The Large Hadron Collider's Beam Wire Scanner Consolidation

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Abstract: *To serve the needs of the High Luminosity Large Hadron Collider (HL-LHC) era, a consolidation of the beam wire scanner has been initiated. The instrument is a crucial tool for measuring the transverse beam profile by moving a thin carbon wire across the beam. It can only withstand a fraction of the LHC's nominal beam intensity but provides a reference to calibrate other instruments that operate non-invasively at higher beam intensities. Since the start of the LHC, the scanners have provided hundreds of thousands of measurements, but the design has technical limitations that need to be addressed to provide the required reliability and performance for the HL-LHC runs. The initial consolidation phase involved testing the injector's acquisition and control electronics in the LHC to assess its suitability for the specific beam conditions. As part of this process, we updated the mechatronic and motion controller. Beam test campaign has revealed higher performance w.r.t the existing system and a higher adaptability to varying beam conditions. Simultaneously, we are developing a novel actuator that uses a permanent magnets-based coupling replacing the standard bellows and long arm that limits the performance and induces vibrations. Before testing this new concept with beam, we have developed a calibration bench to evaluate the mechanism's precision and accuracy of the wire position determination. This contribution presents the 2023 beam and laboratory tests as well as the electromechanical developments.*

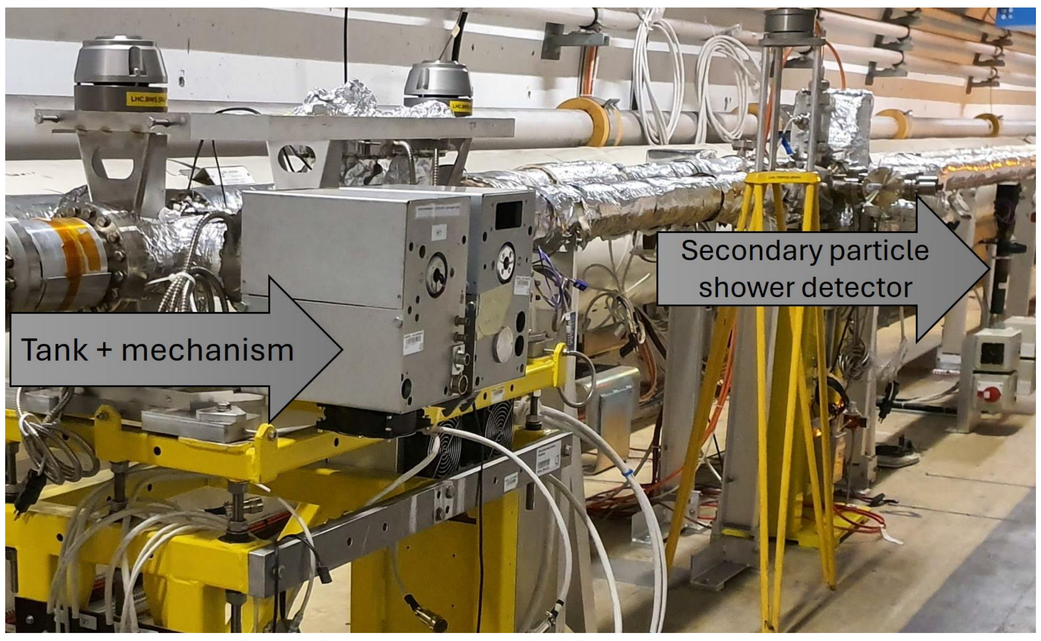


Figure 1: Beam wire-scanners on LHC Beam 1 line.

Table 1: Designs parameters

Parameter	OP[a]	LIU[a]	HL[a]
Wire velocity m/s	1.1	0.85	>=1.1
Wire stroke mm	133	133	133
Beam ϵ_n [b]	3.75	3.75	2.5
Beam σ $450GeV$ ~ µm	800	800	670 [c]
Beam σ $6.8TeV$ ~ µm	200	200	150 [c]
Precision µm [c]	20	10	5
bakeout temp. °C	80	150	150
lifetime in kcycles [d]	10	25	80
motorisation [e]	dc	pmsm	pmsm
transmission	belt	direct	direct
position encoder	resistive	inductive	optical

[a] from design reports [16]
[b] OP: Operational, LIU: intermediate, HL: final system
[c] forecast by scaling from ϵ_n difference
[c] Estimated physical beam size precision
[d] Mechanism lifetime before servicing (by design)
[e] dc: direct current motor, pmsm: permanent magnet synchronous motor

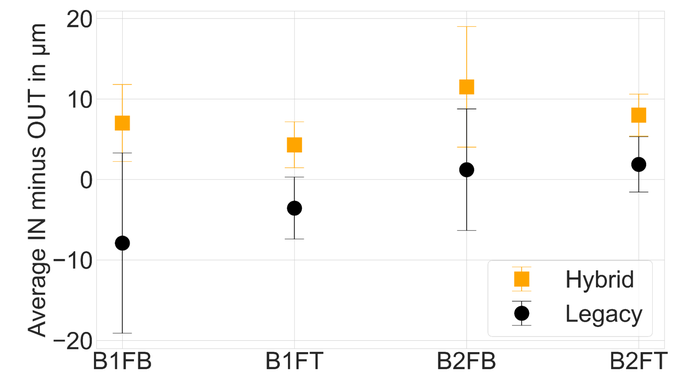


Figure 5: MD#9545 beam size IN - OUT difference (2023).

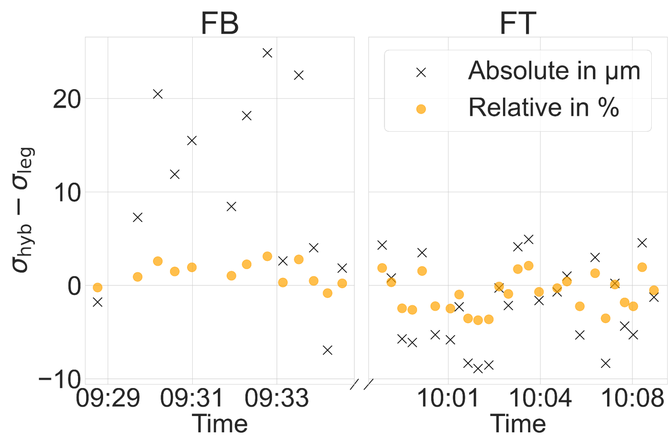
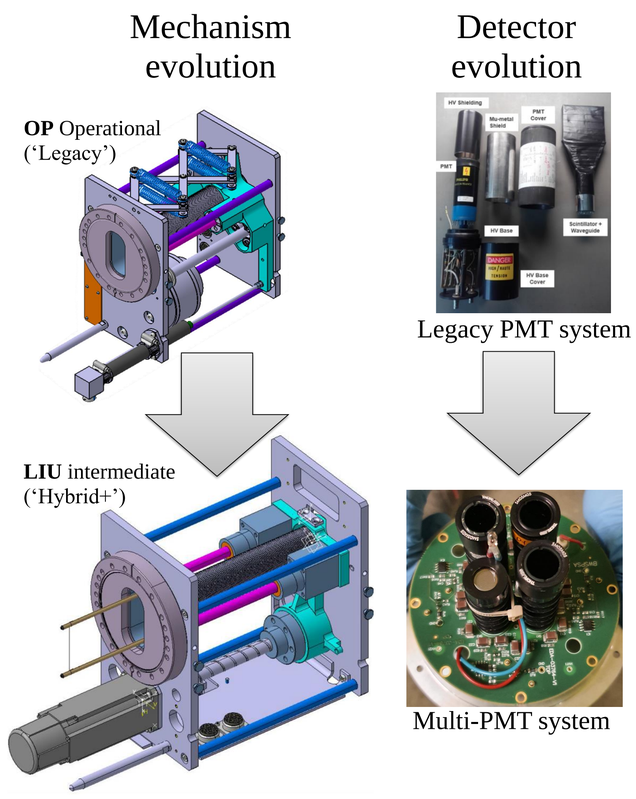
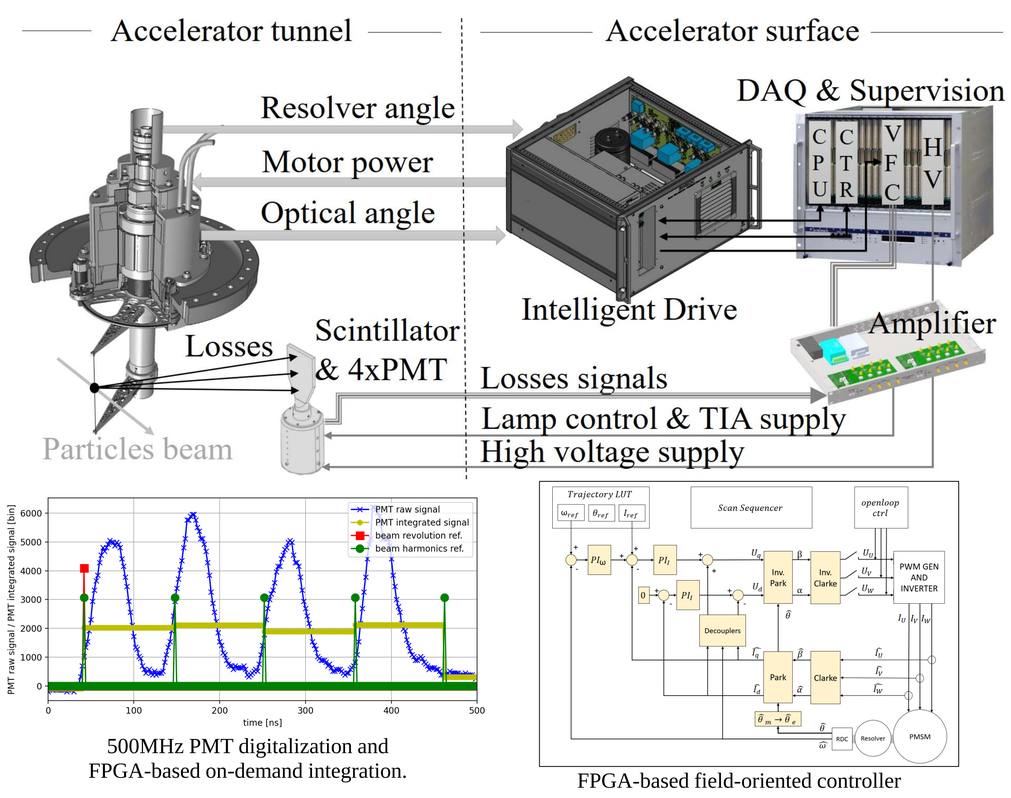


Figure 4: Difference in beam size between systems (2023).

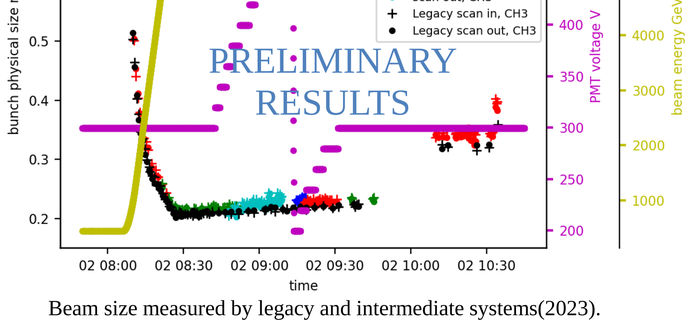
PHASE 1 - CONTROL AND DAQ ELECTRONICS TESTS





500MHz PMT digitalization and FPGA-based on-demand integration.

FPGA-based field-oriented controller



Beam size measured by legacy and intermediate systems(2023).

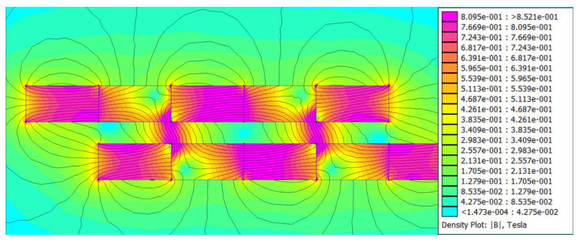


Figure 8: Magnetic flux density plot of the planar link concept with longitudinally magnetised permanent magnets.

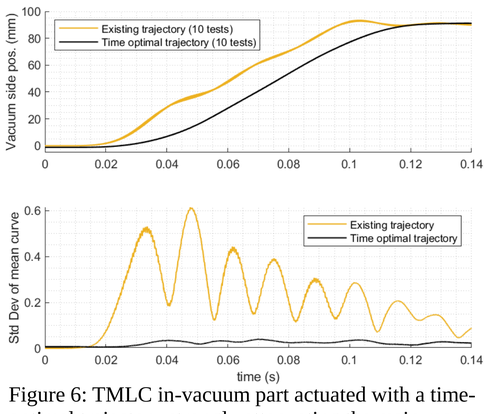
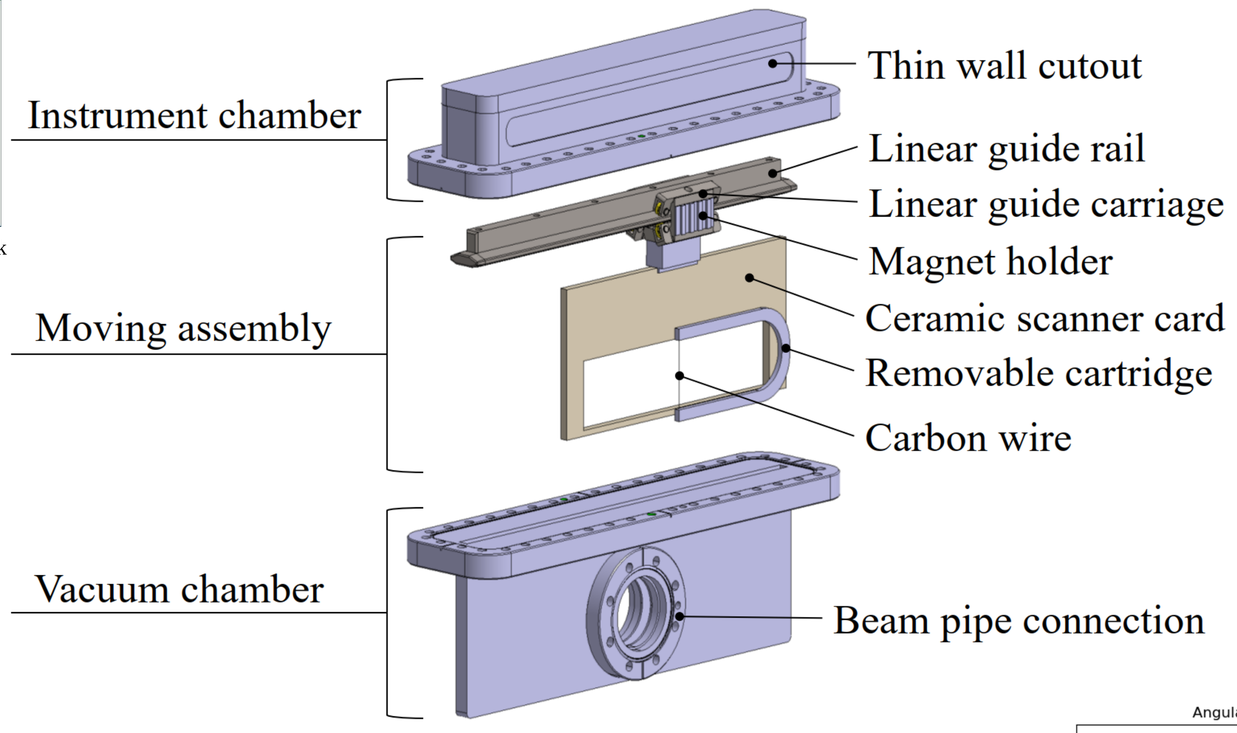
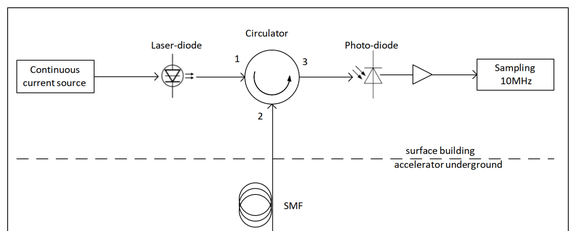
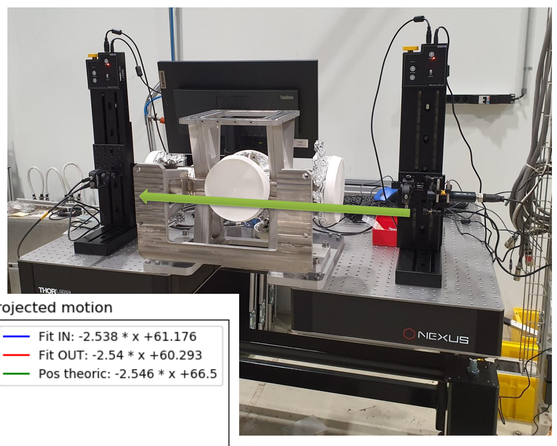


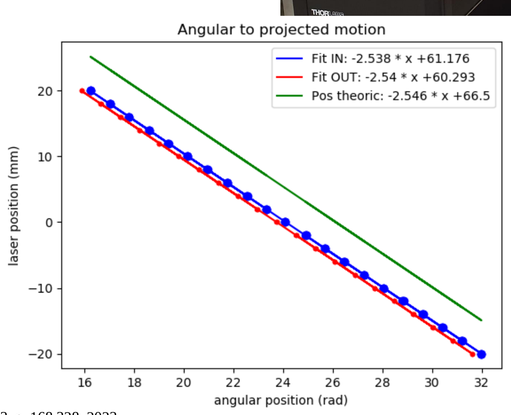
Figure 6: TMLC in-vacuum part actuated with a time-optimal trajectory strongly attenuating the main resonance.





Wire-Scanners optical fiber-based incremental encoder





Laser based linear calibration bench in the laboratory for the assessment of the carbon wire position determination prior to installation on the LHC beam line.

CONCLUSION

The consolidation of the wire scanner is progressing steadily to meet the new requirements for the HL-LHC era. We have successfully assessed and validated the secondary particle shower acquisition chain and scanner controller electronics for LHC beams. Our team is currently prototyping a new scanner mechanism, incorporating an innovative card concept featuring an in-vacuum rail, an optical encoder near the carbon wire, and actuation via a planar magnetic link.

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[18] J. L. Sirvent Blasco, "Design of an optical fibre based angular position sensor for wire scanners complying with ultra-high vacuum, high temperature and radiation conditions of the CERN´s accelerators," Presented 2012, M.S. thesis, Miguel Hernandez U., 2012.
[20] D. Belohrad et al., "The Digital Signal Processing Chain of the CERN LIU BWS," in Proceedings of IBIC'23, Saskatoon, Canada, 2023, pp. 288–292.
[21] A. Guerrero, D. Belohrad, J. Emery, S. Jackson, and F. Roncarolo, "Modular Software Architecture for the New CERN Injector Wire-Scanners," in Proceedings of ICALEPCS'21, Shanghai, China, 2022, paper TUPV037, pp. 487–491.
[26] V. Varadan, "Data-Driven Control Methods for Beam Wire Scanners," Presented 01 Feb 2024, ETH Zurich, 2023.