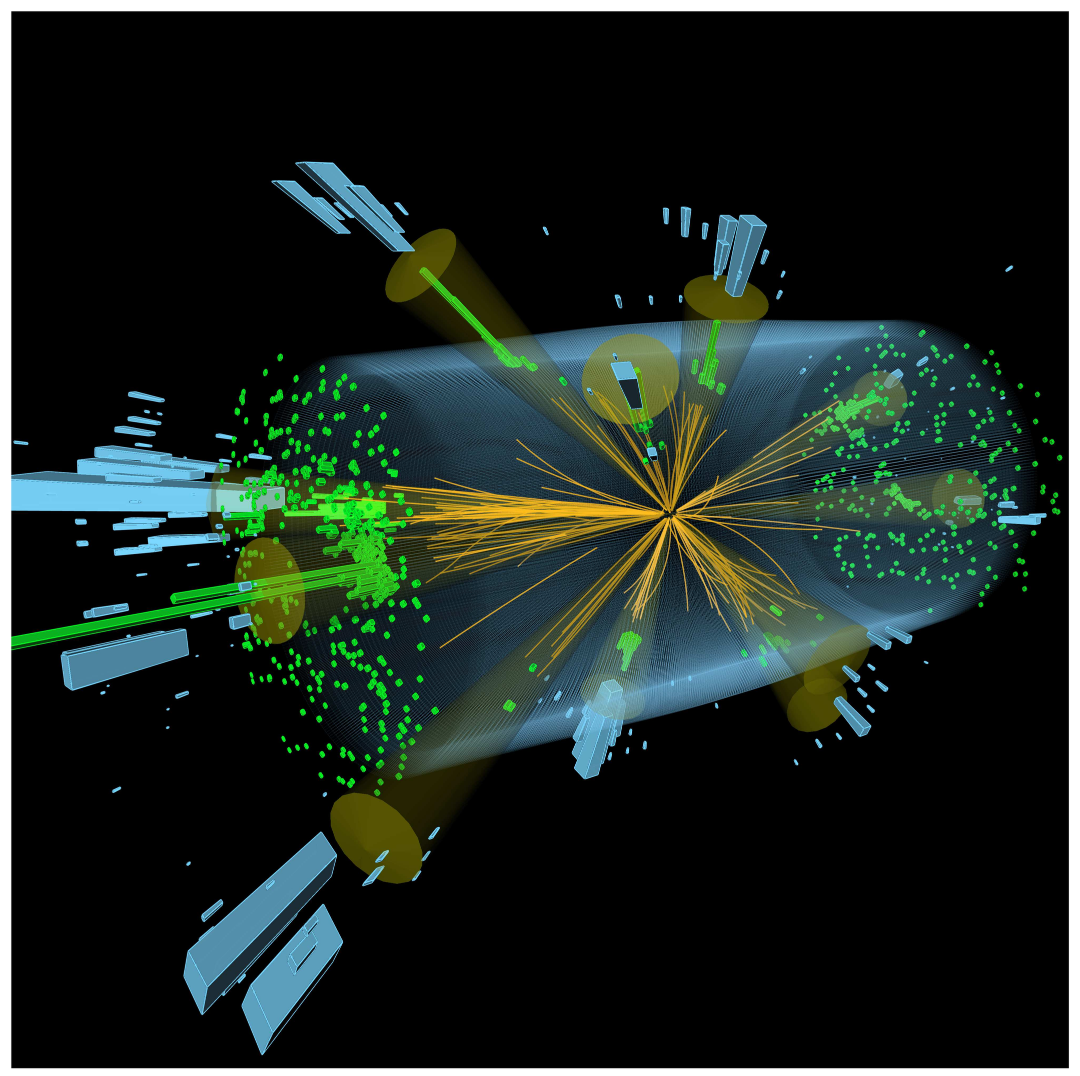
Quantum Algorithms for Collider Physics

PIs: Jesse Thaler (HEP) & Aram Harrow (QIS)
Patrick Komiske, Eric Metodiev, Preksha Naik (HEP) & Eric Anschuetz, Annie Wei (QIS)

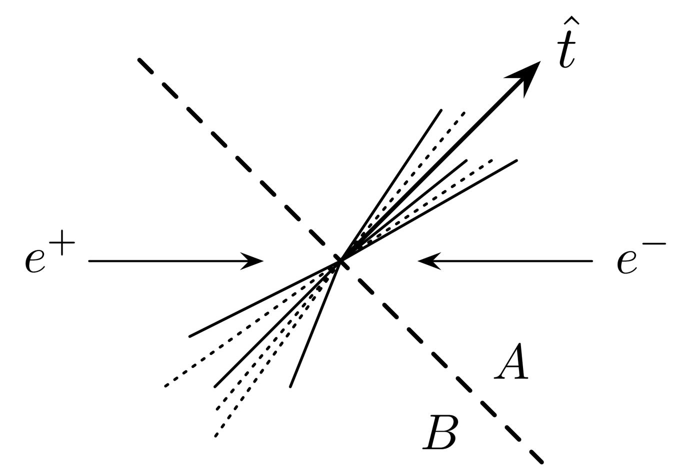
This research aims to unite powerful analysis techniques in HEP with cutting-edge advances in QIS



Almost every event at the Large Hadron Collider (LHC) involves jets, collimated sprays of particles that are copiously produced at high energies. Current LHC algorithms to identify and classify jets are constrained by the limits of classical computation. Quantum algorithms could fundamentally change how collider data is analyzed, by speeding up existing classical algorithms and by enabling new quantum jet representations.

By exposing new jet features that are classically intractable, quantum jet algorithms could enable discoveries at the LHC

Project 1: Revisiting Jet Clustering Algorithms



Warm up: Thrust

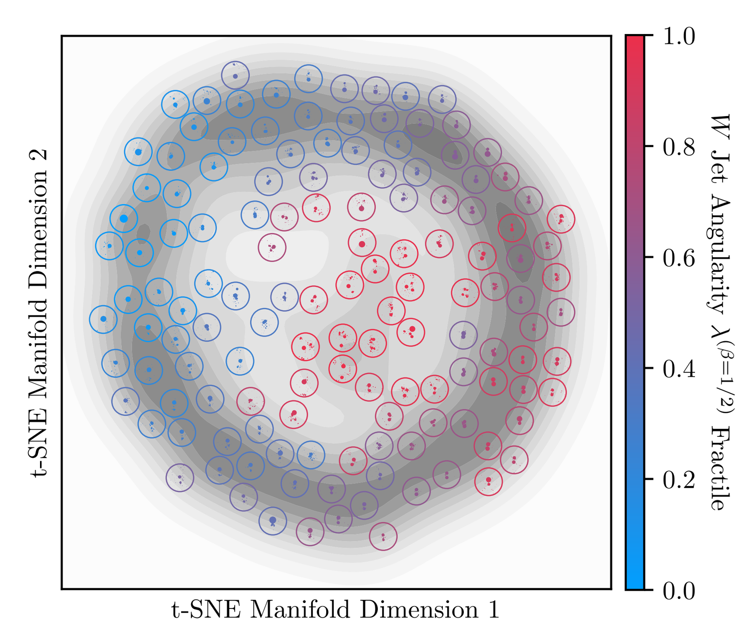
Classic collider event shape (Farhi, 1977)
Classic partitioning problem (Brandt/Dahmen, 1978)
Straightforward extensions to LHC algorithms

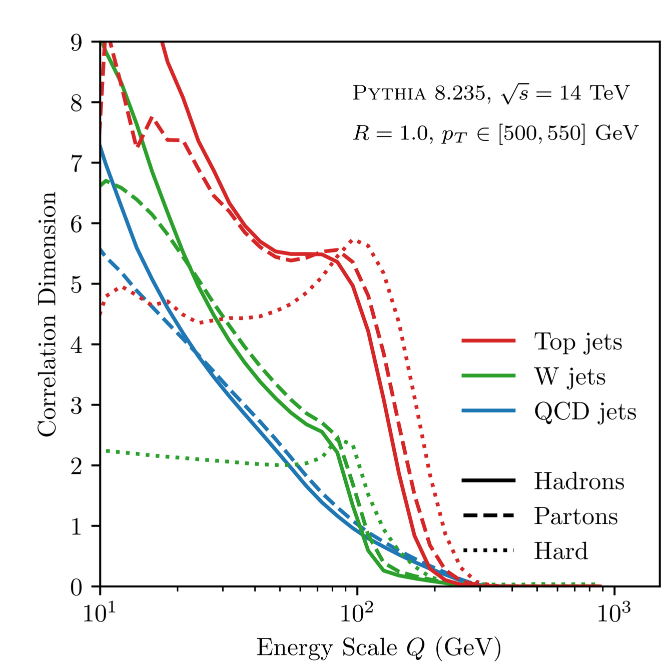
Naive Classical: $O(2^N)$	Best Classical: $O(N^3)$
$\Downarrow$	$\Downarrow$
Partitioning via Quantum Annealing	$O(N^2)$ with Grover-style Algorithm

(Naik, Wei, Harrow, Thaler, in progress)

Could we do quantum *event* clustering?

Because N(events/run) $\gg$ N(particle/event), biggest quantum gains are likely to come from new algorithms designed to act on event ensembles. Below: novel visualization based on $O(N^2)$ "distances" between events. (Komiske, Metodiev, Thaler, in progress)





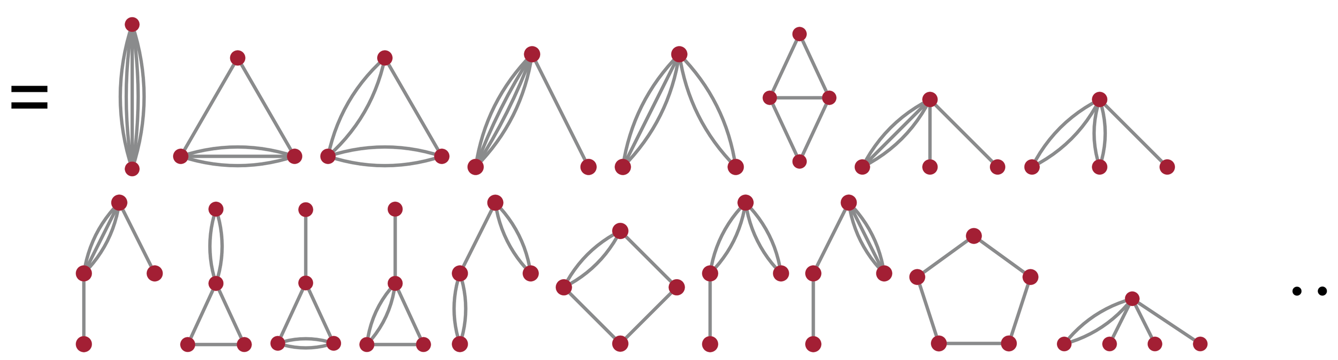
Project 2: Sparse Regression for Energy Flow Polynomials

Complete linear basis for "safe" collider observables:

$$\mathcal{S} = \sum_G s_G \, \mathrm{EFP}_G$$

(Komiske, Metodiev, Thaler, 2017)

G =



A very powerful statement, but thousands of graphs are needed to achieve good performance for collider tasks. Classically, you can regularize using Lasso regularization, but this yields biased results. Is there a better option in the quantum realm?

L_0-Norm Regularization: NP-hard

$\Downarrow$

Quantum Annealing?
Yes! Use redundant qubit encoding of linear coefficients

(Anschuetz, Harrow, Thaler, in progress)

Domain-specific problem in HEP motivates generic solution in QIS

Anticipating more fruitful exchanges at the boundary between HEP & QIS