Reconstructing top quarks with deep learning at the Large Hadron Collider

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Experimentelle Physik IV

based on arXiv:1907.11181
Top quarks at the Large Hadron Collider

\[ E = mc^2 \]
Top quarks at the Large Hadron Collider

\[ E = mc^2 \]
Detection of top quarks and the issue of jet combinatorics

Jet - p

Jet - q

Jet - b

Jet - τ

Jet - W^+
Detection of top quarks and the issue of jet combinatorics

easy to identify

invisible
Detection of top quarks and the issue of jet combinatorics

Which jet belongs to which particle from the decay?

easy to identify

invisible
Standard algorithm

A likelihood-based reconstruction algorithm for top-quark pairs and the KLFitter framework

Johannes Erdmann\textsuperscript{a,b}, Stefan Guindon\textsuperscript{a,c}, Kevin Kröninger\textsuperscript{a}, Boris Lemmer\textsuperscript{a}, Olaf Nackenhorst\textsuperscript{a}, Arnulf Quadt\textsuperscript{a}, Philipp Stolte\textsuperscript{a}

\textbf{NIM A 748 (2014) 18}
\textbf{arXiv:1312.5595}

Basic idea: For each possible combination …

• use particle energies and flight directions
• assign to top-quark decays
• compare to known particle masses
### Standard algorithm

A likelihood-based reconstruction algorithm for top-quark pairs and the KLFitter framework

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### Deep learning

- 36 million simulated LHC collisions
- Dataset: 1 true & many wrong combinations for each simulated LHC collision
- Input: particle energies and flight directions

Binary classification problem

- Separate true and wrong combinations
- For each LHC collision:
  - choose combination with largest output
How often do we pick the right combination?

Hyperparameter optimization:
- 5 hidden layers with 512, 256, 128, 64, 32 nodes
- Batch size: 12,000
- Learning rate (Adam) 0.01
- L₂ regularization: 10⁻⁸

Correct combination in 80.2%

Improvement over best version of the standard algorithm (72.7%)
The harder the problem, the larger the improvement

Correct combination of 4 jets out of 4
⇒ $4!/2 = 12$ combinations

Correct combination 4 jets out of 6
⇒ $6!/4 = 180$ combinations

$\bar{t}t \rightarrow e/\mu + \geq 4$ jets
$\bar{t}t \rightarrow e/\mu + \geq 6$ jets

Events (normalized)

$\Delta R(t_{\text{had}}^{\text{reco}}, t_{\text{had}}^{\text{truth}})$

$\Delta R(t_{\text{had}}^{\text{reco}}, t_{\text{had}}^{\text{truth}})$

(= difference in top-quark direction)