The VTRx+, an Optical Link Module for Data Transmission at HL-LHC

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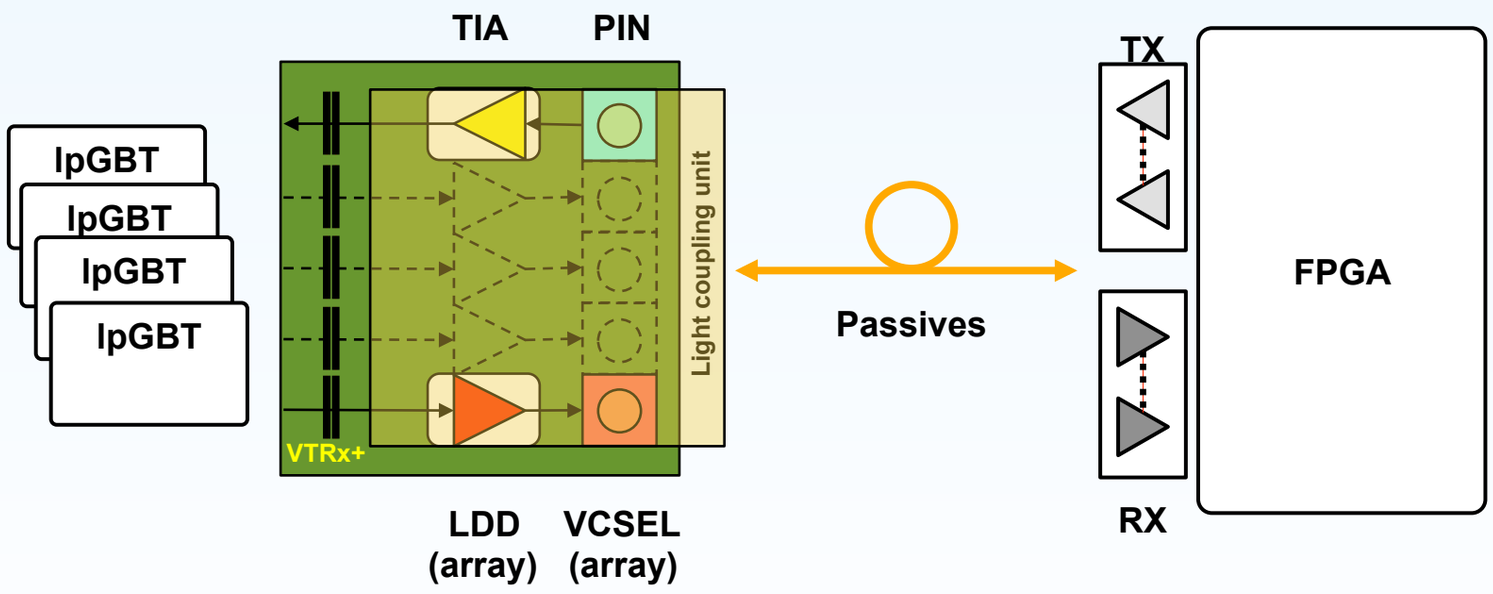
lpGBT & Versatile Link +

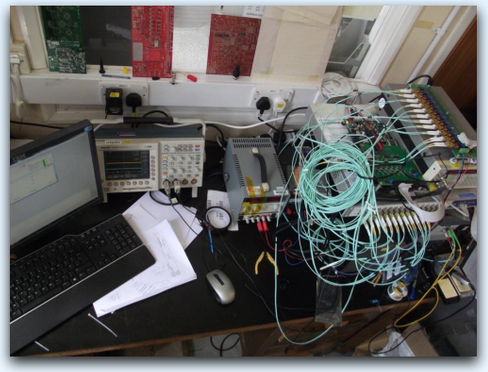
- Front-end to Back-end link targeting Inner Detector use at HL-LHC
  - Tracker-like environment
    - 1 MGy, $3x10^{15}$ n/cm^2
    - -35 to +60 °C
  - Asymmetric Data-rates
    - 5 or 10 Gb/s upstream (out of detector)
    - 2.5 Gb/s downstream



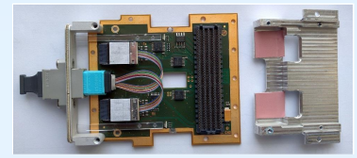
On-Detector
Custom Electronics & Packaging
Radiation Hard

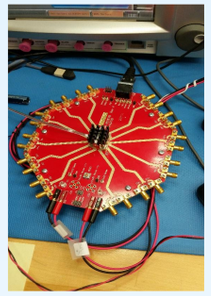
Off-Detector
Commercial Off-The-Shelf (COTS)
Custom Protocol

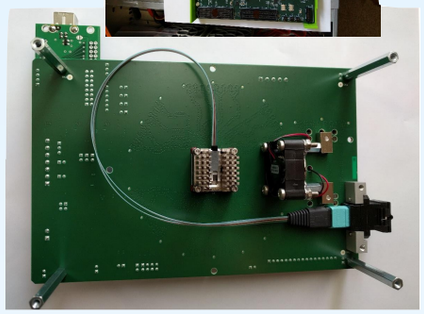
VL+ project collaboration



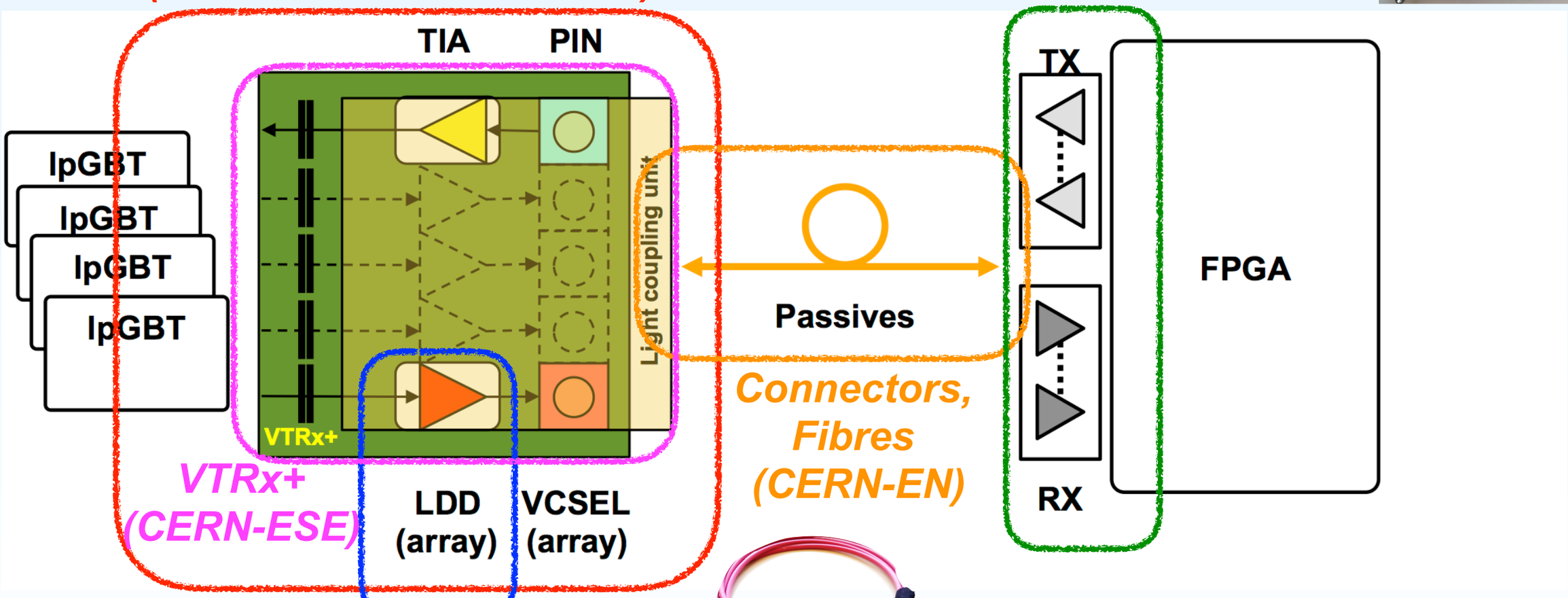
Reliability (Oxford, Academia Sinica)







Commercial Array TRx (FNAL)



VTRx+ (CERN-ESE)

Connectors, Fibres (CERN-EN)

Laser Driver LDQ10 (SMU)

LDD (array)

VCSEL (array)

System Specs

	VTx+ to Rx (10Gbps)	Tx VRx+ (2.5Gbps)
Tx OMA	> -5.2 dBm	> -1.6 dBm
Rx sensitivity	< -11.1 dBm	< -13.1 dBm
Power budget	**> 5.9 dB**	**> 11.5 dB**
Fiber attenuation	< 0.525 dB	< 0.525 dB
Insertion loss	< 1.5 dB	< 1.5 dB
Link penalties	< 1.0 dB	< 1.0 dB
Tx radiation penalty	< 1.0 dB	NA
Rx radiation penalty	NA	< 5.4 dB
Fiber radiation penalty	< 1.5 dB	< 1.5 dB
Margin	**> 0.375 dB**	**> 1.575 dB**

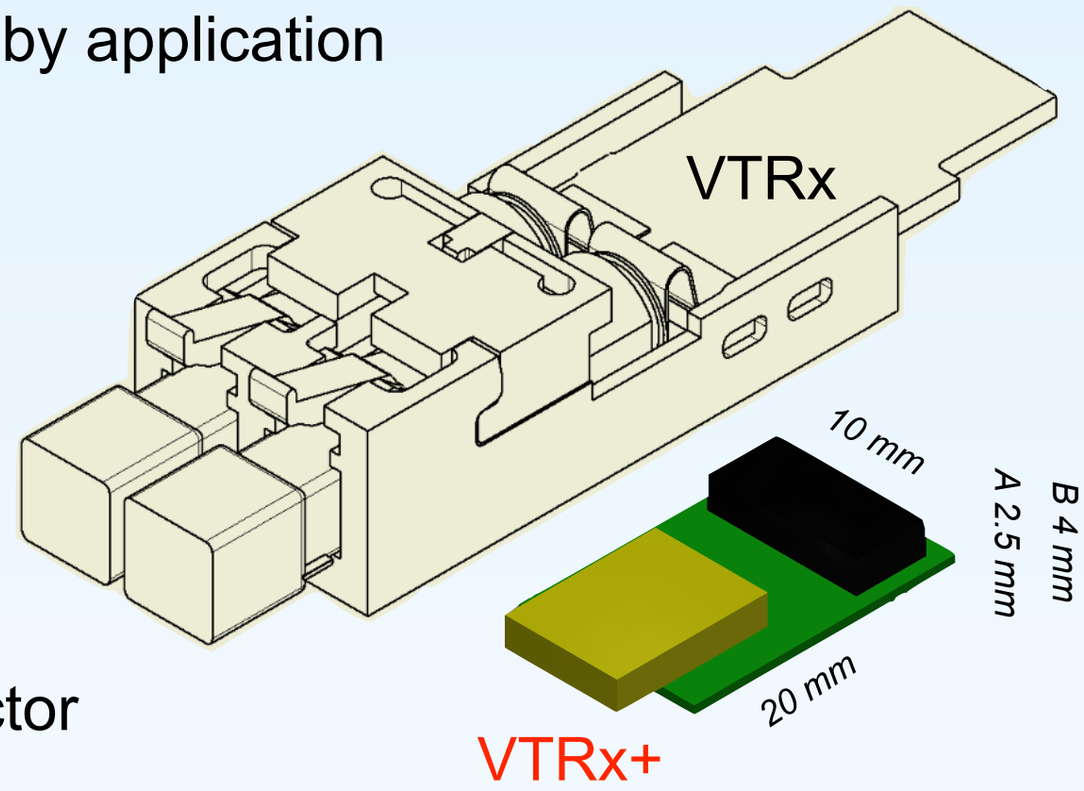
- Link Budget being defined
- Trade-off between requirements at either end of link
  - Penalties are asymmetric
  - Cannot simply apply standard e.g. 10 GbE specs

VTRx+ Module

Commercial Module

VL+ module

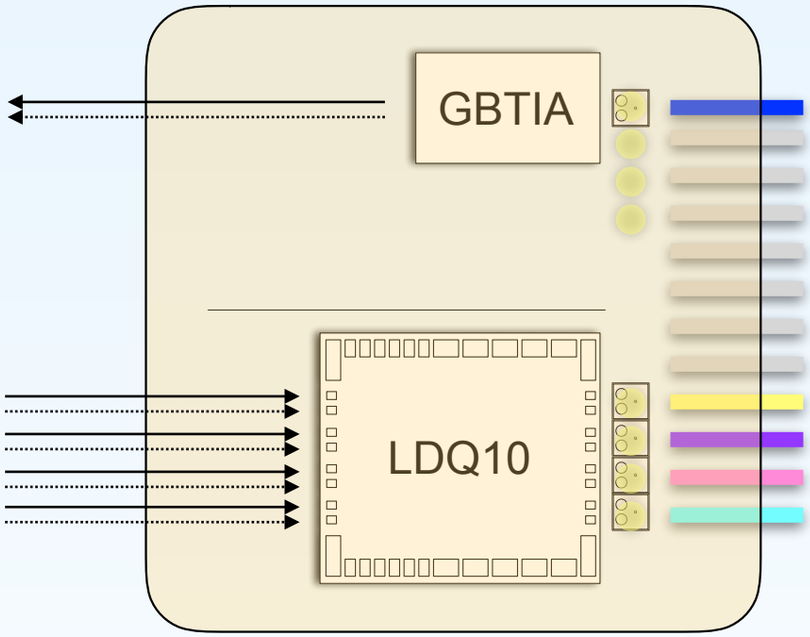
- Versatile
  - multi-channel, Rx/Tx count usage defined by application
- MM only
  - 850 nm VCSEL
  - InGaAs PIN (TBC)
- Miniaturized
  - Target dimensions 20 x 10 x 2.5/4 mm
- Pluggable
  - Either optical or electrical (or both) connector
- Data-rate matching lpGBT:
  - Tx: 5 and 10 Gb/s
  - Rx: 2.5 Gb/s
- Environment
  - Temperature: -35 to + 60 °C
  - Total Dose: 1 MGy qualification
  - Total Fluence: $1x10^{15}$ n/cm^2 and $1x10^{15}$ hadrons/cm^2



Total Quantity
20000-50000 modules

VTRx+ module flavours & users

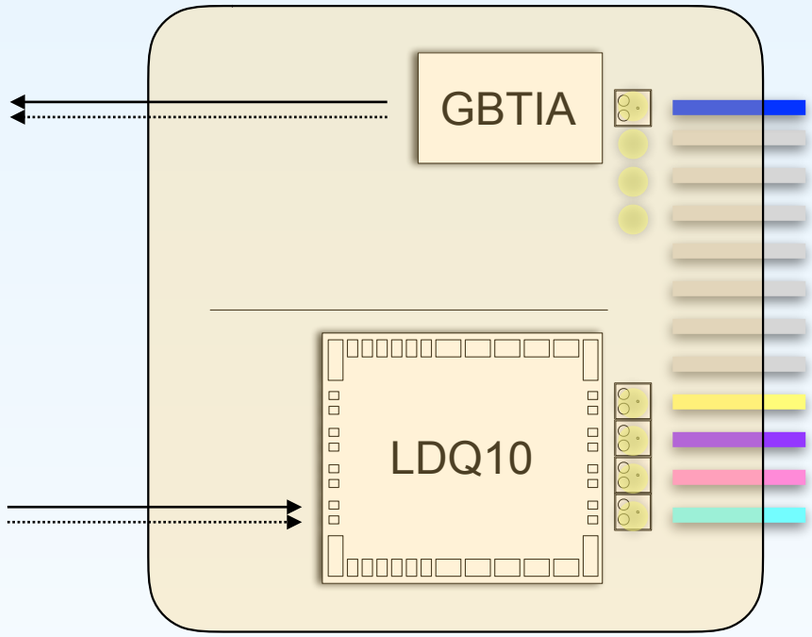
- Settled on using optical coupling block that can support up to 4 Tx and 1 Rx
  - Surveyed potential users to gain insight on the required quantities



4Tx & 1 Rx

ATLAS TileCal
CMS ECAL

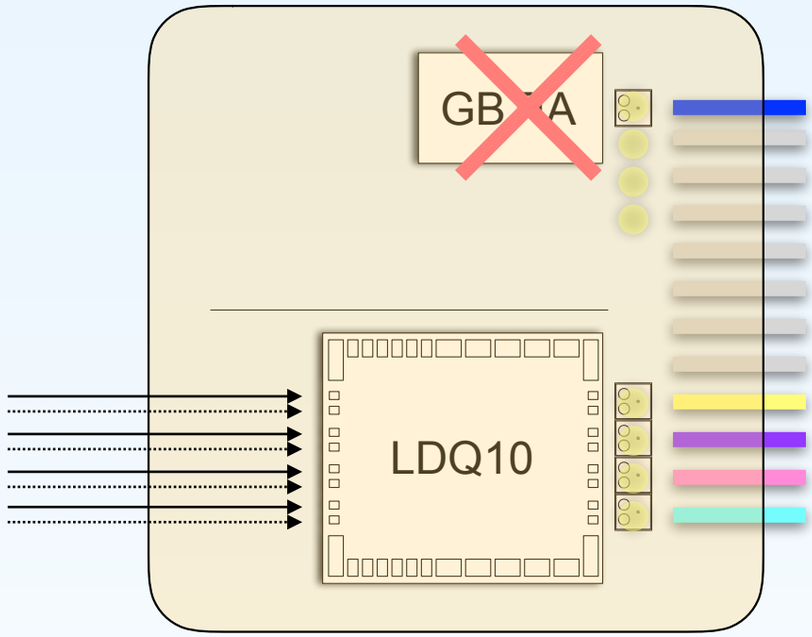
12%



1Tx & 1 Rx

ATLAS LAr, ITk
CMS Tk, HGC, Pix, BTL

60%



4Tx

ATLAS LAr
CMS HGC

28%

Approach to VTRx+ prototyping

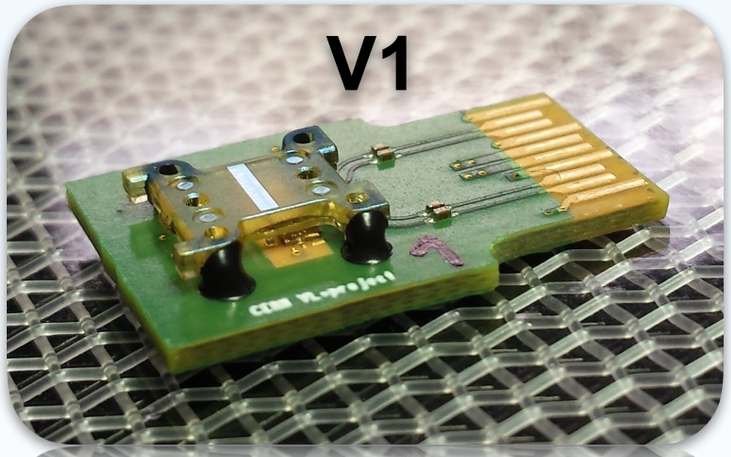
- Modification of existing commercial modules
  - Working in close collaboration with various industrial partners
  - Typical path
    - Identify interesting part
    - Procure opto-die only variant for environmental testing
    - Insert CERN-specified ASICs (LDD, TIA-LA)

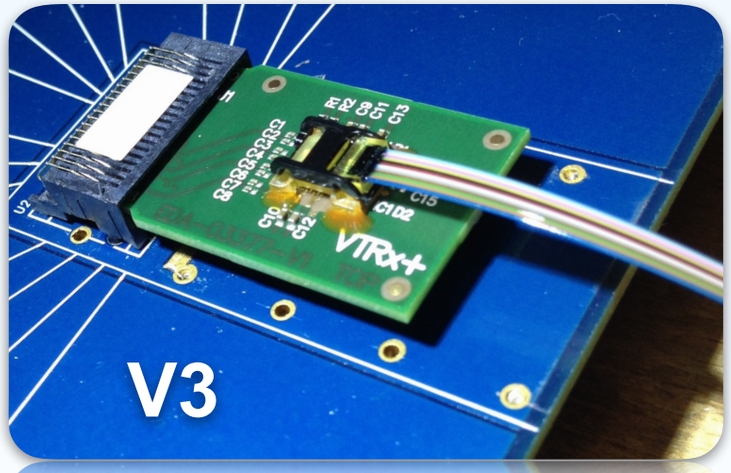
! NDAs ! limit sharing of design details

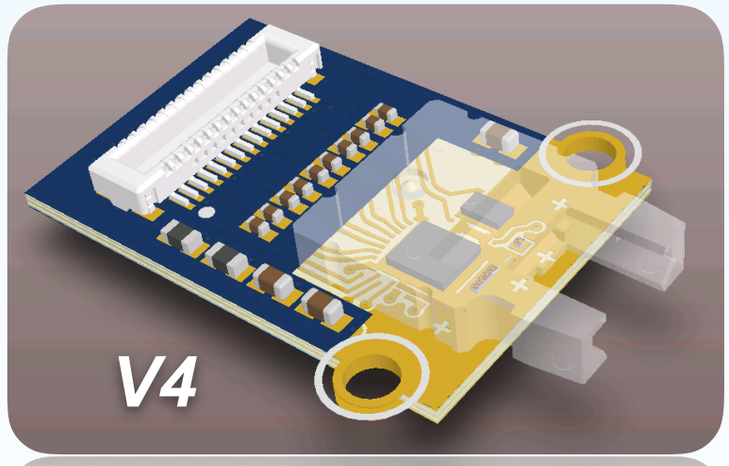
- In-house design of module
  - Working in close collaboration with suppliers of optical coupling blocks
  - Working in close collaboration with industrial partner on integration
    - CERN-designed PCB
    - CERN-specified or procured opto-die
    - CERN-specified or procured ASICs (LDD, TIA-LA)

CERN-design VTRx+ prototypes

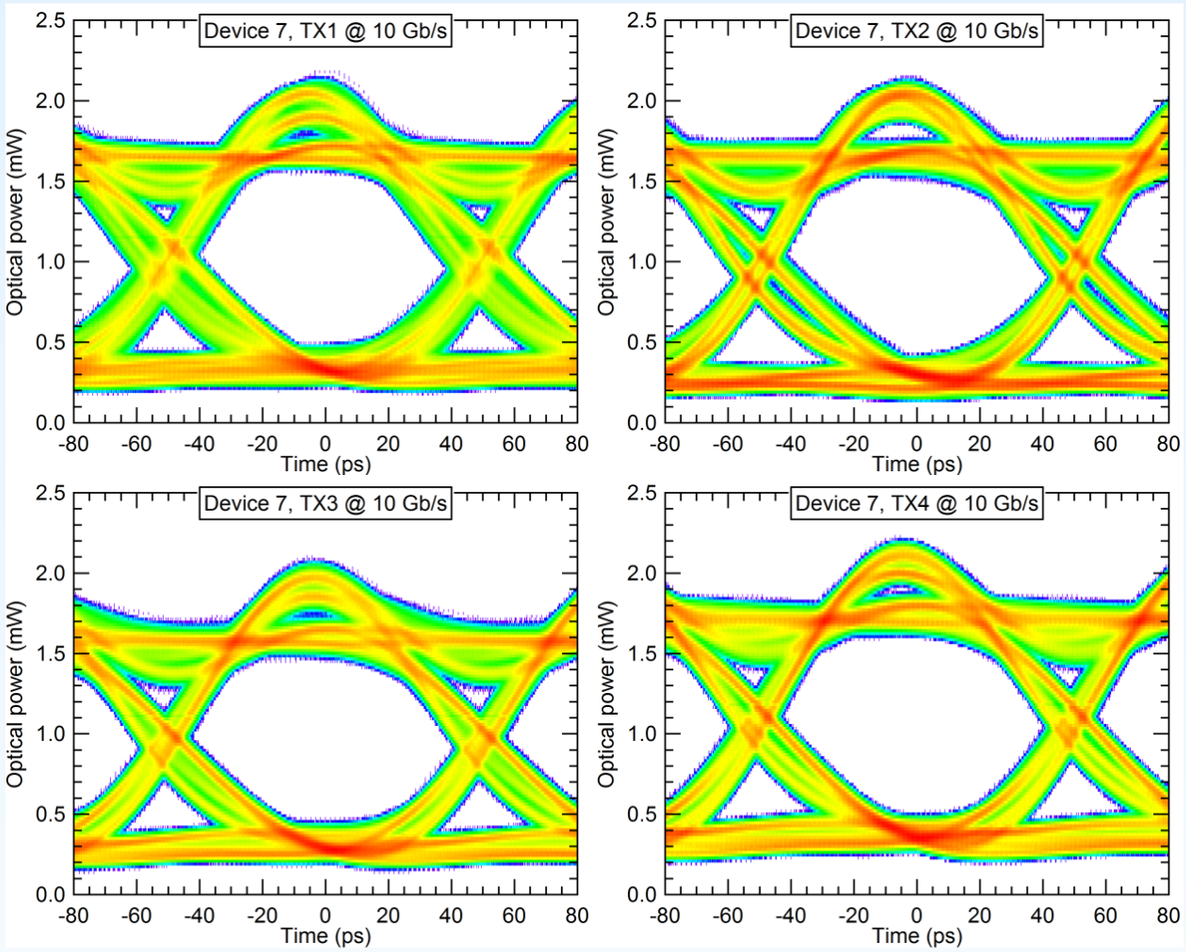
Version	Tx		Rx		Light Coupling Block	Quantities
	LDD	VCSEL	TIA	PD		
V1	COTS	ULM14G	GBTIA	ULM14G PIN	12ch. MOI	9
V2	COTS	ULM14G	GBTIA	ULM14G PIN	2+2 Lightpeak	10
V3	LDQ10	ULM14G array	GBTIA	ULM14G PIN	12ch. MOI	7
V3b	LDQ10P	ULM/II-VI array	GBTIA	ULM14G PIN	12ch. MOI	5-10
V4	LDQ10	ULM/II-VI array	GBTIA	ULM14G PIN	2+2 Lightpeak	tbc

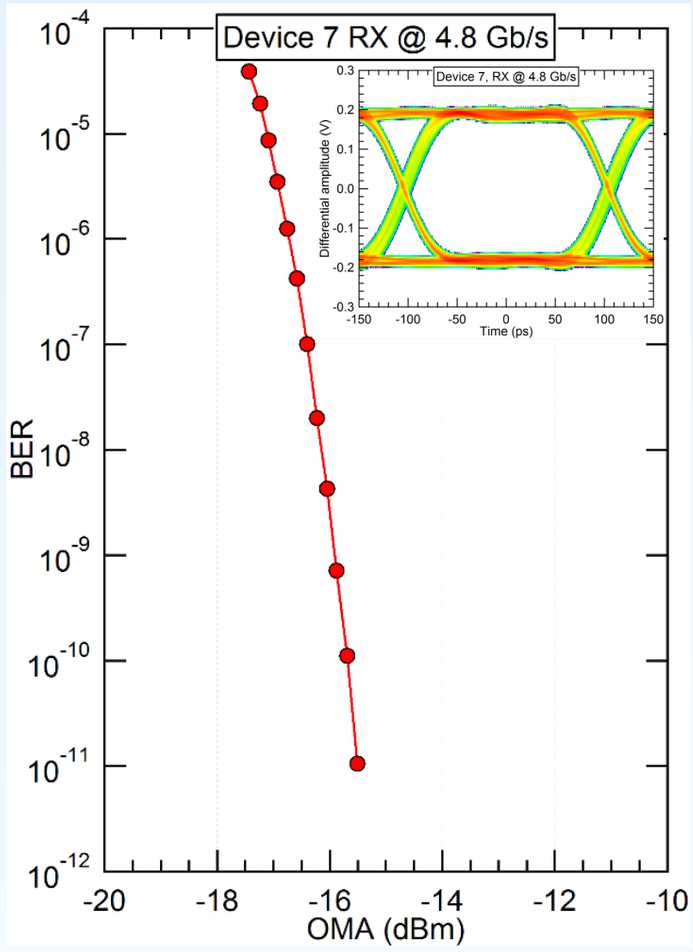






Sample v3 VTRx+ results

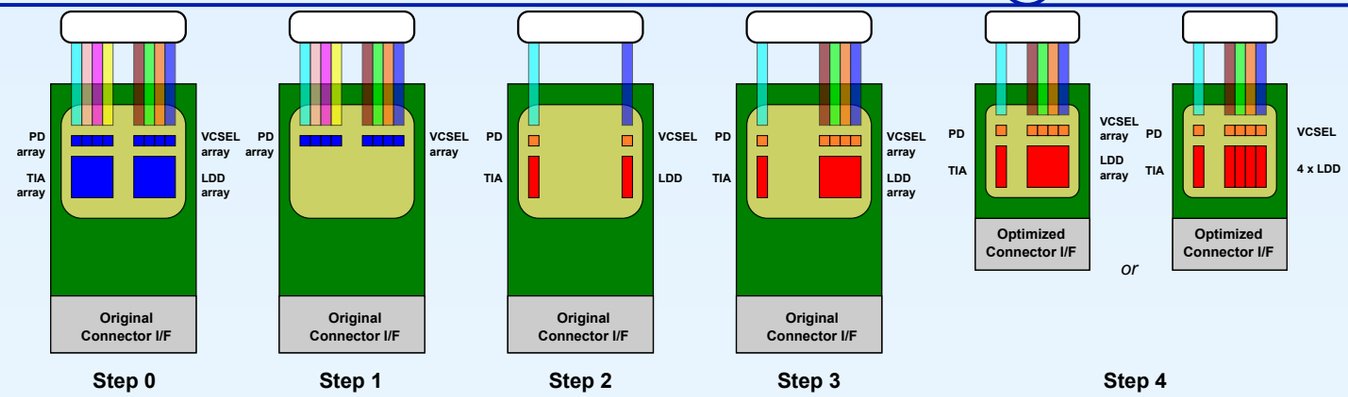




- 10 Gb/s with default settings meets module spec.
  - Good coupling efficiency

- Rx operating with good margin
  - No influence of Tx operation on Rx performance

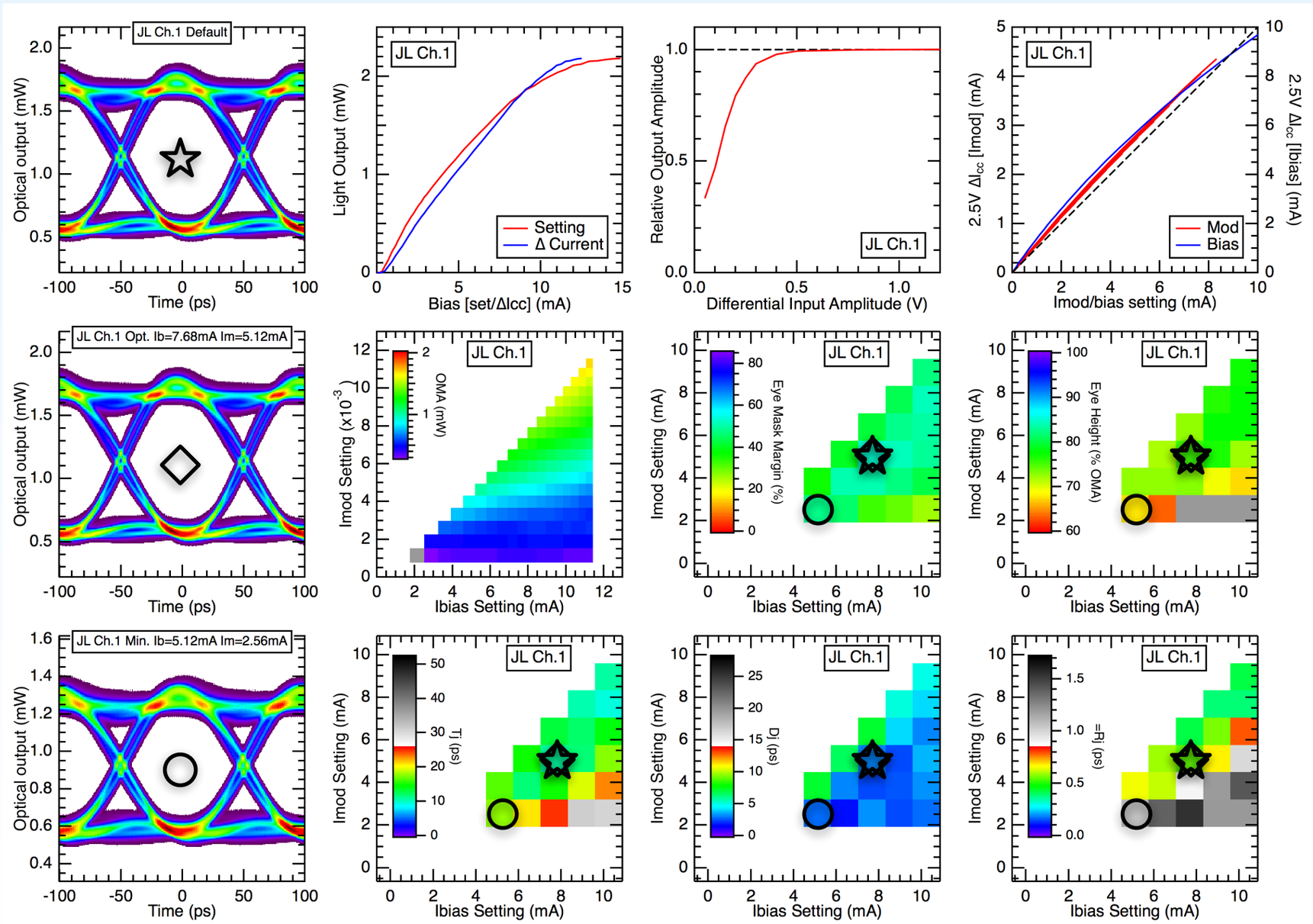
Commercial roadmap



- Development *(until 2018)*
  - CERN Market Survey
    - CERN issues Technical Requirement & Questionnaire
    - Companies return completed Questionnaire
    - CERN reserves the right to order samples (Steps 0, 1) and/or ASIC drop-ins to existing parts for evaluation (Steps 2, 3)
    - CERN qualifies companies having required technology
  - CERN Price Enquiry
    - Qualified companies receive full technical specification for development
    - Qualified companies bid for development (Step 4)
    - CERN develops customised prototypes with selected company(ies)
- Production *(2019 onwards)*
  - Companies having successfully completed development (on time, in budget) will be invited to tender for full production
  - One or two lowest cost bidder(s) will receive production contract

Commercial Modules with LDQ10

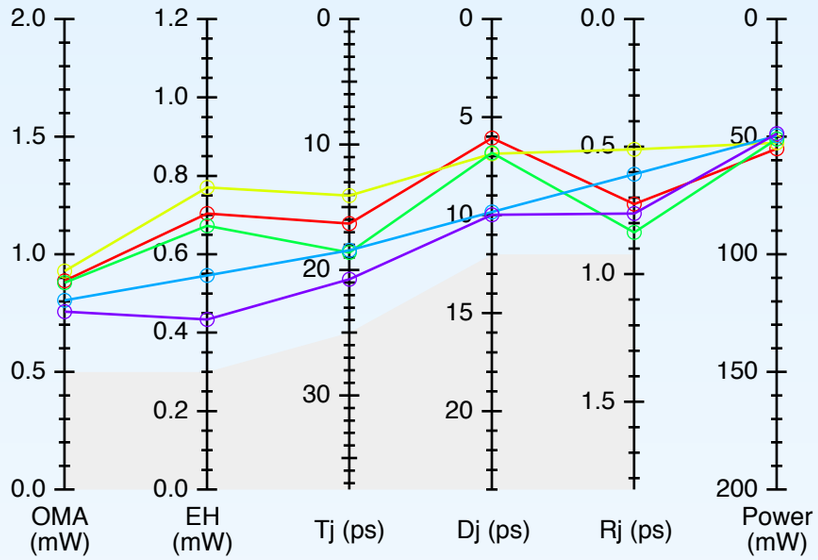
- LDQ10 integrated into commercial packages with multiple vendors
  - Used to explore setting parameter space to optimise performance

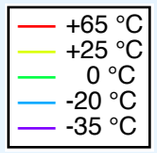


Performance over temperature

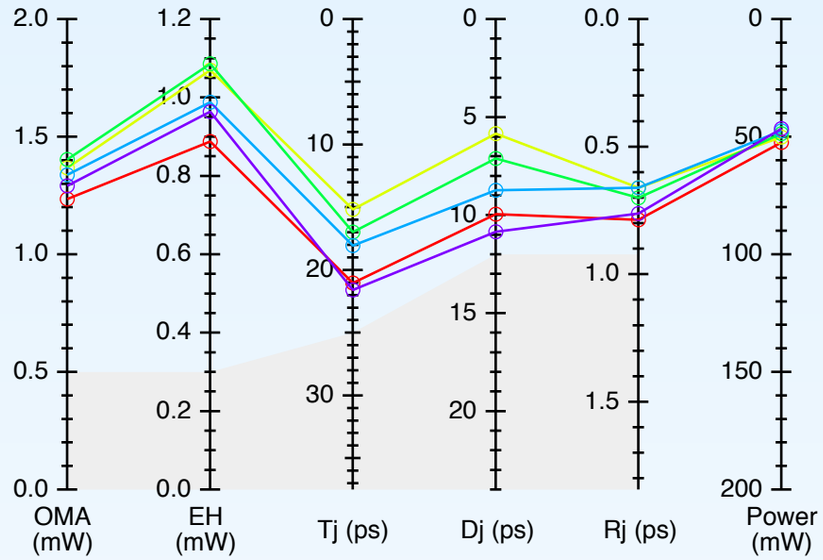
Versatile Link+

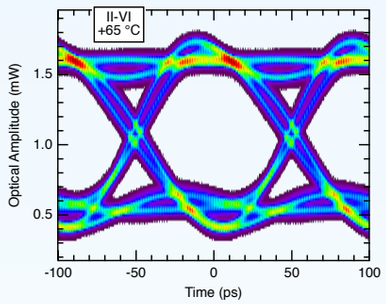
VCSEL A

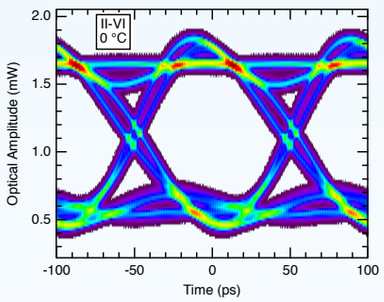


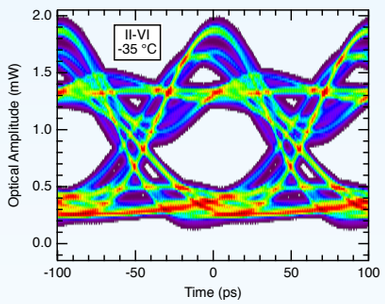


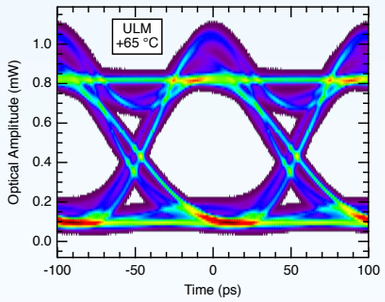
VCSEL B

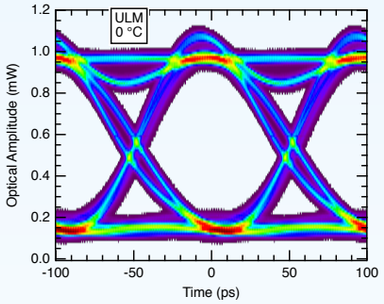


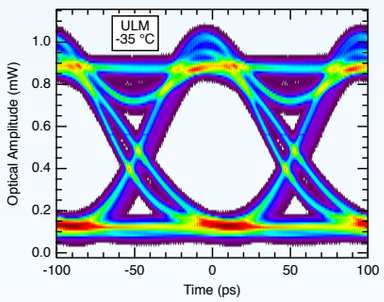








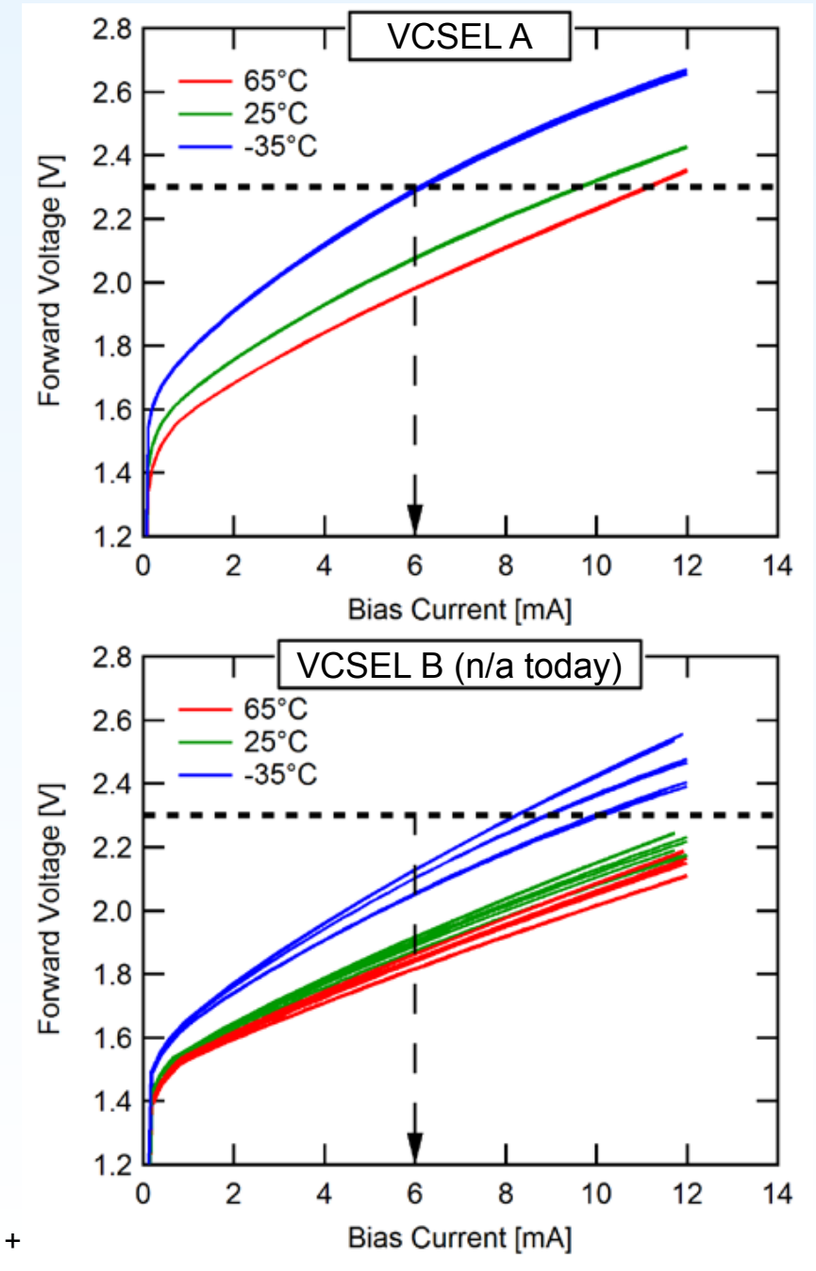


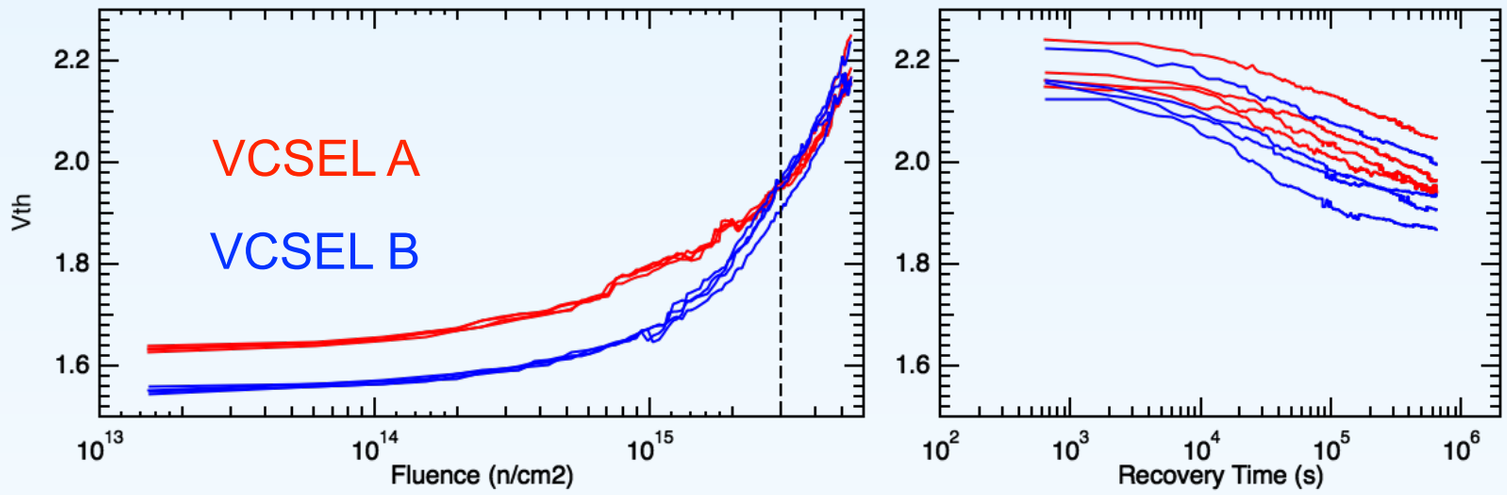


- Measured performance over full temperature range
- Either candidate VCSEL may work
- Power Consumption similar

Design challenges

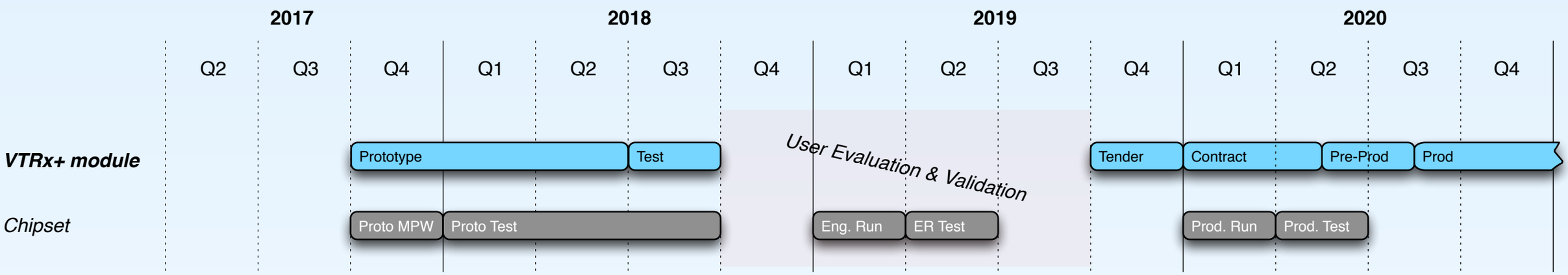
- Largest unique challenge comes from ensuring sufficient voltage headroom for operation of VCSELs with 65 nm CMOS driver that limits voltage rail to 2.5 V





- Going cold and irradiating the VCSEL make the situation worse
  - VCSEL forward voltage increases
- Need some voltage headroom for the driver's output transistor
- Currently validating the margin we have for operation

Schedule overview



- Expecting answers to Price Enquiry for development in next two weeks
  - Development slated for 9 months from order placement
- Will then have several possible designs in hand in sufficient quantity for evaluation by user community
- Tendering for volume production will take place during 2019
  - Final module format only known after tendering
- Coupled with lpGBT project for chipset production

Summary

- Versatile Link + project developing Rad-tolerant link for deployment in HL-LHC experiments
  - Operating at 5 or 10 Gb/s Tx and 2.5 Gb/s Rx to match lpGBT
  - Rad tolerant to Tracker levels
- Front-end module development based on
  - In-house design
  - Minimal customisation of commercial module
- Good results achieved with current prototypes
  - Both in-house and commercial designs
  - Understanding of system margins over temperature and after irradiation ongoing
- Challenging to meet smallest height requirement
  - Special development will be required