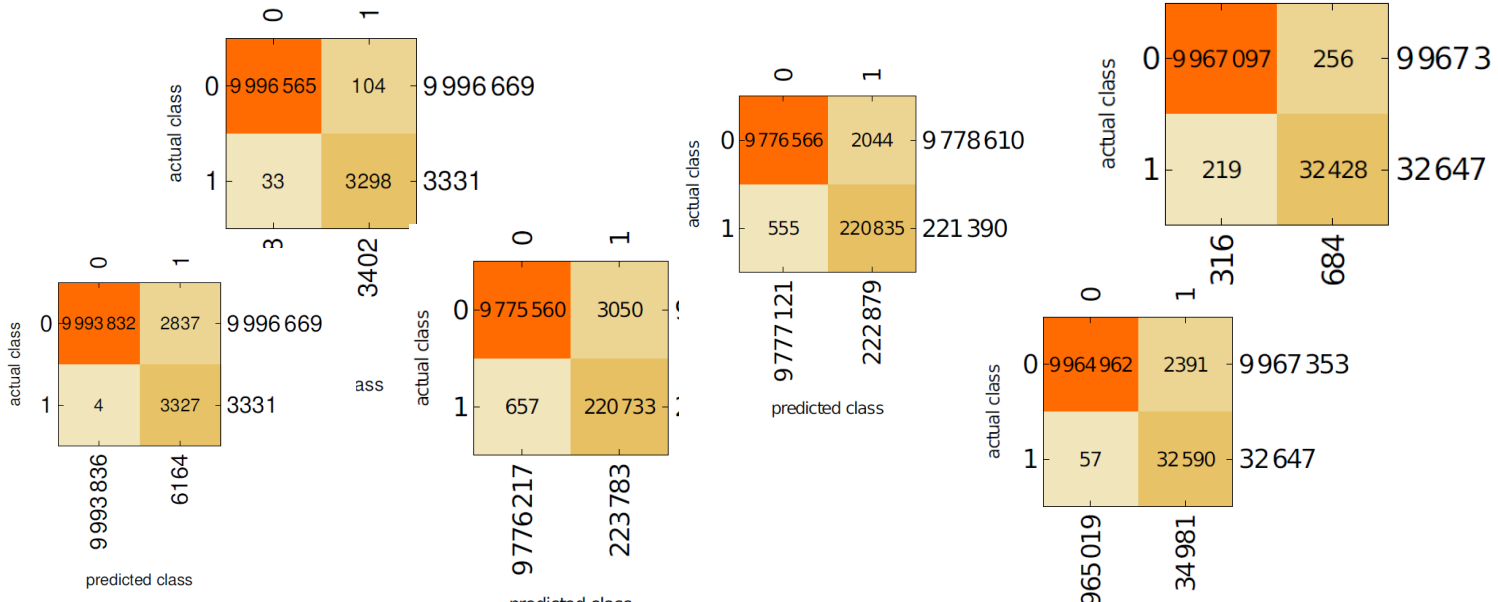
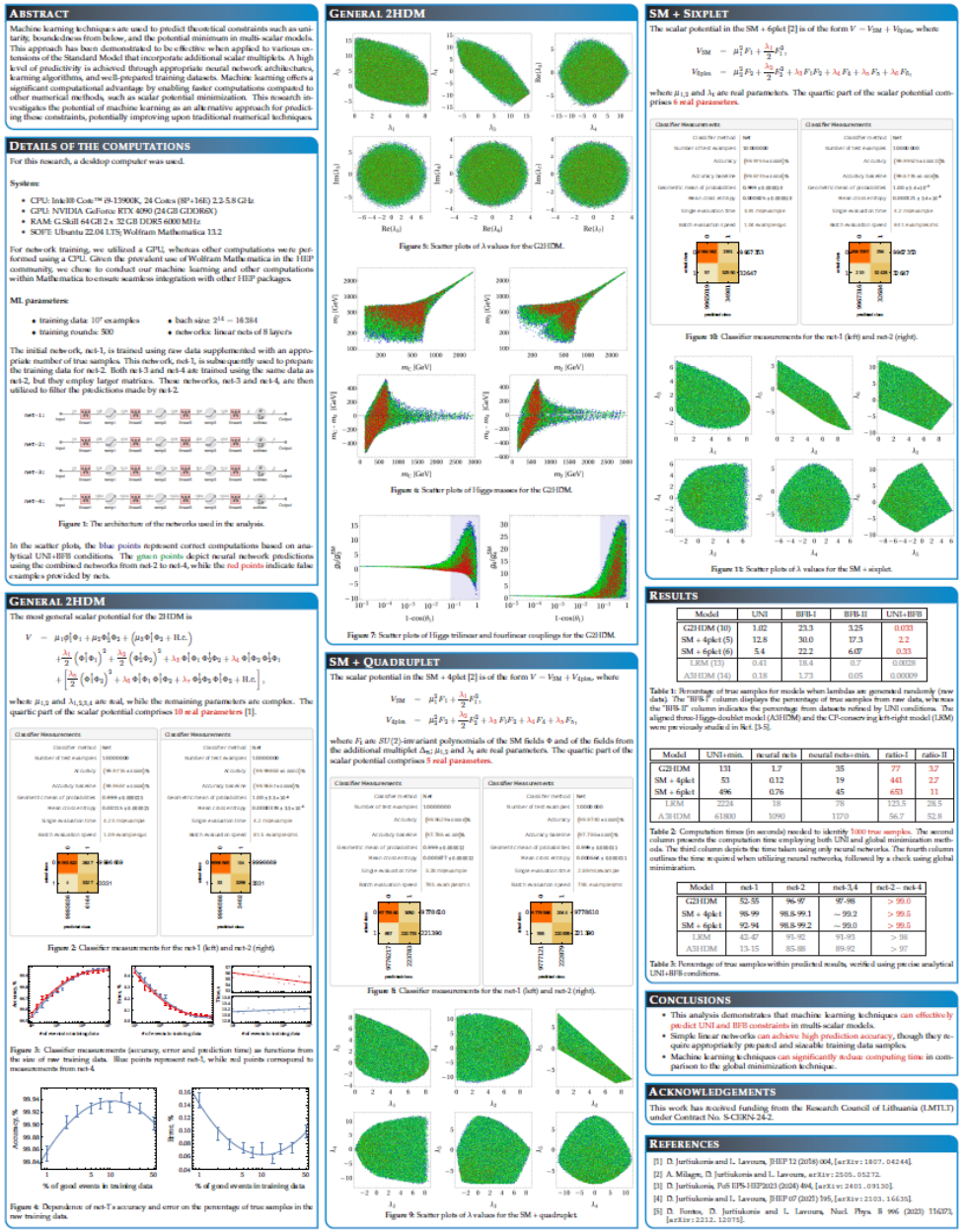
Applications of Machine Learning in Constraining Multi-Scalar Models

Darius Jurčiukonis

Vilnius University, Institute of Theoretical Physics and Astronomy

2025-06-18, EuCAIFCon 2025





Introduction

There are two important theoretical constraints that one must impose on the scalar potential.

- **UNI**: all the (tree-level) scalar–scalar scattering amplitudes must respect unitarity.
- **BFB**: the potential must have a minimum, viz. they prevent the existence of directions in field space along which the potential is unbounded from below.

The simple scalar potential in the SM + multiplet is of the form $V = V_{SM} + V_{multiplet}$, where

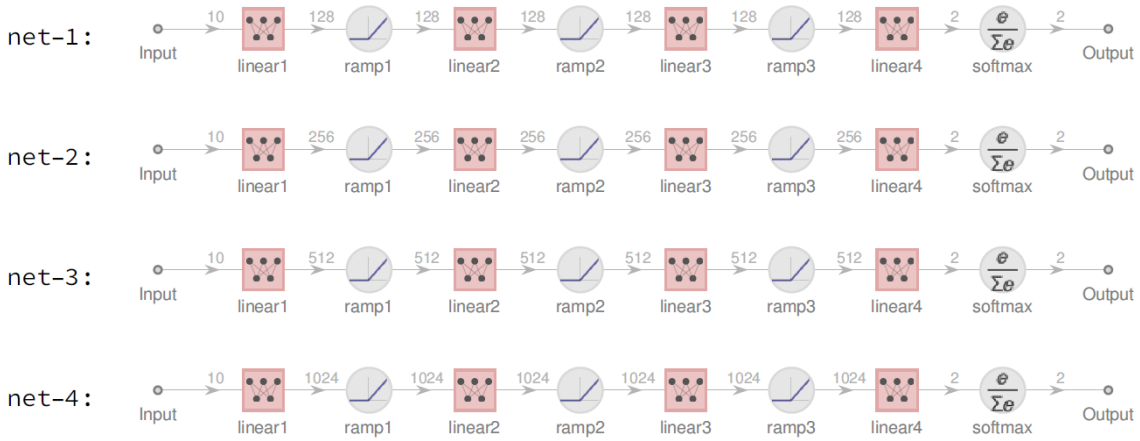
$$V_{\rm SM} = \mu_1^2 F_1 + \frac{\lambda_1}{2} F_1^2,$$

$$V_{\rm multiplet} = \mu_2^2 F_2 + \frac{\lambda_2}{2} F_2^2 + \lambda_3 F_1 F_2 + \lambda_4 F_4 + \sum_{i=5}^{t+3} \lambda_i F_i,$$

where F_i are *SU(2)*-invariant polynomials of the SM fields Φ and of the fields from the additional multiplet Δ_n.

A. Milagre, DJ, L. Lavoura, 2505.05272

Technique



- The initial network, net-1, is trained using raw data.
- This network, net-1, is subsequently used to prepare the training data for net-2.
- Both net-3 and net-4 are trained using the same data as net-2.
- These networks, net-3 and net-4, are then utilized to filter the predictions made by net-2.

Results

Computation times (in seconds) needed to identify 1000 true samples.

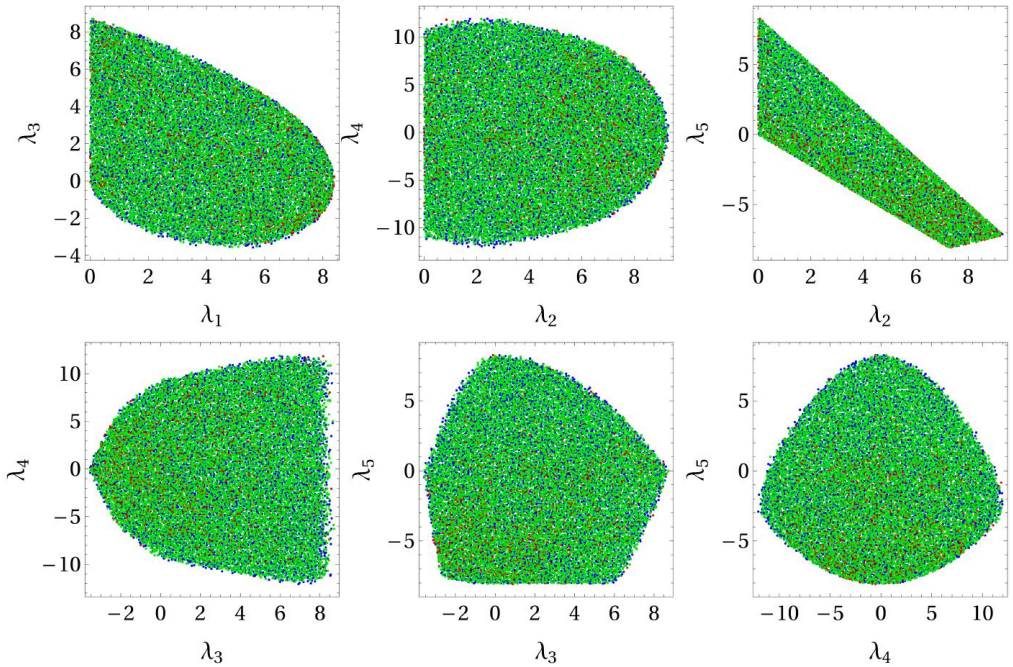
Model	UNI+min.	neural nets	neural nets+min.	ratio-I	ratio-II
G2HDM	131	1.7	35	77	3.7
SM + 4plet	53	0.12	19	441	2.7
SM + 6plet	496	0.76	45	653	11
LRM	2224	18	78	123.5	28.5
A3HDM	61800	1090	1170	56.7	52.8

Percentage of true samples within predicted results (from raw data), verified using analytical UNI+BFB conditions.

Model	net-1	net-2	net-3,4	net-2 – net-4
G2HDM	52-55	96-97	97-98	> 99.0
SM + 4plet	98-99	98.8-99.1	~ 99.2	> 99.5
SM + 6plet	92-94	98.8-99.2	~ 99.0	> 99.5
LRM	42-47	91-92	91-93	> 98
A3HDM	13-15	85-88	89-92	> 97

This work has received funding from the Research Council of Lithuania (LMTLT) under Contract No. S-CERN-24-2.

Conclusions



- Machine learning techniques can effectively predict UNI and BFB constraints in multi-scalar models.
- Simple linear networks can achieve high prediction accuracy, though they require appropriately prepared training data samples.
- Machine learning techniques can significantly reduce computing time in comparison to the global minimization technique.