CLIC main linac RF diagnostics system requirements/characteristics

Proposal (4th version)

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History

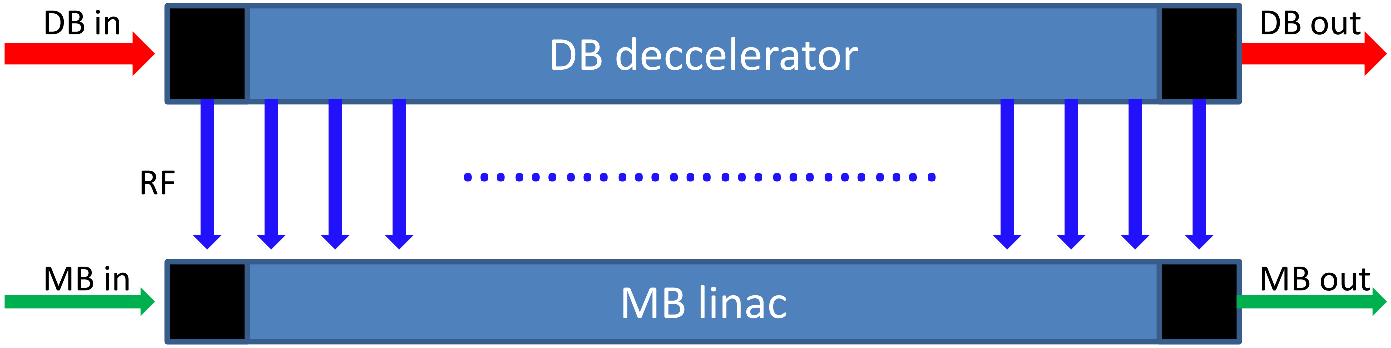
1. First proposal presented and discussed at the RF structure development meeting on 17.02.2010
2. Second version
   1. Few comments has been taken into account for the second version
   2. After the meeting, separate coffee discussion took place with Alex the results are incorporate in this version
   3. Several discussions with other people are acknowledged as well (see last slide)
3. Third version
   1. Important comment of Alex concerning wake field monitors is incorporated
   2. WFM configuration 2 has been introduced as a solution to relax the tolerances on the transmission line phase length difference in the signal combination network
   3. WFM configuration 1 is still our baseline for CDR
4. 4th version
   1. Detailed specification for the **regular unit type 1** and for the **WFM config. 1** has been worked out together with Alex. These specifications are summarized for **CLIC module type 1** and send to Lars Soby (BI) who collects the specs for LAPP collaboration.

List of items where RF diagnostic is required

1. Pure RF diagnostic
    1. RF power production
    2. RF breakdown in PETS and AS
    3. PETS on/off/ramp mechanism (It is the only movable part and will fail, sooner or later)
    4. Measurement of the phase length of the RF circuit (to be discussed)
    5. Degradation of the RF circuit (optional)
2. Wake Field Monitor (WFM) in AS (In principle, it is a BI item but we have it here because structure design is heavily involved)
3. Beam control
    1. MB synchronous RF phase measurement
    2. MB energy measurement
    3. Beam loading transient compensation (MB bunch-to-bunch energy measurement)

4. …?

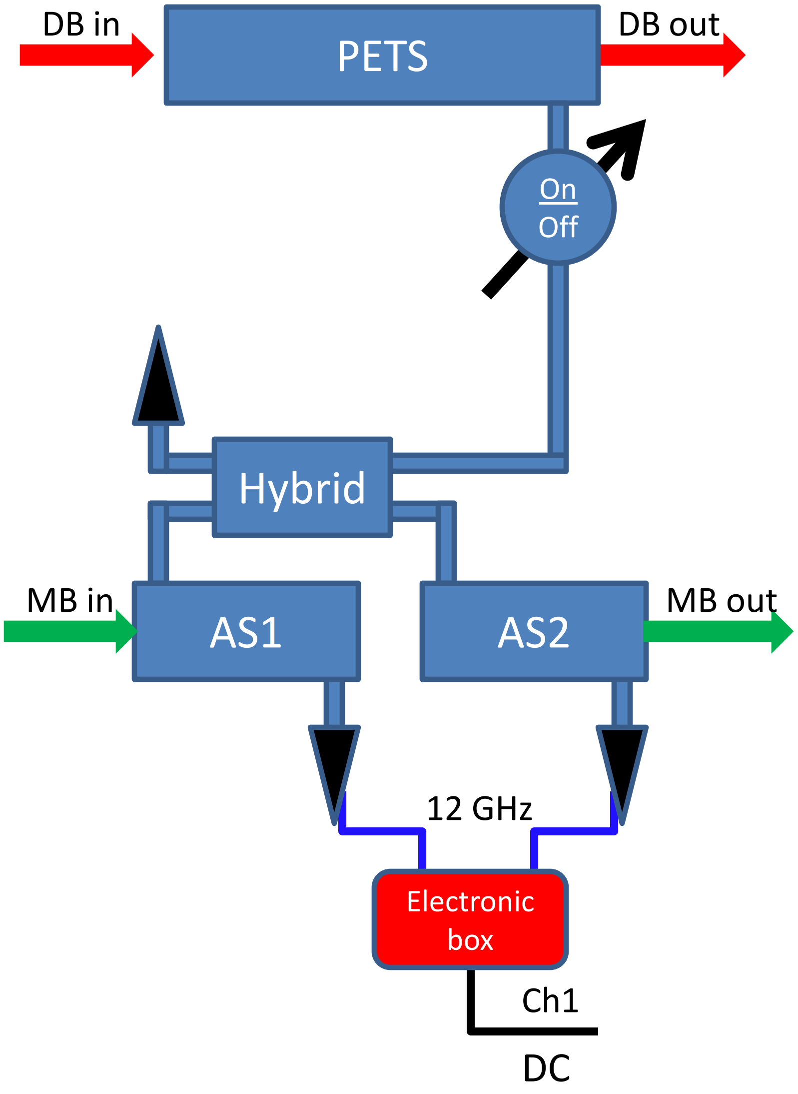
General layout in a DB Sector (~800m)



Two types of PETS+2AS units will be installed:

1. Reference (black) (2 units at the beginning and 2 units at the end of a DB sector)
   - It will have more signals and with higher resolution
   - The signals will be time resolved: dt ~ 0.5 ns (pulse shape)
2. Regular (blue) (all the rest)
   - It will have 1 or 2 signals
   - Integral over the pulse (1 or 2 numbers per pulse)

PETS+2AS unit: Regular 1 (BASELINE)



Channel 1 addresses two things:

1. RF breakdown
2. PETS on/off failure

Diagnostic is based on the comparison of the signals to the reference provided by the reference PETS+2AS units. If readout is different from the reference => something is wrong:

- If it is stable pulse to pulse => on/off failure
- If it is not => breakdown in PETS or one of the AS.

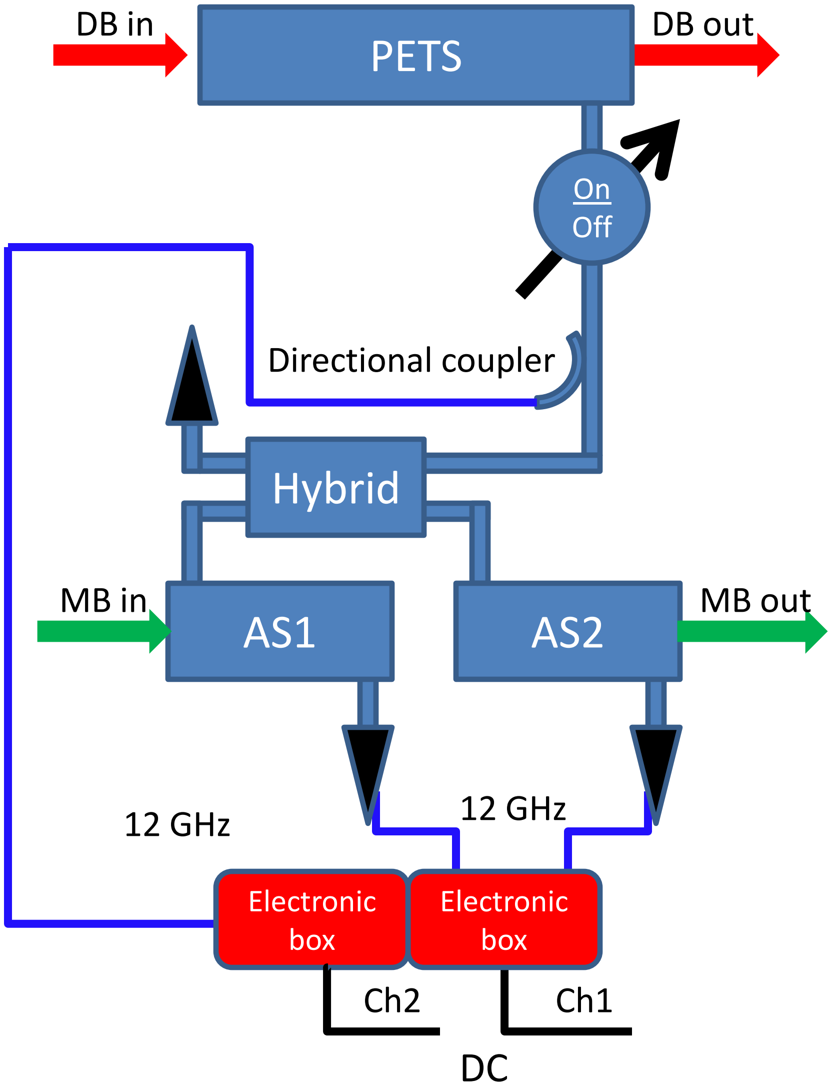
Dynamic range : 20 dB

Amplitude Resolution: 1e-3 linear

Amplitude Accuracy: 1e-2 is OK, **1e-3 is under question**

Signal frequency: RF probe -> 12 GHz -> analog box -> 50 MHz -> ADC -> (>100Ms/>7 effective bits) -> integrator -> 50Hz

PETS+2AS unit: Regular 2



Channel 1 the same as in PETS+2AS Regular 1

Channel 2 addresses the measurement of the changes in the phase length of the RF circuit via the difference between the two signals: dir. coupler after On/Off and one or both of the AS(s) output due to:

- transverse movement of the MB versus DB girders
- temperature variation
- material erosion due to RF breakdowns (in AS mainly)

There are several limitations:

1. All 12 GHz cables must be temperature stabilized
2. The change of the synchronous RF phase is not measured directly
3. The change of the synchronous RF phase due to longitudinal MB versus DB girders movement is not measured
4. According to Alex estimate, 0.1°-0.2° of 12 GHz RF can be achieved

That means that :

Channel 2 helps only if the mechanical stability of the module is worse than 0.1°-0.2° of 12 GHz RF equivalent. (to be checked with CLIC module WG, see next slide)

What alignment will be achieved

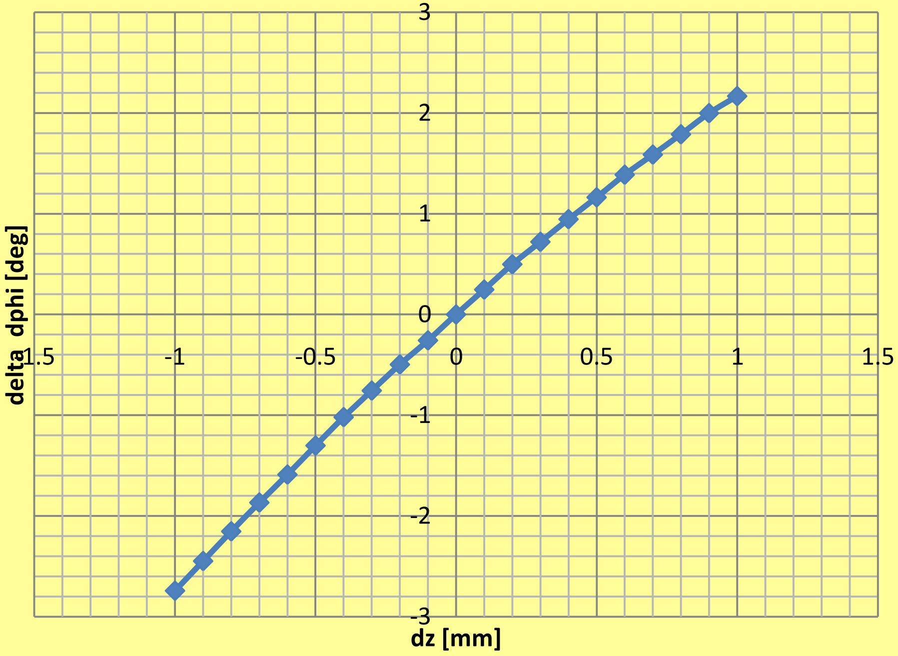
From CLIC module WG :
After CLIC module alignment procedure (without beam) is finished the accuracy of the PETS-to-2ASs alignment will be better than

- dx < ± 0.05mm
- dy < ± 0.05mm
- dz < ± 0.05mm

From Igor and Alessandro:
Choke mode flange RF phase change for different displacement:

- Transverse
  - dx,dy < ±0.05mm => dϕ < ±0.01 deg
- Longitudinal
  - dϕ / dz = 2.4 deg/mm;
  - dz < ± 0.05mm => **dphi < ±0.12 deg**

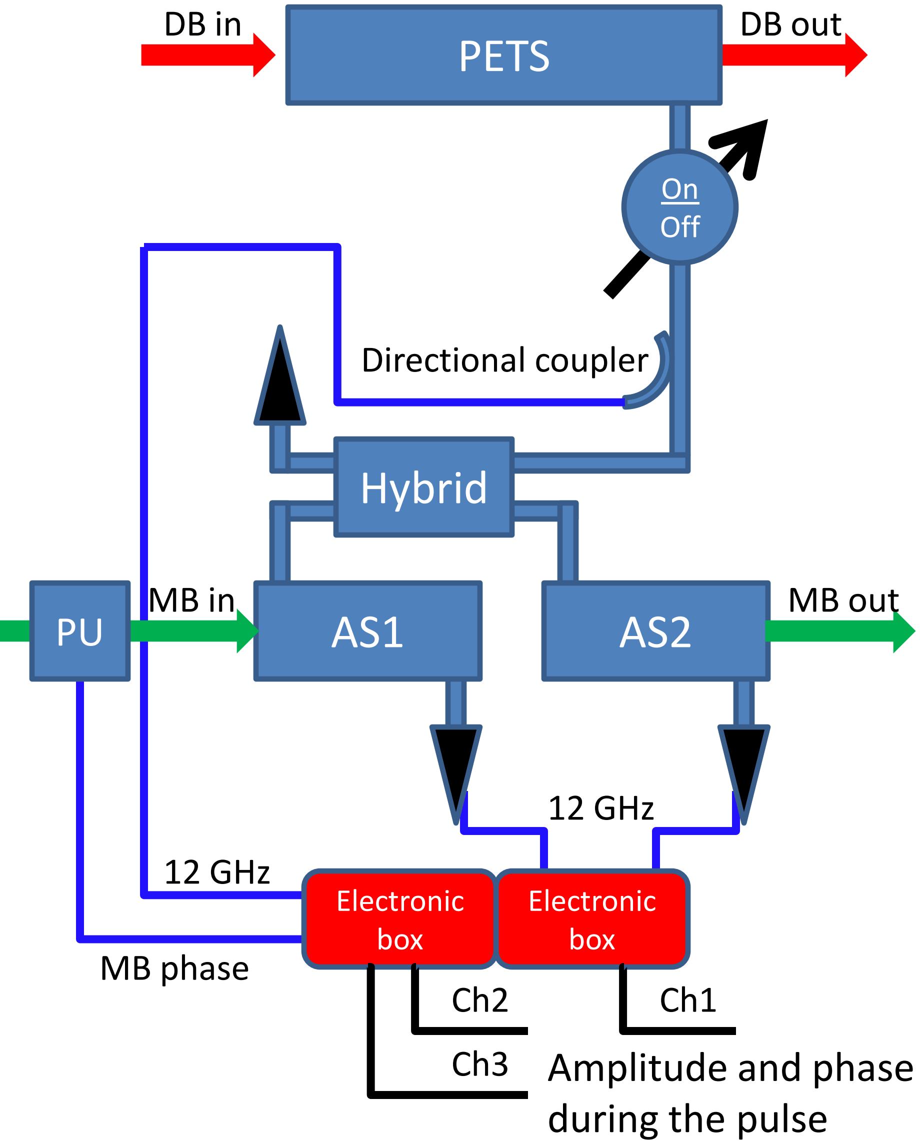
difference between beam phase and RF phase versus long. displacement via CMF



The longitudinal displacement is the most critical for the RF phase change. It will be below ±0.12 deg.
What can be measured is ~0.1-0.2 deg.
In conclusion, the measurement of the RF phase is not more accurate than mechanical alignment which will be achieved and this already satisfies BD requirements of ±0.1 deg correlated and ± 1 deg uncorrelated (Daniel).

No RF phase measurement in PETS+2AS Regular units

PETS+2AS unit: Reference (BASELINE)



Amplitude and phase during the pulse

There are two things to distinguish:

1. Beam control related issues (must be defined together with DB and MB beam control system)
    1. RF power production (also single- and multi-bunch longitudinal DB (in)stability using reference units at the beginning and at the end of the deccelerator)
    2. Energy measurement and Beam loading transient compensation. (requirement for bunch-to-bunch energy spread: dE/E~1e-4, we will go to **1e-3** level based on RF measurement and for the final adjustments we rely on the MB measurements at the end of the MB linac?)
2. RF diagnostic related (similar to Regular units but has more signals, higher amplitude and time resolution to look into details)
    1. RF breakdown in PETS and AS
    2. PETS on/off failure
    3. Provide references for the regular PETS+2AS units

Time sampling rate 0.5 ns or better

MB synchronous RF phase requires independently measured MB phase

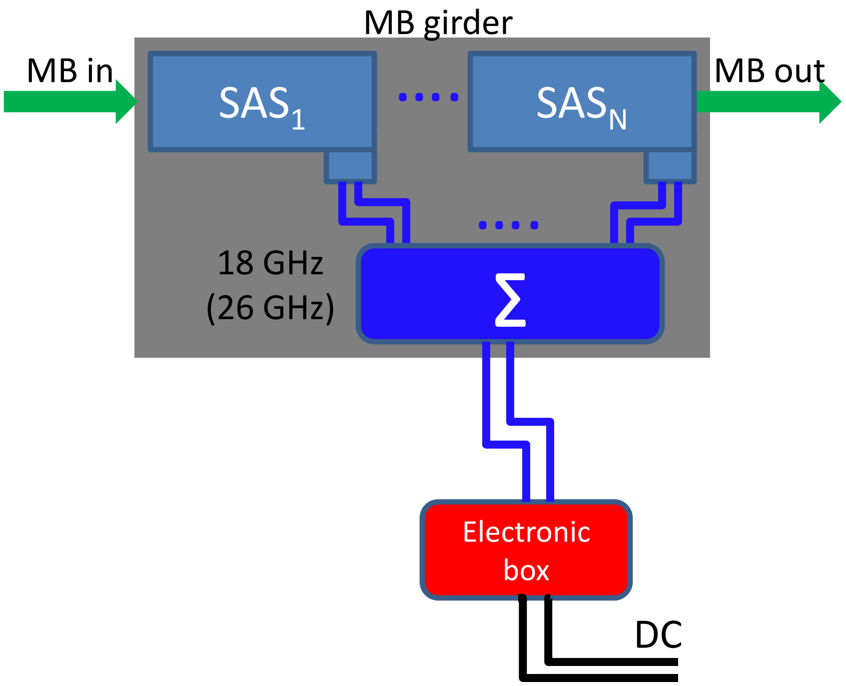
Dynamic range: 40 dB

Phase resolution: 0.1 deg

Amplitude resolution: at least 1e-3 or maybe 1e-4 if it is not too expensive

Again requirements are dominated by the bunch-to-bunch energy measurement (beam control).

WFM Configuration 1 (BASELINE)

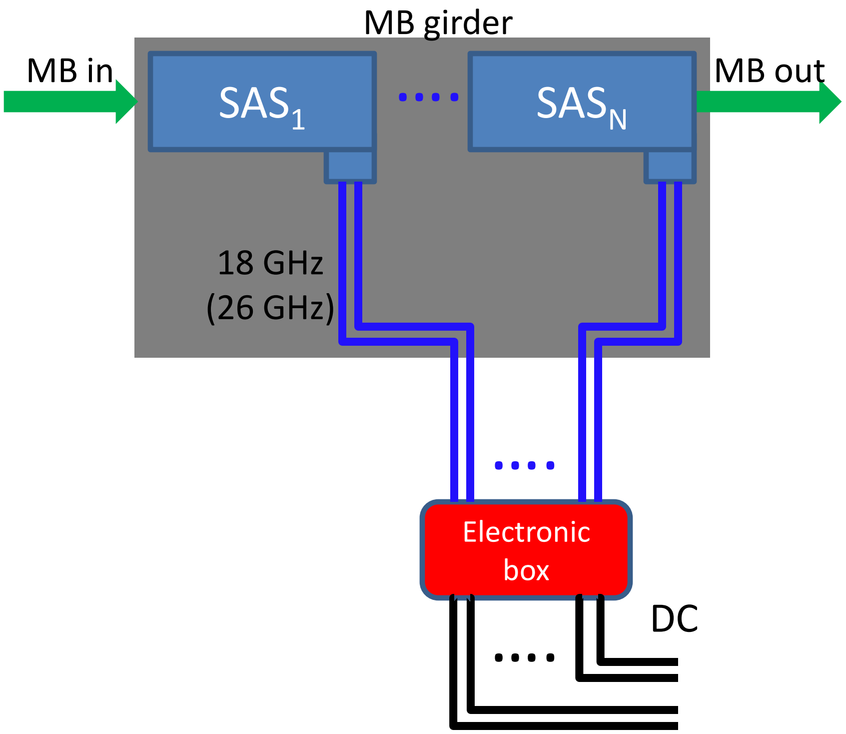


This configuration set tight specification on the relative phase difference of the cables used for signal combination.
10 um SAS-to-SAS misalignment must be averaged down to (3.5µm/√4 ~ 2µm) -> 20% -> 12 degree -> **0.56mm@18GHz**

1. All ASs on a girder have WFM:H+V
2. Both WFM:H and WFM:V operate at 18 GHz using first dipole band wakefields
3. All H and V channels from all the ASs on the girder are summed up separately (H from V) **using phase information** in order to get average position of the ASs.
4. Then the signal is integrated to get the offset but **without the sign**.
5. **Two channels per girder**. Readout on request.
6. If the sign of the offset is needed, then an external RF phase reference is necessary

Accuracy: 3.5 µm
Precision: 3.5 µm
Dynamic range: ≈ 20dB
    Max. SAS misalignments: ± 10 µm
    Must go down to ± 3.5µm/√4 ≈ ± 1.75µm
Signal frequency: WFM -> 18 GHz -> analog box -> 50 MHz -> ADC -> (>100Ms/>7 effective bits) -> integrator -> 50Hz

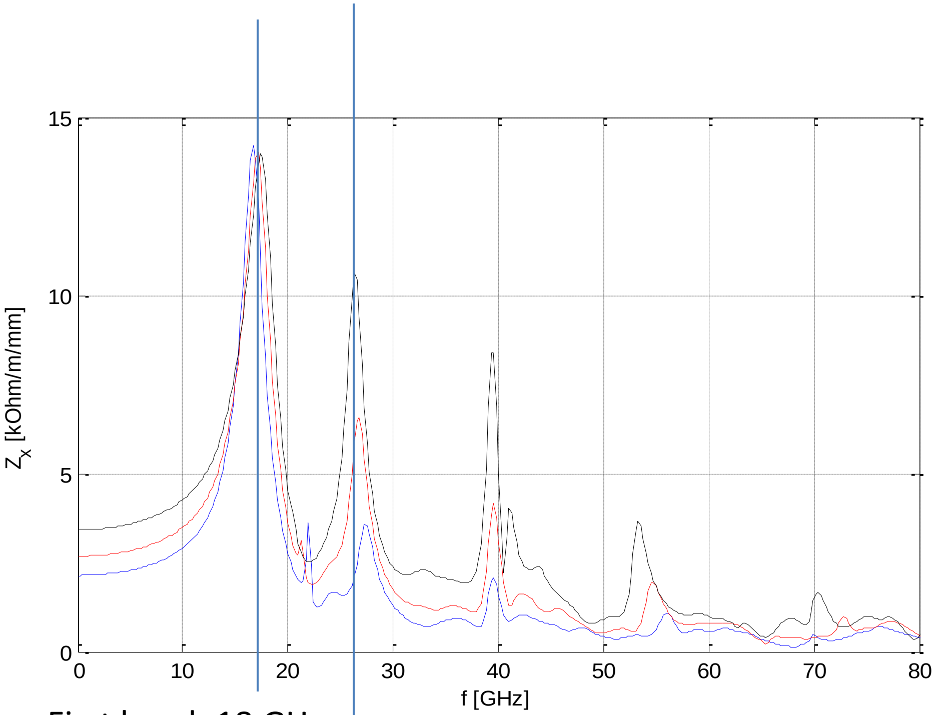
WFM Configuration 2



1. All ASs on a girder have WFM:H+V
2. Both WFM:H and WFM:V operate at 18 GHz and/or 26 GHz using first and/or second dipole band wakefields
3. All H and V channels from all the ASs on the girder are **integrated separately** to get the offset but **without the sign**.
4. **Two channels per SAS**. Readout on request.
5. If the sign of the offset is needed, then an external RF phase reference is necessary

Full demonstration (even more) in TBTS: both dipole bands will be used with and without external RF reference phase. Dynamic range 50dB, Logarithmic resolution.

Wake field monitor frequency



First band: 18 GHz

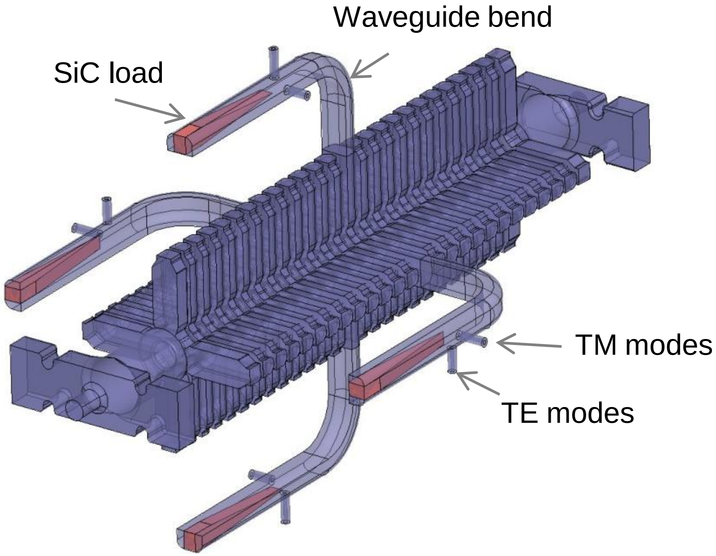
Second band: 26 GHz

Advantages of the first dipole band at 18 GHz compared to the second dipole band at 26 GHz:

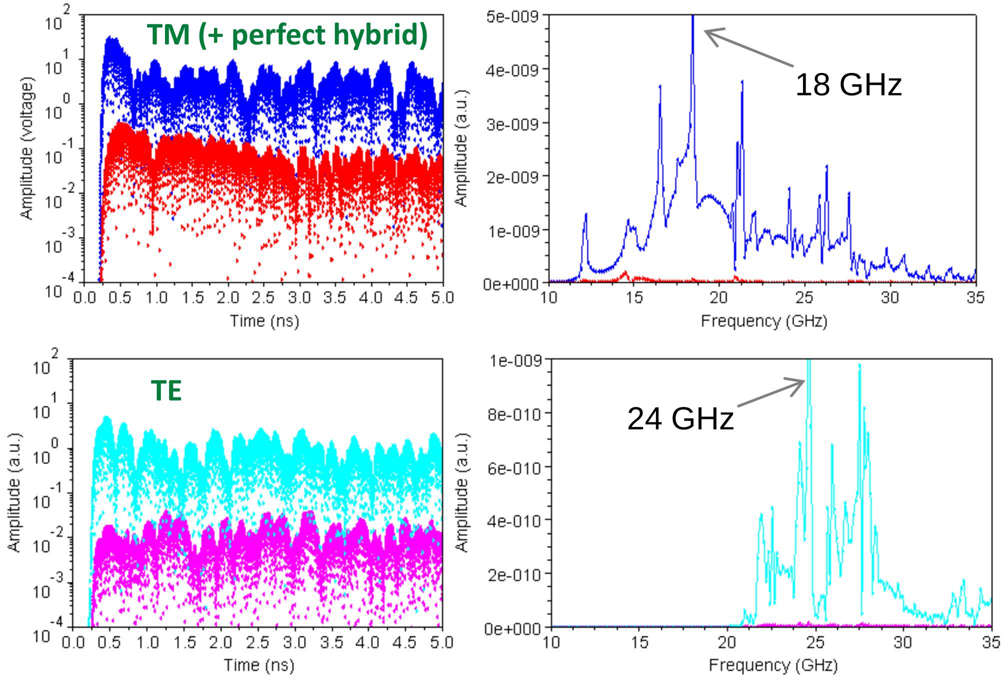
1. Dominates the short range wake which we would like to measure
2. Stronger signal in general and in the first cell (blue curve in the figure) in particular
3. Less tight tolerances on the transmission line length difference

WFM experiment in CLEX

- Wakefield Monitors implemented in two accelerating structures TD24 (tank version, without SiC loads (except for the WFM))
- Each WFM will study two different modes:
  - ☞ TM like mode at ~ 18 GHz (+ hybrid recombination)
  - ☞ TE like mode at ~ 24 GHz
- RF Design finished (GdfidL + HFSS simulations)
- Mechanical design under progress (CERN)
- Connectors, Vacuum cables, 3dB/180° Hybrids <u>ordered</u>



Port signals for beam offset Δx=1mm



Detection scheme

- Waveguide
- Waveguide to coax
- Power limiter
- Low Noise Amplifier
- Down mix with 18GHz / 12GHz → 6 GHz
- Power splitter
- Magnitude detected with logarithmic diode detector
- Bandpass around 6GHz for phase detection
- Compare to phase of the 3GHz CTF3 RF.

Noise

Component	**Loss/Gain [dB]**	**Noise Figure**	**Gain linear**	**Noise, F (linear)**	**Gain casc. (linear)**	**Noise Casc. (linear)**	**Noise Casc. dB/Hz**	**Gain casc. dB**
damped waveguide	-10.0	10.0	0.1	10.0	0.1	10.0	10.0	-10.0
vacuum cable	-2.0	2.0	0.6	1.6	0.1	15.8	12.0	-12.0
vacuum feedthrough	-0.5	0.5	0.9	1.1	0.1	17.8	12.5	-12.5
Waveguide -> sma transition	0.0	0.0	1.0	1.0	0.1	17.9	12.5	-12.5
Waveguide and flanges	-3.7	3.7	0.4	2.3	0.0	42.0	16.2	-16.2
Waveguide -> sma transition	0.0	0.0	1.0	1.0	0.0	42.4	16.3	-16.3
PIN diode limiter	-2.5	2.5	0.6	1.8	0.0	75.4	18.8	-18.8
	-18.8							
Low Noise Amplifier	30.0	2.5	1000.0	1.8	13.3	134.0	21.3	11.2
Mixer	-7.0	**7.0**	0.2	5.0	2.6	134.3	21.3	4.2
Power Splitter	-5.0	5.0	0.3	3.2	0.8	135.2	**21.3**	-0.8
dBm/Hz (-174dBm/Hz + Casc. Noise Figure)			**mW/Hz**	**mW (2GHz BW)**	**dBm**	**W**		
		-152.7	**5.4E-16**	**1.1E-06**	**-59.7**	**1.1E-09**		

Summary Table

		Channels	Per DB sector	Total	
BASELINE	PETS+2AS reference	3 per unit	3 × 4 units = **12**	12 × 24 × 2 = **576**	
	PETS+2AS regular	1 per unit	1 × Nunits ≈ **1600 †**	1600 × 24 × 2 = **76800**	
	WFMs config.1	2 per girder	2 × Ngirders ≈ **800**	800 × 24 × 2 = **38400**	**×4**
	WFMs config.2 Alternative	2 per unit	2 × Nunits ≈ **3200 †**	3200 × 24 × 2 = **153600**	

†Rough (upper) estimate. Exact number depends on the exact layout.

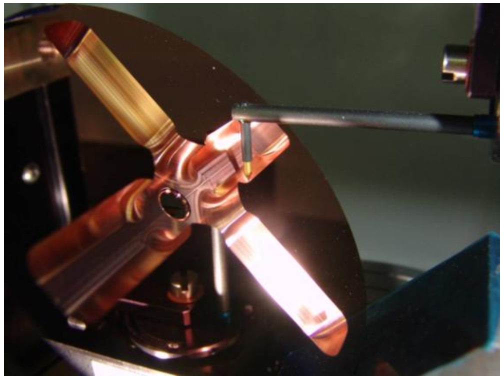
Acknowledgements

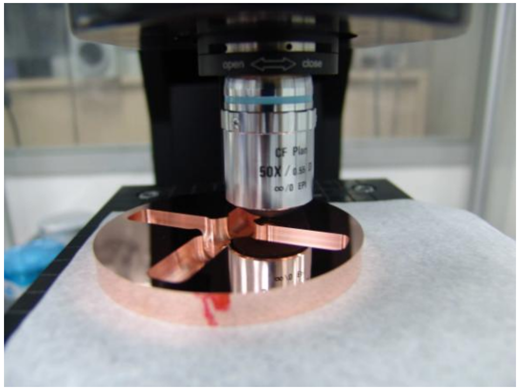
- Daniel Schulte
- Igor Syratchev
- Walter Wuensch

Fabrication of the accelerating structures

- Qualification of three firms for precise machining (2 prototypes)

- Results of Firm n°1:





- Very low roughness of turned surfaces Ra = 0.009 to 0.022 (spec=0.025)
- Roughness of milled faces higher (factor of 10) but can be improved with monocristal cutting tool
- Tolerances within 3 µm (spec=2.5)
- Planarity of 1.7 – 3.2 µm (spec=2µm), can be improved by better stress relieve process

☞ Very promising results

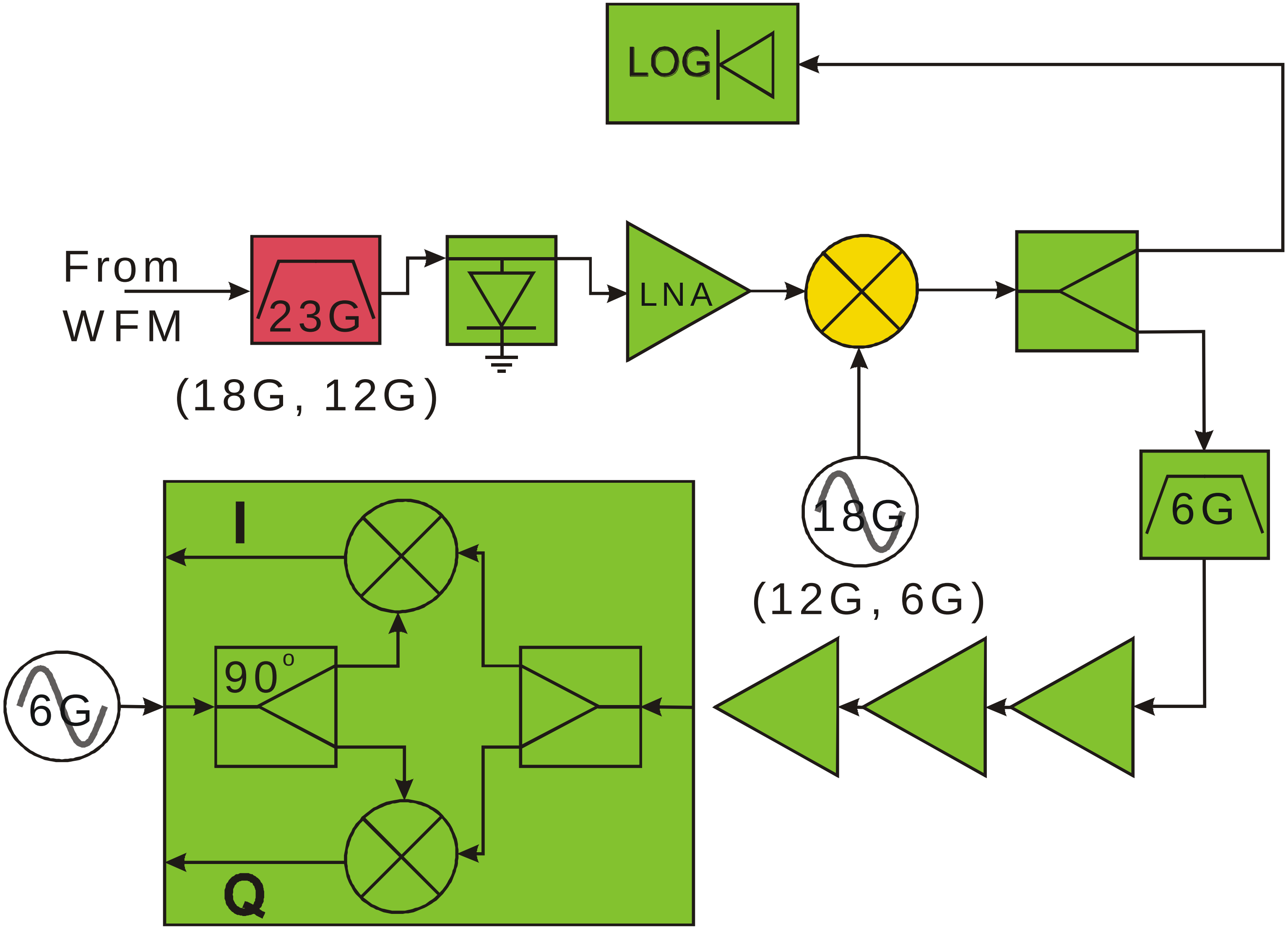
- Results from Firms n°2 and 3 expected in few weeks

- Schedule (target):
  - all the disks for the two structures machined: mid 2010
  - structures ready for test with beam on TBTS: end 2010 ?

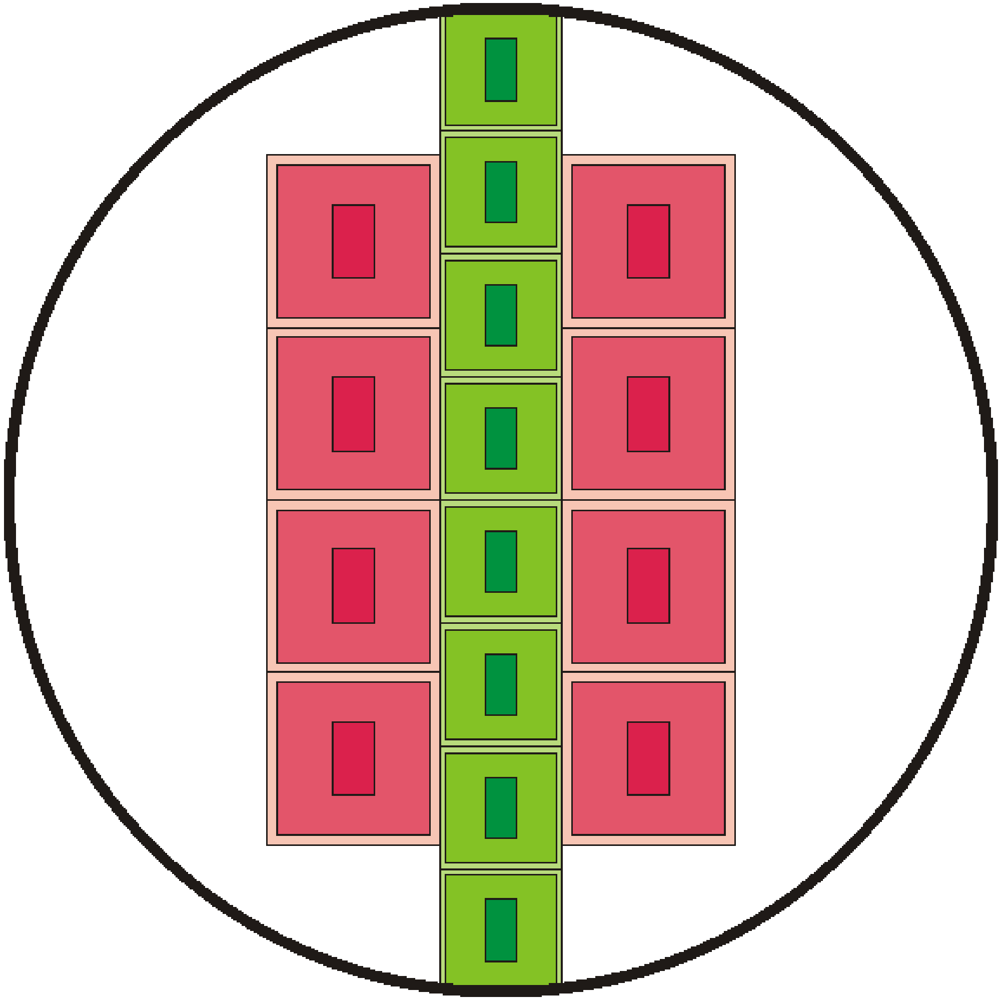
  ☞ But challenging planning

- Note: need maybe an additional BPM on TBTS, just before the structure (to be discussed)

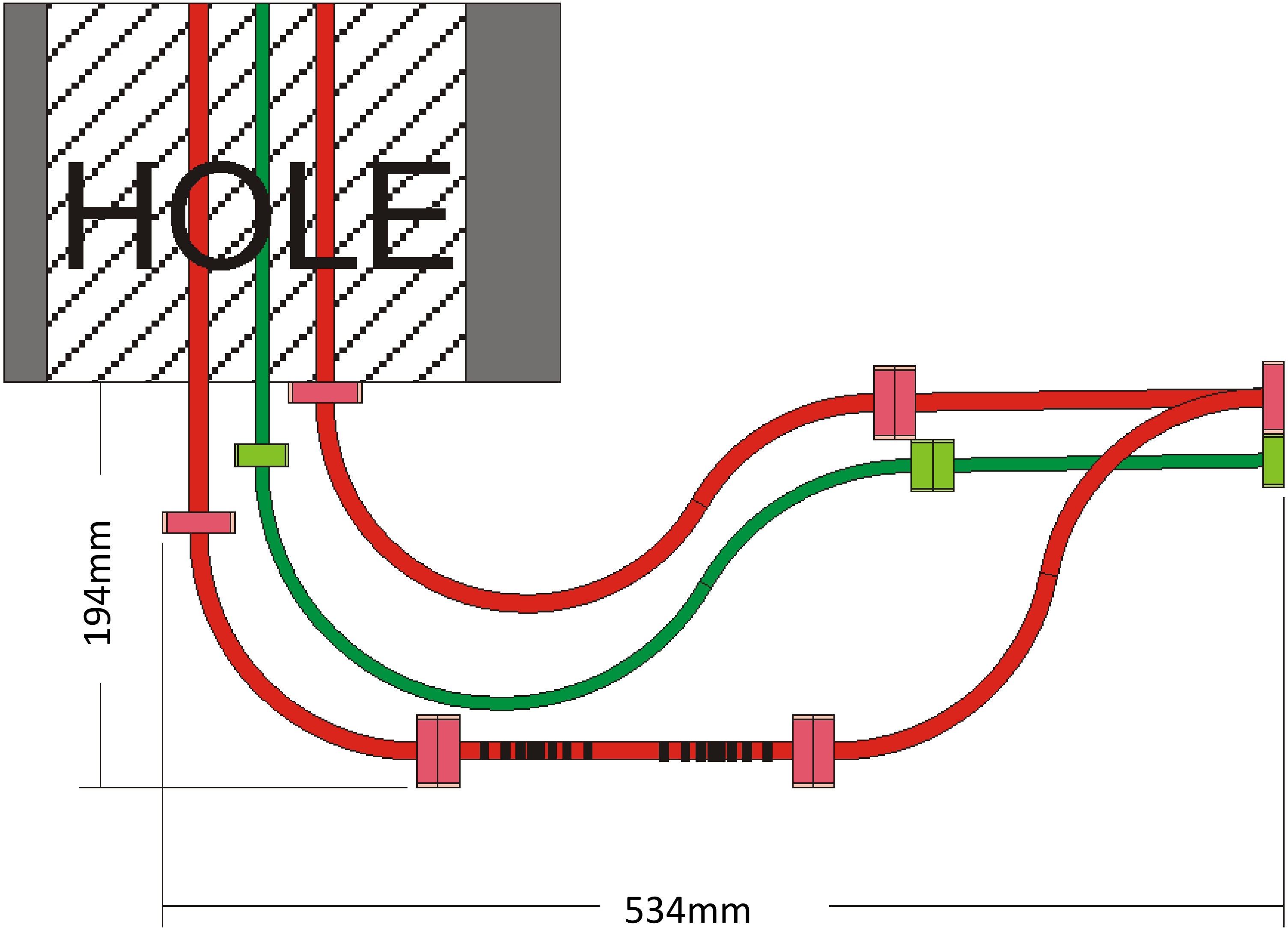
Detection Scheme



Waveguide



Waveguide



Waveguide