Expected performance of the ALPIDE pixel layers in ALICE FoCal

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What is ALPIDE?

ALPIDE (ALice PIxel DEtector) is a **MAPS (Monolithic Active Pixel Sensor)** which was developed for the ITS upgrade and has been in use since the start of Run 3.

ALPIDE offers **high spatial resolution**, and **fast readout capabilities**, making it ideal for tracking particles in high-multiplicity environments.

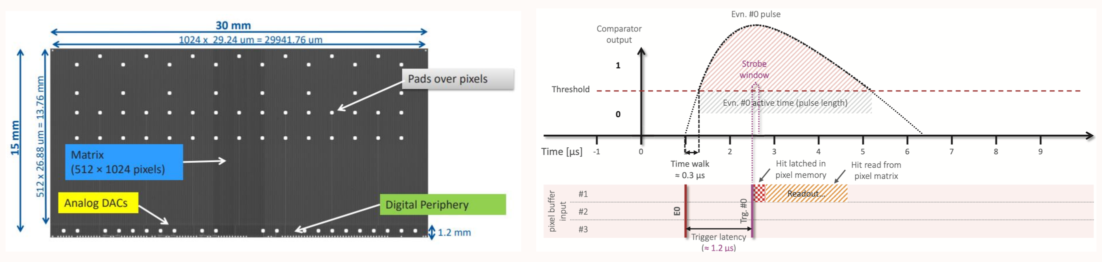


Fig 1: (left) ALPIDE layout with key components. (right) Trigger signal must reach ALPIDE while the front-end pulse remains above threshold.[1]

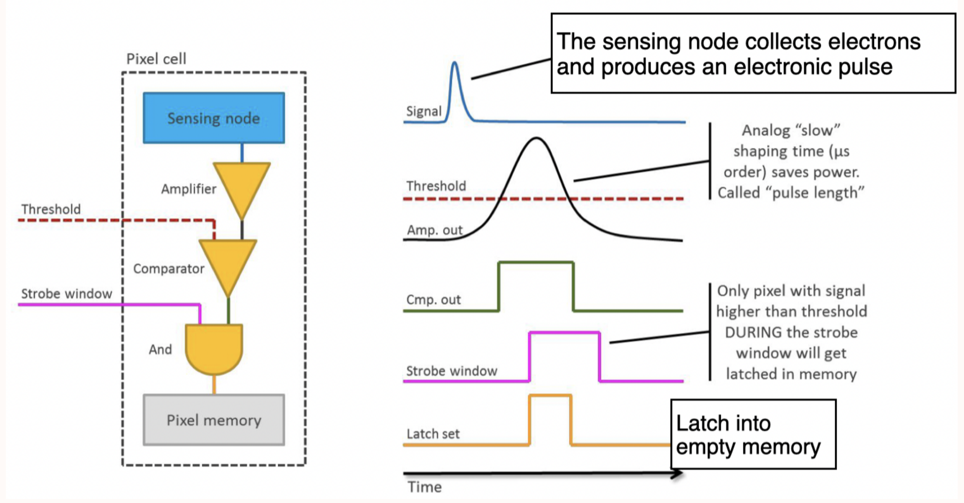


Fig 2: Signal processing in an ALPIDE pixel. Only signals exceeding the threshold within the strobe window are latched into pixel memory.[2]

The FoCal-E pixel layer simulation models the digital response of 264 pixel strings with 15 ALPIDE chips each using **SystemC**. A **self-triggered mode** from the pad layer enables the implementation of a **regional trigger**.

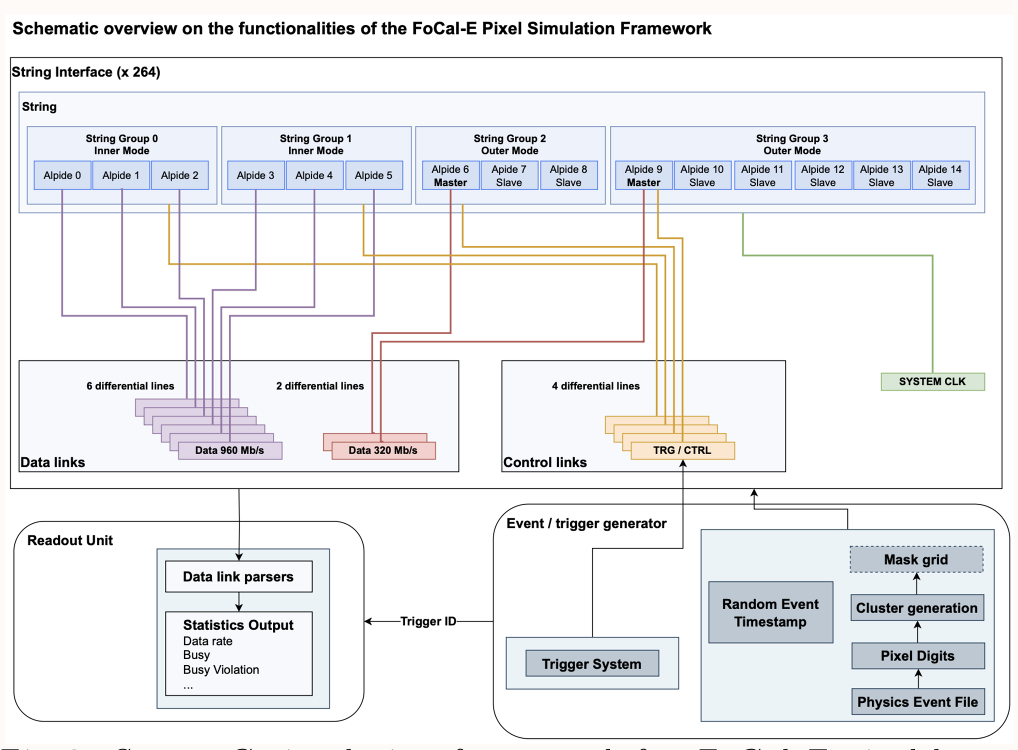
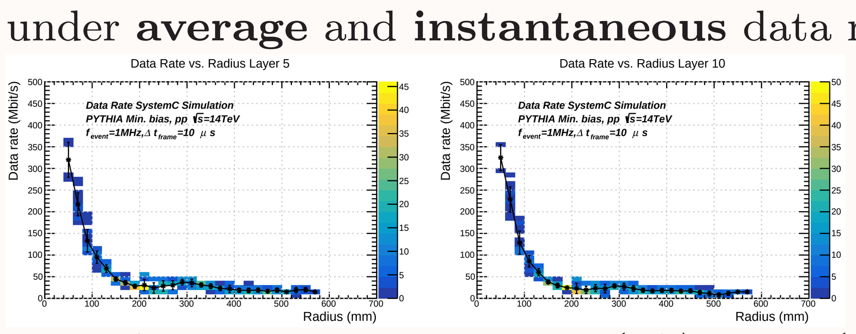


Fig 3: SystemC simulation framework for FoCal-E pixel layers including trigger generation and readout handling.

Data Rate

This SystemC simulation evaluates ALPIDE readout under **average** and **instantaneous** data rates.



	Link Bandwidth
IB Links	960 Mbps
OB Links	320 Mbps

Fig 8: Average data rate in Layer 5 (left) and 10 (right).

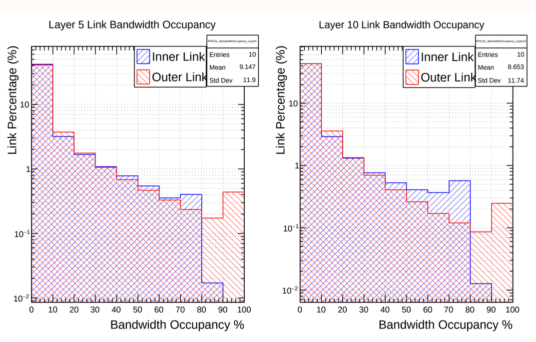


Fig 9: Instantaneous bandwidth occupancy distribution (Layer 5 left, Layer 10 right).

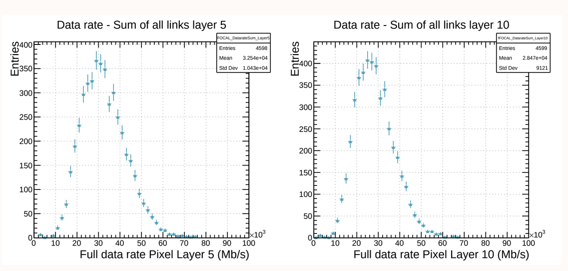


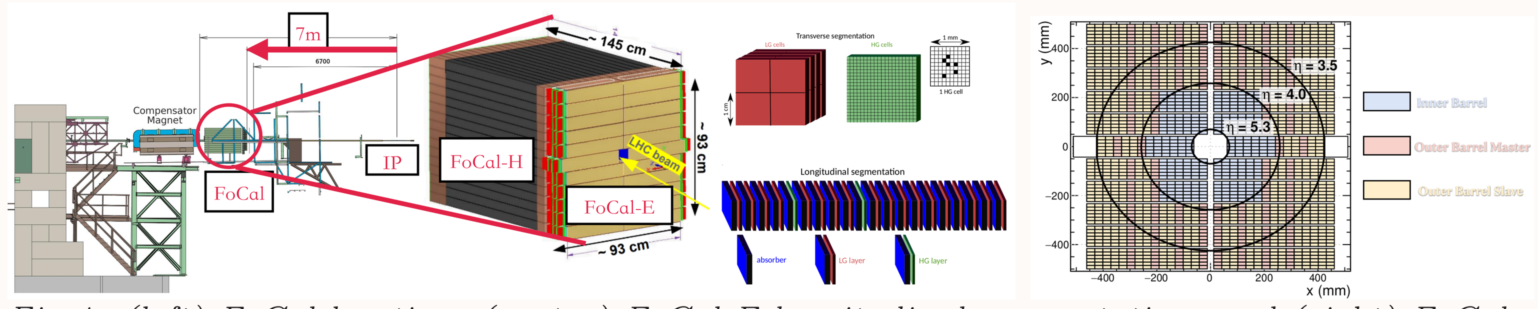
Fig 10: The total estimated data rate amounts to 35 ±11Gbps for layer 5 (left) and 30 ±10Gbps for layer 10 (right)

- Average Rate: At a 1 MHz event rate, the IB and OB links have ample bandwidth.
- Instantaneous Rate: IB links still maintain at least a 10% bandwidth margin, while OB links occasionally reach saturation.

FoCal (Forward Calorimeter)

FoCal is an upgrade to the ALICE experiment aimed at improving measurements of direct photons and neutral mesons in the forward rapidity region.

- **FoCal-H:** Metal-scintillator hadronic calorimeter.
- **FoCal-E:** Highly granular silicon-tungsten (Si+W) electromagnetic calorimeter.



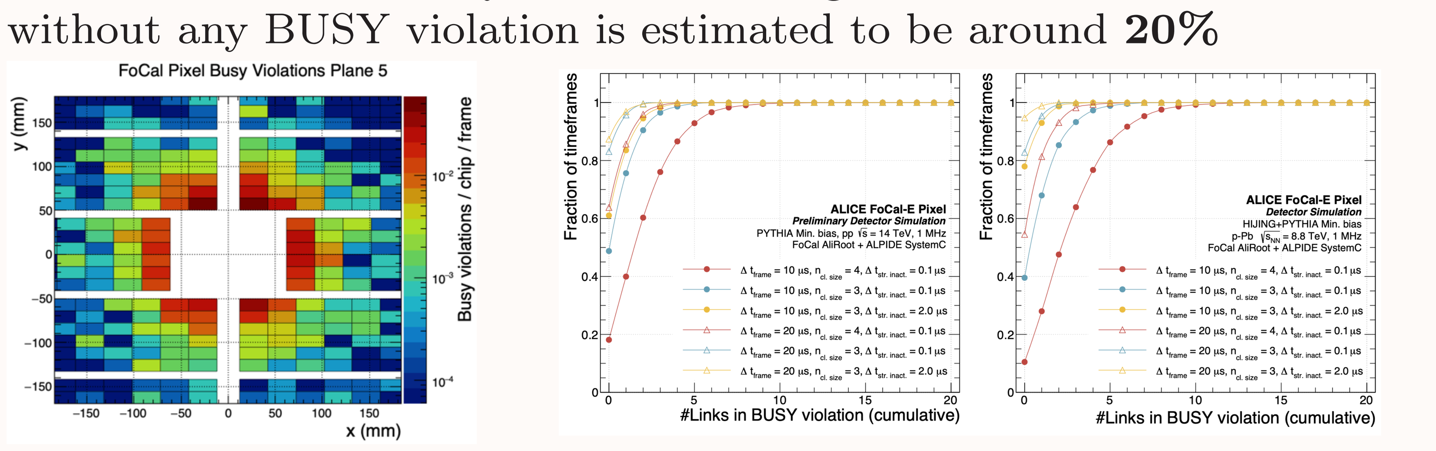
- Isolation from hadronic activity
- Pseudo-rapidity range of $3.2 < \eta < 5.8$
- Energy resolution: $\leq 5\%$
- Shower spatial resolution: $d < 5\,\mathrm{mm}$

Fig 4: (left) FoCal location, (center) FoCal-E longitudinal segmentation, and (right) FoCal pixel layer simulation.

Precise measurement of direct photons and high-p_T neutral pions at forward rapidity is essential for exploring QCD dynamics. Enhancing the spatial resolution of the FoCal-E pixel layers and reducing ALPIDE occupancy are crucial for improving detection efficiency and data quality.

Expected Performance in SystemC Simulation

BUSY violation in layer 5 and 10 ranges from **5–7%** for innermost chips in pp collisions. The fraction of frames without any BUSY violation is estimated to be around **20%**



- **Back bias** reduces pixel cluster size (4 → 3), lowering occupancy to **3/4**.
- Extending **time-frame** ($\Delta t_{\mathrm{frame}}$) reduces duplicate event latching but increases pileup, limited to **20 µs**.
- Increasing **strobe-inactive time** up to **2 µs** improves readout efficiency.

Fig 5: (Left) BUSY violation fraction per chip near the beam pipe in pp collisions. (Right) Cumulative probability of BUSY violations across multiple links in pp and p–Pb collisions.[1]

Beam Test Results

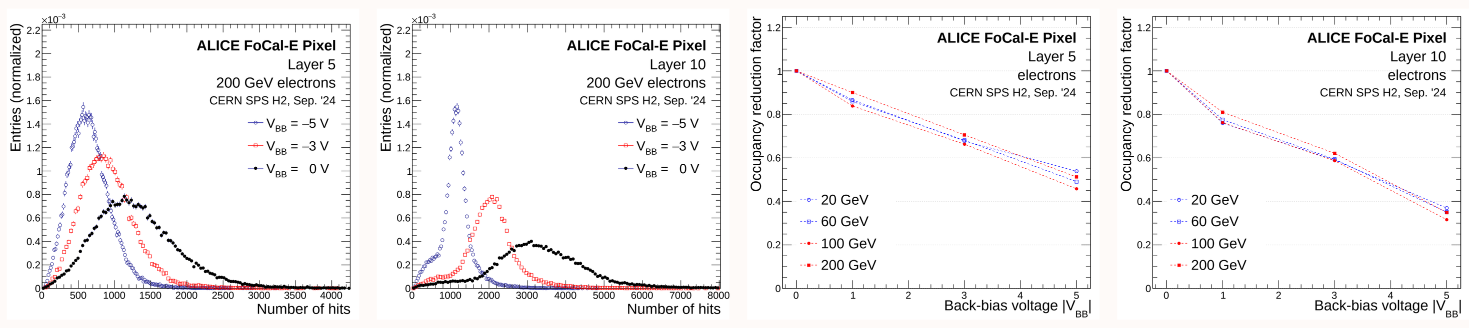


Fig 6: (From left to right) Normalized hits in Layer 5 and 10 vs. $|V_{BB}|$, showing reduced hit counts at higher back-bias voltages; occupancy reduction factor vs. $|V_{BB}|$, decreasing with energy (20–200 GeV). Results from ALICE FoCal-E beam tests at CERN SPS H2.

Applying a **back-bias voltage** $|V_{BB}|$ within the range of 0–5V reduces the recorded particle hit count, thereby helping to decrease pixel layer occupancy.

Exploring Optimization Options

To mitigate **BUSY Violations** and improve **ALPIDE efficiency**, two optimization strategies are considered:

- **Grid Masking**: Reduces pixel occupancy in high-density regions by selectively disabling pixels in a periodic pattern ($d_{\mathrm{grid\ mask}}$). This decreases the active pixel fraction to **56%, 44%, or 25%**, though at the cost of losing some shower microstructure details.

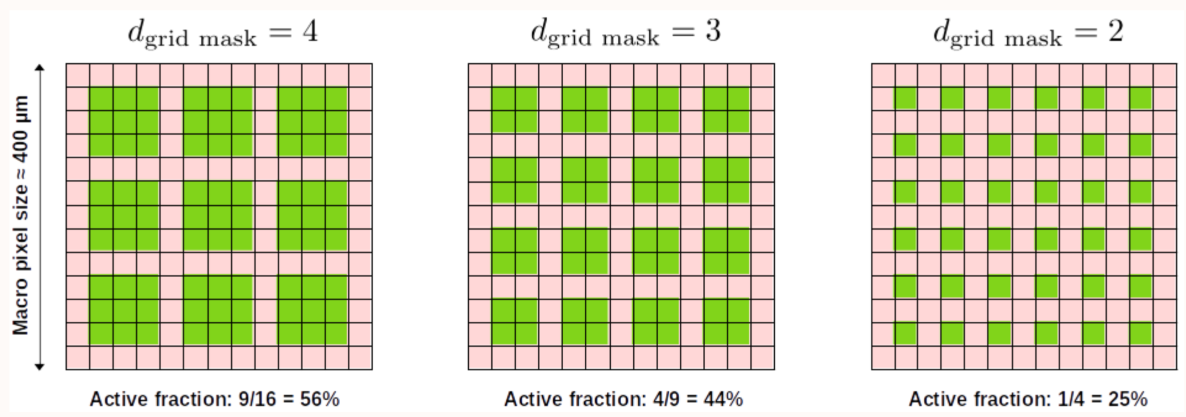


*Fig 11: Simulated **grid masks** for the innermost chips, reducing occupancy by selectively disabling pixels.*[1]

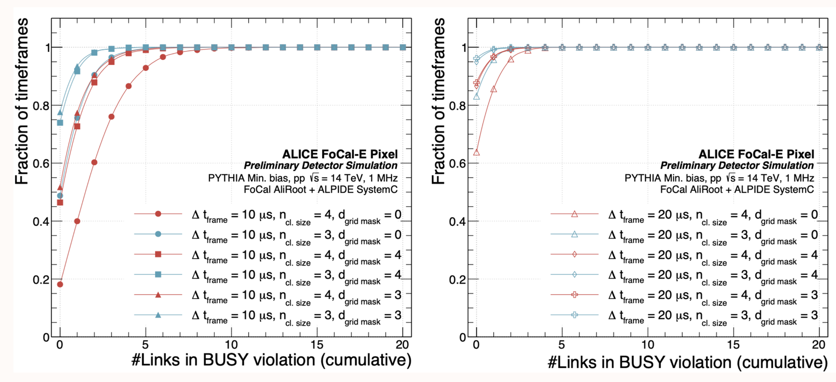


*Fig 12: **BUSY Violation** reduction with different grid masking in **pp collisions**.*

- **Regional Trigger**: Restricts ALPIDE activation to high-energy deposition events in the innermost **FoCal-E** region, effectively reducing occupancy and lowering **BUSY Violation** rates.

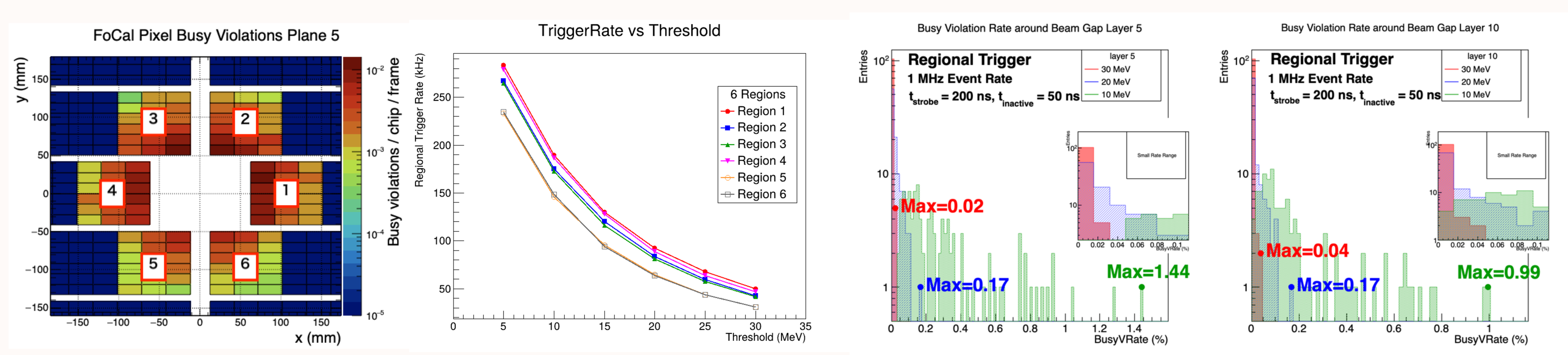


*Fig 13: (Left) **Regional trigger** regions near the beam pipe gap, based on **SystemC** simulation. (Center) Trigger rate vs. energy threshold. (Right) **BUSY Violation** rate at different thresholds.*

Conclusion

FoCal-E adopts ALPIDE-based pixel layers, demonstrating robust performance under high-multiplicity conditions. Data-rate analyses indicate that Inner Barrel links retain at least a 10% bandwidth margin under peak loads, while Outer Barrel links occasionally approach saturation. Beam test and SystemC simulation results confirm that back-bias effectively suppresses pixel occupancy, thereby reducing dead-time frames. To further alleviate potential bottlenecks, grid masking and a regional trigger are under consideration. Overall, these findings validate the feasibility of precise measurements of direct photons and neutral mesons in the forward region.

[1] "Technical Design Report of the ALICE Forward Calorimeter (FoCal)," CERN, Geneva, Tech. Rep., 2024. [Online]. Available: https://cds.cern.ch/record/2890281

[2] P. Giubilato, "Readout electronic – wp10," Internal communication, 2016.