Alice ITS Upgrade

Readout Electronic – WP10

pp rate considerations – 16 February 2016

1 pp maximum rate

This note discusses the maximum rate of pp events that the ITS will be able to sustain at full efficiency. Simulation data are based on physics simulations of events, which occupancy properties are summarized in Table 1.

		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.

1.1 Continuous vs triggered operations

The system (sensor and readout electronic) can operate in continuous (baseline) or triggered mode. In continuous mode the sensor integrates all the signals (all pixel in parallel) for a fixed amount of time, called frame, and then flushes the positons of the those pixel which recorded a hit. Thanks to in-pixel buffering, while one frame is being acquired the previous one is transmitted in background, virtually reducing the dead time between frames to zero. Every frame contains all the information about particles events generated during the integration time, but there is no per-hit timestamp. The maximum time resolution is therefore the duration of the frame itself.

The triggered mode works almost the same way, with the difference that the frame has the minimum practical possible duration (about 1 μs, which at first order depends on the front-end analogue shaping time) and the acquisition of a single frame starts only when the trigger is issued. Operating the system in continuous mode with a frame duration of 1 μs would actually provide the same time resolution of the triggered mode: such a scenario is anyway unpractical due to the bandwidth necessary to ship the data out of the sensor.

Summarizing, triggered mode delivers the best time resolution, but has an upper limit in the maximum average trigger frequency (about 400 kHz) the system can handle, while the continuous mode can operate independently from the actual collision rates, at the price of less time granularity (higher event pileup).

Continuous mode operation is the experiment baseline for the upgrade, and the most effective for high-rate pp collisions tracking with the ITS. For pp events, the trigger mode is less beneficial than for Pb-Pb interactions, due to the much lower track density (Table 1). The cost of shipping with each frame the protocol and encoding information plays in this case a major role in setting the upper limit for the trigger frequency, which is around 400 kHz for an empty, noise-free frame, and which is further diminished by the presence of noise.

1.2 p-p total data rates

1.2.1 Global rates

Rates are expressed in Gbit/s for the full ITS. Every plot is divided into four sectors illustrating the different data rates expected for triggered operation (the leftmost sector) and continuous operations with three different frame lengths of 5 µs, 10 µs and 20 µs. The orange part of the bar represents the actual hit addresses, while the pattern stripes atop shows the protocol overhead. The total required bandwidth is the sum of the two. It is foreseen to reduce the protocol overhead in the ITS Readout Electronic before sending the data to the CRU. Rates have been reported for two noise levels, 10^{-5} and 10^{-6} px^{-1}, which represents respectively a worst case scenario and the actual performance of the ALPIDE sensors. Better noise figures (< 10^{-6}) further reduce the data rate marginally, and are omitted from the graphs for clarity. Figure 1, Figure 2 and Figure 3 illustrates the average data rate produced by the full ITS for pp events rates of 200 kHz, 400 kHz and 1 MHz respectively. The O^2 system first implementation is foreseen to handle up to 320 Gb s^{-1} (40 GB s^{-1}), and this level has been marked with a red dot line.

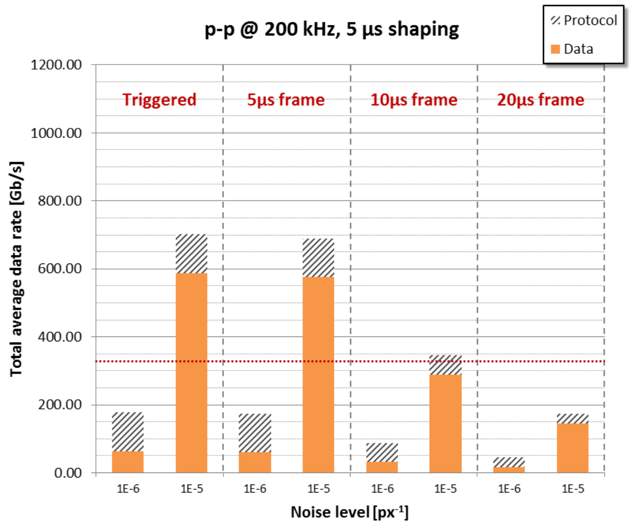

Figure 1 – p-p @ 200 kHz.

In both Figure 2 and Figure 3 the data about the triggered mode are marked in red as the system cannot withstand such trigger frequencies at 10^{-5} px^{-1} noise, the resulting data throughput being not representative (data loss) of the triggered operating condition. At 10^{-6} px^{-1} the trigger mode is instead possible.

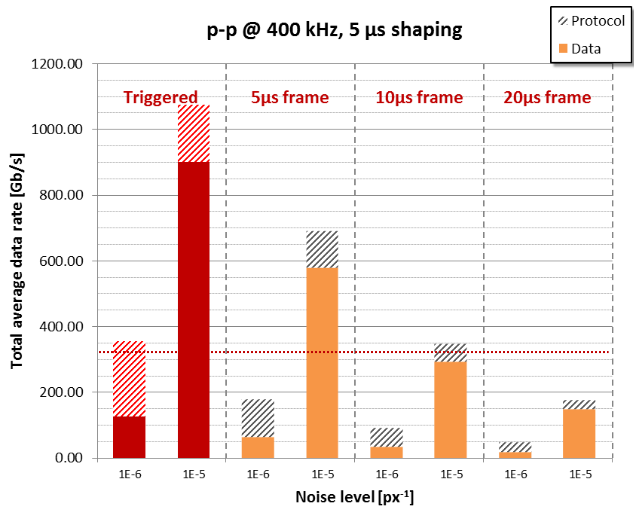

Figure 2 – p-p @ 400 kHz. Trigger mode is ineffective in this scenario.

From all the three cases it is evident how for the expected noise values (10^{-6} px^{-1}) it will be possible to operate the ITS in continuous mode with a frame length down to 10 µs or better.

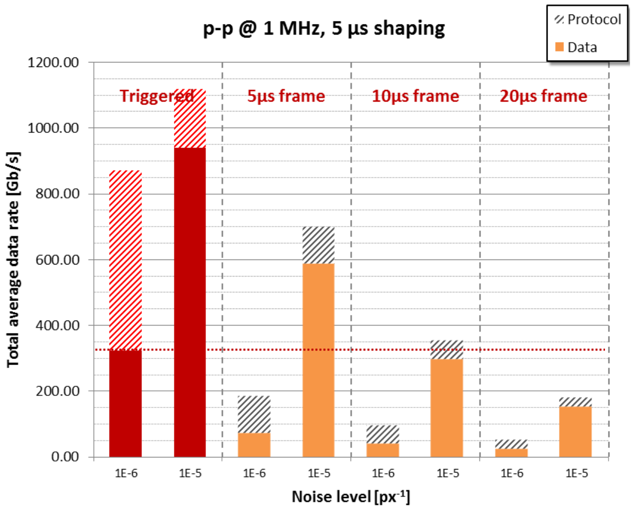

Figure 3 – p-p @ 1 MHz. Trigger mode is ineffective in this scenario.

1.2.2 Per Readout Unit (link) rates

The data presented in the previous graphs have been broken down in the following plots, where the data rate is expresses in function of the layer and per readout unit. In this view, the key parameter is the capacity of the optical channel which connects the readout unit to O^2 the through the CRU, which for the first installation will be of 3.2 Gb s^{-1} (one GBT channel, even if the readout units will be equipped with 3 GBT links per unit). Figure 4 and Figure 5 illustrate the data rate per RU for each layer for p-p interactions at 200 kHz and 400 kHz, while Figure 6 shows the same results for pp collisions @ 1 MHz.

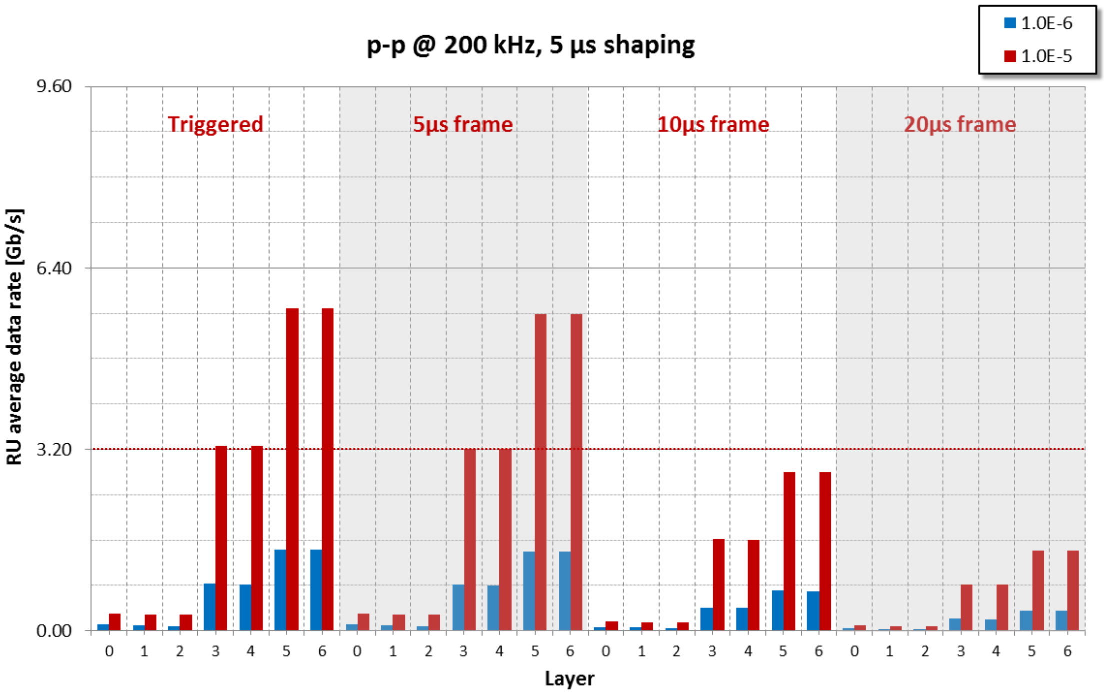

Figure 4 – p-p @ 200 kHz, total payload (data + protocol) per Readout Unit.

p-p collisions @ 200 kHz can be read in triggered mode, but the continuous mode is more efficient from bandwidth point of view. From Figure 4 is clear how with a noise equal or better than 10^{-6} px^{-1}, any operation mode is feasible well within the constraints of the full system (ITS, CRU and O^2).

p-p collisions @ 400 kHz can be fully supported in both continuous and triggered mode as well (all blue bars below the red line, Figure 5) if the noise level is equal or less than 10^{-6} px^{-1}.

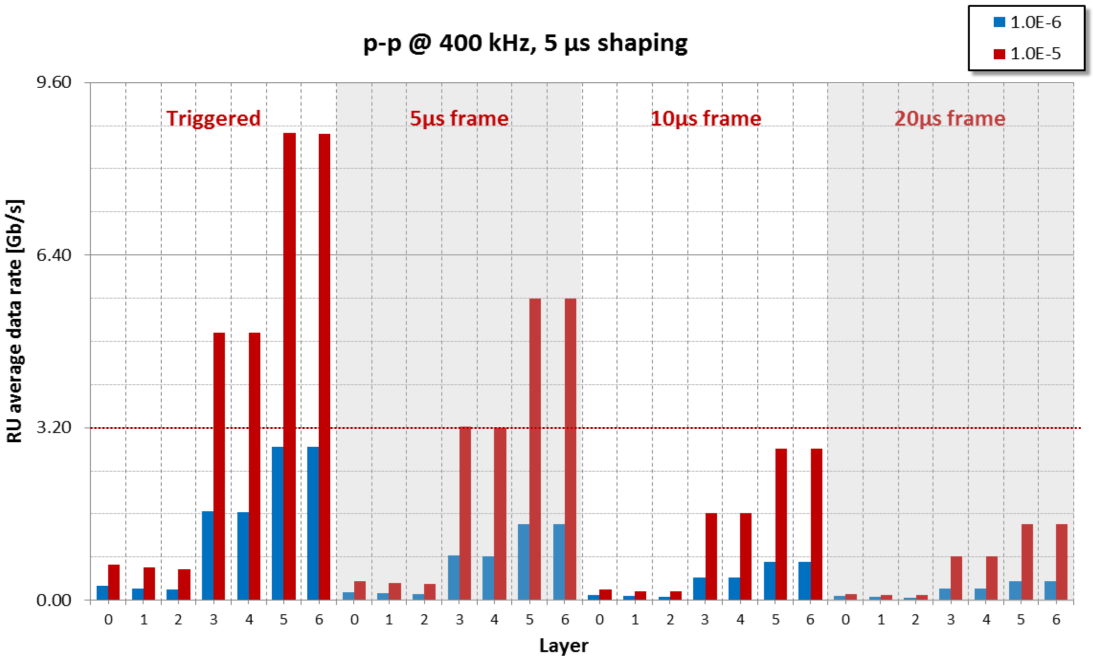

Figure 5 – p-p @ 400 kHz, total payload (data + protocol) per Readout Unit.

p-p collisions @ 1 MHz cannot be read in triggered mode, whichever the noise level, due to lack of bandwidth toward the CRU/O2 and the maximum trigger rate the readout electronic can handle. For a noise level of 10^{-6} px^{-1}, continuous operation readout is possible for any practical frame length.

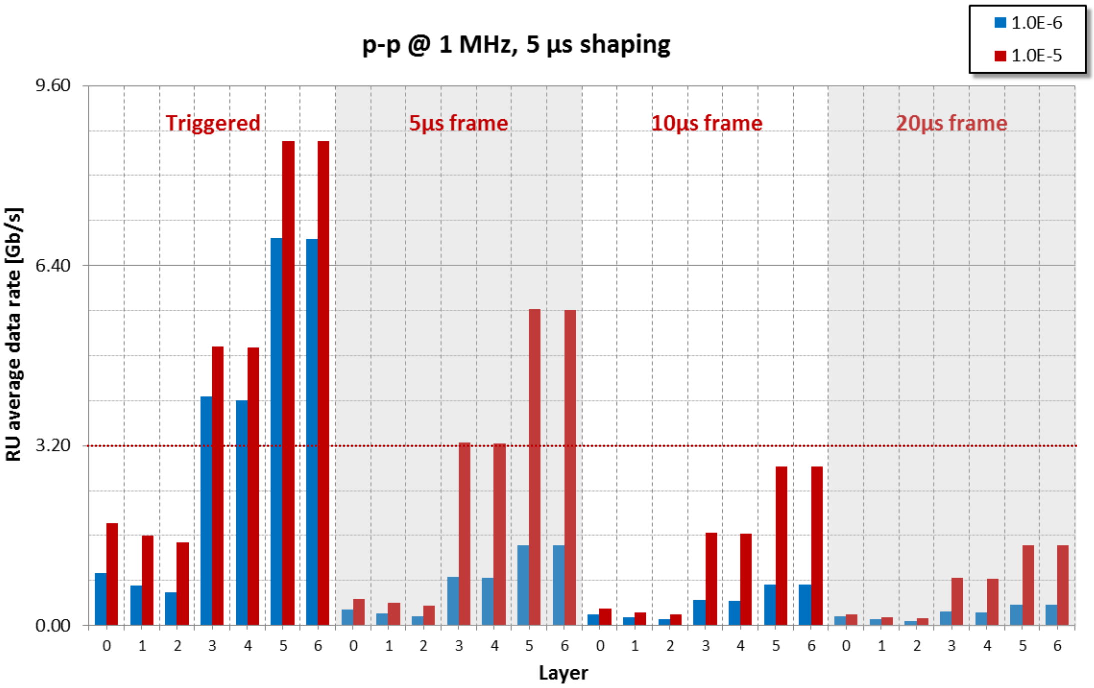

Figure 6 – p-p @ 1 MHz, total payload (data + protocol) per Readout Unit.