FIRST-YEAR EXPERIENCE WITH THE BABAR SILICON VERTEX TRACKER

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9th International Workshop on Vertex Detectors
Sleeping Bear Dunes
National Lakeshore, Michigan, U.S.A.
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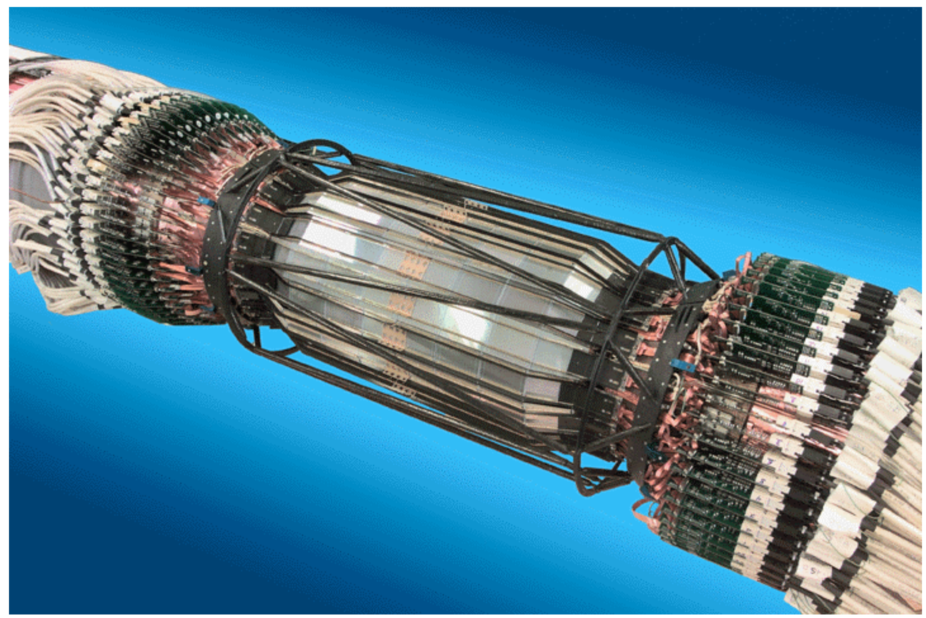


Outline

Mission accomplished !
Operational status
Alignment: local and global
Performance: single hit resolution, dE/dx
SVTRAD system: Radiation monitoring and protection
Effect of radiation exposure
Planning for more luminosity

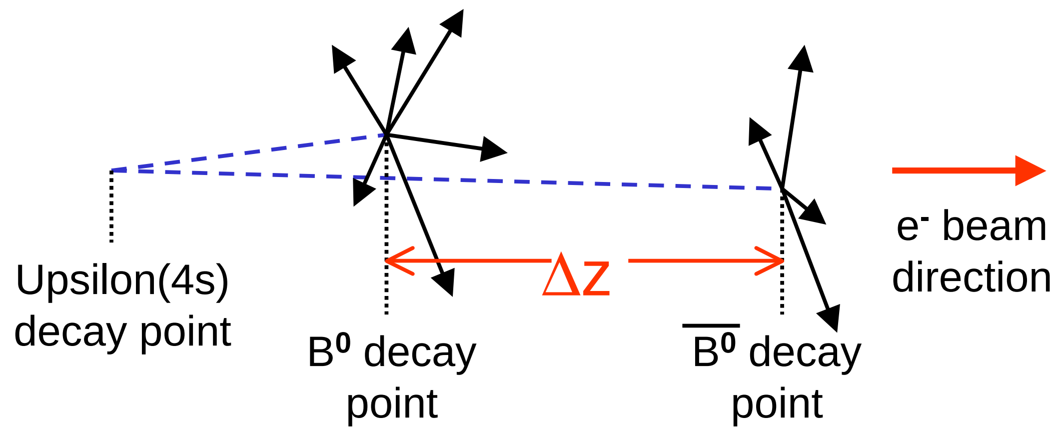
The Mission: Measure CP Violation in the B^0 System

CP violating asymmetry manifests itself in deviation from exp. decay law of the neutral B mesons

- need decay rate as function of time
- vanishes in integral over time

- CP asymmetry depends on separation Δz
- Coherent production of B^0, B^0bar
- Separation after 1 τ_B: $\beta\gamma c\tau_B$ = 250 μm
- Maximum CP asymmetry occurs at 2.2 τ_B

Asymmetric PEPII e+e- collider
(e- 9.0GeV, e+ 3.1GeV) with
Υ(4s) center-of-mass energy
Boost in Lab frame $\langle\beta\gamma\rangle$ = 0.56



Performance Goals:

- Δz resolution < 130 μm
  means point resolution in inner layers of 10-15 μm
- Single-vertex resolution < 80 μm
- Stand-alone tracking for p_t<120 MeV/c
  including particle ID information

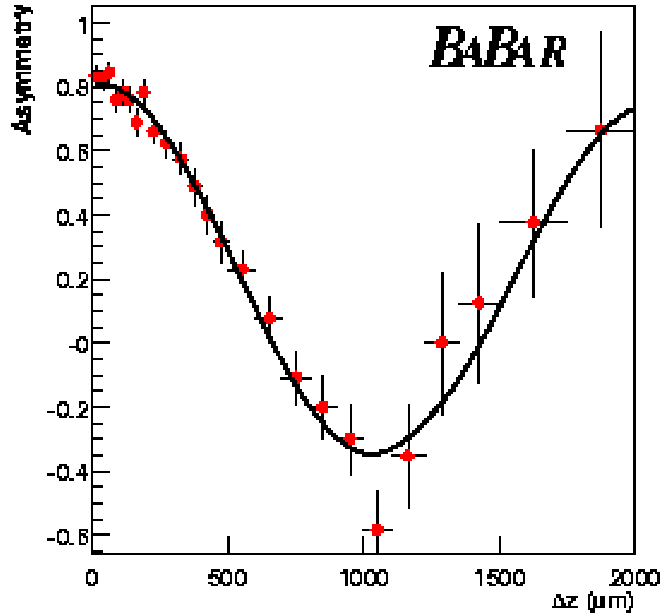
BaBar's first measurement of the CP violating sin2β

Important ingredient for sin2β:
Measure oscillation of B^0(B^0bar) into B^0bar(B^0) in decays with flavor tagging lepton

$$\cos(\Delta m_{B0}\,\Delta t) = \frac{B^0B^0bar - (B^0B^0 + B^0barB^0bar)}{B^0B^0bar + (B^0B^0 + B^0barB^0bar)}$$

No. of events with a B^0 and a B^0bar in the final state

No. of events with 2 B^0bar in the final state



sin2β measured in time dependent decay rate of B^0, B^0bar into CP eigenstate $J/\psi K_s$

Vertex resolution :

- **For the fully reconstructed decay into $J/\psi K_s$:**
  σ_z ~ 45 - 65 μm
- **For the partially reconstructed flavor tagging decay:**
  σ_z ~ 115 μm; bias(charm) ~ 25 μm

Adding in quadrature:
$\sigma(\Delta z)$ ~ 125 - 130 μm

SVT Institutions

USA:

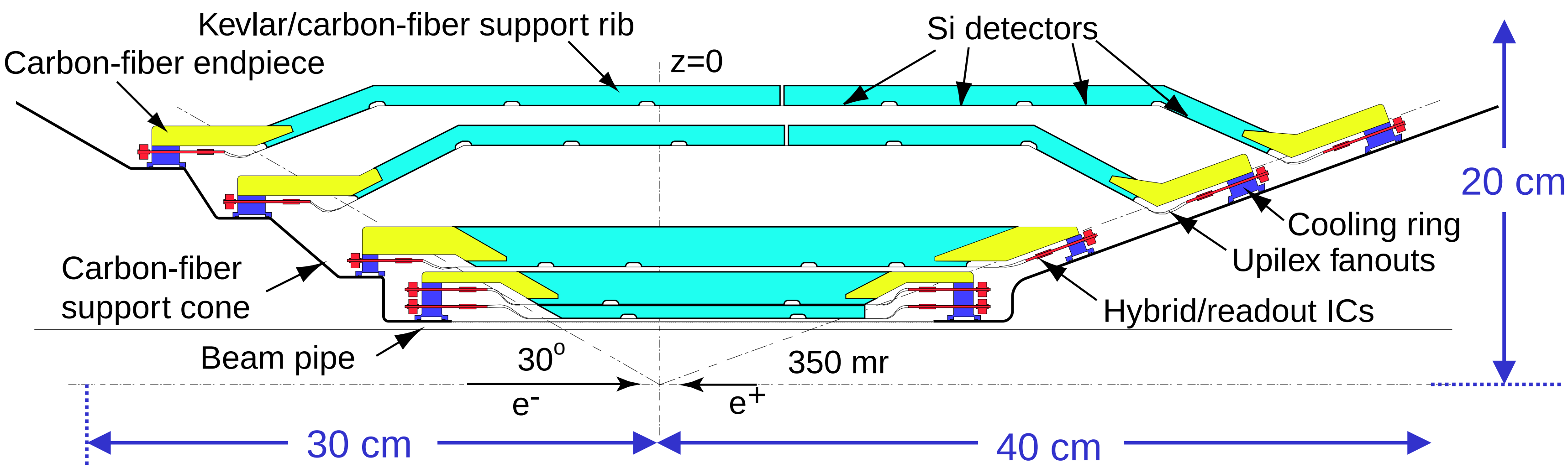
- Lawrence Berkeley National Laboratory
- Stanford University
- University of California, Santa Barbara
- University of California, Santa Cruz
- University of California, San Diego
- University of Maryland
- University of Wisconsin

Italy:

- Ferrara
- Milan
- Pavia
- Pisa
- Torino
- Trieste

SVT layout

1 readout section:
1 view of 1 half module



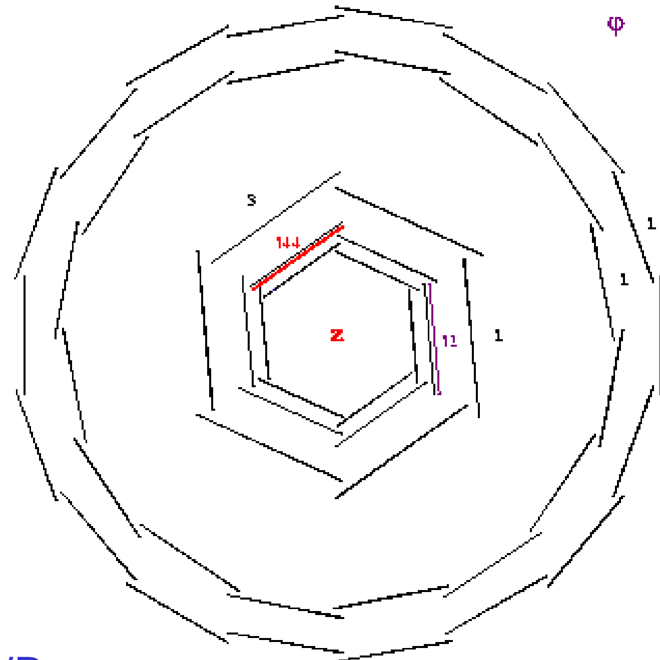
- 5 layers
- Layers1-3 straight modules, layers 4,5 arch shape
- Mounted on PepII permanent dipole magnets, located +/- 20 cm from IP
- Polar angle coverage $17.2^0 < \Theta < 150^0$
- Double-sided, AC-coupled Si (@Micron)
- 300 μm n-type substrate (4-8 kΩcm)

- p+ and n+ strips, perpendicular to each other, measure z and rϕ view
- Custom made readout chip AToM (rad-hard CMOS process, Honeywell) which reads out time-over-threshold
- Front-end electronics floats at module bias voltage (40V - 54V) to avoid putting full voltage across AC coupling capacitor

Operational Status of Modules

Si modules built in Italy, USA
Pieces of final detector put together at LBNL
Jan - Mar 99 cosmics test at LBNL with final SVT
Mar -Apr 99 installation of SVT in BaBar:

- Installation of SVT on PepII dipole magnets
- Insertion of SVT, mounted on PepII beam-line magnets in BaBar

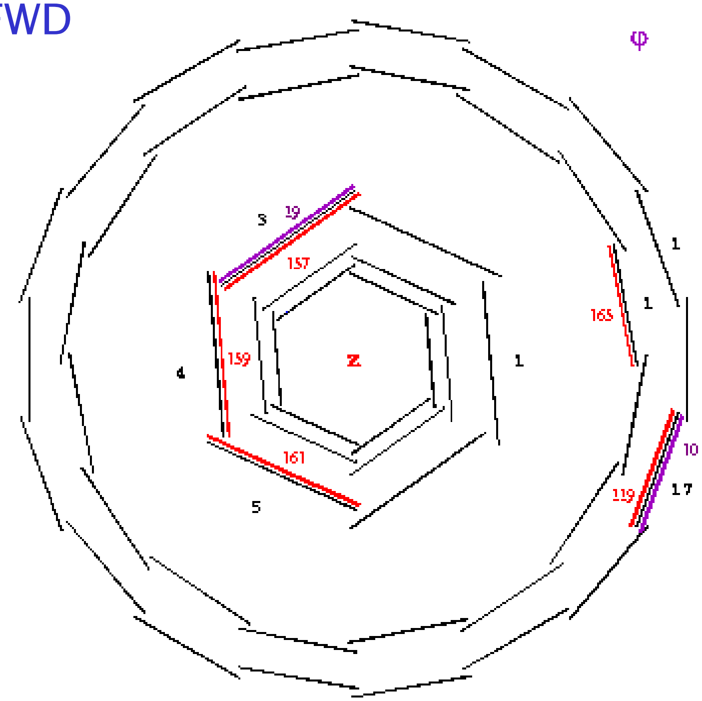


In the course of this process we lost
out of 104 fwd, 104 bwd read-out sections:

- 1 bwd (z)
- 7 fwd (2 rϕ, 5 z)

Power failure in Sept 99 cost 1 bwd rϕ section

BWD
FWD



No action possible now
Access to SVT requires several months of down-time

Crucial layers 1,2 (almost) fully functional
No failure due to radiation

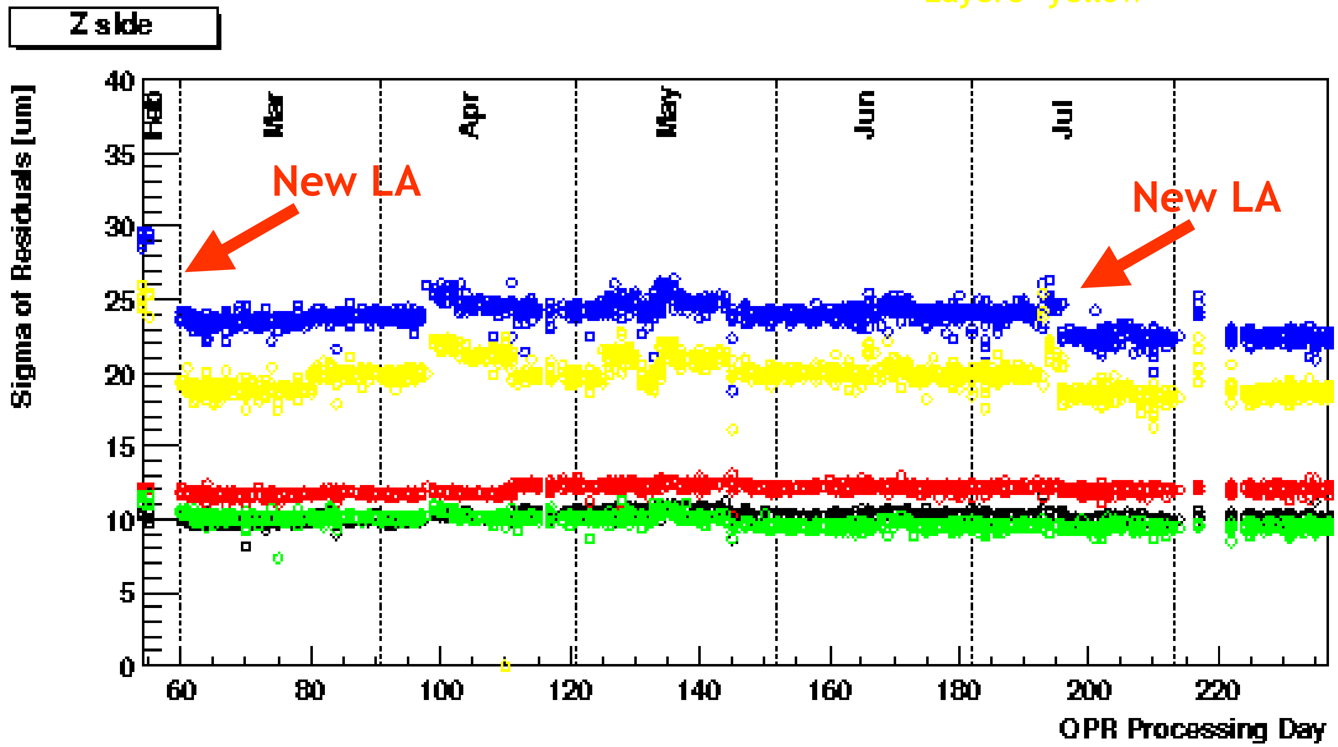
SVT internal ("local") alignment

Layer1 - black
Layer2 - red
Layer3 - green
Layer4 - blue
Layer5 -yellow

Beware: Plot shows combined effect of local and global alignment

OPR -
Online Prompt Reconstruction
Goal of having fully reconstructed each run within few hours of data taking

Plot is output of
SVT data quality monitoring



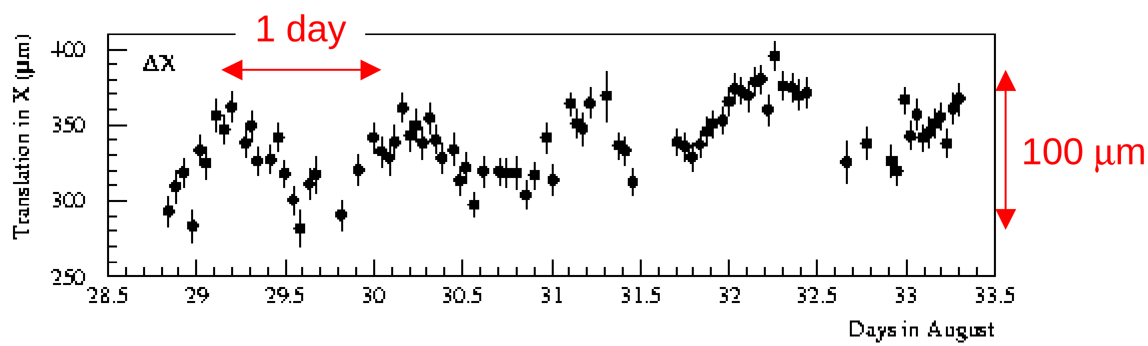
Alignment of Si wafers inside SVT w.r.t. each other

- Di-Muon events (~30K)
- Pair-fit technique with SVT standalone tracks: 2 tracks constrained to be back-to-back in $\Upsilon(4s)$ CMS
- Minimize residuals per individual wafer
- Changes appear typically after access to BaBar, i.e. every few months; no need for rolling calibration (see next slide)

SVT global alignment (SVT–DCH)

Diurnal SVT/DCH Movement - Δx

Observed movement correlated strongly with ambient temperature



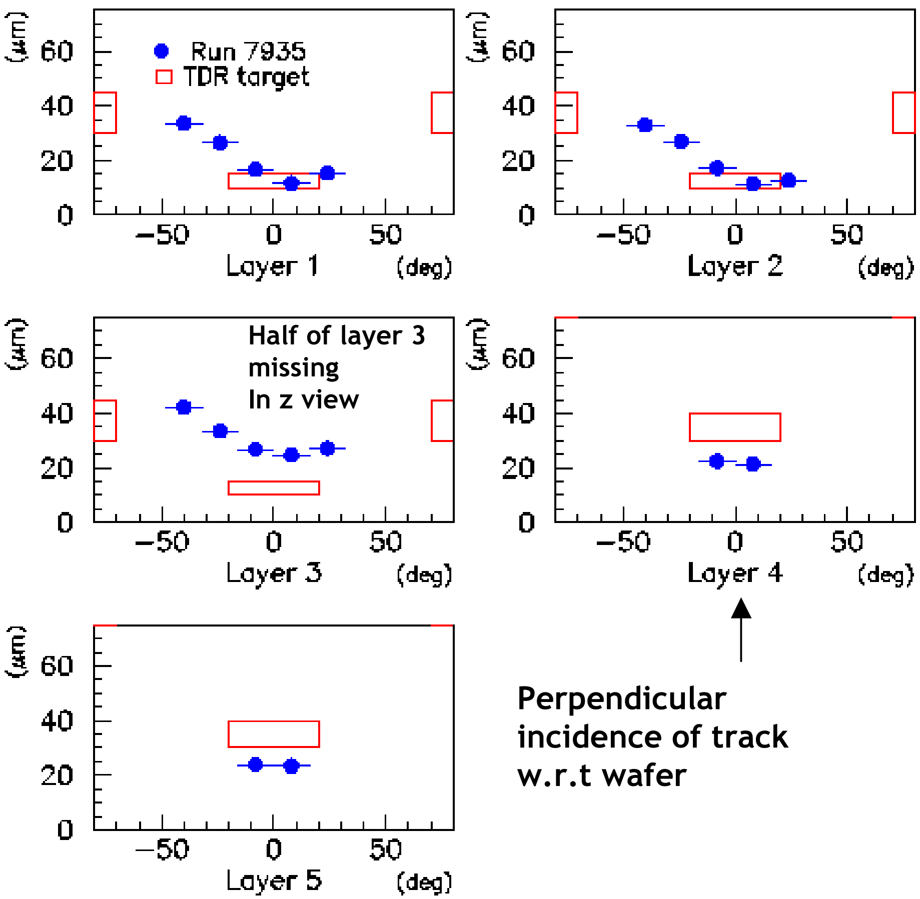
Relative alignment between SVT (treated as rigid body) and BaBar Drift Chamber DCH

- Bhabha and Di-Muon events (~30K)
- Procedure splits stiff high-quality tracks in SVT and DCH part, minimizes mismatch of refit track parts at SVT-DCH border
- Typical amplitude of change 100 µm/day, up to 10 µm within one hour observed, compare to SVT single hit resolution of 10-15 µm in layers1,2,3

- Expected since SVT mounted on PepII magnets, not on BaBar detector
- Recalibrate at least every few hours
- Done as rolling calibration:
  - * Alignment constants extracted during OPR of given run
  - * Result stored in conditions database
  - * Used as input for reconstruction of following run

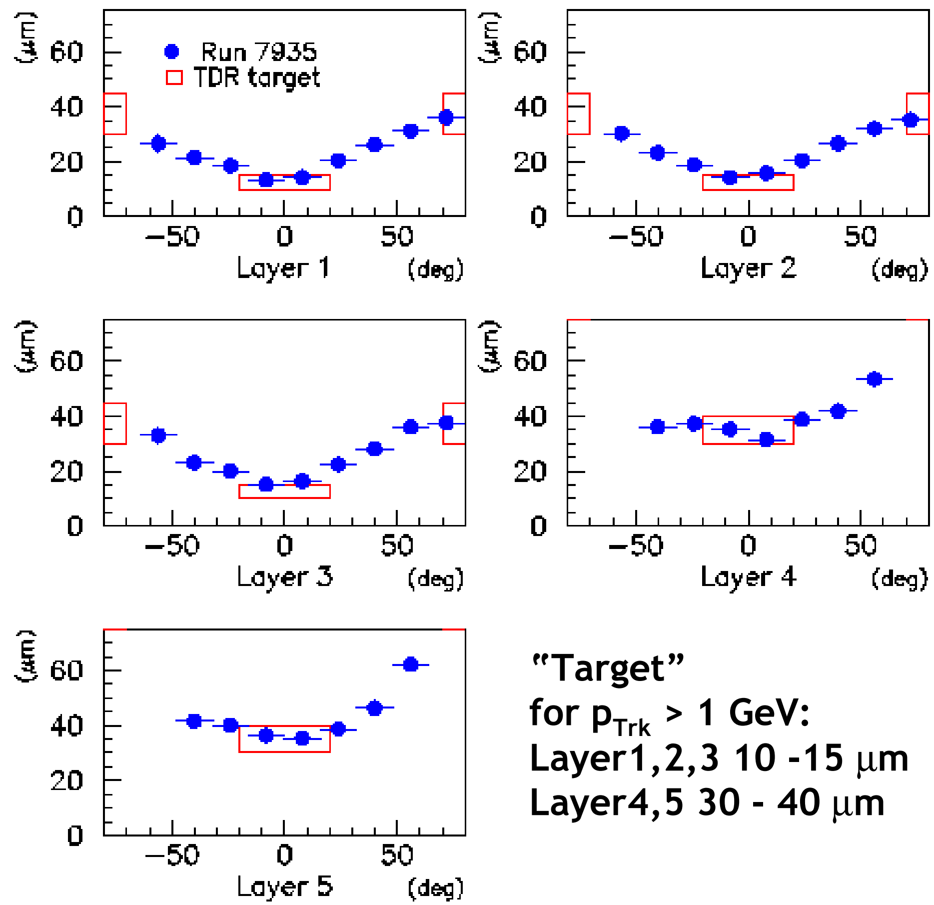
SVT performance: Single hit resolution

SVT Hit Resolution vs Angle - Phi View



Perpendicular incidence of track w.r.t wafer

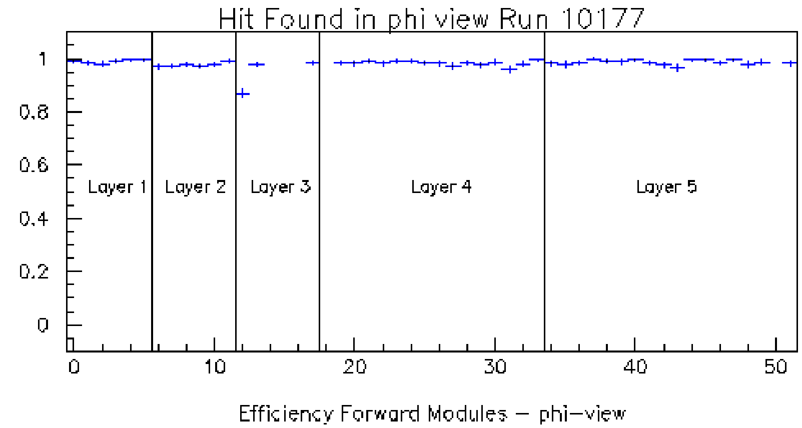
SVT Hit Resolution vs Angle - Zed View

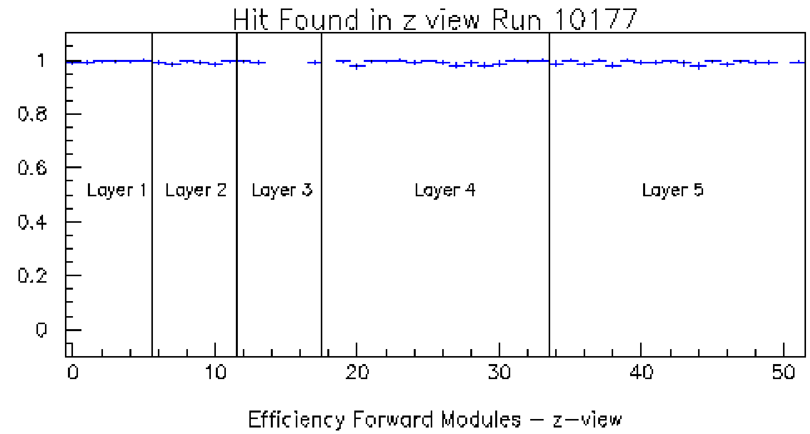


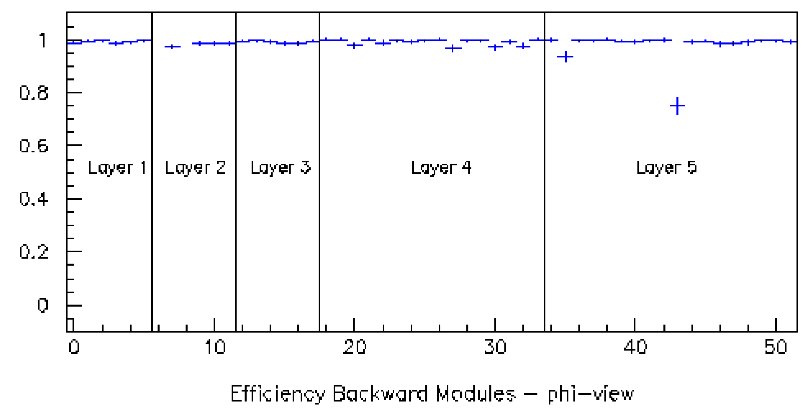
"Target"
for p_{Trk} > 1 GeV:
Layer1,2,3 10 -15 μm
Layer4,5 30 - 40 μm

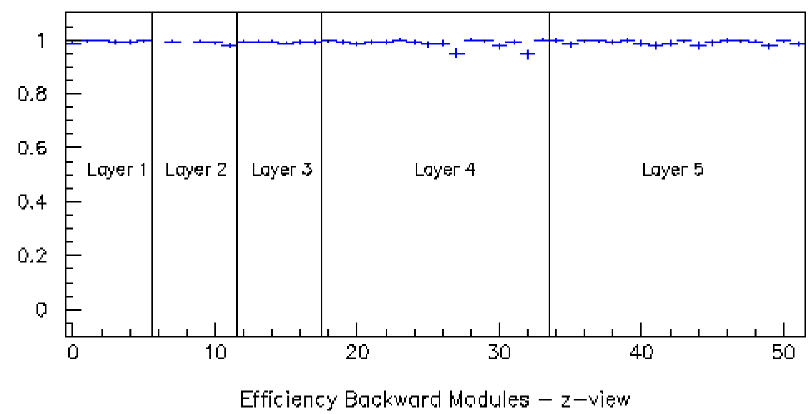
Design goal for resolution achieved

SVT performance: Hit reconstruction efficiency





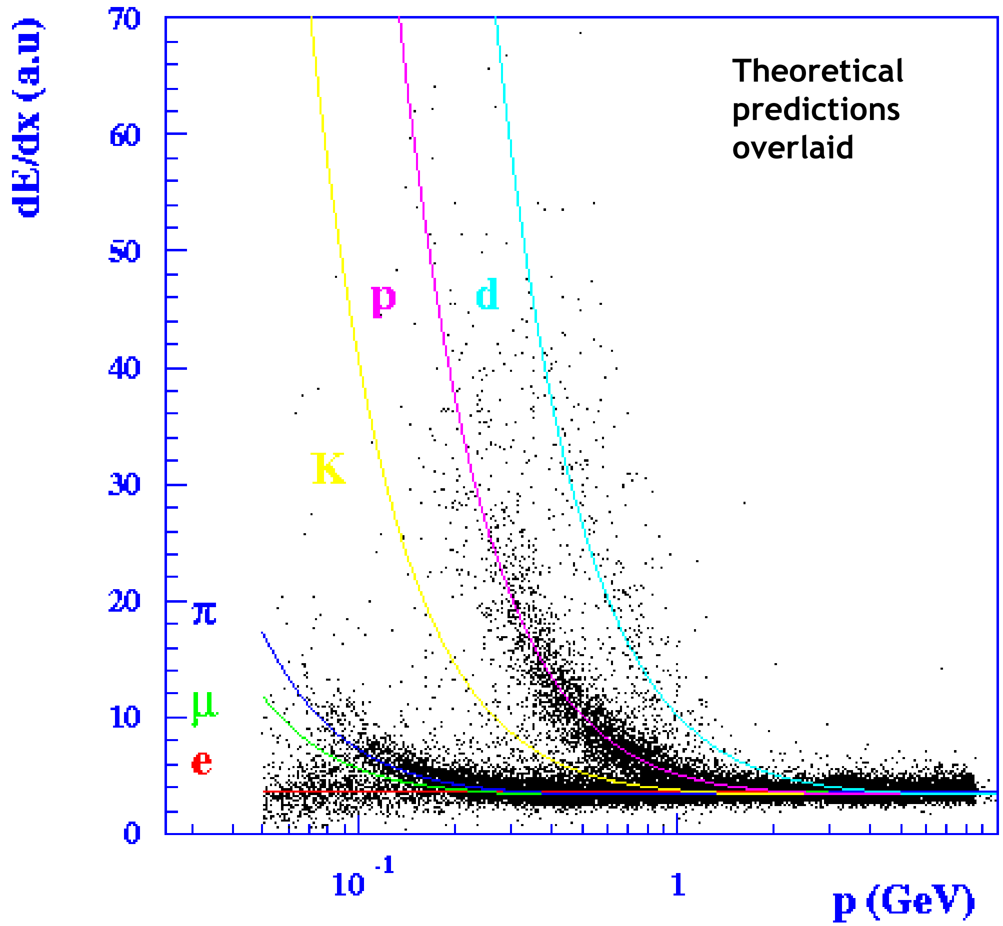




Efficiency typically above 98% in both views

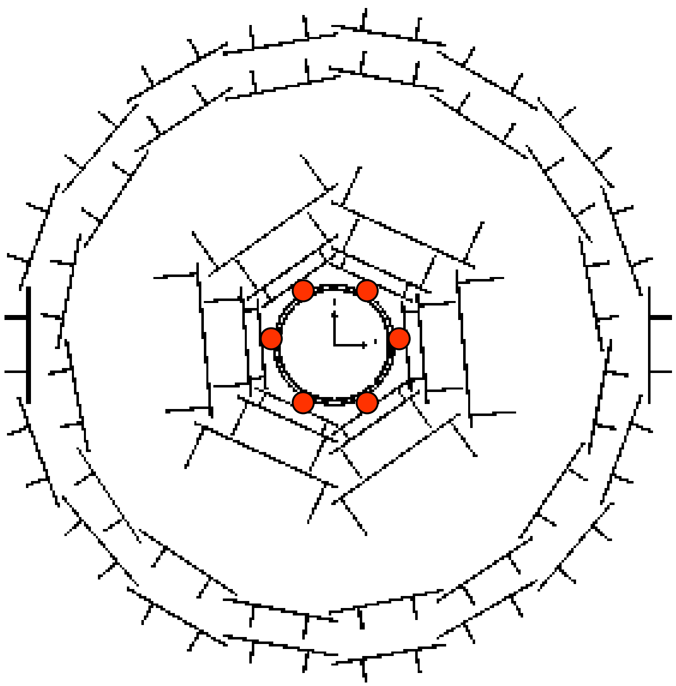
SVT performance: dE/dx measurement

- AToM chip measures Time-over-threshold (ToT)
- ToT approx. log. dependence on pulse height
- dE/dx calculated from 60% truncation (usually 3 charge measurements)
- Resolution on Bhabha electrons ~15% (factor of 2 worse than DCH)
- SVT and DCH dE/dx used for p<700 MeV/c, DIRC above
- PID info exclusively from SVT for p_t < 120 MeV/c



Important tool for B-flavor tagging: Charge of K in B decay
K:π abundance 1:7, with 0.3 (0.4) < pπ (pK) < 0.75 (1.1) GeV/c

SVTRAD: Radiation protection and monitoring system



Principle: **Measure radiation induced increase in leakage current in reverse-biased pin diodes**

200 pC ~ 1 mRad

or 1 nA ~ 5 mRad/s

Instantaneous dose monitored to better than 0.25 mRad/s
Integrated dose monitored with 5% accuracy
Response time 1 ms/Rad

- **Reverse-biased pin diodes with active area 1cm x 1cm x 300 μm**
- **2 rings (fwd, bwd) of 6 diodes each +/- 20cm away from IP on radius 3 cm**
- **West and east diodes monitor radiation in the beam-bend (horizontal) plane**

- **2 tasks:**
  Monitoring
  Protection (beam abort, injection inhibit)
- **2 types of abort thresholds:**
  Acute-dose threshold (mRad/s)
  Chronic-dose threshold (mRad)

SVTRAD: Radiation monitoring

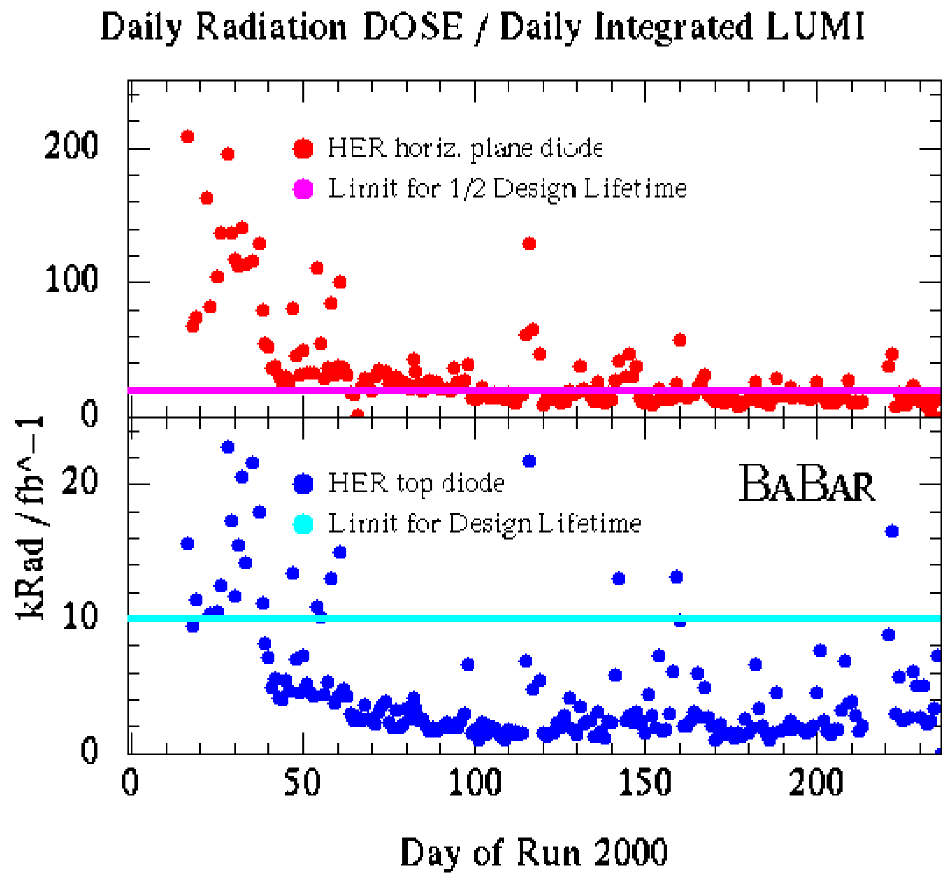
SVT designed with "radiation lifetime" of 2 MRad/10 yr or 300 fb^{-1}/10 yr

Accumulated so far in 2000:

- Horizontal-plane diodes:
  200 - 400 kRad
- Other diodes:
  50 -75 kRad

Diodes in horizontal plane are already running above budget

Radiation conditions vary strongly with time



Assumes budget of ~300 fb^{-1}/10yr

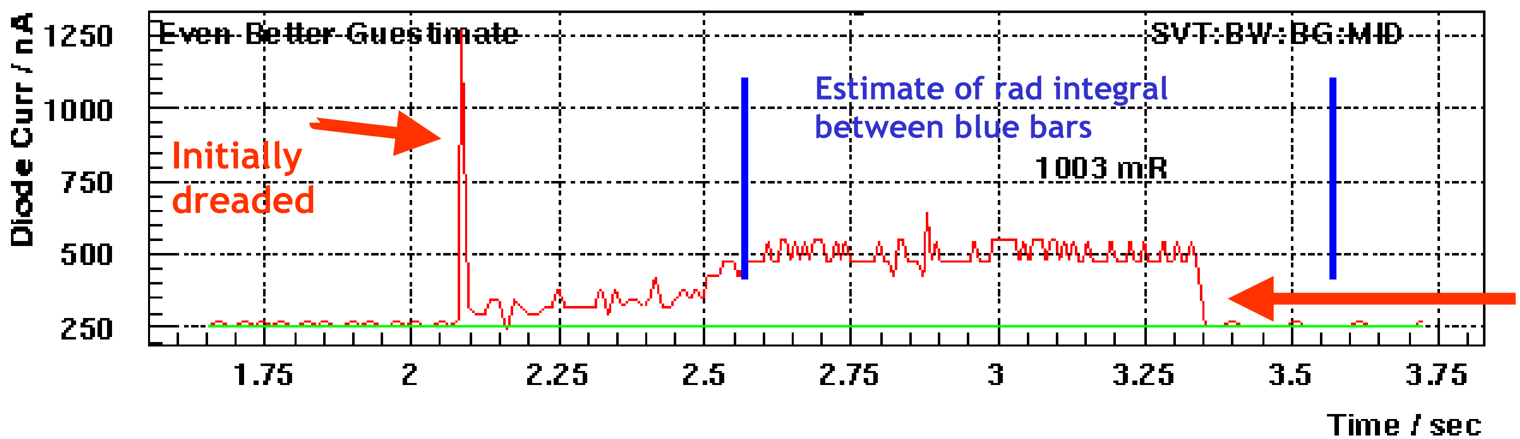
HER - high energy ring, I.e. e-
LER - low energy ring, I.e. e+

SVTRAD threshold evolution

- Initially: Thresholds protect primarily against fast radiation bursts (>1 Rad/ms) which can result in p-stop-shorts/pinholes (shorts through the SiO_2 layer) when V_{bias} drops over bonding-stressed AC coupling capacitor
- Tests showed problem occurs only on acceptable 2% level
  Found that new p-stop-shorts/pinholes typically result from accidents (magnet quench, ..)
- Shift of emphasis to enforcing long-term dose-budget

Goal: Optimize the ratio "Radiation exposure per unit luminosity" for the SVT

Note: SVTRAD thresholds protect only against rather extreme cases, f.i. "dust event" below
Dose-budget mainly enforced by administrative protest when over budget for too long



Output of SVTRAD fast history buffer

Beam abort with current thresholds

SVTRAD: Trip frequency

Find balance:

Risk for SVT
"Radiation cost" of refilling from scratch

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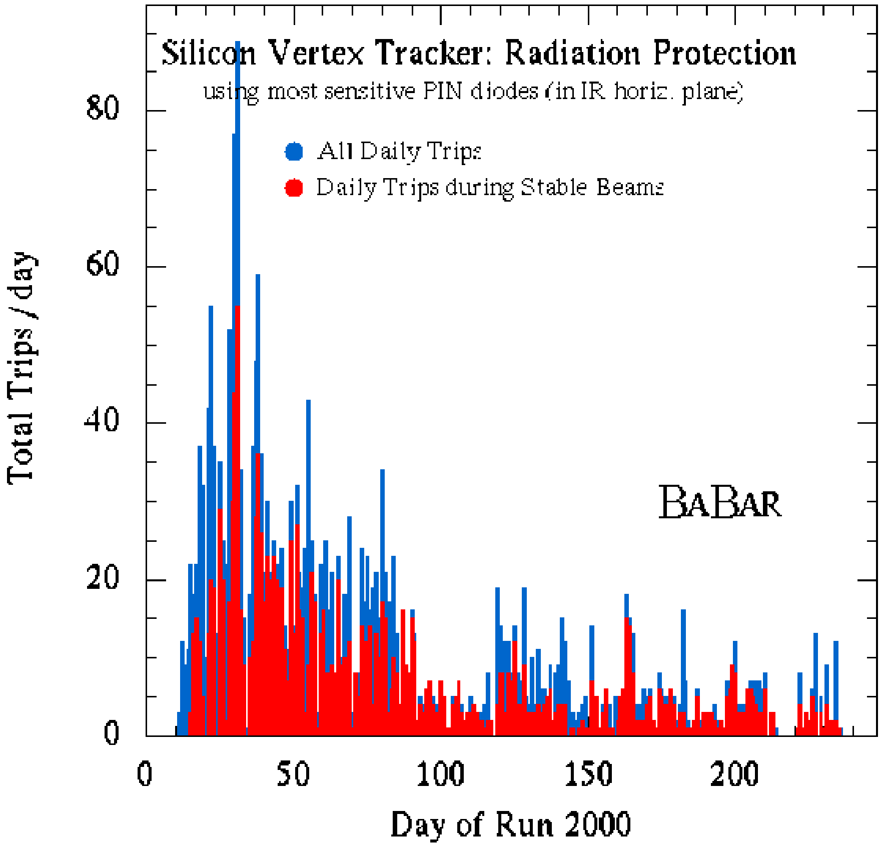
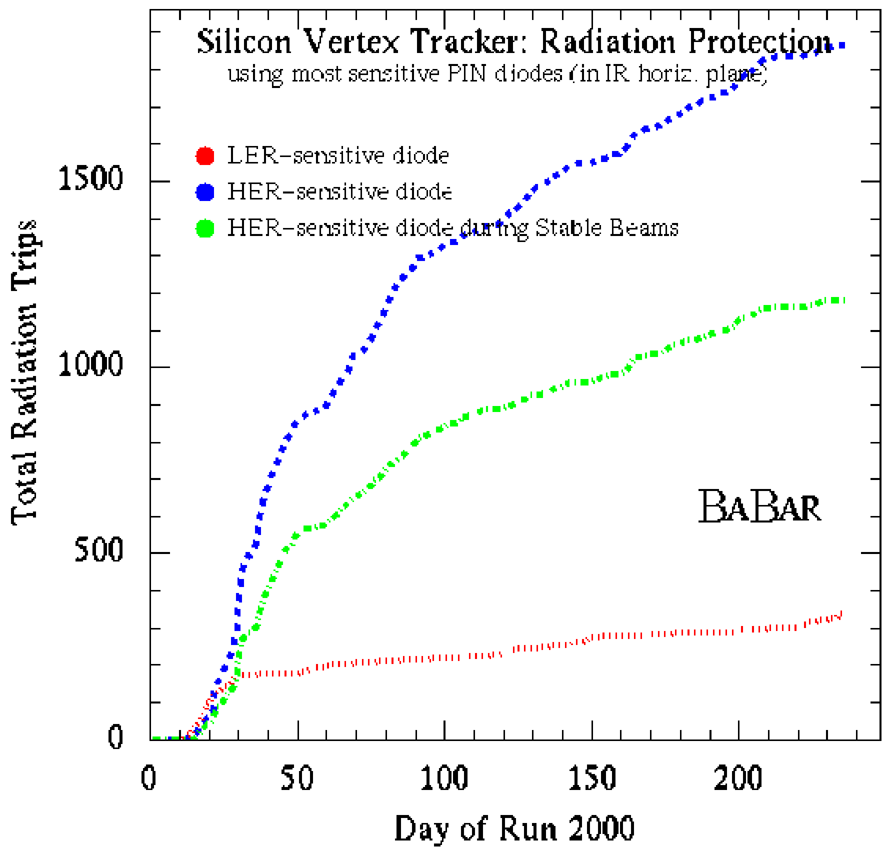
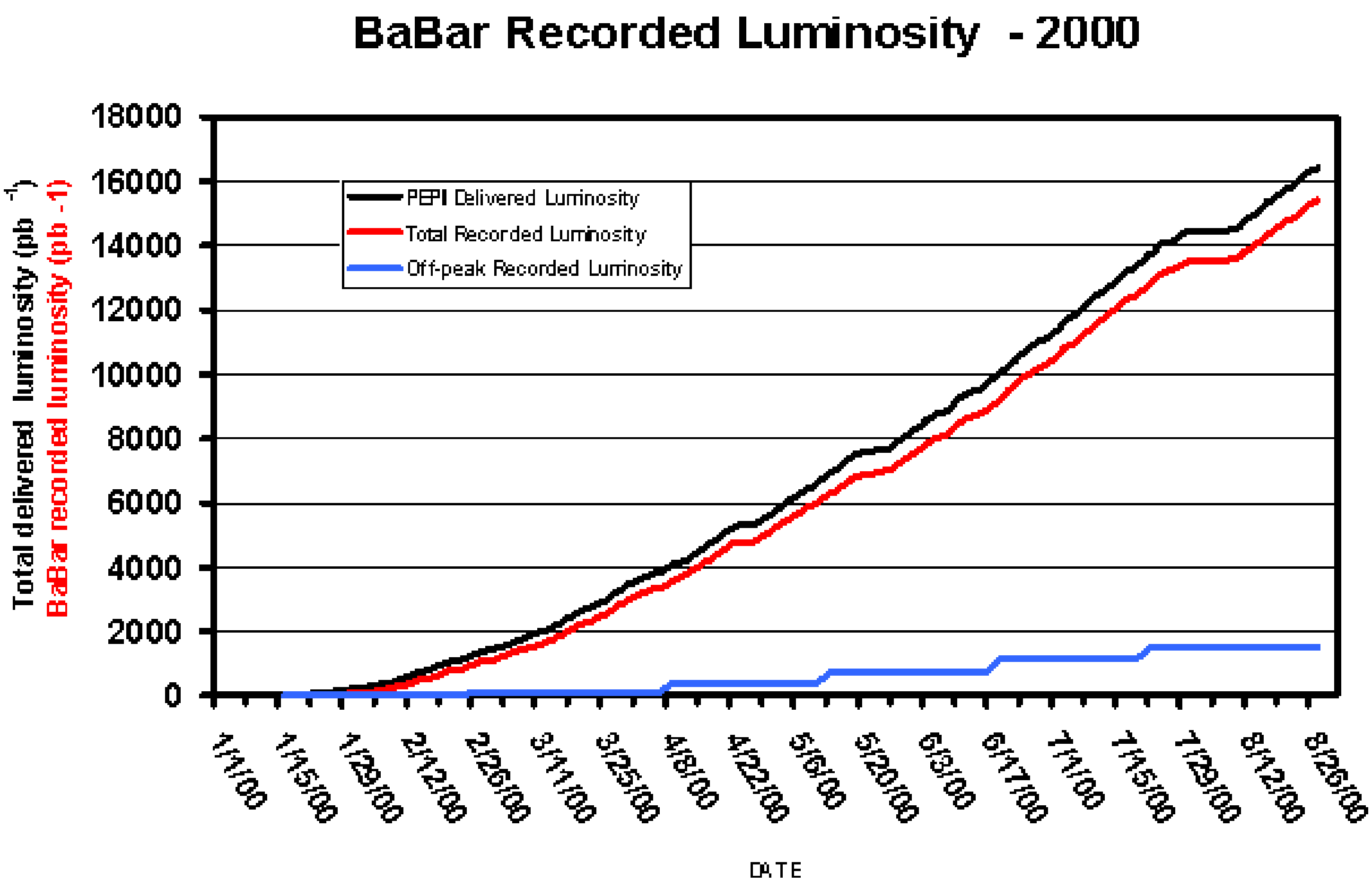
Operational head-room for PepII
Uptime of BaBar



SVTRAD: Trip frequency



PepII and BaBar integrated luminosity in 2000



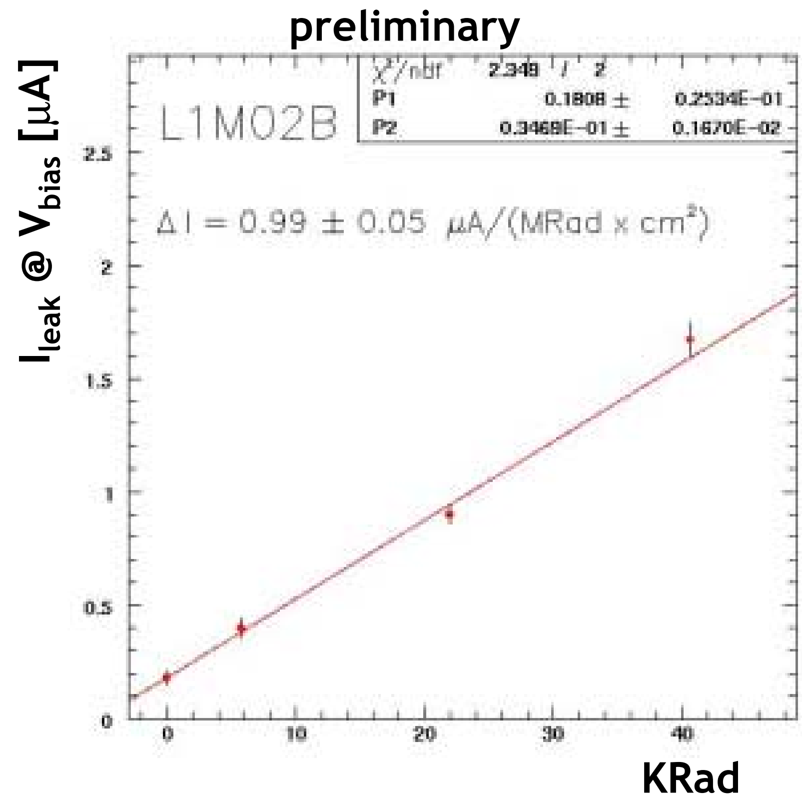
First-year radiation exposure of the SVT

IV curves taken for layers 1,2
in 5/99, 10/99, 4/00, 8/00

Correlate ΔI_{leak}@ V_{bias} with amount of rad.
measured in SVTRAD diode closest to module
Simulation indicates ratio SVT Layer1/diode ~ 0(1)

Difference in slope measures actual
difference in radiation exposure

- L1 non-horizontal-plane modules:
  ~1 μA/ (cm^2 x MRad)
- L1 horizontal-plane modules: 30-40% lower
- L2: 30-40% lower than layer 1



Evidence for rad. damage in SVT, the size of which does not affect SVT performance
Indication that in horizontal plane SVTRAD diodes overestimate rad. seen by SVT modules
(Strong inhomogenity of radiation in bend plane)

Radiation protection: Issues for the future

PepII design:

- Integrated luminosity per year: 30 fb^{-1}
- Peak luminosity 3 x 10^{33} cm^{-2} s^{-1}

PepII in 2000 is almost at design:

- Goal till end of run 2000: 25 fb^{-1}
- Reached to-date (8/31/00):
  2.3 x 10^{33} cm^{-2} s^{-1} and 17 fb^{-1}

PepII plans a series of upgrades that might result in reaching the design 10 year luminosity integral of 300 fb^{-1} as early as end of 2003.

- Taking the radiation measured by the diode closest to the SVT module to be estimate for radiation exposure of that SVT module (could actually be upper limit) and
- Taking into account background projection with increase in currents:

  Non-horizontal-plane modules will have seen 0.1-0.3 MRad }
  Horizontal-plane modules will have seen 1.5 - 2.5 MRad } by 2004

Horizontal-plane modules could be replaced in 2002.
So far "Best before" budget, but where is hard limit ?

Prepare for PepII upgrade: Irradiation tests

- γ from ^{60}Co (during design/construction):
  Since hadron fluence in BaBar expected to be low, surface damage considered limiting effect for SVT rad "lifetime".
  ΔI_{leak} = + 0.5 μA/(MRad x cm^2)
  $\Delta C_{interstrip}$ = + 10-20%
- Shower from 3.1GeV e- on 6 X_0 Cu target (SLAC, Feb 99):
  Lost beam particles in PepII typically cross several X_0 of beam line element Cu in vicinity of IP before they hit BaBar.
  FLUKA simul.: Fluence 1-2 orders of magnitude too low to give observed ΔV_{depl}
- 0.9GeV e- beam and shwr from e- on 6 X_0 Cu (Elettra, Trieste, Mar 00):
  e- fluence factor 2 lower than for SLAC exp.

preliminary

Source	Dose kRad	ΔI_{leak} μA/(MRad cm^2)	ΔV_{depl} V
Elettra e-	250	4.1	8
Elettra shwr	500	6.4	12
SLAC shwr	700	2.0	7

SLAC (Elettra) results obtained 30 (2) days after irradiation

- Results need further study.
- Data in literature only available for e- energies up to 300MeV e-.
- Our results indicate significant contribution of e- to bulk damage.

Several modules in inner layers have V_{depl} = 10-15 V ➡ Type inversion after few MRad
SVT modules not designed to and not (yet) confirmed to be operational after type inversion

Prepare for PepII upgrade: Irradiation tests – fluences

- SLAC

  electrons = 2.6e13 particles/cm^2

  neutrons = e. * 1e-4

  other hadrons = el. * 1e-6

  photons = el. * 10

- Elettra beam dump

  electrons = 1.3e13 particles/cm^2

  neutrons = el. * 1e-3

  other hadrons = el. * 1e-6

  photons = el. * 10

Future plans: Spare modules, irradiation tests

- Started spares production in UCSB and Pisa with timeline 2002 to be prepared for replacing defective modules and those in horizontal bend plane in 2002.

- Investigate effect of type inversion on SVT modules.
  So far a Si detector has been irradiated beyond type inversion, electrical parameters appear ok, need to connect to front-end electronics and measure charge collection efficiency.
  Studies to be finished early 2001.

- Investigate effect on AToM chip of radiation beyond 2 MRad.
  Chips were irradiated with ^{60}Co with 2 MRad, one chip with 5 MRad.
  No catastrophic failures observed, increase in noise, decrease in gain by ~20%.

- Replacement of SVT modules is highly invasive work and requires several months of shut-down.
  Decision on best time to do it depends on behavior of modules with low V_{depl} in SVT, on radiation test results and on repair/upgrade schedule of rest of BaBar and PepII.

Conclusions

- Within its first year of operation, the SVT has accomplished its design goals.
- SVT operation is smooth and reliable, a worthy match for PepII.
- Life for a Si detector next to an over-achieving accelerator is a tough one.
- On the other hand: Radiation protection for the SVT is an invasive measure as far as PepII operation is concerned.
- Radiation damage issues will certainly keep us occupied for the time to come.