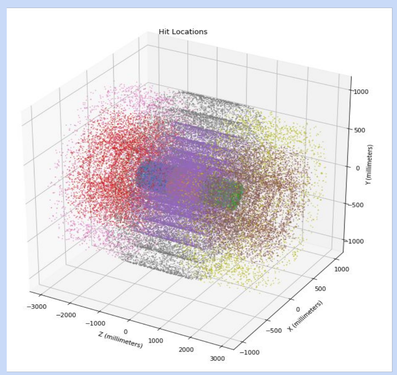
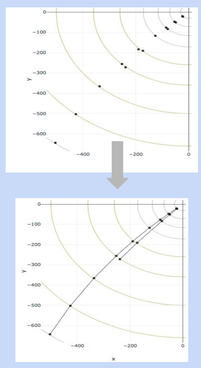
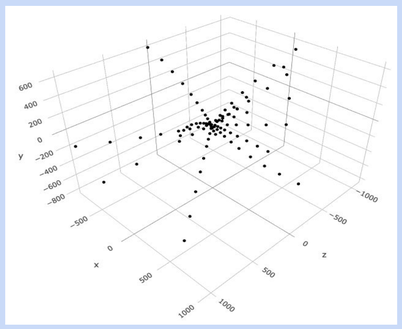
LHC Pattern Recognition Challenge



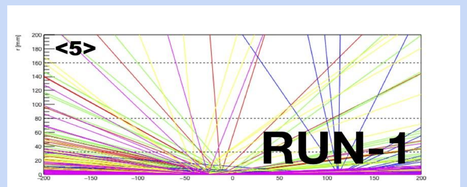
From Detector Measurements...

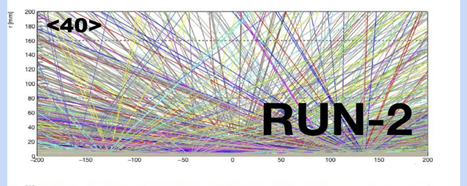


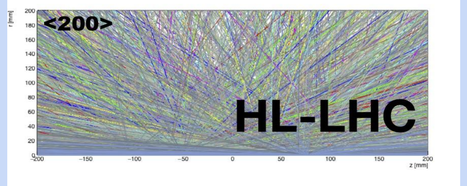
...to Particle Tracks...

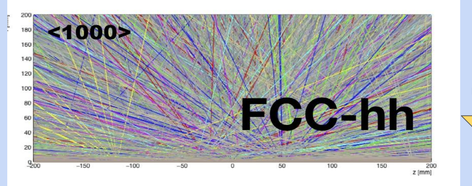


...to Particle Properties









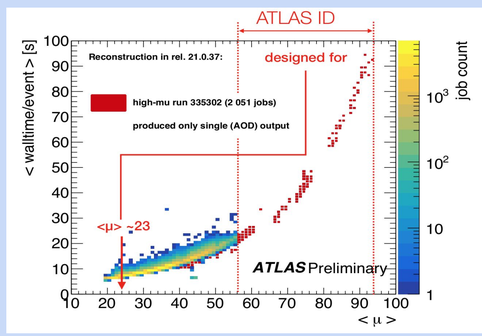
2008

2016

2028

~2040

Combinatorially hard optimization.
Current algorithms show polynomial scaling.



*Can **quantum pattern recognition** provide a solution for **FCC-hh**?*

Wahid Bhimji, *Paolo Calafiura*, Heather Gray (PI), Wim Lavrijsen, Eric Rohm, Amitabh Yadav

https://hep-qpr.lbl.gov

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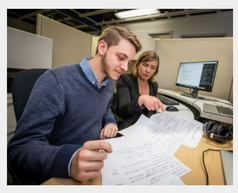
QAOA Global Pattern Recognition

Rationale

Tracking as a global optimization problem

- ***QAOA for* QUBO** (Eric Rohm)



QUBO Minimization

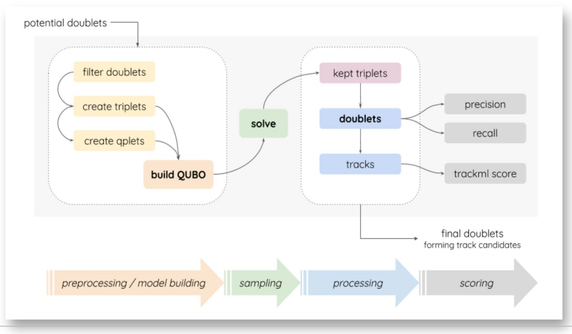
Building on our previous study, we express tracking as a **QUBO**

$$O(a;b;q) = \sum_{i=1}^{N} a_i q_i + \sum_{i}^{N}\sum_{j}^{N} b_{ij} q_i q_j \quad q_i \in \{0,1\}$$

Where q_i are **doublets**, segments composed by two hits.

10.1007/s41781-019-0032-5

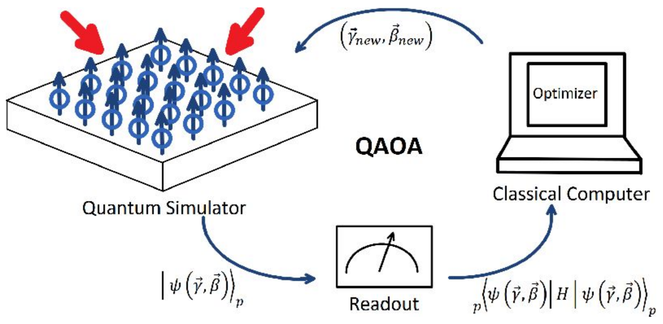
Minimizing *O* means selecting the best **triplets** to form track candidates.



QAOA

Quantum Approximate Optimization Algorithm (QAOA)

Hybrid classical-quantum algorithm that combines quantum circuits and classical optimization of those circuits



A superposition of input states is prepared on a quantum circuit, while each successive iteration of parameters is optimized classically then returned to the quantum machine (Ho, Hsieh 2018).

Implementation

EntropicaQAOA

Implementation on Rigetti QVM and QPU

Apply QAOA directly to QUBOs (and Ising models)

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Status:

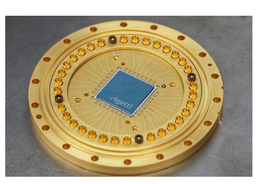
QUBO ✅

↓

QAOA Solver (QVM) ←

↓

QAOA Solver (QPU) ❓



Quantum Hough Transform

Rationale

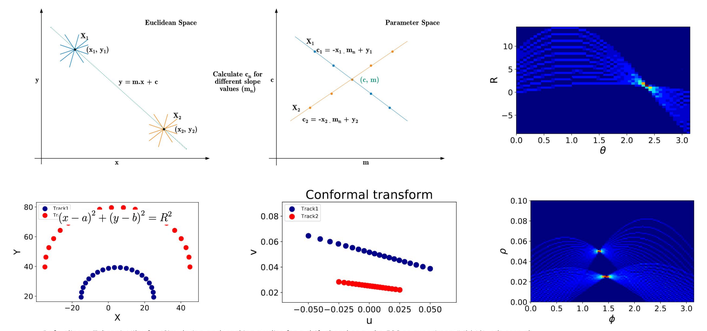
Tracking as a geometrical transformation

- **QLSA**
- **Quantum Counting** (Amitabh Yadav)

Hough Transform

Classic feature extraction algorithm, used for HEP tracking from the ‘70s

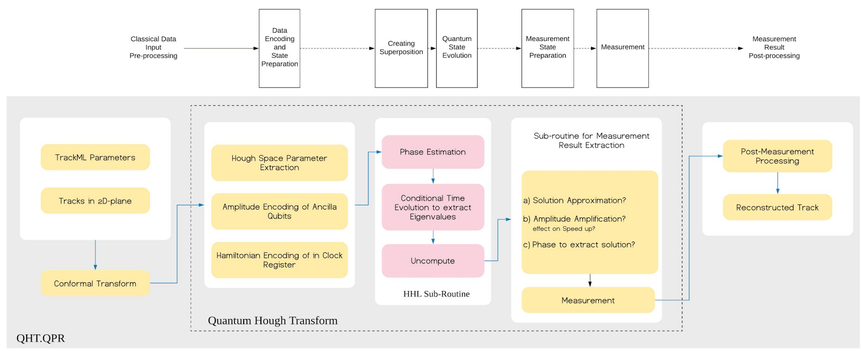
Accumulate points belonging to a line or circle to bins in **Hough Space**



Ref.: Alipour Tehrani, Niloufar “Simulation and tracking studies for a drift chamber at the FCC-ee experiment” (2019). cds.cern.ch

Implementation

QHT.QPR as a Quantum Linear System Algorithm (using HHL)



Current Work

- Algorithmic pipeline design with idealized tracks
- QISKIT Aqua for HHL subroutine
  - HHL offers exponential speed-up for solving linear equations
- Accumulator space formed by superposition of qubits
- Post HHL measurement result extraction subroutine [10.1103/PhysRevLett.110.250504]

Key Challenges:

- |b⟩State encoding
- Measurement result interpretation (i.e. sampling exact solutions from |x⟩measurement)

Alternative Approaches:

- Max/Min finding O(√N) [arXiv:1908.07943v1]
- Quantum counting
- Grover search