SA-CERN/Theory

Theoretical physics is the attempt to qualitatively or quantitatively understand through mathematics and deductive reasoning observations of the natural world and is a critical component of any physics venture.

High energy nuclear and particle physics is the investigation of phenomena at energy scales relevant for nuclei and above, at keV and higher.

Our mission

- Generate world-leading, CERN-related research
  As measured mainly by the publications and citations generated by the members of the group etc.

- Produce world-class human capital
  As measured by degrees granted and the quality of the graduates

- Maintain the high international visibility of South African work in the international arena for CERN-related theoretical physics research

Our visibility will be maintained and enhanced through visits to research institutions and important conferences by our students and academics abroad, most especially at CERN, as well as inclusion on committees and boards

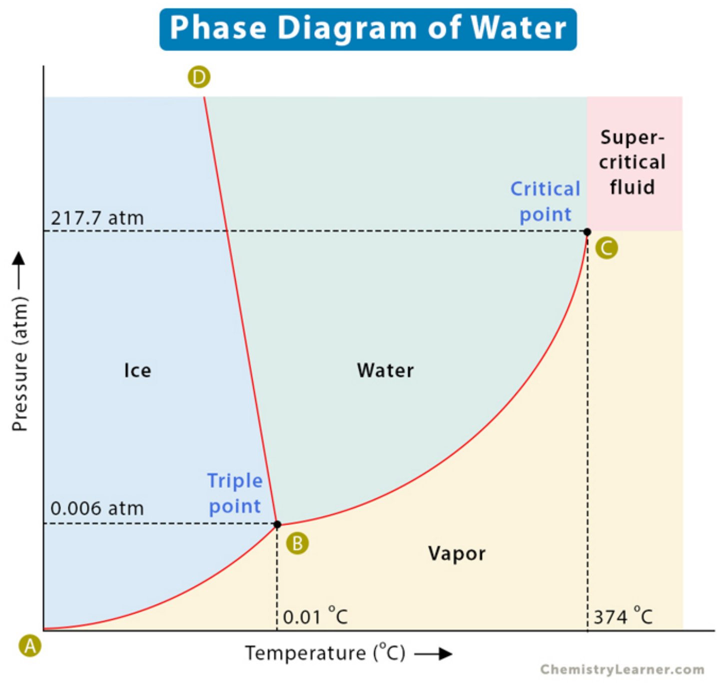
- Be the leader on the African continent for CERN-related theoretical physics research

- Transformation of the South African CERN-related theoretical physics student and faculty communities

- Outreach at all levels
  Including high school, UG, and PG academic levels, this can be through activities like the African School of Physics or the 100UP programme at UCT

Activities in the pillar

Heavy ion physics



The QCD Lagrangian is well verified by experiments over many orders of magnitude. But just as the collective behaviour of electrically charged objects described by the QED Lagrangian lead to the phase diagram of water, it is far from obvious what the bulk dynamics of QCD will be.

With particle colliders the world scientific community has opportunities to explore the state of the universe a few microseconds after the Big Bang by colliding heavy nuclei (QGP). In particular rare high momentum partons, those that produce jets of particles, which provide the most direct probe of the fundamental degrees of freedom in this new phase of QCD matter.

Note that phenomenological application of the AdS/CFT conjecture, as applied to the QGP, leads to a controlled laboratory setting for testing new theoretic ideas by comparing them to the results of both experiment and traditional pQCD methods. This has lead to works produced by members in our UCT group.

High energy phenomenology

Here we focus on the observable consequences of the fundamental particles and their interactions. This has involved work in developing a gauge-Higgs unification model in XDs, which has inspired recent work on using the geometry of hyperbolic XDs to generate, from a purely Yang-Mills theory, a new effective scalar sector.

ML tools are also under development for deployment in generating exclusion plots for classes of BSM theories, as we shall look at more closely later. Such tools may also be of used in XD models of gravity.

Aspects of nuclear physics

The nucleus is elusive and the goal is to understand its structure. Comprised of nucleons it may only be studied through its decays, or reactions with either elementary particles or other nuclei. This is, however, a Catch-22: in order to understand the data coming from those reactions, one must first understand the nuclear structure!

Development of theories of scattering in this group has shed new light, on exotic nuclei (nuclei formed in the laboratory and existing only for very small fractions of a second). Knowledge of those nuclei is critical in the understanding of the creation of the elements in the centres of stars, and in stars' evolution.

Example: Multi-Channel Algebraic Scattering

A formalism for solving the coupled-channel equations of low-energy nucleon-nucleus, or nucleus-nucleus, scattering. Based on the collective model of the target nucleus it requires a little data to determine the coupled-channel potentials, after which the formalism is predictive for descriptions of the (A+1) compound system.

S Karataglidis, K Amos, PR Fraser, L Canton, A new development at the intersection of nuclear structure and reaction theory, (Springer-Nature, 2019)

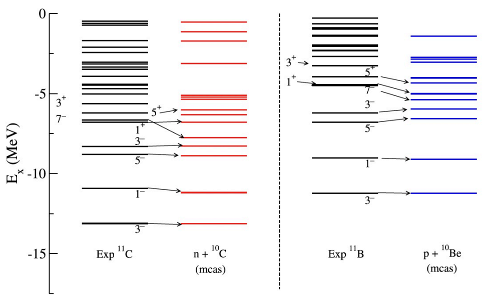


Fig. 1 Experimental spectra of ^{11}C and of ^{11}B [8] compared with the results of MCAS calculations for the $n+^{10}C$ and $p+^{10}Be$ clusters. The zero energy in each is the relevant nucleon separation energy. The spin-parities of the states are indicated as $2J^{\pi}$

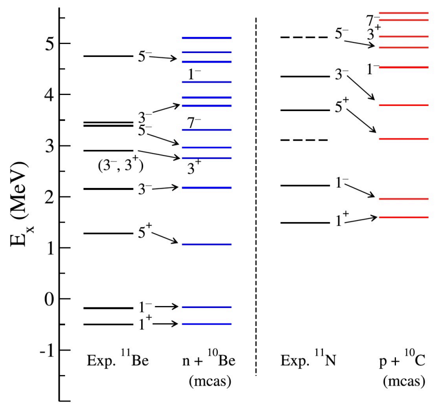


Fig. 2 Experimental spectra of ^{11}Be and of ^{11}N [8] compared with the results of MCAS calculations for the $n+^{10}Be$ and $p+^{10}C$ clusters. The zero energy in each is the relevant nucleon separation energy. The spin-parities of the states are indicated as $2J^{\pi}$

Machine learning applications

Example: Improving the sensitivity to $\tilde{\mu}$ production

- **Aim:** To fully utilise NNs classifiers for use in BSM phenomenology.

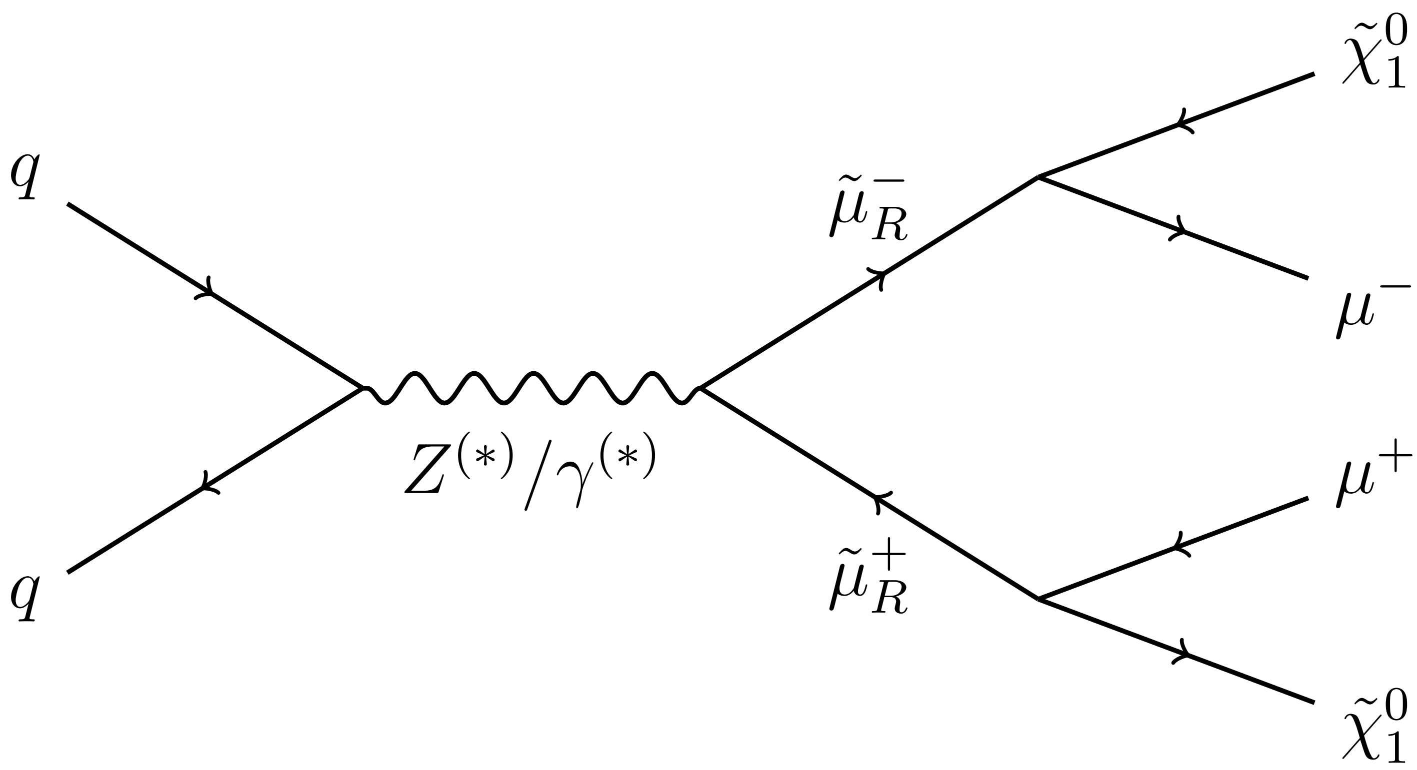
- **Objectives:**

  – Simulate $p\bar{p}$ collisions at LHC's Run 2.

  – Train NN models on bkg (SM) data and subset sig. (BSM) data,
  determine the optimal hyperparameters.

  – Load and apply pre-trained models on a richer sig. dataset and compare with extant cut techniques.

$\tilde{\mu}_R$ production - parton-level/hard process

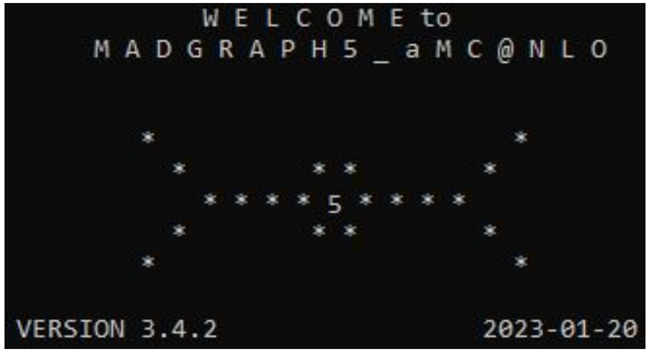


Dominant backgrounds:

$$p\bar{p} \to t\bar{t} + X, \quad p\bar{p} \to \ell^+\ell^-\nu\bar{\nu} + X, \quad p\bar{p} \to \ell\ell\ell\nu + X.$$

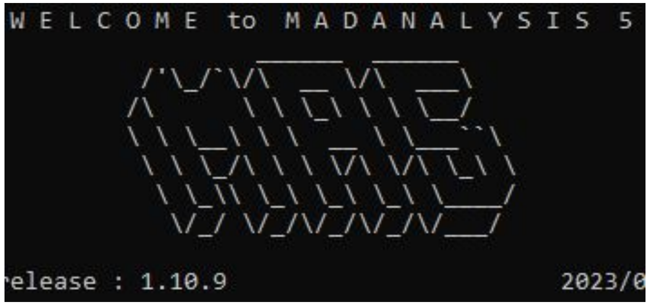
Methodology: data generation + analysis

Sig (BSM) + bkg (QCD) data generation w. Madgraph 5



$\Downarrow$

Initial cuts w. MadAnalysis 5
(e.g. $N(\ell) = 2$, $N(\mu^+) = 1$, $N(\mu^-) = 1$)



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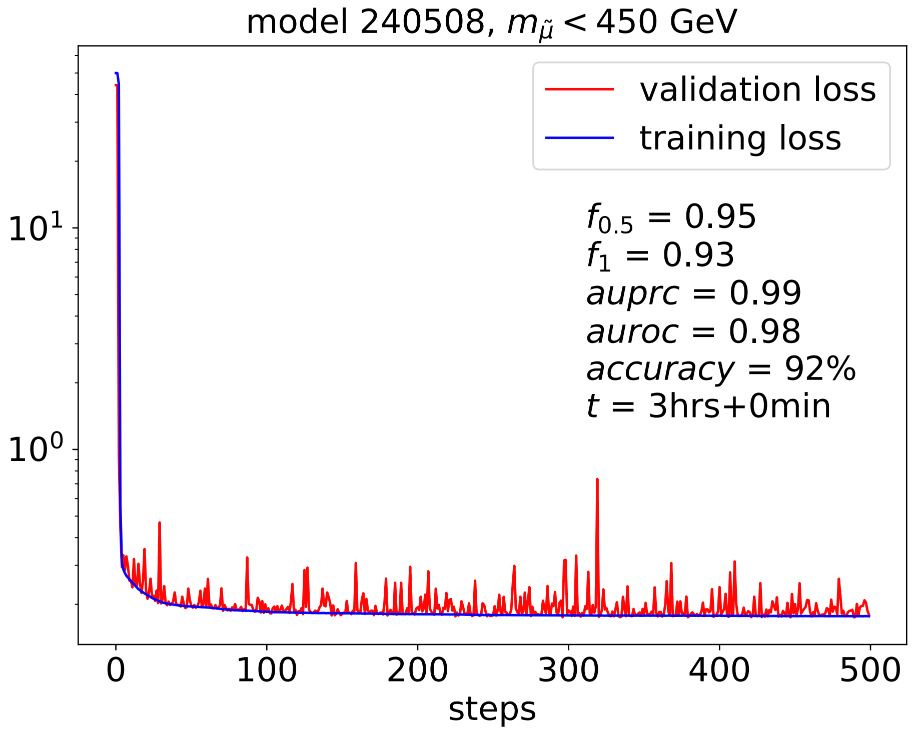
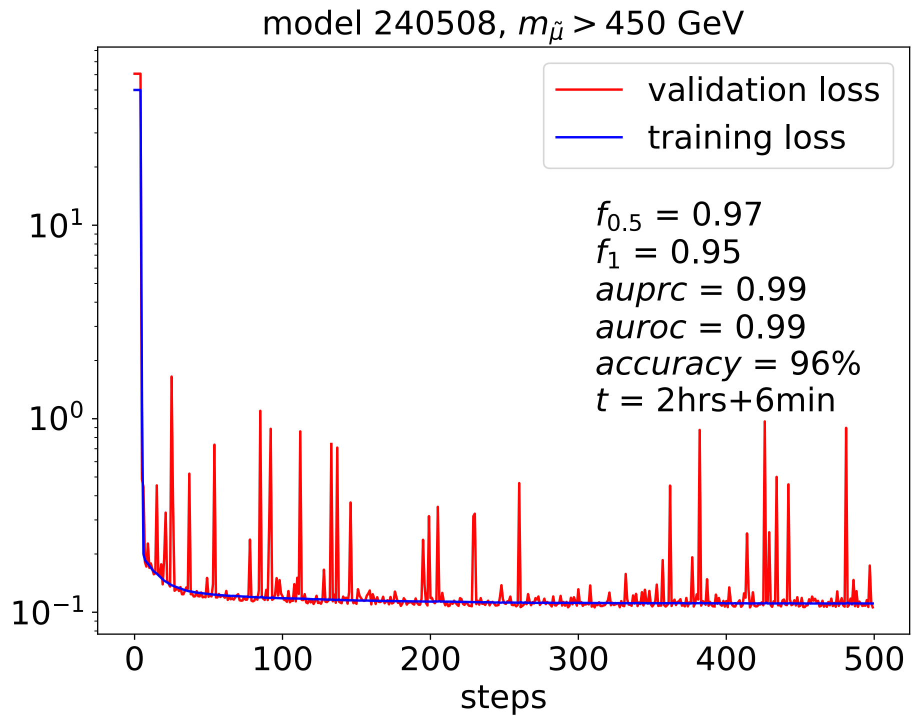
Neural Network (NN) discriminator

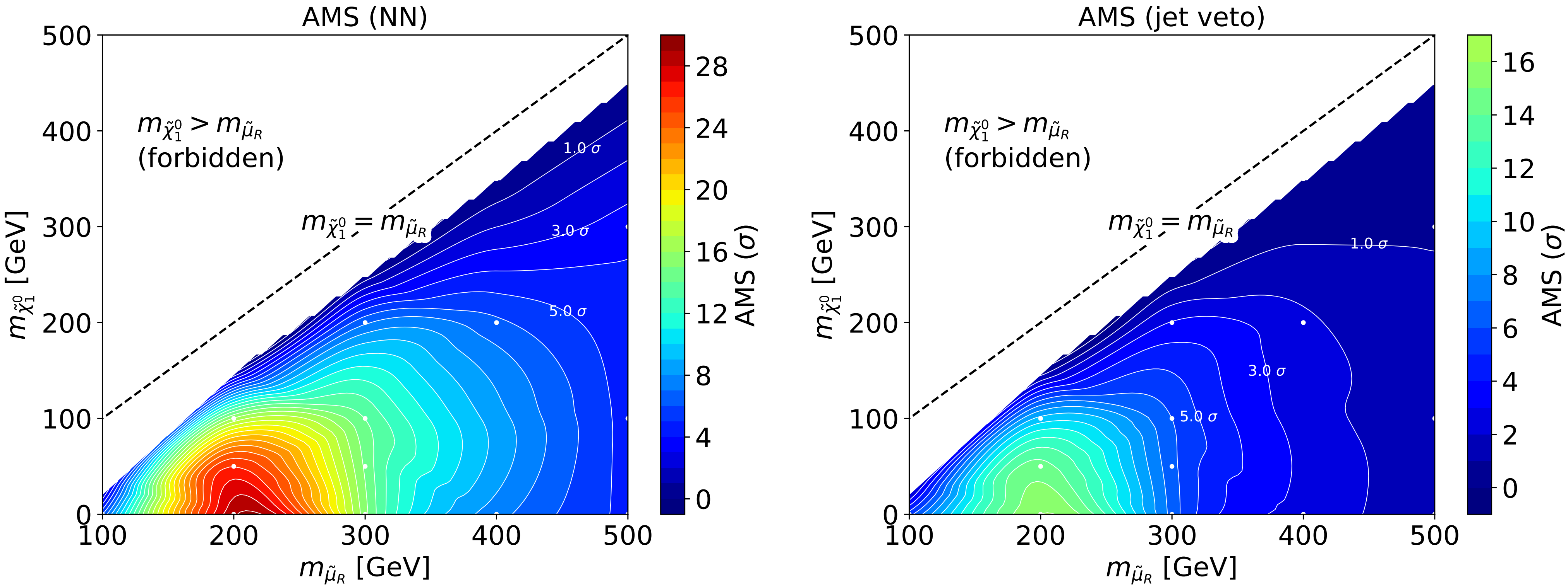
Performance of the model





- 2 NN trained on low mass range ($m_{\mu_R} < 450$ GeV) data and high mass range ($m_{\mu_R} > 450$ GeV) data.
- High scores on various metrics: e.g. $f_{0.5}$ & f_1 scores, AUPRC, etc.

AMS: NN vs. static jet veto



- Static jet veto: $p_T^{\mu_1(\mu_2)} > 50(20)$ GeV, $p_T^{veto} = 25$ GeV.
- Boosted decision trees, dynamic jet veto?

Discussions

- NN yields better sig acceptance + bkg rejection than static jet veto: standardisation, using low- and high-level features important.

- Using the NN in the workflow for confronting new physics model w. real LHC data?

- Improve NN performance using more advanced techniques. How do NNs compare with dynamic jet veto and BDTs?

Concluding thoughts

I have hopefully given you a flavour of what is happening among many of the members of the SA-CERN/Theory group, especially as related with their research directions.

For new or interested members wanting to engage with other projects, this has only been a small cross-section of activities.

Note that this would should provide good overlap with activities in other pillars.