Proton Induced Thermal Stress Wave Measurements in Solid Targets

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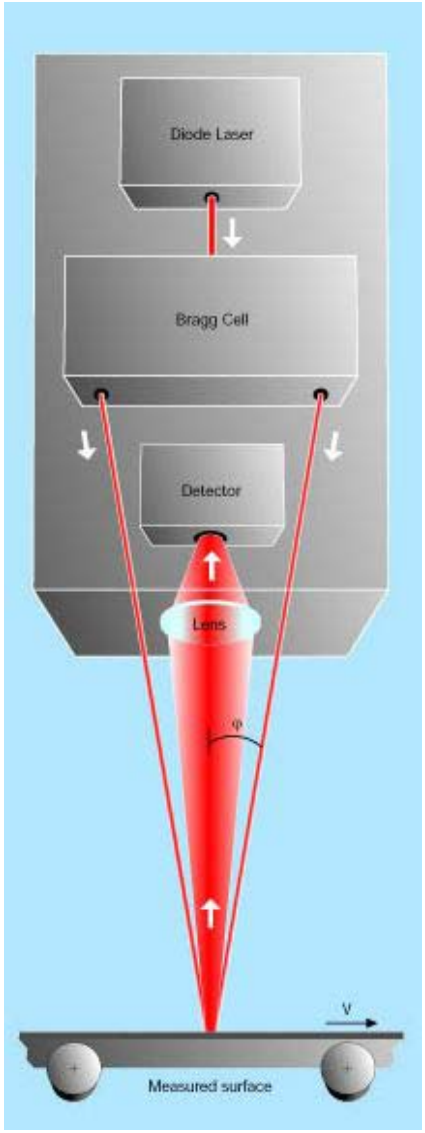
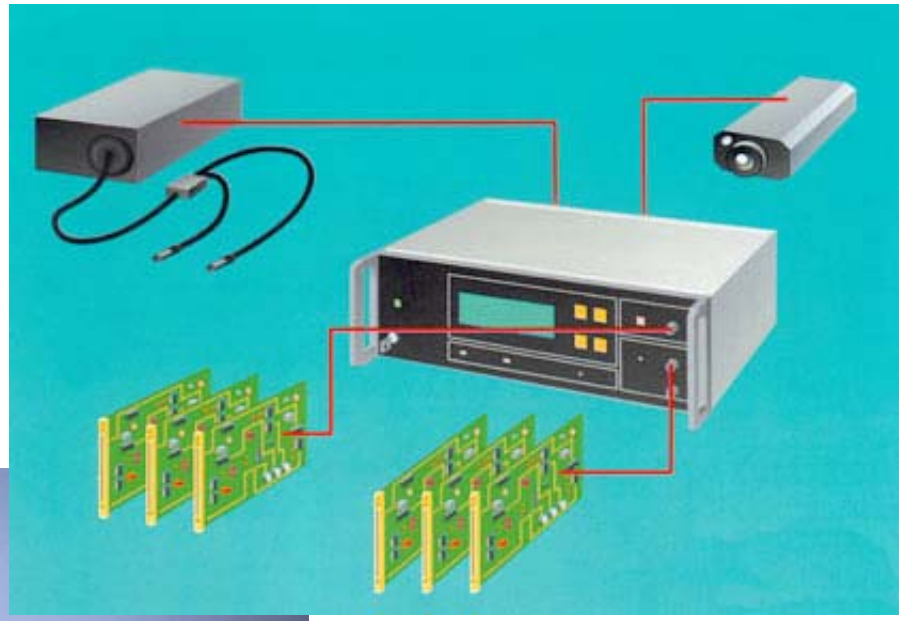
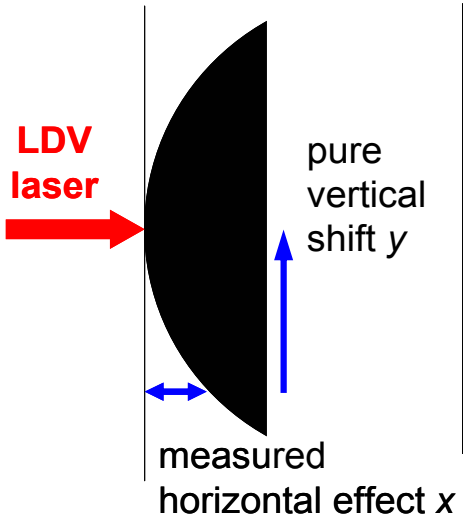
Laser Doppler Vibrometer



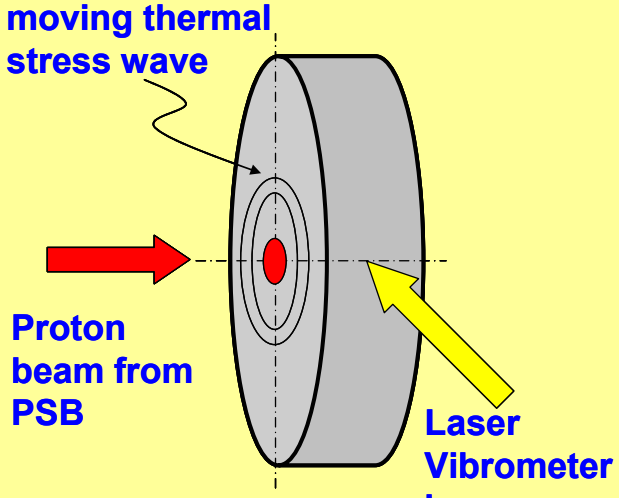
Single-Point Out-of-Plane Laser Doppler Vibrometer from Polytec®



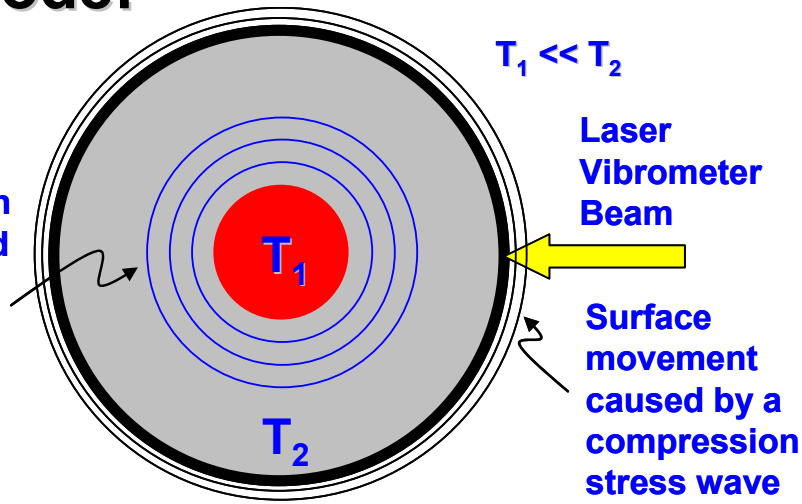


Vibration Modes of a Cylinder

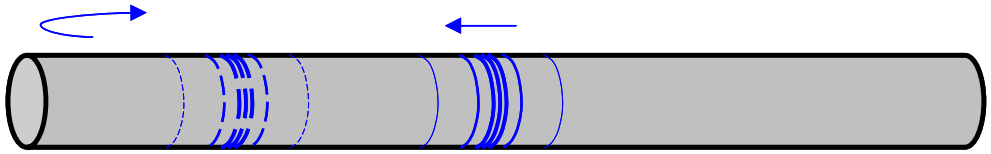
Principle:



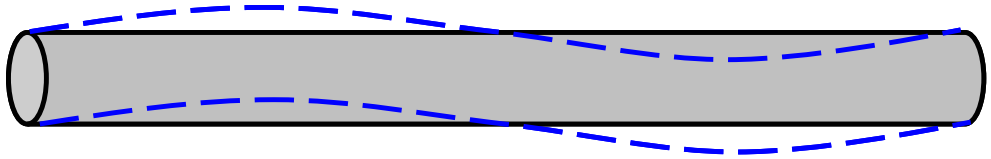
Radial mode:



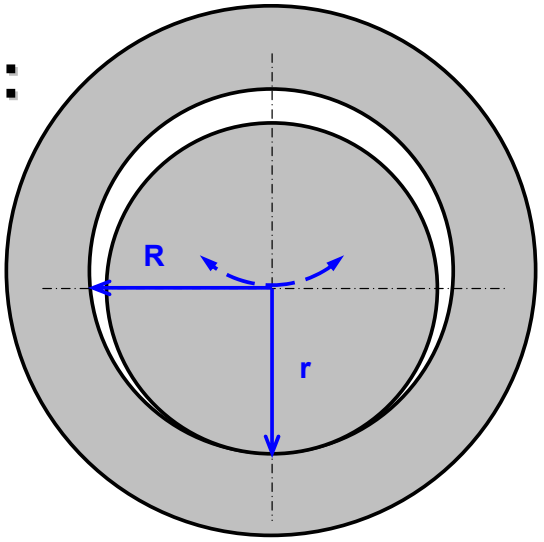
Longitudinal mode:



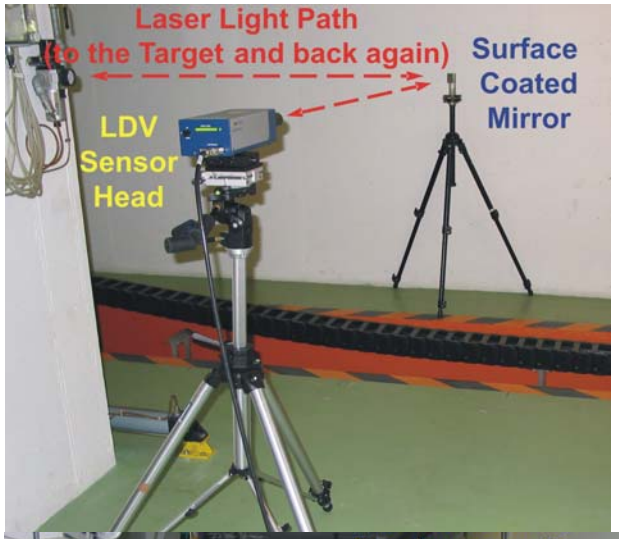
Bending mode:



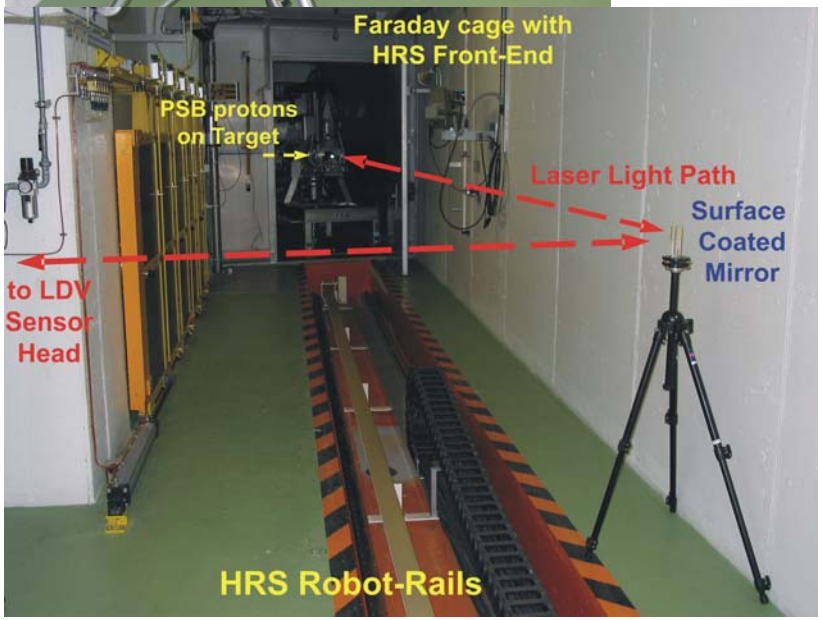
Rolling:



Laser Vibrometer Setup at ISOLDE



LDV-head on a tripod
(between the robot parking of GPS and HRS)



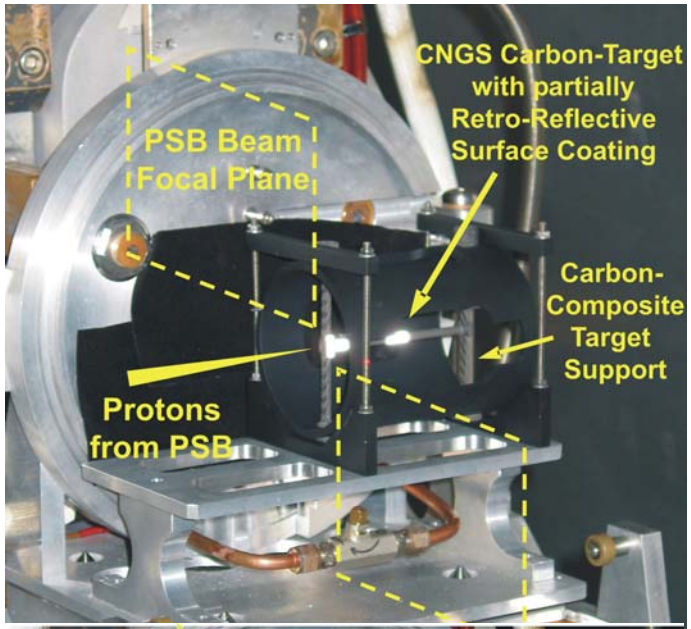
Standard CNGS C-target

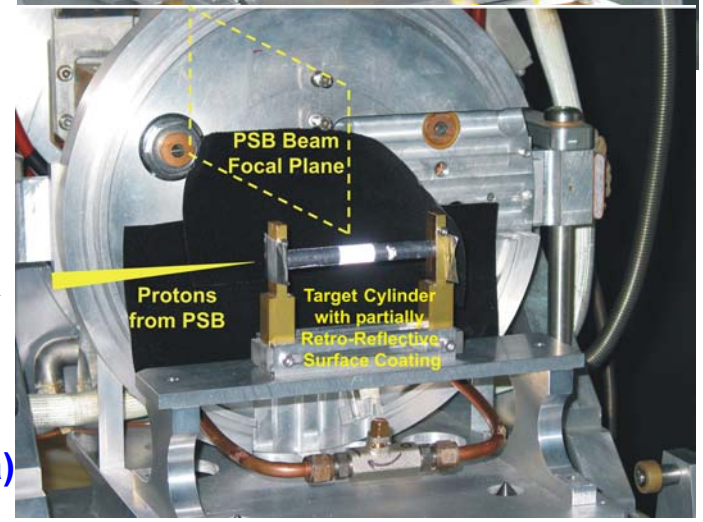
(d = 5 mm, l = 100 mm)

Ta-cylinder

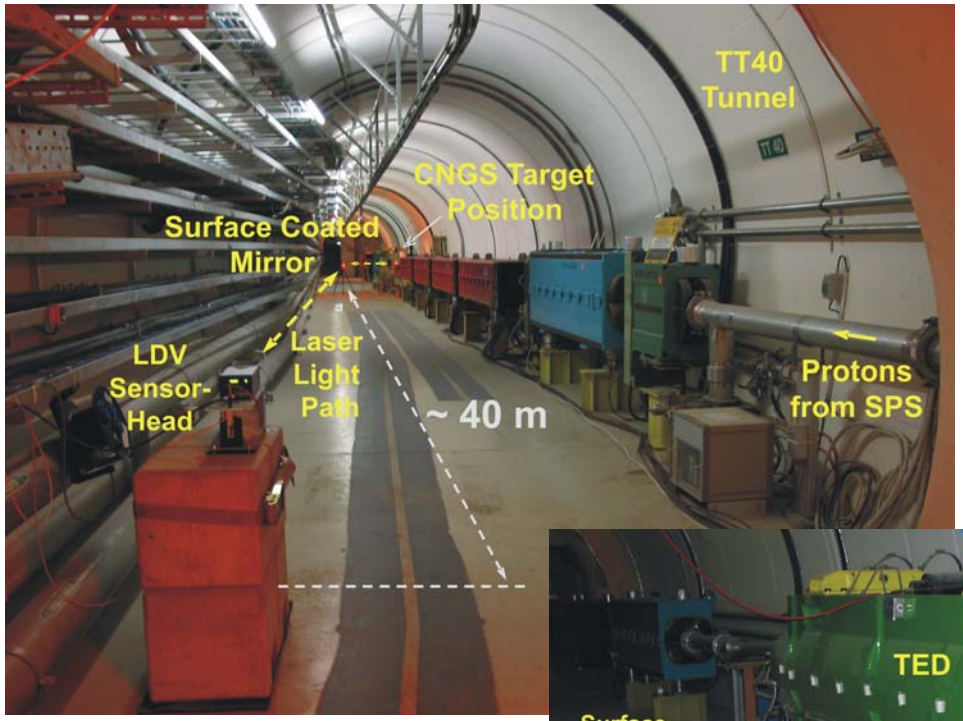
(d = 10mm,
l = 100 mm)

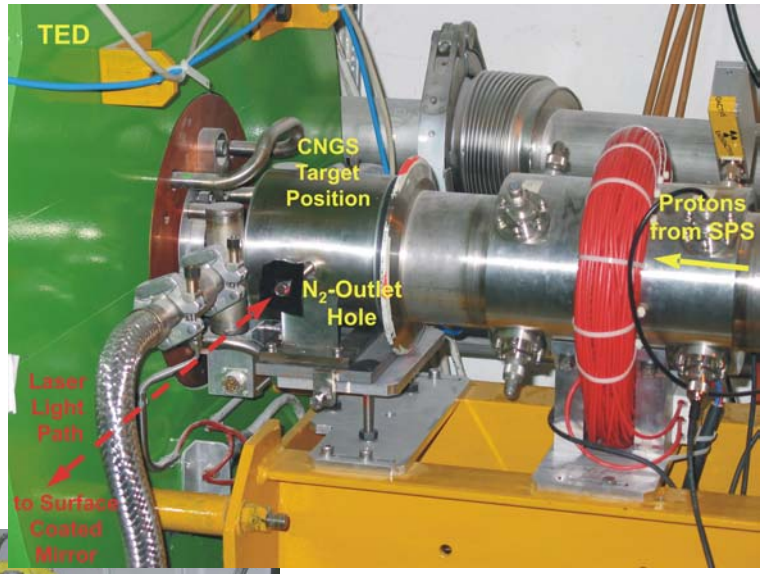
Surface coated mirror on a tripod
(HRS Front-End, ISOLDE Prime Area)

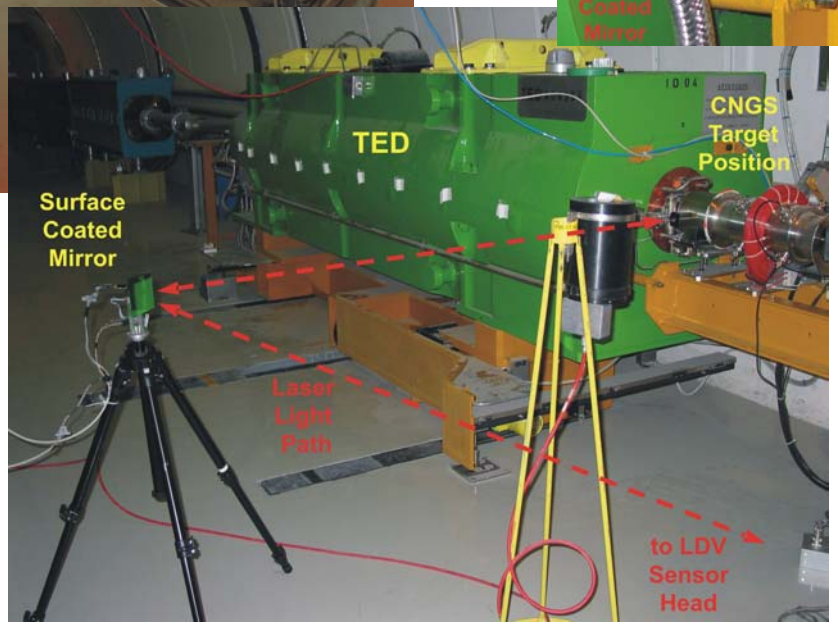




LDV & Target at TT40





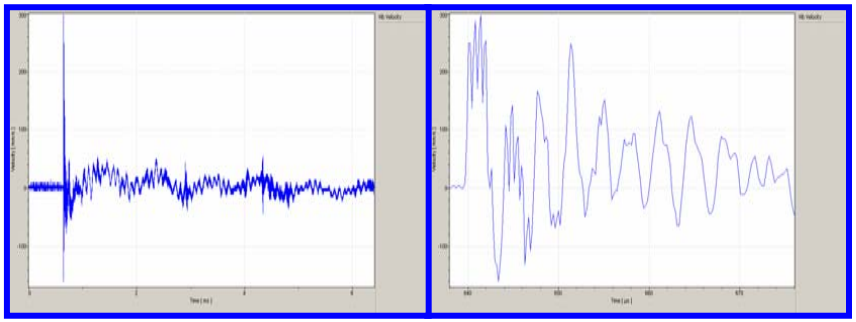


TT40 Tunnel
(LDV-head on concrete blocks, TI8 SPS-LHC transfer-line with dipoles and quadrupoles, TED and CNGS target in 40 m distance)

CNGS Target in front of TED
(Inside a container with N_2-gas)

Laser beam deflection on surface coated mirror
(with remote controlled motors to tilt the mirror)

Analysis

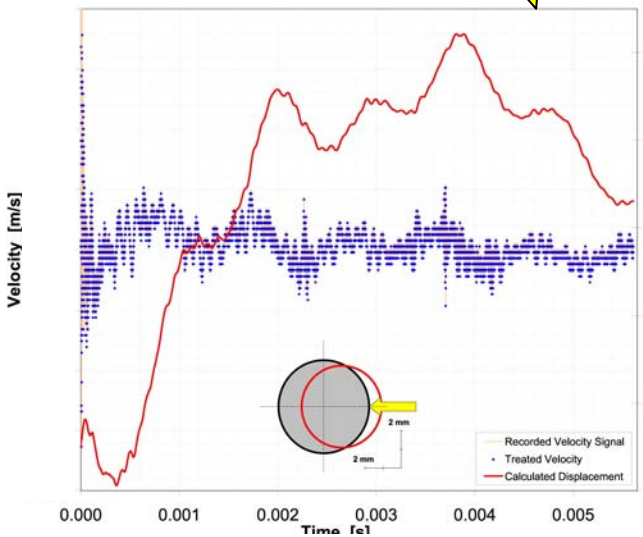


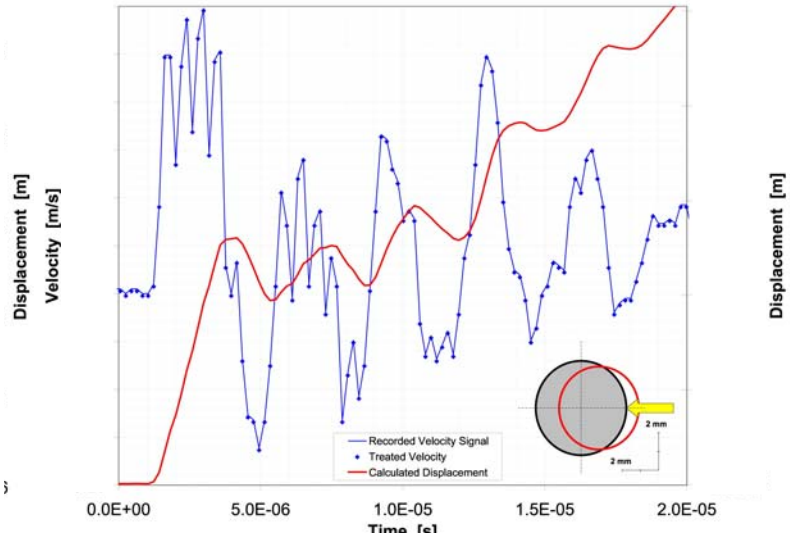
CNGS target (CNGS-14),
proton beam: 4 bunches, 32 TP,
2 mm horizontally displaced,
LDV laser: upstream entrance region of the target (1 cm distance to target end-plate)

Each signal (32.000 data points):

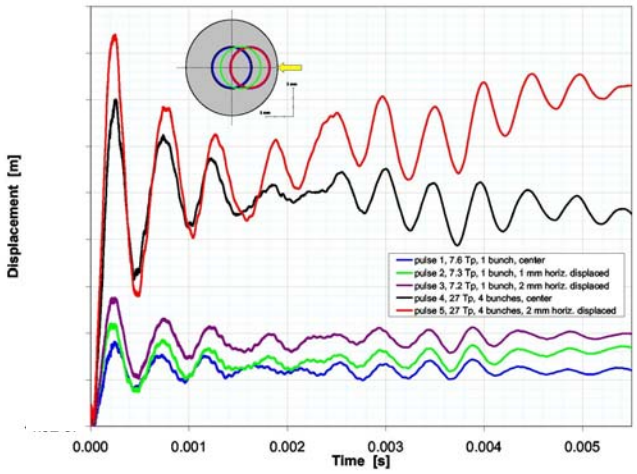
- correct signal drop-outs (manually)
- offset correction
- numerical integration (KEPLER) to receive displacement signal
- time shift to compare with other signals

- qualitative analysis
- quantitative analysis
- FFT
- Time-Frequency analysis

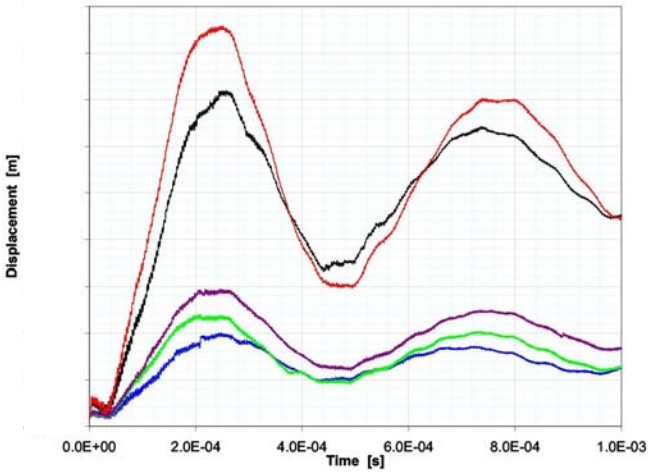




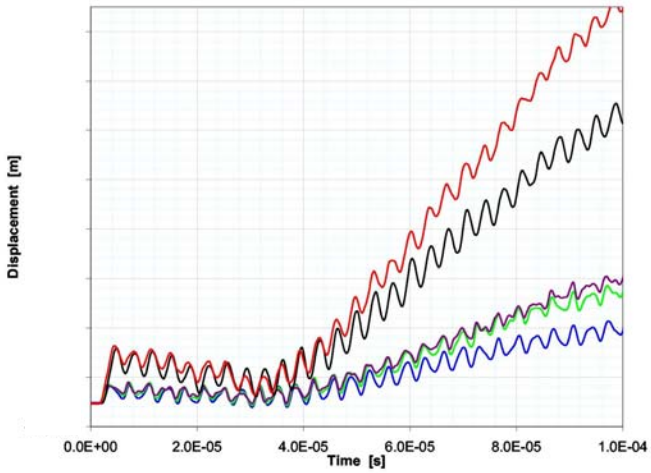
Ta – Cylinder



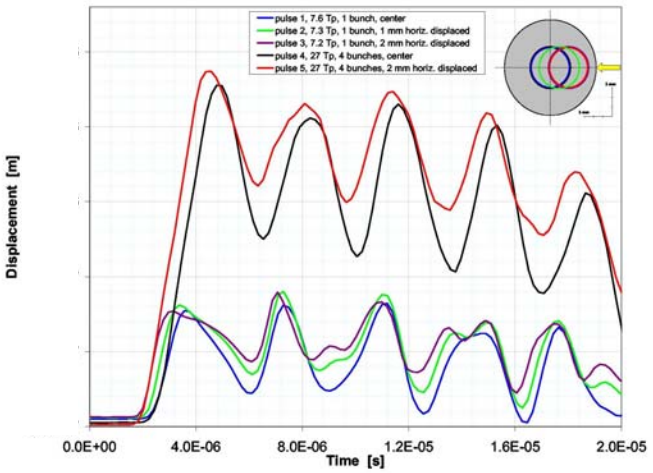
(a) Full time scale.



(b) First 1 ms.



(c) First 100 μs.



(d) First 20 μs.

Tantalum at room-temperature

- .) response according wave motion in elastic solids
- .) transient time increases for displaced beams
- .) radial oscillation:
- .) bending

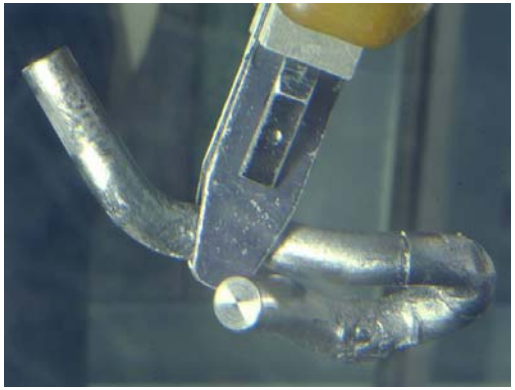
Pb-Cylinder – plastic deform.

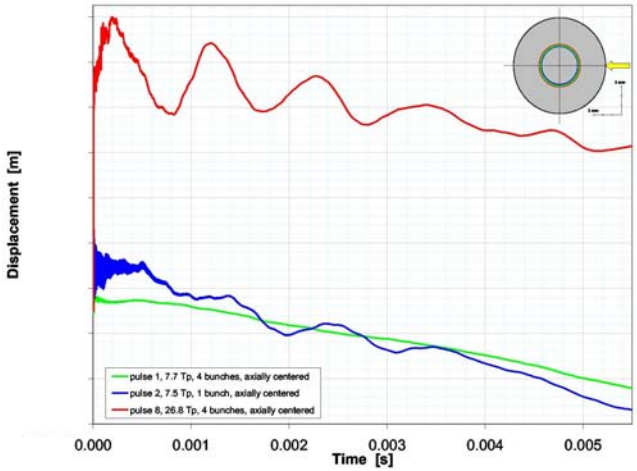
Lead at room-temperature

.) similar material parameters like Tantalum at 2000 °C

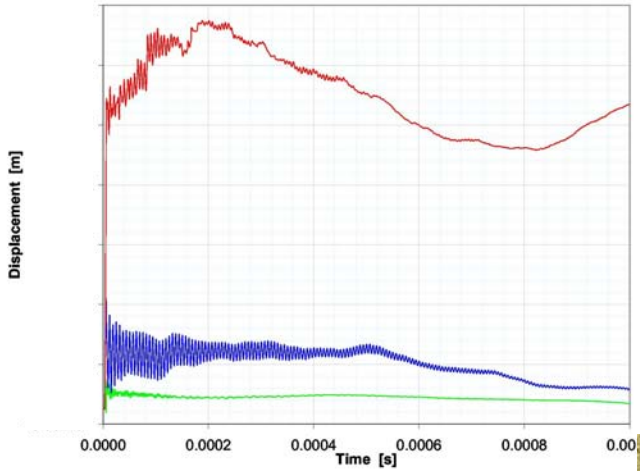
Ta-converter of target #183:

after about 5.5E+18 protons, (around 170'000 pulses with full intensity (32 Tp/pulse))





(a) Full time scale.



(b) First 1 ms.

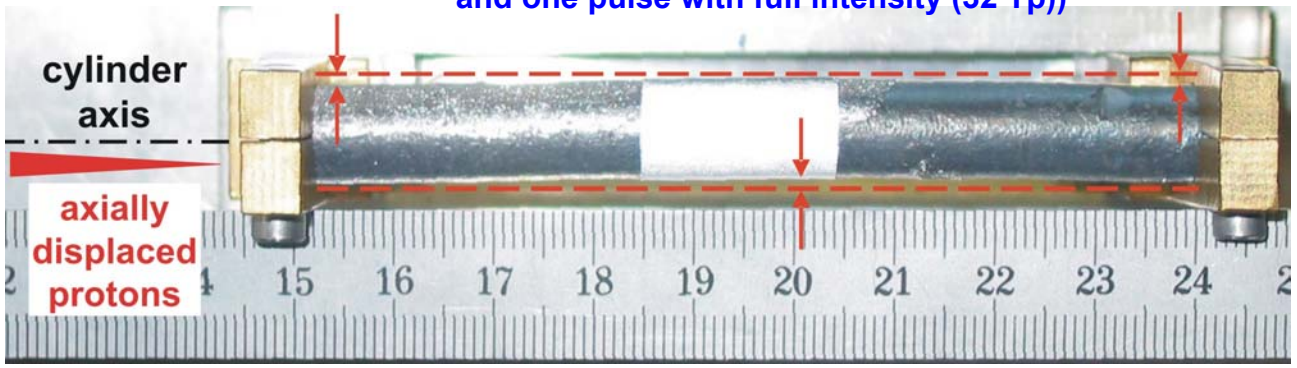
Plastic deformation:

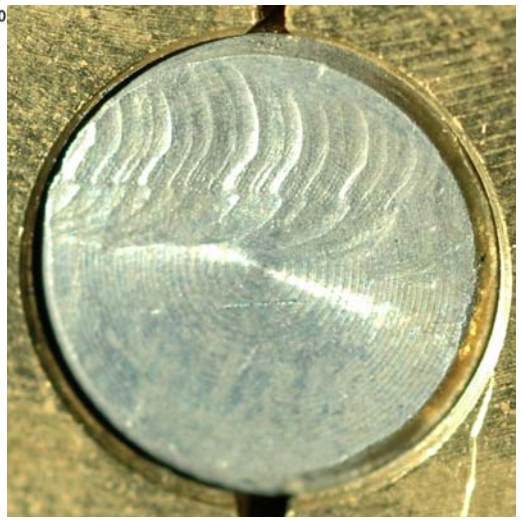
.) melting and recrystallization of grain borders

.) thermal stress wave

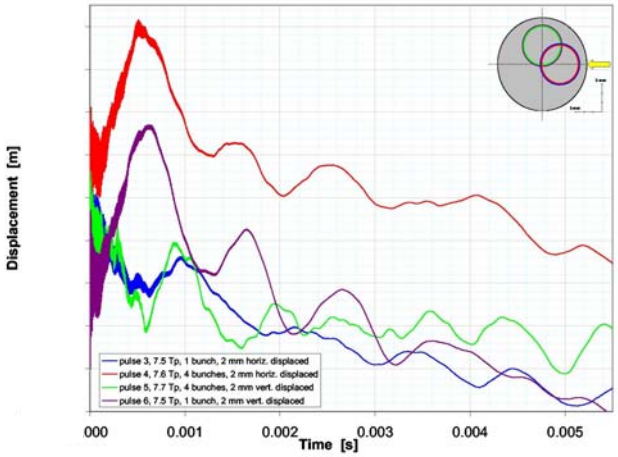
Pb target:

after about 80 Tp protons, (7 pulses with 1 bunch (8Tp) and one pulse with full intensity (32 Tp))

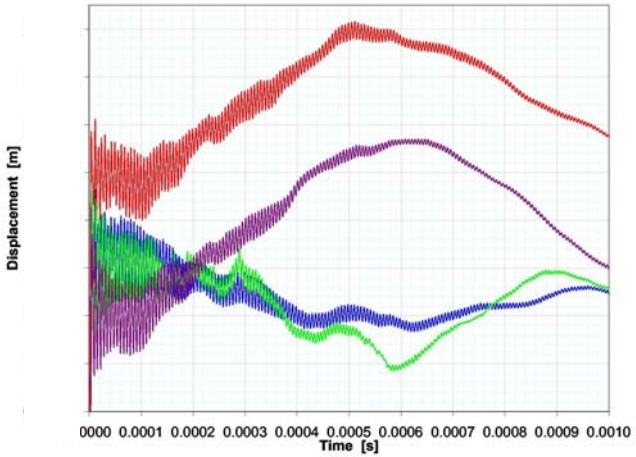




Pb-Cylinder – axiall. displaced

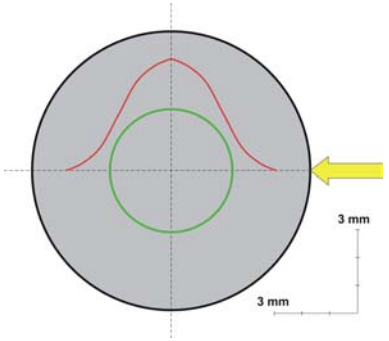


(a) Full time scale.

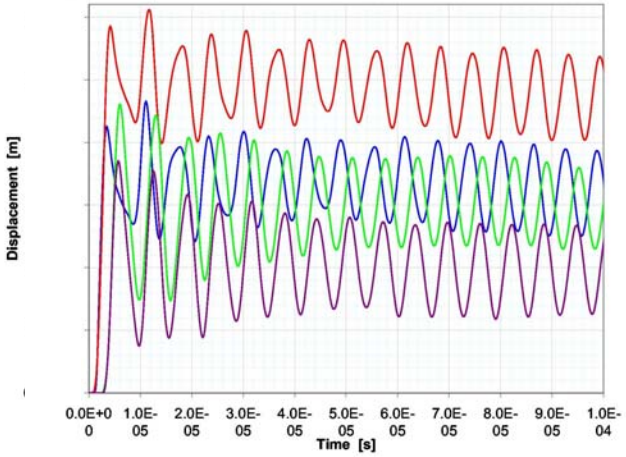


(b) First 1 ms.

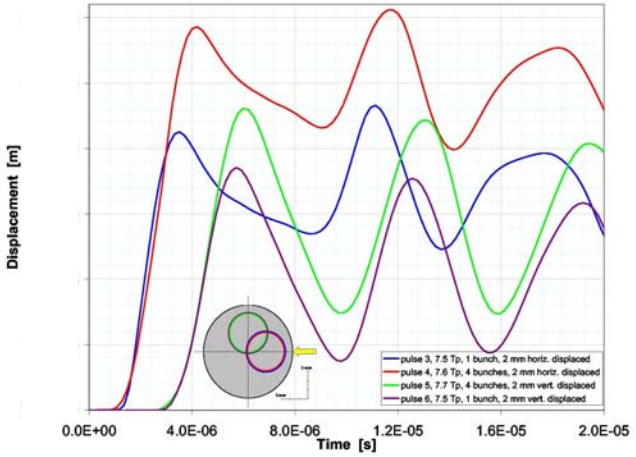
Temperature profile for different proton pulse structures:



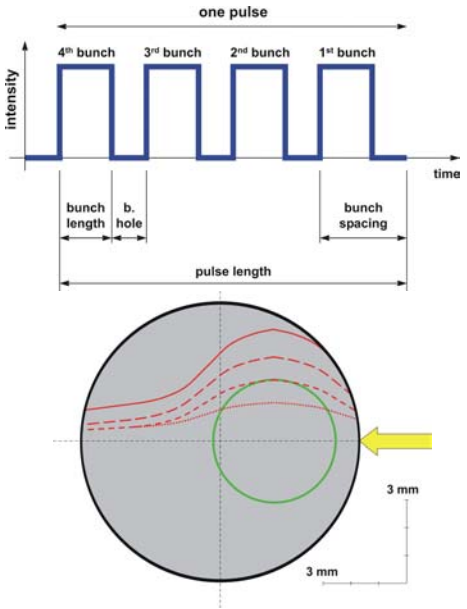
.) All pulses: same proton number, but different pulse length
.) Higher displacement amplitude (radial & bending) for longer pulse length



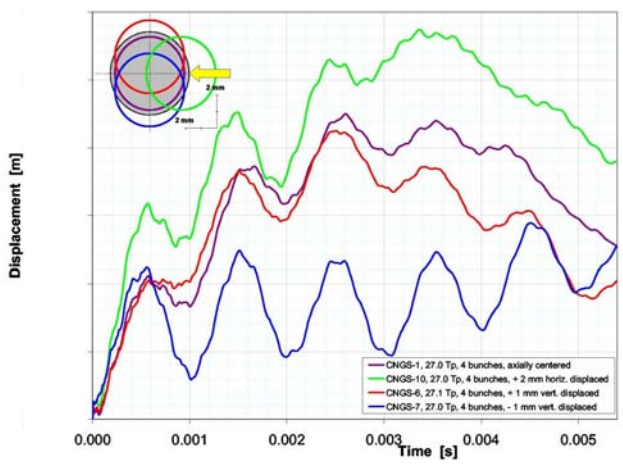
(c) First 100 μs.



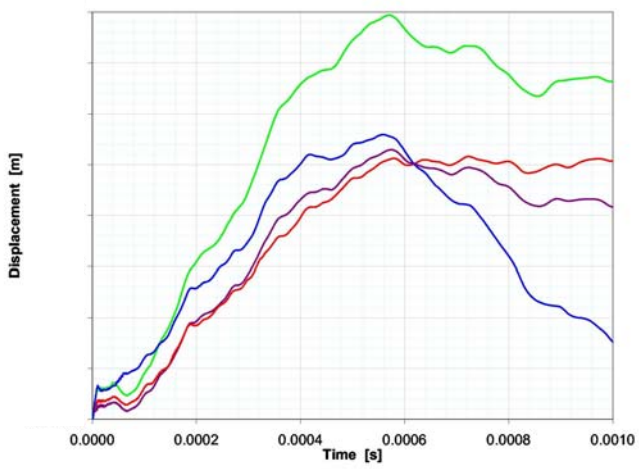
(d) First 20 μs.



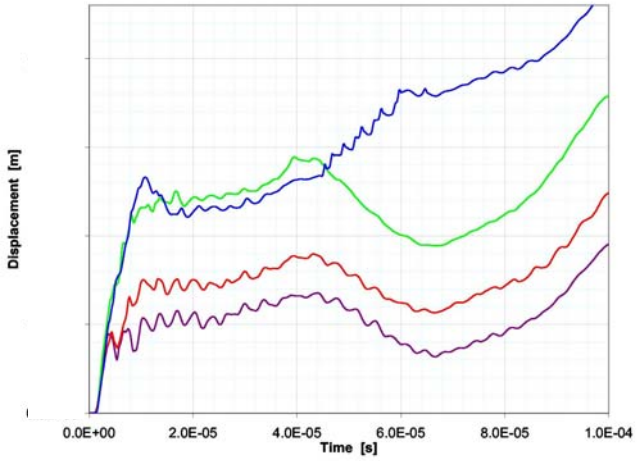
CNGS – vertically displaced



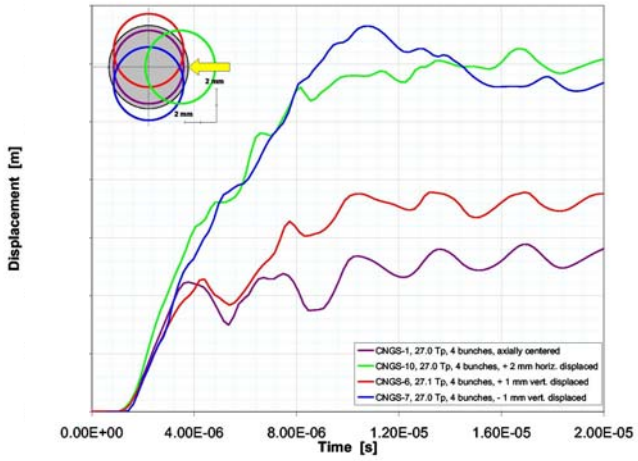
(a) Full time scale.



(b) First 2 ms.



(c) First 100 μs.



(d) First 20 μs.

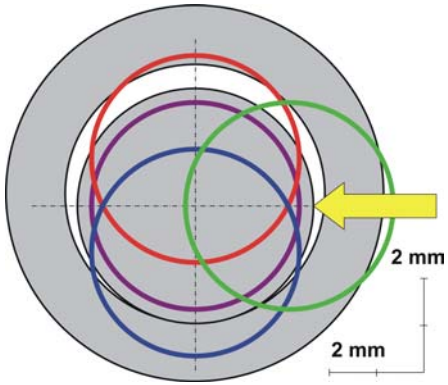
First response:

- .) big difference for vertical (-1 mm) and horizontal (+2 mm) compared to others
- .) doubling of amplitude due to irradiated support.
- .) 1/e-damping: ~130 µs!

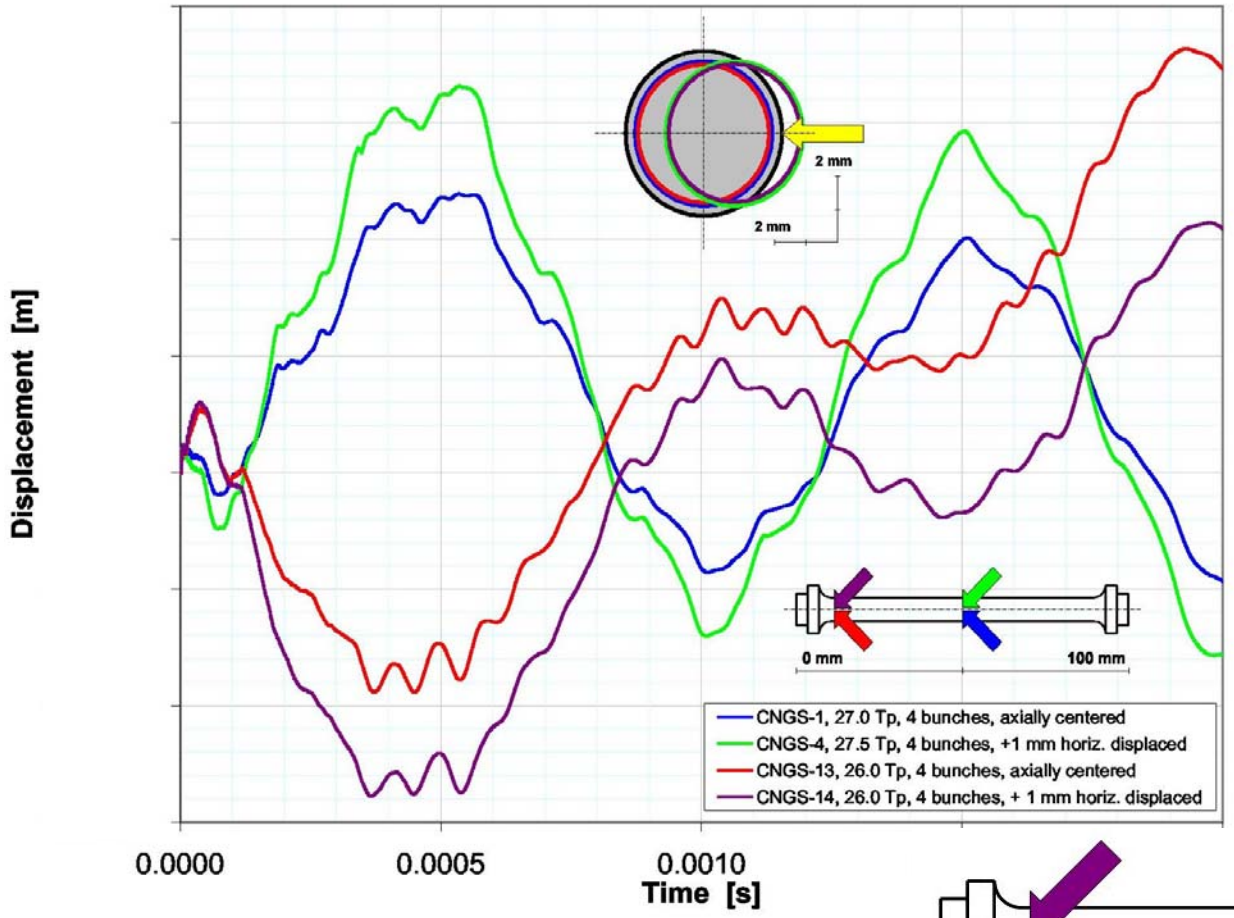
Bending:

- .) triangular shape!
- .) 1/e-damping: up to 16 ms!
- .) difference of CNGS-7 due to jumping & free fall

Therefore no rolling.



CNGS – entrance / center



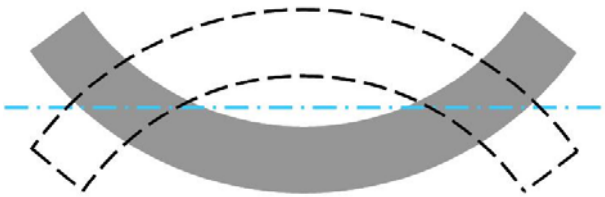
Bending:

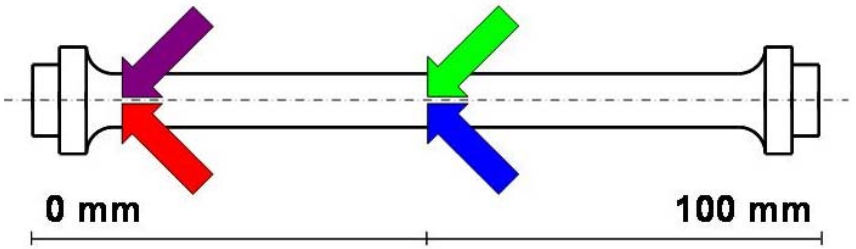
.) 180° phase shift

.) same amplitude for entrance and target center

.) indicating free end oscillation

.) amplitude corresponds directly to beam position





Summary & Outlook

Summary:

- -) no mass load on the object of interest
- -) contact free
- -) measurement parameter: Doppler shifted frequency
- -) distance to target: 0.5 m up to 40 m (verified!)
- -) high dynamic range
- -) reproducibility (for long term tests: fatigue, change of material parameters)
- -) displacements measurable even in nm-range!
- -) useable for frequencies up to 40 (or even 100) MHz
- -) sampling rate: 10 ns (PSB proton bunch length: 230 ns)
- -) for cylindrically shaped surface:
  vertical effects can be analyzed

Outlook:

- -) Record signals at different horizontal positions along the target axis (for different beam parameters). Important for CNGS target and for longitudinal wave analysis.
- -) Test new target materials and geometries.
- -) Transfer function between target and target support / front-end