Implications of $B \to \phi K_S$ Anomaly
for
Super B Factory and Colliders

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May 18, 2004 @ DESY, Hamburg

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Implications of $B \to \phi K_S$ Anomaly for Super B Factory and Colliders

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May 4, 2004 @ CFIF, IST, Lisbon

Implications of $B \to \phi K_S$ Anomaly for Super B Factory and Colliders

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April 22, 2004 @ Rabat

Implications of $B \to \phi K_S$ Anomaly for Super B Factory and Colliders

George W.S. Hou (侯維恕)
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April 20, 2004 @ CERN

New Physics CPV Phase in *the Prese*

Introduction

CPV in Mixing-*Decay*
Interference

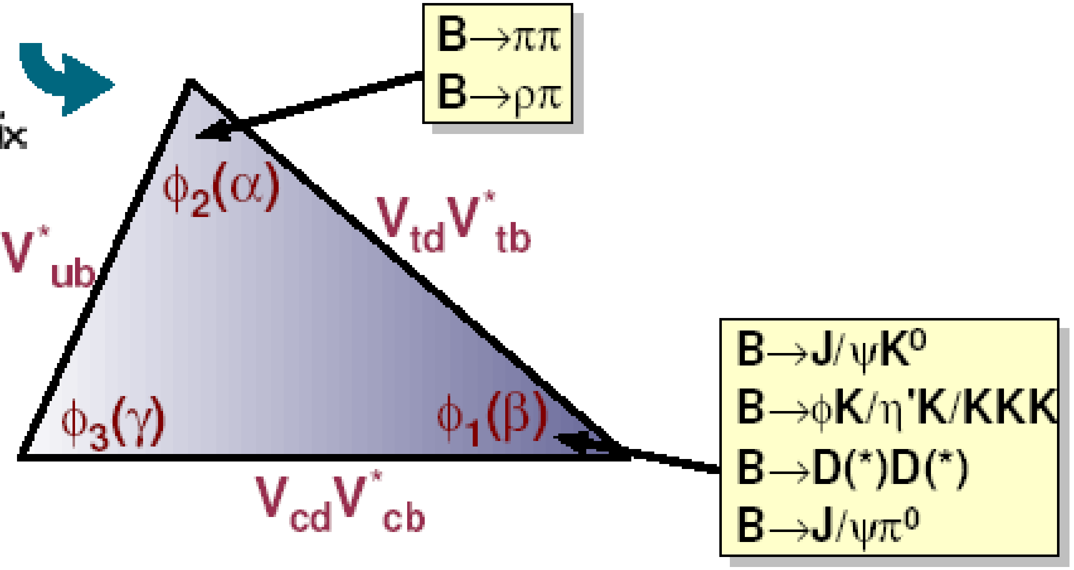
Unitarity Triangle

CPV in the quark mixing matrix

- CPV from the complex phase in the quark mixing matrix:

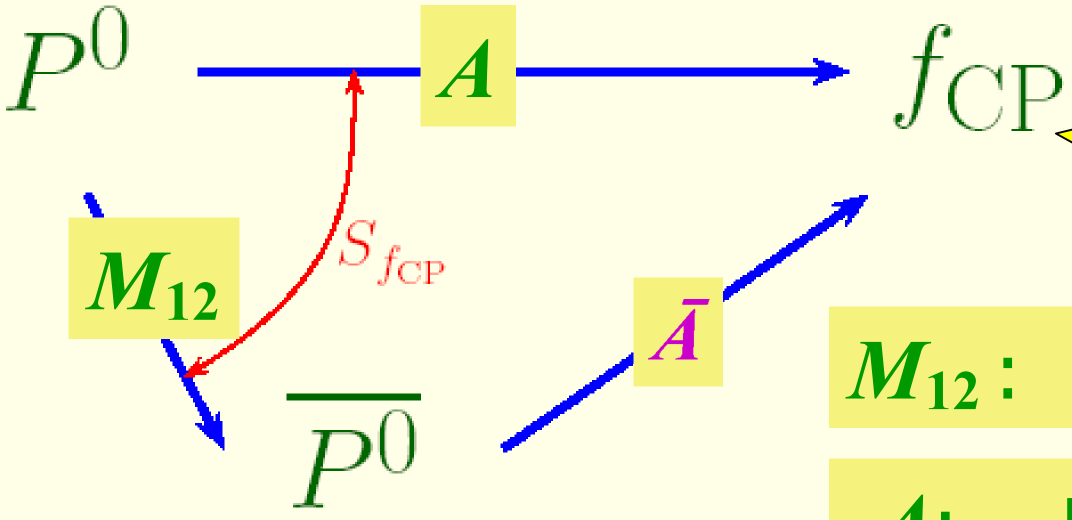
$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-(\lambda^2/2) & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-(\lambda^2/2) & A\lambda^2 \\ A\lambda^3(1-\rho - i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

Property of unitarity matrix



Recall the Physics …

CPV in Mixing-Decay Interference



Double Slit Experiment

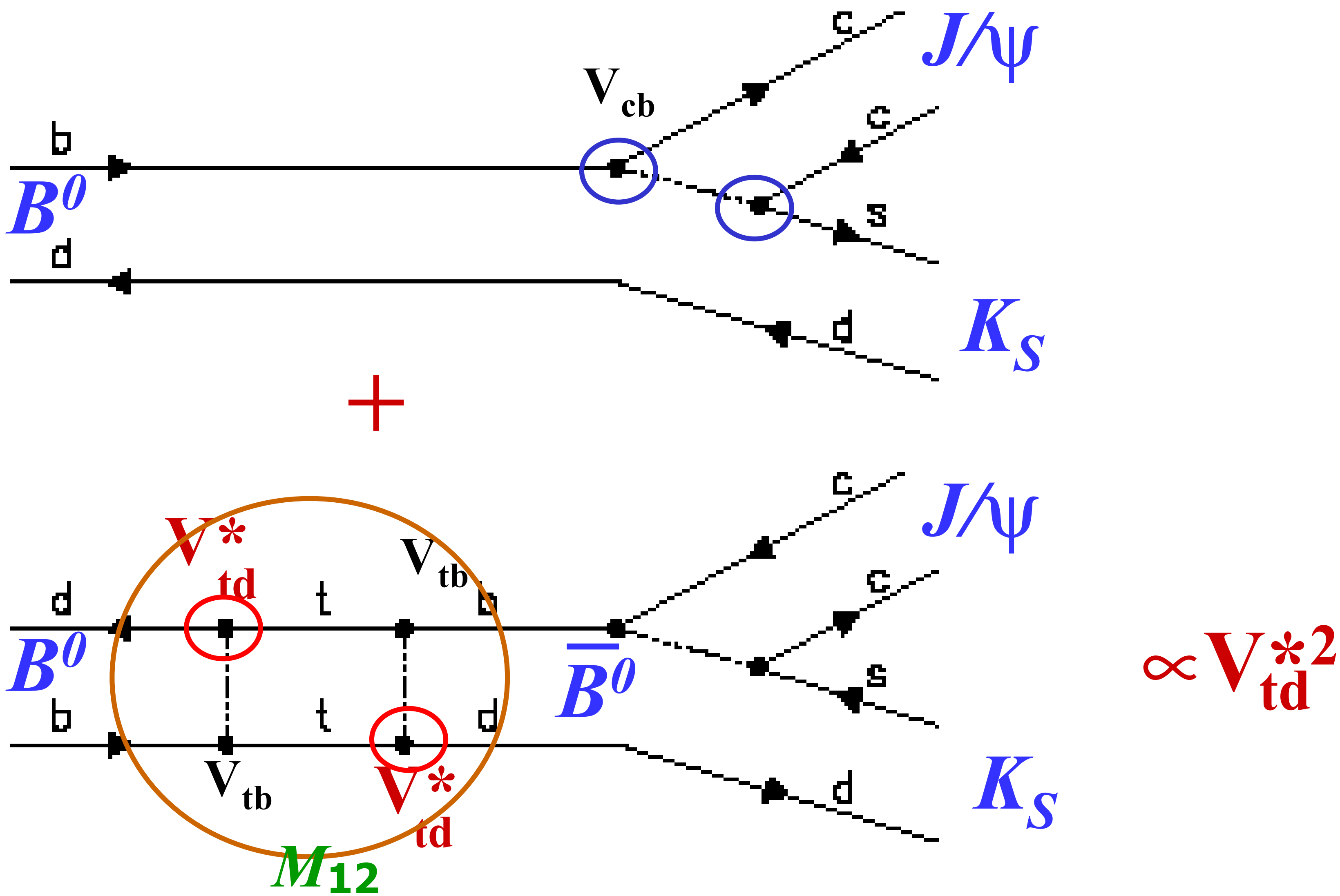
M_{12}: Mixing Amplitude

A: Decay Amplitude

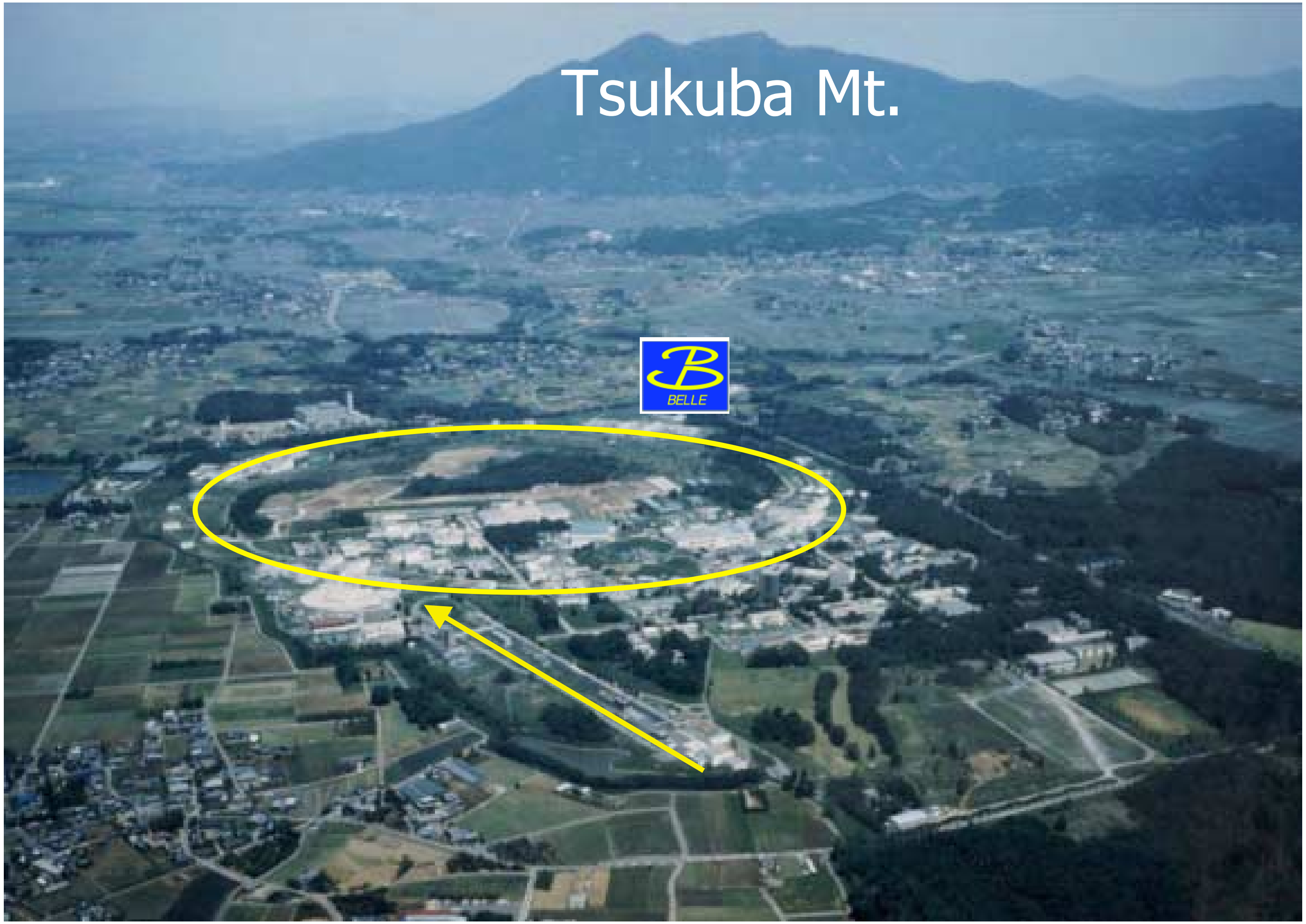
1. Decay dominated by a single CPV phase: $|\bar{A}/A| = 1$
2. CPV in mixing negligible: $|q/p| = 1$
3. The only remaining effect is

$$S_{f_{CP}} = \mathcal{I}m\lambda_{f_{CP}} \sim \sin[\arg(M_{12}) - 2\arg(A)]$$

No CPV in $B^0 \to \bar{B}^0 \psi K_S$ Mixing Decay



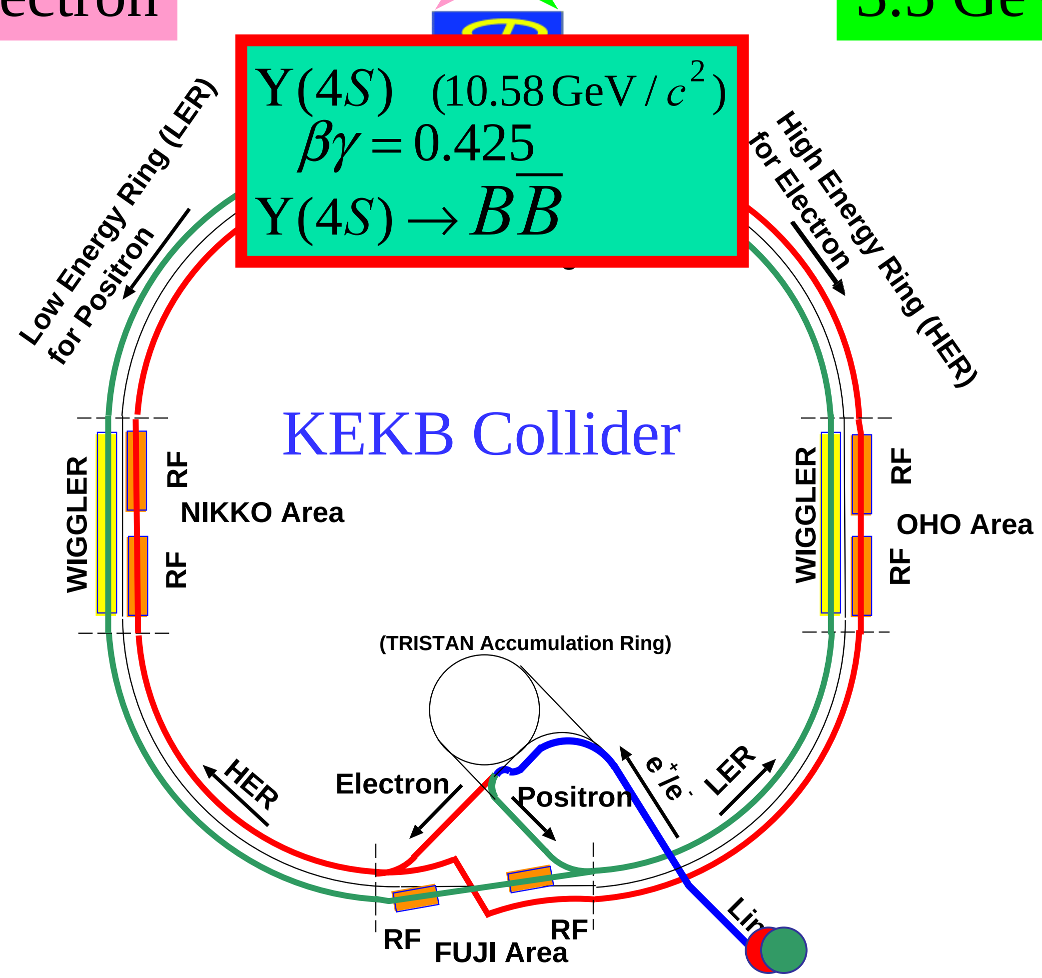
KEK (Japan)



KEKB Accelerator

8 GeV electron → ← 3.5 GeV positron

$$\Upsilon(4S) \quad (10.58\,\mathrm{GeV}/c^2)$$
$$\beta\gamma = 0.425$$
$$\Upsilon(4S) \to B\bar{B}$$

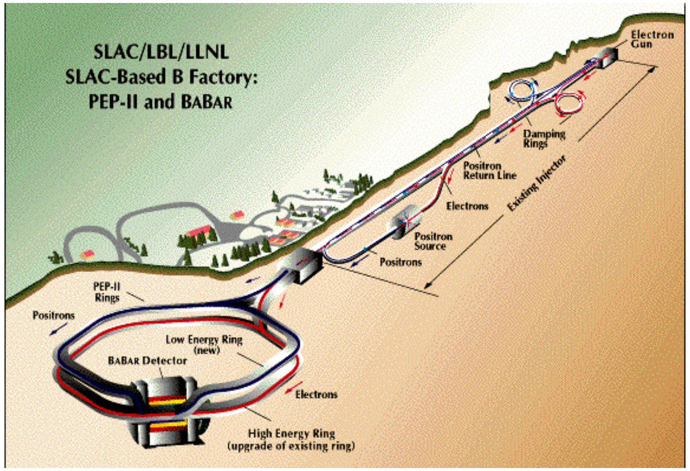


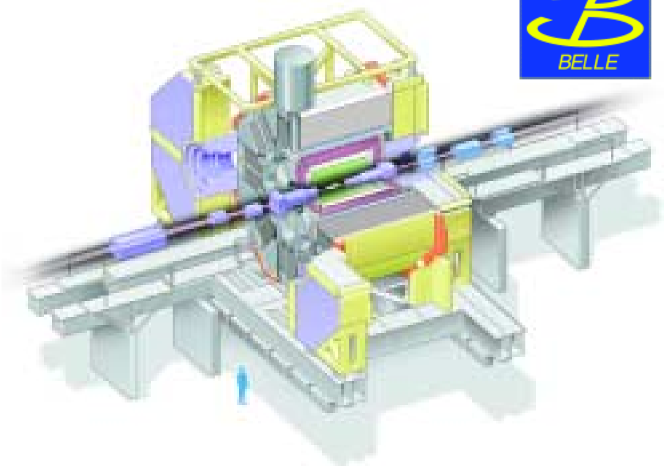
B el le

The Duel of the B Factories

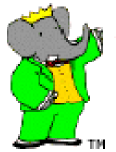
KEK

SLAC

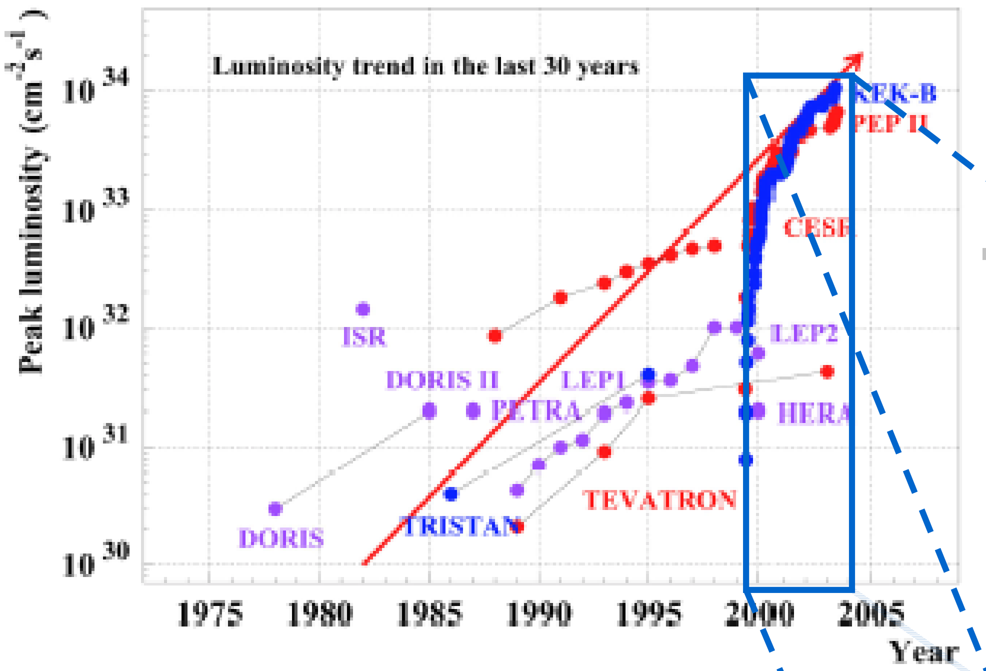




Belle

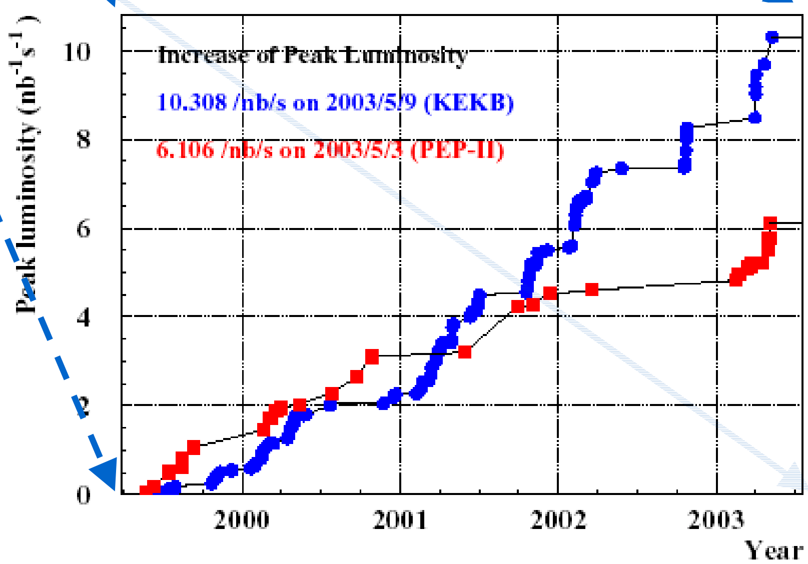


BaBar



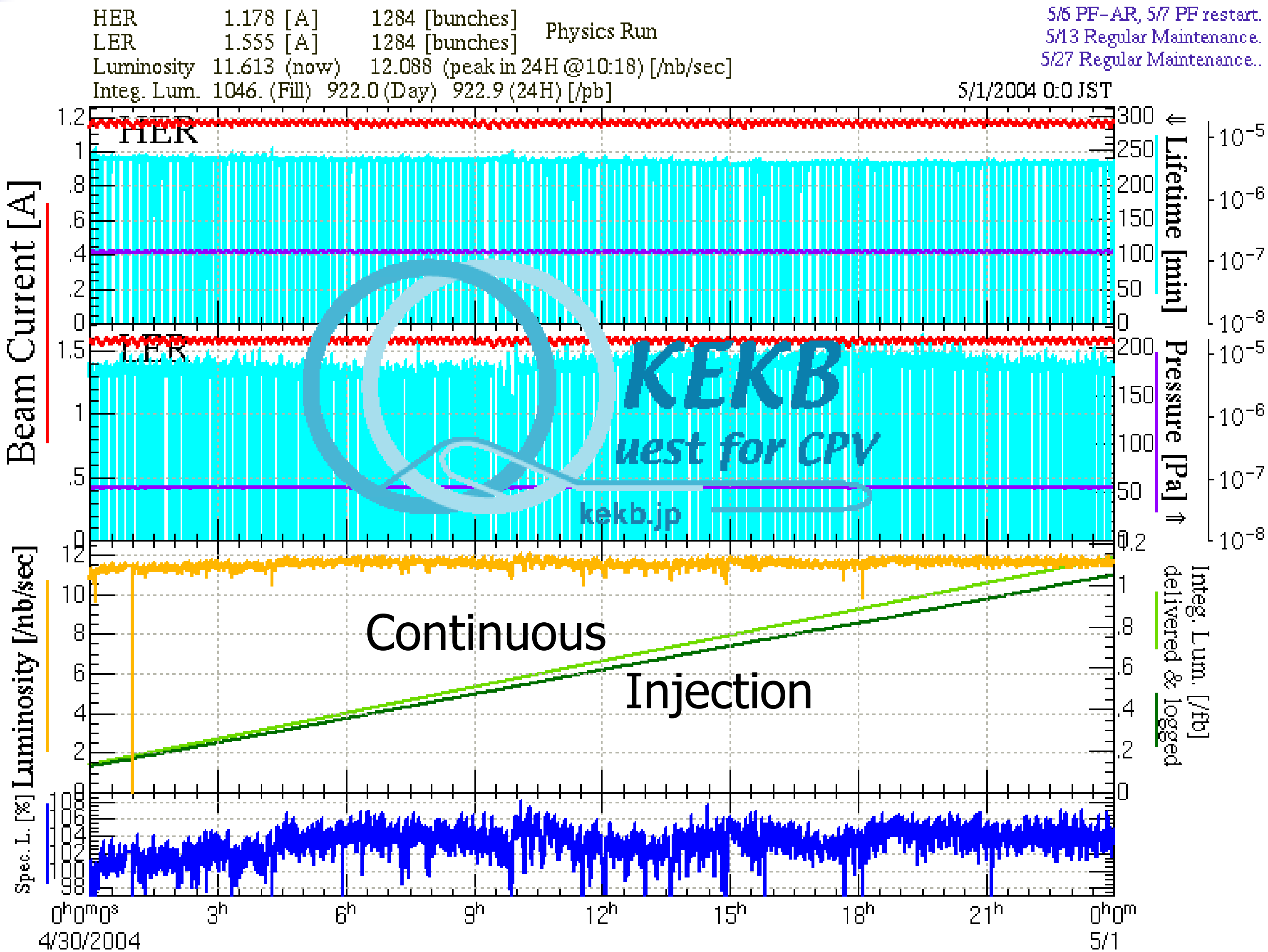
KEKB is
the Brightest
Collider in the World

KEKB Surpassed
PEP-II of SLAC
since Spring ’01

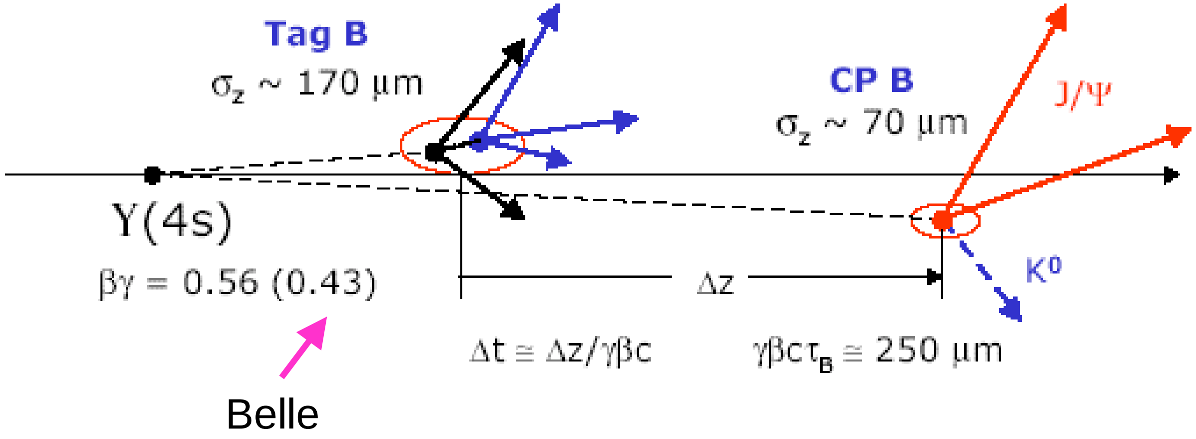


21.279 fb^{-1} (Apr., 2004) New record !!!

922.8 pb^{-1} (Apr.30, 2004) New record !!!



The $1B Question: Mixing-dep. CPV in $B \to J/\psi K_S$



One B Decay CP Eigenstate

Other B Decay Tag Flavor

Measure Both Decay **Vertex**

$J/\psi K_S$, 2001 !

Red Hot !

$\pi^+\pi^-$, $\eta' K_S$, $\phi \boldsymbol{K_S}$, $K_S\pi^0$

The Current Focus

[NTU has a hand in all]

Observation of Large CP Violation

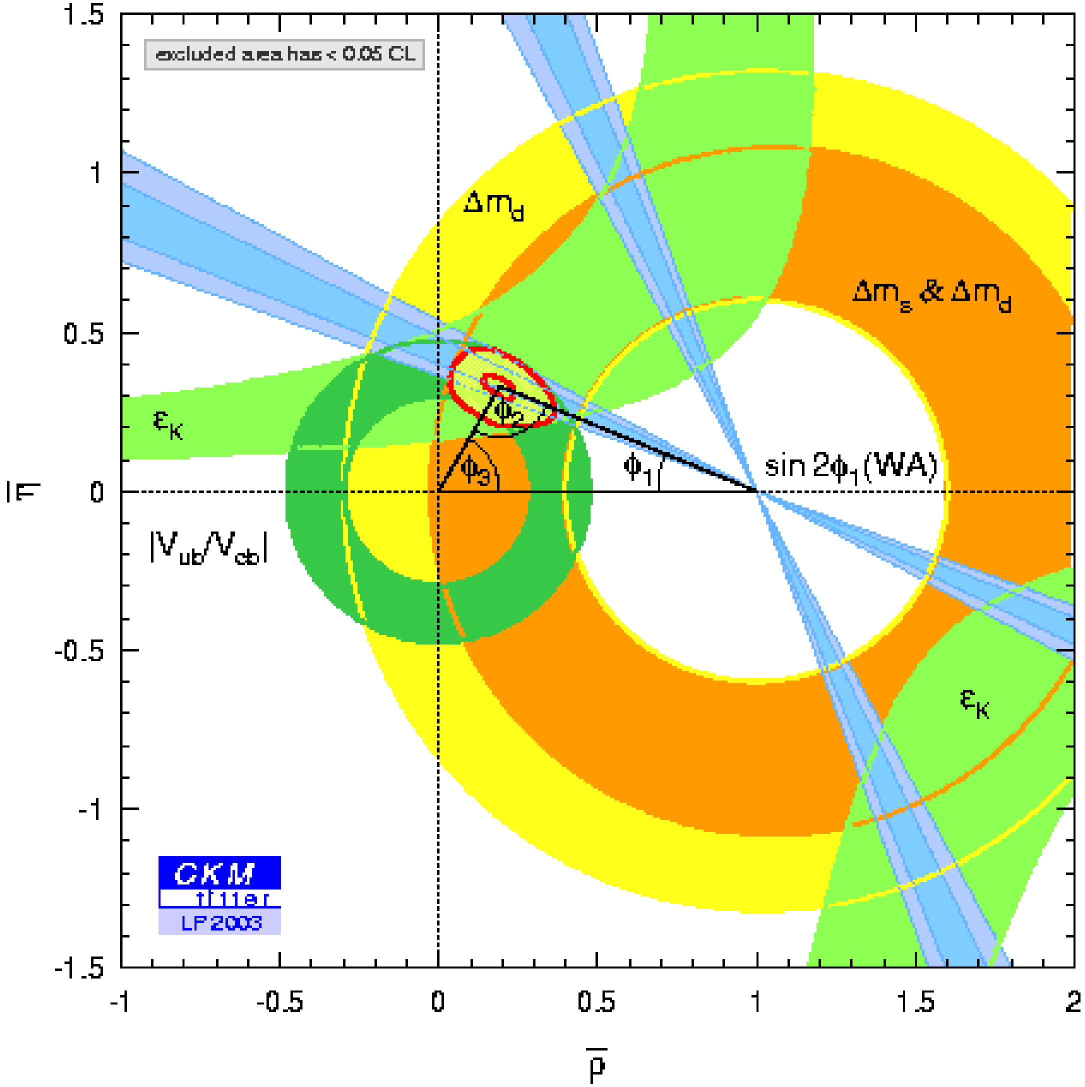
VOLUME 87, NUMBER 9 PHYSICAL REVIEW LETTERS 27 AUGUST 2001

Observation of Large *CP* Violation in the Neutral *B* Meson System $B \rightarrow J/\psi K_S$

K. Abe,[9] K. Abe,[37] R. Abe,[27] I. Adachi,[9] Byoung Sup Ahn,[16] H. Aihara,[39] M. Akatsu,[20] G. Alimonti,[8] K. Asai,[21] M. Asai,[10] Y. Asano,[44] T. Aso,[43] V. Aulchenko,[2] T. Aushev,[14] A. M. Bakich,[35] E. Banas,[25] S. Behari,[9] P. K. Behera,[45] D. Beiline,[2] A. Bondar,[2] A. Bozek,[25] T. E. Browder,[8] B. C. K. Casey,[8] P. Chang,[24] Y. Chao,[24] K.-F. Chen,[24] B. G. Cheon,[34] R. Chistov,[14] S.-K. Choi,[7] Y. Choi,[34] L. Y. Dong,[12] J. Dragic,[19] A. Drutskoy,[14] S. Eidelman,[2] V. Eiges,[14] Y. Enari,[20] R. Enomoto,[9] C. W. Everton,[19] F. Fang,[8] H. Fujii,[9] C. Fukunaga,[41] M. Fukushima,[11] N. Gabyshev,[9] A. Garmash,[2,9] T. J. Gershon,[9] A. Gordon,[19] K. Gotow,[46] H. Guler,[8] R. Guo,[22] J. Haba,[9] H. Hamasaki,[9] K. Hanagaki,[31] F. Handa,[38] K. Hara,[29] T. Hara,[29] N. C. Hastings,[19] H. Hayashii,[21] M. Hazumi,[29] E. M. Heenan,[19] Y. Higasino,[20] I. Higuchi,[38] T. Higuchi,[39] T. Hirai,[40] H. Hirano,[42] T. Hojo,[29] T. Hokuue,[20] Y. Hoshi,[37] K. Hoshina,[42] S. R. Hou,[24] W.-S. Hou,[24] S.-C. Hsu,[24] H.-C. Huang,[24] Y. Igarashi,[9] T. Iijima,[9] H. Ikeda,[9] K. Ikeda,[21] K. Inami,[20] A. Ishikawa,[20] H. Ishino,[40] R. Itoh,[9] G. Iwai,[27] H. Iwasaki,[9] Y. Iwasaki,[9] D. J. Jackson,[29] P. Jalocha,[25] H. K. Jang,[33] M. Jones,[8] R. Kagan,[14] H. Kakuno,[40] J. Kaneko,[40] J. H. Kang,[48] J. S. Kang,[16] P. Kapusta,[25] N. Katayama,[9] H. Kawai,[3] H. Kawai,[39] Y. Kawakami,[20] N. Kawamura,[1] T. Kawasaki,[27] H. Kichimi,[9] D. W. Kim,[34] Heejong Kim,[48] H. J. Kim,[48] Hyunwoo Kim,[16] S. K. Kim,[33] T. H. Kim,[48] K. Kinoshita,[5] S. Kobayashi,[32] S. Koishi,[40] H. Konishi,[42] K. Korotushenko,[31] P. Krokovny,[2] R. Kulasiri,[5] S. Kumar,[30] T. Kuniya,[32] E. Kurihara,[3] A. Kuzmin,[2] Y.-J. Kwon,[48] J. S. Lange,[6] G. Leder,[13] M. H. Lee,[9] S. H. Lee,[33] C. Leonidopoulos,[31] Y.-S. Lin,[24] D. Liventsev,[14] R.-S. Lu,[24] J. MacNaughton,[13] D. Marlow,[31] T. Matsubara,[39] S. Matsui,[20] S. Matsumoto,[4] T. Matsumoto,[20] Y. Mikami,[38] K. Misono,[20] K. Miyabayashi,[21] H. Miyake,[29] H. Miyata,[27] L. C. Moffitt,[19] G. R. Moloney,[19] G. F. Moorhead,[19] S. Mori,[44] T. Mori,[4] A. Murakami,[32] T. Nagamine,[38] Y. Nagasaka,[10] Y. Nagashima,[29] T. Nakadaira,[39] T. Nakamura,[40] E. Nakano,[28] M. Nakao,[9] H. Nakazawa,[4] J. W. Nam,[34] Z. Natkaniec,[25] K. Neichi,[37] S. Nishida,[17] O. Nitoh,[42] S. Noguchi,[21] T. Nozaki,[9] S. Ogawa,[36] T. Ohshima,[20] Y. Ohshima,[40] T. Okabe,[20] T. Okazaki,[21] S. Okuno,[15] S. L. Olsen,[8] H. Ozaki,[9] P. Pakhlov,[14] H. Palka,[25] C. S. Park,[33] C. W. Park,[16] H. Park,[18] L. S. Peak,[35] M. Peters,[8] L. E. Piilonen,[46] E. Prebys,[31] J. L. Rodriguez,[8] N. Root,[2] M. Rozanska,[25] K. Rybicki,[25] J. Ryuko,[29] H. Sagawa,[9] Y. Sakai,[9] H. Sakamoto,[17] M. Satapathy,[45] A. Satpathy,[9,5] S. Schrenk,[5] S. Semenov,[14] K. Senyo,[20] Y. Settai,[4] M. E. Sevior,[19] H. Shibuya,[36] B. Shwartz,[2] A. Sidorov,[2] S. Stanič,[44] A. Sugi,[20] A. Sugiyama,[20] K. Sumisawa,[9] T. Sumiyoshi,[9] J.-I. Suzuki,[9] K. Suzuki,[3] S. Suzuki,[47] S. Y. Suzuki,[9] S. K. Swain,[8] H. Tajima,[39] T. Takahashi,[28] F. Takasaki,[9] M. Takita,[29] K. Tamai,[9] N. Tamura,[27] J. Tanaka,[39] M. Tanaka,[9] G. N. Taylor,[19] Y. Teramoto,[28] M. Tomoto,[9] T. Tomura,[39] S. N. Tovey,[19] K. Trabelsi,[8] T. Tsuboyama,[9] T. Tsukamoto,[9] S. Uehara,[9] K. Ueno,[24] Y. Unno,[3] S. Uno,[9] Y. Ushiroda,[9] S. E. Vahsen,[31] K. E. Varvell,[35] C. C. Wang,[24] C. H. Wang,[23] J. G. Wang,[46] M.-Z. Wang,[24] Y. Watanabe,[40] E. Won,[33] B. D. Yabsley,[9] Y. Yamada,[9] M. Yamaga,[38] A. Yamaguchi,[38] H. Yamamoto,[8] T. Yamanaka,[29] Y. Yamashita,[26] M. Yamauchi,[9] S. Yanaka,[40] J. Yashima,[9] M. Yokoyama,[39] K. Yoshida,[20] Y. Yusa,[38] H. Yuta,[1] C. C. Zhang,[12] J. Zhang,[44] H. W. Zhao,[9] Y. Zheng,[8] V. Zhilich,[2] and D. Žontar[44]

(Belle Collaboration)

Current Belle and BaBar Results for sin(2f $_1$)



$\sin 2\phi_1$ (Belle 2003,140 fb^{1})
$=0.733\pm0.057\pm0.028$

$\sin 2\phi_1$ (BaBar 2002, 81 fb^{-1})
$=0.741\pm0.067\pm0.033$

Precision Measurement

$\sin 2\phi_1$ (New 2003 World Av.) $=0.736\pm0.049$

Thanks to A. Hoecker

Browder @ LP03

Sakharov Conditions: Matter Universe

Sakharov (1964)

Antimatter → Matter if:

(1) Proton Decay
(Baryon # Violation)

(2) Matter-antimatter Asymm
(CP Violation)

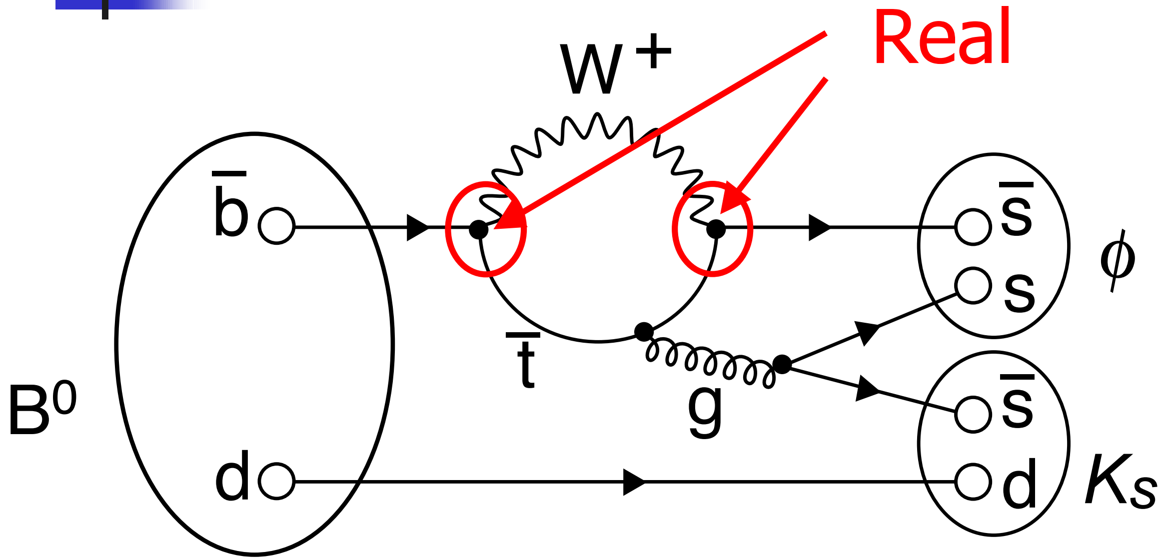
(3) Out of Equilibrium

KM insufficient !

Particle Physics  Astrophysics

tinue Search for CP Violation

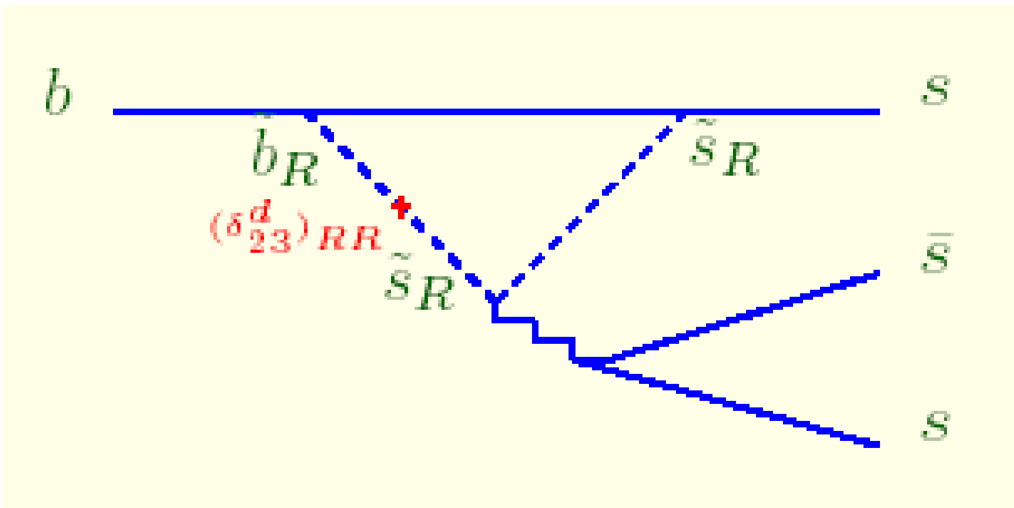
Penguins (Vertex Loops)



SM (KM) Prediction

$$S_{\phi K_S} = \sin 2\phi_1$$

β

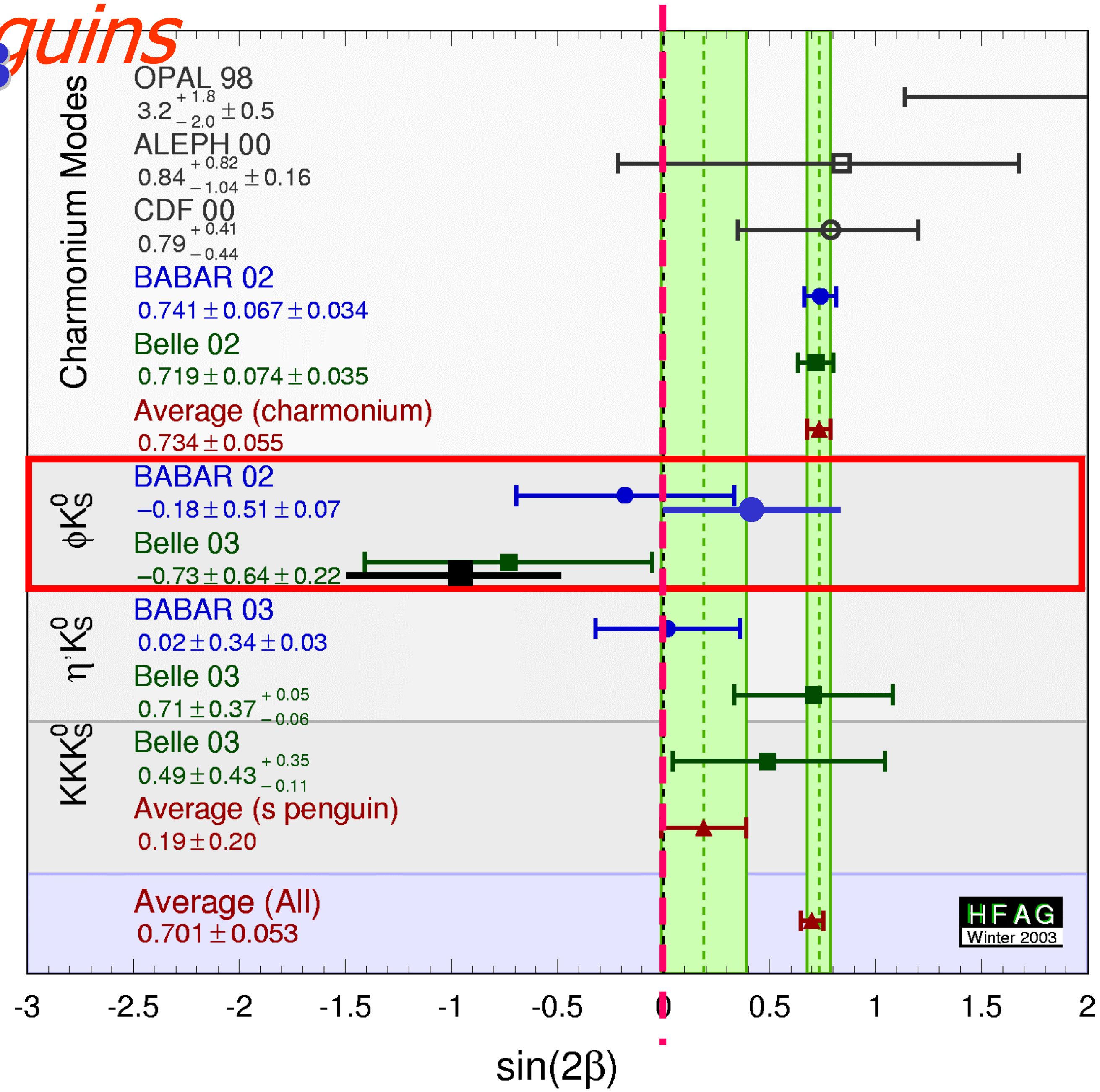


Possible SUSY FCNC/CPV Loop

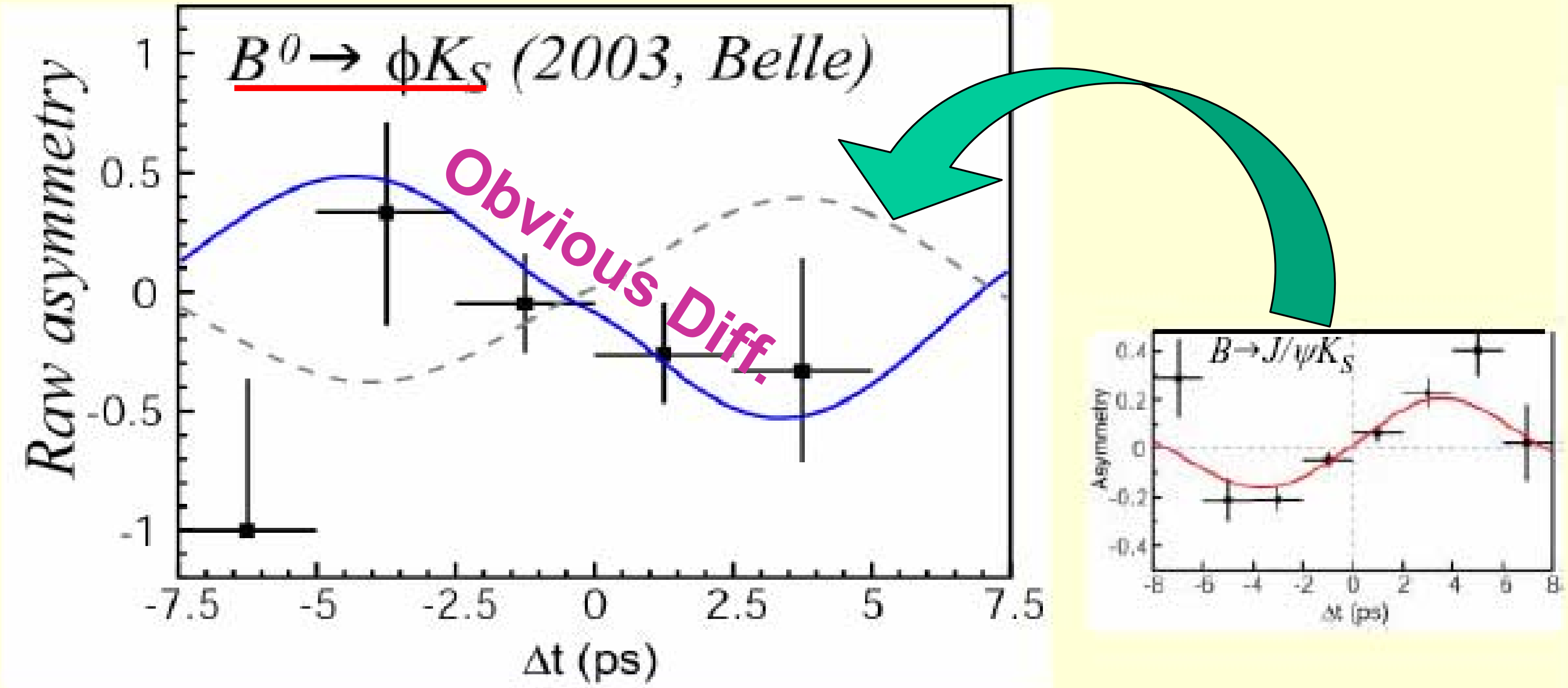
Introduction

$S_{\phi K_S}$ Data and Stating Our Theme

2002 Status of New Phases in $b \to s$ Penguins



□□□□ BBbar Pairs



$S_{\phi K} = -0.96 \pm 0.50$ ⟷ **Opposite Sign** $\sin 2\phi_1 = +0.731$

!!

Belle $B \to \phi K_S$: 2002 vs 2003

78 fb^{-1}: $\sin 2\phi_{1\mathrm{eff}}(\phi K_S) = -0.73 \pm 0.64 \pm 0.22$

↓

140 fb^{-1}: $\sin 2\phi_{1\mathrm{eff}}(\phi K_S) = -0.96 \pm 0.50^{+0.09}_{-0.11}$

- *Results stronger, but consistent (~ doubling of data)*

3.5σ *from* $\sin 2\phi_1 = 0.73$

- *Statistics dominated*
- *2002: published PRD-RC'03*
  2003: published PRL'03

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

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

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

108 fb^{-1}: $\sin 2\beta_{\rm eff}(\phi K^0_S) = +0.47 \pm 0.34 ^{+0.08}_{-0.06}$ submitted PRL 04/04

become consistent w/ 0.73

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

New 29 fb^{-1} : Gives > +1 !!

Browder @ LP03

$S_{\phi K_S}$ Sign Anomaly

[Belle/BaBar Average View]

158 fb^{-1}: $\sin 2\phi_{1\mathrm{eff}}(\phi K_S) = -0.39 \pm 0.41$ 2002

250 fb^{-1}: $\sin 2\phi_{1\mathrm{eff}}(\phi K_S) = -0.15 \pm 0.33$ 2003

Still 2.7σ from 0.73 (~ 2002)

Large, New Physics, $b \to s$ CPV

Effect

- *Large* Effective s-b Mixing
- *New* **CPV** Phase
- *Right-handed* Interaction

[to get $\sin 2\phi_{1\mathrm{eff}}(K_S\pi^0) \sim \sin 2\phi_1$]

Call for Synergies of *Flavor* & SUSY ??

ϕK^* Polarization Anomaly

PRL

$$R_0(B \to \phi K^*) = 0.54 \pm 0.10 \quad \text{(BaBar and Belle)}$$

$$R_\perp(B \to \phi K^*) = 0.41 \pm 0.11 \quad \text{(Belle)}$$

PRL

$$R_0(B \to \rho K^*) = 0.96 \pm 0.16 \quad \text{(BaBar)}$$

$$R_0(B \to \rho\rho) = 0.96 \pm 0.06 \quad \text{(BaBar and Belle)}$$

$$R_0 + R_\perp + R_\parallel = 1 \Rightarrow R_\parallel(B \to \phi K^*) = 0.05 \pm 0.15$$

Large, New Physics, CPC $b \to s$ Effect

Needed ?

- SM prediction: $R_T/R_0 \ll 1$ $\qquad \dfrac{R_T}{R_0} = O\left(\dfrac{1}{m_B^2}\right)$
  - $B \to \rho\rho,\ B \to K^*\rho:\ R_T/R_0 \ll 1$
  - $B \to \phi K^*:\ R_T/R_0 = O(1)$
- SM prediction: $R_\perp/R_\parallel \approx 1$ $\qquad \dfrac{R_\perp}{R_\parallel} = 1 + O\left(\dfrac{1}{m_B}\right)$
  - $B \to \phi K^*:\ R_\perp/R_\parallel \gg 1$

ϕK^* Polarization Anomaly

PRL

$$R_0(B \to \phi K^*) = 0.54 \pm 0.10 \quad \text{(BaBar and Belle)}$$

$$R_\perp(B \to \phi K^*) = 0.41 \pm 0.11 \quad \text{(Belle)}$$

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Large, New Physics, CPC $b \to s$ Effect Needed ?

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  - $B \to \phi K^*:\ R_T/R_0 = O(1)$
- SM prediction: $R_\perp/R_\parallel \approx 1$ $\qquad \frac{R_\perp}{R_\parallel} = 1 + O\left(\frac{1}{m_B}\right)$
  - $B \to \phi K^*:\ R_\perp/R_\parallel \gg 1$

Framework

- (approximate) Abelian *Flavor* Symmetry □ SUSY

Has All Ingredients

AFS Has *Right-handed* $\tilde{s}$ - $\tilde{b}$ *Mixing* w/ CPV Phase

SUSY Brings in *Right-handed Dynamics*

- AFS Model Pre-existed

Nir-Seiberg, PLB'93; Leurer-Nir-Seiberg, NPB'94

$S_{K^{*0}(K_S\pi^0)\gamma}$

Theme for SuperB

- More Definite, yet Generic, Model Context

□ Constraints □ Predictions

Theme

Large *NP CPV Phase* w/ *Crisp* Measurement

"Belle" "BaBar"

$S_{\phi K_S}$ *Sign Anomaly*
[ϕK^* *Polarization Anomaly*]

$S_{K^{*0}(K_S\pi^0)\gamma}$

Kagan (SSI 2002)
Murayama et al. 2002
Khalil & Kou 2003

Chua, WSH, Nagashima '03, accepted PRL

Confession:

We've been saying for years "ICPV in B → ϕK_S is a great place to search for New Physics". It was lip service. The mindset was "Precision Tests".

So, $S_{\phi K_S} < 0$, *for 2nd year*, came as a shocker.

(Abelian) Flavor Symmetry and SUSY

Mass/Mixing Hierarchy & *R.H. Flavor* Sector

$$\hat{M}_u = \frac{M_u}{m_t} \sim \begin{bmatrix} \lambda^7 & \lambda^5 & \lambda^3 \\ \lambda^6 & \lambda^4 & \lambda^2 \\ \lambda^4 & \lambda^2 & 1 \end{bmatrix}, \quad \hat{M}_d = \frac{M_d}{m_b} \sim \begin{bmatrix} \lambda^4 & \lambda^3 & \lambda^3 \\ \lambda^3 & \lambda^2 & \lambda^2 \\ \lambda & 1 & 1 \end{bmatrix}$$

mass

V_{CKM}

no r.h. force

Ansatz $M_{ij} M_{ji} \approx M_{ii} M_{jj}$

Commuting Charges

Or, under *Abelian* Flavor Symmetry ⇒ **Prominent r.-h. elements**

- Nir-Seiberg, PLB'93; Leurer-Nir-Seiberg, NPB'94

Mass/Mixing Hierarchy & *R.H. Flavor* Sector

$$\hat{M}_u = \frac{M_u}{m_t} \sim \begin{bmatrix} \lambda^7 & \lambda^5 & \lambda^3 \\ \lambda^6 & \lambda^4 & \lambda^2 \\ \lambda^4 & \lambda^2 & 1 \end{bmatrix}, \quad \hat{M}_d = \frac{M_d}{m_b} \sim \begin{bmatrix} \lambda^4 & 0 & 0 \\ 0 & \lambda^2 & \lambda^2 \\ 0 & 1 & 1 \end{bmatrix}$$

no r.h. force

Ansatz $M_{ij}M_{ji} \approx M_{ii}M_{jj}$

Commuting Charges

Or, under *Abelian* Flavor Symmetry ⇒ **Prominent r.-h. elements**

- Nir-Seiberg, PLB'93; Leurer-Nir-Seiberg, NPB'94
- Chua-WSH, PRL'01: Because of FCNC, Need 4 Texture Zeros (decouple s flavor)

Arhrib-Chua-WSH '01: *Decouple d flavor* ⇒ Focus: *s* - *b*

Alternative Picture:

$$\nu_\mu - \nu_\tau \text{ Mixing} \xrightarrow[\text{GUT}]{\text{Near Maximal ?}} s_R - b_R \text{ Mixing}$$

Chang, Masiero, Murayama

The new physics flavor scale

$\text{TeV} \sim 4\pi M_W$ hierarchy scale

- K physics: ϵ_K

decouple 1st gen.

$$\frac{s\bar{d}s\bar{d}}{\Lambda^2} \Rightarrow \Lambda \gtrsim 10^4 \text{ TeV}$$

Tension

- D physics: $D - \overline{D}$ mixing

$$\frac{c\bar{u}c\bar{u}}{\Lambda^2} \Rightarrow \Lambda \gtrsim 10^3 \text{ TeV}$$

- B physics: $B - \overline{B}$ mixing and CPV

$$\frac{b\bar{d}b\bar{d}}{\Lambda^2} \Rightarrow \Lambda \gtrsim 10^3 \text{ TeV}$$

There is no exact symmetry that can forbid such operators

Right-handed Quarks Inert in SM

→ Right-handed Squarks

$\tilde{d}_{iR}$-d_{jR}-$\tilde{g}$ Dynamics

SUSY

Assume { Squarks $\approx \tilde{m}$, almost degenerate
AFS not far above SUSY Scale

6 x 6

also important

$$\left(\tilde{M}_q^2\right)_{RL} = \left(\tilde{M}_q^2\right)_{LR}^{*T} \approx M_q \tilde{m}, \qquad \frac{m_q}{\tilde{m}} \text{ suppressed}$$

$$\left(\tilde{M}_Q^2\right)_{LL} \approx \tilde{m}^2 V_{\rm CKM}, \qquad \text{CKM suppressed}$$

$$\text{but } \left(\tilde{M}_d^2\right)_{RR} \approx \tilde{m}^2 \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 1 \\ 0 & 1 & 1 \end{bmatrix}$$

RR Sector
Impact ***b*** □***s***
thru **SUSY**

Level Splitting by Large Mixing → Drive One State Light

$\widetilde{sb}_{1R}$

strange-beauty squ

$$\left(\tilde{M}_q^2\right)_{RR} \approx \tilde{m}^2 \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 1 \\ 0 & 1 & 1 \end{bmatrix} \Rightarrow \left(\widetilde{M}_{RR}^{2(sb)} = \begin{bmatrix} \widetilde{m}_{22}^2 & \widetilde{m}_{23}^2 e^{-i\sigma} \\ \widetilde{m}_{23}^2 e^{i\sigma} & \widetilde{m}_{33}^2 \end{bmatrix} = R \begin{bmatrix} \widetilde{m}_1^2 & 0 \\ 0 & \widetilde{m}_2^2 \end{bmatrix} R^\dagger\right.$$

$$R = \begin{bmatrix} c_\theta & s_\theta \\ -s_\theta e^{i\sigma} & c_\theta e^{i\sigma} \end{bmatrix}$$

- Near Maximal Mixing: $s_\theta \sim 1/\sqrt{2}$
- $\sigma = \arg(\widetilde{M}_d^2)_{RR}^{32}$ similar footing as $\phi_3 \equiv \arg V_{ub}^*$

1 *CP* Phase σ

Light $\widetilde{sb}_1$ w/ Some Tuning: set $\widetilde{m}_{22}^2 = \widetilde{m}_{33}^2 = \widetilde{m}^2$,

With $\widetilde{m}_{23}^2/\widetilde{m}^2 \equiv 1 - \delta \simeq 1$,

$$\widetilde{m}_1^2 \cong \delta\,\widetilde{m}^2, \quad \widetilde{m}_2^2 \cong (2-\delta)\widetilde{m}^2$$

Tunings: take $\widetilde{m} = 2\ (1)$ TeV

$$\delta = \lambda^2,\ \lambda^3,\ \lambda^4 \qquad (\lambda,\ \lambda^2,\ \lambda^3)$$

$$\Rightarrow \widetilde{m}_1 = 440,\ 206,\ 97 \text{ GeV} \quad (470,\ 220,\ 103 \text{ GeV})$$

100 GeV / 200 GeV
Focus on Possibly

Some Remarks

- Fine-tuning to $\lambda^2 - \lambda^3$ to get light $\widetilde{sb}_{1R}$?

  Fine tuning! $\lambda^2 \sim V_{cb}$, $\lambda^3 \sim V_{ub}$

- Why TeV Scale SUSY?

  Large Flavor Violation (s-b)

  □ Stringent Low Energy Constraints

  - *even w/ d decoupled;*
  - all other SUSY partners a "nuisance" :), so pushed high

TeV Scale SUSY w/ *Strange-beauty Squark*

"Light" Particles: $\widetilde{sb}_{1R}$ □ 200 GeV □ σ phase

$\tilde{g}$ □ (□?) 500 GeV

likely $\tilde{\chi}^0_1$ LSP?

Accounting for $S_{\phi K_S}$, $S_{K_S\pi^0}$, $S_{\eta' K_S}$ and $|A_{\square}(\phi K^*)|^2$

A Little Note on Formalism …

- Besides $O_{1,2}$ Tree
  - $O_{3\text{-}6}$ Strong Penguin
  - $O_{7\text{-}10}$ EM/EW Penguin
  - *also* $O_{11,12}$ γ/g Dipole

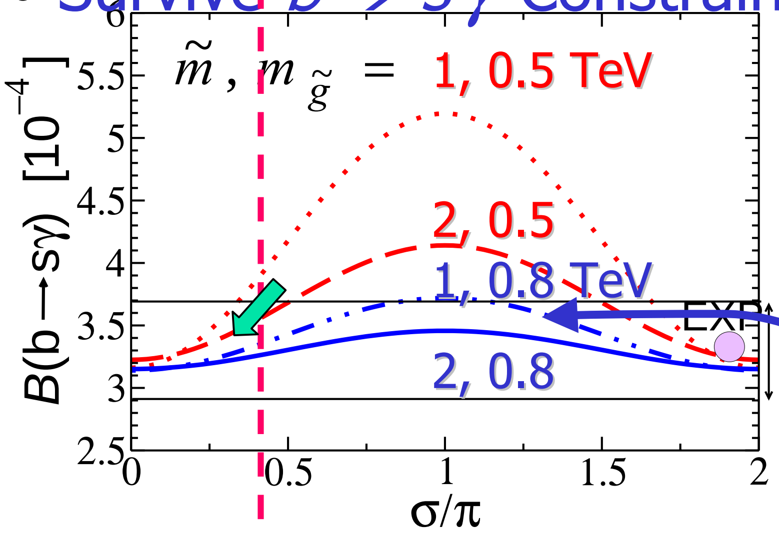
Right-handed Coupling $\longrightarrow O_i'$

Coefficients c_i, c_i' calculated in Mass Basis

Matrix Elements evaluated via Naïve Factorization

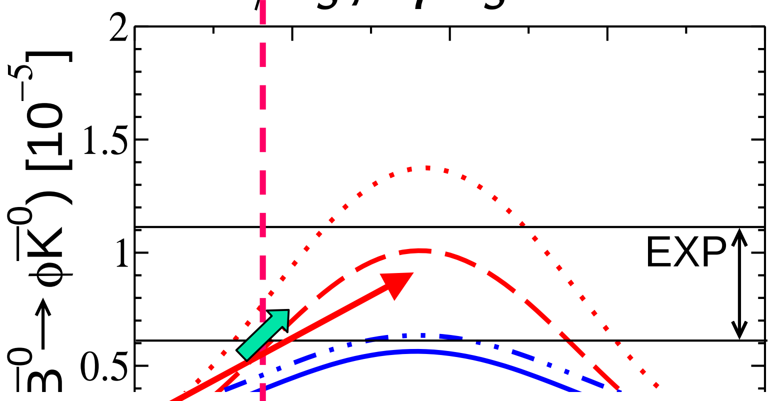
$b \to s\gamma$ (and $B \to \phi K_s$) Rate Constraints

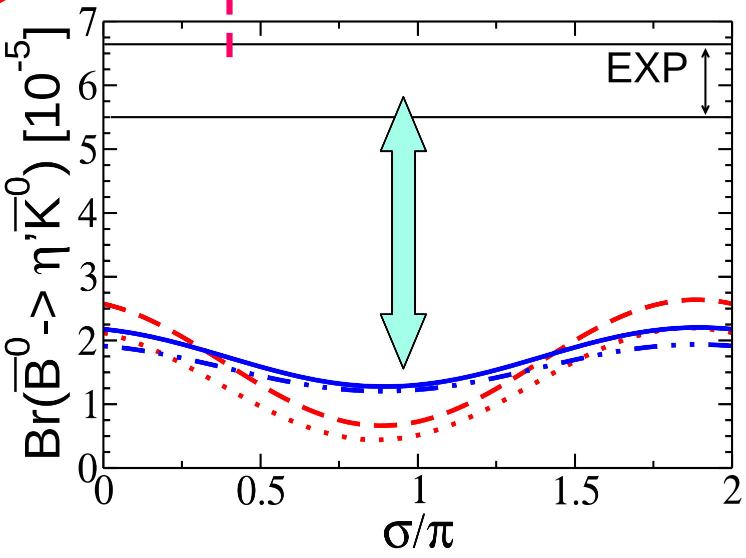
- Survive $b \to s\gamma$ Constraint !!



$m_{\tilde{g}} = 800$ GeV More Conservative

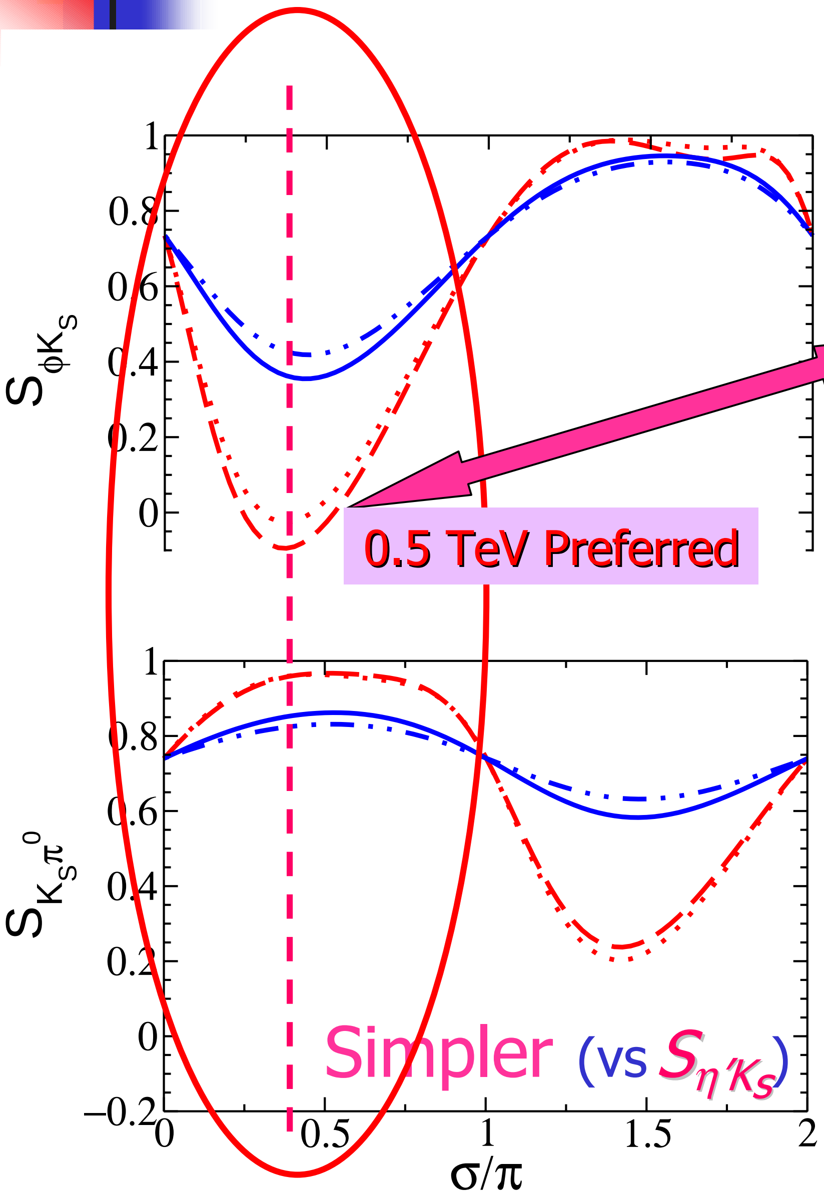
- $B \to \phi K_s$, $\eta' K_s$ Rates





- ϕK_s Rate "Sees Red"
- Cannot Account for $\eta' K_s$ Rate
  Not a New Problem
- Combine $b \to s\gamma$ and $B \to \phi K_s$
  $\to \sigma \sim \pi/2, 3\pi/2$?

Tuning for $S_{\phi K_S}$ □ 0, $S_{K_S\pi^0}$ ~ $S_{\psi K_S}$ Possible



- $S_{\phi K_S}$ □ 0 prefers lower σ-plane
  - □ $S_{K_S\pi^0}$, $S_{\eta' K_S}$ □ $\sin 2\Phi_{B_d}$ as well!
- *Lower gluino mass* lowers $S_{\phi K_S}$
- Hadronic Parameters

  CP phase enters $B \to \phi K_S$ via

$$\frac{\alpha_s m_b^2}{4\pi q^2}(c_{12} + c'_{12})\tilde{S}_{\phi K_S}$$

Lower q^2, and/or larger $\tilde{S}_{\phi K_S}$

□ Larger $|S_{\phi K_S}|$

□ Prefer to keep gluino mass above 500 GeV (L.E. Constraints)

- ***Could σ □ π/2 be it?***

Noticed also by Khalil & Kou '03 for $S_{\eta' K_S}$
[Murayama et al. '03]

Amplitudes

$$\mathcal{A}(\bar{B}^0 \to \phi \bar{K}^0) \;=\; -\sqrt{2} G_F f_\phi m_\phi F_1^{B\to K}(m_\phi^2)\, \varepsilon_\phi \cdot P_B$$

$$V_{tb}V_{ts}^* \Big\{ (a_3 \;+\; a_3') + (a_4 + a_4') + (a_5 + a_5')$$

$$-\frac{1}{2}(a_7 + a_9 \;+\; a_{10}) + \frac{\alpha_s}{4\pi}\frac{m_b^2}{q^2}\, \tilde{S}_{\phi K}\, (c_{12} + c_{12}') \Big\}$$

hadronic uncertainty

V □ A

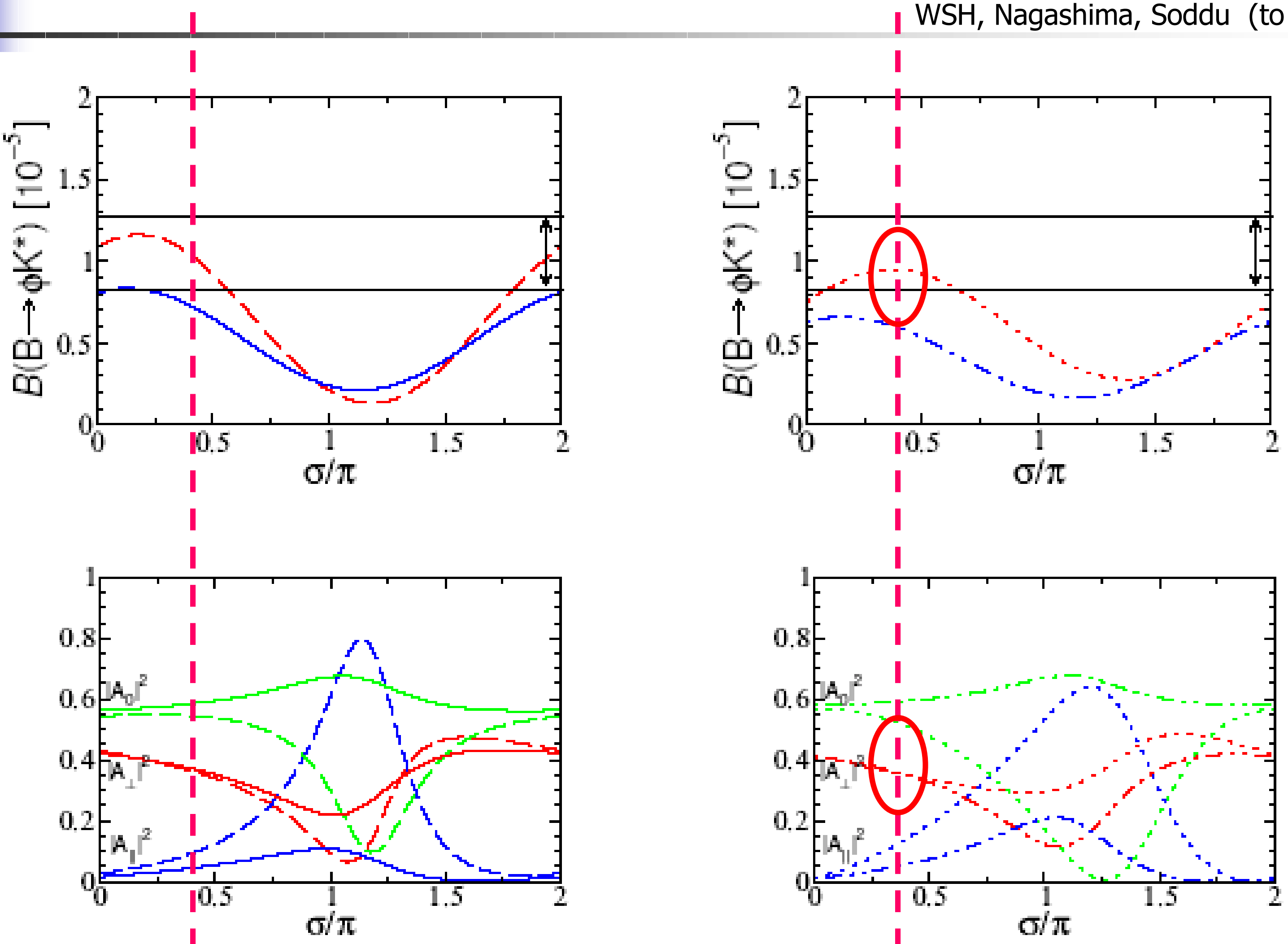
$$\mathcal{A}(\bar{B}^0 \to \bar{K}^0 \pi^0) \propto \Big\{ \cdots + \frac{\alpha_s}{4\pi}\frac{m_b^2}{q^2}\, \tilde{S}_{K^0\pi^0}\, (c_{12} - c_{12}') \Big\}$$

Reason why Opposite Trend in $S_{\phi K_S}$ vs $S_{K_S\pi^0}$, $S_{\eta' K_S}$

Right-handed interactions

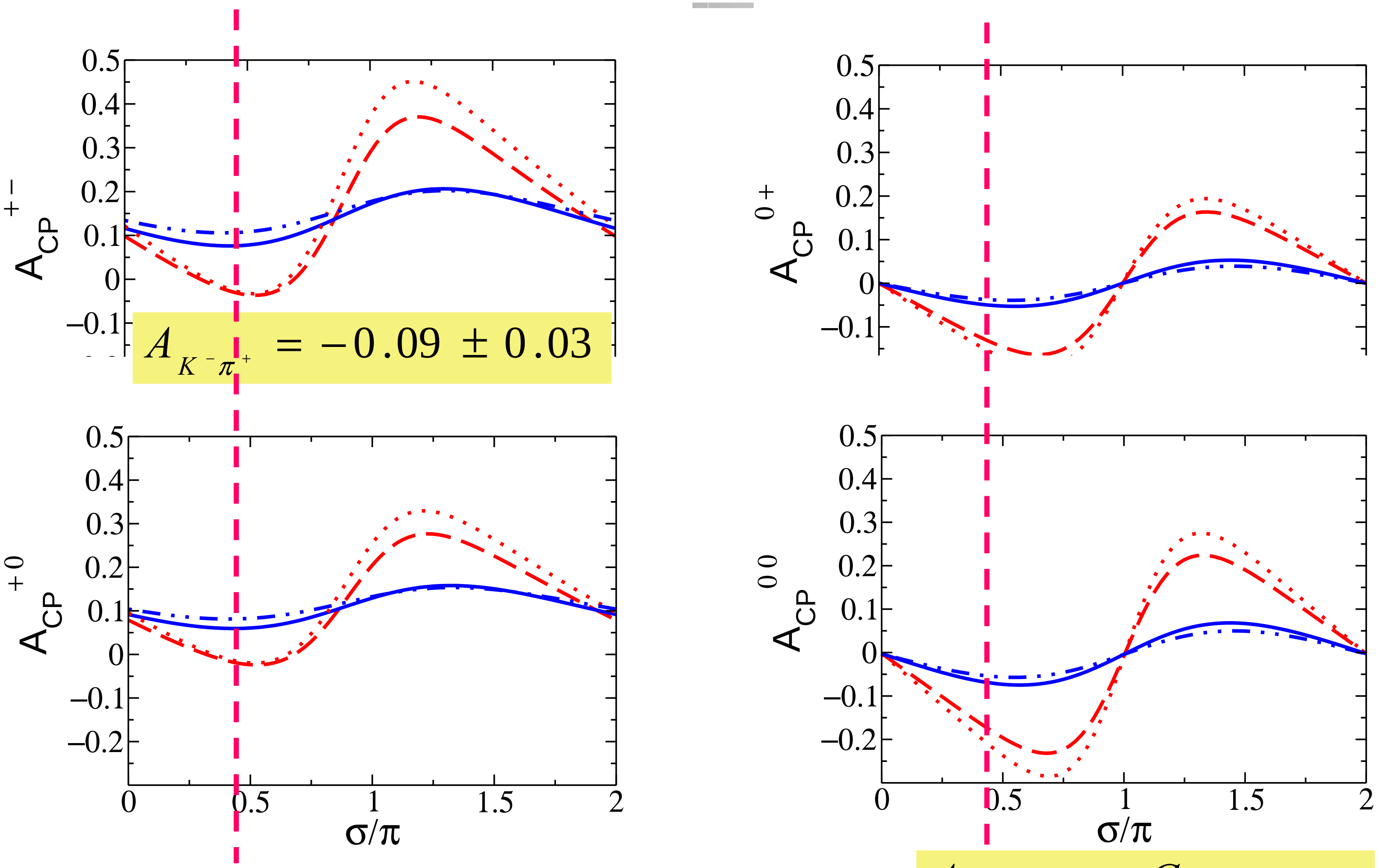
ϕK^* : Br and $|A_{\perp}(\phi K^*)|^2 \sim 0.4$ Attainable

WSH, Nagashima, Soddu (to appear)



At cost of larger *hadronic parameters* $\tilde{S}_{\phi K^*}/q^2$

Direct CPV
Improve Agreement with Data vs QCD Factorization



$$A_{K^-\pi^+} = -0.09 \pm 0.03$$

$$A_{K_S\pi^0} = -C_{K_S\pi^0} = -0.40^{+0.27}_{-0.28} \pm 0.10$$

Upshot

Two Particle System

$\widetilde{sb}_{1R}$	~ 200 GeV
$\tilde{g}$	~ 500 GeV
NP CPV phase	σ ~ 60° - 70°

Collider
Direct Search

Flavor Factory

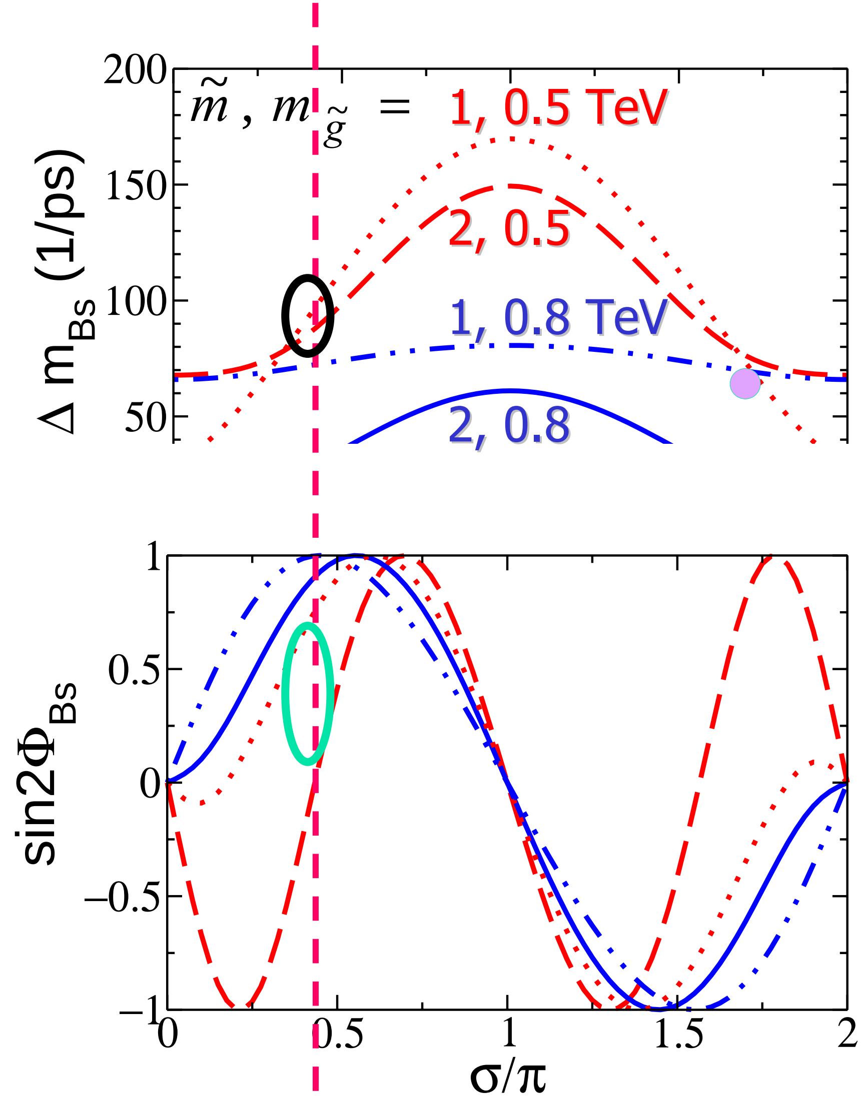
but need to disentangle hadronic effect

Clean Modes

Situation for B_s Mixing

Clean

Consequences: Δm_{B_s} , $\sin 2\Phi_{B_s}$ *Tough* (!?)



ake σ □ π/2 as example

ighter gluino ~ 500 GeV Needed

- Δm_{B_s} > 70 ps^{-1} *Tough !*
- $\sin 2\Phi_{B_s}$ ~ 0 - 1 *Tough ?*

Vould've preferred [Arhib, Chua, WSH 01]

ieavier gluino but for … $S_{\phi K_S}$ □ 0

For lighter gluino,

periodicity change

□ $M_{12} \equiv |M_{12}| e^{2i\Phi_{B_s}} \cong a e^{-2i\sigma} + b e^{-i\sigma} + c$

a -term dominant (two $\widetilde{sb}_{1R}$ exch.)

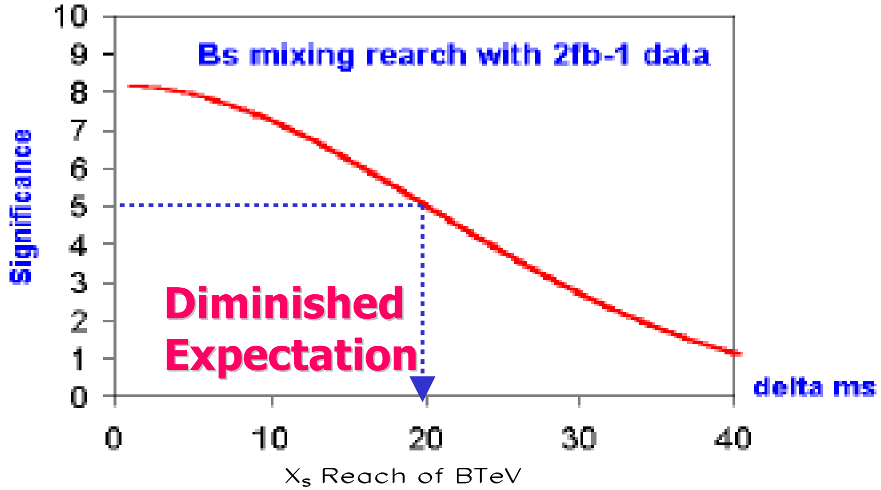
100 GeV $\widetilde{sb}_{1R}$?

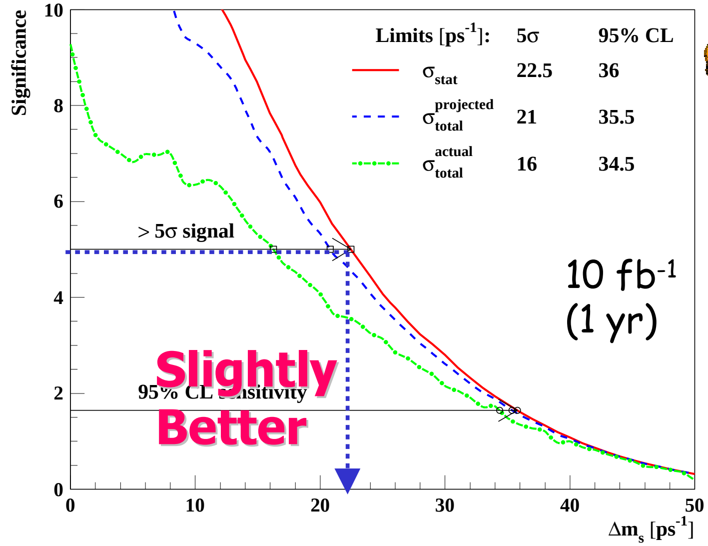
~ 200 GeV case

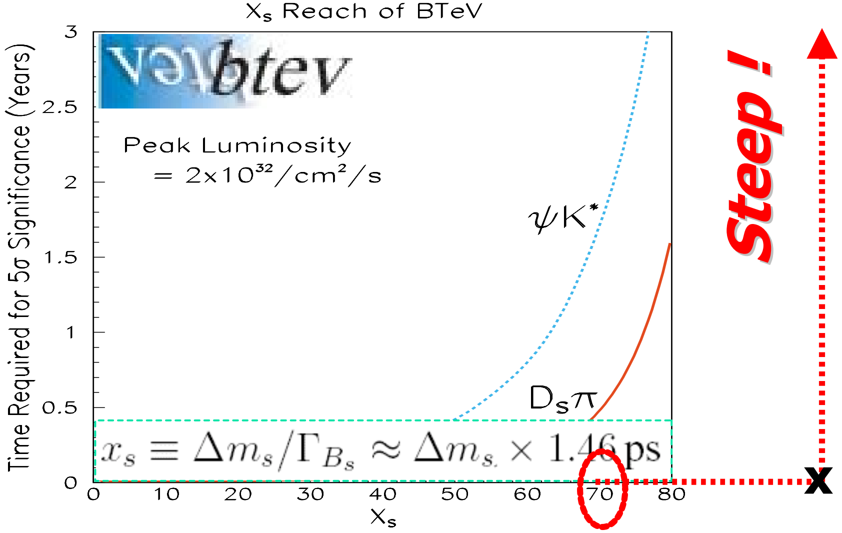
Except, Easier Direct Detection !

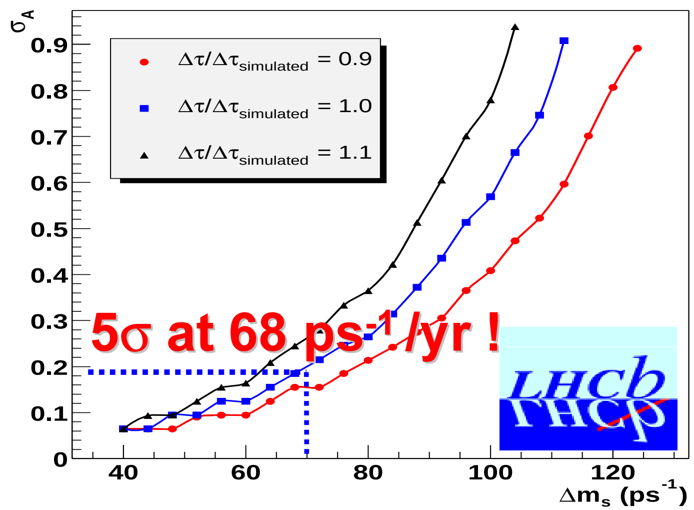
Experimental Prospects for Δm_{B_s}

CDF Bs mixing prospect by 2007









Seems Good.

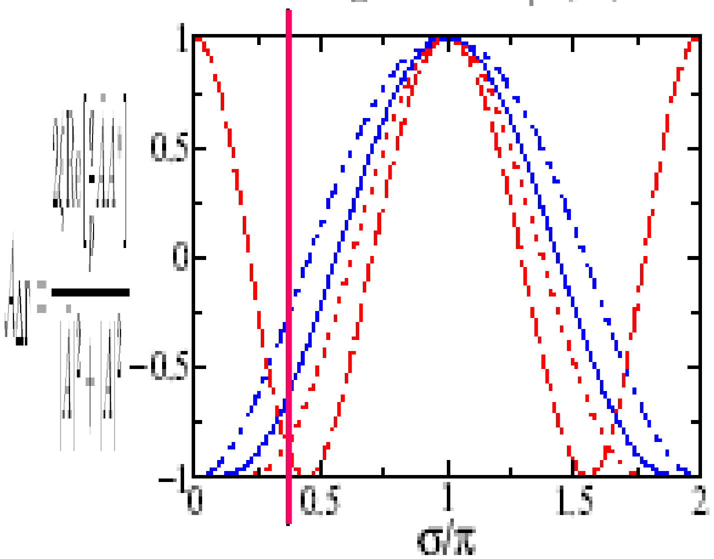
Go for Untagged $\Delta\Gamma_{Bs}$ CPV Effect?

WSH, Nagashima (hep-ph/0404001)

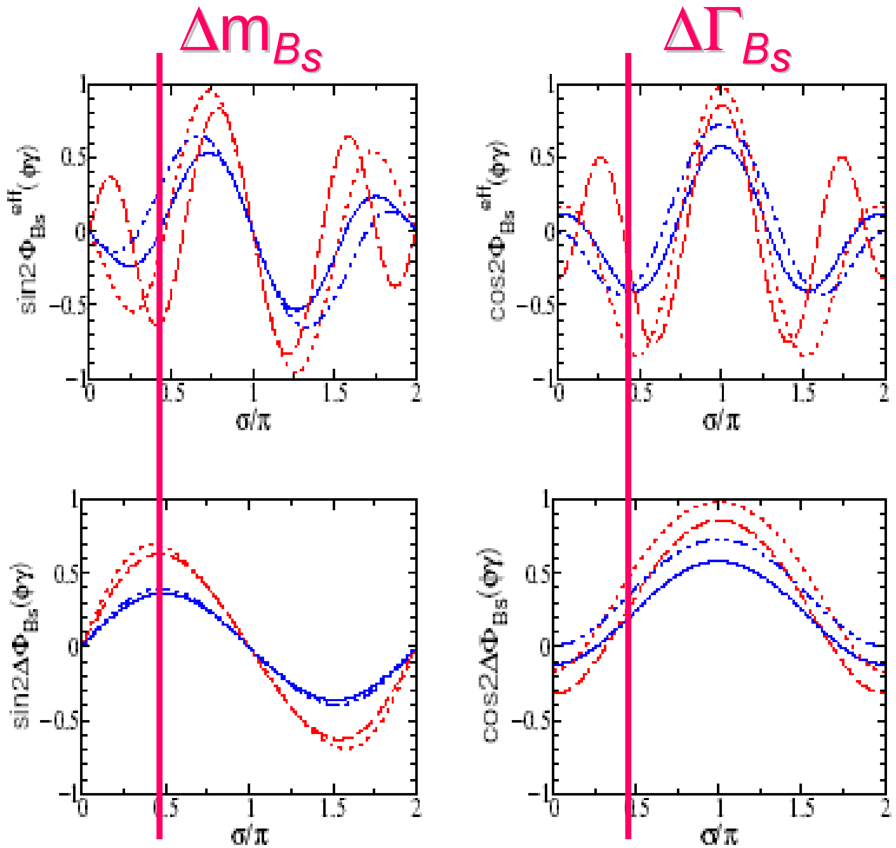
$\sim 10\%\ \Gamma_{Bs}$

Accuracy Poorer

$B_s \to J/\psi\phi$



$B_s \to \phi\gamma$



$$A_{\Delta\Gamma} = \frac{2\xi \mathrm{Re}\left[\frac{q}{p}\bar{A}A^*\right]}{|\bar{A}|^2 + |A|^2} \approx \cos 2\Phi_{B_s}$$

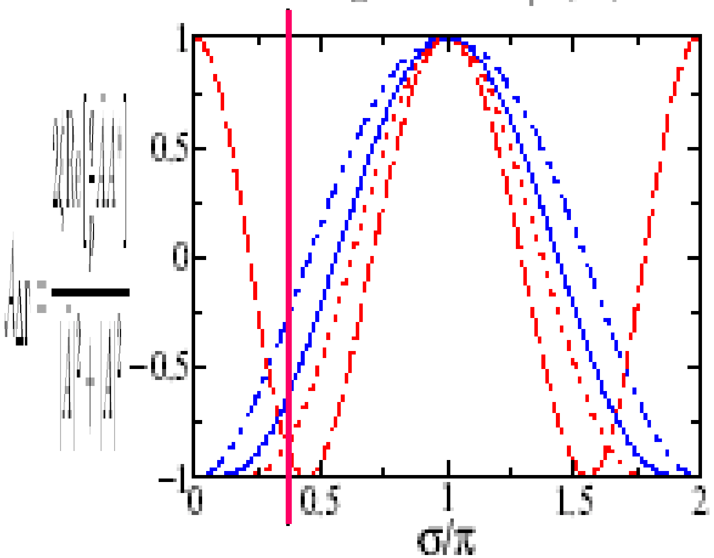
~ -1 for σ □ $\pi/2$

Go for Untagged $\Delta\Gamma_{Bs}$ CPV Effect?

WSH, Nagashima (hep-ph/0404001)

~ 10% Γ_{Bs} Accuracy Poorer

$B_s \to J/\psi\phi$



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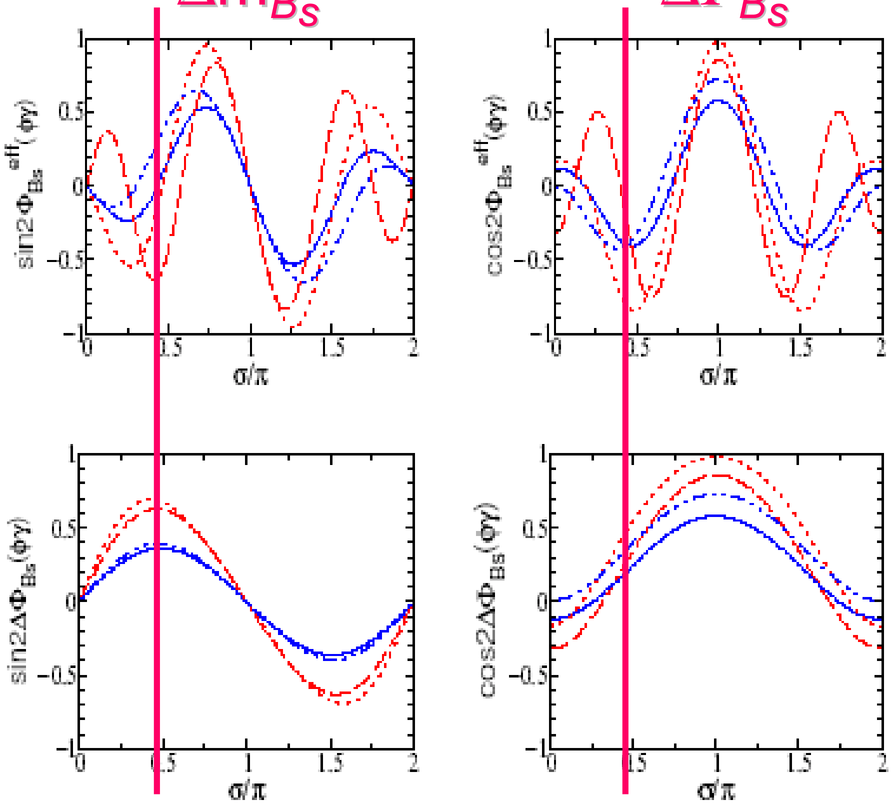
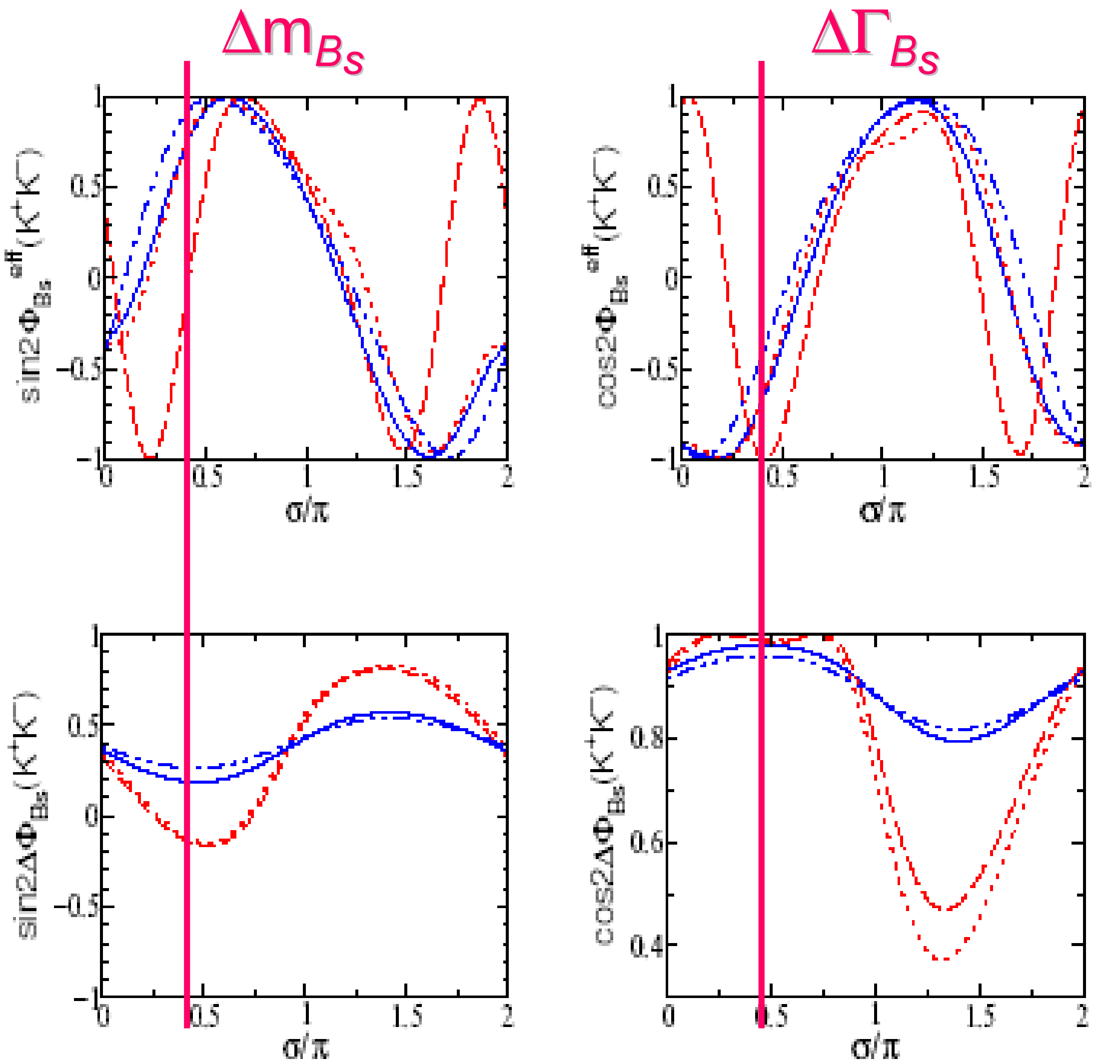
~ −1 for σ □ π/2

$B_s \to \phi\gamma$



$B_s \to K^+K^-$



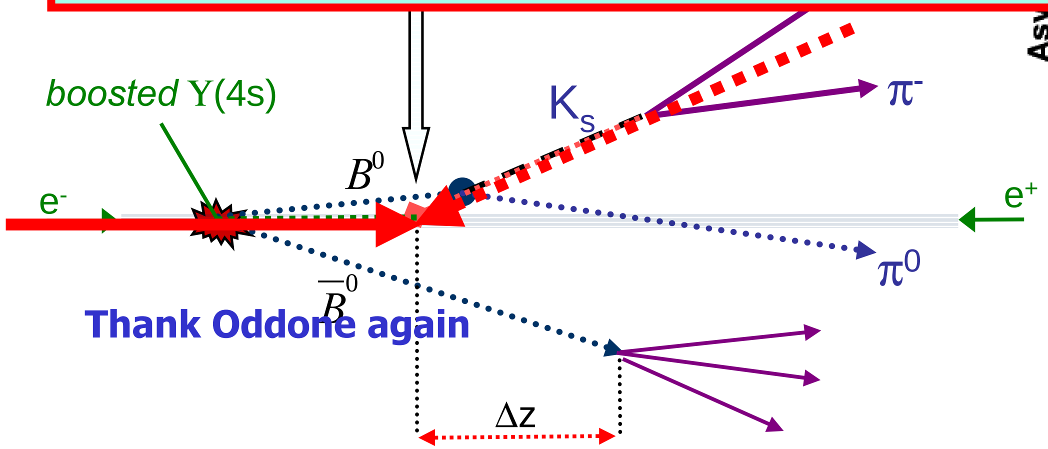
Δm_{Bs}
$\Delta\Gamma_{Bs}$
$\sin 2\Phi_{Bs}^{eff}(K^+K^-)$
$\cos 2\Phi_{Bs}^{eff}(K^+K^-)$
$\sin 2\Delta\Phi_{Bs}(K^+K^-)$
$\cos 2\Delta\Phi_{Bs}(K^+K^-)$
σ/π

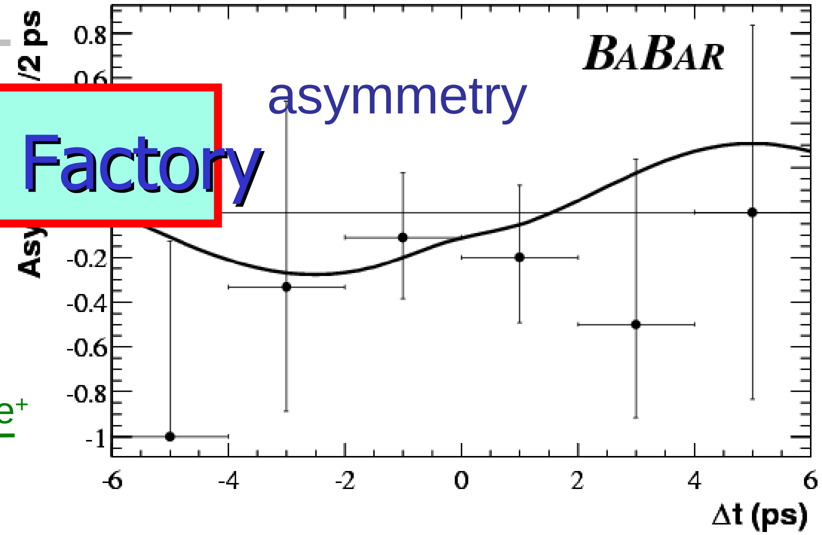
Super B: *C ris p* Measurement $S_{K^{*0}(K_S\pi^0)\gamma}$

Inspired by $S_{K_S\pi^0}$ (BaBar)

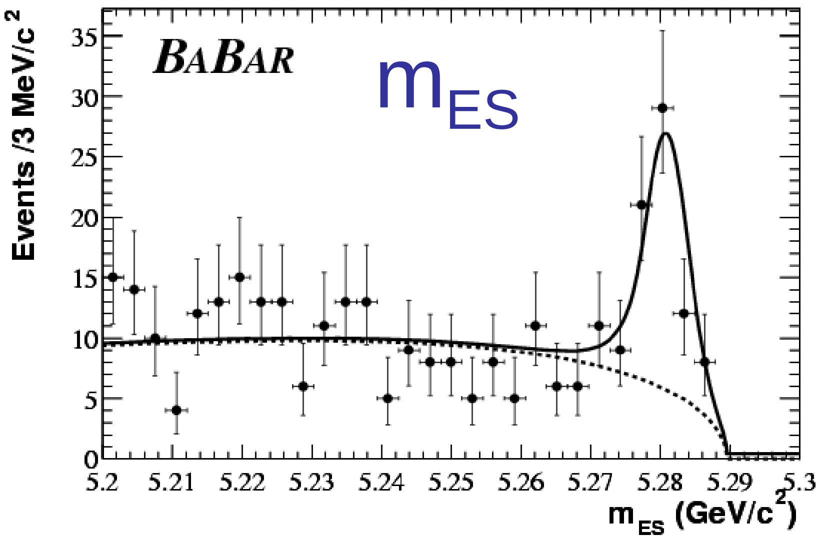
BaBar: CPV with $B^0 \to K_s \pi^0$ [b→s d dbar]

K_S Vertexing: *Unique* to B Factory





N	=	123 ± 16
C	=	$0.40^{+0.27}_{-0.28} \pm 0.10$
S	=	$0.48^{+0.38}_{-0.47} \pm 0.11$
S (C=0)	=	$0.41^{+0.41}_{-0.48} \pm 0.11$



In the absence of New Physics, S = sin(2f $_1$) =0.731±0.056

Browder @ LP03

Implications: Wrong Helicity Photon in $b \to s\gamma_L$

- Strength of Mixing-dep. CPV

$$\sin 2\theta_{\rm mix} = \frac{2|c_{11}c'_{11}|}{(|c_{11}|^2 + |c'_{11}|^2)}$$

$$S_{\gamma M^0} = \sin 2\theta\, \xi \sin(2\phi_{B_d} - \varphi_{11} - \varphi'_{11})$$

Test γ_L component

(**A**twood, **G**ronau, **S**oni, 1997)

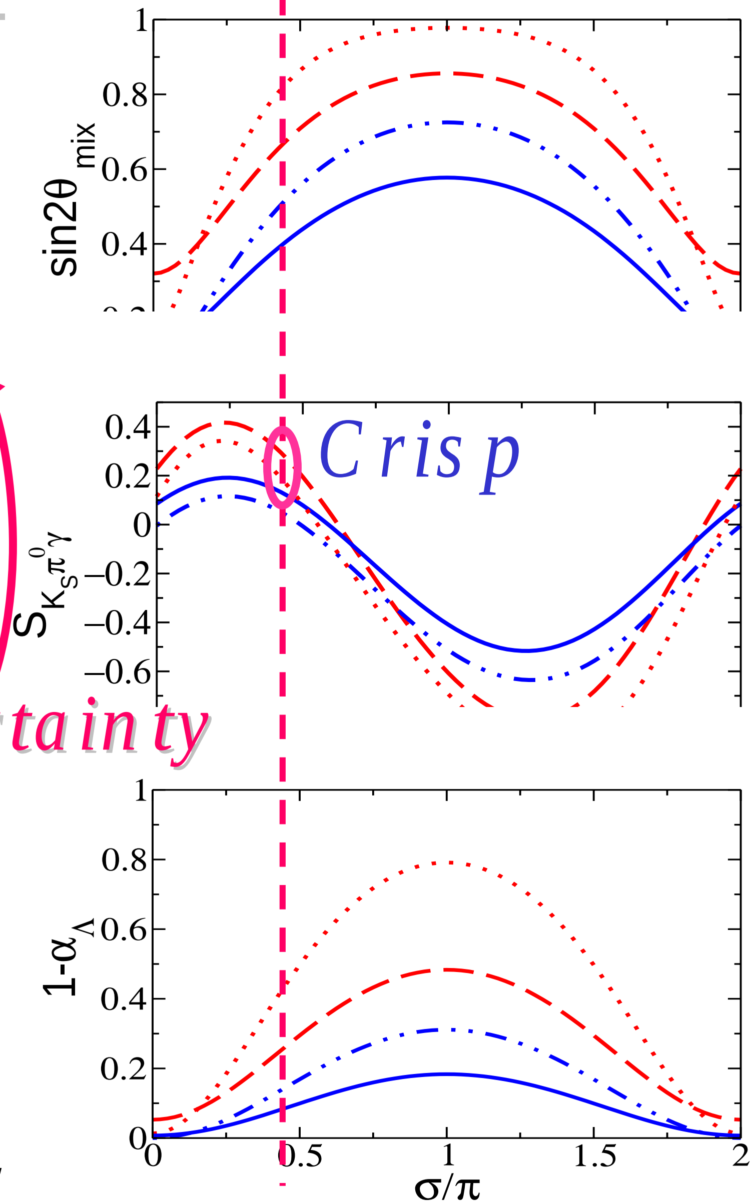
- $S_{K^{*0}(K_S\pi^0)\gamma}$ now *Promising*

Free of hadronic uncertainty

In contrast $B_s \to \phi\gamma$ probably rely on $\Delta\Gamma_{B_s}$

- Can also test γ_L comp. via Λ Polarization in $\Lambda_b \to \Lambda\gamma$

(Mannel, Recksiegel, 1997)



Confession II

- Liked AGS Mechanism since beginning
  Quantum Interference requires two helicities
- Alas, Nature is Cunning: $K^{*0} \to K_S\pi^0$

  No Track!

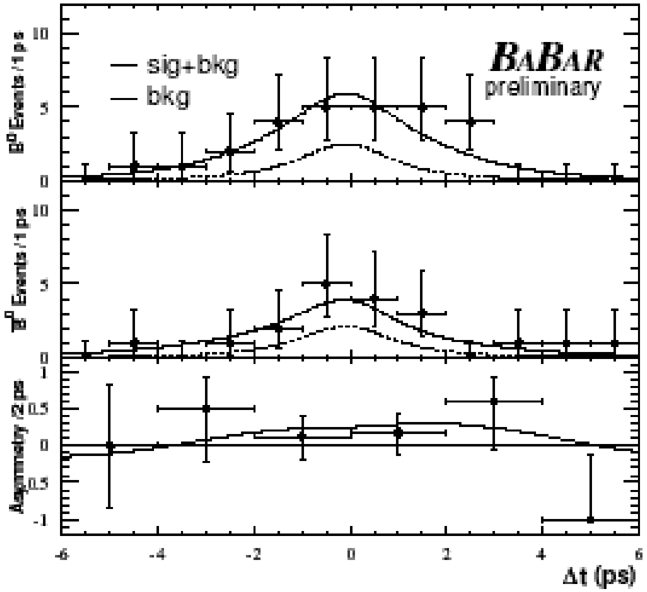
  Pursued $B^0 \to K_1\,(1270)\gamma$ etc. instead (in Belle) or so I thought ...
- So, BaBar's $S_{K_S\pi^0}$ came as a shocker.
  'course, had large(r) Si (than Belle)

⇒ BaBar at Moriond; SuperB Future

Invest in Larger Si !

N.B. $S_{K_S\pi^0\gamma}$ difficult for hadronic

New $B \to K^{*0}\gamma$: CP result on 113 fb^{-1} prelim.



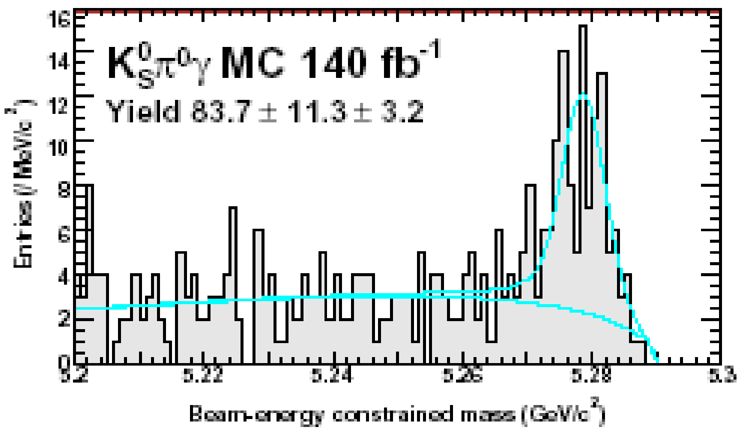
- Multidimensional fit to
  - ▷ *Kinematical variables* m_{ES} , ΔE , $m(K^*)$
  - ▷ *event shape variables*
  - ▷ *proper time* Δt
- The fit takes into account
  - ▷ *Continuum and* $B\overline{B}$ *background*
  - ▷ *Resolution effects on* Δz
  - ▷ *Tagging efficiencies and mistagging probabilities*
- Main systematic from the uncertainties in the CP structure of the background

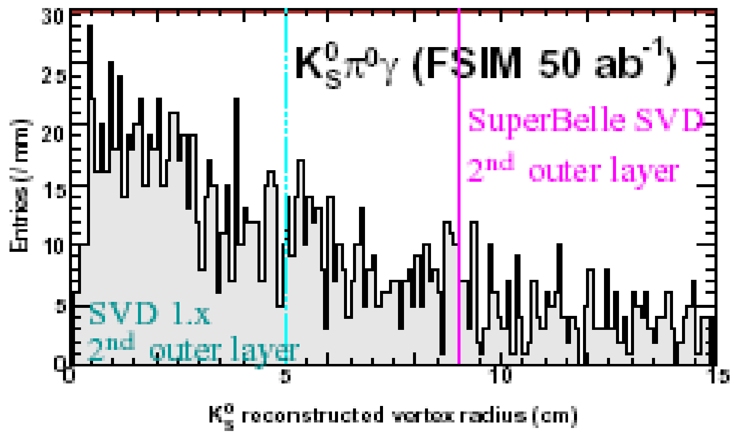
$$S_{K^{*0}\gamma} = 0.25 \pm 0.63 \pm 0.14$$
$$C_{K^{*0}\gamma} = -0.56 \pm 0.32 \pm 0.09$$

- One expects $C_{K^{*0}\gamma} = -A_{CP}(B^0 \to K^{*0}\gamma)$ that is consistent with zero:

$$S_{K^{*0}\gamma} = 0.25 \pm 0.65 \pm 0.14 \qquad (\text{fixing } C_{K^{*0}\gamma} = 0)$$

$B^0 \to K_S^0 \pi^0 \gamma$

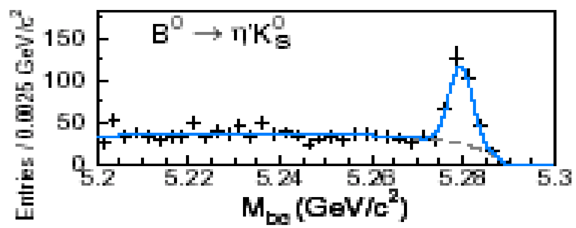




SVD size

- Technique developed by BaBar ($B \to K_S^0 \pi^0$ mixing CPV)
- 50% useful with current SVD / 70% with SuperBelle SVD
- Sensitivity is similar to $B \to \eta' K_S^0$ ($\delta S_{\eta' K_S^0} = 0.27$ for 421 event)

5 ab^{-1}	➡	2000 events	$\delta S = 0.12$
50 ab^{-1}	➡➡	20000 events	$\delta S = 0.04$



5σ measure for S □ 0.2

New physics through $b \to s\gamma$ — Mikihiko Nakao (KEK, IPNS)

Totsuka sensei's Charge to Super-KEKB

(Belle) HL5 @ Izu, 9/04

BELLE's new result on asymmetry in the B → ϕKs

...
Considering all these ... arch programs other than the B factory, the funding for the lumi... ity upgrade of a B-factory is not an easy task for KEK, and for othe... laboratories, too. All I can say at this point is that *I need more good results like the re... nt one* in order to impress MEXT (funding agency) about how ... the super-B factory program is.

One thing I like to hear from ... a nasty question, what you will do once a consensus ... s made to ... ld the LC; whether you will join the LC or you will still be 100% ... lved in the super-B factory. ...

A no-nonsense guy!

I agree w/ him ...

"David & Golia... edux ? B vs SSC, ' 93

SuperB Theme → Large *NP CPV Phase* w/ Crisp Measurement $S_{K_S\pi^0\gamma}$

Large *NP CPV Phase* w/ *Crisp* Measurement

- Large effects in $S_{\phi K_S}$ ($S_{K_S\pi^0}$, $S_{\eta' K_S}$) and $|A_{\perp}(\phi K^*)|^2$ but plagued by *hadronic uncertainties* ...
- Large *NP CPV Phase* implied by $S_{\phi K_S} < 0$

  Projects *Crisp* **Measurement** of $S_{K_S\pi^0\gamma} \neq 0$
- No Target to Shoot for *if* $S_{\phi K_S} < 0$ *Goes Away*

Let's Hope for the Better This Summer !

B Factory was Built based on $B \to J/\psi K_S$

A Clean Mode such as $\boldsymbol{B \to K_S \pi^0 \gamma}$ Justifies **SuperB**

Satisfy Totsuka sensei (MEXT)?

Caveats

as opportunity ?

- D^0-mixing: Just at present limit

  [because V_{us} shifted to uc sector
  generic for Alignment models

- Cannot escape ^{199}Hg edm (Hisano & Shimizu '03)

  [complicated enough

- ...

Collider Study

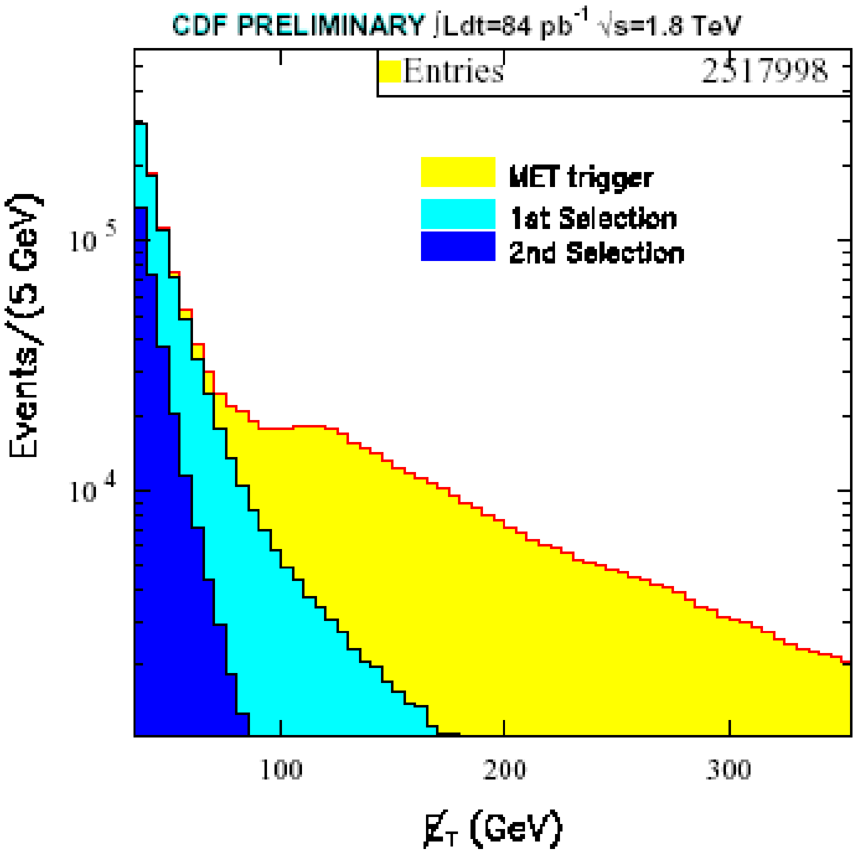
$\widetilde{sb}_{1R}$	~ 200 GeV
$\tilde{g}$	~ 500 GeV
$\tilde{\chi}_1^0$	LSP ?

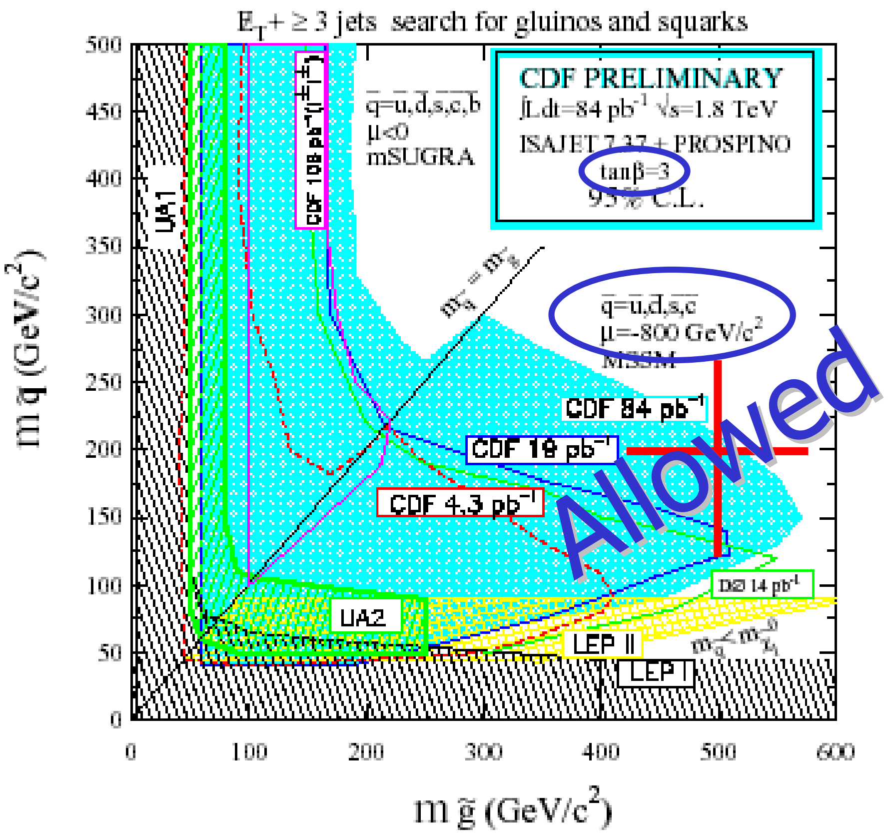
w/ Kingman Cheung, hep-ph/0404041

Generic Squark Bounds

Jets (+ Missing Energy) (+ Leptons)

From Run I, the lessons on reducing a huge MET sample to a few, constraining events:





Most stringent bounds in mSUGRA ⟶ $m_{\tilde{g}}$ >195 GeV, and > 300 GeV when $m_{\tilde{q}} \approx m_{\tilde{g}}$.

NB: *much better than expected a priori…*

From RUN II, a new analysis looking for $\tilde{g} \rightarrow b\tilde{b}_1$ (CDF)

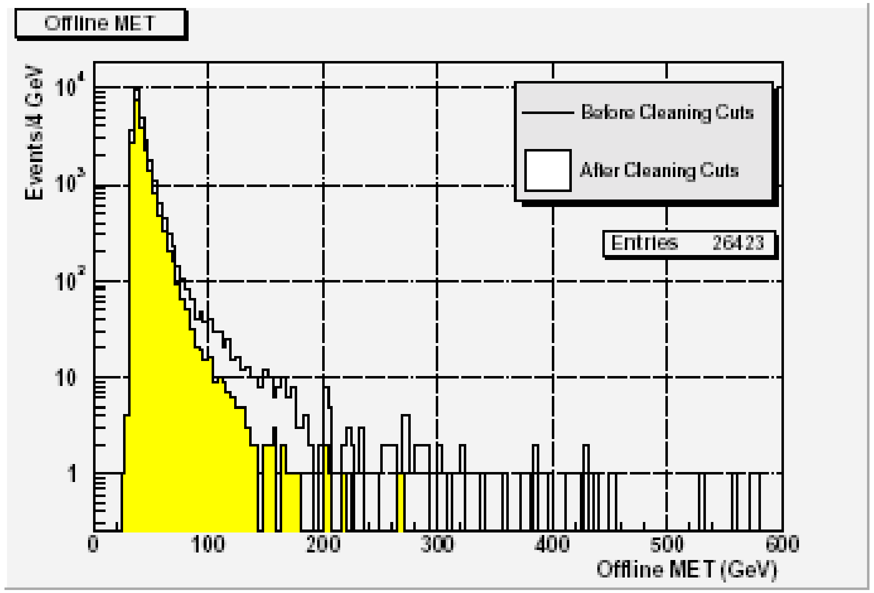
$b\, s\widetilde{b}_1, \quad s\, s\widetilde{b}_1$

Take advantage of the large cross sections for the production of gluinos at a hadron machine.

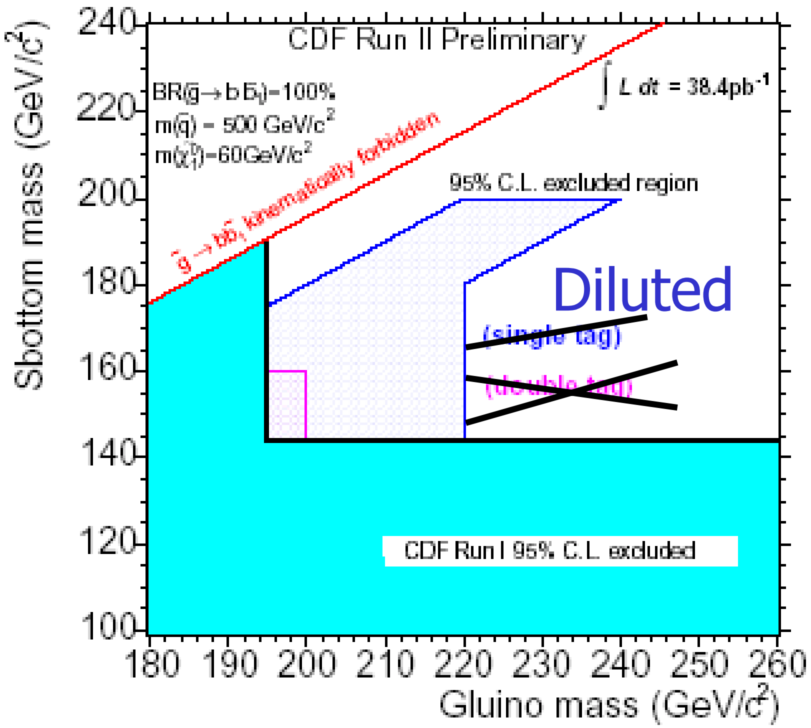
$s\widetilde{b}_1 \rightarrow b\widetilde{\chi}^0_1,\ s\widetilde{\chi}^0_1$

- much better b-jet trigger, greatly improved acceptance
- *b*-tagging (SVX algorithm)
- currently using only a fraction of available data

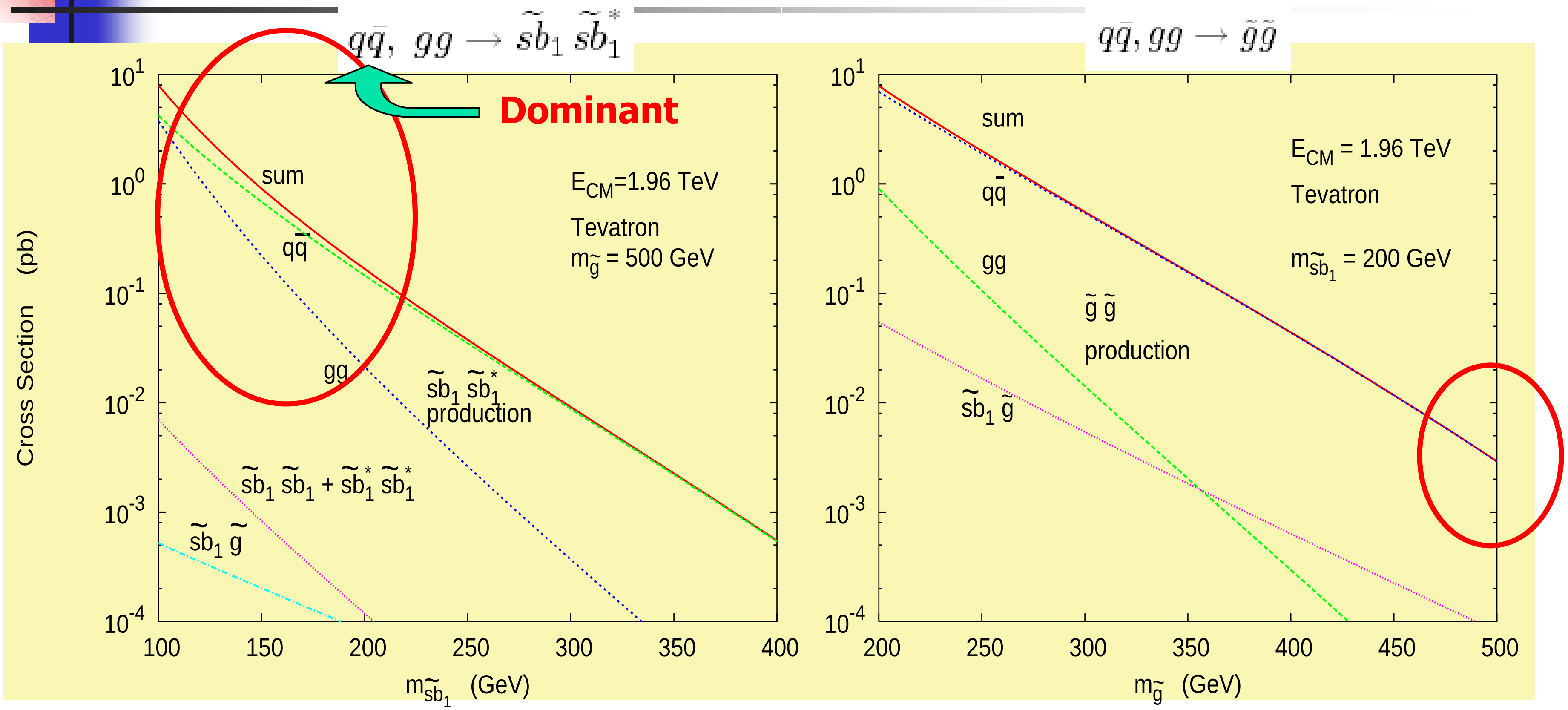
□ (bb+sb+bs+ss)$\widetilde{\chi}^0_1$



Note how much cleaner than in RUN I.



Cross Sections at Tevatron



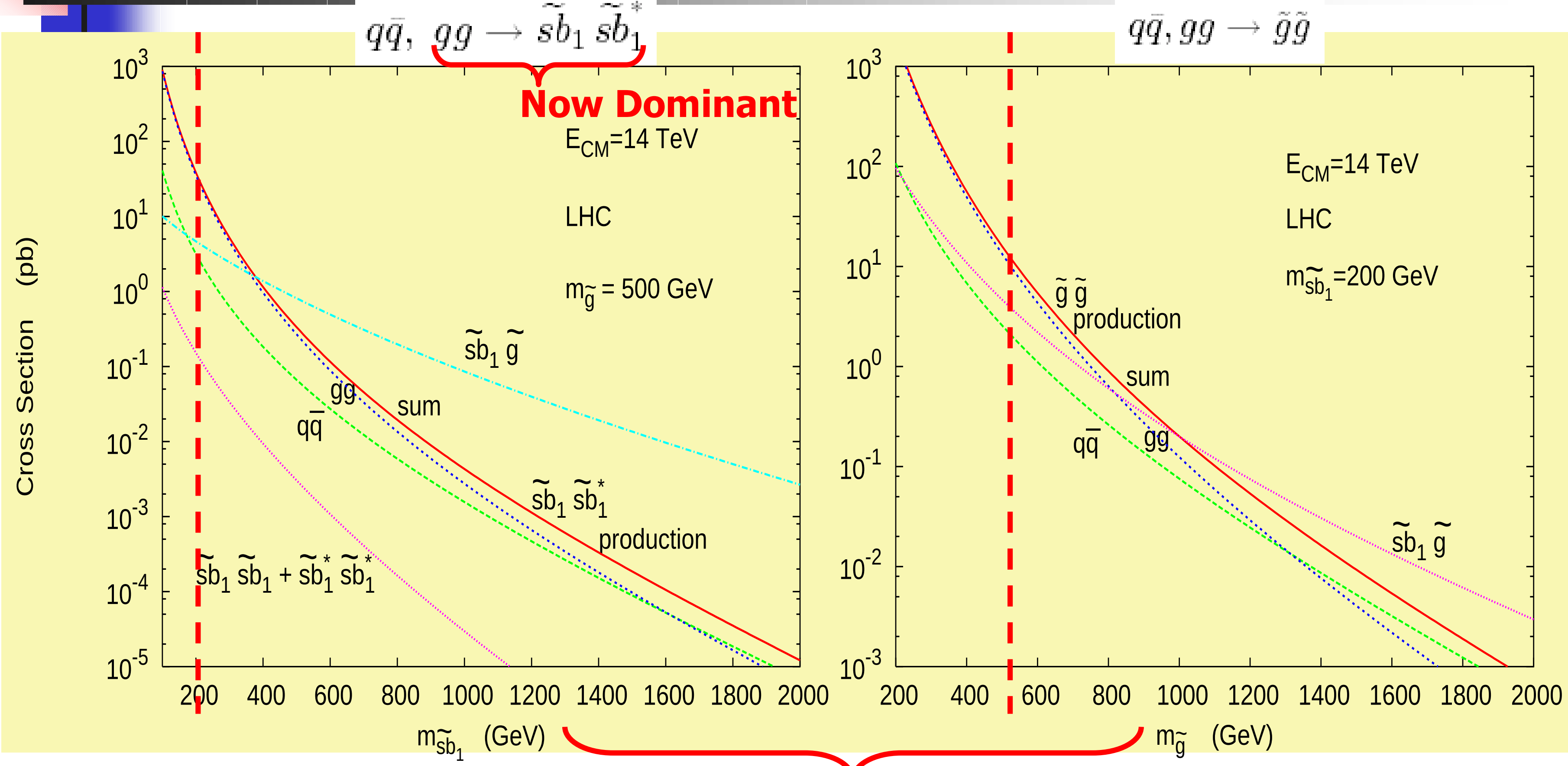
~ 0.1-1 pb

□ 0.01 pb

$$q\bar{q},\ gg \to \widetilde{sb}_1\,\widetilde{sb}_1^*$$

A few hundred events at few fb^{-1}

Cross Sections at LHC

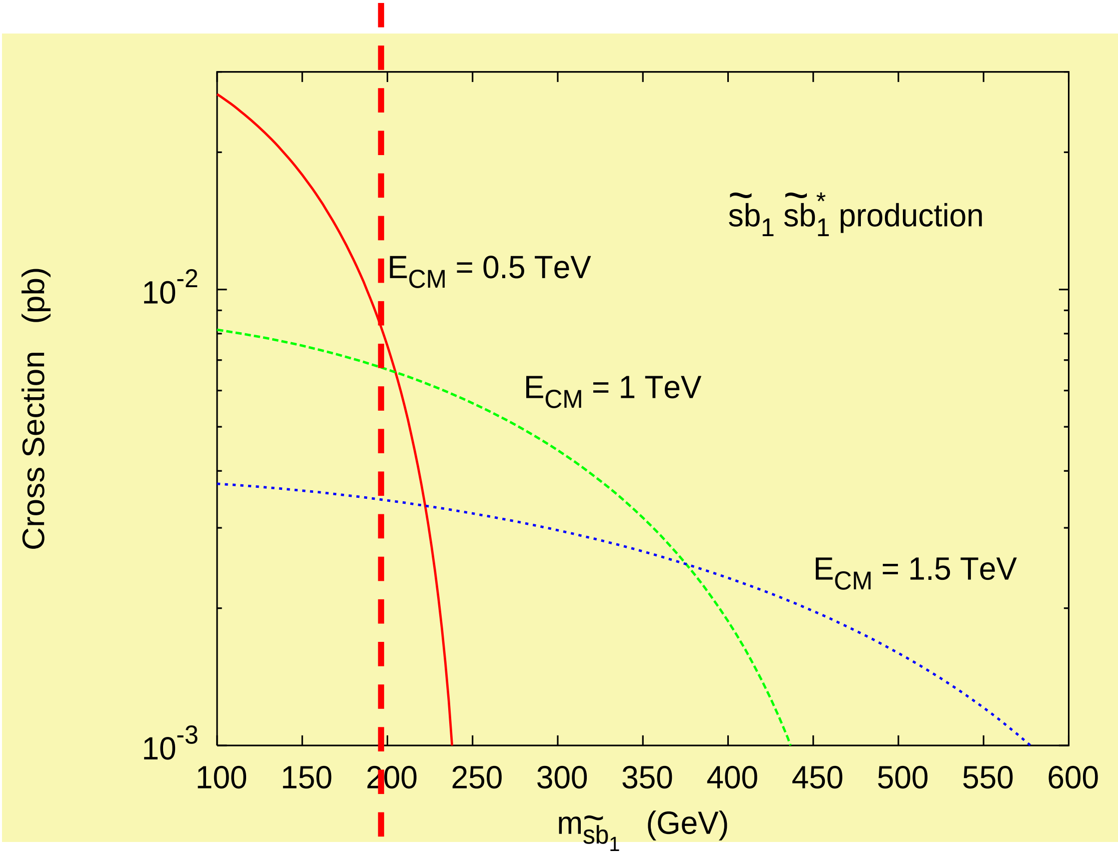


Both ~ 10 pb

$\tilde{sb}_1\,\tilde{sb}_1^*$	**Somewhat forward**
$\tilde{g}\tilde{g}$	**More massive event**

$s(b)g \to \tilde{g}\,\tilde{sb}_1$ **Distinct, probe s → b**

Cross Sections at LC



~ 10 fb

Detection

- Basically, just a light "b"-squark in Production
  so, Discovery not a problem.

- Question is *Decay*: $\widetilde{sb}_1 \to s/b + \tilde{\chi}_1^0$ bino LSP
  or $\widetilde{sb}_1 \to s/b + \tilde{G}$ gravitino

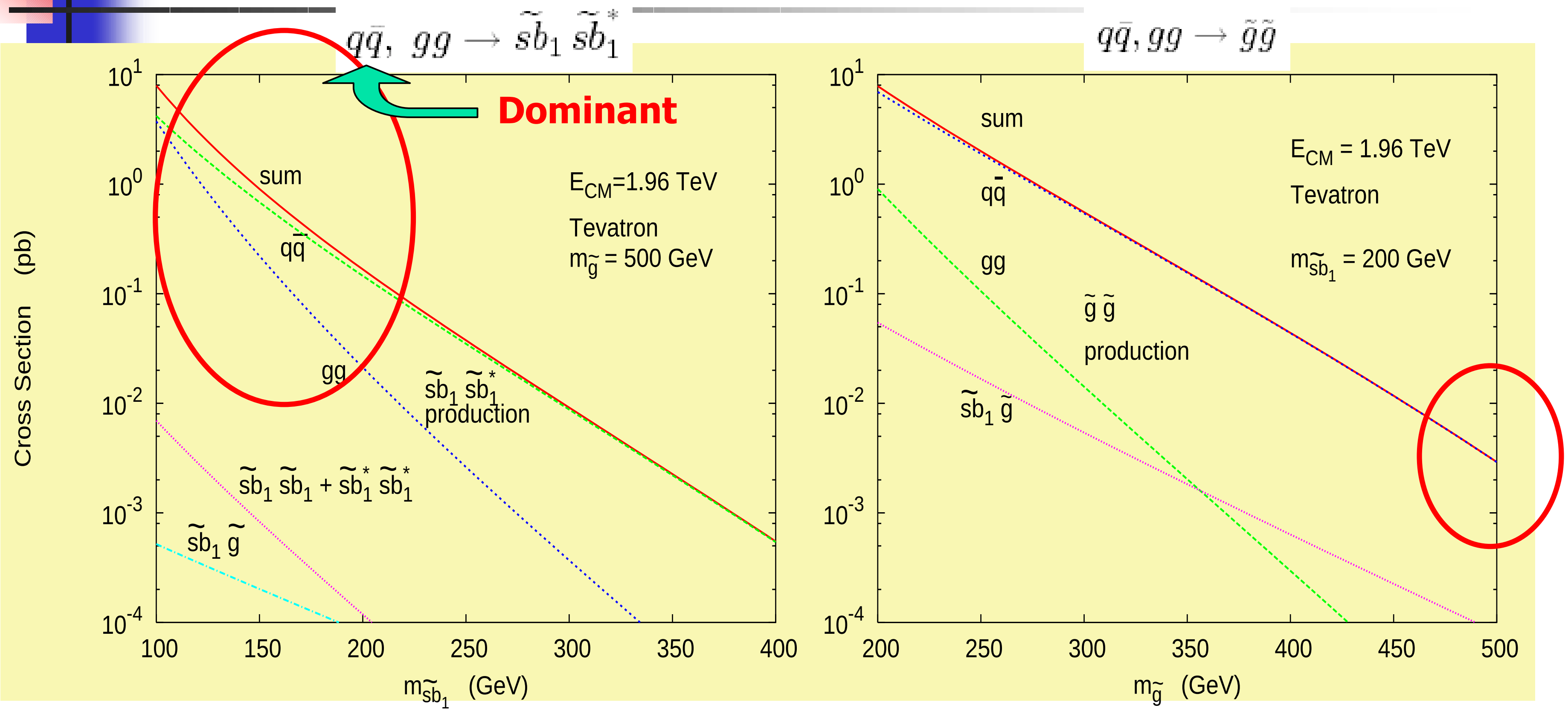
  $\sin^2\theta$ is b fraction

Anyway, need Good b-tagging ! [s-tagging?]

- Can $\widetilde{sb}_{1R}$ be Stable? (LSP)

  In principle → Heavy MIPs

Cross Sections at Tevatron



~ 0.1-1 pb

□ 0.01 pb

$$q\bar{q},\ gg \to \tilde{sb}_1\,\tilde{sb}_1^*$$

A few hundred events at few fb^{-1}

$$\widetilde{sb}_1 \to b\tilde{\chi}_1^0,\ s\tilde{\chi}_1^0$$

- Discovery (> 10 evts) up to 300 GeV w/ 2 fb^{-1} & $\sin^2\theta_m > 0.5$
- Single vs double b-tag contain info on $\sin\theta_m$
- b-tag cross section: check consistency vs mass

TABLE II: Cross sections in fb for direct squark-pair production at the Tevatron with $\sqrt{s}$ = 1.96 TeV, for 0, 1, 2 b-tagged events. The imposed cuts are $p_{Tj} > 15$ GeV, $|\eta_j| < 2$, b-tagging efficiency $\epsilon_{btag} = 0.6$, and a mistag probability of $\epsilon_{mis} = 0.05$. In parentheses, we give the contribution fed down from direct gluino-pair production.

$m_{\tilde{sb}_1}$ (GeV)	0 b-tag	1 b-tag	2 b-tag	0 b-tag	1 b-tag	2 b-tag
	standard	$\sin^2\theta_m = 1$	sbeauty		$\sin^2\theta_m = 0.75$	
150	115(0.11)	288(0.54)	175(2.2)	190(0.29)	284(0.89)	104(1.6)
200	26(0.091)	70(0.49)	47(2.2)	44(0.27)	70(0.85)	28(1.7)
250	6.1(0.090)	17(0.49)	11(2.2)	11(0.27)	17(0.85)	6.8(1.7)
300	1.5(0.090)	4.2(0.49)	2.9(2.2)	2.6(0.27)	4.2(0.85)	1.7(1.7)
350	0.38(0.090)	1.1(0.49)	0.72(2.2)	0.66(0.27)	1.1(0.86)	0.43(1.7)
400	0.094(0.090)	0.26(0.49)	0.18(2.2)	0.16(0.27)	0.26(0.86)	0.11(1.7)
450	0.022(0.096)	0.06(0.51)	0.04(2.2)	0.038(0.28)	0.061(0.87)	0.025(1.7)
	reference	$\sin^2\theta_m = 0.5$	$\tilde{sb}_{1R}$		$\sin^2\theta_m = 0.25$	
150	283(0.66)	243(1.2)	51(1.0)	395(1.3)	165(1.1)	17(0.40)
200	68(0.63)	61(1.1)	14(1.0)	96(1.3)	42(1.1)	4.6(0.42)
250	16(0.62)	15(1.1)	3.3(1.0)	23(1.3)	10(1.1)	1.1(0.42)
300	4.0(0.63)	3.7(1.1)	0.84(1.0)	5.8(1.3)	2.5(1.1)	0.28(0.42)
350	1.0(0.63)	0.93(1.1)	0.21(1.0)	1.4(1.3)	0.64(1.1)	0.071(0.43)
400	0.25(0.63)	0.23(1.2)	0.052(1.1)	0.35(1.3)	0.16(1.1)	0.017(0.43)
450	0.058(0.64)	0.053(1.2)	0.012(1.0)	0.083(1.3)	0.037(1.1)	0.004(0.42)

Conclusion

- $S_{\phi K_S}$, $S_{K_S\pi^0}$, $S_{\eta' K_S}$ Data *May* Call for
  - Large *s-b* Mixing, w/ New CPV Phase
  - New *Right-handed* Interaction
- A Light *Flavor-mixed* $\tilde{sb}_{1R}$ Squark?

Independtly Well Motivated (Flavor & SUSY)

- Survive $b \to s\gamma$ (**!**)
- Can Account for $S_{\phi K_S}$ □ 0, but $S_{K_S\pi^0}$, $S_{\eta' K_S}$ ~ $S_{\psi K_S}$
- Δm_{B_S}, $\sin 2\Phi_{B_S}$ May Become *Difficult*
- $S_{K_S\pi^0\gamma}$ now *Promising !!*

□ **Push for SuperB w/ Large Silicon**

Conclusion-II

- **Study Collider Aspect**

Nonstandard, *Flavor* ful TeV SUSY

w/ light *Strangebeau* $\tilde{sb}_{1R}$

CP Phase !?

B Factory Could Impact on Tevatron/LHC/LC !

Backup Slides …

The move ....

Old result: Fit to ϕK_S, $K_S \to \pi^+\pi^-$ and $K_S \to \pi^0\pi^0$ sample combined (80 fb^{-1})

$S = -0.18 \pm 0.51$
$C = -0.80 \pm 0.38$

Old $K_S \to \pi^+\pi^-$ only: $S = -0.12 \pm 0.52$
$C = -0.77 \pm 0.41$

Overlap between reprocessed (new) Run1+2 and old $K_S \to \pi^+\pi^-$

(80% overlap)

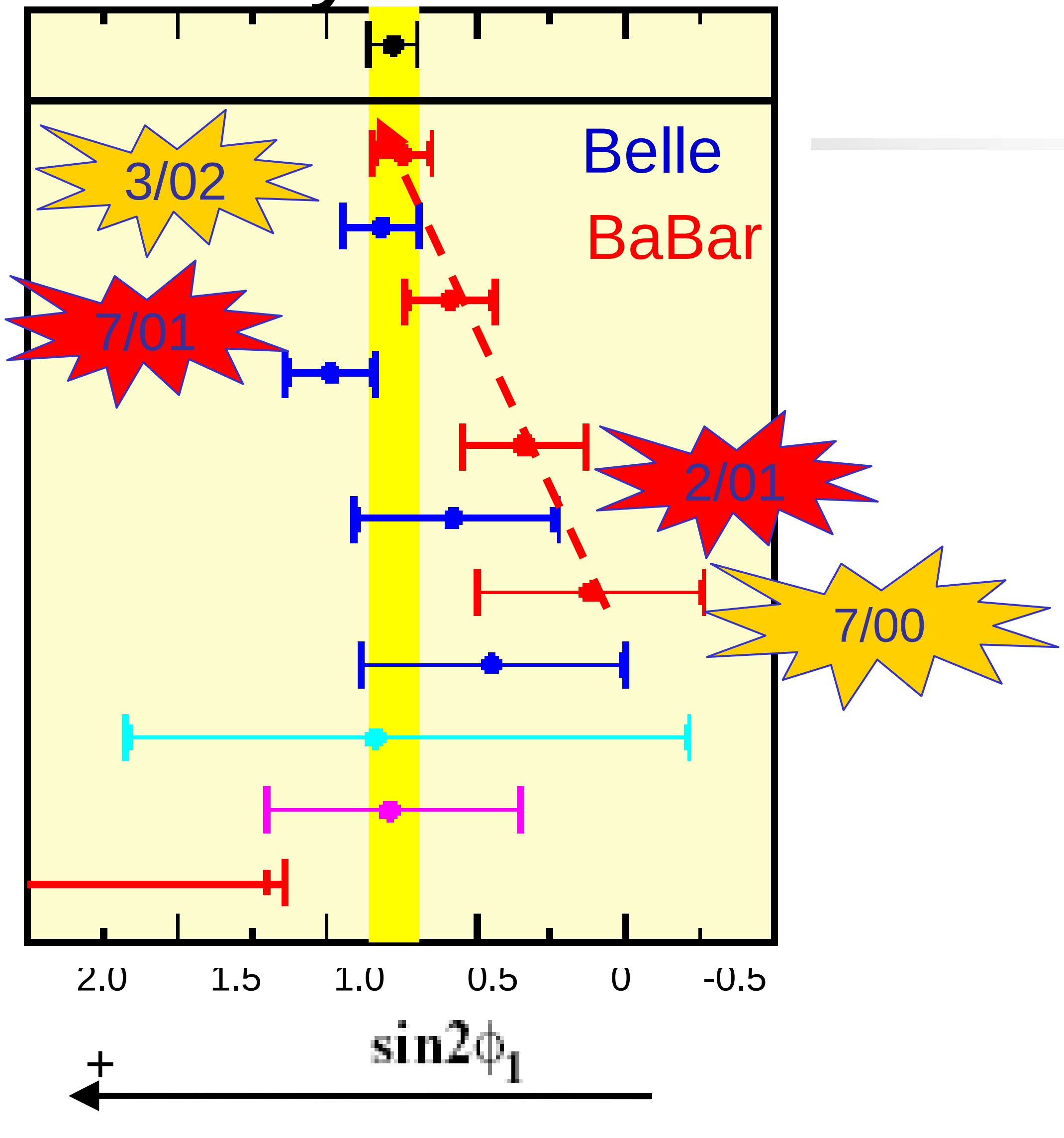
Old $K_S \to \pi^+\pi^-$: $S = 0.02 \pm 0.55$
$C = -0.57 \pm 0.44$

New $K_S \to \pi^+\pi^-$: $S = 0.05 \pm 0.51$
$C = -0.25 \pm 0.48$

$\Delta S \sim 0.0$
$\Delta C \sim 0.3$

New+Run3 $K_S \to \pi^+\pi^-$: (110 fb^{-1}) $S = 0.45 \pm 0.43$
$C = -0.38 \pm 0.37$

Case History



i in Dynamics: CPV & *BAU*

ElectroMagnetism: (everyone can feel

Charge ***e*** is *Real*.

"We" Understand: *Gauge* Charge is Real.

Imagine a ~~Complex Coupling~~ :

True, or, Possible, for Yukawa ( ) Coupling of quarks/leptons to Higgs boson(s)...

Quantum Interference in ***Amplitude*** More Interesting

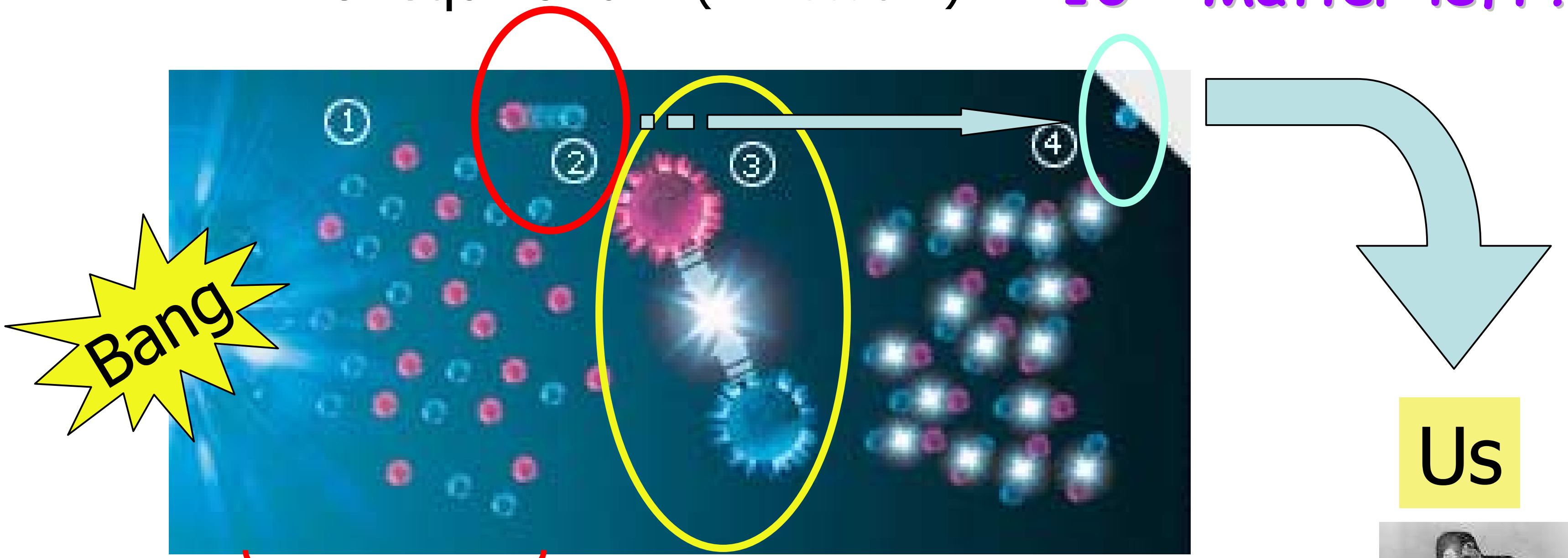
→ How CP Violation Appears

Finally Explain BAU and Sakharov ...

Once More on BAU: The Sakharov View

- *B#V*
- *CPV* ("Direction")
- Nonequilibrium ("Direction")

10^{-9} Matter left !



Equal Matter
-Antimatter

Pair
Annihilation
(→ Cosmic Microwave
Background)

Us