Wireless readout at 60 GHz

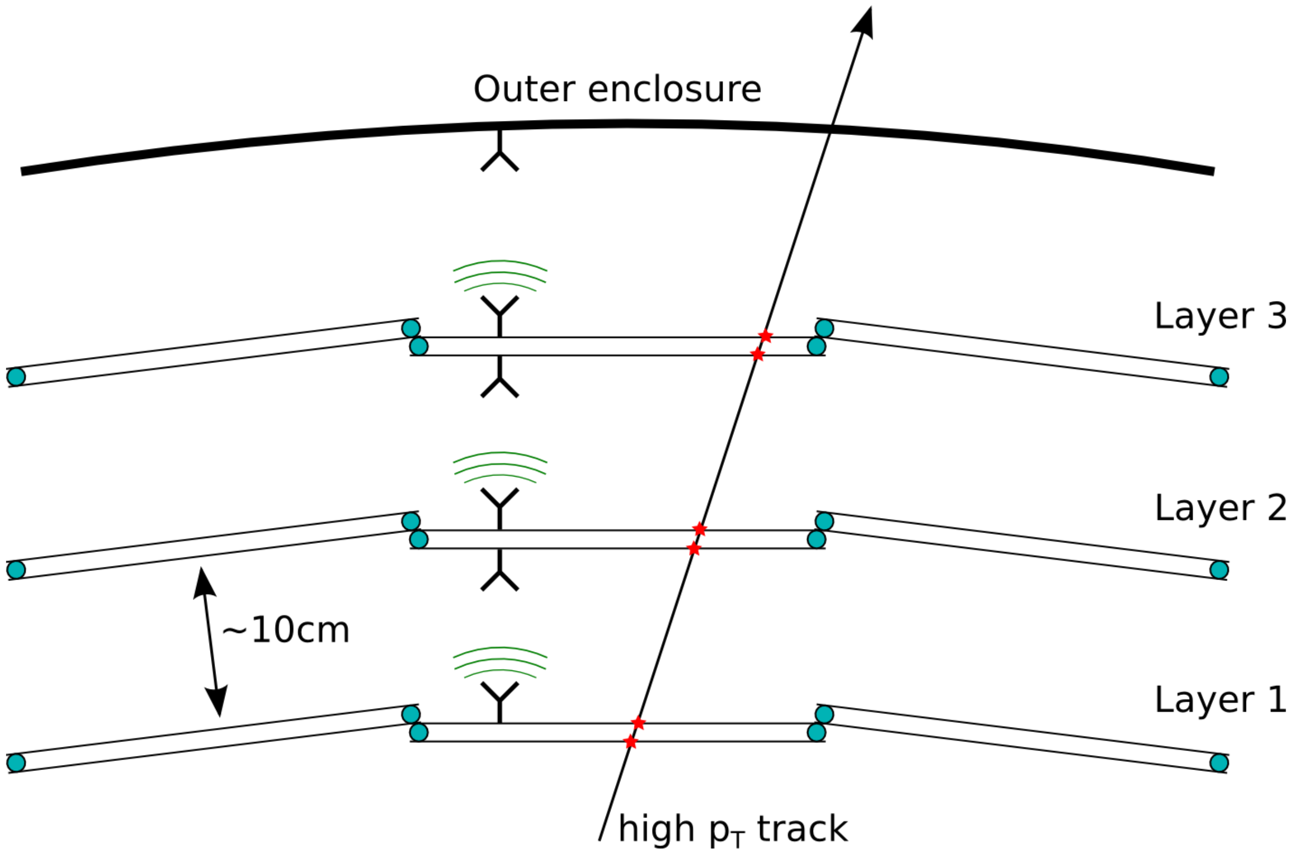
Feasibility studies for particle physics instrumentation

S. Dittmeier, A. Schöning, H.K. Soltveit, D. Wiedner

Physikalisches Institut, Universtität Heidelberg

WADAPT – CERN – 12 June 2015

INTERNATIONAL MAX PLANCK RESEARCH SCHOOL PTFS FOR PRECISION TESTS OF FUNDAMENTAL SYMMETRIES



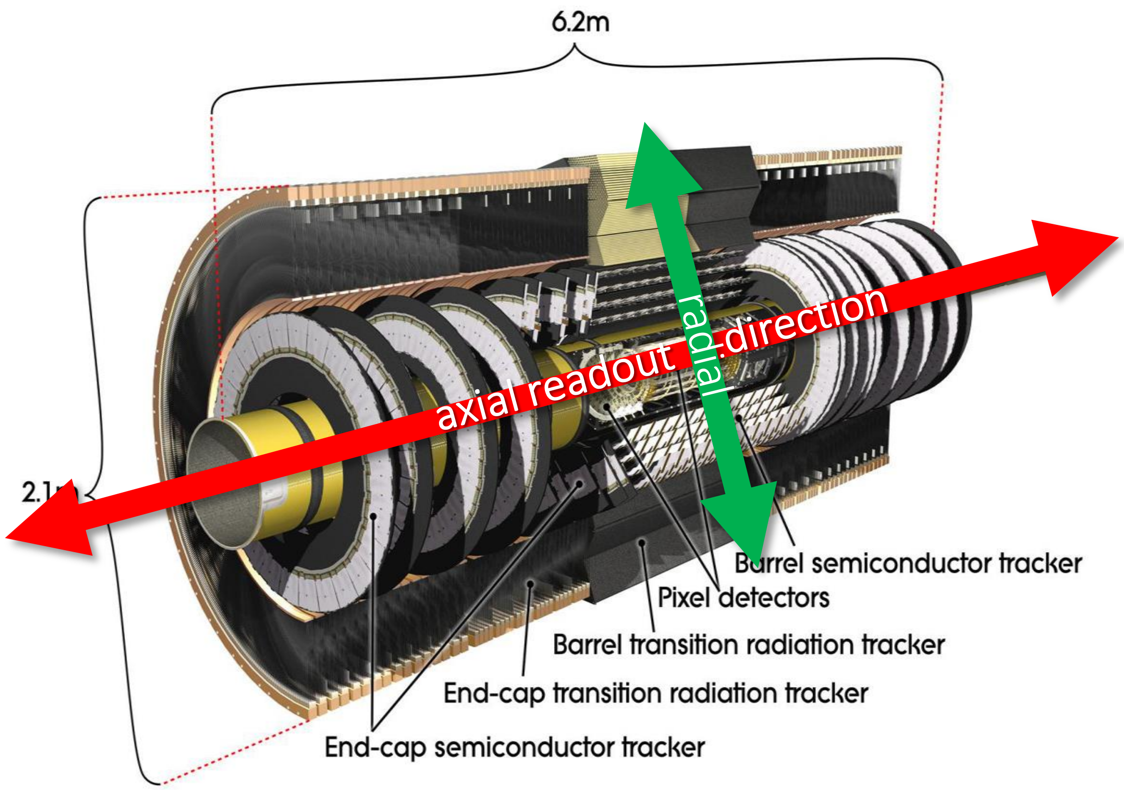
Wireless readout concept

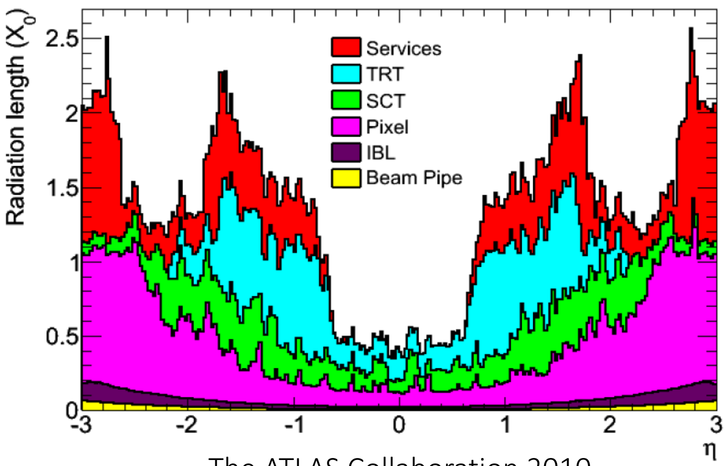
- Radial data transfer
  → Communciation between layers
- Signal cannot penetrate layers
  → Reuseability of frequency channels

Idea by R. Brenner (Uppsala)

Tracking detector readout

- E.g. ATLAS Upgrade: First level track trigger
- Data rates: 50 - 100 Tb/s ~ 20 000 channels 5 Gb/s
- Constraints:
  - Material
  - Space
  - Power consumption





The ATLAS Collaboration 2010
Insertable B-Layer Technical Design Report

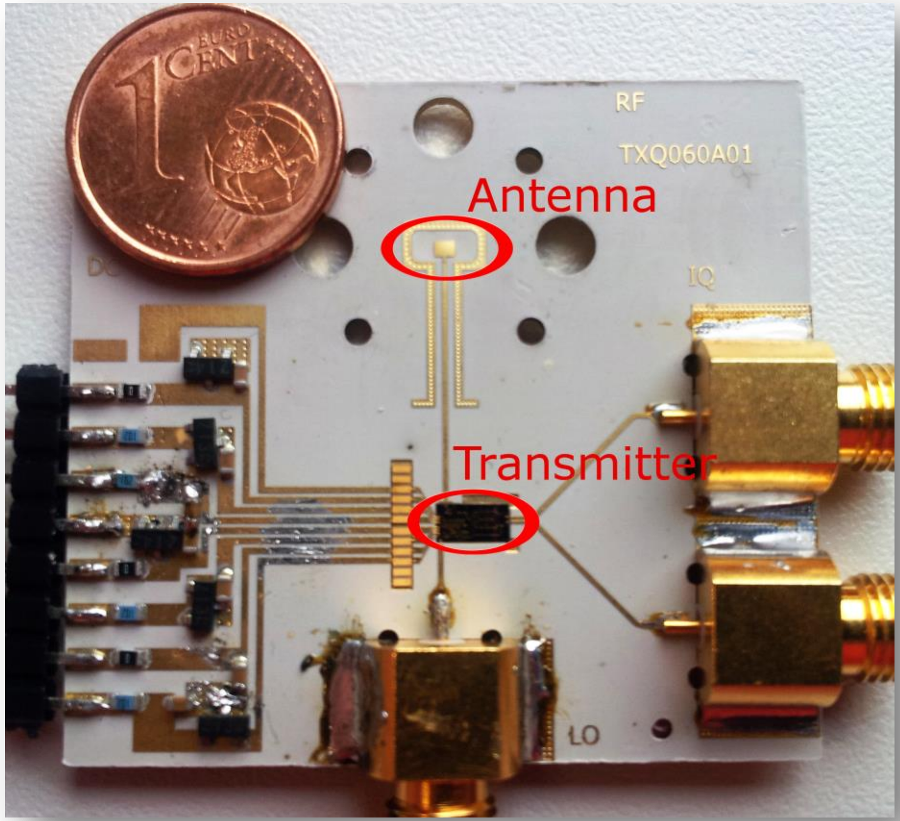
Connectors & Cables

- Material budget
- Fragile

This talk:

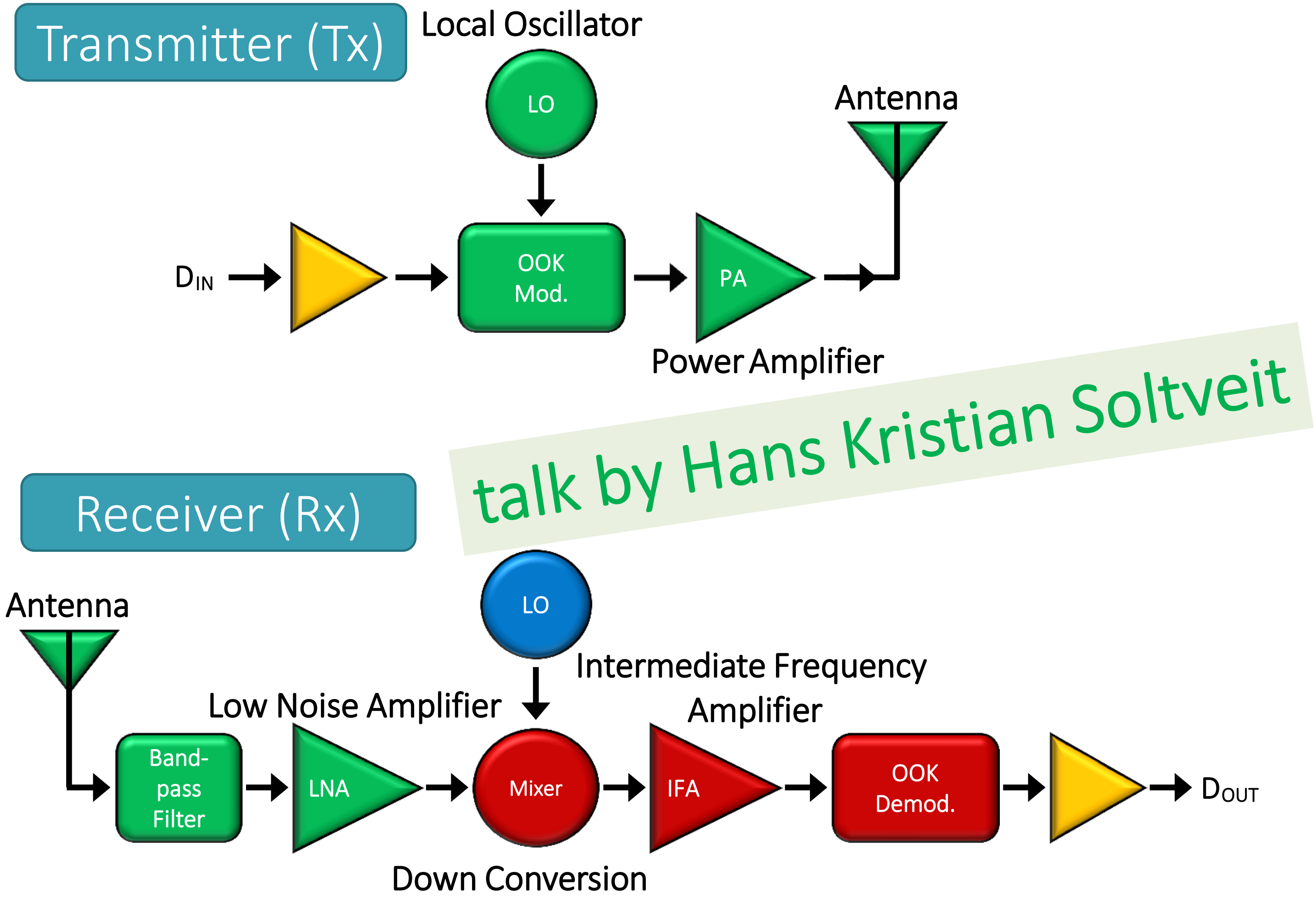
Feasibility studies of integration of 60 GHz wireless in a detector

Example for a 60 GHz transmitter (by Gotmic)



Why 60 GHz?

- Wavelength $\lambda \sim 5\ mm$
  Small form factor
- High level of chip integration
- Bandwidth: 57-66 GHz
  ⟶ Datarates of several Gbps possible



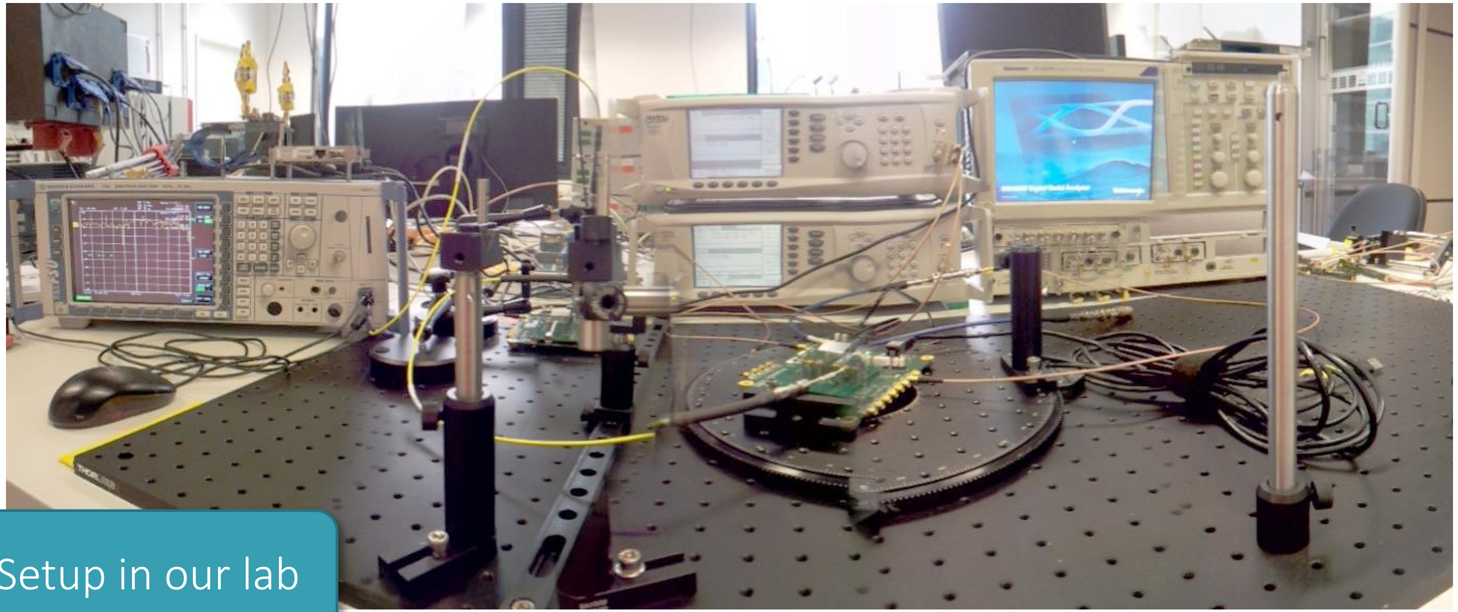
H K Soltveit et al 2013 IEEE dx.doi.org/10.1109/NSSMIC.2013.6829448

Heidelberg transceiver

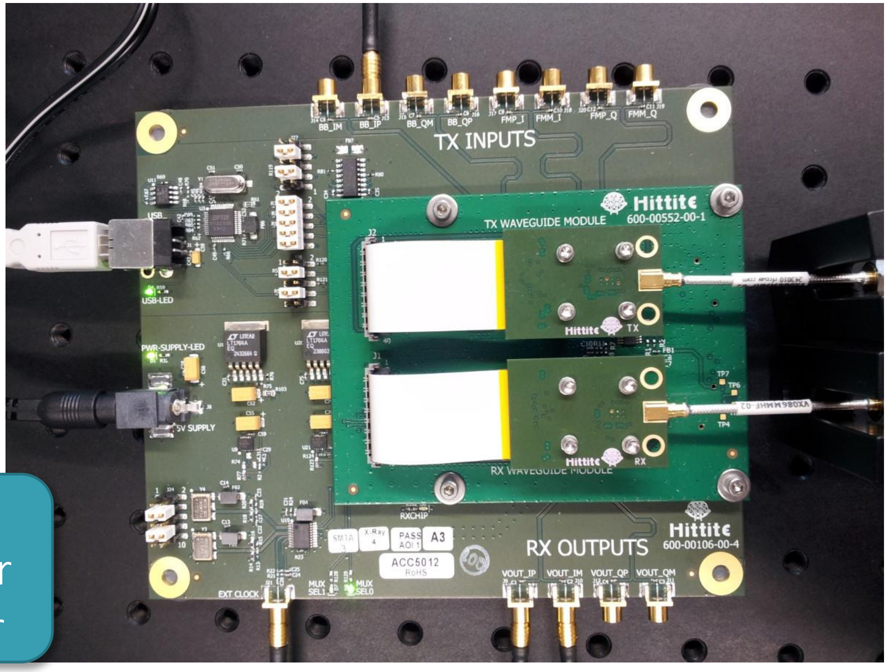
- 130 nm SiGe BiCMOS 8HP technology:
  radiation hard
- Modulation:
  On-Off-Keying
- Design parameters:
  - Data rates: **4.5 Gb/s**
  - Power consumption **≤ 190 mW**

Lab measurements done in Heidelberg

- Data transmission studies
- Material properties
- Antenna characterization
- Cross talk and link density studies
- Noise pickup in a detector module (test done at Uni Freiburg)



Setup in our lab



Hittite Transmitter & Receiver

Tests in Heidelberg: Equipment

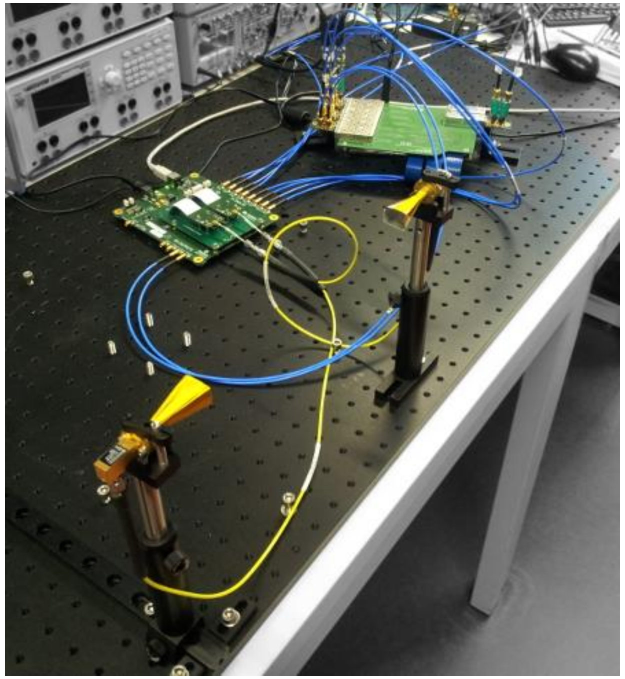
- R&S FSU spectrum analyzer up to 67 GHz
- Signal Generators up to 20 GHz: Anritsu MC3692
- Tektronix DSA8300 serial analyzer
- Hittite HMC6000/6001 transmitter & receiver 1.8 GHz IF-BW

Data transmission studies

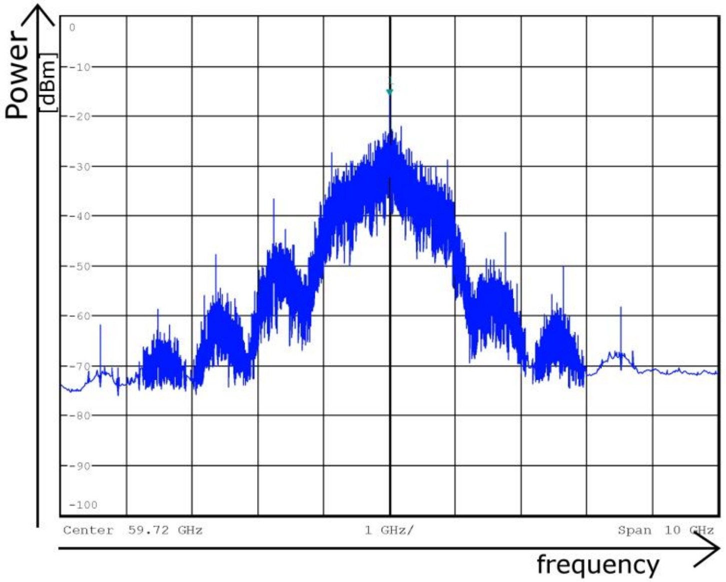
- 60 GHz Tx/Rx byHittite HMC 6000/6001
  - Bandwidth: 1.8 GHz
- Setup: Bit error rate test
  - Data rate: 1.76 Gbps
  - Minimum Shift Keying $\boldsymbol{BER < 10^{-14}}$
- HD-SDI-Video transmission

Setup in the lab

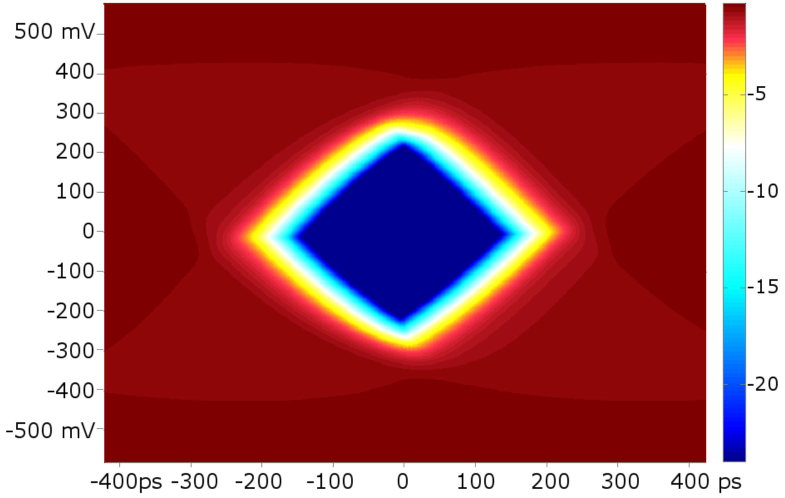
Distance: 22 cm
Horn antennas from
Kapton und aluminium



60 GHz spectrum



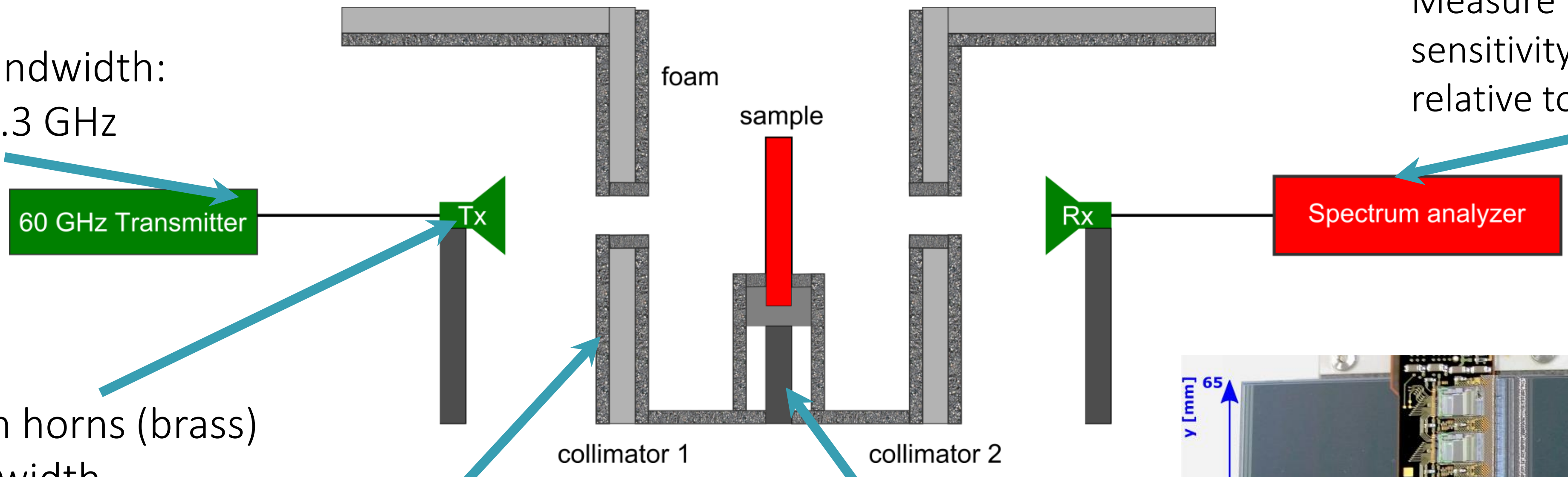
1.76 Gbps eye diagram



Transmission through detector modules

Tested bandwidth:
57.3 – 61.3 GHz

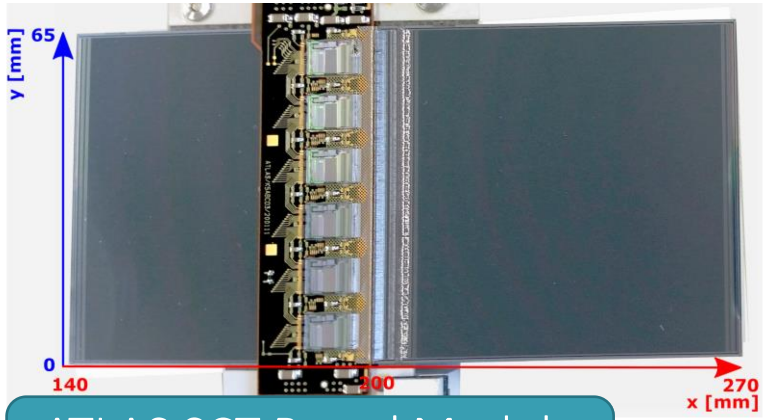
Measure power in RF sensitivity of $\approx -55\text{dB}$ relative to transmitter



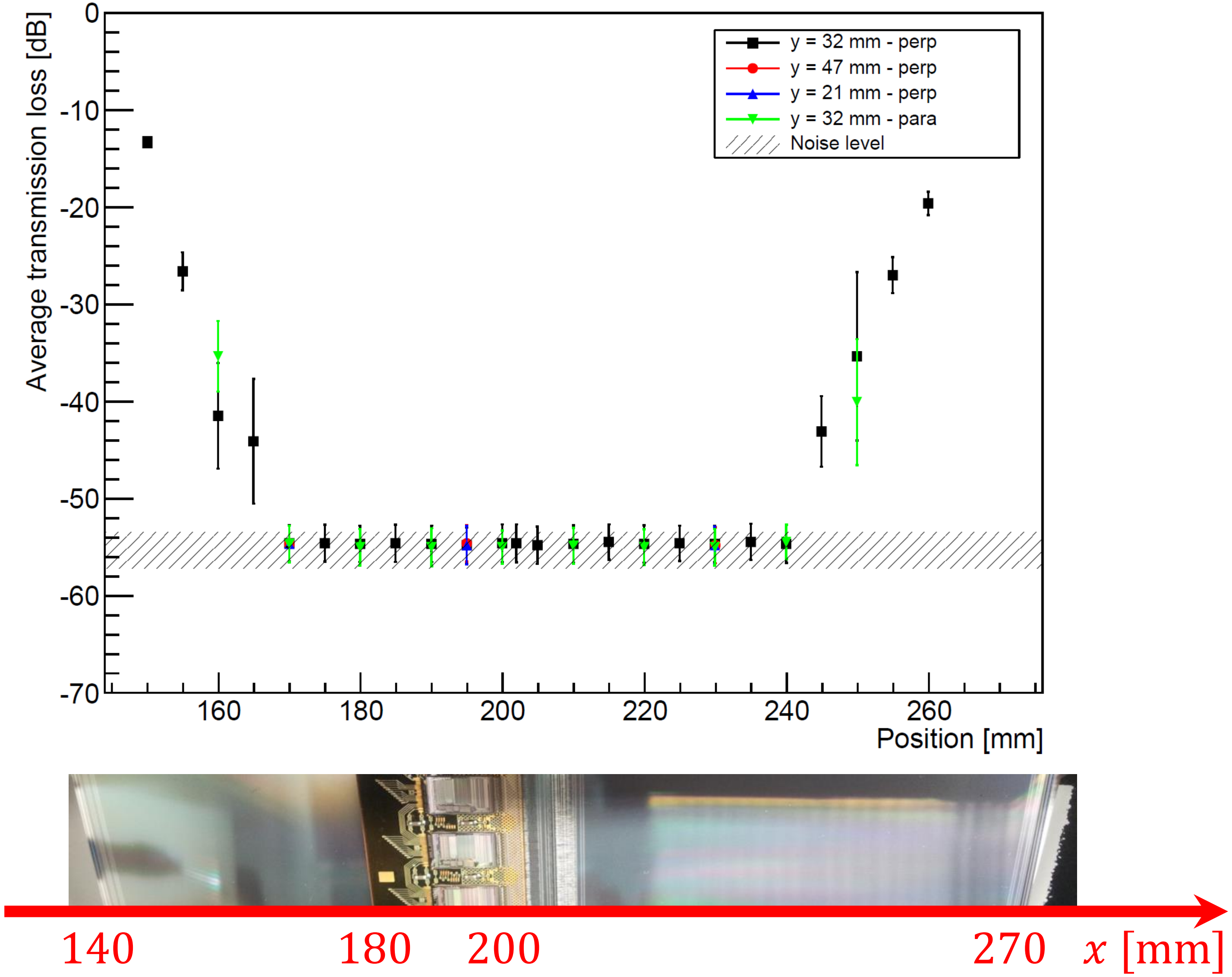
20 dBi gain horns (brass)
20 ° beamwidth
Linear polarization

Aluminum and graphite foam shielding against reflections

Rail and post holder to move sample



ATLAS SCT Barrel Module
R.Brenner (Uppsala)



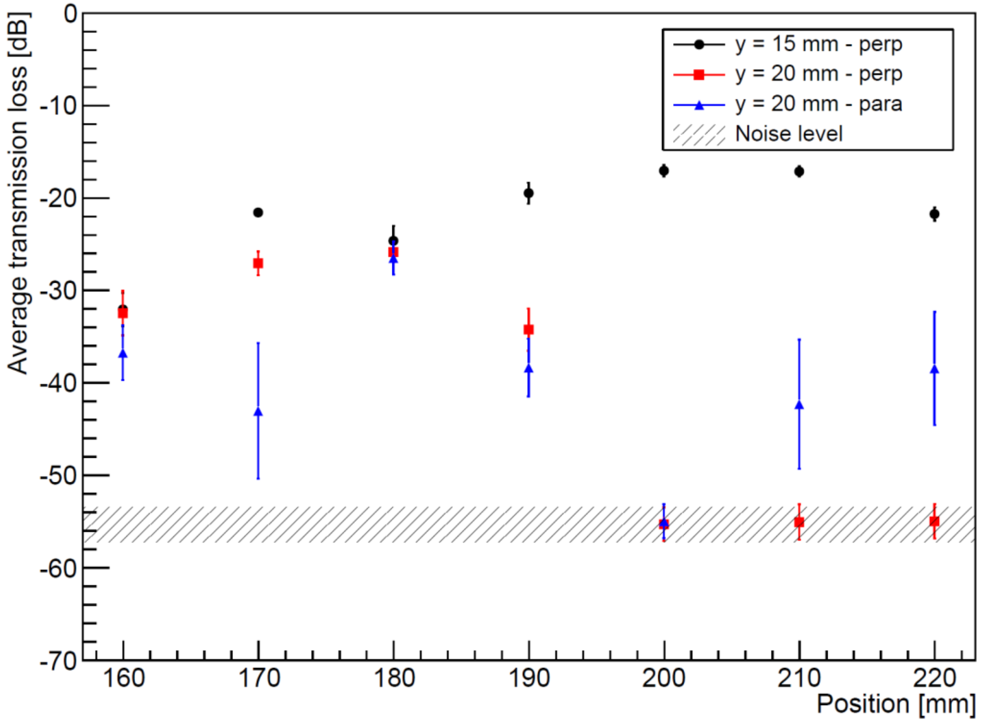
Transmission: SCT Barrel Module

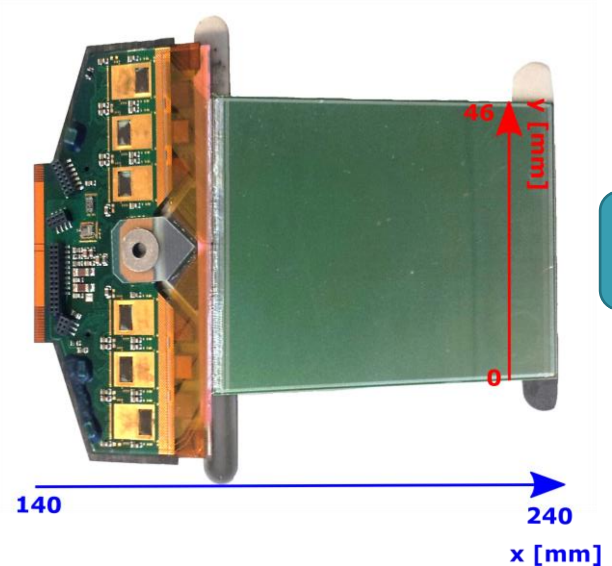
- Transmission loss

  $I_{loss} \geq 55$ dB

- **60 GHz signals are fully reflected**

- Diffraction leads to transmission near edges



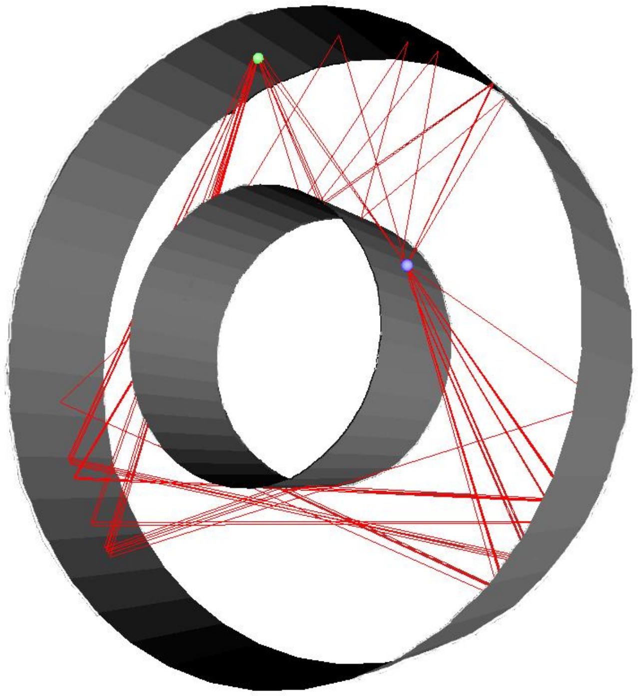


ATLAS SCT Endcap Module
U. Parzefall (Freiburg)

Transmission: SCT Endcap Module

- Smaller than barrel module
- Diffraction near edges + screw hole

→ More transmission

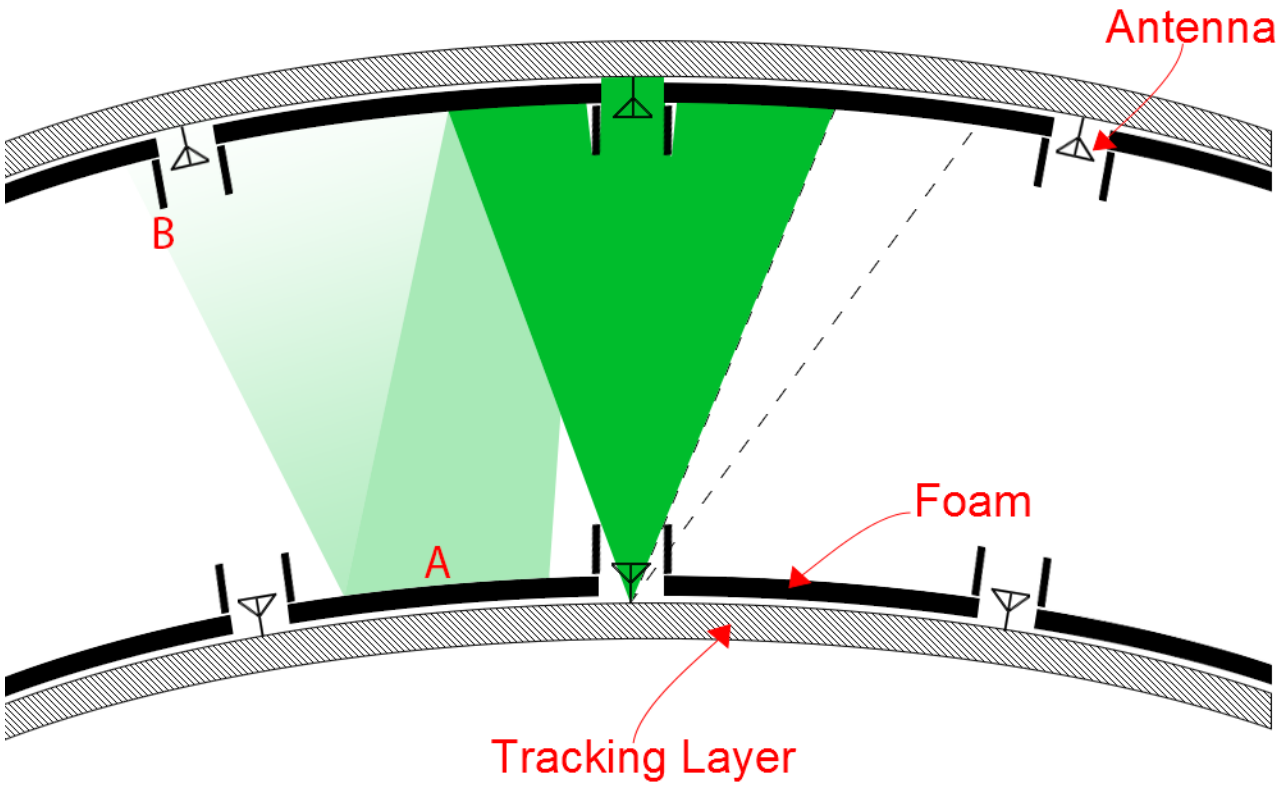


Ray tracing simulations
(B.Sc. thesis by Thomas Hugle)

Directing and / or shielding the radio links is important in a highly reflective environment

Feasibility studies

- Detecor modules: Highly reflective
- High link density expected
- Line of sight communication
- Crosstalk caused by reflections – Issue?

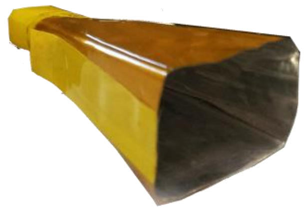


How to avoid crosstalk?

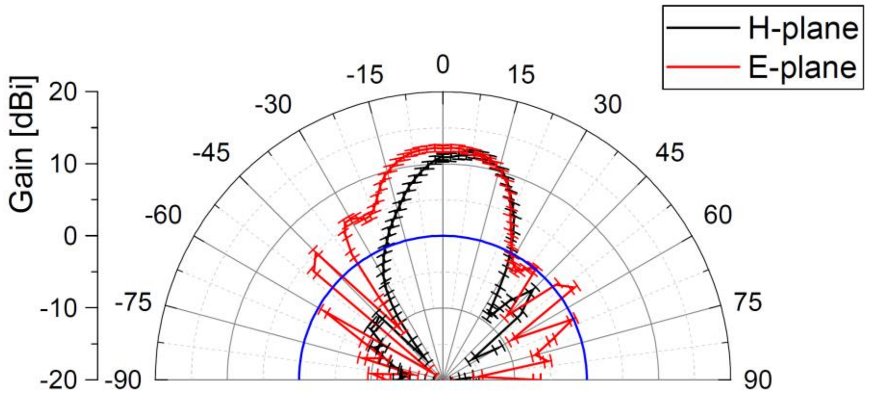
- Directive antennas
- Polarized antennas
- Absorption of reflections
- Frequency channelling

Directive antennas

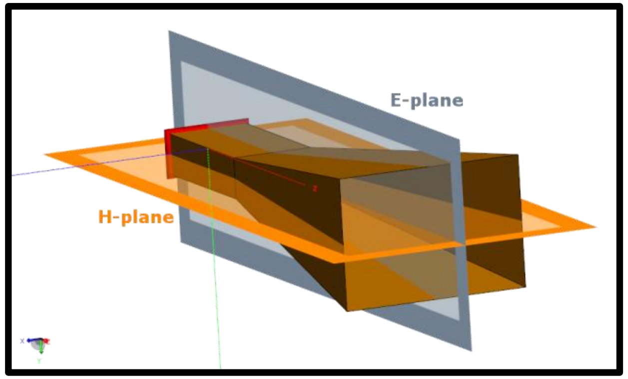
- Kapton and aluminium foil horn antennas
- Drawback: large volume
- More on flat antennas
⟶ Richard Brenner



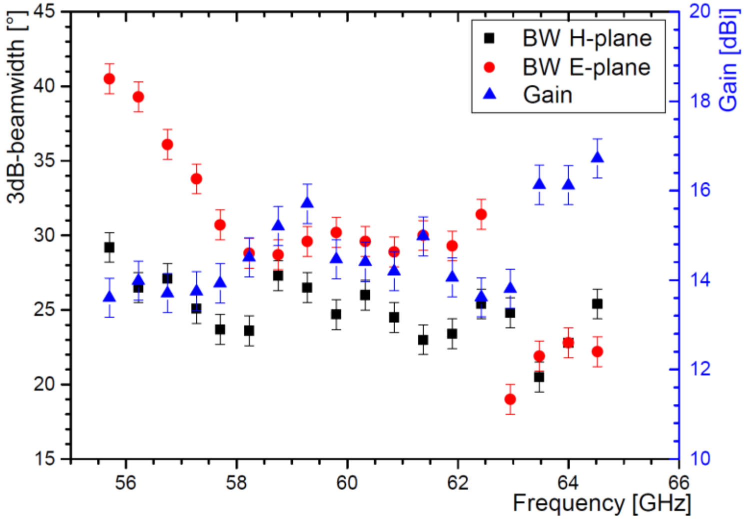
3.5 cm long horn prototype



Polar pattern at f = 60.85 GHz

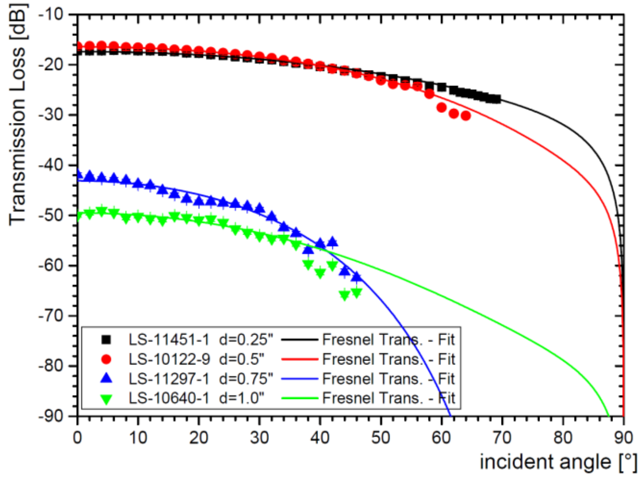


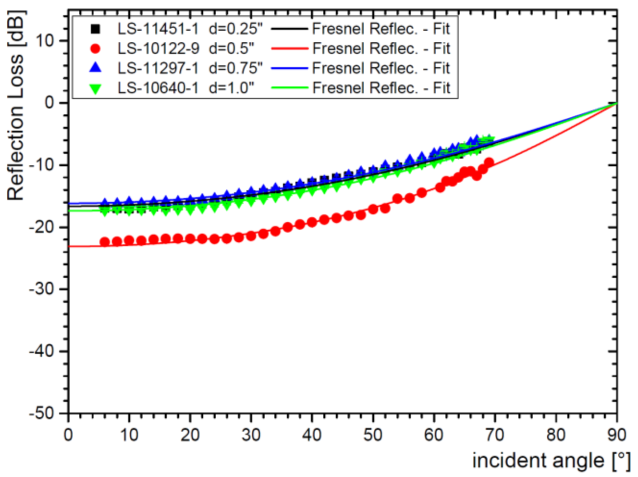
E- and H-plane of an antenna



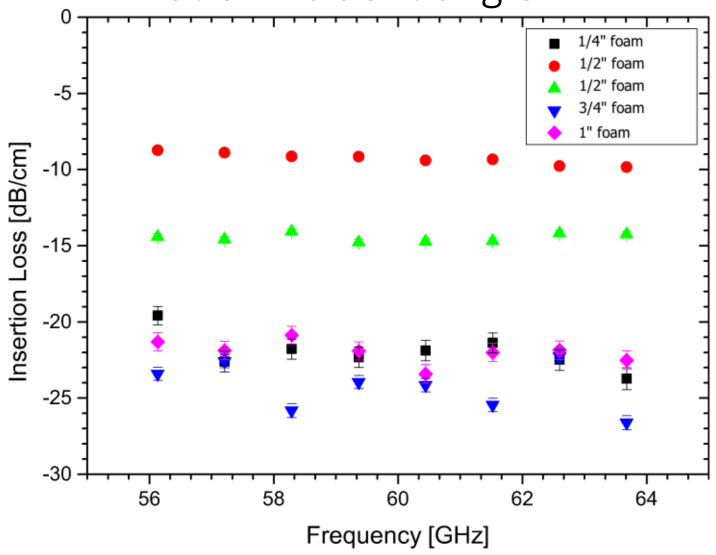
Gain and beamwidth of 3.5 cm long horn

fixed frequency: f = 60.721 GHz

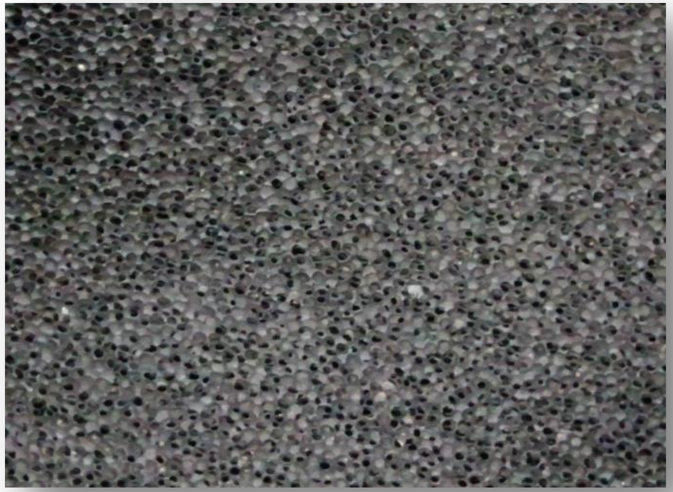




Frequency dependence at 0° incident angle



Foam sample

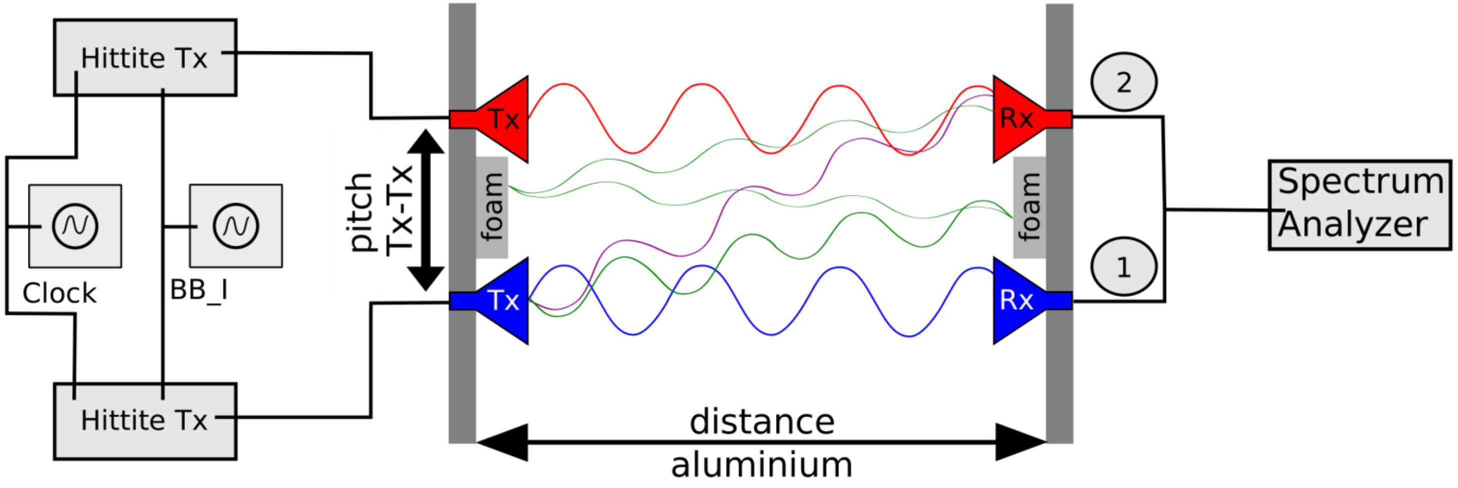


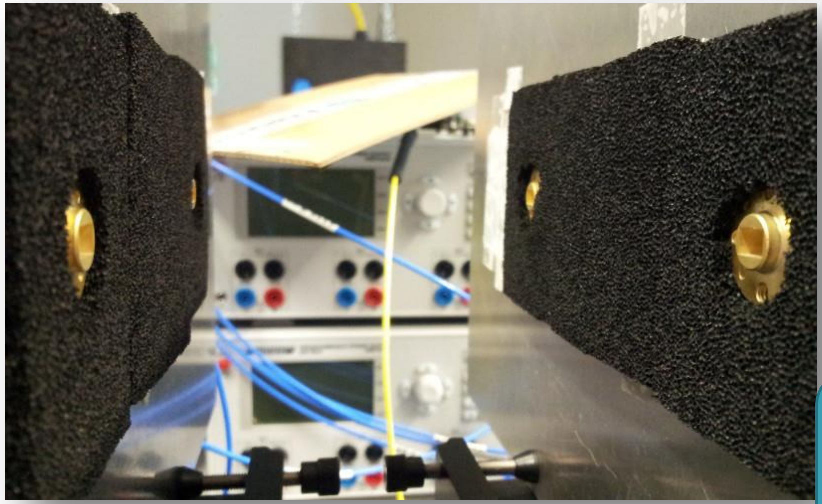
Absorbing reflections: Graphite foam

- Low density material: $\rho = 50 – 70\ mg/cm^3$
- **Transmission reduced by > 15-20 dB**
- **Reflections reduced by > 10 dB** up to large angles

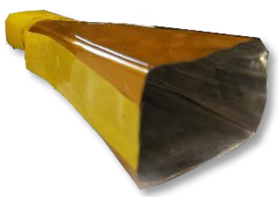
Crosstalk studies with reflections

- Aluminium plates
  ≙ reflective layers
- Under test:
  Directive antennas
  Linear polarisation
  Absorbing foam
- S/N = $\frac{Signal\ Tx1_{@Rx1}}{Signal\ Tx2_{@Rx1}}$

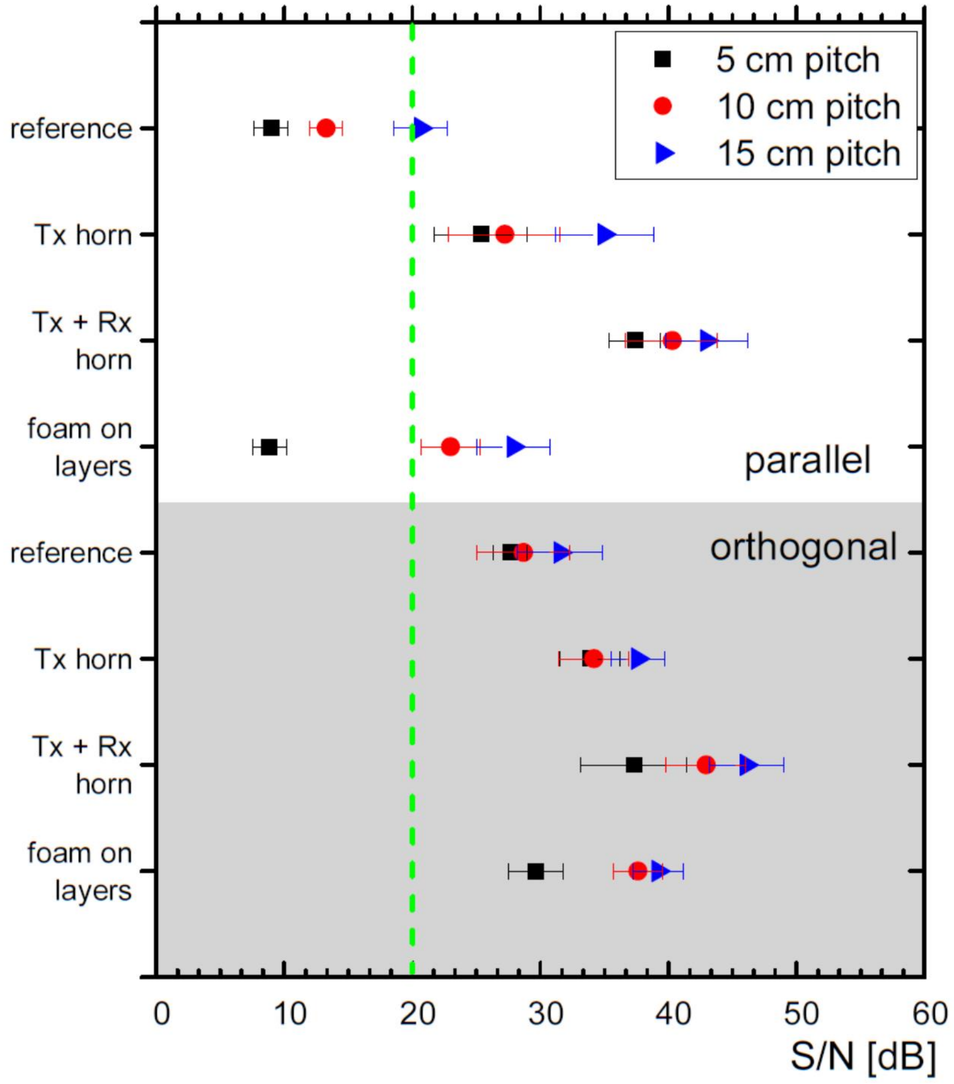




Graphite foam cover



Example for high directivity: Aluminized Kapton horn antennas ~ 12-17 dBi



Distance between layers: 10 cm
Reference: without directive antennas and foam

Crosstalk studies with reflections

- Highly **directive antenans** increase S/N significantly
- Orthogonal linear **polarisation**: S/N > 20 dB
- **Foam on layers** can additionaly reduce crosstalk
- **5 cm pitch between channels is possible**

Does the 60 GHz wireless interfere with other detector electronics?

If so:
How much and
how to avoid it?

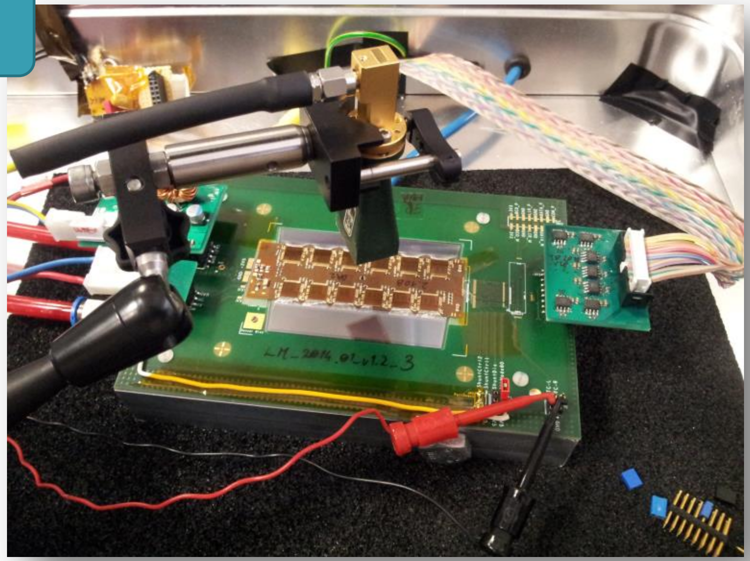
If not:
Secure communication

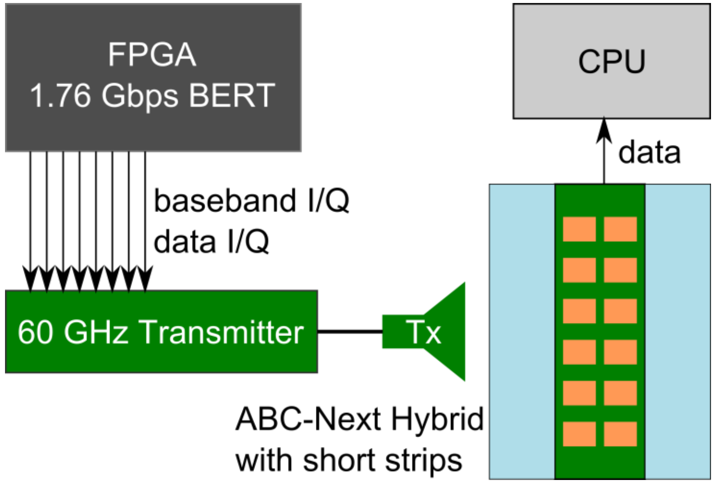
First assumption:
60 GHz above cut off frequency of other electronics

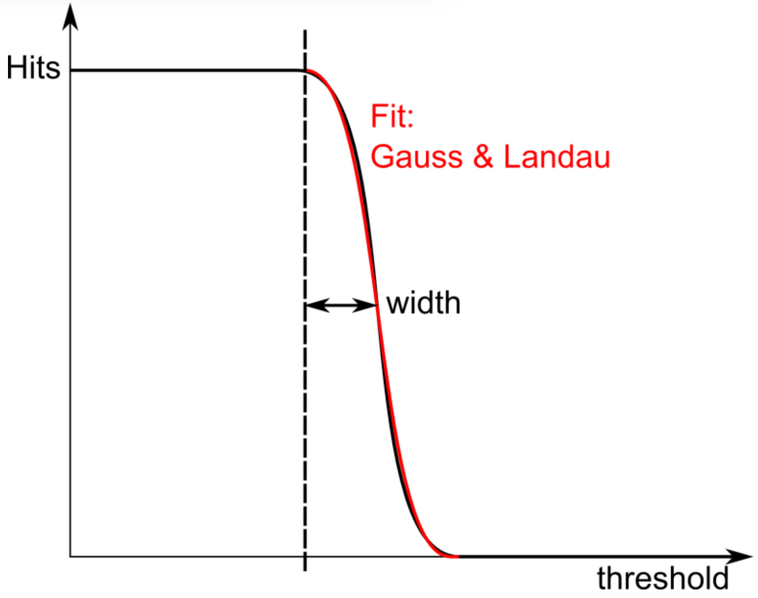
Detector performance under 60 GHz “irradiation”

- Tests done using ABC-Next Hybrid for the upgrade of ATLAS endcap detector
  (kindly supprted by U. Parzefall & S. Kühn, Uni Freiburg)
- Measurement:
  Compare noise in readout chips with and without wireless transmission

Setup



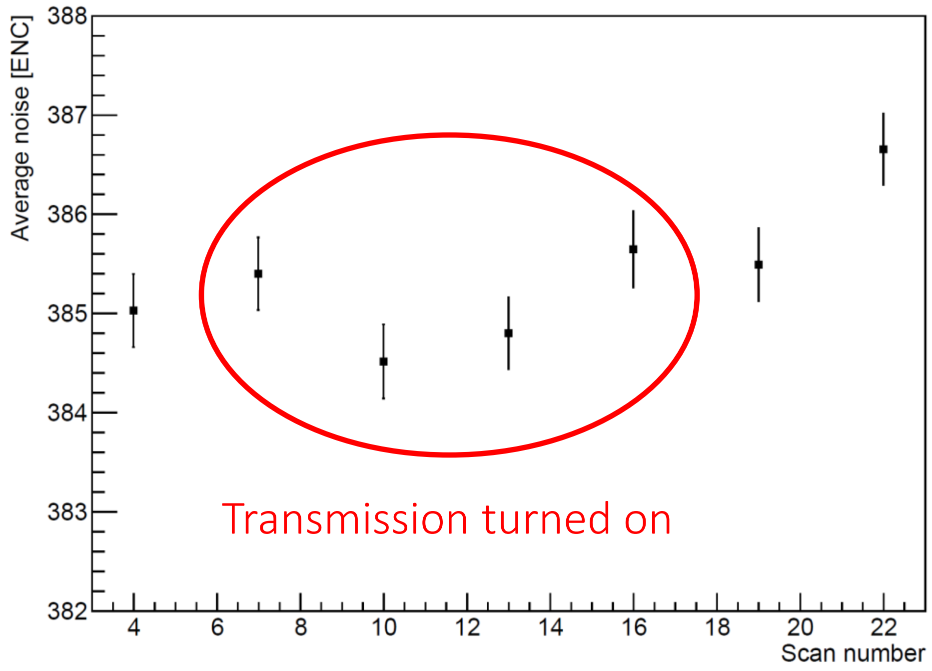




Detector performance under 60 GHz “irradiation”

- No additional noise observed
- Hybrid + sensor: Temperature is dominating effect on noise per channel

Hybrid without strips



Hybrid

$$\delta_{noise} = (0.40 \pm 0.13_{stat} \pm 0.49_{sys})\%$$

of average noise (385.0 ± 0.4) ENC

Hybrid + Strip sensor

$$\delta_{noise} = (0.60 \pm 0.11_{stat} \pm 0.93_{sys})\%$$

of average noise (577.5 ± 0.5) ENC

No significant increase in noise!

Summary

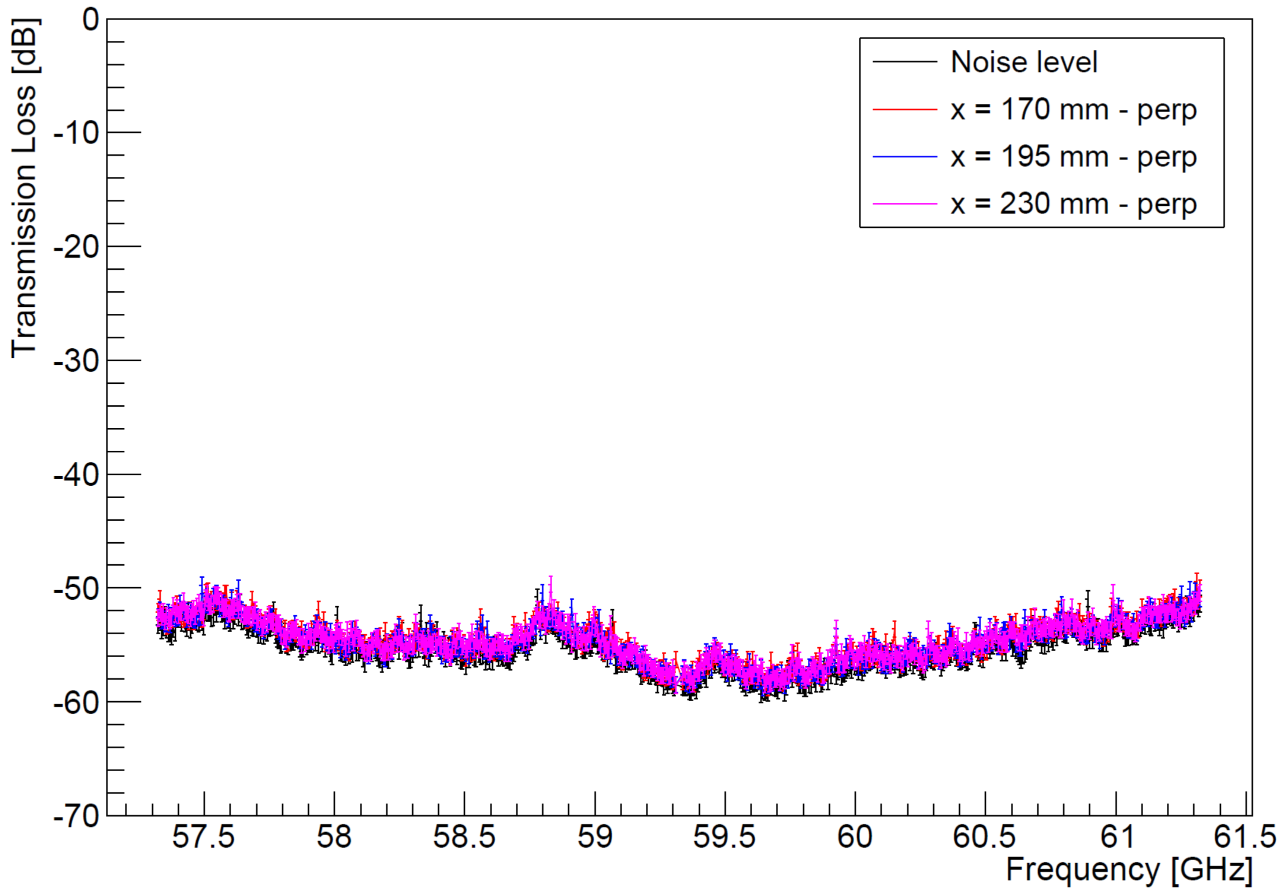
Stable data transmission of 1.76 Gbps with test setup:
$\boldsymbol{BER < 10^{-14}}$

By means of antennas, polarisation and graphite foam, a high link density can be achieved.
Link pitch ≤ 5 cm @ S/N ≥ 20

SCT detector modules attenuate transmission of 60 GHz waves by ≥ **55 dB**

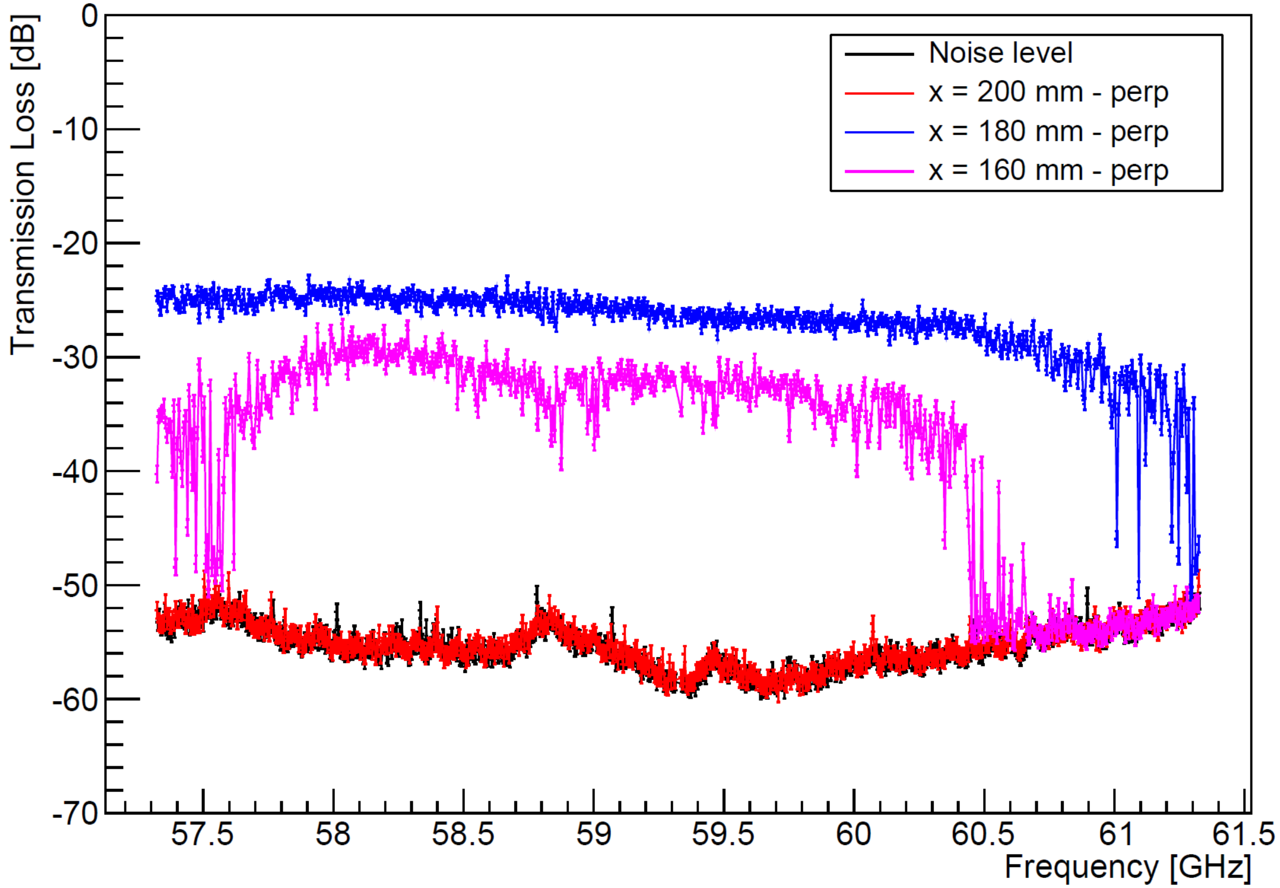
Performance of detector modules will not be degraded by 60 GHz waves

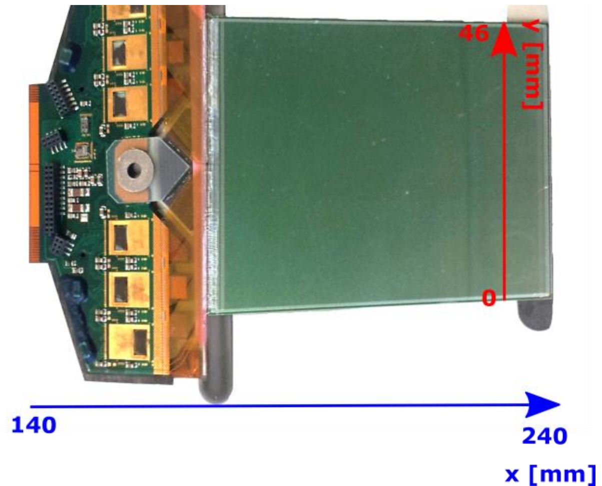
Backup



Transmission: SCT Barrel Module

- Spectrum of transmitted intensity in frequency range 57.3 – 61.3 GHz
- Over entire spectrum: No transmission



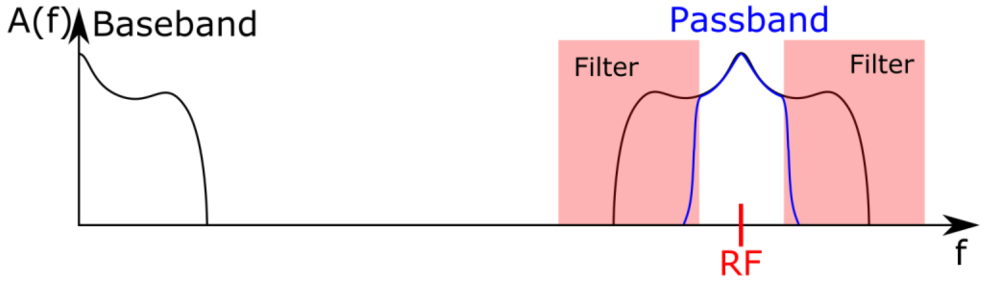


Transmission: SCT Endcap Module

- Spectrum of transmitted intensity in frequency range 57.3 – 61.3 GHz
- Highly frequency dependent!

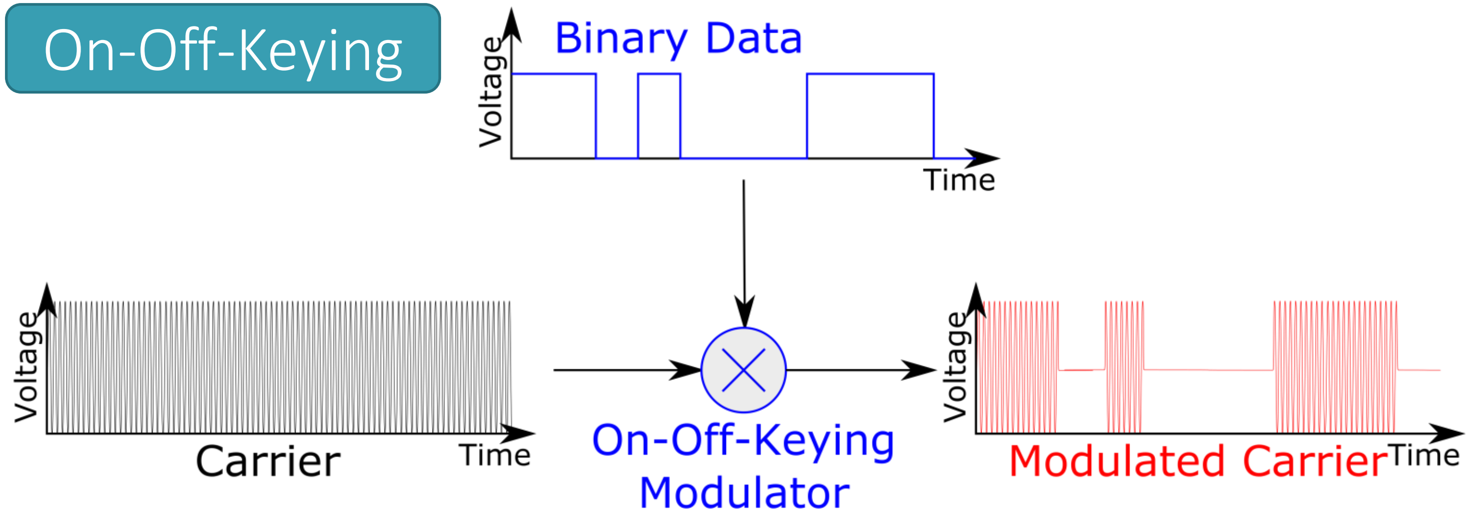
→ Detailed simulation studies for detector modules could be useful

Modulation



Modulation scheme	Spectral efficiency [b/Hz/s]	IQ-Mixer	Coherent Demodulation
OOK	0,5	✗	✗
MSK	1	✓	✗
16-QAM	4	✓	✓

On-Off-Keying



Data transmission scheme

- Modulation of carrier in the 60 GHz frequency band
- Schemes requiring IQ-mixing and coherent demodulation are more complex and power consuming