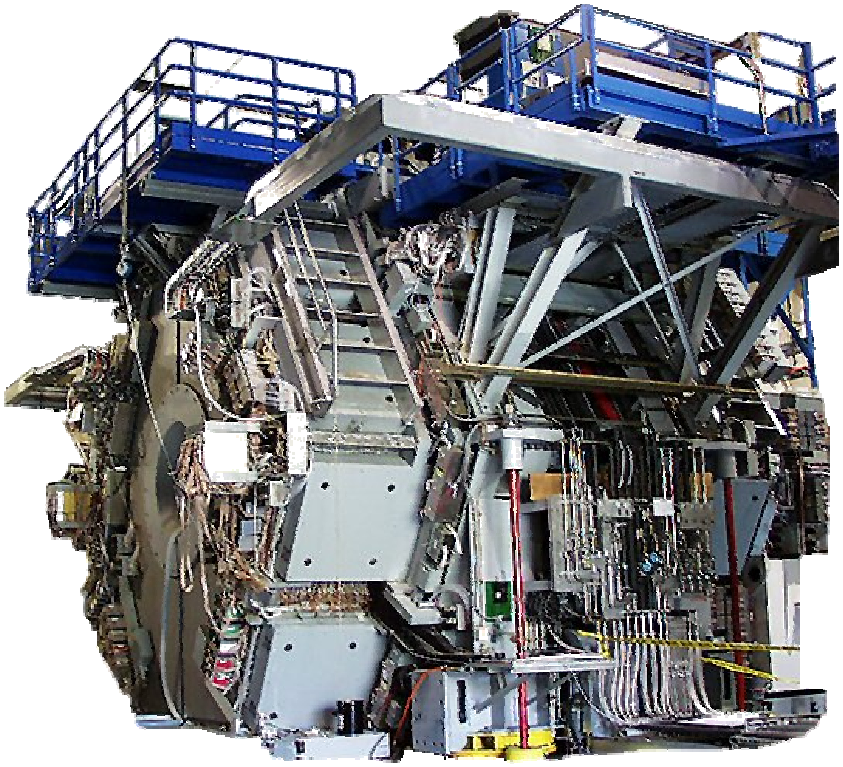
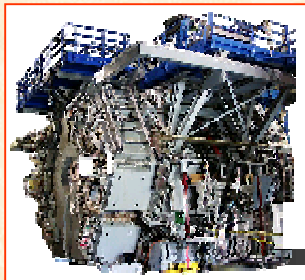
BaBar Status and Plans for the Future



Stewart Smith
Princeton University

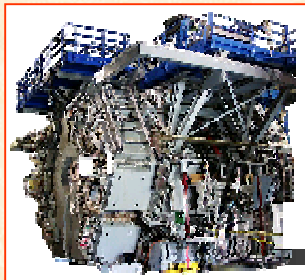
SLAC EPAC Meeting

November 8, 2000



Plan of talk

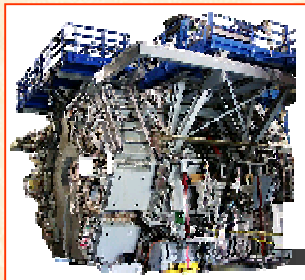
- Summary of 1999 and 2000 Operations
- Selections from first Physics Results
- Background experiments and estimates for future
- Planning for Improvements
- Detector Issues
- Computing Issues
- Conclusions



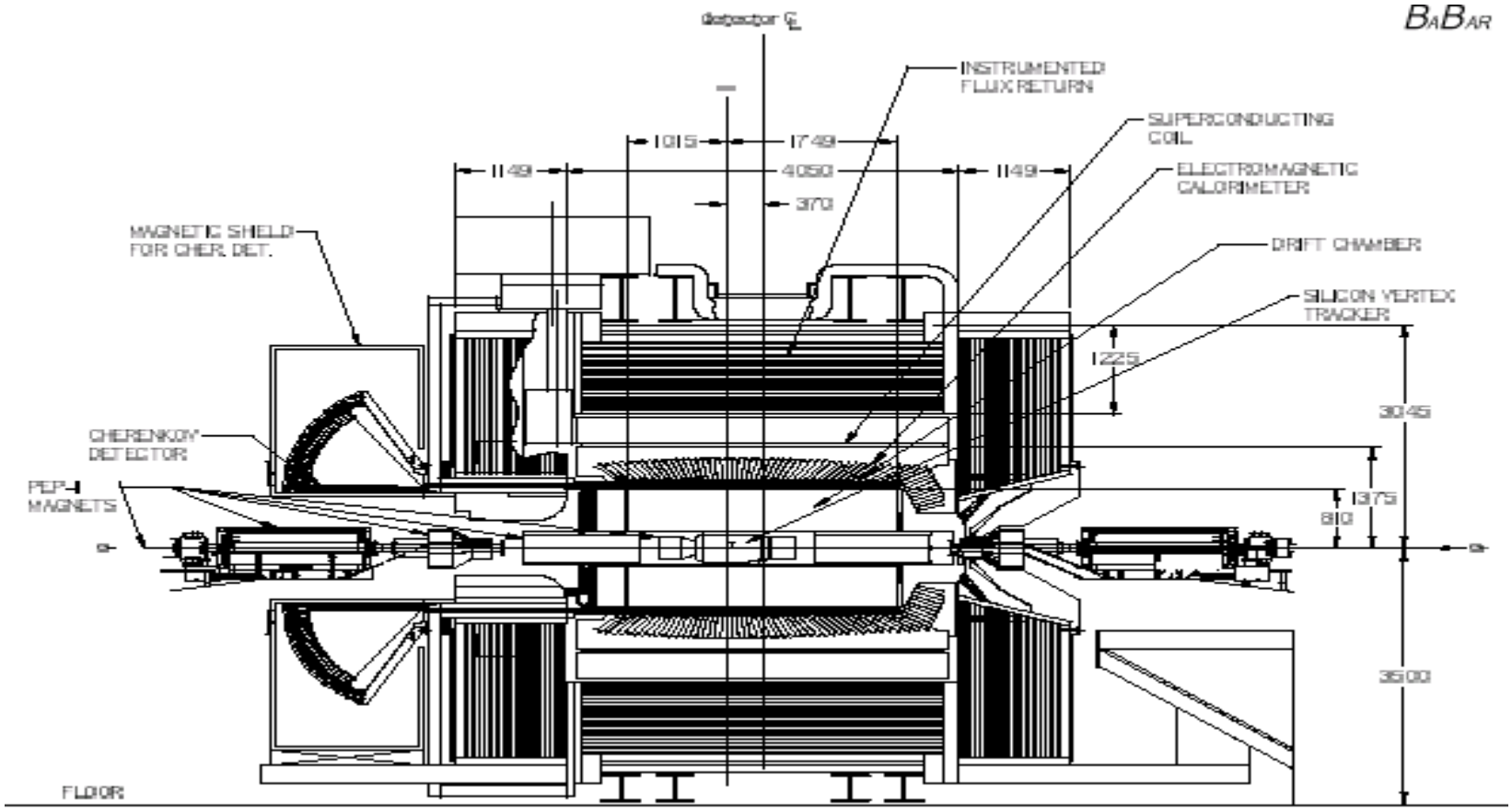
Introduction

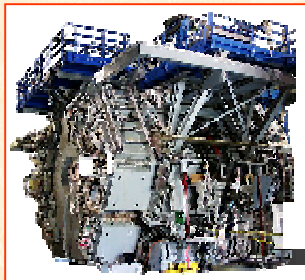
- The BaBar collaboration was founded in 1993 to explore *CP* violation in *B* decay (years of preparation had preceded this).
- Also, to perform comprehensive studies of beauty, charm, and τ.
- Cleanest approach to $\not{C}\not{P}$: via time-dependent asymmetries in correlated B^0 - $\overline{B^0}$ decays from the $\Upsilon(4S)$ resonance.

$\Rightarrow$ 4π detector at an asymmetric e^+e^- *B* Factory



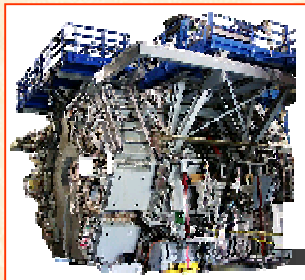
The Detector





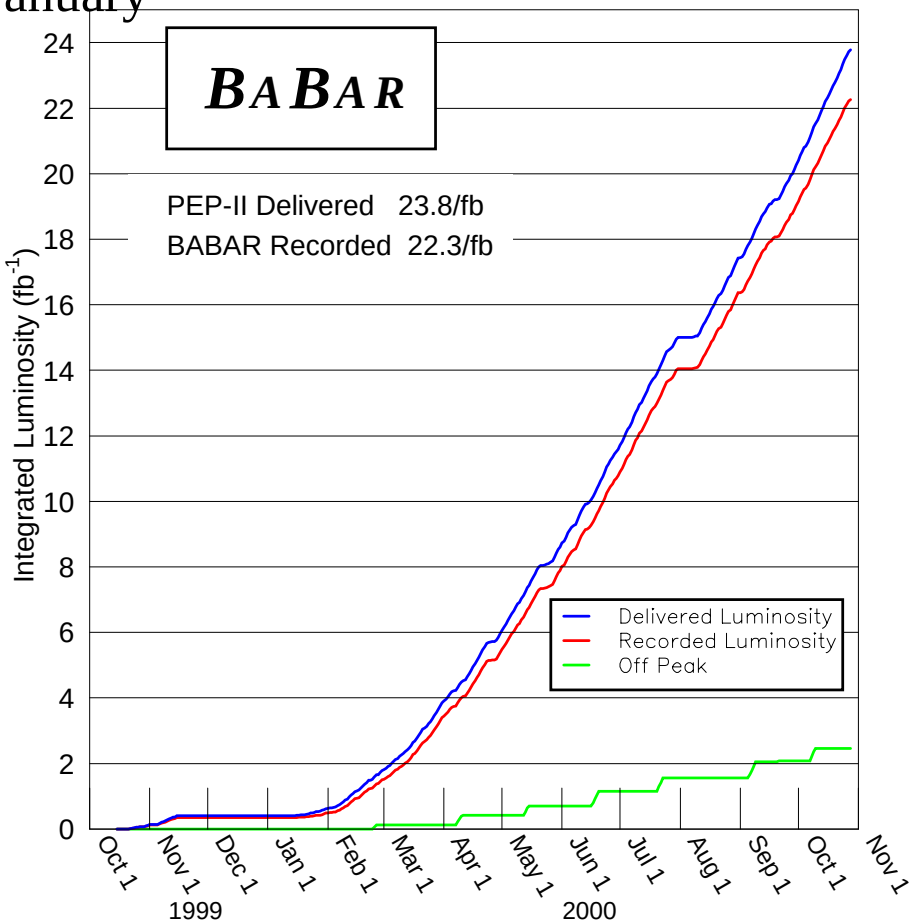
Un peu d'histoire …

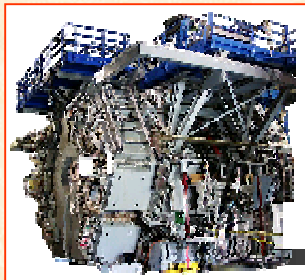
- The first run took place May 26 to September 30, 1999
  - Peak L ~ 10^{33} cm^{-2} s^{-1} , Integrated L ~ 1.3 fb^{-1}
  - Invaluable for commissioning all aspects of BaBar and PEP-II
  - However, data quality compromised by several detector issues, e.g.
    - Only 5 of 12 DIRC sectors installed
    - Majority of IFR disabled by excessive current draw
    - Excessive noise in EMC till mid August
- Two-week shutdown in October 99
  - DIRC Completed
  - water cooling installed on magnet steel for IFR
  - lots of work on EMC electronics to improve noise
- First high-quality data in October-November 99
  - continued development of computing infrastructure, reco code
  - run terminated in Nov by PEPII vacuum leaks
- Shutdown mid Nov 99 to early Jan 00
  - General repairs and maintenance
  - Major computing and Data Base development



Year 2000 Operations

- Running began in earnest mid January
- Steady progress on all fronts
  - ~10 fb^{-1} recorded by June 30
  - ~23 fb^{-1} total by Oct 31
    - ~20 fb^{-1} *Y(4S);*
    - ~ 3 fb^{-1} continuum
- Shutdown Nov 00 - Feb 01
  - PEPII improvements
  - IFR repairs
  - EMC Electronics
  - miscellaneous maintenance
- Computing activities during shutdown:
  - finish production and
  - reprocessing of 2000 data
  - develop hardware and code for 2001 run





Operations context

- We're running at design peak and *average* luminosity!

DESIGN:	3.0 nb^{-1}/sec	135 pb^{-1} /day	~800 pb^{-1}/week	~ 3.3 fb^{-1}/month
ACHEIVED:	3.1	174	970	3.6

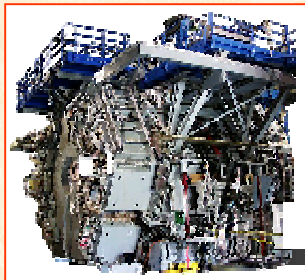
Detector performs just fine at **3.1×10^{33}**

Congratulations to PEP-II!

- Luminosity profile for next few years:

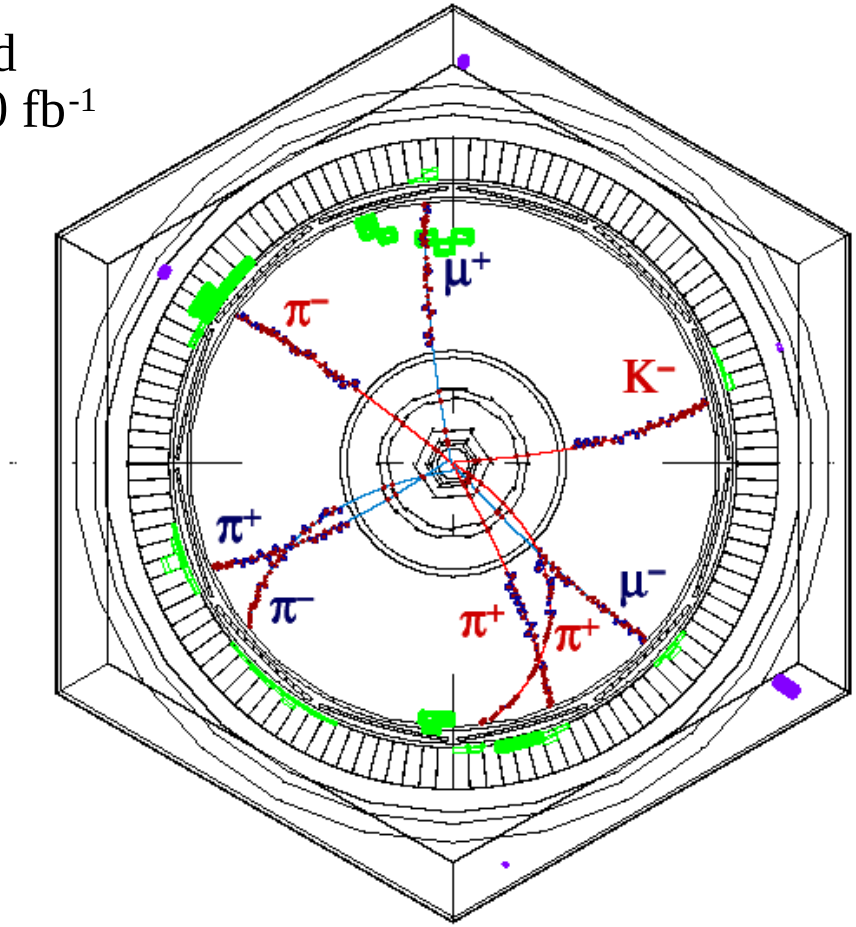
2000	2001	2002	2003	2004	2005	
25	35	70	100	130	180	fb^{-1}

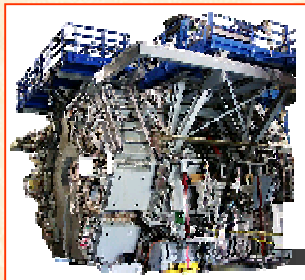
$\Rightarrow$ **$\int Ldt > 500$ fb^{-1} by end of 2005**



Physics Analysis and Results

- First results from BaBar presented in Osaka last July, based on ~7-10 fb^{-1}
  - 13 contributed papers
  - 6 parallel-session talks
  - plenary talk by Dave Hitlin
- Though preliminary, already competitive in several cases
- Publications planned for early next year
  - full 23 fb^{-1} sample
  - improved systematics
  - additional decay modes



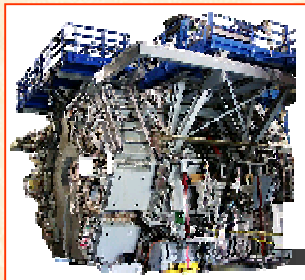


A Few Physics Highlights

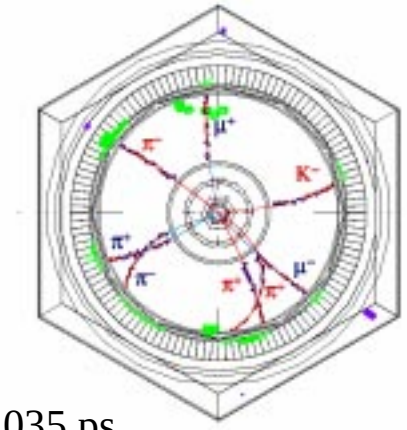
- B^0–$\overline{B}^0$ Mixing
- Lifetimes of charged, neutral B's
- Rare 2-body decays

  $B^0 \to \pi^+\pi^-,\ K^+\pi^-, K^+K^-$
- B decays to charmonium states
- Radiative penguin decays
  - $B^0 \to K^{*0}\gamma$
  - searches: $B^0 \to K^{*0}\ell^+\ell^-,\ B^+ \to K^+\ell^+\ell^-$
- Preliminary ***t***-dependent ***CP***-violating asymmetry
  - Modes used so far: $B^0 \to J/\psi\ K^0_s \quad (K^0_s \to \pi^+\pi^-)$

    $\to \psi(2S)\ K^0_s \quad (K^0_s \to \pi^+\pi^-)$

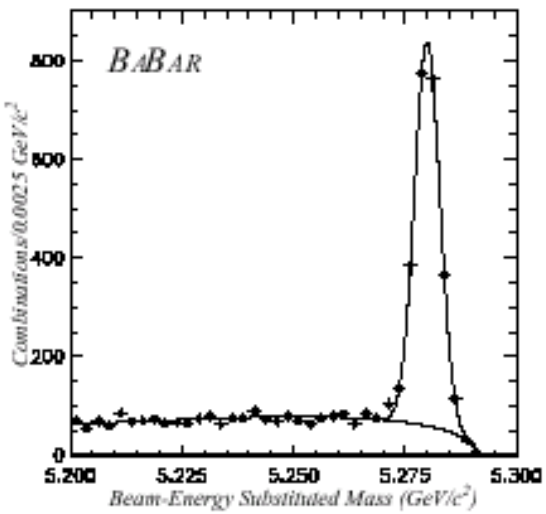


B^0 and B^+ Lifetimes



$\tau_{B^0} = 1.506 \pm 0.052 \pm 0.029$ ps

$\tau_{B^+} = 1.602 \pm 0.049 \pm 0.035$ ps



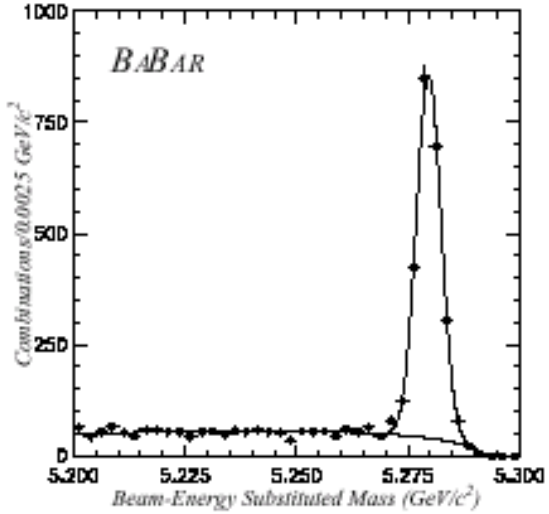
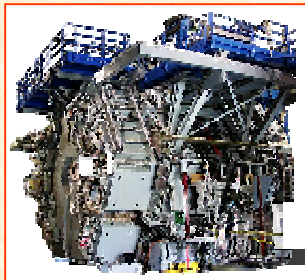
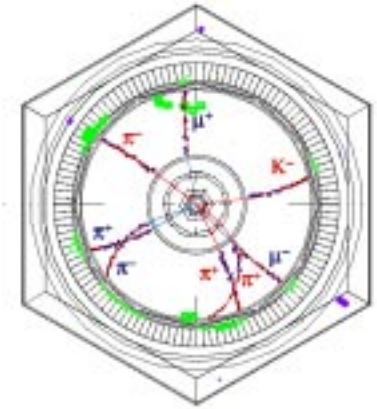


Figure 2: Beam-energy substituted mass m_{ES} distribution for all the hadronic modes for (a) B^0 and (b) B^+. The total numbers of signal events in all B^0 and B^+ modes are 2210 ± 58 and 2261 ± 53 respectively.



$B^0 - \overline{B}^0$ Mixing



$$\Delta m_d = 0.507 \pm 0.015 \pm 0.022\ \hbar\ \mathrm{ps}^{-1}$$

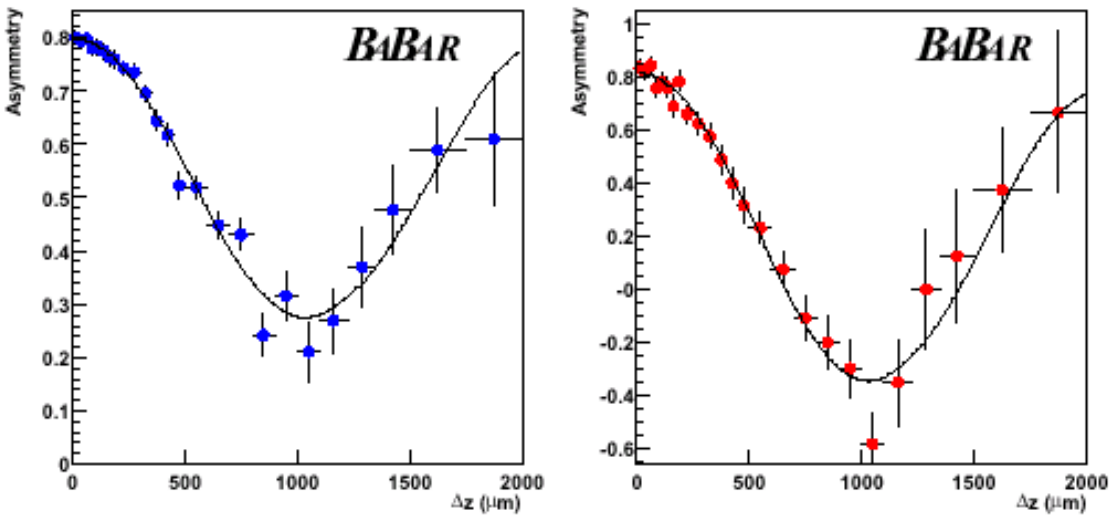
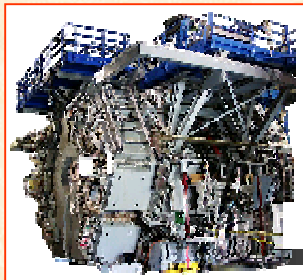
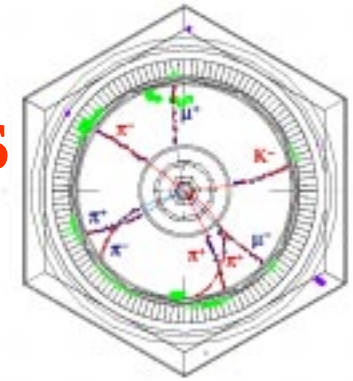
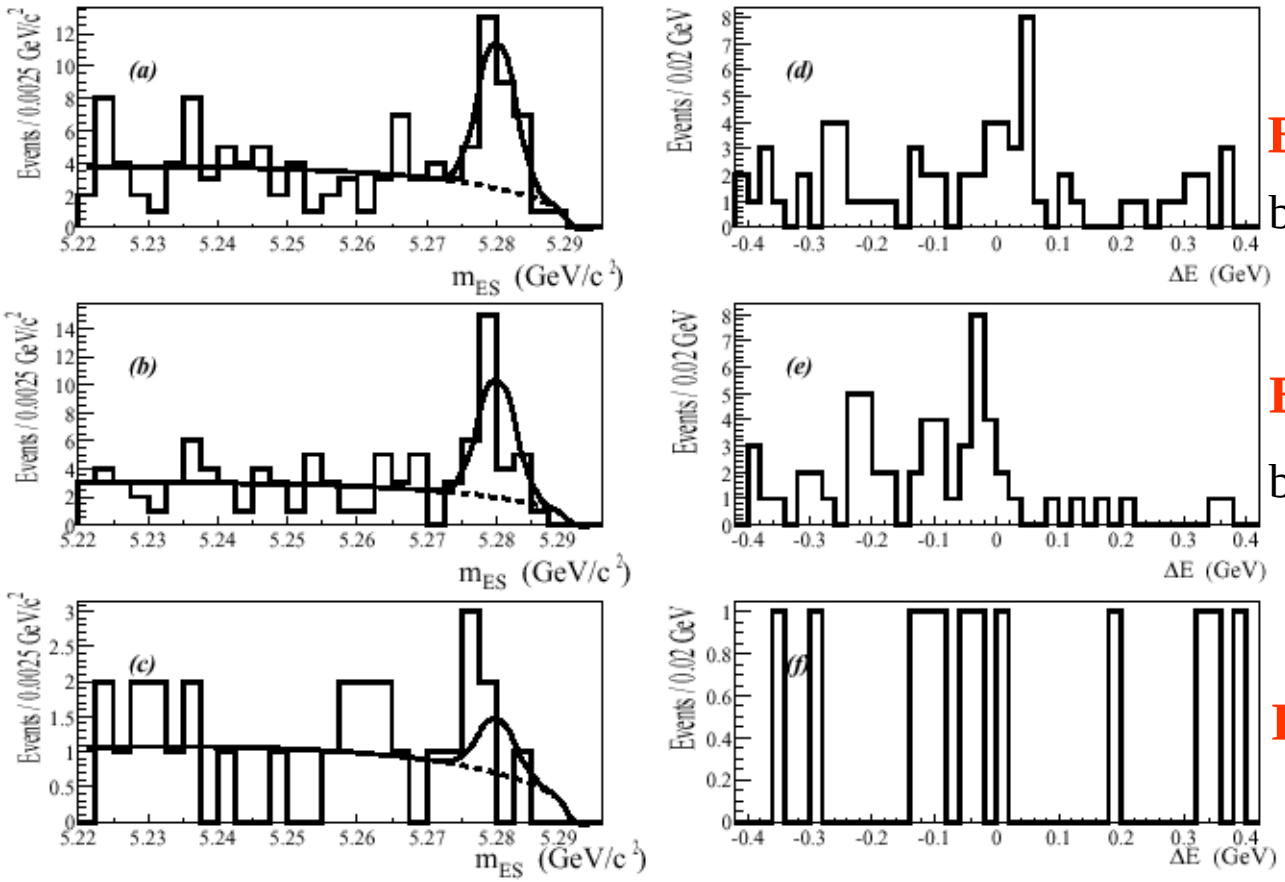


Figure 3: Time-dependent asymmetry between unlike-sign events (ℓ^+, ℓ^-) and like-sign events $(\ell^+, \ell^+) + (\ell^-, \ell^-)$ for (a) the inclusive dilepton sample and (b) the dilepton sample enriched with soft pions.



Charmless 2-Body Decays





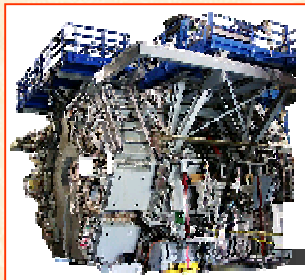
$B^0 \to \pi^+\pi^-$

b.r.= $9.3^{+2.6+1.2}_{-2.3-1.4} \times 10^{-6}$

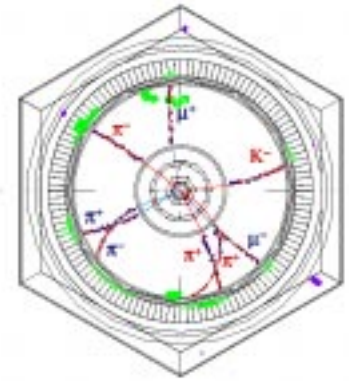
$B^0 \to K^+\pi^-$

b.r.= $12.5^{+3.0+1.3}_{-2.3-1.4} \times 10^{-6}$

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

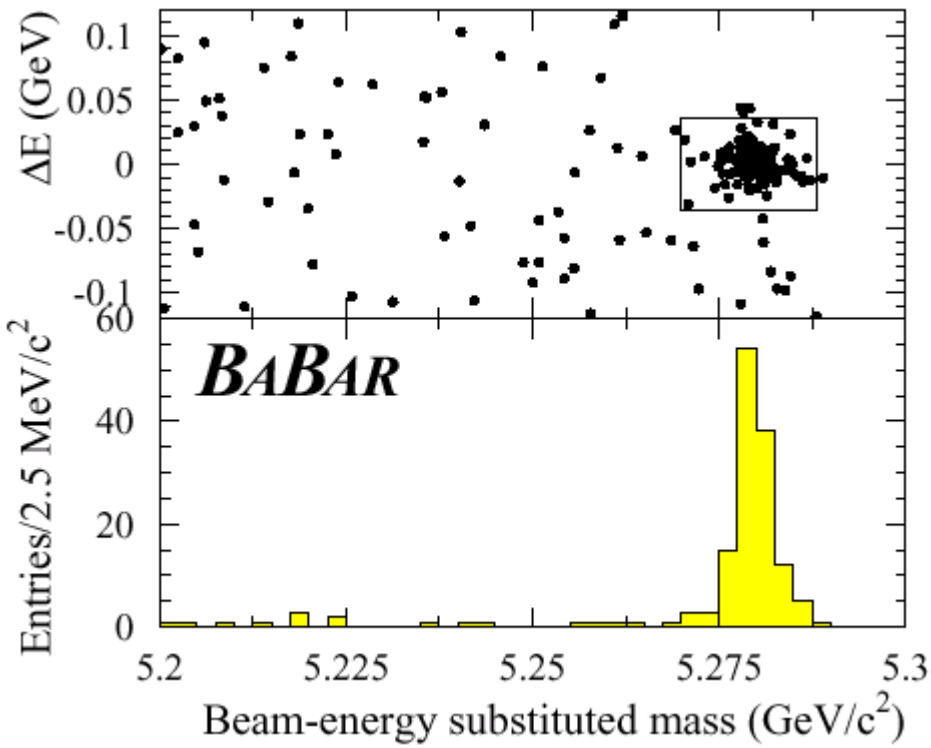


CP-Violation



$B^0 \rightarrow J/\psi \; K^0_s$

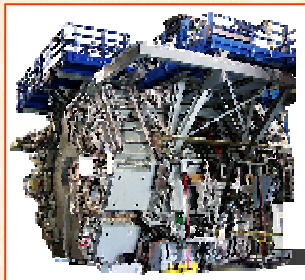
$\quad\quad\quad\quad\quad\quad \hookrightarrow \pi^+\pi^-$



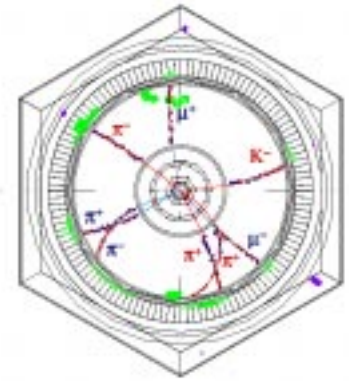
Flavour-tagged sample used in sin2β analysis

Combined with analogous sample of $B^0 \rightarrow \psi(2S)\, K^0_s$ for Osaka result:

sin2β = +0.12 ± 0.37 (stat)
± 0.09 (sys)



Summary of Results

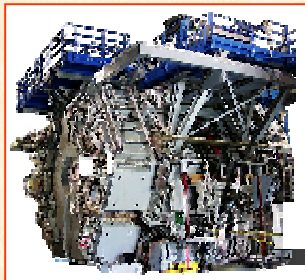


Some projected results for the full 23 fb^{-1} sample

(Estimated errors for combined results shown in blue)

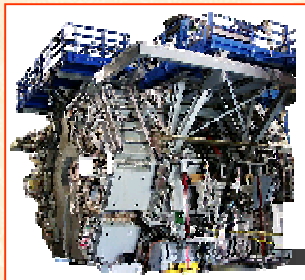
Measurement	Osaka prelim.	Y2K stat.	Y2K syst .	world average [15]
τ_{B^0} (ps)		±0.014 (0.9%)		$1.548 \pm 0.032(2.1\%)$
hadronic	$1.506 \pm 0.052 \pm 0.029$	$\pm 0.030(2.0\%)$	$\pm 0.022(1.5\%)$	
semileptonic		$\pm 0.016(1.1\%)$	?	
τ_{B^+} (ps)		±0.018 (1.1%)		$1.653 \pm 0.028(1.7\%)$
hadronic	$1.602 \pm 0.049 \pm 0.035$	$\pm 0.029(1.8\%)$	$\pm 0.027(1.7\%)$	
semileptonic		$\pm 0.022(1.4\%)$	?	
Δm_d ($\hbar\,ps^{-1}$)		±0.010 (2.0%)		$0.478 \pm 0.018(3.7\%)$
hadronic	$0.516 \pm 0.031 \pm 0.018$	$\pm 0.019(3.7\%)$	$\pm 0.013(2.5\%)$	
semileptonic	$0.508 \pm 0.020 \pm 0.022$	$\pm 0.011(2.2\%)$	$\pm 0.018(3.5\%)$	
dilepton	$0.507 \pm 0.015 \pm 0.022$	$\pm 0.011(2.2\%)$	$\pm 0.010(2.2\%)$	
$\sin 2\beta$	$0.12 \pm 0.37 \pm 0.09$	± 0.2	?	0.9 ± 0.4

(sin2β projection assumes additional modes will be used)



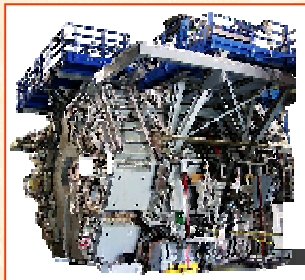
The next few years

- Factor ~ 4 increase in Yearly Luminosity by 2003
  - Broader and deeper physics reach (sin2α, sin2γ, rare decays, etc.)
  - higher rates, backgrounds, radiation
- Detector Issues:
  - performance (trips, trigger deadtime, etc)
  - data quality (pattern recognition, resolutions, etc)
  - aging and deterioration
- Computing issues:
  - Data acquisition, reconstruction and reprocessing capability
  - adequate storage and access for timely analysis



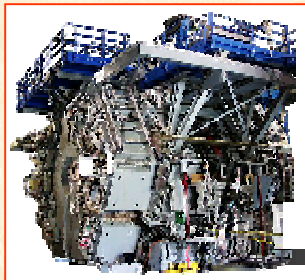
Planning for Higher Luminosity

- Committee Charged in Aug 99 by Dave Hitlin to:
  - assess impact and risks posed by accelerated luminosity profile
  - identify repairs and replacements above normal maintenance
  - recommend strategy to exploit this great physics opportunity
- This study was wide ranging, addressing
  - Detector hardware to
    - withstand higher backgrounds, occupancies, and radiation damage
    - reduce catastrophic risks
    - improve performance over the original specifications
  - Trigger hardware to accommodate rates higher than design
  - DAQ hardware to handle increases in trigger rates and event sizes
  - Computing resources to allow timely utilization of the higher volumes of data



Technical Review of Improvement Plans

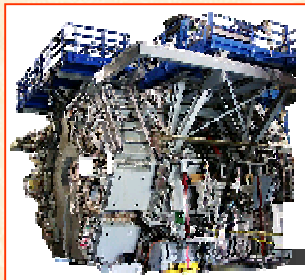
- Requested by BaBar International Finance Committee
  - Chaired by Gil Gilchriese, with experts on detector, electronics, computing
- Charge to the Committee: Evaluate the adequacy of plans for items to be completed by the end of 2003, and comment on the credibility of the projected costs. In particular:
  - Evaluate the computing model:
    - **Has the proper tradeoff between amount (cost) of offline computing hardware and ease and speed of performing various physics analyses been taken?**
    - **Is the model of how data is staged from tape to disk realistic?**
    - **Evaluate the feasibility of locating a significant fraction of the computing at European centers for use by the full collaboration.**



Technical Review ….

Charge to committee, continued

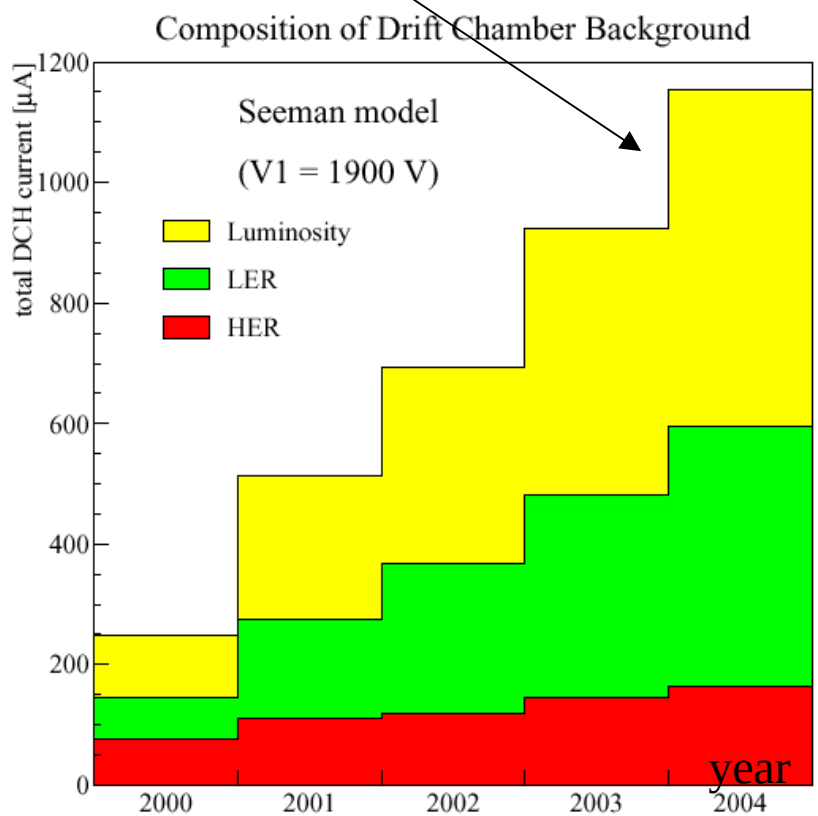
- Evaluate the Instrumented Flux Return (IFR) improvements.
- Evaluate the plans for the trigger, particularly the rejection rates for the L1 z trigger
- Comment on plans for upgrading the front end electronics and DAQ for the various detector components.
- Comment on plans for R&D on detector aging and performance improvements including IFR efficiency, drift chamber aging, DIRC photomultiplier frosting.
- Comment on schedule for replacing SVT modules and on the radiation damage tests and on the schedule of R+D for a later replacement of the SVT.

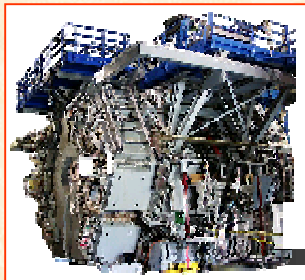


Background Situation

- Background experiments and studies played a dominant role in our planning.
- Good evidence that backgrounds (after scrubbing) grow ~ linearly with total current $I_T = I_{HER} + I_{LER}$
- ∴ we base our improvement plans on linear increase in backgrounds with I_T

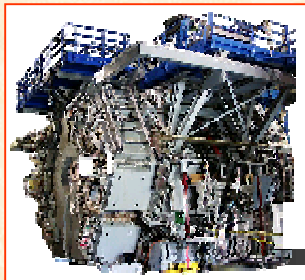
Still well below 2000μa limit of upgraded HV





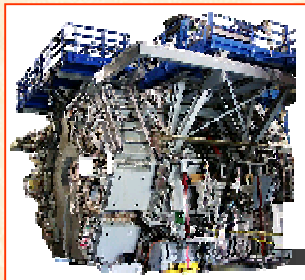
Summary of System Improvements

- Background estimates more benign than originally feared.
  - most detector systems can basically “stand pat” for several years, with due care and feeding
- Drift Chamber, DIRC, and EM Calorimeter
  - only minor modifications
- Silicon Vertex Tracker
  - Spare modules under construction, funding in place
- Instrumented Flux Return
  - Concerns because of decreasing efficiency
  - Intervention may be needed (~$0.5M M&S)



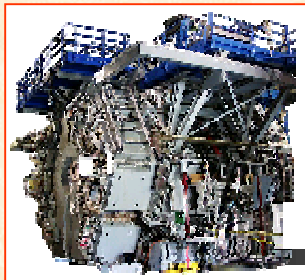
Trigger/DAQ and Computing

- These systems are now operating reliably at design luminosity, as seen by Osaka results . This is a major success!
- Computing in particular bears the brunt of the challenge of higher luminosity. No rest for the weary!
  - data increasing faster than Moore's Law
  - new measures, loads of hard work, major funding required to cope.
  - acute manpower problems.
- The Collaboration has developed an analysis/computing model to understand budgetary impacts and tradeoffs.
  - physics priorities drive this exercise
  - triggering/staging strategy converging
  - for next 2 years, we need to be conservative as we learn
  - system appears scalable



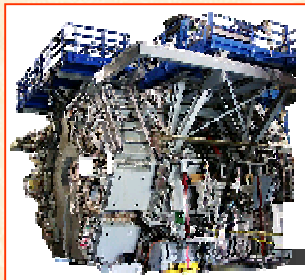
Trigger/DAQ

- Operates reliably at design with negligible deadtime.
- Plans underway to deal with increasing currents.
  - level-1 trigger upgrade to include z info. from drift chamber
  - faster ReadOut Modules
  - Gigabit ethernet
  - improve/expand on-line farm for level 3
- Cost is about $1.3 M, spread over 2001, 2002, 2003
- Plan and budget supported by Technical Review



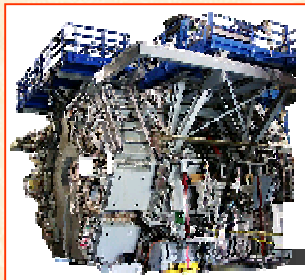
Computing

- Most expensive component of improvements to keep up with luminosity ($7.1 M in FY 2001)
- Technical review committee supports the model:
  - production, data storage, distribution, access, etc.
- Disk cost is the dominant item
  - Stage as much data as possible on tape, driven by physics priority
  - Use cheap disks wherever possible
    - Tests of new, cheap disks in progress
    - May tune disk system quality to the application



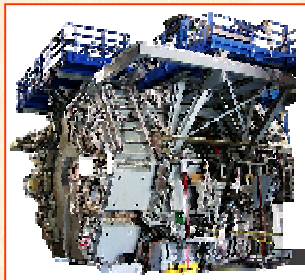
Computing …

- Possibility of Multiple “Tier-A” Sites
  - requirements:
    - storage, CPU, network, etc. to carry >30% of load
    - open access to BaBar members à la SLAC
    - commitment for life of BaBar
  - perhaps a more attractive approach for foreign funding agencies than to fund computing at SLAC directly
  - initially, SLAC and IN2P3 (Lyon)
  - shared data storage between SLAC and IN2P3
    - data samples at the two sites are complementary, not duplicates.

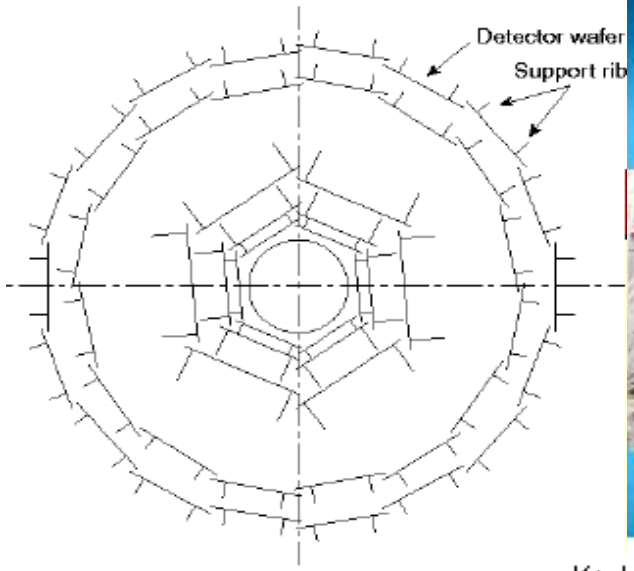


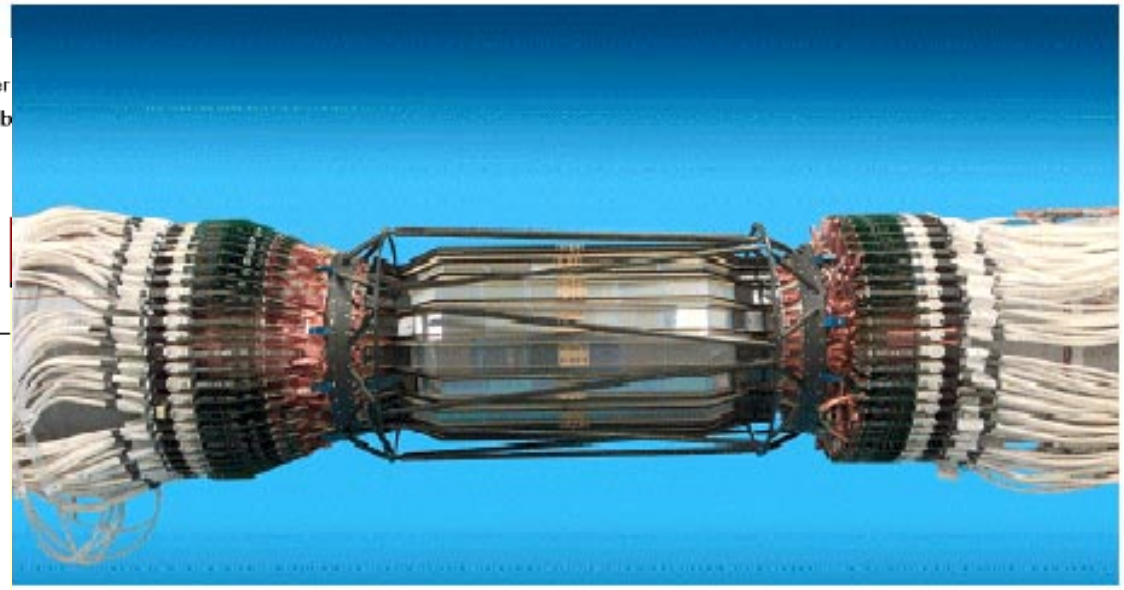
Soundbites from Gilchriese Report

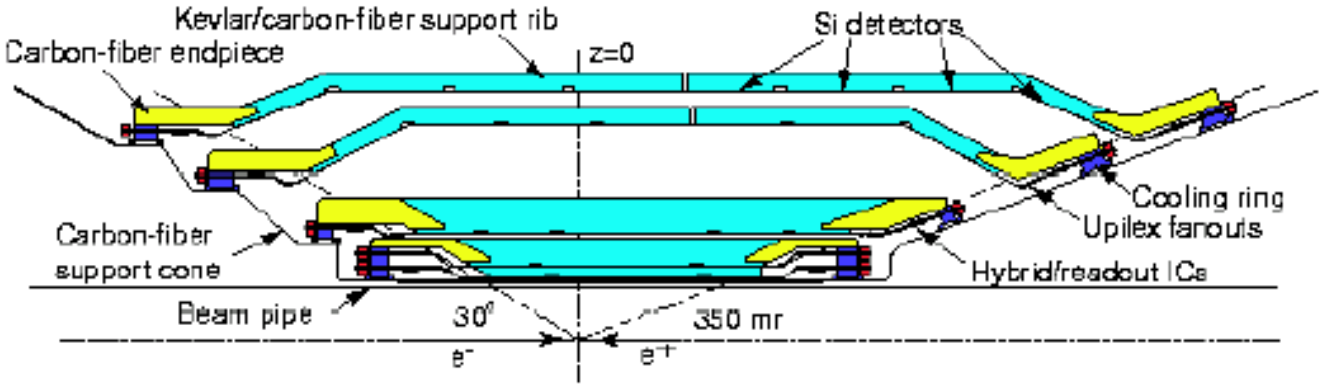
- The Review Committee was generally very impressed with the comprehensive and thorough planning presented by the BaBar Collaboration.
- The detector improvements proposed by the Collaboration are sound and should proceed …..
- Similarly, the enhancements to computing are also judged to be sensible and generally well justified, ….
- The IFR is a matter of serious concern ….

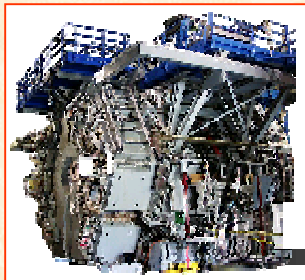


Silicon Vertex Tracker (SVT)



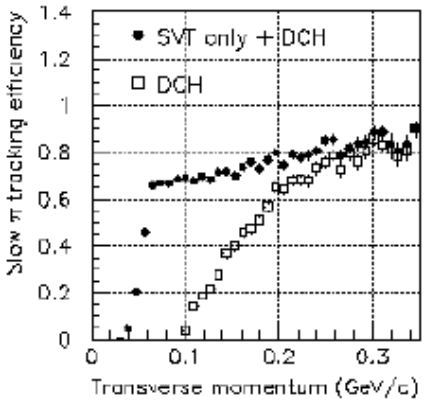


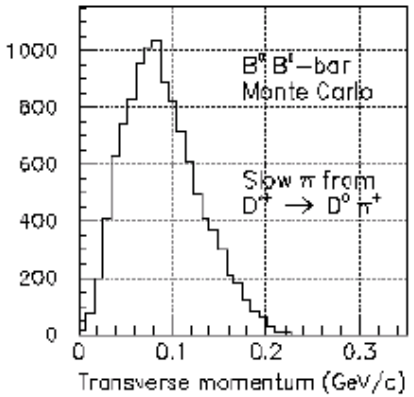


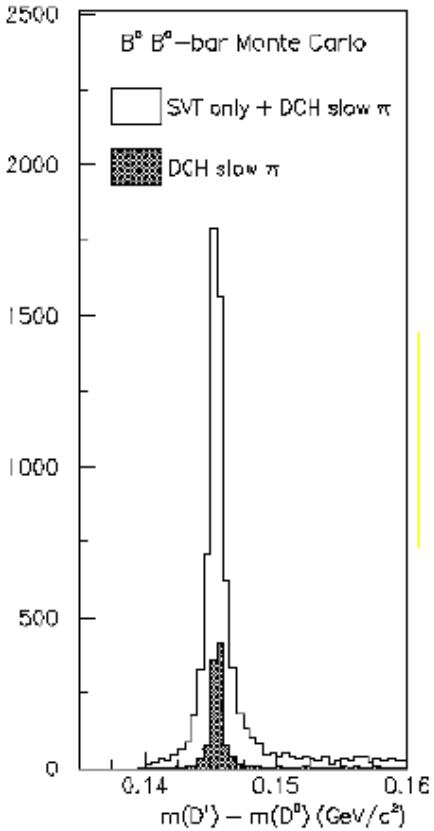


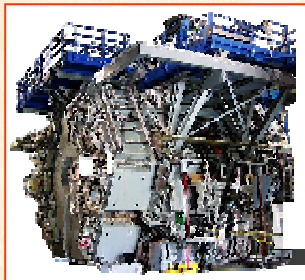
SVT …

- Resolution approaching MC expectation (~20 μ)
- Excellent efficiency (~98%)
- SVT Essential for all B physics
  - Displaced vertex selection
  - Decay time measurement
  - Tracking of low-p_t particles (slow π from D*→D π)
- Project to build spare modules well underway and funded
  - replace defective modules (9/208)
  - replace midplane modules because of radiation damage
  - On schedule for summer 2002 if needed





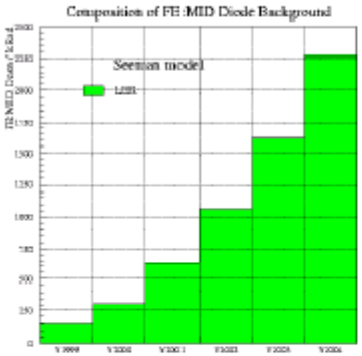




SVT ...

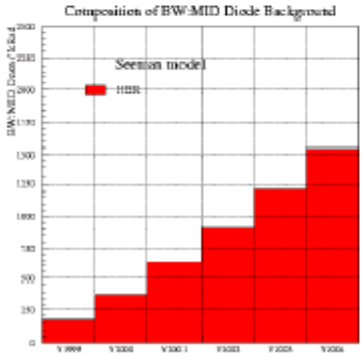
Radiation Studies give preliminary indication SVT will survive till ~2004

Projected cumulative doses

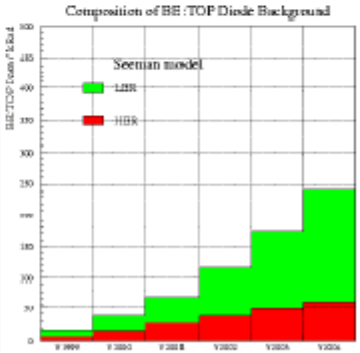


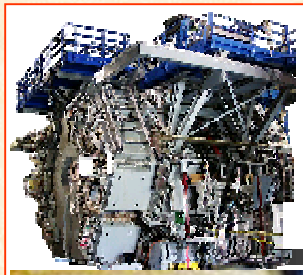
Worst-case MidPlane diodes, 1999-2004 (full scale 2.5 MRad)

Recall: spec up to ~ 2 MRad

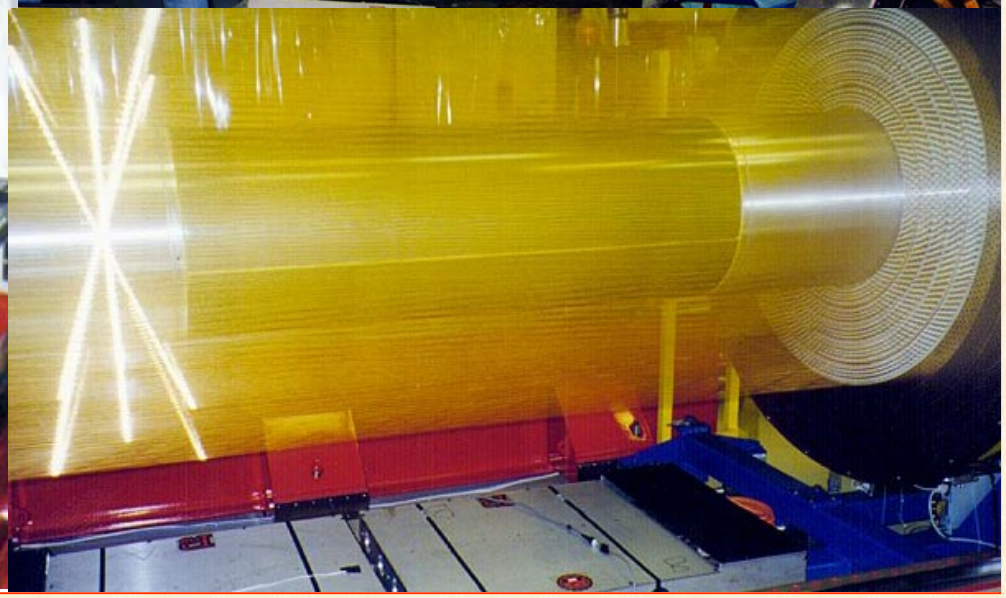


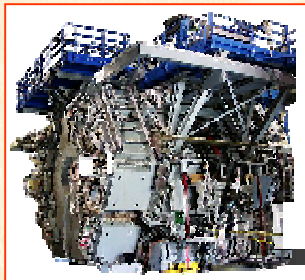
Typical non-MidPlane diode 1999-2004 (full scale 0.5 MRad)



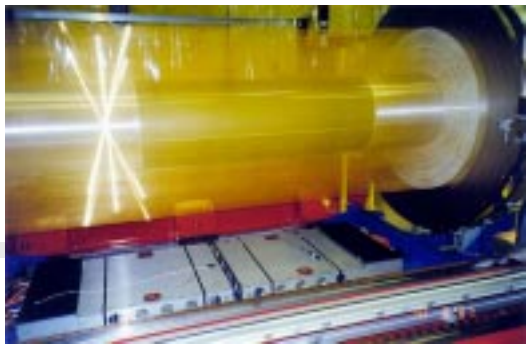


Drift Chamber (DCH)

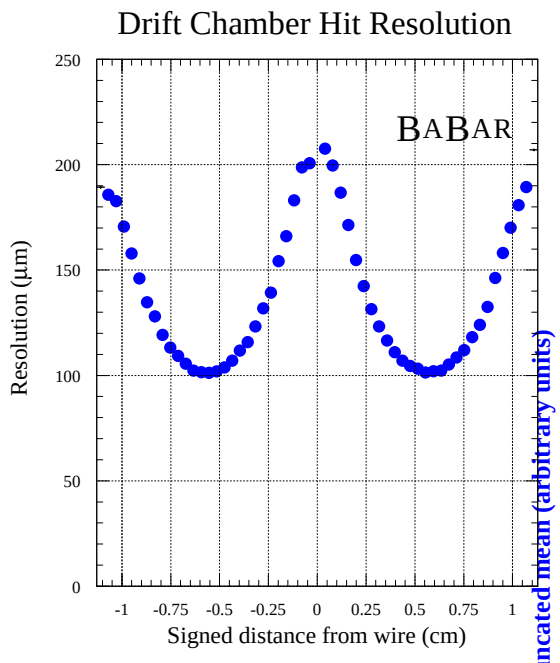


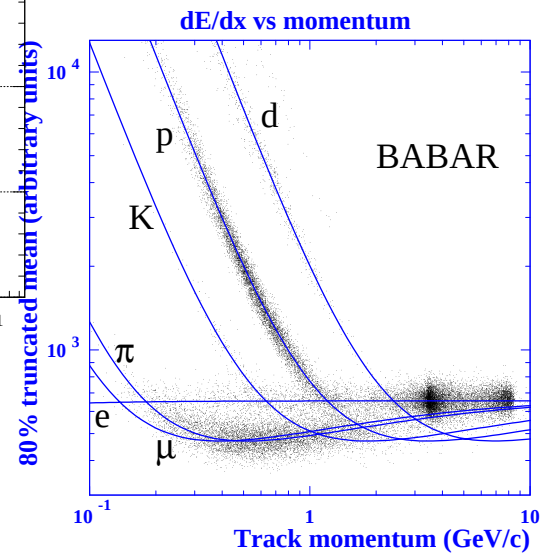


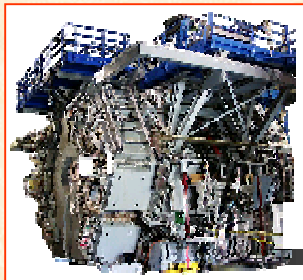
Drift Chamber …



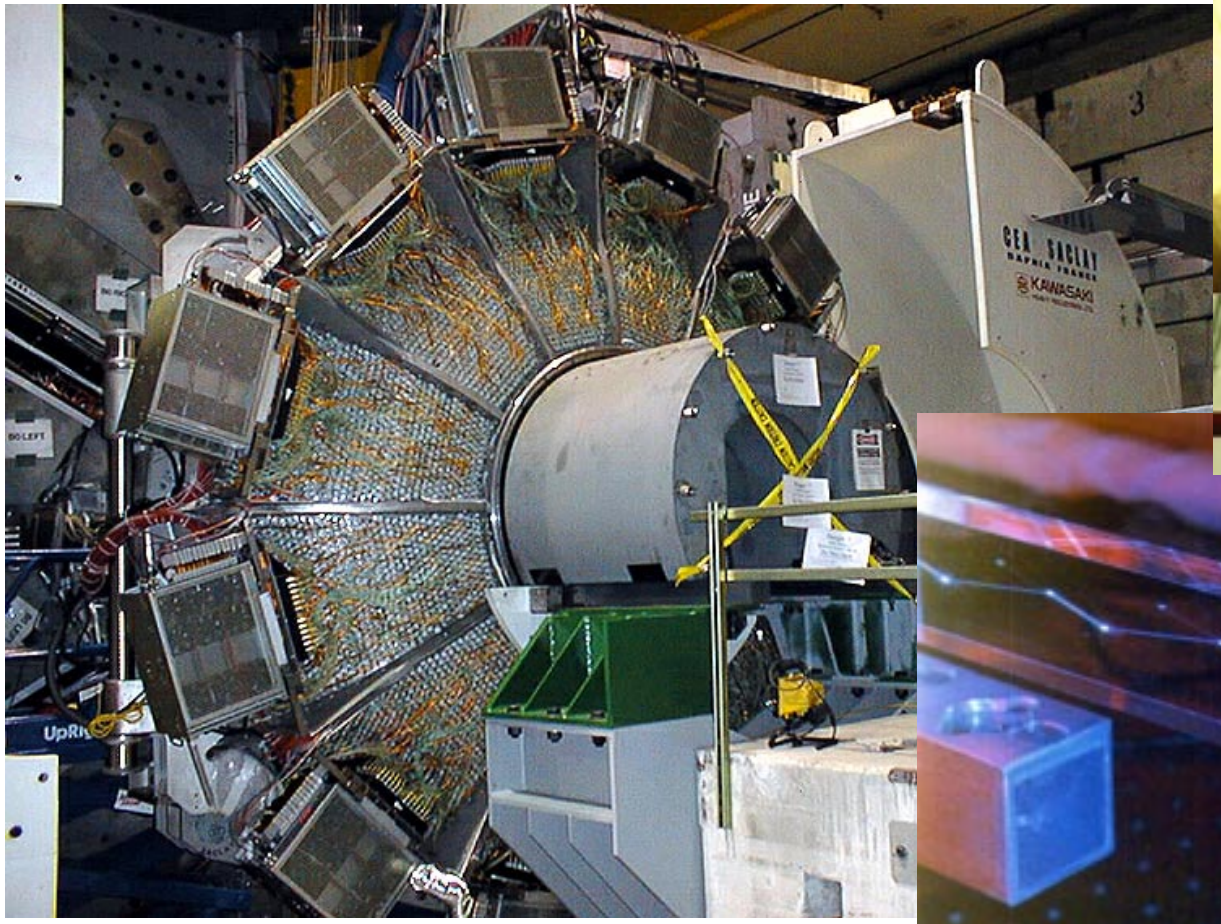
- Position and dE/dx resolutions at design
- Reliable performance after some initial scares
- Background studies show no need for major intervention before 2004-5
- R&D Program underway
- Sudies of aging and rejuvenation techniques

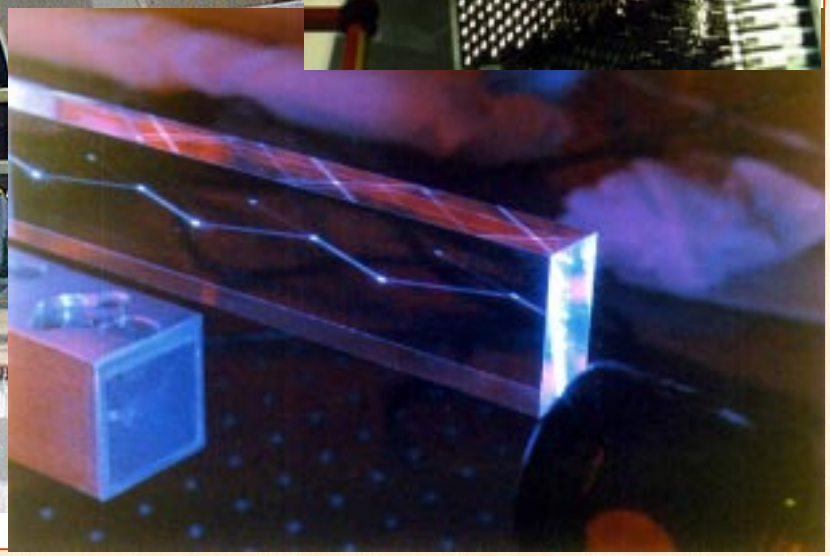


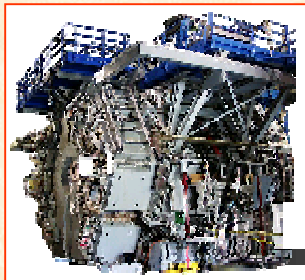




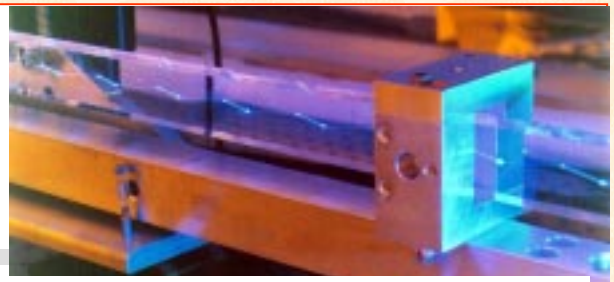
DIRC



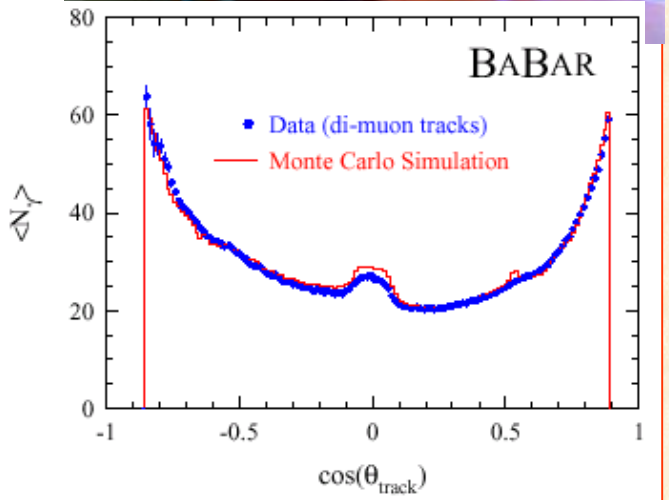


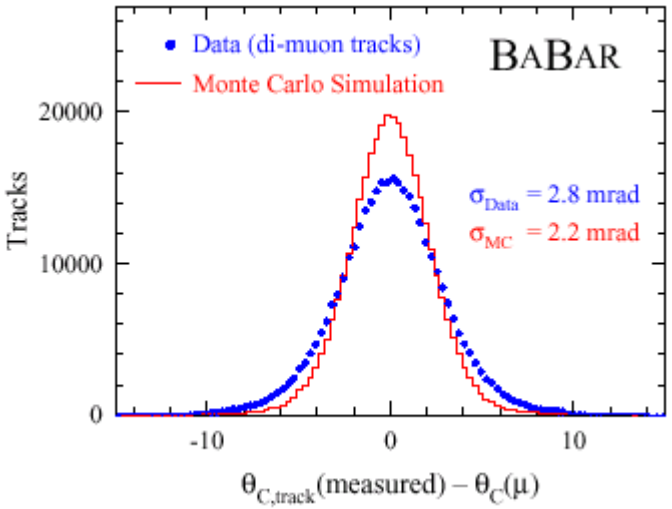


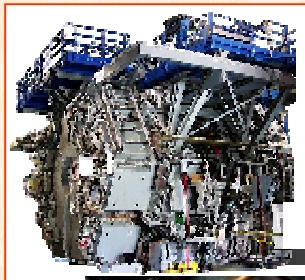
DIRC …



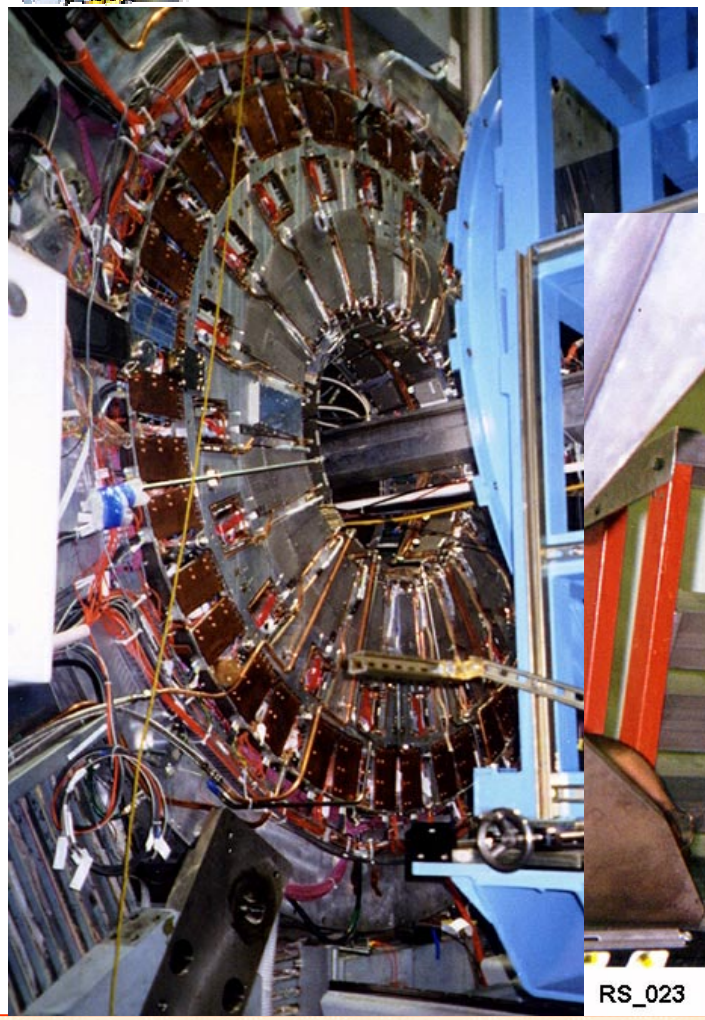
- Main device for π – K identification
- Performance already within 25% of TDR
  - Alignment, tracking improvements in progress
- Backgrounds an issue, but under control
  - Shielding around Stand-off-box (SOB)
  - Faster TDC's to reduce deadtime
- System appears robust till beyond 2004
- R&D underway on focussing DIRC
  - improve resolution
  - get rid of background from SOB

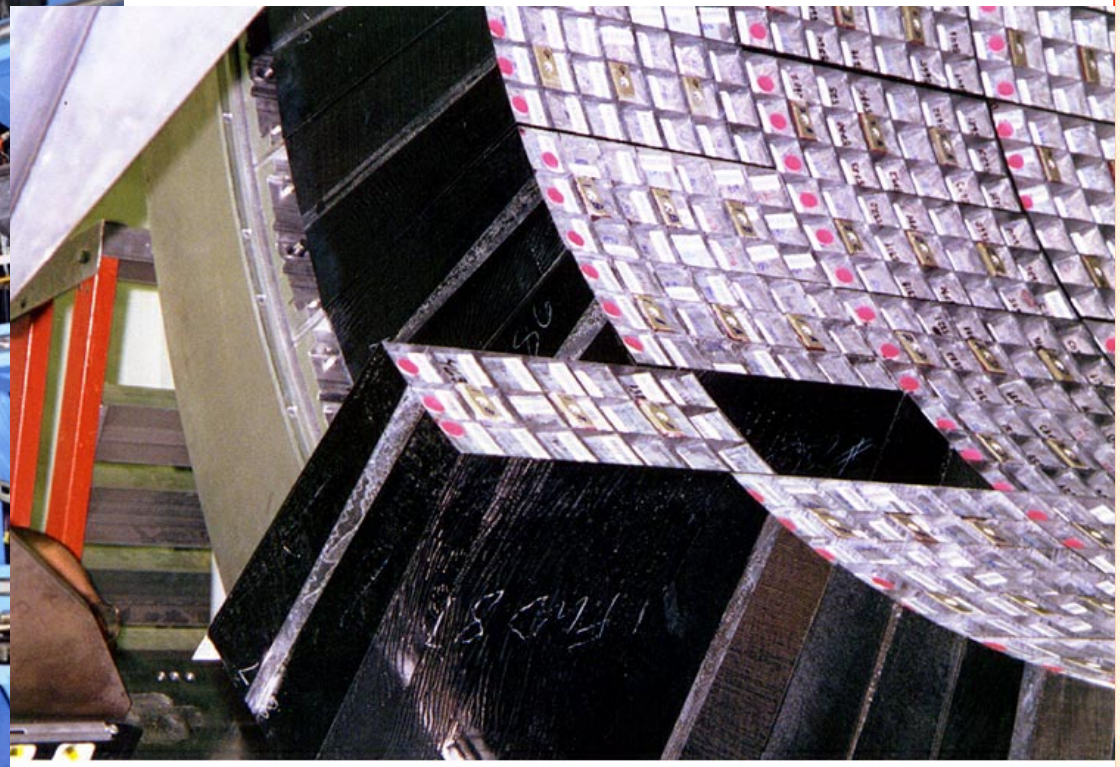




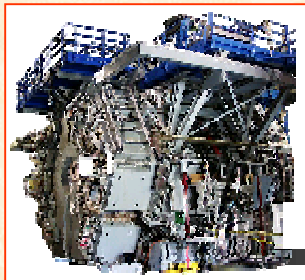


Electromagnetic Calorimeter (EMC)

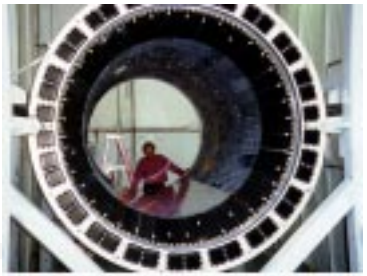




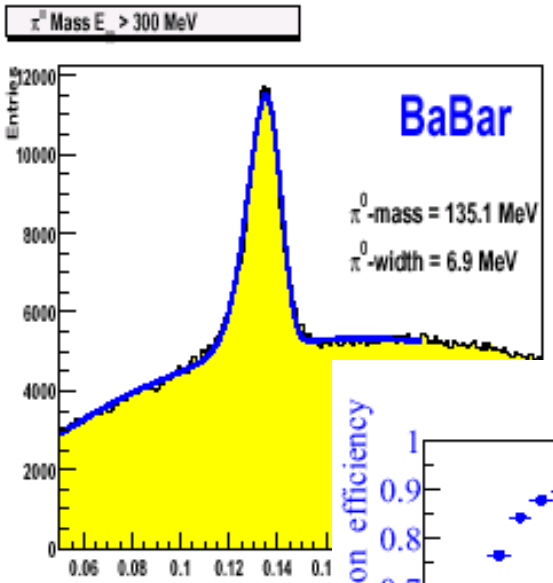
RS_023 Calorimeter - Insertion of last Module 04/13/98

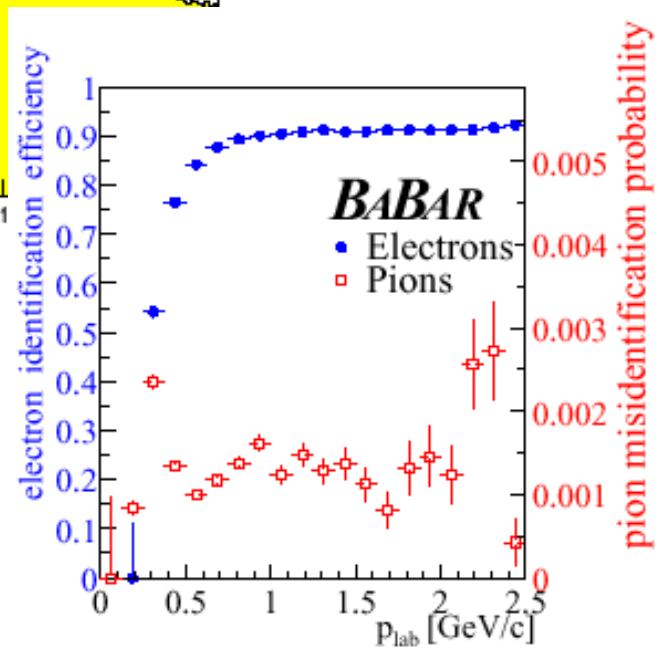


EMC …

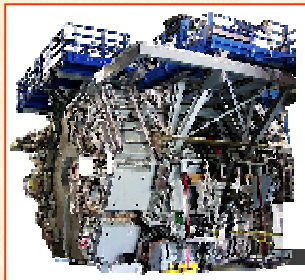


- Performance:
  - Energy resolution not yet as good as corrected TDR
    - Affects π, η mass resolution
  - Improvements in progress
    - Reduce elect. noise
    - Digital filtering
    - Calibration
  - Electron ID OK

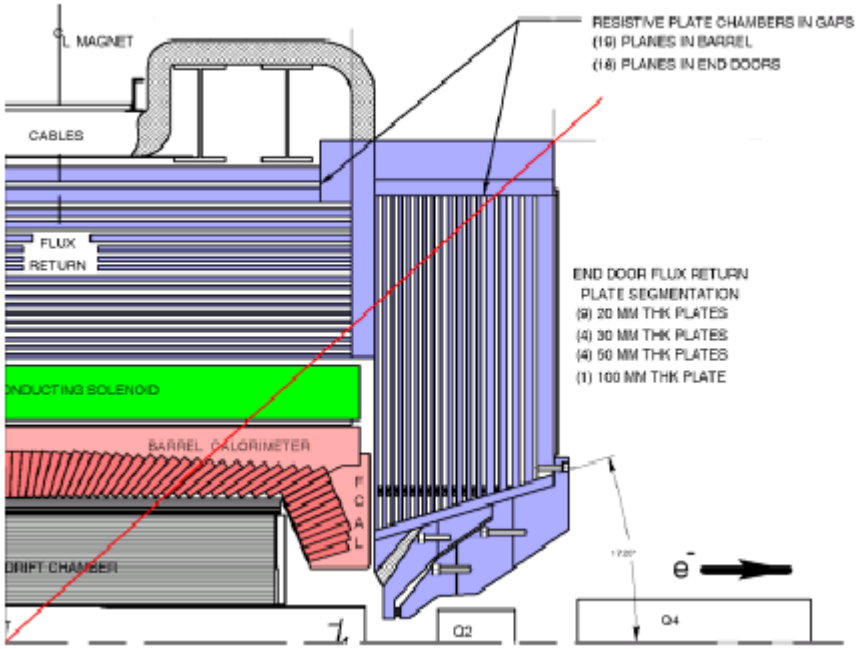


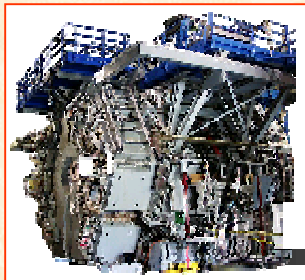


- Radiation Damage
  - Much better than feared
  - All crystals will last till ≥2004



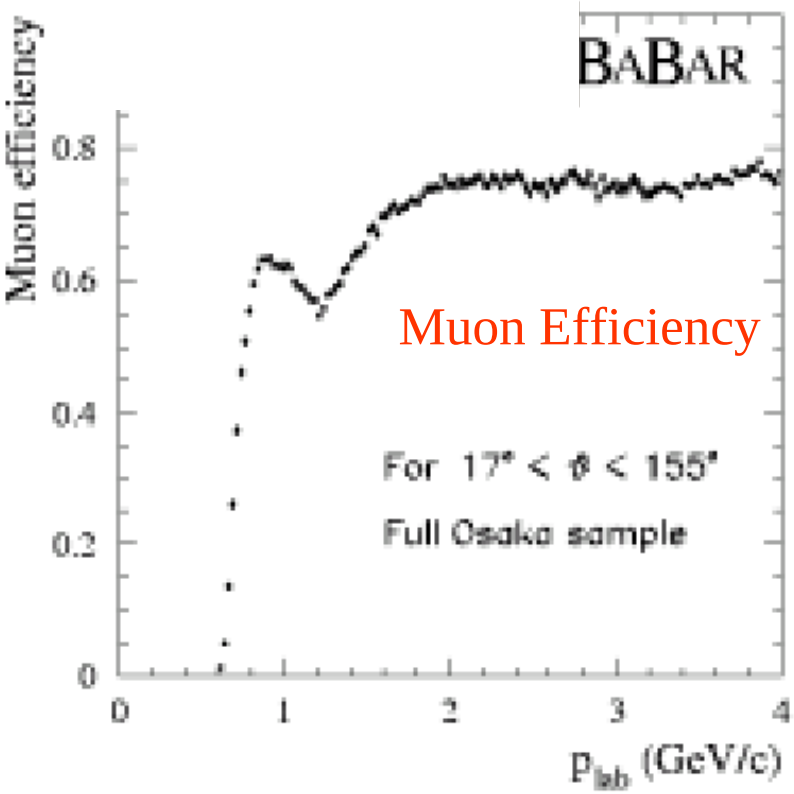
InstrumentedFlux Return (IFR)

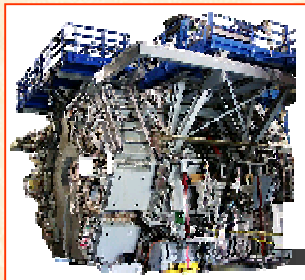




IFR …

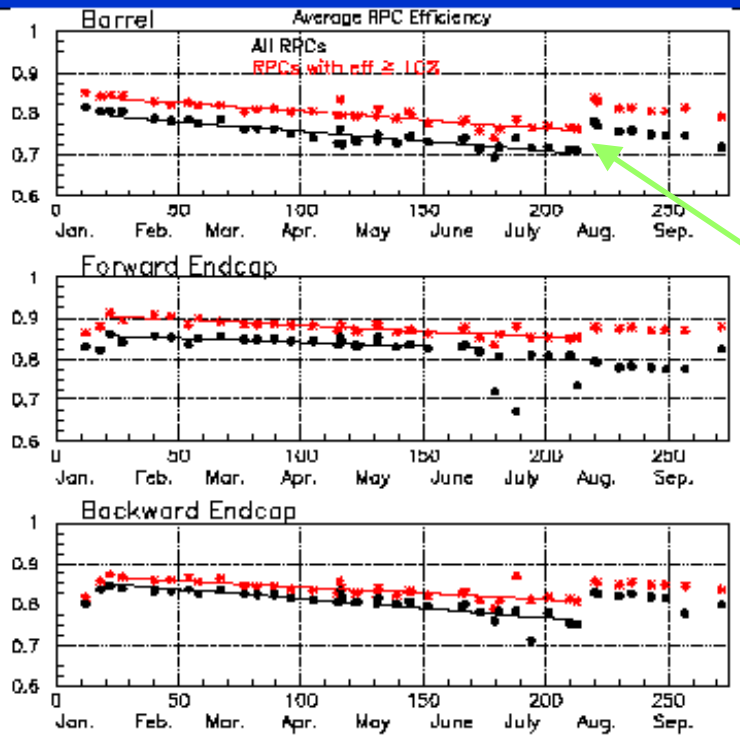
- Resistive plate chambers (RPC) are interspersed in laminations of the barrel and endcaps for μ and K_L identification.
- Since fall 1999 the efficiencies of some of the RPC's have been declining.
  - Intensive program of tests underway
  - Strong evidence that heat in summer of 1999 contributed to the degradatio
  - ~ 12 chambers will be removed in November (some good, some bad) for examination.
  - Possibility that a large fraction of the RPC's may have to be replaced at some future date.





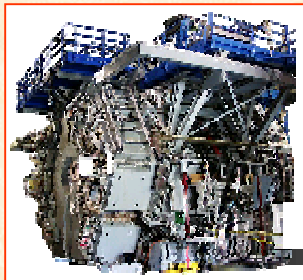
IFR …

Average Efficiency 2000



"Bad" chambers losing efficiency

Gas mixture changed



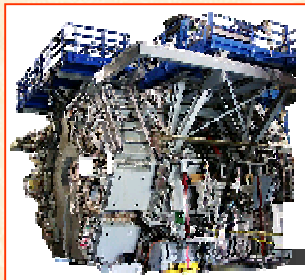
Estimated Cost Envelope

FUNDING NEEDED:

YEAR	2001	2002	2003
DIRC, DCH, EMC	115	25	50
{ IFR replacement	200 M&S	500 M&S	0 (if and when needed) }
TRG/DAQ	420	430	420
COMPUTING	7100	6600	4900

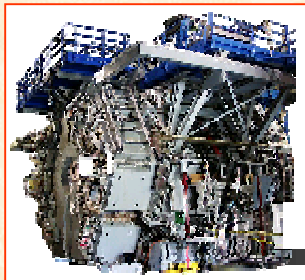
FUNDED:

SVT	INFN	1043 Million Lira (M&S) (~ 500K$)
	US/DOE	1068K$
DIRC	France	90K$
	US/DoE	60K$



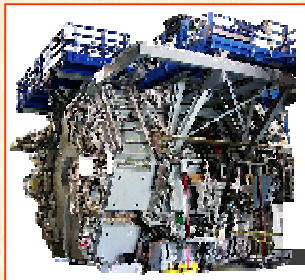
Beyond 2005

- PEP-II Luminosities > 3×10^{34} now appear possible
  - total $\int$ **Ldt > 1,500 fb^{-1}** by 2010!!
- Program must be driven by physics
- Strong interactions between IP design and detector
  - e.g. Hermeticity to reduce backgrounds in rare decay searches
- Planning has begun with weekly PEPII/BaBar meetings, with workshop to follow in Spring 2001
- Now is excellent time for new groups to get in at the ground floor



Extra physics at high luminosity

- Prospects for ~ 100 times present data sample.
- Statistical errors in the modes most sensitive to sin 2α, sin 2β ($J/\psi\ K^0_s$, $\rho\pi$, $\pi\pi$) become comparable to claims of LHCB and BTeV
  - Precision allows full isosopin analysis to remove penguin effects
  - Systematic uncertainties are likely to be smaller in e^+e^- than at hadron machines
  - Meaningful comparisons between modes to look for new physics
- Rare decay searches -- background studies in progress to see if further detector improvements are needed
- Huge samples can be used to reduce systematics



Conclusions

- The BaBar experiment is working well, with excellent physics coming out and in prospect.
- Most of the detector will survive to 2004 or beyond with only minor modifications
- We are working intensively on the IFR efficiency problem.
- Computing, trigger, and DAQ must be enhanced significantly to deal with steady increase in data rates and accumulated samples.