Local Alignment of the BaBar Silicon Vertex Tracking Detector

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BaBar Collaboration

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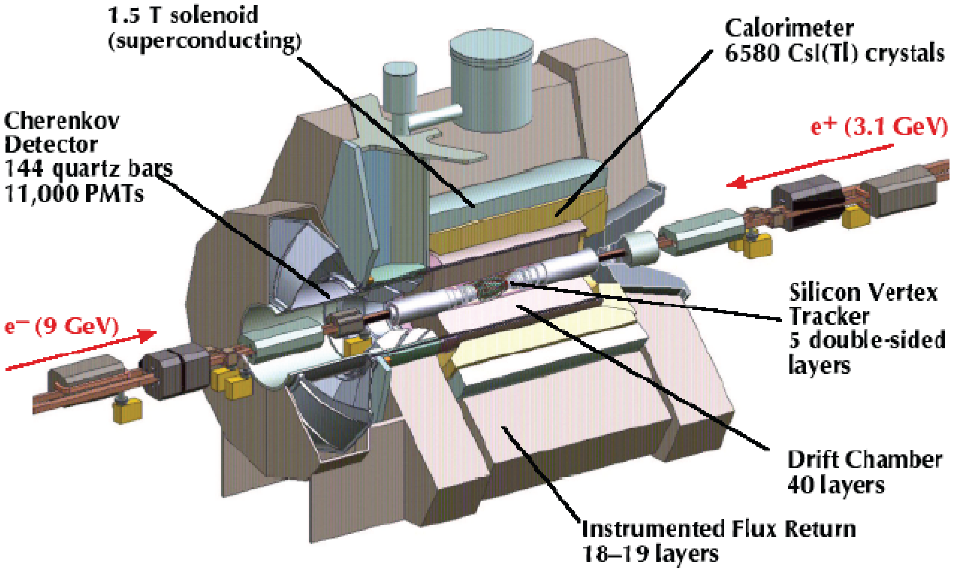
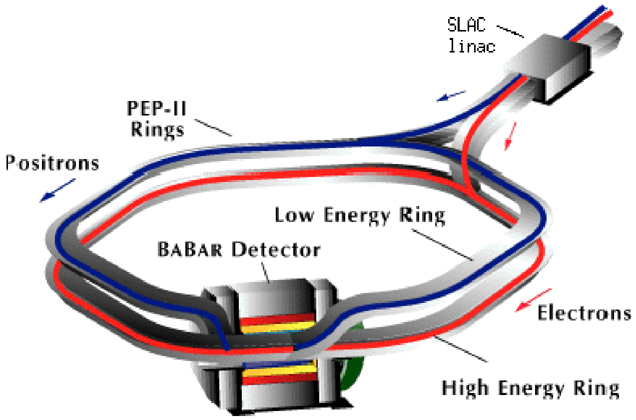
The BaBar Experiment

- Silicon Vertex Tracker (SVT): 5 layers of double-sided Si
- Drift chamber (DCH): P measurement and particle ID through dE/dX (low P)
- Detector of Internally Reflected Cherenkov Light (DIRC): particle ID (high P)
- Electromagnetic calorimeter (EMC): π^0 and K^0-long reconstruction, e ID
- Instrumented Flux Return (IFR): μ ID and K^0-long reconstruction
- Trigger: Two levels: L1 up to 2 KHz, L3 up to 100 Hz
- Offline software and event store: C++ and Object Oriented databases

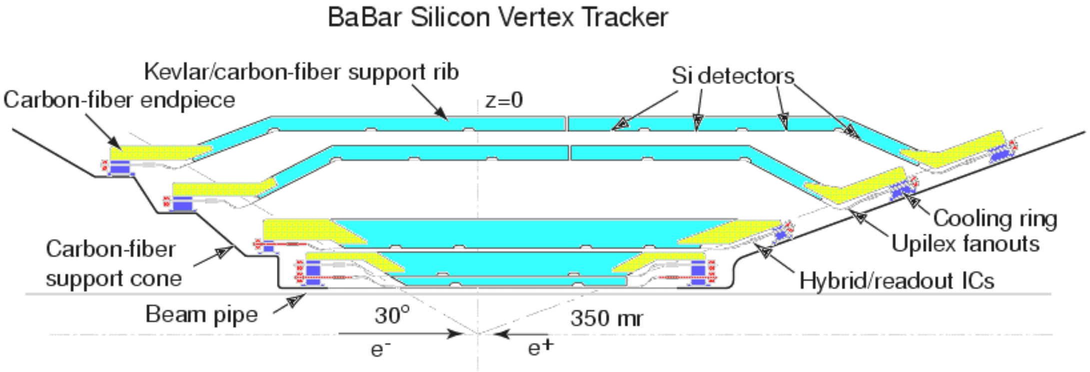


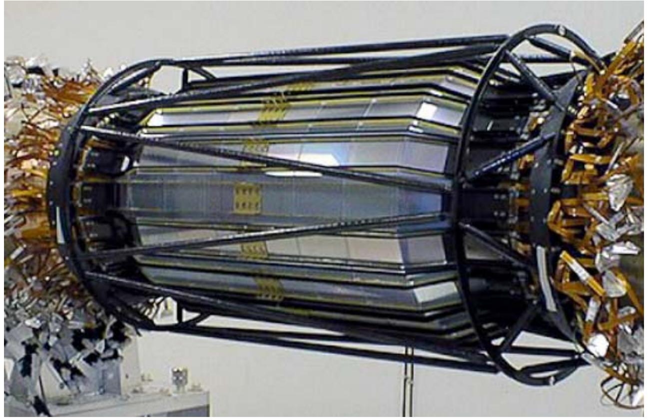
BABAR Detector



PEP-II

The Silicon Vertex Tracker





- 340 double-sided Si wafers ~1m^2 Si
- 5 layers
  independent tracker
- Unique 'arch' in outer layer
  inner three layers planar
- CF support structure
- 4% X_0 total
- ~90% of Ω
- Mounted on the innermost magnets

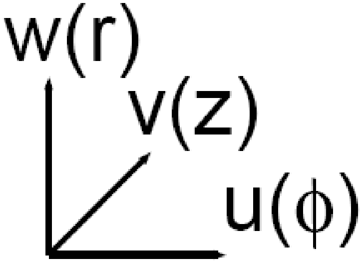
layer	wafers in module	modules in layer	radius (mm)	z (L) (mm)	ϕ (W) (mm)
1	4	6	32	42	41
2	4	6	40	45	49
3	6	6	54	44	71
4	7	16	91–127	54-68	43-53
5	8	18	114–144	68	43-53

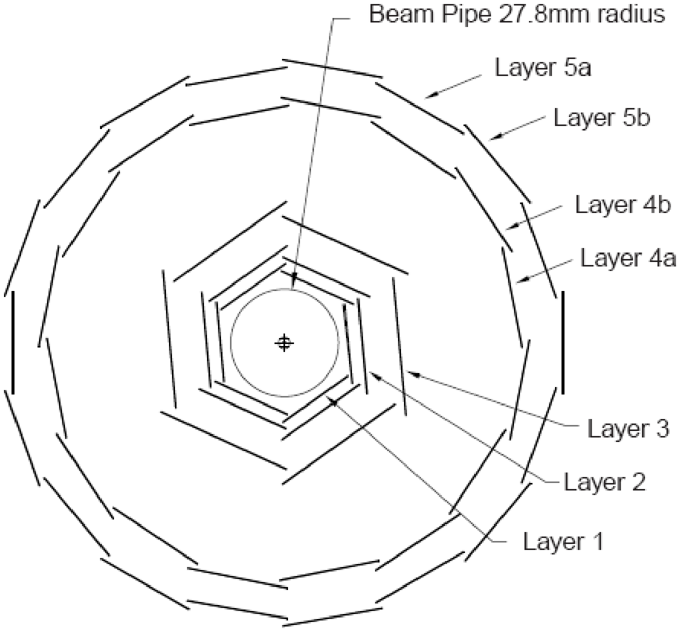
Parameterizing the SVT Local Alignment

- Determine precise relative position of silicon sensors:
  6 parameters for each of 340 SVT wafers
  3 translations and 3 rotations

- Complex process:
  - calculate hit residuals, minimize

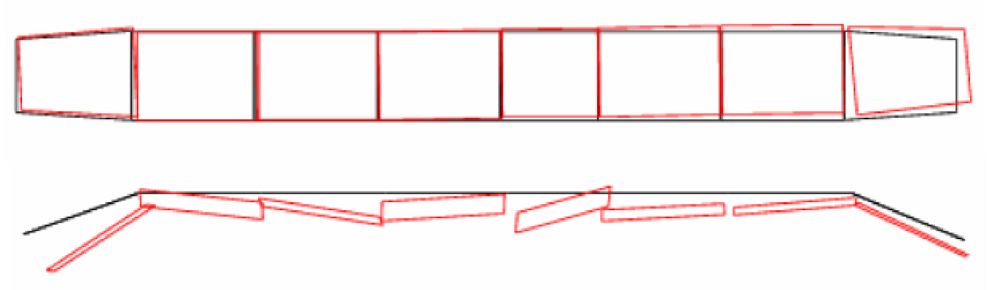
$$\chi^2 \equiv \sum_{i}^{\text{hits}} \epsilon_i^T(\Delta\mathbf{p})\mathbf{V}_i^{-1}\epsilon_i(\Delta\mathbf{p})$$





Optical Survey Constraint in SVT-LA

- We use optical survey information in module plane:



  - Important addition to track residual information
  - Compute wafer residuals with respect to survey
  - χ^2 in module plane (u, v, $\mathcal{R}_w$) weight 1.0 5μm
    in out-of-module plane: (w, $\mathcal{R}_u$, $\mathcal{R}_v$) weight 0.1 20μm

(1) Constrain wafers within modules

(2) Constrain dead readout (Z or/and ϕ) wafers

SVT-LA Goals and Requirements

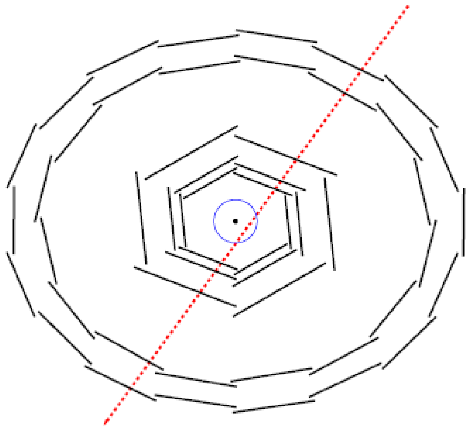
- Determine the local alignment parameters with sufficient accuracy

  average resolution: 10μm for u hits and 20μm for v hits

  statistical precision and control the systematic errors

- Track-based and lab-bench measurements only constrain the relative positions of nearby wafers

  raise the risk of introducing a 'global distortion'

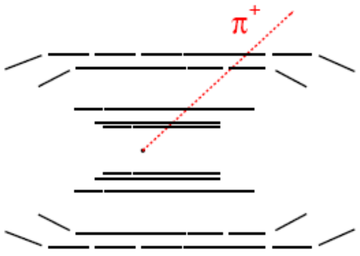


- Following the time-dependence of the actual changes in the detector

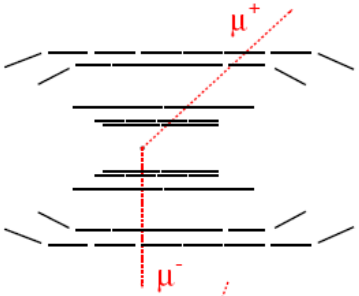
- Quickly detect when the local alignment changes

Track/Hit Selection for SVT-LA

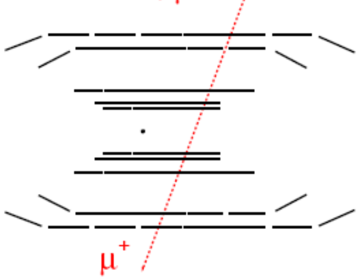
- Define five categories
  (1) "normal" (2) $\mu^+\mu^-$ (3) e^+e^-
  (4) cosmic (5) overlap hits
- Sequence
  - dedicated stream/skim/tag
  - apply cuts, tag events/track/hit
  - distribute uniformly over SVT, ϕ and Z readout, categories
- Select ~ 50,000 tracks
  tag ~ 3-4 hits/track (out of 9-10)



(1)

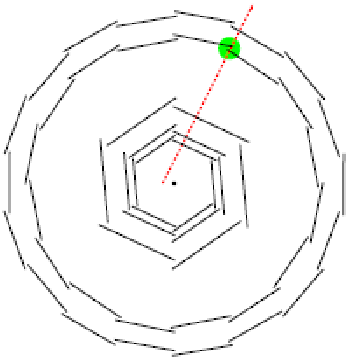


(2,3)



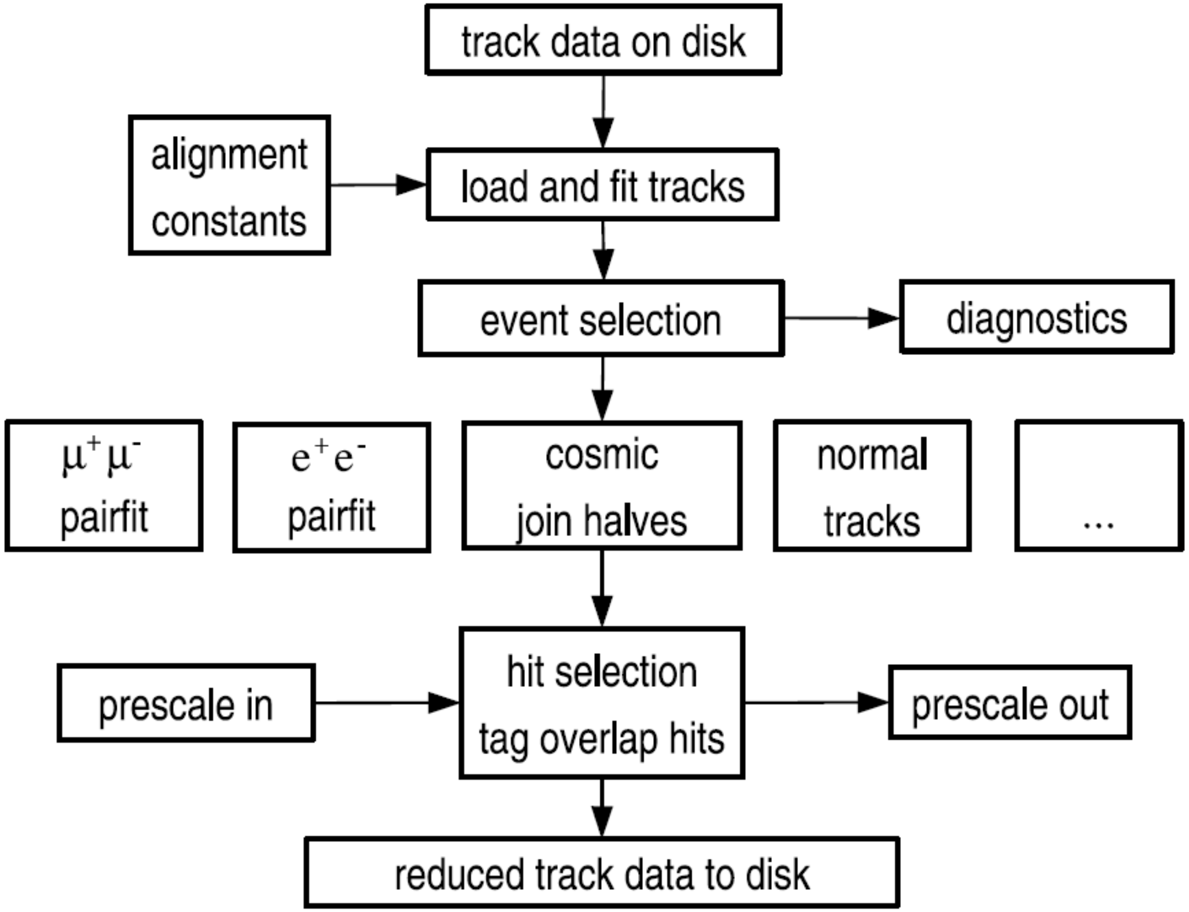
(4)

DCH-only fit ω constraint (inverse curvature) greatly improve the momentum resolution of the constrained SVT-only track



(5)

Track/Hit Selection for SVT-LA



track data on disk

alignment constants

load and fit tracks

event selection

diagnostics

$\mu^+\mu^-$ pairfit

e^+e^- pairfit

cosmic join halves

normal tracks

...

prescale in

hit selection tag overlap hits

prescale out

reduced track data to disk

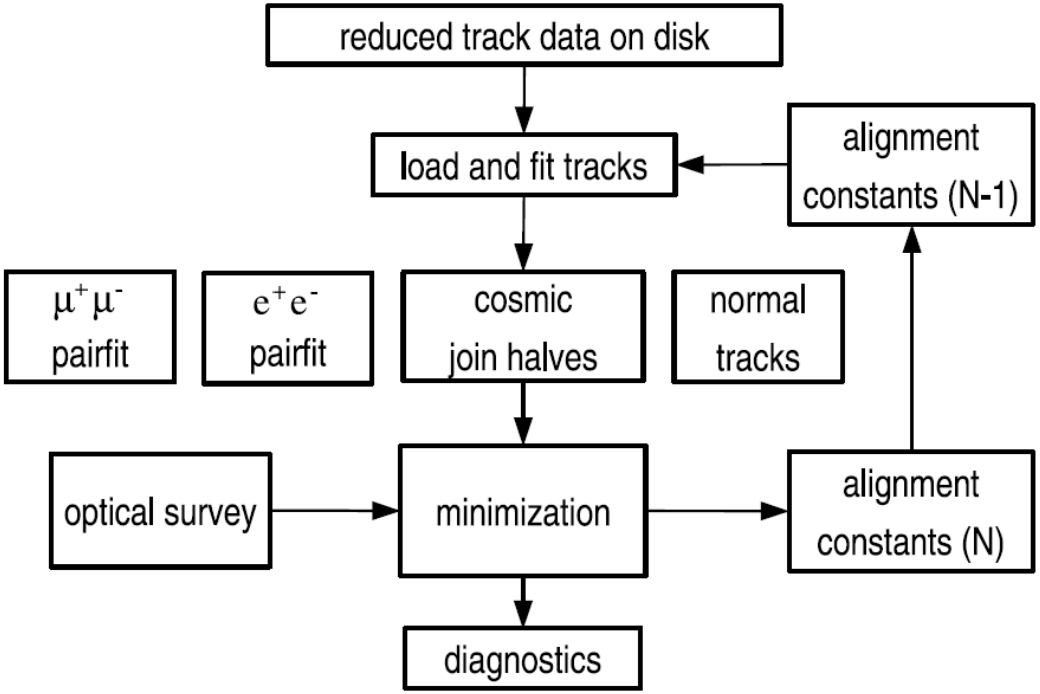
Sequence for the event, track, and hit selection, including calculation of prescale factors

Local Alignment Minimization Procedure

- Minimize 340 separate wafer χ^2 independently

$$\chi^2 \equiv \sum_i^{\text{hits}} \epsilon_i^T(\Delta\mathbf{p})\mathbf{V}_i^{-1}\epsilon_i(\Delta\mathbf{p}) + \epsilon_s^T(\Delta\mathbf{p})\mathbf{V}_s^{-1}\epsilon_s(\Delta\mathbf{p})$$

hit residuals survey residuals



reduced track data on disk

load and fit tracks

alignment constants (N-1)

$\mu^+\mu^-$ pairfit

e^+e^- pairfit

cosmic join halves

normal tracks

optical survey

minimization

alignment constants (N)

diagnostics

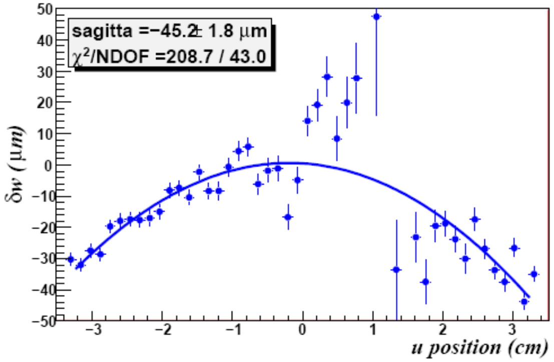
wafer $\Delta\chi^2 < 0.01$
-> converged

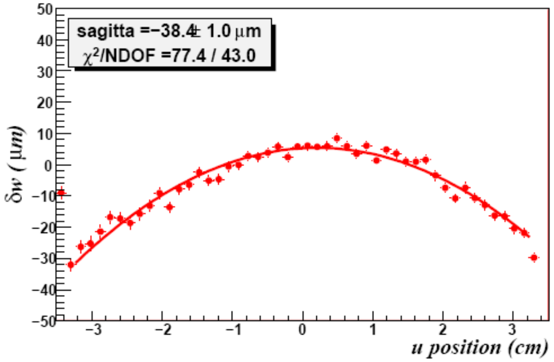
~ 20 min / iteration

~ 100 iterations

Wafer Curvature

- Radial position is measured by overlaps
  - – ϕ overlap hits constrain circumference
  - – assume flat wafer geometry





u and v hit residuals from high momentum tracks

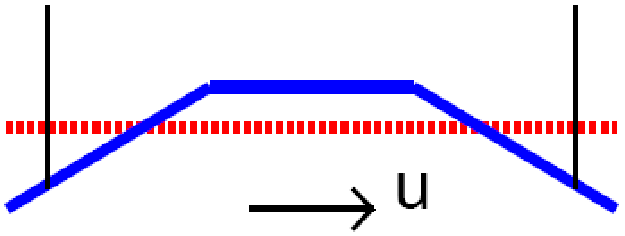
- ➢ non-linear dependence indicates an aplanar wafer distortion, not described by the standard six local alignment parameters
- ➢ wafer bowed in the uw plane
  simple bowing may not be the only aplanar distortion present
- ➢ systematic bias on the transverse impact parameter

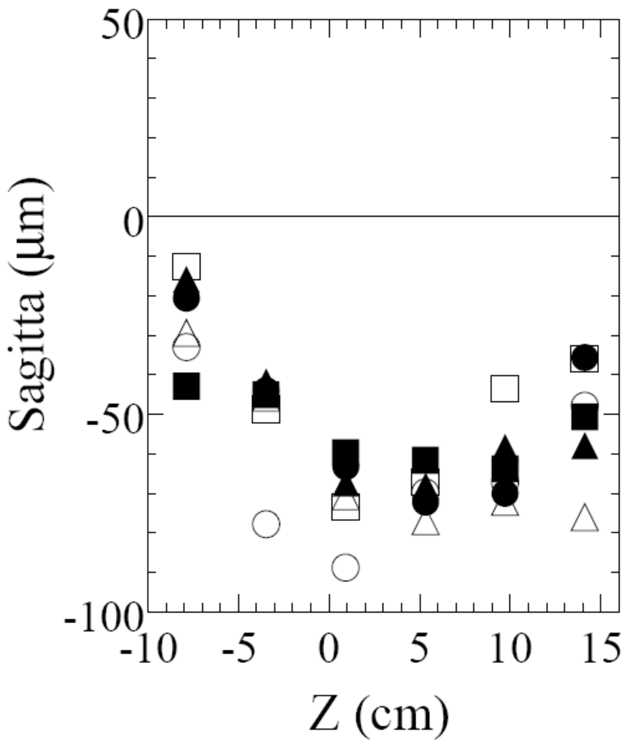
Wafer Curvature

The aplanar wafer distortions must be measured and corrected for the alignment procedure

- Wafer bowing in ϕ
  - model by polygon for Z strips

$$\delta w(u) = (u^2 - u_0^2)/2R$$

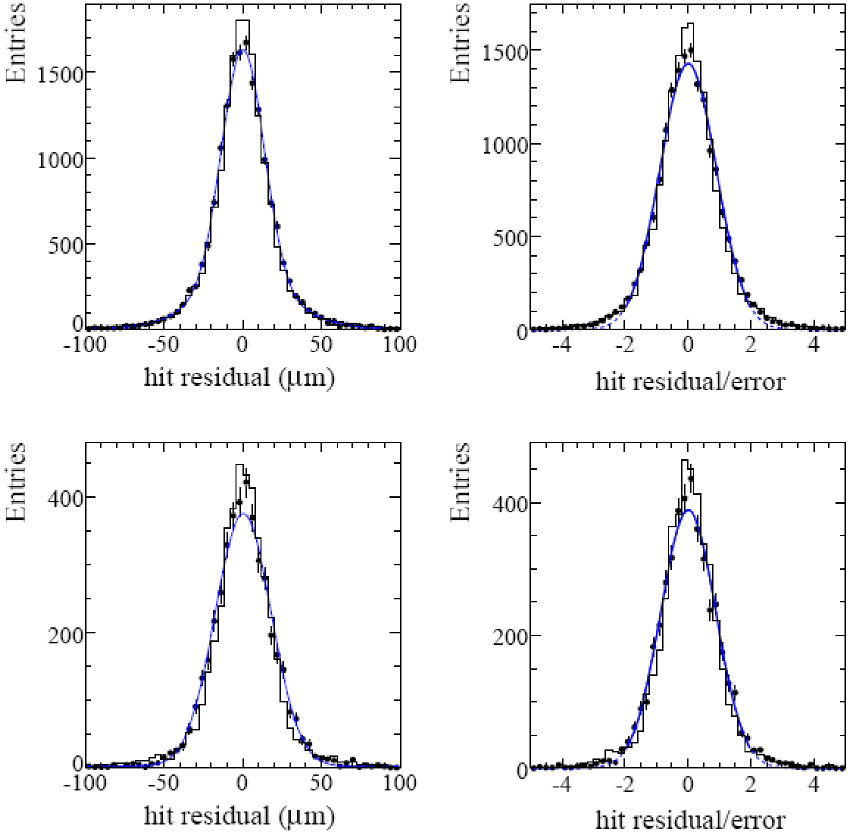




Measure the curvature radius R for each inner-layer wafer by fitting the average u and v residuals dependence on u

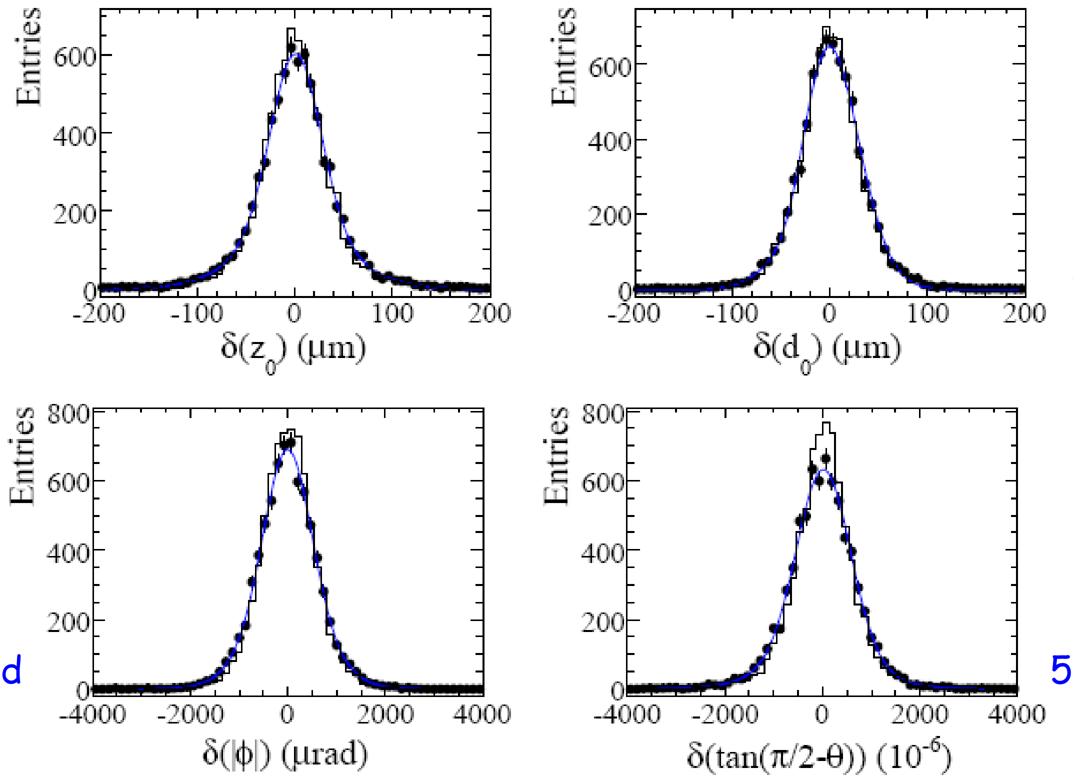
adding 84 more parameters

Validation of the Alignment



- Basic test of alignment self-consistency: hit residuals
  - Inner three layers using $e^+e^- \rightarrow \mu^+\mu^-$
  - 14 (13) μm for data (MC) u hits, 18 (16) for ν hits
  - Good agreement between data and MC

Validation of the Alignment



29 μm

24 μm

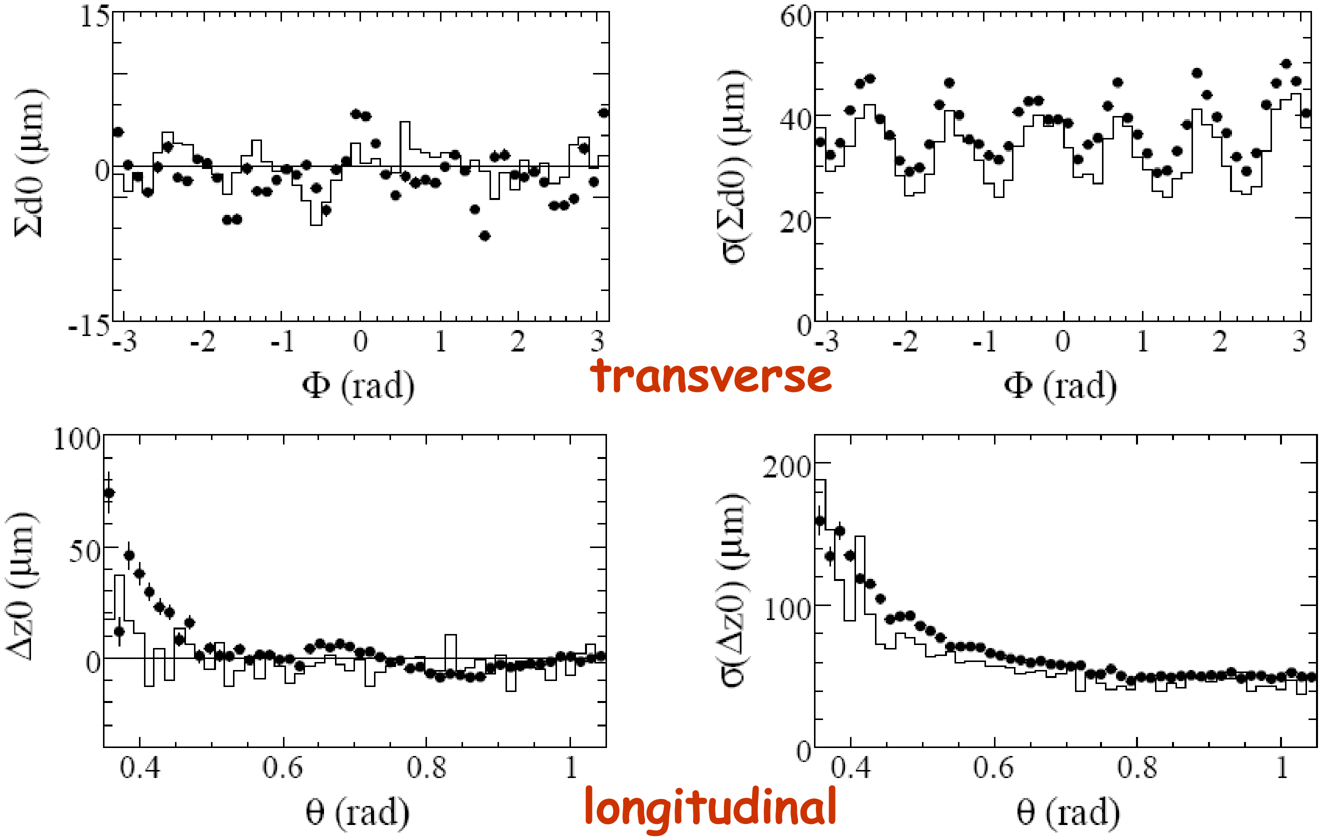
451 μrad

512×10^{-6}

- High-level self-consistency test: cosmic ray splitting

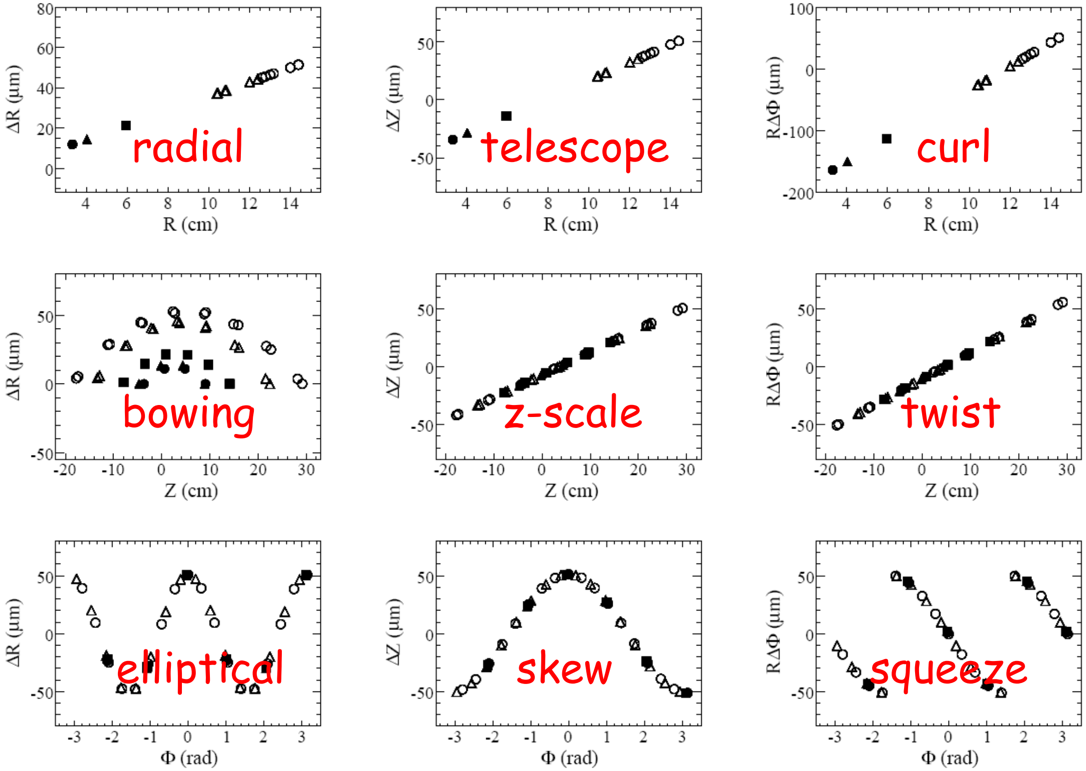
  - incoming and outgoing branches as two separate tracks
  - fit using SVT hits plus a DCH curvature constraint

Validation of the Alignment



- Comparing the reconstructed origin points of the two tracks produced in $e^+e^- \rightarrow \mu^+\mu^-$
  - measure the impact parameter resolution
  - look for systematic biases left by the alignment

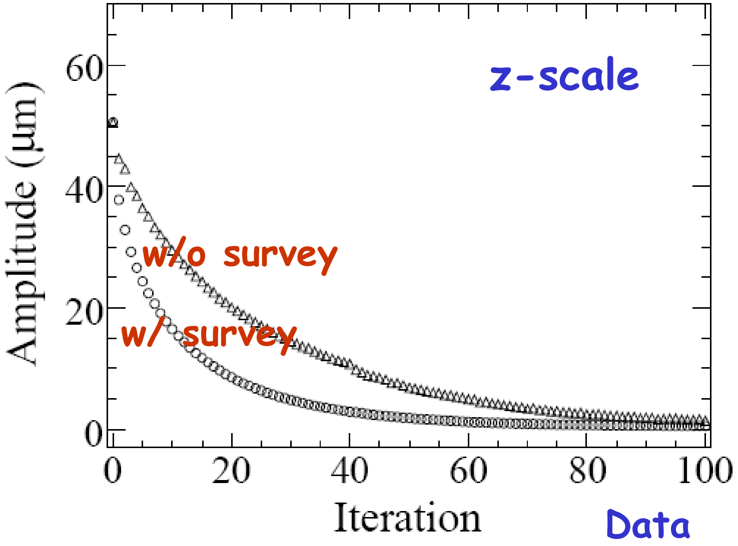
Validation of the Alignment Systematics



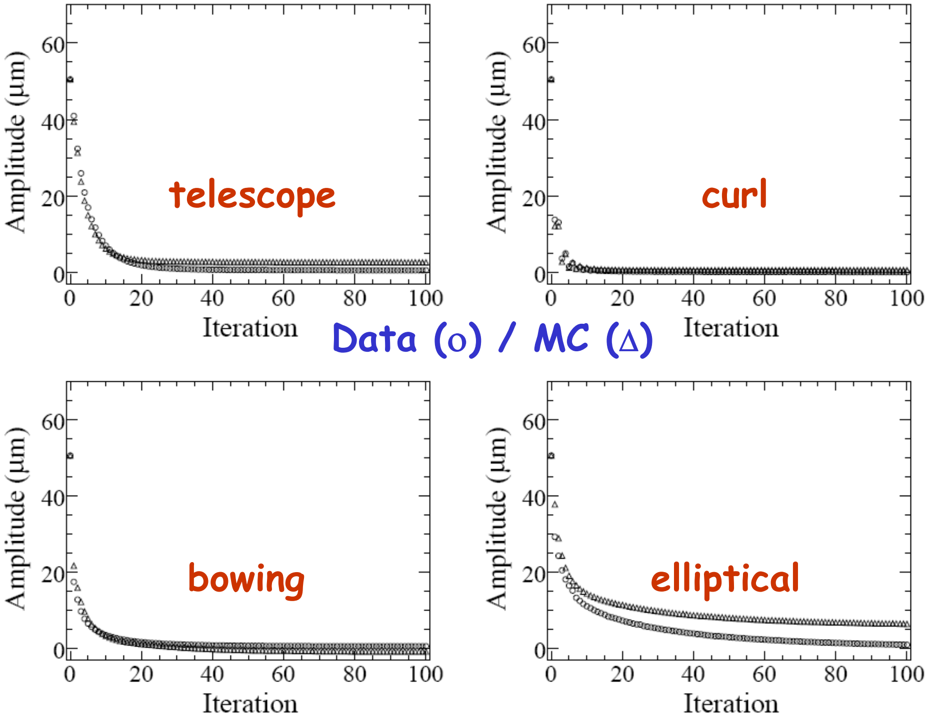
	Δr	Δz	$r\Delta\phi$
vs. r	radial scale	telescope	curl
vs. z	bowing	z-scale	twist
vs. ϕ	eliptical	skew	squeeze

Nine distinct distorted initial conditions
Set the initial scale to 50μm

Validation of the Alignment Systematics



Survey information improves the convergence and reduce the systematic error



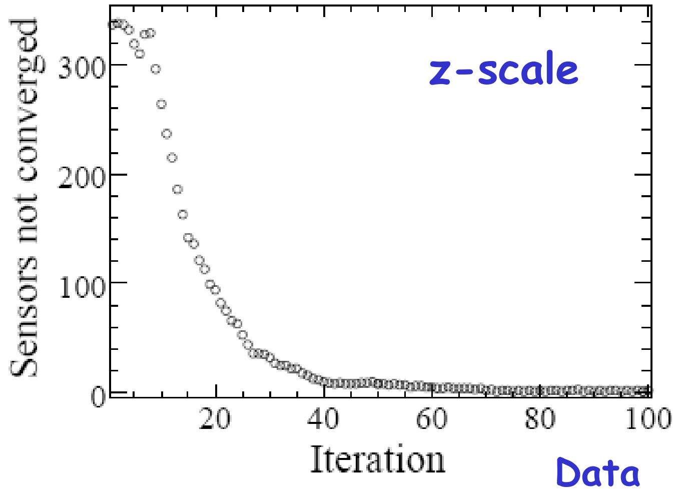
- LA procedure capable of reducing global distortions to a negligible level

Validation of the Alignment Systematics

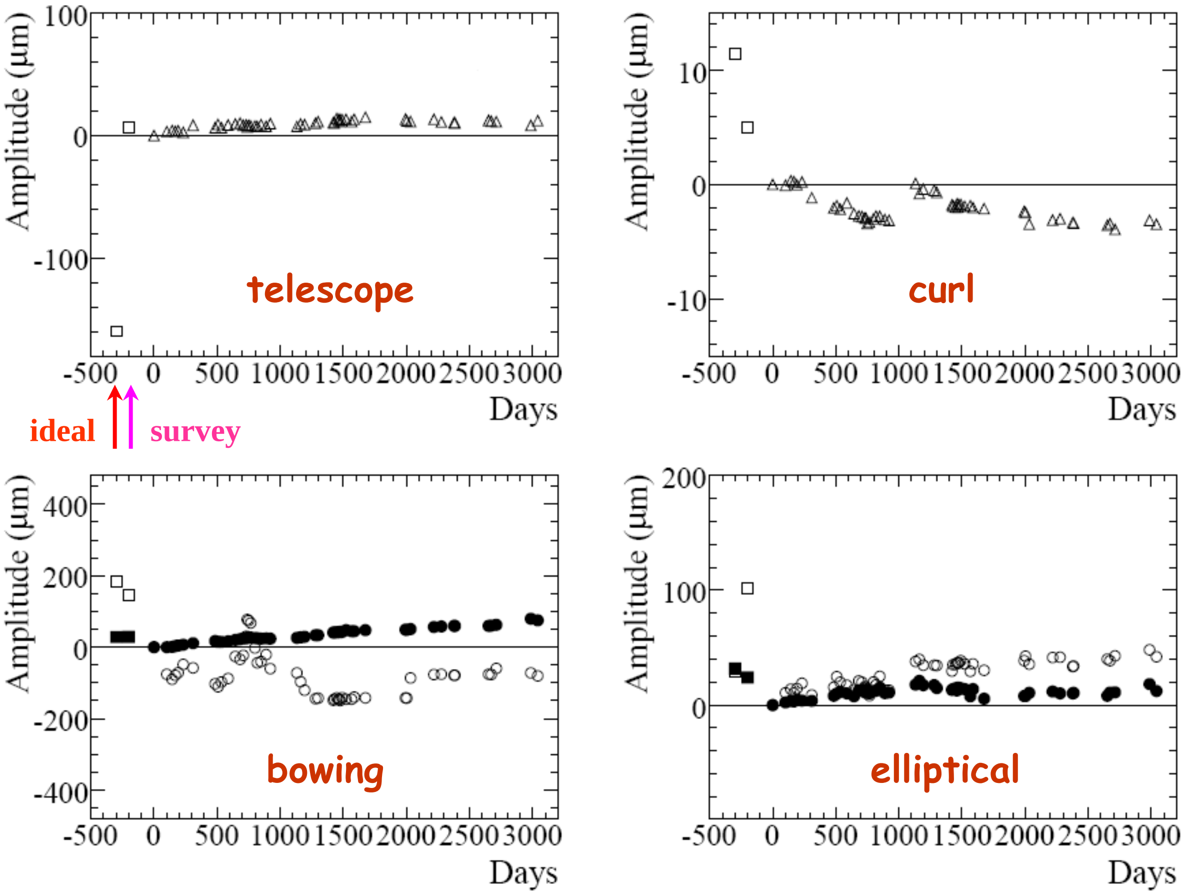
	Δr	Δz	$r\Delta\phi$
vs. r	radial	telescope	curl
decay (iterations)	5.6	5.1	1.3
distortion (μm)	0.7	0.5	0.1
vs. z	bowing	z-scale	twist
decay (iterations)	2.6	11.2	12.0
distortion (μm)	0.6	0.6	0.1
vs. ϕ	eliptical	skew	squeeze
decay (iterations)	11.8	33.6	32.0
distortion (μm)	0.9	4.9	4.5

Decay time and remaining distortion

- Global distortions are the most weakly constrained deformations
- The order of 100 iterations necessary to solve for these deformations
- Convergence requirement chosen empirically to allow convergence of the global distortions

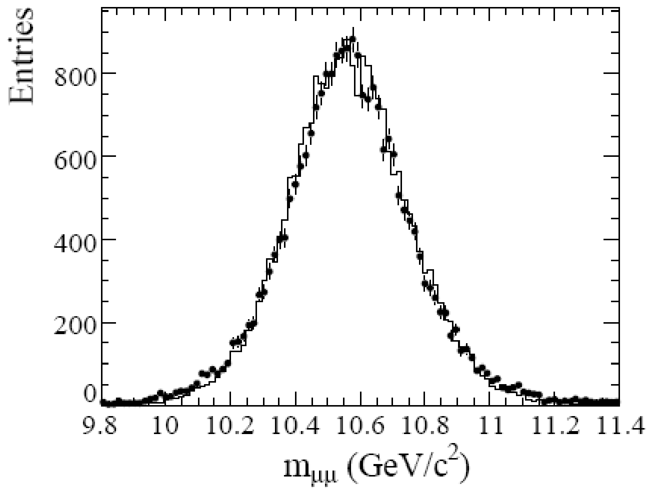


Validation of the Alignment Systematics



- Time-dependence of global distortion, compared to the initial day-one alignment Nov 1999 – Apr 2008 data
- Study of potential distortions places limits on systematic uncertainties in physics measurements

Fit for the e^+e^- Beam Energies



- Fit the average $\mu^+\mu^-$ boost and use it in the four-momentum pair constraint instead of the initial state boost
- Iterate, allowing a simultaneous extraction of the boost value and the geometrical constraints

  - makes the local alignment algorithm more stable
  - allow for monitoring the e^+e^- beam boost

Conclusions

- Described the procedure used to determine BaBar SVT local alignment

  relative positions and orientations of the 340 wafers

- Satisfies the requirements placed on the SVT performance by the BaBar physics goals

- Robust against global distortions