Development of an Optical Wire Position Monitor

CLIC - Study

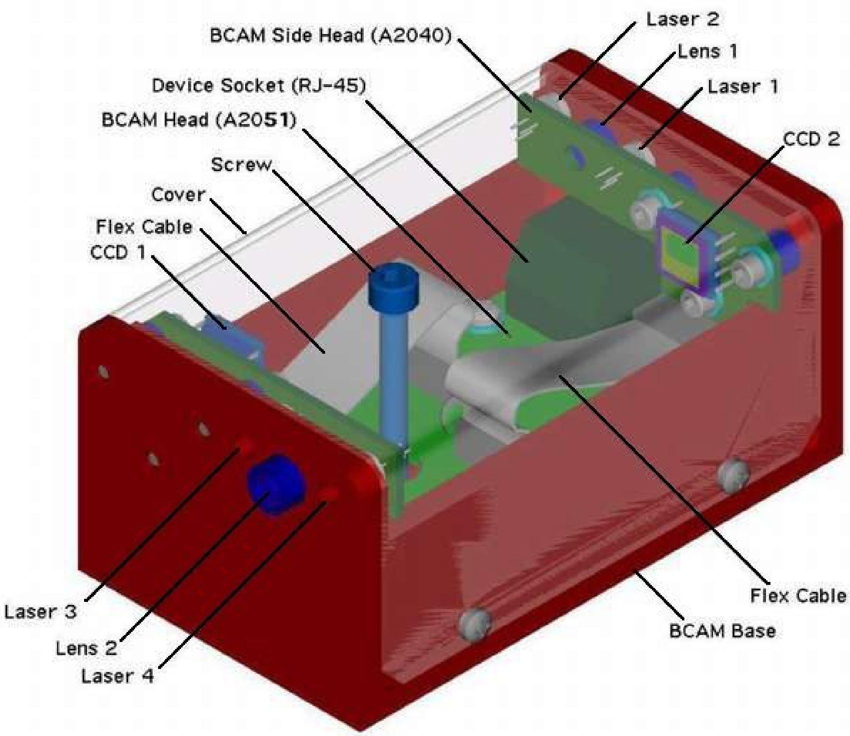
Open Source Instruments, Inc.
Friedrich Lackner (CERN), Kevan Hashemi, Jim Bensinger (OSI),

Friedrich.Lackner@cern.sh

Outline:

- Introduction, History, LWDAQ
- Description
- WPS1
- Wire
- Performance, Calibration
- Conclusion
- Discussion

The history of the collaboration with CERN:



BCAM, Brandeis CCD Angle Monitor

- The angular resolution of a BCAM camera is 5μrad or better at all ranges

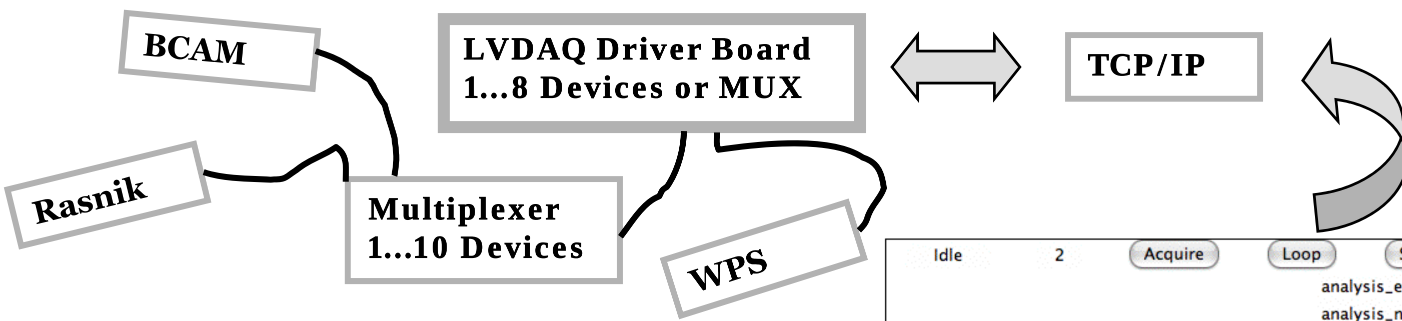
Detector monitoring:

- Used in all the four LHC experiments.
- Simple and cheap concept
- Radiation hard with in the LHC experiment requirements
- Three ball support
- Efficient DAQ concept

Applications @ CERN

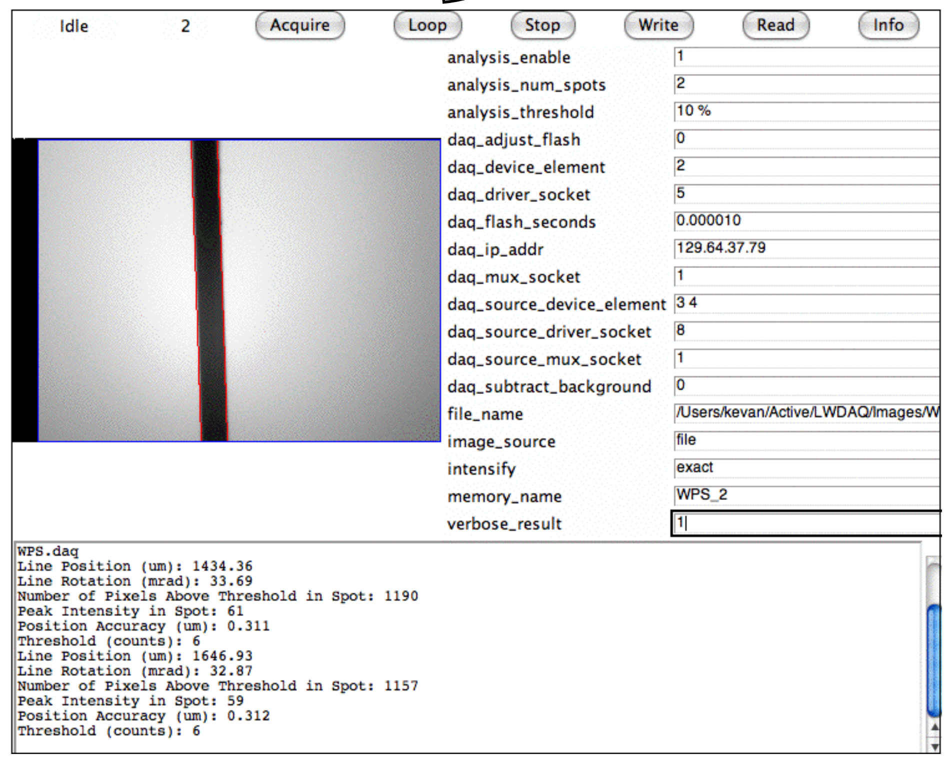
- ATLAS operates 1000 BCAM
- ALICE around 80 devices
- CMS magnet alignment
- LHCb rich1, rich1 shielding

The DAQ concept:

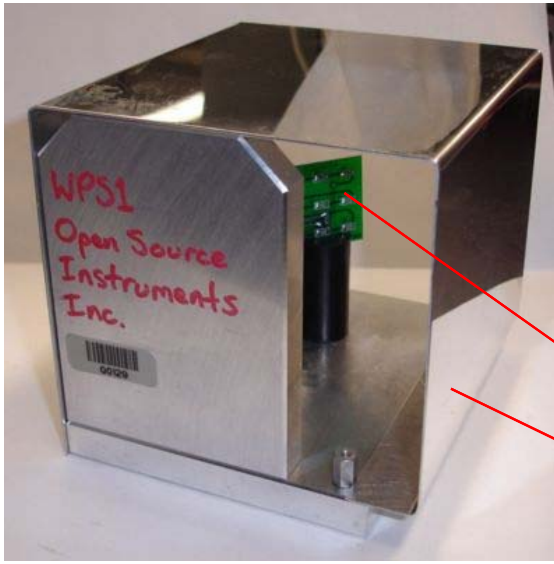


The LWDAQ software is a combination of analysis routines compiled from Pascal source code by GPC (GNU Pascal Compiler) and TCL/TK (Tool comand Language/Tool Kit)

TCL/TK interpreter, called the *Wish Shell*, exists for almost every operating system.



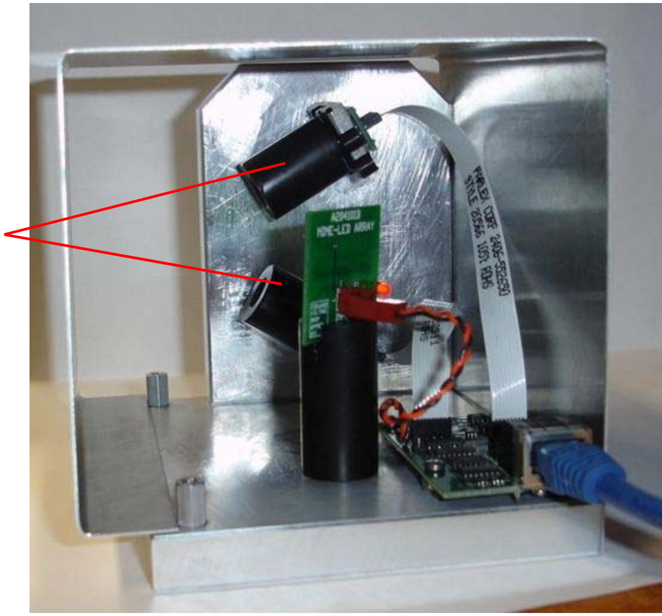
Calibrated sensors are currently tested on the BE/ABP/SU

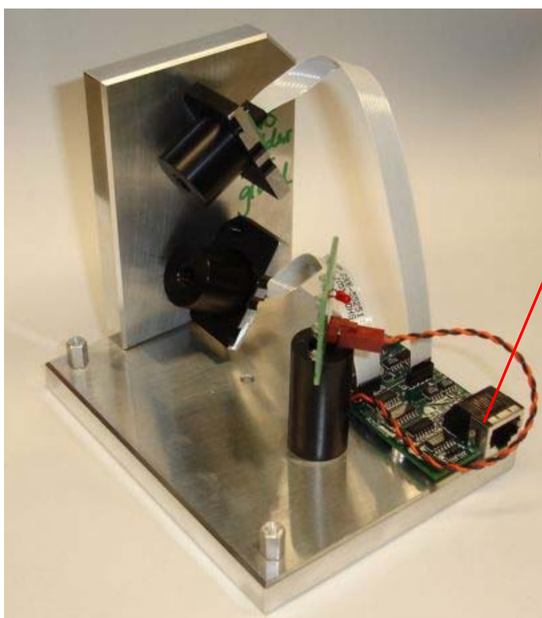


Optics, Texas Instruments CCD, 1 Pixel 10 µm.

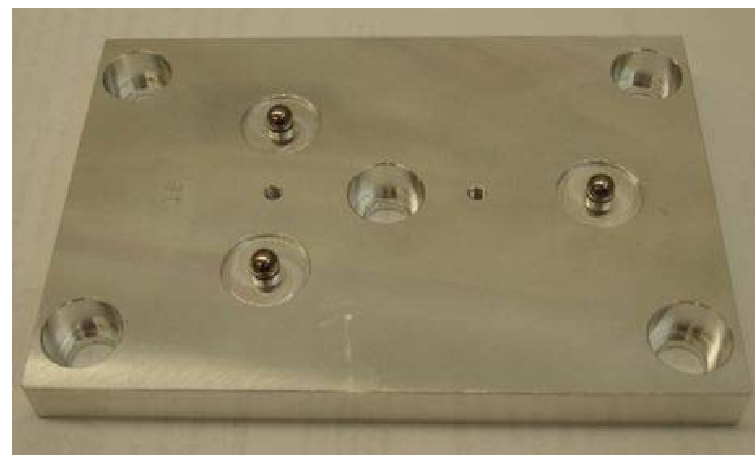
Illumination Nine-LED Array (A2014)

Enclosure



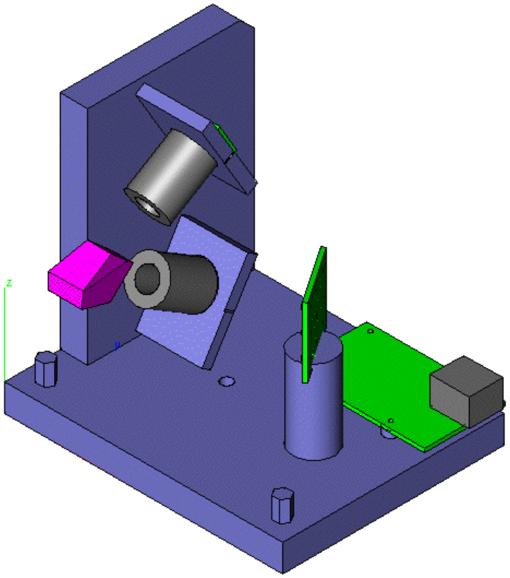


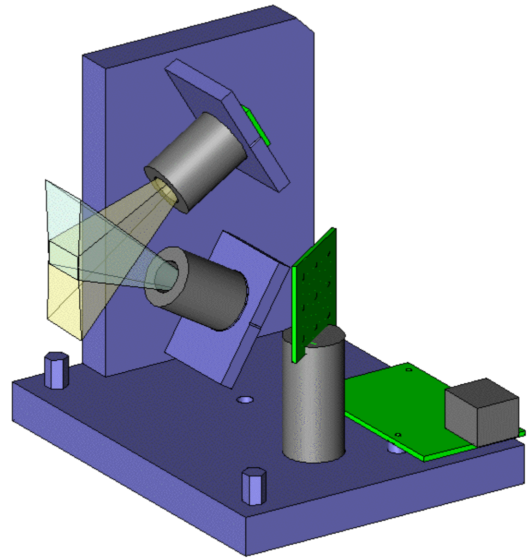
Readout Socket, RJ45 connector for the LWDAQ Readout and Powering

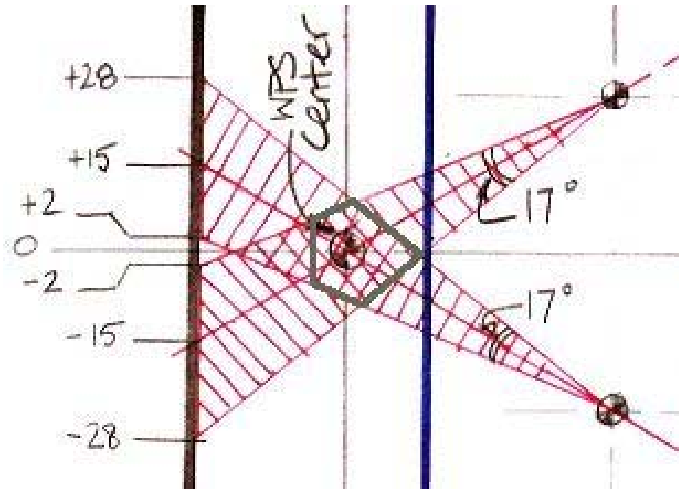


Baseplate, including the kinematic mount; M4 mounting screw

WPS1 - Field of View



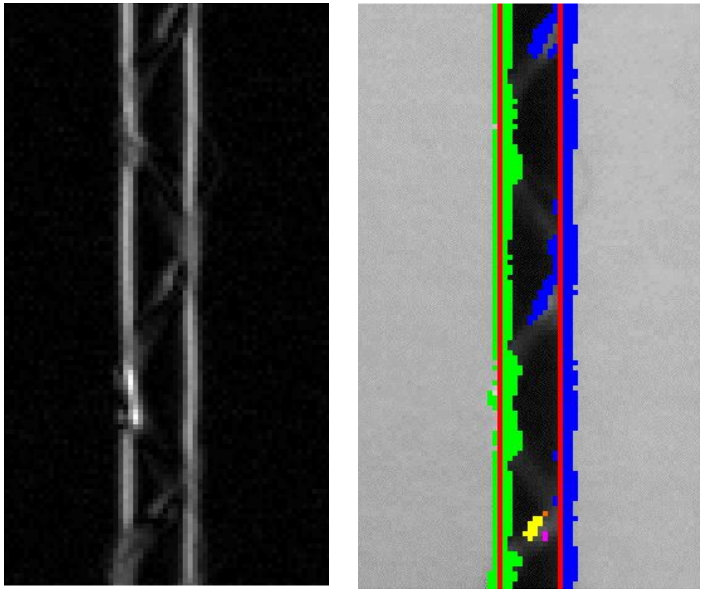




Properties of the WPS1-B Optics:

Parameter	Value
Aperture-CCD	10 mm
Pivot-CCD	10.4 mm
Aperture Diameter	200±5 µm
Aperture Centering	±100 µm
Lens Focal Length	9 mm
Focal Point of Lens to CCD	11 mm
Flat of Lens to CCD	12 mm
CCD Width	3.4 mm
CCD Height	2.4 mm
CCD Pixel Size	10 µm × 10 µm
Field of View	±160 mrad × ±110 mrad
Aperture Height Above End Plate	15 mm
Aperture to Front of CCD Mounting Plate	5 mm

WPS1 Field of View. The nominal position of the optical center, in WPS local coordinates, is (38.0, 62.4, –5) in mm.



WPS Image of a carbon fibre

Horizontal Edge Pixels in Image of Carbon Fiber Wire.

Left: the edge pixels shown in gray-scale to indicate absolute value of horizontal derivative.

Right: the edge pixels used in the derivative analysis for each edge are marked with colors.

Carbon fiber wires tend to fray. Individual fibers separate from the wire, and the wire starts to untangle. To constrain these fibers, the wire manufacturer wraps the wire with two thin plastic threads that wind in opposite directions. The pictures show wires with an approximate thickness of 700 μm.

With two thin wrappers in opposite directions, we estimate that the effect of the wrapper upon both the capacitive WPS and our proposed optical WPS will be less than 3 μm.

Wires for an Optical WPS

New wire from Mammutec available

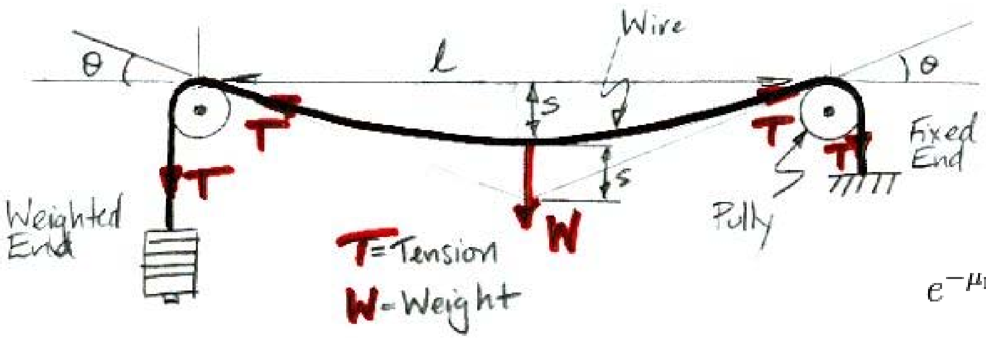
(Monofilaments Vectran, Paraloc,)

Further candidates to be studied…

Material	Density (g/cm³)	Strength (GPa)	Modulus (GPa)	100-m Sag (mm)	CTE ppm/K
Carbon Fiber	1.8	3	300	7.5	-0.5 Longitudinal
Aluminum	2.7	0.5	70	68	25
Tungsten	19.3	1.5	400	160	4
Steel	7.5	1	200	94	17
Copper	8.9	0.2	120	560	17
Vectran	1.1	2.7	70	5.1	<20

Vectran fiber strength is 27 g/denier. A one denier fiber is a fiber 9 km long that weighs one gram. The density of Vectran is 1.1 g/cm^3, so a 1-denier fiber has diameter 10 μm and cross-section 10^{-10}m^2. The breaking stress is therefore 2.7 GPa, which compares well with the 3-GPa breaking strain of carbon fiber.

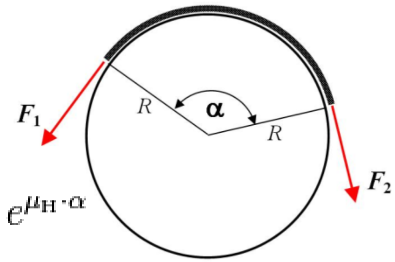
Sag s of a wire with constant mass:



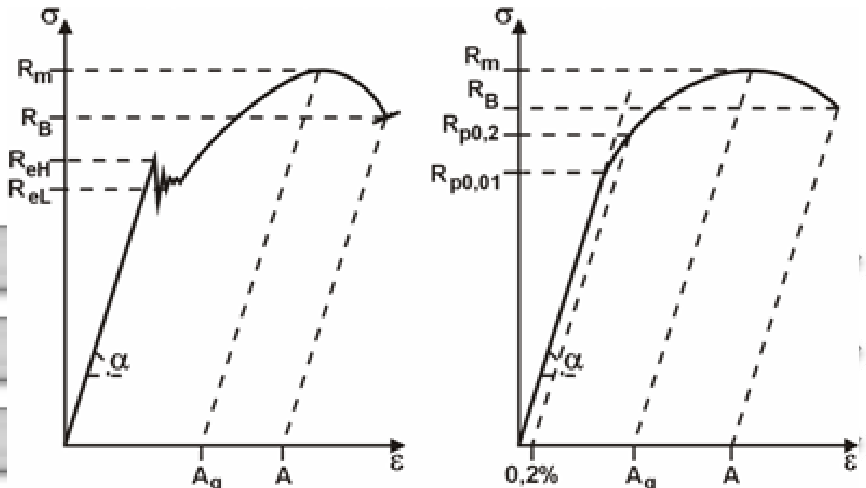
The ideal wire would show a clear linear elastic limit and would be insensitive regarding the following Physical Properties:

- Temperature
- Humidity
- Creeping, aging effects
- Gravity
- Radiation

Mechanical Properties:

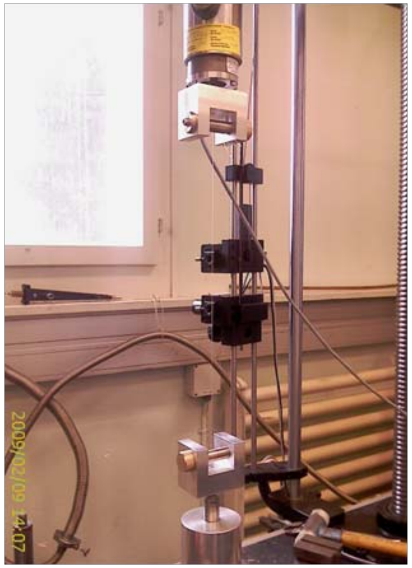


$$e^{-\mu_H \cdot \alpha} < \frac{F_1}{F_2} < e^{\mu_H \cdot \alpha}$$



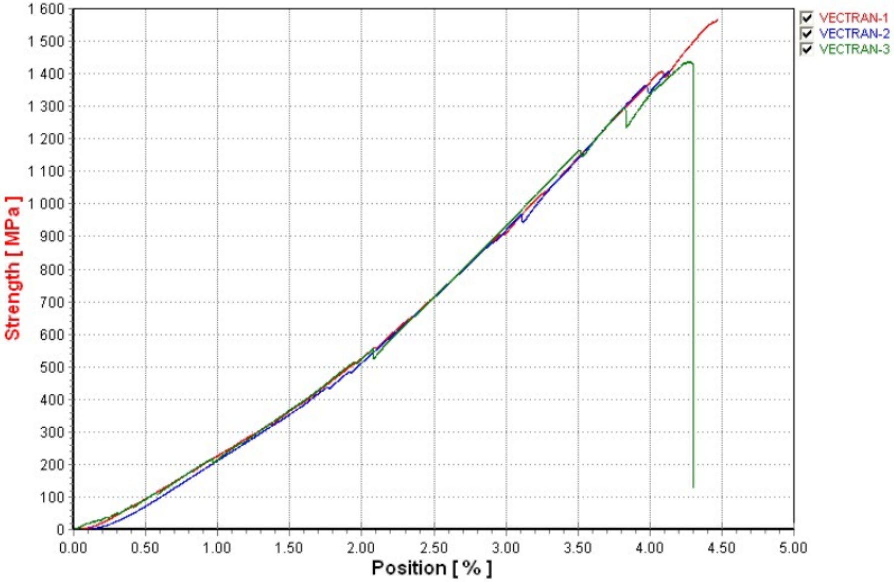
Wires are not showing a clear liner elastic limit given by the various uncertainties (e.g. during the tensile tests)

Wire monitoring in order to study and describe the various influences.
Requires the study of possible sensors and their implementation



New wire support for the Tensile machine , developed from SU

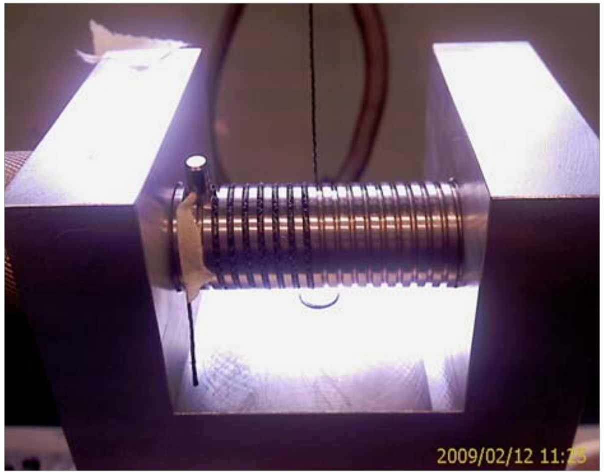
(Monofilament wire requires special support due to friction between filaments)



Sampletemperatur 22 °C

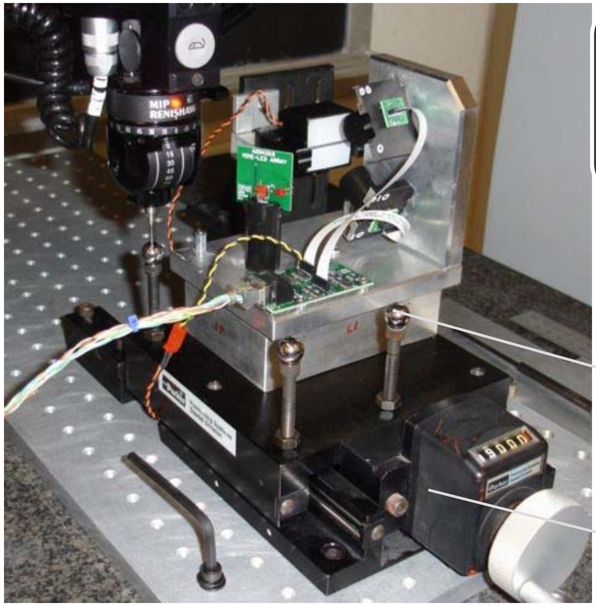
Speed Step1 5.00 mm/min

Tensile tests on wires	Fm [N]	Rm [MPa]	Emod [GPa]	WegFmax [%]
VECTRAN-1	307.49	1566.05	36.70	4.47
VECTRAN-2	276.46	1408.00	38.25	4.13
VECTRAN-3	282.33	1437.88	36.00	4.28
-				
	Fm [N]	Rm [MPa]	Emod [GPa]	WegFmax [%]
min	276.46	1408.00	36.00	4.13
max	307.49	1566.05	38.25	4.47
AM	288.76	1470.65	36.98	4.29
s	16.49	83.96	1.15	0.17



EN Engineering Department

Alexandre Geradin, EN



WPS1 calibration stand, which implements WPS1 calibration with a steel pin, a micrometer stage, and a CMM.

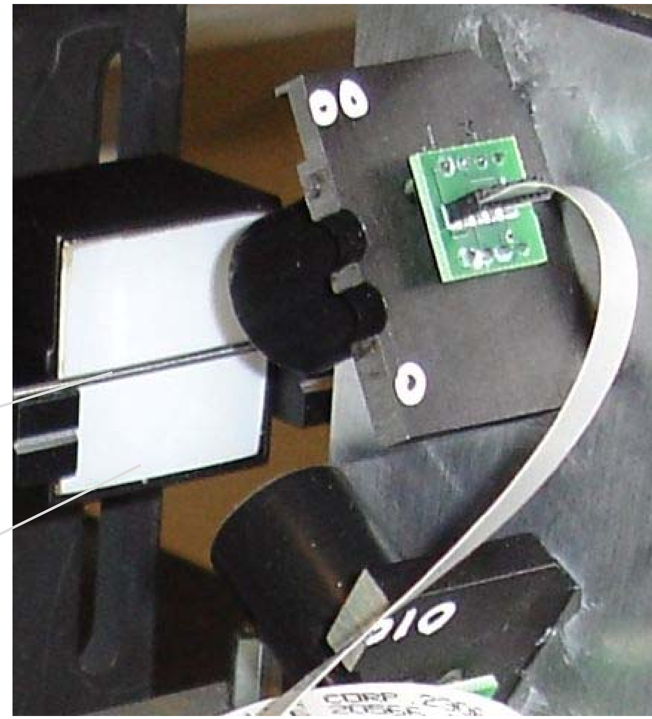
The calibration procedure takes currently 1h/Sensor.

Reference balls

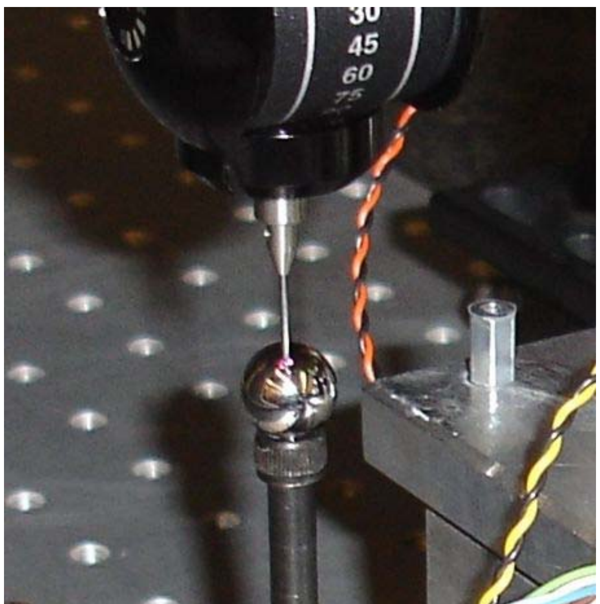
Micrometer Stage

Steel pin

Illumination



Steel pin, diameter = 1.58mm;
LED array and an opal glass diffuser



Reference ball measurement

Calibration Procedure

1. Steel pin measured with CMM, (removing light source)
2. Calculation of pin position in mount coordinates
3. Mounting WPS1 and measuring the pin

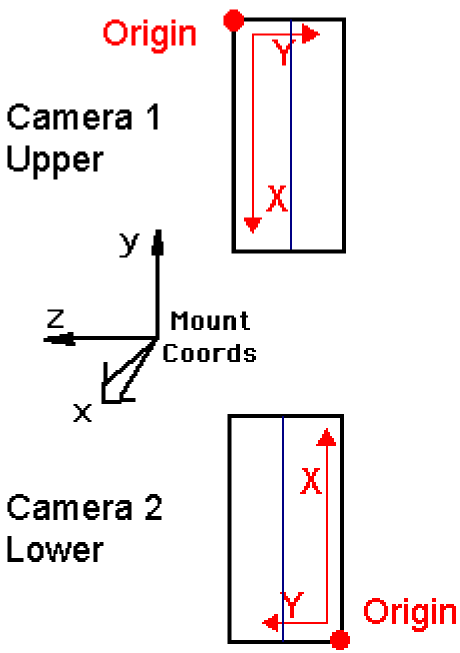


Image Coordinates and Mount Coordinates. The two WPS1 image sensors are rotated by 180° with respect to one another. The Camera 1 sensor is rotated by −90° about the mount coordinate *x*-axis. The Camera 2 sensor is rotated by +90°.

4. Measuring the three reference balls on micrometer stage

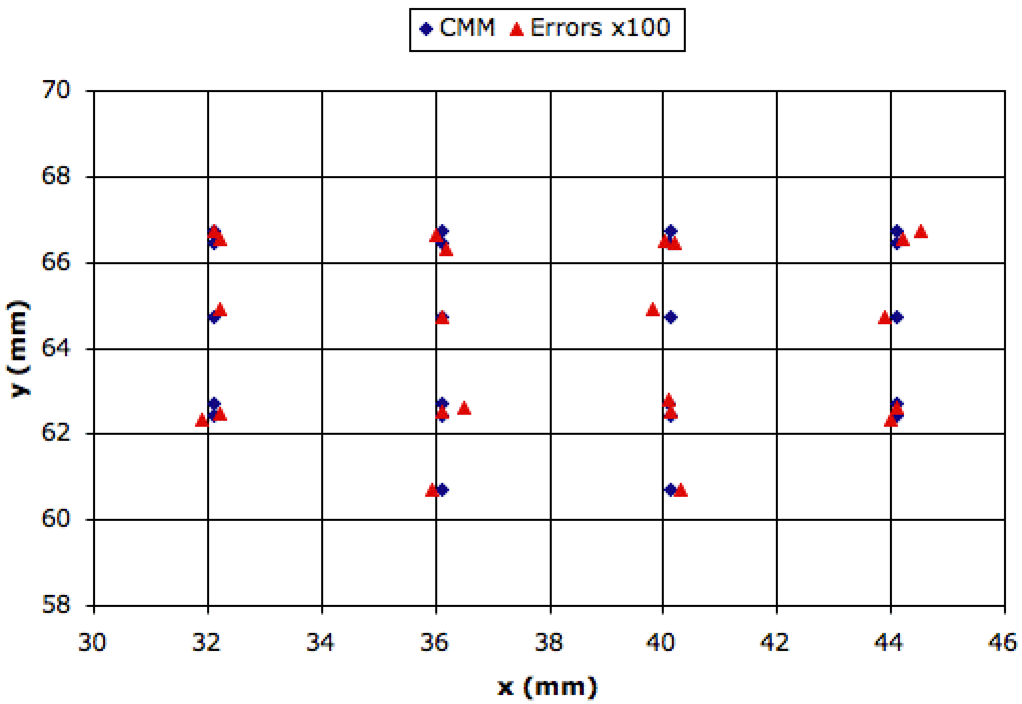
Moving μm stage and re-measure the reference balls

Calculation of mounting ball position

Image taking with WPS

Calculating pin position in the mounting coordinates

Initial measurement of the mounting balls and reference balls allows to determine the mounting ball positions from any future reference ball positions.



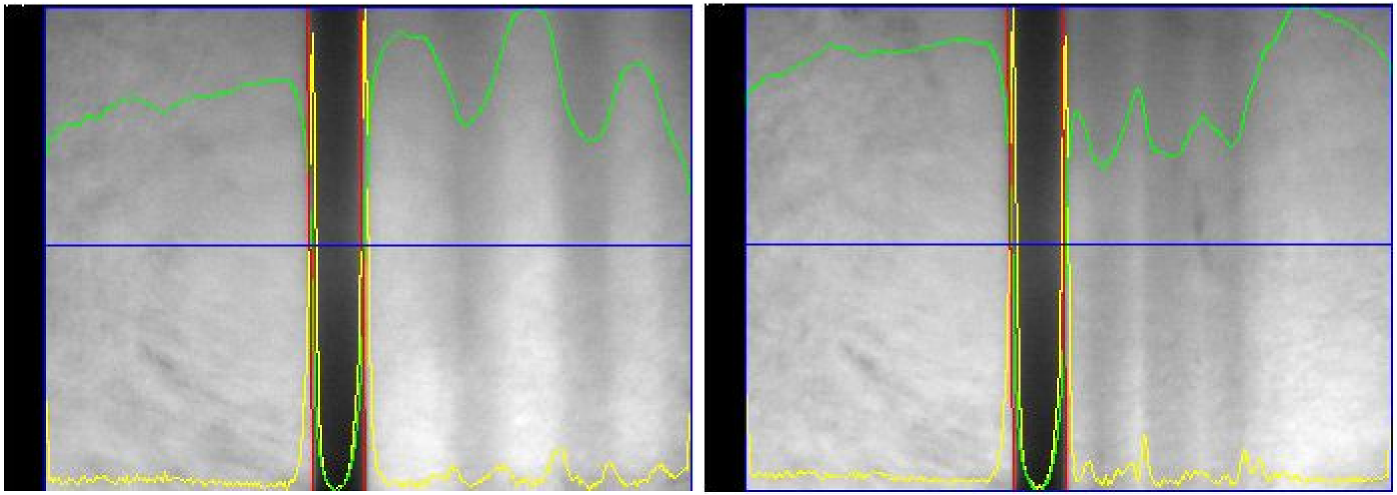
Calibration Constants: WPS1-B. We calculate the difference between the CMM and WPS measurement of wire position at $z=-4$ mm. The CMM wire positions are shown in blue. The red points are the WPS measurements with their deviation from the CMM measurements exaggerated by a factor of one hundred. The rms error is 2 µm.

We determine 9 calibration constants for each camera using images of 22 wire positions. We have over twice as many wire positions as we need to fit our parameters.

	pivot	(mm)		sensor	(mm)		rot	(mrad)		pivot-	error
Camera	x	y	z	x	y	z	x	y	z	ccd (mm)	(mm)
P0195_A_1	-4.3892	88.4846	-4.4033	-13.7607	93.7637	-4.3873	-1577.741	-0.008	-493.211	10.756	0.001
P0195_A_2	-3.8191	39.3077	-4.6536	-12.7098	33.5709	-4.7217	1562.642	-1.805	573.494	10.581	0.001

Calibration constants are highly correlated; RMS value of 2µm

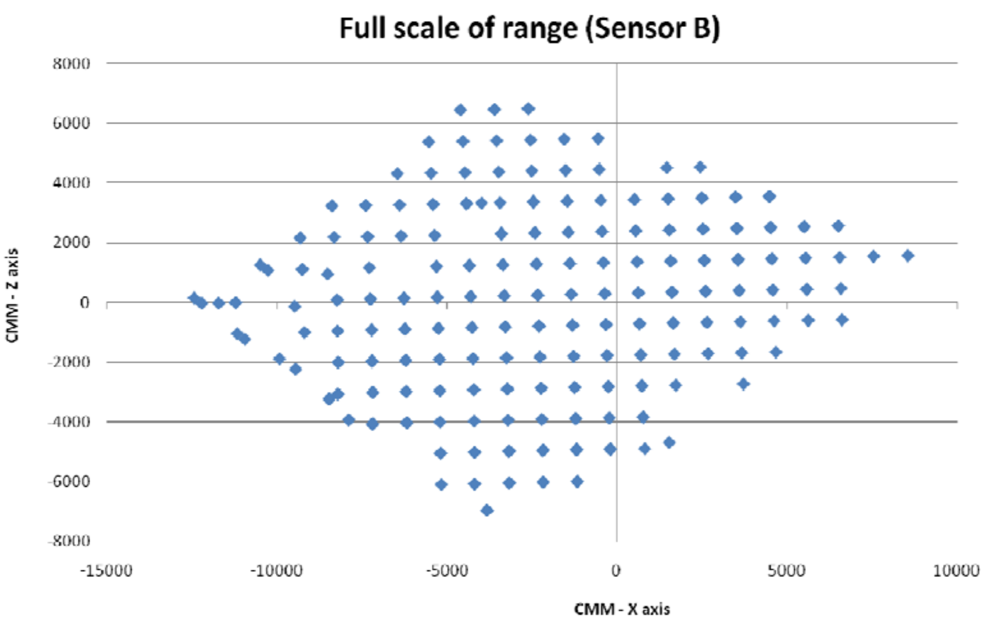
WPS1 Images, Analysis



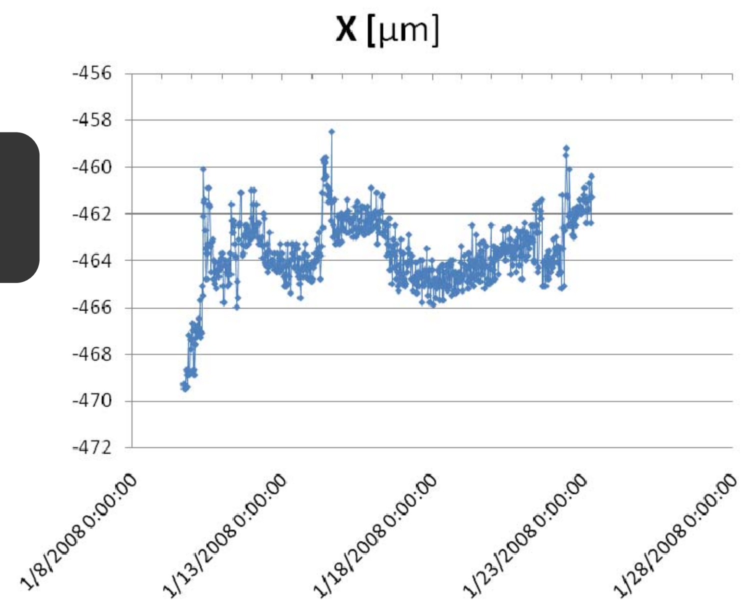
Images with Shadows, Showing Derivative Analysis Results. The wire is 1 mm in diameter. Its outer surface is PVC insulation.

- Red is the horizontal intensity profile.
- Yellow is the slope of the horizontal intensity profile.
- Orange is the fitted center-line of the wire.
- Green is a box to which the fitting restricts its attention.
- Blue is the threshold applied to the horizontal intensity profile that the analysis uses to find the approximate location of the wire.

Full scale of range test and long term stability

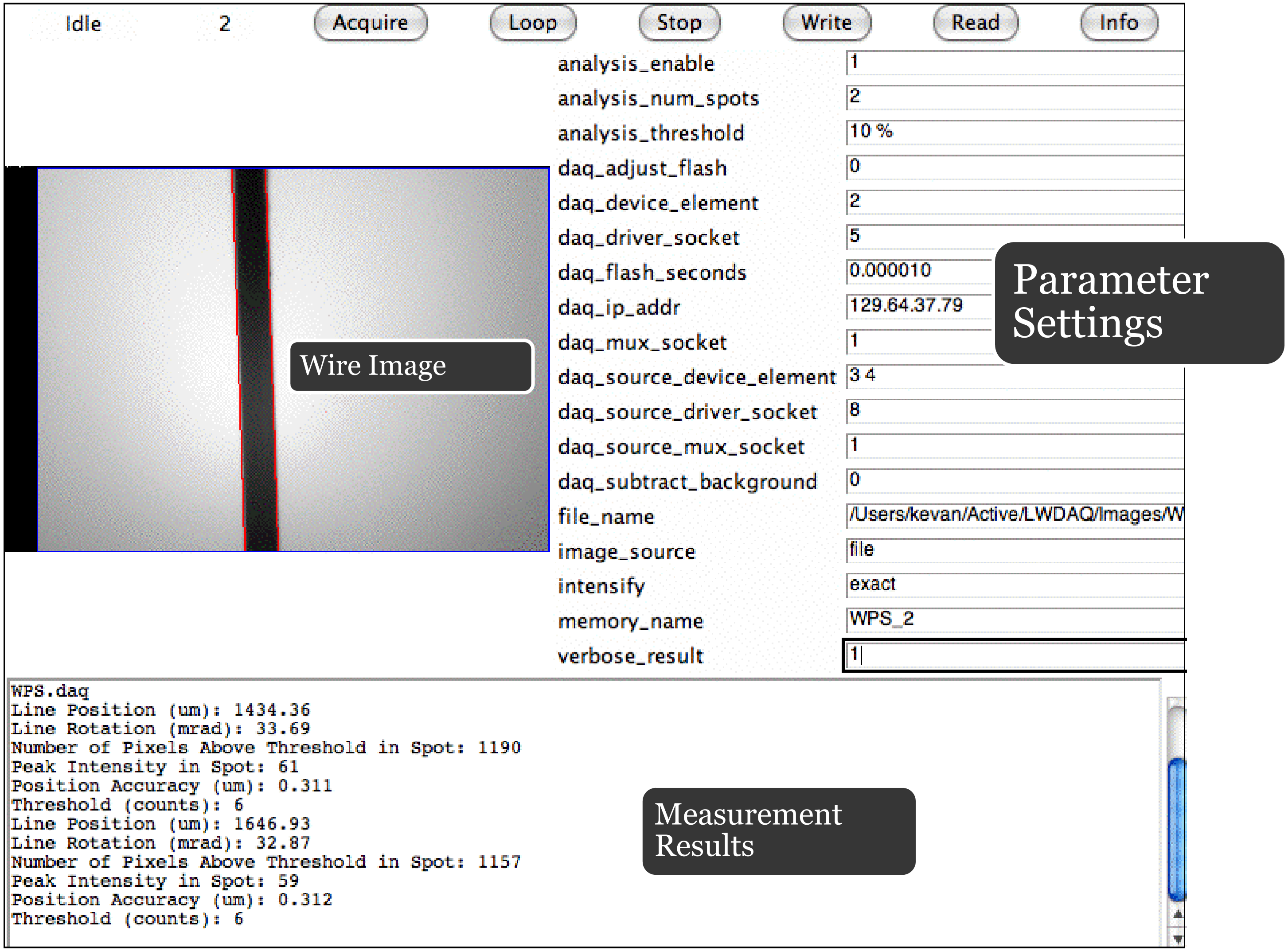


A full scale of range test was performed at CERN, it showed the expected WPS1 range of ±5 mm. The test was performed in 0.5mm steps in the X and Z direction on the Survey CMM.



A long term test at CERN was performed and showed a standard deviation σ was **0.87µm** in **X** and **1.00µm** for the **Y** position.

LWDAQ Window, Wire Image, Paramenters, Results



Summary

- The OSI optical WPS is calibrated to better than 3 µm
- The design and concept represents a high precision low cost monitoring system

Further Implementation and Developments:

- Installation in a CLIC related test setup (TT1)
- The final version, which runs off a battery, will be arranged in sets of one hundred
- A laser will be used to transfer the DAQ results wireless
- Each measurement will take on second and will consume 30mA
- A battery will hold 10,000 mA-hr -> 1 million measurements
- Measurement once every 5 min -> 10 years of wireless operation before battery exchange

Further Information:

OSI	• http://www.opensourceinstruments.com/WPS/
CERN - SU	• https://flackner.web.cern.ch/FLACKNER/dokuwiki/
CLIC	• http://clic-alignment.web.cern.ch/clic-alignment/default.htm