Super*BaBar*: Physics at a 10^{36} Asymmetric B Factory

David Stoker
University of California, Irvine

Overview of Recent Studies♣:

- Physics motivation for a $10^{36}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ e^+e^- asymmetric B Factory
- Design parameters for a 10^{36} Super B Factory
- Super*BABAR* detector design concept
- Schedule and cost estimates

♣All welcome! http://fermi.phy.uc.edu/HyperNews/get/forums/SuperBABAR.html

Physics Motivation: an overview

PEP-II and KEK-B have produced first evidence for CP violation in B decays

- PEP-II upgrades should give *BABAR* $600\,\mathrm{fb}^{-1}$ by end of 2007

Far larger data samples will be needed for:

- overconstrained precision measurements of the CKM Unitarity Triangle
- searches for effects of new physics in rare loop-mediated decays

At $10^{36}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$, an e^+e^- asymmetric B Factory would:

- produce 2×10^{10} B mesons $(10\,\mathrm{ab}^{-1}!)$ per "Snowmass year" $(10^7\,\mathrm{s})$
- be complementary to new hadronic experiments LHCb/ATLAS/CMS/BTeV
- provide some unique capabilities, *e.g.* for $\sin 2\alpha$, V_{ub}, rare decays
- provide a complete range of B physics and tests of CKM picture

(For details of 2001 Snowmass studies see: SLAC-PUB-8970)

CKM Angle Measurement Precision

CKM Angle	*BABAR* ($0.5\,\mathrm{ab}^{-1}$)	Super*BABAR* ($10\,\mathrm{ab}^{-1}$)	BTeV (1 yr)	LHCb (1 yr)	Atlas/CMS (1 yr)
$\sin 2\beta\ (B^0 \to J/\psi K_s^0)$	0.037	0.008	0.025	0.014	0.021/0.025
$\sin 2\beta\ (B^0 \to \phi K_s^0)$	0.25	0.056			
$\sin 2\alpha_{\mathrm{eff}}\ (B^0 \to \pi^+\pi^-)$	0.14	0.032	0.024	0.056	0.10/0.17
$\alpha_{\mathrm{eff}} - \alpha\ (B^0 \to \pi^0\pi^0)$	$< 18^\circ$	$< 7^\circ$	- - -	- - -	- - -
$\sin(2\beta+\gamma)\ (B^0 \to D^*\pi)$	0.15	0.03			
$\gamma\ (B \to DK)$	- - -	$< 2.5^\circ$	$< 10.0^\circ$	$< 19.^\circ$	
$\gamma\ (B_s \to D_s K)$	- - -	$< 15^\circ$	$< 7.0^\circ$	$< 13.^\circ$	

- 10^{36} e^+e^- collider has potential to measure all three CKM angles precisely
- unique contribution: theoretically clean measurement of α
  - ◇ requires separate $B \to \pi^0\pi^0$ and $\overline{B} \to \pi^0\pi^0$ decay rate measurements

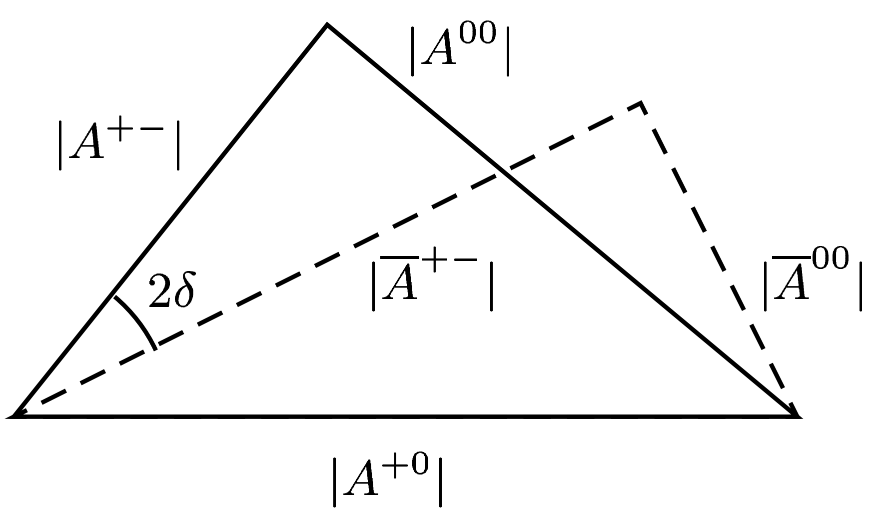
Measurement of $\sin 2\alpha$

Measured asymmetry in $B \to \pi^+\pi^-$: $S_{\pi\pi} \sim \sin 2\alpha_{\rm eff} = \sin(2\alpha + 2\delta_{\rm Penguin})$

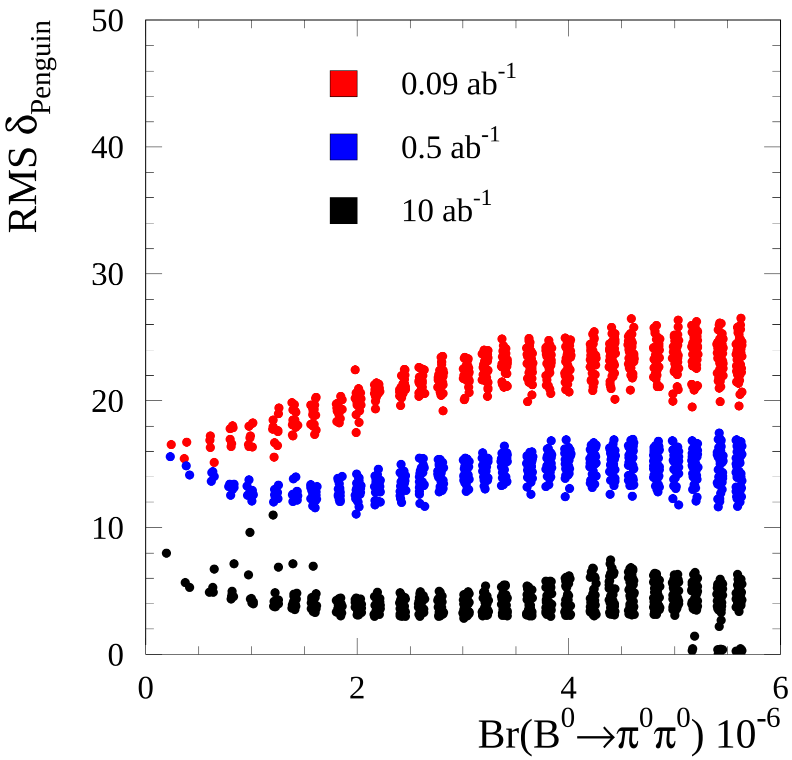
From $31\,{\rm fb}^{-1}$ *BABAR* measures: $S_{\pi\pi} = 0.03^{+0.53}_{-0.56} \pm 0.11$

Estimated uncertainties: $\sigma_{\sin 2\alpha_{\rm eff}} = 0.14$ with $0.5\,{\rm ab}^{-1}$ and 0.032 with $10\,{\rm ab}^{-1}$

Find $\delta_{\rm Penguin}$ from $B, \overline{B} \to \pi\pi$ decay rates — challenge is precision for $\pi^0\pi^0$



Isospin triangles: $B \to \pi\pi$, $\overline{B} \to \pi\pi$



Rare Decays

		Hadron Collider Experiments			e^+e^- B Factories	
Decay Mode	Branching Fractions	**CDF D0** ($15\,\mathrm{fb}^{-1}$)	**BTeV LHCb** (10^7 s)	**ATLAS CMS** (1 Year)	**BABAR BELLE** ($0.5\,\mathrm{ab}^{-1}$)	$\mathbf{10^{36}}$ ($10\,\mathrm{ab}^{-1}$)
$B \to X_s\gamma$	$(3.3 \pm 0.3) \times 10^{-4}$				11K 1.7K (B Tagged)	220K 34K (B Tagged)
$B \to K^*\gamma$	5×10^{-5}	1.3K	25K		6K	120K
$B \to \rho(\omega)\gamma$	2×10^{-6}				300	6K
$B \to X_s\mu^+\mu^-$	$(6.0 \pm 1.5) \times 10^{-6}$		3.6K		300	6K
$B \to X_s e^+e^-$					350	7K
$B \to K^*\mu^+\mu^-$	$(2 \pm 1) \times 10^{-6}$	0.4-1.1K	2.2K/4.5K	665/4.2K	120	2.4K
$B \to K^* e^+e^-$					150	3K
$B \to X_s\nu\overline{\nu}$	$(4.1 \pm 0.9) \times 10^{-5}$				8	160
$B \to K^*\nu\overline{\nu}$	5×10^{-6}				1.5	30
$B_d^0 \to \tau^+\tau^-$	10^{-7}					
$B_s^0 \to \mu^+\mu^-$	10^{-9}	40/10-45	5/11	9/7		
$B_d^0 \to \mu^+\mu^-$	8×10^{-11}	3/1-4	1/2	0.7/20		
$B \to \tau\nu$	5×10^{-5}				17	350
$B \to \mu\nu$	1.6×10^{-7}				8	150
$B^0 \to \gamma\gamma$	10^{-8}				0.4	8

Super B Factory: overview

Use PEP-II tunnel & infrastructure; extend existing RF system

Tentative major parameters for achieving $10^{36}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$:

- high beam currents: LER 24.5 A (e^-), HER 8.4 A (e^+)
  - ◇ PEP-II design: LER 2.14 A (e^+), HER 0.75 A (e^-)
- small IP xy spot size: $106\,\mu\mathrm{m}\times 1.1\,\mu\mathrm{m}$
  - ◇ PEP-II design: $220\,\mu\mathrm{m}\times 6.7\,\mu\mathrm{m}$
- high beam-beam tune shifts: $\xi \approx 0.11$

Major changes from PEP-II

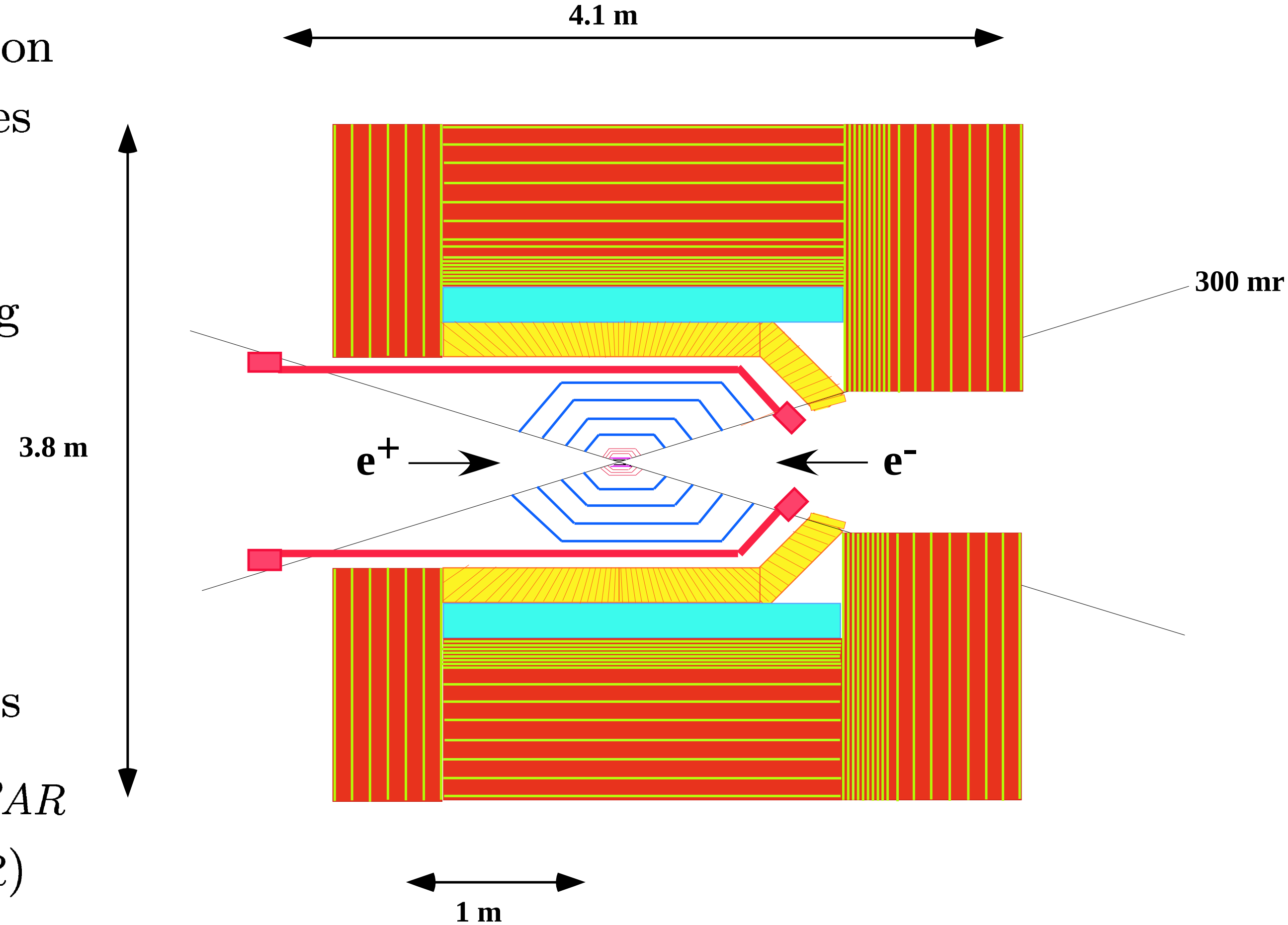
- continuous injection: beam lifetimes $\sim 5\,\mathrm{min}$ with high tune shifts
- crossing angle at IP to help separate beams (3400 bunches, 0.6 m spacing)
- vacuum chamber: welded extrusions for low impedance, fewer fragile parts

Super B Factory: parameters

Parameter	High Energy Ring (HER)	Low Energy Ring (LER)
Beam energy (GeV)	9.0 (e^+)	3.1 (e^-)
Center of mass energy (GeV)	10.58	10.58
Circumference	2200	2200
RF Frequency (MHz)	476	476
RF Voltage (MV)	50	30
Synch. Rad. Power (MW)	23	12
Number of bunches	3400	3400
Total beam current (A)	8.4	24.5
$\beta^*_{y/x}$ (cm)	0.15/15	0.15/15
Emittance (y/x) (nm)	0.75/75	0.75/75
Momentum Compaction	0.001	0.0013
Bunch length (mm)	1.8	1.8
Approx. AC power (MW)	50	27
Beam lifetime (min)	5	5
Injection particles per pulse	7.3×10^{10}	5.3×10^{10}
Continuous injection rate (Hz)	20	80
Beam-Beam tune shifts	0.11	0.11
Transverse beam size (y/x) (μm)	1.1/106.1	1.1/106.1

“Strawman” Super*BABAR* Detector

- High physics and background rates $\Longrightarrow$ high segmentation and short integration times
- 1.0 cm radius beampipe
- Silicon pixel/strip tracking
- DIRC π/K particle ID
- Fast crystal calorimeter
- 3 Tesla solenoid
- IFR with scintillator strips
- Dimensions $\sim 2/3$ of *BABAR* (volume $\sim 30\%$ of *BABAR*) due to compact calorimeter



Silicon Tracker

- 2 layers of silicon pixels, 7 double-sided layers of silicon strips

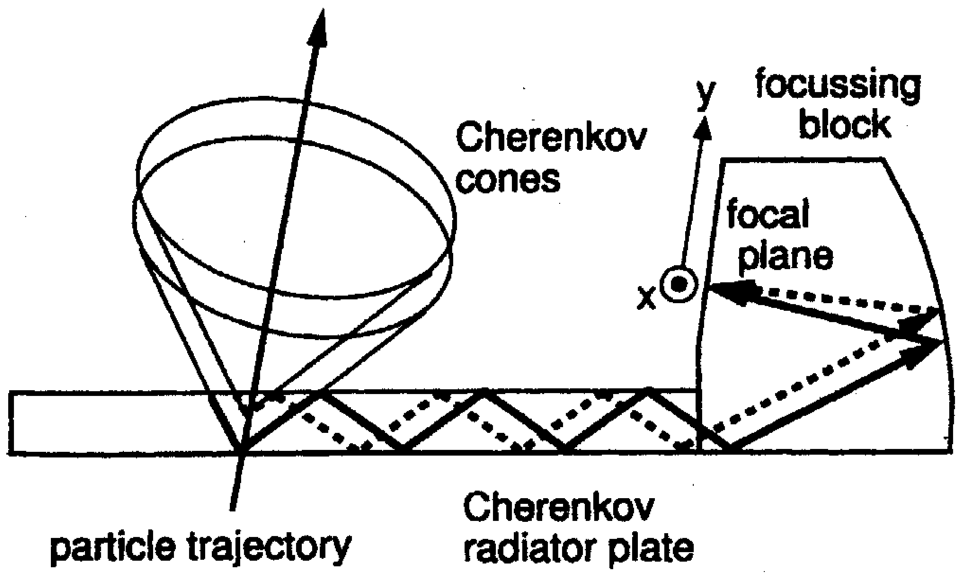
Layer	Type	Radius
1	$50\,\mu$m $\times$ $150\,\mu$m pixels	1.3 cm
2	$50\,\mu$m $\times$ $150\,\mu$m pixels	1.8 cm
3	3 mm $\times$ $50\,\mu$m strips	3.0 cm
4	3 mm $\times$ $50\,\mu$m strips	6.0 cm
5	3 mm $\times$ $50\,\mu$m strips	9.0 cm
6	3 cm $\times$ $50\,\mu$m strips	15.0 cm
7	3 cm $\times$ $50\,\mu$m strips	25.0 cm
8	3 cm $\times$ $50\,\mu$m strips	35.0 cm
9	3 cm $\times$ $50\,\mu$m strips	45.0 cm

- assume 1.0 cm radius beampipe (0.7% X_0); $300\,\mu$m silicon; 3 T field
  - ◇ resolution similar to *BABAR* TDR at high momentum
  - ◇ resolution worsens rapidly below 400 MeV/c as fewer planes traversed
- expect good dE/dx information below $\sim$ 400 MeV/c for π/K separation

Particle Identification: DIRC

Aim for better π/K separation at high momentum than in *BABAR* DIRC

- use quartz bars as Cerenkov light radiators as in *BABAR*
- use new fast ($< 200\,\text{ps}$) compact photo-detectors
- use quartz lens/mirror focusing elements instead of water stand-off box
- expect about $3\times$ better resolution ($2.7\,\text{mradians}$) per photon



Calorimeter

Require:

- performance similar to design goals for *BABAR* CsI(Tl) calorimeter:
  - ◇ $B^0 \to \pi^0\pi^0$ requires good π^0 mass resolution at high momentum
  - ◇ good efficiency for low energy photons; efficient e/π separation
- radiation hard at $\sim 100\,\mathrm{krad/yr}$
- 250–500× reduction in visible background in triggered events
  - ◇ short decay time, better time information, better signal recognition(?)

Possible crystal choice: LSO — lutetium oxyorthosilicate (raw LSO ∼ \$7/cc)

- radiation hard to 100 Mrad; light-yield 27k γ/MeV; decay time 47 ns
- 2.3 cm Molière radius allows reduction of barrel inner radius to 60 cm

Readout:

- ∼ 50% less light than CsI(Tl) $\Longrightarrow$ gain needed for similar performance
  - ◇ avalanche photodiode is most attractive technology at present

Instrumented Flux Return

Need efficient detection of muons for tagging and of neutral hadrons, *e.g.* K_L^0

- High rates $\Longrightarrow$ use plastic scintillator strips instead of RPC's
  - ◇ readout: wavelength-shifting fibers, multianode photomultipliers
- inner surface only 1.0 m from beam line
- improve π/μ separation by increasing steel thickness *vs.* *BABAR*
  - ◇ barrel: 17 steel layers totalling 90 cm (cf. 65 cm for *BABAR*)
  - ◇ forward endcap: 18 steel layers totalling 1.0 m
  - ◇ backward endcap: 7 steel layers totalling 70 cm

Trigger and Data Acquisition

Physics goals $\Longrightarrow$ *open* trigger, highly efficient for almost all B decay modes

- big advantage over highly selective triggers at hadron machines

At design luminosity: 1 nb of cross section $\longrightarrow$ 1000 events/sec

- 1.05 nb for $B\overline{B}$ pairs from $\Upsilon(4S)$, and 1.30 nb for continuum $c\overline{c}$
- $\approx$ 50 nb for Bhabha events within detector fiducial volume

Hardware trigger:

- uses coarse *trigger primitives* from silicon tracker and calorimeter
- $\approx$ 72k triggers/s before any partial Bhabha, background track vetoes

Software trigger:

- operates on complete events using full tracker and calorimeter information
- $\approx$ 6k triggers/s with full efficiency for $B\overline{B}$, + most $c\overline{c}$, $\tau^+\tau^-$ (≥ 4 tracks)

Data acquisition: prior performance proof by ATLAS, CMS expected!

Schedule and Cost Estimates

Approval prospects: difficult if NLC to be built in U.S. — more likely otherwise

Optimistic scenario:

- more people will join studies
  - ◇ all welcome!
- PEP-II reaches 600 fb^{-1} in 2007
- hadron experiments lead by 2008
- install 10^{36} complex in 2008–2009
- Super*BABAR*: 10 ab^{-1}/yr from 2010
- data sample of 65 ab^{-1} by 2015 (1000× present *BABAR* data set)
- Collider cost: ~370M$ (FY2008)
- Detector cost: ~183M$ (FY2008)