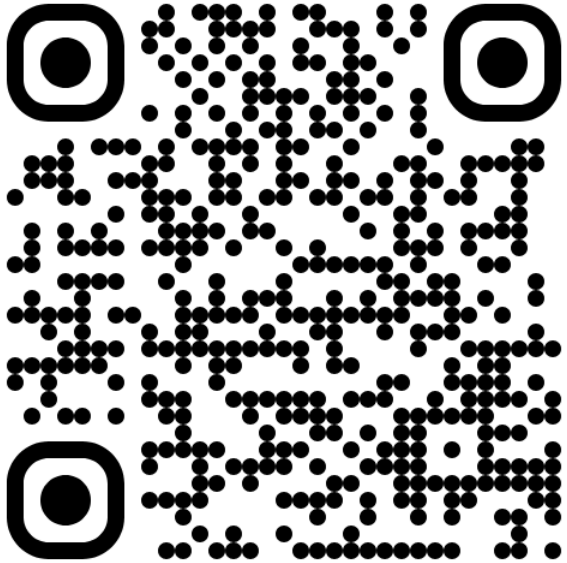
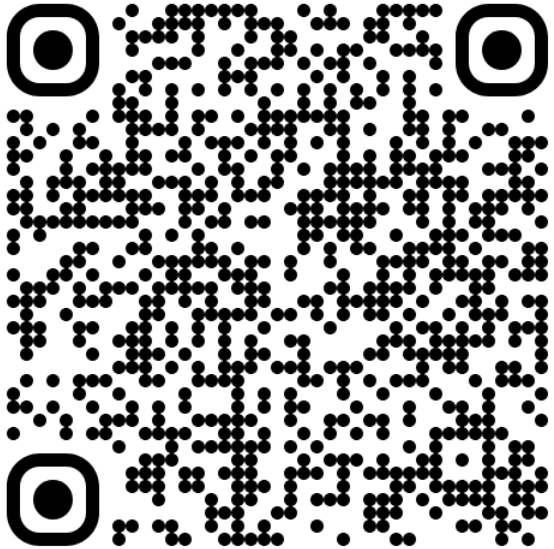
Code Availability

Presentation	Full Research
	
INTRIQ-2024	Photon-Number-Classification

Accurate Unsupervised Photon Counting from Transition Edge Sensor Signals

Nicolas Dalbec-Constant

Some Features

Response time : $\sim 10\mu s$

> L. A. Morais et al. (2024), doi: 10.22331/q-2024-05-23-1355.

Efficiency : $\sim 98\%$

> D. Fukuda et al. (2011), doi: 10.1364/OE.19.000870.

Working temperature : $\sim 50 - 100mK$

> L. A. Morais et al. (2024), doi: 10.22331/q-2024-05-23-1355.

Photon number range : 0 to 33 photons

> M. Eaton et al. (2023), doi: 10.1038/s41566-022-01105-9.

Working Principle

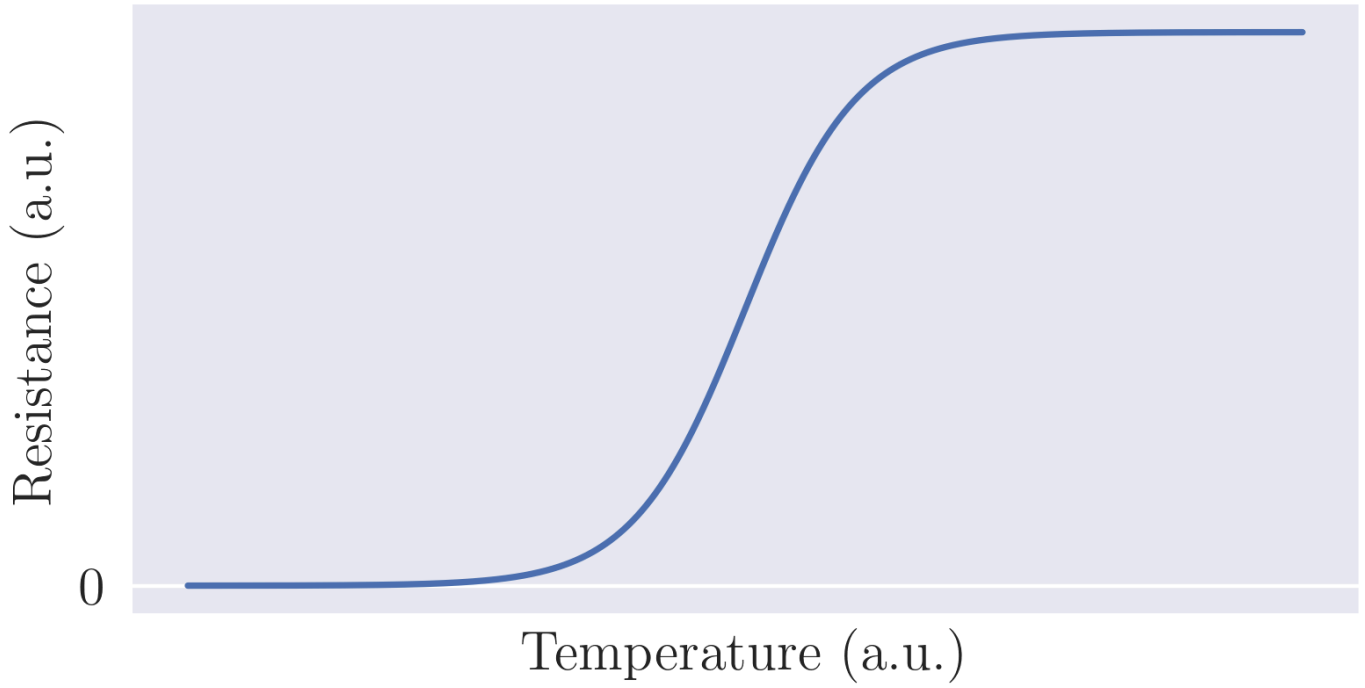


Fig. 1 : Sketch of a TES's resistance variation with temperature.

Signals

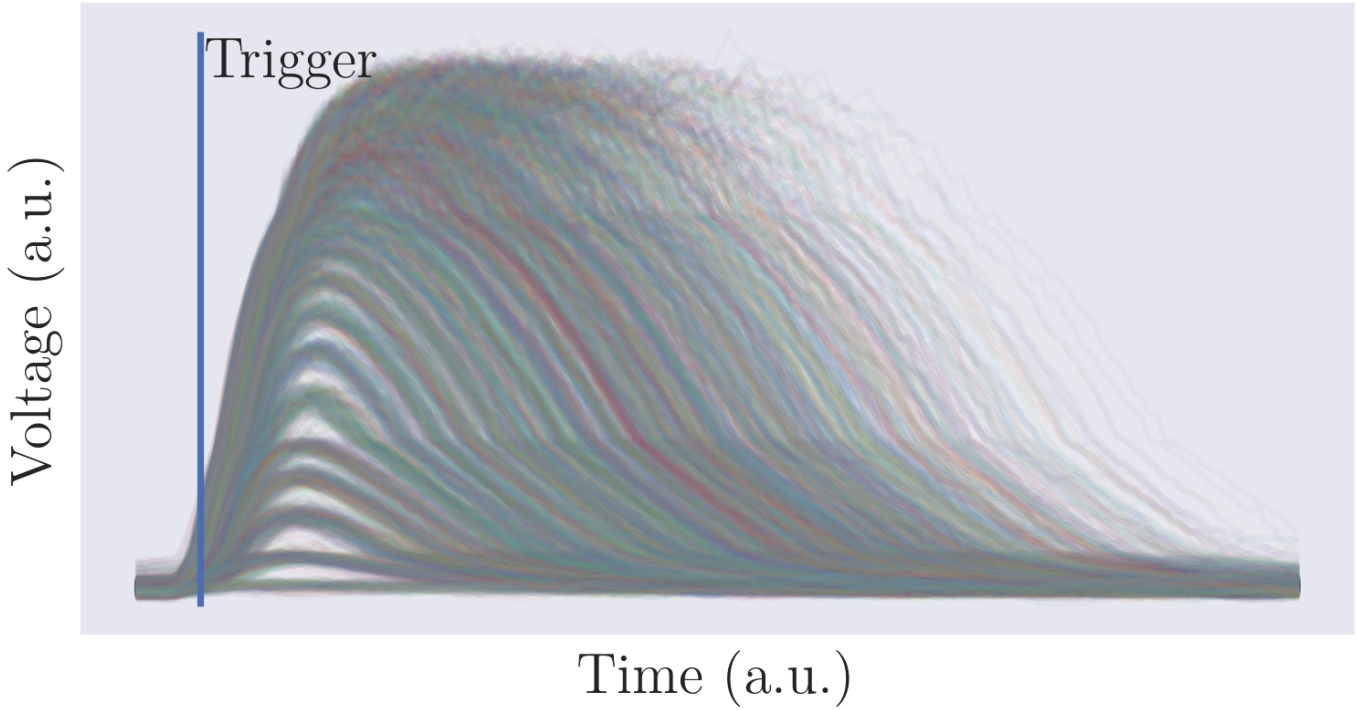
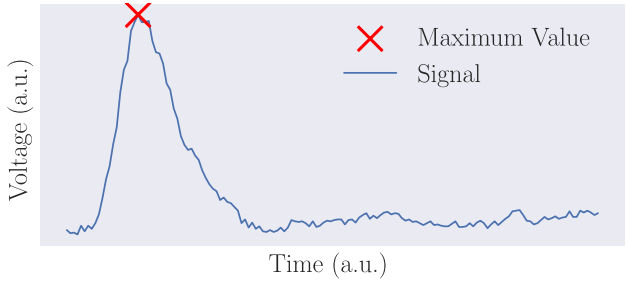
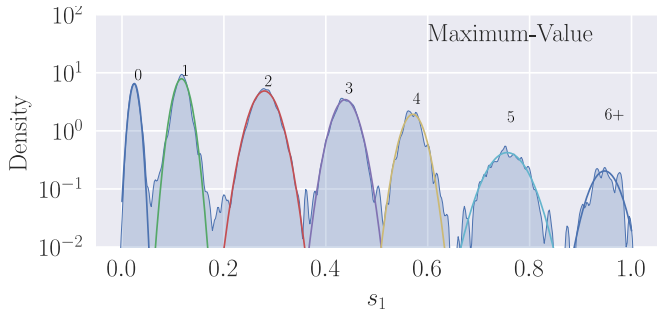
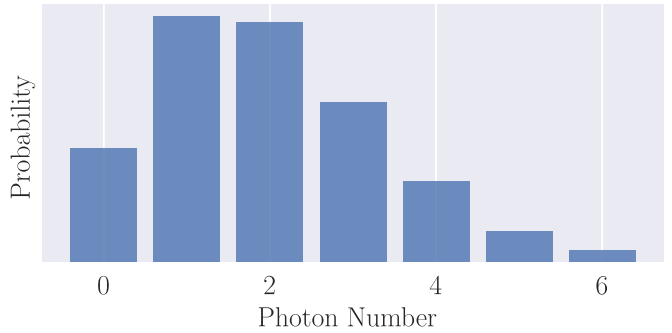
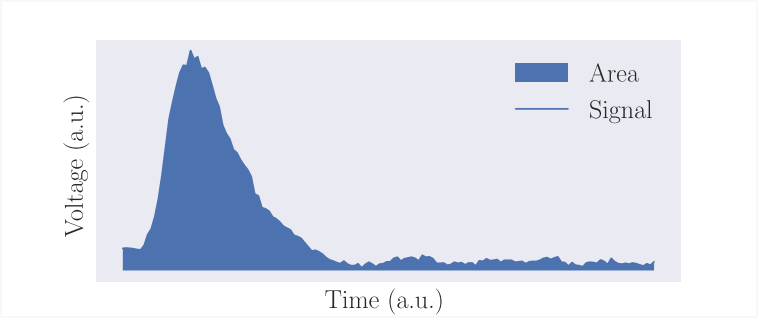
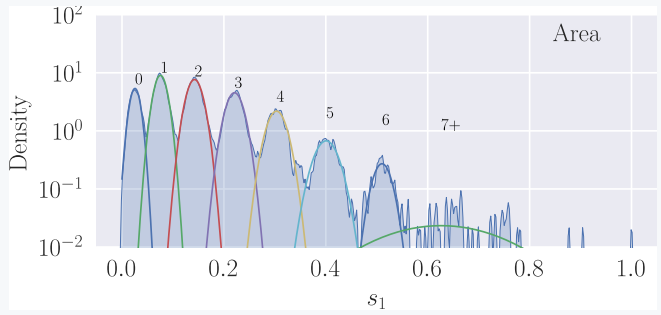
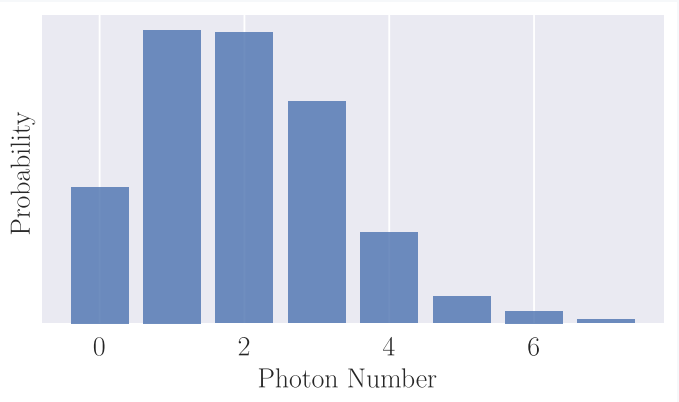


Fig. 2 : 3 000 TES signals.

Historical Methods

1. Operation	2. Latent Space	3. Distribution
		
		

L. A. Morais et al., “Precisely determining photon-number in real time,” Quantum 1355, May 2024.

Dimensionality Reduction

> Process of transforming high-dimensional data into a lower-dimensional representation that retains a maximum of information.

Clustering

> Clustering refers to identifying groups of similar samples inside a latent space based on some criteria.

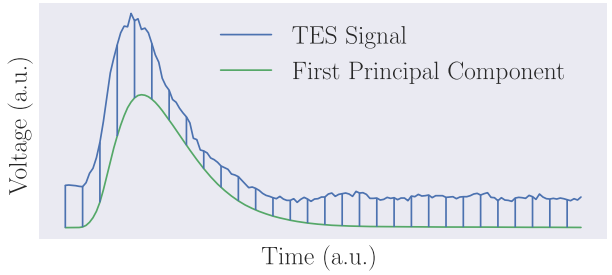
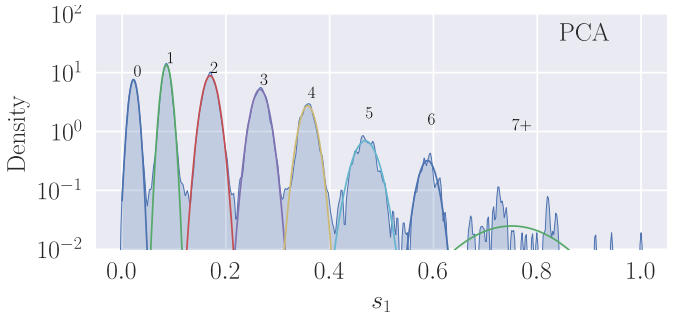
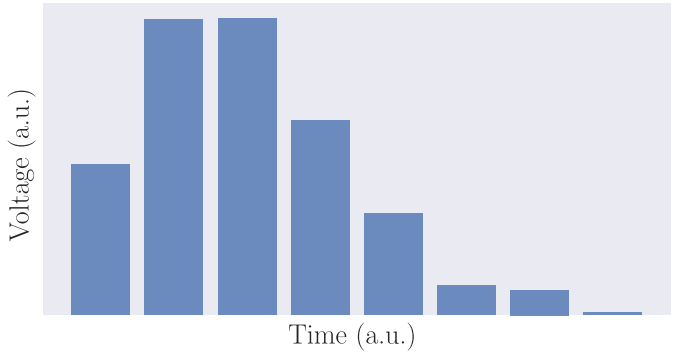
Unsupervised Classification

> Each signal can be associated with a class and the true label of each sample is unknown.

Problem Formulation

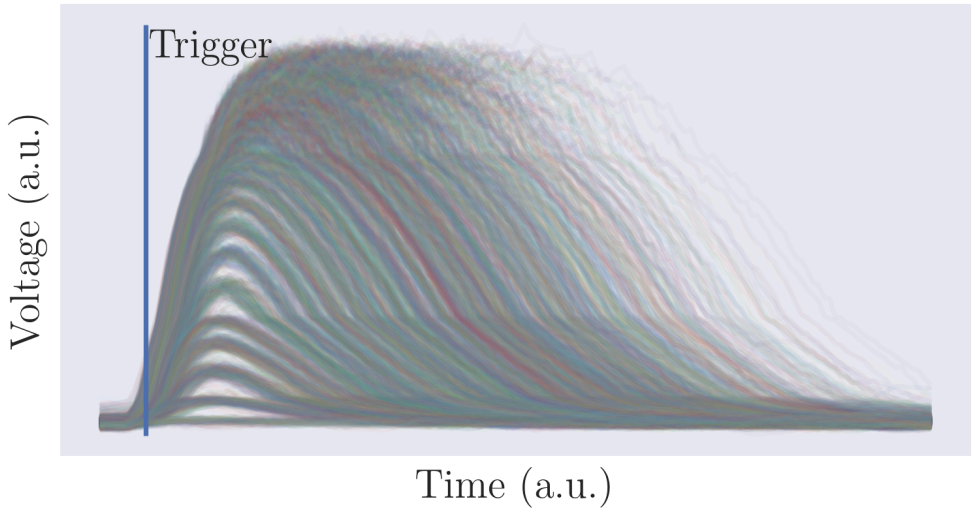
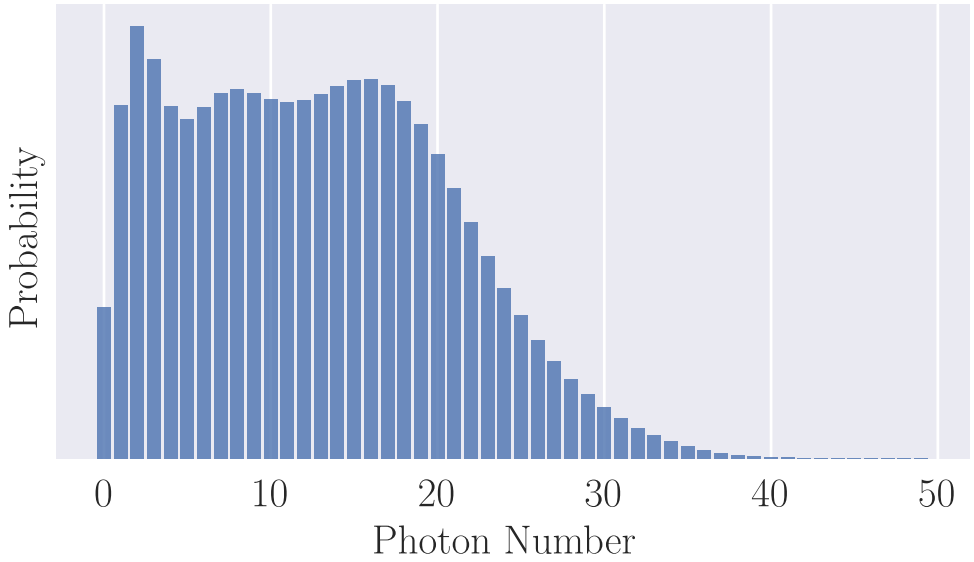
```
def function(Signals : np.array):
  '''
  Function to transform TES signals into photon numbers.

  Parameters
  ----------
  Signals : np.array
    TES signal matrix of shape
    (number of signals, number of time steps in each signal)

  Returns
  -------
  Photon_Numbers : np.array
    Array that contains the photon number associated with each
    signal in `Signals`.

  '''
  return Photon_Numbers
```

Principal Component Analysis (PCA)

1. Signals	2. Latent Space	3. Distribution
		

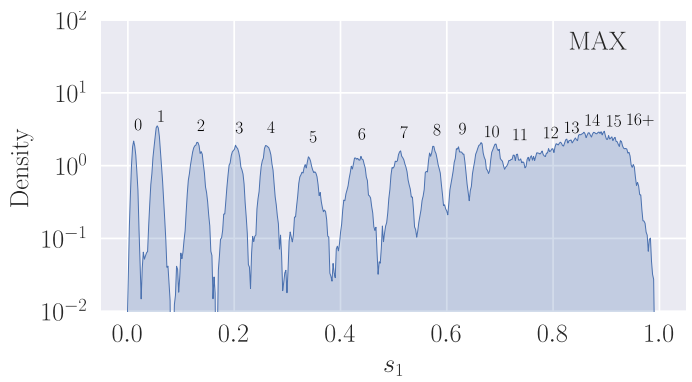
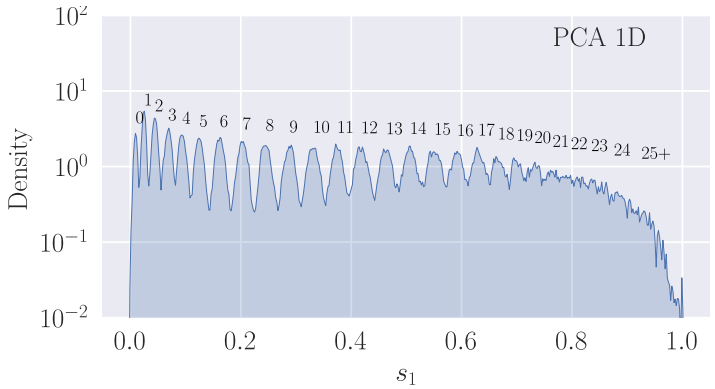
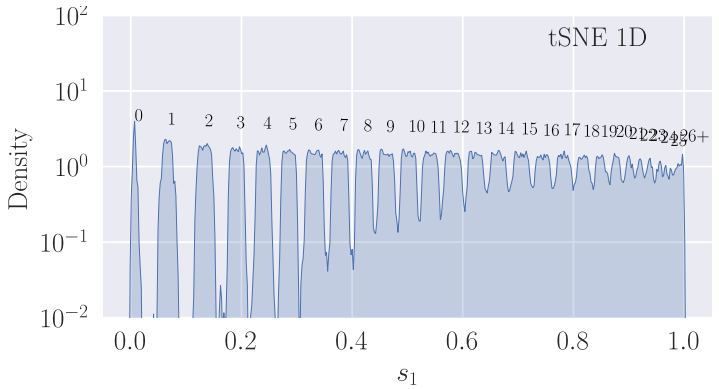
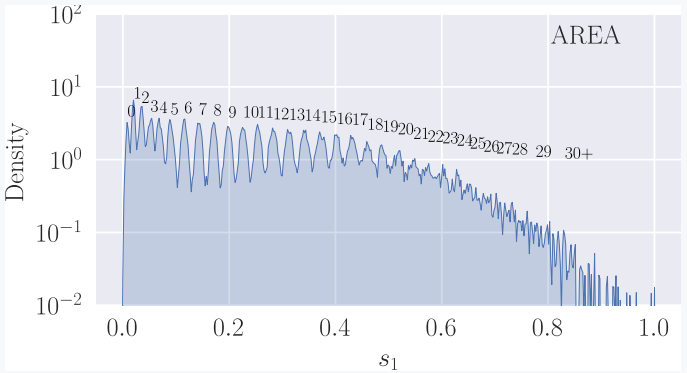
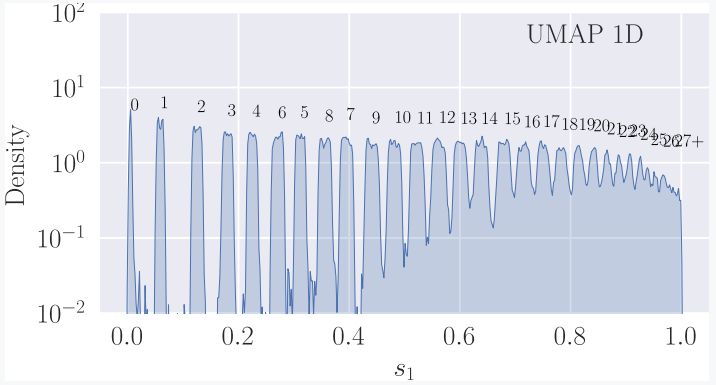
P. C. Humphreys et al., “Tomography of photon-number resolving continuous-output detectors,” New J. Phys., Oct. 2015.

Dataset (NIST)

Signals	Expected Distribution
	

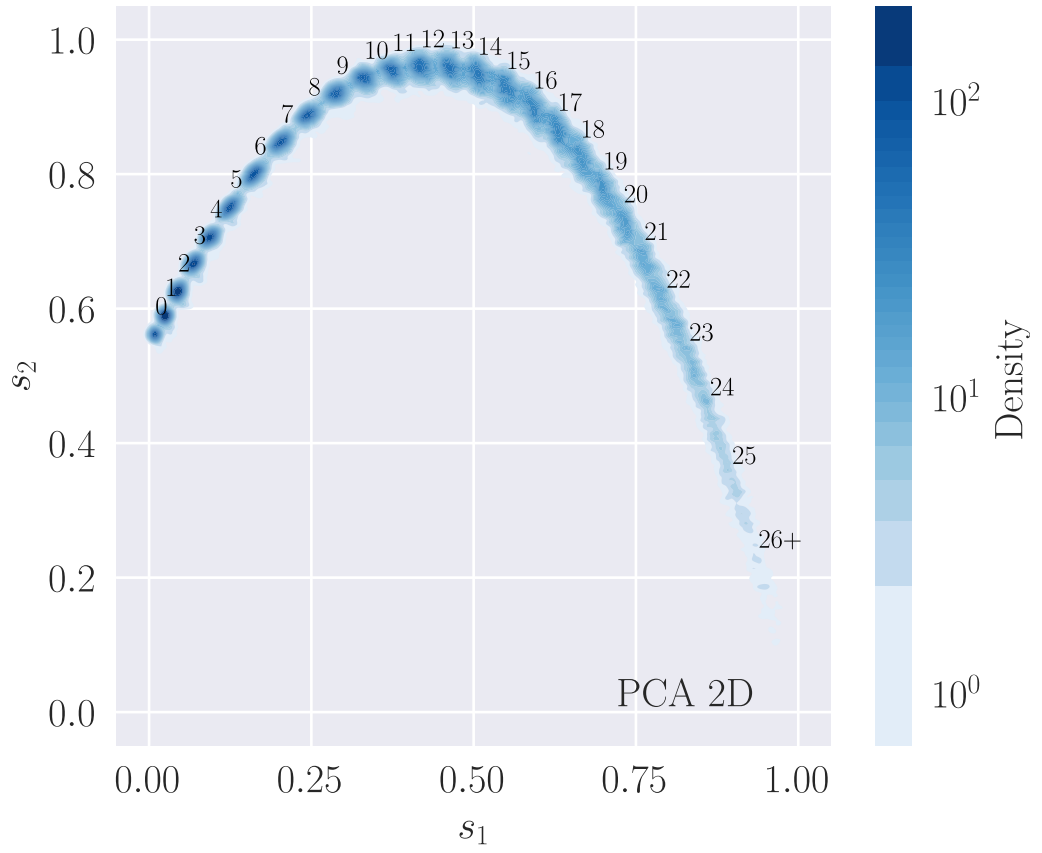
T. Gerrits et al., “Extending single-photon optimized superconducting transition edge sensors beyond the single-photon counting regime,” Opt. Express, Oct. 2012

Exploration of Dimensionality Reduction Techniques

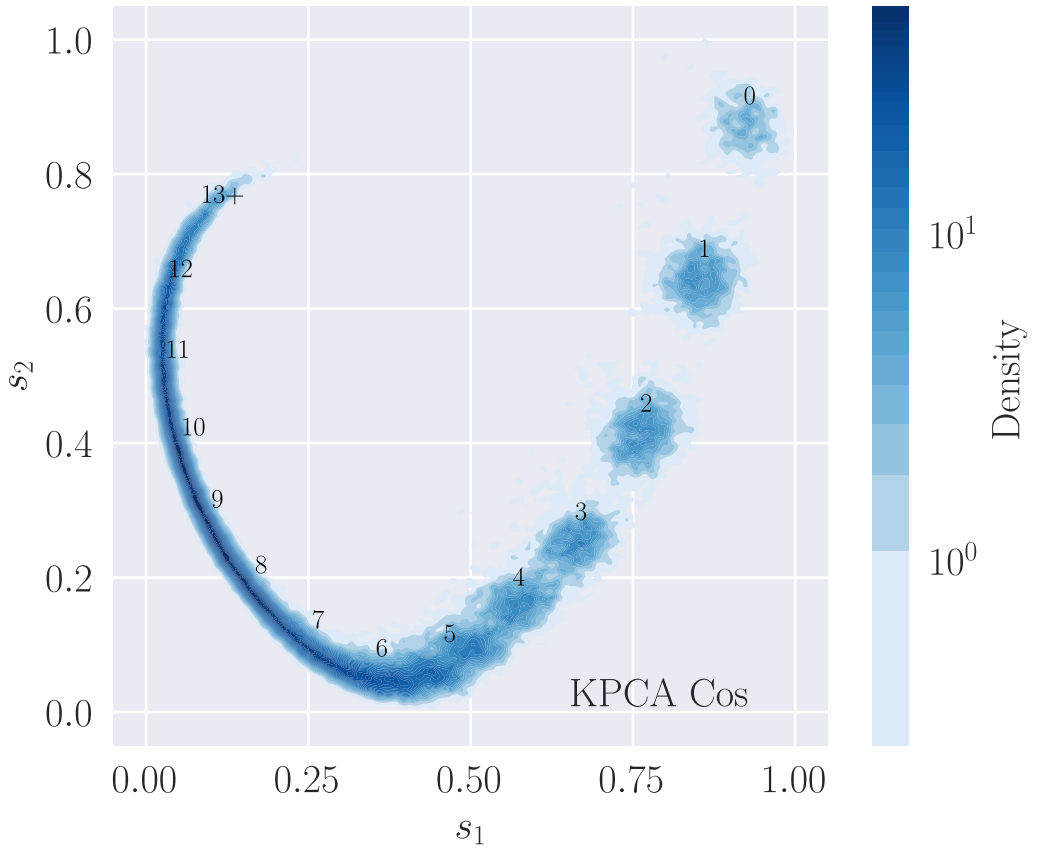
Simple Feature	Predictive	Non-Predictive
		
	fit	

Exploration of Dimensionality Reduction Techniques

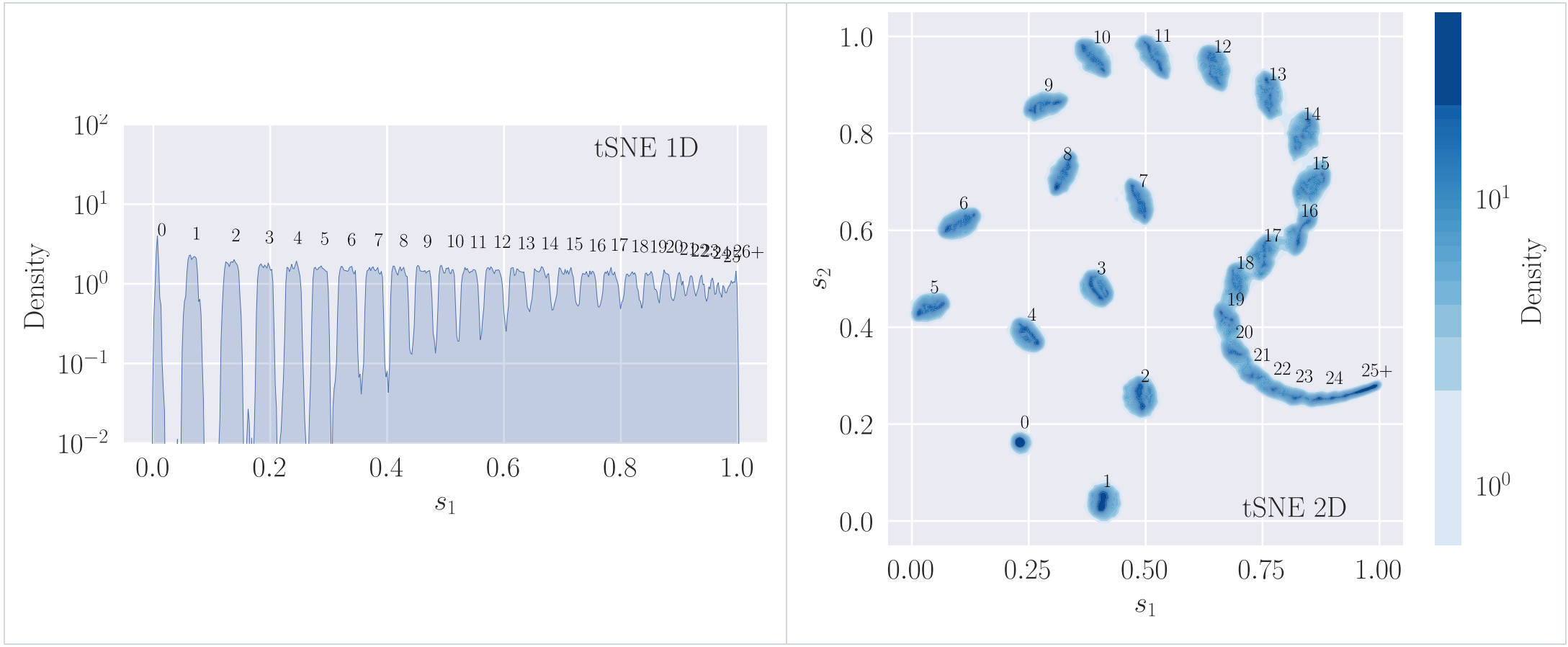
Predictive



Non-Predictive

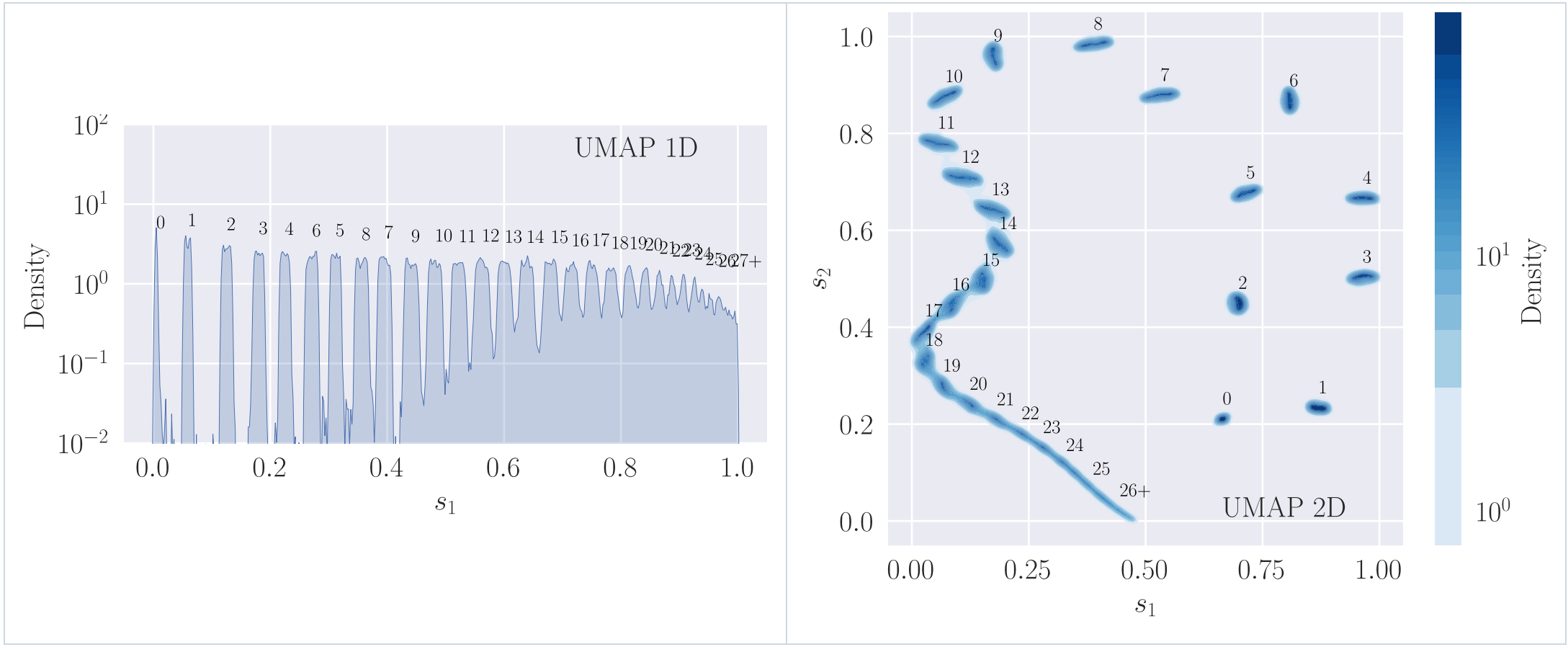


t-distributed stochastic neighbor embedding (t-SNE)



L. Van der Maaten and G. Hinton, “Visualizing data using t-SNE.,” Journal of machine learning research, 2008

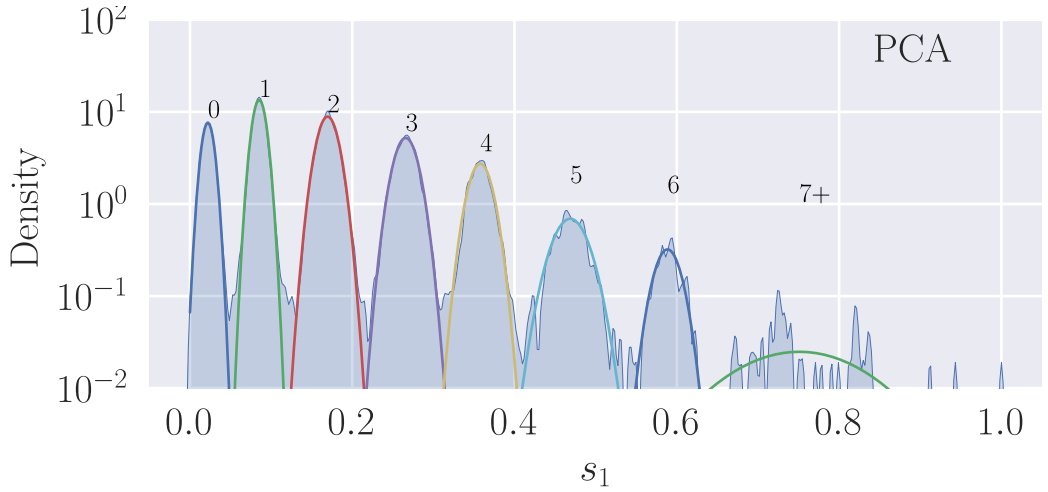
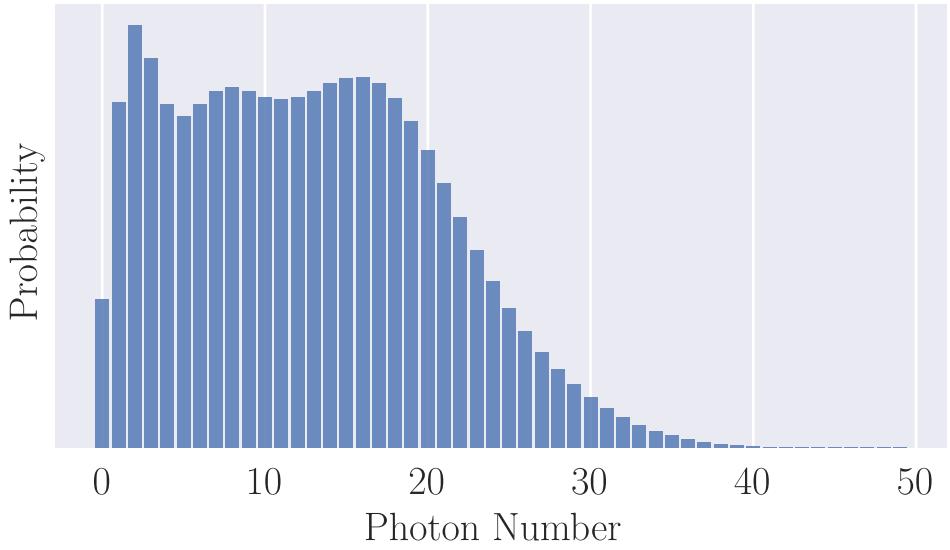
Uniform Manifold Approximation and Projection (UMAP)



L. Van der Maaten and G. Hinton, “Visualizing data using t-SNE.,” Journal of machine learning research, 2008

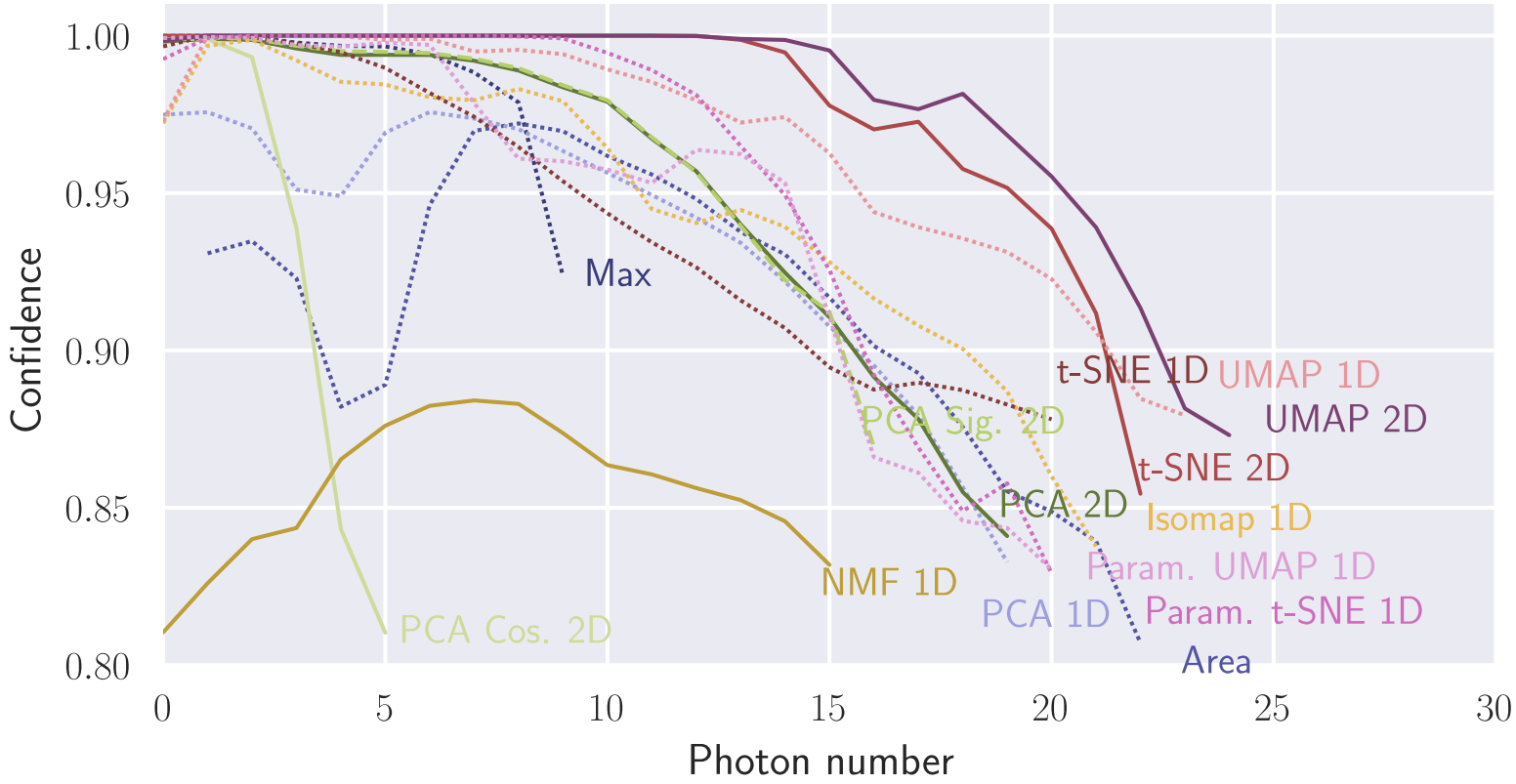
Confidence

$$C_n = \int \frac{p(s|n)^2 p(n)}{\sum_k p(s|k)p(k)} ds$$

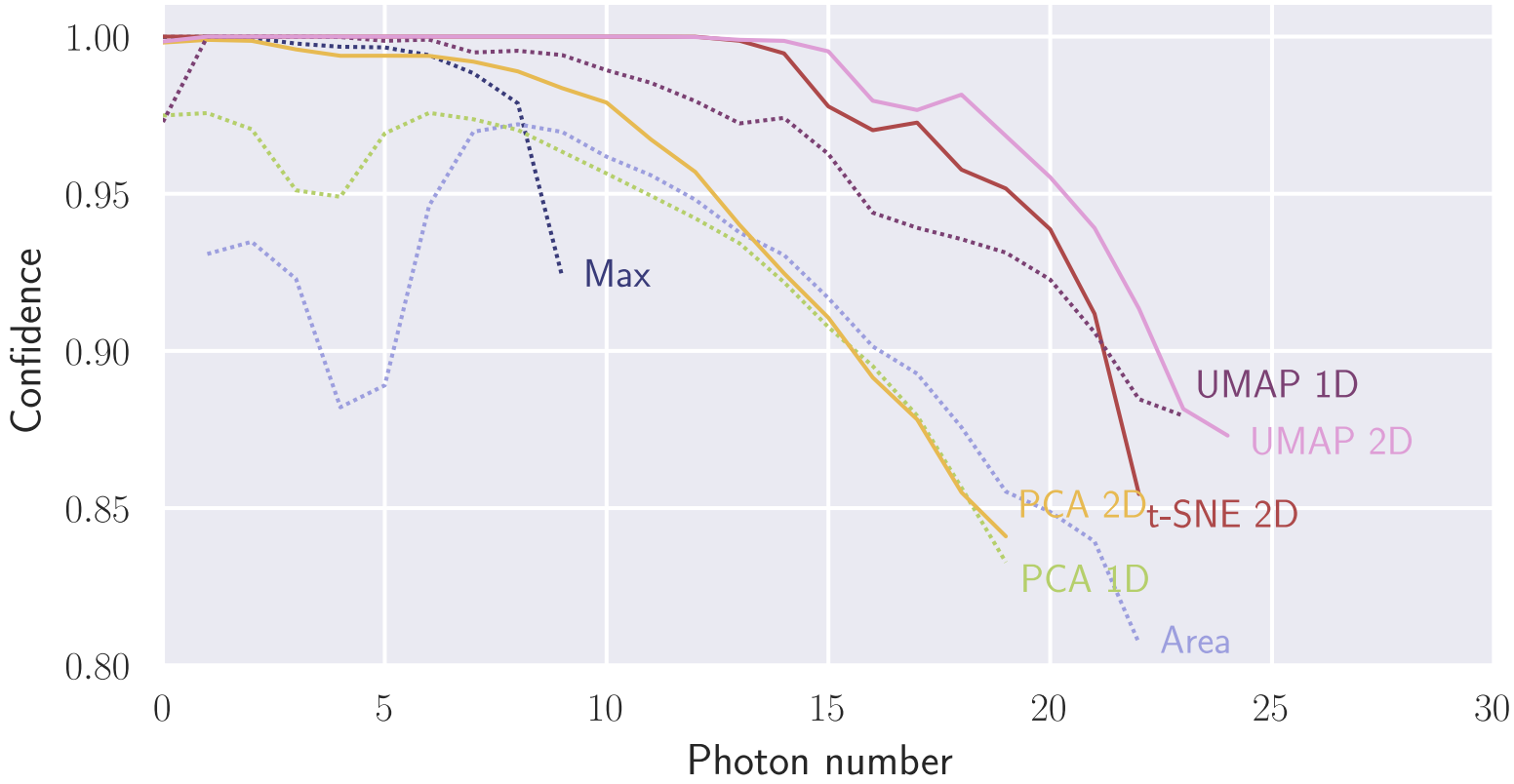
$p(s\|n)$: Gaussians	$p(n)$: Expected Distribution
	

P. C. Humphreys et al., “Tomography of photon-number resolving continuous-output detectors,” New J. Phys., Oct. 2015.

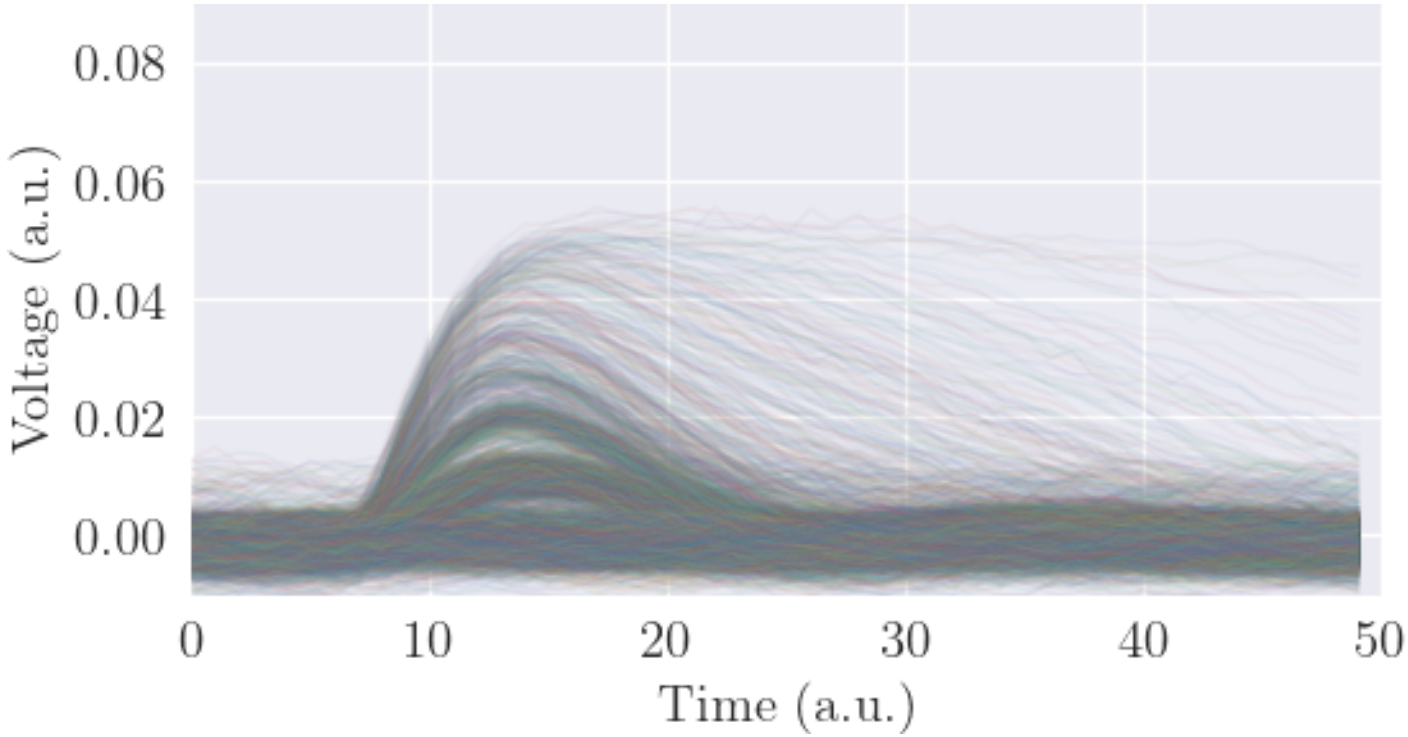
Benchmark


1.00
0.95
0.90
0.85
0.80
Confidence
0
5
10
15
20
25
30
Photon number
Max
t-SNE 1D
UMAP 1D
UMAP 2D
PCA Sig. 2D
t-SNE 2D
PCA 2D
Isomap 1D
Param. UMAP 1D
NMF 1D
PCA 1D
Param. t-SNE 1D
PCA Cos. 2D
Area

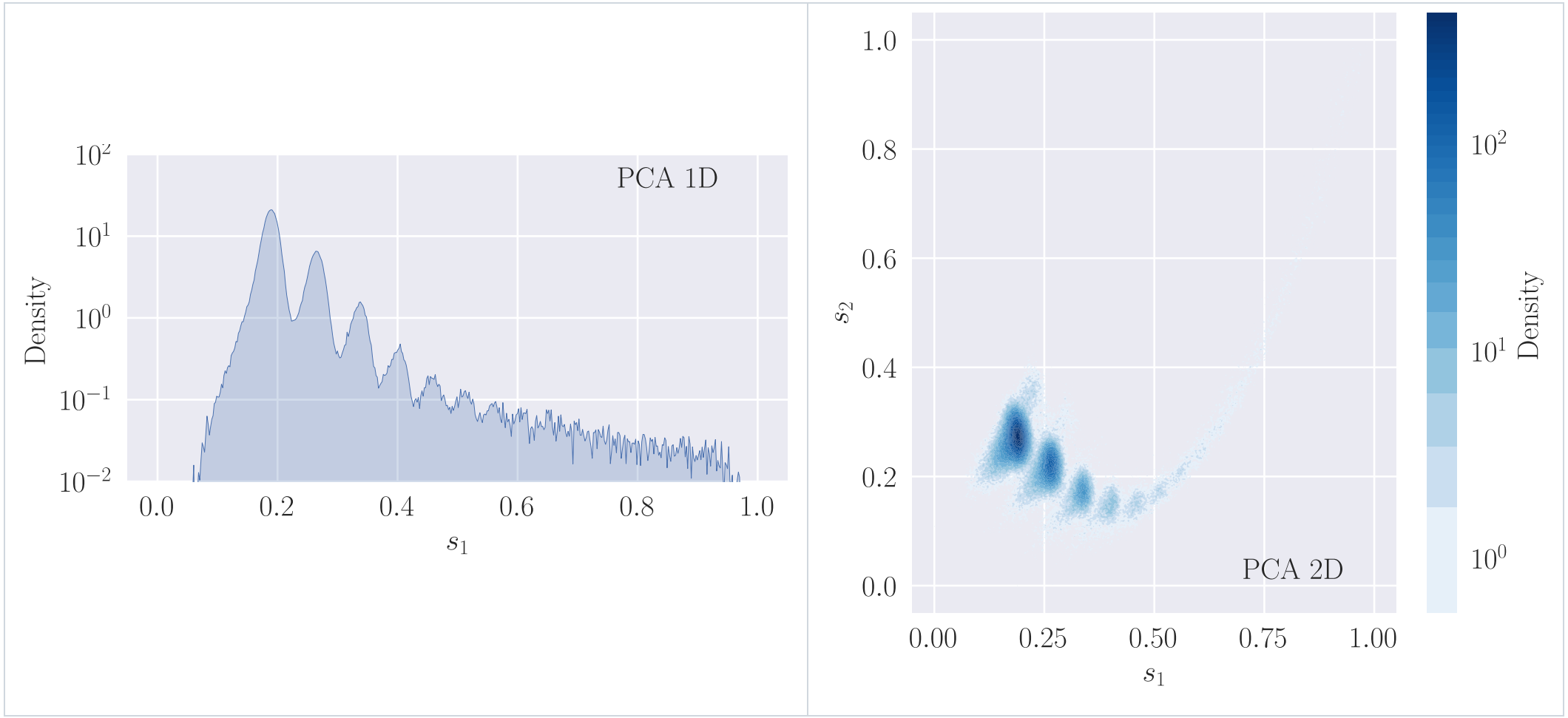
Benchmark


1.00
0.95
0.90
0.85
0.80
Confidence
0
5
10
15
20
25
30
Photon number
Max
UMAP 1D
UMAP 2D
PCA 2D
t-SNE 2D
PCA 1D
Area

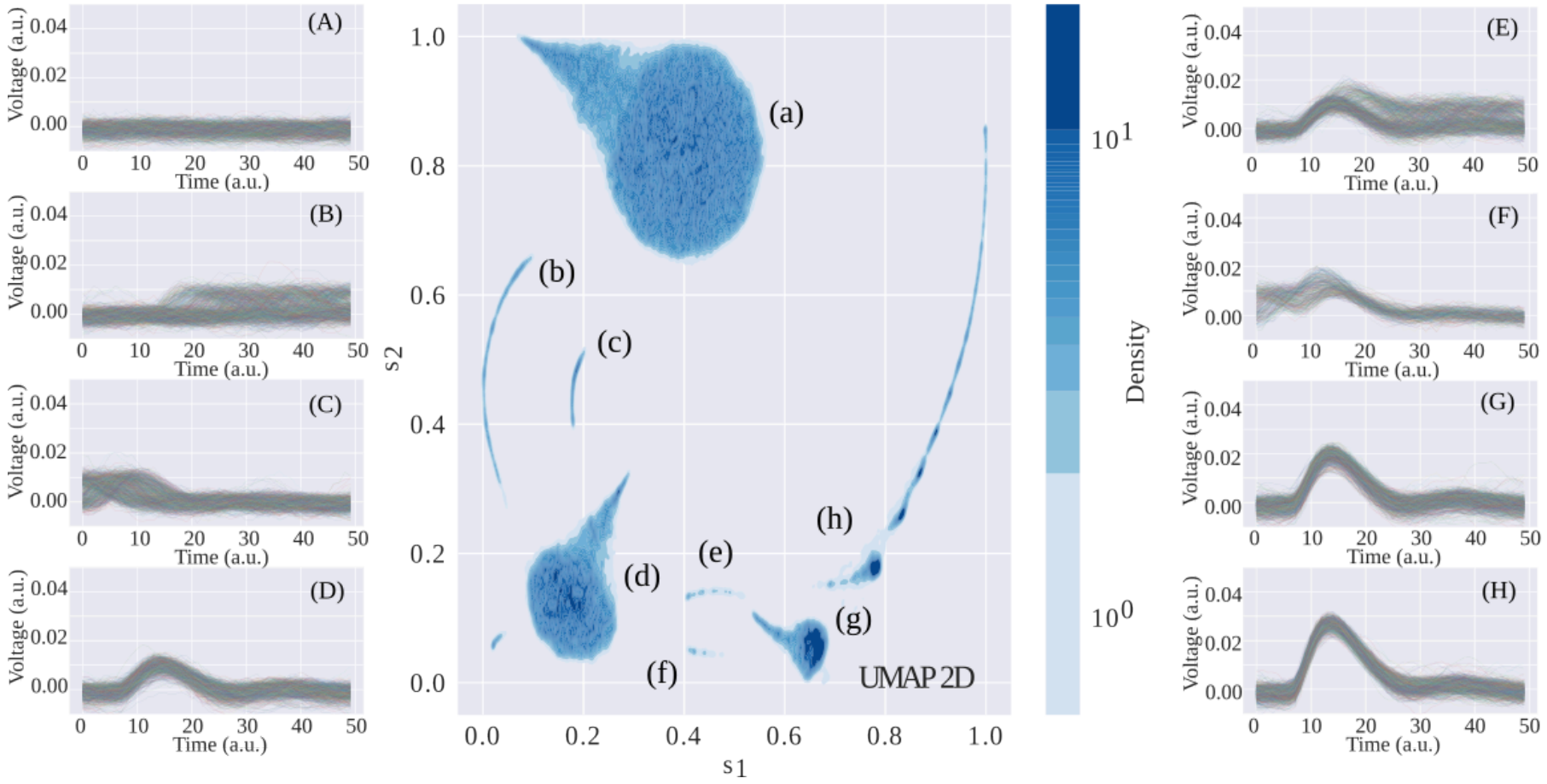
Outlier Detection (NRC)



Outlier Detection



Outlier Detection



Parametric Implementation of UMAP and t-SNE


center

Conclusion

- Dimensionality reduction is useful to understand data.
- Nonlinear techniques can improve the photon number resolution of TESs.
- Neural networks provide a precise and efficient platform to achieve photon number prediction.