Serial Powering Characterisation for the CMS Inner Tracker at the High Luminosity LHC

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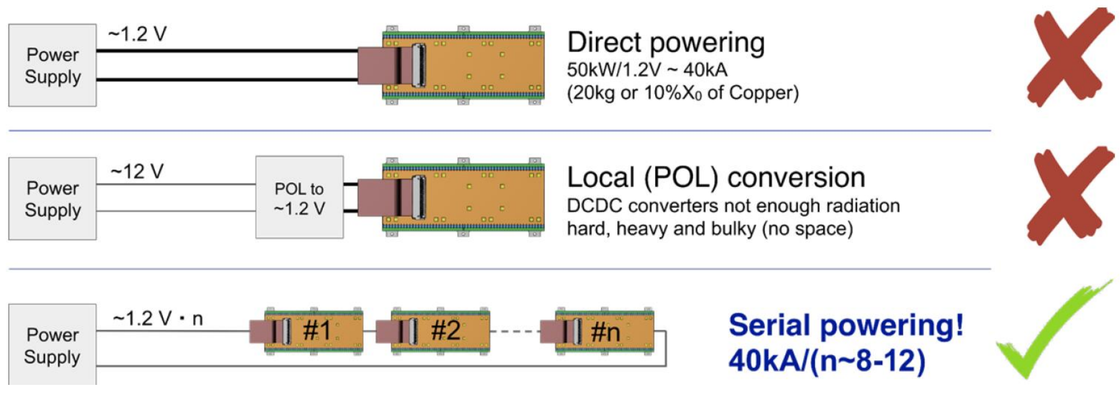
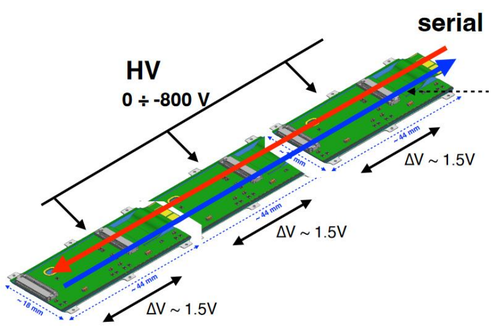
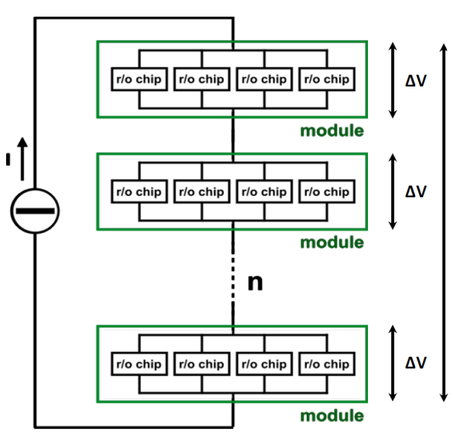
- The CMS Tracker will be completely replaced for HL-LHC:
  - **Inner Tracker (IT): Pixel Detectors**
  - Outer Tracker (OT): Strip and Macro-Pixel Detectors
- Very high power consumption (50 kW for the IT)
  - Large area and high granularity → Large number of channels
  - Thin sensors (small signals) → Low threshold and noise analog circuits
  - High data bandwidth → High digital activity

Possible Powering Schemes for the IT



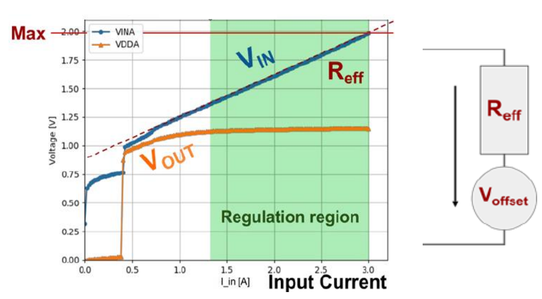


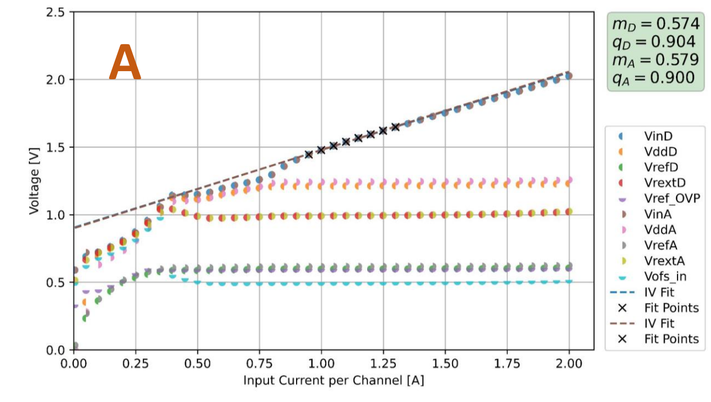
Serial powering chain

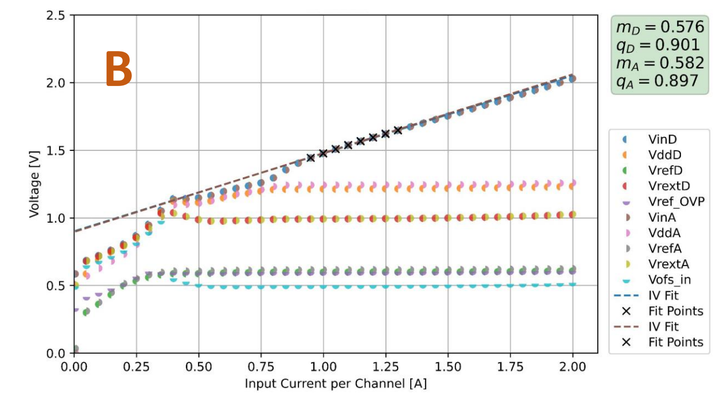


- The serial powering scheme is a technological challenge
  - All the elements of the chain will see the same current, while the voltage is equally shared
  - This is achieved through the **Shunt-LDO**, an IP block of the CMS readout chip (CROC) [RD53 Collaboration]
- The current is shared in **parallel** between the CROCs in the module
  - Each CROC has an analog and a digital domain to be powered in parallel and each domain is powered with a Shunt-LDO
  - 164 chains powered with 4A for 1 × 2 modules [one(two) planar (3D) sensor(s) bump-bonded with 2 CROCs]
  - 336 chains powered with 8A for 2 × 2 modules [one planar sensor bump-bonded with 4 CROCs]
  - **Maximum modules per chain: 11**
- The Shunt-LDO is equivalent to a resistor in series to the power source
  - Plus an offset voltage (V_{ofs})
  - The Shunt functionality is needed to implement the serial scheme
  - The LDO is needed to supply the correct voltage to the electronics (1.2 V)
- The high voltage to bias the pixel sensors is provided in parallel

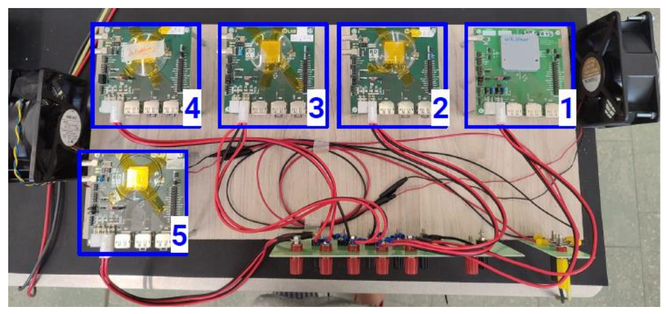
Shunt-LDO IV Curve

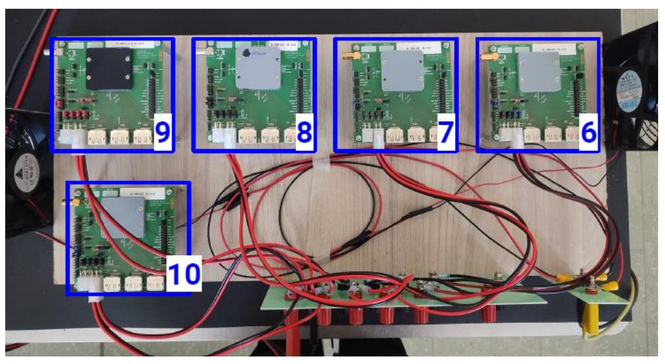


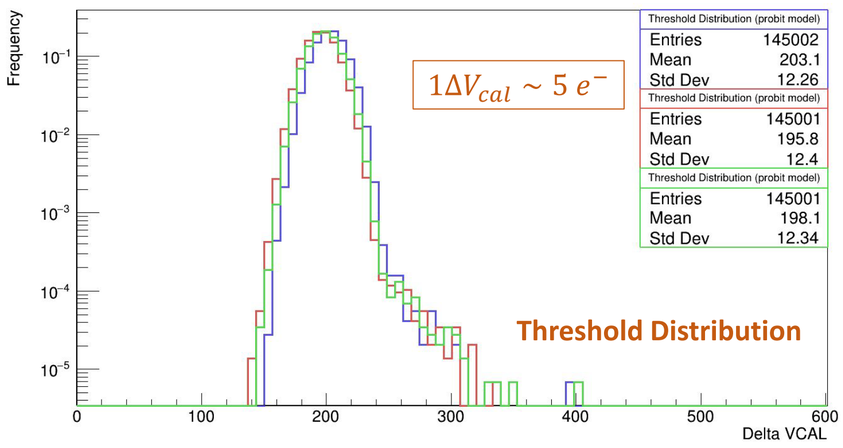


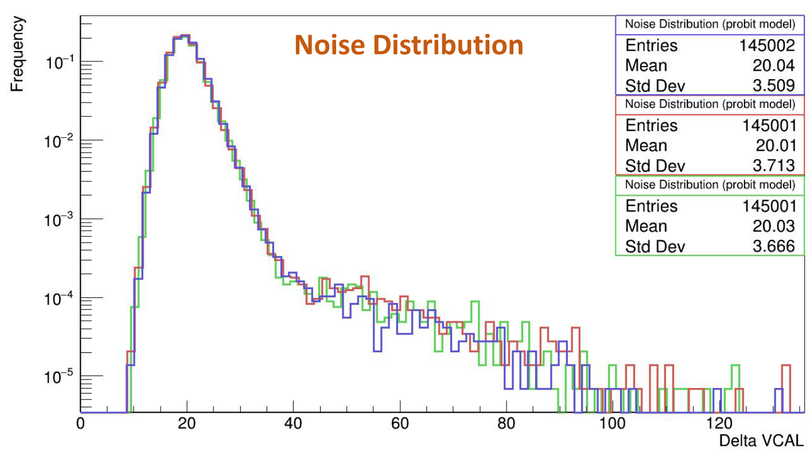


- A serial power chain of 10 modules (with 3D or planar sensors) on single-chip cards (SCC) was tested
  - The SCC is designed for testing, and is useful to check the behaviour of the chip before assembling the full modules
- The Shunt-LDOs of the modules were tested in **standalone [A]** and inside the **chain [B]**
  - No change was observed, proving the effectiveness of the serial powering design
- One module (with a 3D pixel sensor) in the chain was tested in different positions of the chain
  - The module was tuned to 1000 e^- in standalone
  - Threshold and noise were subsequently evaluated for three different positions in the chain:
  - 1st position in the chain
  - 6th position in the chain
  - 10th position in the chain
  - No significant difference was observed









- The offset voltages V_{ofs} of the 4 (2) CROCs in a module are trimmed to ~ 500 mV and shorted together through resistors
  - If 1 CROC stops working, the other 3 (1) in parallel will have a lower V_{ofs}
  - The ohmic behaviour of the Shunt-LDO will start with a higher current → Possible failure scenario
- This scenario was tested by switching OFF one CROC, with other three CROCs in parallel ON
  - The IV curves of the other three CROCs are perfectly superimposed **[C]**
  - The ohmic behaviour of the Shunt-LDO starts at 8 A…
  - …which is the working point
  - The system can sustain this failure scenario

Schematics of the V_{ofs} sharing