# Faithful Pulse Shape Analysis by using Feature Importance Supervision

**Katharina Kilgus[1], Aobo Li[2], Julieta Gruszko[3], Josef Jochum[1]** on behalf of the **LEGEND collaboration**
*Eberhard Karls Universität Tübingen[1], University of California San Diego[2], University of North Carolina at Chapel Hill[3]*

290 members

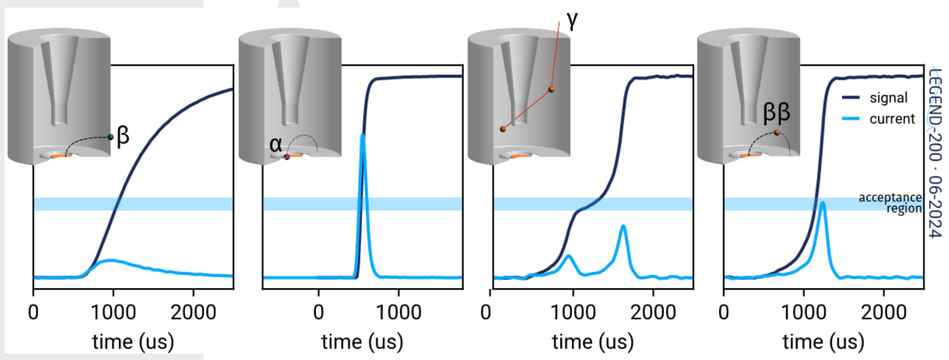
55 institutions

Full list & more:

## 1. Germanium Detectors

The LEGEND experiment uses High purity Germanium Detectors to search for the neutrinoless double beta decay of 76Ge. Critical for this search is a high sensitivity and a low background.
Part of this background supression is the Pulse Shape Analysis (PSA). For the Inverted Coaxial Point Contact Detectors (ICPCs), a high performing PSA is possible due to the high field gradient inside the detector.

The traditional Pulse Shape Analysis in the ICPCs is called A/E, using the amplitude of the current pulse A and energy E.



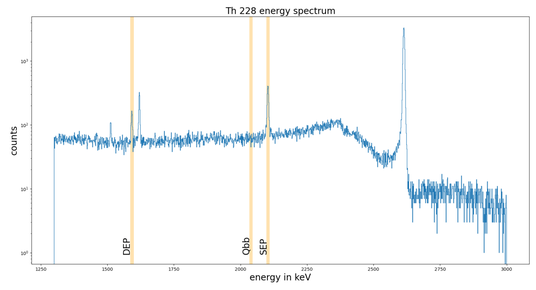

Graphic from Luigi Pertoldi, George Marshall

Different interaction positions inside the detector (and therefore different types of radiation) lead to different types of pulse shapes.

Focus of the following work is the discrimination between single site events (SSE, signal like) and multi site events (MSE, gamma bkg)

## 2. Training possibilities & challenges

The analysis is done by using a Th-228 measurement from the HADES characterization campaign of LEGEND.




For training, the double escape peak (DEP) is used as signal-like and the single escape peak (SEP) as background (both marked in green)

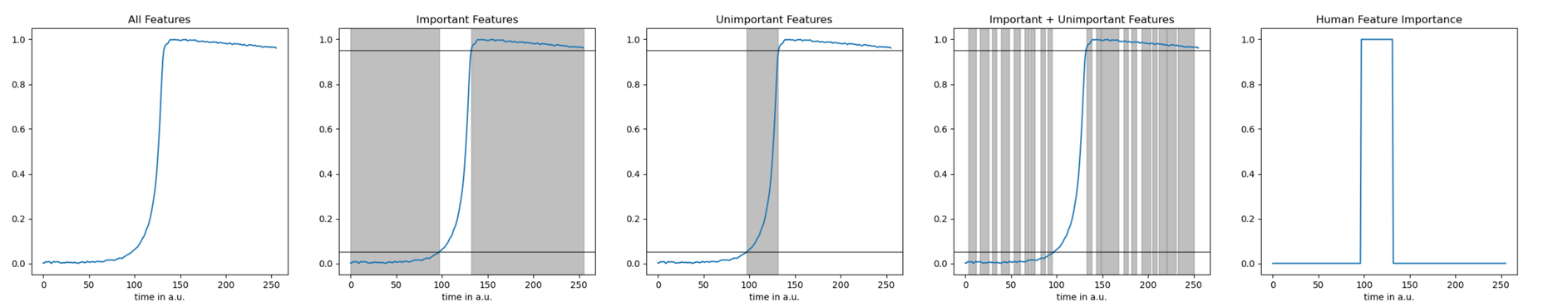
**Challenge:** Getting an energy independent model, even with training samples from different energies. The energy is proportional to the height of the waveform, so they are normalized.

## 3. Feature Importance Supervision (FIS)

**Main idea of FIS:**
Using human knowledge to lead the model taking right decisions

**Physical knowledge:**
Energy information hidden in the noise of baseline and tail
- This is due to the fact, that the noise gets energy dependent during waveform normalization.

**How to deal with it:**
Combine different augmentations of input and train for the best model combining different expectations for these augmentations.
The underlying model can be every Neural Network combined with some kind of explanation metric. The following analysis is done by using a Recurrent Neural Network + attention score(RNN)




Train to give **Accurate Output**

Train to give **Accurate Output**

Train to give **Uncertain Output**

Train to give **Same Output as Important Features**

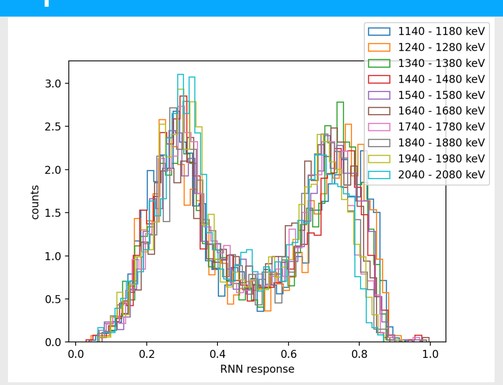
Train for **alignment between Model Importance** and **Human Feature Importance**
→ use of explanation metric

Adapted from Visual Feature Importance Supervision by Ying, Hase, Bansal, https://doi.org/10.48550/arXiv.2206.11212

## 4. Energy dependence

In case of an energy independent model, the histogram shape for the model response at different energy slices shall be the same.

Beside some slight fluctuations, this shape is the same over the range of 1000 keV and no relevant energy dependence can be detected.




Shape of FIS output for different energy slices at compton continuum

## 5. Performance Study

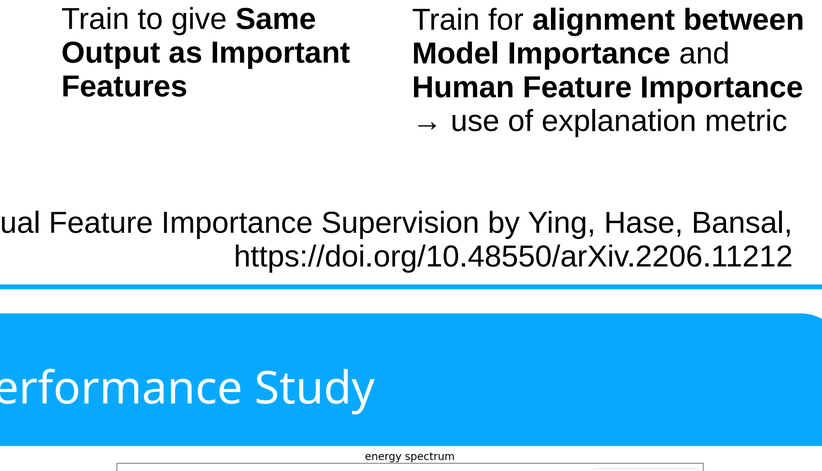
A cut value is set to 90% survival fraction in DEP peak.
As shown in the table below, the survival fractions are a bit higher by the FIS, but still in a feasible and realistic range.

| peak | A/E | FIS |
|---|---|---|
| DEP Tl | 90% | 90% |
| SEP Tl | 3.3% ± 0.13% | 6.6% ± 1.5% |
| FEP Tl | 5.6% ± 0.2 % | 10.1% ± 0.2% |
| FEP Bi | 8% ± 2% | 14.8% ± 2.4% |




DEP and FEP of Bi before and after cuts

In the spectrum on the right, the full spectrum after A/E and FIS cut is drawn. The difference between both spectra is in general very small.




Full spectrum before and after A/E and FIS cut

## 6. Conclusion & Outlook

Possibility to provide a faithful, energy independent and well performing PSA by using FIS, but it is still helpful to investigate the model further.

Especially the events rejected by A/E but accepted by FIS (or vice versa) shall be investigated further.