STAR PXL Detector Sensor Cable Development

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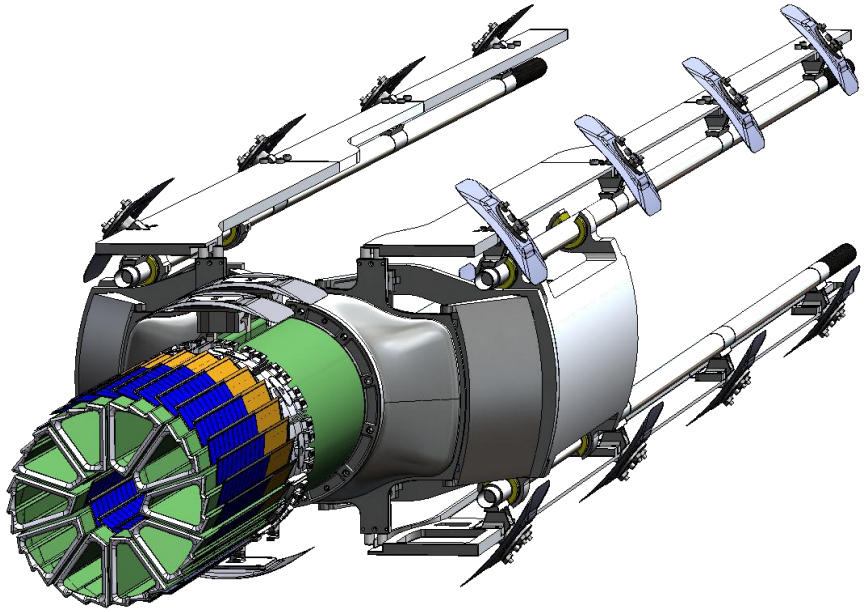

Workshop on system integration of highly granular and thin vertex detectors

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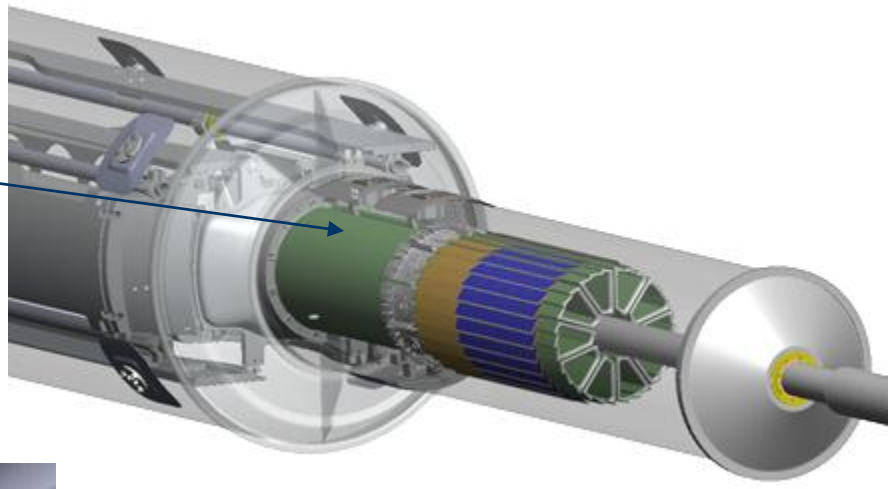
Mont Sainte Odile, France

Outline

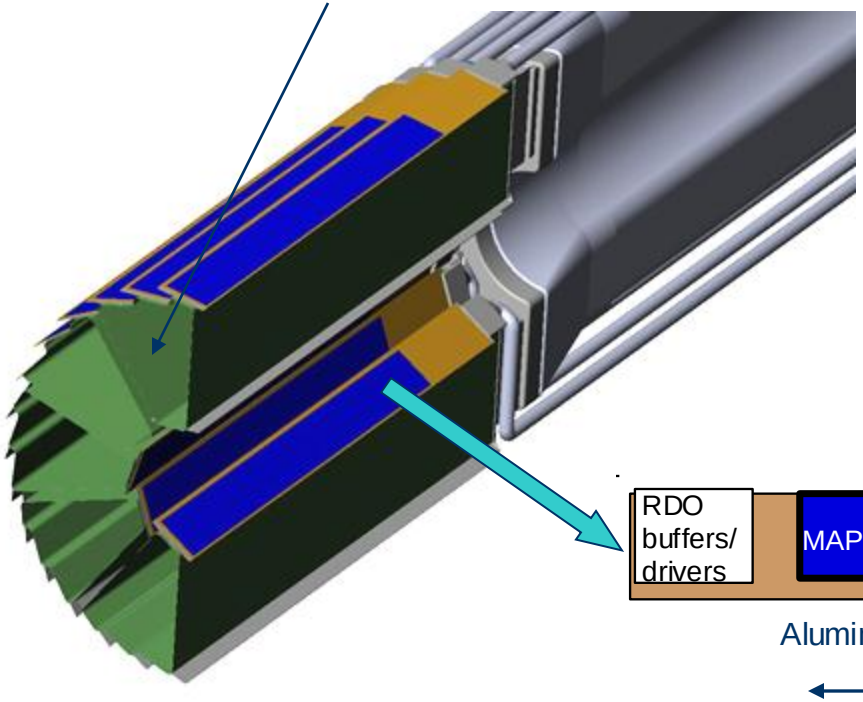
- Introduction
- PXL ladder characteristics
- Cable development plan
- Infrastructure testing board
- Testing parameters
- Testing results
- Summary

PXL detector mechanical design

Mechanical support with kinematic mounts (insertion side)

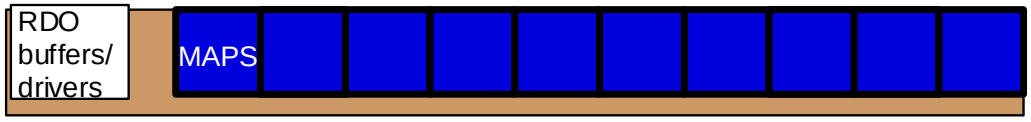


carbon fiber sector tubes (~ 200μm thick)



Insertion from one side
2 layers
5 sectors / half (10 sectors total)
4 ladders/sector

Ladder with 10 MAPS sensors (~ 2×2 cm each)



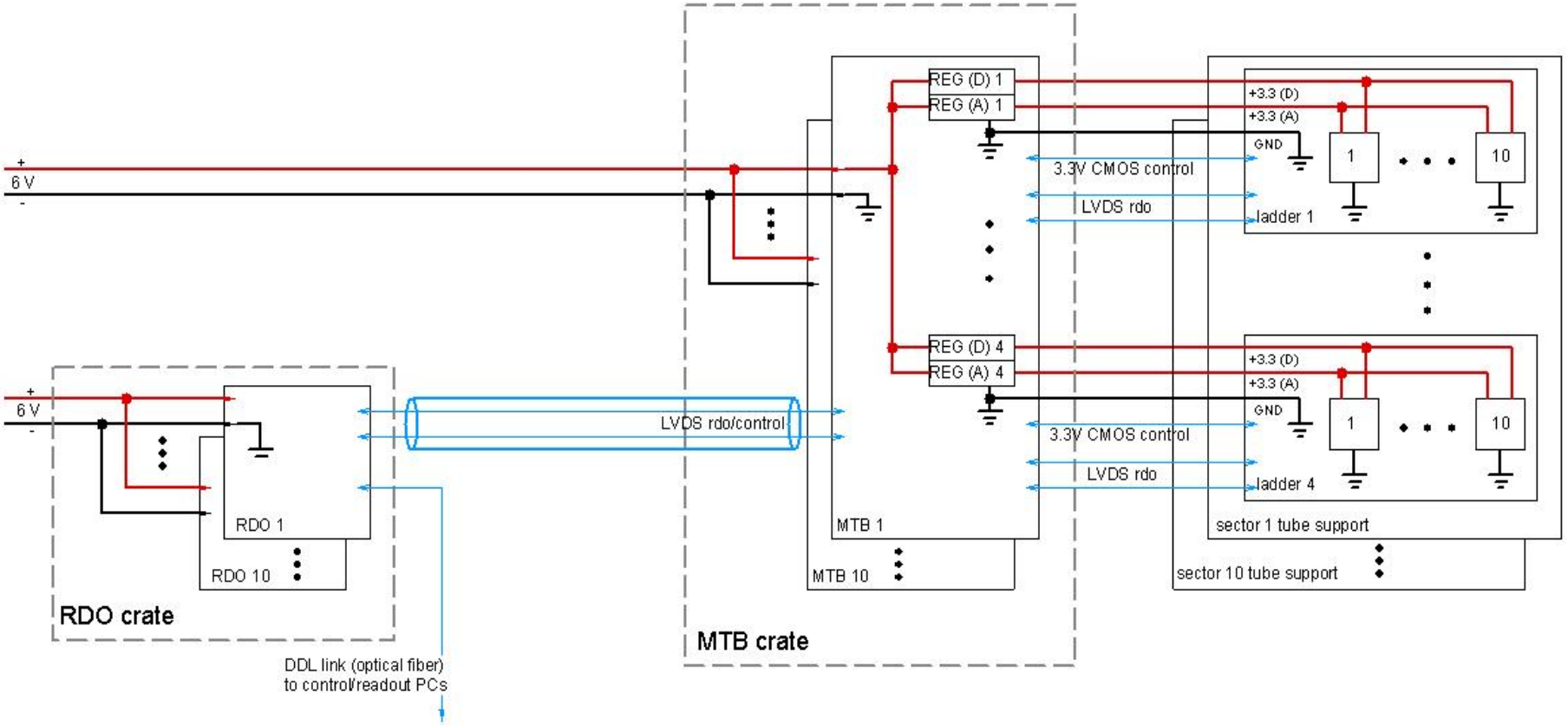
Aluminum conductor Ladder Flex Cable

20 cm

PXL electrical connection diagram

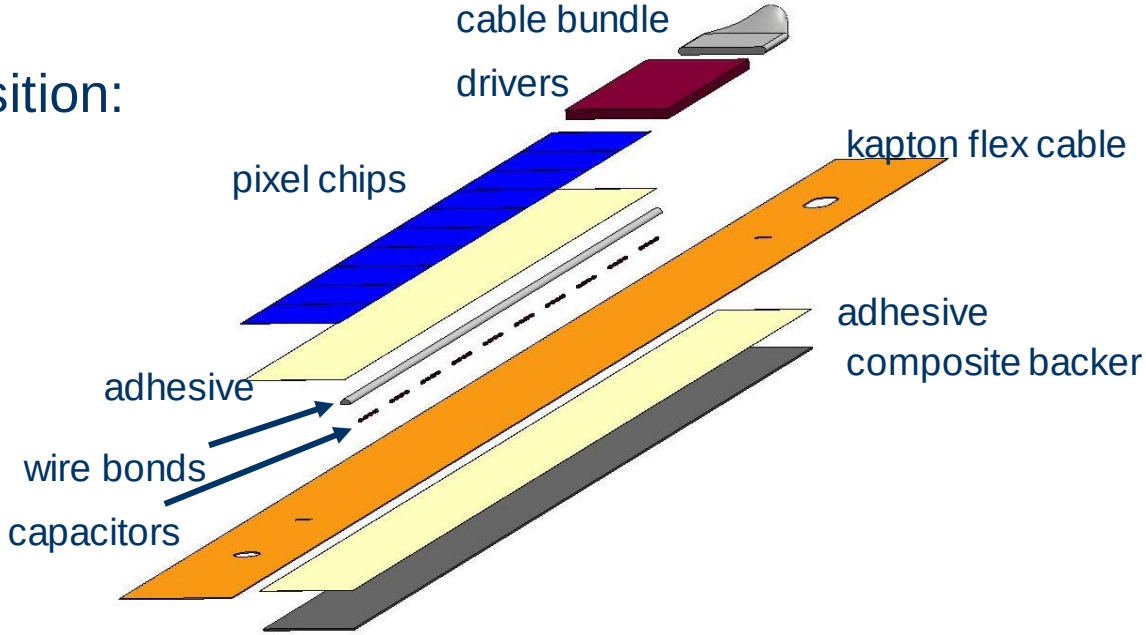
10 parallel systems, each composed of:

- 4 ladders (1 sector)
- Mass Termination Board
- Readout board



PXL ladder and cable

Ladder composition:



Signal count on the cable for 2 generations of PXL sensors:

Signal	# of traces	type	Width (0.005" t&s)
Sensor output (PH-2)	10 x 4 x 2 = 80	LVDS	0.800" (20.32 mm)
Sensor output (Ultimate)	10 x 2 x 2 = 40	LVDS	0.400" (10.16 mm)
CLK	2	LVDS	0.020" (0.51 mm)
CLK_RETURN*	2	LVDS	0.020" (0.51 mm)
Marker*	2	LVDS	0.020" (0.51 mm)
START (PH-2)	1	CMOS	0.010" (0.25 mm)
START (Ultimate)	2	LVDS	0.020" (0.51 mm)
SPEAK*	1	CMOS	0.010" (0.25 mm)
JTAG + RSTB*	5	CMOS	0.050" (1.27 mm)
TEMP	2	analog	0.020" (0.51 mm)
Total (Phase-2)	95		0.950" (24.14 mm)
Total (Ultimate production)	52		0.520" (13.22 mm)

*- signals required for prototyping and testing but not on final production boards.

Phase-1 – challenging

Ultimate – a bit easier

Current goal of cable development

Preliminary Design: Hybrid Copper / Aluminum conductor flex cable

- 2 layer Al conductor cable with vias in low mass region
- 0.004” (100 µm) traces and 0.004” (100 µm) spaces
- 70% fill factor
- Conductor thickness in low mass region is 21 µm (Cu) or 32 µm (Al)
- Kapton thickness is 25 µm.
- Bond wire connection between Al and Cu cable sections.
- Cable size is approximately 2.3 cm x 28 cm.

Low mass region calculated X_0 for Al conductor = 0.073 %
Low mass region calculated X_0 for Cu conductor = 0.232 %

PXL cable development plan

1. **Infrastructure testing board (ITB)**
   - Evaluate general design of running 10 sensors on a ladder
   - Find and test the working envelope of bypass capacitance and power supply and ground connections
2. **Prototype detector cable – FR-4 with Cu traces**
   - Correct size and the same layout geometry as the final cable
   - attempt to have the thickness of the Cu layer mimic the final cable to give the correct power and ground impedances
   - testing of this cable via digital output only
3. **Prototype detector cable – Kapton with Cu traces**
   - direct translation of the previous stage cable into a Kapton flex cable
4. **Prototype detector cable – Kapton with Al traces**

Infrastructure Testing Board (ITB)

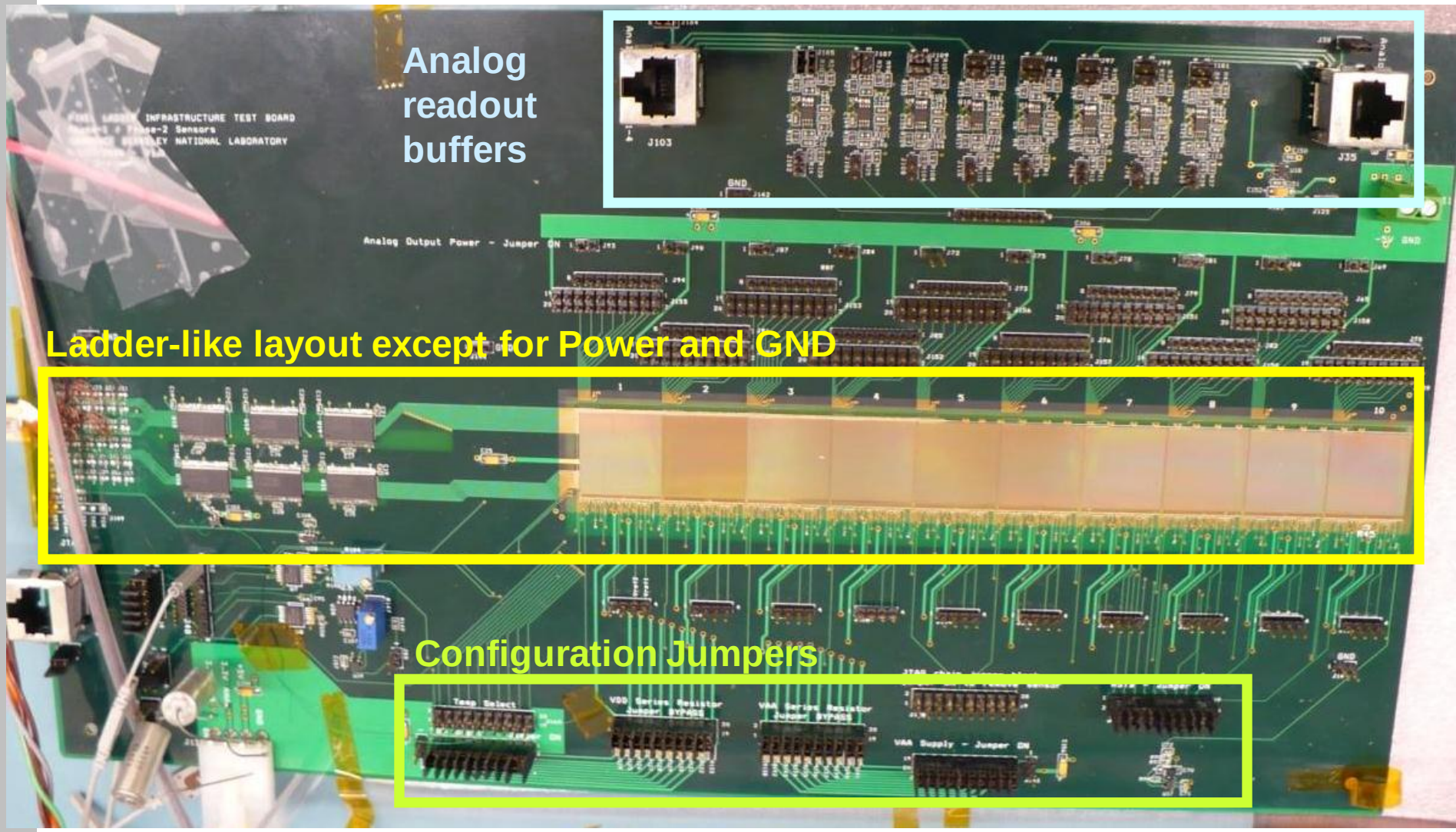
- Phase-1 (Phase-2) sensor

- Phase-1 prototype
  - Reticle size (~ 4 cm²)
    - Pixel pitch 30 µm
    - ~ 410 k pixels
  - Column parallel readout
  - Column discriminators
  - Binary readout of all pixels
  - Data multiplexed onto **4 LVDS outputs @ 160 MHz**
  - **Integration time 640 µs**
- Phase-2 prototype
  - Small mask adjustments to improve discriminator threshold dispersion

ITB with 10 sensors (Phase-1, 2)

- Analog readout - one sensor at a time
- Jumper selectable power source to each individual sensor
- In series replaceable resistor for each sensor power supply (analog and digital)
- Removable board level capacitor bypassing
- Removable individual sensor capacitor bypassing
- Readout over 2 m fine wire as per final ladders
- Readout through the full HFT data path including MTB, 160 MHz LVDS CLK
- All buffering and drivers use the same chips as the final ladder
- First prototype with full-thickness Phase-1, the second prototype with 50 µm Phase-2

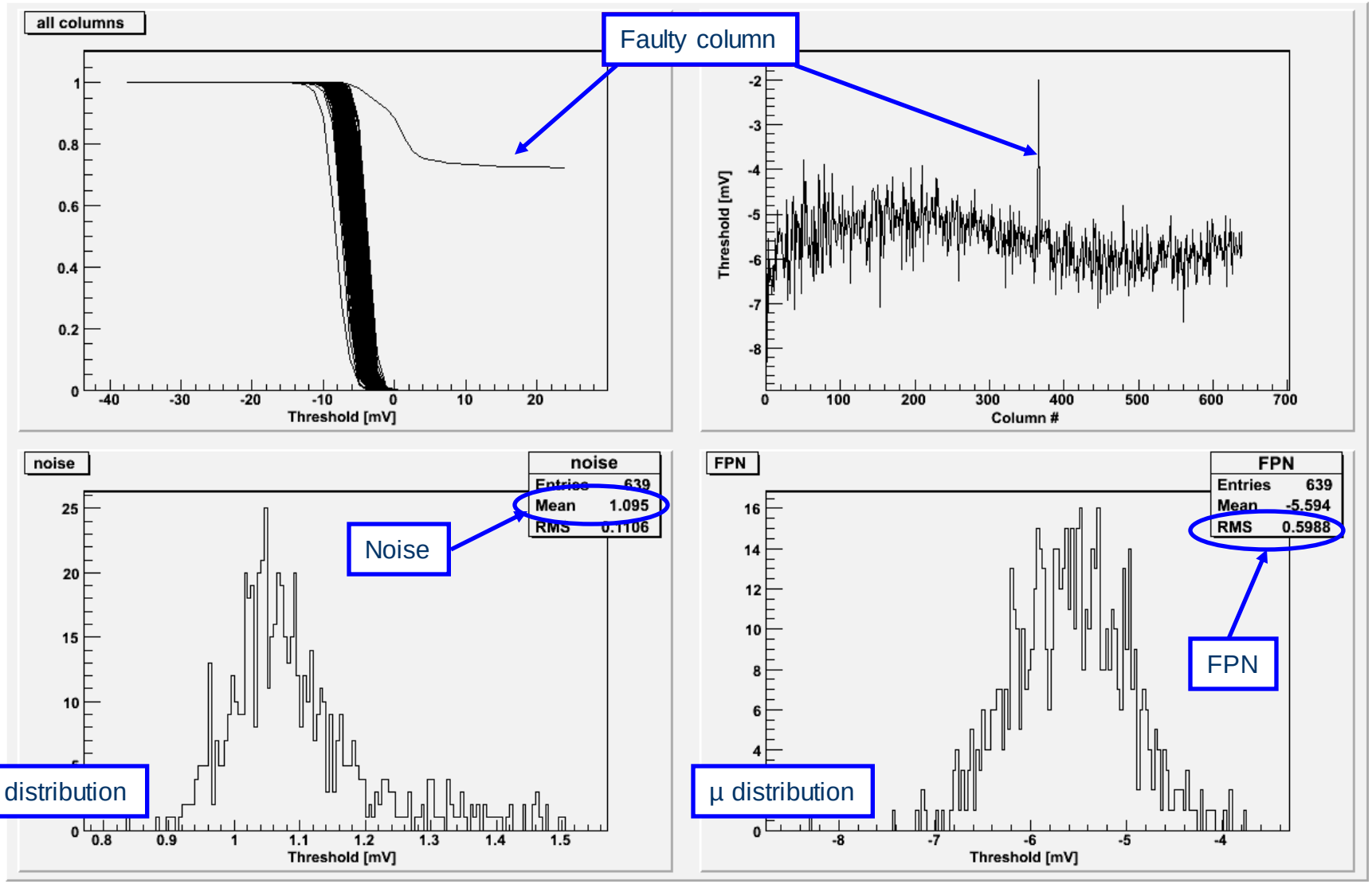
ITB layout



(9× Phase-1, 1× Phase-2)

Test parameters

- Sensor characterization – fit threshold scan data to the error function



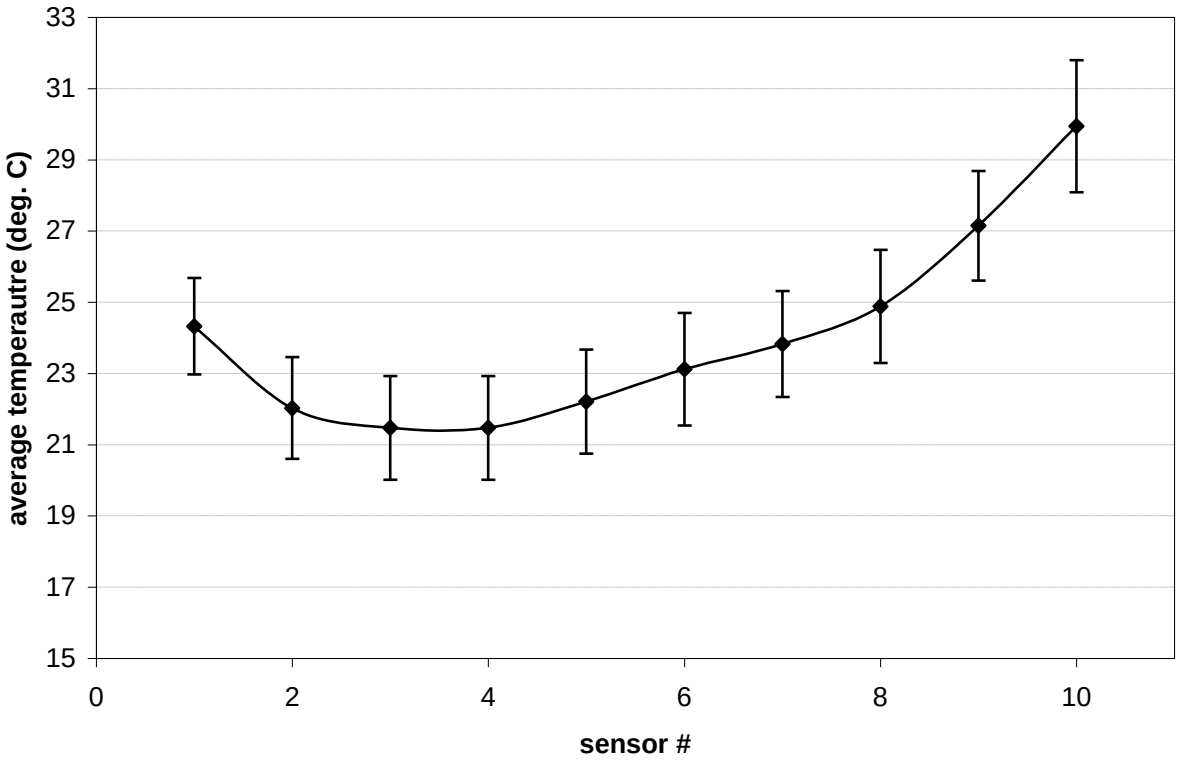
Testing conditions

Data labels used	Testing condition
ref	each sensor measured individually, other sensors OFF
3.3 V	Default voltage
3.0 V	Reduced voltage
5_Ohm	Additional resistance between the ITB power supply and each of the sensors
C34_35	Half of VDA and VDD small bypassing capacitors
C32-25	no VDA, VDD small capacitors
0.5xC	Reduced number of VCLP capacitors
0xC	no VCLP capacitors near sensors
BUS	Bus type power distribution; 2 buses: VDA, VDD
1PWR	Two buses connected together, single power supply
(low activity)*	Low switching activity: all sensors' thresholds set high, at 250 DAC
(high activity)	High switching activity: each sensor was configured for zero threshold

NOTE: progressive capacitor removal (top-to-bottom)
** A Phase-1-based PXL prototype would operate at <300 hits per sensor (inner layer)*

Testing results – temperature

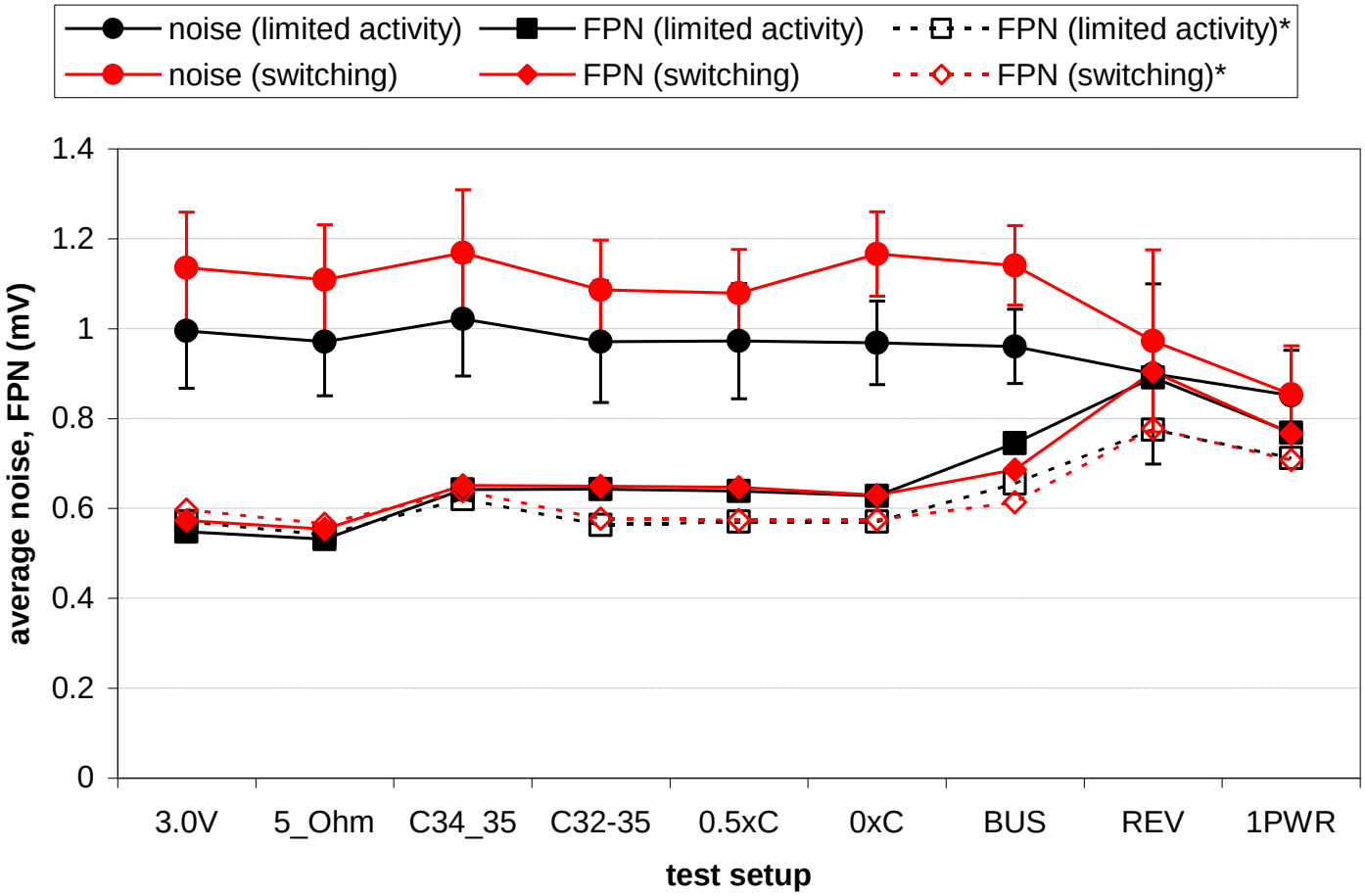
- average ITB temperature profile observed consistently throughout the test (results from the characteristics of the cooling system)



Sensor performance is independent of temperature in this range

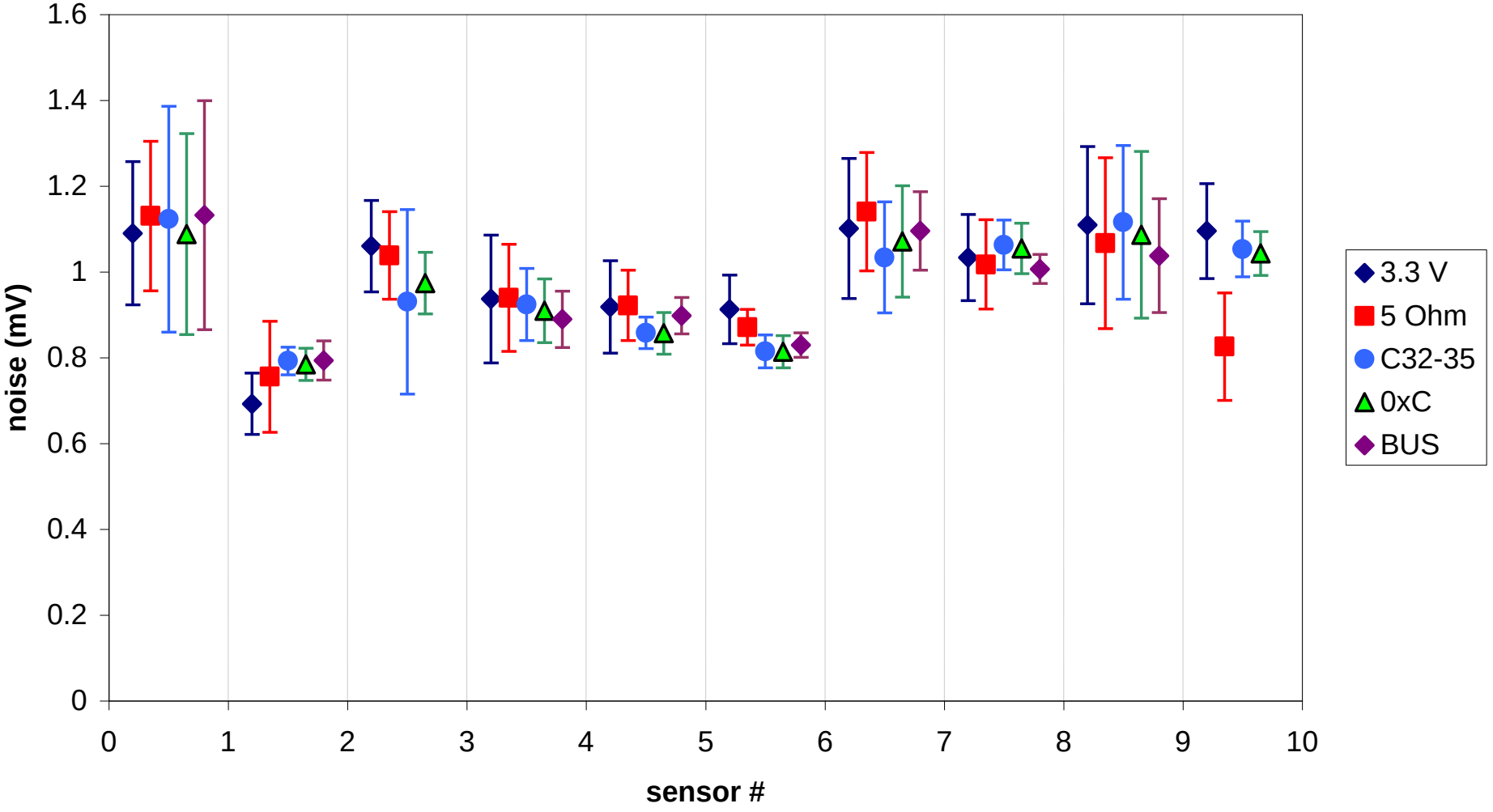
Testing results – noise in the digital readout

- Average noise and FPN extracted from threshold scan measurements for different
- FPN data marked with * excludes the first two sensors in the chain
- Error bars - standard deviation (σ) of the noise distribution.



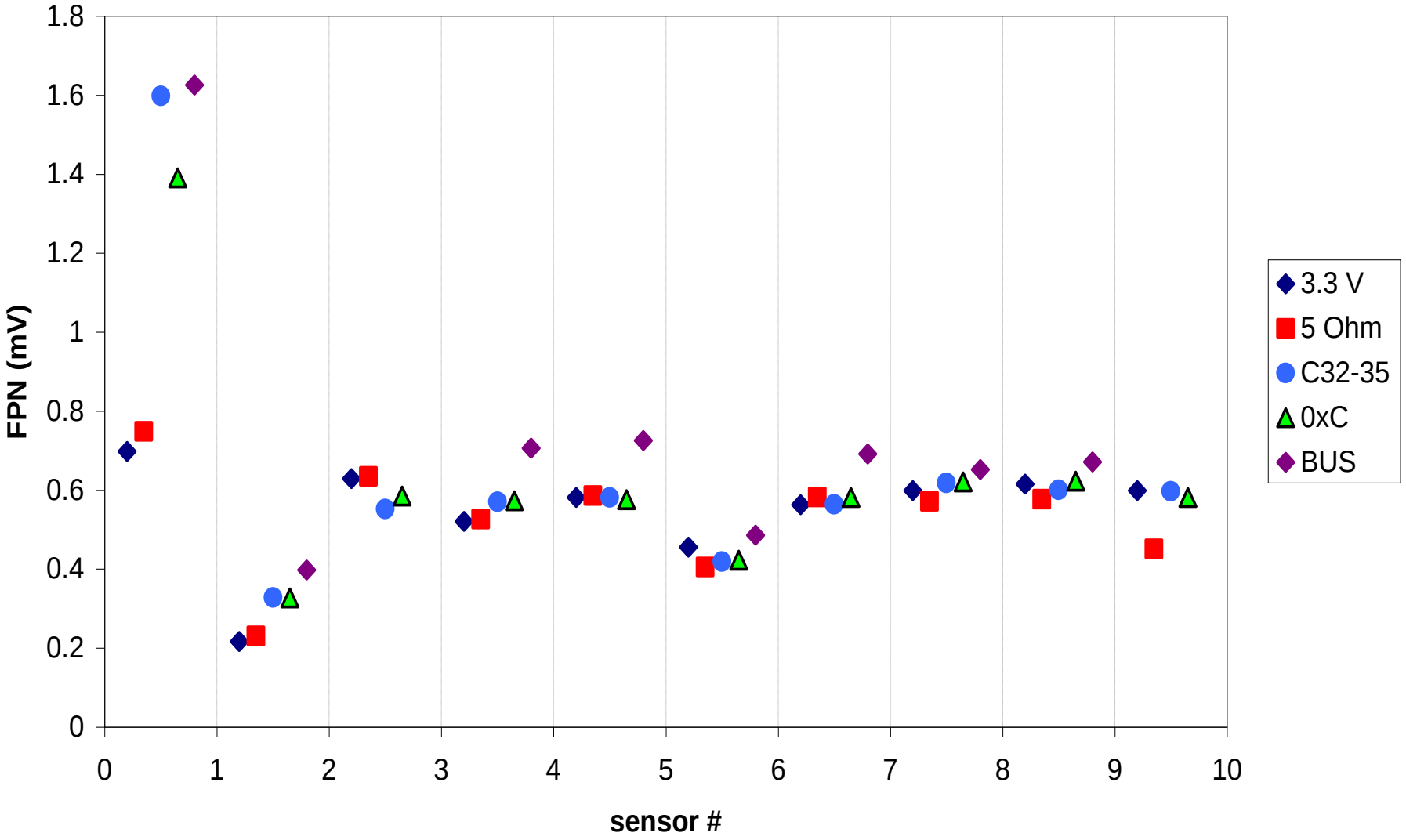
Noise performance

Low switching activity

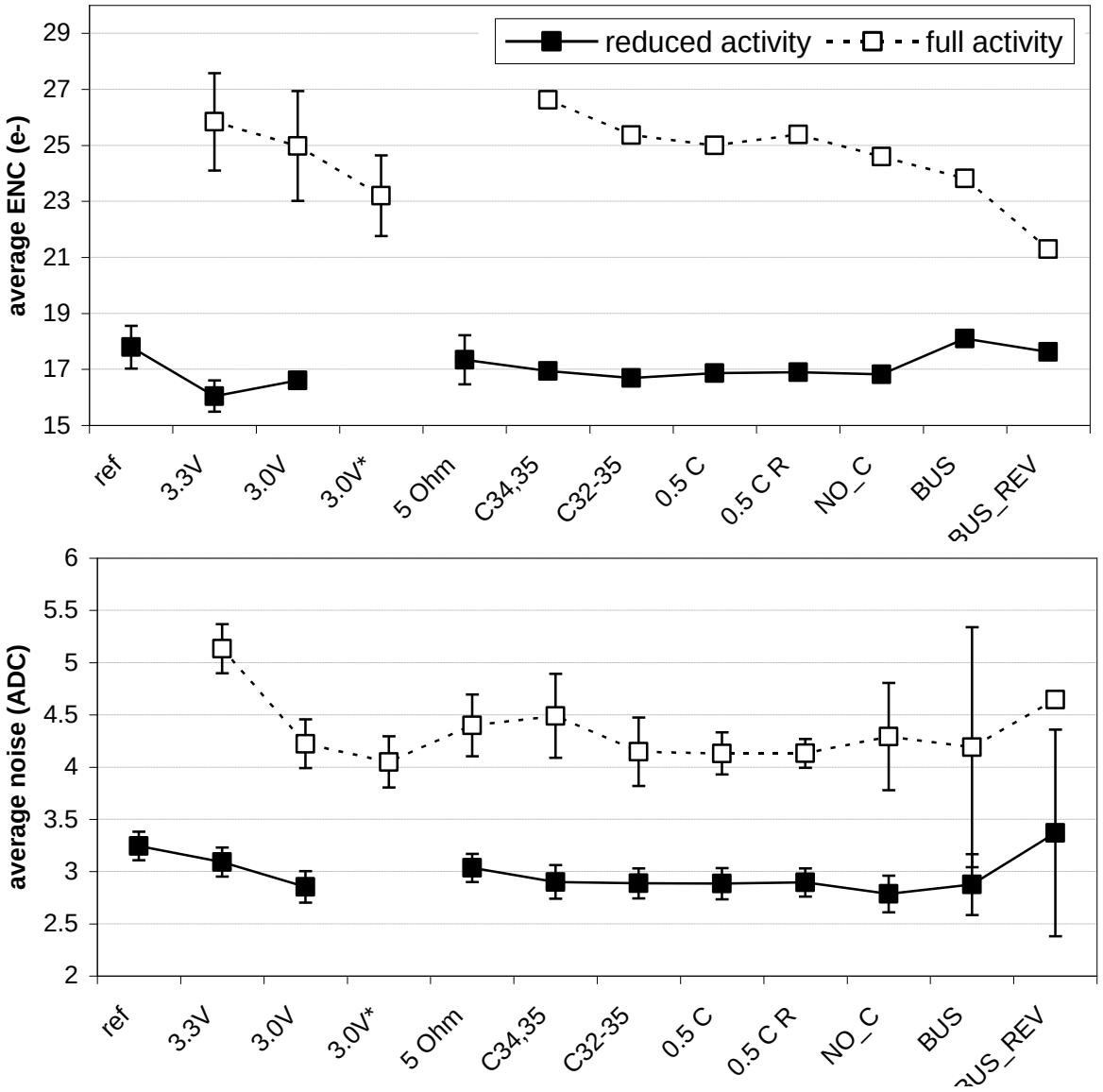


Fixed pattern noise

Low switching activity



Analog output test results



Summary

- Phase-1 sensor performance appears independent of the number of high-frequency decoupling capacitors on the board (confirmed by analog and digital readout)
- Unaffected performance after removing all small capacitors associated with VDD, VDA and VCLP voltages.
- Test results obtained from threshold scans suggest that the bus-type power distribution provides, on average, a slightly better noise performance but with an increased FPN. Both effects are within 10-20 % and with the damaged sensor readout and limited testing capabilities can not be considered accurate.
- ITB equipped with 50 µm Phase-2 sensors is under test
- Stage 2 – FR4 prototype cable is in the design phase for the PXL production sensor (Ultimate)

- Backup slides

PXL grounding plan