# IO Information-Based Component Relevance Estimation in a Mixed-Signal ASIC Analog Circuit

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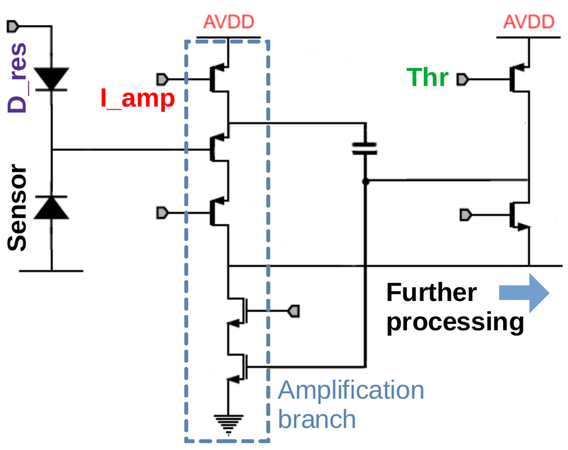
## Introduction & Research Goals

Silicon pixel sensors provide particles' temporal and spatial resolution in high-energy physics experiments. Their analog front-end circuits amplify and discriminate signals from particle interactions in silicon and require parametrization via Digital-to-Analog Converters (DACs), whose interplay remains largely unknown. A **data-driven** approach using Shapley values [2] is proposed,**to quantify the influence of DACs on sensor performance**. By comparing data subsets corresponding to different operational states, it is possible to gain insights into the front-end's black-box behavior. As DACs often correspond to specific **circuit components**, this method can also be used to assess their relevance and impact on sensor performance.

## Use case - application onto MAPS front-end



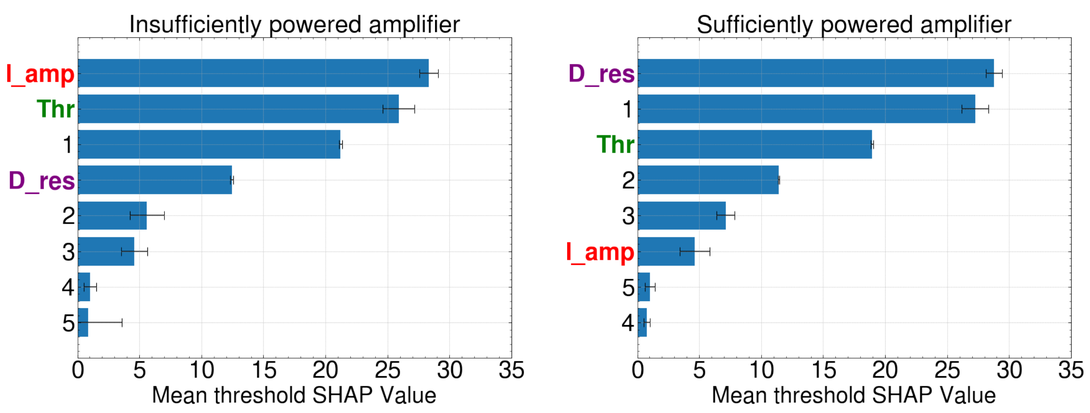

The circuit shown is part of a MALTA2 Monolithic Active Pixel Sensors [1] (MAPS) front-end used as a case study. Three exemplary parameters are highlighted, that influence the circuit's behavior and sensor performance:

- **Diode reset** (**D_res**)
- **Amplifier current** (**I_amp**)
- **Threshold** (**Thr**)

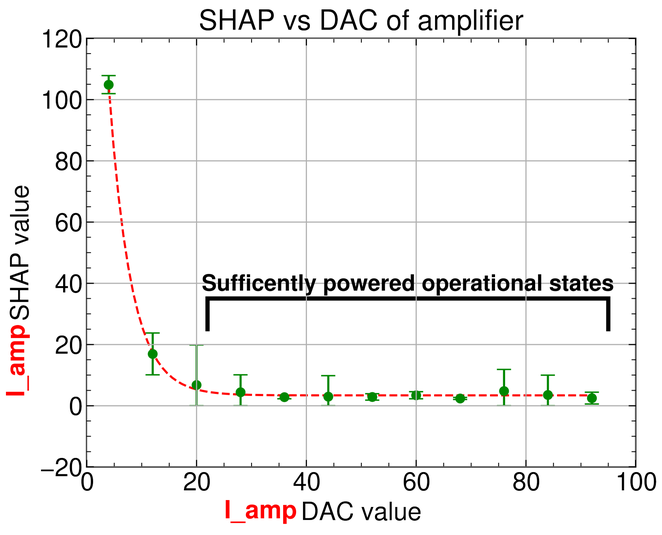
## Results - application onto amplifier current

The bar plots show the normalized SHAP values of a **sufficiently** and **insufficiently** powered amplifier as an example:

- In an underpowered state, the power DAC dominates.
- Diode reset matters less with lower amplification (current).
- With sufficient power, the amplification current is less relevant.



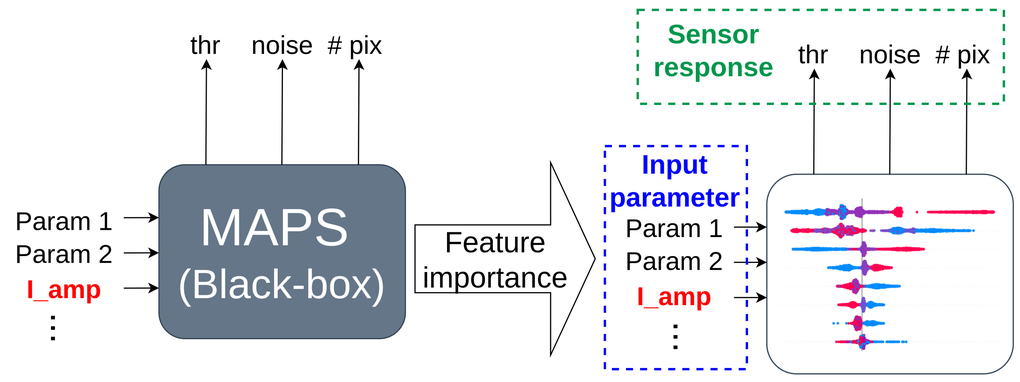

Plotting the SHAP values over the I_amp DAC values allows for the **evaluation** of sufficiently powered **operational states**:




This enables the assessment of **parameter and component importance** and the identification of stable viable states in the front-end parameter space. The resulting information can be used as a search space reduction and **bias**, aiding operators or automated methods in **selecting optimal parameters** for sensor performance.

## Method - data driven relevance estimation

The goal of the method is to provide a **data-driven approach to evaluate the importance of the parameters**, as well as visualize the **relationships between these and the sensor performance**.




The approach is based on SHAP (SHapley Additive Explanations)[3], a concept from interpreted machine learning, based on Shapley values:

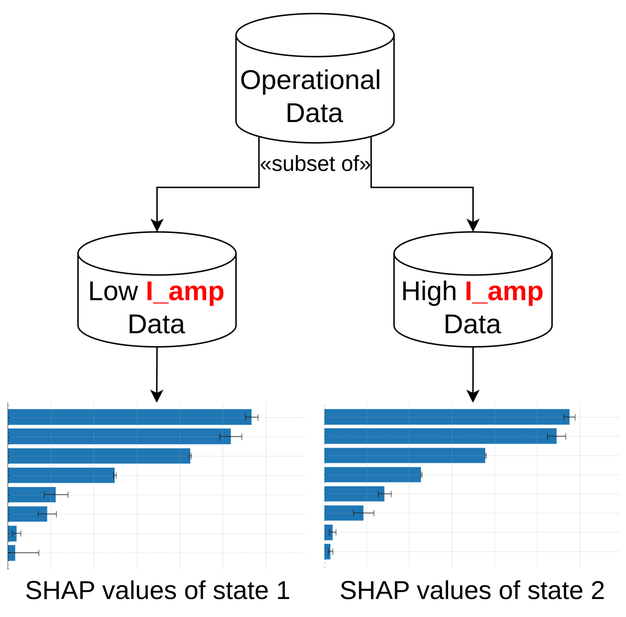
Shapley values are a game-theoretic method to fairly distribute a total contribution among features based on their marginal contributions. The value $\omega_i$ for feature $i$ is:

$$\omega_i = \sum_{S \subseteq F \setminus \{i\}} \frac{|F|!(|F| - |S| - 1)!}{|F|!} \left[ f(x_{S \cup \{i\}}) - f(x_S) \right]$$

where $F$ is the set of all features and $S \subseteq F$. Using the expected function output, **Shapley values can be approximated**, and **missing data and noise** handled by conditioning on available features:

$$f(x) \approx E[f(x) \mid x] \approx E_{x_{\overline{S}}}[f(x)]$$

resulting in SHAP values.




By partitioning the measured operational data from the MAPS into distinct operational states (e.g., current load conditions through the amplifier), it becomes possible to compute **the importance of parameters within each specific state**. This approach enables the rapid assessment of parameter importance across a range of operational conditions.

## References

[1] MALTA: an asynchronous readout CMOS monolithic pixel detector for the ATLAS High-Luminosity upgrade
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