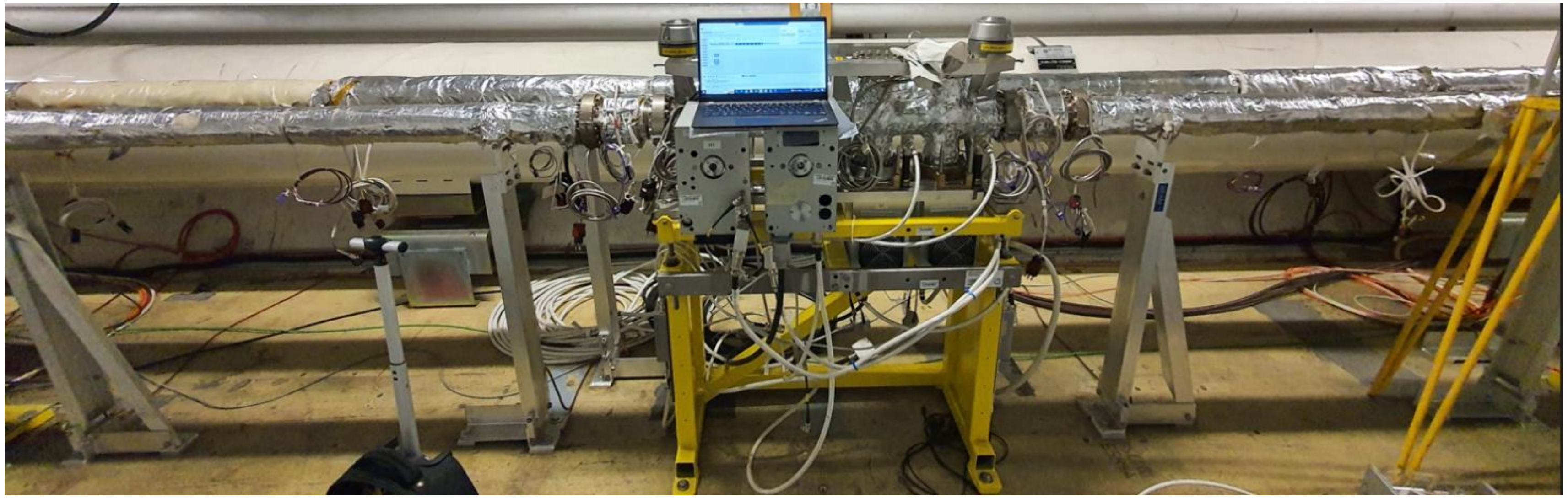
Actuator and control considerations

J. Emery
LHC BWS CONS ad hoc meeting
new design kick off meeting
13.06.2023

Actuator and control considerations

1) actuator specification tentative
2) system orientation (H&V vs 45deg)
3) motor & encoder, control feedback



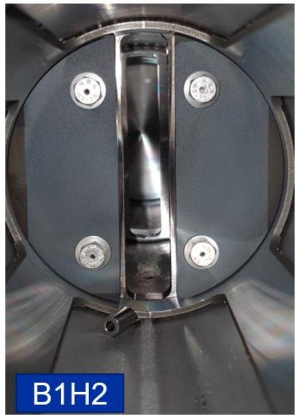
Actuator specification tentative

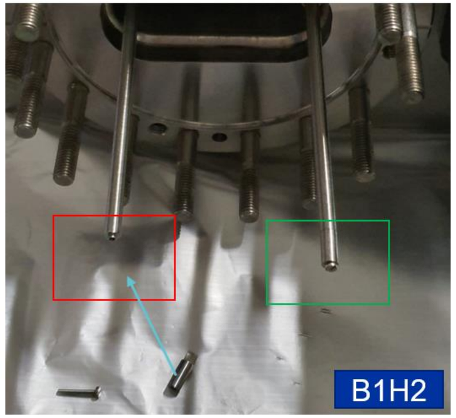
- Basic parameters and failures from the legacy system (table below)
- State of the art from the industry and in other laboratories
- Wishes to augment the usage of the system

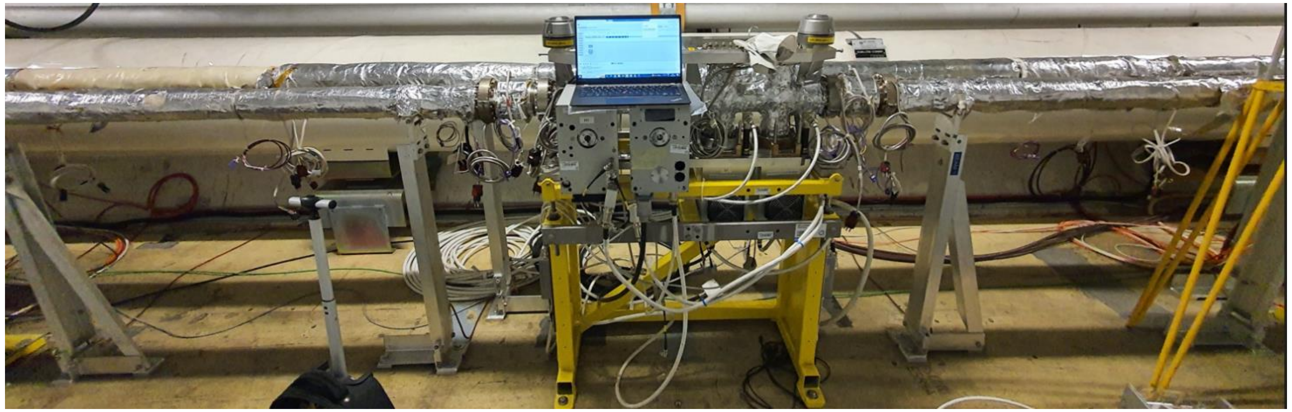
Parameter	Value	unit	Source	bottom line
Wire top speed	1	m/s	legacy system	FB: 3 pts per ~1mm => 3.75 m/s FT: 3 pts per ~200um => 0.75 m/s
Stroke	133	mm	Legacy system	Beam pipe diameter (90mm) + ferrites covering
Wire position accuracy	5	um	beam size at FT	150um/3pts/10 => 5um (direct measure or calibration)
Bakeout temperature min.	150	degC	Legacy motor limit	300 degC for Neg activation
Lifetime target cycles	25k ->	cycles	OP data 2.5kcycle/year	OP design 25kcycle, but B2V1 issue at ~8kcycle…
Reliability target	Lower probability of: - mechanical obstruction (2x in operation) - vacuum leak (2x with different bellows in operation) - scanner staying in (1x 2 scanners staying in) - failures of electronics power stage (2-3 in operation)			
Serviceability	In-situ scanner exchange without moving the tank (B2!), review the insertion guides			

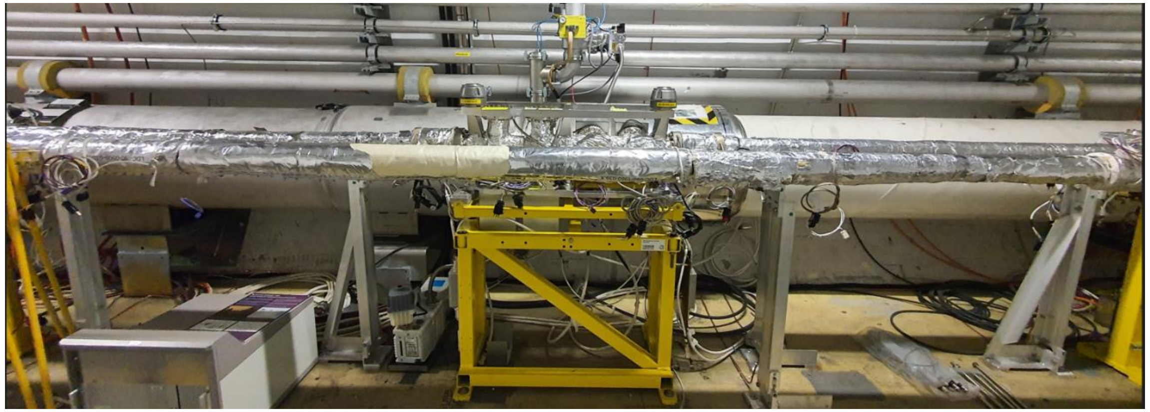
Actuator specification tentative

	Run 1	Run 2	total	start time	end time
LHC.BWS.5L4.B2H1	12772	1807	14579	01/12/2014 14:31	16/05/2023 18:44
LHC.BWS.5L4.B2V1	6400	1589	7989	26/02/2015 09:54	16/05/2023 18:44
LHC.BWS.5L4.B2V2	5754	25	5779	22/04/2015 13:03	24/03/2023 09:14
LHC.BWS.5R4.B1H1	780	1658	2438	23/01/2015 15:36	16/05/2023 18:44
LHC.BWS.5R4.B1V1	407	1281	1688	23/02/2015 09:09	16/05/2023 18:44
LHC.BWS.5R4.B1V2	10484	340	10824	12/05/2015 15:10	24/03/2023 09:12



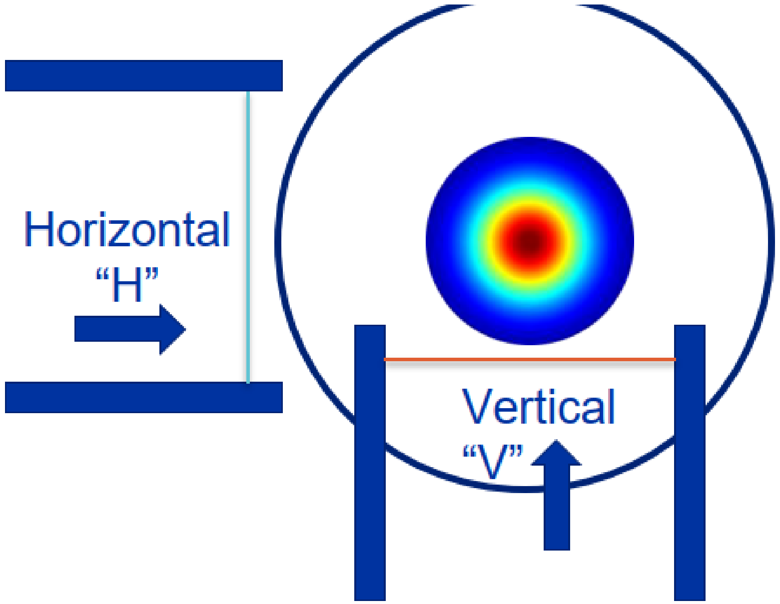


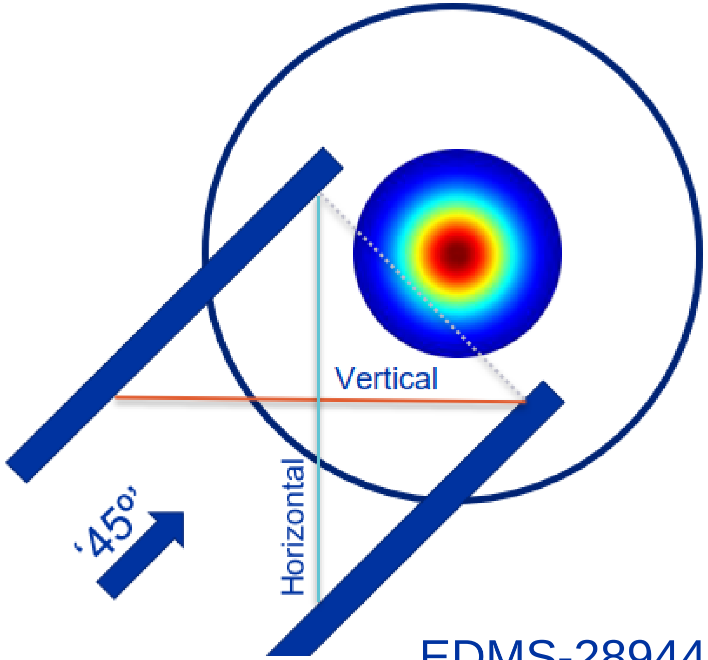




Qualitative comparison of the motion orientation H-V and 45º for the Beam Wire Scanner linear system

	H - V	45 deg	Risk assessment	action / mitigation
C-wire length	1	1.41 x	More mass & resistivity, natural frequency changes	Adapt the wire tension and/or check deflection and calibrate
Forks length	~Beam pipe	Beam pipe + forks aperture	Longer cantilever increases the deflection and risk to elongate the c-wire. More mass to move.	Optimize fork design to increase stiffness while lowering the mass.
Stroke length (= ~wire exposition)	~beam pipe	Beam pipe + forks aperture	Overall wire stay longer in the beam pipe, more exposed to RF heating	Increase of the nominal speed and adapt trajectory to equal the time the wire stay in the vacuum chamber
Wire speed	1	1.41 x	Higher nominal speed required to touch beam at same transverse speed. Means more power requirement, more stress to the mechanism, larger wire deflection?	Change of motion trajectories to use longer stroke to reach the top speed with less stress (at the cost of longer c-wire exposition). Study wire position determination/calibration
Gravitational acceleration	0 (H) 9.81 (V)	4.905	Same acceleration for both planes better compared to H - V case	-
Force / acceleration on the c-wire	100% Perpendicular to the wire length	70.7% perpendicular 29% longitudinal (pulling the wire from its side)	Weight of the c-wire is low. Experience with fast rotational going much faster (20m/s). But no experience with longitudinal acceleration!	Experimental test and qualification on samples to be conducted for this configuration





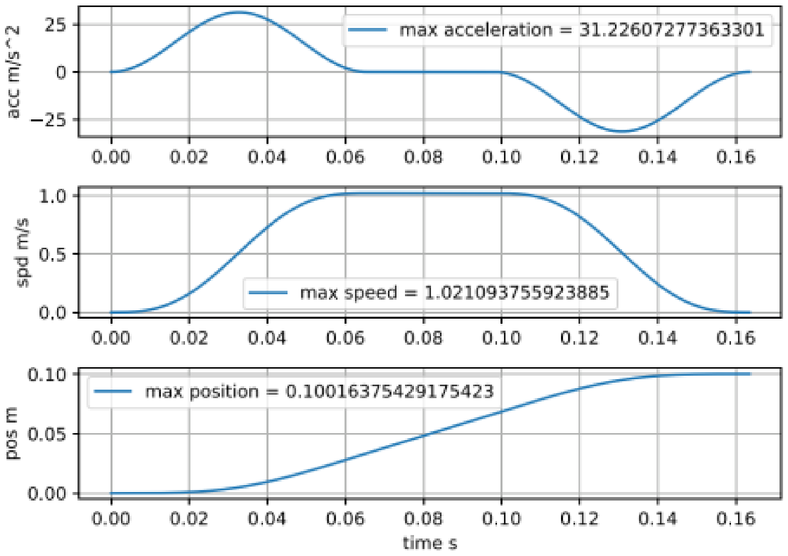
EDMS-2894475

Qualitative comparison of the motion orientation H-V and 45º for the Beam Wire Scanner linear system

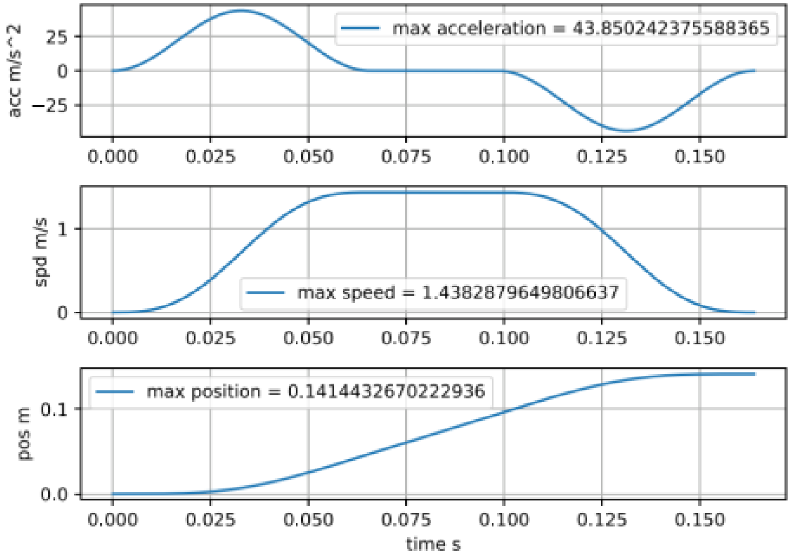
Motion trajectories comparison	H - V	45º	difference
Stroke (mm)	100	141	+41%
Interaction speed (m/s)	1	1.41	+41%
Acc (m/s^2)	31.2	43.9 / 36.7	+41% / +18%
Duration of the wire in the beam pipe (s)	0.16	0.16 / 0.175	0% / +9%

Motion study to equal the time the carbon wire stays in the beam pipe during the scan for all orientation options (H-V & 45). To satisfy this constraint, the 45 option requires a higher acceleration and top speed (41%). This correspond also to the necessary speed increase to touch the beam at the same transverse speed (1m/s).

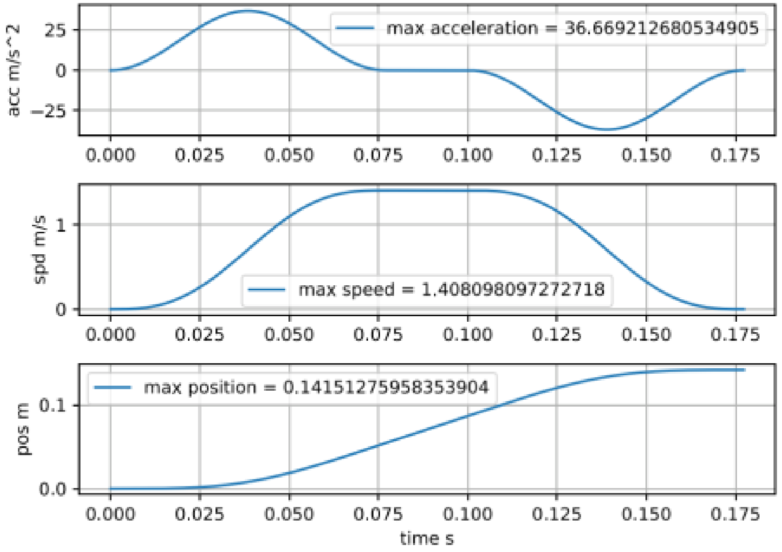
H-V orientation



45º orientation variant 1
(stroke duration equals H-V version)



45º orientation variant 2
(constant speed region equals H-V version)



EDMS-2894475

motor & encoder

- **Legacy scanners:**
  rotative brushed motor + linear potentiometer feedback

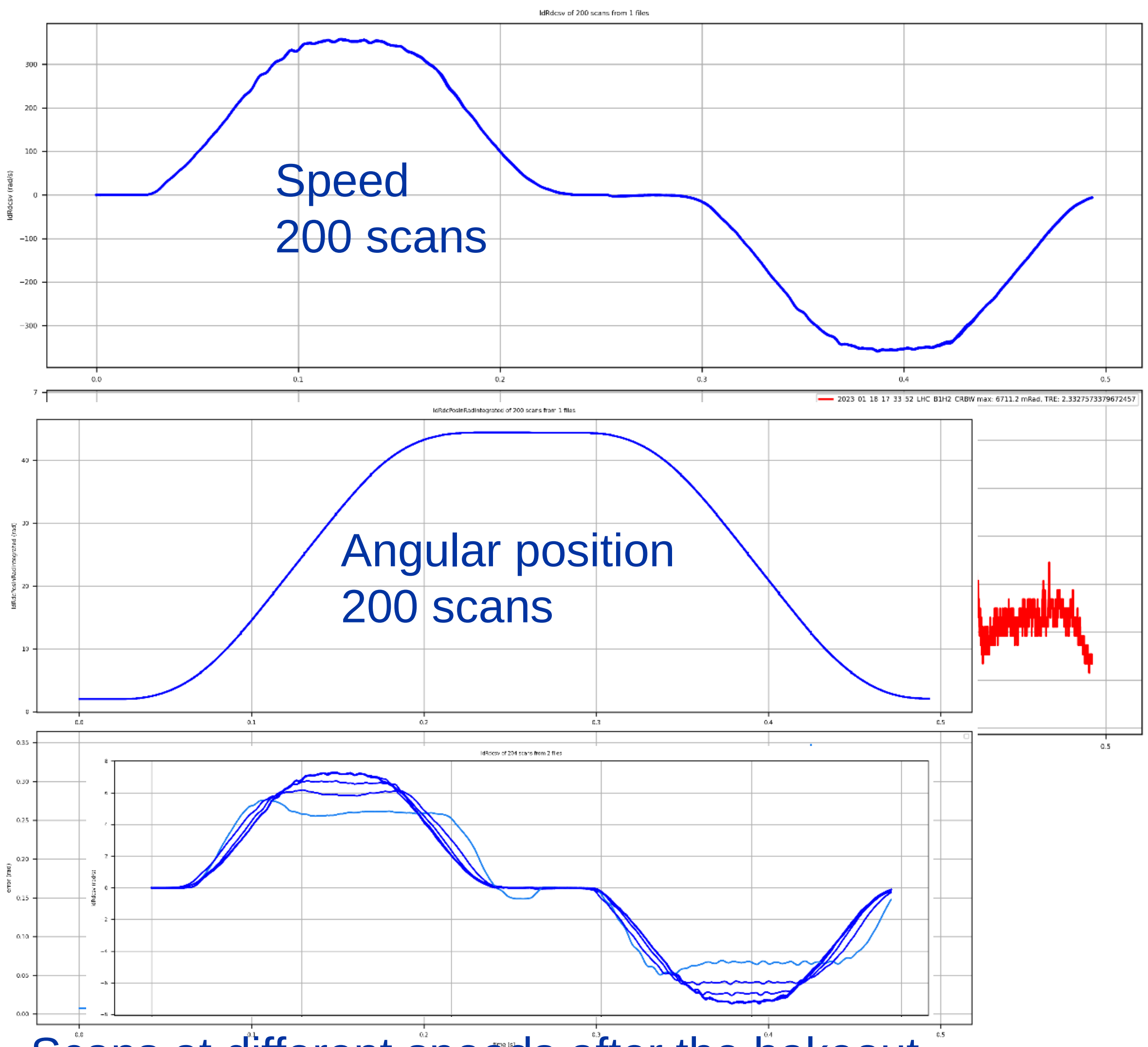
- **Hybrid/Hybrid+:**
  rotative brushless motor and resolver + legacy linear potentiometer
  -for beam tests we are using the resolver as encoder, the pot has large noise with LIU electronics.

- **If we move to linear motor for the Hybrid+ or new design,**
  we will need a radiation tolerant encoder for the feedback and the wire position determination.

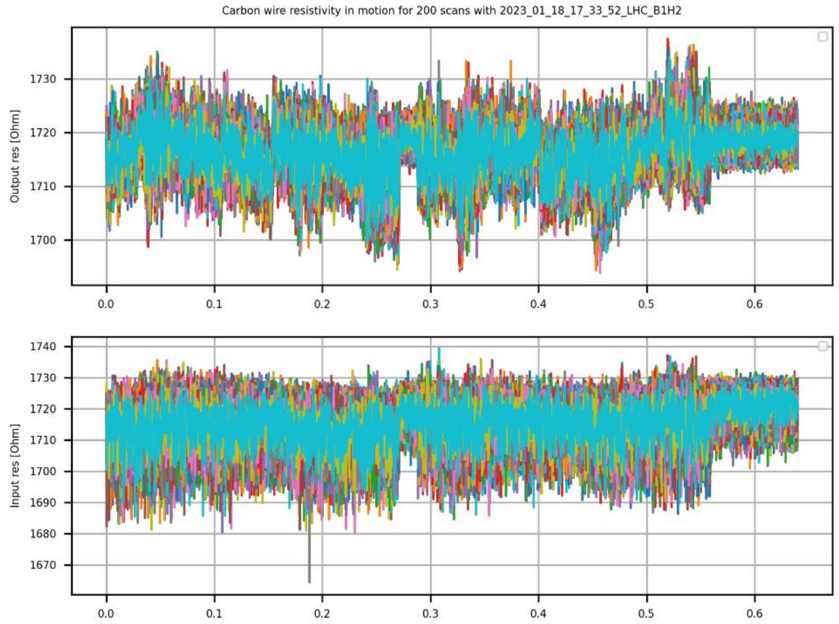
- **The encoder should be without electronics or semiconductor. This excludes standard optical ruler (Heidenhain or other), magnetic rule (RLS) and hall effect (LINMOT).**

- **One candidate is the Linear Variable Differential Transformer (LVDT) that would be probably suitable for the LIU electronics (with an upgrade of the Firmware). Will be tested on the motor bench**

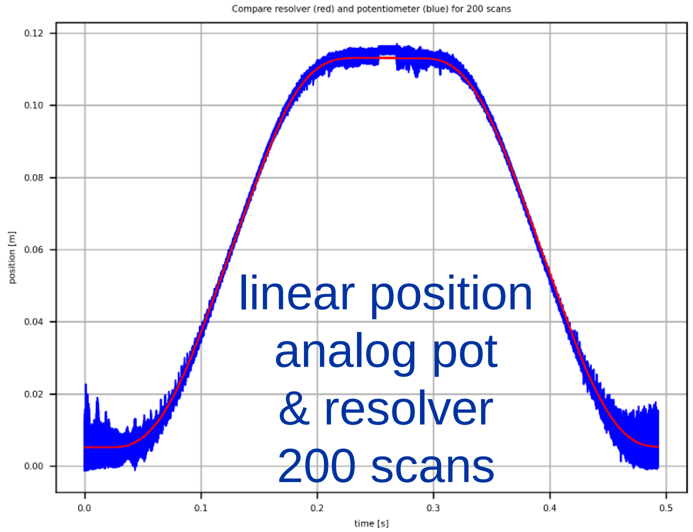
BEAM 1 YETS 22-23 – Prototype B1H2 – 200scans



Scans at different speeds after the bakeout



C-wire resistivity during the 200 scans



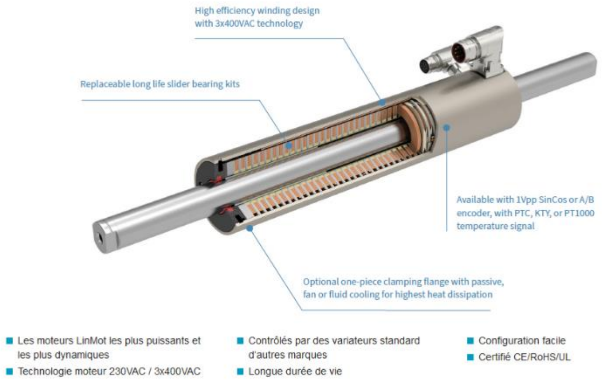
motor & encoder
Linear motor survey EDMS-2819315

	MOVER								STATOR		
Manufacturer	Part Number	length (m)	mass (kg)	Peak force (N)	DC-BUS Voltage (Udc)	BackEMF Vrms/(m/s)	EMF@3m/s	force Cst (N/Arms)	P.N	Stator length	estimated stroke
ETEL	ILF+03-030-KA0W0-A00	0.072	0.1	98.9	600	17.9 / 8.17	53.7	29.5 / 13.4	IWF+030-0256-AA0	0.256	0.184
	ILF+06-030-KB	0.136	0.194	198	600	17.9	53.7	29.5	IWF+030-0256	0.256	0.12
TECNOTION	UM3	0.078	0.084	100		30 / 16	90	36.3 / 19.9	UM150	0.15	0.072
TECNOTION	UL3	0.106	0.25	240		55.5 / 22.5	166.5	68 / 27.5	UL210	0.21	0.104
LINMOT	PS10-70x80-BL-QJ-D01	290	1.36	561	1x230VAC	58.9	176.7	72.1		180	110
IDAM	ULIM4-3P	0.072									-0.072
H2W Technologies											
OMRON											
Kollmorgen (eol?)	IL-06-30-A1(A4)-C4	0.111	0.27	120		9.7 / 4.87	29.1	16.8 / 8.4	MW030-0256-01	0.255	0.1442
Kollmorgen (eol?)	IL06-050-A1(A4)-C4	0.111	0.32	200		16.48 / 8.2	49.44	28.5 / 14.3	MW050-0256-01	0.255	0.144
Parker											

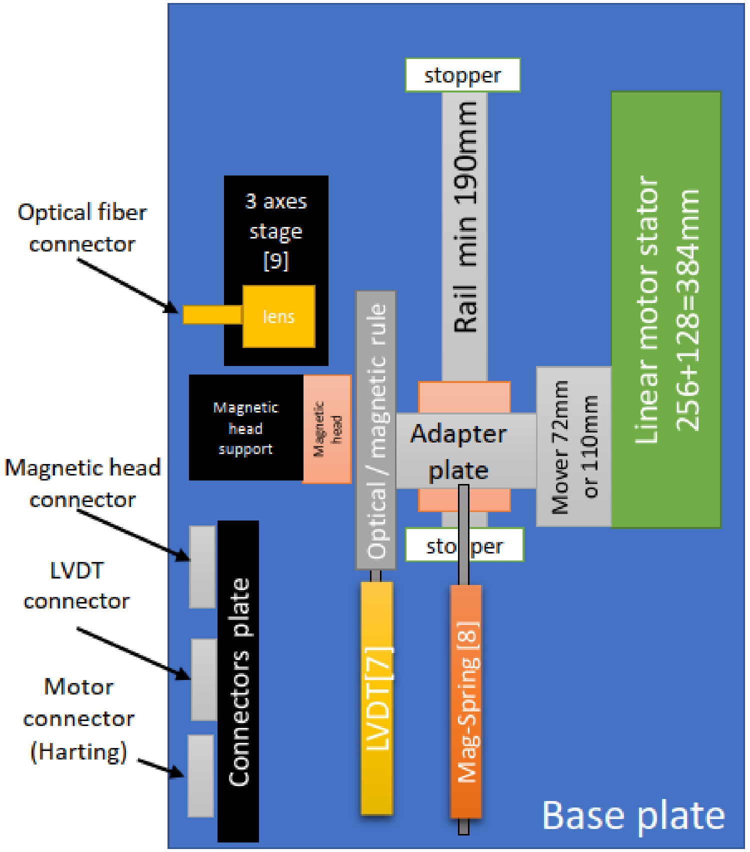
ETEL for prototyping (standard magnet @~80degC, but customization possible)
Offer received from Kollmorgen (but end-of-life is not excluded and no customization for the magnet possible)

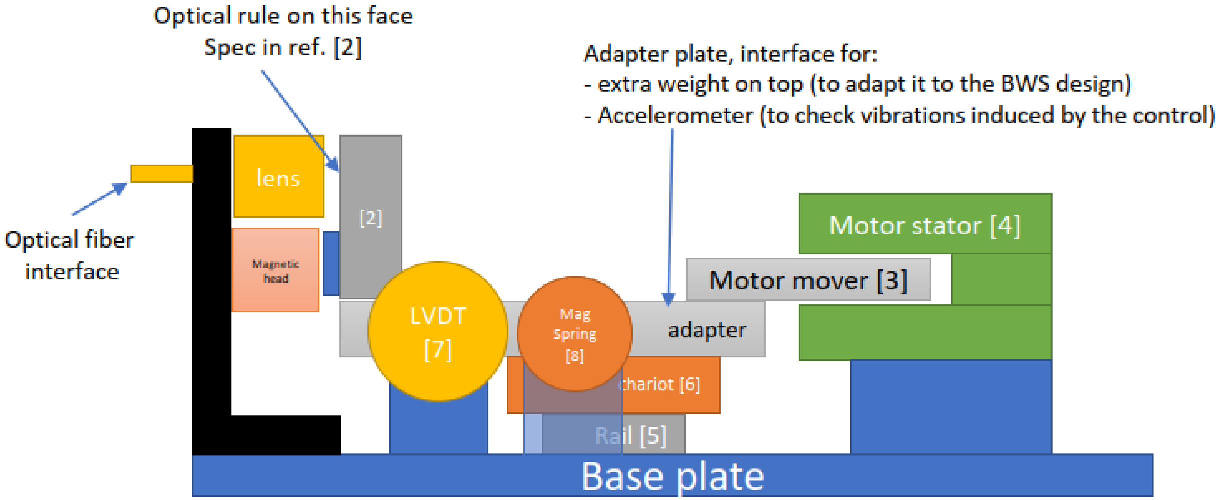
LINMOT compatibility with the LIU BWS electronics

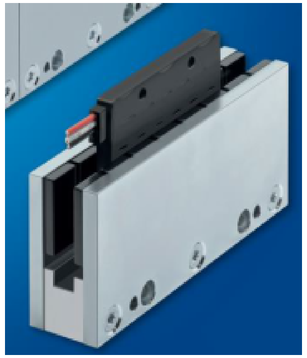
- 17.05.2023 Visio with R&D and Sales.
- They wiling to help and provide custom version for us
- But they technology is based on Hall effect sensor
  (P-N junction, not radiation tolerant by default)
- Small motors are 2 phases with their own electronics
  I have concerns that LIU electronics can work with 2 phases motors….
- Larger motors are 3 phases
- Any option will require an external encoder for the feedback
- We know in vacuum incremental encoder (from the LIU design)
- But an absolute in vacuum encoder is difficult
  Maybe LVDT in vacuum are existing (to study)



Conceptual design of a linear motor bench (LMB) for motion control development and in-vacuum linear optical encoder test targeting a linear actuator for the Beam Instrumentation Group (V2)







Linear motor[3, 4]

MagSpring [8]

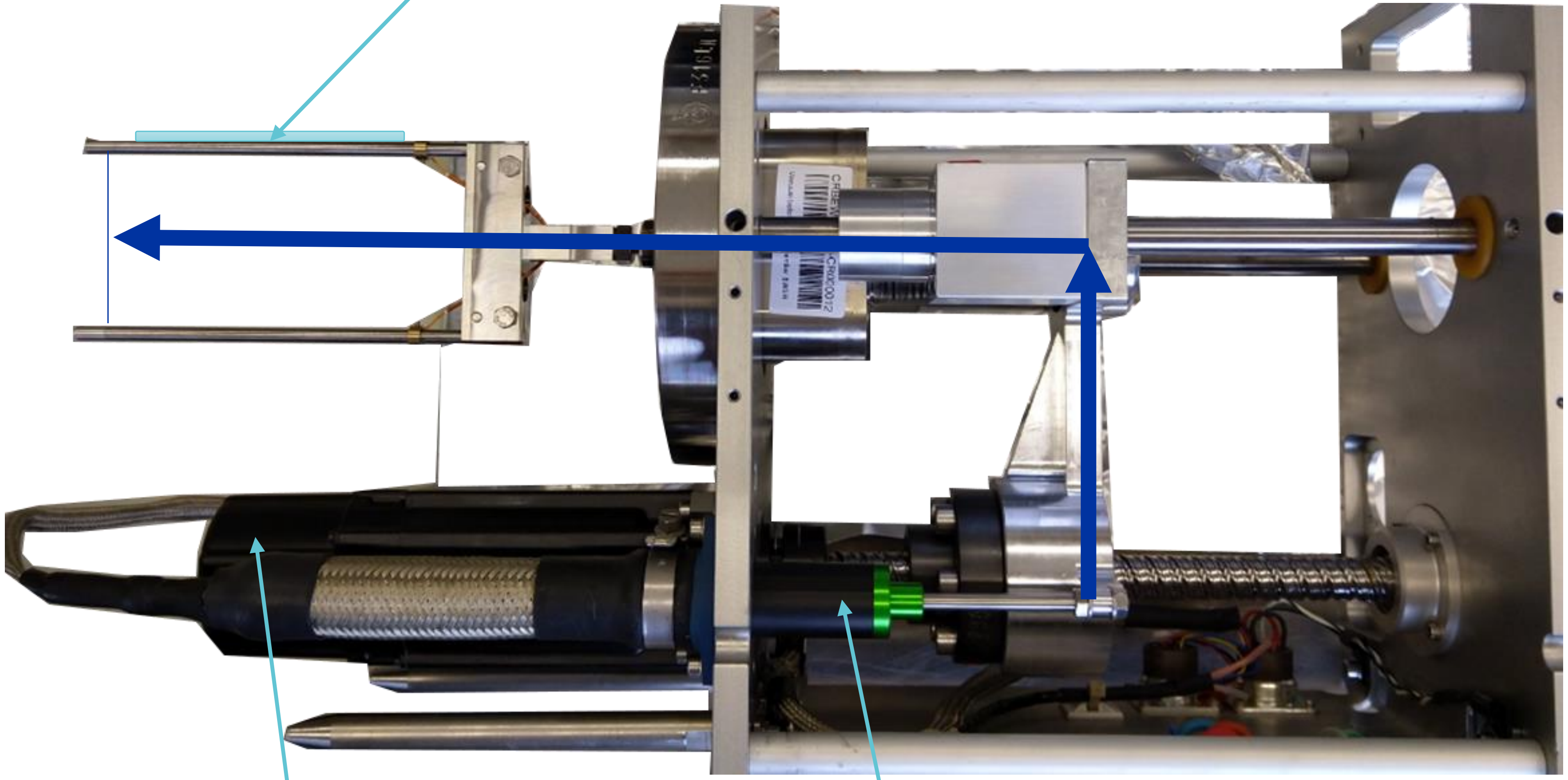
LVDT[7]

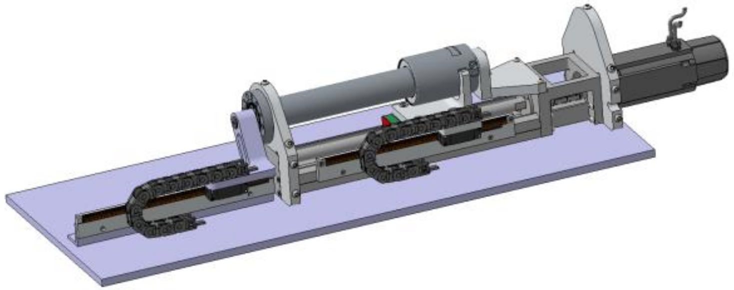
[1] Linear motor survey for the linear wire-scanner: https://edms.cern.ch/document/2819315/1
[2] Optical rule integration into the BWS LHC forks: https://edms.cern.ch/document/2670995/1
+ Magnetic way to use head from RLS "LA11SIC13BKA25DF00" (as on the BAT bench)
[3] Linear motor mover ETEL - ILF+06-030-KB0W0-A00 & ETEL ILF+03-030-KA (2 movers options to test)
[4] Linear motor stator ETEL - IWF+030-0256-AA0 + IWF+030-0128-AA0 (256+128=384mm range)
[5] linear guide MN 15-350-G3-V0 - Guidage linéaire 15/350 mm, Schneeberge (or similar)
[6] MNN 15-G3 - Chariot à guidage linéaire 15 mm, Schneeberger (or similar)
[7] LVDT Solartron Metrology S050.0 ~100mm stroke or S100.0 for 200mm stroke
[8] Mag Spring https://shop.linmot.com/E/magnetic-springs.htm
for 11N 210mm stroke: Stator: M01-20x220/210-11 & Slider: ML01-12x290/240-10
[9] 3 axes manual micro-displacement stage (tbd)

EDMS 2868812 | 21.03.2023 | V2 update 12.06.2023 | J.Emery

In vacuum incremental optical encoder based on LIU design

Custom linear optical ruler
compatible with LIU IOPS sensor – EDMS 2670995





Resolver at the motor axe

Linear potentiometer

Summary

- **Basic specification and experience from the legacy system**
- **Legacy electronics is problematic and will be upgraded to the injector system <u>for all the CONS options we have today</u>.**
- **We need to decide which technology to use for**
  - Driving the linear mechanism: rotational or linear motors
  - <u>Mechanism guides</u>: outside (bellow based) or inside (PushPull or other ideas)
- **We need to decide which <u>encoder for the feedback</u> and for the <u>wire position determination</u> or if we can combine the 2 functions.**
- **Can we prototype the incremental optical encoder on the linear motor bench?**
- **All this should fit in the planning for Beam tests (at the latest run2025) for installation during LS3 (2026-2028)**

Proposal of action and milestones (draft to be complete)

Run 2023:
Validate LIU type Acquisition in LHC

Calibrate push-pull & new forks + optical rule

Study rotational compatibly with LHC RF

Write Functional/technical specification?

Run 2024:
OP switch to hybrid B1V2 and B2V2

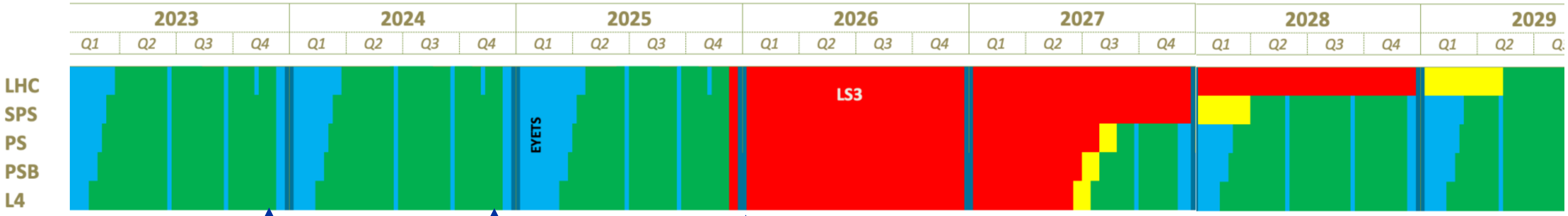
Calibrate linear mot-based scanner

Build new tank + scanners (H & V) for run 2025

Run 2025:
Operate new tank next to existing (B1 ?)

Compare with Operational

Production and installation



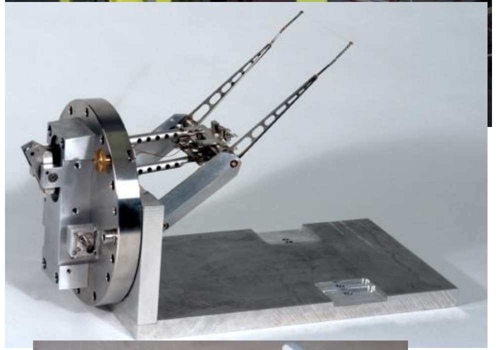
Functional spec for new system + Select ROT/LIN to install for run 2025

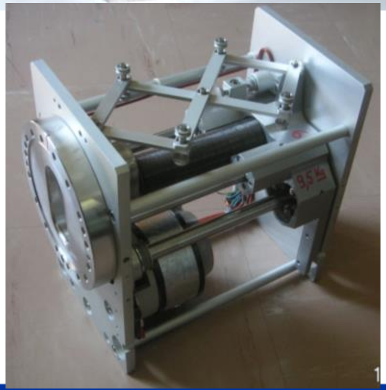
Test tank & scanner ready to install

Decision install new system in LS3

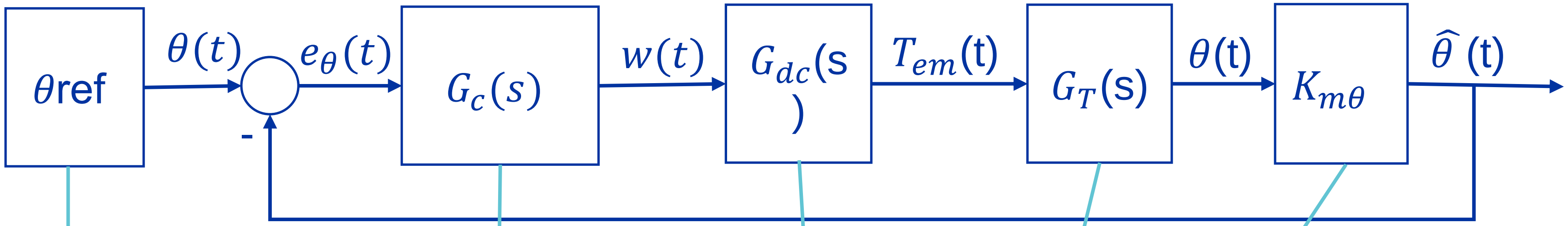
home.cern

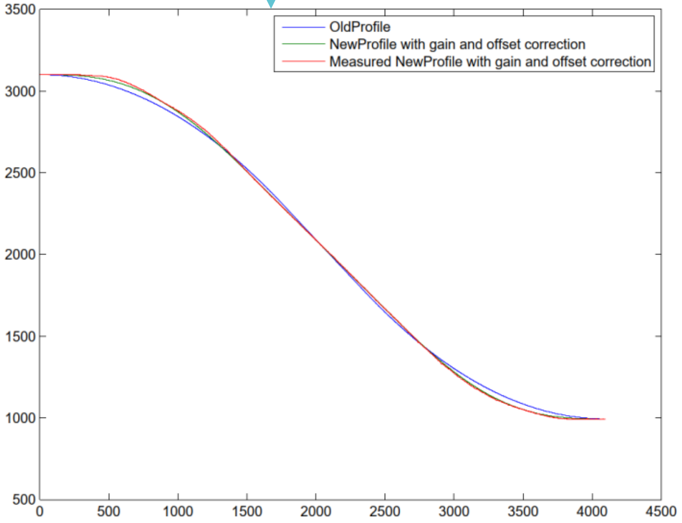
Wire scanner Operational systems ~1980-2021 for all BWS mechanisms





Controller	*Plant*

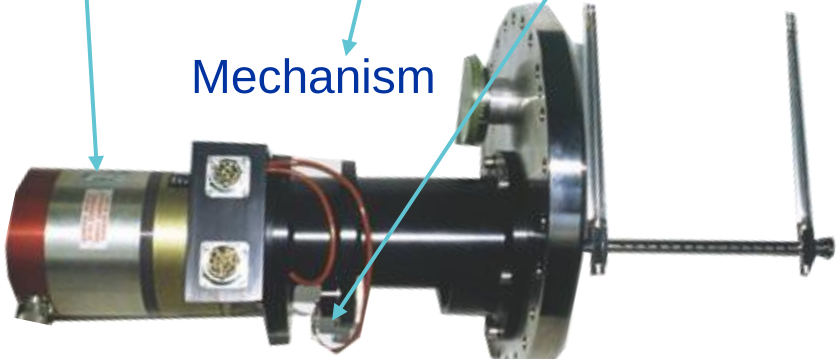




$Gc(s) = Kc$

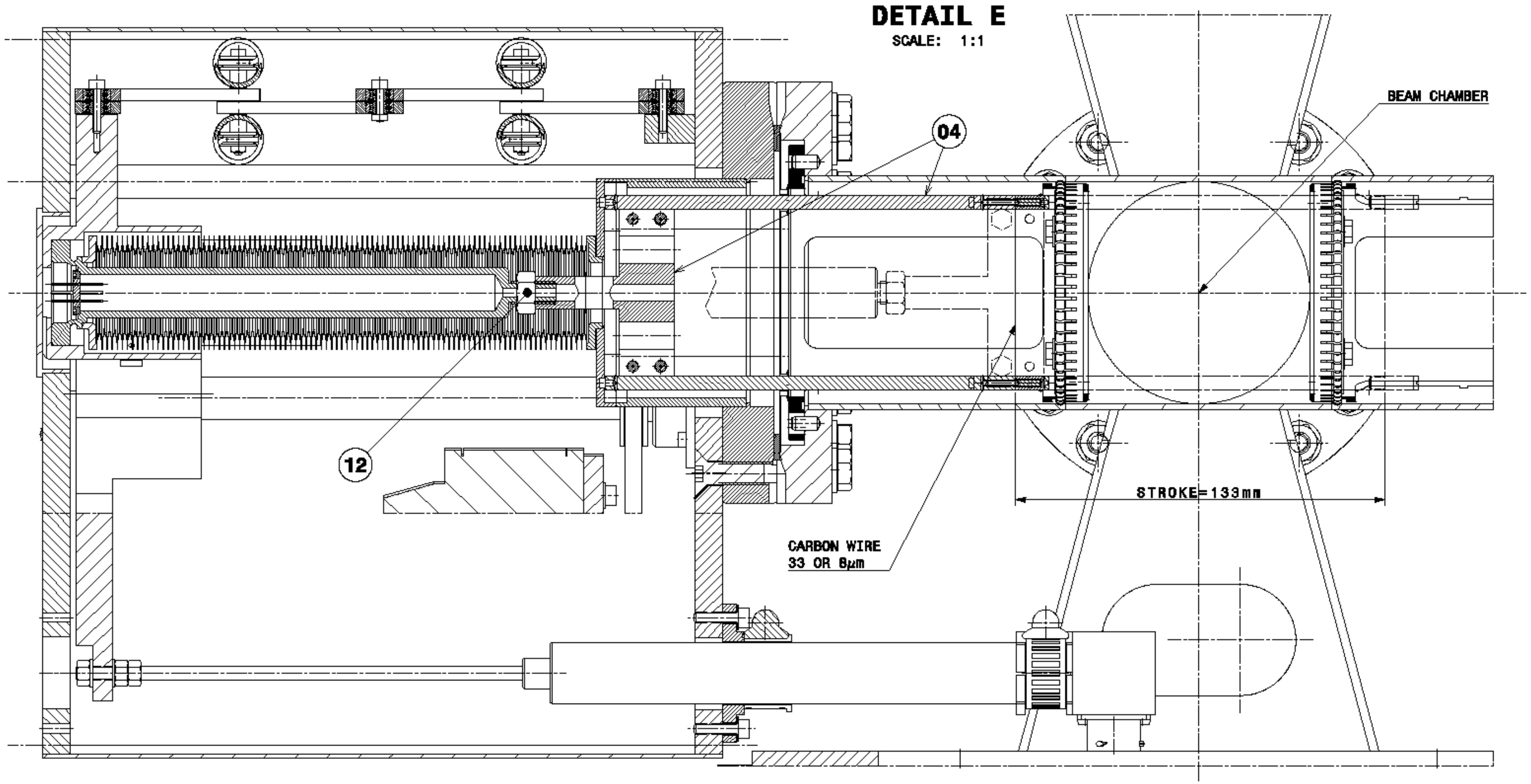
DC motor

Mechanism



Rotary Potentiometer

Interaction (wire-beam) position estimation viewed from the motor resolver (in radian)



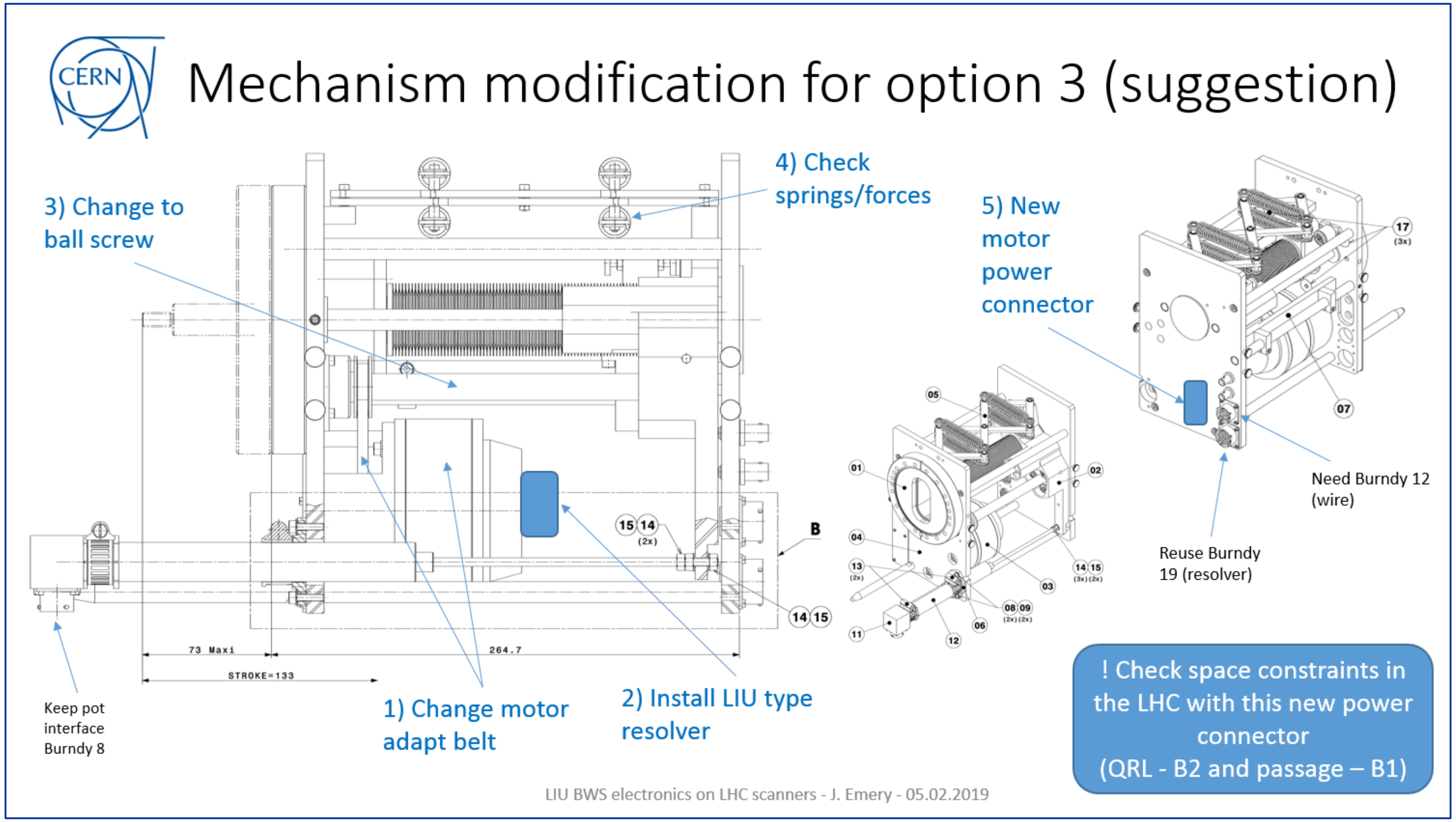
Stroke=133mm
Interaction point=66.5mm
Leadscrew=16mm/(2*pi)rad

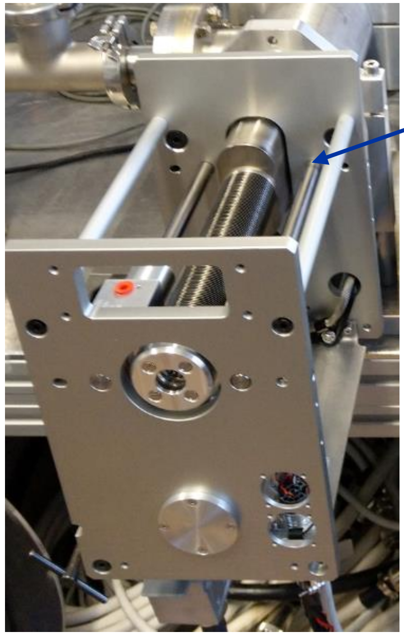
Interaction point in rad:
66.5*2*pi/16=**26.114**rad

Tested acquisition range:
0.02s (capture) * 0.5m/s = 10mm

How precise is the forks and wire installation?

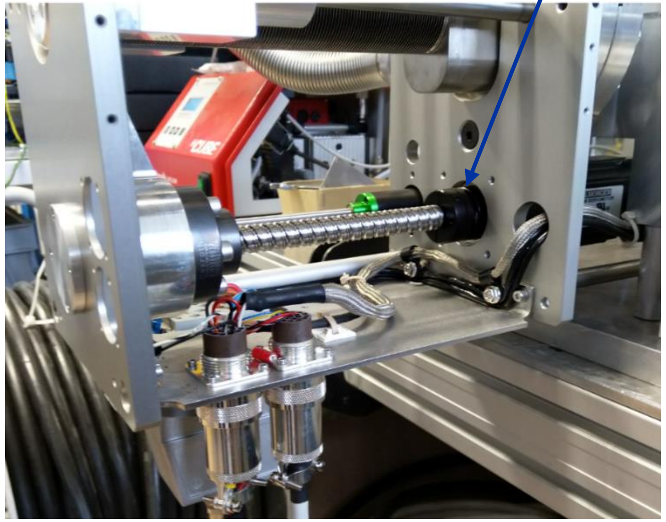
Mechanism consolidation



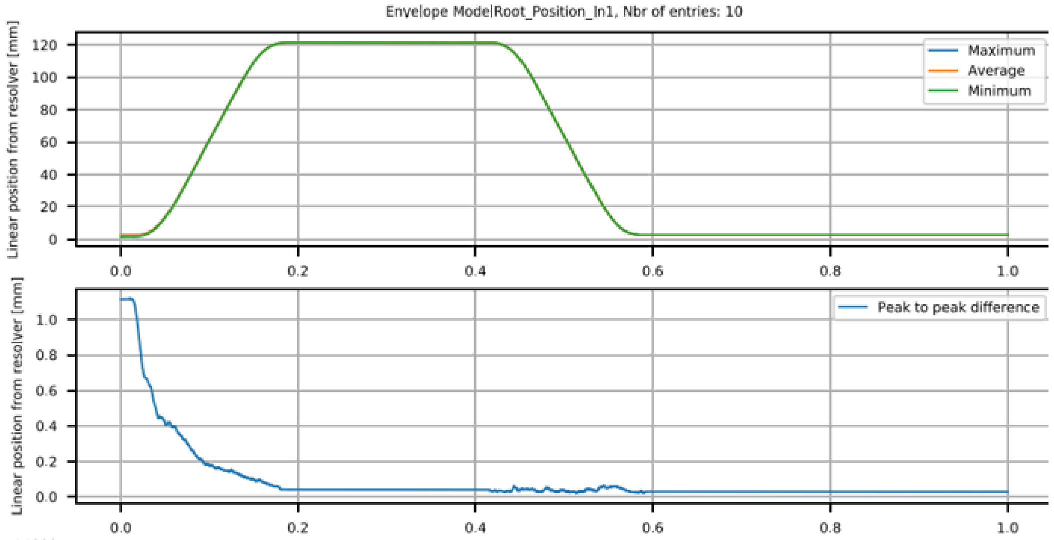


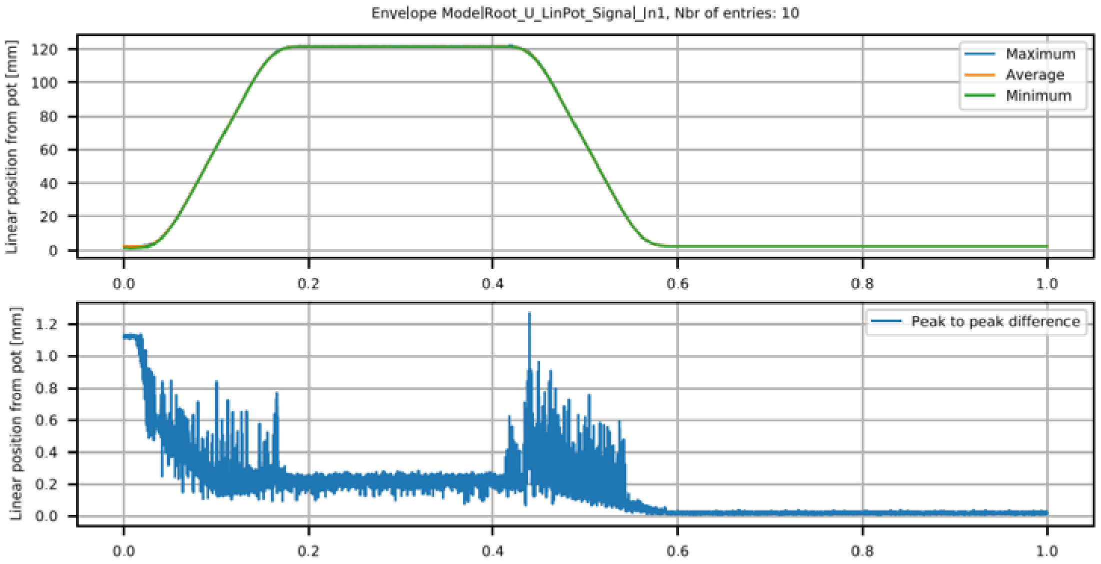
Springs removed

Direct drive instead of a belt



Wire-scan cycles LHC consolidation prototype





Motor resolver

Resolution: 14bits (RDC) over 2π [rad] = 0.383 [mRad]

Accuracy: $2\pi \div 360 \cdot 18 \div 60$[arc/min] = 5.24 [mRad]

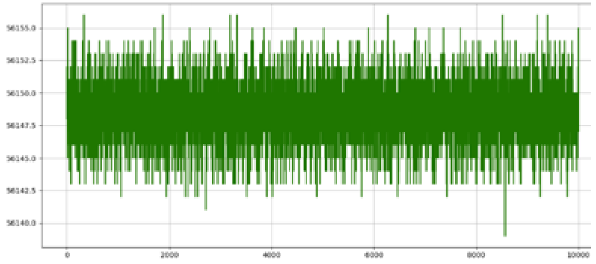
Ratio mechanics: $16 \div 2\pi = 2.546$ [mm/rad]

Linear resolution: $0.383 \cdot 2.546 = 0.975$ [µm]

Linear accuracy: $5.24 \cdot 2.546 =$ 13.34 [µm]

But: Resolver to Digital Converter (RDC)
have a bandwidth of ~1ms at 14 bits resolution…

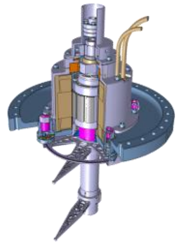
Linear potentiometer



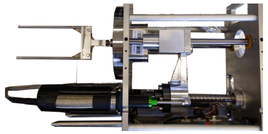
Tested with final electronics (18.06.2019)

Lab test:
Noise on the 16 bits acq chain
std ~3 [bit]
ENOB =< 14bits, 133mm stroke
8[µm] max res.
(before processing)

Motion control challenges with the linear system



LIU Kinematic unit is ideal from control viewpoint
bellow free – low friction

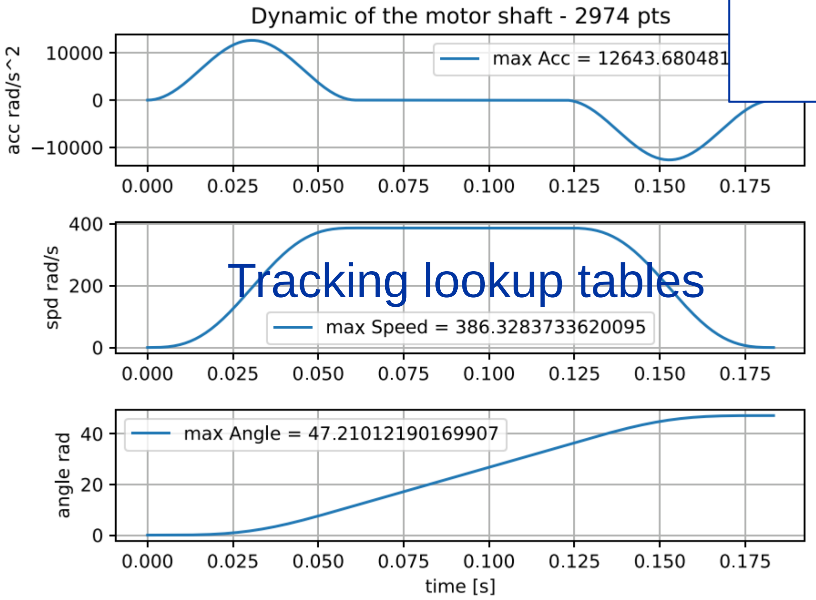


LHC ‘intermediate’ mechanism
has bellows and friction

Successful test with Dspace system with ‘constant’ position feedback with high power charger (400W)

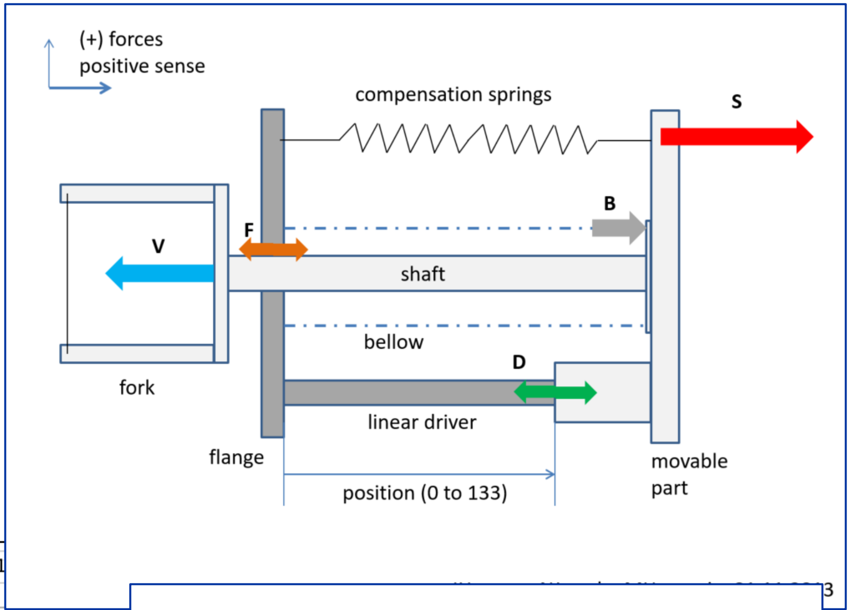
While LIU controller enables feedbacks only during the motion, due to lower power charger (<100W)

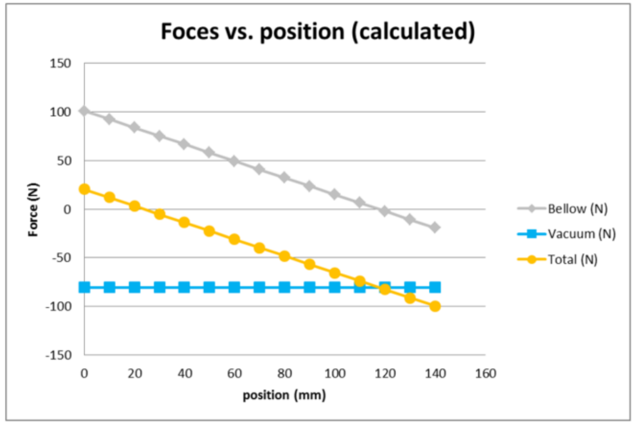
⇒ **Challenge to keep IN position**



Tracking lookup tables

Force unbalances IN/OUT in H and in V!





Vacuum force is constant and negative all along the movement
Bellow spring force is proportionally linear to the position

JHerranz, NJurado, MHamani – 01.11.2013

BWS for LHC Project Advancements 2021

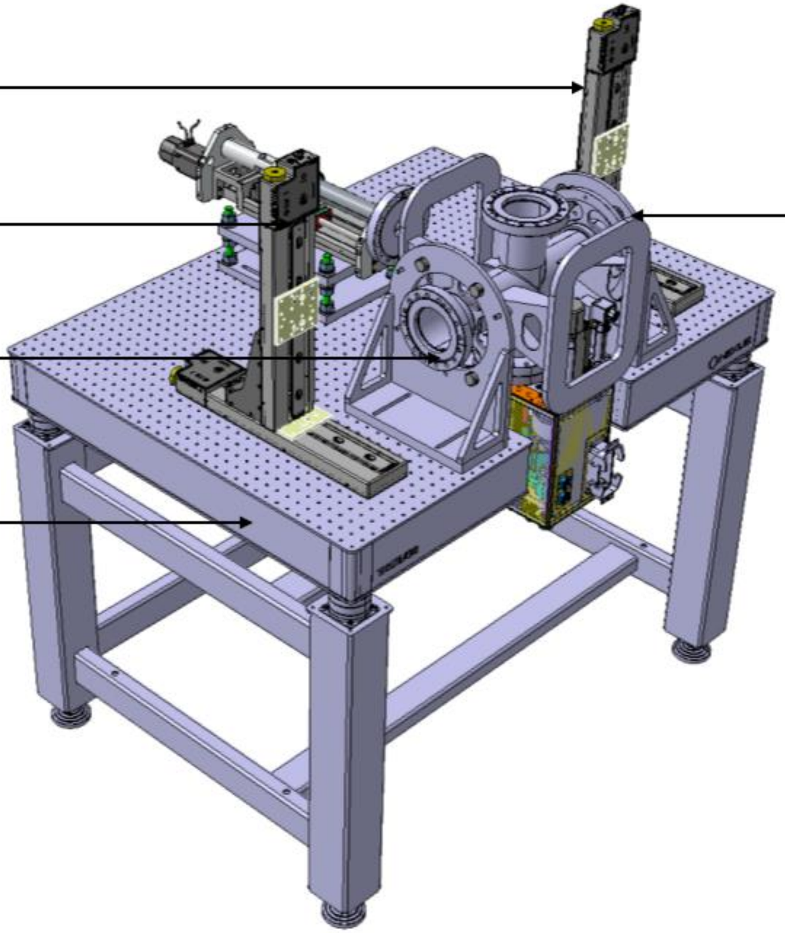
Linear BWS Calibration Bench

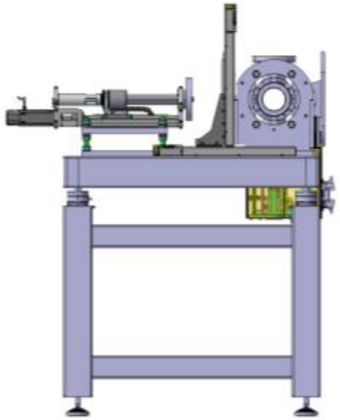
Fast magnetically coupled linear actuator can be tested

Laser positioning in H+V coordinates

Vacuum chamber and viewports for tests under vacuum

Commercial breadboard and supporting frames





Horizontal and Vertical on one bench with no need of transport service for BWS installation

Location: Lab SY-BI 867
Design: 60%
Delivery planned: 2022

All linear BWS can be calibrated:

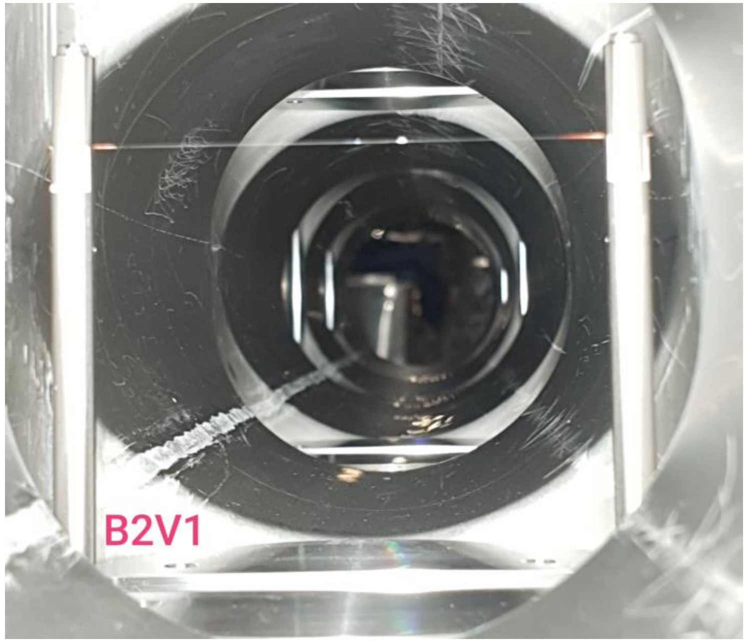
- **Operational LHC BWS (LEP design)**
- **Operational Prototypes (design 2019)**
- **Perspective linear BWS under development**

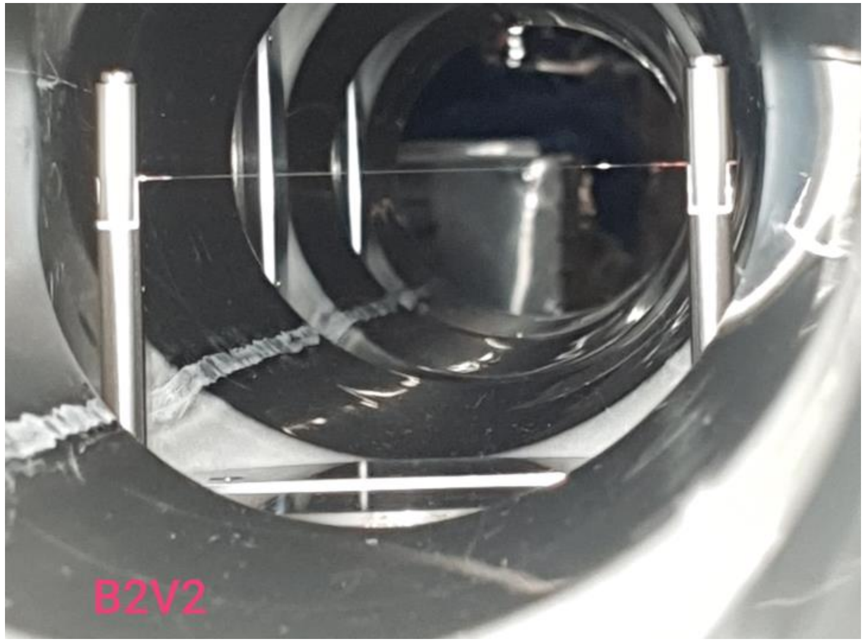
D. Gudkov

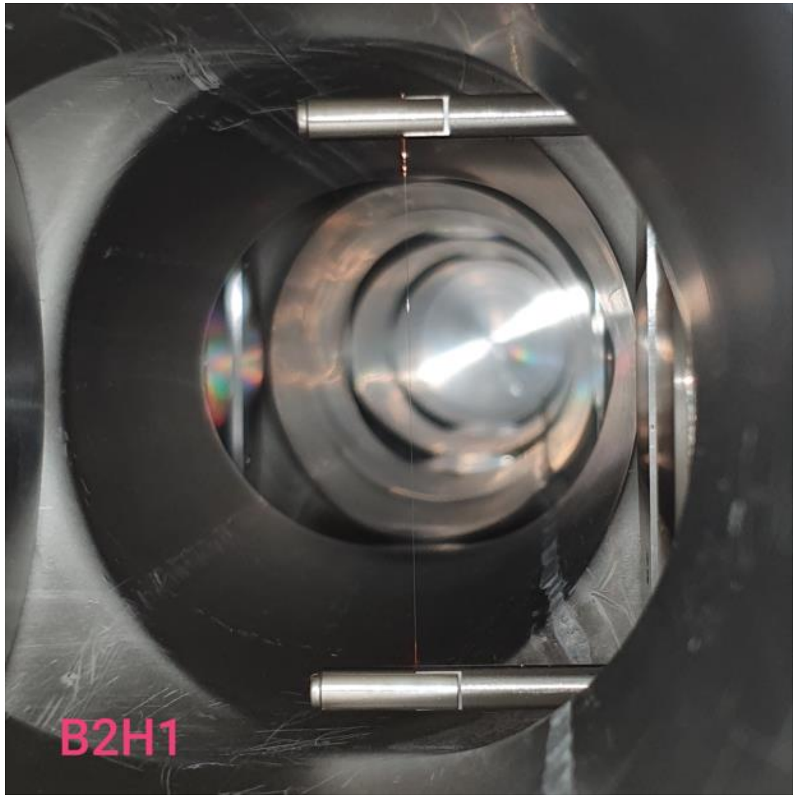
BEAM 2 YETS 22-23

Machine	position	Orient.	Beam	R after bakeout (kOhm)
LHC.B1	BWSH.A5R4.B1	H1	B1	1.699
	BWSH.A5R4.B1	H2	B1	1.706
	BWSV.A5R4.B1	V1	B1	1.877
	BWSV.A5R4.B1	V2	B1	1.634
LHC.B2	BWSH.A5L4.B2E	H1	B2	1.6
	BWSH.A5L4.B2E	H2	B2	1.7
	BWSV.A5L4.B2E	V1	B2	1.7
	BWSV.A5L4.B2E	V2	B2	1.65

- **Beam 2 tank moved to the pass way**
- **B1H1 => Potentiometer damages by transport and exchanged with Jean + new air side connection to avoid resistivity measure errors**
- **B2H1 & B2V1 & B2V2 C-Wire inspected => no sign of damages**







LHC hybrid prototype with LIU electronics

BWSVPA (V2)
For powering the locking safety brake
https://edms.cern.ch/item/EDA-03698-V2-0