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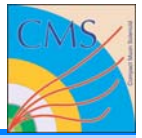

On Chip Regulation in CMS Pixels

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Common ATLAS CMS electronics workshop

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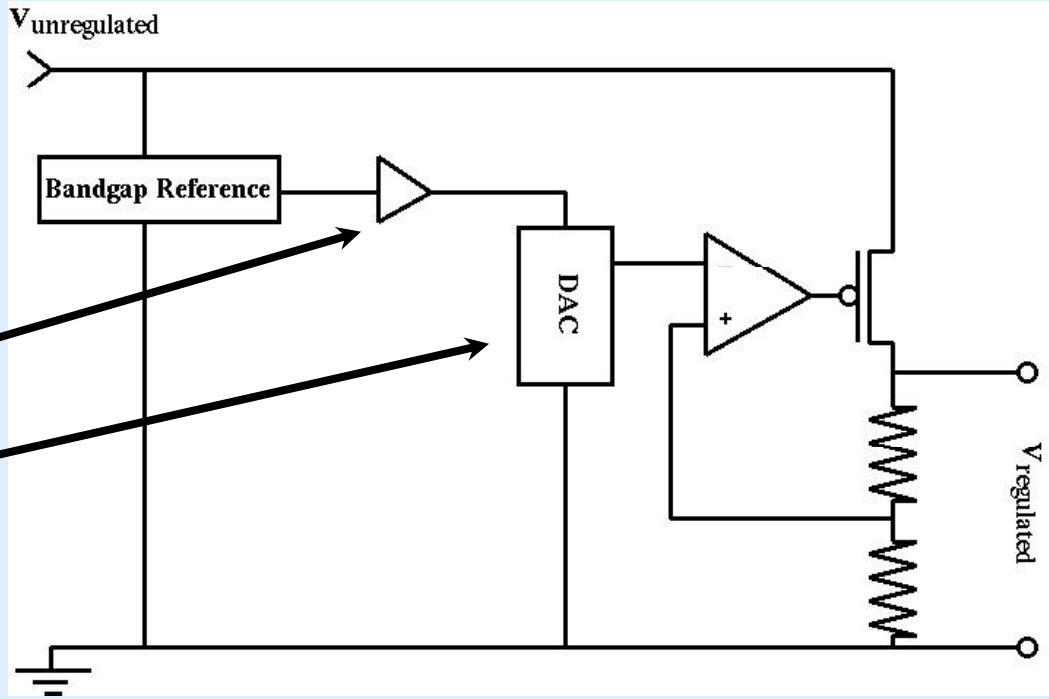
Regulators on pixel readout chip PSI46

- Two unregulated supply voltages. Approximately 1.5V and 2.5V.
- 6 on chip voltage regulators: analog, 3x digital, threshold comparator, sample & hold circuit
- Low drop-out, down to 150mV. Average power dissipation ≈15%
- Cut-off frequency 100 - 500kHz
- 1uF capacitor per chip on $V2.5_{unreg}$. Build low pass filter with cable resistance, $f_{-3db} \approx 0.5$ -1MHz
- Two 1uF capacitors per chip on regulated digital voltages

Regulator Principle

- Power PMOS in series with chip load
- Using Bandgap reference
- All regulators are programmable



Why on chip voltage regulators?

- Allows to save on material budget in cabling
- Improves power noise rejection and chip to chip cross talk on modules
- Needs less services / gives more design freedom

Chip internal supplies

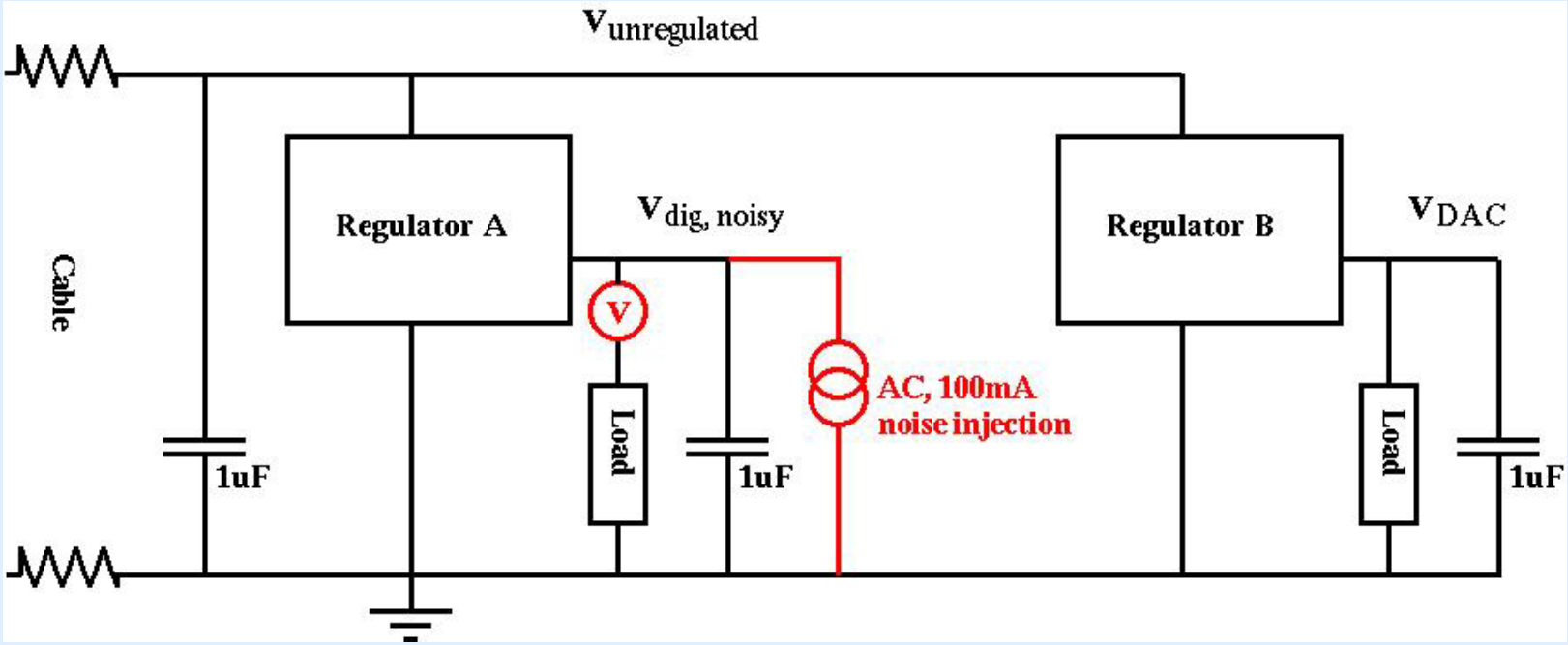
- External supply voltages:
  - 1.5V, 24 mA (analog)
  - 2.5V, 40mA (typical current value, fluence dependent)
- Internal supply voltages:

Supply voltage	Resolution	Minimum [mV]	Maximum [mV]
Digital	4 bit	1700	2100
Analog	8 bit	800	1300
Comparator	4 bit	1800	2100
Sample & hold	8 bit	1000	2100

Power noise rejection (I)

Current or voltage noise injection into one regulator branch

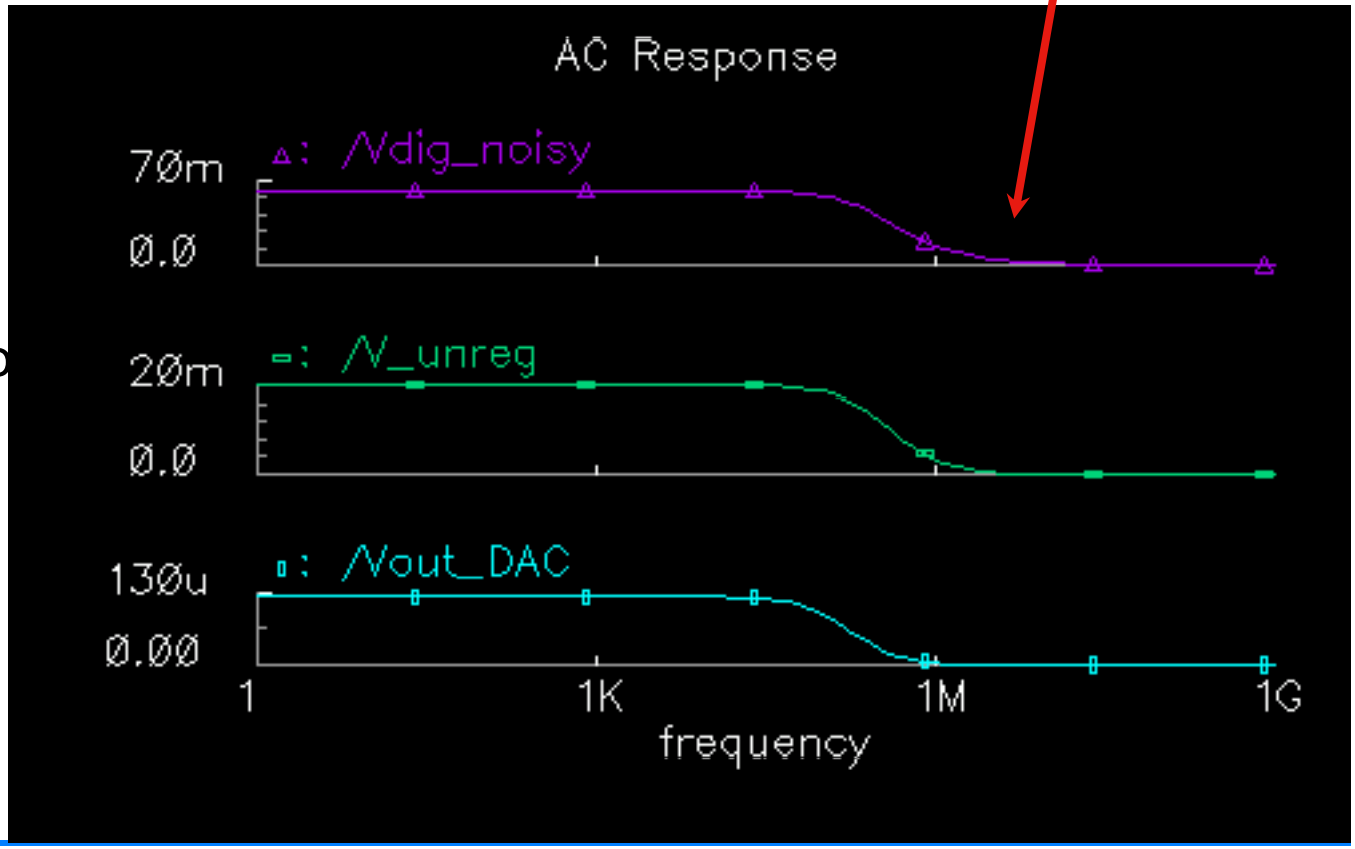
Simulate X-talk to unregulated supply and to second regulator branch



Power noise rejection (II)

100mA noise source on Vdig_noisy

Suppressed by caps



Factor 3 suppressio backward through regulator

DAC supply stays ultra clean

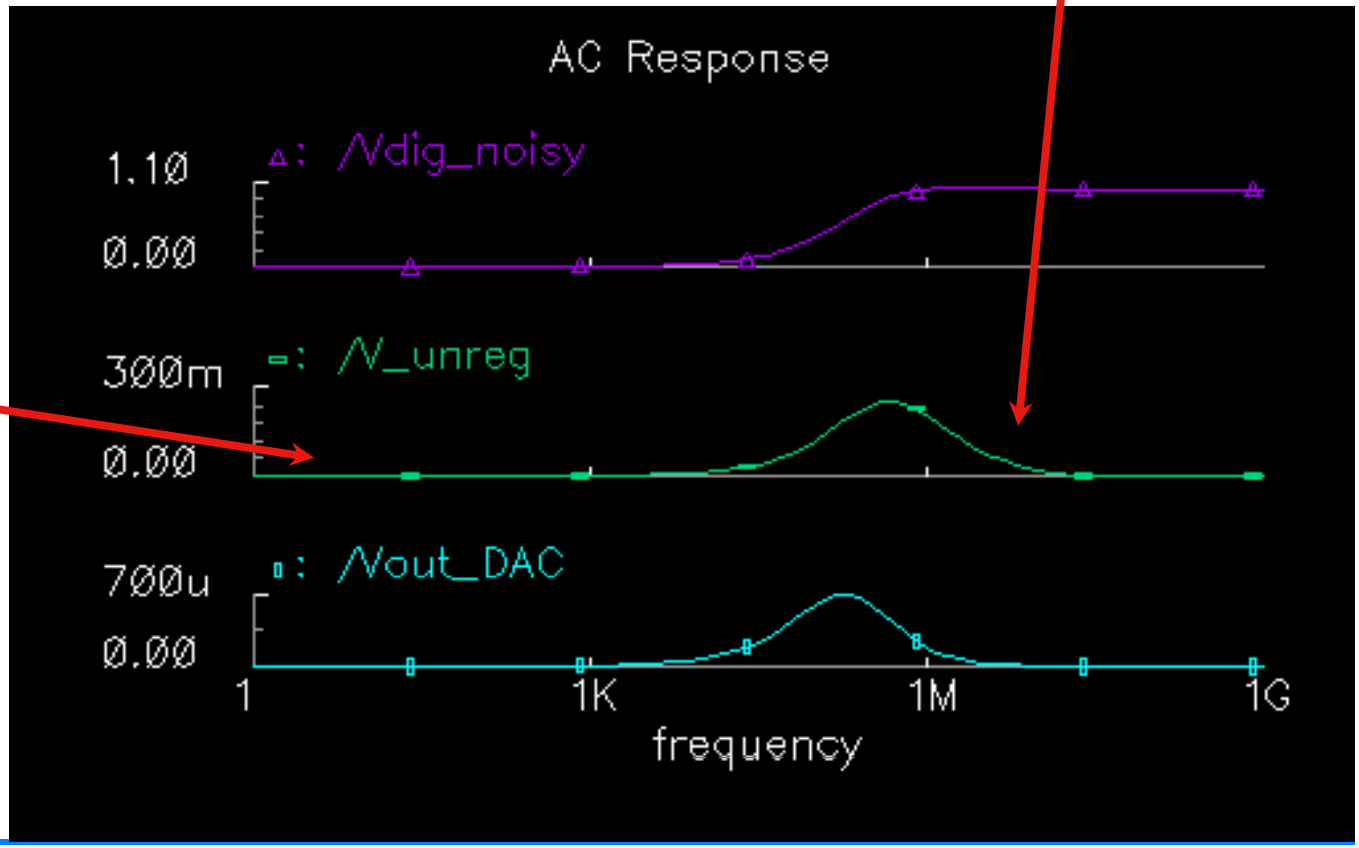
Power noise rejection (III)

Voltage noise source on Vdig_noisy

Suppressed by caps

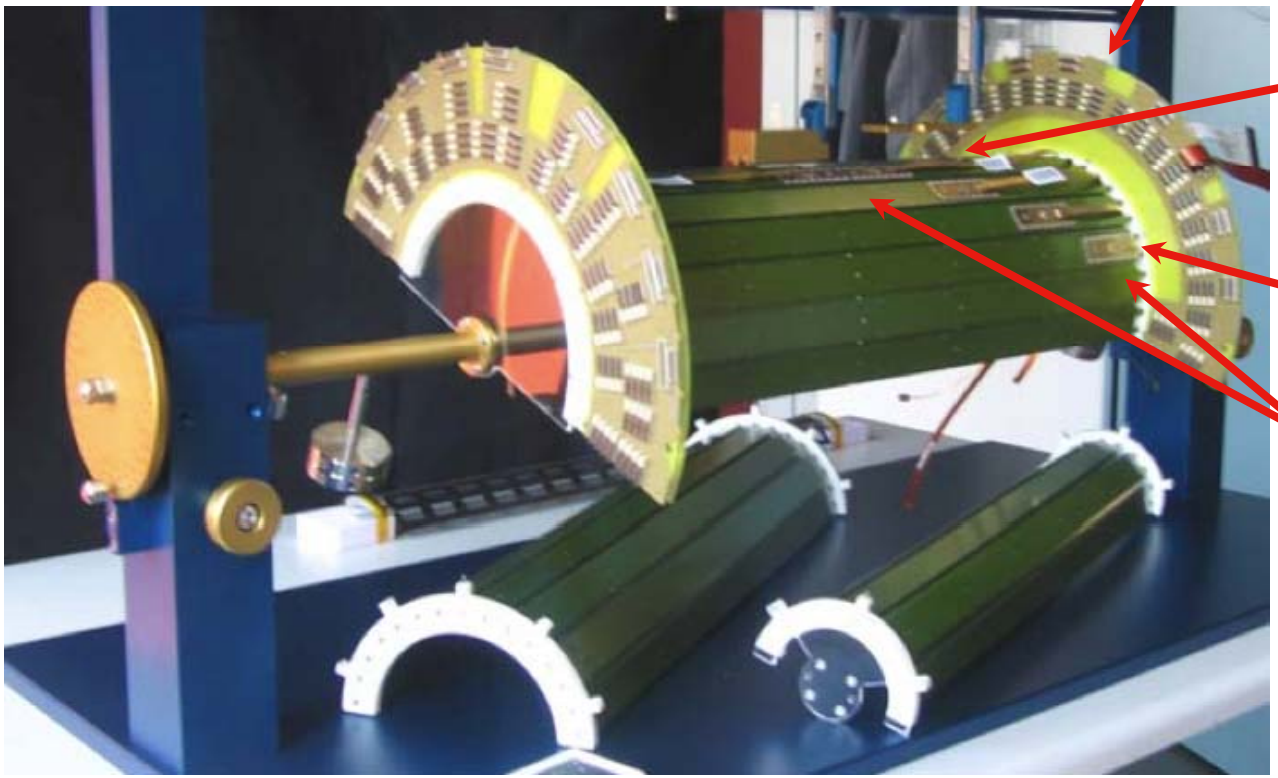
Suppressed by regulator

DAC supply stays clean

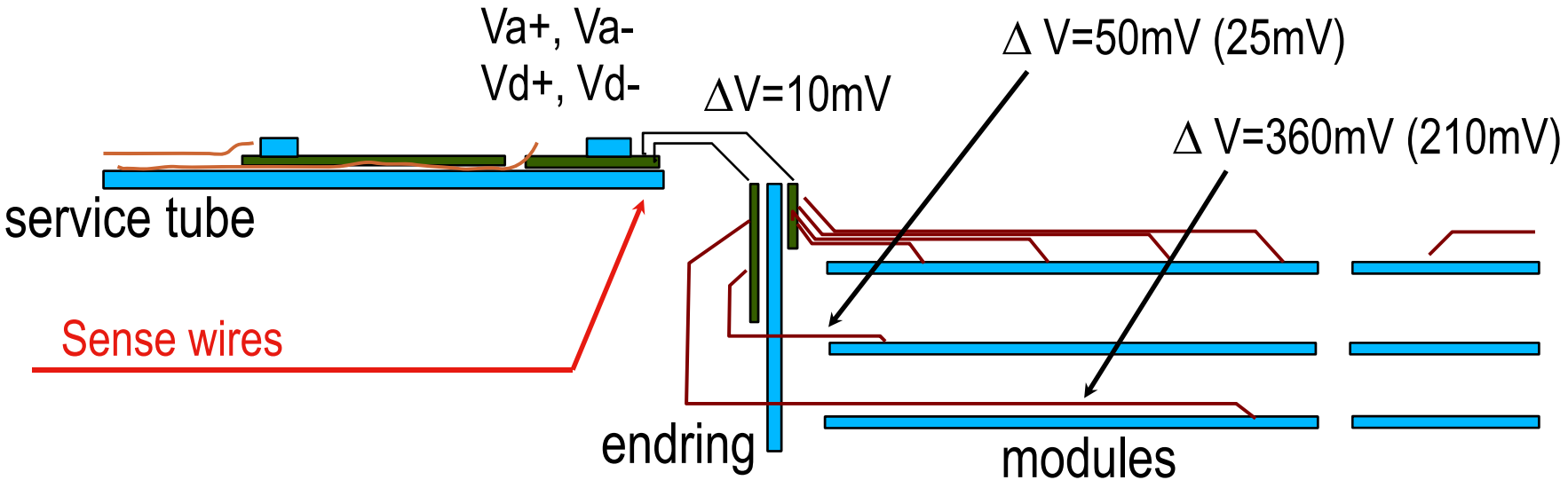


Module power distribution

Mock-up of pixel barrel



Voltage drops in power cables (I)



- Cable lengths differ from 6cm to 37cm
  - ➔ Voltage drop differs considerably
- Want the same voltage on all chips (modules) within ≈ 50mV
  - ➔ Need large cable cross sections or use voltage regulato

Voltage drops in power cables (II)

	Digital	Analog
V drop min (6cm)	50 mV	25 mV
V drop max (37cm)	360 mV	210 mV
Δ V	310 mV	185 mV

For Δ V=50mV need larger cross section by factor 310mV/50mV = 6.2

Copper cladded aluminum wires (CCA)

For material budget relevant quantity is conductivity * radiation length

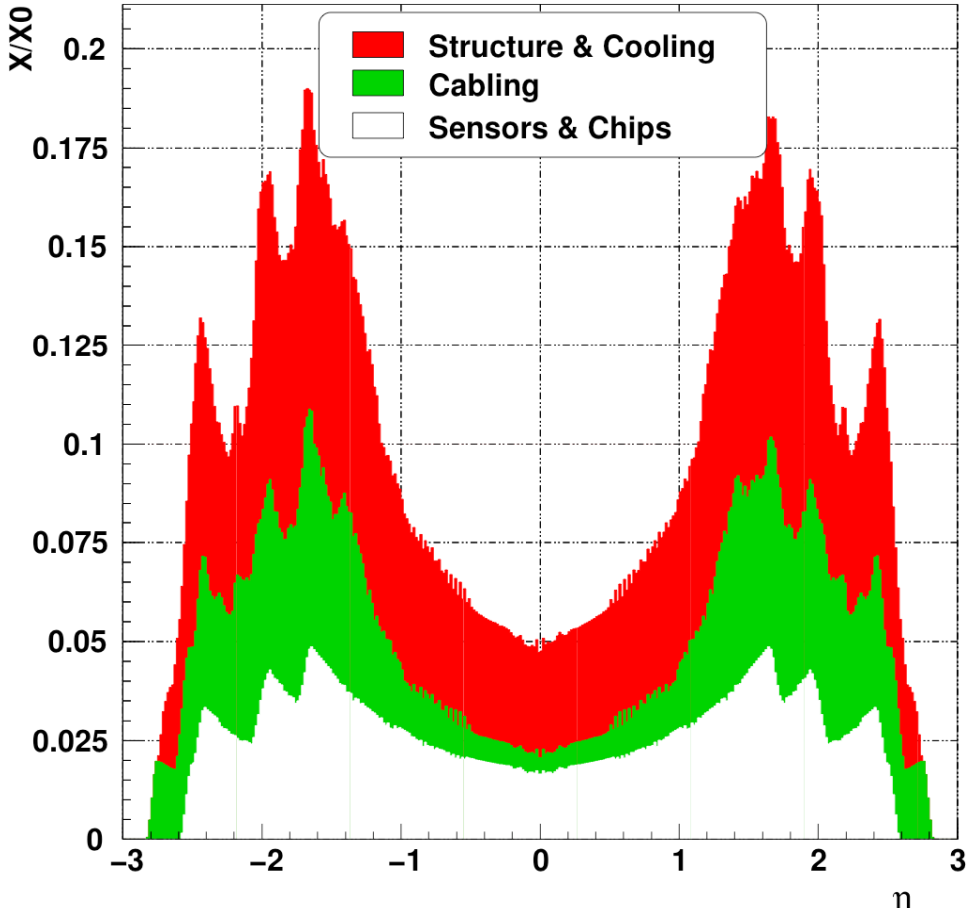
Ideal material is CCA: low density, good solderability. We use 10% Cu cladded Al wires with 0.25mm diameter.

Material	Conductivity [S m / mm^2]	X0 [mm]	Product [S]
Cu	58.5	14.4	8.42E5
CCA	37.7	81.5	3.07E6

➔Gain factor 3.6 with CCA
➔Multiplies factor 6.2 from regulators
➔Can save factor 22 in material budget with regulators and CCA!

Impact on material budget

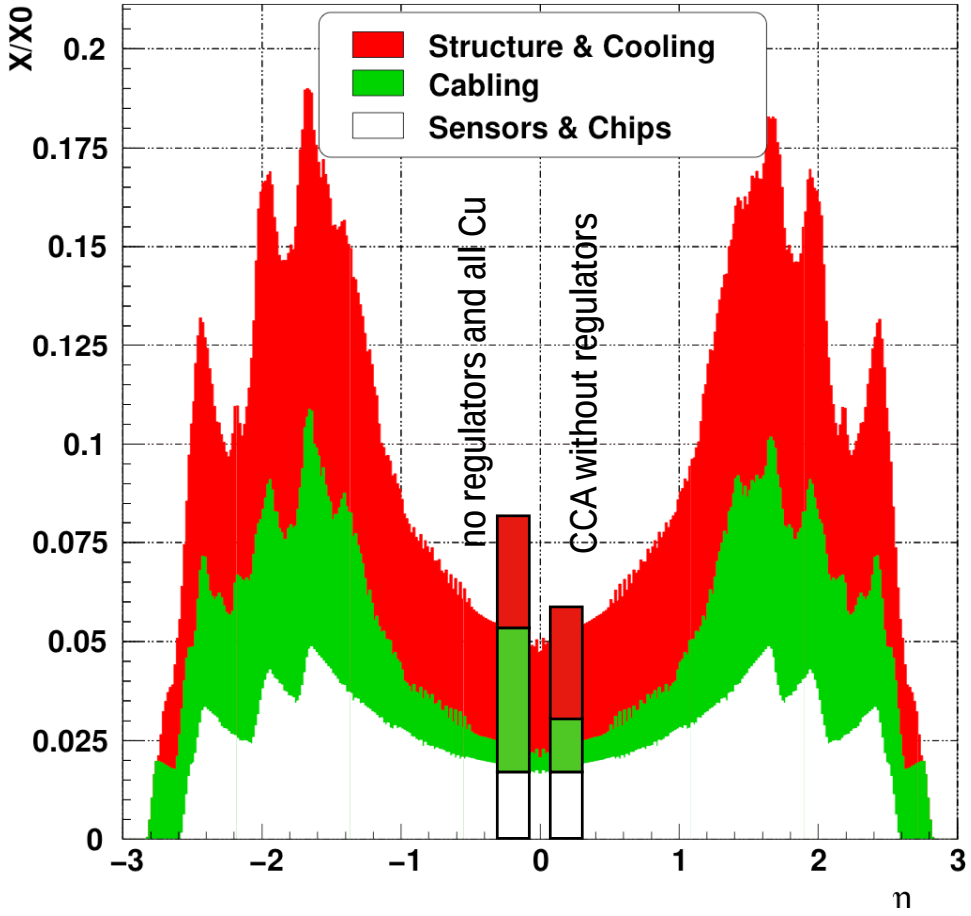
- Material budget for the 3 pixel layers as a function of eta.
- In the region eta<1.1 cabling is about 3% of the full MB. About 27% of thereof are power cables



Impact on material budget

Comparison for eta=0

1. All Cu solution without regulators:
   Power cables are 43% of MB
2. CCA without regulators:
   Power cables are 11% of MB
3. In actual detector:
   Power cables are 3% of MB



Conclusion

The CMS pixel readout chip uses 6 on chip voltage regulators

- Larger voltage drops can be accepted and thus smaller wire cross sections.
- Together with the CCA wires the gain in material budget is substantial.
- Regulators help to keep sensitive supply nodes quiet (power noise rejection)
- The price is some 15% more power consumption on the chips