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Wireless data (and power) transmission

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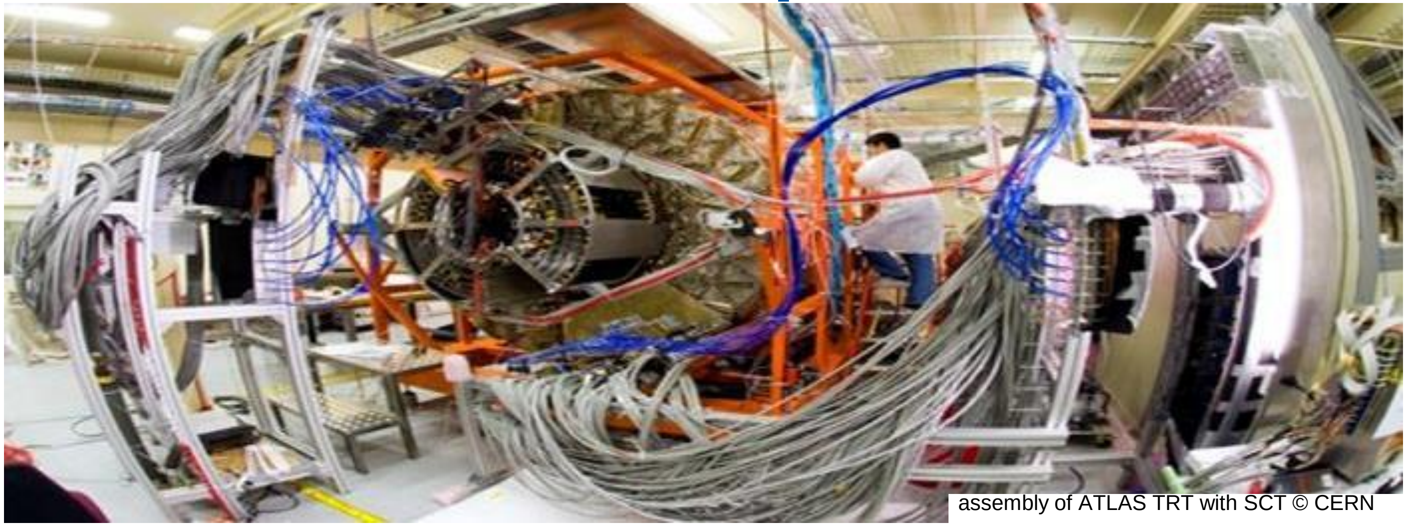
A massive cable plant

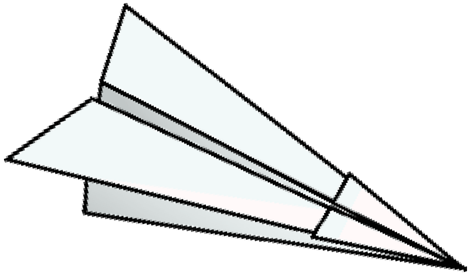


assembly of ATLAS TRT with SCT © CERN

- **Impact on the measurements**
  - Multiple scattering and nuclear interactions
  - Dead-zone areas
- **Impact on the installation and the operation**
  - Cables and connectors are fragile
  - Cable path is not so flexible
  - Design constraints

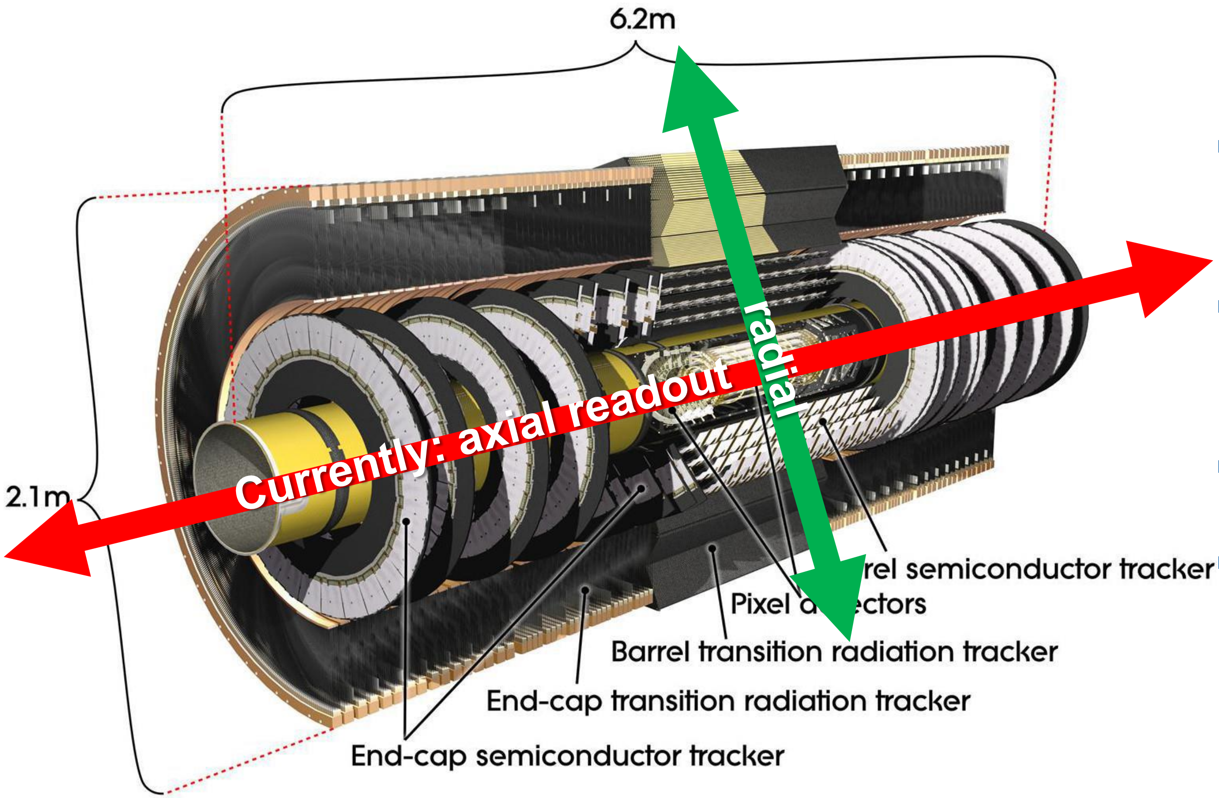
Challenges?

- **High throughput/low latency**
- Precise timing
- High density
- Simple operation
- **Highly reliable**
- Low cost
- **Low mass**
- Small form factor (compactness)
- **Low power consumption**



Why wireless?

- ➔ **Minimize material budget** of cables/connectors
- ➔ No infrared! Detector electronics should be in the dark

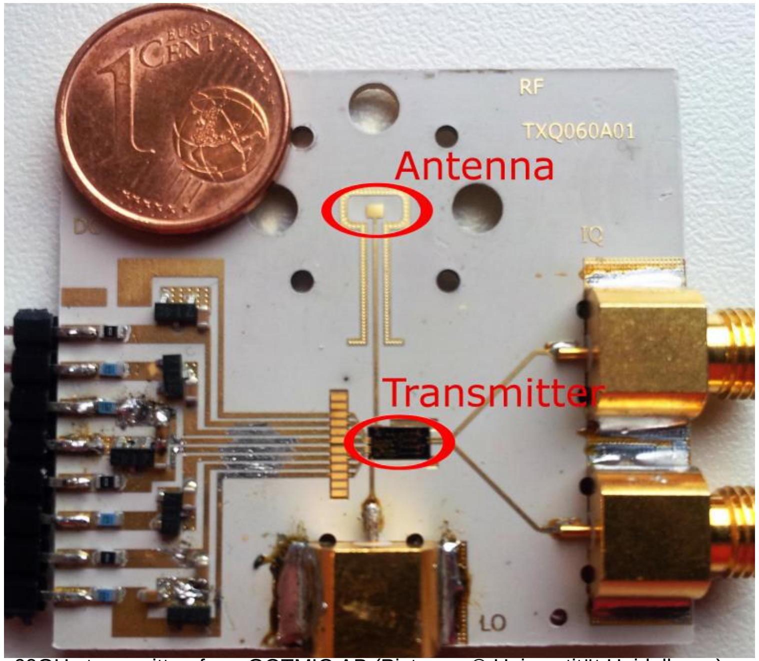


ATLAS inner tracker © ATLAS/CERN

- More **flexible transceiver placement**
- Direct communication between layers possible
- Point-to-Multipoint links
- **Data follows event topology enabling fast triggering**

Millimeter-waves technology

- 30 to 300 giga-Hertz
- Wavelength (λ) of a few mm (e.g. 5mm @60GHz)
- Multiple Gbits/s (Several GHz of bandwidth)
- High “natural” signal attenuation (68dB@1m at 60Ghz)



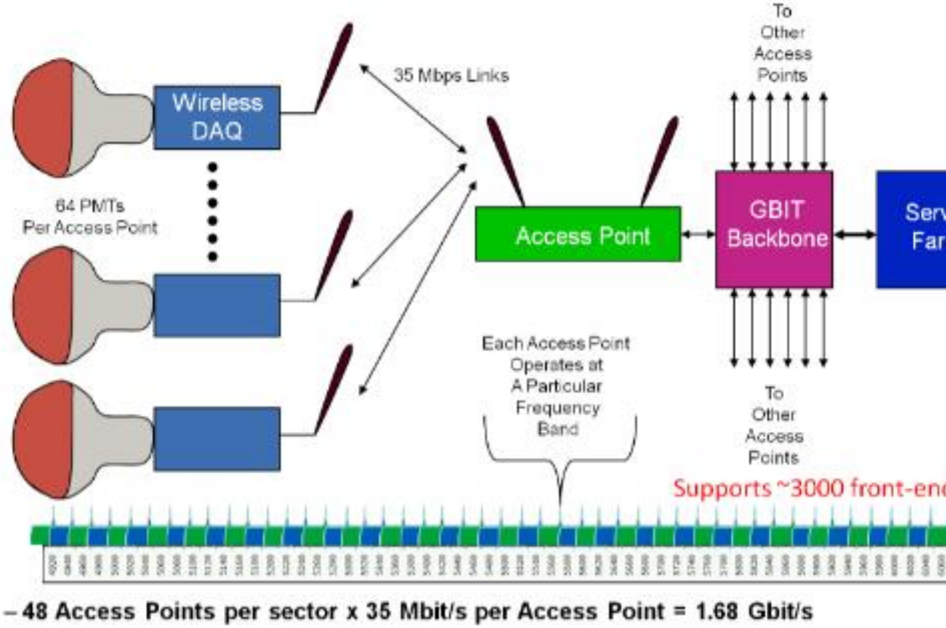
60GHz transmitter from GOTMIC AB (Picture : © Universtität Heidelberg)

- Compact and low power system
- High integration
  - On-chip antenna
- High density
- Lot of development in the industry

Two existing studies

References in the backup slides

A prototype for water Cherenkov neutrino detector from Argonne National Laboratory

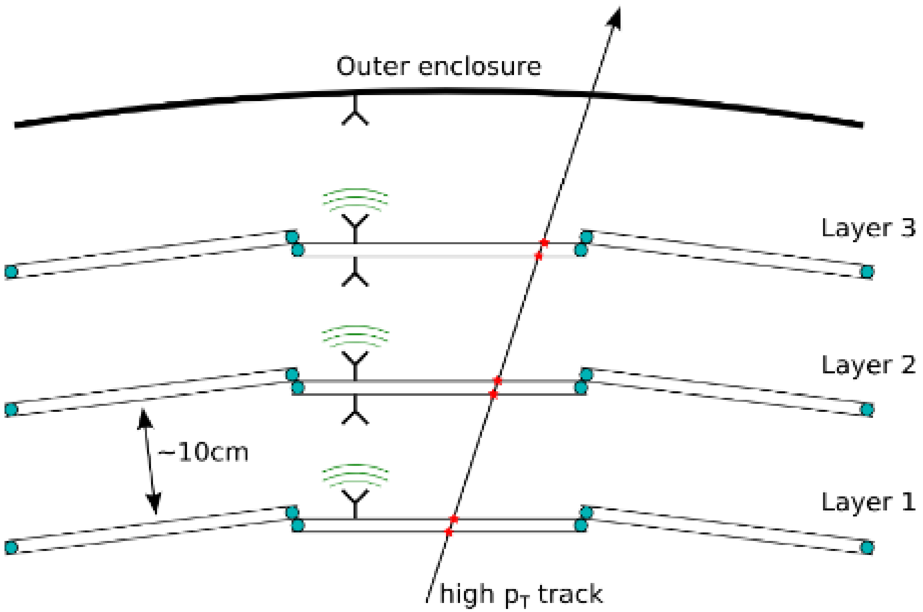


- data acquisition & control system based on 802.11n

Specification	Target
Maximum event rate	10 kHz
Bytes per event	6 (2 pulse height, 4 time-stamp)
Average data rate per front-end channel	60 kB/s
Total power consumption @ 10 kHz	250 mW
Data transfer rate	35 Mb/s
Bit error rate	$< 10^{-12}$

- No need for High throughput

Study for ATLAS silicon tracker from Heidelberg university

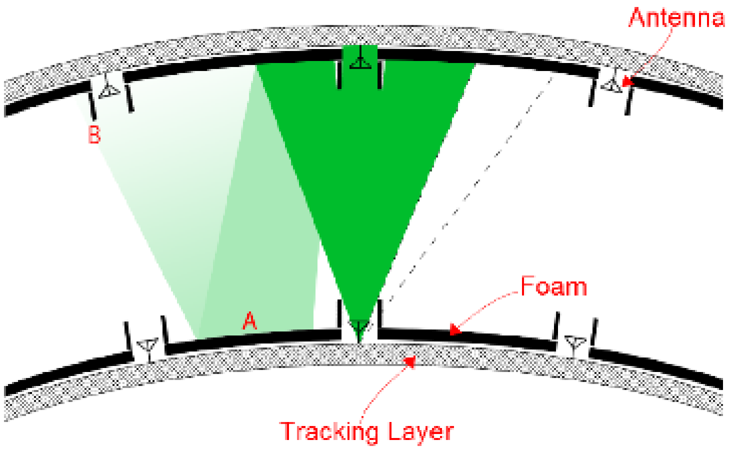


Concept from R.Brenner et Al. (Uppsala Uni.); Pictures: Universtität Heidelberg

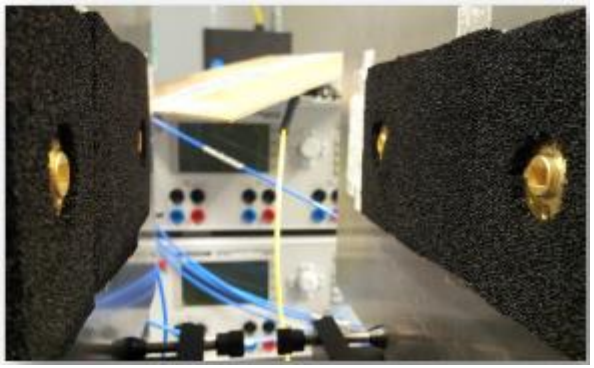
- **60 GHz wireless readout system**
- **Building a 60Ghz demonstrator**
- Simple On-Off Keying modulation
- 4.5Gbps @1m
- 240mW power consumption
- 130nm SiGe Bi-CMOS HBT 8HP technology

- **No signal penetration** through detector layers
- **But** detector layer is an **highly reflective environment**

Study for ATLAS silicon tracker from Heidelberg university



- **Valuable studies achieved!**
  - Bit Error Rate < $4x10^{-15}$
  - Material properties at 60GHz
  - No significant influence on SCT electronics
  - **Crosstalk mitigation**



shielding: Graphite foam cover

high directivity: Aluminized Kapton horn antennas

Future:

- **60Ghz demonstrator**
- **high density integration**
- **On-chip antenna**
- **Operation in extreme environment**
- **Efficiency improvement**

How to improve Wireless payload throughput?

Shannon-Harley's theorem

$$C = B . \log_2\left(1 + \frac{S}{N}\right)$$

C = Channel capacity in b/s
B = Bandwidth in Hz
S = Signal in Watts
N = Noise power in Watts

- Signal-to-Noise-Ratio (SNR)
  - Smart antenna techniques

- Bandwidth (available spectrum)
  - Sub-THz electronics (Leti Proto @276GHz)

How to improve Wireless payload throughput?

- Modulation technique (spectral efficiency)
  - 4096QAM in labs

- Multiplexing technique (multiple the channel capacity)
  - Multiple Input-Multiple Output (MIMO)
  - Orbital angular momentum (OAM)

- Communication protocol (overhead)

Still a tricky trade-off to optimize the performance with regards to power consumption, range, crosstalk mitigation, medium access, system compactness, complexity….

A Millimeter wave readout system

Technology is already available and mature, prototypes are being built

Could a wireless approach surpass an improved wired DAQ?

We propose to answer this question:

- 2018: Feasibility study for an FCC detector
- 2025: Design proposal for a detector

A Millimeter wave readout system

Challenging but doable

Outcomes for HEP and more

Extend the existing collaboration

Backup slides

References

R. Brenner and S. Cheng, “Multigigabit wireless transfer of trigger data through millimetre wave technology”, 2010 *JINST* 5 C07002.

D. Pelikan et al., “Wireless data transfer with mm-waves for future tracking detectors”, 2014 *JINST* **9** C11008.

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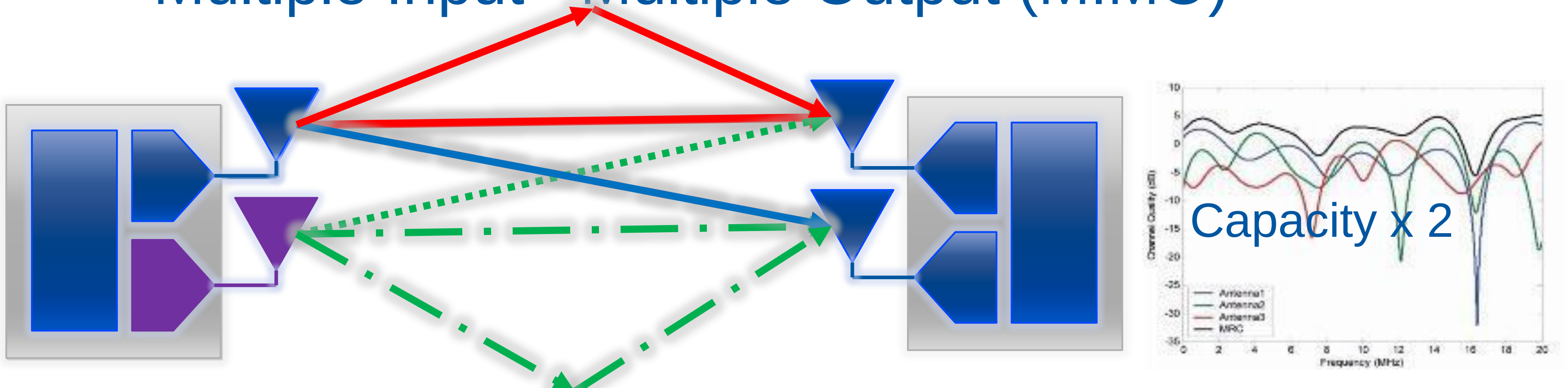
Wireless technology evolution

- Supported by the market for ever higher performance

- **More efficient modulation techniques**
  - Increased spectral efficiency: More than (3bits/s)/Hz
  - Increased resiliency to noise and multipath
  - Contained Power efficiency → Battery life
  - Contained Signal-to-Noise ratio → Signal exposure
  - Mitigated BER → Coding trick
  - But increased complexity and design cost

Wireless technology evolution

- Smart Antenna techniques
  - Improve link reliability (MRC, Beam forming)
  - Multiple Input - Multiple Output (MIMO)



    - multiply channel capacity
    - Benefit from multi-path (with spatial diversity of receiver antennas)

Long term wireless evolution

- Increase of Digital Signal Processor capacity at constant power (Moore’s law)
- Increase of spectral efficiency (4096QAM in labs)
- Development of Smart Antenna (antenna array)
- Sub-THz electronics (Leti Proto @276GHz)
- Orbital angular momentum (OAM) multiplexing technique (far future)

The challenges

- How to achieve Very High Density?
- How to ensure efficient timing?
- How to ensure long-term reliability and operation?
- How to adapt the communication protocol?
- How to adapt the wireless data acquisition system to an extreme environment (CEM, radiation)?

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