Searches for New Sources of CP Violation at BaBar

PLANCK 2012 Conference, Warsaw

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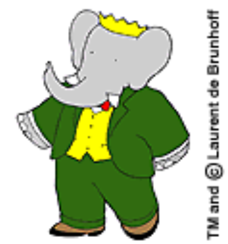
on behalf of the BaBar Collaboration

BaBar → Tremendous success



BaBar (and Belle) met our goals:

- Test Standard Model in CKM sector to excruciating precision
- Perform B decay measurements in hundreds of decay channels to first test, then over-constrain, the CKM mechanism as source of CP violation in Standard Model
- Riccardo Barbieri, in opening talk in this conference:

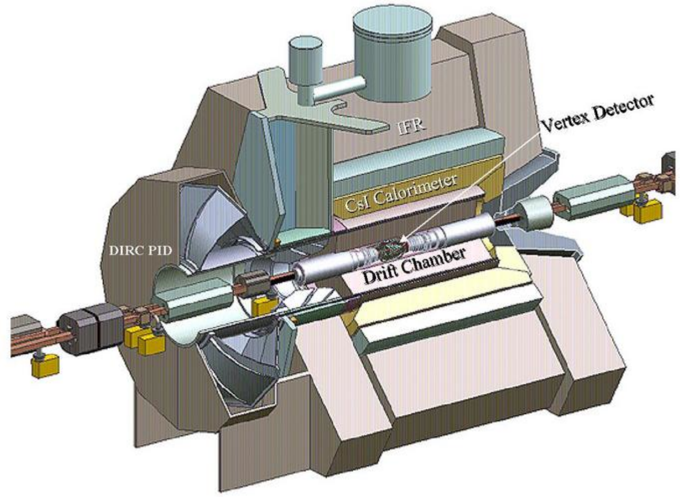
  Scary success of CKM picture

BaBar: 20 year Experimental Program: Quarks, Leptons & CP violation

New CP violation, new particles, precision measurements: Excitement, press releases & surprises

1993: Construction starts on PEP-II, design & prototypes for BaBar Detector

1994-9: BaBar Detector Construction



1999: PEP-II & BaBar complete**, take data!**

2000: PEP-II runs at design luminosity

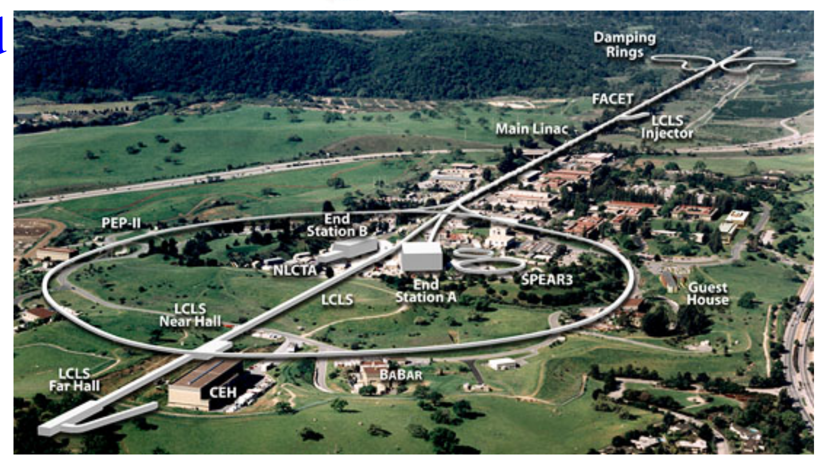
2001: First observation of CP Violation in B system (27 yrs after CPV first seen in K's)

2003: New charmed particle $D_S(2317)$

2004: Direct CP violation observed in B system

2004: PEP-II at 3 × design luminosity

2005: new charmonium-like particles discovered



2006: Precision & consistency in electroweak sector of Standard Model

2007: First observation of D^0 -$\overline{D}^0$ mixing

2008: Babar's Final Run ended April 7, 2008

2008: New Charm Resonances

2008: Nobel Prize to Kobayashi & Maskawa (CKM mechanism as source of CPV– validated)

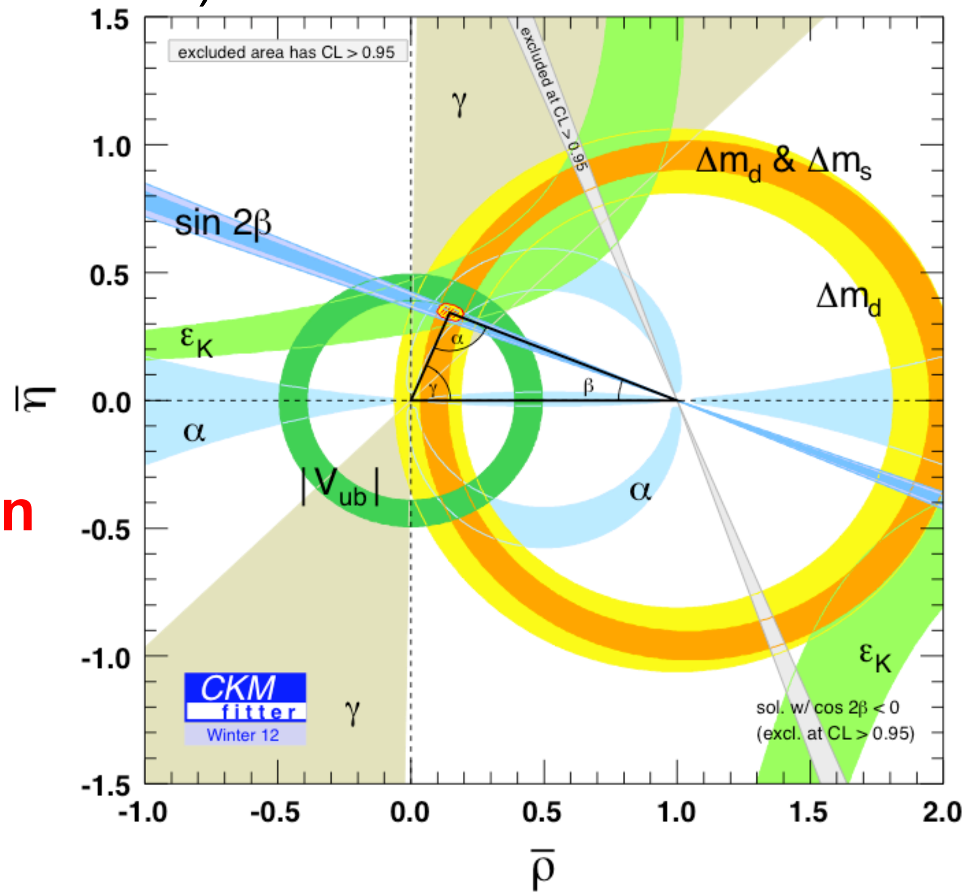
2009-13: 470 million $B\overline{B}$ pairs: Data Mining: New CP sources, New Physics

CKM Measurements

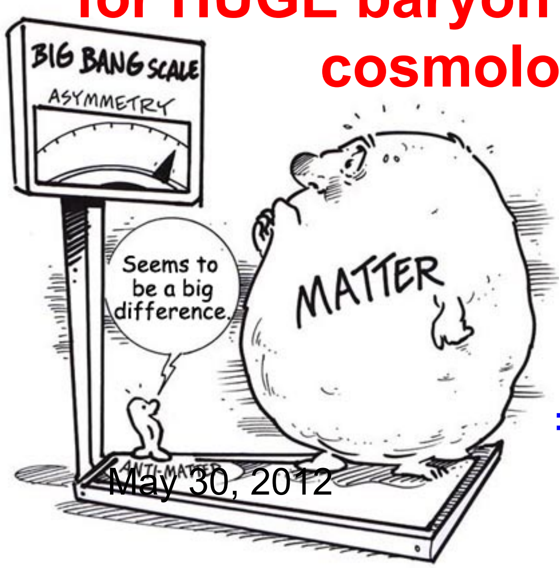
Measurements of CKM parameters: now immensely over-constrained (Barbieri, opening talk of this conference)

Yield one consistent solution

CP violation: accommodated in Standard Model via CKM mechanism



Yet: CKM Mechanism in quark sector in SM cannot account for HUGE baryon asymmetry on cosmological scale

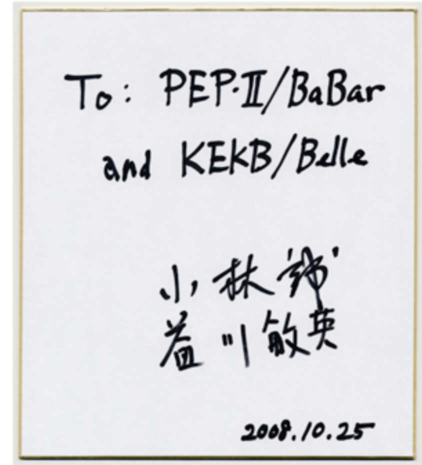


⇒There must be other sources of CP violation

CP Violation in Standard Model: CKM mechanism

2008 Nobel Prize in Physics

Nambu Kobayashi Maskawa



Experimental program immensely successful:
- Initially set out to find where CKM breaks down
- Instead: confirmed beautiful theory to such excruciating precision that K&M were awarded Nobel Prize in 2008

Problems: Not enough CPV to explain Baryon Asymmetry of the Universe

Current Program (and subject of this talk) :

Search for new sources of CP Violation beyond SM, in:

Rare decays, Penguin decays, Lepton sector, T violation

CPV measurements reported here today are NEW 2012.

sin 2β via New Penguin Decay Modes

Measure: sin 2β in radiative & hadronic penguin B decays

New Physics via virtual non-SM particles in loops

Many theorists: Critical place to look for new physics

Babar previously measured CPV in penguin decays (past results):

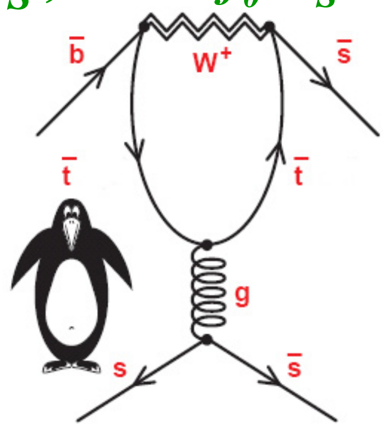
$B^0 \to \phi K^0_S$, $B^0 \to \eta' K^0_S$, $B^0 \to \pi^0 K^0_S$, $B^0 \to f_0 K^0_S$ - consistent with SM

Today: Brand new CPV results:

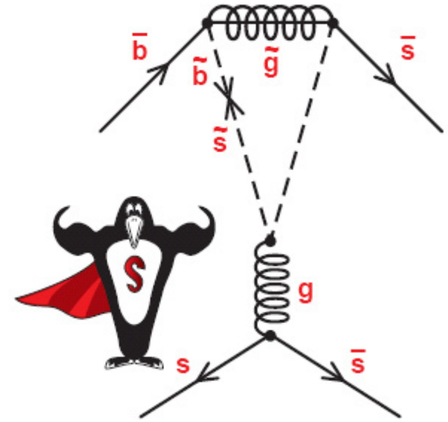
Time-dependant Dalitz analyses

$B^0 \to K^+ K^- K^0_S$ $B^0 \to K^0_S K^0_S K^0_S$

$B^+ \to K^+ K^- K^+$ $B^+ \to K^0_S K^0_S K^+$



Standard Model



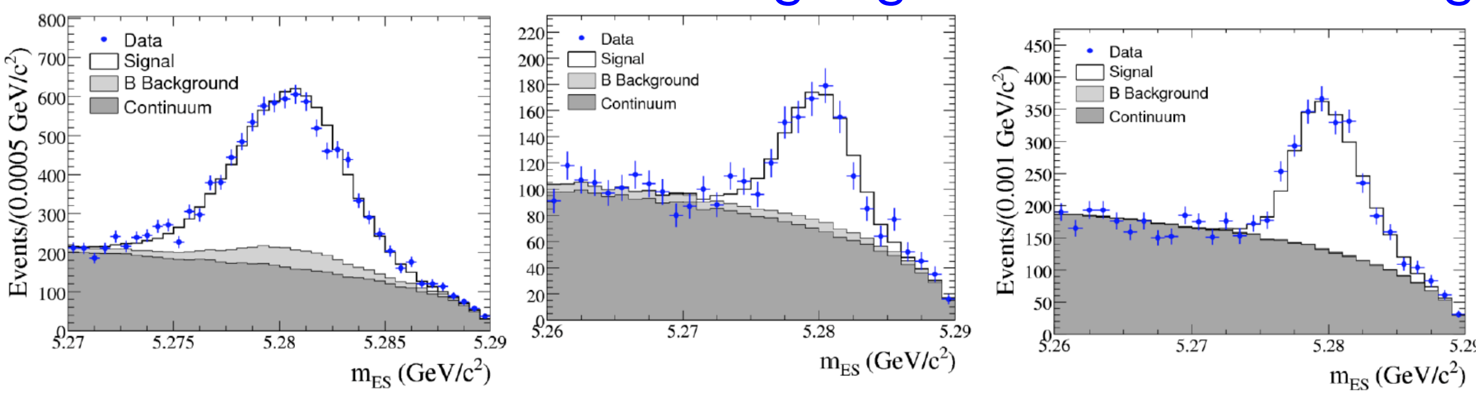
Beyond Standard Model

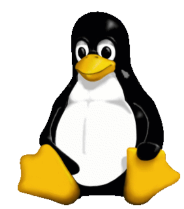
$B \to K\,K\,K$ (charged and/or neutral K's)

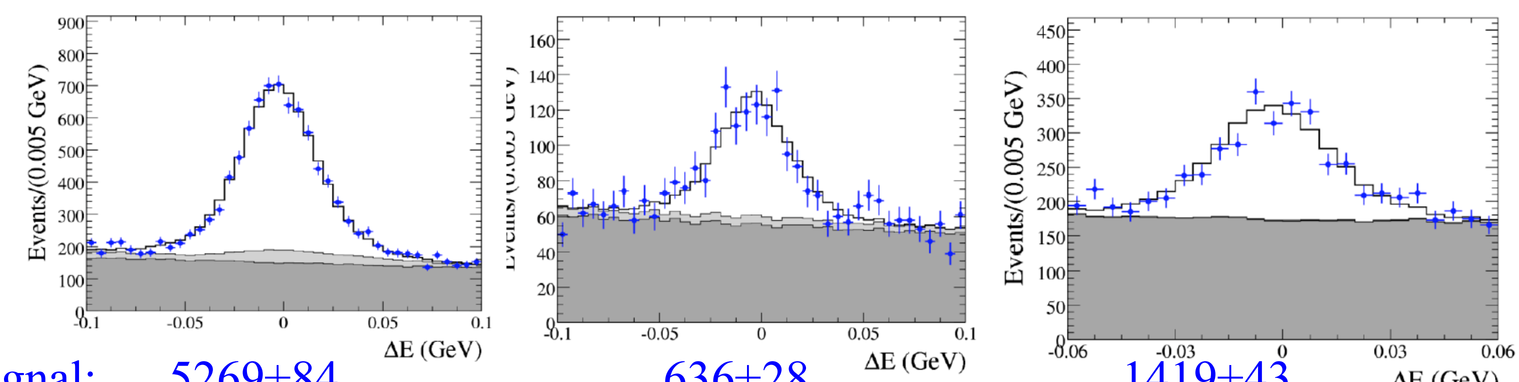
Sensitive to new physics via non-SM particles in loops.
Test deviations from precise SM predictions
Only Direct CPV possible in charged B decays   470million $B\bar{B}$ decays

kinematics to reduce backgrounds: $m_{ES} = \sqrt{\left(\sqrt{s}/2\right)^2 - p_B^{*2}}$ $\Delta E = E_B^* - \sqrt{s}/2$

$B^+ \to K^+K^-K^+$ $B^+ \to K^0_S K^0_S K^+$ $B^0 \to K^+K^-K^0_S$







hep-ex 1201.5897
(Accepted, PRD)

Signal: 5269±84   636±28   1419±43

$B \to K\,K\,K$

Parameters in Dalitz Plot model

Resonance	Parameters	Lineshape
$\phi(1020)$	$m_0 = 1019.455 \pm 0.020$ $\Gamma_0 = 4.26 \pm 0.04$	RBW
$f_0(980)$	$m_0 = 965 \pm 10$ $g_\pi = (0.165 \pm 0.018)\,\mathrm{GeV}^2/c^4$ $g_K/g_\pi = 4.21 \pm 0.33$	Flatté
$f_0(1500)$	$m_0 = 1505 \pm 6$ $\Gamma_0 = 109 \pm 7$	RBW
$f_0(1710)$	$m_0 = 1720 \pm 6$ $\Gamma_0 = 135 \pm 8$	RBW
$f_2'(1525)$	$m_0 = 1525 \pm 5$ $\Gamma_0 = 73^{+6}_{-5}$	RBW
NR decays		see text
χ_{c0}	$m_0 = 3414.75 \pm 0.31$ $\Gamma_0 = 10.3 \pm 0.6$	RBW

hep-ex 1201.5897
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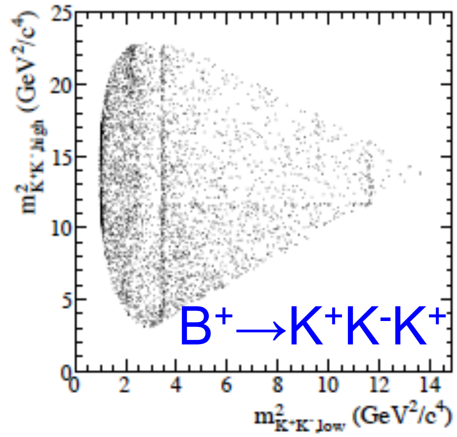
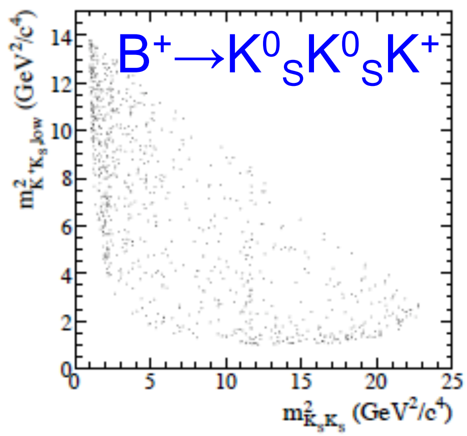
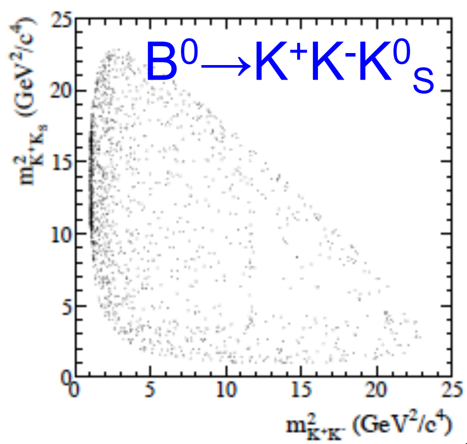






$B^+ \to K^+K^-K^+$ Direct CPV in $B^+ \to \phi K^+$ $A_{CP} = (12.8 \pm 4.4 \pm 1.3)\%$
= larger than SM expectation, non-zero at 2.8σ

$B^+ \to K^0_S K^0_S K^+$ $A_{CP} = (4^{+4}_{-5} \pm 2)\%$

$B^0 \to K^+K^-K^0_S$ CP violating phase $\beta_{eff}(\phi\, K^0_S) = (21 \pm 6 \pm 2)^\circ$

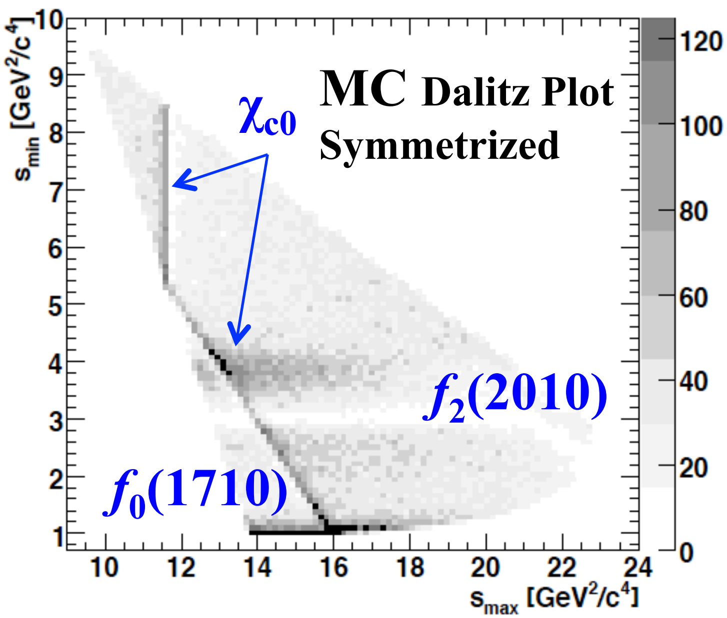
$B^0 \to K^0_S K^0_S K^0_S$ Time-independent analysis

Measure inclusive BF & intermediate resonant states (time-integrated)

CP-even eigenstate, low background: three K^0_S, theoretical uncertainties small.
At least 2 K^0_S decay via clean $\pi^+\pi^-$ – separated vertex
At most one K^0_S decays via $\pi^0\pi^0$ – less clean

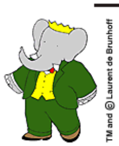
Three identical particles: amplitude is symmetrized

$$d\Gamma(B \to K^0_S K^0_S K^0_S) = \frac{1}{(2\pi)^3} \frac{|\mathcal{A}|^2}{32 m^3_{B^0}} ds_{\min} ds_{\max}$$



Parameters in Dalitz Plot model

Resonance	Parameters	Line shape
$f_0(980)$	$m_0 = (965 \pm 10)$ MeV$/c^2$ $g_\pi = (165 \pm 18)$ MeV$/c^2$ $g_K = (695 \pm 93)$ MeV$/c^2$	Flatté
$f_0(1710)$	$m_0 = (1724 \pm 7)$ MeV$/c^2$ $\Gamma_0 = (137 \pm 8)$ MeV$/c^2$	RBW
$f_2(2010)$	$m_0 = (2011^{+60}_{-80})$ MeV$/c^2$ $\Gamma_0 = (202 \pm 60)$ MeV$/c^2$ $r = r' = 1.5$ GeV^{-1}	RBW
NR decays	$\alpha = (-0.14 \pm 0.02)$ GeV$^{-2}\, c^4$	Exponential NR
χ_{c0}	$m_0 = (3414.75 \pm 0.31)$ MeV$/c^2$ $\Gamma_0 = (10.2 \pm 0.7)$ MeV$/c^2$	RBW

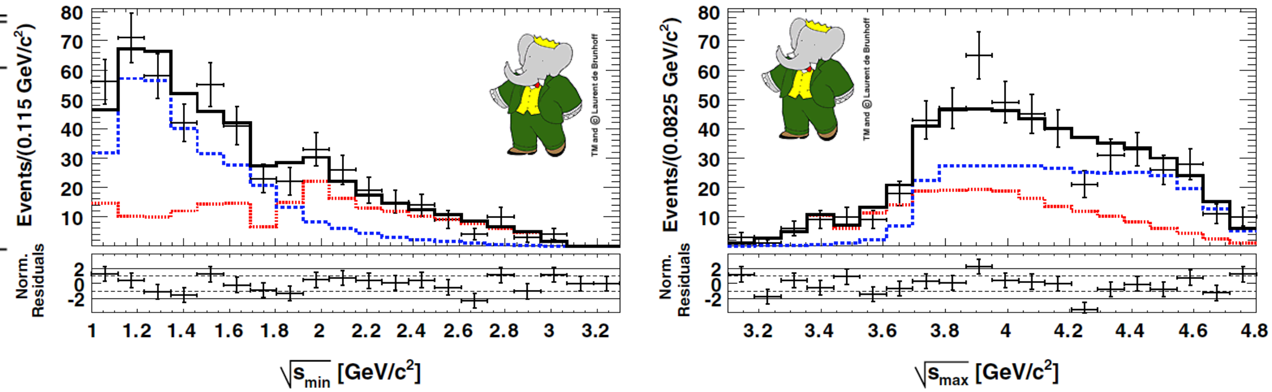


PRD 85, 054023 (2012)

$B^0 \to K^0_S K^0_S K^0_S$ Amplitude Analysis Results

Mode	Parameter	Global minimum Solution 1	Local minimum Solution 2
$f_0(980)K^0_S$	FF	$0.44\,^{+0.20}_{-0.19}$	$1.03\,^{+0.22}_{-0.17}$
	Phase [rad]	0.09 ± 0.16	1.26 ± 0.17
	$-2\Delta\ln\mathcal{L}$	11.7	-
	Significance [σ]	3.0	-
$f_0(1710)K^0_S$	FF	$0.07\,^{+0.07}_{-0.03}$	$0.09\,^{+0.05}_{-0.02}$
	Phase [rad]	1.11 ± 0.23	0.36 ± 0.20
	$-2\Delta\ln\mathcal{L}$	14.2	-
	Significance [σ]	3.3	-
$f_2(2010)K^0_S$	FF	$0.09\,^{+0.03}_{-0.03}$	0.10 ± 0.02
	Phase [rad]	2.50 ± 0.20	1.58 ± 0.22
	$-2\Delta\ln\mathcal{L}$	14.0	-
	Significance [σ]	3.3	-
NR	FF	$2.16\,^{+0.36}_{-0.37}$	$1.37\,^{+0.26}_{-0.21}$
	Phase [rad]	0.0	0.0
	$-2\Delta\ln\mathcal{L}$	68.1	-
	Significance [σ]	8.0	-
$\chi_{c0}K^0_S$	FF	$0.07\,^{+0.04}_{-0.02}$	0.07 ± 0.02
	Phase [rad]	0.63 ± 0.47	-0.24 ± 0.52
	$-2\Delta\ln\mathcal{L}$	18.5	-
	Significance [σ]	3.9	-
	Total FF	$2.84\,^{+0.71}_{-0.66}$	$2.66\,^{+0.35}_{-0.27}$

Signal 200±15, purity 40%



Two solutions

Solution 1 Branching fraction measurements

Mode	$\mathcal{B}$ [$\times 10^{-6}$]
Inclusive $B^0 \to K^0_S K^0_S K^0_S$	$6.19 \pm 0.48 \pm 0.15 \pm 0.12$
$f_0(980)K^0_S$, $f_0(980) \to K^0_S K^0_S$	$2.7\,^{+1.3}_{-1.2} \pm 0.4 \pm 1.2$
$f_0(1710)K^0_S$, $f_0(1710) \to K^0_S K^0_S$	$0.50\,^{+0.46}_{-0.24} \pm 0.04 \pm 0.10$
$f_2(2010)K^0_S$, $f_2(2010) \to K^0_S K^0_S$	$0.54\,^{+0.21}_{-0.20} \pm 0.03 \pm 0.52$
NR, $K^0_S K^0_S K^0_S$	$13.3\,^{+2.2}_{-2.3} \pm 0.6 \pm 2.1$
$\chi_{c0}K^0_S$, $\chi_{c0} \to K^0_S K^0_S$	$0.46\,^{+0.25}_{-0.17} \pm 0.02 \pm 0.21$

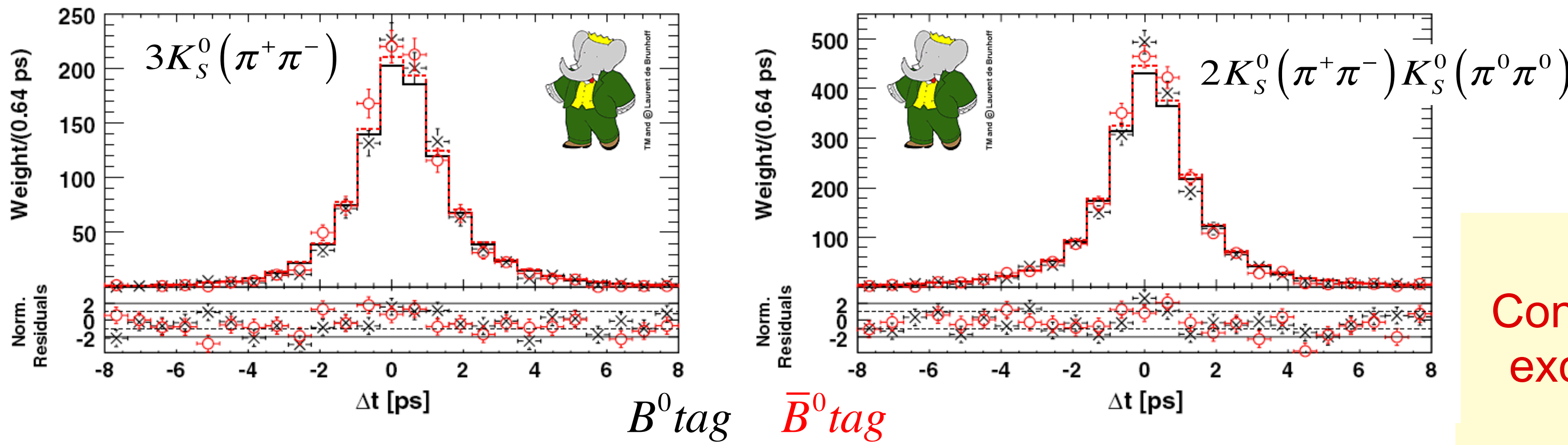
PRD 85, 054023 (2012)

$B^0 \rightarrow K^0_S K^0_S K^0_S$ Time-dependent CP analysis

Determine CPV in time-dependent analysis
Fit for CPV parameters $\mathcal{S}$ (mixing induced) and $\mathcal{C}$ (direct):

Proper-time difference PDF for give flavour tag q_{tag}:

$$\mathcal{P}^i_{sig}\left(\Delta t, \sigma_{\Delta t}; q_{tag}, c\right) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}} \left\{1 + q_{tag}\frac{\Delta D_c}{2} + q_{tag}\langle D_c\rangle\left[\mathcal{S}\sin\left(\Delta m_d \Delta t\right) - \mathcal{C}\cos\left(\Delta m_d \Delta t\right)\right]\right\} \otimes \mathcal{R}_{sig}\left(\Delta t, \sigma_{\Delta t}\right)$$

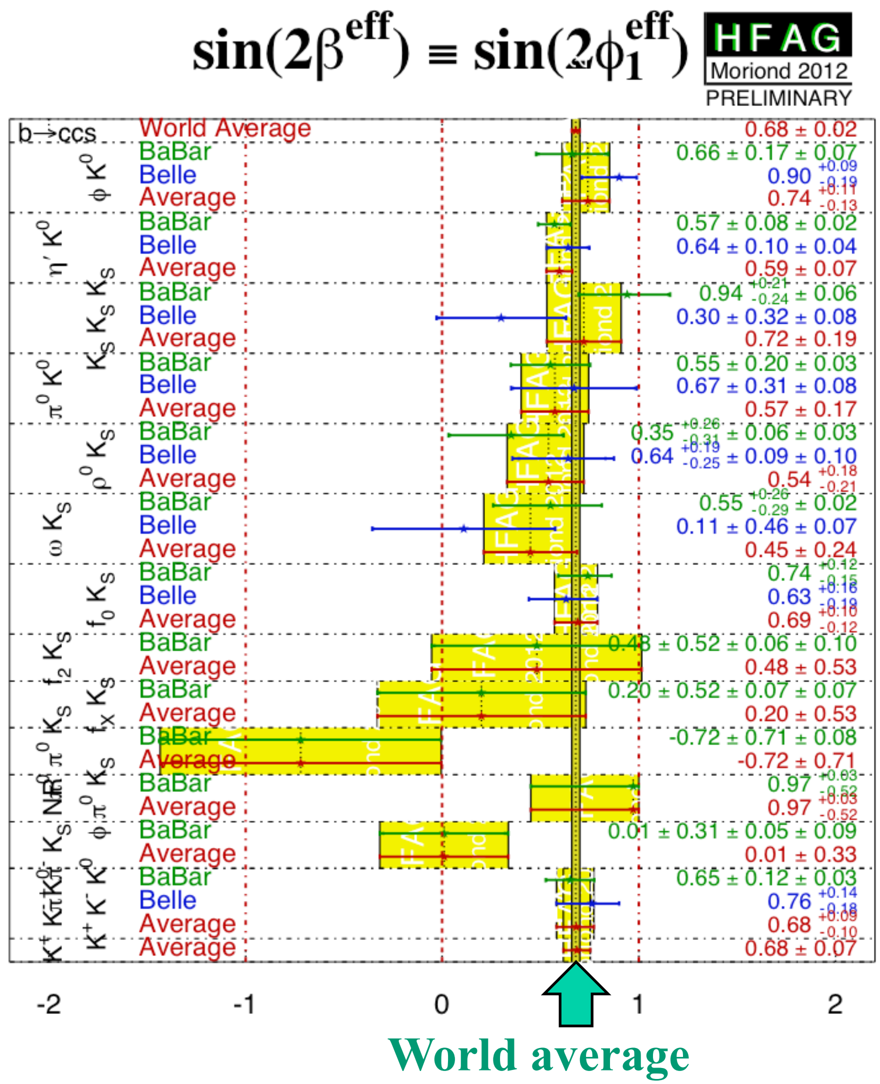


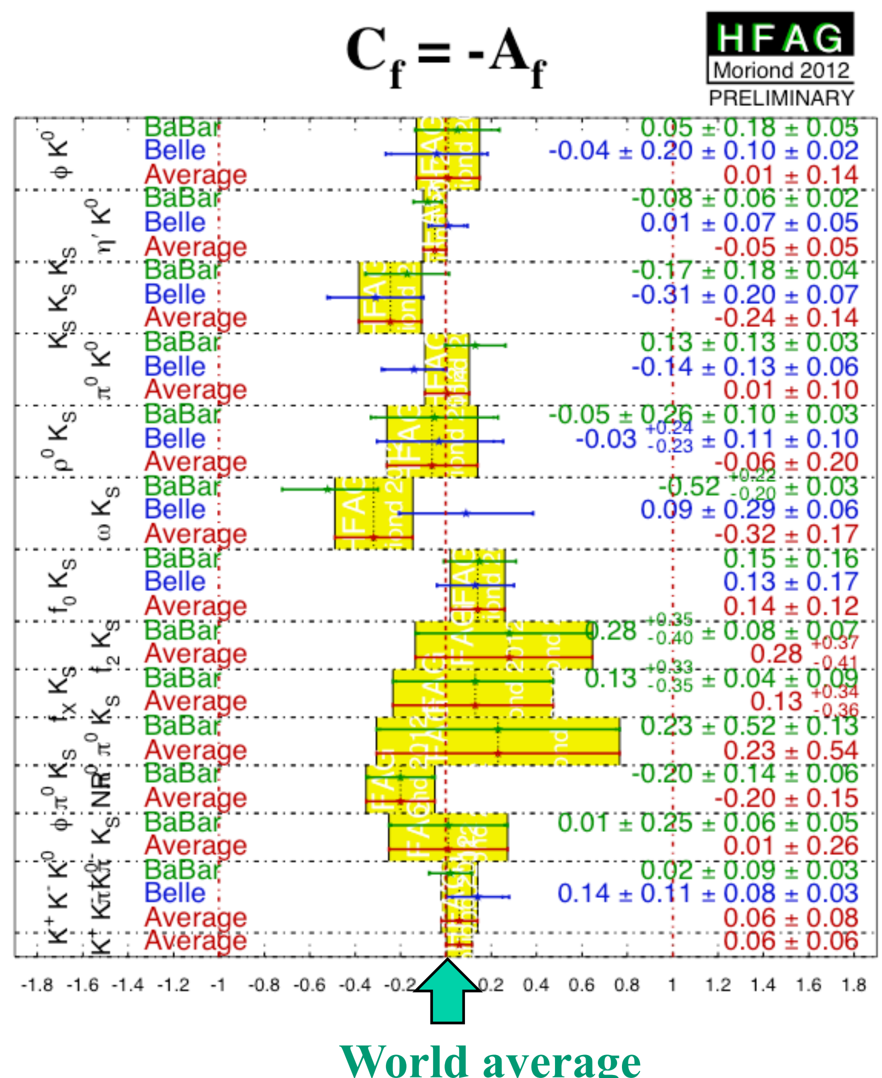
CP Conservation excluded at 3.8σ

Time dependent CPV parameters: $\mathcal{S} = -0.94^{+0.24}_{-0.21}$ $\mathcal{C} = -0.17 \pm 0.18$
Within 2σ of measurements in tree modes such as $J/\psi K^0_S$, as expected in SM

First evidence of CPV in $B^0 \rightarrow K^0_S K^0_S K^0_S$ PRD 85, 054023 (2012)

CP violation in Charmless B decays





CP Violation in τ Decay

In SM, CPV not expected in τ decay, except $\tau^- \to K_S^0 \pi^- \left(\geq 0\pi^0\right)\nu_\tau$

where the K^0_S is the source of CPV Bigi & Sanda, Phys Lett B 625, 47 (2005)

Must include K_S-K_L interference & decay time dependence Grossman & Nir, JHEP 1204 (2012)

$$A_Q = \frac{\Gamma\left(\tau^+ \to K_S^0 \pi^+ \overline{\nu}_\tau\right) - \Gamma\left(\tau^- \to K_S^0 \pi^- \nu_\tau\right)}{\Gamma\left(\tau^+ \to K_S^0 \pi^+ \overline{\nu}_\tau\right) + \Gamma\left(\tau^- \to K_S^0 \pi^- \nu_\tau\right)}$$ predict: (0.33±0.01)%

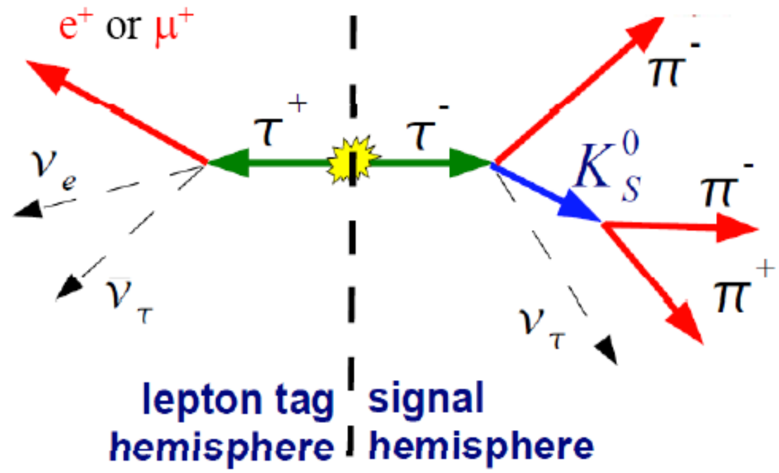
Deviation from this expectation would be sign of new physics.

One or more π^0's doesn't affect asymmetry

437million τ pairs, on/off ϒ(4S) resonance

Require one e or μ in one hemisphere and $K_S^0 \to \pi^+\pi^-$ in the other

Selected event topology



$$\tau^- \to K_S^0 \pi^- (\geq 0\pi^0) \nu_\tau$$

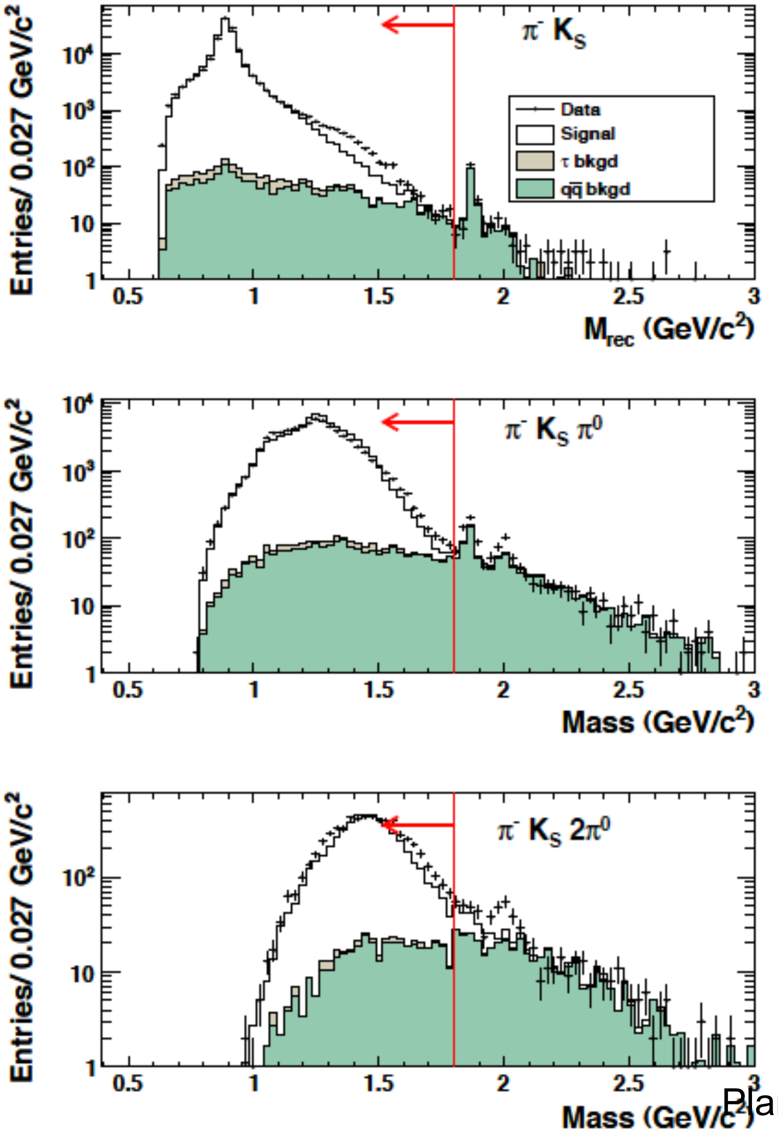


TABLE II: Summary of systematic uncertainties in the decay-rate asymmetries.

	e-tag	μ-tag
Detector and selection bias	0.12%	0.08%
Background subtraction	0.05%	0.06%
$K^0/\overline{K}^0$ interaction	0.01%	0.01%
Total	0.13%	0.10%

$$A_Q = (-0.36 \pm 0.23 \pm 0.11)\%$$

2.8σ from SM prediction of:

$$A_Q = (+0.36 \pm 0.01)\%$$

First time measured

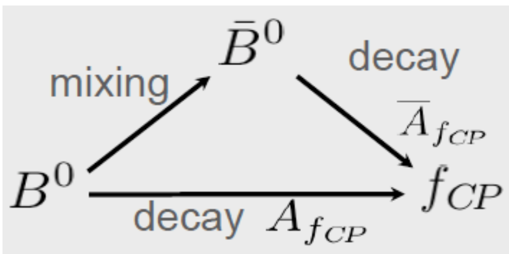
Phys. Rev. D 85, 031102 (2012)

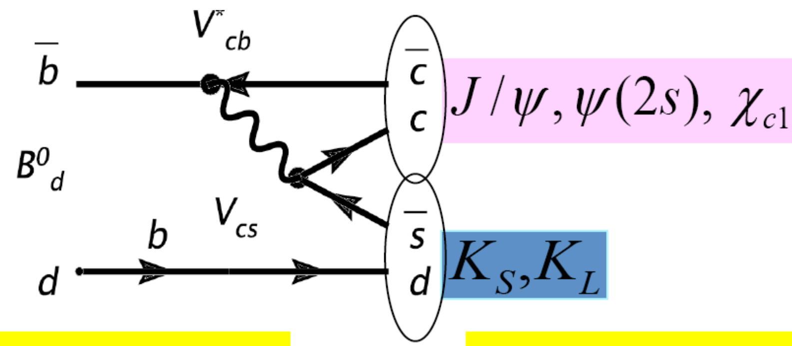
First Direct Observation of T-Violation in B^0 Meson system

CP violation in B system is well-established.

Now, first direct observation of Time Reversal Violation

BaBar Preliminary Result: First shown at FPCP Conference last week P. Villanueva-Pérez





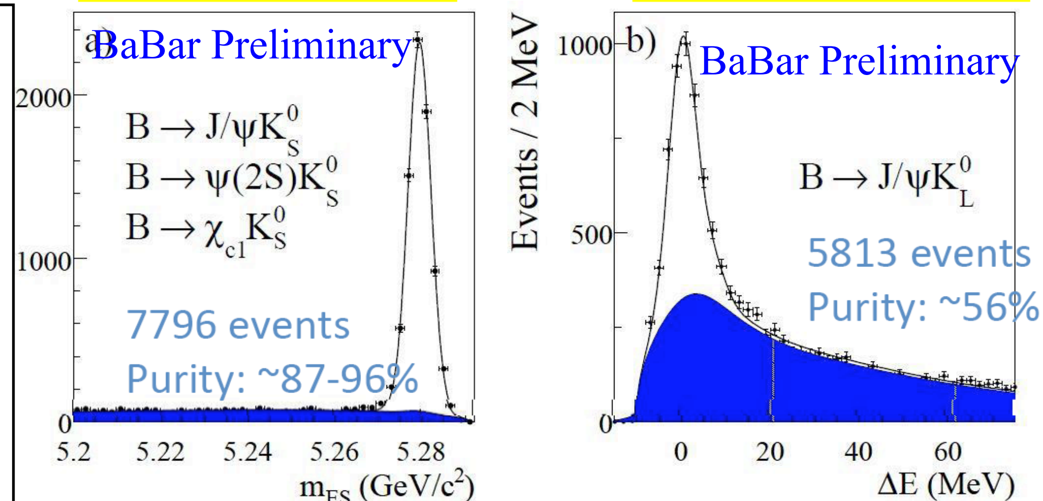
CPT EVEN	
$K^0 \to \bar{K}^0$ $B^0 \to \bar{B}^0$	$K^0 \to \bar{K}^0$ $B^0 \to \bar{B}^0$
CP ↓	T ↘
$\bar{K}^0 \to K^0$ $\bar{B}^0 \to B^0$	$\bar{K}^0 \to K^0$ $\bar{B}^0 \to B^0$

We cannot distinguish CP and T.

Not a DIRECT observation of TRV

Projects CP odd B_-

Projects CP even B_+



First Direct Observation of T-Violation in B^0 Meson system

$\Upsilon(4S)$ produces an entangled $B^0\bar{B}^0$ state:

$$|\psi_i\rangle = \frac{1}{\sqrt{2}}\left[B^0(t_1)\bar{B}^0(t_2) - \bar{B}^0(t_1)B^0(t_2)\right] = \frac{1}{\sqrt{2}}\left[B_+(t_1)\bar{B}_-(t_2) - \bar{B}_-(t_1)B_+(t_2)\right]$$

Two *B* bosons in symmetric state: Bose statistics , C=−

$\Upsilon(4S)$ has J=1, B's are spin 0 ∴ L=1. ➙ B's in opposite state (when one oscillates, so must the other)

Reconstruct one B to CP eigenstate, identify flavour of other B :

T violation: Examine difference: $B^0 \to B_+$ and $B_+ \to B^0$

Physical Process Reconstructed states (X,Y)

Reference (X, Y)	***T-Transformed (X, Y)***
$B^0 \to B_+$ (l^- , $J/\psi\ K_L$)	$B_+ \to B^0$ ($J/\psi\ K_S$, l^+)
$B^0 \to B_-$ (l^- , $J/\psi\ K_S$)	$B_- \to B^0$ ($J/\psi\ K_L$, l^+)
$\bar{B}^0 \to B_+$ (l^+ , $J/\psi\ K_L$)	$B_+ \to \bar{B}^0$ ($J/\psi\ K_S$, l^-)
$\bar{B}^0 \to B_-$ (l^+ , $J/\psi\ K_S$)	$B_- \to \bar{B}^0$ ($J/\psi\ K_L$, l^-)

$\Delta\tau = t_Y - t_X > 0$

Four independent processes to compare

Signal model: T-Violation

Each of 8 transitions has time-dependent decay rate:

$$g^{\pm}_{\alpha,\beta}(\tau) \propto e^{-\Gamma|\tau|}\left\{1+S^{\pm}_{\alpha,\beta}\sin(\Delta m_d \tau)+C^{\pm}_{\alpha,\beta}\cos(\Delta m_d \tau)\right\} \quad \text{with } \alpha=\ell^+X,\ell^-X; \quad \beta = c\bar{c}K^0_S, J/\psi K^0_L$$

$$\mathcal{H}_{\alpha,\beta}(\Delta t) \propto g^{+}_{\alpha,\beta}(\Delta t_{true}) \times H(\Delta t_{true}) \otimes \Re(\delta t, \sigma_{\Delta t}) + g^{-}_{\alpha,\beta}(-\Delta t_{true}) \times H(-\Delta t_{true}) \otimes \Re(\delta t, \sigma_{\Delta t})$$

Γ=average decay width $\quad \Delta t_{true}=t_{CP}-t_{flav} \quad \Delta\tau=t_y-t_x$

Δm=mass difference between B mass eigenstates

H(t)= Heaviside function

C and S coefficients: upper index + or − indicates if the decay to flavour final state α occurred before or after the CP final state β

8 different sets of S and C parameters:

$$\boxed{2\,\Delta t(\Delta t>0, \Delta t<0)} \times \boxed{2\,flavour(B^0, \bar{B}^0)} \times \boxed{2\,CP(K_S, K_L)}$$

Perform unbinned maximum likelihood fit.

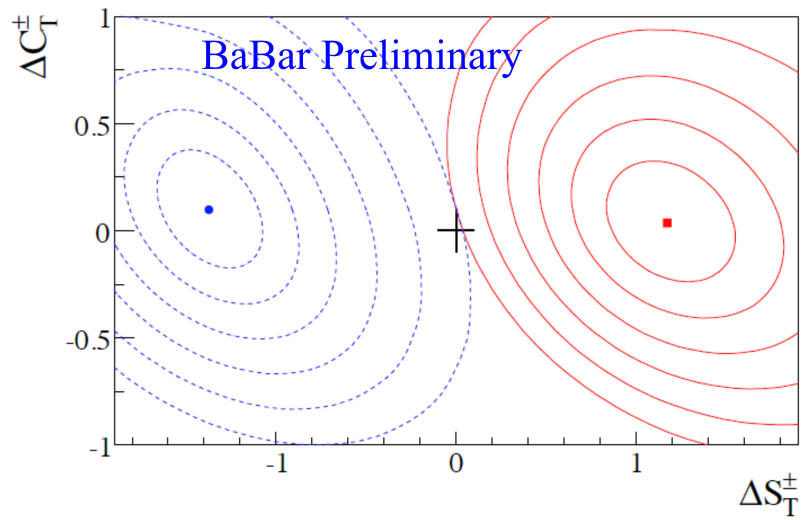
Contrast with "classic" CPV analysis, one set of parameters, S, C:

$$g^{\pm}_{\alpha,\beta}(\Delta t) \propto e^{-\Gamma|\Delta t|}\left\{1 \pm \eta_f S\sin(\Delta m_d \Delta t)+C\cos(\Delta m_d \Delta t)\right\} \quad \text{and assumes CPT and } \Delta\Gamma = 0$$

T-Violation in B^0 Meson system

Parameter	Result
$\Delta S_T^+ = S^-_{\ell^- X, J/\psi K_L^0} - S^+_{\ell^+ X, c\bar{c}K_S^0}$	$-1.37 \pm 0.14 \pm 0.06$
$\Delta S_T^- = S^+_{\ell^- X, J/\psi K_L^0} - S^-_{\ell^+ X, c\bar{c}K_S^0}$	$1.17 \pm 0.18 \pm 0.11$
$\Delta C_T^+ = C^-_{\ell^- X, J/\psi K_L^0} - C^+_{\ell^+ X, c\bar{c}K_S^0}$	$0.10 \pm 0.16 \pm 0.08$
$\Delta C_T^- = C^+_{\ell^- X, J/\psi K_L^0} - C^-_{\ell^+ X, c\bar{c}K_S^0}$	$0.04 \pm 0.16 \pm 0.08$
$\Delta S_{CP}^+ = S^+_{\ell^- X, c\bar{c}K_S^0} - S^+_{\ell^+ X, c\bar{c}K_S^0}$	$-1.30 \pm 0.10 \pm 0.07$
$\Delta S_{CP}^- = S^-_{\ell^- X, c\bar{c}K_S^0} - S^-_{\ell^+ X, c\bar{c}K_S^0}$	$1.33 \pm 0.12 \pm 0.06$
$\Delta C_{CP}^+ = C^+_{\ell^- X, c\bar{c}K_S^0} - C^+_{\ell^+ X, c\bar{c}K_S^0}$	$0.07 \pm 0.09 \pm 0.03$
$\Delta C_{CP}^- = C^-_{\ell^- X, c\bar{c}K_S^0} - C^-_{\ell^+ X, c\bar{c}K_S^0}$	$0.08 \pm 0.10 \pm 0.04$
$\Delta S_{CPT}^+ = S^-_{\ell^+ X, J/\psi K_L^0} - S^+_{\ell^+ X, c\bar{c}K_S^0}$	$0.16 \pm 0.20 \pm 0.09$
$\Delta S_{CPT}^- = S^+_{\ell^+ X, J/\psi K_L^0} - S^-_{\ell^+ X, c\bar{c}K_S^0}$	$-0.03 \pm 0.13 \pm 0.06$
$\Delta C_{CPT}^+ = C^-_{\ell^+ X, J/\psi K_L^0} - C^+_{\ell^+ X, c\bar{c}K_S^0}$	$0.15 \pm 0.17 \pm 0.07$
$\Delta C_{CPT}^- = C^+_{\ell^+ X, J/\psi K_L^0} - C^-_{\ell^+ X, c\bar{c}K_S^0}$	$0.03 \pm 0.14 \pm 0.08$

Fit coefficients:



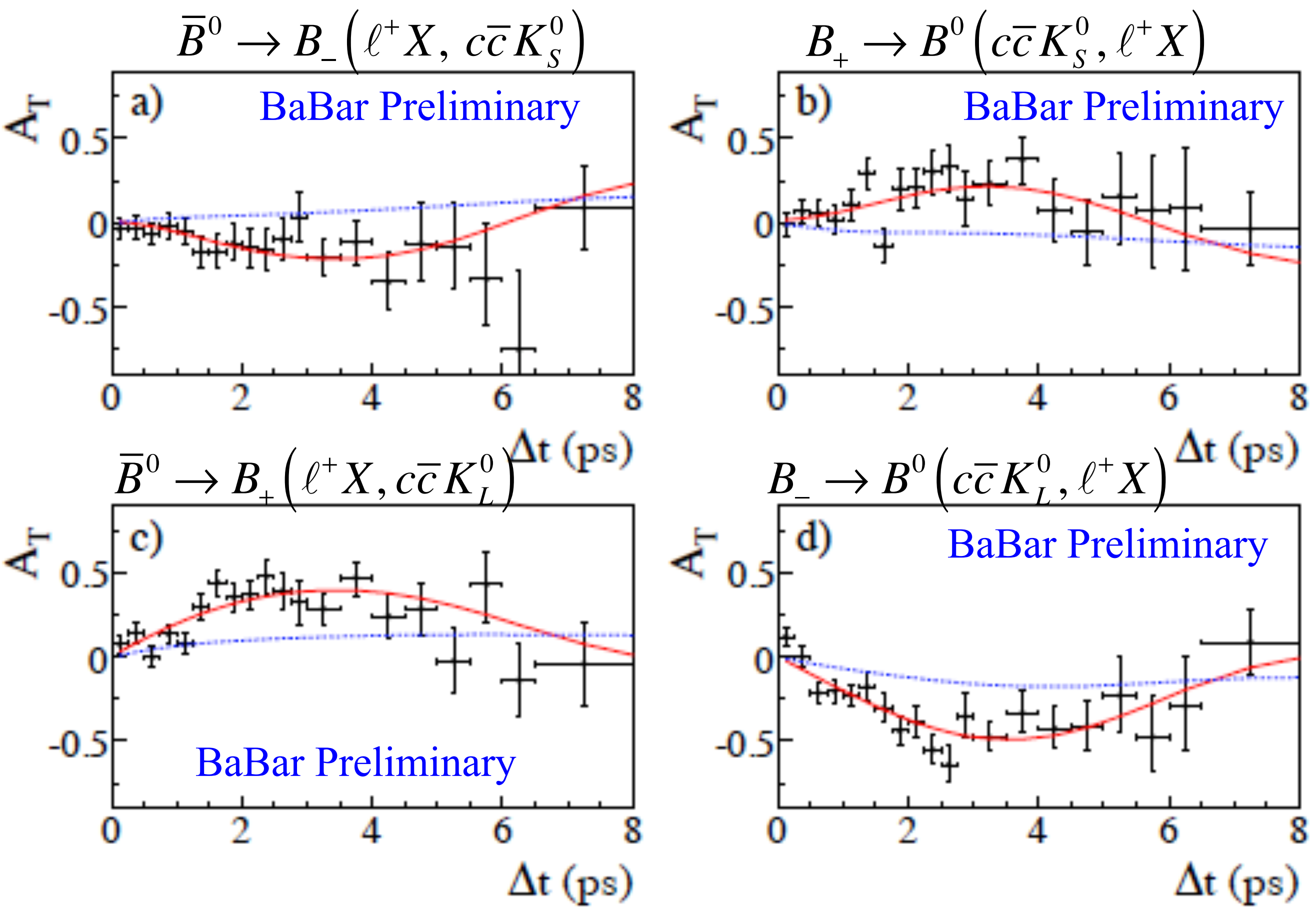
Cross checks:

$$c\bar{c}K^+, J/\psi K^{*+}$$

charged final states
(✓all fit to zero: unbiased)

BaBar Preliminary Result

T-Violation in B^0 Meson system



—Fit with T violation

—Fit without T violation

First direct observation of Time Reversal Violation, in ANY system

$\Delta S_T^{+} = -1.37 \pm 0.14 \pm 0.06$

$\Delta S_T^{-} = 1.17 \pm 0.18 \pm 0.11$

BaBar Preliminary Result

T violation, independent of CP, CPT

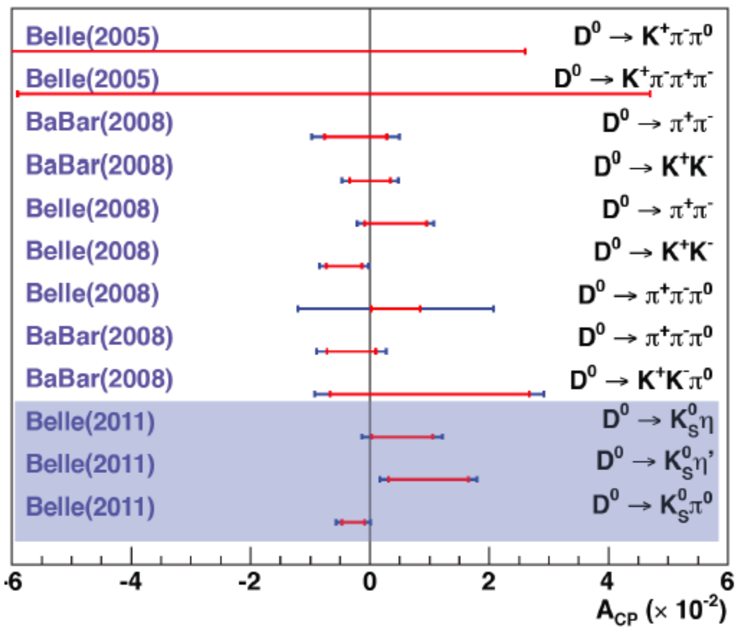
14σ significance

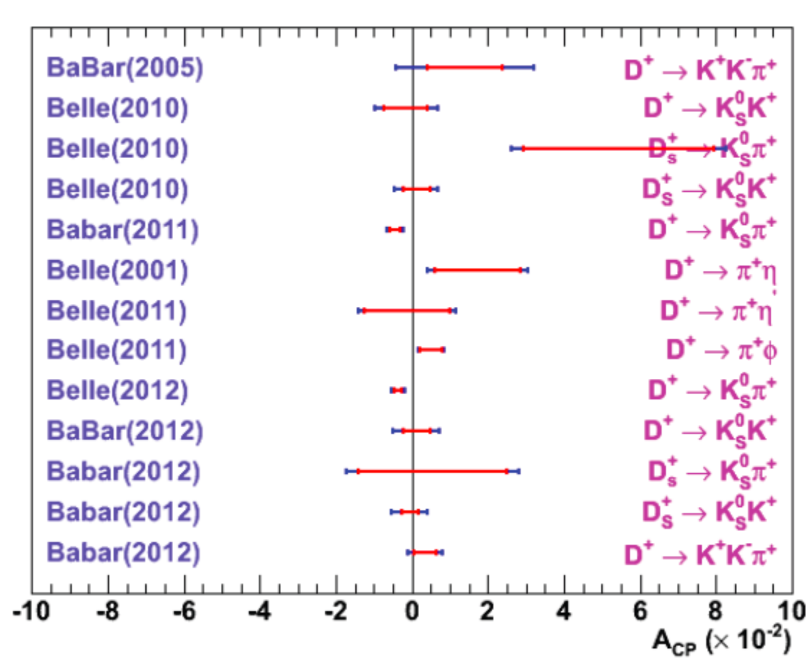
Result consistent with CPV, assuming CPT

BaBar (&Belle) Charm CPV Results

Motivating talk by Jernej Kamenik at this conference:
Direct CP violation in charm decays

Out of time, but: Time-integrated Measurements: CPV in D decays:





Summary from FPCP Conference (May 2012)

LHCb (First) evidence for CPV in charm: Marconi on Friday

Summary

Standard Model is amazingly self-consistent

Verified KM model of CPV: SM is consistent

Searched for and found new results of CP violation in penguins & τs

First time ever, observed direct T violation, independent of CPV.

No new physics beyond SM, all consistent with SM

B Factories will continue to be prime place to look for New Physics.

There must be more CP violation in new physics (here? neutrino sector?)

because phase in CKM theory can't accommodate cosmological asymmetry.

INTERESTING to confirm everything we know about Standard Model.

EVEN MORE INTERESTING to find a place where it breaks down!

Still mining data

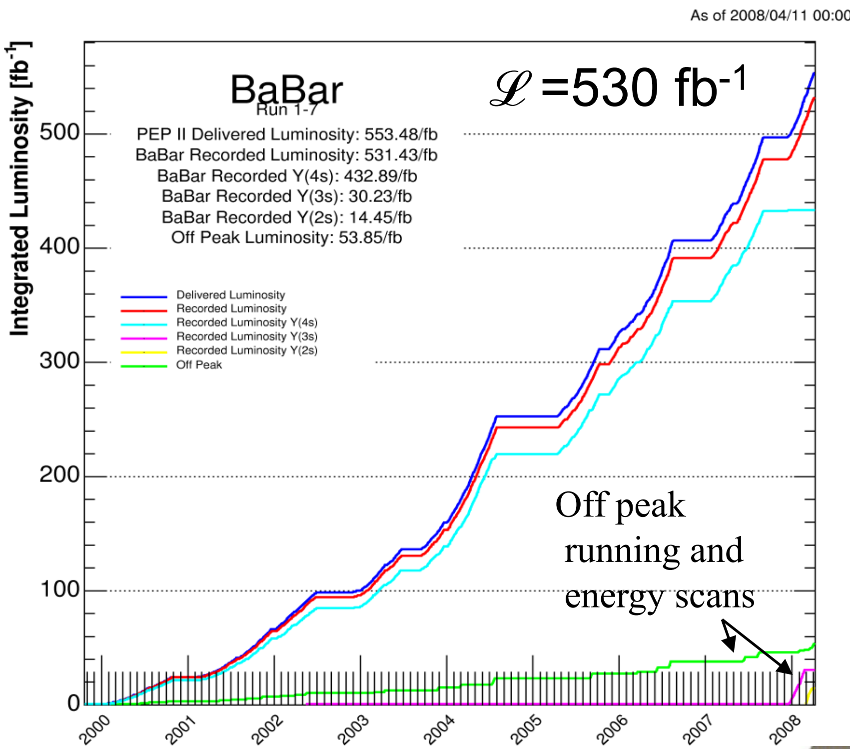
- ♥ We've been looking for inconsistencies in SM
- ♥Measure angles and sides of UT - all 3 for constraints
- ♥ Search for new physics, new sources of CPV

Direct CP violation Rare B decays

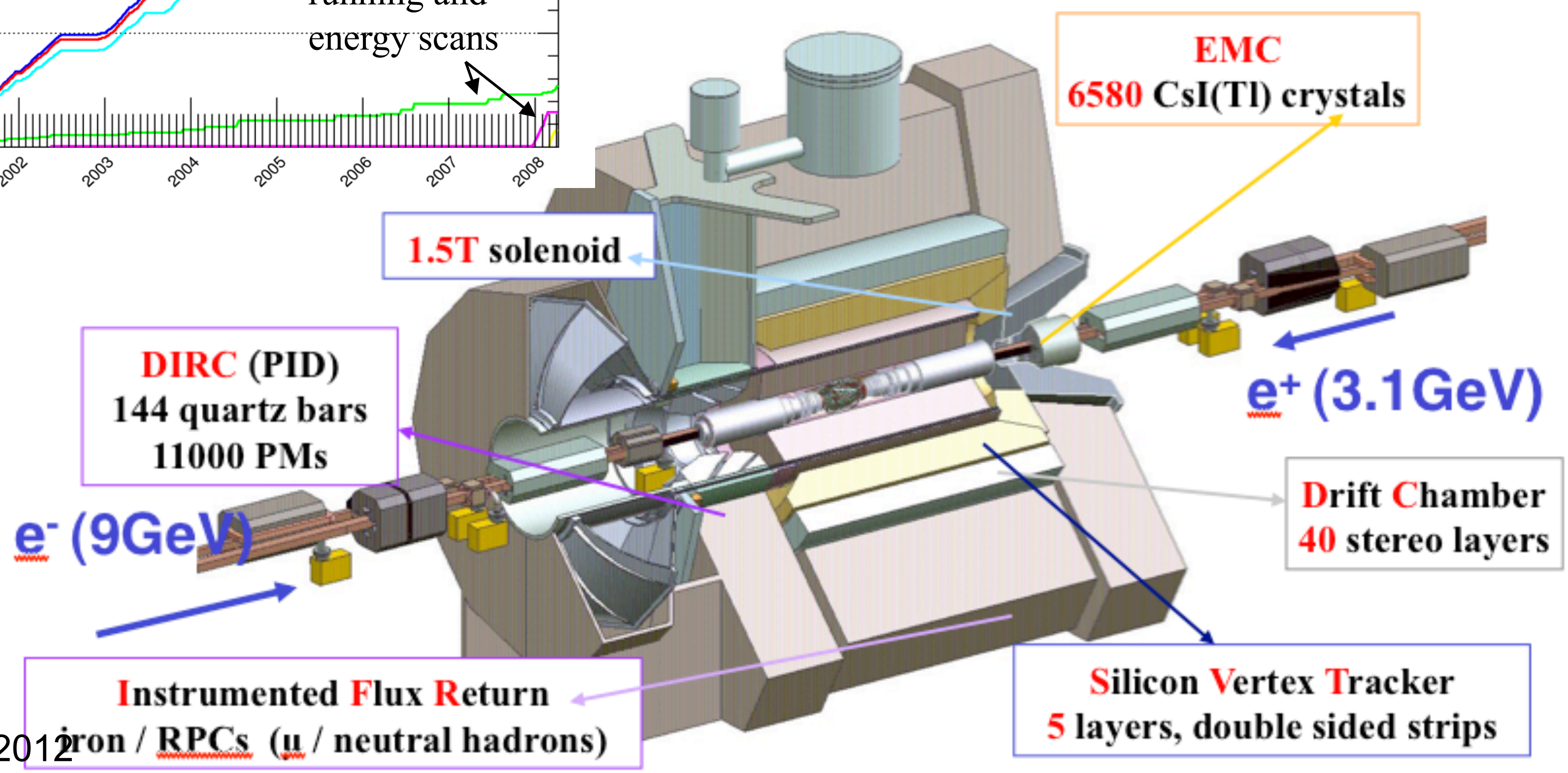
The End

Spares/Backup

BABAR Detector

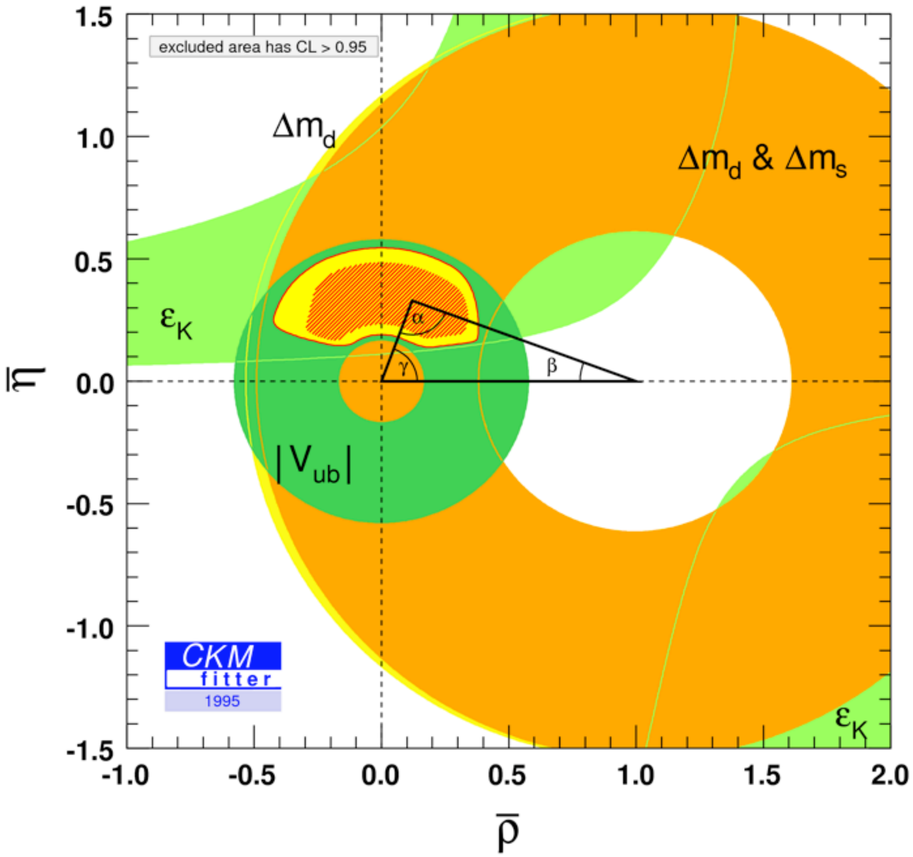


470 million B $\bar{B}$ pairs
> 4 Pb data recorded
> 500 papers

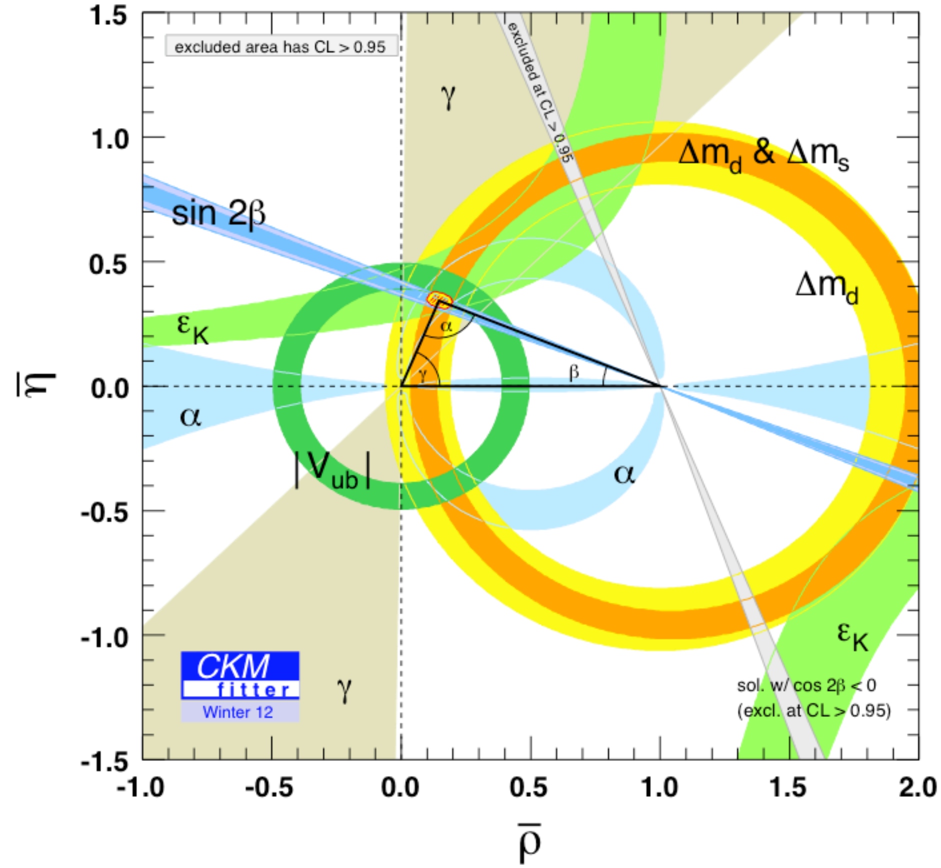


CKM Measurements

1995



2012

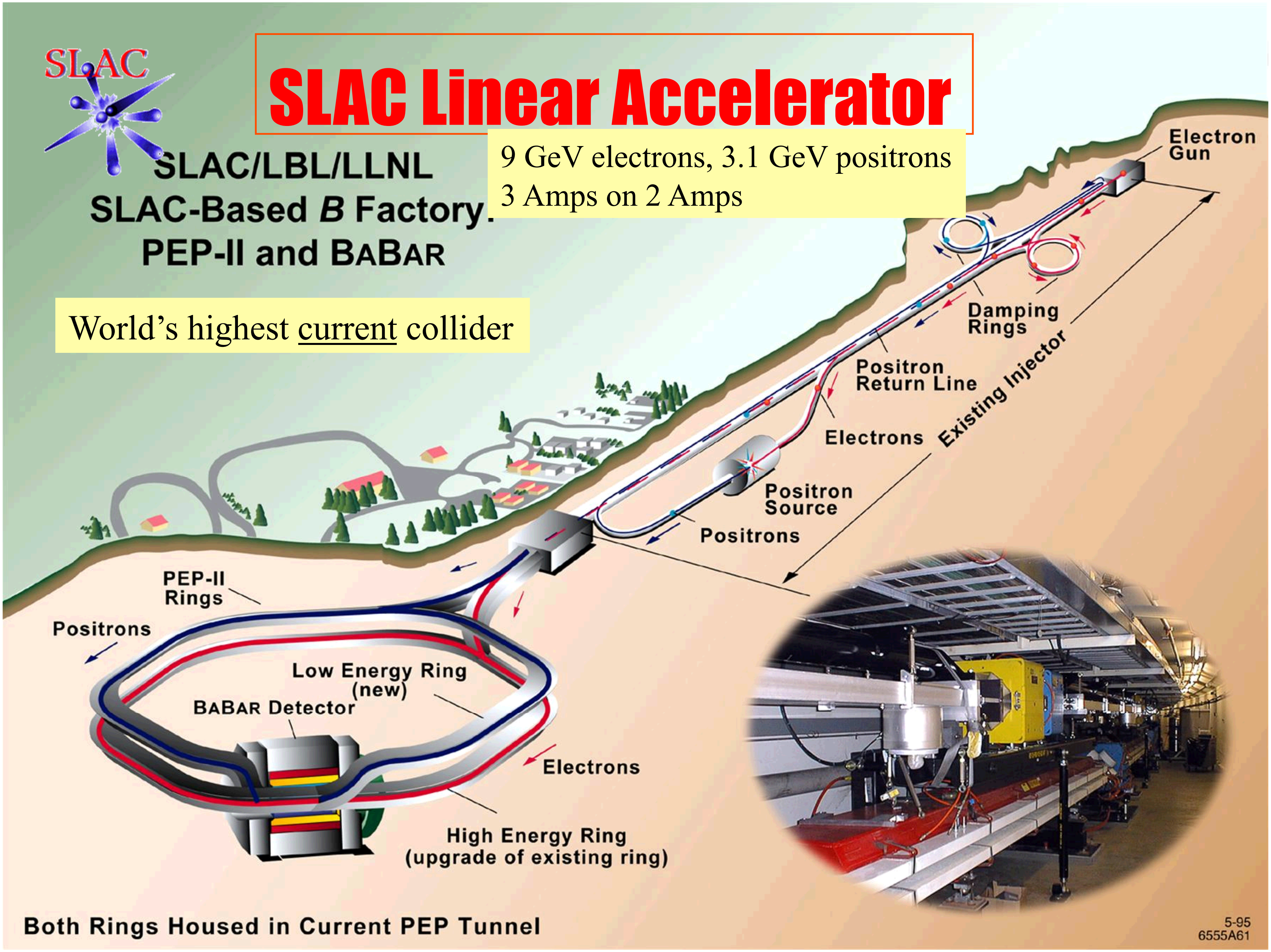


→ amazing precison and consistency

SLAC Linear Accelerator

9 GeV electrons, 3.1 GeV positrons
3 Amps on 2 Amps

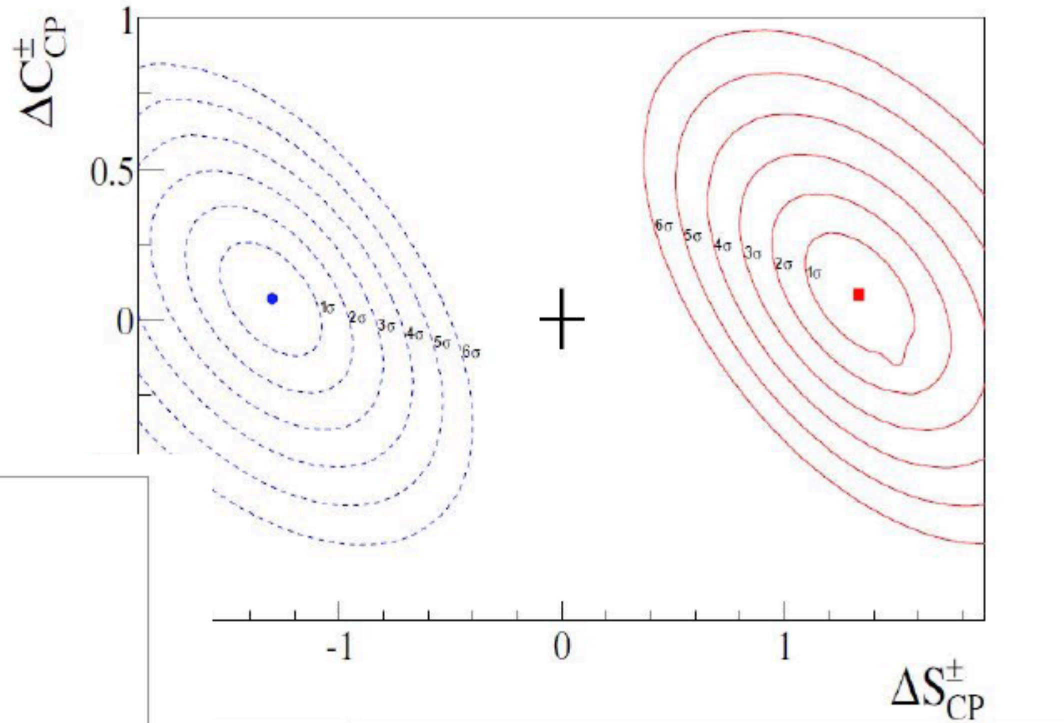
World's highest current collider

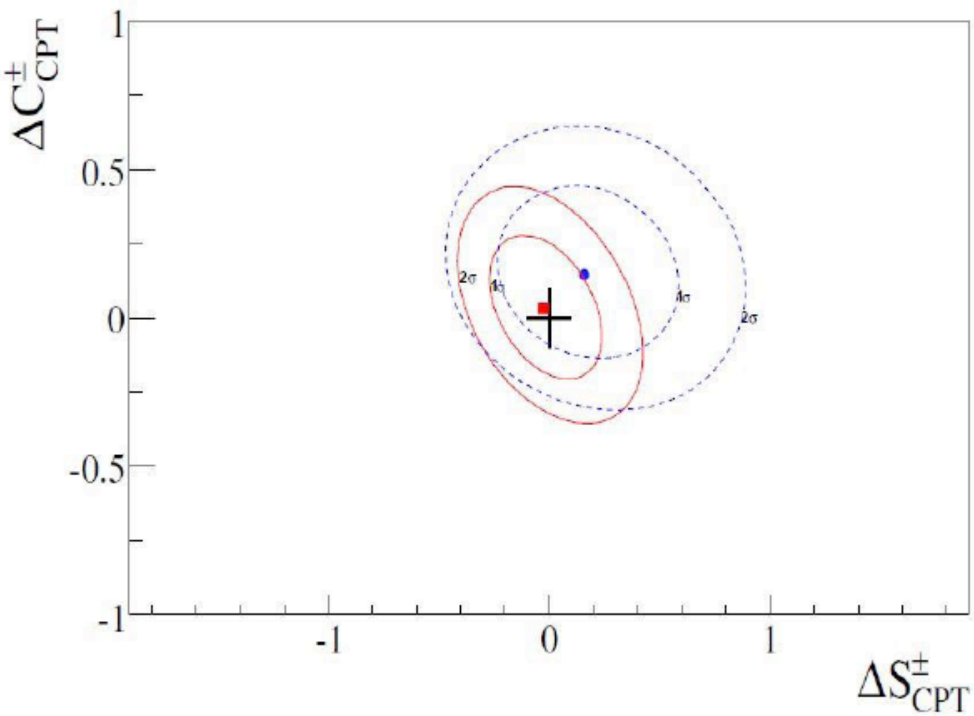


Significance including systematics

T violation analysis

$$
\begin{aligned}
\Delta S^{+}_{CP} &= -1.30 \pm 0.10 \pm 0.07\\
\Delta S^{-}_{CP} &= 1.33 \pm 0.12 \pm 0.06\\
\Delta C^{+}_{CP} &= 0.07 \pm 0.10 \pm 0.03\\
\Delta C^{-}_{CP} &= 0.08 \pm 0.09 \pm 0.04
\end{aligned}
$$





$$
\begin{aligned}
\Delta S^{+}_{CPT} &= 0.16 \pm 0.20 \pm 0.09\\
\Delta S^{-}_{CPT} &= -0.03 \pm 0.13 \pm 0.06\\
\Delta C^{+}_{CPT} &= 0.15 \pm 0.17 \pm 0.07\\
\Delta C^{-}_{CPT} &= 0.03 \pm 0.14 \pm 0.08
\end{aligned}
$$

Significance of T violation only stat.

T invariance	CP invariance	CPT invariance
$\Delta S^+_{\mathrm{T}} = 0$	$\Delta S^+_{\mathrm{CP}} = 0$	$\Delta S^+_{\mathrm{CPT}} = 0$
$\Delta S^-_{\mathrm{T}} = 0$	$\Delta S^-_{\mathrm{CP}} = 0$	$\Delta S^-_{\mathrm{CPT}} = 0$
$\Delta S^+_{\mathrm{CP}} = \Delta S^+_{\mathrm{CPT}}$	$\Delta S^+_{\mathrm{T}} = \Delta S^+_{\mathrm{CPT}}$	$\Delta S^+_{\mathrm{T}} = \Delta S^+_{\mathrm{CP}}$
$\Delta S^-_{\mathrm{CP}} = \Delta S^-_{\mathrm{CPT}}$	$\Delta S^-_{\mathrm{T}} = \Delta S^-_{\mathrm{CPT}}$	$\Delta S^-_{\mathrm{T}} = \Delta S^-_{\mathrm{CP}}$
$\Delta C^+_{\mathrm{T}} = 0$	$\Delta C^+_{\mathrm{CP}} = 0$	$\Delta C^+_{\mathrm{CPT}} = 0$
$\Delta C^-_{\mathrm{T}} = 0$	$\Delta C^-_{\mathrm{CP}} = 0$	$\Delta C^-_{\mathrm{CPT}} = 0$
$\Delta C^+_{\mathrm{CP}} = \Delta C^+_{\mathrm{CPT}}$	$\Delta C^+_{\mathrm{T}} = \Delta C^+_{\mathrm{CPT}}$	$\Delta C^+_{\mathrm{T}} = \Delta C^+_{\mathrm{CP}}$
$\Delta C^-_{\mathrm{CP}} = \Delta C^-_{\mathrm{CPT}}$	$\Delta C^-_{\mathrm{T}} = \Delta C^-_{\mathrm{CPT}}$	$\Delta C^-_{\mathrm{T}} = \Delta C^-_{\mathrm{CP}}$

1. We obtain the likelihood value of the fit to S, C for the 8 independent samples (Standard Fit).
2. We repeat the fit, reassembling the parameters for T-conjugated processes, to forbid T violation.
3. Significance of T violation evaluated from the difference of the likelihood values.
4. Raw asymmetries and fit projections can be now plotted in the standard way.

$$\boxed{\begin{array}{l}\Delta\chi^2 = -2(\ln L_{No\_T\_Violation} - \ln L) \\ \Delta\nu = 8\end{array}}$$

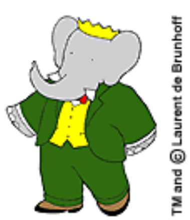
5. CP, and CPT significance is evaluated similarly.
6. Using Gaussian approximation, we evaluate the change of likelihood in 1σ systematic variation.

$$m_j^2 = -2[\ln L(q_j, o_j) - \ln L(p_0)] / s^2_{stat,j}$$

7. We take the $\max\{m_j^2\}$ and we devide our significace (s^2) by ($1+\max\{m_j^2\}$)

SLAC Linear Accelerator

At
Stanford U



May 30, 2012