Experimental Status of sin2β in Golden Modes

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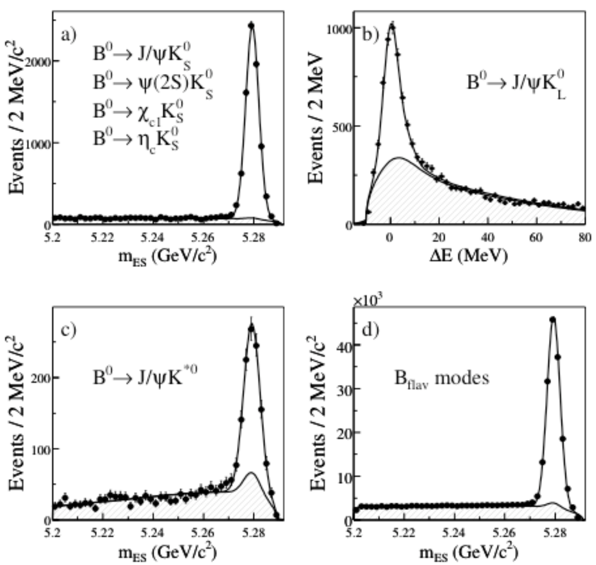
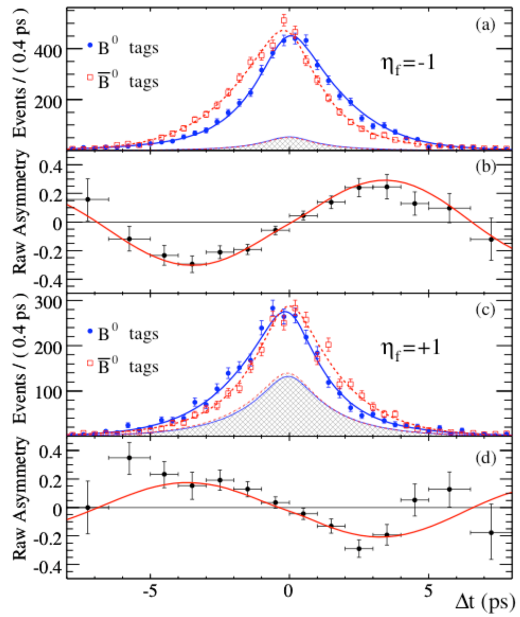
Golden modes

- B^0 decays to a charmonium state plus a $K^{(*)0}$.
- Theoretically clean.
- Copious amount of events: BaBar reconstructs/tags ~33 events/million BBbar at purity of 75%, or ~12 J/ψKs(π+π-) events/million BBbar at purity of 96%.
- BaBar uses $J/\psi K^0_S$, $J/\psi K^0_L$, $\psi(2S) K^0_S$, $\eta_c K^0_S$, $\chi_{c1} K^0_S$, and $J/\psi K^*(892)^0$
- Belle doesn't use as many modes.

Latest results

- BaBar: 465x10^6 BBbar pairs: (final result)





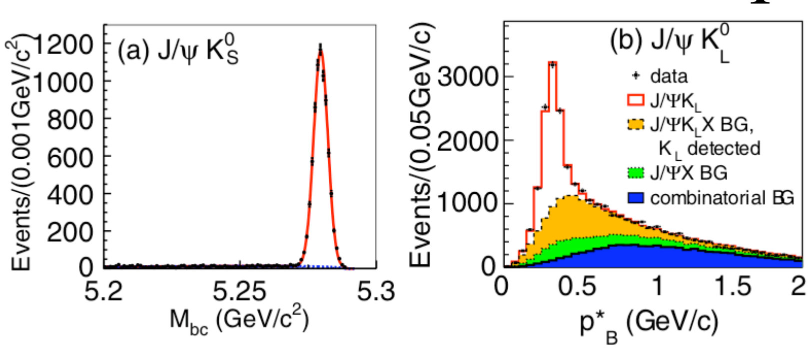
BaBar arXiv:0902.1708 [hep-ex]
accepted by PRD

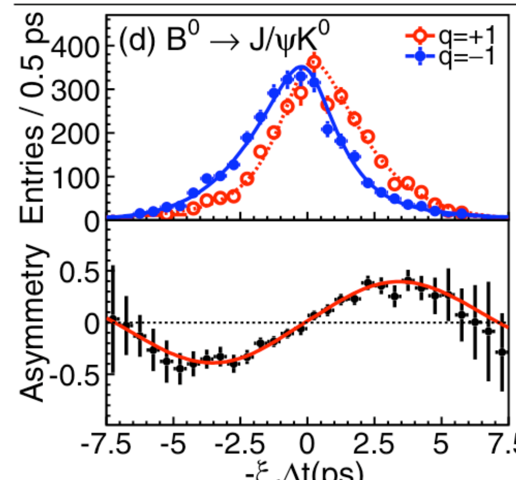
$$C_f = 0.024 \pm 0.020\,(\mathrm{stat}) \pm 0.016\,(\mathrm{syst}),$$
$$-\eta_f S_f = 0.687 \pm 0.028\,(\mathrm{stat}) \pm 0.012\,(\mathrm{syst}),$$

- Belle: 535x10^6 BBbar pairs:

Belle PRL **98,** 031802 (2007)

Mode	$\sin 2\phi_1^{\mathrm{eff}}$	$\mathcal{A}_f = -C_f$
$J/\psi K^0$	$+0.642 \pm 0.031 \pm 0.017$	$+0.018 \pm 0.021 \pm 0.014$

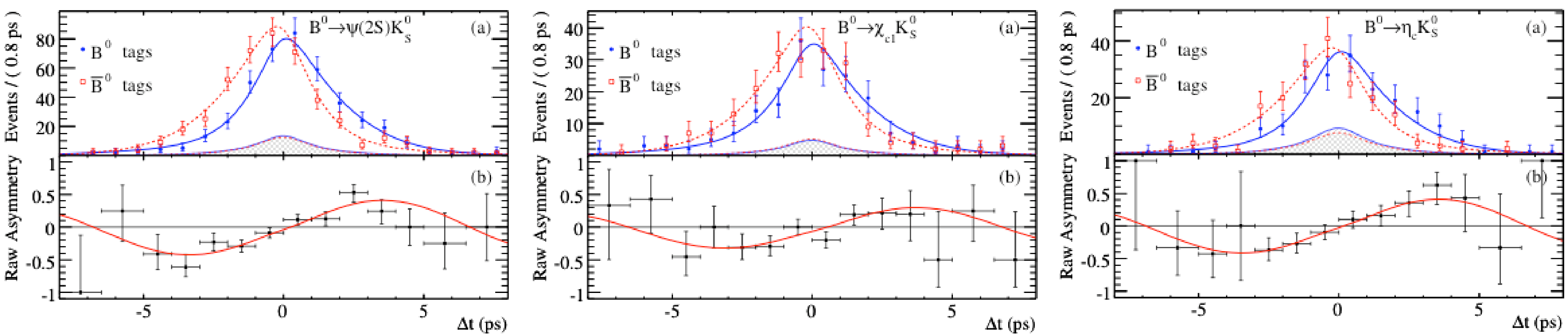




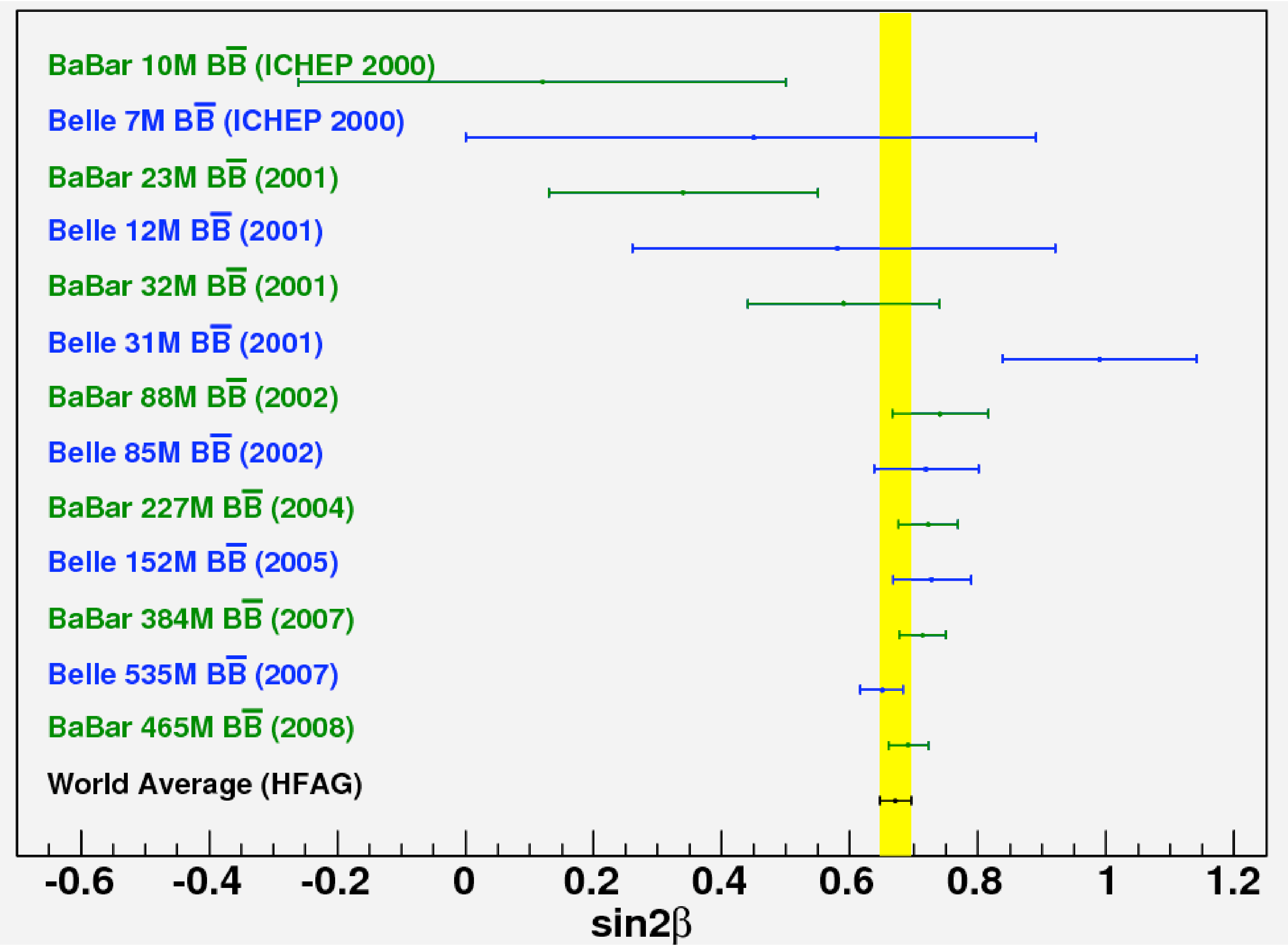
Other charmonium modes are measured quite precisely too

BaBar

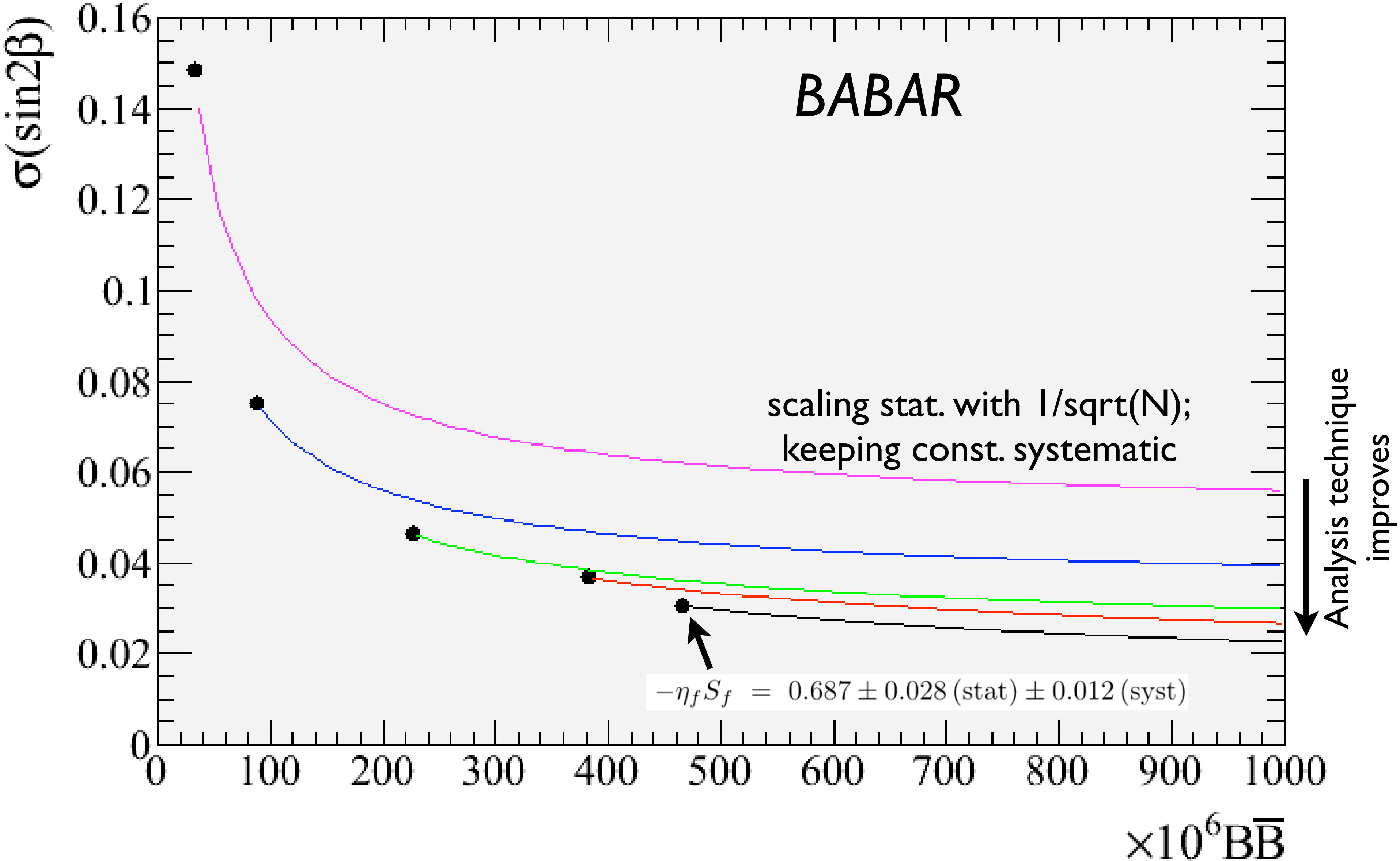
Sample	N_{tag}	$P(\%)$	$-\eta_f S_f$	C_f
Full CP sample	15481	76	0.687 ± 0.028	0.024 ± 0.020
$J/\psi K^0_S(\pi^+\pi^-)$	5426	96	0.662 ± 0.039	0.017 ± 0.028
$J/\psi K^0_S(\pi^0\pi^0)$	1324	87	0.625 ± 0.091	0.091 ± 0.063
$\psi(2S)K^0_S$	861	87	0.897 ± 0.100	0.089 ± 0.076
$\chi_{c1}K^0_S$	385	88	0.614 ± 0.160	0.129 ± 0.109
$\eta_c K^0_S$	381	79	0.925 ± 0.160	0.080 ± 0.124
$J/\psi K^0_L$	5813	56	0.694 ± 0.061	-0.033 ± 0.050
$J/\psi K^{*0}$	1291	67	0.601 ± 0.239	0.025 ± 0.083
$J/\psi K^0_S$	6750	95	0.657 ± 0.036	0.026 ± 0.025
$J/\psi K^0$	12563	77	0.666 ± 0.031	0.016 ± 0.023
$\eta_f = -1$	8377	93	0.684 ± 0.032	0.037 ± 0.023



Sin2β convergence history



Sin2β uncertainty history

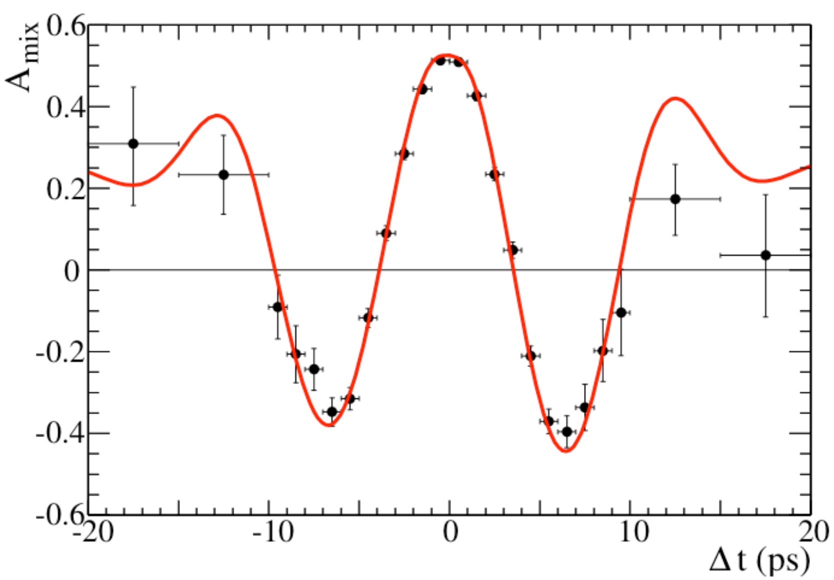


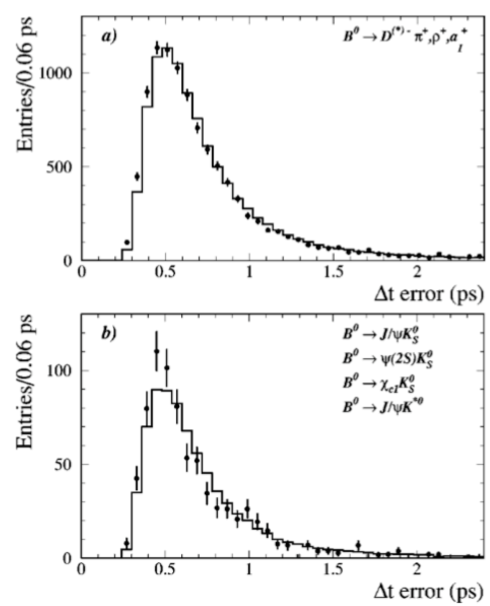
Technique

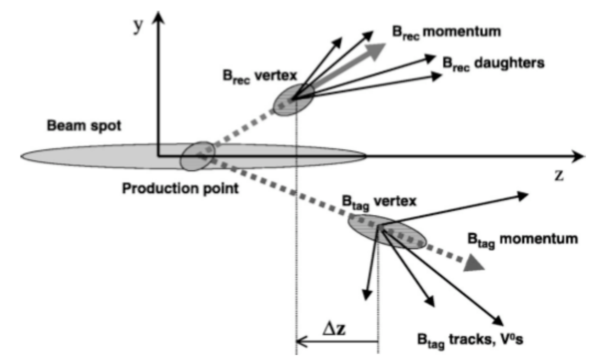
- The physical parameters (S and C), along with many other parameters, are fitted using CP signal sample and flavor-specific control sample (Bflav, e.g. $B \rightarrow D^{*-}\pi^{+}$, which is 10x larger) simultaneously (to reduce systematic uncertainties).
- Events are divided into several tagging categories to increase sensitivity.
- Parameters include resolution function, tagging dilutions, tagging difference between B and Bbar, reconstruction and tagging efficiency differences, (and for background too) etc.

Δt resolution

- The Δt resolution is dominated by the tag-side vertex because of secondary charm decays. It is determined from Bflav sample.







Effectively a B-mixing analysis, but we are not interested in Δmd, but Δt resolution (and tagging)

Flavor tagging

- Flavor of the tag-side B is determined from Bflav sample using a neural network, which exploits several tag signatures such as isolated primary leptons, kaons and pions, soft pion from D*, kaon-pion charge correlation, etc.
- BaBar achieves an overall Q value of better than 31%, which has grown from 27% since the first BaBar sin2β publication due to better particle ID and improved NN. Recently BaBar improves Q even further to 33%.

Category	ε_i (%)	w_i (%)	Δw_i (%)	Q_i (%)
Lepton	8.96 ± 0.07	2.8 ± 0.3	0.3 ± 0.5	7.98 ± 0.11
Kaon I	10.82 ± 0.07	5.3 ± 0.3	-0.1 ± 0.6	8.65 ± 0.14
Kaon II	17.19 ± 0.09	14.5 ± 0.3	0.4 ± 0.6	8.68 ± 0.17
KaonPion	13.67 ± 0.08	23.3 ± 0.4	-0.7 ± 0.7	3.91 ± 0.12
Pion	14.18 ± 0.08	32.5 ± 0.4	5.1 ± 0.7	1.73 ± 0.09
Other	9.54 ± 0.07	41.5 ± 0.5	3.8 ± 0.8	0.27 ± 0.04
All	74.37 ± 0.10			31.2 ± 0.3

$$Q = \epsilon_{\text{tag}}(1 - 2w)^2, \qquad \sigma_{S,C} \propto \frac{1}{\sqrt{Q}}.$$

Major systematics

- For S: (total 0.012)
  - tagging difference between CP and Bflav samples (0.006),
  - Δt resolution (0.007),
  - background characteristics (fraction, CP content) (0.008)
- For C: (total 0.016)
  - tag-side interference (0.014)

How to improve systematics?

- With much larger statistics in SuperB (and thus improved understanding of B decay branching fractions and CP asymmetry) and better simulation, systematics from Δt resolution, background, and part of tagging difference are likely to improve somewhat with statistics without too much effort.
  - caveat: in SuperB the Δt resolution may not be dominated by tag-side anymore b/c reduced boost and better vertexing. More studies are needed to understand the resolution difference.
- We has been ignoring the CPV in Bflav sample [$\sim r_B \sin(2\beta+\gamma)$; $r_B \sim 0.02$]. It plays in part into the tagging difference from CP sample. We expect it to be measured for some Bflav channels in SuperB, thus reduce our systematics.

How to improve systematics?

- Use cleaner modes to reduce background systematics.
- Use lepton tag only to reduce background and eliminate tag-side interference.
  - Lepton tag accounts for >25% of the Q value.
- Other ideas?

Conclusions

- At B-factories, sin2β has been measured at a precision of ~0.03, combining the two factories (10^9 BBbar) the precision is ~0.024.
- At SuperB (aiming for 100x data), the stat. error can achieve 0.002, or 0.004 if using lepton tag only (or better if we improve the detector and algorithm).
- Systematic uncertainty should be able to cut to half to ~0.006 (my personal guesstimate).