LUXE technical meeting, 16th June 2021

Quantum computing for LUXE

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Introduction

- Goal: study the use of quantum computing for charged particle reconstruction.

- Regular (fortnightly) meeting with Karl Jansen, Stefan Kühn, et al.
- https://indico.desy.de/category/851/
- 1st meeting 17th May, 2nd meeting 17th June.

Quantum annealer-based tracking

- Start with the quantum annealer-based tracking from Comput.Softw.Big Sci. 4 (2020) 1, 1 .

Computing and Software for Big Science (2020) 4:1
https://doi.org/10.1007/s41781-019-0032-5

ORIGINAL ARTICLE

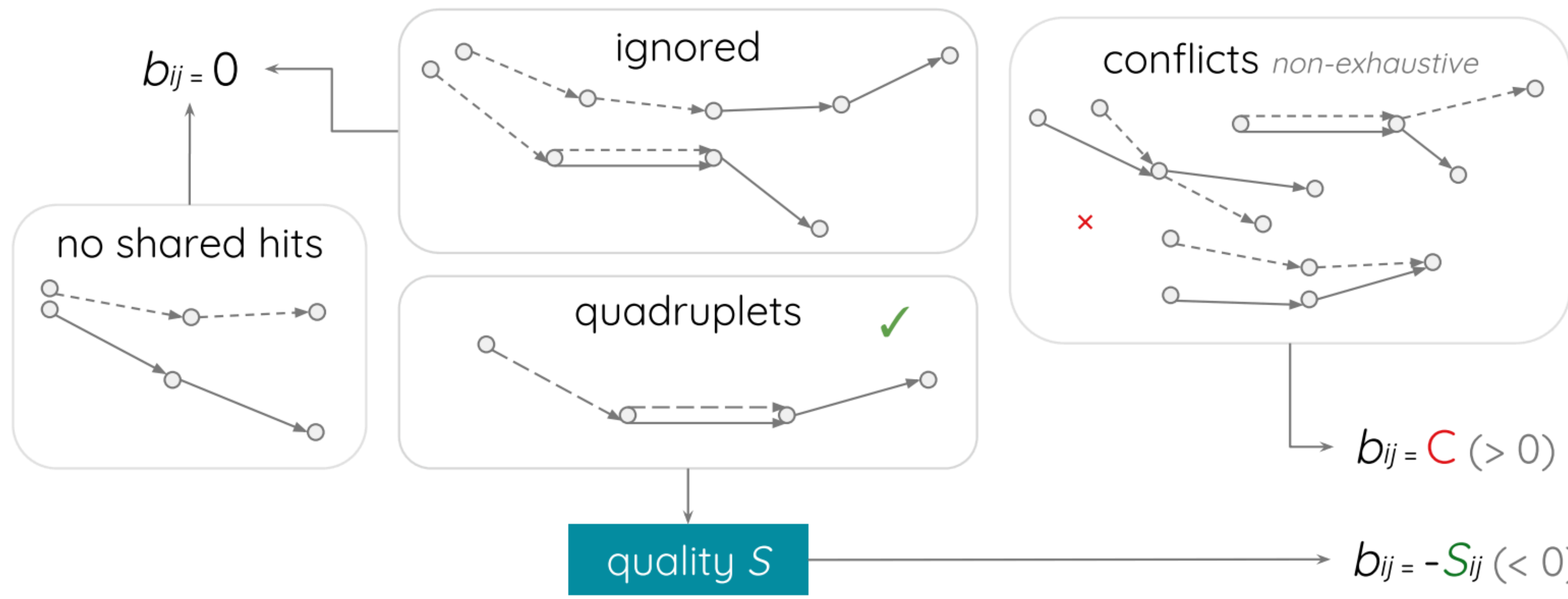
A Pattern Recognition Algorithm for Quantum Annealers

Frédéric Bapst[1] · Wahid Bhimji[2] · Paolo Calafiura[2] · Heather Gray[2,3] · Wim Lavrijsen[2] · Lucy Linder[1] · Alex Smith[3]

- Use case: tracking at HL-LHC (using trackML dataset).
- Optimisation problem expressed as QUBO (Quadratic Unconstrained Binary Optimisation), solved using quantum annealers.
- Performance comparable with state-of-the-art classical pattern recognition algorithms

Quantum annealer-based tracking

- Combine triplets (set of three hits in increasing R) into quadruplets.



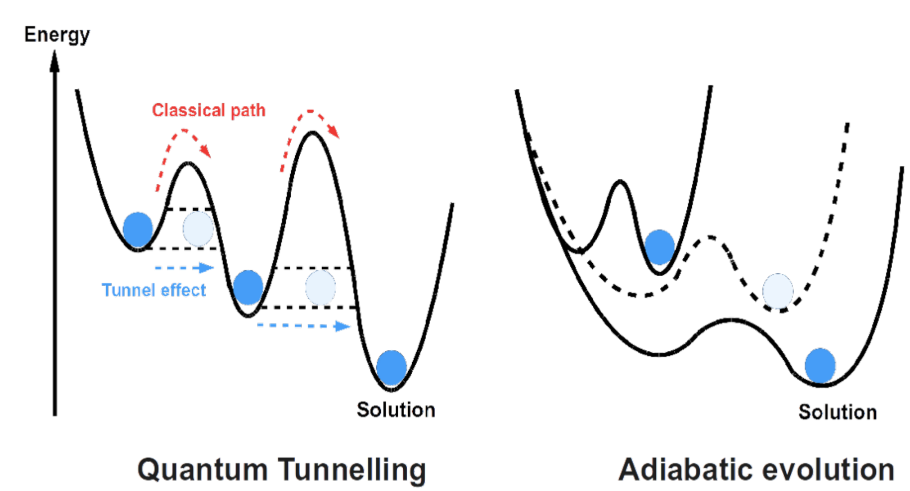
- Minimise:

$$O(a, b, T) = \sum_{i=1}^{N} a_i T_i + \sum_{i}^{N} \sum_{j<i} b_{ij} T_i T_j \quad T_i, T_j \in \{0, 1\}$$

Quality of triplets

Compatibility between triplet pairs

- Quantum annealing: evolve adiabatically to the problem Hamiltonian and find the ground state solution.



Variational Quantum Eigensolver (VQE)

- Objective function O(a,b,T) we want to minimise looks similar to the longitudinal Ising model.

$$\mathcal{H} = -\sum_{n=1}^{N} \sigma_n^x \sigma_{n+1}^x - \alpha \sum_{n=1}^{N} \sigma_n^x$$

- Looking into using variational quantum eigensolver (VQE) to solve that in Qiskit (framework for quantum computing from IBM).

Plans

Rough tentative plans

From simple to complex

Each step should characterise the algorithm as a function of the number of particles and see if the errors of the resulting system can be mitigated.

1. Toy experiment with N (=4) layers, straight lines from (0,0,0)
2. Toy experiment with N layers, straight lines from (0,0,0), gaussian multiple scattering
3. Toy experiment with realistic beamspot size
4. Full detector simulation (including detector inefficiencies)
5. Full detector simulation with beam backgrounds
6. Test algorithms on real data from test-beam campaign

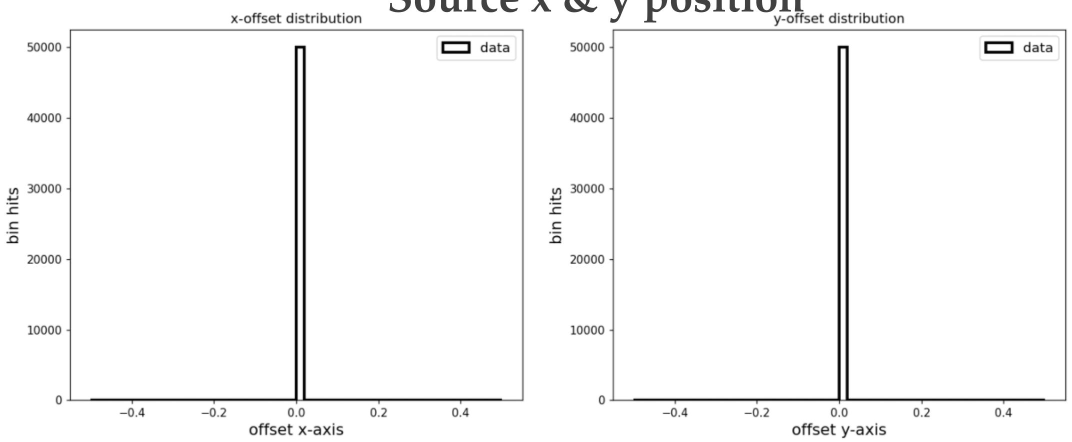
Division of tasks

- David: toy MC generation.
- Annabel: apply quantum annealer-based tracking from Comput.Softw.Big Sci. 4 (2020) 1, 1 to the toy MC data.
- Yee: standard tracking using ACTS.

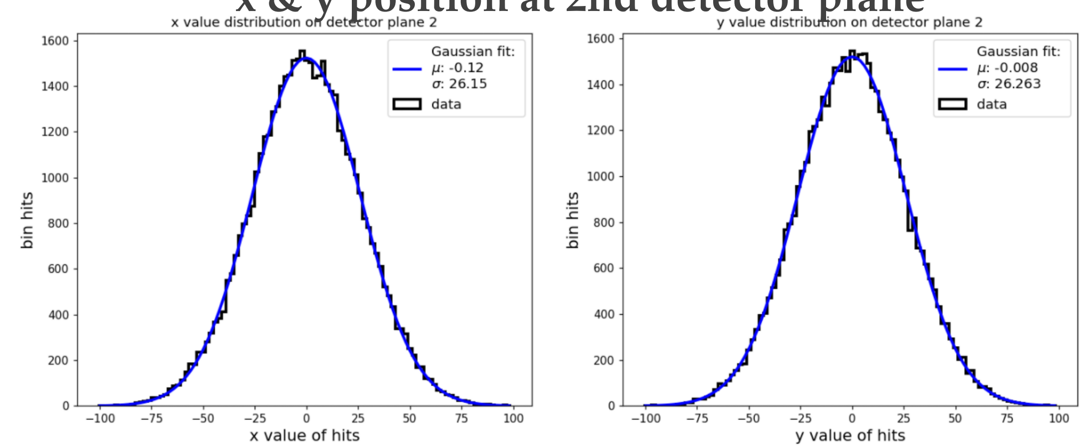
Toy MC

- Point source shooting particles travelling in straight lines through four detector layers such that the “hits” are Gaussian distributed in x and y.

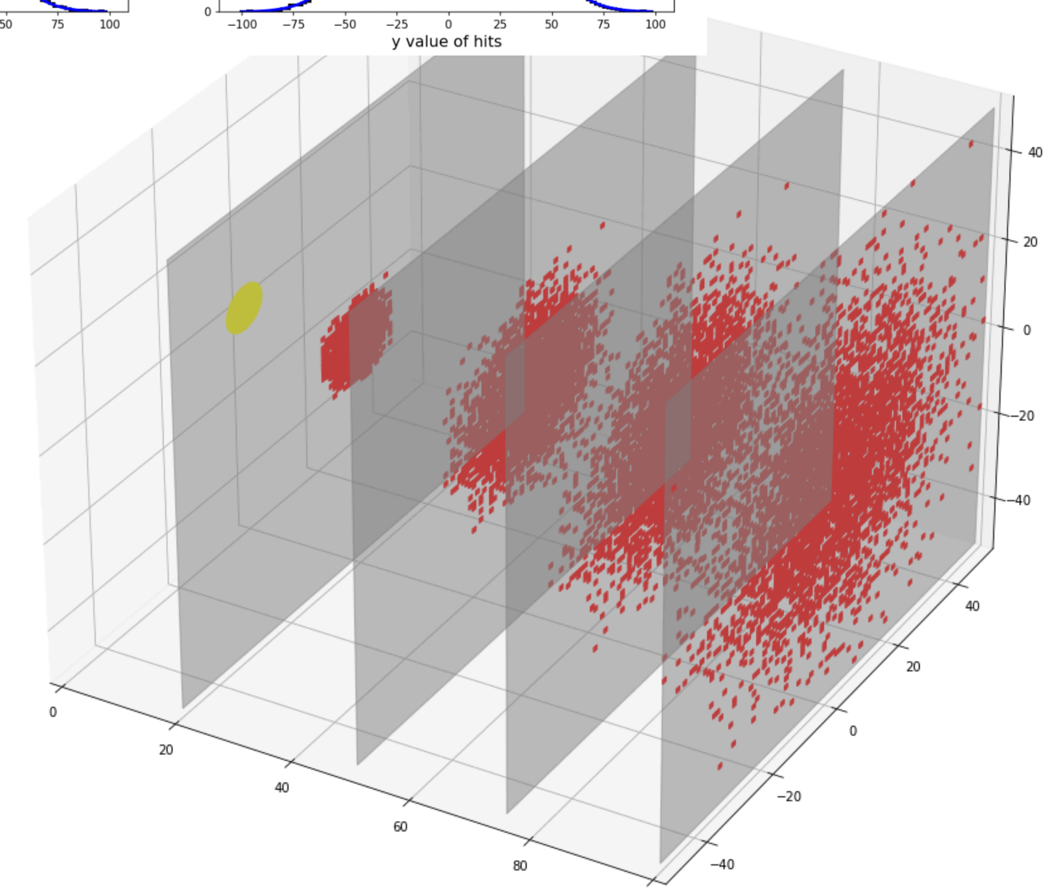
Source x & y position



x & y position at 2nd detector plane



- Hits discretised into pixels.
- Source as well as direction can be configured.
- Next:
  - Implement 3D Gaussian beam spot and multiple scattering.



Tracking on toy MC

- Take the output hits collection and run quantum annealer-based tracking as presented in the paper, but adapted to our conditions.

- Run also standard tracking algorithm to compare performance.
  - Seeding + (combinatorial) Kalman filter.
  - Use ACTS (A Common Tracking Software) for that.
  - Fatras (FAst TRAck Simulation) feature can be used for simulating hits.