Summary WG8: Beam Diagnostics, Instrumentation and Technical Systems

Graham Blair

Hermann Schmickler

Manfred Wendt

Thanks to all presenters, contributors and the audience!

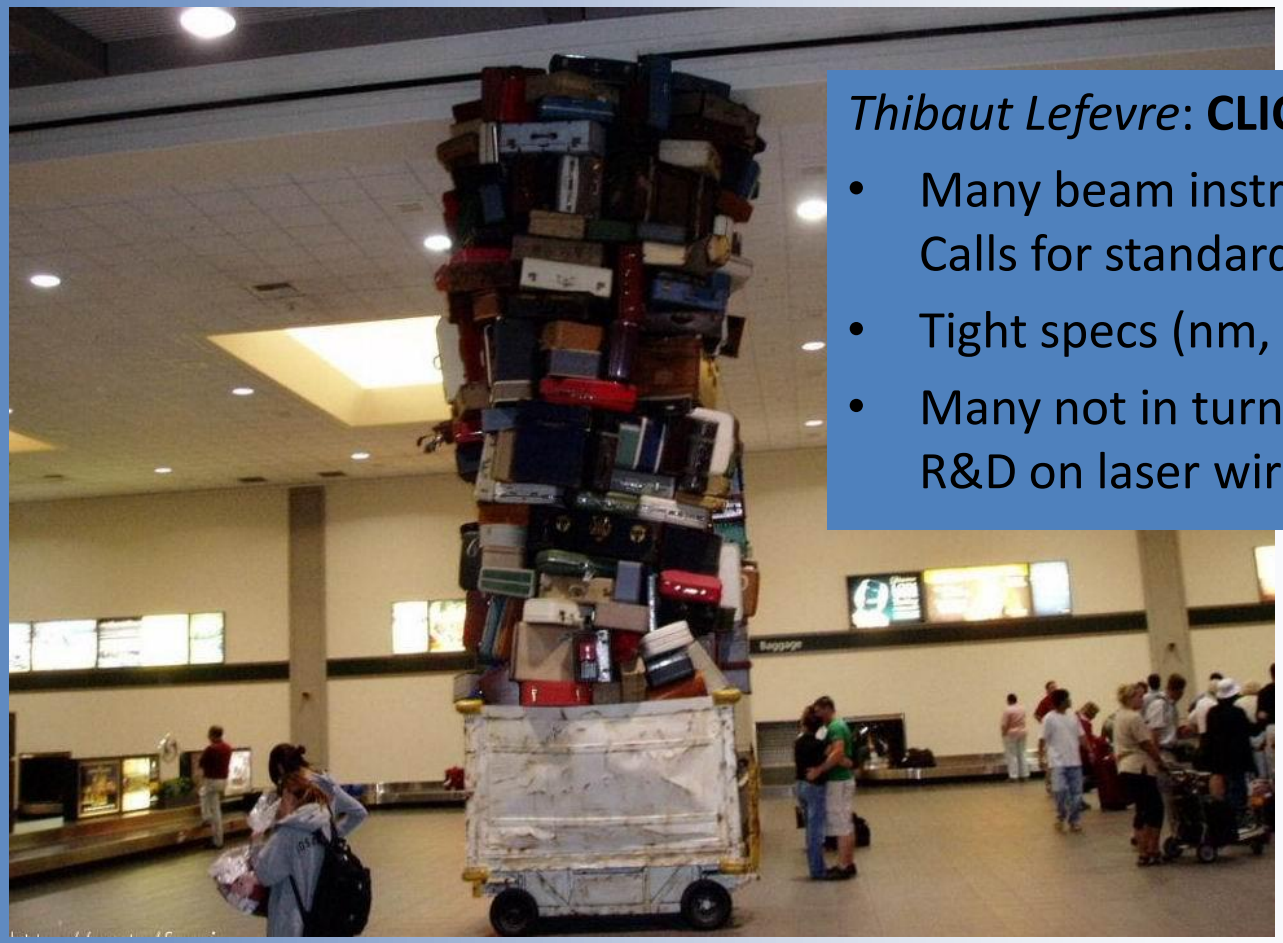
Statistics

- **Seven sessions**
  - **Four sessions dedicated to beam diagnostics, instrumentation and technical systems (what is NOT a "technical system"?)**
  - **Three joint sessions with CLIC Drive Beam / CTF3, Low Emittance Transport, and MDI.**
  - **24 presentations, ~10-20 participants in the sessions.**
  - **No surprise: Many presentations CLIC specific, but: some talks on ATF, ILC and general LC diagnostics & technologies**
- **This summary**
  - **Cannot cover all presentations**
  - **Some presentations were already summaries of many complex R&D activities! (summary of summaries)**
- **Now in somewhat chronologic order:**

What was done for the CDR

1- First iteration on requirements from Beam Dynamic – first iteration in 2008

*- Full set of specifications: More than **200kms of beamlines requiring > 50 000 instruments***

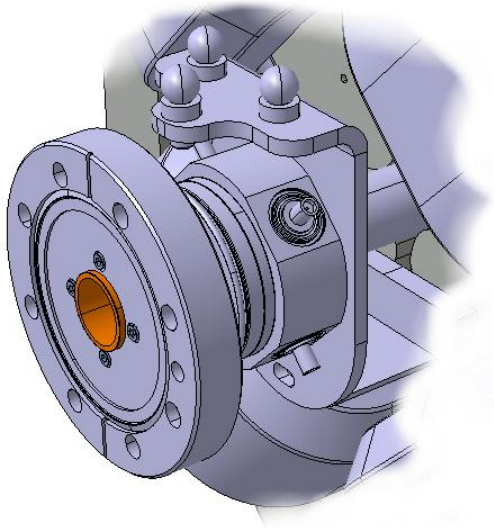


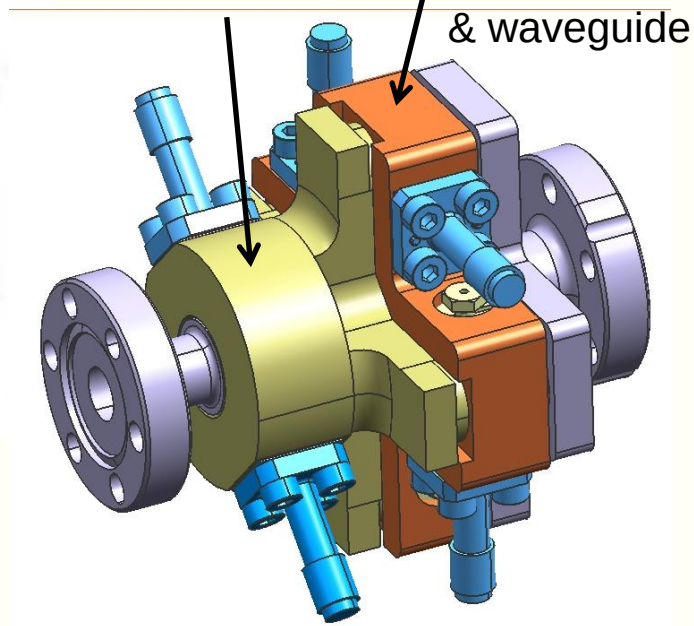
Thibaut Lefevre: **CLIC**

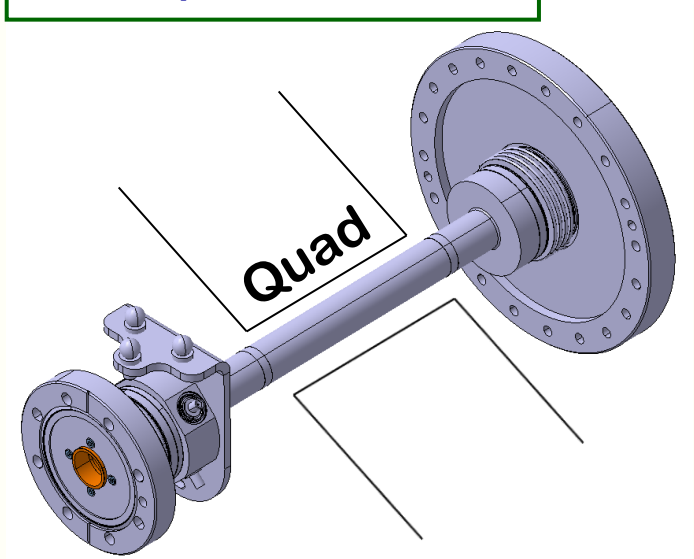
- Many beam instruments! Calls for standardization
- Tight specs (nm, fsec,…)
- Many not in turn-key status, R&D on laser wire, EOS, …

CLIC/CTF3 BPMs

- **Drive Beam BPM (Steve Smith)**
  - **Integrated with quad**
  - **Simple stripline BPM, need ~40000!**
  - **<1 µm resolution (single bunch, nom. charge)**
  - **Detailed analysis, incl. read-out electronics & wakepotentials!**

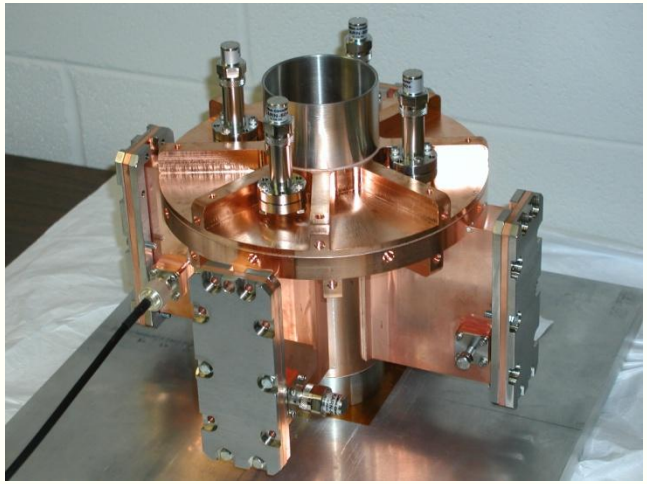


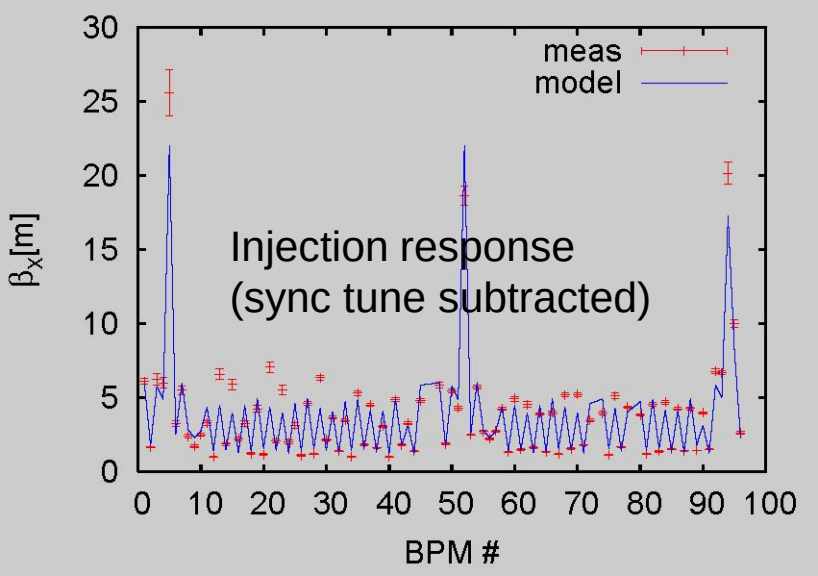




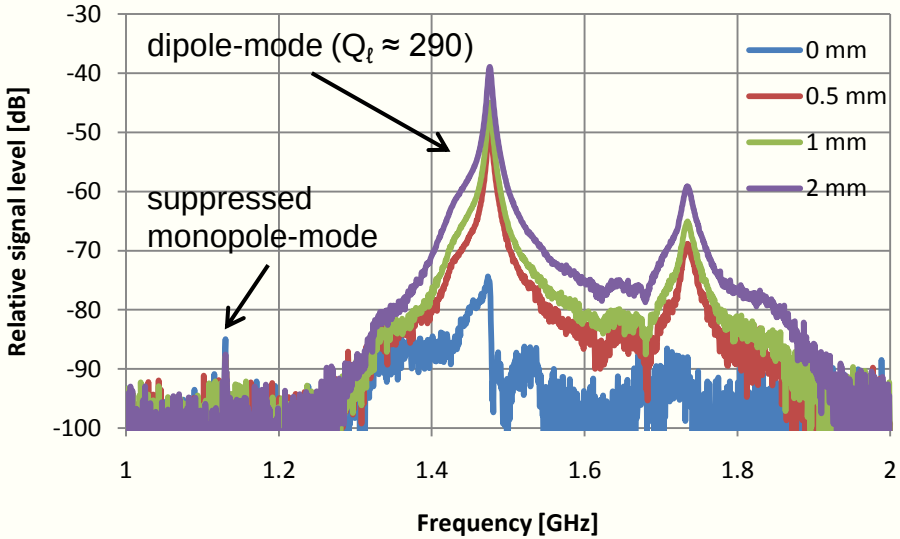
- **Main Beam BPM (CERN/Fermilab)**
  - **WG-loaded cavity BPM, plus reference resonator.**
  - **<50 nm temporal resolution**
  - **<50 nsec time resolution (low-Q)**
  - **Design adapted to CTF3 bunch frequencies: 15 GHz resonators**

First RF Measurements



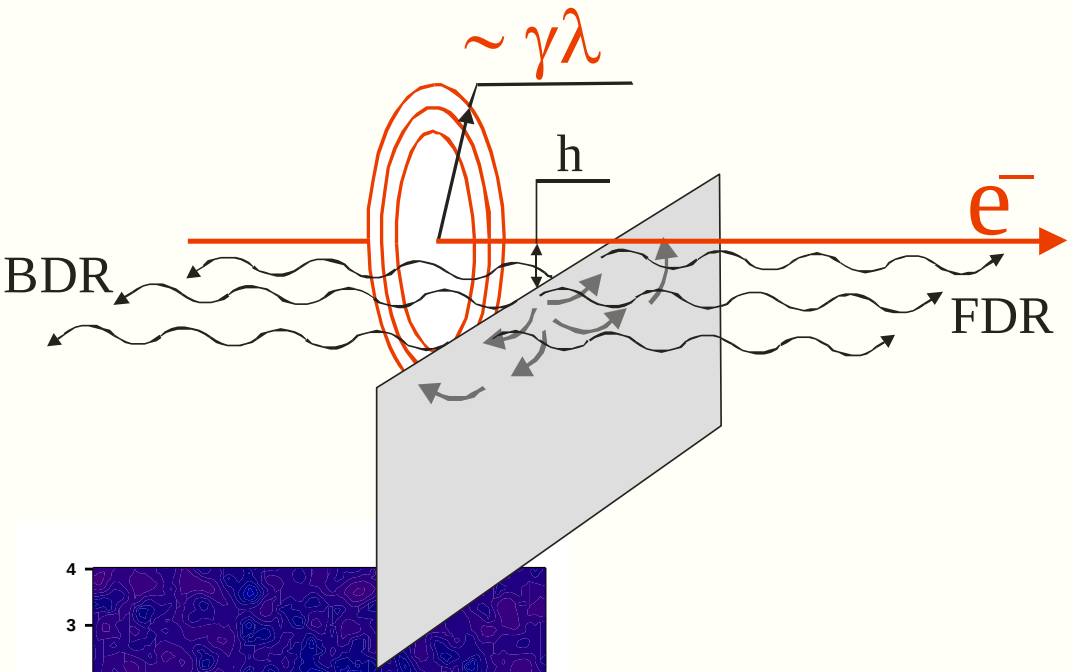


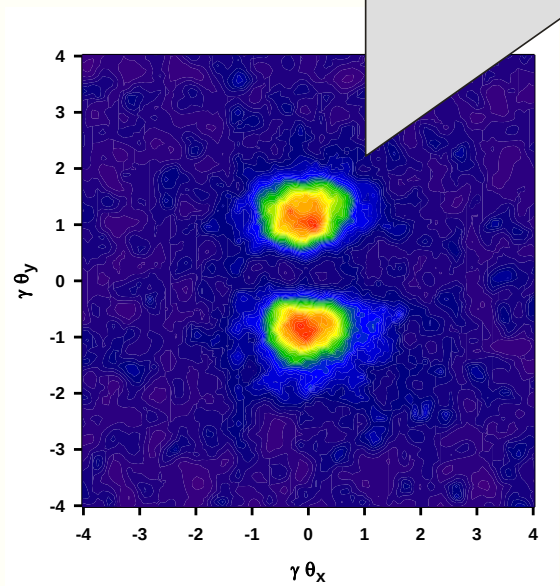
WG-Coupled Signals

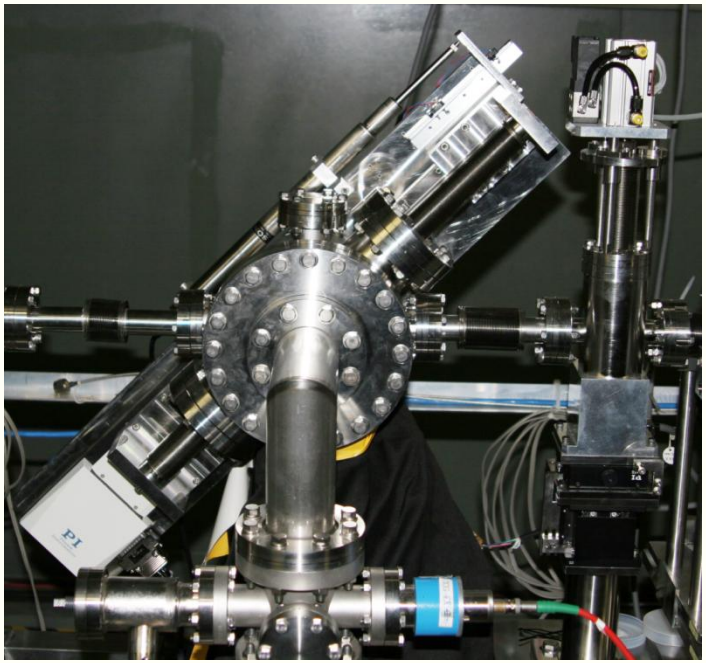


- **ILC Cold Cavity BPM**
  - **Dipole (BPM) & monopole (REF) read-out**
  - **Prototype finalized ("warm" dimensions)**
  - **RF characterization underway**
  - **ILC cryomodule compatible (type III+ or IV)**
- **ATF damping ring BPM read-out R&D**
  - **Analog / digital system w. integrated CAL**
  - **Resolution: <10 µm (TBT), <0.5 µm (NB)**

CLIC Beam Profile: ODR

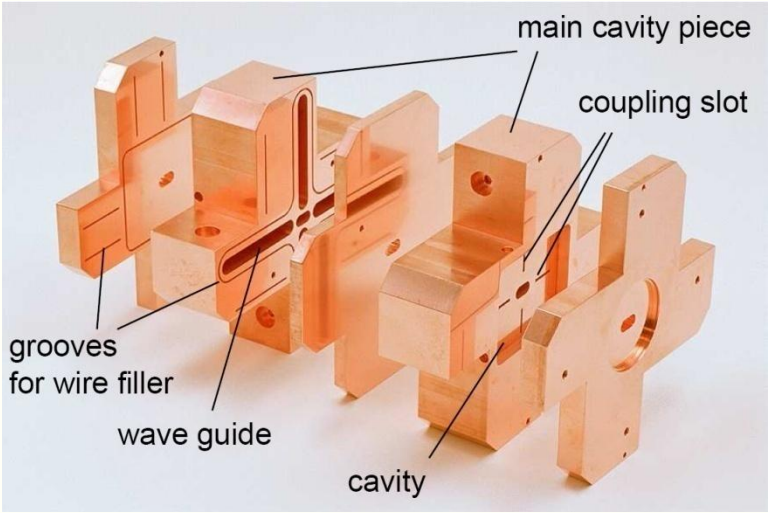


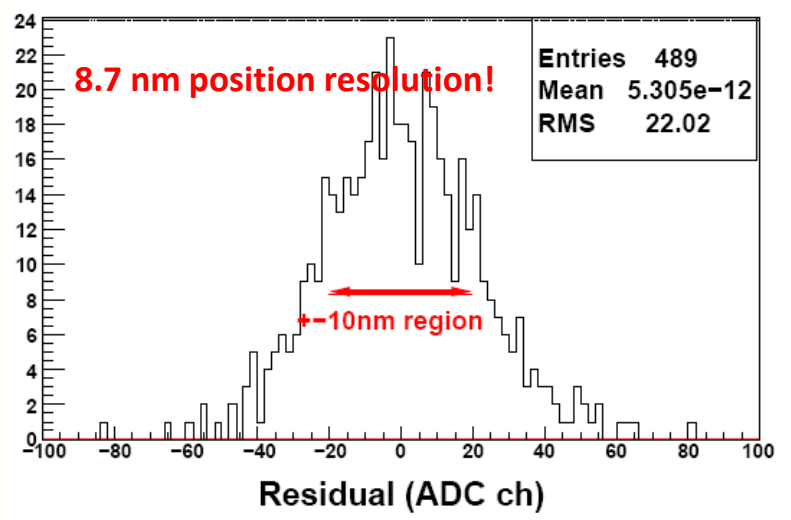




- ***Thibaut Lefevre*: Optical Diffraction Radiation**
  - **Simpler (and cheaper!) than laser wire**
  - **Non-invasive**
  - **Impact parameter vs. beam energy**
  - **Sensitivity & photon yield vs. beam energy (need to go to soft-X/UV range for 1 μm resolution)**
  - **R&D activities in collaboration with CESR-TA**

Summary of ATF2 Diagnostics



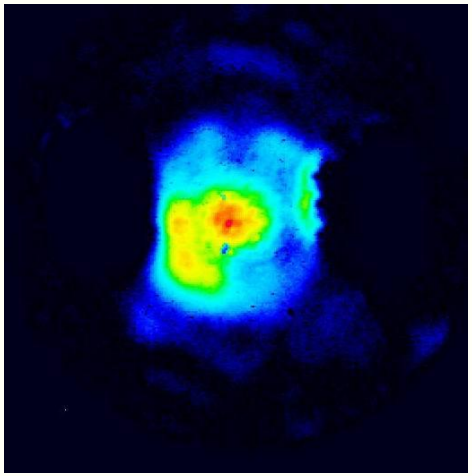


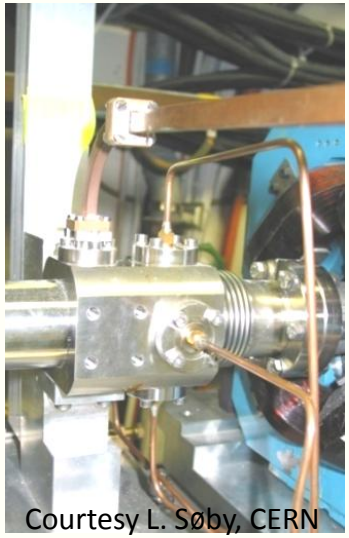
- *Toshiaki Tauchi*: ATF2 Diagnostics R&D
  - FONT feedback system:
    beam jitter reduction 2.1 -> 0.4 μm
  - Laser wire: 3.5 μm resolution!
  - Four OTR systems with < 2μm resolution.
  - S-Band & C-Band cavity BPMs
    C-Band performance:
    200-400 nm resolution with attenuators
    25 nm resolution without attenuator!
  - S-Band tilt monitor
    30 nrad expected resolution
  - Shintake IP Laser interferometer
    first measurements: ~300 nm resolution
  - IP cavity BPM
    <10 nm resolution (world record!)
    Goal: 2 nm

BUT (joint session with MDI):

- CLCI IP BPMs require 13 pm resolution (?!)
  (for 10 sec integration time)
  this BPM also needs BbB capability

More Diagnostics…




Courtesy L. Søby, CERN

- ***Laura Corner*: Fiber lasers**
  - **Photonic crystal fibers: large core, single mode**
  - **Good spatial quality (M^2<1.1), <2 nm spectral spread, high power, low jitter, etc.**
  - **Burst mode amplification up to 100 µJ**
- ***Anne Dabrowski*: Long. Diagnostics**
  - **Technology choices vs. location (Streak camera, EOS, CDR, RF detector)**
  - **Bunch length vs. bunch profile**
  - ***(Personal remark: RF deflector?)***
- ***Rogelio Tomas Garcia*: BDS specs**
  - **CLIC BDS layouts, diagnostics requirements, etc., & polarization measurements**

Consideration on the Conceptual Phase Stabilisation System

D. Schulte for the phase stabilisation team

Main to Drive Beam Tolerance

2% luminosity loss for
-Gradient error of 10^{-3}
-Phase error of 0.3°

-Main beam current stability of 0.1-0.2%

Drive Beam Tolerances

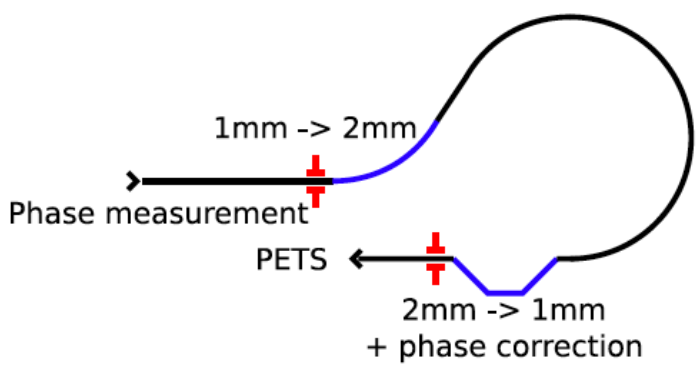
Need to stabilise Drive Beam

-Current – 7.5 10^{-3}
-Bunch length – 1%

Sensitivity

-Phase jitter from DR: 0.2° @ 1GHz
-Phase jitter of BC1: 0.08° @ 4 GHz
-Phase jitter of BC2 : 0.2° @ 12GHz:
-Phase error from DB accelerator: : 0.05° @ 1GHz

Feedforward at Final Turn-Around

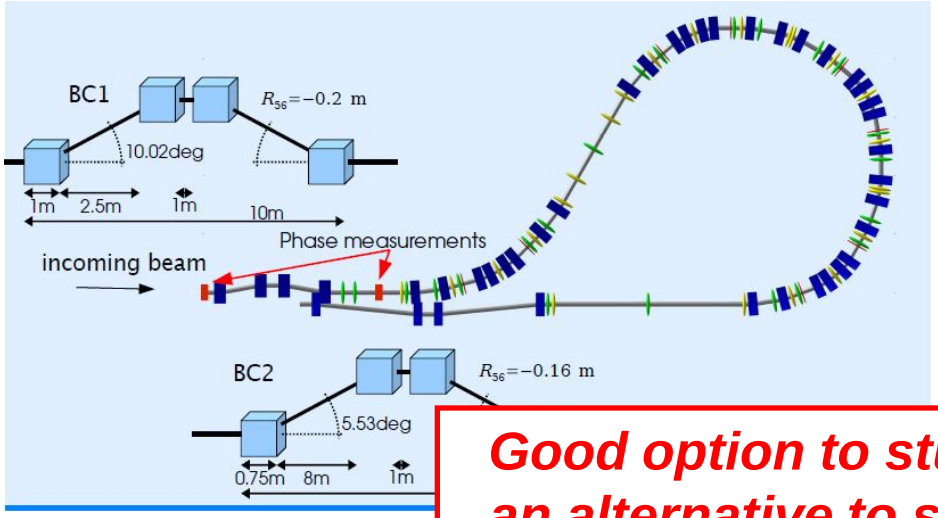


Phase Reference

- We have two options to provided a distributed phase reference system in the main linac
  - use the outgoing main beam
  - X-FEL-like system
  - or a combination
- Decision needs to be based on further input from hardware performance
  - both seem to not be too far

Amplifiers for CLIC Drive Beam Phase Correction

Philip Burrows, John Adams Institute, Oxford University
for Colin Perry



Based on discussion in *August 2009*

Speed: **10ns**

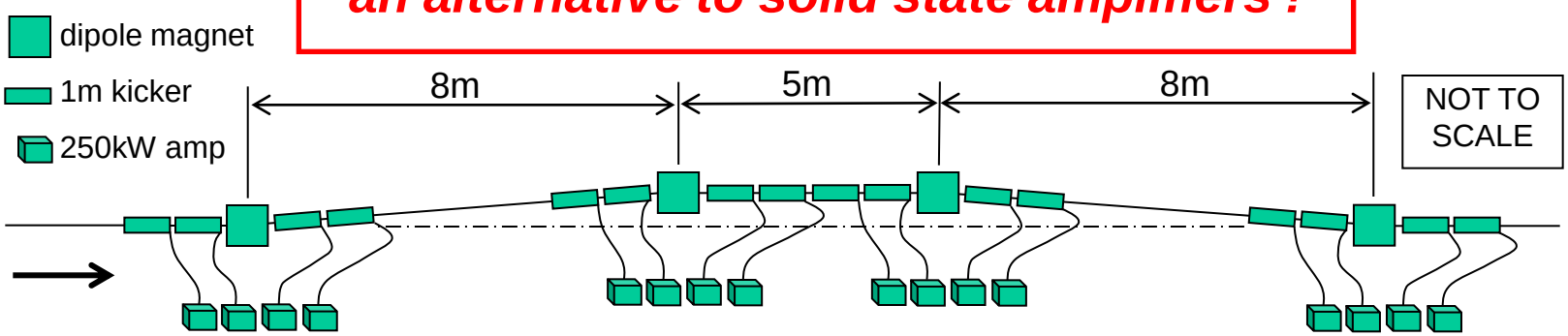
Kickers: **stripline kickers, 20mm clear aperture, 1m long**

Deflection: **+/-720μrad at each bend**

- divided over 4 kickers = +/-180μrad at each

odular, MOSFET

Good option to study vacuum tubes as an alternative to solid state amplifiers !



It can be done – but looks very expensive !

4 kickers at each bend, 250kW peak power amplifier to each kicker, 56 amplifier modules / amplifier

amplifier cost: **£75K per 250kW amplifier** ****** This is all very very approximate ******

768 amplifiers total, 200MW total peak power: - ***SYSTEM COST:*** **£60M** (perhaps +/-£30M)

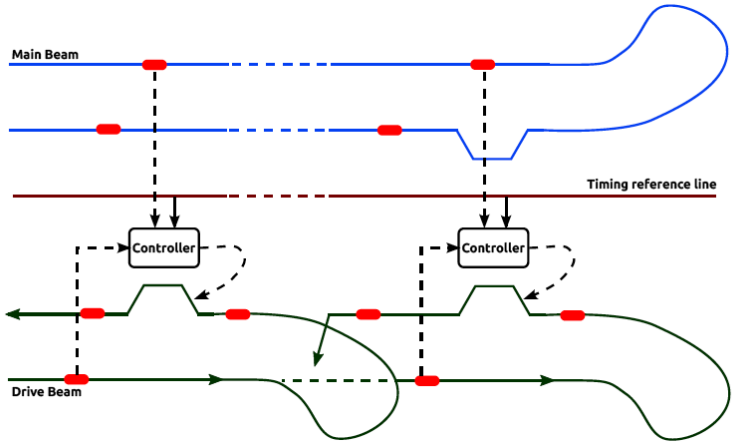
CLIC Fine Timing System

Update on specifications

Javier Serrano

In scope

- Recap usual timing performance specification methods.
- Cast (some) existing requirements into this language.



'Relevant technologies'

Low noise oscillators

Many promising options for both master oscillator and VCO on receiving side. See e.g. F. Ömer İlday's talk in CLIC09.

Fiber link stabilization

Proposed schemes guarantee noise of master oscillator up to the kHz region (limited by speed of light in fibers). Two types, pulsed and CW, have gone under 50 fs but not over 25 km.

'First Clients'

Drive beam RF system

Drive beam phase jitter $< 0.02°$ at 1 GHz ($\approx$ 50 fs).

Inter-beam synchronization using kickers

Similar requirements. See D. Schulte's talk.

Beam-based pulse-to-pulse feedback

Need for coherent time-tagged data. Precision tbd.

'Limitations'

Phase noise Power Spectral Density (PSD)

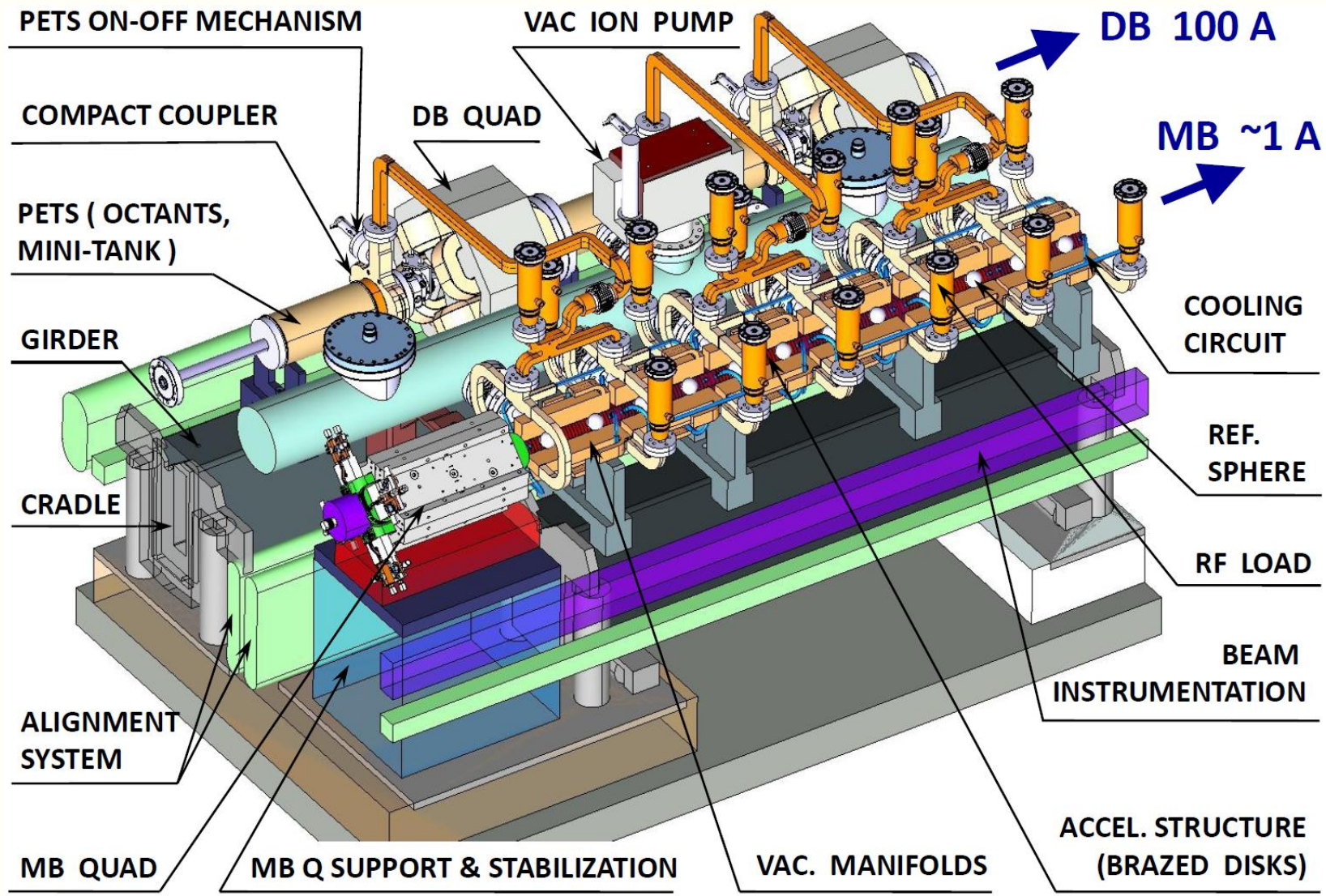
Lower limit

Perturbations below $\sim$ 5 Hz can be corrected through pulse-to-pulse feedback.

Upper limit

Set by the active element with the highest bandwidth (kickers, cavities...). Currently estimated to lie in the MHz region.

CLIC Two-Beam Module



CLIC TB Module (cont.)

- **Five talks**
  - ***Alexander Samoshkin*: Integration**
  - ***Germana Riddone*: Prototyping for CTF3**
  - ***Cedric Garion*: Vacuum system**
  - ***Michele Modena*: Magnets**
  - ***Marc Vanden Eynden*: Data acquisition & control**
- **Very advanced design status (impressive!)**
  - **Many design details and solutions presented**
  - **Very compact, complex mechanics**
  - **Extremely tight tolerances!**
  - **Solutions for assembly and installation**
  - **Need low-power data acquisition concept.**

CLIC Low Emittance Transport

- **Joint session WG7+8**
- **Four presentations with focus on:**
  - **Alignment**
    - ***Helene Mainaud-Durand*: Pre-Alignment Studies**
    - ***Thomas Touze*: Metrological Reference Network**
  - **Stabilization**
    - ***Kurt Artoos*: Status and plans**
    - ***Christophe Collette*: Hard or Soft? (active dampers)**

Results from simulations very promising

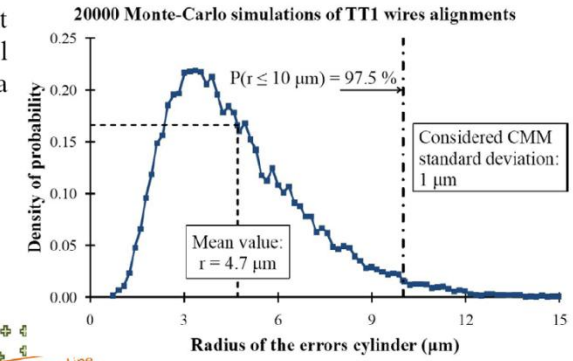
For stabilization (on left),

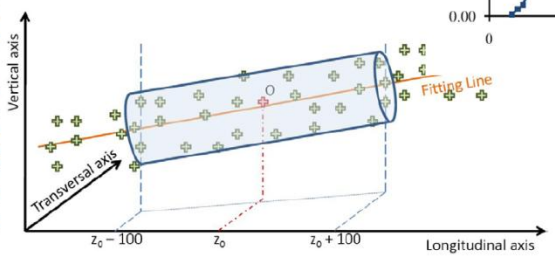
for active pre-alignment (on right)

FINAL ADJUSTMENT

❑ SIMULATIONS OF THE TT1 140 M ERRORS CYLINDER

According to the pre-alignment specifications, we must ensure all the errors fit, along 200 m in a 10 µm error cylinder.





The TT1 simulations are showing that in 97.5 % of the cases, all the pre-alignment error along 140 m fit in a 10 µm cylinder.

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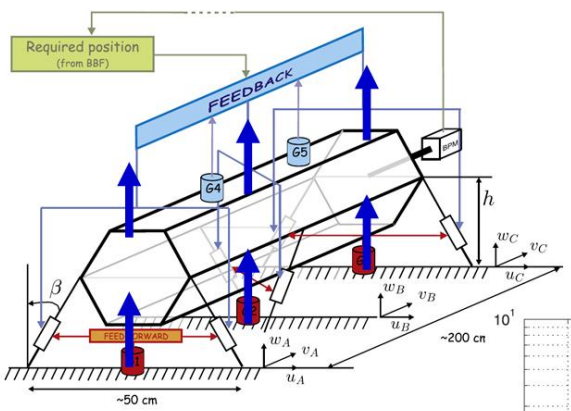
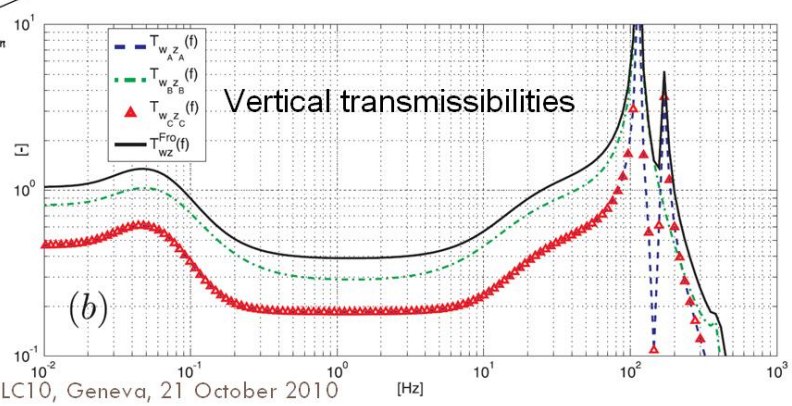
Stability of slender quadrupo



$$M\ddot{\mathbf{x}} + K$$

$$K = k_a B B^T \qquad B = J^T \qquad \dot{\mathbf{q}} = J\dot{\mathbf{x}}$$

C. Collette et al, *Nucl. Instr. meth. in phys. Res. A*, vol.621 (1-3) pp.71-78 (2010).



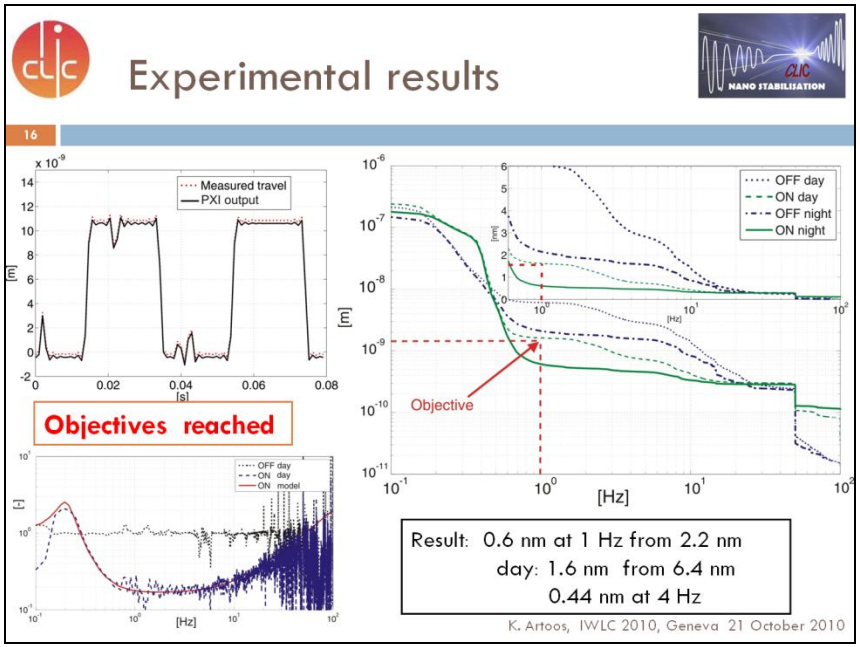
Frobenius norm:

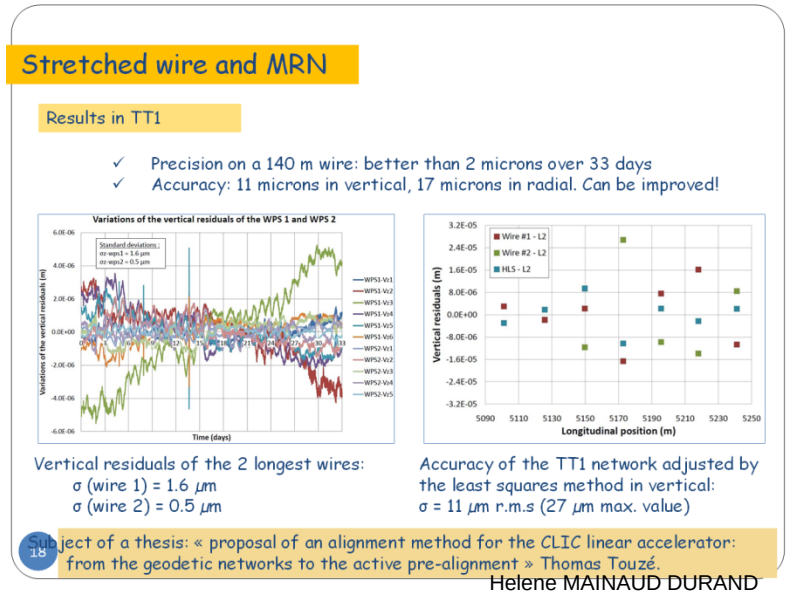
$$\|\mathbf{T}(\omega)\| = (\mathrm{Trace}[\mathbf{T}(\omega)\mathbf{T}(\omega)^{\mathrm{H}}])^{1/2}$$

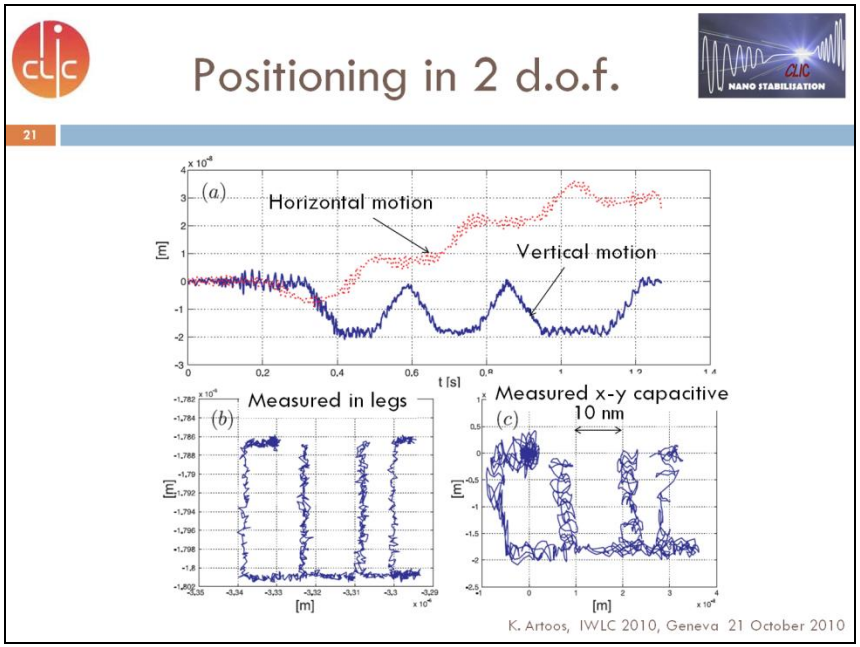
$$= \left(\sum_{i=1}\sum_{j=1} |T_{ij}(\omega)|^2\right)^{1/2}$$

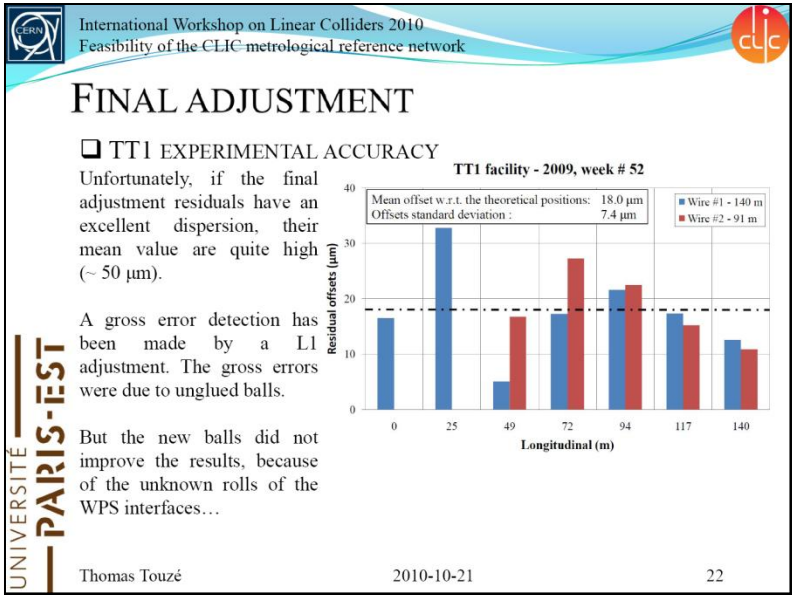
Experimental results very promising

For stabilization (on left), for active pre-alignment (on right)





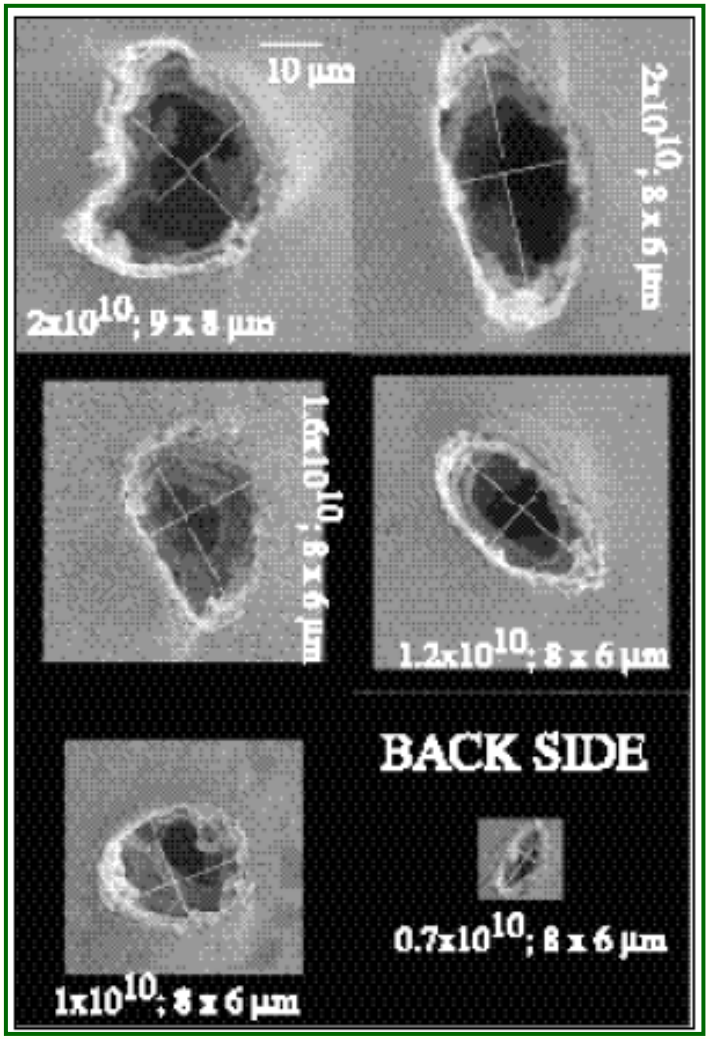




Machine Protection System

- **Two presentations:**
  - ***Marc Ross*: ILC MPS**
  - ***Micheal Jonker*: CLIC MPS**
- **Remarkable discussion**
  - **Neither beam energy (multi GeV), nor beam power (multi MW), but: power density is destructive**
    - **CLIC main beam: 10000 x "safe beam"**
  - **Needs passive and active protection systems, pilot bunch concept, AND: A balanced beam-line design!**

Single pulse damage in 1.4 mm Cu



Last Slide

THANK YOU!

Backup

Requirements and steps towards feasibility

For stabilization (on left), for active pre-alignment (on right)

Requirements

3

3992 CLIC Main Beam Quadrupoles:

Four types :

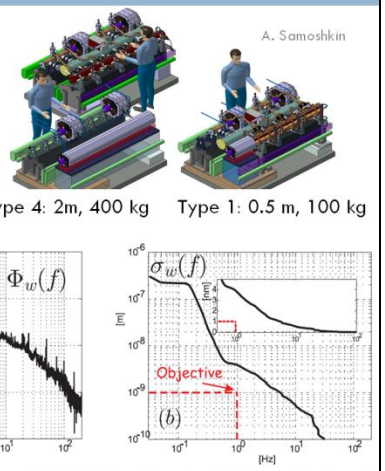
Mass: ~ 100 to 400 kg

Length: 500 to 2000 mm

Stability (magnetic axis):

$$\sigma_x(f) = \sqrt{\int_f^{\infty} \Phi_x(\nu) d\nu}$$

	Main beam quadrupoles
Vertical	**1.5 nm > 1 Hz** *(1 nm)*
Lateral	**5 nm > 1 Hz**



K. Artoos, IWLC 2010, Geneva 21 October 2010

Introduction: hypotheses for study

3 µm over 200 m (1σ) is a target for study and development.

↓

« trade off » with beam dynamics for realistic and achievable values for CDR.

Budget errors → Determination of the position

Steps	RF structures	MB quad
Zero of component to external references	5 µm (1σ)	10 µm (1σ)
External references of component to sensor interface on support	5 µm (1σ)	5 µm (1σ)
Sensor interface to Sensor zero	5 µm (1σ)	5 µm (1σ)
Sensor measurement w.r.t straight reference	5 µm (1σ)	5 µm (1σ)
Stability, knowledge of straight reference	10 µm (1σ)	10 µm (1σ)
TOTAL Error budget (1σ)	**14 µm**	**17 µm**

Main linac mover requirements

- Range: ± 3 mm
- Step size: ~ 1 µm, resolution: ~ 0.5 µm

4

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4 steps toward demonstration

13

2010 : 4 steps toward demonstration on MBQ type 4 (+ type 1):

- **1.** Stabilisation **1 d.o.f. with small weight** ("membrane")
- **2.** Stabilisation **1 d.o.f. with type 1 weight** ("tripod")
- **3.** Stabilisation **2 d.o.f. with type 1 weight** ("quadriped")
- **4.** Stabilisation of **type 4 (and type 1)CLIC MB quadrupole proto type**

K. Artoos, IWLC 2010, Geneva 21 October 2010

Required solutions: feasibility of the concept

	STEPS	ISSUES
Active pre-alignment	Determination of the metrological network w.r.t the straight alignment reference	Stable alignment reference, known at the micron level
	Determination of the position of each sensor w.r.t metrological network	Submicrometric sensors providing « absolute » measurements
	Fiducialisation: determination of the zero of each component w.r.t the sensor (external alignment reference)	Measure 2m long objects within a few microns
	Re-adjustment: displacement of the component supporting structure according to the sensor readings	Submicrometric displacements along 3/5 DOF

Other issues:

- Compatibility with the general strategy of installation and operation
- Compatibility with other accelerator equipment or services

13

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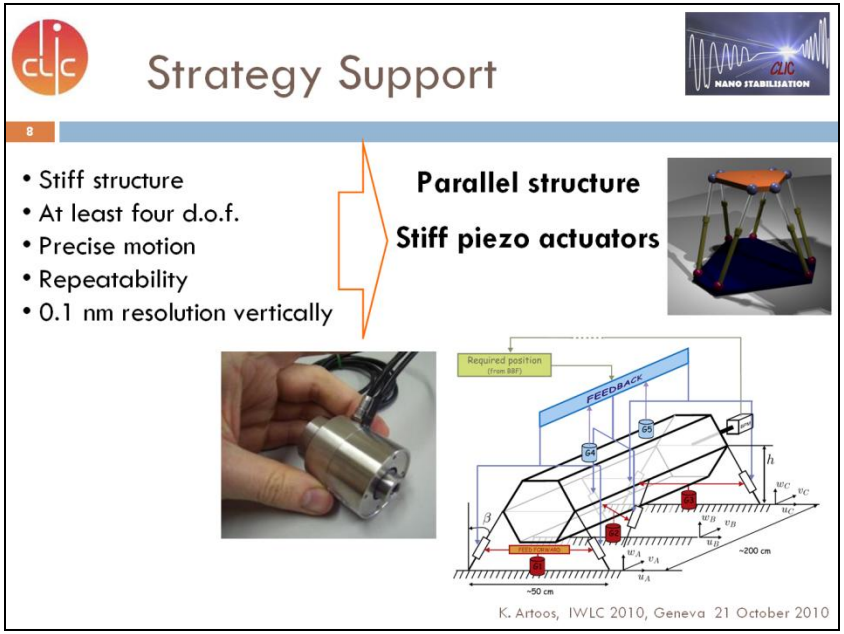
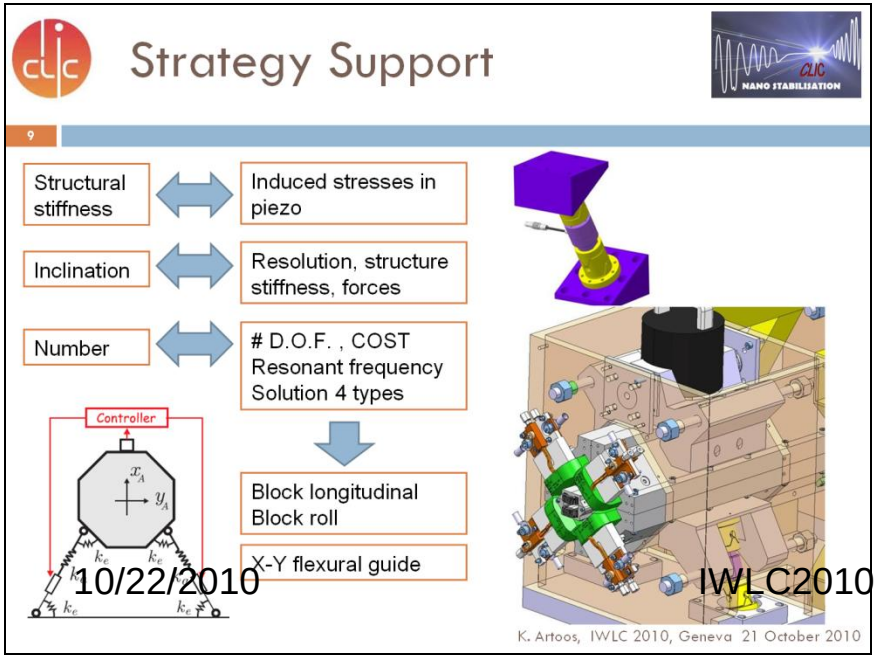
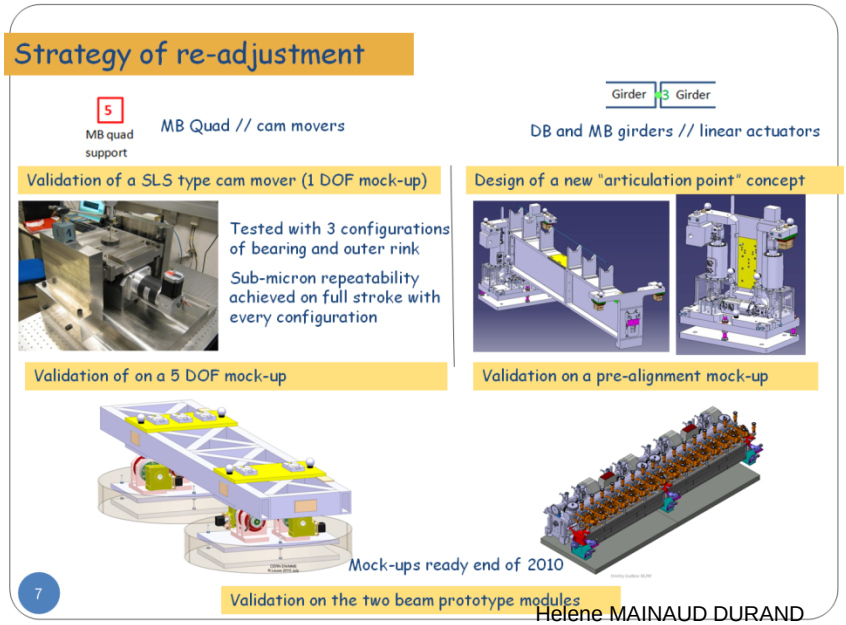
Strategy…

For stabilization (on left), for active pre-alignment (on right)







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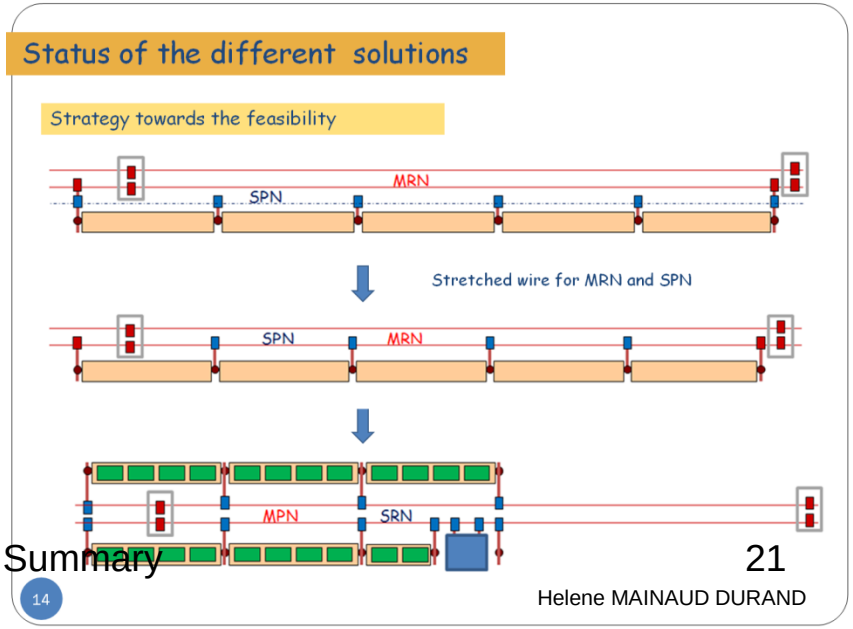

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Development of very good know-how

For stabilization (on left), for active pre-alignment (on right)

Passive vs Active vibration isolation

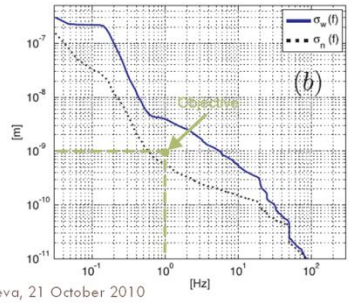
16

Only active isolation can provide both:

- Isolation in a broad frequency range between 1Hz and 20 Hz
- Dynamic stiffness for robustness to disturbances and compatibility with alignment

Conditions:

- Measure the vibrations
- Process the signal in real time
- Apply small dynamic forces



C. Collette, IWLC10, Geneva, 21 October 2010

Comparison

17

Very Soft (1 Hz) — Soft (20 Hz) — Stiff (200 Hz)

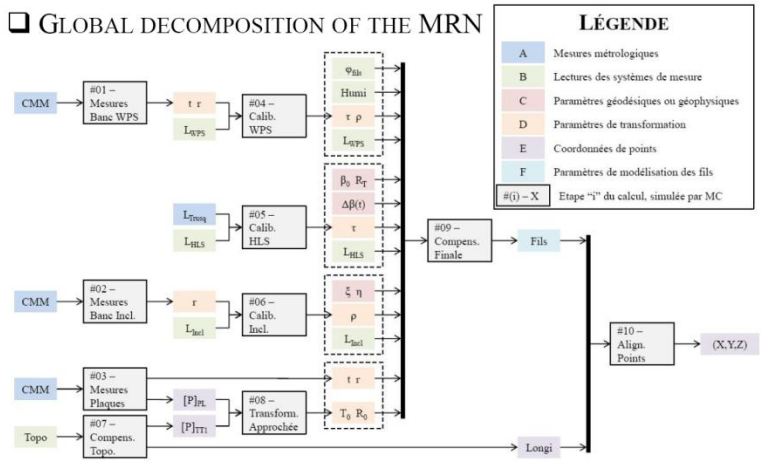
Very Soft (1 Hz)	Soft (20 Hz)	Stiff (200 Hz)
• Pneumatic actuator • Hydraulic actuator	• Electromagnetic in parallel with a spring • Piezo actuator in series with soft element (rubber)	• Piezoelectric actuator in series with stiff element (flexible joint)
COMPARISON		
+ Broadband isolation - Stiffness too low - Noisy	+ Passive isolation at high freq. + Stable - Low dynamic stiffness - Low compatibility with alignment and AE	+ Extremely robust to forces + Fully compatible with AE + Comply with requirements - Noise transmission - Strong coupling

C. Collette, IWLC10, Geneva, 21 October 2010

FINAL ADJUSTMENT

International Workshop on Linear Colliders 2010
Feasibility of the CLIC metrological reference network

❑ GLOBAL DECOMPOSITION OF THE MRN



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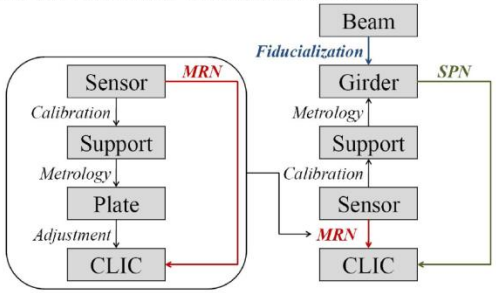
MRN & PRE-ALIGNMENT

International Workshop on Linear Colliders 2010
Feasibility of the CLIC metrological reference network

❑ CLIC PRE-ALIGNMENT METROLOGICAL CHAIN



A WPS or a HLS sensor provides the coordinates of a measured point of a wire or a water surface in its inner coordinate system. The sensor calibration allows the definition of this point in the support coordinate system. And so on…

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Still a lot to do…

For stabilization (on left),

for active pre-alignment (on right)

Alternative studies for TDR

Determination of the position of the components:

- ➔ In collaboration with NIKHEF : development of alternative solutions (laser beam)
  - Design of a short range / long range solution adapted for CLIC requirements
  - Integration of the short range solution on the two beam module prototype
  - Inter-comparison of the long range solution in TT1 / TZ32 tunnels

Re-adjustment:

- ➔ Validation of the concept of articulation point with cam movers

Other studies (in order to reduce the number of sensors):

- ➔ Study of a mono-girder (DB & MB components)
- ➔ Study of longer girders
- ➔ Development of low cost WPS sensors with FOGALE Nanotech (technical specification under definition)

Development of a Laser Alignment Multipoint Based: LAMBDA project

Helene MAINAUD DURAND

Conclusions

22

- With STRATEGY **STIFF** stabilisation support based on parallel piezo actuator structure:
- We DEMONSTRATED in a **model** and on **test benches** the **technical feasibility** to stabilise better than the required level at 1Hz in two d.o.f., from levels that were characterised in a running accelerator in a deep tunnel (LHC). This **with commercially available components**.
- We demonstrated **nano positioning** in two d.o.f.
- We have a concept design of the stabilisation support based on the validated actuator pair with flexural hinges.
- Compatible with module requirements and alignment and robust against external forces

K. Artoos, IWLC 2010, Geneva 21 October 2010