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High Speed Links in HEP @ Fermilab

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Detector R&D Advisory Group

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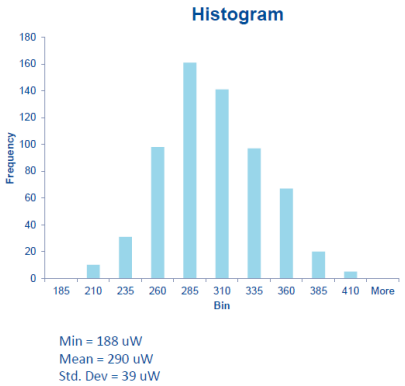
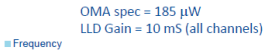
High Speed Links in HEP @ Fermilab
Outline

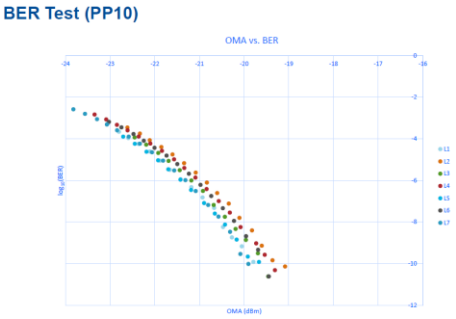
- Some History of Link Development @ FNAL
- Anatomy of Link and Components (Versatile Link Plus)
- Specifications and Measurements
- Demonstration System Testing
- What (Might Be) Next?

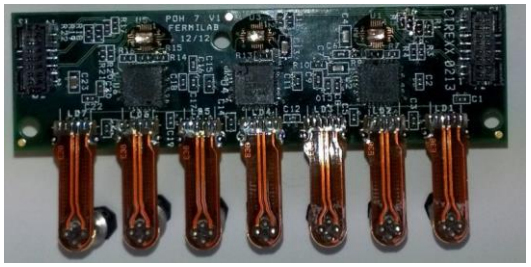
High Speed Links in HEP @ Fermilab
Some History

CMS Phase 1 FPix (SMF @ 400 Mbps)
Design, Production, and Qualification

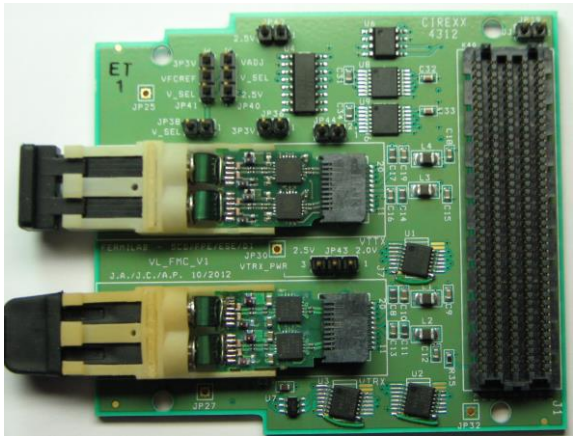




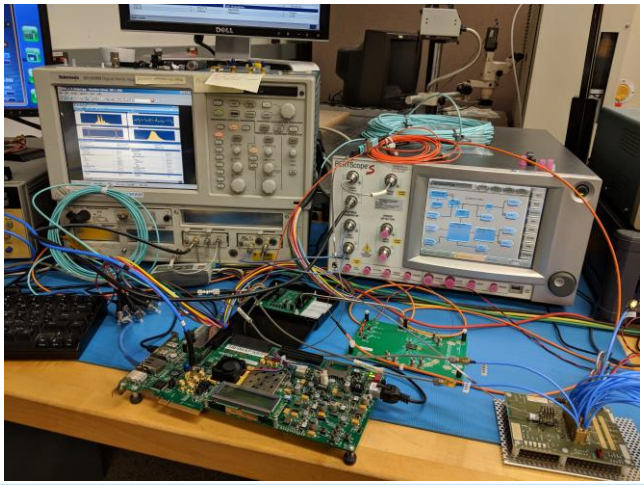




Versatile Link Common Project
MMF, SMF @ 4.8 Gbps
Single Channel or VTTx (Twin Transmitter)



Versatile Link Plus
MMF Only
Multichannel
Asymmetric Link Rates)



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Anatomy of a Link – Example: Versatile Link Plus

Versatile Link Plus

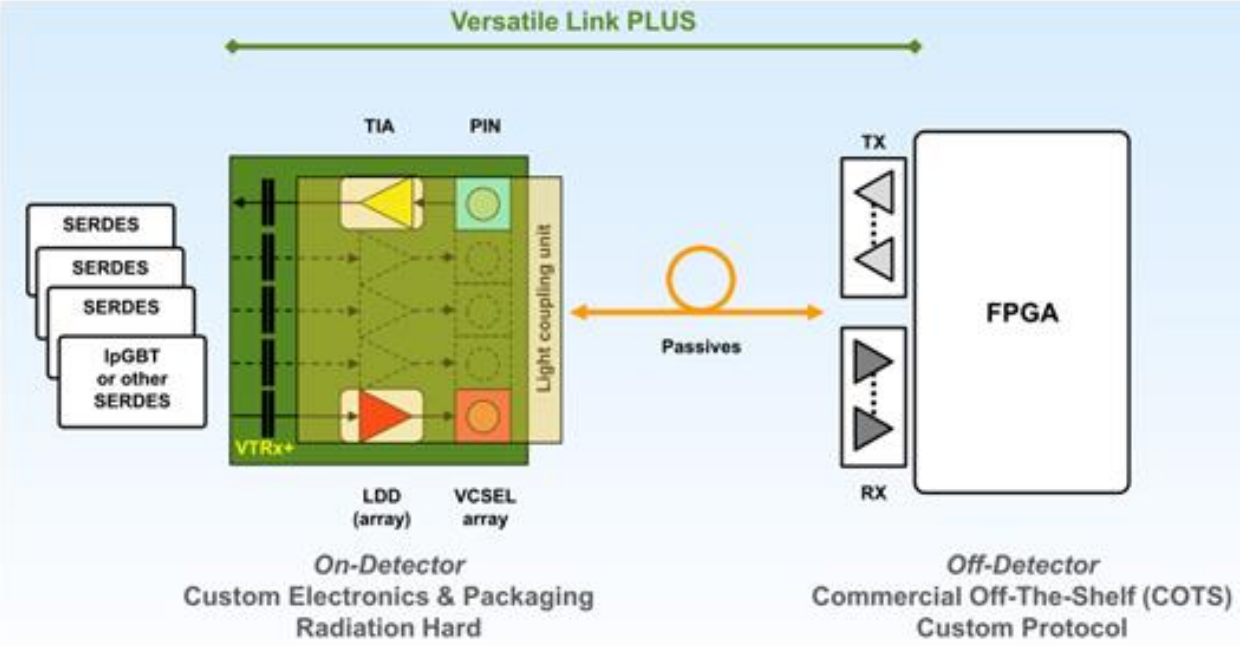

Figure 1: Versatile Link Plus (VL+) Architecture

Parameter	Symbol	Min	Typ	Max	Units
Bit Rate (uplink)	BR(U)	5.0		10	Gbps
Bit Rate (downlink)	BR(D)		2.5	TBD	Gbps
Bit Error Ratio[1]	BER			10^{-12}	
Link length	L		50	150	meter

Ref 1

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Specifications and Measurements

Link and Component Specifications

- Electrical Operating Specifications
- Optical Operating Specifications
- Environmental (PS, Temp, Rad., B Field)

Specification Documents Created for All Components in the Project
+
System Level Specification

Power Budget "minus" Impairments

Tx OMA – Rx Sensitivity

- Dispersion
- Bandwidth Limitation
- Laser Spectral Width
- Attenuation

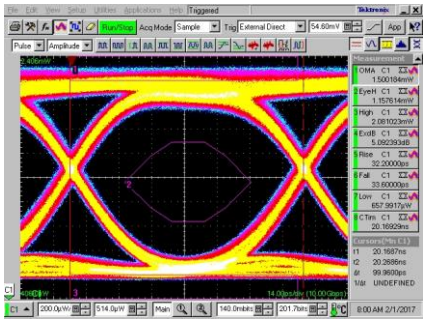
Bit Error Rate Testing

Determine Threshold of Acceptable Error Rate

Link Modelling (IEEE Standard Calculation Spreadsheet)

Eye pattern measurements

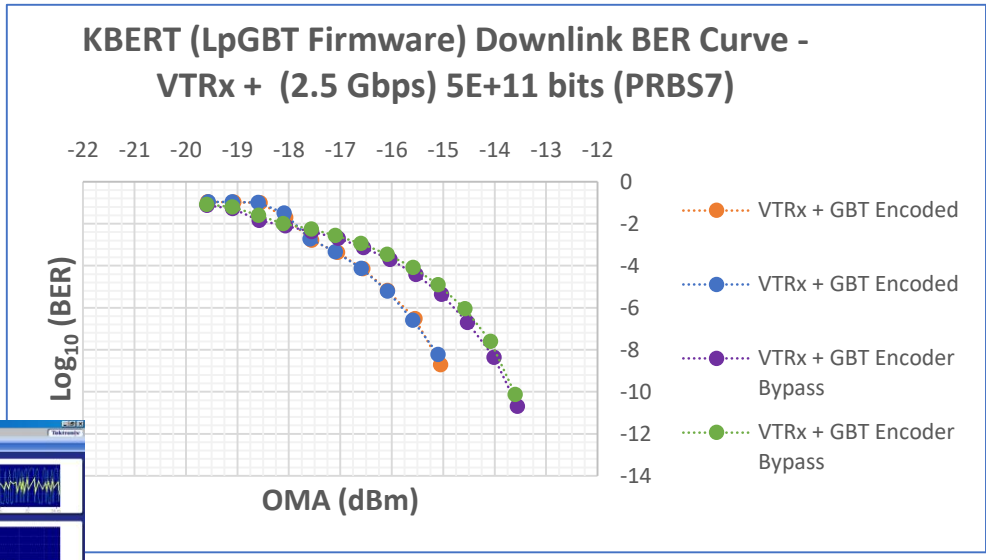
- OMA (dBm)
- Rise/Fall Time (ps)
- Extinction Ratio (dB)
- Eye Opening (% of OMA)



Jitter measurements

- Random Jitter (Gaussian, rms)
- Deterministic Jitter (peak to peak)
  - Duty Cycle Distortion
  - Period Jitter
  - Data Dependent Jitter

Total Jitter = DJ + αRJ



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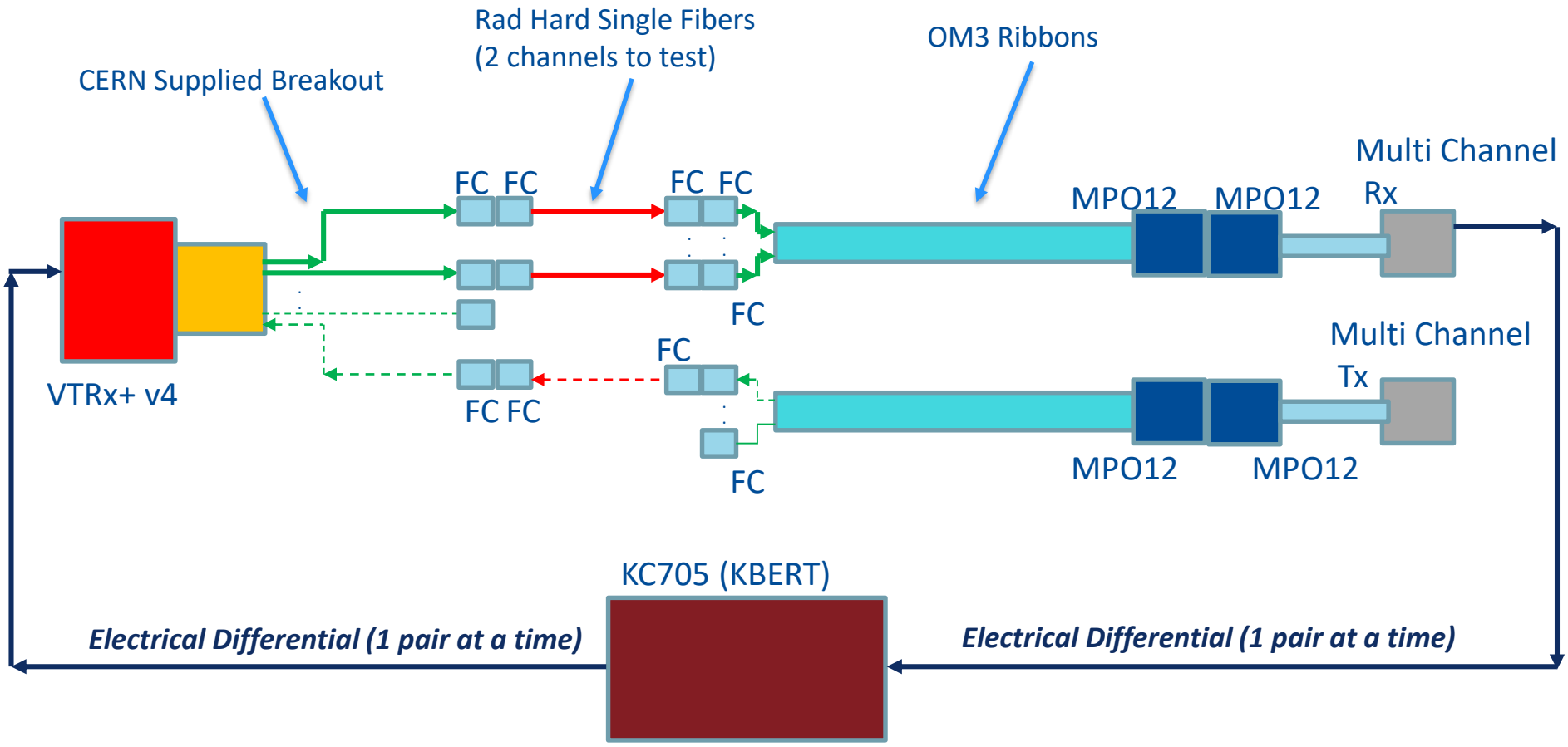
Link Level Testing for VL+

Test Configuration (~ 70 m for CMS Outer Tracker Geometry)



KBERT Implements FEC Encoding of lpGBT @ 10.24 Gbps

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What (Might Be) Next? – Multi-Level Signalling

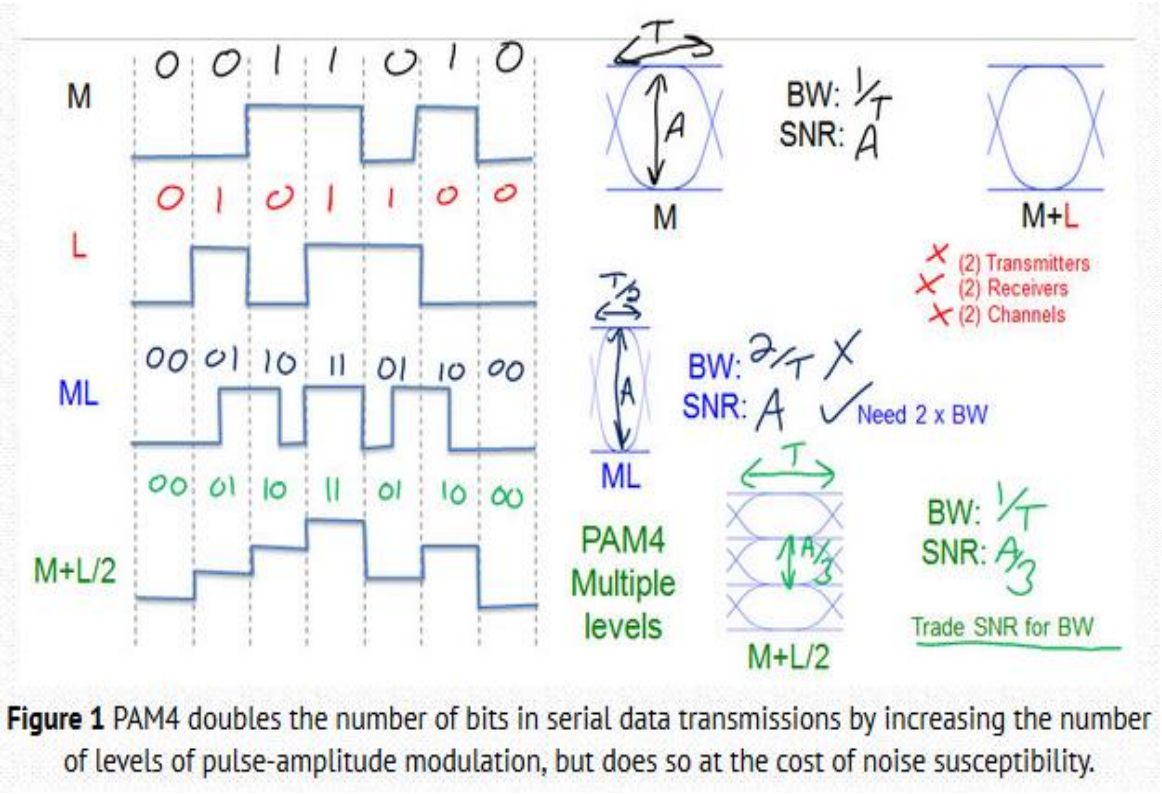
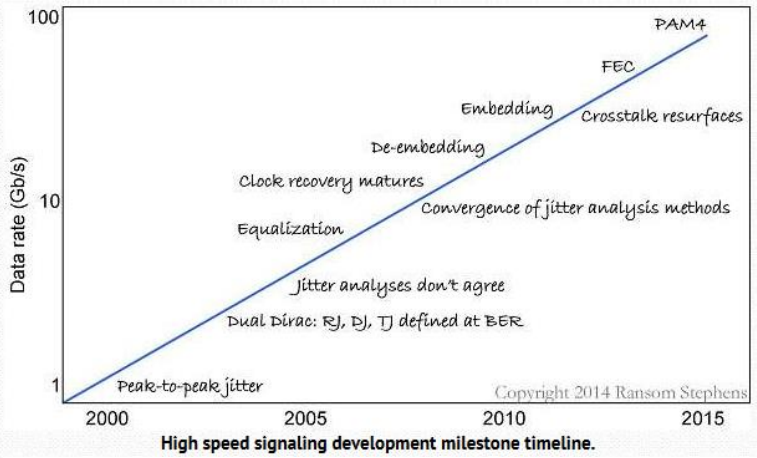
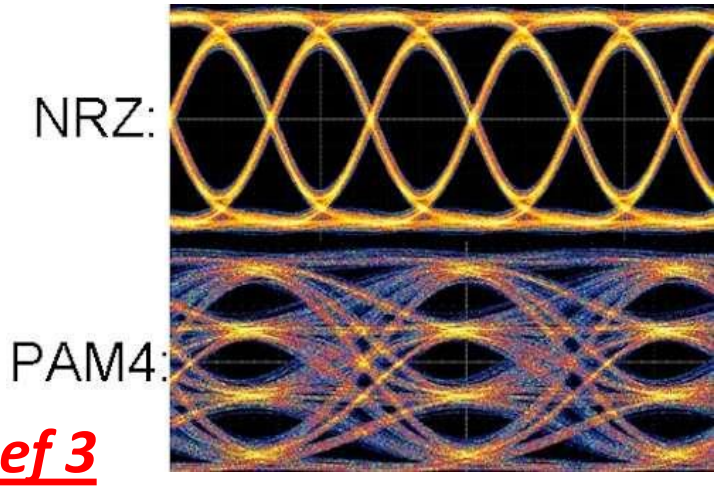


Figure 1 PAM4 doubles the number of bits in serial data transmissions by increasing the number of levels of pulse-amplitude modulation, but does so at the cost of noise susceptibility.

Ref 2



High speed signaling development milestone timeline.



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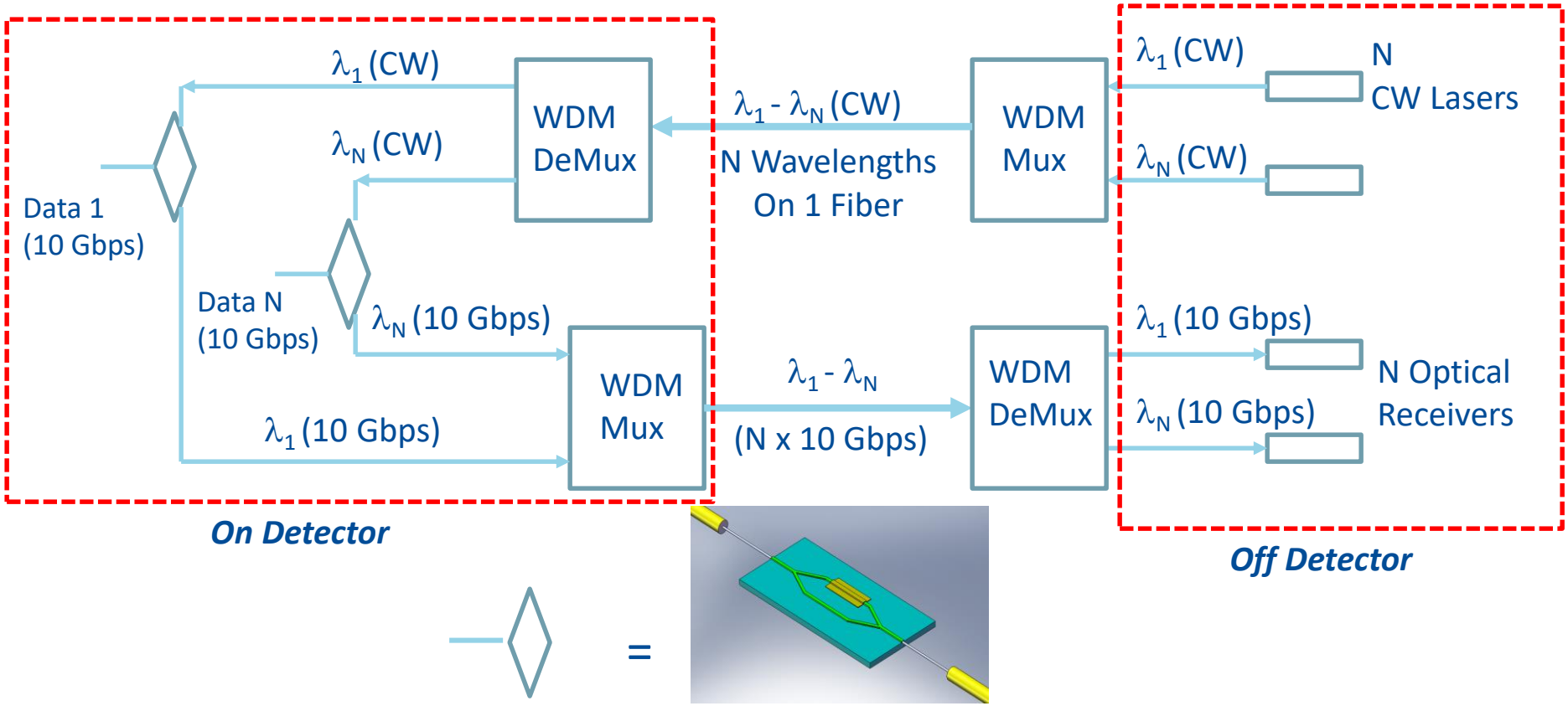
What (Might Be) Next? – WDM



Mach-Zehnder Intensity Modulator

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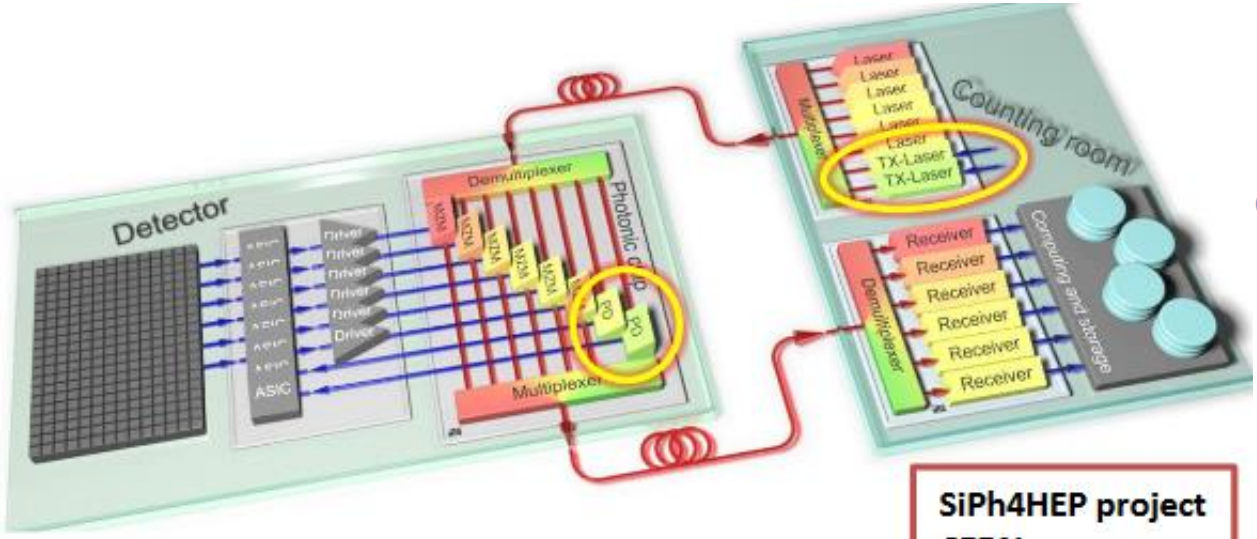
What (Might Be) Next? – WDM + Si Photonics



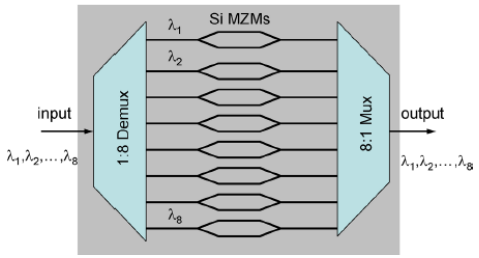
Ref 4

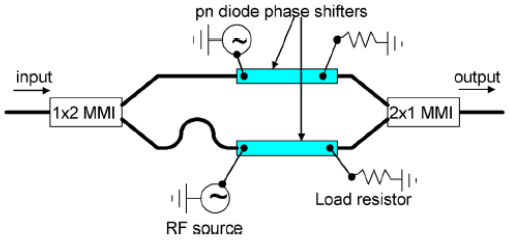
SiPh4HEP project
CERN
KIT
INFN
Bristol

Challenges:

- Still a maturing technology
- Design tools lagging behind ASICs
- MZMs require:
  - High modulation voltages (3 – 8 V_{pp})
  - Into 50 Ω
- MZM insensitive to NIEL but sensitive to TID:
  - But progress has already been made in the community!

IEEE JOURNAL OF SELECTED TOPICS IN QUANTUM ELECTRONICS, VOL. 16, NO. 1, JANUARY/FEBRUARY 2010





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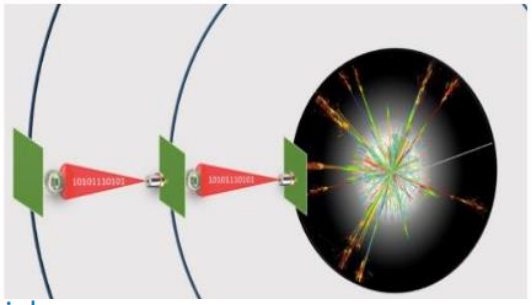
What (Might Be) Next? – Free Space Optics



Principle:

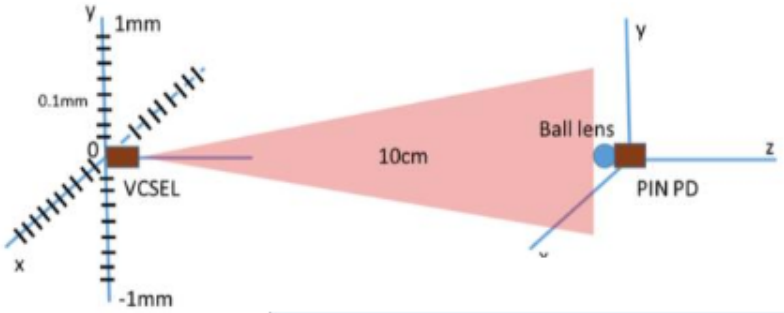
- "Line of sight" optical transmission:
  - Target distance: 10 cm
- Data is repeated at each detector layer
  - Electrical – Optical - Electrical

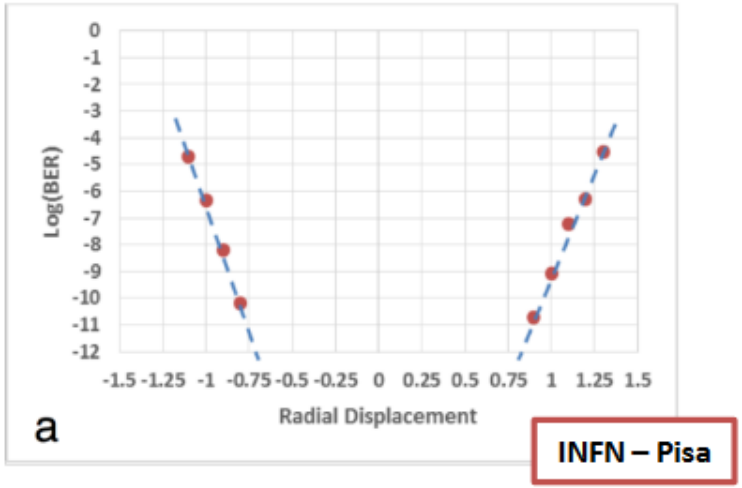
Benefits:

- Enables inter-layer communications (e.g. Triggering)
- Avoids the use and installation of optical fibers
  - Collimating structures (lenses) needed

Challenges:

- NIEL radiation effects on PIN / VCSEL
- The "geometry" of the data transmission system needs to be built into the detectors:
  - Alignment: ±0.75 mm @ 4.25 Gb/s
- Bandwidth increases every time a layer is crossed:
  - Data from successive layers add up
  - Either more bandwidth or channels needed in the outer layers
- Regenerative repeaters are [likely] needed along the repeating chain to contain the BER
- Links between the outer layer and the counting room are likely to be "conventional" optical links





Ref 4

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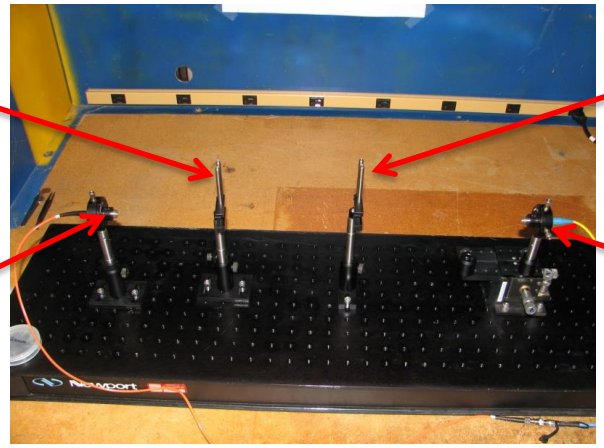
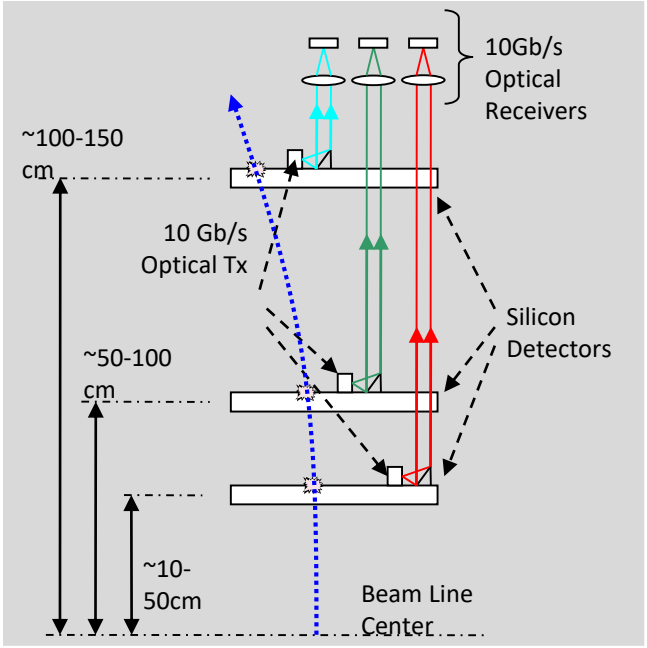
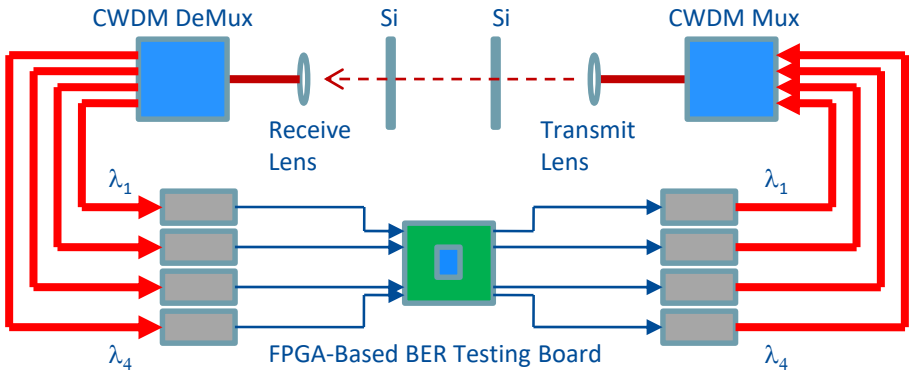
What (Might Be) Next? – Free Space Optics (earlier test @ FNAL)



Test Bench with Optics and Silicon Slices





- Optical fibers removed from detector volume
- Transmission through free space or silicon

Ref 6

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References

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