



BaBar Becomes a Physics Machine: the first 100 fb^{-1}

Stewart Smith
Princeton University

BaBar Symposium
October 27, 2008



To Bob Bell



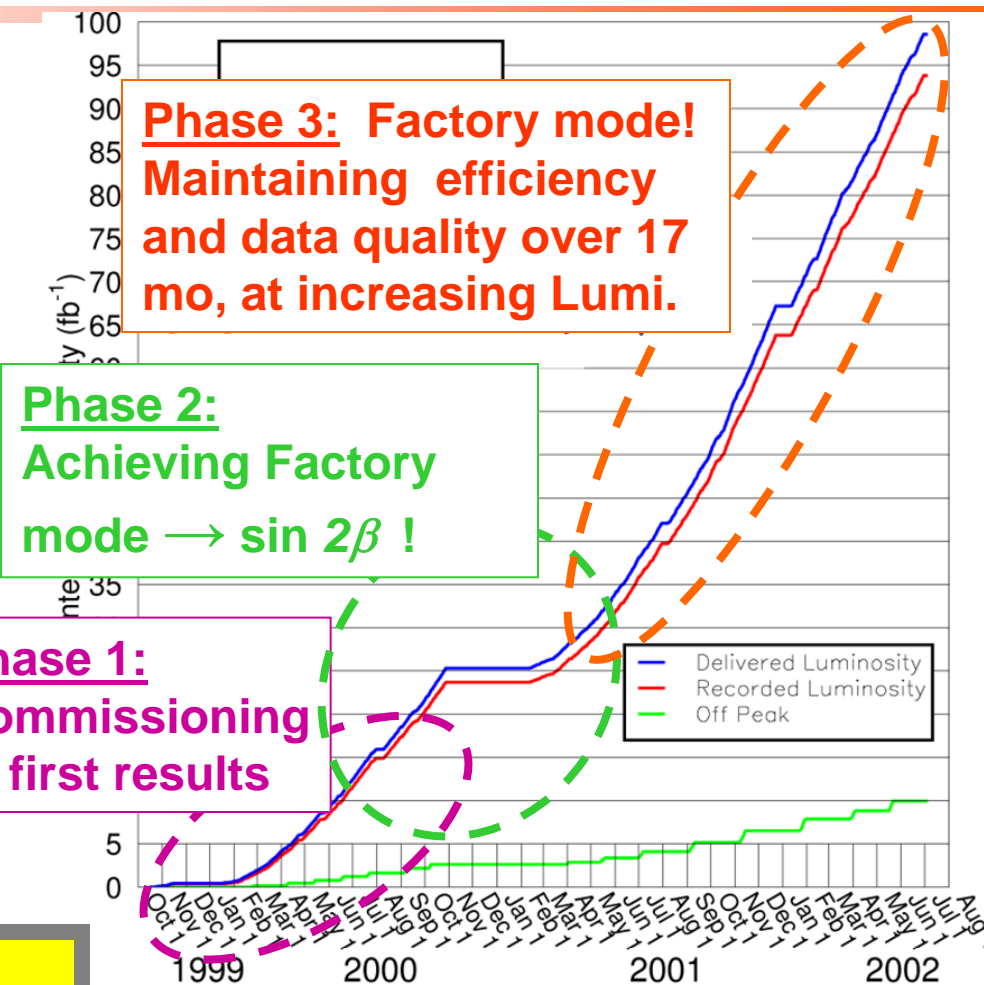
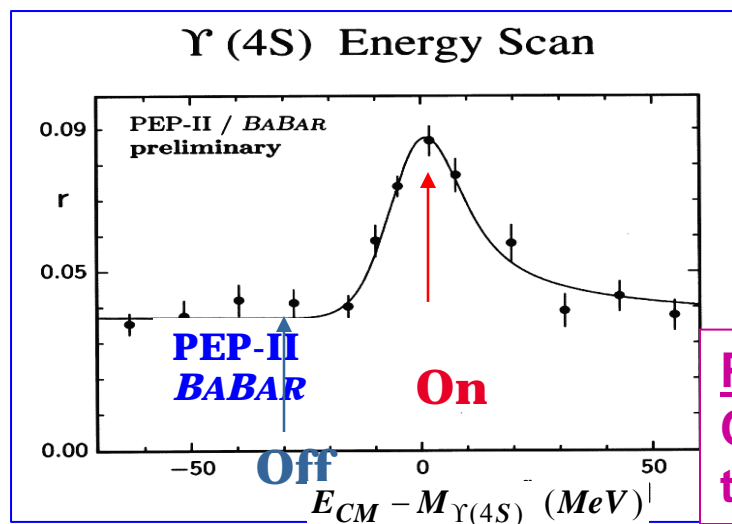


BaBar Data Set at end of the 2002 Run

- Used in most analyses

81.2 fb⁻¹ on peak

9.6 fb⁻¹ off-peak



~88M $B\bar{B}$ pairs



Phase 1: Commissioning to 1st results

(May '99 → July '00)



- ❑ Shakedown of detectors, DAQ, Online, Computing
 - Operations manager and a series of outstanding, dedicated Run Coordinators quickly established procedures, shifter training, Q/A, etc. that served us in good stead all the way "to the end. "
- ❑ Provide feedback to PEP II on backgrounds, protection of SVT, DCH, etc. as they work to increase luminosity.
 - Liason shifter in PEP II Control Room 24/7
 - Meetings every day at 8AM, Friday PEP II/BaBar meeting, Saturday brainstorming.



Phase 1: Improving performance



- ❑ Goal: achieve TDR specs for all systems and physics analyses.
- ❑ Involves “everything and everyone:” Detector, electronics, online, monitoring, offline analysis, computing, physics
- ❑ New forum needed – Technical Board was too high level, and too focused on detector
 - Bring together the people working in the trenches on the detector, computing, and analysis.
 - The ~50-member ATB (Augmented Technical Board) was born in Sept '99.



Mission of the ATB (RIP)



- ❑ Compile realistic resource-loaded schedule
 - Determine and manage critical path to physics results
 - Motivated by 10fb^{-1} expected in time for ICHEP00 (end July 2000).
 - ❑ Identify areas needing and/or profiting from collaboration among systems.
 - ❑ Spot problems in time to minimize impact on schedule or performance.
 - ❑ Encourage cross-fertilization.
-
- ❑ The ATB was an essential tool during its 2 year existence – meeting 21 times, most often for 3-4 hours!
 - ❑ Best of all, it put itself out of business by helping us achieve full factory operations!
 - ❑ If you weren't there and would like to learn about life in BaBar during the early running, good documentation of all the meetings is accessible from the BaBar Organization page.



View in spring '00



- ❑ PEP-II, Detector and Physics Analysis performing well.
- ❑ Prospects for bursting onto the world scene at ICHEP00, in Osaka at the end of July.
- ❑ But, computing group has a tiger by the tail!
 - Luminosity came up very fast, forcing them to concentrate on short-term issues to prevent data “falling on the floor.” (None did!)
 - Performance did not scale to the large number of parallel machines needed to keep up.
 - Ominous cost implications for extended running at luminosities 3-4 times design.



Phase 2: Achieving factory mode and the drive to discovery (5/00 → 7/01)



- ❑ Use experience from first year of running to plan for operating with increased Lumi: from 10^{33} to 10^{34}
- ❑ Upgrades Committee Report – April '00
 - Good news :
 - The SVT, DCH, DIRC, EMC and DAQ will survive for years, and with nominal improvements will maintain their great performance.
 - Backgrounds can be mitigated to be tolerable for years
 - Bad news:
 - Massive increases needed in computing performance and budget.
 - The RPC's have serious problems that, if not understood and mitigated, will require their replacement.
- ❑ The International Finance Committee was supportive, contingent upon a successful external Technical Review (aka Gilchriese review).



Phase 2 gets underway – 5/00



□ Division of forces:

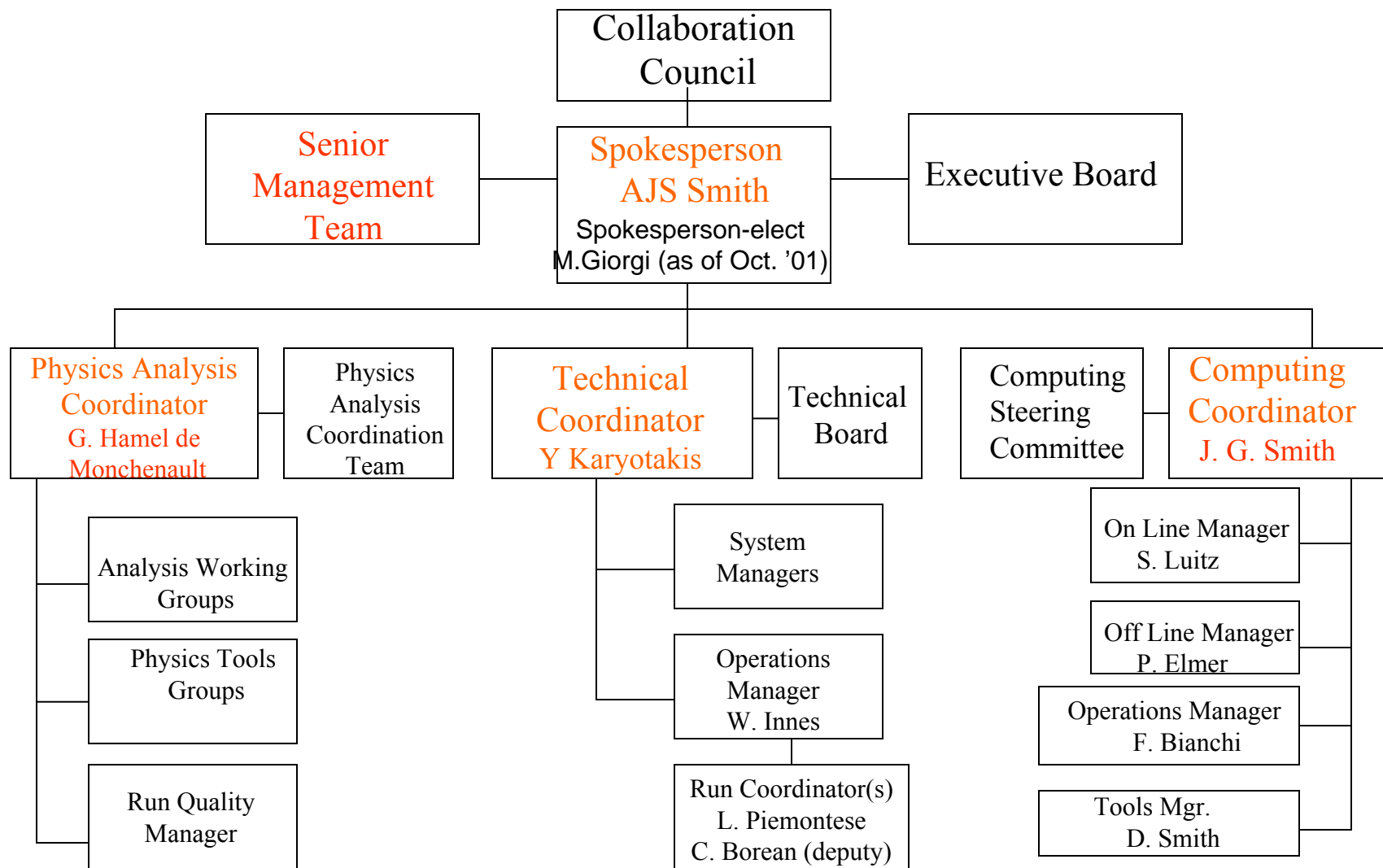
- Spokesperson and his management team focus on run in progress:
 - Operations, computing, analysis.
 - Preparation of first results for ICHEP 00 at end of July.
- Spokesperson-elect deals with the long haul: upgrades, revised management structures for factory operation, assembling new management team.

□ First run is great success: highly-professional, sophisticated, professional analyses produce excellent results for ICHEP00:

- Likelihood fits, fully-blind analyses to increase reliability and precision.
- B^0 Mixing, Lifetimes, CPV ($\sin 2\beta$), etc. based on 10fb^{-1}



New BaBar Organization Chart





Senior Management Team



- Spokesperson
- Technical Coordinator
- Physics Analysis Coordinator
- Computing Coordinator
- Senior Technical Advisor/SLAC contact
 - Bill Wisniewski
- Deputy Computing Coordinator
 - Stephen Gowdy
- Spokesperson-elect (alternate years)
 - Marcello Giorgi (Sept '01)
- Past Spokesperson (alternate years, beginning Sept '02)





Highlights from charge to the BaBar Technical Review Committee



Please evaluate the adequacy of our plans for items to be completed by the end of 2003, to respond to PEP-II luminosities increasing from the current level of 2×10^{33} to 10^{34} ; and comment on the credibility of the projected costs.

In particular, please evaluate and comment on:

1. The **computing model**: CPU, disk, tapes, capability, access, etc.
2. The **Instrumented Flux Return (IFR)**: performance, prognosis, and planned improvements.
3. Upgrade plans for the **detector** systems, front end **electronics**, **DAQ**, and **the trigger**, particularly the rejection rates for the L1 z trigger
4. **R&D on detector aging** and performance improvements
5. Schedule for **replacing SVT modules**, radiation damage tests, and schedule of R+D for a later replacement of the SVT.



Technical Review set for October '00



- ❑ Critical milestone for BaBar's future.
 - What if we failed??
- ❑ Combined with the Upgrades Committee report, this review served as the perfect driver for our long-range planning.
- ❑ Investment in preparations and documentation for the review had a second purpose, to expedite the writing of a comprehensive NIM paper on the BaBar detector.



Technical Review, conclusions



- ❑ Plans and estimates for most of the detector improvements are sound, and should proceed as presented.
- ❑ IFR is a serious problem that must be quickly resolved.
- ❑ Computing enhancements are generally well justified, but serious issues must be addressed, including cost.
 - Multiple Tier-A sites present promising opportunity
 - More attractive to funding agencies than cash contribution to SLAC



Computing Problems



□ Prompt Reconstruction:

- a huge amount of hard work in winter-spring '01 by many people in BaBar and SCS increased performance sufficiently to save the experiment. Linux boxes, multiple farms, etc.

□ Off Line: Data storage, access, processing, simulation, analysis.

- Huge cost of increased luminosity caused crisis in 2000.
- Spurred consideration of distributed model:
 - Countries provide 'in-kind' computing support via large "Tier-A" centers comparable to SLAC.
 - Store and process **complementary** data.
 - Provide convenient, efficient remote access



The solution: a pioneer Grid



- ❑ French proposal at Dec '01 IFC meeting:
 - Include computing resources in Operating Common Fund, with algorithm to calculate credit for CPU's, disks, tapes, etc.
 - To qualify, a Tier-A center must provide efficient access to all.
 - Everyone must contribute to producing the tools to make this work.
- ❑ Agreement reached at special IFC meeting (Paris, Jan 01).
 - New International Computing Steering Committee set up
 - Tier A's set up in France, Italy, UK, and Germany
- ❑ Ensured adequate computing for the balance of the experiment.
- ❑ Engendered an even-stronger level of cooperation throughout the collaboration

Physics Dashboard: Projected Publication Schedule

Charmless B Decays

- Two-body $\pi\pi, \pi K, KK, \pi\pi^0, \pi Ks, \pi^0 Ks, KsKs$
- ϕ modes (with K, Ks or K^*)
- η and η' modes
- ω modes
- Inclusive ϕ, η
- $a^0\pi$ modes
- 3-body decays
- $B \rightarrow K^* \pi$ modes

Submitted!

Spring 2001

Summer 2001

Fall 2001

Winter 2002

B Decays to Open Charm

- Branching fractions: $D^{(*)}D^{(*)}$ modes
- Branching fractions: $D^{(*)}D^{(*)}K$ modes
- Branching fractions: $D^{(*)}K$ modes
- Branching fractions: $D_s^{(*)}D^{(*)}$ modes

Time-Dependent Analyses

- CP-viol. in charmonium sample ($\sin 2\beta$)
- Mixing / Lifetimes with hadronic sample
- CP-violation & Mixing (PRD)
- Mixing & Lifetimes with semileptonic
- Mixing & Lifetimes with dilepton sample
- T, CPT invariance tests with dileptons

Tau/QED

- τ lifetime
- $\tau \rightarrow \mu\gamma$
- CP violation
- ISR Vector Mesons
- Two-photon

Charmonium Physics

- J/ψ production in continuum
- Inclusive branching fractions
- $J/\psi K^*$ angular analysis
- Exclusive branching fractions
- $J/\psi K$ versus $J/\psi \pi$
- $\psi(2S)$ leptonic decays
- Direct CP-violation in $J/\psi K^+$

Penguins B Decays

- $B \rightarrow K^* \gamma$ (CP viol.)
- $B \rightarrow \gamma \gamma$
- $b \rightarrow s \gamma$
- $B \rightarrow K^{(*)} l^+ l^-$
- $B \rightarrow \rho / \omega \gamma$
- $B \rightarrow l^+ l^-$
- $B \rightarrow D^* \gamma$

Detector

Charm Physics

- $D^0 \rightarrow K\pi$ absolute BF
- Charm at threshold (ISR)
- $\Lambda_c \rightarrow p K \pi$
- Dalitz analyses
- D^0 lifetime
- D^0 Mixing

Vub & Vcb measurements

- Semileptonic BF (lepton tag)
- Exclusive charmless semileptonic
- Exclusive $D^* l \nu$ (Vcb)
- Semileptonic BF (fully rec)
- Exclusive $\rho / \omega l \nu$ (Vub)

Partially Reconstructed B Decays

- Branching fractions $D^* \pi / D^* K$
- $B \rightarrow D_s^{(*)} D^*$
- Lifetime & Mixing with $D^* \pi, D^* \rho$
- Lifetime & Mixing with $D^* l \nu$
- CP Violation in $D^* \pi$

Leptonic B Decays

- $B \rightarrow \mu \nu$
- $B \rightarrow \tau \nu$

Inclusive Hadron Spectra

- π, K and p Production



Highlights since last meeting

Summary to June 23, 2001
Collaboration Meeting, at
the height of the push to
observe CP violation

Seems to describe a
physics machine!!

Can we sustain it?

- PEP-II/BaBar performance:
 - ▶ Steady increase in peak and **integrated** luminosity (189 pb^{-1} in 24 hours yesterday; $>150 \text{ pb}^{-1}/\text{day}$ is common).
 - ▶ BaBar efficiency is consistently $\sim 97\text{-}98\%$
- OPR and Reprocessing:
 - ▶ Major improvements: $>400 \text{ pb}^{-1}/\text{day}$ regularly over 3 farms when doing normal runs. (300 till one farm finishes crunching the short runs of Feb/Mar.)
 - ▶ OPR Farm alone: $140 \text{ pb}^{-1}/\text{day}$
 - ▶ 9.2 fb^{-1} of 2001 data is now available, rest next weekend.
 - ▶ Change to linux making good progress
⇒ will let us keep up with data till June 2002
 - ▶ Work underway on longer-term solution for $>10^{34}$.
- Analysis tools and data quality:
 - ▶ Steady improvements in every detector system, alignment, tracking, vertexing, PID, etc.
 - ▶ Equivalent to increasing luminosity while reducing systematics
 - ▶ $\sim 40\%$ more CP events/ fb^{-1} in 2001 data than 2000!!!
- Physics:
 - ▶ Quality standards for results and publications have been set high, and authors have embraced them. A great culture!
 - ▶ Speakers have done us proud with excellent presentations.
 - ▶ The publication schedule is more or less holding.

June 23, 2001

Collaboration Meeting

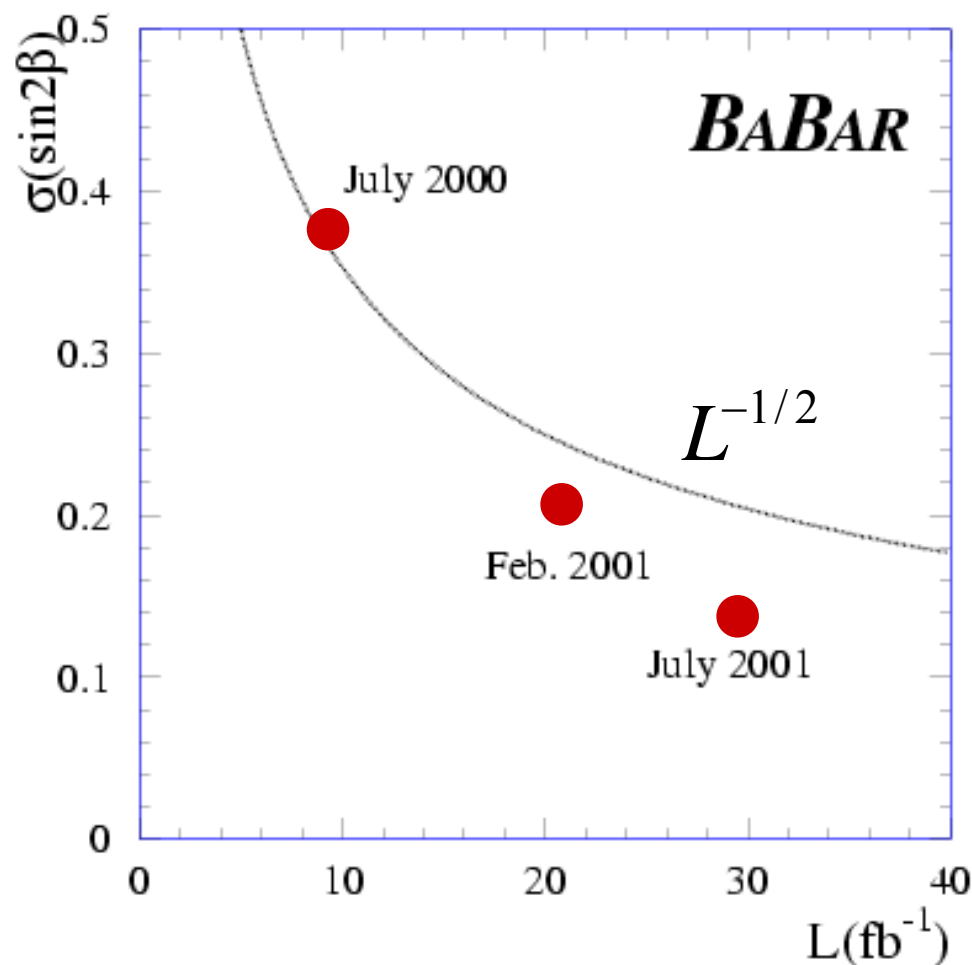
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Analysis improvements in 2001



- ❑ **Steady improvements in alignment, tracking, vertexing, PID, etc.**
- ❑ **Equivalent to increasing luminosity**
 - ~ 40% more CP events/ fb^{-1} in 2001 data than 2000!!!
 - ~ 10% over all efficiency improvement from better alignment
- ❑ **Purity of $J/\psi K_L$ sample improved by 20%**
- ❑ **Additional modes in CP sample**
 - $B \rightarrow J/\psi K^*$
 - $B \rightarrow \chi_c K_S$

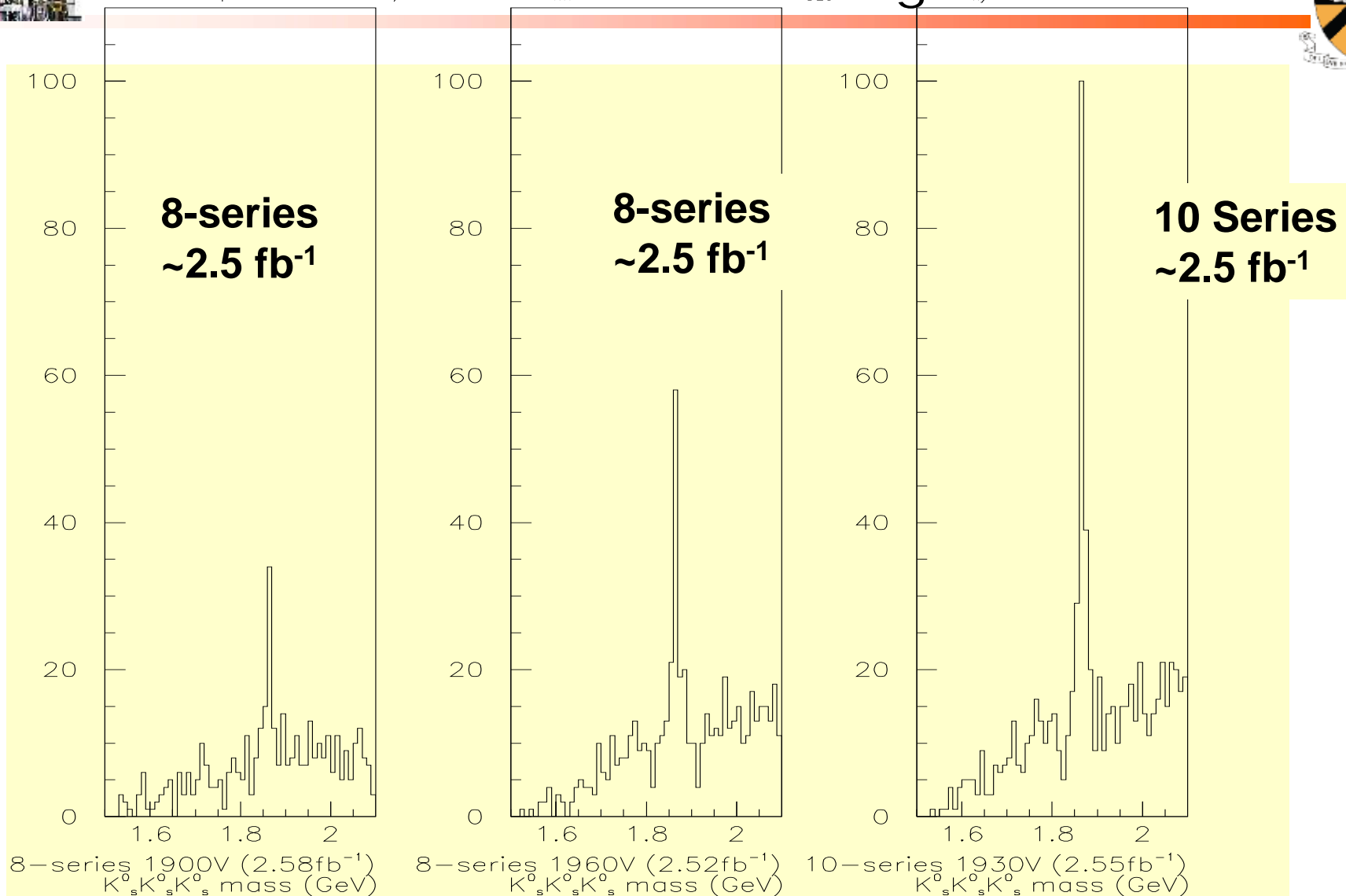




Tracking Performance: Evolution of $D \rightarrow 3 K^0_s$ (S Wagner)

2001/06/29 12.26

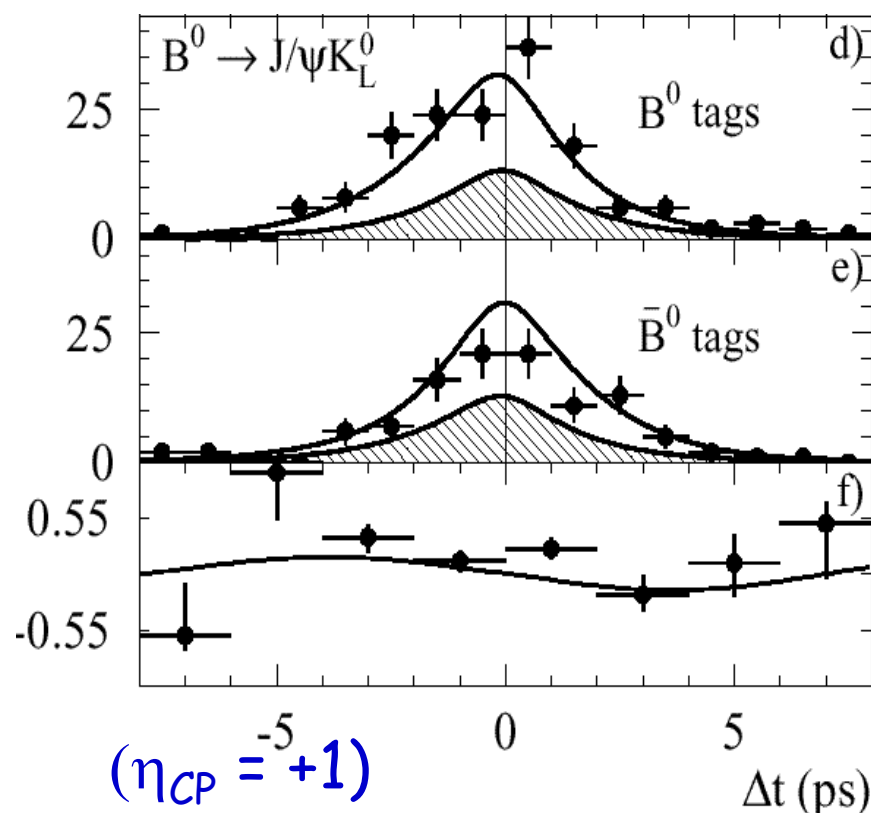
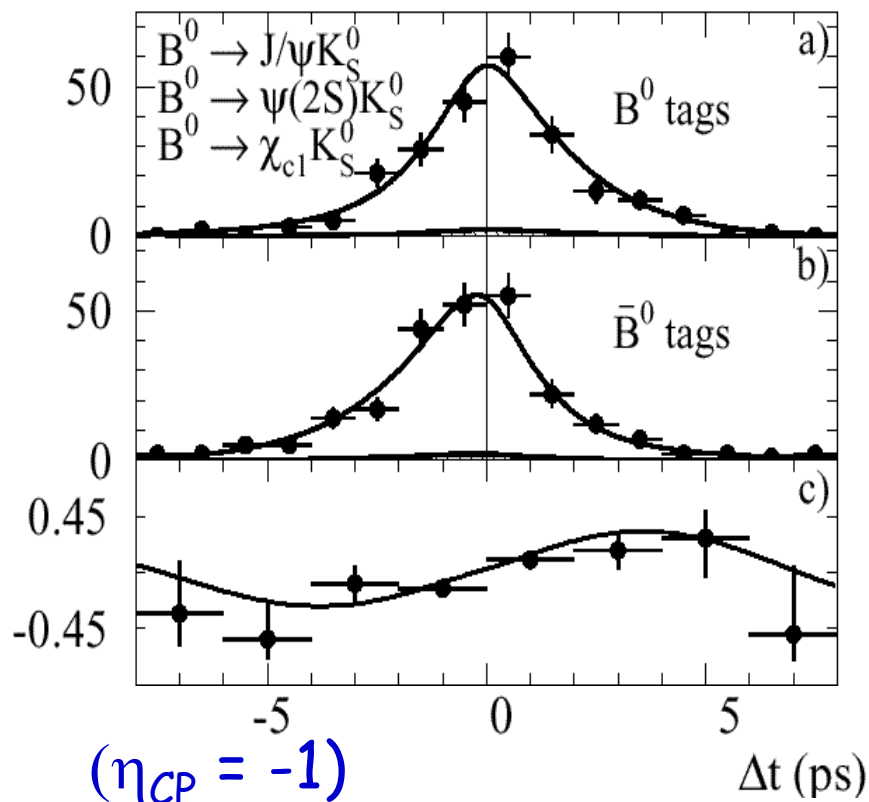
$p^* > 2.48 \text{ GeV}/c, 487 < m_{\pi\pi} < 509 \text{ MeV}, 0.2 < r_{\text{DEC}} < 60 \text{ cm}, \delta_{xy} < 1 \text{ cm}$





The $\sin(2\beta)$ discovery result!

Submitted to PRL July 11, 2001



$$\sin(2\beta) = 0.59 \pm 0.14_{\text{stat}} \pm 0.05_{\text{syst}}$$

Prob. of this result if CP is conserved : $< 3 \times 10^{-5}$



July 6, 2001

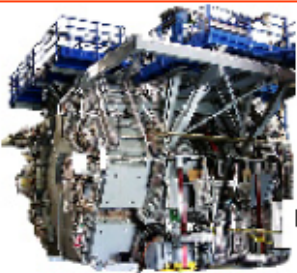




Phase 3: The well-oiled science machine.



- ❑ BaBar becomes flagship accelerator experiment in HEP
- ❑ Postdocs flood the faculties, new cohort joins the fun
- ❑ Detector performance remains excellent, improvements proceed as proposed
 - IFR Group greatly expanded to replace end-cap RPC's
 - Committee appointed to evaluate proposed options for replacing the barrel RPC's. (LST option is chosen.)
- ❑ Tremendous set of results for ICHEP02 in Amsterdam, followed by flood of refereed publications.
- ❑ Pioneer Grid Computing is a big success, but Objectivity event store remains problematic.
- ❑ New "Computing Model 2."
 - Committee appointed in summer '02 recommends Root-based system to be implemented by 2004.
 - Finished in 2003, a year ahead of schedule.

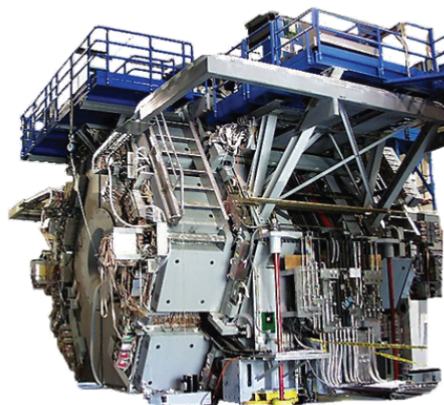


BaBar Highlights

DOE Review
April '02

- BaBar has been running for 14 months now, perhaps a record for a high energy experiment. Three more months to go !!
- Total accumulated luminosity $\sim 77 \text{ fb}^{-1}$. The goal is 100 fb^{-1} by 1st of July.
- Regularly we integrate twice the designed daily luminosity.
- Average overall detector efficiency $\sim 97.5\%$
- Detector performance reaches and in some cases exceeds TDR goals.
- Detector life time higher than initially expected.
- Short term plans
 - ▶ **Replace misbehaving RPC chambers in the forward end cap (this summer) and the barrel, gradually.**
 - ▶ **Improve Level 1 trigger by adding z information to the tracking**
 - ▶ **Replace irradiated SVT modules, and radiation protection system**
- Long term plans
 - ▶ **Work with PEP-II and the laboratory to plan for increasing luminosity**

BaBar Status and Improvement Plans

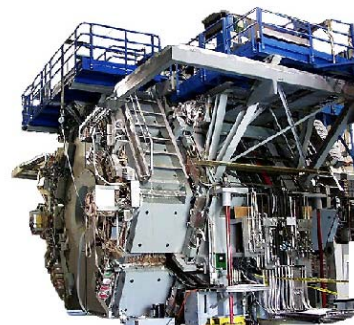


Stewart Smith
Princeton University

Presentation to HEPAP
October 30, 2000



PERFORMANCE

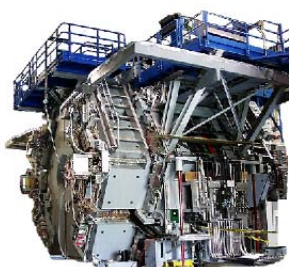


Stewart Smith
Princeton University

HEPAP Meeting
Snowmass
July 13, 2001

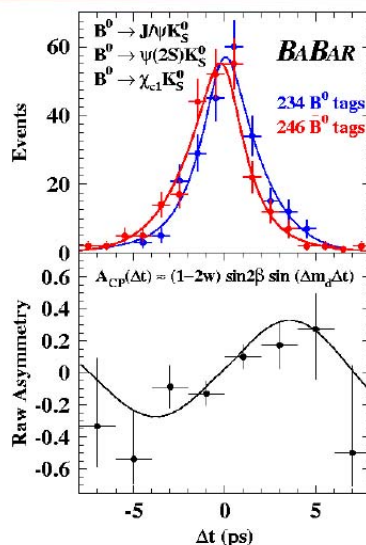


Results and plans

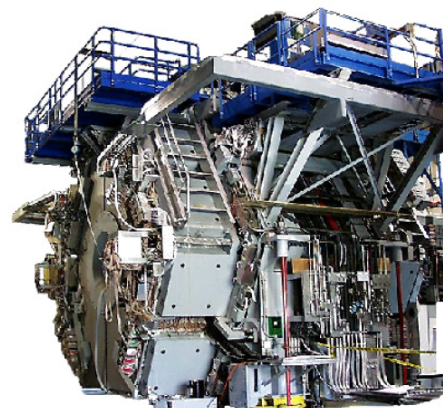


Stewart Smith
Princeton University

Presentation to HEPAP
Washington, October 29, 2001



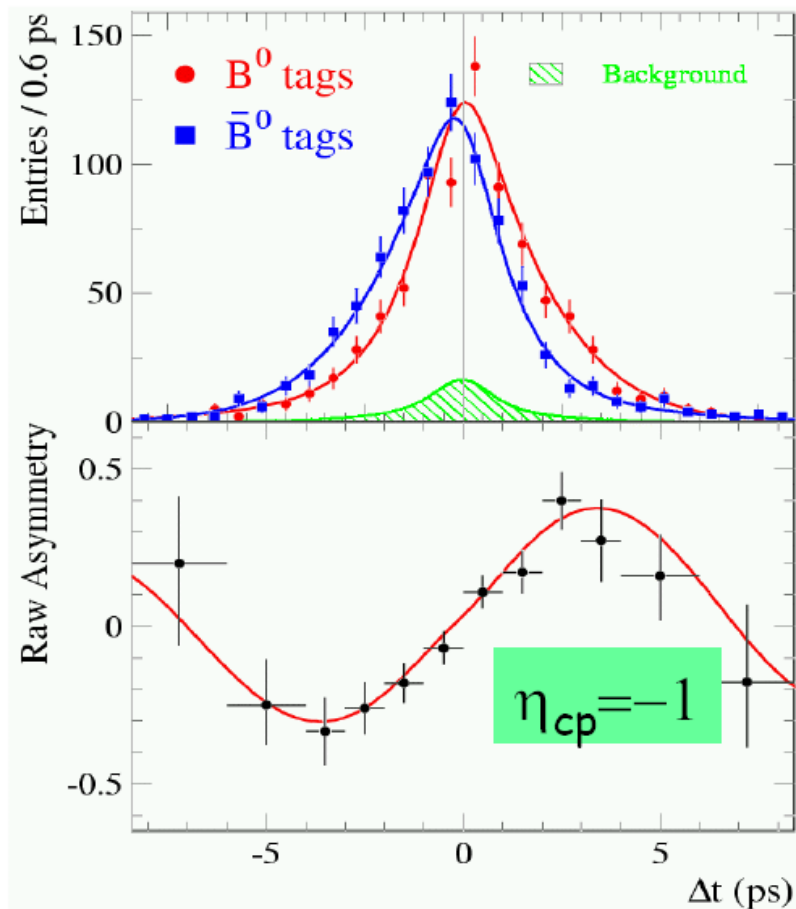
Physics Update



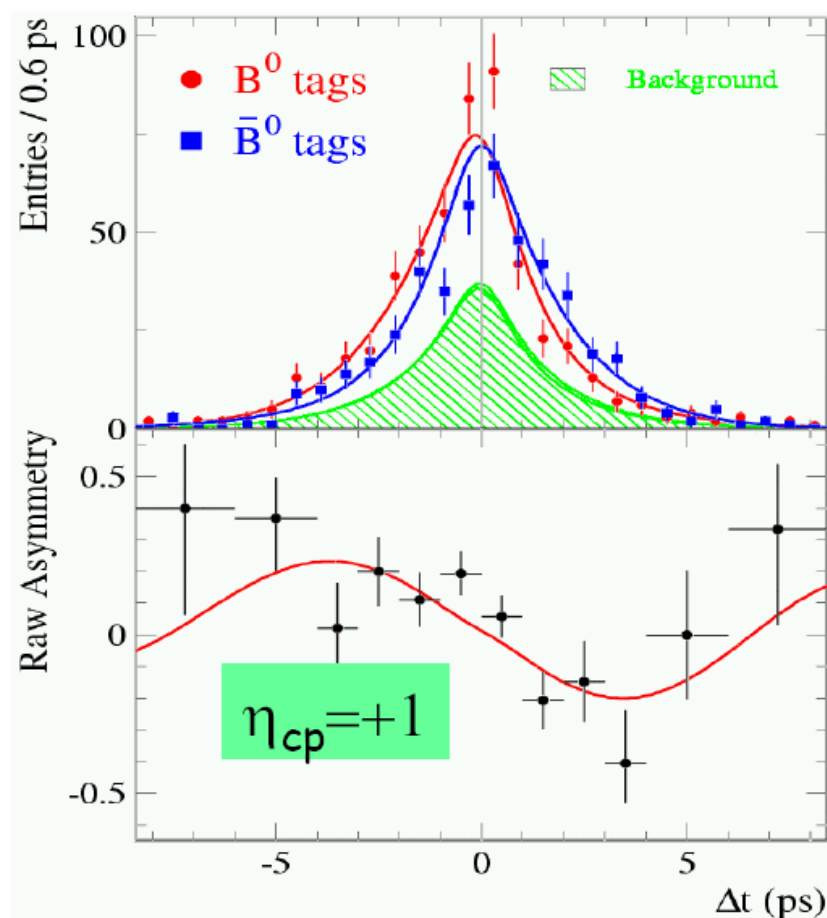
Stewart Smith
Princeton University
(for the collaboration)

HEPAP Meeting
Cornell, August 6, 2002

~~CP~~ in $B^0 \rightarrow \text{Charmonium} + K^{0(*)}$



$$\sin 2\beta = 0.755 \pm 0.074$$



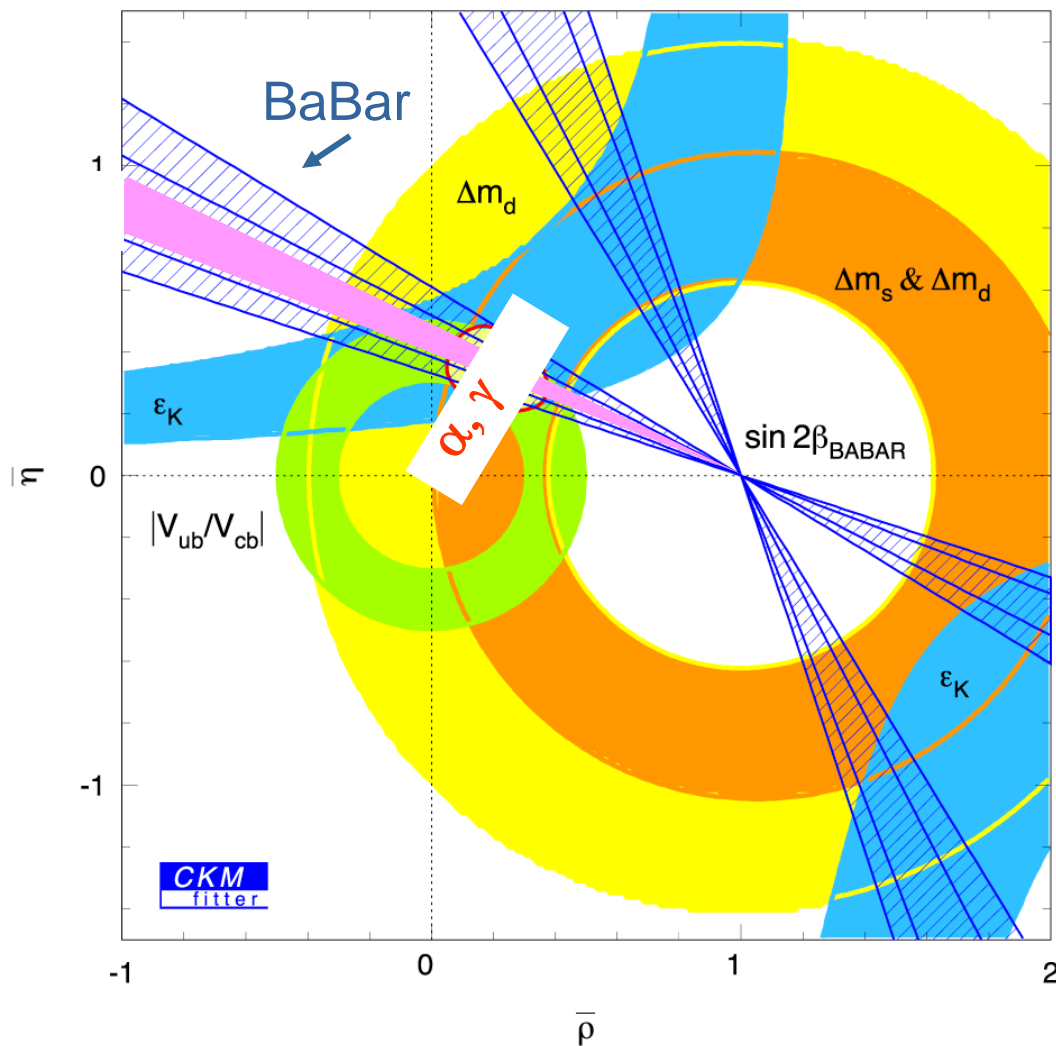
$$\sin 2\beta = 0.723 \pm 0.158$$

$$\sin 2\beta = 0.741 \pm 0.067 \text{ (stat)} \pm 0.033 \text{ (syst)}$$

Submitted to PRL, hep-ex/0207042



Constraining the ρ, η plane



New Belle result July 29:
 $\sin 2\beta = 0.72 \pm 0.074 \pm 0.035$

Unofficial World Average:
 0.73 ± 0.055

**Highly likely that
CKM phase explains
Observed CP Violation
in K's and B's**

(So far!)

Method as in Höcker et al,
Eur.Phys.J.C21:225-259,2001



The SLAC B Factory – A major success story for DOE Science

- PEP-II is the realization of proposals for similar facilities in the US and in different countries
- On-time, on-budget; example of DOE and Office of Science's ability to manage a major multi-lab, multi-nation project
- All design parameters exceeded – two years after first collisions, PEP-II delivers and BABAR records twice the design daily integrated luminosity
- Physics “fountain” – 15 papers in publication chain, including the first discovery paper. ~ 35 more in the “best of” category to follow in next 9 months

And: we've all had a lot of fun!

