

Hunting for $B \rightarrow K\tau\tau$ imprints on the $B \rightarrow K\mu\mu$ dimuon spectrum

Master thesis of
Sascha Liechti

08.08.2018

N. Serra, P. Owen, G. Isidori, C. Cornella, M. Koenig

Abstract

..... Fill in abstract here

Contents

1	Standard Model	4
1.1	Elementary particles and forces	4
1.2	Interaction rules	7
2	Physics beyond the SM	9
2.1	Neutrino Oscillation	9
2.2	New physics	10
3	$\mu \rightarrow eee$ decay	12
3.1	Kinematics	12
3.2	Background events	12
3.2.1	Internal conversions	12
3.2.2	Michel decay	13
3.2.3	Radiative muon decay	13
3.2.4	BhaBha scattering	13
3.2.5	Pion decays	14
3.2.6	Analysis of the background	14
4	Mu3e experiment	15
4.1	Requirements	15
4.2	Phase I	15
4.3	Phase II	15
4.4	Experimental setup	15
4.5	The problem of low longitudinal momentum recurlers	18
5	Machine learning	21
5.1	Introduction	21
5.2	Artificial neural networks	21
5.2.1	General concepts	21
5.2.2	Activation functions	23
5.2.3	Concepts of training	24
5.2.4	Loss functions	24
5.2.5	Stochastic gradient descent	25
5.2.6	Stochastic gradient descent with Momentum	25
5.2.7	RMSProp	25
5.2.8	Adam	26
5.2.9	Decaying learning rate	27
5.2.10	Batch normalisation	27
5.3	Recurrent Neural Networks	27

5.3.1	General concepts	27
5.3.2	Most common architectures	29
5.3.3	Cell types	29
5.4	XGBoost	30
6	Data	32
6.1	General information	32
6.2	Preprocessing	32
6.2.1	Dataset 1	32
6.2.2	Dataset 2	33
7	RNN's used	34
7.1	RNN for track prediction	34
7.2	RNN for classification of tracks	35
8	Analysis	38
8.1	Best χ^2	38
8.2	RNN classifier with RNN track prediction input	38
8.3	XGBoost	40
8.4	Comparison in performance of the RNN and XGBoost	42
9	Results	43
9.1	Results	43
9.2	Outlook and potential	43
10	Acknowledgements	44

References

- [1] MZ Akrawy, G Alexander, J Allison, PP Allport, KJ Anderson, JC Armitage, GTJ Arnison, P Ashton, G Azuelos, JTM Baines, et al. Measurement of the z_0 mass and width with the opal detector at lep. *Physics Letters B*, 231(4):530–538, 1989.
- [2] Mark Thomson. *Modern particle physics*. Cambridge University Press, 2013.
- [3] S Abe, T Ebihara, S Enomoto, K Furuno, Y Gando, K Ichimura, H Ikeda, K Inoue, Y Kibe, Y Kishimoto, et al. Precision measurement of neutrino oscillation parameters with kamland. *Physical Review Letters*, 100(22):221803, 2008.
- [4] P Adamson, C Andreopoulos, R Armstrong, DJ Auty, DS Ayres, C Backhouse, G Barr, M Bishai, A Blake, GJ Bock, et al. Measurement of the neutrino mass splitting and flavor mixing by minos. *Physical Review Letters*, 106(18):181801, 2011.
- [5] A Blondel, A Bravar, M Pohl, S Bachmann, N Berger, M Kiehn, A Schöning, D Wiedner, B Windelband, P Eckert, et al. Research proposal for an experiment to search for the decay $\mu \rightarrow eee$. *arXiv preprint arXiv:1301.6113*, 2013.
- [6] Heiko Augustin, Niklaus Berger, Sebastian Dittmeier, Carsten Grzesik, Jan Hammerich, Qinhua Huang, Lennart Huth, Moritz Kiehn, Alexandre Kozlinskiy, Frank Meier Aeschbacher, et al. The mupix system-on-chip for the mu3e experiment. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 845:194–198, 2017.
- [7] Jonathan Philipp, Lennart Huth, Heiko Augustin, Raphael Philipp, Dirk Wiedner, Niklaus Berger, Mu3e Collaboration, et al. Das hv-maps basierte mupix teleskop. Technical report, Detector RD at DESY Test beam, 2015.
- [8] Heiko Augustin, N Berger, S Bravar, Simon Corrodi, A Damyanova, F Förster, R Gredig, A Herkert, Q Huang, L Huth, et al. The mupix high voltage monolithic active pixel sensor for the mu3e experiment. *Journal of Instrumentation*, 10(03):C03044, 2015.

-
- [9] Jerome T Connor, R Douglas Martin, and Les E Atlas. Recurrent neural networks and robust time series prediction. *IEEE transactions on neural networks*, 5(2):240–254, 1994.
 - [10] Stephen Grossberg. Recurrent neural networks. *Scholarpedia*, 8(2):1888, 2013.
 - [11] Tianqi Chen and Carlos Guestrin. Xgboost: A scalable tree boosting system. *CoRR*, abs/1603.02754, 2016.
 - [12] François Chollet et al. Keras: Deep learning library for theano and tensorflow. *URL: https://keras.io/k*, 7(8), 2015.
 - [13] Martín Abadi, Paul Barham, Jianmin Chen, Zhifeng Chen, Andy Davis, Jeffrey Dean, Matthieu Devin, Sanjay Ghemawat, Geoffrey Irving, Michael Isard, et al. Tensorflow: a system for large-scale machine learning. In *OSDI*, volume 16, pages 265–283, 2016.
 - [14] Günter Klambauer, Thomas Unterthiner, Andreas Mayr, and Sepp Hochreiter. Self-normalizing neural networks. In *Advances in Neural Information Processing Systems*, pages 971–980, 2017.
 - [15] Trishul M Chilimbi, Yutaka Suzue, Johnson Apacible, and Karthik Kalyanaraman. Project adam: Building an efficient and scalable deep learning training system. In *OSDI*, volume 14, pages 571–582, 2014.
 - [16] Sergey Ioffe and Christian Szegedy. Batch normalization: Accelerating deep network training by reducing internal covariate shift. *arXiv preprint arXiv:1502.03167*, 2015.
 - [17] Tim Cooijmans, Nicolas Ballas, César Laurent, Çağlar Gülçehre, and Aaron Courville. Recurrent batch normalization. *arXiv preprint arXiv:1603.09025*, 2016.
 - [18] Mike Schuster and Kuldip K Paliwal. Bidirectional recurrent neural networks. *IEEE Transactions on Signal Processing*, 45(11):2673–2681, 1997.
 - [19] Felix A Gers, Jürgen Schmidhuber, and Fred Cummins. Learning to forget: Continual prediction with lstm. 1999.
 - [20] Junyoung Chung, Caglar Gulcehre, KyungHyun Cho, and Yoshua Bengio. Empirical evaluation of gated recurrent neural networks on sequence modeling. *arXiv preprint arXiv:1412.3555*, 2014.

-
- [21] S Agostinelli. S. agostinelli et al.(geant4 collaboration), nucl. instrum. methods phys. res., sect. a 506, 250 (2003). *Nucl. Instrum. Methods Phys. Res., Sect. A*, 506:250, 2003.
 - [22] Fabian Pedregosa, Gaël Varoquaux, Alexandre Gramfort, Vincent Michel, Bertrand Thirion, Olivier Grisel, Mathieu Blondel, Peter Prettenhofer, Ron Weiss, Vincent Dubourg, et al. Scikit-learn: Machine learning in python. *Journal of machine learning research*, 12(Oct):2825–2830, 2011.
 - [23] Andrew P. Bradley. The use of the area under the roc curve in the evaluation of machine learning algorithms. *Pattern Recogn.*, 30(7):1145–1159, July 1997.
 - [24] CR Gent and CP Sheppard. Special feature. predicting time series by a fully connected neural network trained by back propagation. *Computing & Control Engineering Journal*, 3(3):109–112, 1992.
 - [25] Alex Graves, Abdel-rahman Mohamed, and Geoffrey Hinton. Speech recognition with deep recurrent neural networks. In *Acoustics, speech and signal processing (icassp), 2013 ieee international conference on*, pages 6645–6649. IEEE, 2013.