

Update on the ITk Pixel OptoSystem

9th May 2022

Daniele Dal Santo on behalf of the Bern
ATLAS Group

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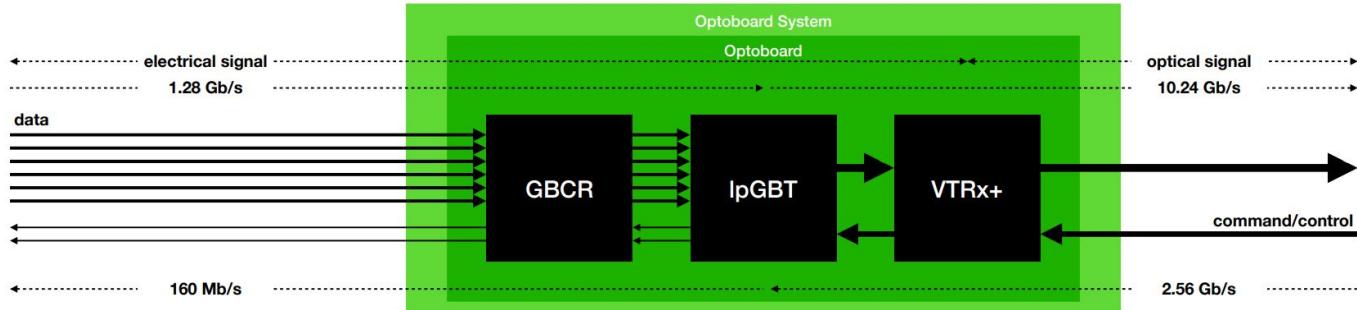
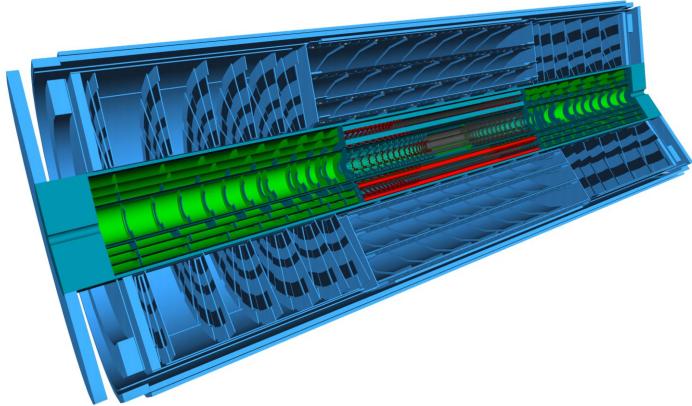
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**UNIVERSITÄT
BERN**

AEC
ALBERT EINSTEIN CENTER
FOR FUNDAMENTAL PHYSICS



ITk Pixel Data Transmission Chain

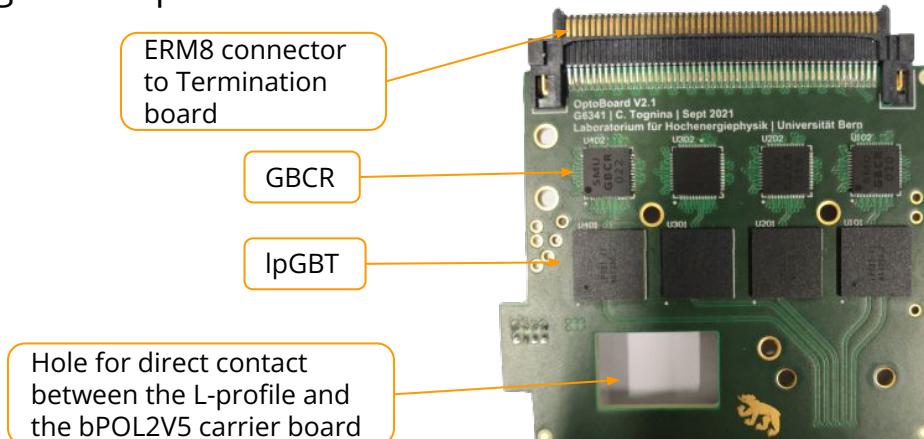
- One of the pivotal components of the ITk is the Optosystem
- This handles the conversion of electrical signals to optical (and viceversa) and their aggregation



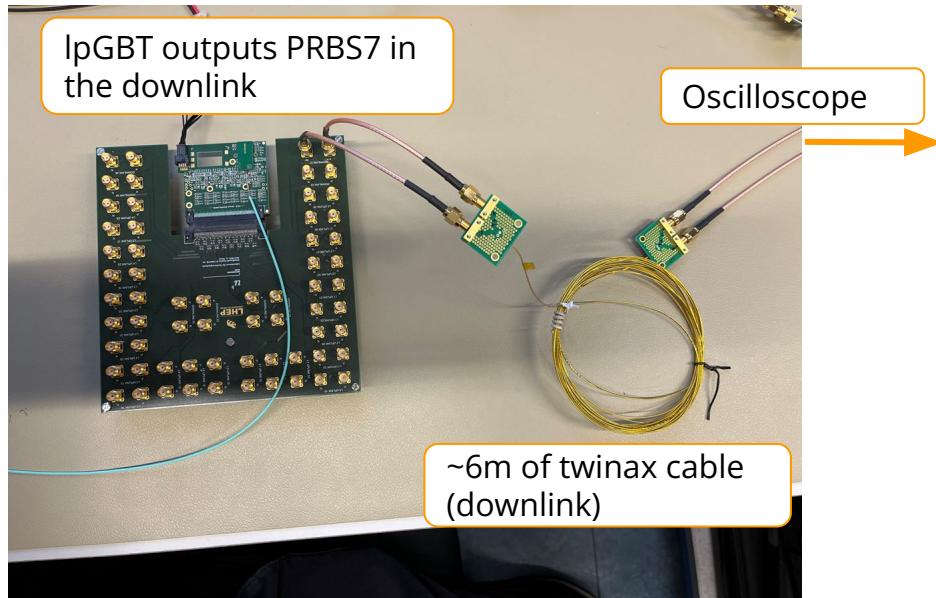
Quality Test of the Data Transmission: new Optoboard versions and readout of ITkPixV1

New Optoboard Versions

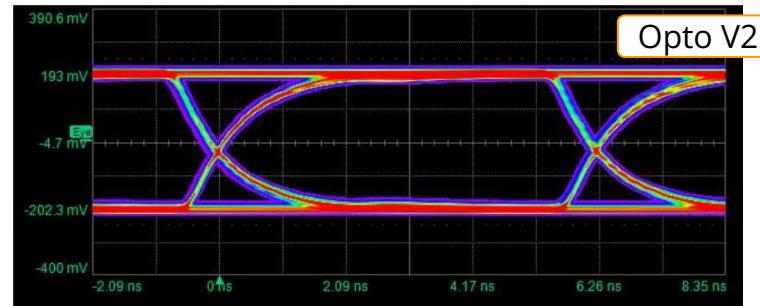
- Opto V2.1: fixes in the I²C connection and clock line, hole for thermal contact between the bPOL2V5 carrier board and the L-profile cooling plate
- Opto V3.0: bypass of the GBCR in the downlink
- Optoboard V2.1 and V3.0 mount the IpGBT v1. Changes in:
 - the frame structure of the IC communication
 - the register map



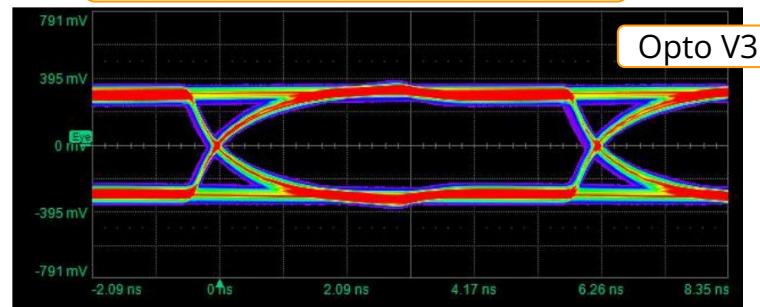
Opto V2.1 vs V3.0: downlink test [A. O'Neill]



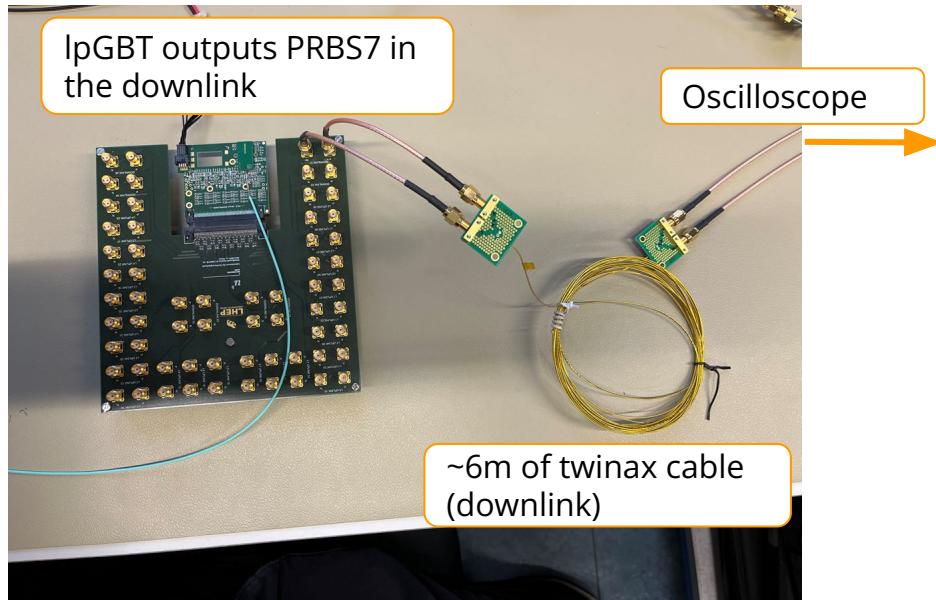
PreEmph = 3.0 mA PreEmphMode = Clock
DriveStrength = 3.0 mA GBCR PreEmph = 6



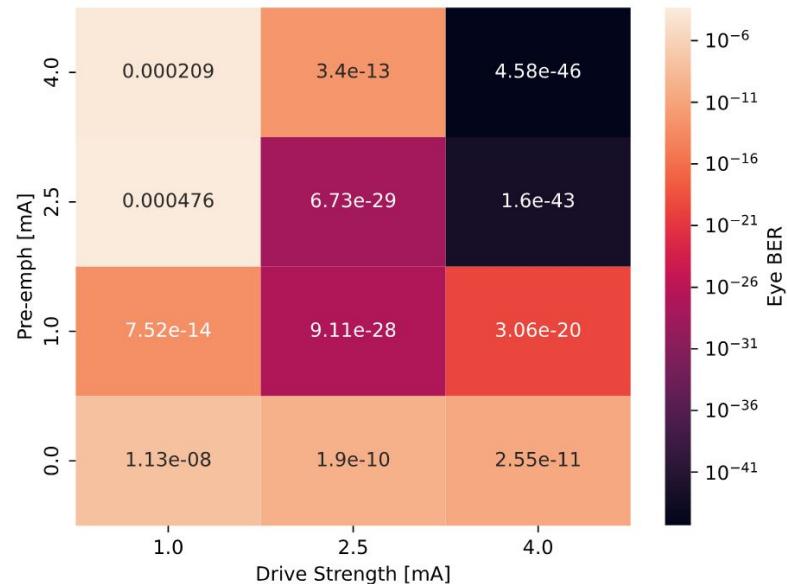
PreEmph = 4.0 mA PreEmphMode = Clock
DriveStrength = 4.0 mA GBCR bypassed



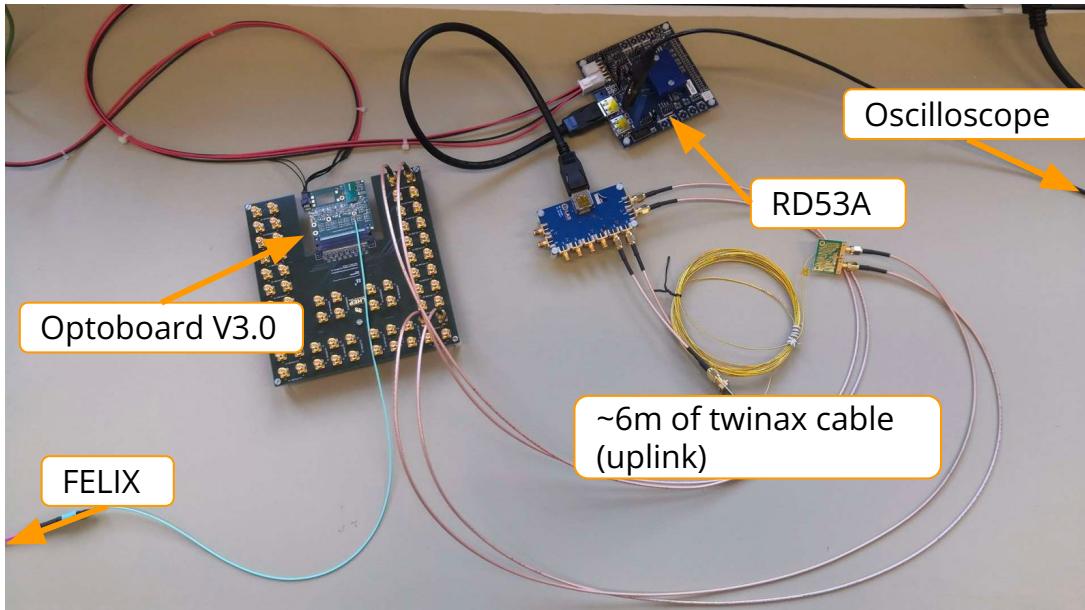
Opto V2.1 vs V3.0: downlink test [A. O'Neill]



Optoboard V3.0: estimated downlink BER limit

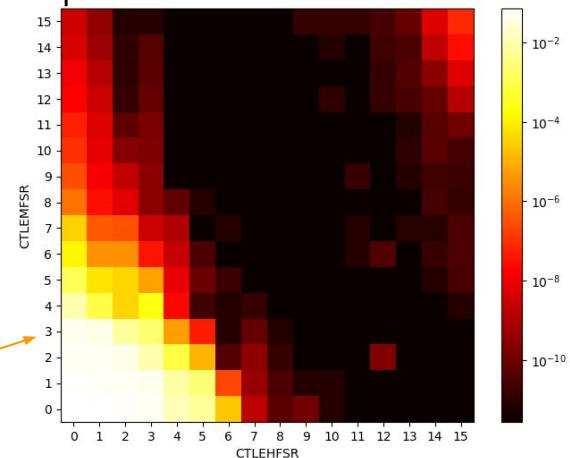


Opto V3.0: BER Test on the uplink [D. Dal Santo]



BER limit varying the parameters of the equalizer of the GBCR

- the RD53A is programmed to output a PRBS7 pattern;
- a pattern checker on the IpGBT 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.



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

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

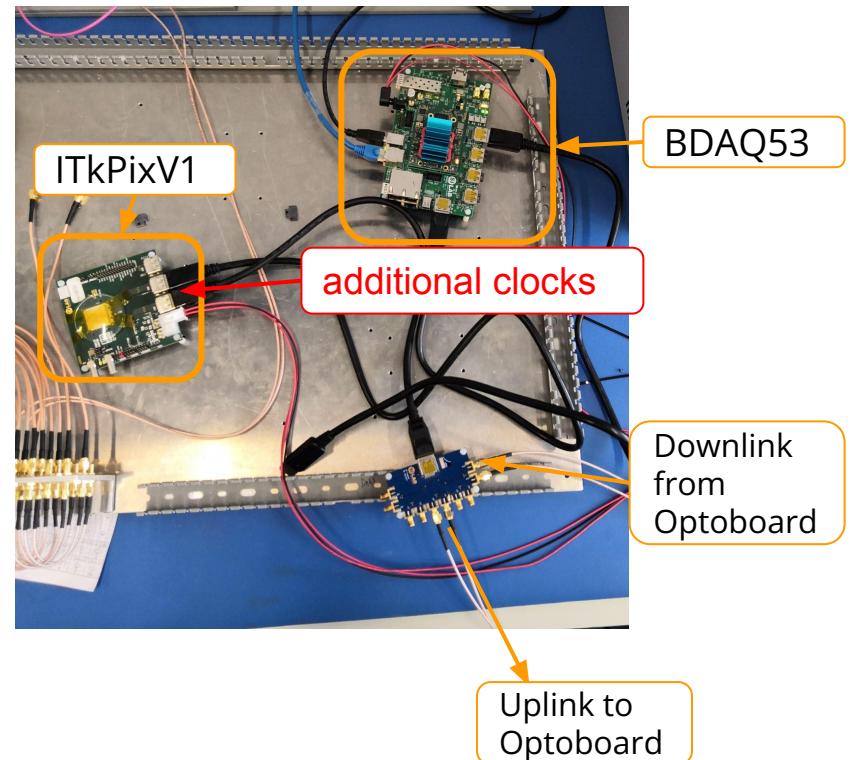
Connect the ITkPixV1 to the BDAQ53 and use it to program it in **bypass mode** (additional clocks required)

PRBS7 in the uplink

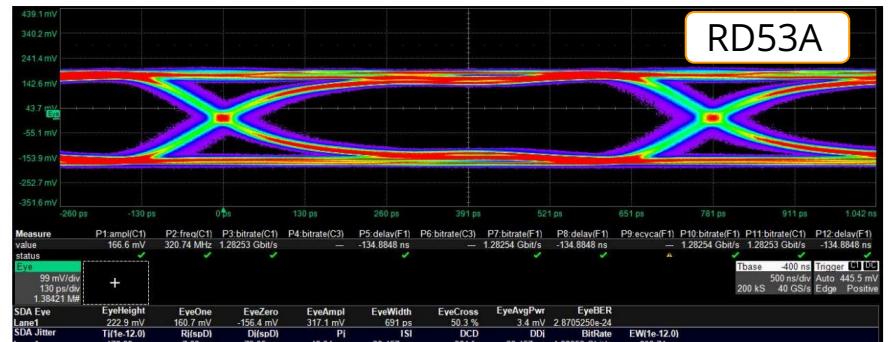
Disconnect the ITkPix from the BDAQ and connect it to the optoboard

ITkPixV1 doesn't reset and recovers the correct clock

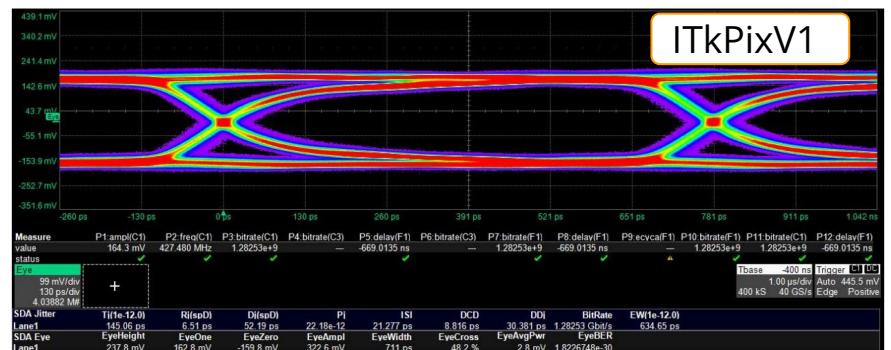
Eye diagram and BERT on the uplink



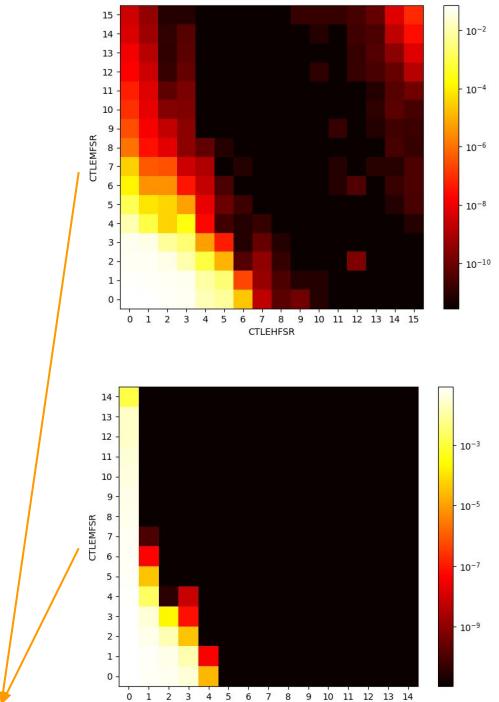
Test of the uplink of the ITkPixV1 [D. Dal Santo]



→ Total jitter: 177ps



→ Total jitter: 145ps

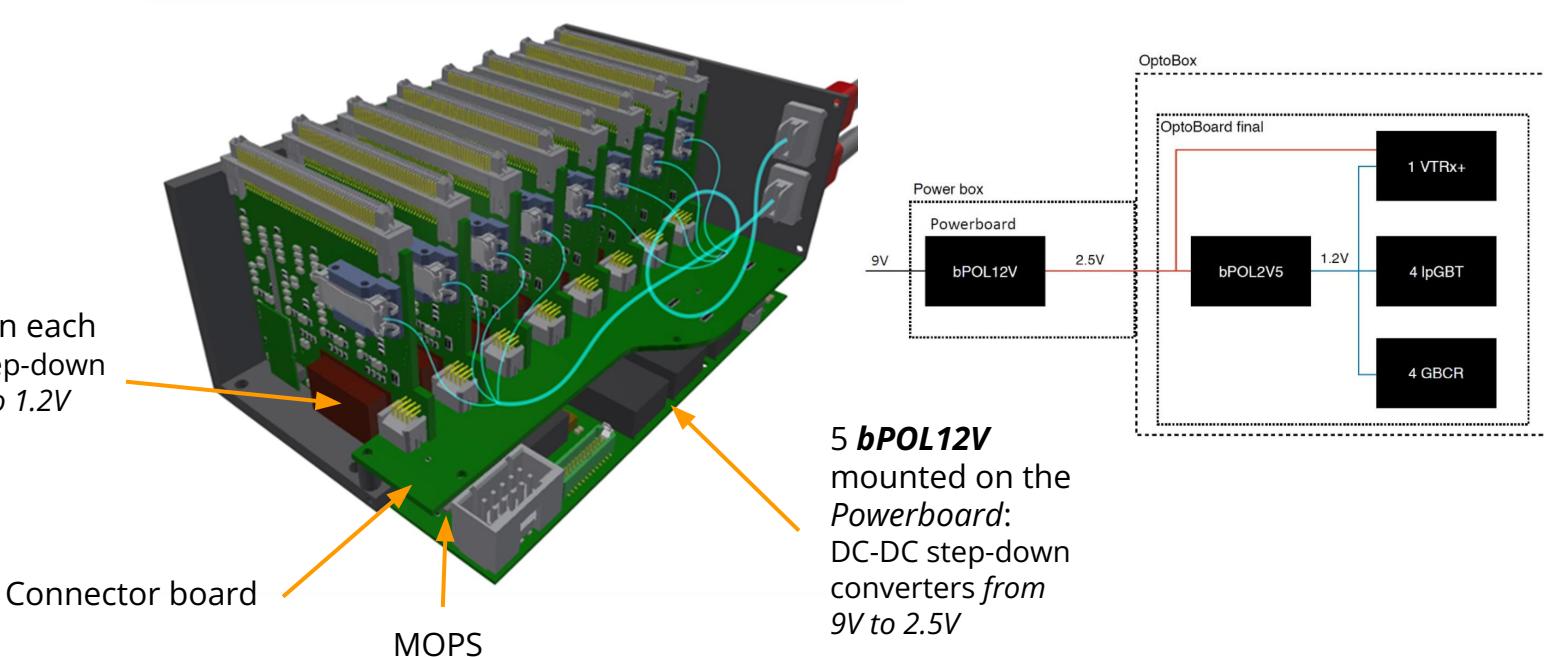


BER limit varying the parameters of the equalizer of the GBCR

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

Powering and monitoring of the Optoboards

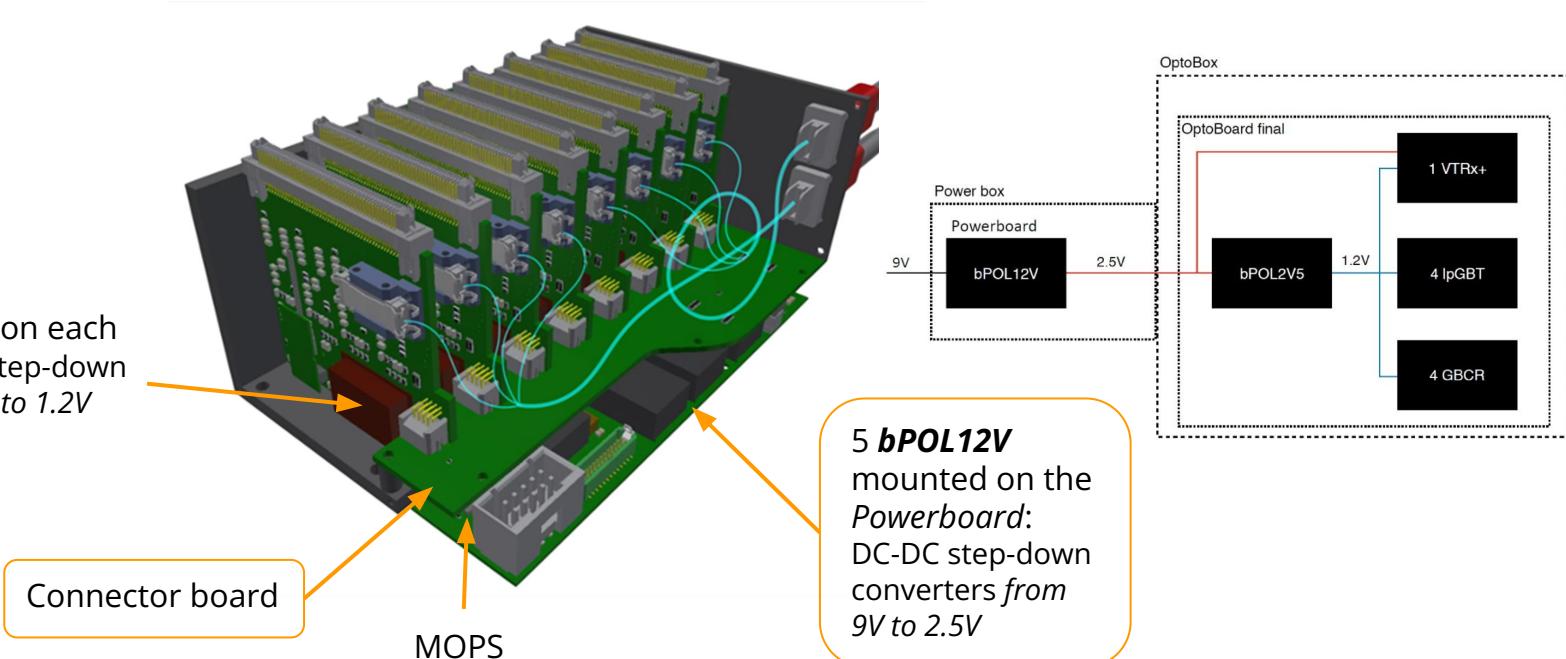
The ATLAS service caverns house power supplies which deliver 9V to the Optosystem



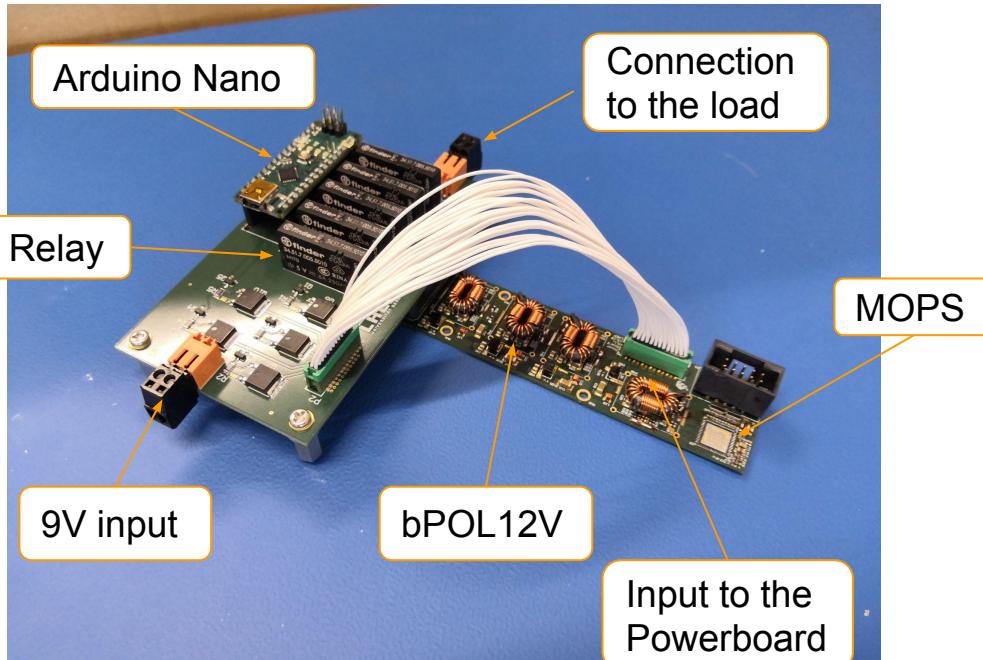
Powering and monitoring of the Optoboards

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



Load Line Test Board



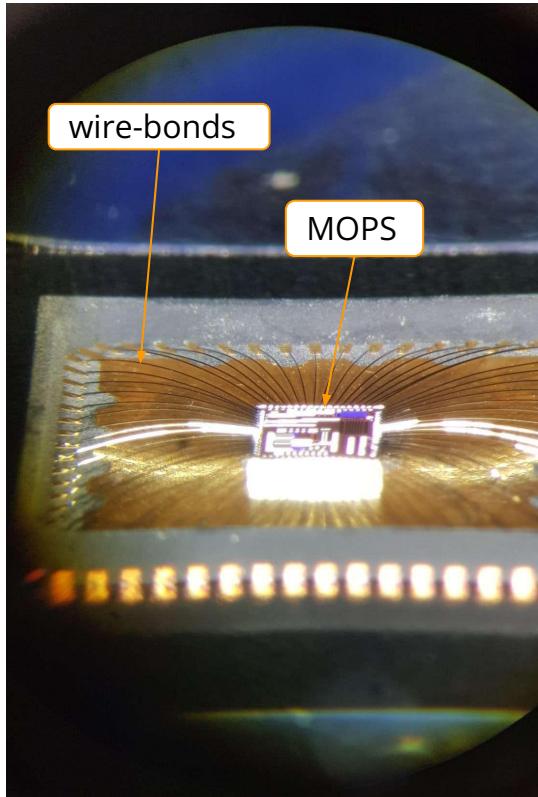
New board for the test of the powerboard:

- 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]

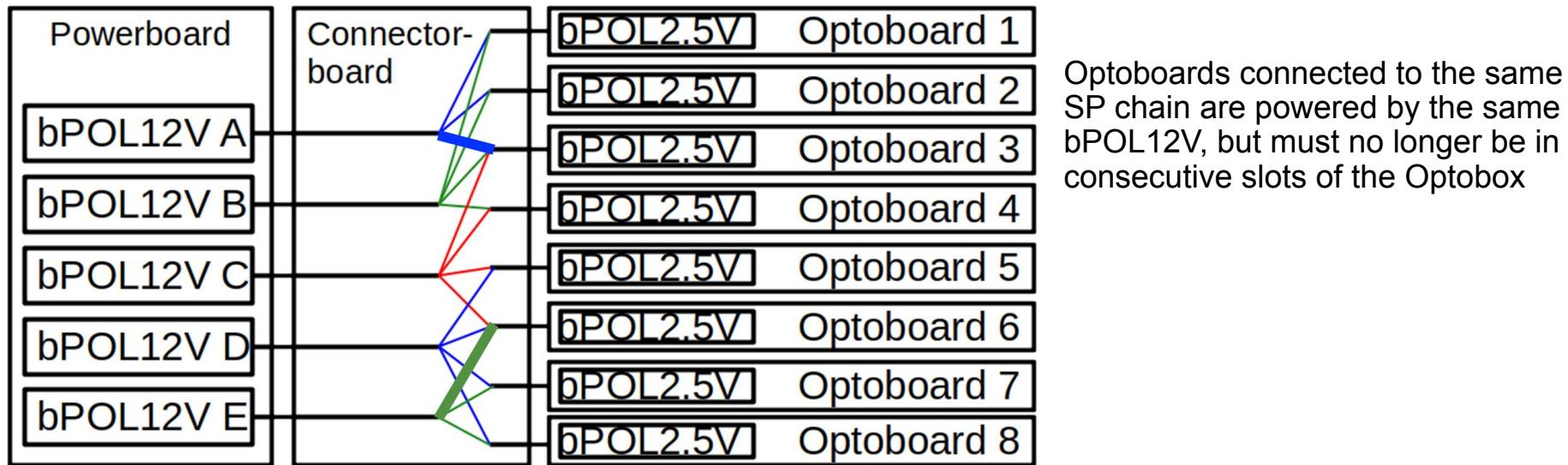
- The Monitoring of Pixel System (MOPS) is an ASIC with 34 channels to monitor the temperature and voltage of the front-end modules and Optosystem
- 40 MOPS were delivered to Bern for packaging: protection of the ASIC and easier deployment on a PCB
- 20 completed MOPS have been brought to Cern for the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



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

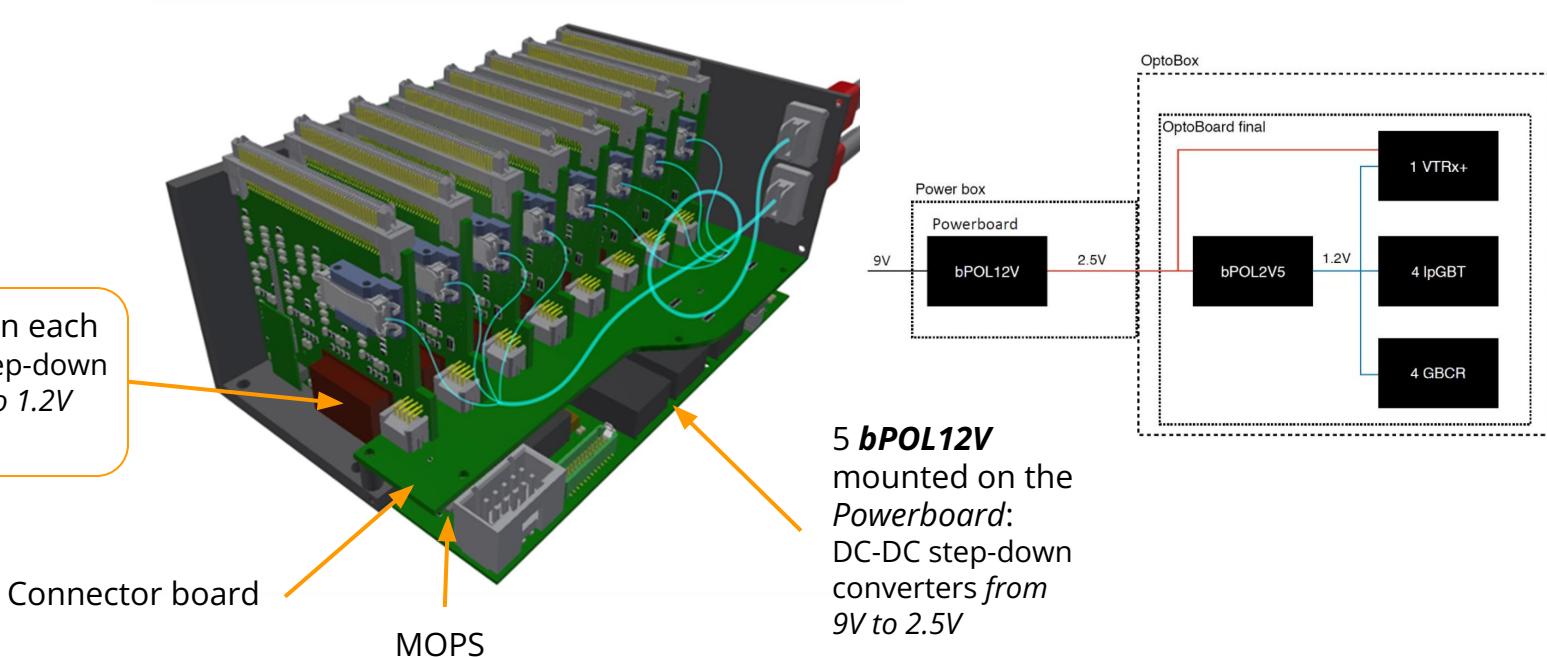
New connectorboard connections [L. Franconi]

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



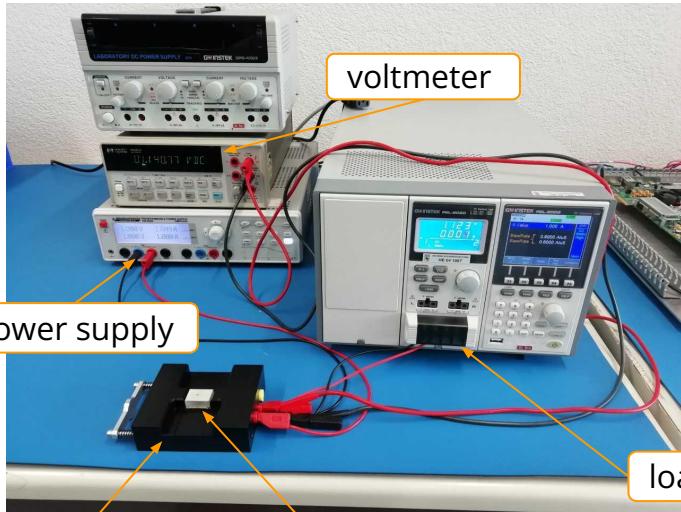
Powering and monitoring of the Optoboards

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



Voltage Tests of the bPOL2V5 [S. Geissmann]

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



power supply

voltmeter

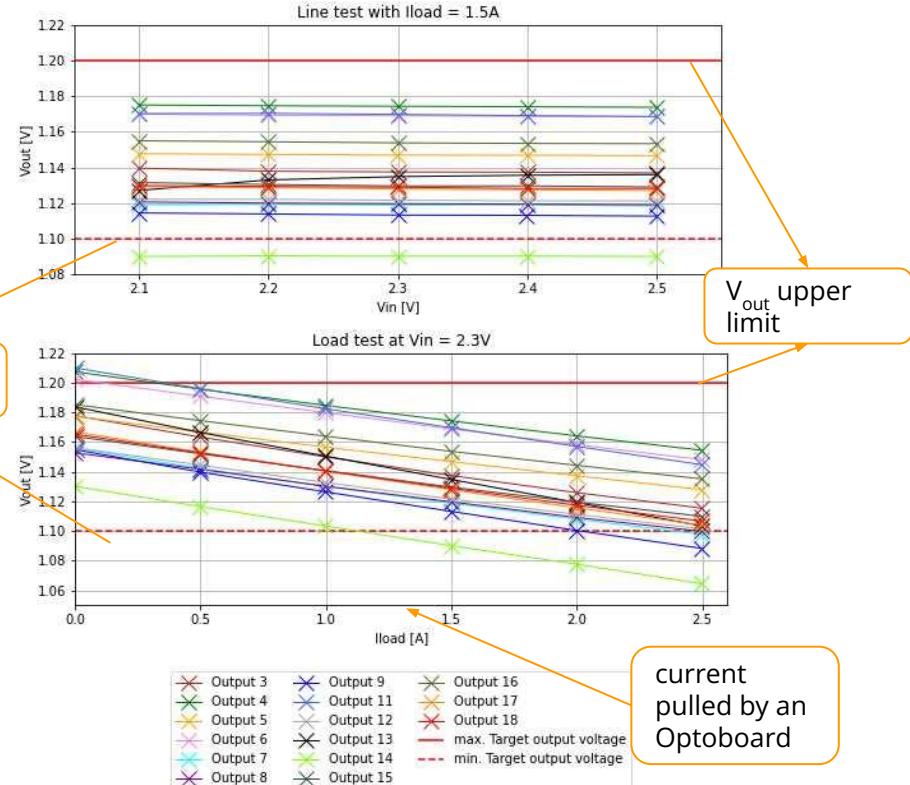
test board

load

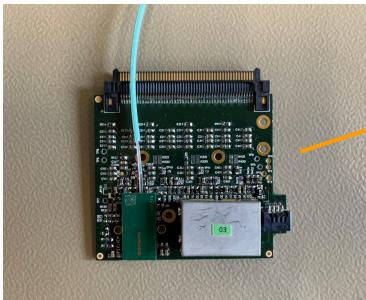
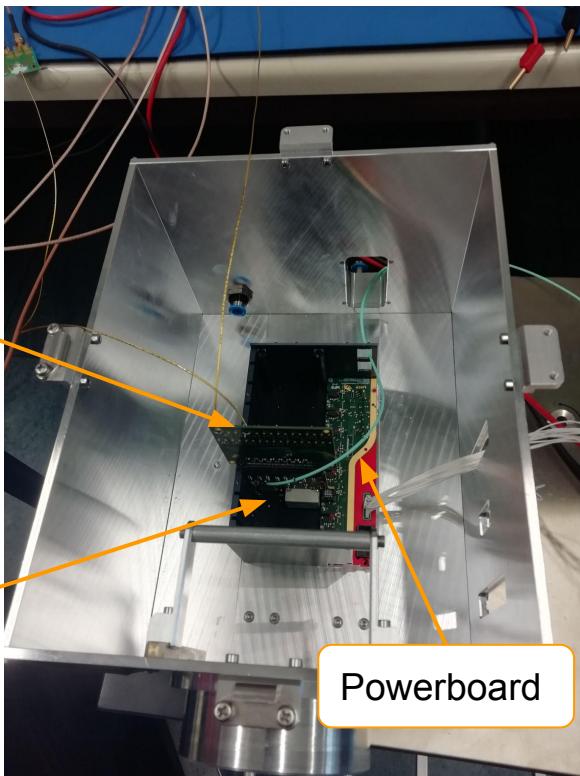
bPOL2V5 with shield

V_{out} lower limit

V_{out} upper limit



Optoboard test with powerboard and bPOL2V5

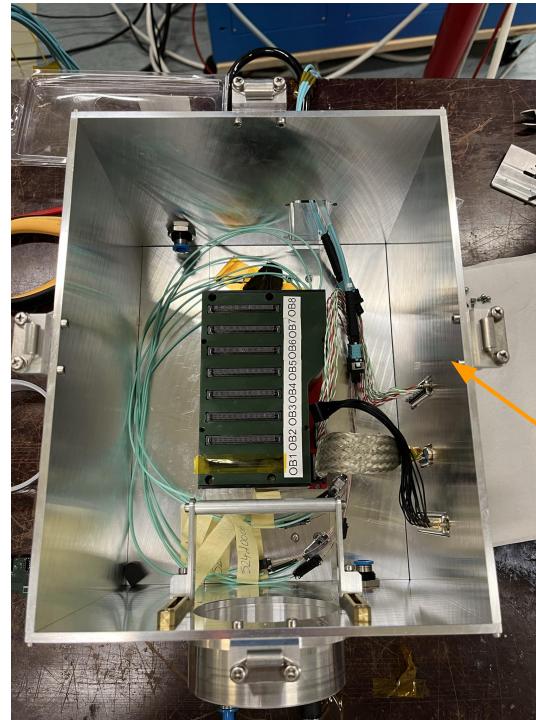


Tests:

- 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]

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 I²C with the IpGBTs (Opto V2.1 and V3.0), was designed.

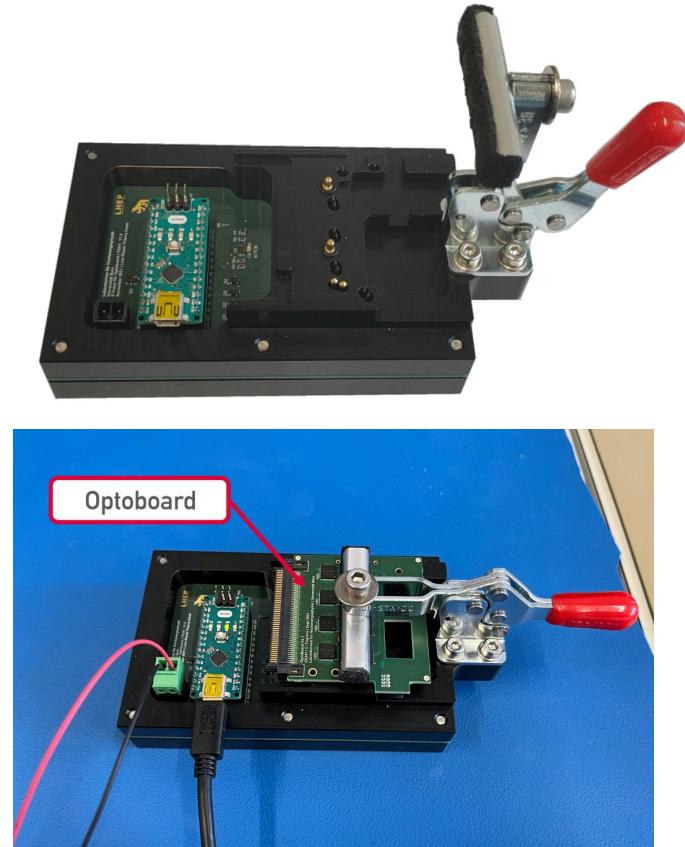
Applications:

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

What is the e-fusing?

Each register of the IpGBT 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

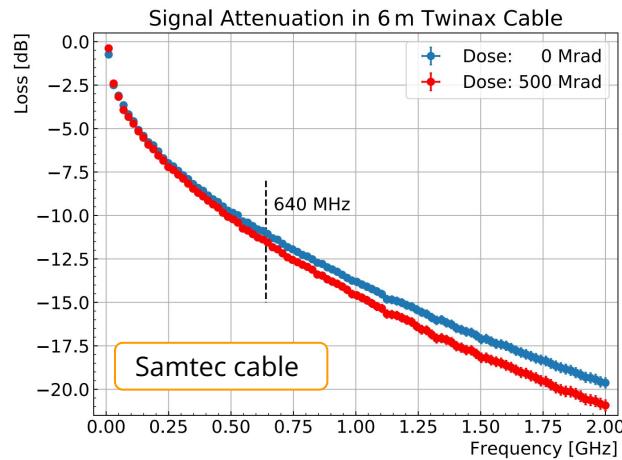
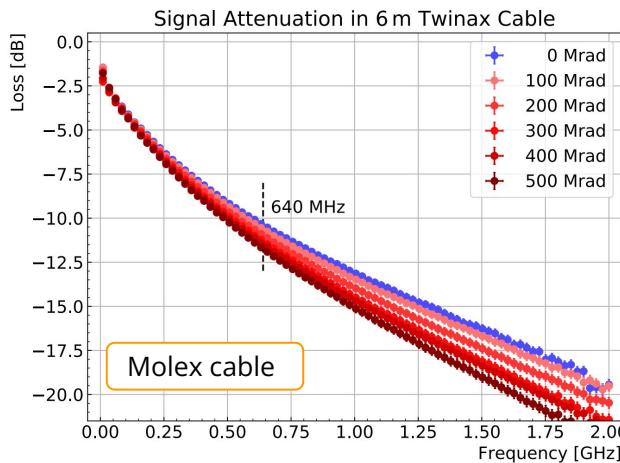
- *useful tool for debugging: IC & I²C communications can work simultaneously (I²C doesn't need any initial configuration)*



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



	Δ loss (6m, 640 MHz)	Δ jitter (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).

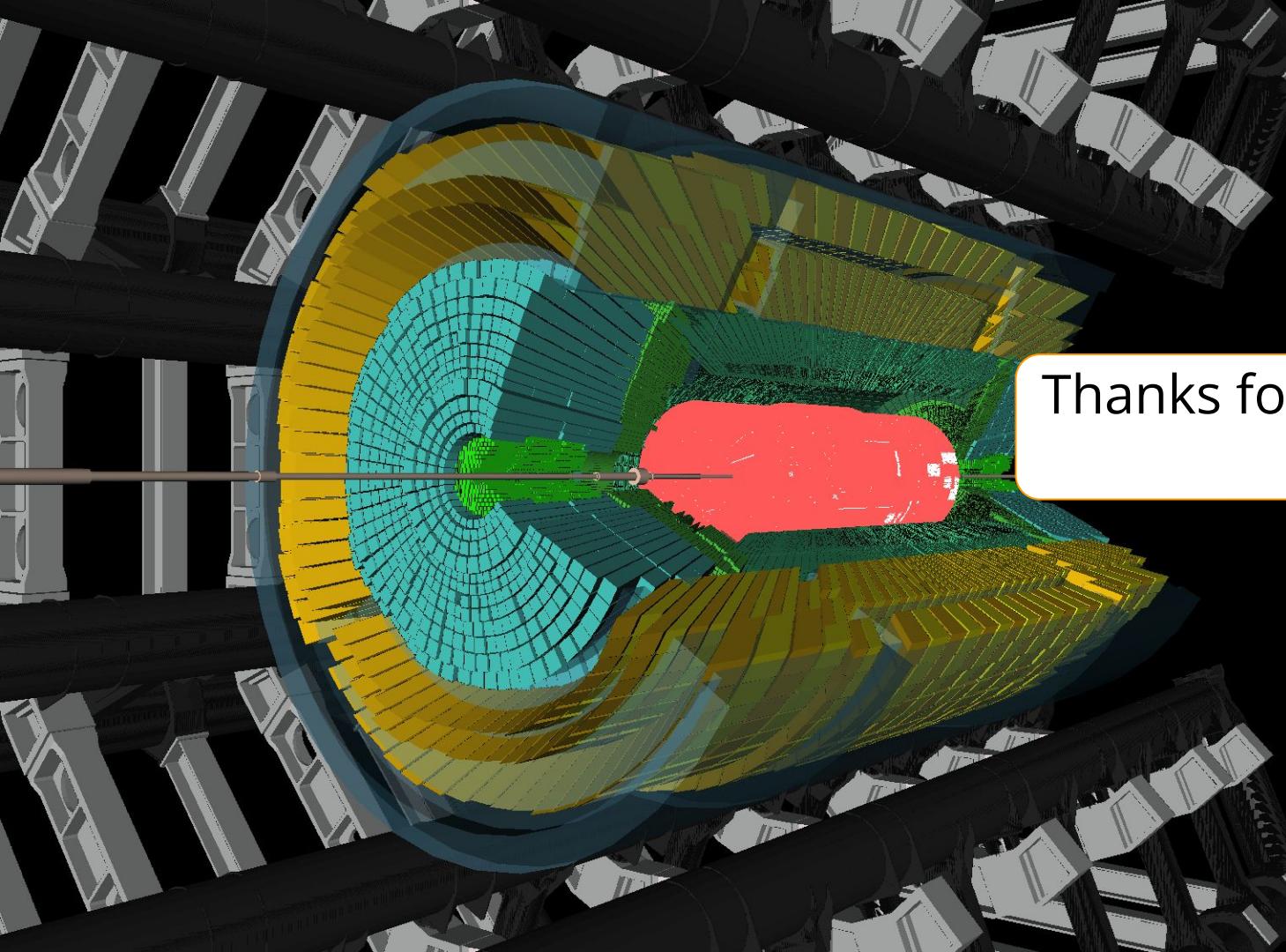
Summary

- 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 IpGBT
- 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 PPO 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

- **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

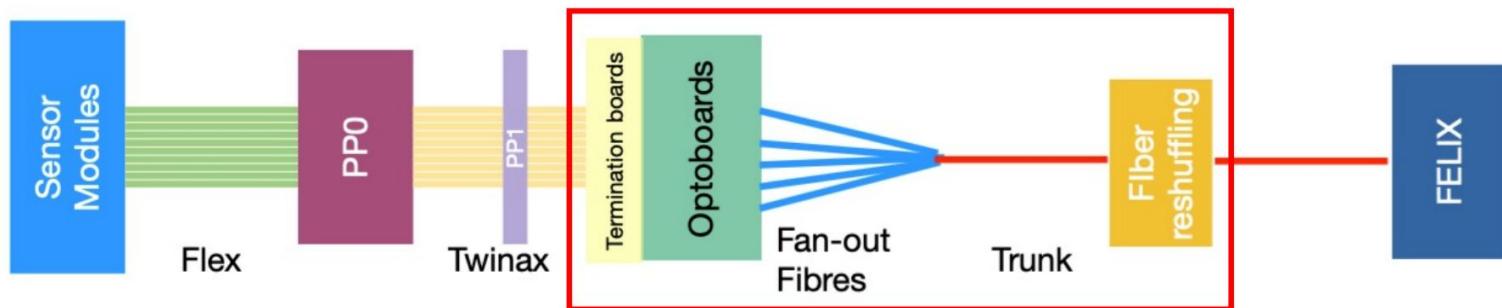
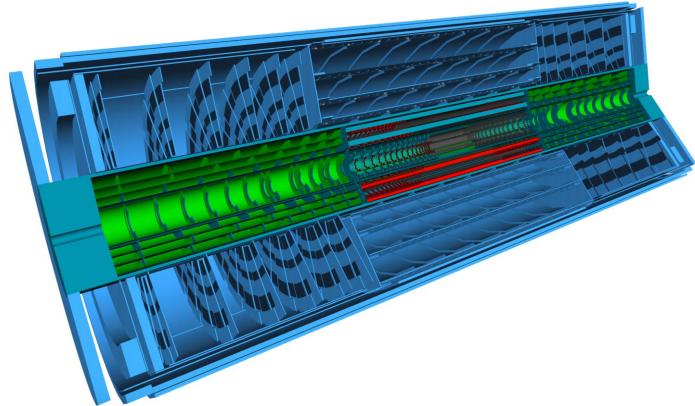


Thanks for the attention
Questions ?

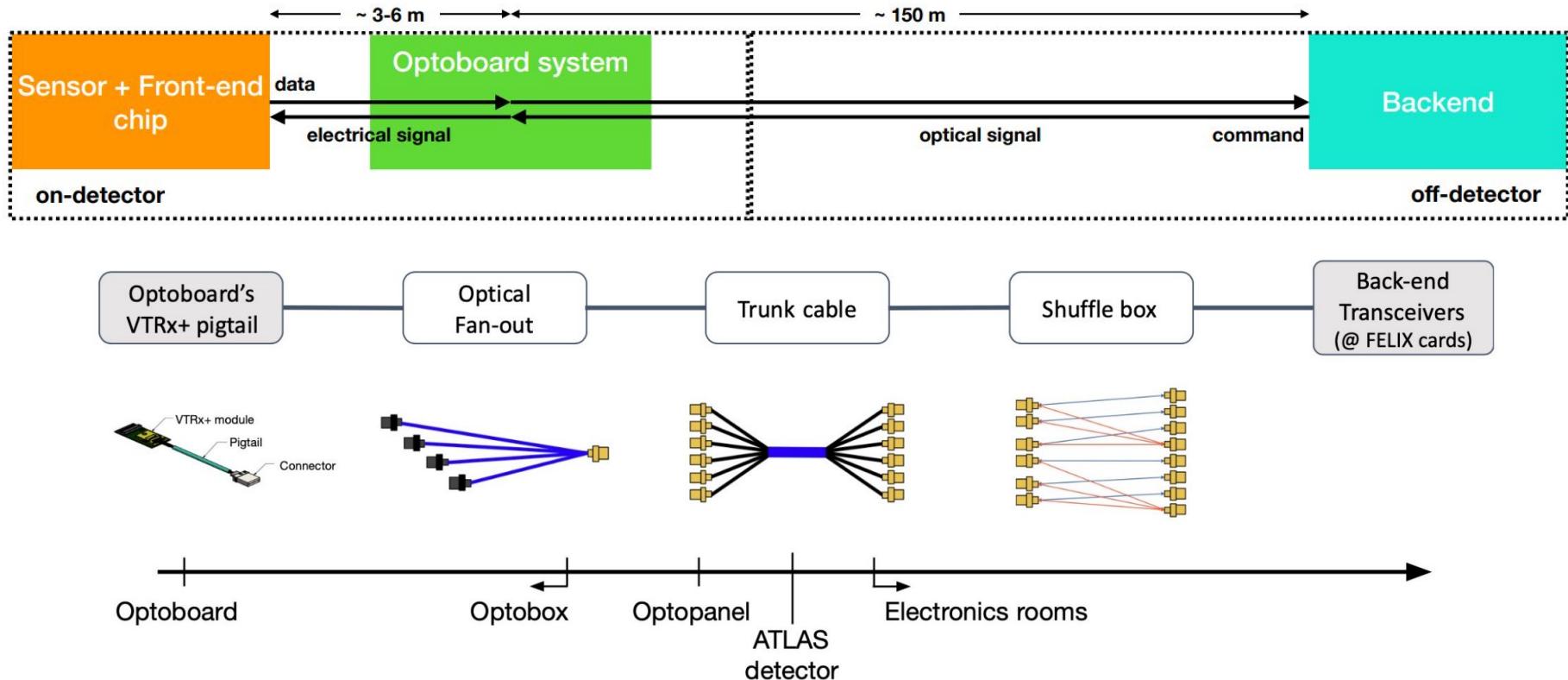
Backup

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]

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

Questions:

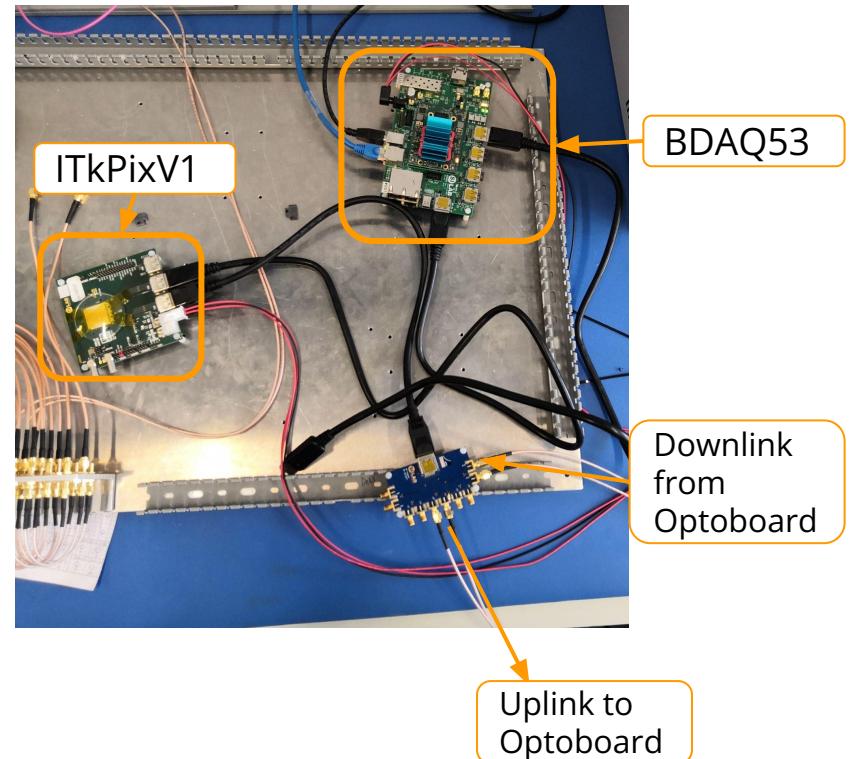
- can the ITkPixV1 recover a good clock from the downlink of the Optoboard?
- can we test the quality of the data sent by the ITkPixV1 using the Optoboard?

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



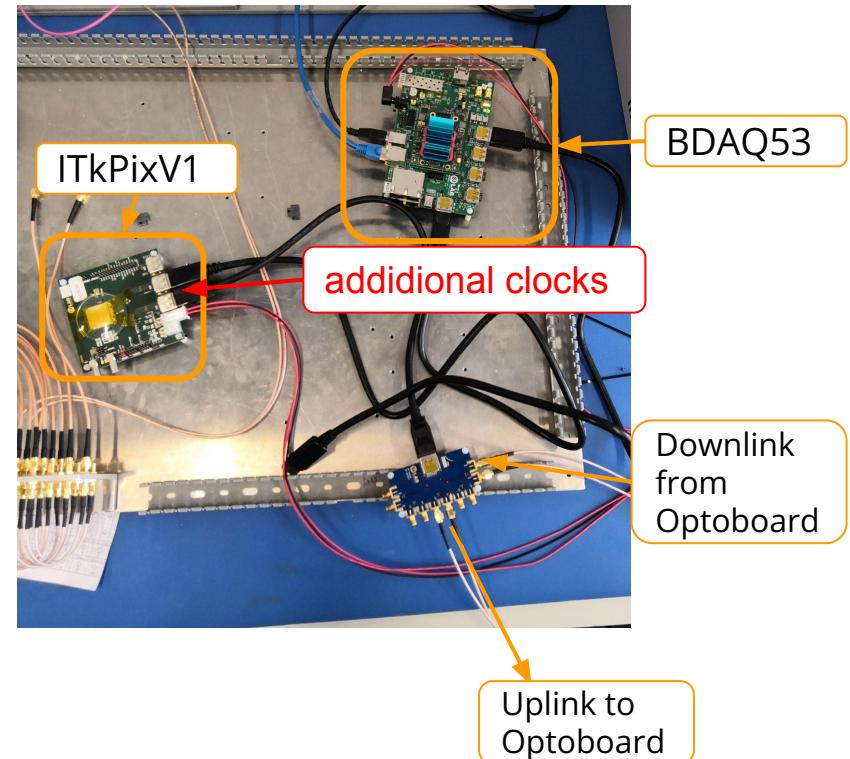
Test of the uplink of the ITkPixV1 [D. Dal Santo]

Issue:

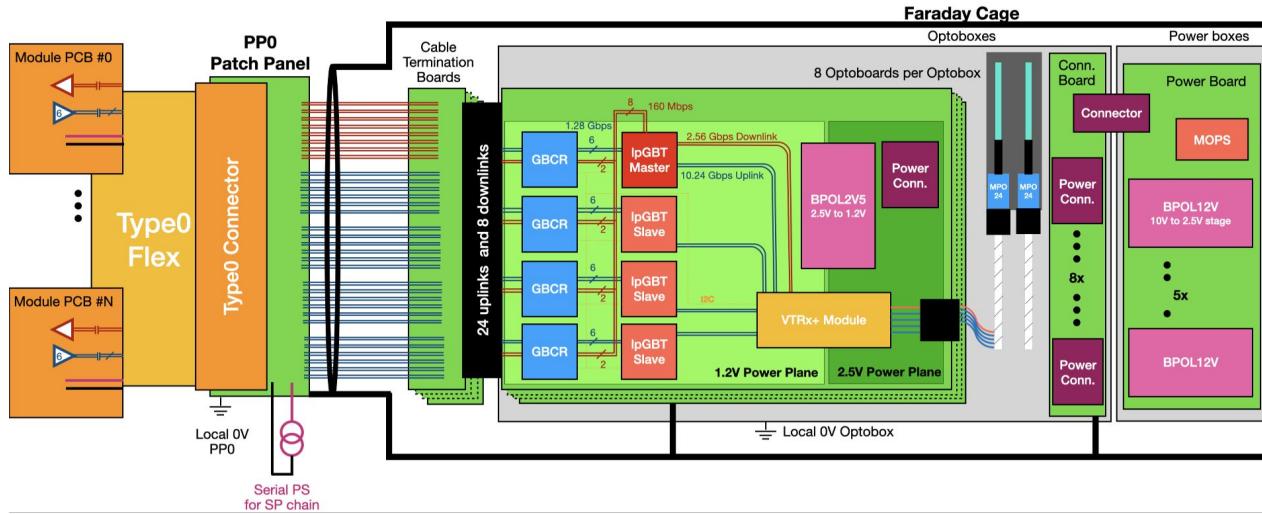
- the ITkPixV1 has only 1 downlink that has to be connected to the BDAQ53 to program it
- if the downlink is disconnected, the ITkPix resets (no PRBS7 in the uplink)

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
IpGBTs



VTRx+

LeCroy Eye BER

Eye BER

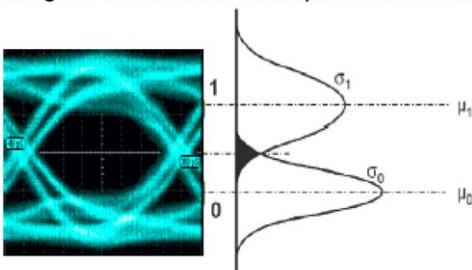
Eye BER is an estimate of the bit error ratio is made from the eye diagram. It is derived from a measurement of the Q-factor, as described below.

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

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 Qfactor 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 Qfactor 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](#))

Optoboard GUI

The screenshot shows the Optoboard GUI interface. At the top, there are tabs for different chips: IpGBT1 (master), ePortClk, GBCR1, IpGBT2 (slave), GBCR2, IpGBT3 (slave), GBCR3, IpGBT4 (slave), GBCR4, VTRX, LpGBT1 direct, LpGBT2 direct, LpGBT3 direct, LpGBT4 direct, and Test outputs. A callout box highlights the 'Tabs for the various chips on the board'.

The main area contains several configuration panels:

- General**: Shows the serial number (08000000), optoboard version (2), and I2C settings (I2C master, address 0). It includes sections for reading and writing registers (Address hex: rom, Read back value: 165) and characteristics (VREF, VDDTX, VDD).
- Uplink settings**: Contains multiple sections for EPRX0, EPRX2, EPRX3, and EPRX4, each with controls for Control, DataRate, and TrackMode.
- Configure downlink pre-emphasis settings**: A large section on the right containing multiple rows for EPTX0, EPTX2, EPTX3, EPTX4, EPTX12, EPTX20, EPTX22, and EPTX30, each with PreEmphasisStrength and DriveStrength controls.
- Optoboard Quick Start**: A section for configuring slaves, selecting Vtx version (12), and specifying a JSON configuration file: /itk_demo_optoboard/config/00000000_test_v0.json.

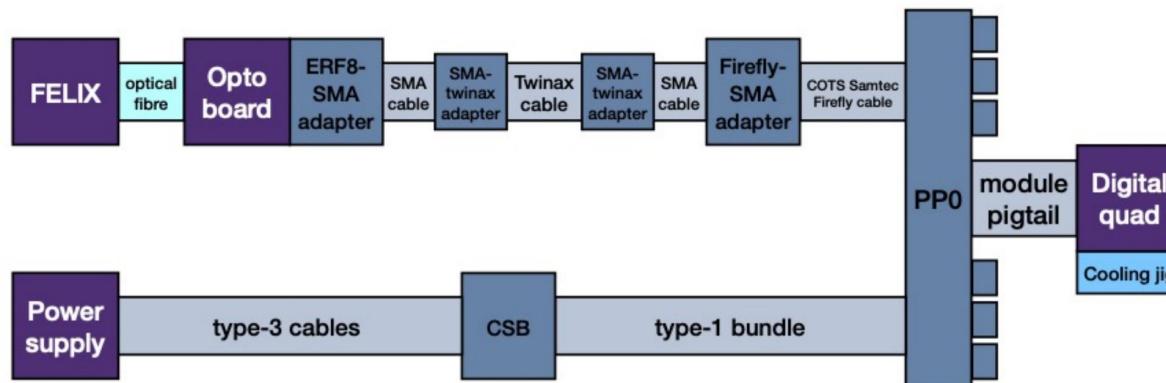
Callout boxes highlight specific features:

- A box around the register read/write section is labeled **Read and write registers**.
- A box around the 'Optoboard Quick Start' section is labeled **Configure the board providing a json file**.
- A box around the bottom of the interface is labeled **Integrated with the ITk-demonstrator software for system test**.

PP0 Data Transmission Chain [Aaron O'Neill]

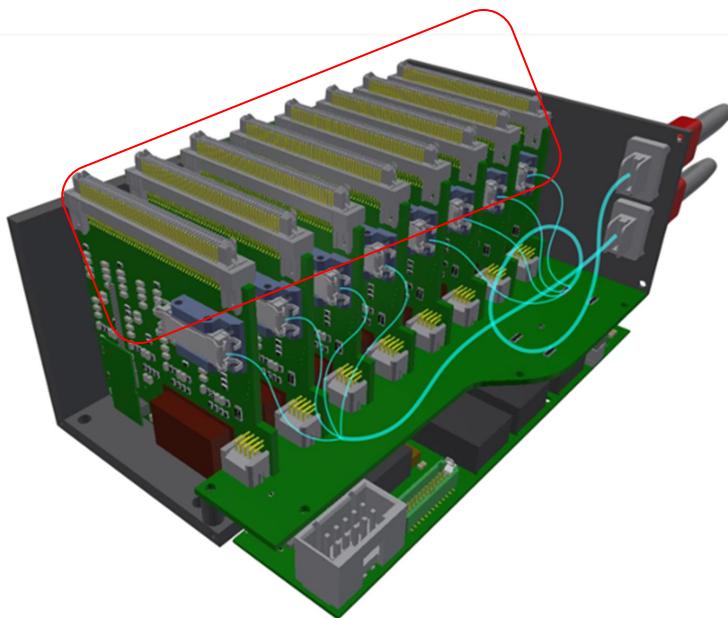
In Bern the construction of the data transmission chain with the final design will commence shortly:

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

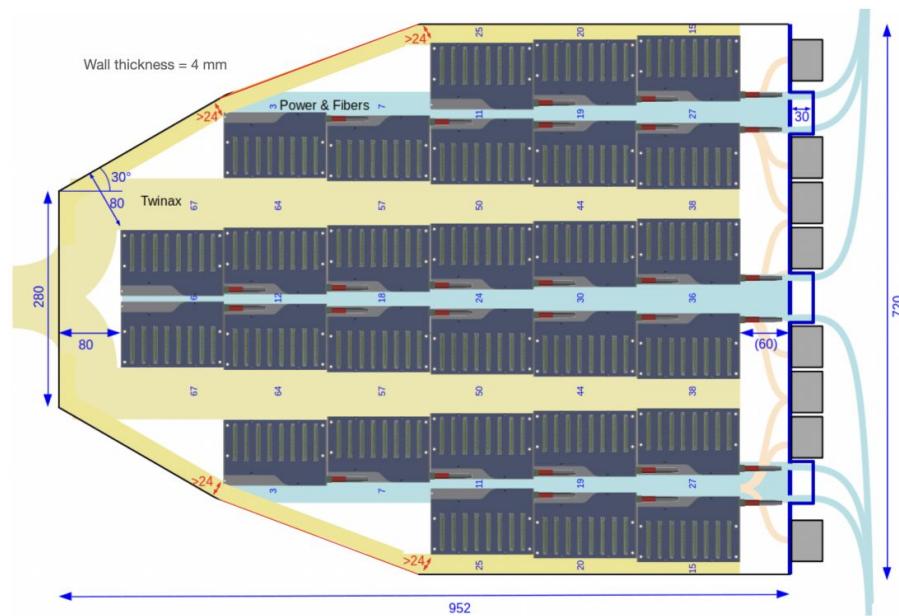


Types of Termination boards [L. Franconi]

Optoboard to twinax
connection: termination
board



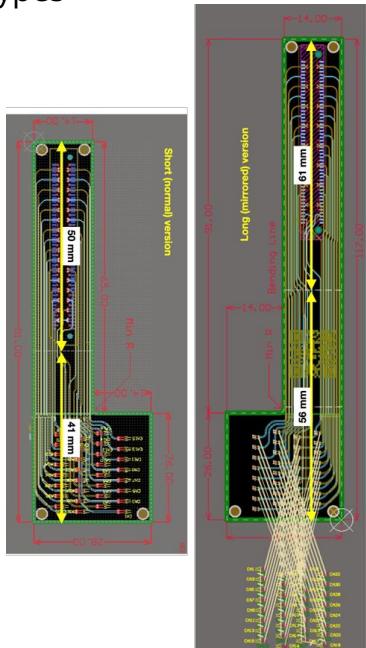
The Optopanel



Types of Termination boards [L. Franconi]

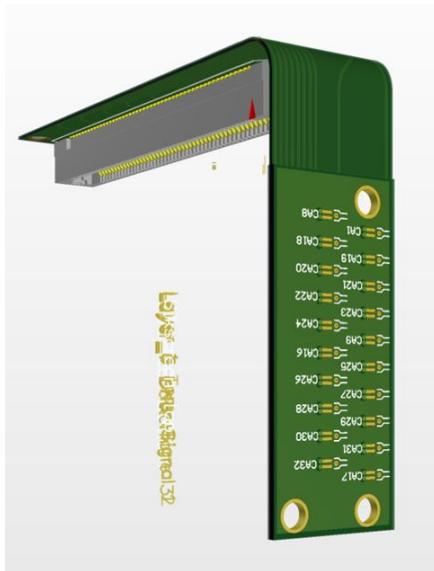
L-shaped

- 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]

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

To be verified by routing

normal	mirrored	normal	mirrored	normal	mirrored
23		76		69	
		Sector 5			
76		75		74	T3
G-OS-L5-A-CAN73 OB IL2&3 8 114	G-OS-L5-A-CAN71 OB IL2&3 8 114	G-OS-L5-A-CAN52 OB IL4 8 114	G-OS-L5-A-CAN42 OB IL4 8 112	G-OS-L5-A-CAN13 IS Quad Rings 8 140	
		226		25	10
G-OS-L5-A-CAN72 OB IL2&3 8 228	G-OS-L5-A-CAN70 OB IL2&3 8 114	G-OS-L5-A-CAN51 OB IL4 8 112	G-OS-L5-A-CAN41 OB IL4 8 112	G-OS-L5-A-CAN11 IS Intermediate Rings 8 140	
		452		460	
G-OS-L5-A-CAN83 OB FL4 7 312	G-OS-L5-A-CAN62 OB FL4 8 84	G-OS-L5-A-CAN50 IS Coupled Rings 8 160	G-OS-L5-A-CAN40 IS Coupled Rings 8 160	G-OS-L5-A-CAN03 OB IL2&3 6 92	
		708		732	232
G-OS-L5-A-CAN61 OB FL2 6 108	G-OS-L5-A-CAN22 IS Coupled Rings 8 160	G-OS-L5-A-CAN22 OB FL3 8 96	G-OS-L5-A-CAN02 OB FL4 8 112	G-OS-L5-A-CAN01 OB FL3 7 84	
		976		912	304
G-OS-L5-A-CAN80 OB FL2 6 312	G-OS-L5-A-CAN21 IS Coupled Rings 8 160	G-OS-L5-A-CAN21 OB FL2 6 108	G-OS-L5-A-CAN01 OB FL2 6 108		
		1244		1120	
G-OS-L5-A-CAN30 OB Barrel 7 1402	G-OS-L5-A-CAN20 IS Barrel 4 158	G-OS-L5-A-CAN20 IS Barrel 4 88	G-OS-L5-A-CAN02 OB FL2 6 108		
		1714		1216	
		3234		1520	

A-side quadrant 2/3

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



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

#bundles								
24	77	132	264	396	720	912	1092	1402
irrorred		G-OS-L9-A-CAN11 EC L3 8 132	G-OS-L9-A-CAN10 EC L3 8 132	G-OS-L9-A-CAN02 EC L3 8 132				1714
normal		G-OS-L9-A-CAN13 EC L4 (rings 1-7) 8 104	G-OS-L9-A-CAN12 EC L4 (rings 1-7) 8 104	G-OS-L9-A-CAN03 EC L4 (rings 1-7) 8 104	G-OS-L9-A-CAN01 OB FL4 8 72	G-OS-L9-A-CAN00 OB FL4 8 72	396	
irrorred	75	78	260	496	720	912	1092	1180 1576
normal	Sector 9	G-OS-L9-A-CAN02 EC L4 (rings 8-9) 8 156	G-OS-L9-A-CAN01 EC L3 8 132	G-OS-L9-A-CAN04 EC L2 (rings 1-5) 8 120	G-OS-L9-A-CAN22 EC L2 (rings 1-5) 8 120	G-OS-L9-A-CAN21 OB FL4 8 96	G-OS-L9-A-CAN20 IS Barrel 4 88	
normal		G-OS-L9-A-CAN03 EC L4 (rings 1-7) 4 52	G-OS-L9-A-CAN01 EC L2 (rings 6-11) 8 160	G-OS-L9-A-CAN05 EC L2 (rings 6-11) 8 160	G-OS-L9-A-CAN02 EC L2 (rings 6-11) 8 160	G-OS-L9-A-CAN01 OB FL3 6 72	G-OS-L9-A-CAN00 IS Barrel 7 158	3462
irrorred	77	79	192	512	832	1064	1208	1366 1886
normal		G-OS-L9-A-CAN07 IS Intermediate Rings 8 140	G-OS-L9-A-CAN07 IS Coupled Rings 8 160	G-OS-L9-A-CAN02 IS Coupled Rings 8 160	G-OS-L9-A-CAN01 OB FL3 6 72	G-OS-L9-A-CAN00 OB FL3 6 72		520
24		T10	200	360	520			1436

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