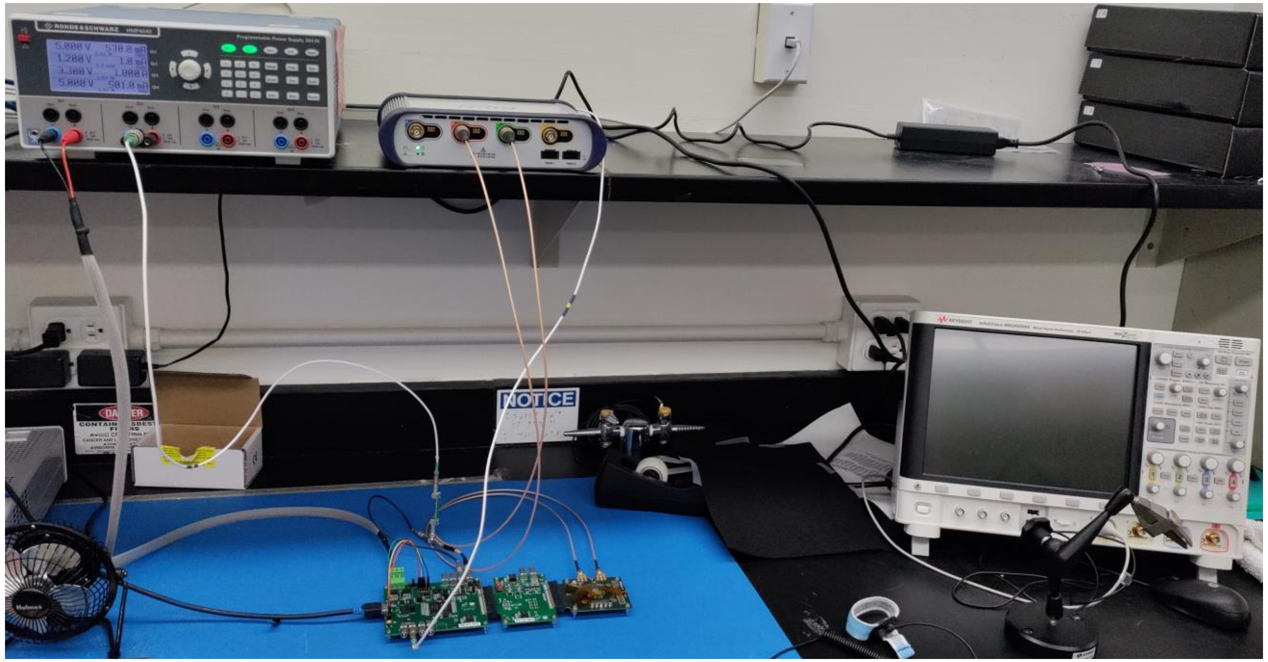
Commissioning Setup at ORNL for ITS3 DPTS Characterization

- Received DAQ board, proximity card, and carrier card with DPTS-X wafer 22, chip 32
- Downloaded apts-dpts-ce65-daq-software from gitlab repository
- Downloaded DAQ board firmware (0x107E6A10.bit)
- Using PicoScope 6425E (750MHz, 5GSPS, 4Gpts memory, 4 channel)
- Followed instructions on the CERN ITS-3 WP3 Twiki page for setup and test procedures
- Successfully did threshold scan and Fake Hit Rate scan at various values of V_{casb} at 300mV, 350mV, and 370mV with Vbb of 1.2V
- Currently in the process of obtaining a Fe-55 source to repeat energy spectrum measurements
- Setup now ready for full characterization of received chip



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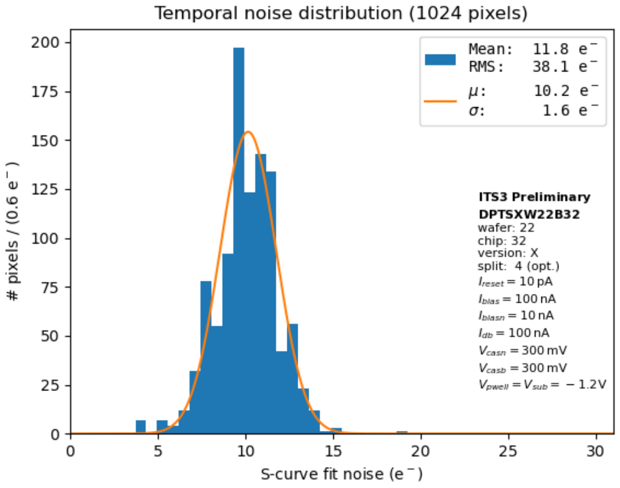
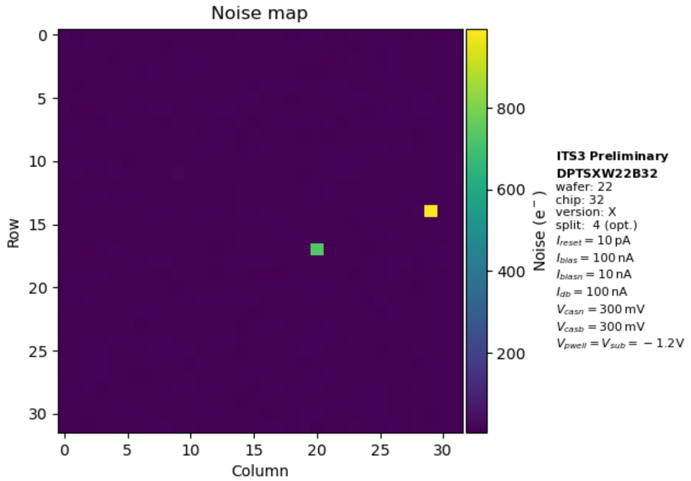
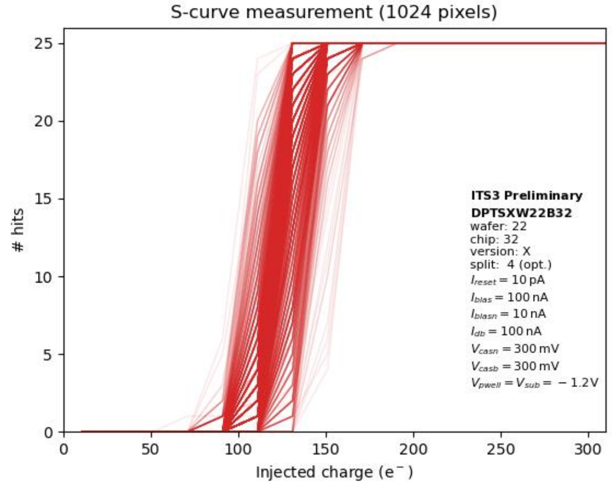
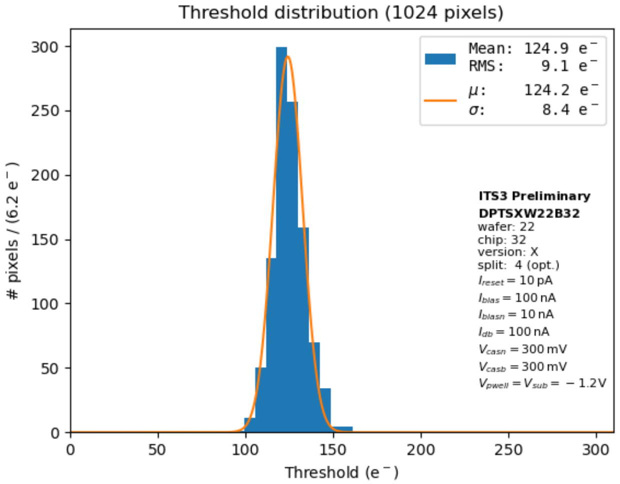
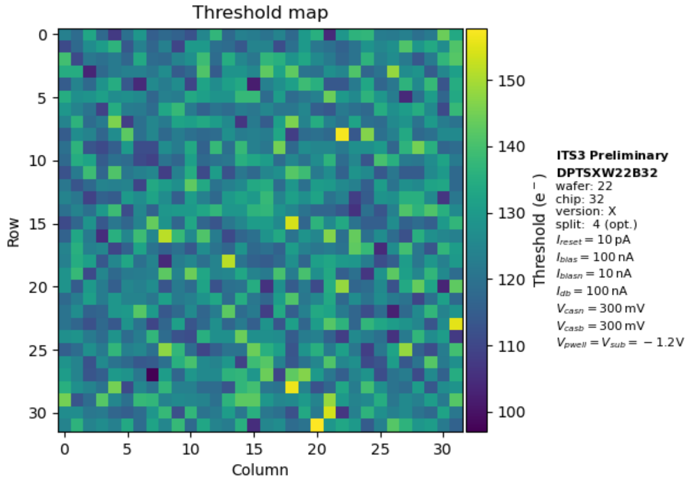
Threshold Scan Example

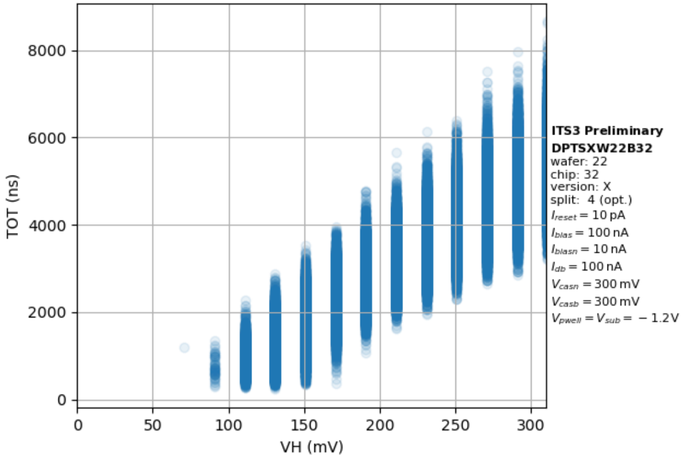












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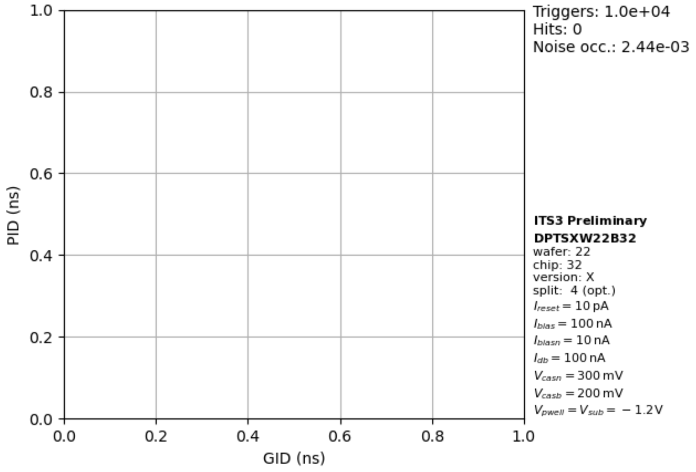
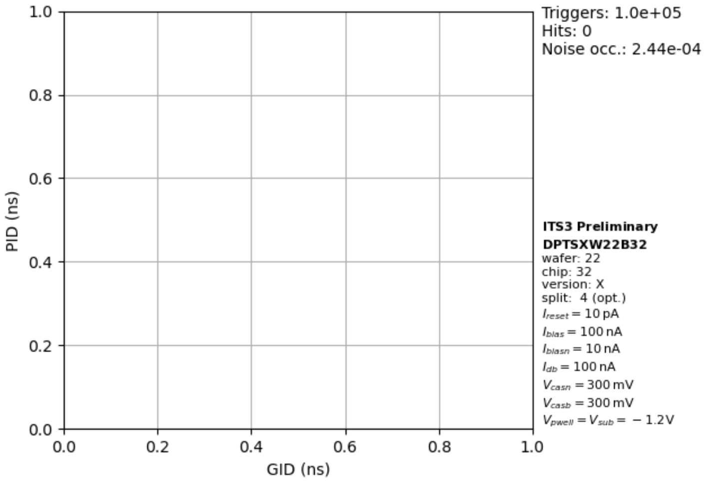
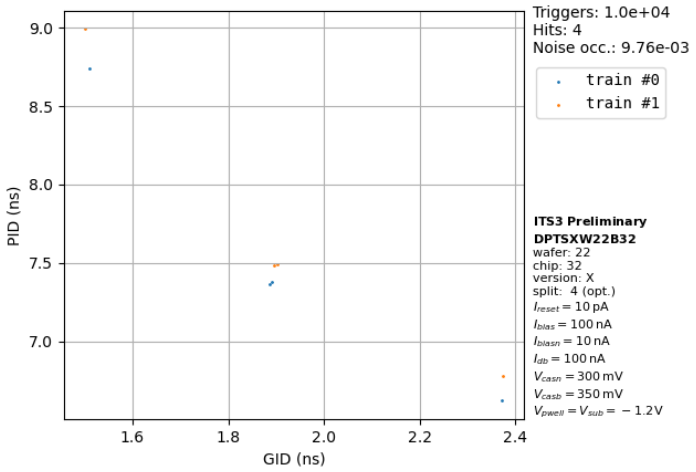
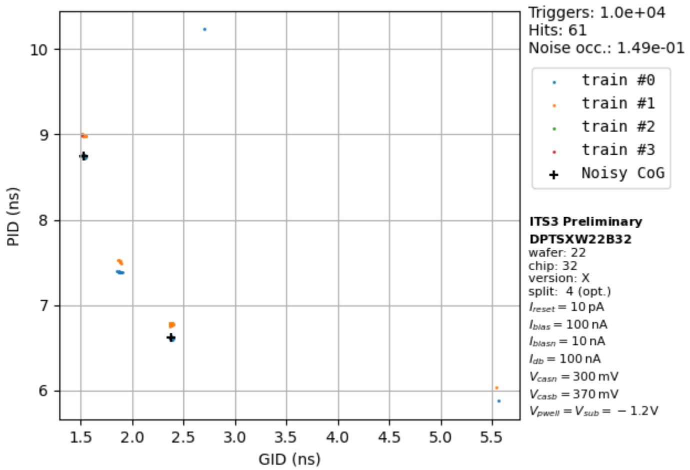
Fake Hit Rate Example









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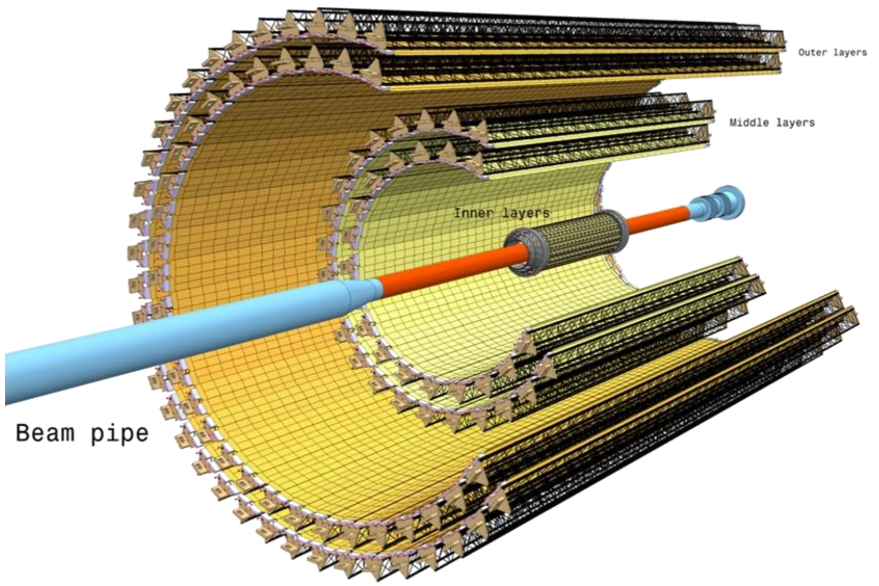
Data Rates from ITS

Total per Layer

RUN TYPE	INTER RATE (kHz)	DATE	ROF RATE (kHz)	Layer 0	Layer 1	Layer2	Layer 3	Layer 4	Layer 5	Layer 6	TOTAL (MB/s)
PbPb	0.03	18/11/2022	67	264	348	215	1000	635	1435	1645	9472
pp	3800	9/8/2022	202	6400	5900	3130	8130	4200	7900	8500	67890
pp	2000	7/8/2022	202	3960	3970	2100	6050	3400	6500	7200	52380
pp	500	23/7/2022	202	1550	1470	994	3830	2200	4900	5530	34098
pp	400	23/07/2022	202	1350	1560	900	3620	2100	4760	5370	32790
pp	3800	27/10/2022	11	2560	2240	1040	2360	1100	1755	1725	18400
pp	3800	27/10/22	22	2740	2430	1135	2650	1250	2070	2080	20890
pp	3800	27/10/22	44	3250	2880	1350	3340	1620	2800	2835	26680
pp	3800	27/10/22	67	3510	3100	1490	3860	1890	3375	3470	30920
pp	3800	27/10/22	101	4070	3570	1730	4680	2335	4335	4490	38100
pp	3800	27/10/22	123	4380	3960	1900	5140	2600	5000	5260	43000
pp	3800	27/10/22	202	5670	5180	2480	7220	3725	7000	7450	59380



Per Stave

RUN TYPE	INTER RATE (kHz)	DATE	ROF RATE (kHz)	Layer 0	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6
PbPb	0.03	18/11/2022	67	22	22	11	42	21	34	34
pp	3800	9/8/2022	202	533	369	157	339	140	188	177
pp	2000	7/8/2022	202	330	248	105	252	113	155	150
pp	500	23/7/2022	202	129	92	50	160	73	117	115
pp	400	23/07/2022	202	113	98	45	151	70	113	112
pp	3800	27/10/2022	11	213	140	52	98	37	42	36
pp	3800	27/10/22	22	228	152	57	110	42	49	43
pp	3800	27/10/22	44	271	180	68	139	54	67	59
pp	3800	27/10/22	67	293	194	75	161	63	80	72
pp	3800	27/10/22	101	339	223	87	195	78	103	94
pp	3800	27/10/22	123	365	248	95	214	87	119	110
pp	3800	27/10/22	202	473	324	124	301	124	167	155

- Coverage: r 22 – 400 mm, $|\eta| \leq 1.22$
- ~24k pixel chips
- ~$10 m^2$ active area

Integration times from 5μs to 90μs

ITS2 Rates simulated (2015)

		Pb-Pb			p-p	
Layer	Radius	Prim. & sec. particles **average** [a]	Prim. & sec. particles **max** [a]	QED electrons [b]	Prim. & sec. particles **average** [c]	Prim. & sec. particles **max** [c]
	[mm]	[cm^{-2}]	[cm^{-2}]	[cm^{-2}]	[cm^{-2}]	[cm^{-2}]
0	22	8.77	12.45	6.56	0.08	0.11
1	31	6.17	8.61	3.39	0.05	0.07
2	39	4.61	6.19	1.84	0.04	0.05
3	196	0.34	0.45	0.01	0.00	0.00
4	245	0.24	0.31	0.00	0.00	0.00
5	344	0.13	0.17	0.00	0.00	0.00
6	393	0.11	0.13	0.00	0.00	0.00

[a] hit densities in Pb-Pb collisions (single event, including secondaries due to material)
[b] for an integration time of 10 μs, a Pb-Pb interaction rate of 50 kHz, a magnetic field of 0.2 T (worst case scenario) and $p_T > 0.3$ MeV/c.
[c] hit densities in central p-p collisions (including secondaries produced in material)

Table 1 – “Physics events” rates for minimum bias events.

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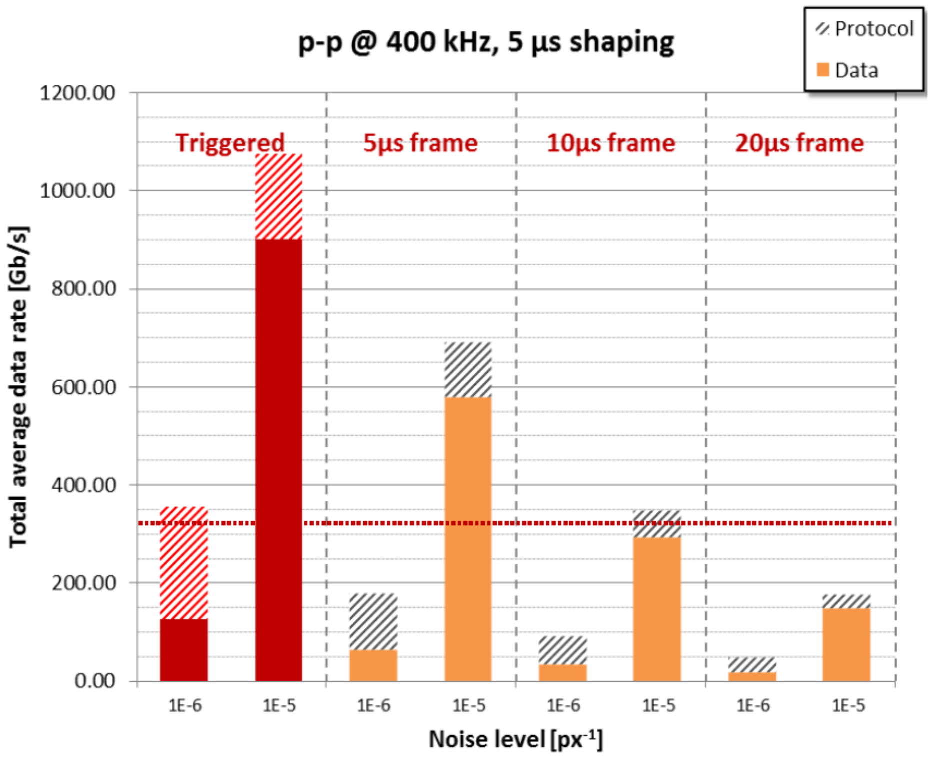
ITS-2 pp Data Rates



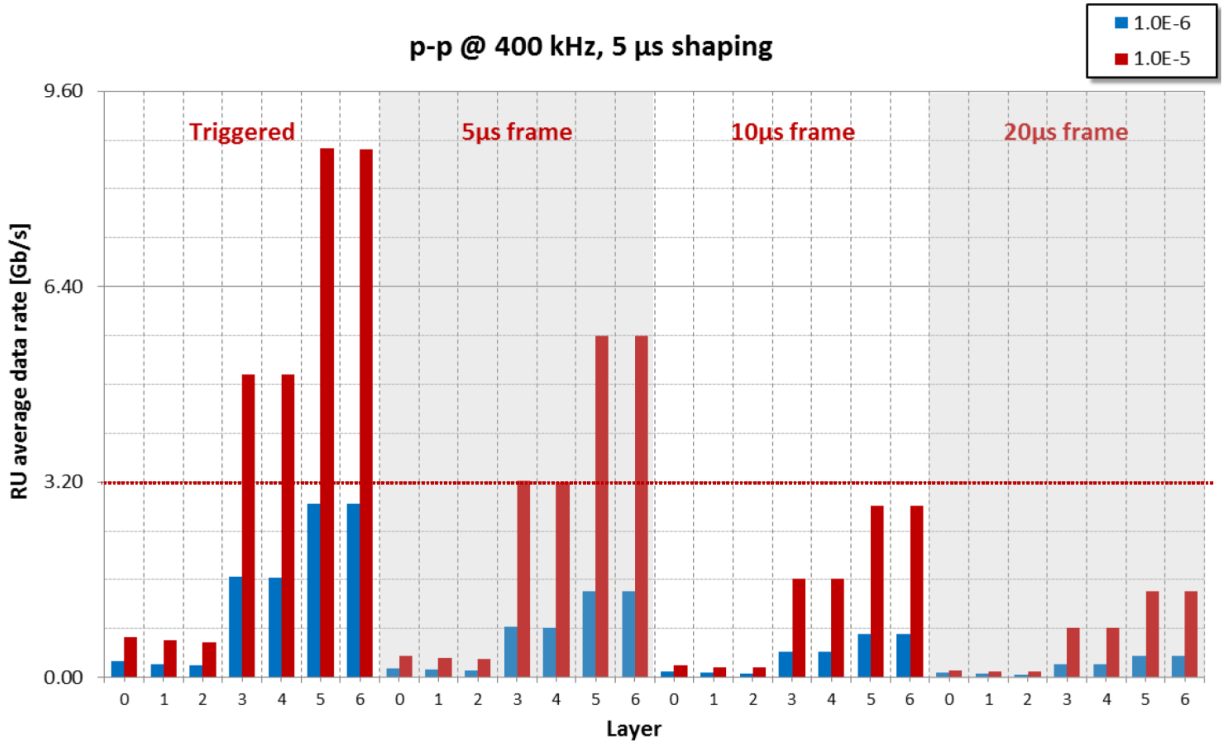
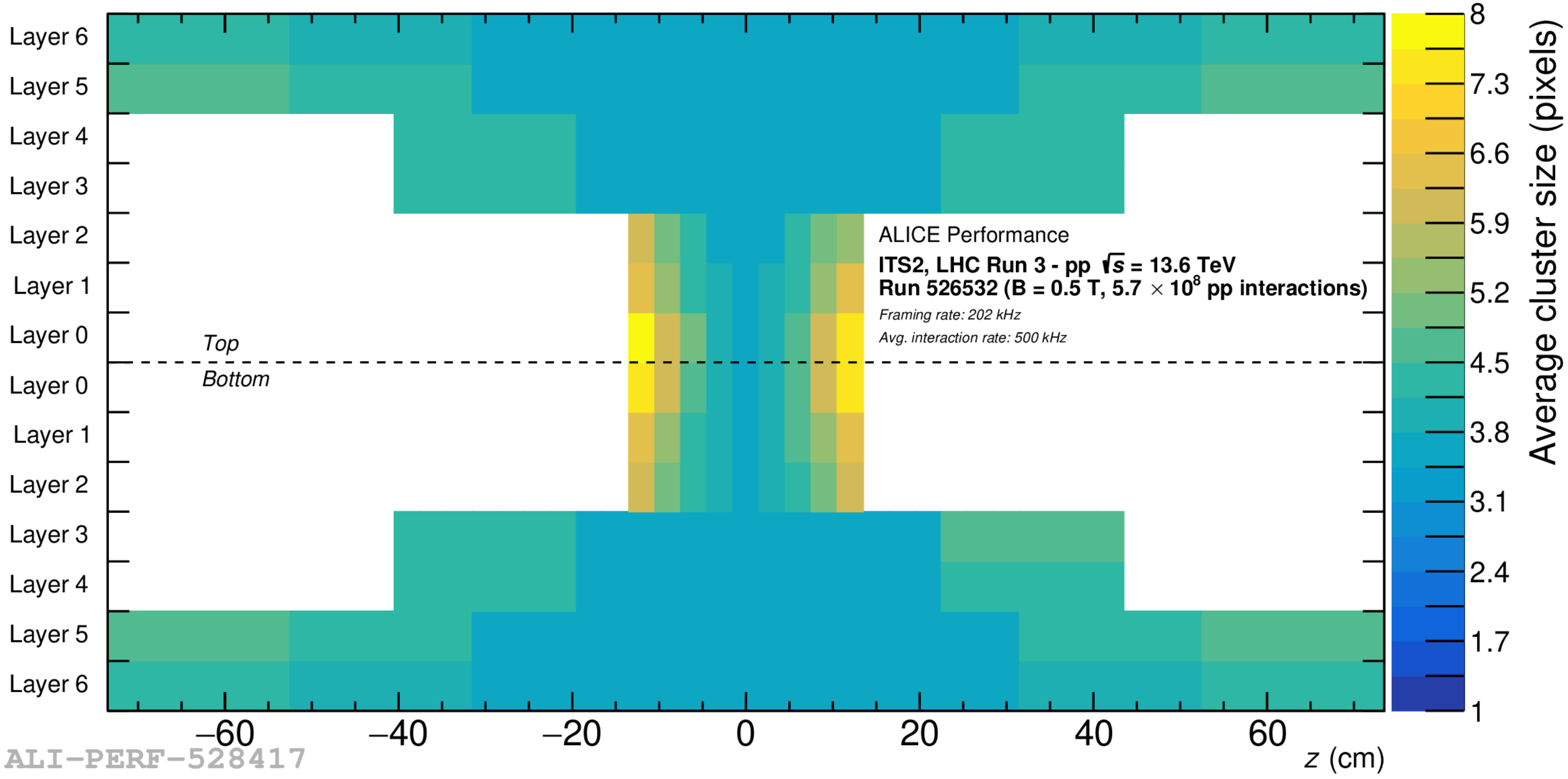
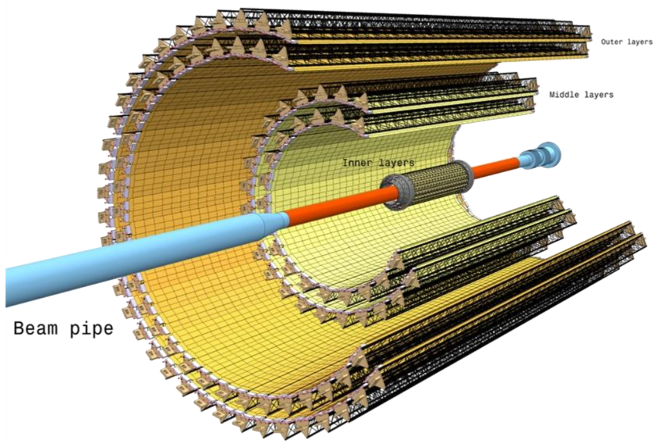


Figure 5 – p-p @ 400 kHz, total payload (data + protocol) per Readout Unit.

Red dotted line indicates 40 GB s^{-1} (320 Gb s^{-1}) which was foreseen the max rate the ALICE O2 system should be able to handle; or the bandwidth available on one GBT link

Cluster Size from ITS2





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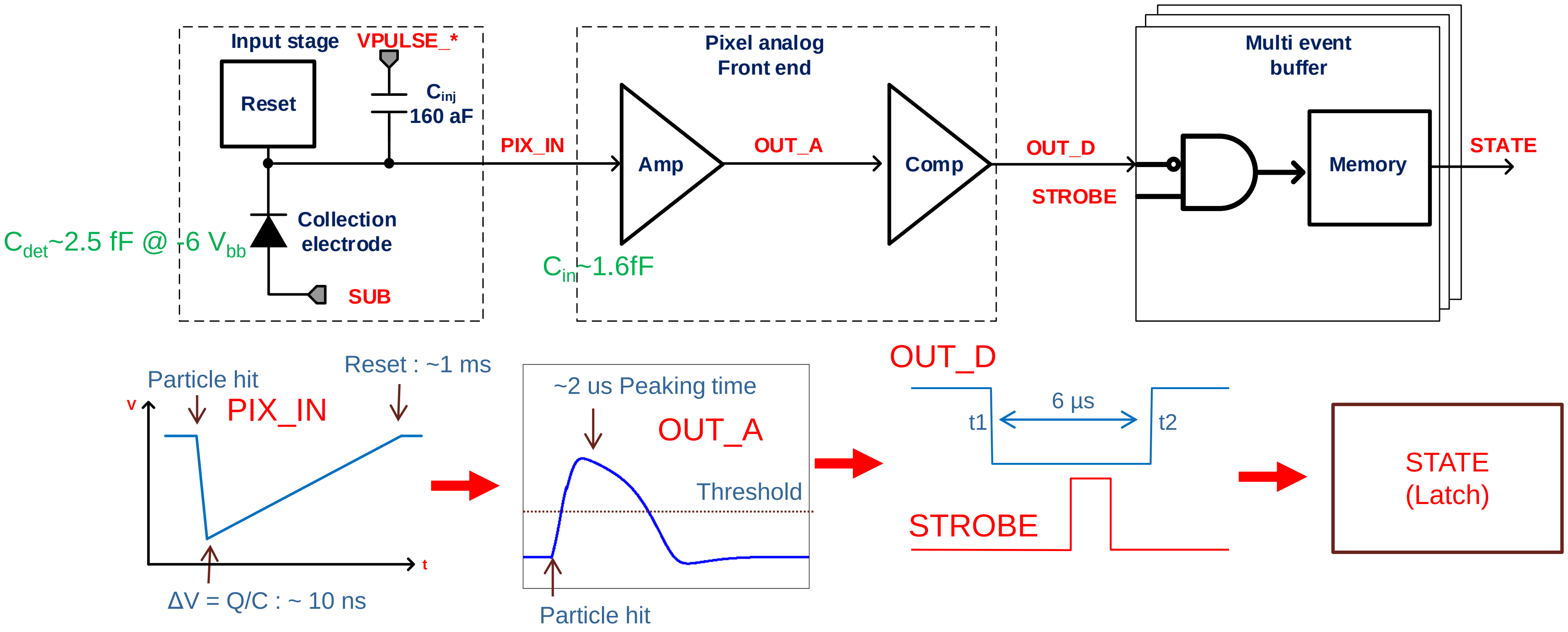
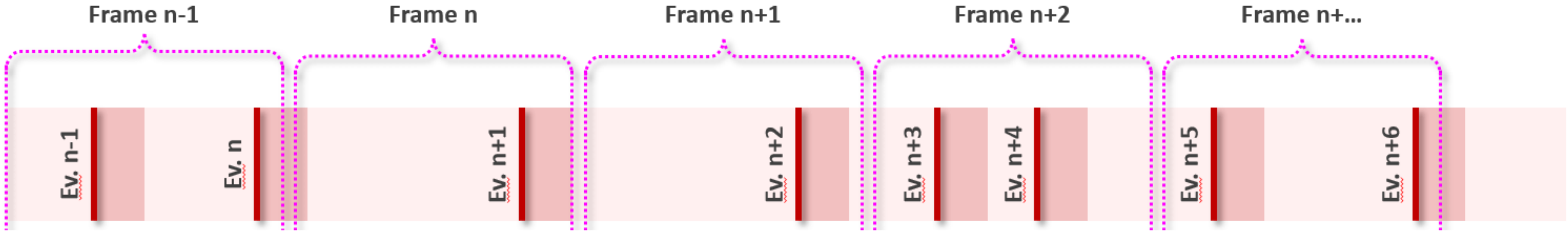
Reminder: ALPIDE Principle of Operation



Continuous Mode: long "strobes" followed by short inter-strobe periods (100 ns) for readout



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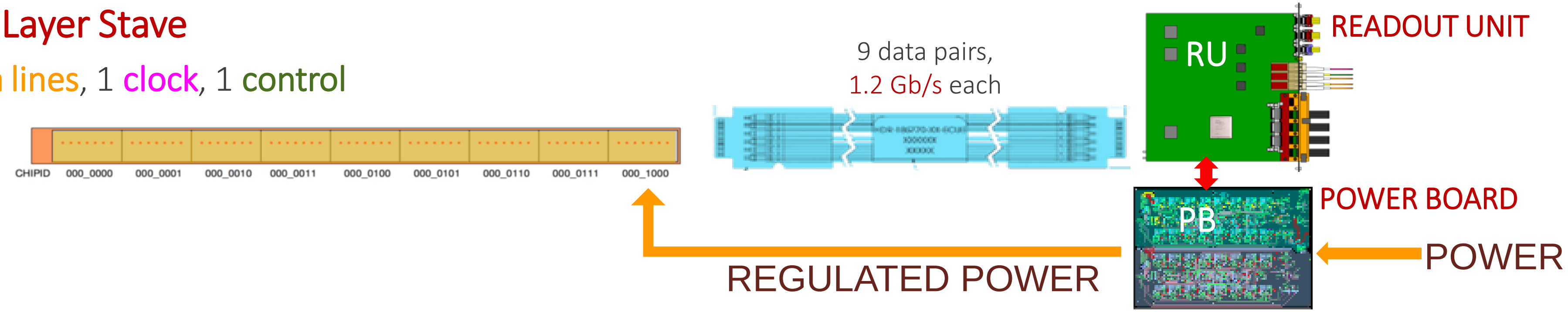
Stave Configurations:

Inner Layer Stave

9 data lines, 1 clock, 1 control

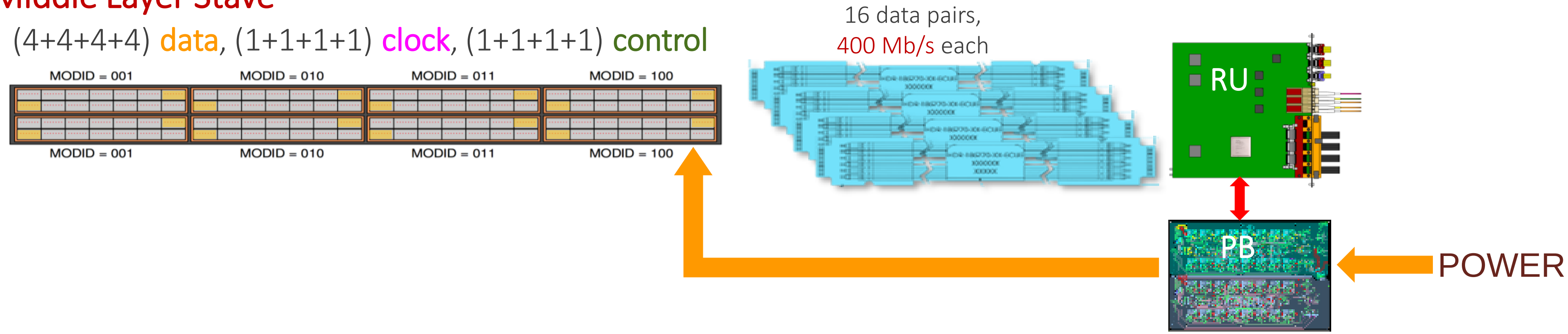


DATA OUTPUT:

9 data pairs,
1.2 Gb/s each
8.6 Gbps payload

Middle Layer Stave

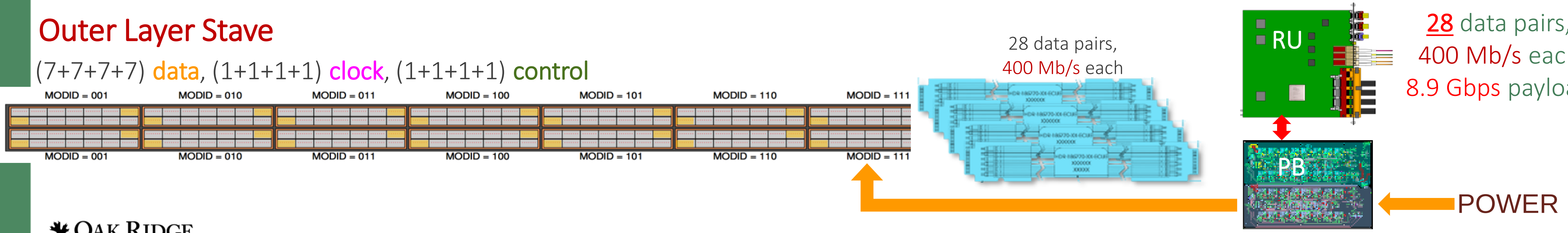
(4+4+4+4) data, (1+1+1+1) clock, (1+1+1+1) control



16 data pairs,
400 Mb/s each
5.1 Gbps payload

Outer Layer Stave

(7+7+7+7) data, (1+1+1+1) clock, (1+1+1+1) control



28 data pairs,
400 Mb/s each
8.9 Gbps payload

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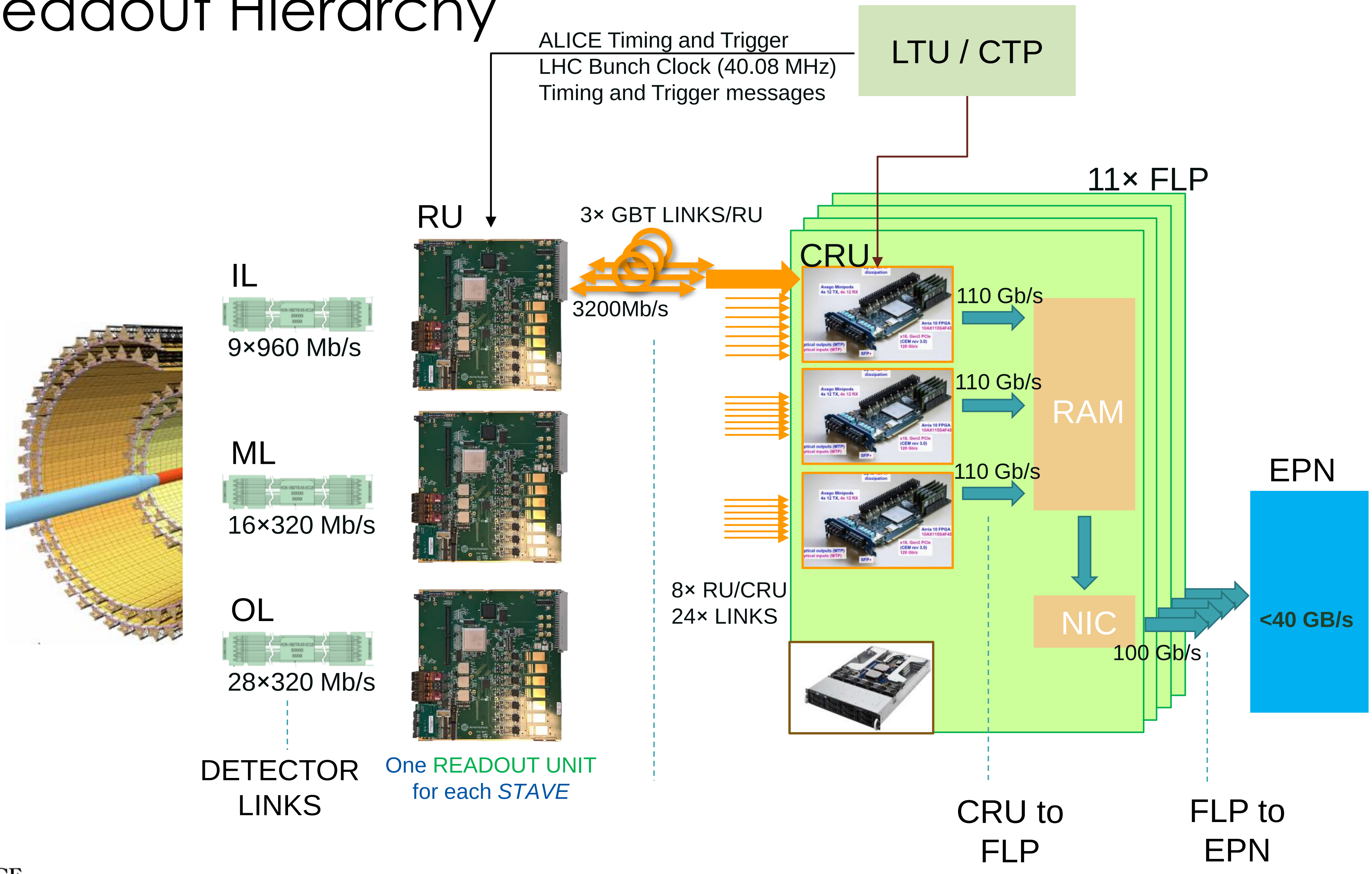
ITS Readout Hierarchy



ePIC MAPS Detector

Barrel						**Sensor**											
Layer Index	**radius (mm)**	**z (mm)**		**Area (mm^2)**	**reticles in width**	**reticles in length**	**# of sensors in r-phi**	**# of sensors in z**						**# pixels**	**# sensors**	**Mechanical**	**# Readout Links**
0	36	270		61,074	3	9	4	1						271,440,000	4	bent ITS3	96
1	48	270		81,432	4	9	4	1						361,920,000	4	bent ITS3	128
2	120	270		203,580	5	9	8	1						904,800,000	8	bent ITS3	320
3	268.4	540		1,017,900	1	9	100	2						4,524,000,000	200	stave	1600
4	418.5	840		2,470,104	1	7	156	4						10,978,240,000	624	stave	624
				LAS	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**				
				# of reticles	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**				
e-endcap																	
Disk index	z (mm)	inner r (mm)	outer r (mm)														
1	-250	36.76	230	133,458	4	4	4	8	12	20	0	0	0	593,146,667	52	stave	52
2	-450	36.76	430	506,688	0	0	0	60	4	12	20	44	8	2,251,946,667	148	stave	148
3	-650	36.76	430	506,688	0	0	0	60	4	12	20	44	8	2,251,946,667	148	stave	148
4	-900	40.0614	430	507,819	0	0	0	62	4	16	18	42	8	2,256,973,333	150	stave	150
5	-1150	46.3529	430	505,557	0	0	0	64	2	16	20	40	8	2,246,920,000	150	stave	150
h-endcap																	
Disk index																	
1	250	36.76	190	133,458	4	4	4	8	12	20	0	0	0	593,146,667	52	stave	52
2	450	36.76	430	506,688	0	0	0	60	4	12	20	44	8	2,251,946,667	148	stave	148
3	700	38.52	430	505,557	0	0	0	62	2	12	20	44	8	2,246,920,000	148	stave	148
4	1000	53.43	430	503,295	0	0	0	64	4	14	20	42	6	2,236,866,667	150	stave	150
5	1350	70.14	530	506,688	0	0	0	62	4	14	24	38	8	2,251,946,667	150	stave	150
TOTAL				**8,149,986**										**36,222,160,000**	**2136**		**4064**

Pixel Size: 15μm
Reticle Size: 18.85 x 30 mm^2

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Readout Thoughts

- An ITS-2 inner barrel stave has **9** links with **1.2 Gbps** each. Layer 0 has 12 total staves, so a total of **130 Gbps** rate capability

- ITS-3 is closer to interaction point. There are a total of **2 sensors** foreseen in layer 0, each with **3** rows of **9** stitched reticles; each reticle has about **2.5M pixels** (vs 0.5M pixels in ITS-2). This results in a need of almost a factor **2** in bandwidth, namely **240 Gbps**. Assuming one can achieve 5 Gbps (copper) links, one would need 48 links for layer 0. So, each row of 9 reticles would have **8** links, or **24** links per sensor with 3 rows of stitched sensors. Would that have to scale with 4 or 5 rows? I.e. would those sensors have 32 and 40 links? For the number of readout links, I assumed these numbers per sensor for layers 0 – 3, and 1 link per sensor otherwise.

- As seen from the rates shown from this year's ALICE run, it is not clear that double the rate is really necessary, maybe it would suffice to have only 4 links per row? The number of readout links shown in the previous slide assumed 8 links per row of 9 reticles.

- We still don't have the equivalent of the readout simulations shown in the previous slides for ITS. The best we can do at the moment are Nico's numbers provided a while ago for e-p collisions (no secondaries, beam-gas, other backgrounds). Nico still has difficulties running these simulations in the new software framework. These also need to be repeated for e-A collisions.

Detector	Average # hits in min. bias pythia6 (10x100 GeV)	Average # hits in High Q2 pythia6 (18x275 GeV)
Full barrel (3 vertex + 2 sagitta)	9.3	30.7
Full forward (5 disks)	16.8	36.3
Full backward (4 disks)	6.4	2.2
Barrel layers (0/1/2/3/4)	2.4 / 1.7 / 1.4 / 1.9 / 1.8	7.2 / 5.8 / 4.9 / 6.6 / 6.2

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Readout Thoughts (continued)

- So, the total number of hits (vertex, sagitta, forward/backward disks) would have around **70** hits. Latest results from DPTS show about 1.2 pixels firing per hit, but no study has yet been done how that changes with incident angle. This would result in about 85 pixels with data. Let's assume the background is about the same size, i.e., a total number of **170 pixels per event**. How much should we assume for the angle effect?

- An assumed collision rate of **500 kHz** would then result in a "Physics" pixel rate of **85 Mega-pixels per second**.

- From recent **DPTS fake hit rate** results, it seems that the current MLR1 prototype sensors have a noise rate of about **10^{-2} $pixel^{-1}$ sec^{-1}** (corresponding to 10^{-7} $pixel^{-1}$ $event^{-1}$ for ALPIDE). For a total number of 36 B pixels in ePIC, this would result in a total of **310 Mega-pixels per second** fired just from noise.

- Adding "Physics" and "Noise" together we need to read out **~400 Mpixels/sec**. So far there are no thoughts yet on the data format out of an ITS-3 sensor, it will probably look very similar to the format from ALPIDE, i.e., region headers followed by double column addresses, followed by (clustered) matrix addresses of hit pixels. Let's assume for simplicity 64 bits per pixel. This results in a total data rate of **25.6 Gbps**, not very much compared to a fiber rate of similar capability for the new Phase-2 FELIX fiber links. Whatever Readout Unit would be developed for ePIC MAPS would mainly be concerned with aggregation of multiple copper links, removing empty frames, and transmission over 10 or 25 Gbps fiber links.

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Readout Thoughts (continued)

- The range of transmission in ITS2 from the staves to the Readout Units is about **8m** at **1.2 Gbps**. Studies by M. Rossevij with the Samtec firefly cables used in ITS-2 show that transmission at that speed already needs proper pre-emphasis and equalization, and that the BER eye closes fully at ~3Gbps. For 5 Gbps transmission lines it seems that an **active repeater** is needed at ~1m from the edge of the flex. In case of ITS3 these would be in the service cone, i.e., not in the active region of the ALICE detector. Where would we be able to place such repeaters in ePIC?

- For ITS-3 the line drivers will likely not be configurable for speed, since the layers in ITS-3 are very close and thus need the same rate capabilities, but some configurability (be it the line rate or how many are actually activated and used) might be envisaged (according to Gianluca), still to be determined in the future.

- Where would we be able to place the above-mentioned Readout Boards? How far would that be from the edge of the flex cables from the sensors?

- A possible means of reduction of the required links out of the MAPS barrel region would be to use a rad-hard FPGA board to multiplex copper links for up and downstream into one or more fibers (combined into a fiber bundle like an MTP assembly) close to the flex circuit of the sensor. Possible candidates for FPGA and fiber converters were identified in earlier work in eRD104: **Microsemi PolarFire** FPGA, and **Samtec optical FireFly**. Rad-tolerance might require use of the **VTRx+** fiber assembly from the lpGBT development (possible use of the lpGBT ASIC as well?) instead of Samtec optical FireFly. Questions: Would it perhaps be possible to incorporate such circuitry into the flex circuit of the sensor? If not, where would such a PCB be possible to place (close to the flex)?

- In ITS we were able to accommodate up to 28 copper links per Readout Unit. For ePIC this aggregation would depend on the number of transceivers available on the FPGA chosen for the RDO board. A (cheap) candidate is the **Xilinx Artix UltraScale+** FPGA family (~$250 for the XCAU10P) which has up to twelve 12.5 Gbps transceivers. Assuming 10 links for copper, and 1 link for fiber, this would mean one would need ~**400 RDO boards** (corresponding to **400 12.5 Gbps fibers**). Each FELIX will likely have up to 48 fiber links. The whole MAPS detector would then need **10 FELIX boards**.

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