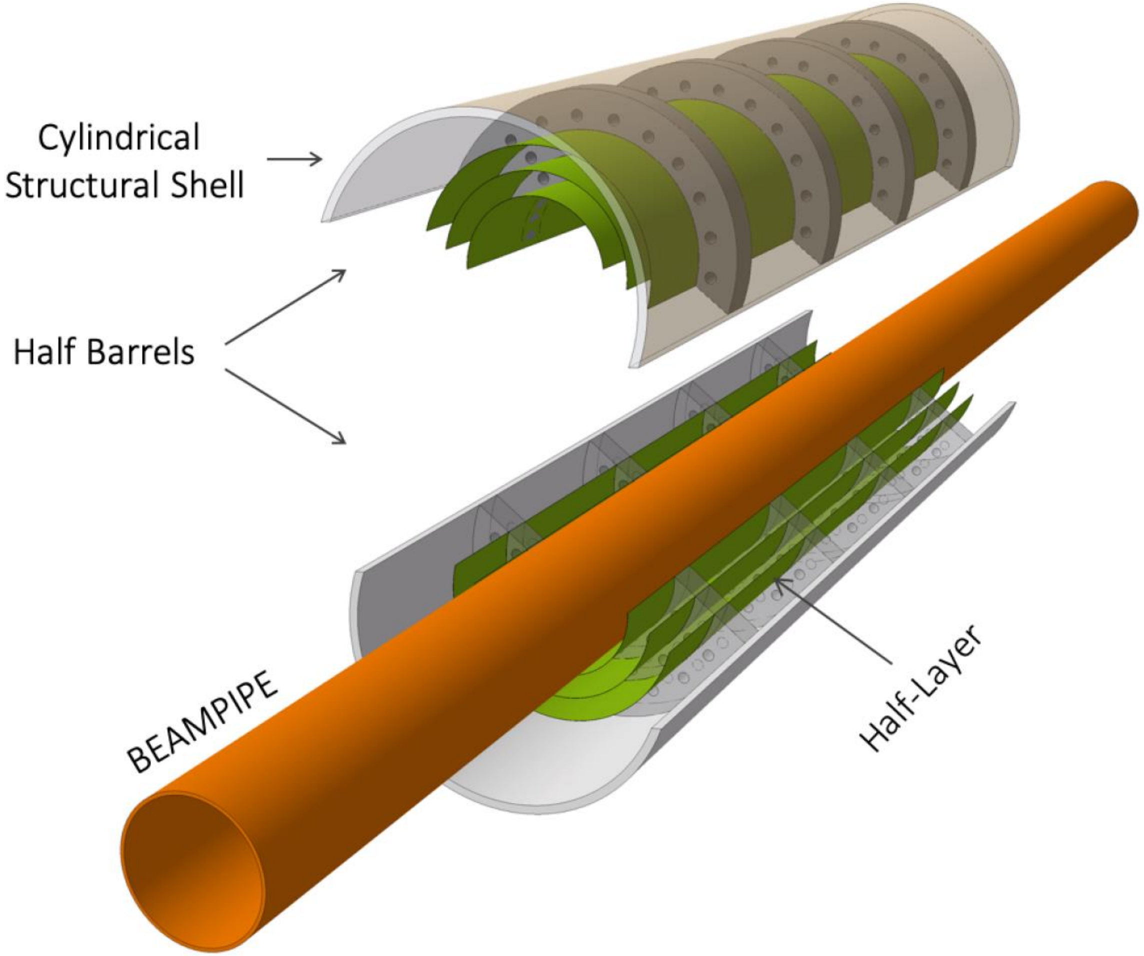
Model and analysis of the data readout architecture for the ITS3 ALICE Inner Tracker System



Manuel Viqueira Rodríguez

TWEPP 3 Oct 2023

ITS3 introduction

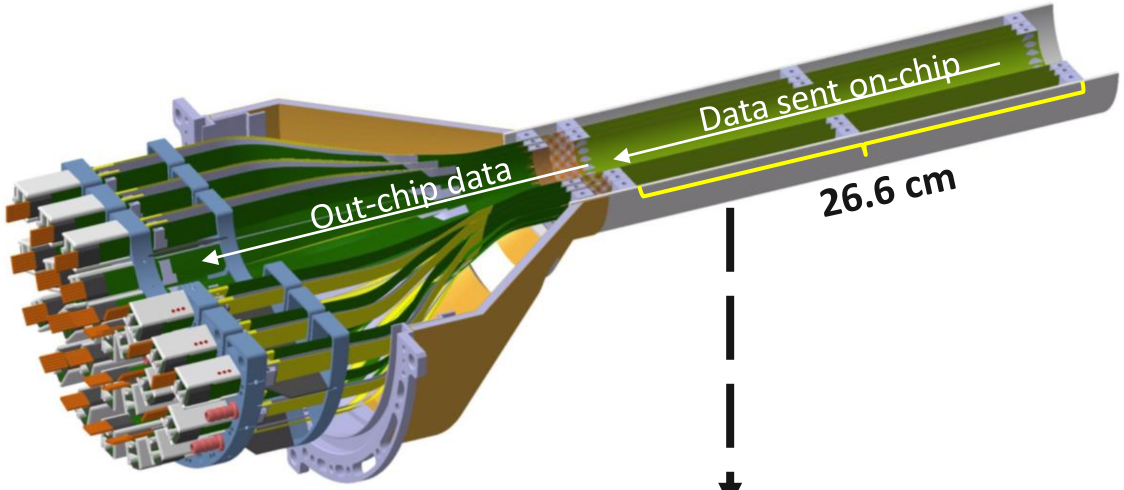
ITS3

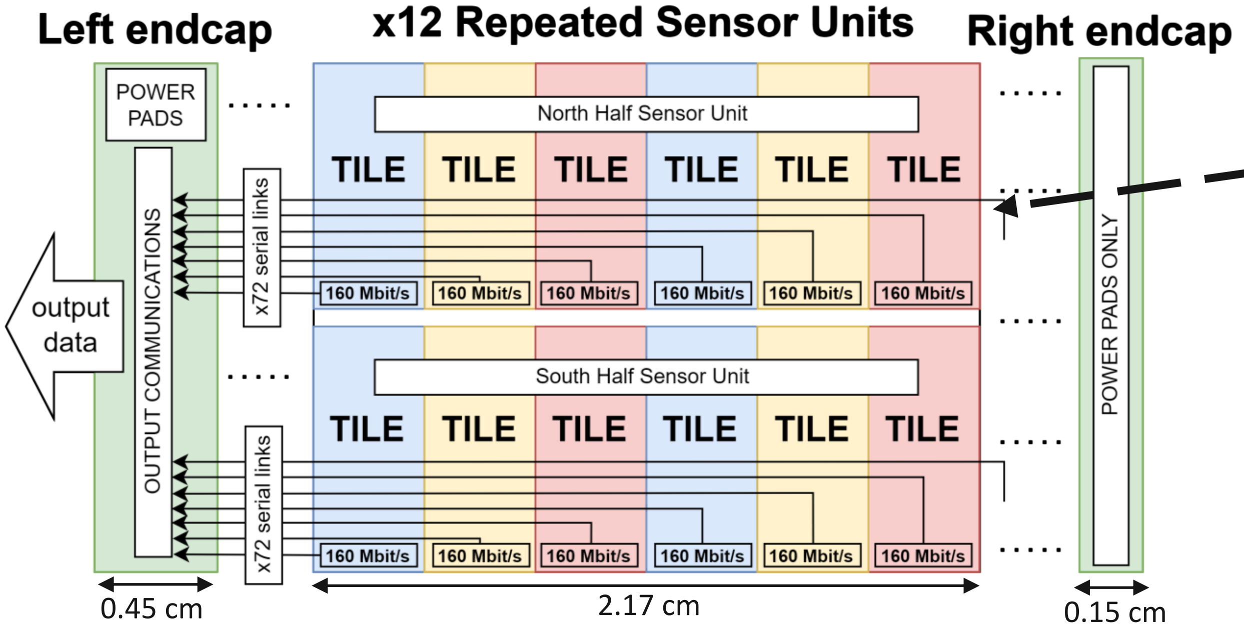
- Wafer-scale Monolithic Active Pixel Sensors (**MAPS**)
- Cylindrical sensors of radii 18/24/30 mm

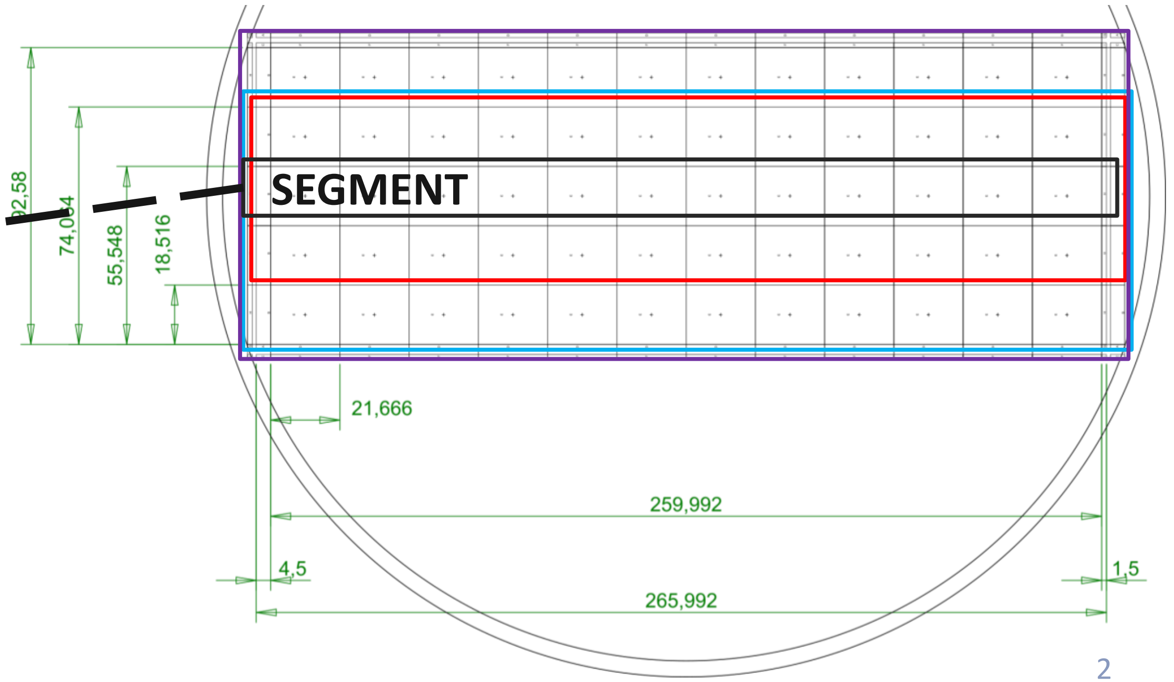
Architecture requirements (**Stitching**)

- Dies divided into 3,4 or 5 **Segments**
  - **2 endcaps** on the edges
  - **12 Repeated Sensor Units** (RSU)
    - *12 tiles per RSU*

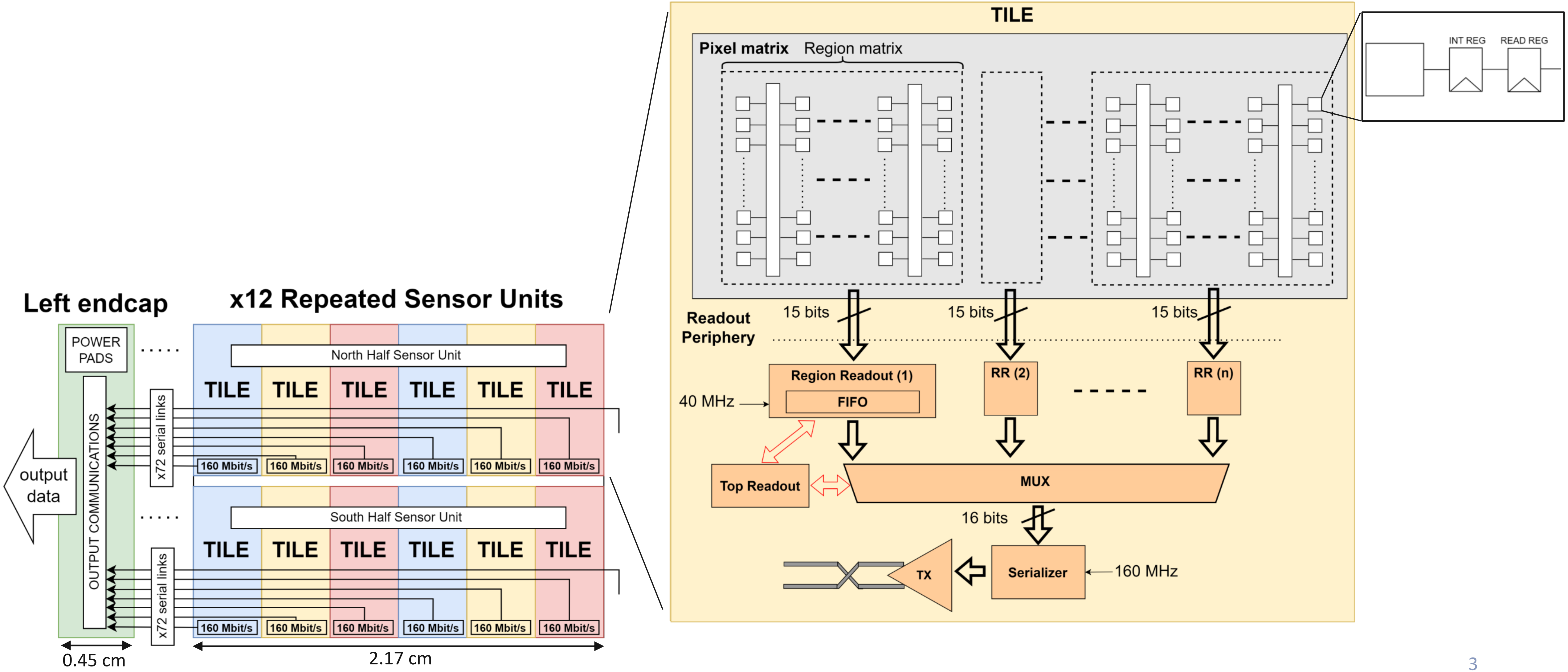
Data transfer on-chip to the left edge (26.6 cm)







On-chip readout scheme

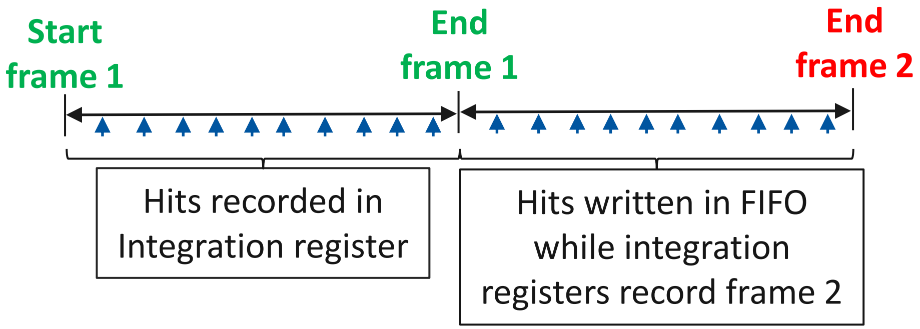


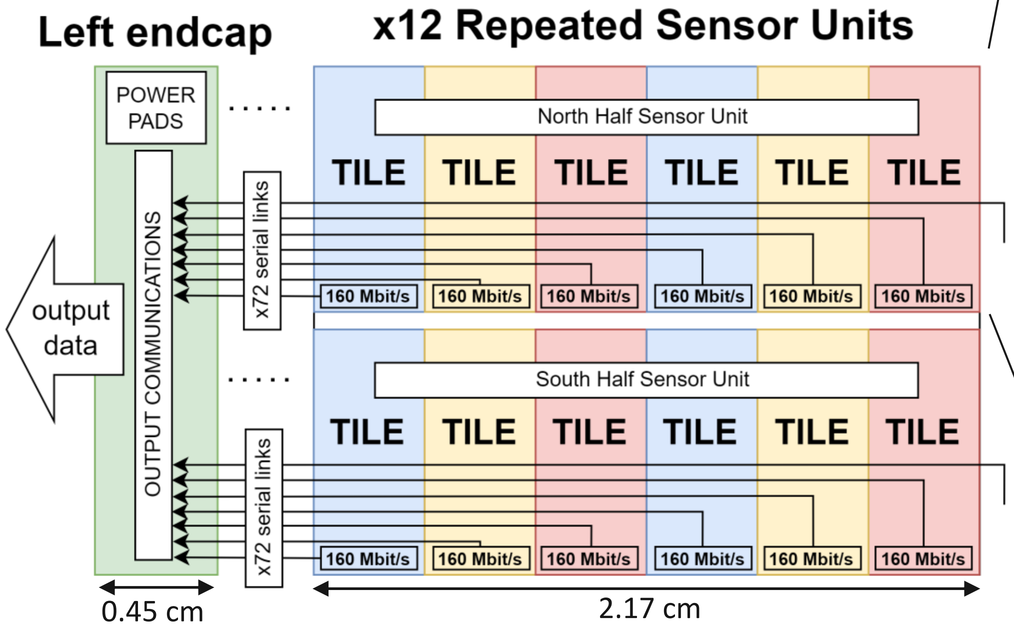
On-chip readout scheme

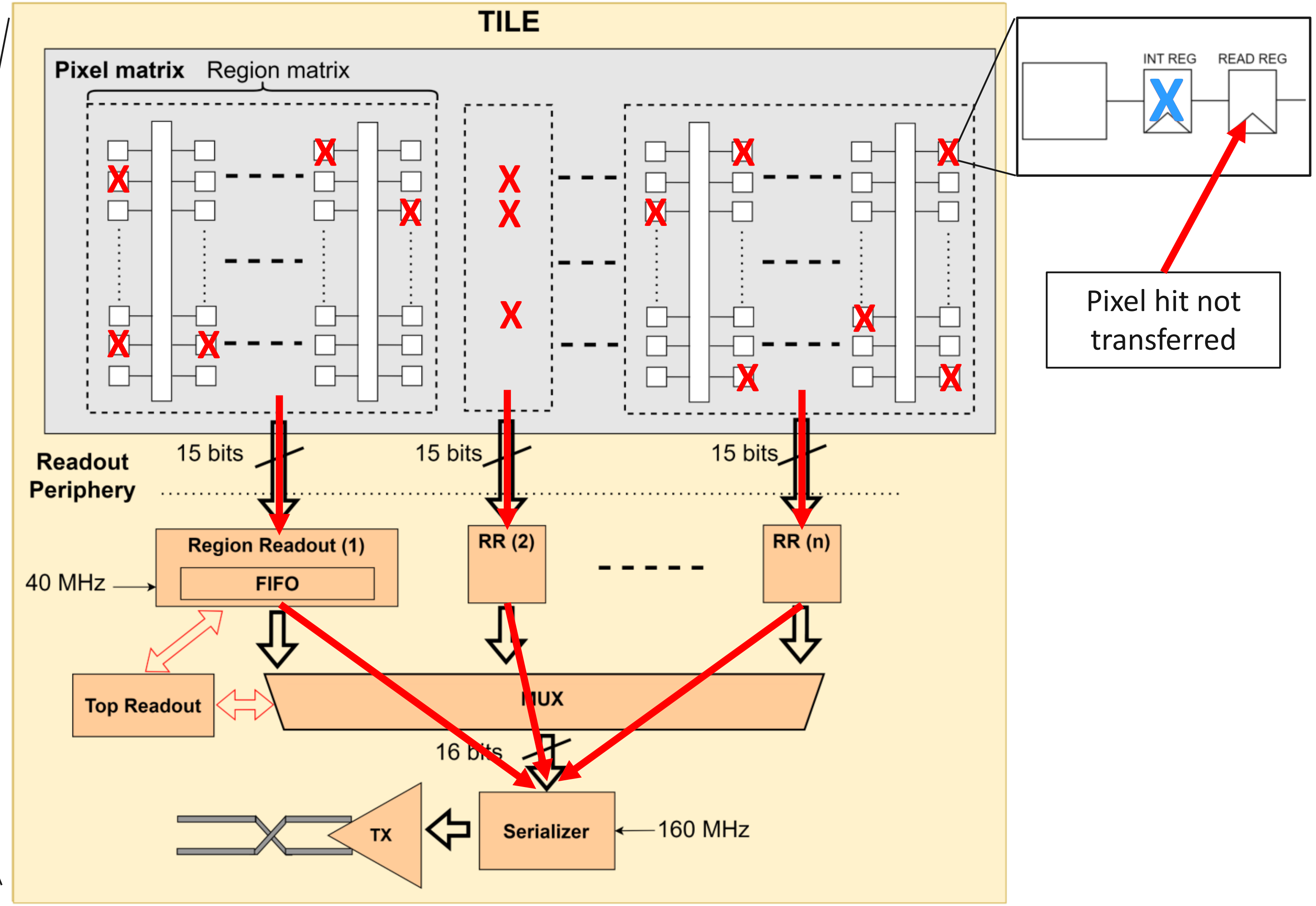
Continuous trigger-less solution

- Hits sent in time stamped packets (**frame packet**)
- **Frame packets must be shipped out completed**

Collision information may be lost depending on the number of detected hits







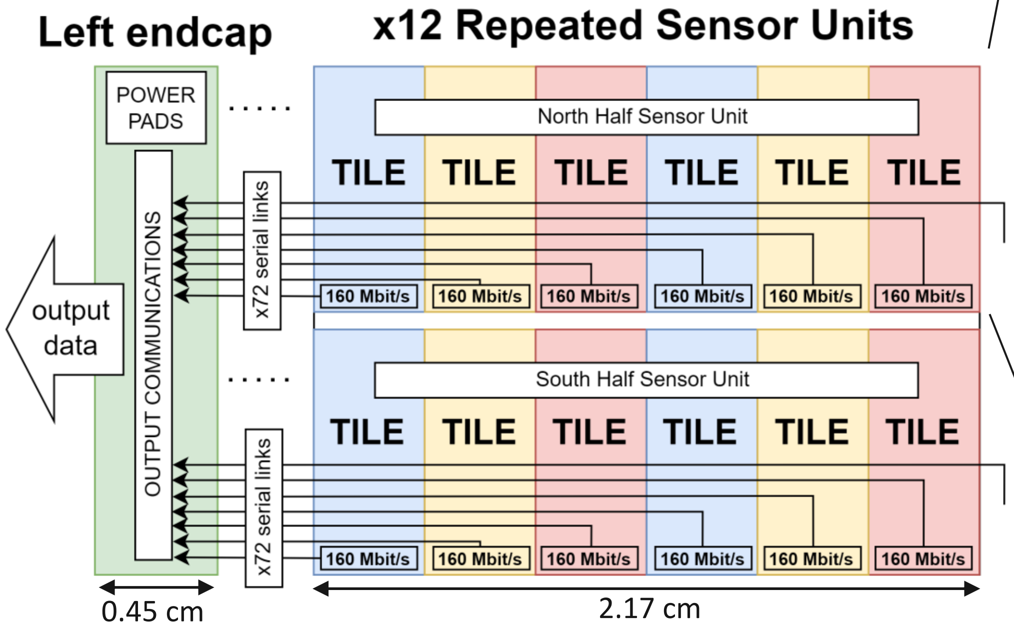
On-chip readout scheme

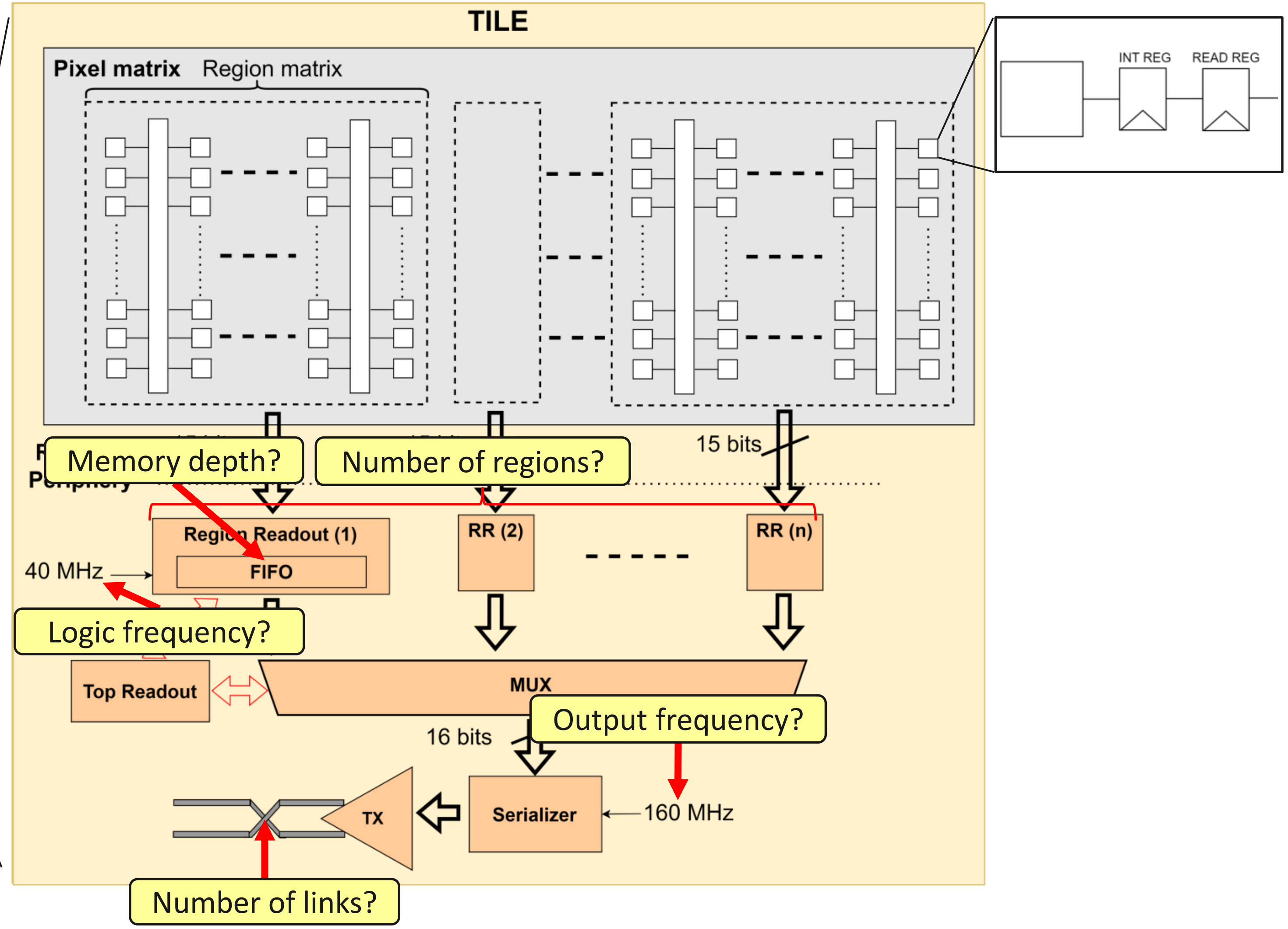
Continuous trigger-less solution

- Hits sent in time stamped packets (**frames**)
- **Packets must be shipped out completed**

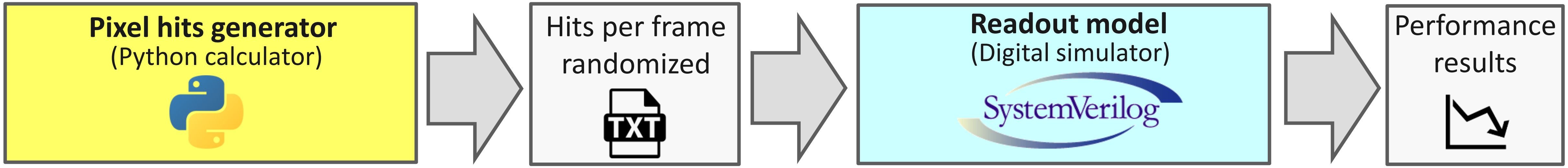
Readout model objective:

- **Define readout parameters**
- Balance **trade-offs** across
  - **Power consumption**
  - **Dead Area**
  - **Readout performance (fraction collisions dropped)**





Proposed readout model



Emulate conditions in ALICE experiment

- **Based on physics MC simulations**
- **Based on ALICE ITS2 data**

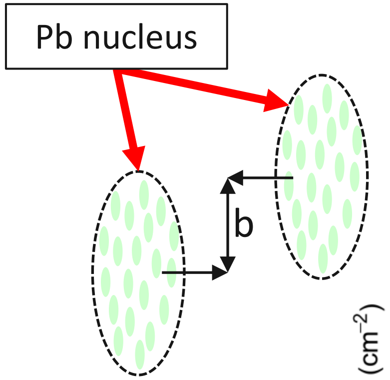
Emulate future RTL implementation

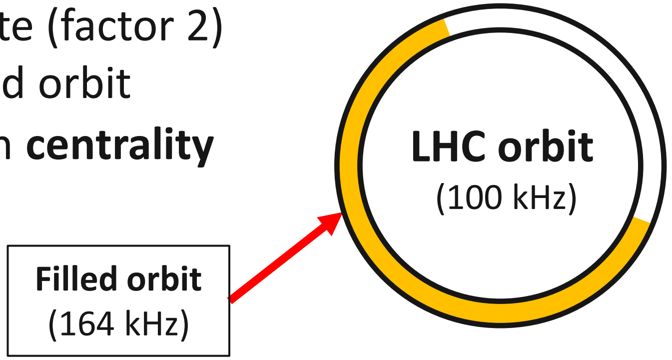
- **Clock accurate**
- **Fully parametrizable**

Pixel hits generator, sources of particles

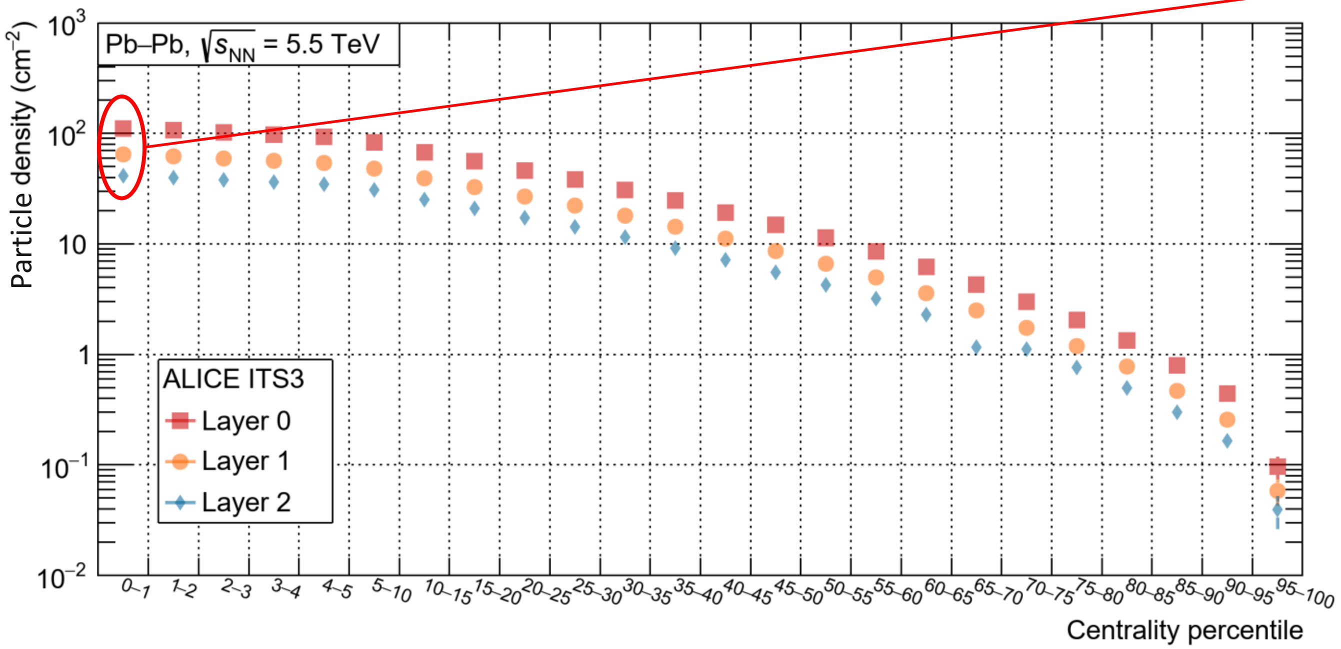
Pb-Pb collision

- **100 kHz Pb-Pb** average interaction rate (factor 2)
- **164 kHz Pb-Pb** interaction rate in filled orbit
- Particle densities depends on collision **centrality**

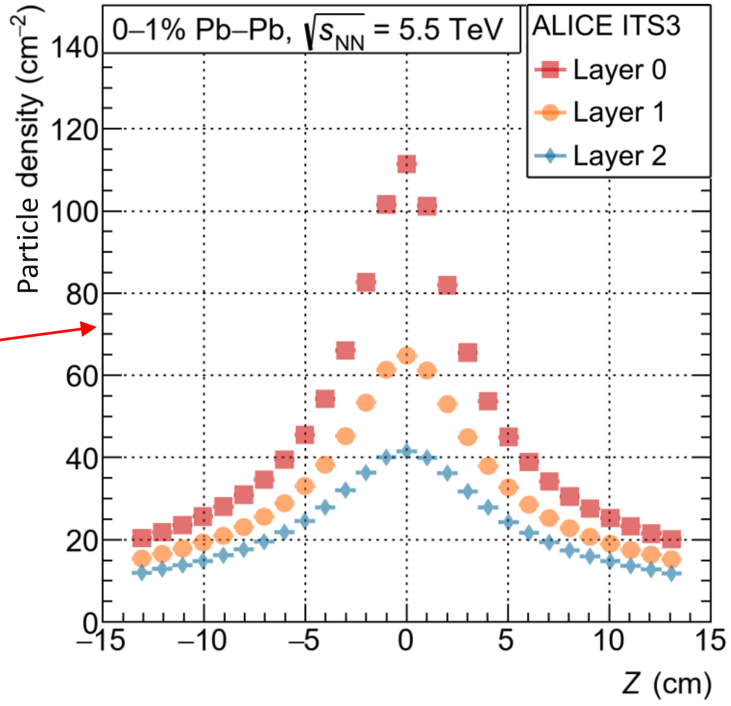




Particle density per collision by centrality percentile



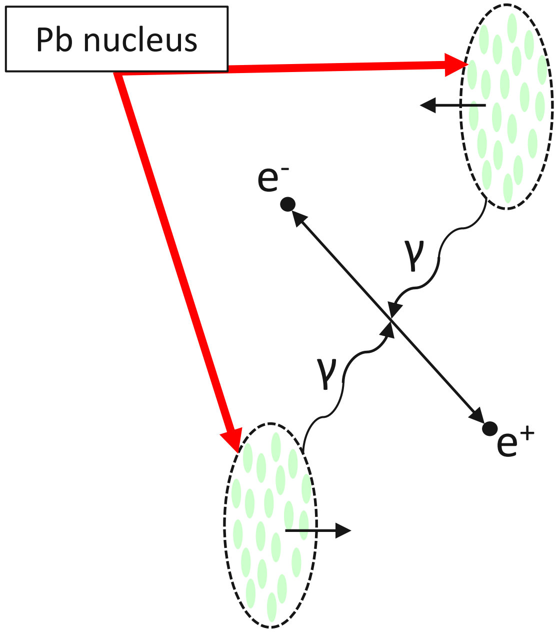
Particle density for a central collision in z=0 over z



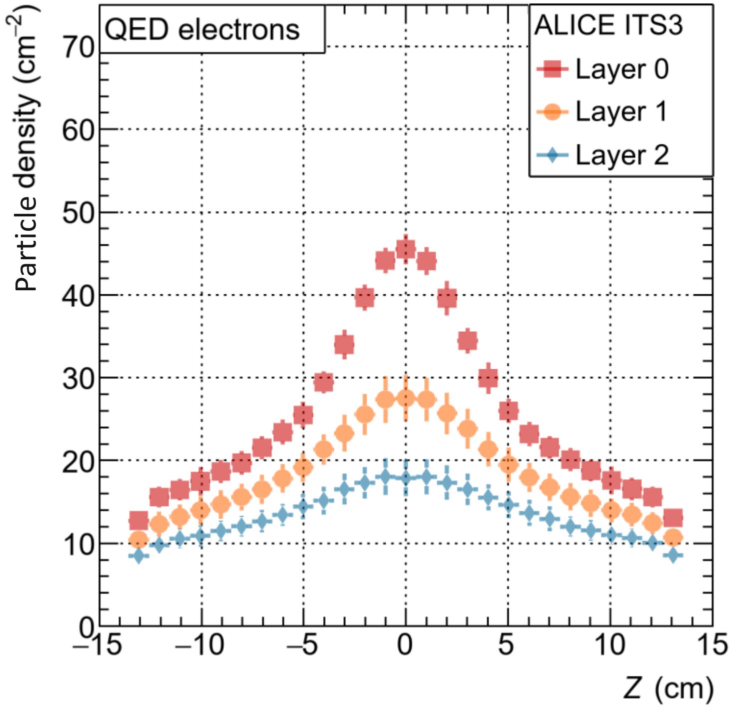
Pixel hits generator, sources of particles

QED (Quantum electro dynamics) electrons

- Generated by electromagnetic interaction between ions
- Photon emission recombine in electron-positron pair
- Electrons and positrons detected as background noise

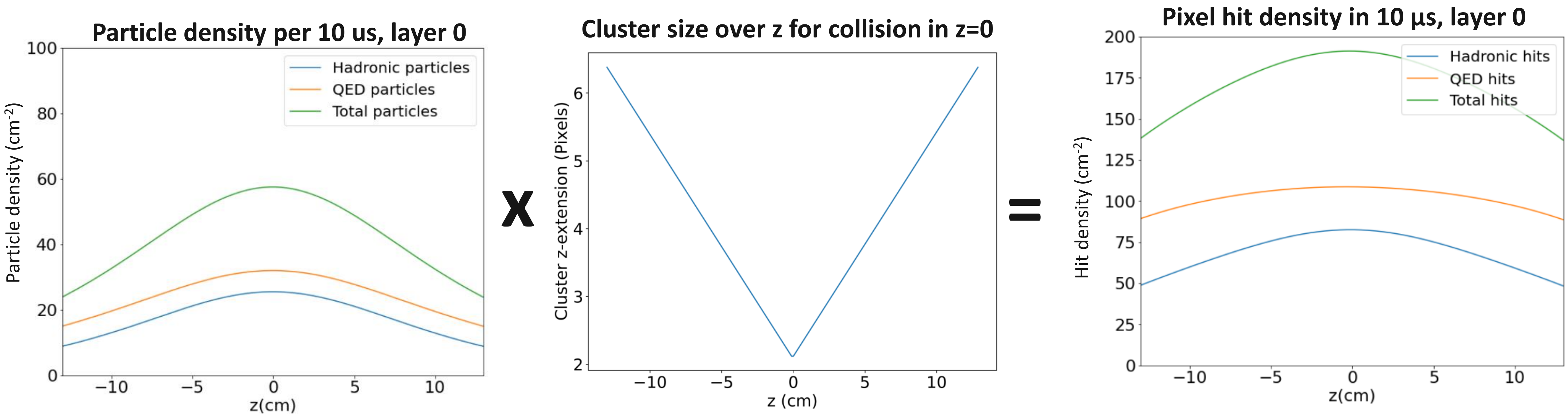


QED particle density in z=0 integrated in 10 µs over z



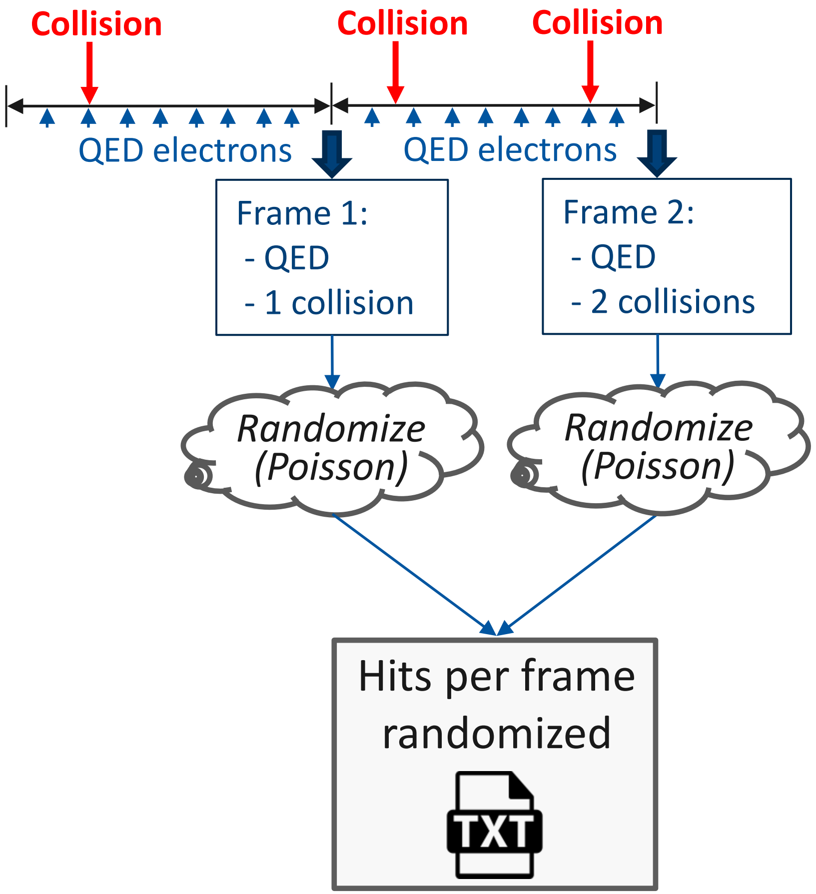
Pixel hit generator, hit densities

- **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/cm^2**
- Particle flux from QED in z=0, layer 0 of **3.55 MHz/cm^2**
- Occupancy in 2 μs period of **2×10^{-4}**



Pixel hit generator procedure

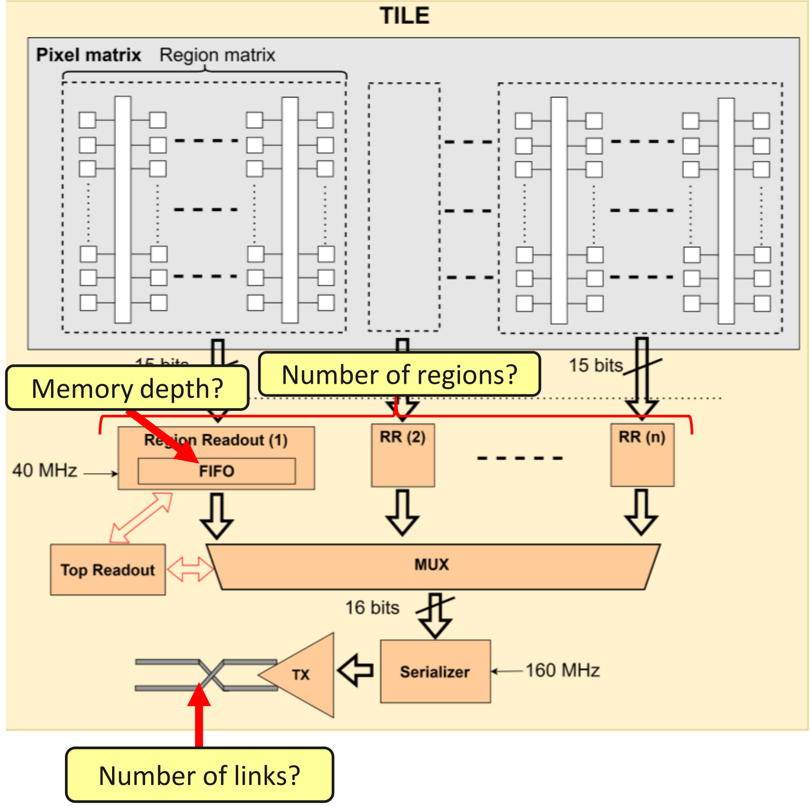
- **FOR_EACH** frame period
  - Determine number of pile-up collision in frame period (random, Poisson)
  - **FOR_EACH** pile-up collision
    - Determine centrality
    - Determine vertex (z) position (random, Gaussian)
    - **FOR_EACH** region
      - Determine cluster size based on z
      - Calculate particle count based on z (random, Poisson)
      - Multiply particle count with cluster to get the number of pixel hits
  - QED electrons
    - Determine vertex (z) position (random, Gaussian)
    - **FOR_EACH** region
      - Determine cluster size based on z
      - Calculate particle count based on z (random, Poisson)
      - Multiply particle count with cluster to get the number of pixel hits

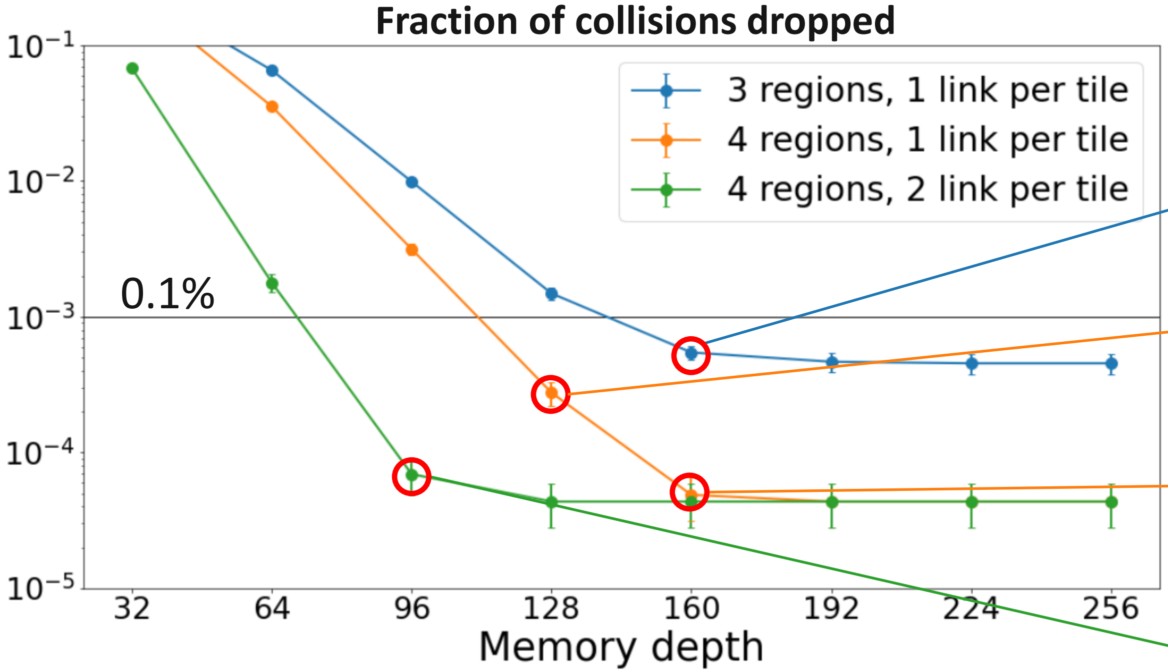


Results – Various regions and links

Parameters:

- 2 us frame period
- Link with left edge throughput 160 Mbit/s
- Results plotted for 1 Segment in Layer 0
- ITS3 requirement, 0.1% collisions dropped





Option 1

Lowest Area
Lowest power consumption

Option 2

2% more area than option 1
2% more power than option 1

Option 3

11% more area than option 1
6% more power than option 1

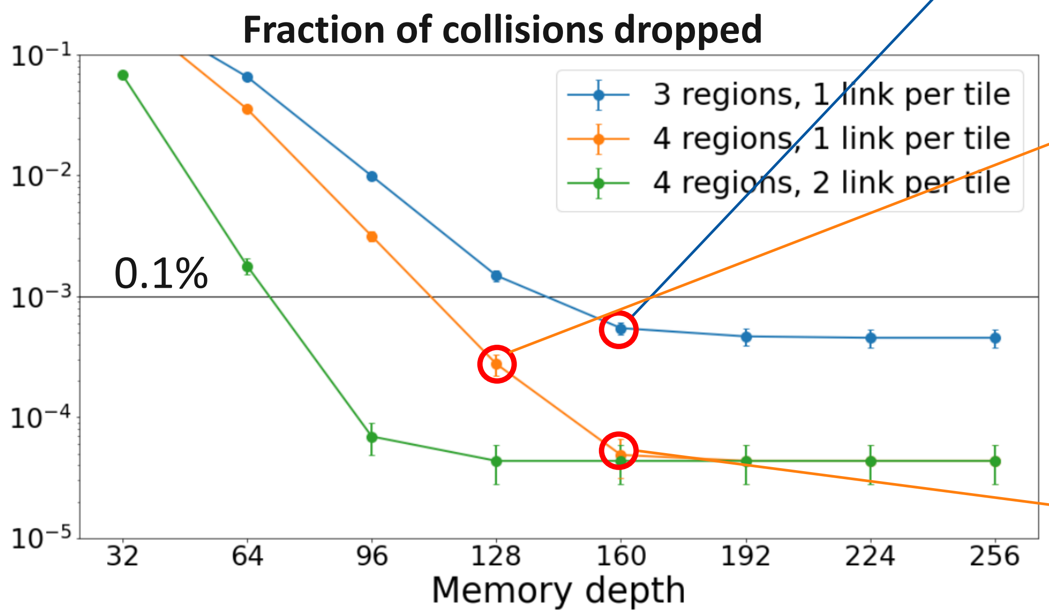
Option 4

34% more area than option 1
38% more power than option 1

Results – Cluster, interaction variations

Parameters:

- 2 us frame period
- 1 Link with left edge throughput 160 Mbit/s
- Results plotted for 1 Segment in Layer 0
- Different cluster sizes in z=0
- Different integration rates



Option 1

cluster size (z=0)	x0.5	x0.75	Base (164 kHz)	x1.25
2.6	0.073%	0.103%	1.613%	38.200%
2.1	0.004%	0.043%	0.057%	1.667%
1.6	0.000%	0.000%	0.002%	0.004%

Interaction rates

Option 2

cluster size (z=0)	x0.5	x0.75	Base (164 kHz)	x1.25
2.6	0.004%	0.098%	4.207%	64.100%
2.1	0.000%	0.003%	0.028%	8.535%
1.6	0.000%	0.000%	0.000%	0.002%

Interaction rates

SELECTED

Option 3

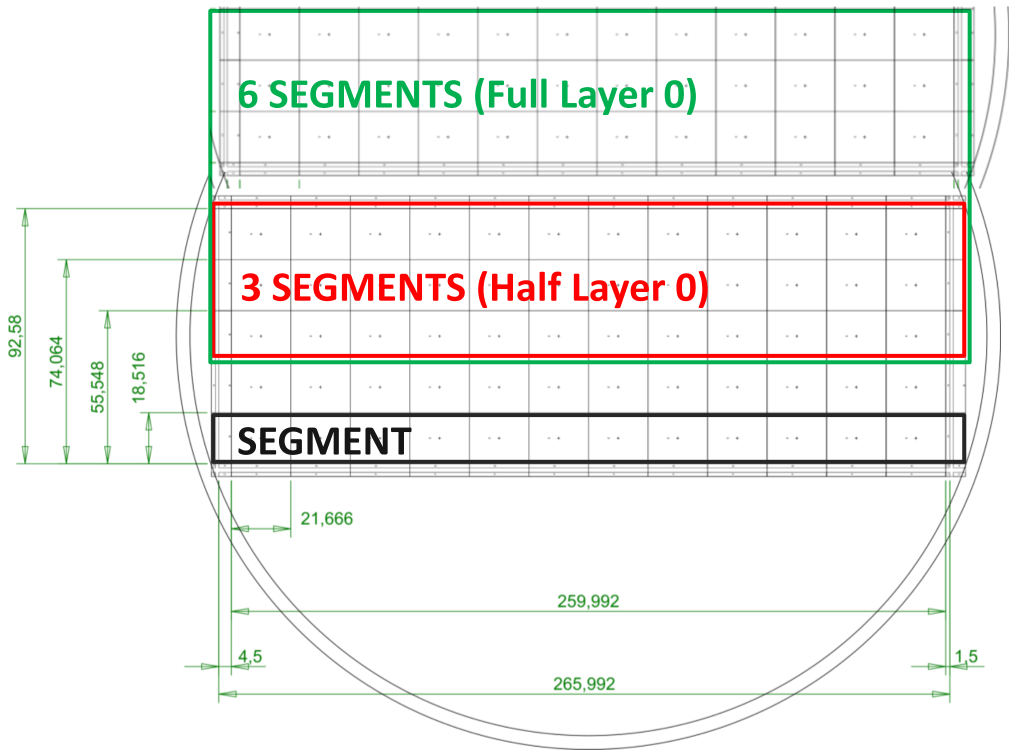
cluster size (z=0)	x0.5	x0.75	Base (164 kHz)	x1.25
2.6	0.000%	0.023%	1.937%	64.100%
2.1	0.000%	0.003%	0.005%	5.167%
1.6	0.000%	0.000%	0.000%	0.000%

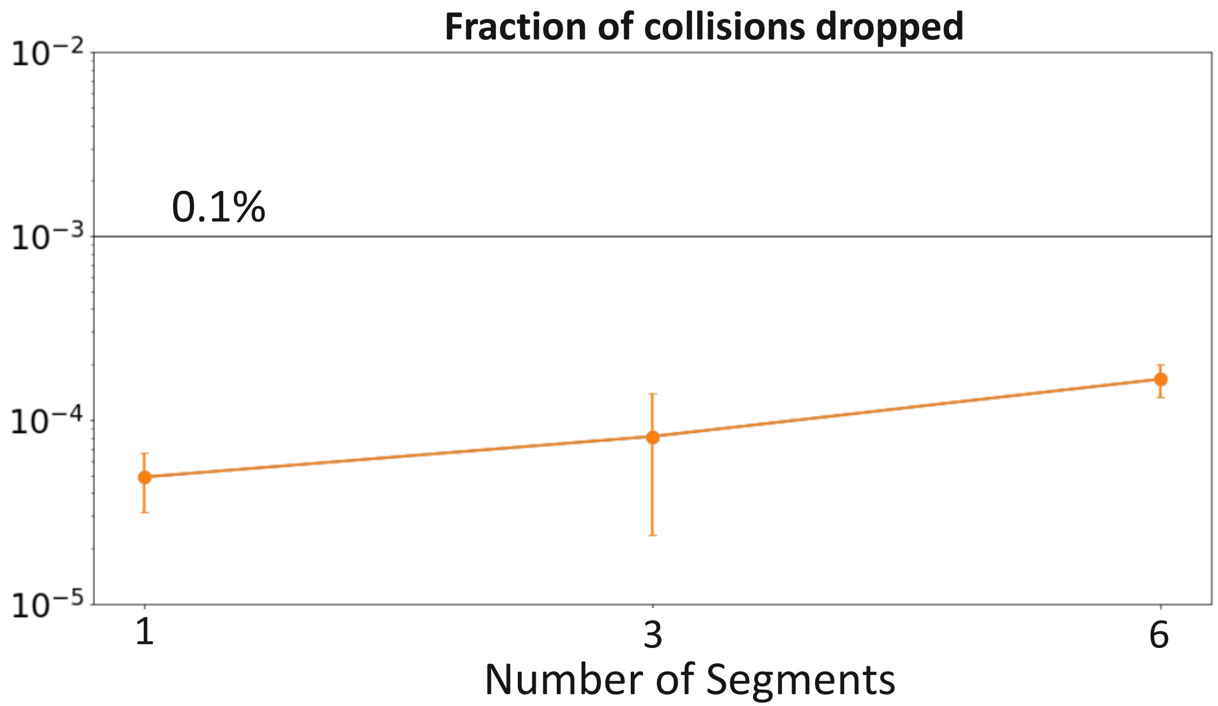
Interaction rates

Results – Number of segments

Parameters:

- 2 us frame period
- 1 Link with left edge throughput 160 Mbit/s
- Results plotted for **different chip dimensions**
- 4 regions, FIFO depth 160





Summary

Readout scheme:

- Input based in physics MC and ITS2 data
- Achieve **trade-off between power consumption, area and readout performance**

Configuration extracted from model:

- 1 link per tile with left endcap of **160 Mbit/s**
- 4 FIFO memories per tile
- Each FIFO memory of **depth 160** words

Performance:

- **0.005% of collisions dropped per segment**, **0.02% for Full Layer 0**
- Achieve **optimal trade-off** with **power consumption and area**

END

More about ITS3 @ TWEPP:

mar. 03/10

09:00

The Monolithic Stitched Sensor (MOSS) Prototype for the ALICE ITS3 and First Test Results *Gianluca Aglieri Rinella*
Mistral Room 09:00 - 09:20

Validation of the 65 nm TPSCo CMOS imaging technology for the ALICE ITS3 *Chiara Ferrero*
Mistral Room 09:20 - 09:40

Tuesday posters session

99. Prototype of a 10.24Gbps Data Serializer and Wireline Transmitter for the readout of the ALICE ITS3 detector.
Arseniy Vitkovskiy (Nikhef National inst... , Dr. Arseniy Vitkovskiy (Nikhef (the Dutch N..., Sr. Marcel Rossewij (Utrecht University), Vladimir Gromov (Nikhef National inst...

jue. 05/10

ALICE ITS3: a bent stitched MAPS-based vertex detector *Ola Slettevoll Groettvik*
Mistral Room 11:20 - 11:40

Prototype measurement results in a 65nm technology and TCAD simulations towards more radiation tolerant monolithi...
Corentin Lemoine

Thursday posters session

89. Development of the data transmission architecture of the stitched sensor prototype towards the ALICE ITS3 upgrade
Piotr Andrzej Dorosz (CERN)
5/10/23, 17:40

Backup

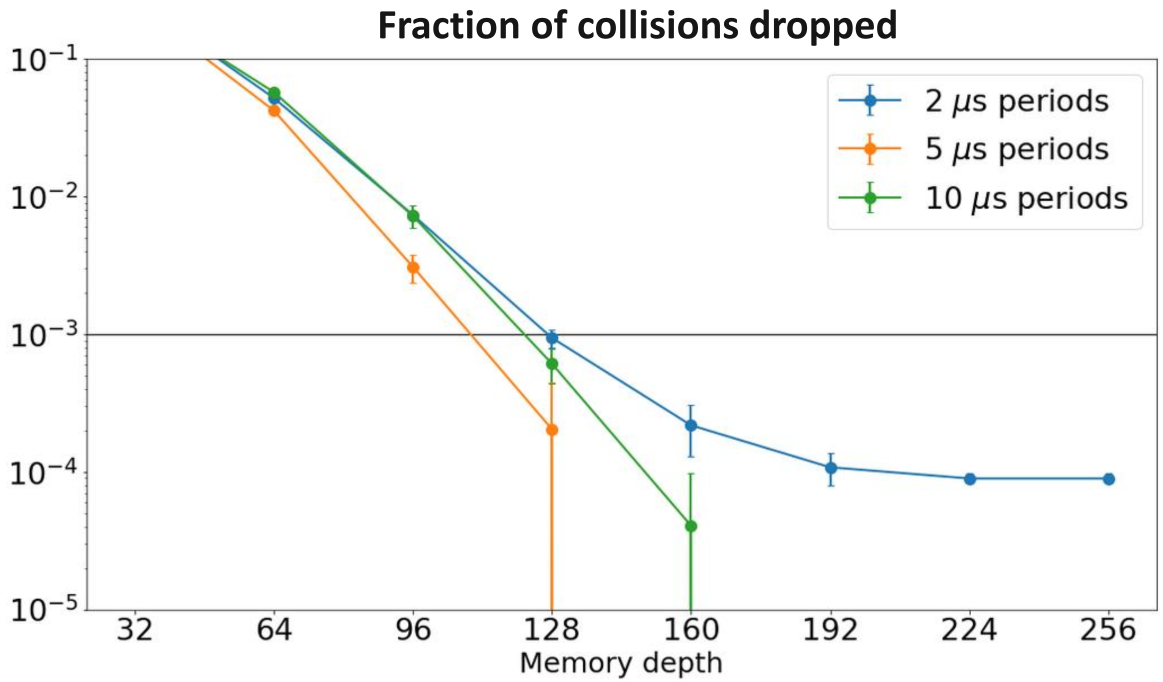
Variations among integration periods

Parameters:

- Various integration period
- Link with left edge throughput 160 Mbit/s
- Readout from matrix at 40 MHz
- Results plotted for 1 Segment
- 1 link, 4 regions

Observations:

- **Higher integration period** allocates more time for reading hits from matrix into memories
- **Shorter integration period** gives better time resolution and improves event reconstruction



Reduce speed from matrix to FIFOs

Parameters:

- Various integration period
- Link with left edge throughput 160 Mbit/s
- Readout from matrix at **20 MHz**
- Results plotted for 1 Segment
- 1 link, 4 regions

Observations:

- **Lower matrix to memory speed** reduces the number of pixel hits that can be read during the integration period
- **Performance of long integration periods** is not affected