60 GHZ Technology and Possible Applications in HEP

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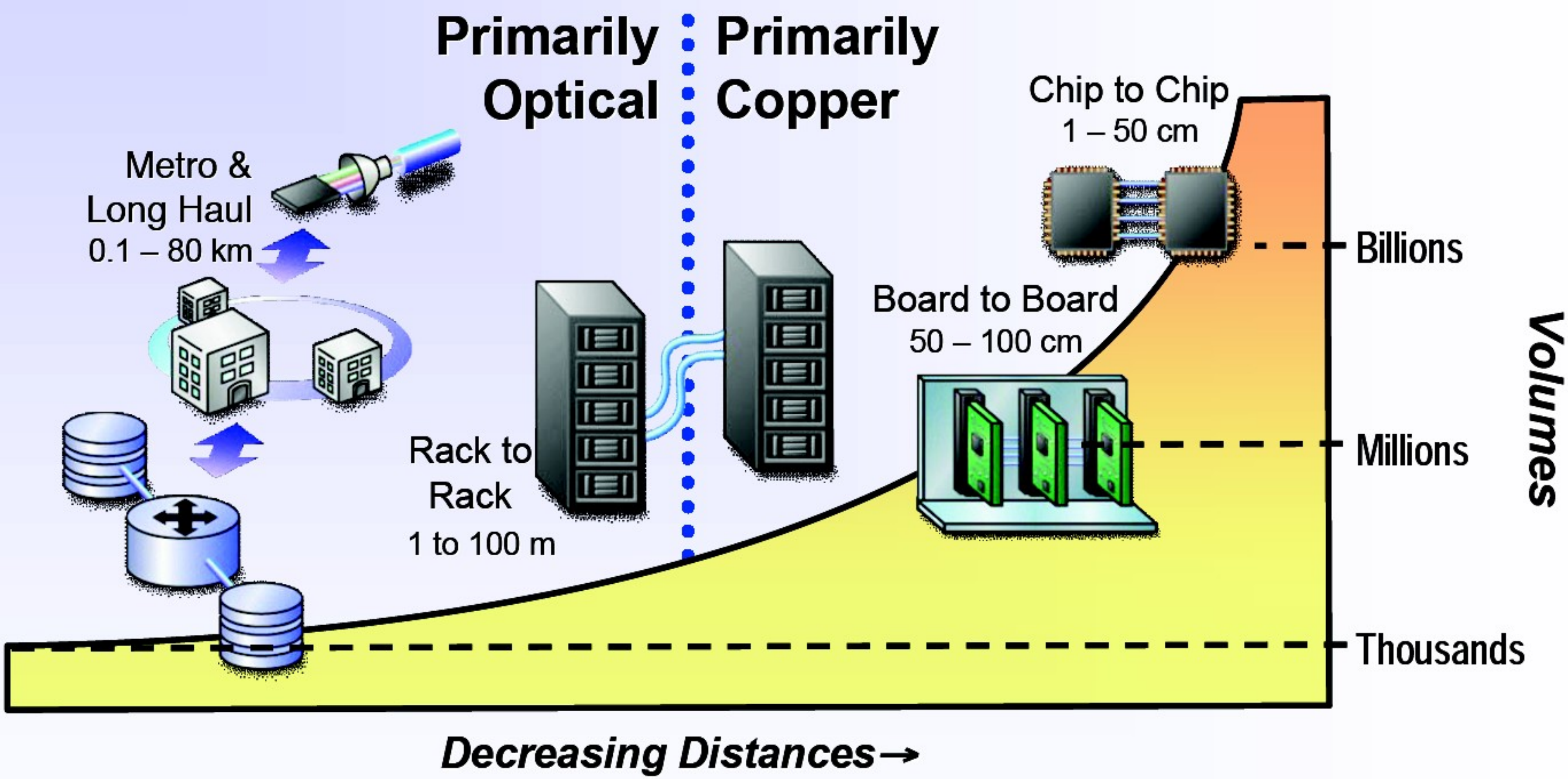
(Fraunhofer Gesellschaft)

Overview

- Introduction to 60 GHz technology
- Motivation to use 60 GHz in HEP
    - ATLAS Track Trigger
- Studies and Results
    - Simulations
    - Hardware Tests
- Heidelberg 60 GHz Transveiver Chip
- Future Applications
    - FCCee?

Today's High Speed Interconnects

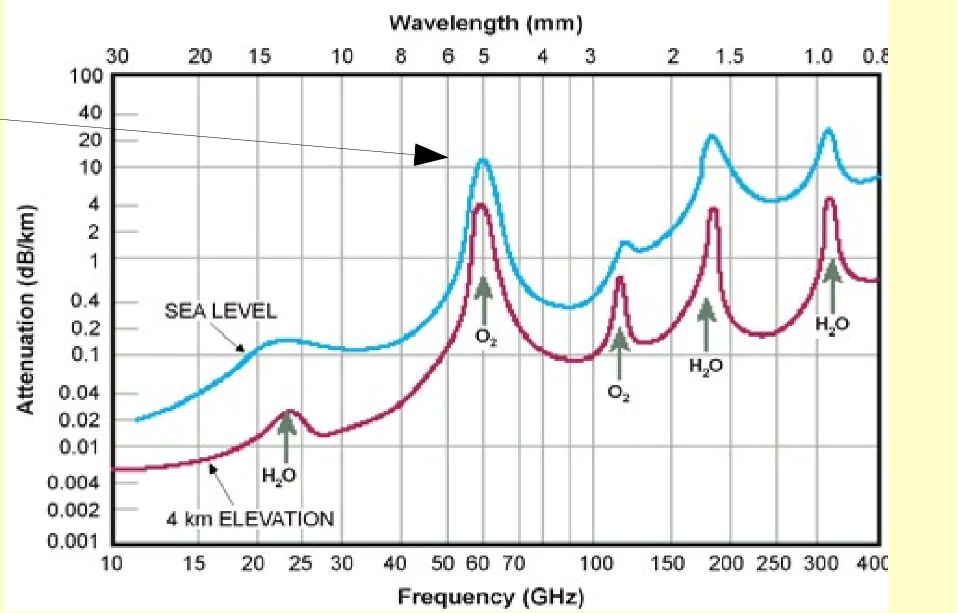


Courtesy of Mario Paniccia, Intel

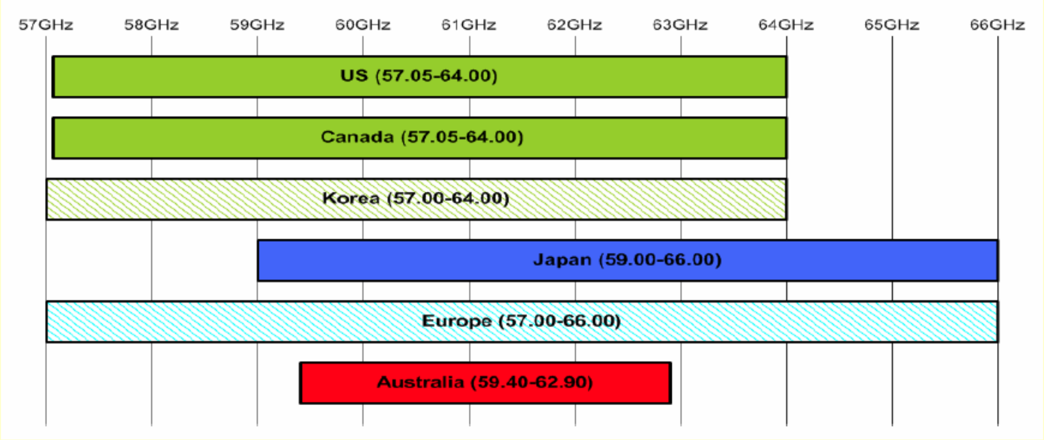
typical detector size ~ 100m

60 GHz Band

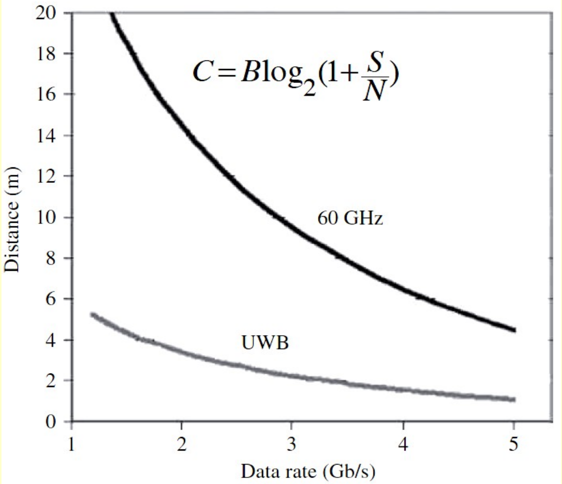
- O_2 absorption at 60 GHz
- large damping over 10m
- unlicensed band 57-66 GHz
- ~ 9 GHz (officially) usable
- multi Gbit/s data transfer
- mm-wafes → small antennas!



license free bands:

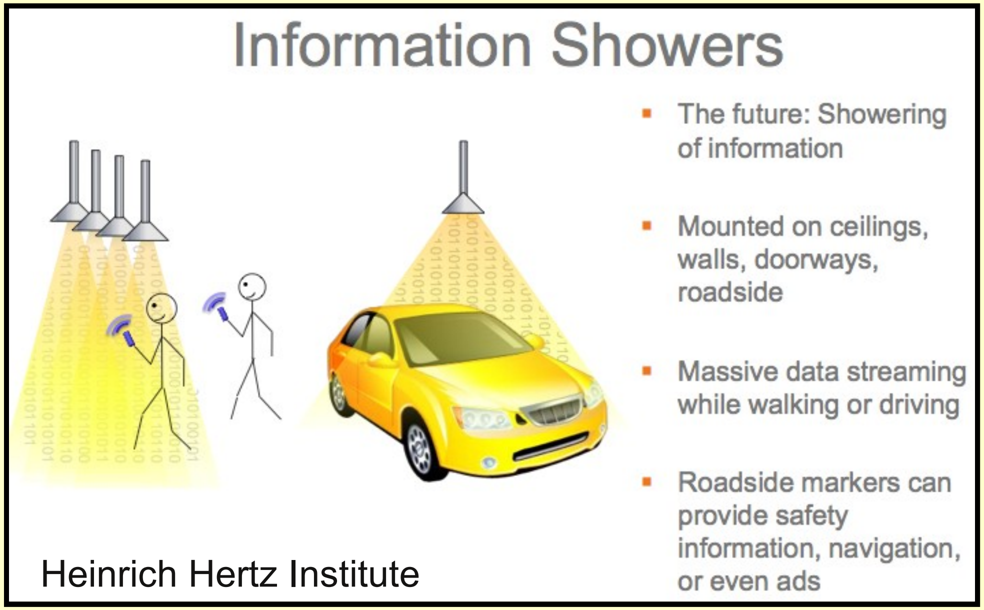


maximum bit rate (Shannon-Hartley)



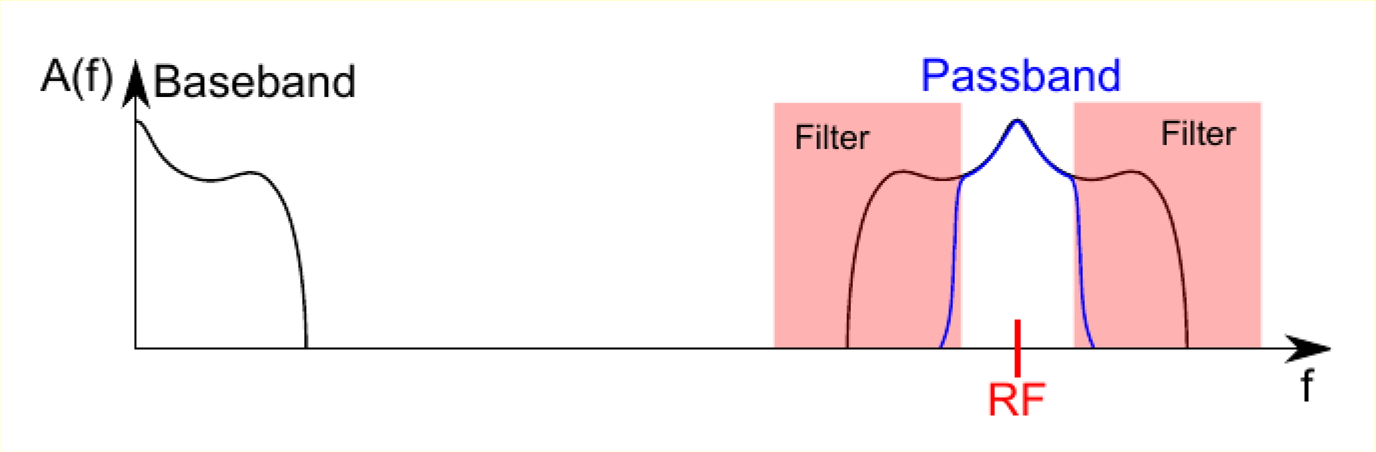
Interests in Industry

- uncompressed video (HDMI → 2 Gb/s)
- airplanes: wireless media system → weight
- home media market → wireless (video, games)
- data kiosk (video, games)
- safe wireless (short range)



Wireless Transmission

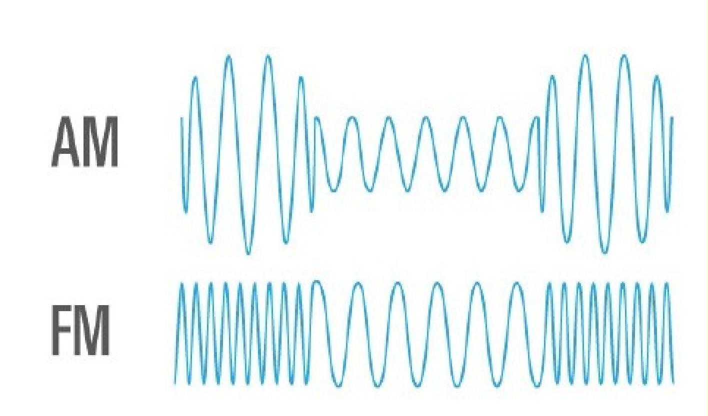
Principle:



baseband ~ 9 GHz   carrier frequency 60 GHz (RF)

Modulation Schemes:

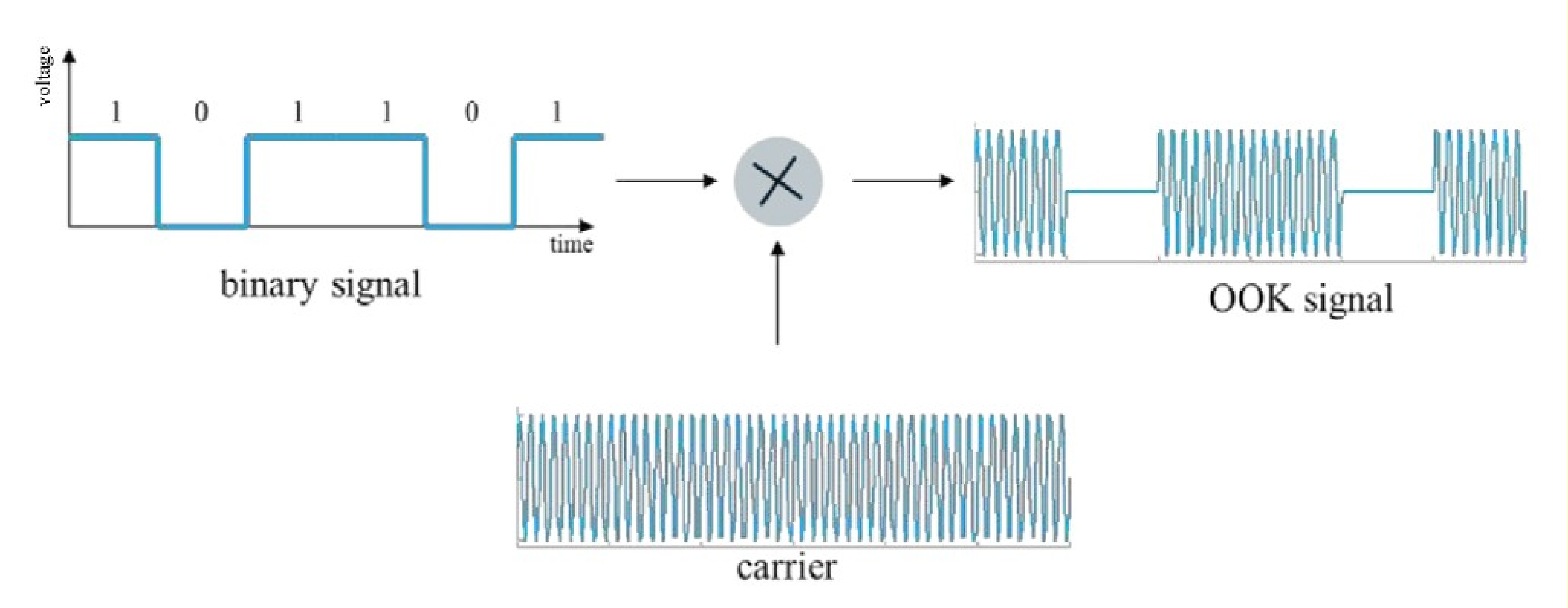
- amplitude modulation (AM)
- frequency modulation (FM)
- phase shift keying (PSK)



Modulation Schemes: On-Off Keying (OOK)

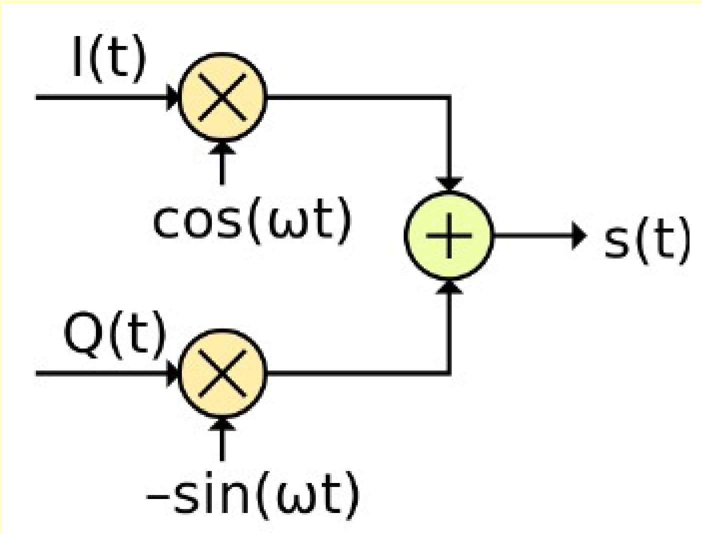
simplest scheme:

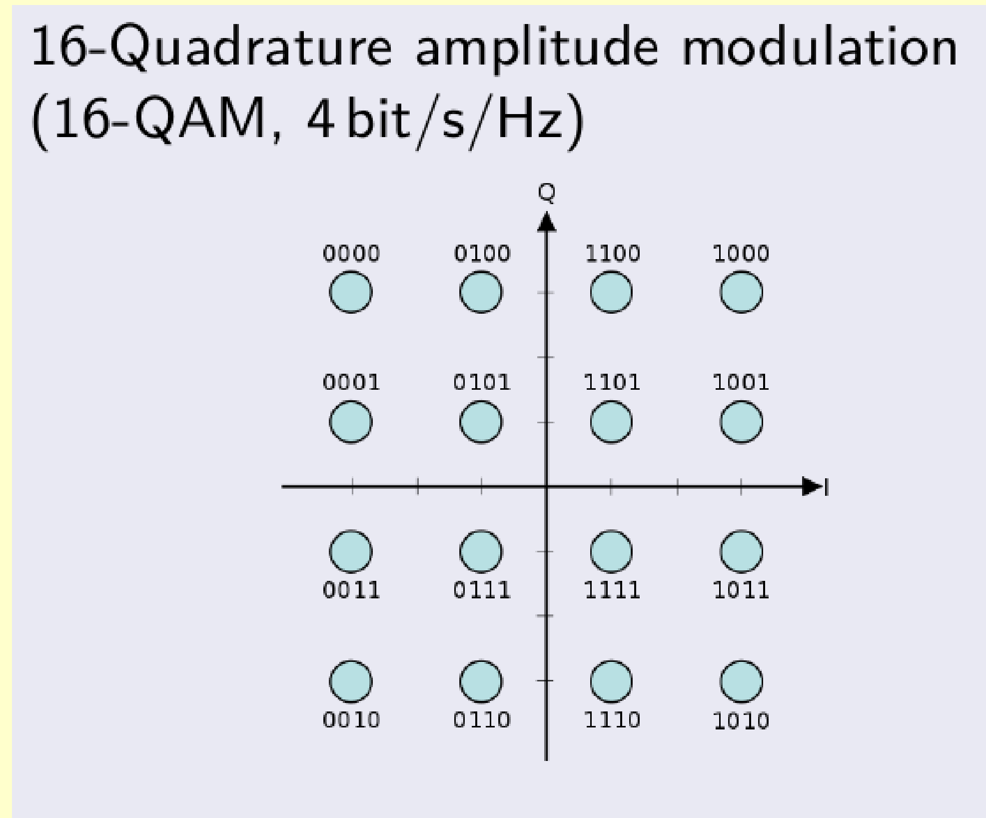
- no large baseband circuitry
- low power consumption
- non-coherent demodulation (clock detection)
- spectral efficiency 0.5 bit/s/Hz



Modulation Schemes: IQ Modulation

IQ modulation:





Requirements:

- coherent modulation*
- ADC baseband circuitry
- high signal to noise

spectral efficiency = 2 bit/s/Hz

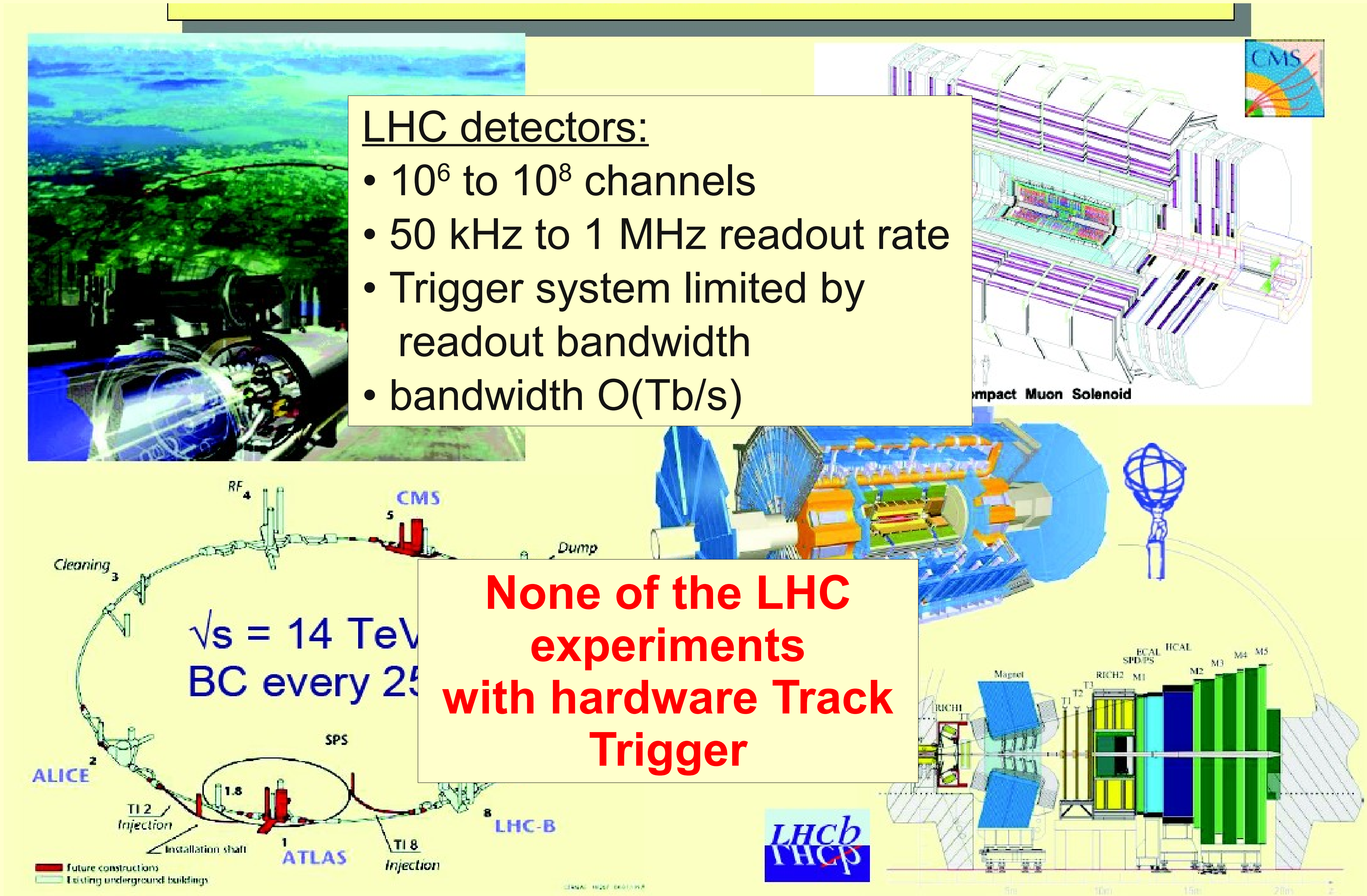
* = receiver needs same clock as receiver

Motivation

Why 60 GHz in HEP?

- high bandwidth
- small form factors (small chip+antennas)
- no connectors (failures)
- low mass
- low power (transmission over short distances)
- high flexibility (readout topology)

Technology Frontier LHC

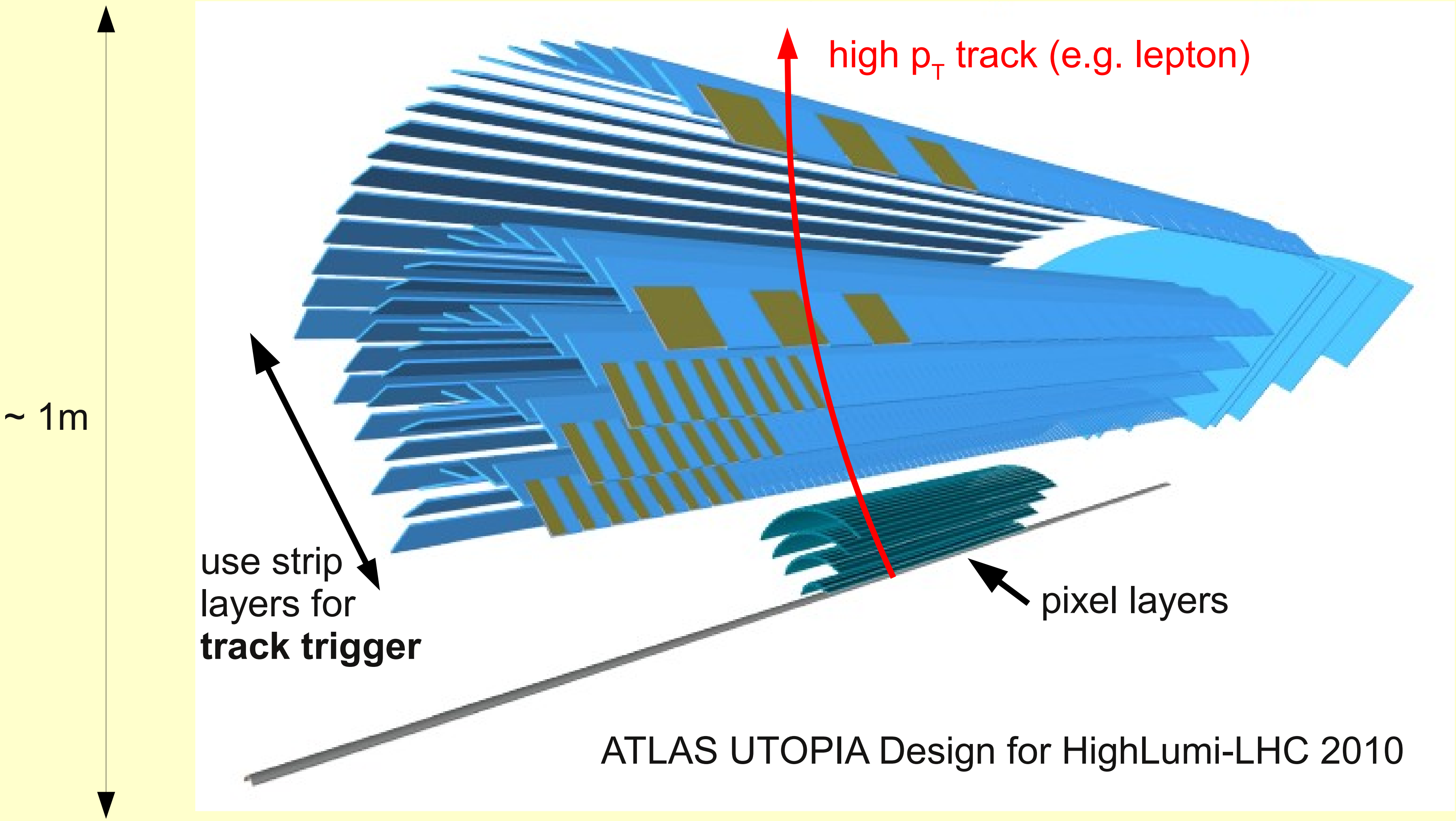


LHC detectors:

- 10^6 to 10^8 channels
- 50 kHz to 1 MHz readout rate
- Trigger system limited by readout bandwidth
- bandwidth O(Tb/s)

None of the LHC experiments with hardware Track Trigger

Self Seeded Track Trigger Concept

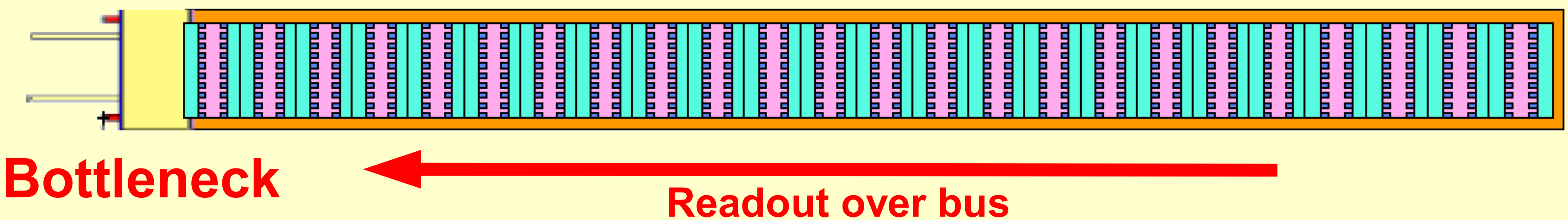


The “First Meter” Bottleneck (ATLAS)

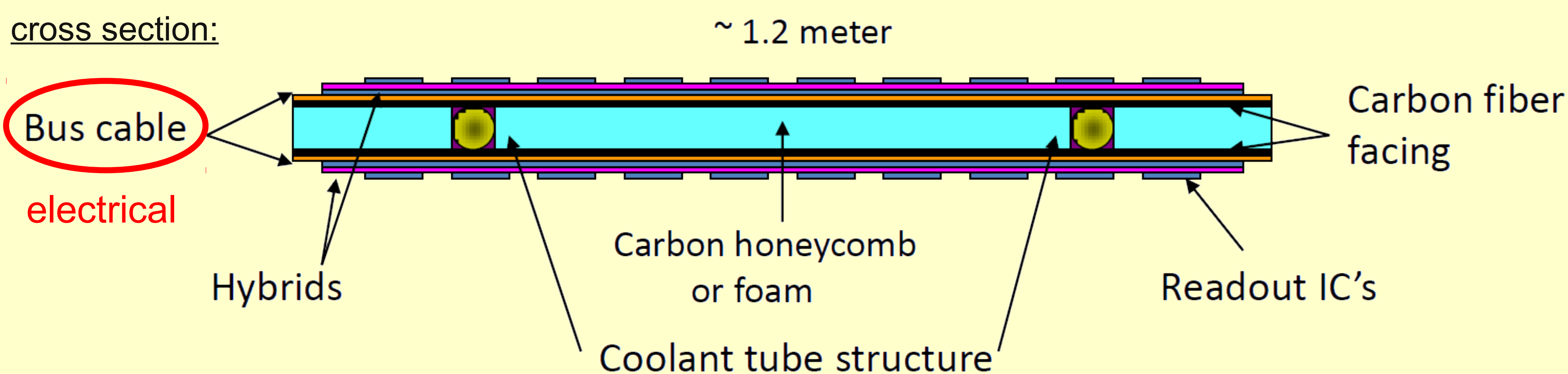
Upgraded ATLAS Barrel Strip Detector

Stave design of stacked strip layers:

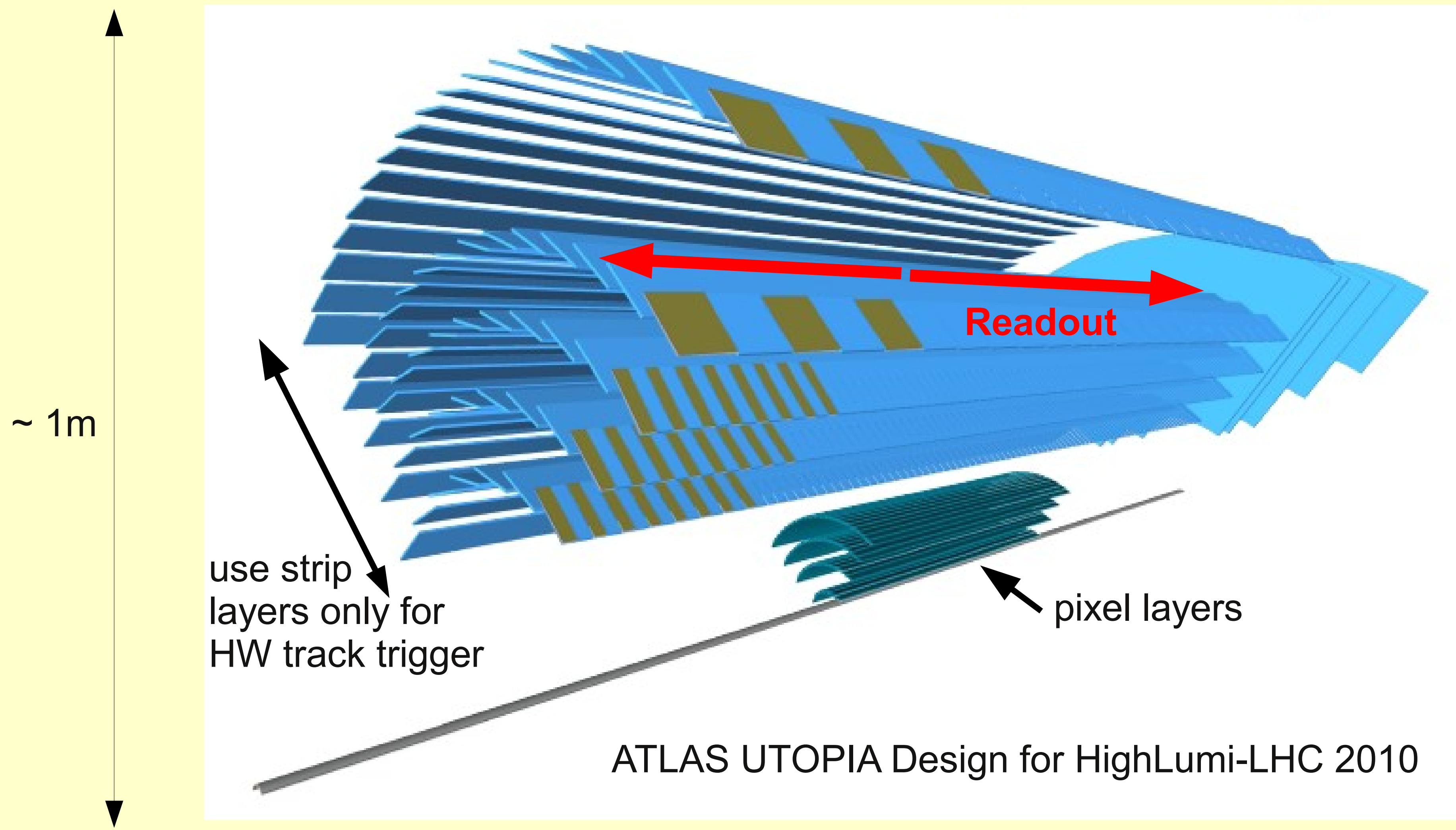
p-type sensors / n-side readout → 160 Mbps per controler



cross section:



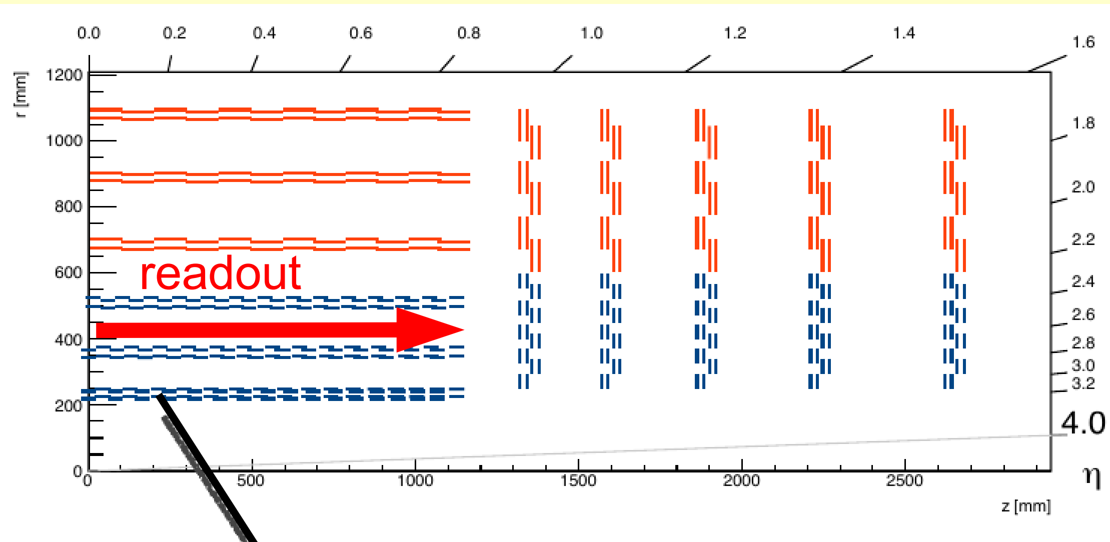
Self Seeded Track Trigger Concept

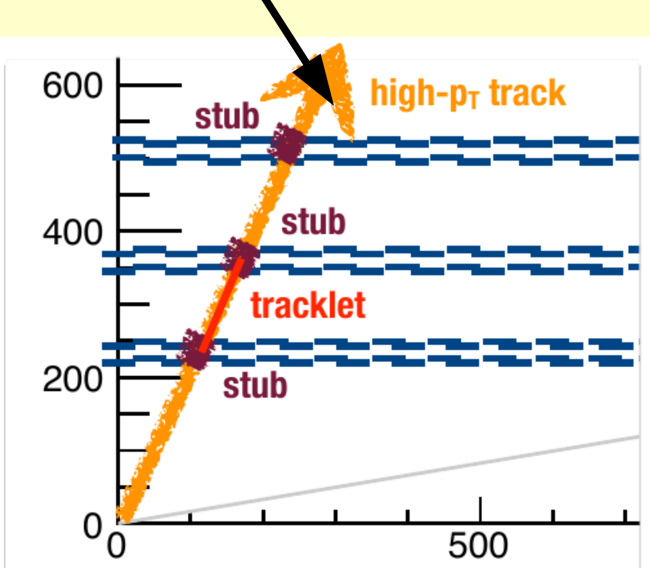


→ additional cables (material) required for hardware track trigger

The “First Meter” Bottleneck (CMS)

CMS Upgrade Detector



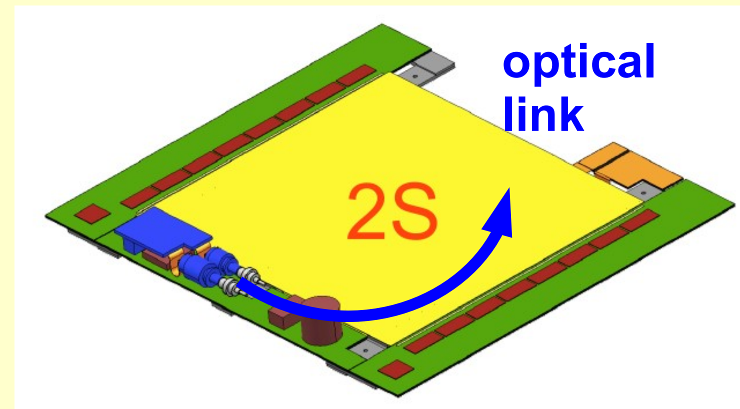


- coincidences define stubs
- stubs define tracklet

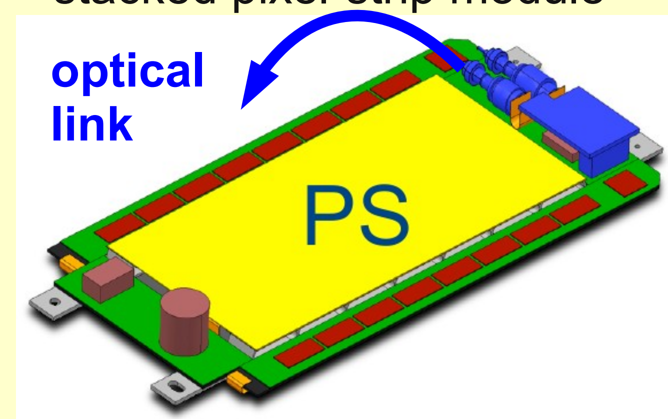
O(10000) links!

Different Modules:

2 strip module (stacked)



stacked pixel-strip module



one of main issues: power consumption!

Critical Parameters

The frontend readout data rate can be characterised by 3 numbers:

Gbps / cm^2

Gbps / g

Gbps / W

new technologies will further improve these numbers up!

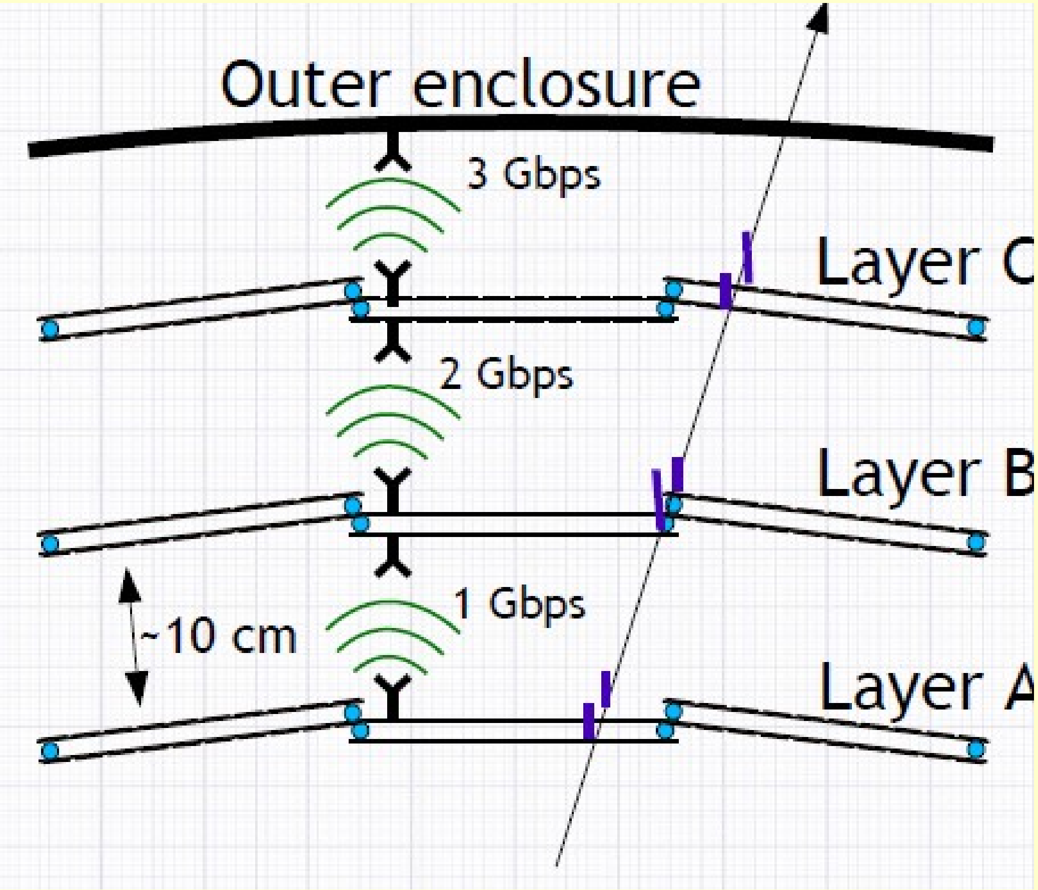
New Concept: Vertical Readout!

Concept

- use 60 GHz wireless for readout
- read out hits along path of tracks
- topology would allow for **local** trigger processing at the frontend
- avoids lot of extra material

Challenges:

- power consumption
- bandwidth
- directional antennas
- noise (reflections)

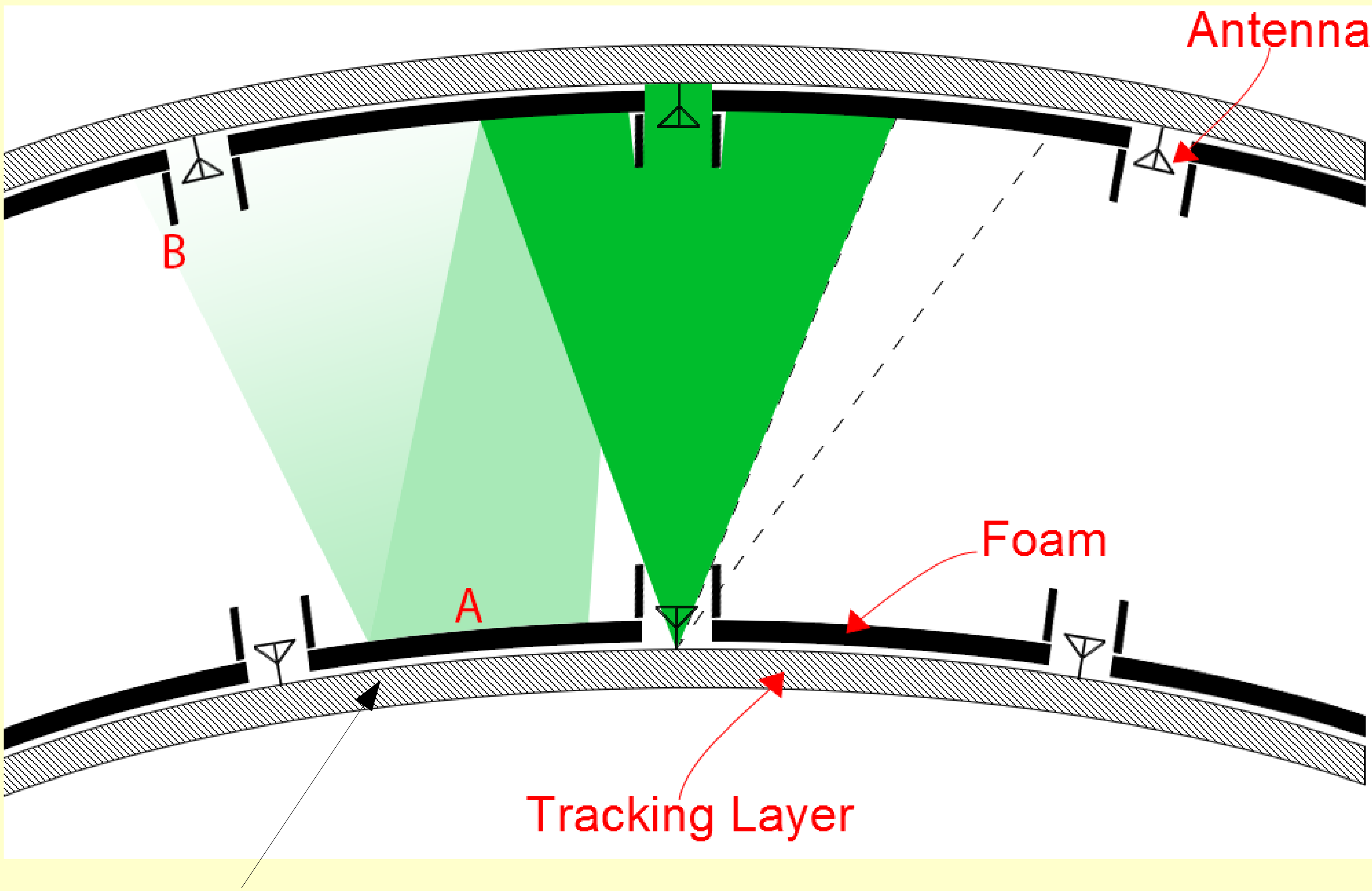


idea by R.Brenner (Uppsala)

Simulations

Noise by reflections:

→ simulated using ray-tracers on GPUs (bachelor thesis Th. Hugle, Heidelberg)

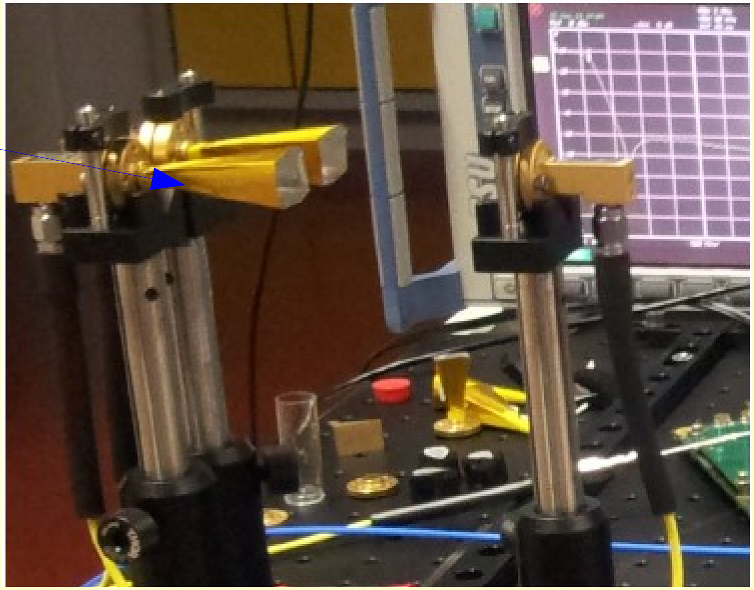


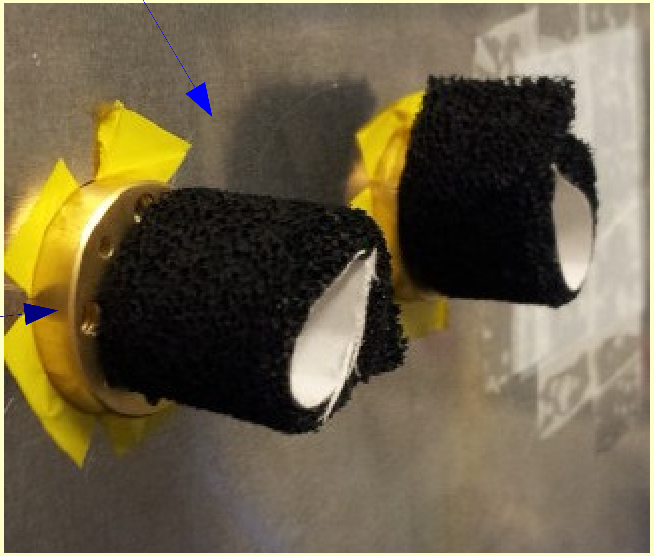
shielding by carbon-foam absorber

Antennas

<u>Different antenna types tested in Heidelberg:</u>

- (massive) brass horns
- self made aluminised thin kapton horns
- only shielding pipes (carbon foam)



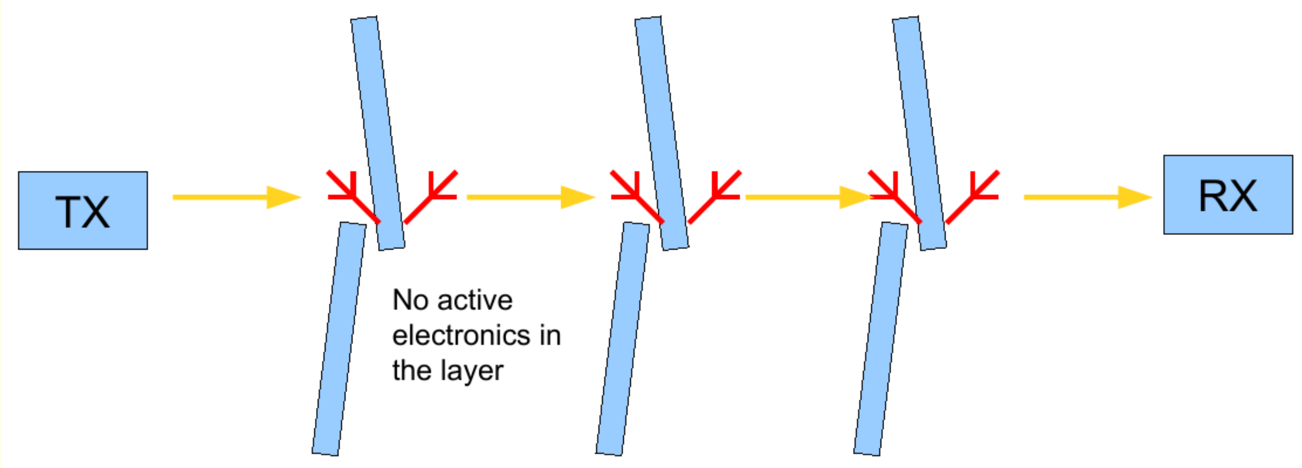


carbon foam
put on
wave guide

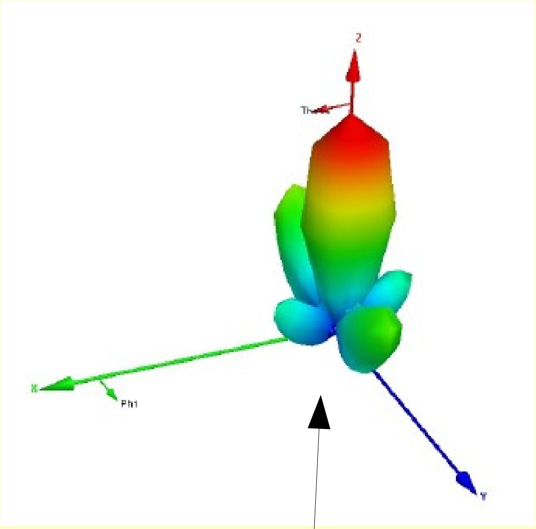
→ no real antenna (no amplification)

Patch Antennas

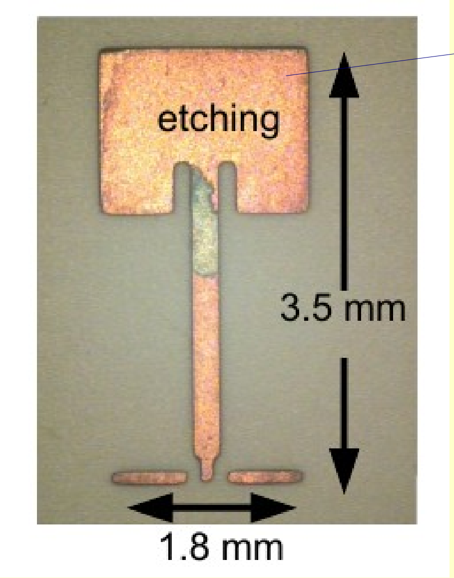
Passive transmission (Uppsala: R.Brenner, D. Pelikan et al.)



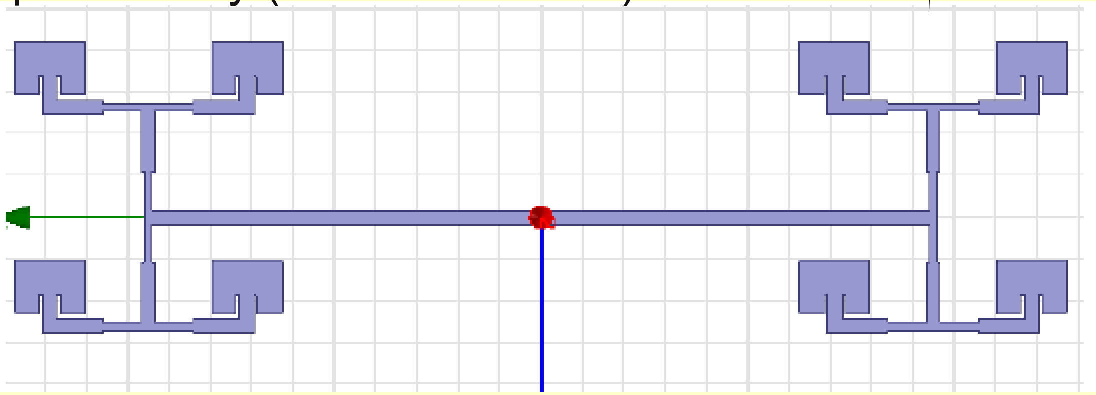
e.m. field (simulation)



etched antenna

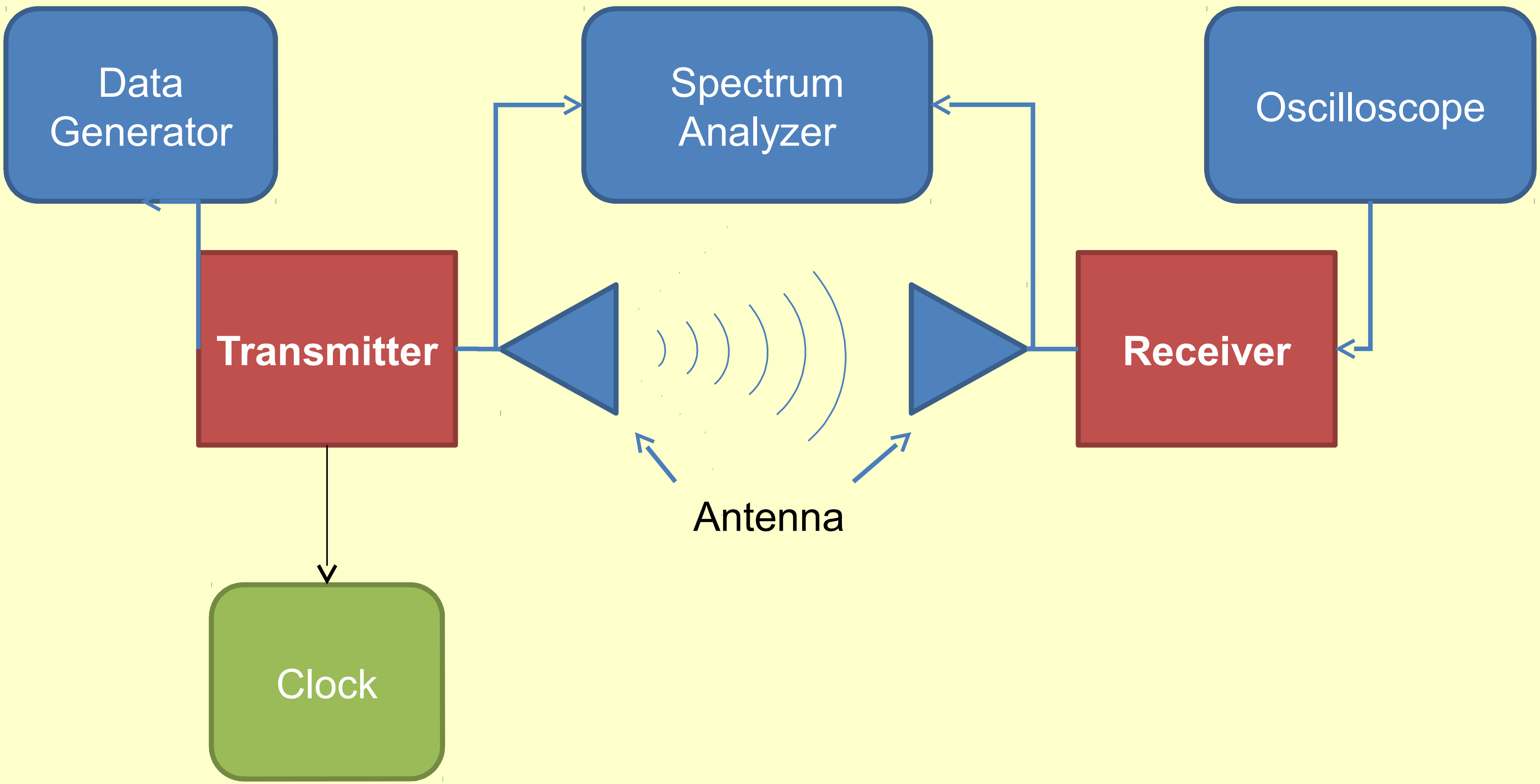


patch array (more directional)



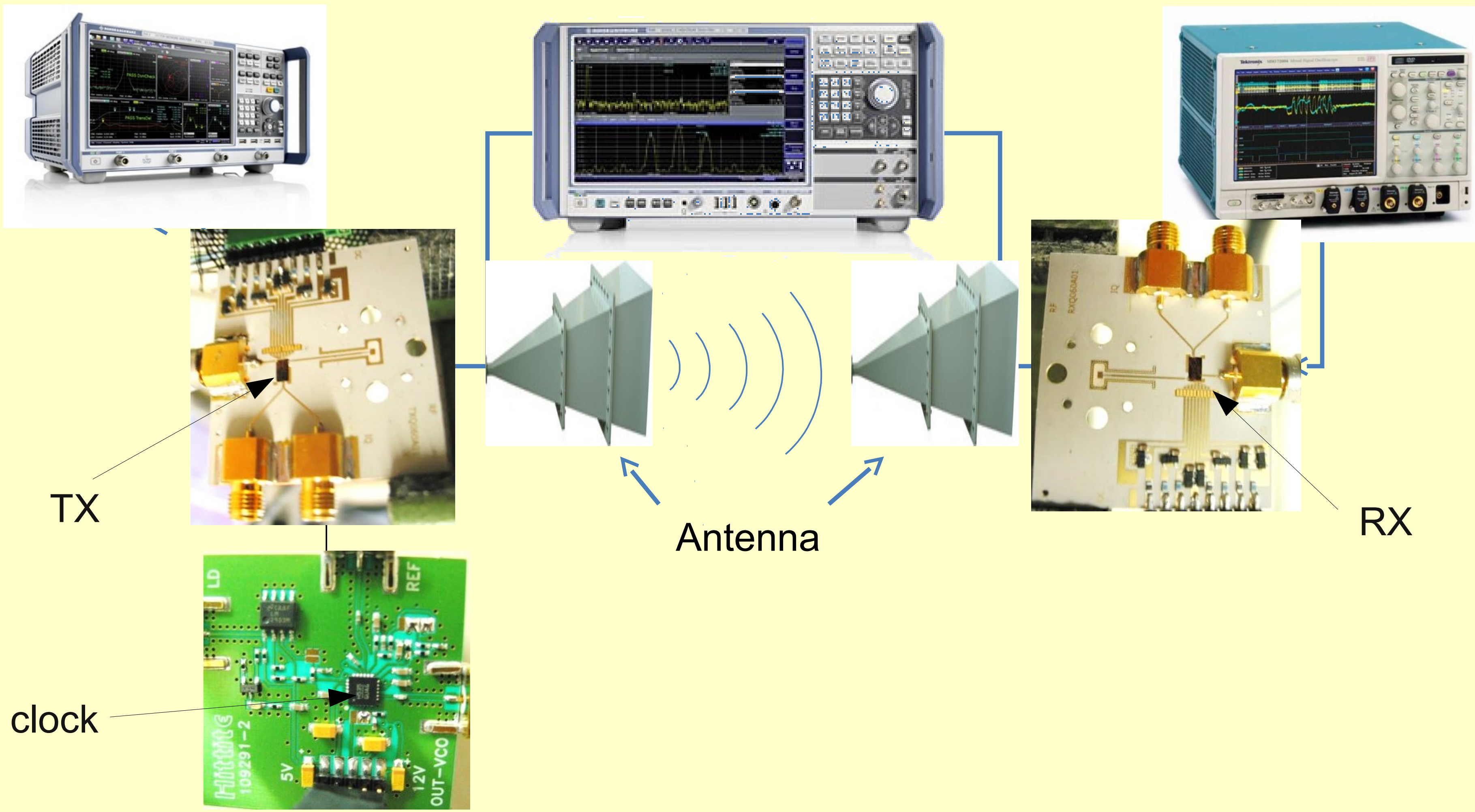
Lab Tests

Commmercial 60 GHz transmitters and receivers:
→ GOTMIC chipsets
→ Hittite evaluation boards (1.8 Gb/s)



Gotmic Lab Test

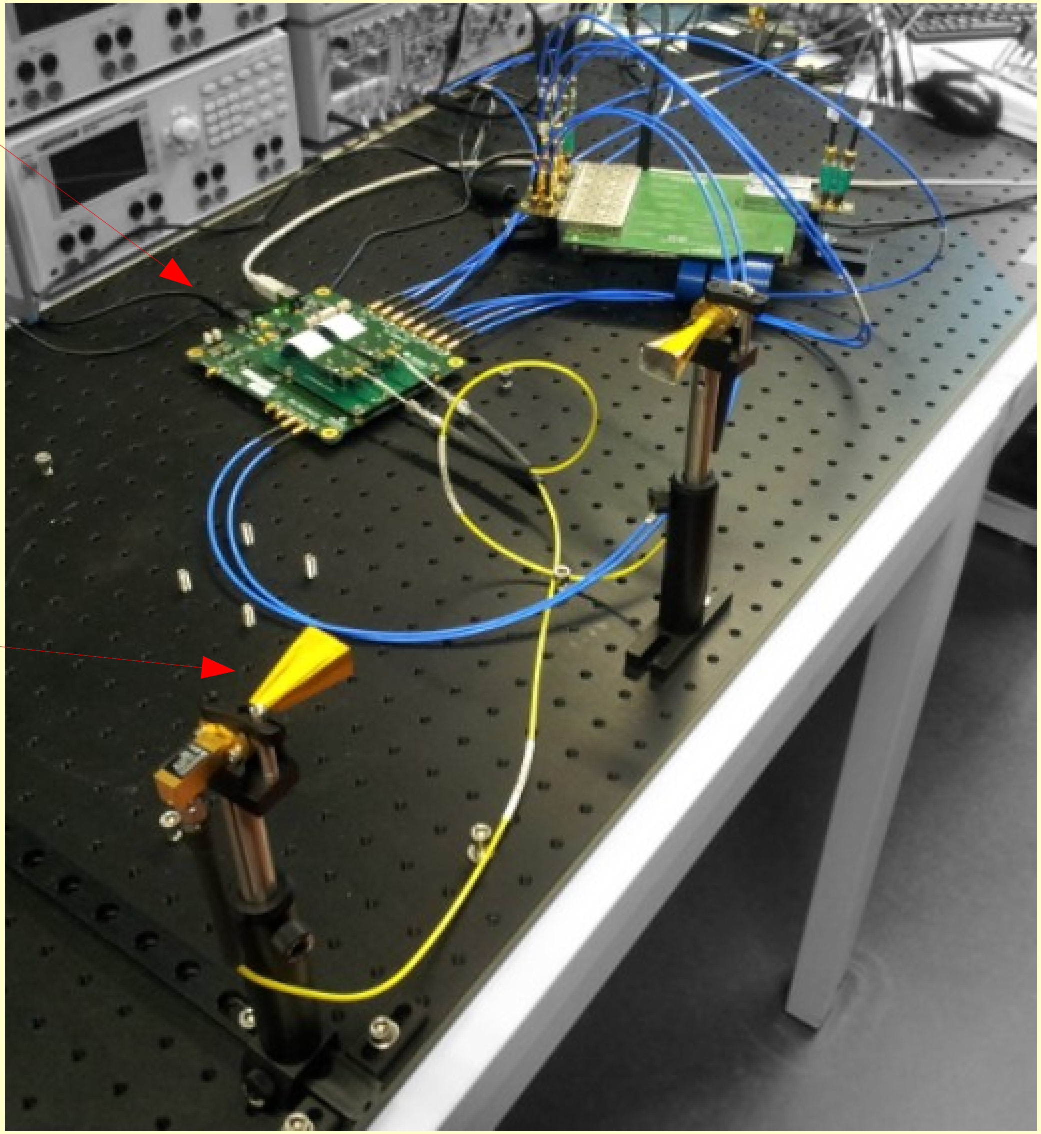
Gotmic chipset test setup (3.5 Gbit/s baseband)



Hittite Lab Test

Hittiite Evaluation Board
with FPGA (1.8 GHz)

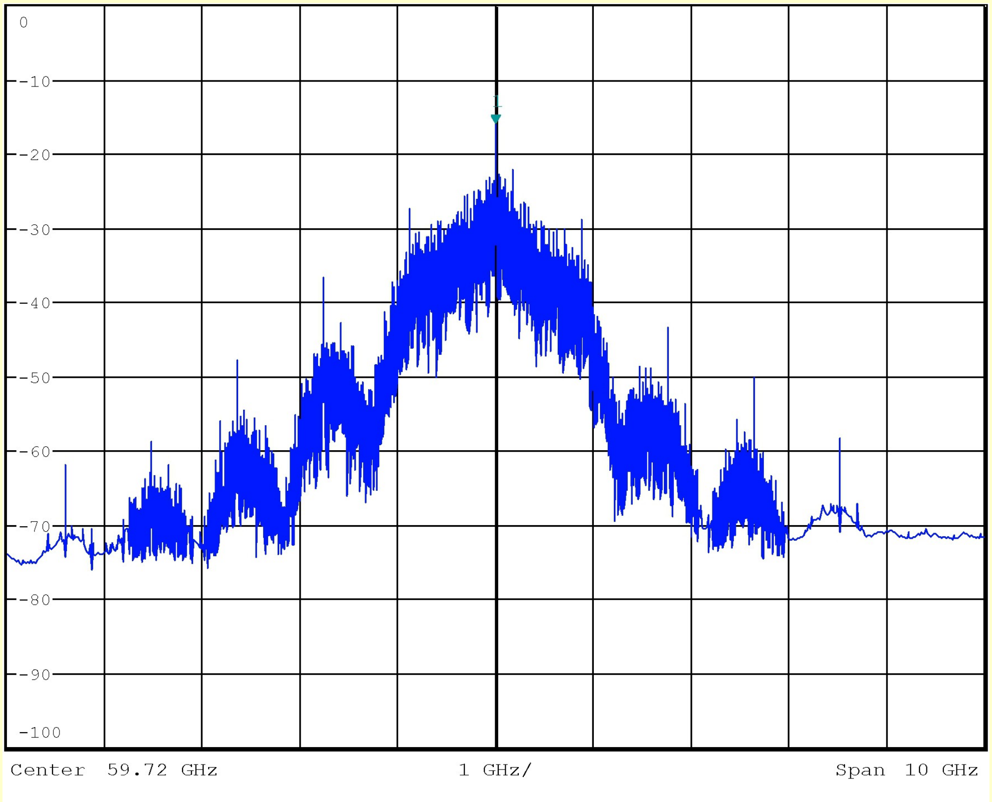
→ used for bit error tests



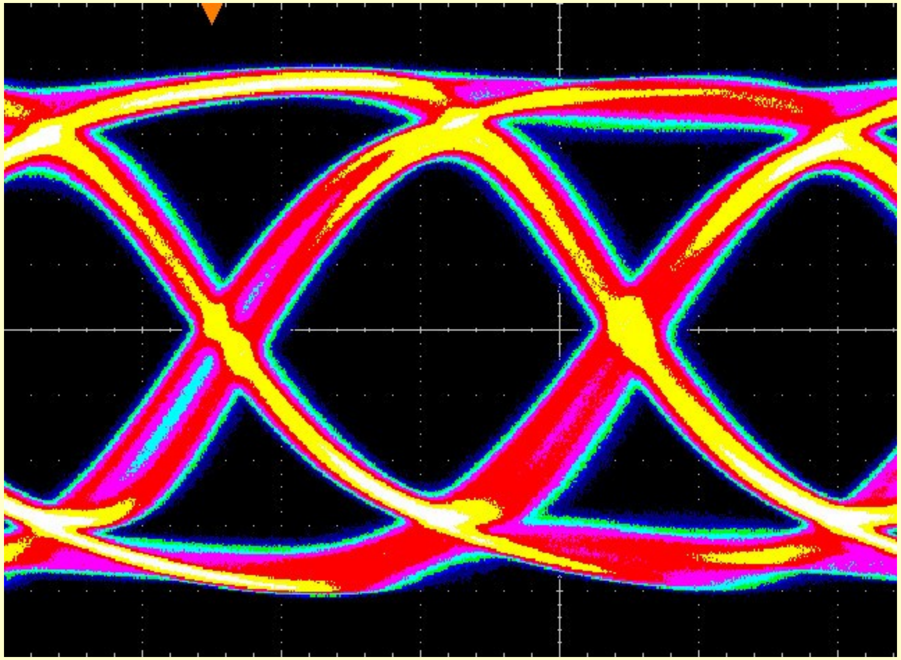
self made
aluminised 50 µm thick
kapton horn antennas
(low mass)

Results

Frequency spectrum:



Eye Plot (1.8 Gbs)



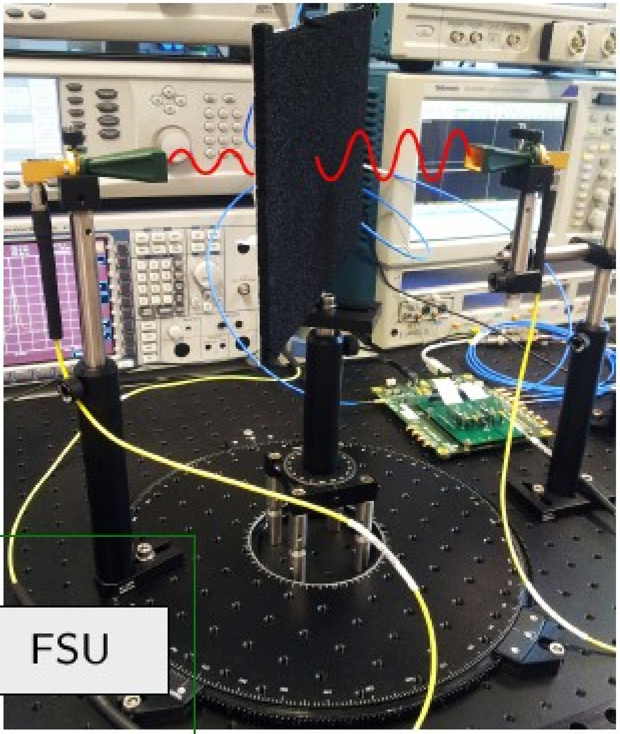
Measured bit error rates at

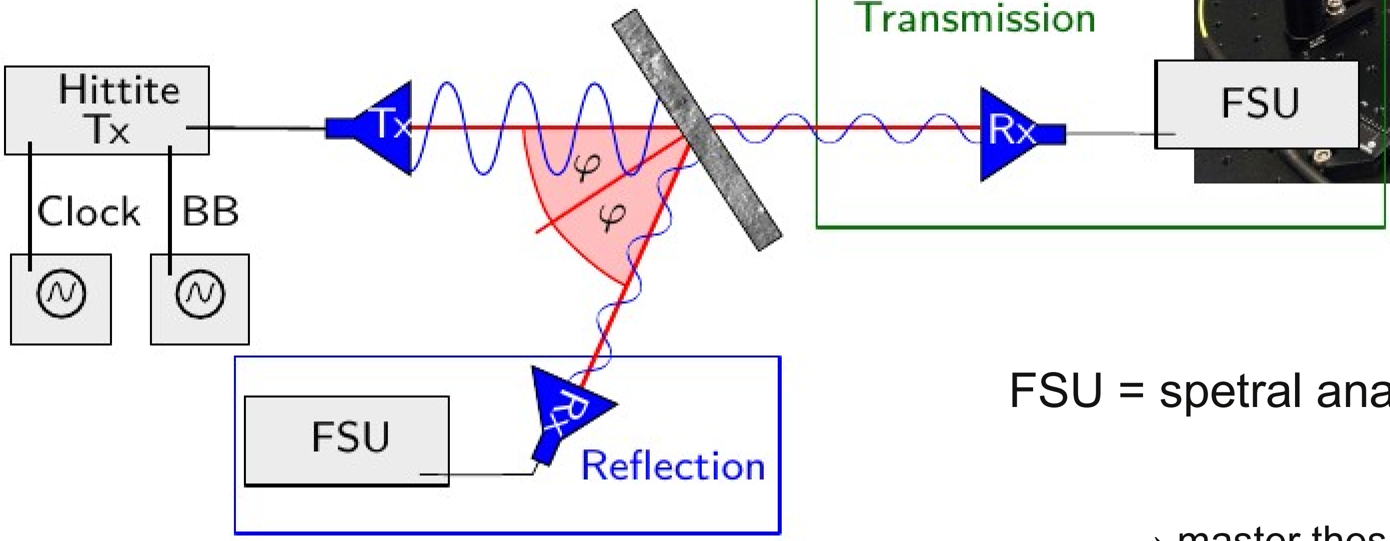
- 1.76 Gbps $BER < 4.0 \times 10^{-15}$
- 2.00 Gbps $BER = 7.5 \times 10^{-13}$

fast and stable data transmission

Characterisation of Materials

- Characterize reflection and transmission of
  - common detector materials to estimate crosstalk signal power
  - graphite foam as a candidate to be used as absorber



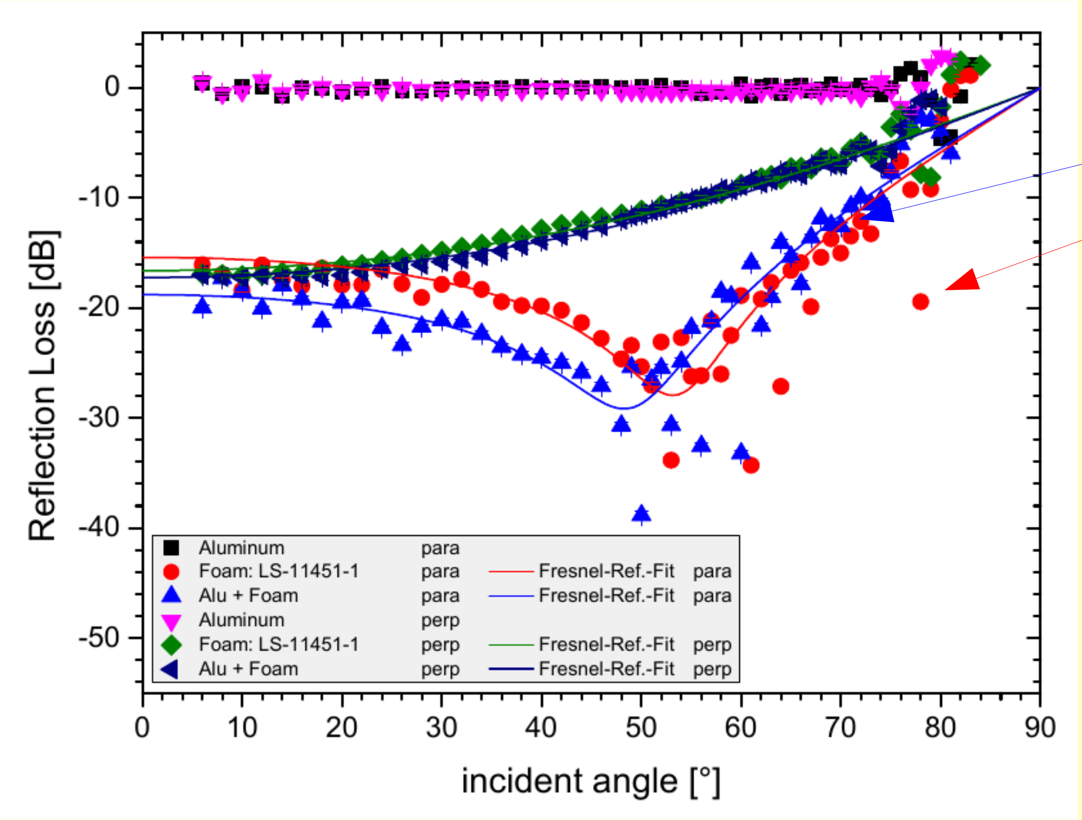


FSU = spetral analyzer

→ master thesis Sebastian Dittmeier

Reflection Measurements

Reflection of different materials:

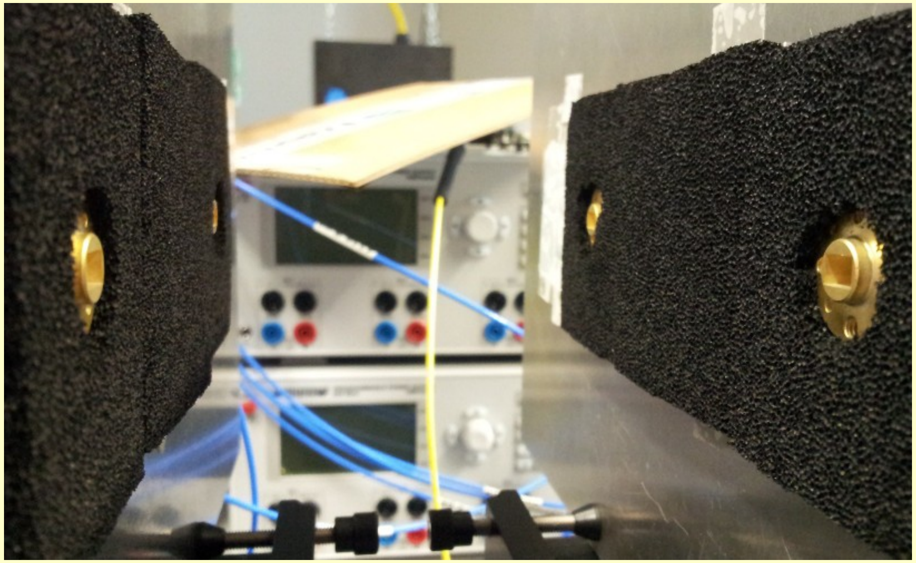


carbon foam + alu

carbon foam

→ motivates to use carbon foam to reduce reflections

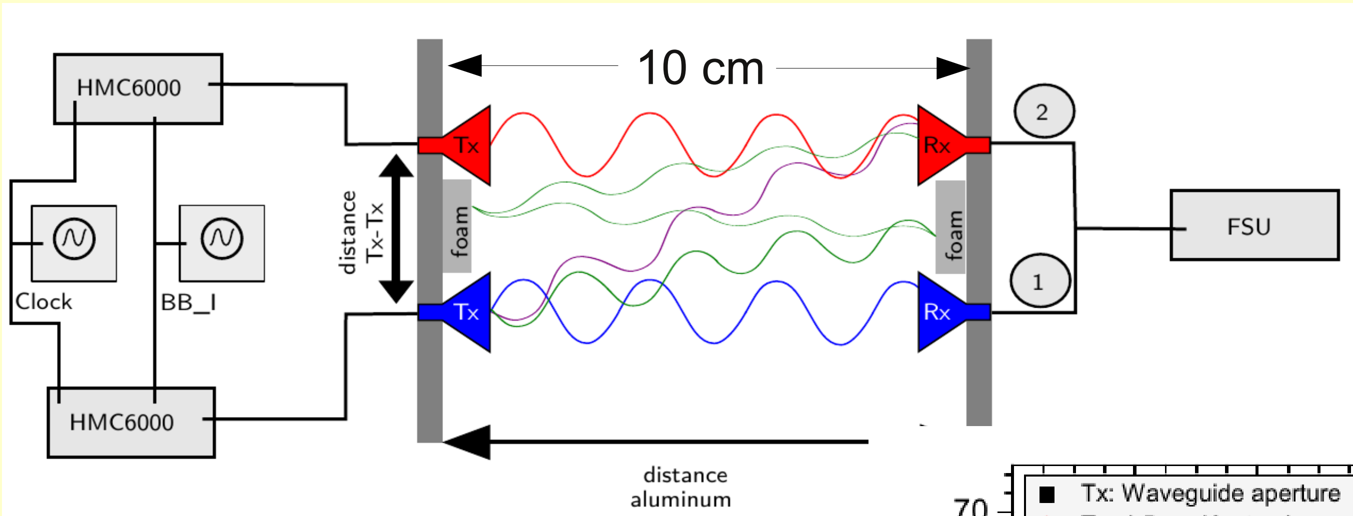
→ master thesis Sebastian Dittmeier



also different polarisations measured:

- parallel to surface
- perpendicular to surface

Operation of Parallel Links

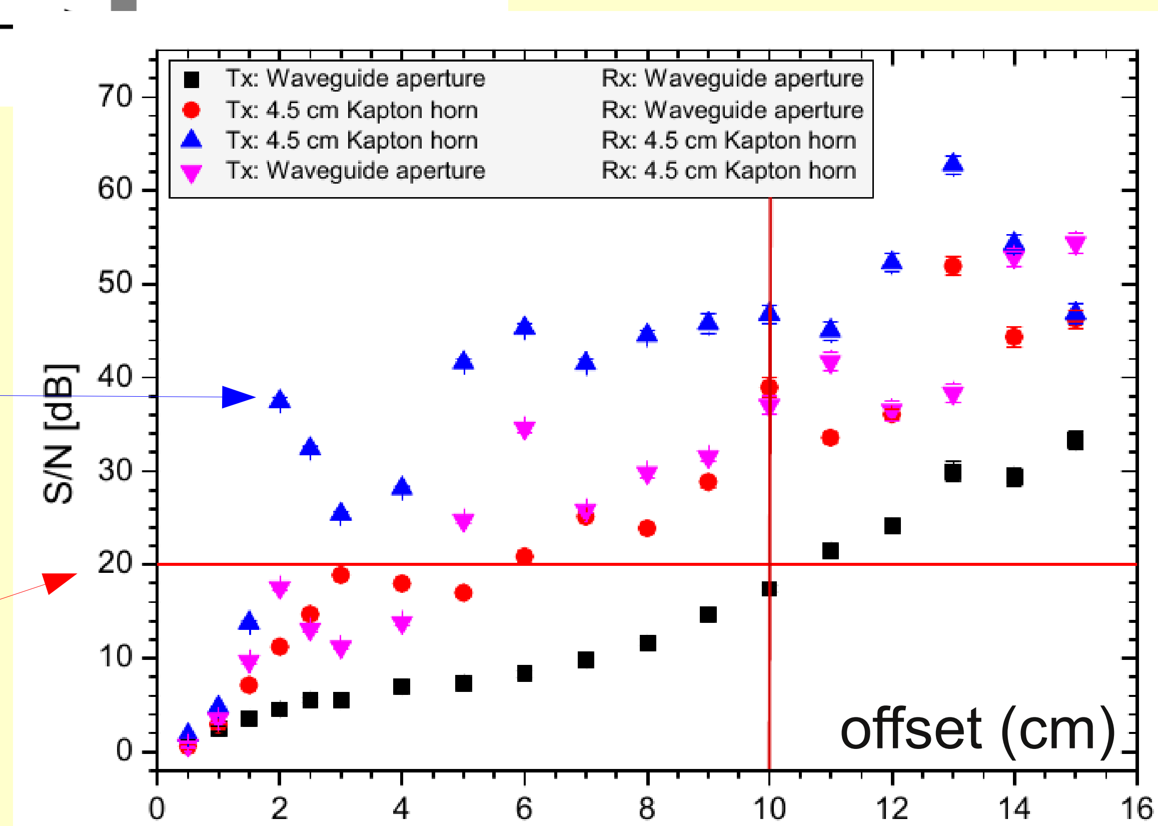


How close can we put wireless links?

Results for transmision distance=10 cm:

Transmitter + Receiver with kapton horn antennas

S/N ~ 20 dB required for stable transmission

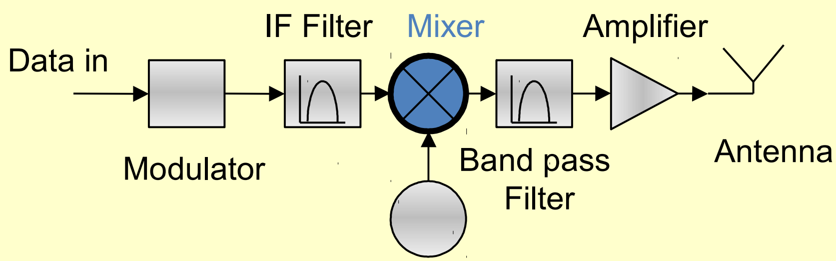


New 60 GHz Transceiver Chip (Heidelberg)

existing 60 GHz chipset not very convenient for HEP application → develop new chip

Transmitter:

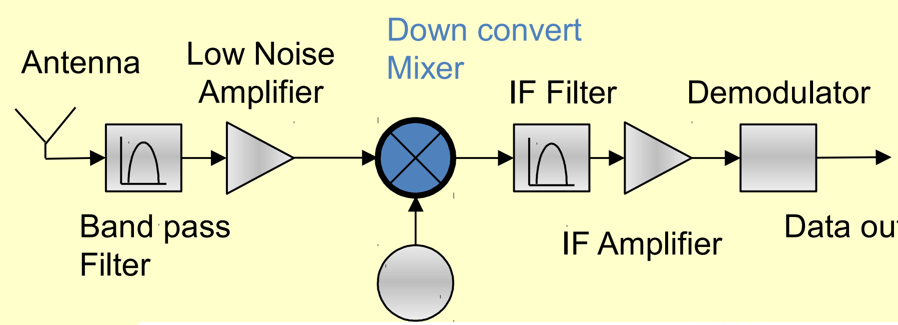
- high power efficiency
- high gain and stability

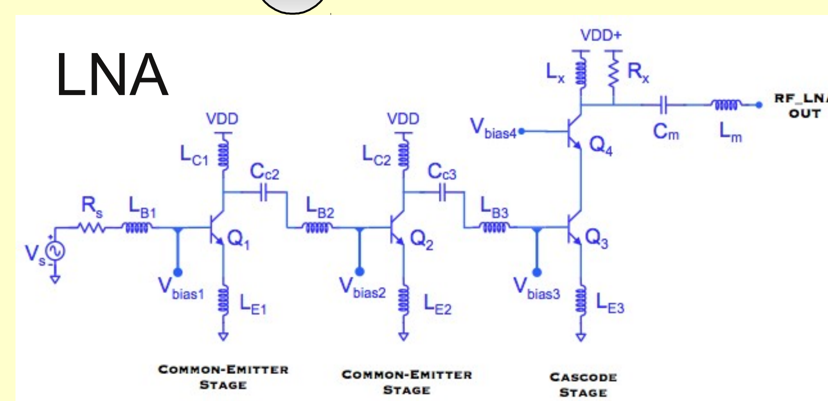


- power dissipation (10 mW)
- noise figure (6dB)
- linearity + stability
- impedance matching
- power gain (16dB)
- bandwidth (>10GHz)
- insensitive to process variation, temperature, etc.

Receiver:

- low noise amplifier
- balance gain, linearity and noise
- low power dissipation





Designer: Hans-Kristian Soltveit

Plans

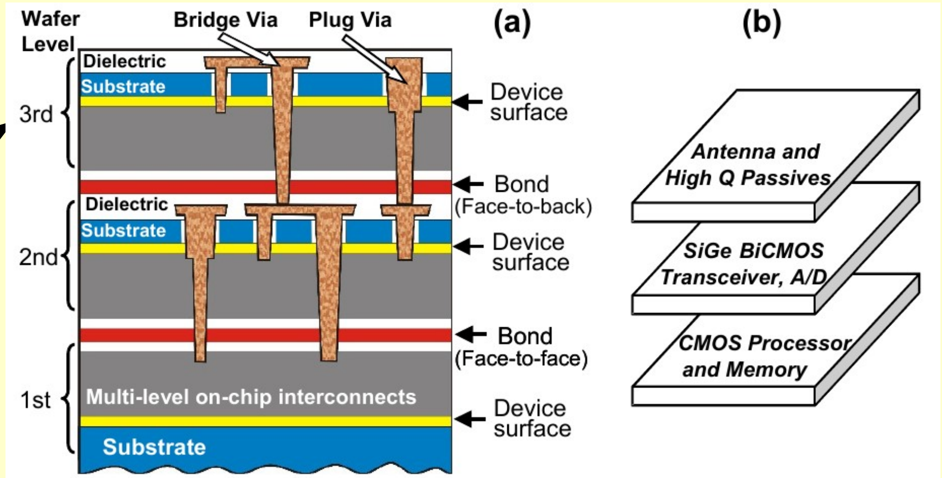
near future:

- finish design of 60 GHZ transceiver prototype (130 nm SiGe BiCMOS HP)
- modulation: on-off keying → bandwidth 3.5 Gbit/s
- submission and test of prototype chip
- build 60 GHz demonstrator for HEP-experiments

long term plan:

- integrate antenna, HF circuitry and RF layer in one single chip
- 3D chip technology

3 tiers



→ presentation by Hans-Kristan Soltveit in September FCC-ee meeting

Possible Applications of 60 GHz technology at FCC

Projection 2035: wireless 100-200 GHz providing ~50 Gbit/s per link?

FCC-pp

- conditions not very different from HL-LHC
  (similar lumi, similar track multiplicities)
- wireless readout of tracker (→ track trigger), colorimeter (→ particle tracking?)

FCC-ee

- particle rates several orders of magnitude smaller compared to FCC-pp
- expect no bandwidth limitations for reading out **all event data**
- all events reconstructed in filter farm (→ no hardware trigger) ?
- wireless readout might be interesting for **inner tracking detector** to save material (radiation lengths)
- However, highly integrated circuitry implemented on silicon pixel sensors will probably allow to construct a monolithic pixel tracker without any additional readout circuitry (e.g. HV-MAPS technology)?

Summary

- 60 GHz technolgy is very promising for HEP applications
- readout densities of ~ 1 Gbit/s/cm^2 seems possible
- radiation hard 60 GHz chip being developed in Heidelberg
- new collaborators are highly welcome!