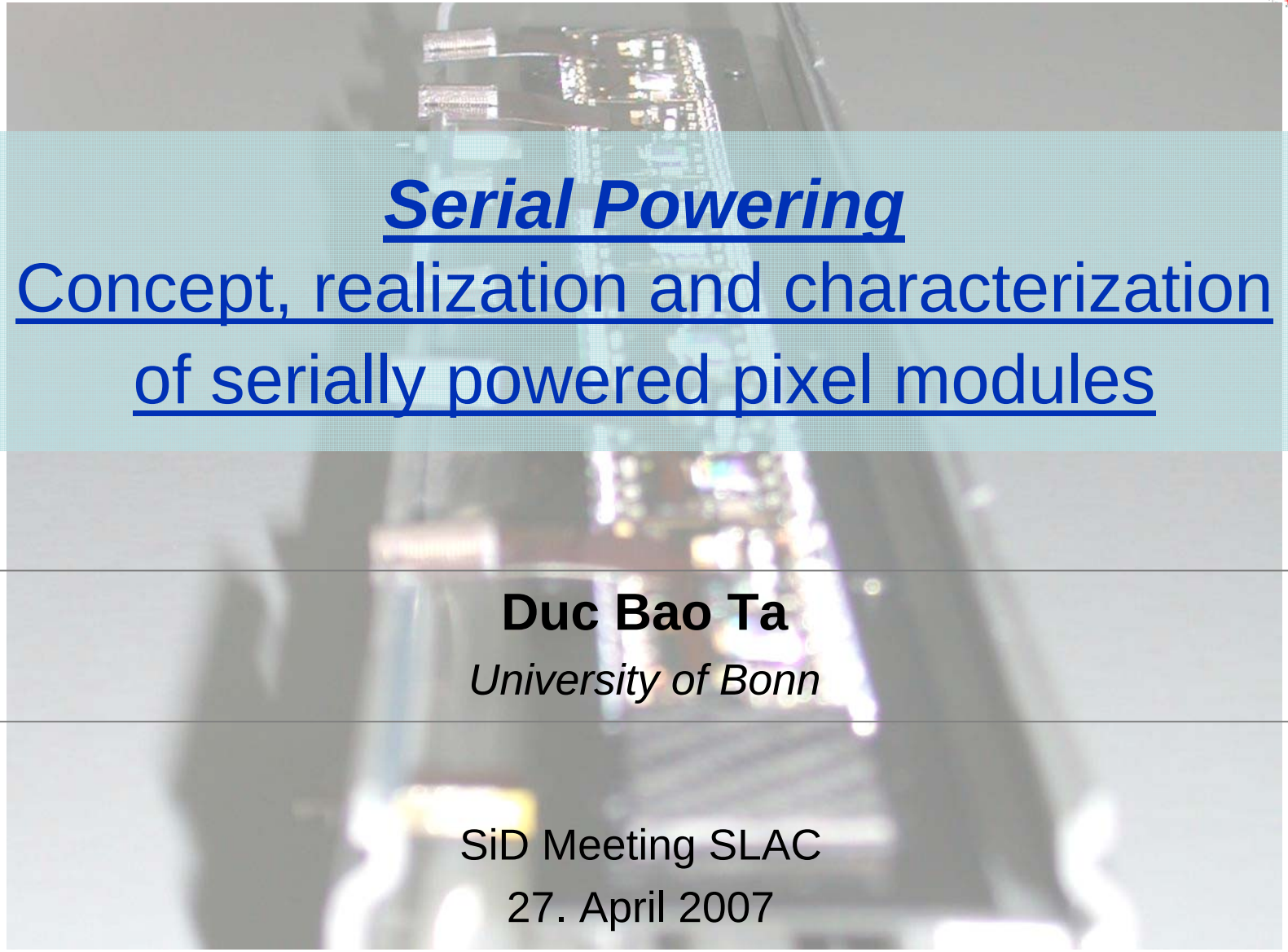


Serial Powering

Concept, realization and characterization of serially powered pixel modules

Duc Bao Ta

University of Bonn

SiD Meeting SLAC

27. April 2007

Overview

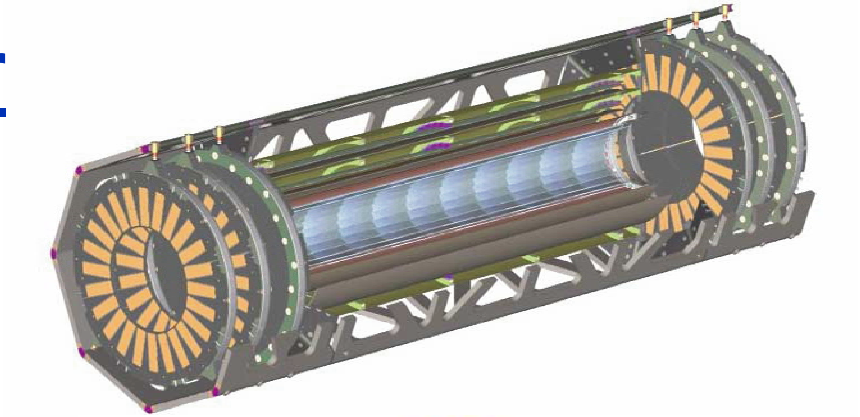
- Motivation for and Concept of *Serial Powering* (example: ATLAS Pixel Detector)

- Implementation on ATLAS Pixel FE-I3 Modules:
  - Regulator Measurements
  - Design and Test of a *Serial Powering* Module
  - Operation of a Chain of *Serial Powering* Modules (half-stave)
  - Noise Pickup Measurements

- Summary and Outlook

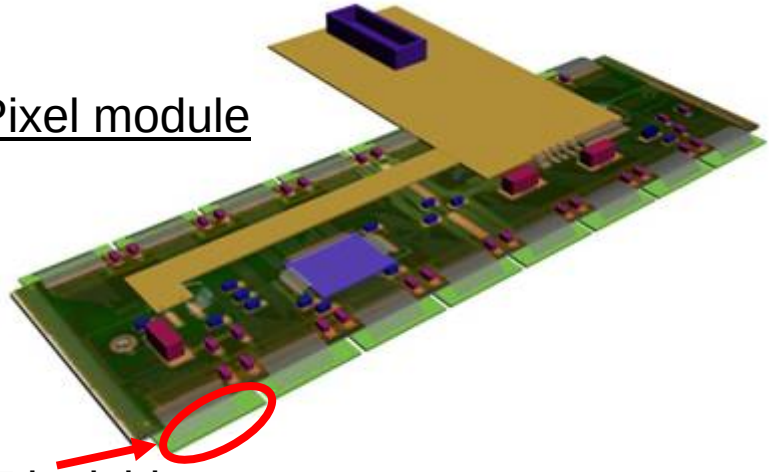
ATLAS Pixel Detector

- High granularity:
  - 80Mio. output channels
  - 1744 modules

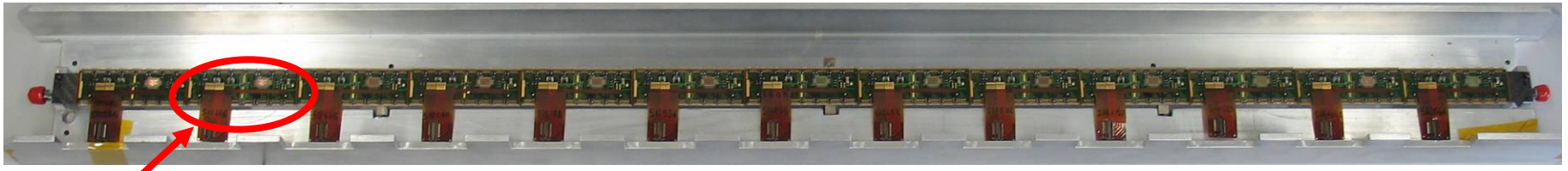


- High power density at low voltages:
  - analog: 1.6V/1.3A
  - digital: 2.0V/1.0A

Pixel module

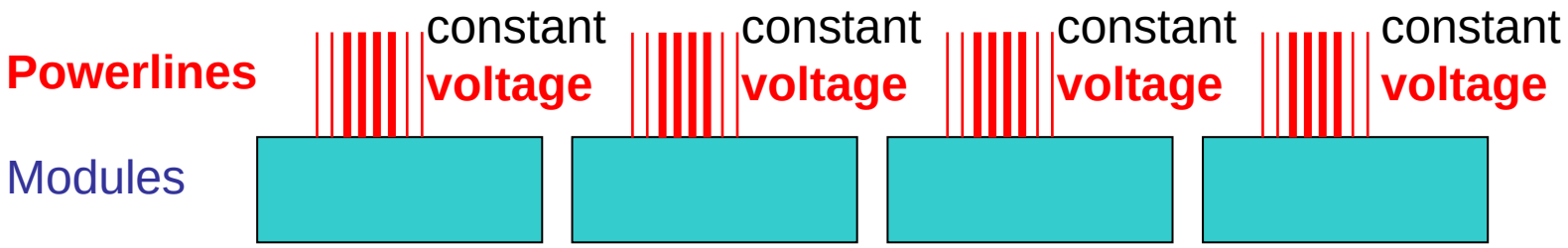


16 Pixelchips

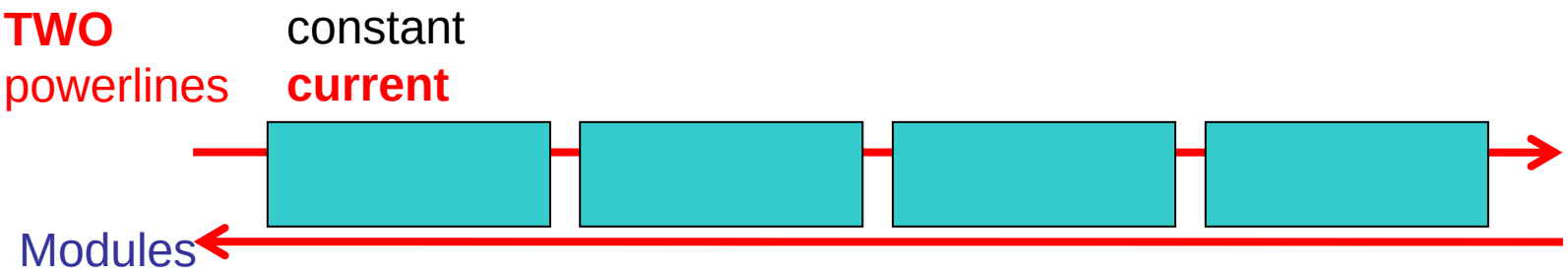


13 Modules

- Currently used in the pixel detector, **Parallel Powering:**

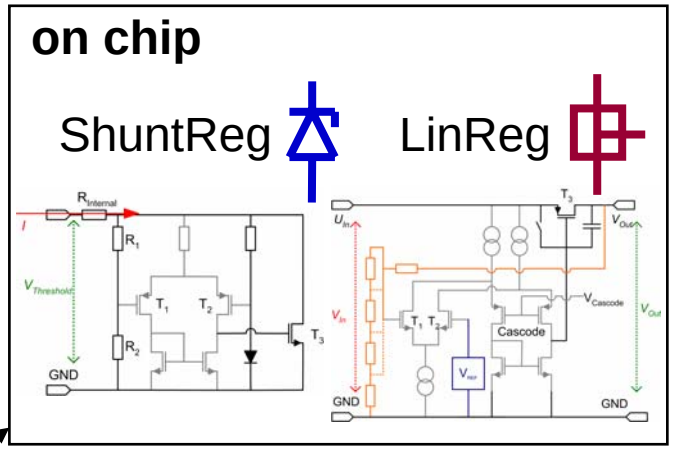


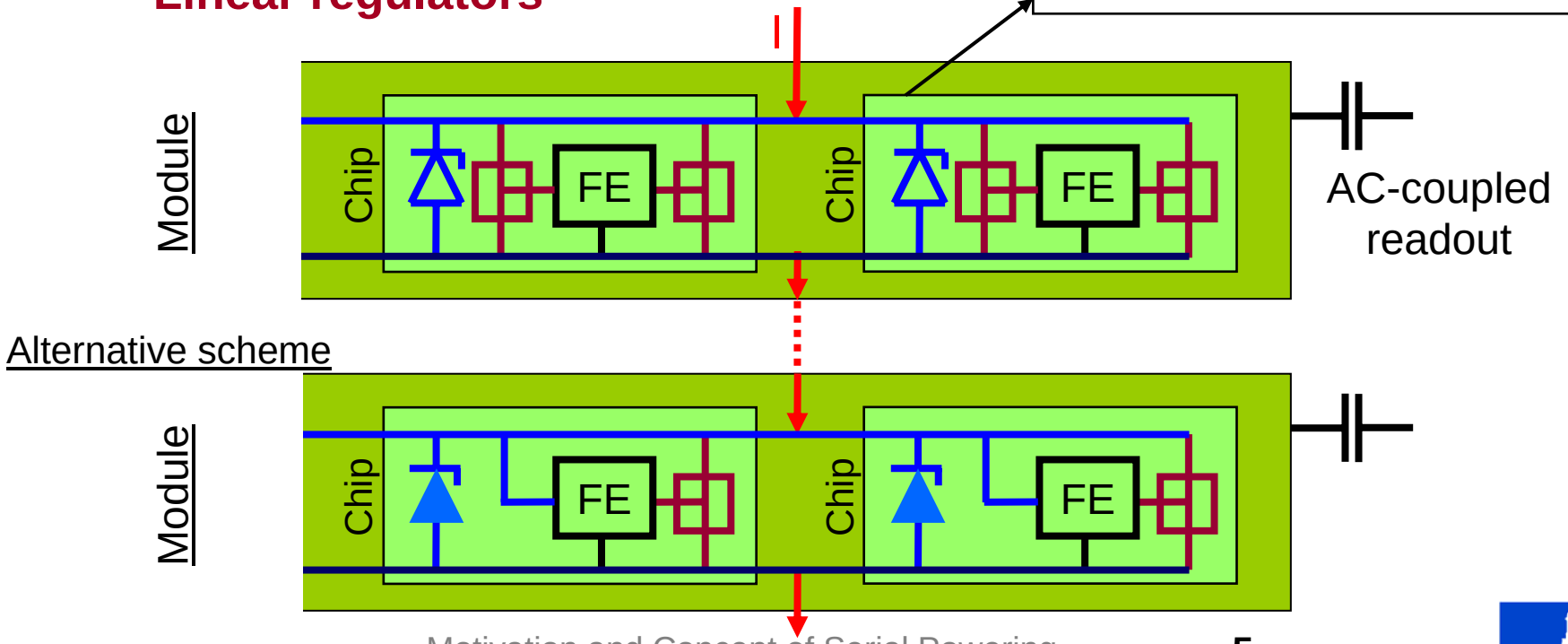
- Idea of ***Serial Powering***:



Basic Principle

- Constant current through all modules
- Voltages generated **on chip** by
  - **Shunt regulators**
  - **Linear regulators**





Advantages of *Serial Powering*

- Less cables therefore less material in detector
  - power cable length per stave: PP 121m, *SP* 2.8m (2.3% of PP)
  - Radiation length: PP 0.073%, SP 0.011% (15% of PP)

- Less power losses in cables
  - Voltage drop: 6.4V
  - power losses per stave: PP max.192W, *SP* max.19.2W (10% of PP)

- No external, distant regulation of voltages necessary

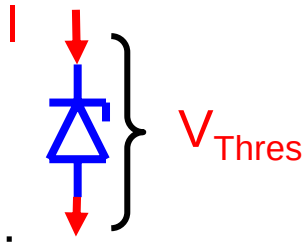
Concerns…

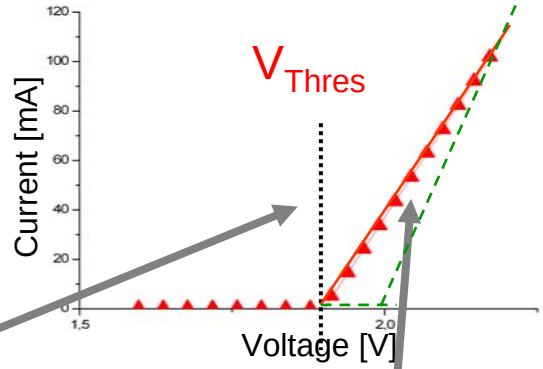
Possible disadvantages	yes,…but
• Higher power consumption of modules due to higher current (nom. increase of power consumption 35%)	• Less heat from cables counterbalance the increase of module heat (max. increase of total heat 17%) • Also: less heat pickup by other systems from cable power losses
• Fear of loss of a whole stave/chain due to one defect regulator	• Parallel use of 16 shunt regulators on a module
• **Noise pickup through power lines**	• This will be addressed later in this talk

Shunt Regulators I3

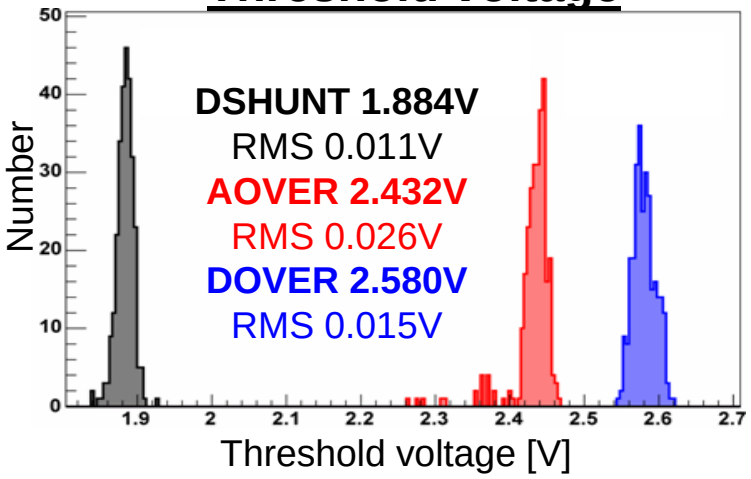
Designed by Laurant Blanquart

- Important properties:
  - Threshold voltage
  - Resistance
- 3 shunt regulators on chip:
  - DShunt (2.0V), AOver (2.4V) and DOver (2.7V)

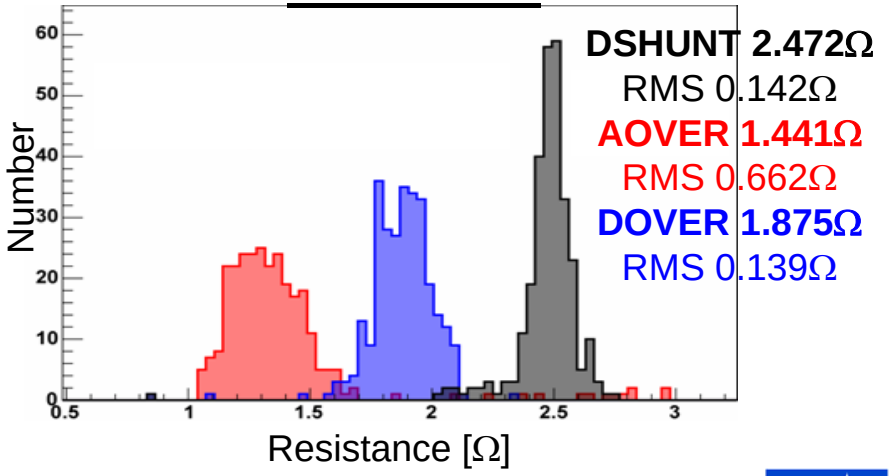




Threshold voltage



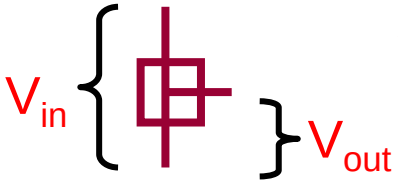
Resistance

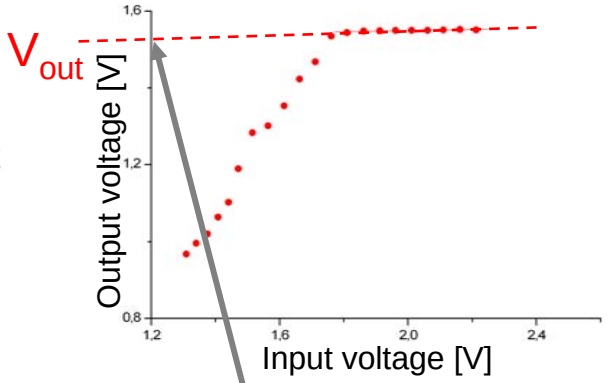


Linear Regulators I3

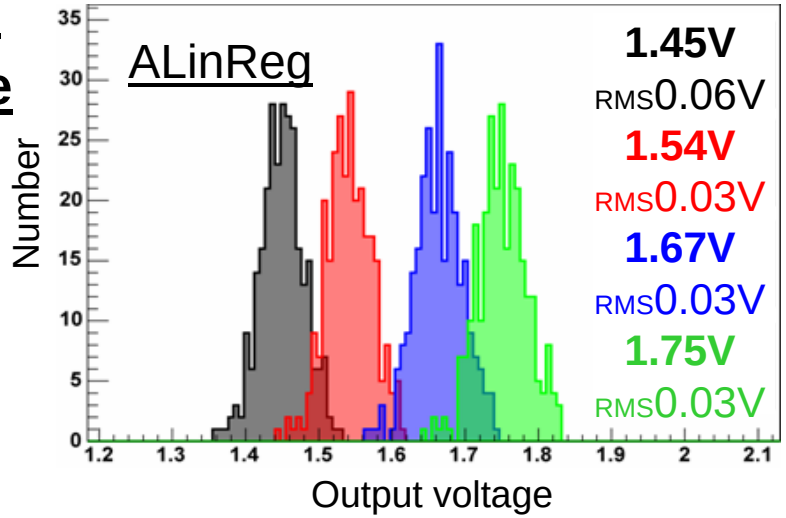
Designed by Laurant Blanquart

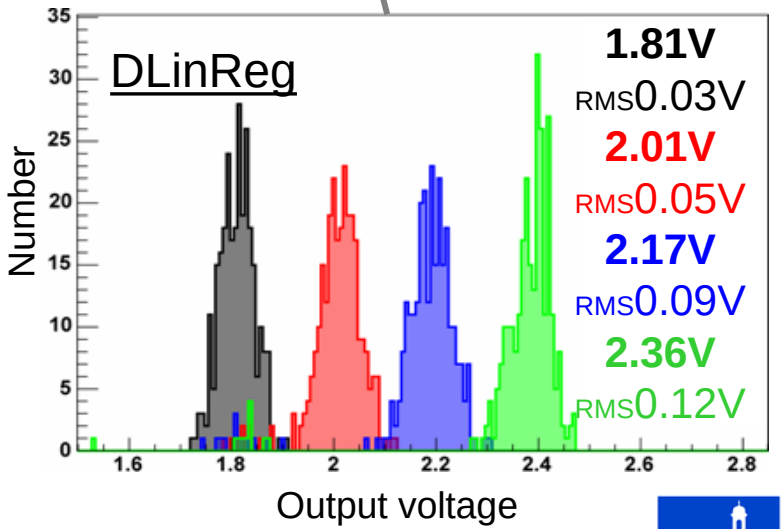
- Important properties:
  - Output voltage
  - Voltage drop ($V_{in} - V_{out}$)
  - Stability vs input voltage or vs load
- 2 linear regulators on chip:
  - ALinReg (1.5V-1.8V) and DLinReg (1.8V-2.4V), both in 4 steps



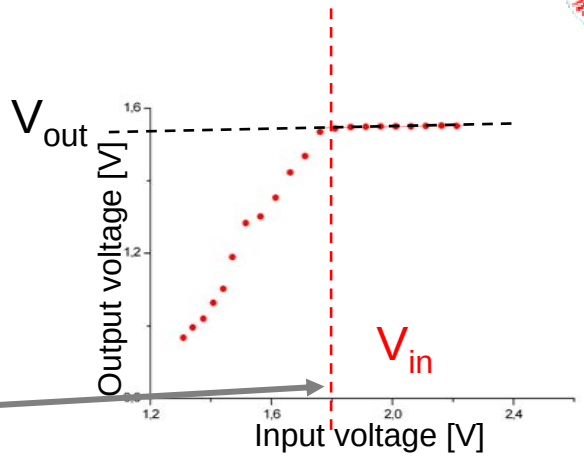


Output voltage of 277 chips:



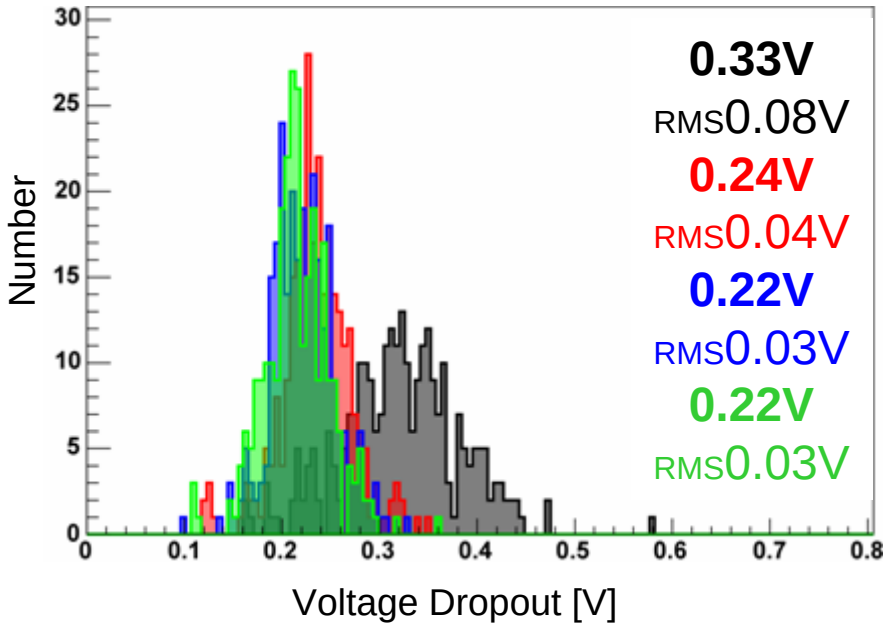


Linear Regulators I3 (cont.)

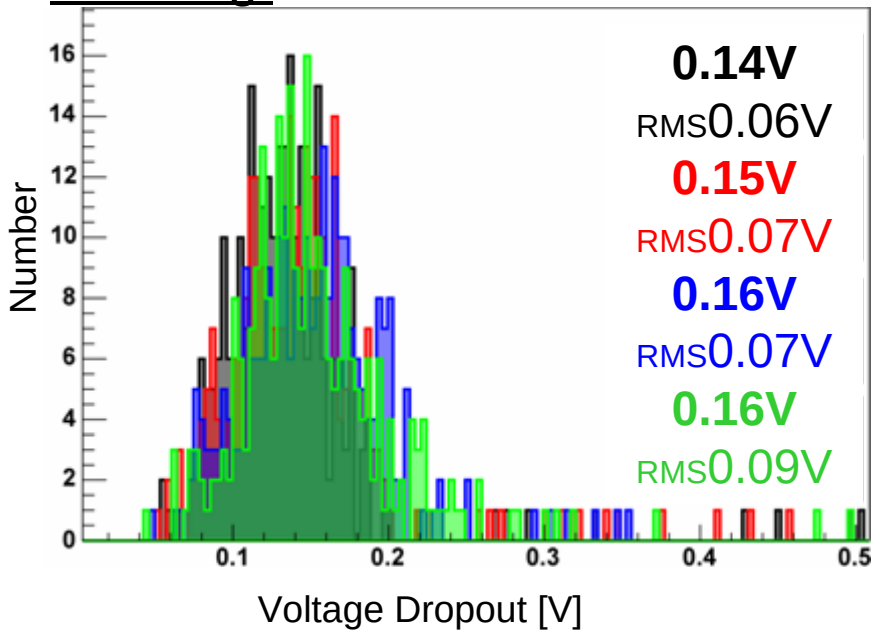


Voltage drop ($V_{in} - V_{out}$)

ALinReg:

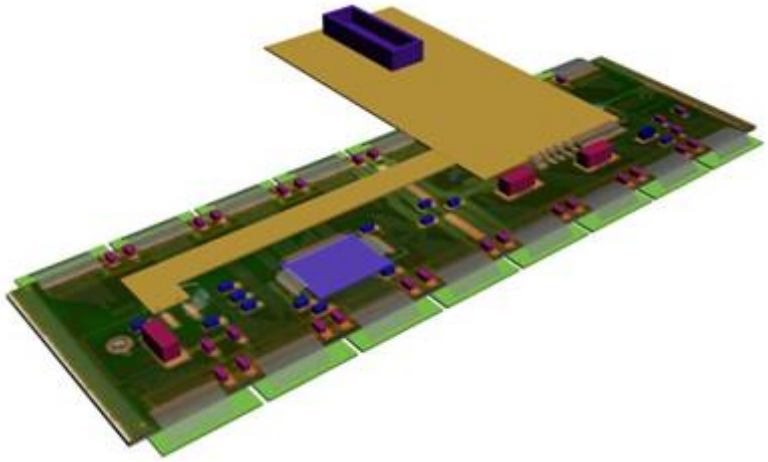


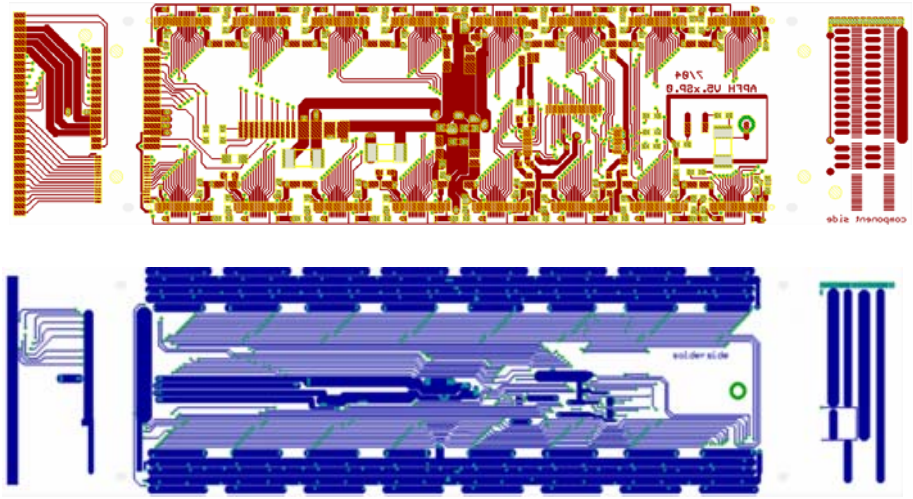
DLinReg:



Single *Serial Powering* module

- Using already available production chips and dummy/damaged module
- Change bonding scheme / Dedicated flex hybrid

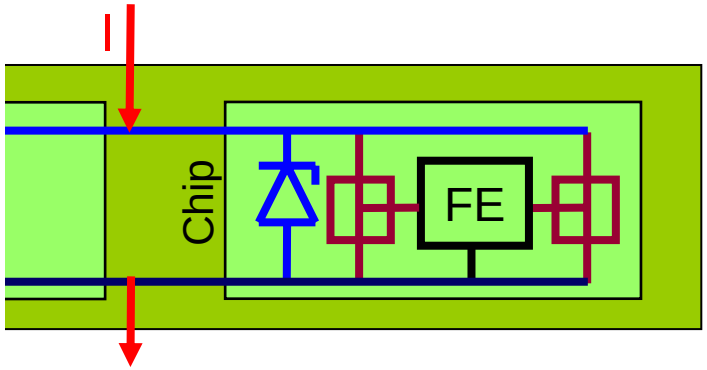




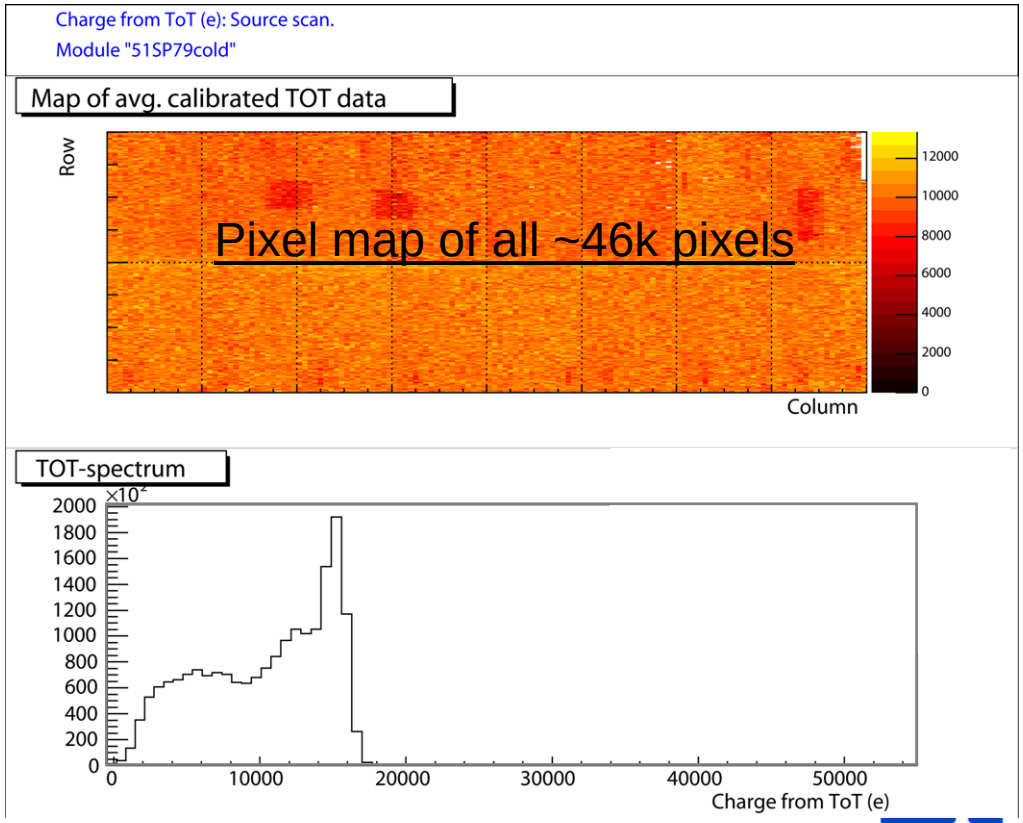
Performance of Single I3 modules

- **Single Serial Powering Module performance as good as Parallel Powering Modules (esp. noise)?**

- Reminder of SP scheme:



- Source scan with ^{241}Am as a qualitative proof



Performance of Single I3 modules (cont.)

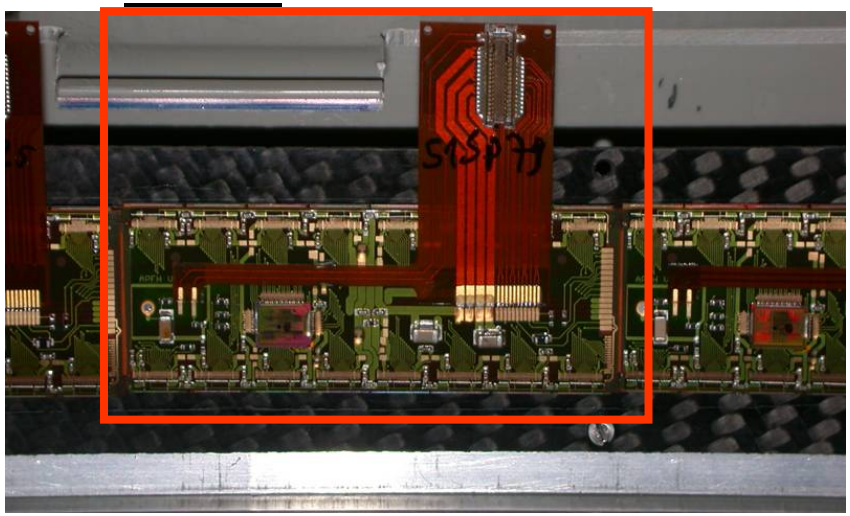
	Serial Powering	Parallel Powering (510471)
Threshold	**4226e$^-$**	4169e$^-$
Dispersion	**90e$^-$**	64e$^-$
Noise	**186e$^-$**	183e$^-$
Autotuning	**4171e$^-$**	
Dispersion	**70e$^-$**	
Noise	**186e$^-$**	
In-Time-Threshold	**5624e$^-$**	5532e$^-$
Overdrive (Timewalk)	**1451e$^-$**	1344e$^-$
Crosstalk	**0.93% (n)**	<1%
ToT@20ke$^-$	**30.2ns**	28.6ns

Fully working, no difference to PP-Modules

Serial Powering Dummy I3 Half-Stave

- 6 Modules (4 with dedicated *Serial Powering* Flex)
  - Dummy stave structure with cooling pipe
  - Approx. 0.3Mpixels

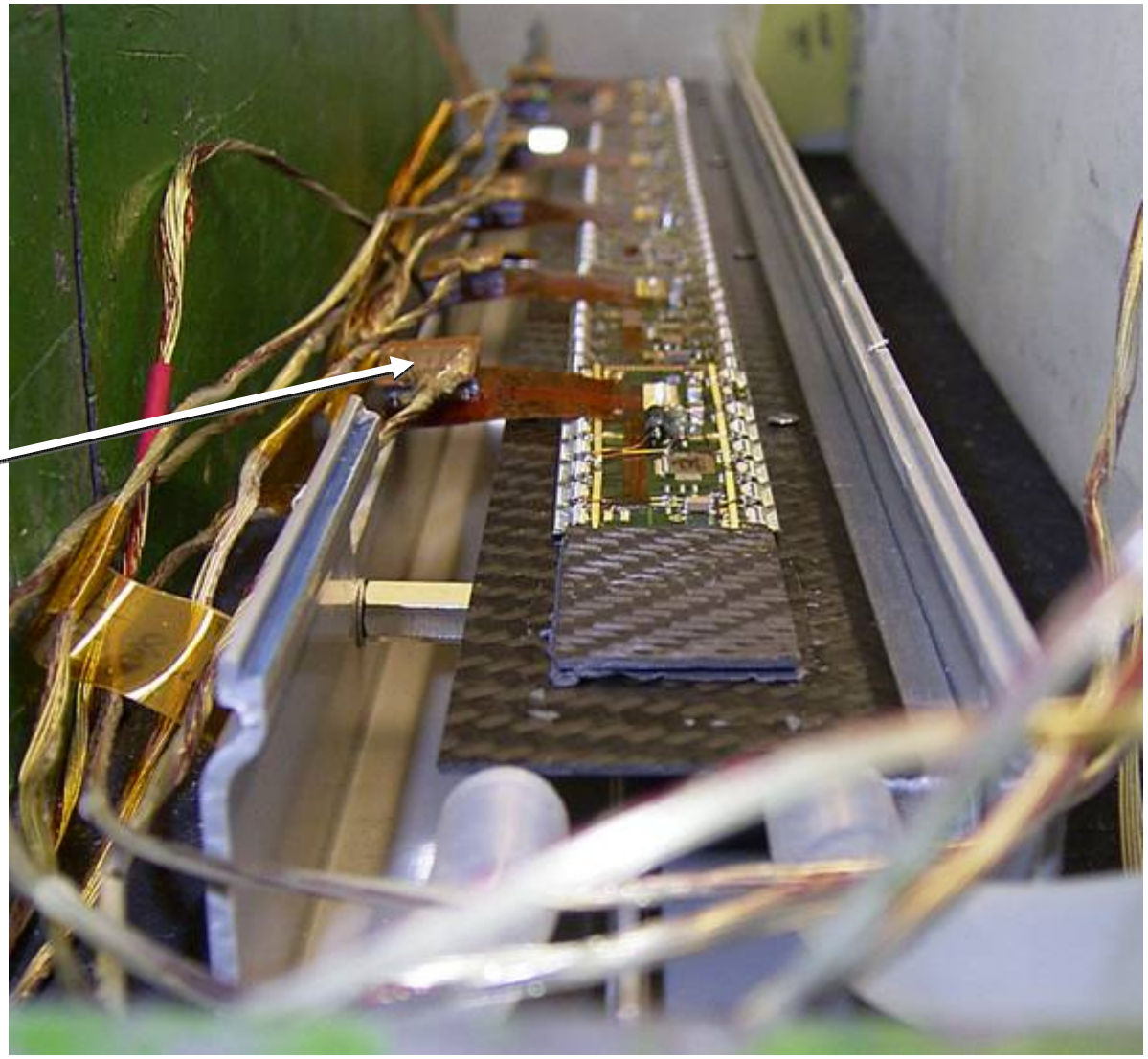
Module



Half stave

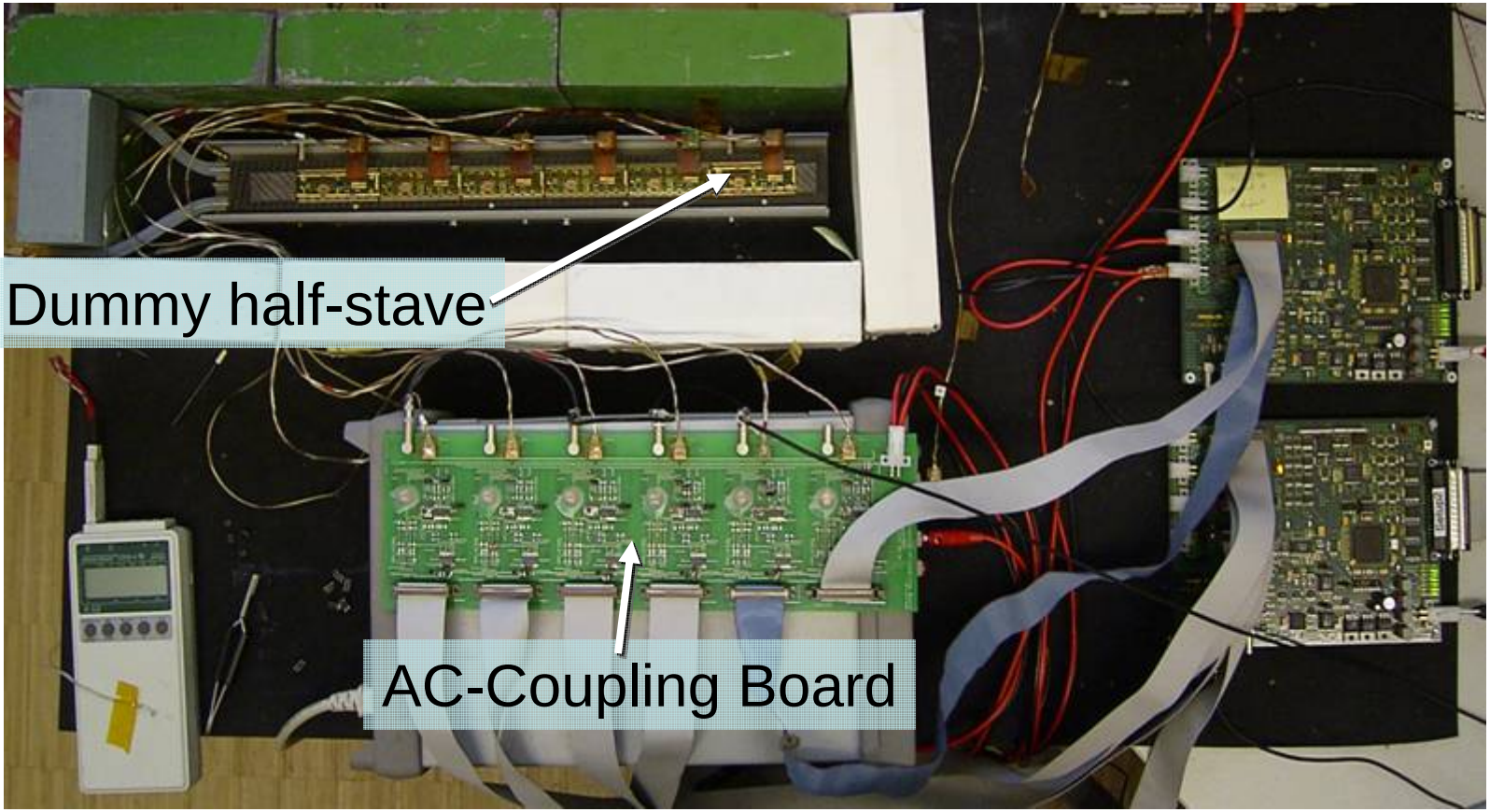
Serial Powering Dummy I3 Half-Stave (cont.)

PP cables,
serial routing done by
AC-Coupling Board



Serial Powering Dummy I3 Half-Stave (cont.)

- AC-Board & 2 read out systems fully working

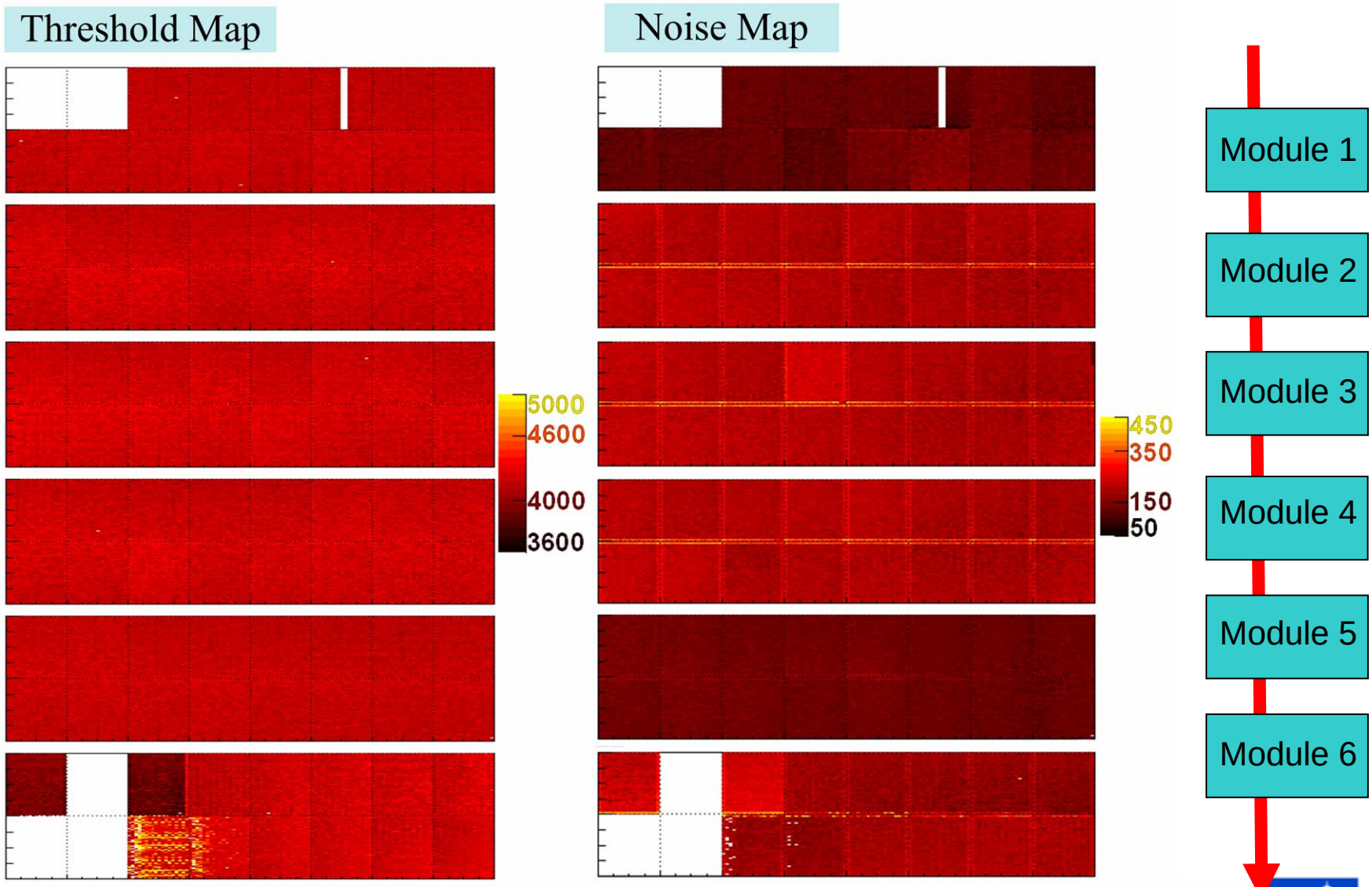


Noise Measurements on Dummy Half-Stave

- **Full half-stave operation, as good as single module operation?**

- XCK and STROBE to all six modules at the same time
- Threshold scan performed on all modules,
  read-out of two modules at the same time

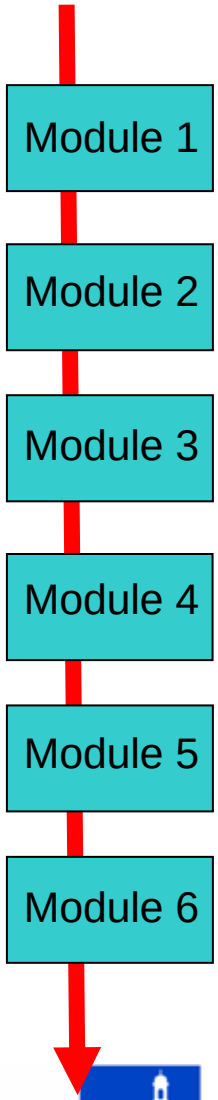
Noise Measurements on Dummy Half-Stave (cont.)



Noise Measurements on Dummy Half-Stave (cont.)

Threshold [e^-] (Dispersion [e^-])	Noise [e^-] (Δ to single SP powered [e^-])
4134 (57)	127 (4.4)*
4156 (69)	182 (-0.6)
4173 (70)	186 (-0.3)
4162 (70)	184 (-4.4)
4132 (58)	133 (0.0)*
4160 (91)	172 (-5.3)

*no sensor



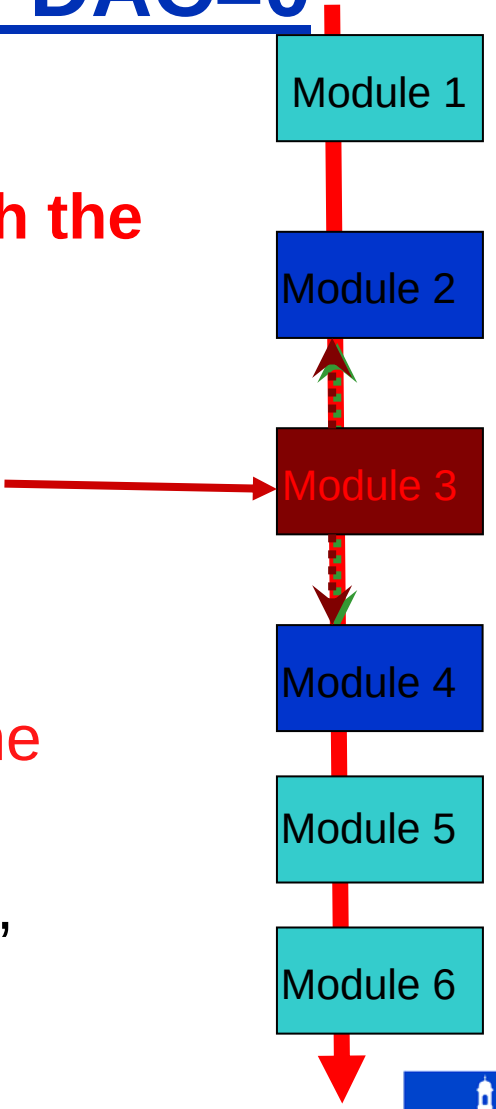
- **No difference to single-module operation and to Parallel Powered modules**

Noise Pickup Global Threshold DAC=0

- **Big concern:**
  Do other modules pickup noise through the power lines?

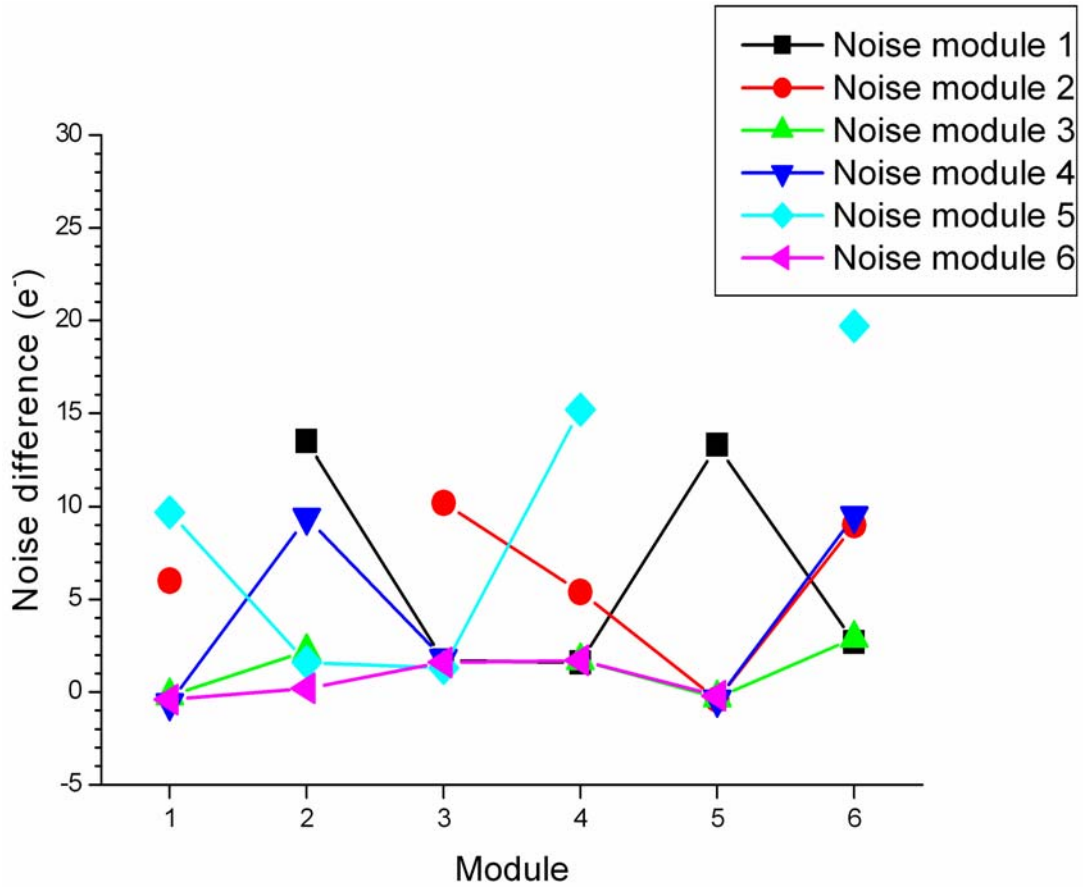
- Noisy module achieved by setting **Global Threshold DAC=0**

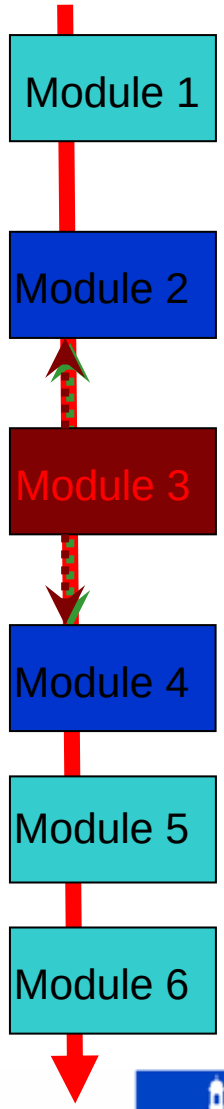
- XCK and STROBE to all six modules at the same time
- Threshold scan performed on all modules, read-out of two modules at the same time



Noise Pickup Global Threshold DAC=0 (cont.)

- Noise difference [e-] to normal half-stave operation





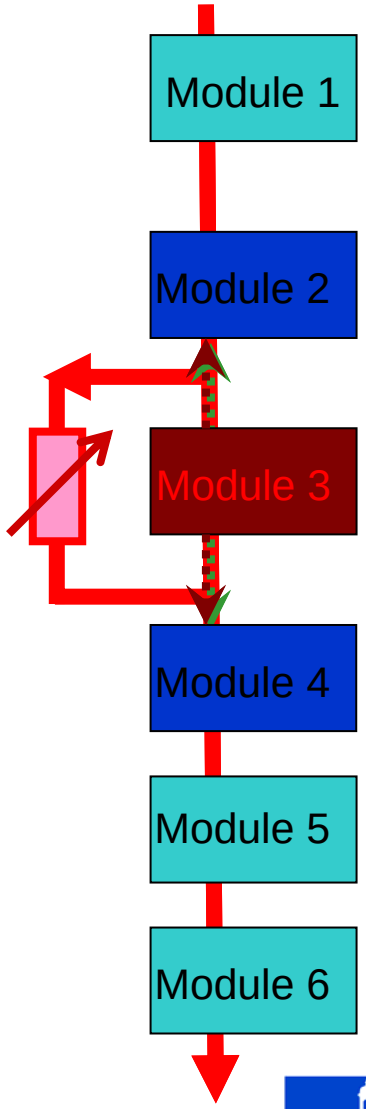
- **Little noise pickup**

Noise Pickup Measurements
Frequency Dependence

- **Again:**
  Do other modules pickup noise through the power lines?

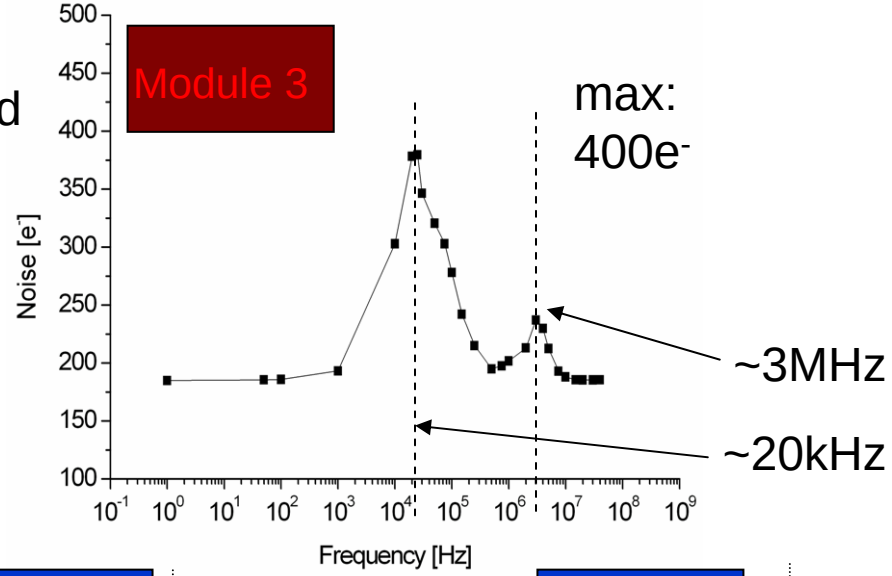
- Noisy module achieved by a **parallel, switchable load** between 300mA and 500mA, frequencies up to 40MHz

- XCK and STROBE to all six modules at the same time
- Threshold scan performed on four modules, read-out of two modules at the same time

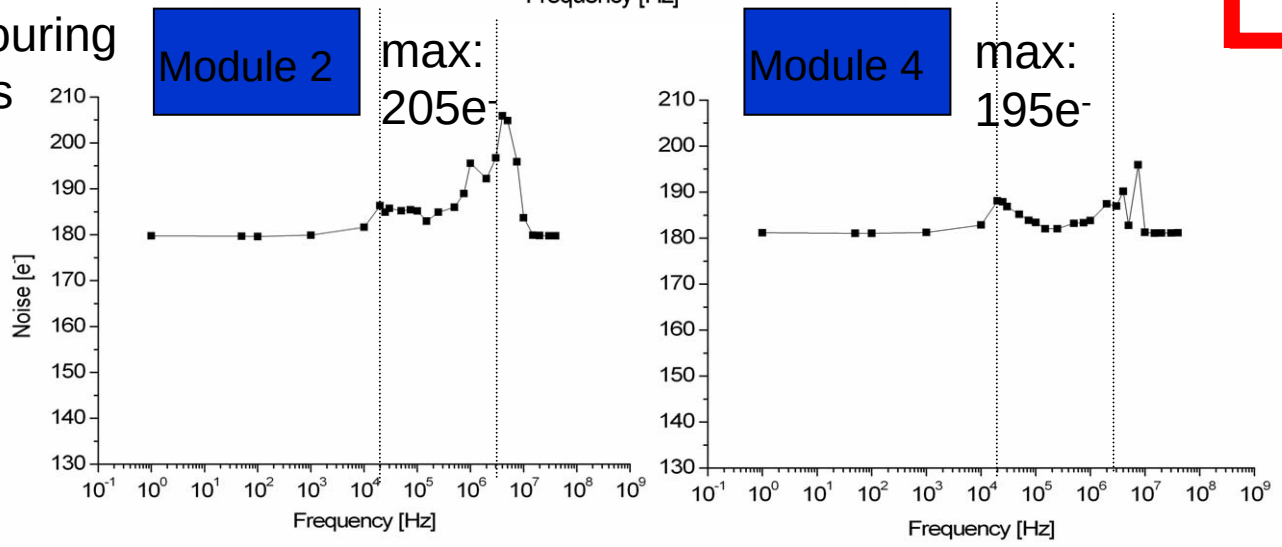


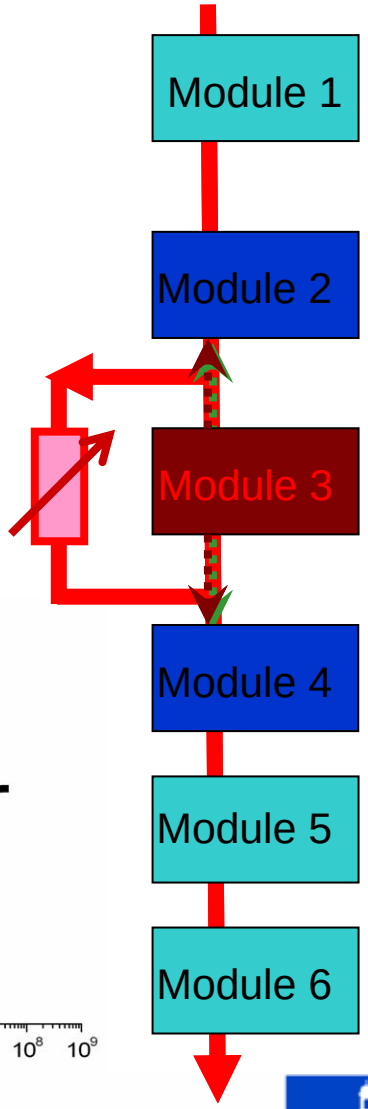
Noise Pickup Measurements
Frequency Dependence (cont.)

Module parallel
to switchable load



Neighbouring
modules





Summary

- The implementation with present I3-modules has shown:
  - Serial Powering module/s performance comparable to Parallel Powering modules
  - Filtering of a chain of modules sufficient, hardly noise pickup from noisy modules

- Serial Powering is a viable and reliable alternative power scheme
  - for the ATLAS pixel detector (upgrade)
  - for pixel detectors, tracking detectors in general

Outlook

- AC-coupled readout → Decoupling via optical readout
- System test with full stave (13 modules)
- Full system design (cables, readout, power supplies)

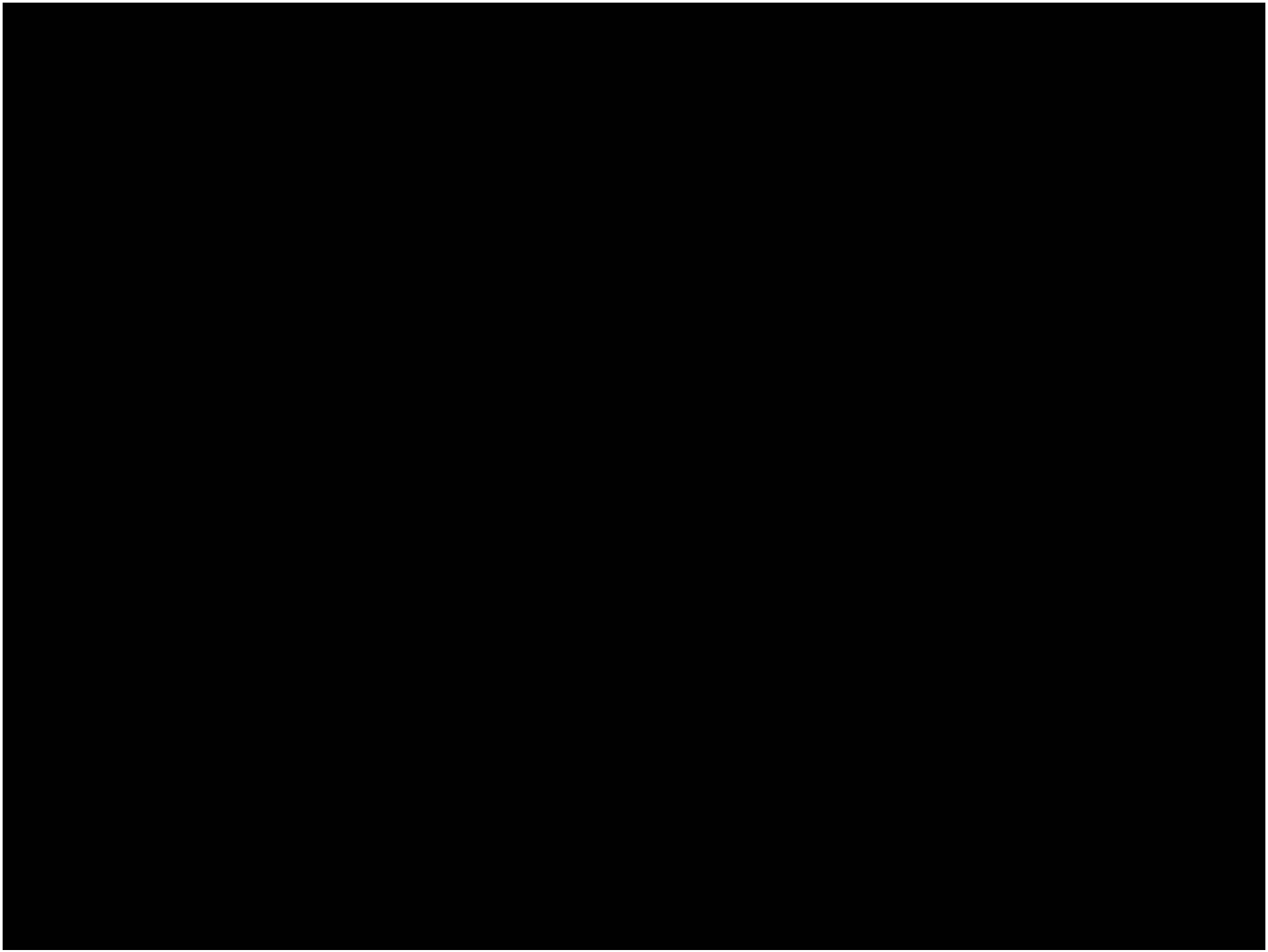
- Temperature dependence, irradiated regulators on chips/modules
- Regulator for Module Control Chip

- New FE-design 130nm (90nm) technology, specially dedicated and optimized to SP

References

- **D.B. Ta et al.** *Serial Powering: Proof of Principle demonstration of a scheme for the operation of a large pixel detector at the LHC*, Nucl. Instr. & Meth. A557 (2006) 445–459.
- **T. Stockmanns et al.** *Serial powering of pixel modules.* Nucl. Instr. & Meth. A511 (2003) 174–179.

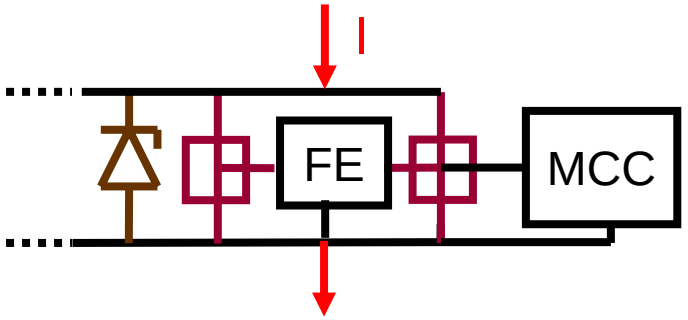
- **T. Stockmanns** *Multi chip module development for the ATLAS pixel detector.* PhD thesis BONN-IR-2004-12 (2004) (in German).
- **D.B. Ta** *Development and demonstration of Serial Powering on ATLAS pixel modules and module ladders (fuctionality and reliability tests)* diploma thesis BONN-IB-2005-04 (2005) (in German)



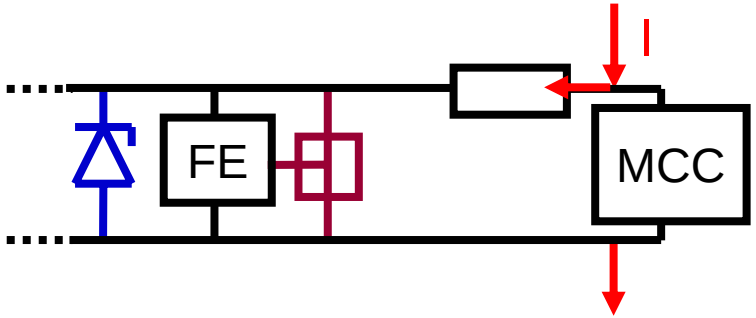
Backup slides

Alternative *Serial Powering Schemes*

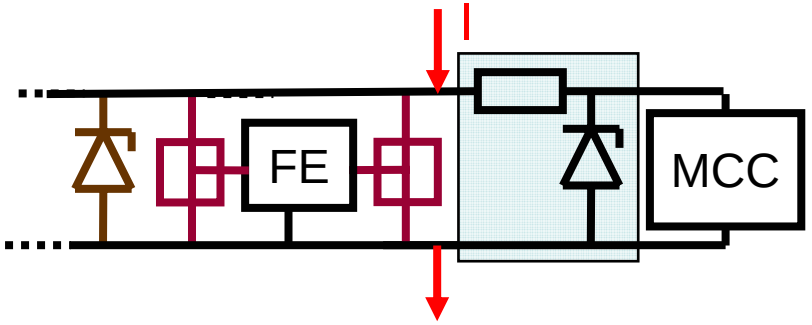
- Extended Scheme
  - Uses: DOVER 2,7V, ALINREG 1,6V and DLINREG 2,0V for FE+MCC



- Basic Scheme
  - Uses: DSHUNT 2,0V and ALINREG 1,6V, MCC ~2,0V



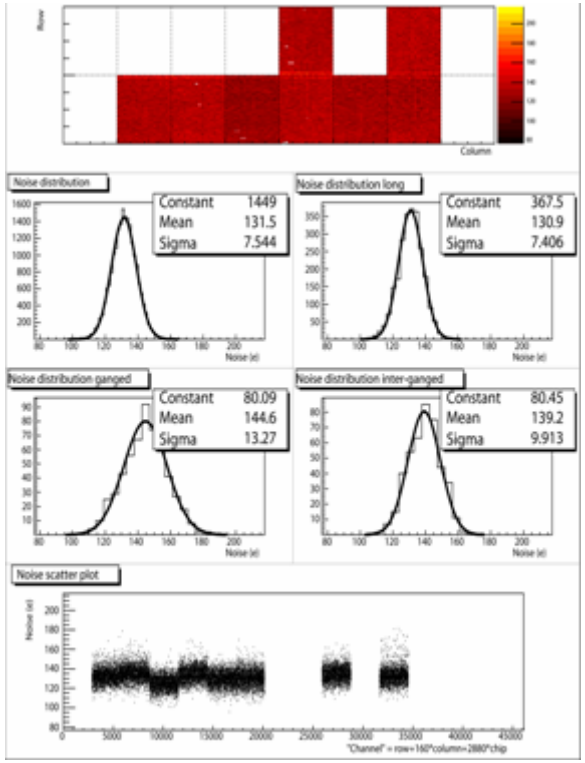
- MCC Extended Scheme
  - Separate Regulator for MCC

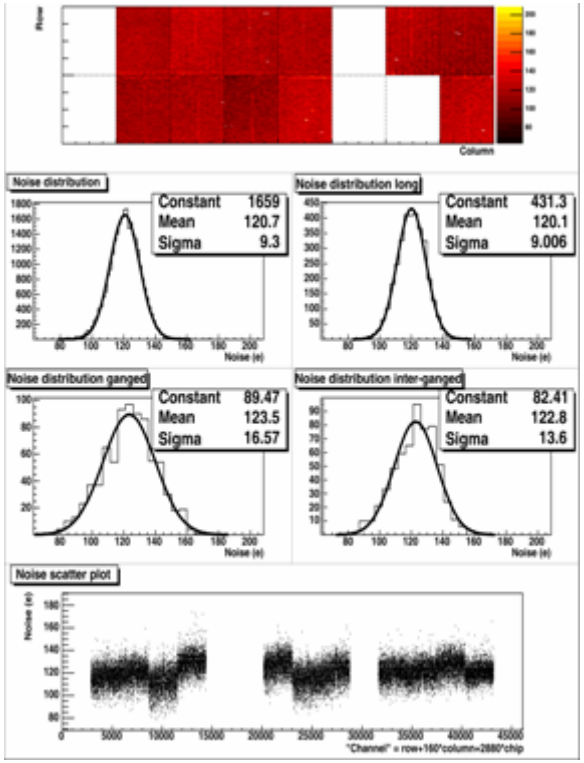


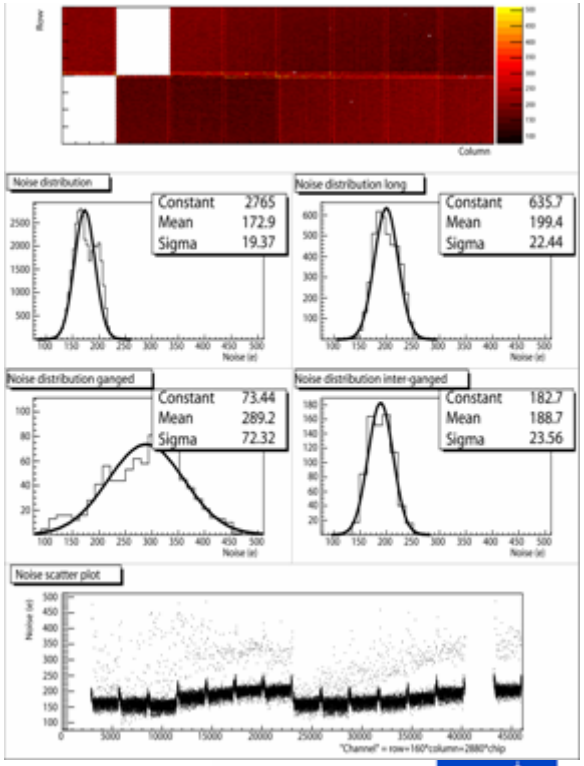
Comparison of Serial Powering Schemes (cont.)

- Three **I3** Modules with different schemes
  - Noise map:

Basic (no sensor)	**Improved** (no sensor)	**separate MCC-Regulator**







Comparison of Serial Powering Schemes (cont.)

	Basic (no sensor)	**Extended** (no sensor)	**MCC Extended**	**Parallel Powered Module** (510970)
Threshold [e$^-$]	4143	4132	4194	4189
Dispersion [e$^-$]	52	51	73	75
Noise [e$^-$]	134	121	179	196

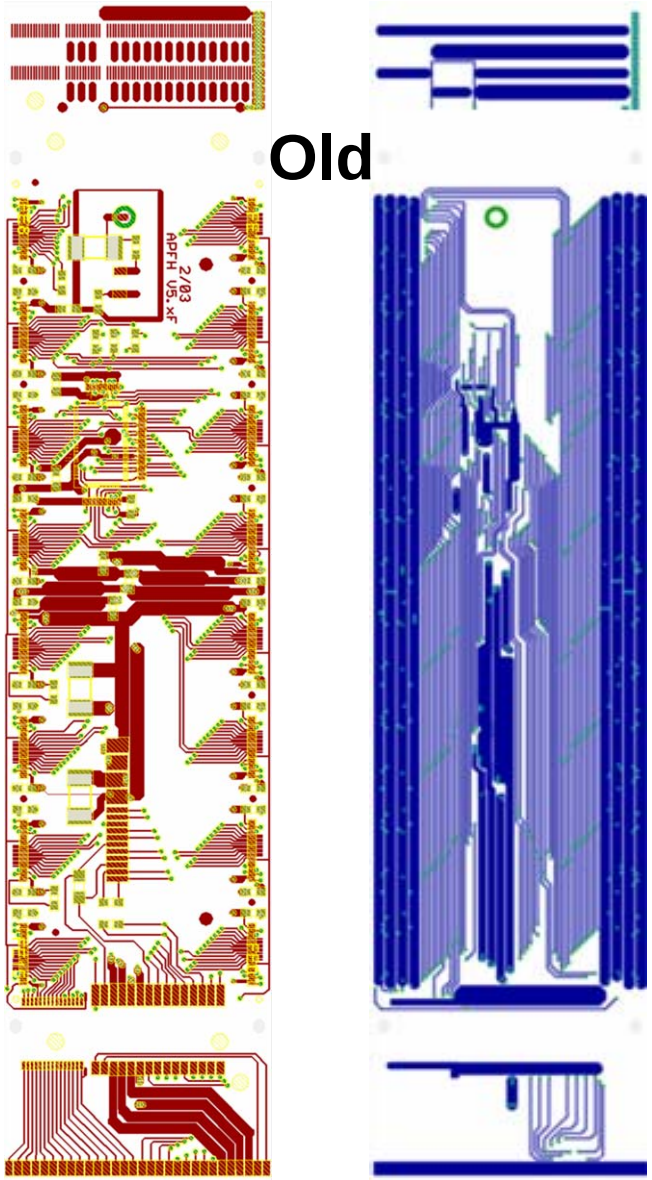
- No difference between schemes, no difference to PP modules
- Decided to use the improved scheme, simple, flexible and DLinReg can handle extra load

Design of a Serial Powering Flex

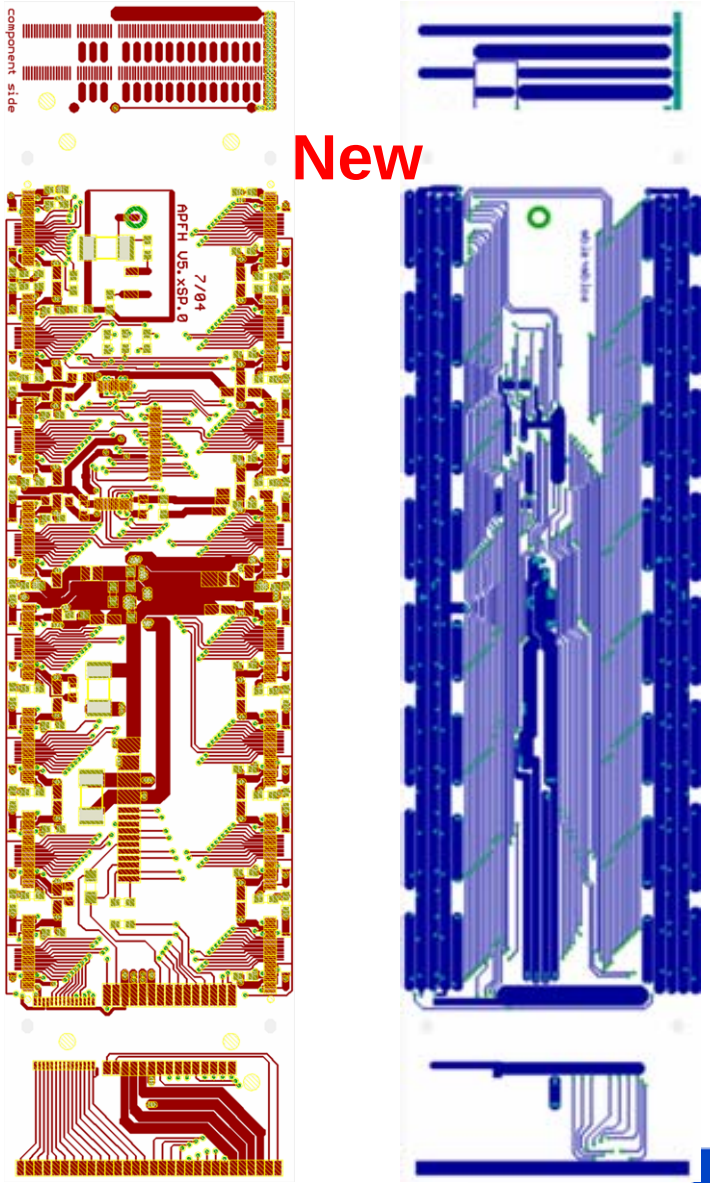
- Extra bond pads for regulator pads
- Separate VDDD and VDDA lines
- Filter capacities for every voltage and every chip
- Increased filter capacities
- Minor improvements on all bond pads
- Useable for several schemes

Design of a Serial Powering Flex (cont.)

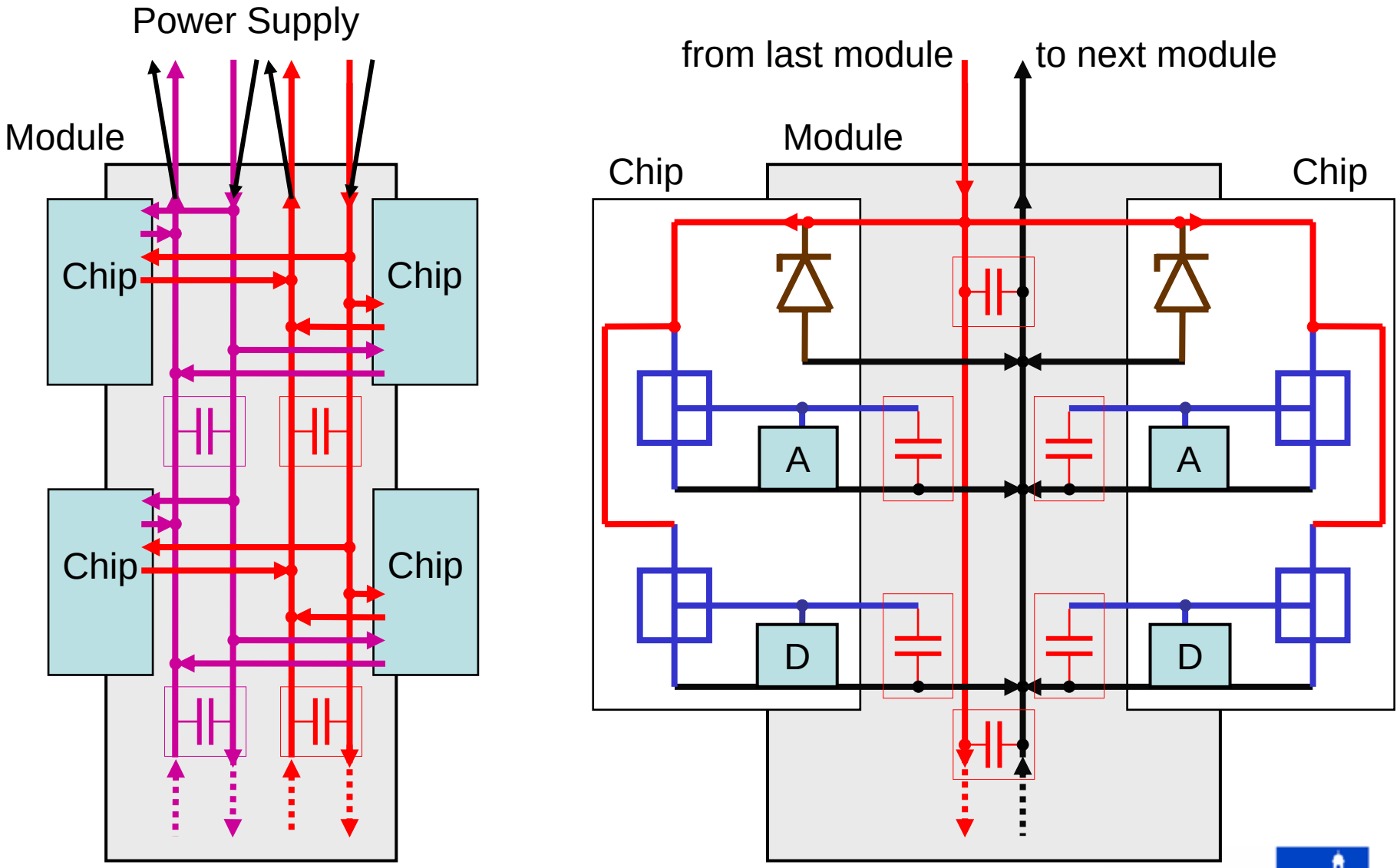
Old



New

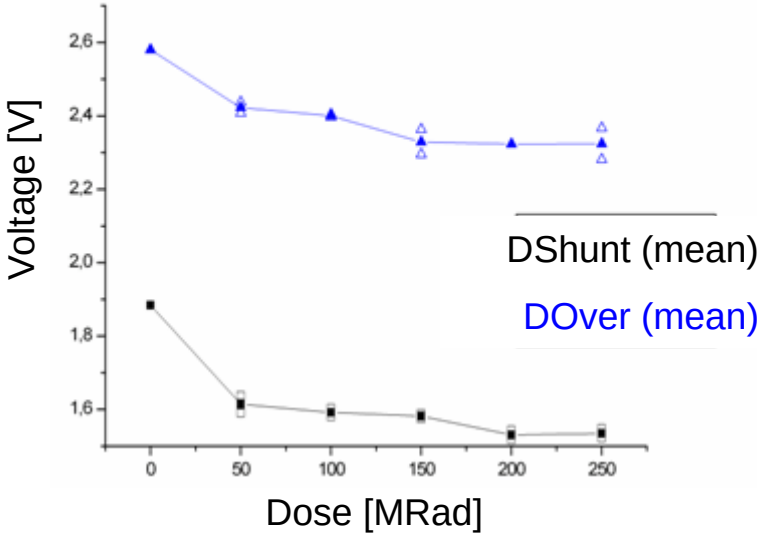


Design of a Serial Powering Flex (cont.)

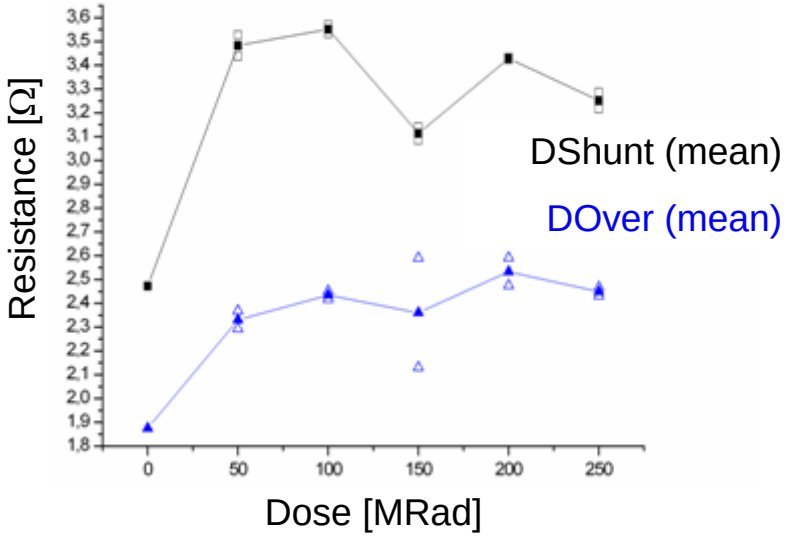


Irradiated Regulators

- 2x5 chips passively irradiated at PS with doses from 50MRad to 250MRad
- Chips & regulators are working, even with dose ~5x ATLAS lifetime
  - **Threshold voltage**



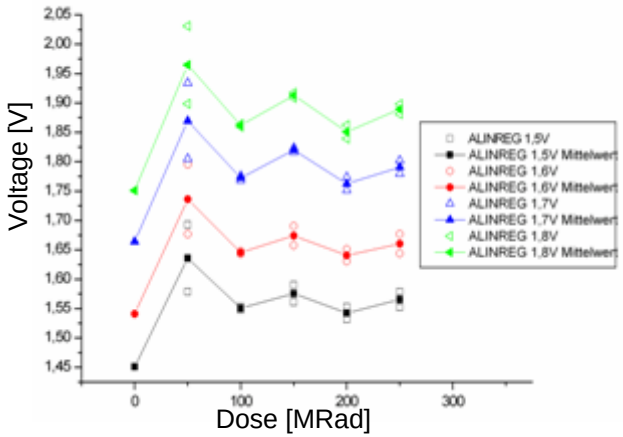
  - **Resistance**



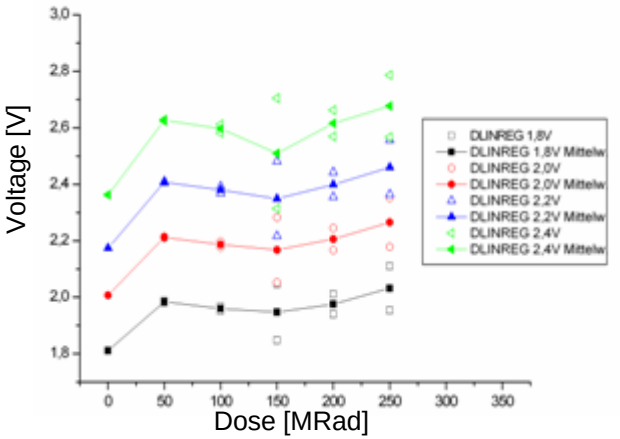
Irradiated Regulators (cont.)

- **Output voltages**

ALinReg:

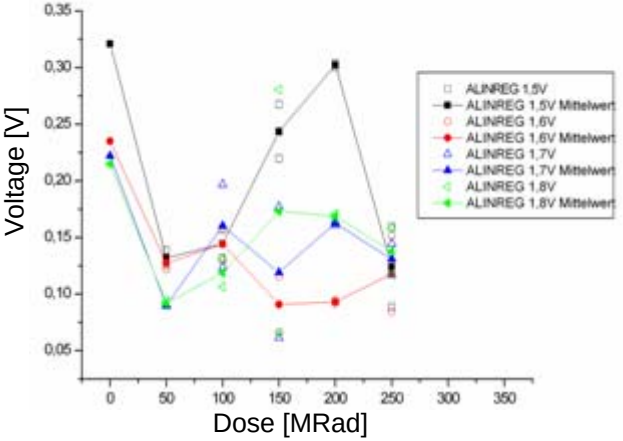


DLinReg:

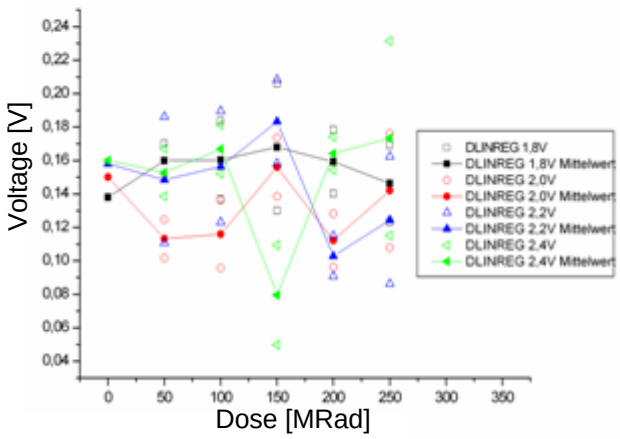


- **Voltage dropout**

ALinReg:



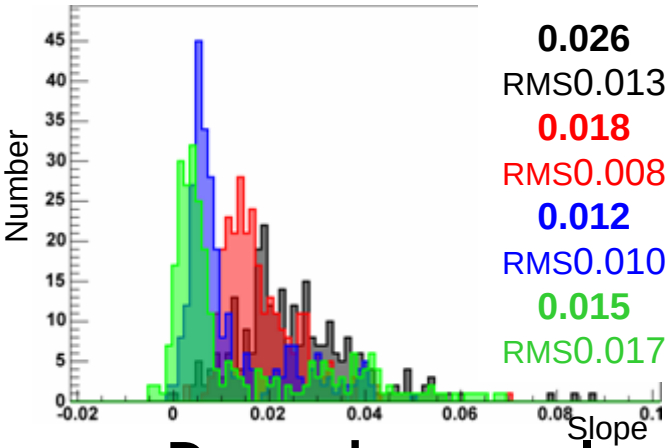
DLinReg:



Linear Regulators I3 (cont.)

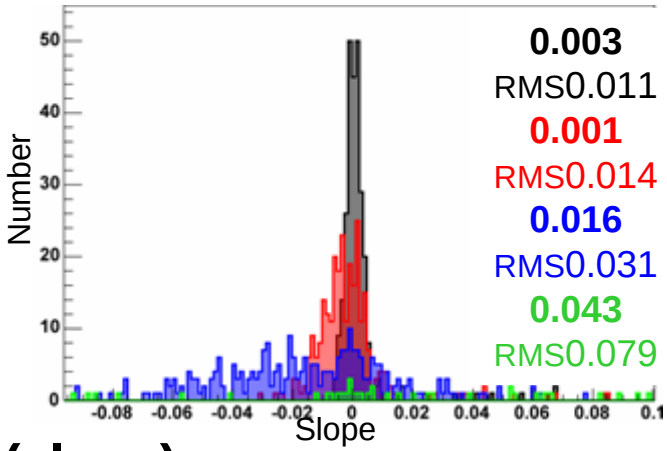
– **Dependence on input voltage (slope)**

ALinReg:

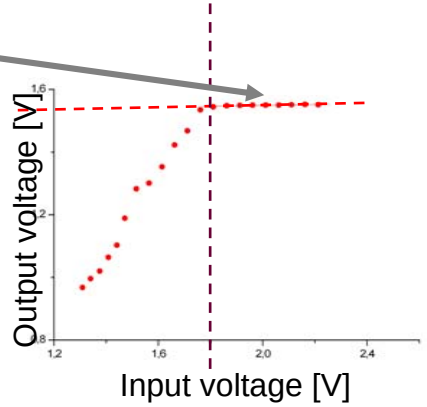


0.026
RMS0.013
0.018
RMS0.008
0.012
RMS0.010
0.015
RMS0.017

DLinReg

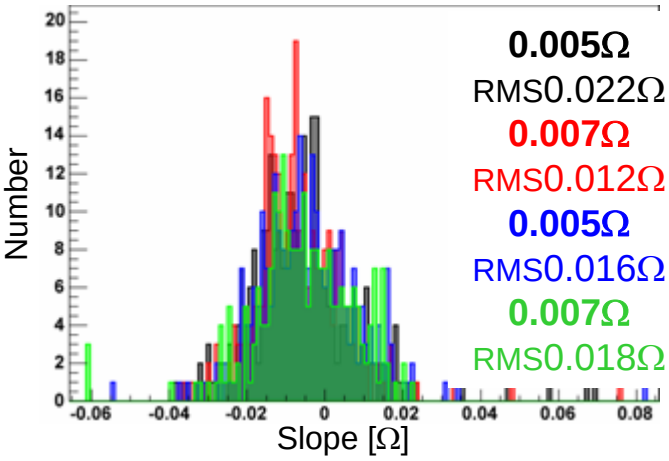


0.003
RMS0.011
0.001
RMS0.014
0.016
RMS0.031
0.043
RMS0.079



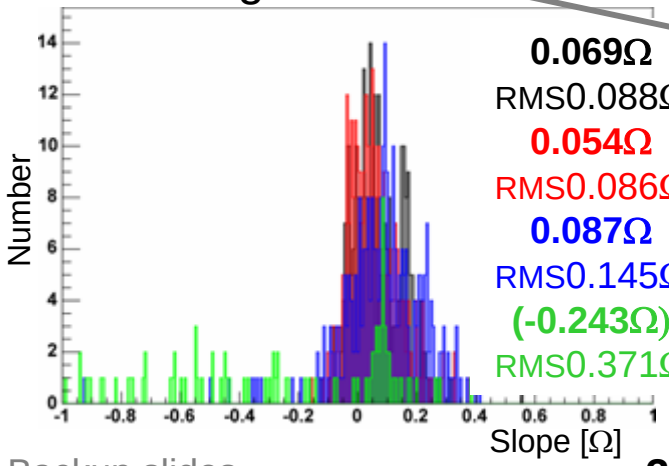
– **Dependence on load (slope)**

ALinReg:

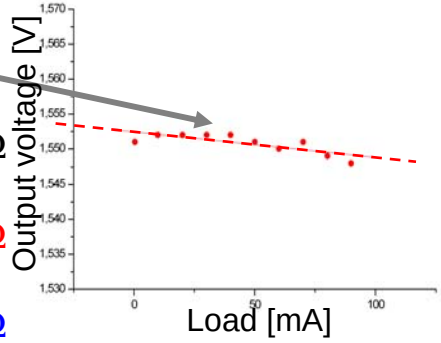


0.005Ω
RMS0.022Ω
0.007Ω
RMS0.012Ω
0.005Ω
RMS0.016Ω
0.007Ω
RMS0.018Ω

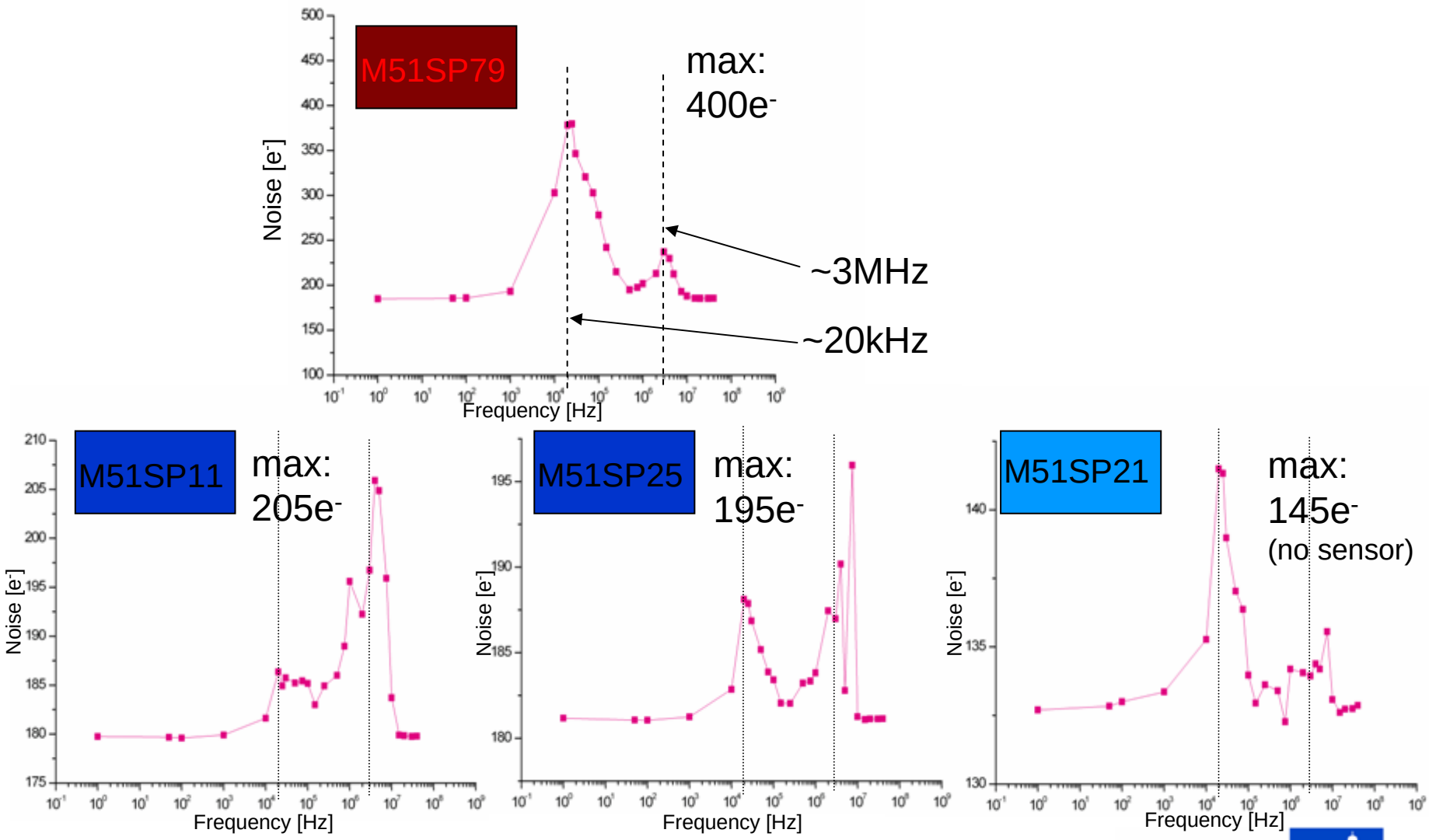
DLinReg



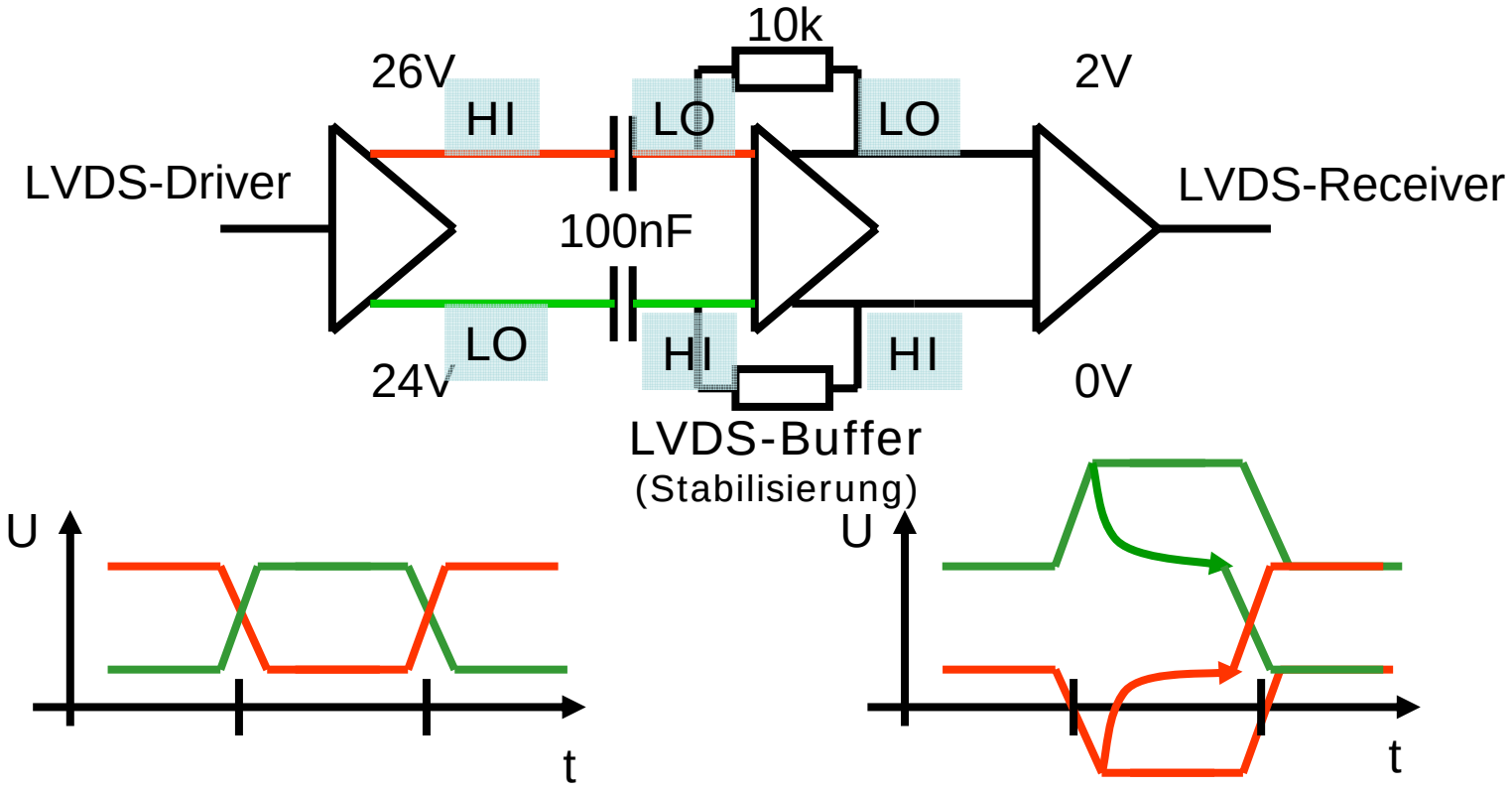
0.069Ω
RMS0.088Ω
0.054Ω
RMS0.086Ω
0.087Ω
RMS0.145Ω
(-0.243Ω)
RMS0.371Ω



Noise Pickup Measurements
Frequency Dependence (cont.)



AC Coupling


10k
26V
HI
LO
LO
2V
LVDS-Driver
100nF
LVDS-Receiver
LO
HI
HI
24V
0V
LVDS-Buffer
(Stabilisierung)
U
t
U
t

AC-Coupling Final Implementation