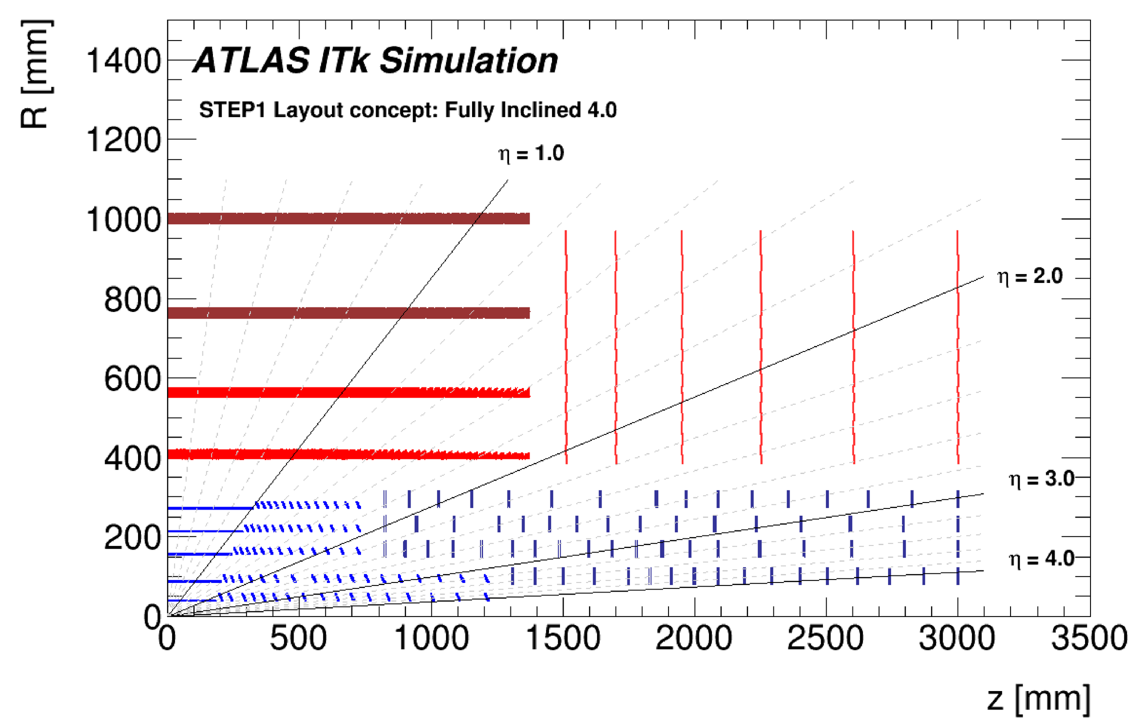
ATLAS Phase-II Upgrade Pixel Data Transmission Development

Jason Nielsen, on behalf of the ATLAS ITk project
Santa Cruz Institute for Particle Physics, University of California, Santa Cruz
jnielsen@ucsc.edu

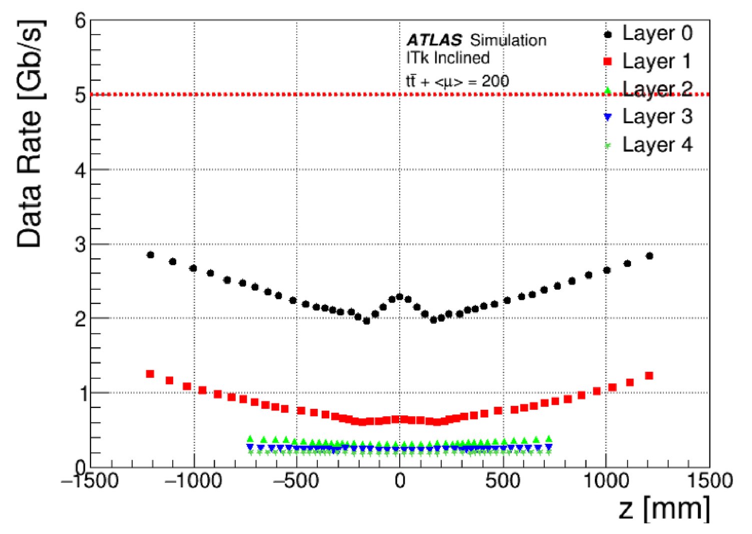
Pixel system of ATLAS ITk project for HL-LHC

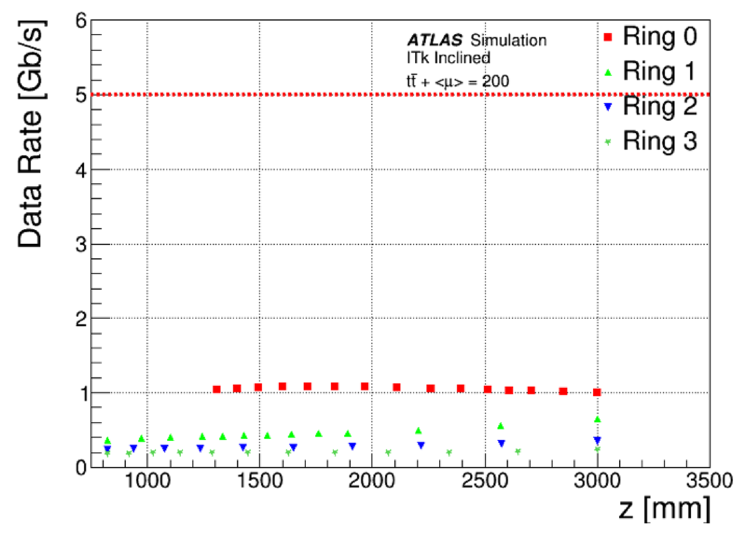


Proposed pixel system (in blue), consists of 5 barrel layers with flat and inclined sensors, plus endcap rings.

Several meters of electrical links run through the high-radiation environment of the pixel volume to the optical transceivers.

Simulated data rates [below] fit within the 5.12 Gb/s bandwidth requirement, assuming $\langle\mu\rangle$ =200 and full read-out at Level-0 trigger rate of 1 MHz (baseline). Outer layers are fully read out at backup mode of operation (Level-0 rate of 4 MHz).





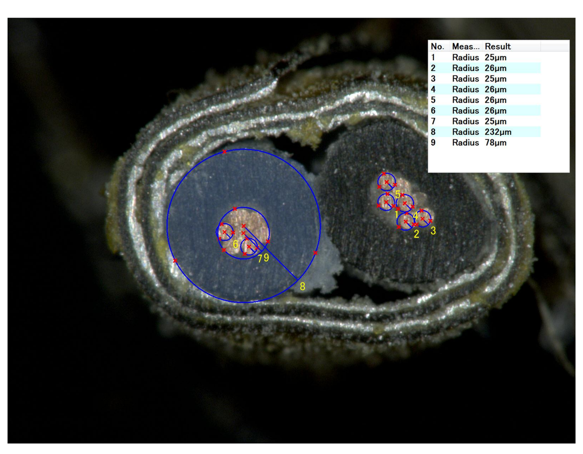
5.12 Gb/s Electrical Data Transmission System Design Goals

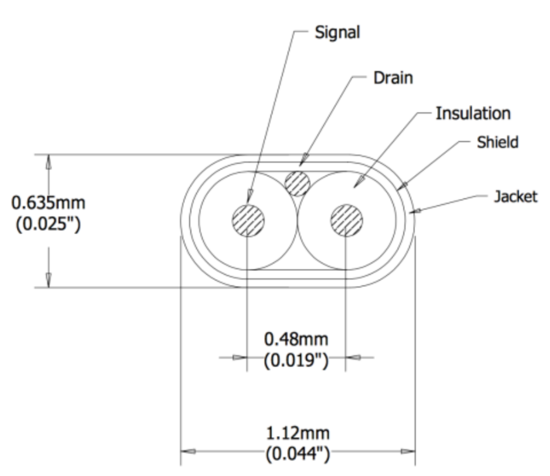
- Differential signaling with 100 or 70Ω impedance, using balanced signal coding (64B/66B) and AC-coupling.
- Attenuation less than 20 dB end-to-end at 3.0 GHz (safely above Nyquist frequency), including connectors. This leads to open eye diagrams with conventional signal conditioning implementations.
- Bit-Error Rates $< 10^{-12}$ with standard pseudo-random data
- Electrical and mechanical tolerance to 10 MGray expected radiation dose in innermost layers.

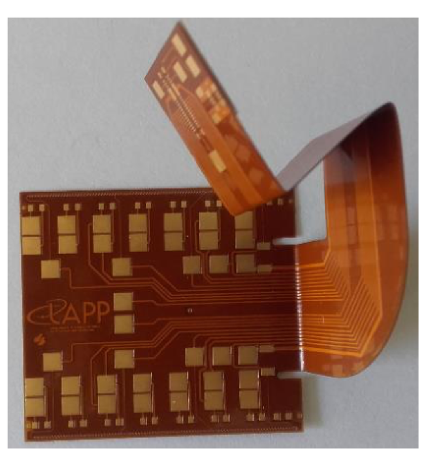
Physical Layer Prototypes

Several low-mass physical implementations are being characterized for use in different parts of pixel detector system:

- Small-gauge shielded twisted wire pairs (TWP) [below left]
- Shielded twin-axial cable (TA) of various gauges [below center]
- Low-mass flexible circuits (flex) [below right]

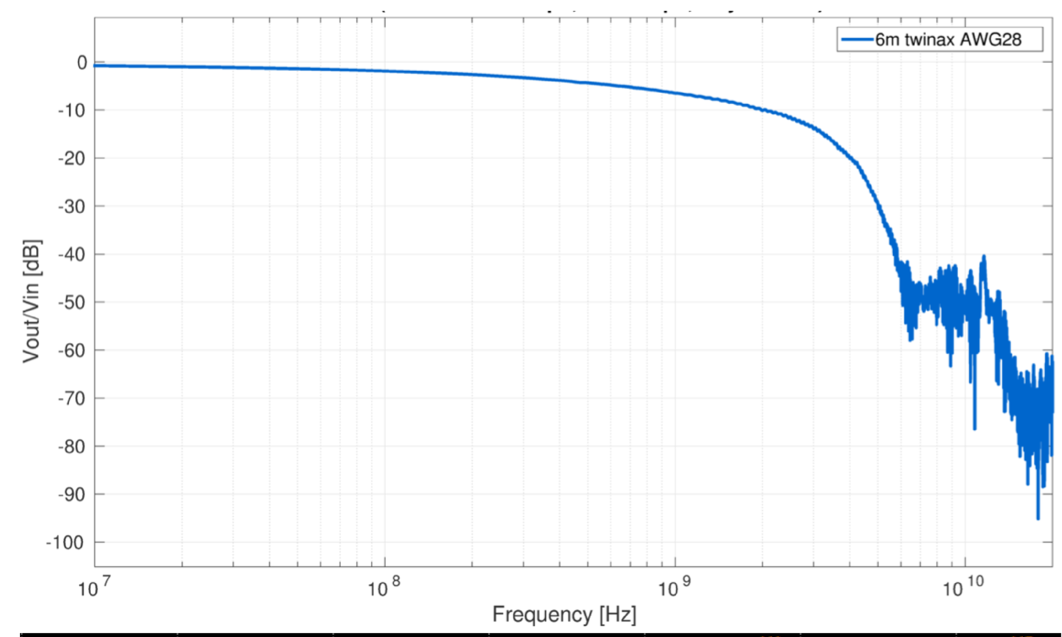


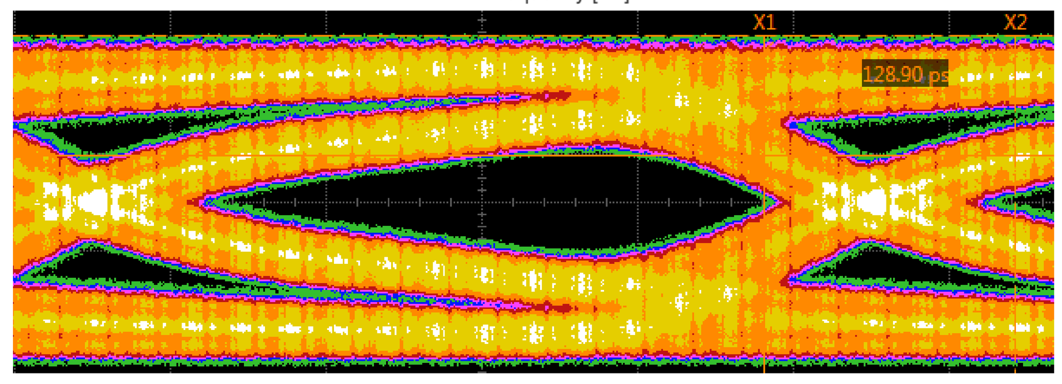




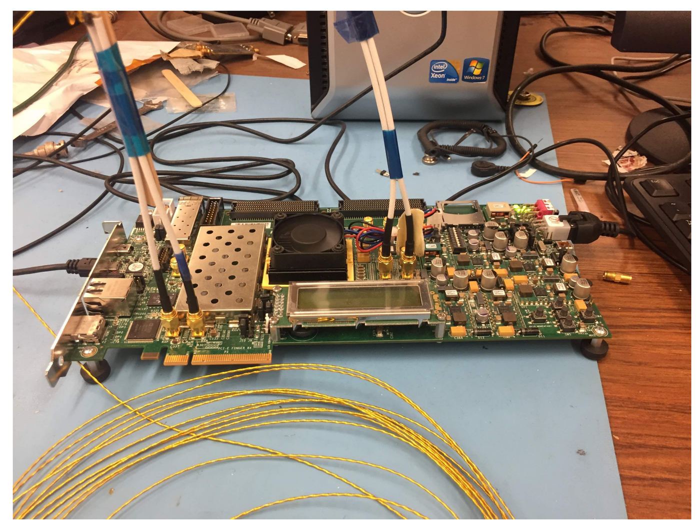
Preliminary Measurements

Differential S-parameters and voltage transfer function measured with 4-port vector network analyzer. Transfer function plot [below], for TA 28 AWG, shows attenuation of approximately 20 dB at 4 GHz. The corresponding open eye diagram at 2.56 GHz shows the relationship between this level of attenuation and a stable electrical link.





Bit-Error Rate (BER) tests use Xilinx FPGA boards [right] with multi-gigabit transceivers. Tests verify maximum transmission rates that satisfy stricter BER $< 10^{-14}$.

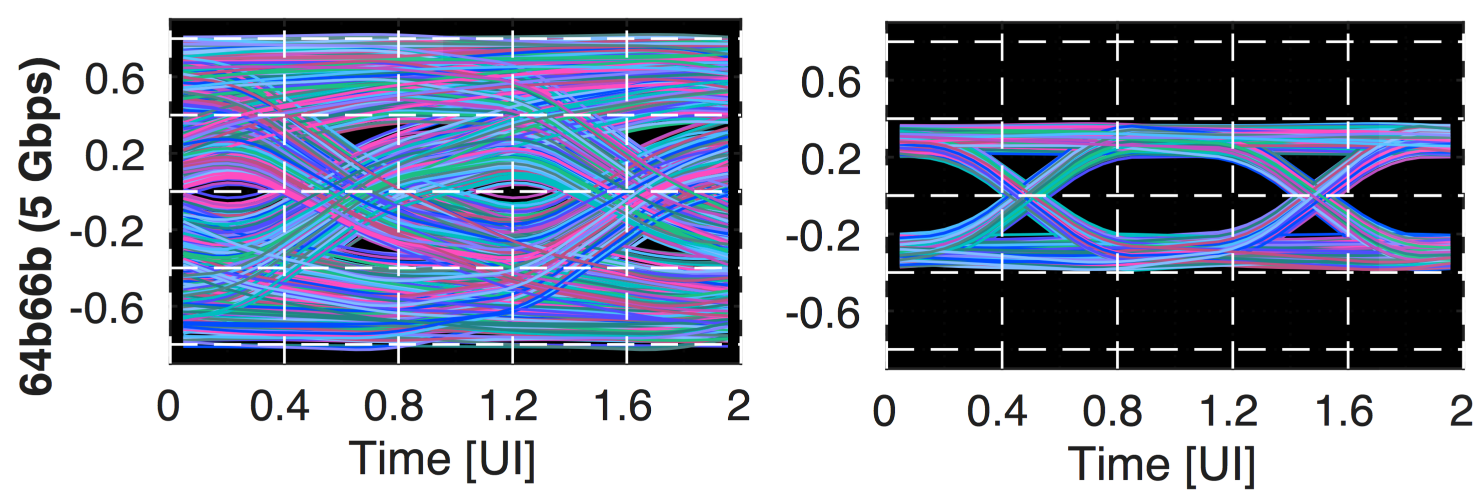


Device	Length	Attenuation @ 3 GHz	Max Rate (DC bal.)
TA 28 AWG	6 m	14 dB	8.000 Gb/s
TA 30 AWG	6 m	17 dB	6.220 Gb/s
TA 34 AWG	4 m	20 dB	6.220 Gb/s
TWP 36 AWG	1 m	5 dB	4.976 Gb/s

Signal Conditioning Development

High-frequency roll-off in system requires active compensation:

- Pre-emphasis boosts the high-frequency components of the waveform, compensating for the specific properties of a chosen system.
- Receiver equalization acts as a high-pass filter, either fixed or based on dynamic feedback to optimize signals (before/after shown below).



Conclusions

- Some prototypes achieve design goals for 5.12 Gb/s transmission over distances up to 6 m; others for shorter total distance.
- Aggressive signal conditioning is a necessity for the final system.

TWEPP 2017 – Topical Workshop on Electronics for Particle Physics, Santa Cruz, California