Considerations on ITS3 Readout

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Slides from Presentations at the ITS3 Plenary in April 2023

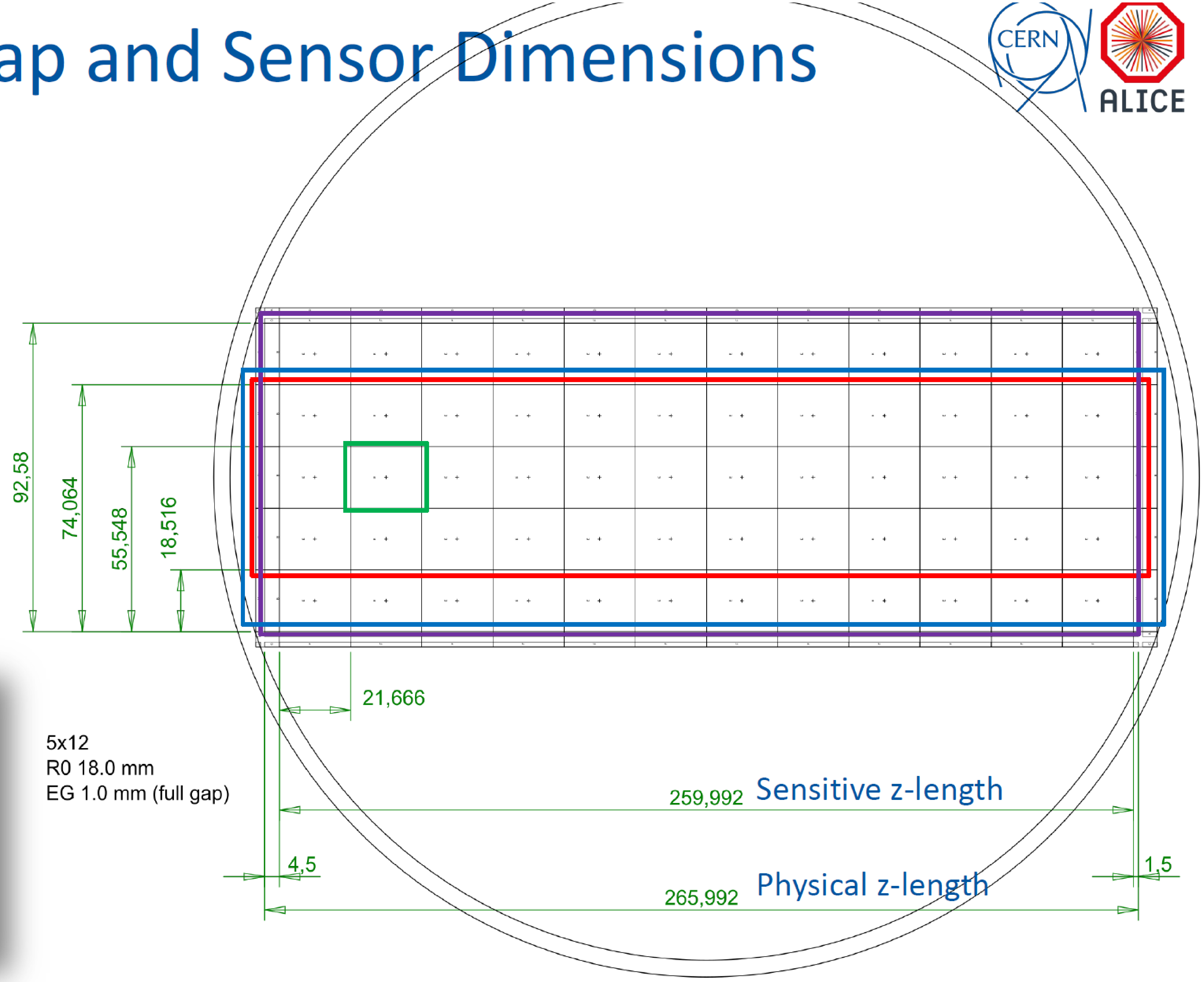
ER2 Stiching Map and Sensor Dimensions

Layer 0: 12 x 3 repeated units+endcaps

Layer 1: 12 x 4 repeated units+endcaps

Layer 2: 12 x 5 repeated units+endcaps

Repeated (Stitched) Sensing Unit

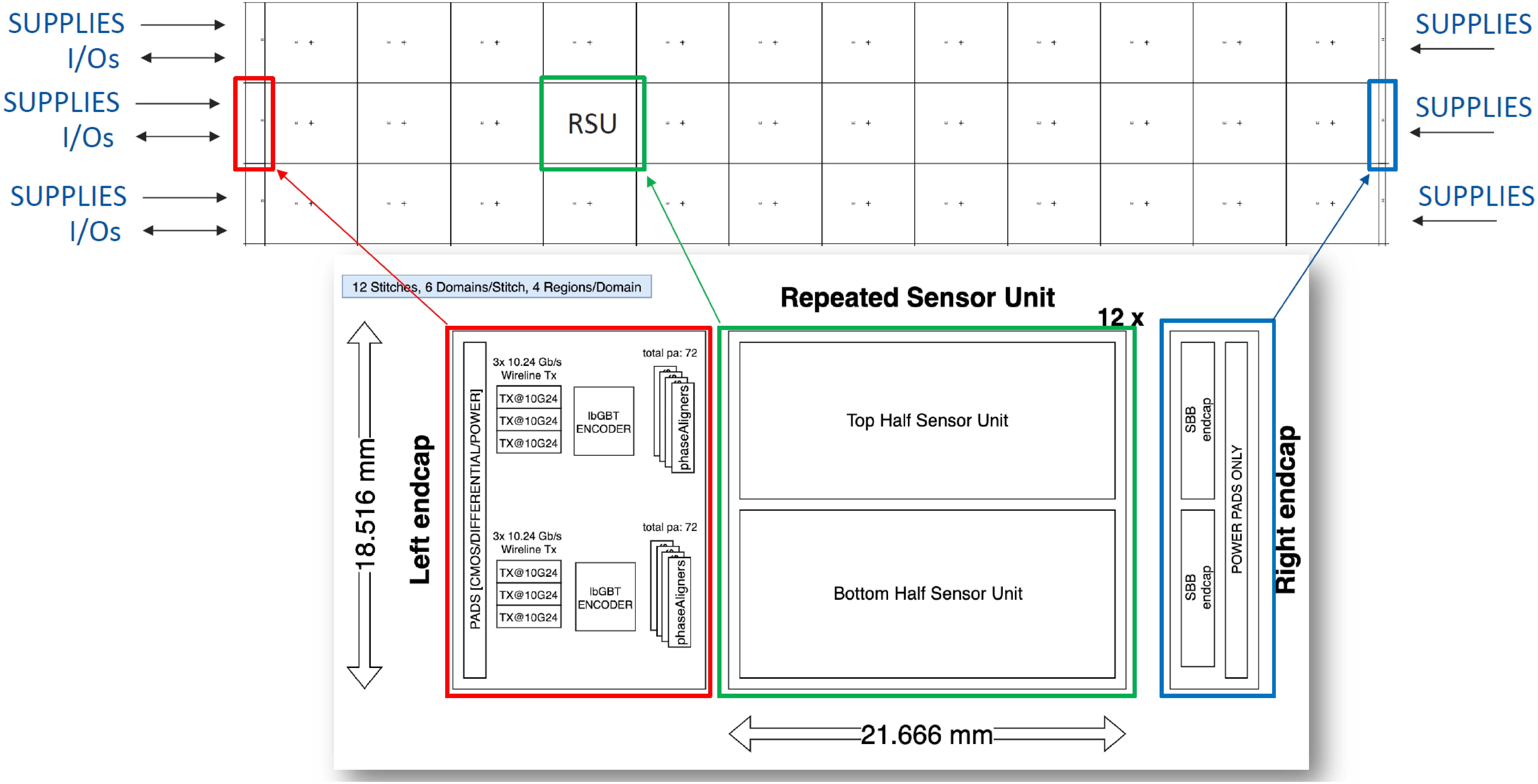


5x12
R0 18.0 mm
EG 1.0 mm (full gap)

TDR Draft

IB Layer Parameters	Layer 0	Layer 1	Layer 2
Sensor length [mm]		265.992	
Sensitive length [mm]		259.992	
Equatorial gap [mm]		1.0	
Sensor azimuthal width [mm]	55.548	74.064	92.58
Radial position [mm]	18	23.9	29.8
Equatorial gap [mm]		1.0	
Sensor azimuthal width [mm]	58.692	78.256	97.820
Radial position [mm]	19.0	25.2	31.5
Equatorial gap [mm]		2.0	
Sensor azimuthal width [mm]	57.684	76.912	96.140
Radial position [mm]	19.0	25.1	31.2

Top Integration Diagram



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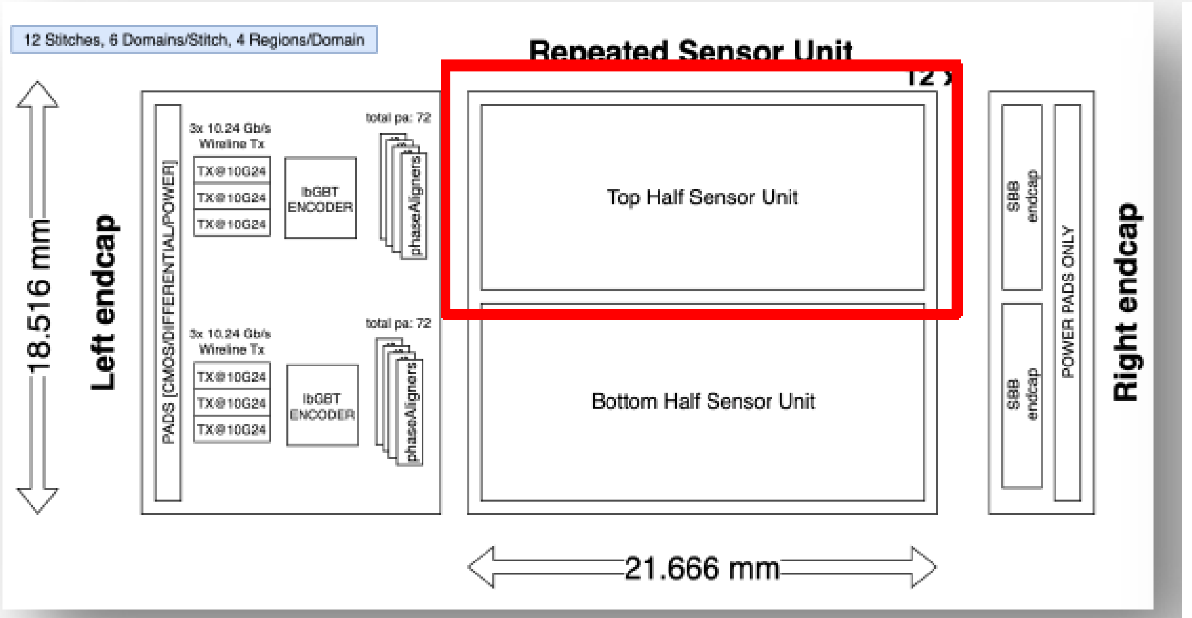
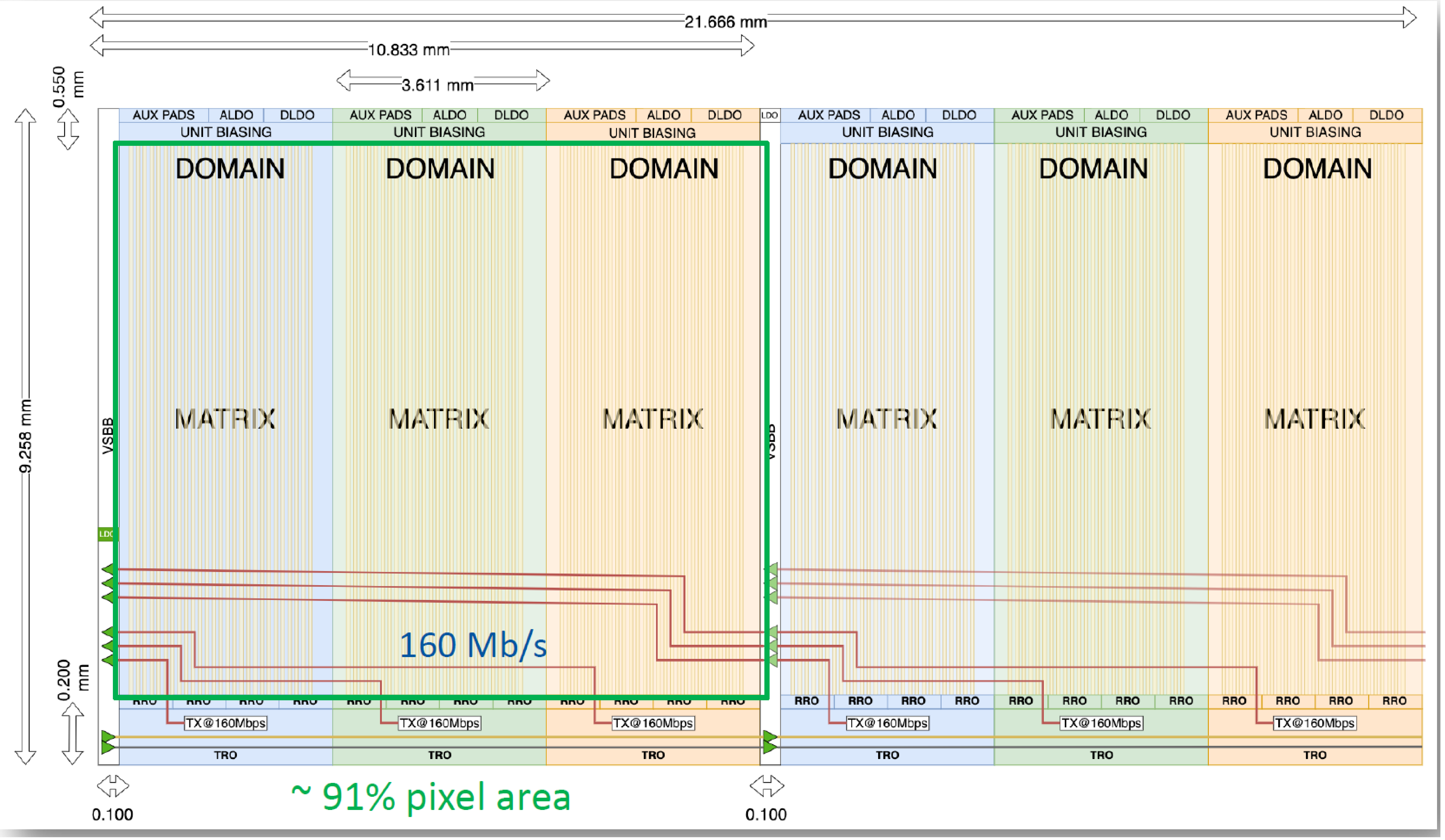




Each Half Unit is segmented in Powering **Domains**

Each Domain acts as independent pixel sensor

- Powering
- Biasing
- Configuration
- Readout Link (160 Mb/s)

Readout Simulations

Optimize *segmentation* and FIFO *size*

Calculate fraction of hits lost and fraction of incomplete frames

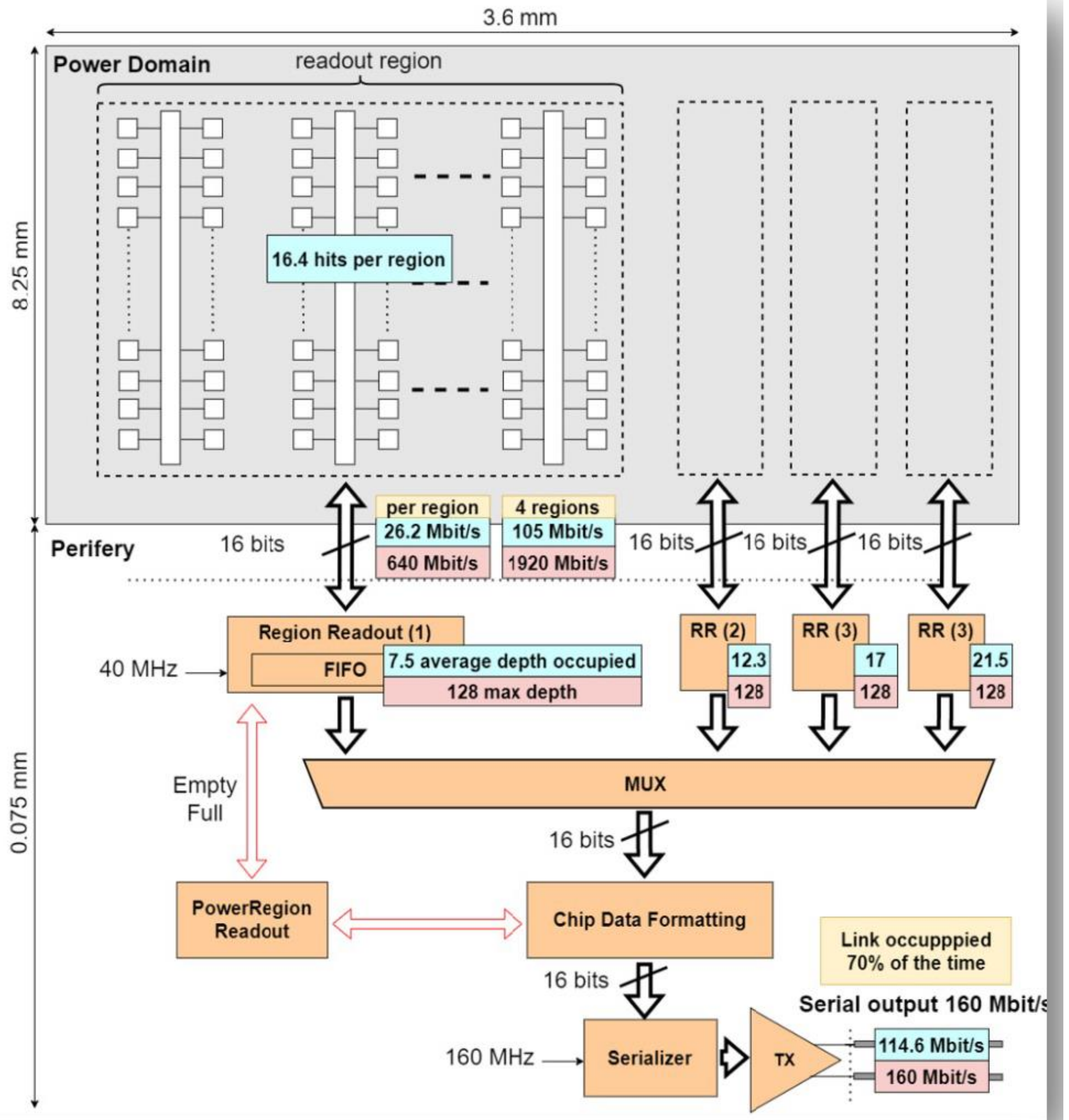
Digital simulation with randomized, uniformly distributed collisions and hit events as input

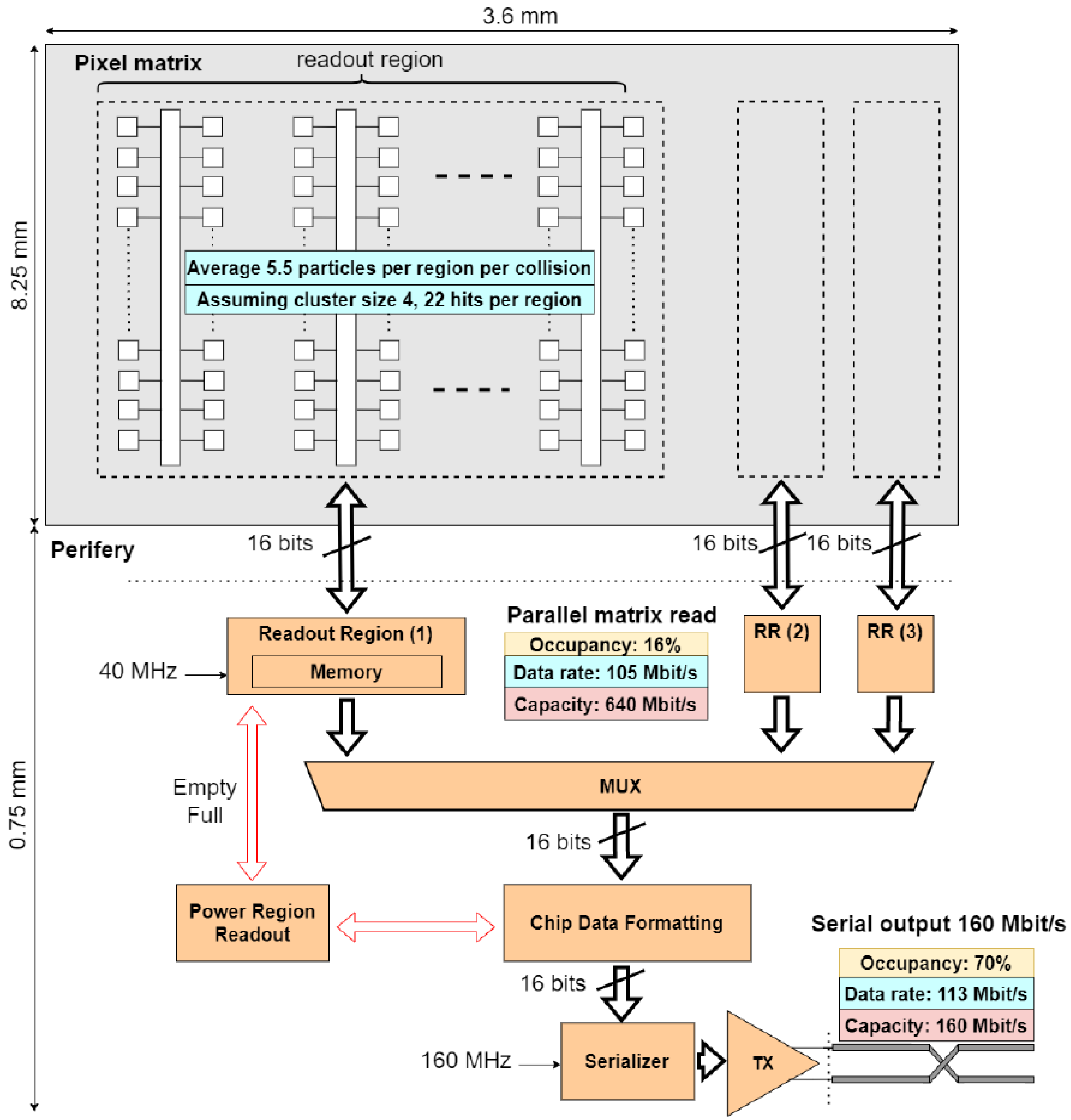
Introducing physics based stimuli

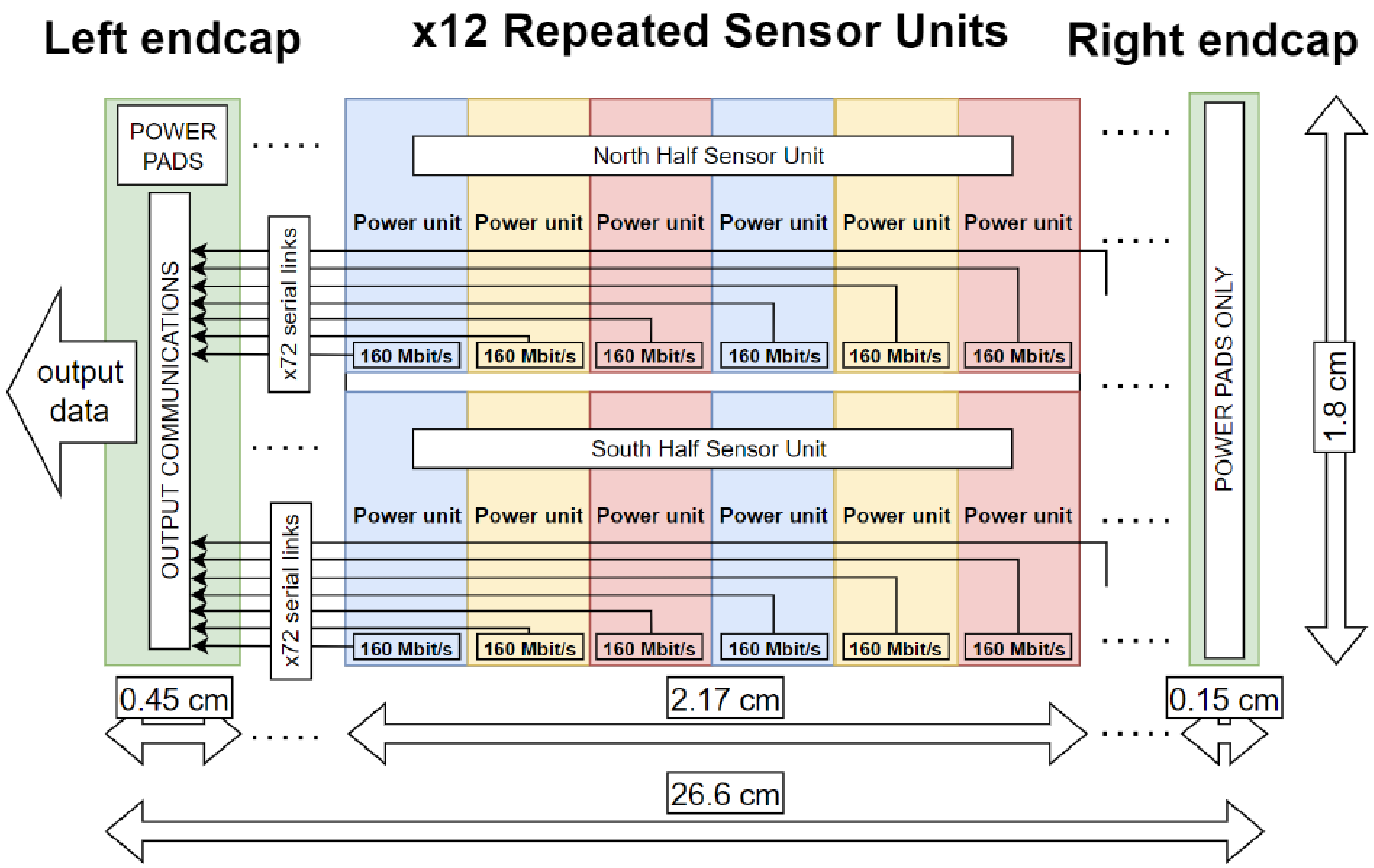
Consistent with and slightly less demanding than previous model at first glance

Studied architecture

- Integration time of 100KHz interaction rate (factor 2) and 4-pixel hits per particle
- 6 power domains, 24 regions, 10 us integration time and 128 FIFO depth
- In light blue, average values
- In light red, average values



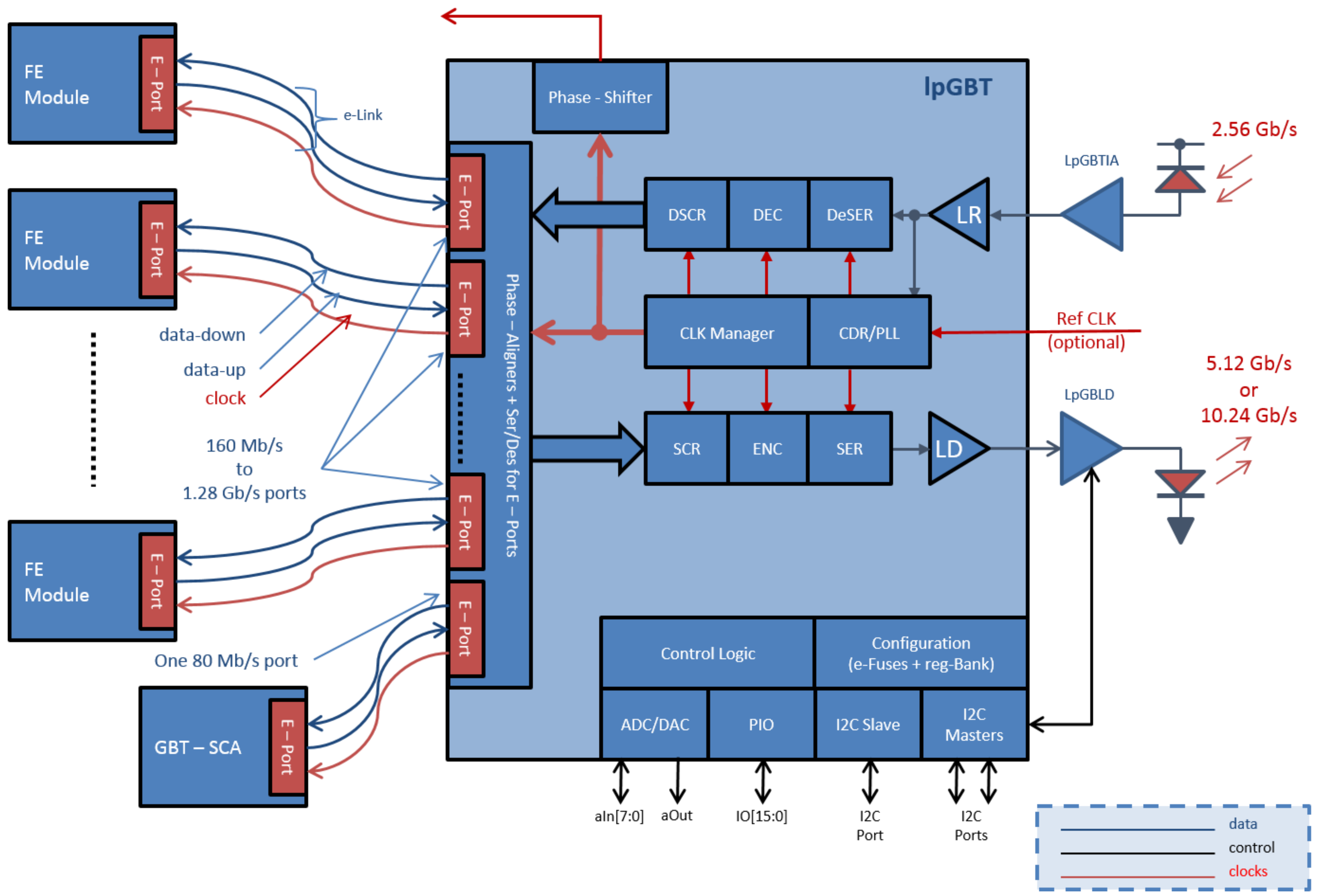

3.6 mm
Pixel matrix
readout region
8.25 mm
Average 5.5 particles per region per collision
Assuming cluster size 4, 22 hits per region
Perifery
16 bits
16 bits
16 bits
0.75 mm
Readout Region (1)
Memory
40 MHz
Parallel matrix read
Occupancy: 16%
Data rate: 105 Mbit/s
Capacity: 640 Mbit/s
RR (2)
RR (3)
Empty
Full
MUX
16 bits
Power Region Readout
Chip Data Formatting
16 bits
Serial output 160 Mbit/s
Occupancy: 70%
Data rate: 113 Mbit/s
Capacity: 160 Mbit/s
160 MHz
Serializer
TX


Left endcap
x12 Repeated Sensor Units
Right endcap
POWER PADS
OUTPUT COMMUNICATIONS
output data
x72 serial links
North Half Sensor Unit
South Half Sensor Unit
Power unit
160 Mbit/s
POWER PADS ONLY
1.8 cm
0.45 cm
2.17 cm
0.15 cm
26.6 cm

lpGBT Capabilities

Communicates with

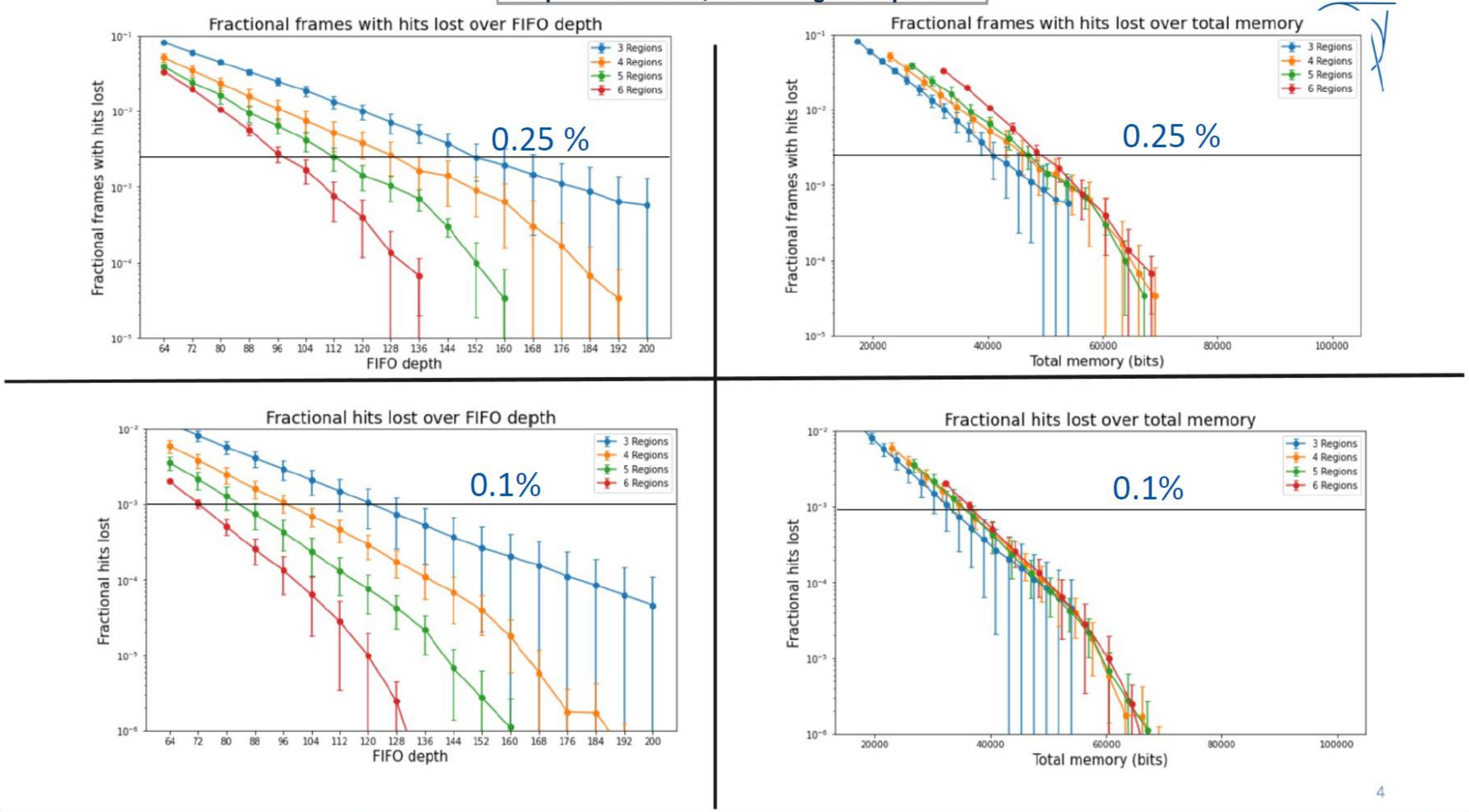
- The counting room
  - Optical fibre links
- The FE modules / ASICs
  - Electrical links (eLinks)
- The Number and Bandwidth of eLinks is programmable
- For Down eLinks
  - Bandwidth: 80/160/320 Mbps
  - Count: 16/8/4
- For Up eLinks



Input eLinks (uplink)												
uplink bandwidth [Gbps]	5.12						10.24					
FEC coding	FEC5			FEC12			FEC5			FEC12		
Bandwidth [Mbps]	160	320	640	160	320	640	320	640	1280	320	640	1280
Maximum number	28	14	7	24	12	6	28	14	7	24	12	6

Data losses (Half RSU) vs FIFO depths

6 power domains, 10 us integration period



Uniform distributions of collisions in bunch crossings and Poisson distribution of particles per collision

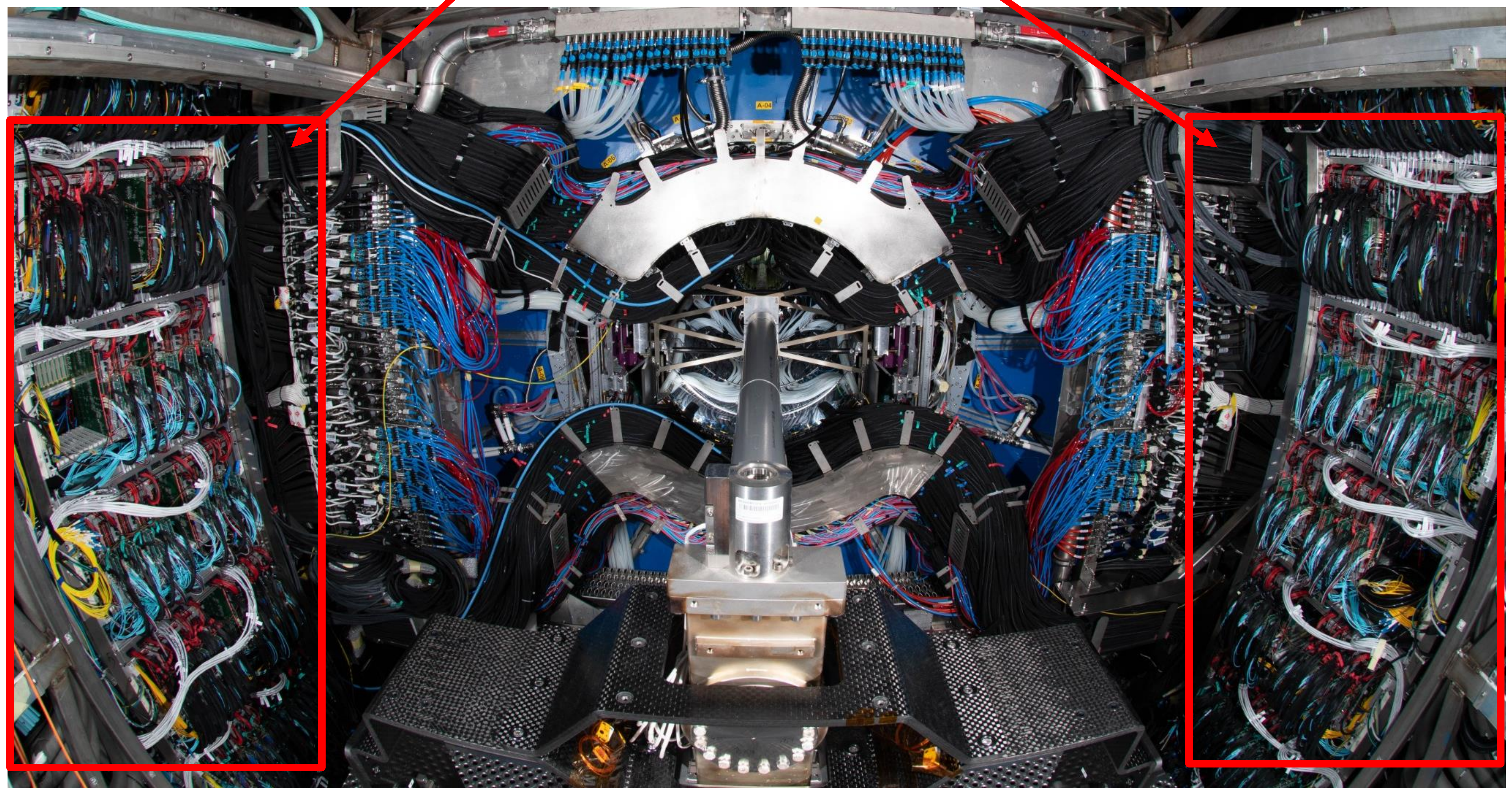
System requirements

- Transmit data upstream
- Supply clock and trigger to detector
- Supply and monitor detector power
- Facilitate detector slow control
- Able to withstand radiation and magnetic field

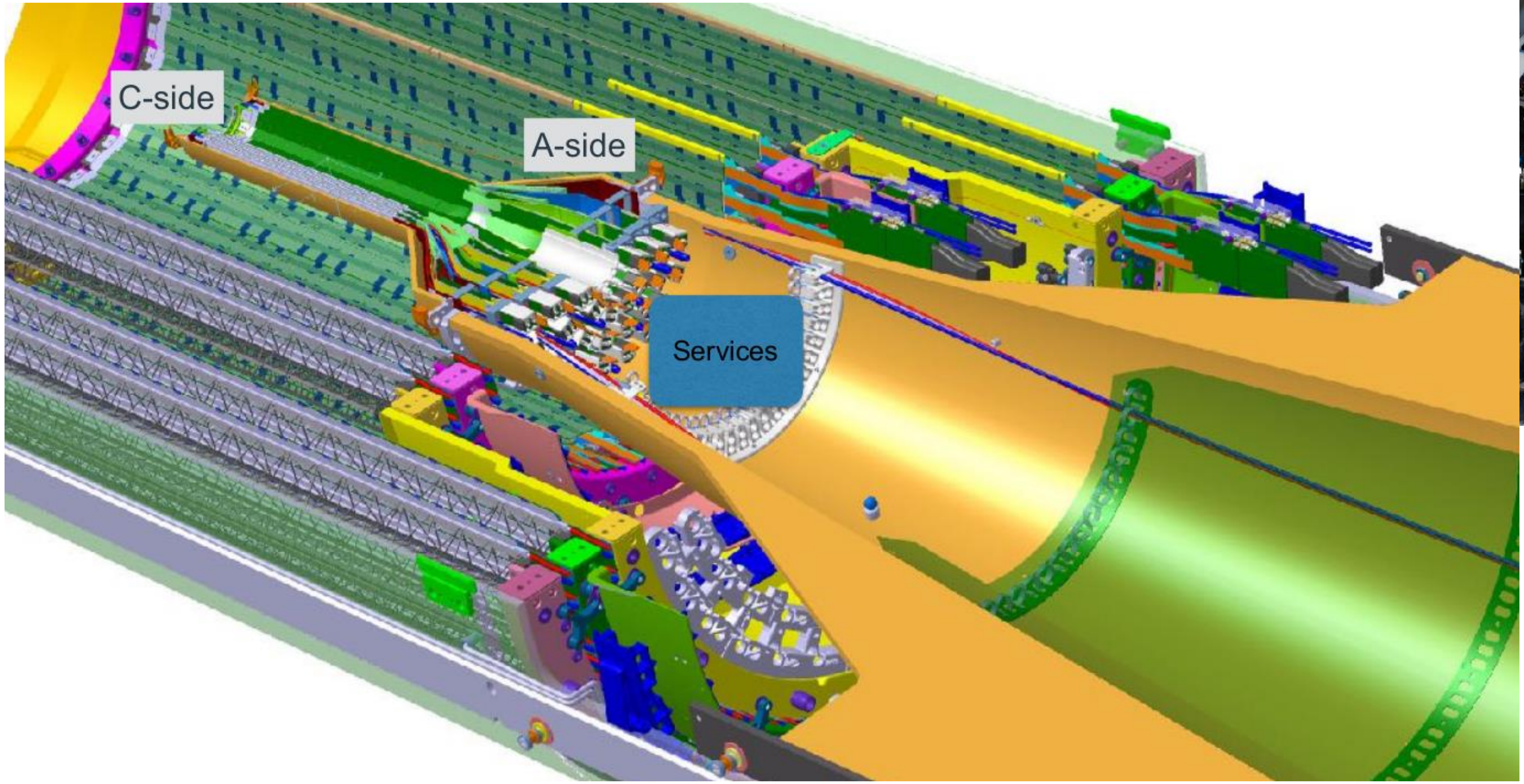
Re-use of current PP-1 infrastructure?

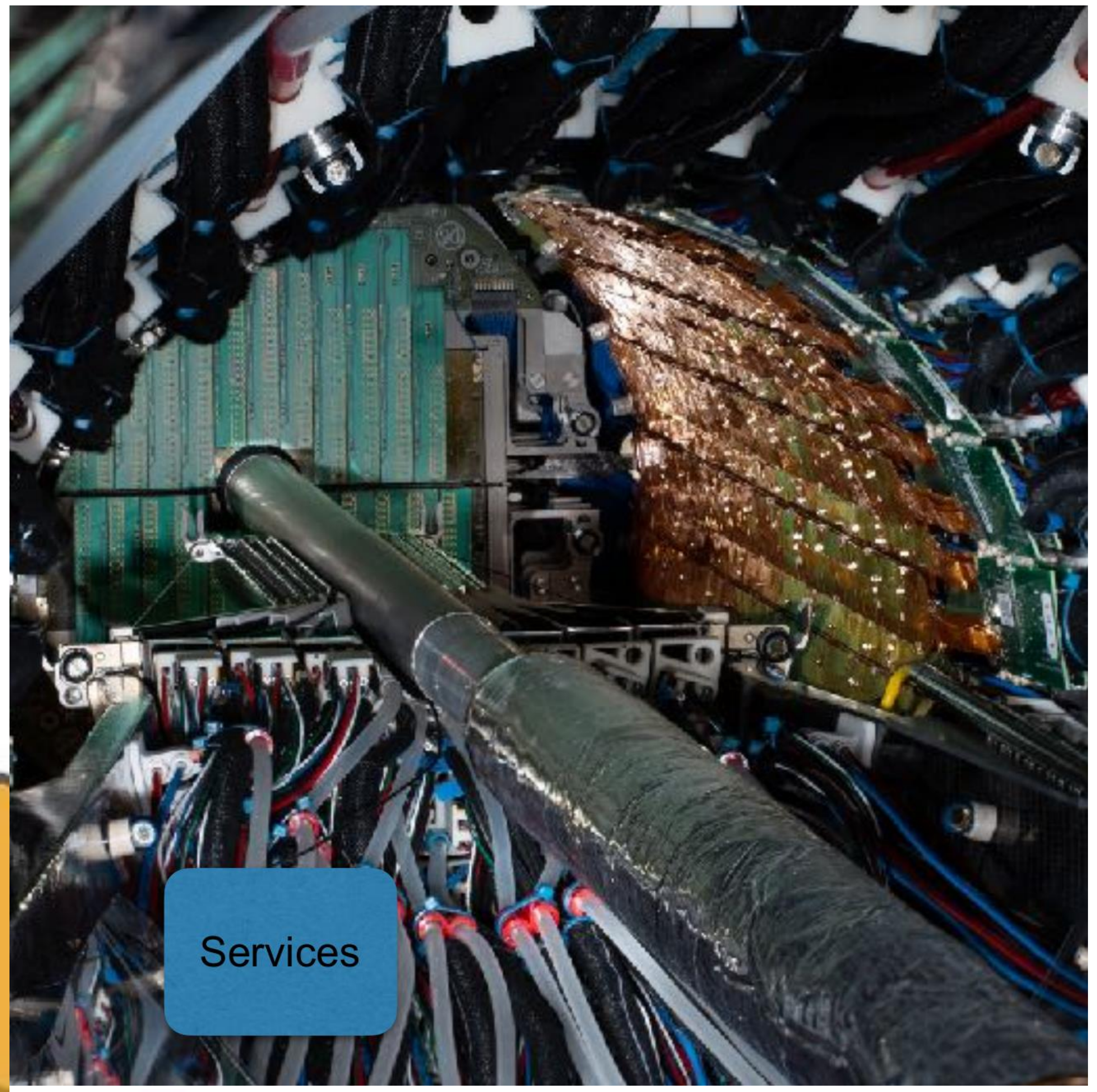
- Current infrastructure:
  - Readout Units (RU)
  - Power Units (PU)
- RUs and PUs most remain in place for ITS2 Outer Barrel
- Consequence of first order data rate estimation:
  - ITS3 (3 layers)-> additional 24 RUs (4 layers -> 44 RUs)
  - Not trivial to find room in cavern close to detector
  - Use of all current spares -> need to produce more RUs
- Increase of link bandwidth [1.2 -> 10.24 Gb/s]
  - Transmission via copper links up to 7m not possible
  - Use of repeaters or electrical-optical transceivers close to detector necessary
- ITS2: conservative powering concept
  - Sensitive to impedance
  - A lot of cables
  - PU dependent on RU for control
- ITS3: utilize recent CERN developments
  - Radiation hard DC/DC converters and control ASIC
  - Regulation close to the detector
  - Drastic reduction of cables due to higher input voltage
- RU and PU replaced by Detector Management Board
  - Avoid use of intelligence (FPGA/ASIC)
  - Make use of in-house expertise (lpGBT/VTRx+/bPols)

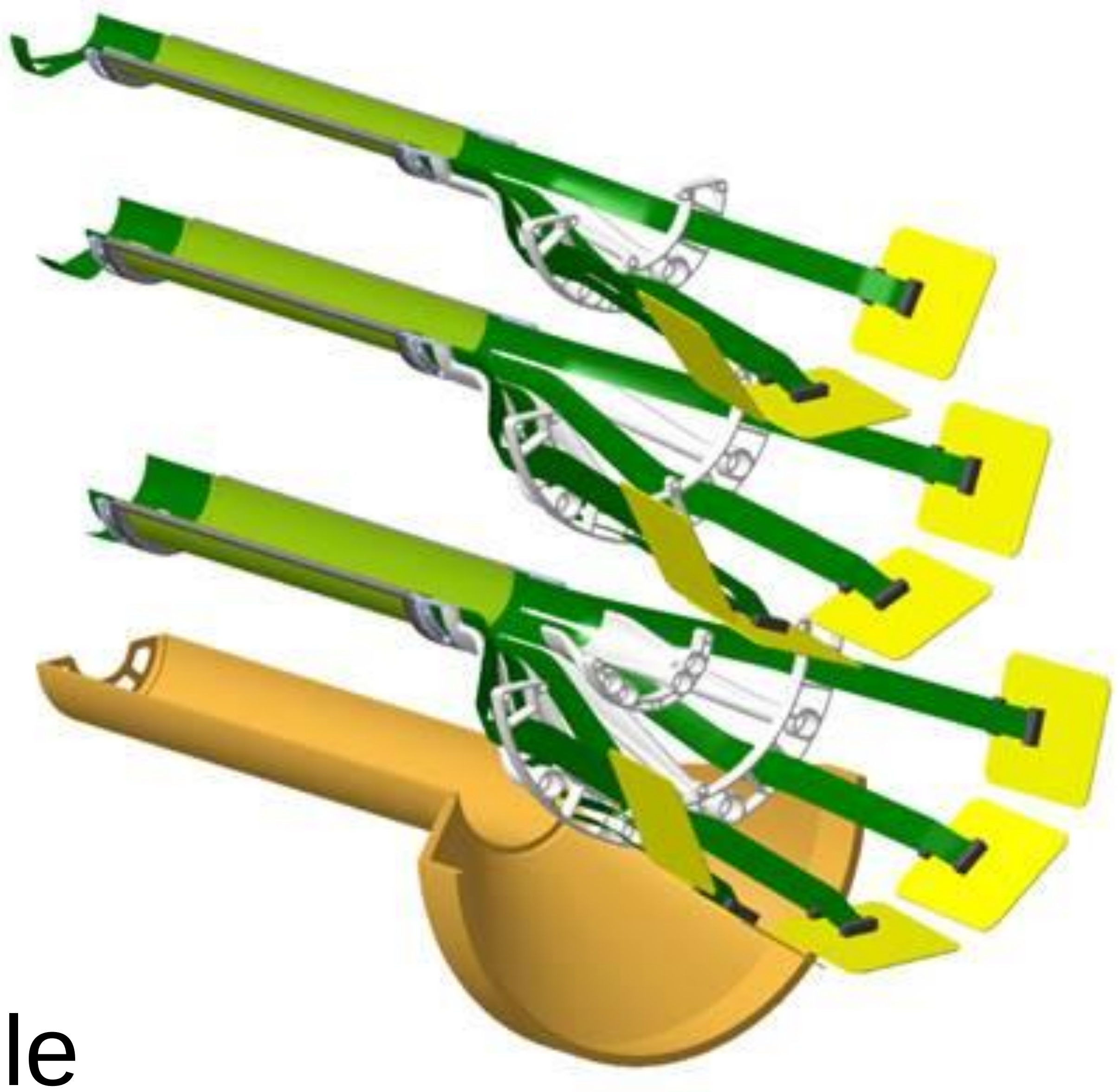
ITS2 RUs and PUs



Services location



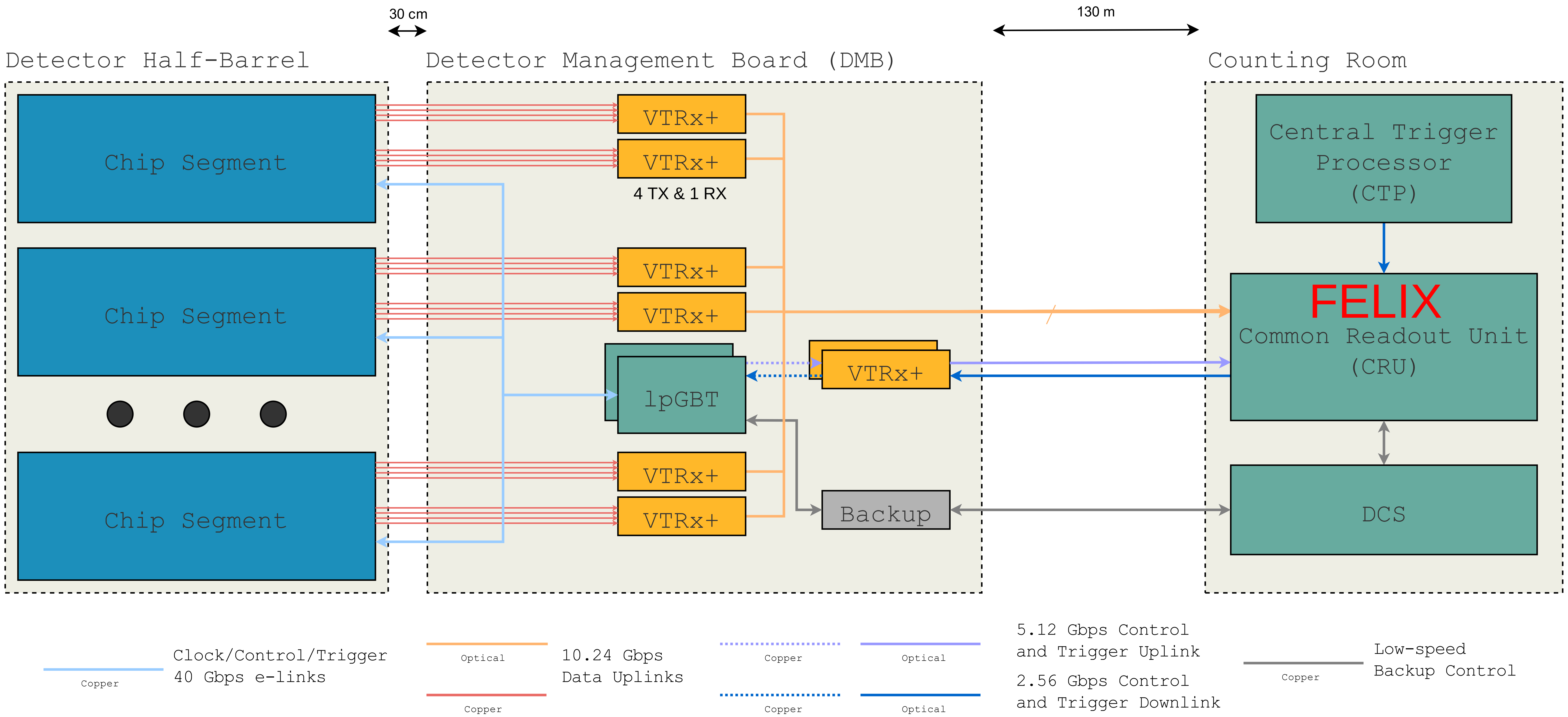




- Services as close as possible to detector
- Volume limited to stay out of acceptance of the forward detectors
- Close collaboration with the mechanics team at CERN and Grenoble

Detector Management Board (DMB) – Data and Control

- Direct connection between detector and optical transceiver (VTRx+)
  - No data processing
  - lpGBT encoding
- Slow control via lpGBT
  - E-links to detector
- Multiple boards with board-to-board connections for control and power
  - A master board for control
- Radiation qualified COTS or CERN-developed components
- Backup control link
  - CANbus, RS-485, ...



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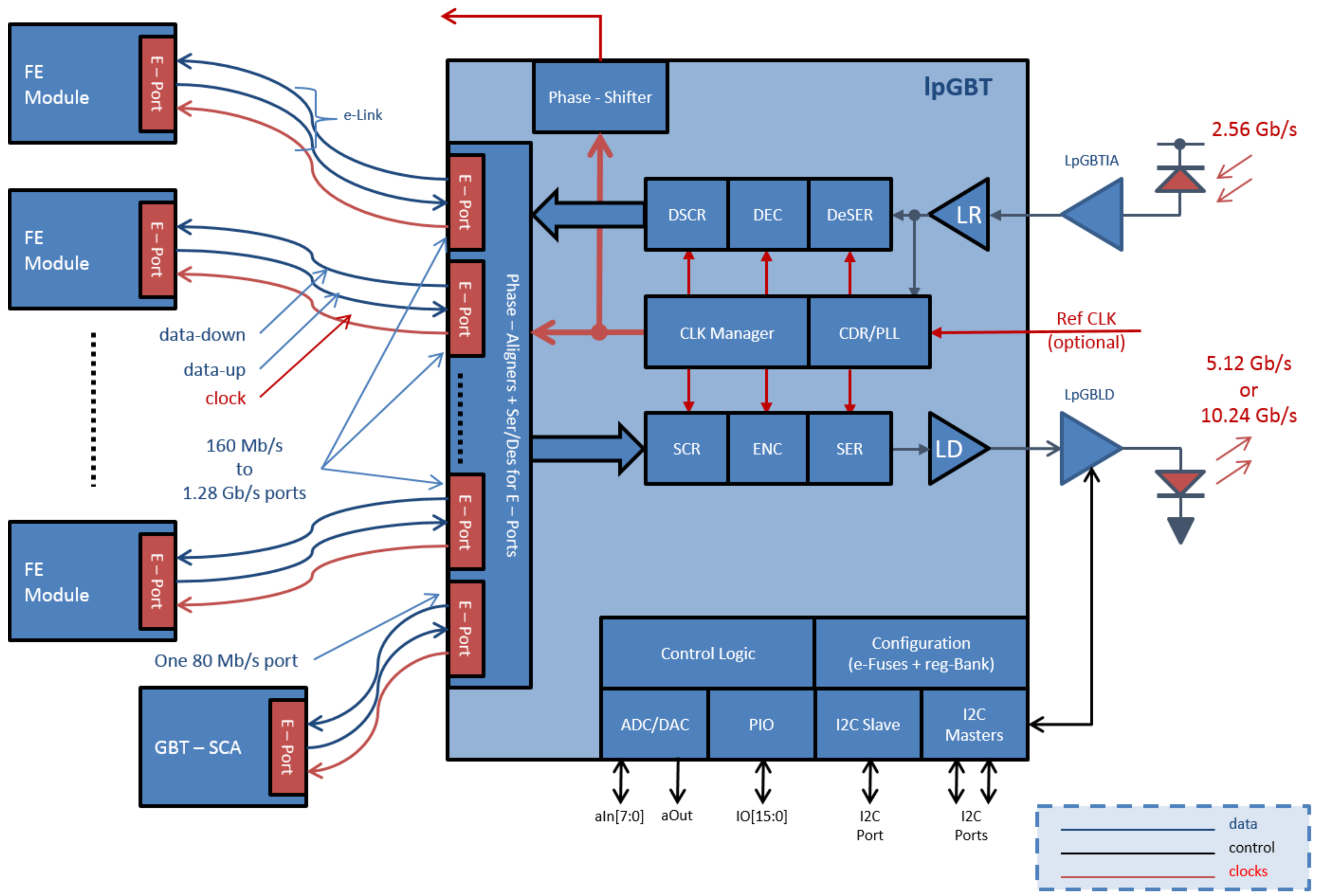

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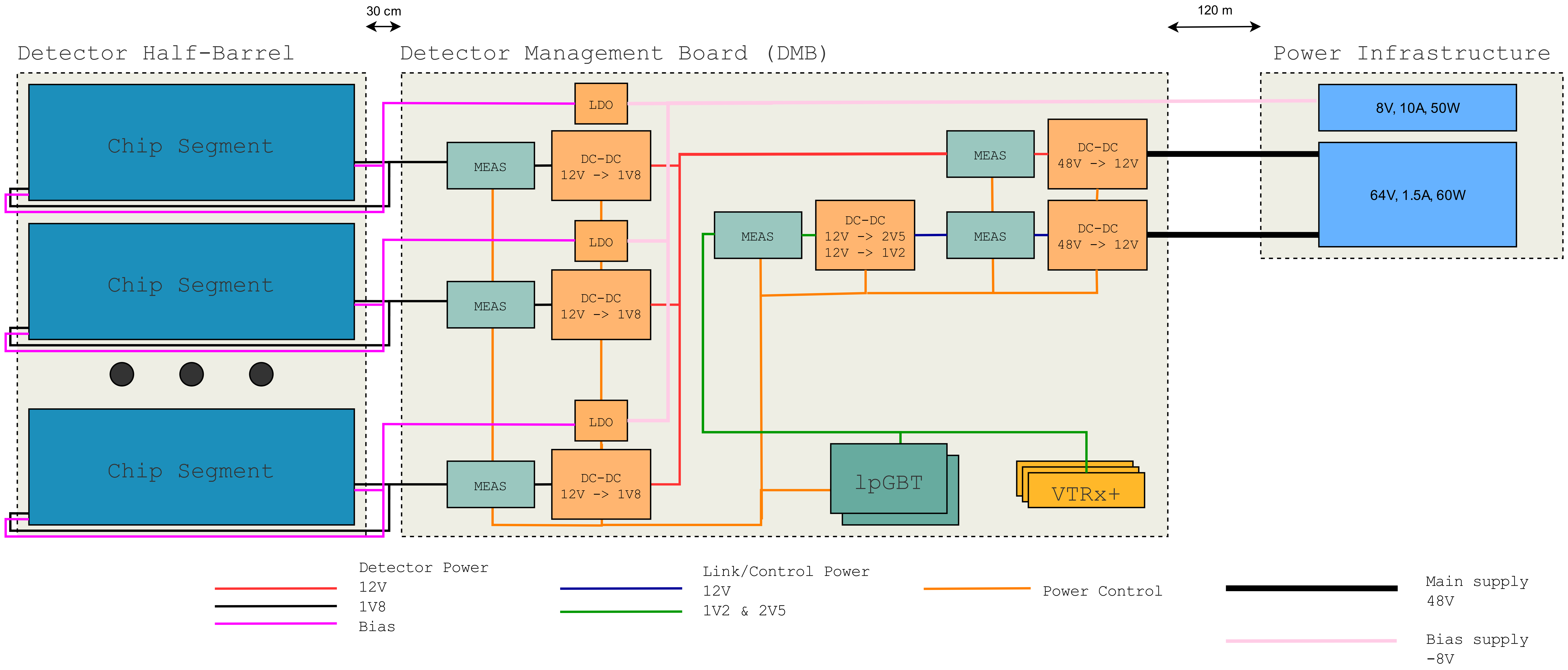
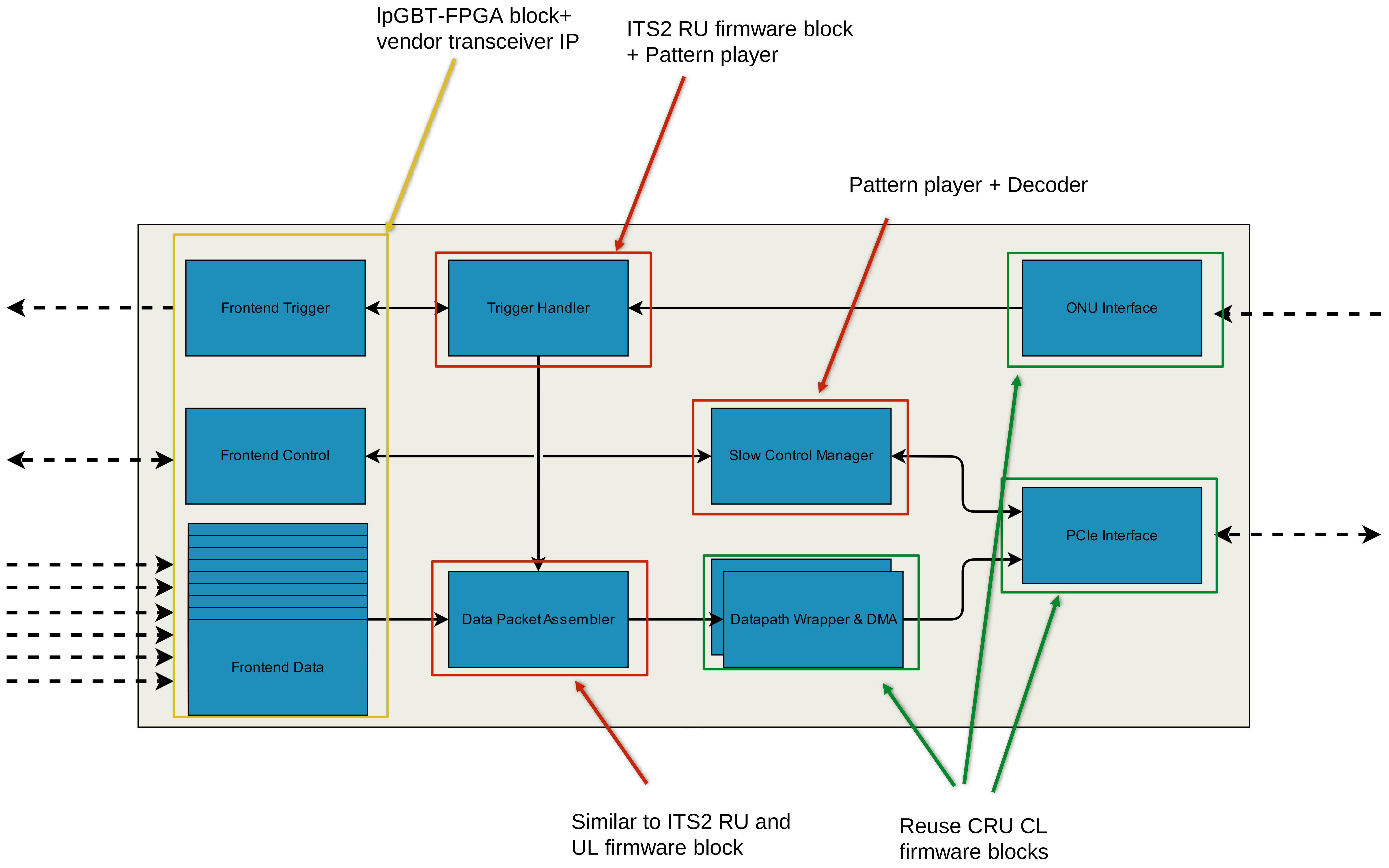
Detector Management Board (DMB) – Power

- Based on DC-DC converters
  - CERN bPols (48V -> 12V, 12V -> 1.8V)
- Supply detector on both A- and C-side
  - Need load balancing to avoid skewed v-drop
- Main power separated between detector and link/control
  - Allow tripping of detector power at various levels without affecting link/control
- Low current towards infrastructure
- Self-monitoring, controlled by lpGBT
- Back-end power infrastructure (e.g. CAEN A2554 & CAEN A2518)
  - Located in CR-4 -> neither magnetic nor radiation field



Back-end electronics – Common Readout Unit

- RU responsibilities => to CRU
  - Trigger Handling
  - Data packing
  - Slow control
- Reuse of major blocks from current CRU firmware
  - ONU interface
  - PCIe interface
  - Datapath wrapper & DMA
- Frontend replaced by lpGBT-FPGA block + vendor transceiver IP
- New blocks needed for trigger handling, slow control and data packet assembling
  - Similar to ITS2 firmware blocks



Simulation model for data rates

- Goal: realistic estimate of the particle load on the detector in Pb-Pb using some reasonable simplifications
  - Focusing on Layer 0 at 18 mm radius exclusively
  - Beam properties
    - **100 kHz** average **interaction rate** (safety factor of 2)
    - 1000 out of 3564 bunches interacting, equal interaction probability for each bunch
    - Assuming all bunches of a strobe to be populated for **bunch spacing of 50 ns** (as foreseen for Pb-Pb)
    - **Smearing** of the **vertex z-position** using a Gaussian distribution with sigma = 6 cm
    - **Interaction probability (and pile-up)** calculation according to a **Poisson** distribution
  - Physics
    - **Random centrality for each interaction** using 20 bins (steps of 5% in centrality), using multiplicity corresponding to 0-1% for the most-central bin*
    - **Multiplicity density:** based on **mean multiplicity for centrality*** and **Poisson distribution****
    - **Pseudo-rapidity dependence table** with 1cm step width*
    - **QED background:** mean of 14 particles / cm^2 in 10 µs, Poisson distribution**
  - Cluster size:
    - Average cluster size: 1.2 in rφ
    - Geometrical determination of cluster z-extension assuming pixel depth of 10 µm and pixel pitch of 20 µm
    - 30% safety margin
  - Assuming hits to only appear in their individual strobe

Your feedback is vital!

- Comparison and unification of our simulations with the ones of the chip design team (WP2) ongoing

* values derived from ITS3-WP1 presentation by F. Schlepper
** to be replaced by a NBD (Negative Binomial Distribution)

Preliminary results

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Current bandwidth and CRU estimates

	Baseline (L0 – L2)		4 Layers (L0 – L3)	
Total link count	144		264	
Detector mean bandwidth from simulation*	96		176	
Link net bandwidth (Gbit/s)	3.84	7.68	3.84	7.68
Detector net bandwidth	550	1100	1000	2000
CRU need based on link count**	6		11	
CRU based on bandwidth***	5	11	10	20
Control	2	2	2	2
Total CRU (net bandwidth)	8	**14**	14	22
	0	6	6	14
				14+6=20

ontrol in a dedicated server

tly used for the ITS2 IB)

* assuming all segments to have the same throughput as on L0
** assuming 24 CRU links
*** assuming 110 Gbit/s CRU output bandwidth

Extra Material

Simulation input numbers / event generation

```python
# Simplified physics model (only for L0 @ 18mm as this is most challenging)
# derived from numbers in https://indico.cern.ch/event/1239383/contributions/5281416/attachments/2597686/4484654/hitDensityRLoad.pdf
#                             0     1   2     3   4   5     6    7    8    9   10  11   12  13   # distance from the center of the layer in the beam dimensions
cParticleDensityPbPbCent=[ 112,  102, 82,   66, 54, 45,  39,  35,  31,  28,  26, 24,  22, 20. ] # /cm^2, 0-1% centrality
cParticleDensityQED     =[  14, 13.5, 12, 10.5,  9,  8, 7.1, 6.6, 6.1, 5.7, 5.4,  5, 4.7,  4  ] # /cm^2, for 10 μs integration time
#                          0-1, 5-10, 10-15, 15-20, 20-25, 25-30, 30-35, 35-40, 40-45, 45-50, 50-55, 55-60, 60-65, 65-70, 70-75, 75-80, 80-85, 85-90, 90-95, 95-100
cParticleDensityPbPbMid= [ 112,   83,    68,    57,    47,    39,    31,    25,    20,    15,    12,     9,     7,     5,     3,     2,   1.5,   0.8,   0.5,    0.1 ] # /cm^2
cParticleDensityPbPbMidRelative=[h/cParticleDensityPbPbMid[0] for h in cParticleDensityPbPbMid]  #  event multiplicity of the centrality classes relative to 0-1% (most central)
```

```python
def generate_event():
    particles = np.zeros(cNRegionsZ)
    centralities  = []  # multiplity scaling factors for the sub-events

    pileup = rng.poisson(meanStrobeInteractionProbability)
    for subevent in range(pileup):
        centralities.append(cParticleDensityPbPbMidRelative[rng.integers(low=0, high=len(cParticleDensityPbPbMidRelative))])
    for region in range(cNRegionsZ):
        z_cm = int(abs((region + 0.5 - float(cNRegionsZ)/2.) * cRegionLengthZ * 100)) # in cm
        assert z_cm < len(cParticleDensityPbPbCent) and z_cm < len(cParticleDensityQED), f"z position: {z_cm}"
        particleMeanRegion = cParticleDensityQED[z_cm]*StrobeLength/10e-6*cRegionArea*100*100
        particles[region] += rng.poisson(particleMeanRegion)
        for cent in centralities:
            particleMeanRegion = cParticleDensityPbPbCent[z_cm]*cent*cRegionArea*100*100
            particles[region] += rng.poisson(particleMeanRegion)
            #print(f"{particles}, {particles_cent}, {particleMeanRegion}, {cent}, {z}")
    return particles
```

Fiber Network

- Fiber network is similar to ITS2
  - Additional 10m + an extra connection
- VTRx+ equals VTRx transmitter minimal output power
- Reusing MiniPOD receiver on CRU-side
- Link coding (FEC5 or FEC12) provide additional margin
- Trunk cables:
  - ITS2
    - Installed: 6 + 2 (backup)
    - IB MPO connectors: 18
    - Backup MPO connectors: 24
  - ITS3
    - 16 (or 26) MPOs for baseline (or 4 layers) assuming remapping in the cavern -> Could use 8 backup MPOs, but remapping difficult to implement
    - 40 (or 70) MPOs for baseline (or 4 layers) w/o remapping -> Installation 2 (or 5) of trunk cables required -> should become baseline

Contributor	**Power**	**Unit**
Transmitter Output (VTRx+)	-5.2	dBm
Receiver Sensitivity (MiniPOD)	-11.3	dBm
Coding gain	1	dB
Power budget	**7.1**	**dB**
Connectors		
CRU MPO Sockets	0.5	dB
MPO-LC patch cords 5m (from CRU)	0.5	dB
MPO to LC 95m (from CR-1 to Mini-Fra)	0.5	dB
MPO to MPO 8 m (from mini-crate to the Service	0.5	dB
VTRx+ pigtail with MT connector	0.5	dB
Fiber		
Fiber attenuation - 135m OM3 3.0 dB/km	0.4	dB
Link penalties	0.5	dB
TX Radiation Penalty	1	dB
Total loss	**4.4**	**dB**
Margin	**2.7**	**dB**

Configuration & calibration - Estimations

- Currently estimating how much time is needed to configure and calibrate detector
- It is obvious that broadcasting to multiple chip segments and RSUs are required

Transactions (per pixel)	Bandwidth (MHz)	Total Transactions	Total Time (s)	Total Time Seq (s)
2	10.0	133760	0.548416	13.161984
2	20.0	133760	0.280896	6.741504
2	40.0	133760	0.147136	3.531264
4	10.0	267520	1.096832	26.323968
4	20.0	267520	0.561792	13.483008
4	40.0	267520	0.294272	7.062528
6	10.0	401280	1.645248	39.485952
6	20.0	401280	0.842688	20.224512
6	40.0	401280	0.441408	10.593792

TRU Bandwidth (MHz)	SC Bandwidth (MHz)	Config time (s)	Trigger time (s)	Readout time chip (s)	Readout time CRU (s)	Total time (s)	Config time seq (s)	Total time seq (s)
160	10	25	55	111	112	304	6050	6329
160	20	14	43	111	112	280	3247	3513
160	40	8	37	111	112	268	1845	2105
320	10	25	55	55	112	248	6050	6273
320	20	14	43	55	112	224	3247	3458
320	40	8	37	55	112	212	1845	2050