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SVT Readout

J. Schambach

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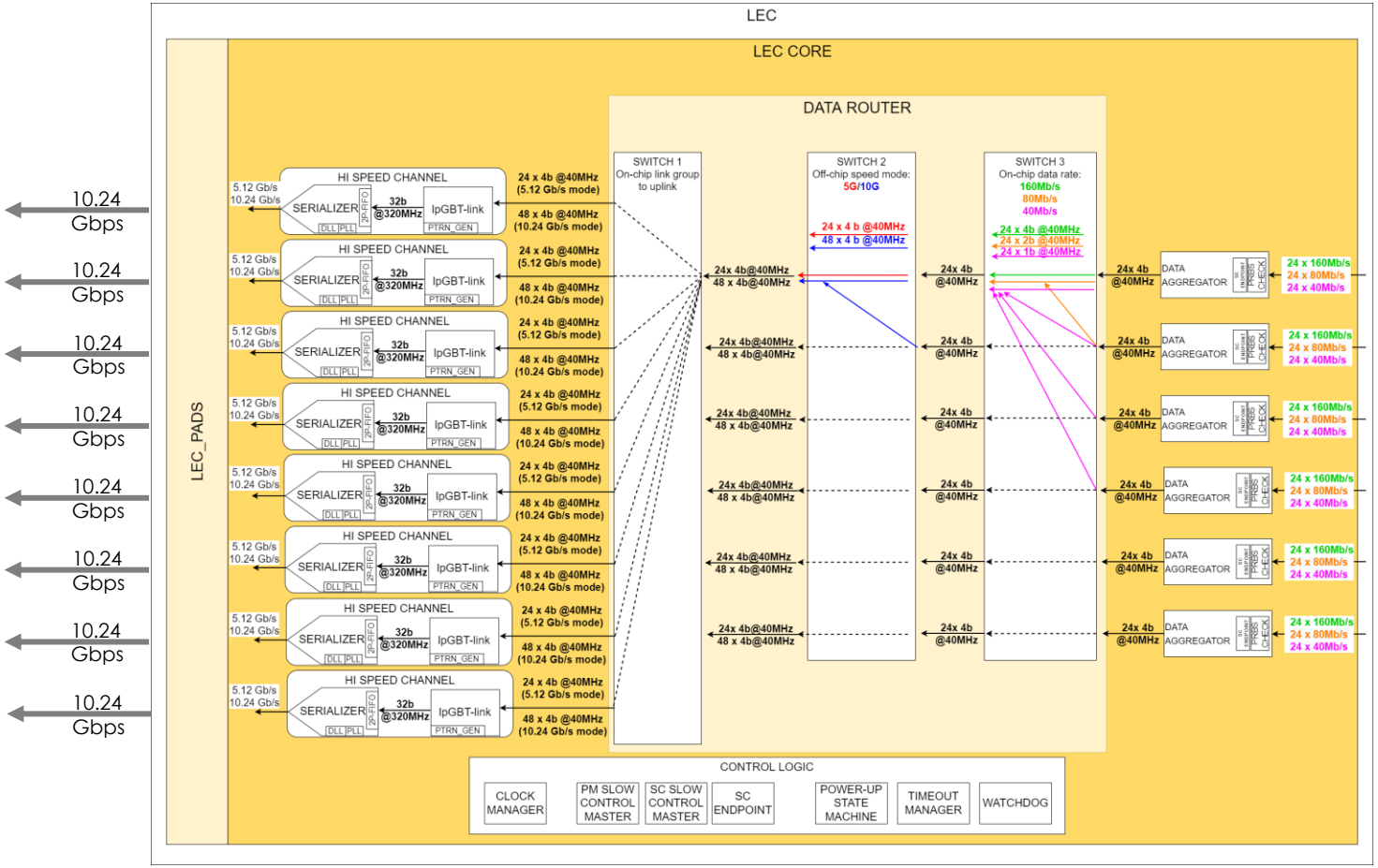
U.S. DEPARTMENT OF ENERGY

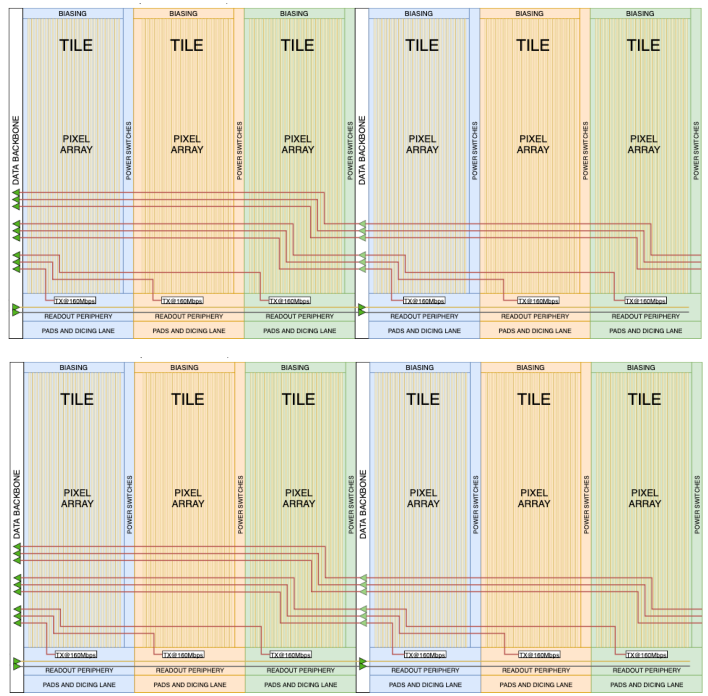
Data Flow – From Tiles to Left Endcap



x 12 RSU

72 Links

72 Links



12-RSU MOSAIX (SVT IB)

The data encoding block is the **lpGBT's TX** core
160 Mbps x 144 = 22.5 Gbps
Full capacity: 8 HS serializers = 80 Gbps (10 Gbps each, only 3 used)
Fallback: 40 Gbps, 5 Gbps each (6 used)
4 serializer data outputs drive one VTRx+

SVT Outer Barrel & Disks

6-RSU LAS
72 Tiles
1 HS serializer = 10 Gbps

5-RSU LAS
60 Tiles
1 HS serializer = 10 Gbps

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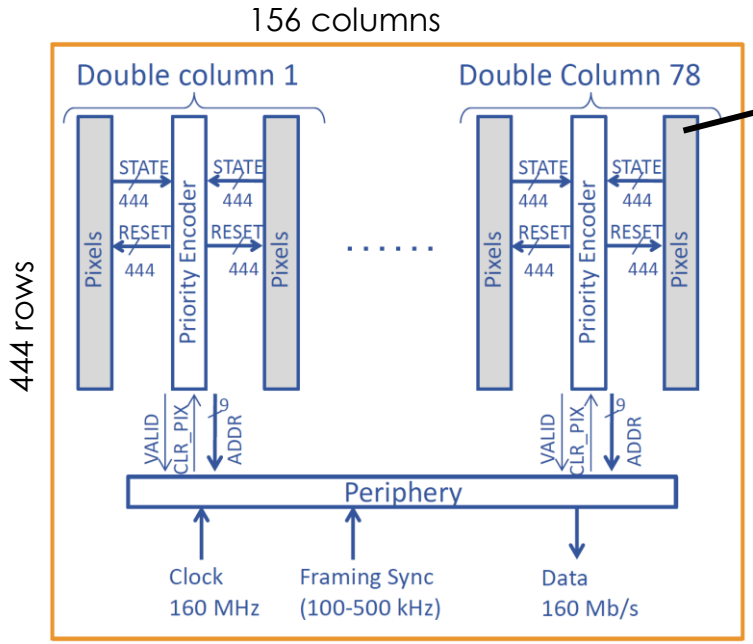
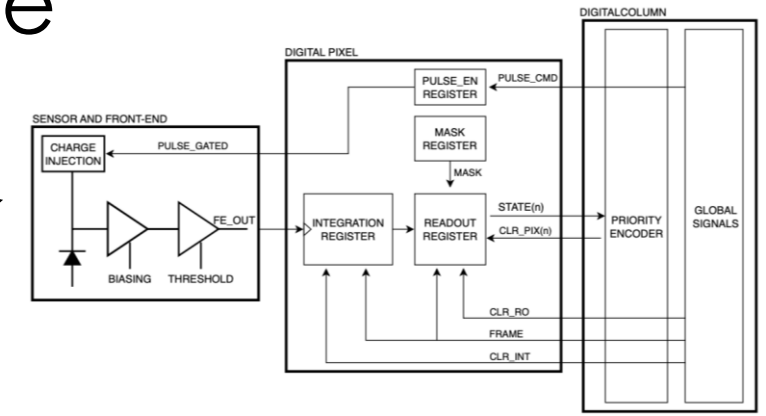
Domain (Tile) Architecture





444 x 156 pixels / domain
831168 pixels per RSU
144 domains / segment
9.974 Mpixels / segment

20.8 µm x 22.8 µm pixel pitch(*)
Continuously active front-end (40 nW typ.)
Global shutter
Zero-suppressed matrix readout
Continuous readout mode
Integration time: 2µs to 2^{16}*25ns = 1.6384ms

(*) **Baseline: 20.8 µm * 22.8 µm**
Abs. Max: 22.5 µm * 25 µm

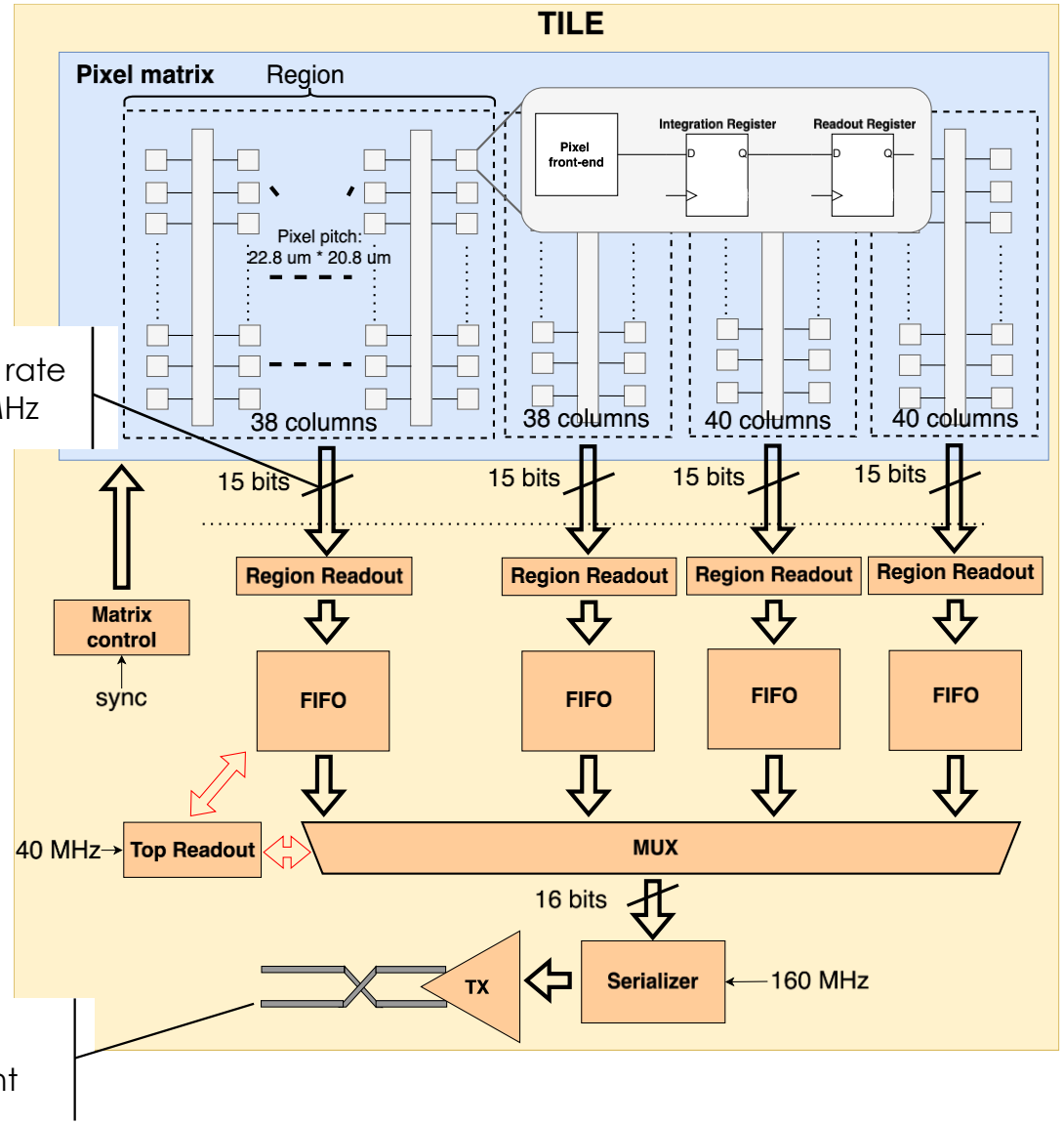
In pixel:

- Amplification
- Discrimination
- Hit integration register and readout register
- Test charge injection
- Digital pulsing
- Masking

Digital pixel designed with low-leakage, high reliability std cells

On-chip Readout Scheme in the Periphery

- Framing time base re-generated in each TILE periphery
  - FRAME local signal synchronizes pixels, Region Readout and Top Readout
  - Global SYNC input signal *aligns in time* the integration intervals across tiles
- Four parallel readout processes in each tile
  - Regions have 38 or 40 columns
  - Double columns in one region are sequentially read out
  - Region data packet is stored in FIFOs
  - Double columns and full regions can be masked
- Serial transmission of tile packet to LEC
  - Top readout aggregates region data packets for the same frame interval
  - Tile transmits one data packet for each frame interval, in order



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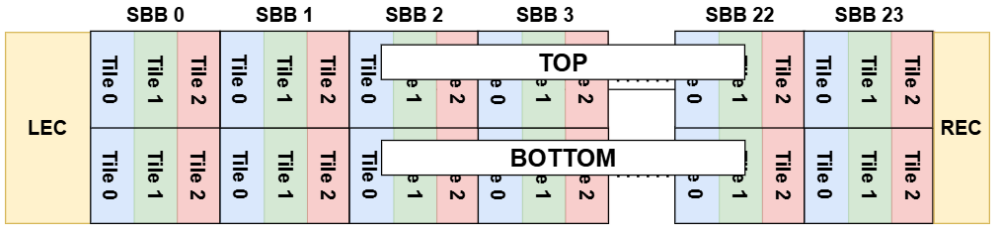
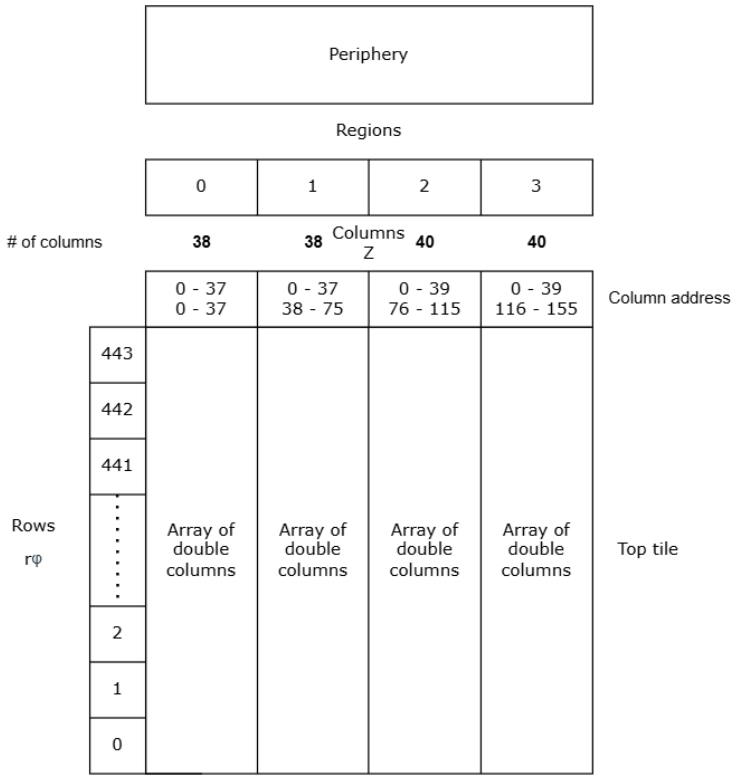
Addressing

- Stitched Back Bone (SBB) -> 5 bits for SBB, 2 bits for tile in SBB, 1 bit for Top/Bottom



- Pixel row: 0 -443 -> 9 bits
- Pixel columns per region 38 or 40 ->6 bits
- 4 regions -> 2 bits



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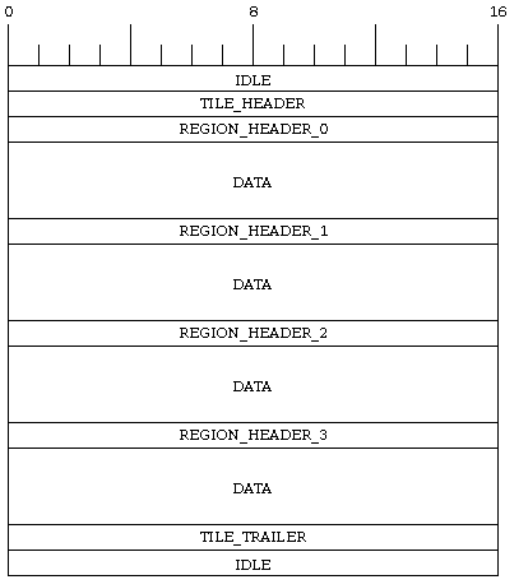
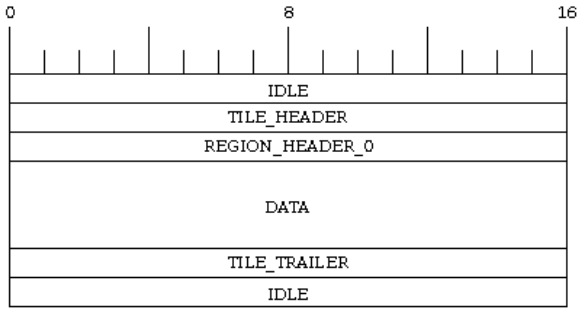
Tile Readout Protocol

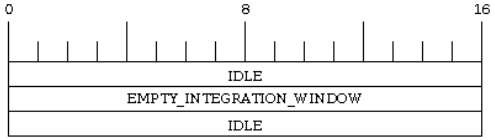
Hits in all 4 regions



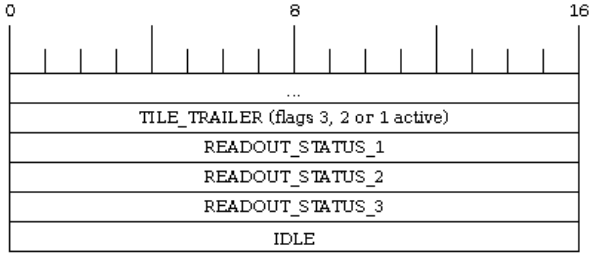
Hits in 1 region



No hits



Status



READOUT PROTOCOL																
Word type	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IDLE	1	1	0	0	0	1	0	1	IDLE config [7:0]							
LOCK	1	1	0	0	1	0	1	0	IDLE config [7:0]							
READOUT_STATUS_1	1	0	0	1	1	1	0	0	Integration Window Counter [15:8]							
READOUT_STATUS_2	1	1	1	1	IWC Checksum [3:0]				Integration Window Counter [7:0]							
TILE_HEADER	1	0	1	0	0	0	0	0	Unit Slice [4:0]					Tile [1:0]		T/B
REGION_HEADER	1	0	1	0	1	1	Region Address.		Integration Window Counter [7:0]							
DATA	0	Pixel Address Row [8:0]								Pixel Address Column [5:0]						
TILE_TRAILER	1	0	1	1	TRU Status Flags [3:0]				Packet Checksum [7:0]							
EMPTY_INTEGRATION_WINDOW	1	1	1	0	TRU Status Flags [3:0]				Integration Window Counter [7:0]							
DROPPED_INTEGRATION_WINDOW	1	1	0	1	TRU Status Flags [3:0]				Integration Window Counter [7:0]							
RECOVERY	1	0	0	1	0	0	1	1	'0							
RESERVED	1	0	0	0	RESERVED											

Text is not SVG - cannot display

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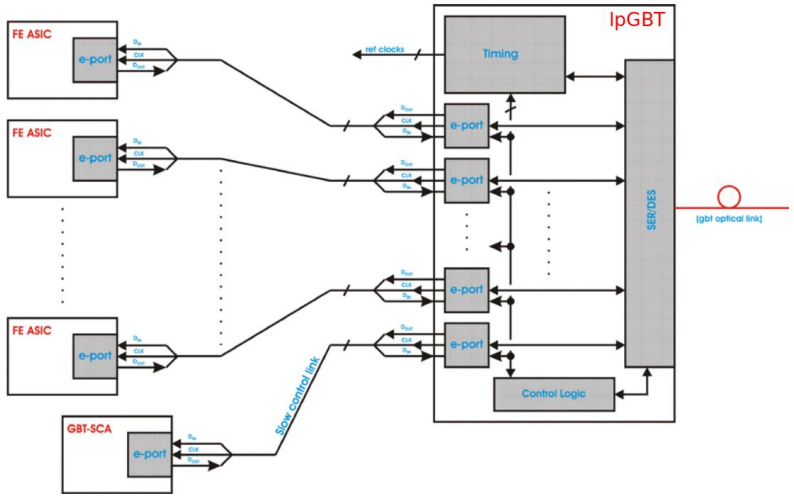
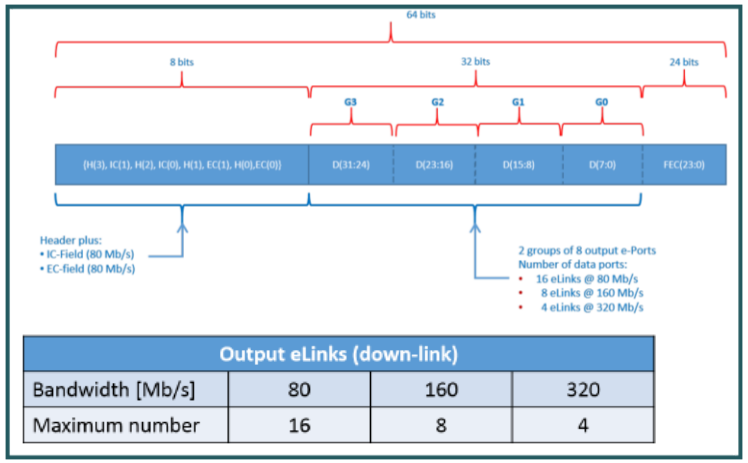
lpGBT Protocol



- Front Ends connect to “e-links”
- The fiber protocol includes “Forward Error Correction”
- Downlink runs at 2.56 Gbps
  - Downlink frame is 64bit wide, of which 32 bits are payload
  - 1.28 Gbps payload
  - Up to 16 e-links @ 80 Mbps
- Uplink runs at either 10.24 Gbps or 5.12 Gbps
  - Uplink frame is either 128bit or 256bit
  - 256bit frame contains 192bits of payload (7.68 Gbps)
  - Up to 24 e-links at either 160 Mbps or 320 Gbps



Output eLinks (down-link)			
Bandwidth [Mb/s]	80	160	320
Maximum number	16	8	4

Downlink

Line Rate: **2.56 Gbps**
32 out of 64 bits are data:
Payload = **1.280 Gbps**

Data Uplink

192 out of 256 bits are data:
Payload = **7.680 Gbps**

Input eLinks (up-link)												
Up-link bandwidth [Gb/s]	5.12						10.24					
FEC coding	FEC5			FEC12			FEC5			FEC12		
Bandwidth [Mb/s]	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

Field	5.12 Gbps FEC5	5.12 Gbps FEC12	10.24 Gbps FEC5	10.24 Gbps FEC12
Frame [bits]	128		256	
Header [bits]	2		2	
IC [bits]	2		2	
EC [bits]	2		2	
D [bits]	112	96	224	192
FEC [bits]	10	24	20	48
LM [bits]	0	2	6	10
Correction [bits]	5	12	10	24
# of eLink groups	7	6	7	6

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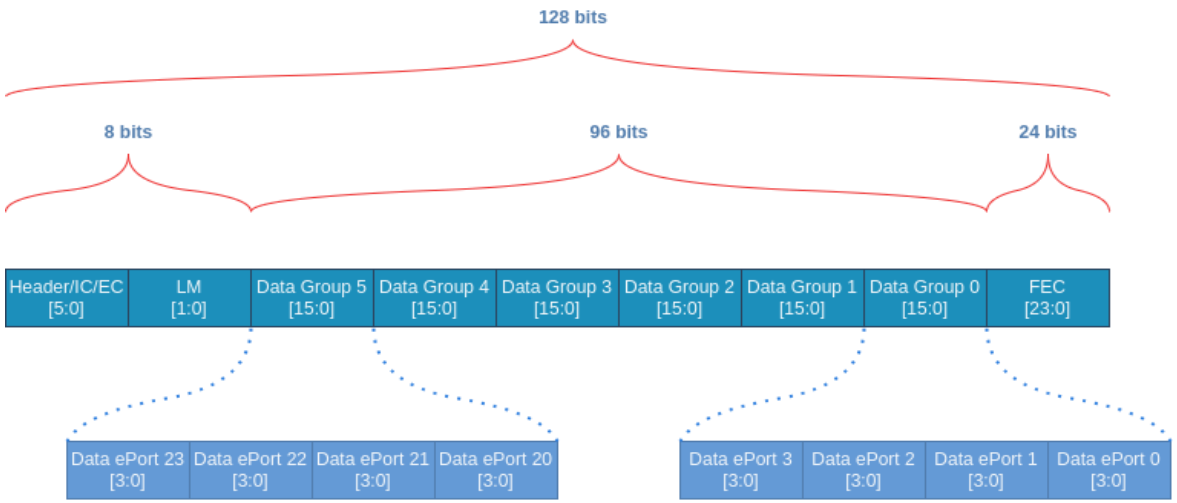
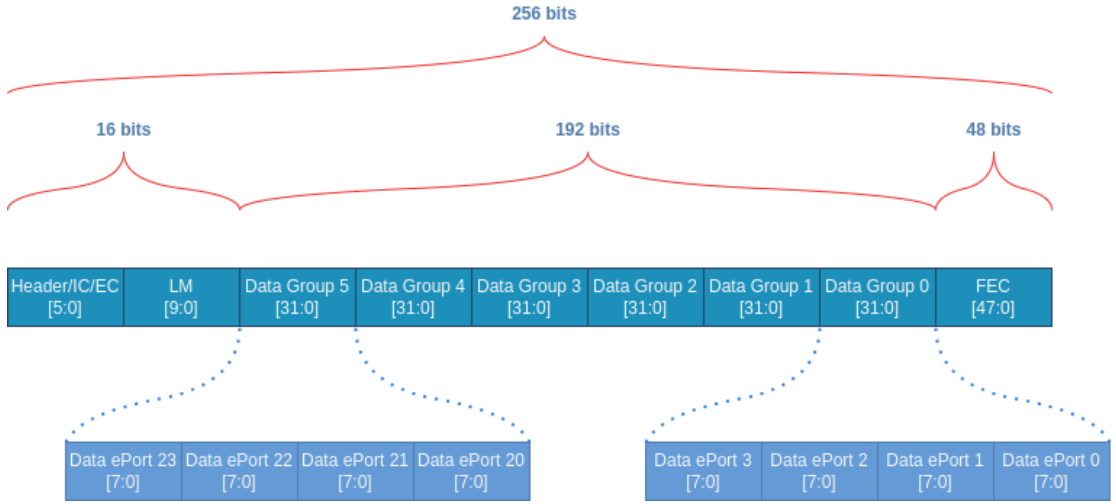
lpGBT ePort Routing

5.12Gbps



10.24Gbps

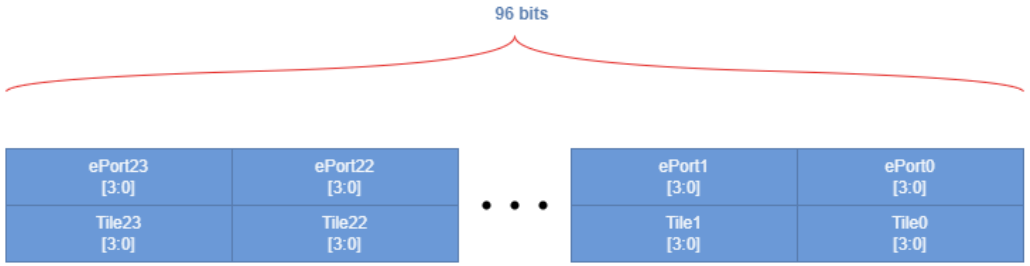


MOSAIX uplink						
Uplink bandwidth (Gbps)	5.12			10.24		
FEC Coding	FEC12			FEC12		
Tile bandwidth (Mbps)	40	80	160	40	80	160
Tiles per uplink [1]	48	48	24	48	48	48
Bits per tile	1	2	4	1	2	4
Tiles per ePort	2	2	1	2	2	2
Bits per ePort	4	4	4	8	8	8
Used bits per ePort	2	4	4	2	4	8
Bandwidth efficiency	50%	100%	100%	25%	50%	100%

1. To simplify routing scheme, 48 tiles are connected in instances where there are bandwidth enough to support a higher number of tiles.

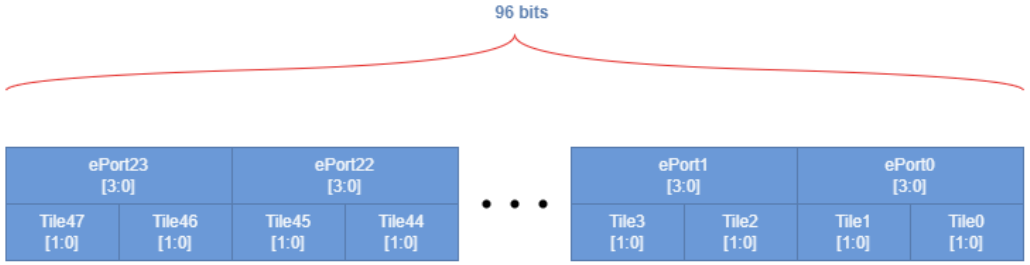
LEC Data Routing

5 Gbps / 160 MHz (6 links)



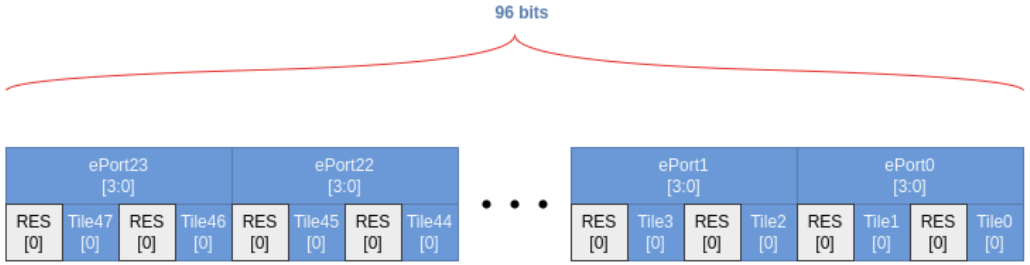
4 frames to reconstruct tile word

5 Gbps / 80 MHz



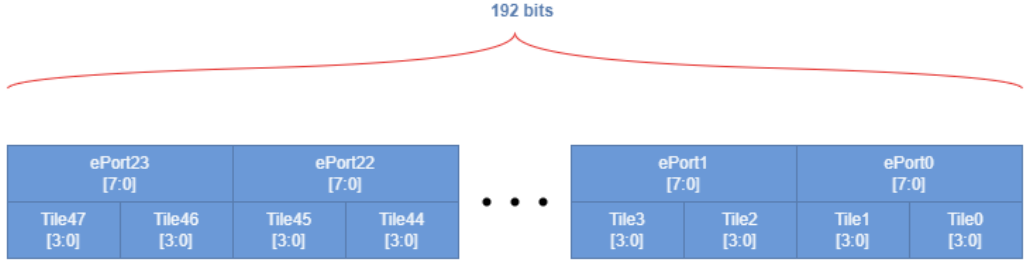
8 frames to reconstruct tile word

5 Gbps / 40 MHz



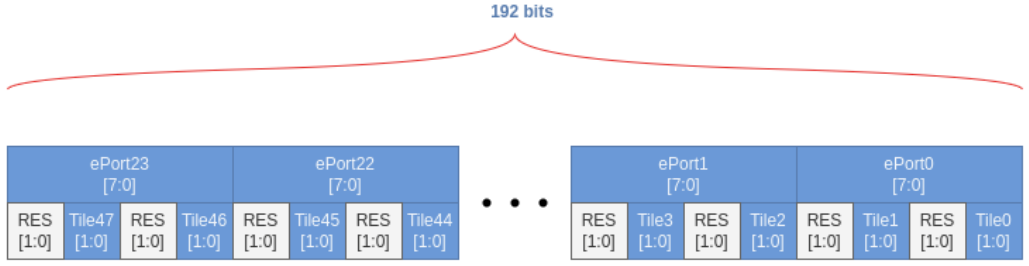
16 frames to reconstruct tile word

10 Gbps / 160 MHz (3 links)



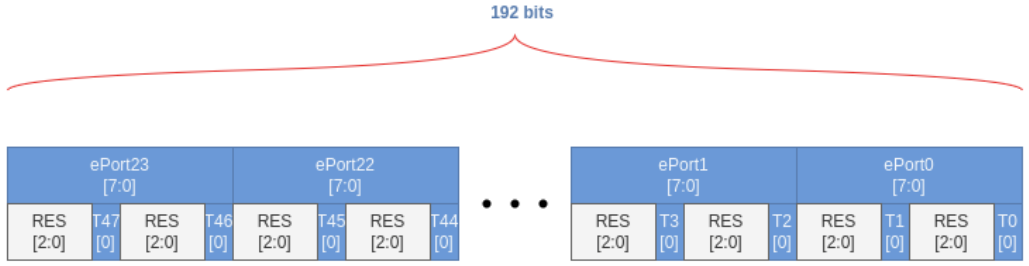
4 frames to reconstruct tile word

10 Gbps / 80 MHz



8 frames to reconstruct tile word

10 Gbps / 40 MHz



16 frames to reconstruct tile word

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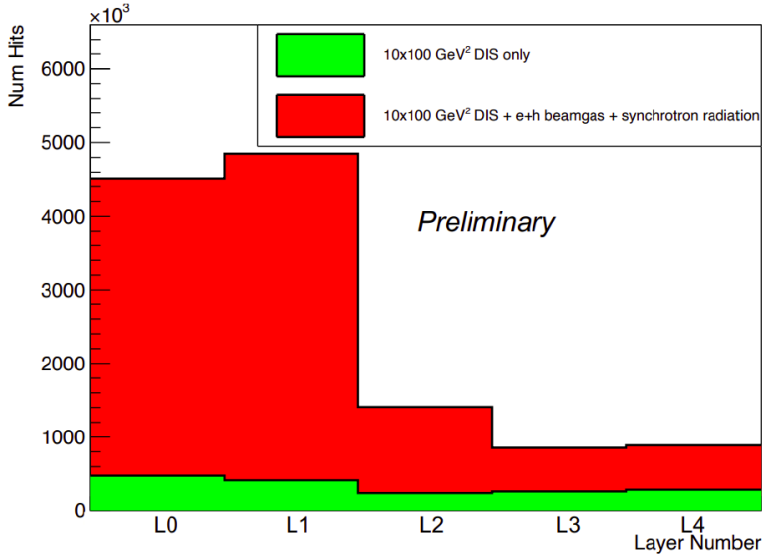
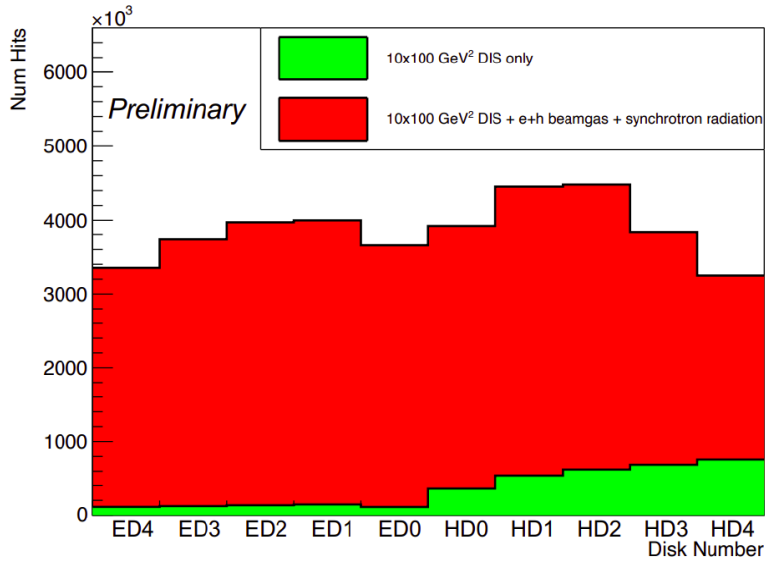
S. Maple's Presentation: SVT Hit Rates





- 10x100 GeV ep, 4.48 x 10^{33} $cm^{-2}s^{-1}$, 184 kHz DIS event rate
- 10 GeV SR
- 10 GeV e beam gas, 10000 Ahr
- 100 GeV proton beam gas, 100 Ahr

10x275 GeV:

(Factor 2 in luminosity?)
Factor 3 in e-p rate

	Hit Rate (Hz)	Area (cm²)	Hits/s/cm²
L0	4.50E+06	610.73	7.37E+03
L1	4.85E+06	814.30	5.96E+03
L2	1.41E+06	2035.75	6.93E+02
L3	8.55E+05	9160.88	9.33E+01
L4	8.89E+05	22167.08	4.01E+01

	Hit Rate (Hz)	Area (cm²)	Hits/s/cm²
ED0	3.66E+06	1767.11	2.07E+02
ED1	4.00E+06	5368.16	7.45E+02
ED2	3.97E+06	5536.32	7.17E+02
ED3	3.74E+06	5532.26	6.76E+02
ED4	3.35E+06	5524.62	6.06E+02

	Hit Rate (Hz)	Area (cm²)	Hits/s/cm²
HD0	3.92E+06	1767.11	2.22E+03
HD1	4.45E+06	5368.16	8.29E+02
HD2	4.48E+06	5533.75	8.10E+02
HD3	3.83E+06	5513.51	6.95E+02
HD4	3.25E+06	5486.76	5.92E+02

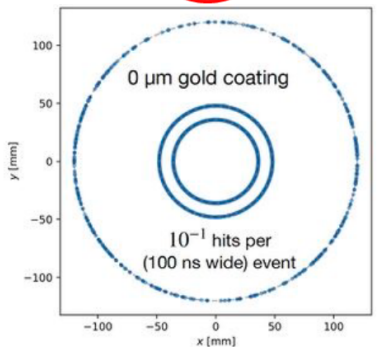
Operational environment

- EIC bunch crossing frequency 98.5 MHz
  - Interaction frequency orders of magnitude lower
- Rates for DIS ep events up to 500 kHz

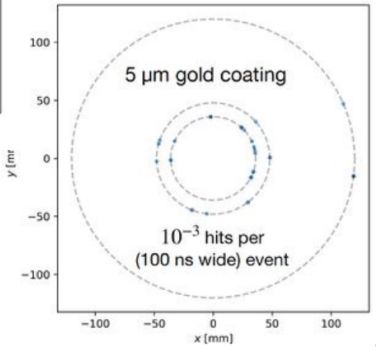
Beam energy [GeV]	5 x 41	5 x 100	10 x 100	10 x 275	18 x 275
L [10^{33}cm^{-2}s^{-1}]	0.44	3.68	4.48	10	1.54
DIS ep rate [kHz]	**12.5**	**129**	**184**	**500**	**83**

EIC Conceptual Design Report, Table 3.3

- Up to O(MHz) rate for background events
  - Hadron and electron beam gas event rate lowers with improving vacuum condition
  - Synchrotron radiation reduced of two orders of magnitude with 5 μm gold coating of the beam pipe
- Manageable readout frame rate



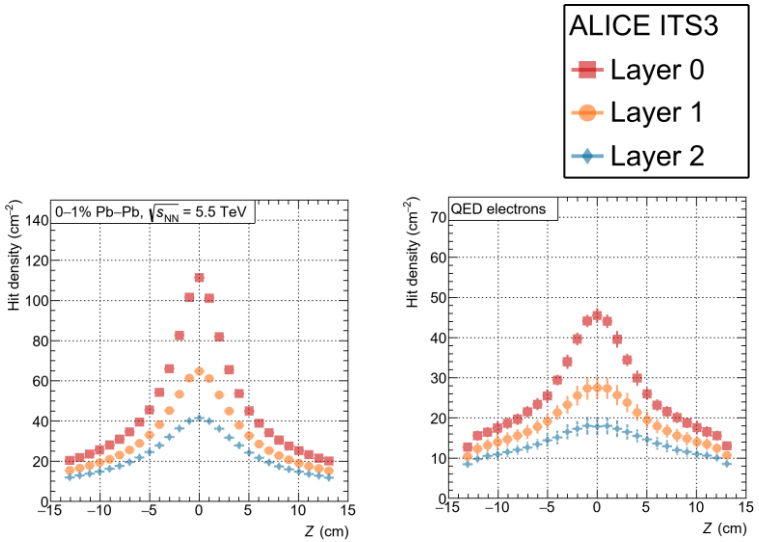
Scatter plot of SR hits in the innermost silicon tracker layers



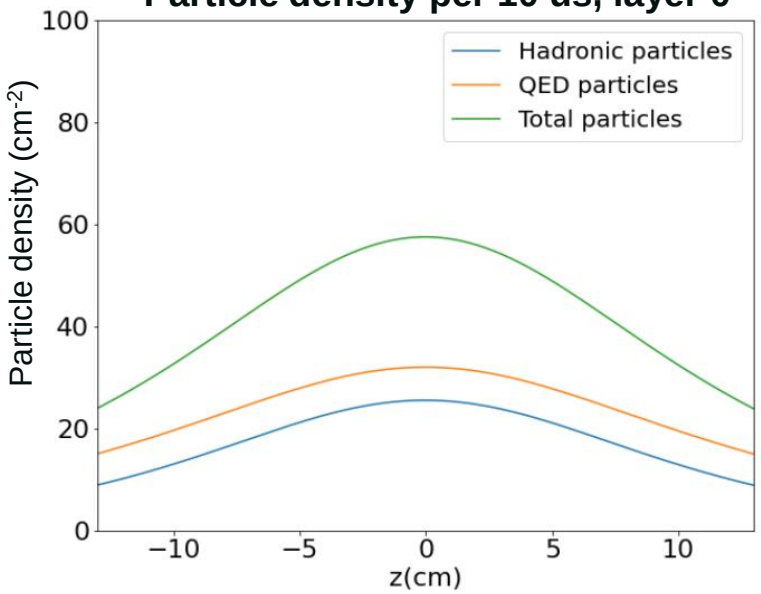
ITS3 simulation for central PbPb

- **Collisions and QED distributed along vertex (z) by gaussian of RMS = 6cm.**
- Particle flux from collisions in z=0, layer 0 of **2.95 MHz/cm²**
- Particle flux from QED in z=0, layer 0 of **3.55 MHz/cm²**
- Occupancy in 2 μs period of **2×10^{-4}**

2 – 6 pixels per hit ("cluster")

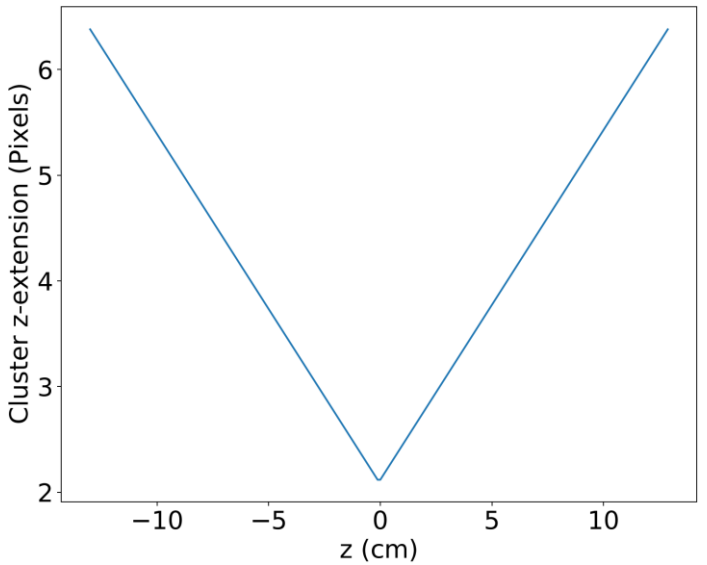


Particle density per 10 us, layer 0



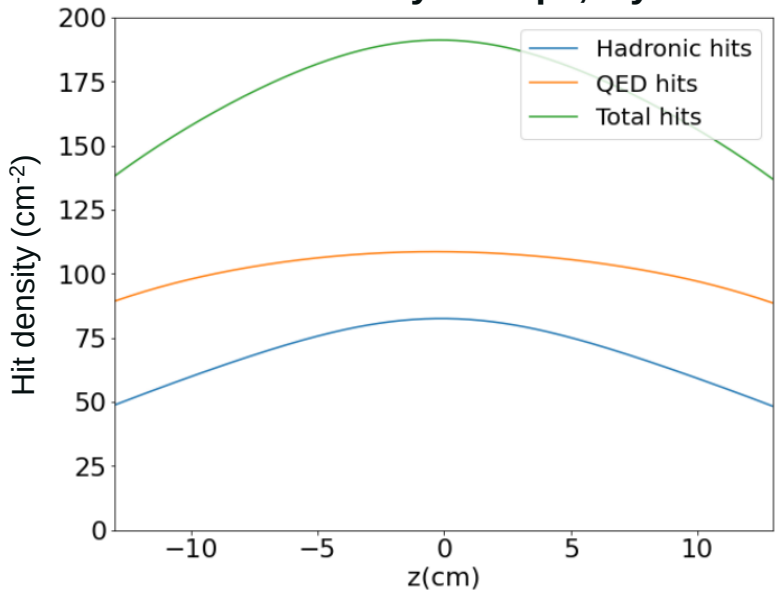
X

Cluster size over z for collision in z=0



=

Pixel hit density in 10 μs, layer 0



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Bit Counts

1 tile noise pixel:
- 1 tile header
- 1 region header
- 1 data
- 1 tile trailer

4 words
-> 64 bits per pixel

1 tile hit (4 pixels):
- 1 tile header
- 1 region header
- 4 data
- 1 tile trailer

7 words
->112 bits
-> 28 bits per pixel

1 hit (4 pixels) per region:
- 1 tile header
- 1 region header
- 4 data
- 1 region header
- 4 data
- 1 region header
- 4 data
- 1 region header
- 4 data
- 1 tile trailer

22 words
-> 352 bits
-> 22 bits per pixel

2 hits (4 pixels) in 1 region:
- 1 tile header
- 1 region header
- 8 data
- 1 tile trailer

11 words
-> 176 bits
-> 22 bits per pixel

4 hits (4 pixels) in 1 region:
- 1 tile header
- 1 region header
- 16 data
- 1 tile trailer

19 words
-> 304 bits
-> 19 bits per pixel

SVT Counts

	width (mm)	length (mm)		# pixels per RSU																				
																		Average						
Reticle size	19.564	21.666		**831,168**														Cluster size	4					
Pixel size	0.0208	0.0228																						
Barrel					Sensor												10x100GeV		10x275GeV					
Layer Index	**radius (mm)**	**z (mm)**		**Area (mm^2)**	**RSU in width**	**RSU in length**	**# of sensors in r-phi**	**# of sensors in z**	**# tiles**	**# pixels**	**# sensors**	**Notes**	**# Readout Links**	**# Staves**	**# Data VTRx+**	**# SC lpGBTs**	**Hit Rate / s**	**Hits/pixel/2 us frame**	**Hit Rate / s**	**Hits/pixel/2us frame**	**Data Rate (Mbps)**	**Data Rate / Link (Mbps)**	**Epty Rate (Gbps)**	**Epty Rate / Link (Mbps)**
L0	36	260		58,811	3	12	4	1	1,728	119,688,192	4	bent ITS3	96		24	6	4.50E+06	6.99E-08	1.22E+07	1.90E-07	1492.71	41.46	12.875	366.211
L1	48	260		78,414	4	12	4	1	2,304	159,584,256	4	bent ITS3	128		32	8	4.85E+06	5.65E-08	1.32E+07	1.54E-07	1608.81	33.52	17.166	366.211
L2	120	260		196,035	5	12	8	1	5,760	398,960,640	8	bent ITS3	320		80	20	1.41E+06	6.57E-09	3.83E+06	1.79E-08	467.72	3.90	42.915	366.211
L3	270	520		882,158	1	6	96	4	27,648	1,915,011,072	384	6 -RSU LAS	384	48	96	12	8.55E+05	8.30E-10	2.32E+06	2.26E-09	283.61	0.74	205.994	549.316
L4	420	840		2,216,706	1	5	148	8	71,040	4,920,514,560	1184	5-RSU LAS	1184	74	296	37	8.89E+05	3.36E-10	2.42E+06	9.13E-10	294.89	0.25	529.289	457.764
e-endcap																								
Disk index	**z (mm)**	**inner r (mm)**	**outer r (mm)**			**5-RSU LAS**	**6-RSU LAS**							**Readout Modules**					0.00E+00					
ED0	-250	36.76	240	176,710		96	0		5,760	398,960,640	96	5-RSU LAS	96	26	26	4	3.66E+06	1.71E-08	9.95E+06	4.64E-08	1214.07	12.65	42.915	457.764
ED1	-450	36.76	415	536,815		334	0		20,040	1,388,050,560	334	5-RSU LAS	334	96	96	12	4.00E+06	5.36E-09	1.09E+07	1.46E-08	1326.85	3.97	149.310	457.764
ED2	-650	36.76	421.4	553,632		334	0		20,040	1,388,050,560	334	5-RSU LAS	334	96	96	12	3.97E+06	5.32E-09	1.08E+07	1.45E-08	1316.90	3.94	149.310	457.764
ED3	-850	40.0614	421.4	552,835		334	0		20,040	1,388,050,560	334	5-RSU LAS	334	96	96	12	3.74E+06	5.01E-09	1.02E+07	1.36E-08	1240.61	3.71	149.310	457.764
ED4	-1050	46.3529	421.4	551,127		334	0		20,040	1,388,050,560	334	5-RSU LAS	334	96	96	12	3.35E+06	4.49E-09	9.10E+06	1.22E-08	1111.24	3.33	149.310	457.764
h-endcap																								
Disk index																								
HD0	250	36.76	240	176,710		96	0		5,760	398,960,640	96	5-RSU LAS	96	26	26	4	3.92E+06	1.83E-08	1.07E+07	4.97E-08	1300.31	13.54	42.915	457.764
HD1	450	36.76	415	536,815		334	0		20,040	1,388,050,560	334	5-RSU LAS	334	96	96	12	4.45E+06	5.96E-09	1.21E+07	1.62E-08	1476.12	4.42	149.310	457.764
HD2	700	38.52	421.4	553,216		334	0		20,040	1,388,050,560	334	5-RSU LAS	334	96	96	12	4.48E+06	6.00E-09	1.22E+07	1.63E-08	1486.07	4.45	149.310	457.764
HD3	1000	53.43	421.4	548,909		334	0		20,040	1,388,050,560	334	5-RSU LAS	334	96	96	12	3.83E+06	5.13E-09	1.04E+07	1.39E-08	1270.46	3.80	149.310	457.764
HD4	1350	70.14	421.4	542,422		334	0		20,040	1,388,050,560	334	5-RSU LAS	334	96	96	12	3.25E+06	4.36E-09	8.83E+06	1.18E-08	1078.07	3.23	149.310	457.764
TOTAL				**8,161,315**					**280,320**	**19,416,084,480**	**4448**		**4976**		**1348**	**187**	**5.12E+07**	hits/s	**1.39E+08**	hits/s				
																	6.10	Gbps	**16.57**	Gbps		**Empty Rate:**	**2088.5**	**Gbps**
										# of segments:	**4500**													
																	Noise Rate		1.00E-08	(1/pixel/10us)				
																	Total Noise Pixels/s		1.94E+07	pixel/s				
																	Total Noise Rate		**1.16**	Gbps				

64bit/pixel

32bit/pixel

48bit/tile

OAK RIDGE National Laboratory