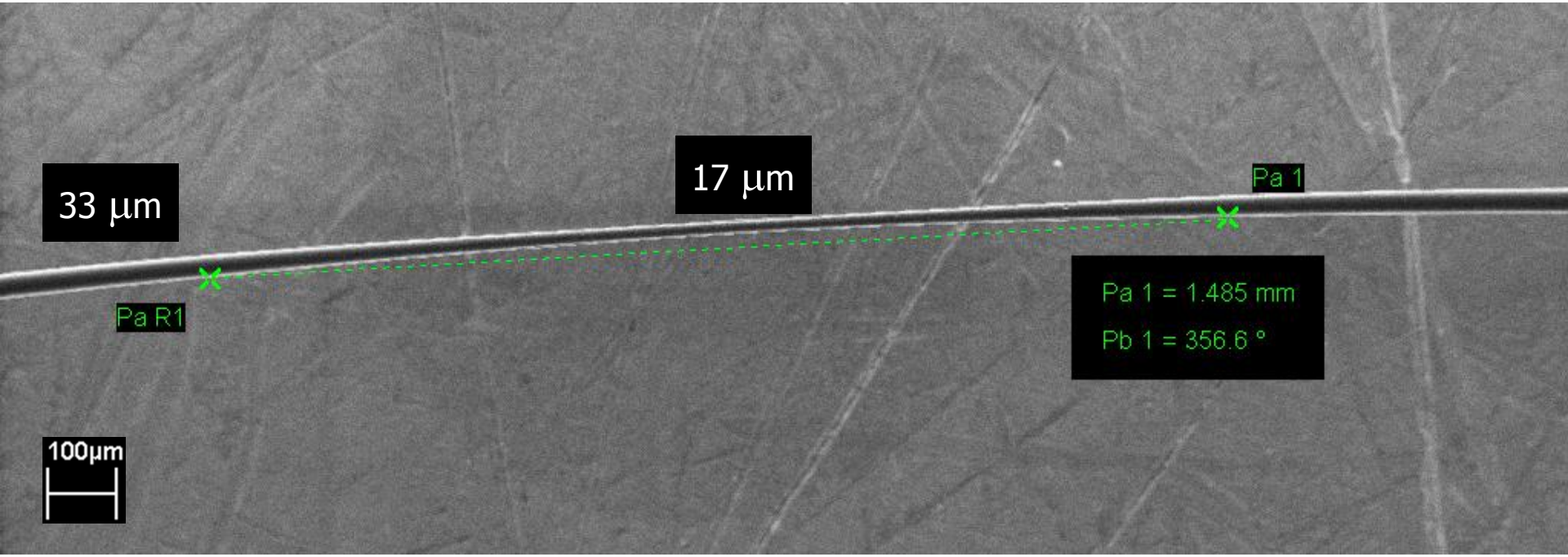
Developments in High Precision Fast Wire Scanners for High Intensity Proton Accelerators

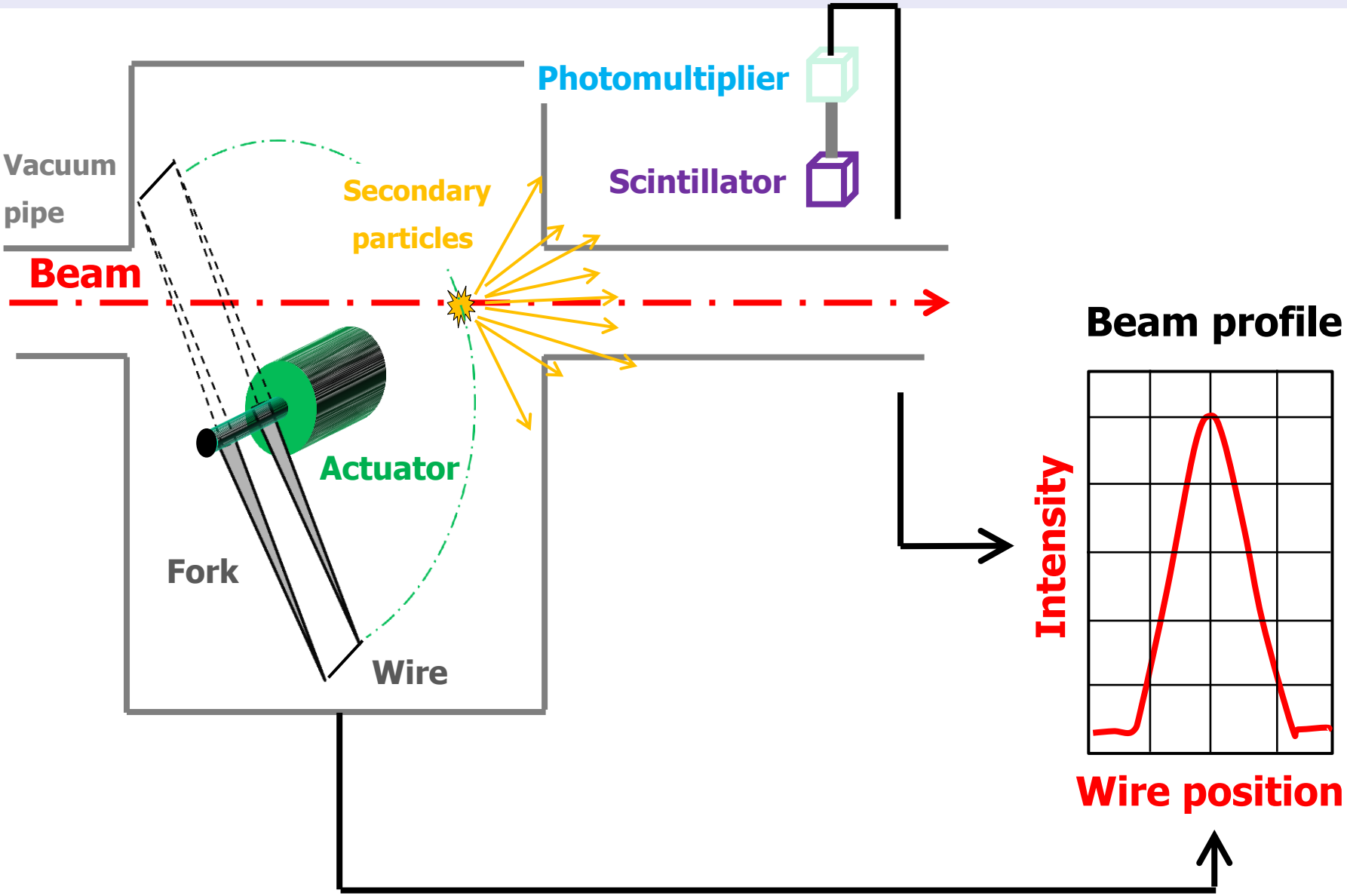
Principle:

- Sampling the transverse beam profile with scatter target
- Measurement of target position and scattered beam intensity

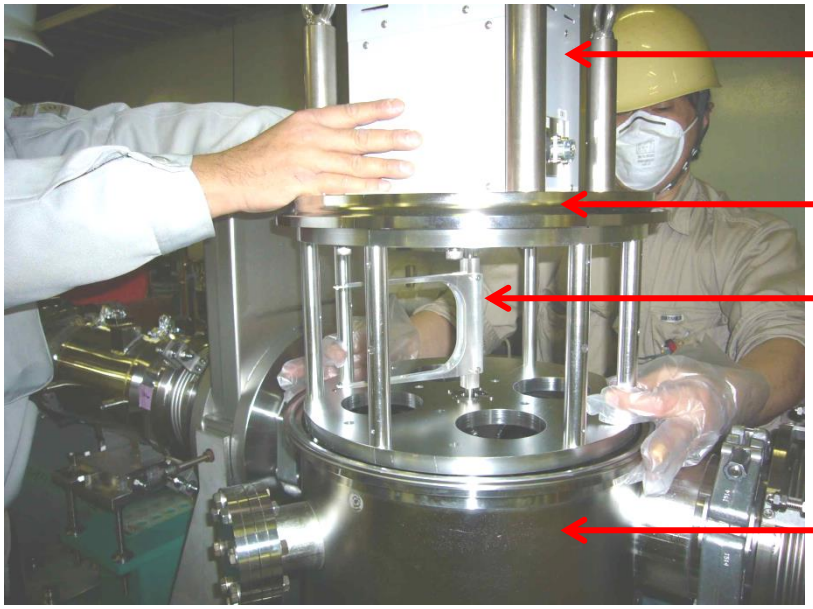
Scatter target: Carbon wire, diameter between 7 to 33 µm, mass about 100 µg



Principle


Photomultiplier
Scintillator
Vacuum
pipe
Secondary
particles
Beam
Actuator
Fork
Wire
Beam profile
Intensity
Wire position

J-PARC Scanners



Housing of

actuator, air- vacuum transition, potentiometer

Vacuum flange

Shaft and wire fork

Vacuum tank and beam pipe

State of the Art (II)

		Diameter [um]	Speed [m/s]	Actuator	Position measurement	Reso-lution [um]	Repro-ducibility [um]	Air – vacuum transition
BNL	AGS	33	10	step				
FNAL	RECICLER TEVATRON	33	7	DC servo	resolver	22	1 to 2 %	Bellow
KEK	PS	7	20	DC servo	potentiometer		300	
JPARC		7	10	DC servo	potentiometer			Ferrofluidic feedthrough
CERN	PSB, PS	11 x 7	20	DC servo	potentiometer		200	Bellow
	SPS	33	6	DC servo	potentiometer			Bellow

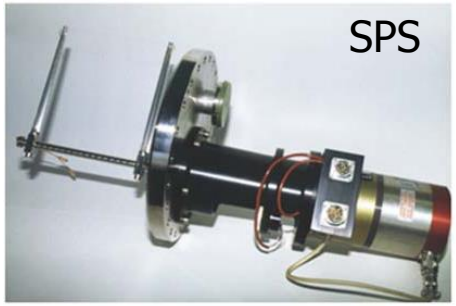
All designs are similar

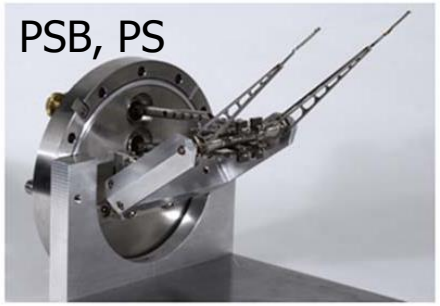
Limitation of Present Designs

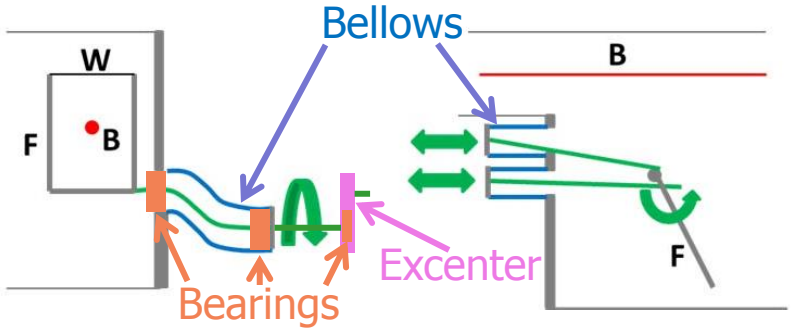
- Reproducibility / Accuracy
  - Wire position measurement error sources
  - Angular encoder
  - Measurement of rotational angle outside of the vacuum ==
    Air – vacuum transition requires complex mechanical solutions
    - Mechanical play
    - Deflections
    - Vibration
- Bellow life time relative low

Example

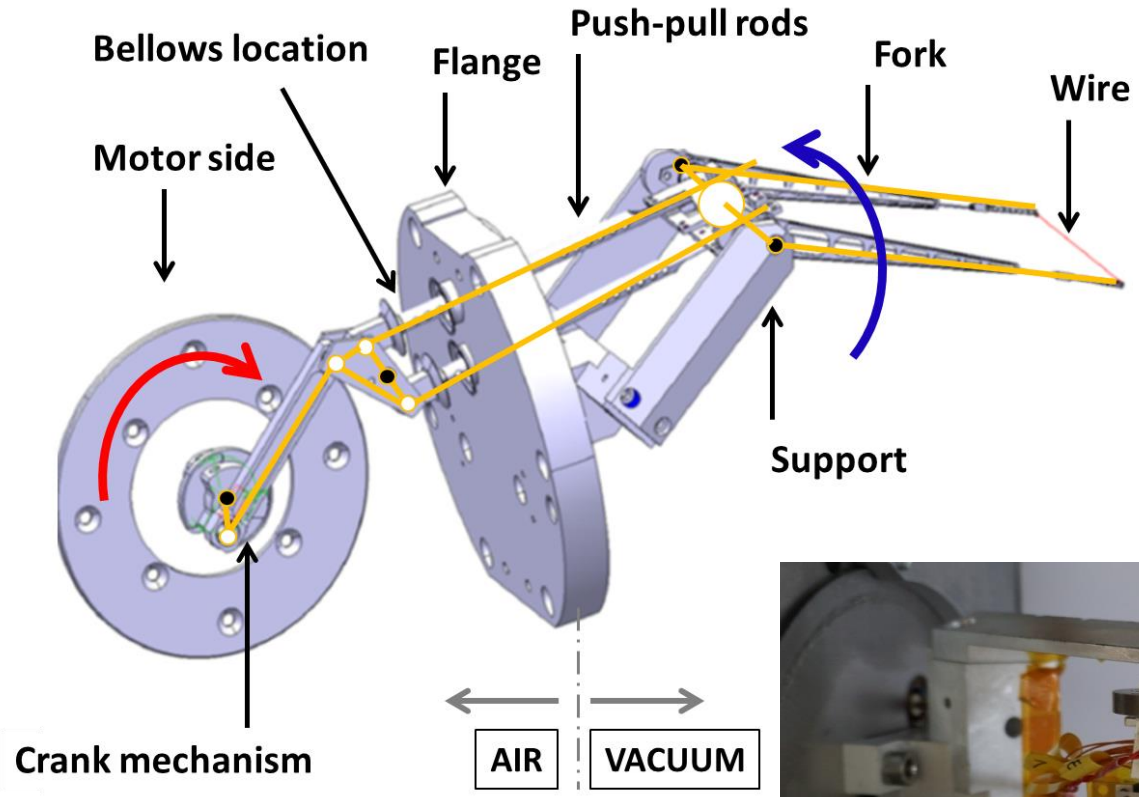
Air – vacuum transition



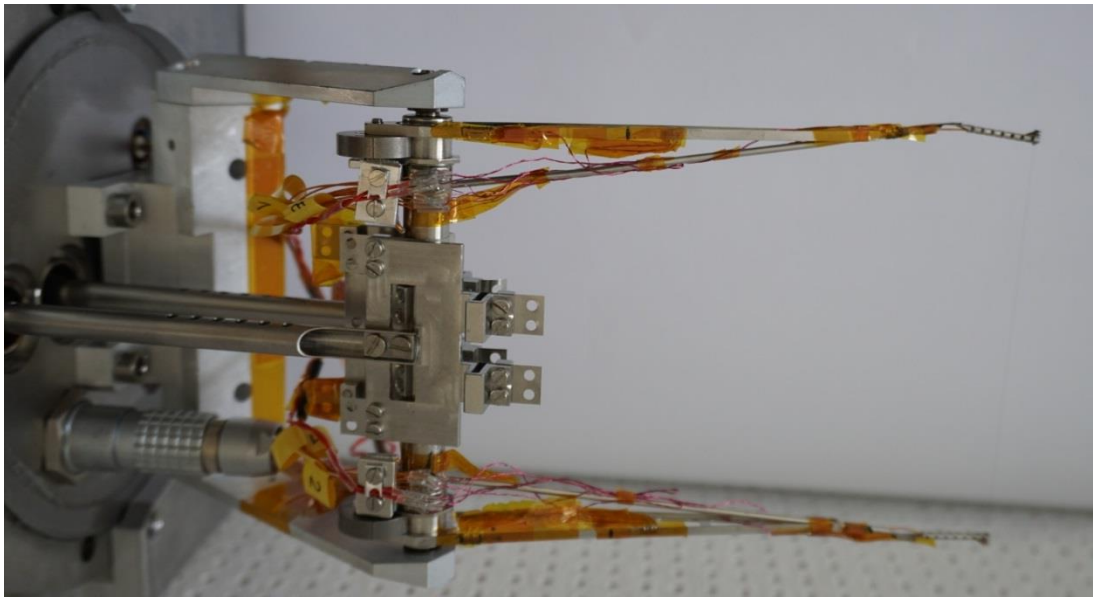




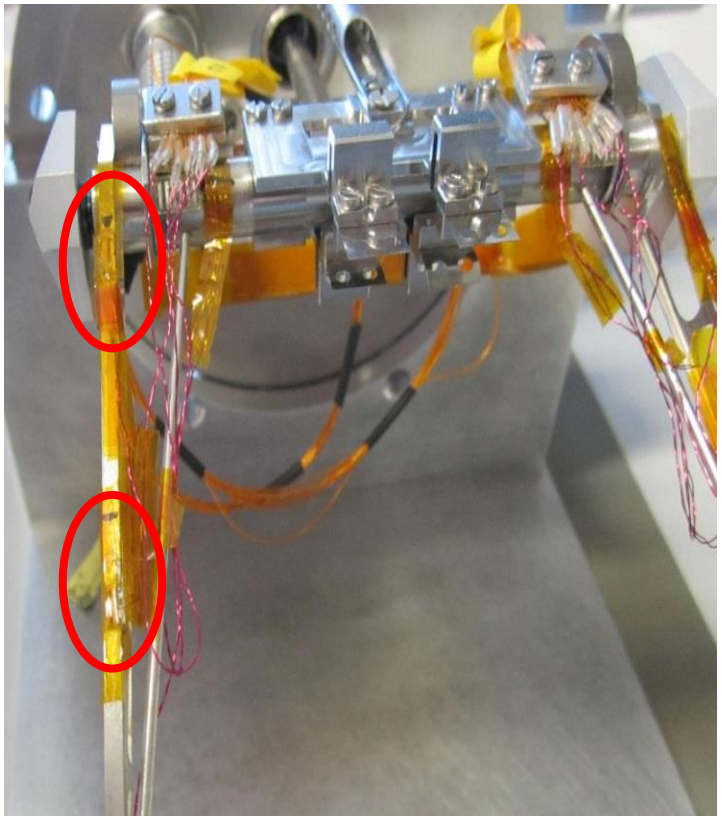
Study of Vibration Effects



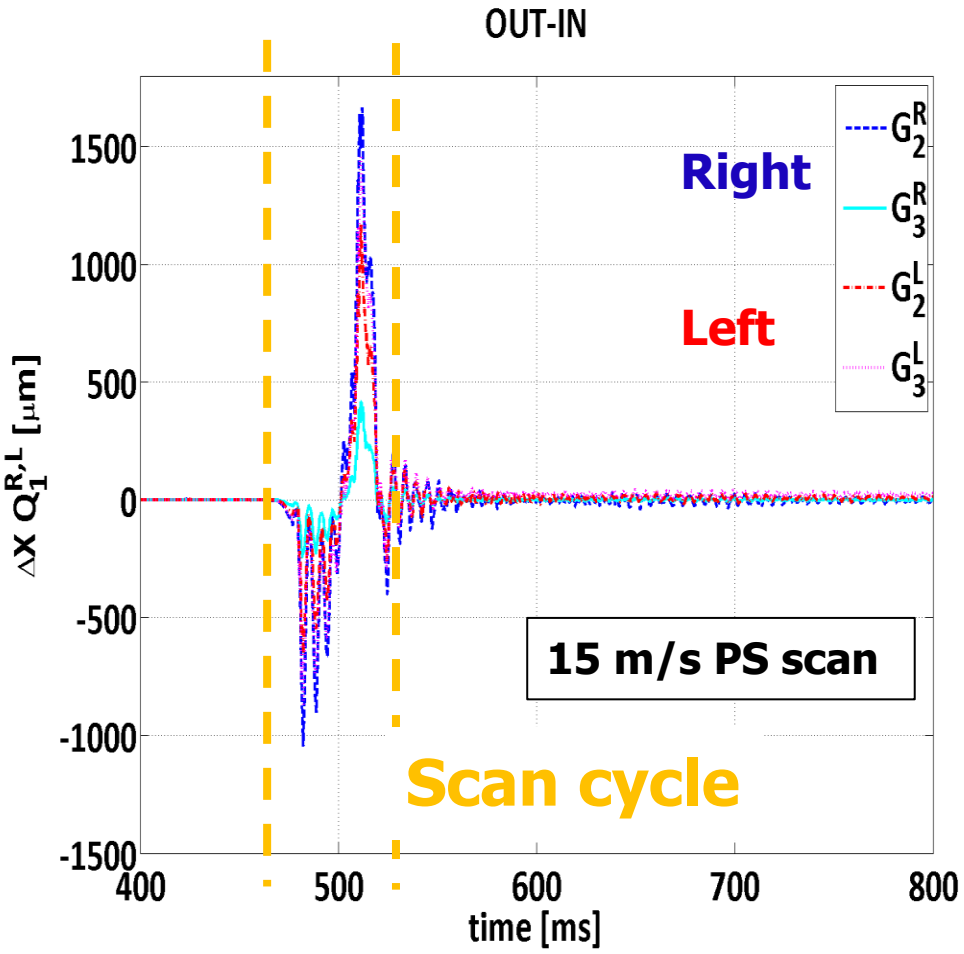
- Vibration measurements by Si strain gauges
  - Three gauges on each fork arm
- Piezoresistive effect of carbon wire



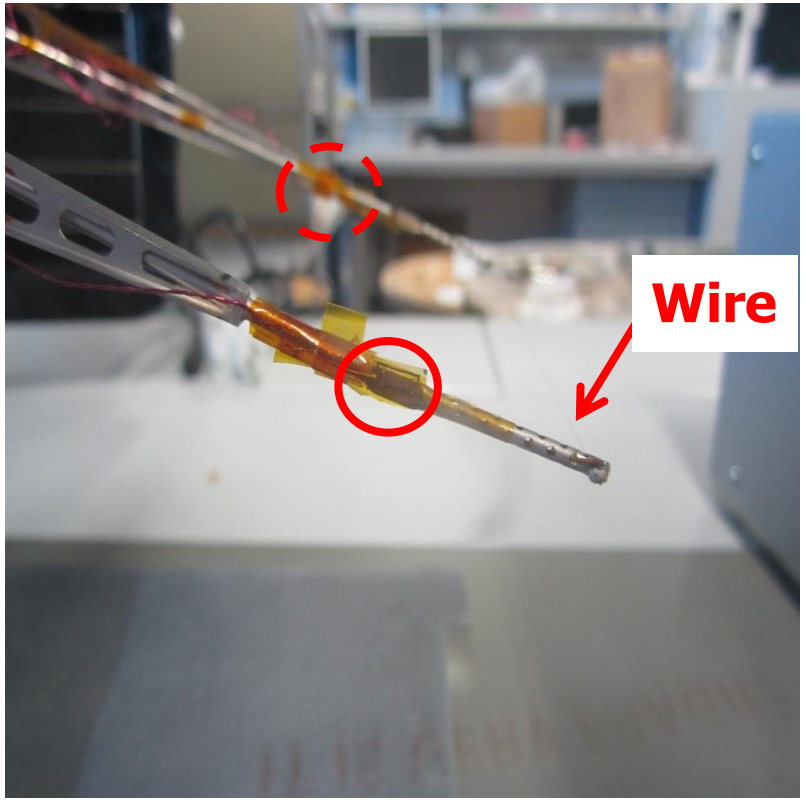
Vibration measurements



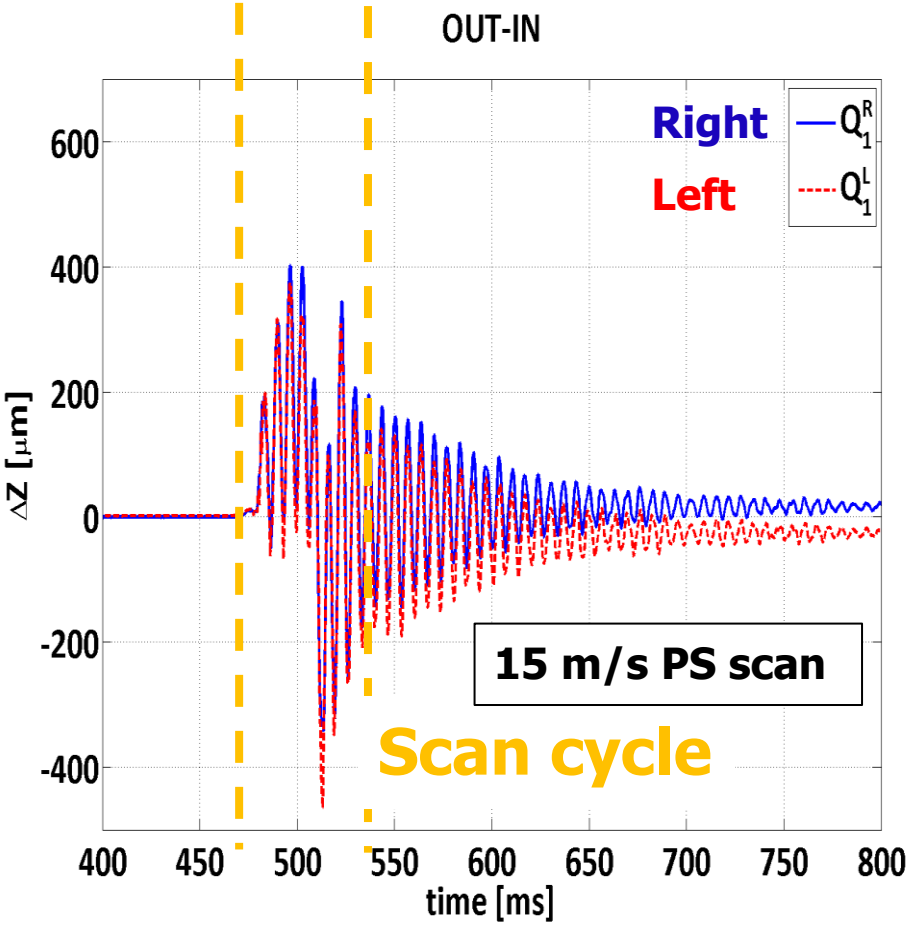
Tip transversal deflection



Vibration measurements

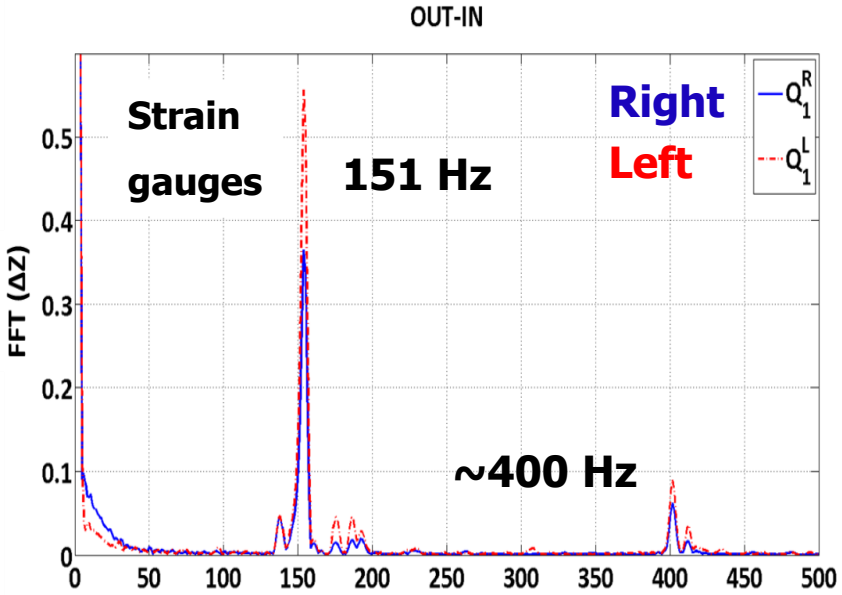


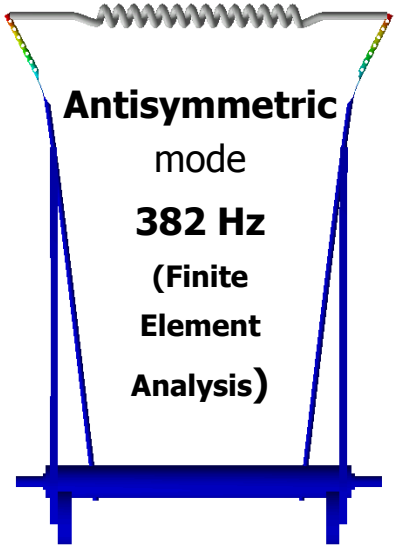
Tip longitudinal deflection



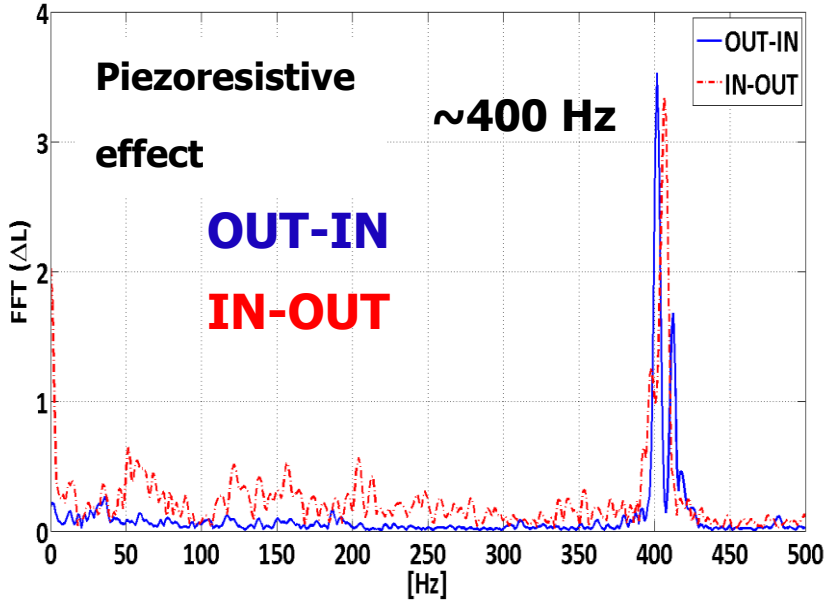
Synchronous right and left tip oscillations

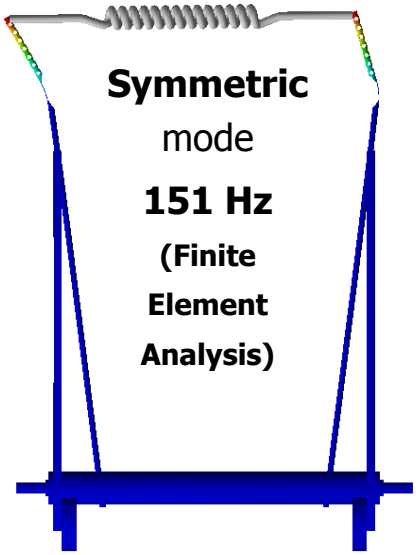
Vibration measurements - Frequency Analysis





Antisymmetric modes measured by strain gauges and wire piezoresistive effect





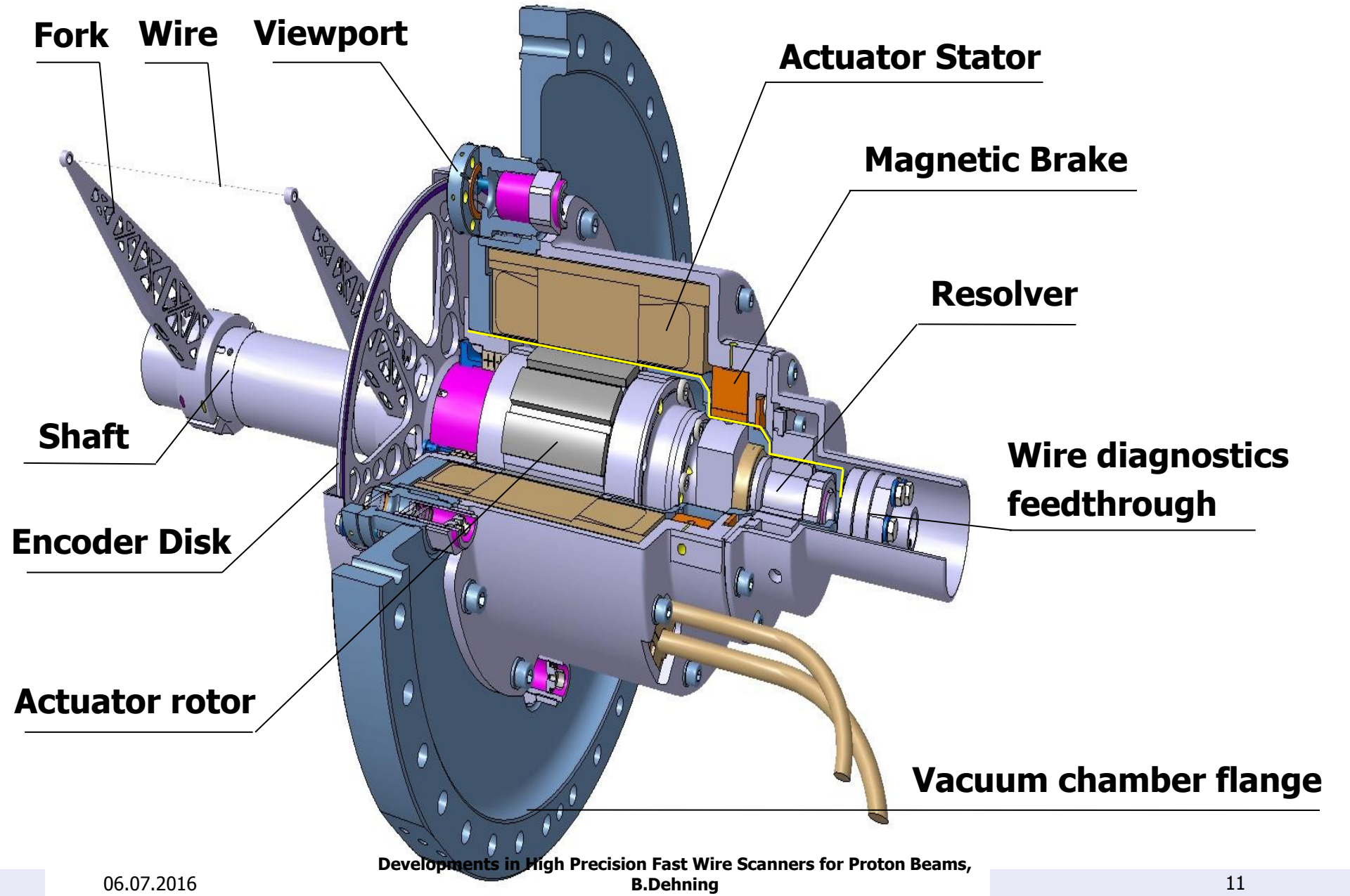
Symmetric mode is recorded only by strain gauges

State of the Art (II)

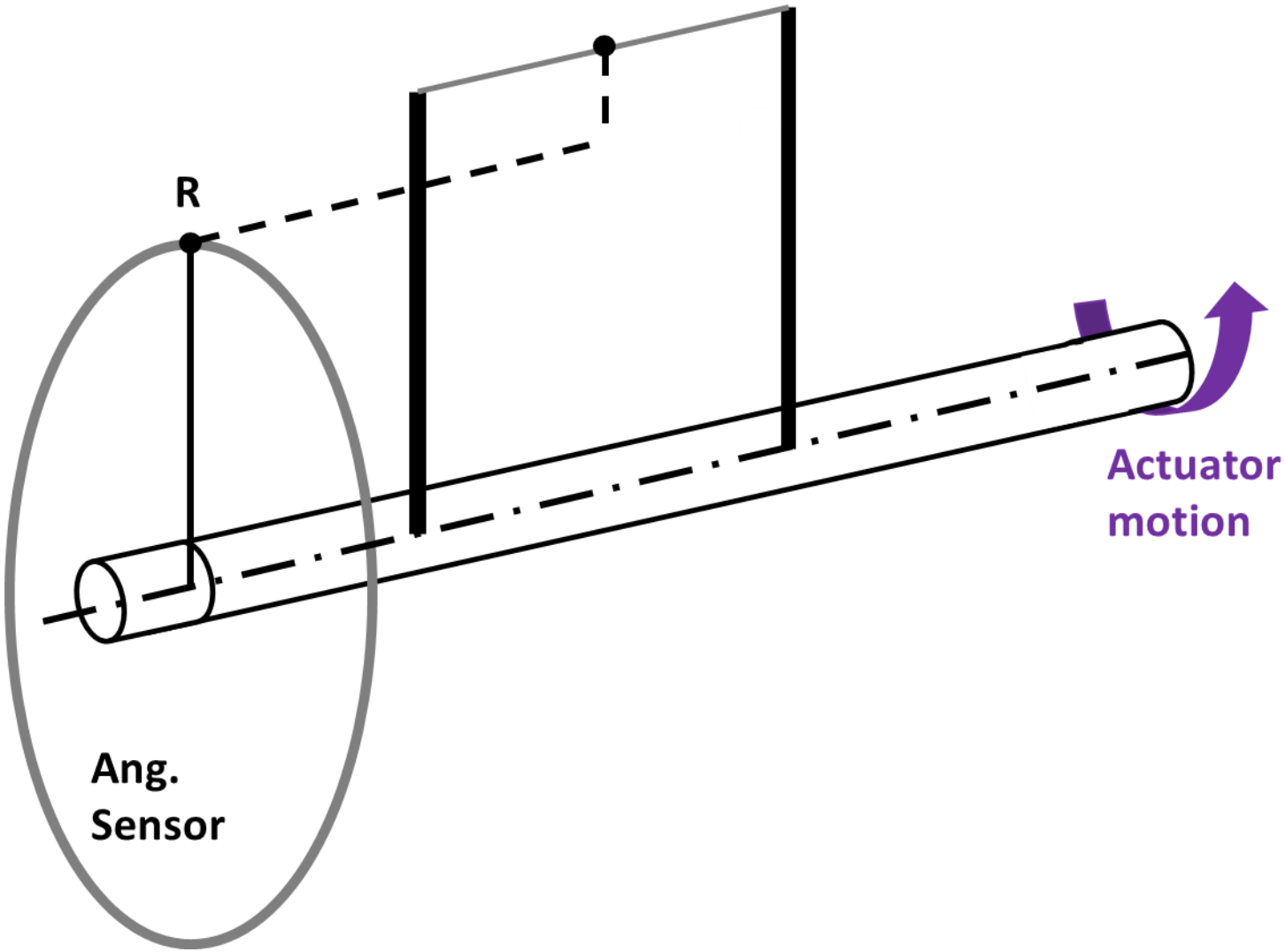
		Diameter [um]	Speed [m/s]	Actuator	Position measurement	Reso-lution [um]	Repro-ducibility [um]	Air – vacuum transition
BNL	AGS	33	10	step				
FNAL	RECICLER TEVATRON	33	7	DC servo	resolver	22	1 to 2 %	Bellow
KEK	PS	7	20	DC servo	potentiometer		300	
JPARC		7	10	DC servo	potentiometer			Ferrofluidic feedthrough
CERN	PSB, PS	11 x 7	20	DC servo	potentiometer		200	Bellow
	SPS	33	6	DC servo	potentiometer			Bellow
	new	investigated	20	brush less 3 phase	resolver & opt. encoder	20	2 (aim)	no

The new design has all moveable components in vacuum

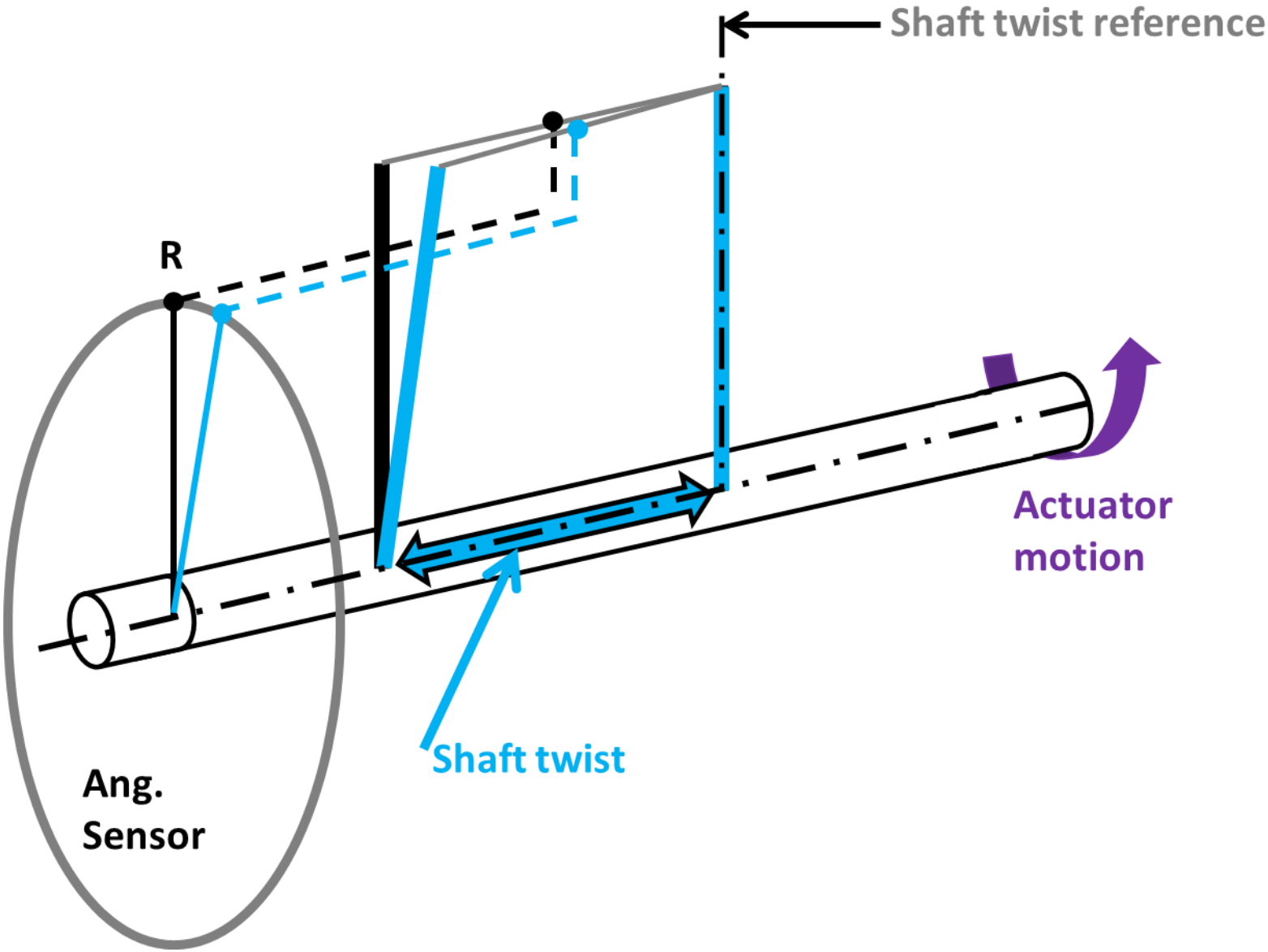
CERN BOOSTER Wire Scanner Design



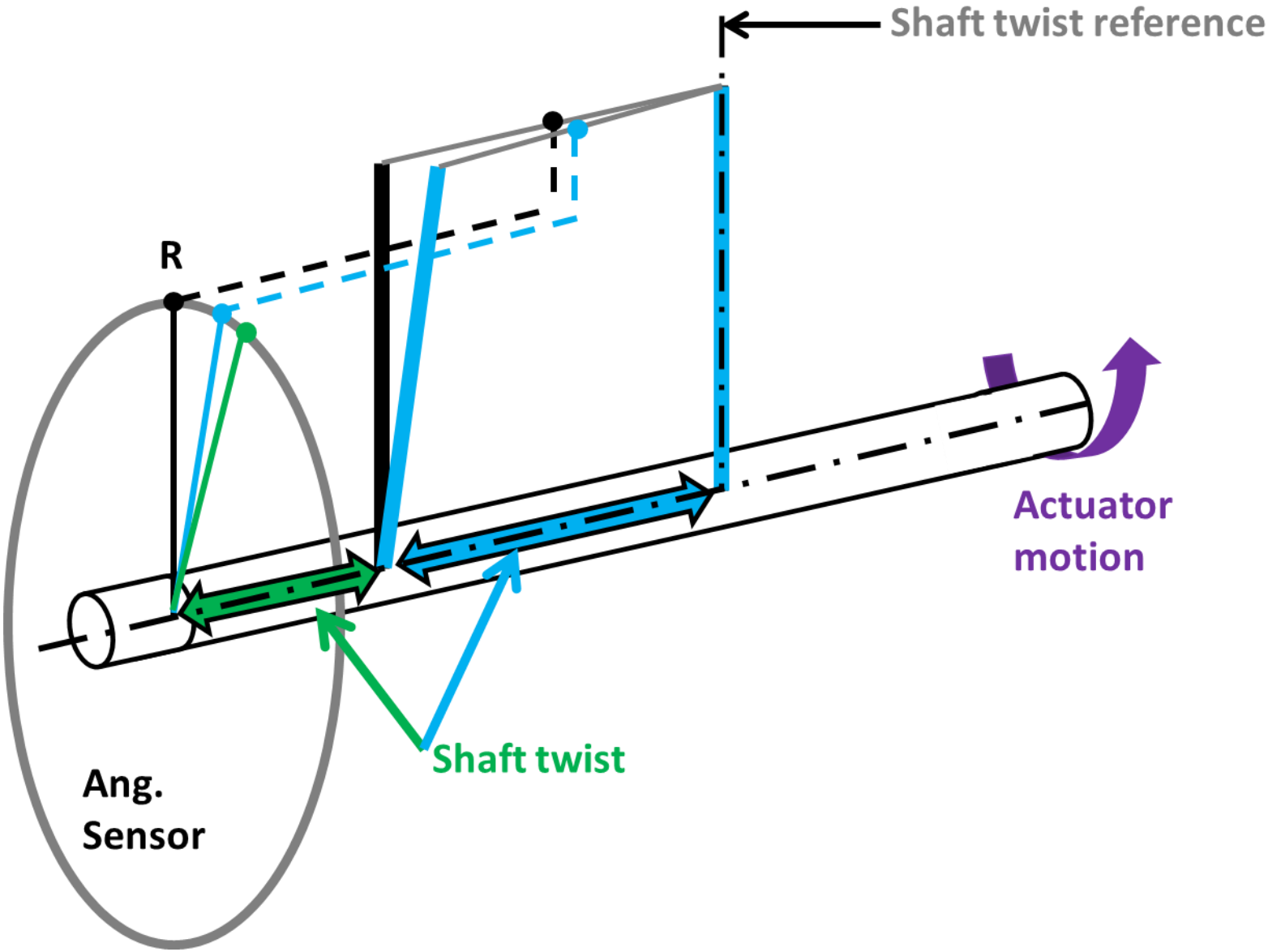
Measurement Errors in Shaft – Fork Assembly



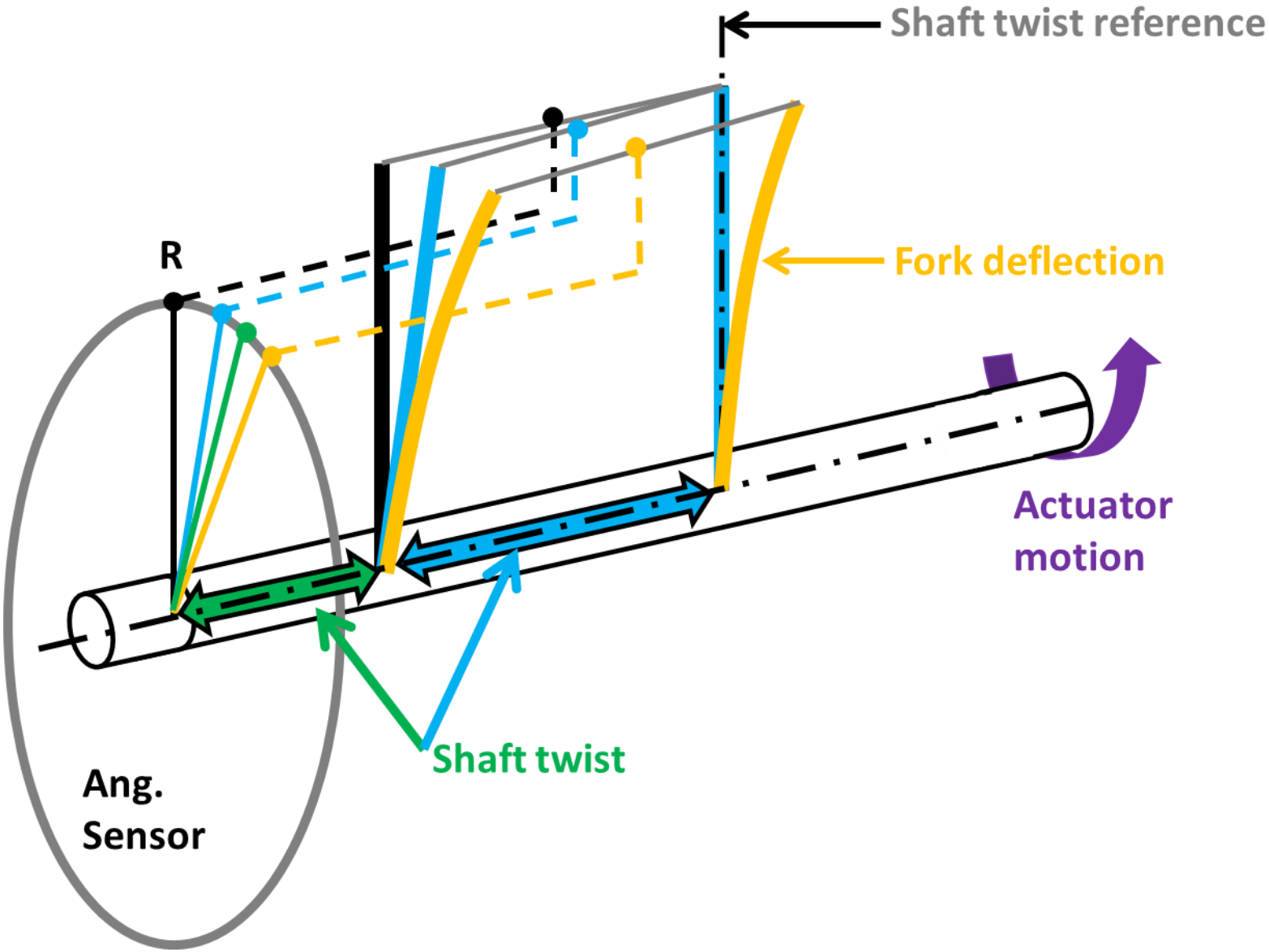
Measurement Errors in Shaft – Fork Assembly



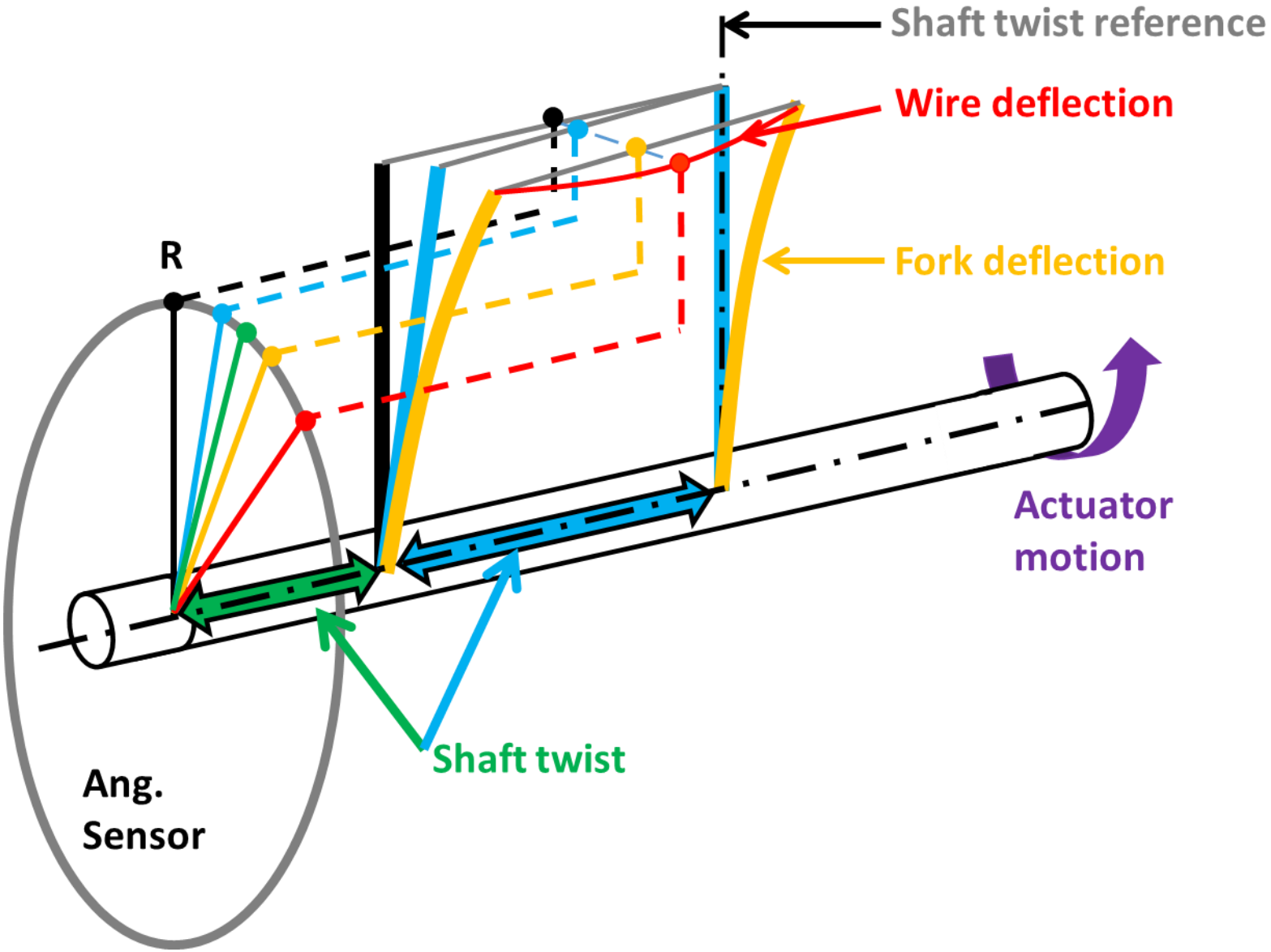
Measurement Errors in Shaft – Fork Assembly



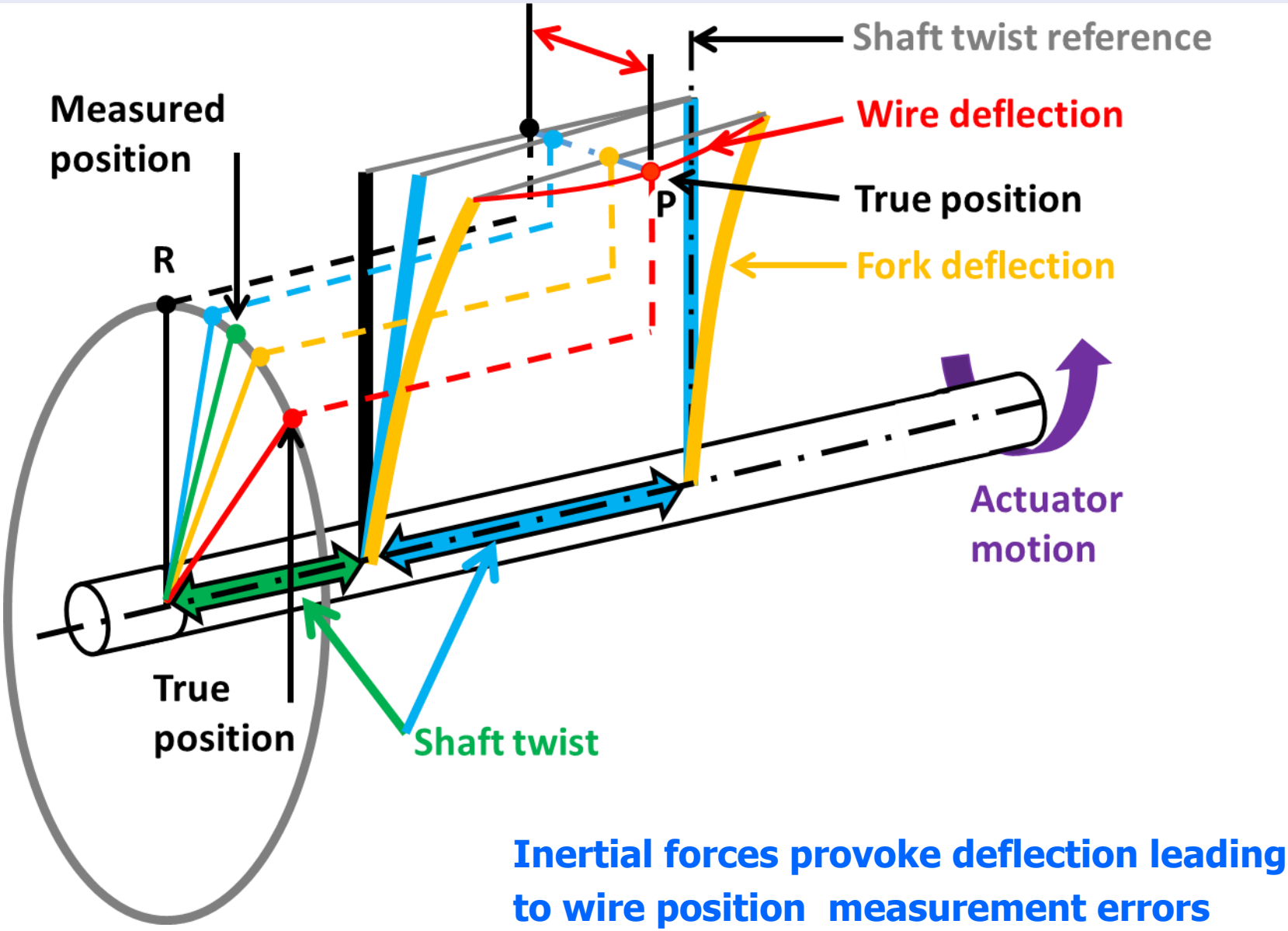
Measurement Errors in Shaft – Fork Assembly



Measurement Errors in Shaft – Fork Assembly



Measurement Errors in Shaft – Fork Assembly

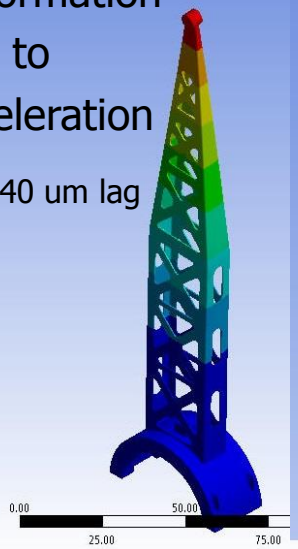


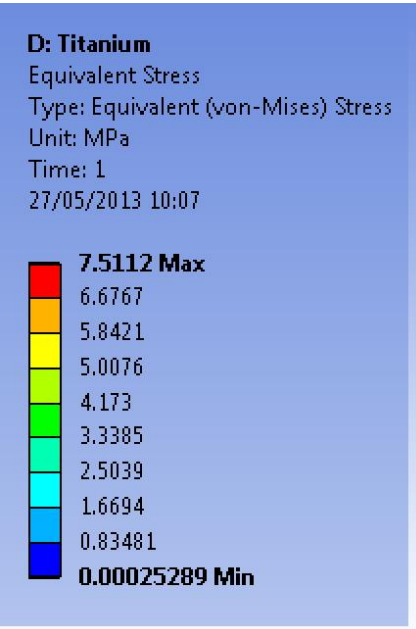
Inertial forces provoke deflection leading to wire position measurement errors

Shaft and Fork Optimization

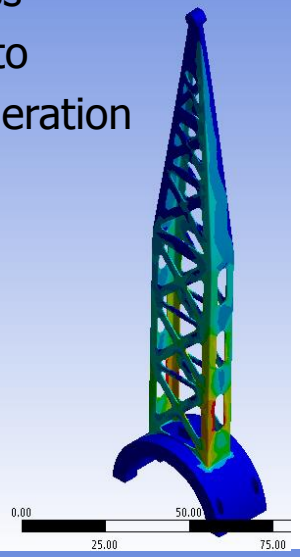
Deformation due to acceleration

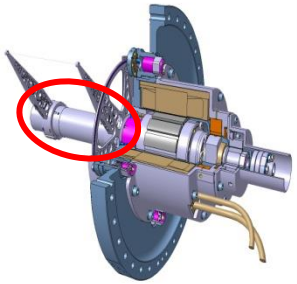
Max 40 um lag



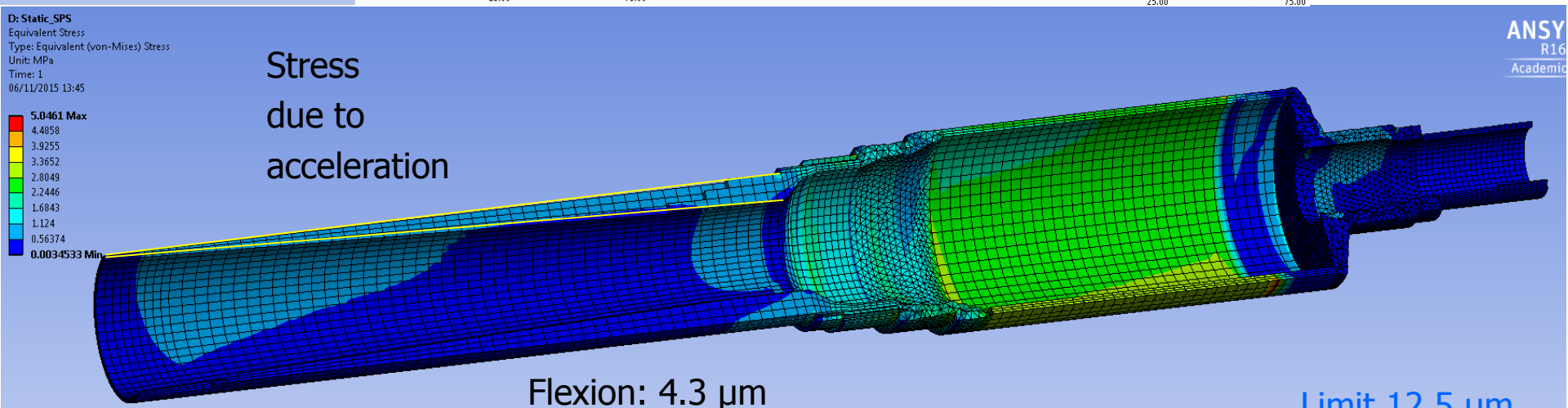


Stress due to acceleration





Additive manufacturing (3D printing)



Stress due to acceleration

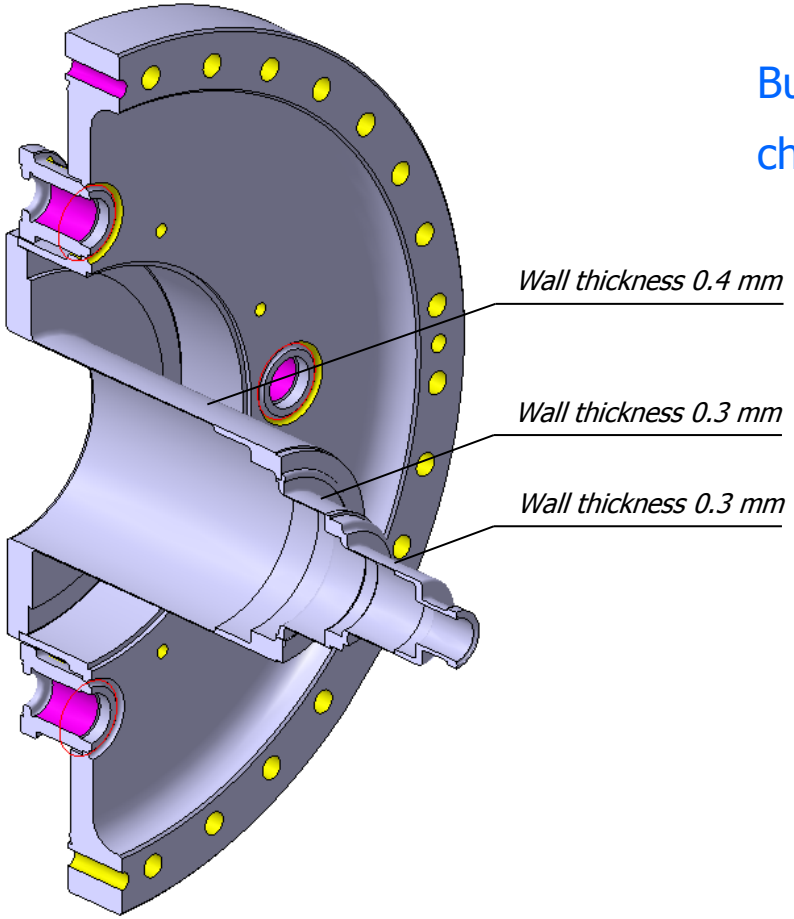
Flexion: 4.3 µm

Rotation between forks: 4.27E-5 rad →7.7 µm

Limit 12.5 µm

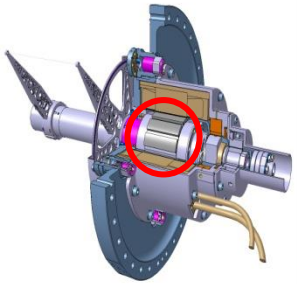
J_{shaft} = 5.43 E-4 kg*m2

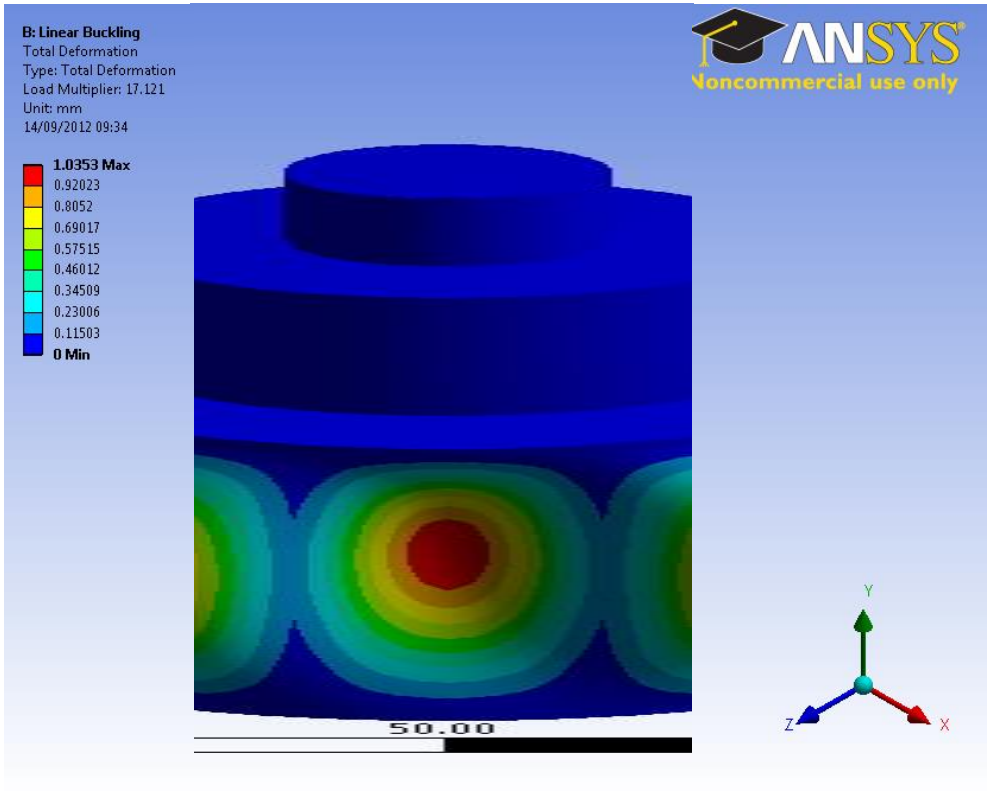
Actuator Step Vacuum Chamber Design



316LN 3D forged

Buckling simulation determine chamber dimensions

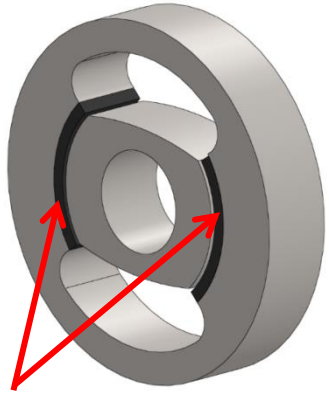




Actuator – Resolver – Brake

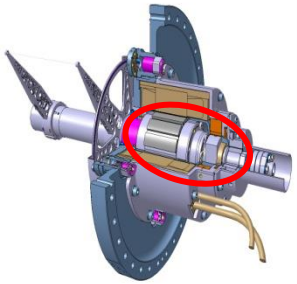
Actuator

Brake



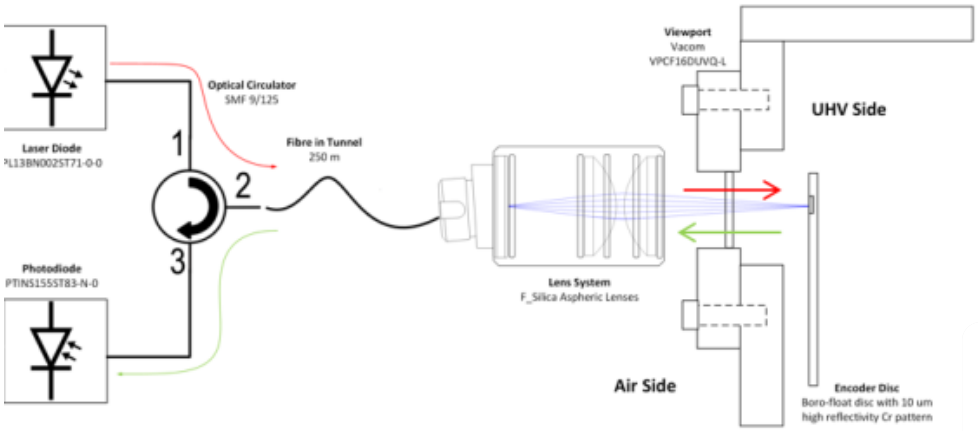
Permanent magnets

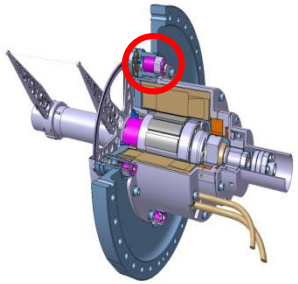
Resolver

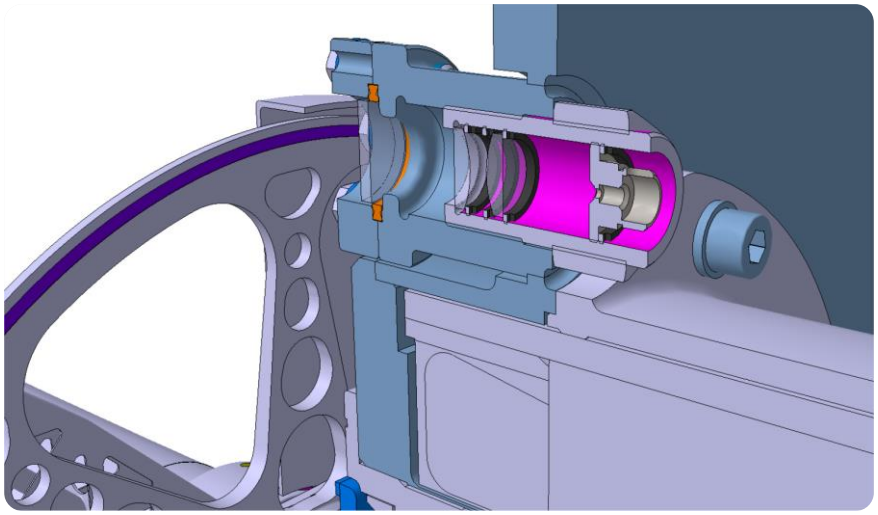


- Actuator
  - Off the shelf with modification
    - Alxion 145STK2M
    - Increased gap, 0.7 mm
    - Samarium-Cobalt (Sm_2Co_{17}) (backing 200 °C)
    - Sleeve for magnet fixation (not glued)
- Resolver
  - Off the shelf
    - Admotec RO5032
    - Accuracy +- 17 mrad
    - Accuracy after calibration +- 1.7 mrad
- Brake
  - Custom
    - Max torque 0.4 Tm

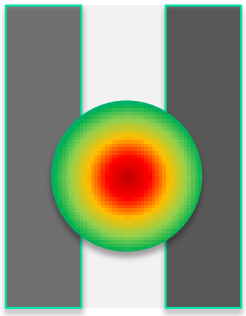
Incremental Optical Vacuum Encoder

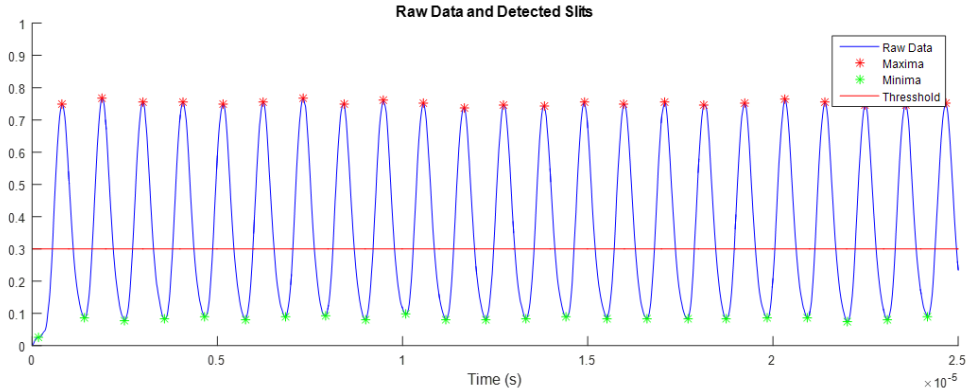






Pitch (um)	Status	GLASS DISK					
		Threshold Det.		Peaks Det.		CDF Det.	
		Slit σ (um)	Pr.Err (um)	Slit σ (um)	Pr.Err (um)	Slit σ (um)	Pr.Err (um)
20	Sample	0.17	0.33	0.33	0.61	0.16	0.31

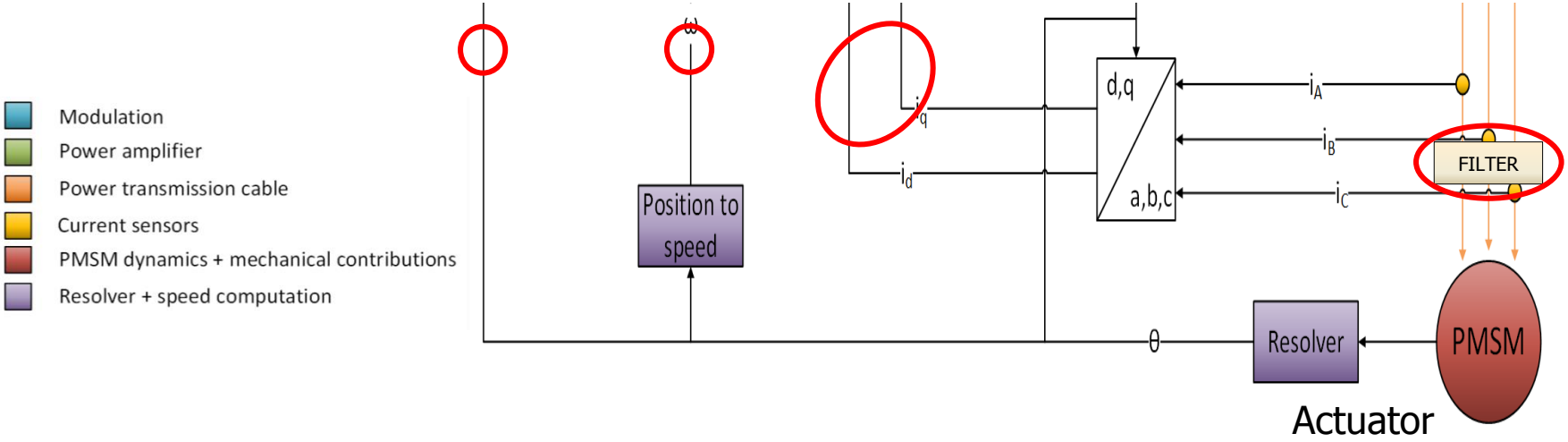




Metallic discs results show a 2 to 3 times decrease of reproducibility

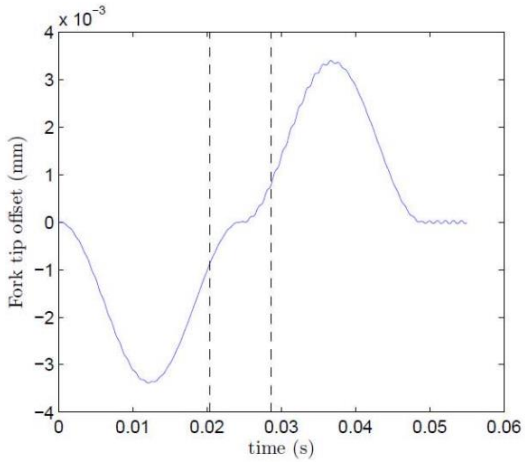
Control

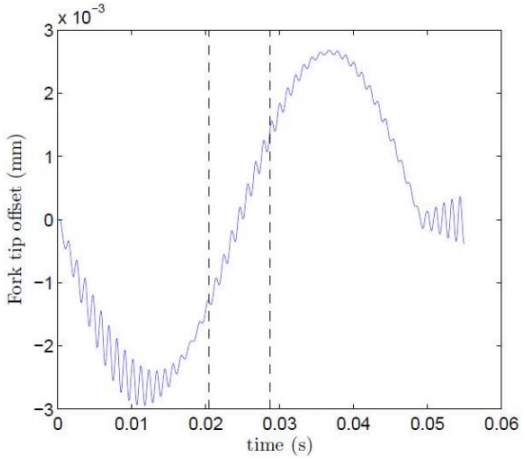
- Sensors
  - Voltage and current transducers
  - Resolver
  - Angular optical encoder
- Carbon wire measurements
  - differential current measurement (thermionic effect)
  - Voltage drop measurement (resistivity)
  - Piezoresistive bridge measurements
- Digital, 3 loop feedback system
  - Current, speed, position (set: position versus time)
  - Development: model in Simulink
  - Fast prototype model test: DSpace system (load of Simulink model)
  - Operational system control in FPGA

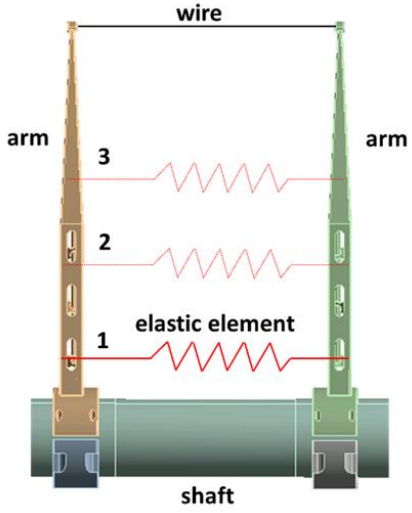


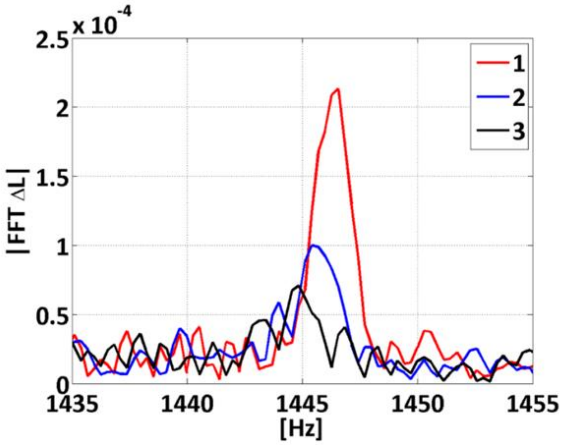
Outlook: Motion Pattern and Wire Resonance Frequency

- Motion pattern optimization
  - Simulation: tip offset variation with and without oscillation pattern => Model driven optimization foreseen
  - Observation by piezoresistive effect









- Monitoring of change of wire tension
  - Optimized excitation by motion pattern
  - Observation by piezoresistive effect

Summary and Outlook

- Deformations of wire scanner fork have been studied
  - Analytical model
  - FE analysis
  - Strain gauge and piezoresistive effect measurements
- Piezoresistive effect is applicable for insitu mentoring of wire tension
- A wire scanner with all moveable parts in vacuum has been produced and is under test (SPS)
  - First measurements have been done with the FPGA based digital control system
- An optimized, second design for the CERN BOOSTER is in production
  - It is planned that this design will be the base for the new scanners to be installed in all LHC injector rings in the technical stop 2019/20
- An acquisition system for the secondary shower detection with an extended dynamic range is under study