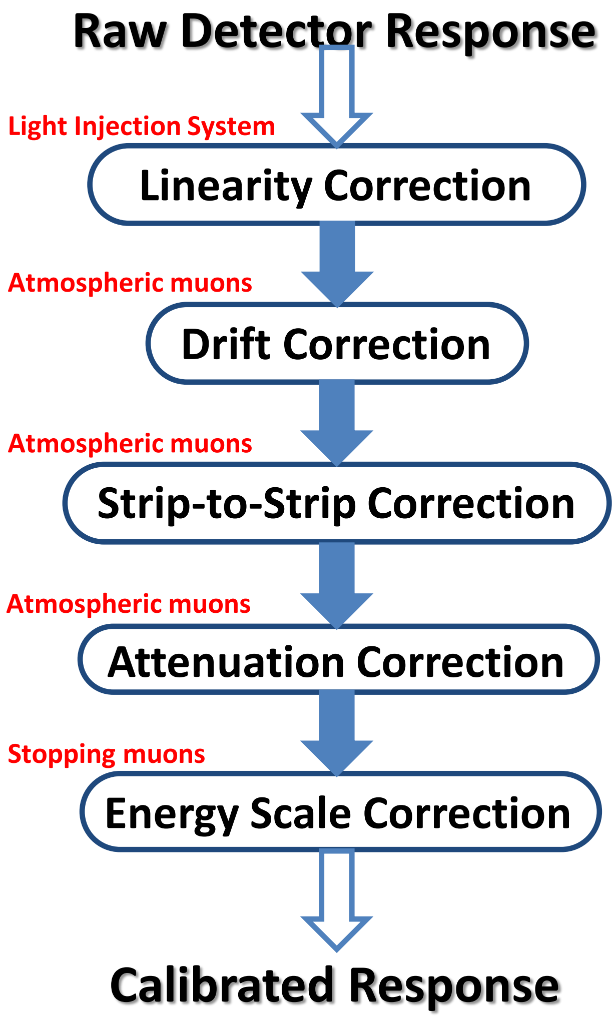
MINOS Calibration Procedure



The MINOS calibration procedure is meant to ensure that for a given energy deposition, the calorimetric response looks the same in space, time and in the different detectors

The PMT response becomes non-linear at ~ 100 photo-electrons. A dedicated light injection system measures the PMT response over a wide range of light levels at least once a month.

The drift calibration measured daily corrects for the combined *time and temperature* dependencies of *all* the detector components at each detector.

The strip to strip calibration removes the channel-by-channel differences accounting for such effects as light yield, read out fiber length and PMT pixel gains.

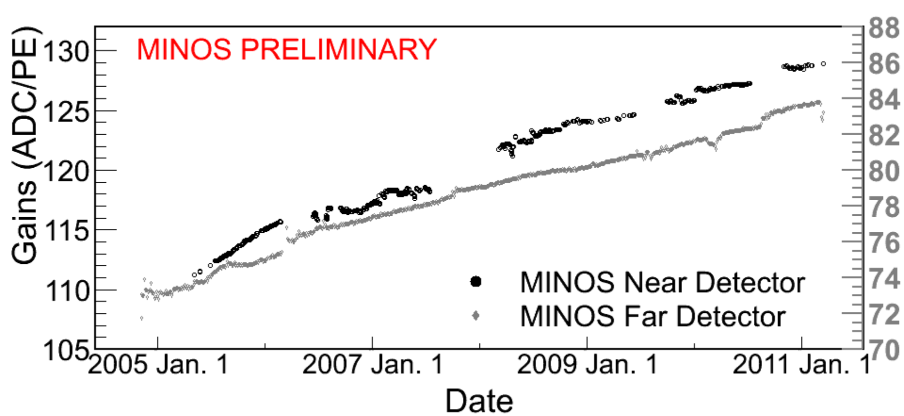
The attenuation calibration corrects for the light lost travelling through the wavelength shifting fibers from the point of production to the end of the scintillator module.

Stopping muons deposit a known amount of energy. These muons are used to link the post-calibration energy scales at each detector.

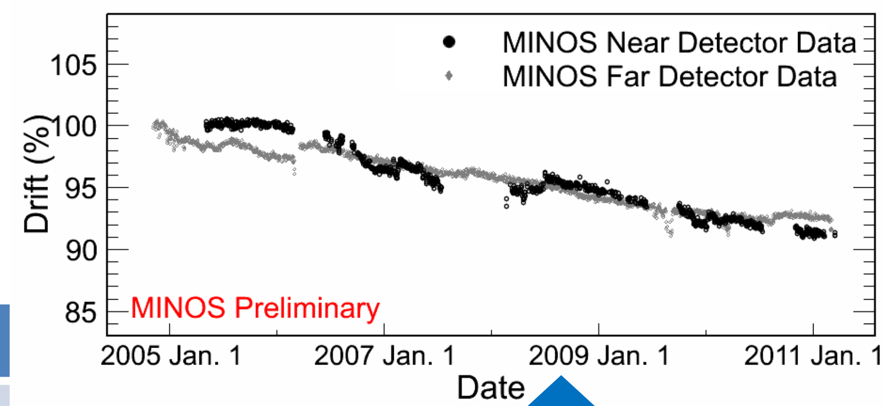
MINOS Detector Behaviour

The MINOS Detectors are steel-scintillator calorimeters. The scintillation light is transported along WLS fibers and read out by Hamamatsu Multi-Anode PMTs.

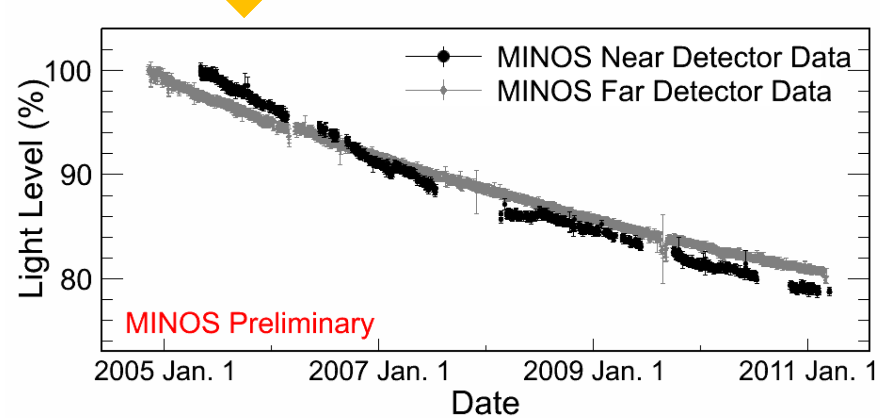
	Near	Far
Gains Increasing By	2.5%/yr	1.8%/yr
Light Level Decreasing By	3.5%/yr	3.0%/yr



Raw Response

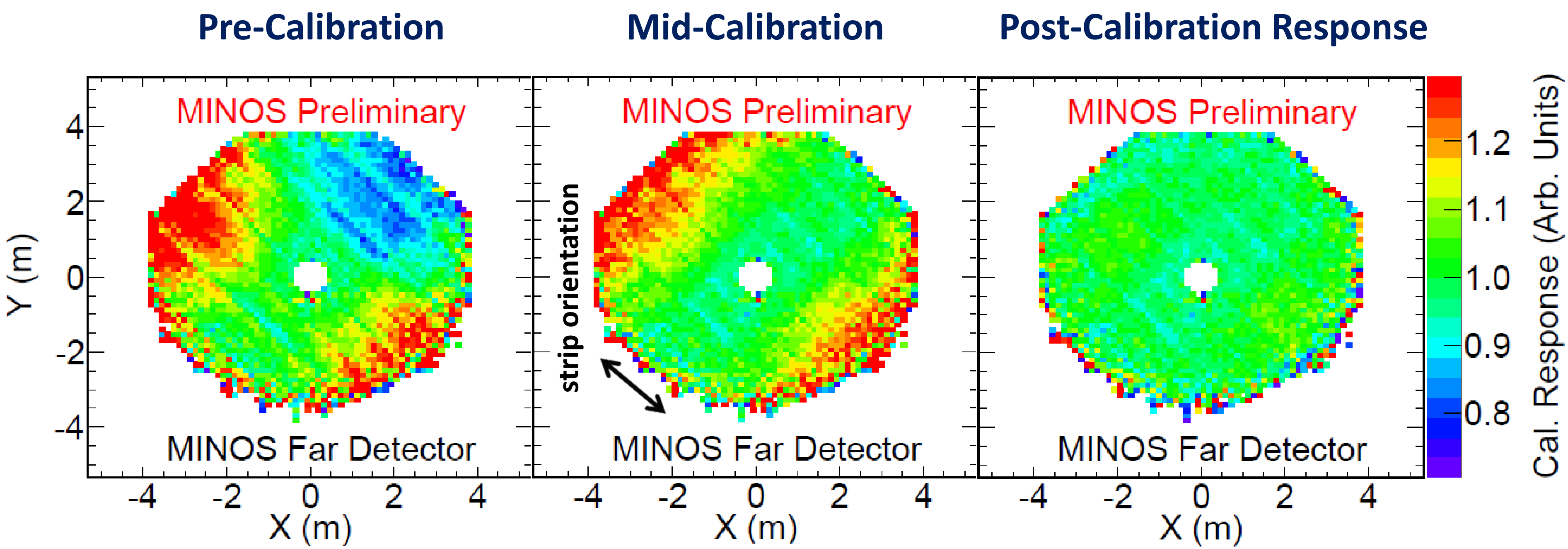


$$\text{Light Level}_i = \frac{\text{Detector Drift}_i}{\text{Average Gains}_i}$$



Calibration of the MINOS Far Det.

The scintillating strips at the MINOS far detector are oriented at 45° to the vertical, and 90° with respect to neighbouring planes. Shown below is the calibration of one of these two views (The NuMI neutrino beam is travelling out of the page)



This is the raw response of the detector

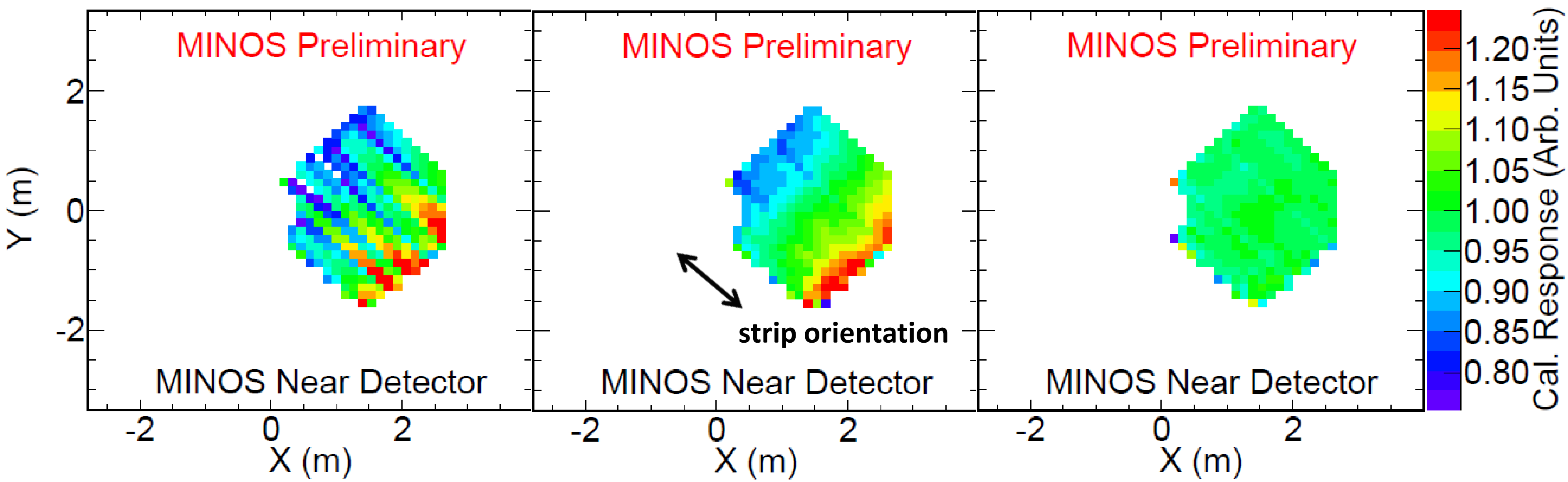
This is the response of the detector after all calibrations except the attenuation correction

This is the fully calibrated response of the detector

Calibration of the MINOS Near Det.

The scintillating strips at the MINOS near detector are oriented at 45° to the vertical, and 90° with respect to neighbouring planes. Shown below is the calibration of one of these two views (The NuMI neutrino beam is travelling out of the page)

Pre-Calibration **Mid-Calibration** **Post-Calibration Response**



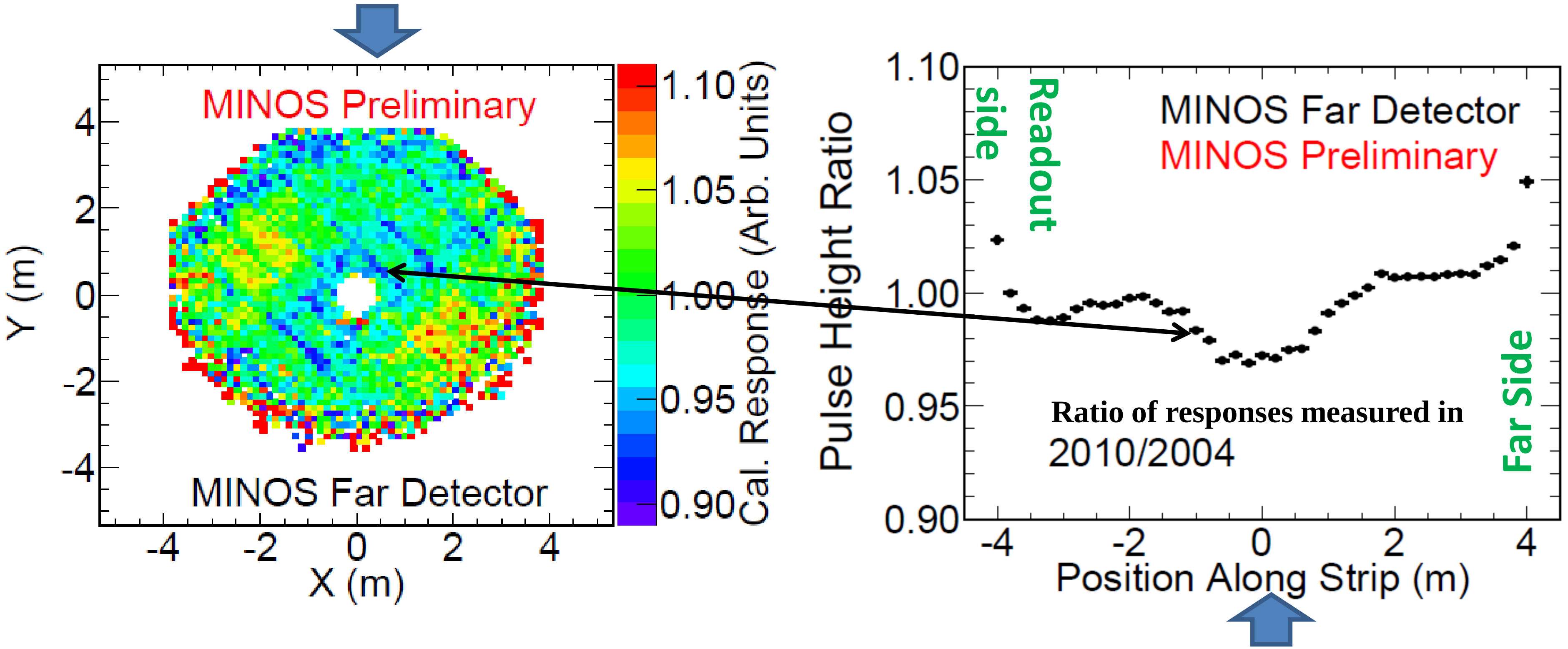
This is the raw response of the detector

This is the response of the detector after all calibrations except the attenuation correction

This is the fully calibrated response of the detector

MINOS Fiber Aging

Even after calibration, the detectors still demonstrate variation across the face of the scintillator planes at the level of a few percent.



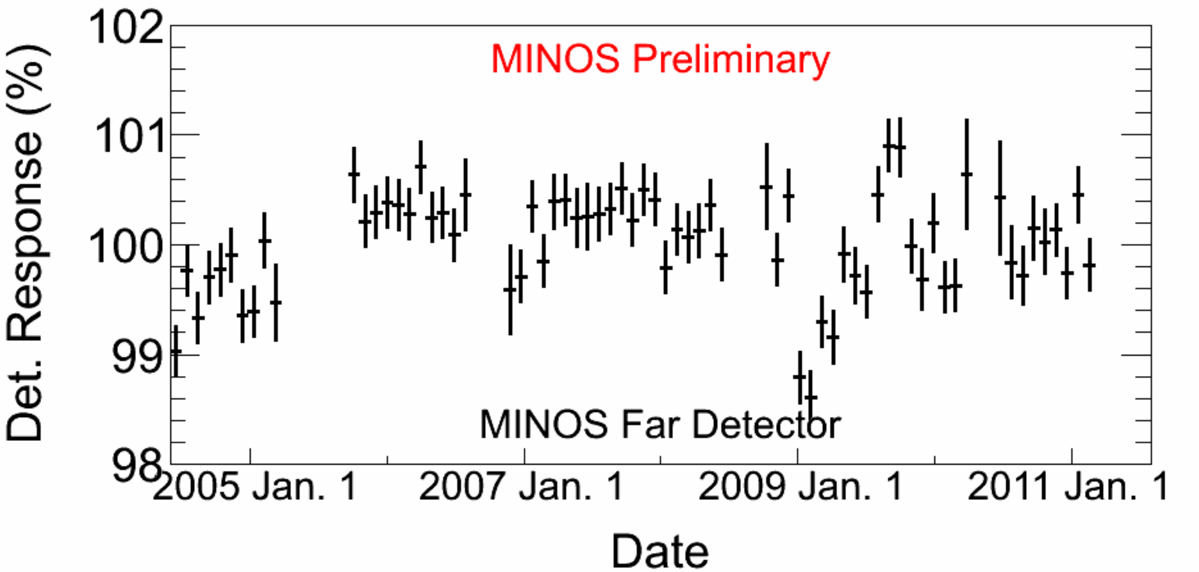
By choosing only the longest strips in the far detector, and taking the ratio of responses from different years we can see how the strips are aging

- Mechanical stresses appear to be aging the center of the scintillator strips faster than the edges
- Left-right differences are caused by the aging of the wavelength shifting fibers.
- These variations are big contributors to the systematuc uncertainties on the energy scale

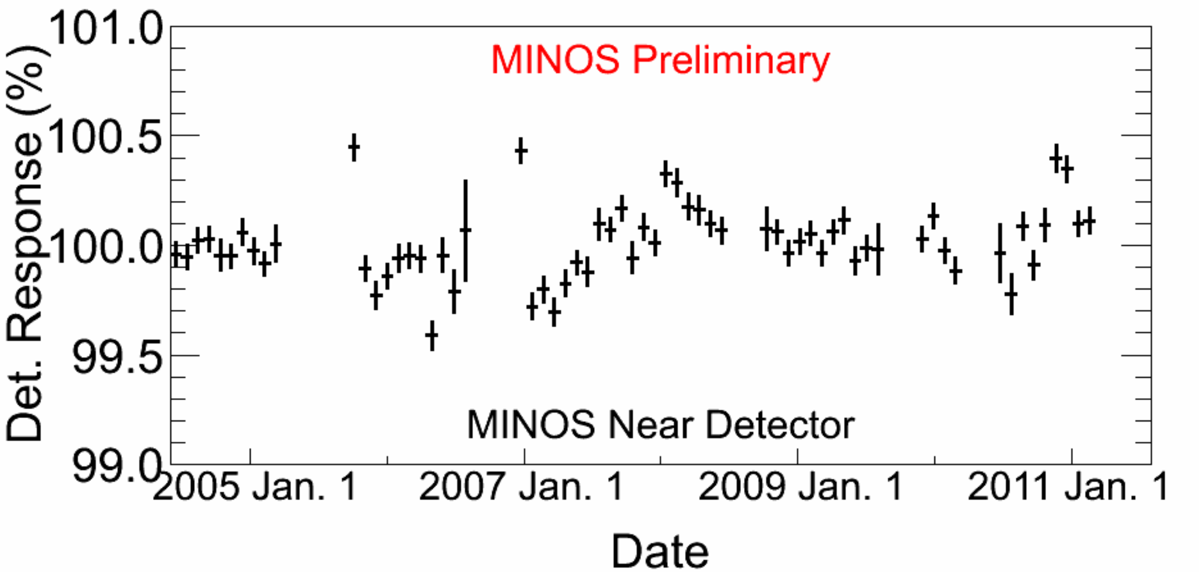
MINOS Calibration Stability

The stability of the calibration procedure is cross-checked on a monthly basis.

The Far Detector Response to stopping-muons is stable in time to within 1.5%



The Near Detector Response to stopping-muons is stable in time to within 0.5%



The monthly fluctuations are mostly statistical, but there are a few systematic outliers.