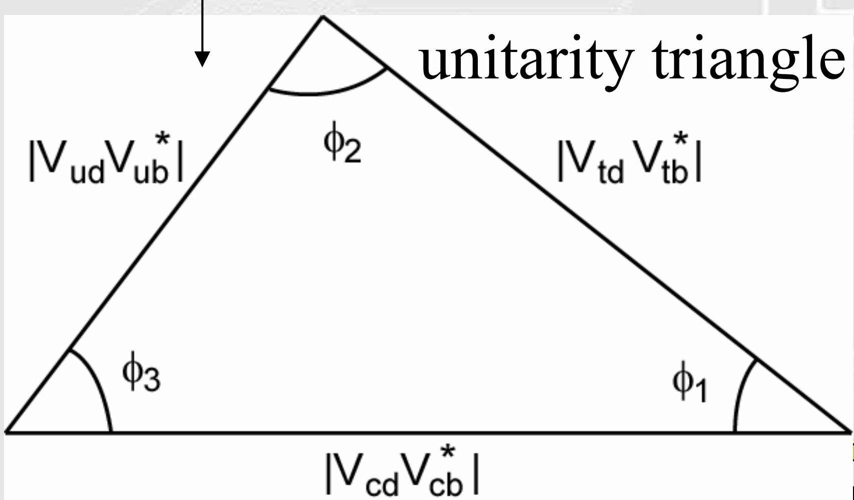
4 independent parameters

$\lambda \sim 0.2, \; A \sim \rho \sim \eta \sim O(1)$

$$\begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

unitarity

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



CP violation (CPV) from just one “KM phase” !

Open questions

More CPV phases from SUSY etc. ?

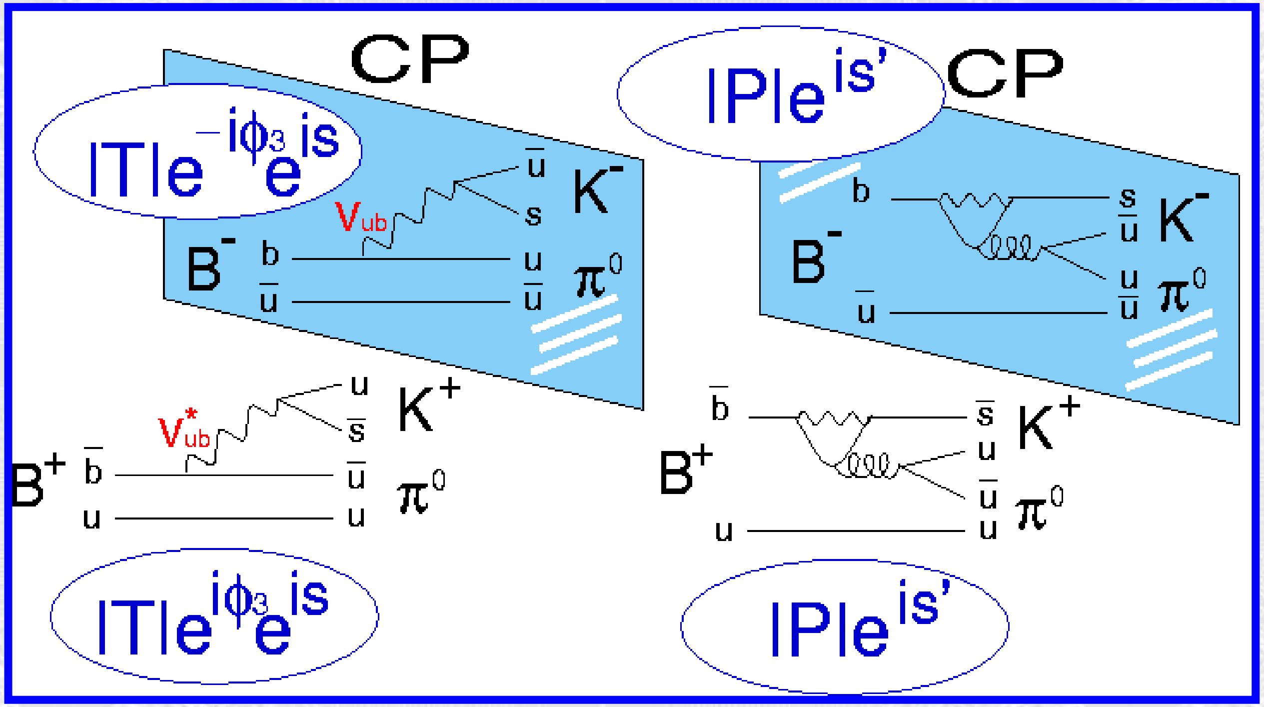
Baryogenesis ?

What's *CP* violation ? the first example

This is "direct" CP violation

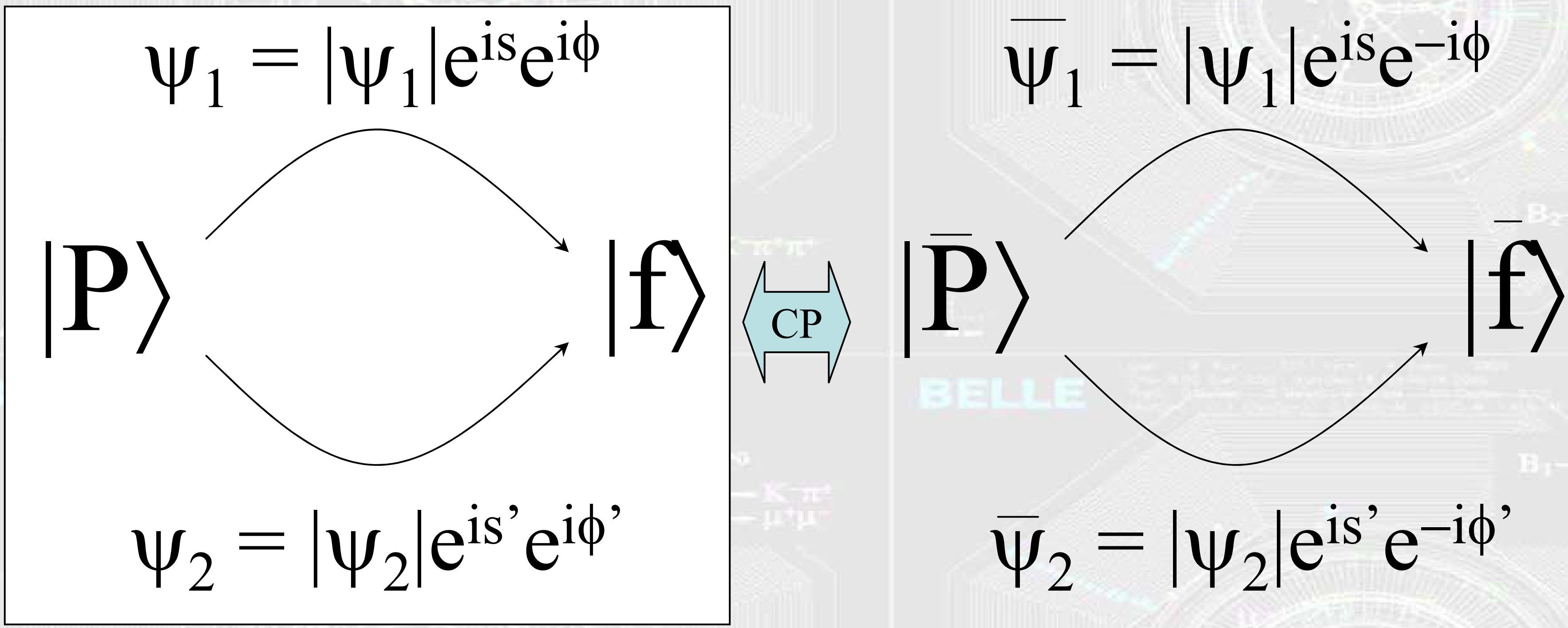
$B^- \to K^-\pi^0$

$B^+ \to K^+\pi^0$



$$\mathcal{A}sym \equiv \frac{\Gamma(B^- \to K^-\pi^0) - \Gamma(B^+ \to K^+\pi^0)}{\Gamma(B^- \to K^-\pi^0) + \Gamma(B^+ \to K^+\pi^0)} = \frac{2\,|T|\,|P|\sin\phi_3\sin(s-s')}{|T|^2 + |P|^2 + 2\,|T|\,|P|\cos\phi_3\cos(s-s')}$$

What's *CP* violation ?
It is a partial rate asymmetry !



$$\mathcal{A}sym \equiv \frac{\Gamma(\overline{P} \to \overline{f}) - \Gamma(P \to f)}{\Gamma(\overline{P} \to \overline{f}) - \Gamma(P \to f)} = \frac{2\,|\psi_1|\,\psi_2\,|\sin(\phi - \phi)\sin(s - s')}{|\psi_1|^2 + |\psi_2|^2 + 2\,|\psi_1||\psi_2|\cos(\phi - \phi')\cos(s - s')}$$

The rules of the game

(very important to develop your own idea !)

I. **Find a decay mode which has two decay paths with different weak phases**
   - **standard model : one of them has Vub or Vtd**
   - **new physics : new CP-violating phase**

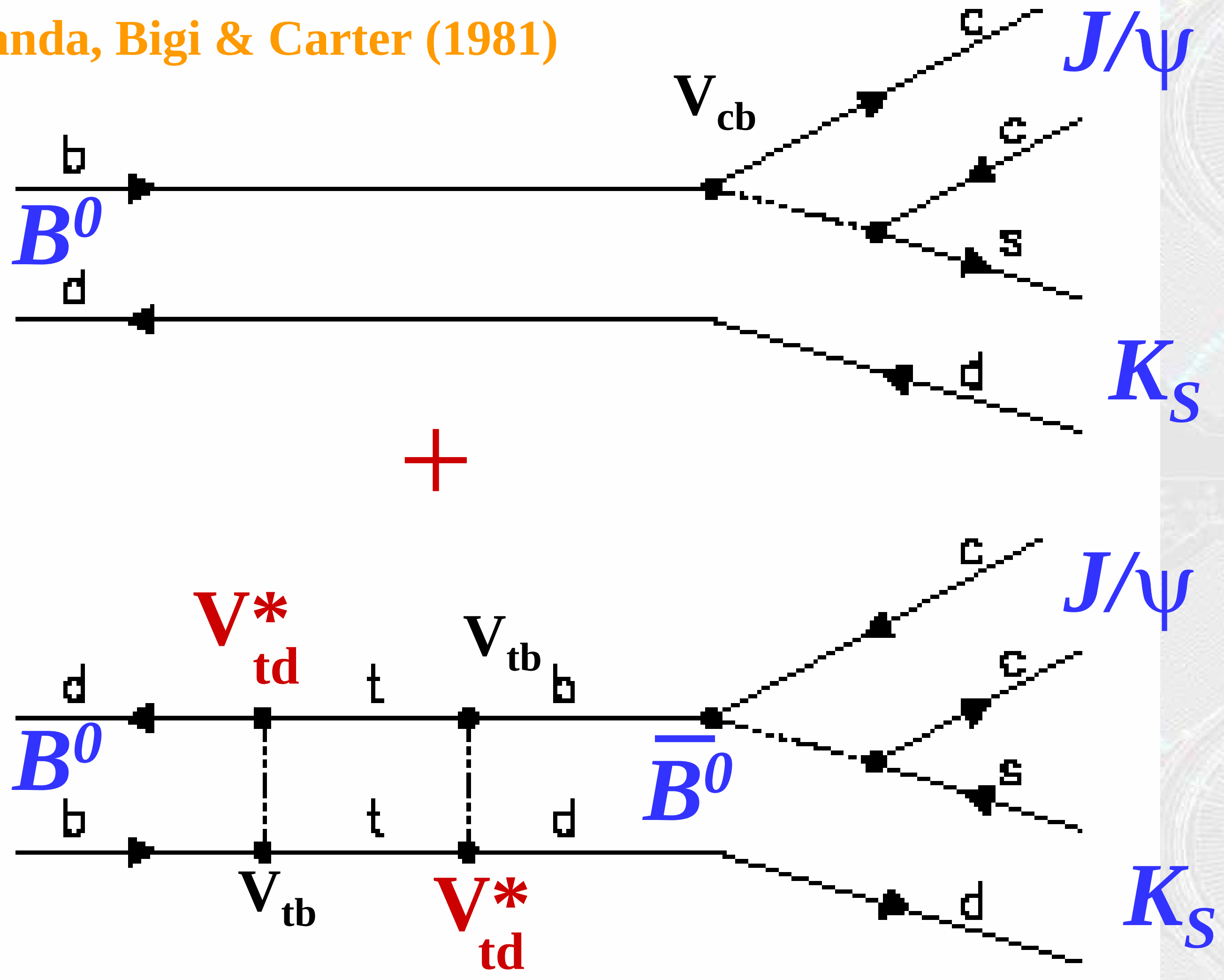
II. **Two paths should have “static” phase difference.**
   - **strong phase difference**
   - **mixing of neutral particles**

III. **Two amplitudes should have a similar size for sizable interference.**

Then, you can observe CP violation !

$\sin 2\phi_1$ from $B \to f_{CP} + B \leftrightarrow \bar{B} \to f_{CP}$ interf.

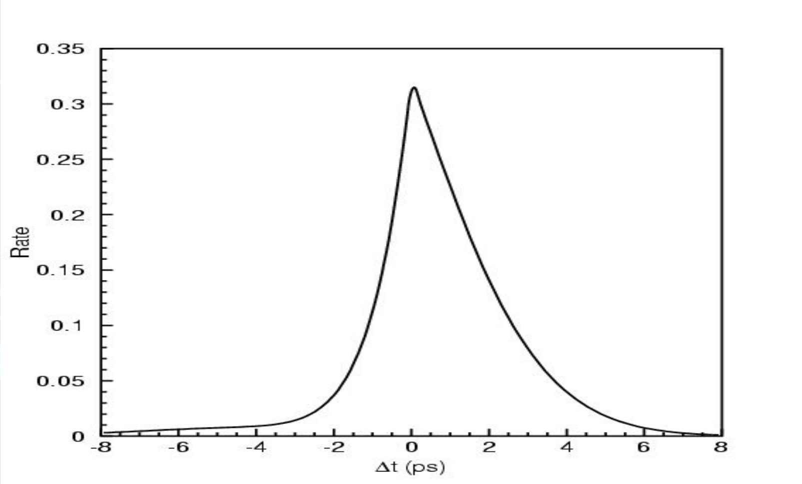
Sanda, Bigi & Carter (1981)

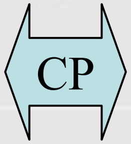


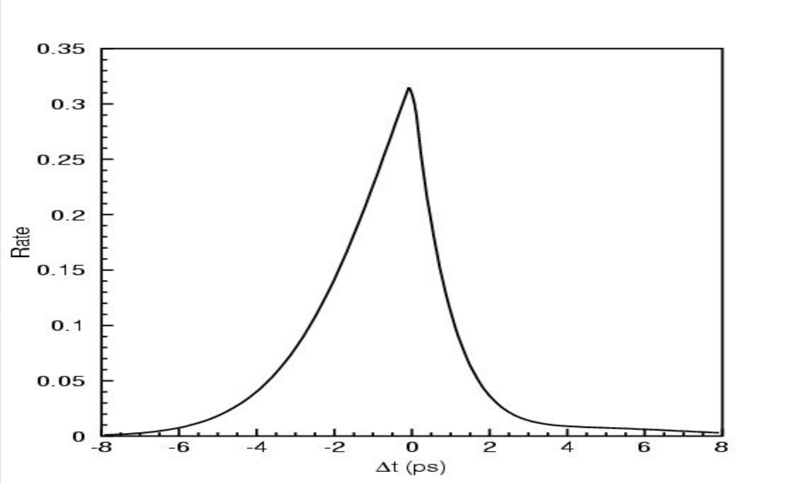
$\propto V^{*2}_{td}$

Time-dependent *CP* violation

$$\Gamma(\overline{B}^0(\Delta t) \to J/\psi K_S^0) \qquad \qquad \Gamma(B^0(\Delta t) \to J/\psi K_S^0)$$







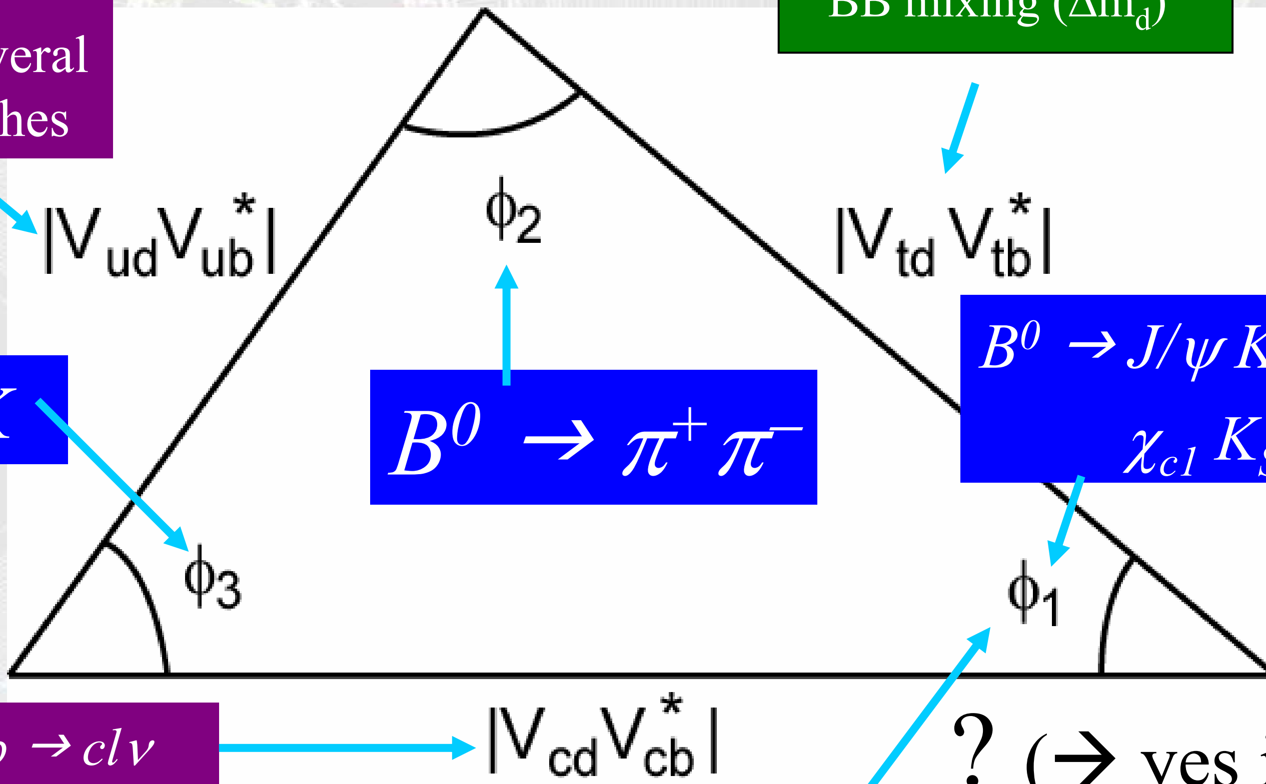
$$\mathcal{A}sym = \frac{\Gamma(\overline{B}^0(\Delta t) \to J/\psi K_S^0) - \Gamma(B^0(\Delta t) \to J/\psi K_S^0)}{\Gamma(\overline{B}^0(\Delta t) \to J/\psi K_S^0) + \Gamma(B^0(\Delta t) \to J/\psi K_S^0)} = \sin(2\phi_1) \cdot \sin(\Delta m \Delta t)$$

Hadronic uncertainty ≤ 1%

UT determination at Belle in 2003

$b \to ul\nu$
with several approaches

$B\bar{B}$ mixing (Δm_d)



$B \to DK$

$B^0 \to \pi^+\pi^-$

$B^0 \to J/\psi K_{S(L)}$, $\psi(2S) K_S$, $\chi_{c1} K_S$, $\eta_c K_S$

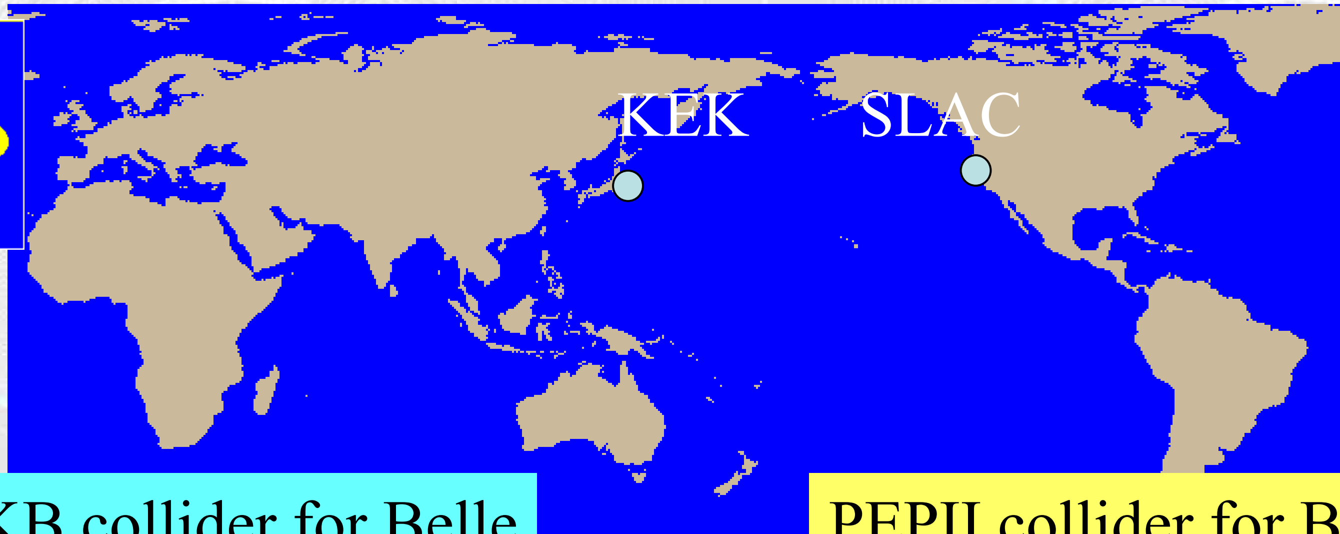
$b \to cl\nu$

? (→ yes in SM)

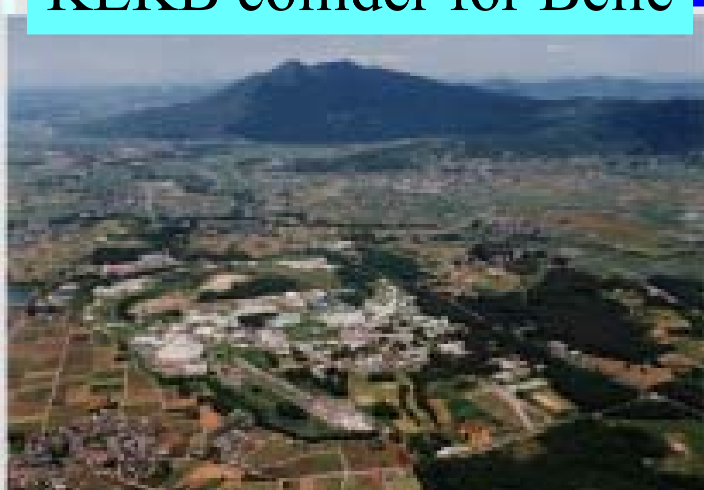
$B^0 \to \phi K_S$, $\eta' K_S$, $K^+K^-K_S$

実験装置と
基礎的な測定

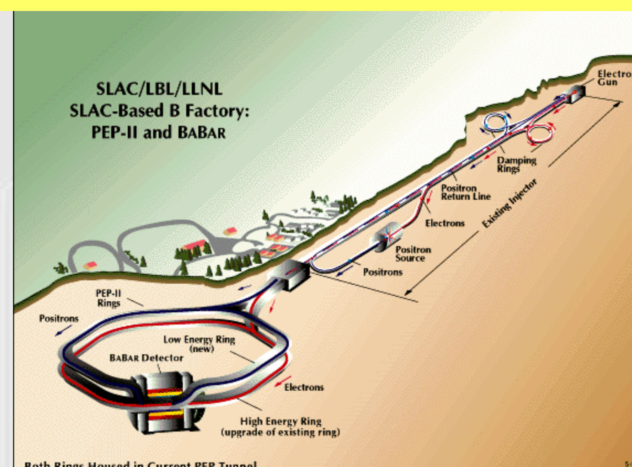
Two *B* factories in operation since 1999
Bを使った研究は始まったばかり



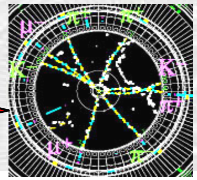
KEKB collider for Belle

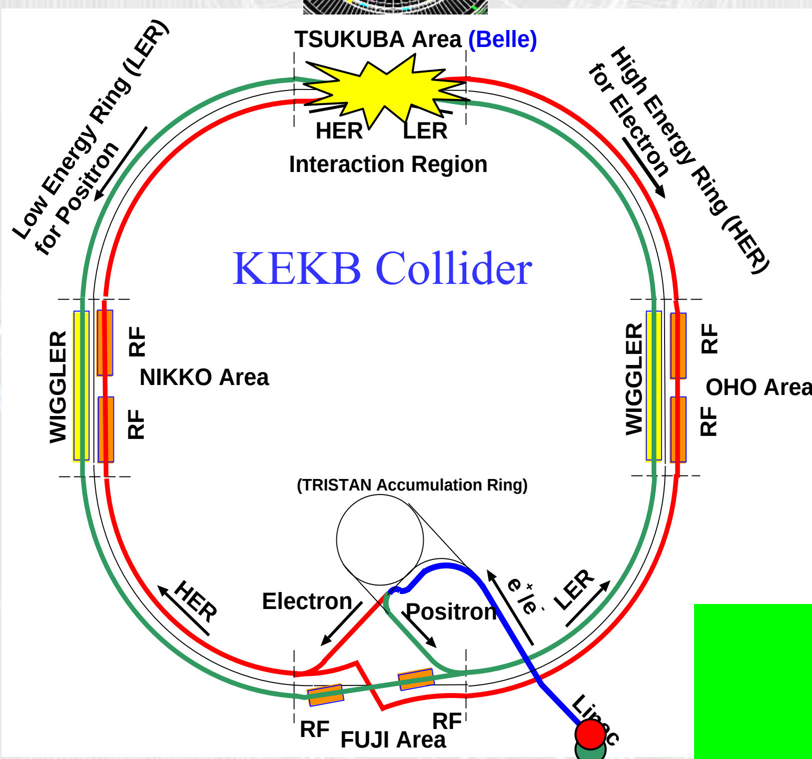


PEPII collider for BaBar



The KEKB Collider

e-(8GeV)  e+(3.5GeV)

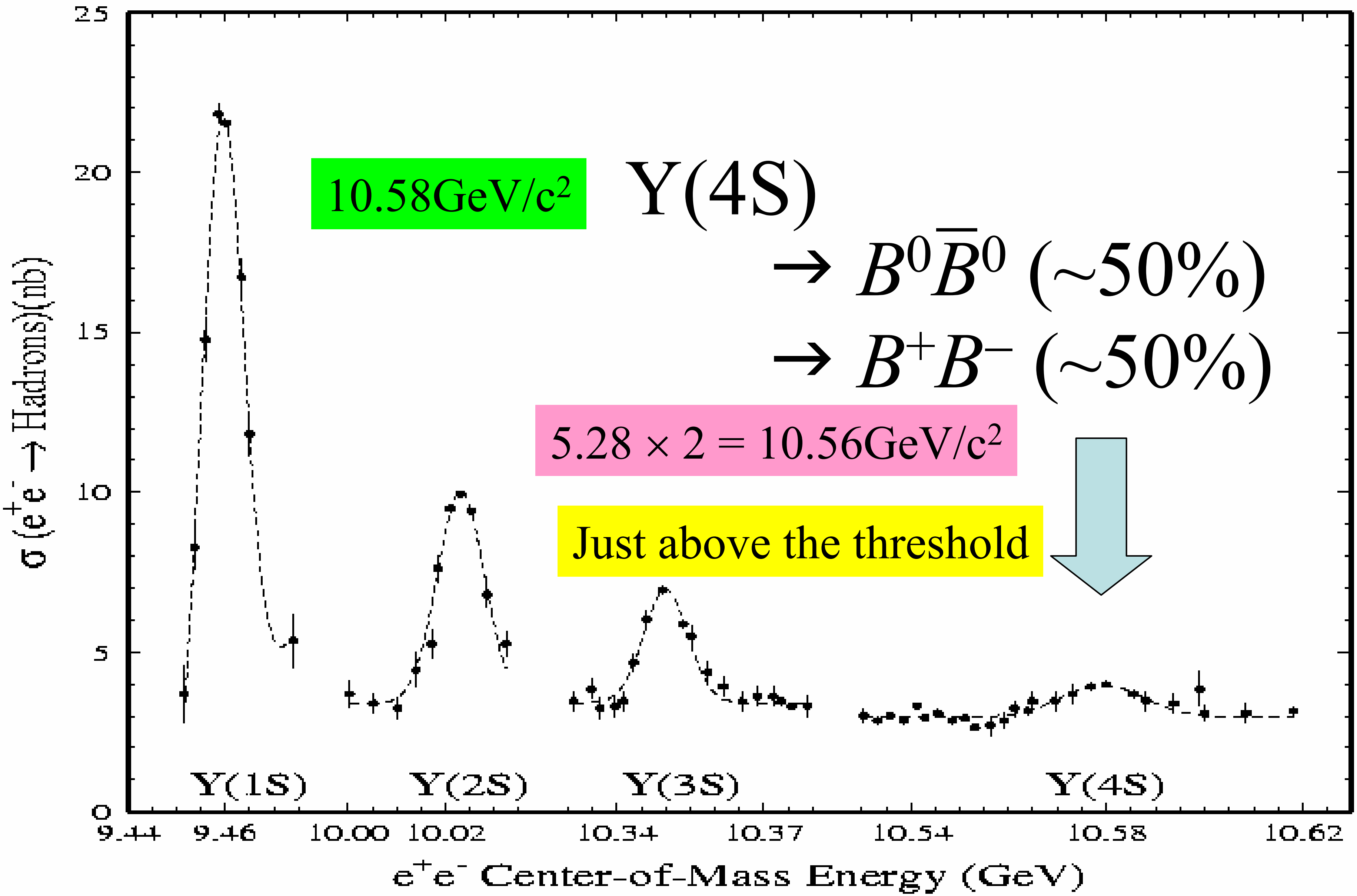


parameters (achieved)

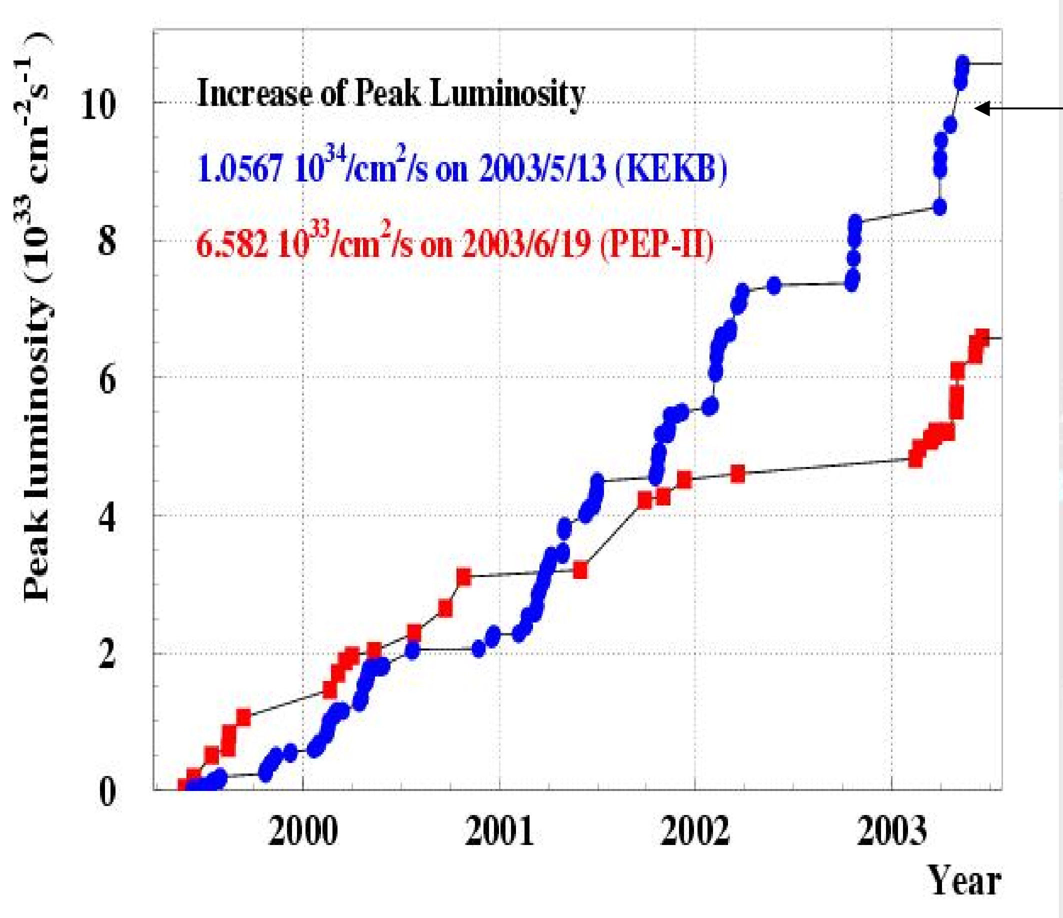
- e– energy, current: 8.0GeV, 1.1A
- e+ energy, current: 3.5GeV, 1.5A
- peak luminosity: $10.567\times10^{33}cm^{-2}s^{-1}$
- Integrated luminosity: $579pb^{-1}$/day
  $12.8fb^{-1}$/month

World records !

key idea
Asymmetric collision
for time-dependent *CP* violation


10.58GeV/c2
Y(4S)
→ B0B̄0 (~50%)
→ B+B− (~50%)
5.28 × 2 = 10.56GeV/c2
Just above the threshold
Y(1S)
Y(2S)
Y(3S)
Y(4S)
σ (e+e- → Hadrons)(nb)
e+e- Center-of-Mass Energy (GeV)
0
5
10
15
20
25
9.44
9.46
10.00
10.02
10.34
10.37
10.54
10.58
10.62

Peak luminosity history (1999-2003)



design luminosity ($1\times10^{34}cm^{-2}s^{-1}$) achieved in May 03

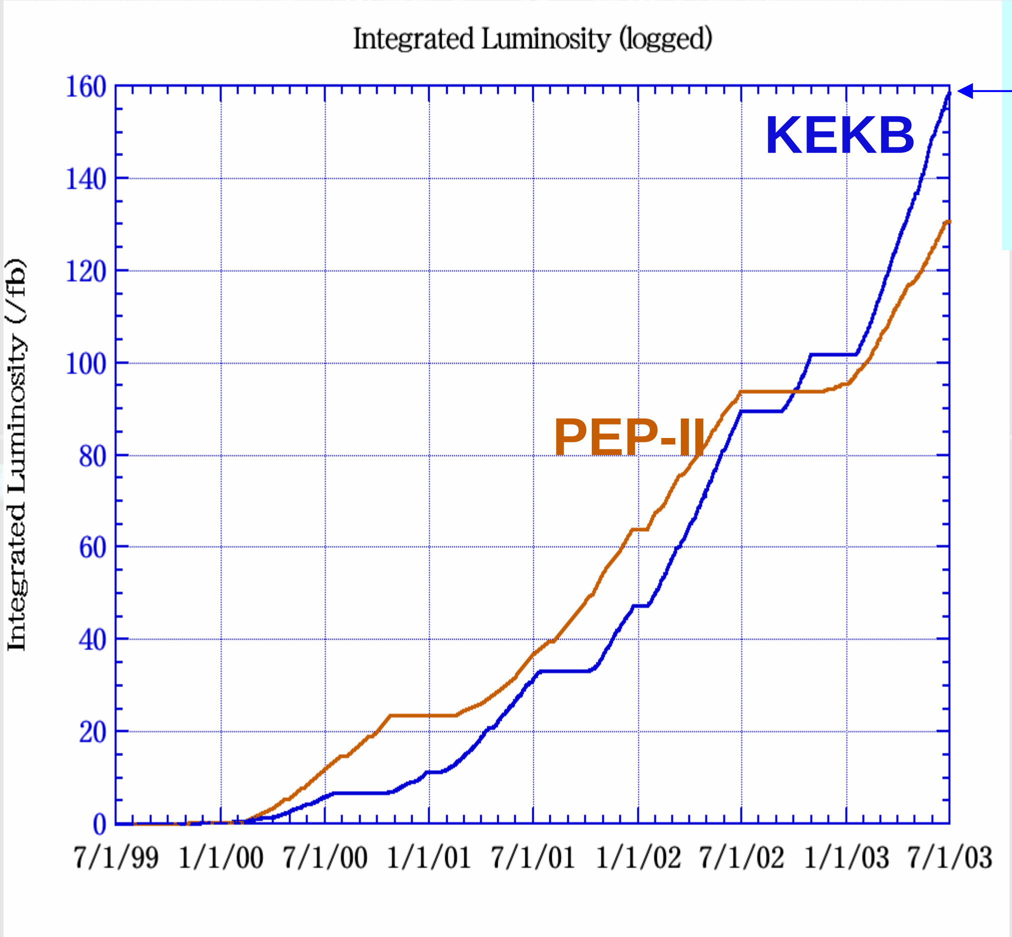
<u>at $1\times10^{34}cm^{-2}s^{-1}$</u>

~10 Υ(4S)/sec

→ ~5 $B^0\bar{B}^0$ pairs/sec

→ ~5 B^+B^- pairs/sec

Integrated luminosity: 1999 - 2003



158fb^{-1} logged by Belle
(July 1, 2003;
on + off resonance)

Most of results shown today based on on-resonance data taken by July 1, 2003

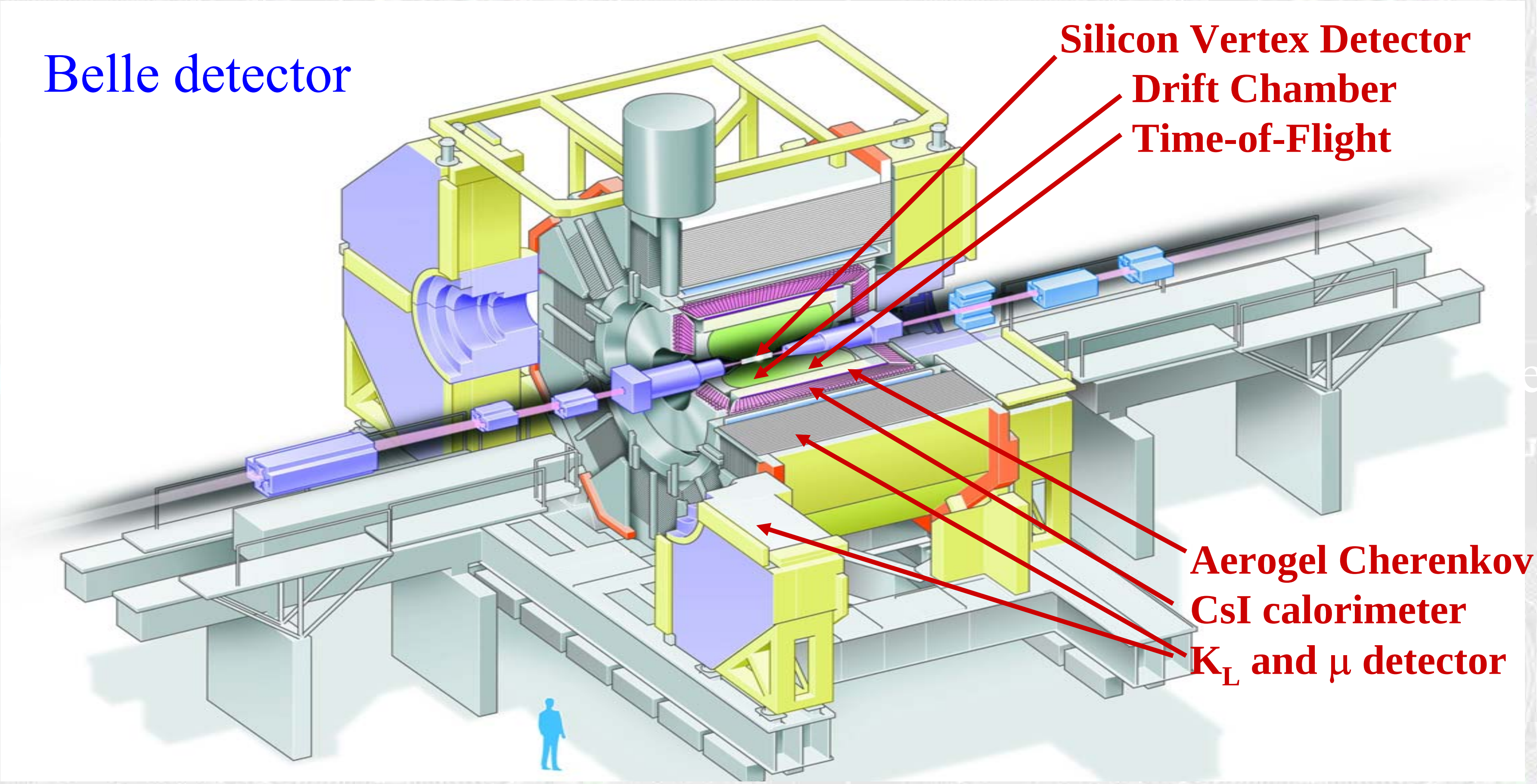
140fb^{-1} (152 million B pairs)

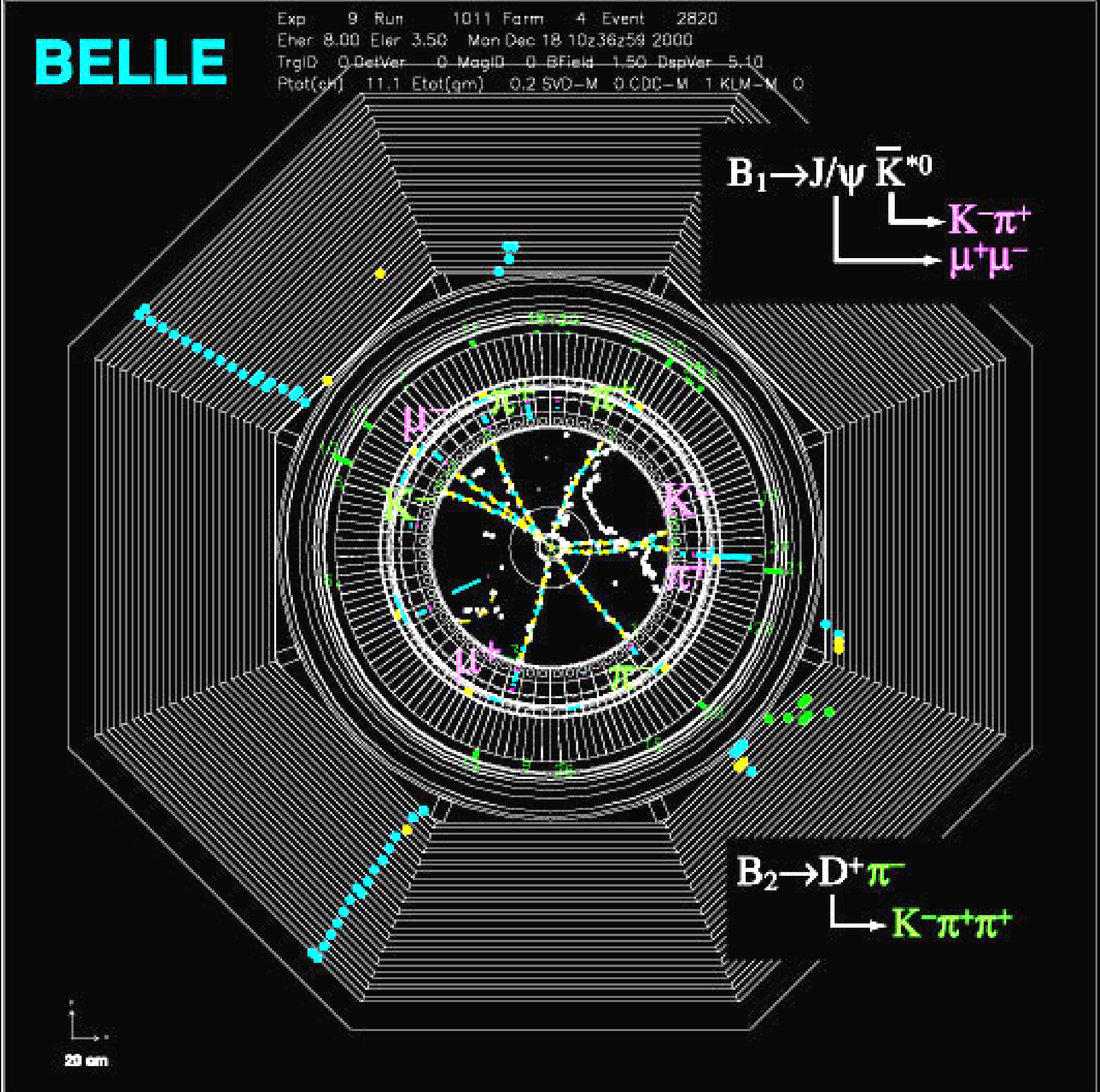
Belle Collaboration

Aomori U.
BINP
Chiba U.
Chuo U.
U. of Cincinnati
Frankfurt U.
Gyeongsang Nat'l U.
U. of Hawaii
Hiroshima Tech.
IHEP, Beijing
ITEP
Kanagawa U.
KEK
Korea U.
Krakow Inst. of Nucl. Phys.
Kyoto U.
Kyungpook National U.
U. of Lausanne
Jozef Stefan Inst.
U. of Maribor
U. of Melbourne
Nagoya U.
Nara Women's U.
National Central U.
Nat'l Kaoshiung Normal U.
Nat'l Lien-Ho Inst. of Tech.
Nat'l Taiwan U.
Nihon Dental College
Niigata U.
Osaka U.
Osaka City U.
Panjab U.
Peking U.
Princeton U.
Riken
Saga U.
USTC
Seoul National U.
Sungkyunkwan U.
U. of Sydney
Tata Institute
Toho U.
Tohoku U.
Tohuku Gakuin U.
U. of Tokyo
Tokyo Inst. of Tech.
Tokyo Metropolitan U.
Tokyo U. of A and T.
Toyama Nat'l College
U. of Tsukuba
Utkal U.
IHEP, Vienna
VPI
Yokkaichi U.
Yonsei U.

~300 collaborators from >10 countries

The Belle detector

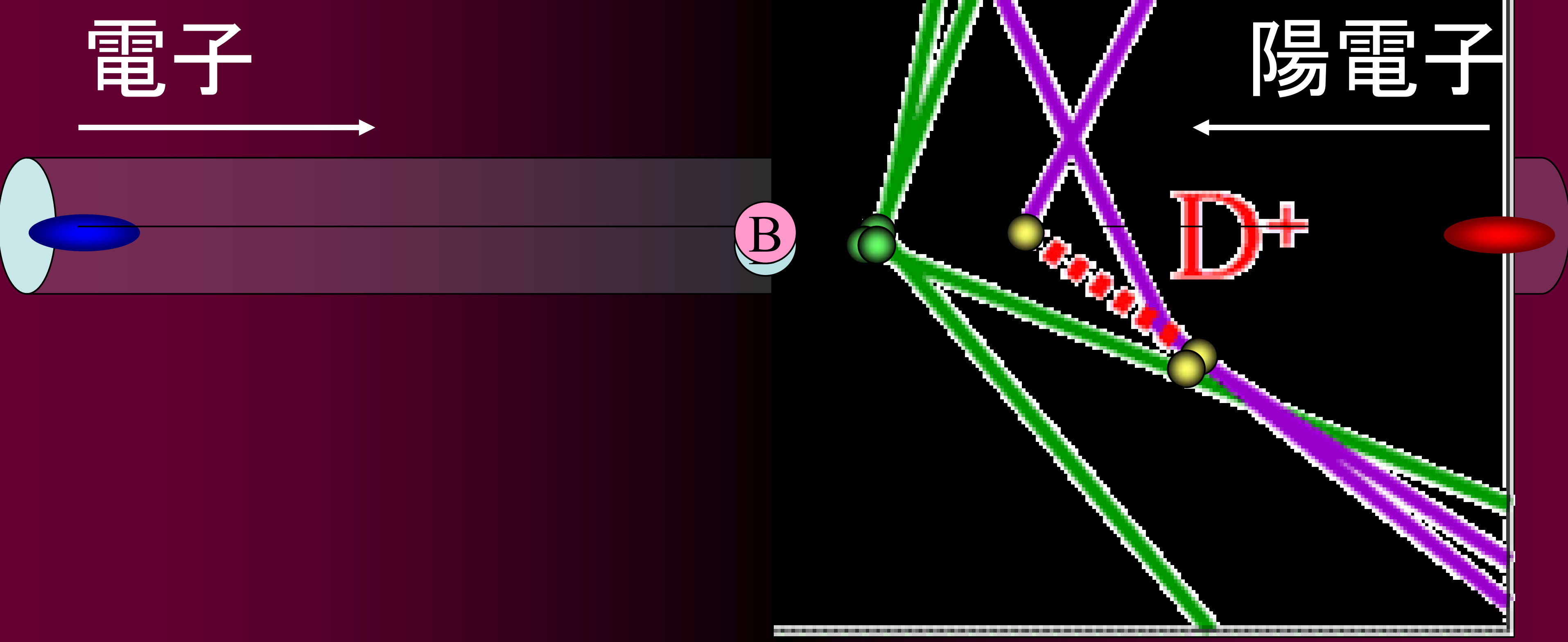


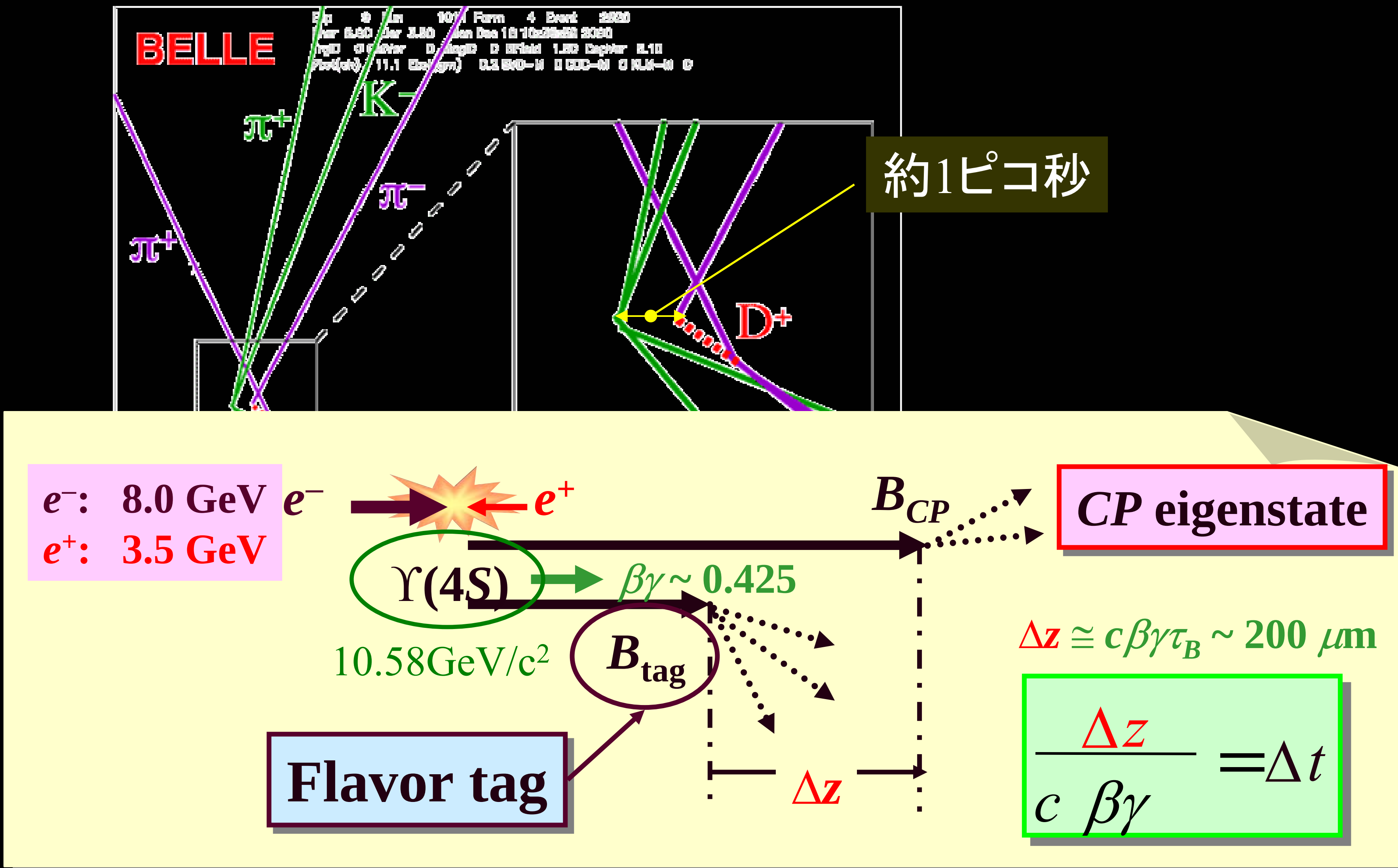


BELLE
Exp 9 Run 1011 Farm 4 Event 2820
Eher 8.00 Eler 3.50 Mon Dec 18 10z36z58 2000
TrgID 0 DetVer 0 MagID 0 BField 1.50 DspVer 5.10
Ptot(ch) 11.1 Etot(gm) 0.2 SVD-M 0 CDC-M 1 KLM-M 0
B1→J/ψ K̄*0
K−π+
μ+μ−
μ−
π+
π+
K−
K−
π+
μ+
π−
B2→D+π−
K−π+π+
20 cm

電子(8GeV)
陽電子(3．5GeV)
B
D+

スローモーション




BELLE
π+
K−
π−
π+
約1ピコ秒
D+
e−: 8.0 GeV
e+: 3.5 GeV
e−
e+
BCP
CP eigenstate
ϒ(4S)
βγ ~ 0.425
10.58GeV/c2
Btag
Flavor tag
Δz
Δz ≅ cβγτB ~ 200 μm
Δz / (c βγ) = Δt

Five Physics Groups at Belle

3 groups for B physics

***Indirect CPV* (time-dependent analyses)**

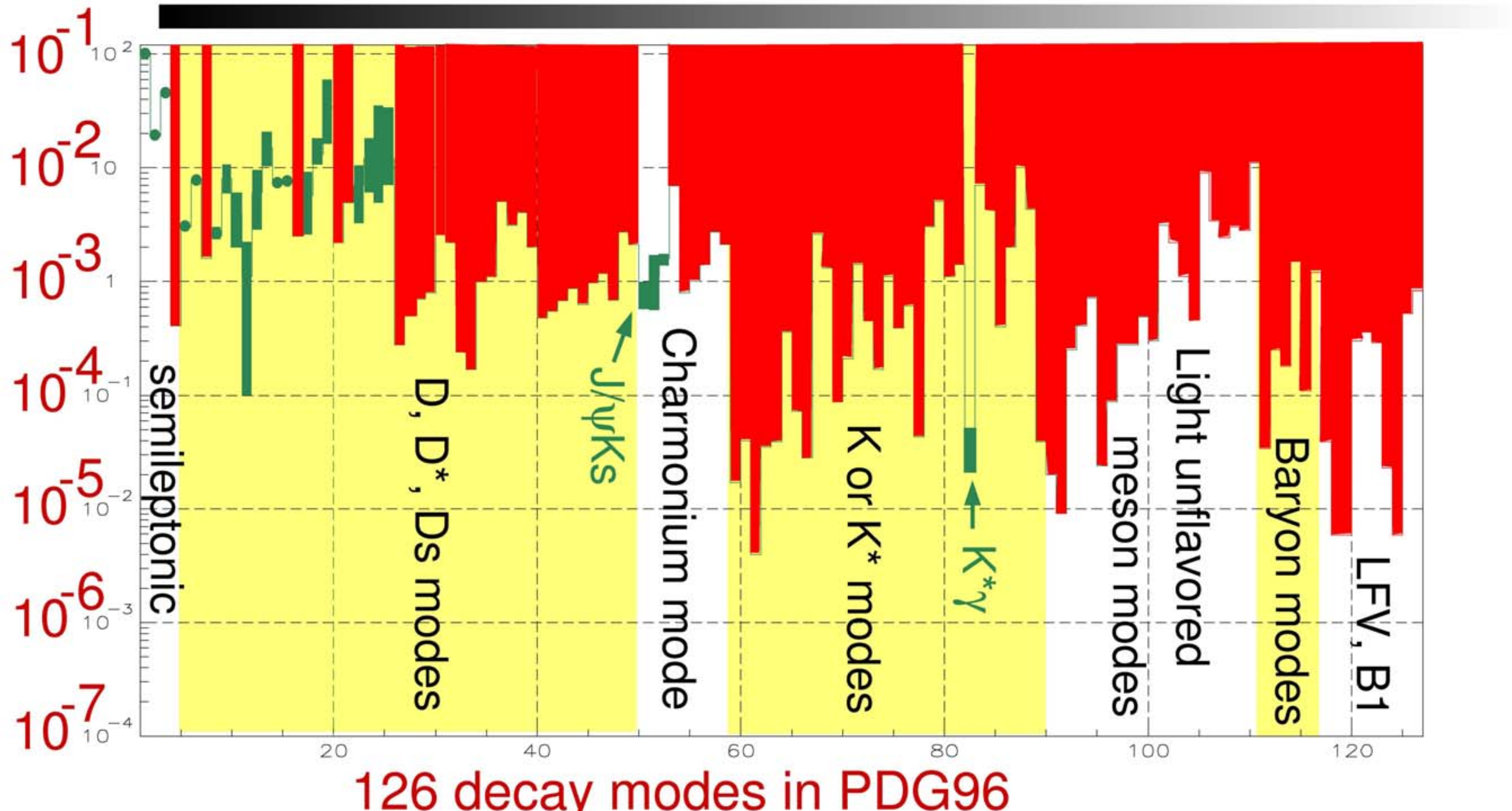
Direct CPV Rare Decays

***CKM* (Vub, Vcb)**

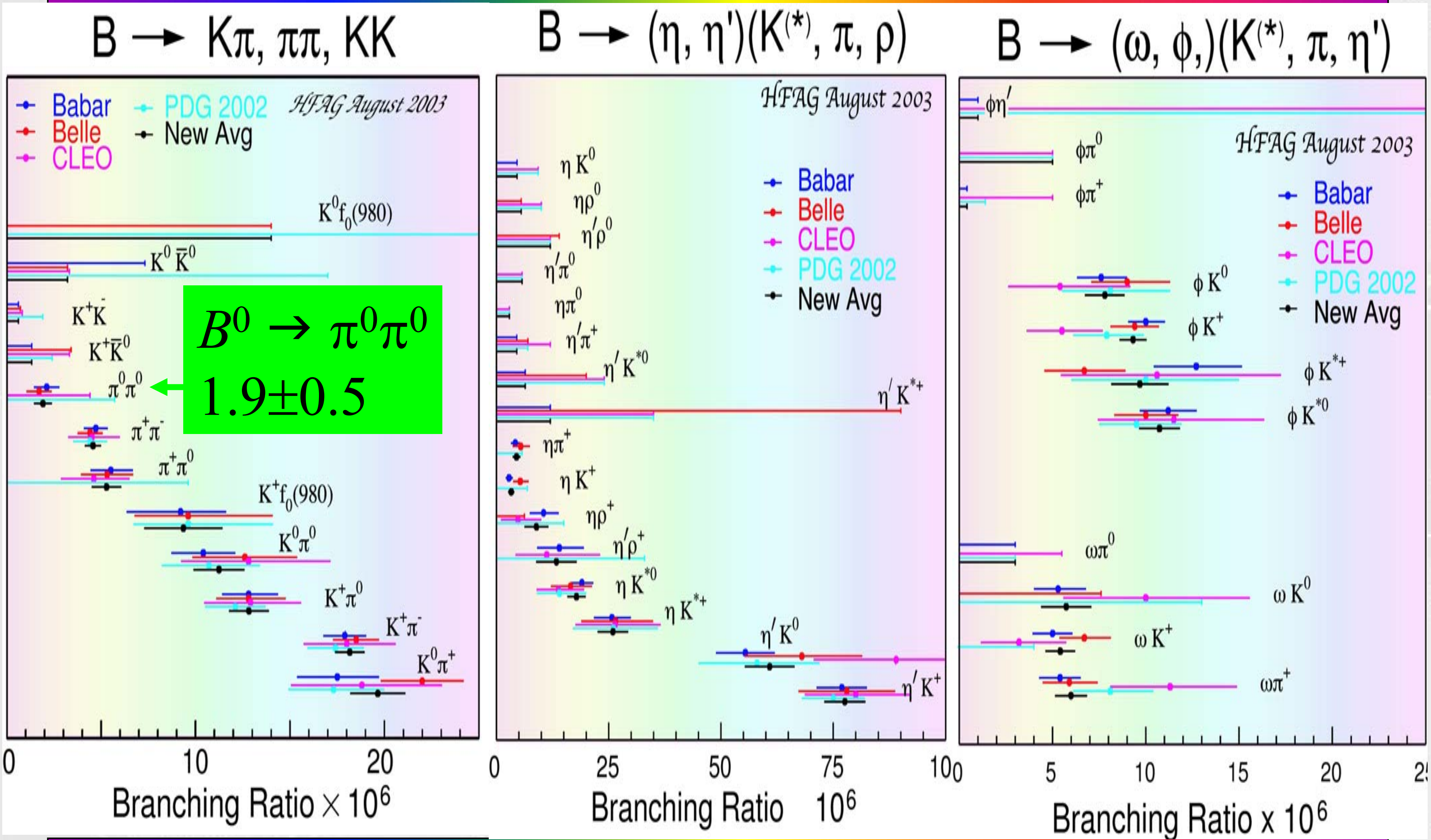
76 submitted/accepted papers as of now to PRL (42), PRD (19), PLB (14)

"First author group" (FAG) introduced at the 19th paper and ~60% of papers have FAG since then.

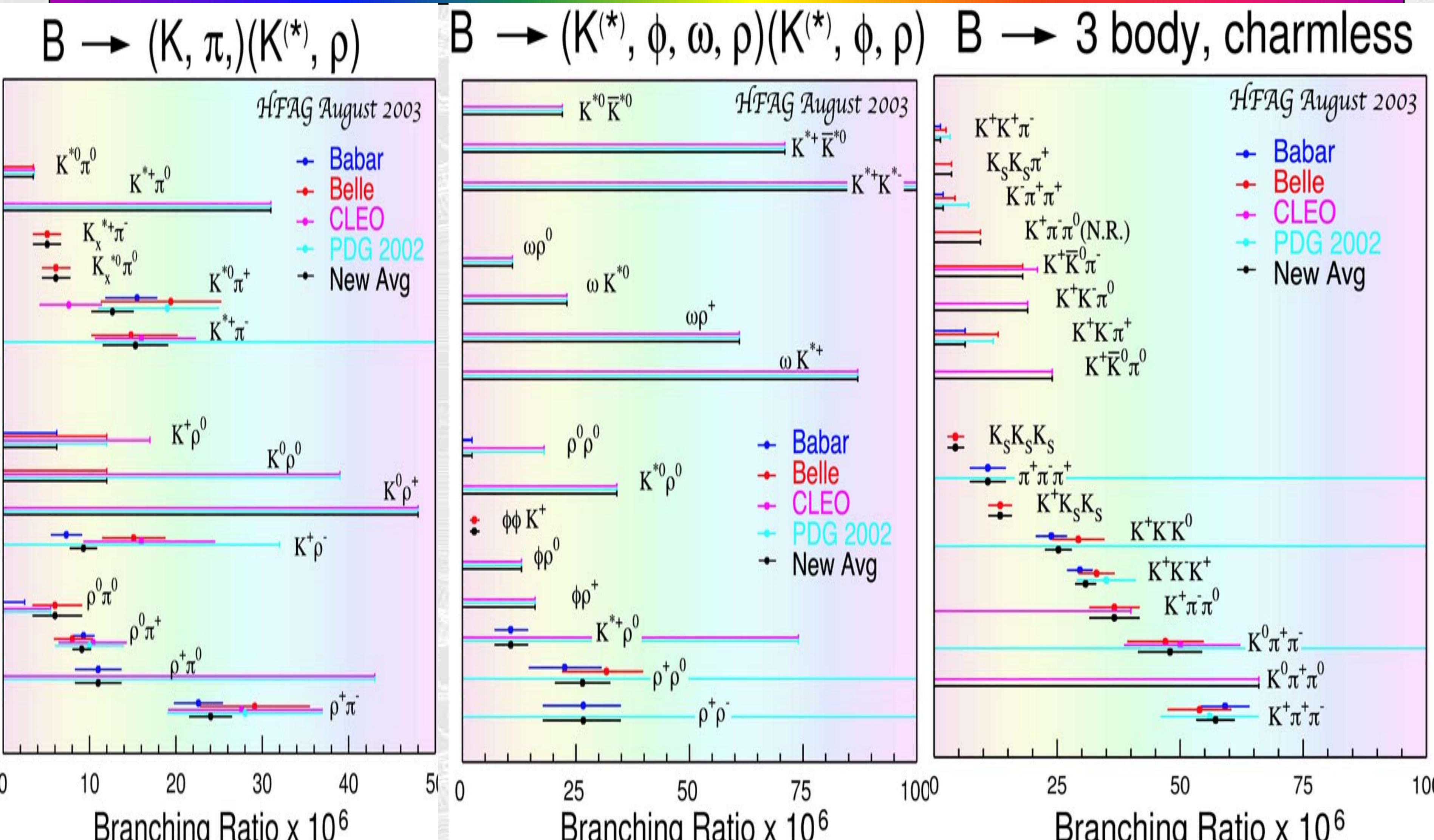
Branching Fractions of Neutral B (taken from PDG96)



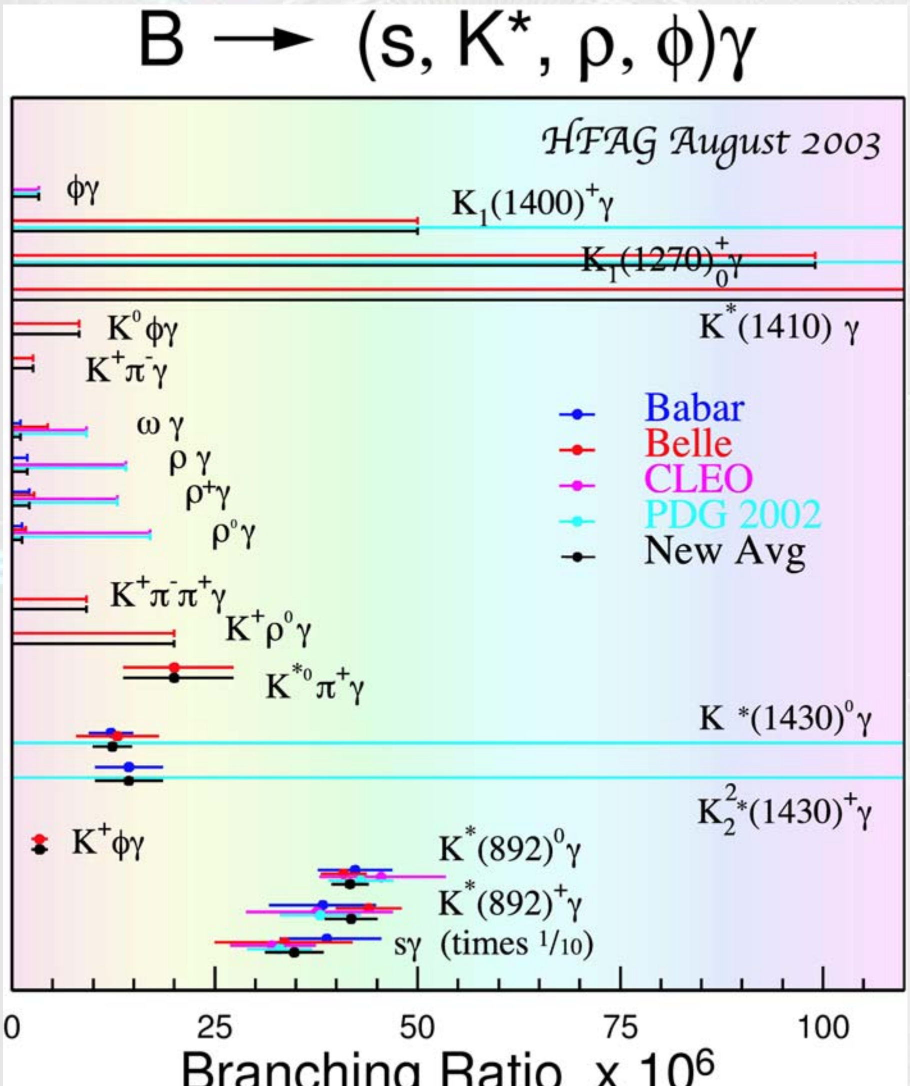
Observation of rare *B* decays (1)

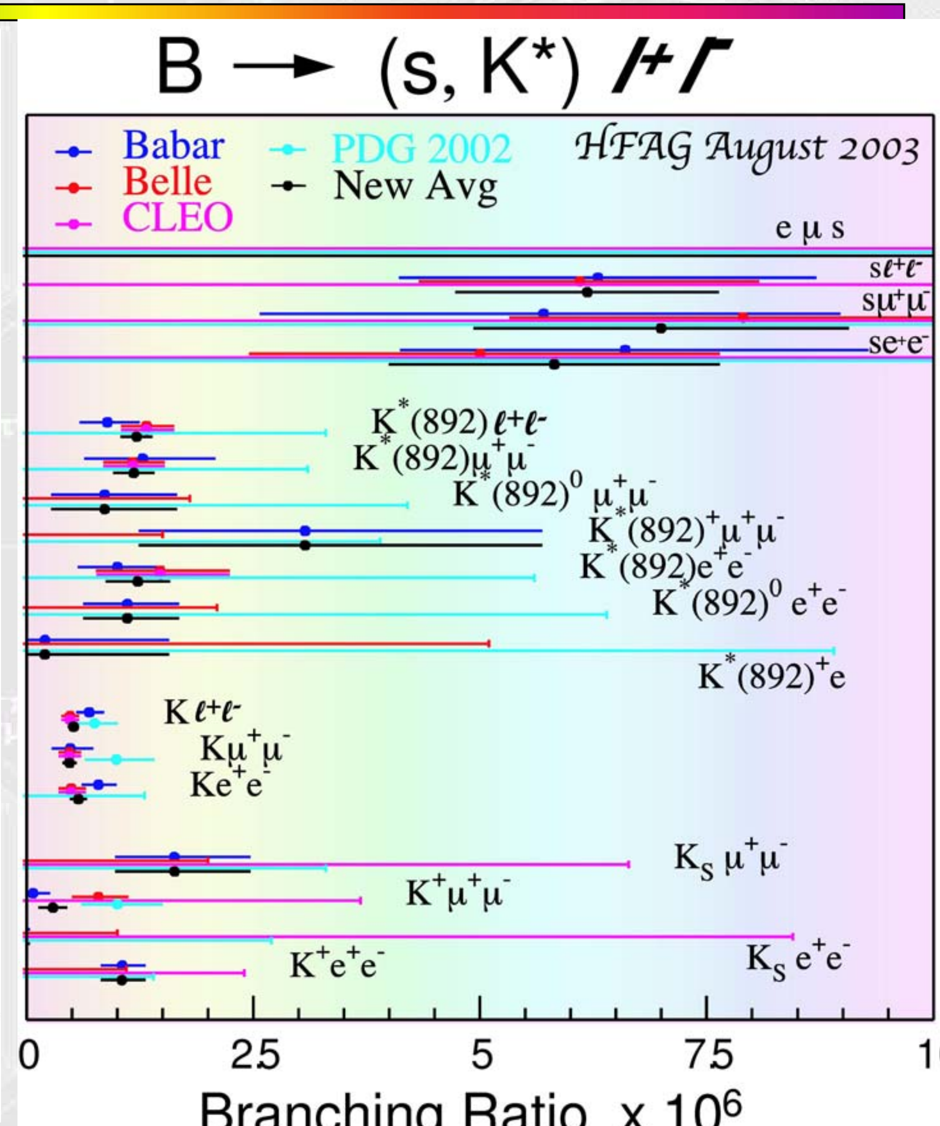


Observation of rare B decays (2)

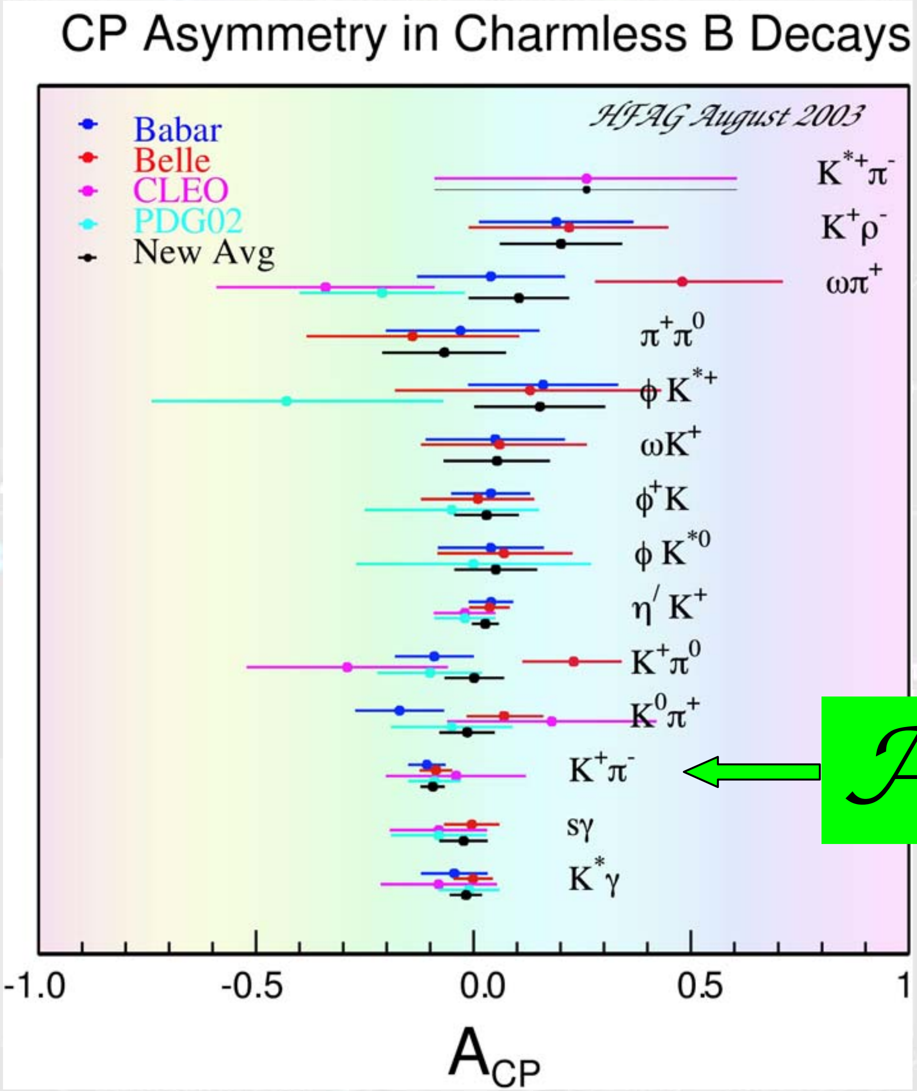


Observation of rare B decays (3)





Direct *CP* Violation

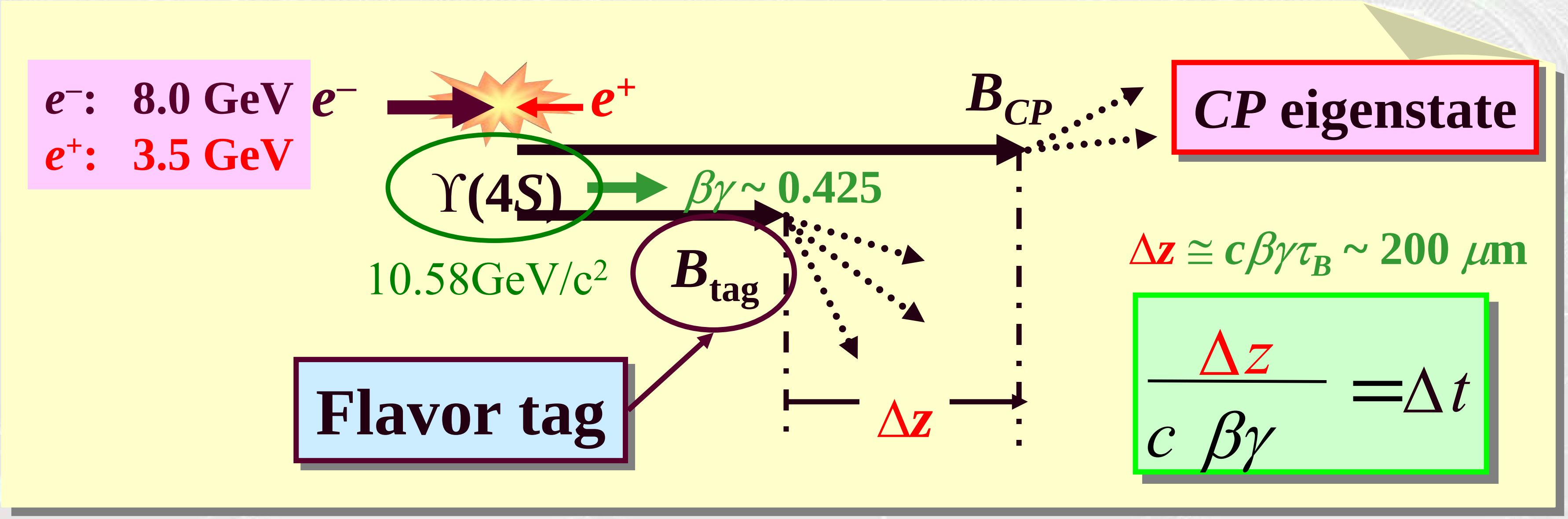


not yet established

$\mathcal{A}(K^+\pi^-) = -0.09 \pm 0.03$

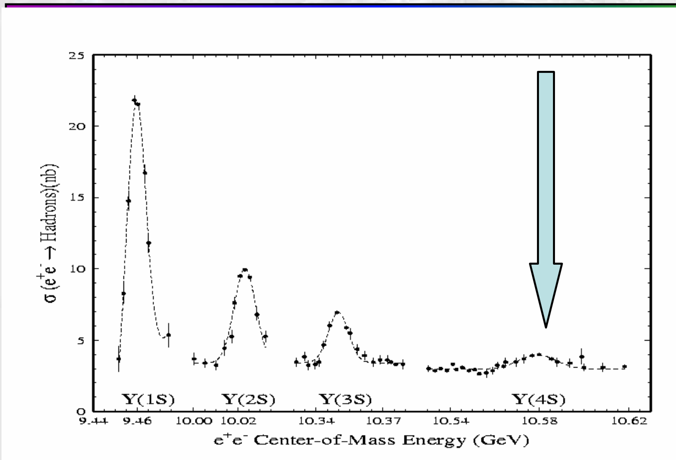
ユニタリ三角形の角度

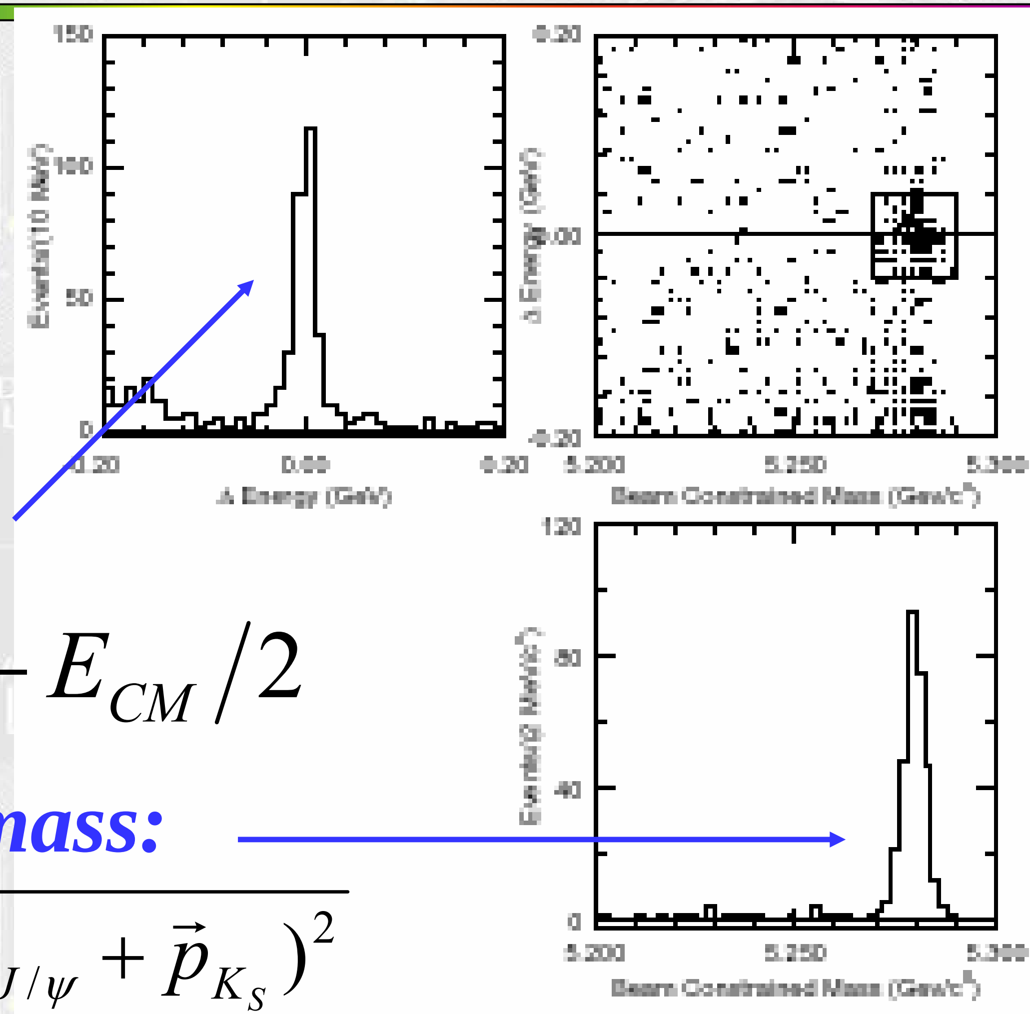
Time-dependent *CP* violation
Analysis Procedure



- CP eigenstate reconstruction
- Vertex reconstruction (Δz)
- Flavor tagging
- Unbinned maximum likelihood fit

Kinematic variables for the Υ(4S)





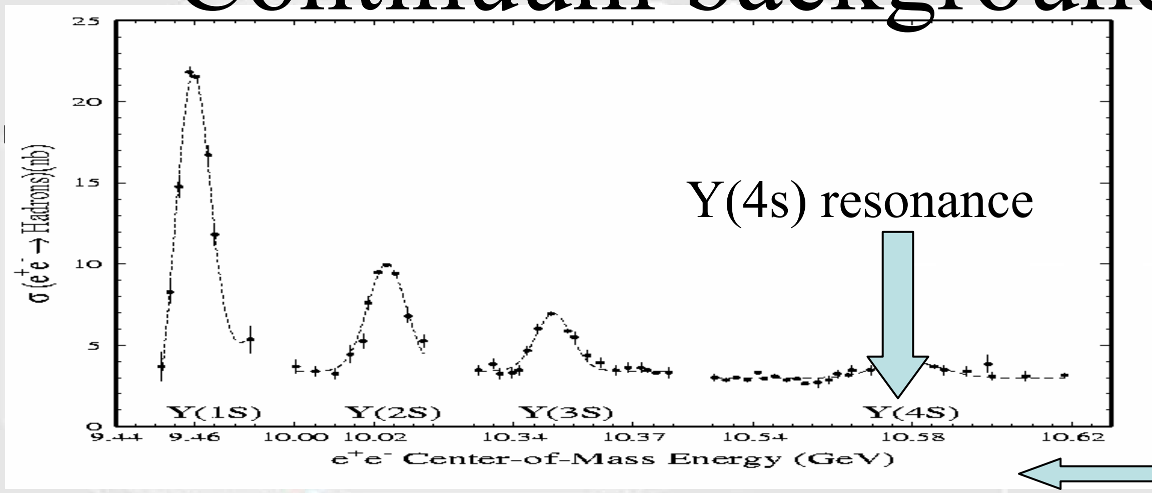
Energy difference:

$$\Delta E \equiv E_{J/\psi} + E_{K_S} - E_{CM}/2$$

Beam-constrained mass:

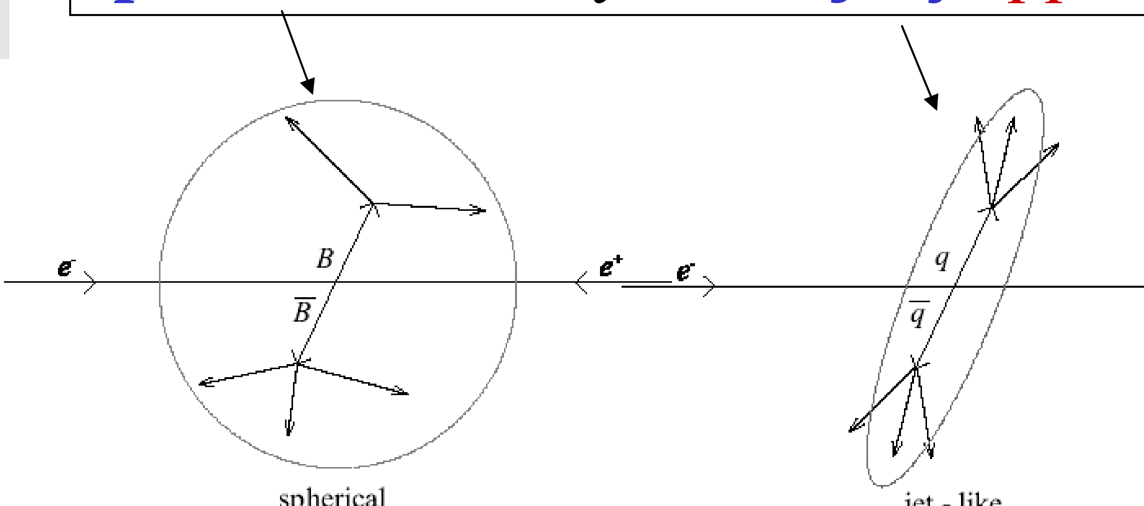
$$m_{bc} = \sqrt{(E_{CM}/2)^2 - (\vec{p}_{J/\psi} + \vec{p}_{K_S})^2}$$

Continuum background suppression



continuum:
e+e– → uu, dd, ss, cc

use ***kinematics*** and ***topology*** to separate ***spherical*** *B* decays from ***jetty*** $q\bar{q}$ events

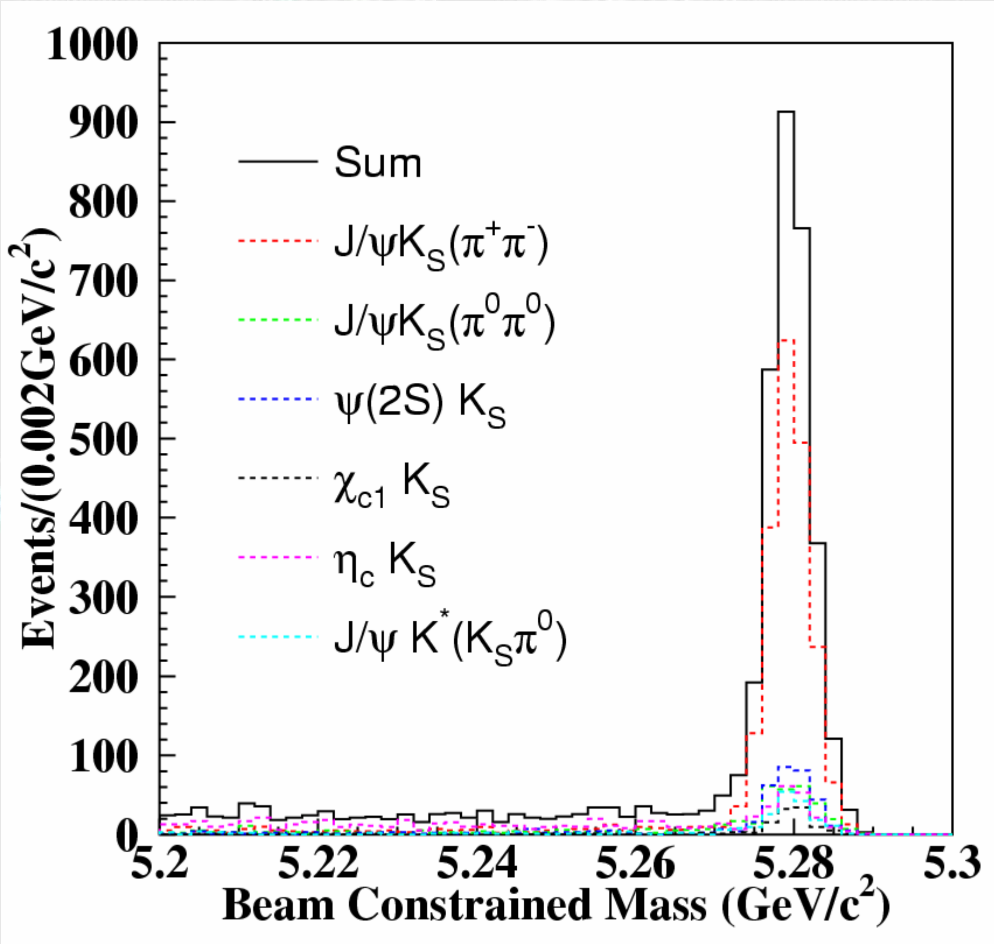


Fisher(5SFW, $\cos\theta_T$, $S_\perp$) x $\cos\theta_B$ x $\cos\theta_H$

common algorithm in almost all the rare decay analyses at Belle

Belle 2003 : CP eigenstates ($b \to c\bar{c}s$)

hep-ex/0308036: full paper in preparation

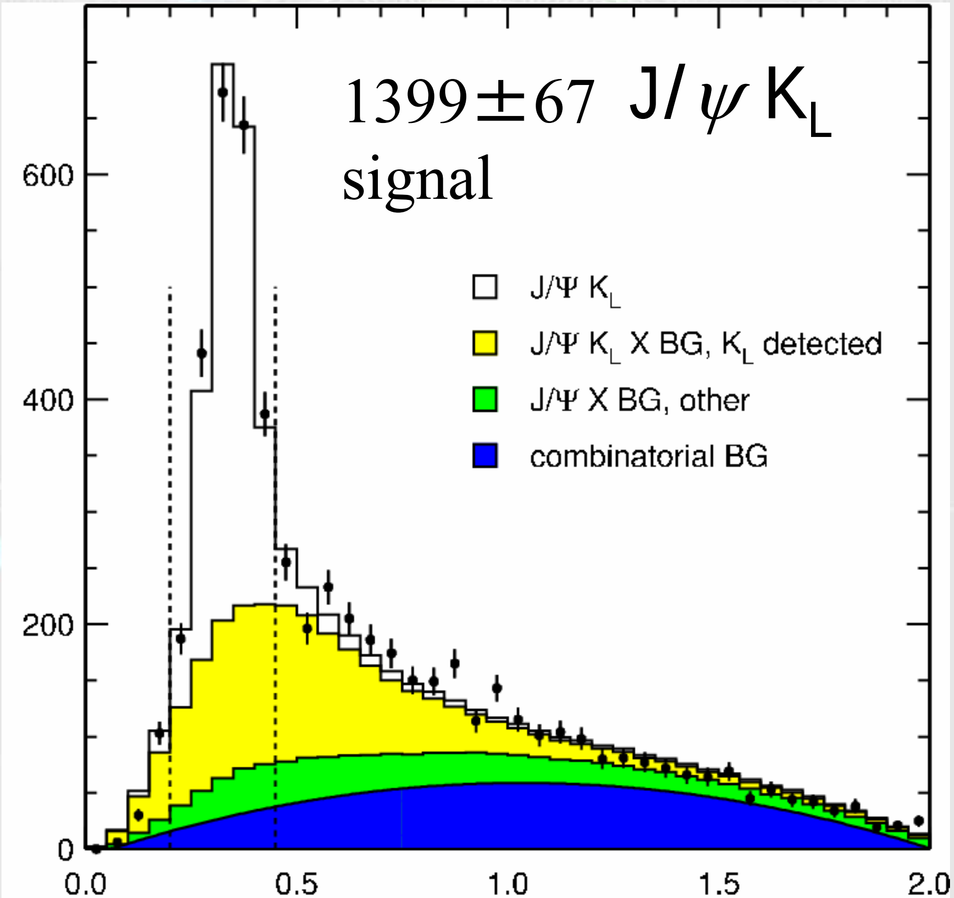


140 fb^{-1} , 152 x 10^6 B$\bar{B}$ pairs

Mode	N_{ev}	Purity
$J/\psi(\ell^+\ell^-)K_S^0(\pi^+\pi^-)$	1997	0.976 ± 0.001
$J/\psi(\ell^+\ell^-)K_S^0(\pi^0\pi^0)$	288	0.82 ± 0.02
$\psi(2S)(\ell^+\ell^-)K_S^0(\pi^+\pi^-)$	145	0.93 ± 0.01
$\psi(2S)(J/\psi\pi^+\pi^-)K_S^0(\pi^+\pi^-)$	163	0.88 ± 0.01
$\chi_{c1}(J/\psi\gamma)K_S^0(\pi^+\pi^-)$	101	0.92 ± 0.01
$\eta_c(K_S^0K^-\pi^+)K_S^0(\pi^+\pi^-)$	123	0.72 ± 0.03
$\eta_c(K^+K^-\pi^0)K_S^0(\pi^+\pi^-)$	74	0.70 ± 0.04
$\eta_c(p\bar{p})K_S^0(\pi^+\pi^-)$	20	0.91 ± 0.02
All with $\xi_f = -1$	2911	0.933 ± 0.002
$J/\psi(\ell^+\ell^-)K^{*0}(K_S^0\pi^0)$	174	0.93 ± 0.01

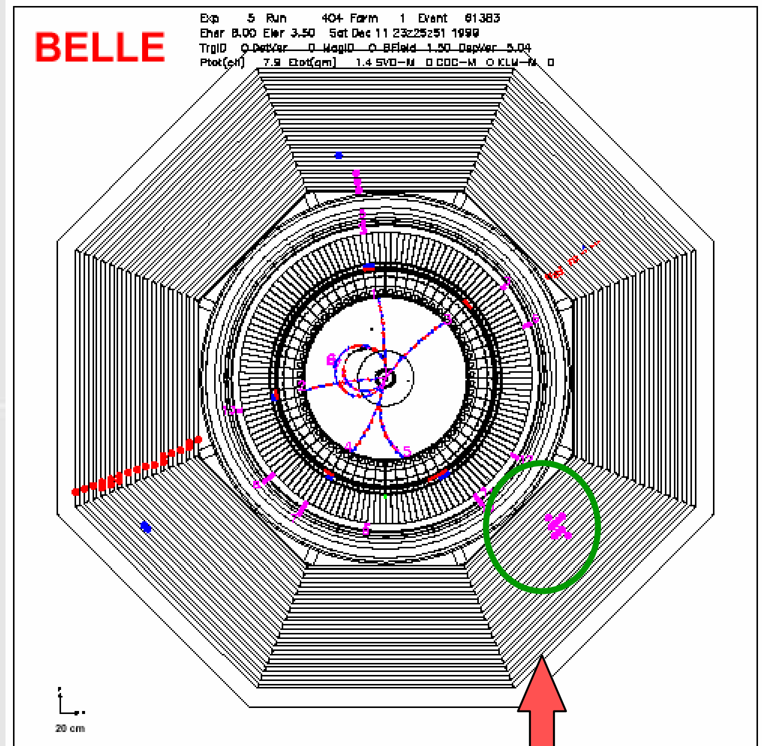
2911 events are used in the fit.

Belle 2003: $B^0 \rightarrow J/\psi\ K_L$ signal



p_B^* (cms)

Event display

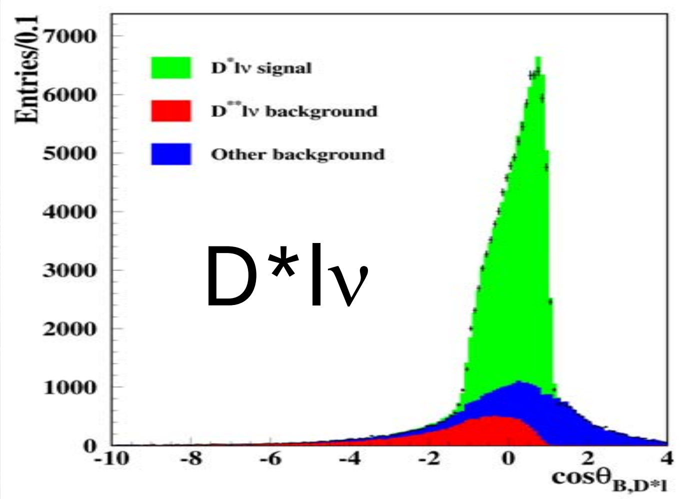


K_L

[2332 events with a purity of 0.60]

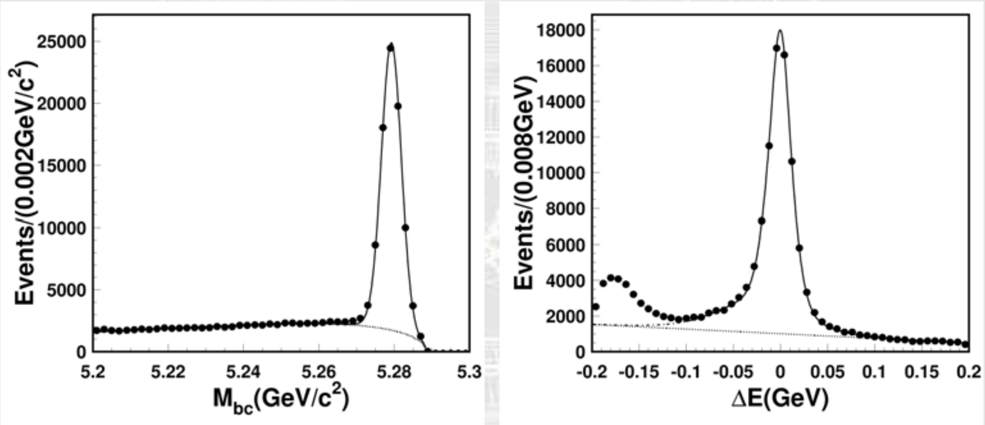
Control samples

for resolution function and wrong tag fractions



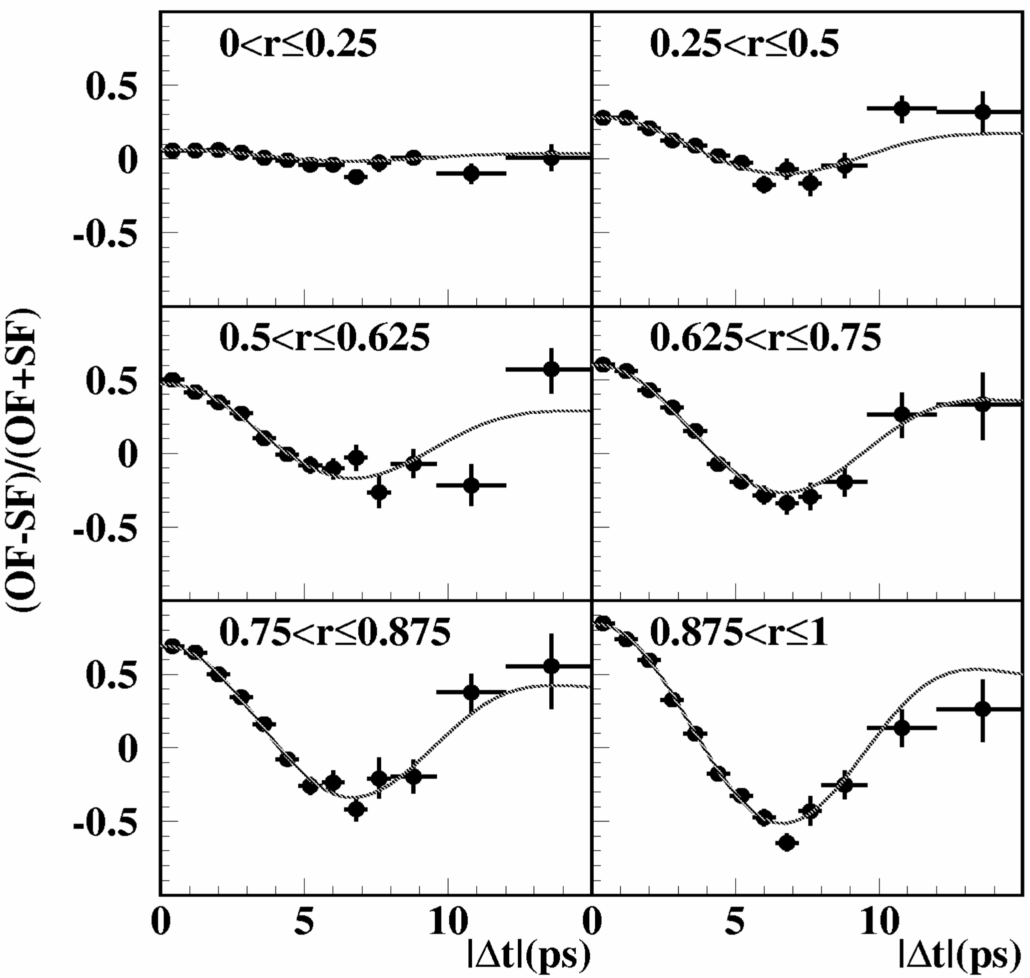
D*lν

hadronic (all)



Mode	$N_{\rm ev}$	Purity
$D^{*-}\ell^+\nu$	84933	0.781
$D^{*-}\pi^+$	12528	0.873
$D^-\pi^+$	11560	0.903
$D^{*-}\rho^+$	9419	0.907
$J/\psi K^{*0}(K^+\pi^-)$	3681	0.954
$J/\psi K^0_S(\pi^+\pi^-)$	1997	0.976
B^0 total	124118	0.817
$\bar{D}^0\pi^+$	48535	0.782
$J/\psi K^+$	8770	0.966
B^+ total	57305	0.810
$B^0 + B^+$ total	181423	0.815

Belle Tagging Performance with control samples



$B^0 - \bar{B}^0$ mixing

(OF-SF)/(OF+SF)

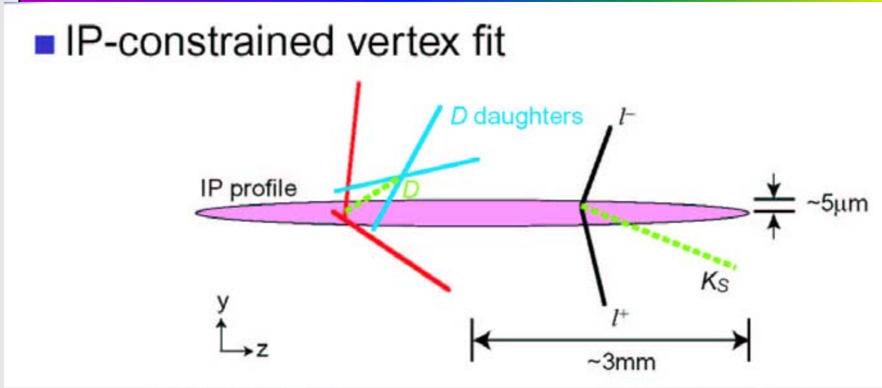
~(1-2 w)cos(Δm t)

Δm_d = 0.511 ± 0.005 ps^{-1}
(PDG2003 0.502 0.007)

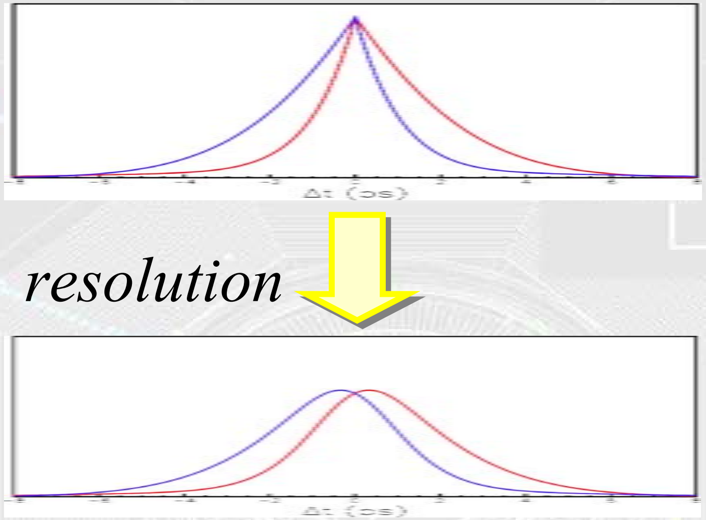
$$\sum_{l=1}^{6} \epsilon_l (1-2w_l)^2 = (28.7 \pm 0.5)\%$$

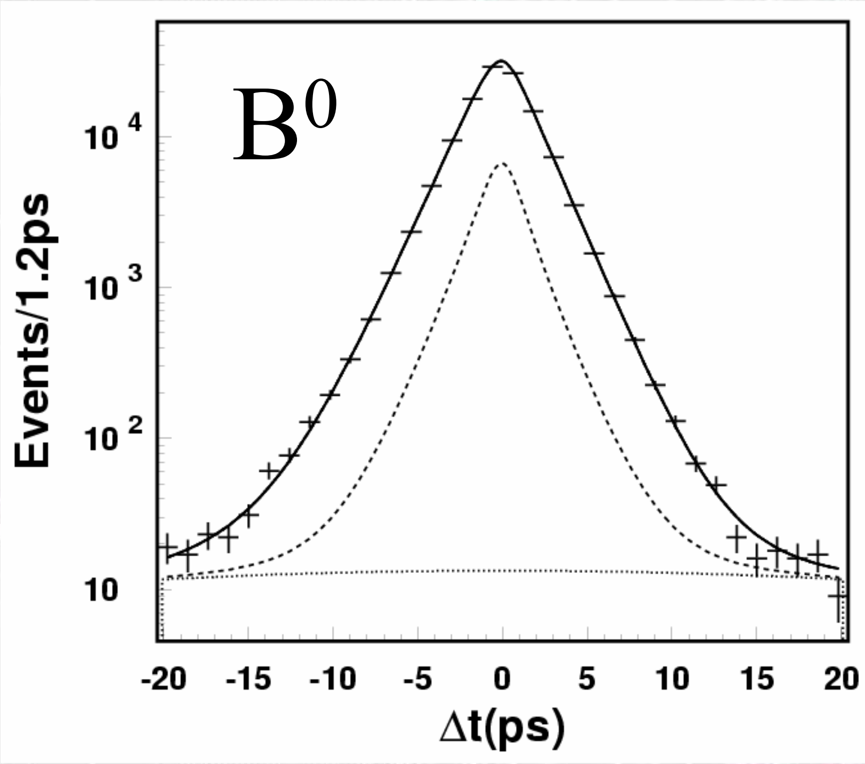
12 r-bins, 6 divisions in r. B^0 and $\bar{B}^0$ tags treated separately.

Proper-time difference (Δt)



Lifetime fit with control sample
→ Resolution function





τ_{B0} = 1.533 ± 0.008(stat) ps
(PDG2003 1.537 0.015)
τ_{B+} = 1.634 ± 0.011(stat) ps
(PDG2003 1.671 0.018)

Analysis Procedure Summary

① CP eigenstates with high purity.

- Purity ~ 90% except for $J/\psi K_L$ (~60% for $J/\psi K_L$)

② Efficient flavor tagging.

- Effective efficiency = 27.0%

③ Efficient vertexing with good resolution

④ B lifetime and mixing measured precisely (high stat. control sample)

→ Ready for unbinned maximum likelihood fit

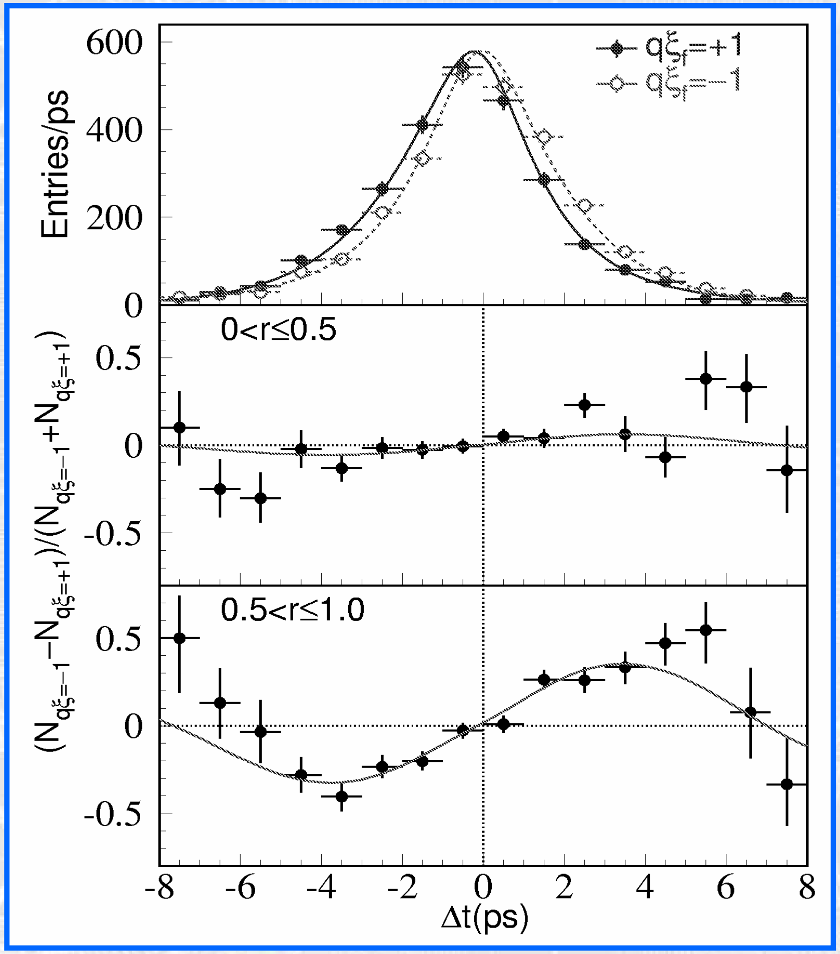
Time-dependent *CP* violation in $B^0 \to J/\psi K$s etc.

NEW $\sin 2\phi_1 = 0.733 \pm 0.057(\text{stat}) \pm 0.028(\text{syst})$

Belle 2003

Poor tags

Good tags

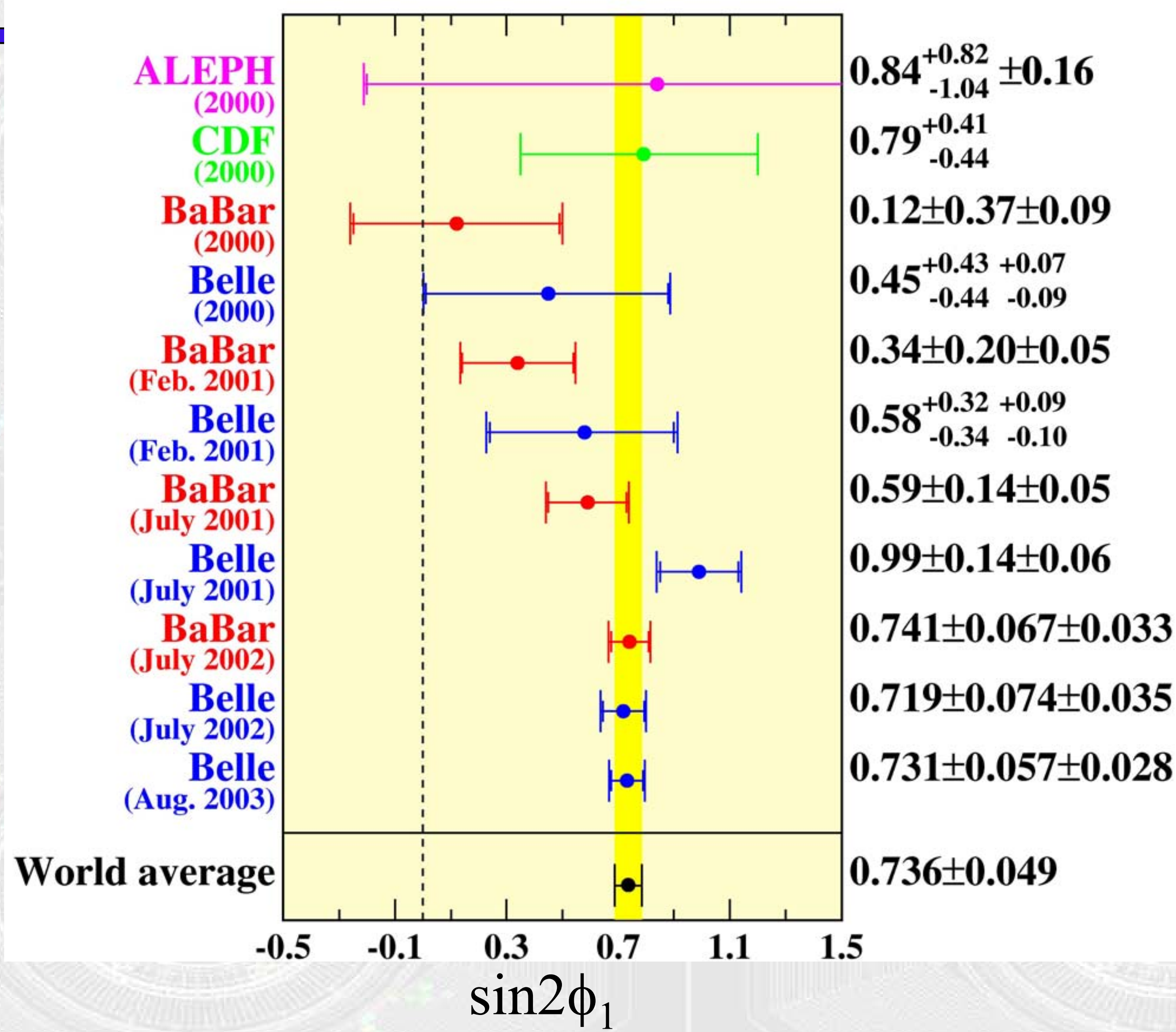


$|\lambda_{ccs}| = 1.007 \pm 0.041(\text{stat})$

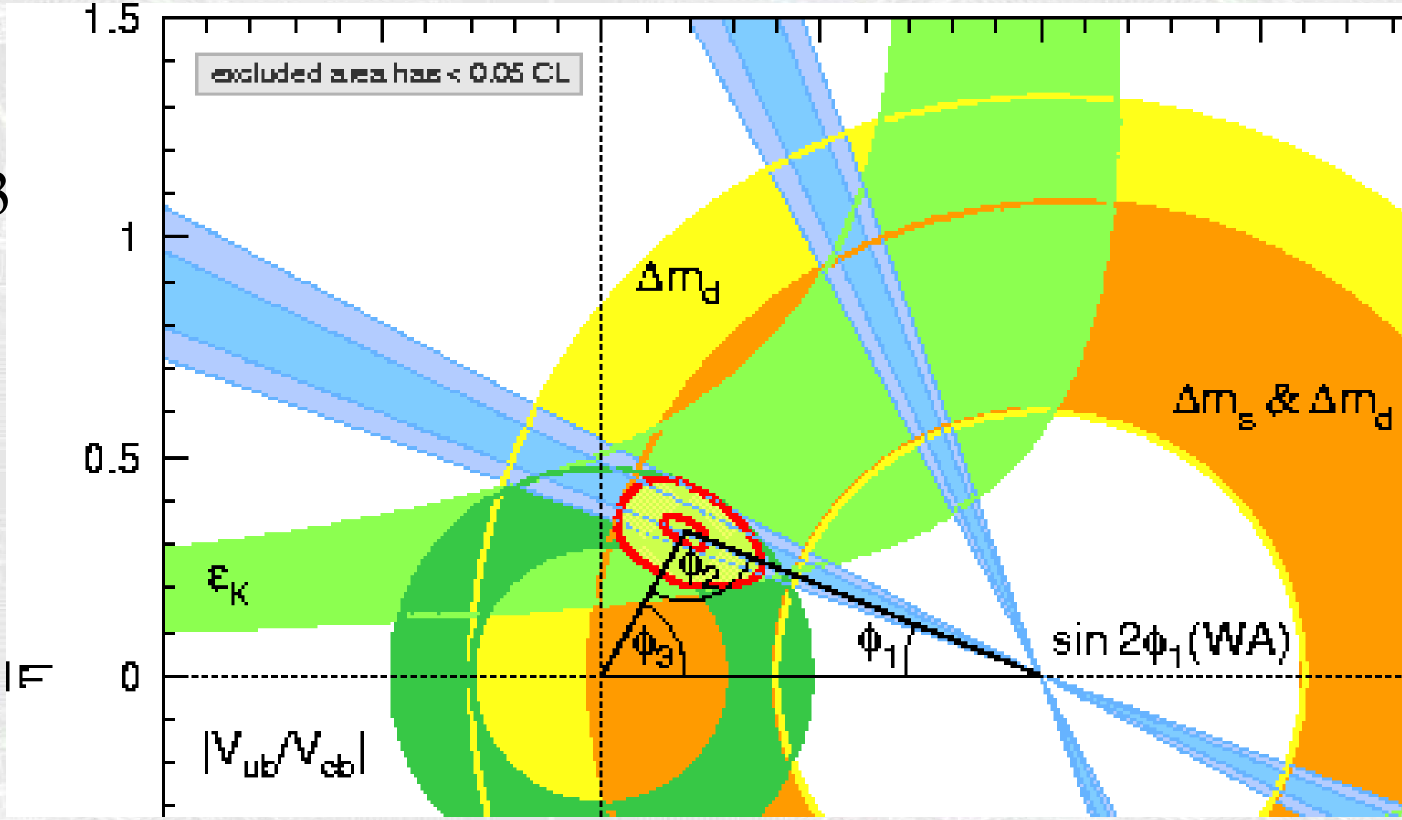
i.e., consistent with

no direct CPV.

$\sin 2\phi_1$ history



Unitarity triangle as of August 2003

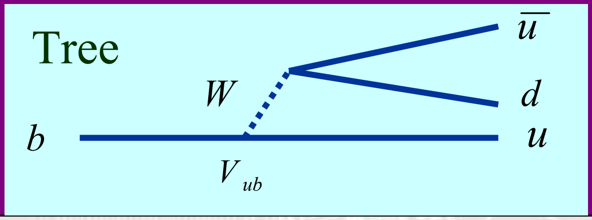


見事な一致！
KMモデルは
CPの破れの
「古典論」と
なった。

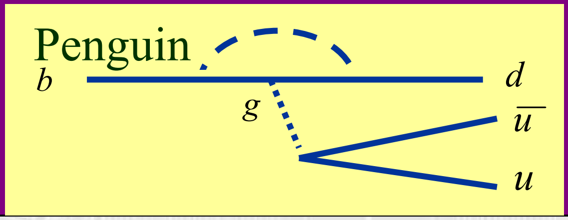
$B^0 \to \pi^+\pi^-$ and ϕ_2 (α)

PRD68, 012001 (2003)

78fb^{-1}



~



$\mathcal{A}$ (direct CP violation) can be large

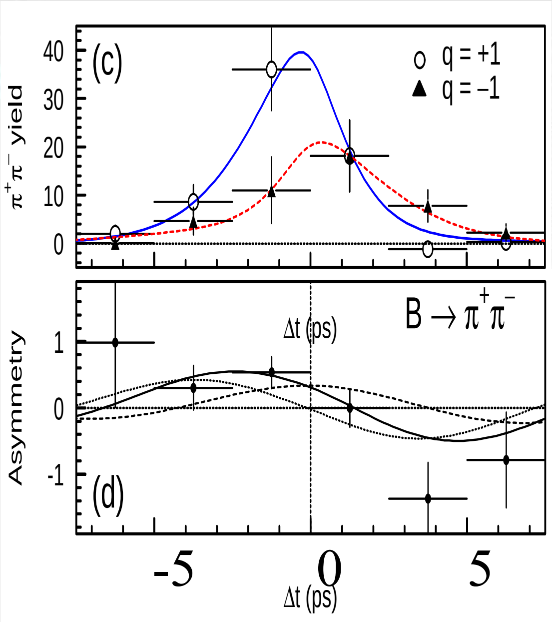
$$\mathcal{P}(\overline{B}^0 \to f_{CP};\Delta t) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}\{1 + q[S\sin(\Delta m_d \Delta t) + \mathcal{A}\cos(\Delta m_d \Delta t)]\}$$

first constraint on ϕ_2

$78° < \phi_2 < 152°$

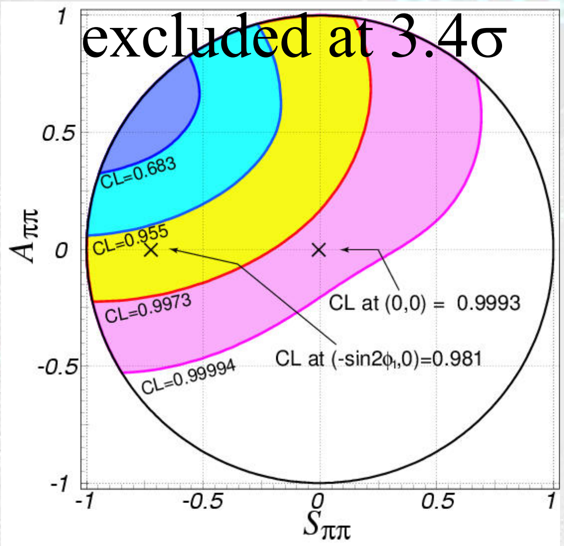
(95.5% C.L.)

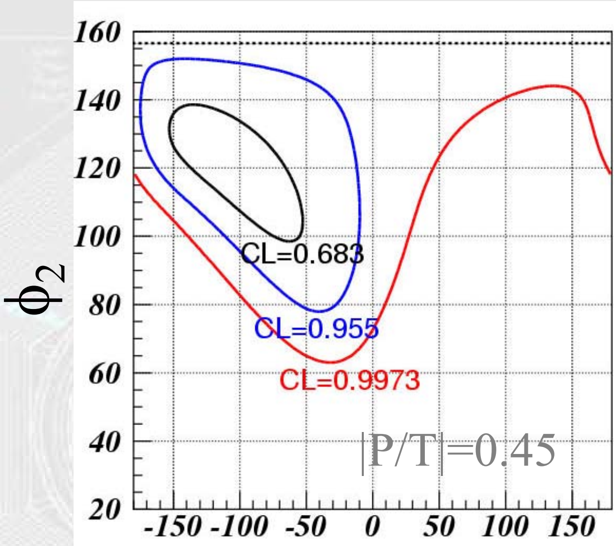
Large asymmetry



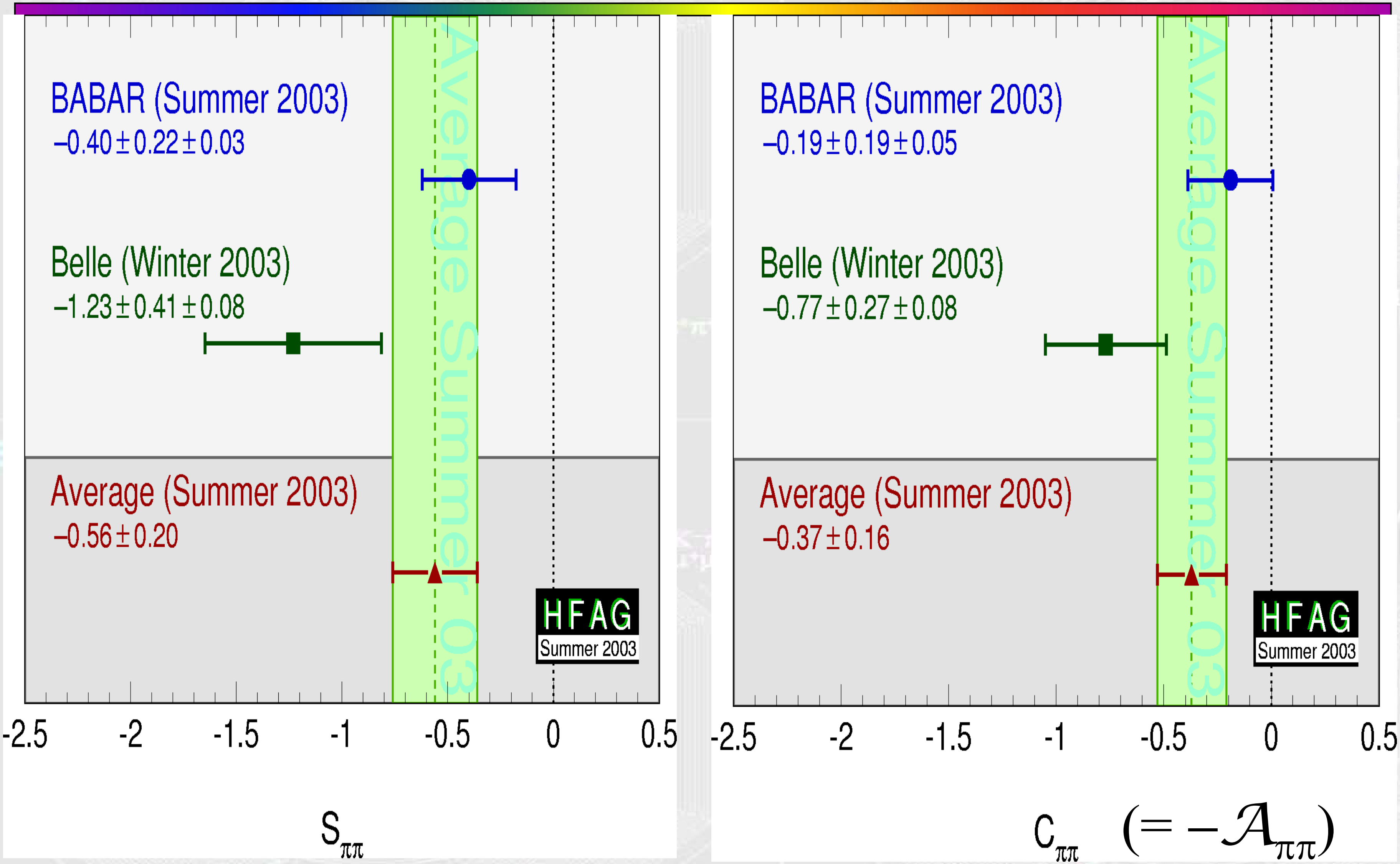
Evidence for CPV

$(\mathcal{A}, S)$=(0, 0) excluded at 3.4σ

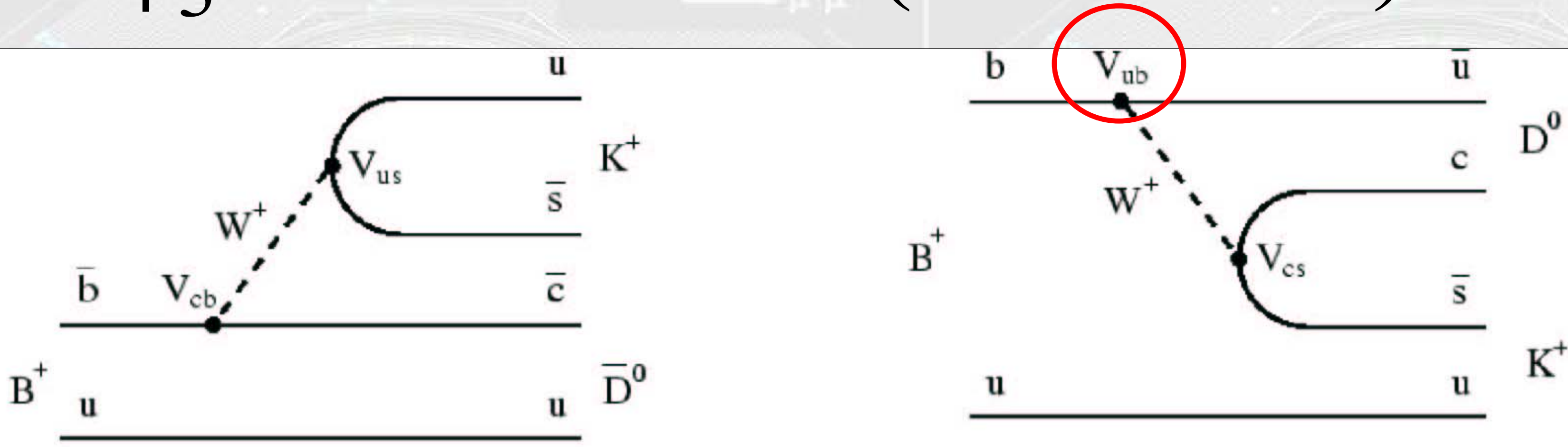




World average



ϕ_3 with $B^{\pm} \to D(\to K_S \pi^+ \pi^-) K^{\pm}$



$M_1 \sim V_{cb} V_{us}^* \sim A\lambda^3$

$M_2 \sim V_{ub} V_{cs}^* \sim A\lambda^3 (\rho + i\eta) \sim e^{i\phi_3}$

If D^0 and $\bar{D}^0$ decay into the same final states

$B^+ \to \bar{D}^0 K$ and $B^+ \to D^0 K$ interfere.

Mixed state is produced: $|\tilde{D}^0 >= |\bar{D}^0 > + a e^{i\theta} |D^0 >$

$a = \frac{|V_{ub} V_{cs}^*|}{|V_{cb} V_{us}^*|} \cdot \frac{|a_2|}{|a_1|} = 0.09/0.22 \cdot 0.35 \simeq \frac{1}{8}$

$\theta = \delta + \phi_3$

Suggested by A.Giri, Yu.Grossman, A.Soffer, J.Zupan: hep-ph/0303187

ϕ_3 with $B^{\pm} \to D(\to K_s \pi^+ \pi^-) K^{\pm}$

Use 3-body final state, identical for D^0 and $\bar{D}^0$: $K_s\pi^+\pi^-$.

3-body decay is characterized by 2 variables: $m^2_{K_s\pi^+}$ and $m^2_{K_s\pi^-}$.

Dalitz plot density

$$d\sigma(m^2_{K_s\pi^+}, m^2_{K_s\pi^-}) \sim |M|^2 dm^2_{K_s\pi^+} dm^2_{K_s\pi^-}$$

$$p(m^2_{K_s\pi^+}, m^2_{K_s\pi^-}) = |f(m^2_{K_s\pi^+}, m^2_{K_s\pi^-}) + ae^{-i\theta} f(m^2_{K_s\pi^-}, m^2_{K_s\pi^+})|^2$$

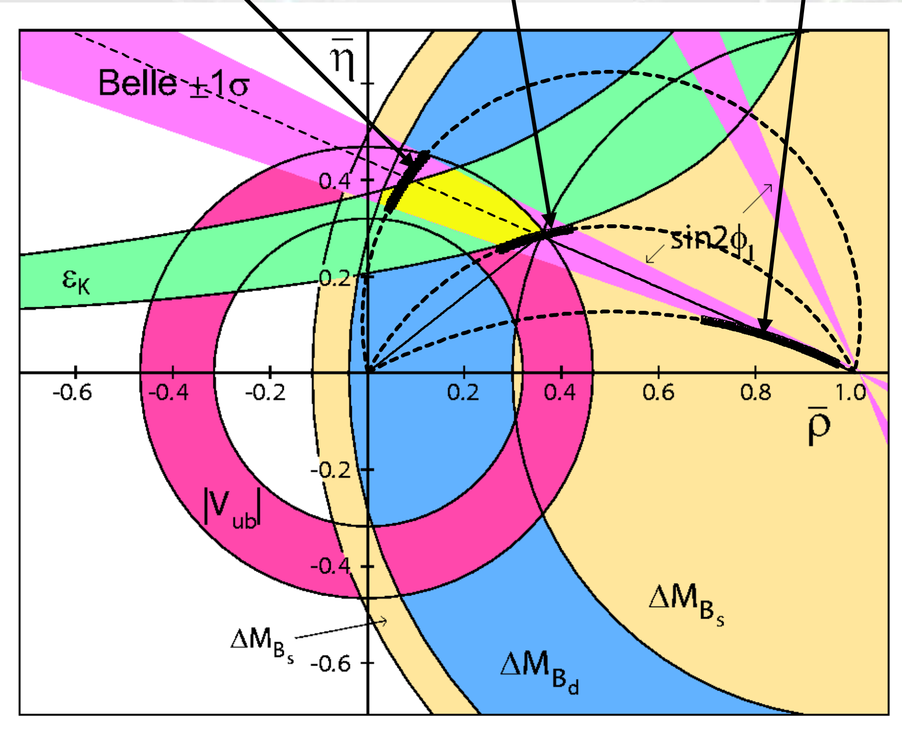
$= \Big|$  $+ ae^{-i\theta}$  $\Big|^2$

ϕ_2, ϕ_3 and Unitarity Triangle

$B^0 \to \pi^+\pi^-$ 78fb^{-1}

95.5% C.L.

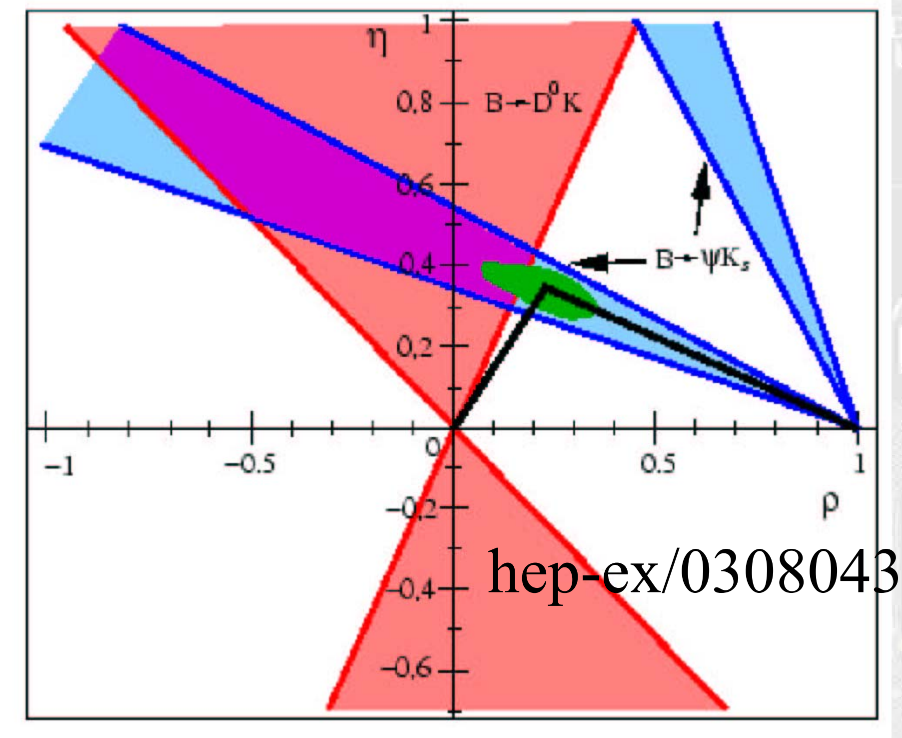
ϕ_2=78º ϕ_2=118º ϕ_2=152º



$B^\pm \to D(\to Ks\pi^+\pi^-)K^\pm$

140fb^{-1}

ϕ_3 (90% C.L.)



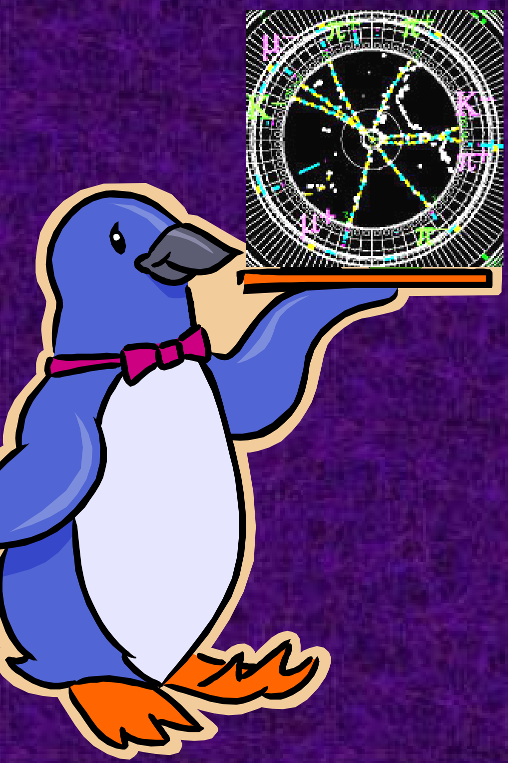
hep-ex/0308043

- ϕ_1: 今や精密測定

- ϕ_2: 初めての測定 (これからだ！）

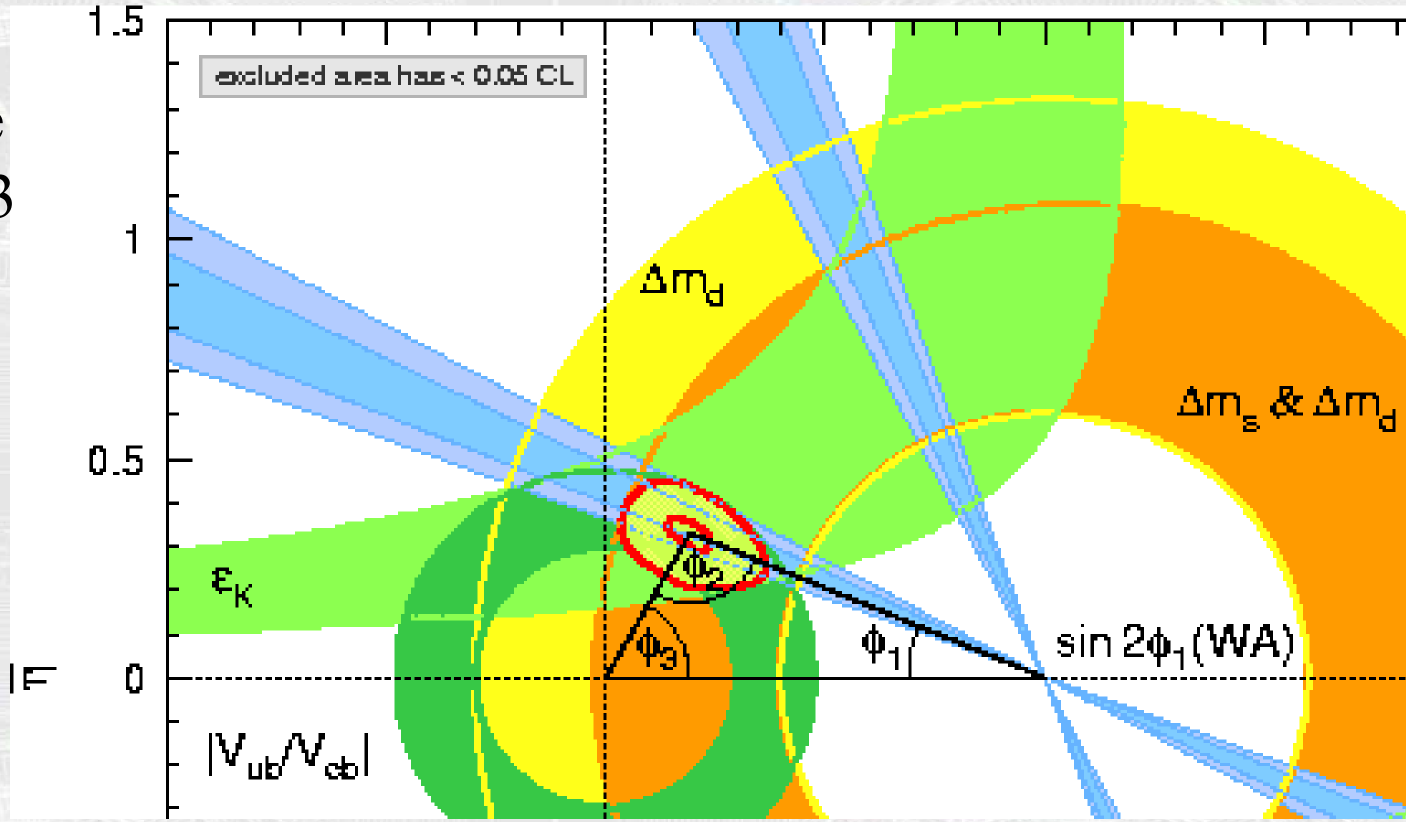
- ϕ_3: 初めての測定 (これからだ！）

b → s ペンギンと
未知のCPの破れ



3↔2世代は、ほとんど寄与していない

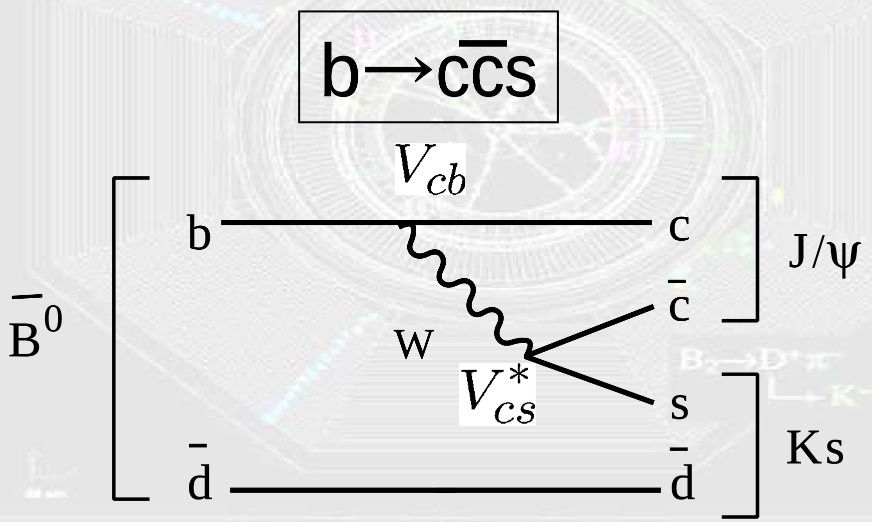
Unitarity triangle
as of August 2003

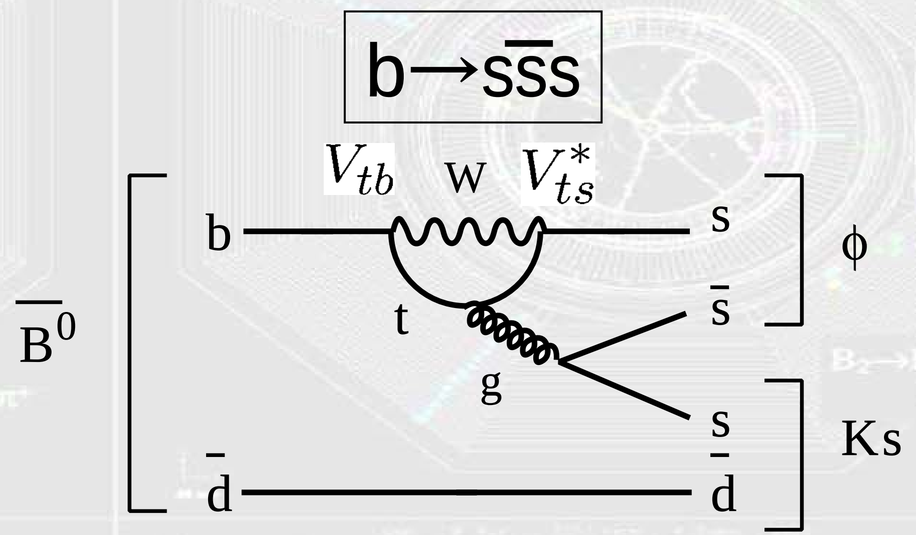


見事な一致！
KMモデルは
CPの破れの
「古典論」と
なった。

3↔1世代
2↔1世代の物理

Standard Model (SM) prediction





- No KM phase in both decays
- CP violation only from the phase in the mixing

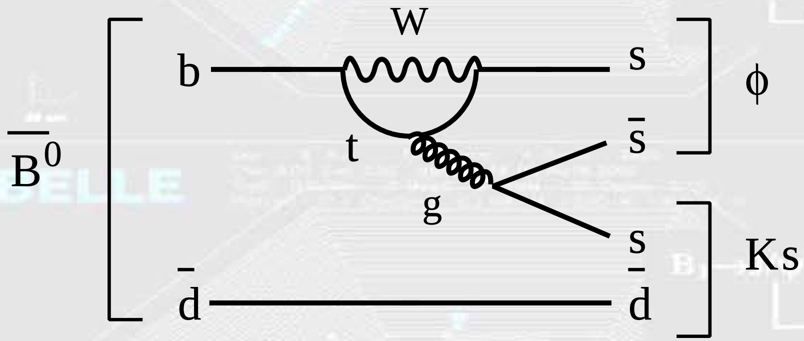
どちらも $Asym = \sin(2\phi_1) \cdot \sin(\Delta m \Delta t)$

Vubによる「汚染」はλ^2の微少量→O(1)%

$b \to s\bar{s}s$ and New Physics (NP)

- $b \to s$ penguin : sensitive to new CP-violating phase

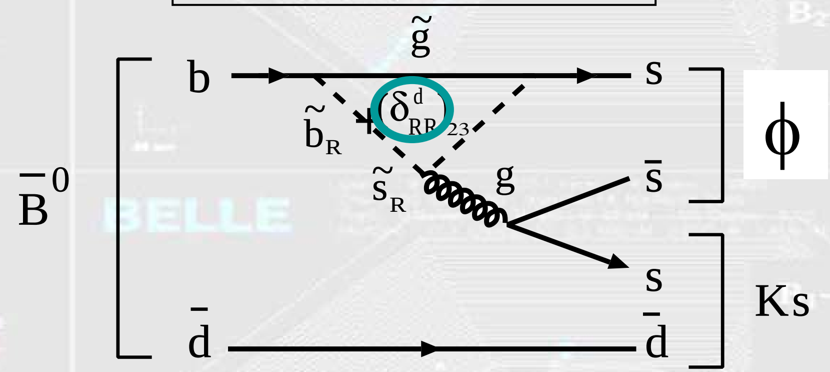
SM



+

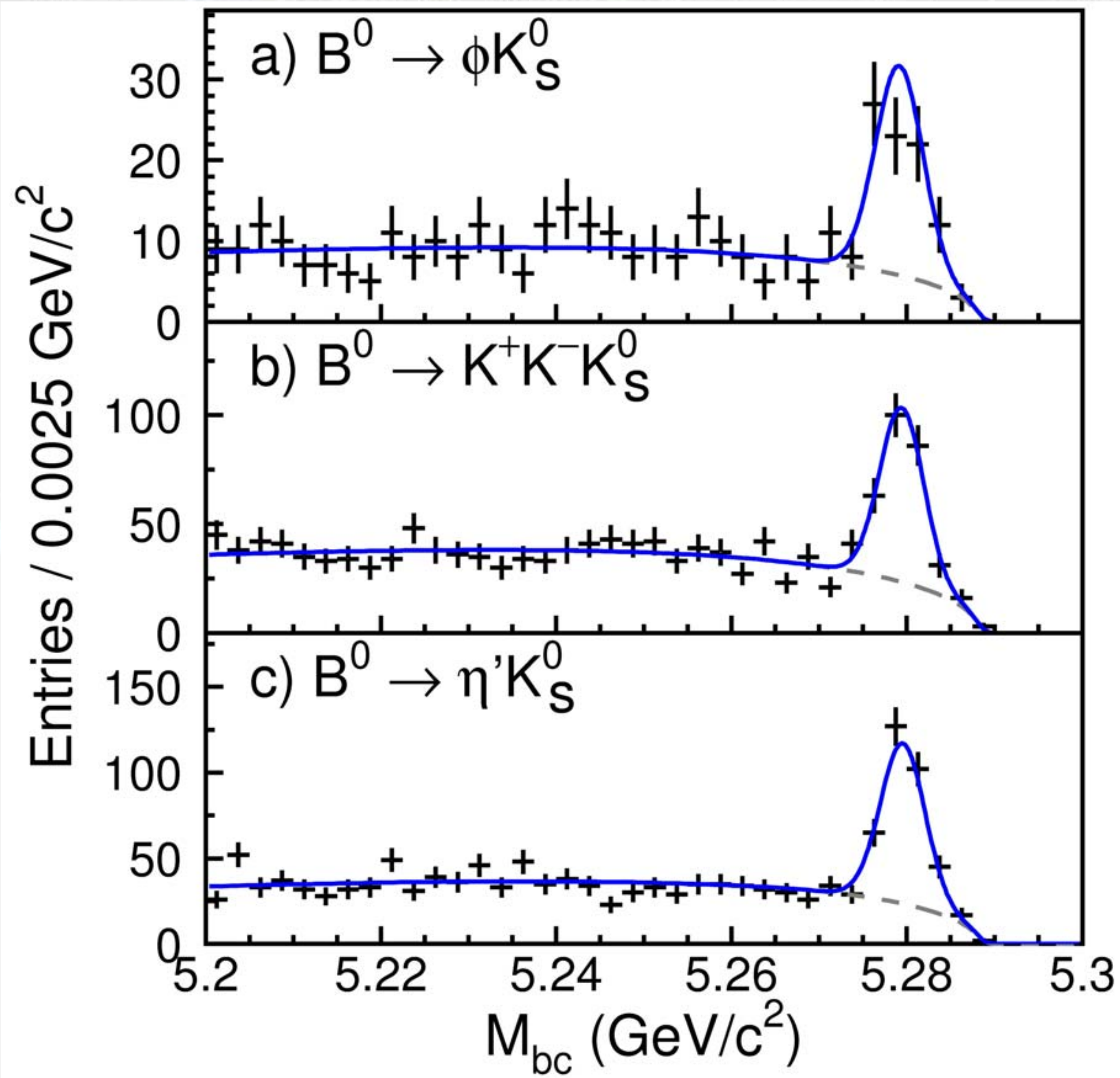
NP

ex) squark penguin



$\mathcal{S} \neq \sin 2\phi_1$ → New Physics

$b \to s\bar{s}s$ candidates



68±11 signals
106 candidates
purity = 0.64±0.10
efficiencyv= 27.3%

199±18 signals
361 candidates
purity = 0.55±0.05
efficiency = 15.7%

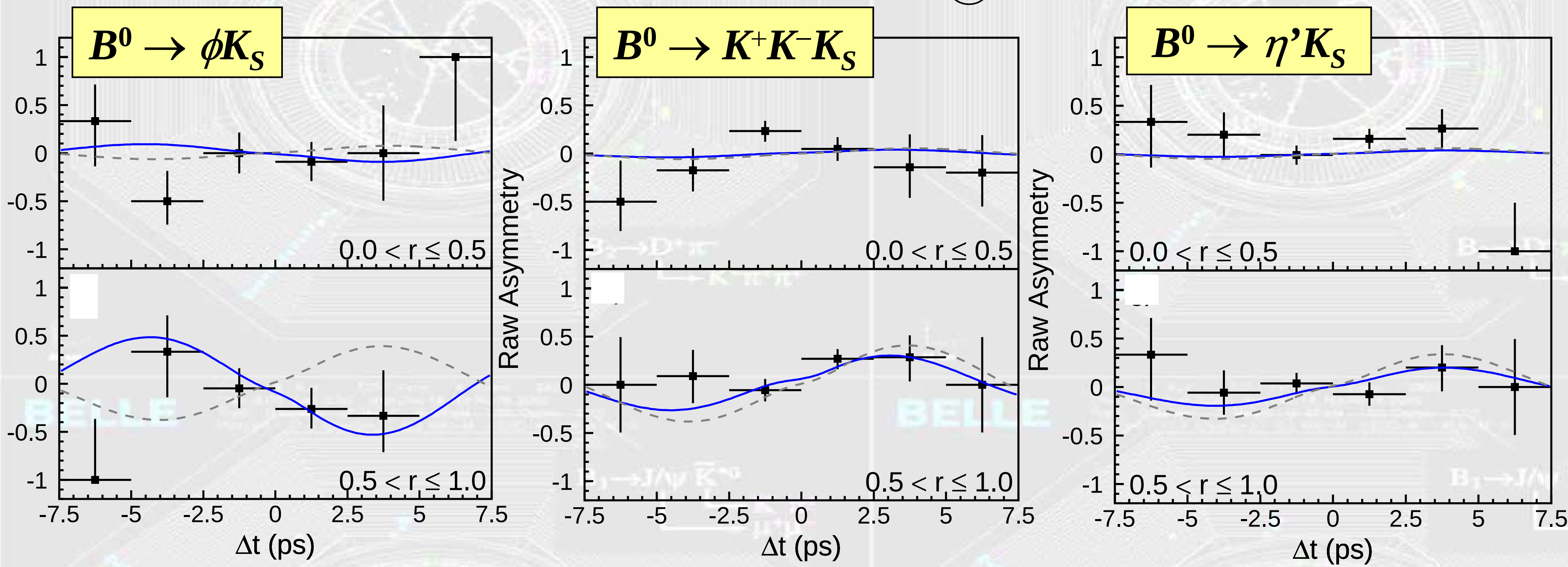
244±21 signals
421 candidates
purity = 0.58±0.05
efficiency = 17.7% ($\eta' \to \eta\pi^+\pi^-$)
15.7% ($\eta' \to \rho\gamma$)

CP Violation in $b \to s\bar{q}q$

hep-ex/0308035

@ 152M $B\bar{B}$

Fit
sin2ϕ_1



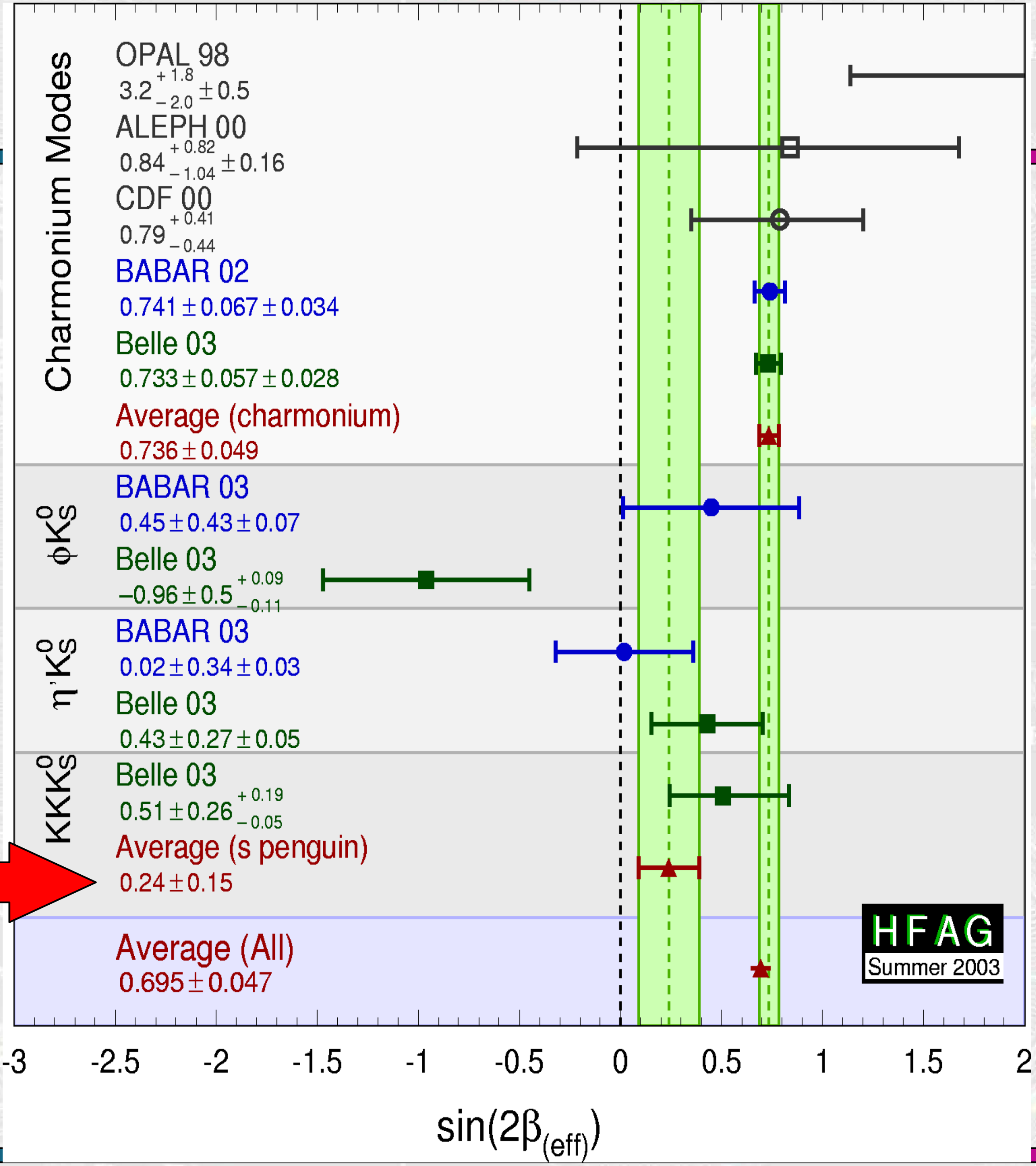
3.5 σ off

$-\xi_f S$	$-0.96 \pm 0.50^{+0.09}_{-0.11}$	$+0.51 \pm 0.26 \pm 0.05^{+0.18}_{-0.00}$	$+0.43 \pm 0.27 \pm 0.05$
A	$-0.15 \pm 0.29 \pm 0.07$	$-0.17 \pm 0.16 \pm 0.04$	$-0.01 \pm 0.16 \pm 0.04$

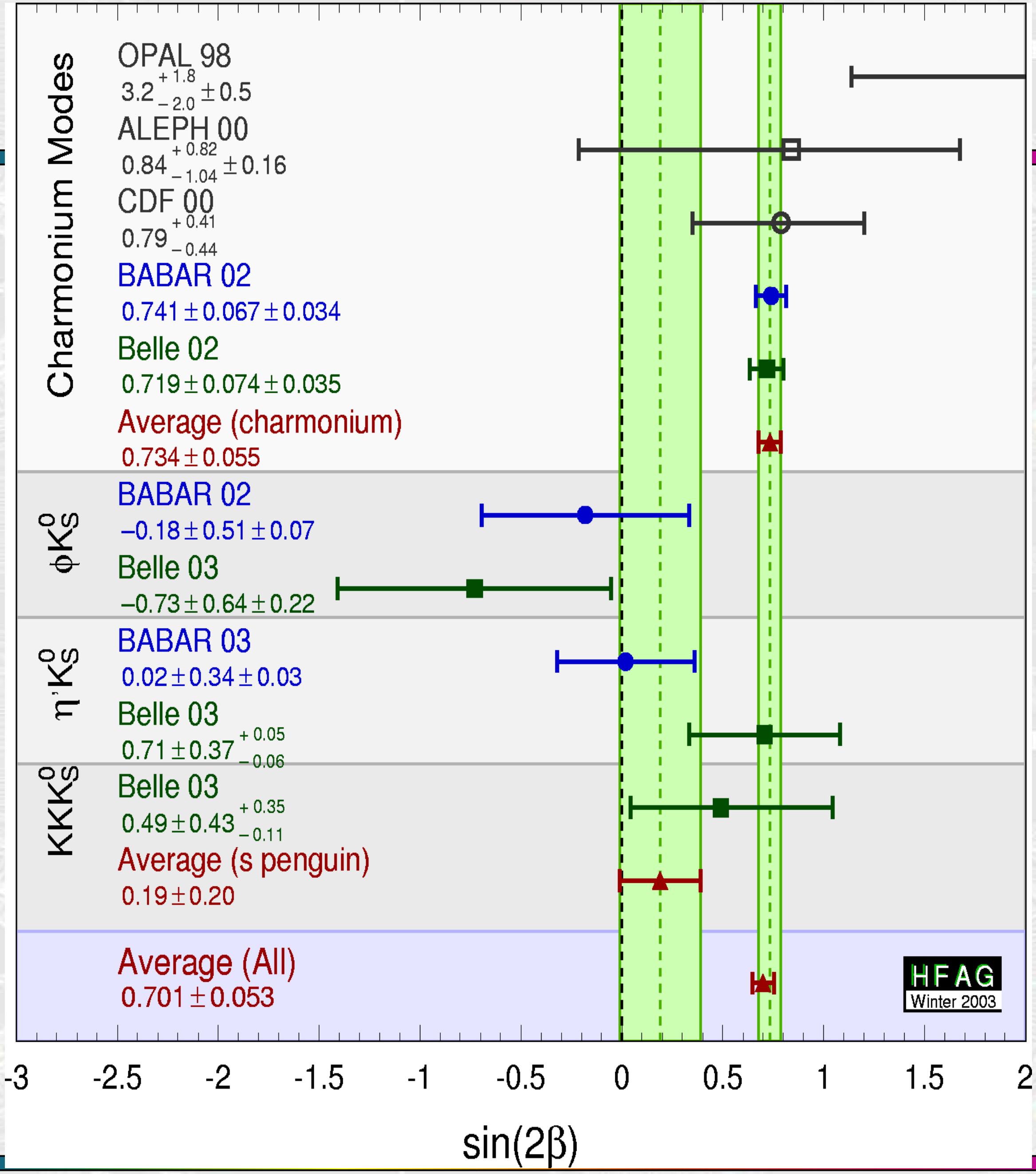
World average (Aug. 2003)

2.6σ

3.1σ from "charmonium"

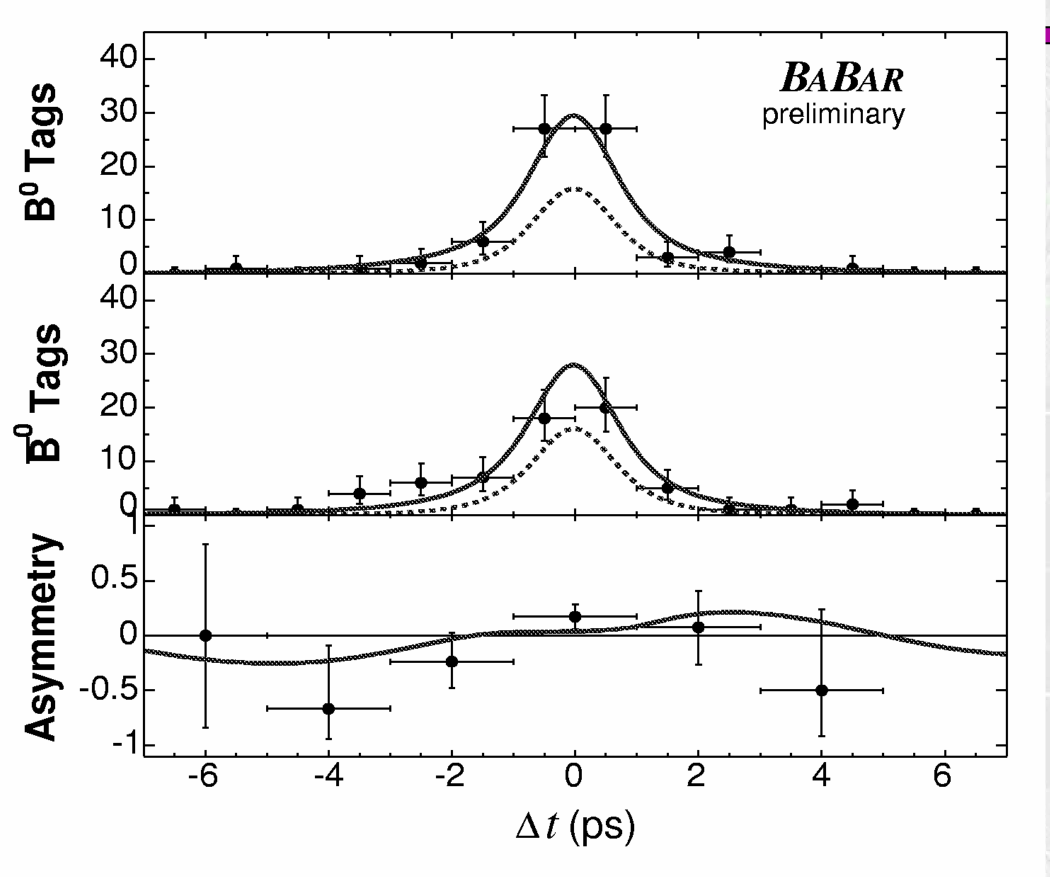


World average (June 2003)



BaBar 2003:CPV in $B \to \phi K_S$

BaBar 2003: 110 fb^{-1}



(A=0.38±0.37±0.12)

BaBar 2003: $\sin 2\phi_{1\mathrm{eff}}(\phi K_S) = +0.45 \pm 0.43 \pm 0.07$

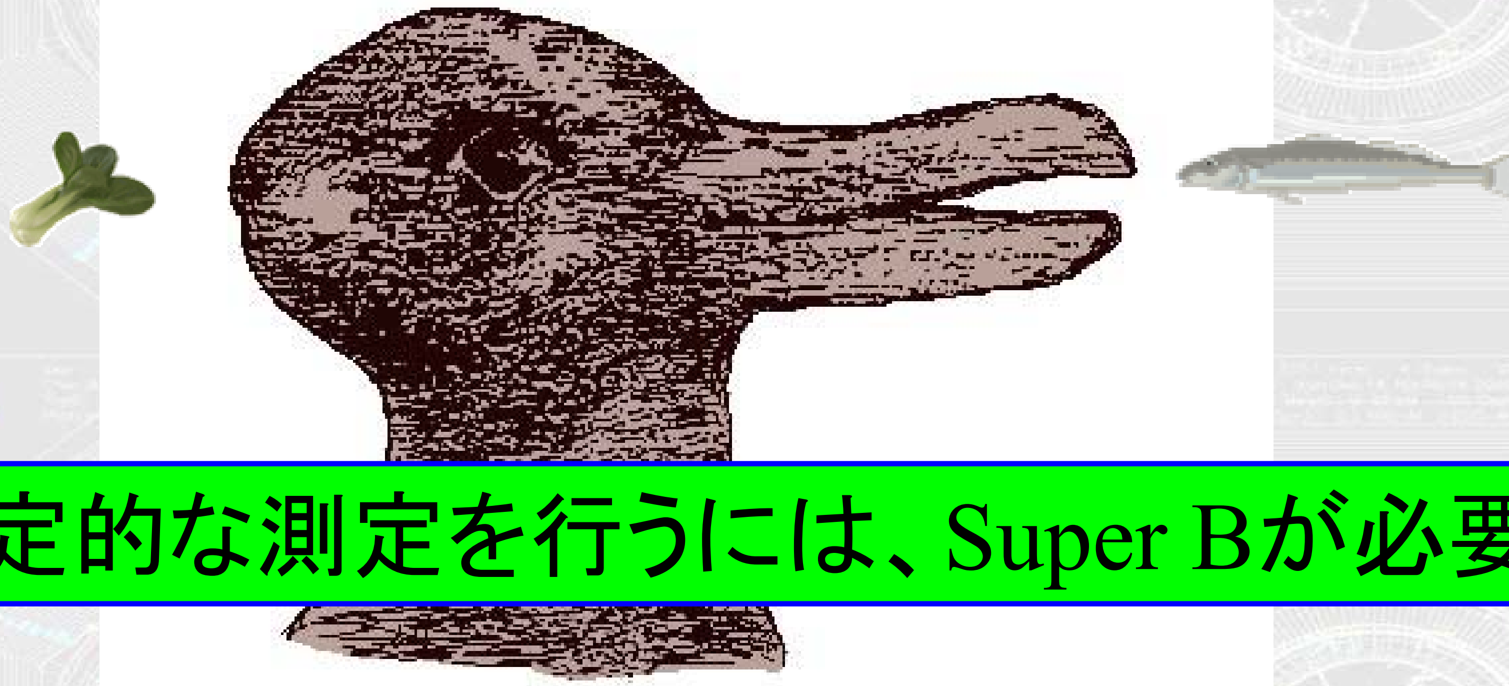
BaBar 2003: $B \to \phi K_S$ Systematic Issues

81 fb^{-1}: $\sin 2\phi_{1\mathrm{eff}}(\phi K_S) = -0.18 \pm 0.51 \pm 0.09$

110 fb^{-1}: $\sin 2\phi_{1\mathrm{eff}}(\phi K_S) = +0.45 \pm 0.43 \pm 0.07$

Data size increased and was reprocessed. Extensive checks with data and Toy MC. The large change is attributed to a 1 σ statistical fluctuation.

$b \to s$ “anomaly”



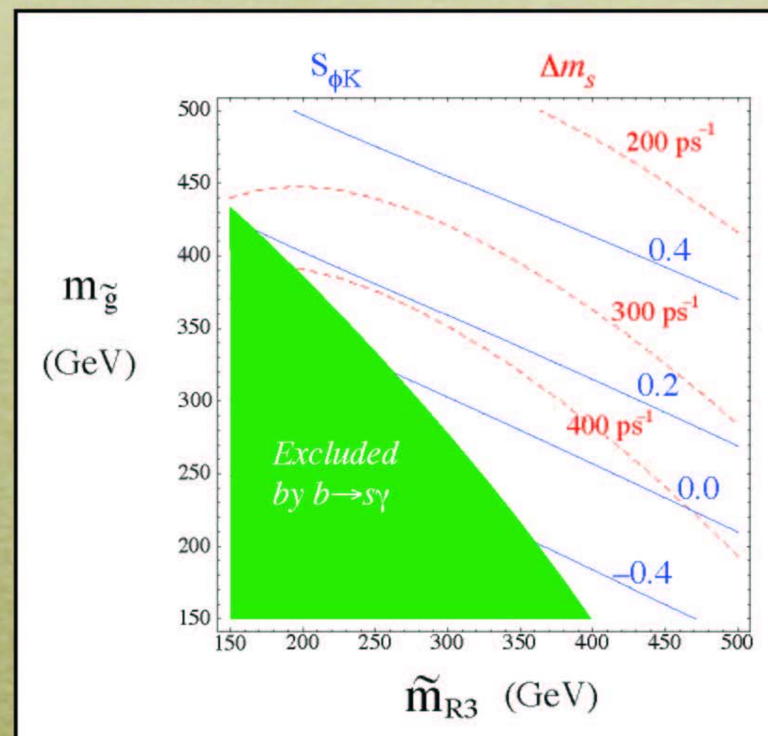
決定的な測定を行うには、Super Bが必要

φKsだけではない。その他の物理量にもずれが期待される。ずれのパターンはモデルによって異なる。

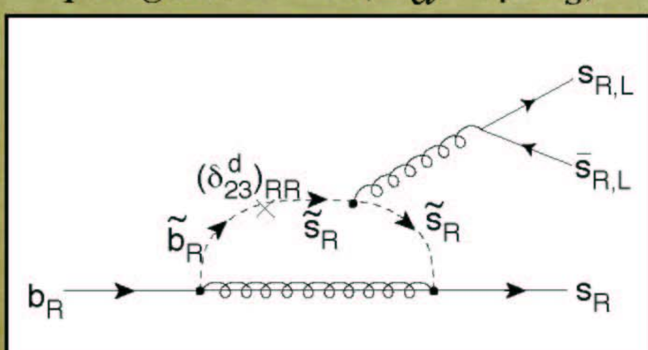
H. Murayama (LP03)

Consequences in B physics

Motivated by large θ23
neutrino mixing:
In GUT context,
Atmospheric Neutrinos
Can Make Beauty Strange !



- *Addt'l CP violation in penguin* $b \Rightarrow s$ ($B_d \Rightarrow \phi K_s$)



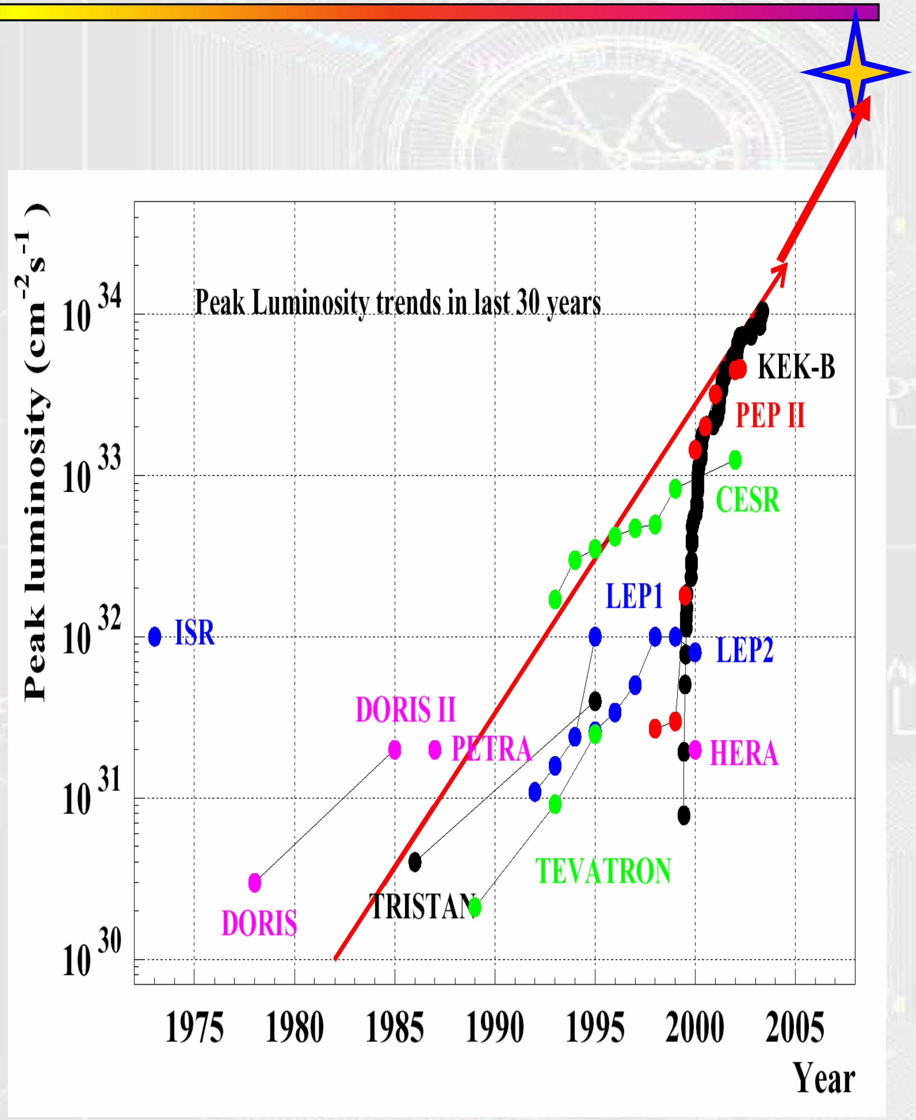
- $B_d \Rightarrow X_s l^+ l^-$

Probes if quarks and leptons have common origin of flavor

Super *B* Factory

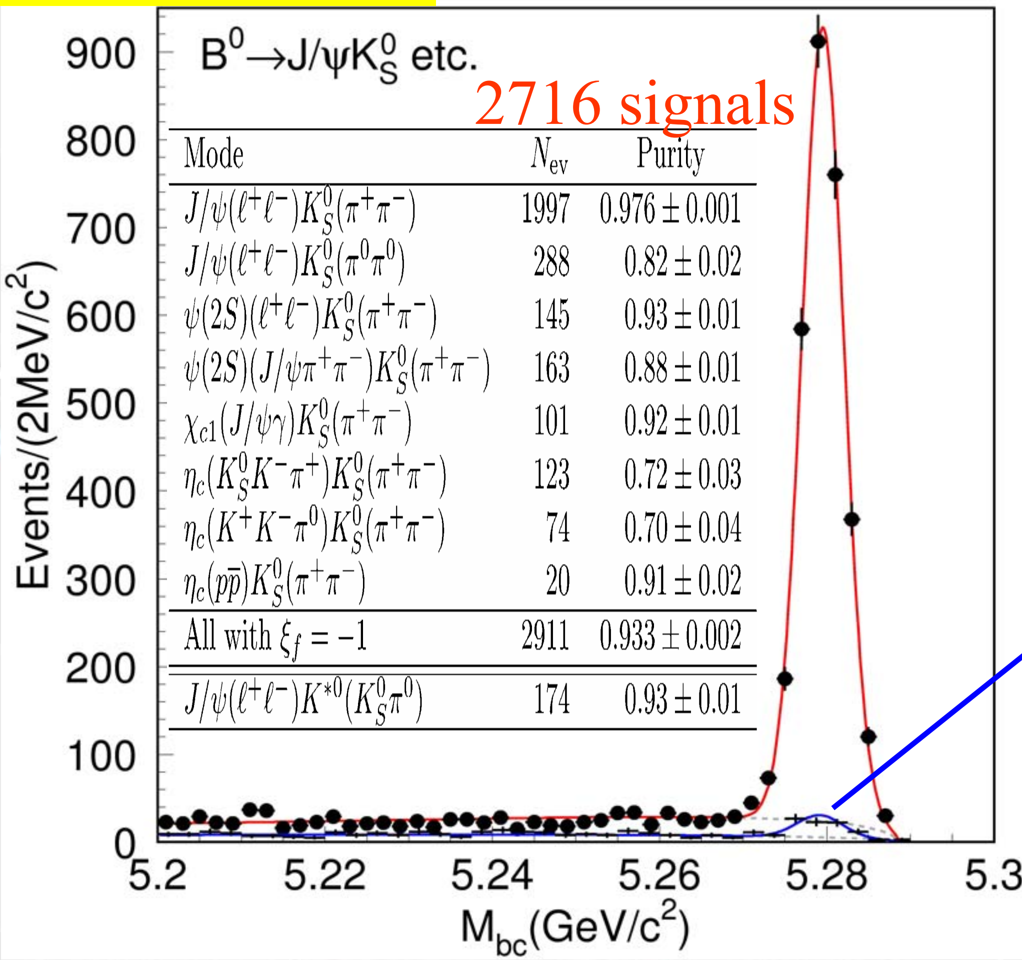
Super B　とは？

- 現在運転中で世界最高のルミノシティ(1.05×10^{34} $cm^{-2}s^{-1}$)を誇るKEKB e+e–コライダーの性能を、さらに
  50倍 (5×10^{35} $cm^{-2}s^{-1}$)
  にする計画。
  - 年間100億個のB中間子
- 既存の設備、人員を最大限利用する(KEKB/BelleのMajor Upgrade)。

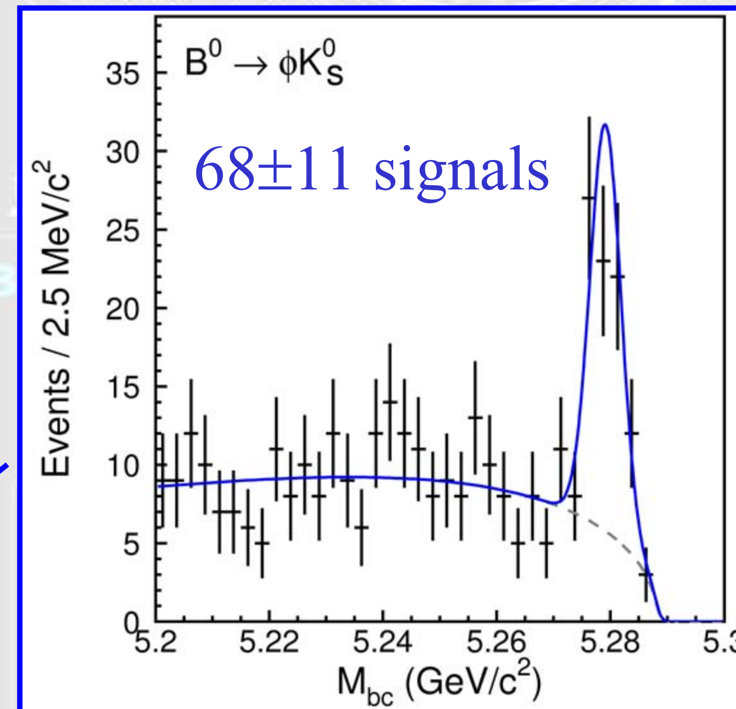


$B^0 \to (c\bar{c})Ks$ vs. $\phi\, Ks$

$\mathcal{L}=5\times 10^{35}$ ⇨ 1999-2003 data set (158fb^{-1}) in 1 week



Mode	N_{ev}	Purity
$J/\psi(\ell^+\ell^-)K^0_S(\pi^+\pi^-)$	1997	0.976 ± 0.001
$J/\psi(\ell^+\ell^-)K^0_S(\pi^0\pi^0)$	288	0.82 ± 0.02
$\psi(2S)(\ell^+\ell^-)K^0_S(\pi^+\pi^-)$	145	0.93 ± 0.01
$\psi(2S)(J/\psi\pi^+\pi^-)K^0_S(\pi^+\pi^-)$	163	0.88 ± 0.01
$\chi_{c1}(J/\psi\gamma)K^0_S(\pi^+\pi^-)$	101	0.92 ± 0.01
$\eta_c(K^0_S K^-\pi^+)K^0_S(\pi^+\pi^-)$	123	0.72 ± 0.03
$\eta_c(K^+K^-\pi^0)K^0_S(\pi^+\pi^-)$	74	0.70 ± 0.04
$\eta_c(p\bar{p})K^0_S(\pi^+\pi^-)$	20	0.91 ± 0.02
All with $\xi_f = -1$	2911	0.933 ± 0.002
$J/\psi(\ell^+\ell^-)K^{*0}(K^0_S\pi^0)$	174	0.93 ± 0.01

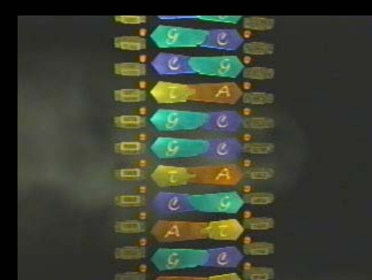


http://belle.kek.jp/superb/workshop/2003/HL05/

Motivation for $L = 5 \times 10^{35}$

- New Physicsの「発見」から「同定」へ
  - by restricting couplings and phase of new particles with mass ~ 1TeV, which can be found at the energy frontier
  - 理論的・実験的にクリーンな物理量の標準模型からのずれのパターン (ユニタリティ三角形は、ゲームの一部)

New Physicsの「DNA鑑定」



Goto,Okada,Shimizu,Shindou,Tanaka
PRD66, 035009 (2003)
hep-ph/0306093

グローバルな解析の一例

SUSY breaking mechanismの同定

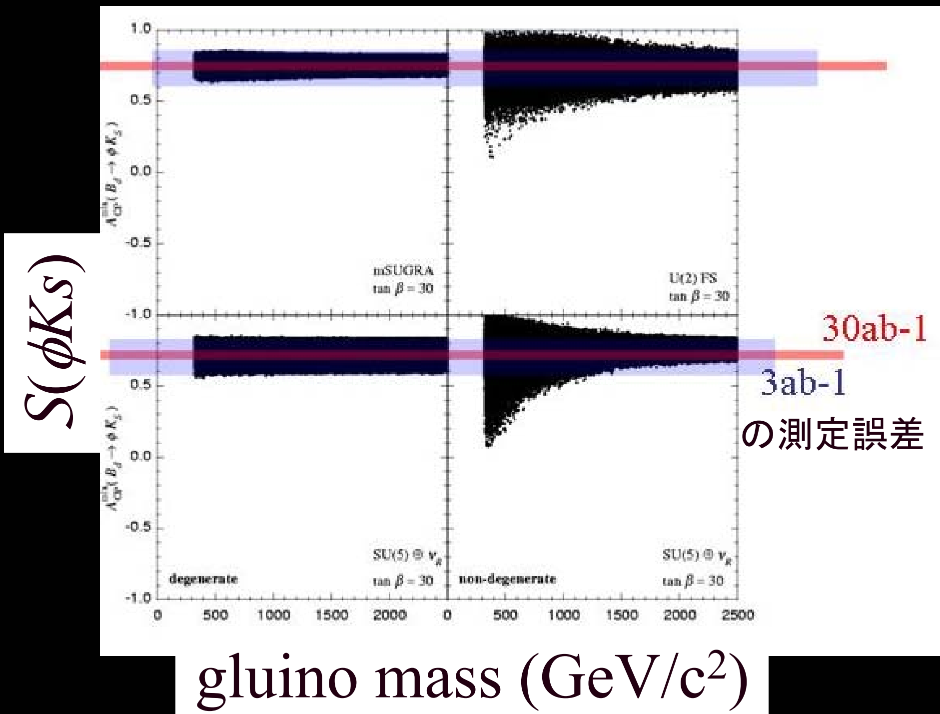
	Bd-unitarity	ε	Δ m(Bs)	B->ϕKs	B->Ms γ time-dep. CP	b->sγ direct CP
mSUGRA	-	-	-	-	-	+
SU(5)SUSY GUT + ν_R (degenerate)	-	+	+	-	+	-
SU(5)SUSY GUT + ν_R (non-degenerate)	-	-	+	+	++	+
U(2) Flavor symmetry	+	+	+	+	++	++

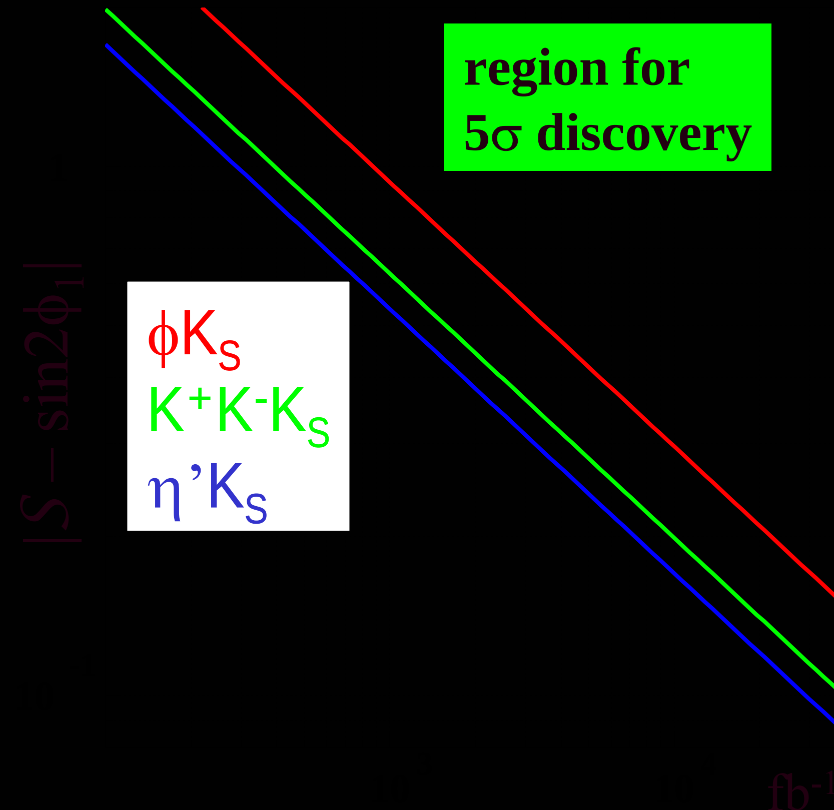
3↔1世代

3↔2世代

- : small deviation
+: sizable
++: large

$B^0 \to \phi Ks$, $\eta' Ks$: 実験精度とdiscovery potential





stat err.	$3ab^{-1}$	$30ab^{-1}$
$\delta S(\phi Ks)$	0.096	0.030
$\delta S(\eta' Ks)$	0.054	0.017

$1ab^{-1} = 10^3 fb^{-1} \leftrightarrow 10^9$ B pairs

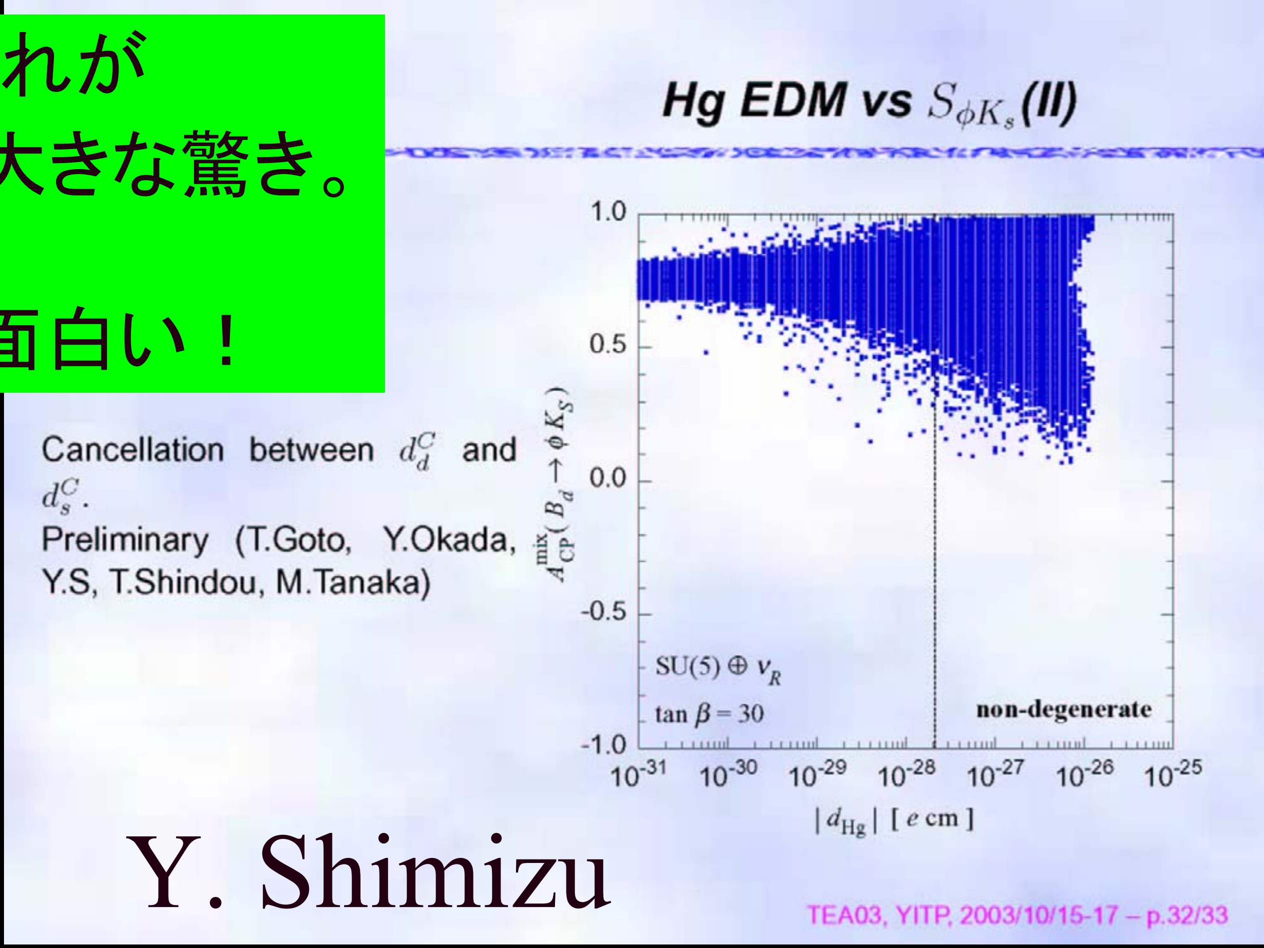
$3ab^{-1} \sim 0.5$year, $30ab^{-1} \sim 5$ years

久野さんの裏切り （by岡田氏）

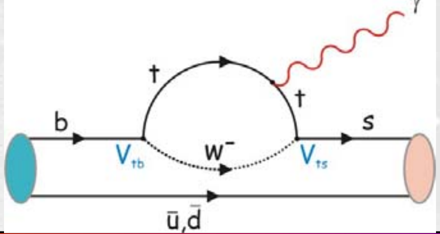
J. Hisano and Y. Shimizu (hep-ph/0308255)

Strong correlation between Hg^{199} EDM and $S(\phi Ks)$

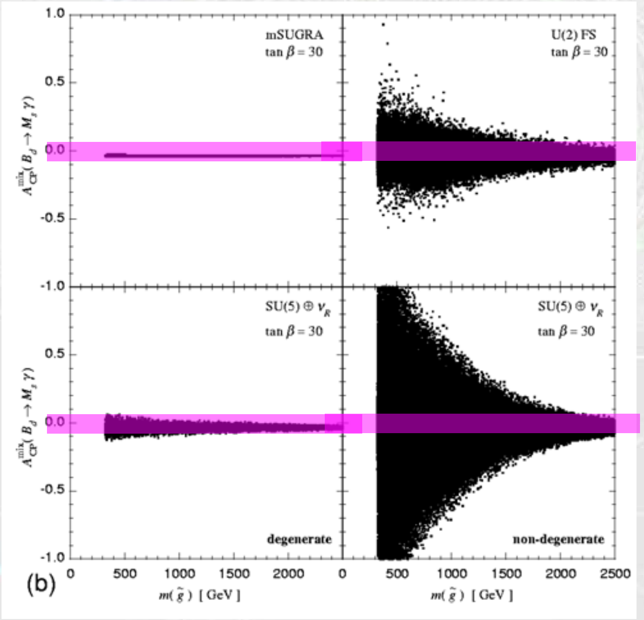
$S(\phi Ks)$の大きなずれが
見つかれば、より大きな驚き。
実験屋にとっては
SUSYの確認より面白い！

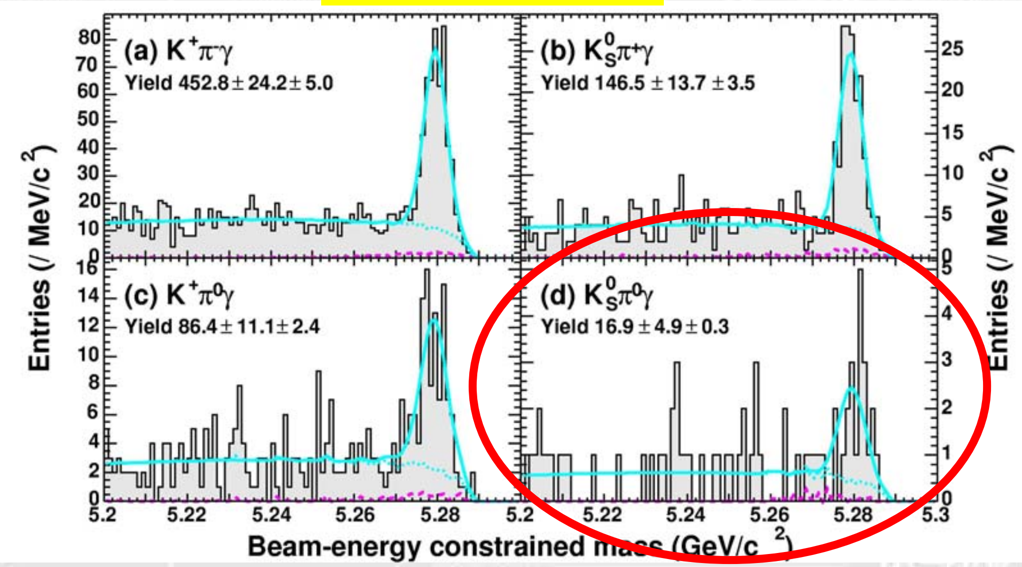


Time-dependent CP violation in $B^0 \to K^{*0}\gamma$



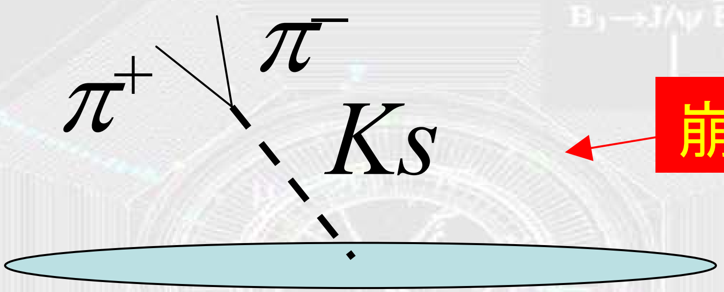
Belle 78fb^{-1}





この終状態
のみ使用可

崩壊点の精度が鍵



Constraint from B decay point

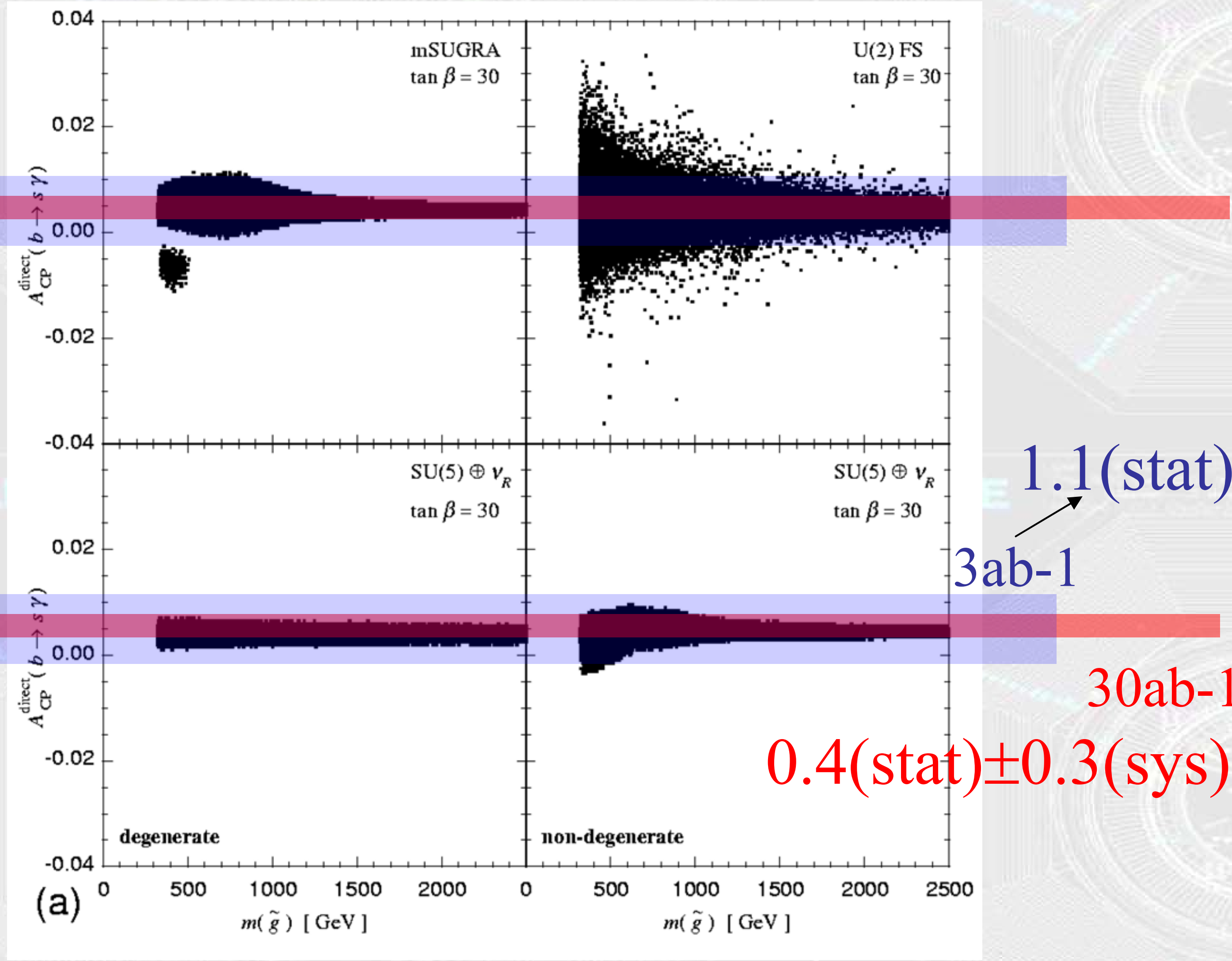
厚さ数十ミクロン（～Bのx-y平面での飛距離）

B factoryでしか出来ない

$\delta S[B^0 \to K^{*0}(\to Ks\,\pi^0)\gamma] \sim 0.2@3ab^{-1}$

$\sim 0.07@30ab^{-1}$

Direct CP violation in b → sγ



Super Bにおける3 ↔ 2世代の物理

- Time-dependent CP violation ($\mathcal{S}$)
  - $B^0 \rightarrow \phi Ks$
  - $B^0 \rightarrow \eta' Ks$
  - $B^0 \rightarrow K^{*0} \gamma$
- Direct CP violation ($\mathcal{A}$)
  - $b \rightarrow s \gamma$ (inclusive)
- Forbidden decays
  - $\tau \rightarrow \mu \gamma$
- その他にも面白い測定あり

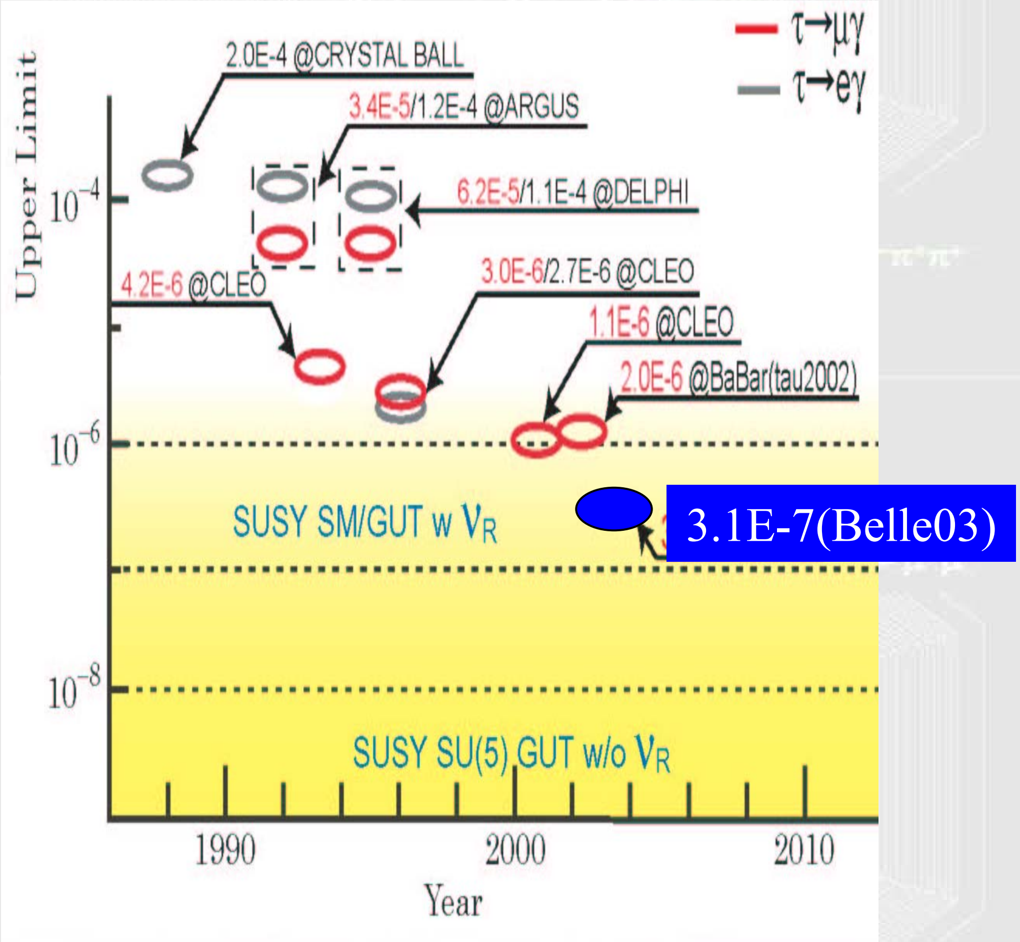
Beyond the Standard Modelの探索を極限まで実行

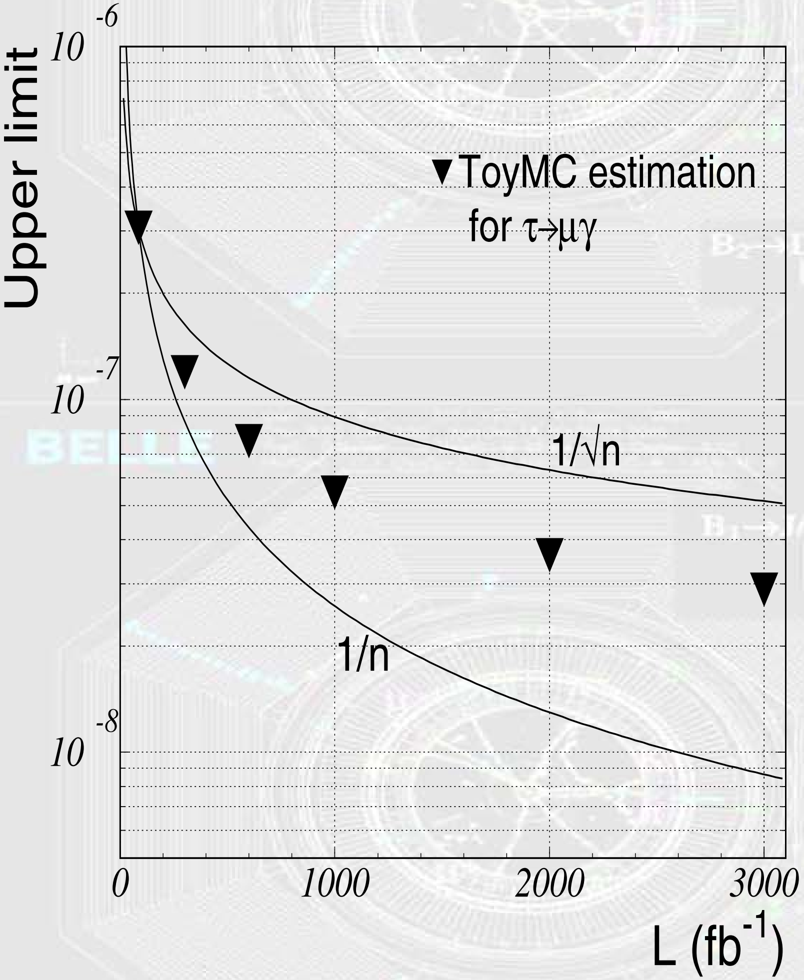
ハドロン不定性　$\sim\lambda^2 \sim O(1)\%$
系統誤差

τ → μ γ

τも年間~100億個

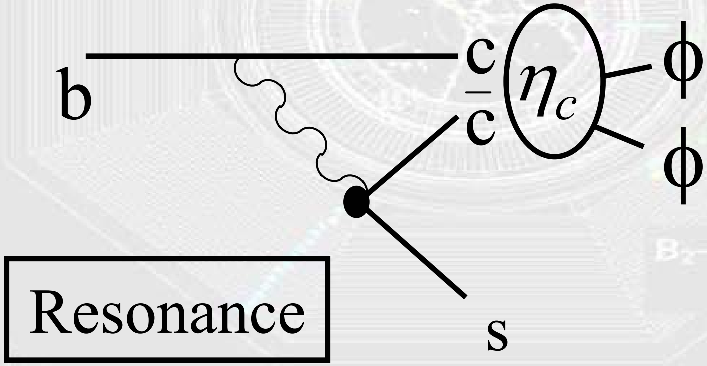
~3×10^{-8} (90%CL) @ 3ab^{-1}



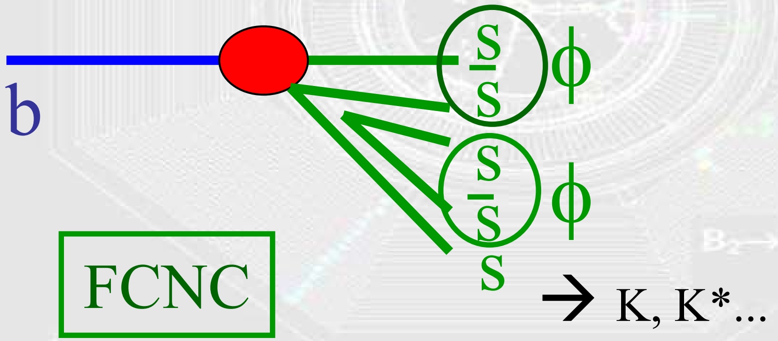


Search for new b→s phase in $B \to \phi\phi X_s$

(M. Hazumi hep-ph/0303089)



+



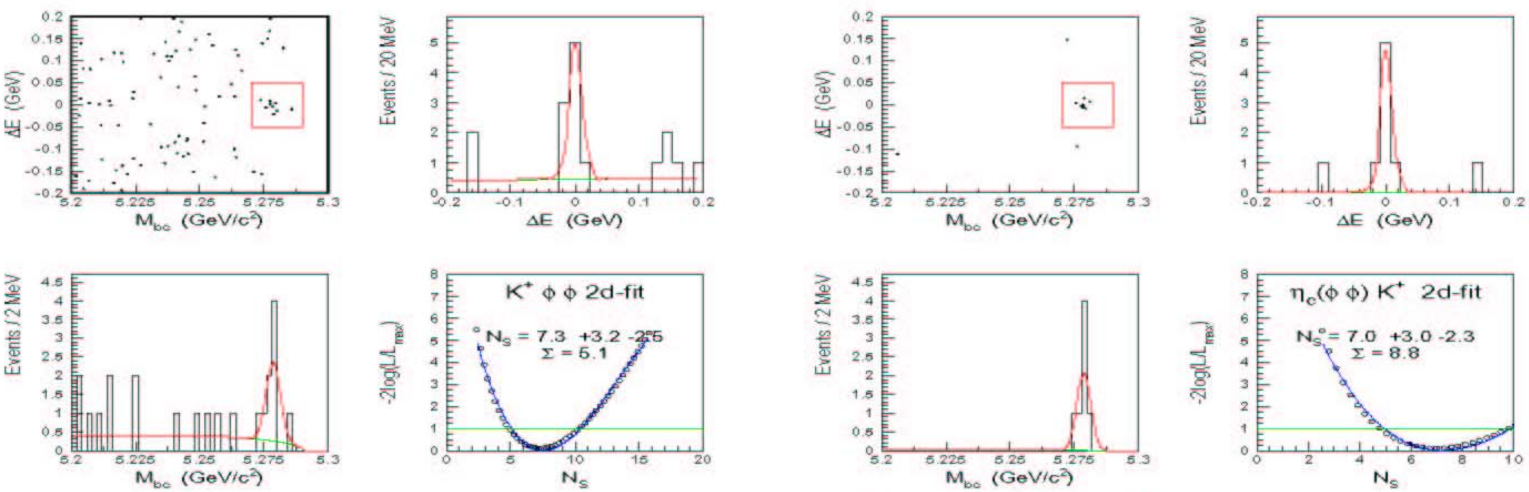
- Standard Model (SM) → direct CPV ~ 0
- with New Physics (NP) → direct CPV can be large
  - CP asymmetry of ~0.4 is allowed.
  - Even larger if we use Belle's new result on Br($\eta_c \to \phi\phi$)

Observation at Belle

(La Thuile Mar. 2003)

hep-ex/0305068

First observation of $B^+ \to \phi\phi K^+$ decay



Belle preliminary $L = 78\ \mathrm{fb}^{-1}$

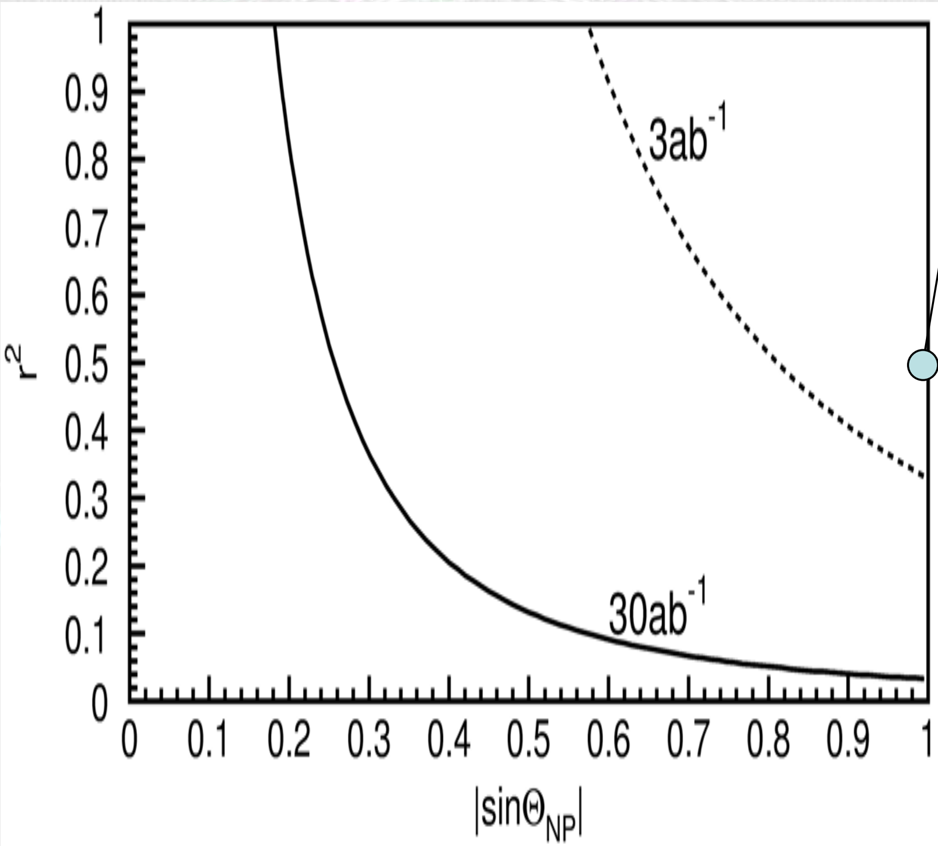
$(B^+ \to \phi\phi K^+) = (2.6^{+1.1}_{-0.9} \pm 0.3) \cdot 10^{-6}$ $\quad (M_{\phi\phi} < 2.85\,\mathrm{GeV/c^2})$.

$(B^+ \to \eta_c K^+) \times Bf(\eta_c \to \phi\phi) = (2.2^{+1.0}_{-0.7} \pm 0.3) \cdot 10^{-6}$ $\quad (2.94 < M_{\phi\phi} < 3.02\,\mathrm{GeV/c^2})$.

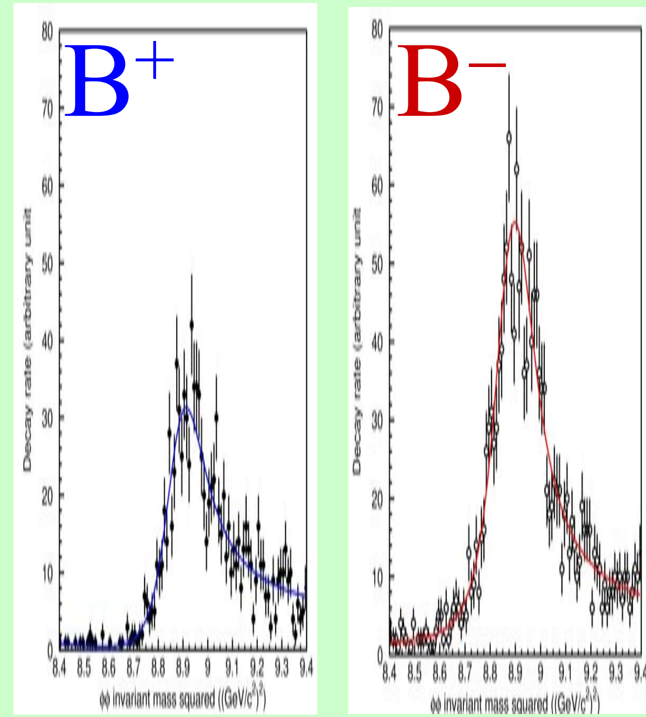
- Almost background-free in the η_c mass region !
- 3-body decays also observed with a reasonable branching fractions

5σ discovery region (with $\phi\phi K^{\pm}$ only)

obtained by unbinned maximum likelihood fits to MC pseudo-experiments
branching fractions based on Belle's observation (hep-ex/0305068)



(30ab^{-1}, $r^2 = 0.5$, $\sin\Theta_{NP} = 1$)

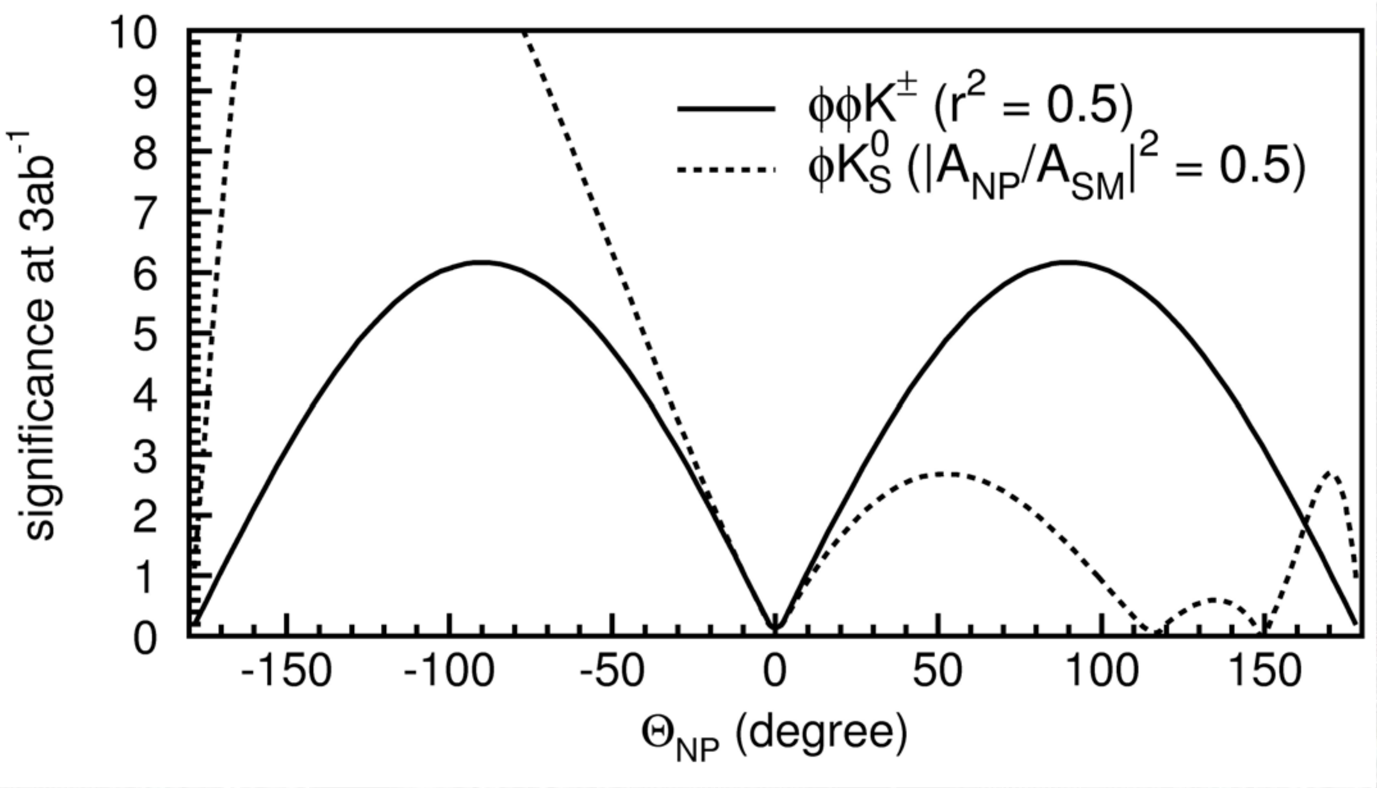


direct CPV seen clearly

- r : non-resonant decay amplitude ratio between NP and SM
- Θ_{NP} : new phase

better significance can be obtained with semi-inclusive $\phi\phi Xs^{\pm}$ analysis

$\phi\phi K^{\pm}$ and ϕKs



Both are important !

Of course not a complete list...

Observable	3ab^{-1}	30ab^{-1}	comment
$\mathcal{S}_{\phi K_S}$	± 0.096(stat)	± 0.030(stat)	$\mathcal{S}_{\phi K_S} - \mathcal{S}_{J/\psi K_S}$ in SM ?
$\mathcal{S}_{\eta' K_S}$	± 0.054(stat)	± 0.017(stat)	$\mathcal{S}_{\eta' K_S} - \mathcal{S}_{J/\psi K_S}$ in SM ?
$\mathcal{S}_{\pi^0 K_S}$	NA	NA	Do it !
$\mathcal{S}_{K^{*0}(\to K_S \pi^0)\gamma}$	NA	NA	~ 1000ev. (before VTX) at 3ab^{-1}
$\mathcal{S}_{J/\psi K_S}$	± 0.017(stat)	± 0.005(stat)	error with $J/\psi K_S$ alone
ϕ_2 $(\pi^+\pi^-)$	$\pm 5.1°$(stat)	$\pm 1.6°$(stat)	$\pm 5 - 7\%$(EWP) for $\lvert A^{00}\rvert$
ϕ_2 $(\rho\pi)$	$\pm 3.5°$(stat)	$\pm 1.2°$(stat)	systematic error ?
ϕ_3 (Dalitz)	$\pm 5 - 7°$(stat)		
ϕ_3 (ADS)		$\pm 9°$(stat)	
$\lvert V_{ub}\rvert$ (inclusive)	$\pm 6.0\%$(total)		± 2.5(stat)± 3.1(sys)± 4.5(th)%
$A_{CP}(b \to s\gamma)$	1.1(stat)± 0.8(sys)%	0.4(stat)± 0.3(sys)± 0.3(th)%	
$\mathcal{B}(B \to D\tau\nu)$			need more BG study
$\mathcal{B}(B \to \tau\nu)$		5σ	3 modes combined (0.1% full. rec)
$\mathcal{B}(B \to K\nu\nu)$		4.9σ	0.1% full. rec
$\mathcal{B}(\tau \to \mu\gamma)$	$< 3 \times 10^{-8}$	$< 1 \times 10^{-8}$	
$\mathcal{B}(\tau \to \mu/e\eta)$	$< 1 \times 10^{-8}$	$< 1 \times 10^{-9}$	

LHCbとの比較

- Time-dependent CP violation ($\mathcal{S}$)
  - $B^0 \rightarrow \phi Ks$
  - $B^0 \rightarrow \eta' Ks$
  - $B^0 \rightarrow K^{*0} \gamma$

Super Bでのみ可能
（但しLHCbはBs → J/ψ ϕあり）

- Direct CP violation ($\mathcal{A}$)
  - $b \rightarrow s \gamma$ (inclusive)

Super Bでのみ可能

- Forbidden decays
  - $\tau \rightarrow \mu \gamma$

LHCbは$\tau \rightarrow \mu\mu\mu$等？

- Unitarity triangle
  - $\phi 1$ 互角 (SuperB 0.017 ↔ 0.022 LHCb)
  - $\phi 2$ ← Super Bでのみ可能
  - $\phi 3$ 互角 (SuperB 5-7° ↔ 4-6° LHCb)
  - Vub ← Super Bでのみ可能

Luminosity Frontier and Energy Frontier

現在

B factory
top quarkのcoupling
（BのCPの破れ発見）

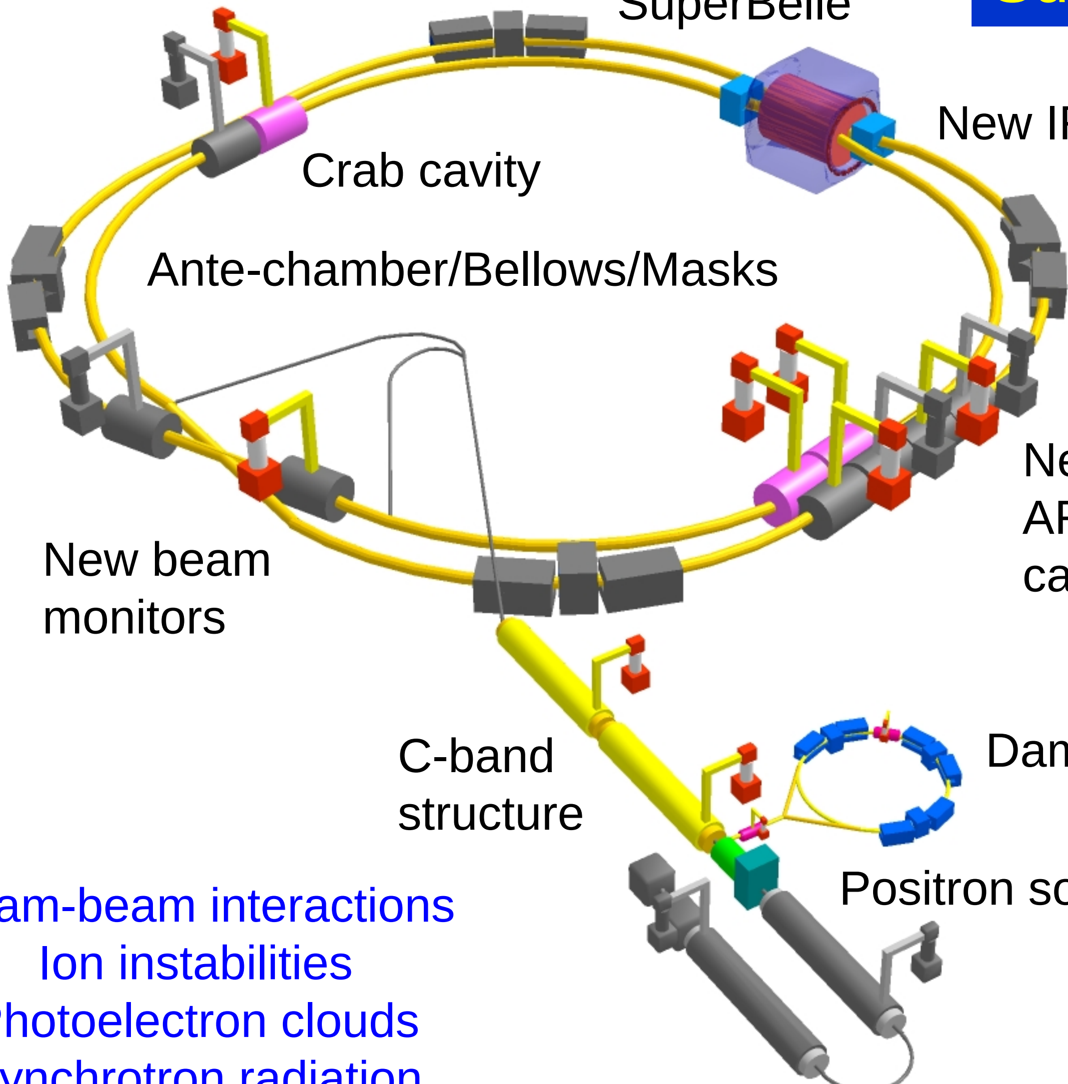
Tevatron
top quark
の発見

将来

B factory
新しい素粒子のcoupling
（新しいCPの破れ発見）

LHC
新しい
素粒子

Super KEKB Overview



Beam-beam interactions
Ion instabilities
Photoelectron clouds
Synchrotron radiation
Higher order mode (HOM)
…

© K. Oide

Beam-beam simulation of crab crossing

K. Ohmi et al.

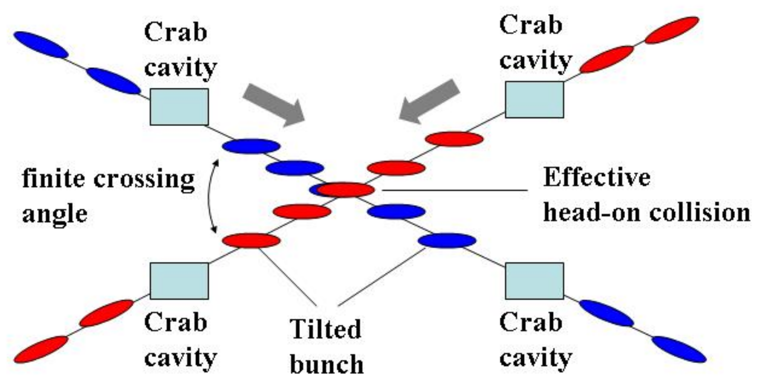
- Target luminosity : $10^{35} \sim 10^{36}$ cm^{-2}s^{-1}
- Number of bunches : 5000
- Beam current : I(HER) = (3.5 GeV/8 GeV) x I(LER)
- Weak-strong simulation

Crab crossing is powerful scheme to achieve higher luminosity.

$$L \approx \frac{\gamma_\pm}{2er_e}\frac{I_\pm \xi_{\pm y}}{\beta_y^*}$$

	HER	LER
I	4.1A	9.4A
N_b	5000	5000
N_e	5.2×10^{10}	1.2×10^{11}
ε_x	24nm	24nm
ε_y	0.18nm	0.18nm
σ_z	3mm	3mm
β_x	20 cm	20 cm
β_y	3mm	3mm
ξ_y	0.23	0.23
L_b	$1.\times10^{32}$	
L	5×10^{35}	

Crab crossing — will be tested in 2005



- Bunches are tilted by crab cavities.

$$\mathcal{L} = 5\times 10^{35}$$

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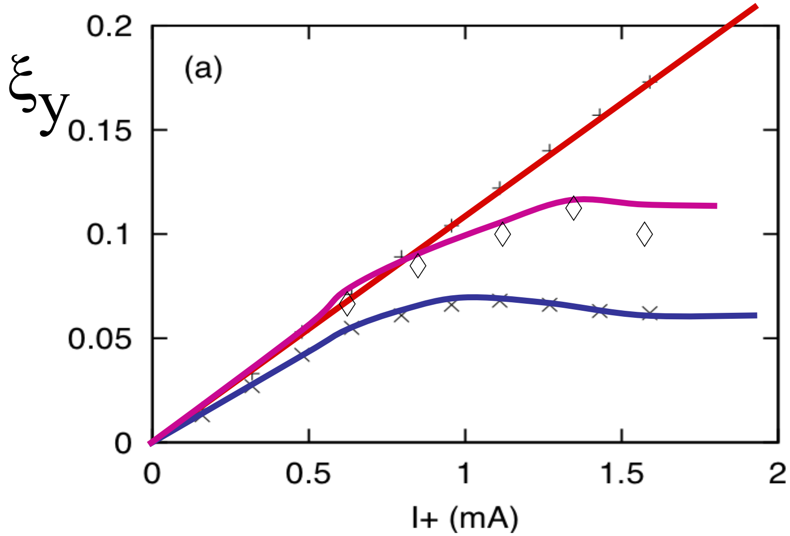
Activities for Super KEKB

● Crab crossing may boost the beam-beam parameter up to 0.2!

K. Ohmi



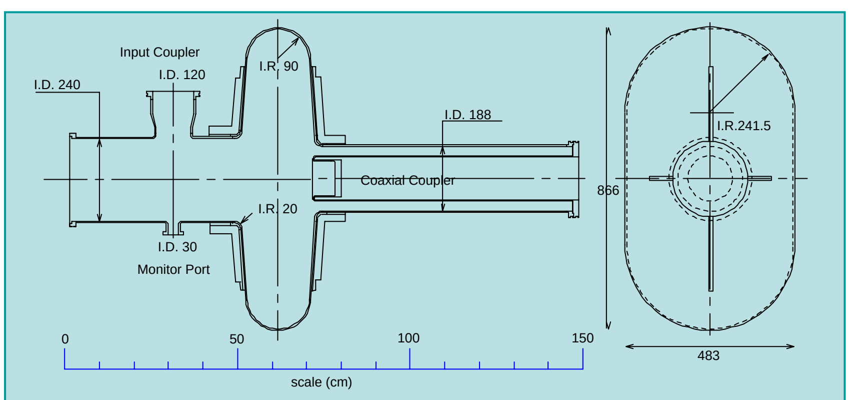
(Strong-weak simulation)

Head-on(crab)

(Strong-strong simulation)

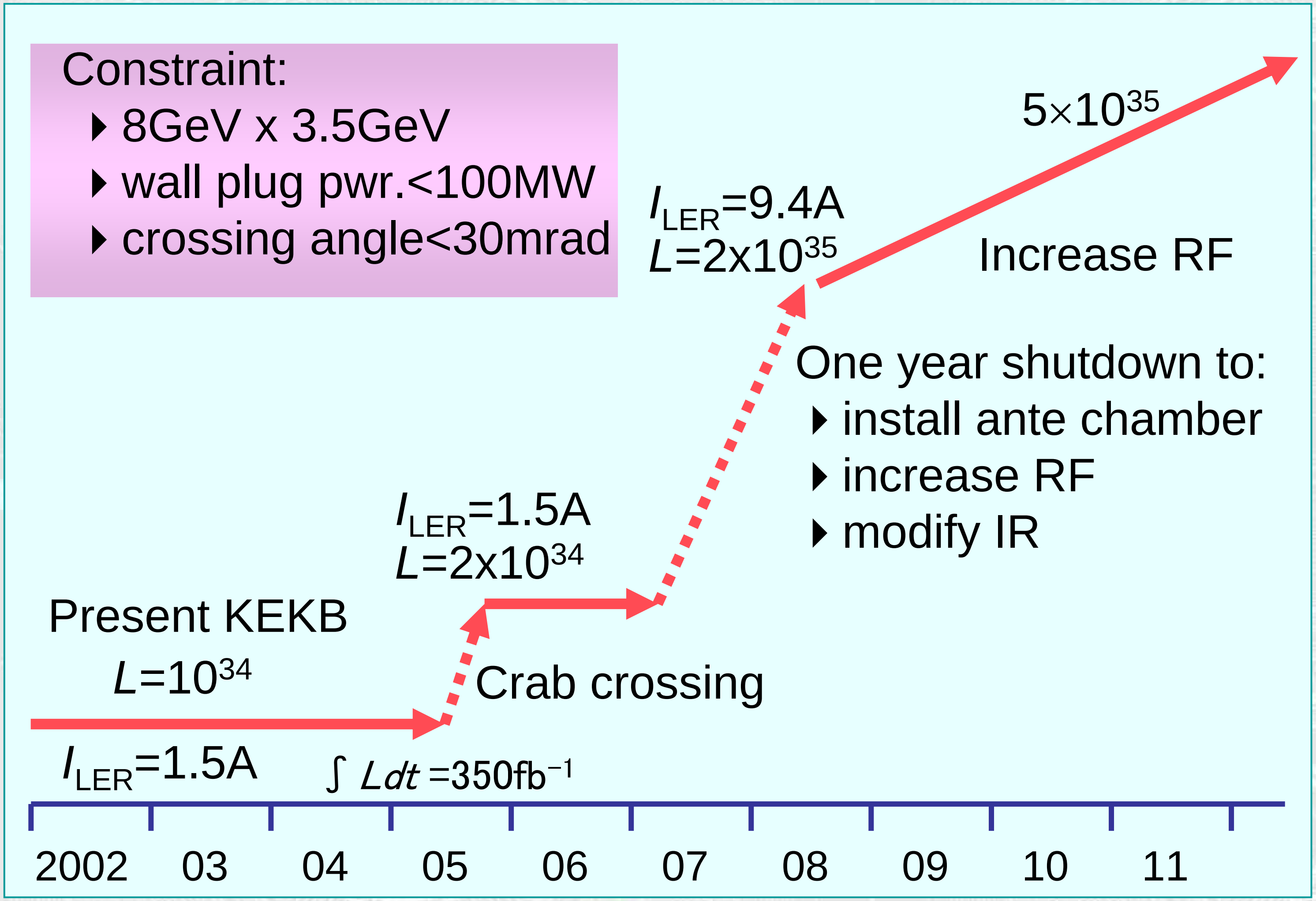
crossing angle 22 mrad

● Superconducting crab cavities are under development, will be installed in KEKB in 2005.

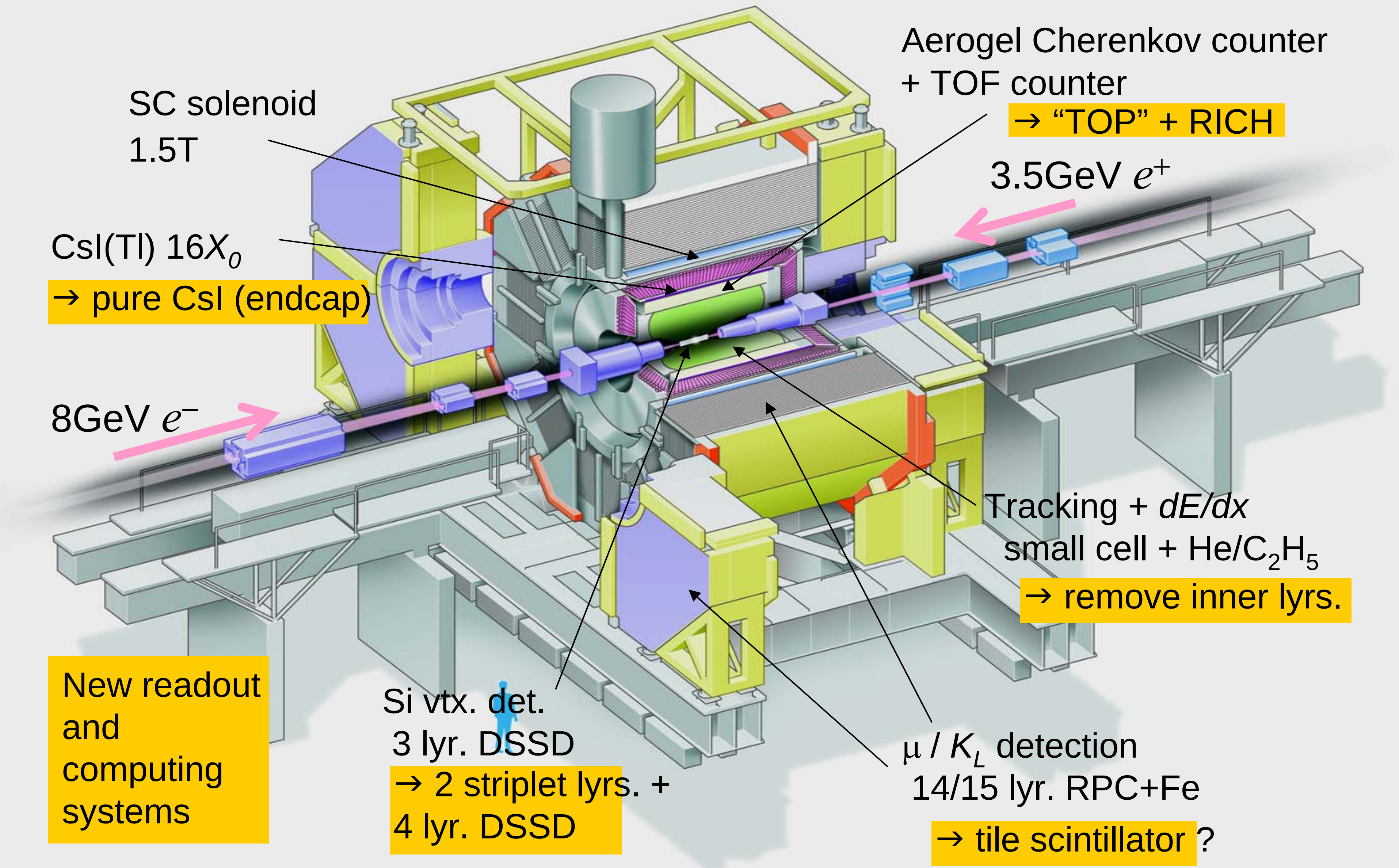


K. Hosoyama, et al

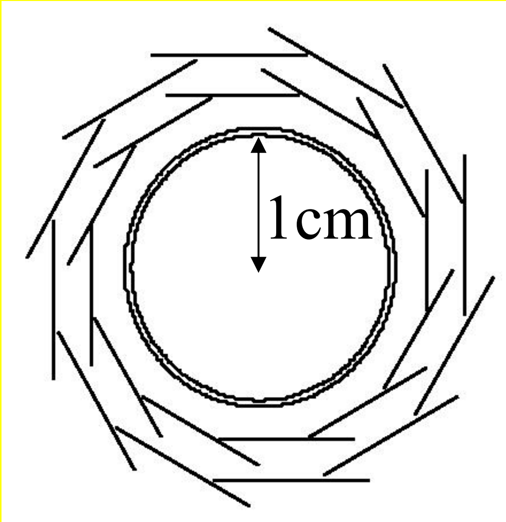
KEK B factory upgrade strategy



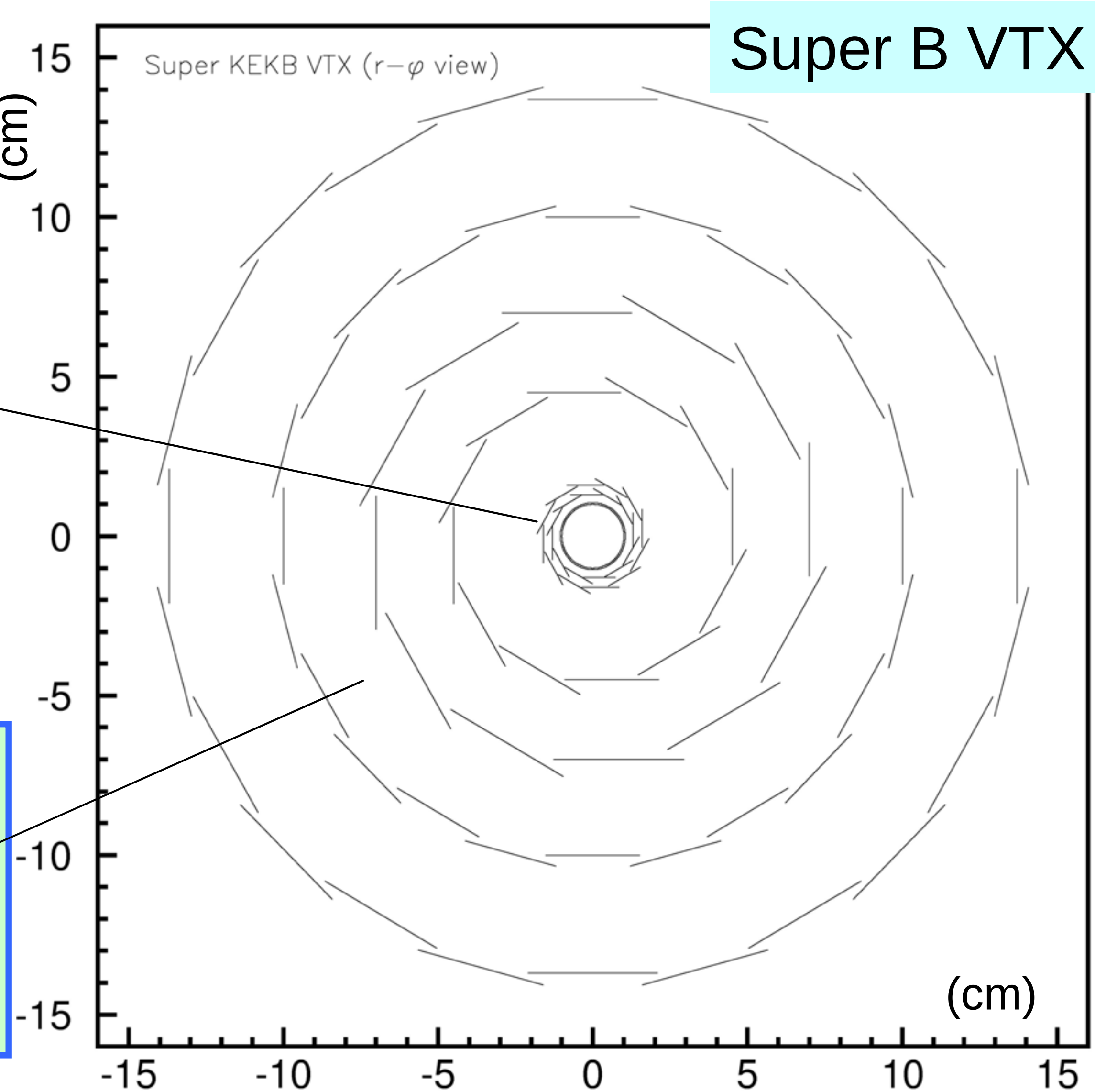
Detector upgrade for Super KEKB



Vertex Detector

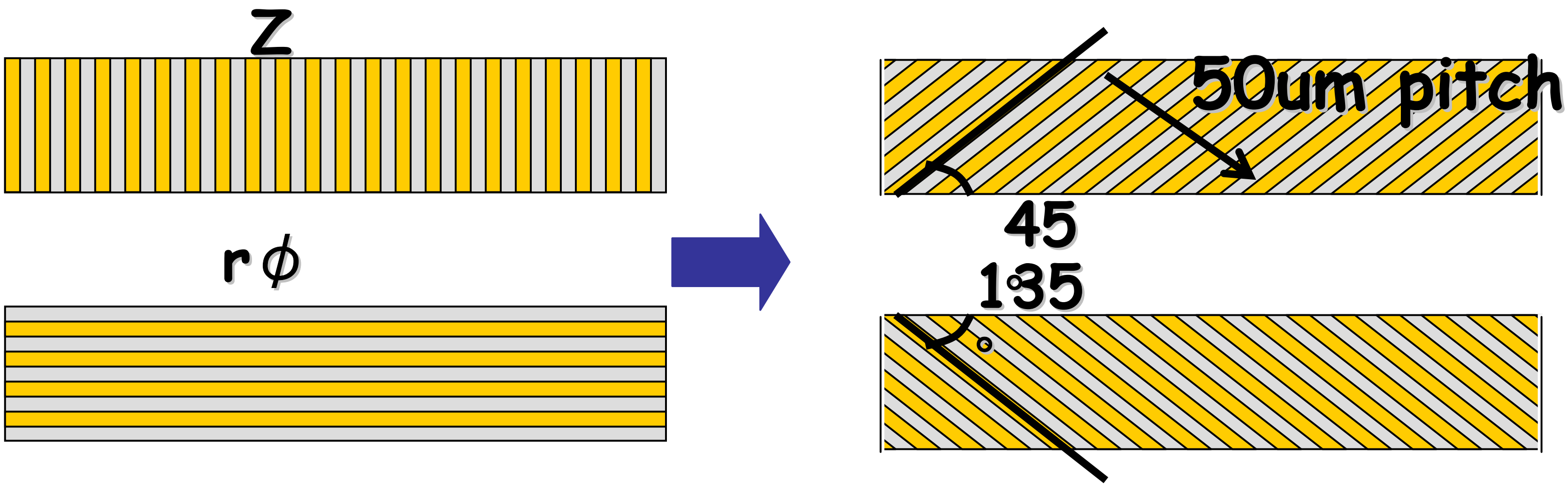


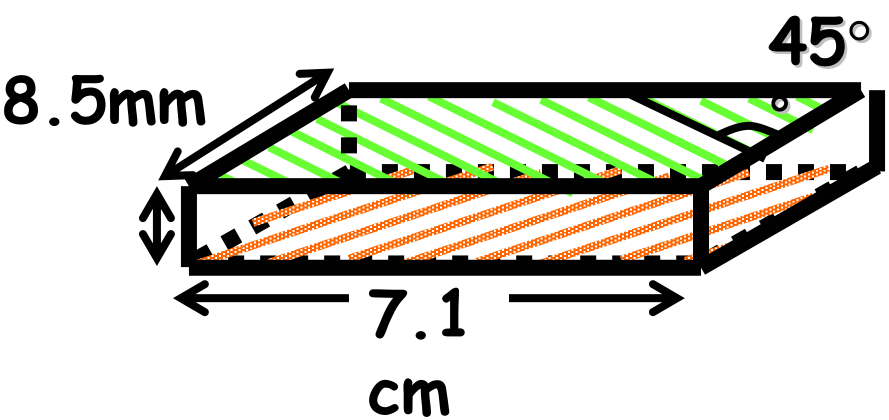
beampipe and 2-layer striplet or pixel sensors



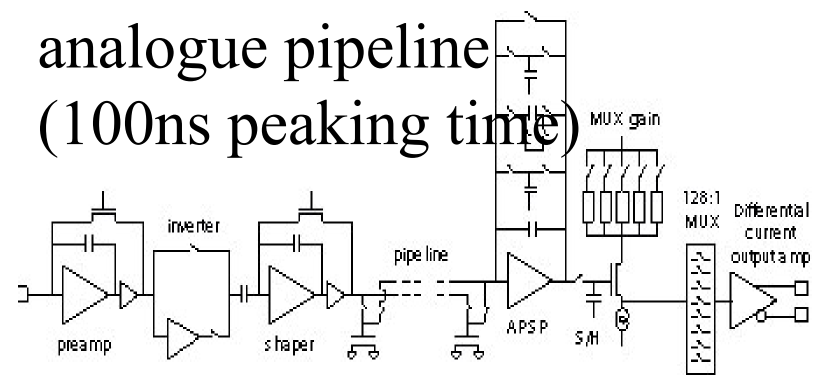
DSSD w/ analog pipeline readout (~4 layers) to cope with high occupancy.
APV25 for CMS as the best candidates

A new design: UV-striplet & analogue pipeline





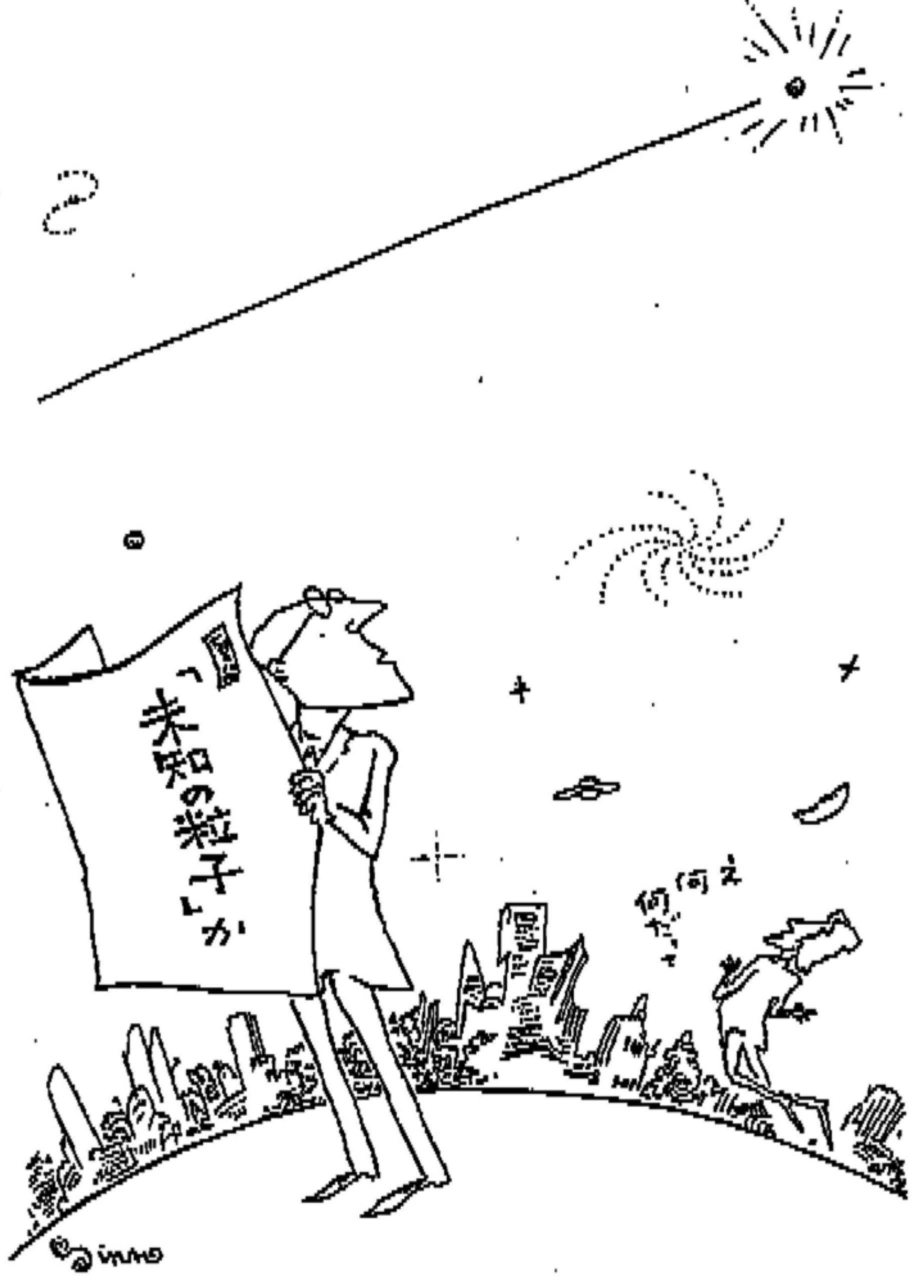
analogue pipeline
(100ns peaking time)



Occupancy → 1/4 × 1/10 = 1/40

まとめ

- KEK Bファクトリーは設計通りの性能で絶好調。BでCPの破れを発見し、小林益川理論の有効性を確認。
- 稀崩壊におけるCPの破れの探求を本格的に開始。3↔2世代遷移の徹底調査は高い発見能力を持つことを示した。
- 50倍にルミノシティ増強で新しいフレーバー物理の地平を切り開く。「発見」の後に新しい物理の「同定」が可能。e+e−のきれいな環境が不可欠。



この「素晴らしい可能性」が「どのくらい素晴らしい」のか見当もつかない　山田　紳