Parallel Computing Studies for the Alignment of the ATLAS Silicon Tracker

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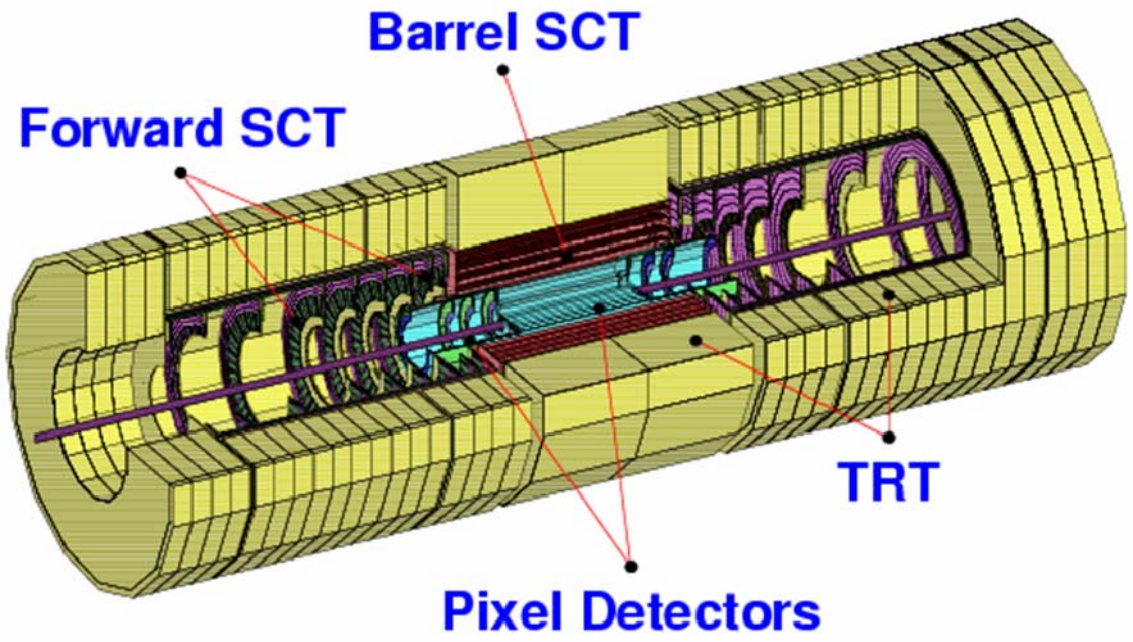
- Motivation: Alignment of Si-tracker
- Tests with random matrices
- Case-studies using ATLAS MC data

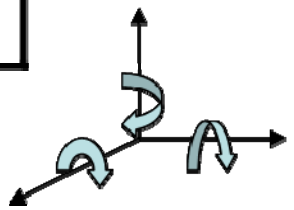
Temple in Tamil Nadu, www.sacredcities.com

The Fact: Atlas Silicon System has ~ 35k DoF



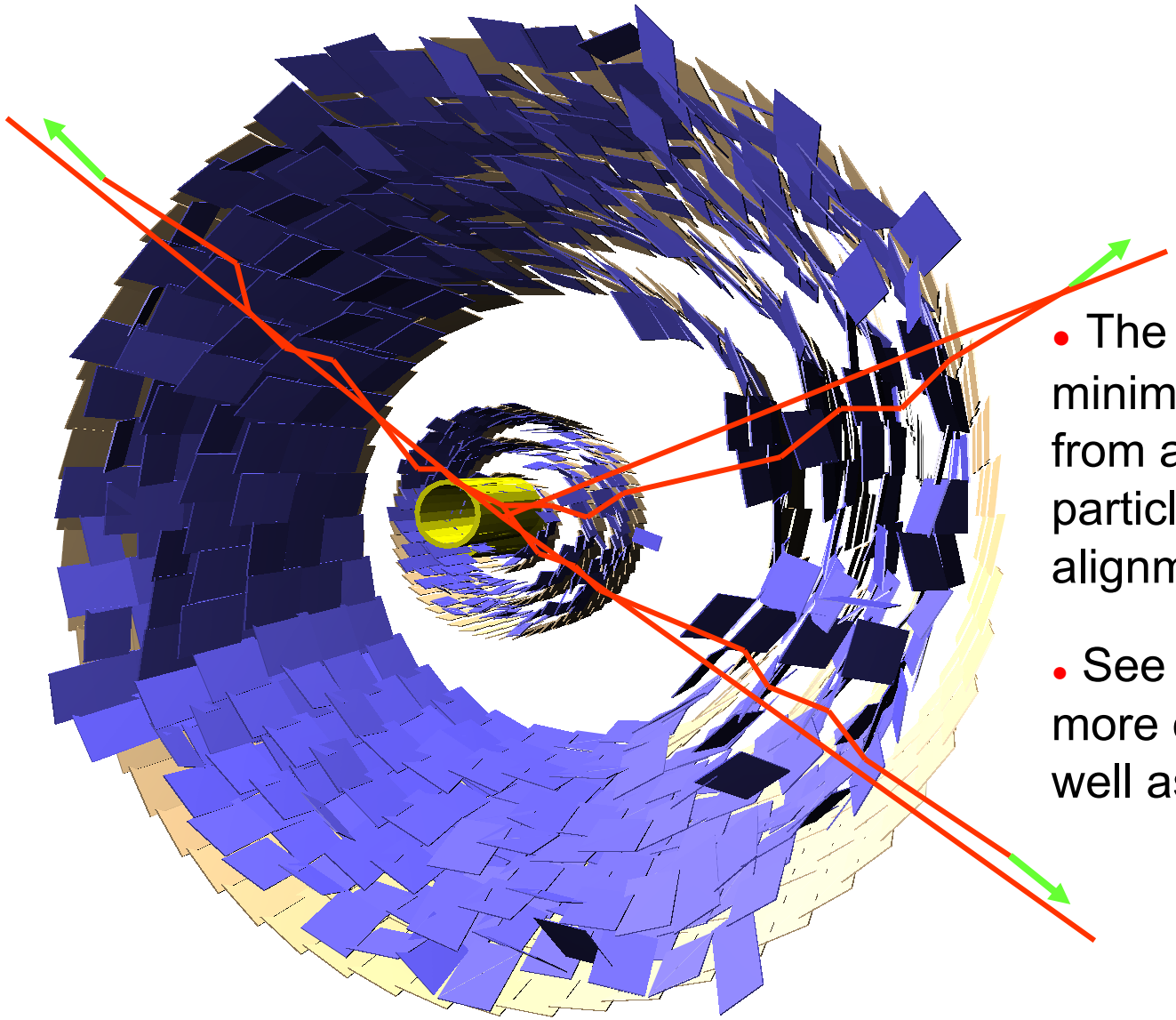
	Barrel		Forward	
Detector	PIX	SCT	PIX	SCT
# of layers/disks	3	4	2x3	2x9
# of modules	1456	2112	2x144	2x988
sub Total	3568		2264	
Total	5832			

3 translations
& 3 rotations
of each module



In total we have to deal with 34,992 DoF's!

The Idea: Global χ^2 Method for Alignment



- The method consists of minimizing a giant χ^2 resulting from a simultaneous fit of all particle trajectories and alignment parameters.
- See Adlene Hicheur's talk for more on Global χ^2 algorithm as well as ATLAS alignment issues.

The Problem: Limitations

- Global χ^2 formalism requires solving large number of linear equations and handling large sized-matrices in its full scope, due to the large number of DoF in the Atlas tracker system.

- Using 32-bit single-CPU platforms is a limiting factor in performance (ATLAS-Marseille):

  - **Size:** * A matrix of N=35k needs 9.8GB disk space and at least the same amount of virtual space for computations. * A 32-bit program can only address 4GB of virtual memory. * By default, Atlas software infrastructure allows only 2GB of memory per job.

  - **Precision:** Conventional 32-bit libraries are not fully adequate for full size solution computational accuracy (35k-DoF). The matrices of alignment problems can have large condition numbers which may compete with the machine precision.

  - **Execution time:** Single-CPU machines can take a good number of hours to solve large-size problems, even if they can!

The Solution: //-processing with 64-bit Architecture

Solution: 64-bit architecture with parallel processing

and distributed-memory libraries for matrix algebra!

- **Size:**
  - e.g., distributed on 16 processors, required memory for 35k-size matrix is only 0.6GB/CPU.
  - Allowance of up to 16GB virtual memory.
- **Precision:** Hope to increase the numerical precision, making use of the enlarged data type sizes and extended-precision libraries.
- **Execution times:** Parallel processing allows faster execution times distributing the CPU load.

The Platform: Beowulf cluster at RAL (SCARF)

- SCARF is a 64-bit AMD Opteron cluster at Rutherford Lab, shared by various groups within the CCLRC users.

- Its hardware matches (and exceeds) the suggested requirements for Atlas alignment algorithms.

	Asgard (ETH Zurich)	Suggested	SCARF (RAL)
Architecture	32-bit	64-bit	64bit
# nodes	dual, 240	Large N	dual, 128
CPU	PIII 500/600 MHz	AMD Opteron 2 GHz	AMD Opteron 248 2.2. GHz
RAM	1 G	4G	4G (122 nodes), 8G (16 nodes)
Persistent	-	40 GB IDE	2x 120 GB IDE
Network	-	1x Gigabit	2x Gigabit

The Platform: Available Software

- SCARF executes x86 code natively.
- It runs Red Hat Enterprise (ES) Linux 3.0.
- Equipped with PGI and GNU compilers for C, C++ and Fortran,
- LSF (v6.1) for queuing system and MPI (v1.2.6..14a) for message-passing,
- AMD Core Math Library (ACML) (v2.5.0) with ScaLAPACK (v1.7) and BLACS (v1.1).
- We used AMD ScaLAPACK libraries for 64-bit compilation.

The Choices: Available Infrastructure

- Available compiler options on SCARF: GNU (GCC 3.2.3-53) vs PGI (5.2).
- Pros&cons:
  - GNU is publicly available, PGI is not.
  - GNU long double size is 16B on 64-bit architecture. PGI does not support quad. precision (l.d. size is 8B).
- We test time and precision performance, by calculating A=B*3-1, B=1.3.
  - Time performances are slightly better for optimized (O3) GNU. 3 orders of magnitude improvement in precision from double to l.d. with GNU. (Note: AMD Opteron holds 80-bit f.p. registers & l.d. f.p. is a 80-bit extended type.)
- We chose to continue to use GNU compiler.

The Choices: Possible Software and Libraries

- A variety of matrix algebra and solver software exists. Some examples:
  - ScaLAPACK and PLAPACK (based on LAPACK)
  - NAG parallel libraries (contains also ScaLAPACK)
- Pros & cons for ScaLAPACK:
  - AMD-ScaLAPACK is optimized for high performance on AMD Opteron.
  - Previous tests showed that ScaLAPACK eigenvalue solver (upcoming slides) performs faster than that of PLAPACK's (HPCx group).
  - ScaLAPACK (non-optimized) is a public domain software and can be downloaded from the web. NAG libraries require licence. However, this means they come with guaranteed tech. support!
  - No general quad. precision library exists for NAG or SCALAPCK… ScaLAPACK has been working on implementation for a new release. NAG already has in place iterative refinement procedures – not real extended precision, however, slows down the solution. Preconditioning the system should help in any case.
- We used ScaLAPACK on SCARF for our initial proof-of-principle studies.

Performance using Randomly-Generated Matrices

- We tested direct matrix inversion, with *pdgesvx* of ScaLAPACK, an expert driver routine to solve linear equations.
- AMD ScaLAPACK for distributed-memory computing for matrix operations; MPI for intra-processor communication, were used.
- The test matrices are symmetric, generated randomly, kept in binary format, double precision. Sizes scale as ~ N*N*8B.
- Processing time and accuracy as a function of Size(A) and N(CPU) were measured.
- A scan of Size(A) and N(CPU) for various block sizes of the matrix distribution was also obtained.

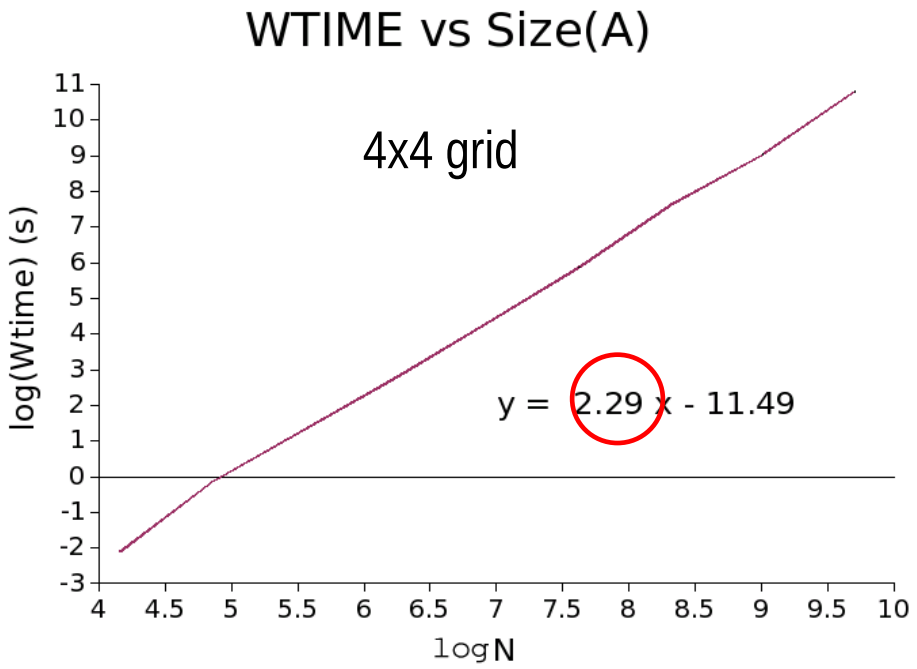
Size(A)	16384
N(CPU)	16 (4x4)
Size(Block)	64x64
Reciprocal Cond(A)	0.000000024834271
Machine ε	0.0000000000000011102
||A*A-1-I||	0.000000047526382
WallTime (for routine)	49005.65s

Performance in Processing Time:

- We measured the wall and CPU times for the ScaLAPACK routine.
- We observed minor dependence of performance on the processor grid block size. However, we found that 32 CPUs with 64MB is optimum for the range we'd like to cover.
- For an 8000 matrix, WallTime shows ~ $N(CPU)^{-0.2}$ dependence.
- 64-bit AMD showed and improvement of a factor of 2.5 in WallTime when compared with a 32-bit AMD @ 2.4GHz using the same parameters.
- We 2D-scanned the time performance in NCPU and S(grid).
- Large CPU cases not easy to test:

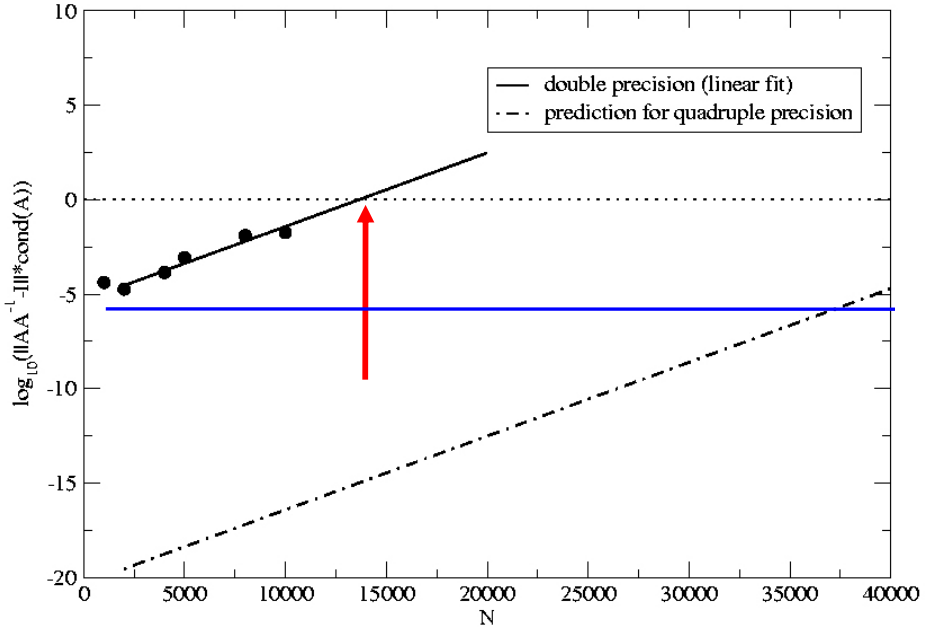
queue-waiting long – it's a shared machine!

- The results for the scan is linked here



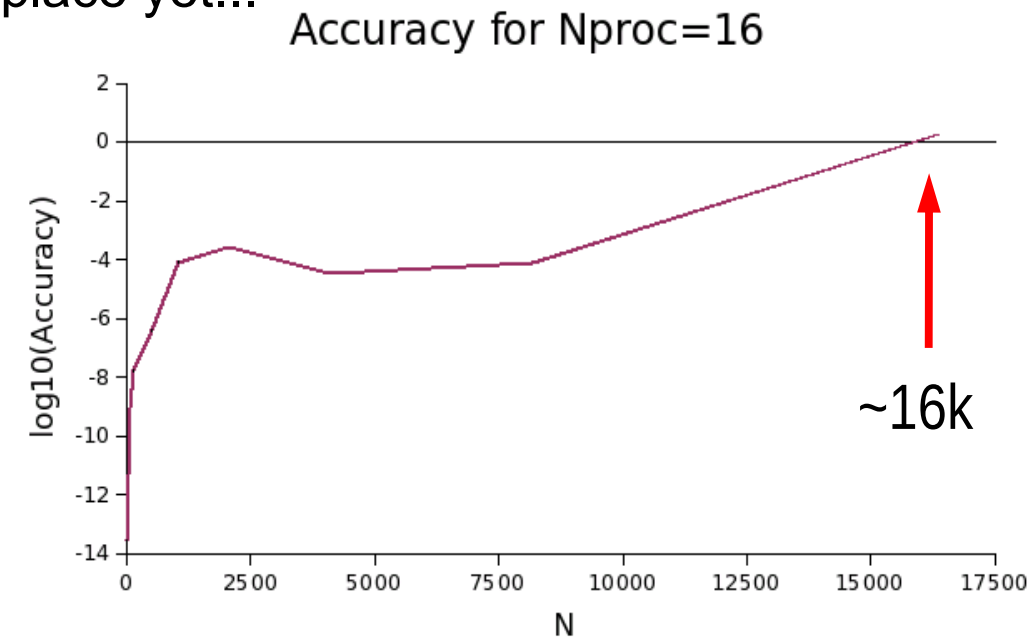
Earlier Results with a 32-bit //-cluster:

- Random matrix Inversion results using system specified earlier (Asgard)
- As a function of size of random matrices: N^3 dependence of CPU time.
- Accuracy loss at around sizes of N=14k.
- No scan of parameters as a function of grid block size was performed.
- Quadrupole precision was tested on MAPLE for N=200 (processing times enormously long) and results used to extrapolate to large sample sizes.



Performance in Precision

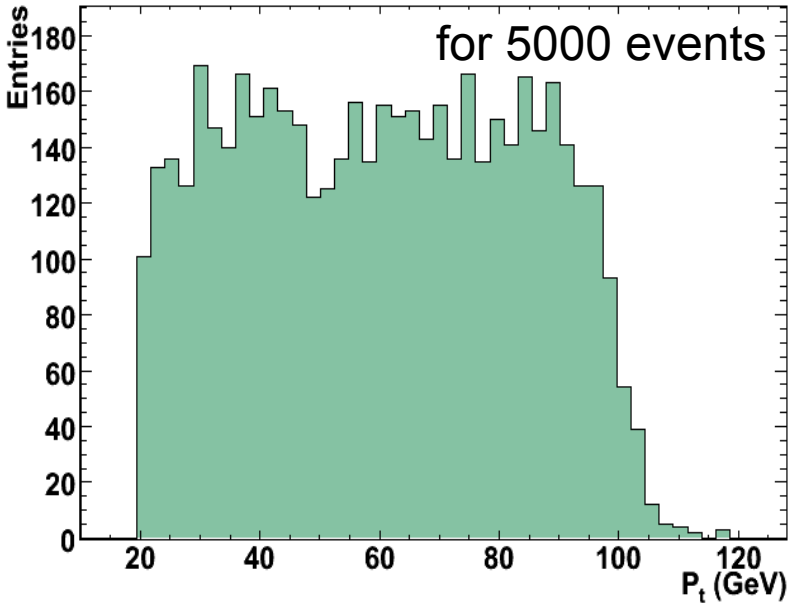
- The number of accurate decimal digits is related to the exponent of condition number of matrix: cond(A).
- Number of digits preserved in the final solution can be calculated as acc= log[(AA^T -I) x cond(A)].
- The precision loss in the final result is improved over earlier results (~N=16k), however not substantially, as we are not able to use quadrupole precision.
- Note: ScaLAPACK has plans on extended precision (iterative refinement using XBLAS), but not in place yet...



Atlas MC Data – The Setup and the Sample

- A single μ sample was simulated and reconstructed in ATLAS inner detector. 825k events exist in the sample: ~1/2 being μ^+.
- Generation, simulation and reconstruction were performed using a very recent release of the ATLAS software framework (ATHENA, v11.0.3).
- Production was carried out on the Oxford Particle Physics Linux cluster, running SLC3, using PBS. One full chain per event took ~5-10 s, integrated processing time of ~1000 hrs .
- Track transverse momenta distribution is flat: ***20 < pT< 100 GeV***.
- η-range is chosen with a flat distribution: **[-2, 2]**, φ is full and uniform.
- Full setup consist of barrel Pix+SCT region, which corresponds to **3568** modules, and **21408** DoF.

Note: As track statistics are not abundant, we will discuss solution performances rather than try to demonstrate the ultimate achievable precision in the solution properties.



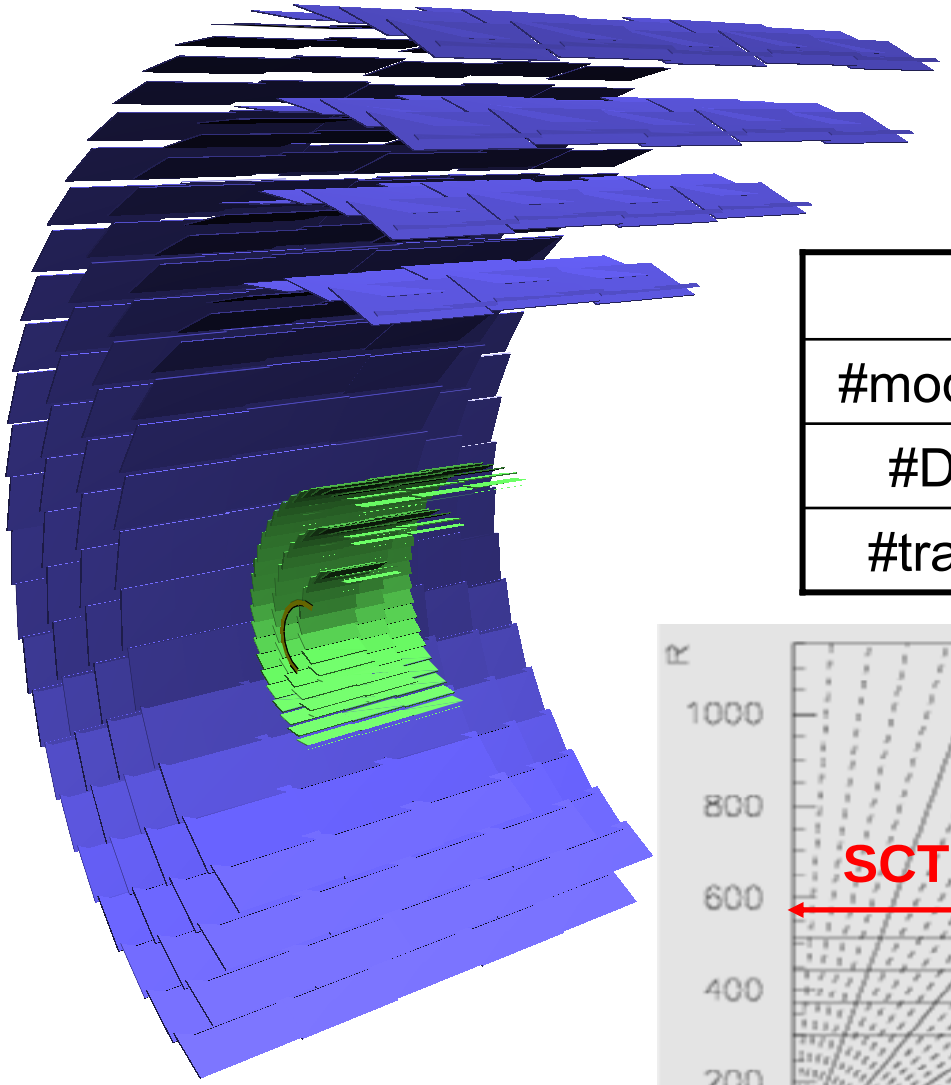
The Software Setup for Solution

- After track processing, the global χ^2 algorithm generates a binary matrix to be solved for the eigenvalues and eigenvectors of the problem.
- For this study, we used a standalone version of the algorithm, ported it also to SCARF, and solved the matrix on the cluster.
- The solution was then used to extract the alignment corrections.
- We compared two platforms for the solver: SCARF vs Intel Pentium machines with 2GB RAM, 2GB swap, and 2.8/2 GHz CPU.

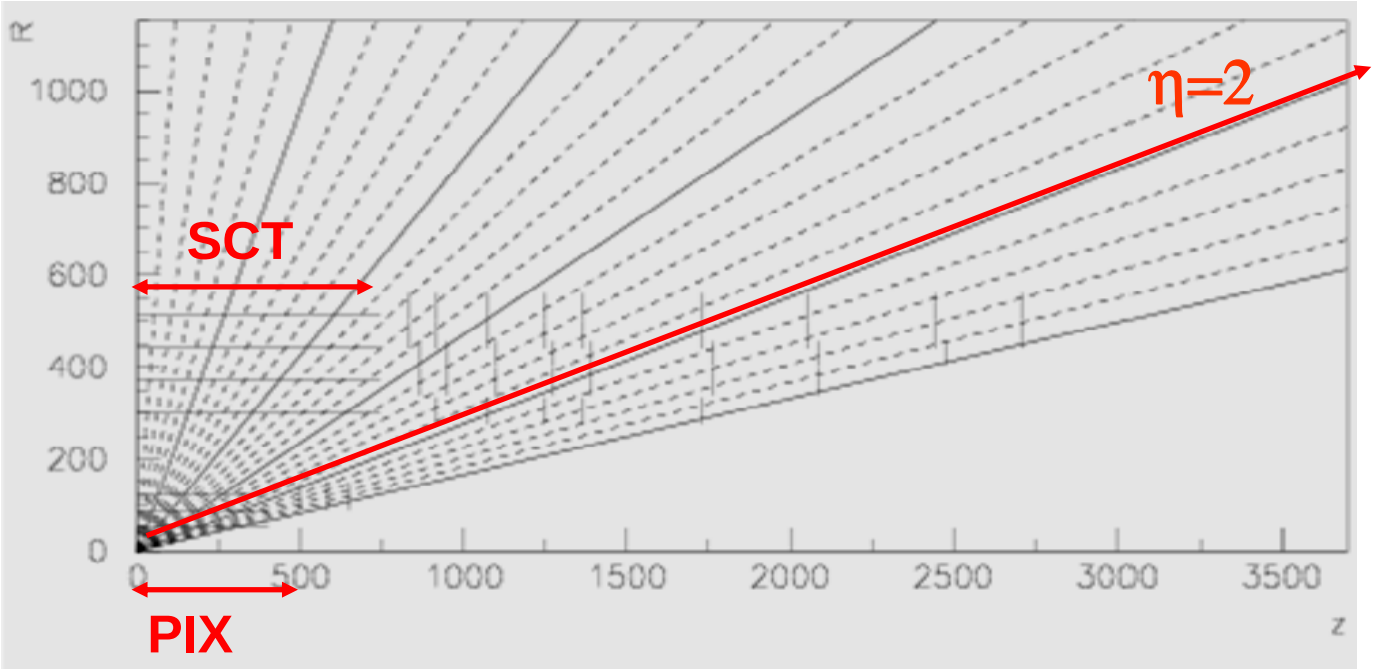
	Intel PentiumIV (32-bit)	//-cluster AMD Opteron (64-bit)
Library	LAPACK	ScaLAPACK
Routine	dspev	pdsyevd
Compiler	g++ (GCC 3.2.3-49)	gcc (GCC 3.2.3-53)
Linux version	2.4.21-32.0.1.ELsmp	2.4.21-37.ELsmp

- ***pdsyevd***: a simple Divide-and-Conquer routine (i.e., recursive reduction of an instance of the problem into one or more smaller instances.)

Solving Various Size Problems for Barrel Tracker:

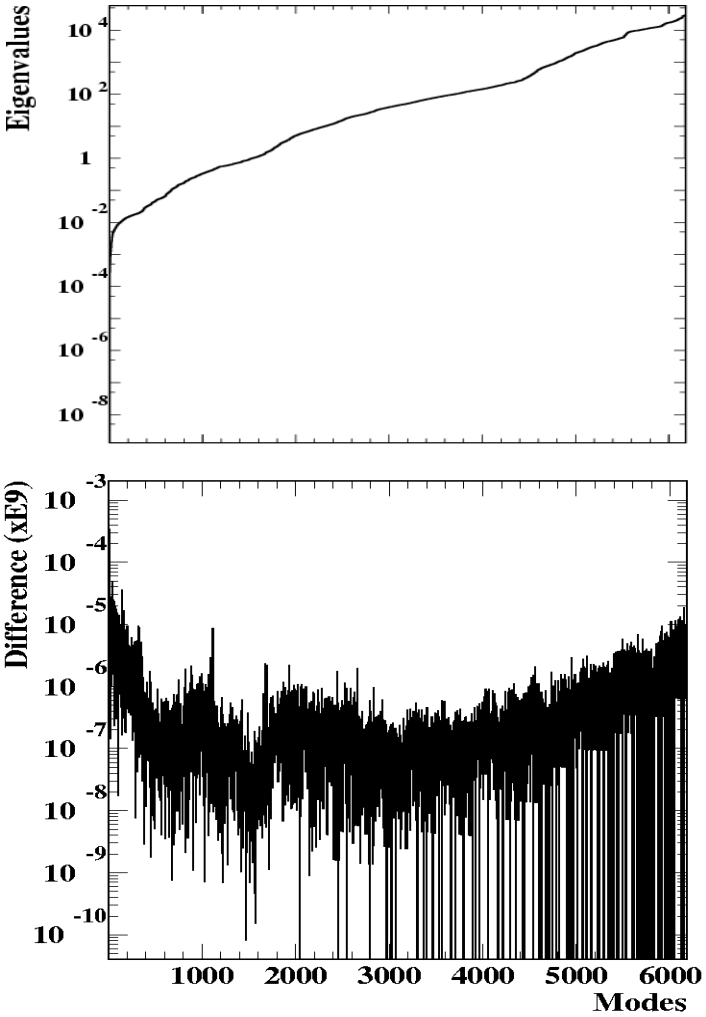


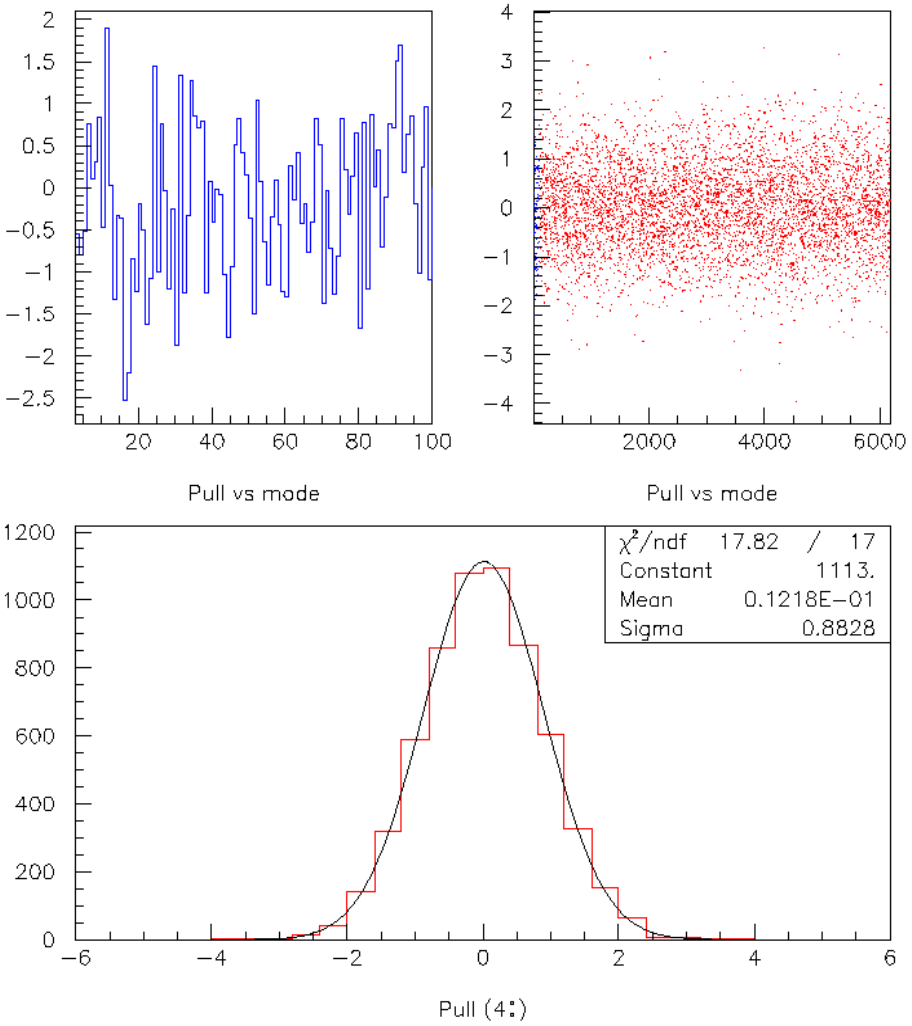
	cone	SCT	PIX+SCT
#modules	1030	2112	3568
#DoF	6180	12672	21408
#tracks	~250k	~550k	~800k



Start with the “cone” Size Problem (6k-DoF)

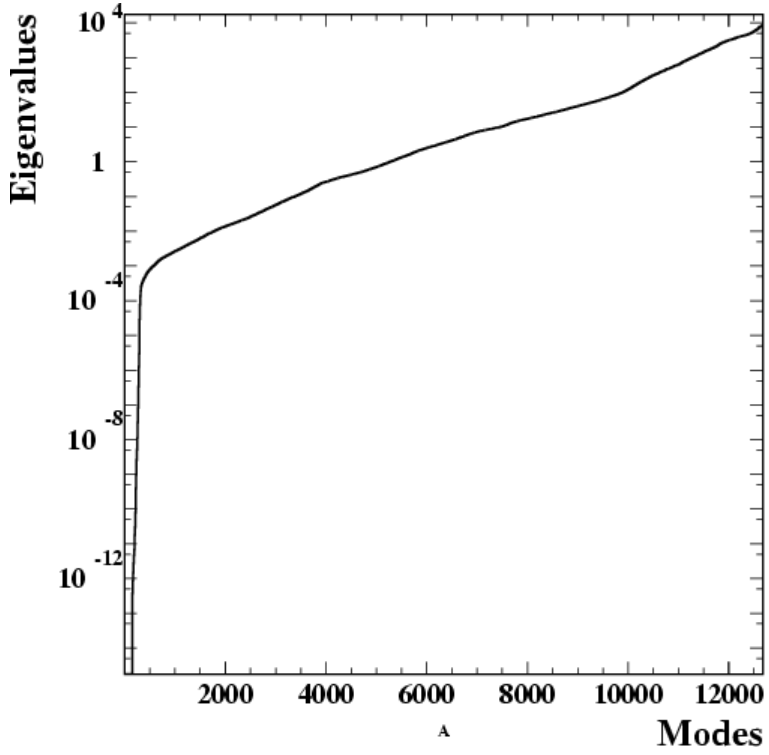
- **Cone** Configuration: Align the limited geometry by using muon tracks in restricted η (~1030 PIX+SCT modules).
- This configuration is the only one studied extensively earlier: small problem size.
- Agreement between Single-CPU and //-CPU is very good.

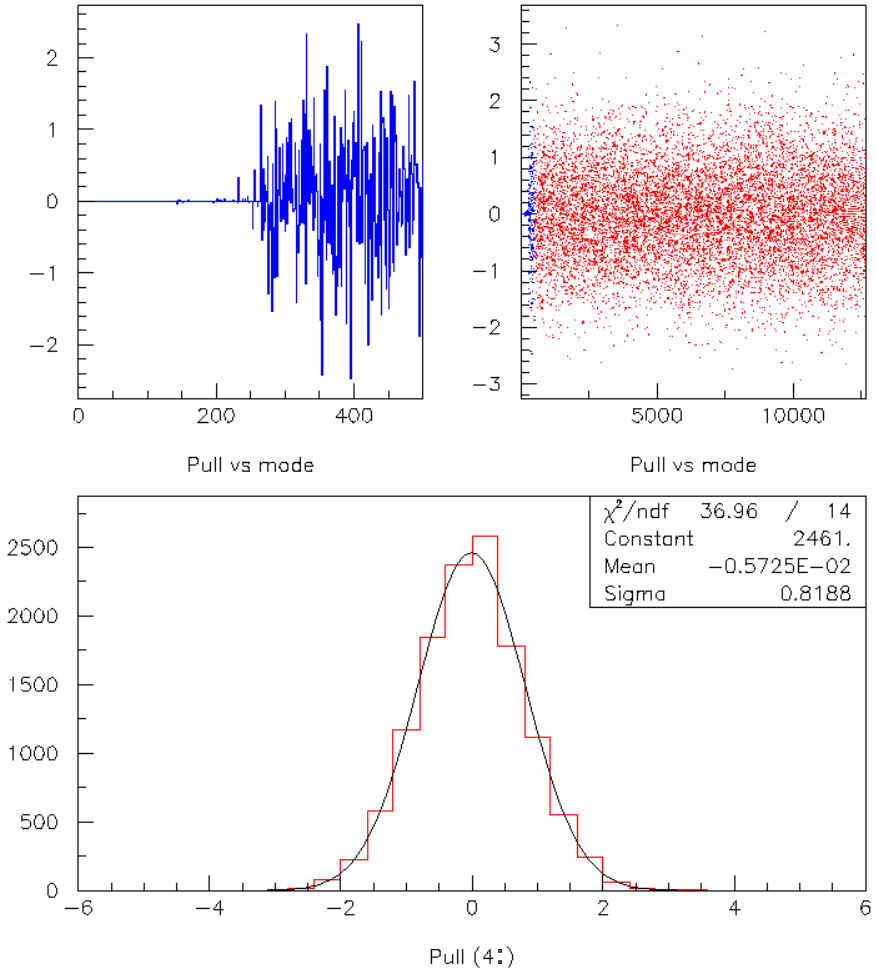




Solve Barrel SCT Problem (12k-DoF):

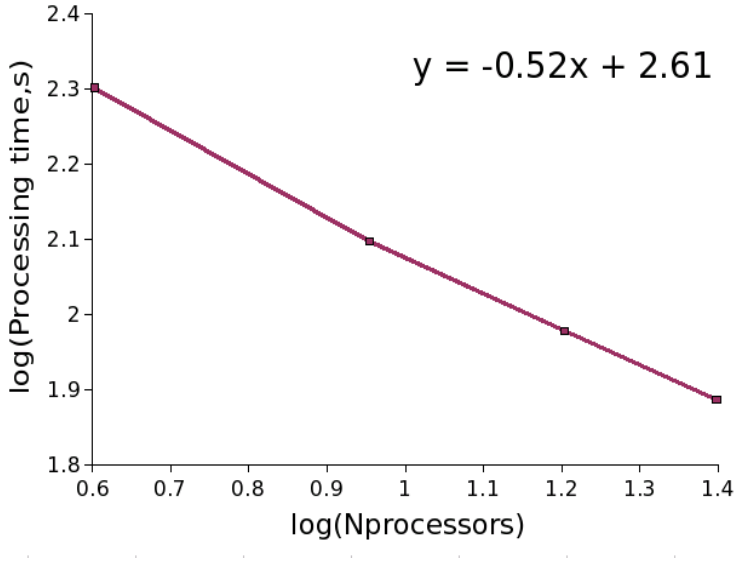
- 1 SCT module remains unpopulated: 6 real spurious modes in matrix as well as some others due to limited statistics.
- This size of a problem can be "solvable" in both single and parallel platforms.
- A factor of ~50 is gained in time performance.

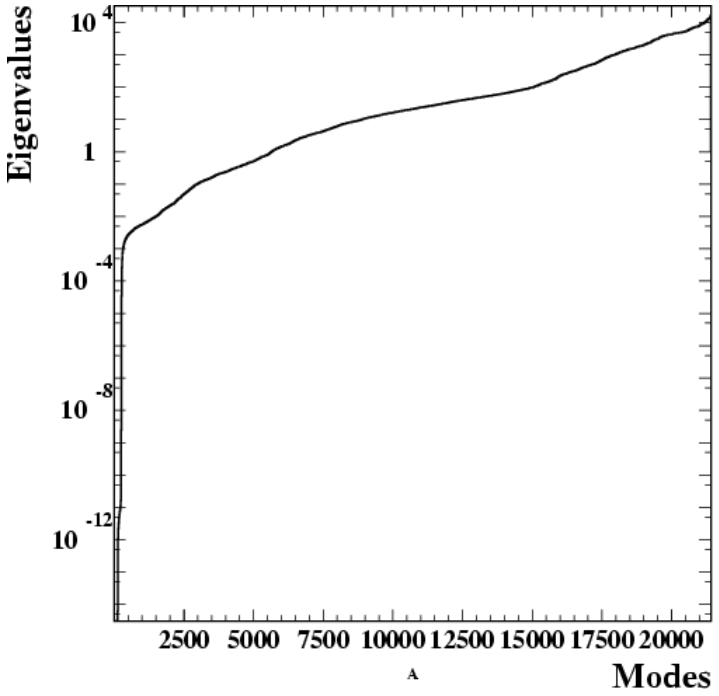




Solve Full Barrel Problem (21k DoF):

- Extended the problem to solve full barrel size.
- A number of pixel modules unpopulated (37), due to coverage limitation in current sample.
- Problem only can be solved on SCARF cluster, unless matrix is written in triangular format (libraries linked with ATLAS software imposes file size limitations of 2GB on the P4 machines)
- Size dependence ~$N^{2.3}$ and N(CPU) dependence ~ $N^{-0.5}$ (using results from our earlier samples with an obsolete Athena release).





Comparison of Platforms for Global χ^2 Solution:

- Parallel-computing allowed for large problem solutions in a very efficient way.
- The time performance looks very advantageous!
- Number of modules in parantheses show the modules not taken into account for alignment.

Nmodule	NDoF	File size(GB) NxN(triang)	Processing time*		
			SCARF NCPU=16 / 4 (2.2GHz, MB=256MB)	Intel PentiumIV	SCARF single-CPU
1030 (0)	6180	0.3 (0.15)	1m53s / 3m	35m (2.8GHz)	39m
2112 (1)	12672	1.2 (0.6)	10m30s / 26m58s	7h34m (2GHz)	5h28m
3568 (37)	21408	3.4 (1.7)	43m43s/ 121m51s	---	**>20 hrs**

* Measurements include the binary file I/O.

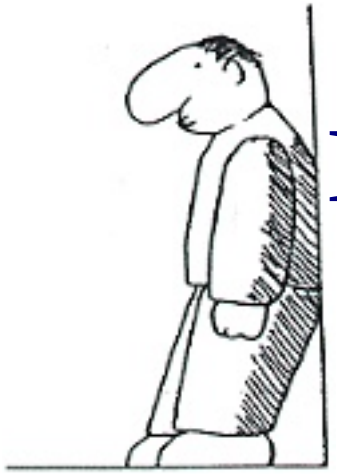
- Also attempted invert these singular matrices. Matrices either found completely singular (as expected) (RCOND=0.0) or RCOND< ε (DoF=6180), and no solution is provided.

Summary & Conclusions:

- We performed tests on using distributed-memory parallel-computing for ATLAS alignment.
- For large scale problems, parallel-computing is very adventageous.
- The performances we obtained are improvements over earlier test results on other platforms.
- Now that we can run on large system sizes and able to obtain final alignment constants, the algorithm and numerical issues will be debugged and understood better.
- ATLAS has plans to port the offline software to 64-bit mid-summer in conjunction with gcc 3.4.4 migration. When this happens, a better infrastructure will be in place for global χ^2 alignment processing.
- We are exploring all possibilities other than we used here (libraries, etc..): this is still work in progress…

Acknowledgments:

- We are grateful to the CCLRC group for their permission to use their Beowulf cluster.
- We are grateful to the OxPP SysOps and Laura Gilbert who is responsible for ATLAS software installations on the OxPP cluster.

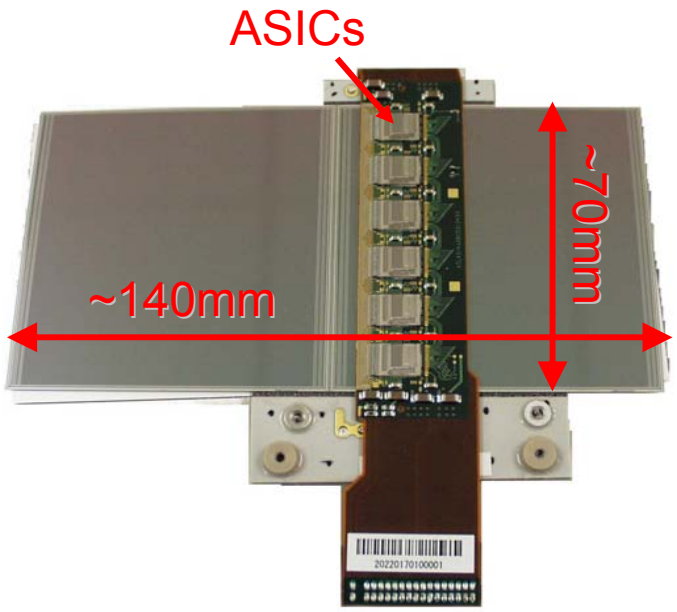


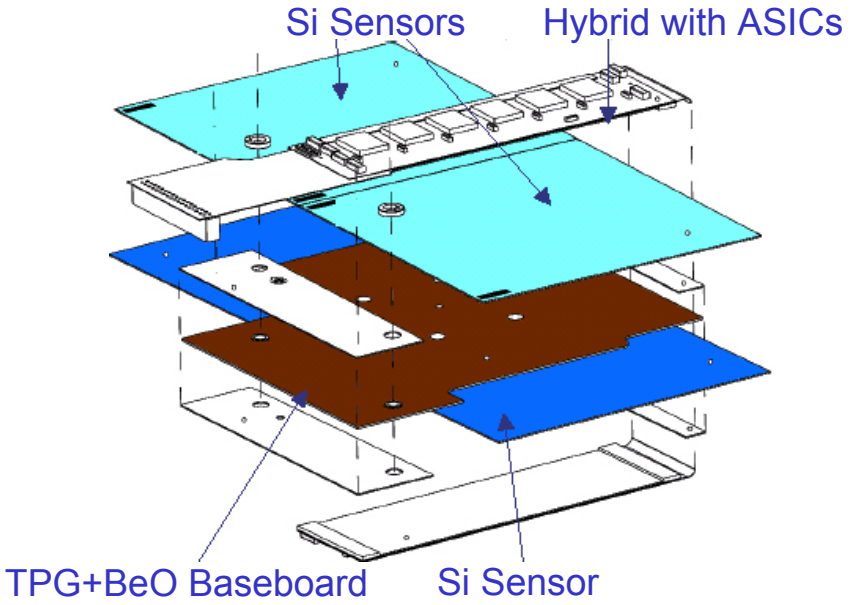
Backup Slides

SCT modules

“Weak” modes

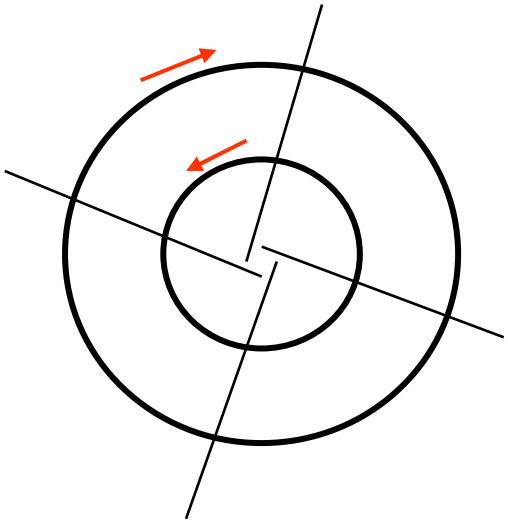
The Building Blocks: Barrel Modules



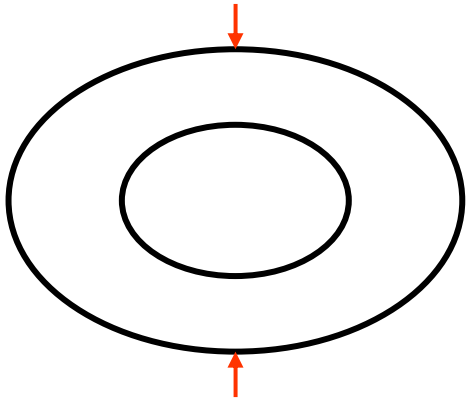


- PIXel detectors provide real 2-D readout.
- Pixels are of size 50×400 μm resulting in 14×115 μm resolution.
- SCT modules are double-sided strip detectors with 1-D readout per side.
- Sensitive strips have pitch of 80 μm giving 23 μm resolution.
- Stereo-angle of 40 mrad gives 580 μm resolution in the other direction.
- Entire tracker is equipped with binary readout.

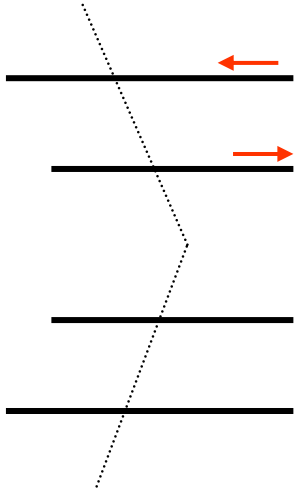
Examples of 'Weak Modes':



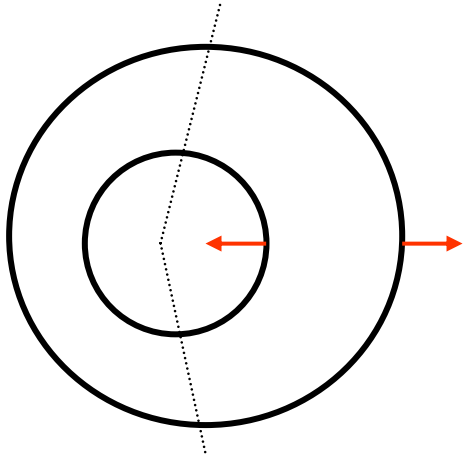
"clocking"
$\delta\phi=\lambda+\beta/R$
(VTX constraint)



radial distortions
(various)



"telescope"
$\delta z \sim R$



ϕ dependent sagitta
$\delta X=a+bR+cR^2$

We need extra handles in order to tackle these.
The natural candidates are:

- Requirement of a common vertex for a group of tracks (VTX constraint),
- Constraints on track parameters or vertex position,
- External constraints on alignment parameters.

η dependent sagitta
"Global twist"
$\delta\phi=\kappa R\cot(\theta)$