Alignment systems: status of development

M. Sosin on behalf of EN/SMM-HPA team

Review of HL-LHC Alignment and Internal Metrology (WP15.4)
CERN, 26-28 August 2019

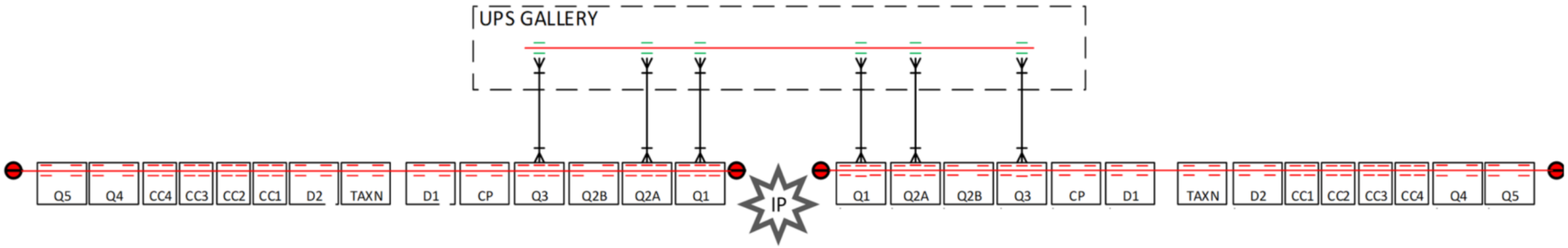
Outline

- Capacitive measurement system R&D summary
  - Capacitive sensors electronics and DAQ system
  - Polyamide PCB WPS (P-WPS) sensor prototype
  - Wire replacement system
  - New wire R&D
- MT-FSI instrumentation – reliability driven
  - Internal metrology equipment(Insulated reflectors, Vacuum FSI heads)
  - Glass ball reflectors
  - iHLS, DoublePass iHLS
  - Inclinometer
  - Short distance measurement
  - Long distance measurements
- Conclusions

New RAD-TOL capacitive sensors acquisition electronics

Low cost WPS sensor

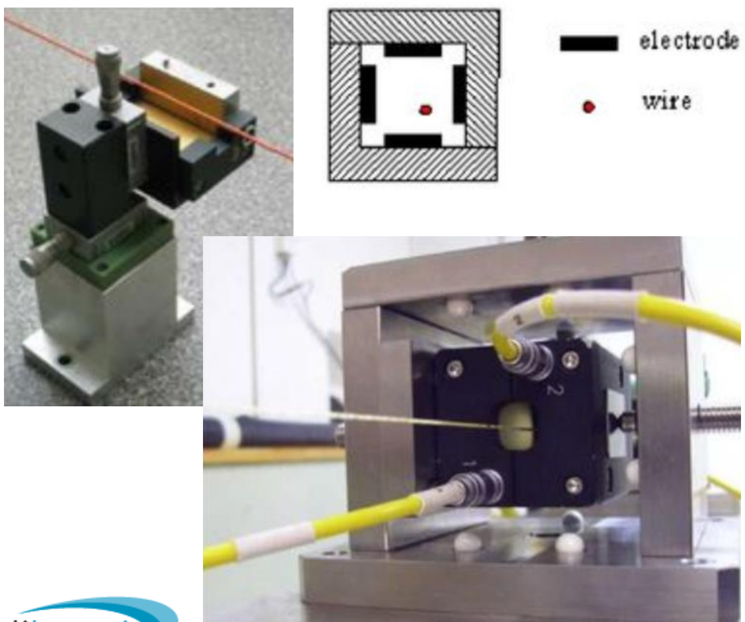
Capacitive Wire Positioning System



Stretched wire (or alternative)
Sensors (radial reference for the cavern)
Sensors (vertical + radial measurements)

WPS sensor

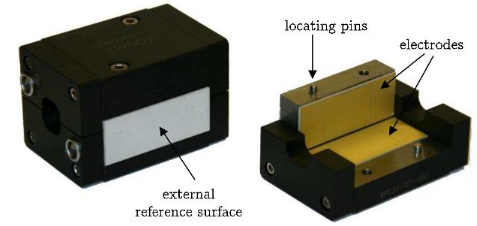
- X-Y measurement w.r.t. stretched conductive wire
- Accuracy < 5µm, Resolution < 1µm
- **Limited cable length (max. 30 .. 50 m)**
  - **Conditioning electronics need to be RAD-TOL**

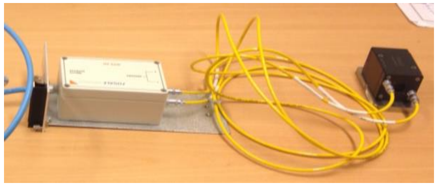


Why new electronics and WPS sensors?

- FOGALE solution
  - „BLACK BOX" solution
  - Delivered in sets (sensor + conditioner + cable)
  - No remote diagnostic possibility
  - Expensive

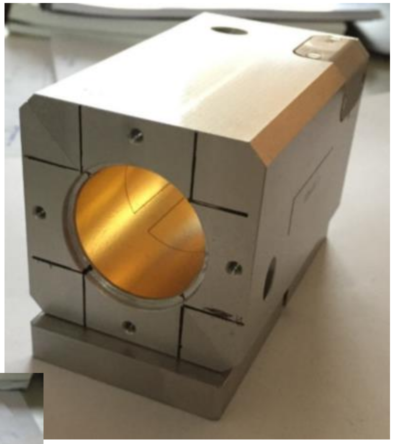
Currently used FOGALE sensor





5 x 5 x 8 cm

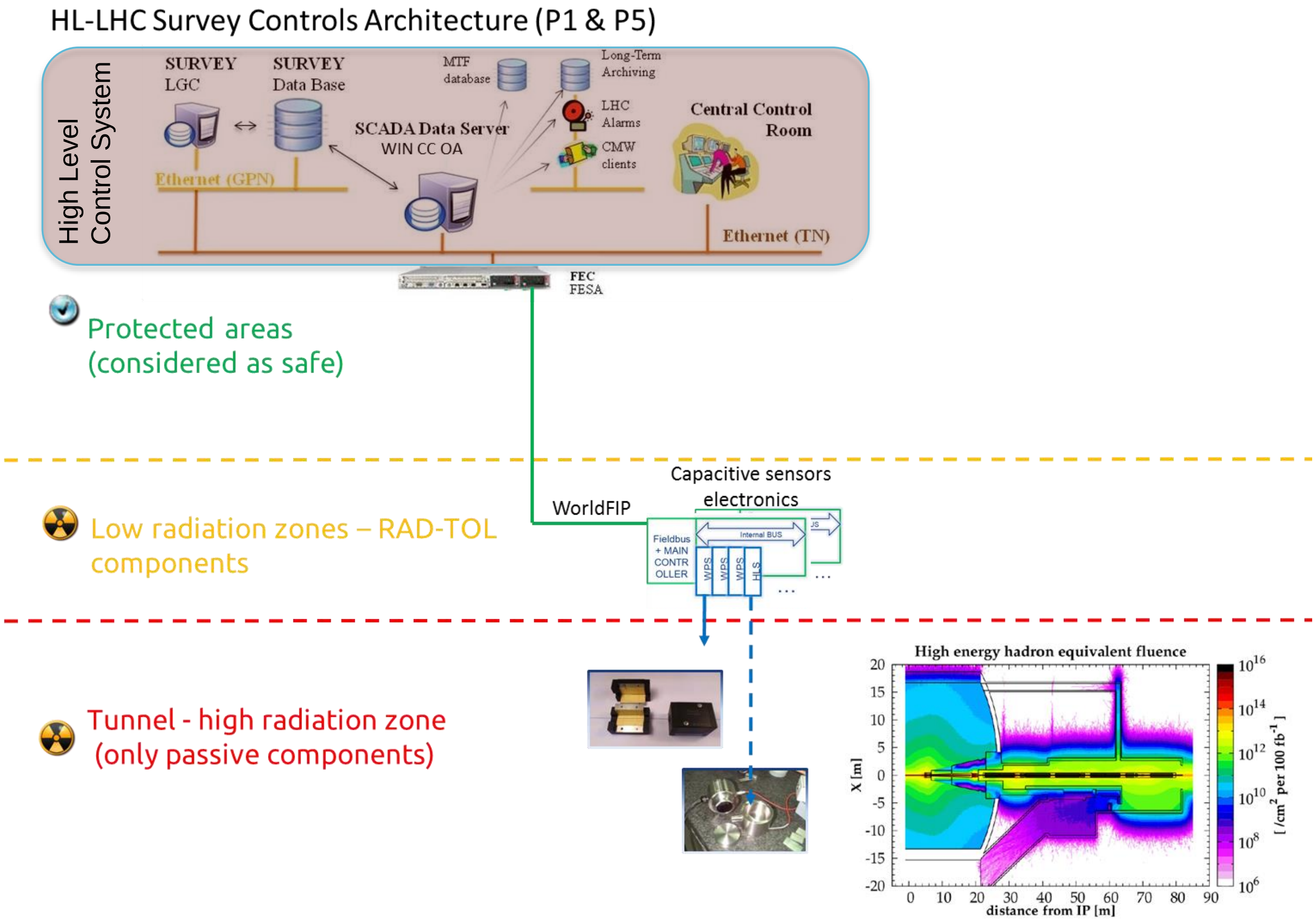
- CERN P-WPS + universal capacitive sensor conditioner
  - Simple and cheap
  - Compatible with current supports
  - Adopted to vacuum wire replacement system (round aperture) – **Broken wire replacement function**
  - Radiation tolerant
  - Designed for use with all capacitive CERN sensor (WPS, HLS, DOMS)
  - Provides remote diagnostics of electronics, sensor performance
  - Provides remote parameters tuning



6 x 6 x 10 cm

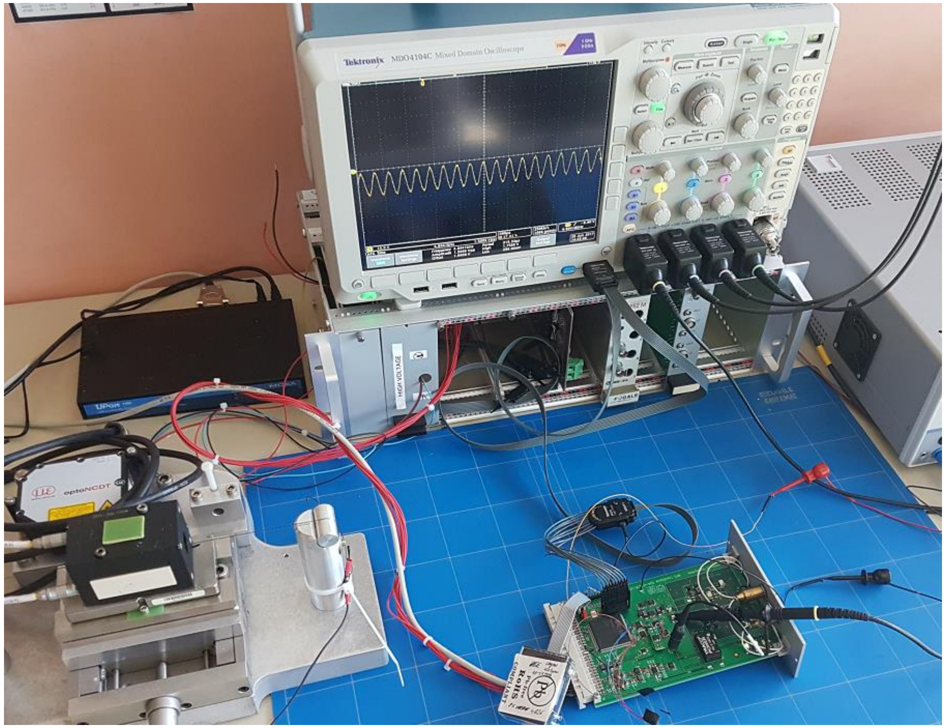
Layout of HL-LHC control/monitoring system

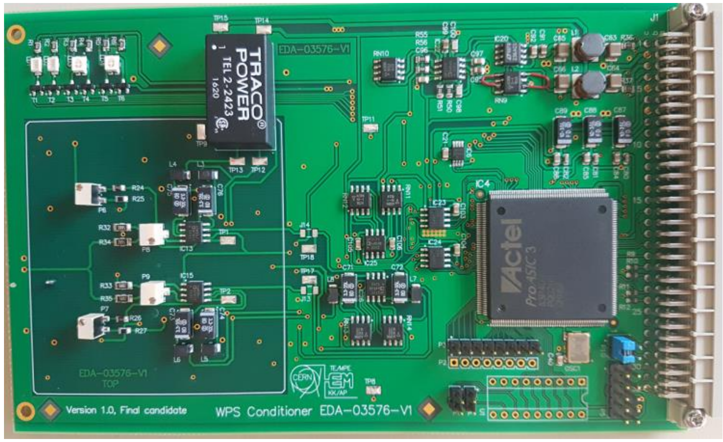
- Capacitive conditioners electronics in radiation zones due to cable length limitation
- Needs to be radiation tolerant

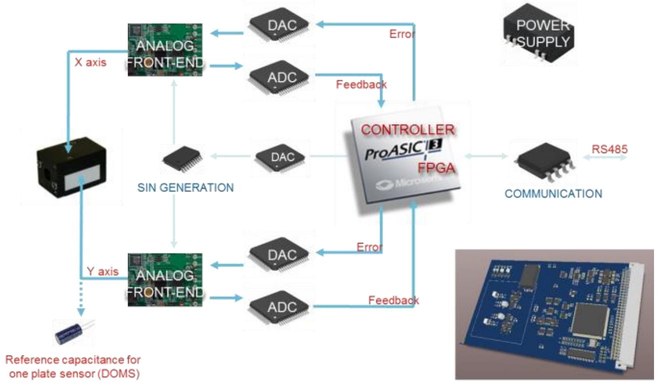


New electronics – standardized modules

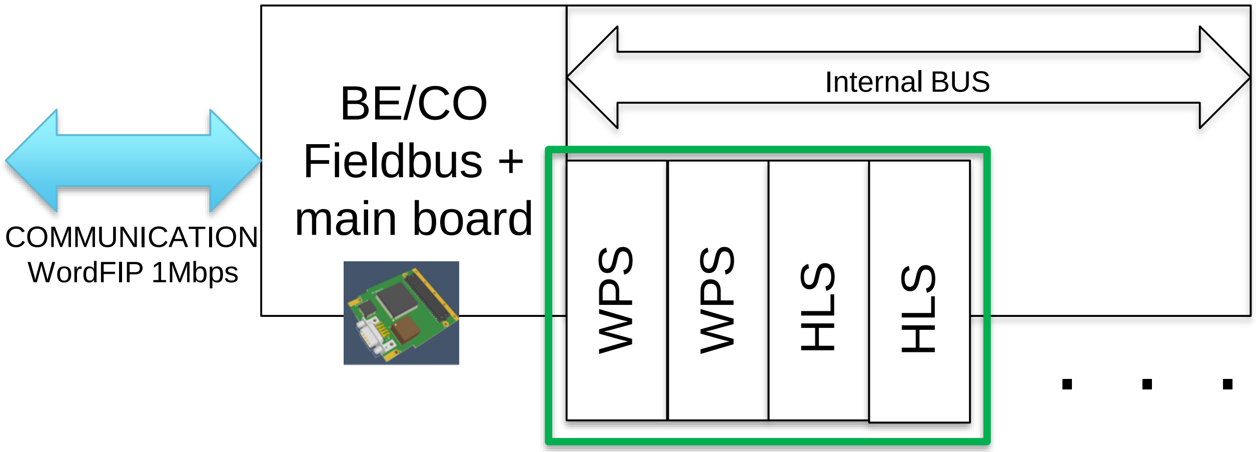
- Standardized capacitive sensors signal conditioner
- Same hardware for WPS, HLS, DOMS
- ‚Deep' diagnostics of signals and sensing chain
- RAD-TOL (200Gy)





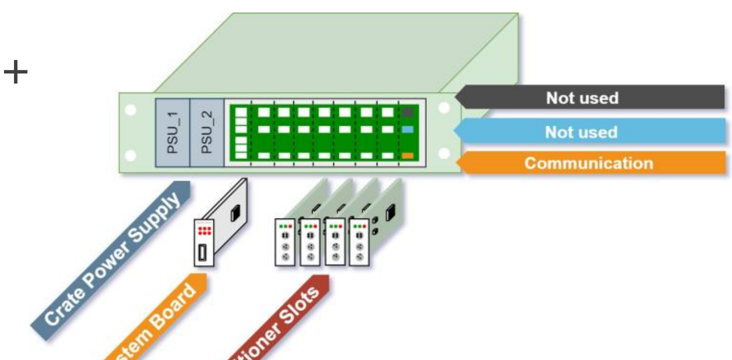


HL-SAS rad-tol chassis



<u>Unified main-board for all kind of used modules</u>

- Single hardware and software development
- HL-SAS chassis for RAD-TOL and safe locations
- Design pending with cooperation of BE/CO (https://wikis.cern.ch/display/DIOT/Distributed+ +Tier+chassis)



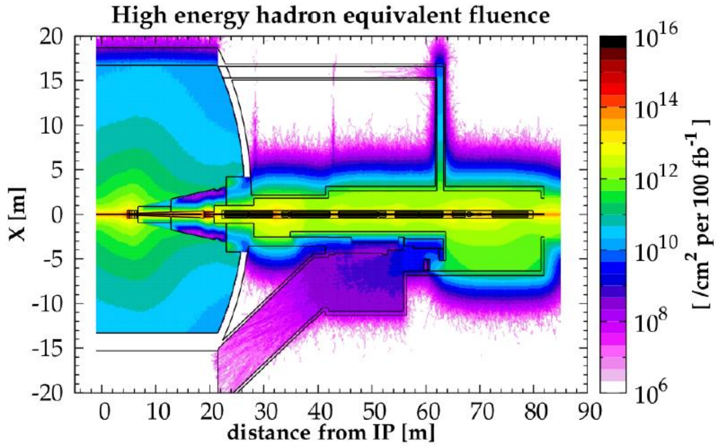
Kamil Kucel, EN-SMM-HPA

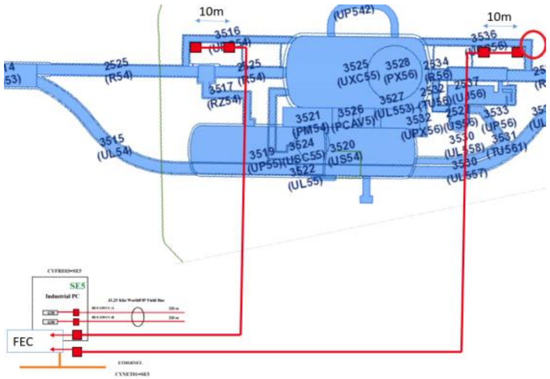
WPS Conditioner – UPS test

UPS test (started @ TS1 2018): test of conditioner in real radiation and noise environment

- Overall installation commissioned and launched in UPS 54
- **No issues observed during 6 months of operation with be beam in LHC**

R. Garcia

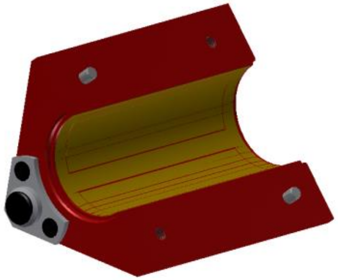




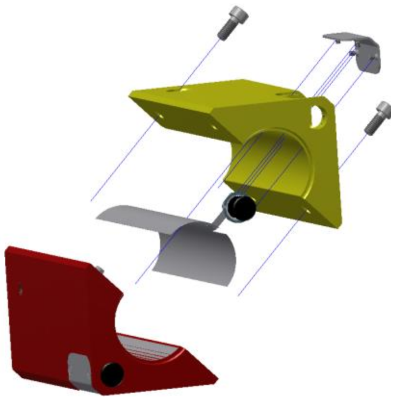
Capacitive Position Sensors Conditioner - status

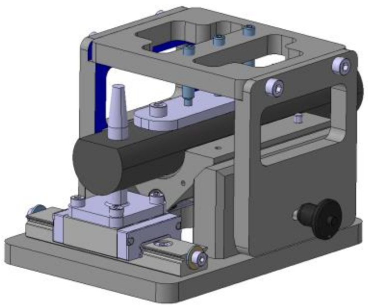
- Digital version of conditioner designed and under upgrade to be compatible with DIOT crate
- Pre-test with all sensors types has been done
- Most of FPGA Firmware developed
- First long term test provides good results
- Thermal tests ongoing
- Radiation tests to be planned when final conditioner PCB ready
- Test with multiple (40..50) sensors on single wire necessary (check possibility of interferences)

Low cost P-WPS (Polymide PCB based WPS sensor)

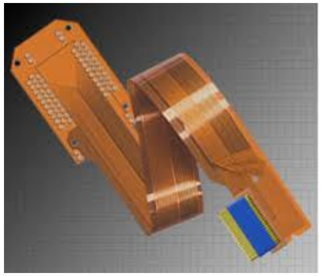


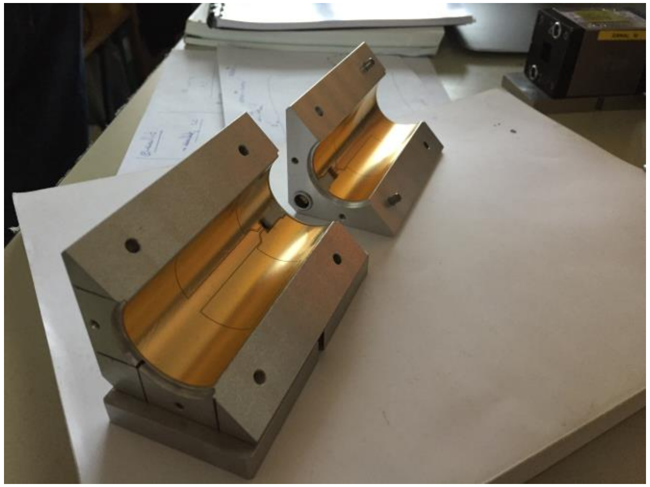
- Electrodes deposed on Polyamide (UBI Upilex Polyamide)
- Al. alloy body + 10um anodization Epoxy glue (Araldite 2011) [rad-hard]
- 25um UBI Upilex Polyamide[250Mrd ~ 2.5MGy]
- 5um Copper
- 1um gold layer as electrode

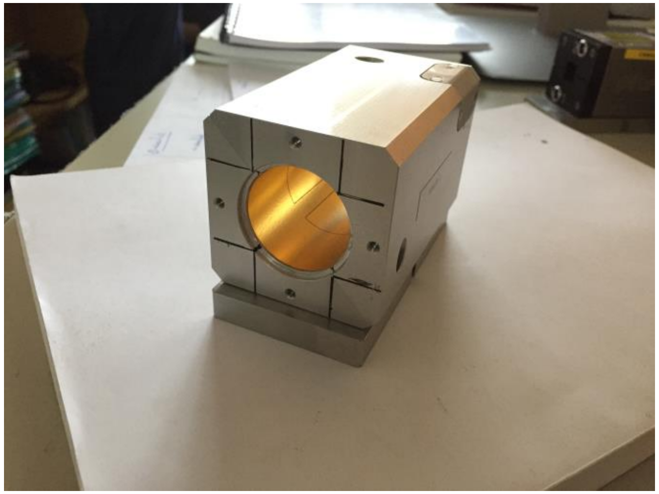




Electrodes gluing tooling



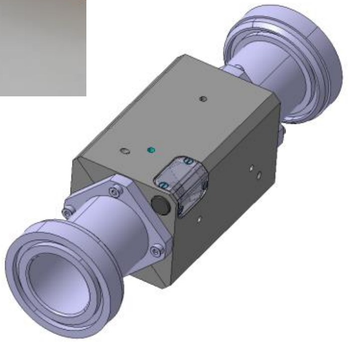




Low cost P-WPS sensor - summary

- Initial series of sensors preliminarily tested with Fogale and CERN electronics
  - **Sensors shows the same performance as original Fogale sensors**
- Radiation tests of Polyamide samples glued on aluminium done in Autumn 2018 in Fraunhofer
  - **No issues observed (TID 5MGy)**
- Next series (15 pieces) of sensors for TT1 tests ready for assembly
- Thermal tests of sensors pending

Dose	unirradiated	irradiated
300 kGy		
1 MGy		

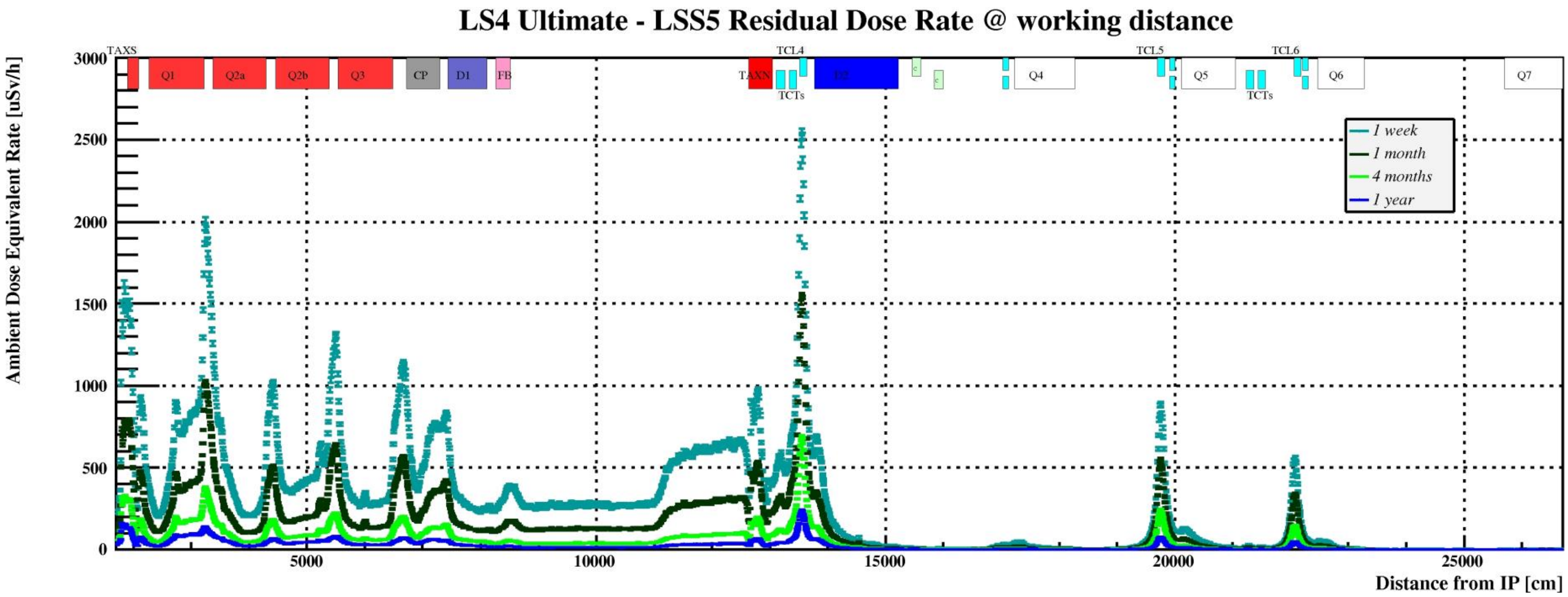


Wire replacement systems

New wire development

Why we need wire replacement system?

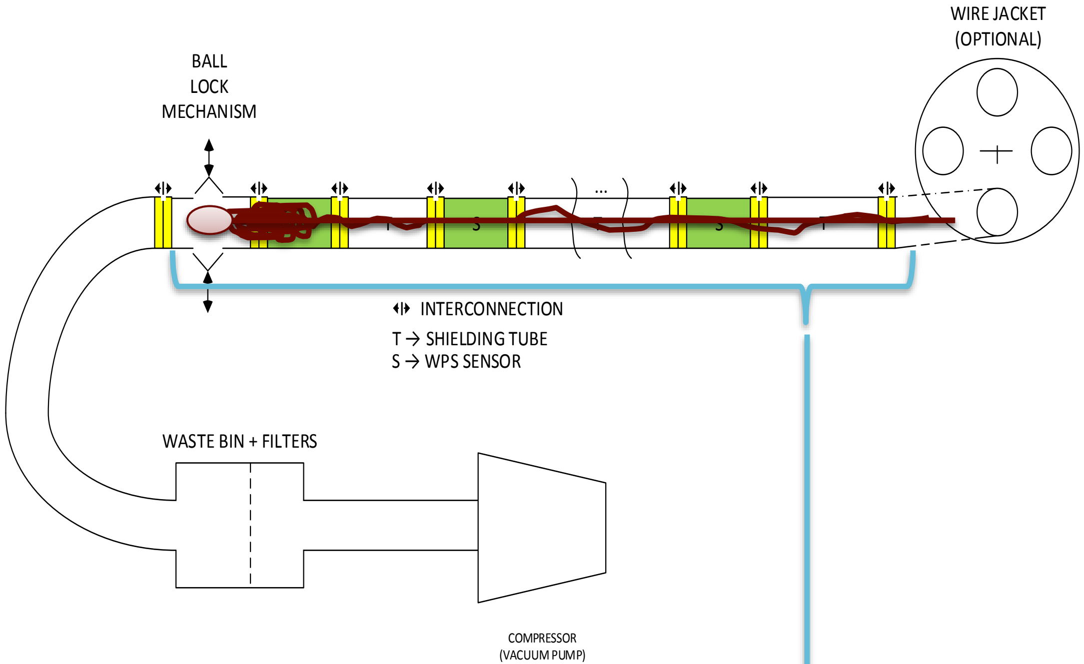
- Residual radiation levels not allow for fast wire replacement in case of break
- Manual replacement feasible only during long technical stop after approporiate „cooling" time



C.Adorisio - WP15 Meeting 24.03.2017

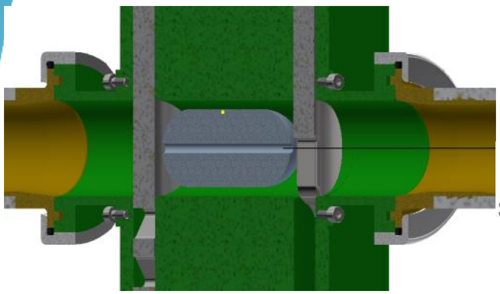
Vacuum Wire Replacement System

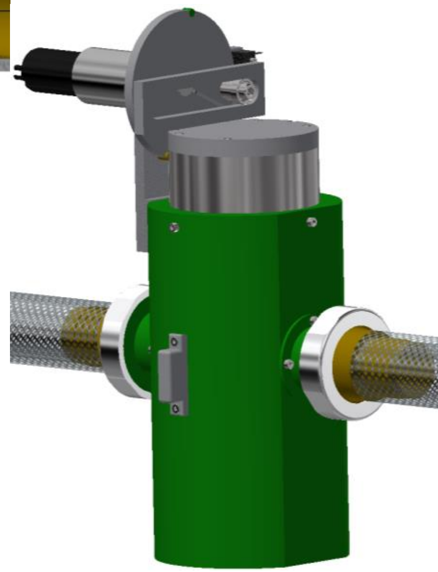
1. Wire
2. Vacuum tube
   - WPS Sensor is a part of vacuum tube
3. Ball-lock-mechanism
4. Wire stretcher
5. Bead

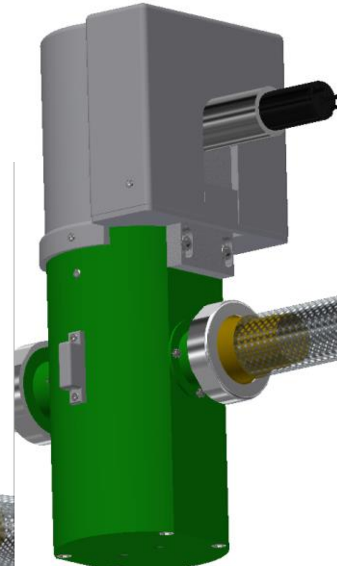


Pulling and clamping of the wire

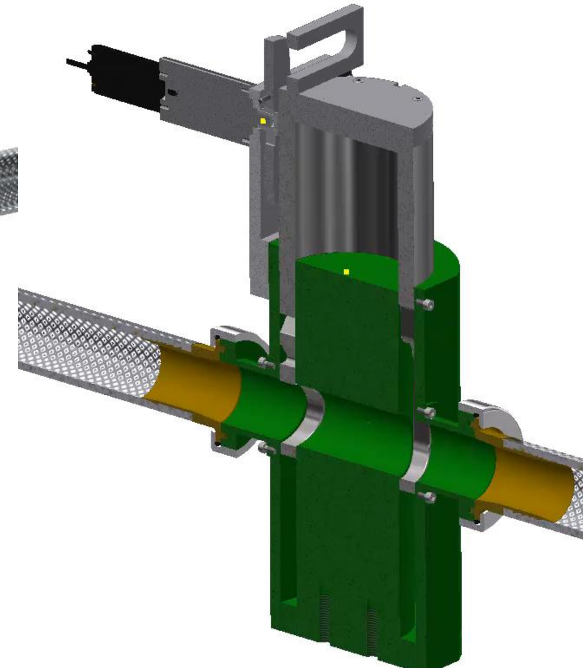
Ball lock mechanism and final bead design





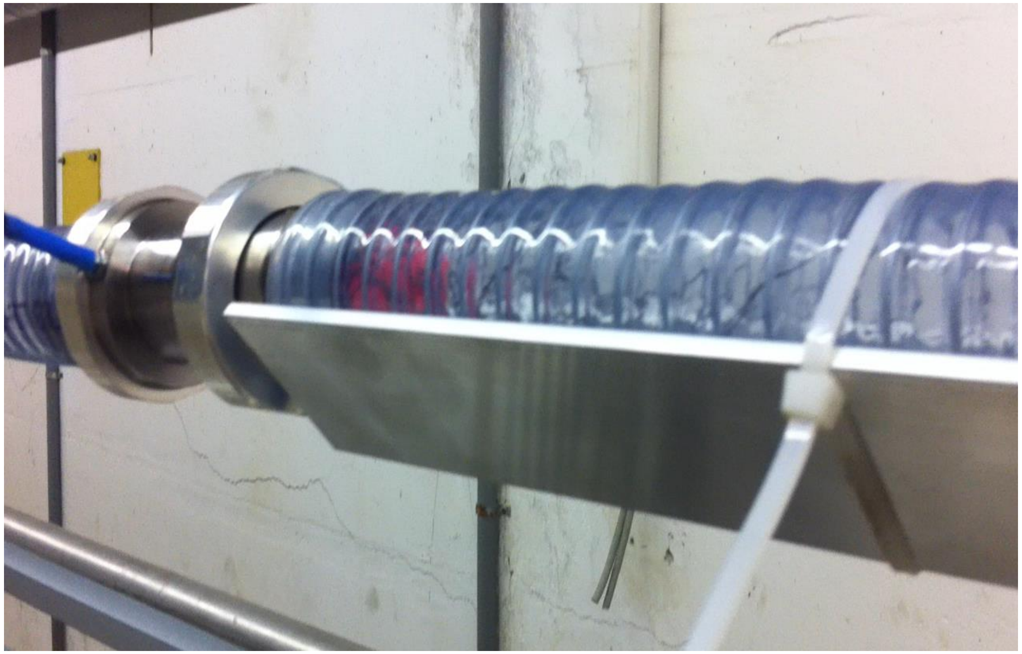


Video:



- Ball lock mechanism under manufacturing
  - Initial tests September 2019
- New beads with wire locking feature initially tested
  - Issues with Carbon-PEEK wire, which is breaking – modifications of bead design pending

WPS – pneumatic wire replacement system



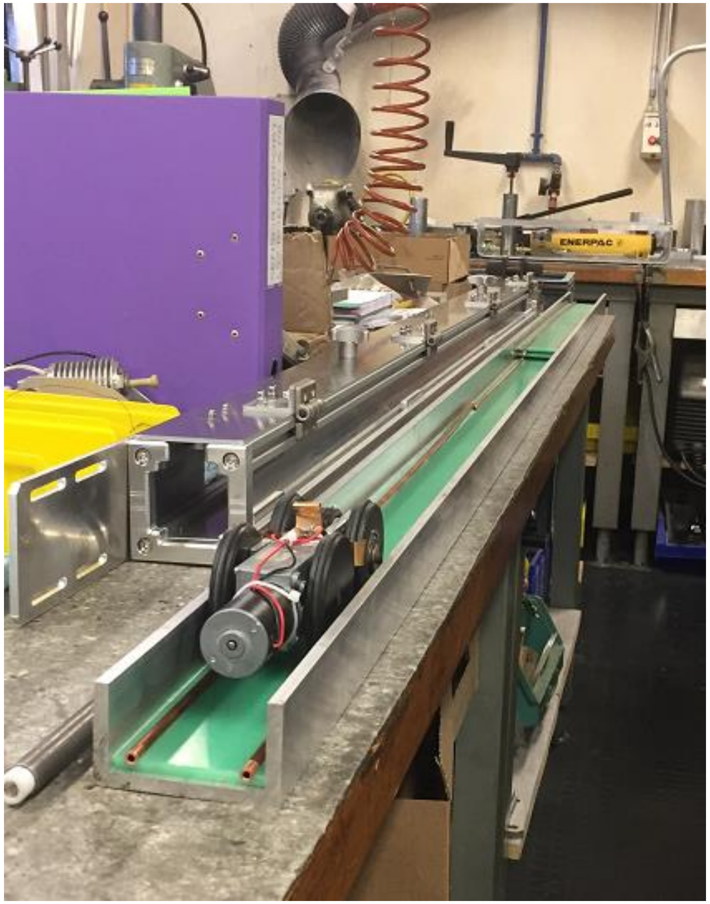
- TT1 installation – full size HL-LHC mock-up
  - 140m of vacuum tube + sensors mock-ups installed
  - Initial tests with different beads and pulling/cleaning scenarios performed in July - August 2018
  - **System showed satisfactory performance**
- Initial radiation tests of vacuum tubes done

J. Jaros, O. Matissov, M. Sosin

HiLumi HL-LHC PROJECT

Car wire replacer system

- Wire replacing system based on motorized „car” unit and open WPS sensor
- Series of prototypes under preparation/investigation by M. Rousseau, B. Perret



HiLumi
HL-LHC PROJECT

New wire development

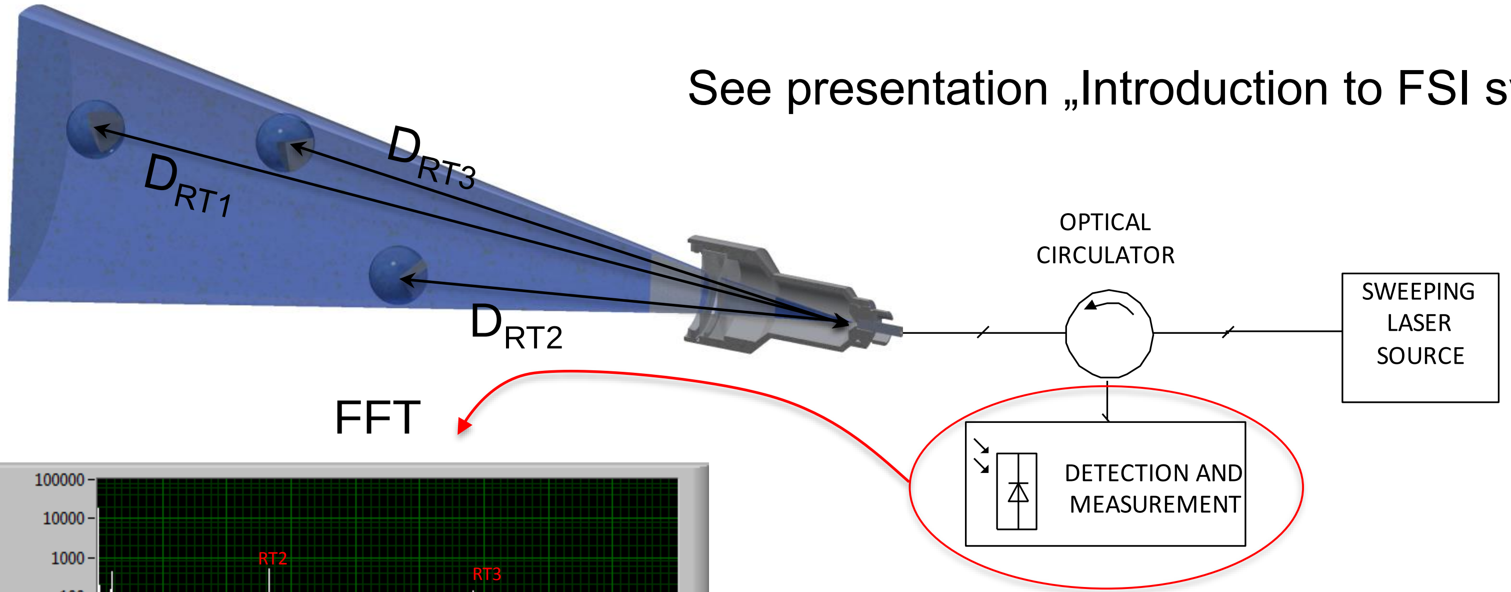
- Development of new Carbon based wire with EMPA with INO Swiss founding
- Carbon-Kevlar wire assumed as a spare LHC solution in case when R&D of new wire will be delayed
  - 20kg load needed to reach same sag as for currently used Carbon-PEEK wire

Multi-target Frequency Scanning Interferometry Instrumentation

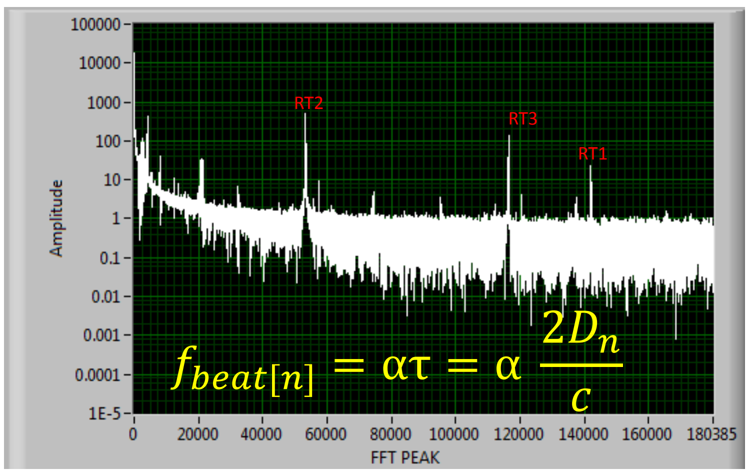
- Triplet and crab cavity internal monitoring vacuum FSI heads
- Optical targets
- Interferometric iHLS sensor for magnets and TAXN
- Inclinometers for magnets, masks and collimators
- Longitudinal (short distance) position sensors for magnets
- Long distance (UPS vs. Triplet) measurement

Multi-target FSI

See presentation „Introduction to FSI systems"



FFT



$$D_n = c \frac{f_{beat[m]}}{2\frac{dv}{dt}n}$$

α – is a sweep rate of the laser ($\alpha = \frac{dv}{dt}$ - laser frequency change in time);

c – speed of light; n – refractive index of light transmission medium;

τ – time of flight of laser to the target

Reliability driven optical sensors design

High radiation levels (see morning G. Lerner presentation) and difficult access forces surveyors to deploy possible-maintenance free systems

Simplified and robust optics to be used in all systems

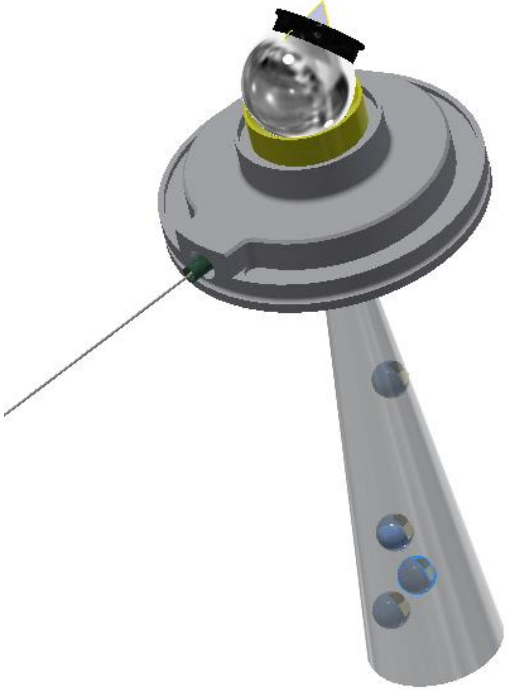
- **Divergent beam** as a **standard solution**, to avoid designing adjustable opto-meachnics
- When possible - the **bare-fibre ferrules** are used as a **divergent beam launch**
- **Glass ball reflectors** considered as the **standardized solution** – cost optimization, reliability
- When possible – single interferometer channel for measurement of multiple distances
- Multi-reflection sensors to increase intra-sensors system performance

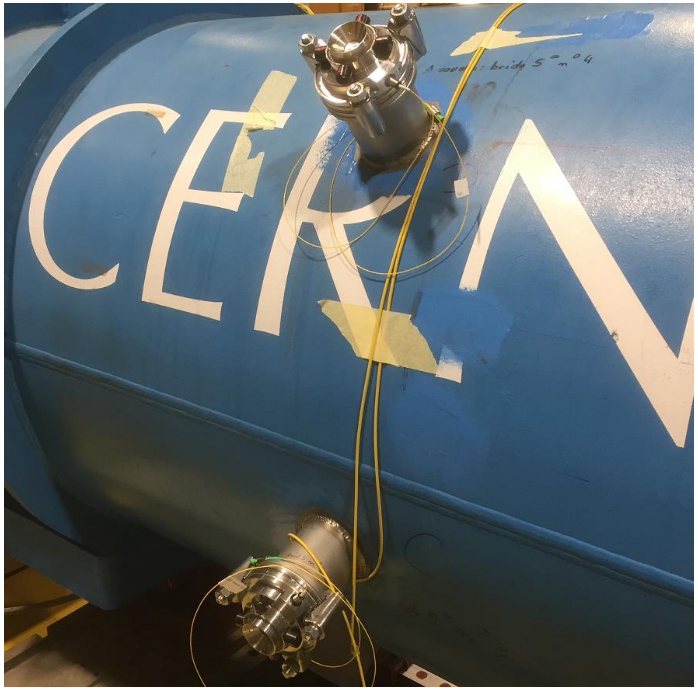
MT - FSI vacuum head

Cost optimized, multi-target, divergent beam FSI head for HL-LHC

- Single metal body ISO-K chassis, no movable parts, minimum amount of optical components, low price -> high system availability targeted

- Prototype tested on DIPOLE
  - No problem with target alignment on the dipole flanges
  - Negligible loss of intensity even with cold mass full contraction

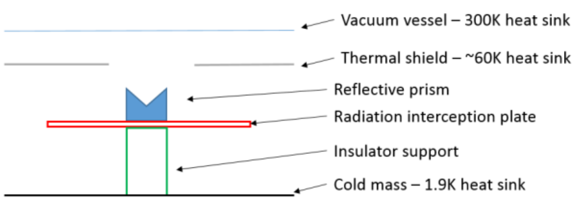




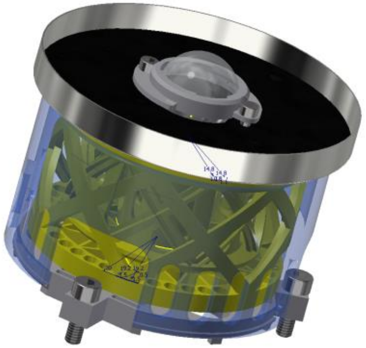
FSI: Cryo-compatible prism support

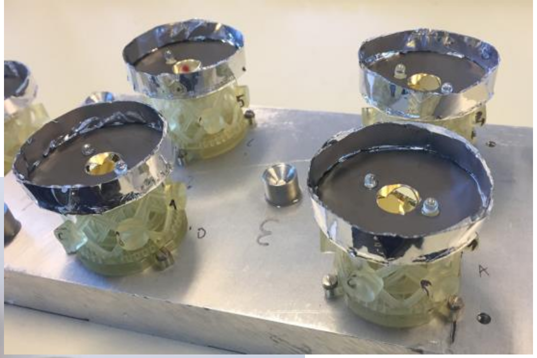
Status

- New DIPOLE test in SM18 under preparation
- The new (4th) generation of targets designed - more robust to shock and rigid insulator shape
- Insulator support 3D printed



F. Micolon





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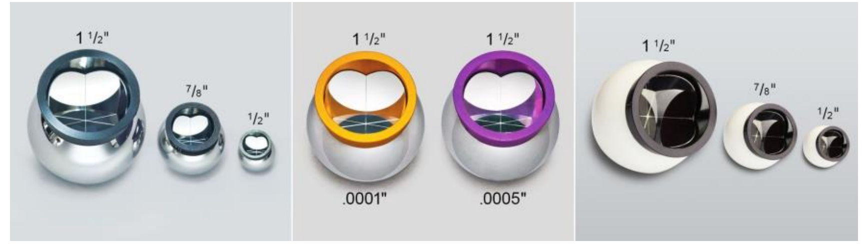
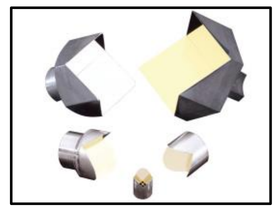
MT-FSI Instrumentation – glass ball reflectors

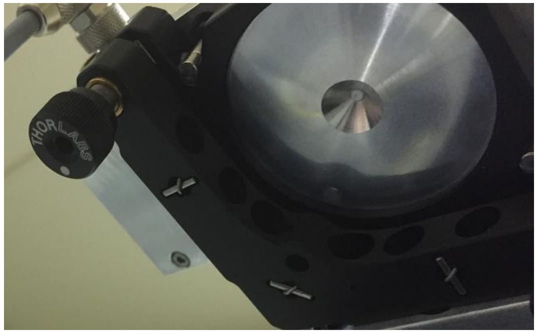




- Cheap, hollow retroreflector already used in dipole test
- Refractive index ≈2 glass ball as a alternative to hollow retroreflectors or replicated reflectors (~40€ vs. ~2k€ vs. 300 €)
- Radiation tests of hollow and glass reflectors (5MGy) done – no impact on measurement
- Coated glass ball reflector and cheap hollow retroreflector used in dipole test – no specific issues observed with MTFSI
- Coated glass ball reflector measurable by laser tracker

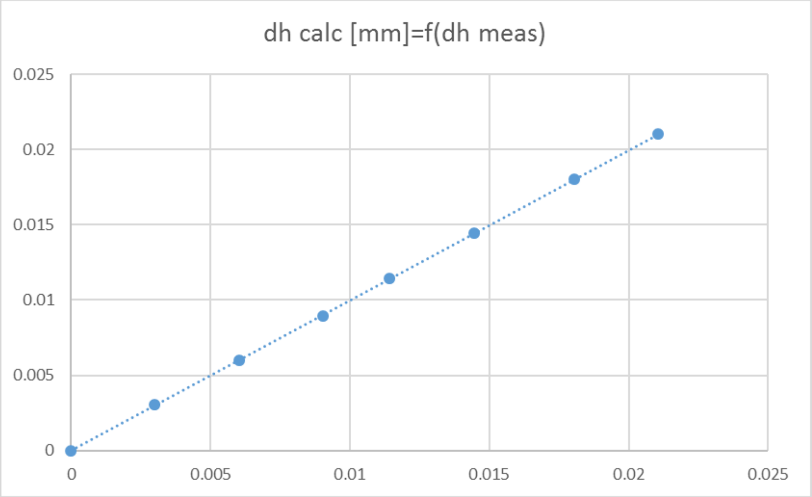
HiLumi HL-LHC PROJECT

Multi-Target FSI – cost optimized *interferometric Hydrostatic Levelling Sensor (iHLS)*



Simple HLS sensor = water wessel + fibre ferrule

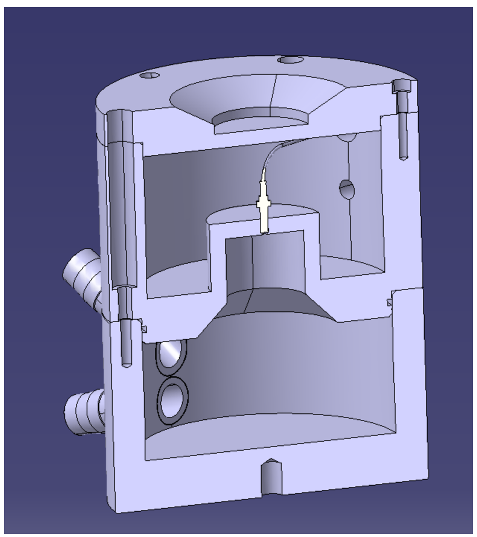
- Minimized cost of the sensor



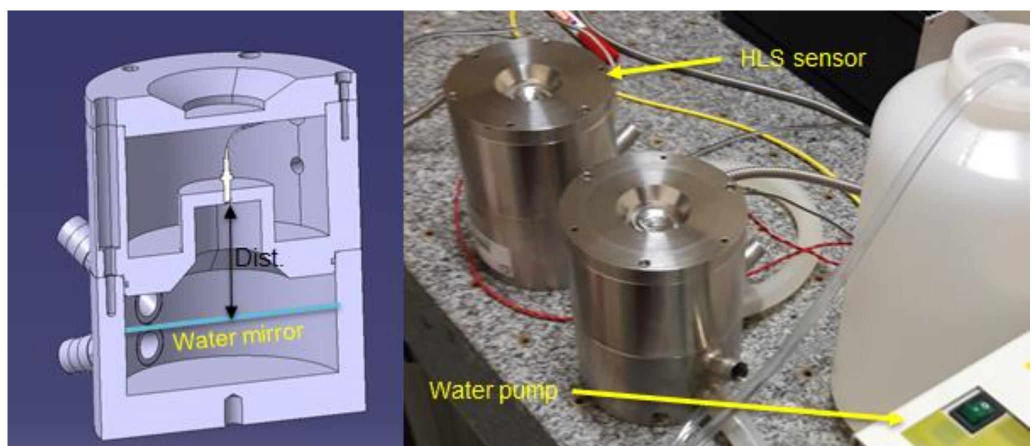
Multi-Target FSI – cost optimized *interferometric Hydrostatic Levelling Sensor (iHLS)*

Cost optimized, divergent beam FSI HLS sensor for HL-LHC

- Single metal body ISO-K chassis, no movable parts, minimum amount of optical components, low price -> high system availability targeted
- Measurement uncertainty < 5µm
- Precision ~1 µm
- Prototype assembled and under tests

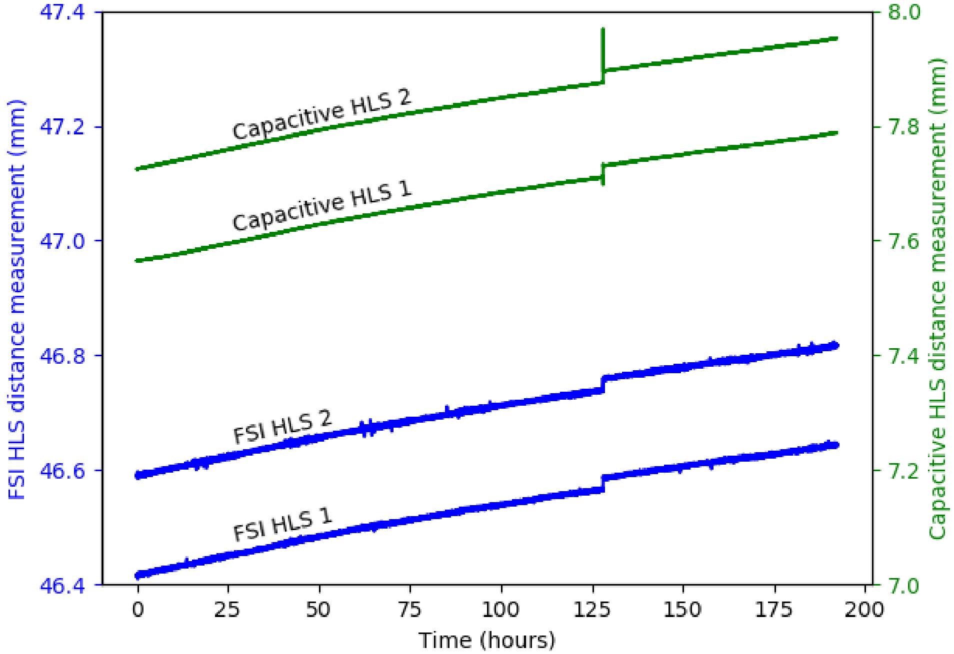


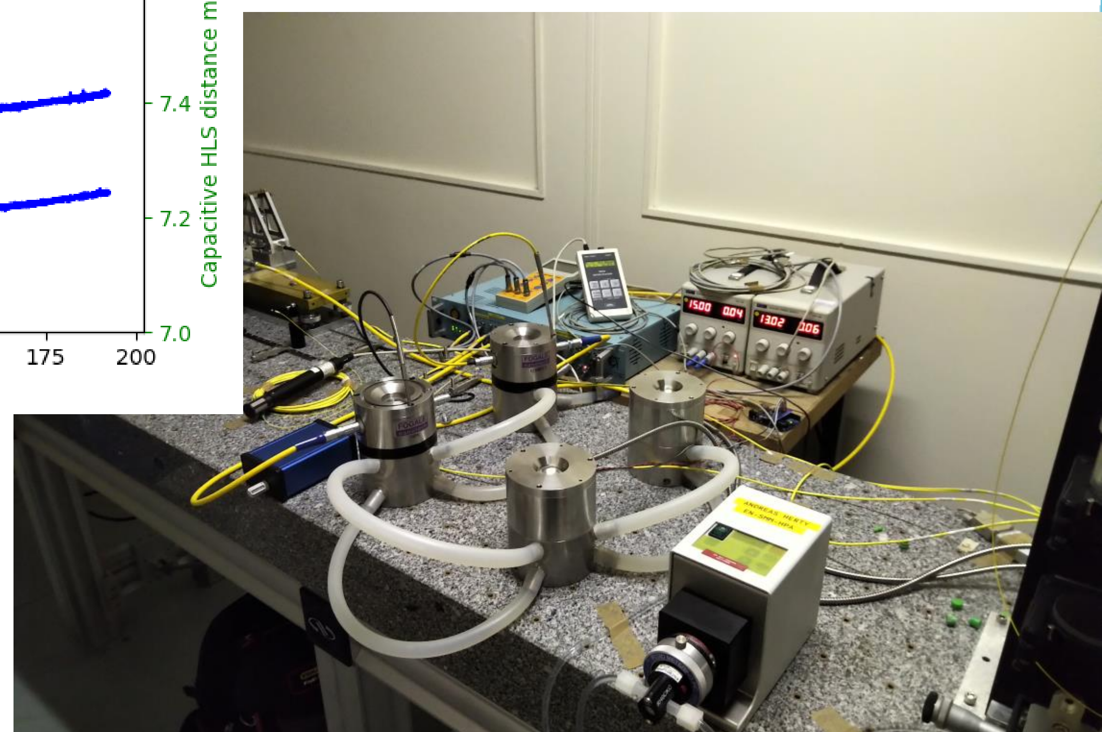
Initial tests shows very good performance of the sensor



Multi-Target FSI – cost optimized *interferometric Hydrostatic Levelling Sensor (iHLS)*

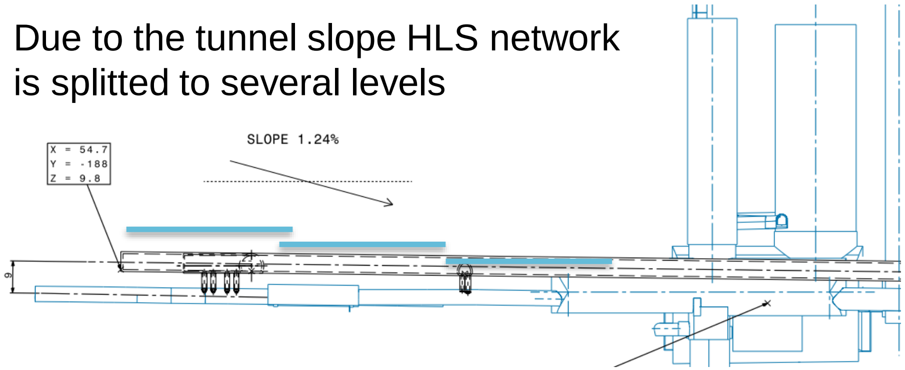
- Long term stability tests pending in Bld. 169 laser lab
- Comparative measurements of 2 iHLS with 2 cHLS
- **Very good performance - capacitive and optical sensors measuremnts are coherent**



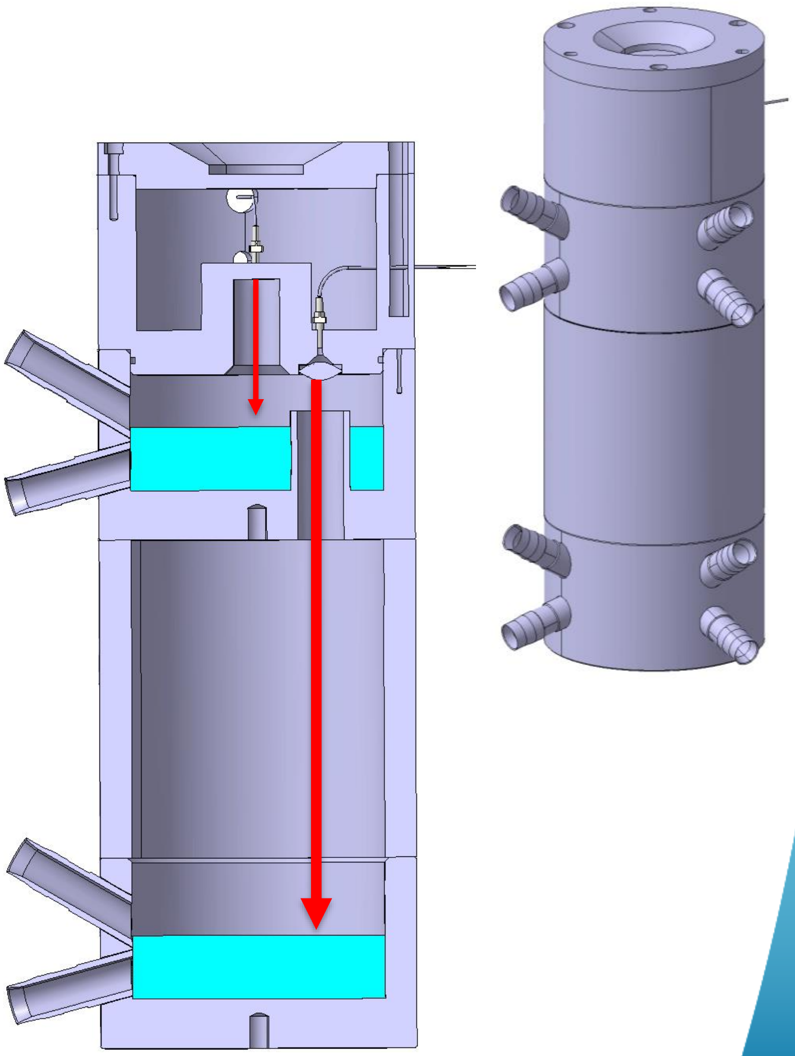


Multi-Target FSI – cost optimized *interferometric Double-Pass Hydrostatic Levelling Sensor (iHLS)*

Due to the tunnel slope HLS network is splitted to several levels



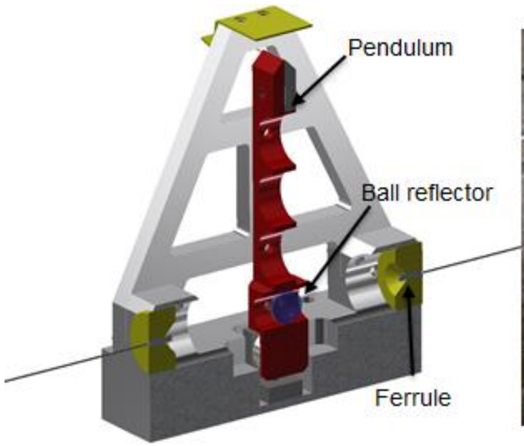
- Possibility to measure multi-water level HLS network is needed
- Double-pass iHLS is under design, to provide double water-surface measurement within single laser sweep
- Intra water-level measurement uncertainty < 5µm

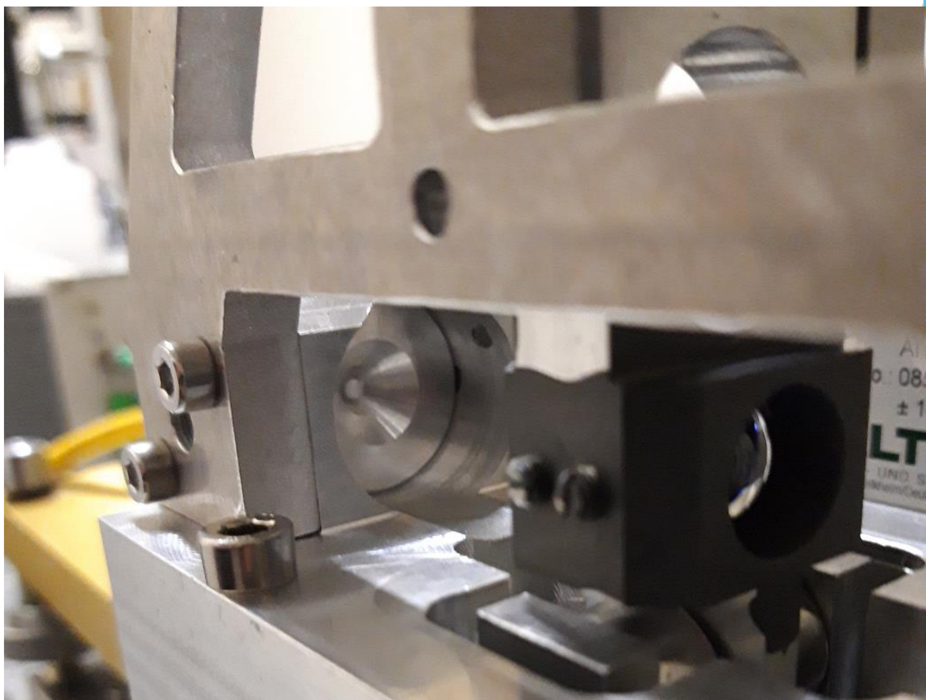


Multi-Target FSI – Optical Interferometer

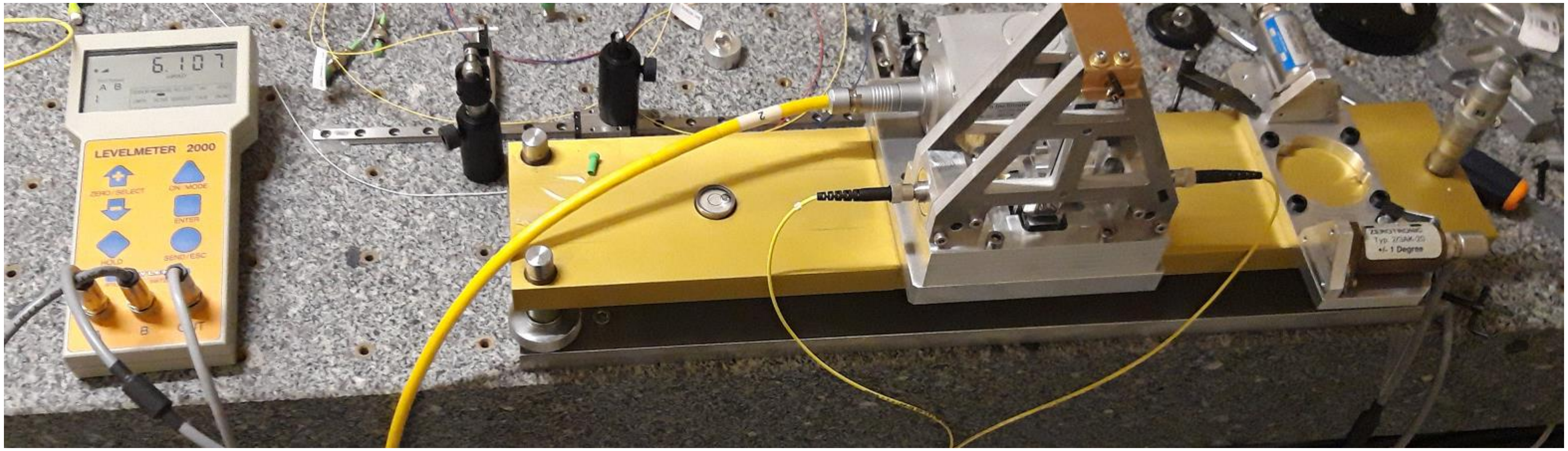
Optical inclinometer prototype

- Expected resolution 10 µrad
- Differential pendulum measurement to anticipate thermal expansion effects
- Flexural pendulum suspension + magnetic break
- Prototype assembled and under tests in optical lab





Multi-Target FSI – Optical Interferometer



Optical inclinometer prototype tested in the laboratory

- Stability test – OK
- Precision tests: 20 µrad

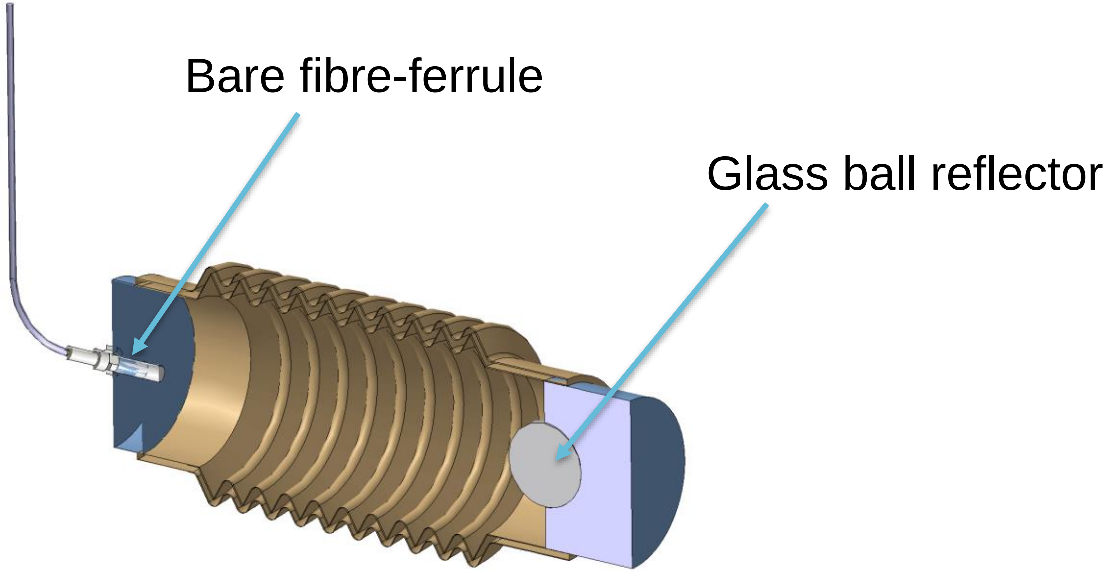
- Pendulum length to be extended (increase of precision needed)
- Next tests planned after design update
- Long term stability test pending (validation of pendulum suspenion stress impact on measured angle)

Multi-Target FSI – Short distance measurement sensor

Distance measurement sensor (short distance, range ±5 .. 10mm)

- To replace current capacitive sensor
- Design with thin wall bellow protection against the dust

- Expected measurement uncertainty < 5µm
- Precision ~1 µm
- Maximally simplified (bare-ferrule + glass ball reflector) to increase reliability

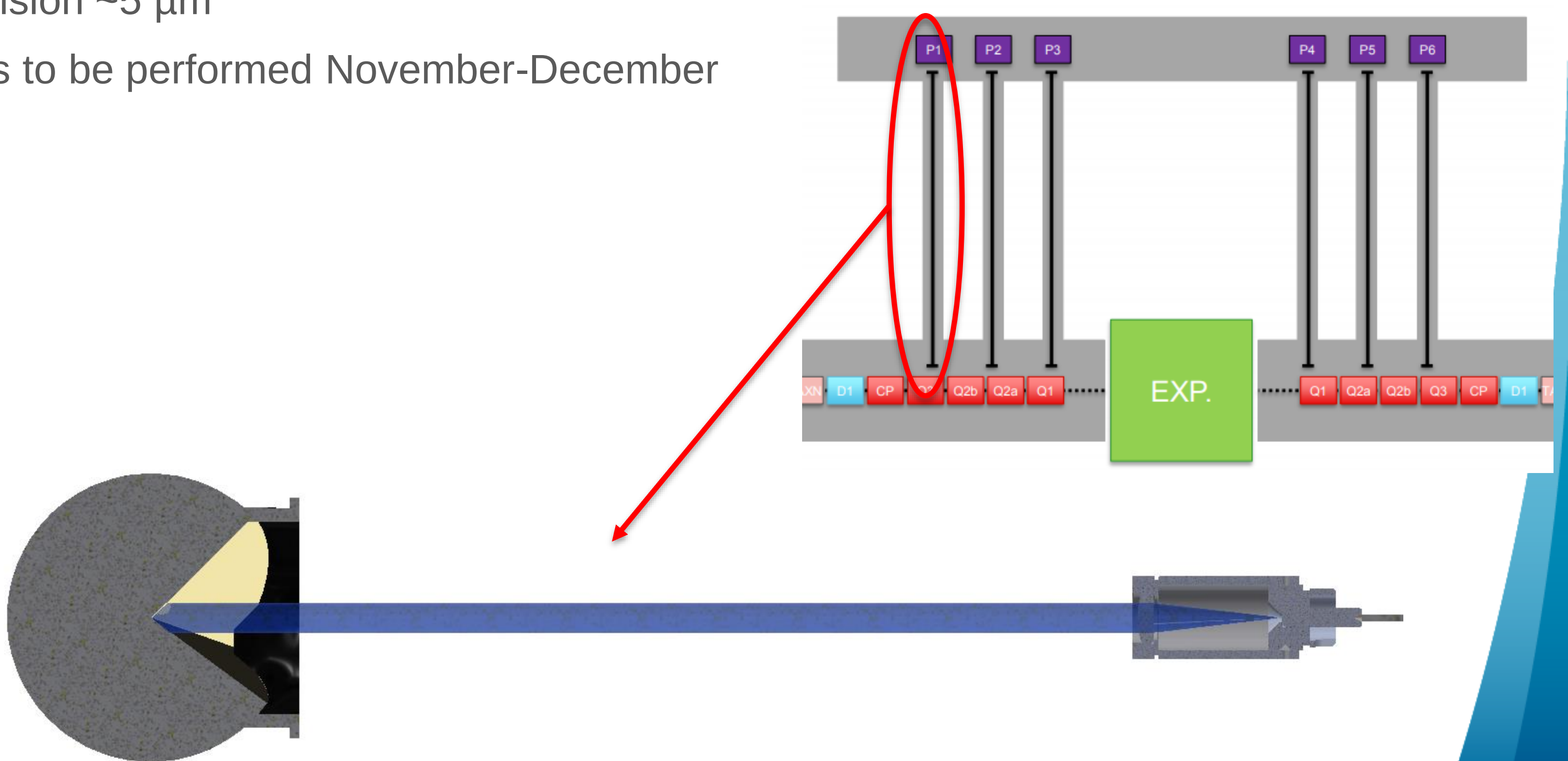


Multi-Target FSI – Long distance measurement

Distance measurement for UPS vs. Tunnel radial reference transmission

- ~15 m distance
- Standardized collimated optics to be used

- Expected measurement uncertainty < 40µm
- Precision ~5 µm
- Tests to be performed November-December



Instrumentation R&D conclusions

- Prototyping and tests of most of sensor solutions in advanced stage
  - Capacitive electronics prototype under tests, with performance similar to FOGALE
  - Prototype of P-WPS sensor tested and showed performance as for FOGALE sensor
  - Polymide technology passed initial irradiation tests (5MGy)
  - Optical sensors design driven by required high reliability
    - Simple construction
    - Limited amount of movable parts
    - Cost optimized
  - iHLS prototype tested, showing very good performance
    - Good reflection of laser light from the water Surface
    - Long term comparative (with cHLS) showed good sensor performance
  - Double-Pass iHLS prototype under design
  - Optical inclinometer prototype preliminarily tested
    - Update of pendulum length needed
    - Long term stability tests pending
- Sensor prototypes planned to be validated before end of 2019
- Final prototypes design for optical sensors to be ready 2nd quarter 2020

HiLumi HL-LHC PROJECT

Thank you for your attention

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