FROM RESEARCH TO INDUSTRY

cea tech

WADAPT: Wireless Allowing Data and Power Transfer

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On behalf of the “WADAPT” consortium

www.cea.fr

leti & list

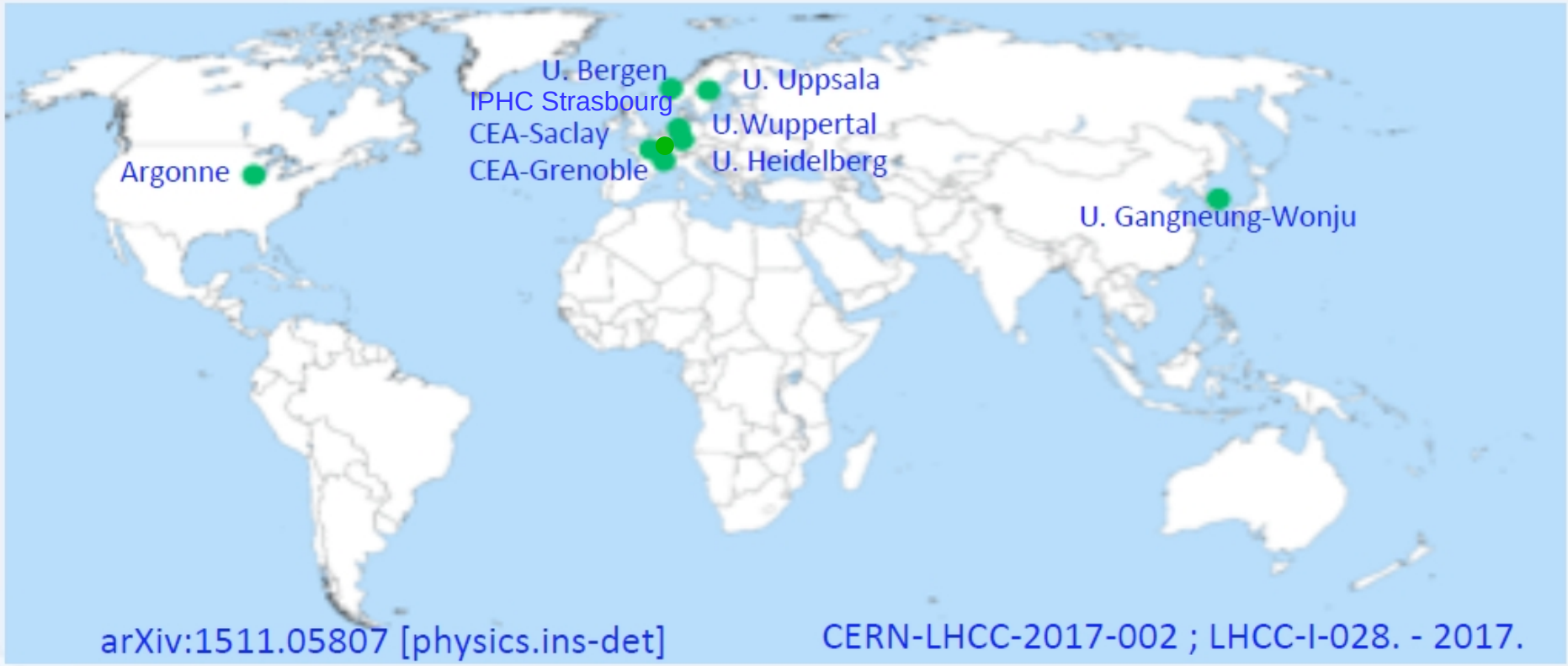
Outline

- Context and motivation, the WADAPT initiative
- Wireless readout using millimeter wave, rationale
- Feasibility tests for HEP
- Perspectives

WADAPT Collaboration

The WADAPT (Wireless for Data and Power Transmission) Project

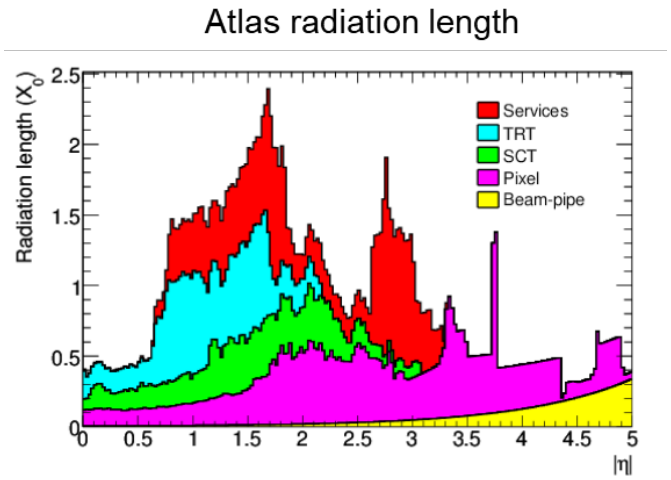
formed to identify specific needs of projects that might benefit from wireless technologies

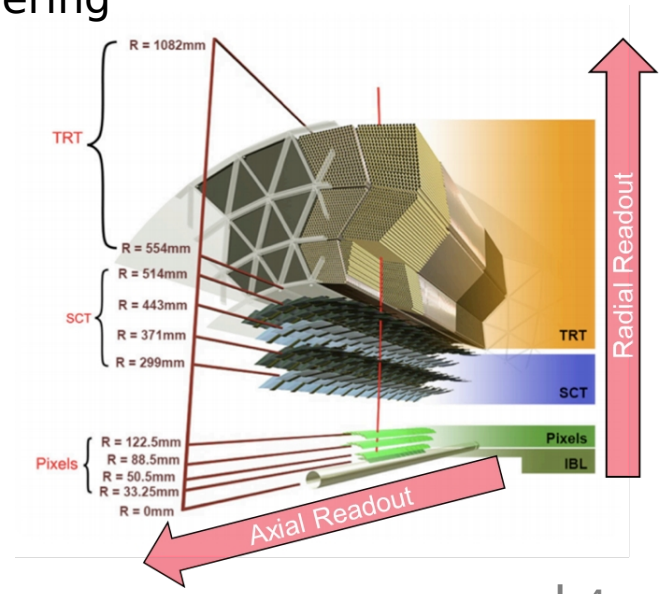


Why Wireless ?

- Cables
  - Create multiple scattering and nuclear interactions, dead-zone areas
  - Impact on the installation and the operation
  - Axial readout induces important latencies

- Wireless
  - Minimize material budget of cables/connectors
    Reducing the radiation length of massive services in region between Barrel and Disks
  - Direct communication between layers (radial readout)
  - More flexible transceiver placement
  - Point-to-Multipoint links, interlayer intelligence
  - Data follows event topology enabling fast triggering

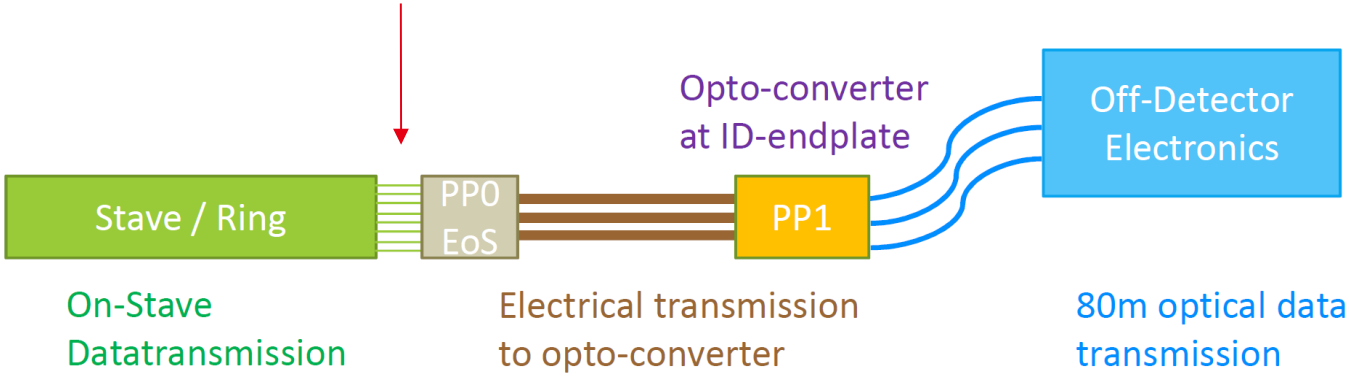




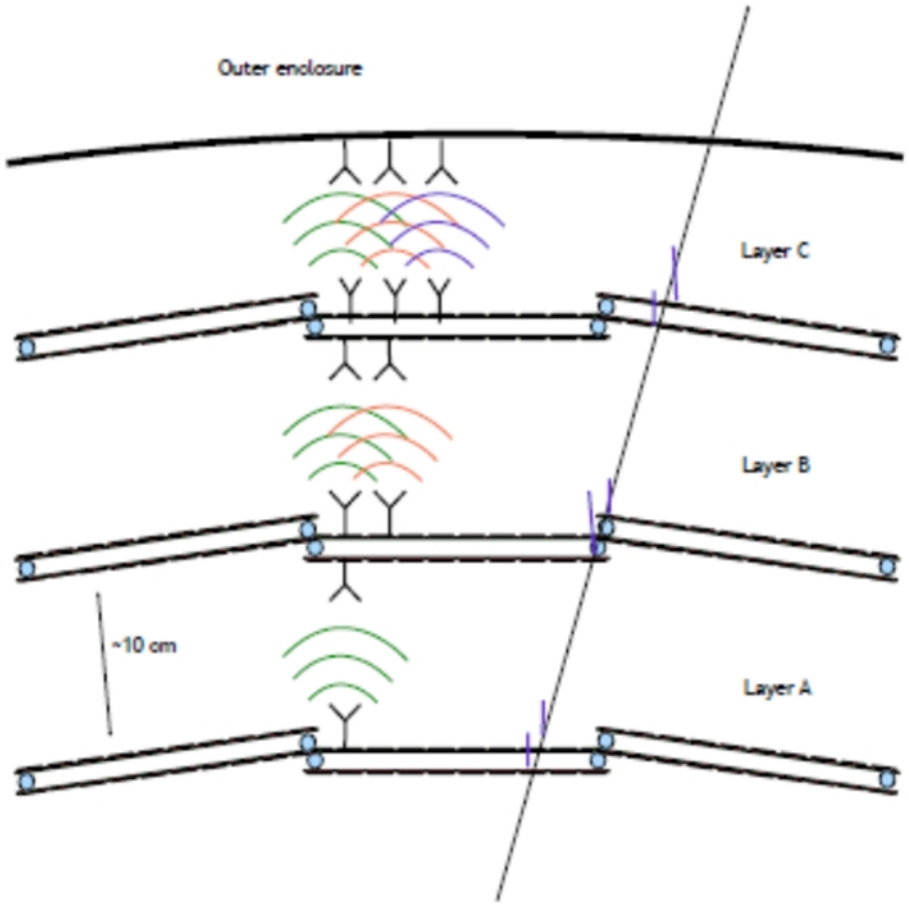
Context: bandwidth requirement

- High demand on bandwidth in present & future experiments
- Especially true for highly granular tracking detectors operated at high beam luminosities

- Example: ATLAS Phase II New Inner Tracker Pixel Detector
  - 1m radius pixel detector with five barrel layers and four end-cap rings and a silicon strip detector with four layers and six end-cap disks
  - Readout at up to 4MHz (25µs) L0 rate
  - Downlink: Broadcast trigger and control signal at 160Mb/s
  - Uplink: over 10000 links at 5 Gb/s
  - Distance between stave and opto-electrical converters: 5 -7 m on copper cables (twisted pair, TwinAx or Flex cables)



Proposed wireless readout approach



Wireless readout concept

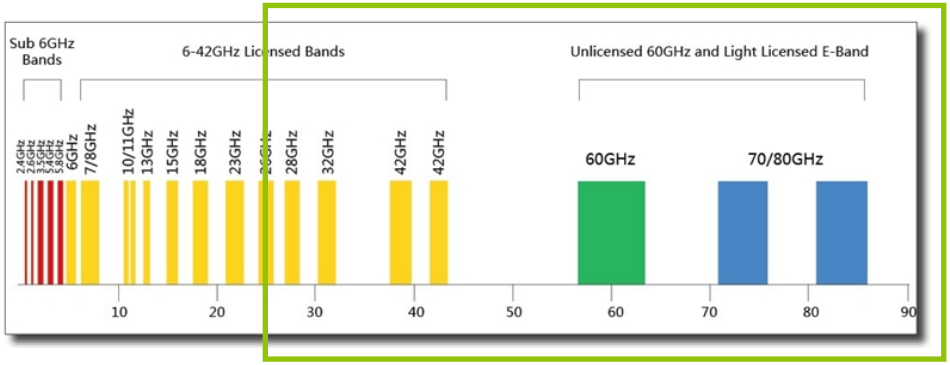
- Radial data transfer
  → Communciation between layers
- Signal cannot penetrate layers
  → Reuseability of frequency channels

Richard Brenner – Uppsala University

Short range, low power, no latency, wireless connectivity required !

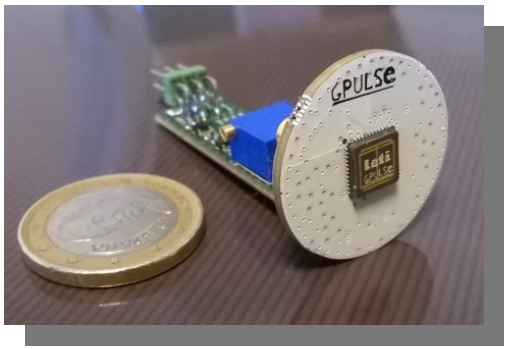
Introduction to millimeter wave

- Definition
  - 1-10mm wavelength
  - 30-300GHz carrier frequency



- MmW rationale
  - Short wavelength
    - High level of integration, compact antenna scheme
  - High free path loss
    - Suitable for short range
    - High frequency reuse
  - Huge available bandwidths for high data rate communication

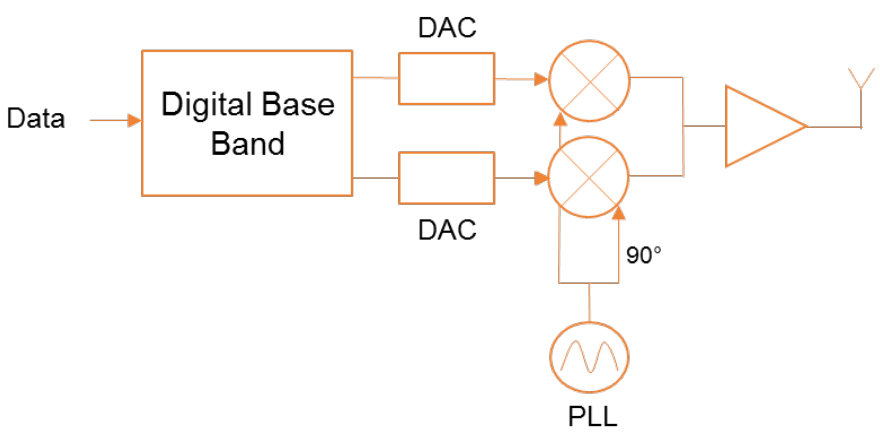
    14GHz in V Band (57-71GHz), 35GHz in D Band
  - Natural immunity to interference
  - RF Integrated Circuits: Frequencies still compatible with low cost and low power CMOS technologies

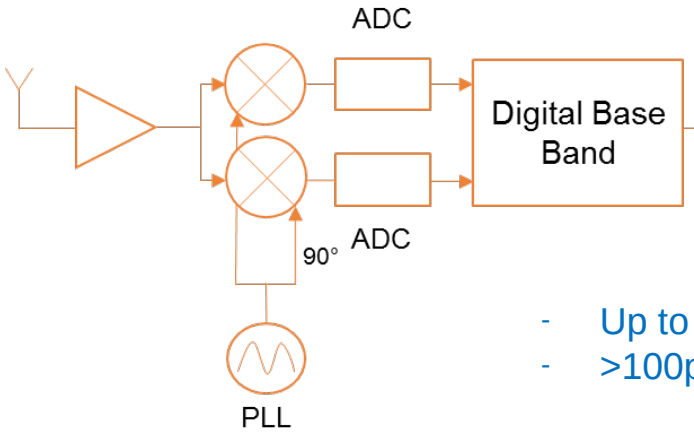


60GHz system in package with integrated antenna

RF Integrated Circuits architectures

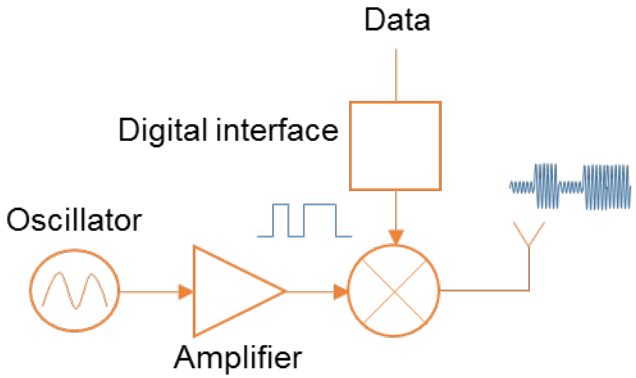
Coherent RFIC architecture

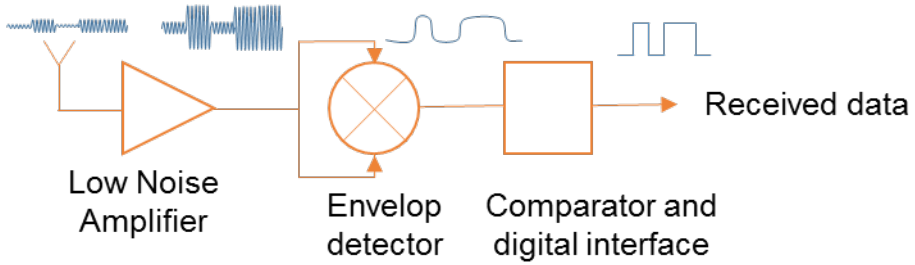




- Up to 6 bit/Hz
- >100pJ/bit

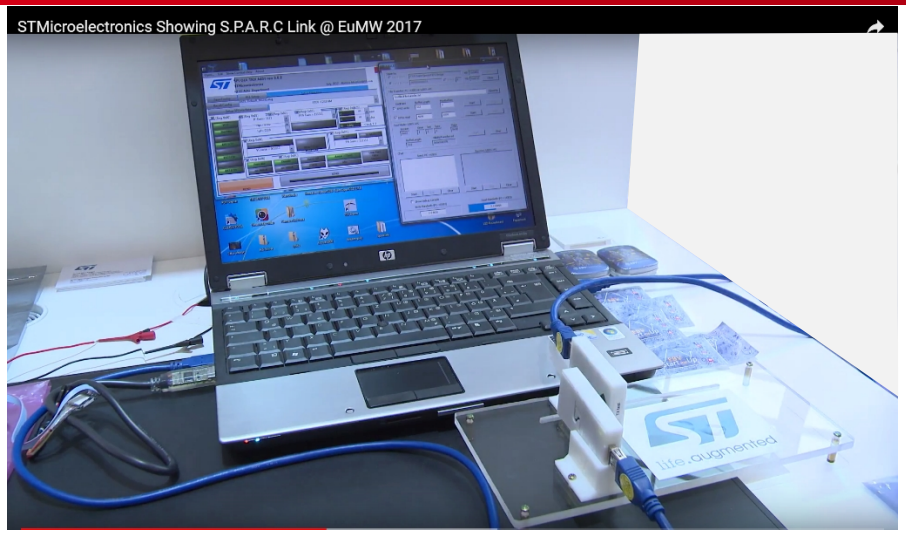
Non coherent RFIC architecture (On/Off keying)



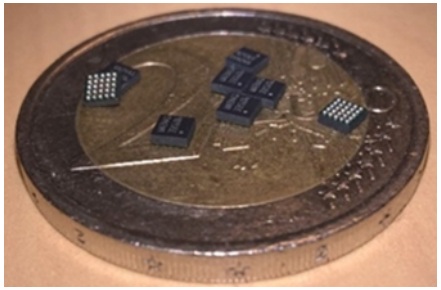


- <1bit/Hz
- ~5pJ/bit

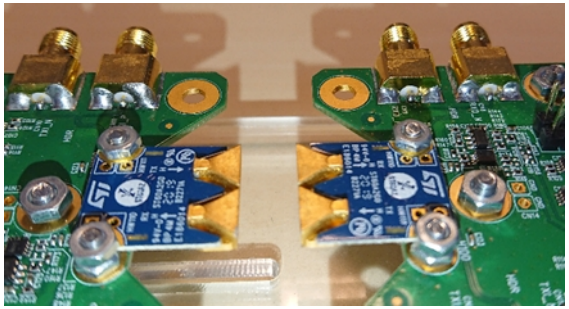
60GHz RFIC



60GHz contactless connector



Technology:
-60GHz ASK transceiver in CMOS 65nm
-Non coherent receiver (envelop detector)
-BGA package (2x2 mm²)
-In package or on PCB antennas, range extension using lens



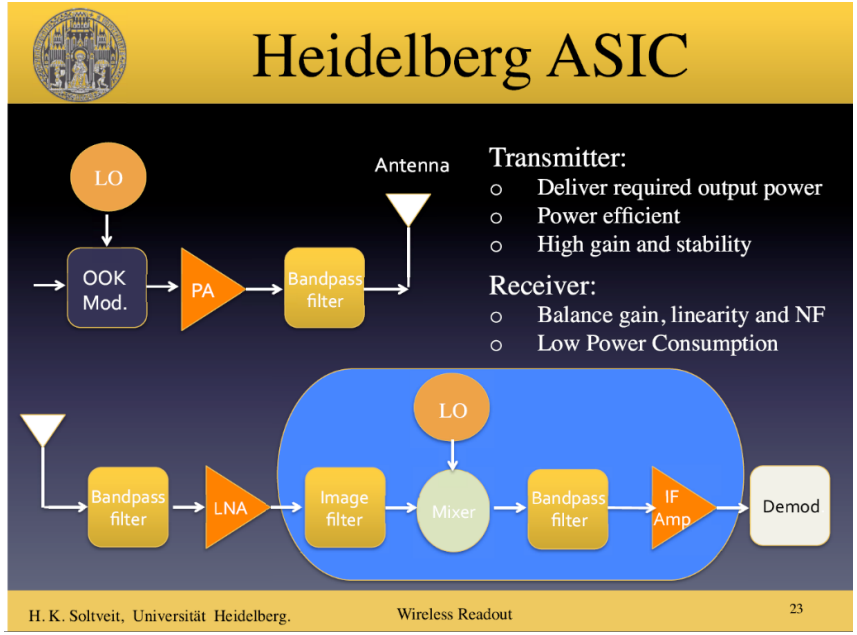
Performances:
-Data rate: 0.1-6Gbps
-Range: 3-20cm function of antenna scheme
-Power consumption: 35mW (<6pJ/bit)

60GHz RFIC

60GHz transceiver design ongoing, dedicated to wireless readout

- Specifications in line with the HEP applications
- Technology and architecture chosen from in-depth studies SiGe HBT BiCMOS technology
- Comprehensive simulations on the RF blocks over PVT, mismatches and coupling effects
- Strong attention paid to robustness and reliability
- Chip under development

Specifications	Value
Frequency band	57-66 GHz
Bandwidth	9 GHz
Data Rate	4.5 Gbps
Modulation	OOK
Minimum sensitivity $S_{rx(min)}$	- 49 dBm
Bit Error Rate (BER)	10^{-12}
Target Power consumption	250 - 150 mW
Transmission Range	20 cm (1m)

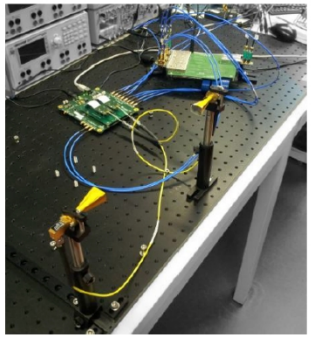


Feasibility studies

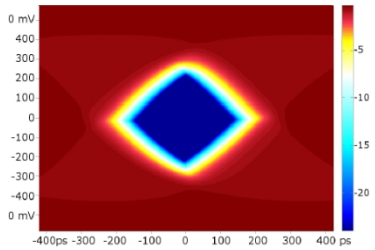
Signal integrity for high data rate data transmission

- 1.76Gbps using commercial coherent RFIC (Heidelberg Univ.)
- 6Gbps using non coherent RFIC (CEA Leti)
- Check spectrum, Bit Error Rate, eye diagram, jitter analysis
- No Loss in Quality of Service

Coherent RFIC



1.76 Gbps eye diagram



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 $BER < 10^{-14}$
- HD-SDI-Video transmission

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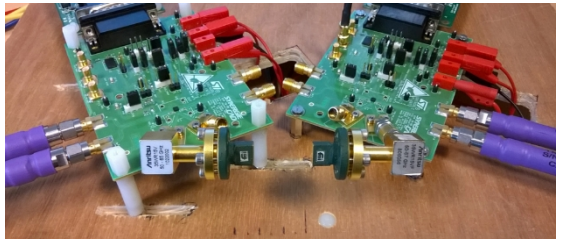
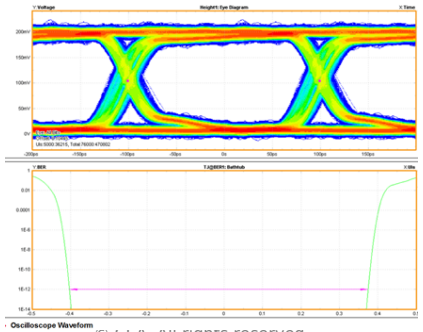


Non Coherent RFIC



5Gbps
BER <1e-12
<35ps rise/fall time
<75ps total jitter
<1ns latency

Feasibility studies

Intra layer signal confinement

No transmission through
SCT Barrel modules

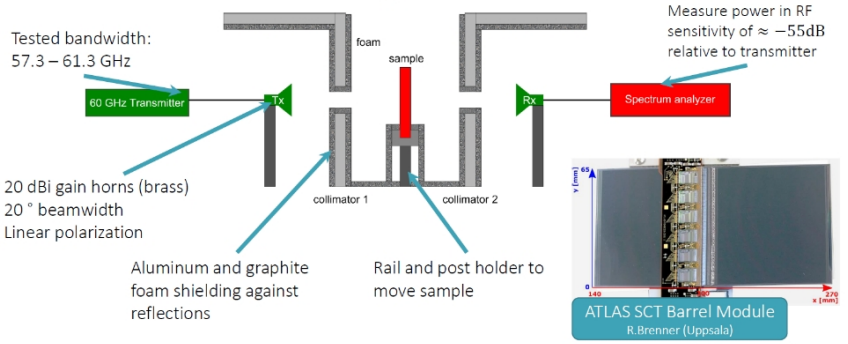
Coexistence with detectors

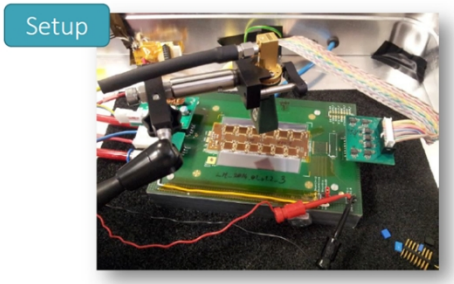
No increase in noise floor under 60GHz

Crosstalk (5cm pitch)

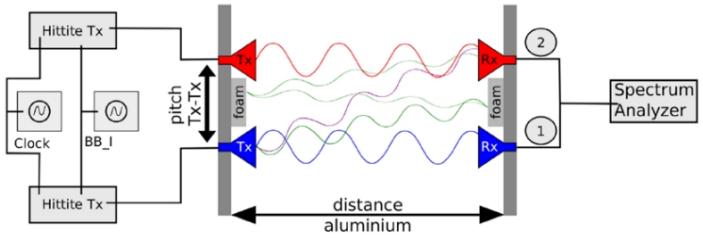
>25dB isolation using directive antennas and polarization diversity

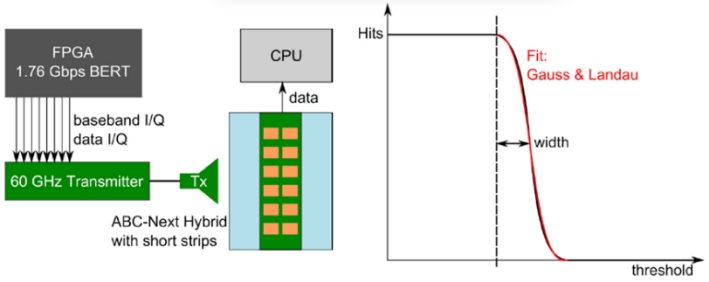
Transmission through detector modules

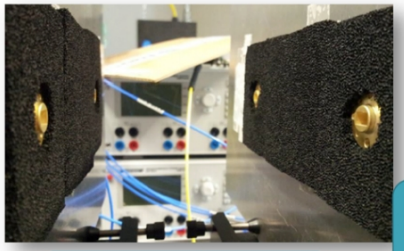


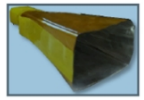


ABC-Next
Hybrid





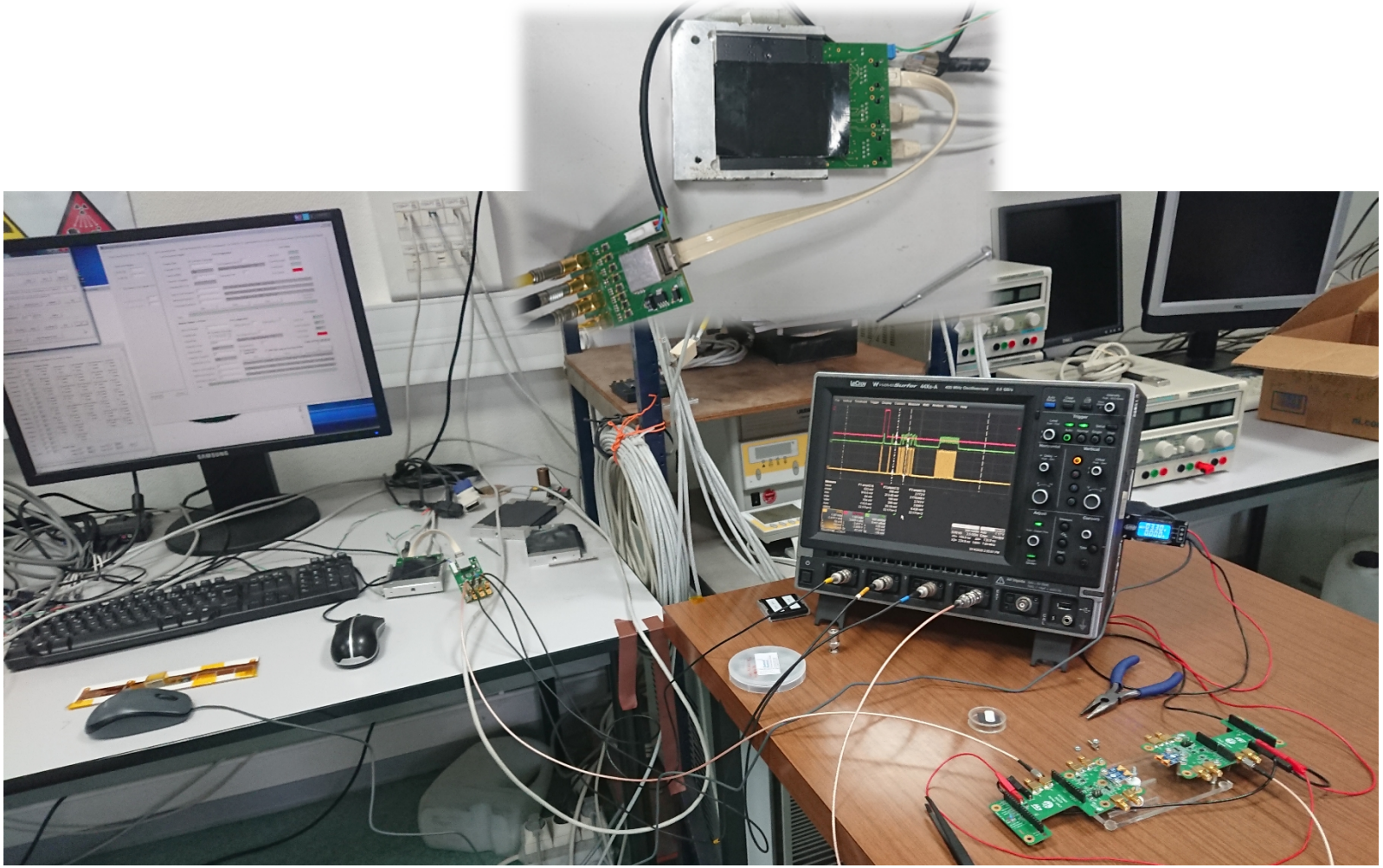




Example for high directivity:
Aluminized Kapton horn
antennas ~ 12-17 dBi

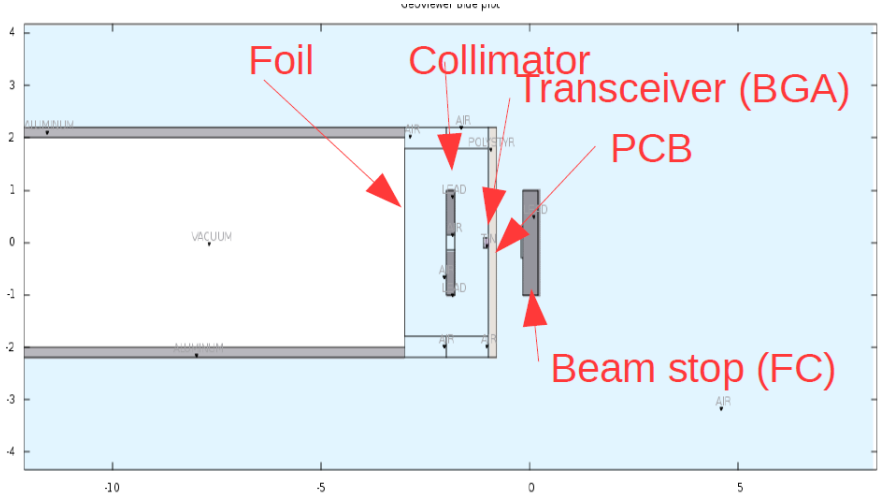
Feasibility studies

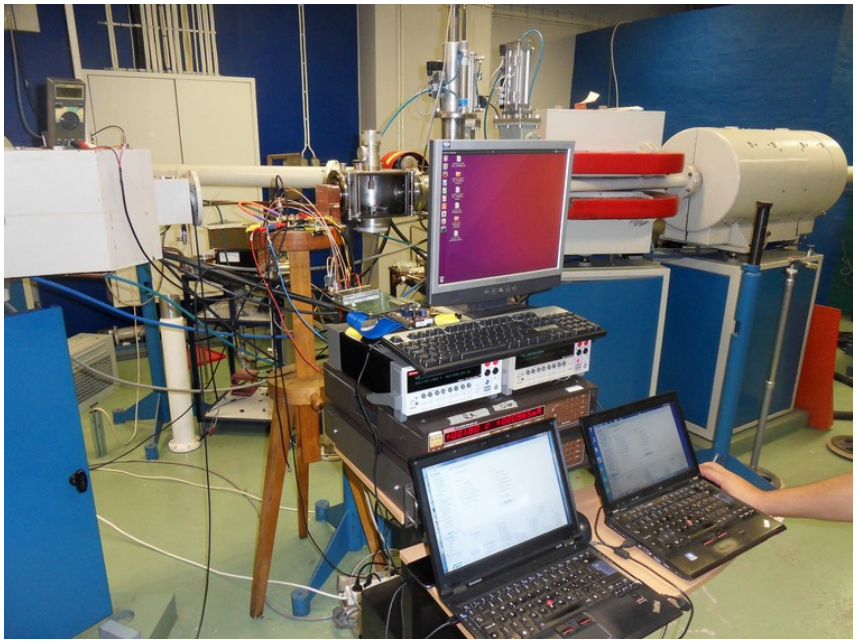
Interfacing with 3M Pixel Detectors (IPHC Strasbourg)



Irradiation tests, Uppsala & Heidelberg univ.

- CMOS65nm transceiver@60GHz in BGA
- No hardening
- Proton beam irradiation
  - Turku Cyclotron set-up with 17 MeV proton beam
  - Target fluence: ~1e14 protons/cm2
  - Sim. energy dose: 192 kGy (19Mrad)
  - Continuous performance assessment of the RFIC transceiver during and after irradiation
  - Few errors detected during irradiation
  - Small alteration of the RFIC performance after full irradiation
- Neutron flux irradiation
  - CERN CLEAR, 50Mrad cumulative dose
  - Band gap voltage reference affected by the irradiation
  - RFIC still functional with limited performance

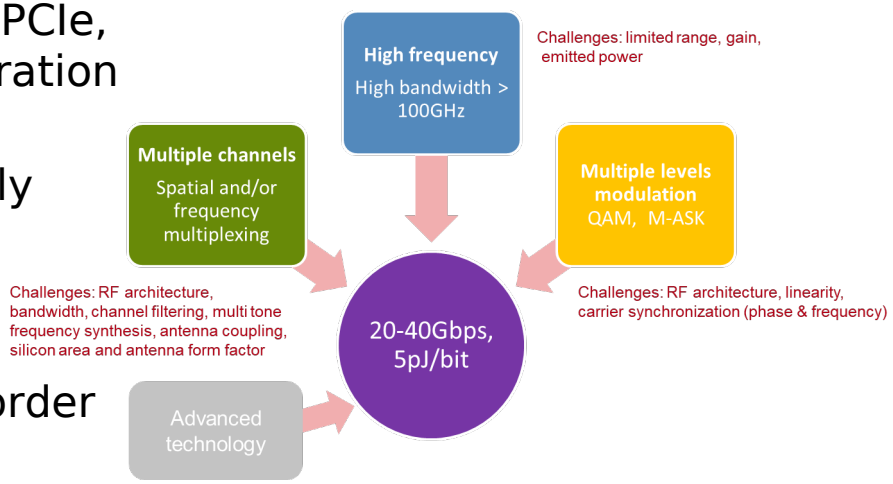




RFIC design: perspectives

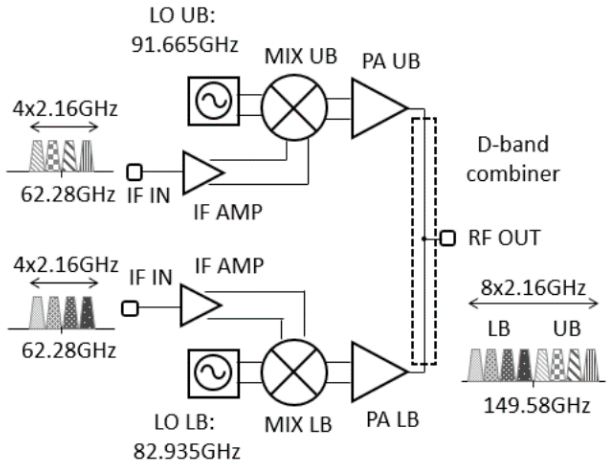
Short range connectivity trends

- **Protocol compliance** (Ethernet, PCIe, USB3, Display Port) with the integration of interfaces and digital control
- **Full duplex operation** with highly isolated antennas in package, low internal coupling transceiver and robust signal modulation
- **Increase data rate** with higher order modulation scheme (PAM, QAM)
- Low power full analog **coherent** receiver



Medium range connectivity trends

- Aggregation of data and relaying using Frequency Division Multiplex
- Channel bonding coherent architecture operating in V or D-Band
- Data rate >100 Gbps



Conclusions

- MmW allows high data rate, low power communication at short range
- Non coherent RFIC architecture for low power and low latency
- Antenna scheme may add directivity gain to increase the range
- Early feasibility studies show no deadlock for their use in HEP
- Commercial products at 60GHz are now available for test and can be customized for particle-physics detector
- HEP dedicated chip and antenna module are under development
- Future developments should challenge optical links at short range
- Proof of concept pixel detector readout under specification
- Power transmission and energy harvesting are also considered for full contactless connectivity

Thanks for your attention

Questions ?

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Main publications

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