Physics Potential at the $\Upsilon(5S)$

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Motivation

New Physics in $B_s - \bar{B}_s$ mixing

sizeable CP-violating phase in $B_s - \bar{B}_s$ mixing is unambiguous signal of NP

CP angle γ

modes in common to B_s and $\bar{B}_s$ as for instance $D_s(^*)K(^*)$ are sensitive to weak phase γ and a sizeable width difference $y=\Delta\Gamma/2\Gamma$ leads to new CP violation phenomena

test of duality

detailed and comprehensive study of Bs decays as crucial quantitative probe of duality; for $\not{CP}$ = f (Vcb, Vub, Vtd, ...) and intellectual curiosity/honesty (I. Bigi)

What is unique about $\Upsilon(5S)$?

Coherent $B_s - \bar{B}_s$ pair production

with anti-symmetric (C= -1) and symmetric wave function (C= +1)

C= -1 for (B_s, $\bar{B}_s$) and (B_s^*, $\bar{B}_s^*$), like $\Upsilon(4S)$
C= +1 for (B_s, $\bar{B}_s^*$) and (B_s^*, $\bar{B}_s$), new

e+e- environment, good photon detection

upgrade of existing facility

beam-energy constraint

average over Δm_s oscillation

Symmetric vs. Anti-symmetric wavefunction
Two realizations of the EPR paradoxon

C=-1	C=+1
Flavor of both Bs remain completely anti-correlated until one Bs decays.	Tagging flavor of one Bs does *NOT* guarantee the other Bs to be in the opposite flavor state at the same instant.
If, at any times, decays occur to CP eigenstates of *equal* CP parity, then there is CP violation.	If, at any times, decays occur to CP eigenstates of *opposite* CP parity, then there is CP violation.
In principle, given a non-zero $y=\Delta\Gamma/2\Gamma$, the $\Delta t = t_1 - t_2$ time distribution can be anti-symmetric.	Even with a non-zero $y=\Delta\Gamma/2\Gamma$ the $\Delta t = t_1 - t_2$ time distribution is always symmetric.

Methods for NP and γ

1) Lifetime Measurements in different B_s final states (the BaBar Method)

2) Time-integrated rate measurements of coherent $B_s \overline{B}_s$ decays to (D_s K) (D_s K) (the Xing Method)

3) Rate measurements of CP tagged B_s decays to D_s K (the Falk-Petrov Method)

Time distribution of untagged B_s

$\Delta = \Gamma \Delta t$, $\lambda = q\bar{A}_f / p A_f$, $y = \Delta\Gamma / 2\Gamma$

For C=-1:

$$P(f,\Delta)_- \propto \exp(-|\Delta|) \{ (1+|\lambda|^2) \cosh(y \Delta) - 2 \, Re(\lambda) \sinh(y \Delta) \}$$

For C= +1:

$$P(f,\Delta)_+ \propto \exp(-|\Delta|) \{ (1+|\lambda|^2 - y (2 \, Re(\lambda))) \cosh(y |\Delta|) (y (1+|\lambda|^2) - 2 \, Re(\lambda)) \sinh(y |\Delta|) \}$$

Flavor states: $\lambda = 0$ ⟹ only second order terms in y

CP eigenstates: $|\lambda| = 1$ and States with interfering amplitudes: $|\lambda| \neq 1$ ⟹ first order terms in y, prefactor scales with $Re(\lambda)$ = cos(CP phase)

In search for NP

1) Measure y in semileptonic decays and CP eigen-states with zero SM prediction of phase

SM: $y_{sl} = y_{CP}$ CP = $J/\Psi\Phi$, Ds+Ds-, $J/\Psi\eta$
NP: $y_{CP} = y_{sl}\cos(\Phi)$ Φ = phase of NP

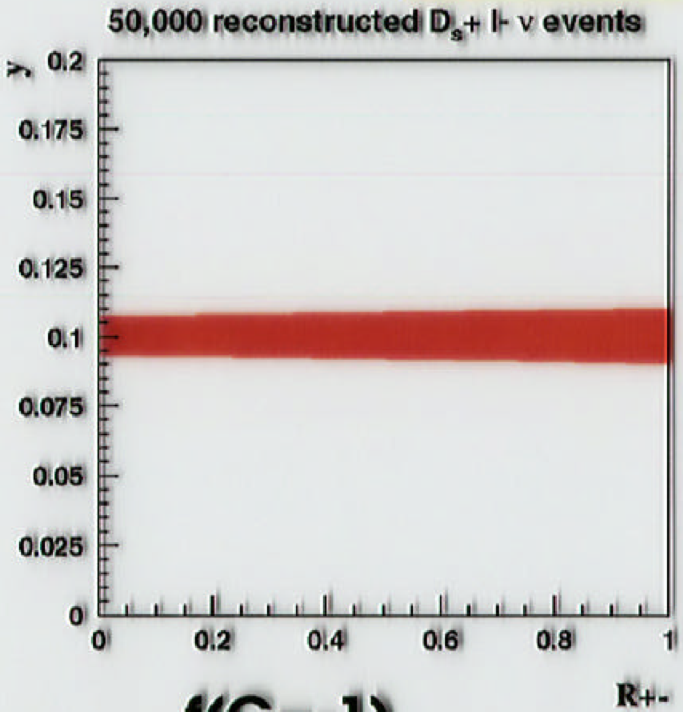
2) Value of y itself depends on NP
(Dunietz, Fleischer, Nierste)

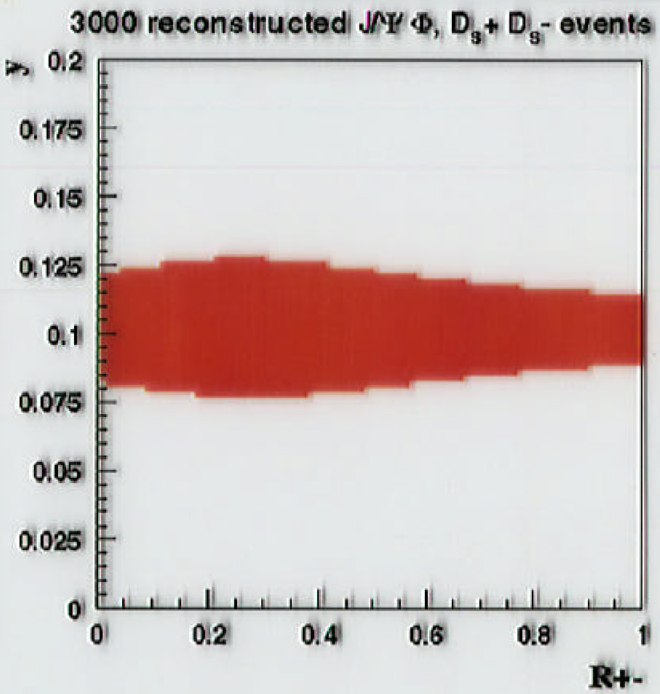
$y = y_{SM}\cos(\Phi)$
y_{SM} from theoretical estimate or
y_{SM} = BR(Ds(*)+Ds(*)-) in Shifman-Voloshin limit

Resolution on y

10^7 Bs(*) $\overline{\text{Bs}}$(*)

1σ error of a measurement with central value y=0.1





$$R_{+-} = \frac{f(C=-1)}{f(C=-1) + f(C=+1)}$$

Experimental situation

Lifetime difference
$y = \Delta\Gamma / 2\Gamma$

	Experiment	Year	# events	Statistical Sensitivity for y
Using B_s Flavor specific states	L3	1998	15,000 (inclusive B, 10% Bs)	~0.15
	DELPHI	1999	1,300	~0.15
	CDF	1999	2,000	~0.15
	BaBar	2005?	50,000	~0.01
Using B_s CP eigenstates	CDF	1998	58	~0.2
	ALEPH	2000	16	~0.25
	BaBar	2005?	3,000	~0.02

Theoretical estimate: $y = 0.075 \pm 0.035$
(Beneke, Buchalla, Dunietz, Greub, Lenz, Nierste and KEK-Hiroshima Group)

LEP B-Lifetime Working Group

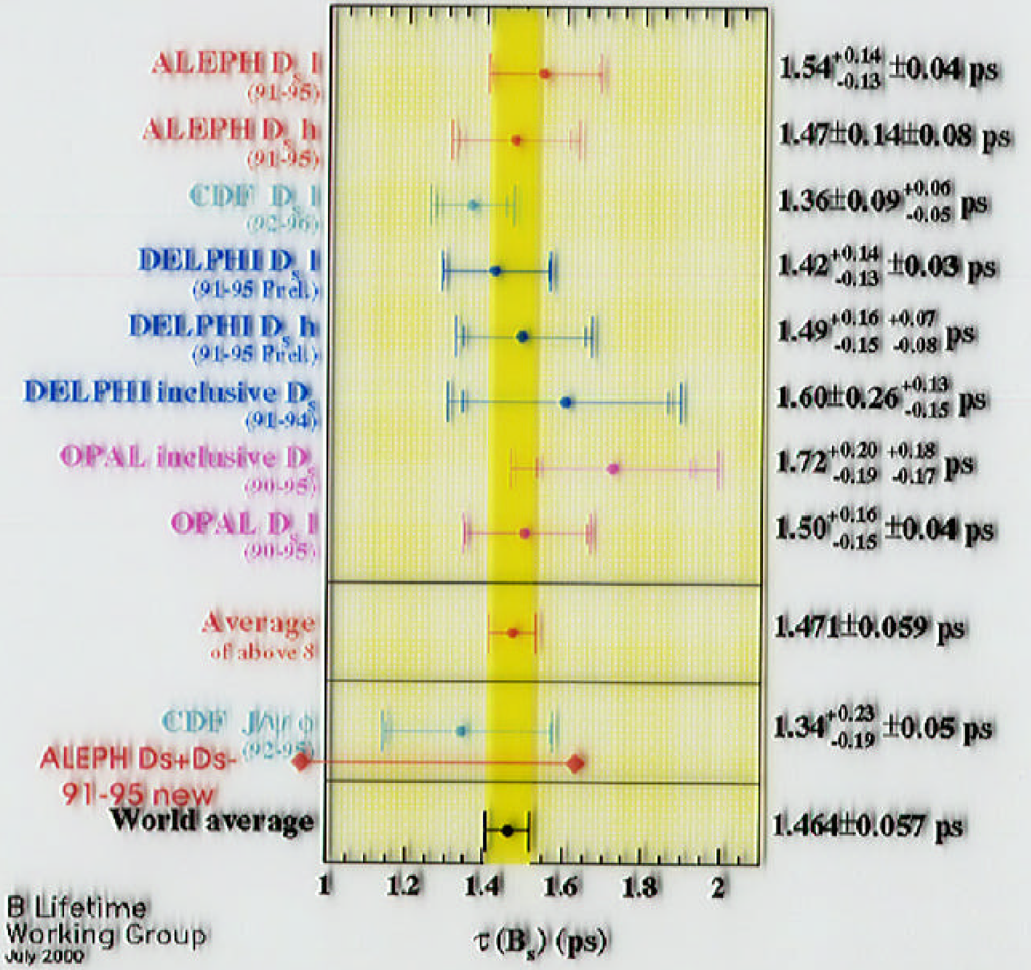
Flavor specific

τ_{fs}=1.471±0.059ps

$y = 1 - \tau_{CP}/\tau_{fs}$
$= 0.10 \pm 0.16$

CP eigenstate

τ_{CP}=1.32±0.19ps



γ dependent modes

Ds+ K- , Ds*+ K- ,
Ds+ K*- , Ds*+ K*-

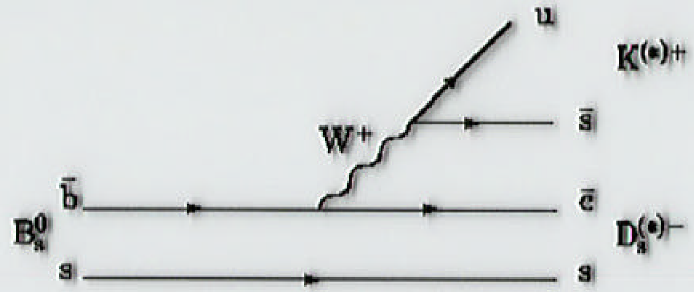


Figure 1: Tree-level diagram $\bar{b} \to \bar{c} u \bar{s}$ in $B_s^0 \to D_s^{(*)-} K^{(*)+}$.

$$|\lambda| = \frac{|V_{ub} V_{cs}|}{|V_{cb} V_{us}|}$$

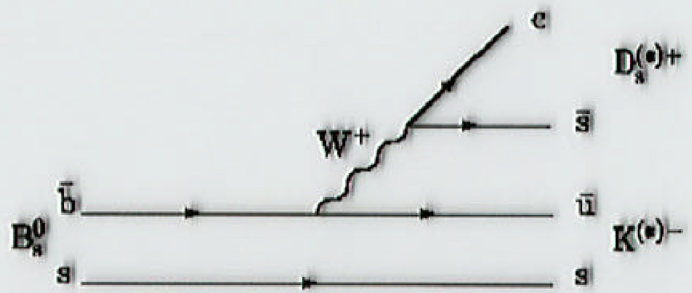
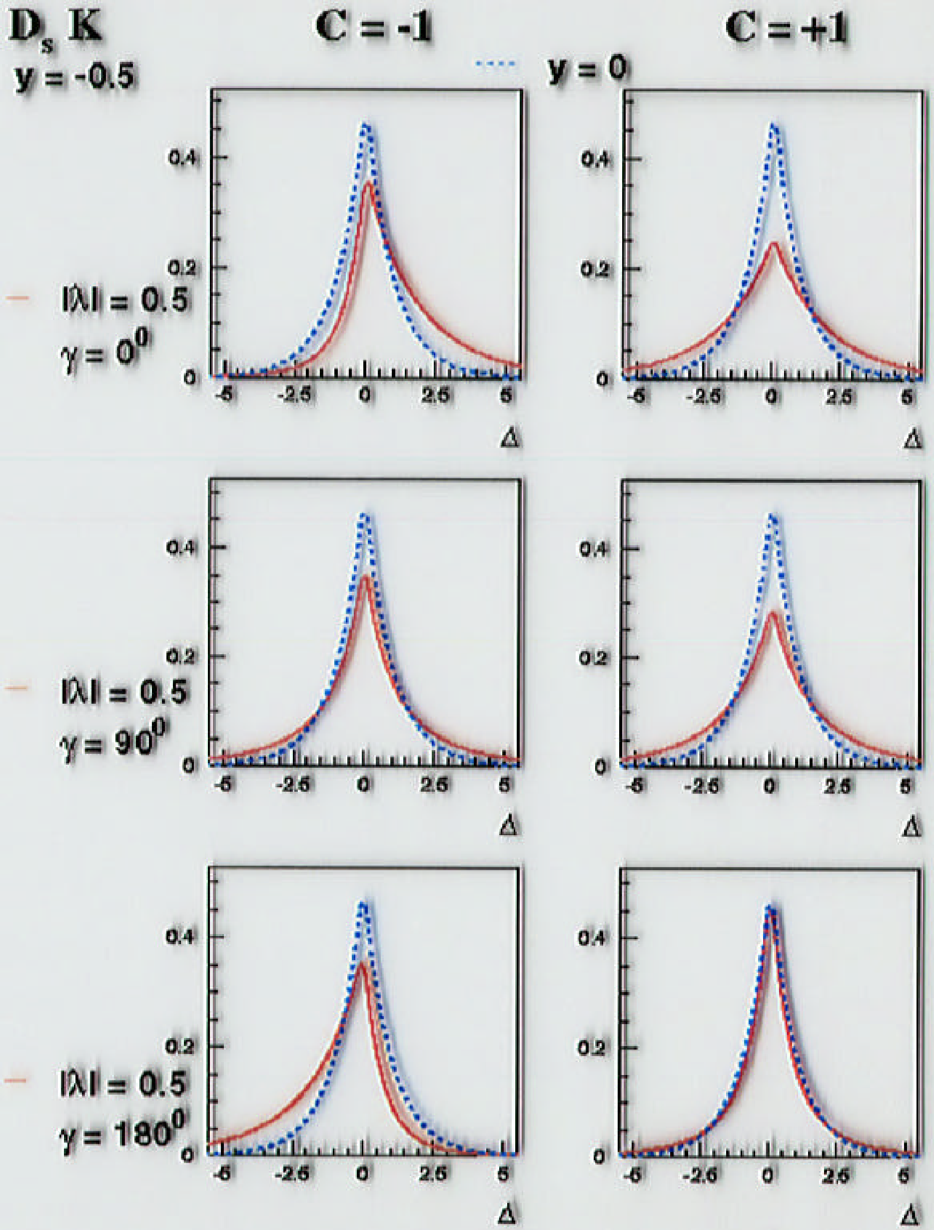


Figure 2: Tree-level diagram $\bar{b} \to \bar{u} c \bar{s}$ in $B_s^0 \to D_s^{(*)+} K^{(*)-}$.

Sensitivity to γ



y=-0.5, |λ|=0.5

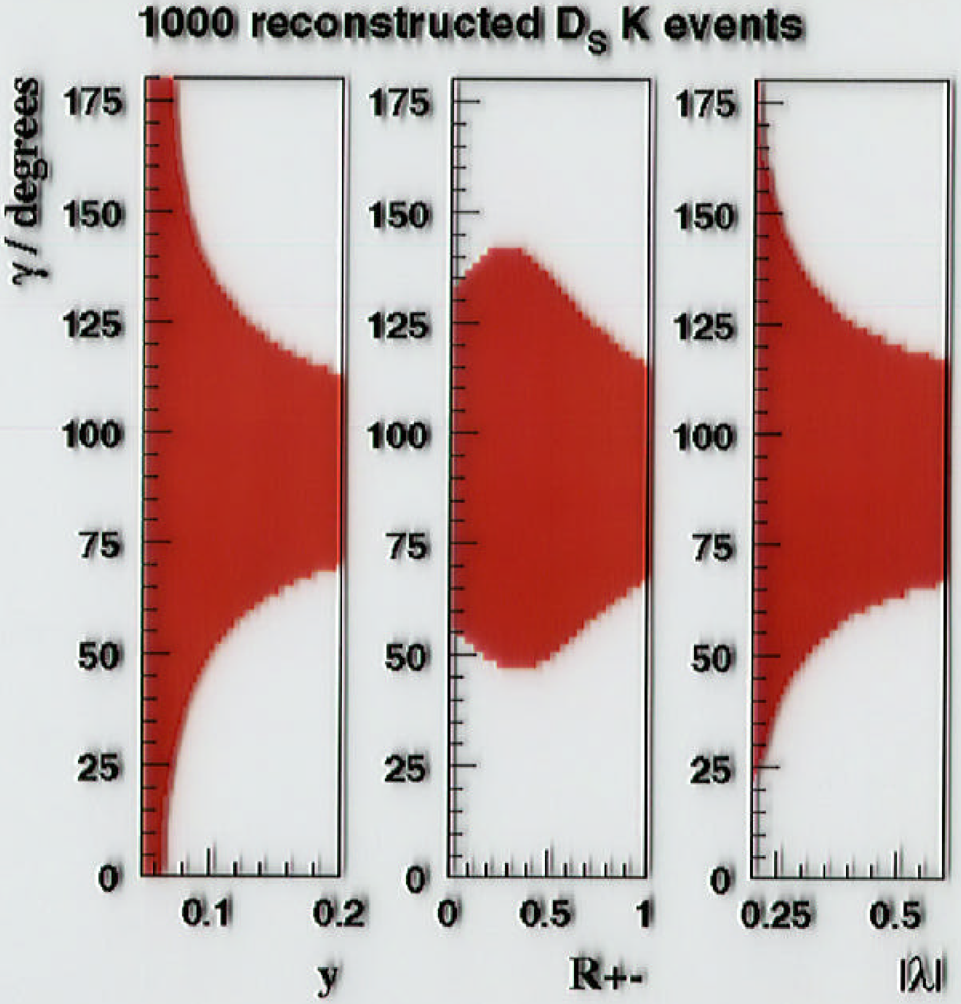
Resolution on γ

10^7 **Bs(*) $\overline{\text{B}}$s(*)**

1σ error of a measurement with central value $\gamma = 90^o$.

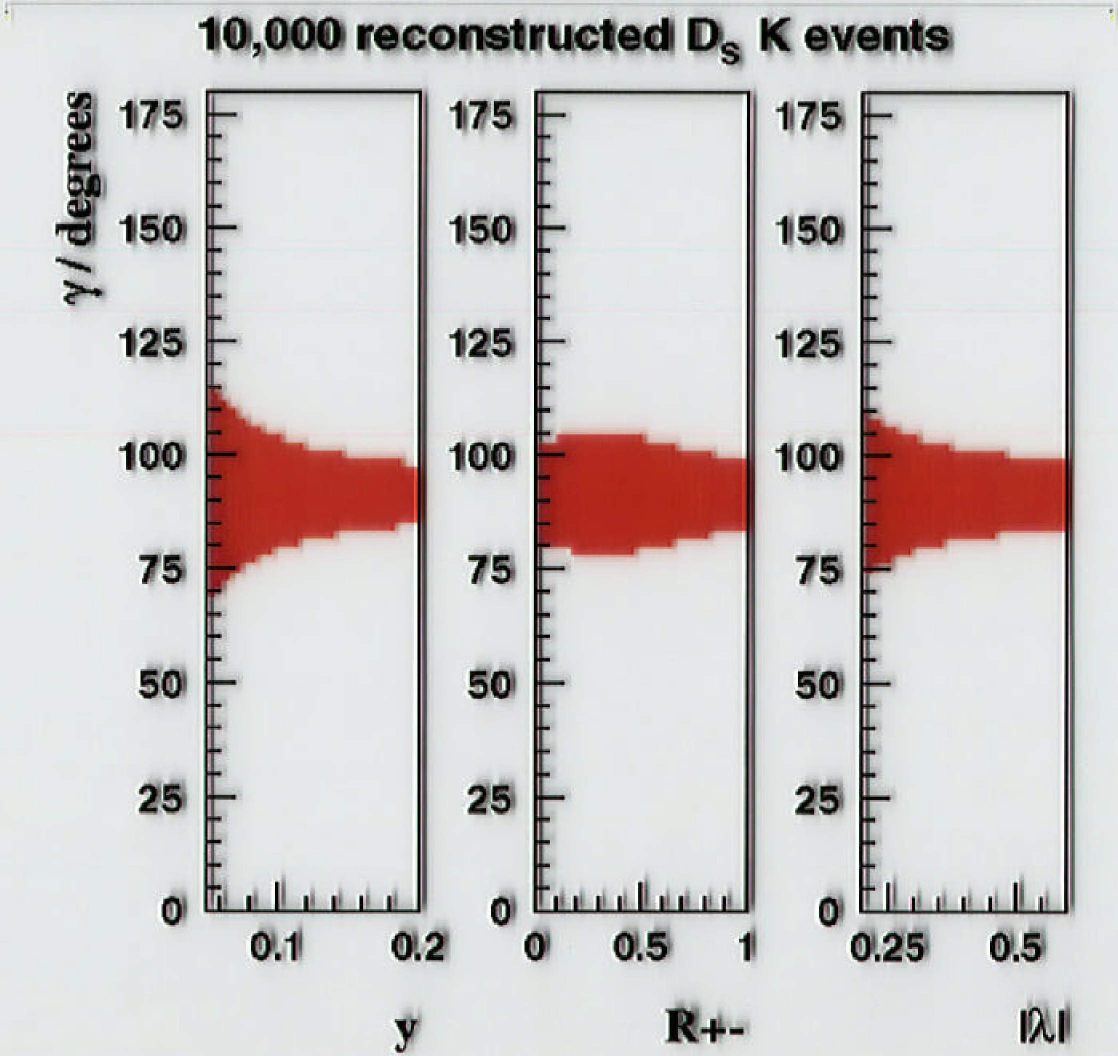
Besides parameter varied other parameters are fixed to y=0.1, R_{+-}=0.5, $|\lambda|$=0.3.

Assumes partial reconstruction of Ds*+ K-.



Resolution on γ

10^8 Bs(*) $\overline{\text{Bs}}$(*)



1σ error of a measurement with central value γ = 90°.

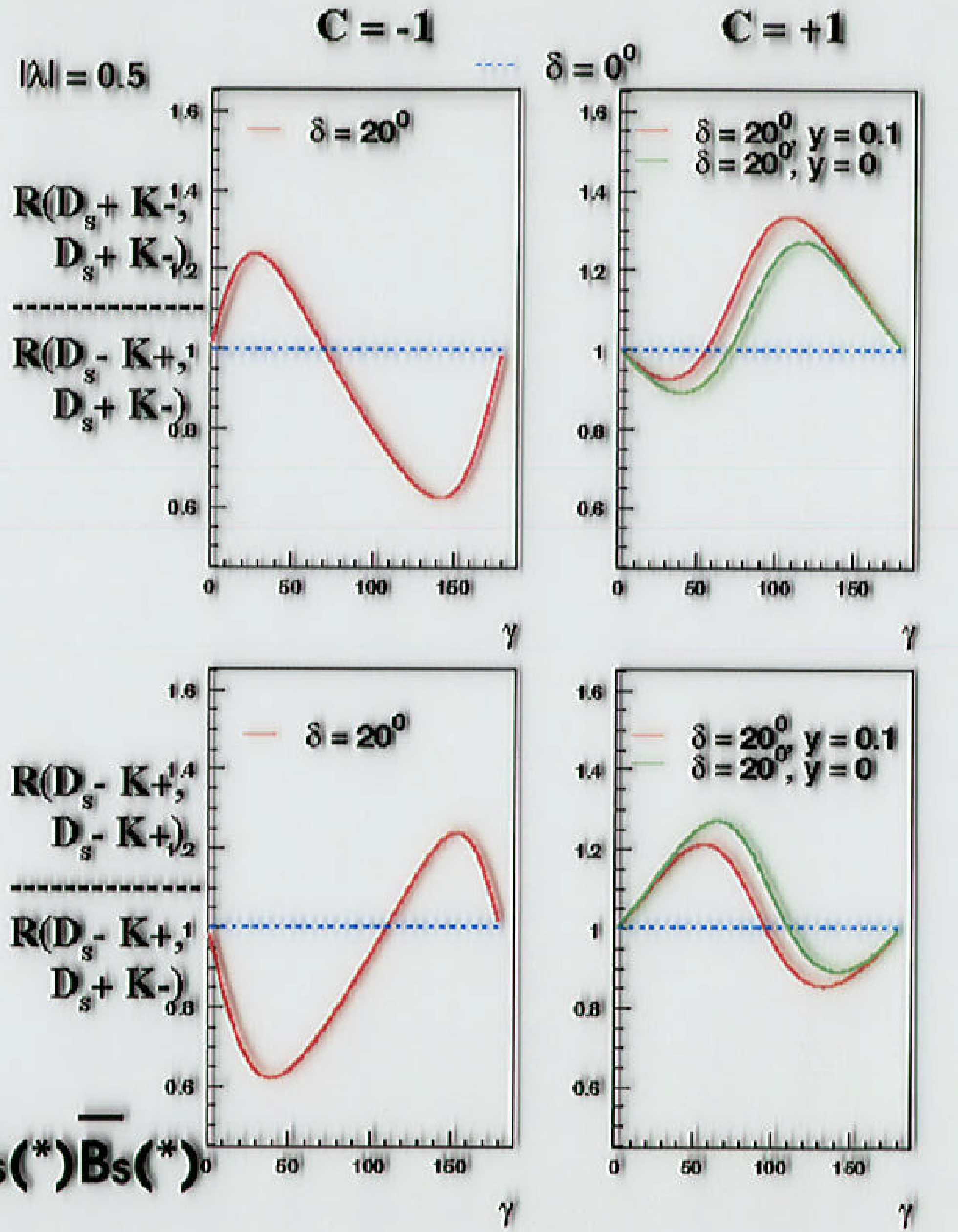
Besides parameter varied other parameters are fixed to y=0.1, R_{+-}=0.5, |λ|=0.3.

Xing Method

Time-integrated rates for joint (B_s, $\overline{B_s}$) decay into (f, f), ($\overline{f}$, $\overline{f}$) and (f, $\overline{f}$) with
f = Ds+ K- , Ds*+ K-, Ds+ K*- , Ds*+ K*-

Two independent ratios (f, f)/(f, $\overline{f}$) and ($\overline{f}$, $\overline{f}$)/(f, $\overline{f}$) for C=±1

Requires hadronic phase $\delta \neq 0$

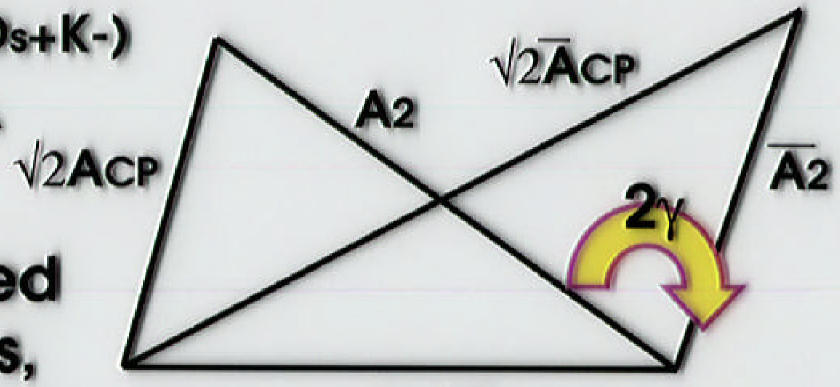


Minimum statistics 10^{11} Bs(*)$\overline{\text{Bs}}$(*)

Falk-Petrov Method

Minimum statistics 10^{11} $B_s(^*)\overline{B}_s(^*)$

$A_{CP}=A(B_{s,CP}\to D_s{+}K{-})$



$A_1=\overline{A}_1$

$A_1=A(B_s\to D_s{+}K{-})$

$A_2=A(\overline{B}_s\to D_s{+}K{-})$

A_{CP} CP-tagged Bs Amplitudes,
measured by e+e- factory at Υ(5S)

A_1,A_2 flavor-tagged Bs Amplitudes,
measured by Fermilab, corrected for x_s oscillation

In SM: only time-integrated rate measurements
NP: triangle becomes time-dependent.

Accelerator Upgrades

BaBar options:

1) same machine at E_{CM}=10.87GeV
drop in luminosity by 30%, similar boost

2) Luminosity optimized machine
requires new RF station and new IP magnet design

3) Luminosity optimized machine with maximum boost
not necessary! Measurement of x_s is for Fermilab only.
Techniques at Υ(5S) must work without flavor-tagging.

Luminosity projections:
up to 2005 500fb^{-1} at Υ(4S), by then 150fb^{-1}/year
$\rightarrow$ 100fb^{-1}/year at Υ(5S) is "conservative" estimate
100fb^{-1} $\cong 10^7$ Bs(*) $\overline{\text{Bs}}$(*)

Comparison to Fermilab

Run II will start in March 2001, 2 fb^{-1} in first 2 years
4000 reconstructed $J/\Psi\Phi$ events,
error on y of 0.02

up to 2006: 10-20 fb^{-1}

1 year of Run II yield $\cong$ 1 year of BaBar $\Upsilon(5S)$ yield,
BUT BaBar would come 3-4 years later.

Nevertheless the $\Upsilon(5S)$ has the unique feature of correlated $B_s\overline{B}_s$ pair production and better photon detection as for instance needed in $J/\Psi\eta$.
Complementary B_s physics program to Fermilab.

CESR run at the $\Upsilon(5S)$

1988 CESR three months run at $\Upsilon(5S)$ with 140 pb^{-1}

Main question addressed is $BR(\Upsilon(5S) \rightarrow Bs(^*)\bar{B}s(^*))$

CLEO measurements were consistent that 1/3 of resonance cross section was due to Bs production. However, statistical significance was limited.

CUSB-II with high resolution BGO calorimeter found clear evidence for Bs* mesons. Excess of 47 MeV photons at $\Upsilon(5S)$, but not at $\Upsilon(4S)$. By width of peak one can tell whether from B* or Bs* (Doppler-broadening). 20%-55% Bs* mesons.

Summary

A sizeable $\Delta\Gamma$ introduces new CP violating effects.

Possibility to detect New Physics by testing the CP phase in channels like $B_s \rightarrow J/\Psi\Phi$ with a negligible Standard Model phase.

$B_s \rightarrow D^*_s K$ samples are a promising source to measure the CP angle γ. Different methods exploit either the time distribution of untagged $B_s \rightarrow D^*_s K$ events or rate measurements of fully reconstructed $\Upsilon(5S)$ events where one B_s decays into $D^*_s K$ and the other into a CP eigenstate or $D^*_s K$.

Methods have been proposed that make explicit use of the correlated $B_s \overline{B}_s$ production at the $\Upsilon(5S)$. Further work is needed to make these techniques experimentally feasible.