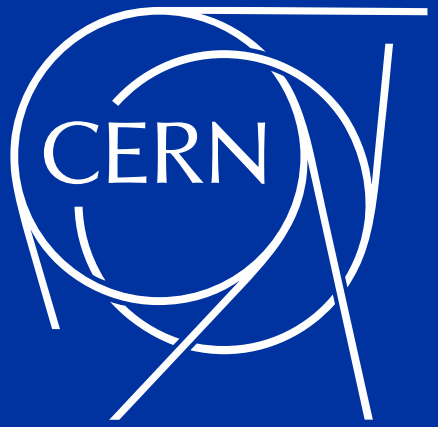
TWEPP 2024

Topical Workshop on Electronics for Particle Physics



The services chain for the upgrade of the Inner Tracker Pixel detector of the ATLAS experiment

Full services from pixel modules to optical readout for the Outer Barrel sub-system

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03/10/2024

[1]On behalf of ITk Collaboration

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Content

1. System description
2. Electrical QC of type-1 data bundles
3. Integration testing – Data path
4. Conclusion

1. System description

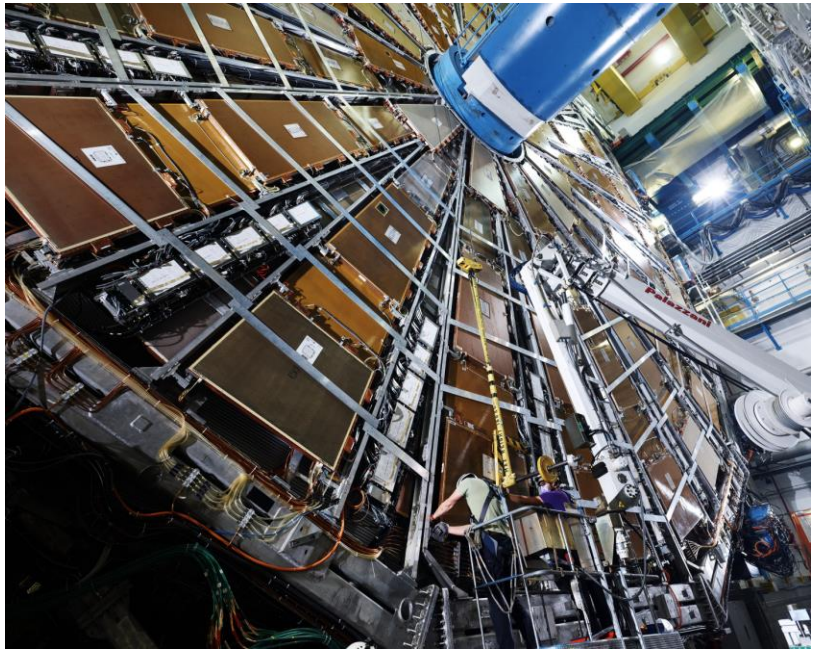
2. Electrical QC of type-1 data bundles

3. Integration testing – Data path

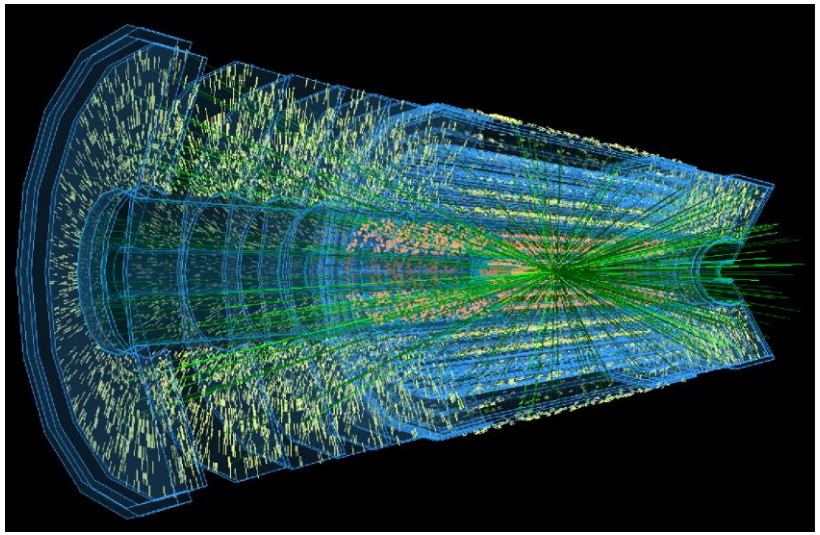
4. Conclusion

ATLAS experiment

- ATLAS (A Toroidal LHC ApparatuS)
- General-purpose experiment including:
  - Inner Detector (ID)
  - Calorimeters
  - Muon Spectrometers
  - Magnet Systems
- ATLAS will undergo a major upgrade for Phase-II (more here)
- The ID will be replaced by an all silicon tracker, the Inner Tracker (ITk):
  - Radiation hardness up to $10^{16} n_{eq}/cm^2$, 5x the current.
  - Increased bandwidth – 1MHz readout. Current detector would have been inefficient even at 60% of the planned HL-LHC luminosity.

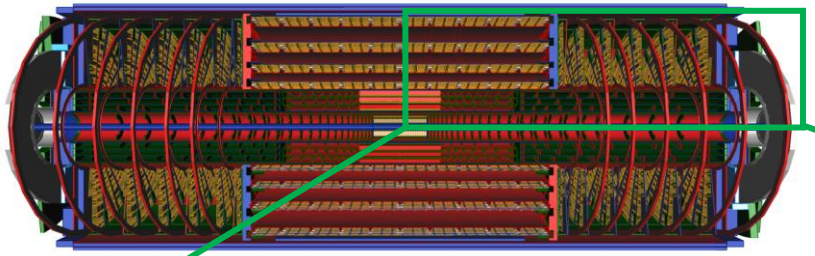


ATLAS detector during LS2 upgrade work 2022

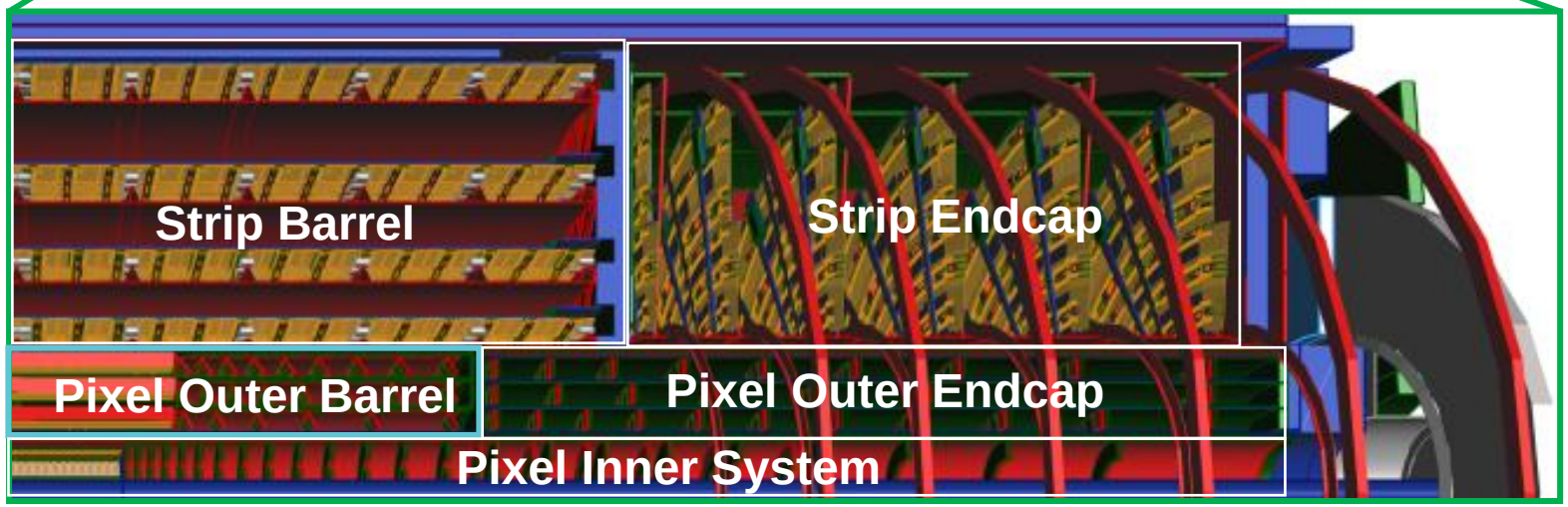


Simulated event from the HL-LHC ITk detector

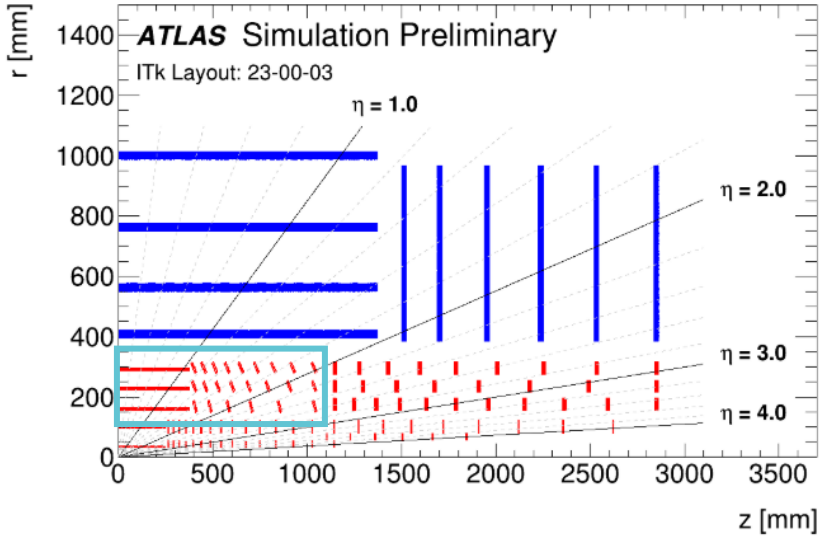
ATLAS ITk and the Outer Barrel sub-system



ITk layout for HL-LHC



3D rendering – One quadrant



ITk Schematic layout – One quadrant, only active components shown

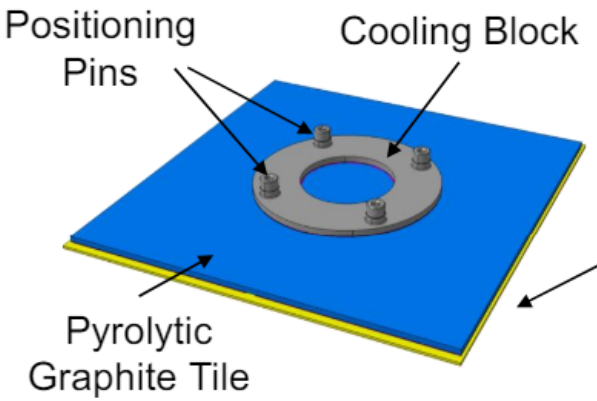
*Pixel sensors in red, strip sensors in blue. The OB in light blue.**

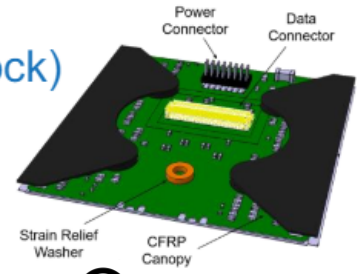
**Technical Design Report for the ATLAS Inner Tracker Pixel Detector, CERN-LHCC-2017-021*

ITk OB mechanics overview

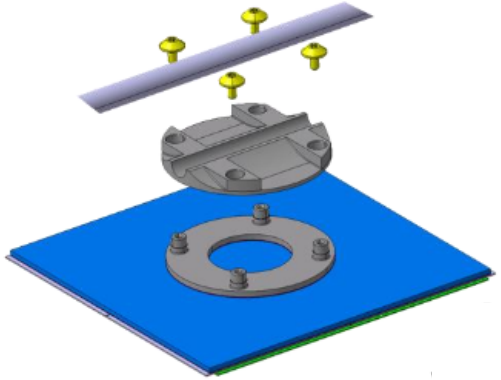
Module Cells

(Module + PG Tile + Cooling Block)



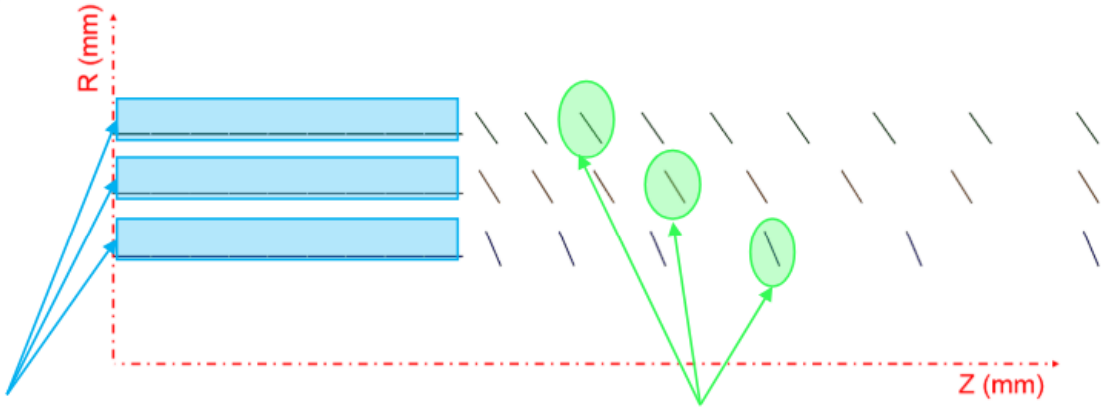


Module Glued on Cell

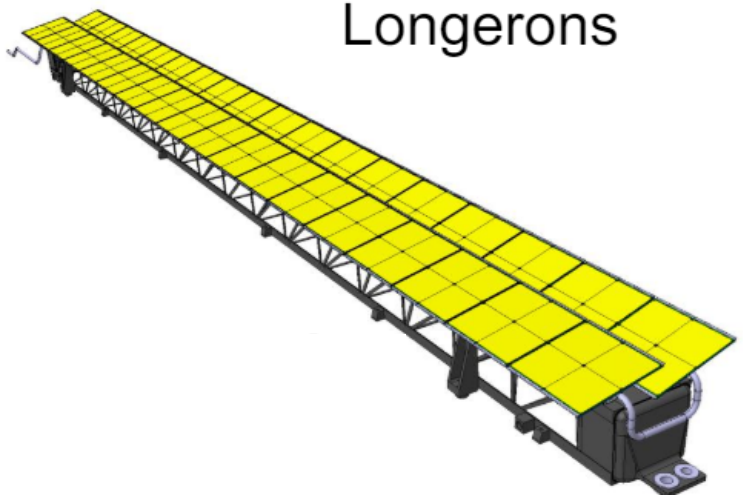


Functional Local Supports

(Base Blocks + Cooling Pipe + CFRP Support Structure)



Longerons



Inclined Half-Rings

ITk OB services overview

DATA

POWER

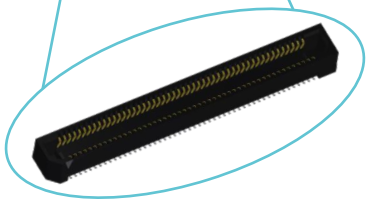
DCS

PP1

Optobox
Electro-optical translation
lpGBT & Vtrx+

Type-1 Power bundle
4 flavors w. many length sub-flavors

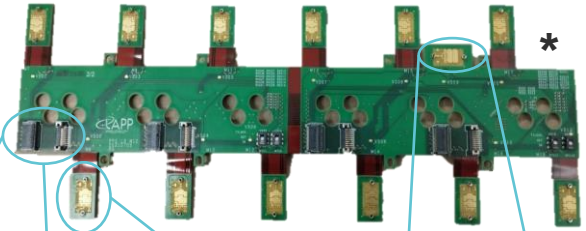
Type-1 Data bundle
14 flavors w. many length sub-flavors



SAMTEC ERF8-050

PP0

8 Flavors



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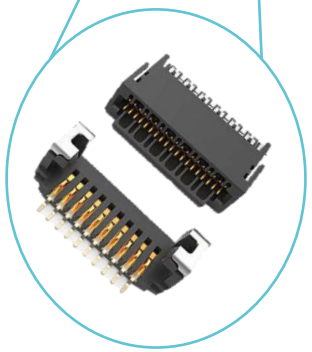
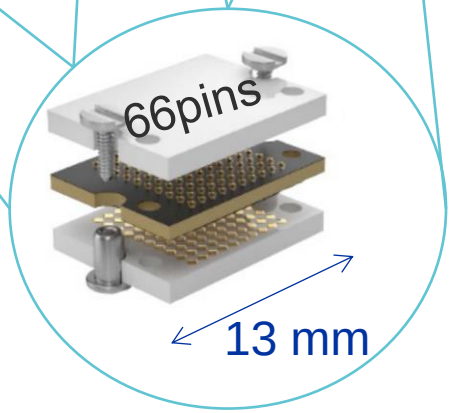


SAMTEC UEC5 UCC8

*

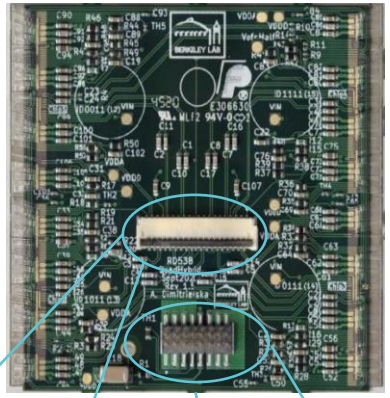
pigtail

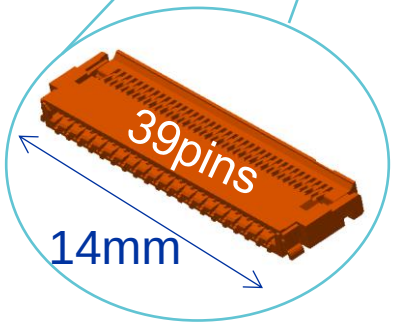
14 Flavors



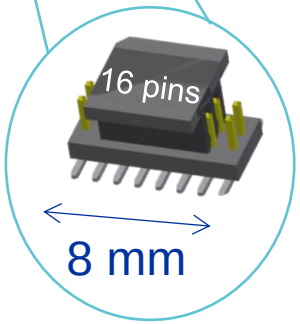
SAMTEC Z-RAY
custom interposer

ITk pixel module





MOLEX 502598-3993



SAMTEC FTM-108-02

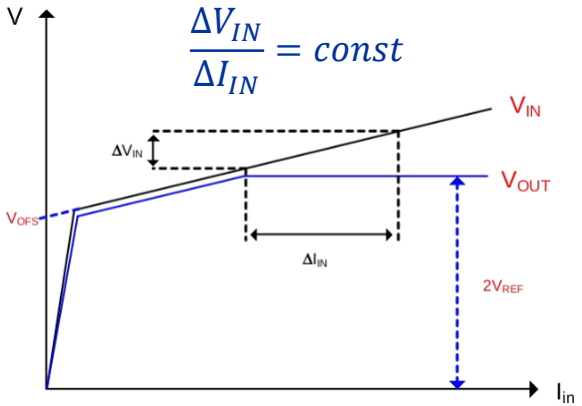
*More on Francesco Costanza's talk: Production of flex circuits for the ATLAS ITk Pixel Outer Barrel

ITk OB Powering

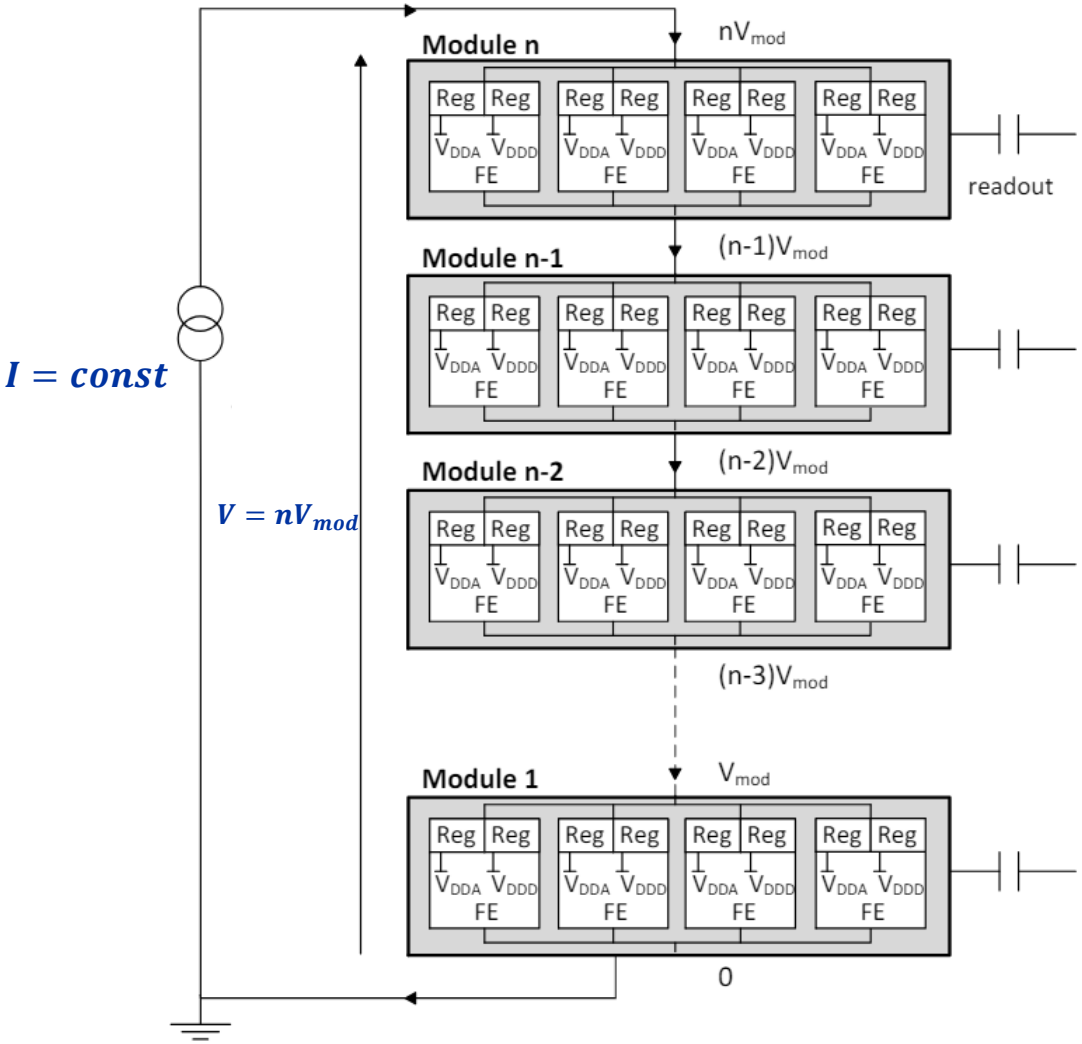
- Up to n=14 modules in series
- 6A nominal current (I), 1.6V per module (V_{mod})
- Shunt-LDO converts current to stable VDDD, VDDA

Repercussions :

- AC coupling required for all input and output signals
- Each module needs AC coupling between its local GND and the “global” PP0 GND.
- And more…



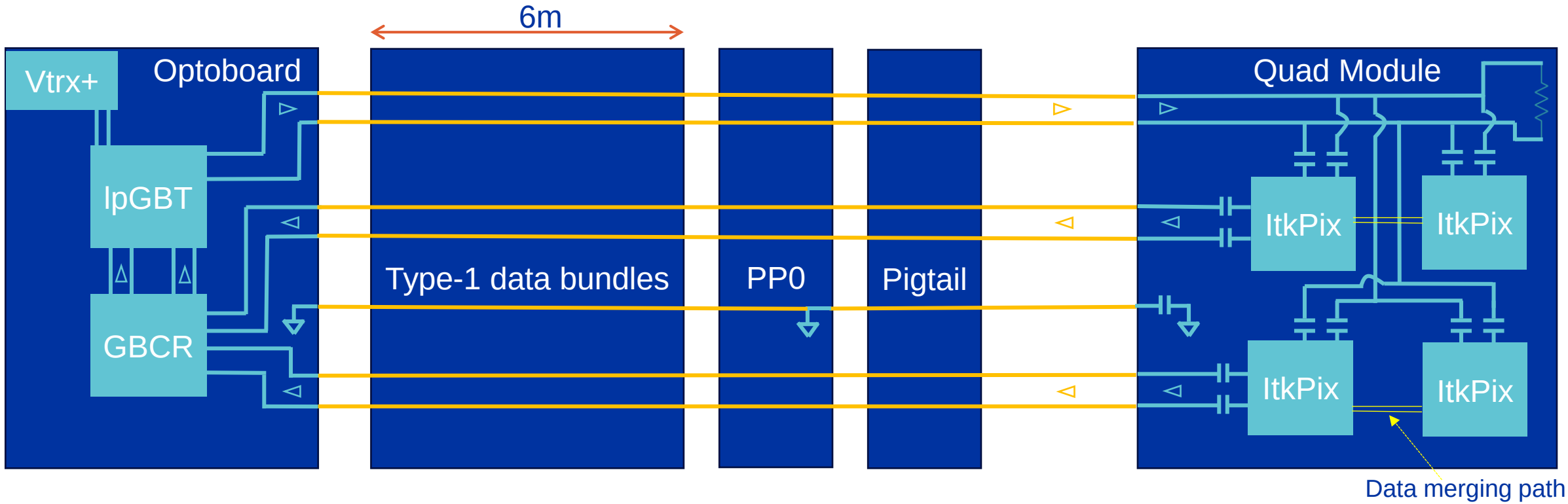
*Shunt-LDO in & out V-I curve**



Serial Powering diagram

*Jeremias Kampkötter et al 2022 J. Phys.: Conf. Ser. 2374 012071

ITk OB Data Transmission



- **Data from each module (4 ASICs) can be sent through 1 or 2 ASICs as needed.**
- **1.28Gb/s uplinks, 160Mb/s downlinks.**
- **Impedance 90-110 Ohm for the full chain.**
- **Specification: max 20dB insertion loss at 640MHz.**

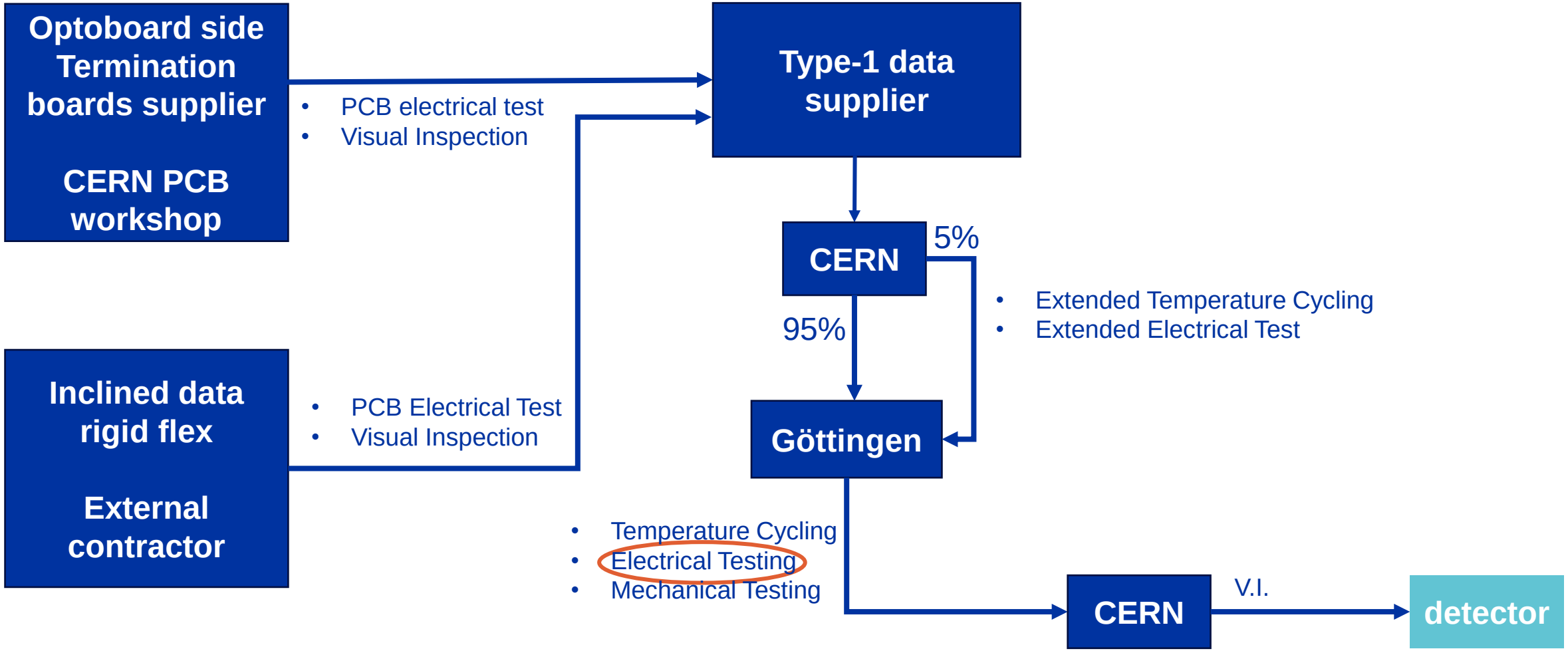
1. System description

2. Electrical QC of type-1 data bundles

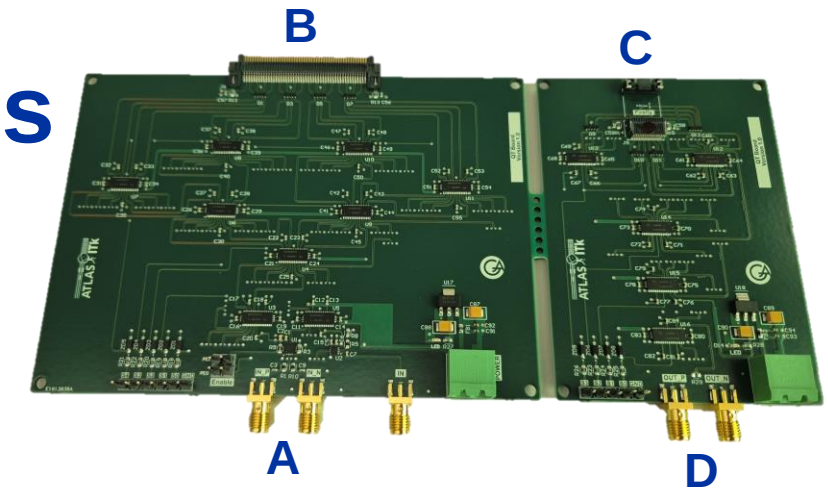
3. Integration testing – Data path

4. Conclusion

QA & QC stages of type-1 data bundles



Electrical Test of type-1 data bundles



PRBS8 generator @1.28Gb/s

CG635

DUT: Type-1 data bundle

A

B

C

SMA IN

Pre-emphasis

DS25BR120

DEMUX 1:32 Diff. pairs

HD3SS3415R

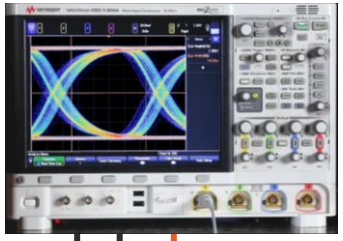
MUX 12:1 Diff. pairs

HD3SS3415R

SMA OUT

Test board

D



MCU

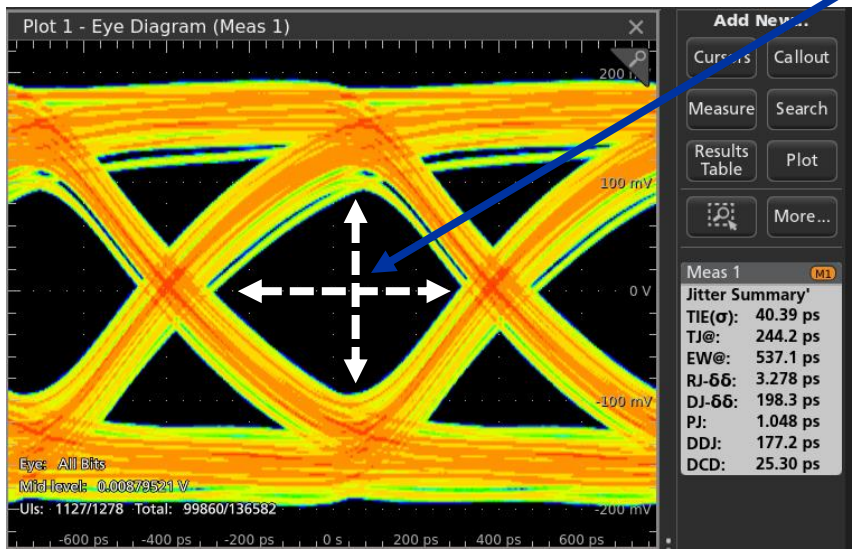
- *Saving data*
- *Control of tests*

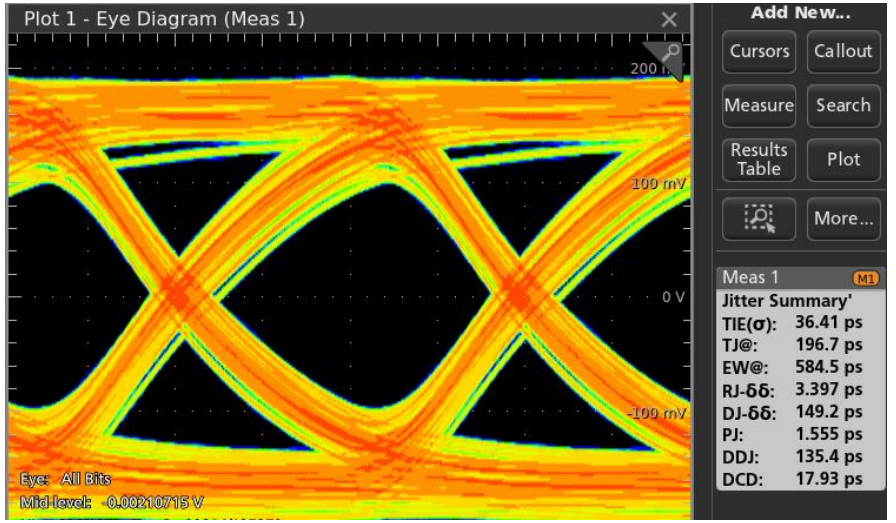
Test time ~minutes

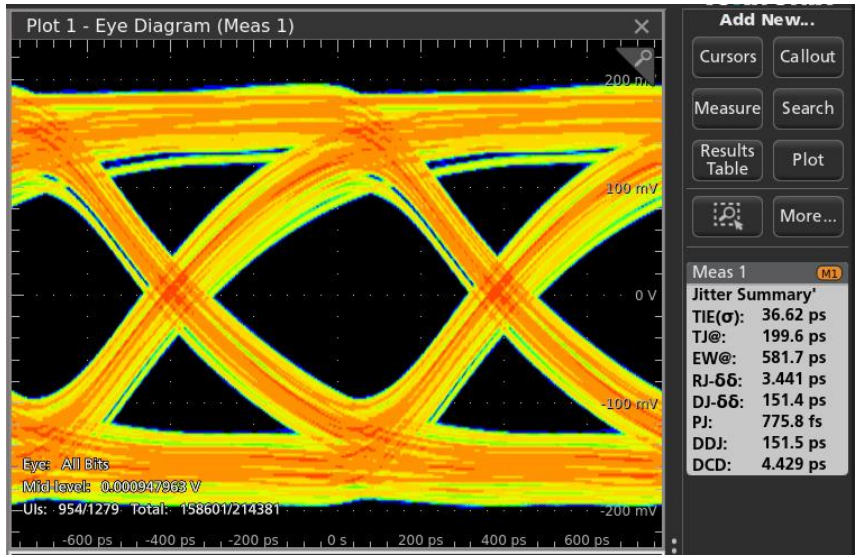
Prototype test system results

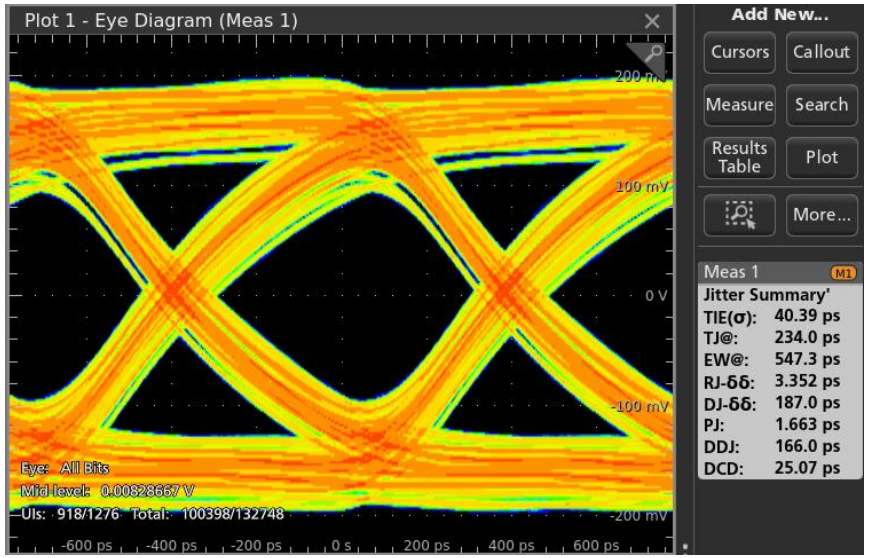
- **Full Pre-emphasis enabled (~7dB @640MHz)**
- **D.U.T: cables with 14dB@640MHz insertion loss (similar to type-1 data bundles)**
- **Eye diagrams of 4 random paths of the test board.**

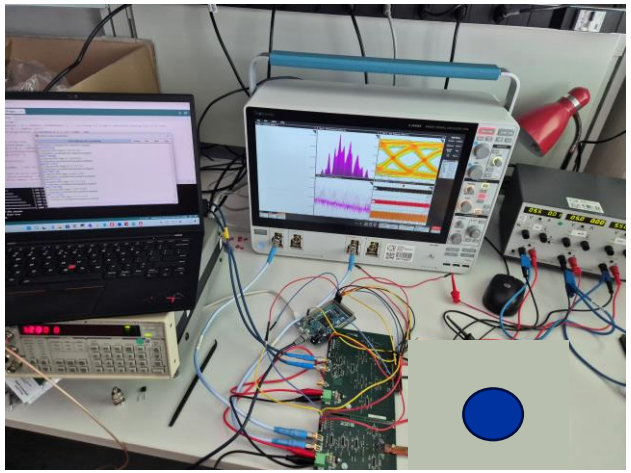
Acceptance: eye height & width











1. System description

2. Electrical QC of type-1 data bundles

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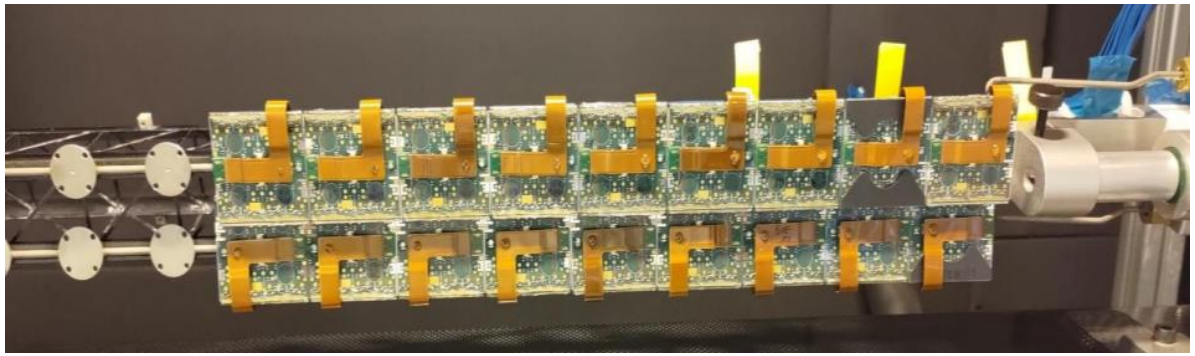
Problem description

During:

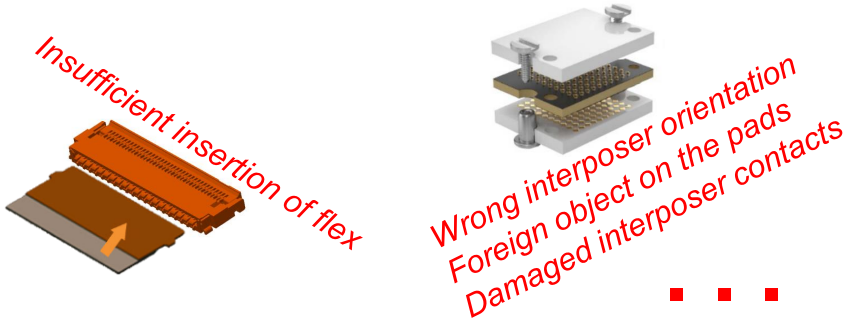
- **Testing in System Test**
- **Quality Control of Loaded Local Support**
- **Testing and QC during Detector Integration**

Before operating the modules, more than 5h are required for the drying of the environmental enclosure.

Any issue* with connectivity along the services chain results in >5h delay to open the enclosure, fix and try again.



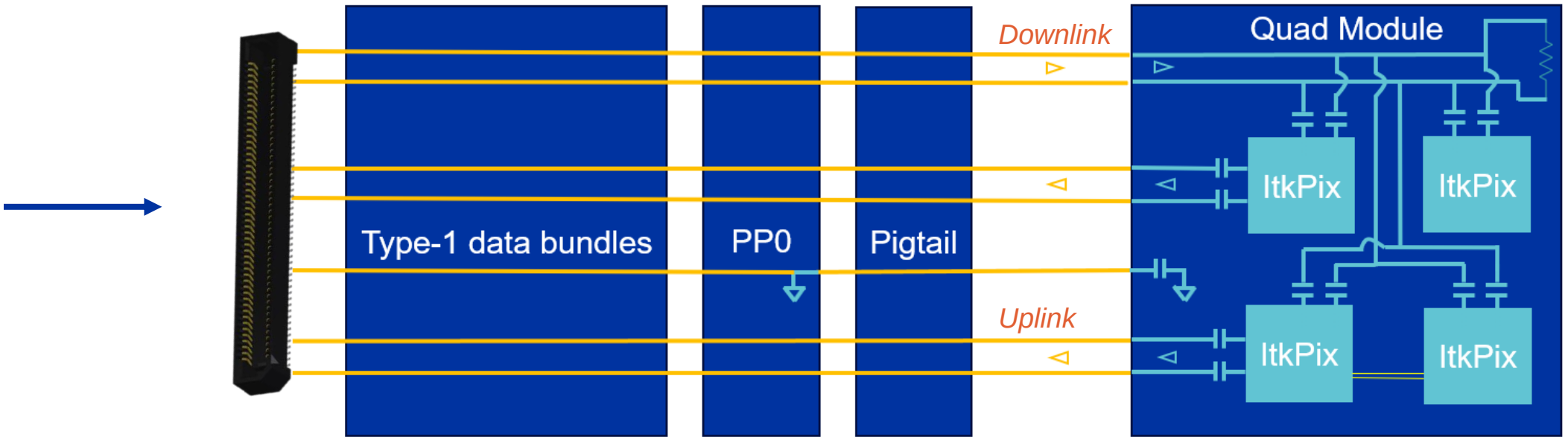
Two SP chains on one local support -Flat



**Open/short on single or multiple differential pairs because of wrong connector mounting, contamination etc*

→ ***Need to test connectivity without even powering!***

The assembled detector from the outside

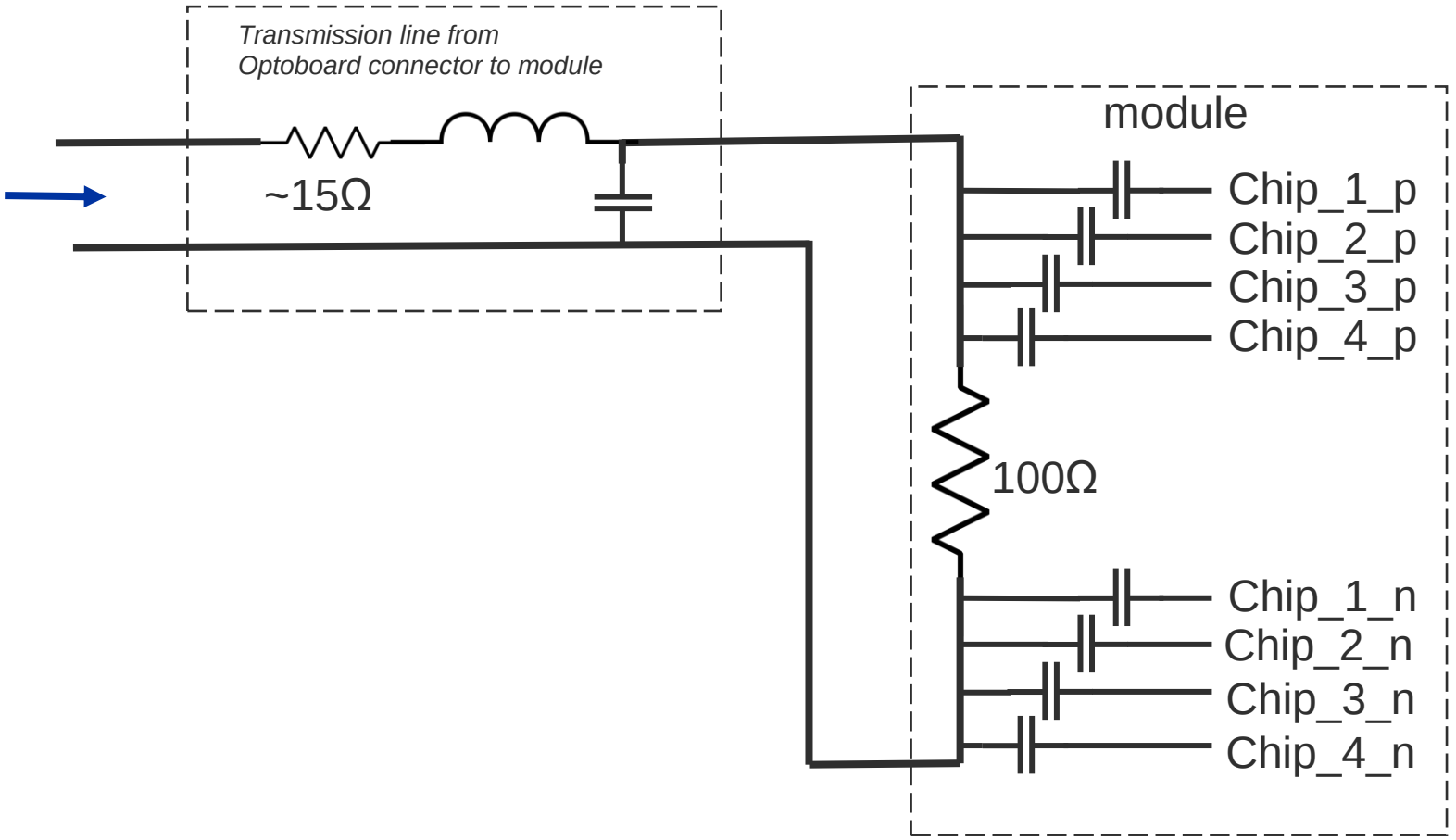


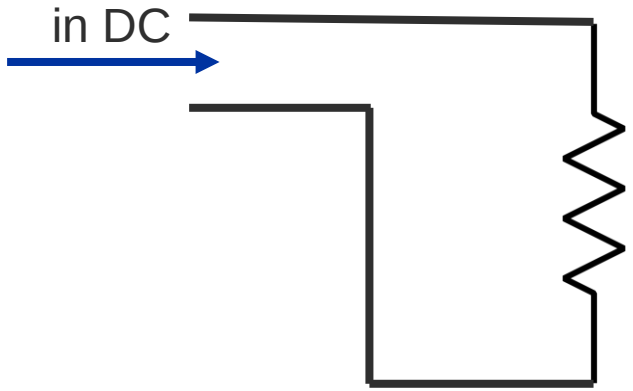
Two types of connections available on each type-1 data connector:

- (Up to 16*) **Uplinks**
- (Up to 8) **Downlinks**

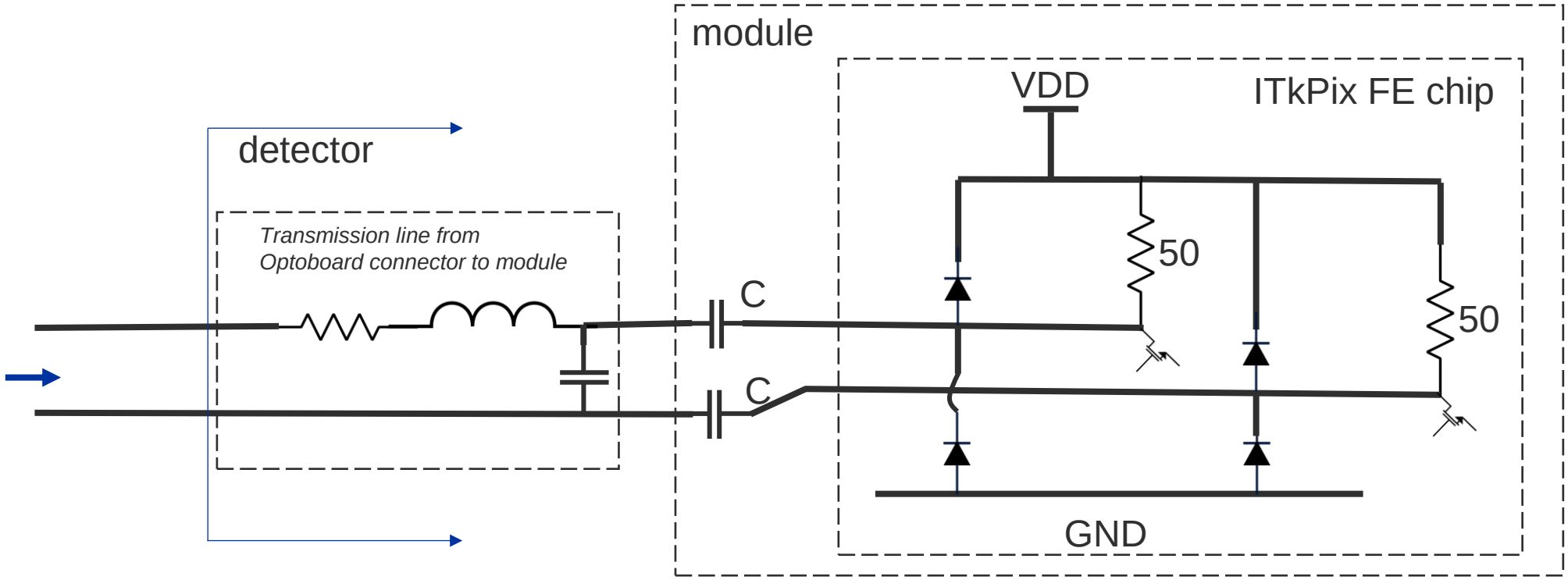
**For the Outer Barrel*

Connectivity check of the downlink



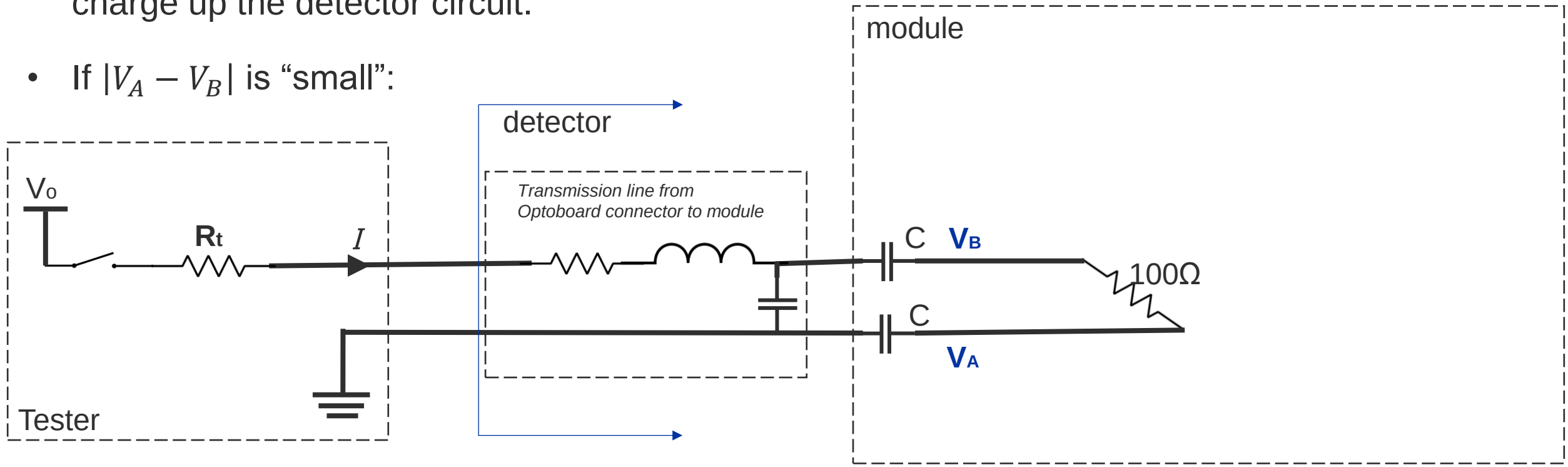


Connectivity check of the uplink



Connectivity check of the uplink

- Assume test circuit “Tester” tries to charge up the detector circuit.
- If $|V_A - V_B|$ is “small”:



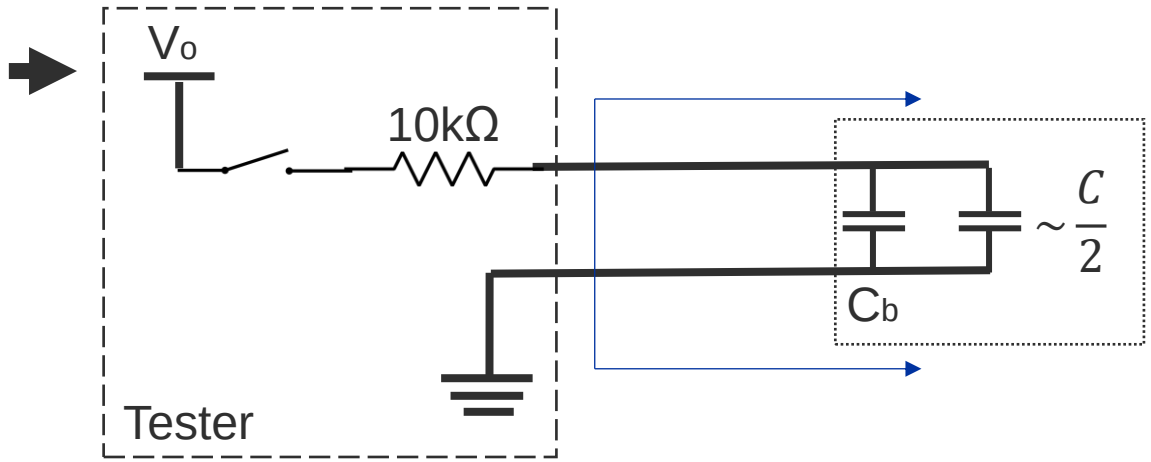
Connectivity check of the uplink

- If we try to charge the capacitors in the detector side “slowly” (w. high Rt)

$For\ \boldsymbol{R} > {}^{2L}/_{\sqrt{L(C_t)}} \Rightarrow Over\ damped\ response$

$I(t) \approx e^{st},\ s = \sqrt{(\frac{R}{2L})^2 - \frac{1}{LC_t}} - \frac{R}{2L}$

Current is governed by C and R only for a wide range of L (nH to mH++)

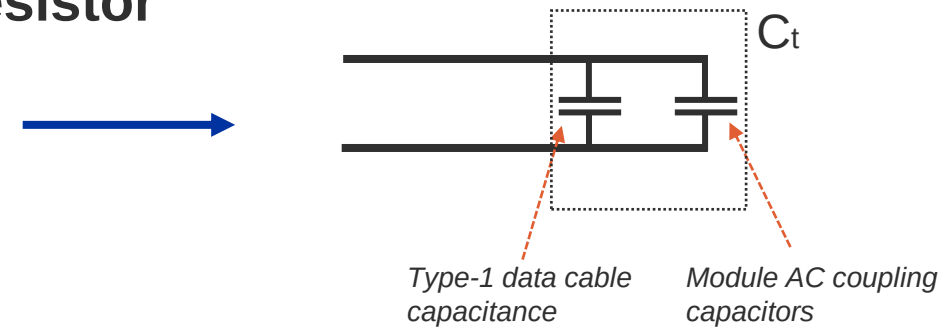


$C_t \approx C_b + \frac{C}{2}$

Type-1 data connectivity tester 1/3

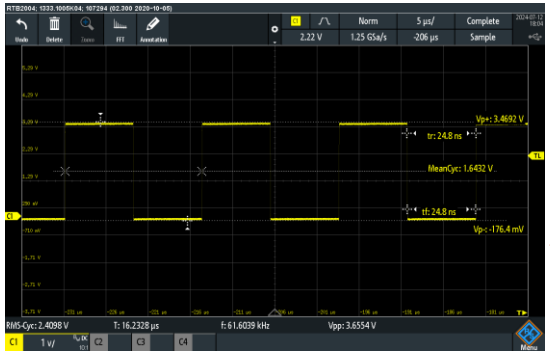
In DC, Downlink appears as :

The step response of the Uplink path, for appropriate series resistor appears as:

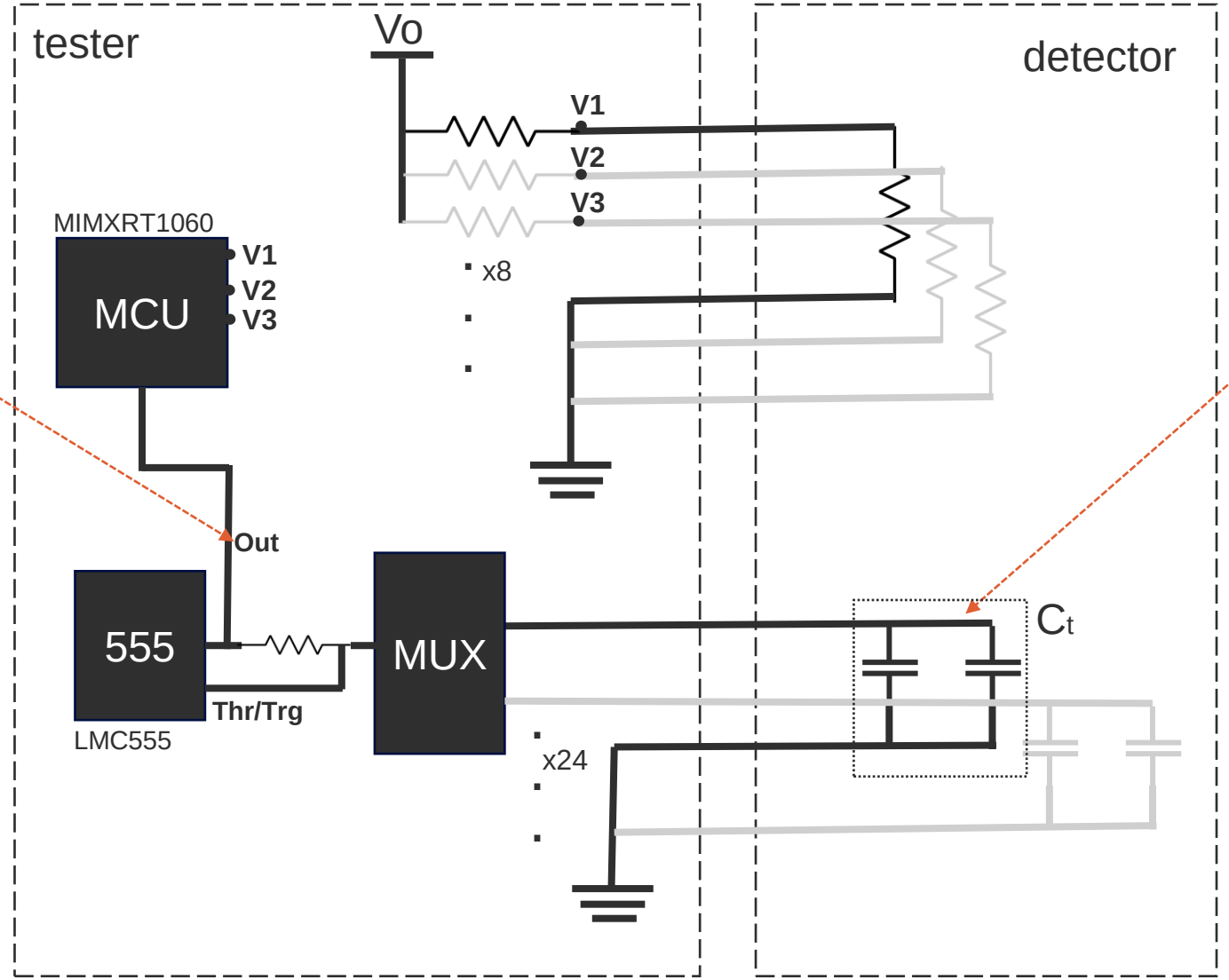


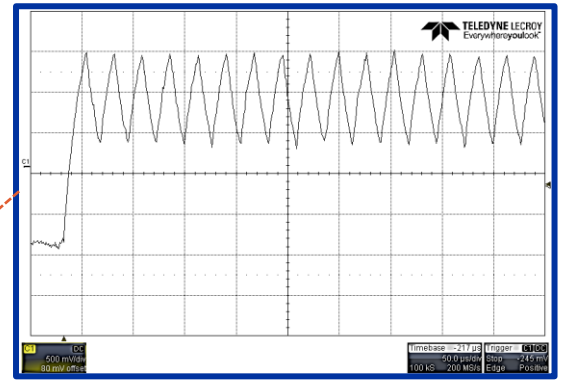
Type-1 data connectivity tester 2/3

555 output:
Frequency ∝ $1/C_t$



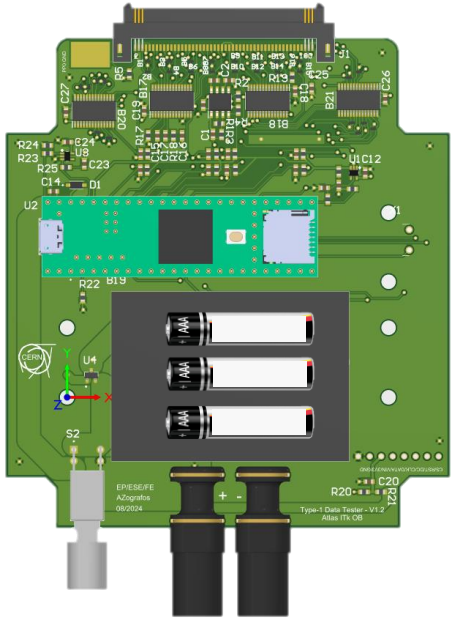
Rect pulse train
3.3Vp-p
60kHz for 1nF



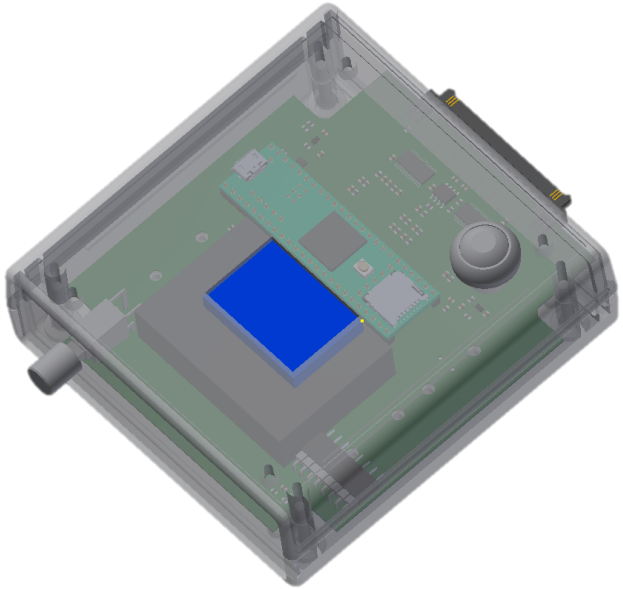


1.1Vp-p

Type-1 data connectivity tester 3/3



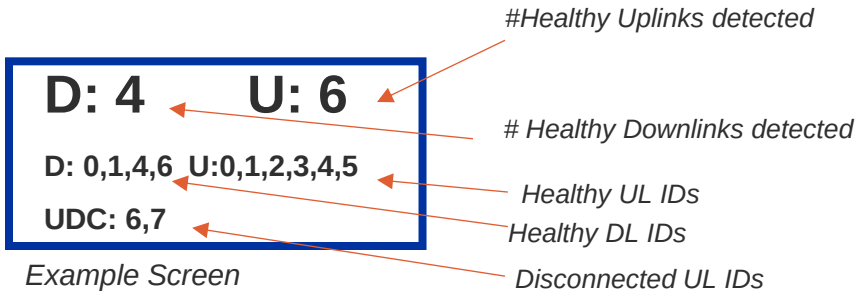
PCB design of the type-1 data tester



3D model of the type-1 data tester

Type-1 Data tester prototype compared to credit card

- **Optional handheld (battery powered) operation**
- **128x32 OLED display**
- **Output: Healthy/Unhealthy uplinks and downlinks count with their IDs**



Example Screen

1. System description

2. Electrical QC of type-1 data bundles

3. Integration testing – Data path

4. Conclusion

Conclusion

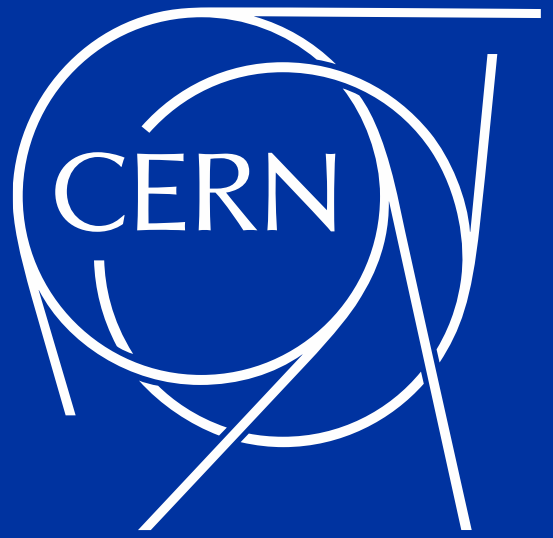
- **ATLAS ITk OB will soon start to come together.**

- **Complex system comprising of dozens of different parts, long and convoluted services chain.**

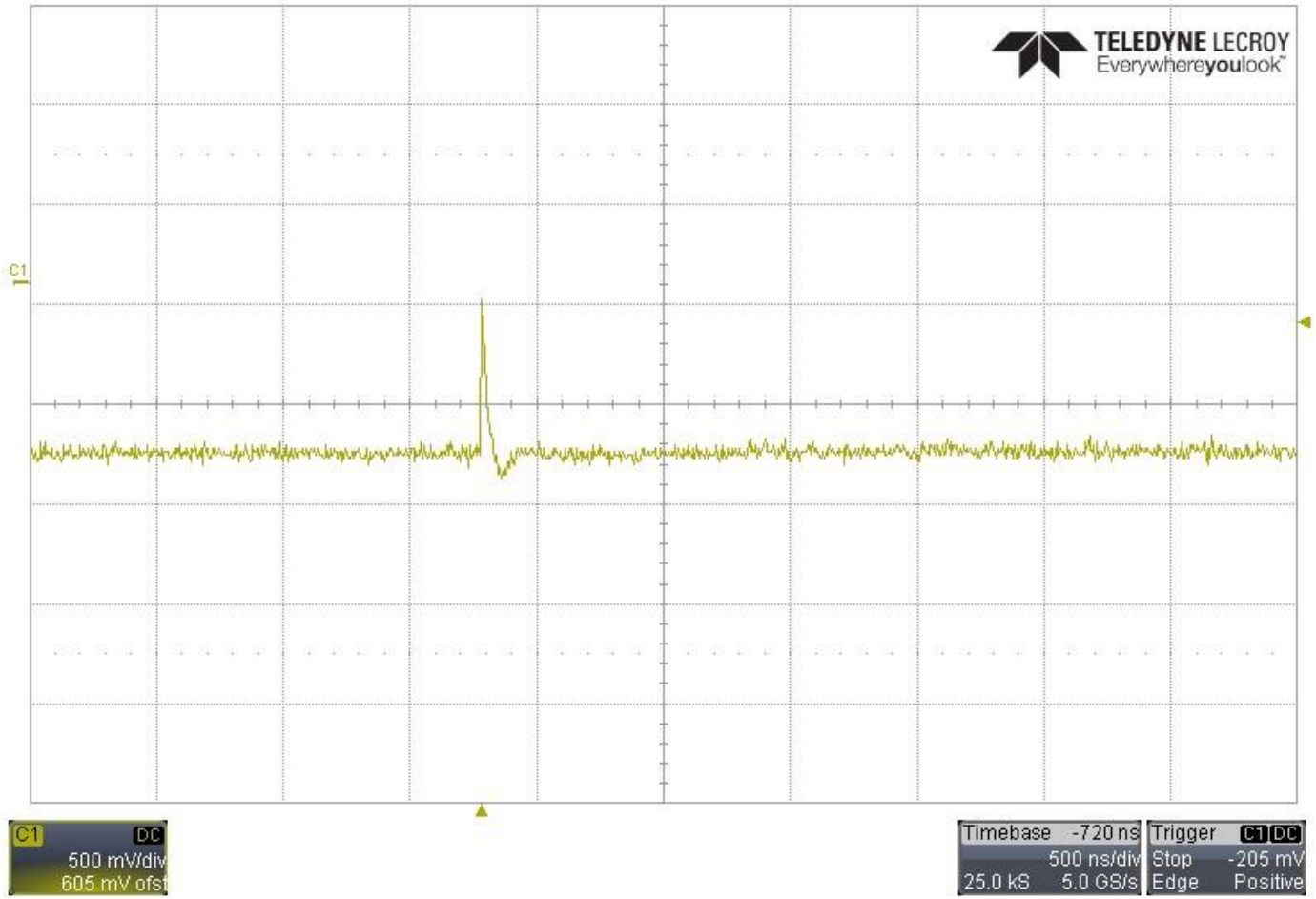
- **Type-1 data electrical QC system was developed, based on a simple concept of multiplexers, signal generator and oscilloscope.**

- **Type-1 data connectivity tester is based on resistance & capacitance measurements → With small changes, such a tester can be used for other systems where checking electrical connectivity in a fast way, without powering anything, can be useful.**

Thank you for your attention


CERN

Backup 1


TELEDYNE LECROY
Everywhereyoulook
C1
C1 DC
500 mV/div
605 mV ofst
Timebase -720 ns
500 ns/div
25.0 kS 5.0 GS/s
Trigger C1 DC
Stop -205 mV
Edge Positive