Track-Based Alignment of the Inner Detector of ATLAS

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Alignment Strategy

To ensure that the requirements on track reconstruction in the ATLAS Inner Detector are met, the position and orientation of each substructure must be known with accuracy such that track parameter resolution is degraded by less than 20% of the design values. This is achieved by minimizing a χ^2 function formed from track residuals.

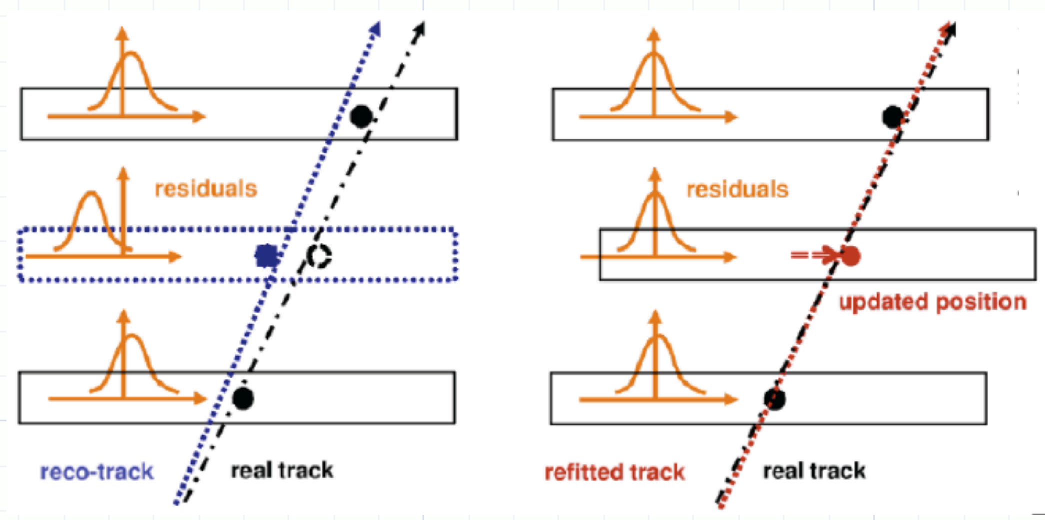
$$\chi^2 = \sum_{Trks} \mathbf{r}(\tau, \mathbf{a})^T V^{-1} \mathbf{r}(\tau, \mathbf{a})$$

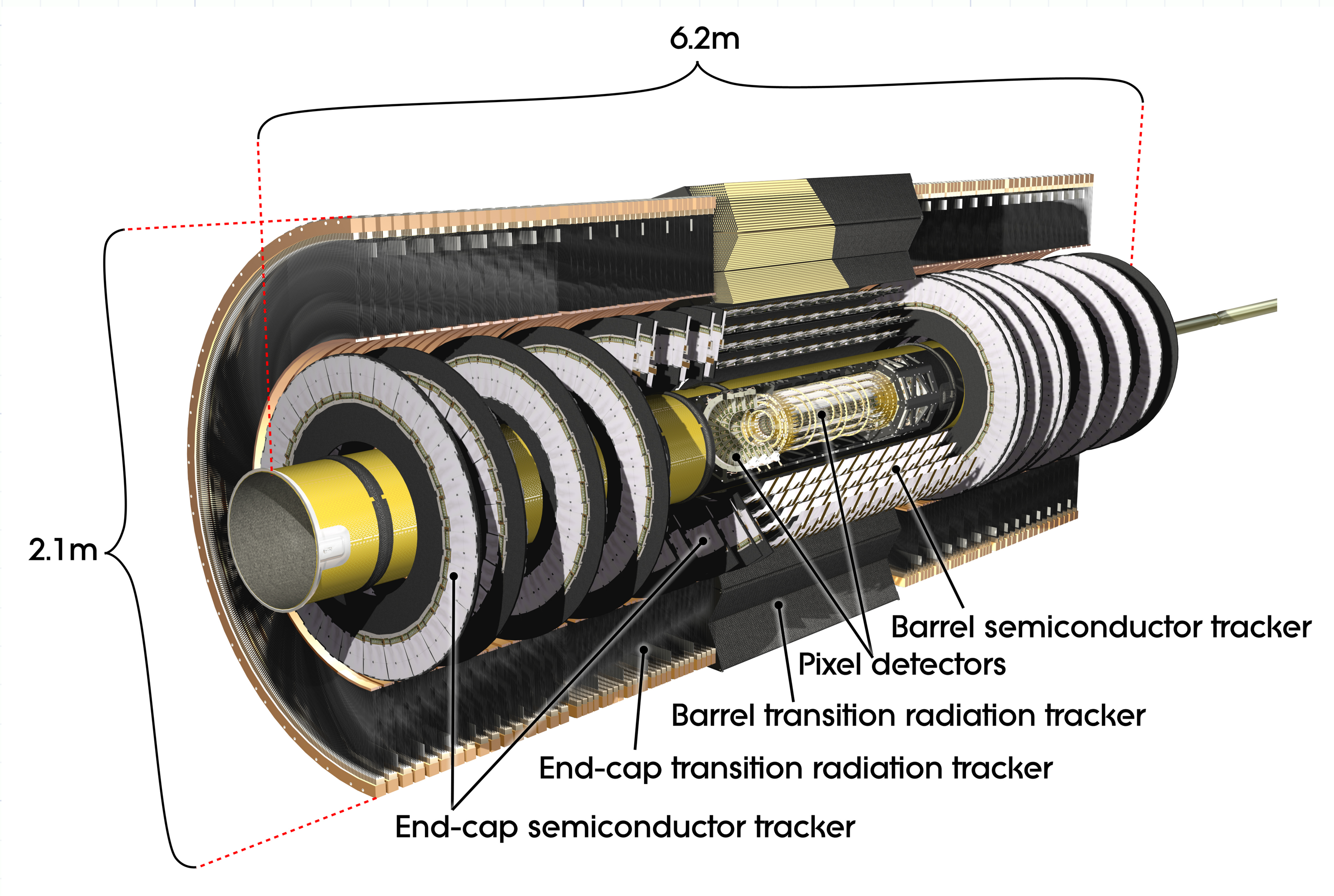
Minimization condition: $\frac{d\chi^2}{d\mathbf{a}} = 0$

$\tau =$ track parameters

$\mathbf{a} =$ alignment constants

$V =$ hit covariance matrix





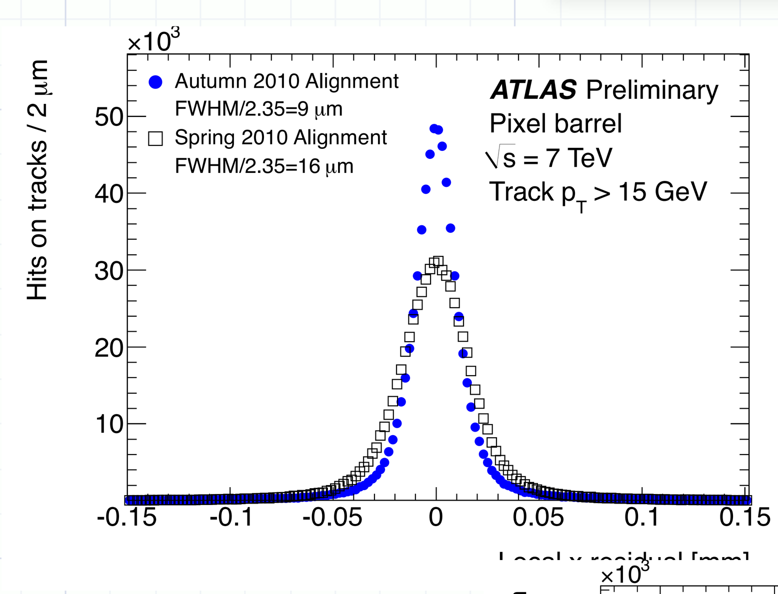
The alignment is performed in several stages. At each stage, the minimization is applied considering a certain combination of DoF, referred to as Level 1, 2 or 3 (see table). Level 1 & 2 both employ the Global χ^2 approach, where the χ^2 function as defined above is minimized while keeping all track parameters and alignment constants as free parameters. This approach ensures that all substructures that contain a hit are correlated. At Level 3, Si modules are aligned again using the Global χ^2, while the TRT wire-by-wire alignment (~700,000 DoF) is rendered less computationally intensive by employing the Local χ^2 approach. In Local χ^2 minimization, module correlations are discarded, making it necessary to perform several iterations to reach convergence.

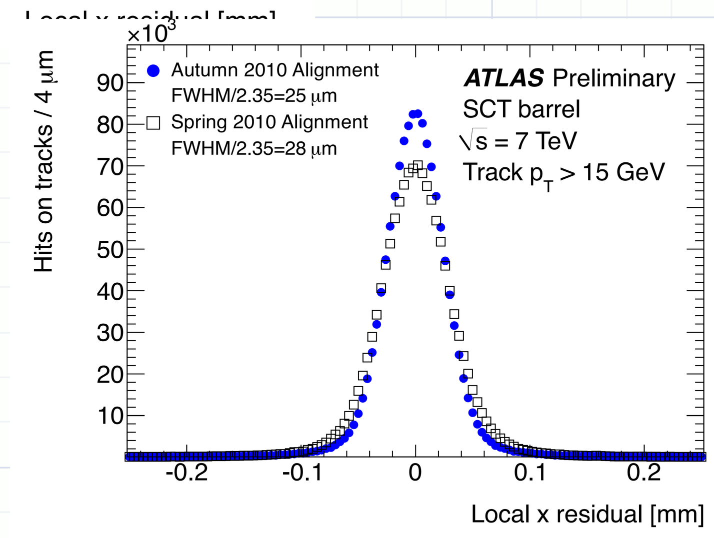
Level 1	PIX: whole SCT: barrel + 2 endcaps TRT: barrel + 2 endcaps	41 DoF	Global χ^2
Level 2	PIX: half shells + disks SCT: layers + disks TRT: modules + wheels	852 DoF	Global χ^2
Level 3	PIX: modules SCT: modules TRT: wires	722104 DoF	Global χ^2:Si Local χ^2: TRT

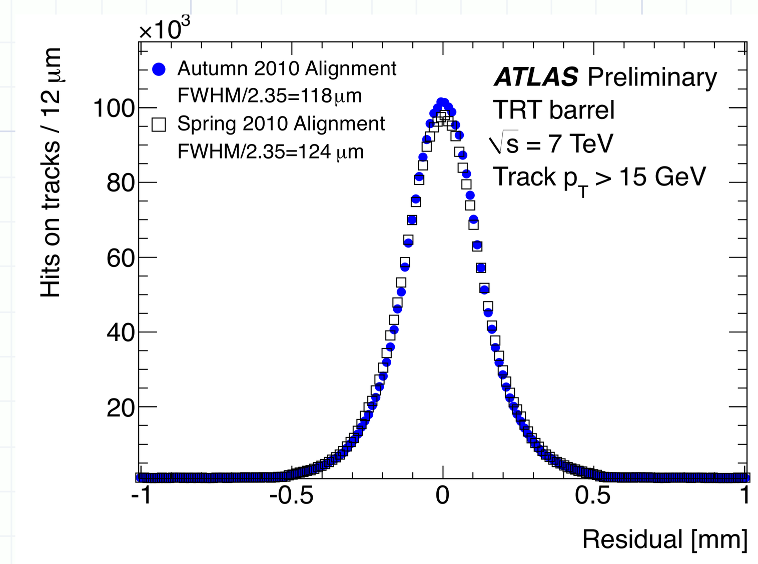
Using both cosmic and collision tracks to ensure correlations between as many alignable structures as possible.

Alignment Performance

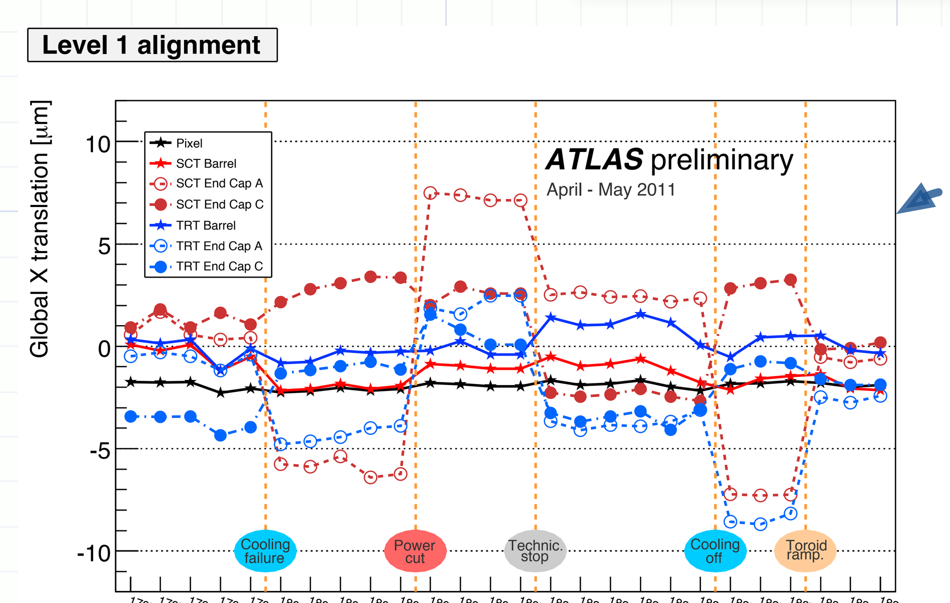
Some of the contributions to the improvement in the alignment from Spring to Autumn 2010 are: addition of input data for pixel module wafer deformations from the production survey, first alignment of the SCT endcaps and first wire-by-wire TRT alignment.







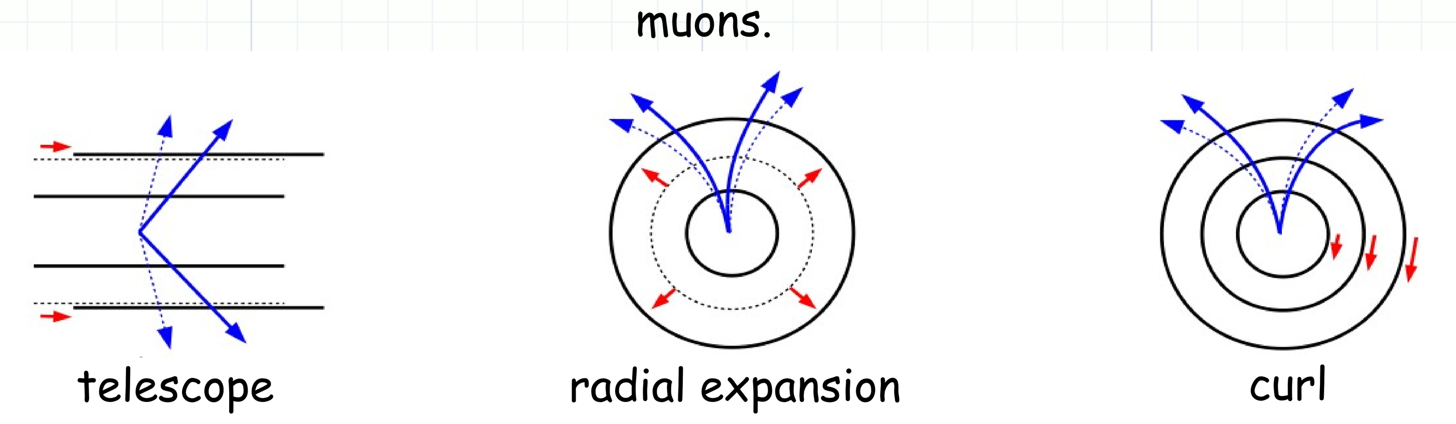
Run-by-run Alignment



After noticing that the alignment changes over time due to external factors (temperature changes, toroid or solenoid ramping, etc.), the Level 1 and 2 alignment constants are now recomputed as a part of the calibration loop on a run-by-run basis. The largest changes are < 10um.

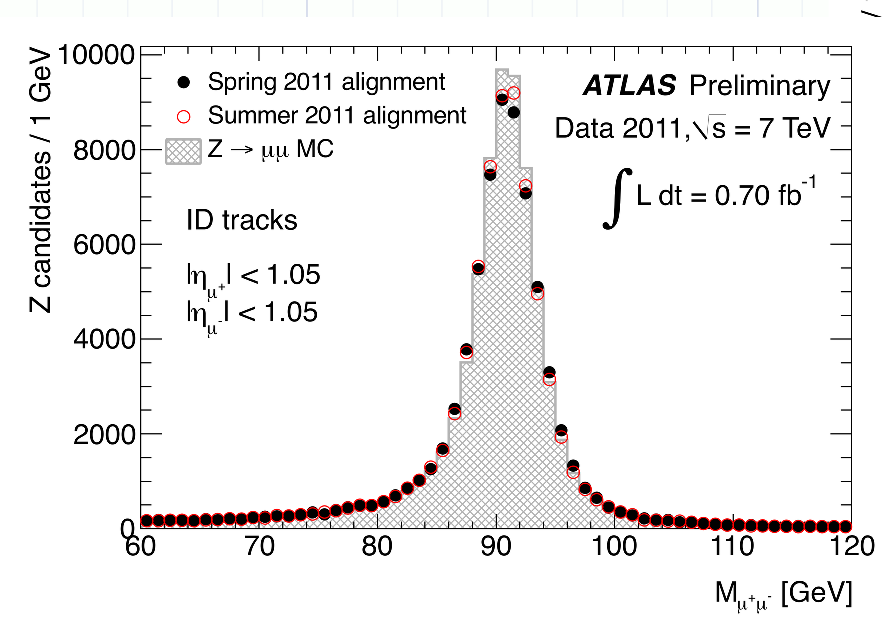
Weak-modes and Constrained Alignment

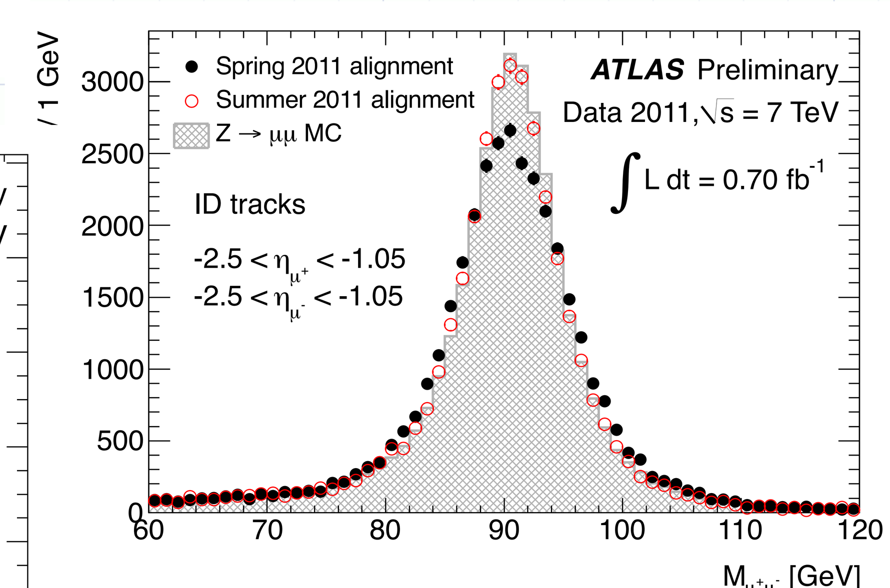
There are systematic deformations which do not affect the χ^2 function described above significantly and therefore remain uncorrected by the outlined alignment procedure. It is, however, possible to tackle these by imposing additional constraints on the alignment, e.g. muon spectrometer momentum measurement, E/p corrections, beam spot and vertex positions. The resulting improvements can be seen by monitoring, e.g. Z decays to muons.

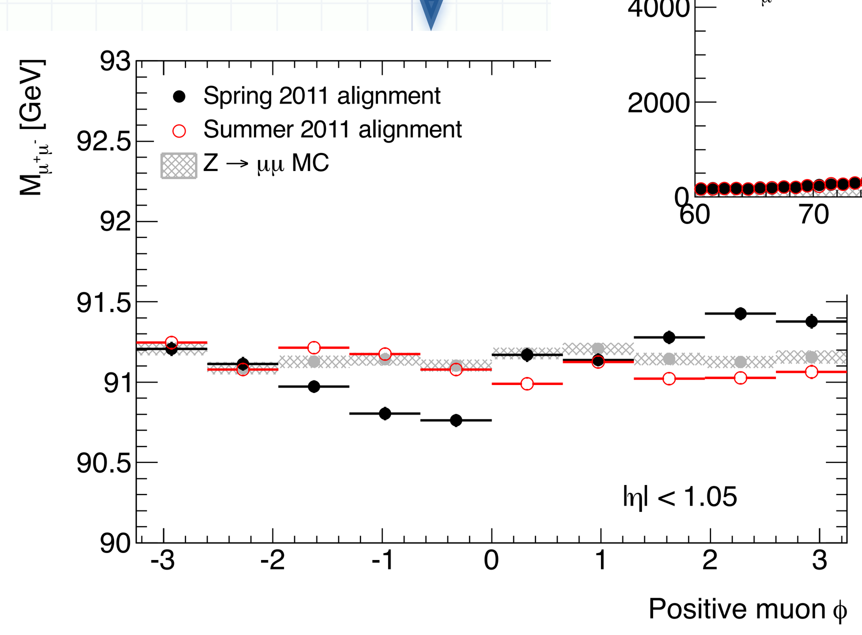


In particular, the E/p constraint has resulted in the latest significant improvement in the alignment. Assuming a sagitta deformation, a momentum correction can be derived by comparing E/p for electrons and positrons from, e.g. Z->ee, and then applied as a momentum constraint during the alignment.

$$\delta = \frac{\langle E/p \rangle^+_{Rec} - \langle E/p \rangle^-_{Rec}}{\langle E_T \rangle^+_{Rec} + \langle E_T \rangle^-_{Rec}}$$

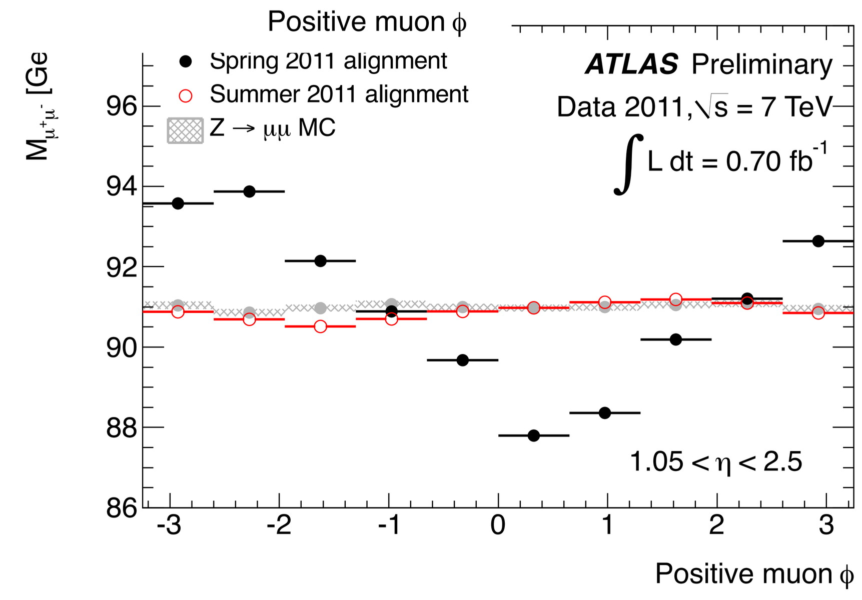






In Progress

With alignment procedure in place and proven to be effective, the next step is to evaluate the systematics caused by any residual misalignments. It has already been seen that resonances are a powerful handle for tackling this problem and ongoing studies will soon provide quantitative measures of the remaining biases.



Run-by-run Monitoring

As the monitoring of the Z invariant mass has been proven to be a powerful probe in uncovering weak mode misalignments and, thereby, momentum biases, plots of the mass vs. various kinematic variables are now produced automatically for every run as part of the ATLAS data-quality monitoring.

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