A Waveguide High Order Mode Reflectometer for the LHC beam-pipe

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www.cern.ch/tkroyer/reflec

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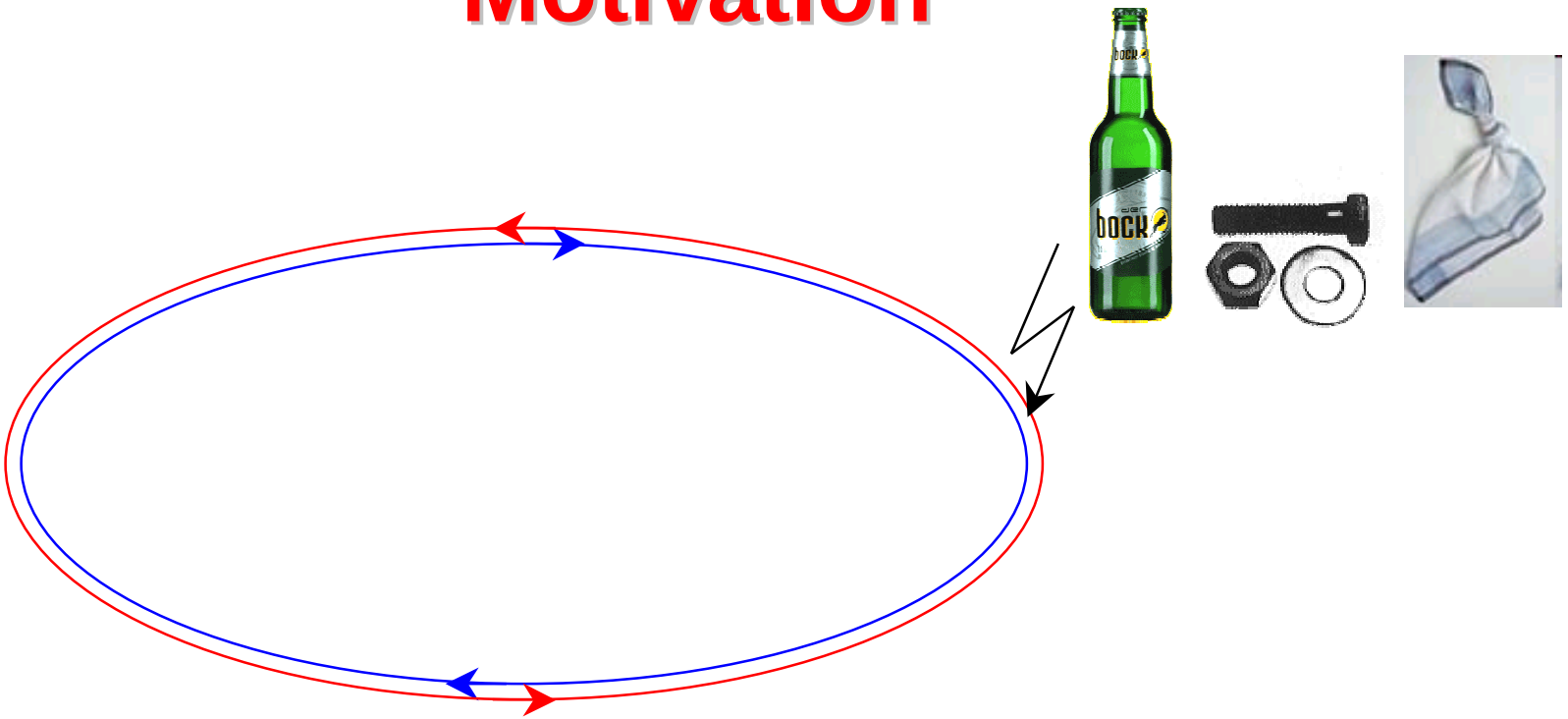
Motivation

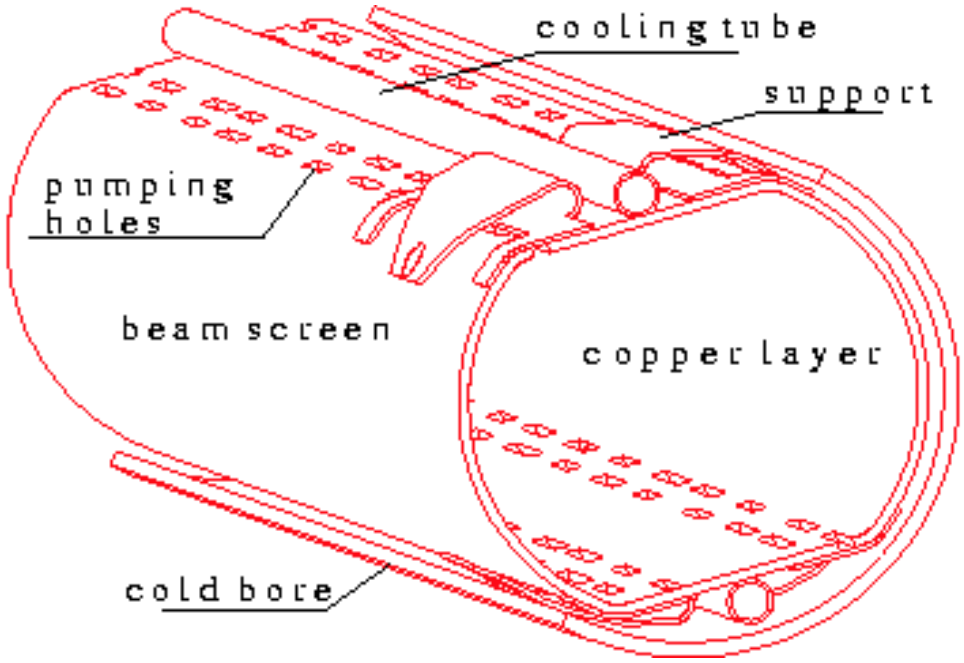


In certain accelerators strange objects were found…
How to locate them without using the beam???

Waveguide modes on the beam-pipe

- TE modes radiate through slots and are trapped by interconnects
- TM modes are almost not affected by the slots, as they have axial wall currents only

➔ TM modes have to be used

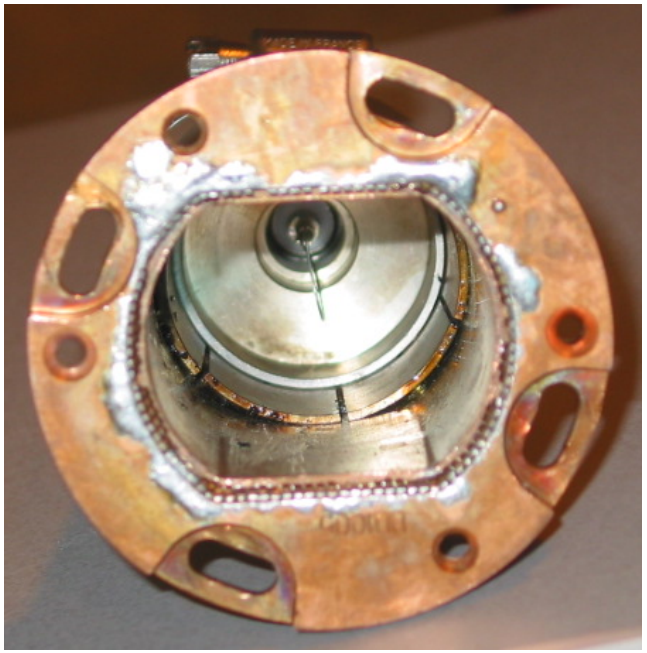


Challenges of synthetic pulse band-pass mode TDR on the beam-pipe

- Attenuation: limits the range of the reflectometer => high dynamic range of the VNA is indispensable (more than 100 dB!)
- Waveguide dispersion => step-by-step “focusing” to short sections required
- A Higher Order Waveguide mode has to be used => Mode Mixing
- Multiple reflections by interconnects: Can we look through 50 or more interconnects?

Launching Waveguide Modes

- Beam-pipe adapter from earlier tests used
- Different mode launchers inserted to excite desired waveguide mode

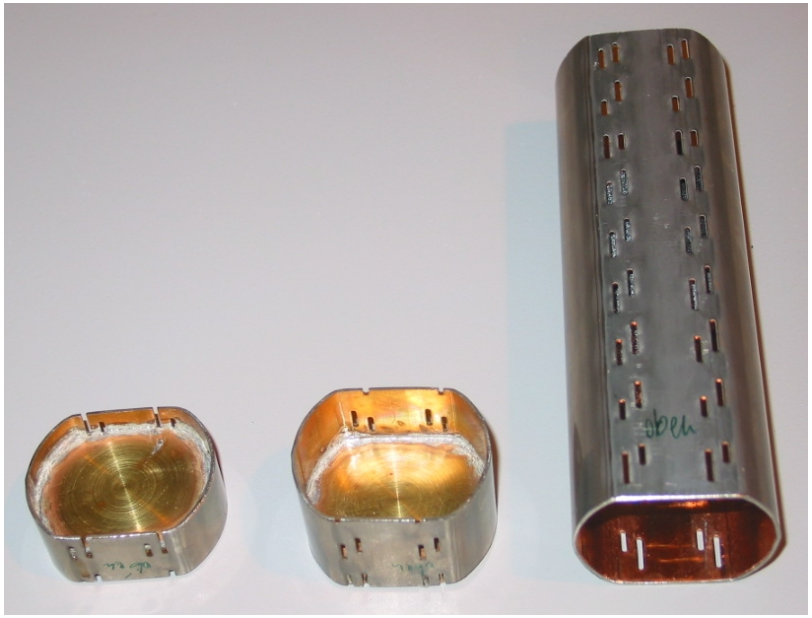


Waveguide calibration

- Potentially allows to correct influence of feed cables and mode launcher
- No calibration standards available for beam-pipe
- ➔ Make them on our own!

- As for ordinary waveguide calibration 3 standards used: 2 offset shorts and one load

Prouved to be very critical:
Bad calibration deteriorates resolution and dynamic range!

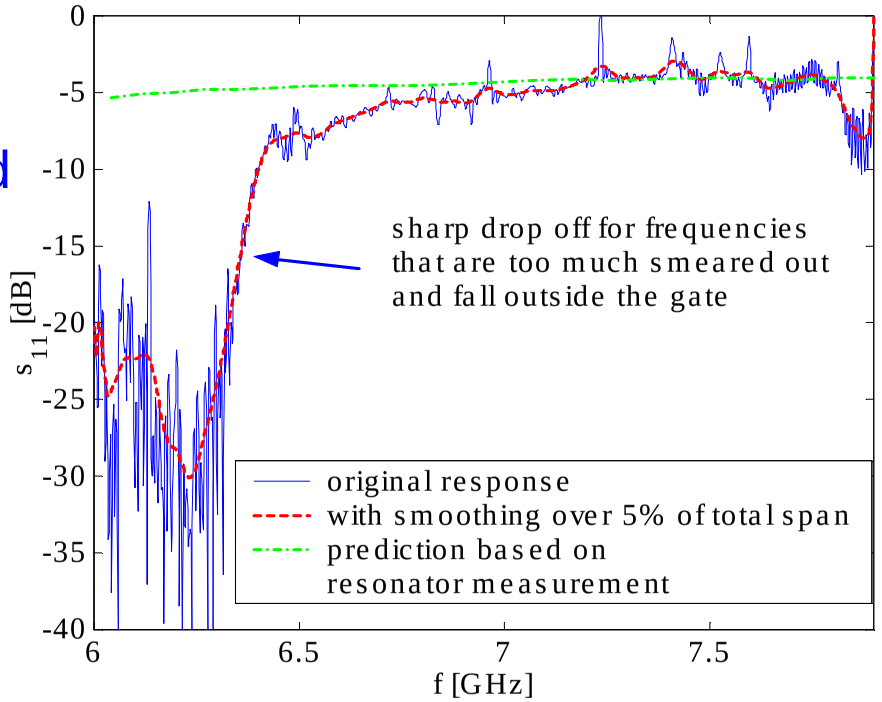


The “50m” test track

- Straight section with two interconnects, 44m long
- Thanks to Noel Hilleret, Juan Knaster and Eric Kos for providing this great installation!!!

Attenuation

- A short was put at the end of the line to reflect all the incoming power
- The short's peak was isolated by time domain gating
- The frequency domain response was found by doing an FFT on this data
- Discrepancies to theoretical curve maybe due to gating process and power reflected by interconnects

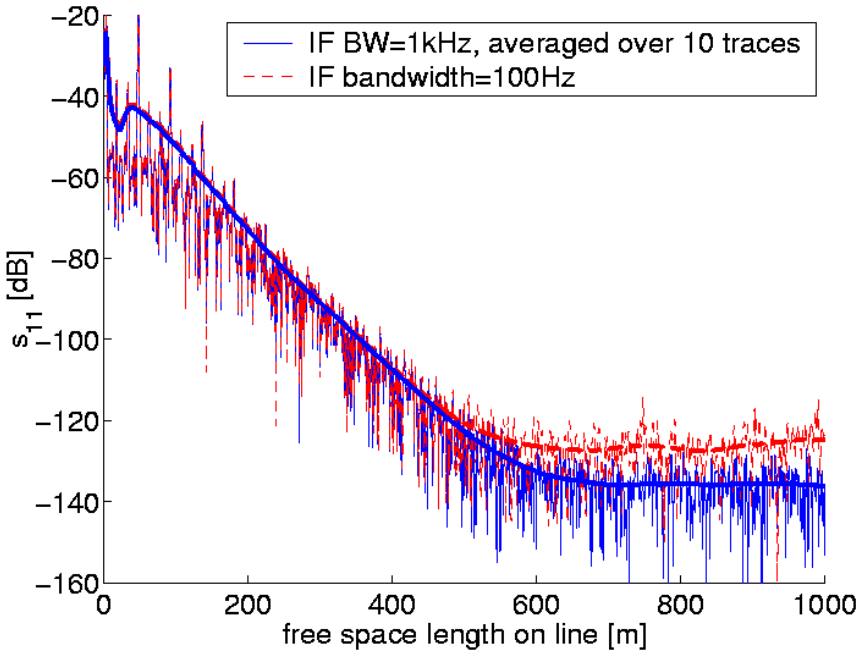


Dynamic range of measurements

- for frequency domain measurements the VNA has a dynamic range of nearly 130dB in the frequency range used
- Bad calibration and drift can deteriorate much the dynamic range in time domain

⇒ Try out external averaging: make measurements on VNA and all the rest and the PC

- In time domain a dynamic range of more than 120dB was obtained this way



Estimation of range

As last time…

- The dynamic range of the current VNA of about 120dB for S_{11}
- The total attenuation (including interconnects) is expected to be smaller than 0.07dB/m
- The smallest obstacle to be found (M3 nut size) should give a reflection of -40dB

⇒ attenuation budget (room temperature) = 80dB,

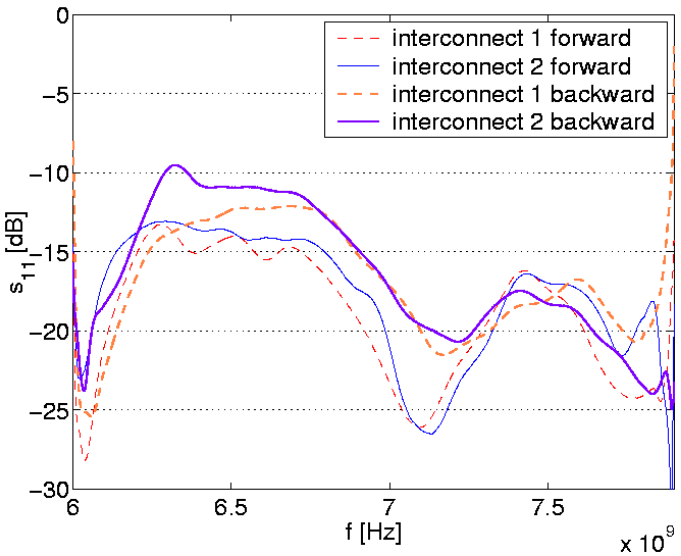
one-way: 40dB

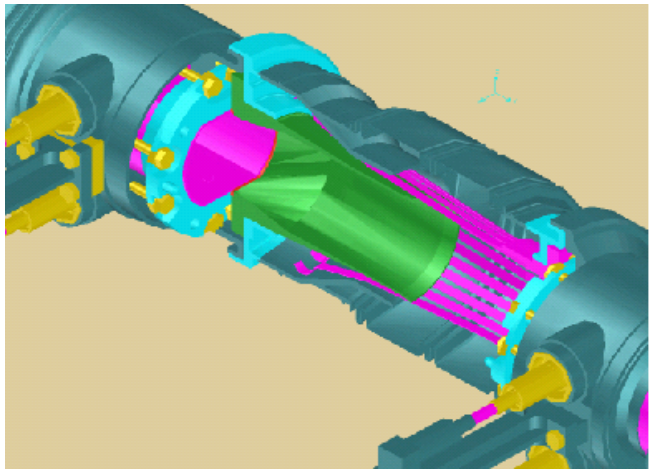
⇒ range = 600m

At low temperature (20K) the attenuation should decrease by a factor 2 to 3, allowing to cover 1 arc (~2.5km) in transmission mode or half an arc in reflection mode

The interconnects

- Response found highly asymmetric
- There exist frequency ranges with low reflections
- It may be difficult to make out one interconnects response when all the multiple reflections are superposed
- Power loss due to reflections considerable, 35% of resistive attenuation for S_{11}=-12dB
- Interconnects that will be installed should be better

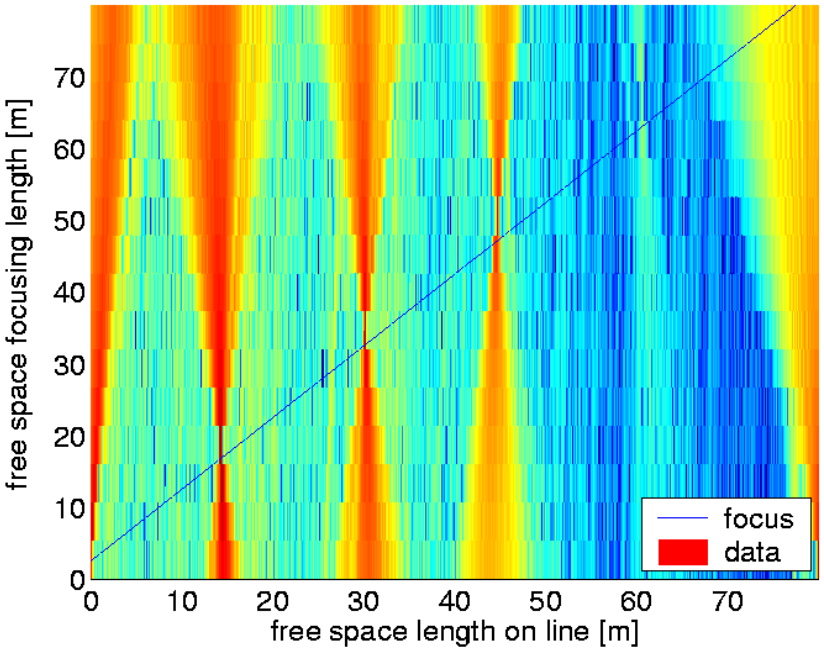


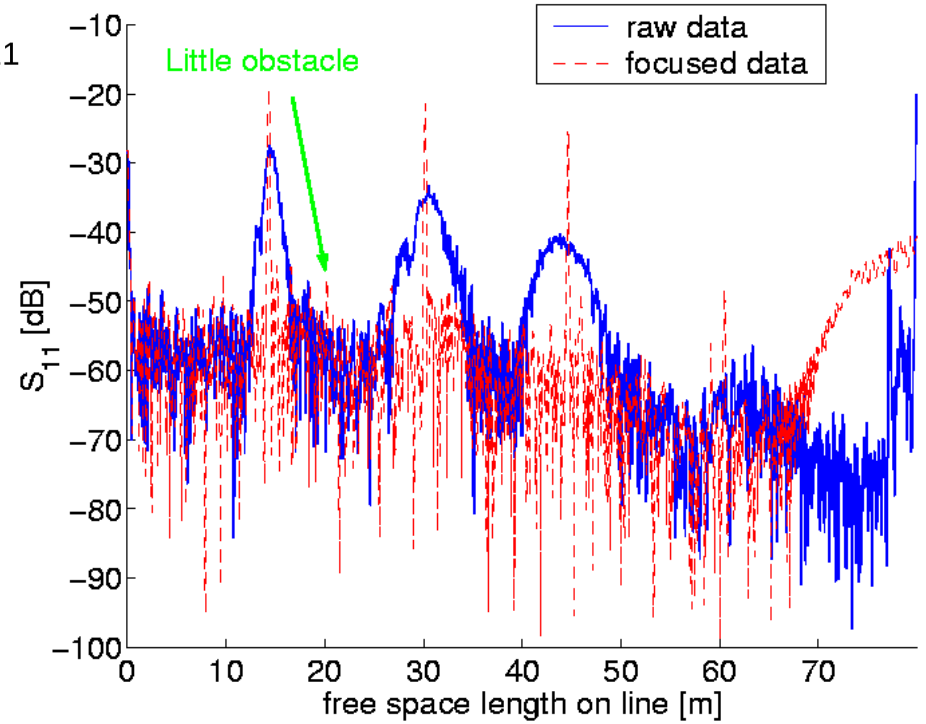


Dispersion compensation

- Worked very well!

Red to blue: high to low amplitude of S_{11}





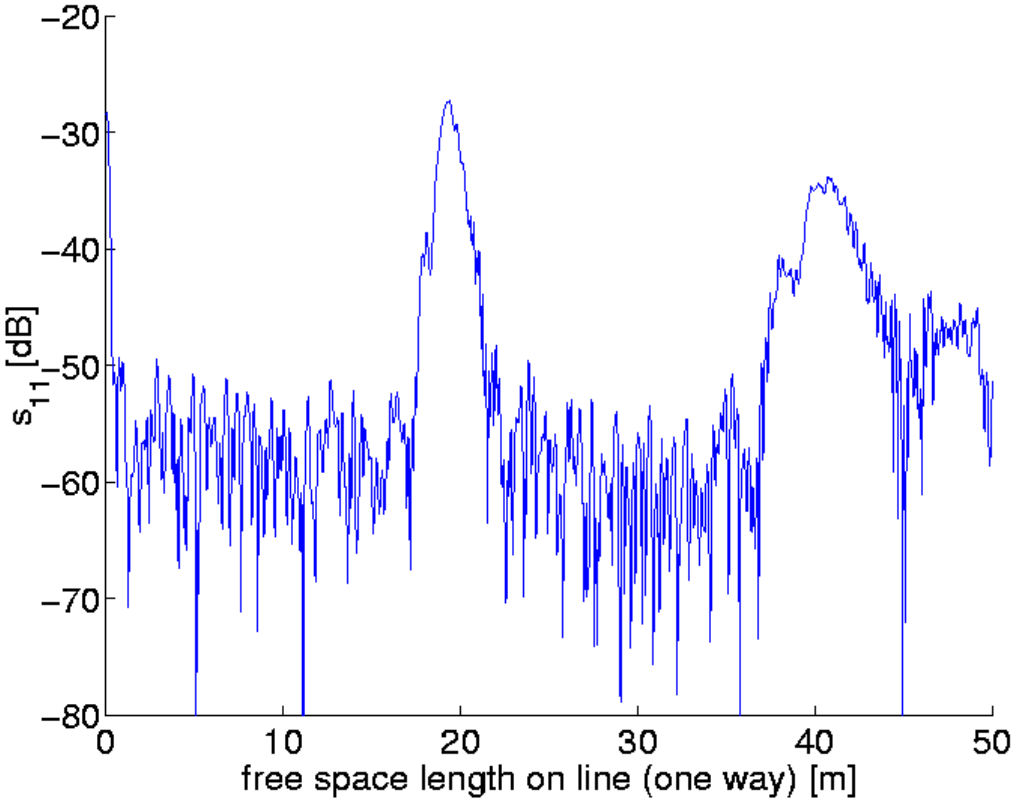
Mode Mixing (1)

- Good news: was not observed!

2 possible reasons:

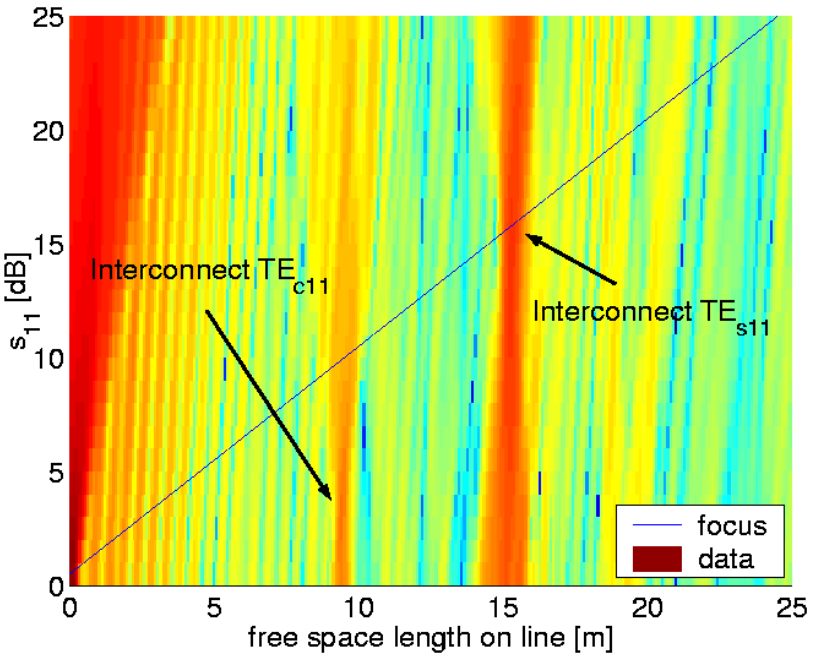
- Very good mode excitation
- It simply does not occur

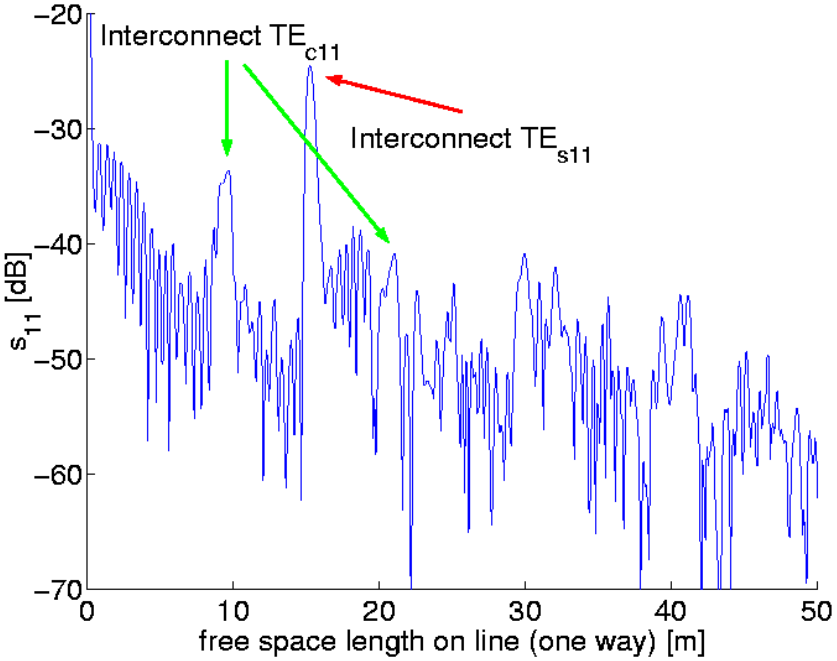
- Check: data was focused for “bad” mode ➔ if this mode is present, additional peak should become visible



Mode Mixing (2)

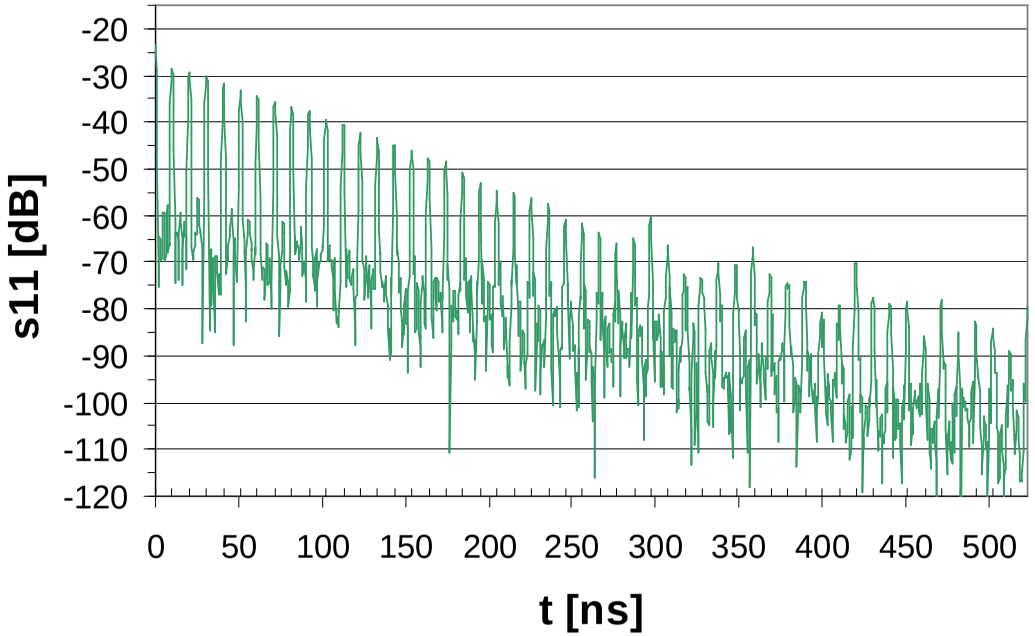
What it would look like: Bad excitation of second TE mode, first TE mode appears:





Multiple Reflections

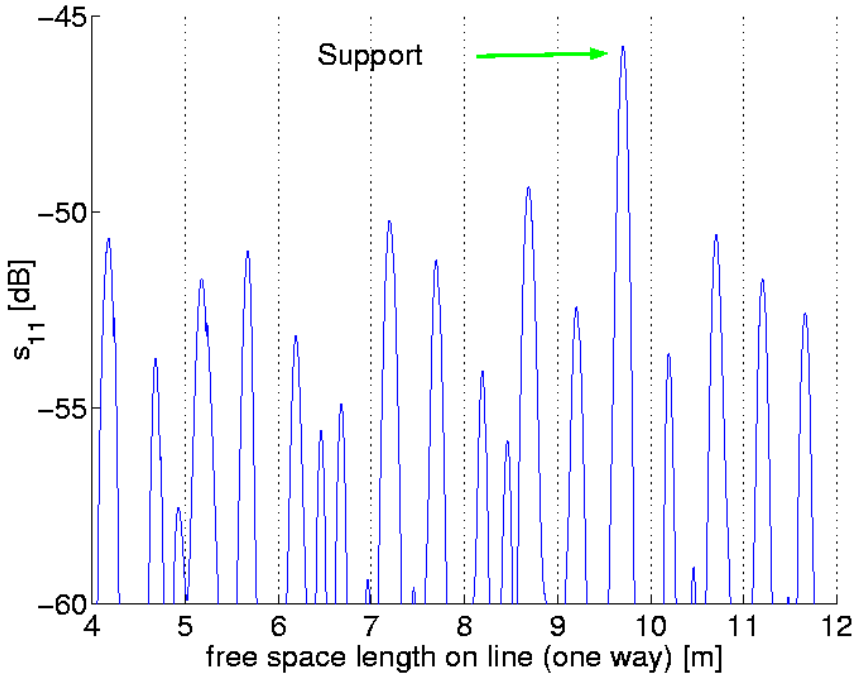
- Well, would have to wait for installation of the first arc…
- Meanwhile let's be satisfied with the old BNC cable experiement
- BNC connectors between two cables simulate effect of interconnects between 2 cryomagnets (similar S_{11})



Ripples

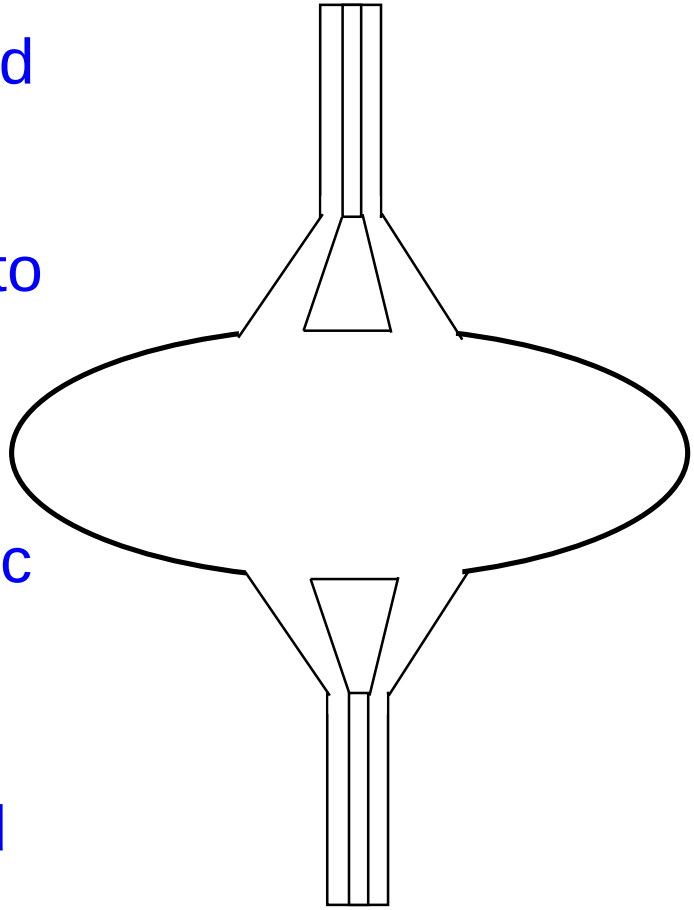
- A quite unforeseen phenomenon…
- Due to the periodicity in the slot pattern, interferences occur and reflections can be observed
- Increases noise background

Zooming in we find the periodicity:



RF Coupler

- In situ operation of the reflectometer in the LHC would be interesting
- Standard LHC buttons do not work well above 0.5GHz due to their high capacity to ground
- Conical design like shown to the right
- Installation at the end of an arc close to a shutter ➔ wave propagation in one direction only
- 32 pick-ups are to be installed



To be done

- Optimization of mode launcher (for inspection during assembly)
- Exact design of RF coupler for in-situ measurements
- Refinement of signal processing
- Implementation of automated measurement techniques on VNA
- …

Conclusion

- A detection of various kinds of obstacles in the beam-pipe appears to be feasible.
- During assembly, at room temperature, it should be possible to cover about 600m
- Range should increase to 1200m and beyond for low temperature operation, if current estimations turn out to be correct.
- Power scattering from slots and increasing noise background for larger distances could become a problem