Wakefield Monitor Development & Tests in the TBTS

CLIC WORKSHOP 2008

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Objectives and development plan

Technical objectives:

1) Accelerating structure (ACS) alignment on girder using probe beam

2) Wakefield monitor (WFM) performance in low and high power conditions (and after a breakdown)

WFM specifications: ***• Resolution = 1 µm***

• Precision = 10 µm

Development plan:

1. WFM prototype

-TBTS, Phase 2: 04 – 07 / 2010

- Add WFM capability to a structure already in testing pipeline

2. Complete ACS with WFM

- TEST MODULE, Phase 1: 09 -12 / 2010

- Full integrated module/system test

In the framework of exceptional contribution of France to CERN

References

The principle of measuring the beam position with respect to the electric field axis of a cavity by the detection of the beam generated dipole modes is not new

- RF beam position monitors are based on this principle

  - M. Ross et al., RF Cavity BPMs as Beam Angle and Beam Correlation Monitors, PAC 2003, Portland
  - C. Simon, RF cavity BPM for FLASH and CALIFES, this workshop

- Experiments at FLASH facility at DESY have demonstrated that the higher order modes induced in superconducting cavities can be used as a high resolution beam position monitor

  - N. Baboi, Preliminary Study on HOM-Based Beam Alignment in the TESLA Test Facility, LINAC 2004, Lubeck
  - S. Molloy et al., High precision superconducting cavity diagnostics with higher order mode measurements, Phys. Rev. ST Accel. Beams 9, 112802 (2006)

- CLIC / CTF2: 3 GHz experiments

  - J. Prochnow, Measurement of beam position using highly-damped accelerating structures, PAC 2003, Portland

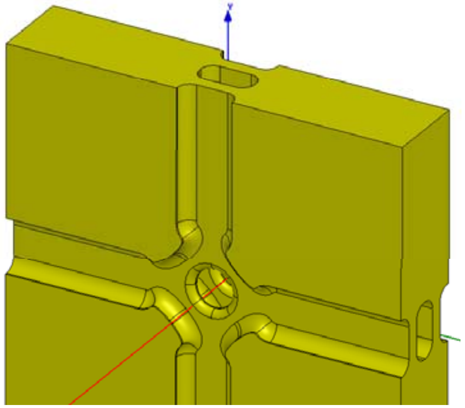
- The use of dipole modes generated in the 11.4 GHz structures was foreseen in the NLC/JLC collider design to align the structures in the micrometer level

  - C . Adolphsen, Wakefield and beam centering measurements of a damped and detuned X-band accelerator structure, PAC 1999, New York

Some references exist → The challenge will be to find the best technique for the dipole mode detection and signal processing, and to implement it in a CLIC structure

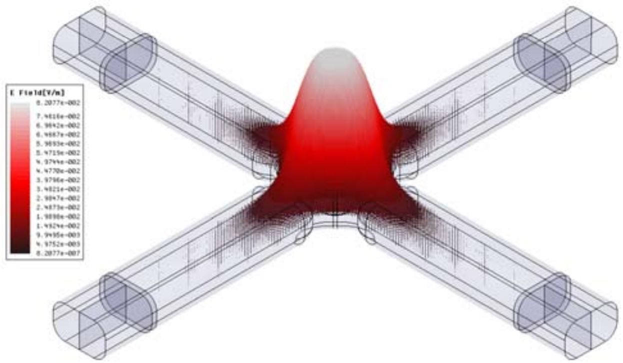
Accelerating structures RF baseline

The objective is to use the waveguide damped CLIC-G structure and to integrate a WFM into it



CLIC-G ACS (2 cells)

Fundamental accelerating mode (E Field)



Parameters	Values	units
Frequency	11.9942	GHz
Phase advance per cell	120	deg
Nb of cells	24	
Cell aperture		
Cell length d	8.332	mm
Active length	230	mm

Main CLIC-G parameters

Why damped structure ?

- reduces the number of parasitic modes (monopoles, quadrupoles…) that could interfere with the dipole mode signal

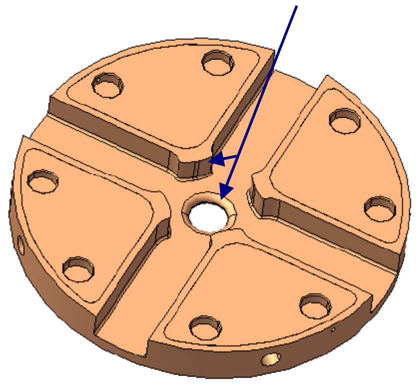
- provides a natural filtering of the fundamental mode with the four orthogonal waveguides (cut-off frequency = 13.3 GHz)

- two opposite waveguides can be used for measurement of one polarization plane of the dipole mode

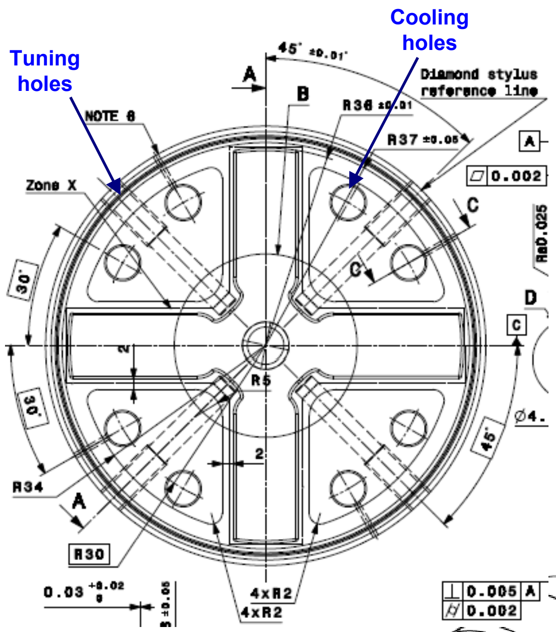
Accelerating structure fabrication

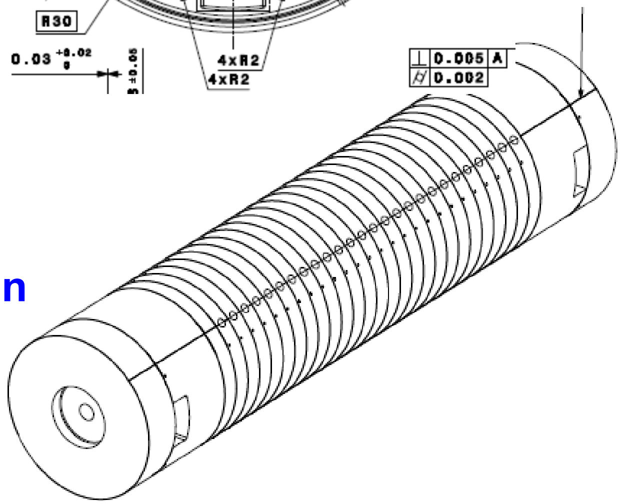
We plan to build a quantity of 2 or 3 structures during this study

The brazed disks technology is chosen for now to test the WFM at nominal gradient 100 MV/m



- Material : CuC2 OFHC
- Diamond machining for high tolerances and very low surface roughness (Ra = 0.025)
- High precision 3D control at constant temperature (20 +/- 0.5°C) (can be done at Saclay)
- No shocks, scratches, marks during and after machining
- Vacuum or H_2 brazing (~ 800 to 1000°C)
- Baking
- …





The fabrication constraints are very high…

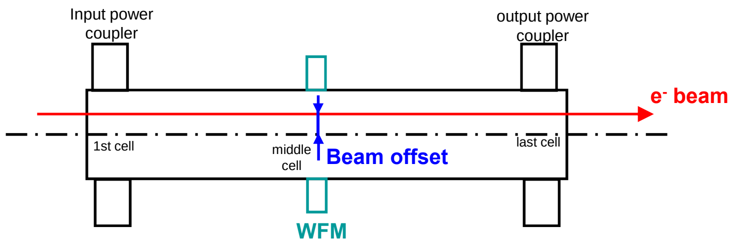
→ qualification test needed if new manufacturers are foressen

Question: sealed structure or structure in vacuum tank ?

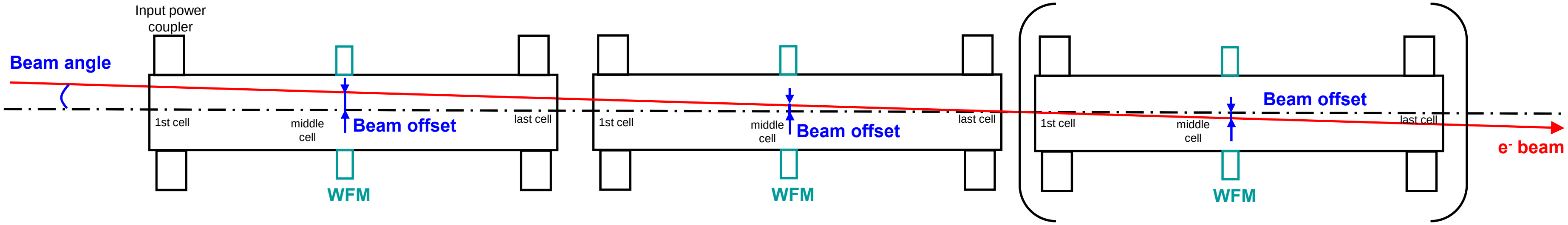
WFM possible configuration

Proposition n°1:

- One WFM per structure
- WFM positioned at the middle cell



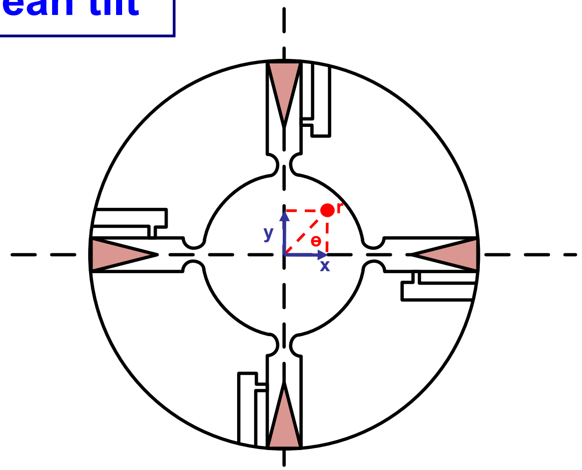
→ ACS mean offset



→ ACS mean tilt

Proposition n°2:

- Four detectors per cell
- Each detector in orthogonal position for (x,y) localisation



$$r = \sqrt{x^2 + y^2}$$

$$\theta = Arc\cos\left(\frac{y}{x}\right)$$

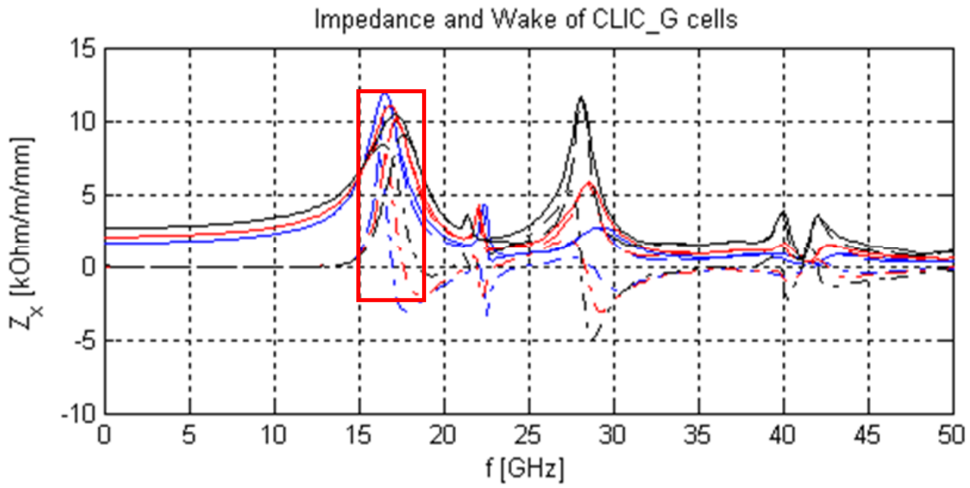
$$\theta = Arc\sin\left(\frac{y}{x}\right)$$

Input data for dipole mode

From A. Grudiev
GdFidL simulations

Parameters of the lowest dipole-band modes in CLIC-G

cell	first	middle	last
Q_1	10	7.7	6.3
A_1 [V/pC/mm/m]	117	140	156
f_1 [GHz]	16.74	17.21	17.67

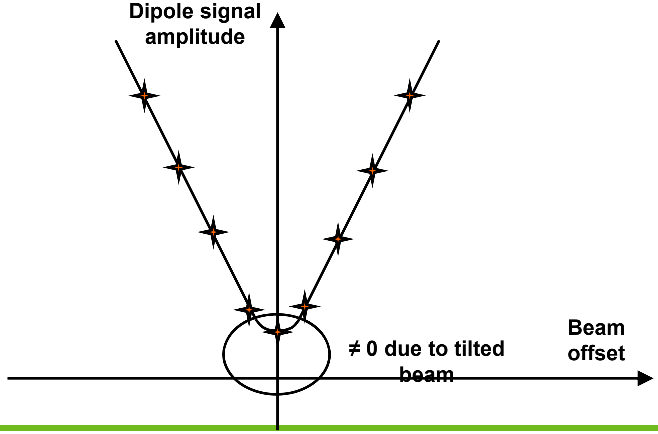


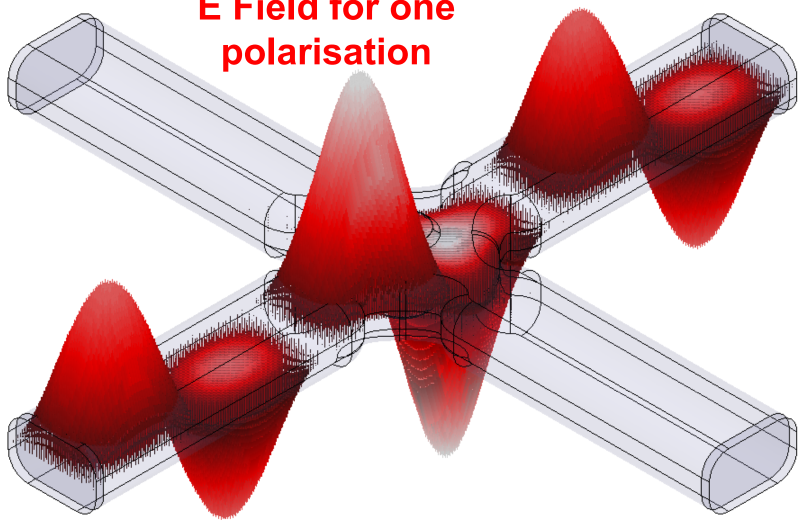
Lowest dipole-band mode

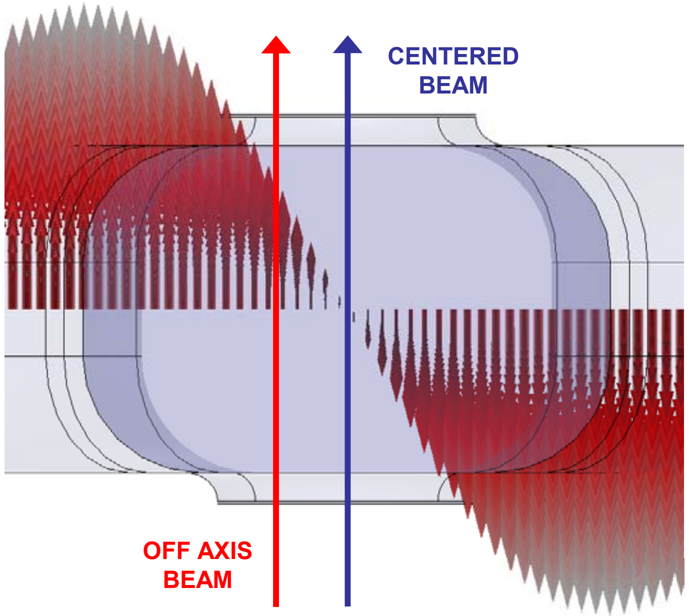
Beam curve in the dispersion diagram for synchronous condition with the beam:

$$\Phi_c(\deg) = 360\frac{F_1(Hz)\cdot d(m)}{C(m/s)} = 172.2°$$

Parameters	Values	units
Cell number	Middle cell	
Cell length d	8.332	mm
Frequency F1	17.21	GHz
Quality factor Q1	7.7	
Loss factor A	140	V/pC/mm/m
Phase advance per cell	172.2	deg







Time shape of the WFM signal

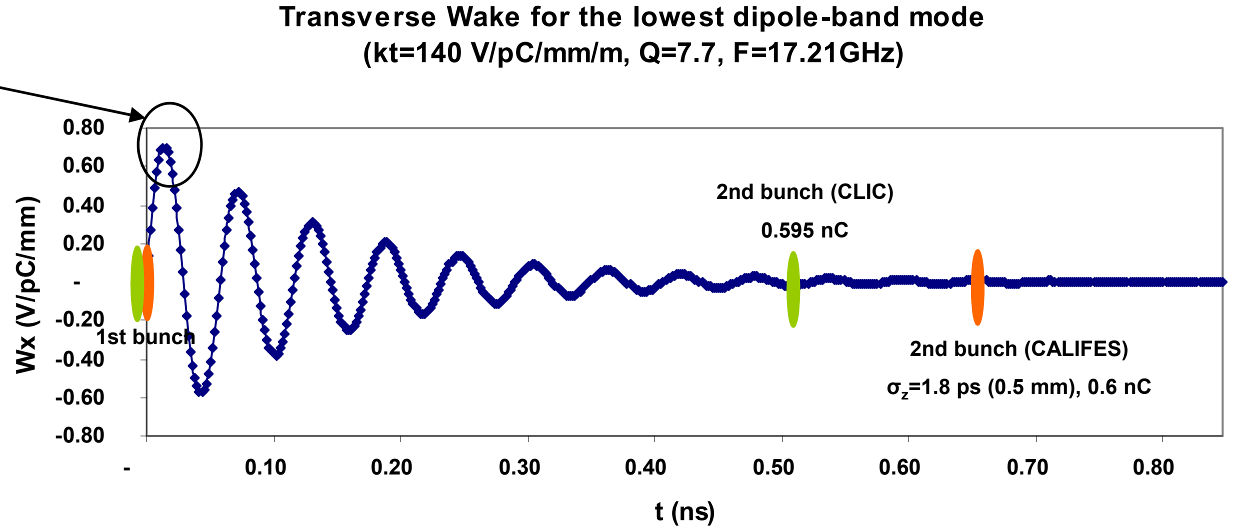
Single mode, in first approximation

Long range wakefield

$$W_t(s) = 2k_t \frac{C}{2\pi F} \sin\left(2\pi F \frac{s}{C}\right) \cdot \exp\left(-\frac{2\pi F \cdot s}{2Q\,C}\right)$$

where s > 0 is the distance behind the bunch and F, k_t and Q are the frequency, the transverse loss factor per unit length and the quality factor of mode

Peak value proportional to beam offset



No accumulation of signals in multi-bunch operation

More precise waveform calculations with…

Multiple mode

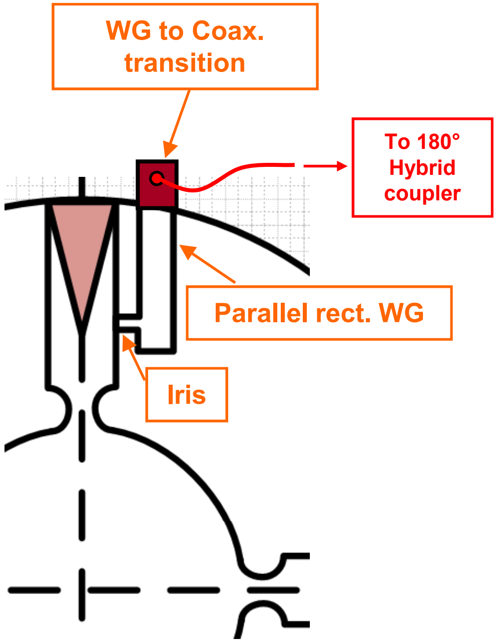
$$W_t(s) = \sum_{\lambda} 2k_{t\lambda} \frac{C}{\omega_\lambda} \sin\left(\omega_\lambda \frac{s}{C}\right) \cdot \exp\left(-\frac{\omega_\lambda s}{2Q_\lambda C}\right)$$

Multiple mode with arbitrary longitudinal bunch shape

$$w_t(s) = \int_0^{\infty} I(s-s') \cdot W_t(s')ds'$$

with $I(s)$ **the longitudinal beam profil**

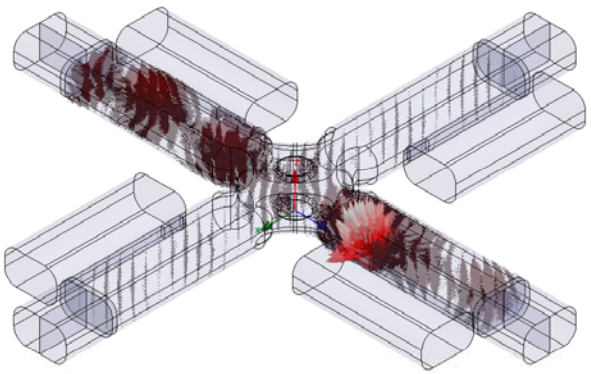
HOM signal coupler



- Parallel rectangular waveguide coupled by an iris to the orthogonal damped waveguide may be the best solution for high power operation and breakdown compatibility
  - ➢ size of iris: determine the amount of coupled power
  - ➢ position of the iris: determine the rejection rate of the fundamental mode (evanescent wave)
  - ➢ easy to implement in a disk structure

+ waveguide to coaxial RF transition

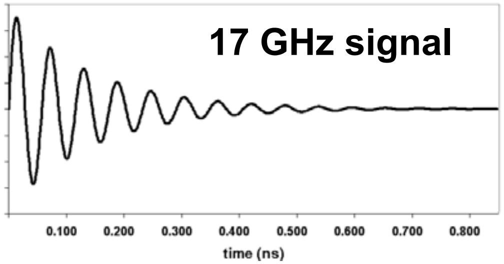
  - door knob transition for broadband matching and high power capability ?



- Other possible coupling solutions:
  - loop : magnetic coupling
  - antenna: electric coupling

Additional GdFidl simulations are needed (power level, waveform …)

Fast Signal Processing



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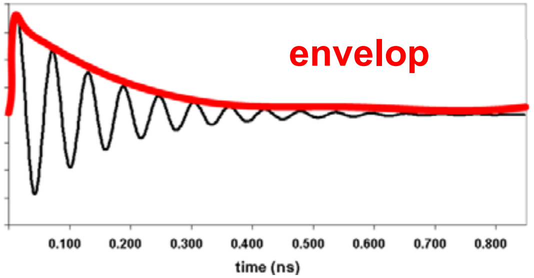


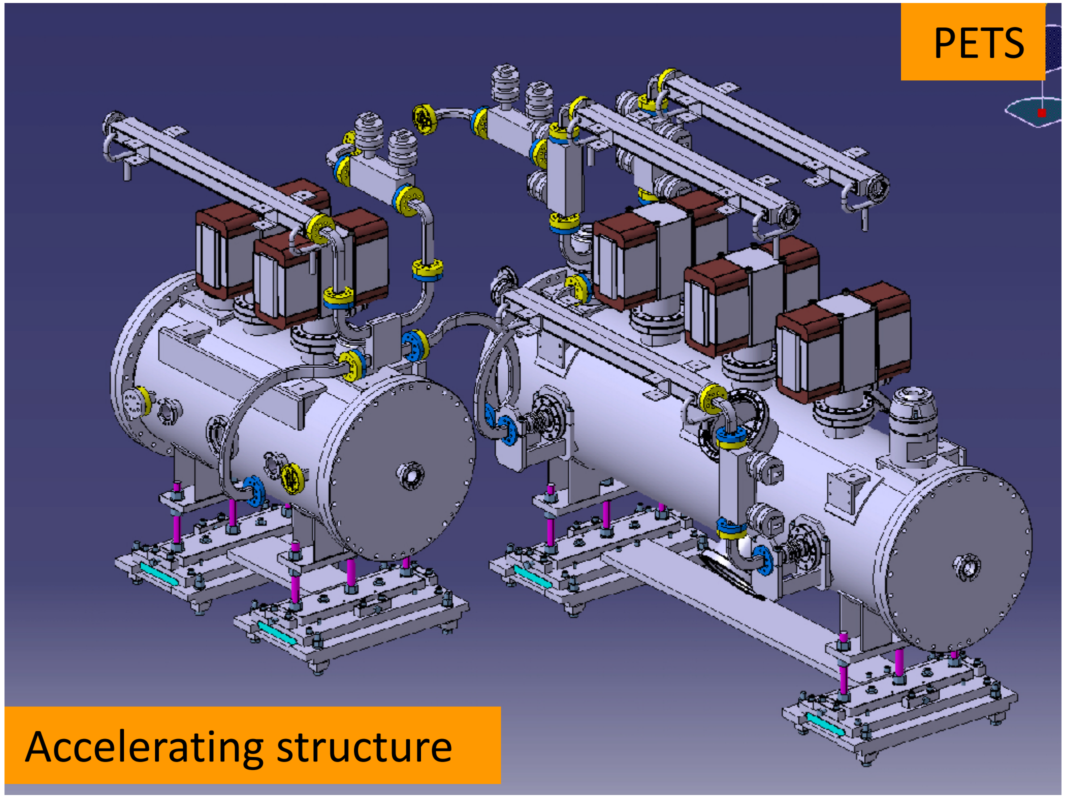
or…

- Implementation of a **180 ° Hybrid couplers** ?
  - ➢ Δ port for offset measurement (dipole signals have opposite phase at the two opposite waveguides)
  - ➢ Σ port for beam intensity measurement (monopole signals have the same phase)
- Do we need a **band pass filter** centered at the dipole mode frequency 17.2 GHz ?
  - ➢ it is used to reject modes of the wrong pass band
  - ➢ could become impossible to tune to a different mode
- Do we need **variable attenuator, amplifier** ?
- Do we have to use a **down mixing detection** ~100 MHz
- Do we need a **schottky diode detector** or can we use directly a **fast digital oscilloscope** ?
  - ➢ Serial Data Analyzers exists up to 18 GHz analog bandwidth, sampling rate 60 GS/s, 1 channel (LeCroy company)
- How to manage the length of the cables, the EM compatibility to reduce noise detection…

The signal processing is not easy (pulse duration and frequency)

WFM experimental program on TBTS

STAGE 1



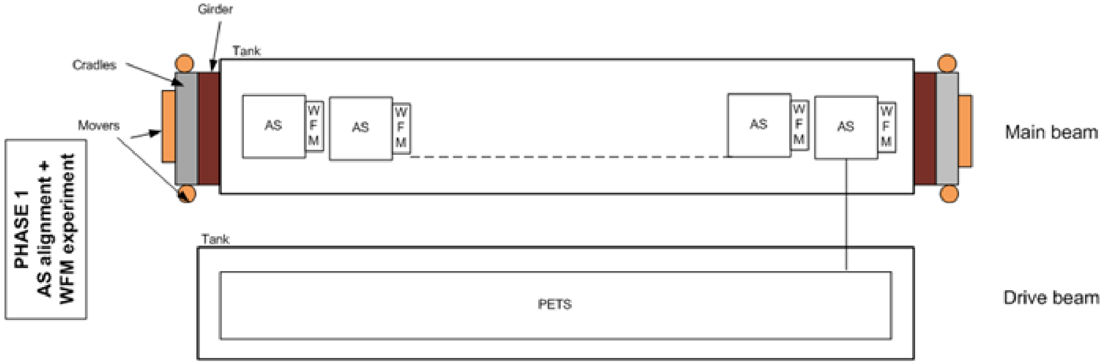
- Integration of a single ACS with the WFM prototype in the existing ACS vacuum tank
- Use of CALIFES for Probe Beam
- Use of Dipole steerers and BPM of TBTS for Beam offset creation and measurement

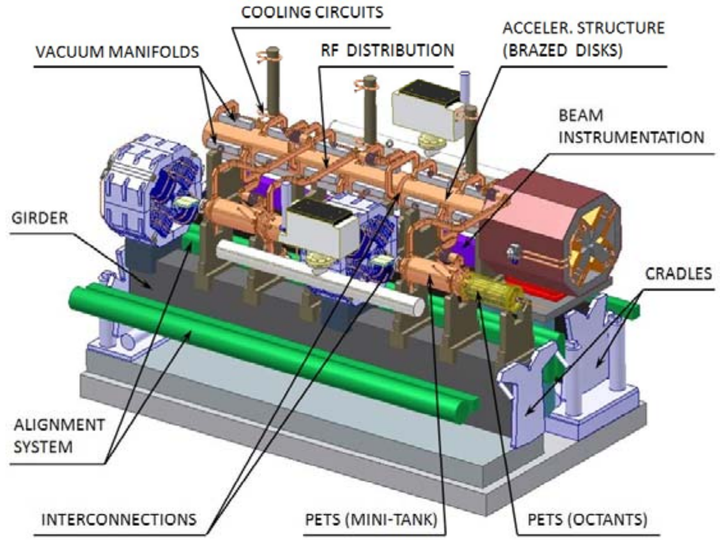
Rq: TBTS BPM resolution = +/- 10 µm and 10 µrad

- Maybe start without RF power from PETS

WFM experimental program on CLIC Module

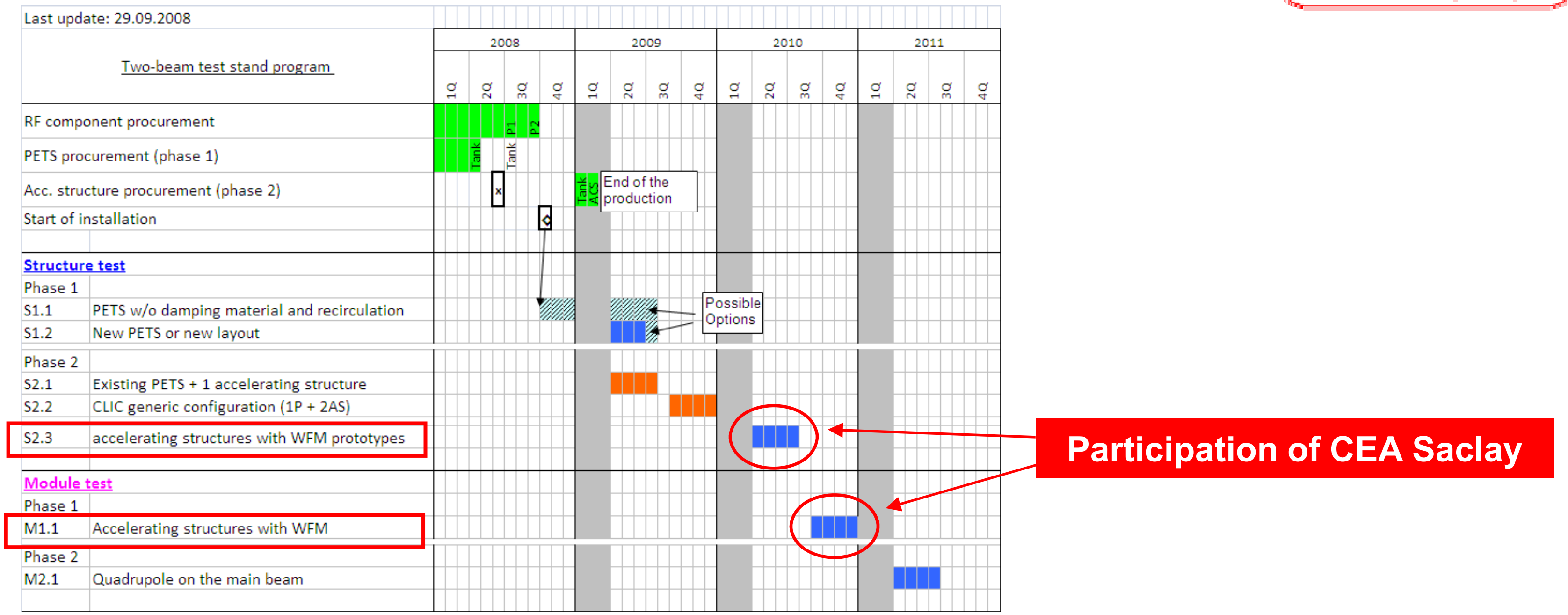
STAGE 2





- Fabrication of complete ACS with WFM
- Integration on the girder of the test module
- Use of CALIFES for Probe Beam and TBTS dipole steerers and BPM for Beam offset measurement and beam tilt

Milestones and deliverables



- **Kick-off meeting:** **Nov 2008**
- **WFM design review:** **March 2009**
- **WFM procurement:** **June 2009**
- **Complete ACS final design review:** **Sep 2009**
- **Complete ACS procurement:** **Mar 2010**

Conclusion

- *Very interesting R&D program for a CLIC Feasibility Demonstration*
- *Development plan in two stages (prototype & series)*
- *Baseline for ACS*
- *Opportunity to manufacture ACS*
- *Better idea of WFM configuration, waveform in time domain, HOM measurement coupler, signal processing…*

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Thank you for your attention