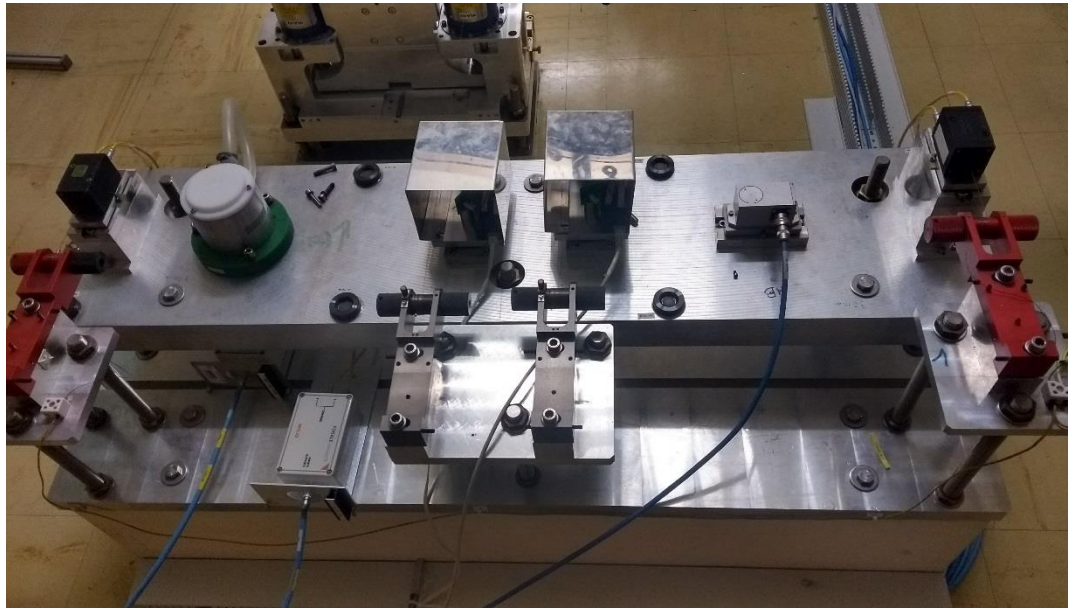
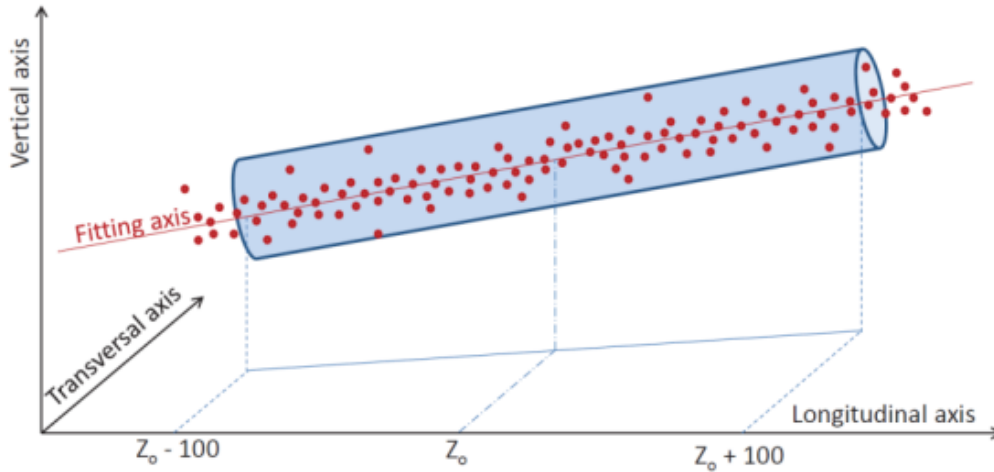


# Active repositioning and sensor characterization for the CLIC module

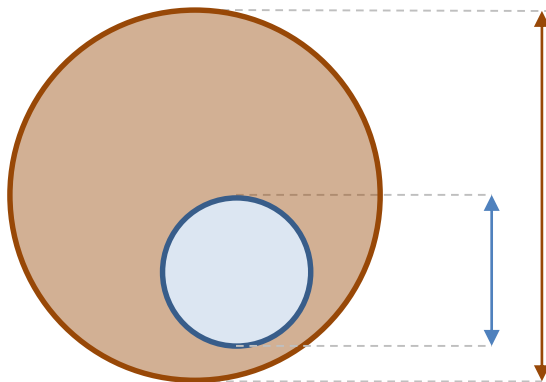


# 1. CLIC has stringent alignment requirements



## Requirement :

- Pre-Alignment :  $\pm 14 \mu\text{m}$  along a 200 m sliding window

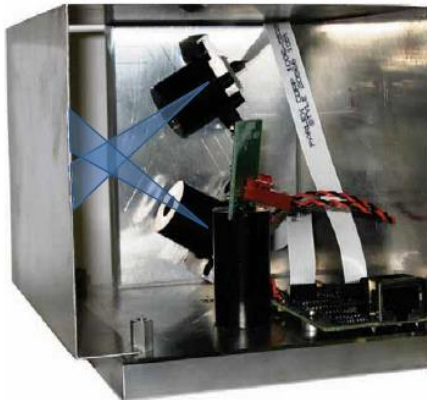
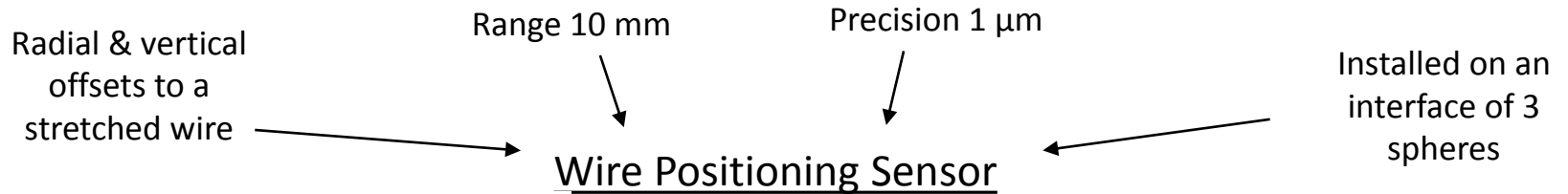


70  $\mu\text{m}$  – an ‘average’ human hair

28  $\mu\text{m}$  – CLIC’s requirement over 200 m



## 2. Sensors for the CLIC module



Optical WPS

Vectran-Silver wire

2 CCD cameras

Calibration of cameras provided by Brandeis University (OSI)



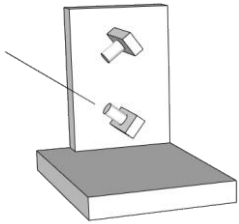
Capacitive WPS

Carbon PEEK / Carbon PES wires

4 electrodes (2 per axis)

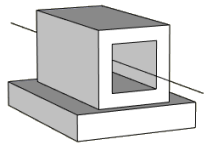
Linear and absolute calibration is required

## 2. Sensors for the CLIC module



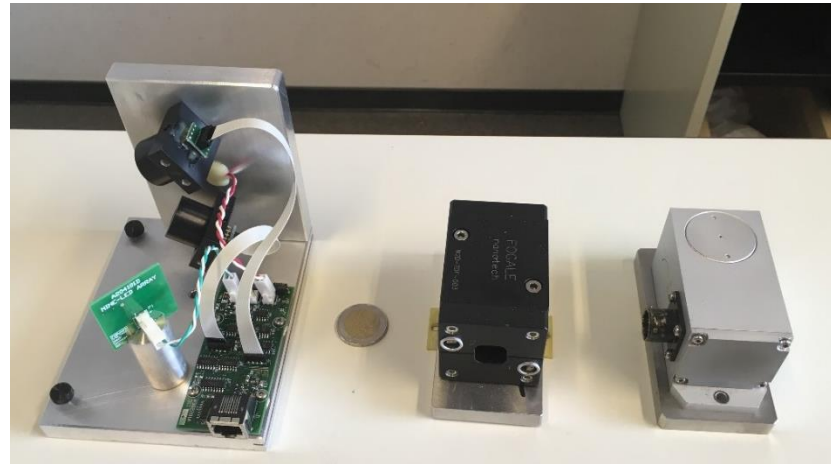
### oWPS:

- Precision : 1  $\mu\text{m}$
- Accuracy : 10  $\mu\text{m}$
- Maximum 500 Gy



### cWPS :

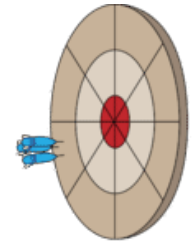
- Precision : 1  $\mu\text{m}$
- Accuracy : 5  $\mu\text{m}$
- Rad-Hard (5 MGy)



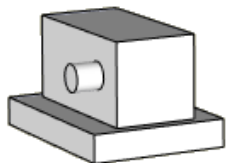
oWPS

cWPS

Tilt meter

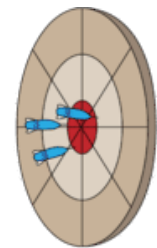
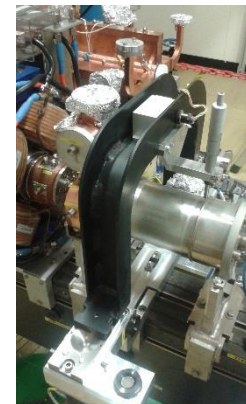


low accuracy  
high precision



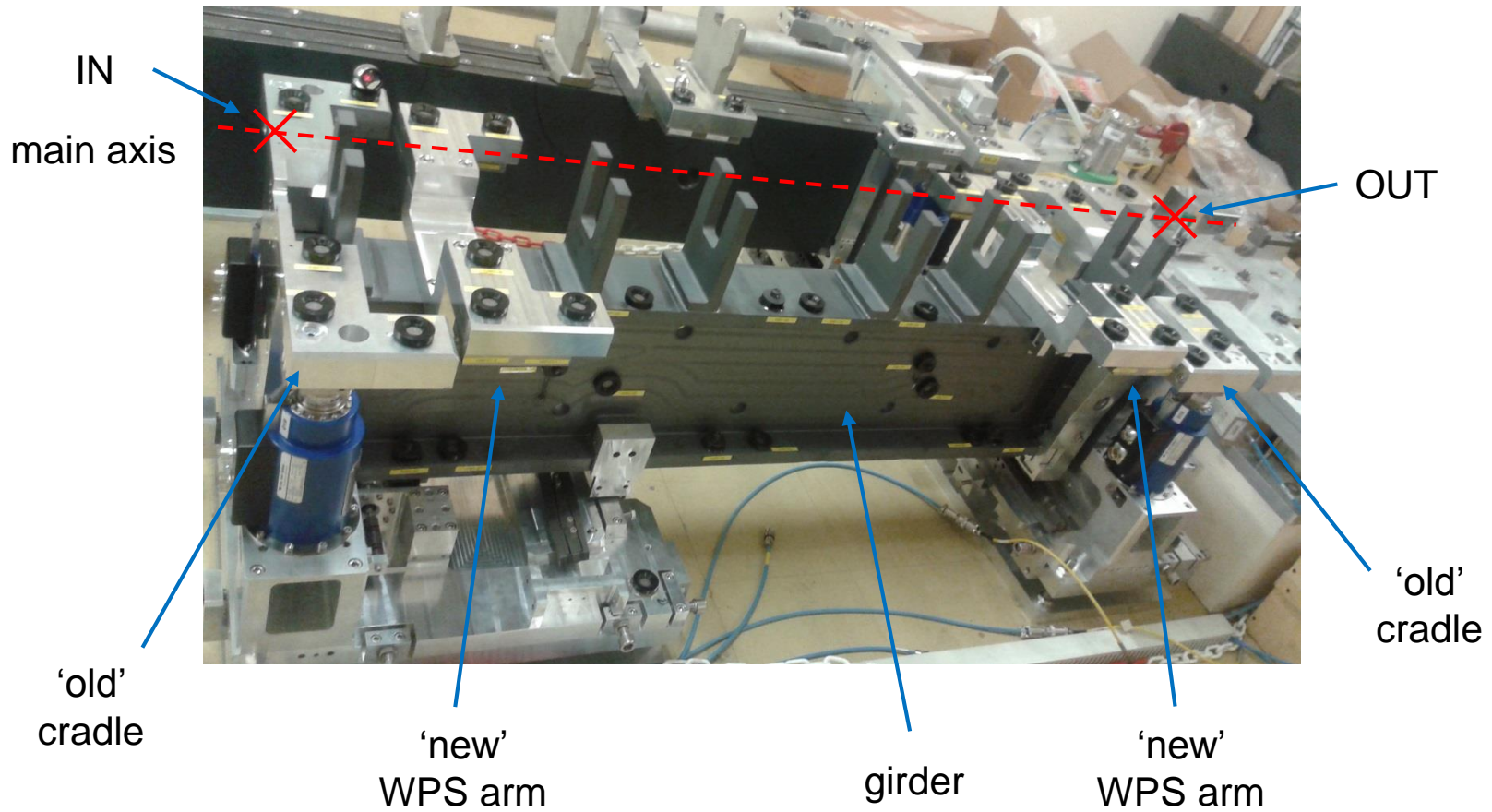
### Tilt meter :

- Precision : 3  $\mu\text{rad}$
- Accuracy (1) : 60  $\mu\text{rad}$
- Accuracy (2) : 10  $\mu\text{rad}$
- Not Rad-Hard



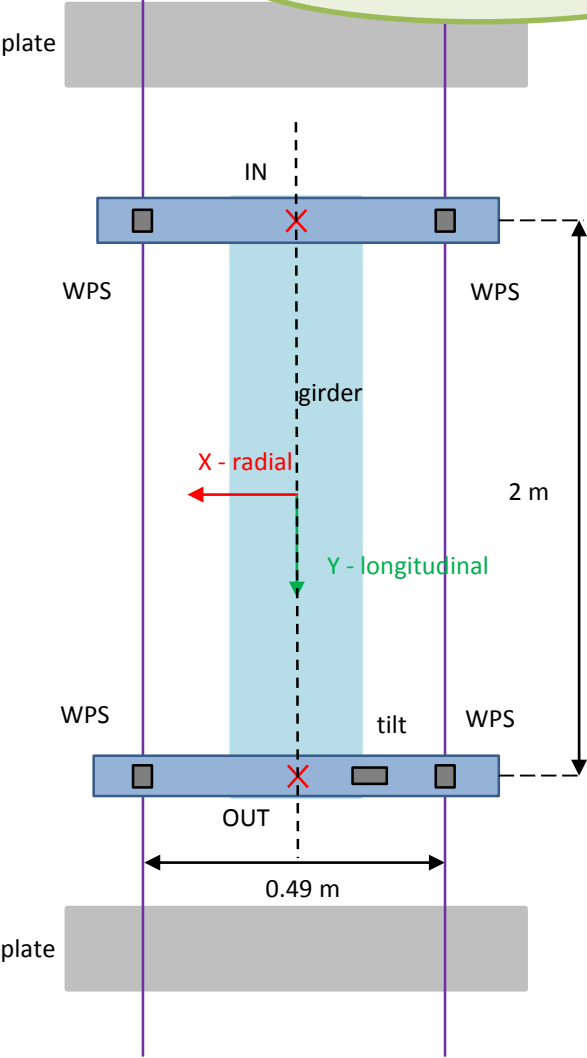
high accuracy  
low precision

### 3. Estimated precision



### 3. Estimated precision

The initial design



#### Simulations:

- Length of the girder 2 m
- Coordinate frame in the middle of the girder
- Sensors located 20 cm lower than the main axis
- 0.49 m between sensors in the radial direction
- Longitudinal distance between sensors 2 m

#### 2 wires:

1. both with an accuracy of 5  $\mu\text{m}$  (cWPS)



Precision	
X [ $\mu\text{m}$ ]	Z [ $\mu\text{m}$ ]
10	7
X – radial, Z – vertical	

2. the first with an accuracy of 5  $\mu\text{m}$  (cWPS), the second with 10  $\mu\text{m}$  (oWPS)



X [ $\mu\text{m}$ ]	Z [ $\mu\text{m}$ ]
13	8

#### 1 wire (with cWPS):

3. 1 tilt meter with an accuracy of 10  $\mu\text{rad}$



X [ $\mu\text{m}$ ]	Z [ $\mu\text{m}$ ]
12	10

4. 1 tilt meter with an accuracy of 60  $\mu\text{rad}$



X [ $\mu\text{m}$ ]	Z [ $\mu\text{m}$ ]
22	20

### 3. Estimated precision

The current solution

#### Simulations:

- Length of the girder 2 m
- Coordinate frame in the middle of the girder
- Sensors located 20 cm lower than the main axis
- 0.49 m between sensors in the radial direction
- Longitudinal distance between sensors 2 m

#### 2 wires:

- both with an accuracy of 5  $\mu\text{m}$  (cWPS)



Precision	
X [ $\mu\text{m}$ ]	Z [ $\mu\text{m}$ ]
11	9

X – radial, Z – vertical

- the first with an accuracy of 5  $\mu\text{m}$  (cWPS), the second with 10  $\mu\text{m}$  (oWPS)



X [ $\mu\text{m}$ ]	Z [ $\mu\text{m}$ ]
15	10

#### 1 wire (with cWPS):

- 1 tilt meter with an accuracy of 10  $\mu\text{rad}$

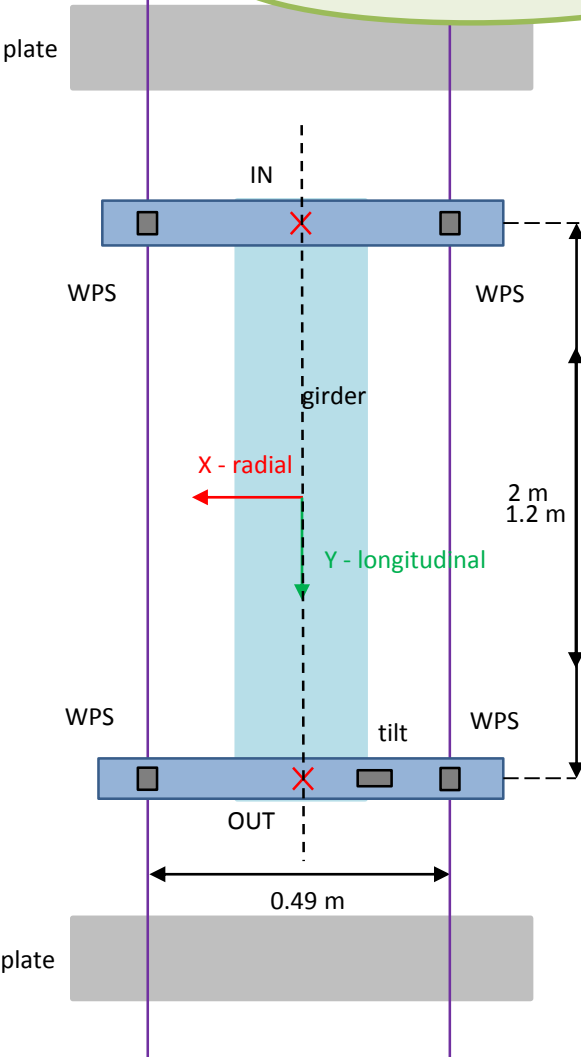


X [ $\mu\text{m}$ ]	Z [ $\mu\text{m}$ ]
14	12

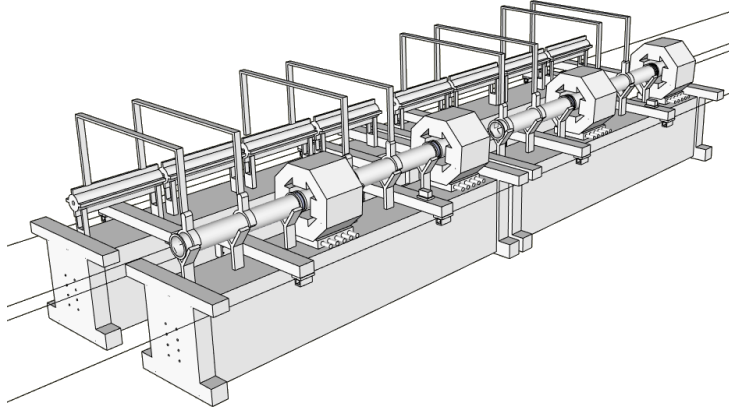
- 1 tilt meter with an accuracy of 60  $\mu\text{rad}$



X [ $\mu\text{m}$ ]	Z [ $\mu\text{m}$ ]
24	22



### 3. Conclusion on estimated precision



Shorter distance between sensors (-80 cm)



Lower precision of the axis' position (+2  $\mu\text{m}$ )

#### 2 wires

- Precision < 15  $\mu\text{m}$
- 8 observations (each sensor gives 2 values)
- 5 parameters to define (2 translations and 3 rotations of the girder)
- Difficult access between MB and DB girders – small distance, a lot of components which connect the two sides

#### 1 wire + tilt meter (10 $\mu\text{rad}$ )

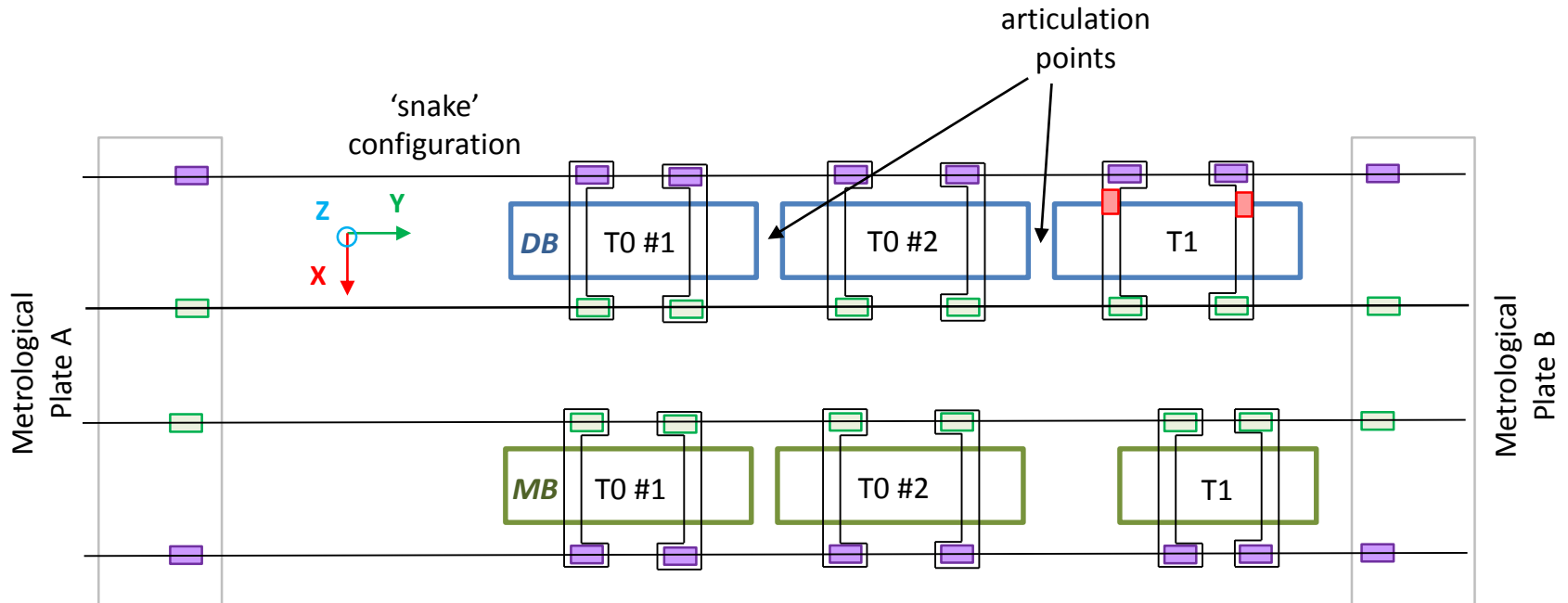
- Precision < 14  $\mu\text{m}$
- 5 observations (2 cWPS + angle from the tilt meter)
- 5 parameters to define
- No redundancy

#### 1 wire + tilt meter (60 $\mu\text{rad}$ )

- Precision < 25  $\mu\text{m}$
- 5 observations
- 5 parameters to define
- No redundancy



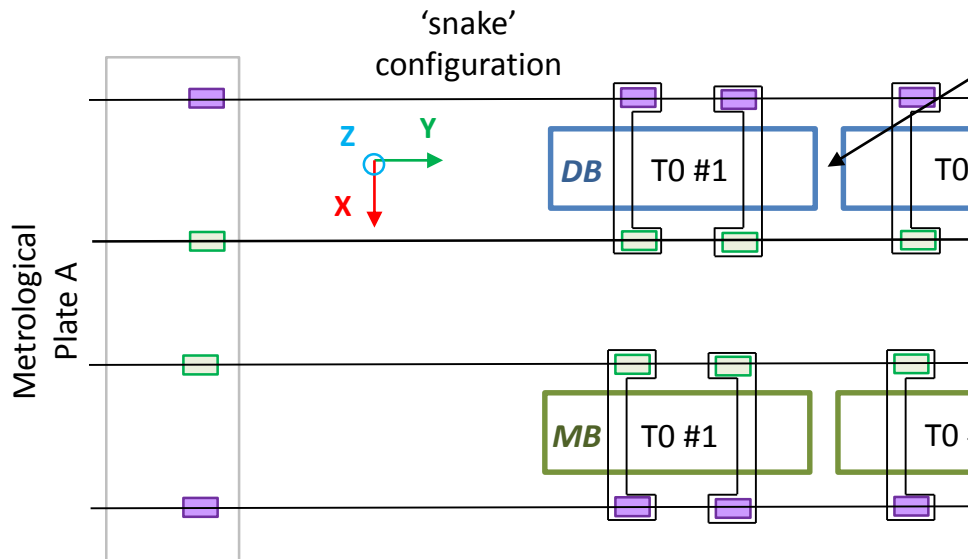
# 4. Configuration of the CLIC mock-up



- cWPS
- oWPS
- tilt meter

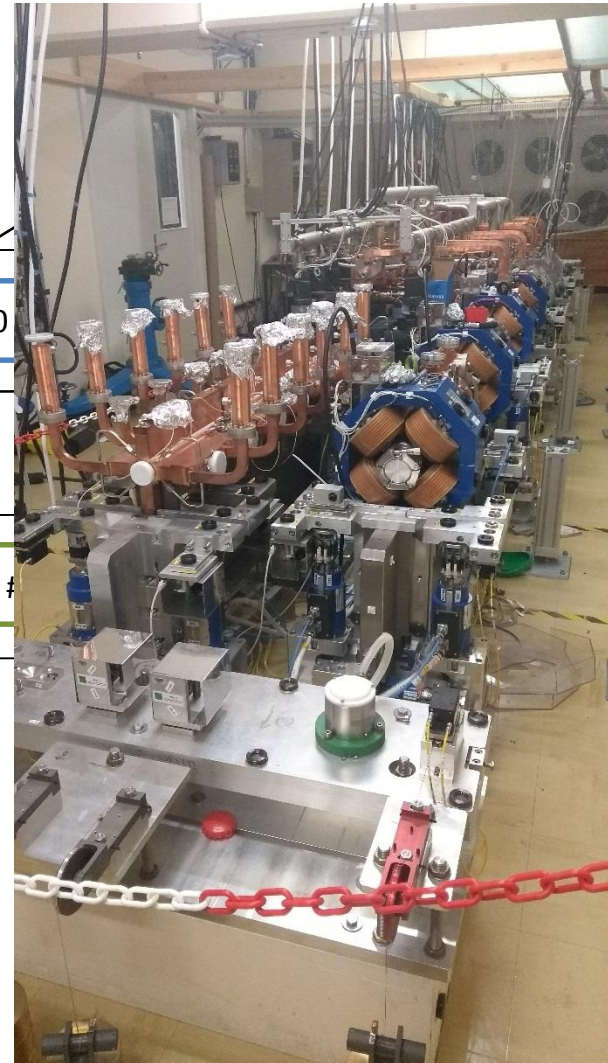
- In total:
- 6 girders
  - 16 cWPS
  - 16 oWPS
  - 2 tilt meters
  - 4 temperature probes
  - 27 actuators for moving the girders

# 4. Configuration of the CLIC mock-up



- cWPS
- oWPS
- tilt meter

- In total:
- 6 girders
  - 16 cWPS
  - 16 oWPS
  - 2 tilt meters
  - 4 temperature probes
  - 27 actuators for moving the girders



Metrological Plate B



# 4. Active alignment – software



## Actuator list

ACT_ID	ACT_NAME	ACT_TYPE	RESOLUTION	SERIAL_NUMBER	MOD_ID	MODULE_NAME
1	AVL_DBM1	ZTS_NEW	0.266		DB1	DBM1
2	AR_DBM1	ZTS_NEW	0.266		DB1	DBM1
3	AVR_DBM1	ZTS_NEW	0.266		DB1	DBM1

## Metrology data

FIDUCIAL_ID	FIDUCIAL_TYPE	SENSOR_ID	SENSOR_NAME	SPHERE_NUMBER	POSITION	MODULE	X	Y	Z	FIDUCIAL_NAME
1	3	0		0	0	1	-623.4429	139.1445	-66.0021	PA-1
2	3	0		0	1	1	-228.9647	143.5128	-66.0971	PA-2
3	3	0		0	1	1	217.3304	143.5836	-66.1123	PA-3
4	3	0		0	1	1	619.267	144.76	-65.9961	PA-4
5	3	0		0	1	1	622.6362	-104.9288	-66.0268	PA-5
6	3	0		0	1	1	220.0746	-103.2516	-66.0519	PA-6
7	3	0		0	1	1	-219.2091	-104.1527	-66.1327	PA-7
8	3	0		0	1	1	-619.7365	-102.7886	-65.997	PA-8
9	2	23	ODB1	1	1	1	-34.5205	17.815	-74.6261	PAB-O1
10	2	23	ODB1	2	1	1	-55.5862	90.803	-74.6394	PAB-O2
11	2	23	ODB1	3	1	1	-76.5281	17.7743	-74.6513	PAB-O3

## Sensor list

SENSOR_NAME	TYPE_ID	WIRE	MODULE	SENSOR_TYPE	SERIAL_NUMBER	POLY_FILE
CDB1	1	1	1	CWPS	7D7-032	c:\ni-rt\APP\POLYF...
CDB2	1	1	3	CWPS	7DE-015	c:\ni-rt\APP\POLYF...

## Laser tracker data

FIDUCIAL	X	Y	Z	FIDUCIAL	MODULE
1	-307.177	-2565.71	-290.495	PA-1	1
2	87.2992	-2561.18	-290.56	PA-2	1
3	533.5942	-2560.94	-290.537	PA-3	1
4	935.5303	-2559.6	-290.387	PA-4	1
5	938.9992	-2809.29	-290.157	PA-5	1
6	536.4369	-2807.77	-290.219	PA-6	1

## Software

## Position of the girders' axes

DBM2_OUT_X	DBM2_OUT_Y	DBM2_OUT_Z	DBM2_Ry	DBM3_IN_X	DBM3_IN_Y	DBM3_IN_Z
-0.012	2000.101	-0.089	0.000263	-0.015	2010.152	-0.018
-0.012	2000.101	-0.089	0.000263	-0.015	2010.152	-0.017
-0.012	2000.101	-0.089	0.000263	-0.015	2010.152	-0.017

## Sensors readout

CMB11 Ux	CMB11 Dx	CMB11 Uy	CMB11 Dy	ODB1 Dx	ODB1 Dy
5.4108	0.6074	6.0982	1.7615	36.7812	63.6624
5.4107	0.6073	6.0978	1.7612	36.7822	63.6619
5.4107	0.6073	6.0978	1.7612	36.7822	63.6619





# 4. Active alignment



CONTROL cWPS oWPS INCL TEMP

Actuators List

AVL_DBM1	ZTS_NEW	20
AR_DBM1	ZTS_NEW	21
AVR_DBM1	ZTS_NEW	22
AVL_DBM2	ZTS_OLD	5
AR_DBM2	ZTS_OLD	7
AVR_DBM2	ZTS_OLD	6
AVL_DBM3	ZTS_OLD	3
AR_DBM3	ZTS_OLD	8
AVR_DBM3	ZTS_OLD	4
AVL_DBM4	ZTS_OLD	1
AR_DBM4	ZTS_OLD	9
AVR_DBM4	ZTS_OLD	2
AVL_DBM5	ZTS_NEW	1
AR_DBM5	ZTS_NEW	2
AVR_DBM5	ZTS_NEW	3
AVL_MBM1	MC	1
AR_MBM1	MC	3
AVR_MBM1	MC	2
AVL_MBM12	MC	4
AR_MBM12	MC	6
AVR_MBM12	MC	5
AVL_MBM2	MC	7
AR_MBM2	MC	9
AVR_MBM2	MC	8
AVL_MBM4	ZTS_NEW	17
AR_MBM4	ZTS_NEW	18
AVR_MBM4	ZTS_NEW	19
AVL_MBM5	ZTS_NEW	4
AR_MBM5	ZTS_NEW	5
AVR_MBM5	ZTS_NEW	6

Commands Displacement ZTS New Orders ZTS Old Orders MC Orders Response

GO RELATIVE -100

Delete all Add to list Send All

ACT STAT 1 ACT STAT 2 ACT STAT 3 ALIGNMENT PLOTS

AUTOMATIC ALIGNMENT RECORD ALIGNMENT

FUV 3.02128

ALIGN ALL

Load Orders DBM1		Load Orders DBM2		Load Orders DBM3		Load Orders DBM4		Load Orders DBM5	
DBM1 A	DBM1 B	DBM2 A	DBM2 B	DBM3 A	DBM3 B	DBM4 A	DBM4 B	DBM5 A	DBM5 B
0.000	0.000	-0.272	0.139	0.122	-0.215	-0.071	0.274	0.000	0.000
0.000	0.000	0.100	2000.101	2010.152	4010.152	4005.655	5981.625	0.000	0.000
0.000	0.000	-0.099	0.142	0.200	-0.107	-0.099	0.122	0.000	0.000
		DBM2 Ry		DBM3 Ry		DBM4 Ry			
		-0.000004		-0.000291		0.001434			

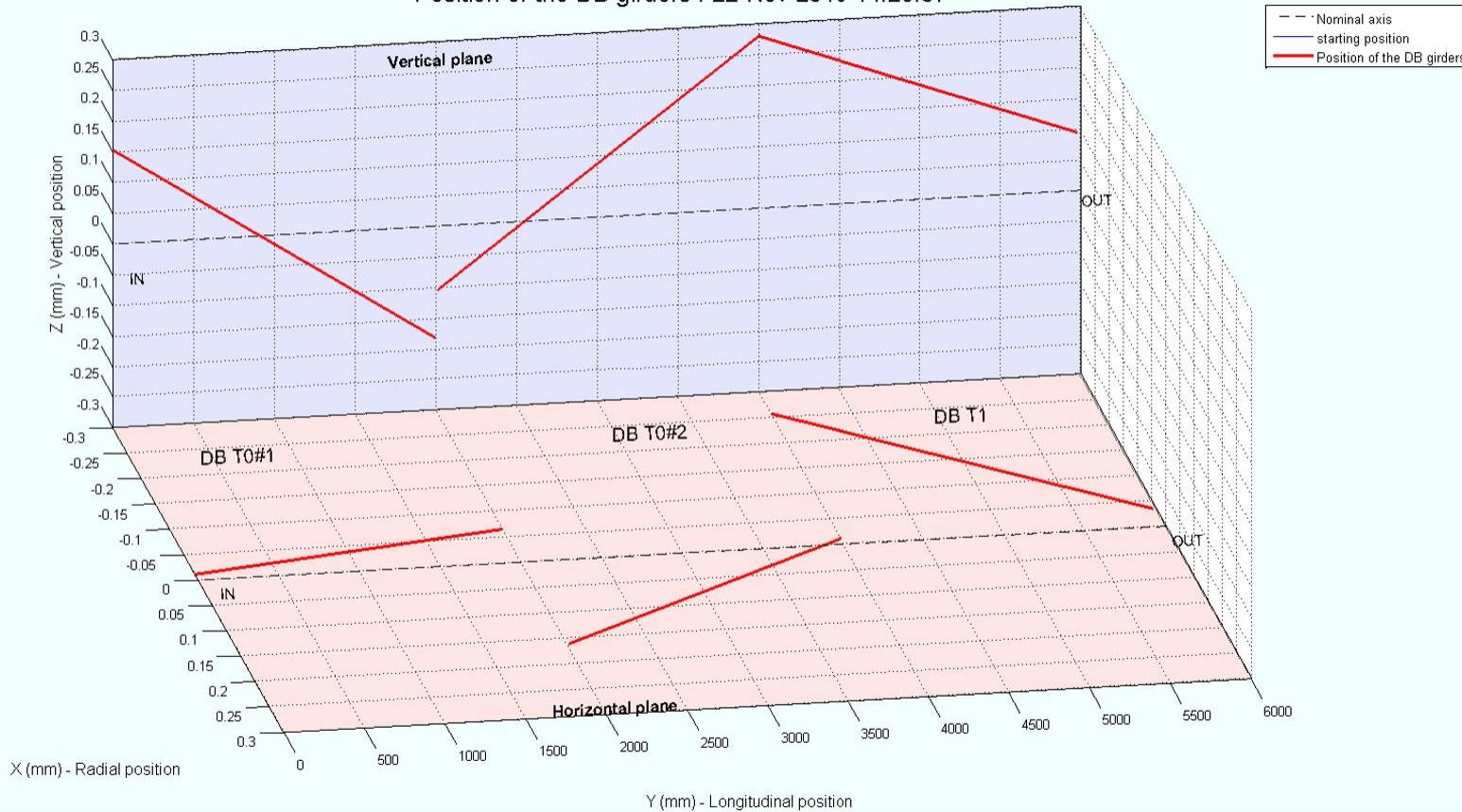
  

Load Orders MBM1		Load Orders MBM12		Load Orders MBM2		Load Orders MBM4		Load Orders MBM5	
MBM1 A	MBM1 B	MBM2 A	MBM2 B	MBM3 A	MBM3 B	MBM4 A	MBM4 B	MBM5 A	MBM5 B
649.838	650.093	650.175	649.741	0.000	0.000	649.653	650.101	0.000	0.000
10.159	2010.158	2022.947	3954.947	0.000	0.000	4727.555	6178.562	0.000	0.000
-0.108	0.122	0.125	-0.114	0.000	0.000	0.100	-0.115	0.000	0.000
	MBM1 Ry		MBM2 Ry			MBM4 Ry			
	-0.000322		-0.000335			-0.000274			

EMERGENCY STOP  
NORMAL MODE  
DISABLE MODE  
ENABLE MODE  
STOP

# 4. Active alignment response

Position of the DB girders : 22-Nov-2016 14:25:07

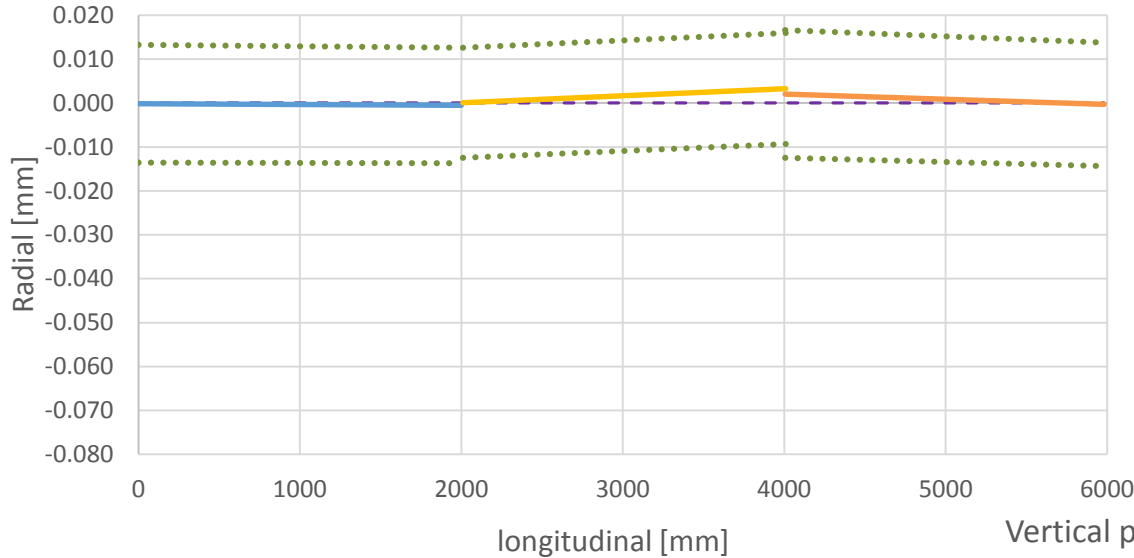




# 4. The results of active alignment



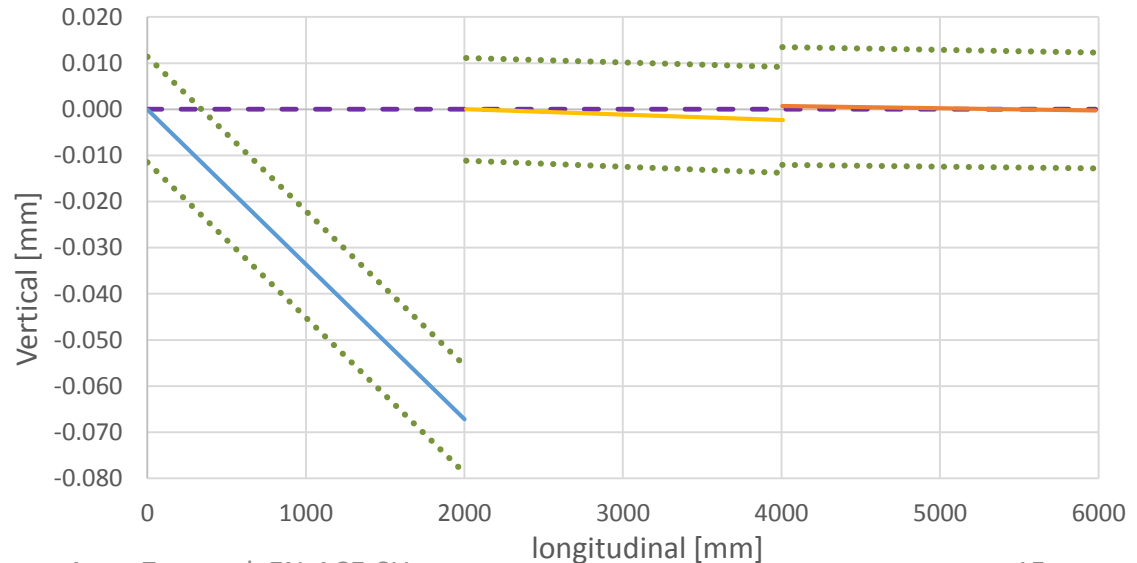
Radial position of the girders axes (DB side)



Precision comparable with the estimated one

- - - nominal
- DBT0#1
- DBT0#2
- DBT1
- ..... precision

Vertical position of the girders axes (DB side)

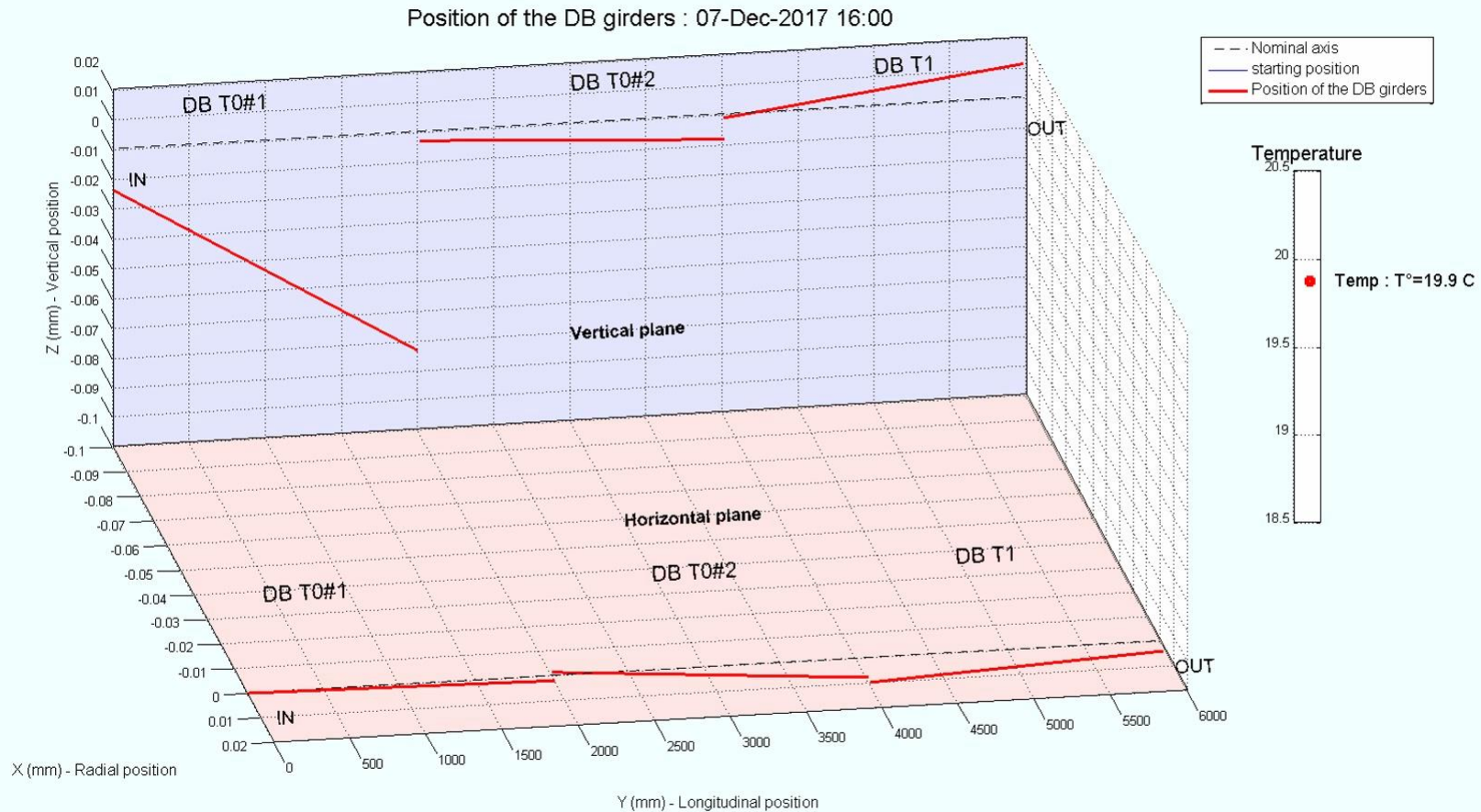




## 4. Good stability of the mock-up



Position of the DB girders during one month  
(07.12.2017 16:00 – 06.01.2018 08:00)





# 5. CLEX / CLEAR

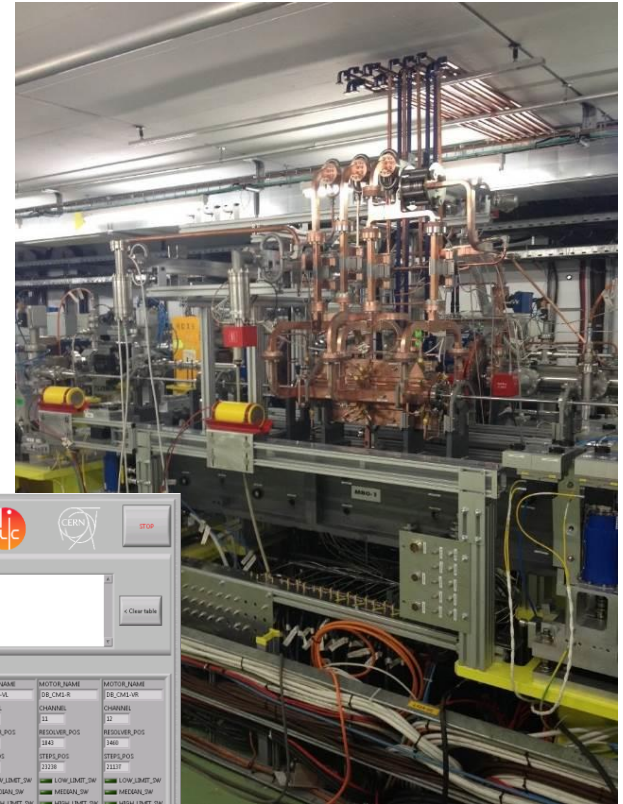
☺ Configuration based on two wires per girder with cWPS

☺ Has already worked for several years in CLEX / CLEAR facilities

☺ The girder can be repositioned to demanding positions during physics tests

☹ No active alignment

☹ Position of the girder has to be calculated by separate software



RECORDING		FREQUENCY		Download measurement file		EMERGENCY STOP		Emergency Stop		NORMAL MODE		Normal Mode			
1 MINUTE		1 SECOND													
<p>ACTUATOR NAME: ALL ACTUATORS</p> <p>COMMAND: NO ABSOLUTE STOP</p> <p>Displacement [mm]: 0</p> <p>Buttons: Add to list, Delete all, Send list, Clear table</p> <p>ZTS Received status: 137880° 18.1807 2018/02/09</p>															
ZTS MOTORS STATUSES				ZTS MOTORS STATUSES				ZTS MOTORS STATUSES				ZTS MOTORS STATUSES			
MOTOR_NAME	MOTOR_NAME	MOTOR_NAME	MOTOR_NAME	MOTOR_NAME	MOTOR_NAME	MOTOR_NAME	MOTOR_NAME	MOTOR_NAME	MOTOR_NAME	MOTOR_NAME	MOTOR_NAME	MOTOR_NAME	MOTOR_NAME		
MB_CMG-VR	MB_CMG-VR	MB_CMG-VR	MB_CMG-VR	MB_CMG-VR	MB_CMG-VR	MB_CMG-VR	MB_CMG-VR	MB_CMG-VR	MB_CMG-VR	MB_CMG-VR	MB_CMG-VR	MB_CMG-VR	MB_CMG-VR		
CHANNEL	CHANNEL	CHANNEL	CHANNEL	CHANNEL	CHANNEL	CHANNEL	CHANNEL	CHANNEL	CHANNEL	CHANNEL	CHANNEL	CHANNEL	CHANNEL		
1	1	1	1	1	1	1	1	1	1	1	1	1	1		
RESOLVER_POS	RESOLVER_POS	RESOLVER_POS	RESOLVER_POS	RESOLVER_POS	RESOLVER_POS	RESOLVER_POS	RESOLVER_POS	RESOLVER_POS	RESOLVER_POS	RESOLVER_POS	RESOLVER_POS	RESOLVER_POS	RESOLVER_POS		
414	594	422	248	305	1912	2062	1924	1912	1918	1918	1918	1918	1918		
STEPS_POS	STEPS_POS	STEPS_POS	STEPS_POS	STEPS_POS	STEPS_POS	STEPS_POS	STEPS_POS	STEPS_POS	STEPS_POS	STEPS_POS	STEPS_POS	STEPS_POS	STEPS_POS		
12142	1787	2229	2229	2229	2229	2229	2229	2229	2229	2229	2229	2229	2229		
LOW_LIMIT_SW	LOW_LIMIT_SW	LOW_LIMIT_SW	LOW_LIMIT_SW	LOW_LIMIT_SW	LOW_LIMIT_SW	LOW_LIMIT_SW	LOW_LIMIT_SW	LOW_LIMIT_SW	LOW_LIMIT_SW	LOW_LIMIT_SW	LOW_LIMIT_SW	LOW_LIMIT_SW	LOW_LIMIT_SW		
MEDIA_SW	MEDIA_SW	MEDIA_SW	MEDIA_SW	MEDIA_SW	MEDIA_SW	MEDIA_SW	MEDIA_SW	MEDIA_SW	MEDIA_SW	MEDIA_SW	MEDIA_SW	MEDIA_SW	MEDIA_SW		
HIGH_LIMIT_SW	HIGH_LIMIT_SW	HIGH_LIMIT_SW	HIGH_LIMIT_SW	HIGH_LIMIT_SW	HIGH_LIMIT_SW	HIGH_LIMIT_SW	HIGH_LIMIT_SW	HIGH_LIMIT_SW	HIGH_LIMIT_SW	HIGH_LIMIT_SW	HIGH_LIMIT_SW	HIGH_LIMIT_SW	HIGH_LIMIT_SW		
CMS	CMS	CMS	CMS	CMS	CMS	CMS	CMS	CMS	CMS	CMS	CMS	CMS	CMS		
MOTION_STATUS	MOTION_STATUS	MOTION_STATUS	MOTION_STATUS	MOTION_STATUS	MOTION_STATUS	MOTION_STATUS	MOTION_STATUS	MOTION_STATUS	MOTION_STATUS	MOTION_STATUS	MOTION_STATUS	MOTION_STATUS	MOTION_STATUS		
MCCH	MCCH	MCCH	MCCH	MCCH	MCCH	MCCH	MCCH	MCCH	MCCH	MCCH	MCCH	MCCH	MCCH		
COMMAND	COMMAND	COMMAND	COMMAND	COMMAND	COMMAND	COMMAND	COMMAND	COMMAND	COMMAND	COMMAND	COMMAND	COMMAND	COMMAND		
NOCC	NOCC	NOCC	NOCC	NOCC	NOCC	NOCC	NOCC	NOCC	NOCC	NOCC	NOCC	NOCC	NOCC		
MOTOR_RESOLUTION	MOTOR_RESOLUTION	MOTOR_RESOLUTION	MOTOR_RESOLUTION	MOTOR_RESOLUTION	MOTOR_RESOLUTION	MOTOR_RESOLUTION	MOTOR_RESOLUTION	MOTOR_RESOLUTION	MOTOR_RESOLUTION	MOTOR_RESOLUTION	MOTOR_RESOLUTION	MOTOR_RESOLUTION	MOTOR_RESOLUTION		
0.18024	0.18024	0.18024	0.18024	0.18024	0.18024	0.18024	0.18024	0.18024	0.18024	0.18024	0.18024	0.18024	0.18024		
ERRORS	ERRORS	ERRORS	ERRORS	ERRORS	ERRORS	ERRORS	ERRORS	ERRORS	ERRORS	ERRORS	ERRORS	ERRORS	ERRORS		
ERROR1	ERROR1	ERROR1	ERROR1	ERROR1	ERROR1	ERROR1	ERROR1	ERROR1	ERROR1	ERROR1	ERROR1	ERROR1	ERROR1		
ERROR2	ERROR2	ERROR2	ERROR2	ERROR2	ERROR2	ERROR2	ERROR2	ERROR2	ERROR2	ERROR2	ERROR2	ERROR2	ERROR2		
ERROR_FLAGS	ERROR_FLAGS	ERROR_FLAGS	ERROR_FLAGS	ERROR_FLAGS	ERROR_FLAGS	ERROR_FLAGS	ERROR_FLAGS	ERROR_FLAGS	ERROR_FLAGS	ERROR_FLAGS	ERROR_FLAGS	ERROR_FLAGS	ERROR_FLAGS		
ERROR_FLAGS1	ERROR_FLAGS1	ERROR_FLAGS1	ERROR_FLAGS1	ERROR_FLAGS1	ERROR_FLAGS1	ERROR_FLAGS1	ERROR_FLAGS1	ERROR_FLAGS1	ERROR_FLAGS1	ERROR_FLAGS1	ERROR_FLAGS1	ERROR_FLAGS1	ERROR_FLAGS1		



## 6. Conclusion



- Current solutions (with available sensors) can in two cases provide axis-precision below  $14\ \mu\text{m}$ : 2 wires with cWPS or 1 wire and tilt meter with an accuracy of  $10\ \mu\text{rad}$
- At a fixed temperature of  $20^\circ\text{C}$ , the stability over 10 days is below  $5\ \mu\text{m}$  in the radial direction, while it is below  $10\ \mu\text{m}$  in the vertical position
- The software provides fast and precise alignment of the girders
- The implemented solution, tested in realistic conditions (CLEX / CLEAR), gives satisfying results

Thank you for your  
attention

Special acknowledgements to Vivien Rude, Mateusz Sosin and H el ene Mainaud Durand