Wireless Allowing Data and Power Transmission (WADAPT)

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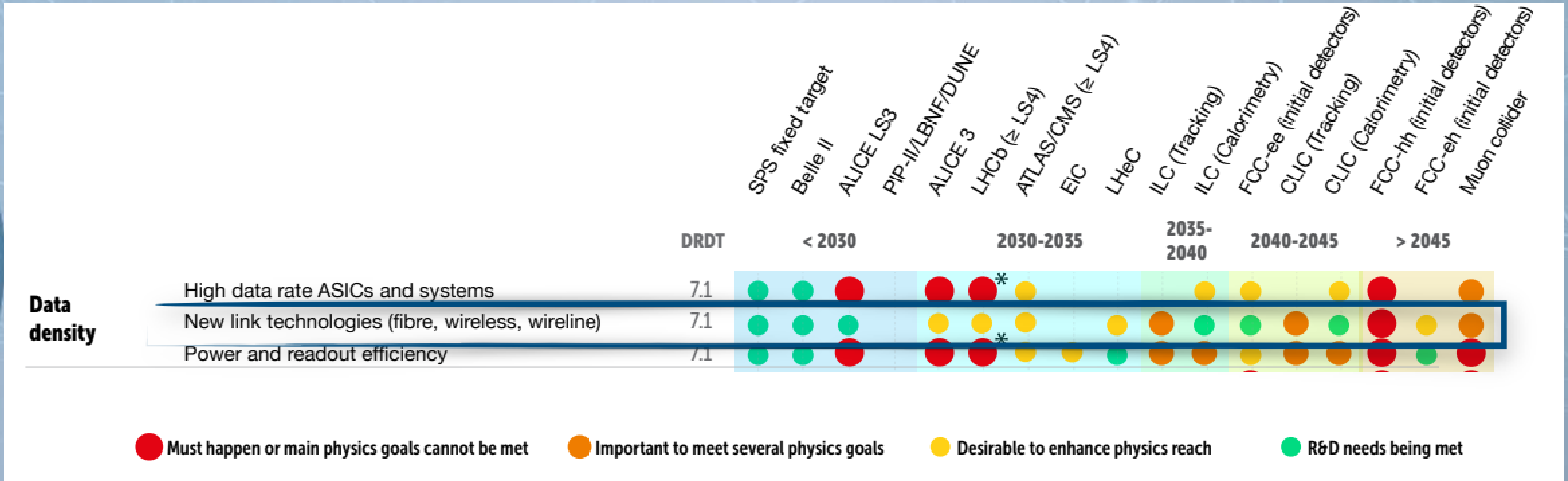
WADAPT consortium

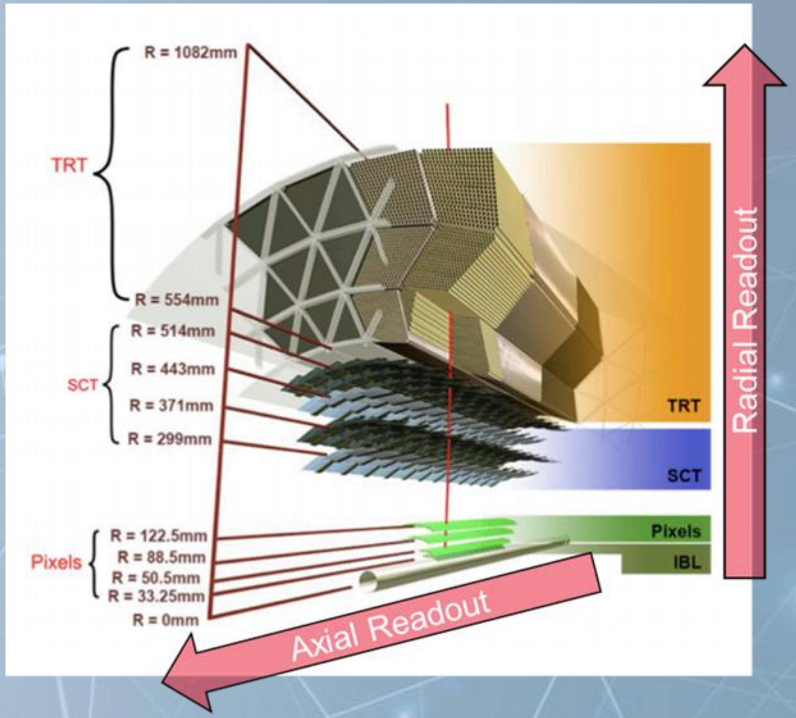
Context

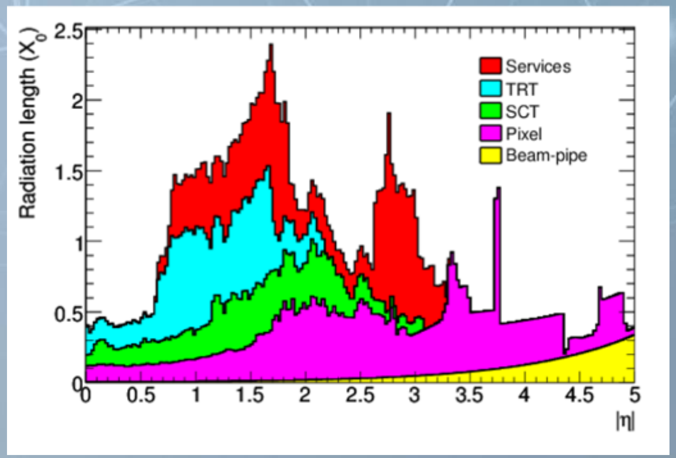
- Wireless technologies proposed as key « New link technologies » to ECFA roadmap, Fabrizio Palla DRD7 workshop 14-15 March 2023
- Wireless Free Space Optic (FSO) and Radio Frequency (RF) technologies for high density data transmission in harsh environment



Motivations

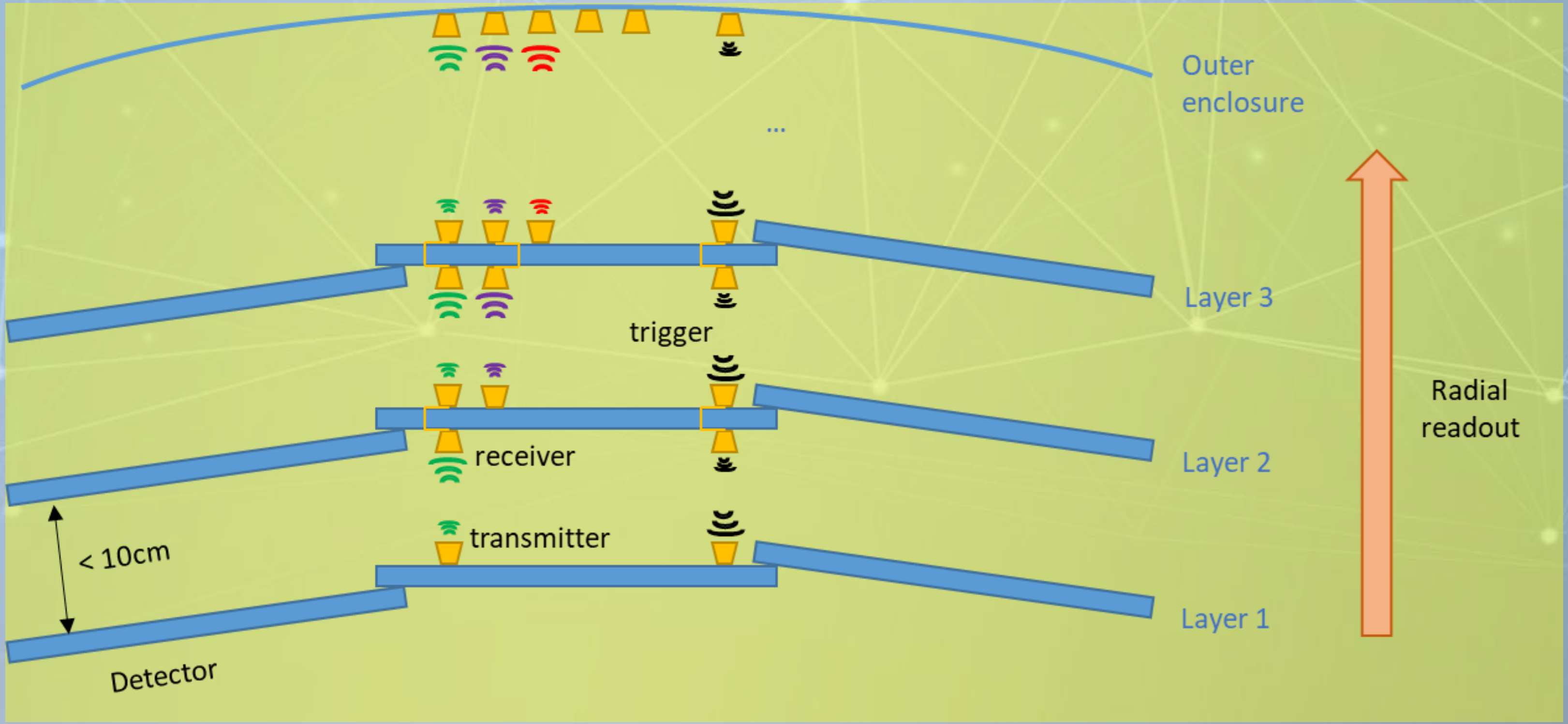
- Cables
  - Create multiple scattering and nuclear interactions, dead-zone areas
  - Impact on the installation and the operation
  - Axial readout induces important latencies
- Wireless
  - Minimize material budget of cables/connectors
    Reducing the radiation length of massive services in region 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





Proposed approach

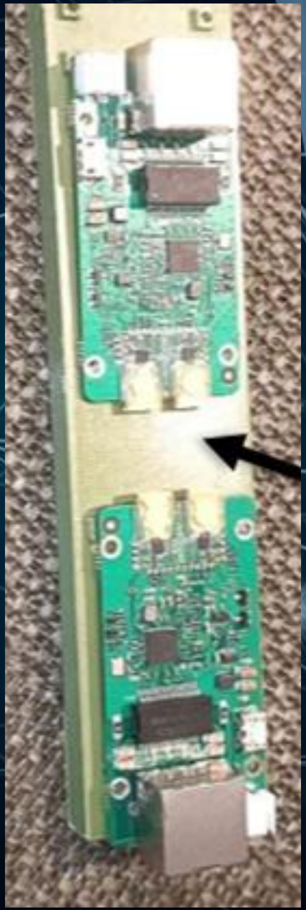
- Multi-hop data transmission between inner detector layers
  - Directive and short range transmission using millimeter wave RF or Free Space Optic
  - Use of non-coherent modulation scheme (OOK, ASK, PAM), up to 10Gbps per link
  - Compatibility with wired standards (modulation, QoS), and high energy efficiency



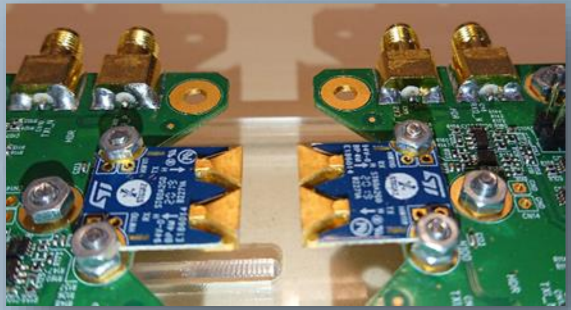
Past works

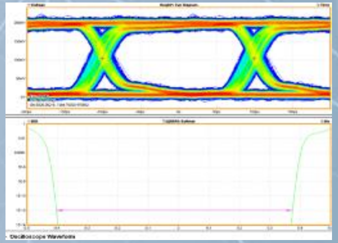
Feasibility studies on P2P link with commercial components (Heidelberg)

- Signal integrity
- Intra layer signal confinement
- Interface with pixel detector
- Coexistence with detectors
- Interference and cross talks
- Robustness to irradiation
- Identification of limitations of the commercially available components

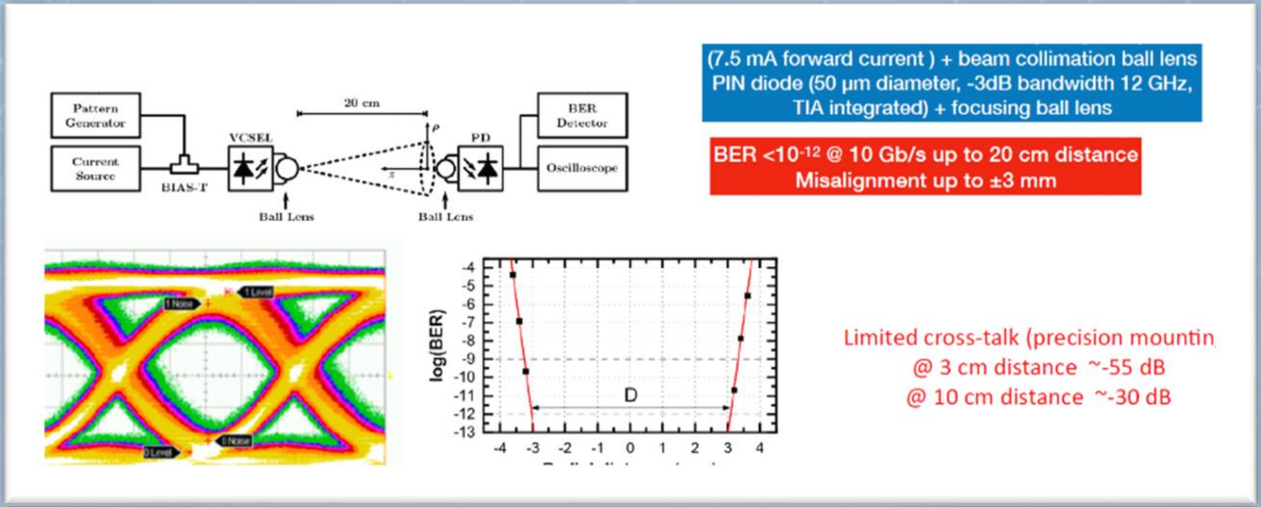


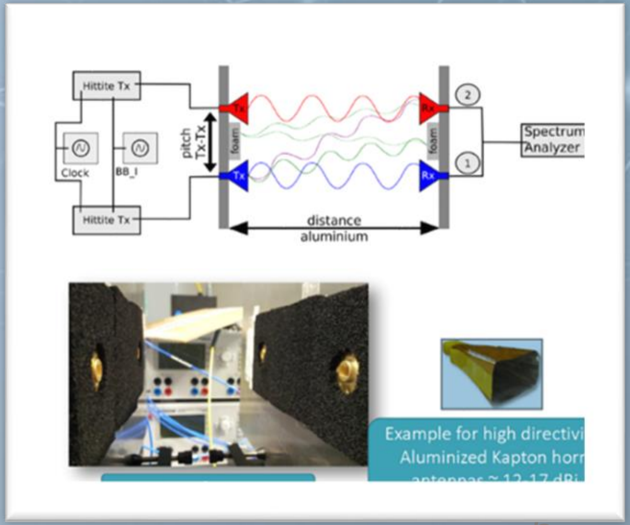
SK202 60GHz





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





Road map and proposed work plan

- Objectives
  - Propose viable use cases for integration of wireless technologies in HEP
  - Boost ongoing works with extra funding and contributors
  - Compare the pros and cons of the different and complementary wireless technologies
  - Push forward the limit of commercially available components by custom design
  - Allow the scaling from a few transmission links to a full network with low mass, low latency, low power and high data rate
  - Build proof of concepts can be used by the HEP community
  - Bring support to their dissemination

Road map and proposed work plan

*WP1. **Readout system level definition**, including new link technologies (T0-T0+6m)*

- Objectives: reduction of cable mass, power consumption, more network flexibility, improved overall bandwidths and data rates, increasing the network synchronization, taking into account the environmental constrains of HEP.

WP2. **System level analysis**, signal integrity (T0+3-T0+9m)

- Objectives: assess the key performances of the proposed network, give global specifications for the different components, building of a system level simulator to evaluate the signal integrity in a multi-hop scenario with interferers from cross talks, throughout the different nodes of the network.

WP3. Millimeter integrated **circuit, packaging and antenna** design (T0+6-T0+9m)

- Objectives: Use the system analysis and signal integrity simulator to define the millimeter wave integrated circuit architecture and its components, the type of chip assembly, the packaging and antenna scheme.

WP4. Proof of concept **demonstrator** with commercial products (24m)

- Objectives: a proof of concept by building and interconnecting a three (or four) layer silicon detector, based on commercial ICs (with reduced performance) and custom on board antennas.

WP5. Design of **custom Millimeter Wave Integrated Circuit** (T0+12-T0+36m)

- Objectives: design of a dedicated radiation hardened millimeter-wave transceiver IP in advanced technology node, to be integrated either as a companion chip or as an IP within the silicon trackers. The transceiver shall reach high energy efficiency, while providing enough margin and robustness to operate during a long period in harsh environment.

WP6. Design of an integrated **multi-channel readout electronics** (T0-T0+36m)

- Objectives: design of an integrated multi-channel readout electronics for detectors to be interfaced to the multi gigabit wireless data transmission module.

WP8. Realize and test a **FSO system solution** for a FCC-ee tracker (T0-T0+36m)

- Objectives: maximum data rate as a function of distance, signal integrity and latency, material budget and power reduction compared to a plastic fiber solution.

WP7 **Dissemination**, training on RF/mmw technologies (T0-T0+36m)

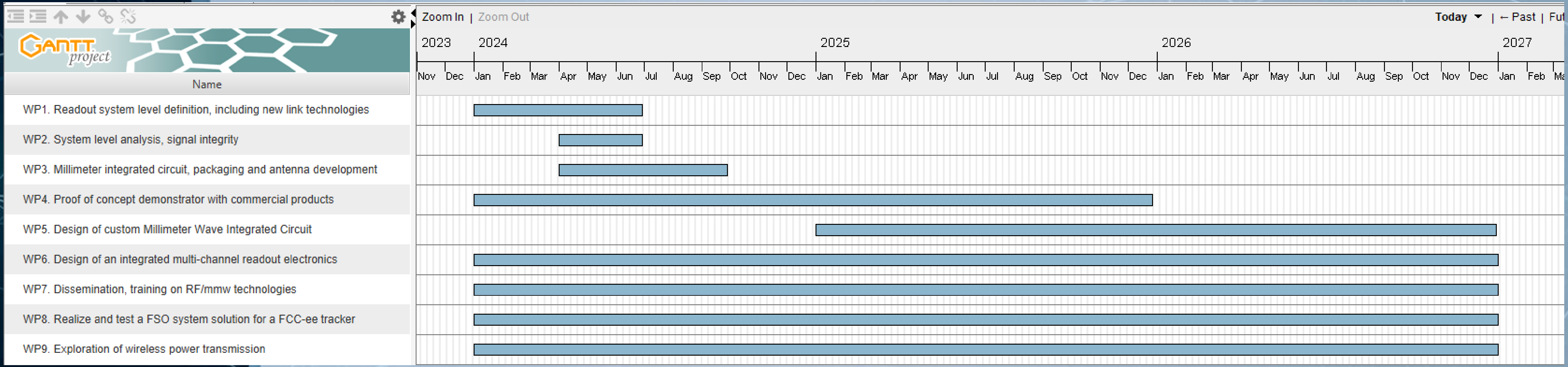
- Objectives: organization of workshop and training on RF/mmw technologies. The training will use the proof-of-concept demonstrator to feel the physical behavior of the wireless propagation.

WP9. Exploration of **wireless power transmission** (T0-T0+36m)

- Objectives: selection of power transmission means, building of demonstrators

Road map and proposed work plan

3 years planning



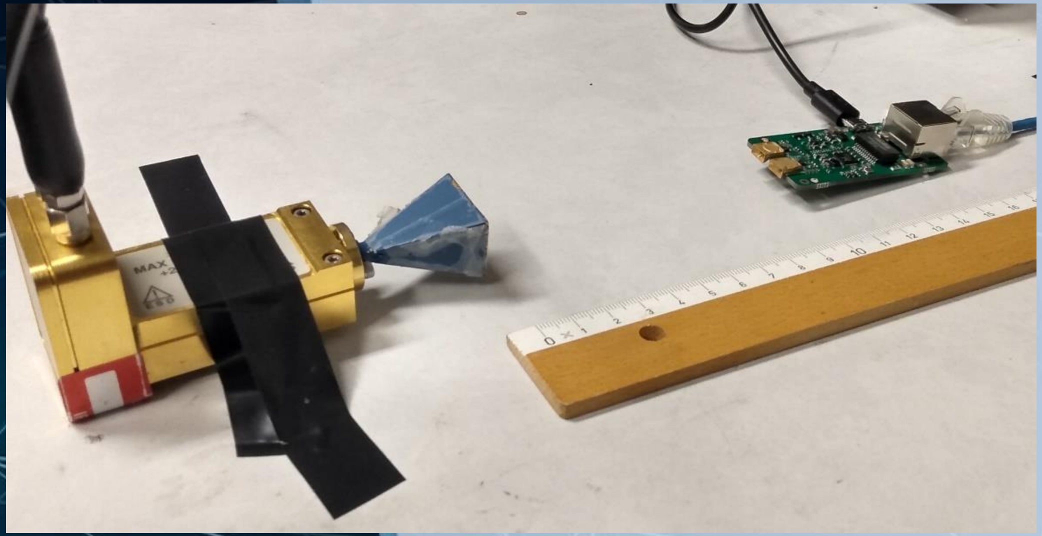
WP3 - WP4 : current work

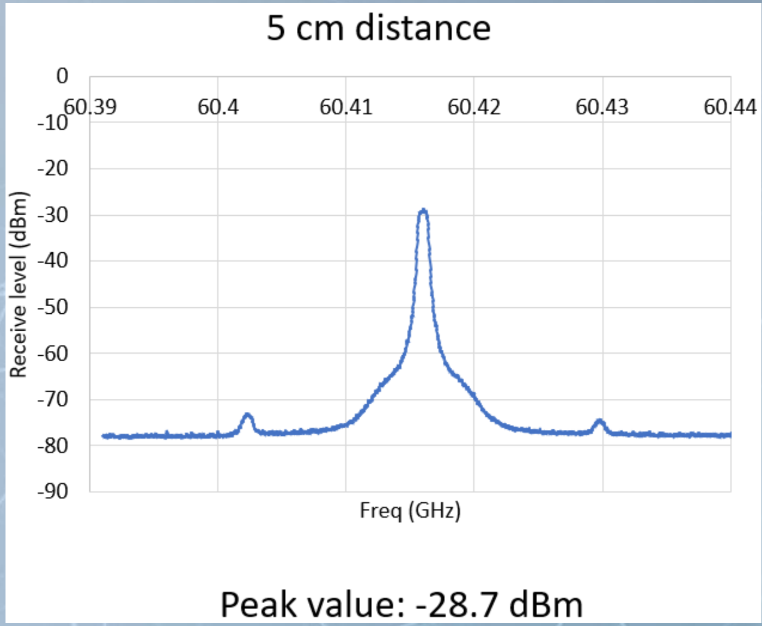
- Uppsala University: AIDAinnova (WP13- Blue sky project). Fund from the Eurpoean Union's Horizon 202 research and innovation program under grant agreement No 101004761
- Study of components and antennas integration
- Full link demonstrator(s) from 1 tile to 2 and 3 tiles – several mock-ups to be tested
- Use and integrate commercially available components
- Study the performance of the system (data rate, bit error rate, modulation schemes, usage of bandwidth, crosstalk in repeater, etc.)

deliverables

- Deliverable 1: First mock-up assembled and tested during the first year, including study of antenna technologies allowing a seamless integration in such a harsh environment (strong irradiation and magnetic fields); specification of the antennas.
- Deliverable 2: Second mock-up assembled and tested during the two next years. Three or four layers of silicon detector with their readout, equipped with low power consumption transceiver and antennas.
- Deliverable 3: Published study of performance in HEP environment and access to technology for new user communities. Make packages available with user support.
- Deliverable 4: (in option depending on the time left) Study of the cumulative noise in multi-hop data transmission and jitter, development of wireless communications strategies for managing crosstalk

KS202 radiation power measurements





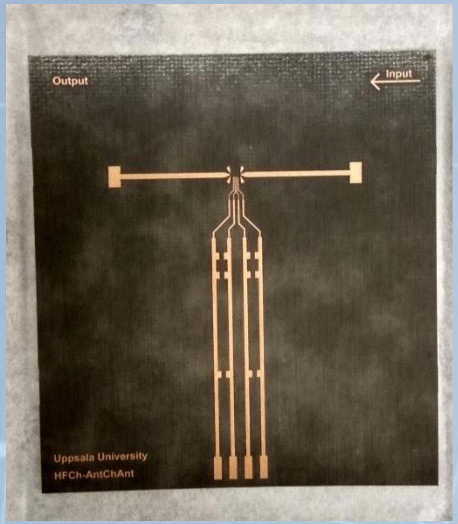
- Power measurements of the SK202 board to horn antenna harmonic mixer with a 20 GHz spectrum analyser. Measurements at different distances,
- i.e., 5 cm, 10 cm, 15 cm and 20 cm

distance	5	10	15	20	cm
received power	-28.7	-31.9	-34	-37.8	dBm

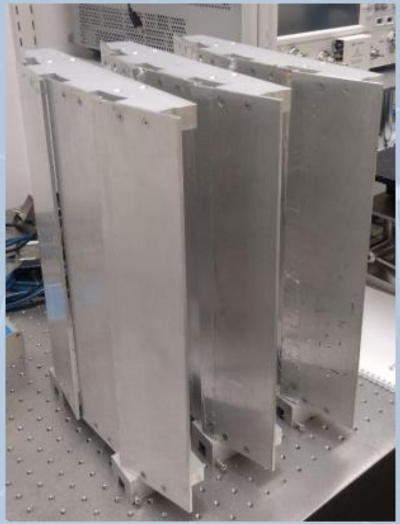
In conclusion: **the SK202 doesn't operate at distances higher than 5 cm and thus, it seems that a minimal power level of -28.7 dBm (µW) is needed for the down-conversion.**

Plan now is to integrate a PA after the Tx on a new repeater mm-wave board to extend this range to 20 cm.

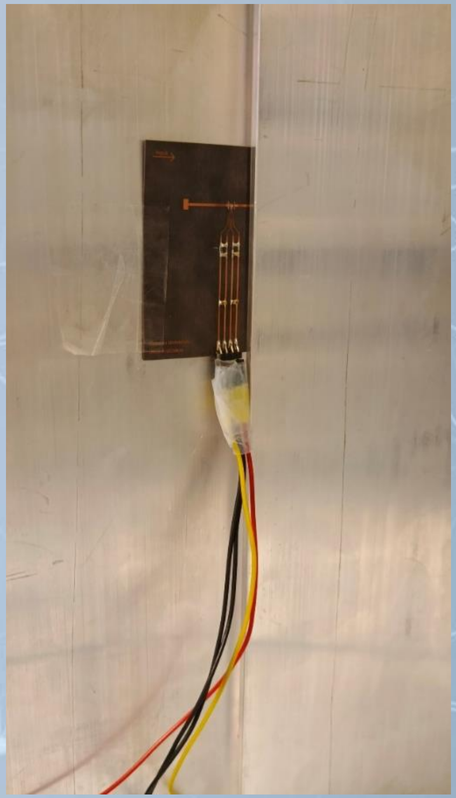
Repeater board measurement setup



(a) Repeater PCB



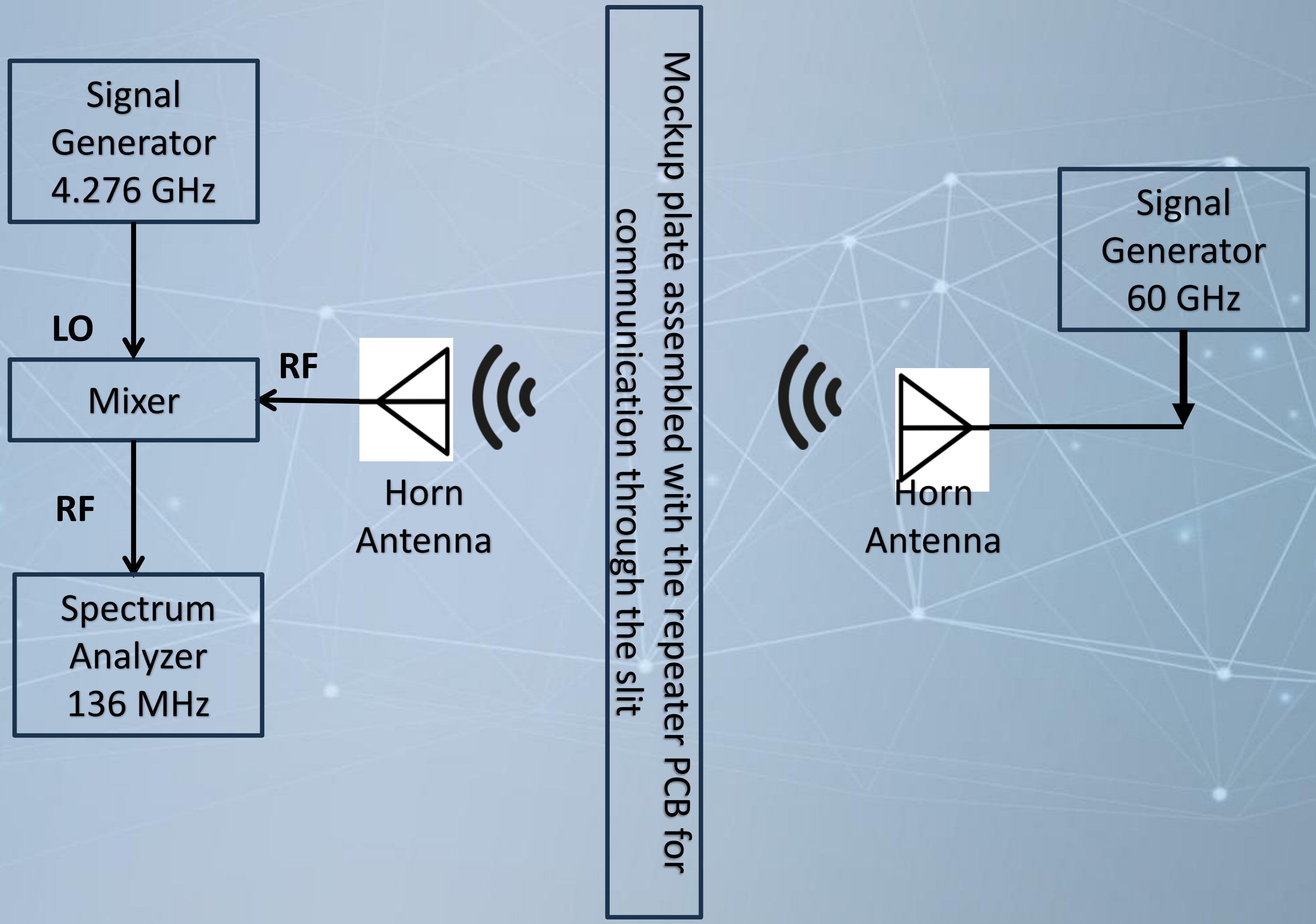
(b) Mockup to test communication through slit



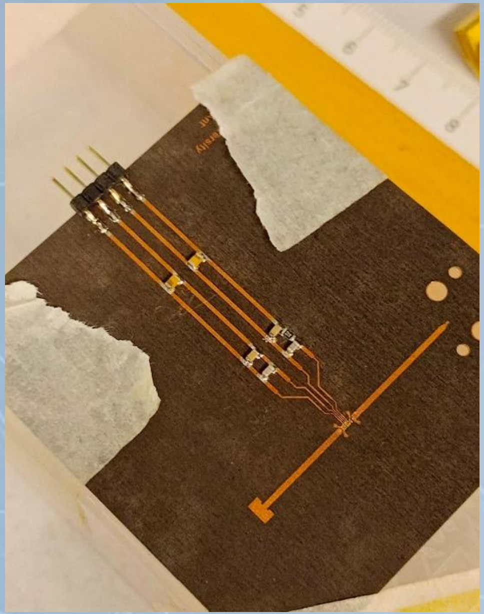
(c) Inner side of the mockup from where the input patch antenna on the PCB receives the signal

(d) Outer side of the mockup where the second patch antenna transmits the amplified signal

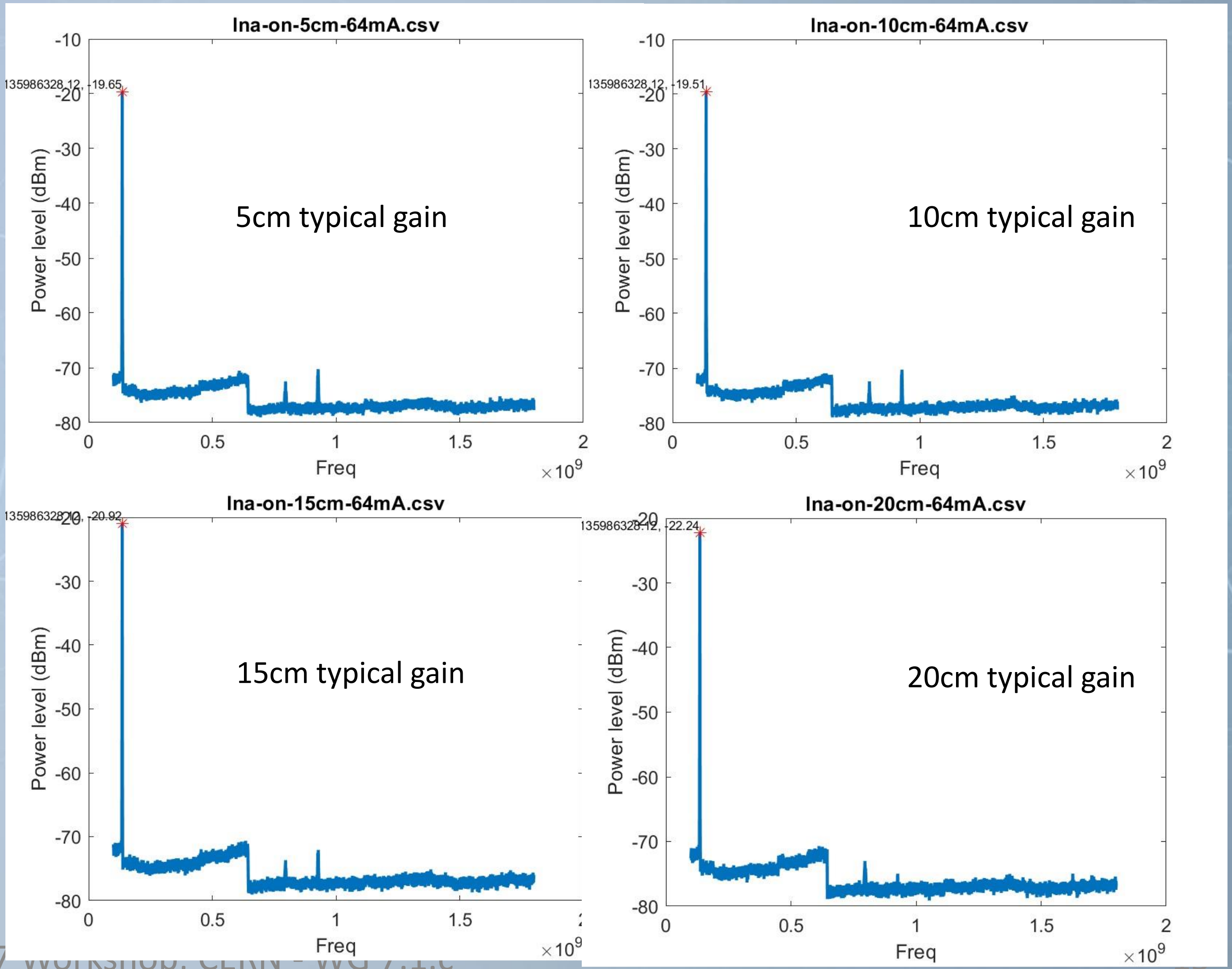
Schematic of the measurement setup



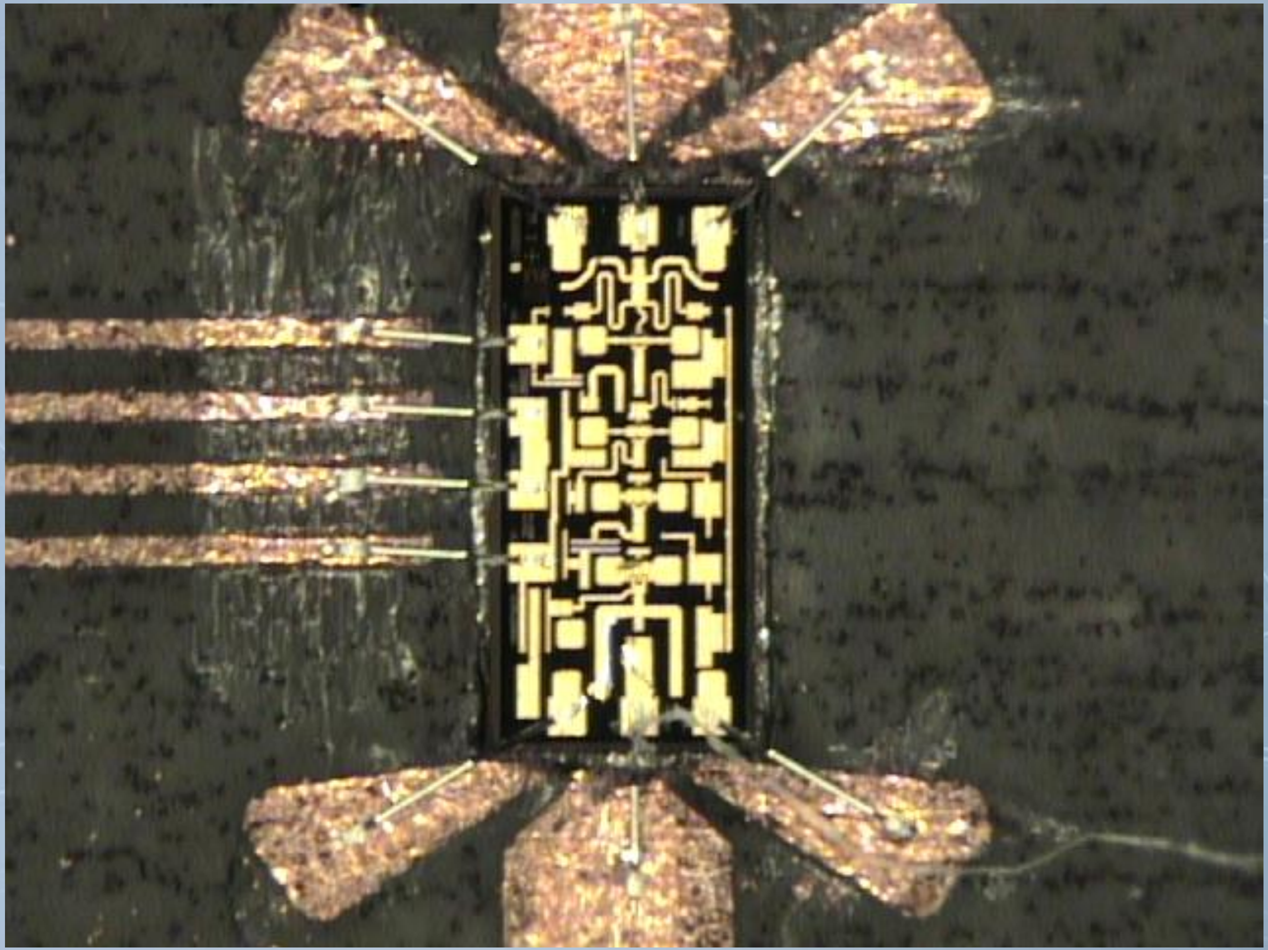
Repeater board development: radiation power measurements



- The received power level is comparatively higher at higher distances, maybe because of far-field distance of the horns.
- The distance is one way, total wireless path is double of the mentioned distance



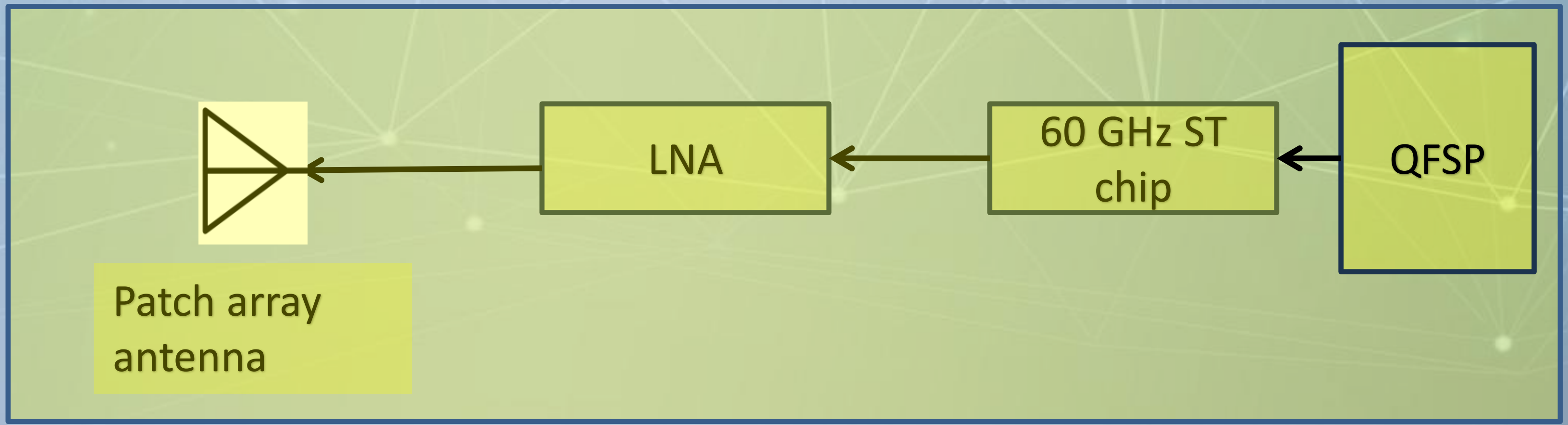
Hittite LNA assembled on the repeater board



Wire-bonds are too long than needed, causing losses and impedance mismatching. Alternative mounting, such as flip chip or direct SMD mounting are considered.

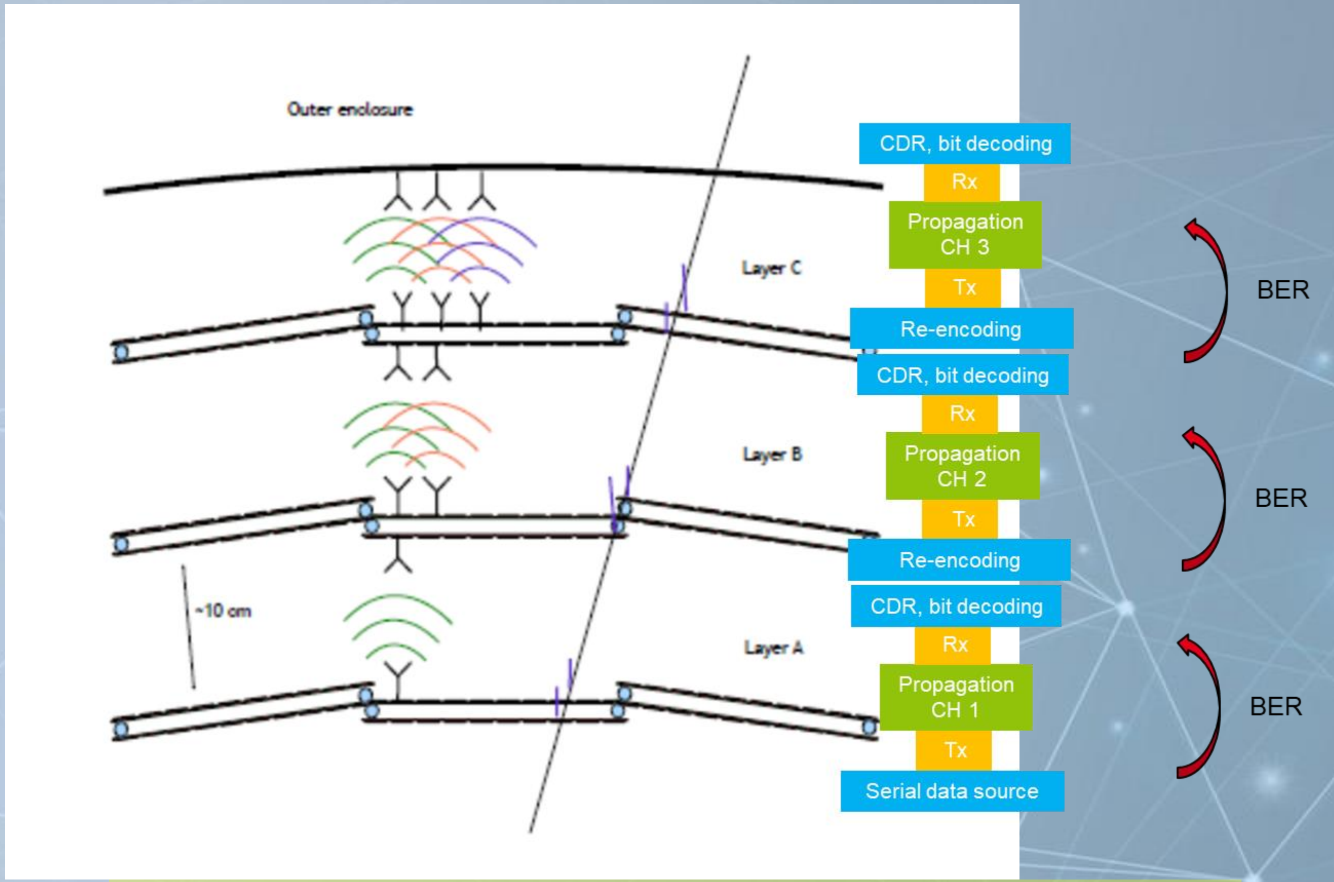
WP3- WP4 summary

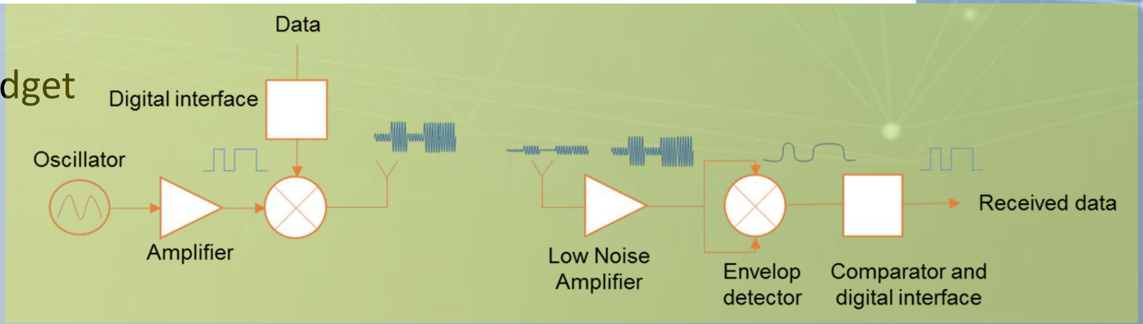
- Compared to the SK202 to Horn antenna measurements, we see higher power levels when using the repeater board
- We still have some losses coming from the wire bonding, and connector transition and will investigate further other mounting schemes as to use flip chip mounting instead of wire-bonding
- We are working further on the integration of the ST chip, followed by the LNA and then the antenna array on a QFSP interface.



WP1 - WP2 : CEA-Leti

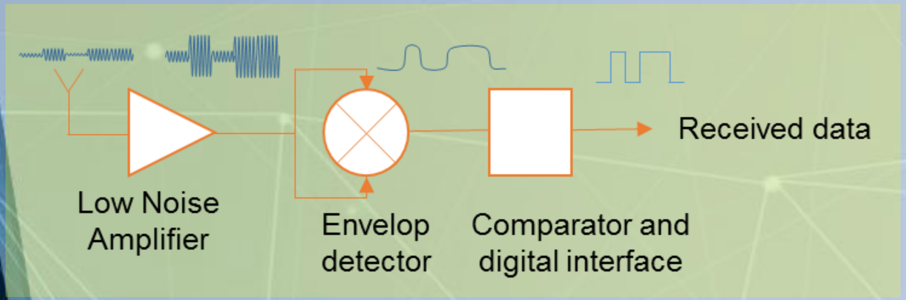
- system level analysis, ongoing works
- Multi-hop readout scenario
- Evaluation of what type of relaying
  - Amplify and forward
  - Decode and forward
- Definition of metrics for signal integrity
  - Eye diagram (TIE)
  - Jitter
  - Bit Error rate
- Development of tools for system analysis
  - Multi-hop jitter computation and link budget
  - System simulation





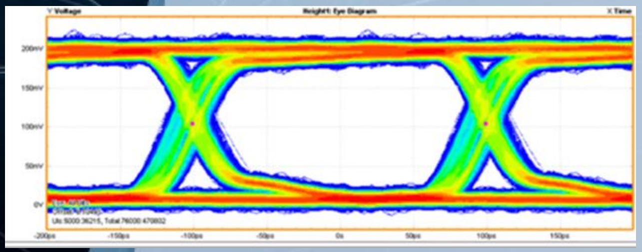
System level analysis

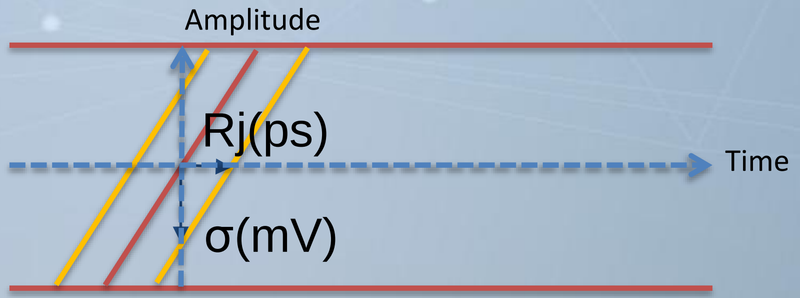
- The quadratic receiver degrades the signal to noise ratio



$$SNR = \frac{\frac{S}{N_0}^2}{3 + 2\frac{S}{N_0}}$$

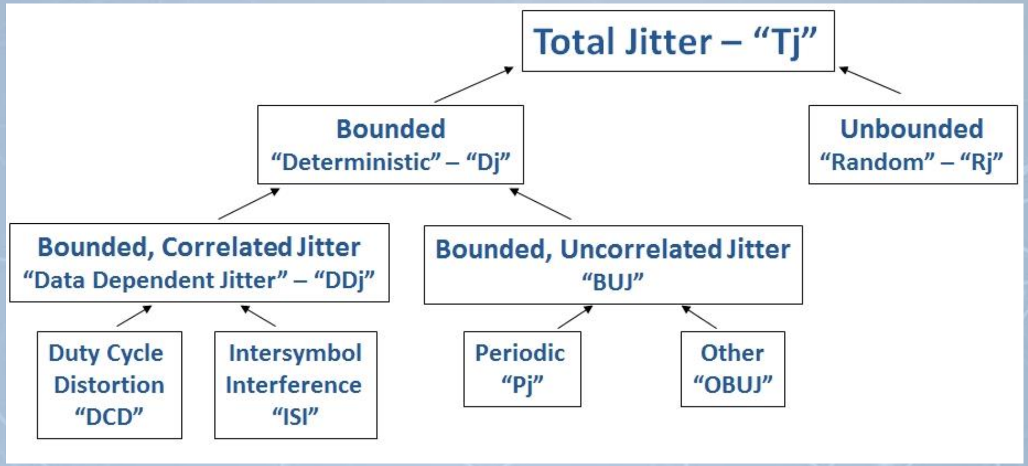
- Thermal noise is translated into random jitter in eye diagram, function of slew rate (rise/fall time)



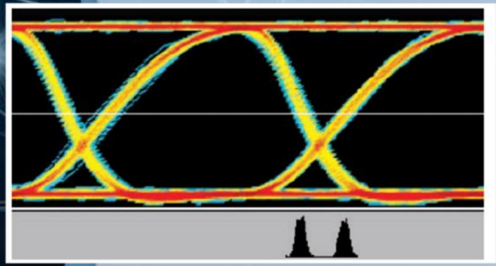


System level analysis

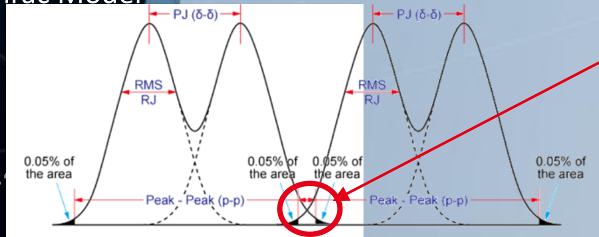
- Jitter classification



- Total jitter $TJ = \sum_n DJ(n) + Q_{BER}\sqrt{\sum_n RJ(n)^2}$



Dual Dirac Model



Error distribution

Gaussian Statistics Reference Table

BER	N ("crest," or scaling, factor) DTD = 50% (Most Data)	DTD = 100% (Clocks)
1E-1	2.563	3.290
1E-2	4.653	5.152
1E-3	6.180	6.581
1E-4	7.438	7.781
1E-5	8.530	8.834
1E-6	9.507	9.783
1E-7	10.399	10.653
1E-8	11.224	11.461
1E-9	11.996	12.219
1E-10	12.723	12.934
1E-11	13.412	13.613
1E-12	14.069	14.261
1E-13	14.698	14.882
1E-14	15.301	15.479
1E-15	15.883	16.054
1E-16	16.444	16.610

BER=10-x for Tj=Ts

TJ must be below Ts to guarantee the targeted BER

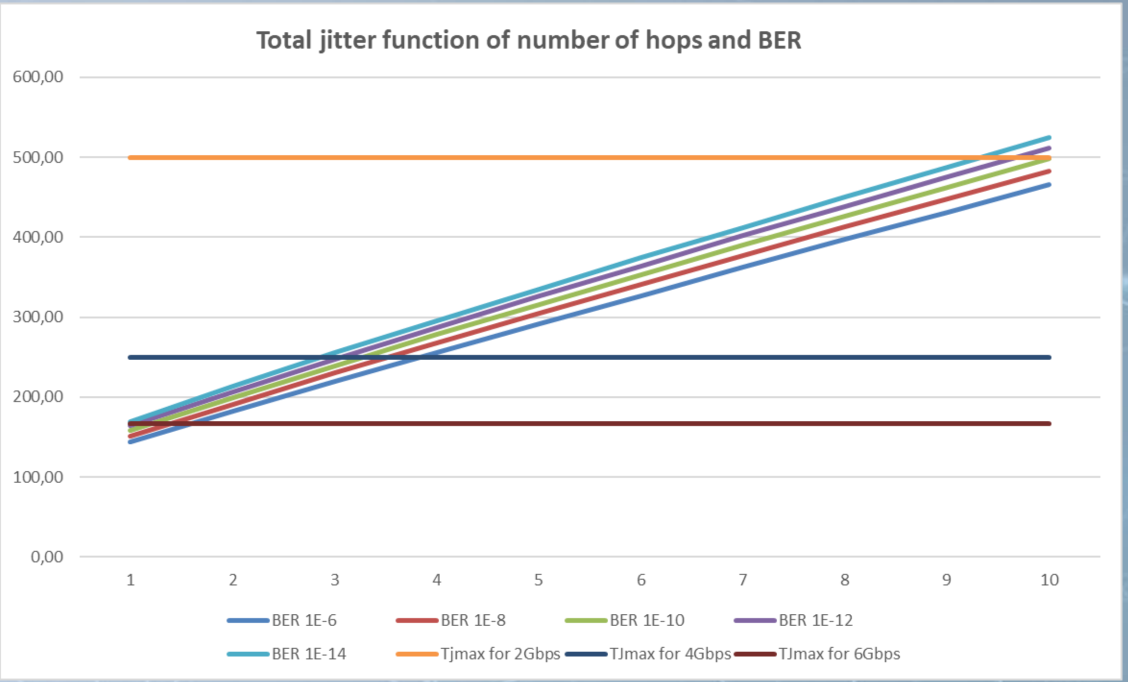
System level analysis

- Impact of relaying type
  - **Amplify and forward**

Deterministic jitter are summed: $DJ = \sum_n DJ_n$

Random jitter are quadratically summed:

$$RJ = \sqrt{\sum_n {RJ_n}^2}$$



  - **Decode and forward**

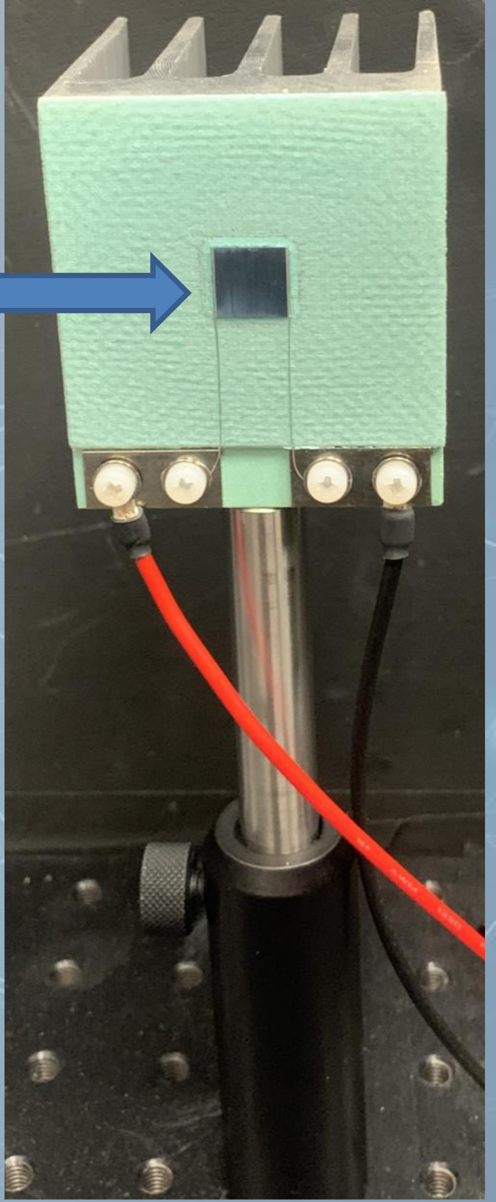
The total BER is the one of a single link multiplied by the number of layers

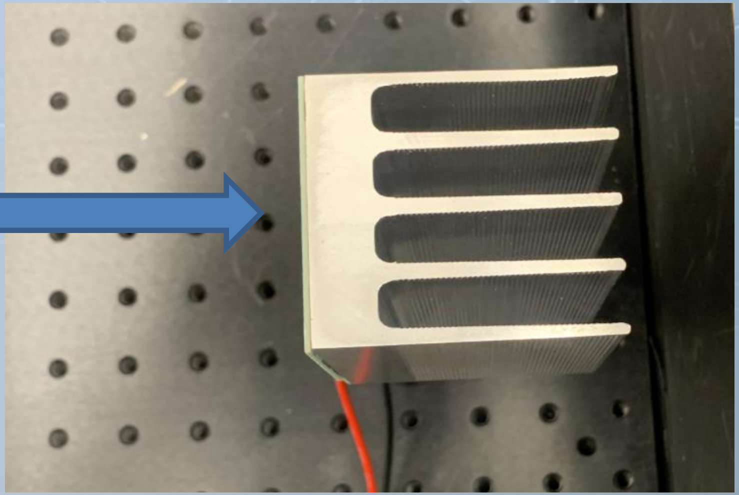
  - **Decode, correct and forward**

The total BER is the one of a single link

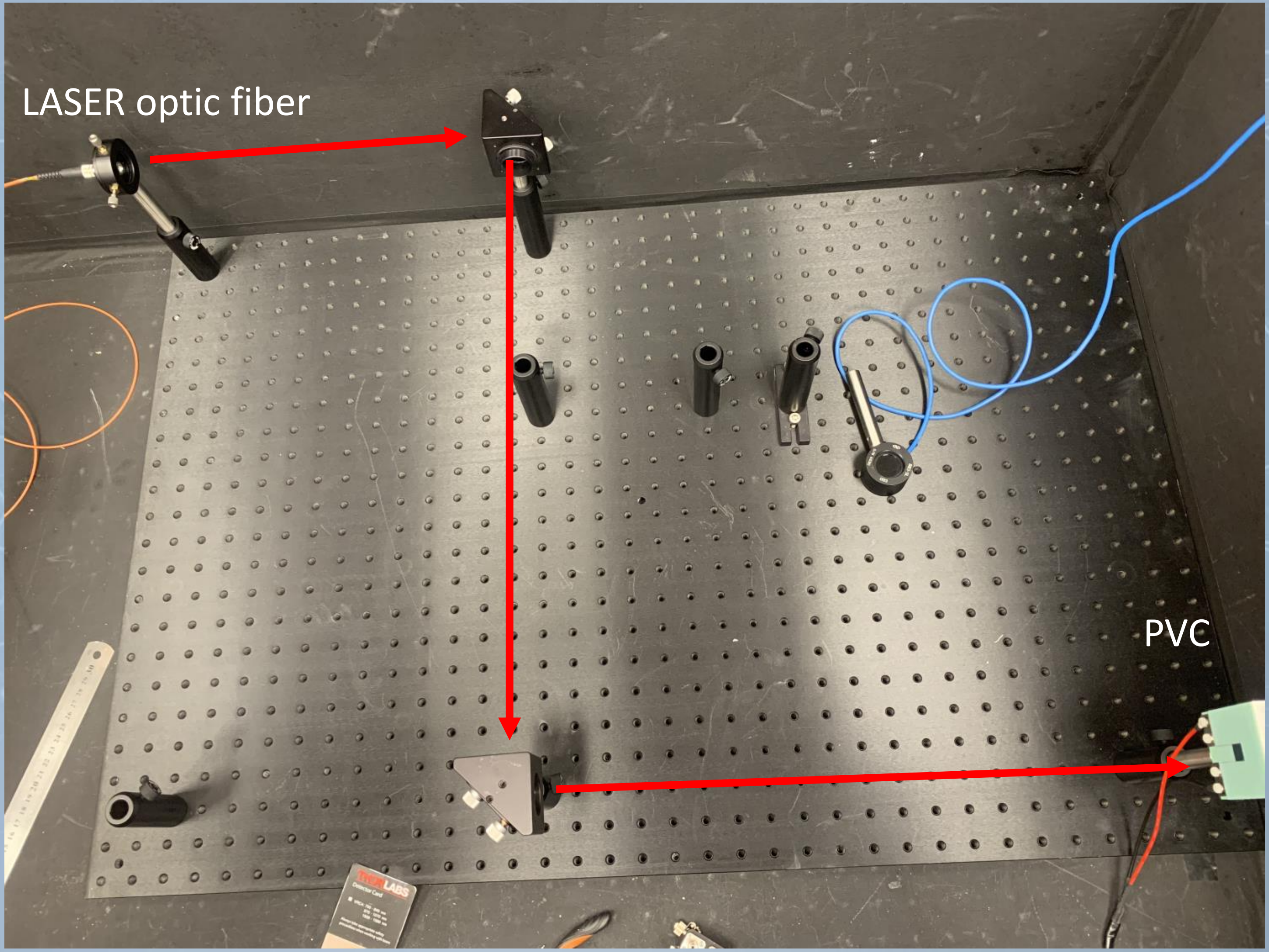
WP9: current work

- Laser power transmission (LPT) @ Tel Aviv University
- Purchased:
  - 10W laser 980 nm
  - 2 photovoltaic cells (PVC):
    - 10x10 mm cell
    - Si based vertical multi-junction PV cell
    - High voltage density with low current
    - Optimal efficiency for 9xx nm lasers
    - High efficiency
  - Optical bench

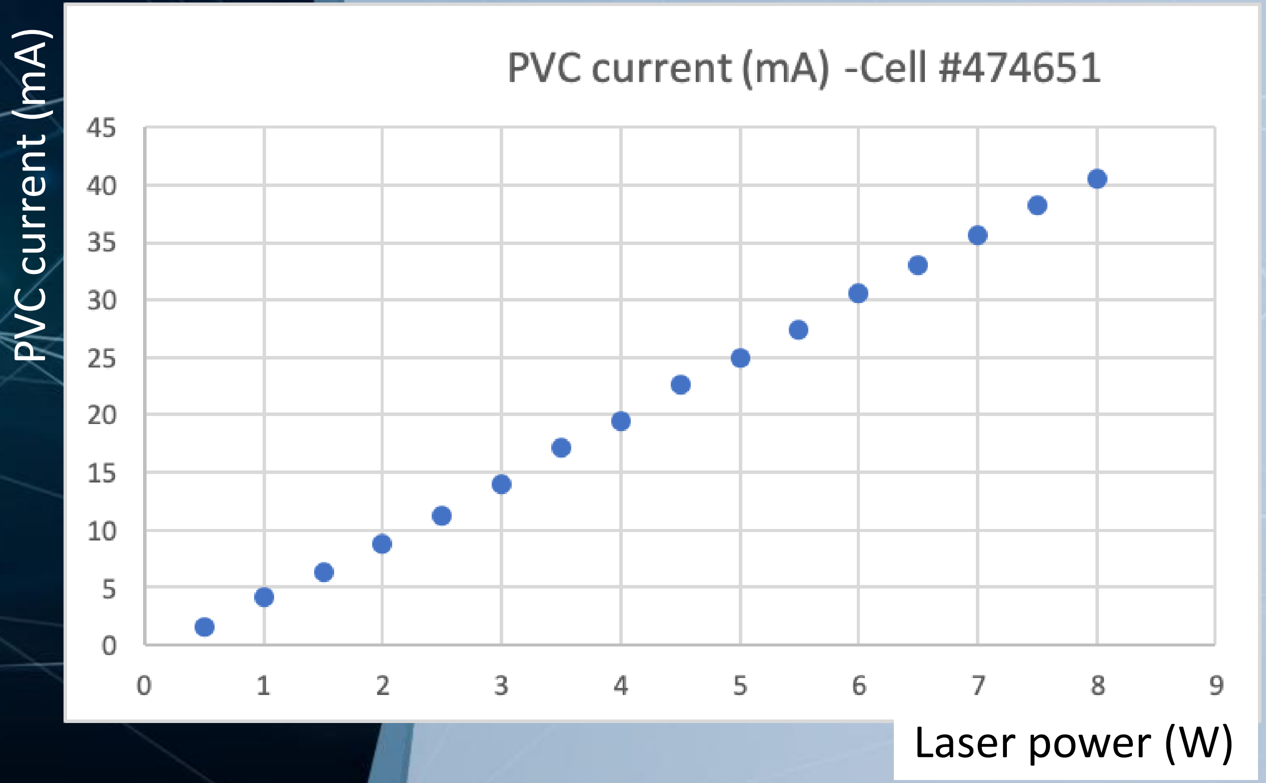


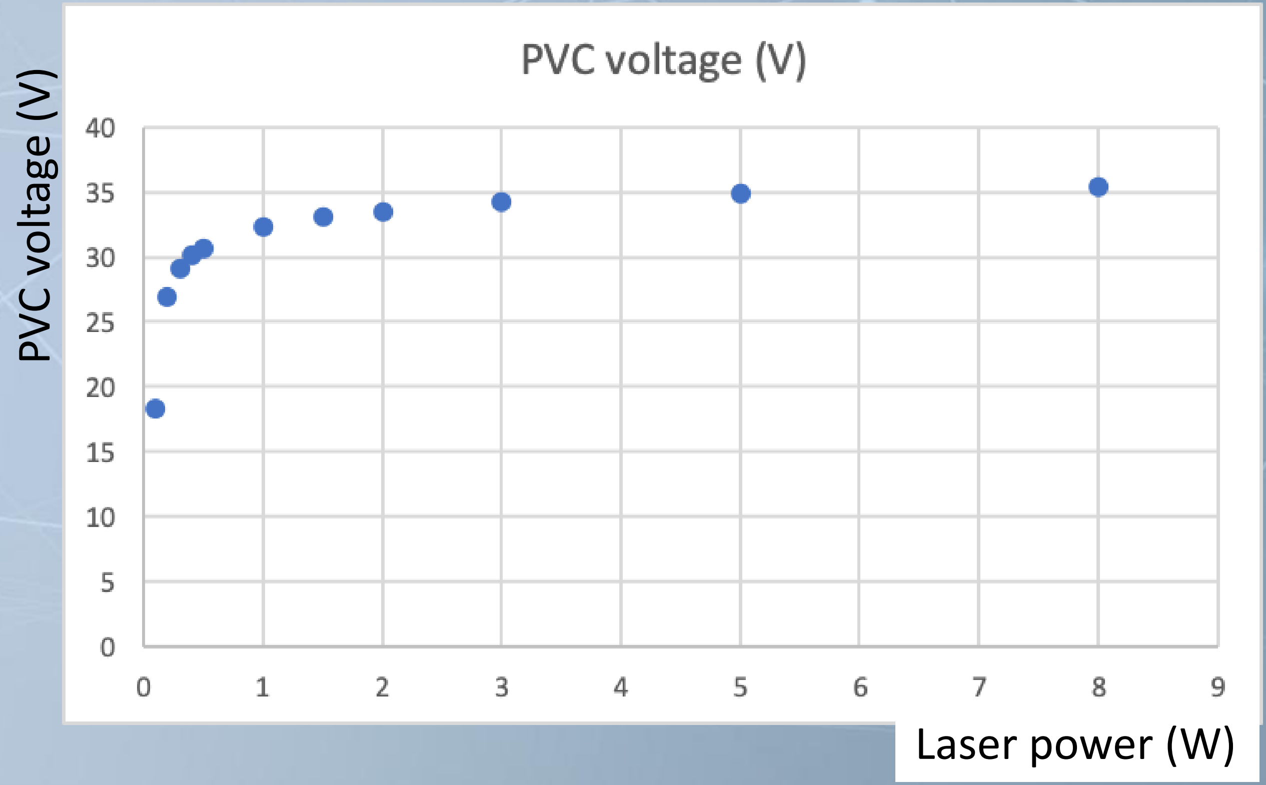


LPT: setup

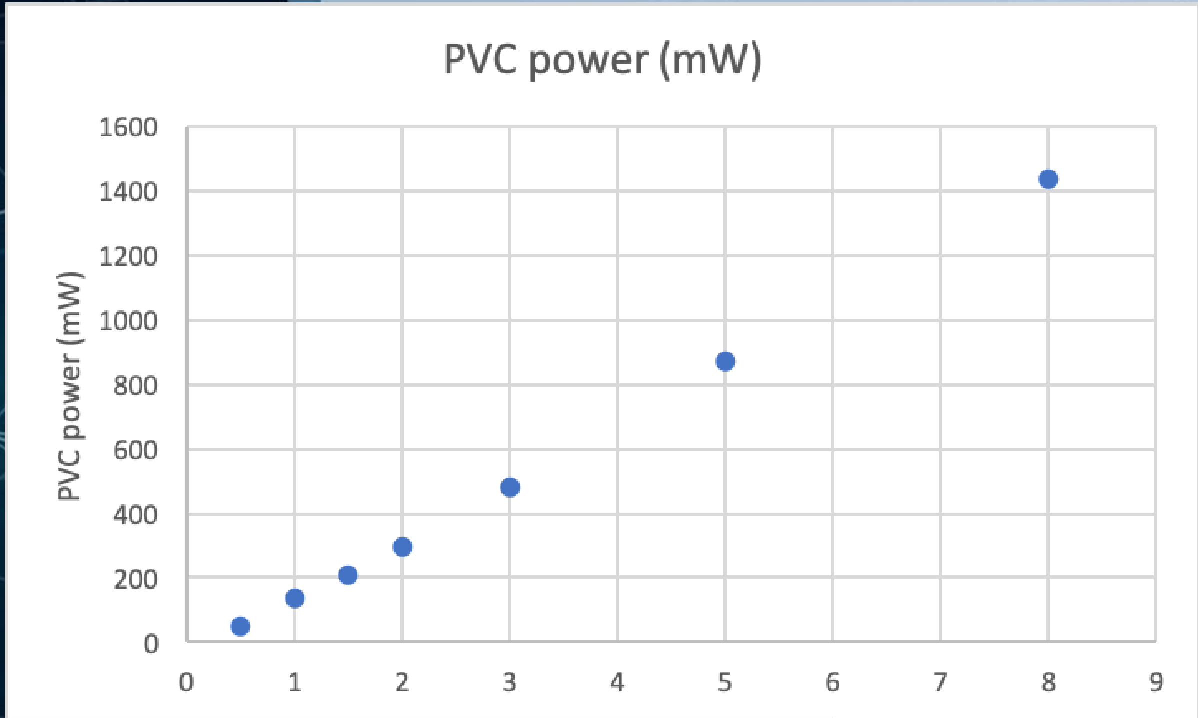


LPT: first measurements with PVC#1

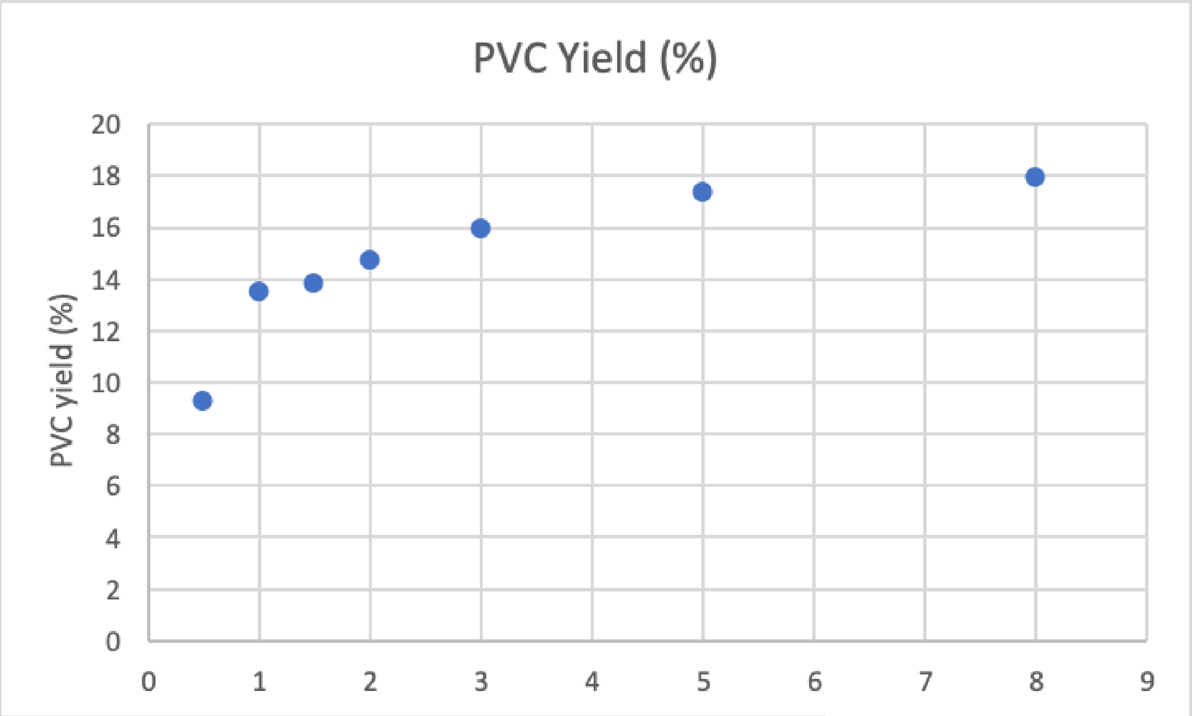




LPT: first measurements with PVC#1



Laser power (W)



Laser power (W)

LPT: next steps

- Near future
  - Test the second PVC
  - Influence of the distance laser-PVC
  - Temperature (PVC) study
  - Laser beam split
  - First DC/DC circuit
- Future
  - Connect detector and start noise analysis

conclusion

- Some groups didn’t get funding for this year but are investigating new opportunities.
- mm wave allows high data rate, low power communication at short range
- Commercial products at 60GHz are been purchased and tested
- Repeater boards produced and tested to extend the wireless signal
- Integration of the 60 GHz chip with LNA and antenna array
- System level analysis : noise study
- Power transmission: study started

Thank you !