EuCARD NCLinac
9.3 Linac and FF Stabilisation
Highlight talk: Stabilization to 1nm

A.Jeremie

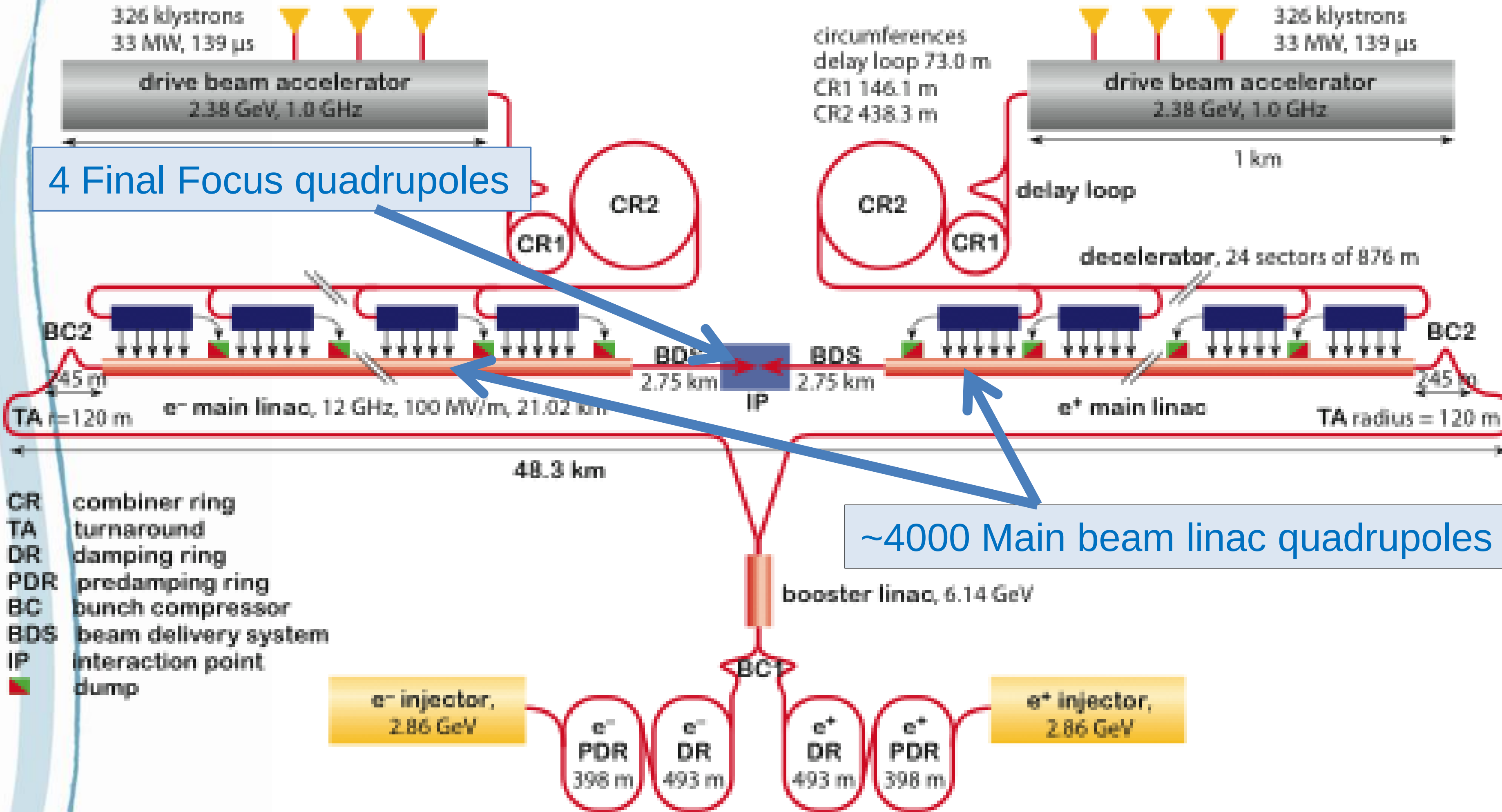
Main objective of task 9.3

- Address quadrupole stabilisation issues on CLIC

Object of highlight talk

  - Main linac quadrupole stabilisation
    - Design, build and test for stabilisation a CLIC quadrupole module in an accelerator environment where a stability of 1 nm above one Hz is required.
  - Final Focus quadrupole stabilisation
    - Design, build and test for stabilisation a Final Focus test stand where a stability of 0.1 nm above a few Hz is required.

CLIC layout


326 klystrons
33 MW, 139 μs
drive beam accelerator
2.38 GeV, 1.0 GHz
circumferences
delay loop 73.0 m
CR1 146.1 m
CR2 438.3 m
326 klystrons
33 MW, 139 μs
drive beam accelerator
2.38 GeV, 1.0 GHz
1 km
4 Final Focus quadrupoles
CR2
CR1
CR2
CR1
delay loop
decelerator, 24 sectors of 876 m
BC2
BC2
BDS
2.75 km
BDS
2.75 km
IP
245 m
245 m
TA r=120 m
e⁻ main linac, 12 GHz, 100 MV/m, 21.02 km
e⁺ main linac
TA radius = 120 m
48.3 km
~4000 Main beam linac quadrupoles
CR combiner ring
TA turnaround
DR damping ring
PDR predamping ring
BC bunch compressor
BDS beam delivery system
IP interaction point
dump
booster linac, 6.14 GeV
BC1
e⁻ injector,
2.86 GeV
e⁻
PDR
398 m
e⁻
DR
493 m
e⁺
DR
493 m
e⁺
PDR
398 m
e⁺ injector,
2.86 GeV

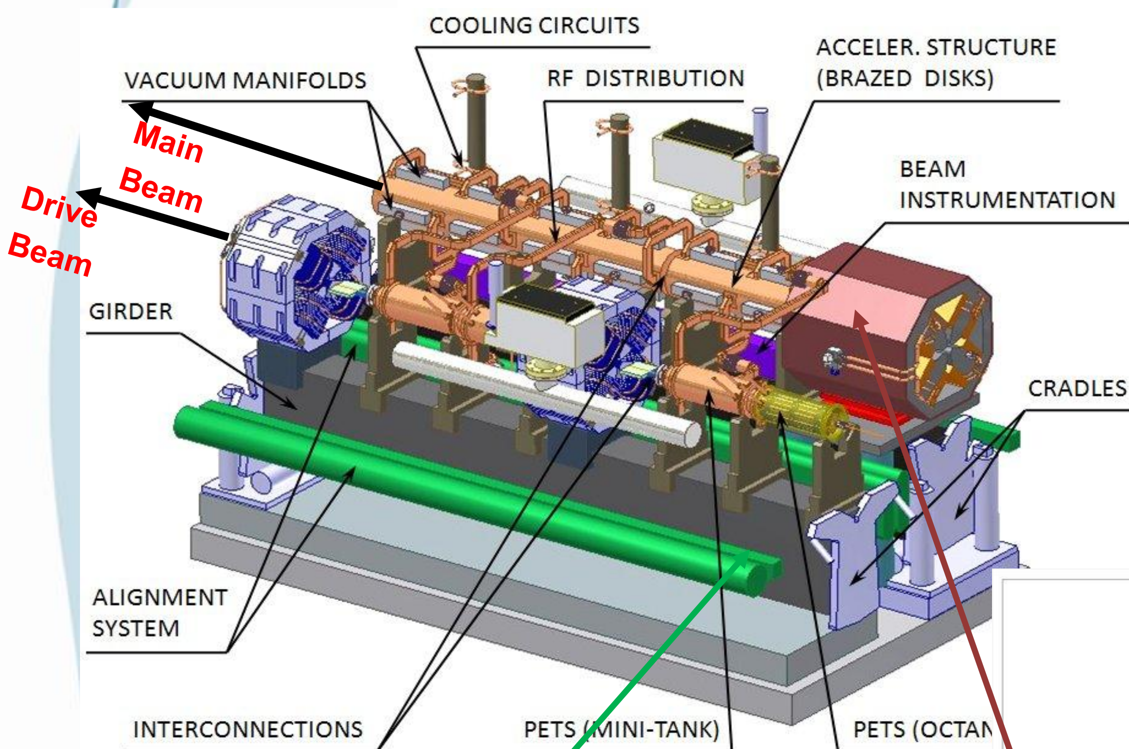
J.P.Delahaye CLIC'08

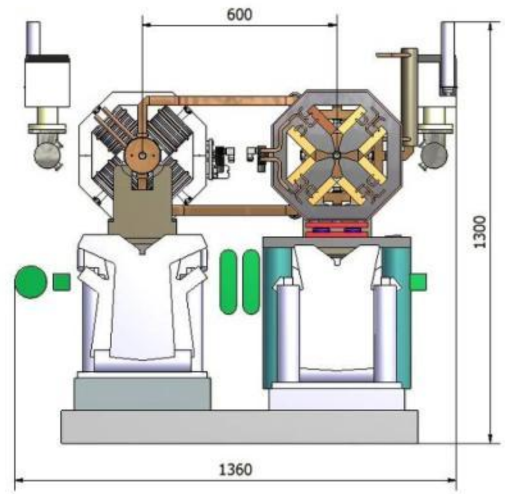
CLIC feasibility issues

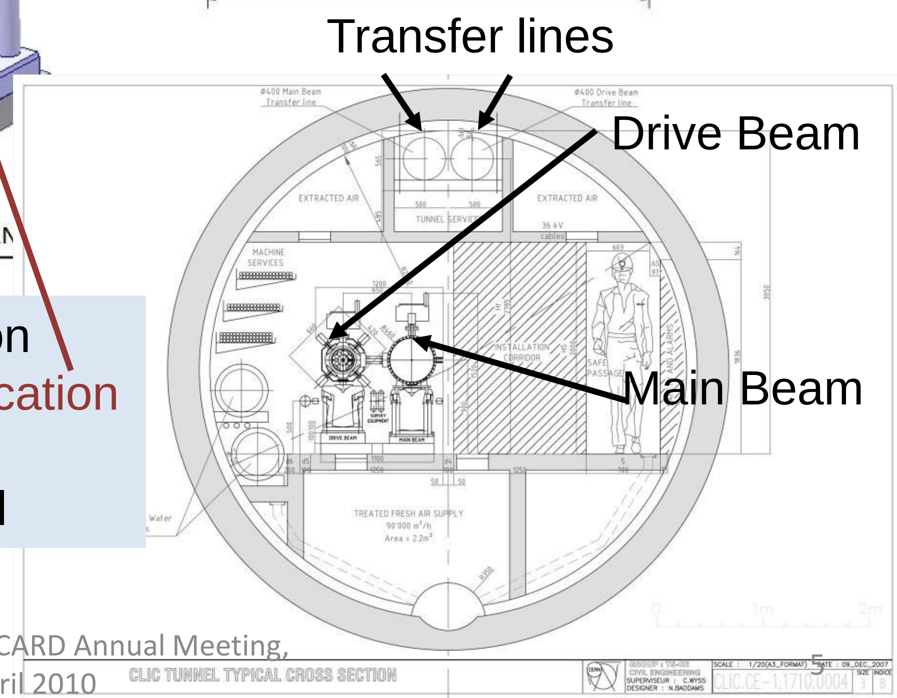
	SYSTEMS (level n)	Critical parameters	Feasibility issue	Performance issue	Cost issue
Structures	**Main beam acceleration structures** Demonstrate nominal CLIC structures with damping features at the design gradient, with design pulse length and breakdown rate .	100 MV/m 240 ns 3·10-7 BR/(pulse*m)	X	X	X
Structures	**Decelerator structures** Demonstrate nominal PETS with damping features at design power, with design pulse length, breakdown rate on/off capability	136 MW 240 ns	X		X
Drive Beam	**Validation of drive Beam** - production - phase stability , potential feedbacks - MPS appropriate for beam power	0.2 degrees phase stability at 12 GHz	X	X	
Two Beam	Test of a relevant linac sub-unit with both beams	NA	X		
Beam Physics	- Preservation of low emittances (main linac + RTML)	Absolute blow-up Hor: 160nradm Vert: 15 nradm	X	X	
Stabilization	Main Linac and BDS Stabilization	Main Linac : 1 nm vert (>1 Hz) BDS: 0.15...1 nm vert (>4 Hz) depending on implementation of final doublet girder	X	X	X
Operation and reliability	Commissioning strategy Staging of commissioning and construction MTBF, MTTR Machine protection	Handling of drive beam power of 72 MW	X	X	X

!

CLIC Two Beam Acceleration Module







20760 modules
(2 meters long)

Task also includes work on
- Magnet design and fabrication
- Pre-alignment
- Compatibility between all

Teams involved

slides taken from different presentations within the CLIC stabilisation WG

- Task Coordinator: A.Jeremie

- Oxford University/ JAI (John Adams Institute)
  - D. Urner et al; Interferometry;
  - P.Burrows et al Feedback; simulation
- LAPP/Annecy CNRS
  - A. Jeremie et al; stabilisation, feedback
- CERN
  - C. Hauviller/K.Artoos et al; stabilisation
  - H. Mainaud-Durand et al; pre-alignment
  - M. Modena et al; magnets

Things needed to be studied for nm stabilisation

- Instrumentation:
  - nm , low frequency (0.5Hz-100Hz), compact, rad hard, insensitive to magnetic field
- Mechanics=> design and dynamic calculations
  - Maximise rigidity, Minimise weight, Minimise beam height, Optimise support positions
- Stabilization strategy
  - automatics, active or passive isolation, feedback etc…

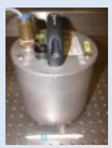
Instrumentation

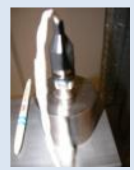
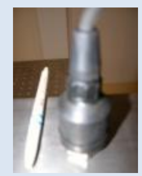
Sensors that can measure nanometres

Absolute velocity/acceleration studied at LAPP:

Type of sensors	Electromagnetic geophone	Electrochemical geophone	Piezoelectric accelerometers		
Model	GURALP CMG-40T	SP500-B	ENDEVCO 86	393B12	4507B3
Company	Geosig	PMD Scientific	Brüel & Kjaer	PCB Piezotronics	Brüel & Kjaer
Sensibility	1600V/m/s	2000V/m/s	10V/g	10V/g	98mV/g
Frequency range	[0.033; 50] Hz	[0.0167; 75] Hz	[0.01; 100] Hz	[0.05; 4000] Hz	[0.3; 6000] Hz
Measured noise (f > 5Hz)	0.05nm	0.05nm	0.25nm >50Hz: 0.02nm	11.19nm >300Hz: 4.8pm	100nm

Sub-nanometre measurements




Relative displacement/velocity:

Capacitive gauges :Best resolution **10 pm (PI) , 0 Hz to several kHz**

Linear encoders best resolution 1 nm (Heidenhain)

Vibrometers (Polytec) ~1nm at 15 Hz

Interferometers (SIOS, Renishaw, Attocube) <**1 nm at 1 Hz**

CERN test bench : membrane and interferometer

<u>OXFORD MONALISA (laser interferometry)</u>

Optical distance meters

Compact Straightness Monitors (target 1 nm at 1 Hz)

ATF2 vibration and vacuum test
⇒Validation
⇒Next: optical test

Characterisation of vibration sources

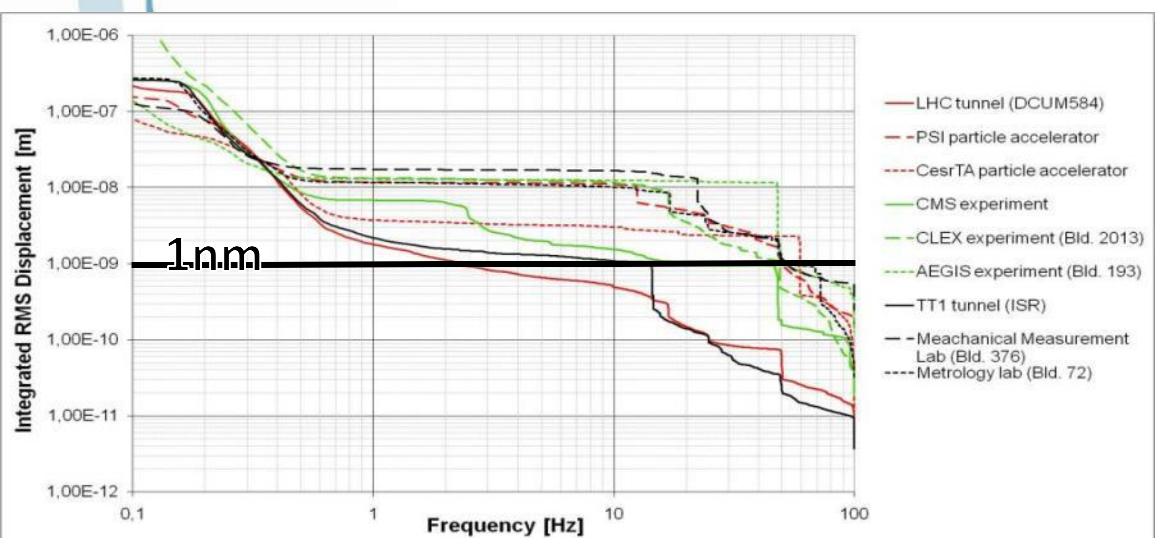
What level of vibrations can be expected on the ground?

Several measurement campaigns: LAPP (LHC, ATF2, SuperB)**, DESY** (LHC, DESY etc…)**….**

Effort continued by CERN in 2009

2009

M. Sylte, M. Guinchard



Under 3Hz, none of the places measured are in the right tolerances => need active isolation

Modelling of Ground Motion ongoing:

A.Seryi + O.Napoly: DAPNIA/CEA 95-04

B.Bolzon et al PAC 2009

C.Colette et al ILC-CLIC LET WS 2009

Actuators

Selection actuator type: comparative study in literature

First selection parameter: Sub nanometre resolution and precision

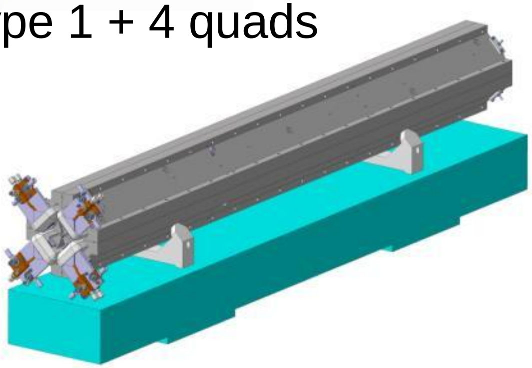
This excludes actuator mechanisms with moving parts and friction, we need **solid state mechanics**

Actuator type	Rigidity	Properties
Piezo electric materials	High rigidity	+ Well established - Fragile (no tensile or shear forces), depolarisation
Magneto Strictive materials	High rigidity	-Rare product, magnetic field, stiffness < piezo, - force density < piezo + No depolarisation, symmetric push-pull
Electrostatic plates	No rigidity, ideal for soft supports	Risk of break through, best results with µm gaps, small force density, complicated for multi d.o.f. not commercial
Electro magnetic (voice coils)	No rigidity, ideal for soft supports	Heat generation, influence from stray magnetic fields for nm resolution
~~Shape Memory alloys~~		Slow, very non linear and high hysteresis, low rigidity, only traction
~~Electro active polymers~~		Slow, not commercial

Mechanics

Dynamic analysis support, alignment and magnet

Type 1 + 4 quads



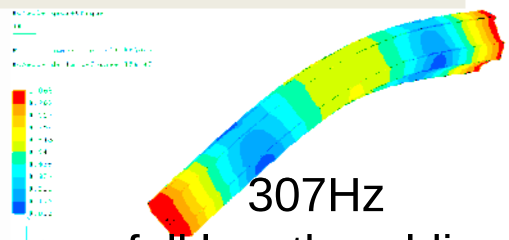
M. Modena/CERN

Mounting and stiffness

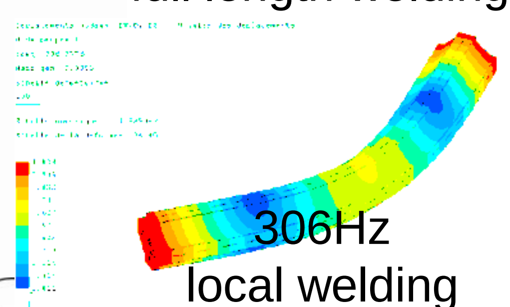
Features to decrease vibrations from water cooling

Dynamic analysis LAPP

Guillaume Deleglise



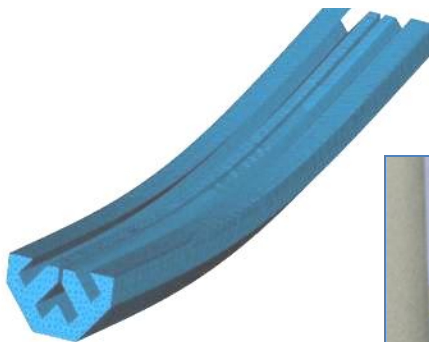
307Hz
full length welding

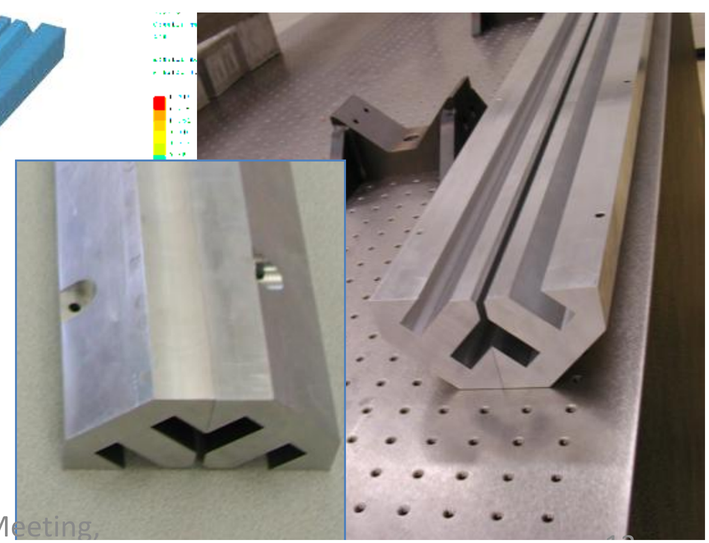


306Hz
local welding

Prototype (aluminium) for modal testing + assembly

Comparison between eigenfrequencies from calculations and measurements: Δ<5%





Dynamic analysis of magnet plus support is needed for beam simulations and support optimisation

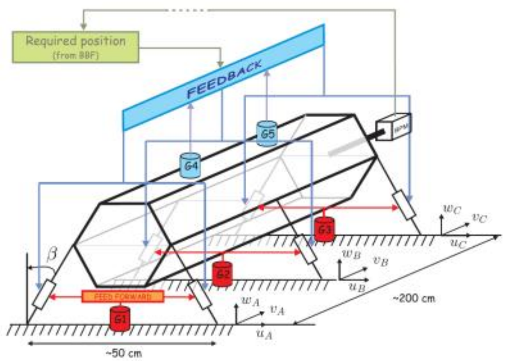
Stabilisation strategy

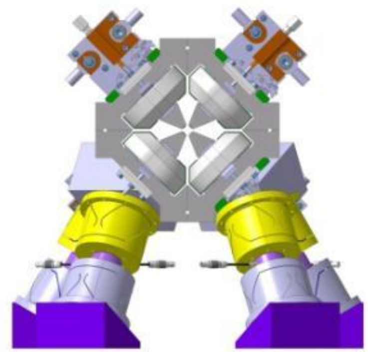
- Two options studied => still in R&D phase
- Preliminary results expected end of 2010
- Study both options and eventually choose one, or take the best of each

Option CERN: Rigid support and active vibration control

Approach: PARALLEL structure with inclined actuator legs with integrated length measurement (<1nm resolution) and flexural joints

Rigid: less sensitive to external forces but less broadband damping

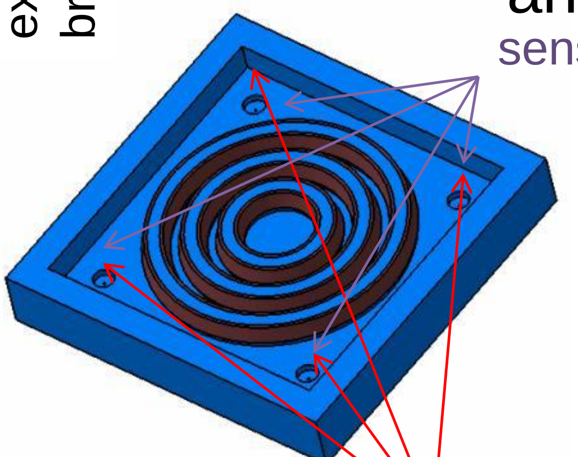




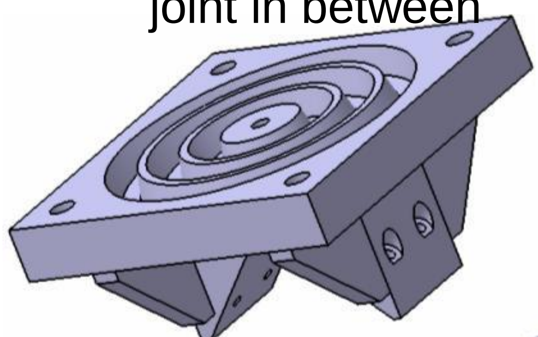
Concept drawing

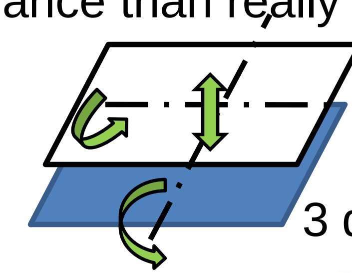
Up to 6 d.o.f.

Option LAPP: Soft support (joint more for guidance than really « soft ») and active vibration control

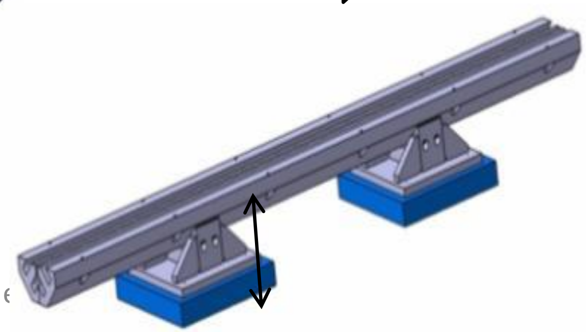


Soft elastomere joint in between





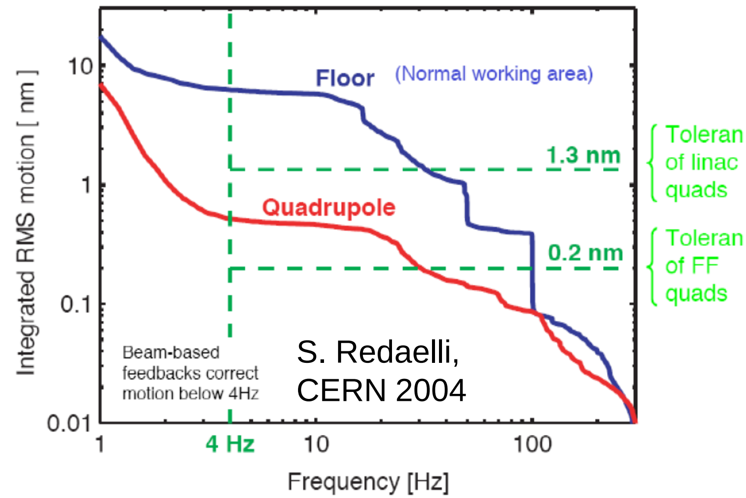
3 d.o.f. :



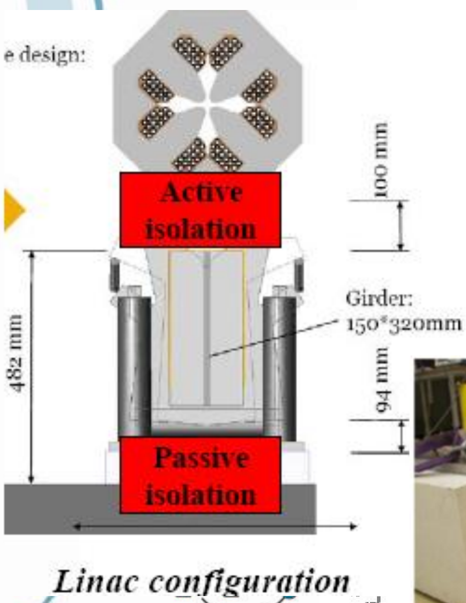
LAPP option

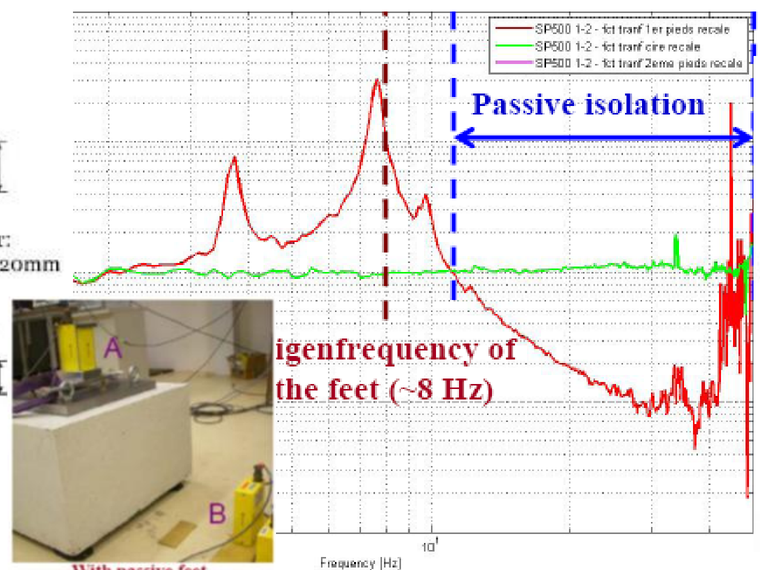
Until now, the isolation function was studied on a TMC commercial active table: almost CLIC specifications but too big/expensive! (2.4mx0.9mx0.6m)

Integrated *vertical* RMS motion versus frequency

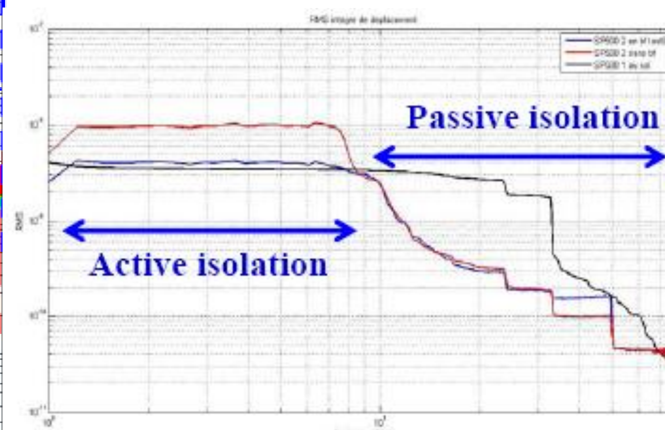


Approach: « Replace » TMC table by a more compact device



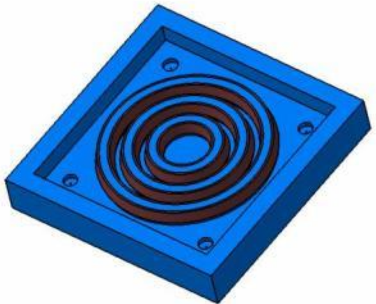


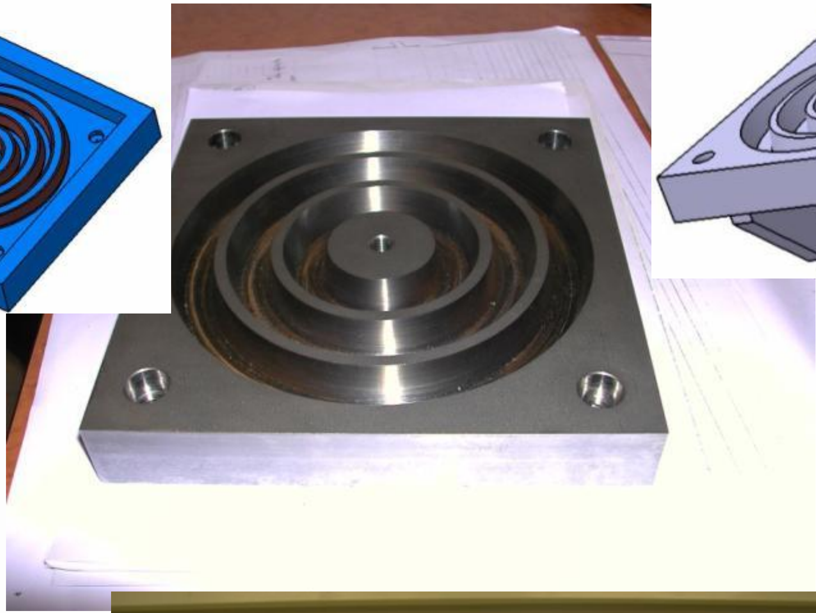
And adding active isolation

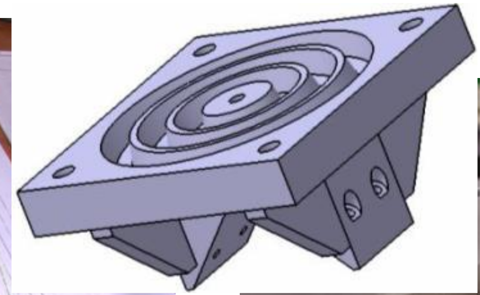


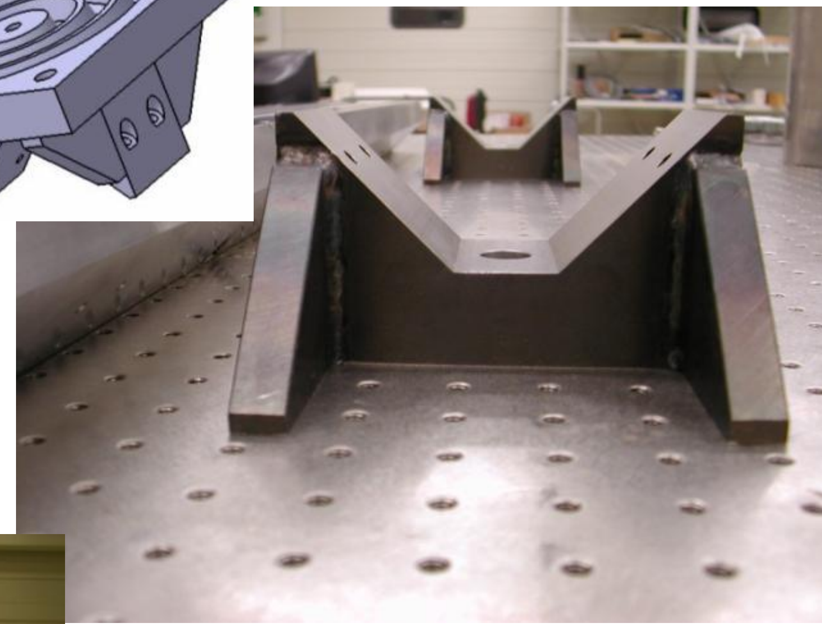
rms

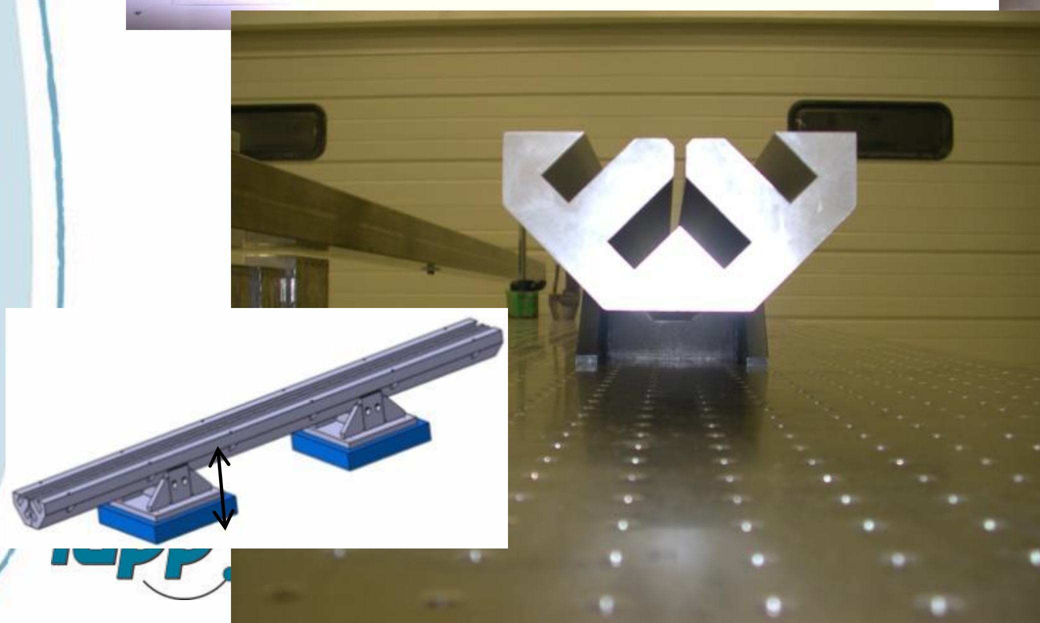
Status: Construction + tests on elastomer





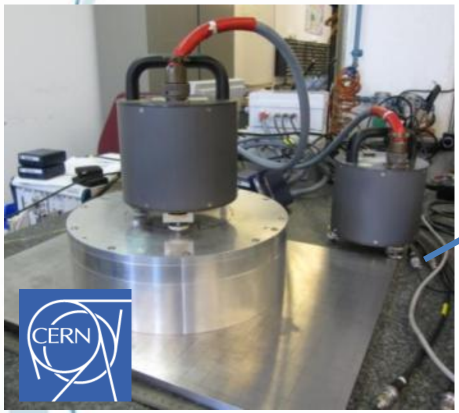




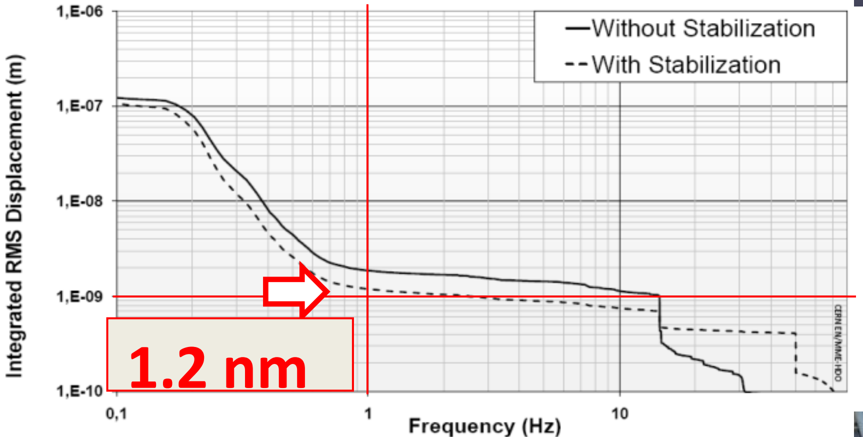


CERN option: Steps toward performance demonstration

Step 1: Stabilisation single d.o.f. with small weight ("membrane")



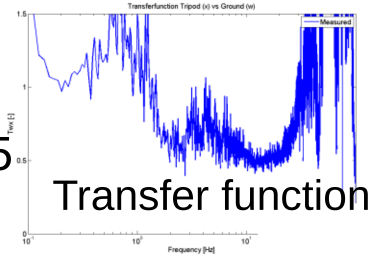
This is not a TMC table...



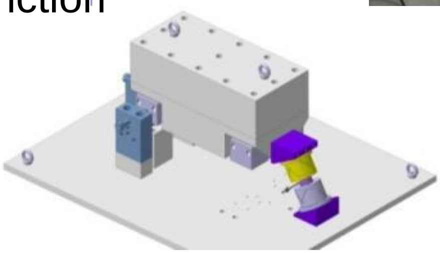
Step 2: Stabilisation single d.o.f. with type 1 weight ("tripod")

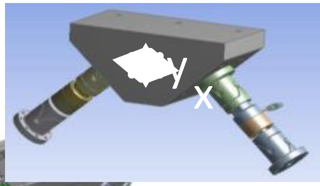
S. Janssens

Preliminary result

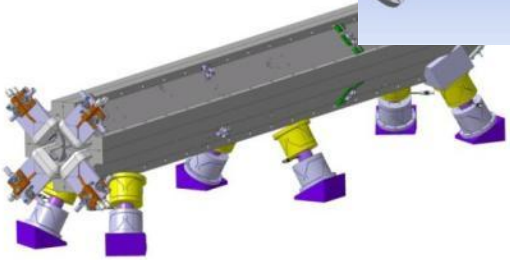


Step 3:
a. Inclined leg with flexural joints
b. Two inclined legs with flexural joint
c. Add spring guidance
d. Test equivalent load per leg





Step 4: Stabilization of type 4 (and type 1) Main beam Quadrupole



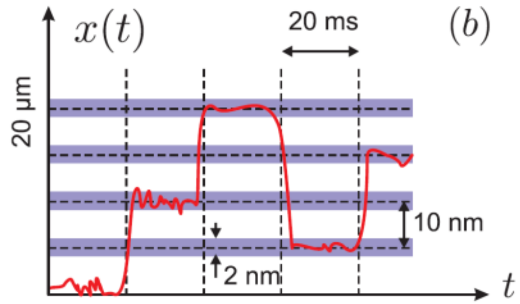
Option CERN: Rigid support and active vibration control

Bonus: possibility to **nano position** the Quadrupole

Ref. D. Schulte CLIC-ACE4 : “Fine quadrupole motion”

“Modify position quadrupole in between pulses (~ 5 ms) “

“Range 20 μm, precision 2nm »



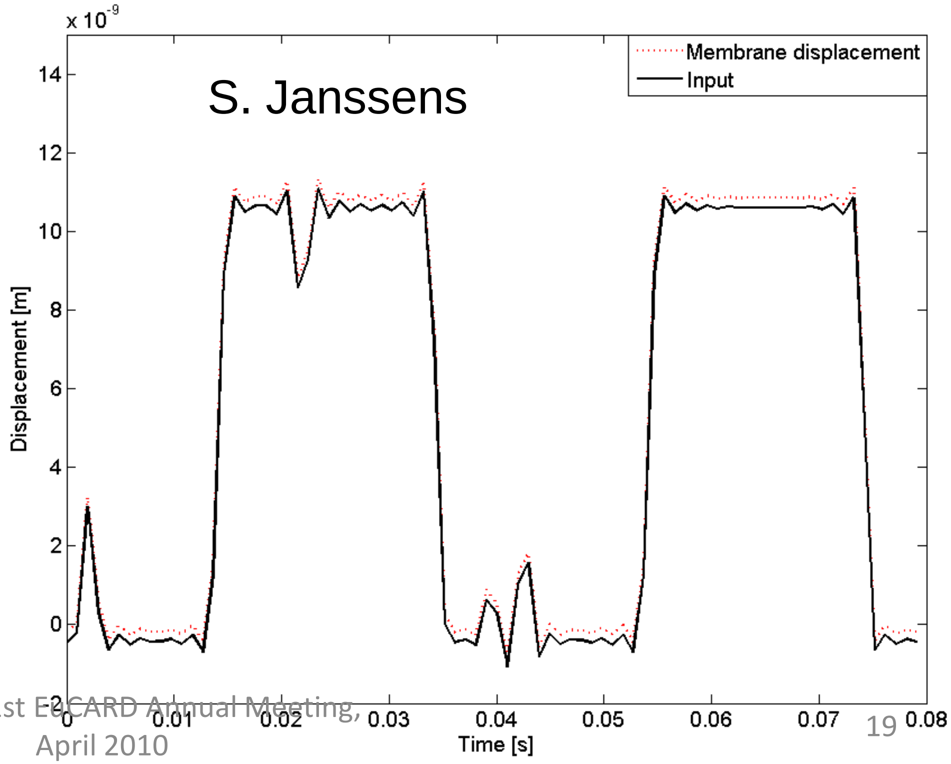
Demonstration nano positioning :

open loop

Measured with PI capacitive gauge

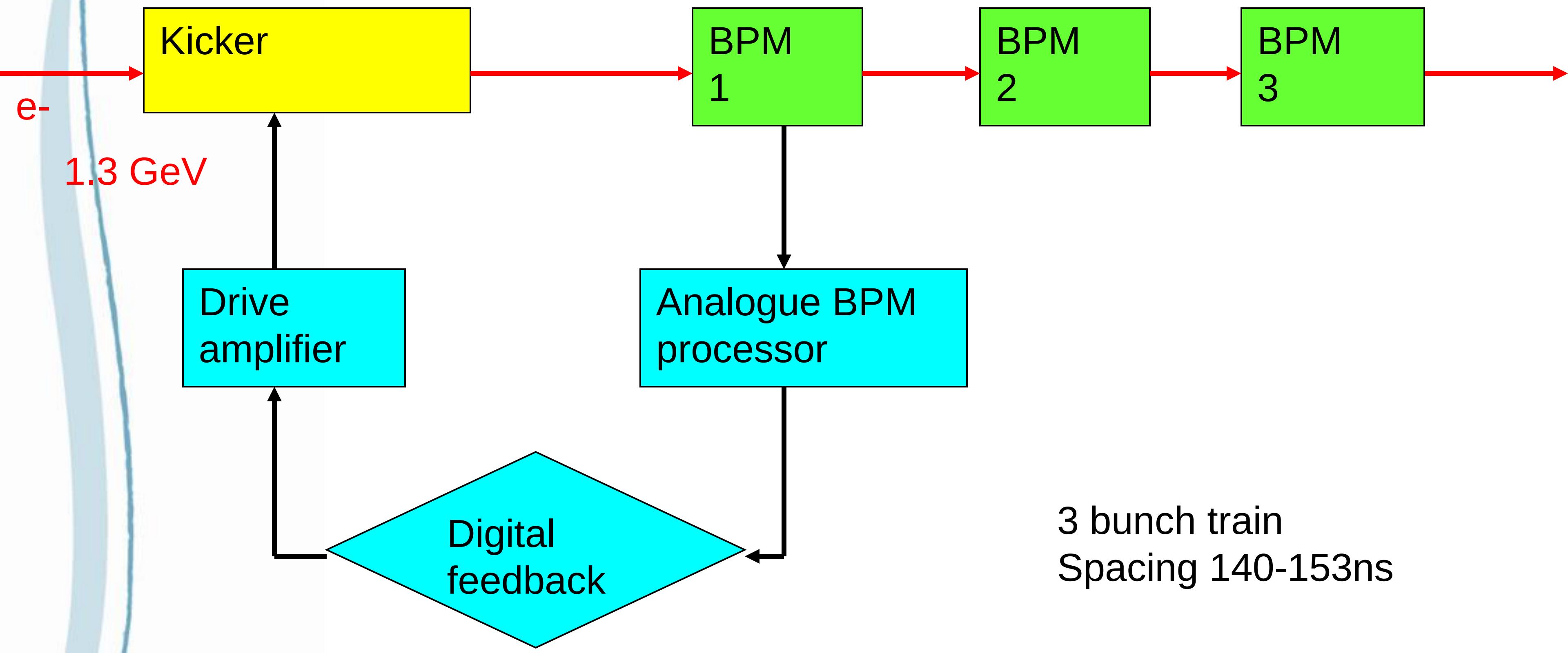
10 nm, 50 Hz

For FREE



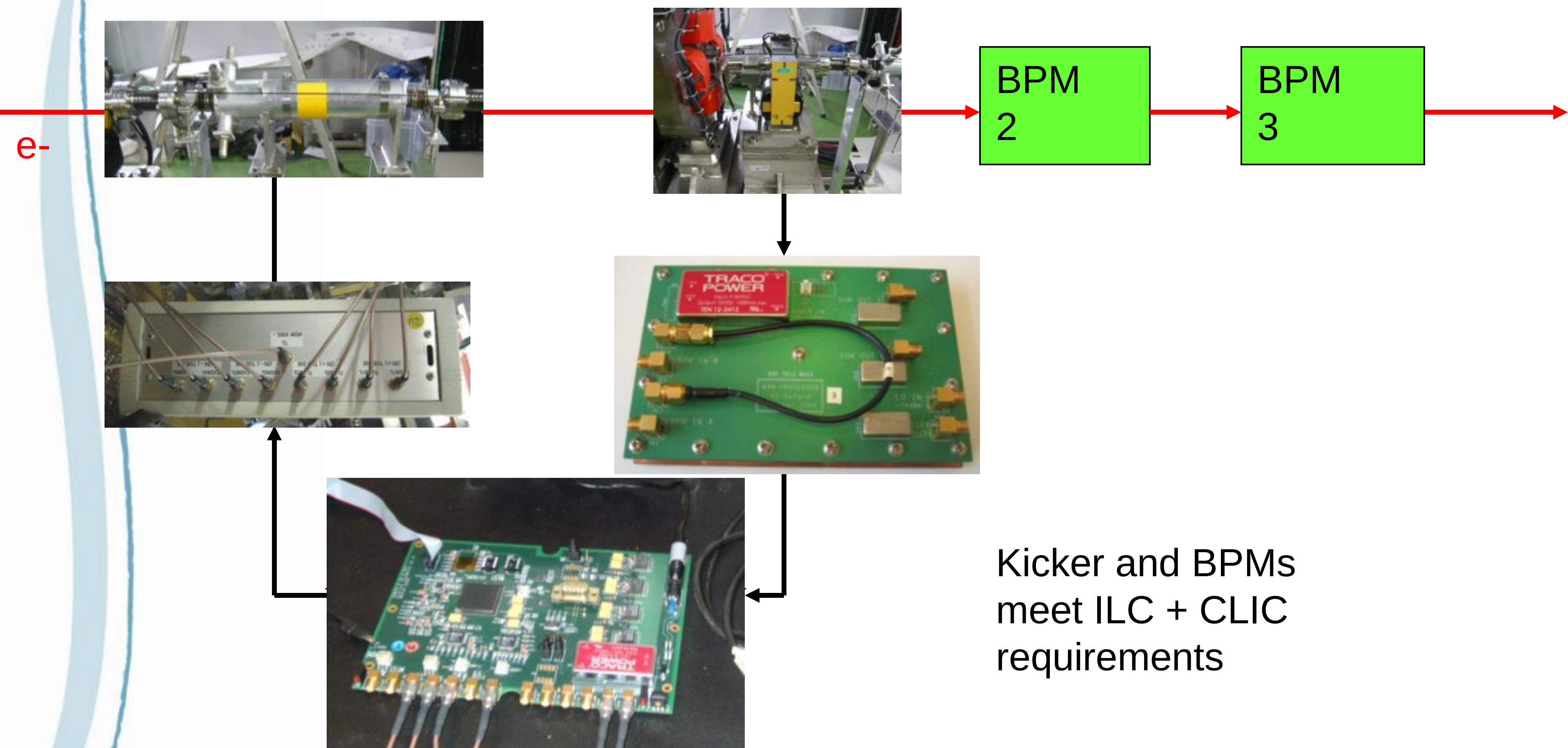
Stabilizing beam

FONT prototype at KEK/ATF: stabilising the ATF 1GeV beam to the um level



3 bunch train
Spacing 140-153ns

FONT prototype at KEK/ATF

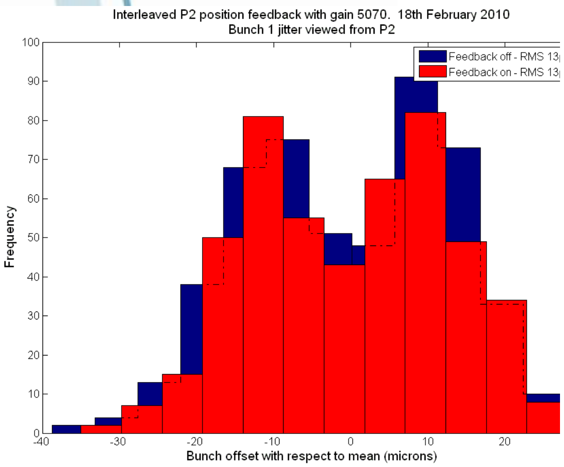


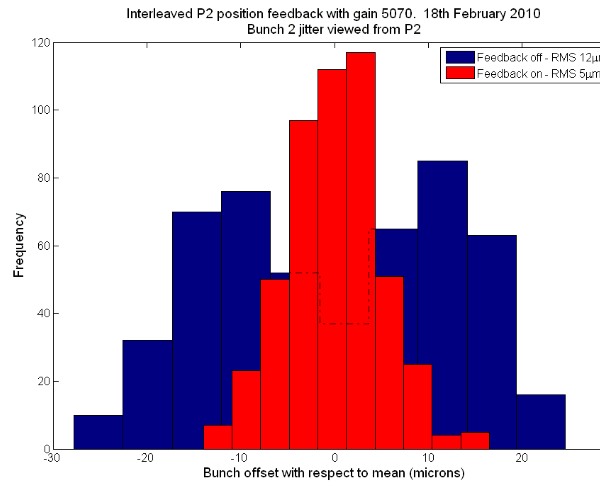
Kicker and BPMs meet ILC + CLIC requirements

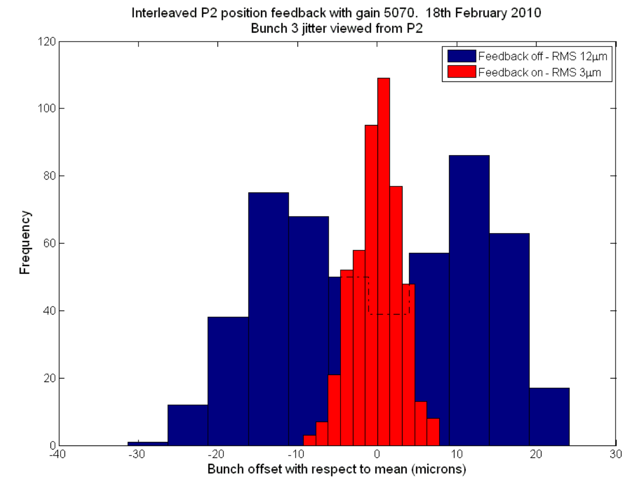
Beam jitter reduction

(February 2010)

Bunch 1	Bunch 2	Bunch 3
Not corrected	Corrected	Better corrected







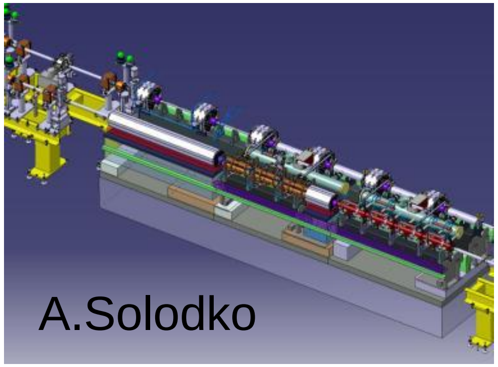
13 um → 5 um → 3 um

Publications

- <EuCARD-CON-2009-028> "CLIC OVERVIEW“
- <EuCARD-CON-2009-026>,"FUNCTIONAL REQUIREMENTS ON THE DESIGN OF THE DETECTORS AND THE INTERACTION REGION OF AN E+E- LINEAR COLLIDER WITH A PUSH-PULL ARRANGEMENT OF DETECTORS“
- <EuCARD-CON-2009-019>,"SUPERCONDUCTING MAGNETS FOR A FINAL FOCUS UPGRADE OF ATF2"
- <EuCARD-CON-2009-025>,"BEAM TEST RESULTS WITH THE FONT4 ILC PROTOTYPE INTRA-TRAIN BEAM FEEDBACK SYSTEM“
- <EuCARD-CON-2009-024>,"DESIGN AND PERFORMANCE OF INTRA-TRAIN FEEDBACK SYSTEMS AT ATF2“
- <EuCARD-CON-2009-023>, "DEVELOPMENT OF A FAST MICRON-RESOLUTION BEAM POSITION MONITOR SIGNAL PROCESSOR FOR LINEAR COLLIDER BEAMBASED FEEDBACK SYSTEMS“
- <EuCARD-CON-2009-022>,"PROPAGATION ERROR SIMULATIONS CONCERNING THE CLIC ACTIVE PREALIGNMENT“
- <EuCARD-CON-2009-021>,"GROUND VIBRATION AND COHERENCE LENGTH MEASUREMENTS FOR THE CLIC NANO-STABILIZATION STUDIES“
- <EuCARD-CON-2009-020>,"STUDY OF THE STABILIZATION TO THE NANOMETER LEVEL OF MECHANICAL VIBRATIONS OF THE CLIC MAIN BEAM QUADRUPOLES“
- <EuCARD-DIS-2009-001>,"Qualification de l’instrumentation pour des mesures nanométriques«
- <EuCARD-CON-2009-018>,"ATF2 COMMISSIONING“

Conclusions

- Active isolation devices still in R&D phase :
  - CERN rigid option (hexapod)
  - LAPP soft option (isolation feet)
  - Test both options on CLIC module prototypes



- But no device isolates perfectly and only by a given factor (x2 to x30): need a quiet background to stabilise to tolerances demanded for CLIC=> impact on the whole CLIC design (support, module, tunnel etc…

- spare

Güralp CMG-40T

Sensor type: electromagnetic geophone broadband

Signal: velocity x,y,z

Sensitivity: 1600V/m/s

Frequency range: 0,033-50Hz

Mass: 2,5kg

Radiation: ?

Magnetic field: no

Feedback loop

First resonance 440Hz

Temperature sensitivity: 0,6V/10°C

Electronic noise measured at >5Hz: 0,05nm

Stable calibration

Endevco 86

Sensor type: piezoelectric accelerometer

Signal: acceleration z

Sensitivity: 10V/g

Frequency range: 0,01-100Hz but useful from 7Hz 

Mass: 771g

Radiation: piezo OK, but resin? ICP electronics will not.

Magnetic field: probably OK but acoustic vibrations?

Feedback loop

First resonance 370Hz

Temperature sensitivity: <1%

Electronic noise measured at >5Hz: 0,25nm, >50Hz 0,02nm

Stable calibration, flat response

Doesn’t like shocks

SP500

Sensor type: electrochemical, special electrolyte

Signal: velocity

Sensitivity: 20000V/m/s

Frequency range: 0,016-75Hz

Mass: 750g

Radiation: no effect around BaBar (don't know exact conditions)

Magnetic field: tested in 1T magnet => same coherence, amplitude?

Feedback loop

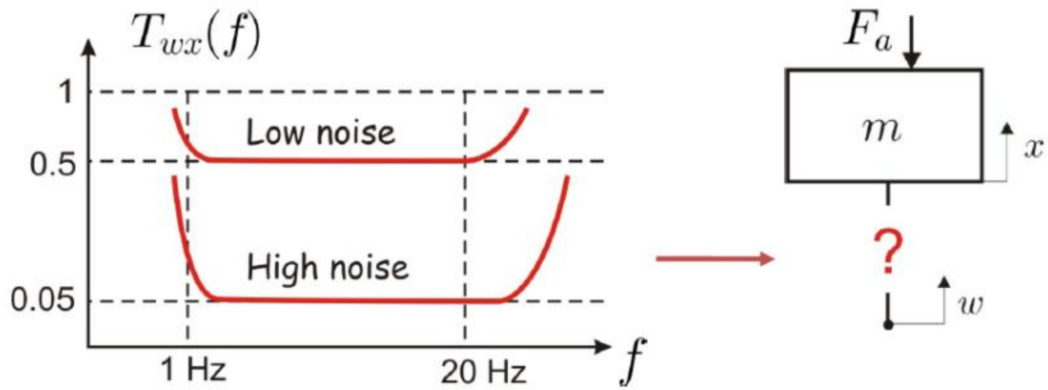
First resonance >200Hz

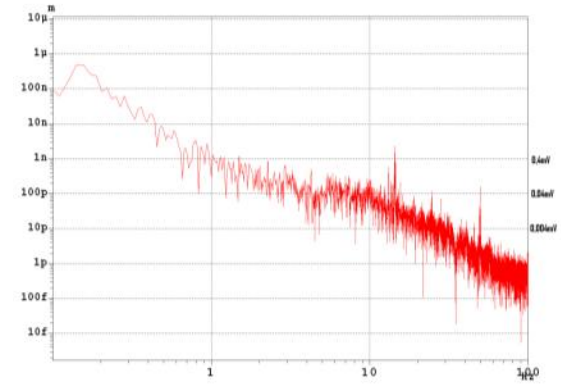
Electronic noise measured at >5Hz: 0,05nm

Unstable calibration, response not flat

Robust

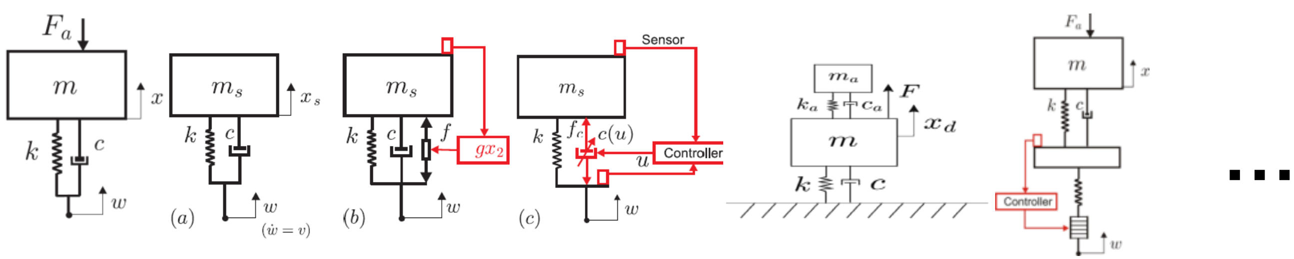
How to support the quadrupoles?





Comparison control laws and former stabilisation experiments

Ch. Collette
Stabilisation WG 7



	DESY, 1996	CERN, 2004	LAPP, 2007	SLAC, 2002
Experiment description	1 d.o.f	1 d.o.f	1 d.o.f	6 d.o.f, 42 kg
Actuator	Piezo	Piezo	Piezo	Electrostatic
Control strategy	FB	TMC	TMC	FB
Positioning	NO	NO	NO	NO
Rigidity	Stiff	Soft	Soft	Soft
(RMSw/RMSx)@1Hz	~3	~3	~2	~50
Stages	1	2	2	1

Deliverables & Milestones

Deliverable	Description/title	Nature	Delivery month
9.3.1	CLIC Quadrupole Module final report	R	M48
9.3.2	Final Focus Test Stand final report	R	M48

Milestone	Description/title	Nature	Delivery month	Comment
9.3.1	Characterization of noise/vibrations sources in an accelerator	O	M24	
9.3.2	Installation of interferometers at CTF3 Module	D	M24	
9.3.3	Installation of ATF2 final-focus alignment monitoring system	D	M6	
9.3.4	Installation of ILC prototype FB/FF at ATF2	O	M24	
9.3.5	Commissioning of CLIC quadrupole module	D	M30	Complete module with girder and accelerating structure
9.3.6	Quadruple mock-up manufactured and ready for installation	D	M30	