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FSP ATLAS
Erforschung von Universum und Materie

ATLAS ITk

PROTOTYPING SERIAL POWERING WITH RD53A AND ITKPIXV1.1

FLORIAN HINTERKEUSER FOR THE ATLAS COLLABORATION

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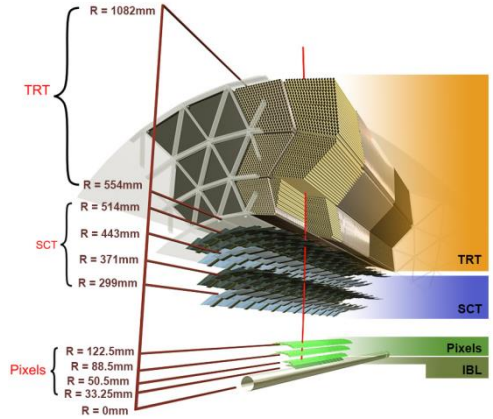
INTRODUCTION

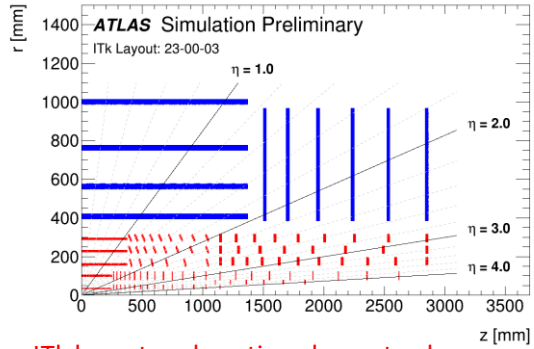
- New all-silicon ATLAS inner detector for HL-LHC: Itk
  - **Same volume** as current tracking detector, see also **talk** by **S. D'Auria** earlier this session, **poster** by **B. Moser**
- Pixel detector consists of O(10k) **multi-chip modules**
- One design goal: Excellent performance with minimal material budget
  - Use a **serial powering** scheme

	ATLAS Pixel Detector + IBL	ITk Pixel Detector
Modules	2000	8500
Pixel Size	50x400 μm^2 or 50x250 μm^2	50x50 μm^2 or 25x100 μm^2
Readout Channels	80 million	5000 million
Silicon Area	1.7 m^2	14m^2
TID	500 kGy	10 MGy
Fluence	10^{15} n_{eq}/cm^2	$1.4x10^{16}$ n_{eq}/cm^2
Trigger Rate	100 kHz L1	4 MHz L0
FE Data Rate	160 Mbps	5.12 Gbps
Powering	parallel	serial
Cooling Budget	15 kW	100 kW



Current ATLAS tracking detector

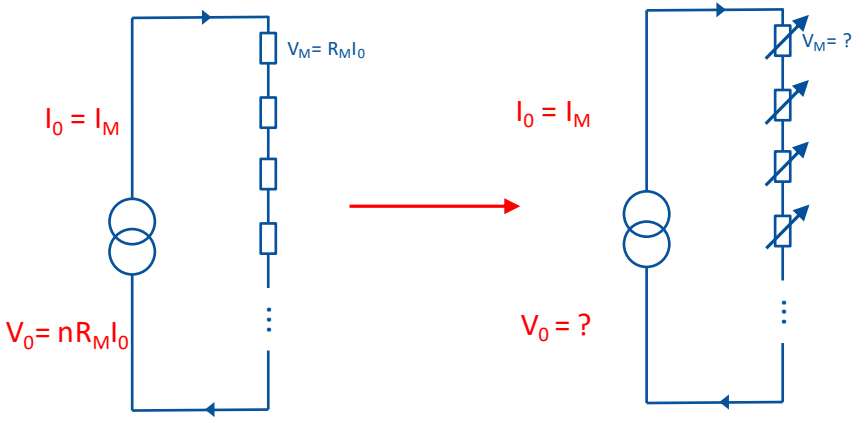
https://cds.cern.ch/record/2723878



ITk layout, only active elements shown. Pixels in red

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2021-024/

SERIAL POWERING SCHEME

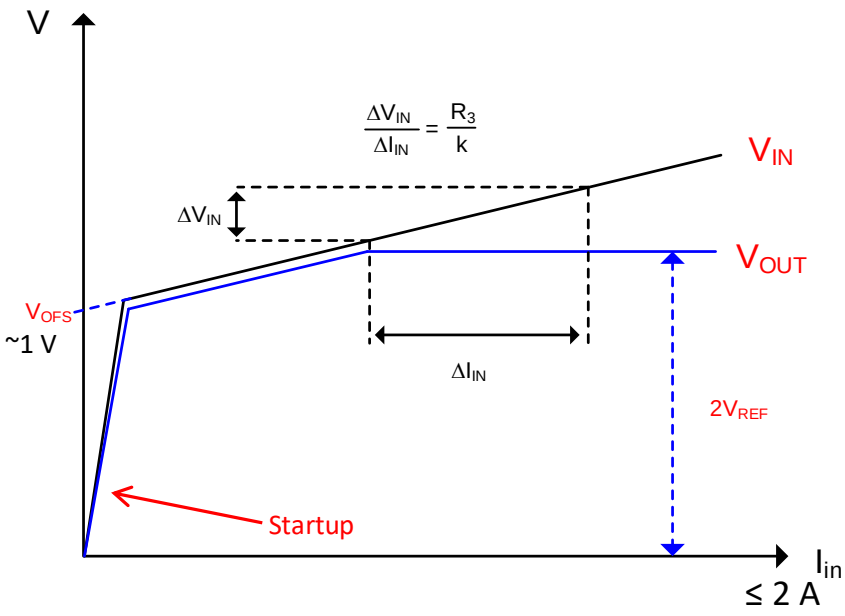


This would be easy

This is harder

- *N* **modules** connected **in series**
  - **Each module** consists of ***m*** **readout chips** in **parallel**
- Total **current** defined by **single module**
  - **Reduces** power **losses on cables**, **material budget**, requires less space
- **But:** Module is not an ohmic resistor
- **On-chip SLDO** regulators **convert I_{in}** to constant readout **chip supply voltage V_{DD}**
  - **Module** now has **ohmic** characteristic
    - Defined by resistor R_3 and scaling factor k

SERIAL POWERING SCHEME



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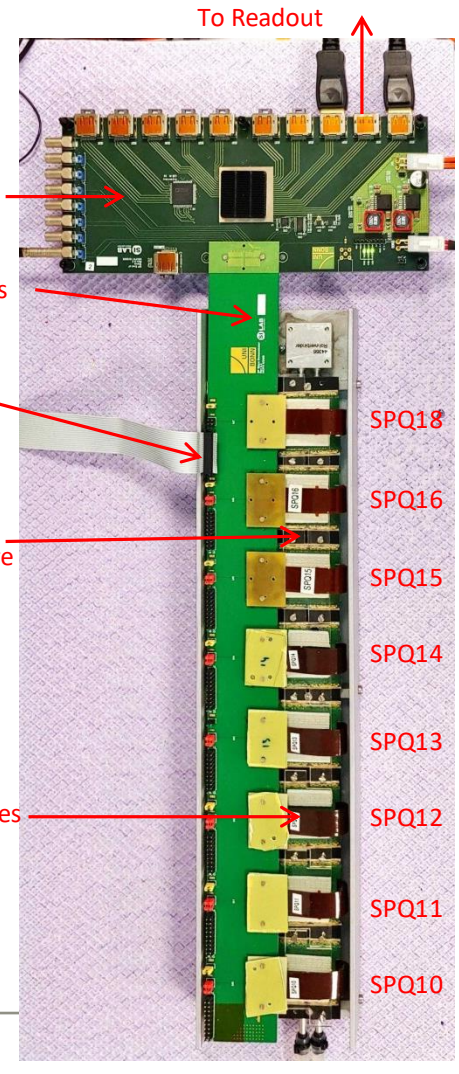
PLANAR QUAD SP CHAIN

- In Bonn: **Serial powering prototype** to investigate the electrical behaviour of **current-generation pixel modules** in a serial powering chain
- **Up to 8** quad modules on a local support, serial chain GND **decoupled** from system GND, EoS-Card offers **daisy chaining**
- **Compatible** with **RD53A** and future **ITkPixV1.X** modules
  - **RD53A** has **three** FE flavours (**SYNC, LIN & DIFF**), **ITkPixV1** only **DIFF**
- **Dedicated services** designed for this prototype, offers **easy-to-access testpoints**
- **Module performance** & **SLDO** measurements with **RD53A** modules
- Startup measurements with **ITkPixV1.1** digital modules



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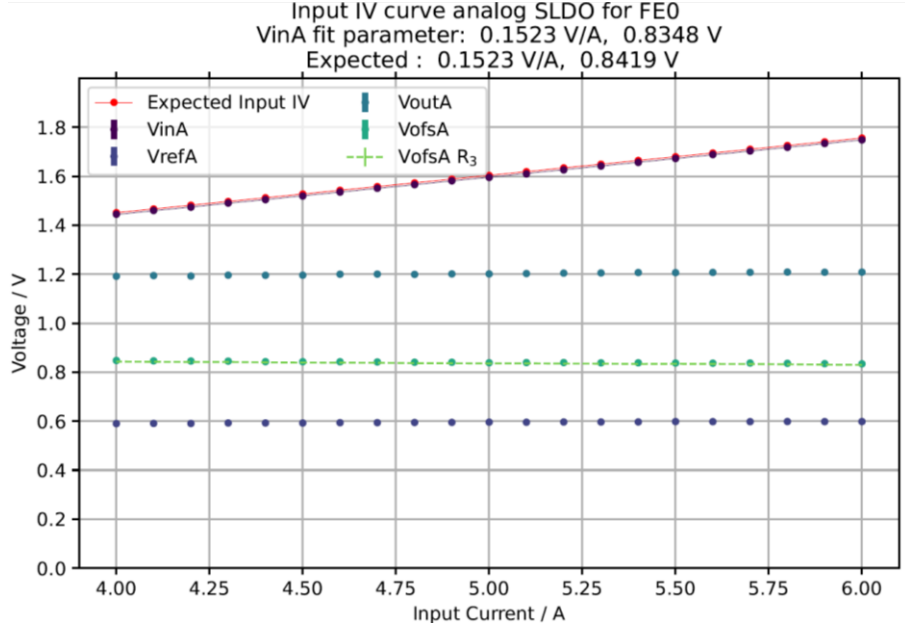
RD53A PLANAR SERIAL POWERING CHAIN – MODULE IV CURVES

- Measure **SLDO IV** curve for each quad in serial chain
  - **Target working point**: **V_{ofs} = 0.9 V, V_{in} ≈ 1.6 V @ Iin = 4.5 A**
  - **Measure** SLDO voltages using **on-chip MUX**
  - **Compare** with **Spice model** fed with **wafer-probing data**
- **Measure on-module current** via slope resistor R_3 and scaling factor k
  - **R_3** and **k** define **slope** of **SLDO** input IV
  - **Useful** to **determine** minimum **current headroom**

RD53A PLANAR SERIAL POWERING CHAIN – MODULE IV CURVES

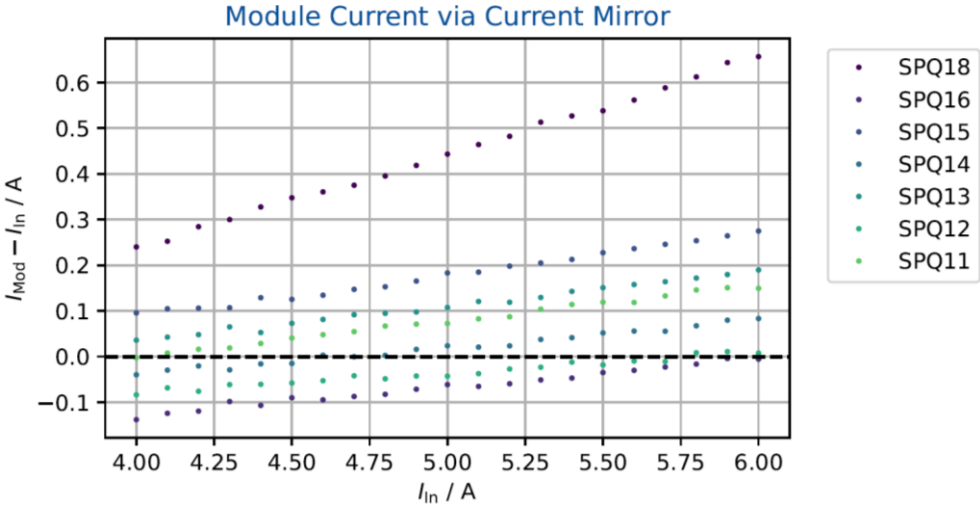
- Example: Module SPQ14
  - $V_{IN\_A,D}$ **tied** together on flex
  - > V_{IN} **nearly same** for all SLDOs
- **Good agreement** with expectation

Spice	Full SPQ14
Slope	0.15 V/A
Offset	0.84 V



RD53A PLANAR SERIAL POWERING CHAIN – CURRENT SHARING

- **Estimate** on-module **current distribution** using voltage drop on SLDO **slope resistors**
- Scaling factor ***k*** from **slope fit** on **wafer-probing data**



- Plot I_{in} vs $(I_{mod} - I_{in})$
  - **Expect $(I_{mod} - I_{in}) \approx 0$**
  - Large **uncertainties** on k O(10%)
- Generally **meets expectation**
- Large slope on module **SPQ18 unexpected**
  - Likely due to incomplete wafer probing data

RD53A PLANAR SERIAL POWERING CHAIN – CURRENT SHARING

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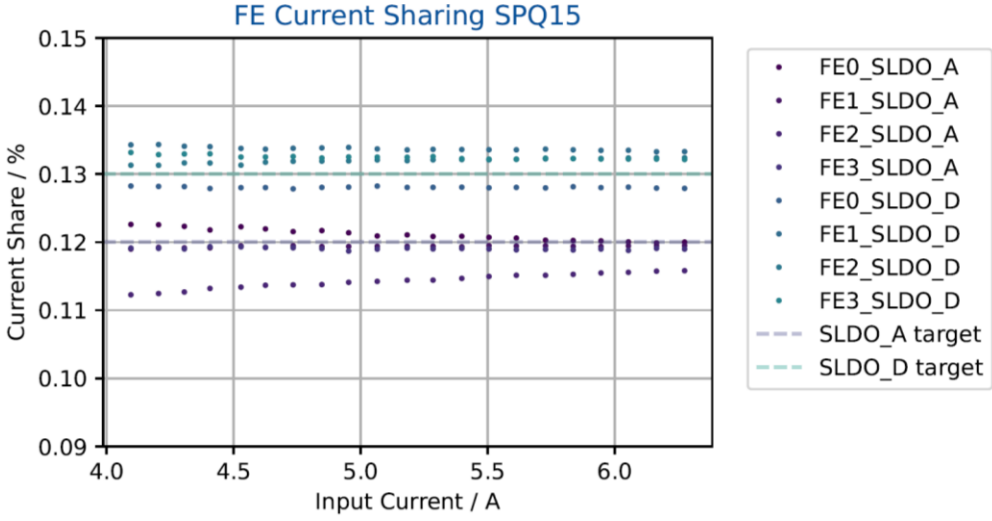
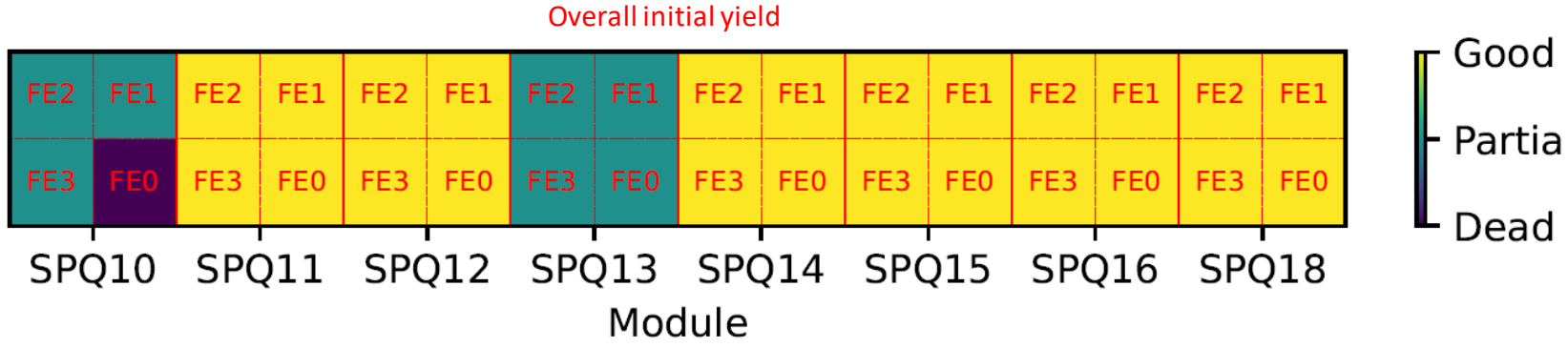


- **Estimate** module current I_{mod} by **scaling current** through **Rext**
- Plot **relative current sharing** between SLDOs on a quad (**ideal case: 13 % Digital, 12 % Analog**)
- Roughly **fits** expectation
- **Slope** understood as **differing k(I_{in})** dependencies for each SLDO

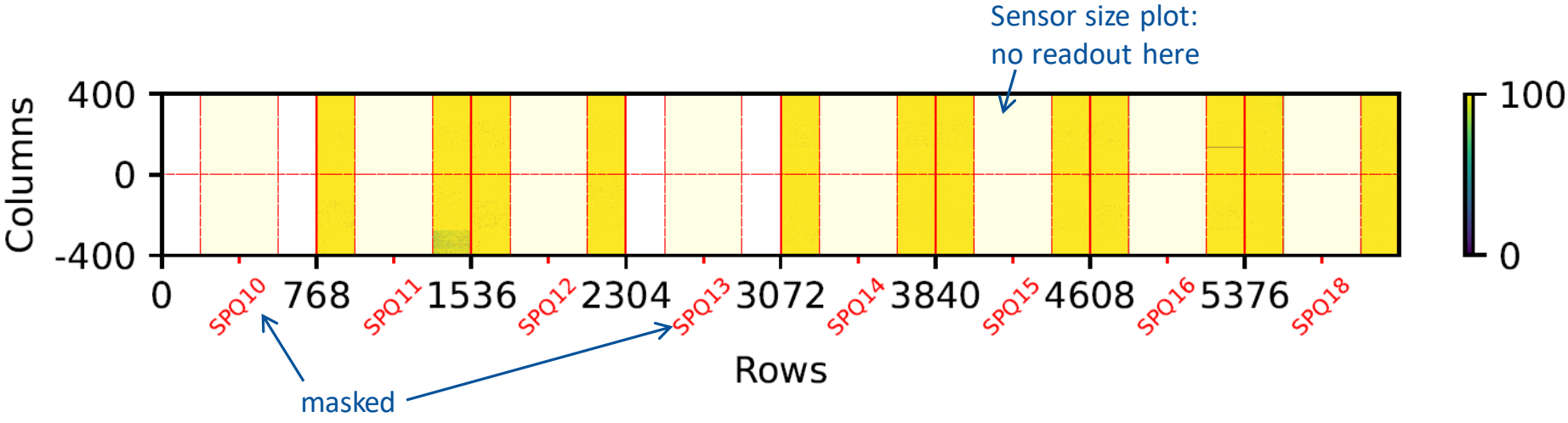
RD53A PLANAR QUAD SP CHAIN – MODULE YIELD

- **Most modules working**
  - **SPQ10_FE0** has **faulty SLDO, high noise,** masked in scans
  - **SPQ13: very high** sensor **leakage** O(100uA), not tunable, masked in scans
  - Both **known from reception** tests
- **SPQ11** lost during operation



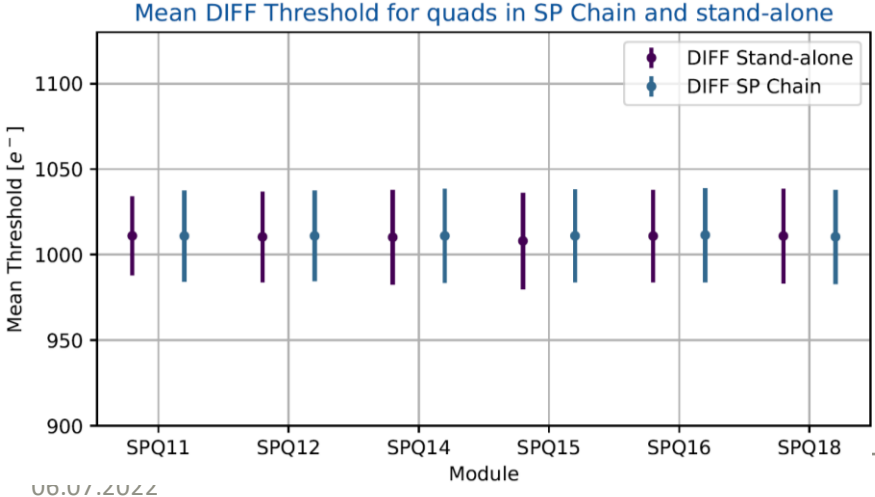
RD53A PLANAR QUAD SP CHAIN – MODULE YIELD

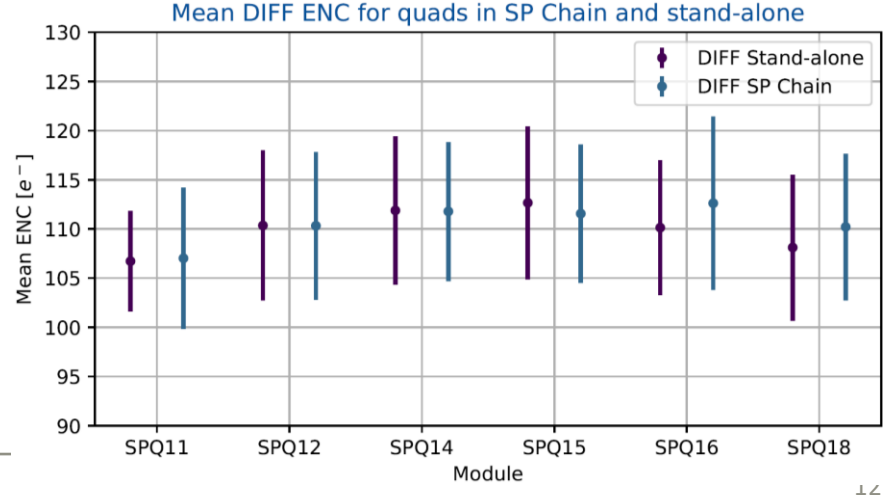
- **Analog test injections** @ 2ke threshold
  - LIN & DIFF FE tuned, SYNC untuned



RD53A PLANAR SERIAL POWERING CHAIN – MODULE PERFORMANCE

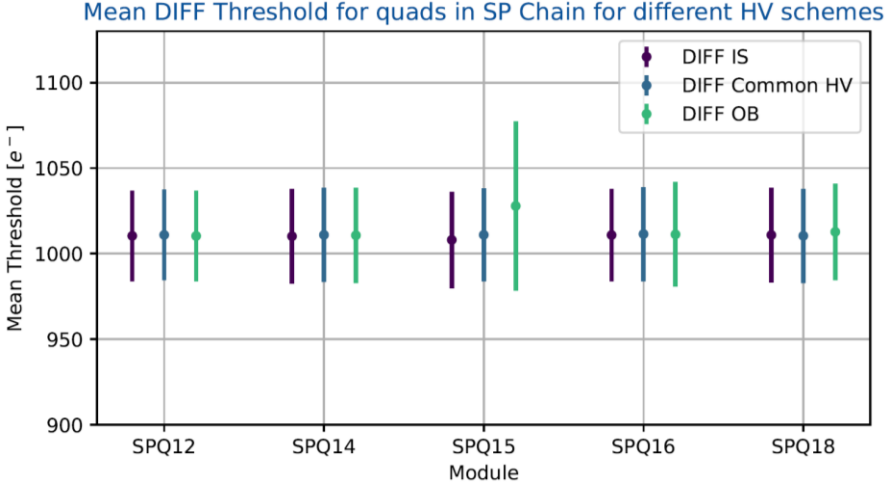
- For all modules: tuning of **LIN & DIFF** to **2ke & 1ke**, measure **threshold distr., noise**
  - **Shown** are **mean** values & distribution **widths**
- **Fits results from reception tests**
  - **Negligible difference** between stand-alone and SP chain

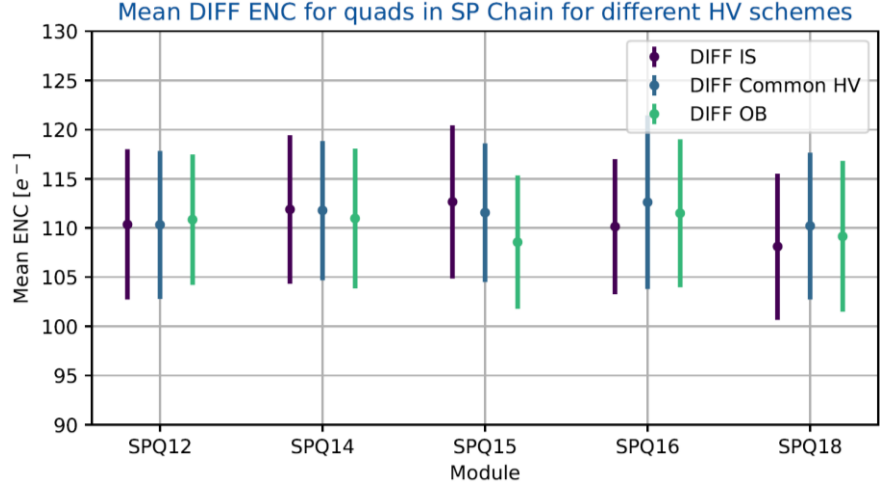




RD53A PLANAR SERIAL POWERING CHAIN – MODULE PERFORMANCE

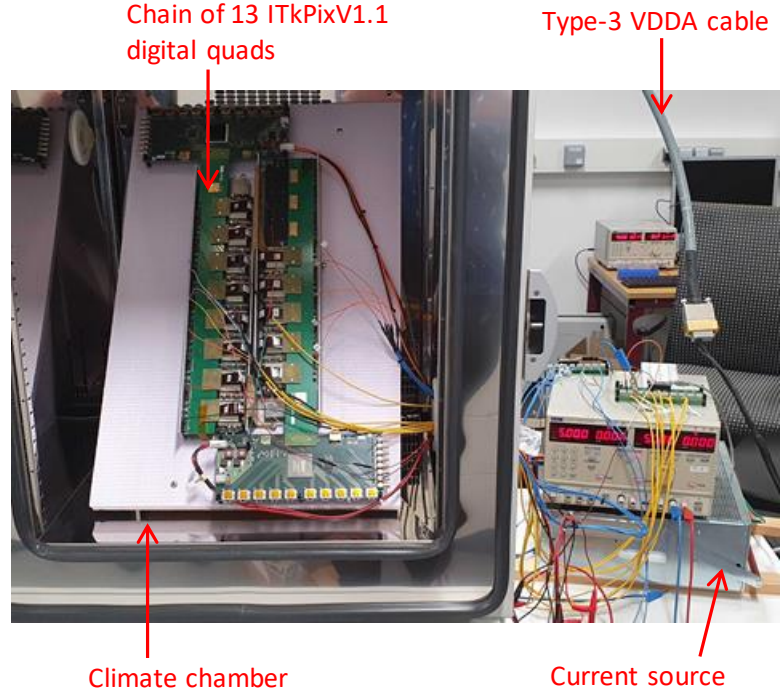
- For all modules: tuning of **LIN & DIFF** to **2ke & 1ke**, measure **threshold distr., noise**
- **Compare** different **HV distribution** schemes
  - Mostly **fits expectations**





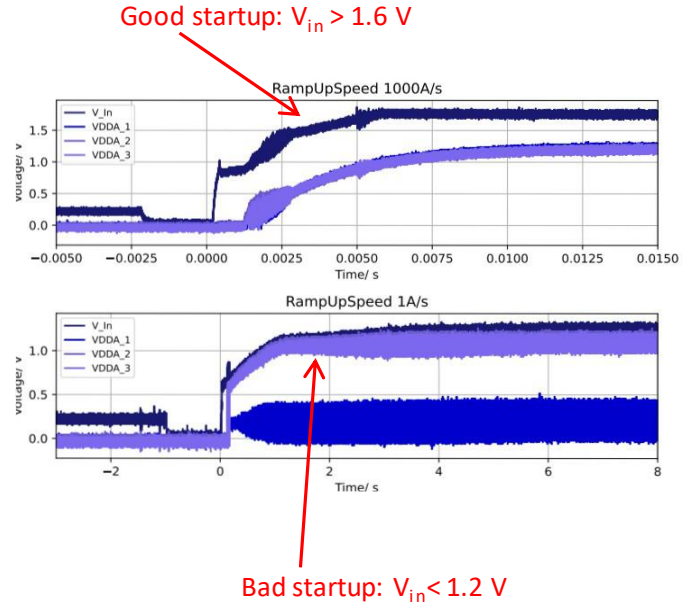
ITKPIX SERIAL POWERING CHAIN

- **Exchanged RD53A** quad modules with **digital ITkPixV1.1** quad modules
- Intention to **support** the ITk Pixel LV **PSU specifications** review
  - Including **current ramp rate**, noise levels and fast load changes
- **First measurements** focusing on **start-up** of **ITkPix** modules
  - Using a **current source prototype** with **adjustable ramp** rate (1-10000 A/s)
  - Connection using a **60m long Type-3 VDDA** cable



ITKPIX SERIAL POWERING CHAIN

- **ITkPix SLDO** generally much **more reliable** than **RD53A SLDO**
- **Observed issues** at **slow ramp** speeds @ 25°C
  - **Unirradiated** modules
  - **Unrealisticly** low ramp speeds < **10 A/s**
  - **Behaviour compatible** with SLDO **bandgap not starting** properly
- **At -40°C** significant **start-up issues** also for **high ramp rates**
  - O(**1000A/s**), **short chain** lengths



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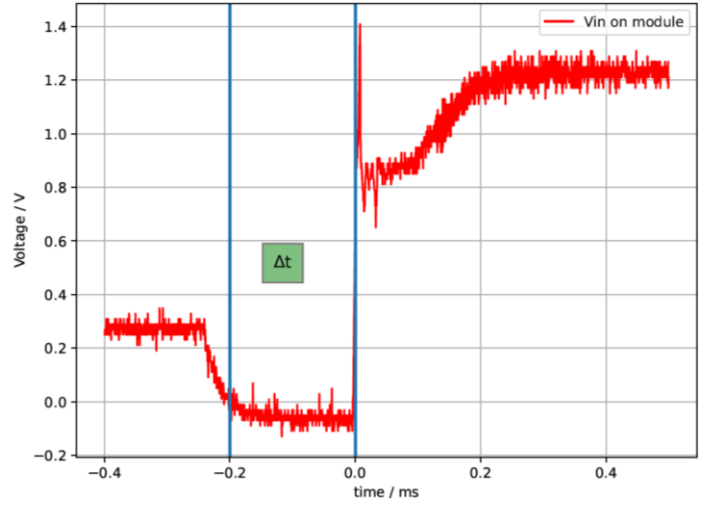
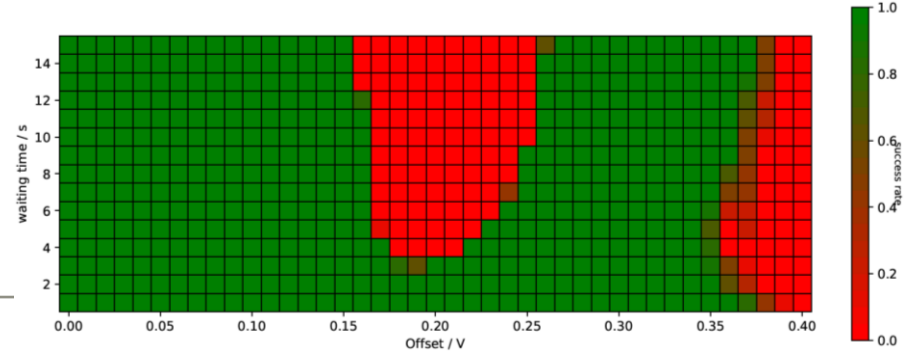
ITKPIX SERIAL POWERING CHAIN

- **Cause** for issues @ fast ramps **suspected** in **current source**
  - **Small leakage** current (**uA**) on output when **switched off**
- Causes **residual voltage** on SP chain
- Upon **switching on** LV, **output voltage** is **0V** for a time **Δt**
  - Duration **depends** on **ramp speed**
- **Reproduced** with a Rohde&Schwarz **voltage source**
  - Configurable **offset,** followed by **Δt@0V**





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SUMMARY & OUTLOOK

- **Integration** and **characterisation** of the **Bonn serial powering test setup**
  - Setup includes a promising **prototype current source**
- **Characteristics and performance** of RD53A modules **in serial chain meet expectations**
- **Transitioned** to **ITkPixV1.1** digital Quads, **first measurements** to validate **LV PSU specifications**
- Encountered **unexpected** startup **issues**, likely caused by PSU
  - More investigations required
  - **Without non-zero current** before startup, **no issues** have been observed with the **ITkPixV1.1 SLDO**
- Possible **solutions**: **Update** PSU **specs**
  - crowbar, limited leakage current, fixed time @ 0V before ramp
- **Currently:** studying **fast load changes** in the serial **chain**

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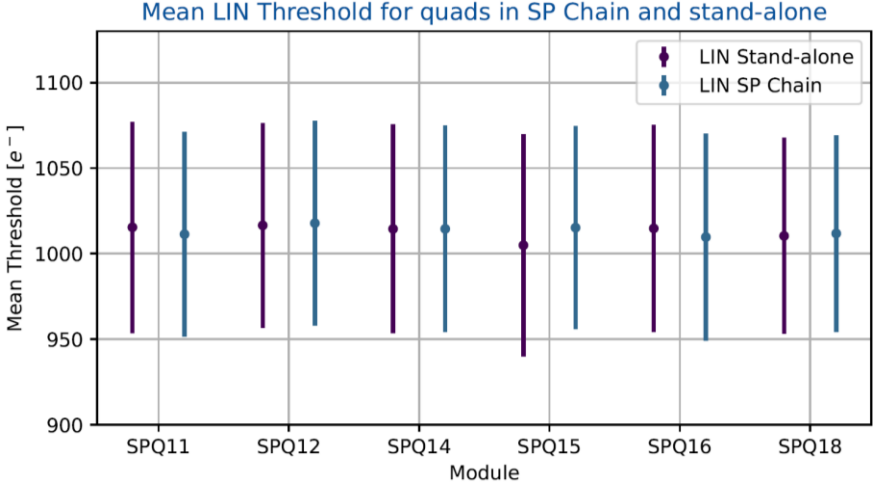
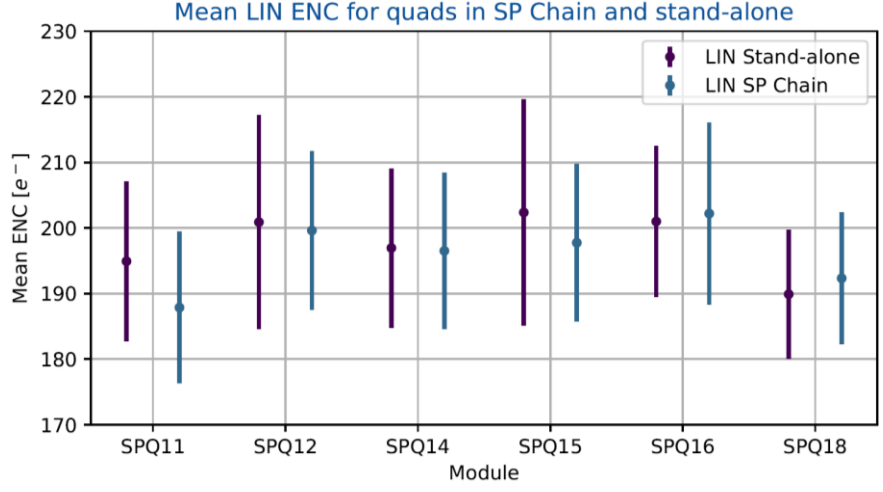
THANK YOU

RD53A PLANAR SERIAL POWERING CHAIN – MODULE PERFORMANCE

- For all modules: tuning of **LIN & DIFF** to **2ke & 1ke**, measure **threshold distr., noise**
  - **LIN FE very noisy**
- **Fits results from reception tests**





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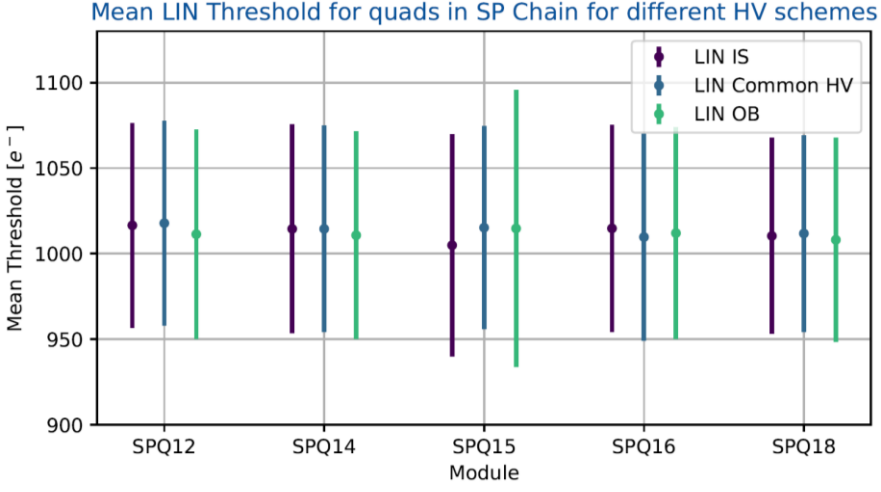

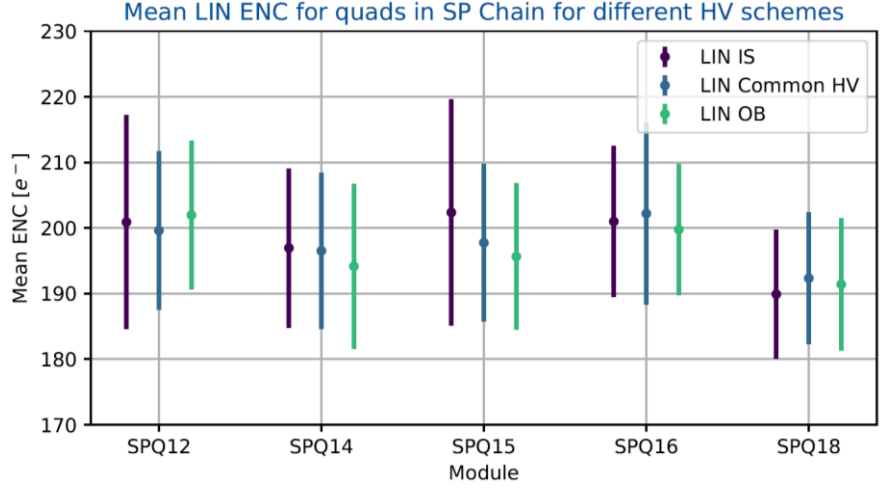

ITKPIX SERIAL POWERING CHAIN

- Cause for startup issues suspected in current source
  - Small leakage current (uA) on output when switched off
- Causes residual voltage on SP chain O(<500mV)
  - Per-module voltage drop decreases with chain length