Update on the ITk Pixel OptoSystem

9th May 2022

Daniele Dal Santo on behalf of the Bern ATLAS Group

UNIVERSITÄT BERN

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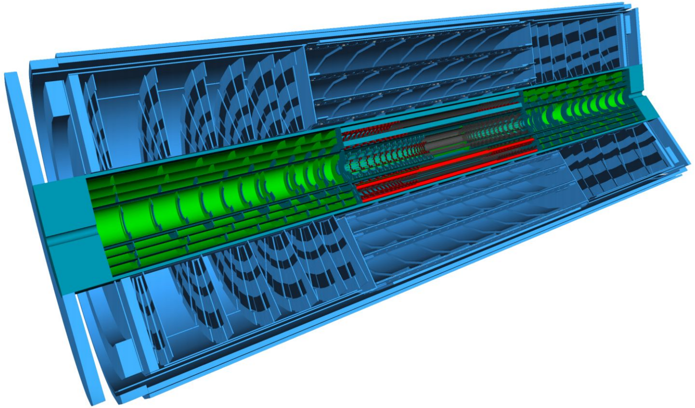
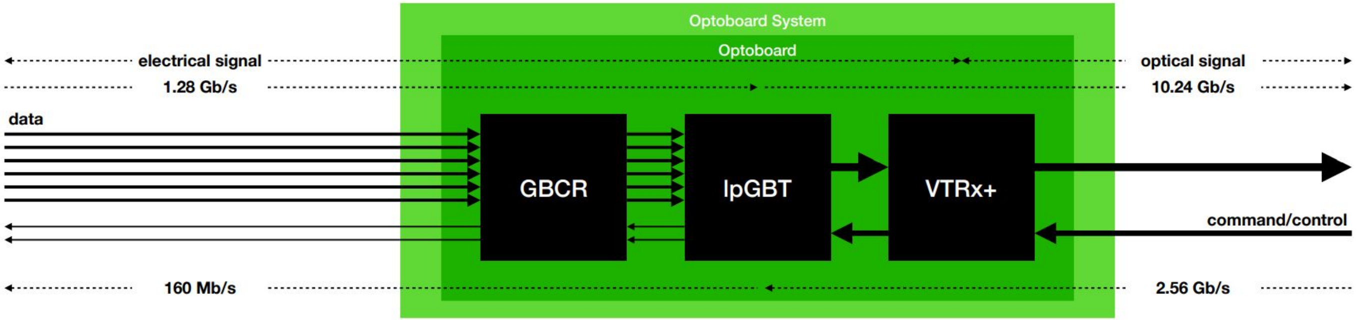
ATLAS EXPERIMENT

ITk Pixel Data Transmission Chain

- One of the pivotal components of the ITk is the Optosystem
- This handles the conversion of electrical signals to optical (and viceversa) and their aggregation

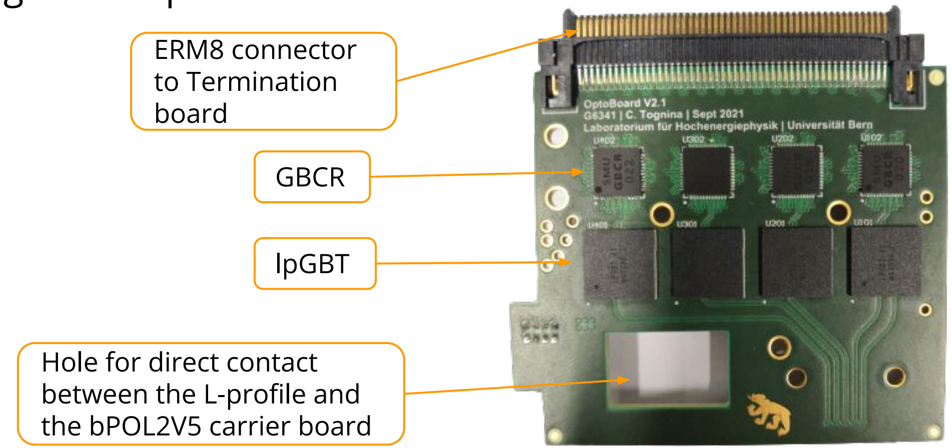




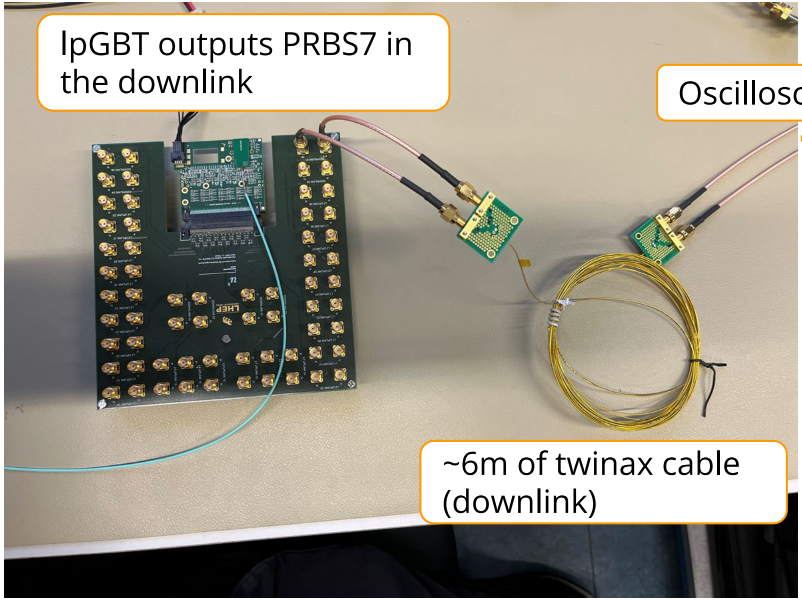
Quality Test of the Data Transmission: new Optoboard versions and readout of ITkPixV1

New Optoboard Versions

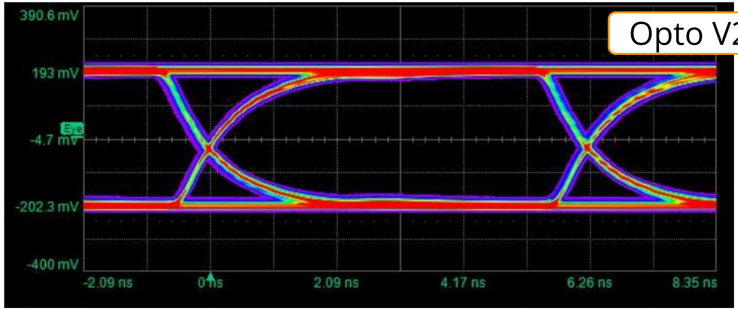
- Opto V2.1: fixes in the I^2C connection and clock line, hole for thermal contact between the bPOL2V5 carrier board and the L-profile cooling plate
- Opto V3.0: bypass of the GBCR in the downlink
- Optoboard V2.1 and V3.0 mount the lpGBT v1. Changes in:
  - the frame structure of the IC communication
  - the register map



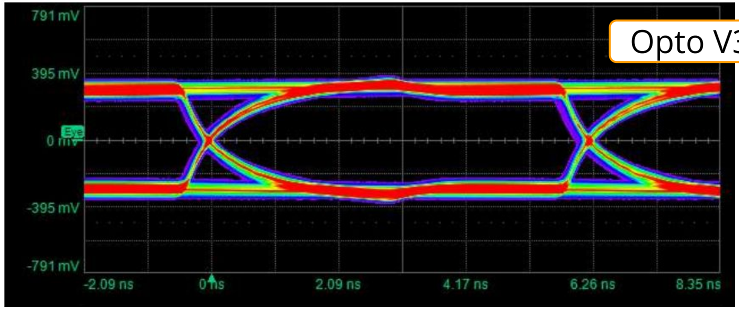
Opto V2.1 vs V3.0: downlink test [A. O'Neill]



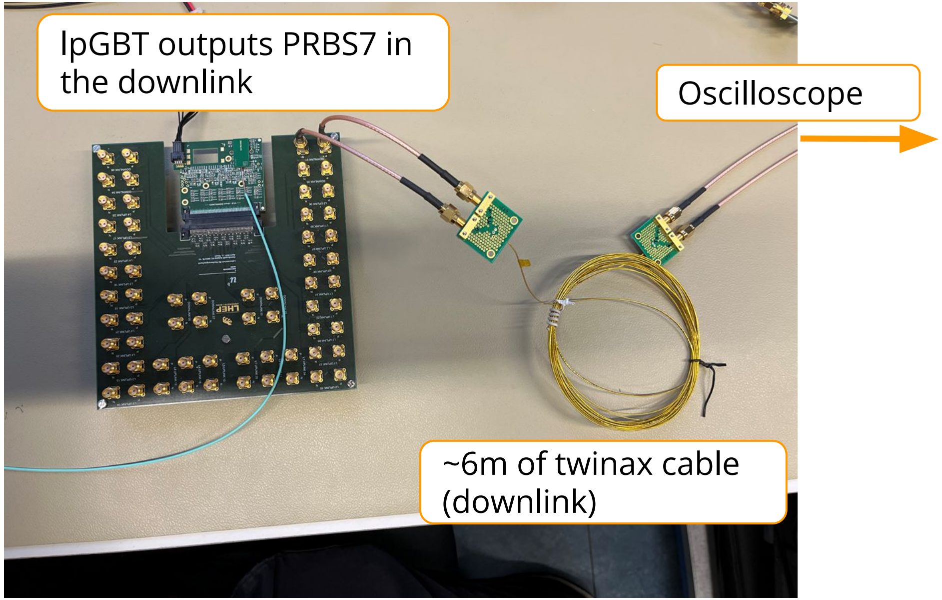
PreEmph = 3.0 mA PreEmphMode = Clock
DriveStrength = 3.0 mA GBCR PreEmph = 6

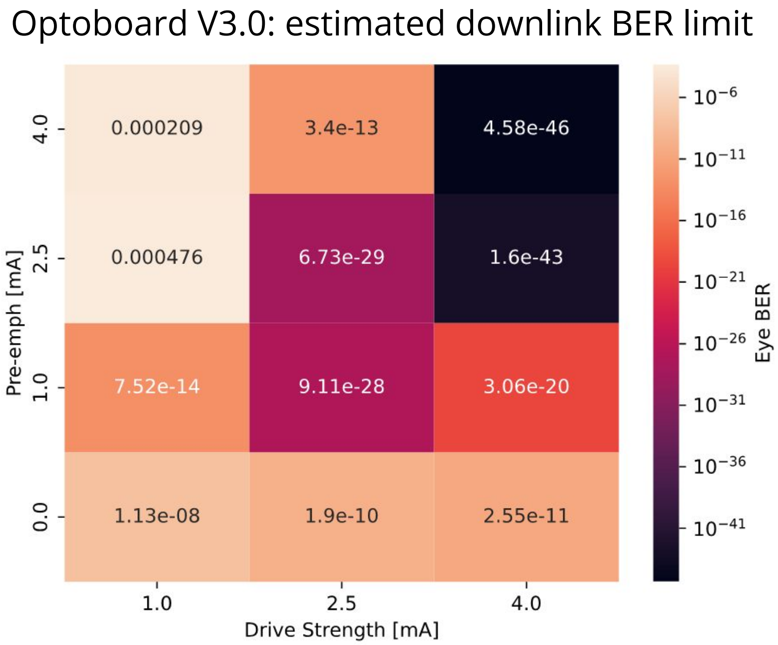


PreEmph = 4.0 mA PreEmphMode = Clock
DriveStrength = 4.0 mA GBCR bypassed

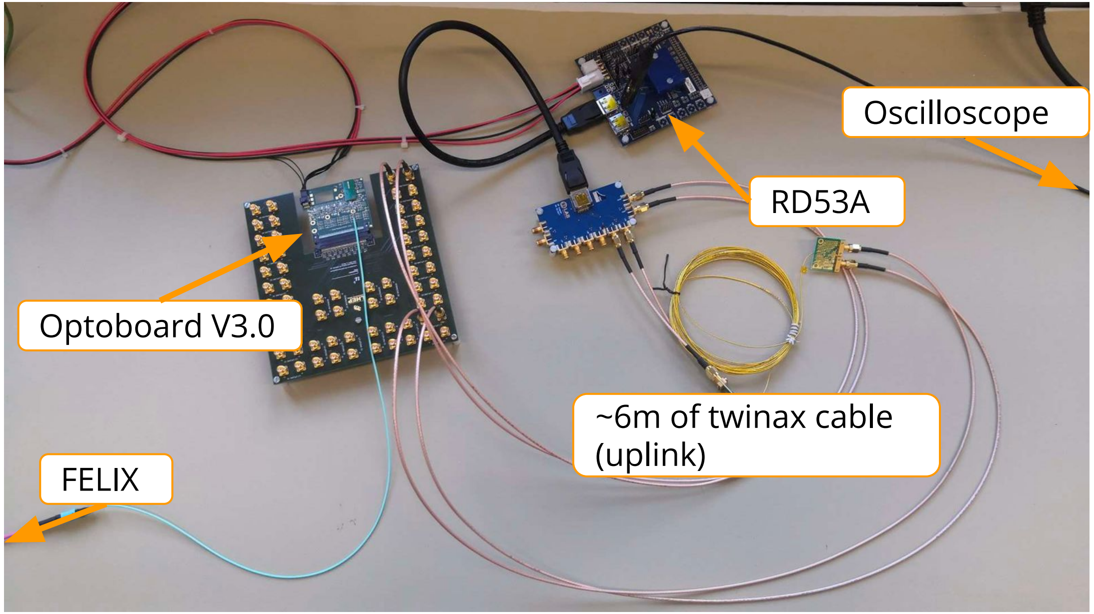


Opto V2.1 vs V3.0: downlink test [A. O'Neill]

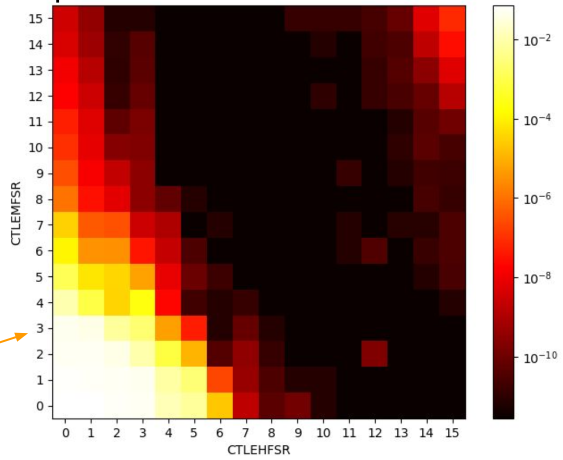




Opto V3.0: BER Test on the uplink [D. Dal Santo]



- the RD53A is programmed to output a PRBS7 pattern;
- a pattern checker on the lpGBT can execute a BERT; the result is then sent via optical fiber to FELIX;
- multiple BERT are performed changing the parameters of the equalizer of the GBCR.



BER limit varying the parameters of the equalizer of the GBCR

Test of the uplink of the ITkPixV1 [D. Dal Santo]

Problem: FELIX still doesn't support the configuration of the ITkPixV1

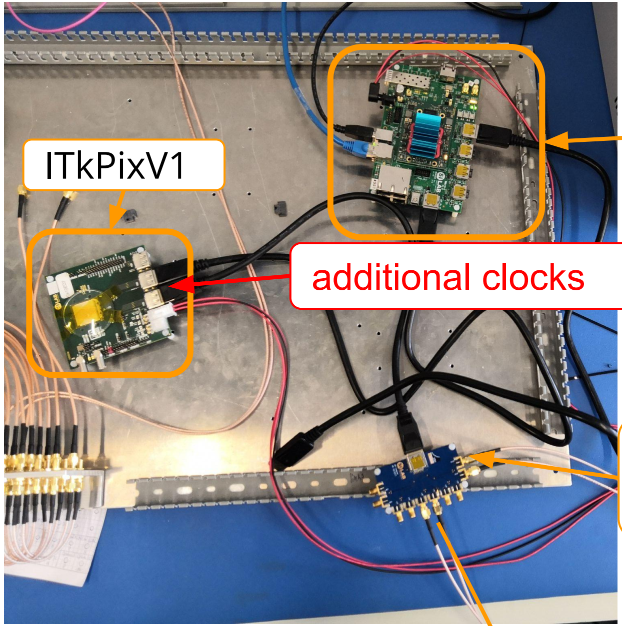
Connect the ITkPixV1 to the BDAQ53 and use it to program it in ***bypass mode*** (additional clocks required)

PRBS7 in the uplink

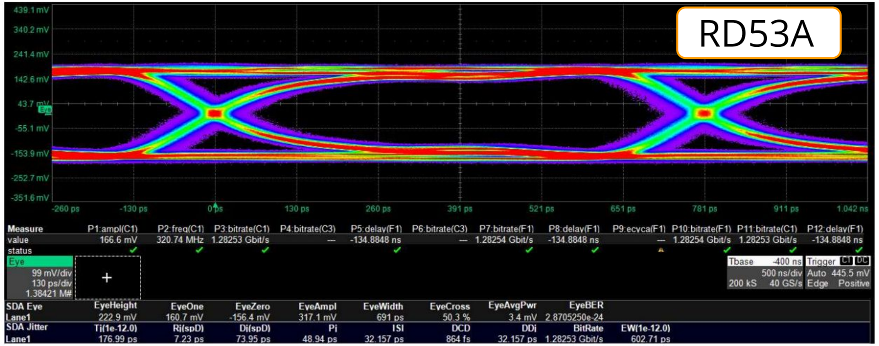
Disconnect the ITkPix from the BDAQ and connect it to the optoboard

ITkPixV1 doesn't reset and recovers the correct clock

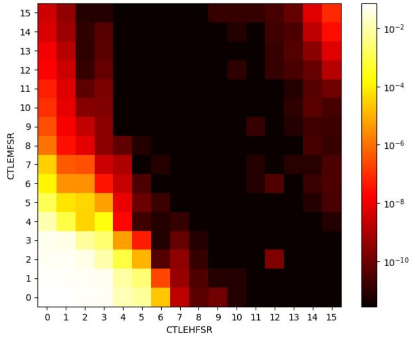
Eye diagram and BERT on the uplink

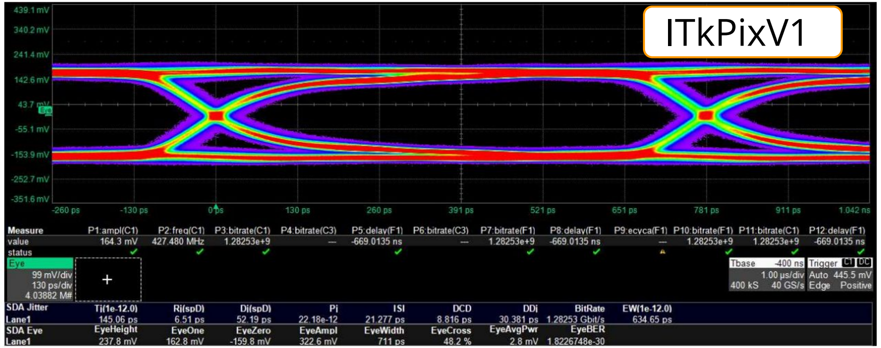


Test of the uplink of the ITkPixV1 [D. Dal Santo]

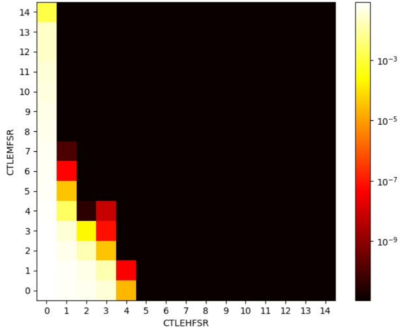


Total jitter: 177ps





Total jitter: 145ps

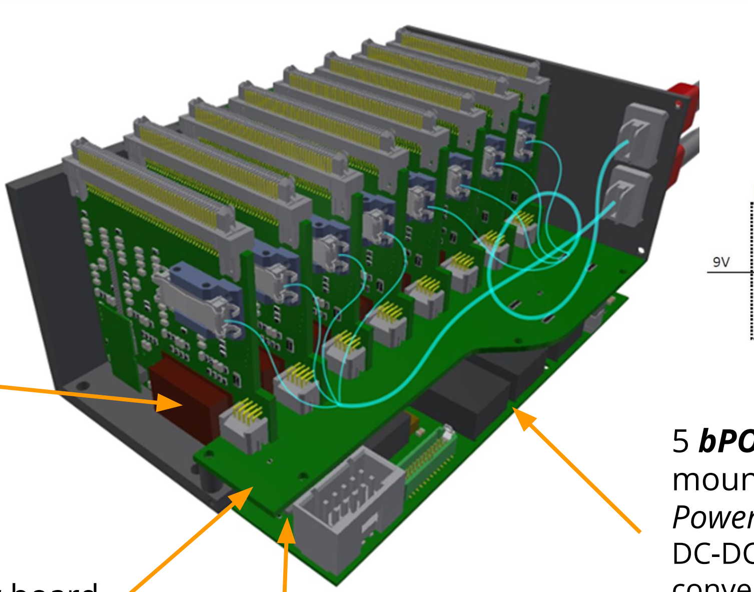


BER limit varying the parameters of the equalizer of the GBCR

Tests of the Power supply system: bPOL12V & bPOL2V5 → first complete Optobox

Powering and monitoring of the Optoboards

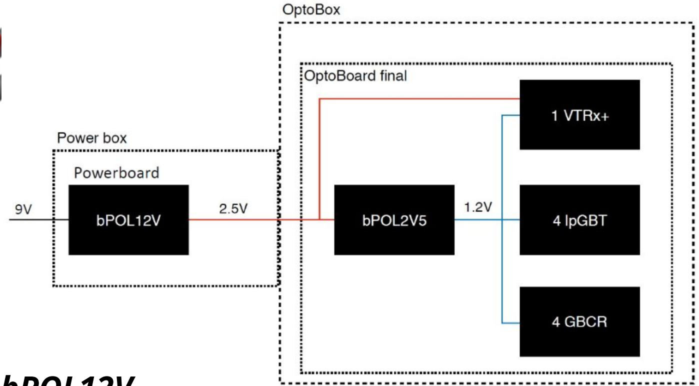
The ATLAS service caverns house power supplies which deliver *9V* to the Optosystem



bPOL2V5 mounted on each *Optoboard*: DC-DC step-down converters *from 2.5V to 1.2V*

Connector board

MOPS



5 ***bPOL12V*** mounted on the *Powerboard*: DC-DC step-down converters *from 9V to 2.5V*

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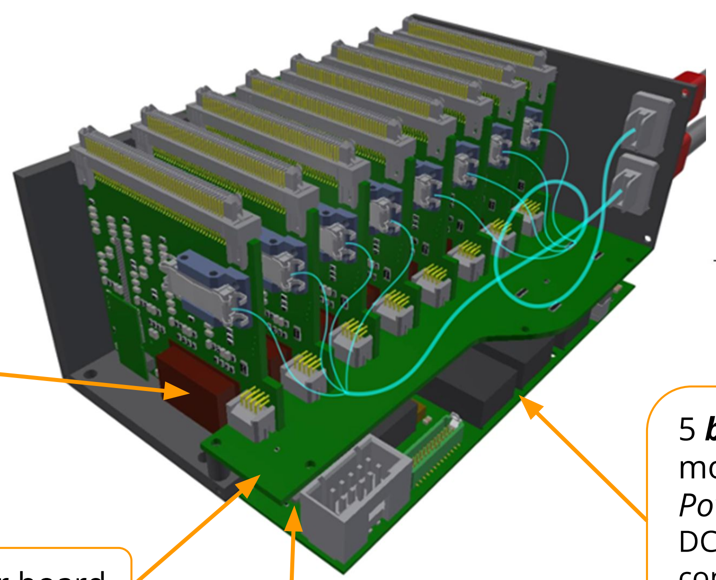

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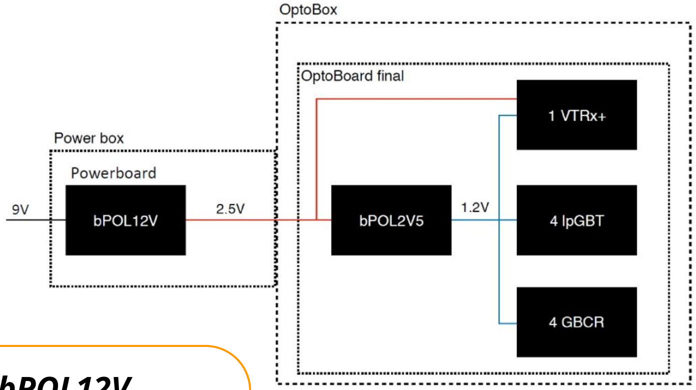
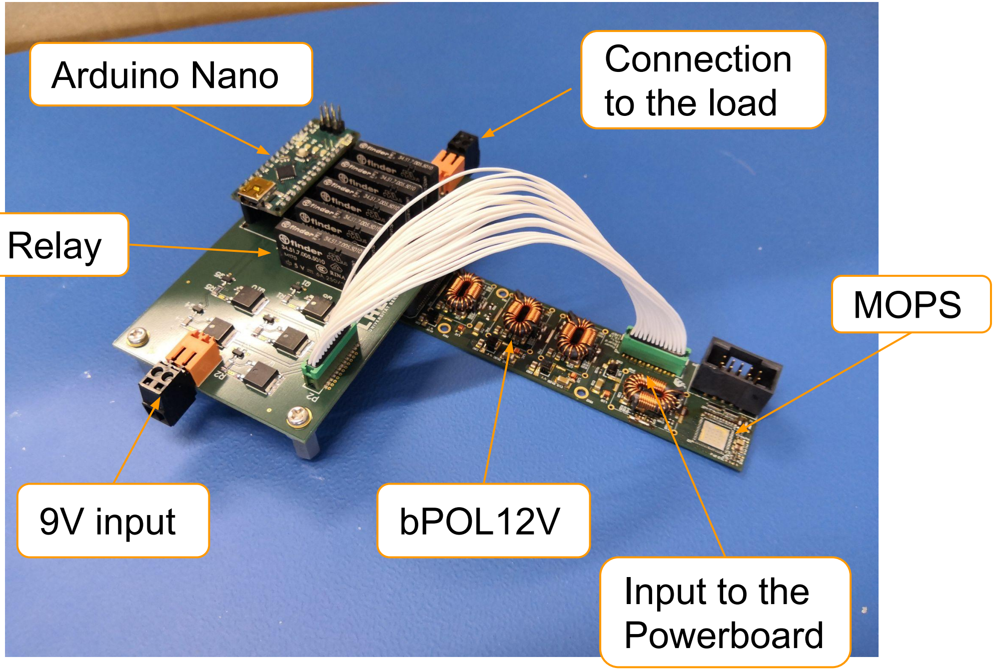


Load Line Test Board



New board for the test of the powerboard:

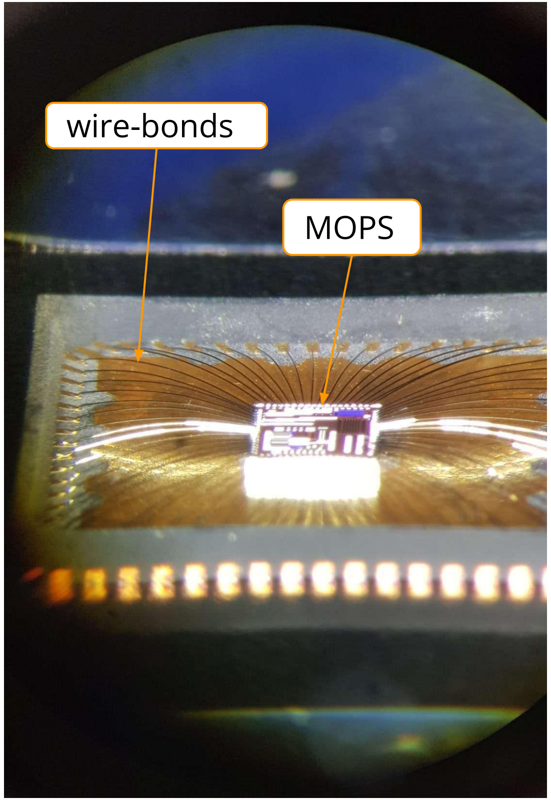
- allows to test each bPOL12V independently
- optical relays:
  - require a very small current → controllable by an Arduino nano

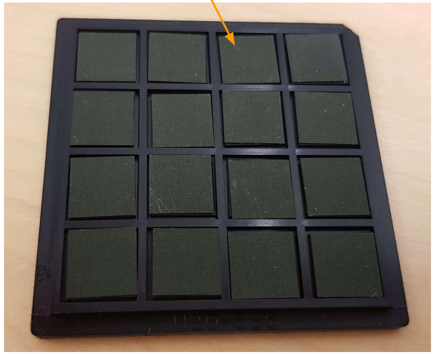
Beginning of testing is foreseen in the next weeks

MOPS status and wire-bonding [L. Franconi]

- The Monitoring of Pixel System (MOPS) is an ASIC with 34 channels to monitor the temperature and voltage of the front-end modules and Optosystem
- 40 MOPS were delivered to Bern for packaging: protection of the ASIC and easier deployment on a PCB
- 20 completed MOPS have been brought to Cern for the handover to the Wuppertal group

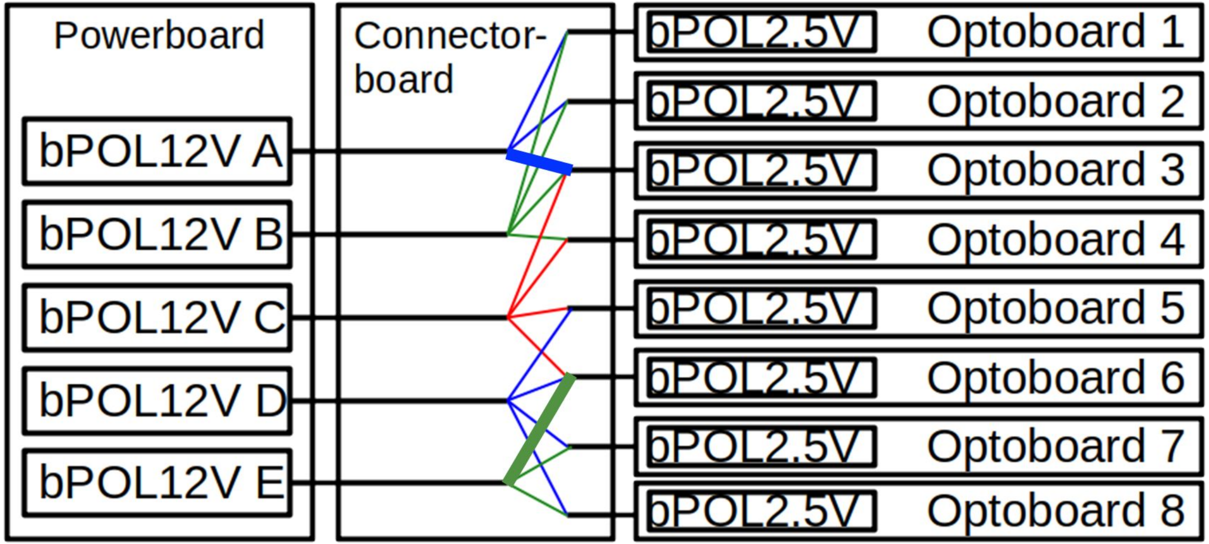
MOPS are crucial to test interference effects among bPOLs in the same Optobox [S. Geissmann]





New connectorboard connections [L. Franconi]

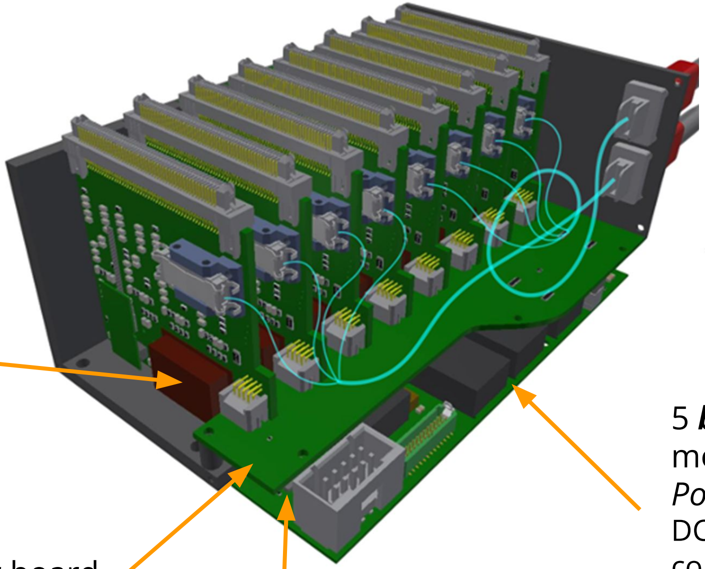
Added the extra connections (thick lines) to increase flexibility in routing of the twinax



Optoboards connected to the same SP chain are powered by the same bPOL12V, but must no longer be in consecutive slots of the Optobox

Powering and monitoring of the Optoboards

The ATLAS service caverns house power supplies which deliver *9V to the Optosystem*

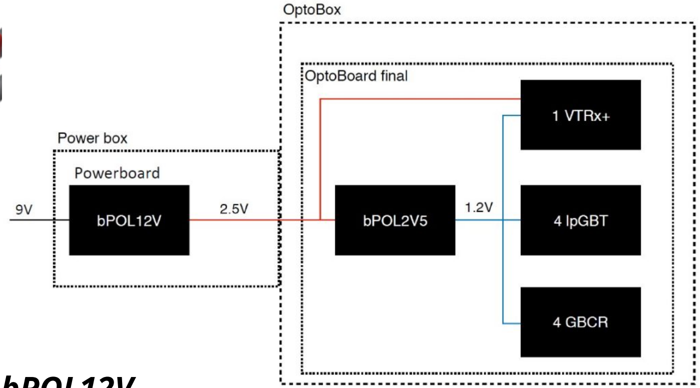


bPOL2V5 mounted on each *Optoboard*: DC-DC step-down converters *from 2.5V to 1.2V*

Connector board

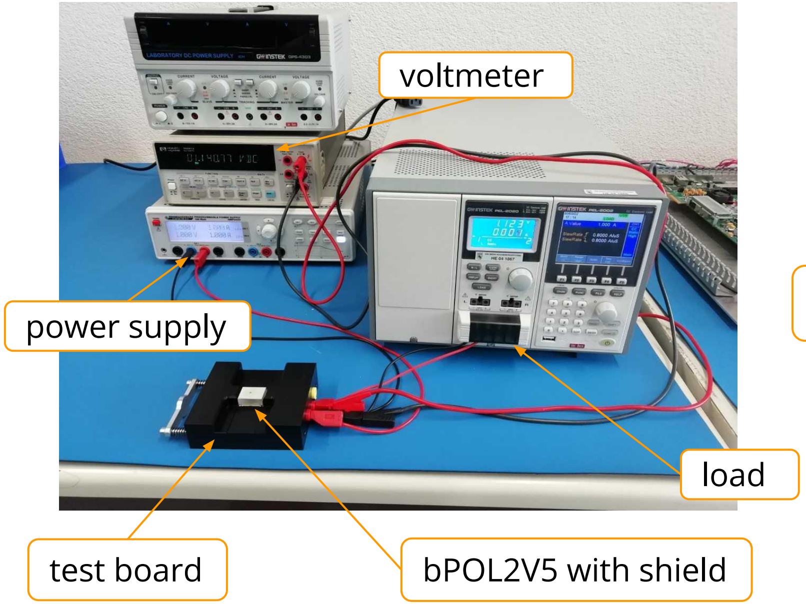
MOPS

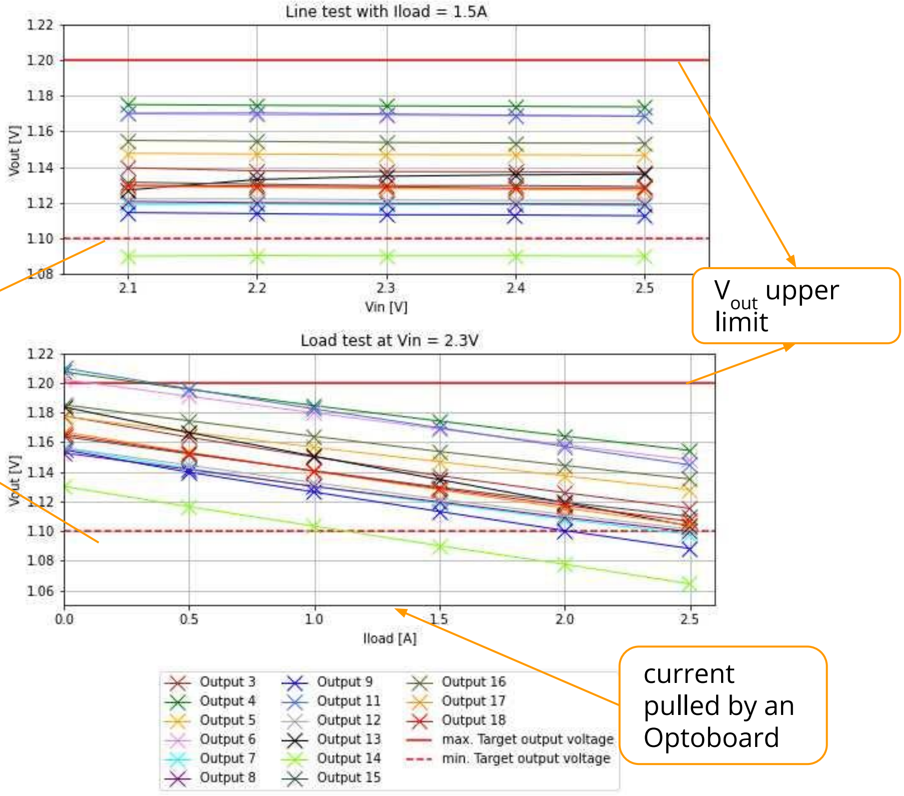
5 **_bPOL12V_** mounted on the *Powerboard*: DC-DC step-down converters *from 9V to 2.5V*



Voltage Tests of the bPOL2V5 [S. Geissmann]

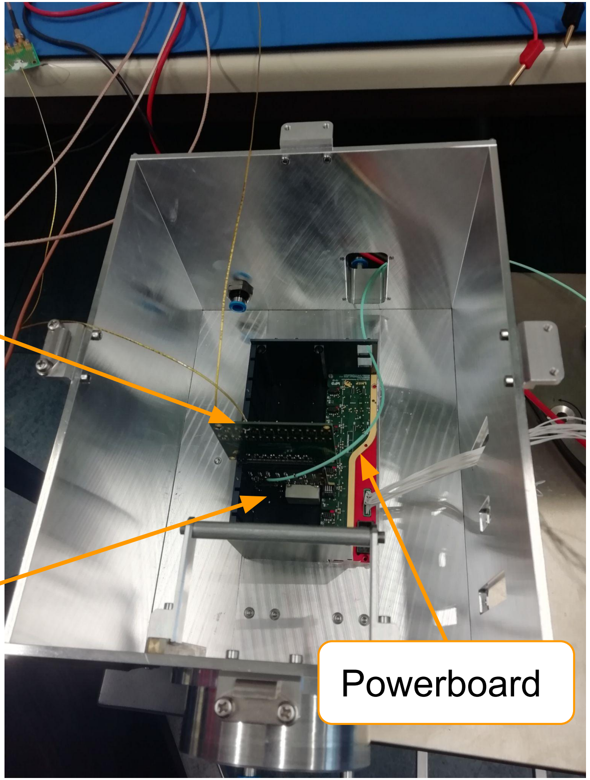
A new test board for the QC of the bPOL2V5 with the shield mounted has been produced

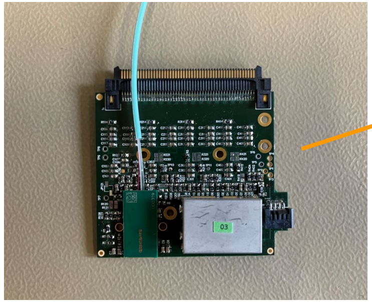




Optoboard test with powerboard and bPOL2V5

SMA-to-twinax adapter board





Powerboard

Tests:

- configuration of the optoboard powered by the bPOL2V5
- configuration of the optoboard powered by the bPOL12V and bPOL2V5
- digital scan of the RD53A

The first fully populated Optobox [A. O’Neill]

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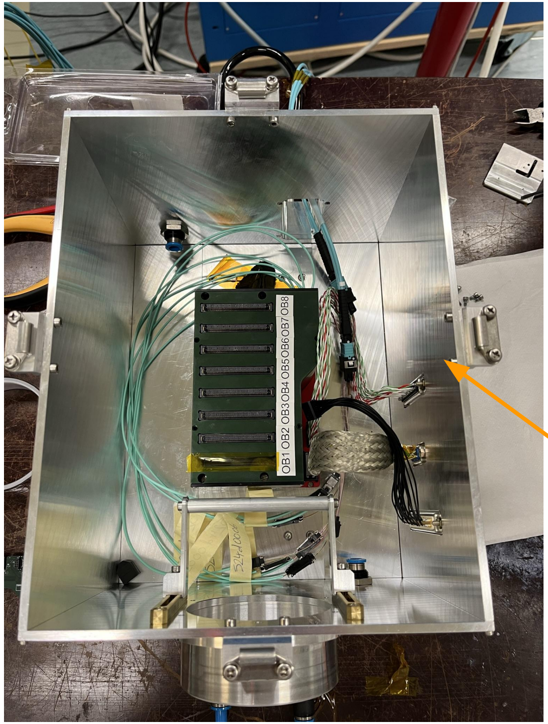
First populated optobox in SR1 with realistic power supply system



Single box optopanel

Additional activities: test of the e-fusing and irradiation campaign

Test of the e-fusing procedure [T. Harte]

The E-Fuser, a device for direct communication via I^2C with the lpGBTs (Opto V2.1 and V3.0), was designed.

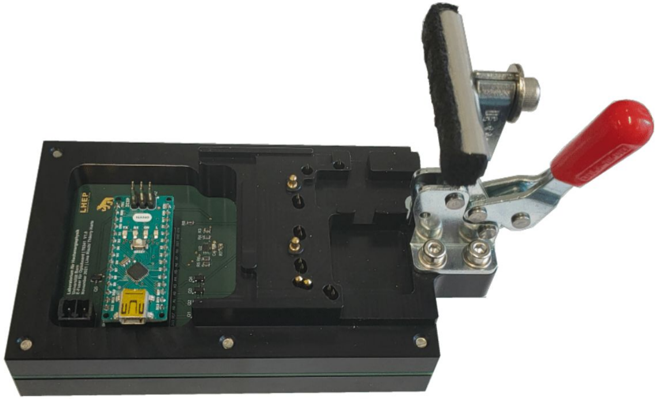
Applications:

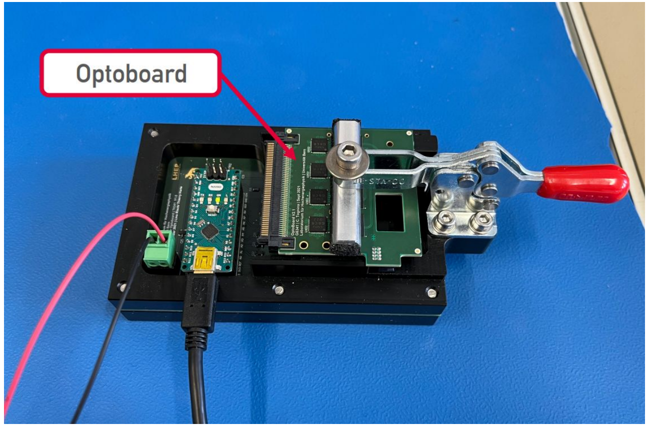
- *first test of the e-fusing of the lpGBT*

  What is the e-fusing?

  Each register of the lpGBT has an e-fuse that can be blown to change the default configuration of the chip; it is an irreversible procedure → substantial time saving during the operation of ATLAS

- *useful tool for debugging*: IC & I^2C communications can work simultaneously (I^2C doesn't need any initial configuration)

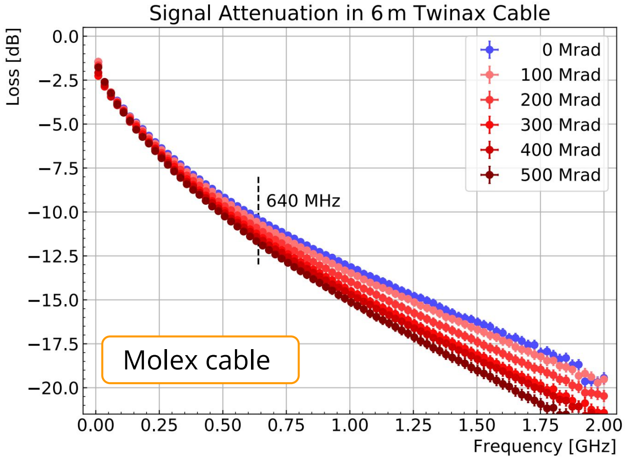


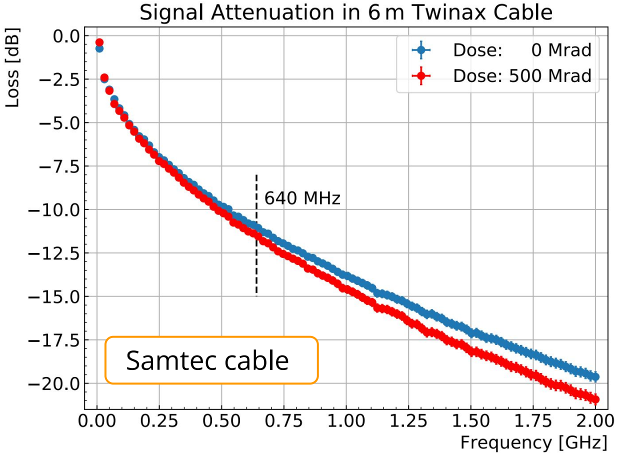


Irradiation tests [S. Juillerat & L. Halser]

The irradiation campaign of twinax cables at the Bern cyclotron has been completed (A facility for radiation hardness studies based on a medical cyclotron - IOPscience). The new version of the molex cable has been irradiated but not tested yet.

- aim: verify the quality of the data transmission after irradiation





	Δloss (6m, 640 MHz)	Δjitter (1.28 Gbps)
6m Samtec Cable	0.5 dB	20 ps
6m Molex Cable	1.4 dB	30 ps

Tab 3: Difference in loss and jitter before and after irradiation to total dose (500 Mrad).

Summary

- test of Data Transmission with the Opto V2.1 and V3.0
- test of bPOL2V5 with shield
- first fully populated Optobox has been built in SR1 with the final design of the powering system
- first test with the Optoboard of the uplink of the ITkPixV1
- first test of the e-fusing procedure of the lpGBT
- irradiation campaign of twinax cables has been concluded

- procedure for **testing the Optoboards** have been defined and documented
- **new GUI** integrated with the **ITk-demonstrator software** has been built (repository: itk-demo-sw, talk by Jonas at AUW: GUI microservices for System Tests)
- **production of the optoboxes and optopanel** for the LLS is underway
- new EDMS documents for the **mapping of the Optosystem**: Pin-to-pin Mapping between PP0 and the FELIX card connectors in the Data Transmission Chain for the ATLAS ITk Pixel Detector, ICD Optobox Interfaces
- paper about the cyclotron facility: A facility for radiation hardness studies based on a medical cyclotron - IOPscience

Outlook

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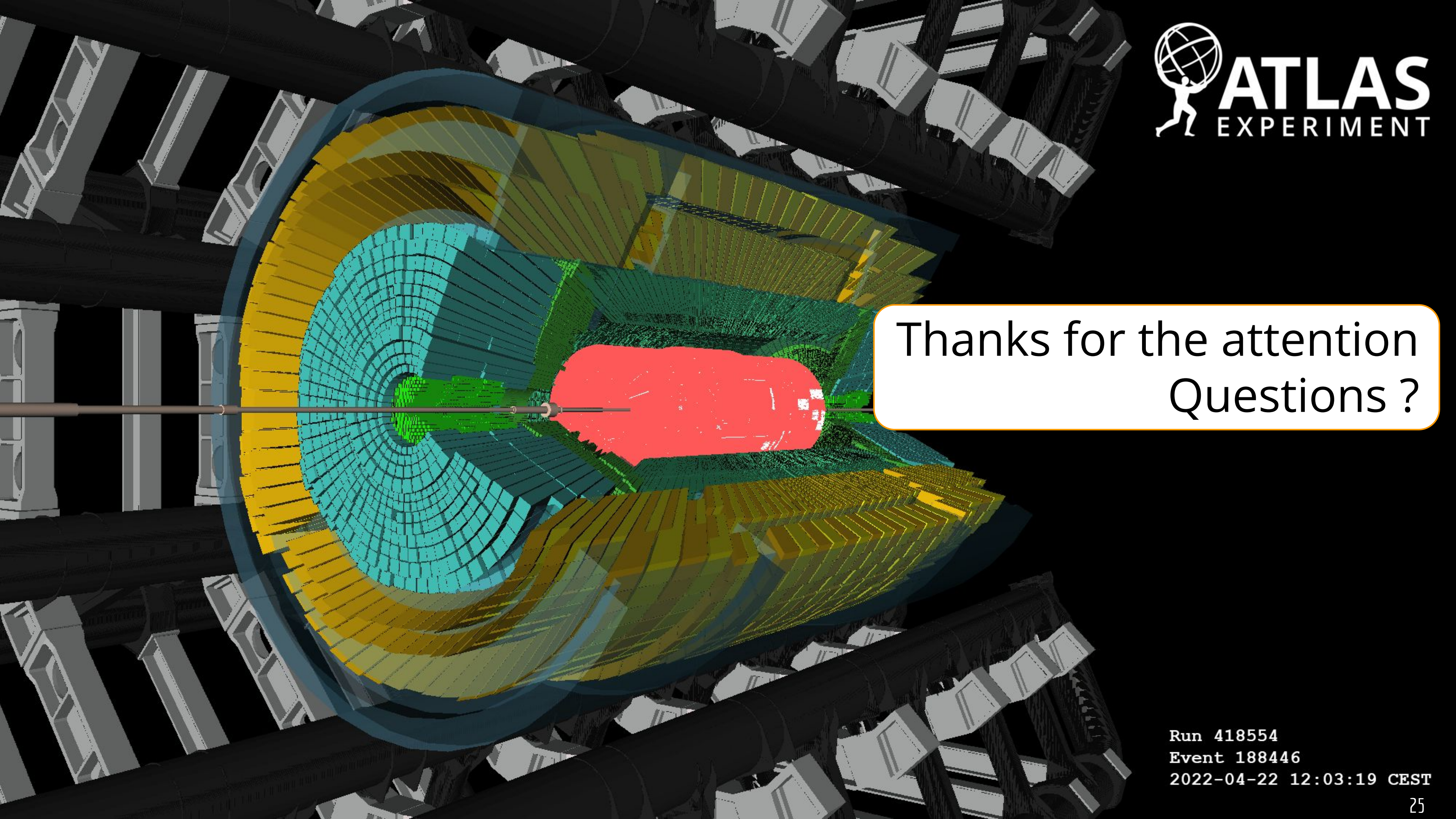
- **support activities** for the SR1 laboratory (mattermost channel: Optoboard-mattermost, talk: OB pre-demonstrator tests)
- implementation of **additional features for the debugging** of the Optosystem
- population of the **production database**
- **destructive voltage test of the GBCR**
- **radiation hardness** test of the **optoboard**
- tests of the **thermal properties** of the optopanels with heat dummies

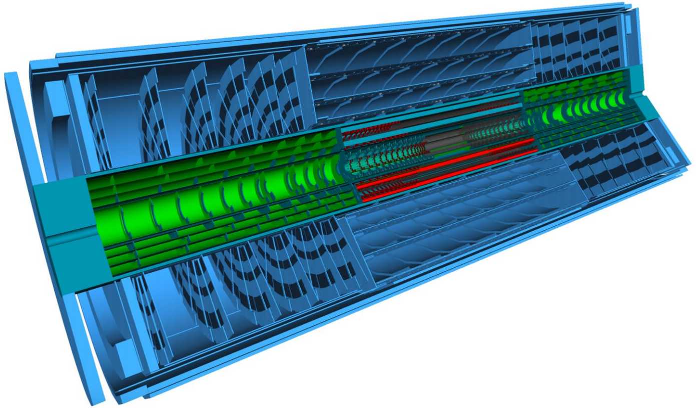


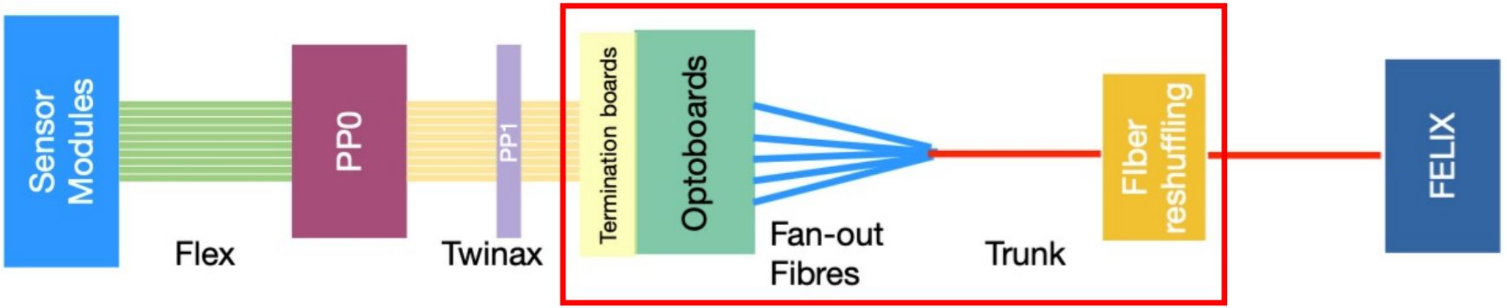
Thanks for the attention
Questions ?

Backup

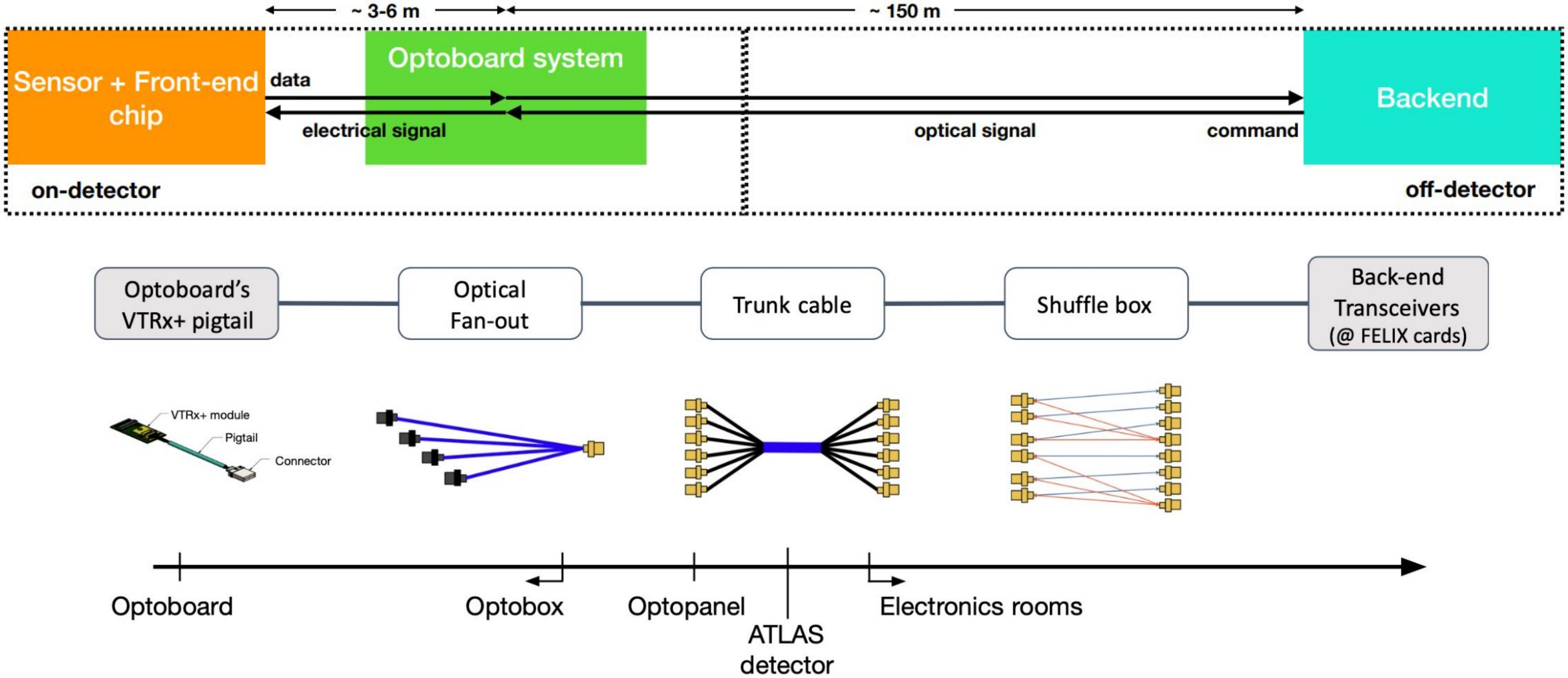
ITk Pixel Data Transmission Chain

- The ITk Pixel must be read out at 1MHz
- One of the pivotal components is the Optosystem
- This handles the conversion of electrical signals to optical (and viceversa) and their aggregation





ITk Pixel DTC



Test of the uplink of the ITkPixV1 [D. Dal Santo]

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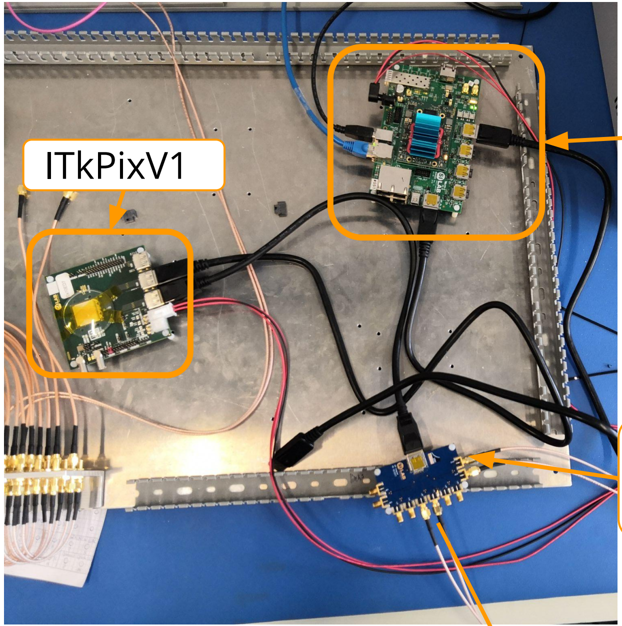
Problem: FELIX still doesn't support the configuration of the ITkPixV1

Questions:
- can the ITkPixV1 recover a good clock from the downlink of the Optoboard?
- can we test the quality of the data sent by the ITkPixV1 using the Optoboard?

Ideal strategy:

Connect the module (3 UL, 1 DL) to the BDAQ53 and use it to program it (PRBS7 in the uplink) → Disconnect the ITkPix from the BDAQ and connect it to the optoboard → BERT on the uplink



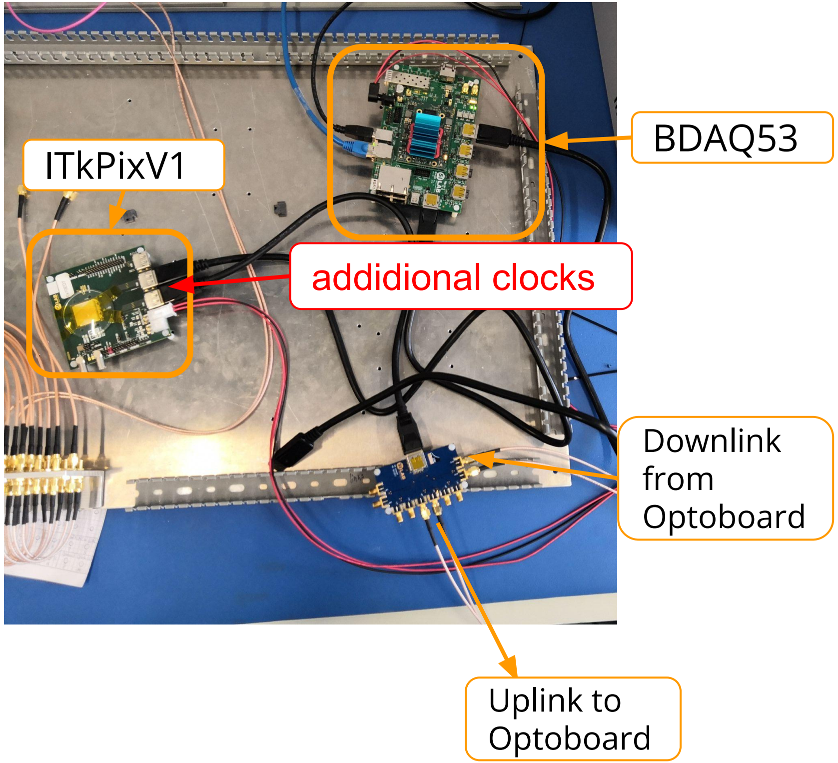
Test of the uplink of the ITkPixV1 [D. Dal Santo]

Issue:

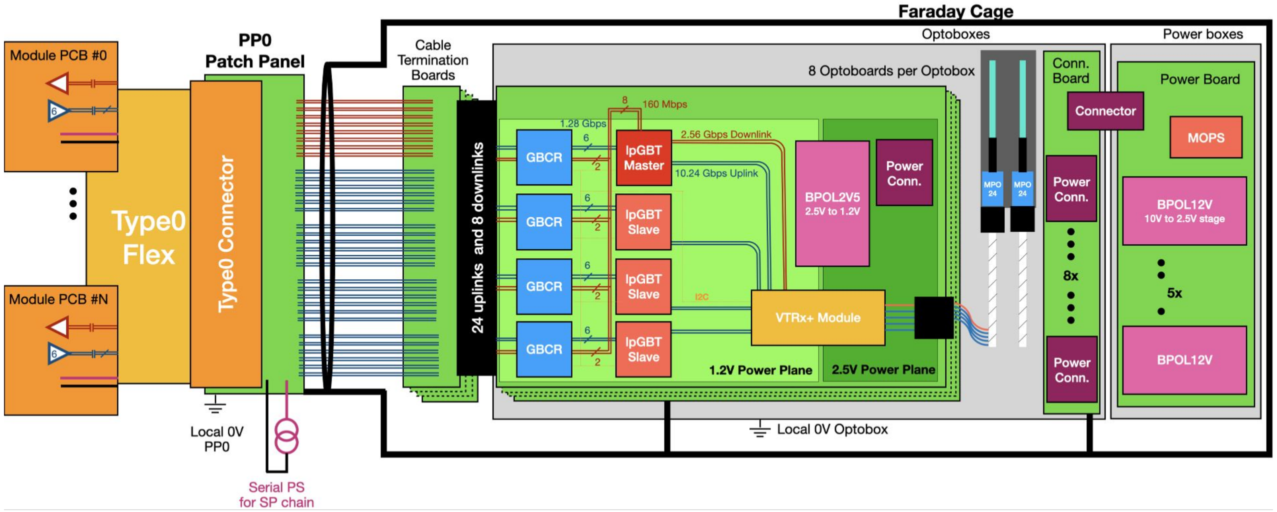
- the ITkPixV1 has only 1 downlink that has to be connected to the BDAQ53 to program it
- if the downlink is disconnected, the ITkPix resets (no PRBS7 in the uplink)

Solution: program the chip in **bypass mode**

- provide additional clocks to the module => the chip doesn't reset when we disconnect the command line
- when the downlink from the Optoboard is connected, the correct clock is recovered



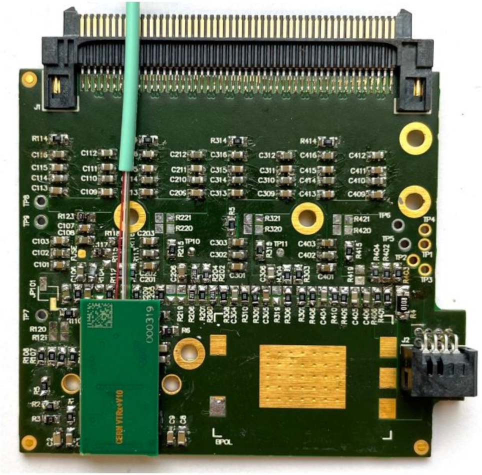
Technical Design of the OptoSystem



The Optoboard V2.0

GBCRs

lpGBTs



VTRx+

LeCroy Eye BER

Eye BER

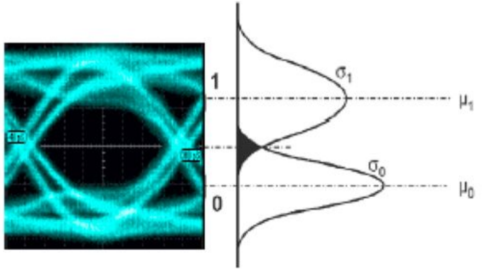
Eye BER is an estimate of the bit error ratio is made from the eye diagram. It is derived from a measurement of the Q-factor, as described below.

$$BER_{eye} = \frac{e^{\frac{-Q_{eye}}{2}}}{Q_{eye}\sqrt{2\pi}}$$

This measurement algorithm is best suited to eye diagrams that are rendered from optical rather than electrical signals. In the presence of inter-symbol interference and/or equalization, it may not give reasonable results. The Q factor is a measure of the overall signal-to-noise ratio of the data signal. It is computed by taking the eye amplitude (the difference between the mean values of the **1** and **0** levels) and dividing it by the sum of the noise values (standard deviations of the **1** and **0** levels).

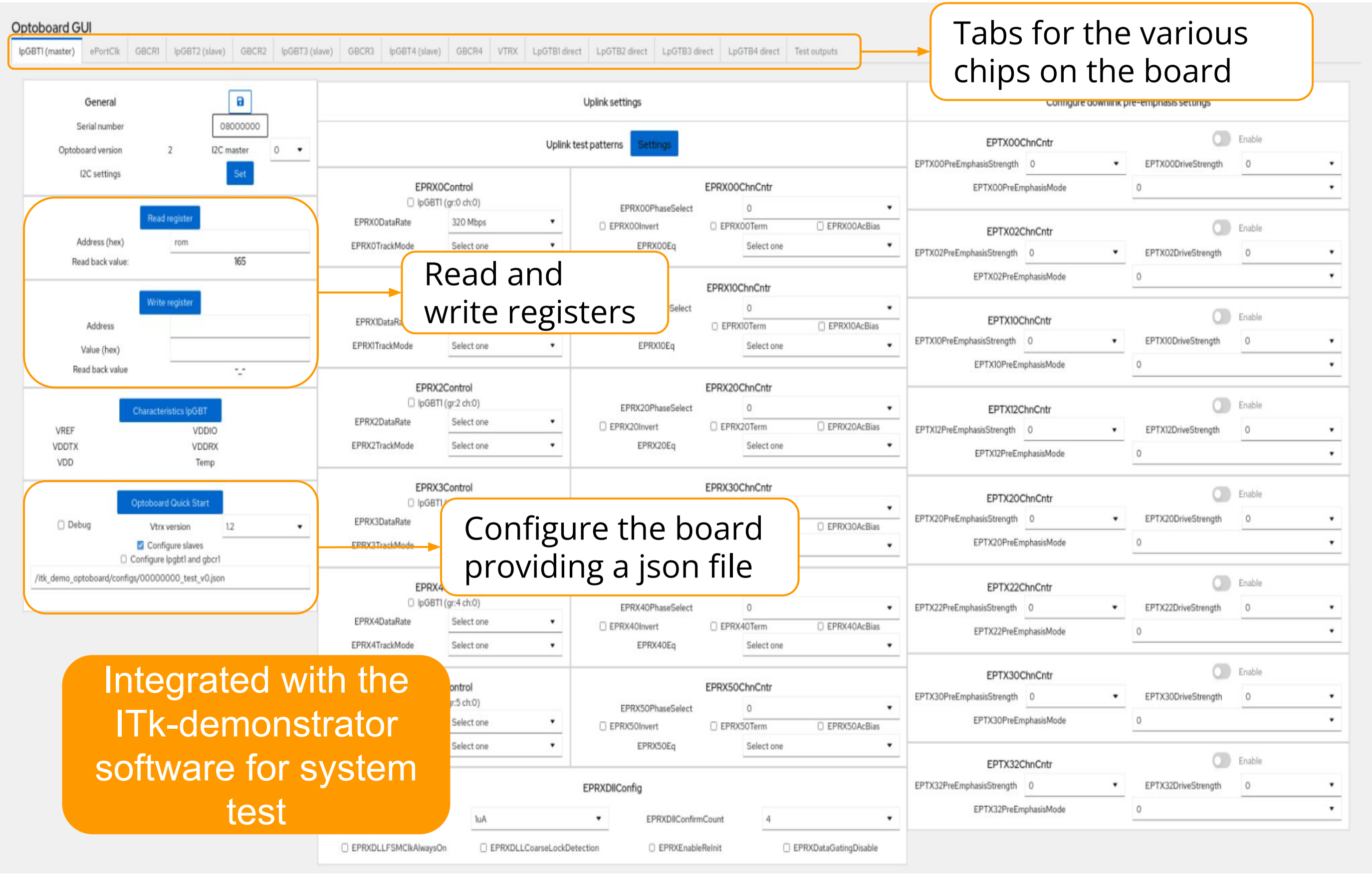
$$Q_{eye} = \frac{\mu_1 - \mu_0}{\sigma_1 + \sigma_0}$$

All of these measurements are taken in the center (usually 20%) of the eye. You can measure the Q factor using the standard oscilloscope Measure feature.



The Optoboard GUI [D. Dal Santo]

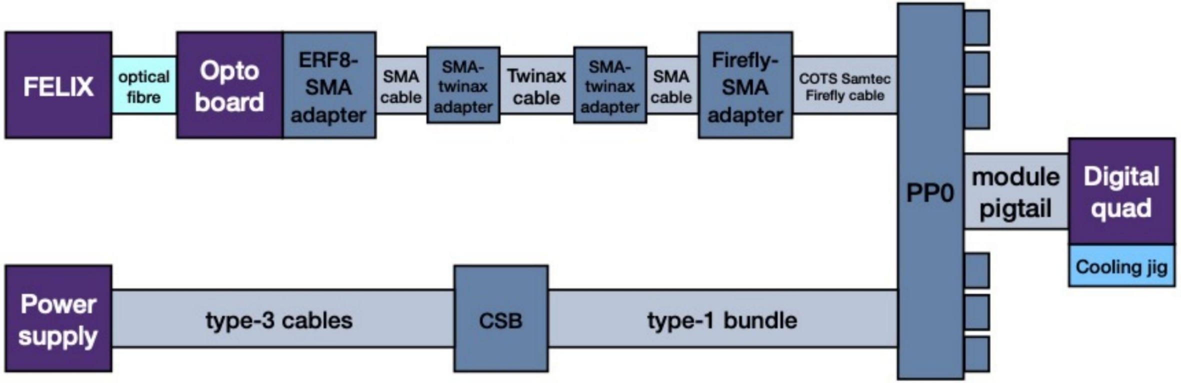
- easier configuration of the optoboard
- integration with production and configuration database is foreseen
- the leader of the project is Dr. Gerhard Brandt from Wuppertal (itk-demo-sw)
- J. Schmeing will give a talk this week about the status of the project (GUI microservices for System Tests)



PP0 Data Transmission Chain [Aaron O'Neill]

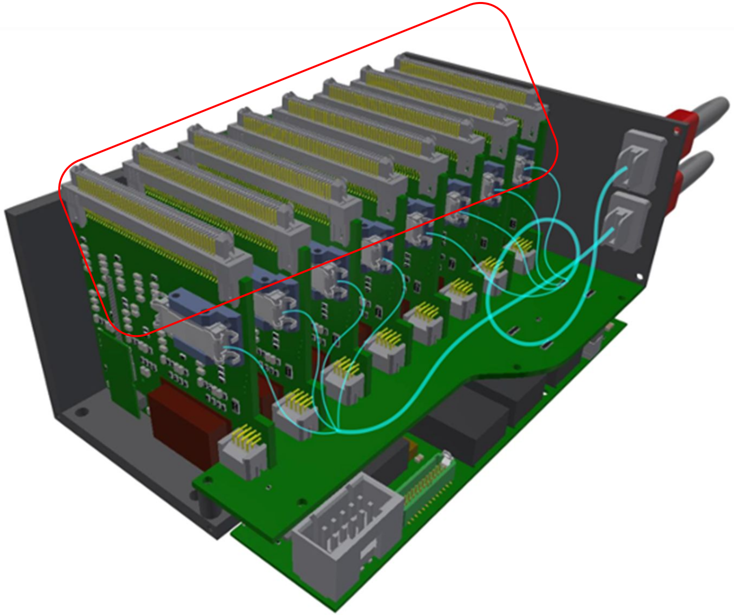
In Bern the construction of the data transmission chain with the final design will commence shortly:

- finalized the cooling of the digital quad module;
- acquired the final cables for the powering.

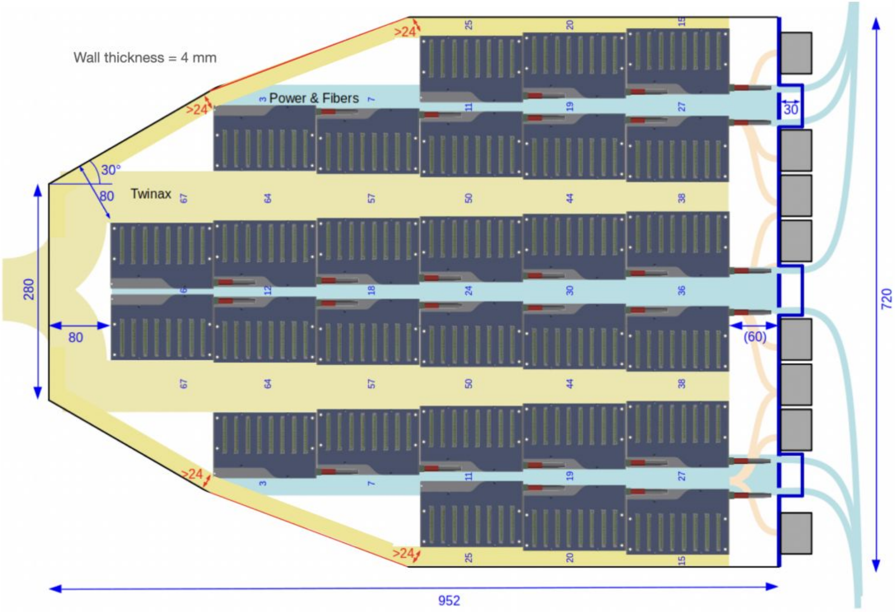


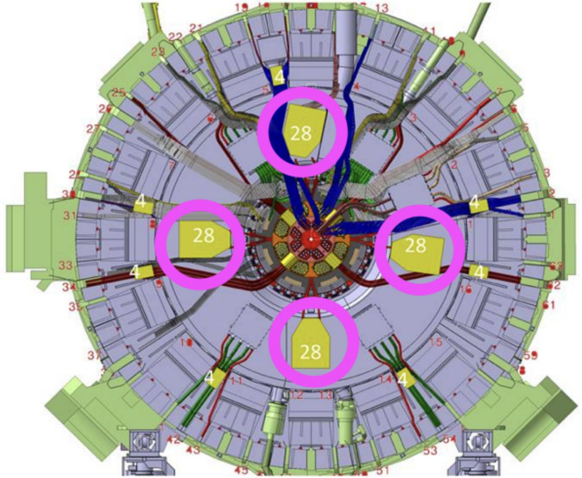
Types of Termination boards [L. Franconi]

Optoboard to twinax connection: termination board



The Optopanel





- 28 optoboxes are housed in each optopanel
- the twinax and fiber cables are routed in different channels therefore *normal and mirrored optoboxes* are needed

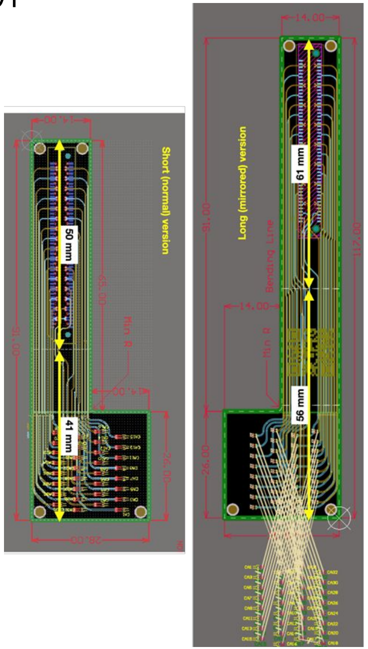
- 4 optopanels on the PP1 of each side (A&C) of ATLAS

Types of Termination boards [L. Franconi]

L-shaped

-24 uplink available

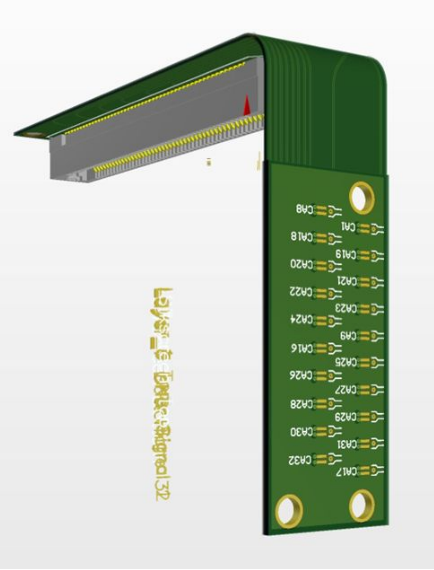
-Normal/mirrored, long/short types



Slim

-12 uplink available

-Normal/mirrored types



Super-Slim

NEW!

- 6 uplink available
- comes in normal type only
- Needed for sub-system layers with 6 uplinks/bundle:

Motivation: if the slim TB was used, 2 uplink fibres (lpgbt master and one from lpgbt 3) would be needed

Design not available yet

New optopannel mapping [L. Franconi]

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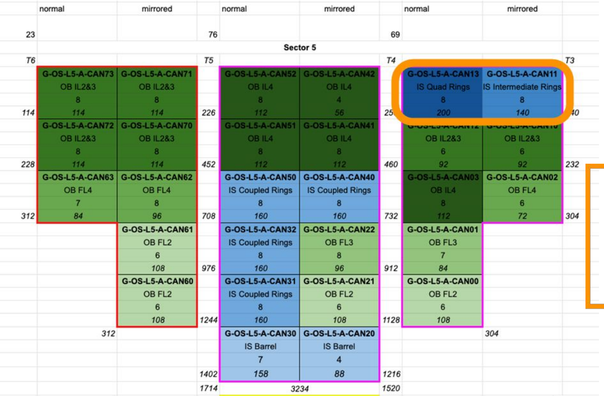
Motivation: reduce the number of bundle flavours by limiting to either normal or mirrored type

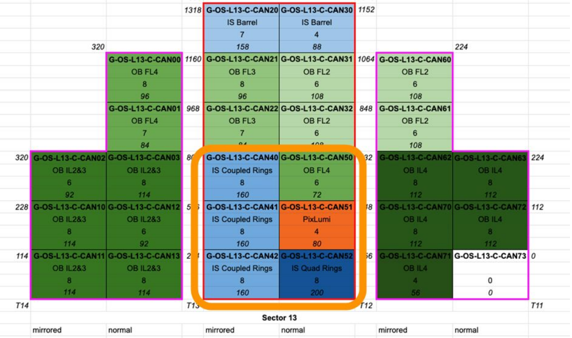
To be verified by routing



A-side quadrant 2/3

This new mapping allows to have:
All IS QR normal
All IS IR mirrored

C-side quadrant 6/7



All EC L2 (rings 1-5) mirrored
All EC L2 (rings 6-11) normal
All EC L3 mirrored
All EC L4 (rings 1-7) normal
EC L4 (rings 8-9) mirrored

Optosystem Mapping [L. Franconi]

Electrical:

- Optoboxes have different number of Optoboards
- Each box reads out modules of a single subsystem

Optical:

	SP Chain types	Modules/ SP chain	Links/Module Upl.	Links/Module Downl.	FEs./ SP	Upl./ FE	Upl./ SP	Downl. sharing	Downl./ SP	Twinax/ SP	lpGBT's/ SP	Optoboards/ SP	bPOL12V/ Optoboard	Optoboard flavours OB1 Upl.	OB1 Downl	OB2 Upl.	OB2 Downl
IS 1L0+L1 (IS Barrel)	L0-T	12	4	0.33	12	4	48	no	4	52	8	2	0.5	24	2	24	2
	L1-Q	6	2	1.00	24	0.5	12	no	6	18	2	1	1	12	6		
IS L0+2L1 (IS Barrel)	L0-T	12	4	0.33	12	4	48	no	4	52	8	2	0.5	24	2	24	2
	L1-Q	6	2	1.00	24	0.5	12	no	6	18	2	1	1	12	6		
	L1-Q	6	2	1.00	24	0.5	12	no	6	18	2	1	1	12	6		
IS Coupled Ring	EC0-T	9	3	0.33	9	3	27	no	3	30	5	2	0.5	18	2	9	1
	EC1-Q	10	4	1.00	40	1	40	no	10	50	8	2	0.5	20	5	20	5
IS Intermediate Ring	EC0-T	15	2	0.33	15	2	30	no	5	35	5	2	0.5	18	3	12	2
IS Quad Ring	EC1-Q	10	4	1.00	40	1	40	no	10	50	8	2	0.5	20	5	20	5
OB Flat Layer 2	short chain	6	2	1.00	24	0.5	12	no	6	18	2	1	1	12	6		
	long chain	12	2	1.00	48	0.5	24	no	12	36	4	2	0.5	12	6	12	6
OB Flat Layer 3	short chain	6	1	1.00	24	0.25	6	no	6	12	1	1	1	6	6		
	long chain	12	1	1.00	48	0.25	12	no	12	24	2	2	0.5	6	6	6	6
OB Flat Layer 4	short chain	6	1	1.00	24	0.25	6	no	6	12	1	1	1	6	6		
	long chain	12	1	1.00	48	0.25	12	no	12	24	2	2	0.5	6	6	6	6
OB Inclined Layer 2	half ring US	8	2	1.00	32	0.5	16	no	8	24	3	1	1	16	8		
	half ring USA	8	2	1.00	32	0.5	16	no	8	24	3	1	1	16	8		
OB Inclined Layer 3	half ring US	11	1	1.00	44	0.25	11	no	11	22	2	2	0.5	6	6	5	5
	half ring USA	11	1	1.00	44	0.25	11	no	11	22	2	2	0.5	6	6	5	5
OB Inclined Layer 4	half ring US	14	1	1.00	56	0.25	14	no	14	28	3	2	0.5	8	8	6	6
	half ring USA	14	1	1.00	56	0.25	14	no	14	28	3	2	0.5	8	8	6	6
EC Layer 2 "1 MHz" (rings 6-11)	half ring	8	4	1.00	32	1	32	no	8	40	6	2	0.5	16	4	16	4
EC Layer 2 "4 MHz" (rings 1-5)	half ring	8	2	1.00	32	0.5	16	no	8	24	3	1	1	16	8		
EC Layer 3	half ring	11	2	1.00	44	0.5	22	no	11	33	4	2	0.5	12	6	10	5
EC Layer 4 "flavour 1" (rings 1-7	half ring	13	1	1.00	52	0.25	13	no	13	26	3	2	0.5	8	8	5	5
EC Layer 4 "flavour 2" (rings 8-9	half ring	13	2	1.00	52	0.5	26	no	13	39	5	2	0.5	16	8	10	5
PixLumiRing & PLR+	ring	12	4	0.33	12	4	48	no	4	52	8	2	0.5	24	2	24	2