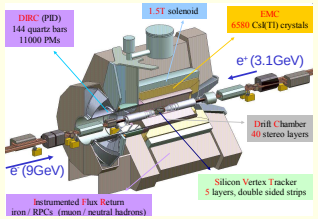
LBNL *BABAR* Group

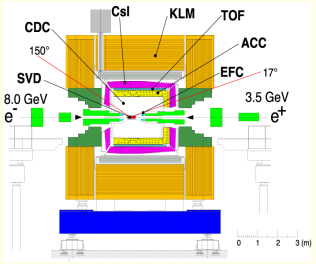
Robert Cahn

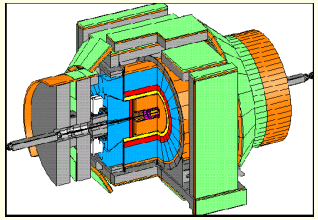
November 10, 2004

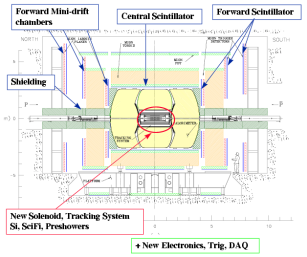
B Physics: Why Everyone's Doing It.

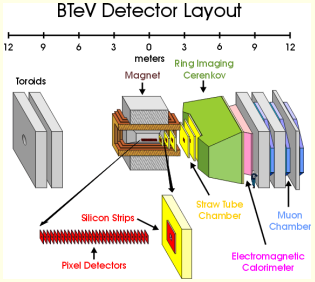
- CP violation effects in B mesons expected to be of O(1).
- Neutral B mesons mix, just as neutral K mesons do.
- Oscillation frequency ($\Delta m = 0.5\ \mathrm{ps}^{-1}$), lifetime (1.5 ps) convenient.
- Interference between B^0 and $\overline{B}^0$ gives time-dependent signal of CP violation.
- Source of pure $B^0 - \overline{B}^0$ and $B^+ - B^-$ pairs available: $\Upsilon(4S)$.

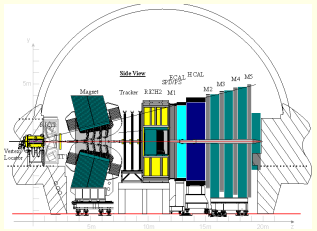








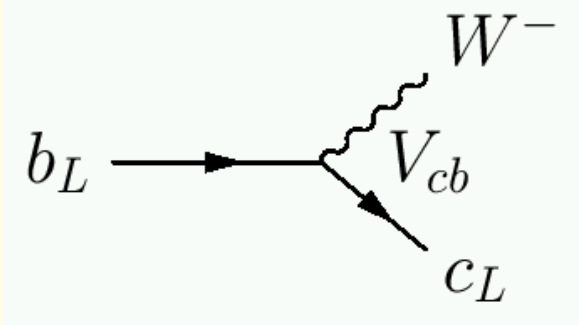




B Physics: Window on Weak Interactions

Study mismatch between physical quarks and weak interaction states:

$$\begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix}$$



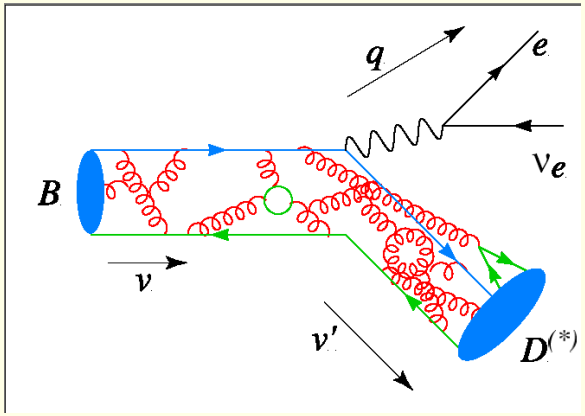
Produced B^0 evolves as superposition of B^0 and $\overline{B}^0$.
Interference when both can decay to the same final state,
General time dependence:

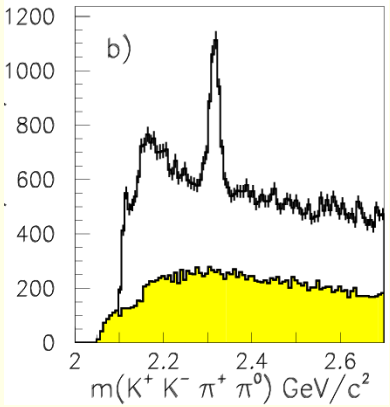
$$dN/dt \propto (1 \mp C \cos \Delta m t \pm S \sin \Delta m t) e^{-\Gamma t}$$

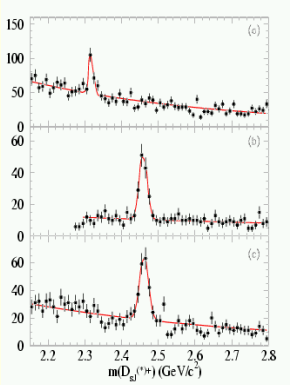
S (and sometimes C) tells us about CP violation.

B Physics: Window on Strong Interactions

- Heavy quark (b) simplifies QCD.
- Can we understand semileptonic decays?
- Do nonleptonic decays have two independent parts?
- Can we predict polarization of decay products of B?
- Dramatic discoveries already in charm spectroscopy.





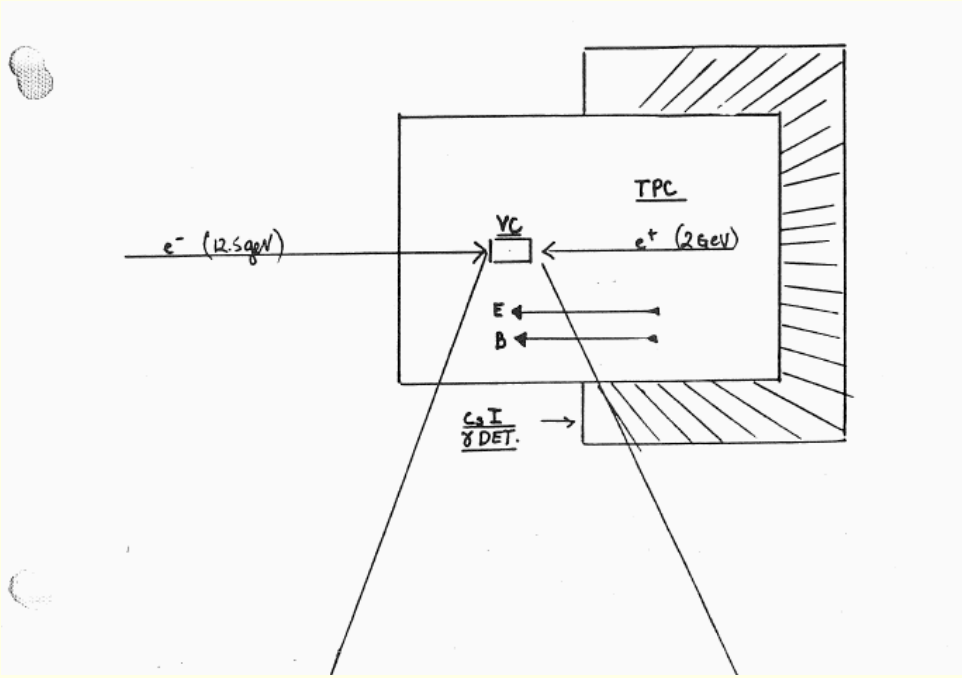


Why Questions Remained Unanswered after 20 Years

- Branching fractions $\mathcal{O}(10^{-3}) - \mathcal{O}(10^{-6})$: not enough events at LEP.
- Tevatron produces lots of Bs but hard to find in such complex events.
- At CESR, typical B flight path is 30μ, too small to measure.
- Can't measure time dependent CP violation at CLEO/CESR.
- Need copious, clean, high-momentum B events measured with high precision.
- These requirements seem mutually exclusive.

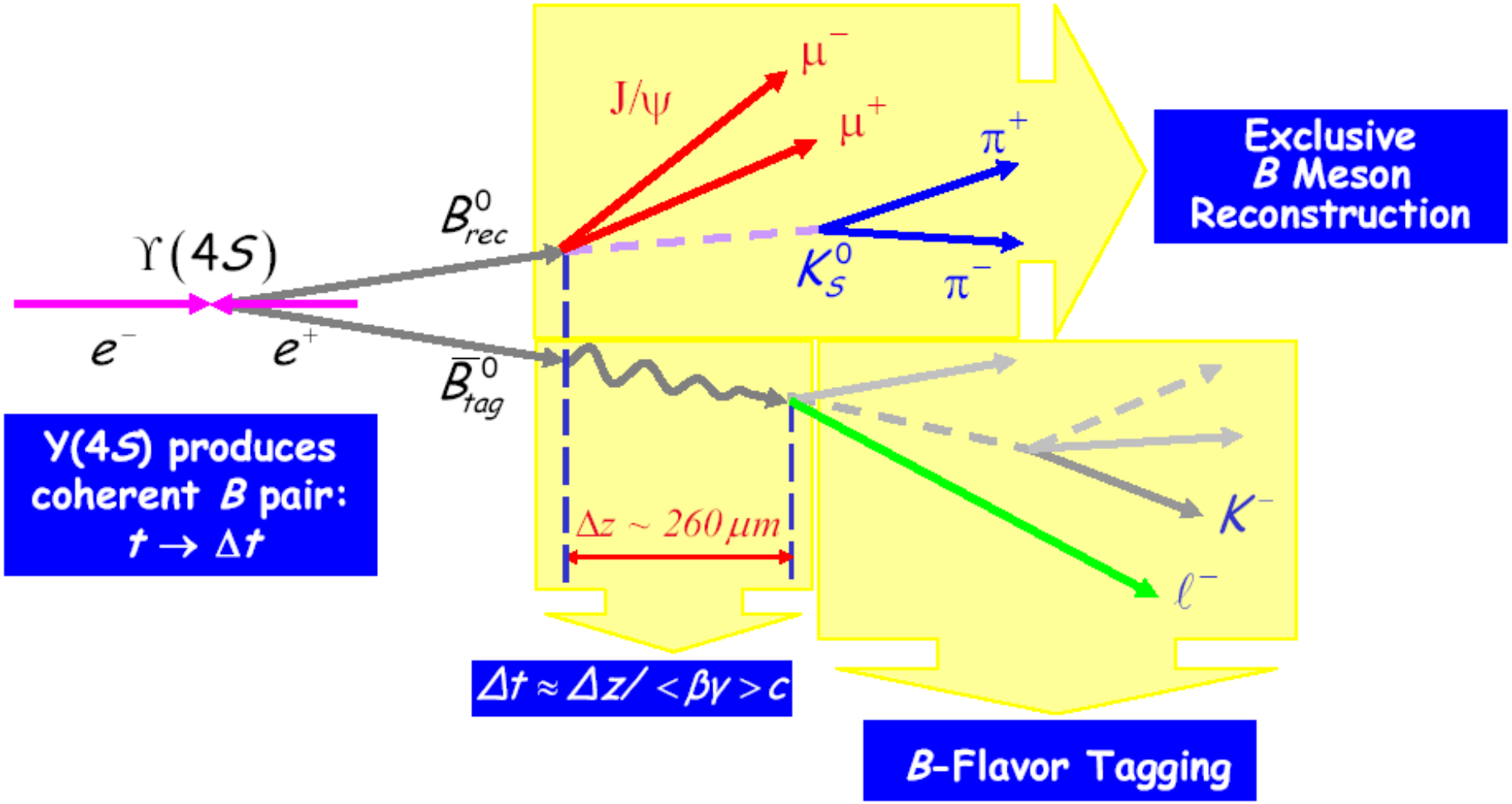
Conception of the B Factory

How can we do time-dependence measurements in the clean e^+e^- environment?.



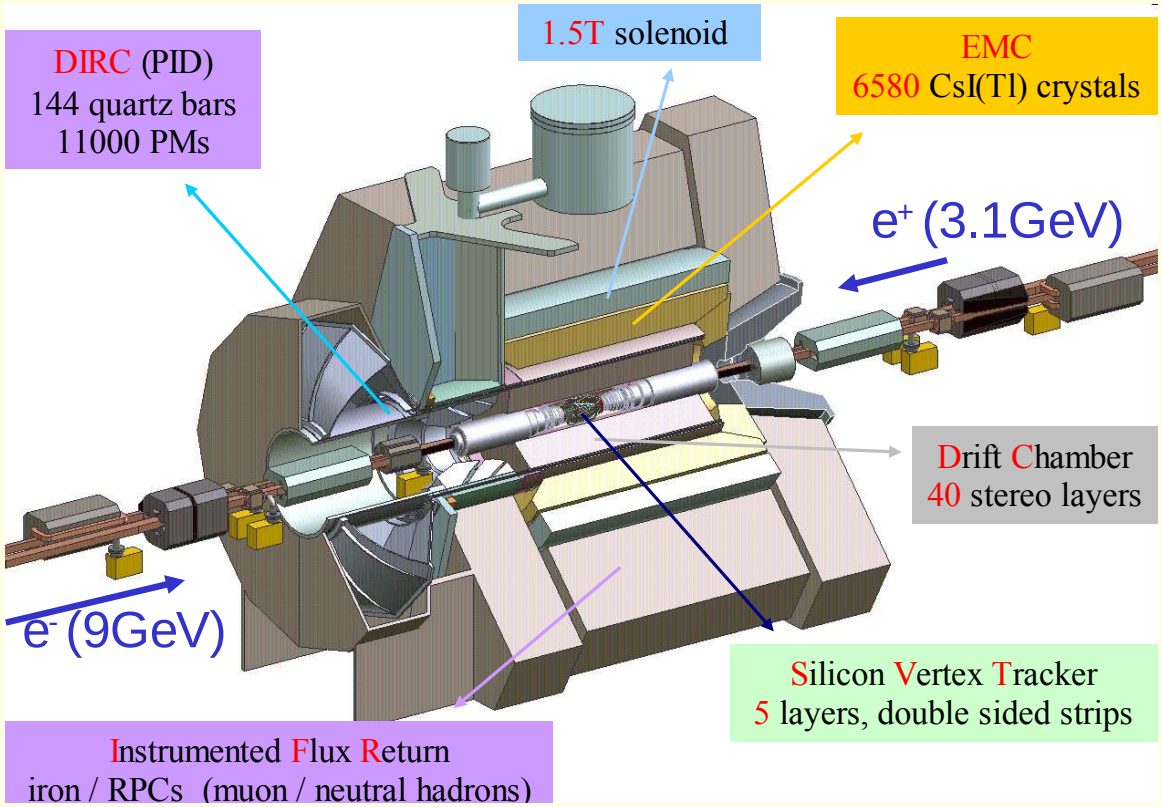
Pier Oddone has won the 2005 Panofsky Prize "For his insightful proposal to use an asymmetric B-Factory to carry out precision measurements of CP violation in B-meson decays, and for his energetic leadership of the first conceptual design studies that demonstrated the feasibility of this approach."

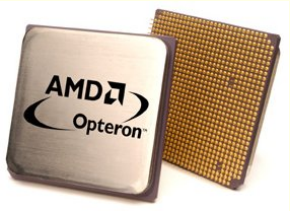
Time-Dependent CP Asymmetry Measurements



The *BABAR* Experiment

Detector + Computing



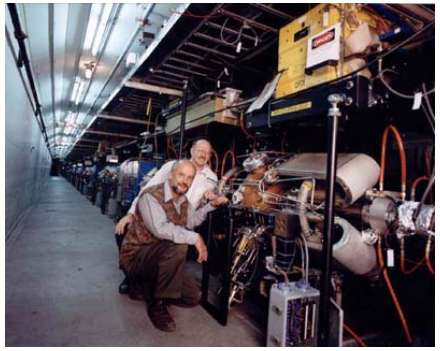
10,000 × 

500 TBytes

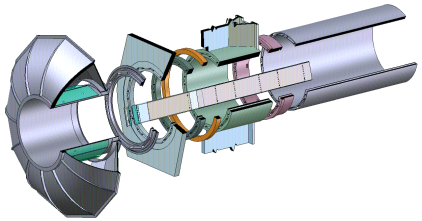
3×10^6 lines of C++

LBNL BaBar:

Doing the Physics from Start to Finish



Conception



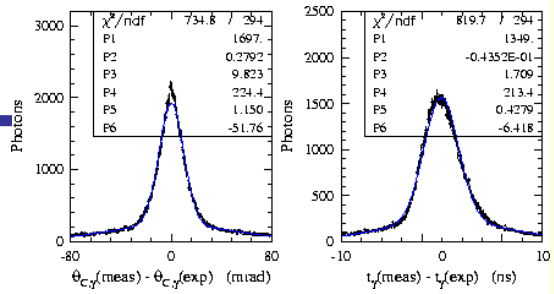
Design

BaBar team - LBNL
XBD9902-00245-07

Fabrication

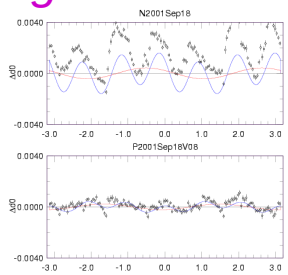
SVT upgrade

DIRC

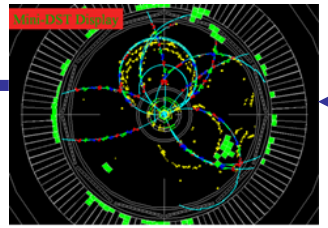


Commissioning

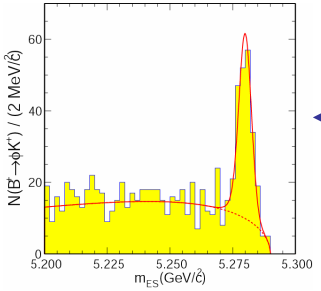
Alignment



Operations/
Calibration



Reco/
Simulation



Analysis

B→VV

B→φ K

B→Ds π

B→ρπ

CPT,ΔΓ

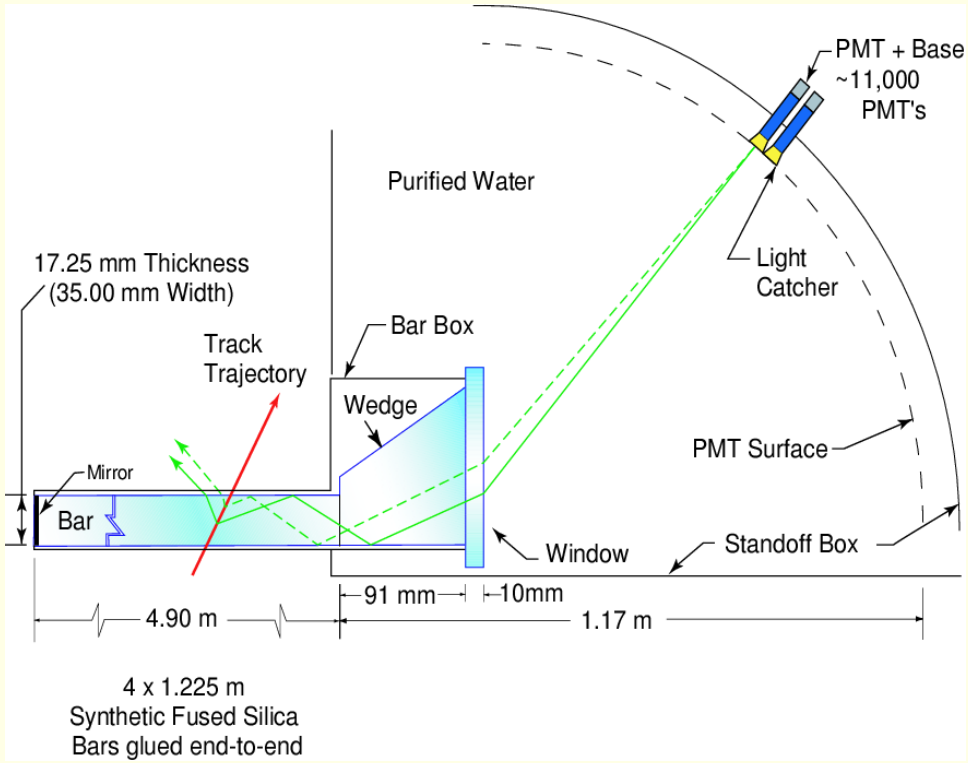
New computing model

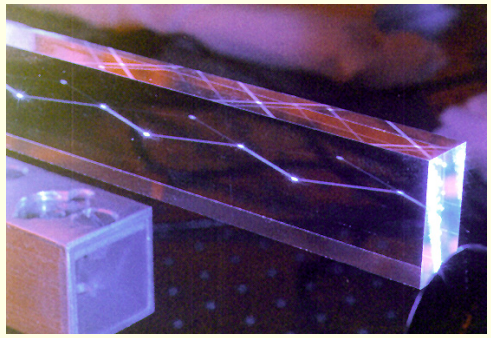
Trigger

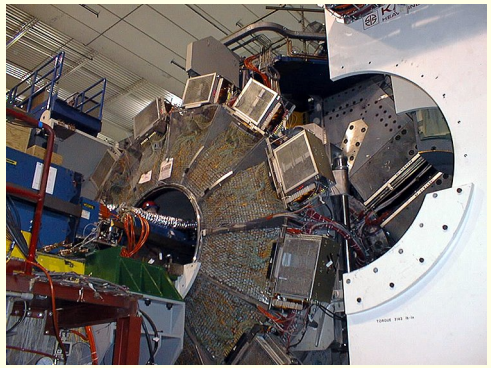
LBNL in *BABAR* Design and Fabrication: SVT

- Natalie Roe co-system manager.
- Design of AToM chip.
- Roy Kerth/Fred Goozen lead on mechanical.
- LBNL lead in electronics.

LBNL in *BABAR* Design and Fabrication: DIRC



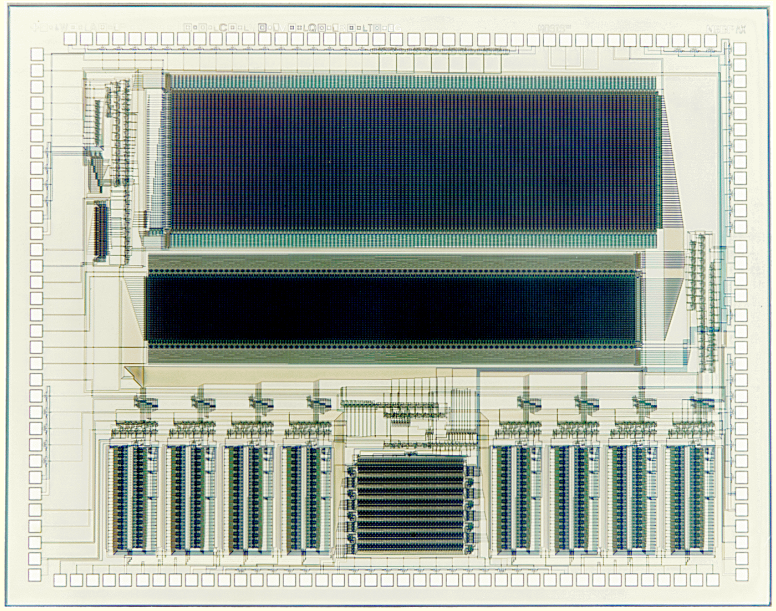




- The Detector of Internally Reflected Cherenkov light used high-quality quartz bars.
- LBNL central to selection of DIRC
  (J. Kadyk, M. Long, G. Lynch, M. Pripstein, J. Rasson, W. Wenzel).
- LBNL lead role in long-bar assembly, boxes for bars(Kadel), engineering of barrel (J. Rasson, et al.), DAQ (Brown, Shelkov).

Trigger and Drift Chamber Readout

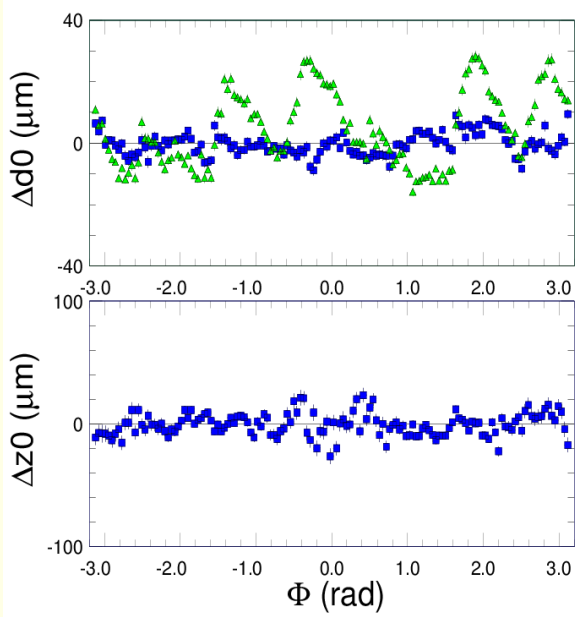
LBL lead in Level 1 trigger (F. Kral, K. Marx, M. Levi, T. Liu, A. Meyer, A. Borgland, Y. Groysman, M. Gill, C. LeClerc)



LBL designed integrated drift chamber read-out chip "ELEFANT" (M. Levi, S. Dow, A. Karcher)

Tracking and Alignment

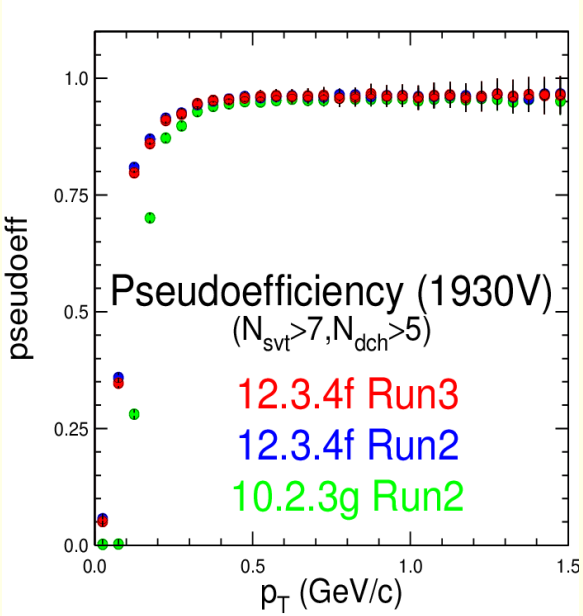
LBNL led original track reconstruction software. (D. Brown, G. Lynch)
Continuing development of tracking and alignment at LBNL.
(+ E. Charles, A. Gritsan, G. Kukartsev)



2002
2003

SVT alignment at first dominated systematic uncertainty in $\sin 2\beta$.

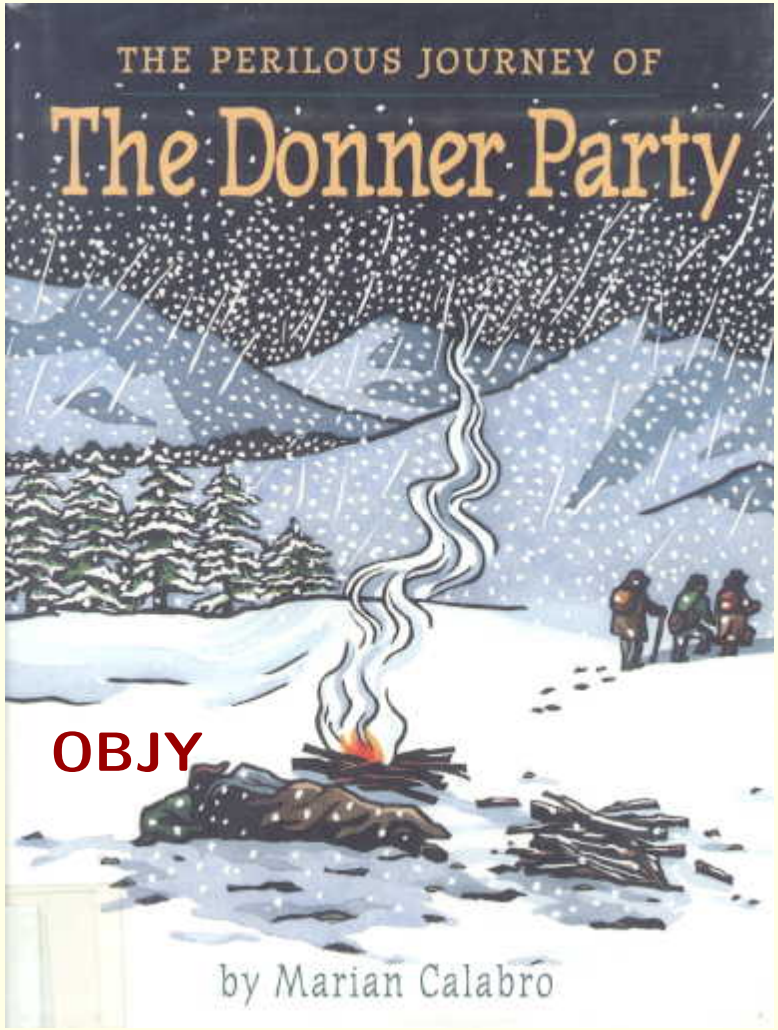
Now monitored continuously and updated as needed.



Improved tracking increased efficiency for low-momentum soft pions.

BABAR Computing Innovations

- First large collaboration using object-oriented software design.
- C++ is primary online and offline language.
- Collaboration of computing professionals and physicists.
- Open-source development philosophy.
- World-wide distributed computing (SLAC = 50%)
- Use of commercial software.‡



Earlier Pioneering Effort in California

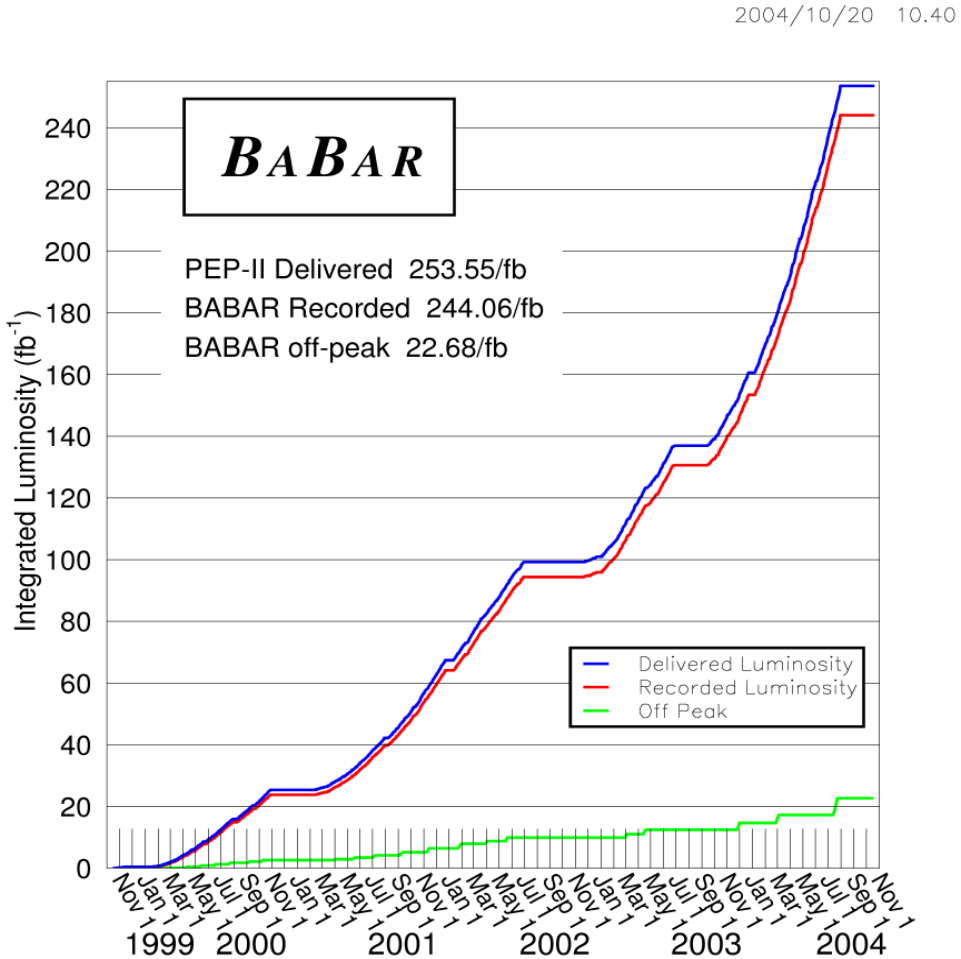
Computing Model Upgrade

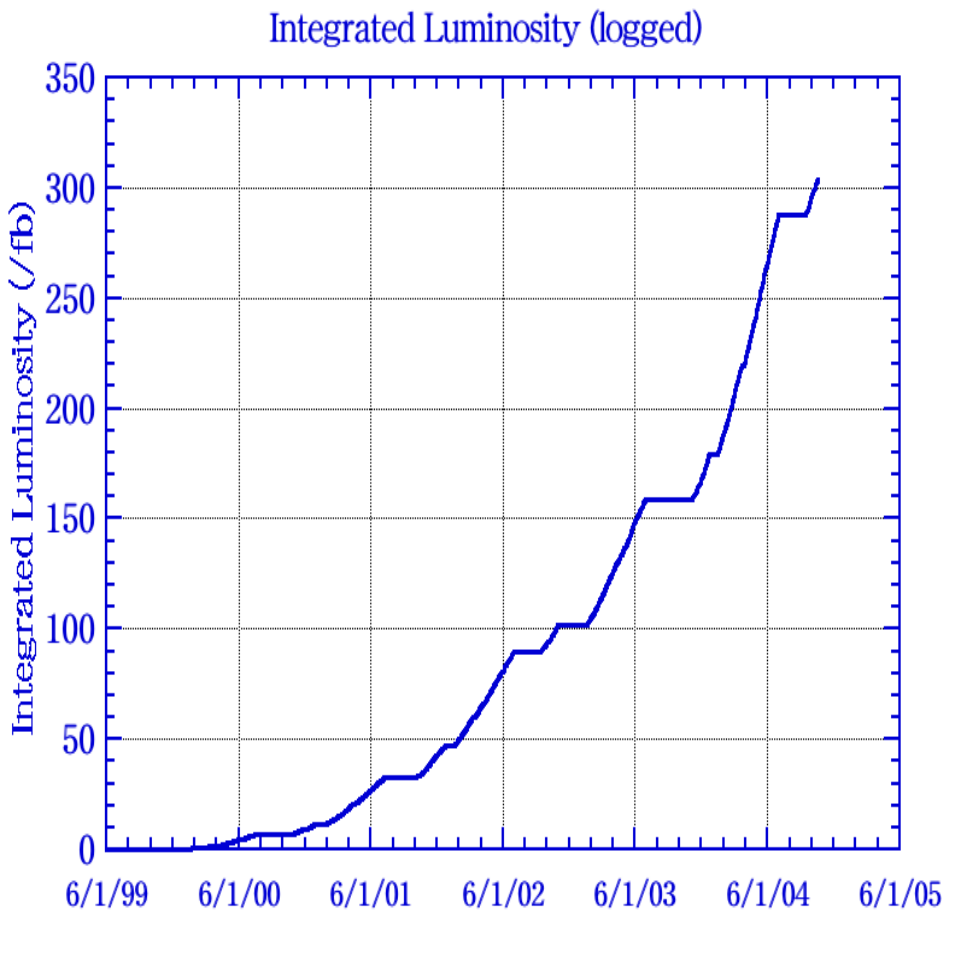
- Internal review (2002): past analysis inefficiencies unacceptable.

Feb. 2003	First BaBar talk on $D_s(2317)$
April 2003	BaBar submits $D_s(2317)$ draft to PRL
June 2003	CLEO and Belle confirm $D_s(2317)$
June 2003	Belle finds $B \to D_s(2317)D$
Oct. 2003	Belle submits $B \to D_s(2317)D$ to PRL
Aug. 2004	BaBar confirms $B \to D_s(2317)D$ to PRL

- New model deployed in January, 2004:
  - Objectivity $\to$ ROOT An Object-Oriented Data Analysis Framework
  - Retains full power of the detector for analysis.
  - Customizability.
- LBNL led design and implementation.
- Success demonstrated in results below.

PEP-II Performance vs. KEK-B



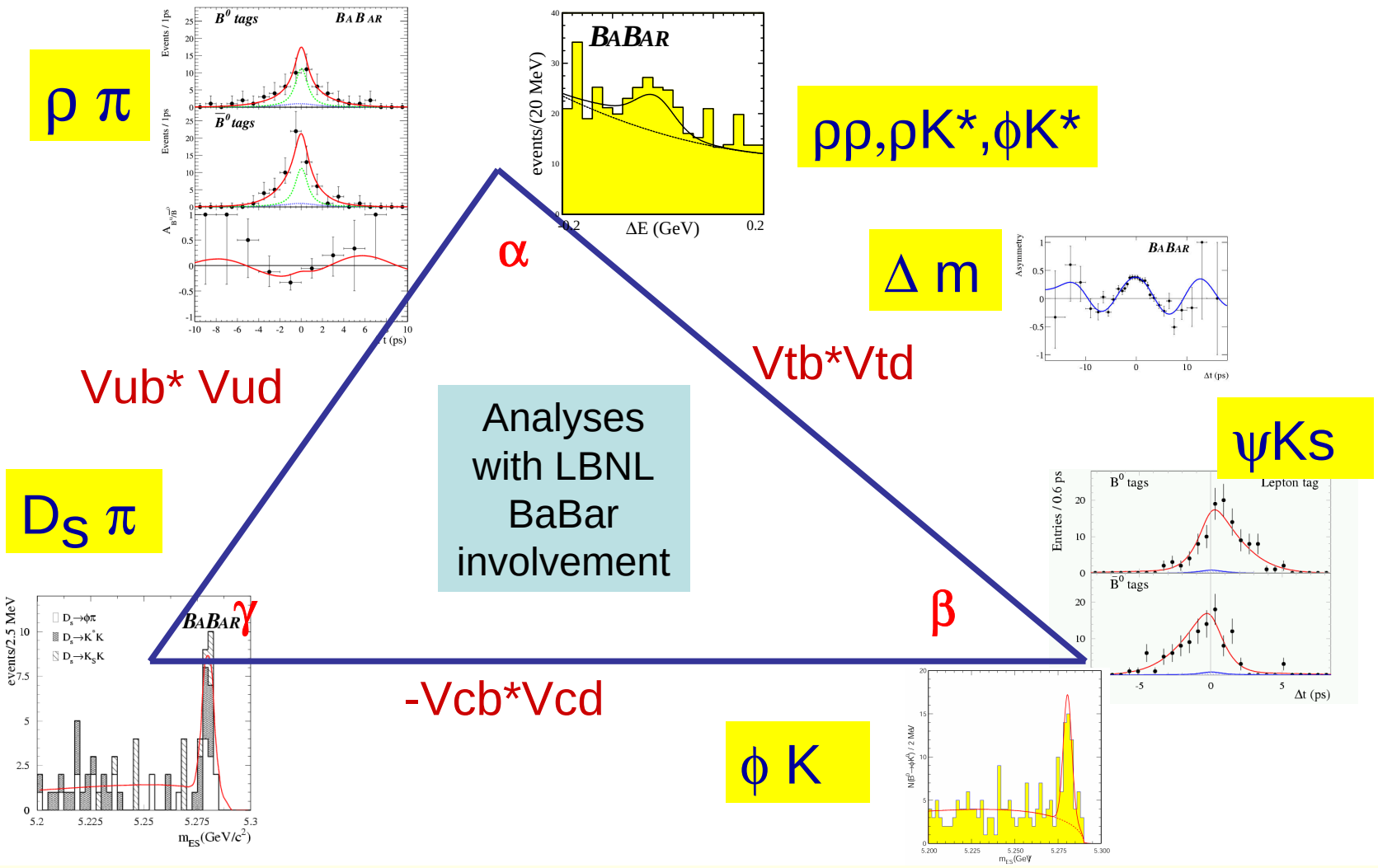


- 1 fb^{-1} $\approx 10^6$ $B\overline{B}$ pairs.
- SLAC operations currently off for safety evaluation.

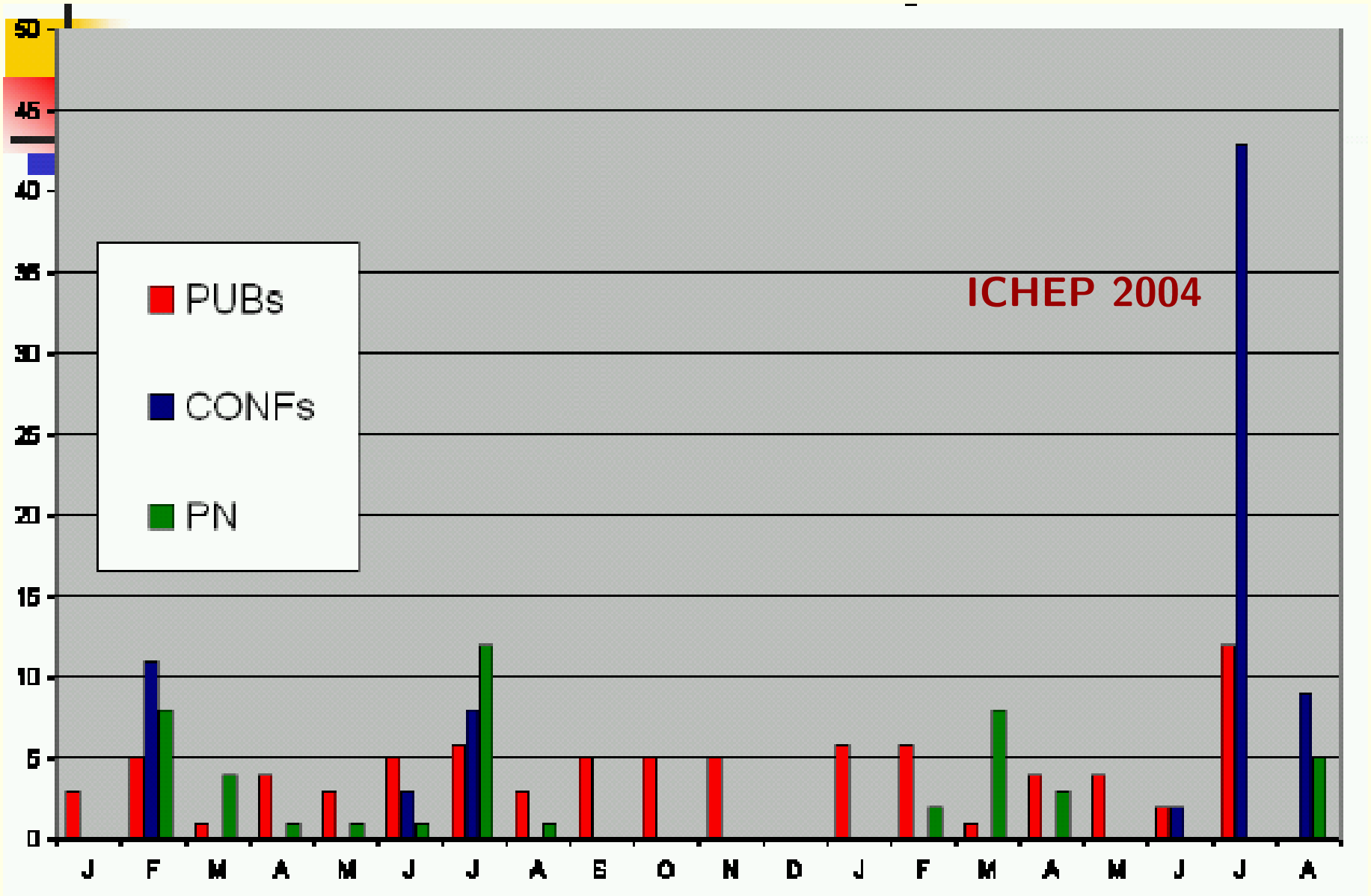
Current LBNL *BABAR* Team

Senior/ Faculty:	Gerry Abrams, Marco Battaglia, Dave Brown, Bob Cahn, Bob Jacobsen, Yury Kolomensky
Postdocs:	Eric Charles, Andrei Gritsan, Lluisa Mir, (Open position)
Students:	[Mandeep Gill], Yuriy Groysman, Gena Kukartsev, Toyoko Orimoto, Kerstin Tackmann
Retirees:	Janice Button-Shafer, John Kadyk, Roy Kerth, Gerry Lynch, Bill Wenzel
Visitors::	David Lopes Pegna

Attacking the Unitarity Triangle from All Sides (and Angles)



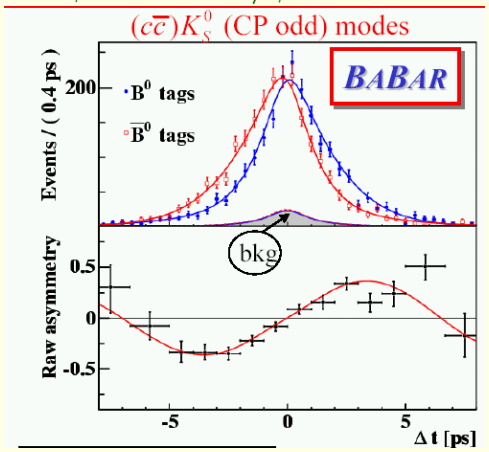
BABAR Publication Progress



Gallery of BaBar Results at ICHEP 2004

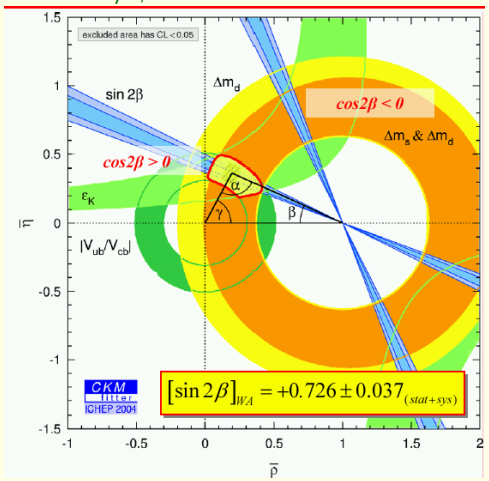
- 62 brand new results submitted to ICHEP 2004 (Beijing).
- 12 simultaneously submitted for publication.
- 12 recent, but already public, results submitted as well.
- 30 used new computing model.
- 20 used data only two weeks old!

$\sin 2\beta$ in $B \to J/\psi K^0$



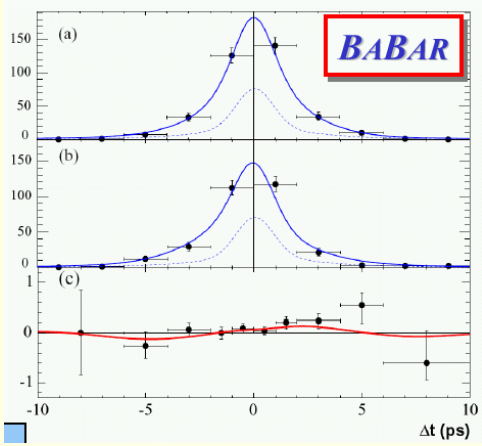
$\sin 2\beta = 0.722 \pm 0.040 \pm 0.023$

$B \to J/\psi K^*$:



$\cos 2\beta > 0$ 86% CL

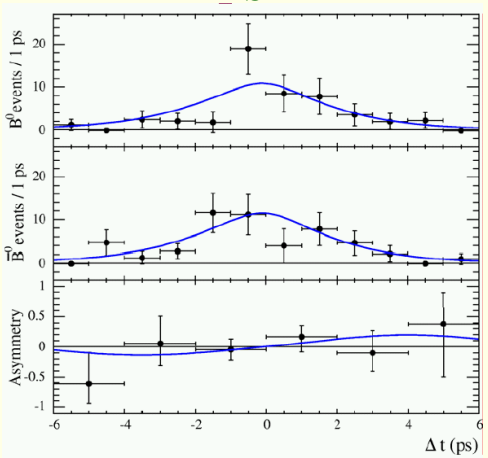
$\sin 2\beta : B \to \eta' K_S$



$\sin 2\beta = 0.27 \pm 0.14 \pm 0.03$

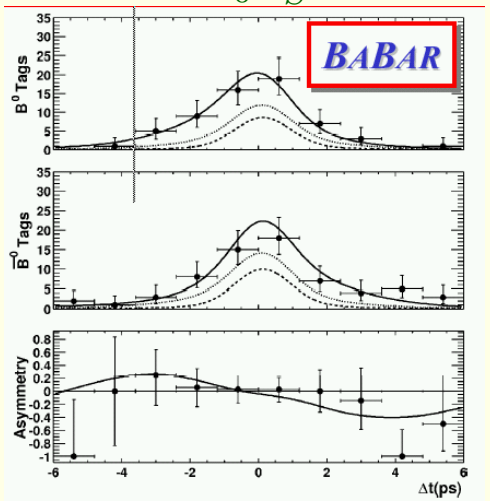
Gallery of BaBar Results at ICHEP 2004, cont.

$\sin 2\beta : B \to K_S \pi^0$



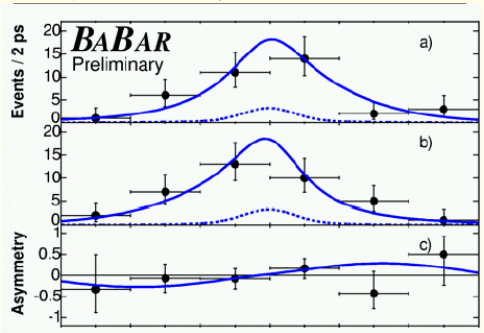
$\sin 2\beta = 0.35 \,^{+0.30}_{-0.33} \pm 0.04$

$\sin 2\beta : B \to f_0 K_S$



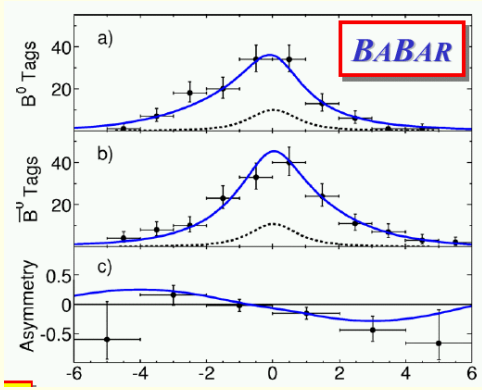
$\sin 2\beta = 0.95 \,^{+0.32}_{-0.23} \pm 0.10$

$\sin 2\beta : B \to \phi K^0$



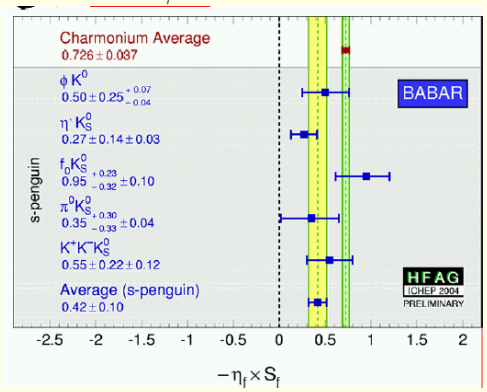
$\sin 2\beta = 0.50 \pm 0.25 \,^{+0.07}_{-0.04}$

$\sin 2\beta : B \to K^+ K^- K_s$



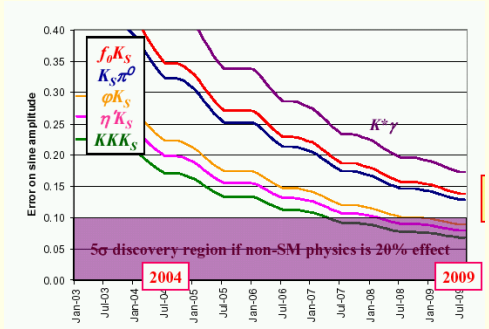
$\sin 2\beta \approx 0.71 \pm 0.28$

BaBar $\sin 2\beta$ measrements



2.7 σ discrepancy?

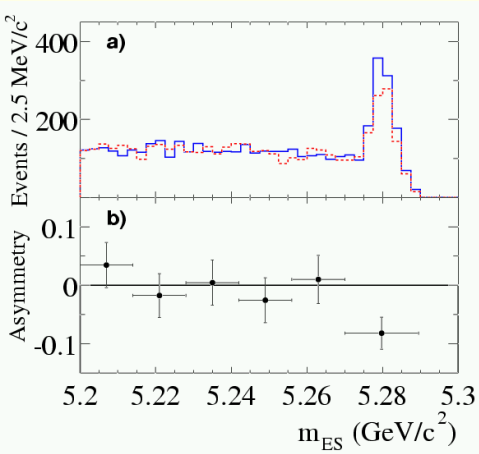
Projections for $\sin 2\beta$



Serious around 2007-8

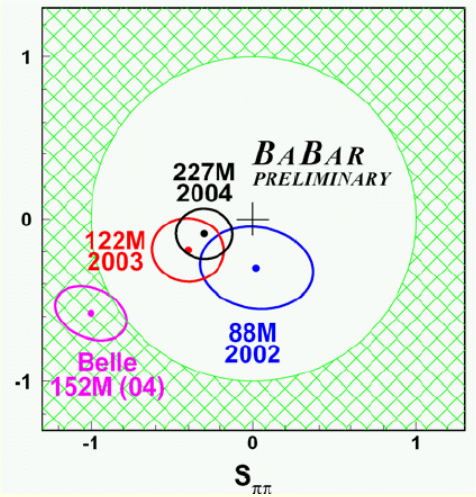
Gallery of BaBar Results at ICHEP 2004, cont.

Direct CP Violation: $B \to K\pi$



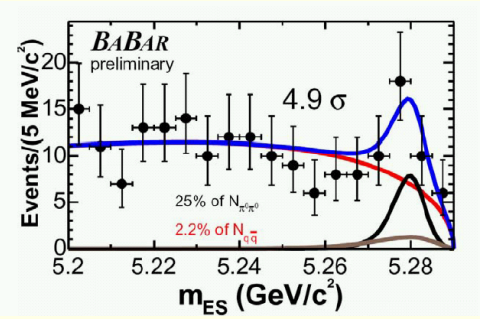
$A_{CP} = -01.33 \pm 0.030 \pm 0.009$

CP Violation: $B \to \pi^+\pi^-$



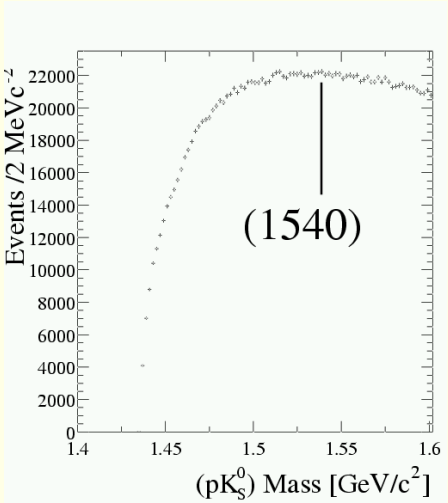
$S_{\pi\pi} = -0.30 \pm 0.17 \pm 0.03$

BF($B \to \pi^0\pi^0$)



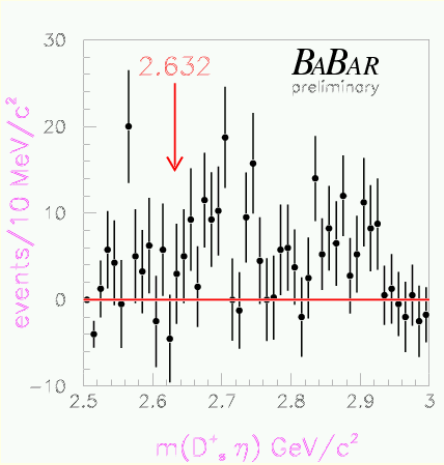
BF= $(1.17 \pm 0.32 \pm 0.10) \times 10^{-6}$

Search for Θ^+ pentaquark



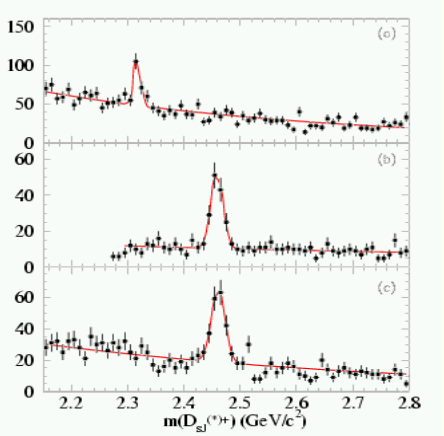
No sign of it.

SELEX $D_s(2632)$



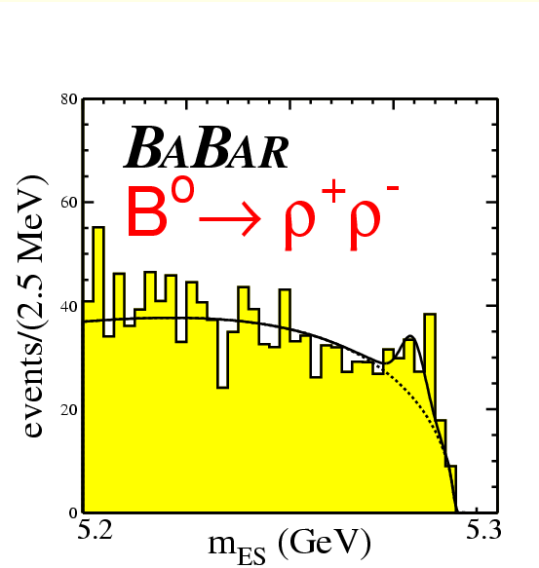
No sign of it.

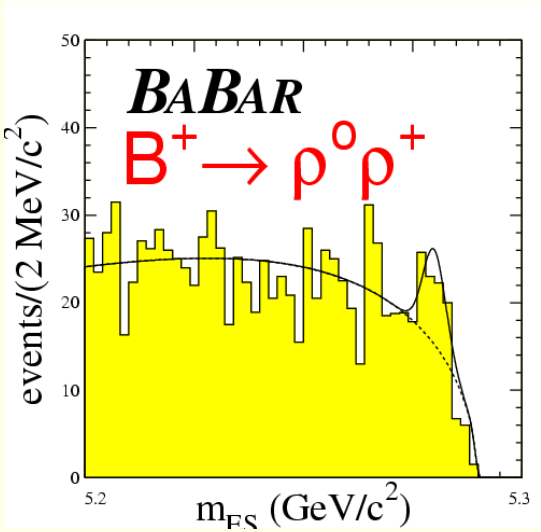
$B \to D_{sJ} D^{(*)}$

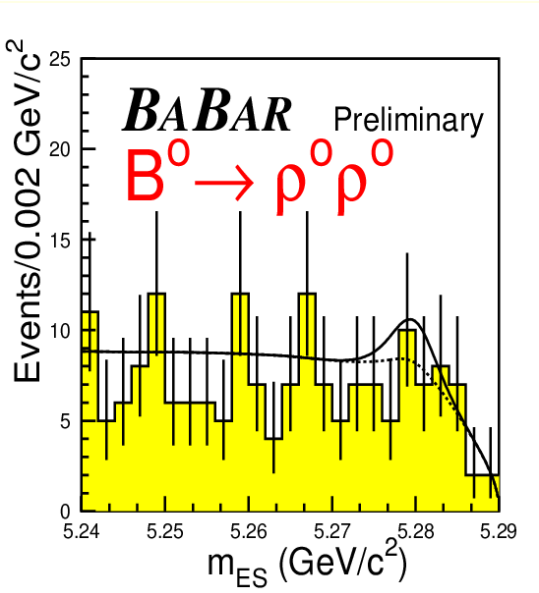


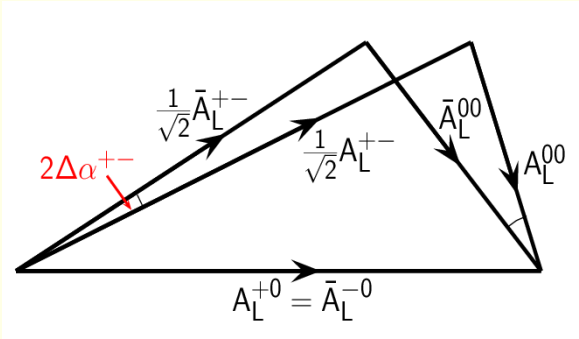
First observation with D^*

α from $B \to \rho\rho$ (Gritsan, Groysman, Mir)



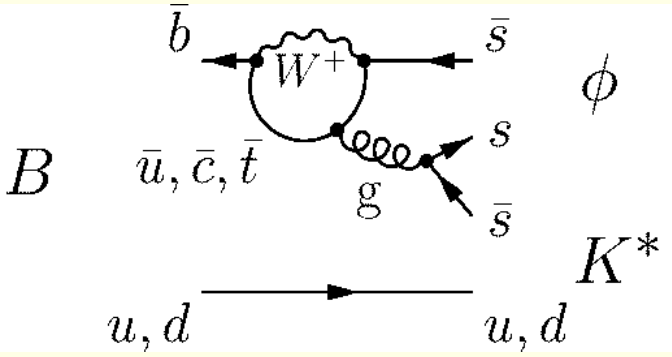


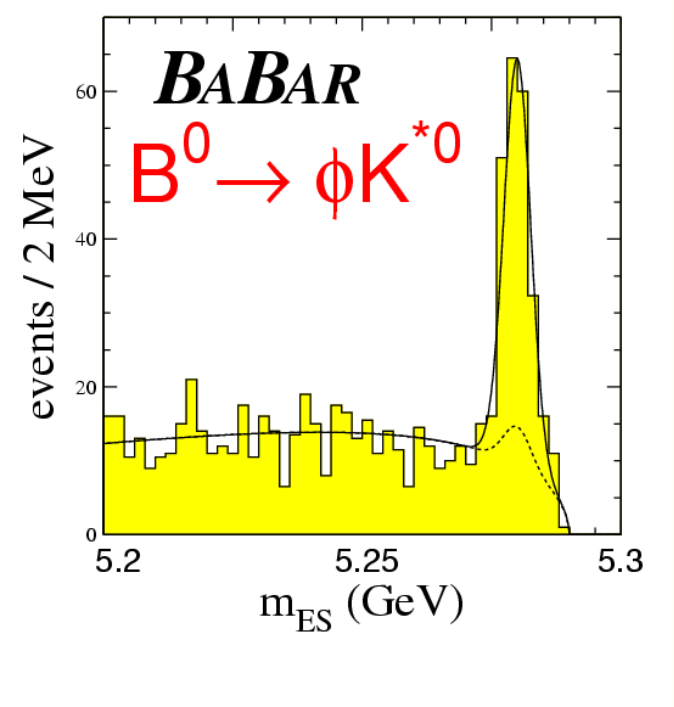




- Pure longitudinal polarization simplifies.
- α_{eff} from time dependence in $B \to \rho^+\rho^-$.
- Other $\rho\rho$ channels determine $\alpha - \alpha_{eff}$ (penguin).
- ICHEP04: $\alpha = (96 \pm 10(\text{stat}) \pm 4(\text{syst}) \pm 11(\text{penguin}))^o$
- Small $\rho^0\rho^0$ BF ($< 1.1 \times 10^{-6}$) makes this best α measurement.

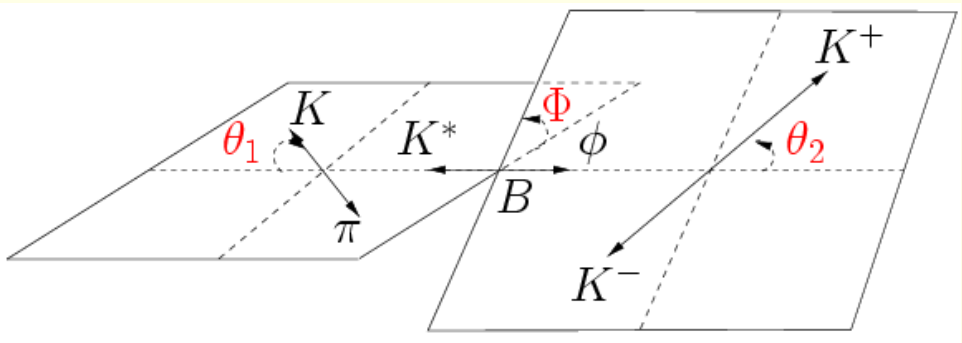
Full Angular Distribution: $B \to \phi K^*$ (Gritsan)

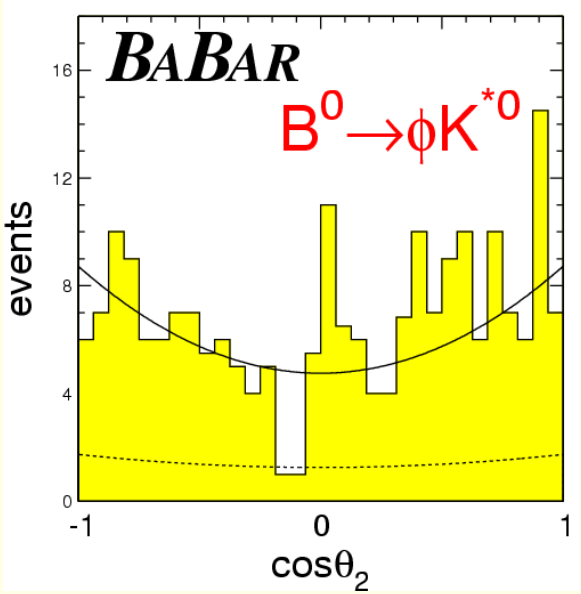


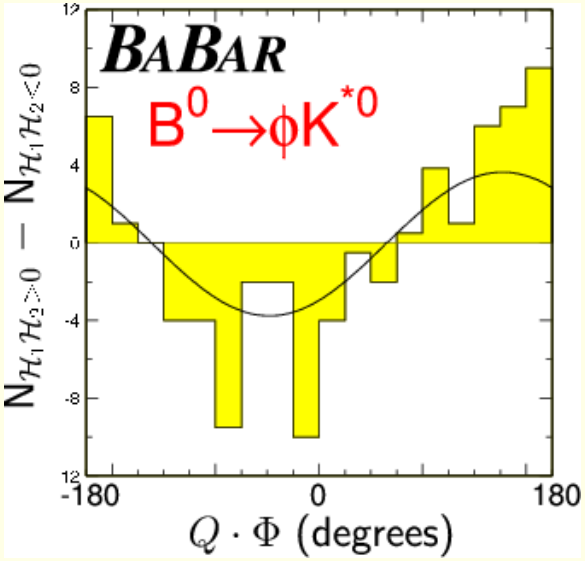


- Determine magnitude of amplitudes, relative phases for B^0 and $\overline{B}^0$.
- Are there final state interactions (strong phases)? CP violation?
- Look for differences between B^0 and $\overline{B}^0$.

$B \to \phi K^*$ Angular Distributions, cont.



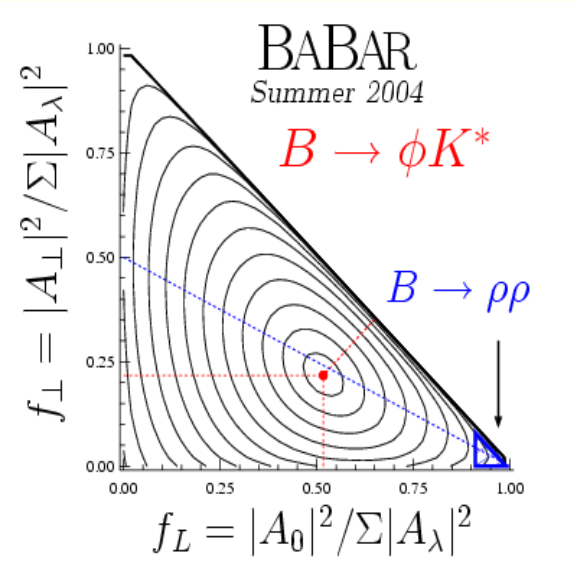




- Not purely longitudinal polarization.
- Strong-interaction phase seen in Φ plot.
- Both contrary to naive expectation (factorization).

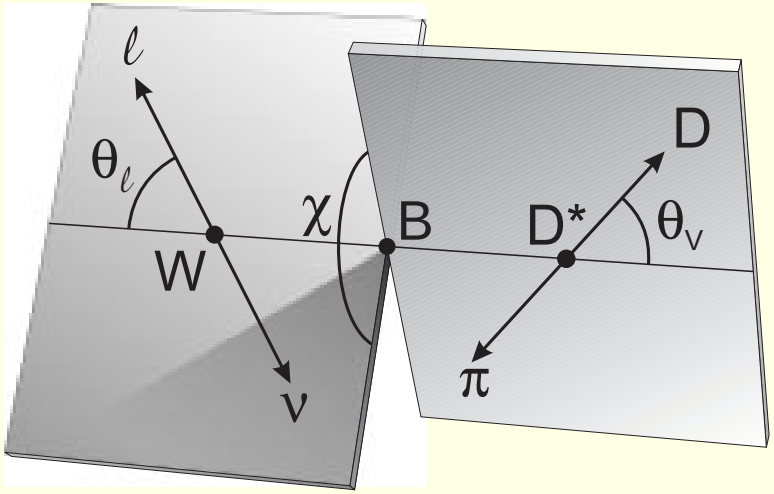
Summary of Results on $B \to VV$

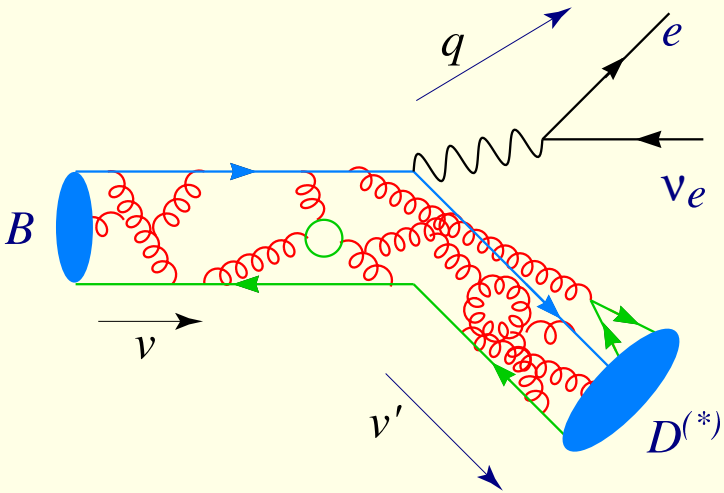
B decay	$\mathcal{B}$ (10^{-6})	f_L	$N_{B\bar{B}}(10^6)$	Inst.
$\rho^-\rho^+$	$30 \pm 4 \pm 5$	$0.99 \pm 0.03^{+0.04}_{-0.03}$	89	LBL, Saclay, UK
$\rho^0\rho^+$	$23\ ^{+6}_{-5} \pm 6$	$0.97^{+0.03}_{-0.07} \pm 0.04$	89	LBL
$\rho^0\rho^0$	< 1.1 (90%)	–	227	LBL, Saclay
ϕK^{*0}	$9.2 \pm 0.9 \pm 0.5$	$0.52 \pm 0.05 \pm 0.02$	227	LBL
ϕK^{*+}	$12.7\ ^{+2.2}_{-2.0} \pm 1.1$	$0.46 \pm 0.12 \pm 0.03$	89	LBL
$\rho^0 K^{*+}$	$10.6\ ^{+3.0}_{-2.6} \pm 2.4$	$0.96^{+0.04}_{-0.15} \pm 0.04$	89	LBL
$\rho^- K^{*0}$	$17.0 \pm 2.9 \pm 2.0^{+0.0}_{-1.9}$	$0.79 \pm 0.08 \pm 0.04 \pm 0.02$	89	Saclay
$\rho^- K^{*+}$	< 24 (90%)	–	123	Wisconsin



- Longitudinal in polarization in $\rho\rho$, ρK^*.
- Clear deviation in polarization in ϕK^* from pure longitudinal.

$B \to D * \ell\nu$ form factors (Gill)

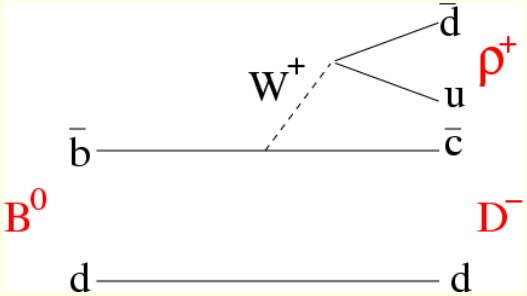


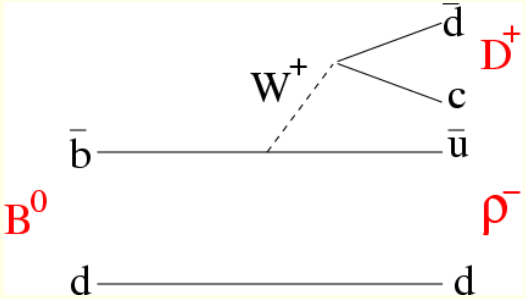


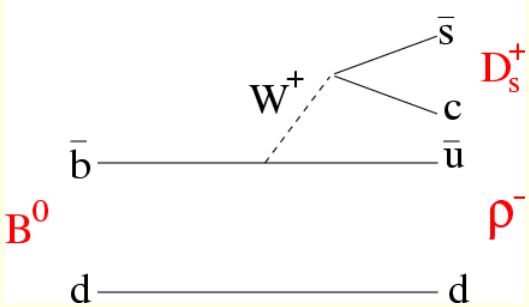
- Three form factors. Use heavy quark approximation to simplify.
- Three parameters to measure: two ratios of form factors, R_1, R_2, one slope, ρ^2.
- Results valuable both as test of heavy quark models and for other measurements.

	BaBar	CLEO
R_1	$1.328 \pm 0.055 \pm 0.025 \pm 0.025$	$1.18 \pm 0.30 \pm 0.12$
R_2	$0.920 \pm 0.044 \pm 0.020 \pm 0.013$	$0.71 \pm 0.22 \pm 0.07$
ρ^2	$0.769 \pm 0.039 \pm 0.019 \pm 0.032$	$0.91 \pm 0.15 \pm 0.06$

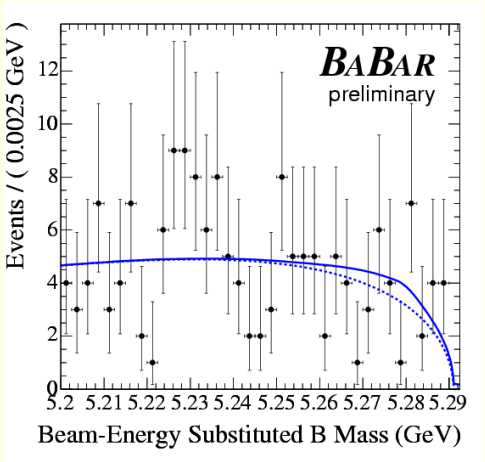
$B \to D_s\rho$ and γ (Kolomensky, Orimoto)







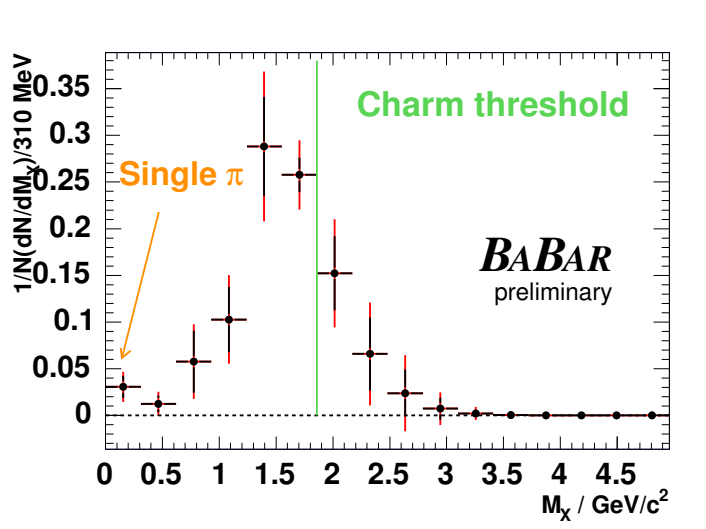
- To study $2\beta + \gamma$ need ratio of first two.
- Second is too small to measure. Third is bigger and related by $SU(3)$.



- Very little signal! BF $< 1.9 \times 10^{-5}$. $r(D\rho) < 9.5 \times 10^{-3}$ 90% CL
- Bad news for $\sin(2\beta + \gamma)$ measurement with $B \to D\rho$.

$B \to X_u \ell \nu$ (Battaglia, Brown, Tackmann)

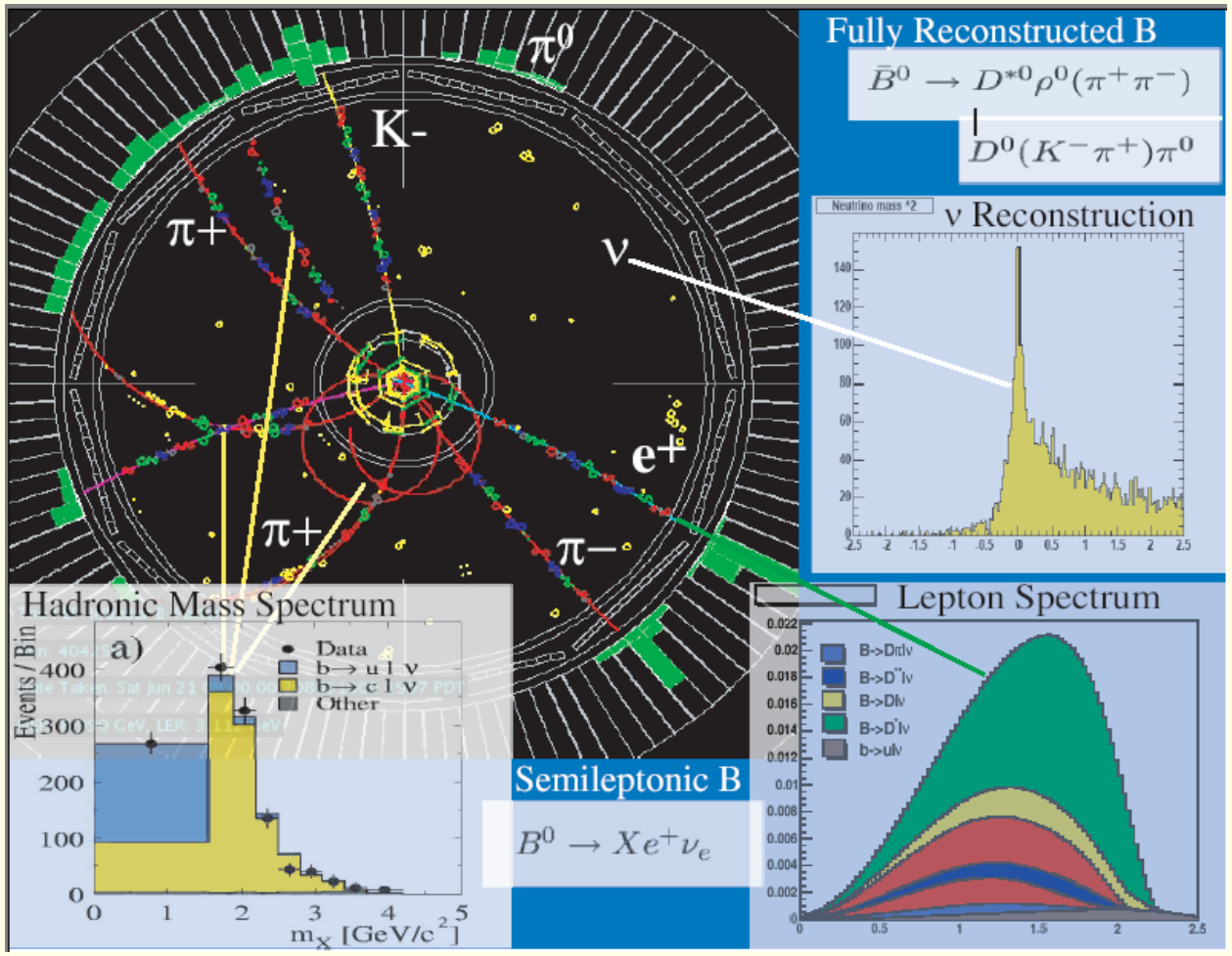
- Corrected $m(X_u)$ spectrum from semileptonic events.
- Use moments of spectrum to determine m_b as in $B \to X_c \ell \nu$.



$B \to X_c \ell \nu$	$B \to X_u \ell \nu$
$V_{cb} = (41.4 \pm 0.8) 10^{-3}$	$V_{ub} = (4.9 \pm 0.7) 10^{-3}$
$m_b = (4.61 \pm 0.07)\,\mathrm{GeV}$	$m_b = ? \pm 0.15\,\mathrm{GeV}$

Exploiting *BABAR*'s Power in Semileptonics (Battaglia, Brown, Tackmann)

- Use detailed information from CM2 for each event.
- 30% of "lost" tracks actually leave signal.
- Save many poorly reconstructed tracks.
- "Reconstruct" neutrino.



Great Opportunities at BaBar

- 500 fb^{-1} by end of 2006?
- Resolve discrepancies in $\sin 2\beta$ in different channels?
- High precision measurement of α.
- Some precision measurement of γ.
- Precision determination of $|V_{cb}|, |V_{ub}|$.
- Explore D and D_s systems and $X(3872)$.
- Strong dynamics in weak decays: $B \to VV$, etc.
- New physics searches: $B \to X_s \ell\ell$,

LBNL in *BABAR* physics from start to finish

- LBNL has made major contributions to *BABAR*.
- Postdoc and student efforts have collaboration-wide impact: $\rho\rho$, ϕK^*, $B \to D^* \ell \nu$, $B \to D_s \rho$,...
- CM2 has transformed analysis paradigm.
- Move from core-computing and publication oversight tasks to analysis.
- New effort in semileptonics led by Prof. Marco Battaglia.
- Earlier worries of very rapid close-out alleviated. Currently looking for postdoc. Gradual phase-out by 2008?