The Read-Out Driver (ROD) card for the ATLAS experiment: commissioning for the IBL detector and upgrade studies for the Pixel Layers 1 and 2

R.Travaglini

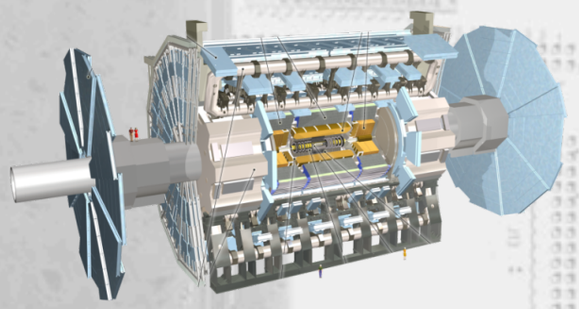
G. Balbi, M. Bindi, D. Falchieri, A. Gabrielli, L. Lama (INFN and Physics and Astronomy Department, University of Bologna, Italy)**, S.-P. Chen, S.-C. Hsu, S. Hauck** (University of Washington, Seattle, USA)**, A. Kugel** (Ruprecht-Karls-Universitaet Heidelberg/ZITI , DE)**, T.Flick, M. Wensing** (Fachbereich C Physik Wuppertal, DE)

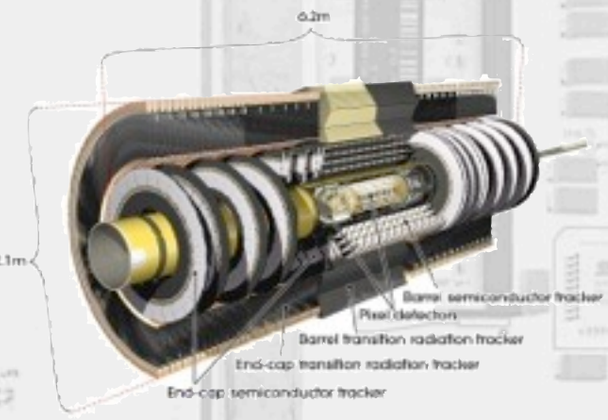
TWEPP 2013

Topical Workshop on Electronics for Particle Physics
Perugia, Italy, September 23-27, 2013

Session B2 : Systems, Planning, installation, commissioning and running experience

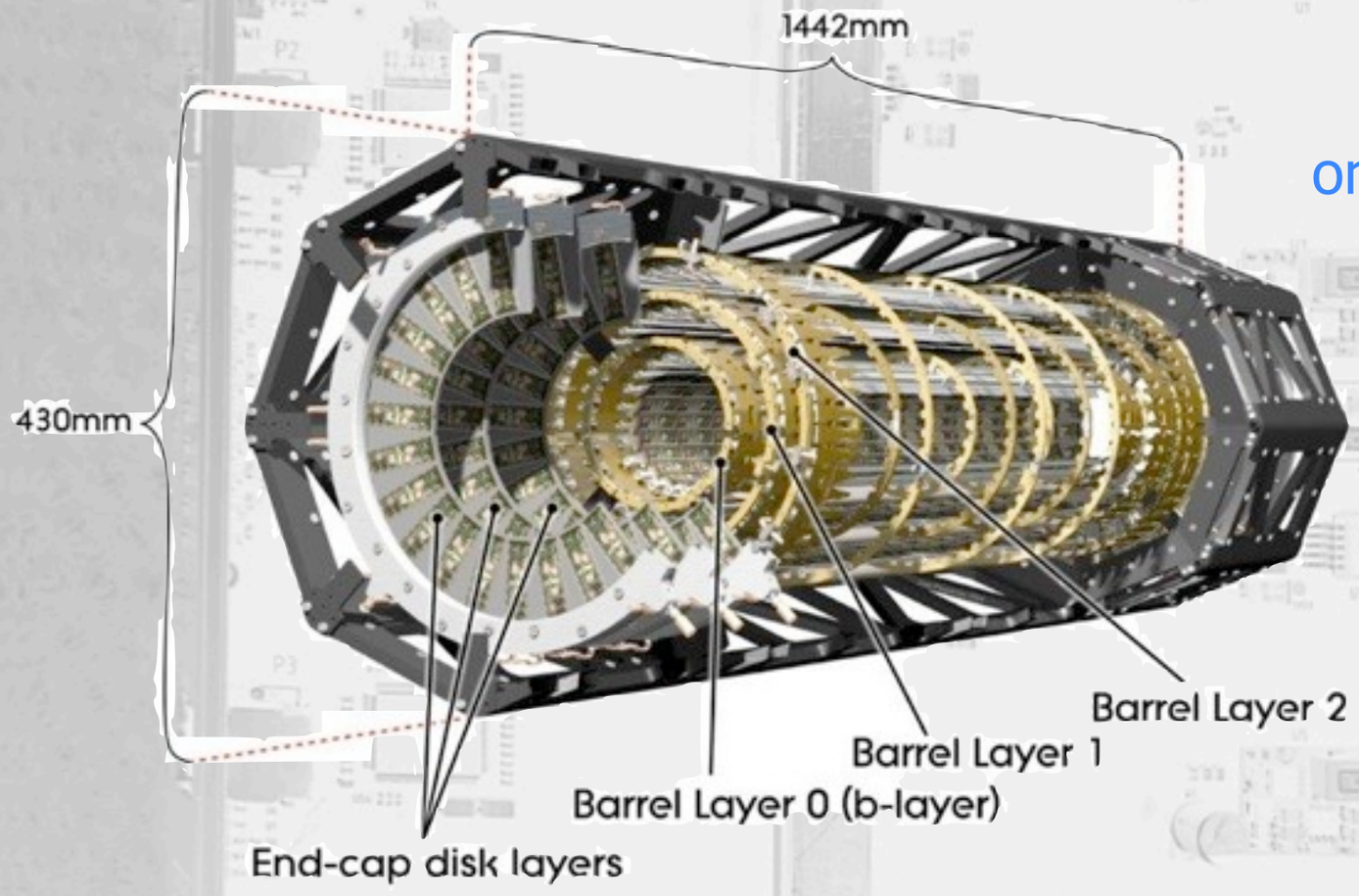
Atlas Pixel Detector Overview





innermost detector: tracking and vertexing
3 barrel layers - b-layer closer the beam pipe
(<r>=5cm)
80 millions pixel in total (50 um x 400 um)

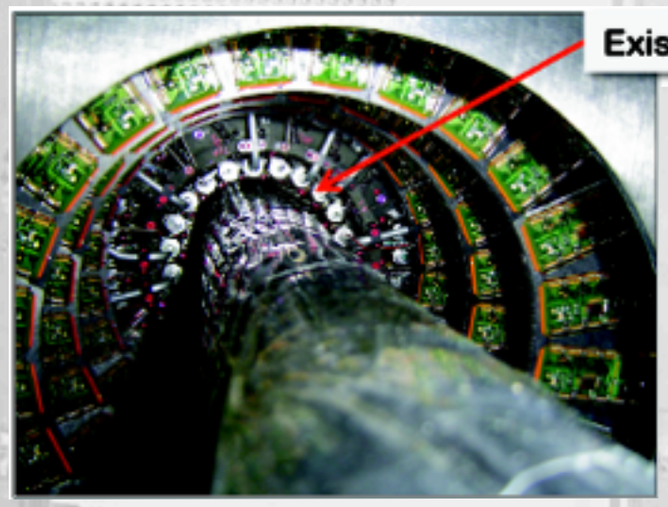
front-end chip : FE-I3 (2880 channels x chip)
basic unit: module (sensitive region coupled with 16 FE-I3)
1774 modules in total

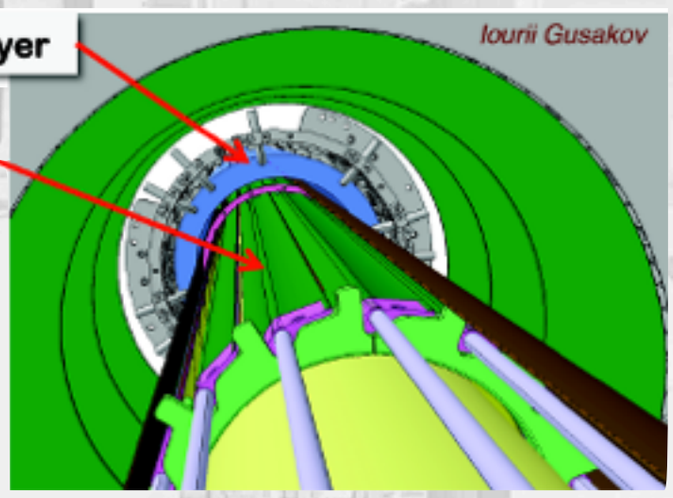


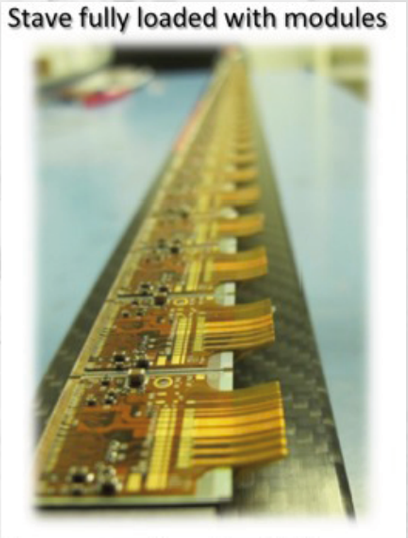
one Module Control Chip (MCC) x module
different readout schemes:
b-layer: 2 link @ 80 Mb/s (160 Mb/s)
layer 1: 1 link @ 80 Mb/s
layer 2: 1 link @ 40 Mb/s

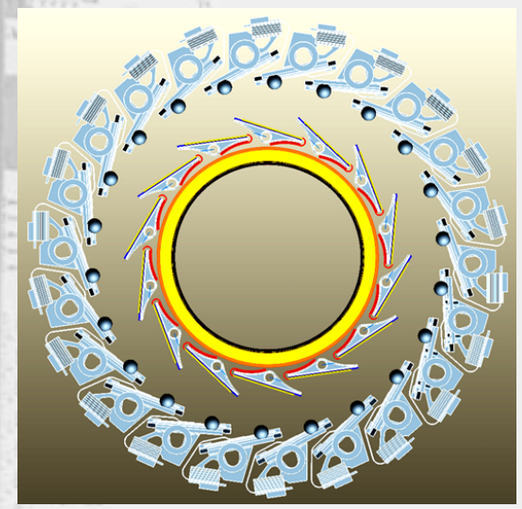
Each **off-detector readout unit handles up to 160 MB/s**
(2 link @ full speed)
(1 S-Link)

Pixel Detector Upgrade: Inner Barrel Layer (IBL)

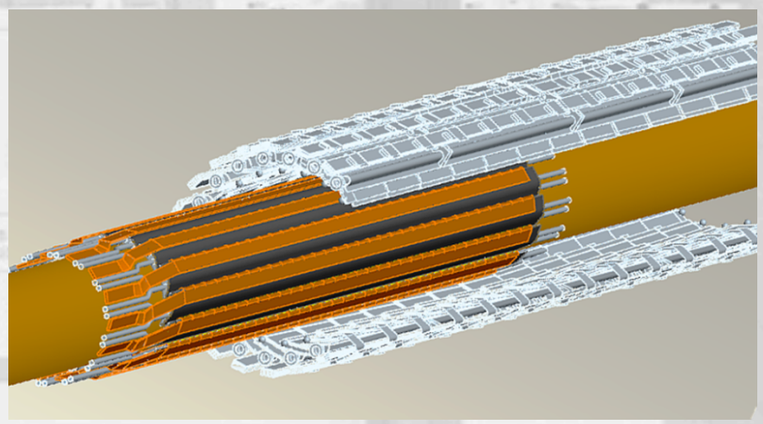








12 millions pixels
Pixel size : 50 x 250 um
<R> = 33 mm
|Z| < 33.2 cm
14 Staves
224 Modules



Major Goals:

- strengthen the **tracking capability** by increasing both redundancy and precision;
- **preserve the performances** of the Pixel Detector for effects due to the increased luminosity expected after LHC upgrades (greater pile-up and radiation doses).

Installation during LHC long shutdown 1
(ends in June 2014)

New Read-Out electronics for IBL

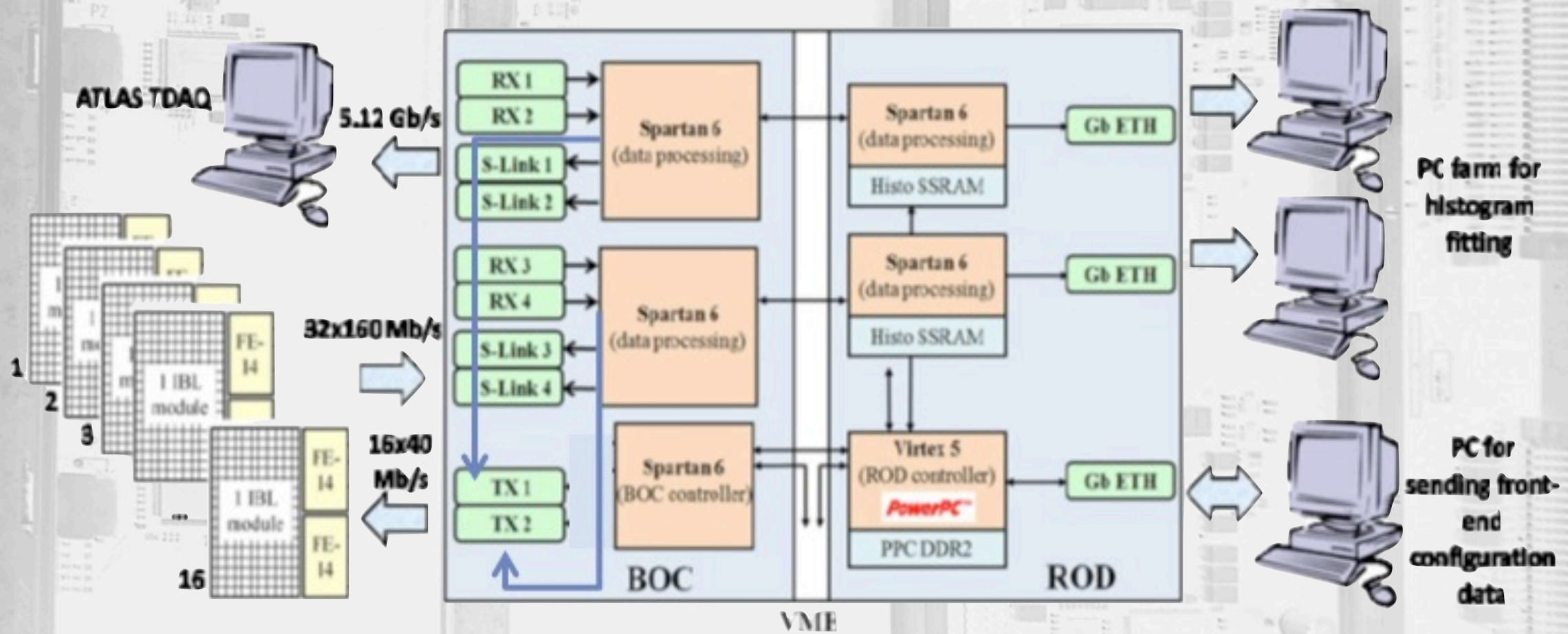
A **new front-end** ASIC, called **FE-I4** has been designed to face the **larger occupancy** as well as to manage the **increased bandwidth** expected for IBL.

New off-detector electronics have been foreseen as well, in order to overcome limitations in the current system: **two 9U-VME cards: Back-of-Crate (BOC) and Read-Out Driver (ROD)** respectively implementing optical I/O interface and data processing.

Each card pair processes data received from **32 FE-I4** data links for a total I/O bandwidth of 5.12 Gb/s.

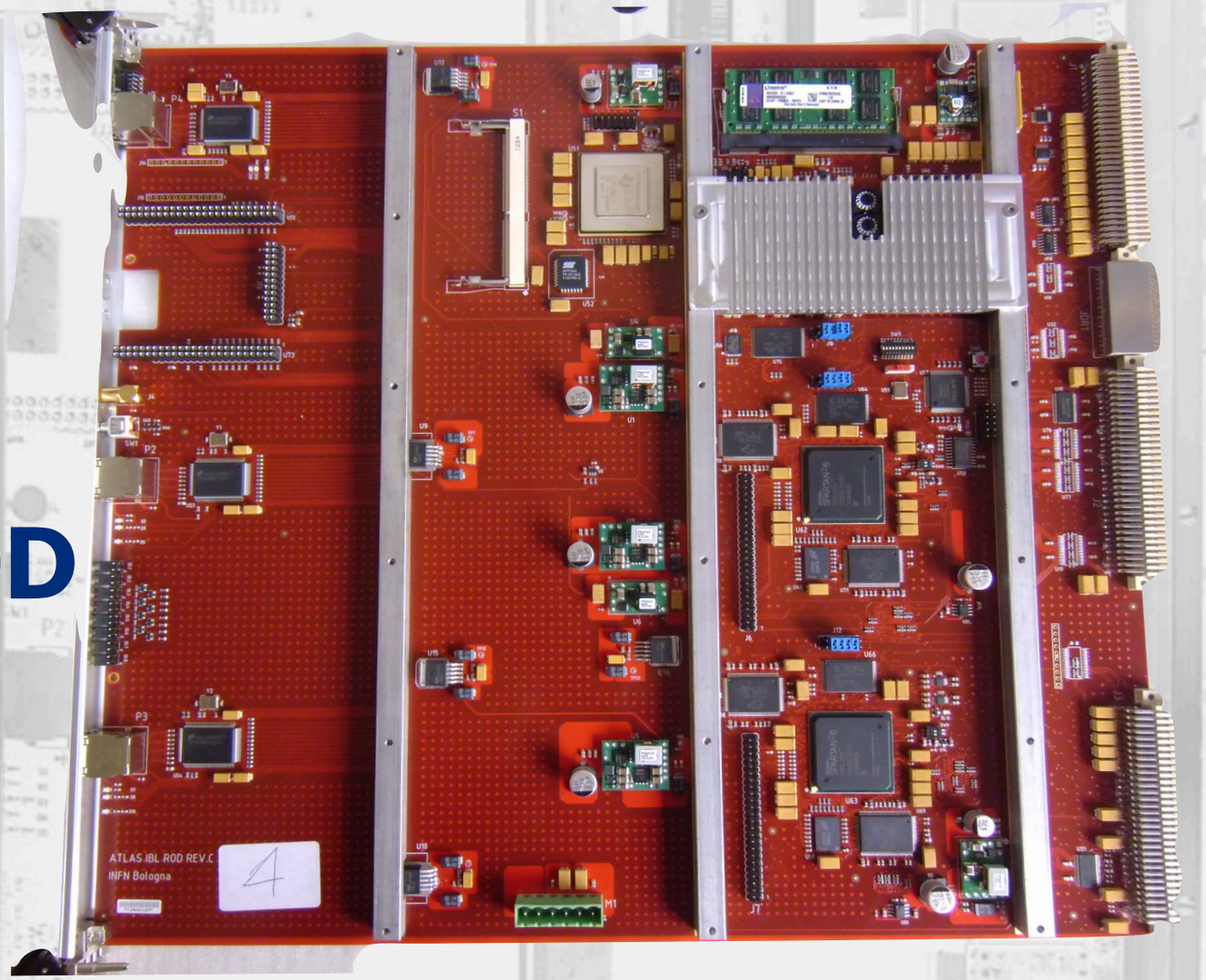
BOC-ROD Output through **4 S-Links** per pair to drive the data out.

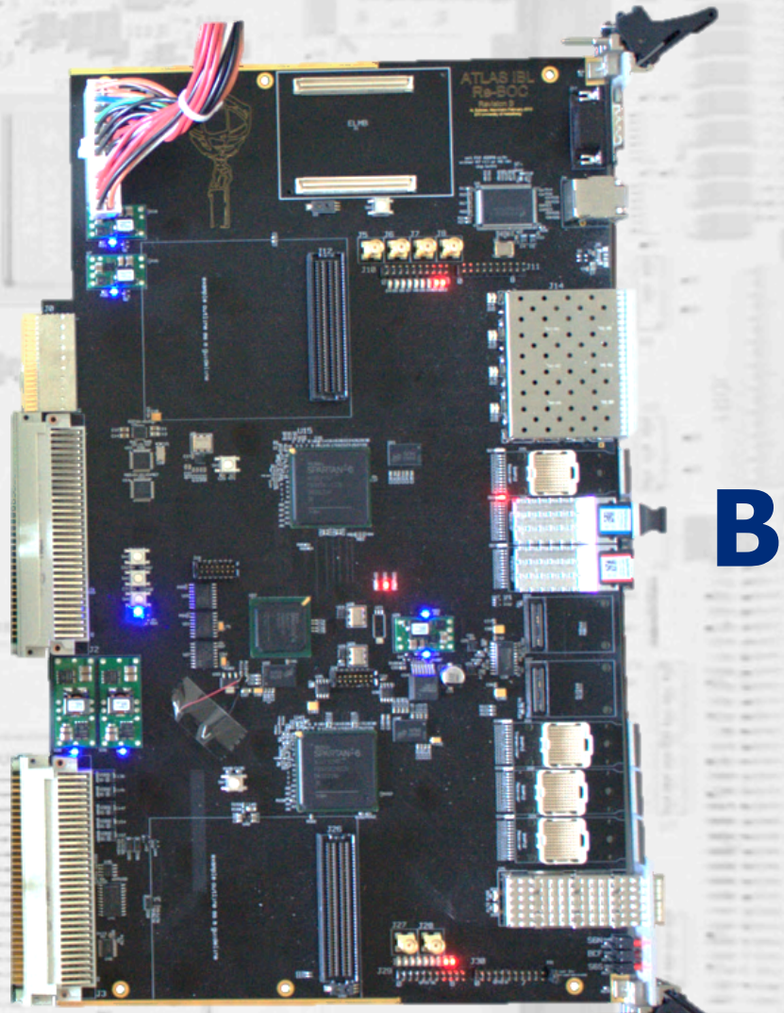
Faster **calibration** link by using **Gb Ethernet** instead of the VME bus for data transfer.



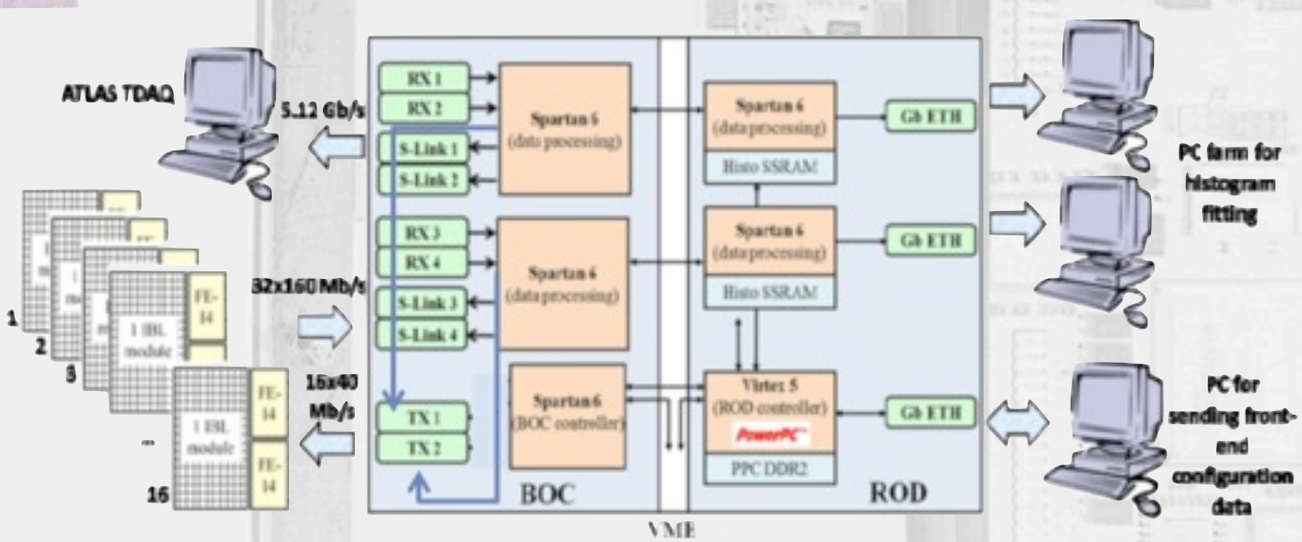
The ROD-BOC

ROD





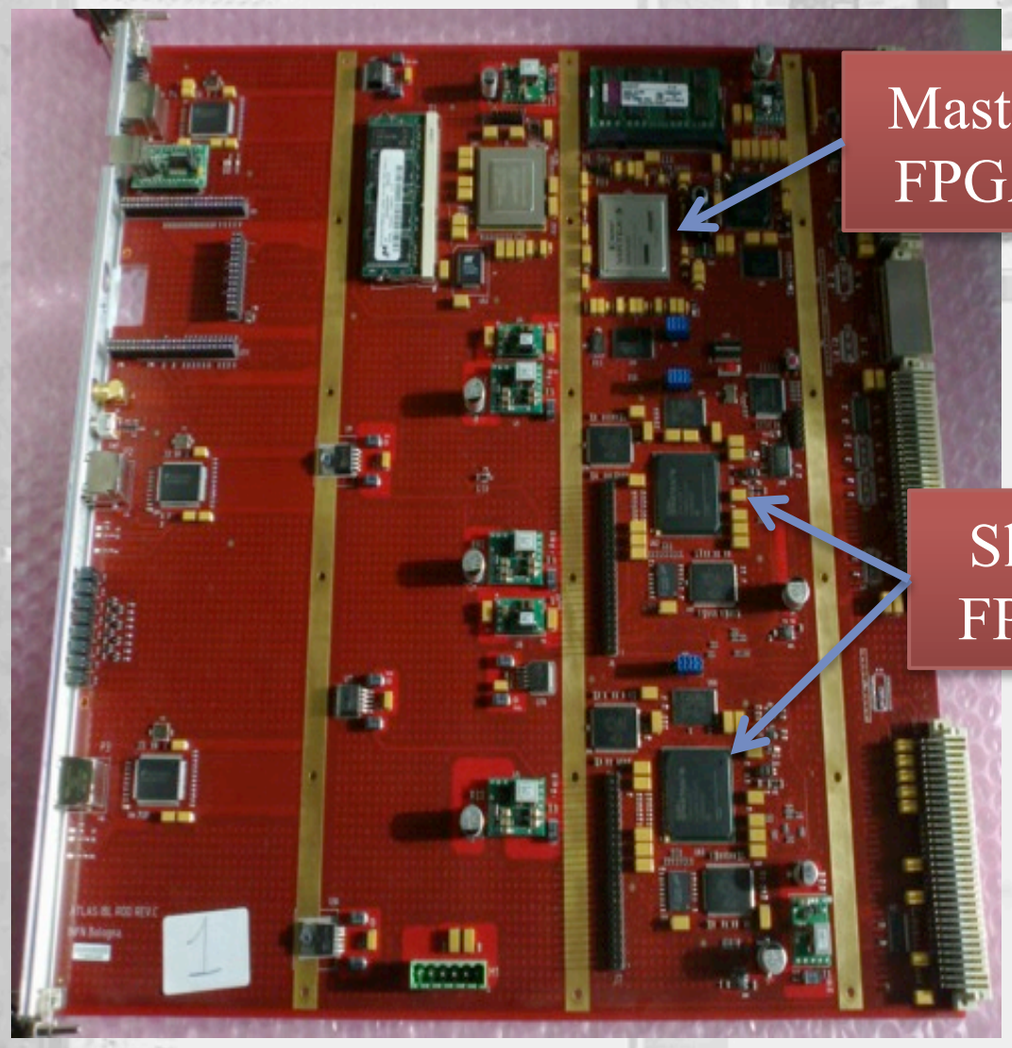
BOC



14 pairs to be installed in total

(+1 for Diamond detector)

the ReadOut Driver (ROD) card



rev C - february ’13 - 5 cards - pre-production

Control:
commands to FE-I4 (configuration, triggers)
configure BOC

Data taking:
gathering of front-end output
event building

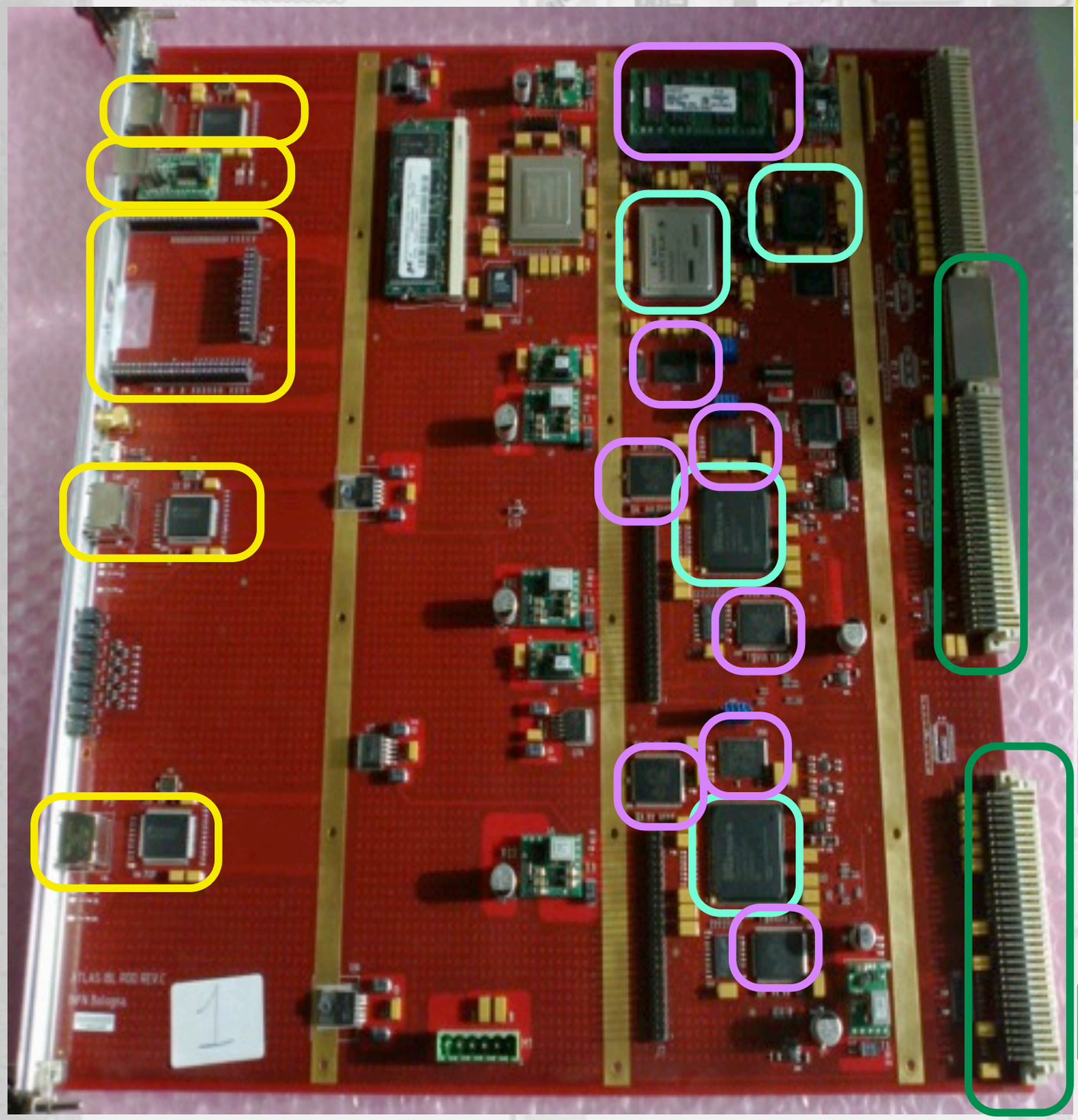
Detector calibration and monitoring:
Scan performing
histogramming

rev A - sept. ’11
3 cards
1st proto

rev B - february ’12
5 cards
distributed at labs

ROD - Hardware

14 layers PCB - 9U VME



Control, debug and interface with Calibration Farm/PC:

- 3 Gbit Ethernet Connectors:
  - 1 receiving config. from PC
  - 2 sending histos to PC farm
- 1 USB mezzanine
- 1 TTCrq mezzanine

Main Firmware components:

- 1 Spartan6 (Xil.) Prog. Res. Man.
- 1 Virtex5 (Xil.) Master: operation control (PowerPC)
- 2 Spartan6 (Xil.) Slaves: data processing (MicroBlaze)

Other components:

- 4 SSRAM (2 per Sp6)
- 1 Flash (Atmel) for the Vtx5
- 3 DDR2 (1 per each Sp6 + 1 Vtx5)

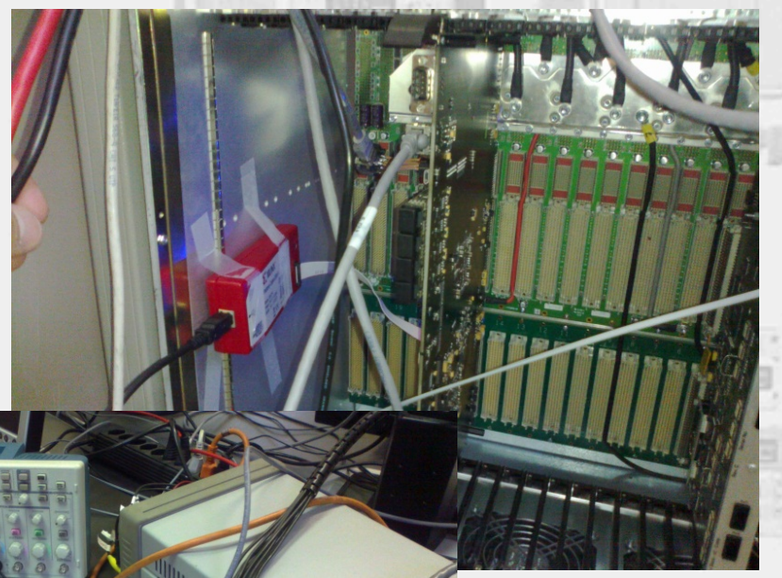
Interface with BOC (FE-I4&ROS):

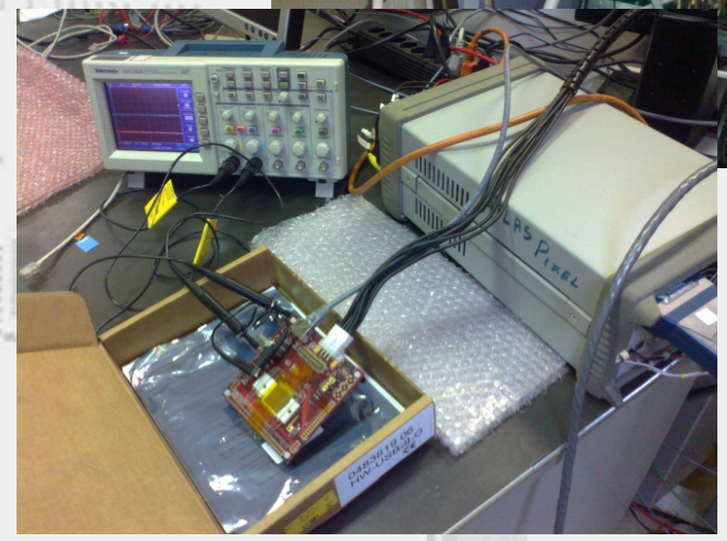
- P0/P2/P3 connectors 40-80Mhz

martedì 24 settembre 13

ROD commissioning strategy

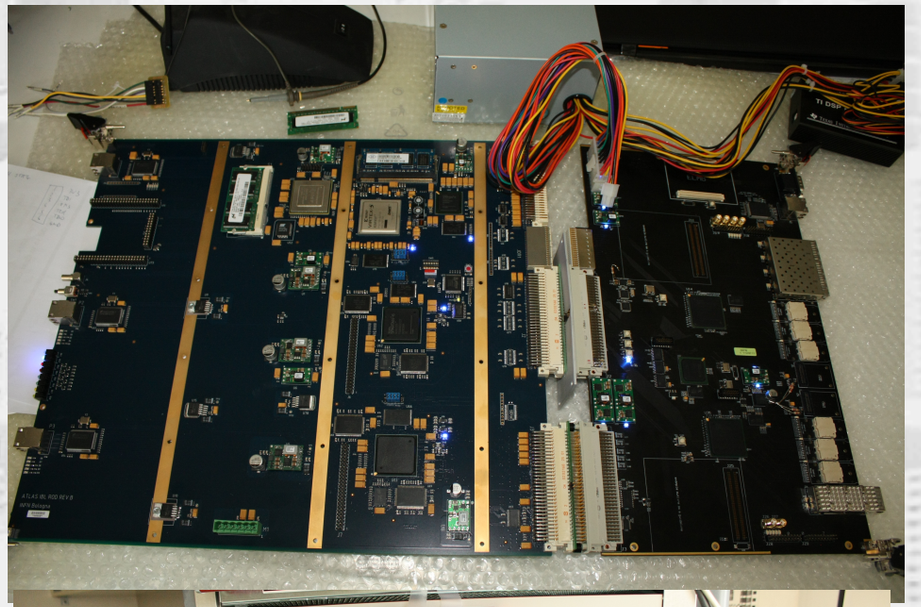
integration tests with FE-I4 at the Pixel lab (CERN)

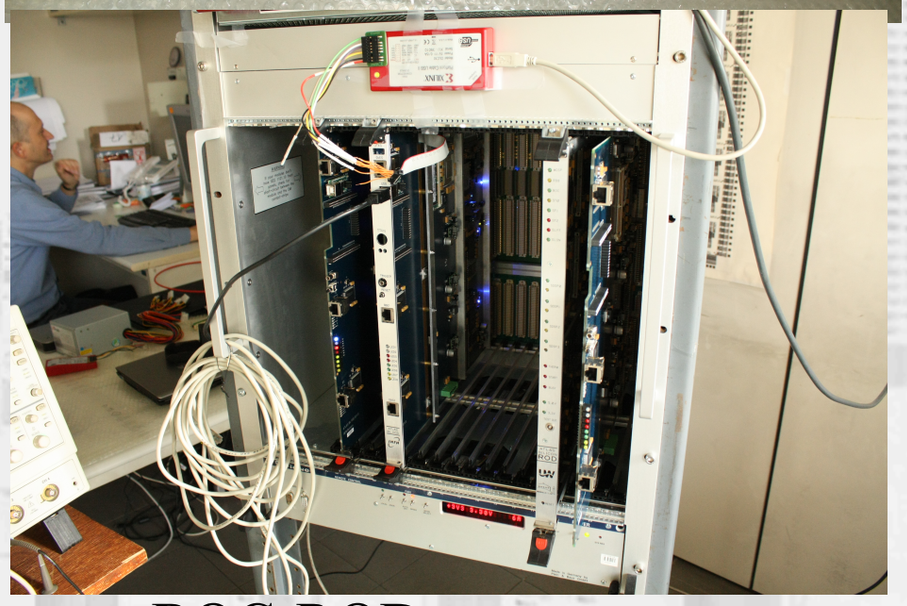




Many test stands have been assembled; different functionalities have been verified as well as distinct parts of firmwares are developed based on local setups

BOC-ROD off-crate test





BOC-ROD on-crate test

6 labs with different setups:
CERN, Bologna, Wuppertal, Mannheim, Genova, Gottingen

ROD commissioning

test	status	comments
power supply	DONE	25.7 W with current fw
temperature	DONE	V5 < 42 C ; SP6 < 50 C
clock distribution	DONE	
interface with TIM	almost done	electrical test w. chipscope
interface with DDR2 and FLASH mem	DONE	
VME	DONE	
On-board and to BOC slow control Bus	DONE	
BOC -> ROD	DONE	96 lines (SSTL3 @ 80 MHz)
ROD -> BOC	ongoing	tested with full speed but not with S-Link protocol
interface with SRAM	almost done	stand alone @ 200 MHz (36 bit) full fw @ 140 MHz (32 bit)
Ethernet	DONE	3 gigabit links
V5 fw and sw upload from VME	DONE	
SP6 fw upload from VME	DONE	
SP6 sw upload from ETH	DONE	
Integration with FE-I4	well advanced	see next slides

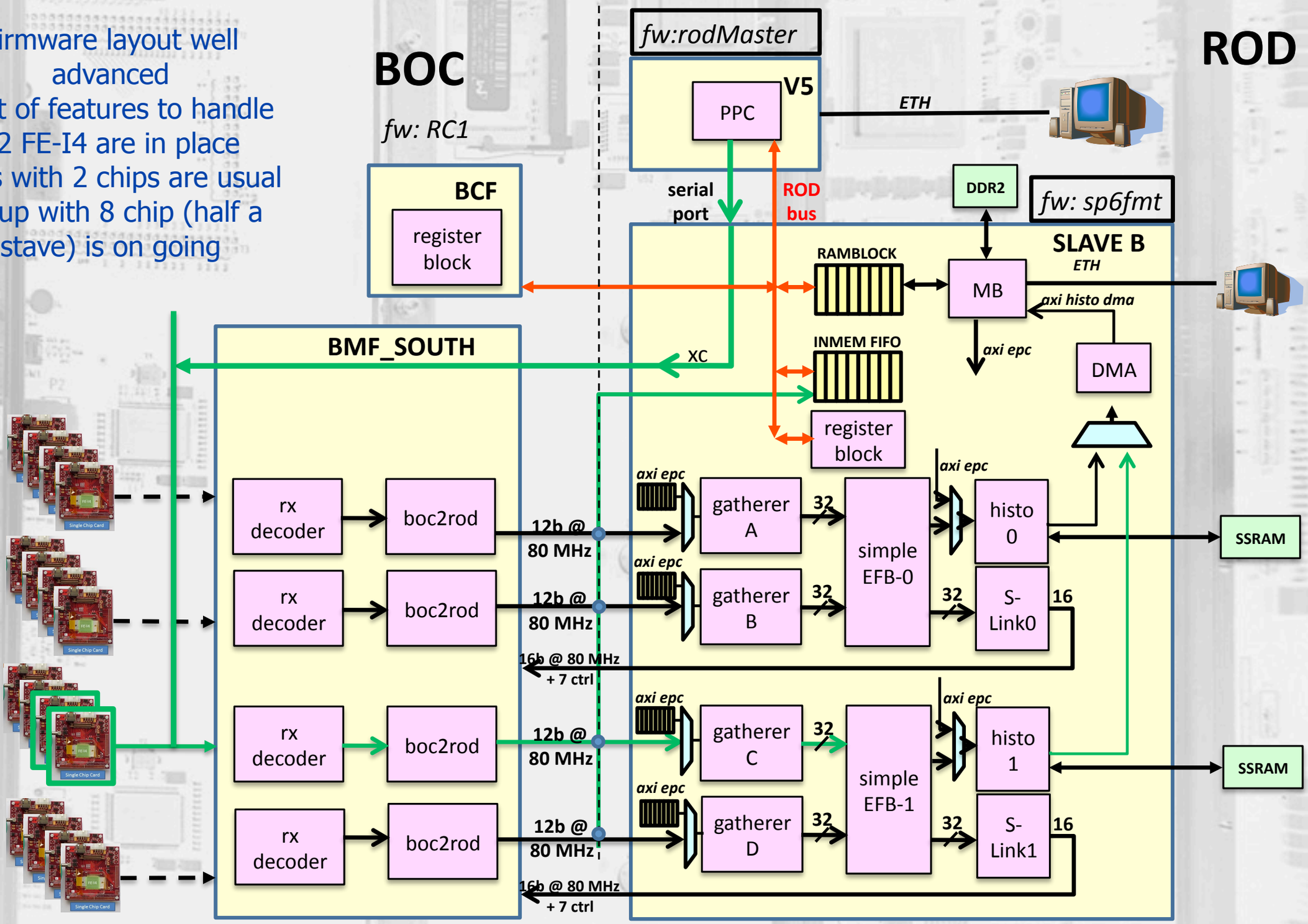
Example test #1 :BOC-ROD trasmission

Data are sent @ **80 Mb/s on the 96 bit-wide bus (SSTL3 logic)**
Different phases of the sampling clocks
2 hour running per phase
good uniformity: same sampling windows **for all 5 rev C cards**

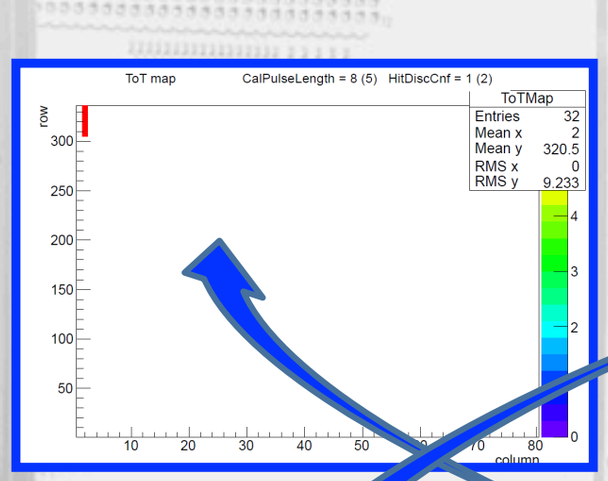
Phase (degrees)	Device	Status	Problems
0	SP6A	FAIL	Multiple errors on every bus
	SP6B	FAIL	Multiple errors on every bus
90	SP6A	FAIL	One error in 2 hours of test
	SP6B	OK	
180	SP6A	OK	
	SP6B	OK	
270	SP6A	OK	
	SP6B	OK	

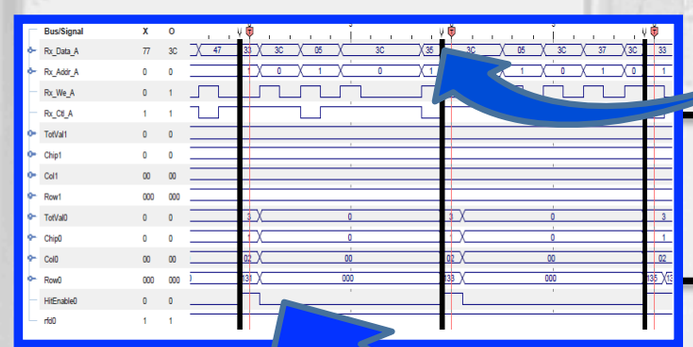
Example tests #2: Integration with FE-I4 (1)

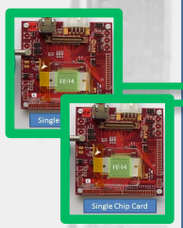
Firmware layout well advanced
Most of features to handle 32 FE-I4 are in place
Tests with 2 chips are usual
Setup with 8 chip (half a stave) is on going

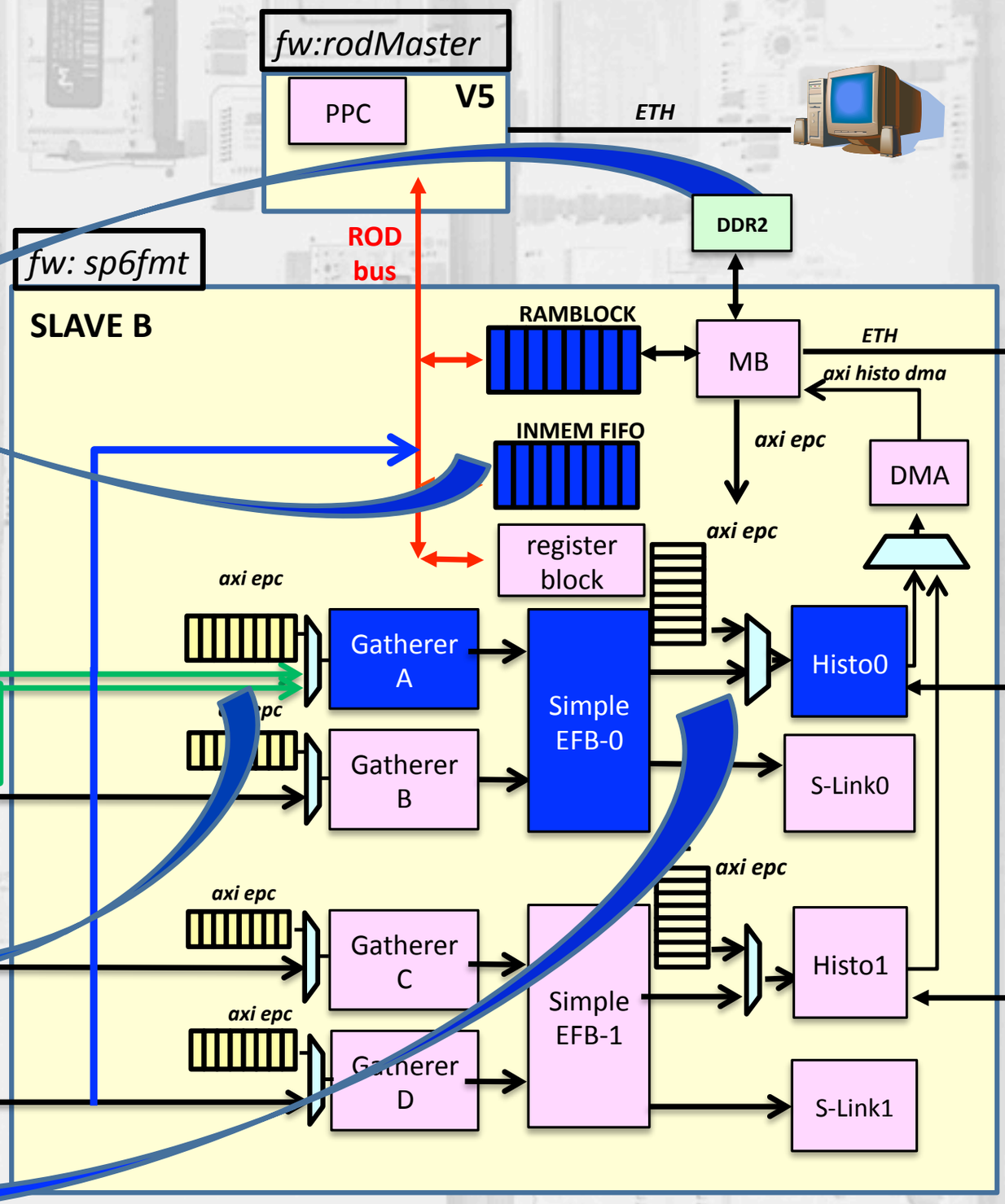


Example tests #2: Integration with FE-I4 (2)

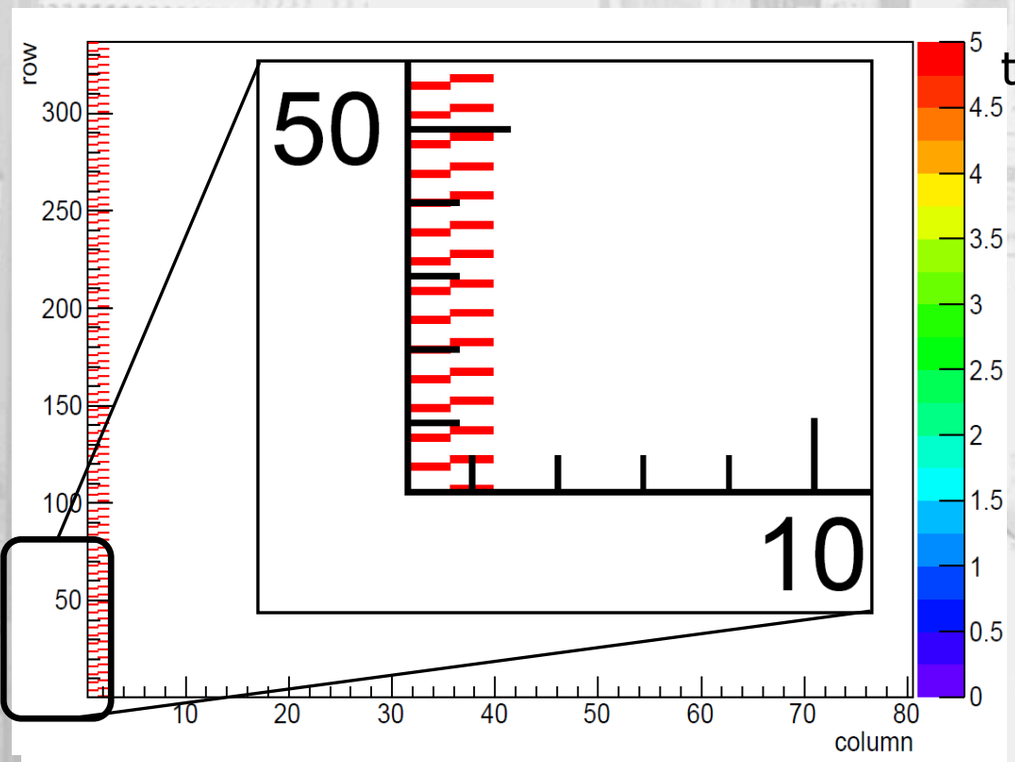






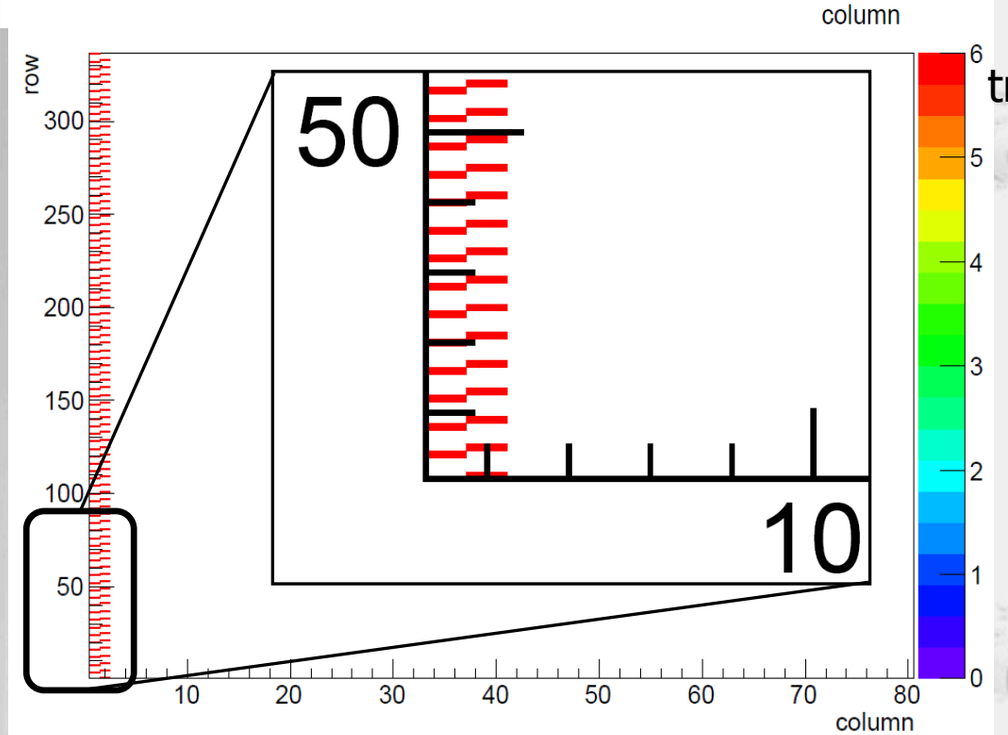


Example tests #2: Integration with FE-I4 (3)



CHIP #0
¼ PixelMask
Cal Pulse Length = 5 BC
First Mask Stage

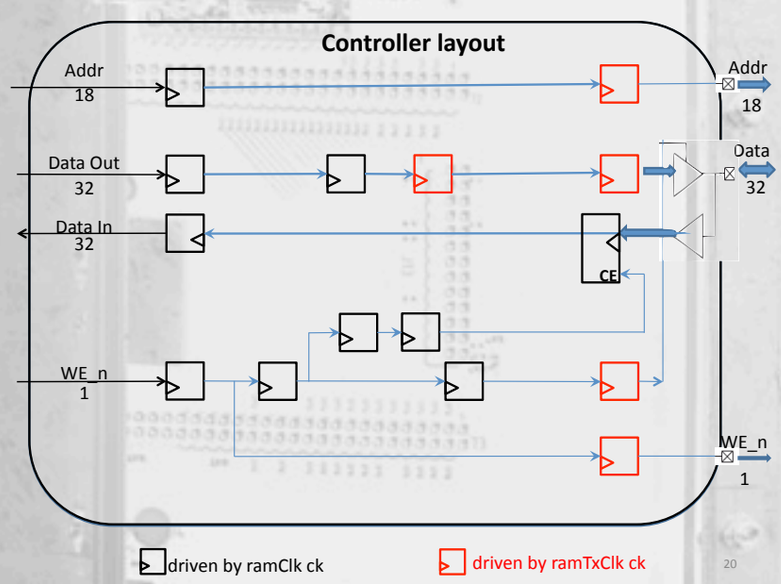
```
MPixNum 0 Hist 0,Chip 0, Odd_Col 1, Row 4, Result 0x100281: occ 1, tot 2, tot² 4
MPixNum 80 Hist 0,Chip 0, Odd_Col 1, Row 8, Result 0x100281: occ 1, tot 2, tot² 4
MPixNum 160 Hist 0,Chip 0, Odd_Col 1, Row 12, Result 0x100281: occ 1, tot 2, tot² 4
MPixNum 240 Hist 0,Chip 0, Odd_Col 1, Row 16, Result 0x100281: occ 1, tot 2, tot² 4
MPixNum 320 Hist 0,Chip 0, Odd_Col 1, Row 20, Result 0x100281: occ 1, tot 2, tot² 4
MPixNum 400 Hist 0,Chip 0, Odd_Col 1, Row 24, Result 0x100281: occ 1, tot 2, tot² 4
MPixNum 480 Hist 0,Chip 0, Odd_Col 1, Row 28, Result 0x100281: occ 1, tot 2, tot² 4
MPixNum 560 Hist 0,Chip 0, Odd_Col 1, Row 32, Result 0x100281: occ 1, tot 2, tot² 4
MPixNum 640 Hist 0,Chip 0, Odd_Col 1, Row 36, Result 0x100281: occ 1, tot 2, tot² 4
MPixNum 720 Hist 0,Chip 0, Odd_Col 1, Row 40, Result 0x100281: occ 1, tot 2, tot² 4
MPixNum 800 Hist 0,Chip 0, Odd_Col 1, Row 44, Result 0x100281: occ 1, tot 2, tot² 4
MPixNum 880 Hist 0,Chip 0, Odd_Col 1, Row 48, Result 0x100281: occ 1, tot 2, tot² 4
MPixNum 960 Hist 0,Chip 0, Odd_Col 1, Row 52, Result 0x100281: occ 1, tot 2, tot² 4
```

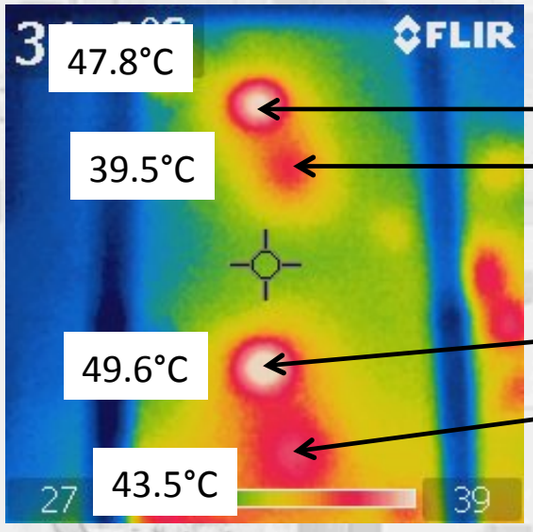


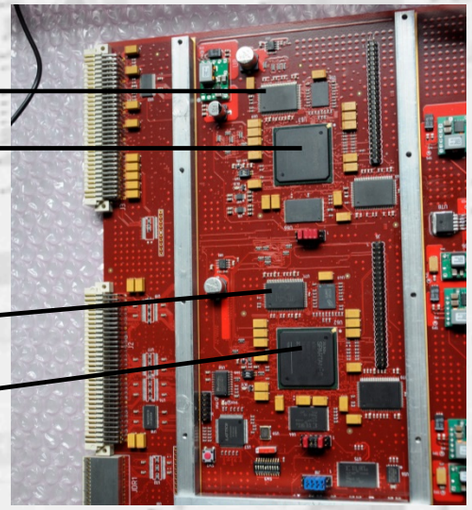
CHIP #1
¼ PixelMask
Cal Pulse Length = 6 BC
First Mask Stage

```
MPixNum 6720 Hist 0,Chip 1, Odd_Col 1, Row 4, Result 0x240381: occ 1, tot 3, tot² 9
MPixNum 6800 Hist 0,Chip 1, Odd_Col 1, Row 8, Result 0x240381: occ 1, tot 3, tot² 9
MPixNum 6880 Hist 0,Chip 1, Odd_Col 1, Row 12, Result 0x240381: occ 1, tot 3, tot² 9
MPixNum 6960 Hist 0,Chip 1, Odd_Col 1, Row 16, Result 0x240381: occ 1, tot 3, tot² 9
MPixNum 7040 Hist 0,Chip 1, Odd_Col 1, Row 20, Result 0x240381: occ 1, tot 3, tot² 9
MPixNum 7120 Hist 0,Chip 1, Odd_Col 1, Row 24, Result 0x240381: occ 1, tot 3, tot² 9
MPixNum 7200 Hist 0,Chip 1, Odd_Col 1, Row 28, Result 0x240381: occ 1, tot 3, tot² 9
MPixNum 7280 Hist 0,Chip 1, Odd_Col 1, Row 32, Result 0x240381: occ 1, tot 3, tot² 9
MPixNum 7360 Hist 0,Chip 1, Odd_Col 1, Row 36, Result 0x240381: occ 1, tot 3, tot² 9
MPixNum 7440 Hist 0,Chip 1, Odd_Col 1, Row 40, Result 0x240381: occ 1, tot 3, tot² 9
MPixNum 7520 Hist 0,Chip 1, Odd_Col 1, Row 44, Result 0x240381: occ 1, tot 3, tot² 9
MPixNum 7600 Hist 0,Chip 1, Odd_Col 1, Row 48, Result 0x240381: occ 1, tot 3, tot² 9
MPixNum 7680 Hist 0,Chip 1, Odd_Col 1, Row 52, Result 0x240381: occ 1, tot 3, tot² 9
```

Example #3: Interface with SRAM for Histogramming



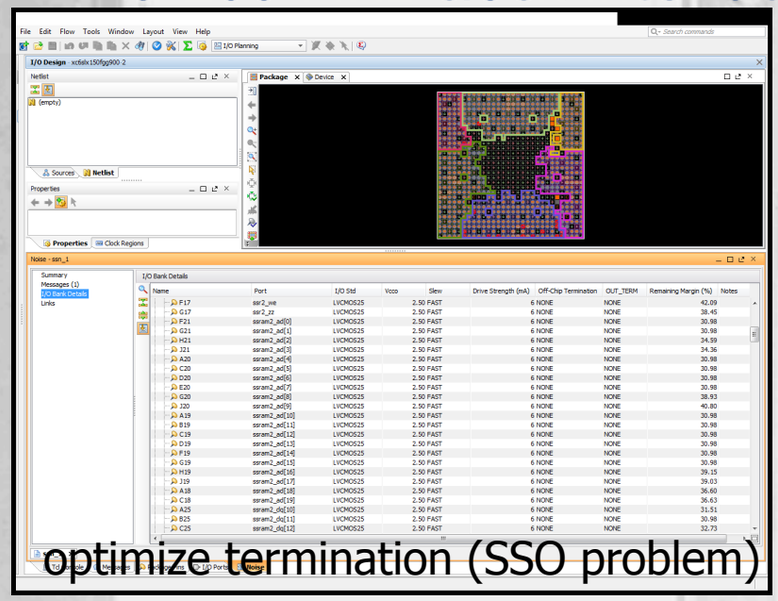




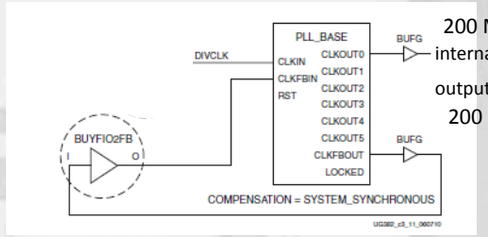
★ Custom fw solutions are developed in order to enhance the calibration scan

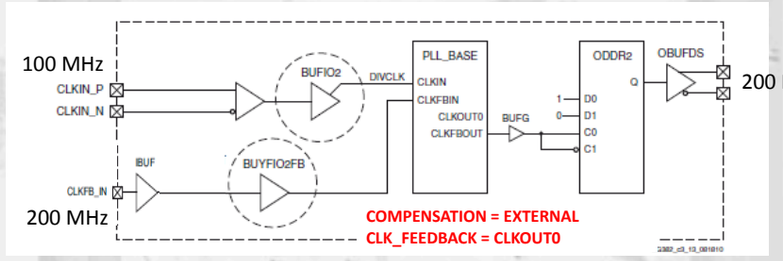
★ High frequency interface with SRAMs is on study:

- a 140 MHz clock interface has been successfully integrated in the latest fw release
- a 200 MHz clock interface has been successfully tested stand-alone



Clock distribution





ROD production plan and testing procedures

ROD ready for production for IBL

We defined a **list of minimal procedures to validate the ROD cards after production:**

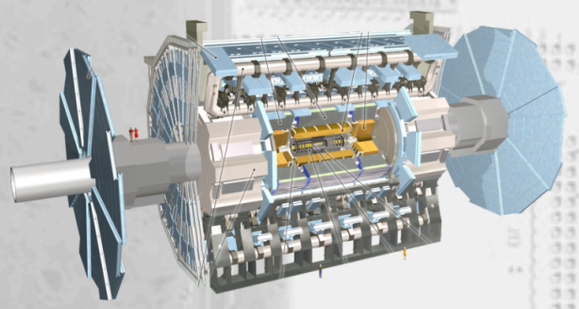
- ✦Firmware-software upload from VME, JTAG and Gb/s-Ethernet ports
- ✦ROD-2-BOC (and BOC-2-ROD) dataflow over all I/O lines
- ✦R/W tests for Virtex5 and Spartan6 external memory modules
- ✦Dataflow tests on the 3 Gb/s ports
- ✦TIM card connectivity test

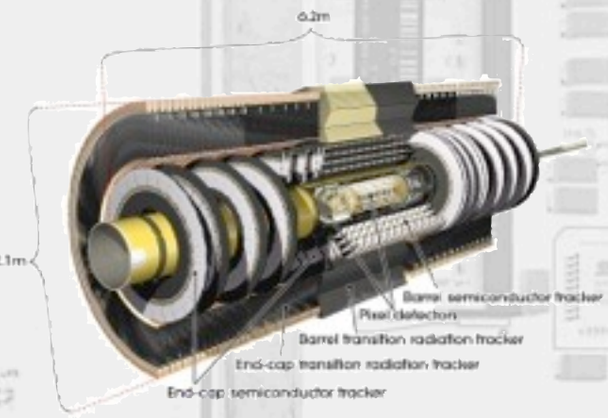
Test committed-delegated to the **ROD manufacturer company** (the same we asked for ROD ver B and C cards):

- ✦Electrical test after component supply
- ✦RX test for large BGA-packaged components

15 RevC IBL ROD board production started on August 26th 2013
Boards are expected on the first week of October
Distribution to CERN might start at the end of October

Overview reminder





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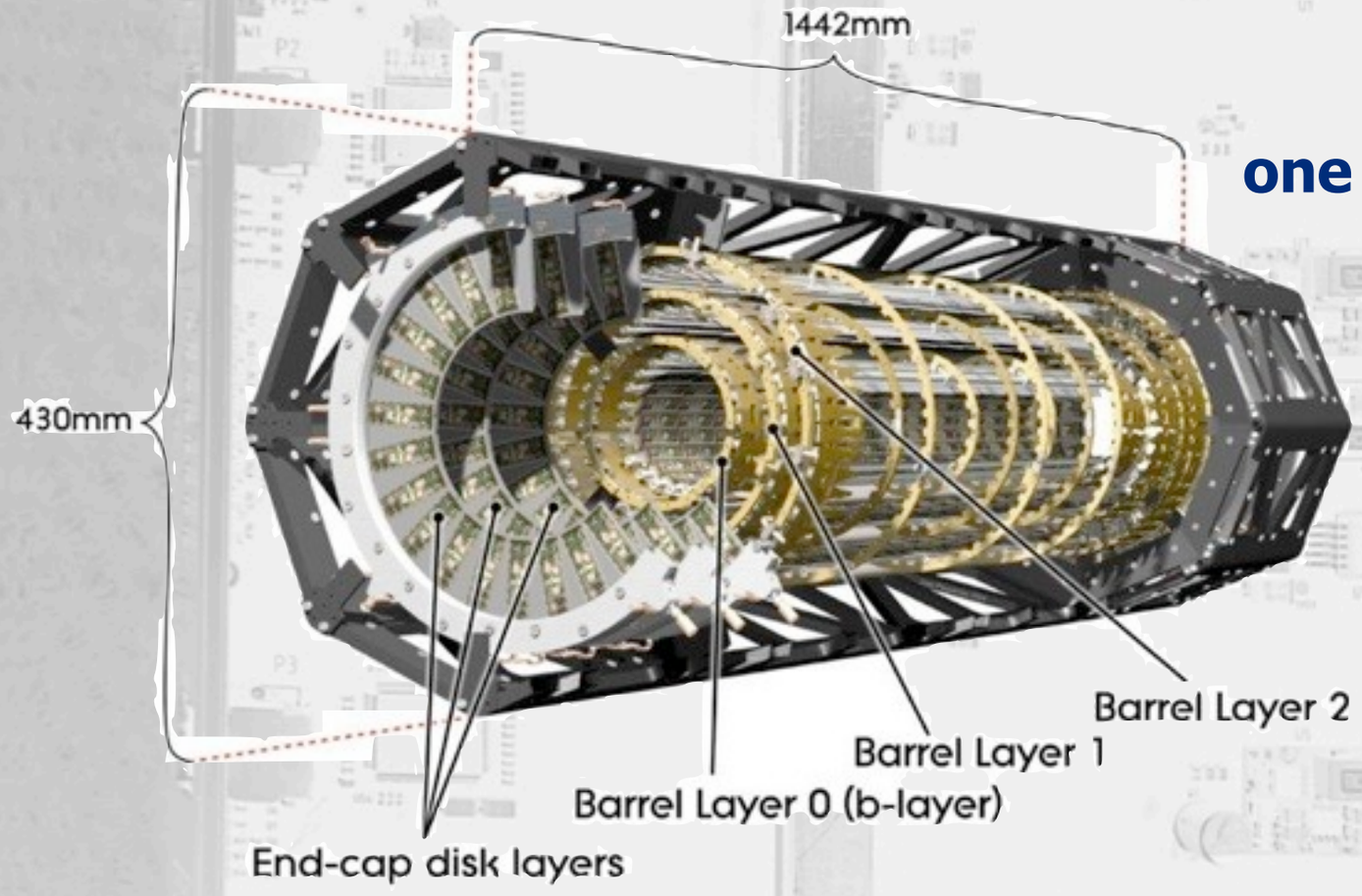

one Module Control Chip (MCC) x module
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layer 1: 1 link @ 80 Mb/s
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Each off-detector readout unit
handles up to 160 MB/s
(2 link @ full speed)
(1 S-Link)

Pixel Layer 1 and 2 future limitations

With the **restart of LHC** we expect a **higher luminosity**, which will increase even more in the next years.

The link occupancy for the Pixel readout link will suffer from bandwidth limitations.

(reminder: link bandwidth is a function of both occupancy and trigger rate)

Module and link occupancy have been extrapolated using the experience gained from the last year(s).

Suffering for **Layer2** could be observed already in the last run period.

Possible Action: Increase link bandwidth to 80 Mb/s

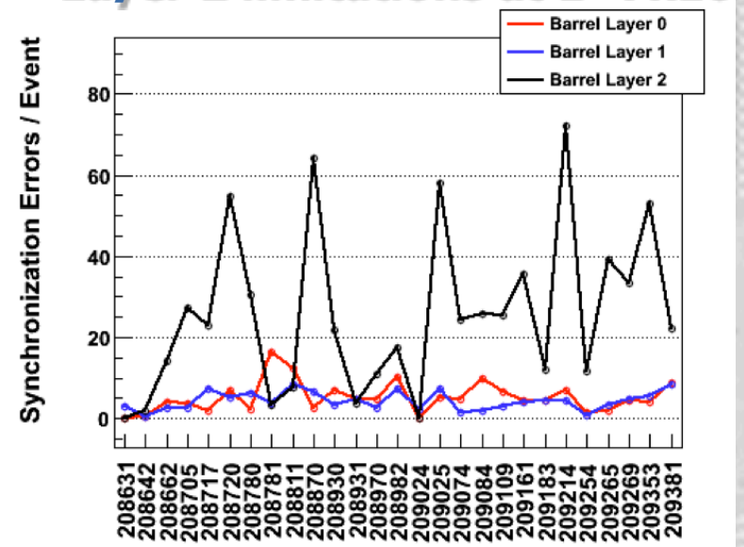
Layer 1 will experience at ~ $2x10^{34}$ luminosity

Layer 1 is already read out at 80 Mb/s

Possible Action: Double the links per module and upgrade the bandwidth to 2x 80 Mb/s,

(requires installing additional fibres now)

Layer 2 limitations at $L=7x10^{33}$



Adopting ROD for layer 1 and 2

Therefore, **using the presented IBL ROD and BOC cards is a viable solution** also for the Pixel upgrade to overcome the bandwidth limitations.

Firmware of the ROD needs modification to handle the Pixel module data.

No Atlas official plan at the time being but **discussion** well advanced.

We can **propose** to repeat the **same roadmap for Layer2**
(caveat:
new boards production should start soon; to be installed mid next year)

Whatever needed for Layer 1 will be probably postponed after IBL and Layer 2 commissioning; only components might be bought earlier

Further benefits:

No major further development is needed as the ROD and BOC are there for the IBL anyhow

Firmware adaptation to Pixel needs

This will uniform our readout system:

Common spares for the 4-Layers Pixel

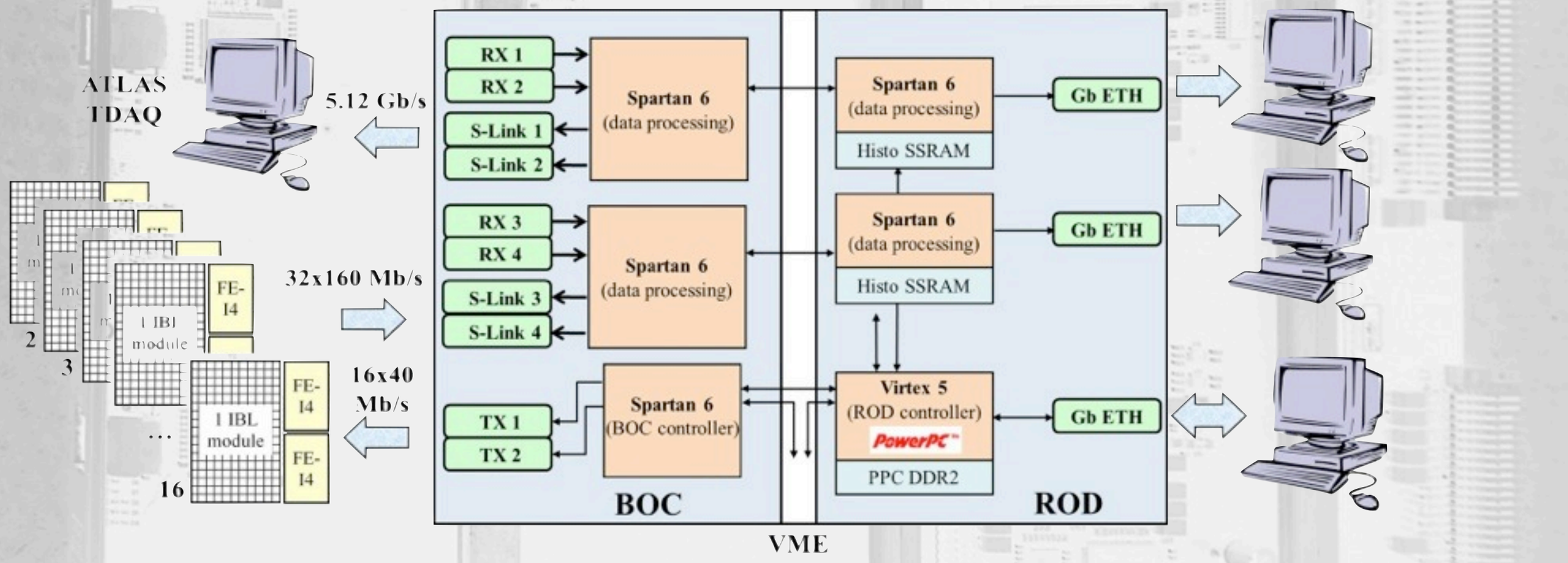
Summary and conclusions

- The **ROD card** for the readout of the **Atlas IBL** pixel has been presented
- **Tests** on the pre-production batch have been **discussed** and selected results shown
- The **final production** has been **launched** (15 cards)
- **Bandwidth limitation** of existing Pixel **layers 1 and 2** have been **analyzed**
- The **benefits** of adoption of the **IBL ROD** even for layer 1 and 2 have been pointed out

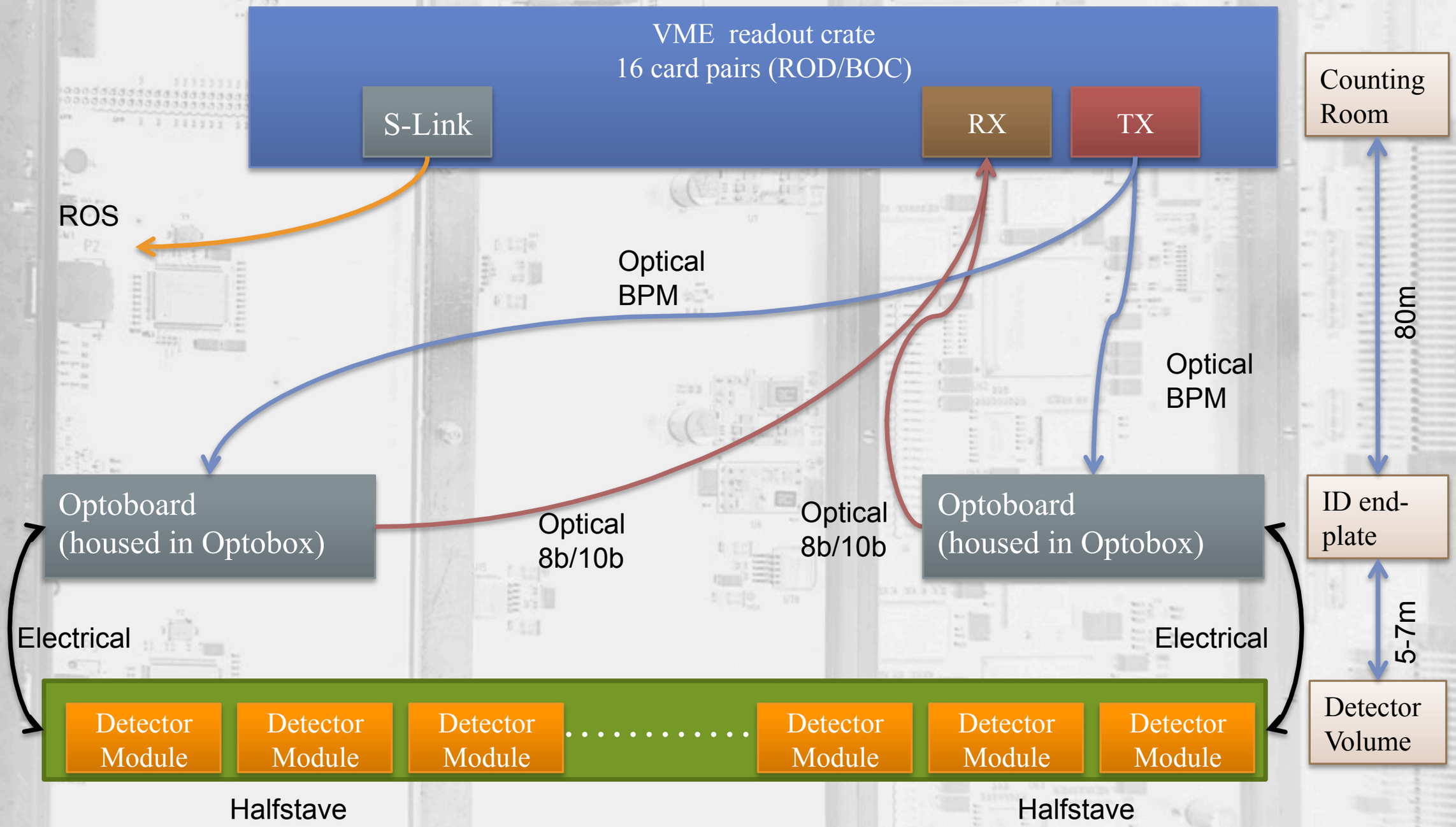
Additional Material

IBL ReadOut system summary

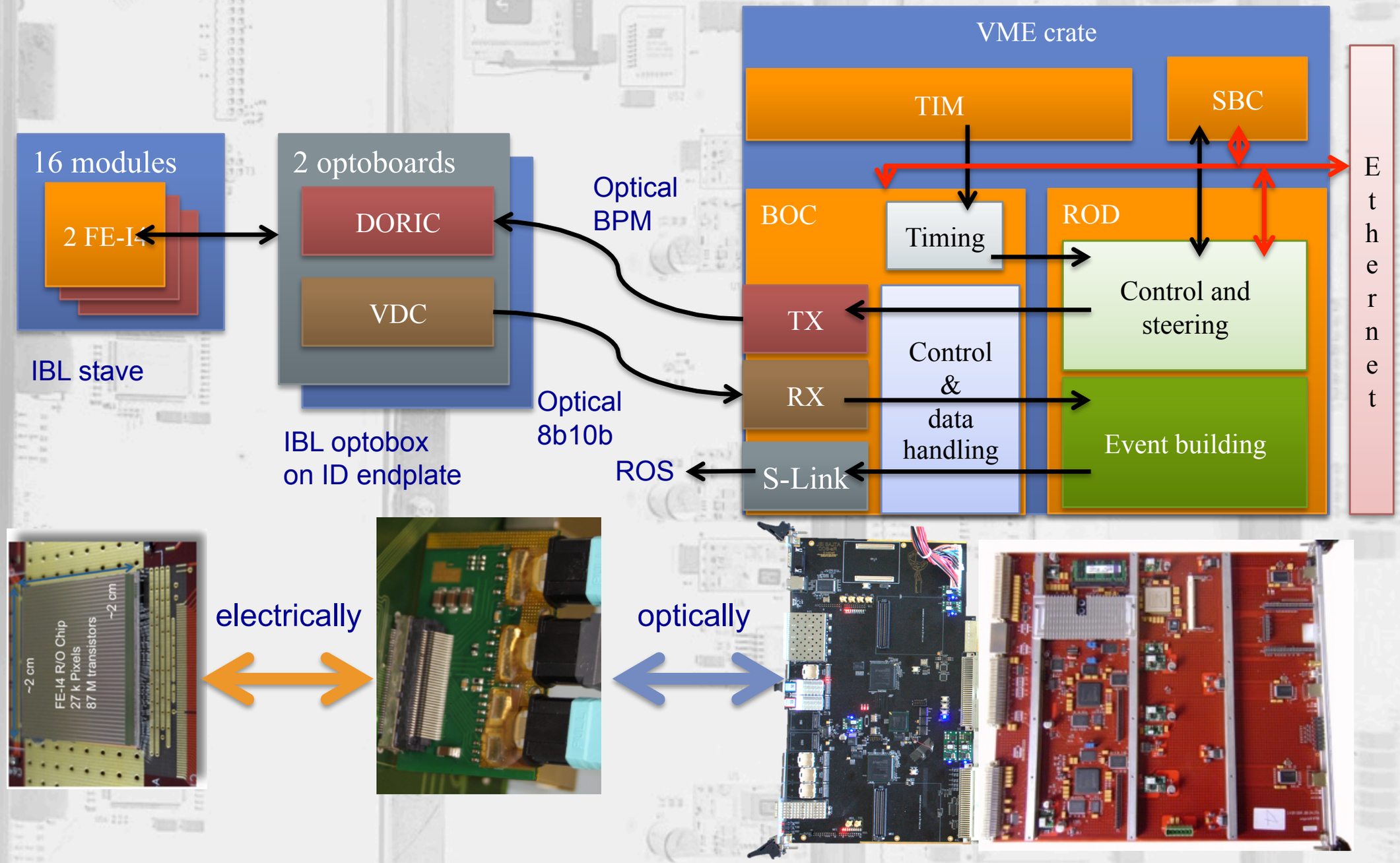
Number of IBL Staves /ROD-BOC pair	14
# DAQ Modules per ROD-BOC pair	16
# FE-I4s chip per ROD-BOC pair	32
Total # of FE-I4s in IBL	448 (32*14)
Number of Pixels per FE-I4	26880
Total # of read-out channels	~12 M



Readout Scheme Overview



ATLAS IBL Readout Structure

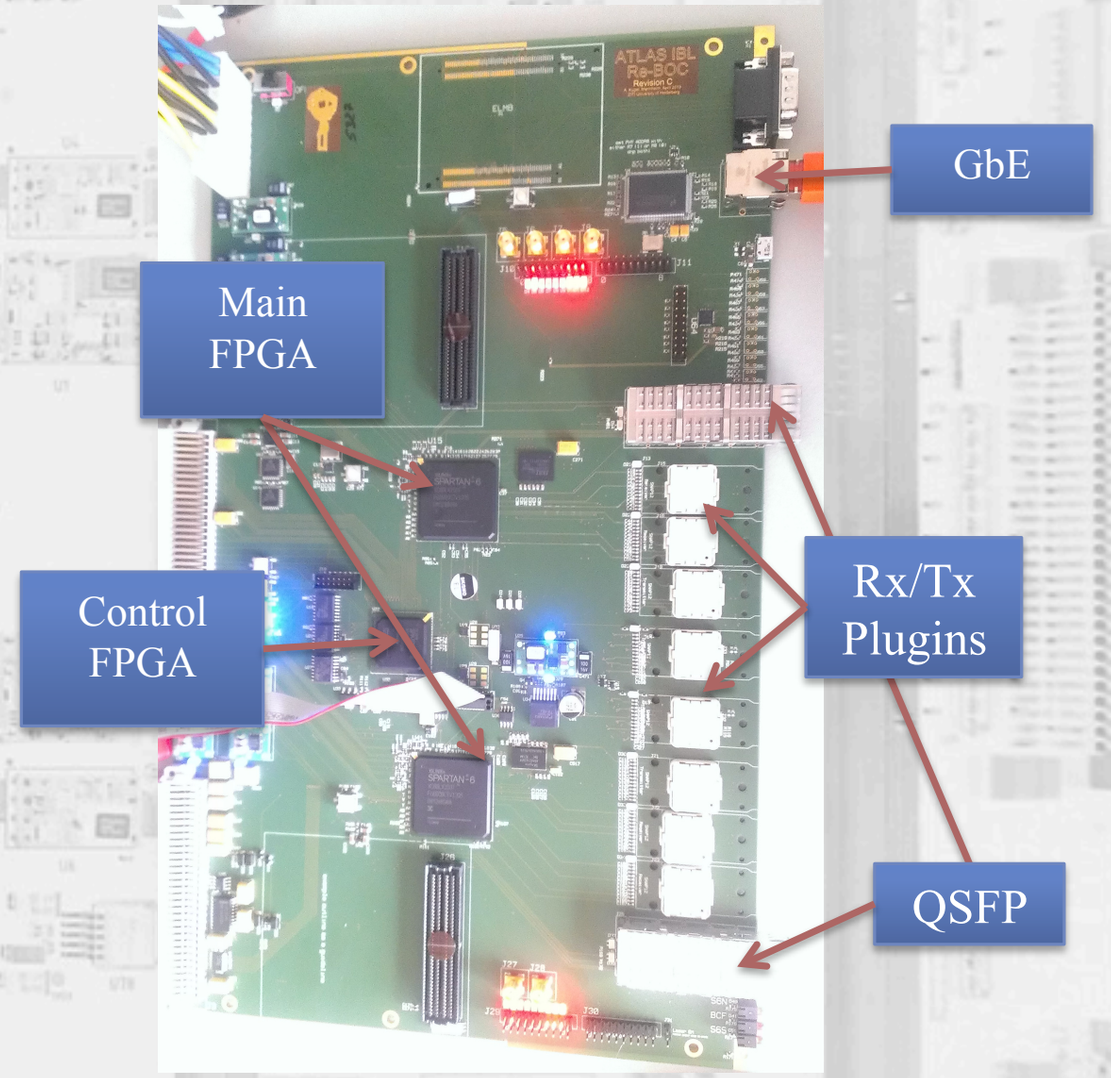


Production & Installation Schedule

Installation items	Expected time	comment
Card production	From July 2013	Prototypes ready in revC
Systemtesting	June 2013 -	Set-up phase ongoing
IBL full test	November 2013	Have all the readout and services ready in SR1
Installation of off-detector parts for readout and power	Jan/Feb 2014	Whenever they can be taken from final SR1 tests
Cabling of detector in pit	Mar 2014	After IBL installation
Commissioning tests and sign-off for closure	April-June 2014	Sequence of warm/cold test
Ready for closure	End June 2014	

IBL Back of Crate Card

- Timing interface
  - Receive clock from TIM
  - Distribute the clock to detector components and ROD
- Optical interface to/from detector and readout buffers
  - SNAP12 plugins (Tx / Rx)
  - S-Link plugins (QSFP)
- Data en-/decoding for detector communication
  - BPM encoding towards the detector
  - 8b/10b decoding for the detector data to hand over to the ROD
- Monitoring functionalities for detector data



BOC RevC