The LHC Reflectometer: Obstacle Detection in the LHC Beam Screen

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www.cern.ch/tkroyer/reflec

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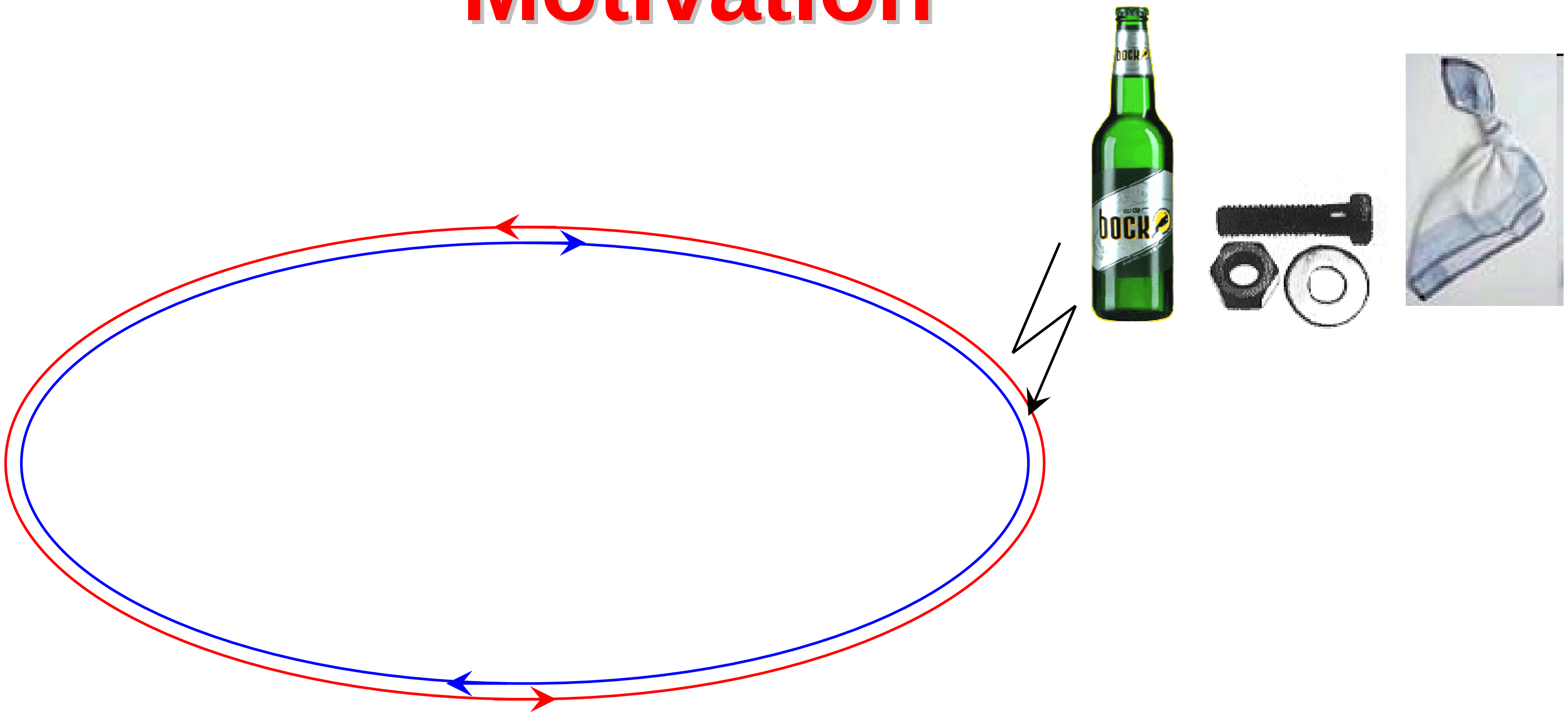
Motivation



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

Waveguide Mode Time Domain Reflectometry

- Waveguide mode time domain reflectromety (TDR) has been used for more than 20 years to locate undesired deformations on long waveguides in telecommunication towers
- It was used at ESRF to locate discontinuities in their vacuum chamber during assembly.

Synthetic pulse TDR

All measurements are done in the frequency domain, conversion to time domain by FFT

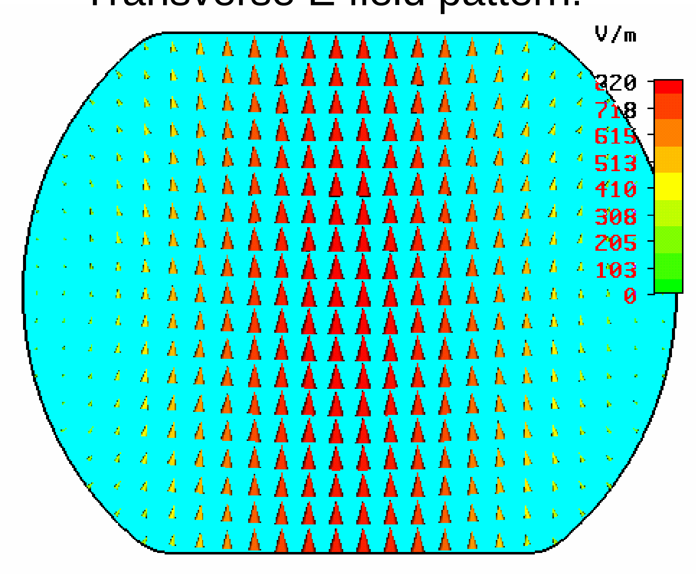
Avantages:

- A state-of-the-art vector network analyzer (VNA) can be used
- All parameters can be well controlled => good reproducibility and wide range of settings
- Waveguide calibration and dispersion compensation is possible
- High dynamic range due to frequency domain measurement

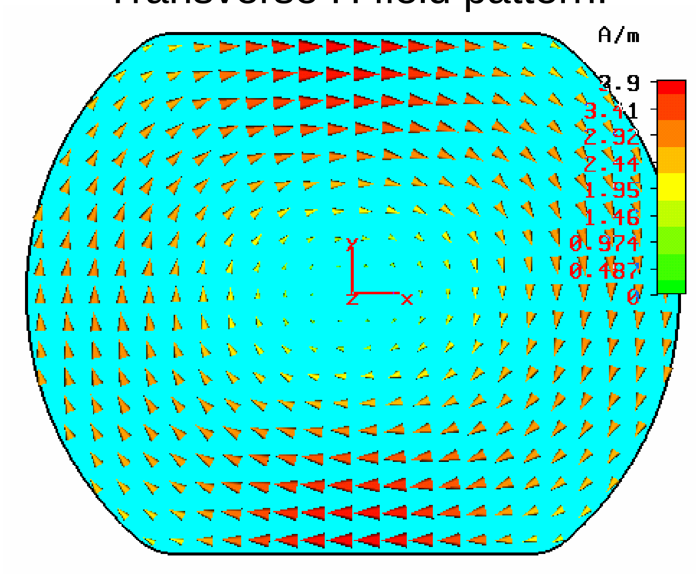
Waveguide modes on the beam screen

- On the LHC beam screen, waveguide modes propagate in the microwave frequency range.
- Two modes were found to be suitable for reflectometer operation:

The first TE mode: TE_{c11}
cut-off frequency: 3.6 GHz
Transverse E field pattern:



The first TM mode: TE_{01}
cut-off frequency: 5.3 GHz
Transverse H field pattern:



Challenges of waveguide mode TDR on the beam screen

- 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
- Higher order waveguide mode can propagate => Mode Mixing can occur
- Multiple reflections by interconnects: Can we look through 50 or more interconnects?

Estimation of range

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

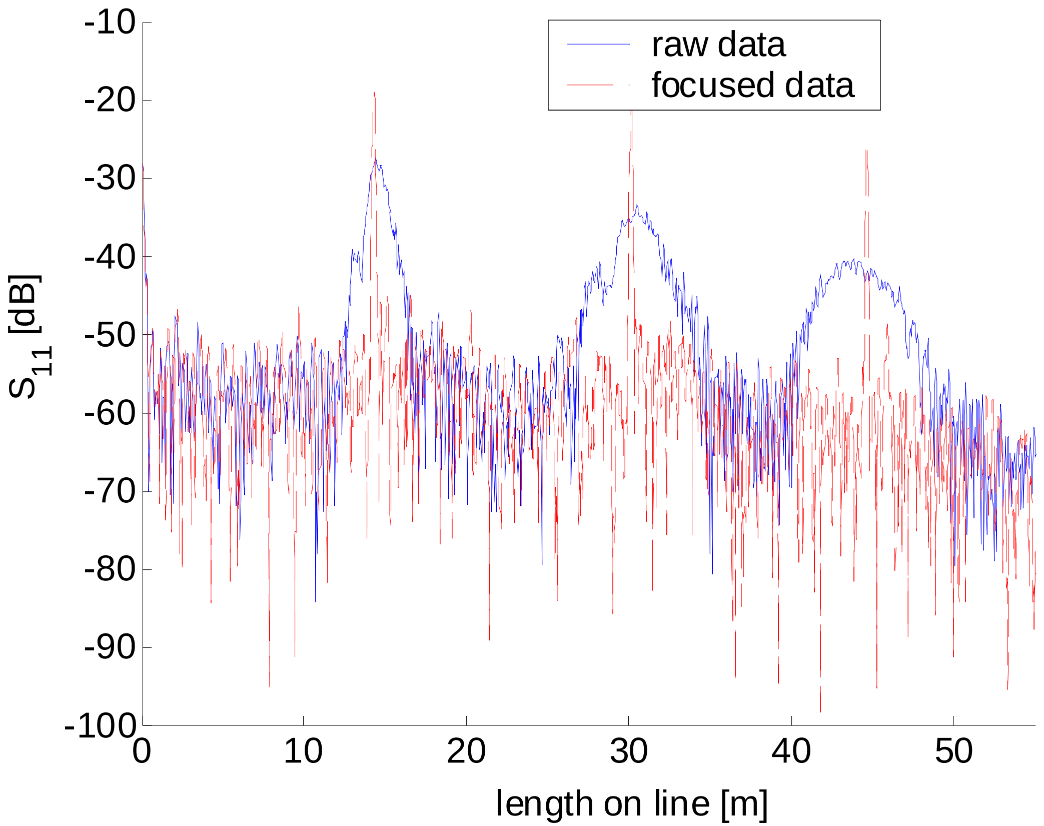
⇒ attenuation budget: 80 dB

⇒ one-way attenuation budget: 40 dB

⇒ range: 600 m

Dispersion compensation

- Example: 50 m test track of beam screen without cold bore
- Interconnects close to 15 m and 30 m
- Measurement with TM_{01} mode



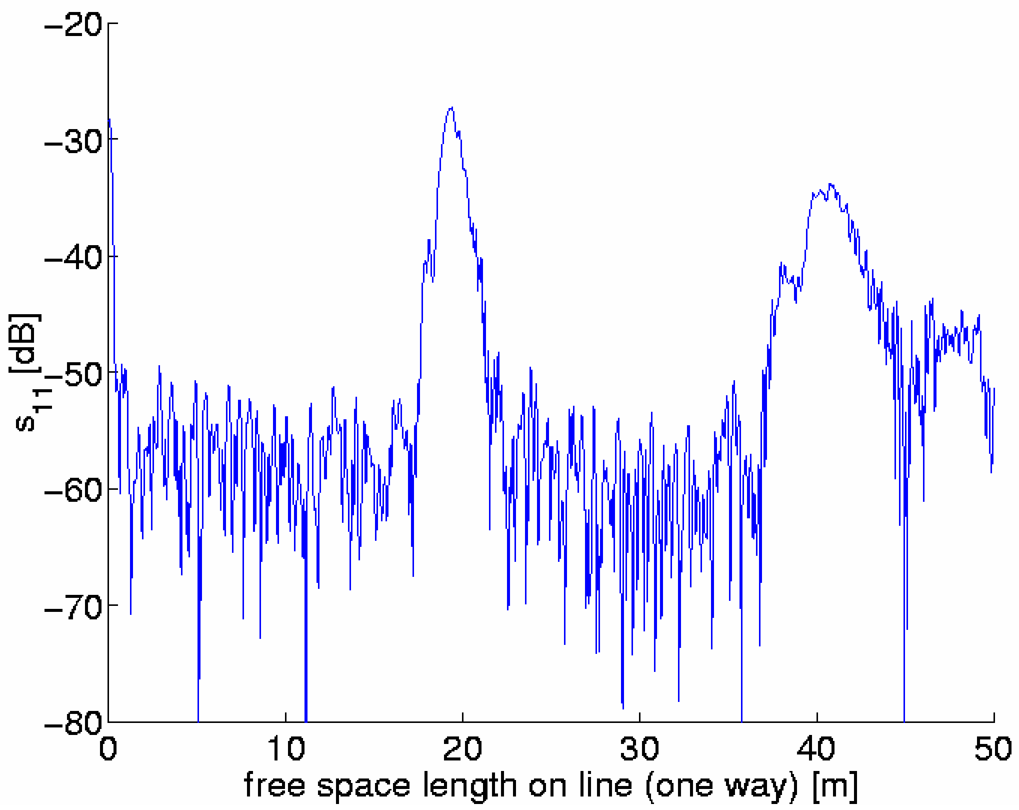
Mode Mixing (1)

- Good news: was not observed!

2 possible reasons:

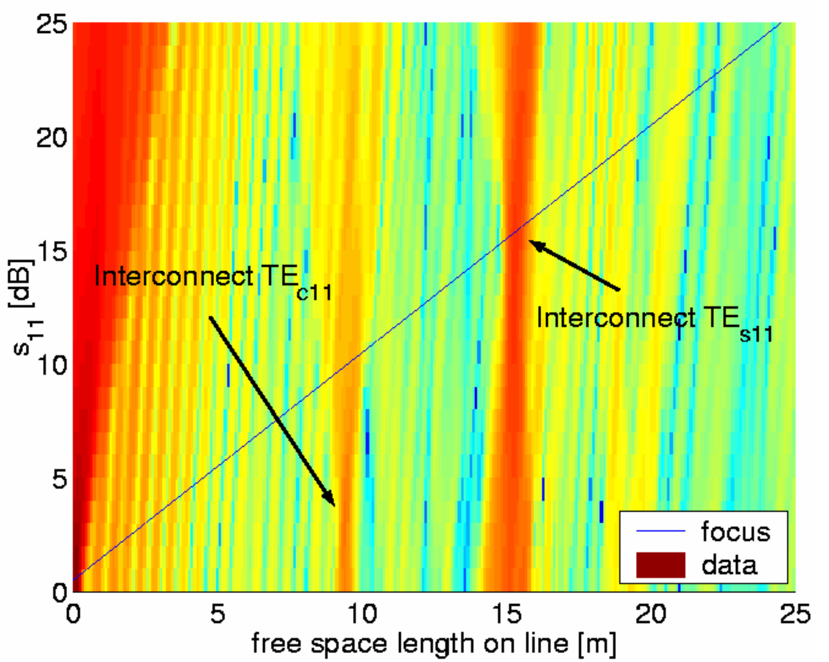
- Very good mode excitation
- It simply does not occur

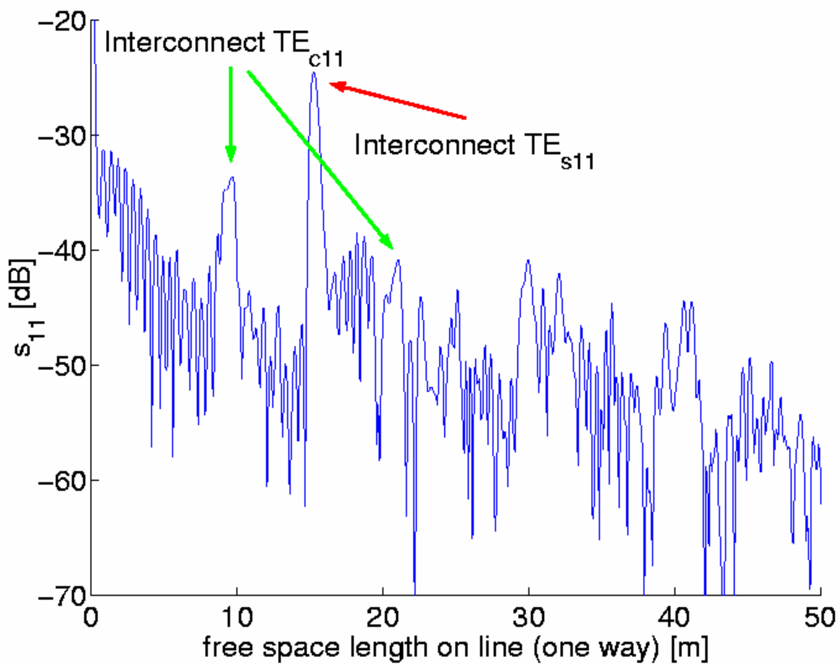
- Check: data was focused for “bad” mode ➔ if this mode is present, additional peak should become visible



Mode Mixing (2)

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

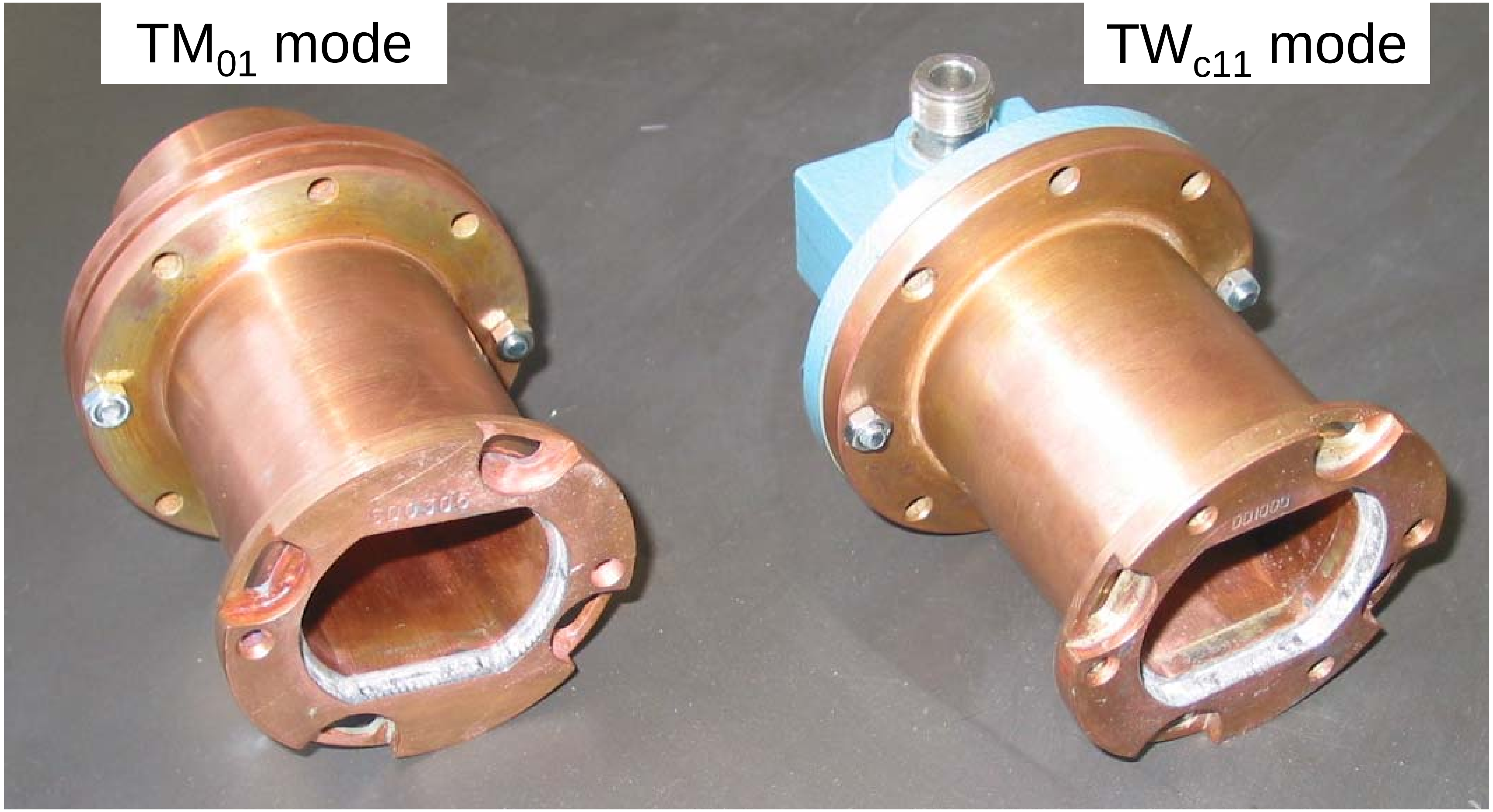




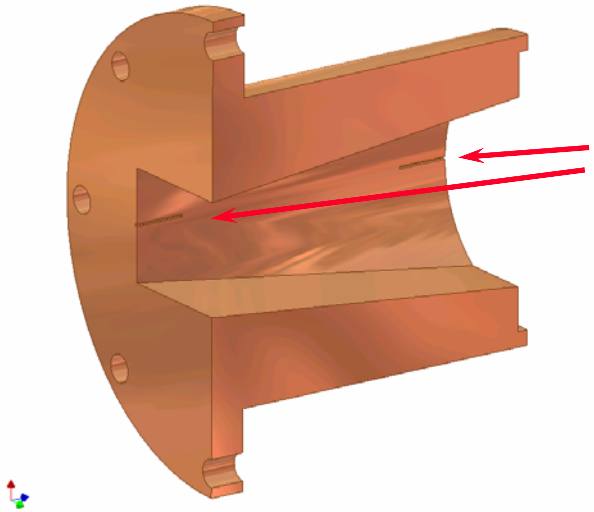
The Measurement Equipment

- Modern network analyser (Agilent E8358x)
- Notebook for number crunching (optional)
- Two kind of mode launchers, one for each mode used
- Signal processing and data archiving software

Prototypes of the Mode Launchers

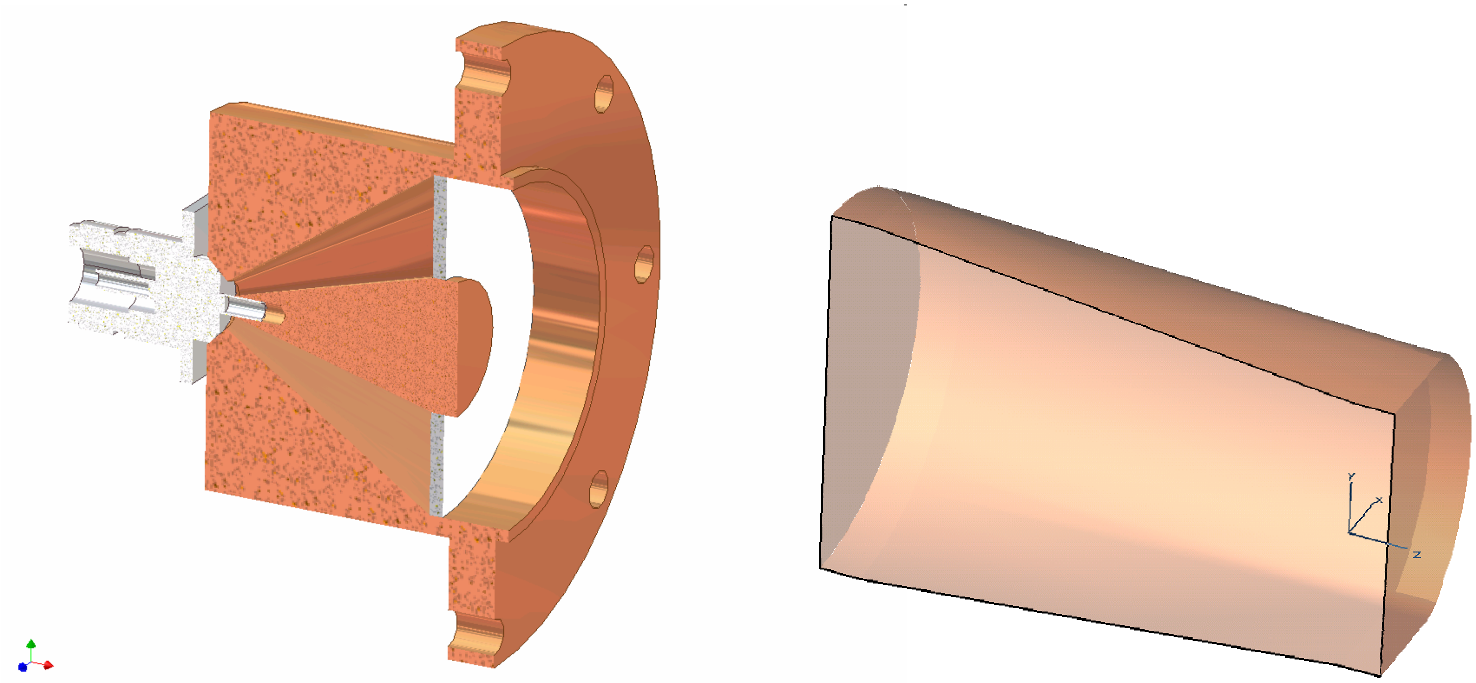


TE_{10} mode launcher



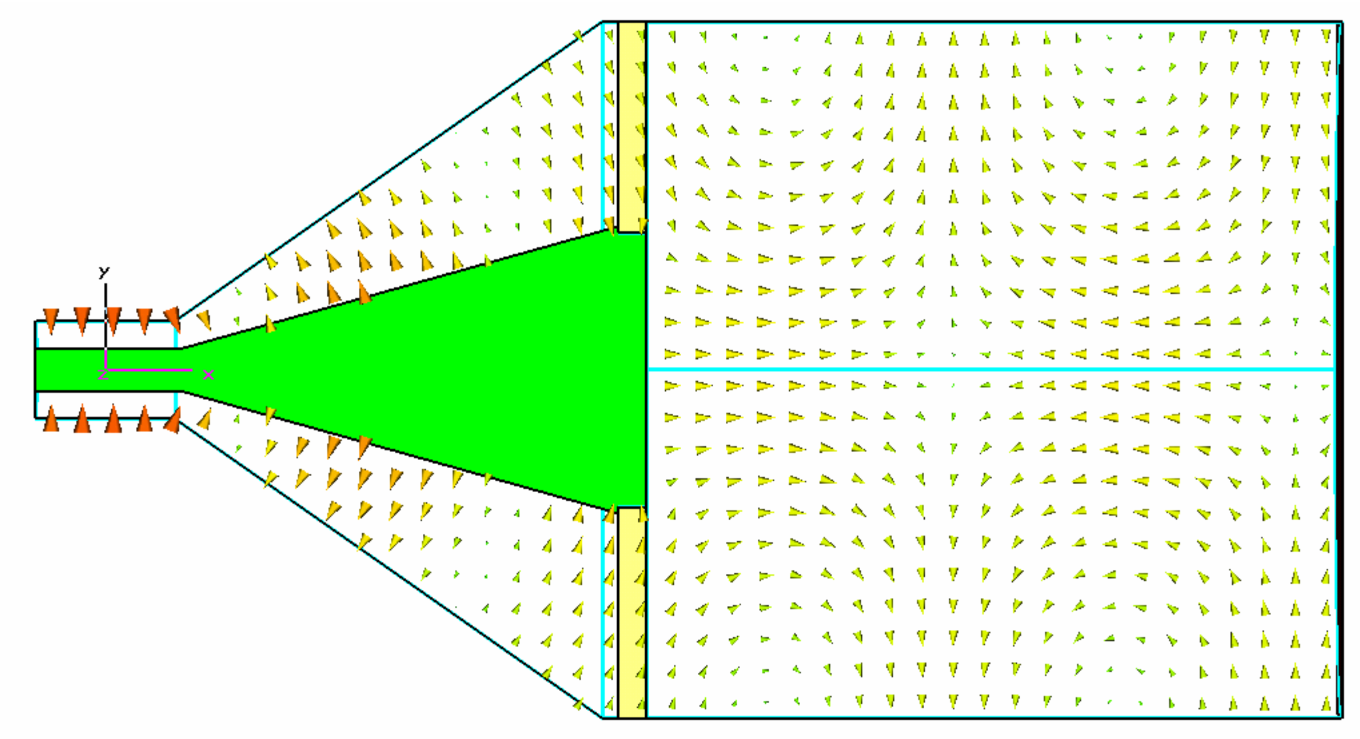
- Flat waveguide necessary for a spurious mode-free excitation
- => Use commercial C-band coax to waveguide junction to excite rectangular TE_{10} mode (nominal frequency range: 3.95 to 5.85GHz)
- Transition to TE_{c11} in beam-pipe (with the index c for cosine defining the polarization of the electric field for the TE_{11} mode being vertical)
- -23 dB reflection averaged over the frequency range of interest

TM_{01} mode launcher



- Conversion from TEM mode on 50 Ω coax line into TM_{01} on circular waveguide, inspired by conical transmission line as used for low reflection diameter changes
- Transition to TM_{01} mode on beam-pipe
- Very good rotational symmetry required
- -20 dB reflection averaged over the frequency range of interest

TM$_{01}$ field pattern



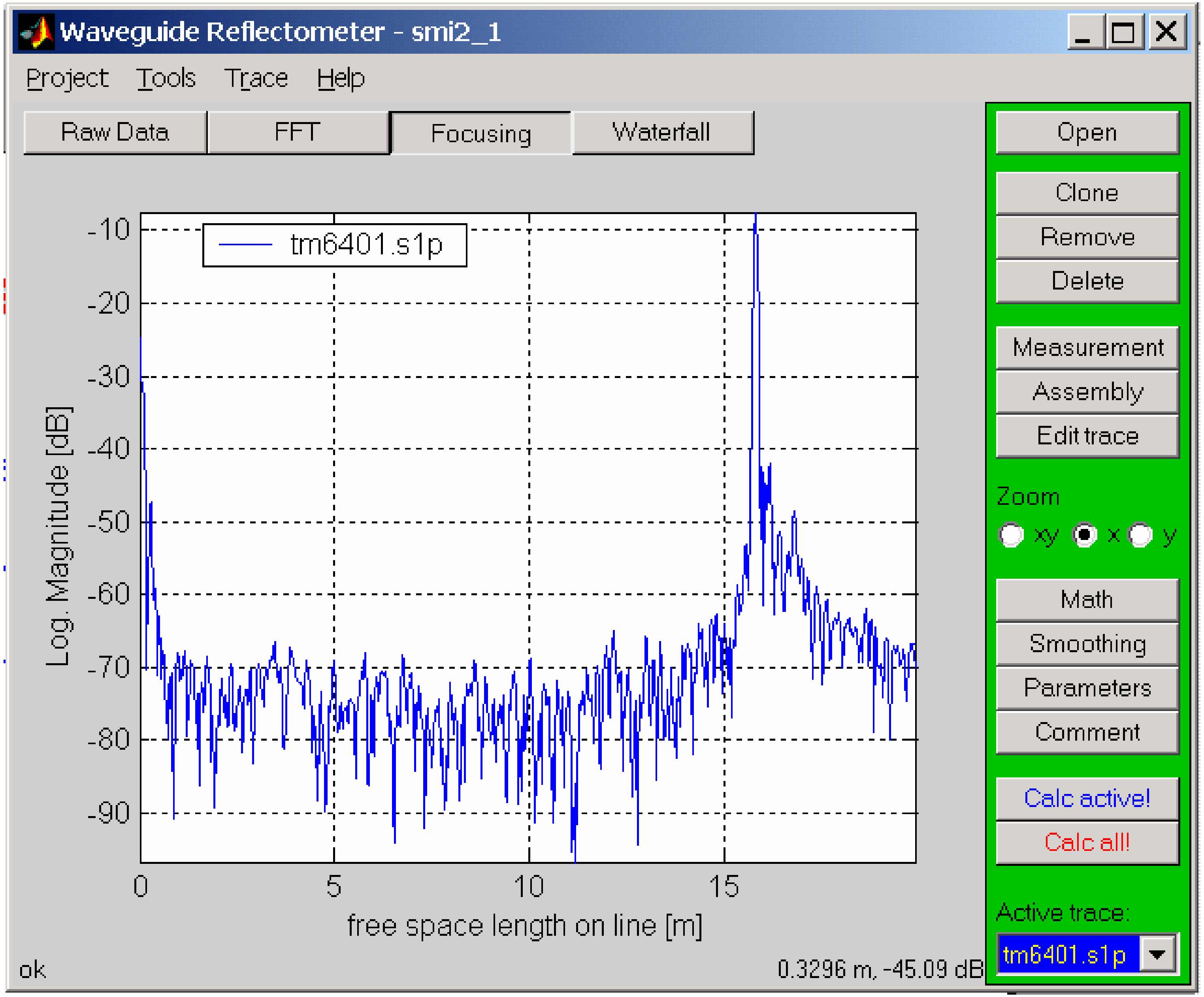
- Field pattern at 7.5 GHz
- Smooth transition between coax line and circular waveguide
- Dielectric plate to keep inner cone in place

Signal Processing Software (1)

- Matlab is used for the signal processing
- Communicates with network analyser
- Waveguide dispersion is corrected numerically
- Different data representations to allow easy interpretation of the data
- A user-friendly interface is currently under development

- On the next slide: screen-shot depicting a typical dipole inspection. For this measurement the TM mode was used. The first reflections are due to the mode launcher, while the peak at roughly 15 m coms from the second extremity of the beam screen

Signal Processing Software (2)



Meausurement Procedure and Performance

- Measurements can be performed on dipoles and on longer sections, up to a several hundred meters
- A typical one-way inspection of a dipole should take not more than 10 minutes
- For longer sections the total time is expected to be longer. However, it is possible to do the number crunching and the actual visual inspection off-line
- The spatial resolution of the reflectometer is about 10 cm for a dipole measurements. This means the peak from any obstacles is about 10 cm wide (6 dB width)
- Obstacles as small as M3 nuts can be seen
- An obstacle is any object disrupting the continuity of the beam screen, corresponding to a change in beam pipe geometry, conductivity or dielectric permittivity

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