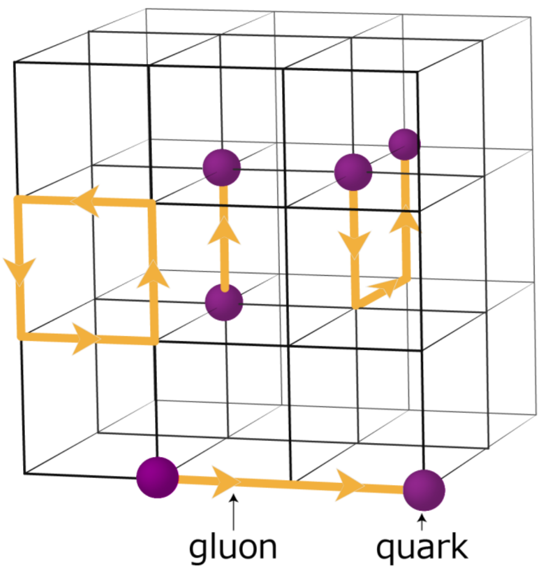
Applying Machine Learning to Computational Quantum Chromo-Dynamics

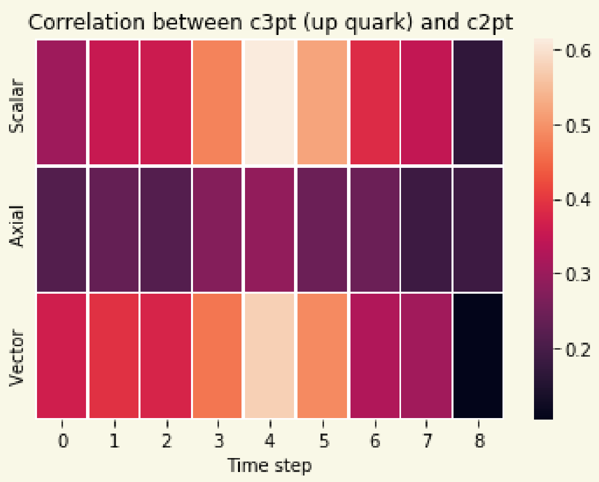


Introduction

- Quantum Chromodynamics (QCD) is the theory of strong interactions between quarks and gluons
  - These are subatomic particles that make up protons and neutrons
- QCD is asymptotically free, which means that the strength of strong interactions asymptotically decreases as distance decreases
- This makes it very hard to simulate using standard methods
- We turn to Lattice QCD, a method which confines quarks to a grid
- This allows us to simulate physical scenarios, but it is expensive
  - We are working on a possible way to make it cheaper, with Machine Learning

Motivation

- Certain intermediary quantities cross-correlate
- A machine learning program can learn these
- For example, so called "correlation functions"
  - Types: 2-point (c2pt, cheap) and 3-point (c3pt, expensive)
  - c3pt comes in axial, scalar, vector, and more varieties
- At relevant time slices, these correlate:



Bias Correction

- An ML model may introduce systematic bias
- At some computational cost, can be reduced
  - Test model on some fraction of data to determine bias
  - Correct for this bias with a "bias correction" (X_{BC}) term

$$X_{BC} = \frac{1}{N} \sum_{i \in \{Data_{BC}\}} X_{pred} - X_{real}$$

$$X \approx X_{pred} + X_{BC}$$

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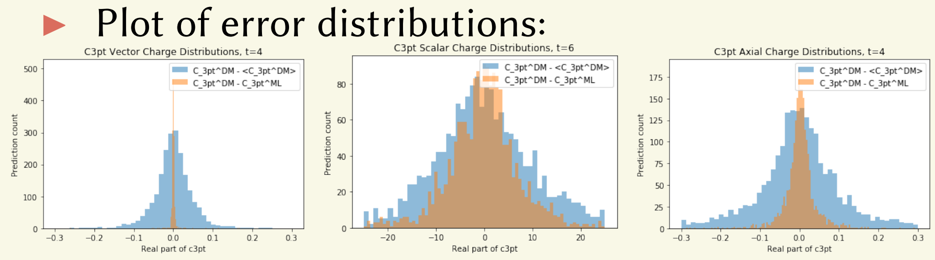
Model Architecture

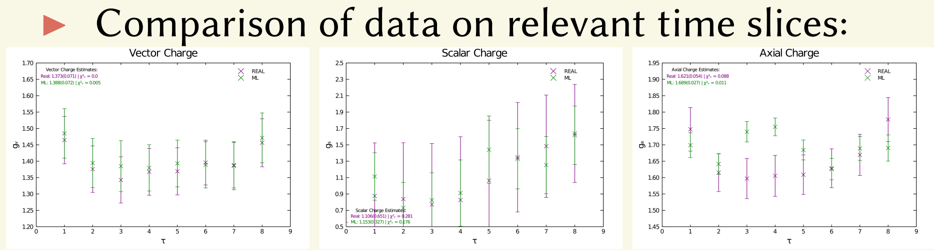
- How to choose a Machine Learning model?
  - Must capture physical symmetries
  - Past that, this is an engineering question: what works?
- A Boosted Decision Tree (BDT) is a fairly simple model which makes a series of branching choices
  - Learns best choices, self-corrects to reduce overfitting
- Must also determine how to sample data
  - We find that random sampling is the least biased

Results

- Predictive power on all varieties
- Plot of error distributions:



- Error significantly reduced in axial, vector c3pt
- Smaller error=less data needed=faster runtime
- Comparison of data on relevant time slices:



- Statistically consistent with real data
- This technique could be applied to more data sets

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