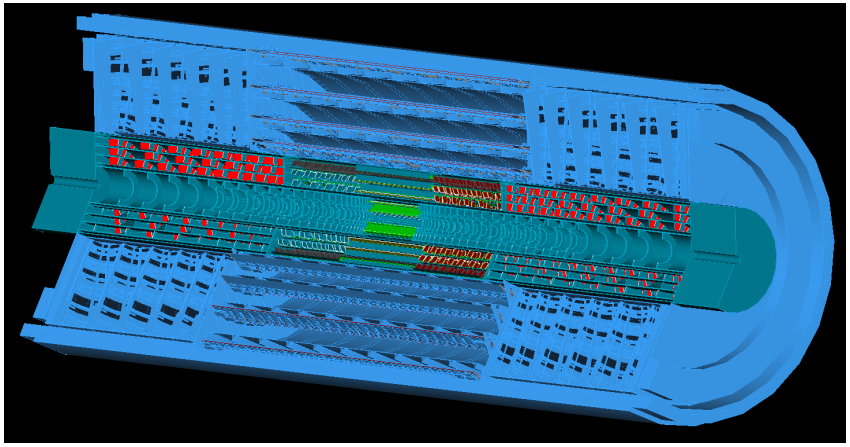
ATLAS RD53A serial powering tests and plans: Bonn, CERN, Liverpool

Serial powering for ATLAS and CMS pixel detectors
15.10.2018

Susanne Kuehn, CERN
System test activity

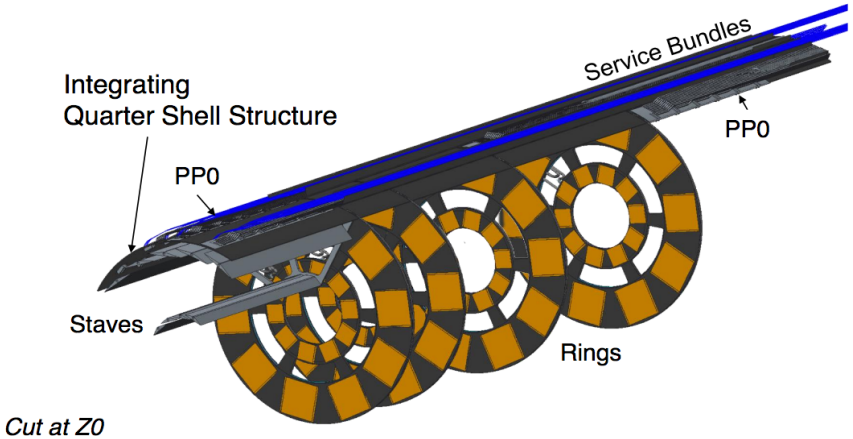


Content

- Requirements to qualify for serial powering
- System tests conducted with prototypes based on FE-i4 modules
    - Observations and features
- Foreseen future tests with RD53A chips and modules

ATLAS Inner tracker pixel layout

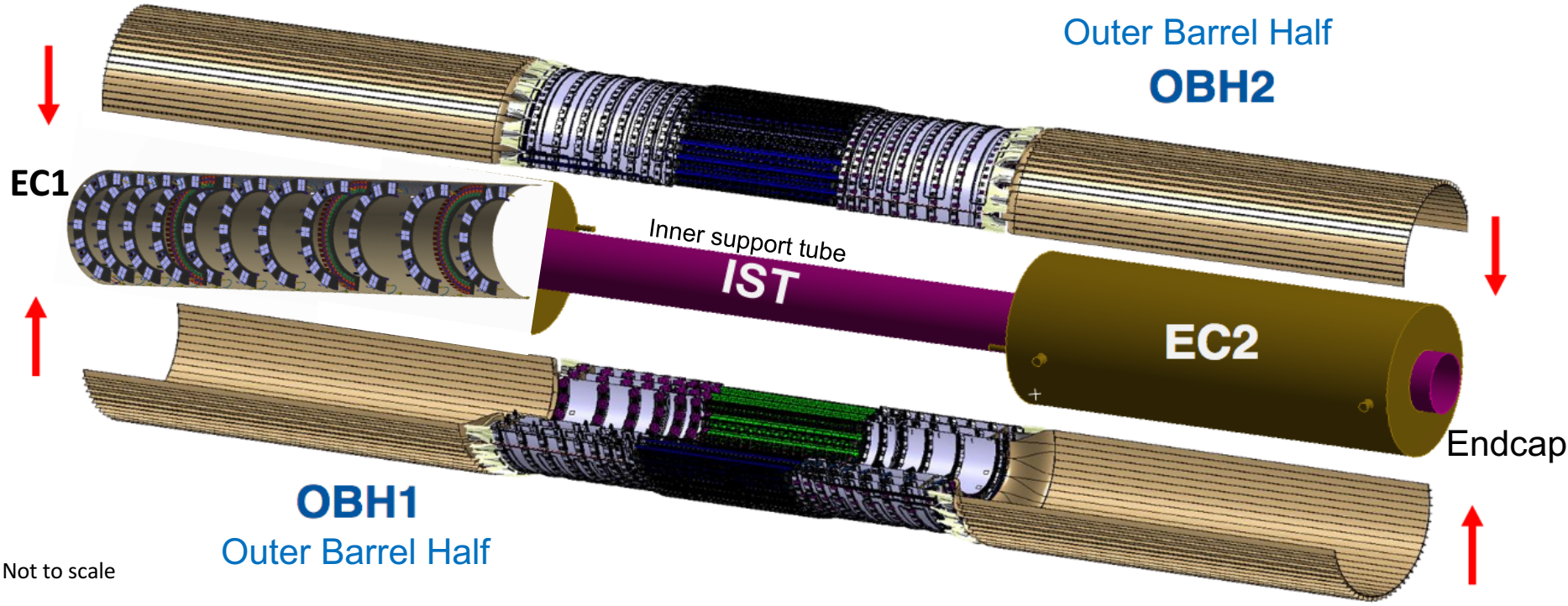
- Inner system



Cut at Z0

→ Varying serial powering chain length and different realizations of same concept
→ Validation in different prototypes

- Outer system



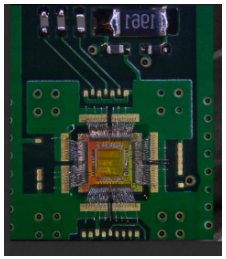
Not to scale

Requirements to qualify for serial powering

- **In ATLAS ITk pixel serial powering chains of varying length**
  - Max. length 14 quad modules, average modularity 10 quads
  - Qualification of chain with up to 16 quad modules
  - Several HV lines per chain possible

Subsystem	SP chain length	Number of chains
Inner (Layer 0)	20/28 singles (powered as pseudo quads)	124
Inner (L1)	10/12 quads	116
Outer Barrel (L2-4)	8/10 quads	264
Outer Inclined Rings (L2-4)	8/11/14 quads	184
Outer Endcap (L2-4)	8/11/13 quads	224

- **Serial powering protection chip PSPP**
  - For bypass and to monitor module parameters (temperature, low voltage current)

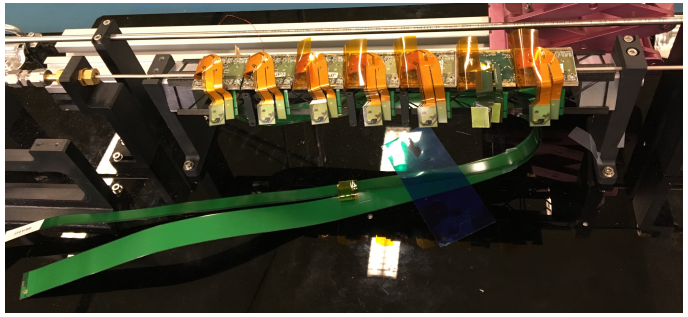


PSPPv3 on power flex

- **To qualify are behaviour of**
  - LV, HV, LV_DCS power supplies
  - Temperatures during operation
  - Currents, common return line, HV multiplicity
  - PSPP/bypass functionality, tuning of resistors for PSPP
  - (multi-module readout), …

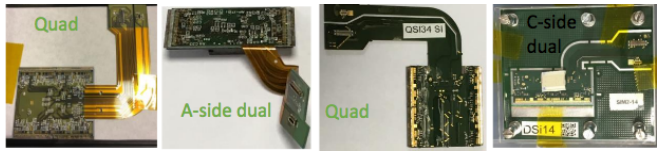
System tests with FE-i4 based prototypes

- Some years ago initial FE-i4 modules tested in SP chain in Bonn
- Since 2017 prototyping programs ongoing within ITk pixel
  - For outer barrel: demonstrator program including electrical 7-quad structures and full-size prototype with 32 duals and 14 quads

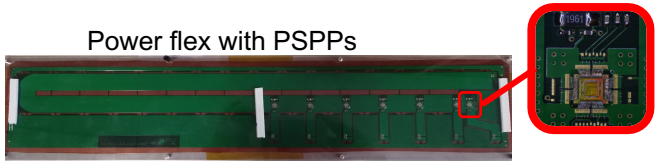


7-cell longeron with FE-i4 quads and stave flexes

→ Measured and evaluated

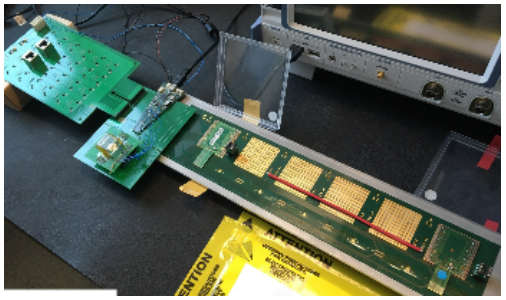


Outer barrel dual and quad modules



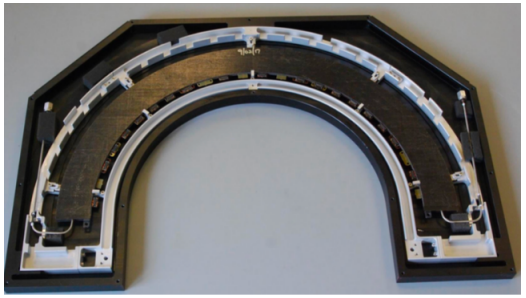
→ In assembly

- For endcaps: stave with 13 quad modules and ring-0 with 12 quad modules



End-of-structure card test with FE-i4 module for endcaps

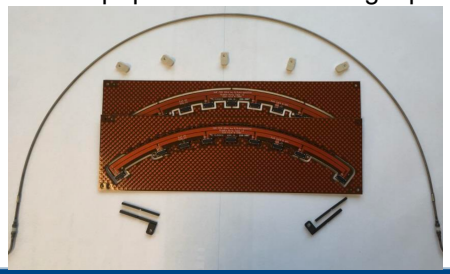
→ Measured and evaluated



Local support for ring-0 of endcaps

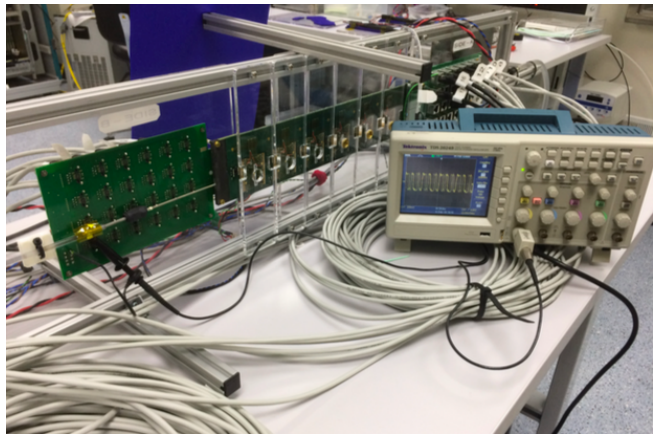
→ In assembly

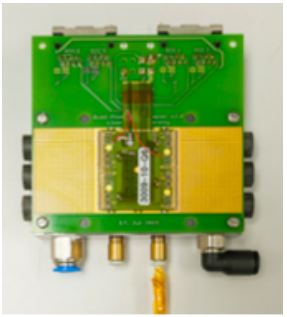
Endcap quad module and ring tape



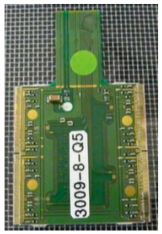
Results from Endcap stave I

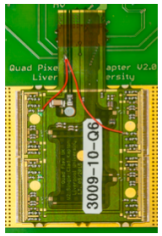
- 12 quad modules on stave + single quad





Power supplies:
LV TTi QL355TP
(30V, 2-2.5A)
HV Keithley 2410





Side A: 6 Kapton flex modules, draw higher current
Side B: 6 FR4 flex modules, more copper, older version

DIL8 connector next to each module on tape allows monitoring of SP and manual shunting of individual modules if needed.

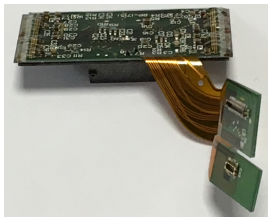
→ 48/52 FE's can be read out and there are 4 FE's that don't deliver data, however, they still have working regulators → still part of SP chain

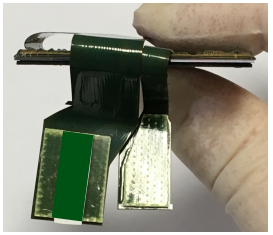
- Configuring the chain: start with module of highest voltage drop, then individually configured and more uniform power distribution can be achieved
- Noise and tuning functional
- Large leakage current when HV off observed (more later)
- Extension of chain to 14 modules ongoing

Quad no.	Quad name	ROCs read out	RCE ports	Stave connections	Voltage (before configuring)	Voltage (after configuring)
0	3009-10-Q2	4,3	0,14	Side B: 1.4, 1.3	1.84	2.10
1	3009-10-Q3	4	1	Side B: 2.4	1.81	2.18
2	3009-8-Q4	4	2	Side B: 3.4	2.06	2.16
3	3009-8-Q5	4	3	Side B: 4.4	2.21	2.16
4	Yellow (no ID)	4	4	Side B: 5.4	2.20	2.16
5	3164-2-Q4 (200um)	4,3	5,15	Side B: 6.4, 6.3	1.99	2.13
6	3009-10-Q6	4,3	6,16	Side A: 1.4 1.3	1.65	2.21
7	3009-8-Q3	4	7	Side A: 2.4	2.44	2.41
8	3009-10-Q4	4	8	Side A: 3.4	2.2	2.24
9	2935-18-Q1	(4 dead), 3	9,10	Side A: 4.4, 4.3	1.84	2.27
10	2935-18-Q5	4	11	Side A: 5.4	2.08	2.27
11	3009-10-Q5	4,3	12,17	Side A: 6.4, 6.3	1.87	2.17
12	3164-2-Q3 (200um)	4	13	Chuck: ROC4**	2.2	2.16

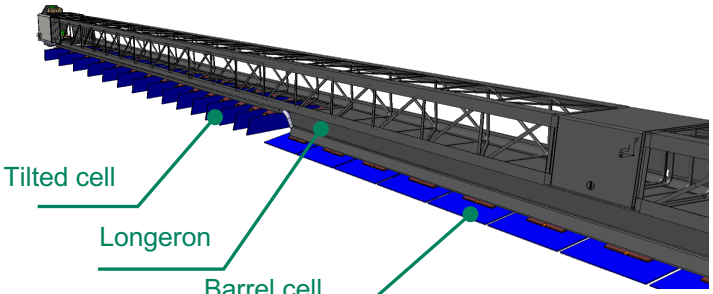
Results from Outer Barrel Demonstrator program

- Several prototypes for thermo-fluidic, thermal and full electrical system test including serial powering, DCS and CO_2 cooling
- Longeron with 2 cooling lines with flat quad and inclined dual modules based on FE-i4, 14 quads, 32 duals
- Modules on cells (local supports) with bent module flex tails



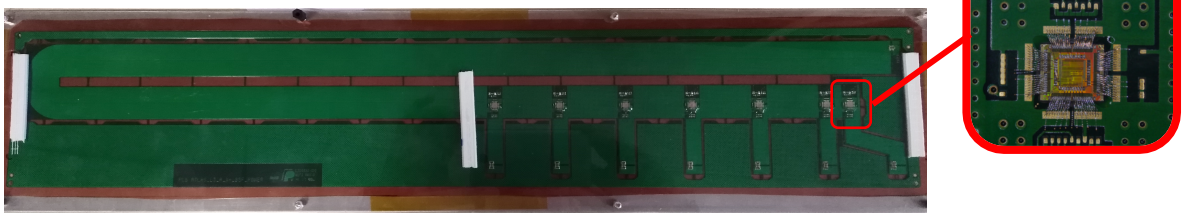


Quad module on cell



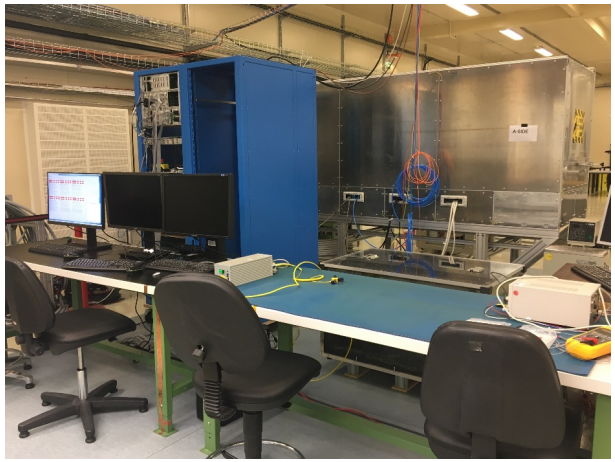
services not shown

- Data and power routed via stave flexes



System test setup at CERN

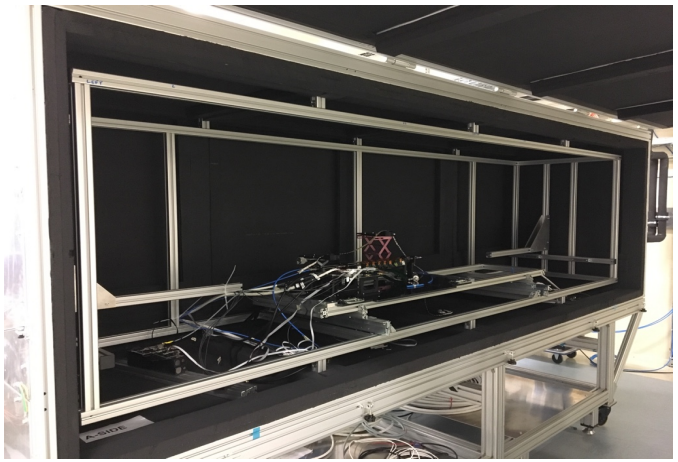
System Test Facility with CO_2 cooling, DCS, PSUs for serial powering (for outer barrel)



- **Rack** for DCS, interlock matrix, PSUs
- **Rack** for different readout systems and for NIM crate
- **PCs** for WinCC GUI and DCS, for readout systems and for stage control

PSUs:

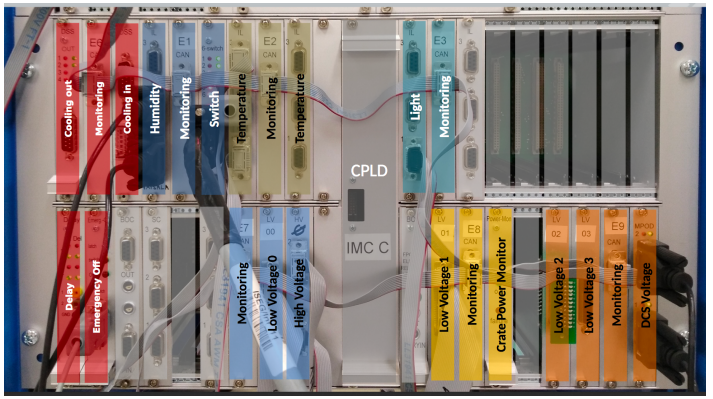
- LV: WIENER PL512 60V/5A, 16C/16A
- HV: ISEG HV (high ohmic off-mode)
- V_DCS: WIENER MPOD Crate and OMPV8060



- Light-tight **box**, insulated with 45 mm armaflex, hosts scintillators for triggering
- **Sensors** for dewpoint (Vaisala), humidity, temperature, light, door switch,
- **Mounts** for prototype and CO_2 piping
- **Dry-air** supply
- **Motorized stage** for sources

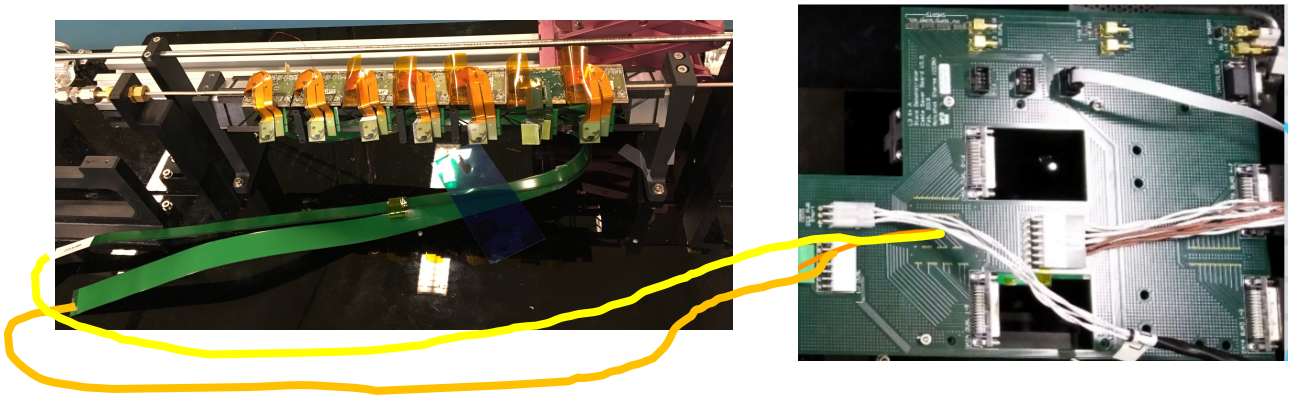
- IBL **CO_2 plant** currently getting upgraded to 2 kW at -30° C

- **DCS** for detector interlock, control/monitoring and diagnostics, independent operation



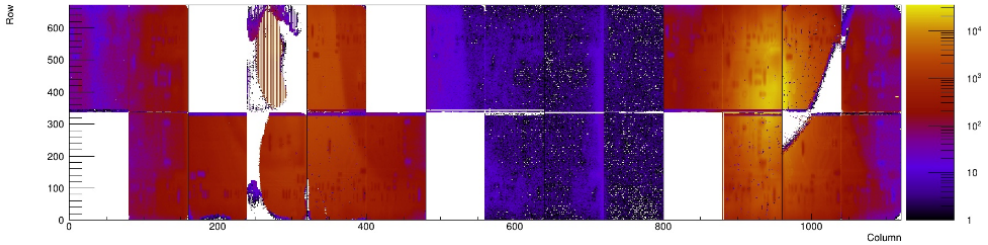
Results from 7-cell structure

- Loaded local support with 7 FE-i4 quad modules in one serial powering chain including PSPPs v3. Two HV lines and common return line



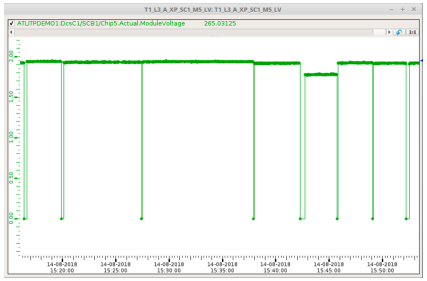
To PSU, Readout and DCS

Sr90 source scan results (first/B-grade modules were used)



User Interface for SP chain operation (up to 6 chains)

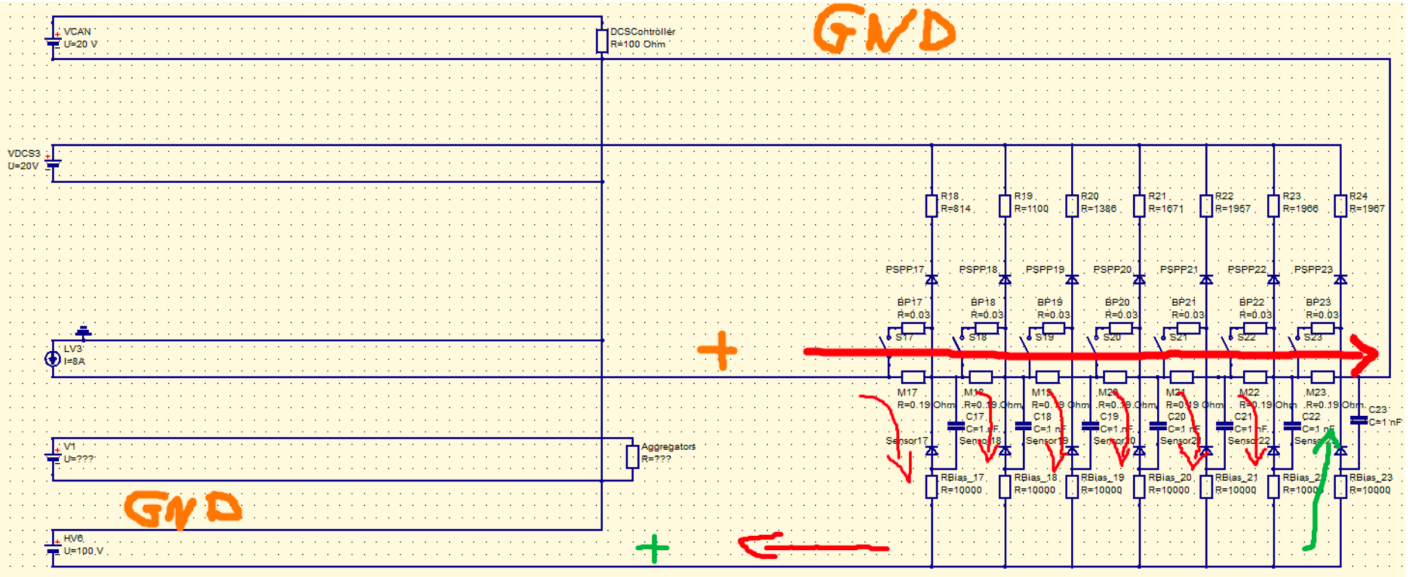
Status and history



Serial powering features on 7-cell structure I

In current layout shared LV/LV_DCS/HV return line:

- HV power supply has high-ohmic off-modes (O(MOhm)
- Leakage current return will generate a forward bias on the last module(s) in a long SP chain, the one with lowest local ground (several 100 mV)
- Measurement with sense wires
- To be checked with irradiated modules due to higher leakage current
- Relevant for selection of HV PSU



Module	Voltage Drop [V]	R_HV [Ohms]	Vglobal [V]	Vsensor [V]	Drop over R_HV [V]	ISensor [uA]
BM1	2.12	11000	0.701	0.368	0.333	30.27272727
BM2	1.78	10000	0.701	0.724	-0.023	-2.3
BM3	1.95	11000	0.701	0.92	-0.219	-19.90909091
BM4	1.99	11000	0.701			
BM5	2	11000	0.701			
BM6	2	11000	0.701	0.742	-0.041	-3.727272727
BM7	2.01	11000	0.701	0.754	-0.053	-4.818181818

For common HV line: On our prototype > 95% of leakage current returned through last sensor (5 modules – 30uA)
Might be < 15 mA in final detector

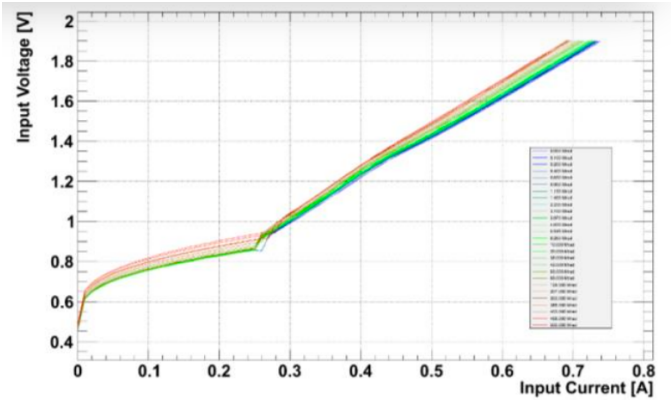
Serial powering features on 7-cell structure II

Feature of LV_DCS with LV and HV off

- Negative voltage drop generated on modules if LV power supply has low ohmic off-mode
- Positive voltage drop on modules with high ohmic off-mode of LV PSU

	LV Open (PSPP)	LV on PL512 (Probed)	LV with 10 kΩ (PSPP)
M1	0.00 V	-0.14 V	0.00 V
M2	0.59 V	-0.14 V	0.59 V
M3	0.55 V	0.00* V	0.55 V
M4	0.55 V	-0.12 V	0.55 V
M5	0.55 V	-0.10 V	0.54 V
M6	0.53 V	+0.17 V	0.52 V
M7	0.62 V	+0.50 V	0.62 V

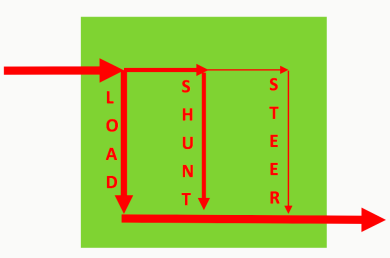
*Hard to probe on module

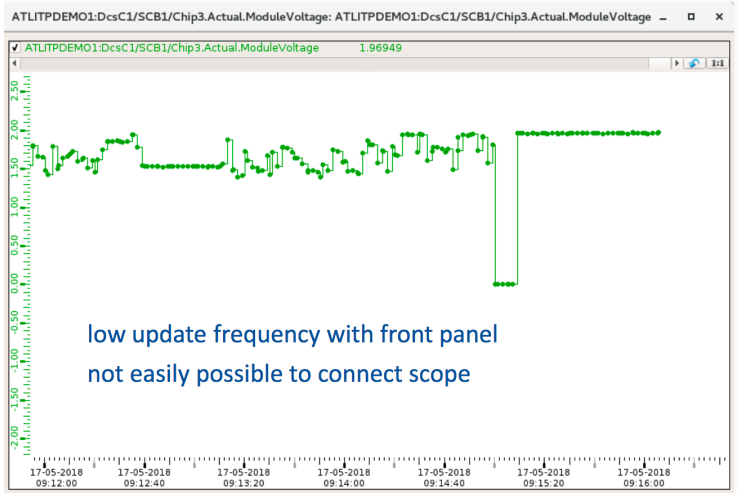


- Current of about 1 uA through sensor/FE chips with the FE off (for FE-i4 modules about 600 mV drop)
- In final detector depending on offset of power regulators

Further features from 7-cell tests

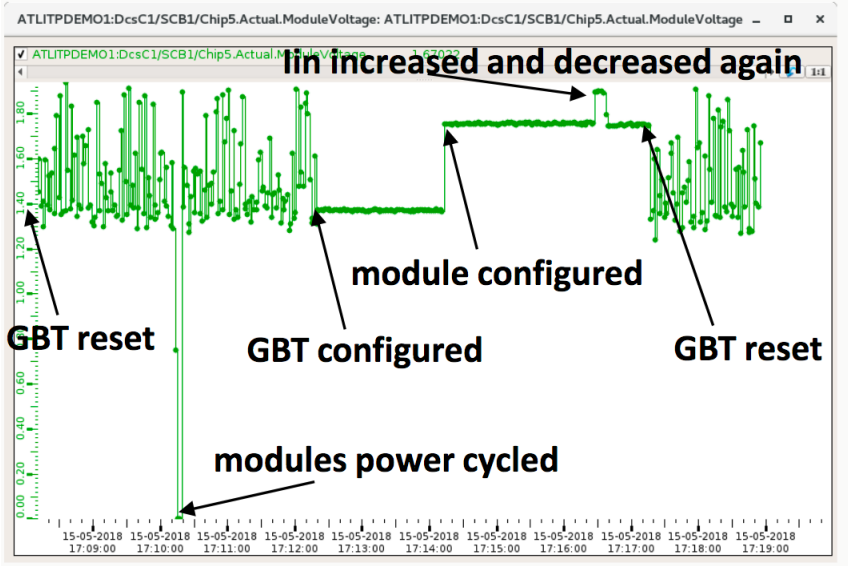
- SLDO-LDO regulators have three major current paths which can be overloaded





- GBT induced power fluctuations: to be checked with lpGBT

- Differences in power in module voltage after startup and first configuration (up to 600 mV)
  - Feature how resgisters are set at startup (hopefully only in FE-i4)



- Other features:
  - Cross-talk
  - No extra noise from SCB lines of PSPPs

Future prototyping of larger structures – System tests

1. **Testing with RD53A single chip and module assemblies**
   - Continue common tests (now)
   - Getting irradiated SCC modules from module group for loan to work on a chain with irradiated modules (coming weeks)

   Aim: features of RD53A quads and measurement of features from current tests (see slides of Dominik and Florian)

2. **Subsystem independent serial powering chain with RD53A quad modules** asap (target for results spring/summer 2019)
   - Working on serial chain with digital chain only started
   - As soon as first quads will arrive: system independent chain

   Aim:
   - Qualify full-length serial powering chain (16 modules) including HV serially applied and AC-coupling on readout side
   - Qualify bypass behaviour of PSPP
   - Data rate tests with 1.28 Gbit/s including type-0 services → design time required, not final since aggregator etc. not available for design and protocol different for final chip
   - Readout of multiple-modules with FELIX based readout

Future prototyping of larger structures – System tests

3. **For all subsystems: specific local support with RD53A quads** (target for results end 2019)
    - Inner: Ring-0
    - Endcap: Ring-1
    - Outer barrel: Inclined Ring and flat longeron

    Aim:

    Validate assembly, loading, SP-chain operation, PSPP bypassing, readout tests, data rate test with realistic services on local supports, grounding&shielding behaviour

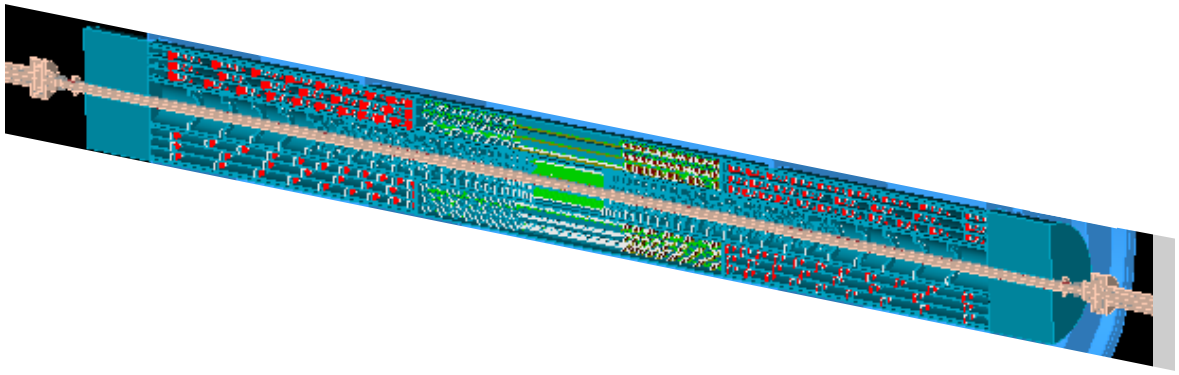
4. **System test setups including current sources**

→ **Launched production of RD53A quad modules** for preparation of modules assembly, loading, serial powering test, system test

- First modules to arrive in late spring 2019

Summary

- All three sub-systems in ATLAS ITk working on validation of serial powering
- Several lessons learnt and features found with FE-i4 based serial powering chains
    - Forward sensor bias, overloading of regulators, negative module voltage
- More to come with program of RD53A SCCs and quad modules



Thank you to Paul Dervan and Jon Taylor (Univ. Liverpool)
and Matthias Hamer and Florian Hinterkeuser (Univ. Bonn)

Thanky you!

Questions?

Spare

System testing

Tests:

- Readout for multi-modules Multi-module readout
  - Tuning of FE
  - Variation of HV
  - Module cross talk, modules close to each other etc…
  - Reduction of noise

- Powering + DCS
  - Serial powering tests on multi-modules
  - DCS bypass tests, test of DCS controller
  - Tuning of resistors

- Grounding and shielding
  - HV tests, point to point or one line with switches or one line and no switches
  - Variation of scheme (for barrel on adapter board at the end of services, before PP0)
  - Noise injection test
  - Understand protection of RF shield

- Cooling:
  - Run at different temperatures, preferably at operation temperature (difficult with any currently available cooling plants)
  - For non-electrical prototypes: variation of vapour quality, fluidic tests, dryout tests

- Source tests
  - Move source with motorized stages on each module
  - In case of running in testbeam/with cosmics: first attempt of tracking

System testing with 7-cell structure

Tests:

- Readout for multi-modules
  - **Multi-module readout**: possible with 7 quads for Pybar, RCE, FELIX, Yarr, comparison of results
    Tuning of FEi4: standard done, to minimum threshold
  - ✓ **Variation of HV:** two modules without HV, performed ramping tests, two lines per chain on 7-cell no problem seen, needs more tests on demonstrator with 16 modules
  - ✓ **Module cross talk**, modules close to each other etc…: tests with stave flexes with Pybar and scope. Cross-talk seen on data lines of type-0 services (stronger effect on VHDCI cables), inducing power fluctuations
  - ✓ **Reduction of noise**: optimization of grounding, cells to module not grounded and noise as low as in lab setup, noisy modules have no impact on other modules in SP chains, new tests with ITKpix-V1 required (also with RD53A)
  - ✓ **Impact of misconfigured GBT** on modules seen, further study triggered

- Powering + DCS
  - ✓ **Serial powering tests on multi-modules**: monitoring of currents, several features discovered which have impact on serial powering with full SP chain including PSPP chips on all positions
    - ✓ Impact from off-mode of HV power supplies seen for different operation modes (LV on/off, HV on/off, etc.) – result: modifications of power supplies required, needs fast ramping and fast voltage regulation
  - **DCS bypass tests, test of DCS controller**: DCS controller and PSPP running fine, two features in PSPP discovered, interlock fully functional, bypass tests need faster current source, one more test with Add-on box
  - ✓ **Tuning of resistors:** not with FE-i4
  - Test of transients of coupling capacitors with long chain for readout and DCS controller
  - ✓ **Noise injection test:** tests with noisy tuned modules performed, test of noise from SCB lines, analysis of double trigger noise tests ongoing

System testing with 7-cell structure

Tests:

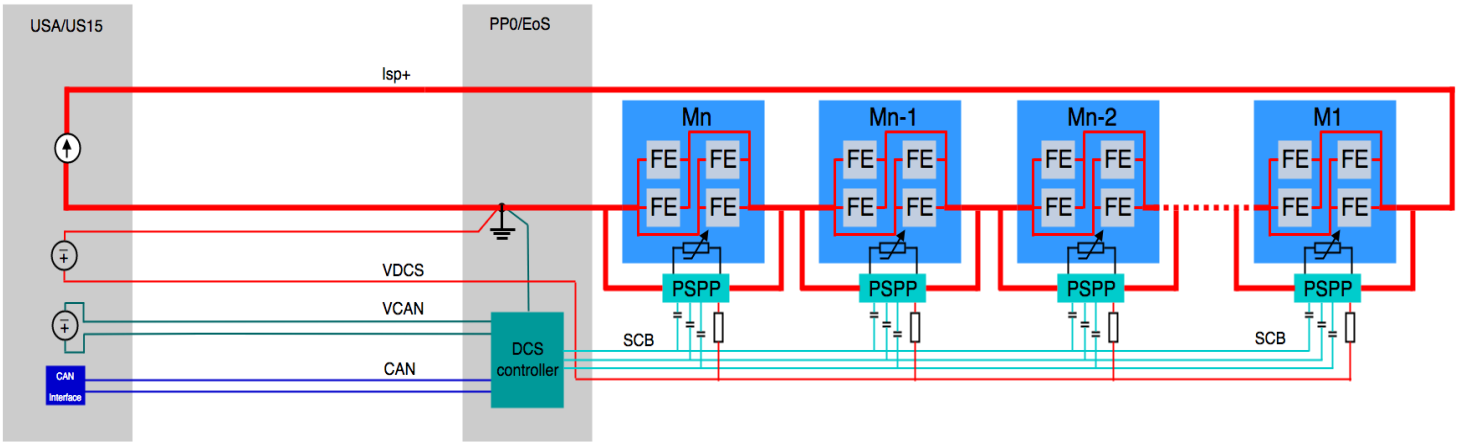
- **Grounding and shielding**
  - ✓ Understand protection of shielding, HV tests, variation of scheme: possible tests with 7-cell done (several HV lines per SP chain tested, further testing with more uniform modules required)

- **Cooling**:
  - ✓ Run at different temperatures, preferably at operation temperature: runs at 17C and -15C. Comparison of results ongoing
  - For non-electrical prototypes: variation of vapour quality, fluidic tests, dryout tests: ongoing

- **Source tests**
  - ✓ Source test for all modules performed: scans with different readout systems

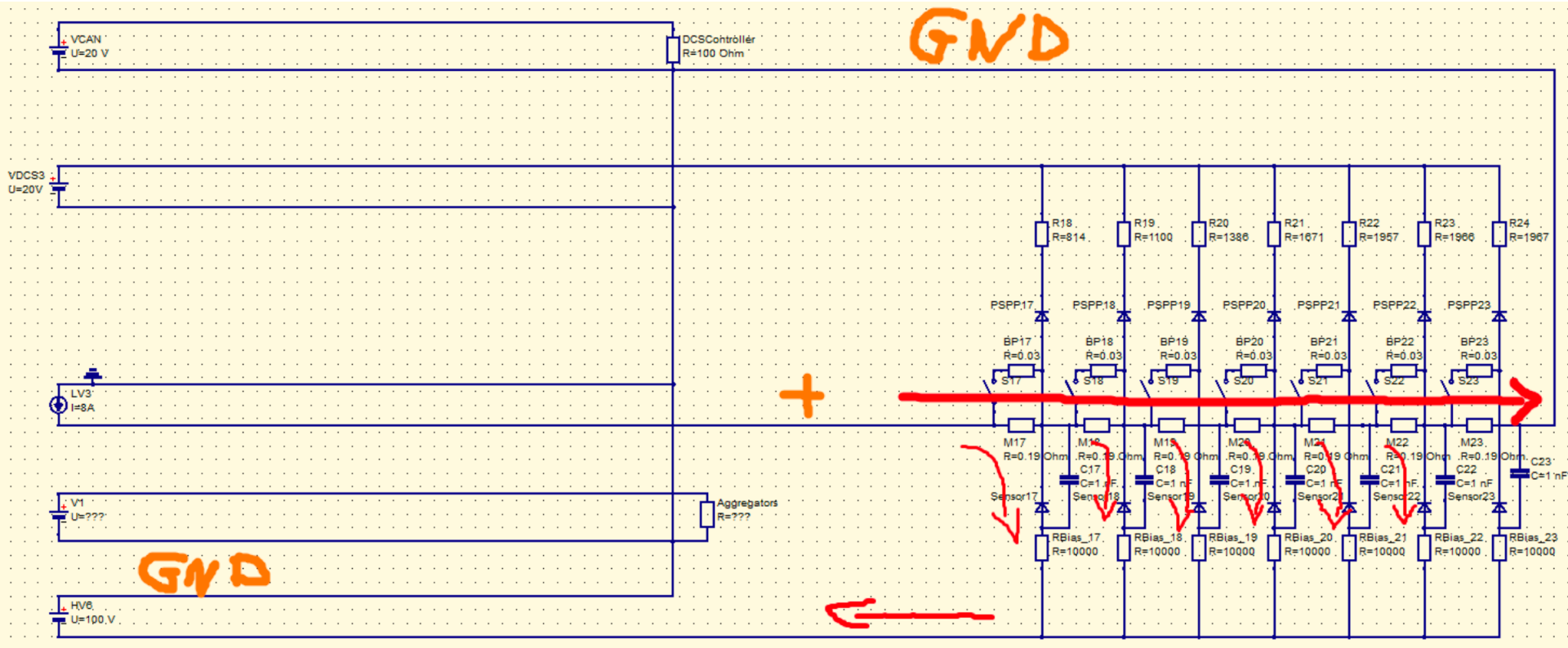
ITk Pixel PSPP and DCS

- Connection diagram of PSPP chip and DCS controller



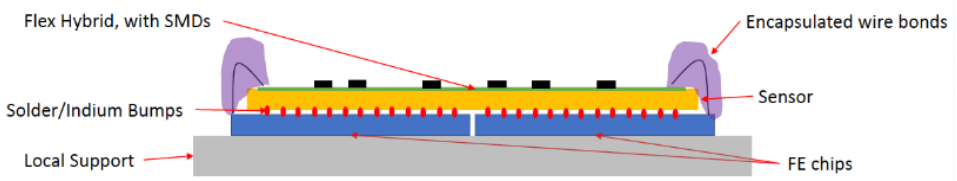
Serial powering features on 7-cell structure

In current layout shared LV/LV_DCS/HV return line:



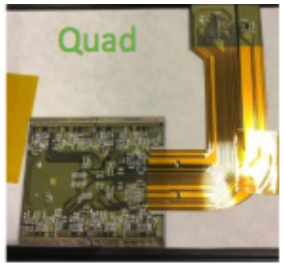
Modules

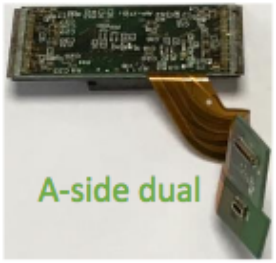
- **Many quad and dual modules produced based on FE-i4 FE for system test prototypes**
- Collecting currently lessons learnt from these productions

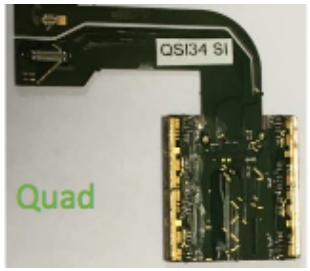


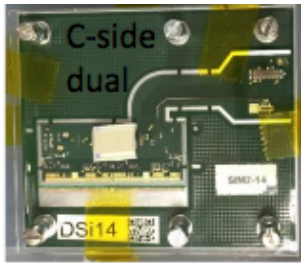
Endcap quad module

Outer barrel modules

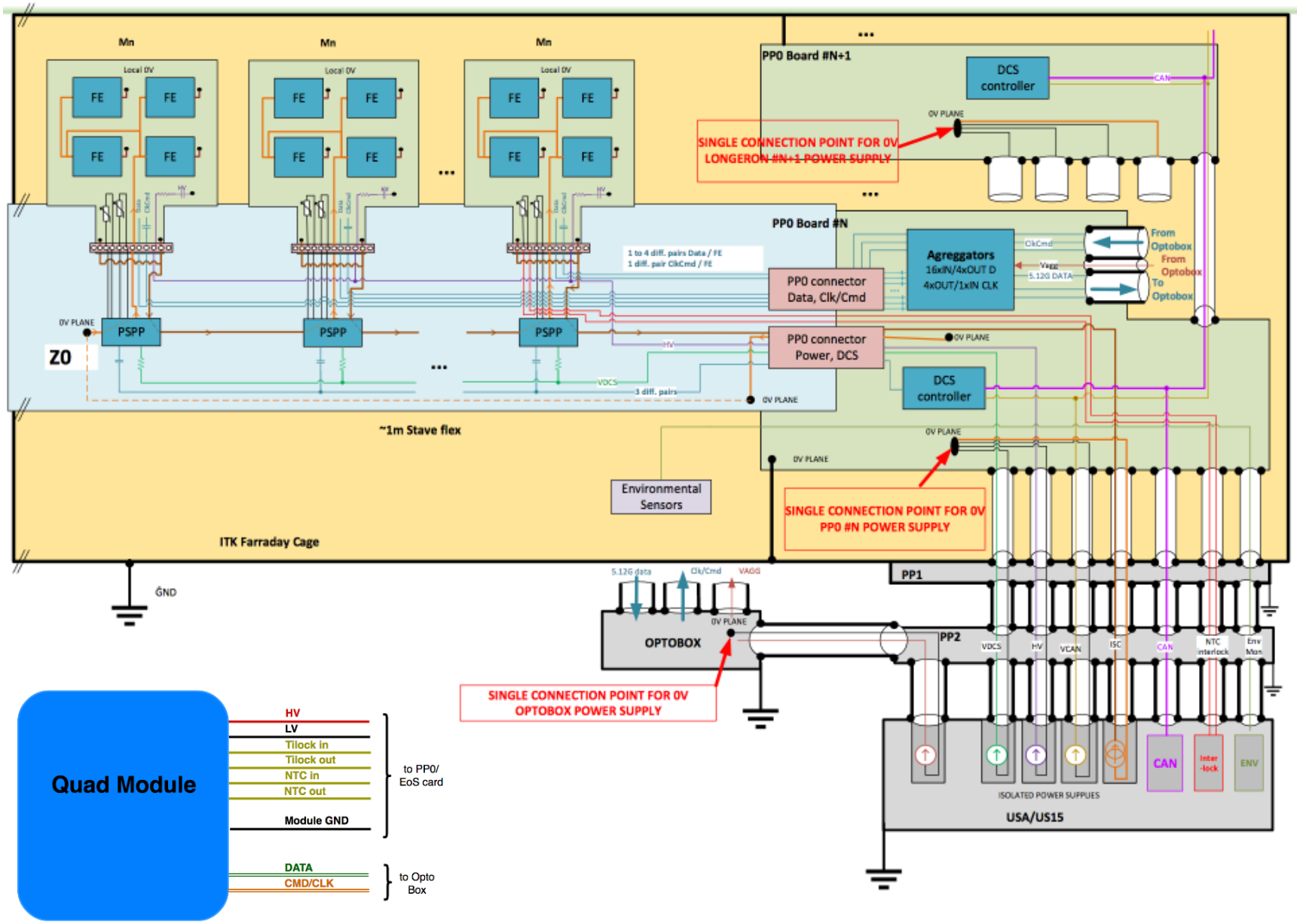








Services


Mn
Local 0V
FE
PSPP
Z0
PP0 Board #N+1
DCS controller
SINGLE CONNECTION POINT FOR 0V LONGERON #N+1 POWER SUPPLY
0V PLANE
PP0 Board #N
Agreggators 16xIN/4xOUT D 4xOUT/1xIN CLK
From Optobox
From Optobox
To Optobox
1 to 4 diff. pairs Data / FE
1 diff. pair ClkCmd / FE
PP0 connector Data, Clk/Cmd
PP0 connector Power, DCS
VDCS
3 diff. pairs
~1m Stave flex
Environmental Sensors
SINGLE CONNECTION POINT FOR 0V PP0 #N POWER SUPPLY
ITK Farraday Cage
GND
PP1
PP2
OPTOBOX
5.12G data
Clk/Cmd
VAGG
SINGLE CONNECTION POINT FOR 0V OPTOBOX POWER SUPPLY
VDCS
HV
VCAN
ISC
CAN
NTC interlock
Env Mon
ISOLATED POWER SUPPLIES
USA/US15
Quad Module
HV
LV
Tilock in
Tilock out
NTC in
NTC out
Module GND
to PP0/ EoS card
DATA
CMD/CLK
to Opto Box

Readout requirements for RD53A system tests

Requirements:

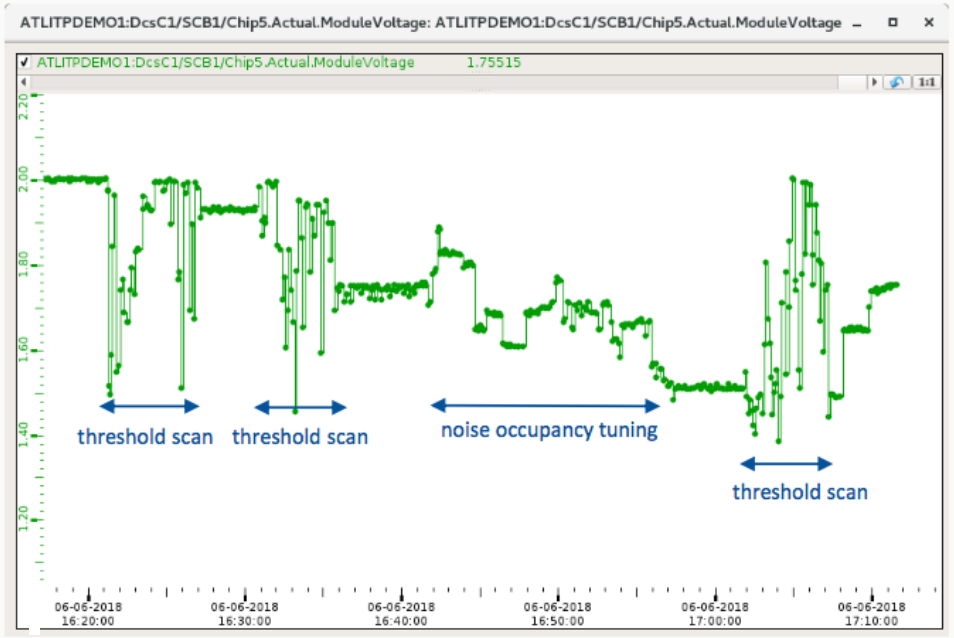
- Multi-module readout in parallel with reasonable duration of scans
- Hardware, firmware and software
- Common adapter to match to different subsystems loaded local supports and in case of development of different readout systems.
- Readout is subsystem independent
- Scans as described before (source scans with additional hitor lines in services or external trigger)
- Systems for at least four different sites/institutes plus single quad module readout for many institutes

N.B. Module performance needs to be determined before in lab setups → readout for quad modules at many institutes required (ahead in time)

Features of the system

X-talk Feature

- BM5 disconnected from clk and cmd by disconnecting the Ethernet cables on the RJ45 to VHDCI Adapter
- running threshold (high activity) and noise occupancy (low activity) tests on the other 6 modules
- observing voltage oscillations on BM5
  - more severe during high activity tests
- we suspect that this is x-talk on the data services
  - we know that the VHDCI cables are not ideal in terms of x-talk
  - with this measurement, can't exclude the VHDCI cable as main source



compare to effect of GBT reset:

-> sending rubbish to FE on CLK/CMD can cause these oscillations